

The Future of US Particle Physics

**Report of the 2021 US Community Study
on the Future of Particle Physics
organized by the APS Division of Particles and Fields**

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Foreword

In this space, the DPF chairs will describe their view of the Study, and thank everyone who needs to be thanked.

Executive Summary

The 2021 Community Study, known as “Snowmass 2021,” brought together nearly all of the physicists in the world working in this area to create a unified vision for particle physics.

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Summary of the 2021 US Community Study on the Future of Particle Physics

Already we are boldly launched upon the deep; but soon we shall be lost in its unshored, harbourless immensities. Ere that come to pass; ere the Pequod's weedy hull rolls side by side with the barnacled hulls of the leviathan; at the outset it is but well to attend to a matter almost indispensable to a thorough appreciative understanding of the more special leviathanic revelations and allusions of all sorts which are to follow.

It is some systematized exhibition of the whale in his broad genera, that I would now fain put before you. Yet is it no easy task. The classification of the constituents of a chaos, nothing less is here essayed. Listen to what the best and latest authorities have laid down.

"No branch of Zoology is so much involved as that which is entitled Cetology," says Captain Scoresby, A.D. 1820 [1].

"It is not my intention, were it in my power, to enter into the inquiry as to the true method of dividing the cetacea into groups and families. . . . Utter confusion exists among the historians of this animal" (sperm whale), says Surgeon Beale, A.D. 1839 [2].

"Unfitness to pursue our research in the unfathomable waters." "Impenetrable veil covering our knowledge of the cetacea." "A field strewn with thorns." "All these incomplete indications but serve to torture us naturalists." [3, 4, 5]

Thus speak of the whale, the great Cuvier, and John Hunter, and Lesson, those lights of zoology and anatomy.

[. . .]

Finally: It was stated at the outset, that this system would not be here, and at once, perfected. You cannot but plainly see that I have kept my word. But I now leave my cetological System standing thus unfinished, even as the great Cathedral of Cologne was left, with the crane still standing upon the top of the uncompleted tower. For small erections may be finished by their first architects; grand ones, true ones, ever leave the copestone to posterity. God keep me from ever completing anything. This whole book is but a draught—nay, but the draught of a draught. Oh, Time, Strength, Cash, and Patience!

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Energy Frontier

Meenakshi Narain, Laura Reina, Alessandro Tricoli

M. Begel, A. Belloni, T. Bose, S. Dawson, C. Doglioni, A. Freitas, J. Hirschauer, S. Hoeche, A. Korytov, Y.-J. Lee, H.-W. Lin, E. Lipeles, Z. Liu, P. Meade, S. Mukherjee, P. Nadolsky, I. Ojalvo, S. Pagan Griso, C. Royon, M. Schmitt, R. Schwienhorst, N. Shah, J. Tian, C. Vernieri, D. Wackerroth, L.-T. Wang

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Thus speak of the whale, the great Cuvier, and John Hunter, and Lesson, those lights of zoology and anatomy. Nevertheless, though of real knowledge there be little, yet of books there are a plenty; and so in some small degree, with cetology, or the science of whales. Many are the men, small and great, old and new, landmen and seamen, who have at large or in little, written of the whale. Run over a few: The Authors of the Bible; Aristotle; Pliny; Aldrovandi; Sir Thomas Browne; Gesner; Ray; Linnæus; Rondeletius; Willoughby; Green; Artdi; Sibbald; Brisson; Marten; Lacépède; Bonnetterre; Desmarest; Baron Cuvier; Frederick Cuvier; John Hunter; Owen; Scoresby; Beale; Bennett; J. Ross Browne; the Author of Miriam Coffin; Olmstead; and the Rev. T. Cheever. But to what ultimate generalizing purpose all these have written, the above cited extracts will show.

Of the names in this list of whale authors, only those following Owen ever saw living whales; and but one of them was a real professional harpooneer and whaler. I mean Captain Scoresby. On the separate subject of the Greenland or right-whale, he is the best existing authority. But Scoresby knew nothing

and says nothing of the great sperm whale, compared with which the Greenland whale is almost unworthy mentioning. And here be it said, that the Greenland whale is an usurper upon the throne of the seas. He is not even by any means the largest of the whales. Yet, owing to the long priority of his claims, and the profound ignorance which, till some seventy years back, invested the then fabulous or utterly unknown sperm-whale, and which ignorance to this present day still reigns in all but some few scientific retreats and whale-ports; this usurpation has been every way complete. Reference to nearly all the leviathanic allusions in the great poets of past days, will satisfy you that the Greenland whale, without one rival, was to them the monarch of the seas. But the time has at last come for a new proclamation. This is Charing Cross; hear ye! good people all,—the Greenland whale is deposed,—the great sperm whale now reigneth!

There are only two books in being which at all pretend to put the living sperm whale before you, and at the same time, in the remotest degree succeed in the attempt. Those books are Beale's and Bennett's; both in their time surgeons to English South-Sea whale-ships, and both exact and reliable men. The original matter touching the sperm whale to be found in their volumes is necessarily small; but so far as it goes, it is of excellent quality, though mostly confined to scientific description. As yet, however, the sperm whale, scientific or poetic, lives not complete in any literature. Far above all other hunted whales, his is an unwritten life.

Now the various species of whales need some sort of popular comprehensive classification, if only an easy outline one for the present, hereafter to be filled in all its departments by subsequent laborers. As no better man advances to take this matter in hand, I hereupon offer my own poor endeavors. I promise nothing complete; because any human thing supposed to be complete, must for that very reason infallibly be faulty. I shall not pretend to a minute anatomical description of the various species, or—in this place at least—to much of any description. My object here is simply to project the draught of a systematization of cetology. I am the architect, not the builder.

But it is a ponderous task; no ordinary letter-sorter in the Post-Office is equal to it. To grope down into the bottom of the sea after them; to have one's hands among the unspeakable foundations, ribs, and very pelvis of the world; this is a fearful thing. What am I that I should essay to hook the nose of this leviathan! The awful tauntings in Job might well appal me. Will he (the leviathan) make a covenant with thee? Behold the hope of him is vain! But I have swam through libraries and sailed through oceans; I have had to do with whales with these visible hands; I am in earnest; and I will try. There are some preliminaries to settle.

First: The uncertain, unsettled condition of this science of Cetology is in the very vestibule attested by the fact, that in some quarters it still remains a moot point whether a whale be a fish. In his *System of Nature*, A.D. 1776, Linnæus declares, "I hereby separate the whales from the fish." But of my own knowledge, I know that down to the year 1850, sharks and shad, alewives and herring, against Linnæus's express edict, were still found dividing the possession of the same seas with the Leviathan.

The grounds upon which Linnæus would fain have banished the whales from the waters, he states as follows: "On account of their warm bilocular heart, their lungs, their movable eyelids, their hollow ears, penem intransantem feminam mammis lactantem," and finally, "ex lege naturæ jure meritoque." I submitted all this to my friends Simeon Macey and Charley Coffin, of Nantucket, both messmates of mine in a certain voyage, and they united in the opinion that the reasons set forth were altogether insufficient. Charley profanely hinted they were humbug.

Be it known that, waiving all argument, I take the good old fashioned ground that the whale is a fish, and call upon holy Jonah to back me. This fundamental thing settled, the next point is, in what internal respect does the whale differ from other fish. Above, Linnæus has given you those items. But in brief, they are these: lungs and warm blood; whereas, all other fish are lungless and cold blooded.

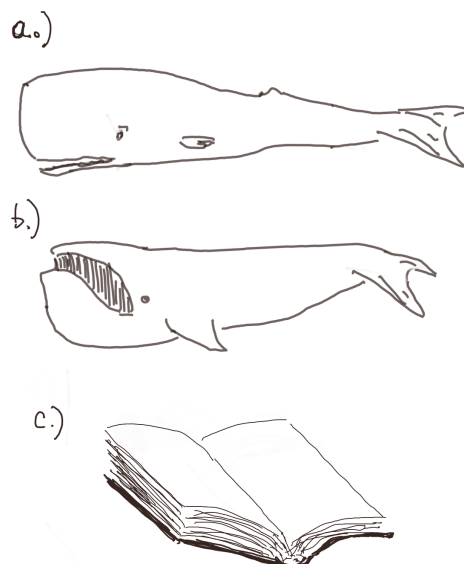


Figure 2-1. (a) *Sperm Whale* (b) *Right Whale*, (c) “... or, *The Whale*”.

Next: how shall we define the whale, by his obvious externals, so as conspicuously to label him for all time to come? To be short, then, a whale is a spouting fish with a horizontal tail. There you have him. However contracted, that definition is the result of expanded meditation. A walrus spouts much like a whale, but the walrus is not a fish, because he is amphibious. But the last term of the definition is still more cogent, as coupled with the first. Almost any one must have noticed that all the fish familiar to landsmen have not a flat, but a vertical, or up-and-down tail. Whereas, among spouting fish the tail, though it may be similarly shaped, invariably assumes a horizontal position.

By the above definition of what a whale is, I do by no means exclude from the leviathanic brotherhood any sea creature hitherto identified with the whale by the best informed Nantucketers; nor, on the other hand, link with it any fish hitherto authoritatively regarded as alien ¹ Hence, all the smaller, spouting, and horizontal tailed fish must be included in this ground-plan of Cetology. Now, then, come the grand divisions of the entire whale host.

First: According to magnitude I divide the whales into three primary BOOKS (subdivisible into CHAPTERS), and these shall comprehend them all, both small and large.

I. THE FOLIO WHALE; II. the OCTAVO WHALE; III. the DUODECIMO WHALE.

As the type of the FOLIO I present the Sperm Whale; of the OCTAVO, the Grampus; of the DUODECIMO, the Porpoise.

¹I am aware that down to the present time, the fish styled Lamatins and Dugongs (Pig-fish and Sow-fish of the Coffins of Nantucket) are included by many naturalists among the whales. But as these pig-fish are a noisy, contemptible set, mostly lurking in the mouths of rivers, and feeding on wet hay, and especially as they do not spout, I deny their credentials as whales; and have presented them with their passports to quit the Kingdom of Cetology.

2.1 Folio

FOLIOS. Among these I here include the following chapters:—I. The Sperm Whale; II. the Right Whale; III. the Fin-Back Whale; IV. the Hump-backed Whale; V. the Razor Back Whale; VI. the Sulphur Bottom Whale. (See Fig. 2-1.)

2.1.1 Sperm Whale

BOOK I. (Folio), CHAPTER I. (Sperm Whale).—This whale, among the English of old vaguely known as the Trumpha whale, and the Physeter whale, and the Anvil Headed whale, is the present Cachalot of the French, and the Pottsfich of the Germans, and the Macrocephalus of the Long Words. He is, without doubt, the largest inhabitant of the globe; the most formidable of all whales to encounter; the most majestic in aspect; and lastly, by far the most valuable in commerce; he being the only creature from which that valuable substance, spermaceti, is obtained. All his peculiarities will, in many other places, be enlarged upon. It is chiefly with his name that I now have to do. Philologically considered, it is absurd. Some centuries ago, when the Sperm whale was almost wholly unknown in his own proper individuality, and when his oil was only accidentally obtained from the stranded fish; in those days spermaceti, it would seem, was popularly supposed to be derived from a creature identical with the one then known in England as the Greenland or Right Whale. It was the idea also, that this same spermaceti was that quickening humor of the Greenland Whale which the first syllable of the word literally expresses. In those times, also, spermaceti was exceedingly scarce, not being used for light, but only as an ointment and medicament. It was only to be had from the druggists as you nowadays buy an ounce of rhubarb. When, as I opine, in the course of time, the true nature of spermaceti became known, its original name was still retained by the dealers; no doubt to enhance its value by a notion so strangely significant of its scarcity. And so the appellation must at last have come to be bestowed upon the whale from which this spermaceti was really derived.

2.1.2 Right Whale

BOOK I. (Folio), CHAPTER II. (Right Whale).—In one respect this is the most venerable of the leviathans, being the one first regularly hunted by man. It yields the article commonly known as whalebone or baleen; and the oil specially known as “whale oil,” an inferior article in commerce. Among the fishermen, he is indiscriminately designated by all the following titles: The Whale; the Greenland Whale; the Black Whale; the Great Whale; the True Whale; the Right Whale. There is a deal of obscurity concerning the identity of the species thus multitudinously baptised. What then is the whale, which I include in the second species of my Folios? It is the Great Mysticetus of the English naturalists; the Greenland Whale of the English whalemens; the Baleine Ordinaire of the French whalemens; the Growlands Walfish of the Swedes. It is the whale which for more than two centuries past has been hunted by the Dutch and English in the Arctic seas; it is the whale which the American fishermen have long pursued in the Indian ocean, on the Brazil Banks, on the Nor’ West Coast, and various other parts of the world, designated by them Right Whale Cruising Grounds.

Some pretend to see a difference between the Greenland whale of the English and the right whale of the Americans. But they precisely agree in all their grand features; nor has there yet been presented a single determinate fact upon which to ground a radical distinction. It is by endless subdivisions based upon the

most inconclusive differences, that some departments of natural history become so repellingly intricate. The right whale will be elsewhere treated of at some length, with reference to elucidating the sperm whale.

2.1.3 Fin-Back Whale

BOOK I. (Folio), CHAPTER III. (Fin-Back).—Under this head I reckon a monster which, by the various names of Fin-Back, Tall-Spout, and Long-John, has been seen almost in every sea and is commonly the whale whose distant jet is so often descried by passengers crossing the Atlantic, in the New York packet-tracks. In the length he attains, and in his baleen, the Fin-back resembles the right whale, but is of a less portly girth, and a lighter colour, approaching to olive. His great lips present a cable-like aspect, formed by the intertwisting, slanting folds of large wrinkles. His grand distinguishing feature, the fin, from which he derives his name, is often a conspicuous object. This fin is some three or four feet long, growing vertically from the hinder part of the back, of an angular shape, and with a very sharp pointed end. Even if not the slightest other part of the creature be visible, this isolated fin will, at times, be seen plainly projecting from the surface. When the sea is moderately calm, and slightly marked with spherical ripples, and this gnomon-like fin stands up and casts shadows upon the wrinkled surface, it may well be supposed that the watery circle surrounding it somewhat resembles a dial, with its style and wavy hour-lines graved on it. On that Ahaz-dial the shadow often goes back. The Fin-Back is not gregarious. He seems a whale-hater, as some men are man-haters. Very shy; always going solitary; unexpectedly rising to the surface in the remotest and most sullen waters; his straight and single lofty jet rising like a tall misanthropic spear upon a barren plain; gifted with such wondrous power and velocity in swimming, as to defy all present pursuit from man; this leviathan seems the banished and unconquerable Cain of his race, bearing for his mark that style upon his back. From having the baleen in his mouth, the Fin-Back is sometimes included with the right whale, among a theoretic species denominated Whalebone whales, that is, whales with baleen. Of these so called Whalebone whales, there would seem to be several varieties, most of which, however, are little known. Broad-nosed whales and beaked whales; pike-headed whales; bunched whales; under-jawed whales and rostrated whales, are the fishermen's names for a few sorts.

In connection with this appellative of "Whalebone whales", it is of great importance to mention, that however such a nomenclature may be convenient in facilitating allusions to some kind of whales, yet it is in vain to attempt a clear classification of the Leviathan, founded upon either his baleen, or hump, or fin, or teeth; notwithstanding that those marked parts or features very obviously seem better adapted to afford the basis for a regular system of Cetology than any other detached bodily distinctions, which the whale, in his kinds, presents. How then? The baleen, hump, back-fin, and teeth; these are things whose peculiarities are indiscriminately dispersed among all sorts of whales, without any regard to what may be the nature of their structure in other and more essential particulars. Thus, the sperm whale and the humpbacked whale, each has a hump; but there the similitude ceases. Then, this same humpbacked whale and the Greenland whale, each of these has baleen; but there again the similitude ceases. And it is just the same with the other parts above mentioned. In various sorts of whales, they form such irregular combinations; or, in the case of any one of them detached, such an irregular isolation; as utterly to defy all general methodization formed upon such a basis. On this rock every one of the whale-naturalists has split.

But it may possibly be conceived that, in the internal parts of the whale, in his anatomy—there, at least, we shall be able to hit the right classification. Nay; what thing, for example, is there in the Greenland whale's anatomy more striking than his baleen? Yet we have seen that by his baleen it is impossible correctly to classify the Greenland whale. And if you descend into the bowels of the various leviathans, why there you will not find distinctions a fiftieth part as available to the systematizer as those external ones already enumerated. What then remains? nothing but to take hold of the whales bodily, in their entire liberal

volume, and boldly sort them that way. And this is the Bibliographical system here adopted; and it is the only one that can possibly succeed, for it alone is practicable. To proceed.

2.1.4 Hump Back Whale

BOOK I. (Folio) CHAPTER IV. (Hump Back).—This whale is often seen on the northern American coast. He has been frequently captured there, and towed into harbor. He has a great pack on him like a peddler; or you might call him the Elephant and Castle whale. At any rate, the popular name for him does not sufficiently distinguish him, since the sperm whale also has a hump though a smaller one. His oil is not very valuable. He has baleen. He is the most gamesome and light-hearted of all the whales, making more gay foam and white water generally than any other of them.

2.1.5 Razor Back Whale

BOOK I. (Folio), CHAPTER V. (Razor Back).—Of this whale little is known but his name. I have seen him at a distance off Cape Horn. Of a retiring nature, he eludes both hunters and philosophers. Though no coward, he has never yet shown any part of him but his back, which rises in a long sharp ridge. Let him go. I know little more of him, nor does anybody else.

2.1.6 Sulphur Bottom Whale

BOOK I. (Folio), CHAPTER VI. (Sulphur Bottom).—Another retiring gentleman, with a brimstone belly, doubtless got by scraping along the Tartarian tiles in some of his profounder divings. He is seldom seen; at least I have never seen him except in the remoter southern seas, and then always at too great a distance to study his countenance. He is never chased; he would run away with rope-walks of line. Prodigies are told of him. Adieu, Sulphur Bottom! I can say nothing more that is true of ye, nor can the oldest Nantucketer.

Thus ends BOOK I. (Folio), and now begins BOOK II. (Octavo).

2.2 Octavo

OCTAVOES.*—These embrace the whales of middling magnitude, among which present may be numbered:—I., the Grampus; II., the Black Fish; III., the Narwhale; IV., the Thrasher; V., the Killer.

*Why this book of whales is not denominated the Quarto is very plain. Because, while the whales of this order, though smaller than those of the former order, nevertheless retain a proportionate likeness to them in figure, yet the bookbinder's Quarto volume in its dimensioned form does not preserve the shape of the Folio volume, but the Octavo volume does.

2.2.1 Grampus

BOOK II. (Octavo), CHAPTER I. (Grampus).—Though this fish, whose loud sonorous breathing, or rather blowing, has furnished a proverb to landsmen, is so well known a denizen of the deep, yet is he not popularly classed among whales. But possessing all the grand distinctive features of the leviathan, most naturalists have recognised him for one. He is of moderate octavo size, varying from fifteen to twenty-five feet in length, and of corresponding dimensions round the waist. He swims in herds; he is never regularly hunted, though his oil is considerable in quantity, and pretty good for light. By some fishermen his approach is regarded as premonitory of the advance of the great sperm whale.

2.2.2 Black Fish

BOOK II. (Octavo), CHAPTER II. (Black Fish).—I give the popular fishermen's names for all these fish, for generally they are the best. Where any name happens to be vague or inexpressive, I shall say so, and suggest another. I do so now, touching the Black Fish, so-called, because blackness is the rule among almost all whales. So, call him the Hyena Whale, if you please. His voracity is well known, and from the circumstance that the inner angles of his lips are curved upwards, he carries an everlasting Mephistophelean grin on his face. This whale averages some sixteen or eighteen feet in length. He is found in almost all latitudes. He has a peculiar way of showing his dorsal hooked fin in swimming, which looks something like a Roman nose. When not more profitably employed, the sperm whale hunters sometimes capture the Hyena whale, to keep up the supply of cheap oil for domestic employment—as some frugal housekeepers, in the absence of company, and quite alone by themselves, burn unsavory tallow instead of odorous wax. Though their blubber is very thin, some of these whales will yield you upwards of thirty gallons of oil.

2.2.3 Narwhale

BOOK II. (Octavo), CHAPTER III. (Narwhale), that is, Nostril whale.—Another instance of a curiously named whale, so named I suppose from his peculiar horn being originally mistaken for a peaked nose. The creature is some sixteen feet in length, while its horn averages five feet, though some exceed ten, and even attain to fifteen feet. Strictly speaking, this horn is but a lengthened tusk, growing out from the jaw in a line a little depressed from the horizontal. But it is only found on the sinister side, which has an ill effect, giving its owner something analogous to the aspect of a clumsy left-handed man. What precise purpose this ivory horn or lance answers, it would be hard to say. It does not seem to be used like the blade of the sword-fish and bill-fish; though some sailors tell me that the Narwhale employs it for a rake in turning over the bottom of the sea for food. Charley Coffin said it was used for an ice-piercer; for the Narwhale, rising to the surface of the Polar Sea, and finding it sheeted with ice, thrusts his horn up, and so breaks through. But you cannot prove either of these surmises to be correct. My own opinion is, that however this one-sided horn may really be used by the Narwhale—however that may be—it would certainly be very convenient to him for a folder in reading pamphlets. The Narwhale I have heard called the Tusked whale, the Horned whale, and the Unicorn whale. He is certainly a curious example of the Unicornism to be found in almost every kingdom of animated nature. From certain cloistered old authors I have gathered that this same sea-unicorn's horn was in ancient days regarded as the great antidote against poison, and as such, preparations of it brought immense prices. It was also distilled to a volatile salts for fainting ladies, the same way that the horns of the male deer are manufactured into hartshorn. Originally it was in itself accounted an object of great curiosity. Black Letter tells me that Sir Martin Frobisher on his return from that voyage, when Queen Bess did gallantly wave her

jewelled hand to him from a window of Greenwich Palace, as his bold ship sailed down the Thames; “when Sir Martin returned from that voyage,” saith Black Letter, “on bended knees he presented to her highness a prodigious long horn of the Narwhale, which for a long period after hung in the castle at Windsor.” An Irish author avers that the Earl of Leicester, on bended knees, did likewise present to her highness another horn, pertaining to a land beast of the unicorn nature.

The Narwhale has a very picturesque, leopard-like look, being of a milk-white ground colour, dotted with round and oblong spots of black. His oil is very superior, clear and fine; but there is little of it, and he is seldom hunted. He is mostly found in the circumpolar seas.

2.2.4 Killer Whale

BOOK II. (Octavo), CHAPTER IV. (Killer).—Of this whale little is precisely known to the Nantucketer, and nothing at all to the professed naturalist. From what I have seen of him at a distance, I should say that he was about the bigness of a grampus. He is very savage—a sort of Feegee fish. He sometimes takes the great Folio whales by the lip, and hangs there like a leech, till the mighty brute is worried to death. The Killer is never hunted. I never heard what sort of oil he has. Exception might be taken to the name bestowed upon this whale, on the ground of its indistinctness. For we are all killers, on land and on sea; Bonapartes and Sharks included.

2.2.5 Thrasher Whale

BOOK II. (Octavo), CHAPTER V. (Thrasher).—This gentleman is famous for his tail, which he uses for a ferule in thrashing his foes. He mounts the Folio whale’s back, and as he swims, he works his passage by flogging him; as some schoolmasters get along in the world by a similar process. Still less is known of the Thrasher than of the Killer. Both are outlaws, even in the lawless seas.

Thus ends BOOK II. (Octavo), and begins BOOK III. (Duodecimo).

2.3 Duodecimo

DUODECIMOES.—These include the smaller whales. I. The Huzza Porpoise. II. The Algerine Porpoise. III. The Mealy-mouthed Porpoise.

To those who have not chanced specially to study the subject, it may possibly seem strange, that fishes not commonly exceeding four or five feet should be marshalled among WHALES—a word, which, in the popular sense, always conveys an idea of hugeness. But the creatures set down above as Duodecimoes are infallibly whales, by the terms of my definition of what a whale is—i.e. a spouting fish, with a horizontal tail.

2.3.1 Huzza Porpoise

BOOK III. (Duodecimo), CHAPTER 1. (Huzza Porpoise).—This is the common porpoise found almost all over the globe. The name is of my own bestowal; for there are more than one sort of porpoises, and

something must be done to distinguish them. I call him thus, because he always swims in hilarious shoals, which upon the broad sea keep tossing themselves to heaven like caps in a Fourth-of-July crowd. Their appearance is generally hailed with delight by the mariner. Full of fine spirits, they invariably come from the breezy billows to windward. They are the lads that always live before the wind. They are accounted a lucky omen. If you yourself can withstand three cheers at beholding these vivacious fish, then heaven help ye; the spirit of godly gamesomeness is not in ye. A well-fed, plump Huzza Porpoise will yield you one good gallon of good oil. But the fine and delicate fluid extracted from his jaws is exceedingly valuable. It is in request among jewellers and watchmakers. Sailors put it on their hones. Porpoise meat is good eating, you know. It may never have occurred to you that a porpoise spouts. Indeed, his spout is so small that it is not very readily discernible. But the next time you have a chance, watch him; and you will then see the great Sperm whale himself in miniature.

2.3.2 Algerine Porpoise

BOOK III. (Duodecimo), CHAPTER II. (Algerine Porpoise).—A pirate. Very savage. He is only found, I think, in the Pacific. He is somewhat larger than the Huzza Porpoise, but much of the same general make. Provoke him, and he will buckle to a shark. I have lowered for him many times, but never yet saw him captured.

2.3.3 Mealy-mouthed Porpoise

BOOK III. (Duodecimo), CHAPTER III. (Mealy-mouthed Porpoise).—The largest kind of Porpoise; and only found in the Pacific, so far as it is known. The only English name, by which he has hitherto been designated, is that of the fishers—Right-Whale Porpoise, from the circumstance that he is chiefly found in the vicinity of that Folio. In shape, he differs in some degree from the Huzza Porpoise, being of a less rotund and jolly girth; indeed, he is of quite a neat and gentleman-like figure. He has no fins on his back (most other porpoises have), he has a lovely tail, and sentimental Indian eyes of a hazel hue. But his mealy-mouth spoils all. Though his entire back down to his side fins is of a deep sable, yet a boundary line, distinct as the mark in a ship's hull, called the "bright waist," that line streaks him from stem to stern, with two separate colours, black above and white below. The white comprises part of his head, and the whole of his mouth, which makes him look as if he had just escaped from a felonious visit to a meal-bag. A most mean and mealy aspect! His oil is much like that of the common porpoise.

2.4 Miscellaneous papers

Beyond the DUODECIMO, this system does not proceed, inasmuch as the Porpoise is the smallest of the whales. Above, you have all the Leviathans of note. But there are a rabble of uncertain, fugitive, half-fabulous whales, which, as an American whaler, I know by reputation, but not personally. I shall enumerate them by their fore-castle appellations; for possibly such a list may be valuable to future investigators, who may complete what I have here but begun. If any of the following whales, shall hereafter be caught and marked, then he can readily be incorporated into this System, according to his Folio, Octavo, or Duodecimo magnitude:—The Bottle-Nose Whale; the Junk Whale; the Pudding-Headed Whale; the Cape Whale; the Leading Whale; the Cannon Whale; the Scragg Whale; the Coppered Whale; the Elephant Whale; the

Iceberg Whale; the Quog Whale; the Blue Whale; etc. From Icelandic, Dutch, and old English authorities, there might be quoted other lists of uncertain whales, blessed with all manner of uncouth names. But I omit them as altogether obsolete; and can hardly help suspecting them for mere sounds, full of Leviathanism, but signifying nothing.

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Neutrino Physics Frontier

P. Huber, K. Scholberg, E. Worcester

J. Asaadi, B. Balantekin, N. Bowden, P. Coloma, P. B. Denton, L. Fields, M. Friend, C. Giunti, B. Jones, J. Link, B. Littlejohn, G. Karagiorgi, L. Kaufman, J. Klein, L. Koerner, Y. Koshio, P. Machado, K. Mahn, A. Machado, A. Marino, M. Messier, J. Newbry, P. Ochoa, G. D. Orebi Gann, E. O’Sullivan, D. Parno, D. Schmitz, I. Shoemaker, A. Sousa, J. Spitz, R. Strauss, H. Tanaka, I. Tamborra, W. Wang, J. Yu

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“No branch of Zoology is so much involved as that which is entitled Cetology,” says Captain Scoresby, A.D. 1820 [1].

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“Unfitness to pursue our research in the unfathomable waters.” “Impenetrable veil covering our knowledge of the cetacea.” “A field strewn with thorns.” “All these incomplete indications but serve to torture us naturalists.”

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Rare Processes and Precision Measurements

M. Artuso, R. Bernstein, A. A. Petrov

T. Blum, A. Di Canto, S. Davidson, B. Echenard, P. Fileviez Perez, S. Gori, E. Goudzovski, R. Lebed, S. Meinel, E. Passemar, A. Pocar, T. Skwarnicki, M. Williams, P. Winter

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Cosmic Frontier

A. Chou, M. Soares-Santos, T. M. P. Tait

R. Adhikari, L. Anchordoqui, J. Annis, C. Chang, C. Chang, J. Cooley, A. Drlica-Wagner, K. Fang, B. Flaugher, J. Jaeckel, T. Lin, H. Lippincott, L. Newburgh, J. Newman, C. Prescod-Weinstein, G. Rybka, B. S. Sathyaprakash, D. Schlegel, D. Shoemaker, T. Slatyer, A. Slosar, K. Tollefson, L. Winslow, H.-B. Yu

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Theory Frontier

N. Craig, C. Csaki, A. El-Khadra

Z. Bern, R. Boughezal, S. Catterall, Z. Davoudi, P. Draper, P. Fox, A. de Gouvêa, D. Green, D. Harlow, R. Harnik, V. Hubeny, T. Izubuchi, S. Kachru, G. Kribs, H. Murayama, Z. Ligeti, J. Maldacena, F. Maltoni, I. Mocioiu, E. Neil, S. Pastore, D. Poland, L. Rastelli, I. Rothstein, J. Ruderman, B. Safdi, J. Shelton, L. Stringari, S. Su, J. Thaler, J. Trnka

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Accelerator Frontier

S. Gourlay, T. Raubenheimer, V. Shiltsev

G. Arduini, R. Assmann, C. Barbier, M. Bei, S. Belomestnykh, S. Bermudez, J. Galambos, C. Geddes, G. Hoffstaetter, M. Hogan, Z. Huang, M. Lamont, S. Lund, R. Milner, P. Musumeci, E. Nanni, Q. Qin, M. Palmer, N. Pastrone, F. Pellemoine, E. Prebys, M. Ross, G. Sabbi, Y.-E. Sun, J. Tang, A. Valishev, H. Weise, S. Zlobin, B. Zwaska

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Instrumentation Frontier

P. Barbeau, P. Merkel, J. Zhang

D. Acosta, T. Affolder, A. Apresyan, J. J. Beatty, G. Carini, T. Cecil, E Dahl, J. Estrada, J. Fast, R. Guenette, K. Irwin, W. Ketchum, R. Maruyama, S. Majewski, M. Garcia-Sciveres, M. Newcomer, J. Parsons, M. Pyle, M. Sanchez, J. Raff, C. Rogan, I. Shipsey, B. Surrow, M. Titov, S. Vahsen, A. Viereg, A. White, S. Worm, M. Yeh, R. Yohay

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Computational Frontier

S. Gottlieb, O. Gutsche, B. Nachman

W. Bhimji, P. Boyle, G. Cerati, M. Carrasco Kind, K. Cranmer, G. Davies, V. D. Elvira, R. Gardner,
K. Heitmann, W. Hopkins, T. Humble, P. Onyisi, J. Qiang, G. Perdue, A. Roberts, M. Savage,
P. Shanahan, K. Terao, D. Whiteson, F. Weurthwein

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Underground Facilities

L. Baudis, J. Hall, K. Lesko, J. Orrell

(topical group conveners are not listed on the Snowmass wiki)

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[. . .]

Finally: It was stated at the outset, that this system would not be here, and at once, perfected. You cannot but plainly see that I have kept my word. But I now leave my cetological System standing thus unfinished, even as the great Cathedral of Cologne was left, with the crane still standing upon the top of the uncompleted tower. For small erections may be finished by their first architects; grand ones, true ones, ever leave the copestone to posterity. God keep me from ever completing anything. This whole book is but a draught—nay, but the draught of a draught. Oh, Time, Strength, Cash, and Patience!

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Community Engagement Frontier

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Already we are boldly launched upon the deep; but soon we shall be lost in its unshored, harbourless immensities. Ere that come to pass; ere the Pequod's weedy hull rolls side by side with the barnacled hulls of the leviathan; at the outset it is but well to attend to a matter almost indispensable to a thorough appreciative understanding of the more special leviathanic revelations and allusions of all sorts which are to follow.

It is some systematized exhibition of the whale in his broad genera, that I would now fain put before you. Yet is it no easy task. The classification of the constituents of a chaos, nothing less is here essayed. Listen to what the best and latest authorities have laid down.

"No branch of Zoology is so much involved as that which is entitled Cetology," says Captain Scoresby, A.D. 1820 [1].

"It is not my intention, were it in my power, to enter into the inquiry as to the true method of dividing the cetacea into groups and families. . . . Utter confusion exists among the historians of this animal" (sperm whale), says Surgeon Beale, A.D. 1839 [2].

"Unfitness to pursue our research in the unfathomable waters." "Impenetrable veil covering our knowledge of the cetacea." "A field strewn with thorns." "All these incomplete indications but serve to torture us naturalists."

Thus speak of the whale, the great Cuvier, and John Hunter, and Lesson, those lights of zoology and anatomy.

[. . .]

Finally: It was stated at the outset, that this system would not be here, and at once, perfected. You cannot but plainly see that I have kept my word. But I now leave my cetological System standing thus unfinished, even as the great Cathedral of Cologne was left, with the crane still standing upon the top of the uncompleted tower. For small erections may be finished by their first architects; grand ones, true ones, ever leave the copestone to posterity. God keep me from ever completing anything. This whole book is but a draught—nay, but the draught of a draught. Oh, Time, Strength, Cash, and Patience!

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Conclusions

We are happy and relieved to conclude.

Glossary

This glossary, from the 2013 volume, is a start on the glossary required for the 2021 volume. Please send requests for changes or new entries to Michael Peskin (mpeskin@slac.stanford.edu), who is maintaining the production version.

$0\nu\beta\beta$: Neutrinoless double-beta decay, a nuclear decay process in which two electrons and zero neutrinos are emitted.

$2\nu\beta\beta$: Double-beta decay, a nuclear decay process in which two electrons and two neutrinos are emitted.

2HDM : Two-Higgs-Doublet Model, a model with two Higgs fields, usually with natural flavor conservation in Higgs boson couplings.

AAAS : American Association for the Advancement of Science.

ACTA : Augmented Cherenkov Telescope Array, the next-generation atmospheric Cherenkov telescope project for gamma ray detection.

ADMX : Axion Dark Matter Experiment, an experiment at the University of Washington searching for axions using a large electromagnetic cavity in a static magnetic field.

ADS : Accelerator-Driven Systems, a technology for driving nuclear reactors with particle beams.

AGILE : Astro-Rivelatore Gamma a Immagini Leggero, a space-based X-ray and gamma ray observatory.

AGN : Active Galactic Nucleus.

AIP : American Institute of Physics.

ALCF : Argonne Leadership Computer Facility.

ALICE : A Large Ion Collider Experiment, an experiment at the **LHC** focusing on heavy ion collisions and the quark-gluon plasma.

ALP : Axion-Like Particle.

ALPS, ALPS-II : Any Light Particle Search, a series of experiments at **DESY** searching for **axions** and similar particles using laser light conversion in a strong magnetic field.

AMANDA : Antarctic Muon and Neutrino Detector Array, the first-generation neutrino telescope experiment in Antarctica.

AMR : Adaptive Mesh Refinement.

AMS, AMS-02 : Alpha Magnetic Spectrometer, an antimatter detector located on the International Space Station.

ANITA : Antarctic Transient Antenna, a balloon experiment in Antarctica for detection of radio signals of ultra-high-energy neutrino events.

ANL : Argonne National Laboratory.

ANTARES : Astronomy with a Neutrino Telescope and Abyss environmental RESearch, a neutrino telescope experiment in the Mediterranean Sea.

APEX : A Prime EXperiment, an experiment at **JLab** searching for the production of dark photons using an intense electron beam.

APS : American Physical Society.

ARA : Askaryan Radio Array, a radiofrequency neutrino antenna experiment at the South Pole.

ArgoNeuT : Argon Neutrino Teststand, a small liquid argon **TPC** experiment at **Fermilab**.

ARIANNA : Antarctic Ross Ice-shelf ANTenna Neutrino Array, a radiofrequency neutrino antenna experiment in Antarctica.

ART : An Intensity Frontier software framework developed by the **Fermilab** Scientific Computing Division and used by **NOvA**, **mu2e**, **Muon $g - 2$** , **LArSoft**, **DarkSide**, **LArIAT**, and others.

ASIC : Application Specific Integrated Circuit, a silicon chip processor designed for a particular purpose.

ASTA : Advanced Superconducting Test Accelerator, an accelerator test facility at **Fermilab**.

ATCA : Advanced Telecommunications Computing Architecture.

ATF, ATF2 : Accelerator Test Facility, an accelerator test complex at **KEK** built to study beam dynamics issues for the *ILC*.

ATLAS : A Toroidal LHC ApparatuS, a large experiment at the **LHC** optimized for high transverse momentum particle production.

ATR : Advanced Test Reactor, a research reactor at the Idaho National Laboratory.

Auger : Pierre Auger Observatory, experiment in Argentina that detects ultra-high-energy cosmic rays through both fluorescence and surface water Cherekov detectors.

Axion : A hypothetical, very light particle, with couplings to quarks that reverse under **P** transformations. Such particles could make up the dark matter of the Universe.

BaBar : An experiment at **SLAC**, using e^+e^- annihilation at approximately 10 GeV to study rare heavy quark and lepton decays.

Baikal : A neutrino telescope in Lake Baikal in Siberia.

Baksan : An underground laboratory in the Caucasus mountains in Russia.

BAO : Baryon Acoustic Oscillations.

Baseline : In neutrino physics, the distance between the neutrino production point, near an accelerator, and the neutrino detector.

BELLA : Berkeley Lab Laser Accelerator, a facility at **LBNL** for the development of laser-driven accelerators.

Belle : An experiment at **KEK**, using e^+e^- annihilation at approximately 10 GeV to study rare heavy quark and lepton decays.

Belle-II : An experiment at **KEK**, using e^+e^- annihilation at approximately 10 GeV to study rare heavy quark and lepton decays with 50-100 times the data set produced by **BaBar** and **Belle**.

BESIII : An experiment at **IHEP**, using e^+e^- annihilation at approximately 3–4 GeV to study charm quark and tau lepton physics.

BEST : Baksan Experiment on Sterile Transitions, a proposed radioactive source experiment in Russia with a gallium detector.

BINP : Budker Institute for Nuclear Physics, a high-energy physics laboratory in Novosibirsk, Russia.

BNB : Booster Neutrino Beam , a neutrino beamline at **Fermilab** using the Booster.

BNL : Brookhaven National Laboratory.

Borexino : A solar neutrino experiment at **Gran Sasso**.

Boson : A type of elementary particle whose intrinsic spin is an integer (0, 1, 2, ...) multiple of \hbar . Such particles can make up a macroscopic force field such as the electromagnetic field.

BOSS : Baryon Oscillation Spectroscopic Survey, a galaxy survey aiming to measure baryon acoustic oscillations.

BR : Branching Ratio, the probability that an unstable particle decays to a particular final state.

BSM : Beyond the Standard Model, a reference to new physics associated with an extension of the **SM**.

C : Charge conjugation, the interchange of particles and antiparticles.

CALICE : CALorimeter for Linear Collider Experiment, an experimental collaboration aimed at improving the technology of hadron calorimeters, especially with the **PFA** method.

Canfranc Underground Laboratory : An underground scientific facility in a former railway tunnel in the Spanish Pyrenees under Monte Tobazo in Canfranc, Spain.

Capability : In computing, refers to high-speed, highly parallel computing that might require a large fraction of a supercomputer.

Capacity : In computing, refers to computing in which many moderately parallel jobs are run alongside one another.

CAPTAIN : Cryogenic Apparatus for Precision Tests of Argon INteractions, a liquid argon R&D detector.

CAST : CERN Axion Solar Telescope, an experiment at **CERN** searching for **axions** radiated from the Sun.

CC : Charged Current weak interactions.

CCD : Charge Coupled Device, a class of pixel silicon detectors.

CDF : Collider Detector at Fermilab, a large experiment at the **Fermilab** Tevatron optimized for high transverse momentum particle production.

CDM : Cold Dark Matter, a class of dark matter models in which the dark matter particles move at nonrelativistic speeds.

CDR : Conceptual Design Report.

Ce-LAND : A ^{144}Ce source to be placed in **KamLAND** to study the reactor neutrino anomaly.

CENNS : Coherent Elastic Neutrino-Nucleus Scattering, an **NC** neutrino process and also a proposed experiment to be sited at the **BNB**.

CE&O : Communication, Education, and Outreach, a topic of one of the “frontiers” in this study.

CERN : Conseil Européen pour la Recherche Nucleaire, the major European high energy physics laboratory, located in Geneva.

CESR : Cornell Electron Storage Ring, an e^+e^- colliding beam accelerator at Cornell University that operated in the energy range 3.5-12 GeV from 1979 to 2008. The accelerator is still in operation as a synchrotron light source (CHESS) and as an accelerator physics testbed.

CesrTA : CESR Test Accelerator, a configuration of **CESR** to study the design of electron damping rings, in particular, for **ILC**.

Chameleon : A new particle that has properties that depend on its environment.

CHIPS : CHerenkov detectors In mine PitS, a proposed experiment to use the **Fermilab** beams and massive Cherenkov detectors in flooded mine pits.

CHOOZ : A first-generation reactor neutrino experiment located in Chooz, France.

CKM : Cabibbo-Kobayashi-Maskawa matrix, the matrix relating the weak interaction and mass eigenstates of quarks.

CL : (Statistical) Confidence Level.

CLEAN : Cryogenic Low Energy Astrophysics with Noble gases, a cryogenic noble liquid experiment for dark matter and solar neutrinos.

CLEO : A general-purpose particle detector at **CESR** studying heavy quark decays and spectroscopy.

CLFV : Charged Lepton Flavor Violation.

CLIC : Compact LInear Collider, a concept for an e^+e^- linear collider, with center of mass energies up to 3 TeV, based on two-beam acceleration.

CM : Center of Mass, the system for viewing a particle collision or decay in which the overall system is at rest.

CMB : Cosmic Microwave Background, the approximately isotropic microwave radiation in the universe created in the original formation of atoms from electrons and ionized protons.

CMS : Compact Muon Spectrometer, a large experiment at the **LHC** optimized for high transverse momentum particle production.

CoGeNT : COherent GERmanium Neutrino Technology, a germanium detector for dark matter and other signals requiring low background.

COMET : An experiment at **J-PARC** searching for muon to electron conversion in the field of a heavy nucleus.

COUPP : Chicagoland Observatory for Underground Particle Physics, a dark matter detector using a bubble chamber, now located in the Sudbury Mine in Sudbury, Ontario.

CP : The combination of a **C** and a **P** transformation, converting particles to antiparticles, plus mirror (left-right) reflection. This is a very accurate, but not perfect, approximate symmetry of nature.

CPAD : Coordinating Panel for Advanced Detectors, an advisory panel on detector technology created by the **APS DPF**.

CPT : The combination of a **C**, and a **P**, and a **T** transformation, converting particles to antiparticles, plus mirror (left-right) reflection, plus reversal of the direction of time. Local quantum field theory predicts this to be a perfect symmetry of nature.

CPU : Central Processing Unit of a computer.

CRADA : Cooperative Research and Development Agreement, an agreement between a government laboratory and a private company to pursue R&D on a technology or project.

CSI : Coherent Scattering Investigations at the SNS, a proposed **CENNS** search experiment for the **SNS**.

CTA : Cherenkov Telescope Array, a planned large-area array of telescopes for high energy gamma rays.

CTF3 : CLIC Test Facility 3, the most recent in a series of test accelerators for **CLIC** at **CERN**.

CUDA : Compute Unified Device Architecture, which defines a parallel computing architecture for NVIDIA GPUs.

CUORE : Cryogenic Underground Observatory for Rare Events, an experiment searching for neutrinoless double beta decay, located at **Gran Sasso**, Italy.

DØ : D-zero, a large experiment at the **Fermilab** Tevatron optimized for high transverse momentum particle production.

DAEδALUS : Decay At rest Experiment for δ_{CP} studies at the Laboratory for Underground Science, a neutrino oscillation experiment based on beams created by cyclotrons.

DAMA : DArk MAtter experiment, a scintillator-based dark matter search experiment at **Gran Sasso**.

DAMIC : DArk Matter In CCD experiment, an experiment at **Fermilab** searching for light dark matter particles.

DANSS : Detector of the reactor AntiNeutrino based on Solid-state plastic Scintillator, a reactor neutrino experiment in Russia.

Dark Light : An experiment at **JLab** searching for dark photons using an **FEL**.

DarkSide : A dark matter search experiment at **Gran Sasso** using a liquid argon detector.

Daya Bay : A reactor neutrino experiment located near Daya Bay, China.

DeepCore : A low-energy extension to the **IceCube** experiment with a high density of photodetectors in a central region of the cube.

DES : Dark Energy Survey.

DESI : Dark Energy Spectroscopic Instrument.

DESY : Deutsches Elektronen SYNchrotron, the major high energy physics laboratory in Germany, located in Hamburg.

DIRC : Detection of Internally Reflected Cherenkov light, a detector using quartz bars for tracking and particle identification.

DIS : Deep Inelastic Scattering, a process of lepton scattering from a nucleon or nucleus with large momentum transfer, especially when only the lepton recoil is observed.

DM : Dark Matter.

DOE : U.S. Department of Energy.

Double Chooz : A reactor neutrino experiment in Chooz, France, utilizing detectors at two distances from the source.

DPF : Division of Particles and Fields, a division of the American Physical Society.

DREAM : Dual REAdout Method, a method for hadron calorimetry that corrects the charge/neutral response ratio by separate measurement of Cherenkov and scintillation light.

Drive beam : A high energy particle beam used to create an electromagnetic field that can then accelerate another beam to high energy.

DSNB : Diffuse Supernova Neutrino Background.

dSphs : dwarf Spheroidal satellite galaxies of the Milky Way.

EAS : Extensive Air Shower, produced by high energy cosmic rays in the Earth's atmosphere.

EBL : Extra-galactic Background Light.

ECHo : Electron Capture ^{163}Ho experiment, a proposed neutrino mass microcalorimeter experiment.

EDM : Electric Dipole Moment.

EFT : Effective Field Theory, a method of quantum field theory in which the effects of new particles or interactions that might be present at high energies are expressed by the addition of more complex operators to the equations of motion of the **SM**.

ESA : European Space Agency.

ESS : European Spallation Source, a future facility in Lund, Sweden.

ESS ν SB : European Spallation Source Neutrino Super Beam, a proposal to use the **ESS** proton linac to generate a neutrino superbeam.

\cancel{E}_T : Missing Transverse Energy, unobserved momentum in a high-energy particle collision carried away by weakly interacting neutral particles.

Euclid : A dark energy space mission currently under development by the European Space Agency.

EVA : ExaVolt Antenna, a proposed balloon-based neutrino antenna experiment in Antarctica.

EW : ElectroWeak interaction, the unified description of the electromagnetic and weak interactions.

EWSB : ElectroWeak Symmetry Breaking.

Exascale : Of the order of 10^{18} , used in computing to refer to next-generation computation resources in memory or speed.

EXO : Enriched Xenon Observatory, an experiment searching for neutrinoless double beta decay of the isotope Xe^{136} .

FACA : Federal Advisory Committee Act, the legislation that governs questions of openness and transparency for certain Federal committees. The act generally covers grant review panels of the **NSF** but not those of the **DOE**.

FACET : Facility for advanced ACcelerator Experimental Tests, a user facility at **SLAC** for experiments on high-gradient electron accelerator technology.

FCNC : Flavor-Changing Neutral Current.

FEL : Free Electron Laser, an electron accelerator that produces high-intensity coherent synchrotron radiation.

Fermi : Femtometer = 10^{-13} cm.

Fermi-LAT : Fermi Large Area Telescope, a space-based gamma-ray detector.

Fermion : A type of elementary particle whose intrinsic spin is a half-integer ($\frac{1}{2}, \frac{3}{2}, \dots$) multiple of \hbar . Such particles can form rigid structures of matter such as atoms and atomic nuclei.

Fermilab : Fermi National Accelerator Laboratory, in Batavia, Illinois.

FFAG : Fixed-Field Alternating Gradient accelerator, an accelerator design concept with time-independent magnetic bending fields and strong focusing.

FPGA : Field Programmable Gate Array, a type of programmable integrated circuit.

FNAL : Fermi National Accelerator Laboratory, or **Fermilab**.

FRIB : Facility for Rare Isotope Beams, a linear accelerator at Michigan State University for isotope production and nuclear structure research.

FrPNC : Francium Parity Non-Conservation, at experiment at **TRIUMF** to measure **P**-violating atomic transitions in francium atoms.

FSR : Final State Radiation, radiation from a lepton, quark, or gluon produced in a high-energy scattering process.

GALLEX : GALLium EXperiment, a radiochemical solar neutrino experiment located at **Gran Sasso**.

GammeV-CHASE : An experiment at **Fermilab** to search for **axions** using a laser beam in a strong magnetic field.

GAPS : General Antiparticle Spectrometer, an experiment to detect anti-matter, especially deuterons, produced by annihilating dark matter particles.

GC : Galactic Center.

GDE : Global Design Effort, the collaboration responsible for the **ILC** Technical Design Report.

GEANT4 : A library of simulation programs describing the passage of high-energy particles through matter.

GEM : Gas Electron Multiplier, a type of **MPGD** ionization detector.

GEMMA : Germanium Experiment for measurement of the Magnetic Moment of Antineutrino, a neutrino magnetic moment experiment at the Kalinin nuclear power plant in Russia.

GERDA : Ge experiment searching for neutrinoless double beta decay.

GeV : Giga-electron Volt (10^9 eV), the energy scale of the proton mass and the subnuclear strong interactions.

GIM : Glashow-Iliopoulos-Maiani mechanism, a method for coupling quarks to the weak interactions that avoid flavor-changing **NC** processes, realized in the **SM**.

GLACIER : Giant Liquid Argon Charge Imaging Experiment, a proposed large liquid argon detector in Europe.

GNO : Gallium Neutrino Observatory, a radiochemical solar neutrino experiment at **Gran Sasso** (successor to **GALLEX**).

GPU : Graphics Processing Unit.

GR : General Relativity, Einstein's theory of gravity.

Gran Sasso : An Italian national laboratory under a mountain of the same name, about 120 km from Rome.

Grid : In computing, a network of distributed computer and storage resources. Typically, it refers to a network in which users need not know at which node the processor or data they are using resides.

GUT : Grand Unified Theory, a unified theory of all microscopic particle interactions.

GZK neutrinos : Greisen-Zatsepin-Kuzmin neutrinos, produced by ultra-high energy cosmic ray protons scattering off **CMB** photons.

HALO : Helium And Lead Observatory, lead-based supernova neutrino detector at **SNOLAB**.

HAWC : High-Altitude Water Cherenkov, a gamma-ray detector currently operating in Mexico.

HE-LHC : High-Energy LHC, a proposed stage of the **LHC** in which the bending magnets are replaced by higher-field magnetics, to create pp collisions at center-of-mass energies of 26–33 TeV.

H.E.S.S. : High Energy Stereoscopic System, a telescope for high-energy gamma rays seen as air showers in Cherenkov radiation, located in Namibia.

HEP : High-Energy Physics, the generic term for the areas of research described in this report.

HEPAP : High-Energy Physics Advisory Panel, a panel convened by the U.S. **DOE** and **NSF** to advise the federal government on high-energy physics research.

HERA : Hadron Elektron Ring Anlage, an electron-proton and positron-proton collider at **DESY** that operated from 1990 to 2007.

- HETDEX** : Hobby-Eberly Telescope Dark Energy Experiment.
- HFIR** : High Flux Isotope Reactor, reactor facility at Oak Ridge National Laboratory.
- HHCAL** : Homogeneous Hadron Calorimeter, a concept for hadron calorimetry based on total absorption of hadrons in large crystals equipped with dual readout (see **DREAM**).
- HIGS** : High Intensity Gamma-ray Source, a free electron laser at Duke University.
- HiRes** : High Resolution Fly’s Eye cosmic ray experiment in Utah.
- HLbL** : Hadronic Light-by-Light scattering contributions to the muon anomalous magnetic moment.
- HL-LHC** : High Luminosity LHC, the highest-luminosity phase of the **LHC** program, with plans to collect 3000 fb^{-1} of data between 2022 and 2030.
- HPC** : High Performance Computing, such as that done using supercomputers.
- HPS** : Heavy Photon Search, an experiment at **JLab** searching for the decay of dark photons to e^+e^- .
- HSC** : Hyper-Suprime Cam, wide-field camera for the Subaru telescope.
- HTC** : High Throughput Computing, i.e, data-intensive computing.
- HTS** : High-Temperature Superconductivity.
- Hyper-K** : Hyper-Kamiokande, a proposed large water Cherenkov detector at Kamioka in Japan.
- IACT** : imaging Atmospheric Cherenkov Telescope.
- IAEA** : International Atomic Energy Agency.
- IAXO** : International Axion Observatory.
- IBD** : Inverse Beta Decay, usually referring to the reaction $\bar{\nu}_e + p \rightarrow e^+ + n$.
- ICAL** : Iron CALorimeter atmospheric neutrino experiment at **INO**.
- ICARUS** : Imaging Cosmic And Rare Underground Signals, a liquid argon neutrino detector located at **Gran Sasso**.
- IceCube** : A neutrino telescope located at the Amundsen–Scott South Pole station in Antarctica.
- IceTray** : A software framework developed and used by the IceCube experiment for both online and offline processing.
- IDS** : International Design Study (for the Neutrino Factory).
- IHEP** : Institute of High Energy Physics of the Chinese Academy of Sciences, the major particle physics laboratory in China, located in Beijing.
- ILC** : International Linear Collider, an electron-positron linear collider with design **CM** energy 500 GeV.
- ILD** : International Linear collider Detector, a large detector proposed for **ILC** and **CLIC**.
- INO** : India-based Neutrino Observatory, a future underground laboratory in Tamil Nadu, India.
- IOPS** : Input/output Operations Per Second.

IOTA : Integrable Optics Test Accelerator, an electron storage ring to be constructed at **ASTA** to study nonlinear beam optics.

IPPOG : International Particle Physics Outreach Group, a network of science educators and communicators based at **CERN**.

ISIS : Research center at Rutherford Appleton Laboratory near Oxford.

IsoDAR : Isotope Decay At Rest experiment, a proposed cyclotron-based sterile neutrino experiment.

ISR : Initial State Radiation, radiation from a high-energy lepton, quark, or gluon emitted as it scatters from another high-energy particle.

JLab : Thomas Jefferson National Accelerator Facility, in Newport News, Virginia.

J-PARC : Japan Proton Accelerator Research Complex, the laboratory hosting the major Japanese proton accelerator, located in Tokai.

JEM-EUSO : Extreme Universe Space Observatory onboard the Japanese Experiment Module, proposed ultra-high energy cosmic ray detector on the International Space Station.

JUNO : Jiangmen Underground Neutrino Observatory, a proposed large scintillator experiment for reactor neutrino oscillations located in China.

K2K : KEK to Kamioka, the first-generation long-baseline oscillation experiment using beam from **KEK** to **Super-K**.

KamLAND : Kamioka Liquid scintillator ANTineutrino Detector, a reactor neutrino experiment at Kamioka in Japan.

KamLAND-Zen : Zero neutrino double beta decay search, a neutrinoless double beta decay experiment using a Xe-doped balloon deployed in **KamLAND**.

KATRIN : KArlsruhe TRItium Neutrino experiment, an experiment to measure neutrino mass from the endpoint of the tritium beta decay spectrum.

KEK : Ko-Enerugi Kenkyusho, the major high energy physics laboratory in Japan, located in Tsukuba.

KLOE, KLOE-2 : An experiment at **LNF** studying e^+e^- annihilation at energies near 1 GeV.

KM3NET : Multi-Km³ Neutrino Telescope, a future deep-sea neutrino telescope in the Mediterranean sea.

KOTO : An experiment at **J-PARC** to study the rare decay $K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$.

kt : Kilotonne = 10⁶ kilograms.

Λ CDM : The standard model of cosmology in which the Universe consists of known particles, cold dark matter (CDM), and dark energy (Λ).

L/E : Length (**baseline**) / Energy, a figure of merit for neutrino oscillation experiments.

LAGUNA : Large Apparatus studying Grand Unification and Neutrino Astrophysics, a collaborative project to assess the possibilities for a deep underground neutrino observatory in Europe; includes the **GLACIER**, **MEMPHYS**, and **LENA** concepts.

LANL : Los Alamos National Laboratory.

LANSCE : Los Alamos Neutron Science Center.

LAPPD : Large Area Picosecond Photo-Detectors project, a collaboration working to develop large-area flat-panel photon detectors.

LAr : Liquid argon.

LAr1 : A proposal to add additional liquid argon TPCs to the **Fermilab** Booster neutrino beamline.

LAr1-ND : A proposal to add a liquid argon TPC near detector in the **Fermilab** Booster neutrino beamline.

LArIAT : Liquid Argon In A Testbeam, a liquid argon TPC test beam experiment at **Fermilab**.

LARP : LHC Accelerator Research Program, a collaboration of U.S. national laboratories to develop technology for the current and future stages of the **LHC**.

LBNE : Long Baseline Neutrino Experiment: An experiment to measure neutrino oscillations, with beams from **Fermilab** and a detector at **SURF** in South Dakota.

LBL : Lawrence Berkeley National Laboratory (formerly LBL, Lawrence Berkeley Laboratory).

LBNO : Long-Baseline Neutrino Oscillation experiment, a proposed accelerator-based neutrino oscillation experiment in Europe.

LCF : Leadership Computing Facility, one of the **DOE**'s high-performance computing centers.

LENA : Low Energy Neutrino Astronomy, a proposed next-generation liquid scintillator detector.

LENS : Low Energy Neutrino Spectroscopy, a low-energy indium-based solar neutrino experiment.

LEP, LEP-2 : The Large Electron-Positron collider at **CERN**, which performed precision studies of the Z meson and searches for new phenomena from 1989 to 2000.

LHC : Large Hadron Collider, a large proton-proton collider at **CERN**, with design **CM** energy 14 TeV.

LHCb : LHCb, an experiment at the Large Hadron Collider specialized to measure the production in the forward direction of hadrons containing heavy quarks.

LHeC : Large Hadron-electron Collider, a proposal for a high-energy electron beam colliding with the proton beam of the **LHC** at **CERN**.

LNF : Laboratori Nazionali di Frascati, the leading particle physics laboratory in Italy, located in Frascati, near Rome.

LO : Leading Order, applied to the level of a quantum field theory calculation (see also **NLO**).

LPA : Laser Plasma Acceleration.

LSND : Liquid Scintillator Neutrino Detector, an experiment at Los Alamos National Laboratory searching for sterile neutrinos.

LSO : Lutetium Silicate (Lu_2SiO_5).

LSST : Large Synoptic Survey Telescope.

- LUX** : Large Underground Xenon detector, a large dark matter detector using liquid Xenon.
- LVD** : Large Volume Detector, a neutrino observatory at **Gran Sasso** studying low-energy neutrinos from gravitational stellar collapse.
- LXe** : Liquid Xenon.
- LYSO** : Lutetium Yttrium OxyorthoSilicate ($\text{Lu}_2(1-x)\text{Y}_2(x)\text{SiO}_5$).
- LZ** : LUX-Zeplin, a next-generation xenon TPC dark matter detector.
- MAGIC** : Major Atmospheric Gamma-ray Imaging Cherenkov telescope, a telescope for high-energy gamma rays seen as air showers in Cherenkov radiation, located in the Canary Islands.
- MAJORANA** : An experiment searching for neutrinoless double-beta decay in Ge, located at **SURF**.
- MAMI** : MAInzer MICROtron, a low-energy electron accelerator at the University of Mainz.
- Many-core** : Refers to computer chips that contain many more cores than **multi-core CPUs**, i.e., more than 16 **CPUs**.
- MAPS** : Monolithic Active Pixel Sensor.
- MCP** : Micro-Channel Plate.
- MEG** : MuEGamma experiment, an experiment at **PSI** searching for the decay $\mu \rightarrow e\gamma$.
- MEMPHYS** : MEgaton Mass PHYSics, a large water Cherenkov detector proposed for **CERN** or **ESS**.
- MESA** : Mainz Energy-Recovering Superconducting Accelerator, a proposed electron accelerator at the University of Mainz.
- MicroBooNE** : Liquid argon TPC experiment in the Booster neutrino beamline at **Fermilab**.
- MicroMegas** : Micro-Mesh gas detector, a type of **MPGD** ionization detector.
- Milagro** : A water Cherenkov gamma-ray telescope located near **LANL**.
- MINER ν A** : Main Injector Experiment for ν -A, a neutrino scattering experiment in the NuMI beamline at **Fermilab**.
- MiniBooNE** : A short-baseline neutrino oscillation experiment using a mineral oil-based Cherenkov detector in the Booster neutrino beamline at **Fermilab**.
- MIND** : Magnetised Iron Neutrino Detector, a proposed neutrino factory detector.
- MINOS** : Main Injector Neutrino Oscillation Search, a neutrino oscillation experiment located at **Soudan** using the NuMI beamline at **Fermilab**.
- MKID** : Microwave Kinetic Inductance Detector.
- MNS** : Maki-Nakagawa-Sakata matrix (see **PMNS**).
- MOLLER** : An experiment at **JLab** to measure the **P**-violating asymmetry in electron-electron scattering.
- MPGD** : Micro-Pattern Gas Detector.
- MPPC** : Multi-Pixel Photon Counter.

\overline{MS} : Modified Minimal Subtraction, a prescription for removing divergences commonly used in high-precision quantum field theory calculations.

MS-DESI : Mid-Scale Dark Energy Spectroscopic Instrument.

MSSM : Minimal Supersymmetric Standard Model, the simplest (though, not very simple) model that extends the **SM** by the addition of **SUSY**.

MSW : Mikheyev-Smirnov-Wolfenstein effect, the modification of the neutrino oscillation probability as neutrinos pass through matter.

Multi-core : Refers to computer chips that contain up to about 16 **CPUs**.

Muon $g - 2$: An experiment at **Fermilab** to measure the anomalous magnetic moment of the muon.

mwe : Meters water-equivalent, a measure of the depth of an underground detector.

NA62 : An experiment proposed at **CERN** to measure the rare kaon decay $K^+ \rightarrow \pi^+ \nu \bar{\nu}$.

NC : Neutral Current weak interactions.

NERSC : National Energy Research Scientific Computing Center.

NESSiE : Neutrino Experiment with SpectrometerS in Europe, a proposed experiment to search for sterile neutrinos using the **CERN** SPS beam and the **ICARUS** detector.

NEXT : Neutrino Experiment with Xenon TPC, a neutrinoless double beta decay experiment at the **Canfranc Underground Laboratory**.

NF : Neutrino Factory.

NH : Normal Hierarchy.

NIST : National Institute of Standards and Technology.

NLCTA : Next Linear Collider Test Accelerator, an accelerator at **SLAC** now used for tests of advanced accelerator concepts.

NLO, NNLO : Next-to-Leading Order, Next-to-Next-to-Leading Order, terms designating a quantum field theory calculation with two and three terms, respectively, in the power series in the coupling constant.

NLWCP : New, Light, Weakly-Coupled Particles.

NNbarX : An experiment proposed at **Fermilab** to search for neutron-antineutron oscillations.

NOMAD : Neutrino Oscillation MAgnetic Detector, a neutrino oscillation experiment at **CERN**.

NO ν A : NuMI Off-Axis electron-neutrino Appearance experiment, a neutrino oscillation experiment in the **NuMI** beamline at **Fermilab**.

NREN : National Research and Education Network, a high performance network designed for large scale data movement.

NSF : U.S. National Science Foundation.

NUFO : National User Facility Organization, the umbrella group for U.S. national user facility users' organizations.

NuMAX : Neutrinos from Muon Accelerators at Project X, a proposed neutrino oscillation experiment using a muon-storage ring as a source of neutrinos.

NuMI : Neutrinos at the Main Injector, a neutrino beamline at **Fermilab** using the Main Injector, extending to **Soudan** and Ash River, Minnesota.

nuSTORM : Neutrinos from STORed Muons, a proposed short-baseline neutrino experiment to study sterile neutrinos using a muon storage ring as a source of neutrinos.

NVRAM : Non-Volatile Random Access Memory.

OHEP : Office of High Energy Physics of the U.S. **DOE**.

OLCF : Oak Ridge Leadership Computing Center.

OPERA : Oscillation Project with Emulsion-tRacking Apparatus, an emulsion- and tracker-based neutrino oscillation experiment at **Gran Sasso**.

ORCA : Oscillation Research with Cosmics in the Abyss, a proposed experiment to measure the neutrino mass hierarchy using the **KM3NeT** neutrino telescope.

ORKA : A proposed **Fermilab** experiment to measure the rate of the decay $K^+ \rightarrow \pi^+ \nu \bar{\nu}$.

ORNL : Oak Ridge National Laboratory.

OscSNS : Oscillations at the Spallation Neutrino Source, a proposed sterile neutrino search using the SNS facility.

P : Parity, the inversion of all spatial coordinates.

PAMELA : Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics, space-based anti-matter detector.

PANDA : antiProton ANnihilation at Darmstadt, a proposed experiment at the GSI Helmholtzzentrum in Darmstadt, Germany, studying proton-antiproton annihilation at few-GeV energies.

PandaX : A liquid xenon dark matter experiment to be located in the Jin-Ping Underground Laboratory in Sichuan, China.

PB : PetaByte, equal to 10^{15} bytes of information.

PDF : Parton Distribution Function, a function that describes the internal structure of the proton by giving the momentum distribution of a particular constituent, for example, the up quark or gluon.

PEN : An experiment at **PSI** to measure the ratio of decay rates $\pi^+ \rightarrow e^+ \nu$ / $\pi^+ \rightarrow \mu^+ \nu$.

Persistency management : Management of persistent data on disk, tape, or other media. This includes reducing the risk of loss to an appropriate level.

PEP-II : An e^+e^- collider operated at **SLAC** from 1998 to 2008 in the center-of-mass energy region of 10 GeV.

PF : PetaFlop, 10^{15} floating point operations (usually, per second).

PFA : Particle Flow Analysis, a method for hadron calorimetry based on separate measurement of the components of a hadronic shower with charged particles, photons, and neutral hadrons.

PFS : Prime Focus Spectrograph, wide-field multi-object spectrograph for the Subaru telescope.

PIENU : An experiment at **TRIUMF** to measure the ratio of decay rates $\pi^+ \rightarrow e^+ \nu$ / $\pi^+ \rightarrow \mu^+ \nu$.

PINGU : Precision IceCube Next Generation Upgrade, a proposed low-energy extension to **IceCube**.

Pipeline computing : Data analysis that proceeds in stages.

pMSSM : phenomenological Minimal Supersymmetric Standard Model, a 19-parameter subspace of the full MSSM.

PMNS : Pontecorvo-Maki-Nakagawa-Sakata matrix, the matrix linking the mass and flavor eigenstates of neutrinos.

PMT : PhotoMultiplier Tube.

Port : To adjust and test a computer program to run on a new architecture, or the result of this process.

PQ : Peccei-Quinn symmetry, an approximate symmetry of quark-Higgs boson interactions, which must also be spontaneously broken, that allows the possible **CP**-violating term in **QCD** to be set to zero. A consequence of this symmetry is the existence of the **axion**.

PREM : Preliminary Reference Earth Model, a model for the Earth's density distribution.

PREP : Physics Research Equipment Pool.

Project 8 : A proposed tritium-based neutrino mass experiment.

Project X : A planned upgrade of the proton accelerator injector complex at **Fermilab**, with a superconducting proton linear accelerator capable of producing multi-megawatt beams.

PROSPECT : Precision Reactor Neutrino Oscillation and Spectrum Experiment, a U.S.-based reactor short-baseline oscillation search experiment.

PSI : Paul Scherrer Institute, a national laboratory and accelerator center in Switzerland.

PTOLEMY : Princeton Tritium Observatory for Light Early-universe Massive neutrino Yield, a proposed relic Big Bang neutrino background experiment.

PWFA : Plasma Wake Field Acceleration.

QCD : Quantum Chromodynamics, the well-established theory describing the strong subnuclear interactions.

QE : Quasi-Elastic scattering. In neutrino physics, a reaction such as $\nu n \rightarrow \mu^- p$ in which no mesons are produced. In other contexts, a quasi-elastic reaction on a nucleon can involve production of a low-lying nucleon resonance.

QED : Quantum ElectroDynamics.

Qweak : An experiment at **JLab** to measure Q_{weak} , the charge with which the proton couples to the Z boson at very low momentum transfer.

RADAR : R&D Argon Detector at Ash River, proposal to add a **LAr TPC** to the **NO ν A** far detector building in Ash River, Minnesota.

RAT : A simulation and analysis package for optical detectors developed for the Braidwood project and now used within **SNO+**, **MiniClean**, and **DEAP**.

REAPR : Resonantly Enhance Axion Photon Regeneration, an experiment at **Fermilab** to search for **axions** using a laser beam in a strong magnetic field, the successor to **GammeV-CHASE**.

RENO : Reactor Experiment for Neutrino Oscillations, a reactor neutrino experiment in South Korea.

RENO-50 : A proposed reactor-based experiment with **baseline** ~ 50 km to measure the neutrino mass hierarchy with a large scintillator detector.

RF : Radio Frequency.

RHIC : Relativistic Heavy Ion Collider, a colliding beam accelerator for protons and heavy ions at **BNL**.

RICE : Radio Ice Cherenkov Experiment, neutrino detector in Antarctica.

RICOCHET : A proposed bolometric sterile neutrino search using **CENNS**.

RICH : Ring Imaging Cherenkov detector.

RIKEN : Rikagaku Kenkyujo, a major Japanese research institute covering physics, chemistry, and engineering, operating multiple research groups in Japan and one in the U.S. at **BNL**.

ROI : Region Of Interest. In neutrino physics, the region of a measured energy spectrum where the signal (typically a peak or dip from an oscillation) lies. In collider physics, a region of a detector whose data is used in trigger calculations.

RPC : Resistive Plate Chamber, a type of particle tracking detector.

SAGE : Soviet American Gallium Experiment, a solar neutrino experiment in the **Baksan** Neutrino Observatory in Russia.

SBIR : Small Business Innovation Research, a grant category of the **DOE** for collaboration of small businesses with experimental projects.

SciDAC : Scientific Discovery through Advanced Computation, a program of the **DOE**.

Science DMZ : A portion of a computer network designed for high-performance scientific applications rather than general-purpose computing such as web browsing.

SciNO ν A : A proposed neutrino scattering experiment adding a fine-grained scintillator detector at the **NO ν A** near detector site.

SDSS : Sloan Digital Sky Survey, a survey of more than a quarter of the sky using the 2.5-meter telescope at Apache Point Observatory, New Mexico.

SiD : Silicon Detector, a detector with silicon tracking proposed for **ILC** and **CLIC**.

SIMD : Single Instruction Multiple Data style of parallel programming.

SiPM : Silicon PhotoMultiplier, a silicon-based photodetector operated in Geiger mode.

SKA : Square Kilometer Array radio telescope.

SLAC : Stanford Linear Accelerator Center, a U.S. national laboratory in Menlo Park, California, featuring a 3 km electron linear accelerator.

SLC : SLAC Linear Collider, an electron-positron collider operated at **SLAC** from 1989 to 1998 to study the Z boson and develop the technology of linear colliders.

SM : Standard Model of particle physics, which describes the strong, electromagnetic, and weak interactions as mediated by vector fields.

SNO : Sudbury Neutrino Observatory, a solar neutrino experiment located in Sudbury, Ontario, Canada.

SNO+ : A successor to the **SNO** experiment aimed at the measurement of neutrinoless double-beta decay of tellurium.

SNOLAB : Underground science laboratory in the Vale Creighton Mine located near Sudbury, Ontario.

SNS : Spallation Neutron Source, at Oak Ridge National Laboratory.

Soudan : An underground laboratory in northern Minnesota, housing **MINOS** and low-background experiments.

SOX : A chromium and/or cesium source used with the **Borexino** detector to study the reactor neutrino anomaly.

SRF : Superconducting Radio Frequency (**RF**) cavities and associated technology.

STTR : Small business Technology TRansfer, a **DOE** program for this purpose.

STAR : Solenoidal Tracker at RHIC, a relativistic heavy ion collider experiment at Brookhaven.

STEM : Science, Technology, Engineering, and Mathematics, typically describing a domain of education.

STEREO : Search for Sterile Neutrinos at ILL reactor, a reactor short-baseline oscillation search in France.

SPS : Super Proton Synchrotron at **CERN**.

Subaru : An optical/infrared telescope on Mauna Kea operated by the National Observatory of Japan.

Super-K : Super-Kamiokande experiment, water Cherenkov detector in the Kamiokande mine in Japan studying proton decay as well as solar, atmospheric, and accelerator-produced neutrinos.

SuperKEKB : A high-luminosity electron-positron collider, with **CM** energy about 10 GeV, at **KEK**.

Super-NEMO : Super Neutrino Ettore Majorana Observatory, a neutrinoless double beta decay experiment in the Fréjus underground laboratory in France.

SURF : Sanford Underground Research Facility: An underground laboratory in the former Homestake Mine in Lead, South Dakota.

SUSY : SuperSYmmetry, a symmetry that links together **fermions** and **bosons**. In any realistic theory, supersymmetry requires a new space-time structure extending and generalizing that of relativity.

T : Time reversal, the transformation of reversing the direction of time.

T2K : Tokai to Kamiokande experiment, a neutrino oscillation experiment in Japan, using the **J-PARC** neutrino beam and the **Super-K** detector.

TA : Telescope Array, ultra-high-energy cosmic ray detector in Utah.

TCA : Telecommunications Computing Architecture.

TeV : Tera-electron Volt (10^{12} eV), the order-of-magnitude energy scale of Higgs boson physics.

TDR : Technical Design Report.

TES : Transition Edge Sensor, a cryogenic sensor based on the very small amount of energy needed to destroy superconductivity in a thin film painted on the surface of a detector.

TLEP : Triple Large Electron-Positron collider, a proposed e^+e^- collider in a large circular tunnel, with **CM** energies from 90 to 350 GeV.

TPC : Time Projection Chamber, a type of particle detector in which ionization from a track flows to a wall of a detector and the arrival time and location are measured, producing a 3-dimensional image of the track.

TREK : Time Reversal Experiment with Kaons, an experiment at **J-PARC** to search for **T**-violating muon polarization in the decay $K^+ \rightarrow \pi^0 \mu^+ \nu$.

TRIUMF : TRI-University Meson Facility, the national accelerator laboratory of Canada, located in Vancouver. It is now operated by a consortium of 15 universities.

UHE : Ultra High Energy, typically applied to cosmic rays with energies $> 10^{18}$ eV.

VCSEL : Vertical Cavity Surface Emitting Laser.

VEPP : One of a series of electron-positron colliders at the Budker Institute of Nuclear Physics in Novosibirsk, Russia.

VERITAS : Very Energetic Radiation Imagine Telescope Array System, a telescope for high energy gamma rays seen as air showers in Cherenkov radiation, located in Arizona.

Vev : Vacuum expectation value, the value of a condensed field, such as the Higgs field, at every point in space.

VLHC : Very Large Hadron Collider, a concept for a proton-proton collider with center of mass energy approximately 100 TeV.

Volunteer computing : A distributed computing effort in which computer resources are donated by the owner, for example, the SETI At Home project.

Wakefield : The electromagnetic field trailing a bunch of high-energy particles in an accelerating structure.

WATCHMAN : WATer CHerenkov Monitoring of Anti-Neutrinos, a collaboration of U.S.-based universities and laboratories conducting a site search for an advanced water Cherenkov demonstration detector.

WFIRST-AFTA : Wide-Field InfraRed Survey Telescope-Astrophysics Focused Telescope Assets

WIMP : Weakly Interacting Massless Particle, a category of particle that might make up the dark matter of the universe.

WIPP : Waste Isolation Pilot Plant, an underground facility located in New Mexico.

YBCO : Yttrium Barium Copper Oxide, $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$, one of the first high-temperature superconductors.

TOPICAL GROUP REPORTS

Energy Frontier

Higgs Boson Properties

S. Dawson, A. Korytov, C. Vernieri

(contributors from the community)

Already we are boldly launched upon the deep; but soon we shall be lost in its unshored, harbourless immensities. Ere that come to pass; ere the Pequod's weedy hull rolls side by side with the barnacled hulls of the leviathan; at the outset it is but well to attend to a matter almost indispensable to a thorough appreciative understanding of the more special leviathanic revelations and allusions of all sorts which are to follow.

It is some systematized exhibition of the whale in his broad genera, that I would now fain put before you. Yet is it no easy task. The classification of the constituents of a chaos, nothing less is here essayed. Listen to what the best and latest authorities have laid down.

"No branch of Zoology is so much involved as that which is entitled Cetology," says Captain Scoresby, A.D. 1820 [1].

"It is not my intention, were it in my power, to enter into the inquiry as to the true method of dividing the cetacea into groups and families. . . . Utter confusion exists among the historians of this animal" (sperm whale), says Surgeon Beale, A.D. 1839 [2].

"Unfitness to pursue our research in the unfathomable waters." "Impenetrable veil covering our knowledge of the cetacea." "A field strewn with thorns." "All these incomplete indications but serve to torture us naturalists."

Thus speak of the whale, the great Cuvier, and John Hunter, and Lesson, those lights of zoology and anatomy.

[. . .]

Finally: It was stated at the outset, that this system would not be here, and at once, perfected. You cannot but plainly see that I have kept my word. But I now leave my cetological System standing thus unfinished, even as the great Cathedral of Cologne was left, with the crane still standing upon the top of the uncompleted tower. For small erections may be finished by their first architects; grand ones, true ones, ever leave the copestone to posterity. God keep me from ever completing anything. This whole book is but a draught—nay, but the draught of a draught. Oh, Time, Strength, Cash, and Patience!

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Higgs Boson as a Portal to New Physics

P. Meade, I. Ojalvo

(contributors from the community)

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Heavy Flavor and Top Quark Physics

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Electroweak Precision Physics

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QCD and Strong Interactions: Precision QCD

M. Begel, S. Hoeche, M. Schmitt

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QCD and Strong Interactions: Hadronic Structure and Forward Reactions

H.-W. Lin, P. Nadolsky, C. Royon

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QCD and Strong Interactions: Heavy Ions

Y.-J. Lee, S. Mukherjee

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Beyond the Standard Model: Model-Specific Explorations

J. Hirschauer, E. Lipeles, N. Shah

(contributors from the community)

Already we are boldly launched upon the deep; but soon we shall be lost in its unshored, harbourless immensities. Ere that come to pass; ere the Pequod's weedy hull rolls side by side with the barnacled hulls of the leviathan; at the outset it is but well to attend to a matter almost indispensable to a thorough appreciative understanding of the more special leviathanic revelations and allusions of all sorts which are to follow.

It is some systematized exhibition of the whale in his broad genera, that I would now fain put before you. Yet is it no easy task. The classification of the constituents of a chaos, nothing less is here essayed. Listen to what the best and latest authorities have laid down.

"No branch of Zoology is so much involved as that which is entitled Cetology," says Captain Scoresby, A.D. 1820 [1].

"It is not my intention, were it in my power, to enter into the inquiry as to the true method of dividing the cetacea into groups and families. . . . Utter confusion exists among the historians of this animal" (sperm whale), says Surgeon Beale, A.D. 1839 [2].

"Unfitness to pursue our research in the unfathomable waters." "Impenetrable veil covering our knowledge of the cetacea." "A field strewn with thorns." "All these incomplete indications but serve to torture us naturalists."

Thus speak of the whale, the great Cuvier, and John Hunter, and Lesson, those lights of zoology and anatomy.

[. . .]

Finally: It was stated at the outset, that this system would not be here, and at once, perfected. You cannot but plainly see that I have kept my word. But I now leave my cetological System standing thus unfinished, even as the great Cathedral of Cologne was left, with the crane still standing upon the top of the uncompleted tower. For small erections may be finished by their first architects; grand ones, true ones, ever leave the copestone to posterity. God keep me from ever completing anything. This whole book is but a draught—nay, but the draught of a draught. Oh, Time, Strength, Cash, and Patience!

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- [1] J. Scoresby, "Journals", 1820.
- [2] A. Beale, "Surgical Writings", 1839.

Beyond the Standard Model: General Explorations

T. Bose, Z. Liu, S. Pagan Griso

(contributors from the community)

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- [1] J. Scoresby, "Journals", 1820.
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Beyond the Standard Model: Dark Matter at Colliders

C. Doglioni, L.-T. Wang

(contributors from the community)

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- [1] J. Scoresby, "Journals", 1820.
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TOPICAL GROUP REPORTS

Neutrino Physics Frontier

Neutrino Oscillations

P. B. Denton, M. Friend, M. Messier, H. Tanaka

(contributors from the community)

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Thus speak of the whale, the great Cuvier, and John Hunter, and Lesson, those lights of zoology and anatomy. Nevertheless, though of real knowledge there be little, yet of books there are a plenty; and so in some small degree, with cetology, or the science of whales. Many are the men, small and great, old and new, landmen and seamen, who have at large or in little, written of the whale. Run over a few: The Authors of the Bible; Aristotle; Pliny; Aldrovandi; Sir Thomas Browne; Gesner; Ray; Linnæus; Rondeletius; Willoughby; Green; Artedi; Sibbald; Brisson; Marten; Lacépède; Bonnetterre; Desmarest; Baron Cuvier; Frederick Cuvier; John Hunter; Owen; Scoresby; Beale; Bennett; J. Ross Browne; the Author of Miriam Coffin; Olmstead; and the Rev. T. Cheever. But to what ultimate generalizing purpose all these have written, the above cited extracts will show.

Of the names in this list of whale authors, only those following Owen ever saw living whales; and but one of them was a real professional harpooneer and whaleman. I mean Captain Scoresby. On the separate subject of the Greenland or right-whale, he is the best existing authority. But Scoresby knew nothing and says nothing of the great sperm whale, compared with which the Greenland whale is almost unworthy mentioning. And here be it said, that the Greenland whale is an usurper upon the throne of the seas. He is not even by any means the largest of the whales. Yet, owing to the long priority of his claims, and

the profound ignorance which, till some seventy years back, invested the then fabulous or utterly unknown sperm-whale, and which ignorance to this present day still reigns in all but some few scientific retreats and whale-ports; this usurpation has been every way complete. Reference to nearly all the leviathanic allusions in the great poets of past days, will satisfy you that the Greenland whale, without one rival, was to them the monarch of the seas. But the time has at last come for a new proclamation. This is Charing Cross; hear ye! good people all,—the Greenland whale is deposed,—the great sperm whale now reigneth!

There are only two books in being which at all pretend to put the living sperm whale before you, and at the same time, in the remotest degree succeed in the attempt. Those books are Beale's and Bennett's; both in their time surgeons to English South-Sea whale-ships, and both exact and reliable men. The original matter touching the sperm whale to be found in their volumes is necessarily small; but so far as it goes, it is of excellent quality, though mostly confined to scientific description. As yet, however, the sperm whale, scientific or poetic, lives not complete in any literature. Far above all other hunted whales, his is an unwritten life.

Now the various species of whales need some sort of popular comprehensive classification, if only an easy outline one for the present, hereafter to be filled in all its departments by subsequent laborers. As no better man advances to take this matter in hand, I hereupon offer my own poor endeavors. I promise nothing complete; because any human thing supposed to be complete, must for that very reason infallibly be faulty. I shall not pretend to a minute anatomical description of the various species, or—in this place at least—to much of any description. My object here is simply to project the draught of a systematization of cetology. I am the architect, not the builder.

But it is a ponderous task; no ordinary letter-sorter in the Post-Office is equal to it. To grope down into the bottom of the sea after them; to have one's hands among the unspeakable foundations, ribs, and very pelvis of the world; this is a fearful thing. What am I that I should essay to hook the nose of this leviathan! The awful tauntings in Job might well appal me. Will he (the leviathan) make a covenant with thee? Behold the hope of him is vain! But I have swam through libraries and sailed through oceans; I have had to do with whales with these visible hands; I am in earnest; and I will try. There are some preliminaries to settle.

First: The uncertain, unsettled condition of this science of Cetology is in the very vestibule attested by the fact, that in some quarters it still remains a moot point whether a whale be a fish. In his *System of Nature*, A.D. 1776, Linnæus declares, "I hereby separate the whales from the fish." But of my own knowledge, I know that down to the year 1850, sharks and shad, alewives and herring, against Linnæus's express edict, were still found dividing the possession of the same seas with the Leviathan.

The grounds upon which Linnæus would fain have banished the whales from the waters, he states as follows: "On account of their warm bilocular heart, their lungs, their movable eyelids, their hollow ears, penem intransantem feminam mammis lactantem," and finally, "ex lege naturæ jure meritoque." I submitted all this to my friends Simeon Macey and Charley Coffin, of Nantucket, both messmates of mine in a certain voyage, and they united in the opinion that the reasons set forth were altogether insufficient. Charley profanely hinted they were humbug.

Be it known that, waiving all argument, I take the good old fashioned ground that the whale is a fish, and call upon holy Jonah to back me. This fundamental thing settled, the next point is, in what internal respect does the whale differ from other fish. Above, Linnæus has given you those items. But in brief, they are these: lungs and warm blood; whereas, all other fish are lungless and cold blooded.

Next: how shall we define the whale, by his obvious externals, so as conspicuously to label him for all time to come? To be short, then, a whale is a spouting fish with a horizontal tail. There you have him. However contracted, that definition is the result of expanded meditation. A walrus spouts much like a whale, but the walrus is not a fish, because he is amphibious. But the last term of the definition is still more cogent, as

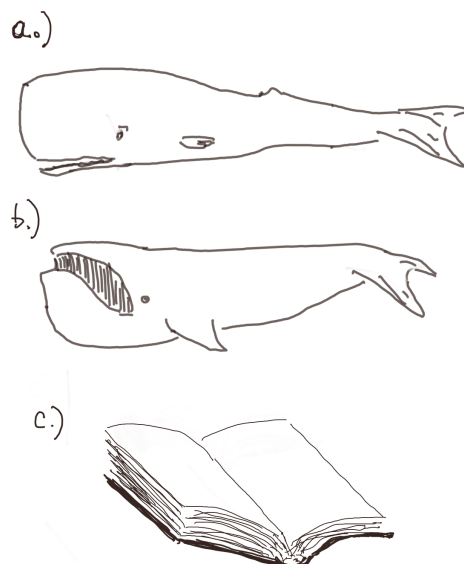


Figure 1-1. (a) *Sperm Whale* (b) *Right Whale*, (c) “... or, *The Whale*”.

coupled with the first. Almost any one must have noticed that all the fish familiar to landsmen have not a flat, but a vertical, or up-and-down tail. Whereas, among spouting fish the tail, though it may be similarly shaped, invariably assumes a horizontal position.

By the above definition of what a whale is, I do by no means exclude from the leviathanic brotherhood any sea creature hitherto identified with the whale by the best informed Nantucketers; nor, on the other hand, link with it any fish hitherto authoritatively regarded as alien ¹ Hence, all the smaller, spouting, and horizontal tailed fish must be included in this ground-plan of Cetology. Now, then, come the grand divisions of the entire whale host.

First: According to magnitude I divide the whales into three primary BOOKS (subdivisible into CHAPTERS), and these shall comprehend them all, both small and large.

I. THE FOLIO WHALE; II. the OCTAVO WHALE; III. the DUODECIMO WHALE.

As the type of the FOLIO I present the Sperm Whale; of the OCTAVO, the Grampus; of the DUODECIMO, the Porpoise.

1.1 Folio

FOLIOS. Among these I here include the following chapters:—I. The Sperm Whale; II. the Right Whale; III. the Fin-Back Whale; IV. the Hump-backed Whale; V. the Razor Back Whale; VI. the Sulphur Bottom Whale. (See Fig. 1-1.)

¹I am aware that down to the present time, the fish styled Lamatins and Dugongs (Pig-fish and Sow-fish of the Coffins of Nantucket) are included by many naturalists among the whales. But as these pig-fish are a noisy, contemptible set, mostly lurking in the mouths of rivers, and feeding on wet hay, and especially as they do not spout, I deny their credentials as whales; and have presented them with their passports to quit the Kingdom of Cetology.

1.1.1 Sperm Whale

BOOK I. (Folio), CHAPTER I. (Sperm Whale).—This whale, among the English of old vaguely known as the Trumpha whale, and the Physeter whale, and the Anvil Headed whale, is the present Cachalot of the French, and the Pottsfich of the Germans, and the Macrocephalus of the Long Words. He is, without doubt, the largest inhabitant of the globe; the most formidable of all whales to encounter; the most majestic in aspect; and lastly, by far the most valuable in commerce; he being the only creature from which that valuable substance, spermaceti, is obtained. All his peculiarities will, in many other places, be enlarged upon. It is chiefly with his name that I now have to do. Philologically considered, it is absurd. Some centuries ago, when the Sperm whale was almost wholly unknown in his own proper individuality, and when his oil was only accidentally obtained from the stranded fish; in those days spermaceti, it would seem, was popularly supposed to be derived from a creature identical with the one then known in England as the Greenland or Right Whale. It was the idea also, that this same spermaceti was that quickening humor of the Greenland Whale which the first syllable of the word literally expresses. In those times, also, spermaceti was exceedingly scarce, not being used for light, but only as an ointment and medicament. It was only to be had from the druggists as you nowadays buy an ounce of rhubarb. When, as I opine, in the course of time, the true nature of spermaceti became known, its original name was still retained by the dealers; no doubt to enhance its value by a notion so strangely significant of its scarcity. And so the appellation must at last have come to be bestowed upon the whale from which this spermaceti was really derived.

1.1.2 Right Whale

BOOK I. (Folio), CHAPTER II. (Right Whale).—In one respect this is the most venerable of the leviathans, being the one first regularly hunted by man. It yields the article commonly known as whalebone or baleen; and the oil specially known as “whale oil,” an inferior article in commerce. Among the fishermen, he is indiscriminately designated by all the following titles: The Whale; the Greenland Whale; the Black Whale; the Great Whale; the True Whale; the Right Whale. There is a deal of obscurity concerning the identity of the species thus multitudinously baptised. What then is the whale, which I include in the second species of my Folios? It is the Great Mysticetus of the English naturalists; the Greenland Whale of the English whalemens; the Baleine Ordinaire of the French whalemens; the Growlands Walfish of the Swedes. It is the whale which for more than two centuries past has been hunted by the Dutch and English in the Arctic seas; it is the whale which the American fishermen have long pursued in the Indian ocean, on the Brazil Banks, on the Nor’ West Coast, and various other parts of the world, designated by them Right Whale Cruising Grounds.

Some pretend to see a difference between the Greenland whale of the English and the right whale of the Americans. But they precisely agree in all their grand features; nor has there yet been presented a single determinate fact upon which to ground a radical distinction. It is by endless subdivisions based upon the most inconclusive differences, that some departments of natural history become so repellingly intricate. The right whale will be elsewhere treated of at some length, with reference to elucidating the sperm whale.

1.1.3 Fin-Back Whale

BOOK I. (Folio), CHAPTER III. (Fin-Back).—Under this head I reckon a monster which, by the various names of Fin-Back, Tall-Spout, and Long-John, has been seen almost in every sea and is commonly the whale

whose distant jet is so often descried by passengers crossing the Atlantic, in the New York packet-tracks. In the length he attains, and in his baleen, the Fin-back resembles the right whale, but is of a less portly girth, and a lighter colour, approaching to olive. His great lips present a cable-like aspect, formed by the intertwisting, slanting folds of large wrinkles. His grand distinguishing feature, the fin, from which he derives his name, is often a conspicuous object. This fin is some three or four feet long, growing vertically from the hinder part of the back, of an angular shape, and with a very sharp pointed end. Even if not the slightest other part of the creature be visible, this isolated fin will, at times, be seen plainly projecting from the surface. When the sea is moderately calm, and slightly marked with spherical ripples, and this gnomon-like fin stands up and casts shadows upon the wrinkled surface, it may well be supposed that the watery circle surrounding it somewhat resembles a dial, with its style and wavy hour-lines graved on it. On that Ahaz-dial the shadow often goes back. The Fin-Back is not gregarious. He seems a whale-hater, as some men are man-haters. Very shy; always going solitary; unexpectedly rising to the surface in the remotest and most sullen waters; his straight and single lofty jet rising like a tall misanthropic spear upon a barren plain; gifted with such wondrous power and velocity in swimming, as to defy all present pursuit from man; this leviathan seems the banished and unconquerable Cain of his race, bearing for his mark that style upon his back. From having the baleen in his mouth, the Fin-Back is sometimes included with the right whale, among a theoretic species denominated Whalebone whales, that is, whales with baleen. Of these so called Whalebone whales, there would seem to be several varieties, most of which, however, are little known. Broad-nosed whales and beaked whales; pike-headed whales; bunched whales; under-jawed whales and rostrated whales, are the fishermen's names for a few sorts.

In connection with this appellation of "Whalebone whales", it is of great importance to mention, that however such a nomenclature may be convenient in facilitating allusions to some kind of whales, yet it is in vain to attempt a clear classification of the Leviathan, founded upon either his baleen, or hump, or fin, or teeth; notwithstanding that those marked parts or features very obviously seem better adapted to afford the basis for a regular system of Cetology than any other detached bodily distinctions, which the whale, in his kinds, presents. How then? The baleen, hump, back-fin, and teeth; these are things whose peculiarities are indiscriminately dispersed among all sorts of whales, without any regard to what may be the nature of their structure in other and more essential particulars. Thus, the sperm whale and the humpbacked whale, each has a hump; but there the similitude ceases. Then, this same humpbacked whale and the Greenland whale, each of these has baleen; but there again the similitude ceases. And it is just the same with the other parts above mentioned. In various sorts of whales, they form such irregular combinations; or, in the case of any one of them detached, such an irregular isolation; as utterly to defy all general methodization formed upon such a basis. On this rock every one of the whale-naturalists has split.

But it may possibly be conceived that, in the internal parts of the whale, in his anatomy—there, at least, we shall be able to hit the right classification. Nay; what thing, for example, is there in the Greenland whale's anatomy more striking than his baleen? Yet we have seen that by his baleen it is impossible correctly to classify the Greenland whale. And if you descend into the bowels of the various leviathans, why there you will not find distinctions a fiftieth part as available to the systematizer as those external ones already enumerated. What then remains? nothing but to take hold of the whales bodily, in their entire liberal volume, and boldly sort them that way. And this is the Bibliographical system here adopted; and it is the only one that can possibly succeed, for it alone is practicable. To proceed.

1.1.4 Hump Back Whale

BOOK I. (Folio) CHAPTER IV. (Hump Back).—This whale is often seen on the northern American coast. He has been frequently captured there, and towed into harbor. He has a great pack on him like a peddler;

or you might call him the Elephant and Castle whale. At any rate, the popular name for him does not sufficiently distinguish him, since the sperm whale also has a hump though a smaller one. His oil is not very valuable. He has baleen. He is the most gamesome and light-hearted of all the whales, making more gay foam and white water generally than any other of them.

1.1.5 Razor Back Whale

BOOK I. (Folio), CHAPTER V. (Razor Back).—Of this whale little is known but his name. I have seen him at a distance off Cape Horn. Of a retiring nature, he eludes both hunters and philosophers. Though no coward, he has never yet shown any part of him but his back, which rises in a long sharp ridge. Let him go. I know little more of him, nor does anybody else.

1.1.6 Sulphur Bottom Whale

BOOK I. (Folio), CHAPTER VI. (Sulphur Bottom).—Another retiring gentleman, with a brimstone belly, doubtless got by scraping along the Tartarian tiles in some of his profounder divings. He is seldom seen; at least I have never seen him except in the remoter southern seas, and then always at too great a distance to study his countenance. He is never chased; he would run away with rope-walks of line. Prodigies are told of him. Adieu, Sulphur Bottom! I can say nothing more that is true of ye, nor can the oldest Nantucketer.

Thus ends BOOK I. (Folio), and now begins BOOK II. (Octavo).

1.2 Octavo

OCTAVOES.*—These embrace the whales of middling magnitude, among which present may be numbered:—I., the Grampus; II., the Black Fish; III., the Narwhale; IV., the Thrasher; V., the Killer.

*Why this book of whales is not denominated the Quarto is very plain. Because, while the whales of this order, though smaller than those of the former order, nevertheless retain a proportionate likeness to them in figure, yet the bookbinder's Quarto volume in its dimensioned form does not preserve the shape of the Folio volume, but the Octavo volume does.

1.2.1 Grampus

BOOK II. (Octavo), CHAPTER I. (Grampus).—Though this fish, whose loud sonorous breathing, or rather blowing, has furnished a proverb to landsmen, is so well known a denizen of the deep, yet is he not popularly classed among whales. But possessing all the grand distinctive features of the leviathan, most naturalists have recognised him for one. He is of moderate octavo size, varying from fifteen to twenty-five feet in length, and of corresponding dimensions round the waist. He swims in herds; he is never regularly hunted, though his oil is considerable in quantity, and pretty good for light. By some fishermen his approach is regarded as premonitory of the advance of the great sperm whale.

1.2.2 Black Fish

BOOK II. (Octavo), CHAPTER II. (Black Fish).—I give the popular fishermen's names for all these fish, for generally they are the best. Where any name happens to be vague or inexpressive, I shall say so, and suggest another. I do so now, touching the Black Fish, so-called, because blackness is the rule among almost all whales. So, call him the Hyena Whale, if you please. His voracity is well known, and from the circumstance that the inner angles of his lips are curved upwards, he carries an everlasting Mephistophelean grin on his face. This whale averages some sixteen or eighteen feet in length. He is found in almost all latitudes. He has a peculiar way of showing his dorsal hooked fin in swimming, which looks something like a Roman nose. When not more profitably employed, the sperm whale hunters sometimes capture the Hyena whale, to keep up the supply of cheap oil for domestic employment—as some frugal housekeepers, in the absence of company, and quite alone by themselves, burn unsavory tallow instead of odorous wax. Though their blubber is very thin, some of these whales will yield you upwards of thirty gallons of oil.

1.2.3 Narwhale

BOOK II. (Octavo), CHAPTER III. (Narwhale), that is, Nostril whale.—Another instance of a curiously named whale, so named I suppose from his peculiar horn being originally mistaken for a peaked nose. The creature is some sixteen feet in length, while its horn averages five feet, though some exceed ten, and even attain to fifteen feet. Strictly speaking, this horn is but a lengthened tusk, growing out from the jaw in a line a little depressed from the horizontal. But it is only found on the sinister side, which has an ill effect, giving its owner something analogous to the aspect of a clumsy left-handed man. What precise purpose this ivory horn or lance answers, it would be hard to say. It does not seem to be used like the blade of the sword-fish and bill-fish; though some sailors tell me that the Narwhale employs it for a rake in turning over the bottom of the sea for food. Charley Coffin said it was used for an ice-piercer; for the Narwhale, rising to the surface of the Polar Sea, and finding it sheeted with ice, thrusts his horn up, and so breaks through. But you cannot prove either of these surmises to be correct. My own opinion is, that however this one-sided horn may really be used by the Narwhale—however that may be—it would certainly be very convenient to him for a folder in reading pamphlets. The Narwhale I have heard called the Tusked whale, the Horned whale, and the Unicorn whale. He is certainly a curious example of the Unicornism to be found in almost every kingdom of animated nature. From certain cloistered old authors I have gathered that this same sea-unicorn's horn was in ancient days regarded as the great antidote against poison, and as such, preparations of it brought immense prices. It was also distilled to a volatile salts for fainting ladies, the same way that the horns of the male deer are manufactured into hartshorn. Originally it was in itself accounted an object of great curiosity. Black Letter tells me that Sir Martin Frobisher on his return from that voyage, when Queen Bess did gallantly wave her jewelled hand to him from a window of Greenwich Palace, as his bold ship sailed down the Thames; “when Sir Martin returned from that voyage,” saith Black Letter, “on bended knees he presented to her highness a prodigious long horn of the Narwhale, which for a long period after hung in the castle at Windsor.” An Irish author avers that the Earl of Leicester, on bended knees, did likewise present to her highness another horn, pertaining to a land beast of the unicorn nature.

The Narwhale has a very picturesque, leopard-like look, being of a milk-white ground colour, dotted with round and oblong spots of black. His oil is very superior, clear and fine; but there is little of it, and he is seldom hunted. He is mostly found in the circumpolar seas.

1.2.4 Killer Whale

BOOK II. (Octavo), CHAPTER IV. (Killer).—Of this whale little is precisely known to the Nantucketer, and nothing at all to the professed naturalist. From what I have seen of him at a distance, I should say that he was about the bigness of a grampus. He is very savage—a sort of Feegee fish. He sometimes takes the great Folio whales by the lip, and hangs there like a leech, till the mighty brute is worried to death. The Killer is never hunted. I never heard what sort of oil he has. Exception might be taken to the name bestowed upon this whale, on the ground of its indistinctness. For we are all killers, on land and on sea; Bonapartes and Sharks included.

1.2.5 Thrasher Whale

BOOK II. (Octavo), CHAPTER V. (Thrasher).—This gentleman is famous for his tail, which he uses for a ferule in thrashing his foes. He mounts the Folio whale's back, and as he swims, he works his passage by flogging him; as some schoolmasters get along in the world by a similar process. Still less is known of the Thrasher than of the Killer. Both are outlaws, even in the lawless seas.

Thus ends BOOK II. (Octavo), and begins BOOK III. (Duodecimo).

1.3 Duodecimo

DUODECIMOES.—These include the smaller whales. I. The Huzza Porpoise. II. The Algerine Porpoise. III. The Mealy-mouthed Porpoise.

To those who have not chanced specially to study the subject, it may possibly seem strange, that fishes not commonly exceeding four or five feet should be marshalled among WHALES—a word, which, in the popular sense, always conveys an idea of hugeness. But the creatures set down above as Duodecimoes are infallibly whales, by the terms of my definition of what a whale is—i.e. a spouting fish, with a horizontal tail.

1.3.1 Huzza Porpoise

BOOK III. (Duodecimo), CHAPTER 1. (Huzza Porpoise).—This is the common porpoise found almost all over the globe. The name is of my own bestowal; for there are more than one sort of porpoises, and something must be done to distinguish them. I call him thus, because he always swims in hilarious shoals, which upon the broad sea keep tossing themselves to heaven like caps in a Fourth-of-July crowd. Their appearance is generally hailed with delight by the mariner. Full of fine spirits, they invariably come from the breezy billows to windward. They are the lads that always live before the wind. They are accounted a lucky omen. If you yourself can withstand three cheers at beholding these vivacious fish, then heaven help ye; the spirit of godly gamesomeness is not in ye. A well-fed, plump Huzza Porpoise will yield you one good gallon of good oil. But the fine and delicate fluid extracted from his jaws is exceedingly valuable. It is in request among jewellers and watchmakers. Sailors put it on their hones. Porpoise meat is good eating, you know. It may never have occurred to you that a porpoise spouts. Indeed, his spout is so small that it is not

very readily discernible. But the next time you have a chance, watch him; and you will then see the great Sperm whale himself in miniature.

1.3.2 Algerine Porpoise

BOOK III. (Duodecimo), CHAPTER II. (Algerine Porpoise).—A pirate. Very savage. He is only found, I think, in the Pacific. He is somewhat larger than the Huzza Porpoise, but much of the same general make. Provoke him, and he will buckle to a shark. I have lowered for him many times, but never yet saw him captured.

1.3.3 Mealy-mouthed Porpoise

BOOK III. (Duodecimo), CHAPTER III. (Mealy-mouthed Porpoise).—The largest kind of Porpoise; and only found in the Pacific, so far as it is known. The only English name, by which he has hitherto been designated, is that of the fishers—Right-Whale Porpoise, from the circumstance that he is chiefly found in the vicinity of that Folio. In shape, he differs in some degree from the Huzza Porpoise, being of a less rotund and jolly girth; indeed, he is of quite a neat and gentleman-like figure. He has no fins on his back (most other porpoises have), he has a lovely tail, and sentimental Indian eyes of a hazel hue. But his mealy-mouth spoils all. Though his entire back down to his side fins is of a deep sable, yet a boundary line, distinct as the mark in a ship's hull, called the "bright waist," that line streaks him from stem to stern, with two separate colours, black above and white below. The white comprises part of his head, and the whole of his mouth, which makes him look as if he had just escaped from a felonious visit to a meal-bag. A most mean and mealy aspect! His oil is much like that of the common porpoise.

1.4 Miscellaneous papers

Beyond the DUODECIMO, this system does not proceed, inasmuch as the Porpoise is the smallest of the whales. Above, you have all the Leviathans of note. But there are a rabble of uncertain, fugitive, half-fabulous whales, which, as an American whaler, I know by reputation, but not personally. I shall enumerate them by their fore-castle appellations; for possibly such a list may be valuable to future investigators, who may complete what I have here but begun. If any of the following whales, shall hereafter be caught and marked, then he can readily be incorporated into this System, according to his Folio, Octavo, or Duodecimo magnitude:—The Bottle-Nose Whale; the Junk Whale; the Pudding-Headed Whale; the Cape Whale; the Leading Whale; the Cannon Whale; the Scragg Whale; the Coppered Whale; the Elephant Whale; the Iceberg Whale; the Quog Whale; the Blue Whale; etc. From Icelandic, Dutch, and old English authorities, there might be quoted other lists of uncertain whales, blessed with all manner of uncouth names. But I omit them as altogether obsolete; and can hardly help suspecting them for mere sounds, full of Leviathanism, but signifying nothing.

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Understanding Experimental Neutrino Anomalies

B. Littlejohn, G. Karagiorgi, P. Machado, A. Sousa

(contributors from the community)

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It is some systematized exhibition of the whale in his broad genera, that I would now fain put before you. Yet is it no easy task. The classification of the constituents of a chaos, nothing less is here essayed. Listen to what the best and latest authorities have laid down.

"No branch of Zoology is so much involved as that which is entitled Cetology," says Captain Scoresby, A.D. 1820 [1].

"It is not my intention, were it in my power, to enter into the inquiry as to the true method of dividing the cetacea into groups and families. . . . Utter confusion exists among the historians of this animal" (sperm whale), says Surgeon Beale, A.D. 1839 [2].

"Unfitness to pursue our research in the unfathomable waters." "Impenetrable veil covering our knowledge of the cetacea." "A field strewn with thorns." "All these incomplete indications but serve to torture us naturalists."

Thus speak of the whale, the great Cuvier, and John Hunter, and Lesson, those lights of zoology and anatomy.

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Neutrino Physics Beyond the Standard Model

P. Coloma, L. Koerner, I. Shoemaker, J. Yu

(contributors from the community)

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Neutrinos from Natural Sources

Y. Koshio, G. D. Orebi Gann, E. O’Sullivan, I. Tamborra

(contributors from the community)

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Neutrino Properties

C. Giunti, B. Jones, L. Kaufman, D. Parno

(contributors from the community)

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Neutrino Interaction Cross Sections

J. Asaadi, B. Balantekin, K. Mahn, J. Newbry

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Neutrino Applications

N. Bowden, J. Link, W. Wang

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Artificial Neutrino Sources

L. Fields, A. Marino, P. Ochoa, J. Spitz

(contributors from the community)

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Neutrino Detectors

J. Klein, A. Machado, D. Schmitz, R. Strauss

(contributors from the community)

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TOPICAL GROUP REPORTS

Rare Processes and Precision Frontier

Weak Decays of b and c Quarks

A. Di Canto, S. Meinel

(contributors from the community)

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Weak Decays of Strange and Light Quarks

E. Goudzovski, E. Passemar

(contributors from the community)

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Fundamental Physics in Small Experiments

P. Winter, T. Blum

(contributors from the community)

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Baryon and Lepton Number Violation

P. Fileviez Perez, A. Pocar

(contributors from the community)

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Charged Lepton Flavor Violation

B. Echenard, S. Davidson

(contributors from the community)

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Dark Sector at High Intensities

M. Williams, S. Gori

(contributors from the community)

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Hadron Spectroscopy

T. Skwarnicki, R. Lebed

(contributors from the community)

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TOPICAL GROUP REPORTS

Cosmic Frontier

Particle-Like Dark Matter

J. Cooley, T. Lin, H. Lippincott, T. Slatyer

(contributors from the community)

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Wave-Like Dark Matter

J. Jaeckel, G. Rybka, L. Winslow

(contributors from the community)

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Cosmic Probes of Dark Matter

A. Drlica-Wagner, C. Prescod-Weinstein, H.-B. Yu

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Dark Energy and Cosmic Acceleration in the Modern Universe

J. Annis, J. Newman, A. Slosar

(contributors from the community)

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C. Chang, L Newburgh, D. Shoemaker

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Cosmic Probes of Fundamental Physics

R. Adhikari, L. Anchordoqui, K. Fang, B. S. Sathyaprakash, K. Tollefson

(contributors from the community)

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TOPICAL GROUP REPORTS

Theory Frontier

String Theory, Quantum Gravity, and Black Holes

D. Harlow, S. Kachru, J. Maldacena

(contributors from the community)

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Techniques of Effective Field Theory

P. Draper, I. Rothstein

(contributors from the community)

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Conformal Field Theory and Formal Quantum Field Theory

D. Poland, L. Rastelli

(contributors from the community)

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Theory of Scattering Amplitudes

Z. Bern, J. Trnka

(contributors from the community)

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Lattice Gauge Theory

Z. Davoudi, T. Izubuchi, E. Neil

(contributors from the community)

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Theory Techniques for Precision Physics Calculation

R. Boughezal, Z. Ligeti

(contributors from the community)

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Theory of Collider Phenomena

F. Maltoni, S. Su, J. Thaler

(contributors from the community)

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Model-Building for Physics Beyond the Standard Model

P. Fox, G. Kribs, H. Murayama

(contributors from the community)

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Theory of Astro-Particle Physics and Cosmology

D. Green, J. Ruderman, B. Safdi, J. Shelton

(contributors from the community)

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Quantum Information Science

S. Catterall, R. Harnik, V. Hubeny

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Theory of Neutrino Physics

A. de Gouvêa, I. Mocioiu, S. Pastore, L. Strigari

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TOPICAL GROUP REPORTS

Accelerator Frontier

Beam Physics and Accelerator Education

M. Bai, Z. Huang, S. Lund

(contributors from the community)

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Accelerators for Neutrinos

J. Galambos, B. Zwaska, G. Arduini

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Accelerators for Electoweak and Higgs Boson Processes

G. Hoffstaetter, Q. Qin, M. Ross

(contributors from the community)

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Multi-TeV Colliders

M. Palmer, N. Pastrone, J. Tang, A. Valishev

(contributors from the community)

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Accelerators for Fixed Target and Rare Processes

R. Milner, E. Prebys, M. Lamont

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Advanced Accelerator Concepts

R. Assman, C. Geddes, M. Hogan, P. Musumeci

(contributors from the community)

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- [2] A. Beale, "Surgical Writings", 1839.

Beam Physics and Accelerator Education

C. Barbier, S. Belomestnykh, S. Bermudez, E. Nanni, F. Pellemoine, G. Sabbi,
Y.-E. Sun, H. Weise, S. Zlobin

(contributors from the community)

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TOPICAL GROUP REPORTS

Instrumentation Frontier

Quantum Sensors

T. Cecil, K. Irwin, R. Maruyama, M. Pyle

(contributors from the community)

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Photon Detectors

J. Estrada, M. Sanchez, C. Rogan

(contributors from the community)

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Solid State Detectors and Tracking

T. Affolder, A. Apresyan, S. Worm

(contributors from the community)

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Trigger and Data Acquisition Systems

D. Acosta, W. Ketchum, S. Majewski

(contributors from the community)

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Micro-Pattern Gas Detectors

B. Surrow, M. Titov, S. Vahsen

(contributors from the community)

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Calorimetry

A. White, M. Yeh, R. Yohay

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Detector Electronics and ASICs

G. Carini, M. Newcomer, J. Parsons

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Noble Gas and Liquid Detectors

E. Dahl, R. Guenette, J. Raaf

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Detector Systems Integration and Cross-Cutting Issues

J. Fast, M. Garcia-Sciveres, I. Shipsey

(contributors from the community)

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Radio Detection

A. Connolly, A. Karle

(contributors from the community)

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TOPICAL GROUP REPORTS

Computational Frontier

Experimental Algorithms and Parallelization

G. Certai, K. Heitmann, W. Hopkins

(contributors from the community)

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Theoretical Computation and Simulations

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(contributors from the community)

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Machine Learning

P. Shanahan, K. Terao, D. Whiteson

(contributors from the community)

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Storage and Processing Resources for Particle Physics Computing

W. Bhimij, M. Lin, F. Wuerthwein

(contributors from the community)

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End User Analysis for Particle Physics Computation

G. Davies, P. Onyisi, A. Roberts

(contributors from the community)

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Quantum Computing

T. Humble, G. Perdue, M. Savage

(contributors from the community)

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Reinterpretation and Long-Term Preservation of Data and Code

K. S. Cranmer, M. Carrasco Kind

(contributors from the community)

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TOPICAL GROUP REPORTS

Underground Facilities

Underground Facilities for Neutrinos

conveners

(contributors from the community)

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Underground Facilities for the Cosmic Frontier

conveners

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Underground Detectors

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Supporting Capabilities for Underground Facilities

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Synergies in Research at Underground Facilities

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An Integrated Strategy for Underground Facilities and Infrastructure

conveners

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TOPICAL GROUP REPORTS

Community Engagment Frontier

Higgs Boson Properties

S. Dawson, A. Korytov, C. Vernieri

(contributors from the community)

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Career Pipeline and Development in Particle Physics

J. Hogan, A. Karadzhinova-Ferrer, S. Malik

(contributors from the community)

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Diversity and Inclusion in Particle Physics

C. Bonifazi, J. S. Bonilla, M.-C. Chen, Y.-H. C. Lin

(contributors from the community)

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Physics Education

S. de Jong, S. Malik, R. Ruchti

(contributors from the community)

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Finally: It was stated at the outset, that this system would not be here, and at once, perfected. You cannot but plainly see that I have kept my word. But I now leave my cetological System standing thus unfinished, even as the great Cathedral of Cologne was left, with the crane still standing upon the top of the uncompleted tower. For small erections may be finished by their first architects; grand ones, true ones, ever leave the copestone to posterity. God keep me from ever completing anything. This whole book is but a draught—nay, but the draught of a draught. Oh, Time, Strength, Cash, and Patience!

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- [1] J. Scoresby, "Journals", 1820.
- [2] A. Beale, "Surgical Writings", 1839.

Public Education and Outreach

S. Demers, J. Jepson, D. Lincoln, A. Murongo

(contributors from the community)

Already we are boldly launched upon the deep; but soon we shall be lost in its unshored, harbourless immensities. Ere that come to pass; ere the Pequod's weedy hull rolls side by side with the barnacled hulls of the leviathan; at the outset it is but well to attend to a matter almost indispensable to a thorough appreciative understanding of the more special leviathanic revelations and allusions of all sorts which are to follow.

It is some systematized exhibition of the whale in his broad genera, that I would now fain put before you. Yet is it no easy task. The classification of the constituents of a chaos, nothing less is here essayed. Listen to what the best and latest authorities have laid down.

"No branch of Zoology is so much involved as that which is entitled Cetology," says Captain Scoresby, A.D. 1820 [1].

"It is not my intention, were it in my power, to enter into the inquiry as to the true method of dividing the cetacea into groups and families. . . . Utter confusion exists among the historians of this animal" (sperm whale), says Surgeon Beale, A.D. 1839 [2].

"Unfitness to pursue our research in the unfathomable waters." "Impenetrable veil covering our knowledge of the cetacea." "A field strewn with thorns." "All these incomplete indications but serve to torture us naturalists."

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Public Policy and Government Engagement for Particle Physics

B. C. Choudhary, R. Fine, L Suter

(contributors from the community)

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Environmental and Societal Impacts of Particle Physics

K. Bloom, V. Boisvert, M. Headley

(contributors from the community)

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