Life as a High Energy Physicist

made possible by E.O. Lawrence

- Who am I?
- What is HEP?
- Accelerators and detectors
- Interactions and what we measure
- What keeps us coming back to work
- What we actually do at work

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Iowa State University

Who am I?

- Lived in Sioux Falls, SD from 1975 until college
- College at USD, majoring in
  - Business Administration -- Management
  - Physics
- Graduate School at University of Nebraska -- Lincoln

  Solid State Physics, then High Energy Physics - Ph.D. 1998
- Research Associate at Iowa State University
  - Living “in residence” at Fermilab, member of the D0 Collaboration

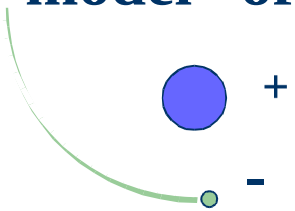
What is High Energy Physics?

	Typical Size	Very Small Size
Typical Energies	Classical Physics	Quantum Physics
Very High Energies	Relativistic Physics	High Energy (Particle) Physics

The events that occurred in the first "moments" of the universe fall in the realm of HEP.

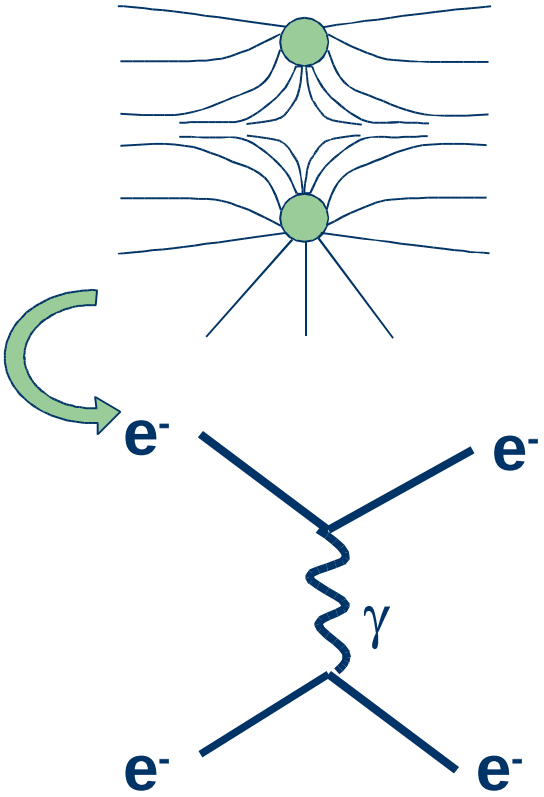
By recreating the conditions of those moments (but with much less material!) we strive to understand nature at its most fundamental level.

Ye olde "planetary model" of atoms



Particle Types

- Protons constituents
  - Quarks
  - Gluons
- Electrons
- Photons
- Neutrinos
- Exotic particles



How does one study these particles?! It is only possible with high energies…started with cosmic rays

1 TeV = 1 trillion electron-Volts
…convenient units for us

The Accelerator

Near Chicago, IL

TeVatron has
1km radius

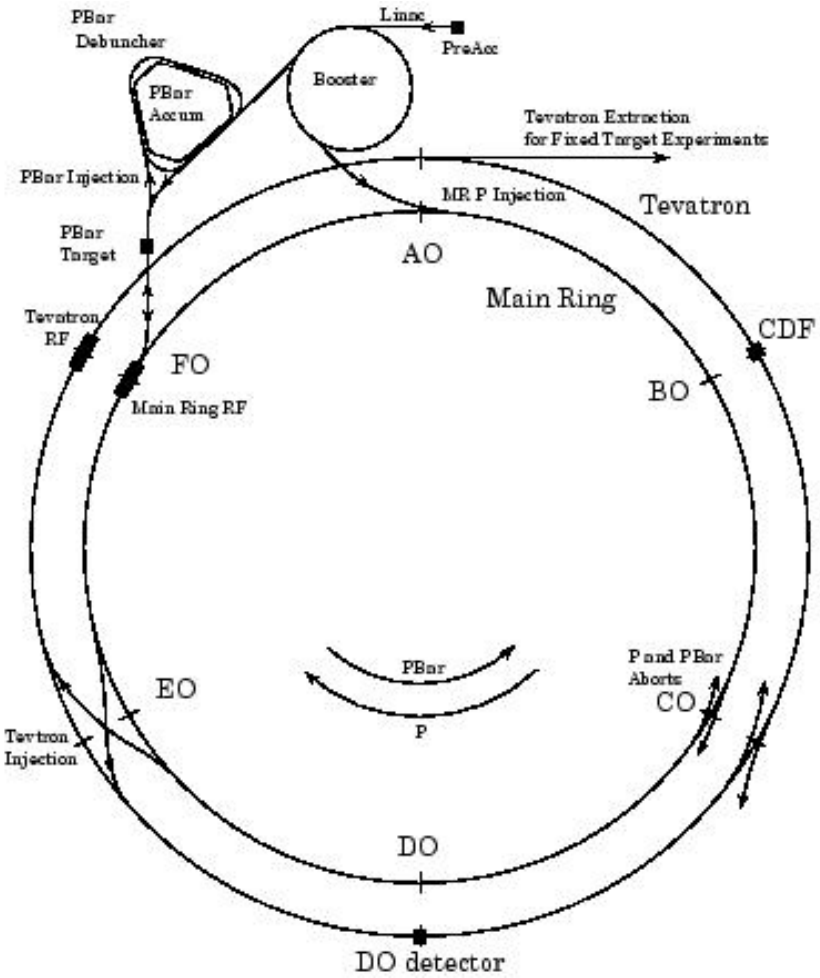
Construction started
in 1968

The TeVatron

The particle beams are a thousand times thinner than a human hair

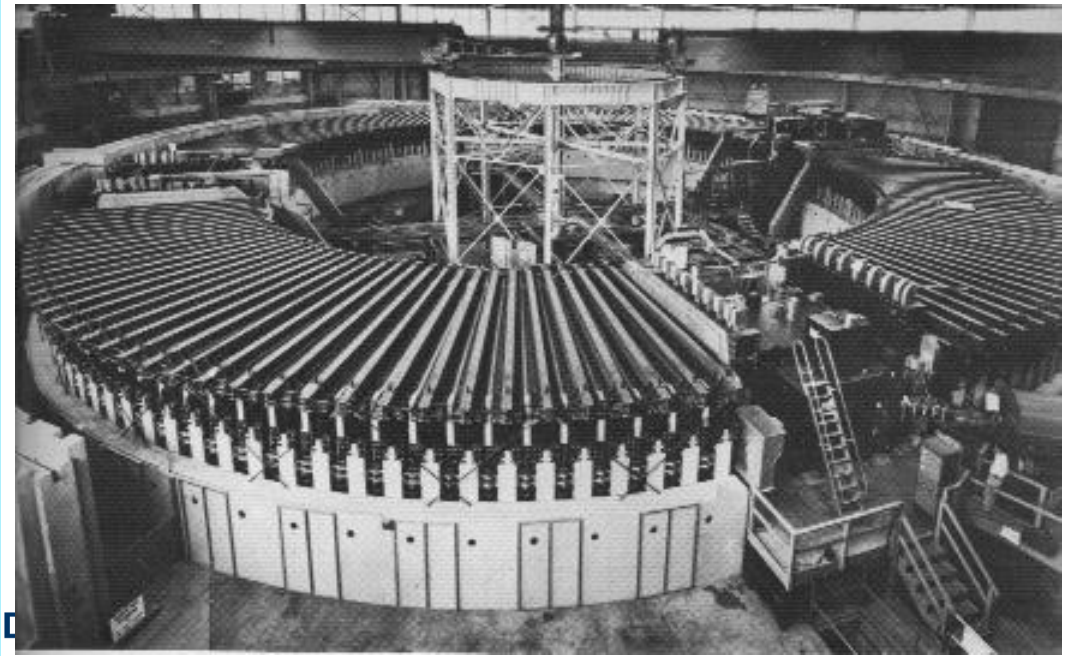
1 TeV ~ 1 erg ~ energy of a mosquito landing

Three circular accelerators and two linear accelerators create and collide proton and antiproton particle beams



Compare to…the BeVatron

- Construction began 1949
- Top energy: 6 Billion eV
- Discovered antiproton



} 6 ft

E.O. Lawrence with an early 37.5 inch version

The DØ Collaboration

18 countries

79 Univ. & institutes

399 people

(Regular people!)

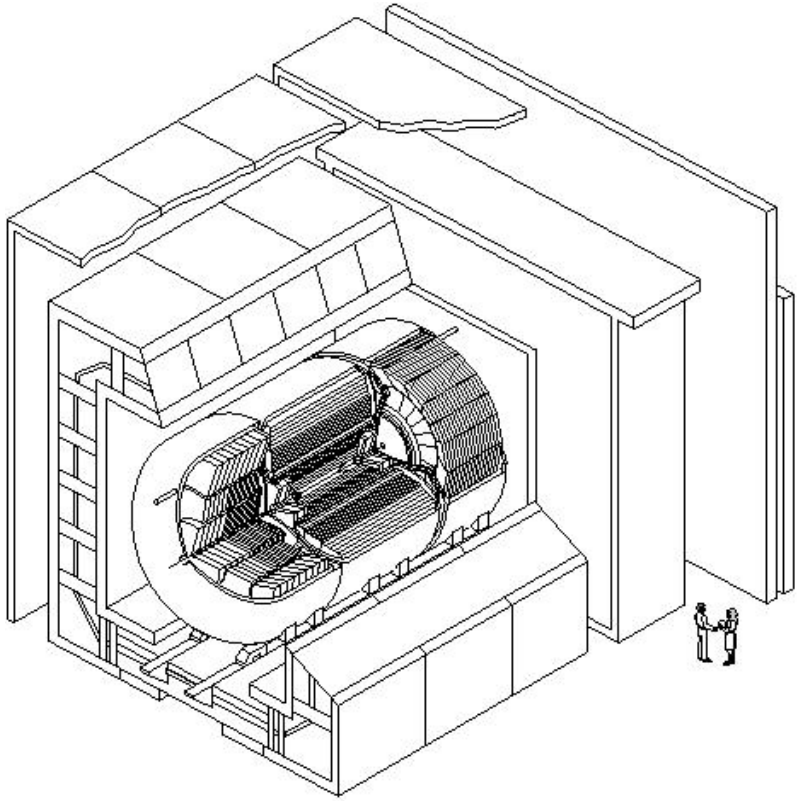
Compare to…

This collaboration built a 60 inch cyclotron at Berkeley

The DØ Detector

Most modern detectors possess three basic design modules:

- Tracking
- Calorimetry
- Muon ID and tracking



DØ Detector

What are we detecting?

At their most basic, all detectors work via ionization or photon creation

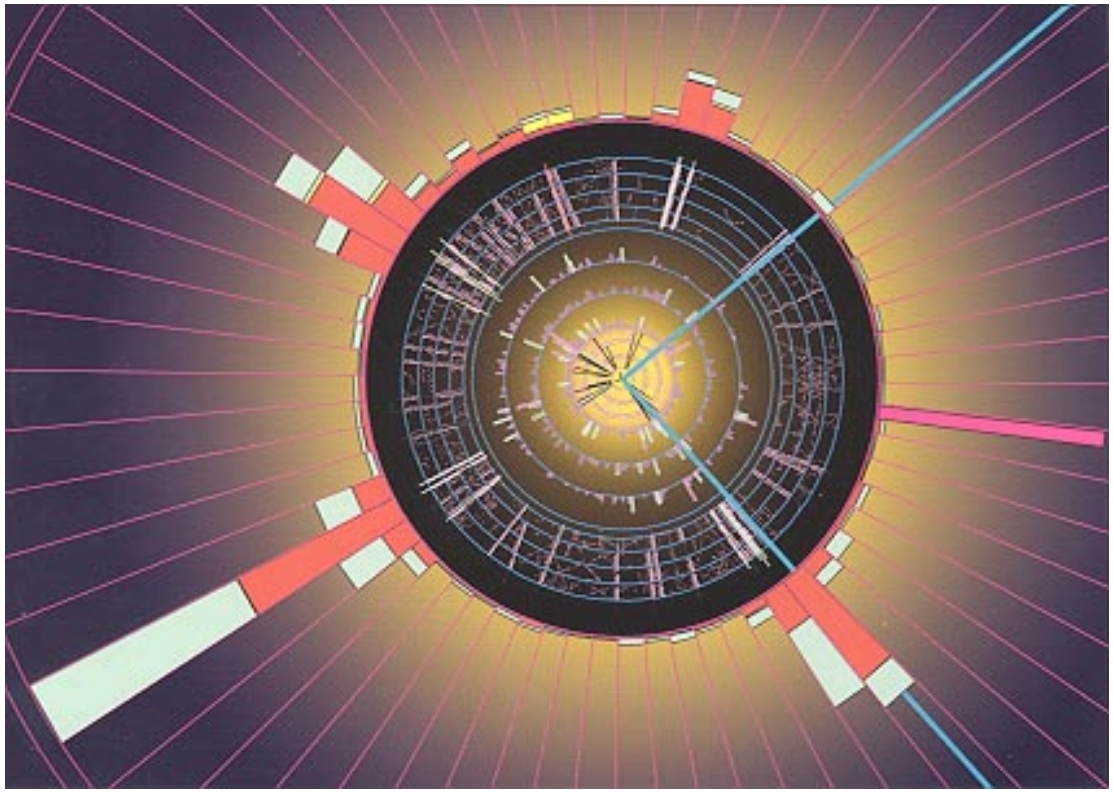
- Charged particles pass through “active” material (ℓ Ar, Si wafers, scintillating fibers)
- Near each molecule, the particle can liberate an electron
- These ionization electrons are collected on charged plates

What does an interaction look like?

Beams traveling into and out of the screen

Tracker finds many ion traces

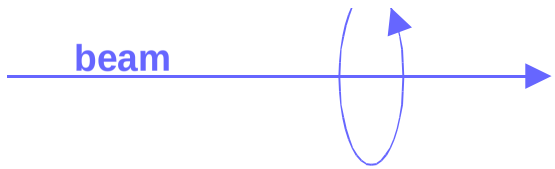
Calorimeter energy represented by "lego blocks"



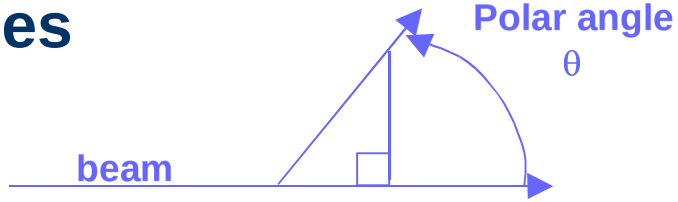
Muon detector (not shown) finds two tracks: the blue lines.

What we measure

- Azimuthal angle



- Transverse momentum (p_T) = energy * sin(θ)
  - Neglect most particle masses



- Relative angles $\rightarrow$ invariant mass

A Cross Section Measurement

- A "cross section" is really an observation frequency

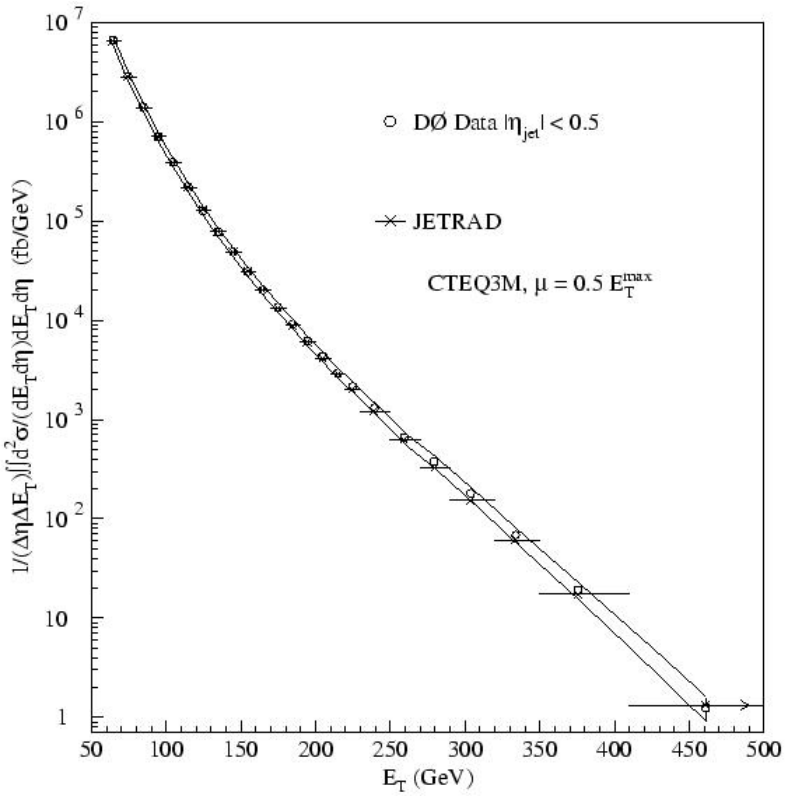
$$\sigma = \frac{N}{L}$$

number of observations

number of opportunities

or

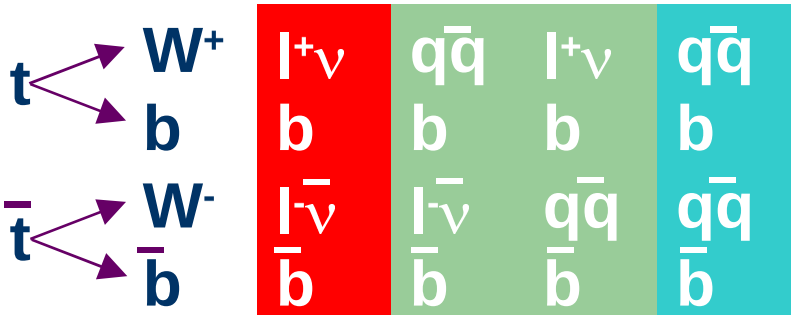
$$\frac{d\sigma}{dp_T} = \frac{N}{L\,\Delta p_T}$$

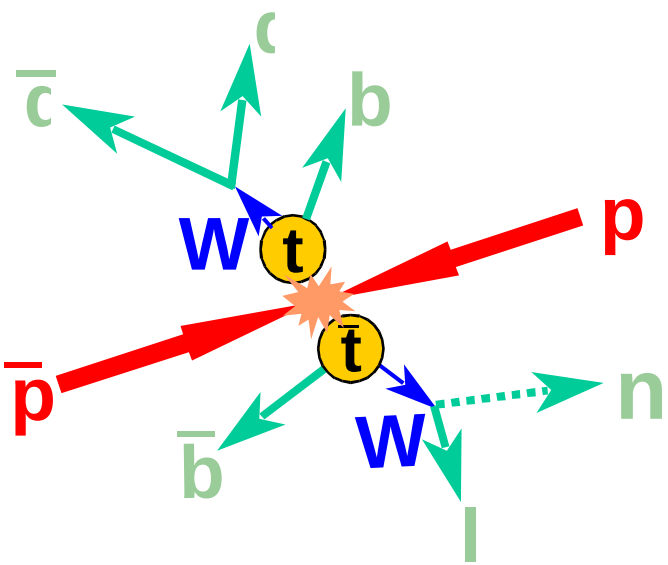


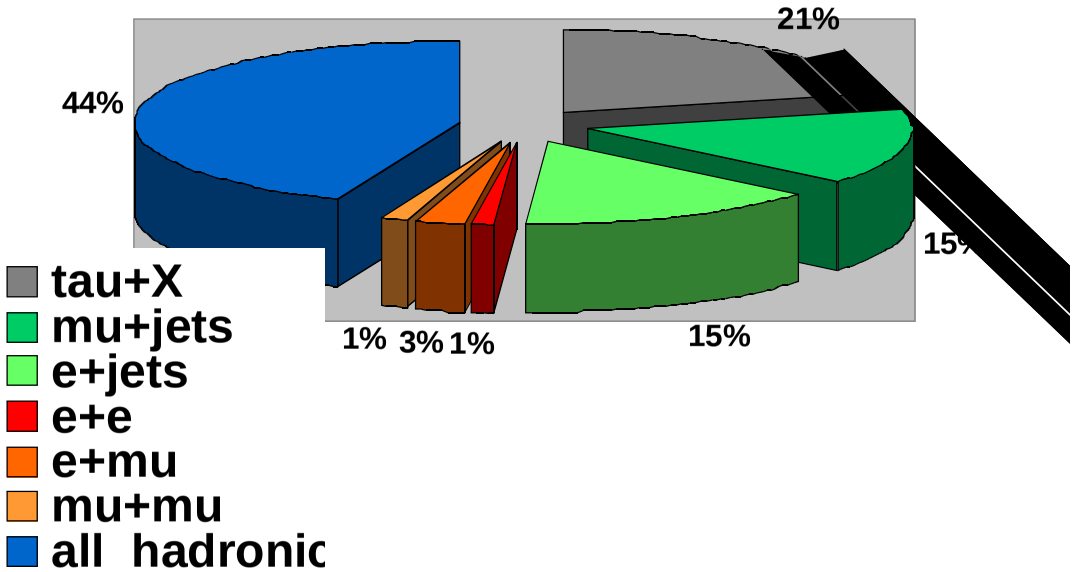
- The cross section for particle jets

The Top Quark Discovery

- **Decay modes and "signatures"**

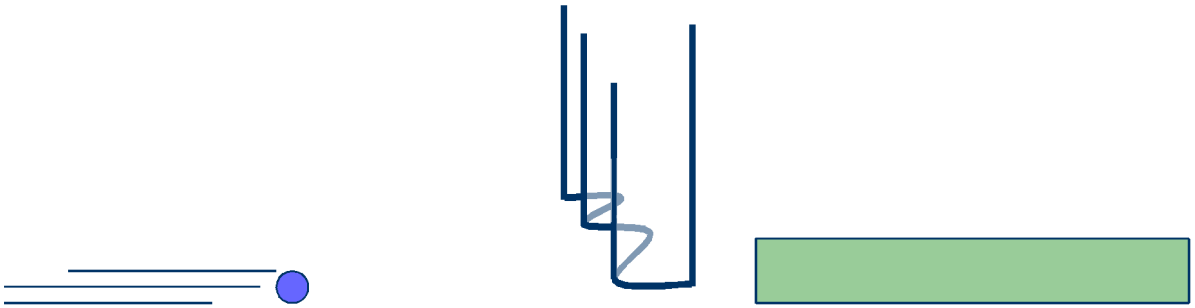




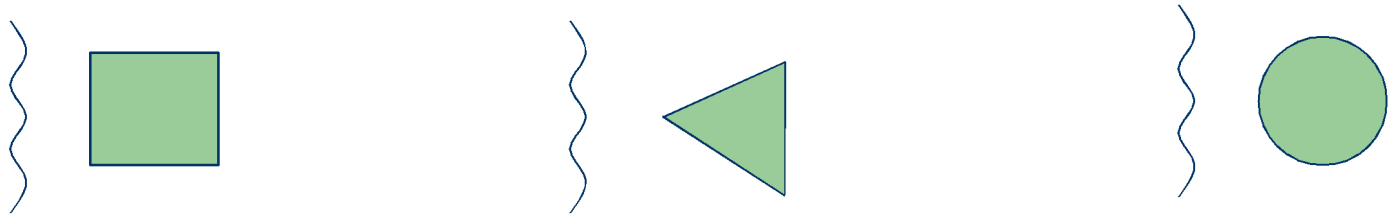


Analogy of a Signature

Imagine a game with a curtain hiding an unseen structure?

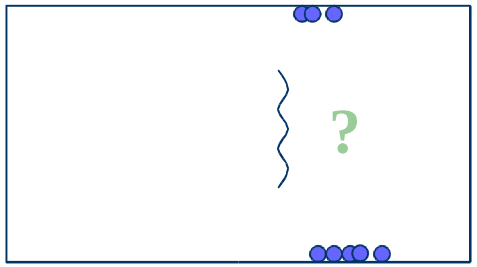


Consider these different cases:



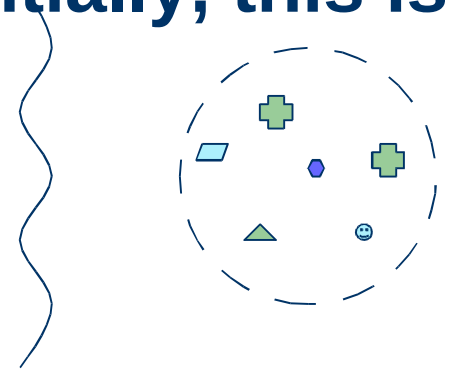
Studying distributions

Let's say you can't play the game one roll at a time…



…and you only get a few shots

Essentially, this is what we do in an HEP analysis!

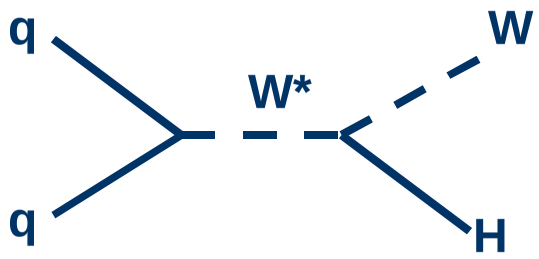


Observation of the Top Quark
Phys. Rev. Letters {74} 2632 (1995)

Had 17 top quark events.

Looking for the Higgs

- Origin of mass
- Most sensitive channel is

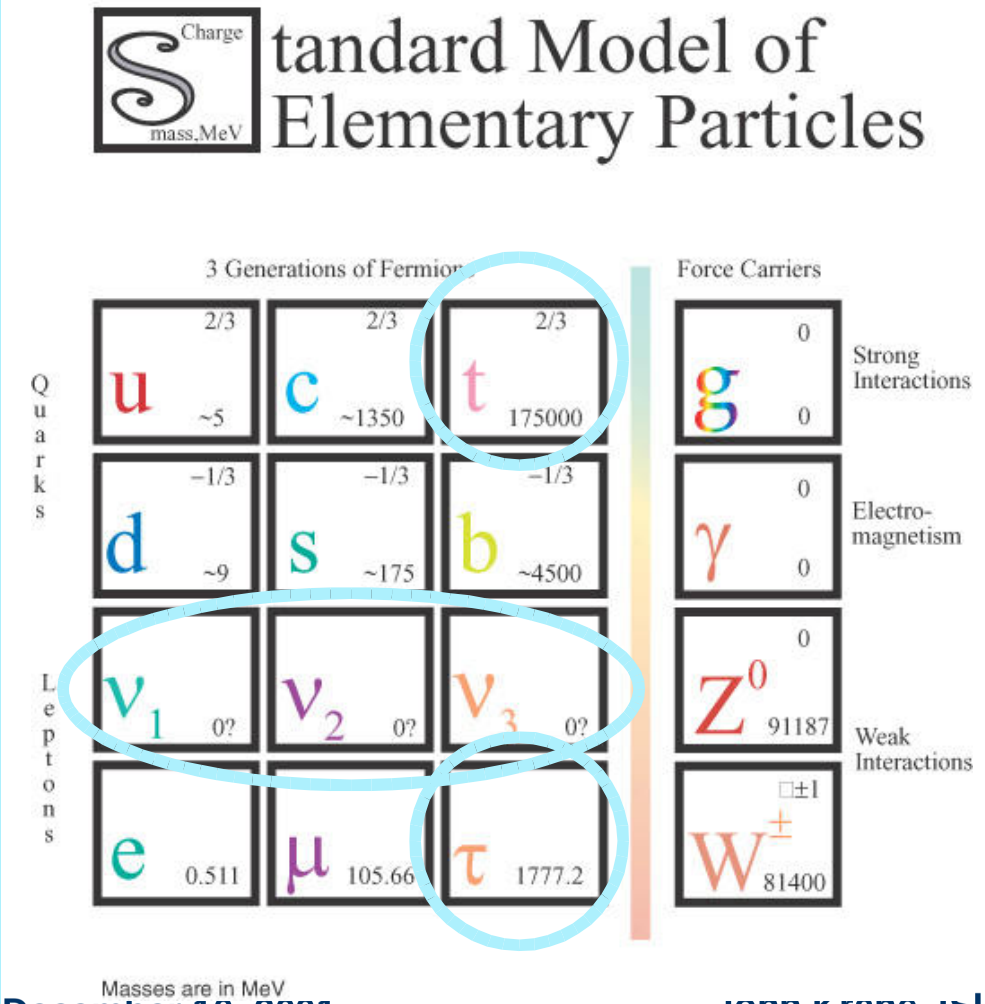


…followed by decay of H to bb and decay of W to e or μ and a ν

- Two "jets" with associated μ, and an extra e or μ
- We might get ~10 events, with ~40 background

Note: I personally am more interested in the force carriers (g, γ, etc.)

Work in Progress



t discovered 1994, mass is 174300 MeV

Neutrinos (n) have non-zero mass 1998

τ discovered 2000

$H_{130?}$

5-15 years?

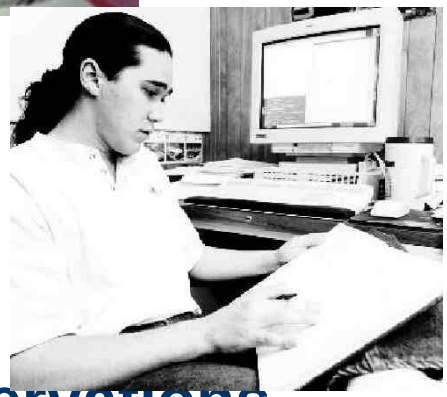
Why do we care?

- **We are curious and our questions are large**
  - HEP is a handle on the first moments, cosmology
  - Current theories become inconsistent at high energies, gravity
- **The tools we need become useful to others**
  - Accelerators used in cancer treatment, diagnosis
  - Particle detectors for imaging of internal organs
  - Parallel computing
  - www created at a HEP lab for our use
- **Today’s abstract knowledge is tomorrows industry**
  - Quantum physics (transistors, lasers)
  - Superconductivity (MRI, mag-lev)
  - Molecular manipulation (plastics and pharmaceuticals)
  - Electricity…

What do we do, daily?

- Design and build the hardware

- Operate the data acquisition syste



- Analyze the data
- Develop theories to explain or predict observations
- Manage efforts of any of the above
- Some mix of things

If it were not for E. O. Lawrence, we would still be working with cosmic rays…

Summary

- Educational path that brought me to HEP
- Defined particle physics, and showed you the tools we use (accelerators, really big detectors)
- Illustrated how to understand quantum-level physics with macroscopic instruments
- Listed recent accomplishments in HEP and what our work means to everyone else
- Showed you a few things physicists do