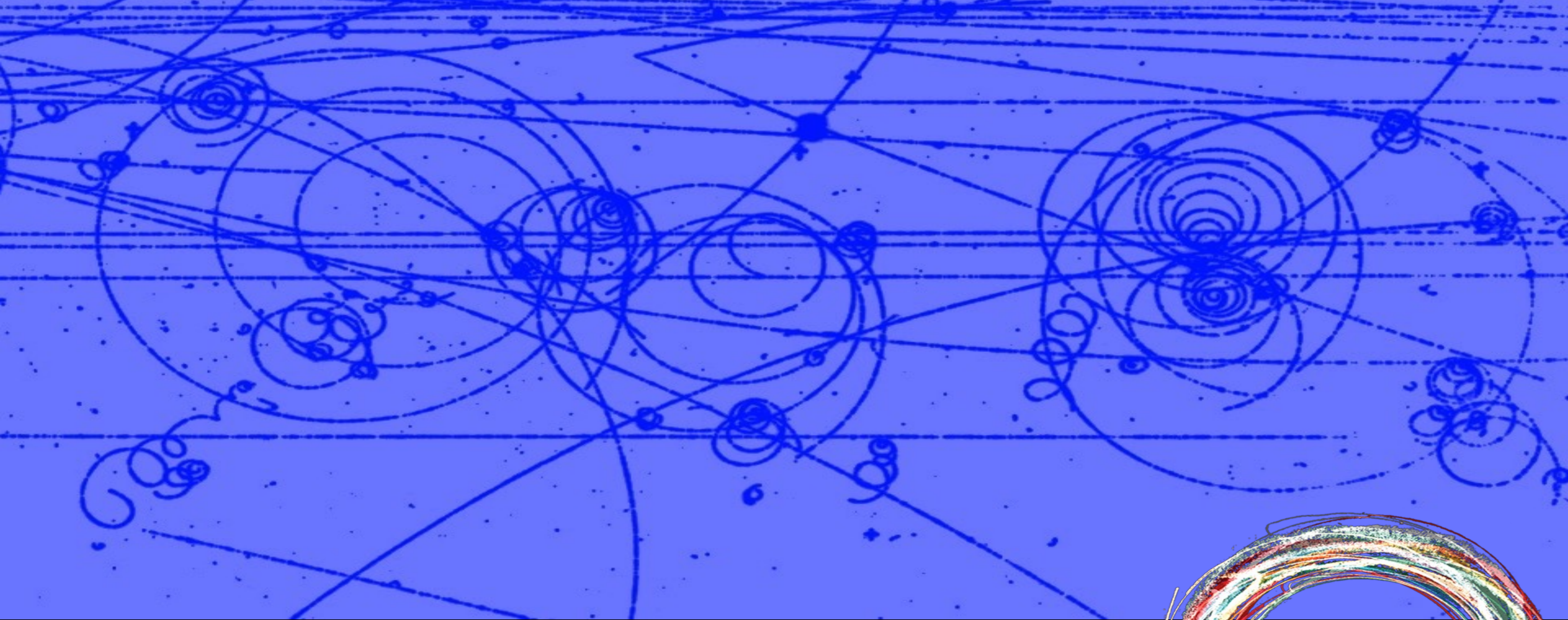


LECTURE 1
INTRODUCTION, OVERVIEW & BASIC CONCEPTS

PHY 493/803

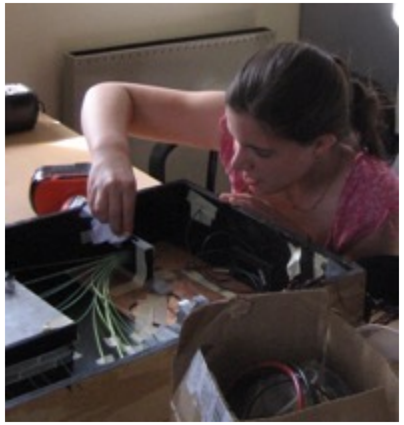
Prof. Berkman: A Brief Background

Education:
- B.A. Physics, Reed College
- Ph.D. Physics, University of British Columbia
- Postdoc, Fermi National Accelerator Laboratory

Research: Experimental neutrino physics

Undergrad

Double Chooz Experiment
Reactor neutrinos
(Scintillator detector)

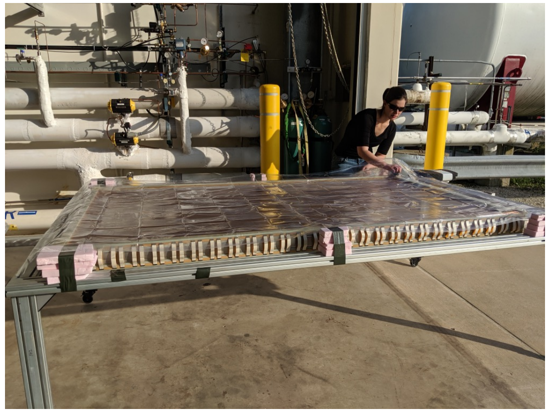


PhD

Super-Kamiokande & T2K
Beam, atmospheric, solar neutrinos
(Water Cherenkov detector)

Postdoc, and now at MSU

MicroBooNE/SBN/DUNE
Beam, atmospheric, solar neutrinos
(Liquid argon time projection chamber)



PHY 493/803

Lecturer: Prof. Sophie Berkman (Office 3231 BPS)
sberkman@msu.edu

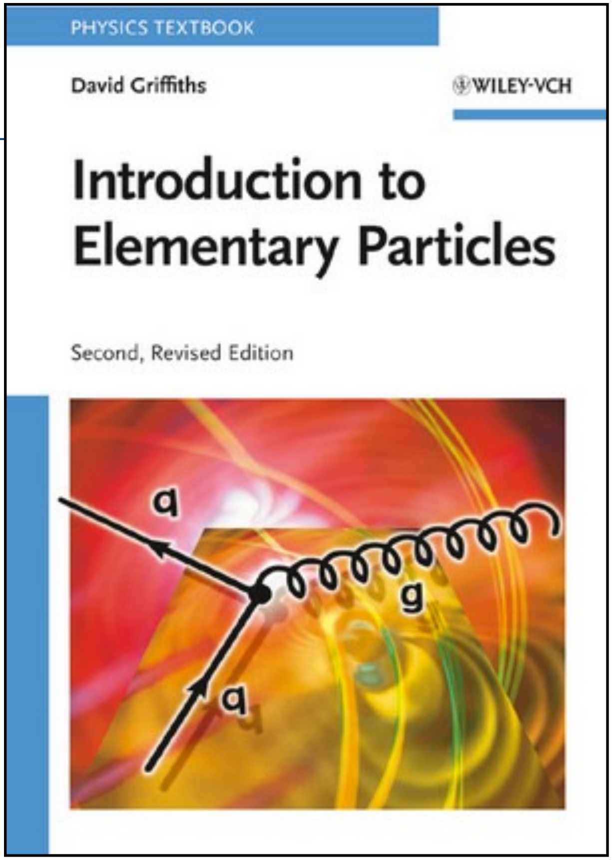
Office Hours: Friday 4:00-5:00pm

Class: M,W,F 03:00 – 03:50 in BPS 1415

Textbook: “Introduction to Elementary Particles”
(D. Griffiths, 2nd Edition)

Optional Reading:
“Particle Physics” (B.R. Martin & G. Shaw, 3rd Edition)
“Theory of Relativity” (W. Pauli, 3rd Edition)

Course Website:
D2L: “Elementary Particle Physics SS25 Merged PHY803 PHY493”

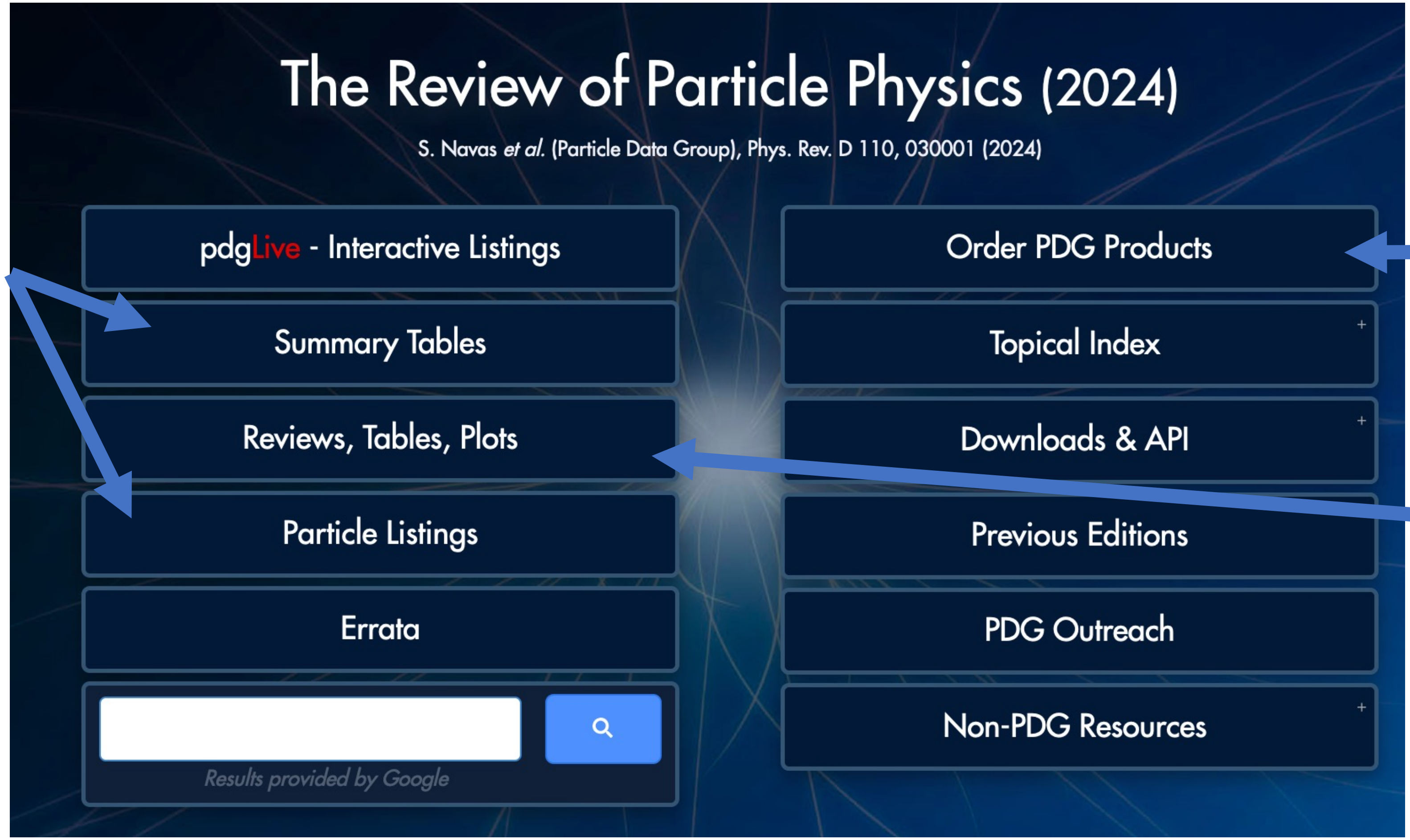


Useful Resource: Particle Data Book

Particle Physics:

http://pdg.lbl.gov

Particle data (mass, charge, etc)



Order free copies of the latest versions

(Or it's all available online here)

Review articles and Tools/Formulas

Grade Components (PHY 493)

Tier II Writing Assignment (493) (15%)

You are required to write a paper on a topic within particle physics and manageable within the length requirements. You may select a topic from the list provided in the syllabus or pick your own. Each paper milestone is worth 1% of this grade; ie. missing the outline will result in a maximum of 14%.

Review Assignment (10%)

You will review a sample paper and provide comments at the level of a journal review. Details will follow later in the semester.

Homework (30%)

There will be 7 homework assignments with due dates.

The schedule and problems will be posted on D2L, hand in answers on gradescope.

Exams (15% x 2)

There will be two in class midterm exams (closed book and notes) during class time. The dates are indicated in the course schedule. There is no final exam.

Quizzes (15%)

There will be weekly quizzes, starting next week (open book and notes). The quizzes will be based on the lectures and reading for the week and on material from previous weeks. There will be no quizzes the weeks of the midterm exams.

Grade Components (PHY 803)

Publication Summary (803) (15%)

You will choose an existing long-form paper on a topic in particle physics and write a novel summary in short-form (letter) format appropriate for publication in PRL or similar. Each paper milestone is worth 1% of this grade; ie. missing the outline will result in a maximum grade of 14%.

Review Assignment (10%)

You will review a sample paper and provide comments at the level of a journal review. Details will follow later in the semester.

Homework (30%)

There will be 7 homework assignments with due dates. **+1 Extra Problem**

The schedule and problems will be posted on D2L, hand in answers on gradescope.

Exams (15% x 2)

There will be two in class midterm exams (closed book and notes) during class time. The dates are indicated in the course schedule. There is no final exam.

Quizzes (15%)

There will be weekly quizzes, starting next week (open book and notes). The quizzes will be based on the lectures and reading for the week and on material from previous weeks. There will be no quizzes the weeks of the midterm exams.

Term Paper/Project Milestones

Select Topic : February 14 (Friday)

Outline Due : February 28 (Friday)

First draft due for feedback **(OPTIONAL)**: March 28 (Friday)
First draft due for credit : April 11 (Friday)

Final draft due : April 25 (Friday)

If you do not want to select your own topic, please let me know before the deadline and I will assign one to you.

Each of the milestones are worth 1% of your final grade.

Term Paper Guidelines

Examples of papers :

1) Paper in Nature

http://www.nature.com/nature/journal/v449/n7165/full/nature06213.html

nature Vol 449|25 October 2007|doi:10.1038/nature06213

LETTERS

Discovery of ^{40}Mg and ^{42}Al suggests neutron drip-line slant towards heavier isotopes

2) Paper in Physical Review Letters

https://journals.aps.org/prl/pdf/10.1103/PhysRevLett.128.241801

PHYSICAL REVIEW LETTERS **128,** 241801 (2022)

Editors' Suggestion Featured in Physics

Search for an Excess of Electron Neutrino Interactions in MicroBooNE Using Multiple Final-State Topologies

Guidelines for the style, outline and first draft

1) Double-spaced format, Word or PDF files (see syllabus!)
2) Paper should include:
   - title, author, abstract, main text (figures), references (At least 5, likely more. All information from external sources should be properly cited)
3) **For the outline:**
   - write a title and a preliminary abstract (around 10 lines)
   - make up the logical structure of the paper. Eg, sections (intro, physics principles, method, results, discussion, conclusions), one sentence for each.
4) **For the first draft:**
   - Paper should be at least 50% done

Questions ?

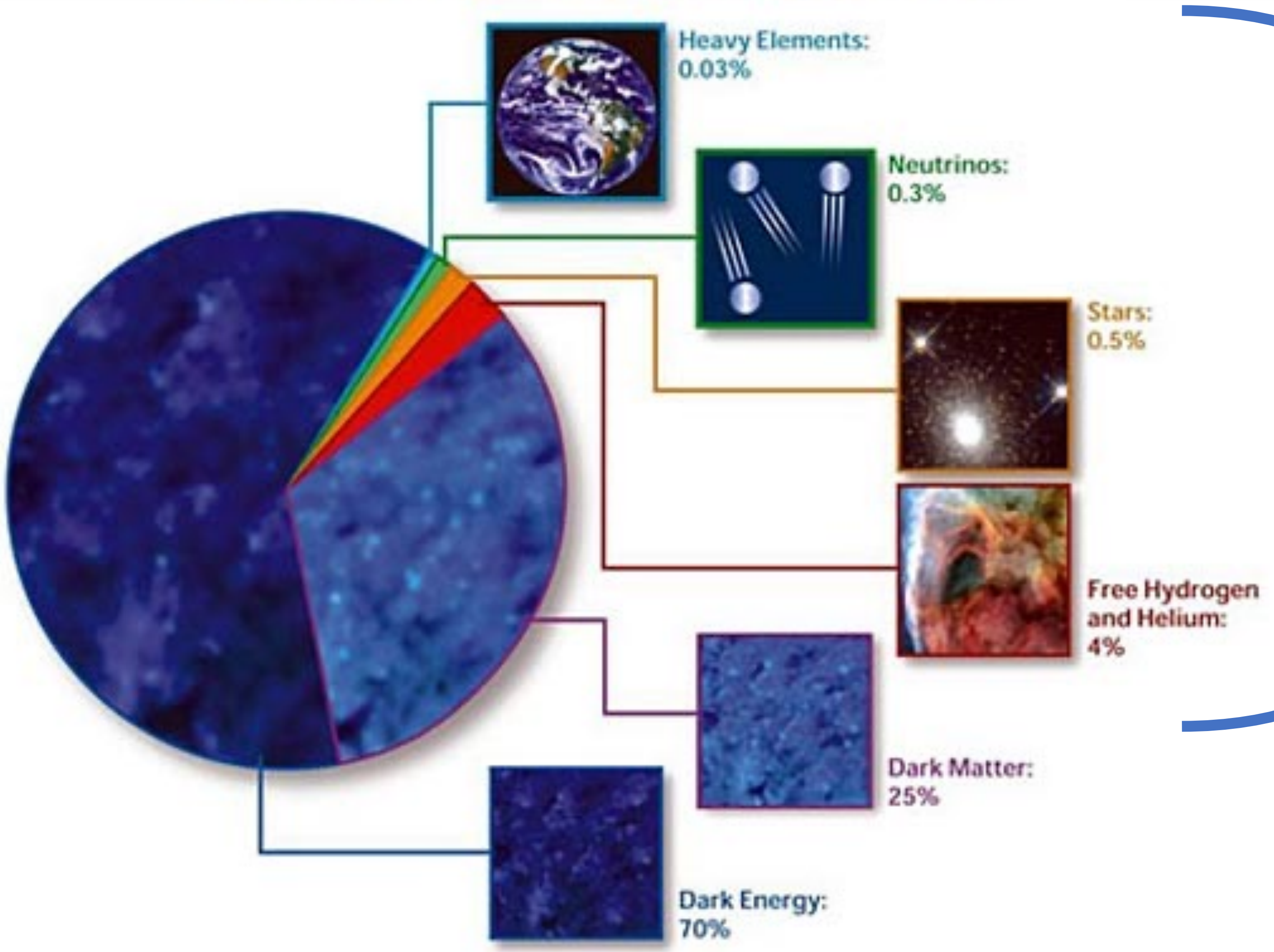
Today

1. What is particle physics?

2. Brief high level overview of topics in class

What is the World Made of and Why?

Most of our universe is something we know very little about!



In this class we will focus on this ~4-5% of the universe

https://www.bnl.gov/newsroom/news.php?a=22913

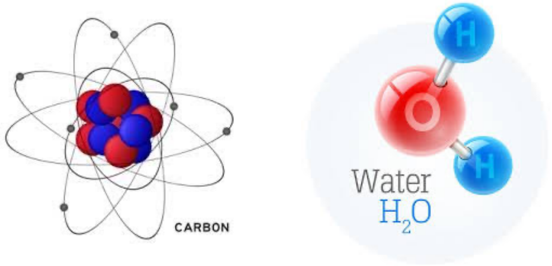
What are the fundamental components of the universe?

What is a tree made of?

A: branches, leaves, trunk, roots …

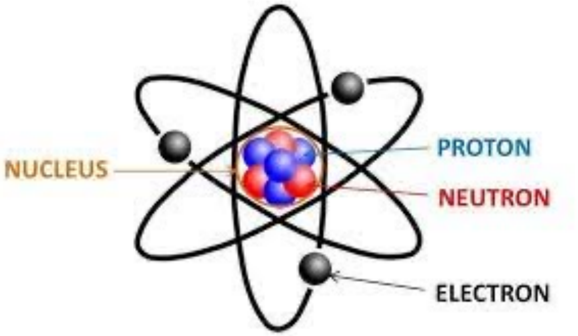
What are those made of?

A: Molecules (H2O), atoms (C, O), etc



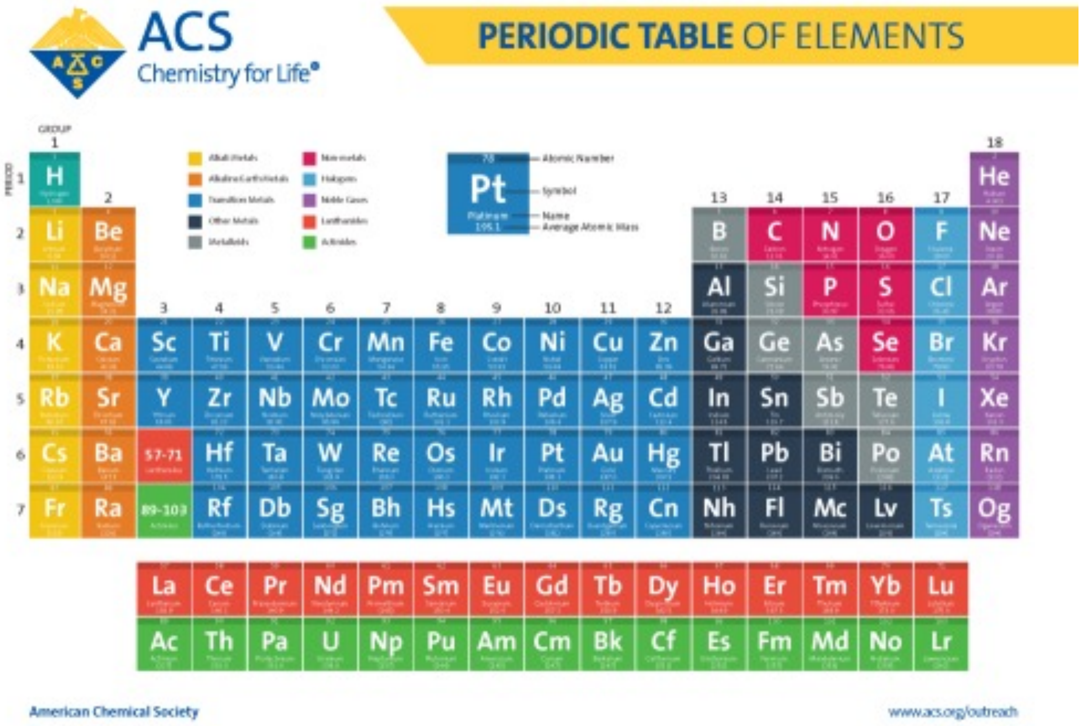
What are those made of?

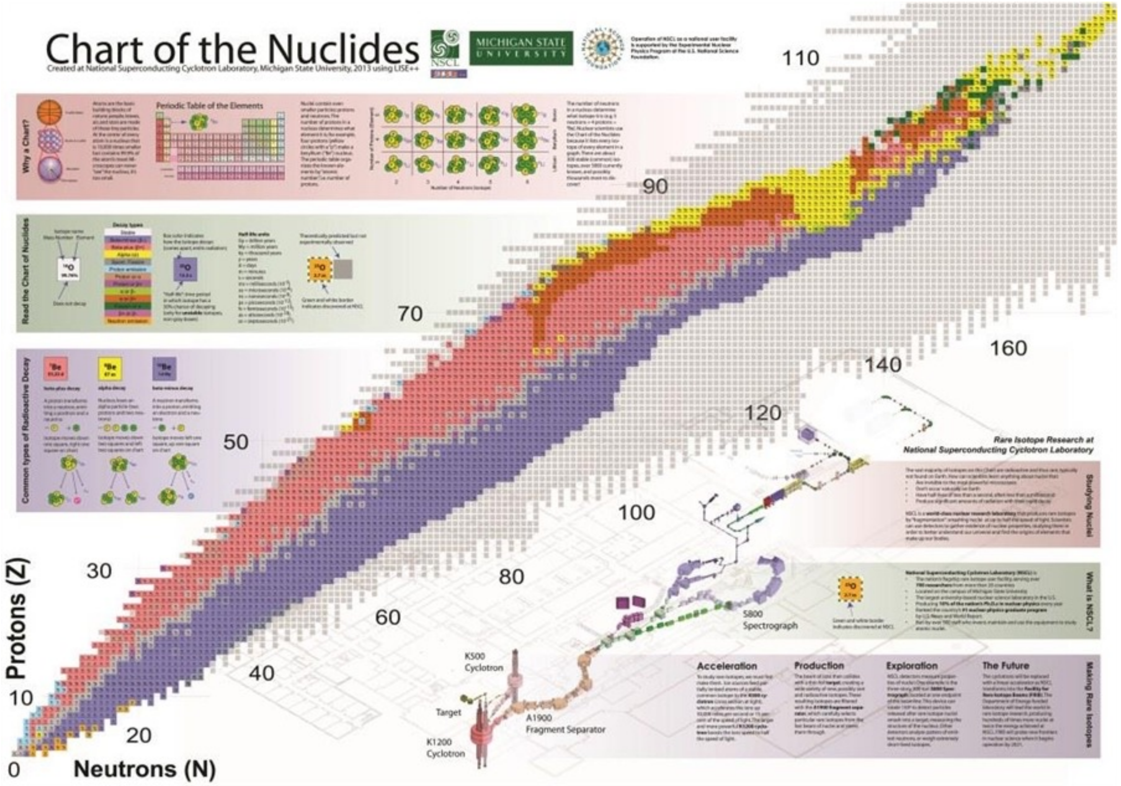
A: protons, neutrons, electrons



Organizing our Universe

Everything is made up of protons, neutrons, and electrons





Particle Physics

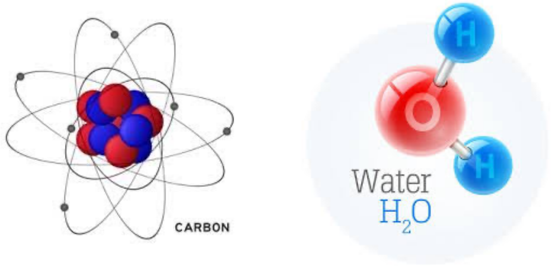
What are the fundamental components of the universe?

What is a tree made of?

A: branches, leaves, trunk

What are those made of?

A: Molecules (H2O), atoms (C, O), etc



What are those made of?

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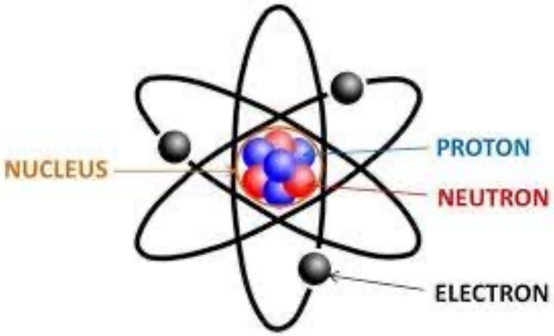
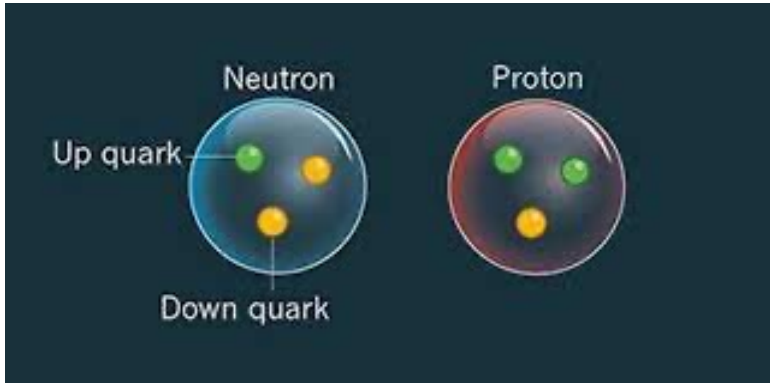


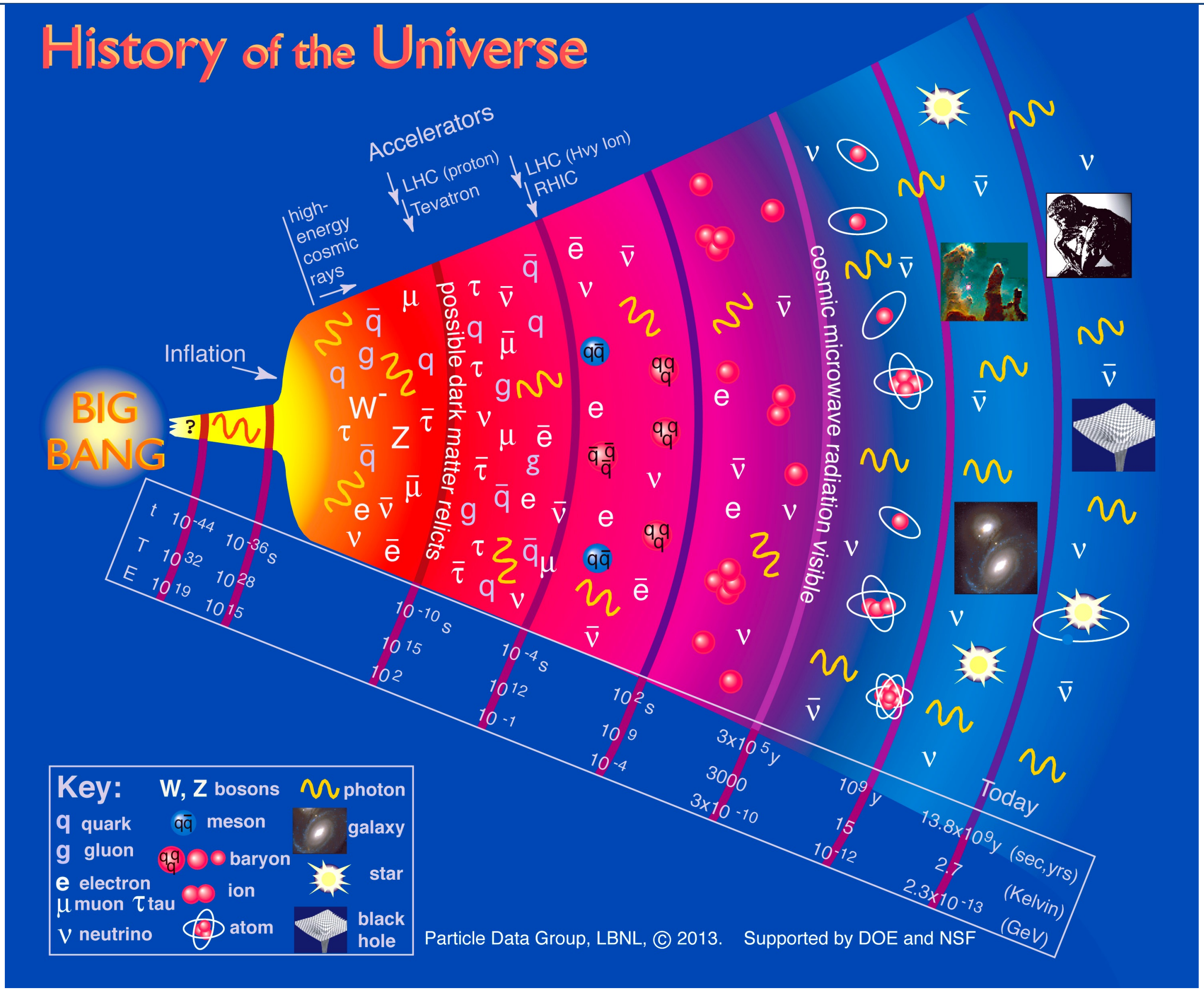
What are those made of?

A: quarks
(electrons, so far as we know are fundamental)



Particle physicists break matter down into its smallest components and study the properties of these components: What are their masses? How do they interact?

Why Particle Physics?



Soon after the big bang: hot dense particle soup

Today: colder, large scale structure

A Bit of History

The Nobel Prizes in Physics (Chemistry) from 1900 to the present trace the development of modern nuclear and particle physics.

Particle/nuclear physics
Experimental devices

Radioactivity (1903 Becquerel, Mme&M Curie)
Discovery of electron (1906 J.J.Thompson)
Disintegration of the elements (1908 Rutherford)
Quantization of Energy (1918 Planck)
Photoelectric Effect (1921 Einstein)
Structure of atoms (1922 Niels Bohr)
Elementary electron charge (1923 Millikan)
Cloud Chambers (1927 Wilson)
Quantum Mechanics (1932 Heisenberg)
Advances in Atomic Theory (1933 Schroedinger, Dirac)
Discovery of neutron (1935 Chadwick)
Discovery of positron (1936 Anderson)
Nuclear reactions (1938 Fermi)
Cyclotron (1939 Laurence)
Pauli Exclusion Principle (1945 Pauli)
Cosmic Radiation (1948 Blackett)
Nuclear Forces (1949 Yukawa)
Photographic Emulsions (1950 Powell)
Electrostatic Particle Acceleration (1951 Cockcroft, Walton)
Nuclear Magnetic Resonance (1952 Bloch & Purcell)
Parity violation (1957 Yang & Lee)
Discovery of antiproton (1959 Segre & Chamberlain)

Bubble Chamber (1960 Glaser)
Electron scattering (1961 Hofstadter)
Symmetry Principles (1963 Wigner)
Nuclear shell model (1964 Mayer and Jensen)
Quantum Electrodynamics (1965 Tomonaga, Schwinger, Feynman)
Resonant States (1968 Alvarez)
Quarks (1969 Gell-Mann)
Collective and particle motion in nuclei (1975 Bohr & Mottelson)
Heavy Mesons (1976 Richter, Ting)
Unified Theory (1979 Glashow, Salam, Weinberg)
CP Violation (1980 Cronin, Fitch)
Discovery of W and Z bosons (1984 Rubia & van der Meer)
Neutrino Beams (1988 Lederman, Schwartz, Steinberger)
Deep Inelastic Scattering (1990 Friedman, Kendall, Taylor)
Multi Wire Proportional Chamber (1992 Charpak)
Discovery of tau and detection of neutrino (1995 Perl, Reines)
Electroweak unification (1999 ‘t Hooft, Veltman)
Detection of Cosmic Neutrinos (2002 Davis, Koshiba)
Asymptotic Freedom (2004 Gross, Politzer, Wilczek)
CKM matrix element (2008 Kobayashi & Masukawa)
Higgs Boson (2013 Englert, Higgs)
Neutrino Oscillations (2015 Kajita & McDonald)

………. *More to come*

Ten Science Questions for the 21st century

National Academic Press, 2000

1. What is dark matter?
2. What is the nature of dark energy?
3. How did the universe begin?
4. Did Einstein have the last word on gravity?
5. What are the masses of the neutrinos, and how have they shaped the evolution of the universe?
6. How do cosmic accelerators work and what are they accelerating?
7. Are protons unstable?
8. What are the new states of matter at exceedingly high density and temperature?
9. Are there additional space-time dimensions?
10. Is a new theory of particle dynamics needed at the highest energies?

This came out 25 years ago, and we still don't have these answered!
-> Lots more to do!

Questions ?

Today

2. Brief high-level overview of topics in the course
   -> Where is particle physics now?

Course outline:

Very closely follows the textbook

- Particles
- Particle Dynamics (interactions between particles, forces)
- Relativistic Kinematics
- Symmetries
- Bound States
- Particle Accelerators
- Particle interactions with matter
- Particle detectors
- Feynman Rules
- Quantum Electrodynamics, Chromodynamics, EW Theory
- Gauge Theories
- Neutrinos
- The Future!

In this class we will discuss

What are the particles that make up our universe?

How do they interact?

How are these particles measured?

What do we still have to learn?

In order to do this, we also need some tools:

1. Relativistic kinematics
2. Feynman rules

Course outline:

Very closely follows the textbook

- Particles
- Particle Dynamics (interactions between particles, forces)
- Relativistic Kinematics
- Symmetries
- Bound States
- Particle Accelerators
- Particle interactions with matter
- Particle detectors
- Feynman Rules
- Quantum Electrodynamics, Chromodynamics, EW Theory
- Gauge Theories
- Neutrinos
- The Future!

Course Schedule

We will be studying all
about Elementary
Particle Physics!

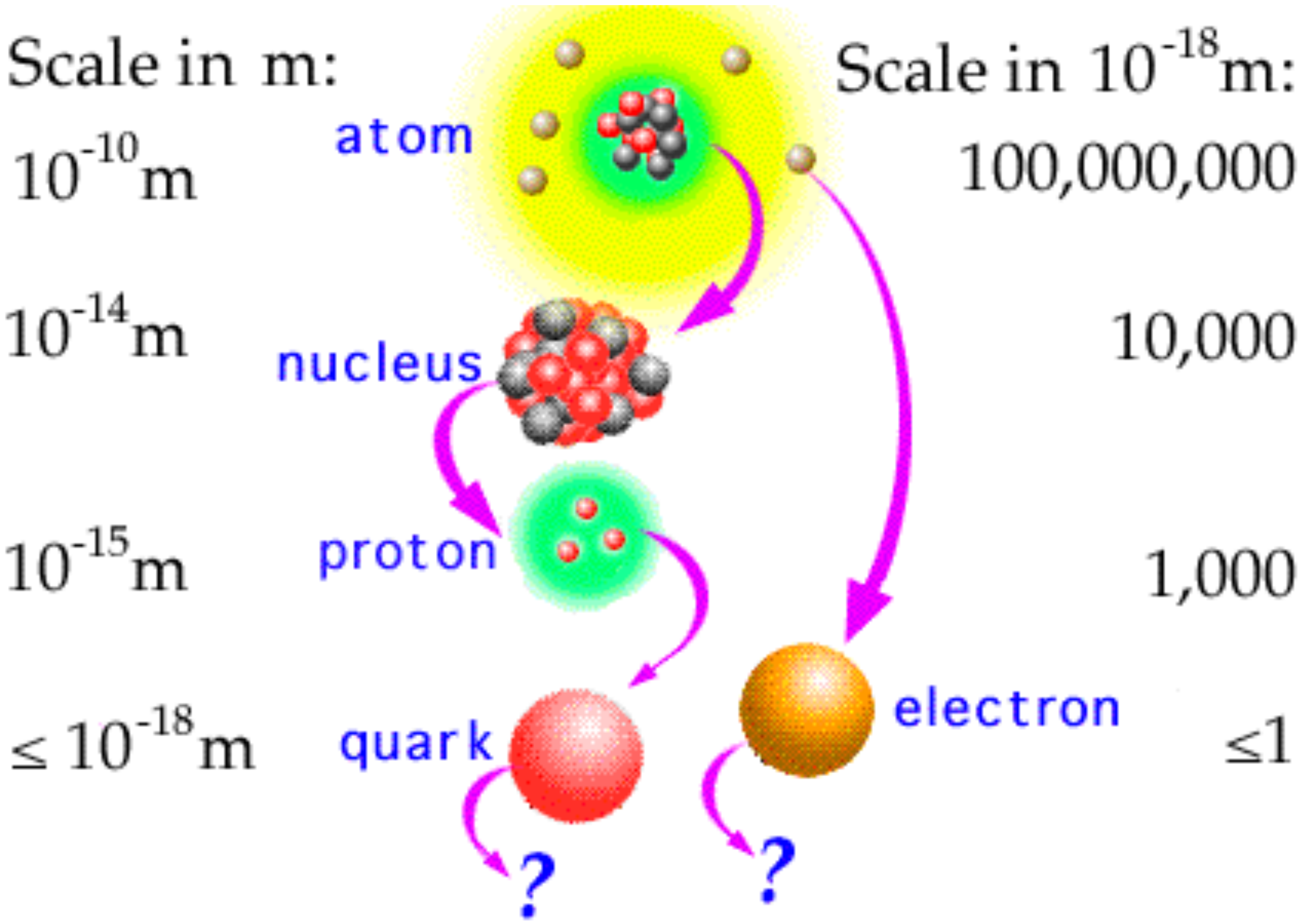
It will be a busy semester.

This course schedule can also be found in the syllabus, posted on D2L

PHY 493/803 Schedule, Spring 2025

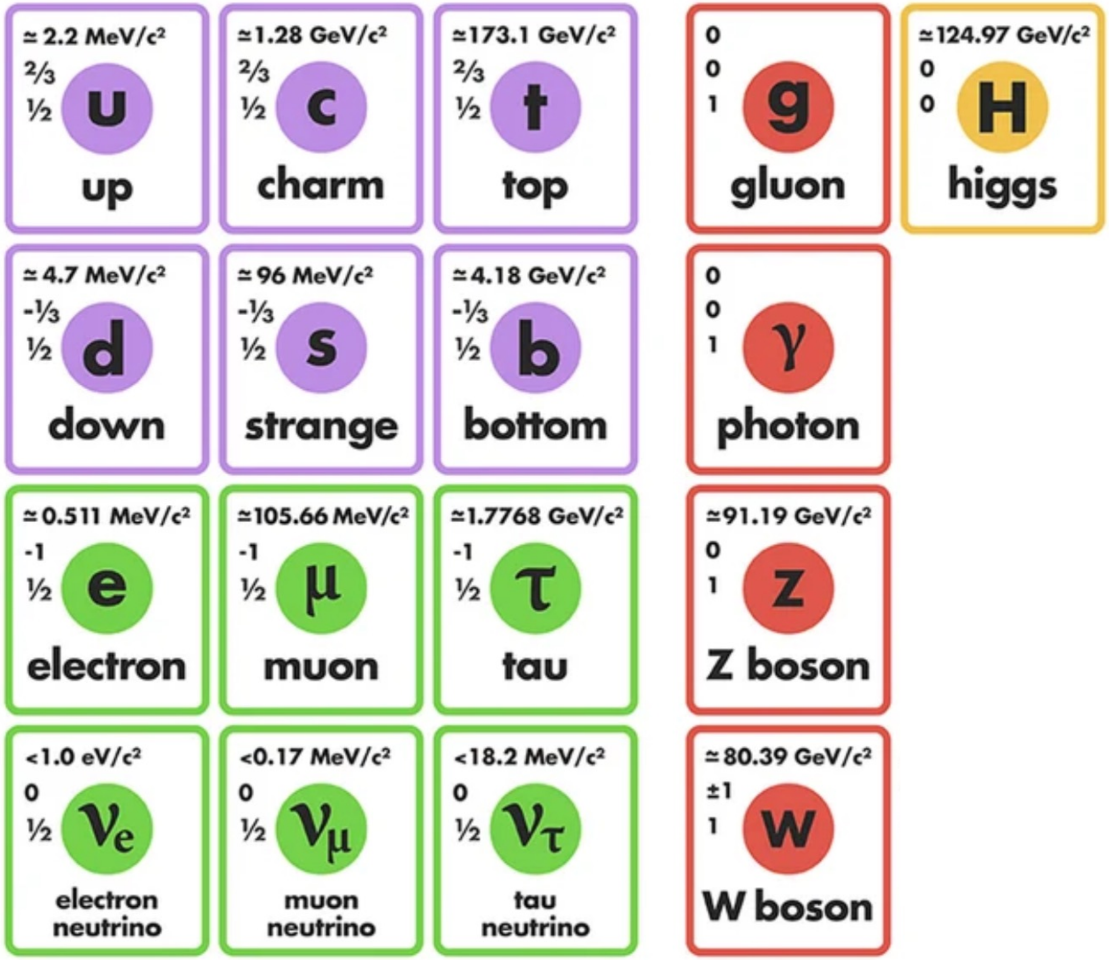
W	D	Date	Subjects Covered	Reading	HW Due	Paper Milestone
1	M	1/13	Introduction	Griffiths, Ch1		
	W	1/15	Particles			
	F	1/17				
2	M	1/20	**MLK Day: No class!**			
	W	1/22	Particle Dynamics	Griffiths, Ch2		
	F	1/24				
3	M	1/27	Relativity	Griffiths, Ch3	#1	
	W	1/29				
	F	1/31				
4	M	2/3	Symmetries	Griffiths, Ch4		
	W	2/5				
	F	2/7				
5	M	2/10	Bound States	Griffiths, Ch5	#2	
	W	2/12	Feynman Rules	Griffiths, Ch6		
	F	2/14				Select Topic
6	M	2/17				
	W	2/19	Particle Accelerators	PDG Review, Ch 29		
	F	2/21	Exam #1			
7	M	2/24			#3	
	W	2/26				
	F	2/28	Particle Interactions with Matter	PDG Review, Ch 32		Outline Due
8		3/2-3/9	**Spring Break: No Class!**			
9	M	3/10				
	W	3/12	Particle Detectors	PDG Review, Ch 33 & 34		
	F	3/14				
10	M	3/17	Modern HEP Experiments		#4	
	W	3/19	QED	Griffiths, Ch 7		
	F	3/21				
11	M	3/24				
	W	3/26	Quark Dynamics	Griffiths, Ch8		
	F	3/28				First Draft Due for feedback **(optional)**
12	M	3/31				
	W	4/2	Exam #2			
	F	4/4	Weak Interactions	Griffiths, Ch9		
13	M	4/7			#5	
	W	4/9				
	F	4/11	Gauge Theories	Griffiths, Ch 10		First Draft Due for credit
14	M	4/14	Neutrinos	Griffiths, Ch11		
	W	4/16			#6	
	F	4/18				Review Due
15	M	4/21	The Future!	Griffiths, Ch12		
	W	4/23				
	F	4/25			#7	Final Draft Due
16		4/28-5/2	**No Final Exam!**			

Elementary Particle Physics



Standard Model of Particle Physics

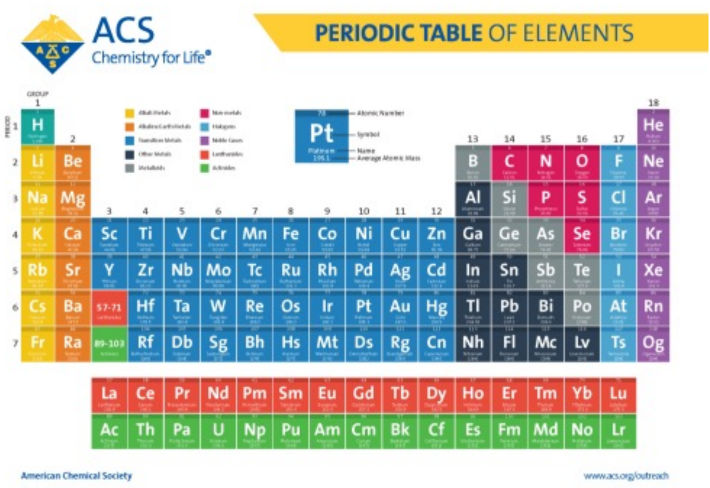
Rigorously experimentally validated model of the universe, with some known caveats

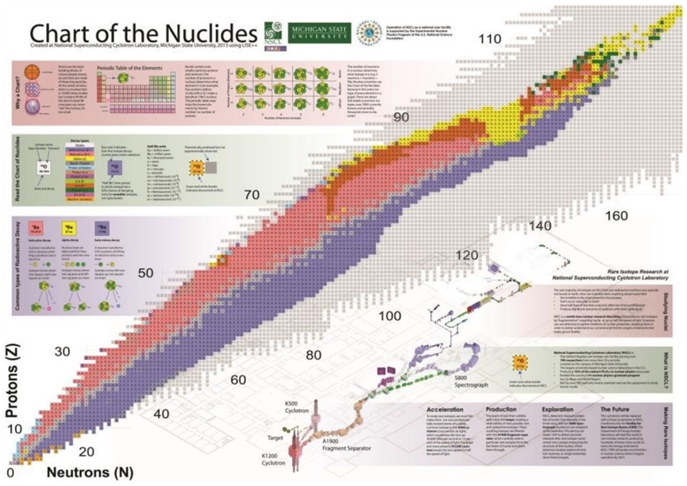


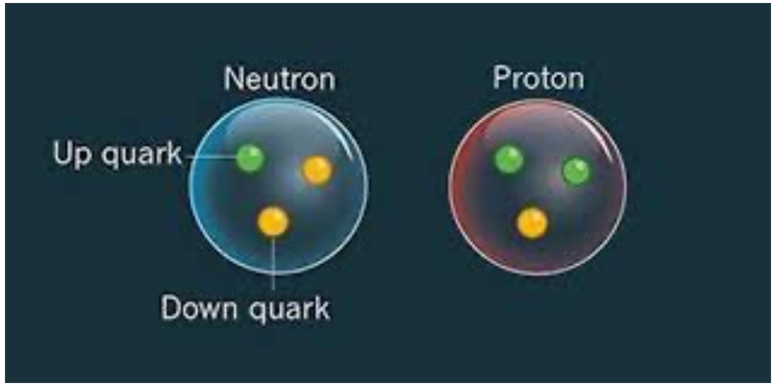
Periodic table of the elements, particle-physics-style!

Standard Model of Particle Physics

Rigorously experimentally validated model of the universe, with some known caveats







Standard Model of Particle Physics

Rigorously experimentally validated model of the universe, with some known caveats

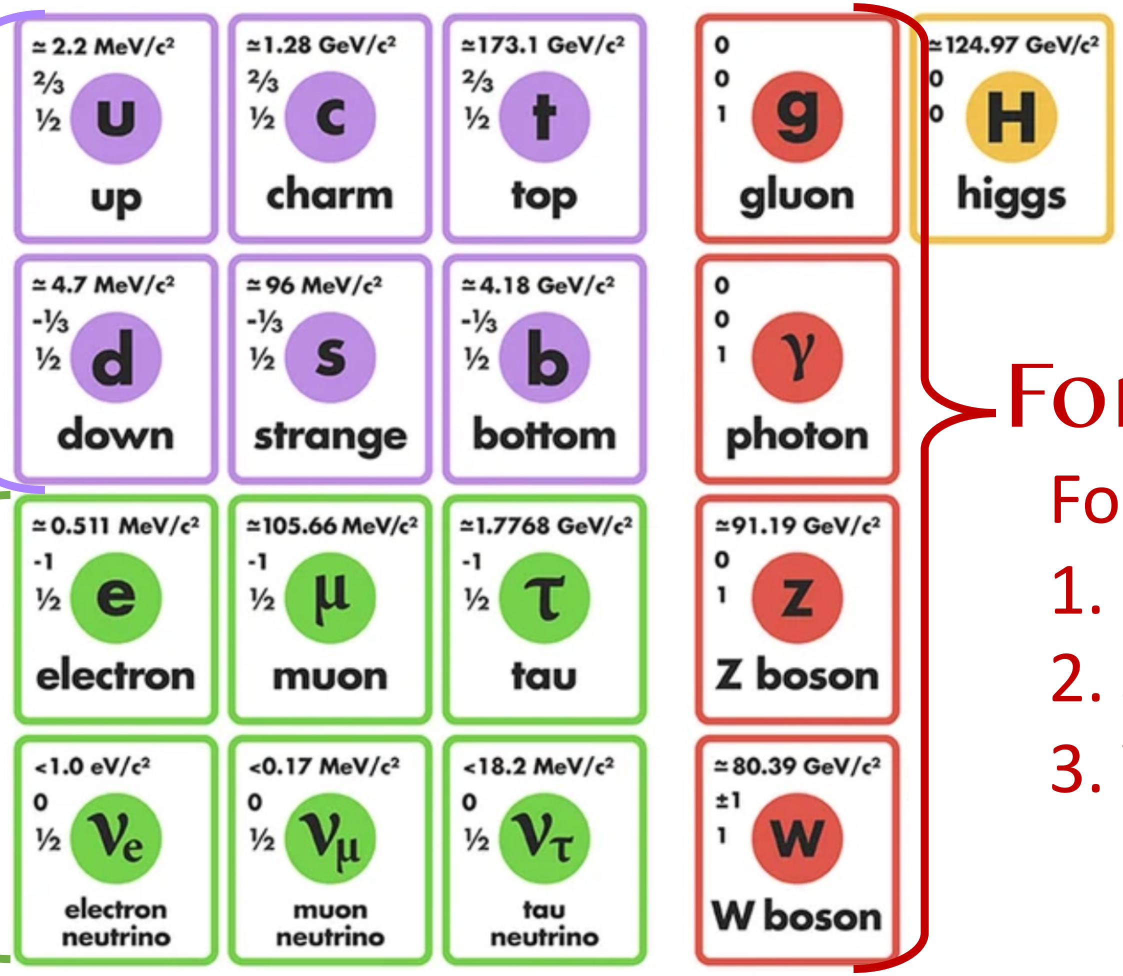
Matter:

Quarks

Combine to make protons, neutrons, pions

Leptons

Electrons, and heavier partners. Neutrinos



Force Carriers

Forces of nature:

1. Electromagntic
2. Strong nuclear force
3. Weak nuclear force

Standard Model of Particle Physics

Rigorously experimentally validated model of the universe, with some known caveats

Matter:

Quarks

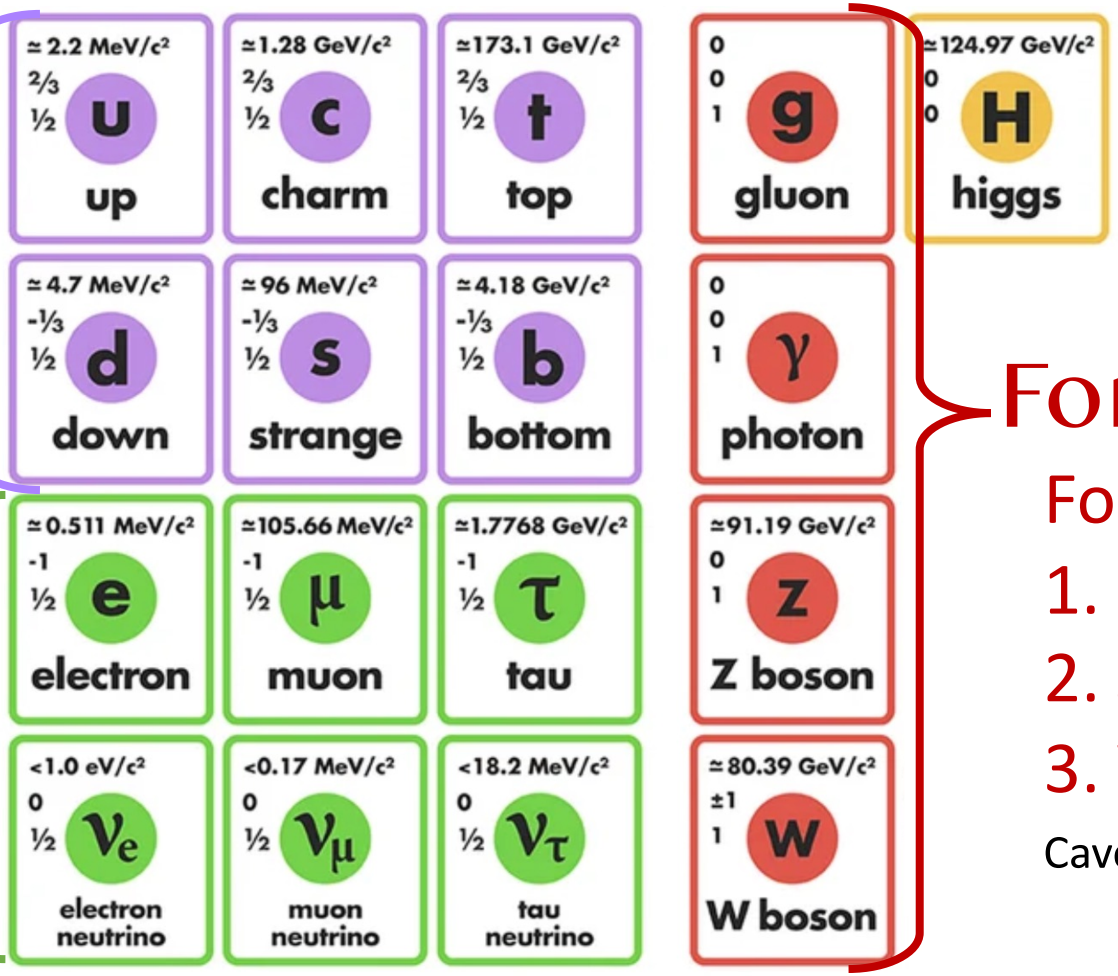
Combine to make protons, neutrons, pions

Leptons

Electrons, and heavier partners.

Neutrinos

Caveat: neutrinos are massless



Force Carriers

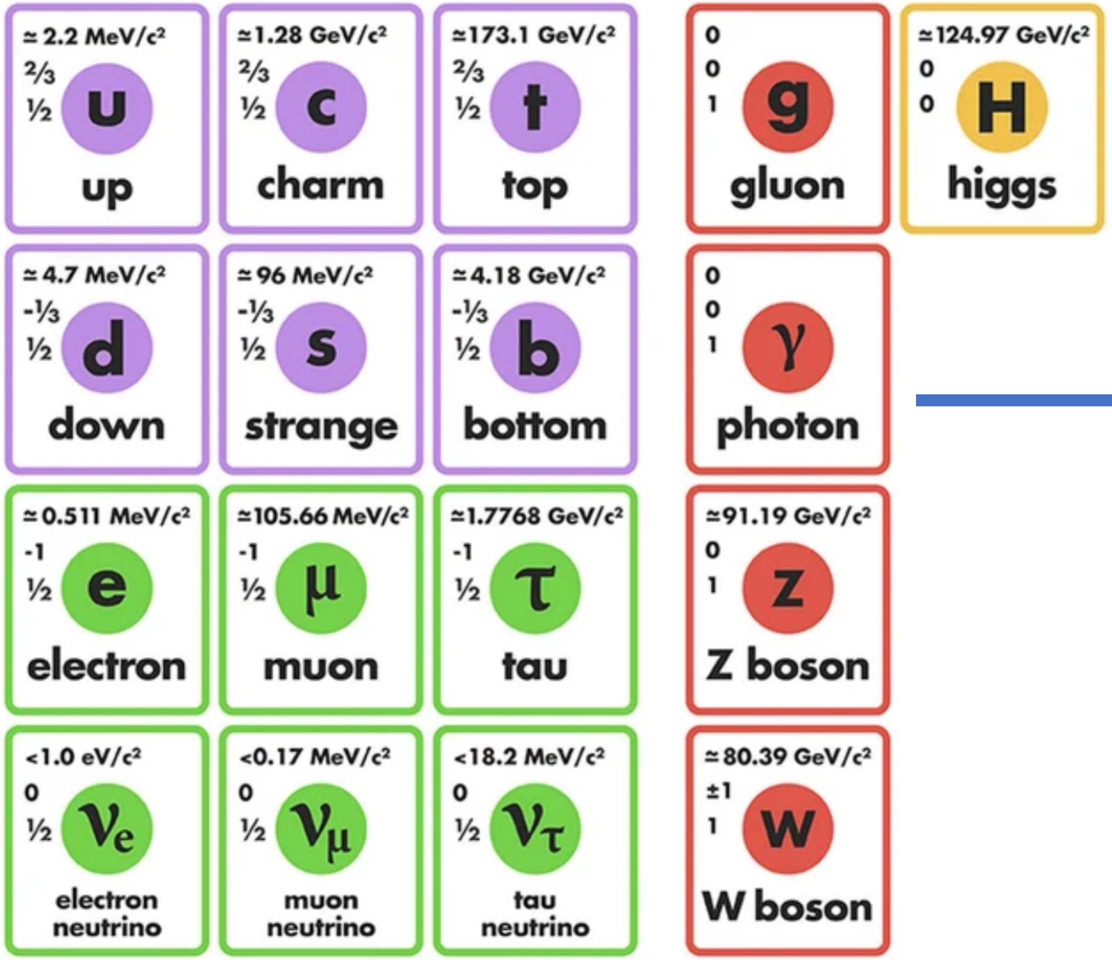
Forces of nature:

1. Electromagntic
2. Strong nuclear force
3. Weak nuclear force

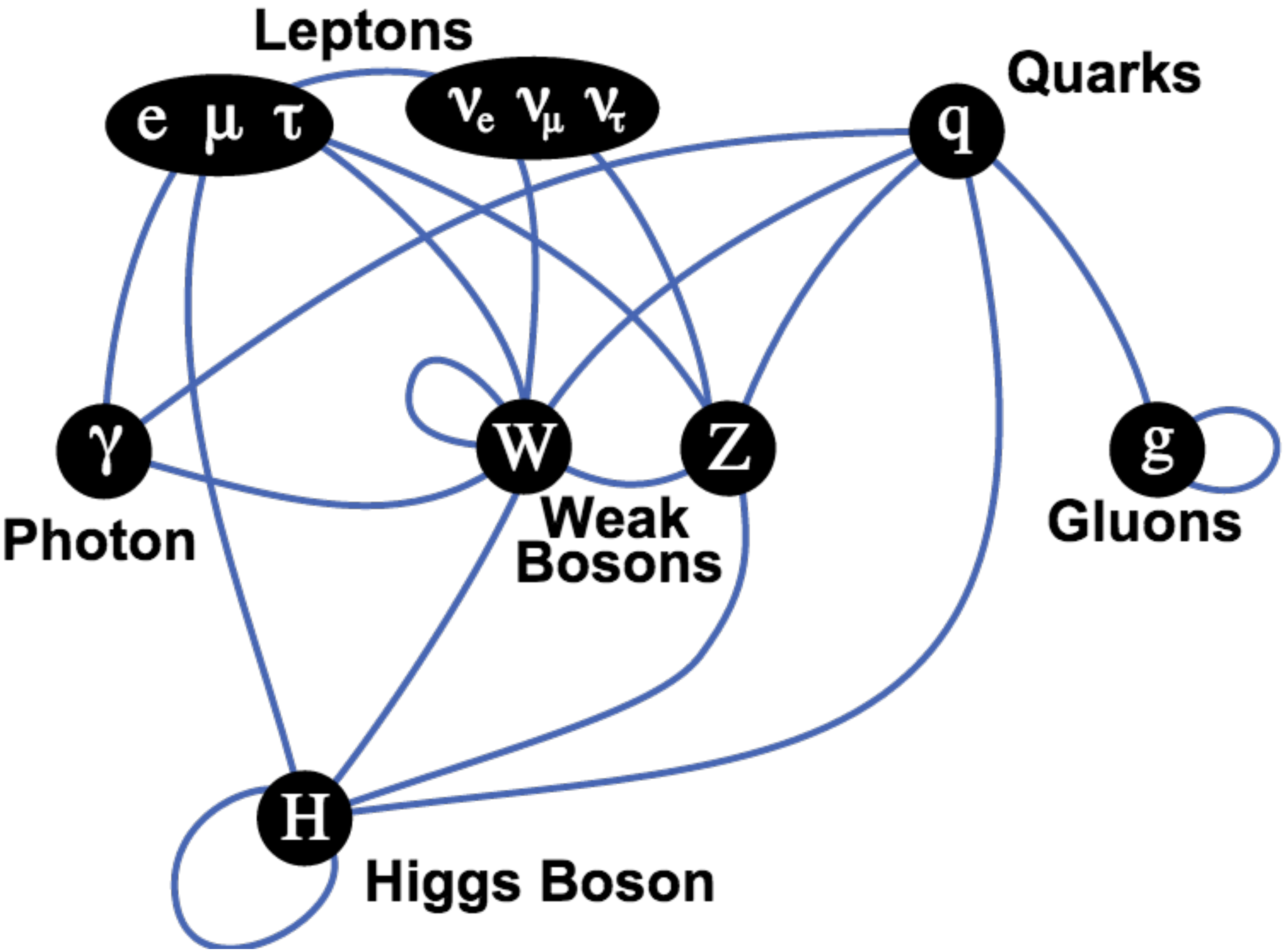
Caveat: gravity is not included

In this class: focus on the Standard Model, and get to the caveats and future directions towards the end

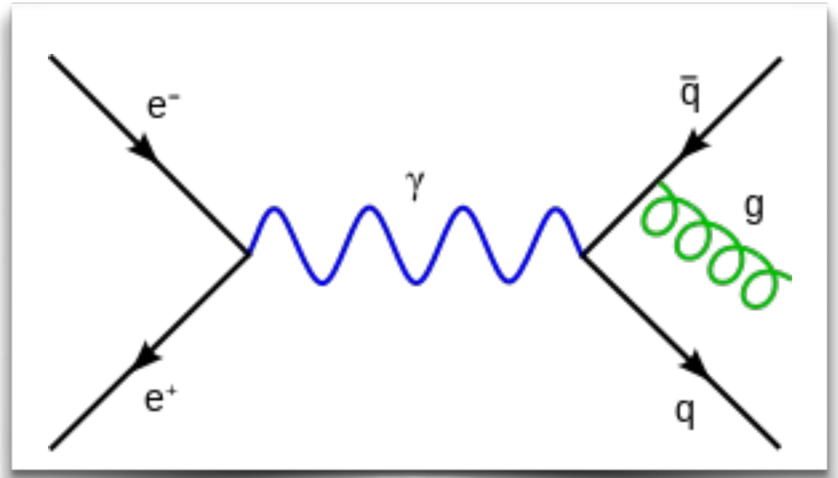
Elementary Particles

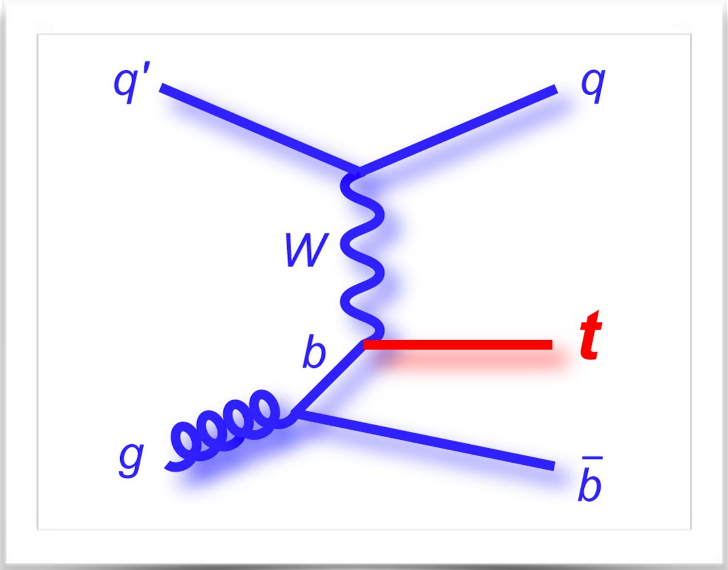


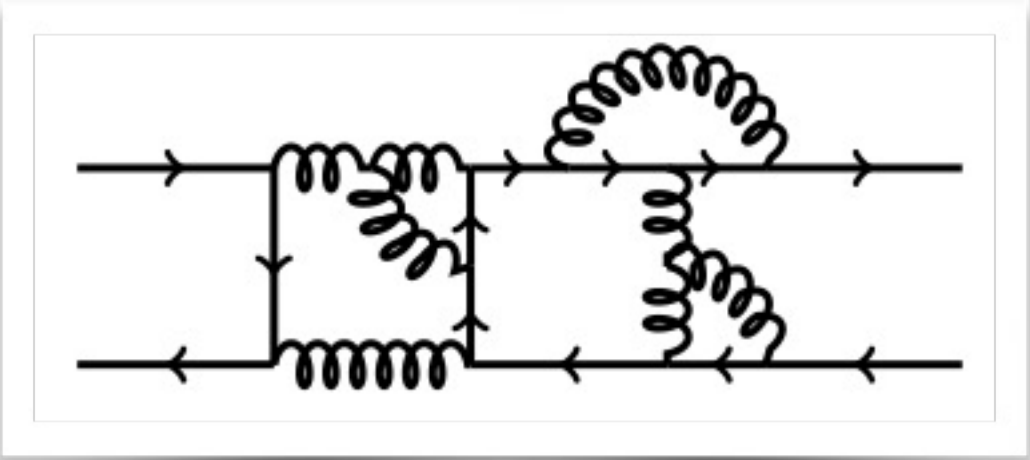
How do these particles interact?



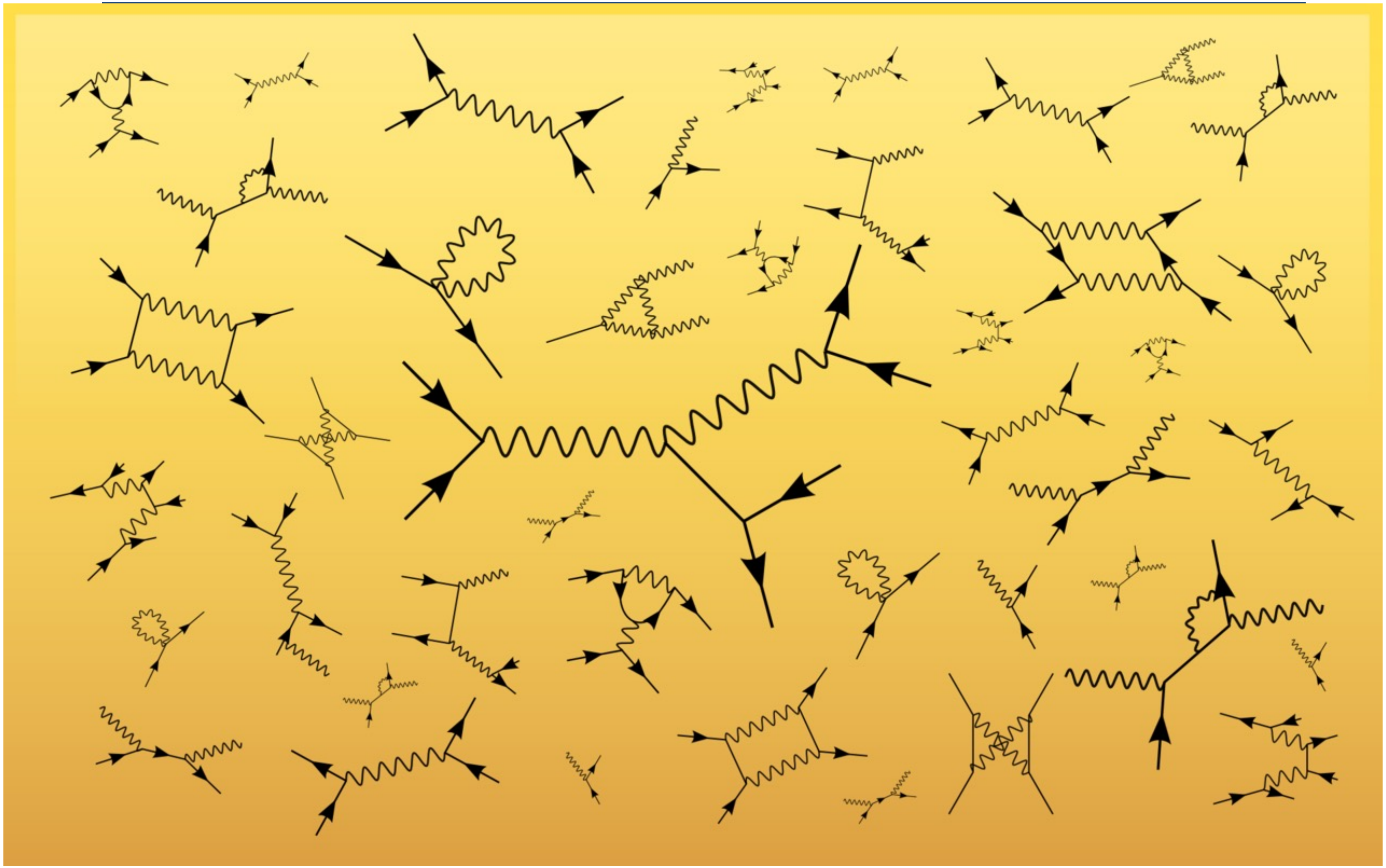
Feynman Diagrams: writing down how particles interact



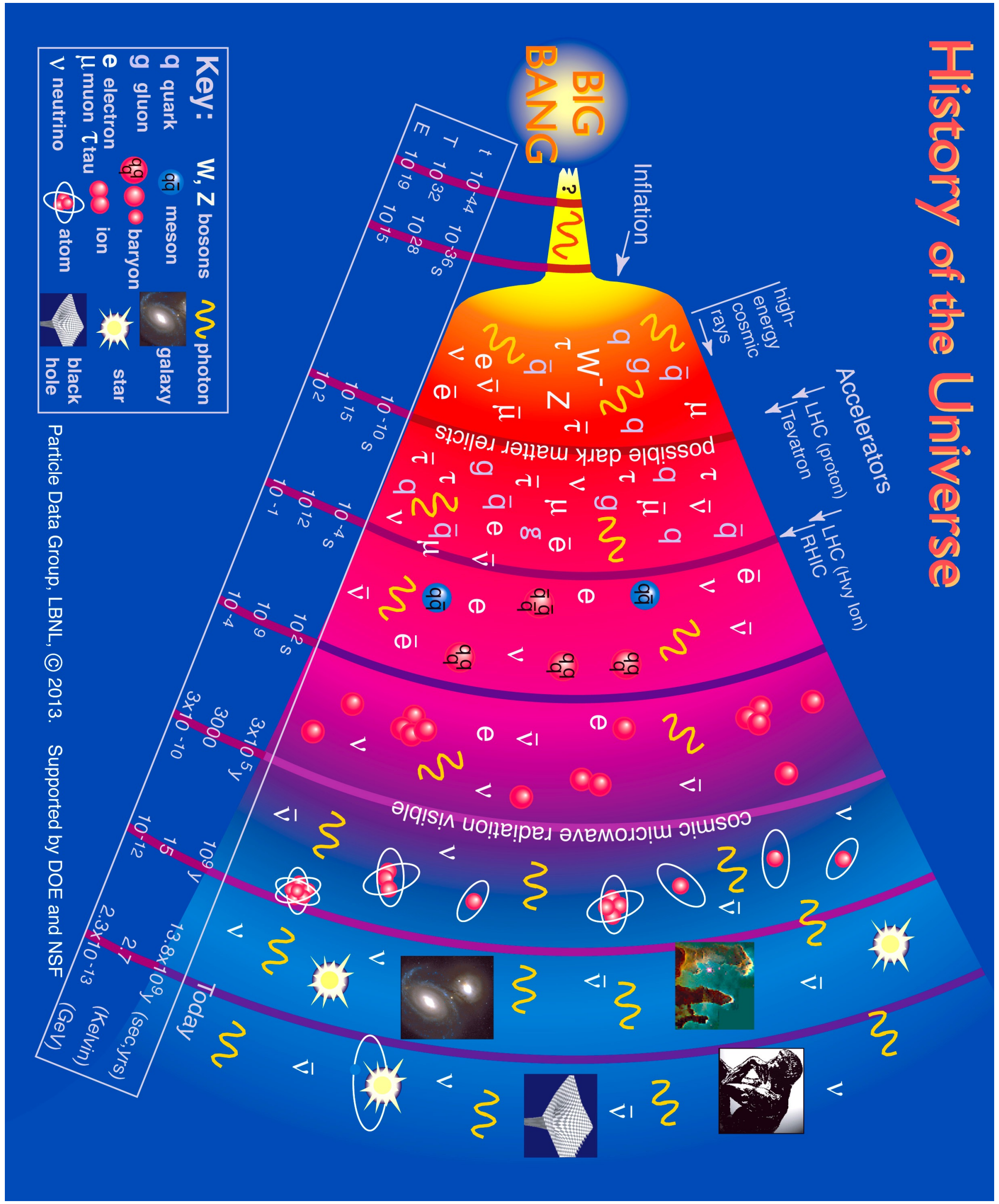


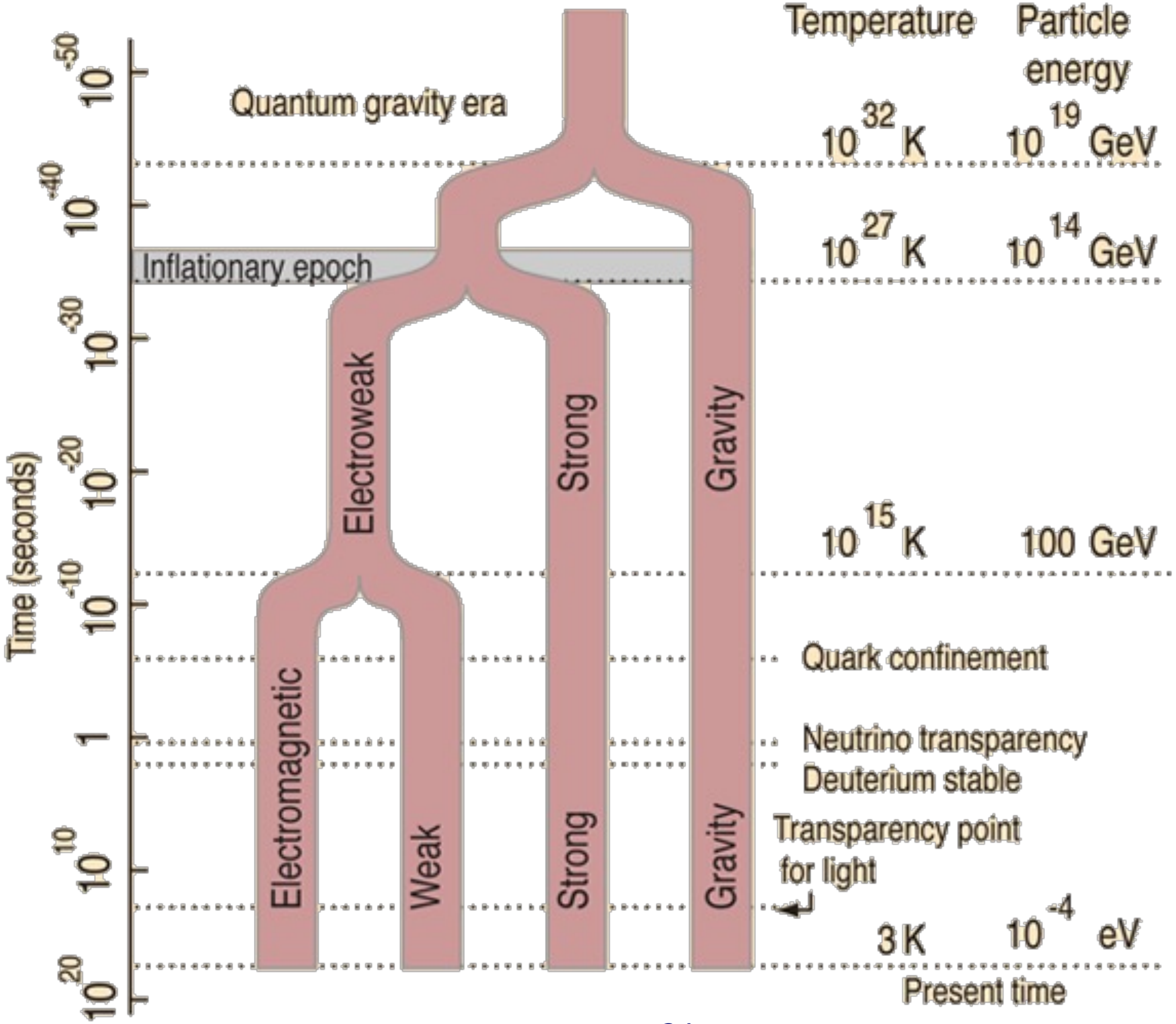


Particle Interactions

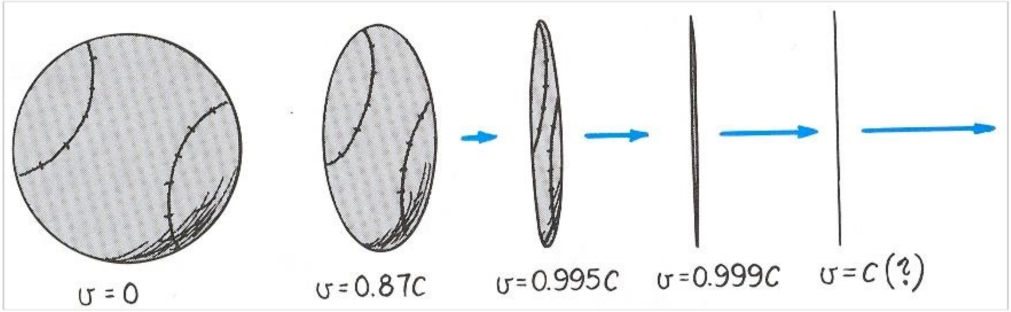


Particle Forces

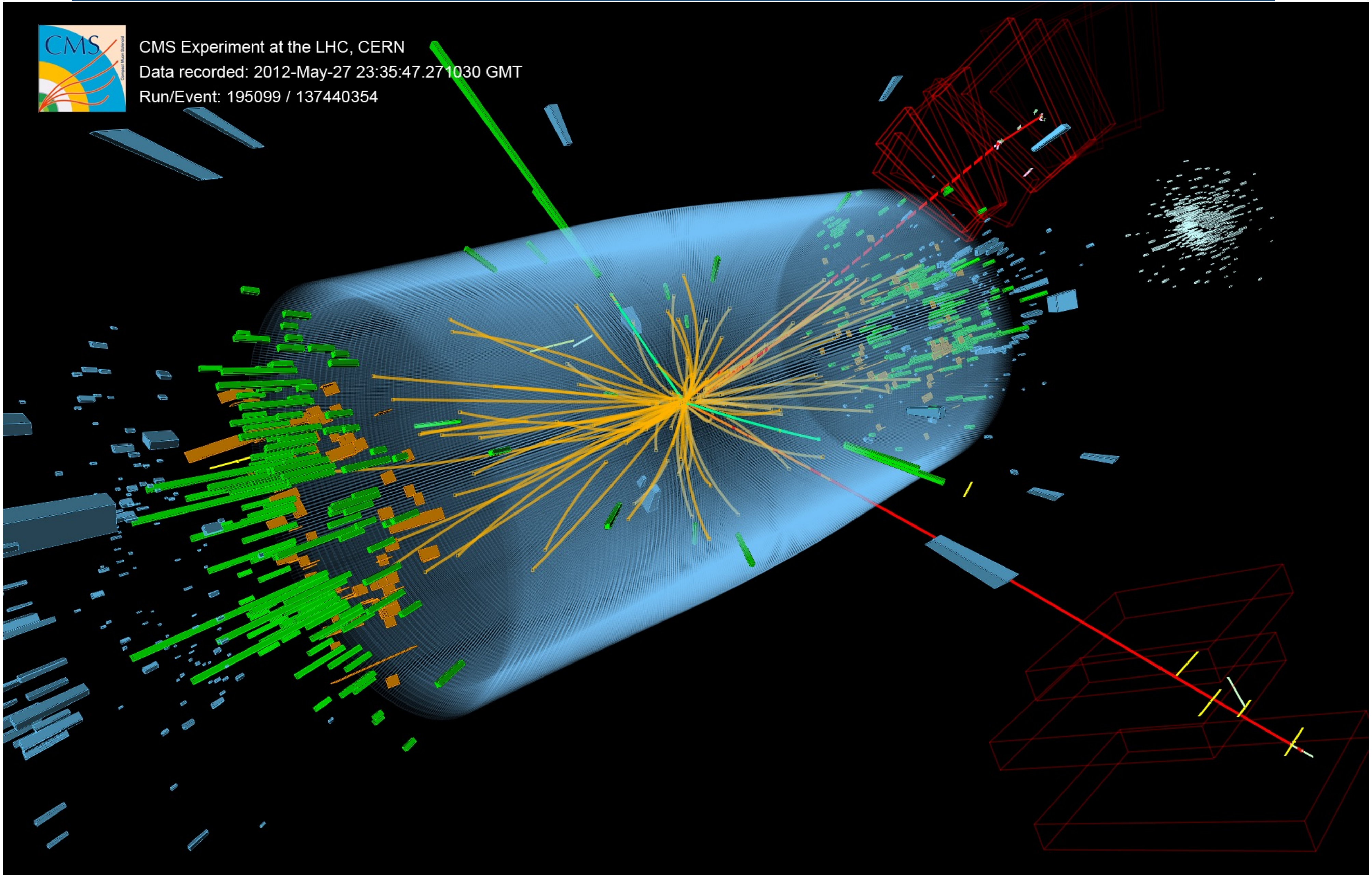




Tool: Special Relativity

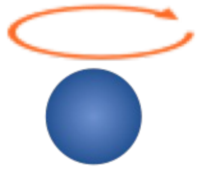


Special Relativity



What symmetries do these particles obey?

Rotational symmetry



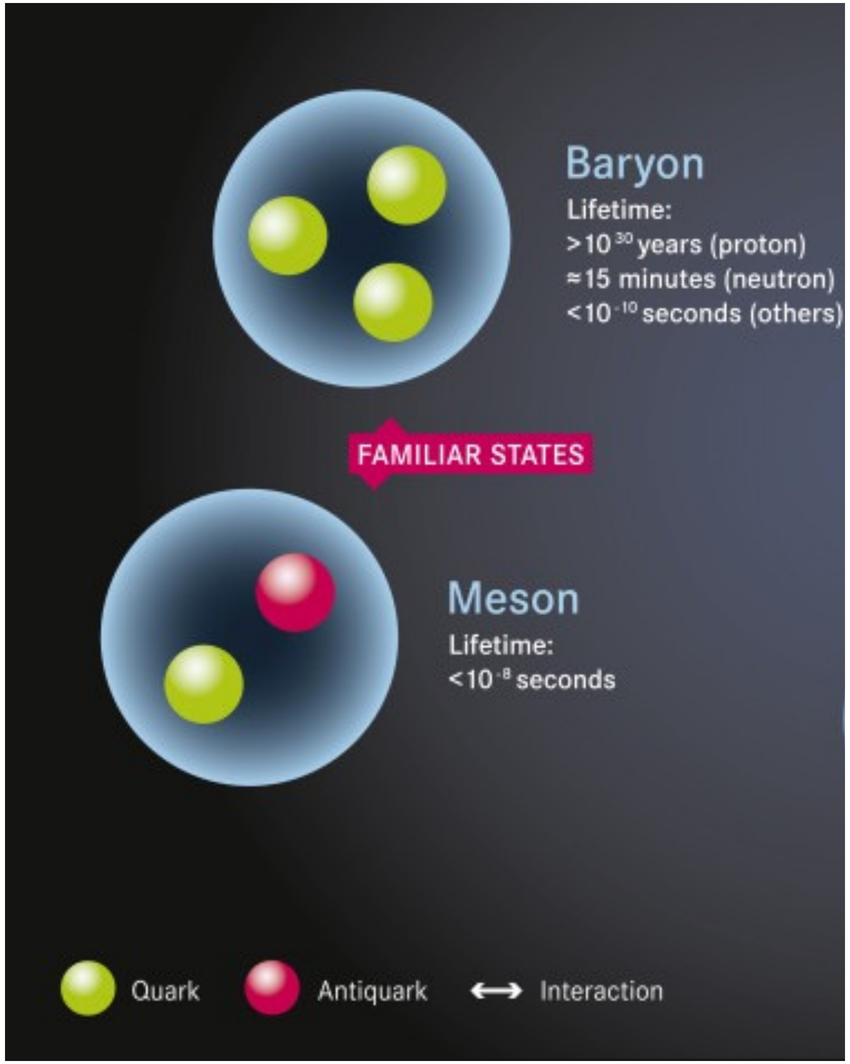
Transitional symmetry

Time translation symmetry

Important discrete symmetries in Nuclear and Particle Physics

- Parity (P)
- Charge conjugation (C)
- Time (time reversal) (T)

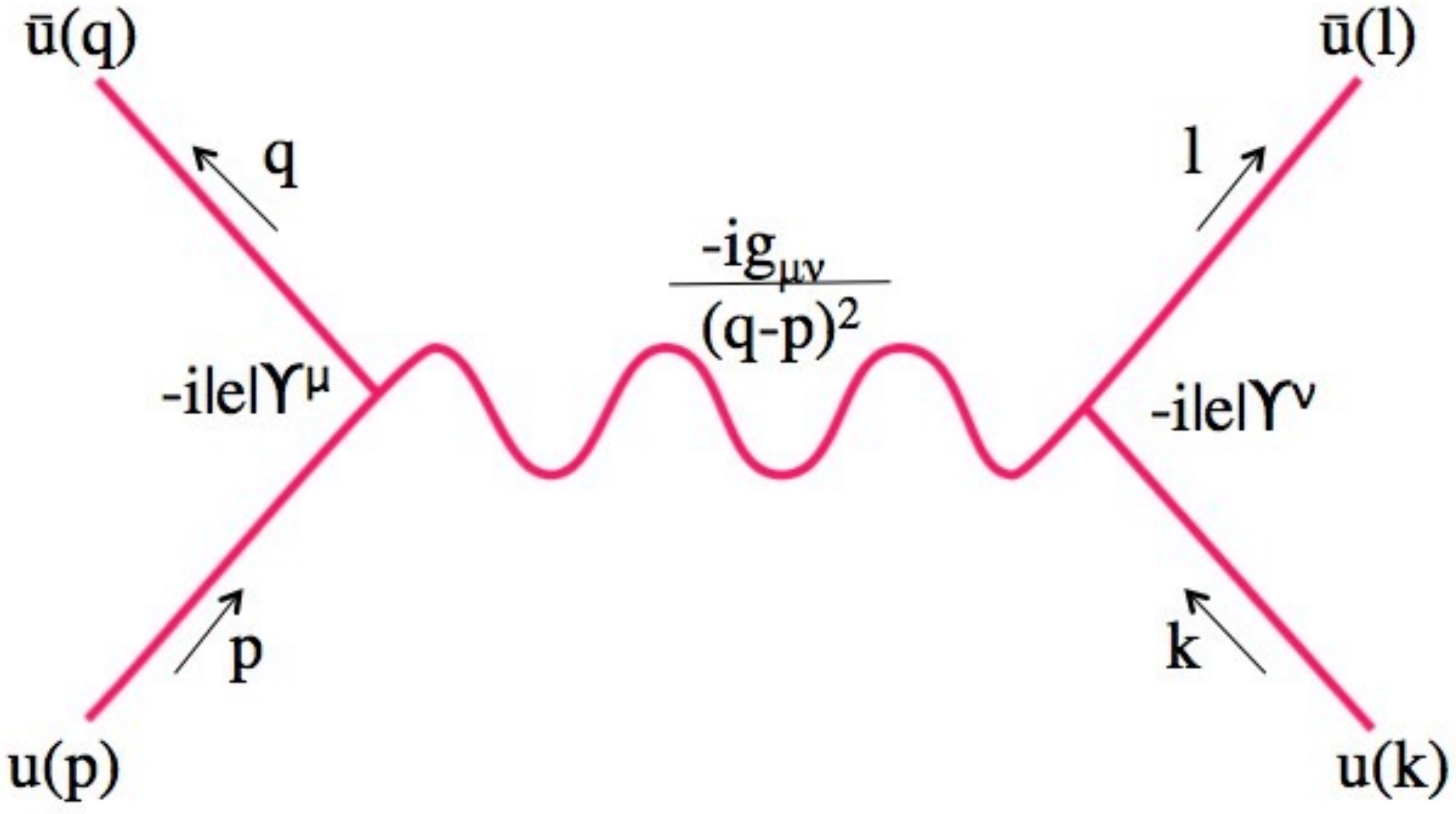
What bound states do particles form?



We often see bound states of quarks experimentally:

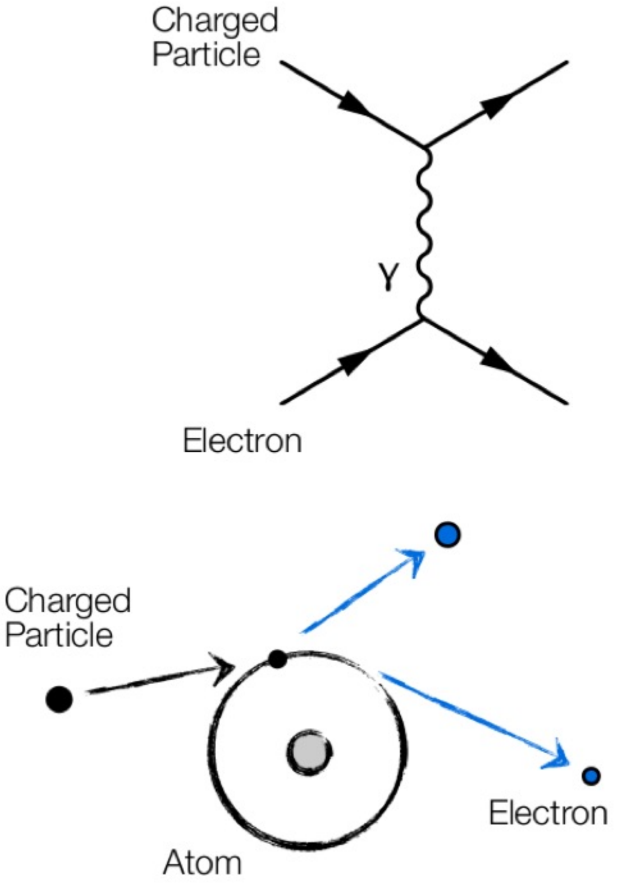
Proton
Neutron
Charged pion
Neutral pion

Tool: Feynman Rules

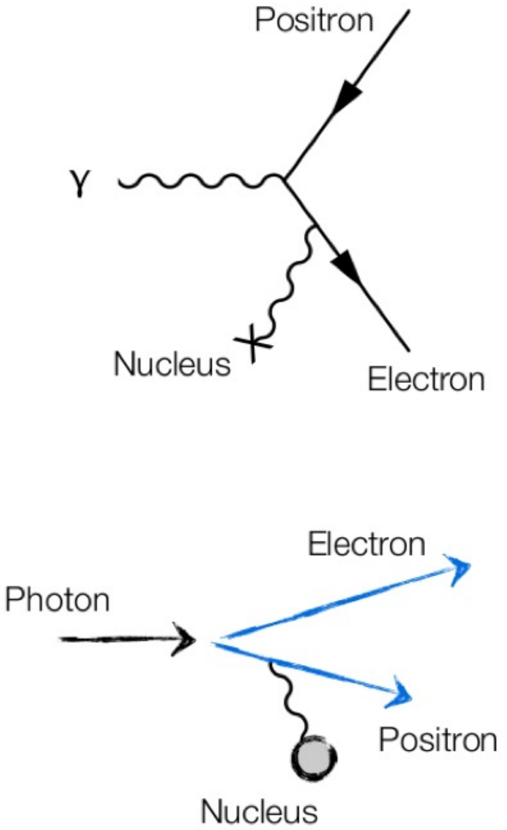


How do Particles Interact with Matter?

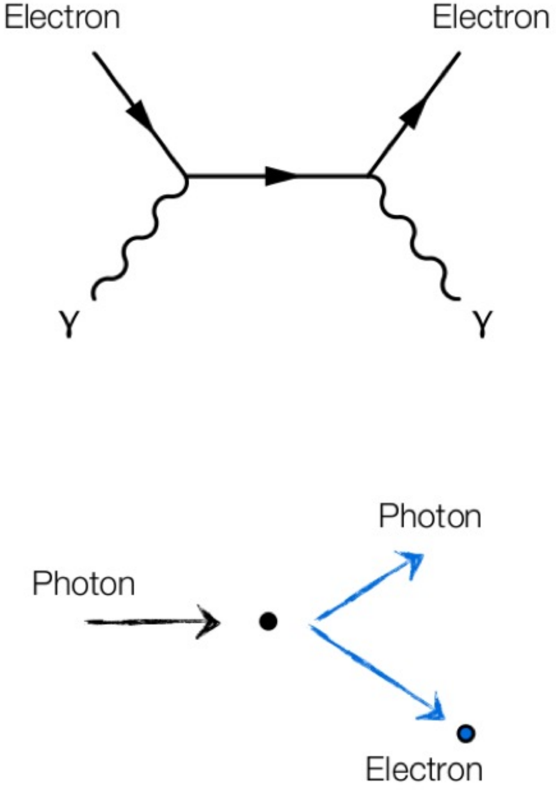
Ionization:



Pair production:



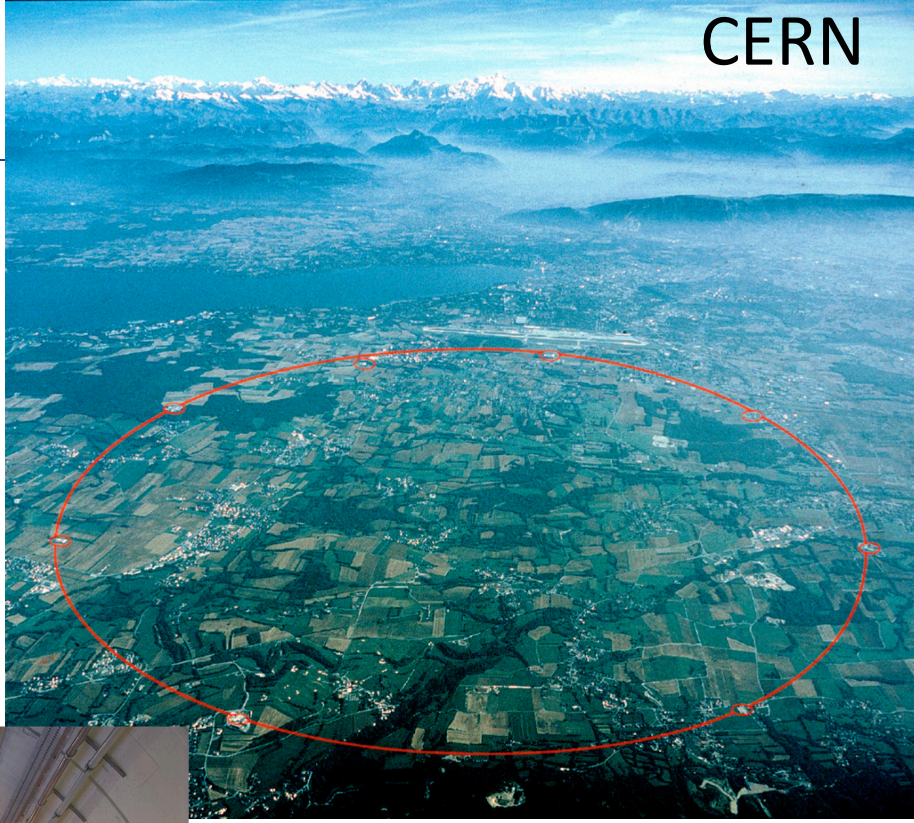
Compton scattering:

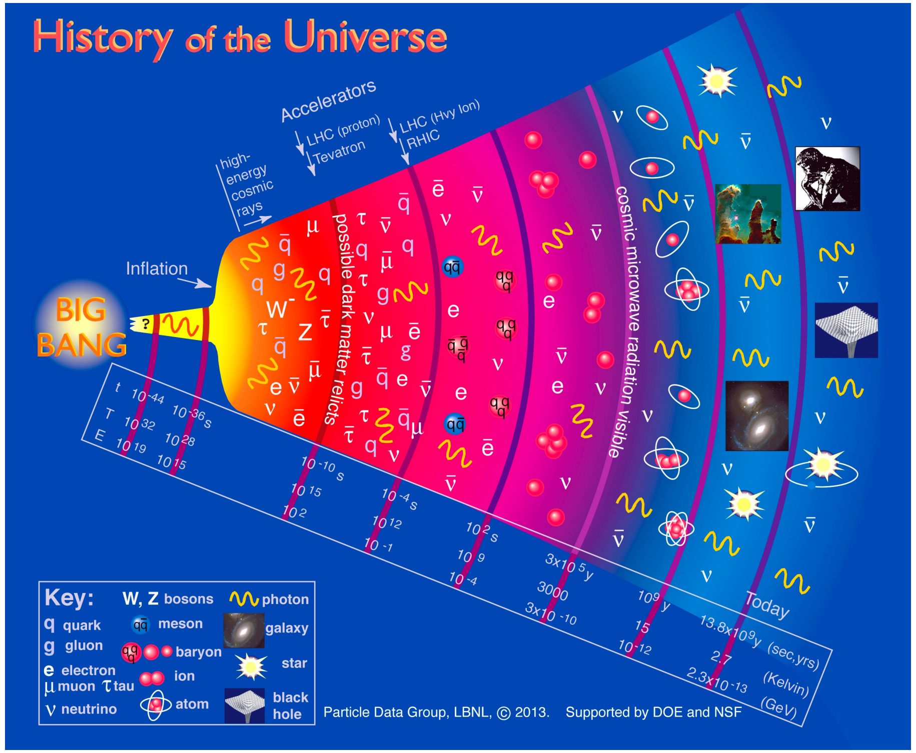


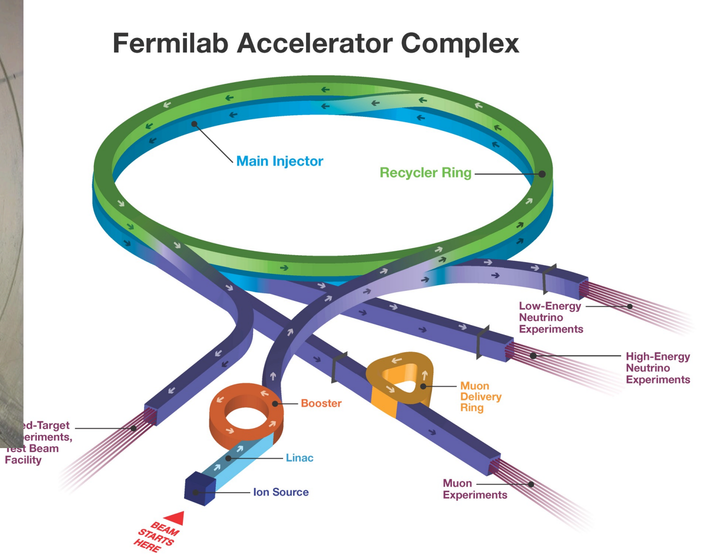
Needed to measure particle interactions in detectors!

Particle Accelerators

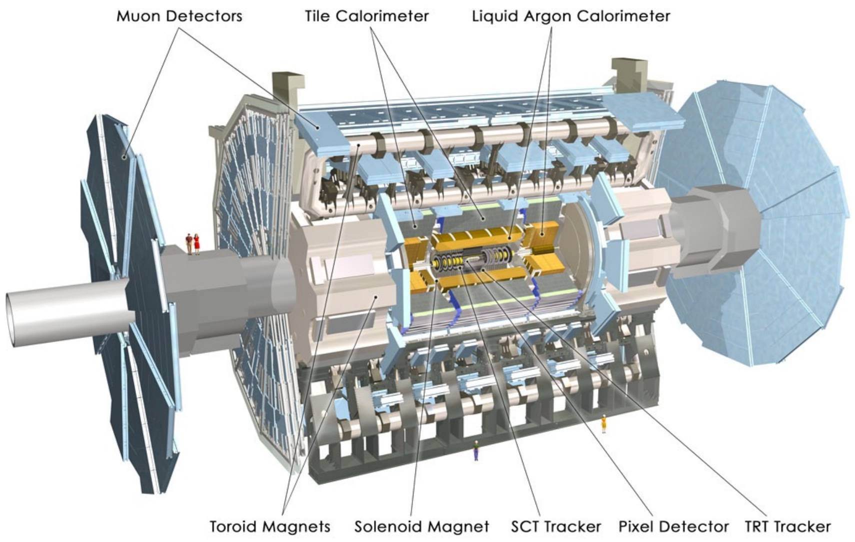
1. What are particle accelerators?
2. Why are they used?



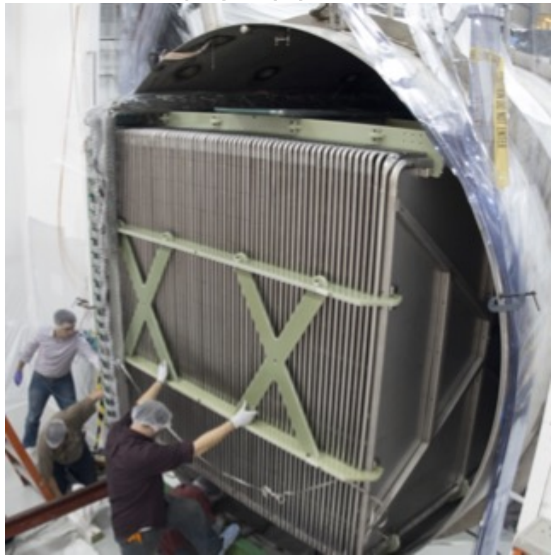




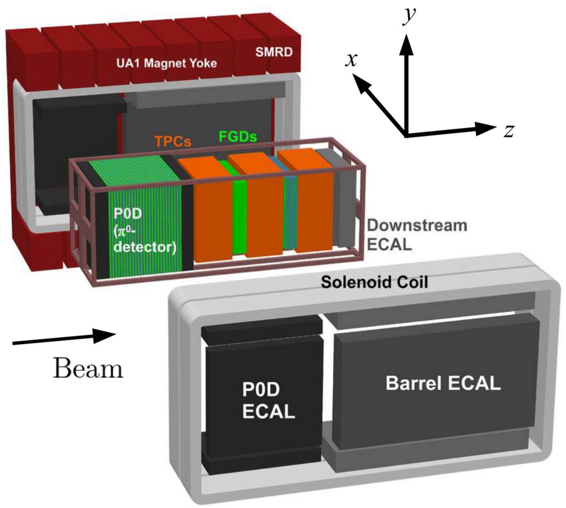
How do we detect particles?



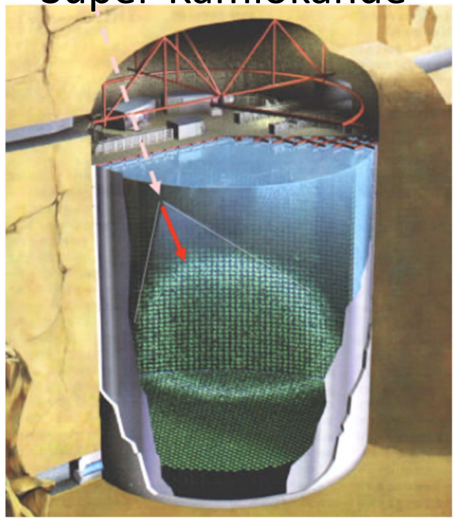
MicroBooNE



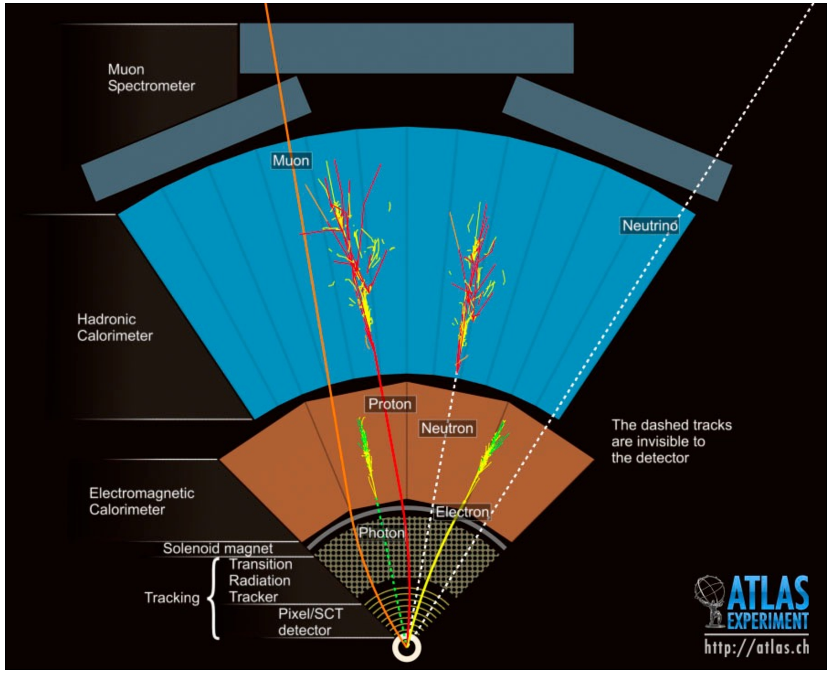
T2K Near Detector



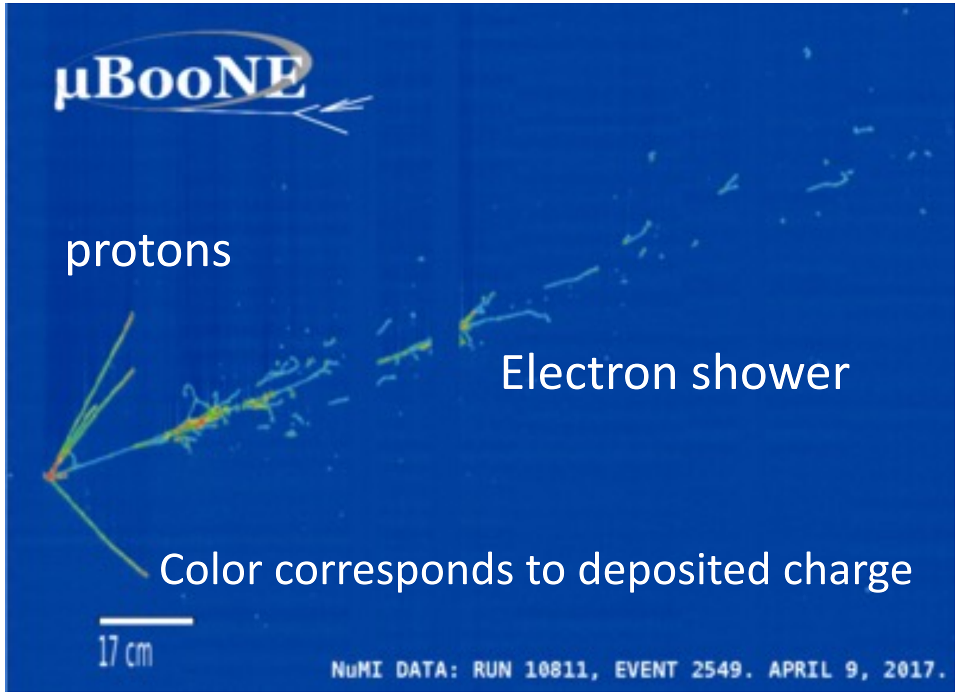
Super-Kamiokande



What do we measure in particle detectors?

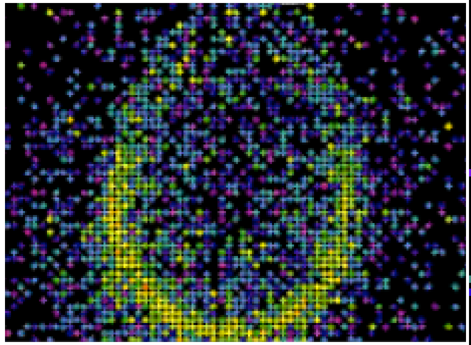


Time (Drift Direction)

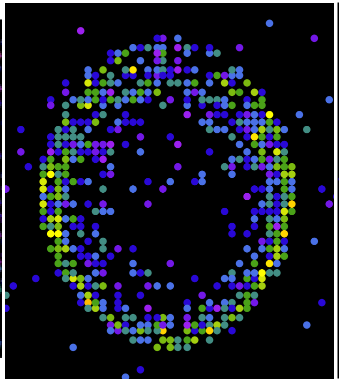


Wire (Beam Direction)

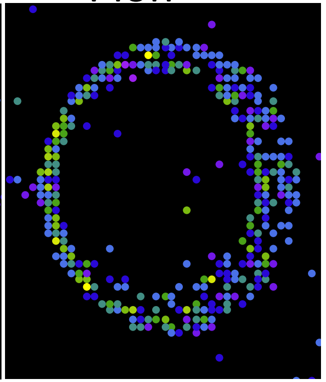
Electron



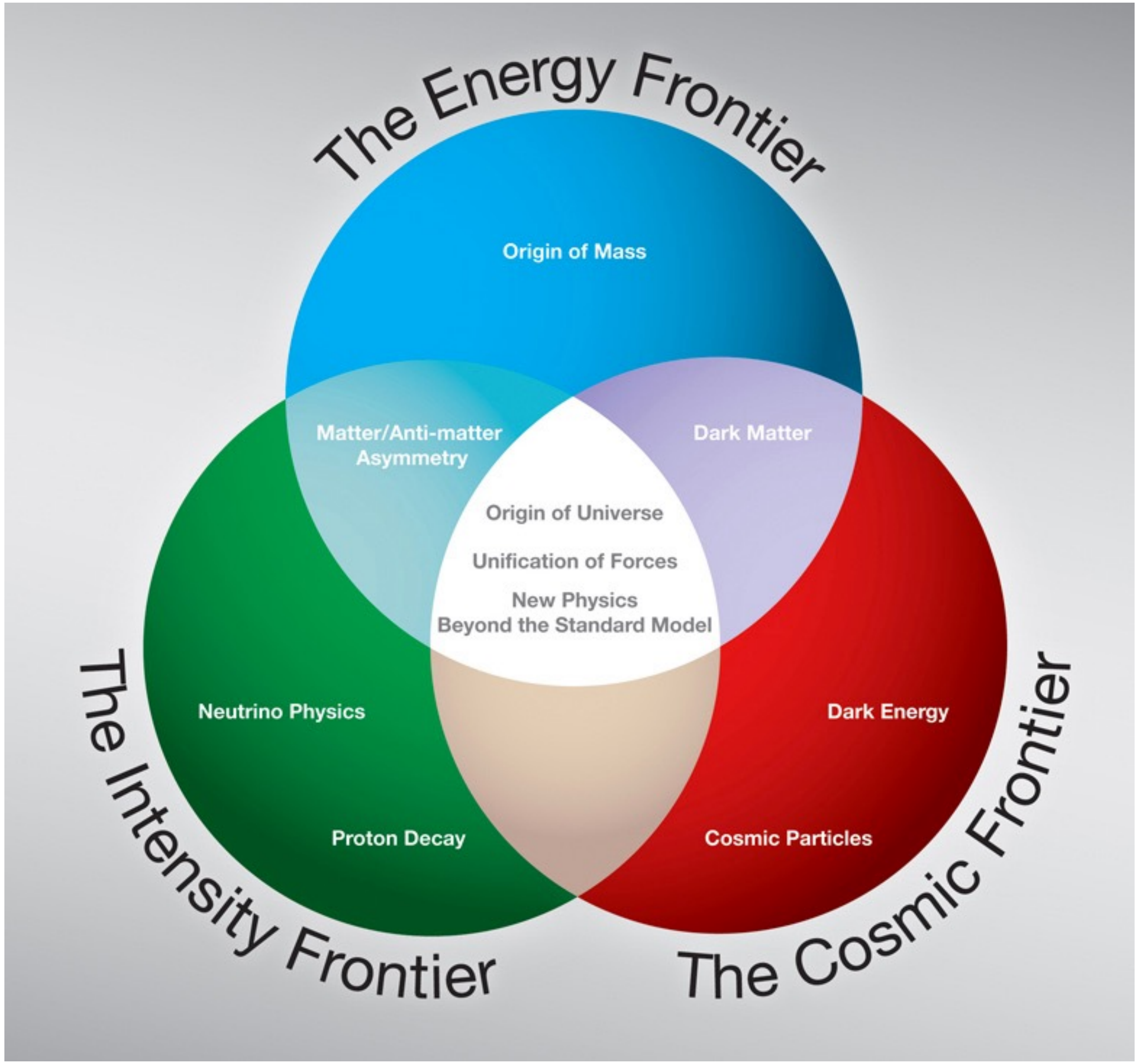
Muon



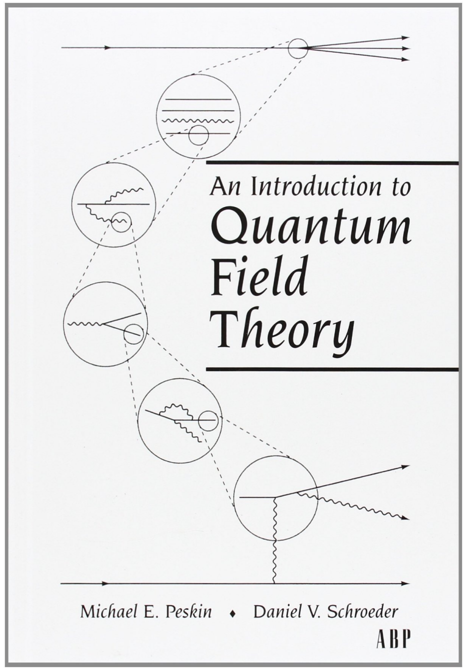
Pion

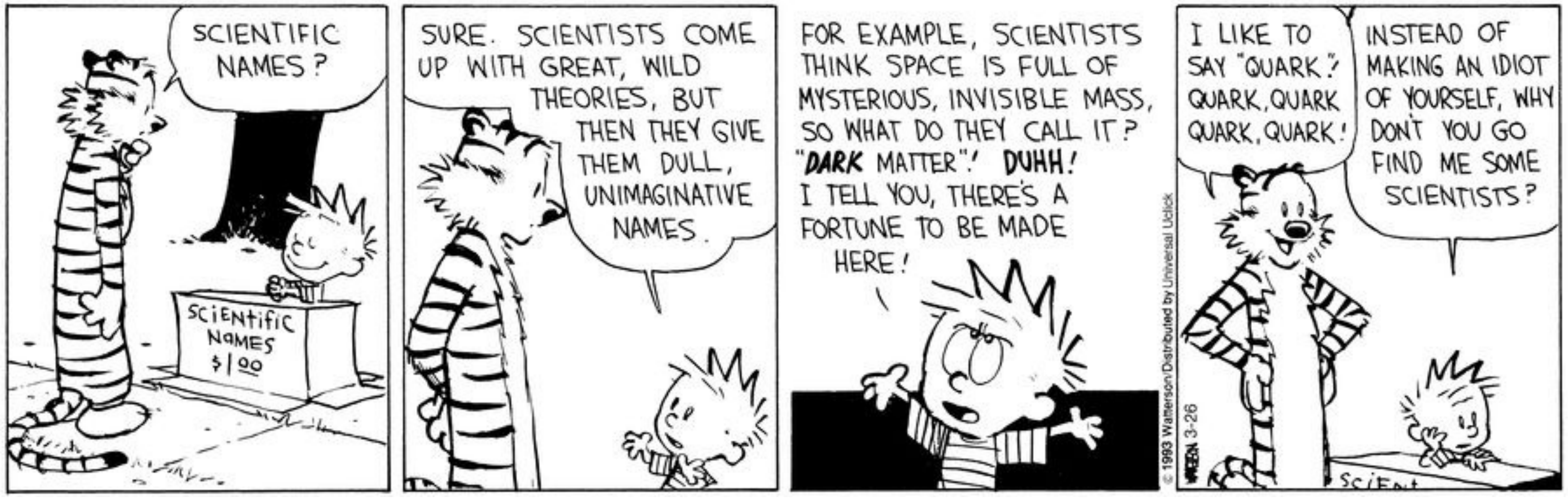


What experimental efforts are ongoing?



How do we describe particle interactions with theory?

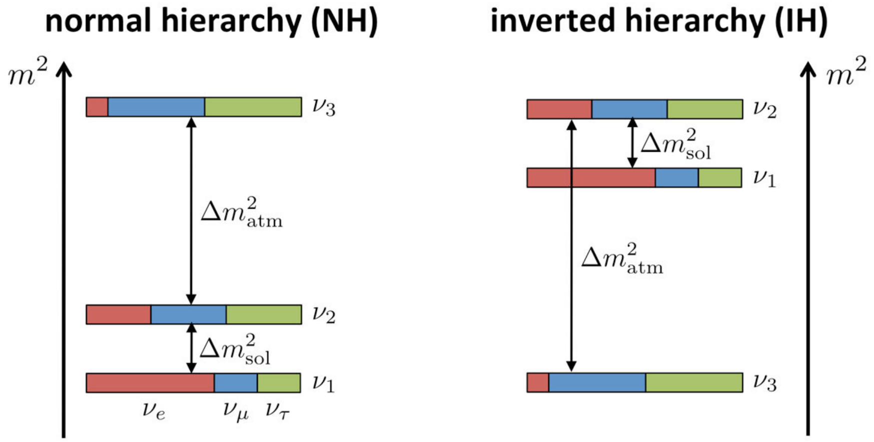




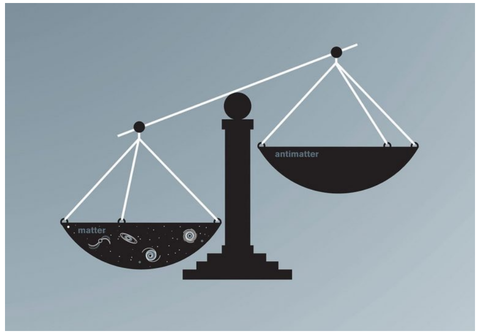
Neutrinos: We know there is “beyond the standard model” physics here

What is the mass of the neutrino?

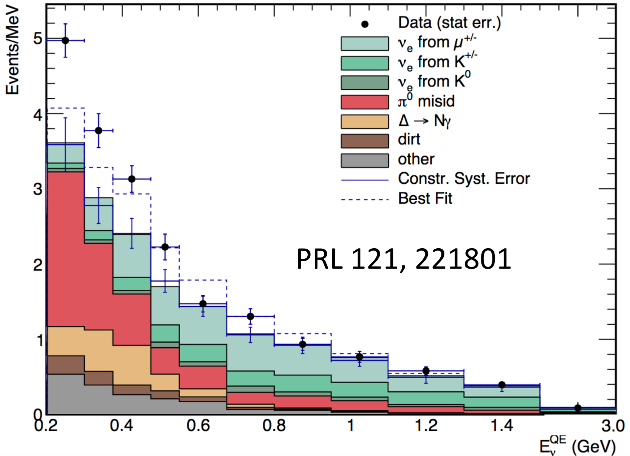
Mass Ordering?



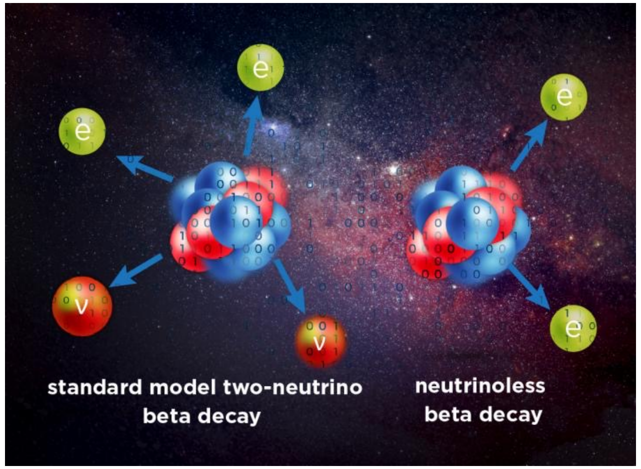
Is there charge-parity violation in neutrinos? Could neutrinos explain why we are made of matter?



Do anomalies point to additional neutrinos, explanations for dark matter, or other new physics?

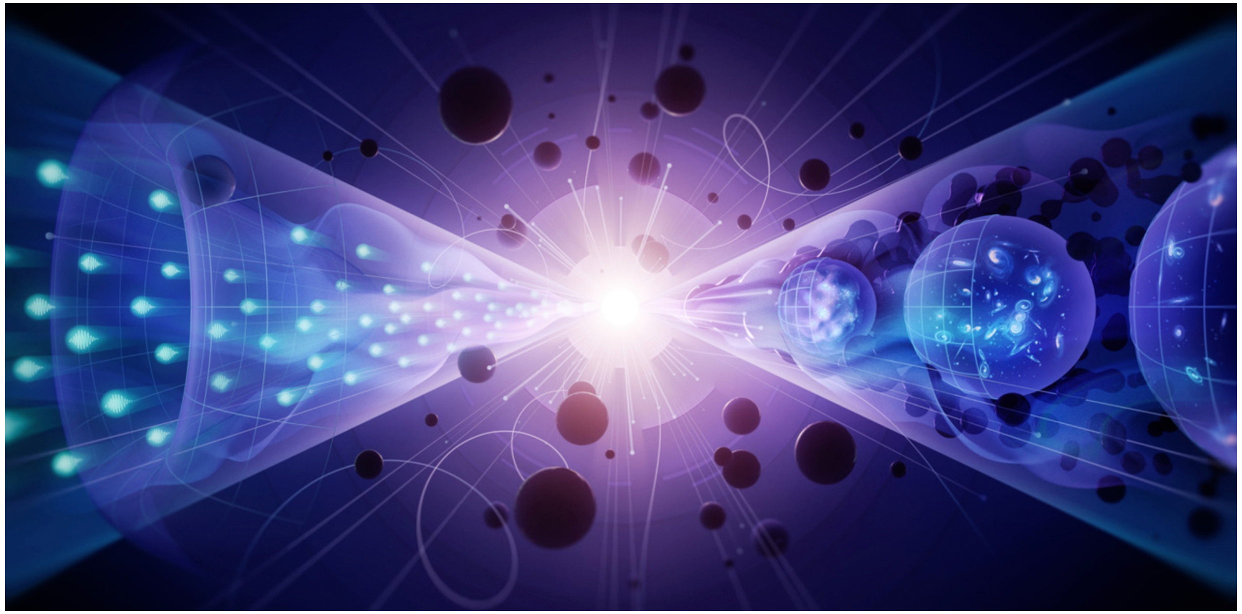


Are neutrinos the same as anti-neutrinos?



What does the future look like?

Choose your own adventure!



- Extra dimensions
- Dark Matter
- Dark Energy
- The Higgs boson
- New, exotic matter theories
- Universe stability
- Multiverse
- Supersymmetry
- ???

Exploring the Quantum Universe

https://www.usparticlephysics.org/2023-p5-report/