The Music in the Atom

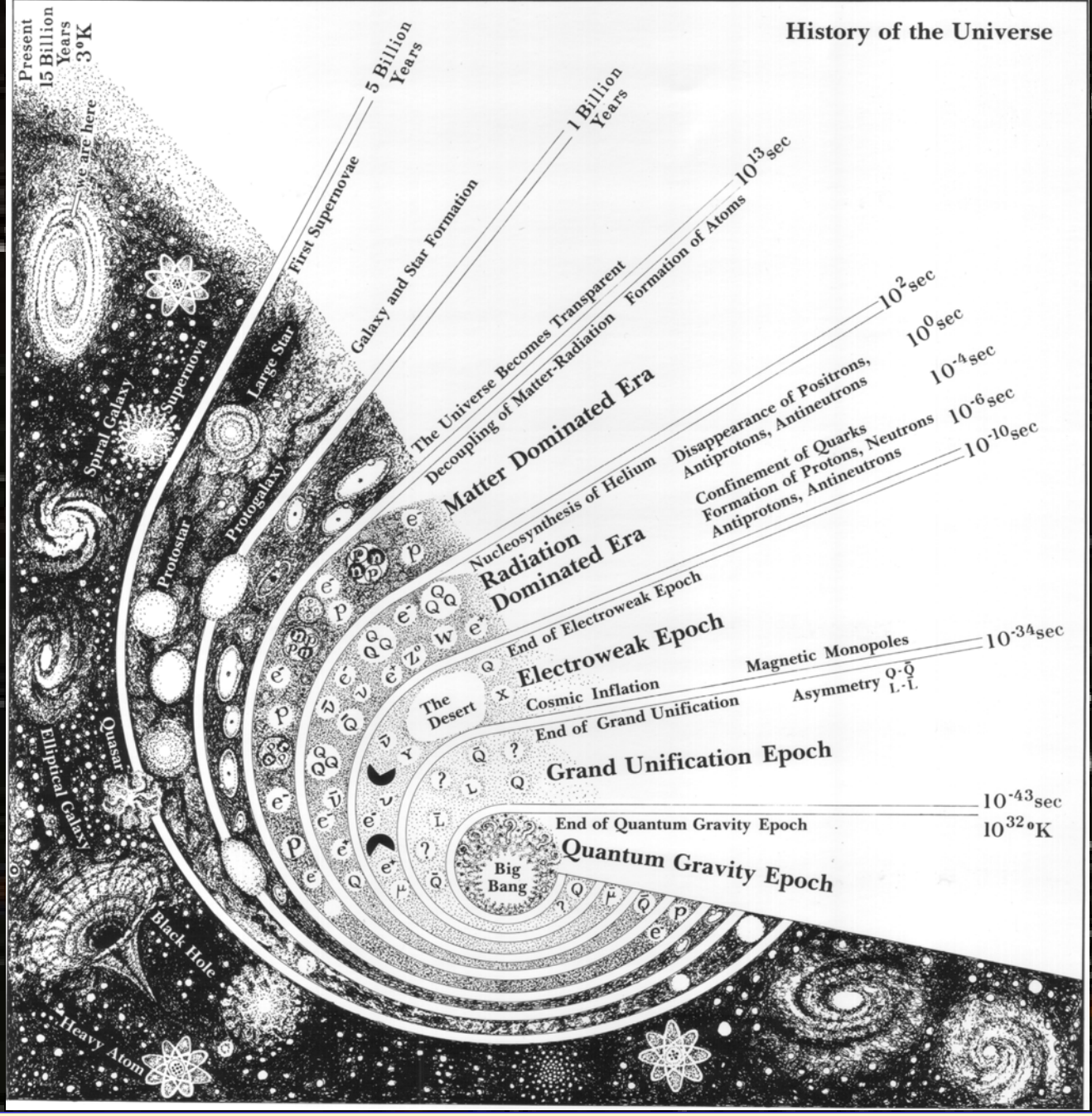
Physics For All

Music For All?

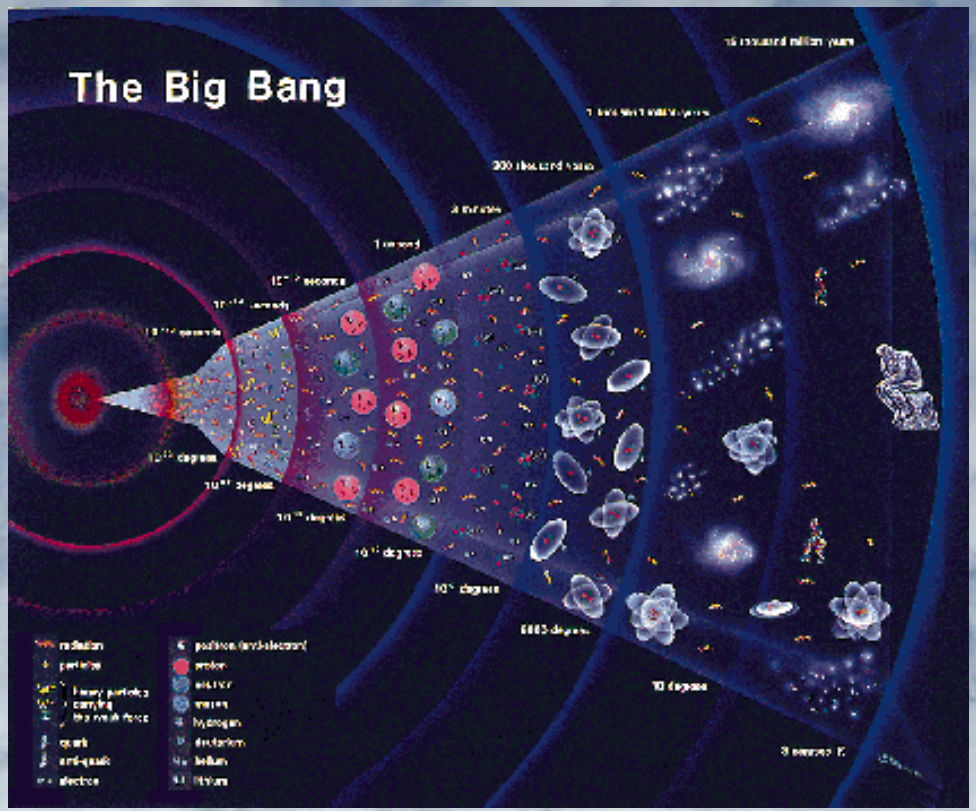
AP Photo

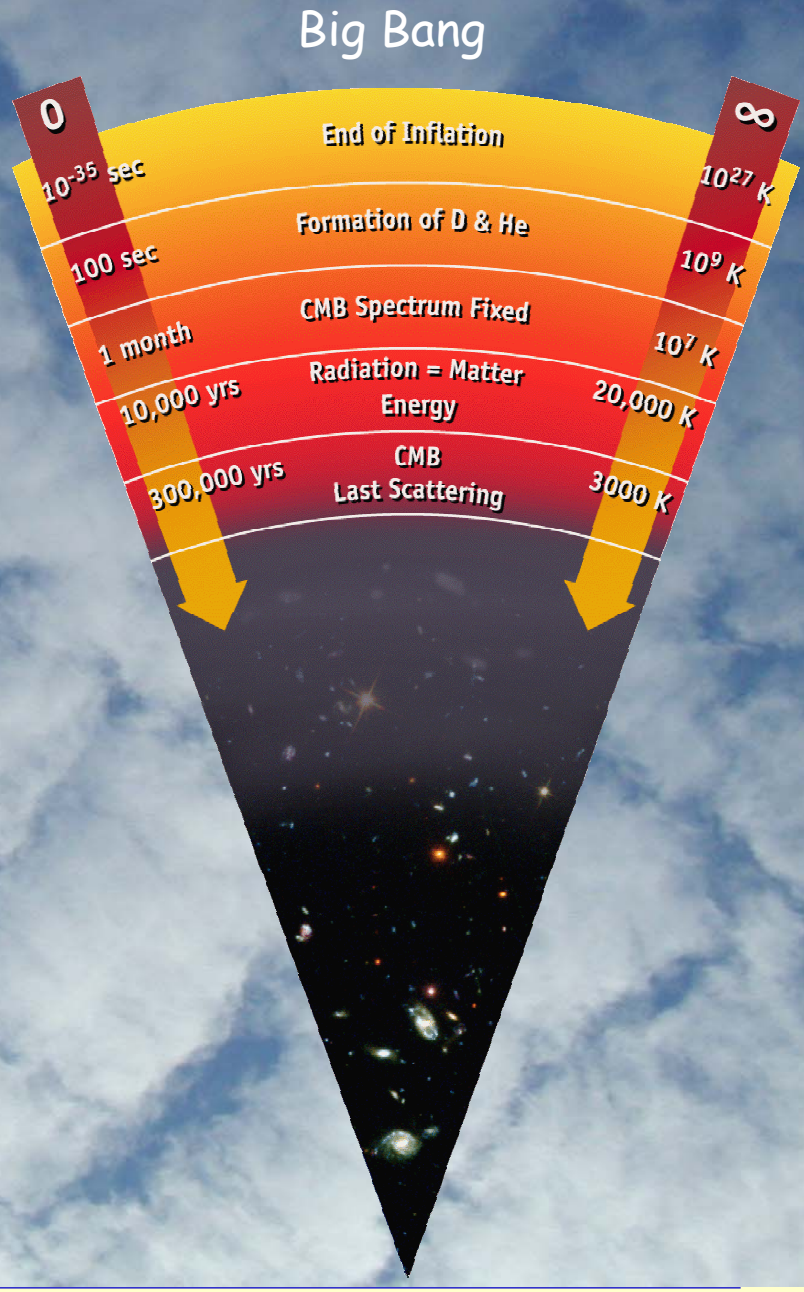
In this illustration, an arrow points to the doomed star. Part of its mass, shown by the white stream, was swallowed by the black hole.

Star No Match for Black Hole

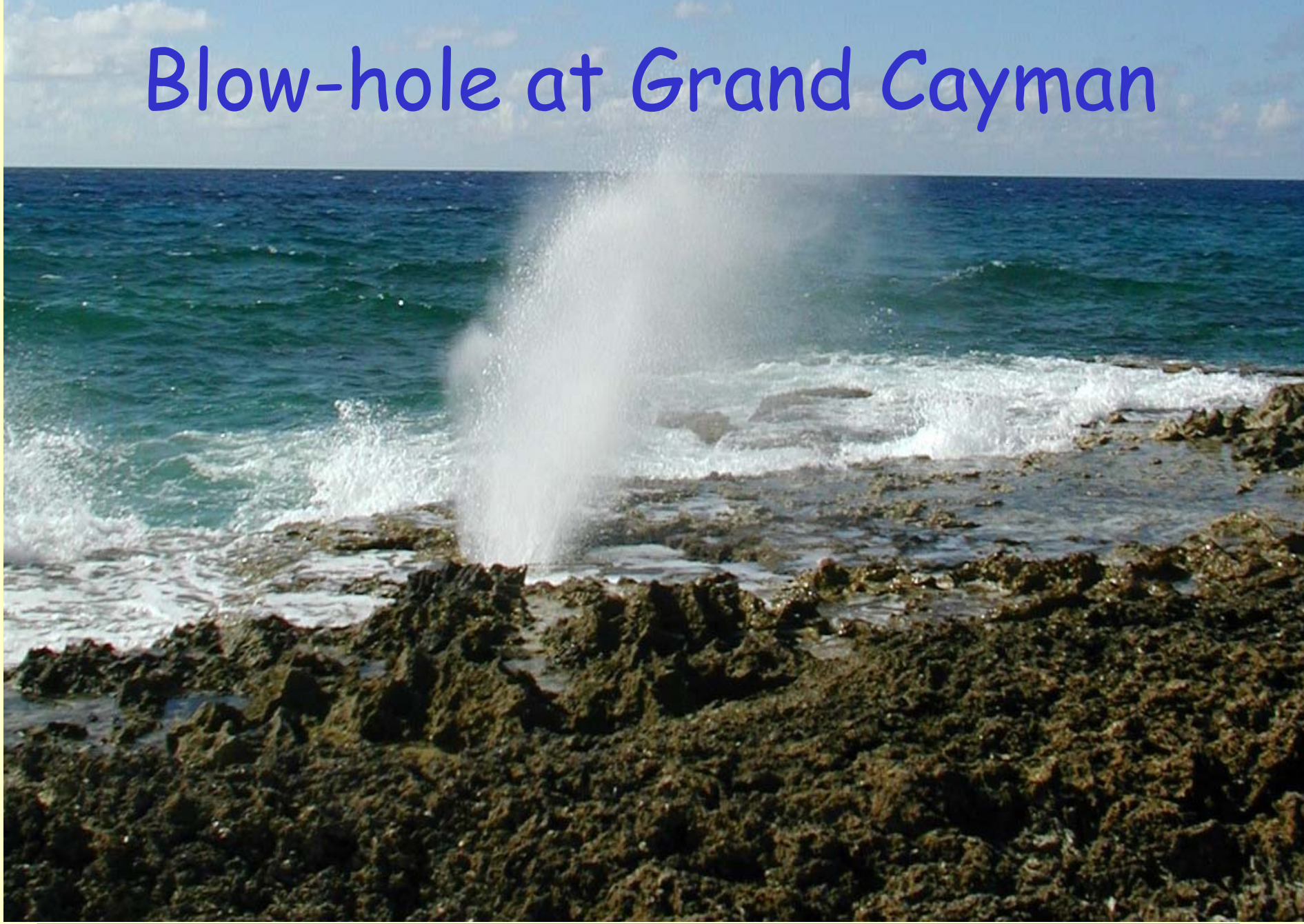

History of the Universe
Present
15 Billion Years
3°K
we are here
5 Billion Years
First Supernovae
1 Billion Years
Galaxy and Star Formation
10^{13}sec
The Universe Becomes Transparent
Decoupling of Matter-Radiation
Formation of Atoms
Matter Dominated Era
10^{2}sec
10^{0}sec
Nucleosynthesis of Helium
Disappearance of Positrons, Antiprotons, Antineutrons
10^{-4}sec
Confinement of Quarks
Formation of Protons, Neutrons
Antiprotons, Antineutrons
10^{-6}sec
10^{-10}sec
Radiation Dominated Era
End of Electroweak Epoch
Electroweak Epoch
The Desert
Cosmic Inflation
Magnetic Monopoles
10^{-34}sec
End of Grand Unification
Asymmetry
Grand Unification Epoch
10^{-43}sec
End of Quantum Gravity Epoch
10^{32}°K
Quantum Gravity Epoch
Big Bang
Spiral Galaxy
Supernova
Large Star
Protostar
Protogalaxy
Quasar
Elliptical Galaxy
Black Hole
Heavy Atom

In the beginning…

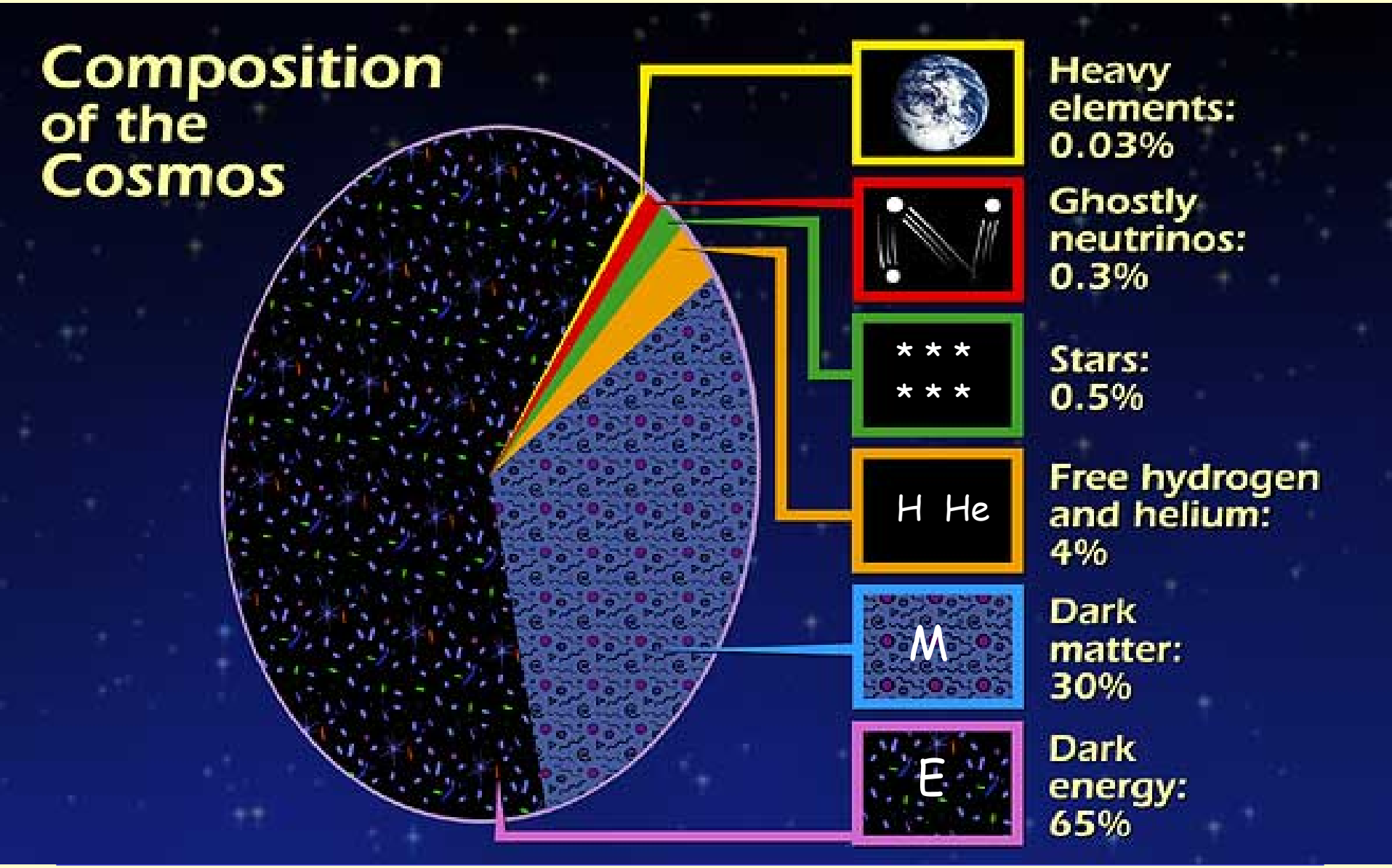




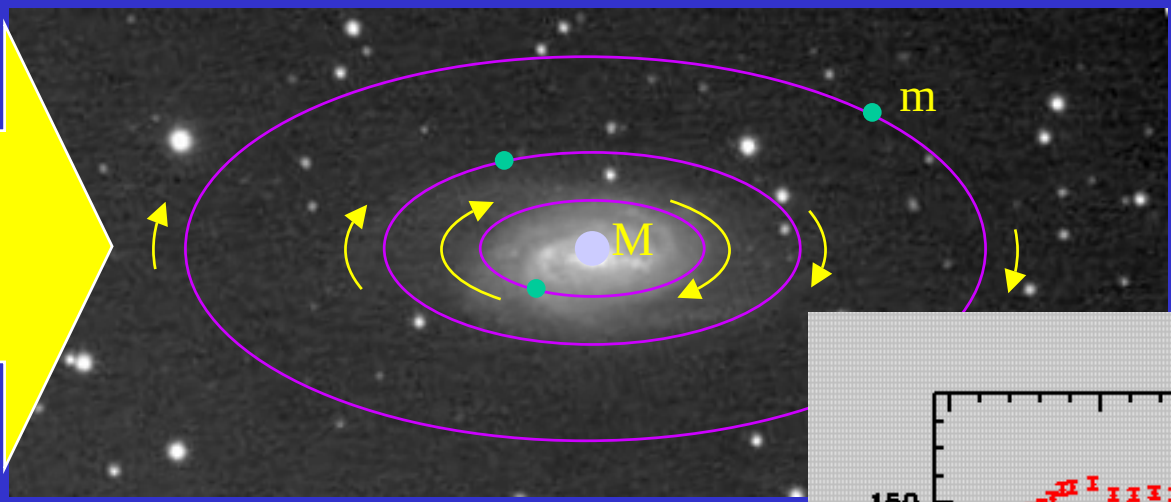
Blow-hole at Grand Cayman



Energy Budget of the Universe



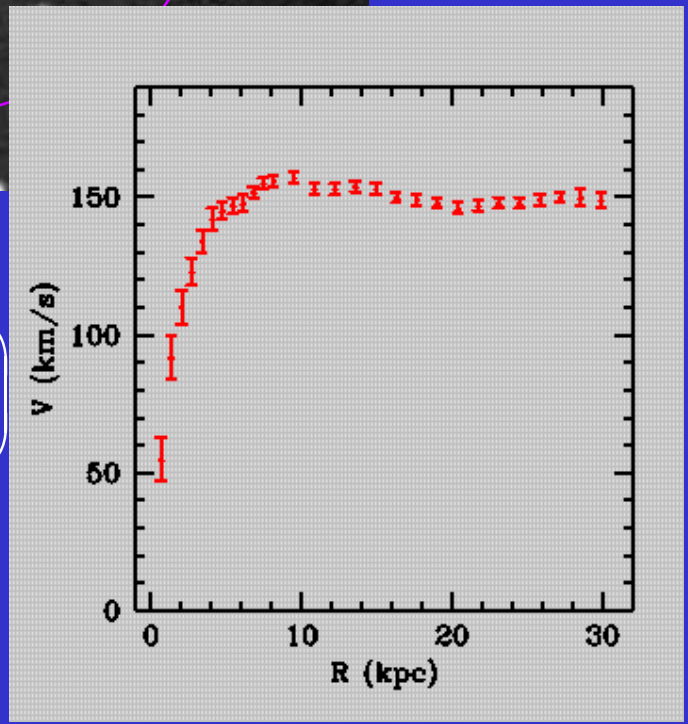
Dark Matter



Use light as a guide for mass

Expect $v^2 = G\frac{M}{R}\left(m\frac{v^2}{R} = G\frac{M \cdot m}{R^2}\right.$

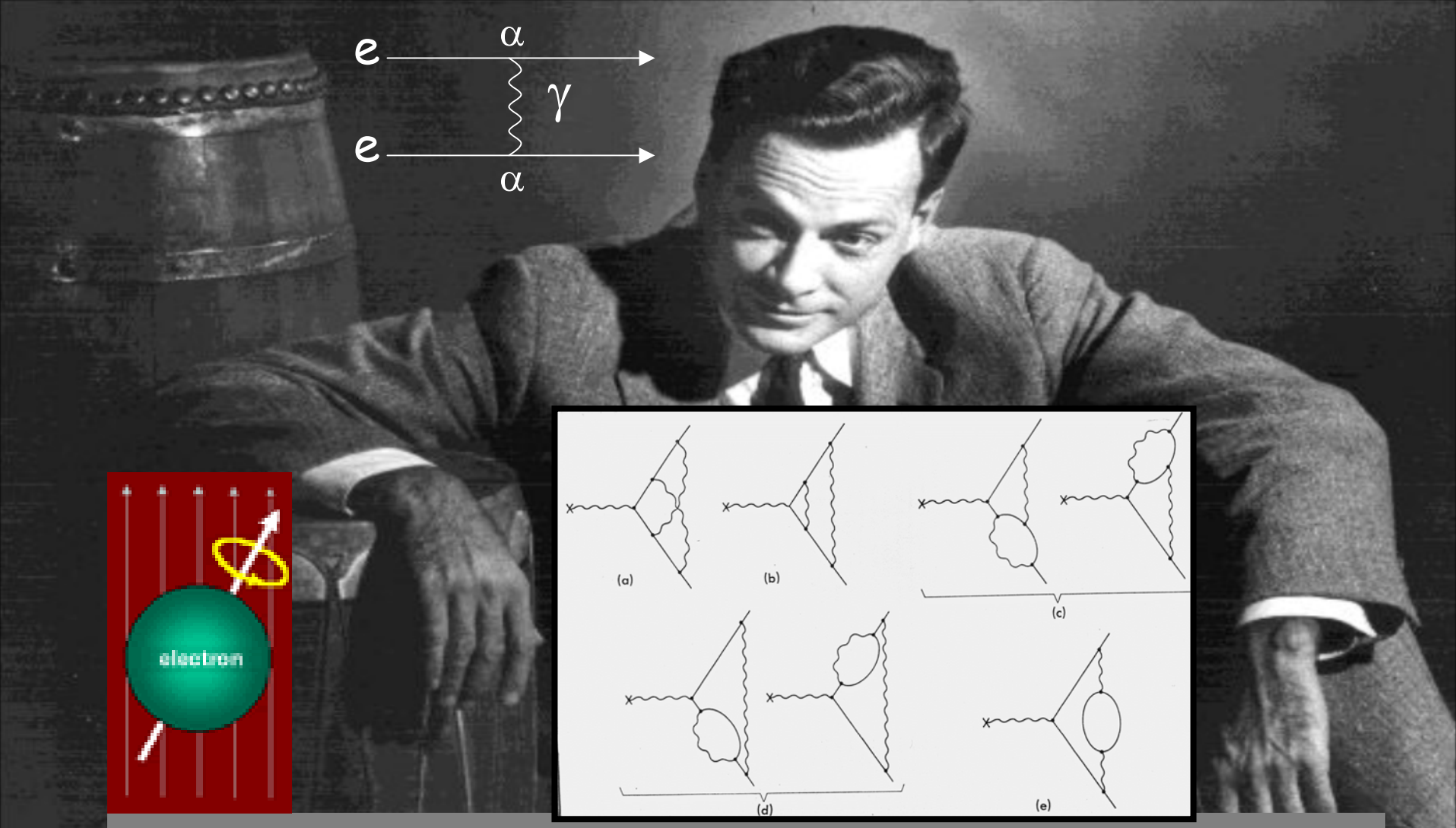
Is there mass where there is no light?
...Dark Matter !



§

• Photo courtesy of Blas Cabrera
§ Rotation curve for the galaxy NGC3198 from Begeman 1989

(slide from Clarence Chang, Aspen 2004 Winter Conference on Particle Physics)

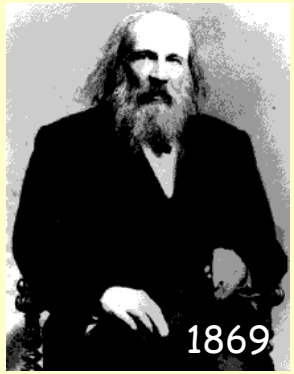


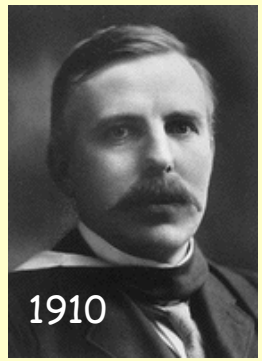
$$\mu = 1.00115965219 \pm 0.00000000001$$

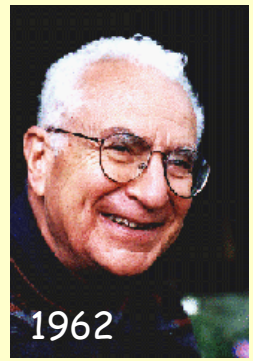
$$\mu = 1.00115965219 \pm 0.00000000003$$

Elementary Particles

450 BC



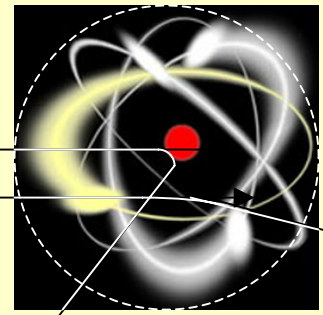




Aristotle	Demokritos	Mendeleyev	Thomson	Rutherford	Gell-Mann
earth water air fire	atom	periodic table	electron	nucleus	quarks

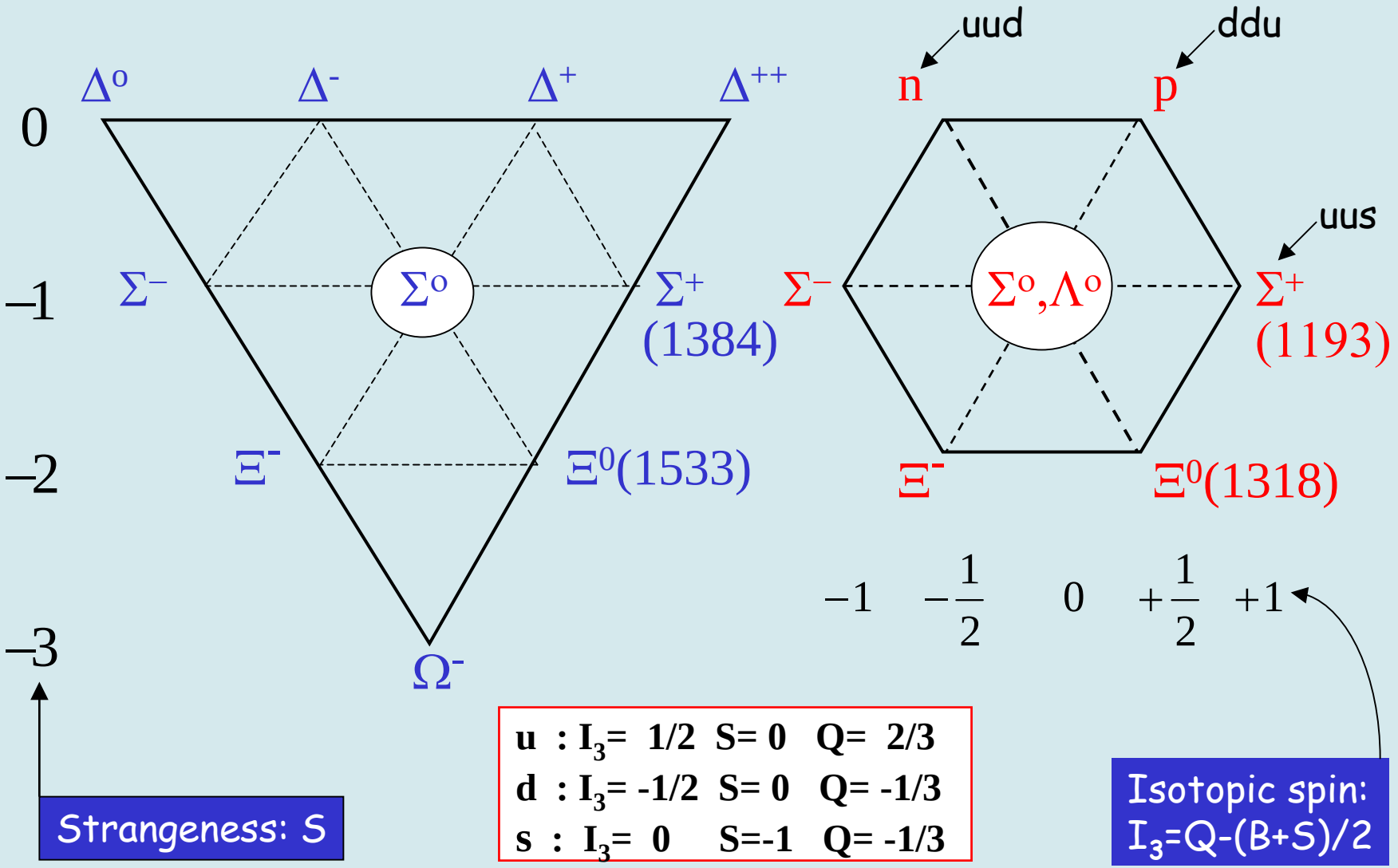
Rutherford Experiment

Source → α-particles

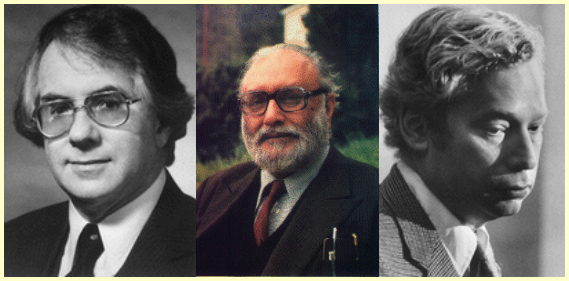


Large angle scattering → atoms have nuclei

SU3: Law and Order in the Particle Zoo



u : I_3= 1/2 S= 0 Q= 2/3
d : I_3= -1/2 S= 0 Q= -1/3
s : I_3= 0 S=-1 Q= -1/3



The Standard Model

Glashow, Salam, and Weinberg

Elementary Particles

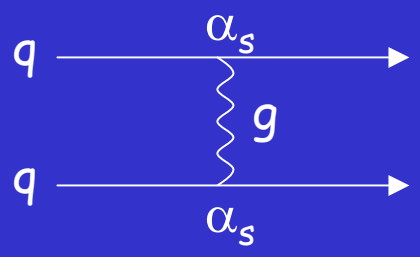
Quarks	u up	c charm	t top	g gluon	Force Carriers
	d down	s strange	b bottom	γ photon	
Leptons	ν_e e neutrino	ν_μ μ neutrino	ν_τ τ neutrino	W W boson	
	e electron	μ muon	τ tau	Z Z boson	
3 →	I	II	III	← Generations	

$M_\gamma, g = 0$ $\quad M_{W,Z} \sim 100\, M_p$ $\quad M_{top} \sim M_{gold}$

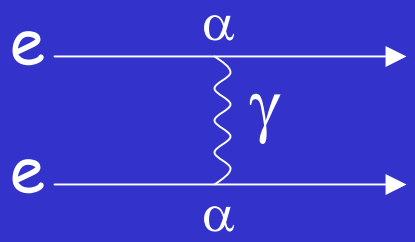
Higgs field generates Mass !

Unification of forces

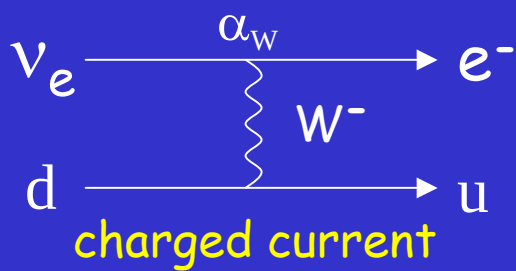
STRONG ~ 1



ELECTROMAGNETIC ~ 10^{-2}

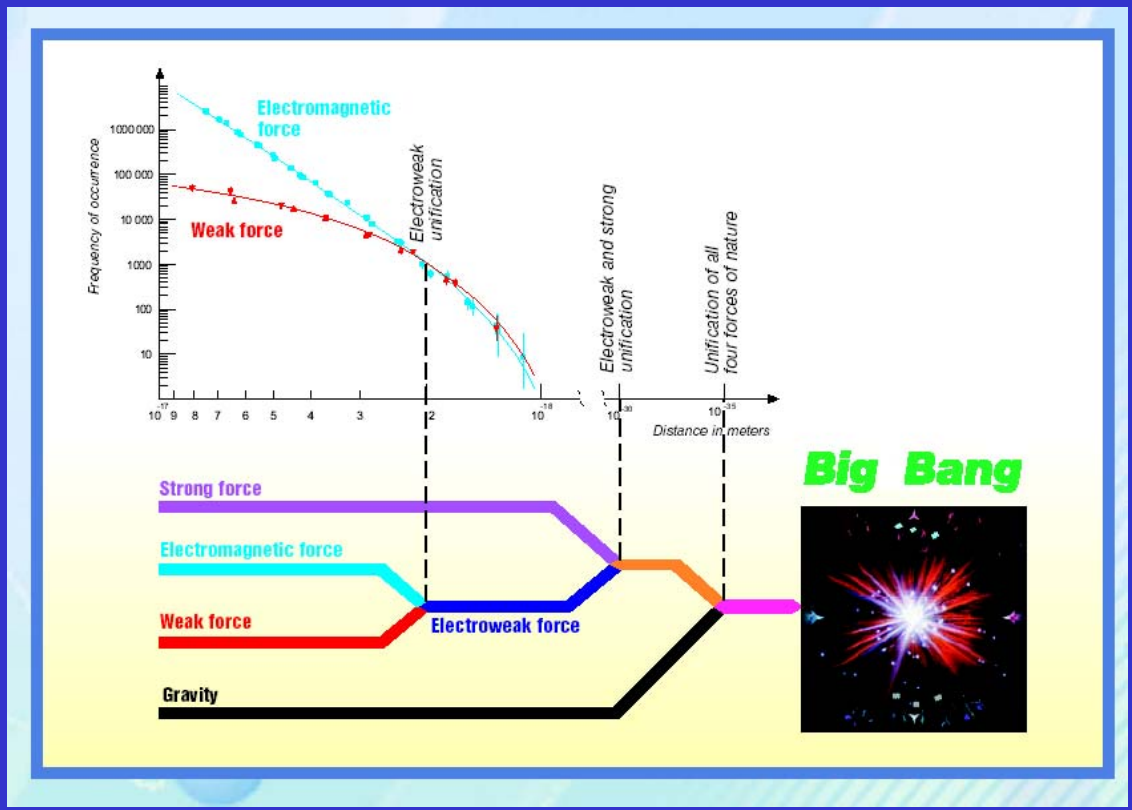


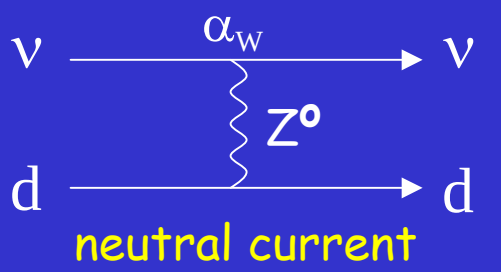
WEAK ~ 10^{-14}



charged current

$\nu_e + n \rightarrow p + e^-$



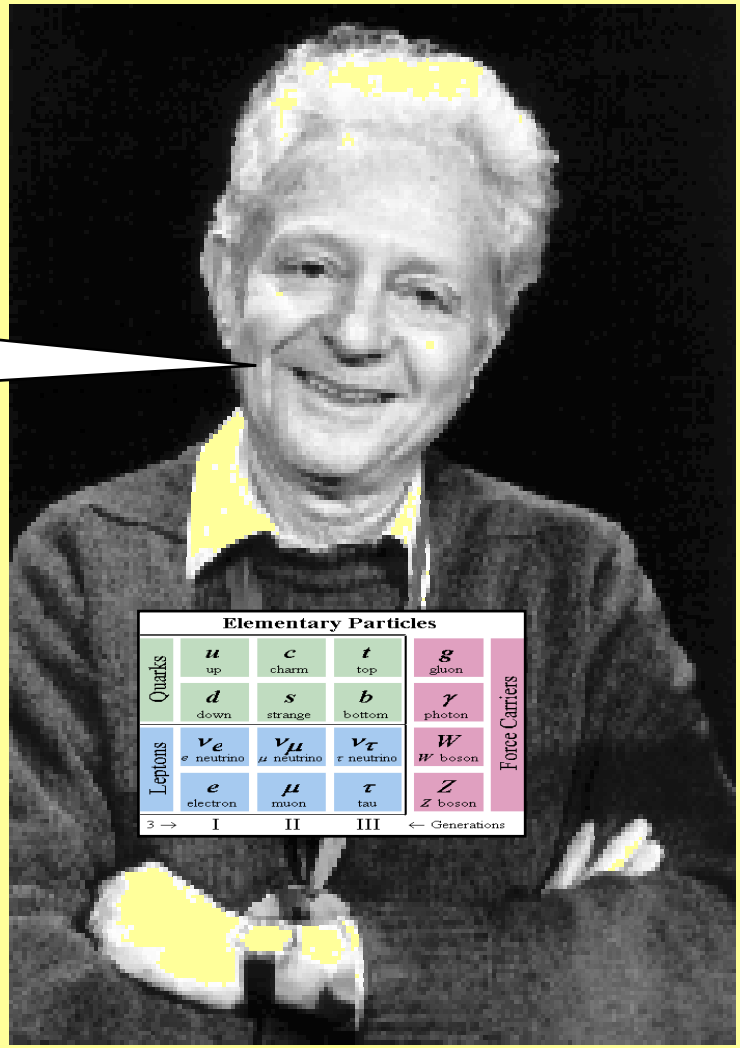


neutral current

$\nu_e + p \rightarrow \nu_e + p$

Leon Lederman & the SM

A good theory should fit on a T-shirt!



But what about interactions?

$$L = -\frac{1}{4}\mathrm{W}_{\mu\nu}\mathrm{W}^{\mu\nu} - \frac{1}{4}\mathrm{B}_{\mu\nu}\mathrm{B}^{\mu\nu}$$

$$+\bar{\mathrm{L}}\gamma^{\mu}\left(i\partial_{\mu} - g\frac{1}{2}\tau.\mathrm{W}_{\mu} - g'\frac{\mathrm{Y}}{2}\mathrm{B}_{\mu}\right)\mathrm{L}$$

$$+\bar{\mathrm{R}}\gamma^{\mu}\left(i\partial_{\mu} - g'\frac{\mathrm{Y}}{2}\mathrm{B}_{\mu}\right)\mathrm{R}$$

$$+\left[\left(i\partial_{\mu} - g\frac{1}{2}\tau.\mathrm{W}_{\mu} - g'\frac{\mathrm{Y}}{2}\mathrm{B}_{\mu}\right)\phi\right]^2 - \mathrm{V}(\phi)$$

$$-\left(\mathrm{G}_1\bar{\mathrm{L}}\phi\mathrm{R} + \mathrm{G}_2\bar{\mathrm{L}}\phi_c\mathrm{R} + \text{hermitian conjugate}\right)$$

AND WHAT ABOUT GRAVITY?

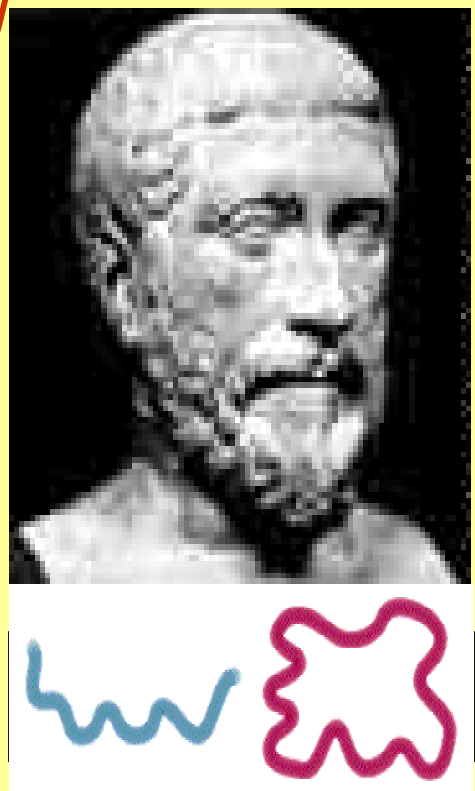
String Theory, then?

http://www.aboutscotland.com/harmony/prop.html

Particles correspond to the vibration modes of a string in 10 dimensions

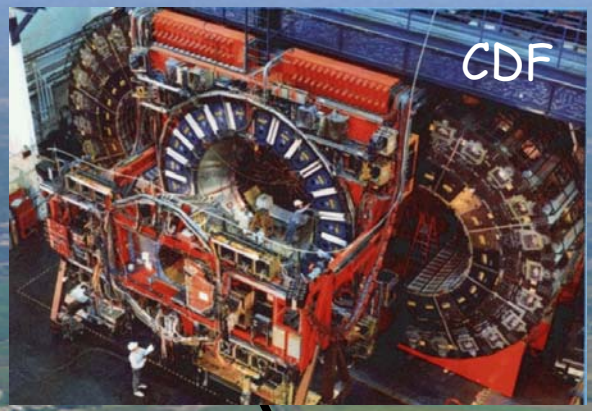
Gravity is included!

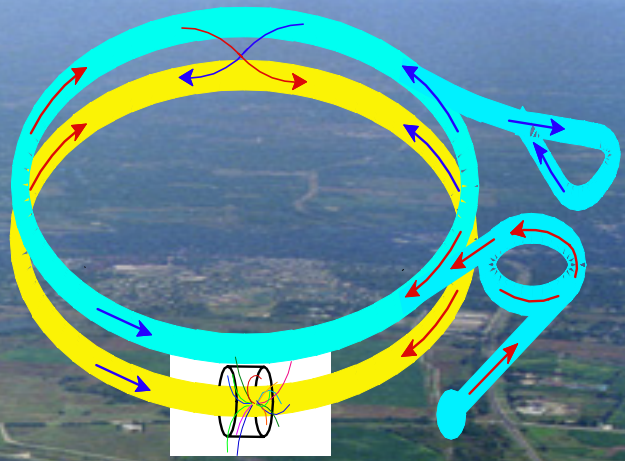
Pythagoras applied it to music in 400 BC:
1+2+3+4=10



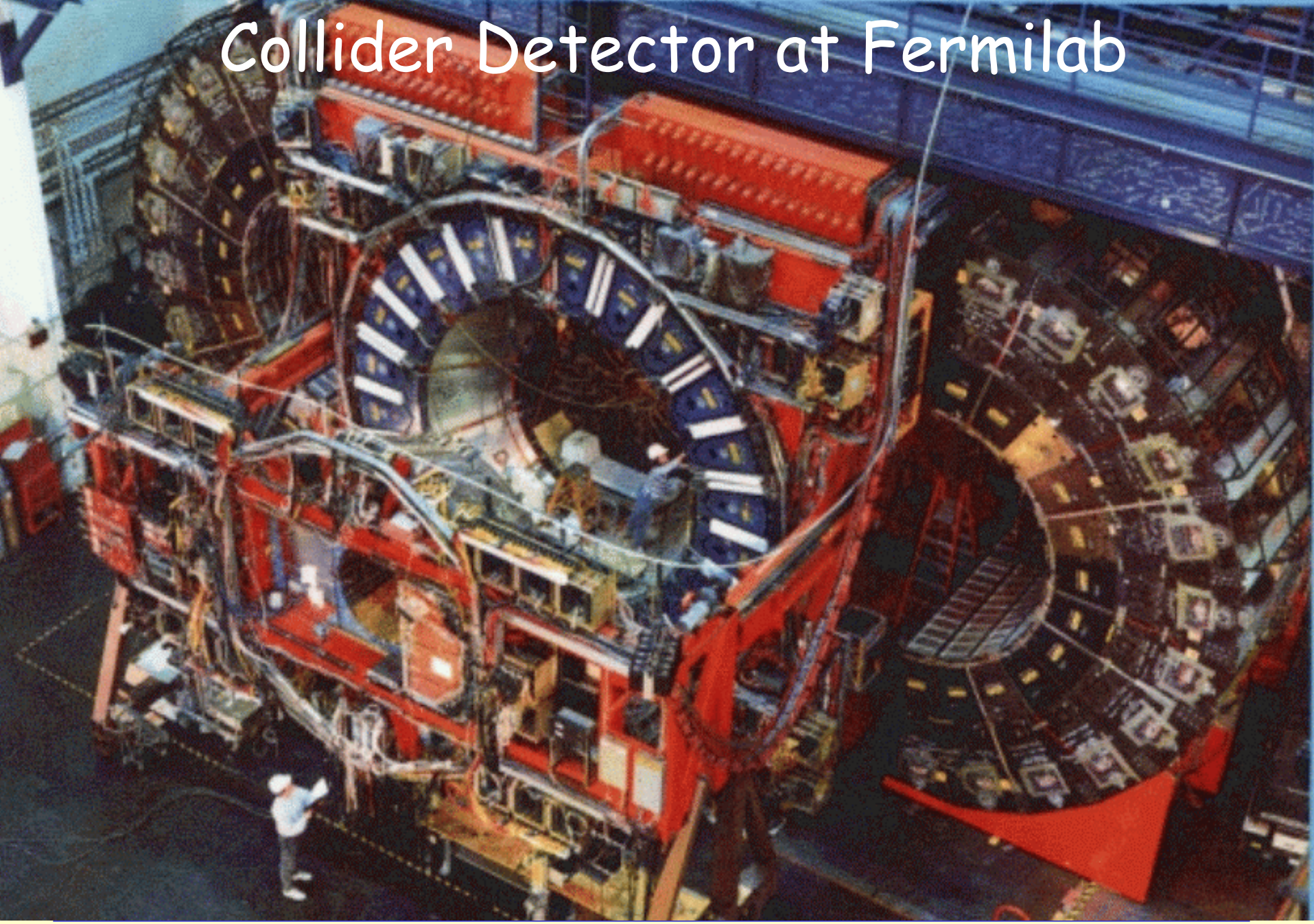
It surely makes an interesting T-shirt!

The Tevatron $\bar{p}$-p Collider





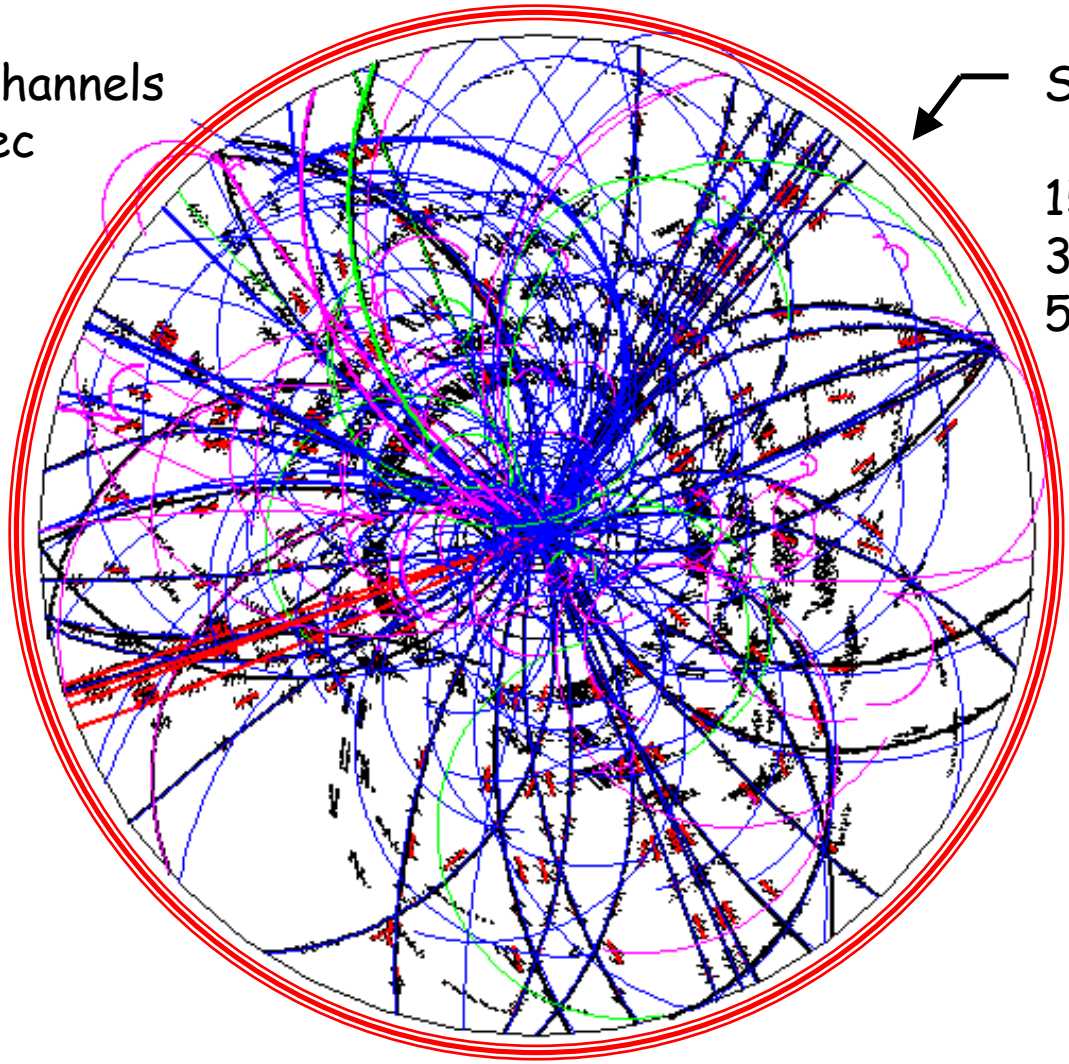
Collider Detector at Fermilab



CDF event in central tracker

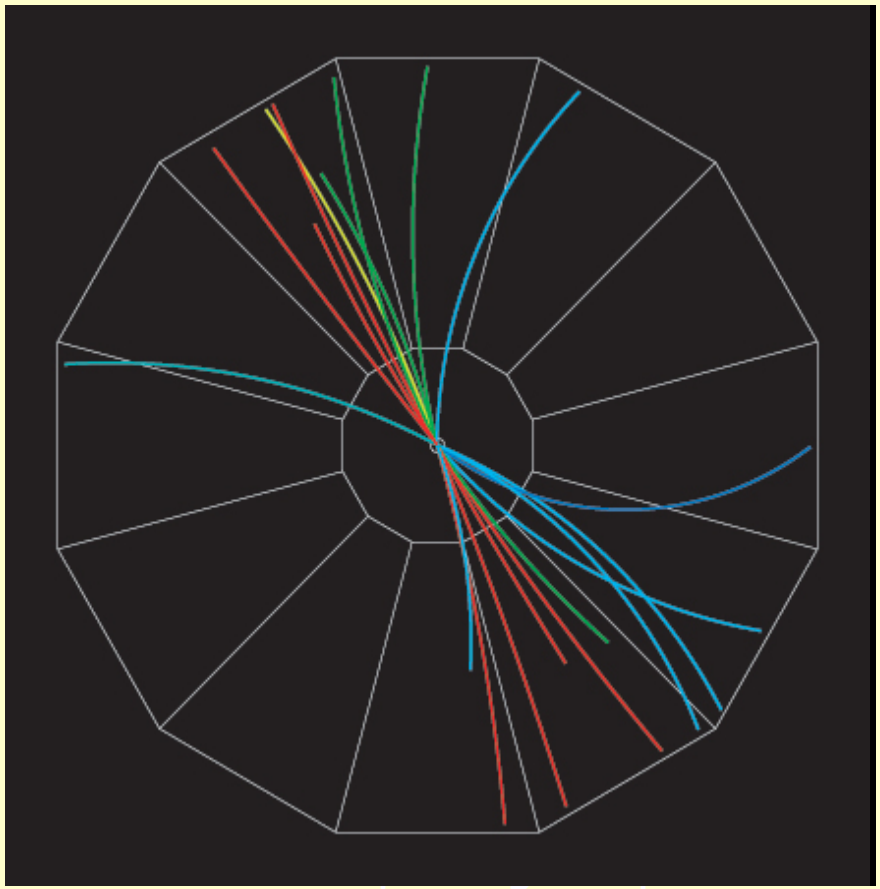
10^6 electronic channels
10^6 collisions/sec

Trigger:
L1: 100 K/sec
L2: 1 K/sec
L3: 100/sec

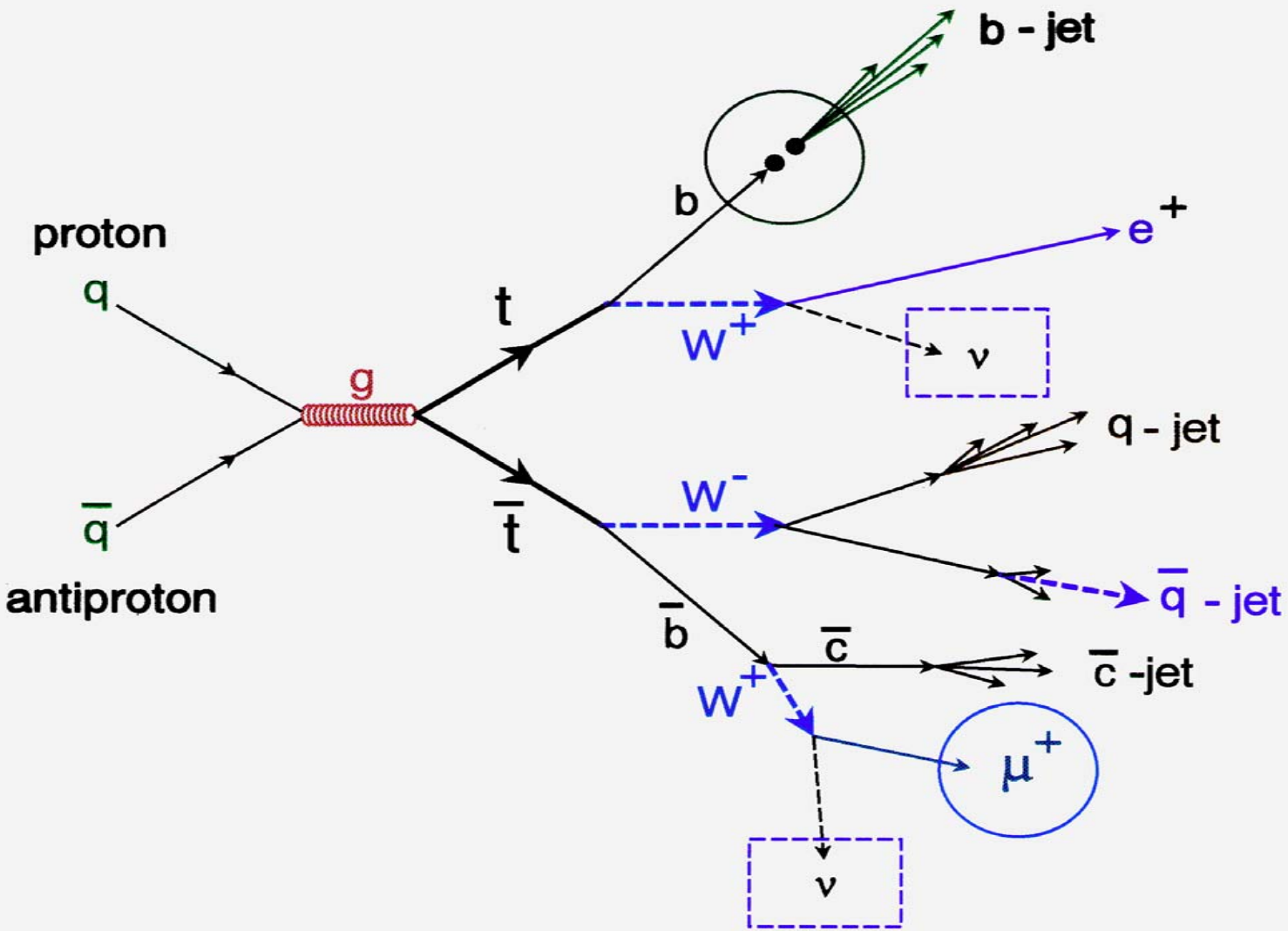


Superconducting solenoid
15 Kgauss
3 m diameter
5 m long

Selecting the information of interest

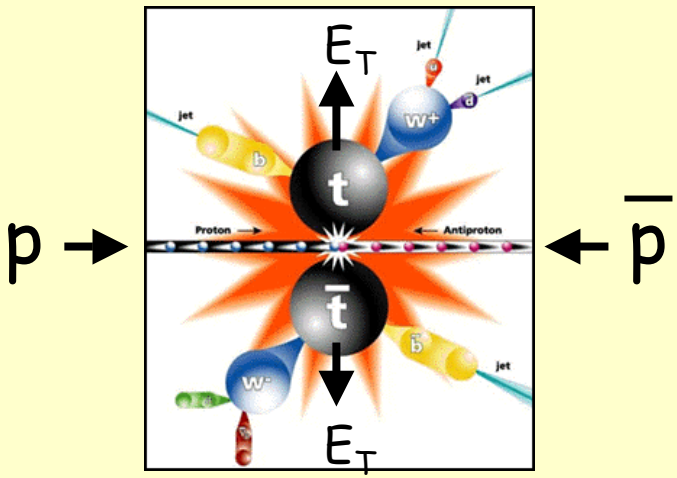


The Top Quark



Top Quark Discovery

The top quark was co-discovered in 1995
by the CDF and D0 Collaborations at Fermilab



One of the discovery tools was the expected high value of the sum of the transverse energy in an event

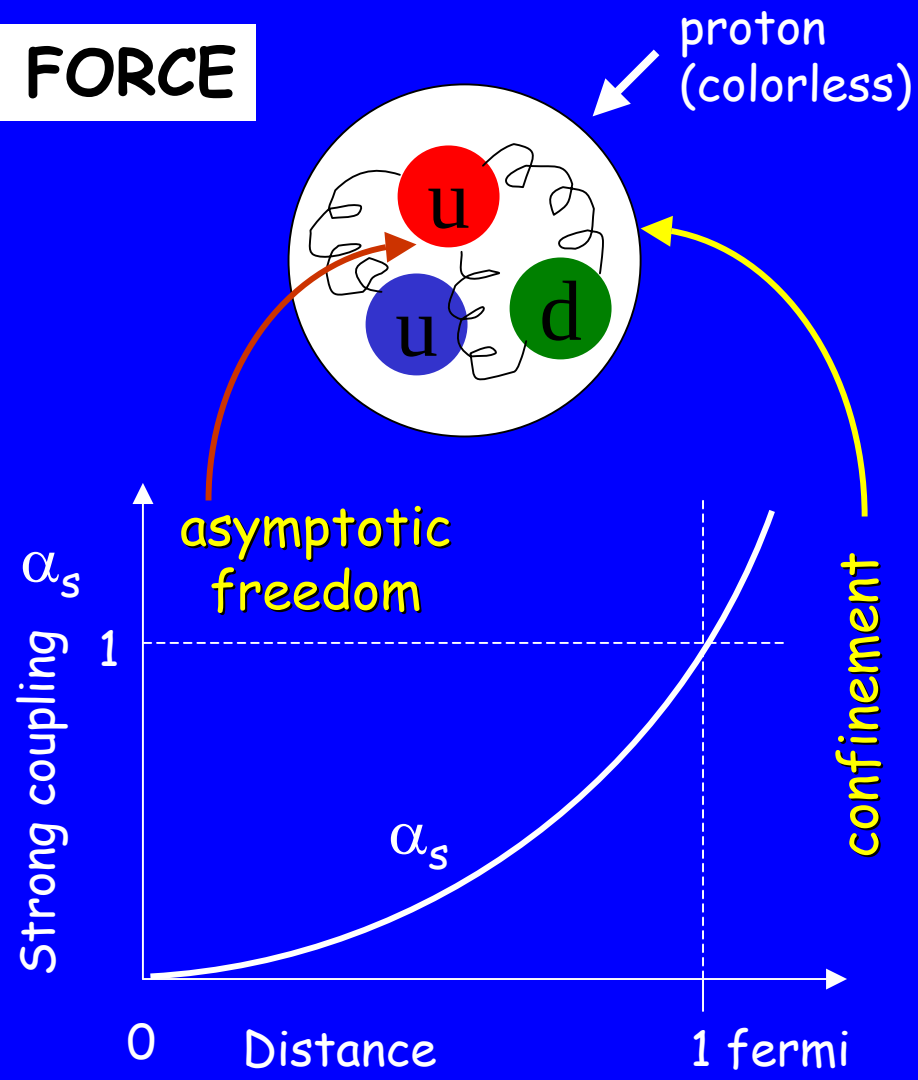
$$H=\Sigma E_T$$

http://www.fnal.gov/pub/news05/TopTurnsTen.html

QCD - Quantum Chromo-Dynamics

The Theory of Strong Interactions

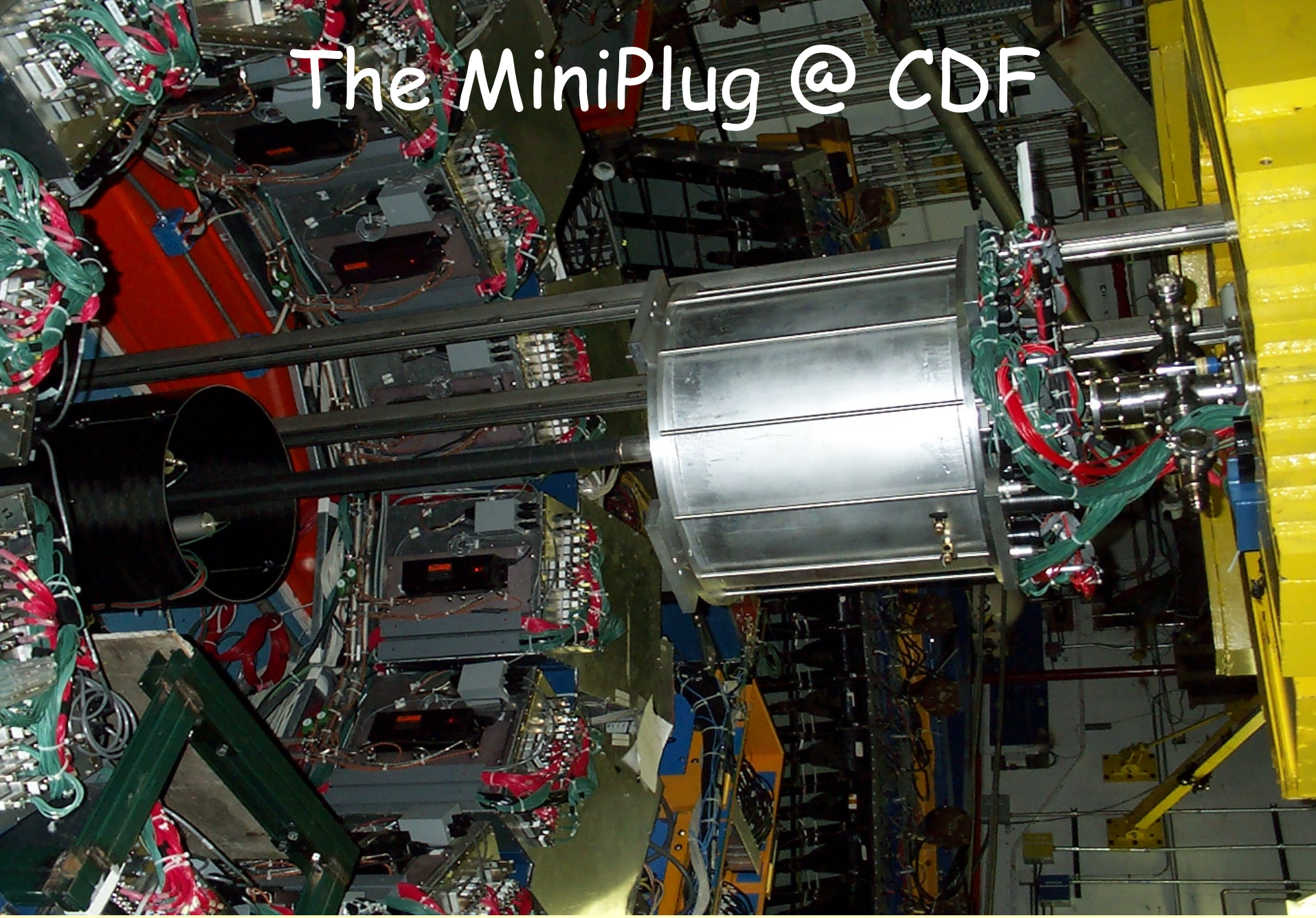
COLOR FORCE



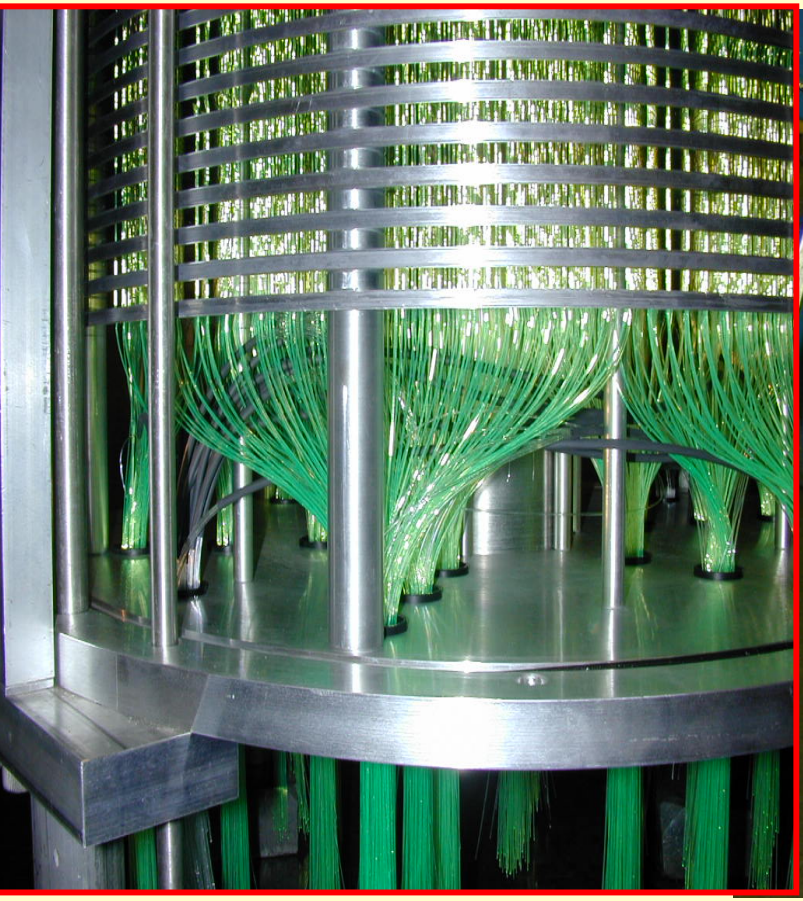
David Politzer

2004 Nobel Prize
in Physics
w/
David Gross and
Frank Wilczek

The MiniPlug @ CDF

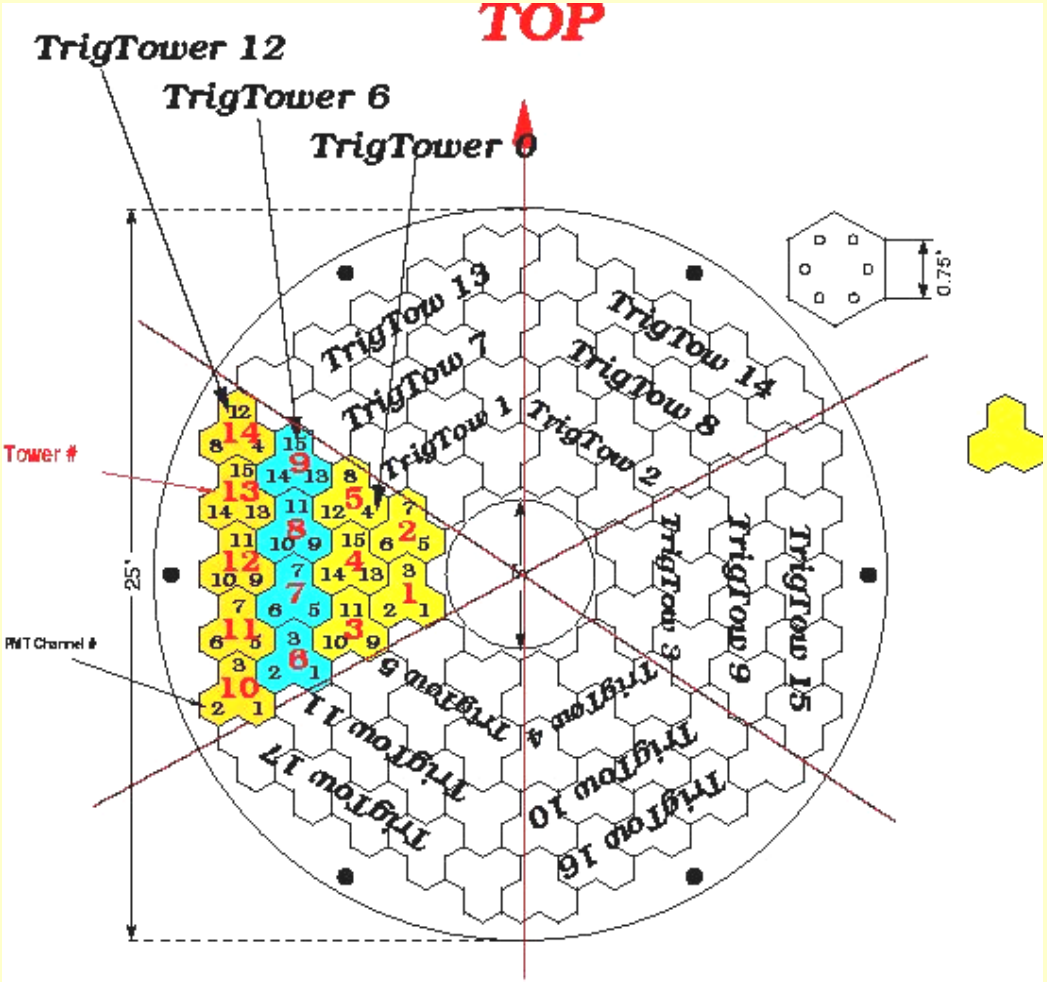


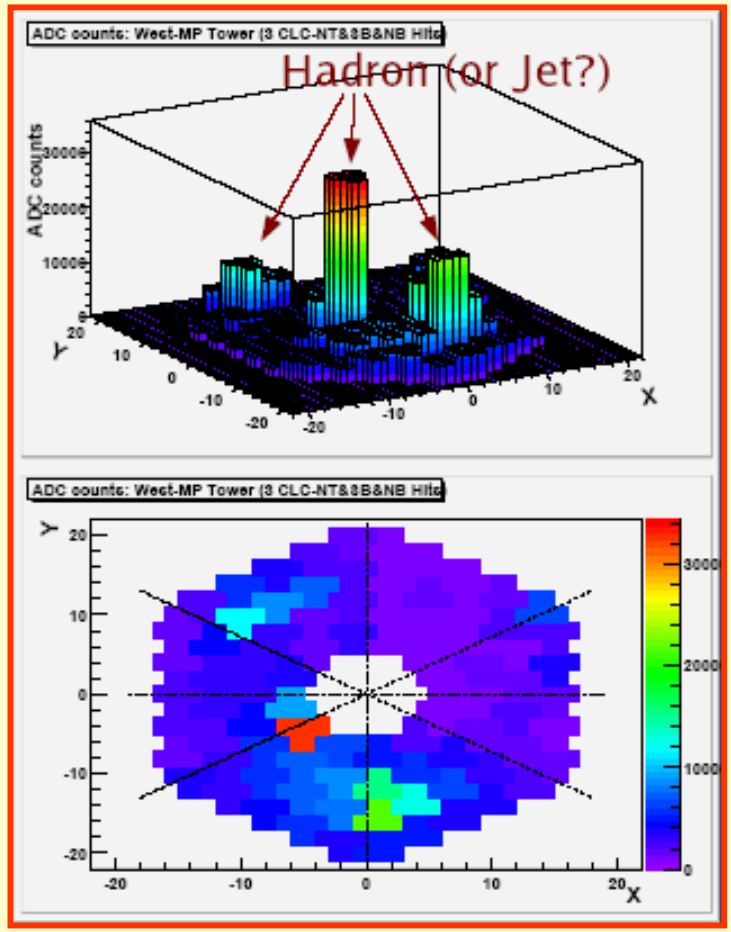
MiniPlug Construction at Rockefeller



About 1500 wavelength shifting fibers of 1 mm dia. are 'strung' through holes drilled in 36 lead plates sandwiched between reflective Al sheets and guided into bunches to be viewed individually by multi-channel photomultipliers.

An Event in the MiniPlug

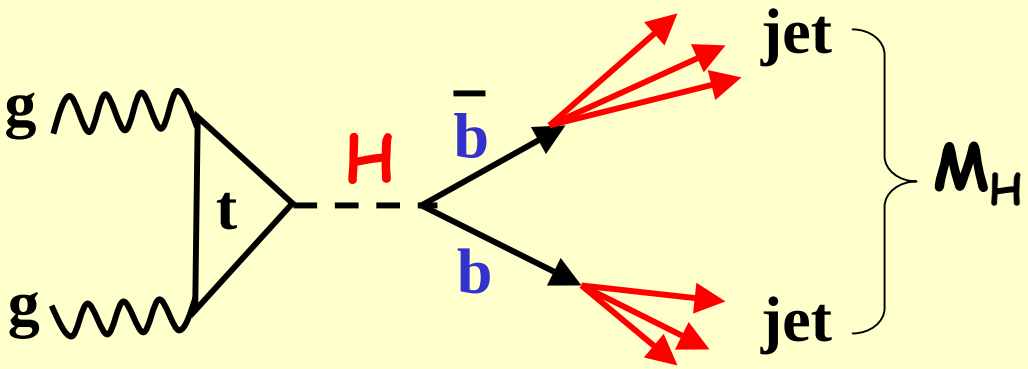


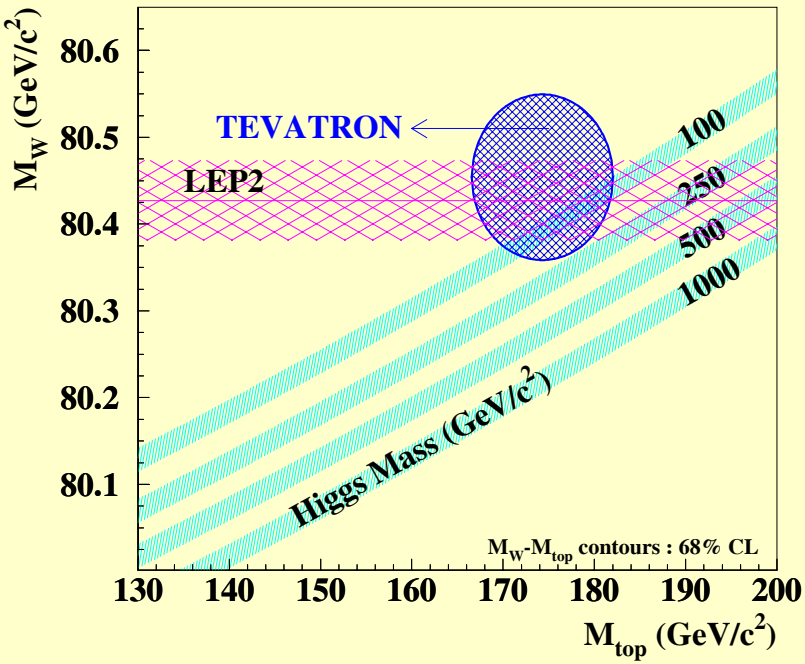


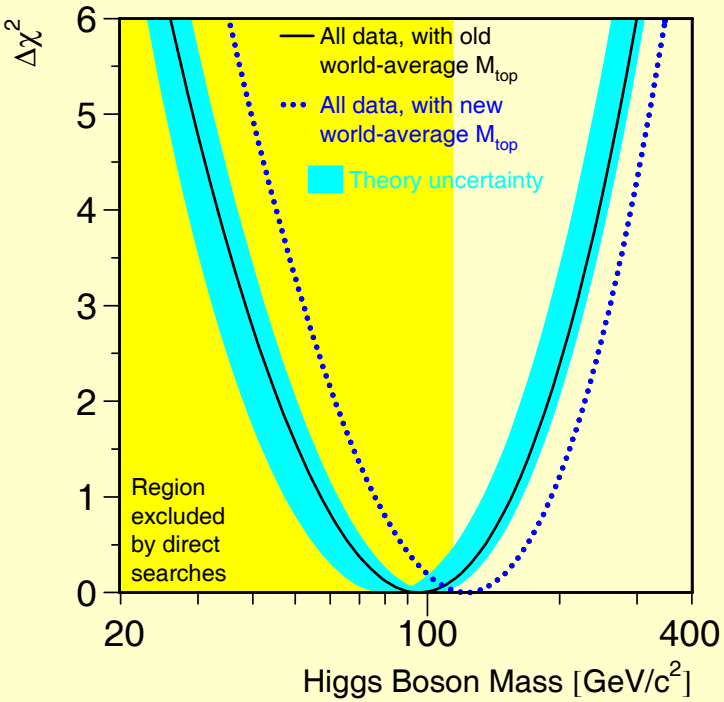
The Higgs Mechanism for generating Mass

The vacuum is filled with the Higgs field, the quanta of which are Higgs particles – named after Peter Higgs.

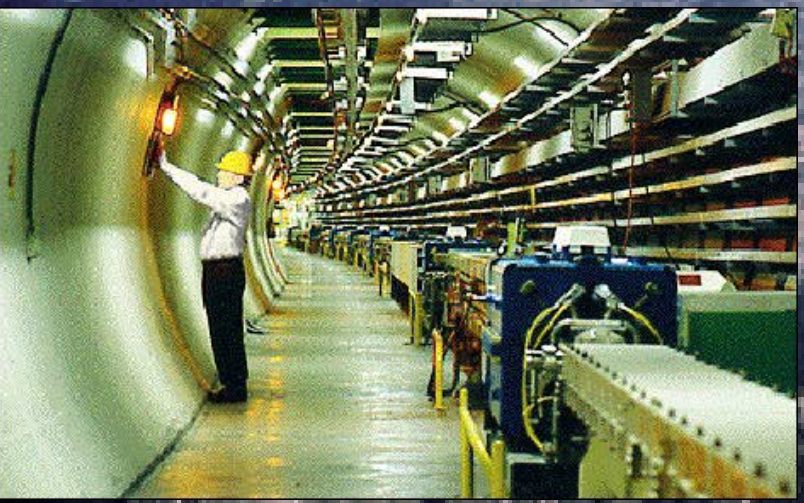
Search for the Higgs

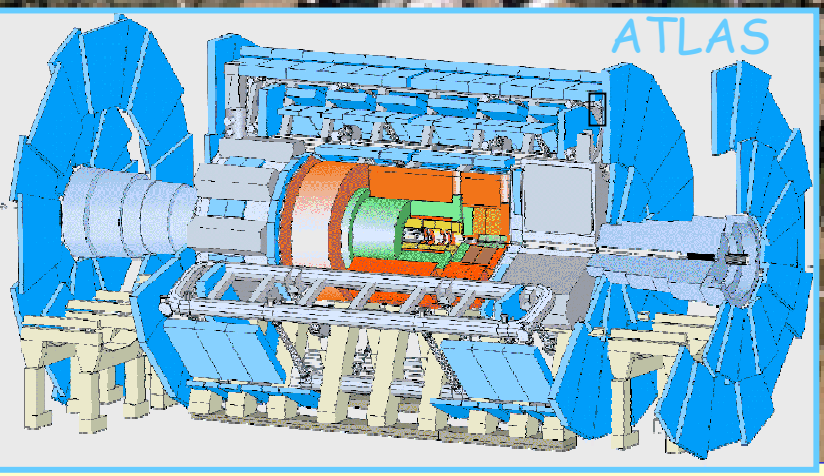






LHC at CERN





Many thanks to my Colleagues!

Anwar Luc Stefano Michele Mary Koji Christina Andrea Ken

http://www.rockefeller.edu/events/string_fever.php