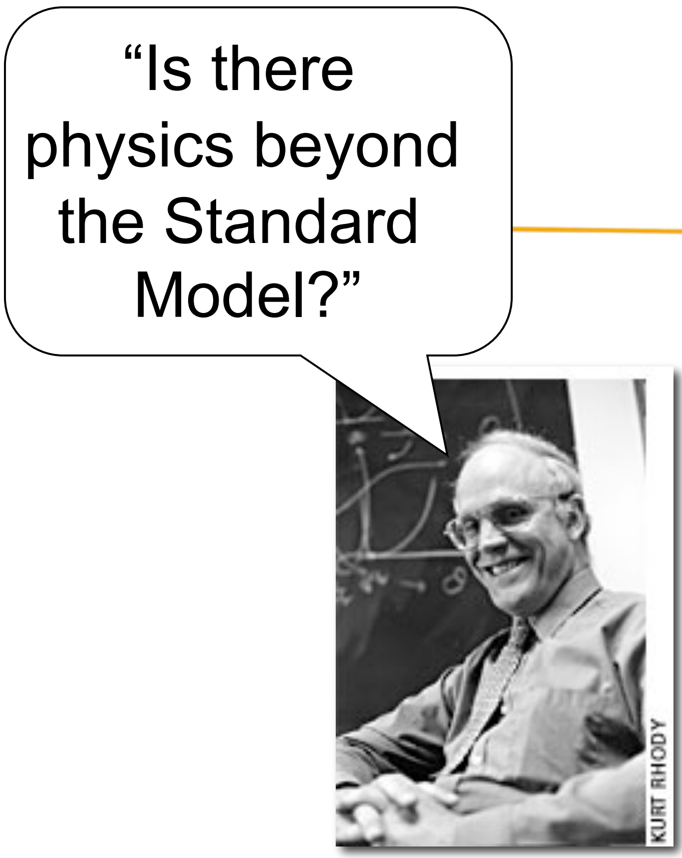
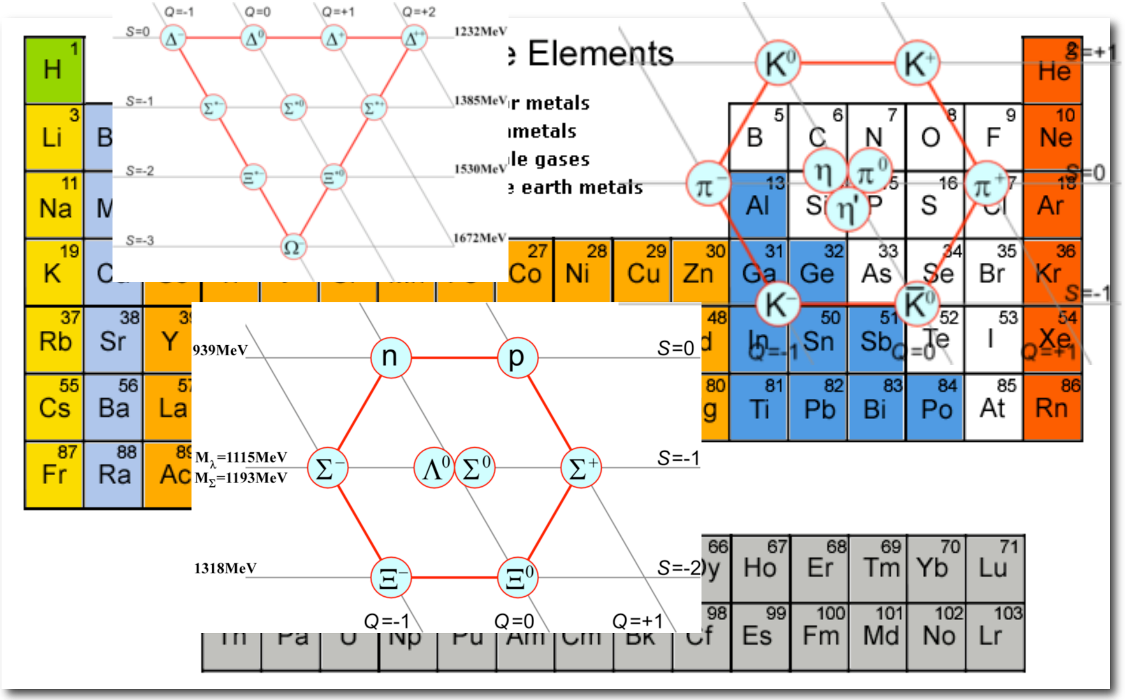
A Short Introduction to Particle Physics

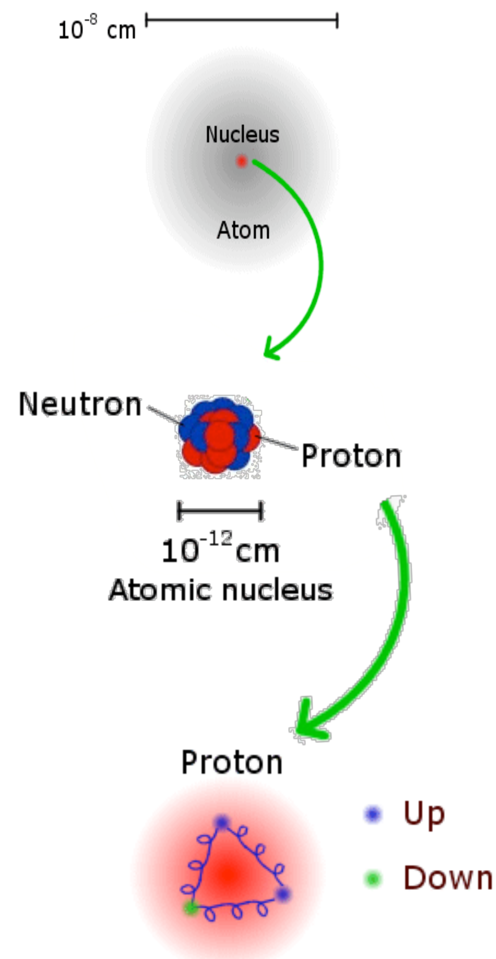


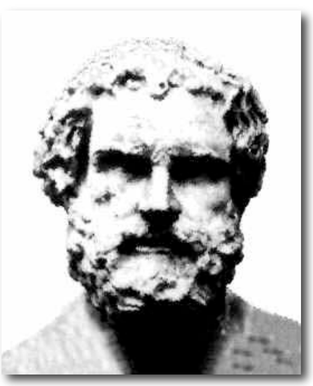
What do we know?

How do we know?

What next?







Democritus

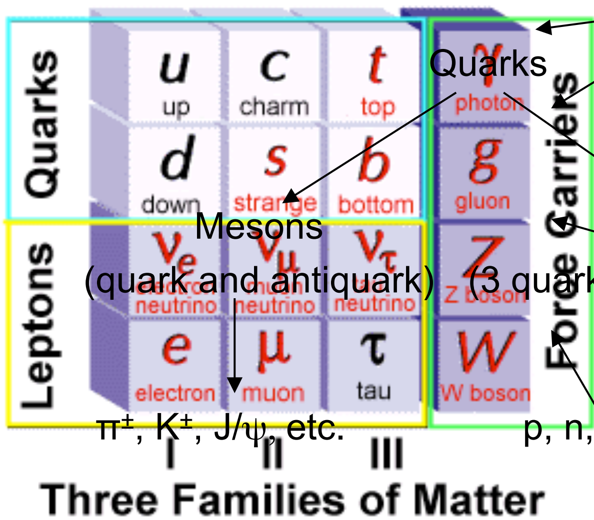
Dalton

Rutherford

Gell-Mann

The Standard Model

Elementary Particles



Quarks

Mesons (quark and antiquark)

$\pi^\pm$, $K^\pm$, J/ψ, etc.

Baryon (3 quarks or 3 antiquarks)

p, n, Σ^+, Δ^0, etc.

Leptons

Electrons and neutrinos

Bosons

Gluon, photon, Z boson, and W boson

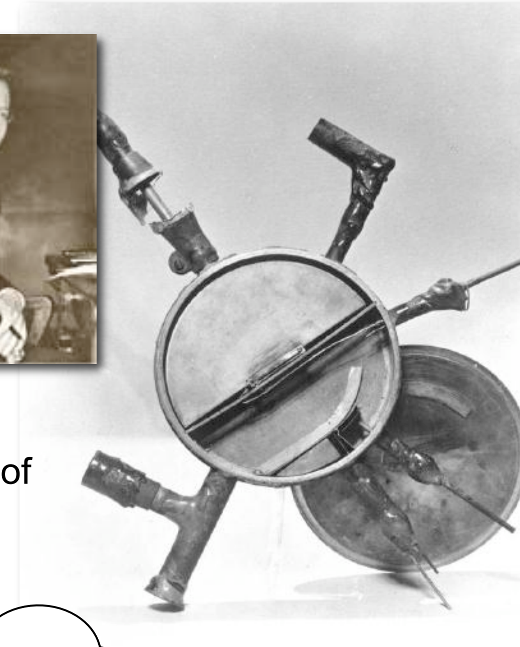
Weak Strong Electromagnetic

Generation 1						
Fermion (left-handed)	Symbol	Electric charge	Weak isospin	Hypercharge	Color charge *	Mass **
Electron	e^-	-1	$-1/2$	$-1/2$	1	511 keV
Positron	e^+	$+1$	0	$+1$	1	511 keV
Electron-neutrino	ν_e	0	$+1/2$	$-1/2$	1	< 2 eV
Up quark	u	$+2/3$	$+1/2$	$+1/6$	3	~ 3 MeV ***
Up antiquark	$\bar{u}$	$-2/3$	0	$-2/3$	$\bar{3}$	~ 3 MeV ***
Down quark	d	$-1/3$	$-1/2$	$+1/6$	3	~ 6 MeV ***
Down antiquark	$\bar{d}$	$+1/3$	0	$+1/3$	$\bar{3}$	~ 6 MeV ***

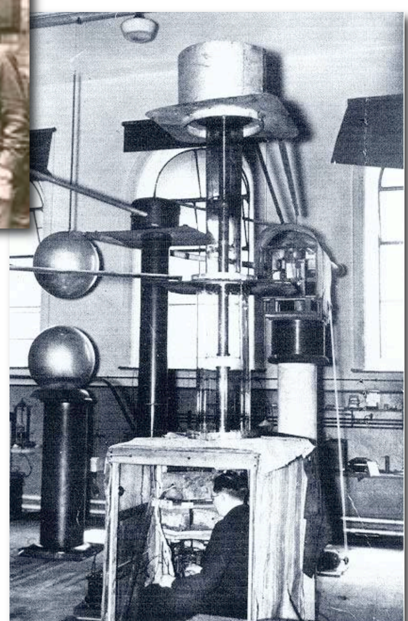
Generation 2						
Fermion (left-handed)	Symbol	Electric charge	Weak isospin	Hypercharge	Color charge *	Mass **
Muon	μ^-	-1	$-1/2$	$-1/2$	1	106 MeV
Antimuon	μ^+	$+1$	0	$+1$	1	106 MeV
Muon-neutrino	ν_μ	0	$+1/2$	$-1/2$	1	< 2 eV
Charm quark	c	$+2/3$	$+1/2$	$+1/6$	3	~ 1.3 GeV
Charm antiquark	$\bar{c}$	$-2/3$	0	$-2/3$	$\bar{3}$	~ 1.3 GeV
Strange quark	s	$-1/3$	$-1/2$	$+1/6$	3	~ 100 MeV
Strange antiquark	$\bar{s}$	$+1/3$	0	$+1/3$	$\bar{3}$	~ 100 MeV

Generation 3						
Fermion (left-handed)	Symbol	Electric charge	Weak isospin	Hypercharge	Color charge *	Mass **
Tau lepton	τ^-	-1	$-1/2$	$-1/2$	1	1.78 GeV
Anti-tau lepton	τ^+	$+1$	0	$+1$	1	1.78 GeV
Tau-neutrino	ν_τ	0	$+1/2$	$-1/2$	1	< 2 eV
Top quark	t	$+2/3$	$+1/2$	$+1/6$	3	171 GeV
Top antiquark	$\bar{t}$	$-2/3$	0	$-2/3$	$\bar{3}$	171 GeV
Bottom quark	b	$-1/3$	$-1/2$	$+1/6$	3	~ 4.2 GeV
Bottom antiquark	$\bar{b}$	$+1/3$	0	$+1/3$	$\bar{3}$	~ 4.2 GeV

Robert Van de Graaff's 1 MeV generator was demonstrated in 1929.



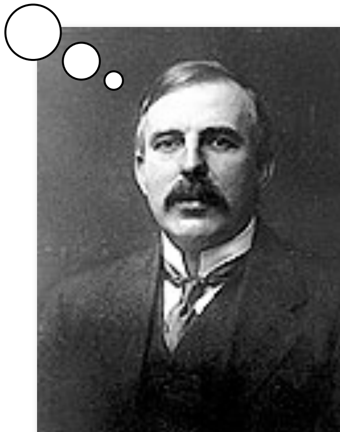
In 1932 E.O. Lawrence's cyclotron achieved energies of 1.2 MeV and nuclear events similar to Cockroft-Walton.

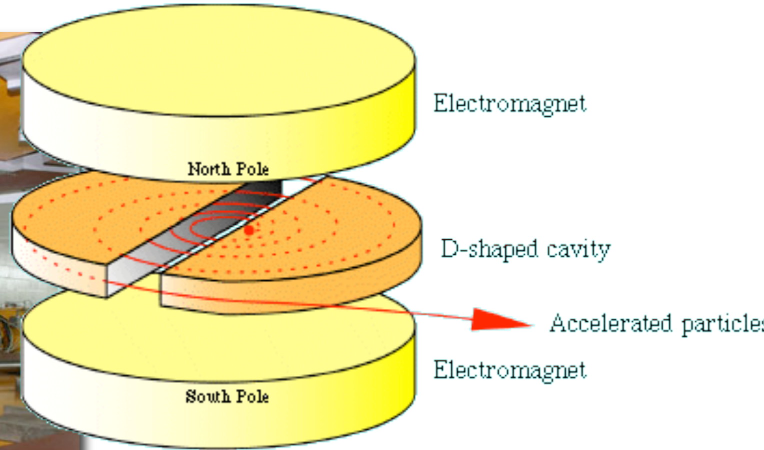


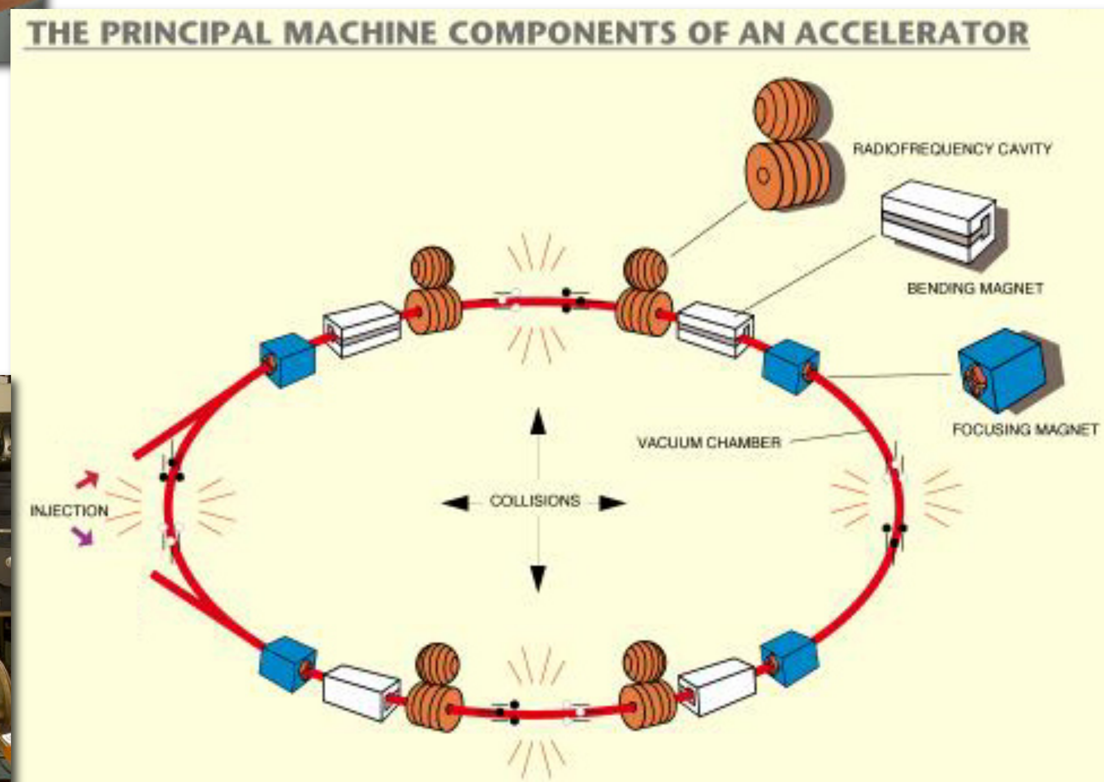
John Cockcroft and Ernest Walton demonstrate the first man-made nuclear reaction in 1930 using their 0.4 MeV accelerator.

One day we will be able to accelerate charged particles to energies larger then radioactive decay.... 1927

In 1909 Rutherford's famous experiment used 5 MeV alpha particles to probe the gold atom and revel the nucleus.





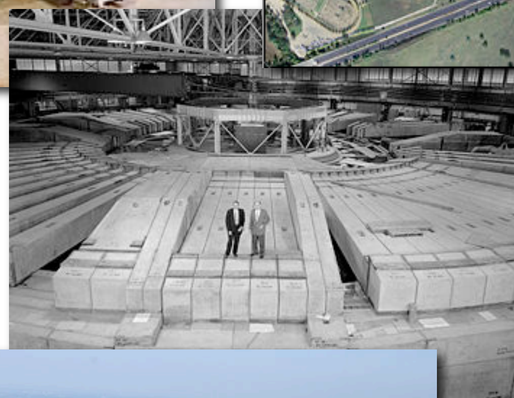


[Cyclotron Simulation]()

[RF Cavity Simulation]()

Bigger Machines - More Energy

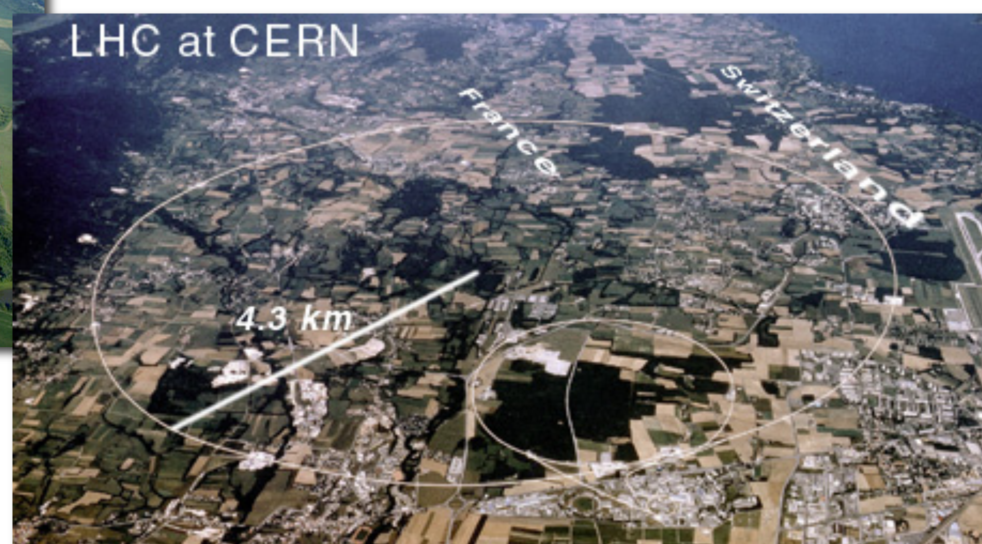
Cosmotron
3.3 GeV protons



Bevatron
6.2 GeV protons

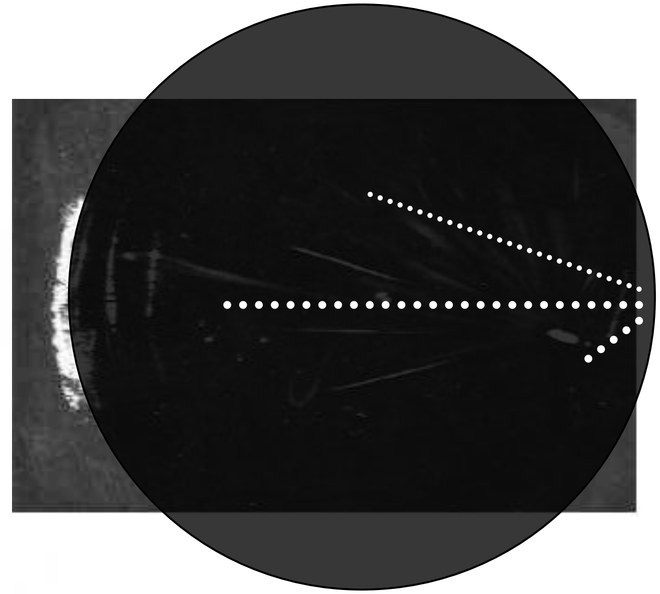
Stanford Linear Accelerator
50 GeV electron-positron

Fermi Lab - 1 TeV protons/antiprotons

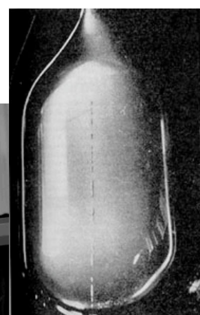


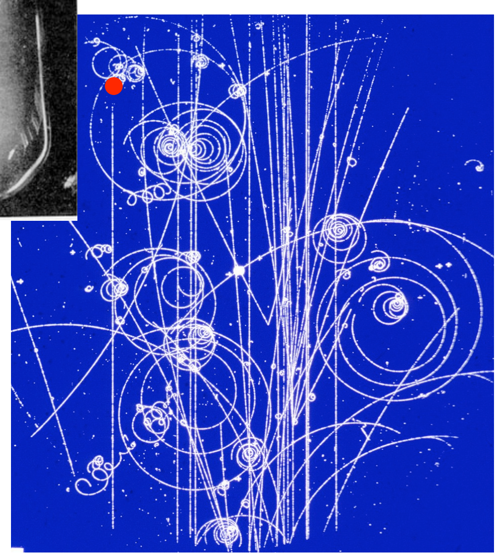
Large Hadron Collider
14 TeV protons/protons

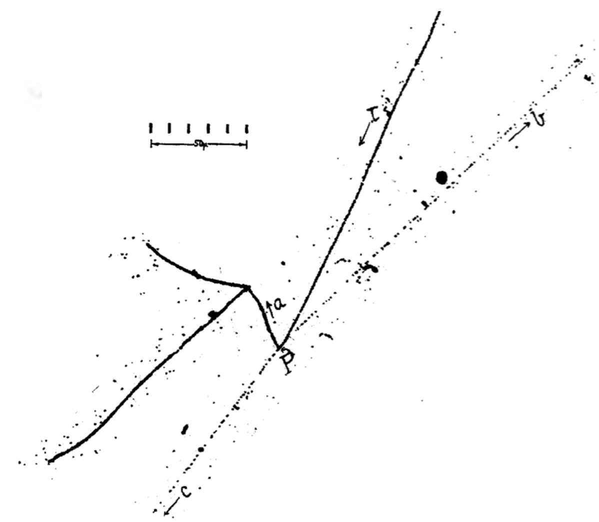
C. R. T. Wilson introduced the cloud chamber in 1912.



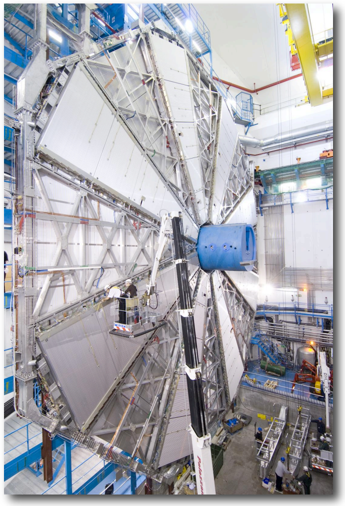
Donald Glaser invented the bubble chamber in 1952. His first detector was only a few inches in diameter. The last one used was 15 ft by 10 ft.

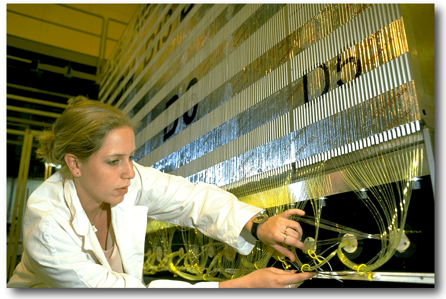


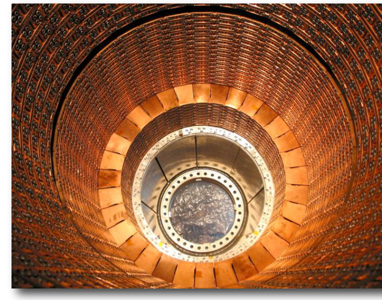


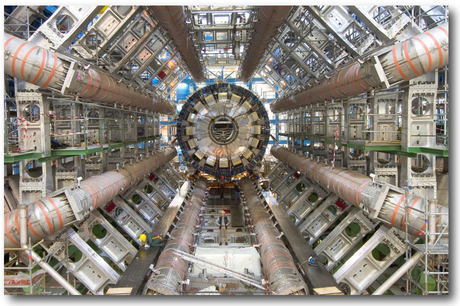


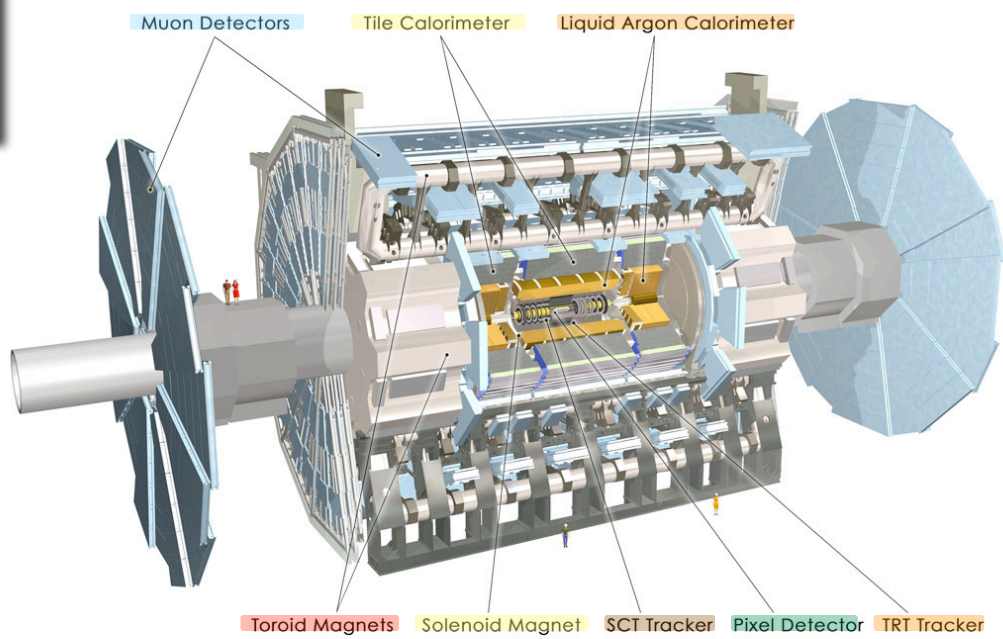
Photographic emulsions have been used since the time of Becquerel in 1896. This is an image of a cosmic ray pion event from 1947.





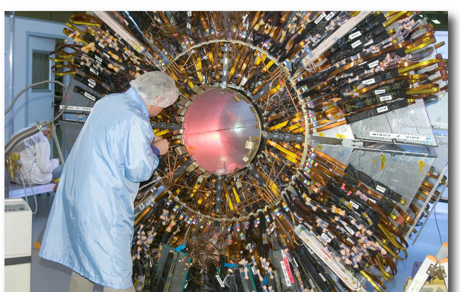


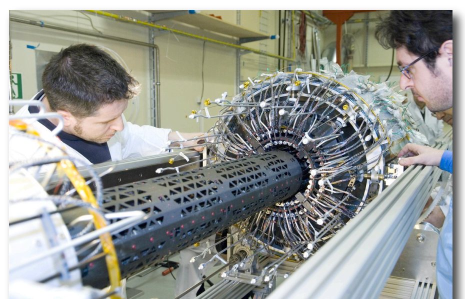


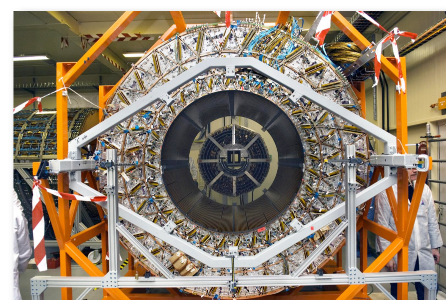


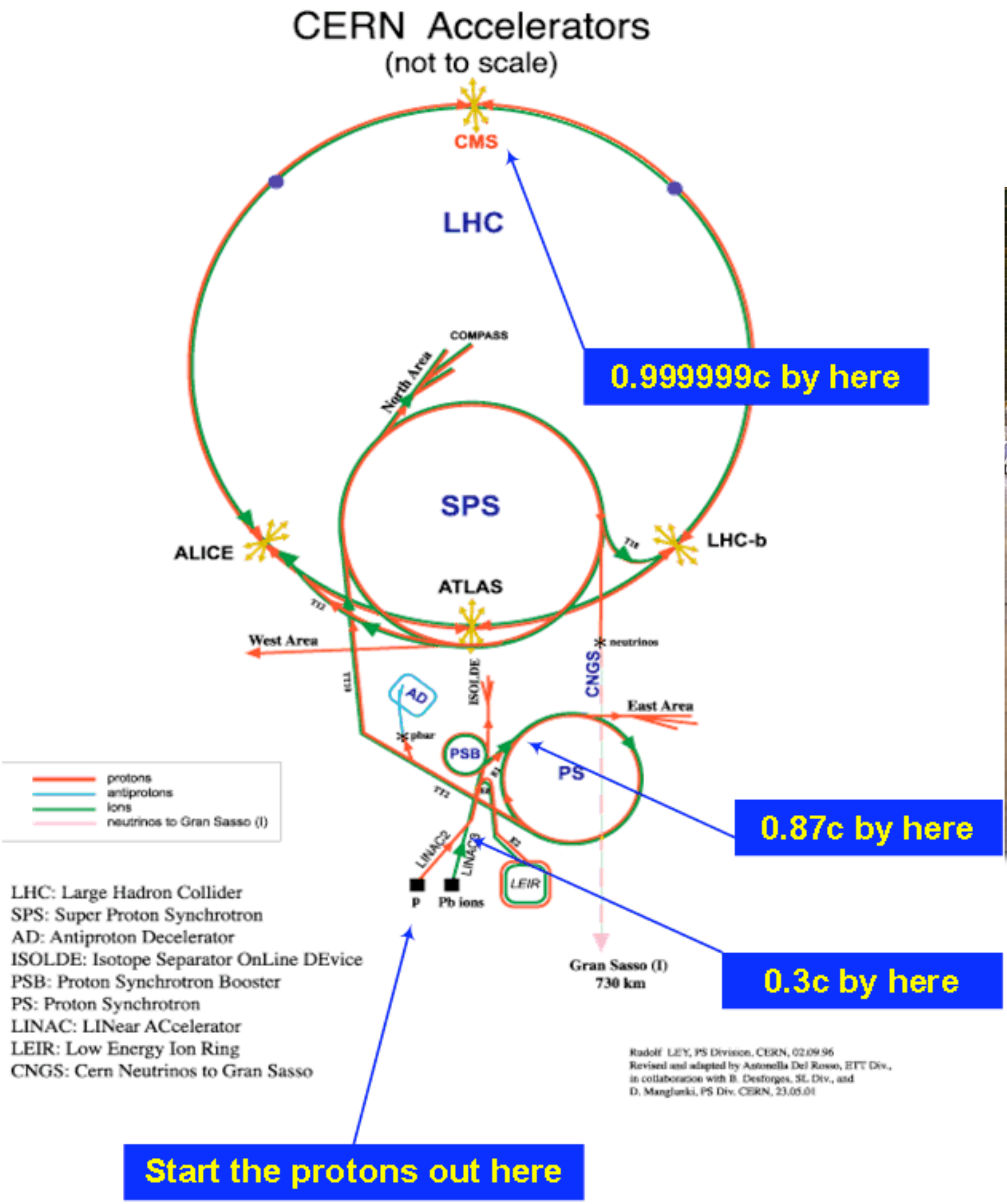
ATLAS

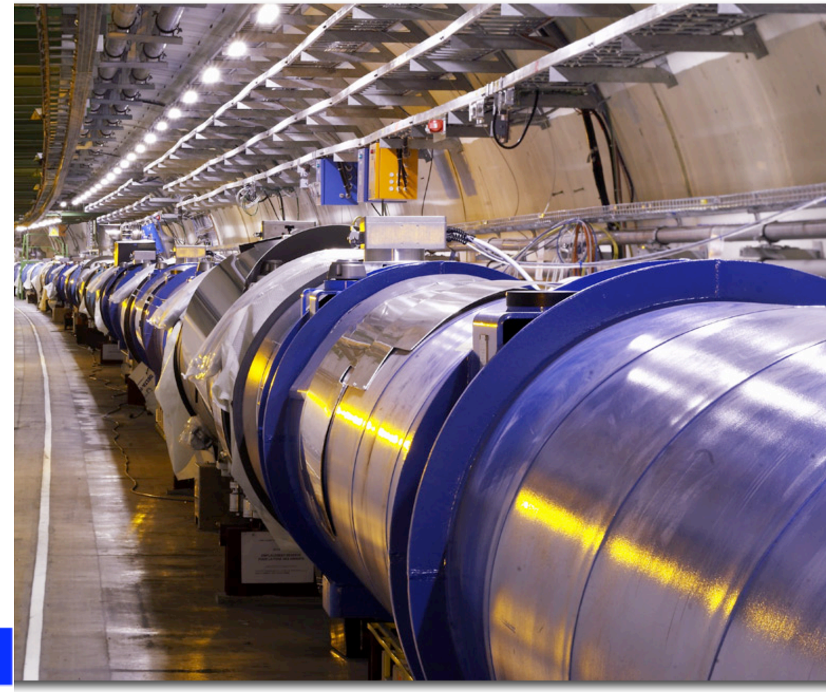
Detailed Description





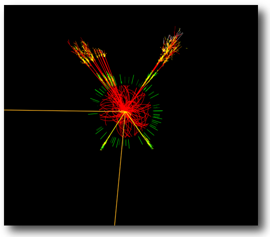


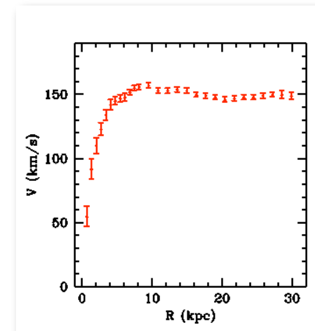




LHC Simulation

Why Do We Need the LHC?
The Standard Model and Beyond.





What is Mass?

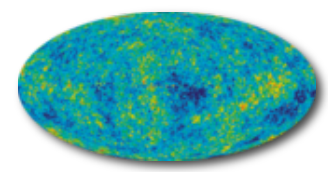
The Higg's boson

What are dark matter and dark energy?

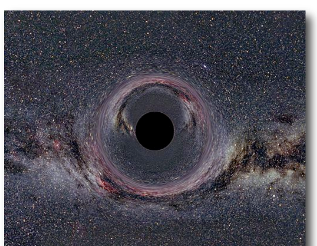
Supersymmetric particles

Why is there more matter then antimatter

Symmetry breaking



What was it like just after the Big Bang?



Quark-gluon plasma

What about Gravity?

Extra dimensions, string theory

Problems to Ponder

A quick review of some important ideas from earlier in the year.

1. In the Cockcroft-Walton experiment a proton was accelerated into a ^{7}Li atom to produce two ^{4}He atoms. What is the minimum amount of kinetic energy the proton must have to make this happen?

2. We wish to build a cyclotron and need to know the frequency of the a.c. signal we should supply. Use what you know about the force on a charge in a B-field, centripetal force, and the relationship between angular velocity and frequency to show that:

$$f = \frac{qB}{2\pi m}$$

Use your work from above and what you know about kinetic energy to derive:

$$KE = \frac{q^2 B^2 r^2}{2m}$$

If you wish to build a 30 cm diameter cyclotron to accelerate protons to 2 MeV what must be the strength of the B-field? What must be the frequency of the applied accelerating voltage?

3. How does 1 TeV compare to the amount of energy needed to raise the temperature of 1 g of water 1 °C? Give your answer in terms of a ratio.

4. If a proton has a rest energy of 938 MeV and an electron's is 0.511 MeV find the relativistic γ for a proton and electron with 20 MeV of kinetic energy.

   What adjustments would have to be made if you were going to make a cyclotron that operated at energies above 20 MeV. Which particle needs more adjustment?

5. An electron traveling at 1×10^7 m/s enters a detector. What must be the B-field in the detector to bend the path of the electron in a 2 cm radius curve? If the electron is traveling through a bubble chamber what would you expect to happen to the path as the electron continued?

6. What is the change in kinetic energy for a proton accelerated from 0.99c to 0.9999c?

7. What is the total energy of a proton accelerated through a potential difference of 200 MV?

8. Using Newton's Law of Universal Gravitation and the equation for centripetal force to derive an equation for the velocity of an orbiting body in terms of the mass inside the orbit and the radius of the orbit. What does this have to do with the discovery of dark matter?

9. If the 2.7 K cosmic background radiation is an example of blackbody radiation what is the peak wavelength? What region of the EM spectrum is this?