Particle Physics: The energy frontier

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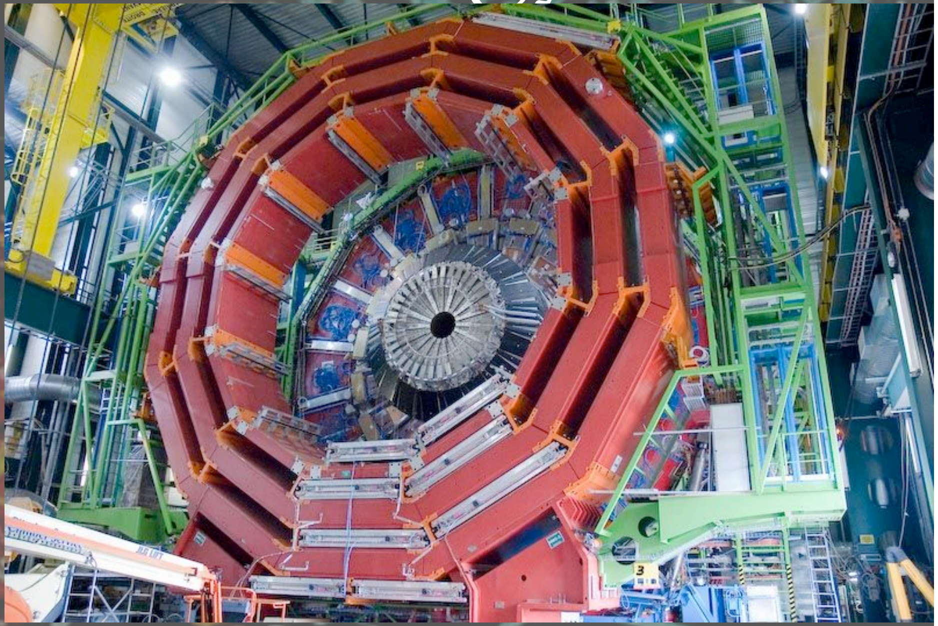
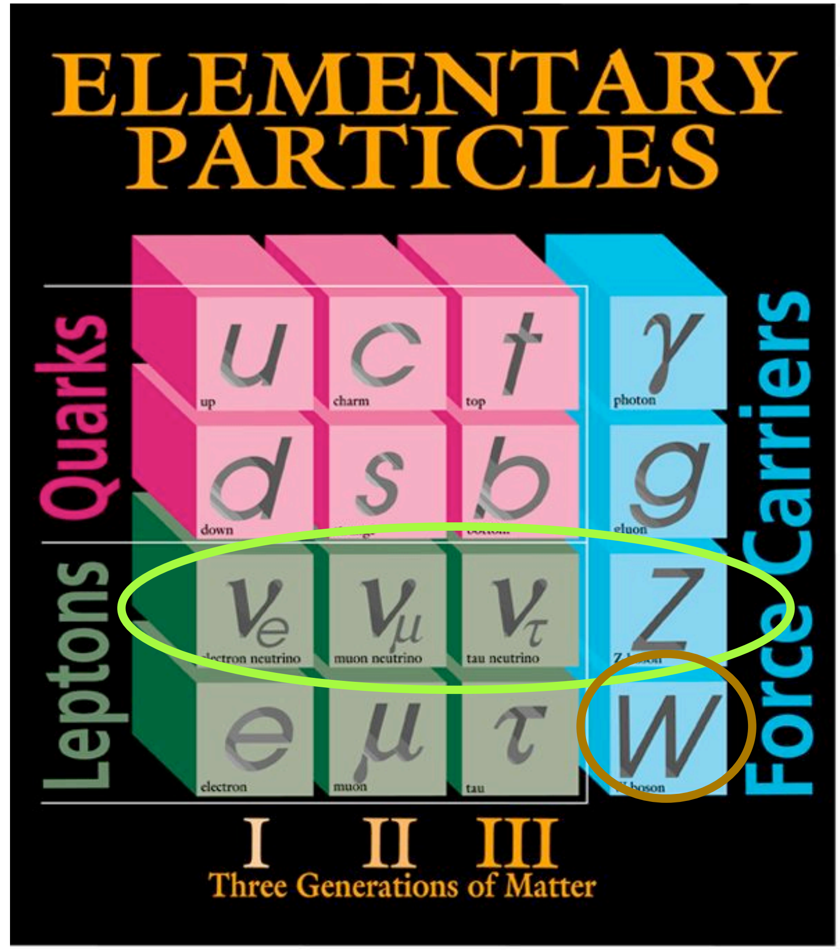


Cornell University
Laboratory for
Elementary-Particle Physics

Particle Physics in one slide: Standard Model

- All matter is made up of spin ½ *fermions: quarks* and *leptons*
- Four forces
  - (Gravity)
  - Electromagnetic
  - Weak
  - Strong
- Forces from spin 1 *gauge bosons*
  - γ, *Z*, *W*, *g*



Fermilab 95-759

Standard model tested to high precision

How many neutrinos? (LEP @ CERN)

$$\begin{pmatrix} e & \mu & \tau \\ \nu_e & \nu_\mu & \nu_\tau \end{pmatrix}$$

$$\Gamma(Z \to \nu\bar{\nu})$$

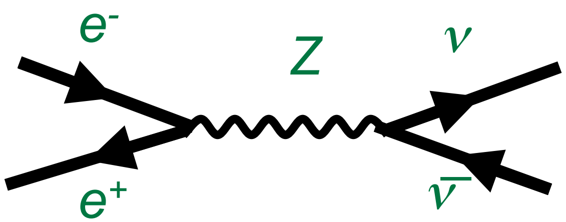
(Early 1990's)

- Measure "invisible width" of Z boson:

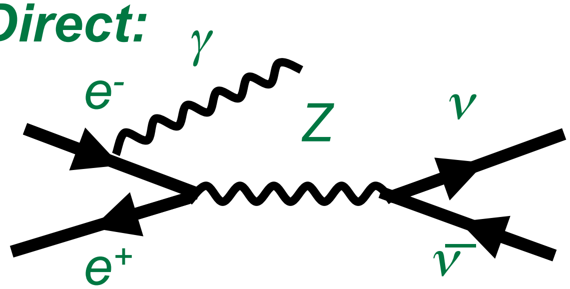
$$N_\nu = \frac{\Gamma_{inv}}{\Gamma_{ll}} \times \left(\frac{\Gamma_{\nu\nu}}{\Gamma_{ll}}\right)^{-1}_{SM} = 2.9841 \pm 0.0083$$

- ***Excellent Agreement w/Standard Model***

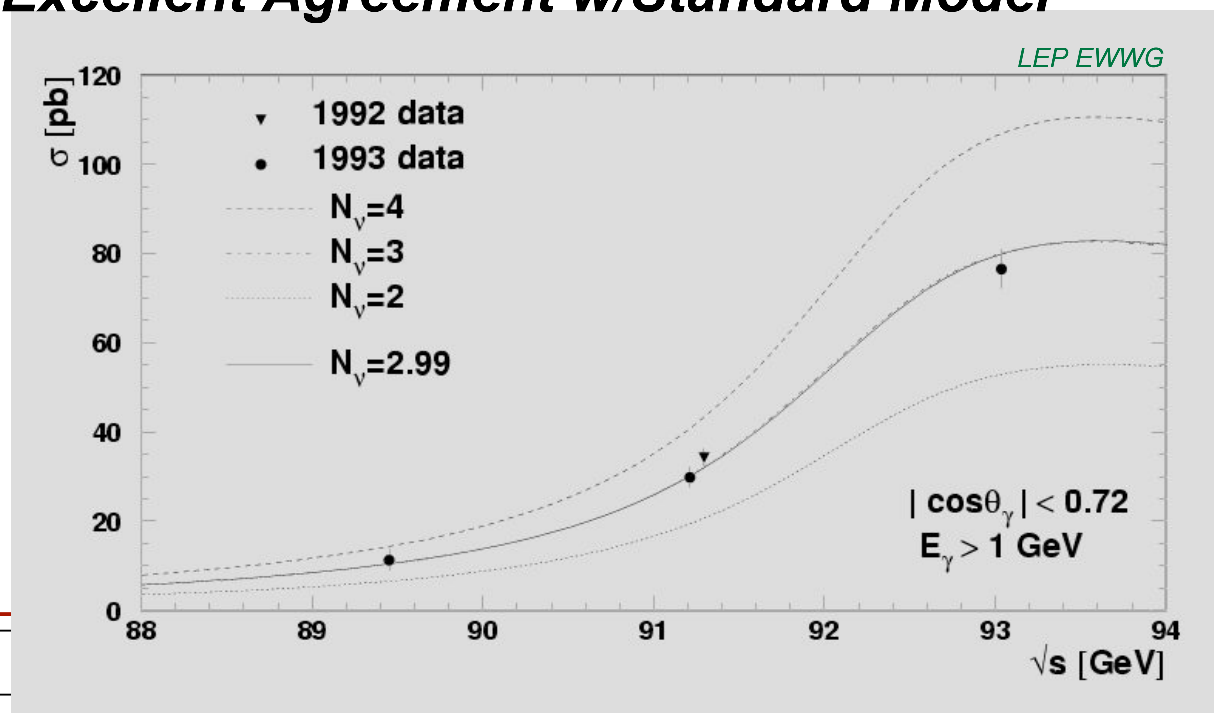
Indirect:



Direct:

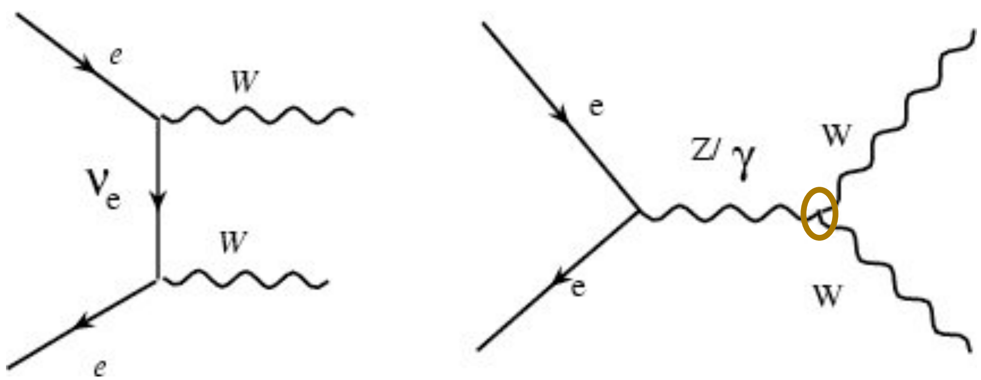


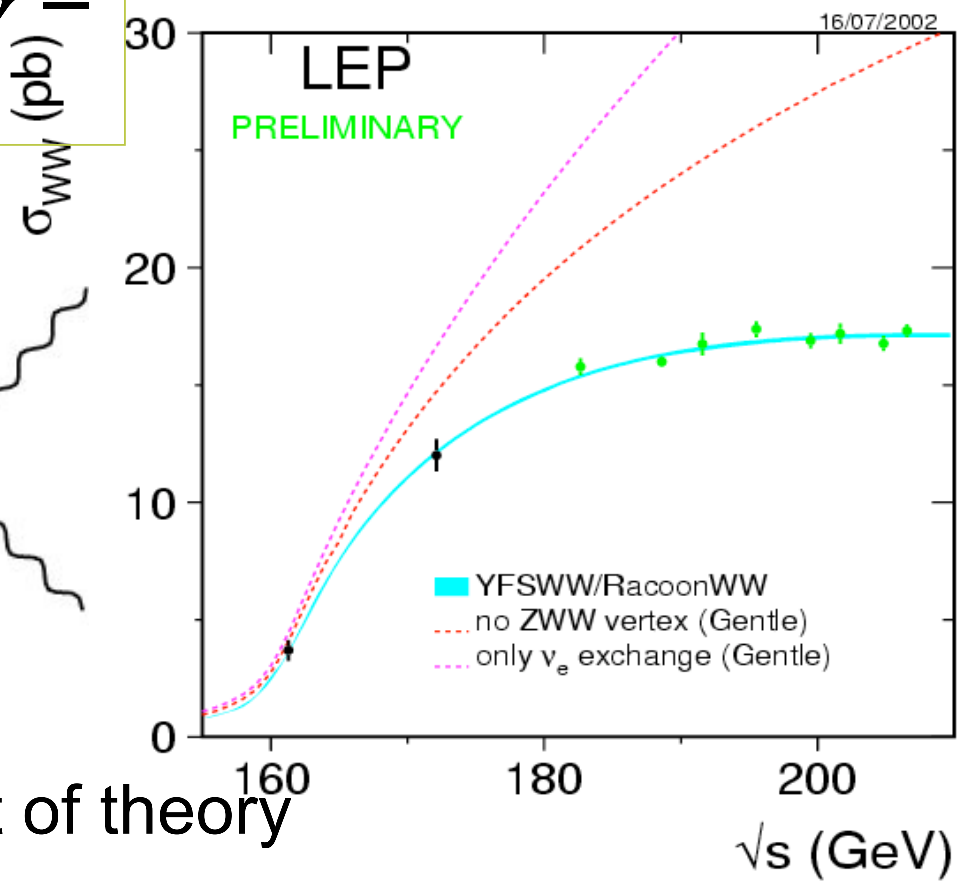
$$e^+e^- \to Z\gamma \to \nu\bar{\nu}\gamma$$



Interference in Production of W boson pairs

$$e^+e^- \rightarrow W^+W^-$$



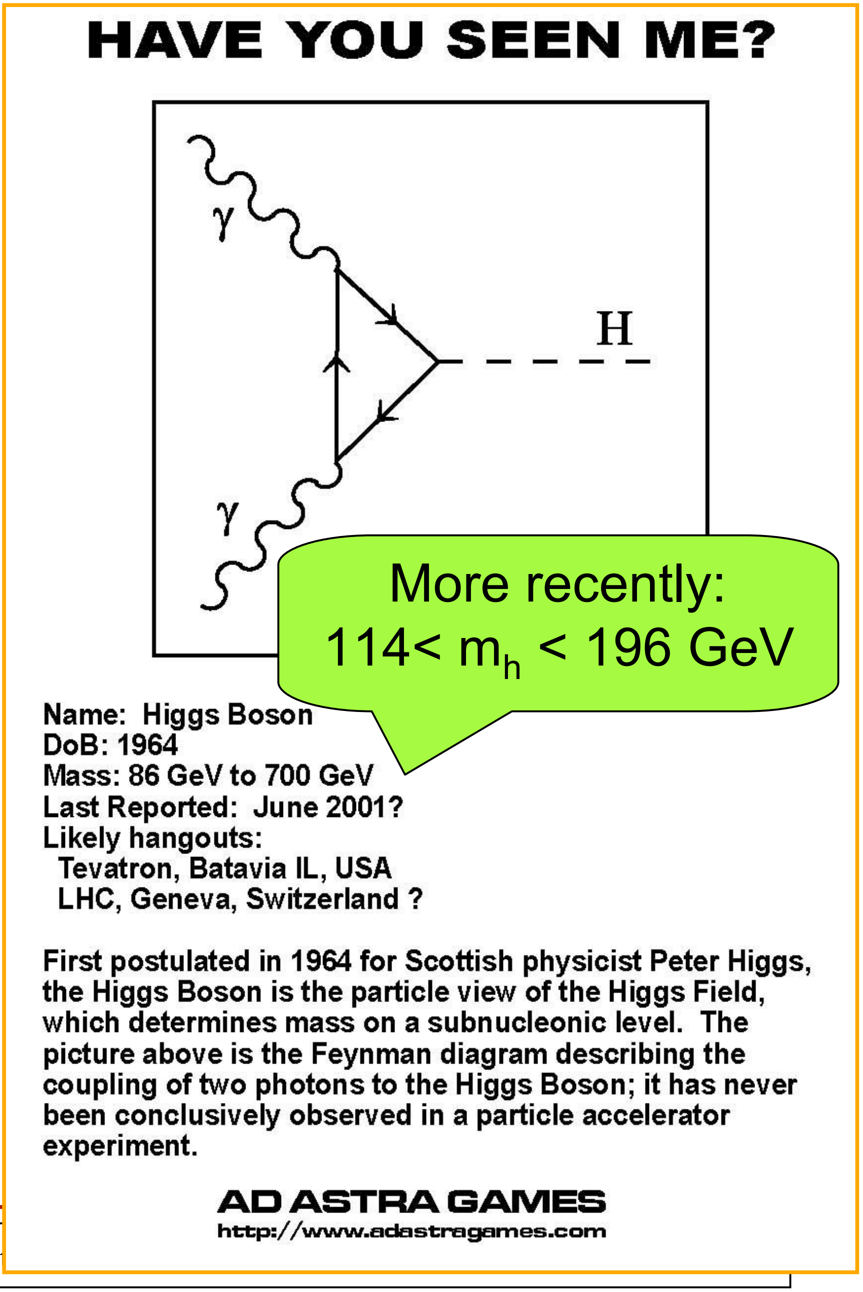


- Cross section sensitive test of theory
  - Three contributions
- **LEP data in excellent agreement with model**

Why keep looking?

- The Standard Model is very successful
  - As of now, we have nothing in experiment that contradicts this model
- Missing: Higgs boson
  - Final piece of puzzle
- The Higgs boson is responsible for the spontaneous breaking of electroweak symmetry
- Consequence of breaking of electroweak symmetry:
  - Matter particles become massive
  - W and Z bosons become massive

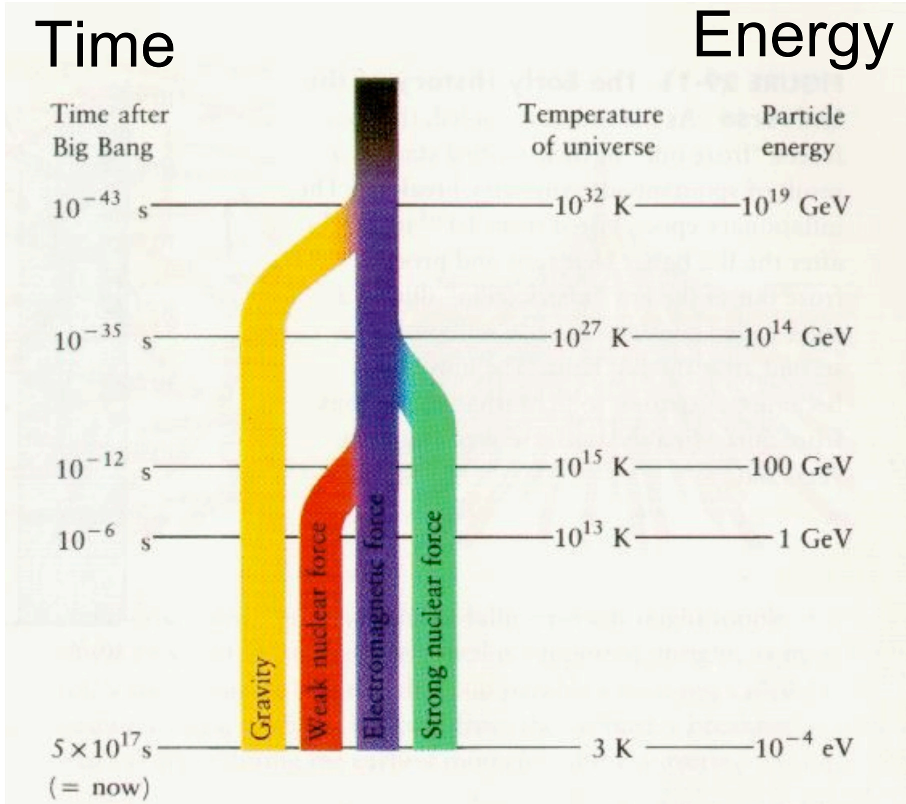
→ We need to find it!



Beyond the Standard Model

$$\frac{m_b}{m_t} = \frac{1}{35}; \frac{m_e}{m_t} = \frac{1}{35{,}000}$$

- Many questions are left unanswered:
  - Gravity?
  - Matter-antimatter asymmetry?
  - Dark energy?
  - Particle masses?
- Internal inconsistencies
  - "Hierarchy problem"
- We need "something else"
  - Grand Unified Theories
  - String theories
  - Technicolor

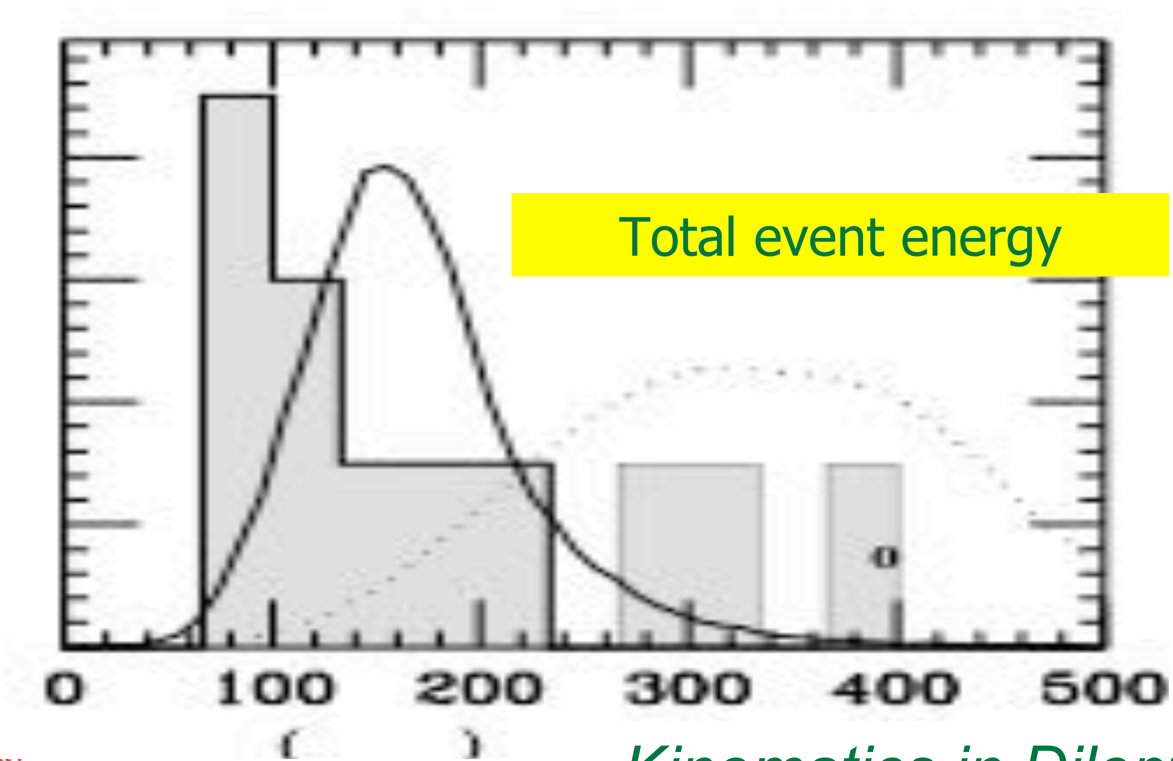


New physics hints already in data?

Last time we looked, we saw something intriguing here….

$t\bar{t}$

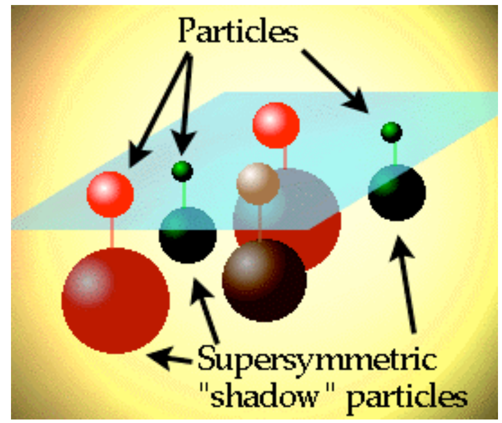
Standard Model top or top + something else?



Supersymmetry – one possibility

$$e^- \longrightarrow e^+$$

- Based on fundamental symmetries
- Many string theories are supersymmetric
- Solves some technical problems of Standard Model
- How: double particle spectrum!
  - Worked before: postulate positron for quantum mechanics
- Introduce "super-partners" with different spin
  - Makes theory self-consistent
  - Also provides dark matter candidate
- But: where are they?
  - M(positron)=M(electron)
  - But not so for ~e
  - SUSY is broken!
- Should be visible in near fu



Particle	Super-partner
e,ν,u,d	$\tilde{e},\tilde{\nu},\tilde{u},\tilde{d}$
γ,W,Z,h	$\tilde{\chi}_1^{\pm},\tilde{\chi}_2^{\pm},$ $\tilde{\chi}_1^0 \ldots \tilde{\chi}_4^0$

Dark Matter Candidate

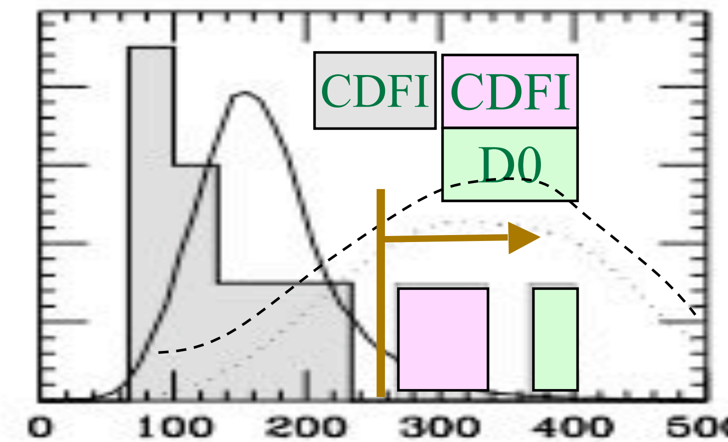
Re-examine those events – SUSY?

Could that intriguing set of events have been a hint for SUSY?

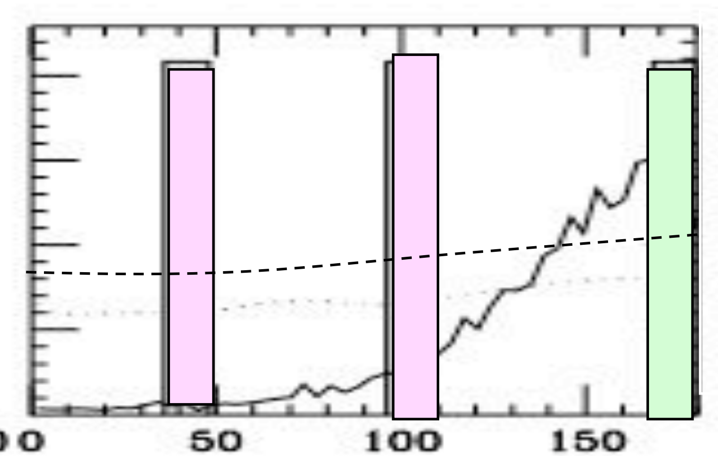
—— $t\bar{t}$

········ $\tilde{l} \to l\nu\tilde{\chi}_1^0$

Regular top or SUSY?



Total event energy



Angle btw leptons

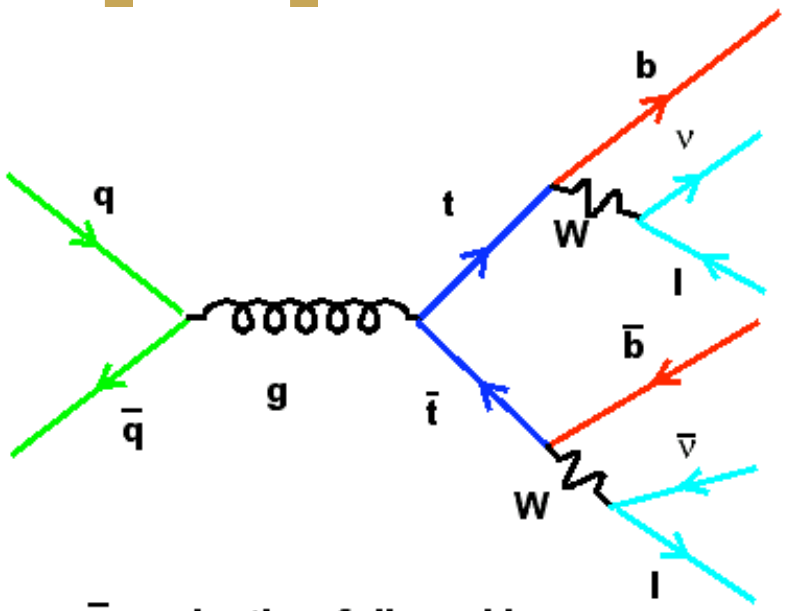
ttbar or cascade decay of squarks with masses around 300 GeV?

Kinematics in Dilepton Events

Theory interest from Barnett and Hall, *Phys. Rev. Lett.* **77** 3506 (1996)

Switch gears: let's look at some data

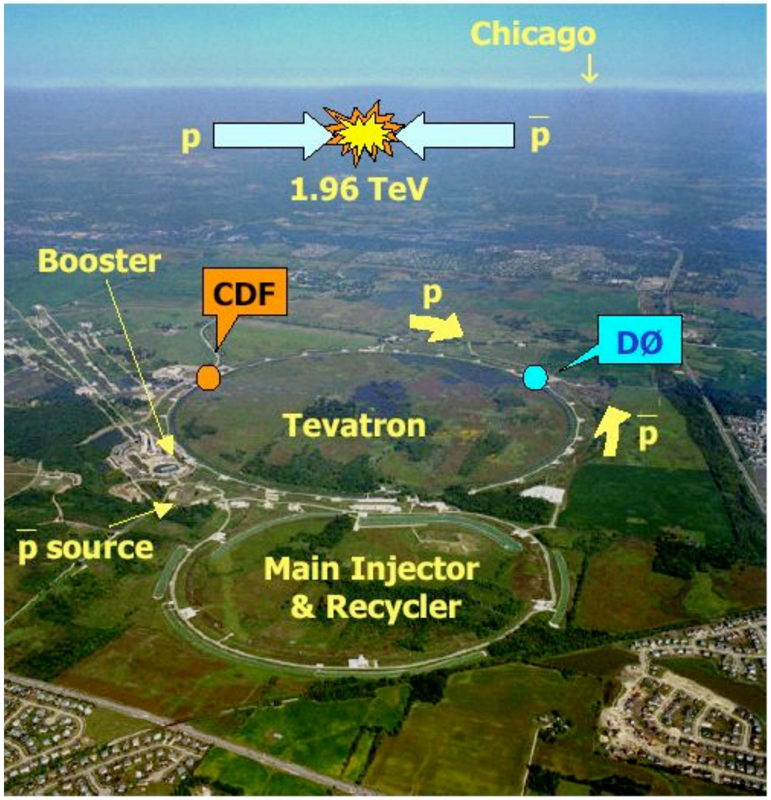
top quarks

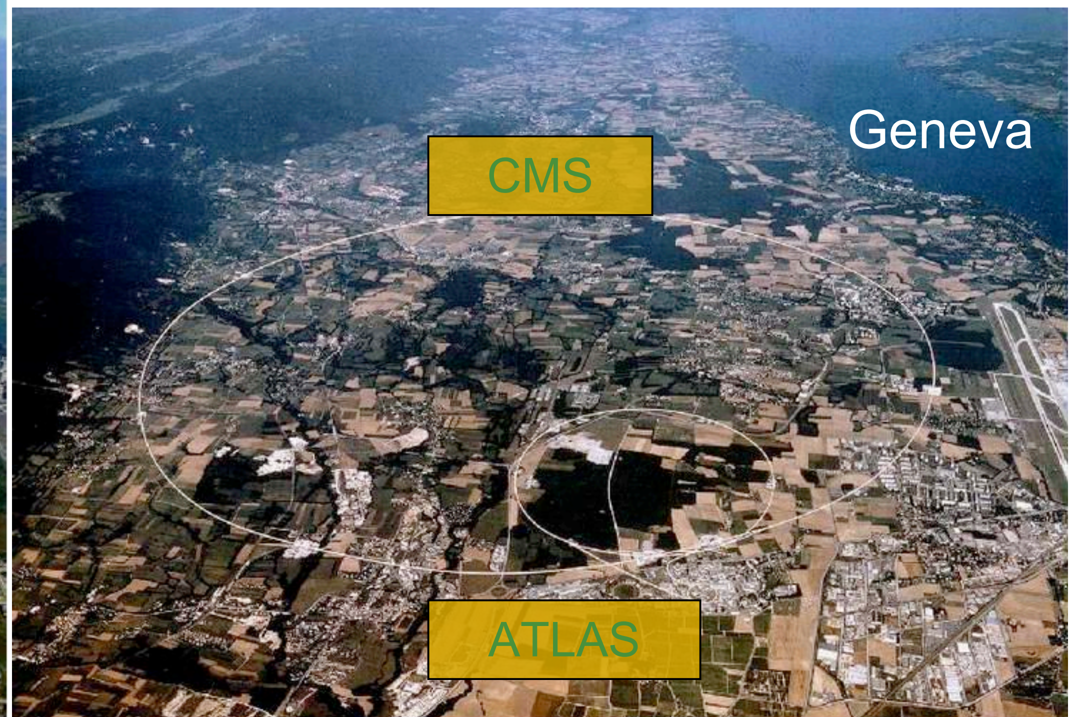


p p̄ production, followed by
t t̄ decay into di-lepton mode

- Study details of particles we know about
- Final state is "simple:"
  - Two electrons or muons
  - Two neutrinos, which we don't detect
  - Two b quarks
- We use these to infer the presence of top quarks
- But is it really that simple?

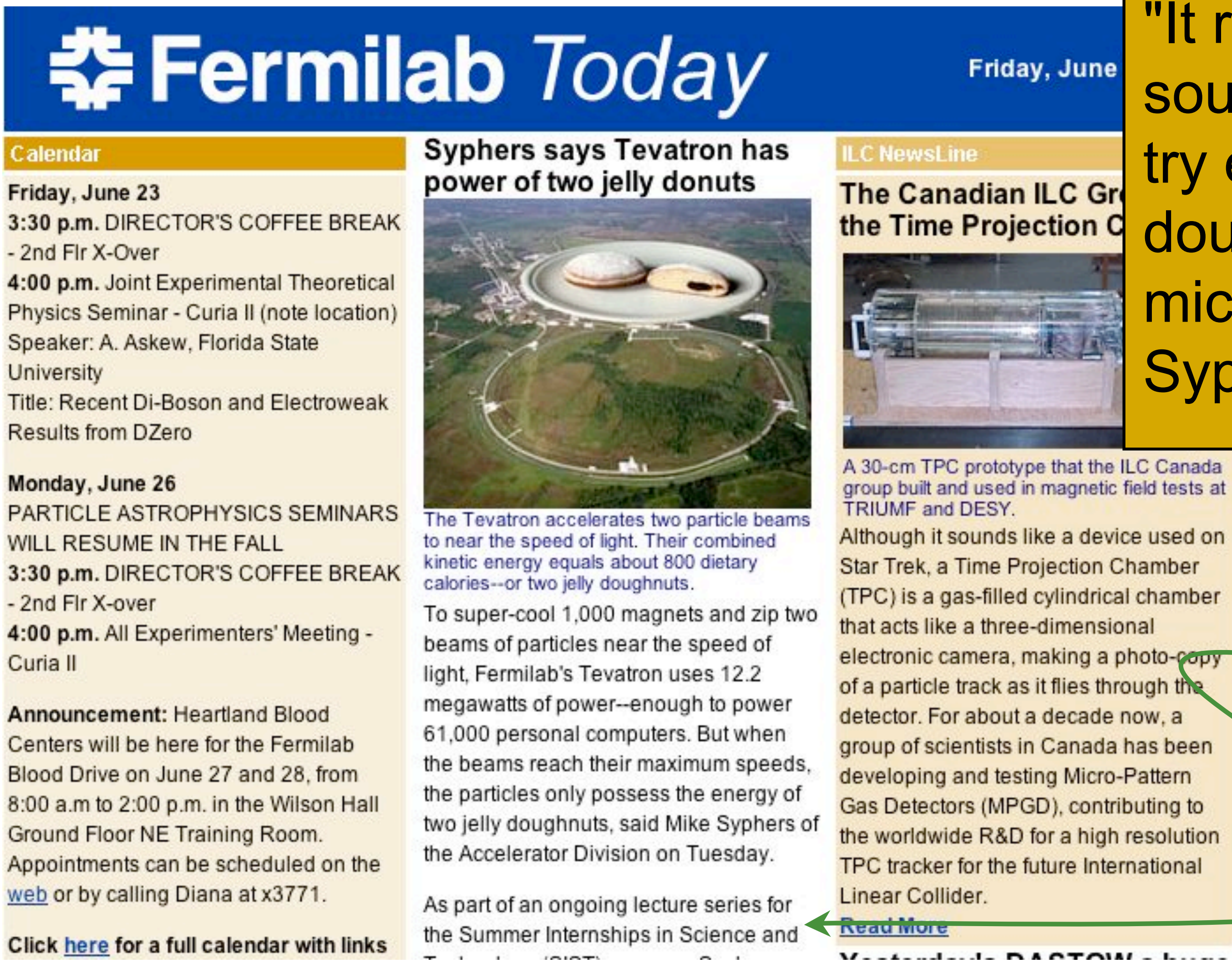
Particle Accelerators (not here!)





- Collide protons and (anti)protons at some of the largest machines in the world!

Aside: Jelly Donuts?



Fermilab Today

Friday, June

Calendar

Friday, June 23
3:30 p.m. DIRECTOR'S COFFEE BREAK - 2nd Flr X-Over
4:00 p.m. Joint Experimental Theoretical Physics Seminar - Curia II (note location)
Speaker: A. Askew, Florida State University
Title: Recent Di-Boson and Electroweak Results from DZero

Monday, June 26
PARTICLE ASTROPHYSICS SEMINARS WILL RESUME IN THE FALL
3:30 p.m. DIRECTOR'S COFFEE BREAK - 2nd Flr X-over
4:00 p.m. All Experimenters' Meeting - Curia II

Announcement: Heartland Blood Centers will be here for the Fermilab Blood Drive on June 27 and 28, from 8:00 a.m to 2:00 p.m. in the Wilson Hall Ground Floor NE Training Room. Appointments can be scheduled on the web or by calling Diana at x3771.

Click here for a full calendar with links

Syphers says Tevatron has power of two jelly donuts

The Tevatron accelerates two particle beams to near the speed of light. Their combined kinetic energy equals about 800 dietary calories--or two jelly doughnuts.

To super-cool 1,000 magnets and zip two beams of particles near the speed of light, Fermilab's Tevatron uses 12.2 megawatts of power--enough to power 61,000 personal computers. But when the beams reach their maximum speeds, the particles only possess the energy of two jelly doughnuts, said Mike Syphers of the Accelerator Division on Tuesday.

As part of an ongoing lecture series for the Summer Internships in Science and

ILC NewsLine

The Canadian ILC Gr... the Time Projection C...

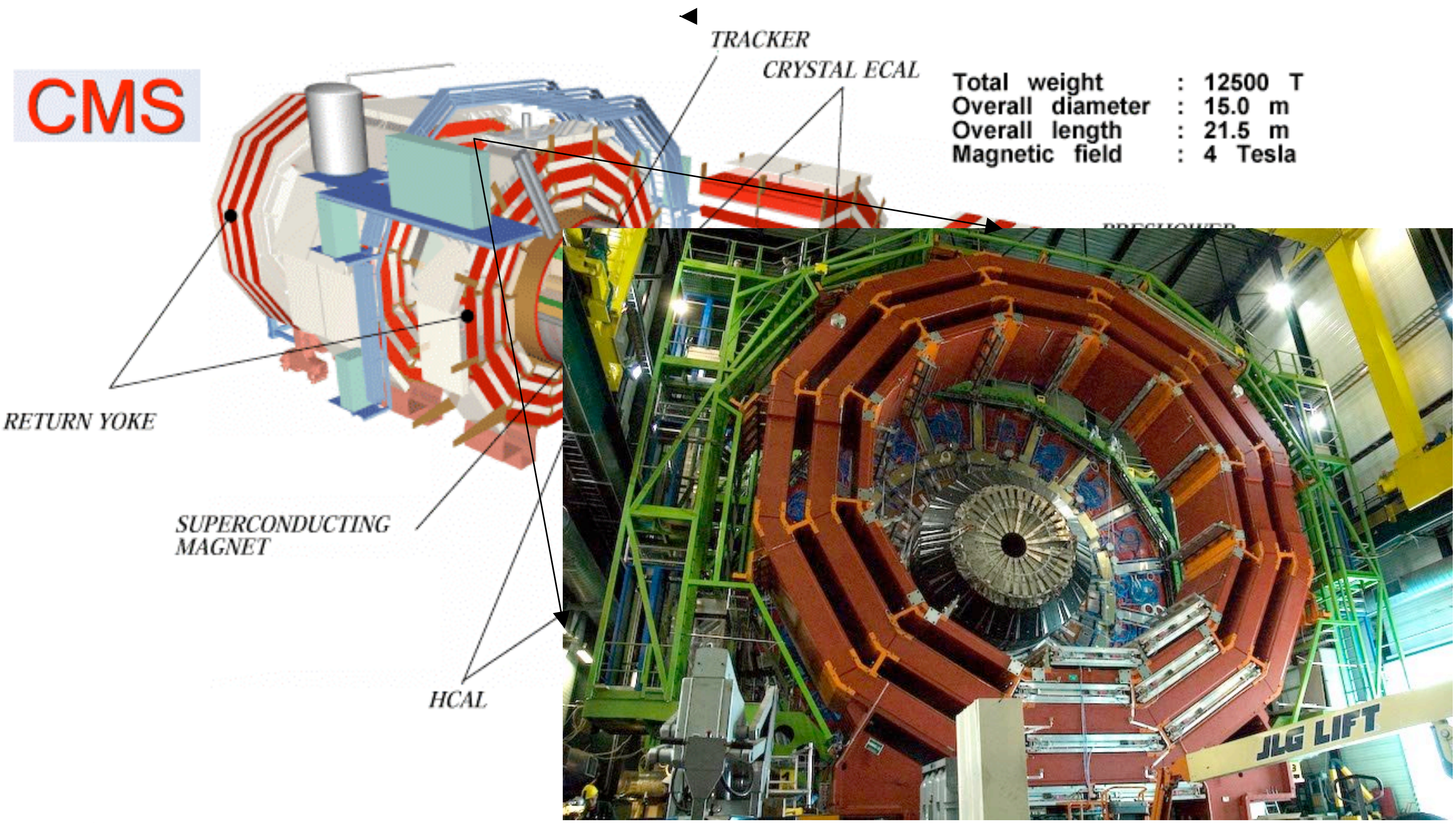
A 30-cm TPC prototype that the ILC Canada group built and used in magnetic field tests at TRIUMF and DESY.

Although it sounds like a device used on Star Trek, a Time Projection Chamber (TPC) is a gas-filled cylindrical chamber that acts like a three-dimensional electronic camera, making a photo-copy of a particle track as it flies through the detector. For about a decade now, a group of scientists in Canada has been developing and testing Micro-Pattern Gas Detectors (MPGD), contributing to the worldwide R&D for a high resolution TPC tracker for the future International Linear Collider.

Read More

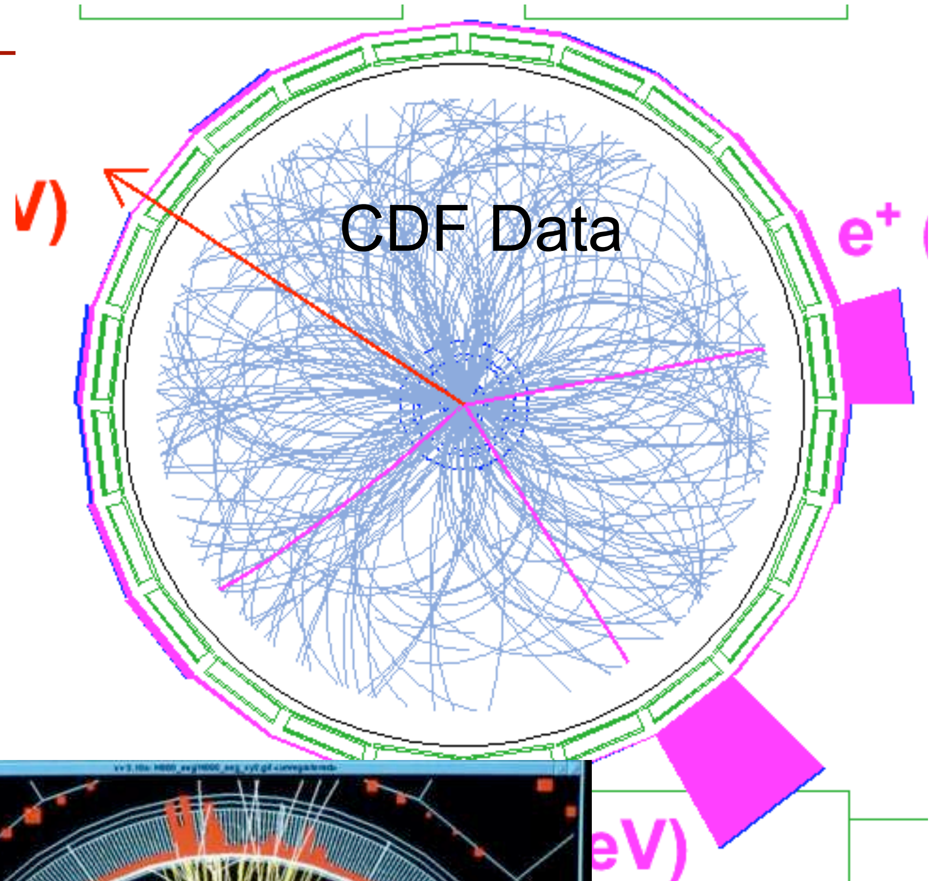
"It really doesn't sound like a lot, but try eating two jelly doughnuts in 21 microseconds," Syphers said.

CMS detector overview

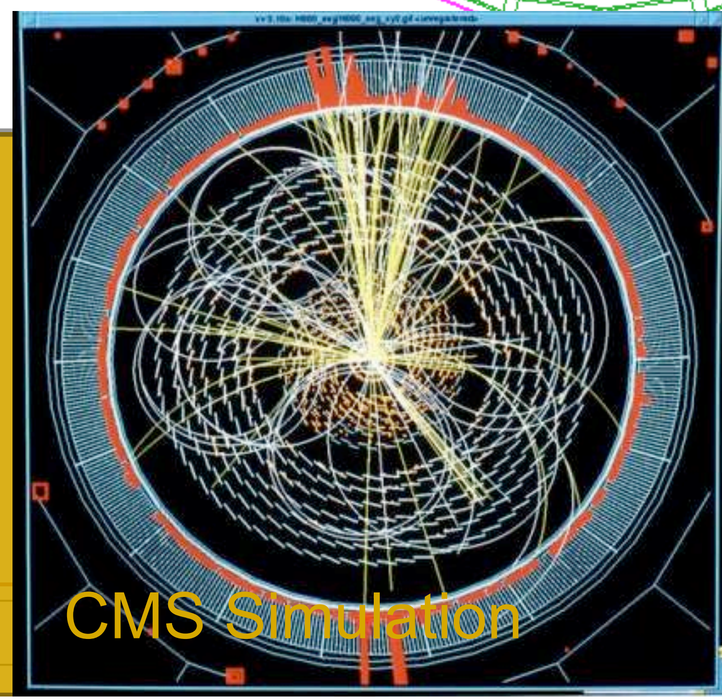


Real life is messier..

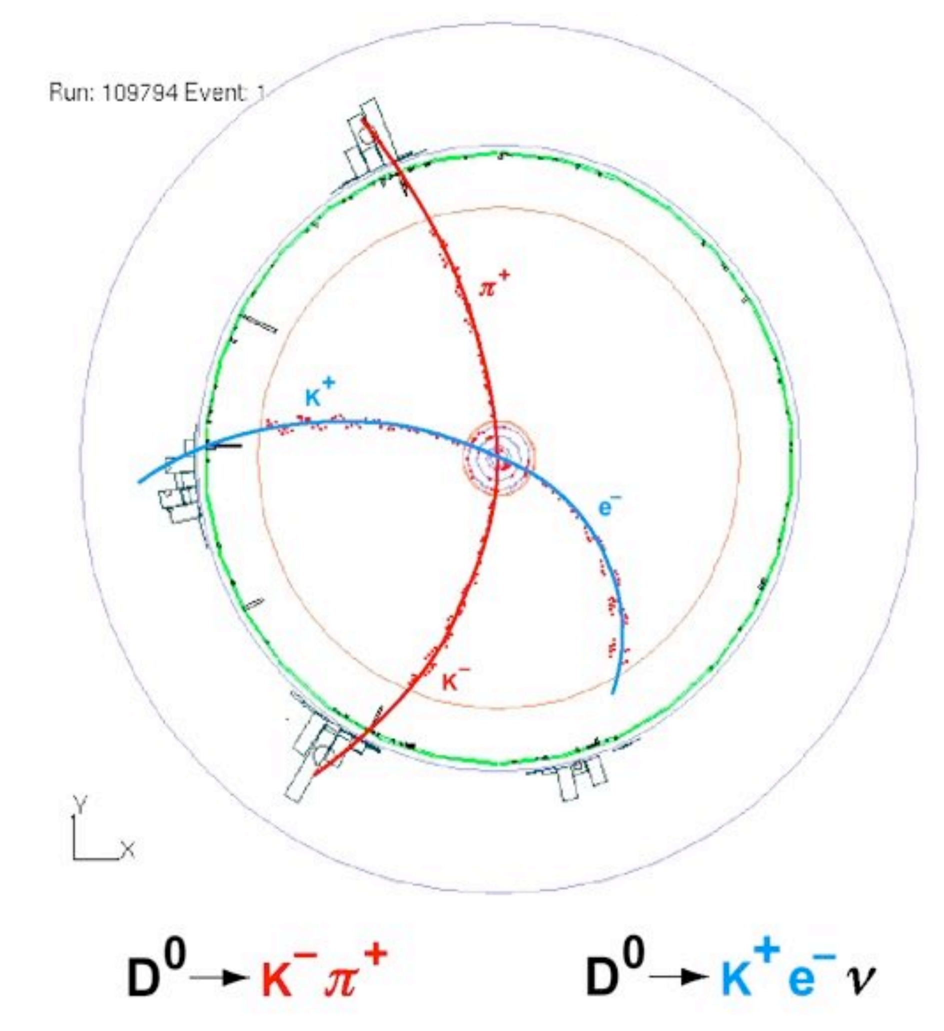
Chaos!



- More than 60,000,000 channels
- Lots of other particles you don't care about
- How can you make sense of it?

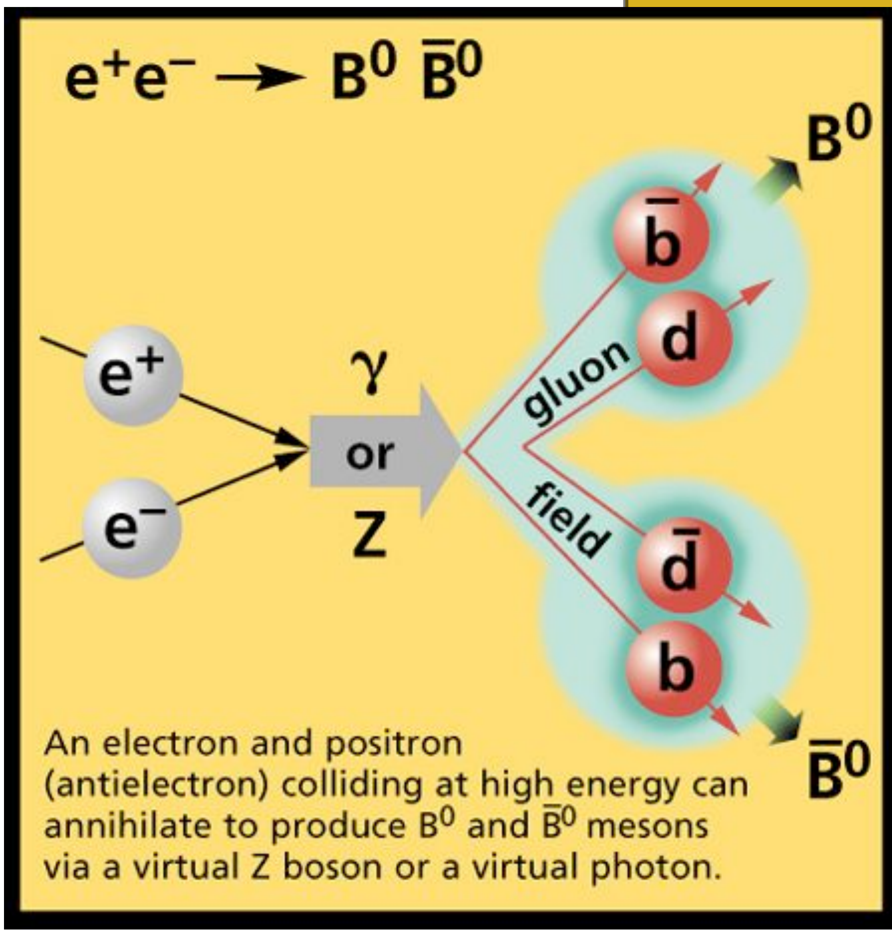


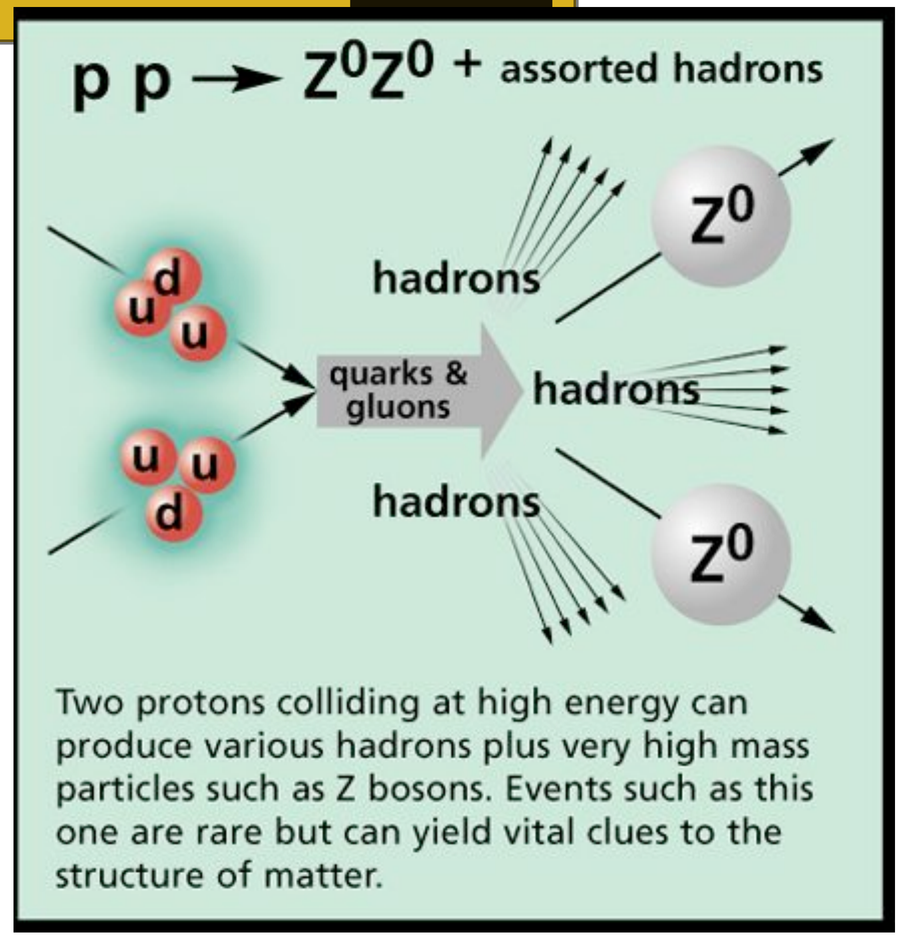
Aside: Compare to CLEO event



- Ritchie showed this picture a few weeks ago
- CLEO events really do look this nice
  - Clean
  - Very few tracks
- What's the difference?

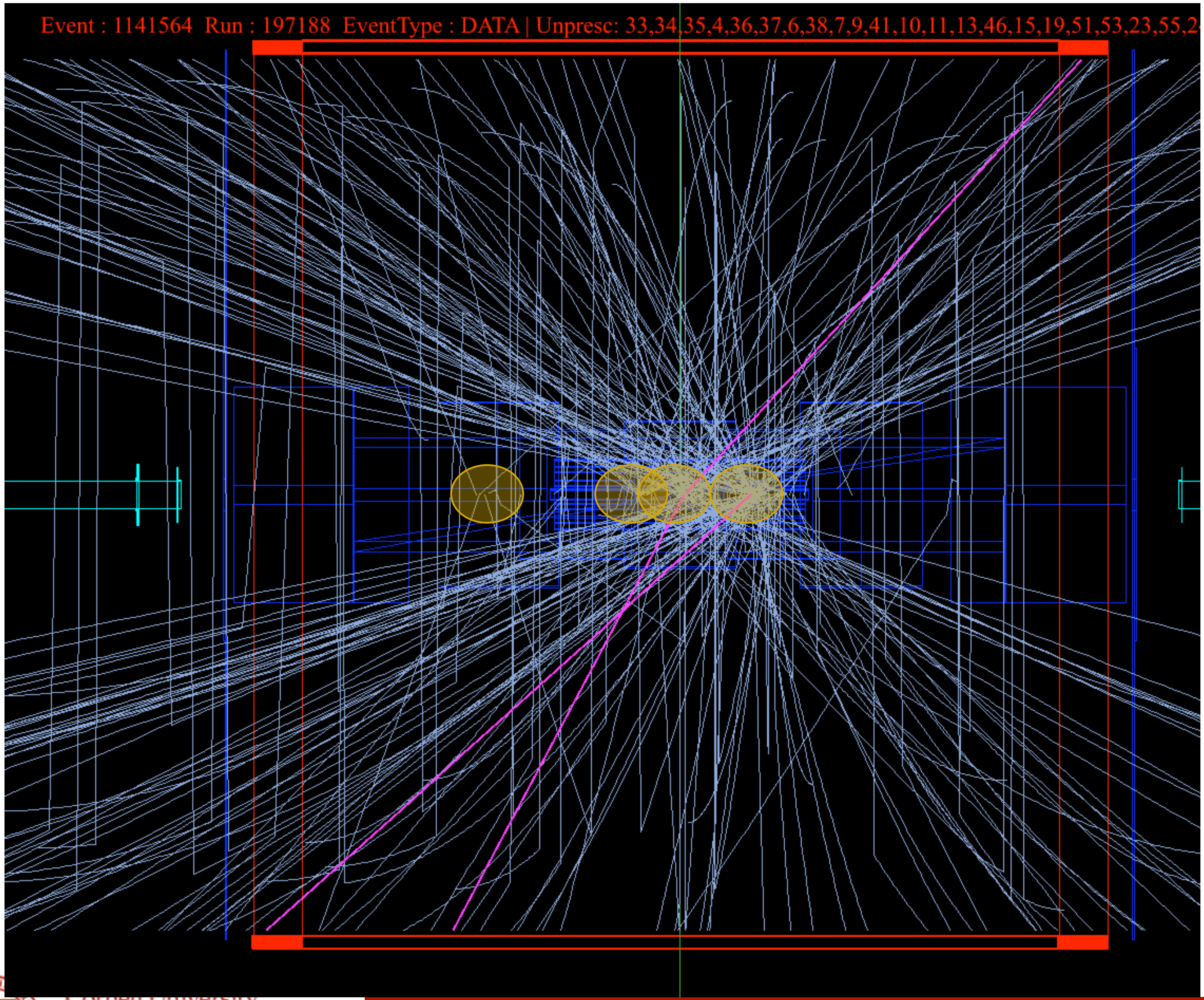
Compare: [redacted]





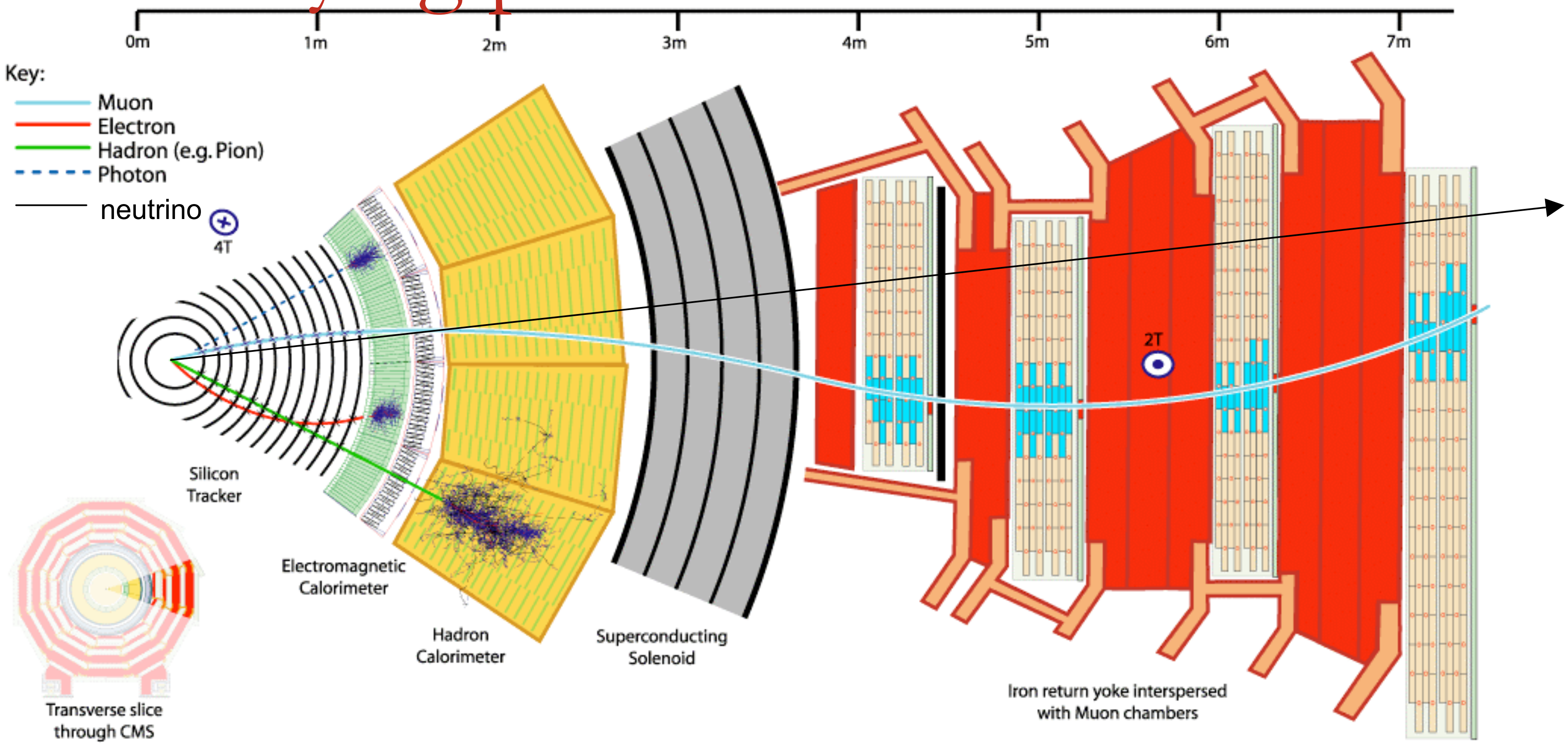
- Other quarks and protons also interact!

Can see extra interactions



- Particles come from multiple points

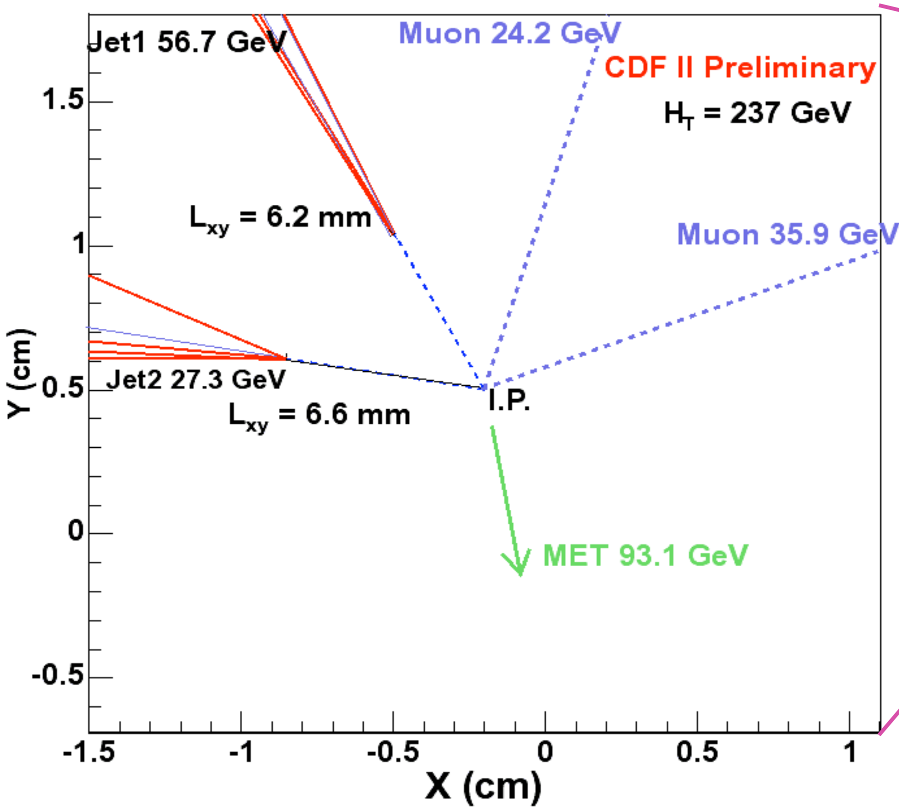
Identifying particles

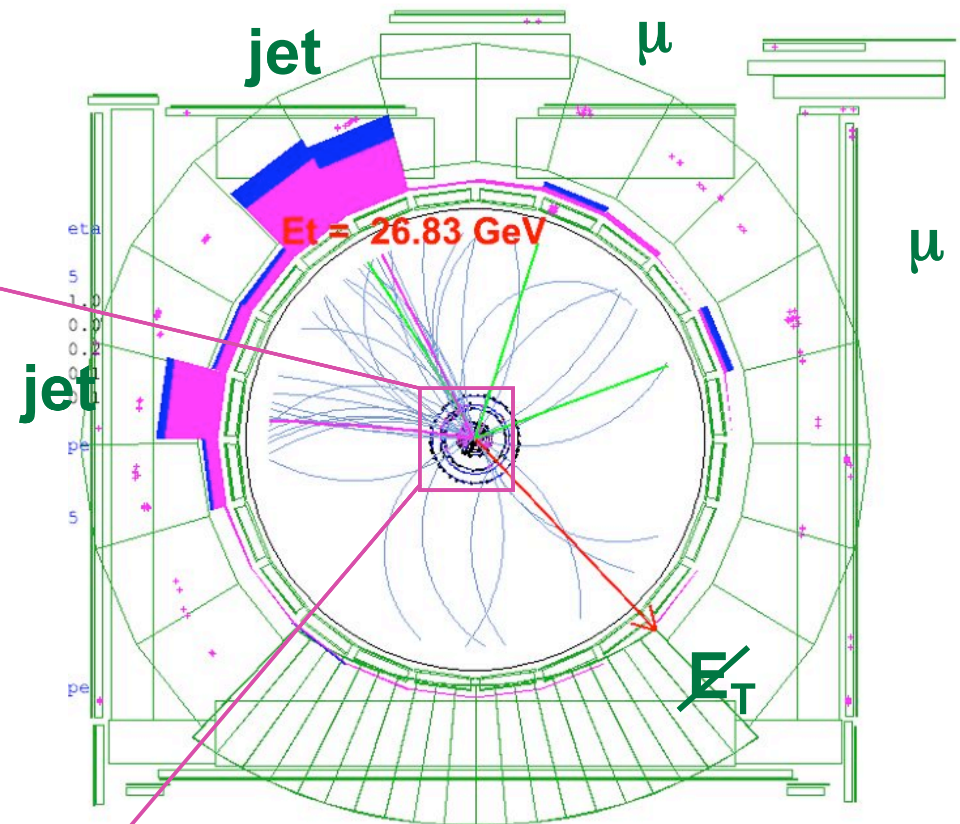


Particles interact differently: build a detector to allow you to use this: measure charge, lat. & long. shower profile gives it all!

Putting it all together: a top candidate

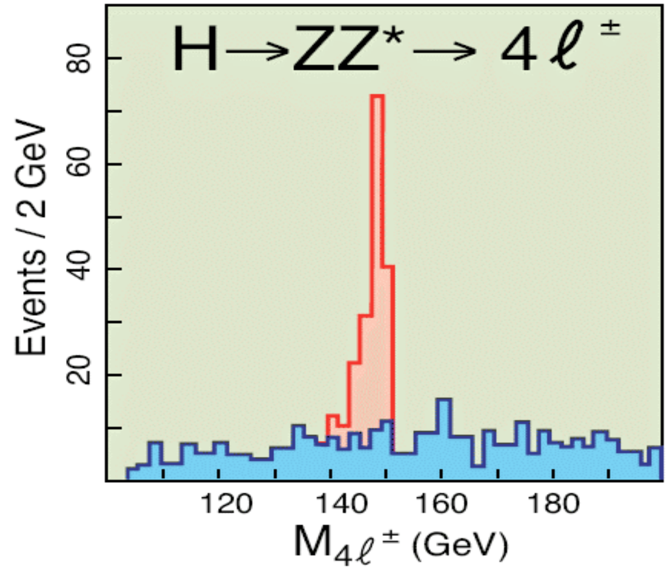
- Tracks – position, momentum, charge
- Calorimeter – position,

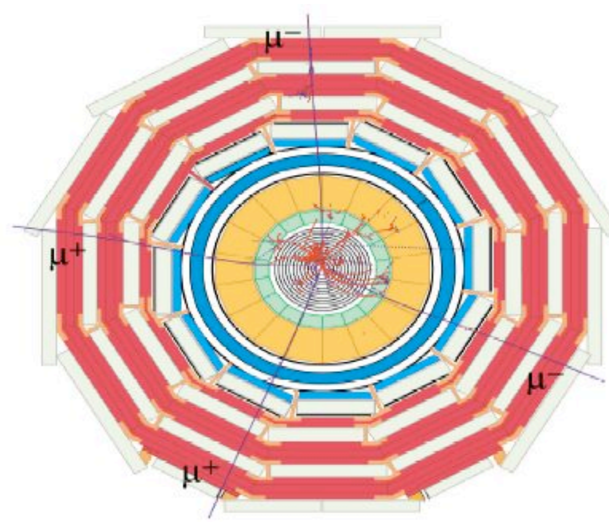




Now we have the tools: what can we do?

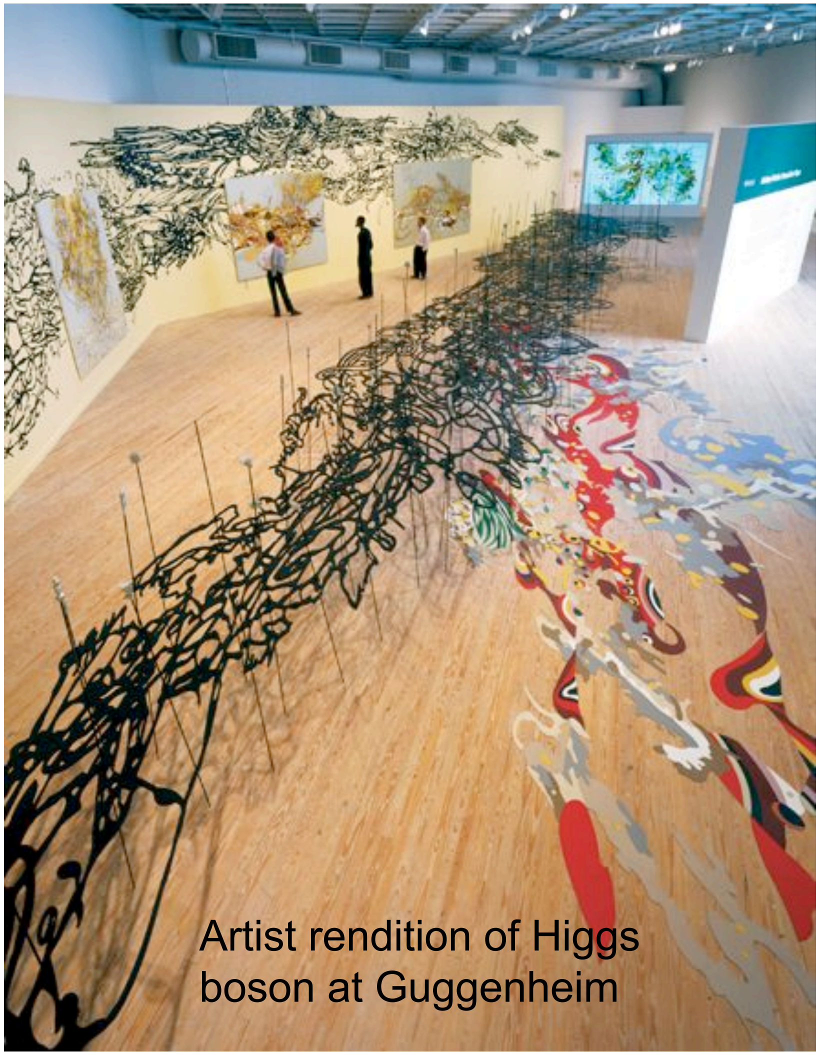
- Study the physics we know
  - Top quarks
  - Force carriers: W, Z, etc
- Look for the physics we expect
  - Where is the Higgs?
- Hope for something new to help us answer the big questions…





M_{Higgs} = 150 GeV

To Summarize



Artist rendition of Higgs boson at Guggenheim

- Particle Physics tries to answer the big questions
  - How do gravity, strong, weak and EM forces fit together? Why do particles have mass?
- We build huge detectors to answer these questions
  - Always pushing technology to its limits
- We expect great things in the next few years!