Physics : Part 2 : Video 6 : Phenomenological Enquiry

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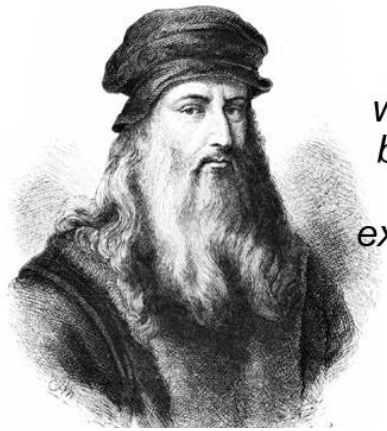
Contents:

- What is Phenomenology ?
- What are Heuristic Questions ?
- Can we do Guesstimation ?
- Ask Dimensionality questions ?
- Is there a guiding Philosophy ?
- What is a good Phenomenological Theory?

What is Phenomenology ?

Very often at the frontier of research, scientists do not have a good theory to begin with but they may have a lot of data. So what do we do ?

In this case, we have to follow Leonardo da Vinci's advice, and do something interesting at the level of phenomenology.



"A painter should begin every canvas with a wash of black, because all things in nature are dark except where exposed by the light."

— Leonardo da Vinci

Although nature commences with reason and ends in experience, it is necessary for us to do the opposite, that is, to commence with experience and from this to proceed to investigate the reason

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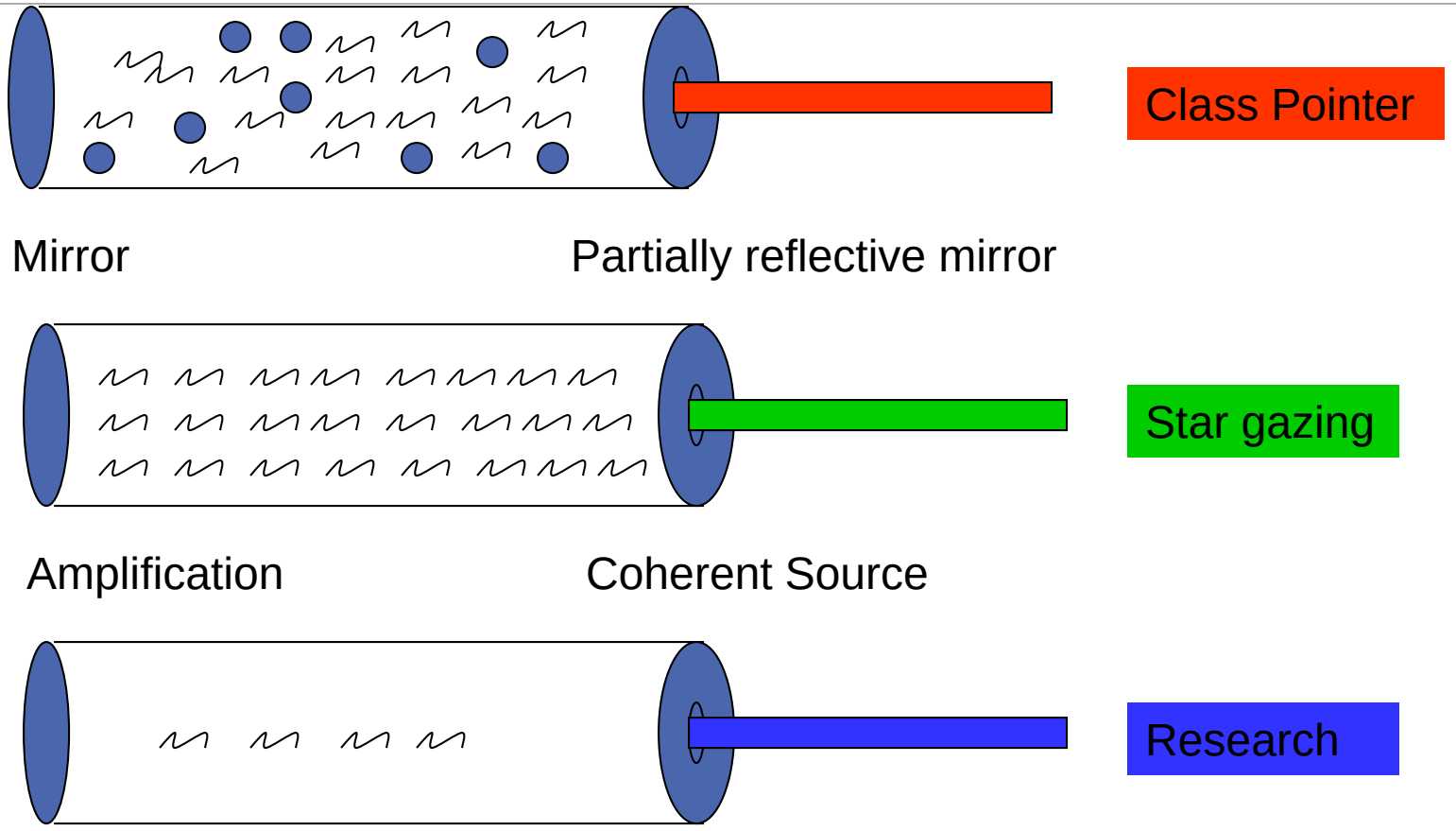
Heuristic Questions

Heuristic reasoning is reasoning not regarded as final and strict but as provisional and plausible only, the purpose of which is to discover the solution of the present problem ... before obtaining certainty, we must often be satisfied with a more or less plausible guess.

We may need the provisional before we attain the final reasoning. Heuristic reasoning is good in itself. What is undesirable is to mix up heuristic reasoning with rigorous proof. What is worse is to sell heuristic reasoning for rigorous proof.

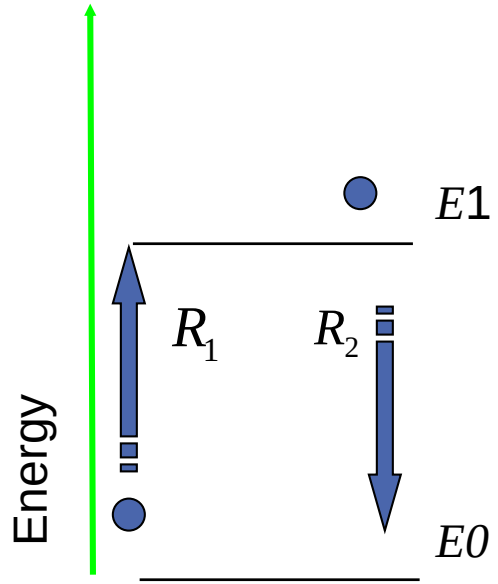
G. Polya, *How to Solve it*, 2014, New Princeton Science Library Edition.

Example : LASER (Maser)

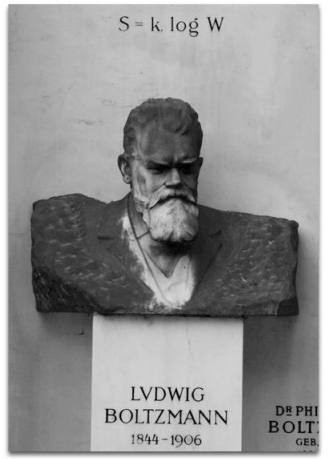


How did Einstein do it ?

Consider a 2 energy levels Atom.



One could say that the average number of excited atoms in the level with energy E would be proportional to Boltzman's $e^{-E/kT}$



$E0 \rightarrow E1$ Transitions; only possible thru an Induced process

$E1 \rightarrow E0$ Transitions; Spontaneous process

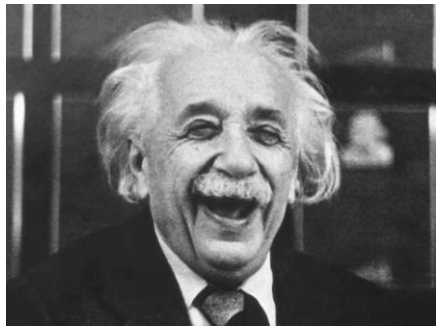
Einstein argued that one should get Planck's Law $\rho(f,T) = \frac{8\pi f^2}{c^3} \frac{hf}{e^{\frac{hf}{kT}} - 1}$

? ? ?

Milking Planck's Law !

$R_1 = \rho(f,T)Be^{\frac{-E_0}{kT}}$ Upward induced transition

$R_2 = \rho(f,T)Be^{\frac{-E_1}{kT}}$ Downward spontaneous transition



R_n means number of transitions per sec

Thought that $R_1 = R_2$? But he cannot get Planck's Law !

He postulated that there must be another process, so $R_1 = R_2 + R_3$

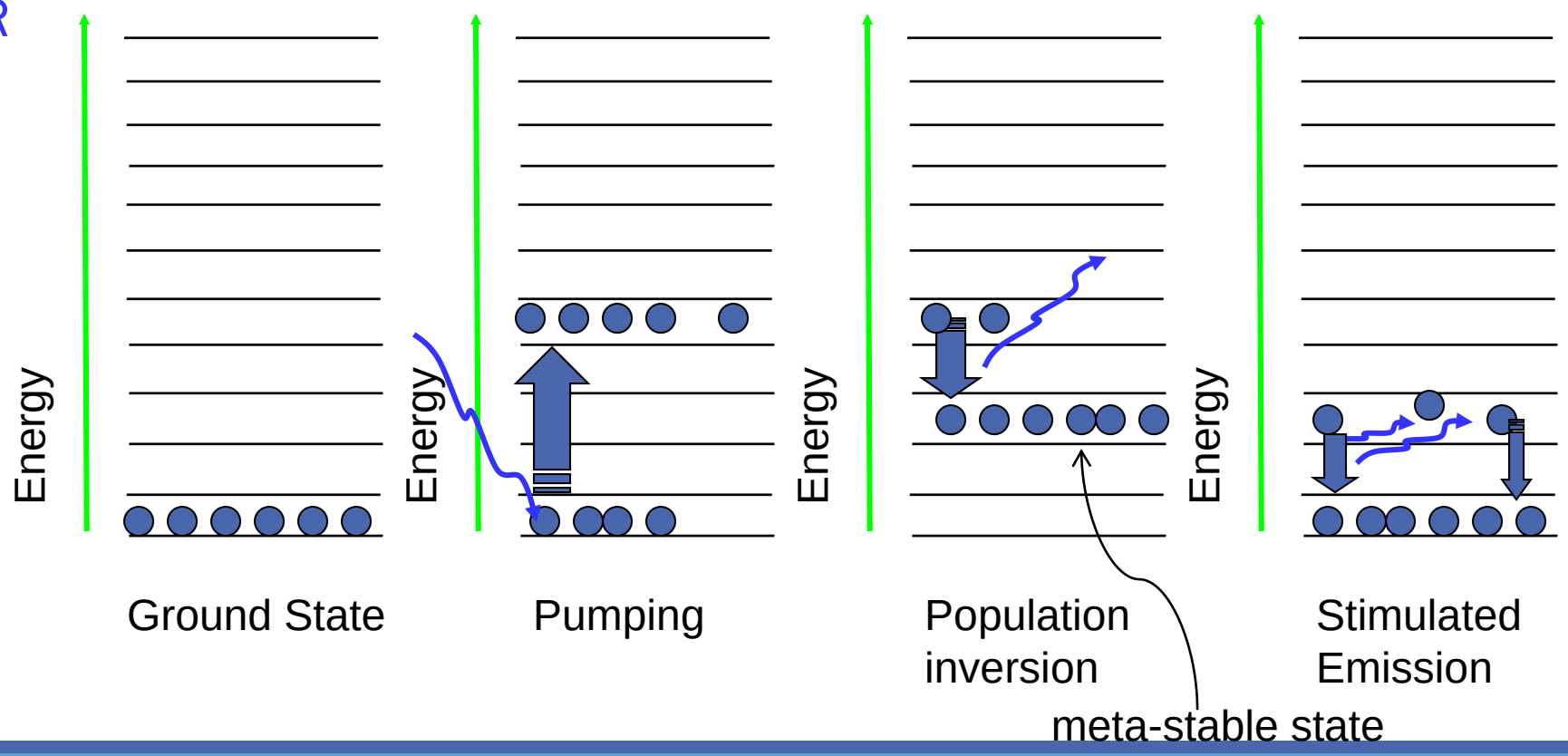
$R_3 = \frac{8\pi f^2}{c^3} Ae^{\frac{-E_1}{kT}}$ **New downward induced transition**

You will be delighted to get Planck's Law if you choose constants as $\frac{A}{B} = hf$

Einstein's Lasing !

Light Amplification by the Stimulated Emission of Radiation

LASER



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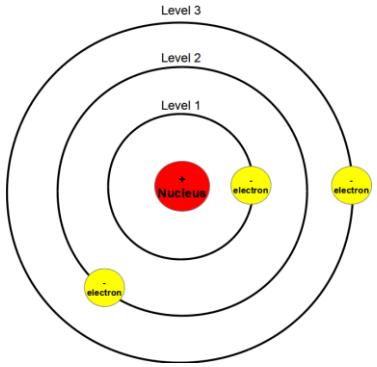
Example : Some Favourite Estimates ?

a) We all know that the atom is very small, so how big is an atom ?



b) Have you ever wondered why there are no mountains higher than Mount. Everest … ~10km high ? Is there a height limit on earth ?

V. Weisskopf, *Modern Physics from an Elementary Point of View*, CERN Archives, Geneva

How about the back of the Envelope or Napkin Physics ?

Aim of this is to make arguments, guesses, and put upper limits or lower limits ?

Example : In Particle Physics, we are very interested in asking whether the proton is stable or can undergo radioactivity decay.

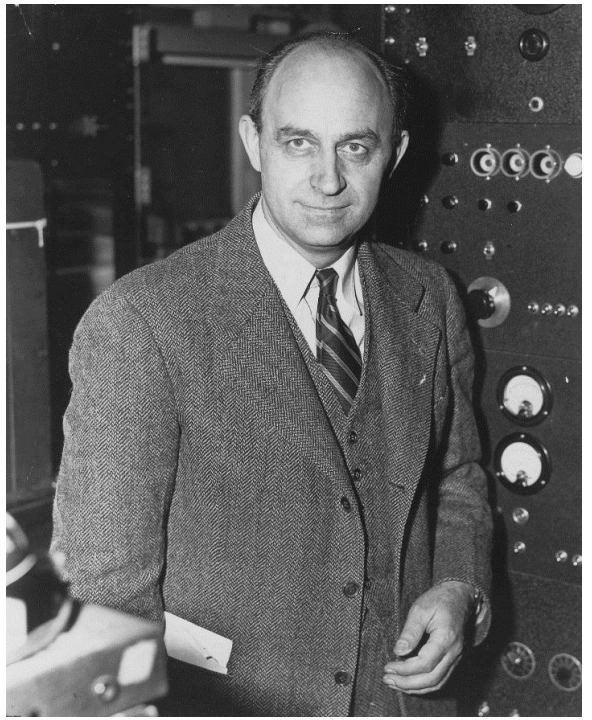
"We know from our bones that if the proton decays, it must have an average lifetime greater than 10^{16} years".

C. Swartz, *Back of the Envelope Physics, 2003*, John Hopkins U. Press.
V. Weisskopf, *Modern Physics from an Elementary Point of View*, CERN Archives, Geneva

Can we do a Guesstimation ?

Question for his student :

Can you estimate the number of pianos in Chicago ?



Enrico Fermi (1901–1954) Italian

L. Weinstein, *Guesstimation 2,* 2012, Princeton U. Press.

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Is Guessing Unscientific ?

It is not unscientific to make a guess although many people who are not in science think it is … But that is the way … that is scientific !. It is scientific only to say what is more likely and what is less likely, and not to be proving all the time the possible and the impossible.

Dirac discovered the correct laws for relativistic quantum mechanics simply by guessing the equation.

The method of guessing the equation seems to be a pretty effective way of guessing new laws.

R. P. Feynman (on seeking new laws), *The Character of Physical Law,* 1967, MIT Press.
P. Dirac join 1933 Nobel Prize with E. Schrodinger.

Guessing the Solution to the Theory

Example: Say one has worked through a physics theory and eventually arrives at this differential equation :

$$\frac{d^2y}{dt^2} + 3\frac{dy}{dt} + 2y = 2e^{3t}$$

A physicist will normally say try this "Trial" solution; we call it "Ansatz".

$$y = Ae^{3t}$$

Why don't we ? Perhaps use an established mathematical procedure to find it ? Method of undetermined coefficients is called the method of "*judicious guessing*".

S. Farlow, *Intro. to Differential Equations and Their Applications*, 1994, Dover.
https://en.wikipedia.org/wiki/Ansatz

Guessing is Scientific too !

Everything we hold to be true in science is tested in the same way, and Feynman explains it clearly here. No matter how smart a person is; no matter how elegant their hypothesis, if it does not agree with experimentation, it is wrong. Feynman calls this the “key to science.”

Guessing is not unscientific though it may seem that way to non-scientists. Rather, it would be unscientific to just accept a guess because it is comforting or easy.

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Dimensional Analysis : only 3 quantities : *Length*, *Mass* and *Time*

$$\Phi = eL^a M^b T^c$$

where e and a, b, c are constants to be determined.

Φ is the quantity of interest.

	Quantity	Definition	Formula	Units	Dimensions
Basic machanicals	**Length or Distance**	*fundamental*	d	m (meter)	*L (Length)*
	Time	*fundamental*	t	s (second)	*T (Time)*
	Mass	*fundamental*	m	kg (kilogram)	*M (Mass)*
	Area	distance^2	$A = d^2$	m^2	L^2
	Volume	distance^3	$V = d^3$	m^3	L^3
	Density	mass / volume	$d = m/V$	kg/m^3	M/L^3
	Velocity	distance / time	$v = d/t$	m/s c (speed of light)	L/T
	Acceleration	velocity / time	$a = v/t$	m/s^2	L/T^2
	Momentum	mass × velocity	$p = m \cdot v$	$kg \cdot m/s$	ML/T
	Force Weight	mass × acceleration mass × acceleration of gravity	$F = m \cdot a$ $W = m \cdot g$	N (newton) = $kg \cdot m/s^2$	ML/T^2
	Pressure or Stress	force / area	$p = F/A$	Pa (pascal) = N/m^2 = $kg/(m \cdot s^2)$	M/LT^2

Example : Buckingham Theorem

We are interested in the oscillation of a celestial star, in particular the frequency ω. We suspect ω depends on the properties of the star, such as density, ρ, the radius R and Newton's law of universal gravitational constant, G.

$$Guess\ \omega = e\rho^a R^b G^c \quad and\ recall\ \omega = T^{-1}$$

$$convert\ to\ \ \Phi = eL^a M^b T^c$$

https://en.wikipedia.org/wiki/Buckingham_%CF%80_theorem

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Example: Dimensions of G is $M^{-1} L^3 T^{-2}$

$$\omega = e\rho^a R^b G^c$$

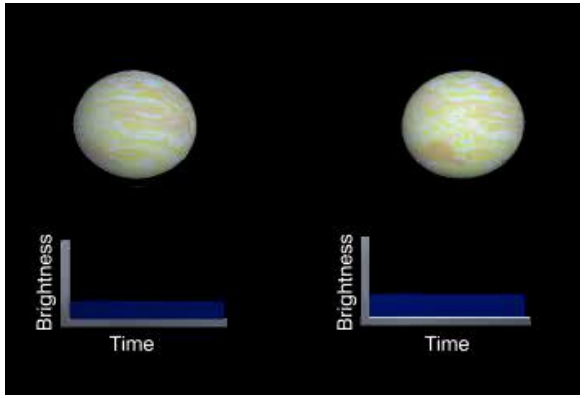
$$T^{-1} = M^{a-c} L^{-3a+b+3c} T^{-2c}$$

Comparing Powers:

$$a - c = 0, \quad -3a + b + 3c = 0, \quad -2c = -1$$

$$\textit{hence} \quad a = c = \frac{1}{2}, b = 0$$

H. Hornung, *Dimensional Analysis*, 2006 Dover Pub.



Finally the oscillation of a star,

$$\omega = e\sqrt{G\rho}$$

Notice that the radius *R* disappeared from the final equation above … which was our original guess.

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What is the working Philosophy ?

Any sound scientific theory, whether of time or of any other concept, should in my opinion be based on the most workable philosophy of science -- the positivist approach put forward by Karl Popper and others. According to this way of thinking, a scientific theory is a mathematical model that describes and codifies the observations we make. A good theory will describe a large range of phenomena on the basis of a few simple postulates and will make definite predictions that can be tested.

S. Hawking, *The Universe in a NutShell*, 2001, Bantam Book. S. Fuller, Kuhn vs Popper, 2004, Columbia U. Press.

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What is a good Phenomenological theory ?

If the predictions agree with the observations, the theory survives that test, though it can never be proved to be correct. On the other hand, if the observations disagree with the predictions, one has to discard or modify the theory.

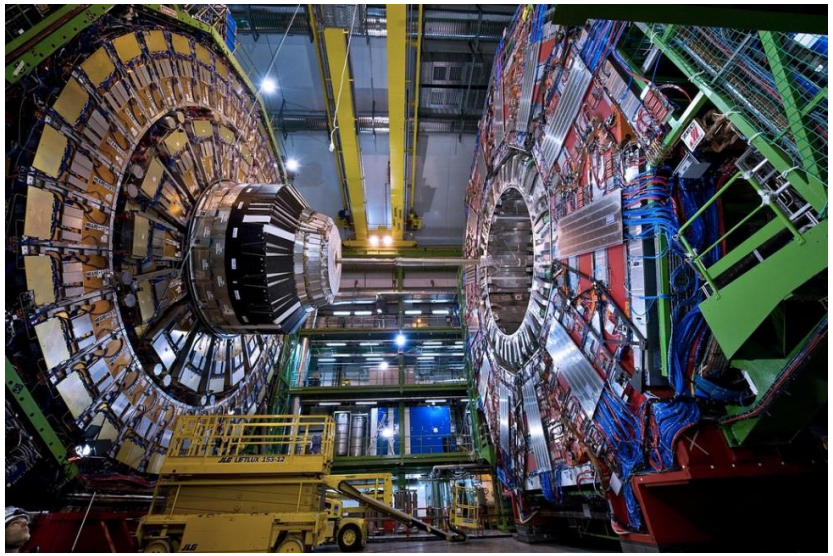
If one takes the positivist position, as I do, one cannot say what *time* actually is. All one can do is to describe what has been found to be a very good mathematical model for time and say what predictions it makes.

S. Hawking, *The Universe in a NutShell*, 2001, Bantam Book. S. Fuller, Kuhn vs Popper, 2004, Columbia U. Press.

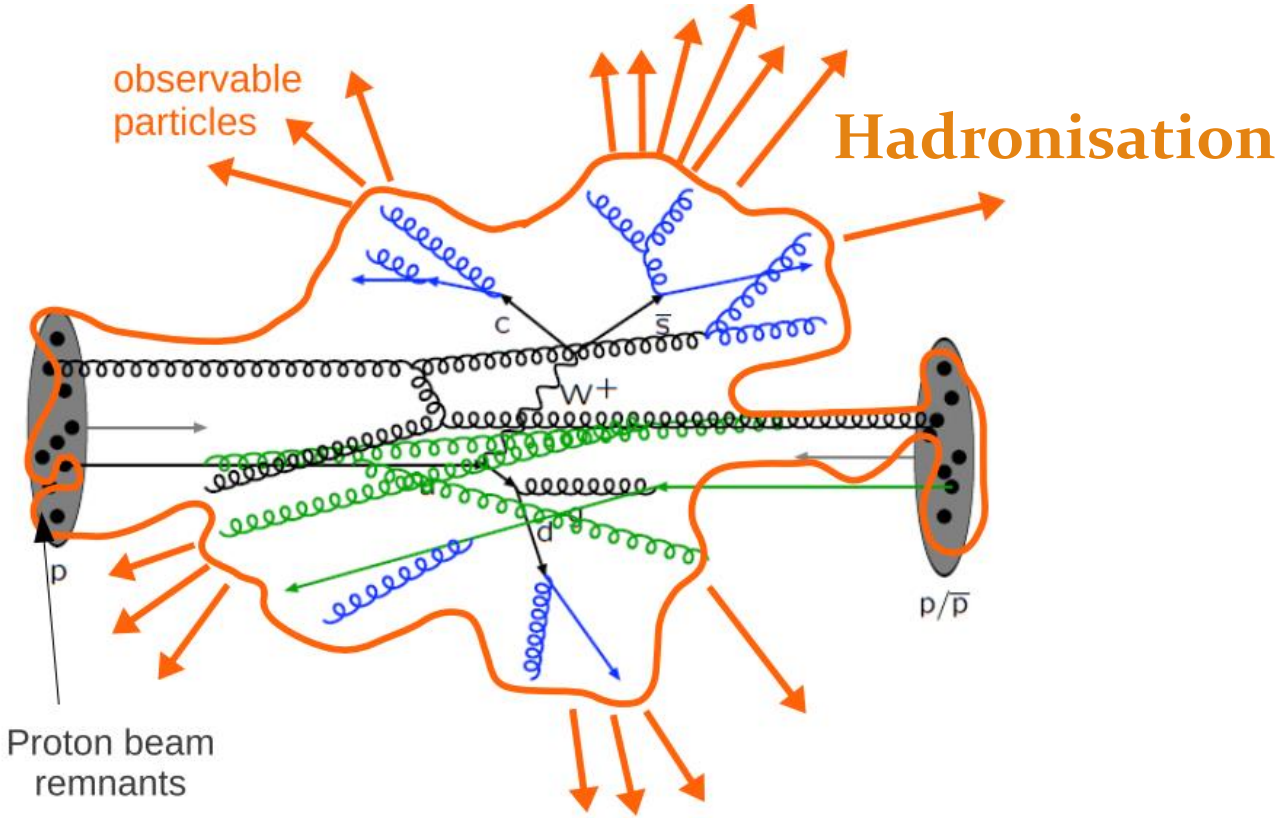
NUS Example : Our understanding of *pp* collisions

The picture of proton-proton collisions

- Hadronisation
- pQCD Theory fails

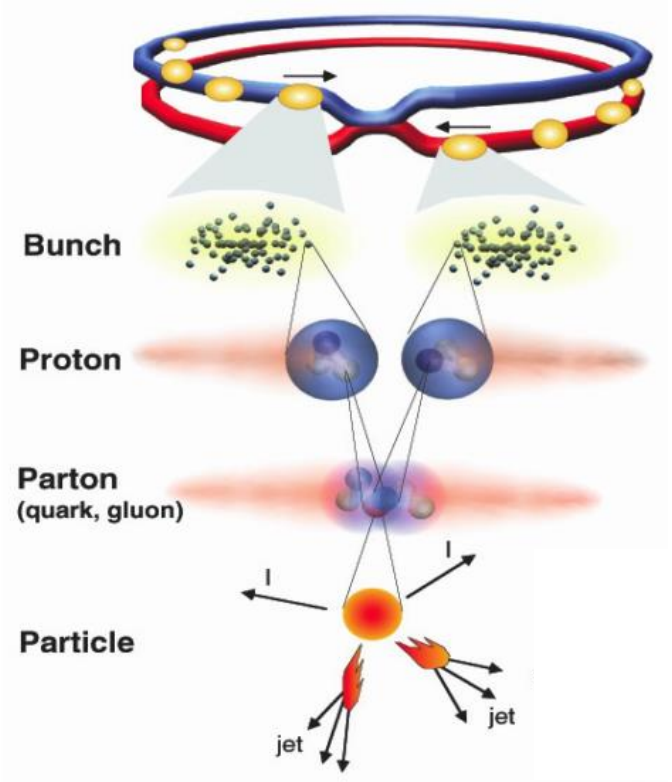


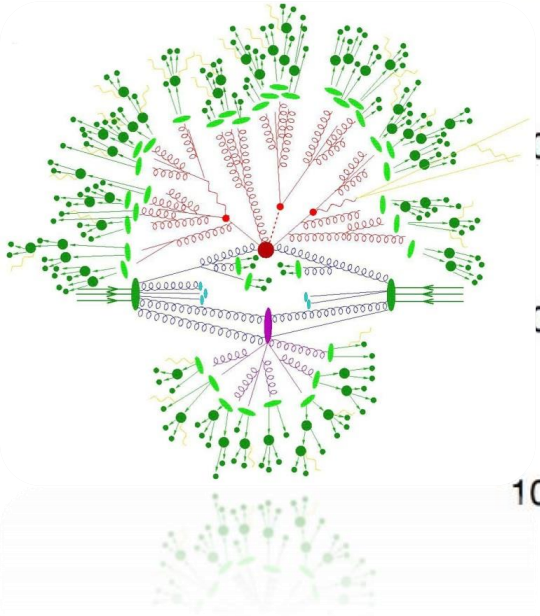
NUS is part of CERN : CMS Collaboration

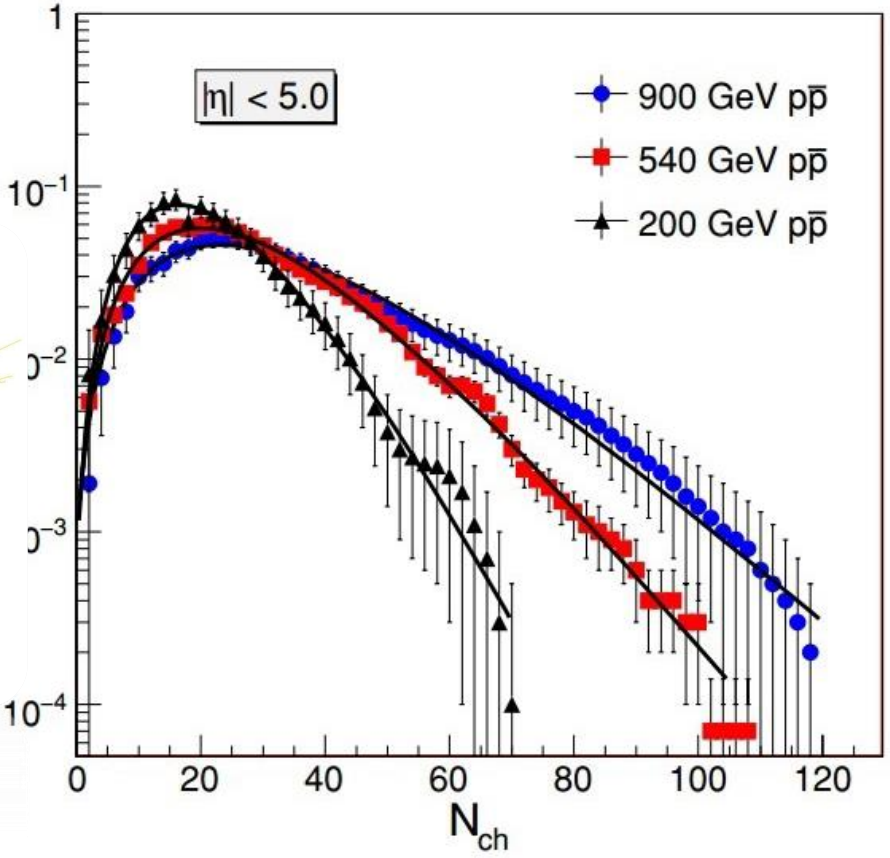


NUS Example :

$$P(n) = \frac{(n+k-1)!}{(n-k')!(k+k'-1)!}\left(\frac{\bar{n}-k'}{\bar{n}+k}\right)^{(n-k')}\left(\frac{k+k'}{\bar{n}+k}\right)^{(k+k')}$$







Chan and Chew (Generalised) Multiplicity Distribution, UA5 Collab. CERN-EP/89-135 : more than 30 pub. papers

About Phenomenological Questions ?

Phenomenology is greatly undervalued. We need good phenomenologists to point the way and guide experimental and theoretical physicists.

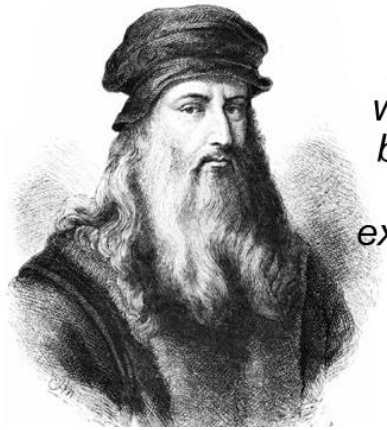
Harry Lipkin

Like Error Analysis, phenomenological skills is a big industry which can lead university students to many exciting jobs as this enquiry involves computing, coding, mathematics, statistics and the attitude of judicious guessing of a solution.

Harry Lipkin (Well known Israeli Nuclear Physicist), Physics Today.

Summary :

Phenomenology can be thought of as half way between Experimental and Theoretical enquiries. With clues gathered from existing (plausible) theories, phenomenological questions can be used to guide future experiments.



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