Supercomputing in High Energy Physics

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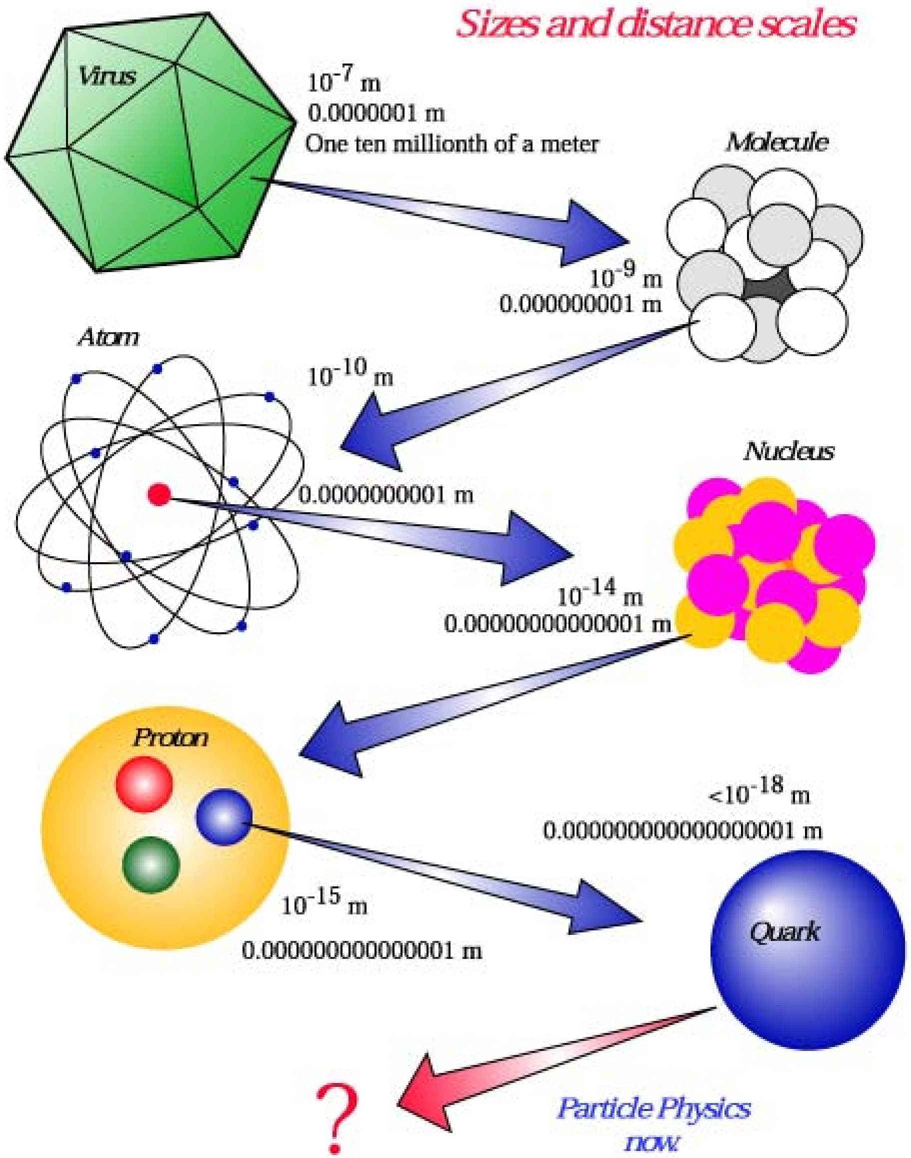
Outline:

- Why do Particle Physics?
- How are Particles being Detected?
- Who is doing it?
- Why do we Need so Much Computing Power?
- What Have we Found - What Will we Find?
- Bonus: Spinoffs

What's the Point?



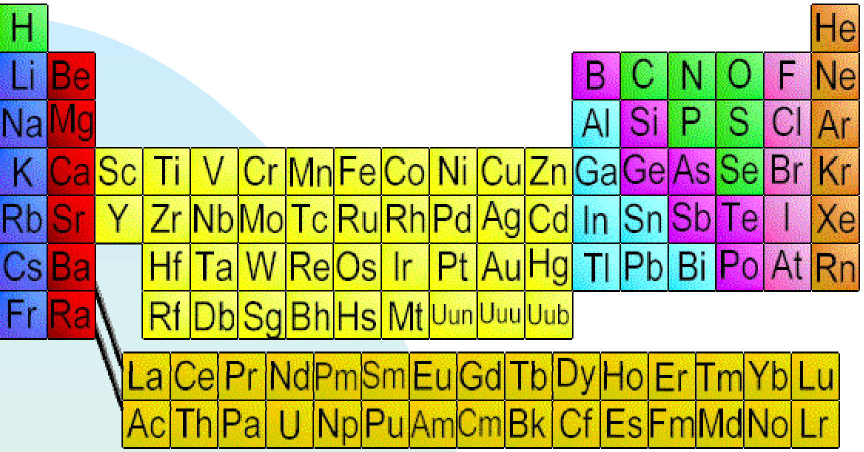
High Energy Particle Physics is a study of the smallest pieces of matter.

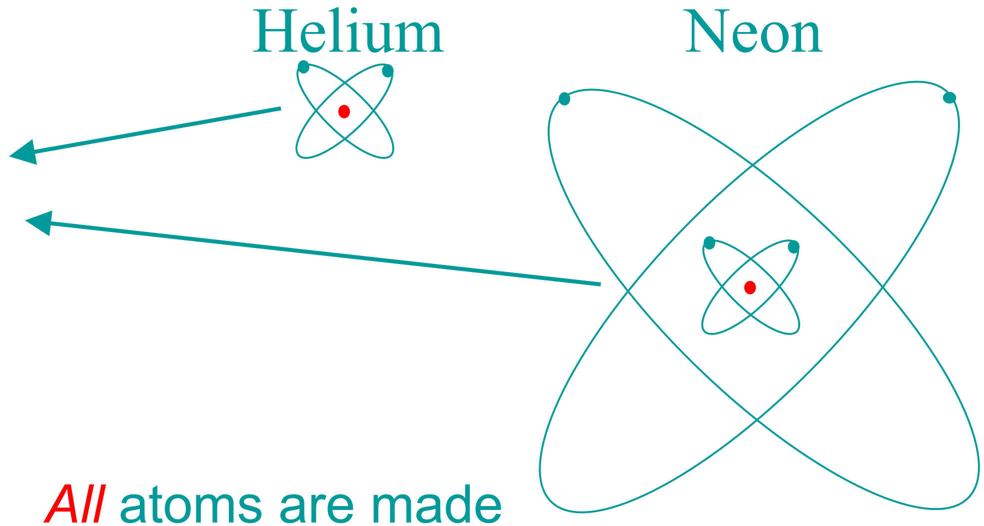
It investigates (among other things) the nature of the universe immediately after the Big Bang.

It also explores physics at temperatures not common for the past 15 billion years (or so).

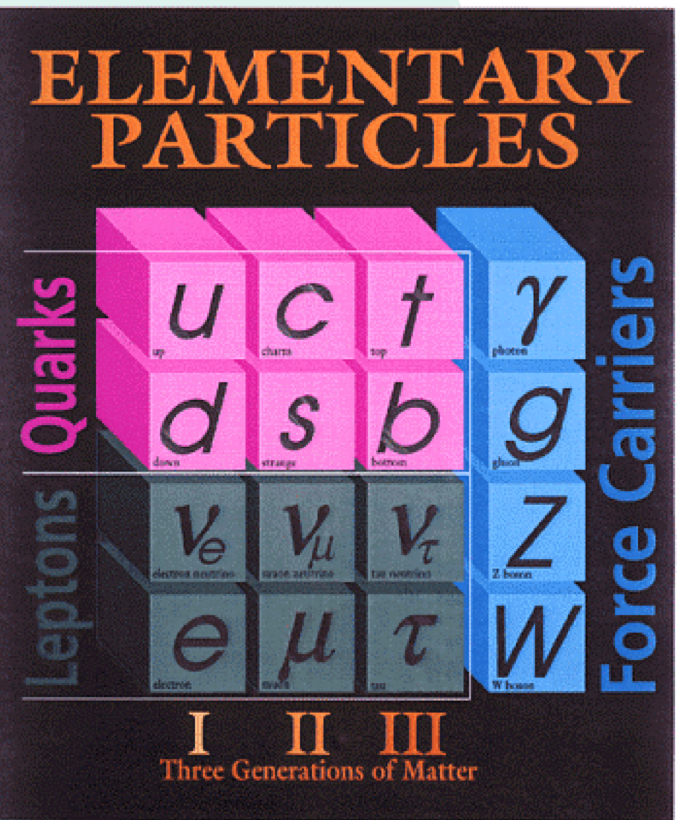
It's a lot of fun.

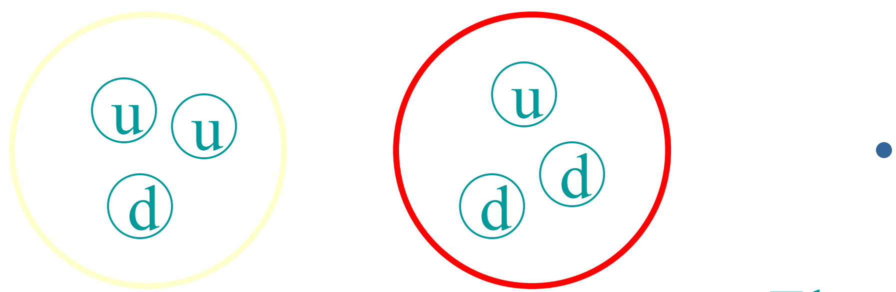
Periodic Table





All atoms are made of protons, neutrons and electrons





Proton Neutron Electron

Gluons hold quarks together
Photons hold atoms together

Particle Physics

"Everything in the universe seems to be made of simple, small objects which like to stick together"

- **Modern realization of this: The Standard Model**
  - **A quantum field theory in which point-like, spin-1/2 fermions interact through the exchange of spin-1 vector bosons**
  - **Electroweak interaction**
    - **photons, W and Z bosons**
  - **Strong interaction (QCD)**
    - **gluons**

- Three generations of leptons (electron, muon, tau, 3 neutrinos)
    - electroweak interaction only
- Three generations of quarks (u,d,s,c,t,b)
    - electroweak and strong interactions

- Standard Model predictions have been verified at the 10^{-3} level up to energies of a few hundred GeV
- Point-like nature of quarks and leptons tested up to TeV scales

Isn’t this good enough?

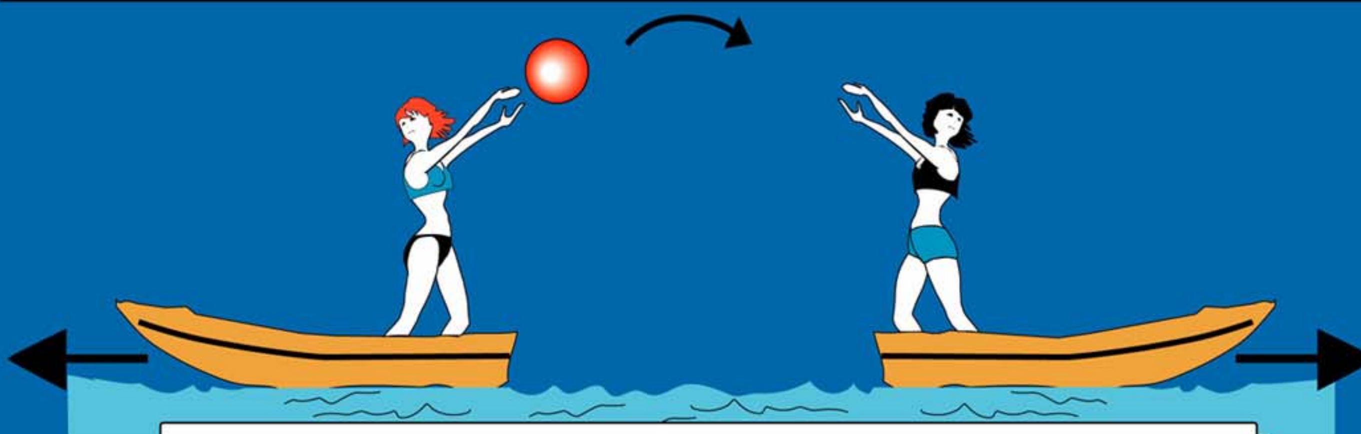
- No: at least one extra field is needed — the Higgs field
  - without it, the WW scattering amplitude becomes infinite at energies of ~ 1 TeV
    - real experiments in the next decade would see this!
  - with it, “electroweak symmetry breaking” explained
  - the Higgs field is a property of spacetime, but at least one real particle will result
- Even with the Higgs, the Standard Model requires unreasonable fine tuning of parameters to avoid ~ infinite Higgs masses from quantum corrections

- leads to strong belief that it is merely an effective (low energy) theory valid up to some scale, where additional physics appears
  - mass scale of Higgs -> that scale is close (few hundred GeV)
  - also, the Higgs boson is unlike any other particle in the SM (no other elementary scalars)
  - the patterns of fermion masses hint at deeper structures
- most popular theoretical option: supersymmetry

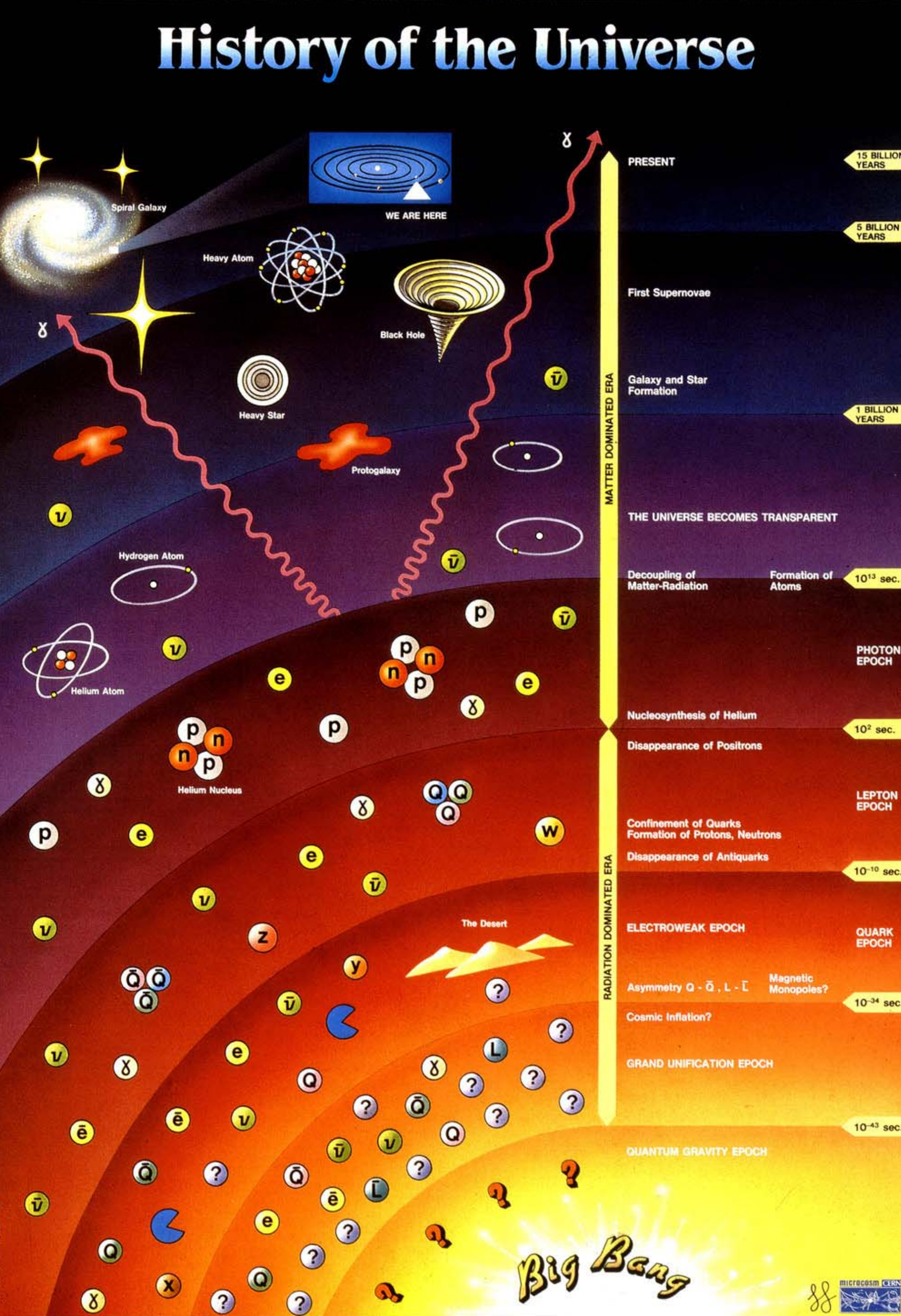
- Current accelerators can access these energy scales
  - make discoveries!

The forces in Nature

TYPE	INTENSITY OF FORCES (DECREASING ORDER)	BINDING PARTICLE (FIELD QUANTUM)	OCCURS IN :
STRONG NUCLEAR FORCE	~ 1	GLUONS (NO MASS)	ATOMIC NUCLEUS
ELECTRO -MAGNETIC FORCE	$\sim 10^{-3}$	PHOTONS (NO MASS)	ATOMIC SHELL ELECTROTECHNIQUE
WEAK NUCLEAR FORCE	$\sim 10^{-5}$	BOSONS Z^0 , W^+ , W^- (HEAVY)	RADIOACTIVE BETA DESINTEGRATION
GRAVITATION	$\sim 10^{-38}$	GRAVITONS (?)	HEAVENLY BODIES



THE EXCHANGE OF PARTICLES IS RESPONSIBLE FOR THE FORCE



Now (15 billion years)

Stars form (1 billion years)

Atoms form (300,000 years)

Nuclei form (180 seconds)

Protons and neutrons form (10^{-10} seconds)

Quarks differentiate (10^{-34} seconds?)

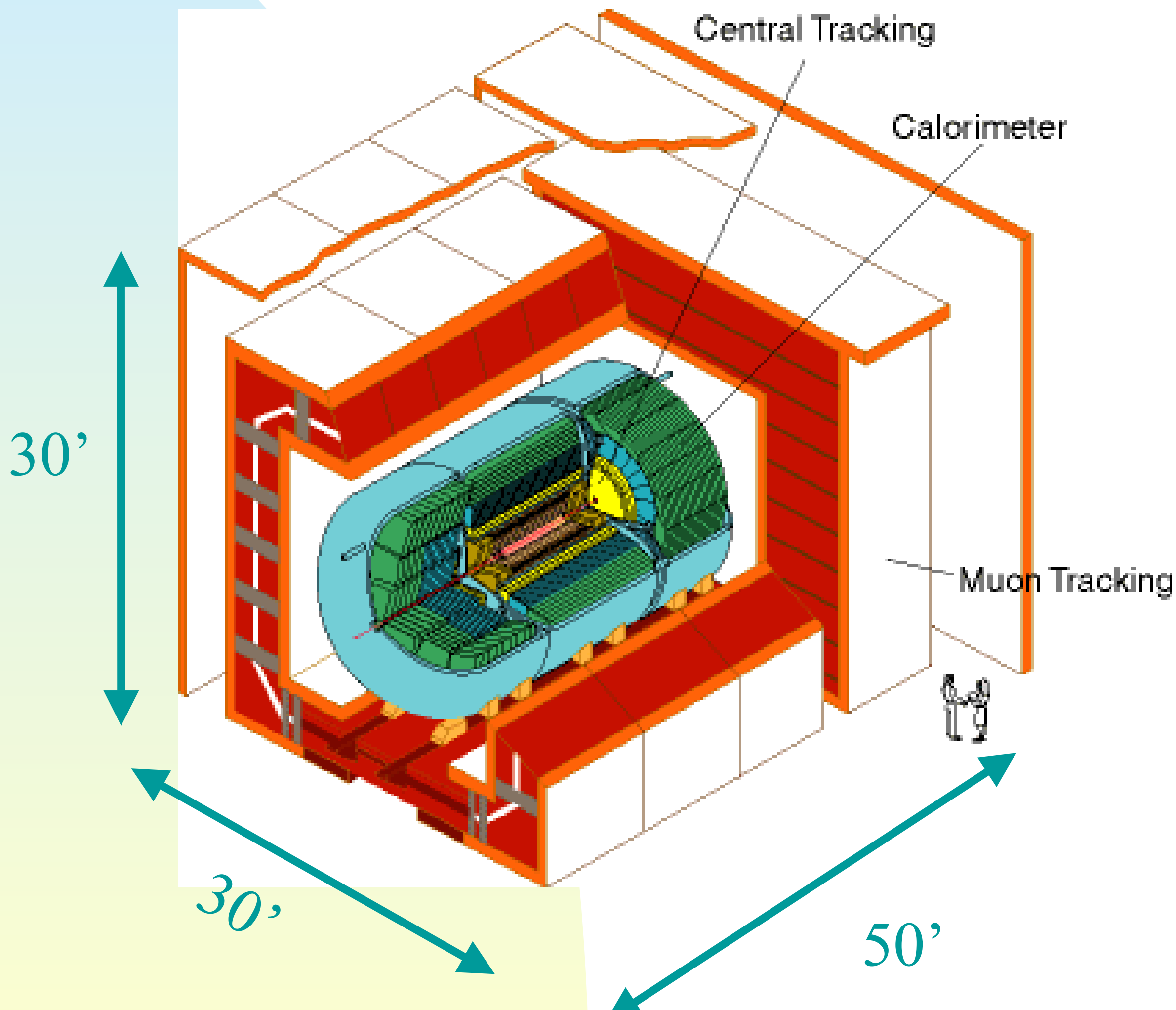
??? (Before that)

Fermilab
4×10^{-12} seconds
LHC
10^{-13} Seconds

How Do You Detect Collisions?

- Use one of two large multi-purpose particle detectors at Fermilab (DØ and CDF).
- They're designed to record collisions of protons colliding with antiprotons at nearly the speed of light.
- They're basically cameras.
- They let us look back in time.

DØ Detector: Run II



- Weighs 5000 tons
- Can inspect 3,000,000 collisions/second
- Will record 50 collisions/second
- Records approximately 10,000,000 bytes/second
- Will record 10^{15} (1,000,000,000,000,000) bytes in the next run (1 PetaByte).

U. of Arizona
U. of California, Berkeley
U. of California, Davis
U. of California, Irvine
U. of California, Riverside
Cal State U., Fresno
Lawrence Berkeley Nat. Lab.
Florida State U.
Fermilab
U. of Illinois, Chicago
Northern Illinois U.
Northwestern U.
Indiana U.
U. of Notre Dame
Iowa State U.
U. of Kansas
Kansas State U.
Louisiana Tech U.
U. of Maryland
Boston U.
Northeastern U.
U. of Michigan
Michigan State U.
U. of Nebraska
Columbia U.
U. of Rochester
SUNY, Stony Brook
Brookhaven Nat. Lab.
Langston U.
U. of Oklahoma
Brown U.
U. of Texas, Arlington
Texas A&M U.
Rice U.
U. of Washington

U. de Buenos Aires

LAFEX, CBPF, Rio de Janeiro
State U. do Rio de Janeiro
State U. Paulista, S×o Paulo

IHEP, Beijing

U. de los Andes, Bogot‡

Charles U., Prague
Czech Tech. U., Prague
Academy of Sciences, Prague

U. San Francisco de Quito

ISN, IN2P3, Grenoble
CPPM, IN2P3, Marseille
LAL, IN2P3, Orsay
LPNHE, IN2P3, Paris
DAPNIA/SPP, CEA, Saclay
IPN, IN2P3, Villeurbanne

IOP, U. Mainz
Ludwig-Maximilians U, Munich

Panjab U., Chandigarh
Delhi U., Delhi
Tata Institute, Mumbai

KDL, Korea U., Seoul

CINVESTAV, Mexico City

FOM-NIKHEF, Amsterdam
U. of Amsterdam/NIKHEF
U. of Nijmegen/NIKHEF

INP, Krak–w

JINR, Dubna
ITEP, Moscow
Moscow State U.
IHEP, Protvino
PNPI, St Petersburg

Lund U.
RIT, Stockholm
Stockholm U.
Uppsala U.

Lancaster U.
Imperial College, London
U. of Manchester

Jim Heinson UC Riverside

550 scientists involved | 400 authors | 63 institutions | 17 countries

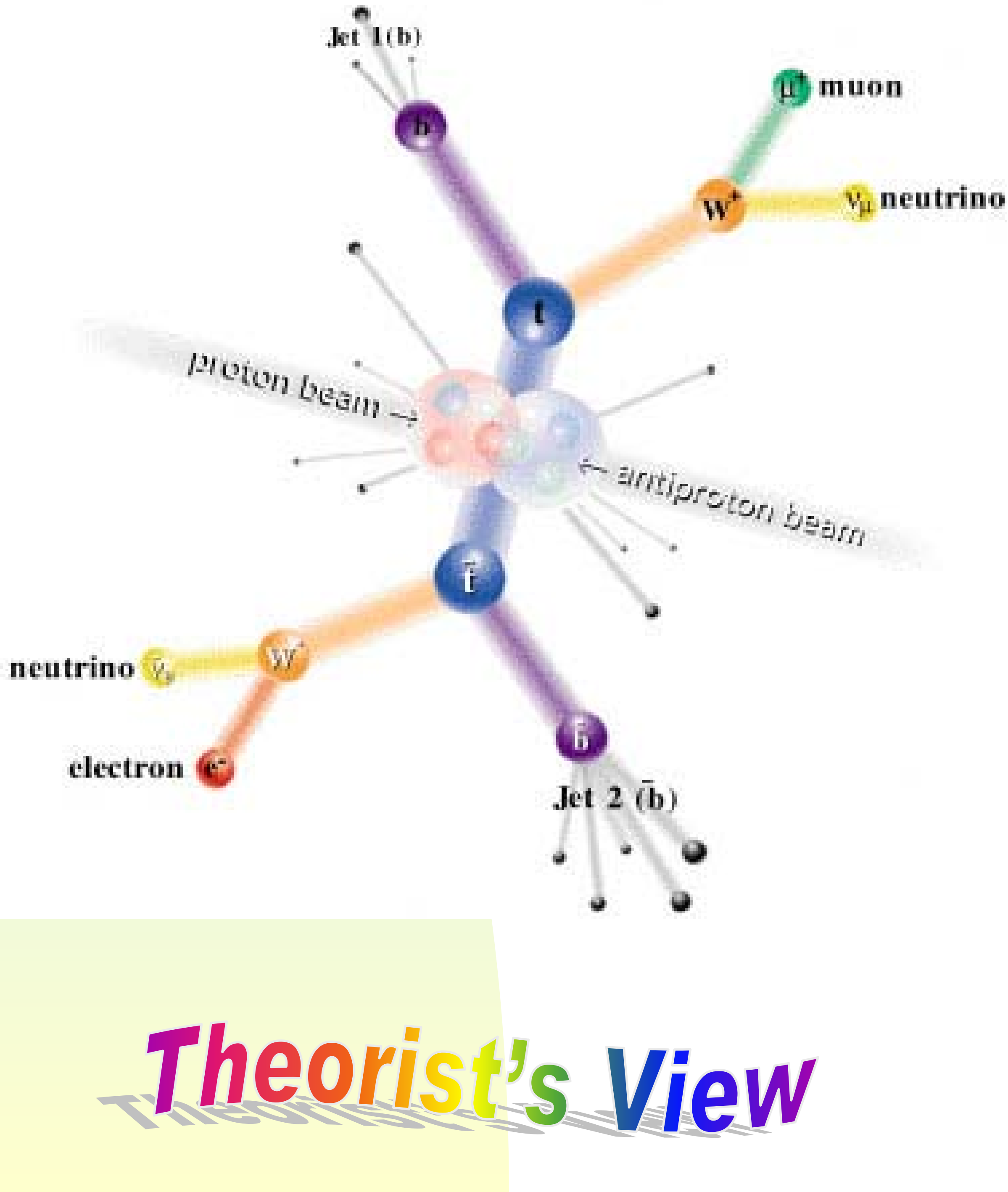
Collaborations and Partnerships

- Not only Large International Collaborations, but also Partnerships between Universities in Oklahoma
- University of Oklahoma and Langston University Collaborating on both ATLAS and D0 Experiments
- University of Oklahoma and Oklahoma State University Collaborating in Theoretical Particle Physics

Computing Needs

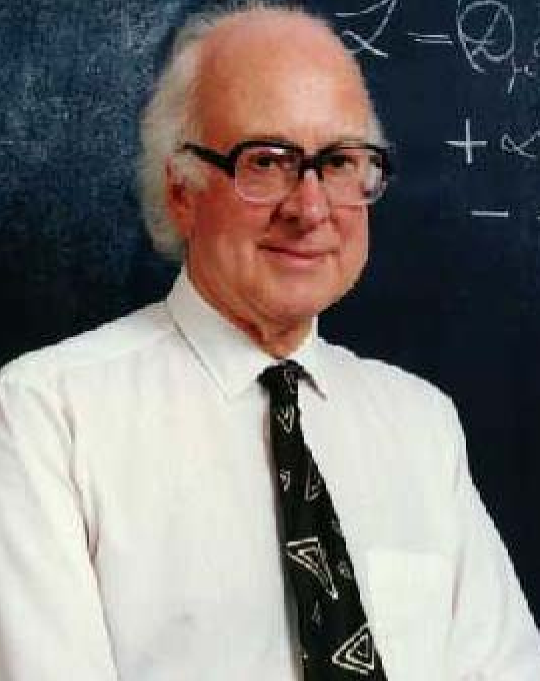
- CPU, Network, and Storage Needs
- Large Experiments Produce PetaBytes (1000 TeraBytes, or 1000 Trillion Bytes) of Data per Year
- These Data need to be Transferred to Worldwide Collaborators, Therefore necessitating GigaBit Network Capabilities

- Large Scale Monte Carlo Simulations necessary to Understand the Physics behind the Collision Events
- Need to simulate Billions of Events for that;
- each Event takes several Hundred Seconds of CPU Time, even with today’s Fastest Processors!



Top Facts

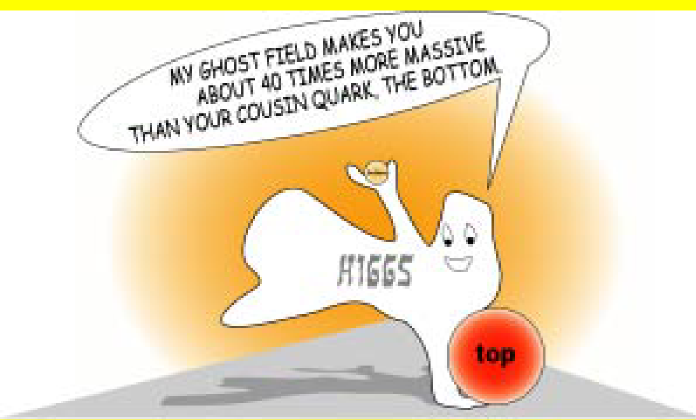
- Discovery announced March 1995
- Produced in pairs
- Decays *very* rapidly ~10^{-24} seconds
- You can't see top quarks!!!
- Six objects after collision



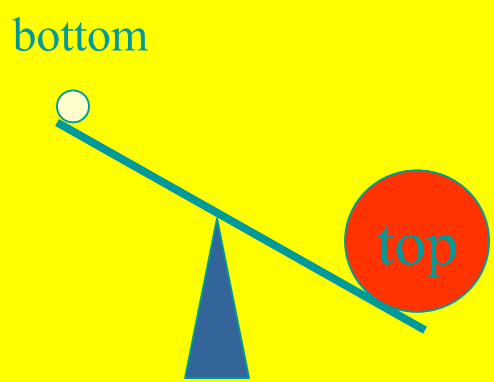
In 1964, Peter Higgs postulated a physics mechanism which gives all particles their mass.

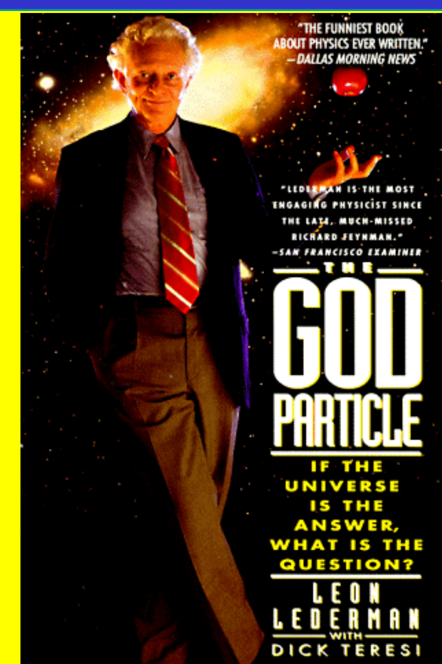
This mechanism is a field which permeates the universe.

If this postulate is correct, then one of the signatures is a particle (called the *Higgs Particle*). Fermilab's Leon Lederman co-authored a book on the subject called *The God Particle*.



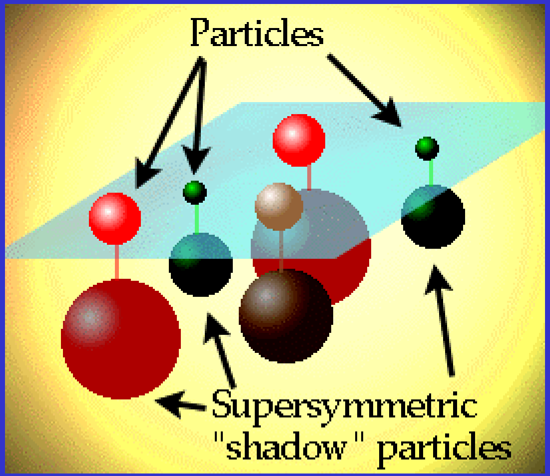
Undiscovered!





Run II: What are we going to find?

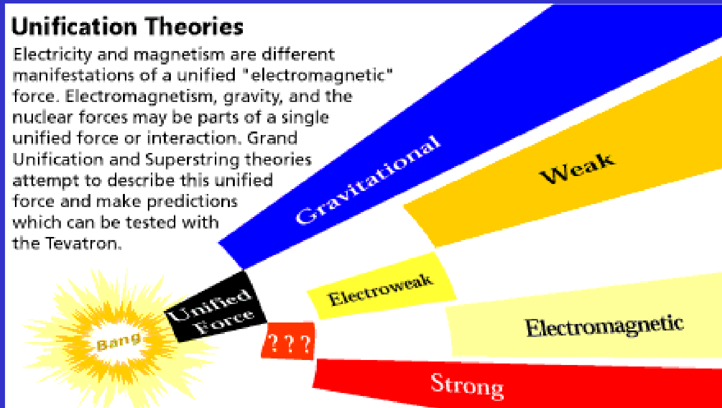
I don't know!



Improve top mass and measure decay modes.

Do Run I more accurately

Supersymmetry, Higgs, Technicolor, particles smaller than quarks, something unexpected?



Bonus: Spinoffs

- Basic Science cannot Guarantee an Immediate Payoff, but there will always be Useful Spinoffs that nobody envisioned beforehand
- In Particle Physics:
- Better Particle Detectors used for Medical Imaging
- Better Magnets for more Powerful Tomography Equipment

- More Powerful Computers and Faster Networks because we Need it to Analyze Data
- The World Wide Web was invented by Particle Physicists to Share Scientific Data among Colleagues
- Now a Billion Dollar Industry