Today

- Announcements:
  - HW#10 is due April 9 at 8:00 am.
  - The Spring Break Story Winner is …
- What is matter? What is mass?

Department of Physics and Astronomy

MICHIGAN STATE UNIVERSITY

Standard Model

- The fundamental theory of nature's constituents and their interaction is called the Standard Model
- The theory includes:
  - Strong interactions due to the color charges of quarks and gluons.
  - A combined theory of weak (weak charge) and electromagnetic interaction (charge), known as electroweak theory.
- The theory does not include the effects of gravity. Gravity is tiny compared to the other forces and can be neglected in describing atoms.

What is matter

• Matter is the collection of objects made of baryons and leptons.

• Objects have quantum numbers that describe their nature

Electron:
Charge, lepton number, baryon number, etc.

Electrons also have mass. What is mass?

Four Fundamental Forces

Force	Particles	Strength	Range	Mediator
Gravity	All	6E-39	Infinite	Graviton
Weak	All	1E-5	1E-17 m	$W^{\pm}$, Z^0
Electro-magnetic	Charged Particles	1/137	Infinite	Photon
Strong	Hadrons (protons and neutrons)	1	1E-15 m	Gluon

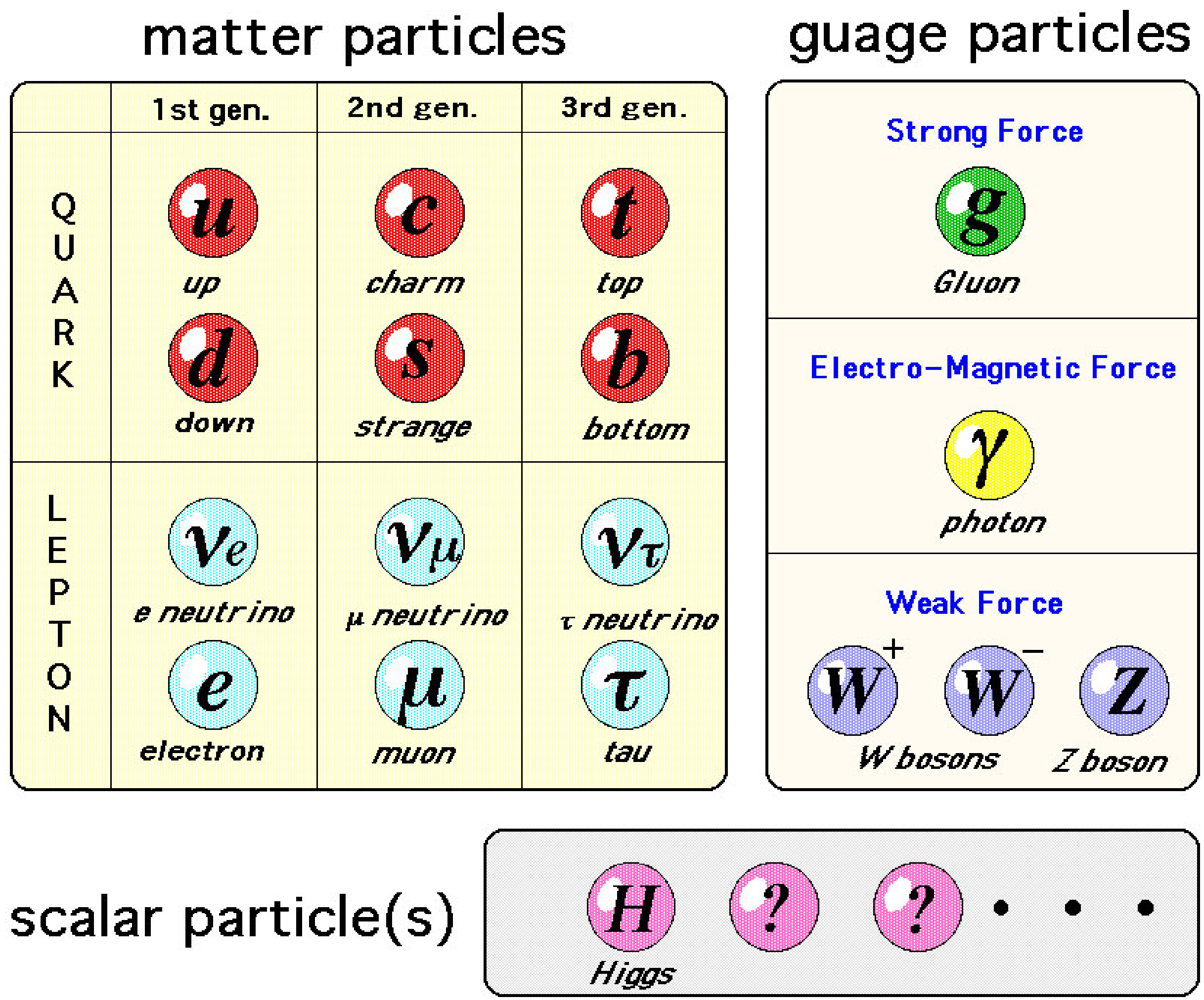
Standard Model Particles

Charge

+2/3 →

-1/3 →

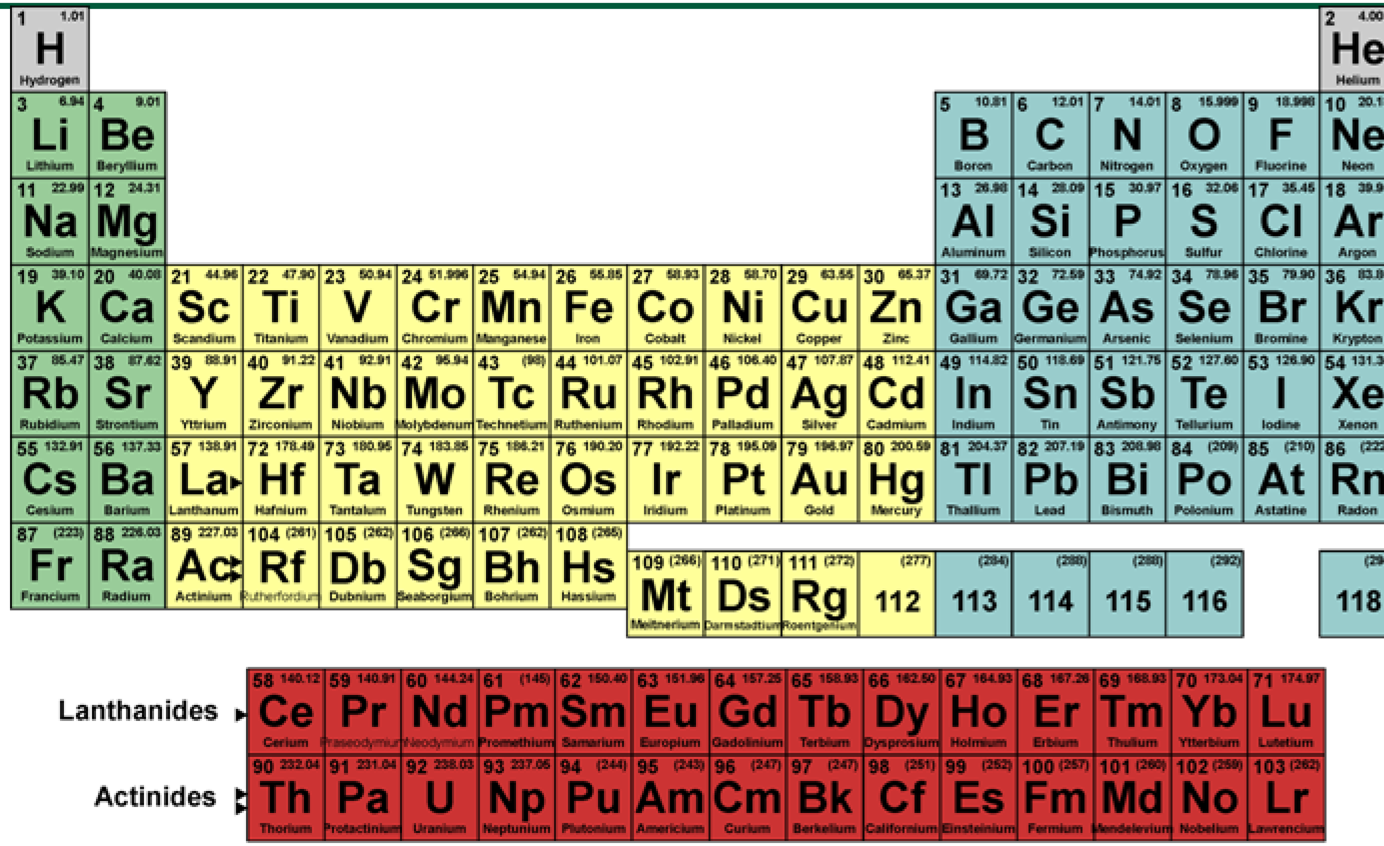
Anti-particles have the opposite charge.



Quantum Numbers (1)

The row gives the principle quantum number.

n = 1
n = 2
n = 3
n = 4
n = 5
n = 6
n = 7



- The structure of the periodic table arises from the underlying quantum numbers.

Quantum Numbers (2)

- Names like top, charm, strange, color, etc. do not mean the same things they do in everyday life. They are just identifiers.
- These names represent a set of quantum numbers that explain the number and types of particles that we observe.
- Chemistry, nuclear science, and particle physics all use different sets of quantum numbers, although they are all based on related ideas.

Rules for particle interactions

Example: $e^- + \overline{e}^+ \rightarrow u + \overline{u}$ ALLOWED

$n \rightarrow p^+ + e^-$ NOTALLOWED (lepton number)

$n \rightarrow p^+ + e^- + \overline{\nu}$ ALLOWED

Conserved: Electric charge, lepton number (e = +1, $\overline{e}$ = -1), color charge, baryon number (could also count quarks: quarks +1/3, antiquarks -1/3), energy, momentum, and angular momentum.

$n + p^+ \rightarrow \pi^+ + \pi^+ + \pi^-$ $\pi^- \rightarrow e^- + \overline{\nu}$

The standard model explains how particles interact and transform.

What is mass

- Most mass in matter comes from energy: $E=mc^2$
- The mass of the quarks that make up a proton is only a few percent of the mass. Most of the mass is in gluons (the carriers of the force).

What is mass? The interaction with a field

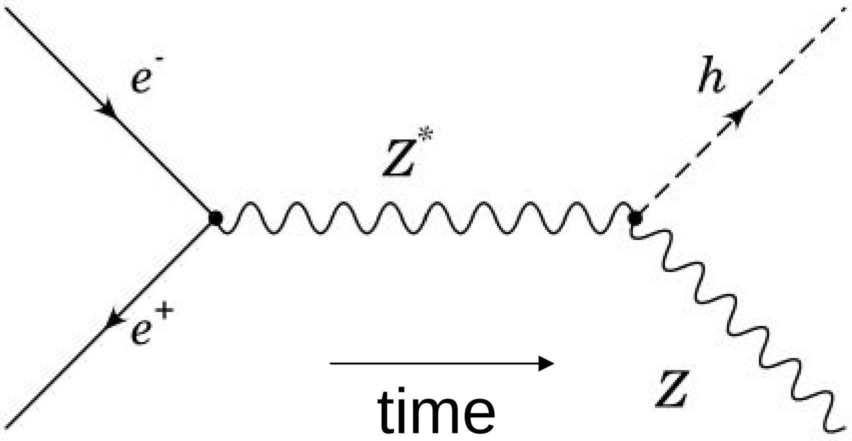
Space is filled with a (scalar) particle called the Higgs boson. The more a particle interacts with the Higgs field, the greater its mass is.

CERN

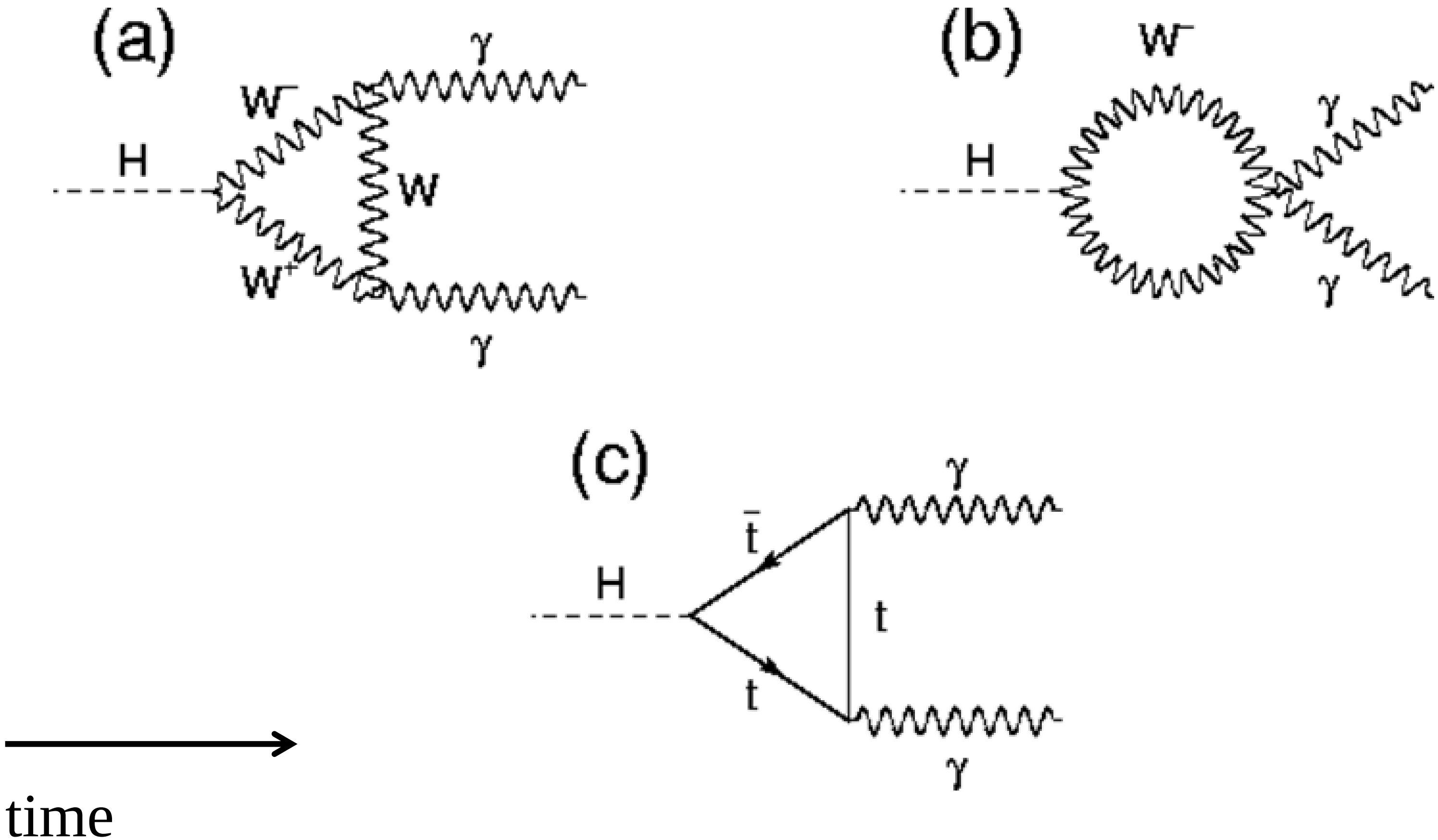
Higgs Particle

- The Higgs is the most famous undiscovered particle. A new collider called the Large Hadron Collider may find it.
- The world community is spending 10 billion $ to find this.

Here is how to produce one:



How the Higgs will decay and be detected



Problems with the Standard Model

- Why so many particles?
- Are there more particles we don’t know about yet?
- What is charge? Why does it come in fixed units? Same for lepton number and baryon number…
- Why is the standard model so complicated?
- Why 4 forces?
- How is gravity related to the other forces?
- In general the standard model does not answer the WHY question. Everyone agrees it is not a complete theory.

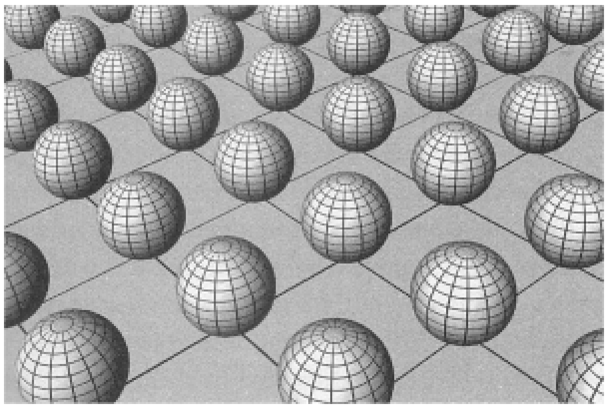
What comes next?

- There are attempts to extend the standard model to include gravity; these are called supersymmetric theories.
- These say that all fermions (which make up matter) and bosons (that transmit forces) have a corresponding partner boson (to go with our standard fermions) and fermion (to go with our standard bosons).
- Supersymmetric theories predict a whole set of new particles called s-particles, e.g. selectron, sneutrino, photino, Wino, and so on
- A new accelerator (Large Hadron Collider at CERN [Europe]) may be able to produce some of these particles in the next two years.

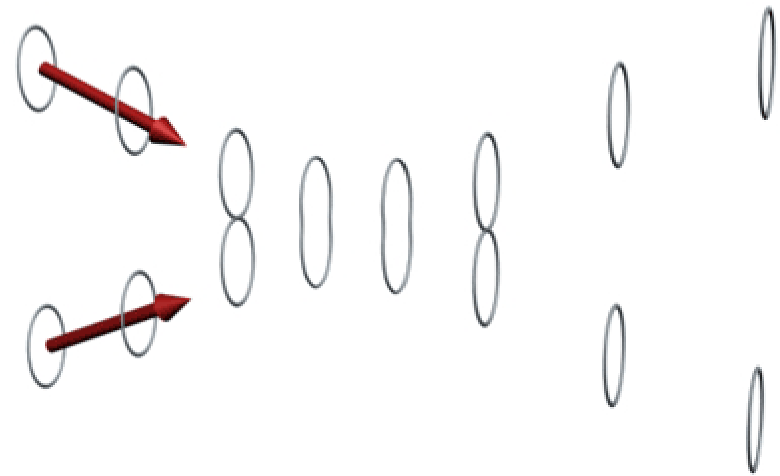
Superstring Theory

- One of the promising new theories is string theory. It says that the fundamental building blocks of nature are tiny (10^{-35} m) strings.
- The particles we observe in nature are difference ways for strings to vibrate.
- String theory is not accepted because so far it has not devised an experiment that could test it.
- String theories require at least 10 dimensions.
- Gravity is weak because the graviton exists mostly in another dimension, but there is a slight overlap with us

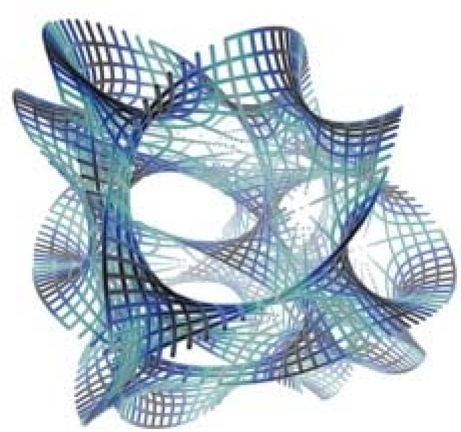
String Theory Pictures



Extra Dimensions



What one of the dimensions might look like (Calabi-Yau space)



<u>Interaction of Strings:</u>
The finite size (10^{-35} m) overcomes many of the problems with the interaction of point particles.

More energy – smaller wavelength

- It is a quirk of nature that, the smaller a particle is, the greater is the energy need to see it.
- To study a particle you have to have sufficient concentrated energy to create it.
- This has fueled the construction of particle accelerators, then colliders, which have continuously increased in size.

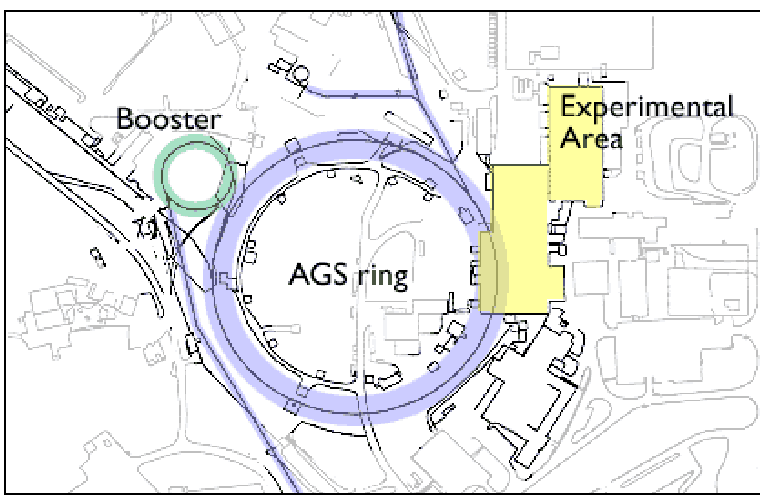
Scale of Energy (per Particle)

- Chemistry Experiment ~0.1-5 eV
- First Cyclotron (USA) 8E4 eV
- National Superconducting Cyclotron Laboratory (USA) 1.4E8 eV
- Super Proton Synchrotron (Europe) 4E11 eV
- Relativistic Heavy Ion Collider (USA) 1E11 eV
- Tevatron (USA) 1E12 eV
- Large Hadron Collider (Europe) 7E12 eV
- [Superconducting Super Collider (USA)] 2E13 eV

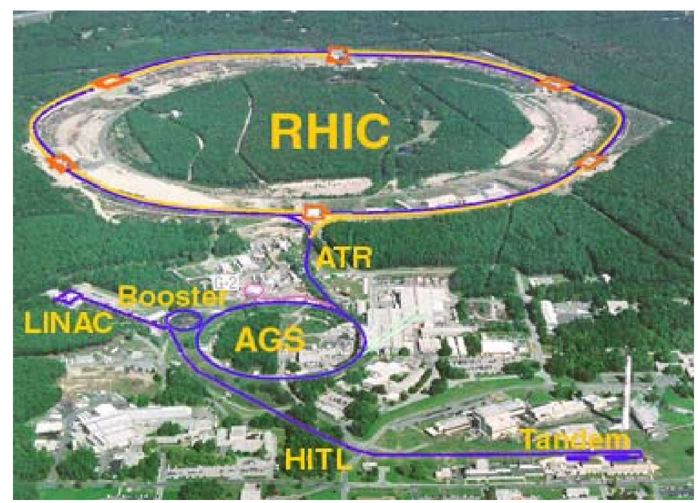
Relativistic Heavy-Ion Collider

Long Island (New York)

RHIC from space!

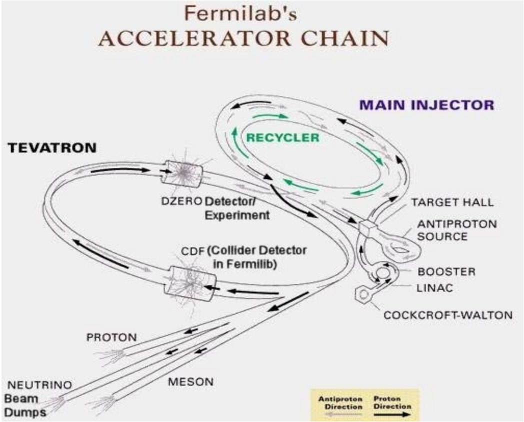


The Alternating Gradient Synchrotron complex



Goal: Create a plasma of quarks and gluons

Tevatron – Fermilab (Illinois)



Goal: Produce the top quark

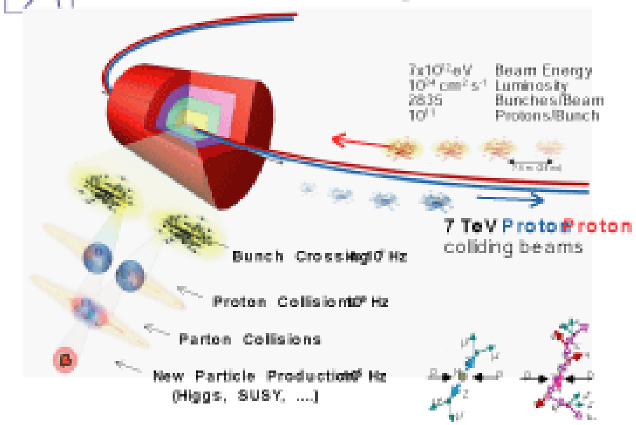
Tevatron - Fermi National Laboratory (Illinois)

Goal: Produce the top quark

Drift Tube Linac

Large Hadron Collider – CERN (Europe)

Collisions at the Large Hadron Collider



Introduction to CERN

David Barney, CERN

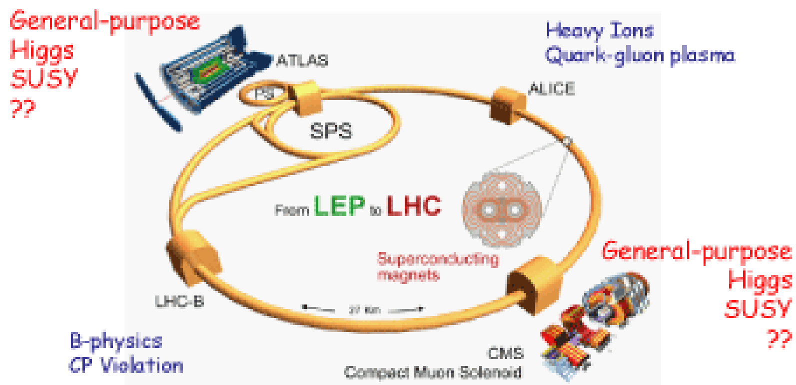
CERN in numbers

CERN openlab for DataGrid applications

- Financed by 20 European countries
  - Special contributions also from other countries:
    - USA, Canada, China, Japan, Russia, etc.
- 1000 CHF (650 M€) budget to cover operation + new accelerators
- 2,200 staff (and diminishing)
- 6,000 users (researchers) from all over the world
  - broad visitor and fellowship program

May 2004 Sverre Jarp

LHC Detectors



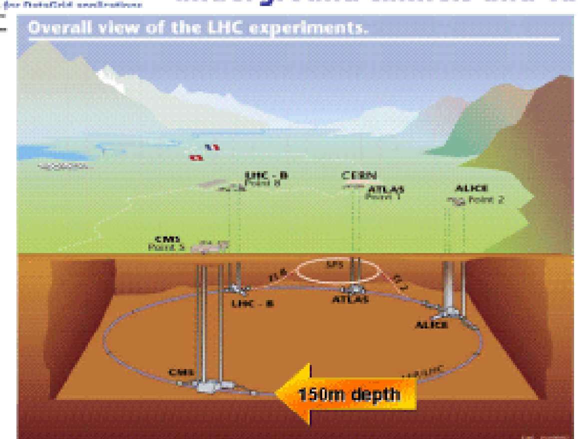
Introduction to CERN

David Barney, CERN

Lec

Accelerators and detectors in underground tunnels and caverns

CERN openlab for DataGrid applications



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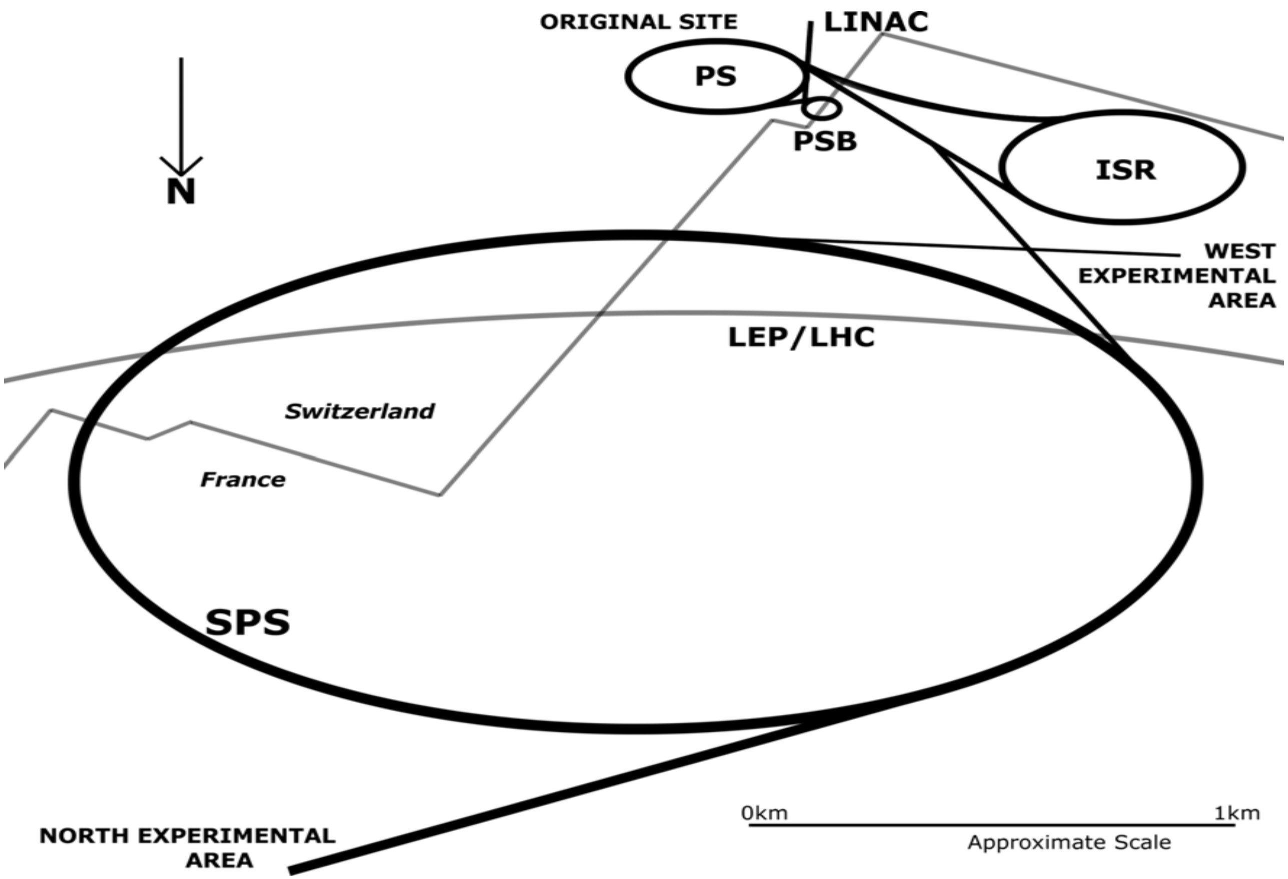
CERN Beam Gymnastics (2)



Cost

- It is worth noting that these experiments are very expensive. The cost of a single particle:
  - Burning one carbon atom tiny, almost free
  - Gold small, almost free
  - Radioactive isotope (^{64}Fe) ~$0.001
  - Superheavy nucleus (^{272}Rg) ~$200,000
  - Higgs particle $0.1-1 billion
- How much are you/we willing to pay for a greater understanding of the universe?