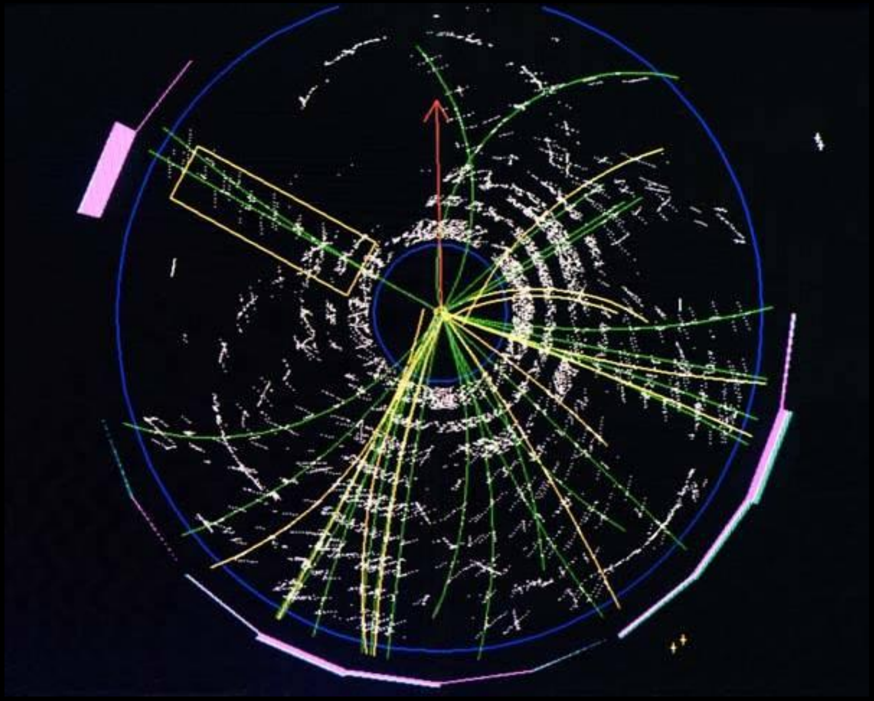
The Hunt for the Higgs
(and other interesting stuff at the Tevatron)

Robert Roser
Fermi National Accelerator Laboratory



MISSING PARTICLE:

Name: *Higgs boson*

Age: *13.7 billion years*

Missing: *45 years*

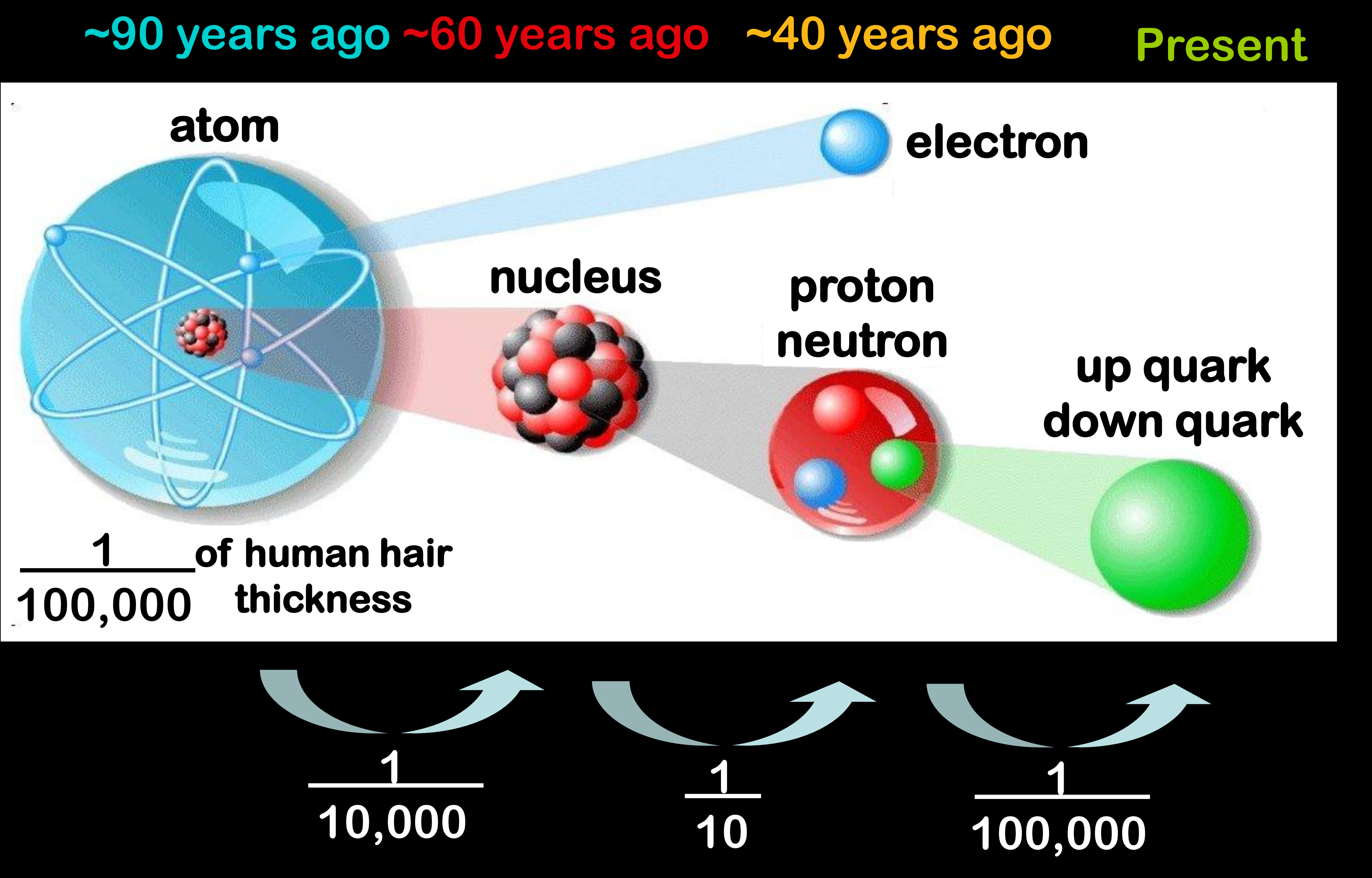
Birthday: *Every few days at Fermilab*

Favorite trait: *Mass*

Favorite particle: *top quark*

Favorite Hangout: *Tevatron*

The Past Century…

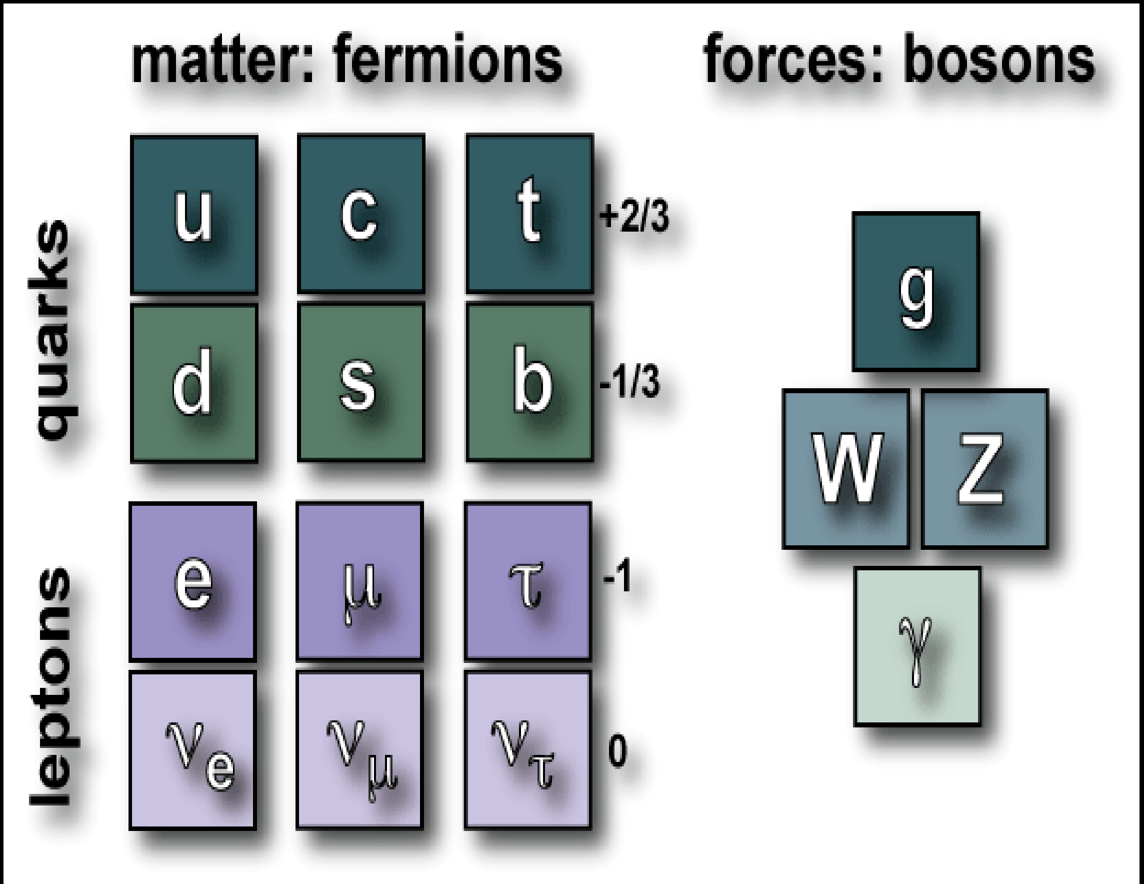


The Big Picture!

The Standard Model of Particle Physics states:
The world is comprised of Quarks and Leptons that interact by exchanging Bosons

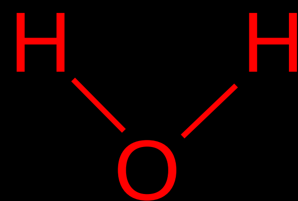
- World is comprised of quarks and leptons
- Each particle has its own anti particle
- Quarks have fractional charge!
- Good description of particles and their interactions
- Extensively tested

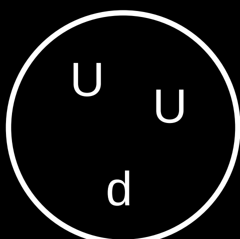
Periodic Table of the Particles



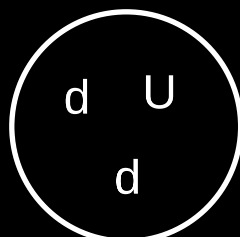
An example – Water!

- H_20



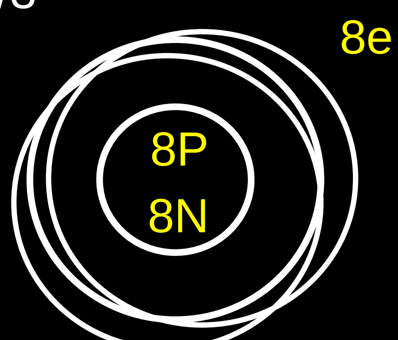


Proton
2/3+2/3-1/3



Neutron
2/3-1/3-1/3

Hydrogen



Oxygen

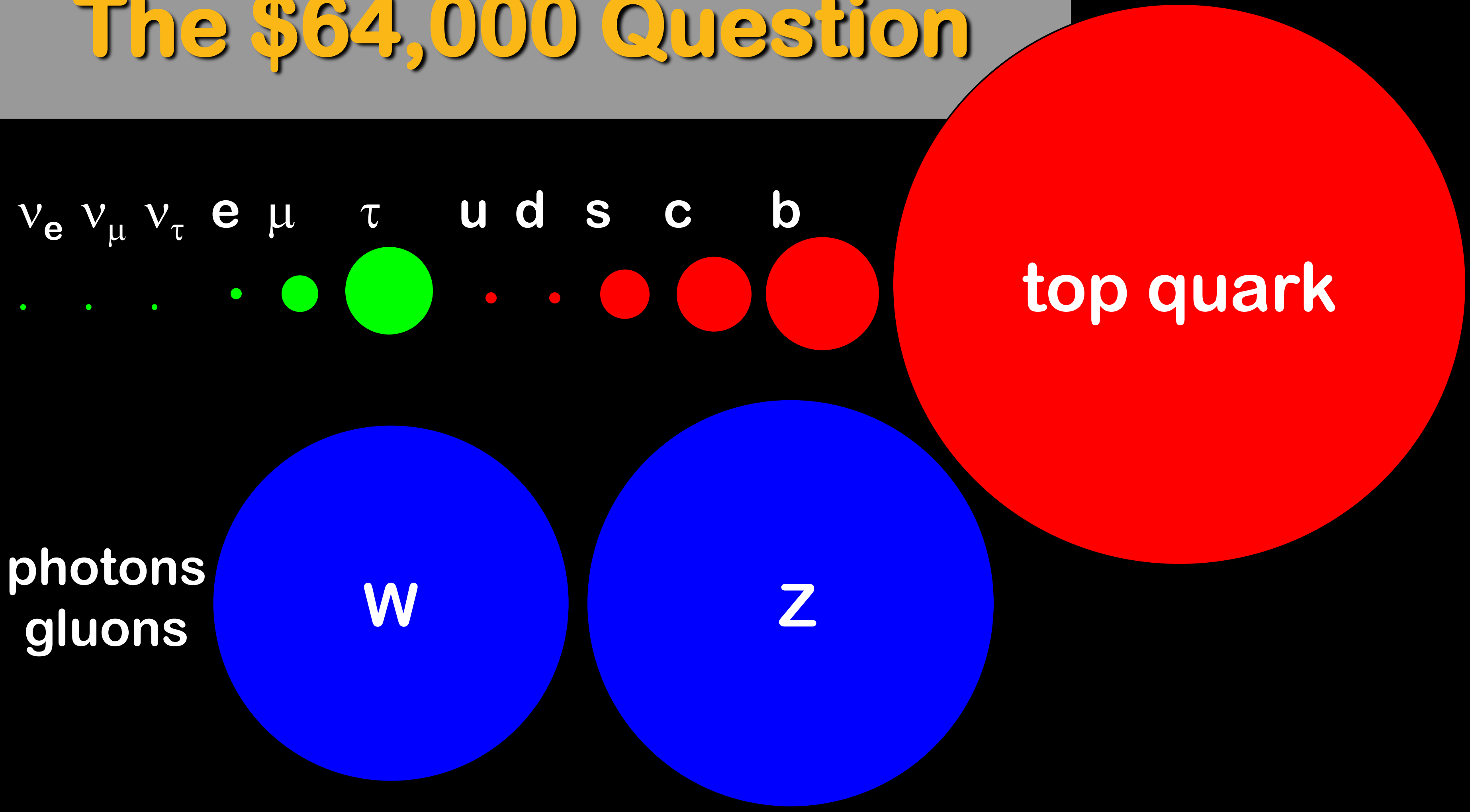
H_2O ➡

28 Up Quarks

26 down quarks

10 electrons

The $64,000 Question



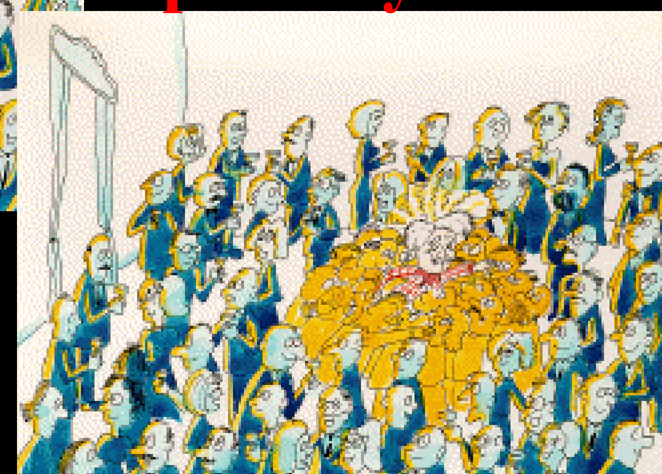
Why is top so heavy?

"Why are there so many particles?"

"<u>Where does mass come from</u>?"

Enter the Higgs Mechanism

Popularity $\propto$ Mass

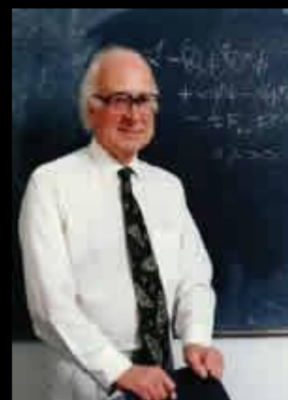


Analogy by Prof. David Miller
University College of London

2010 Sakurai Prize

... for "elucidation of the properties of spontaneous symmetry breaking in four-dimensional relativistic gauge theory and of the mechanism for the consistent generation of vector boson masses."






Engler **Brou** **Higgs** **Guralnik** **Hagen** **Kibble**

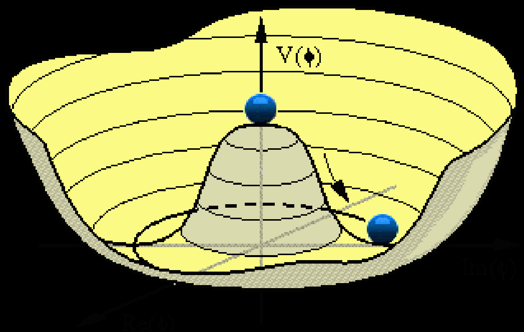
PRL 13, 321-323 (1964)   **PRL 13, 508-509 (1964**   **PRL 13, 585-587 (1964)**

So in honor of their work ...

The Solution: Brout-Englert-Higgs-Hagen-Guralnik-Kibble (BEHHGK) mechanism

[pronounced "beck", preserves author grouping, publication ordering, and much catchier than "EBHGHK"]

- Add scalar field throughout the universe
  - Potential is symmetric
  - Ground state breaks symmetry



- Cleverly
  - Masses are generated for the fermions due to their interaction with this non-zero field
  - Theory preserves symmetry (gauge invariance)
  - Standard Model calculations no longer fail
  - A new particle is predicted: the BEHHGK boson
- Finding the BEHHGK boson
  - Means BEHHGK field exists
    - Means we confirm our theory for the origin of mass

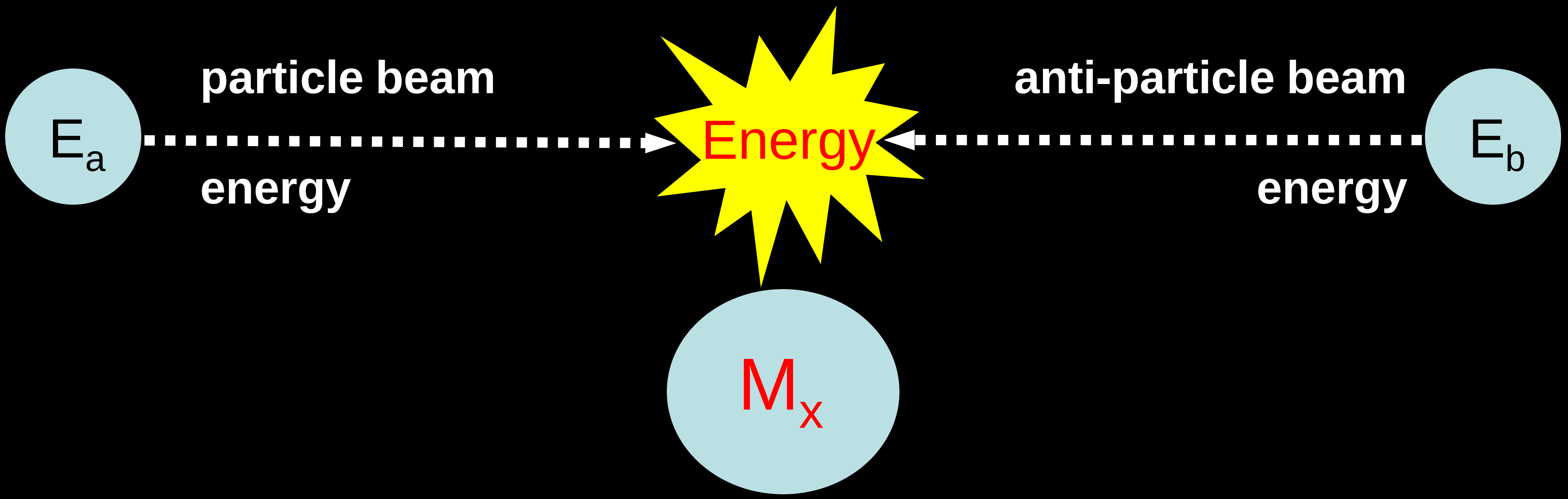
I will use “Higgs” and “BEHHGK” boson interchangeably in this talk, but will refer to the H particle

How does one search for the BEHHGK (Higgs) boson?
(or anything else for that matter)

Making Particle X

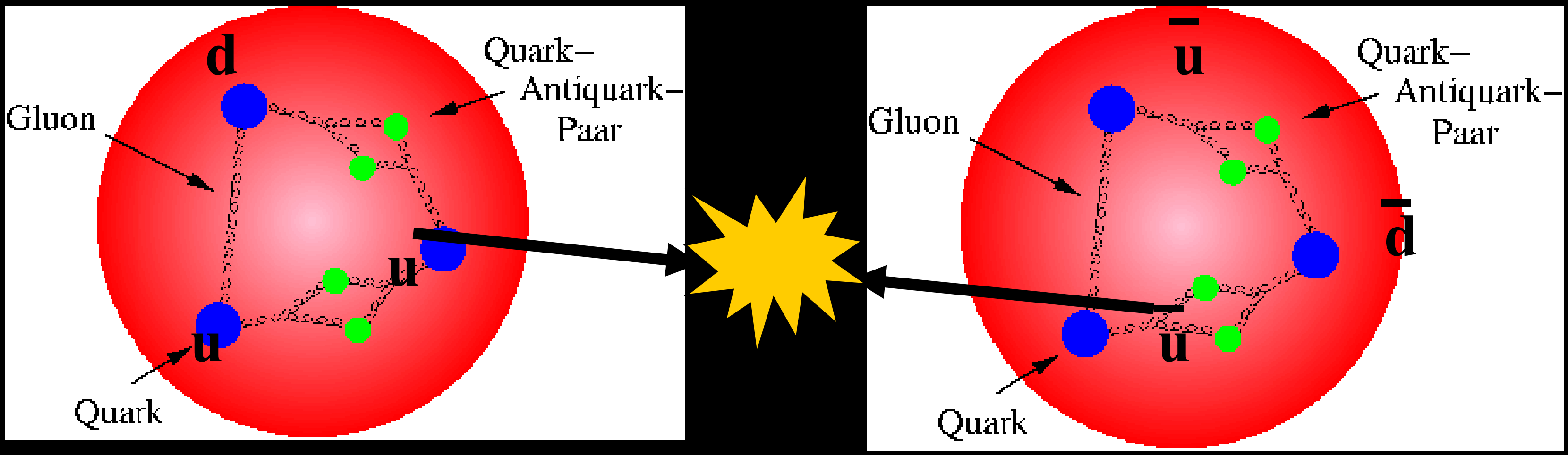
Thanks to Einstein we know that a high energy collision of particle A and B can result in the creation of particle X

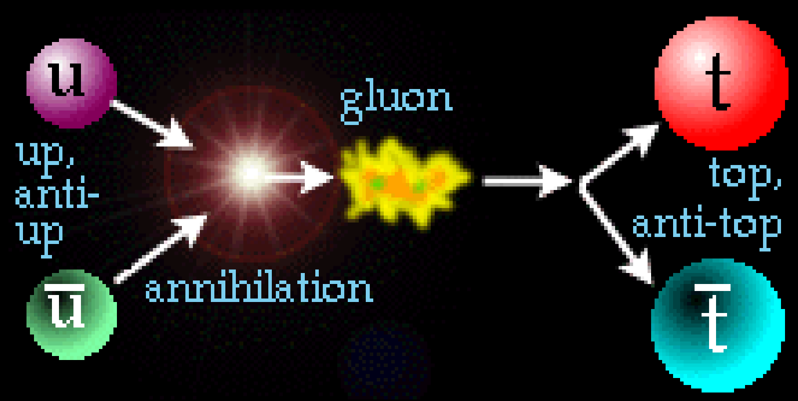
$$E = mc^2$$



As long as $E_a + E_b >> M_x c^2$

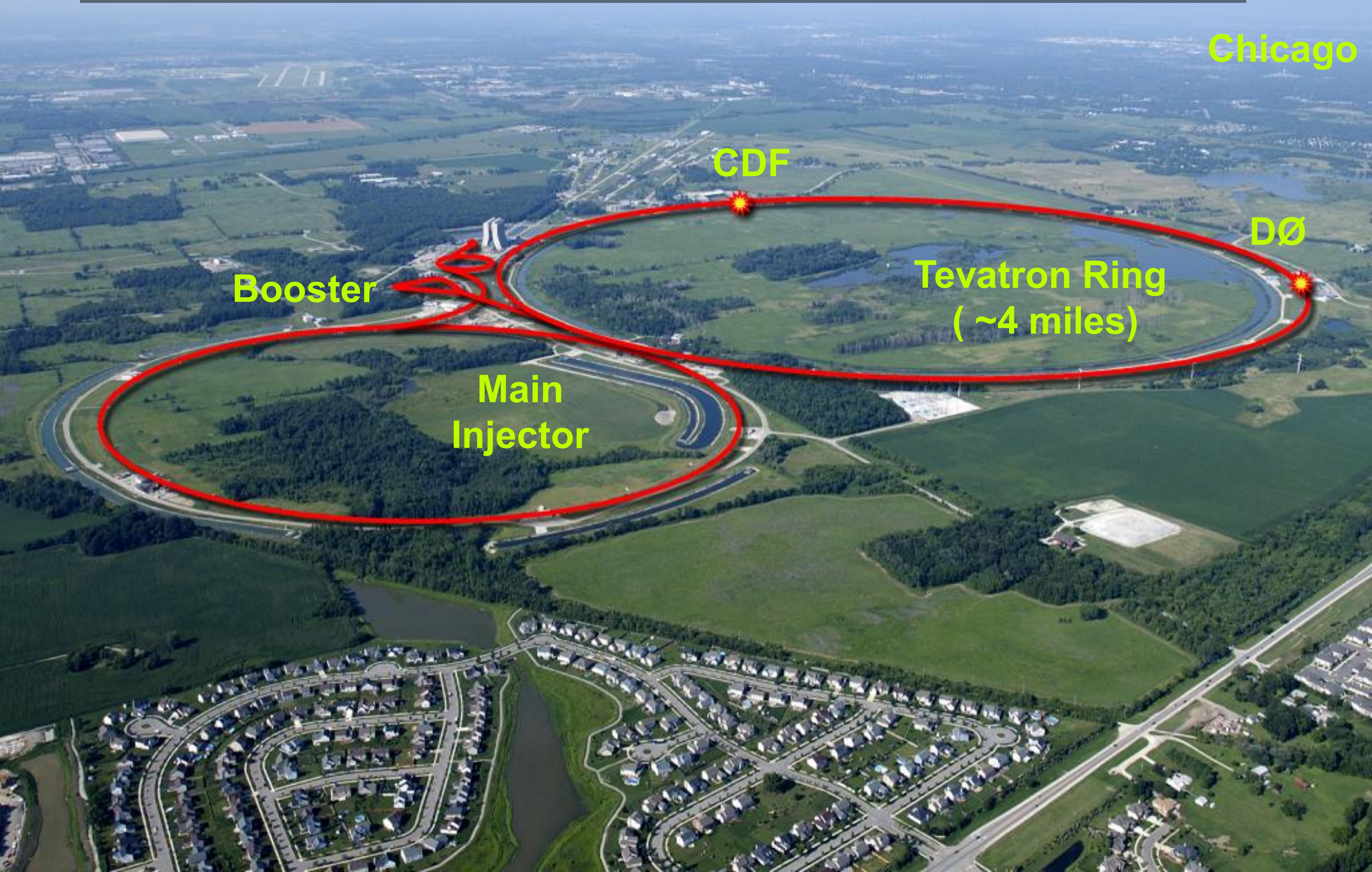
It's a bit more complicated…





$$E_u + E_{\bar{u}} >> M_t + M_{\bar{t}}$$

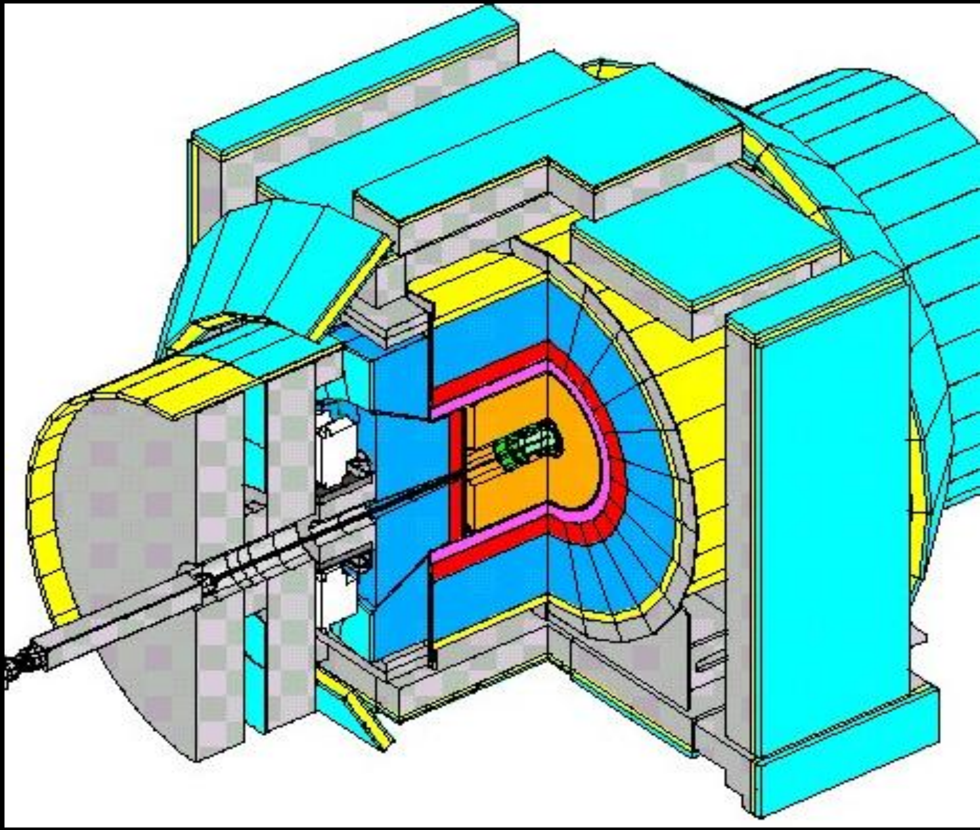
America's Most Powerful Accelerator: Fermilab's Tevatron



Colliding Beam Detectors

- Detector design is always a compromise
  - $$$
  - available space
  - technological risk
  - readout time and construction time
- Goal is to completely surround collision with detectors
- Arrange detectors in layers based on functionality
  - Measure particle's position, momentum and charge first
  - Type and kinetic energy second

CDF II Detector cross section



Collecting the Data You Want!

- The Collider Challenge
  - 1.7 Million Collisions/second inside our detectors
- Detectors
  - Very complicated with lots of information available on each collision
- The problem
  - You can't write out each collision to tape!
  - Don't worry – not every collision is interesting and warrants saving…
- The Solution
  - A Device called a "trigger"
  - Examines every event in real time and identifies the most "interesting"
  - Reject 99.991% of events and collect data at ~50-100 hz

The Life of an Experimentalist…

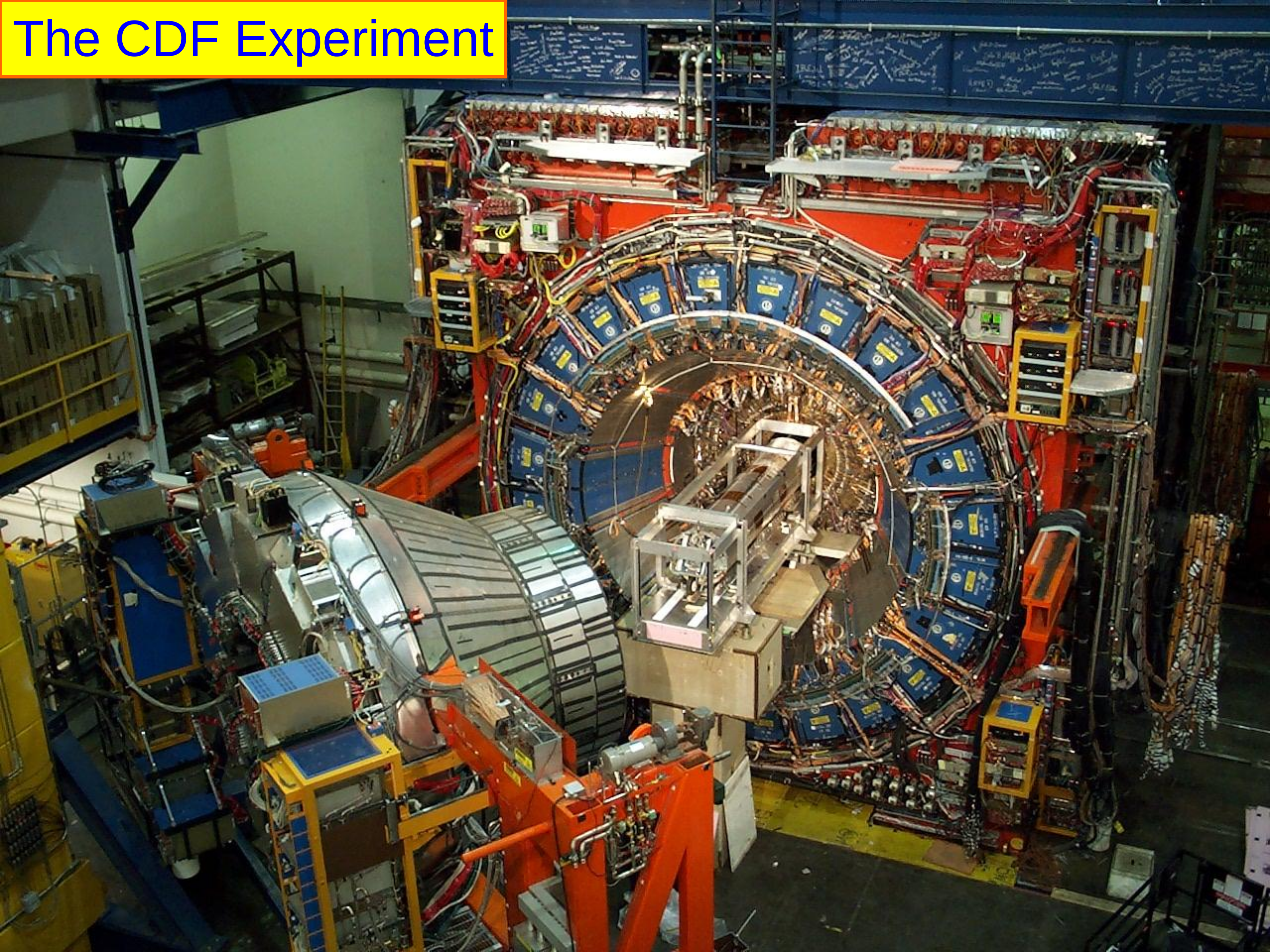
- Our "camera" is not fast enough to take a picture of say a top quark!   We have to infer based on the information provided!!!!

- What do we know?
  - Conservation of Energy
  - Conservation of Momentum
  - $E=mc^2$
- What do we want to identify?
  - Electrons
  - Muons
  - Quarks
  - Neutrinos
  - b quarks

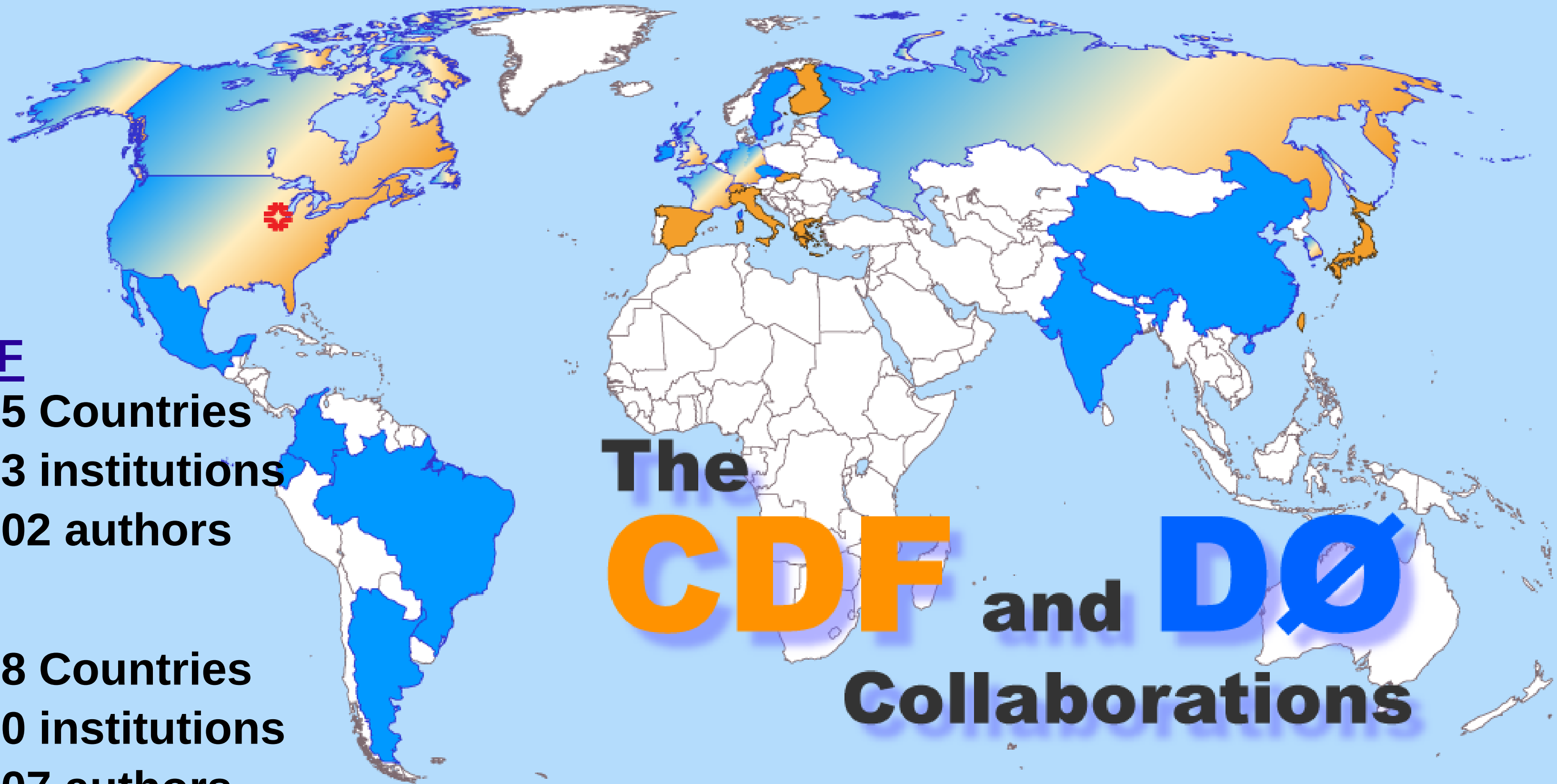
(Helps!)

The D0 Experiment

The CDF Experiment



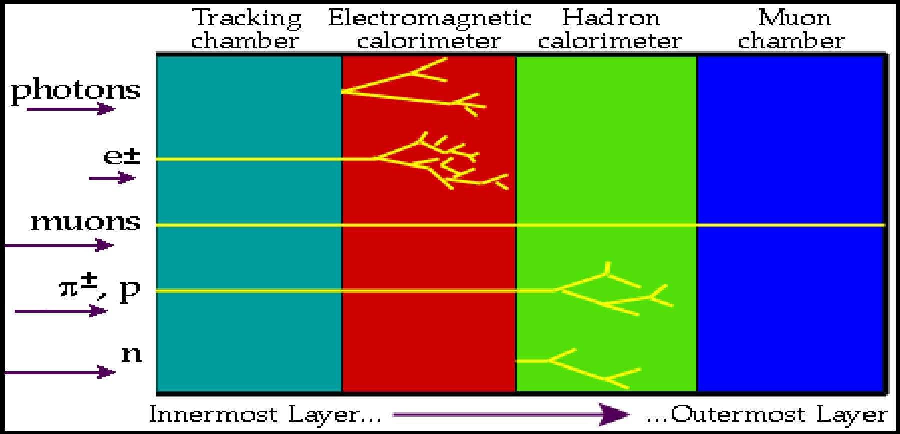
The CDF and DØ Collaborations

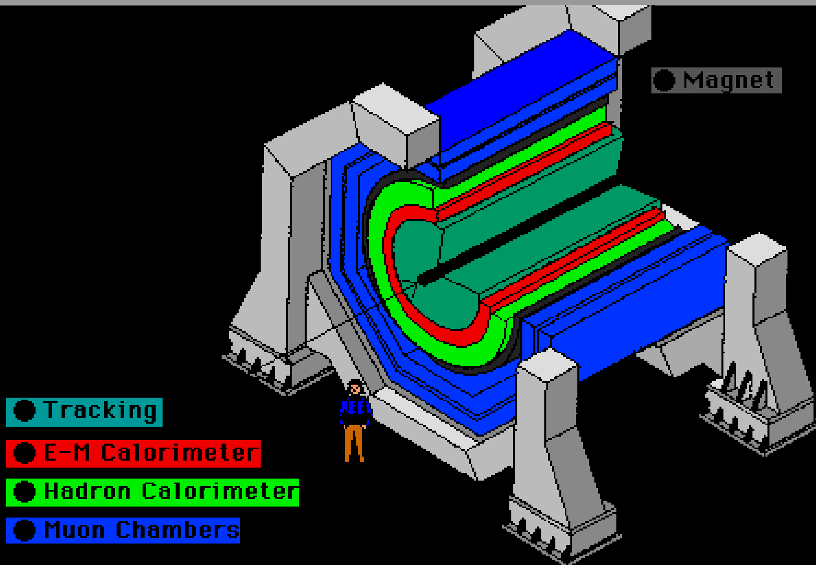


CDF
- ♦ 15 Countries
- ♦ 63 institutions
- ♦ 602 authors

D0
- ♦ 18 Countries
- ♦ 90 institutions
- ♦ 507 authors

Principle of a Collider Detector

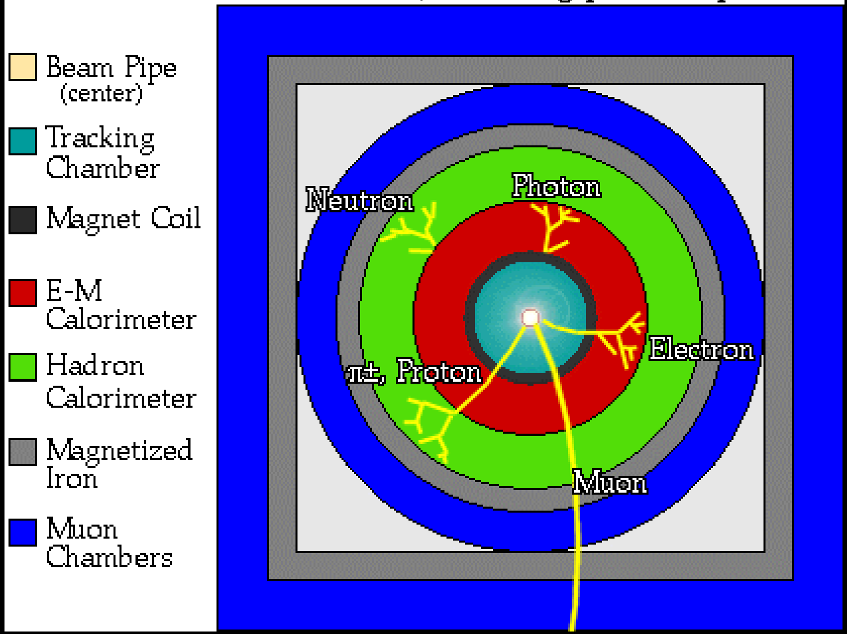




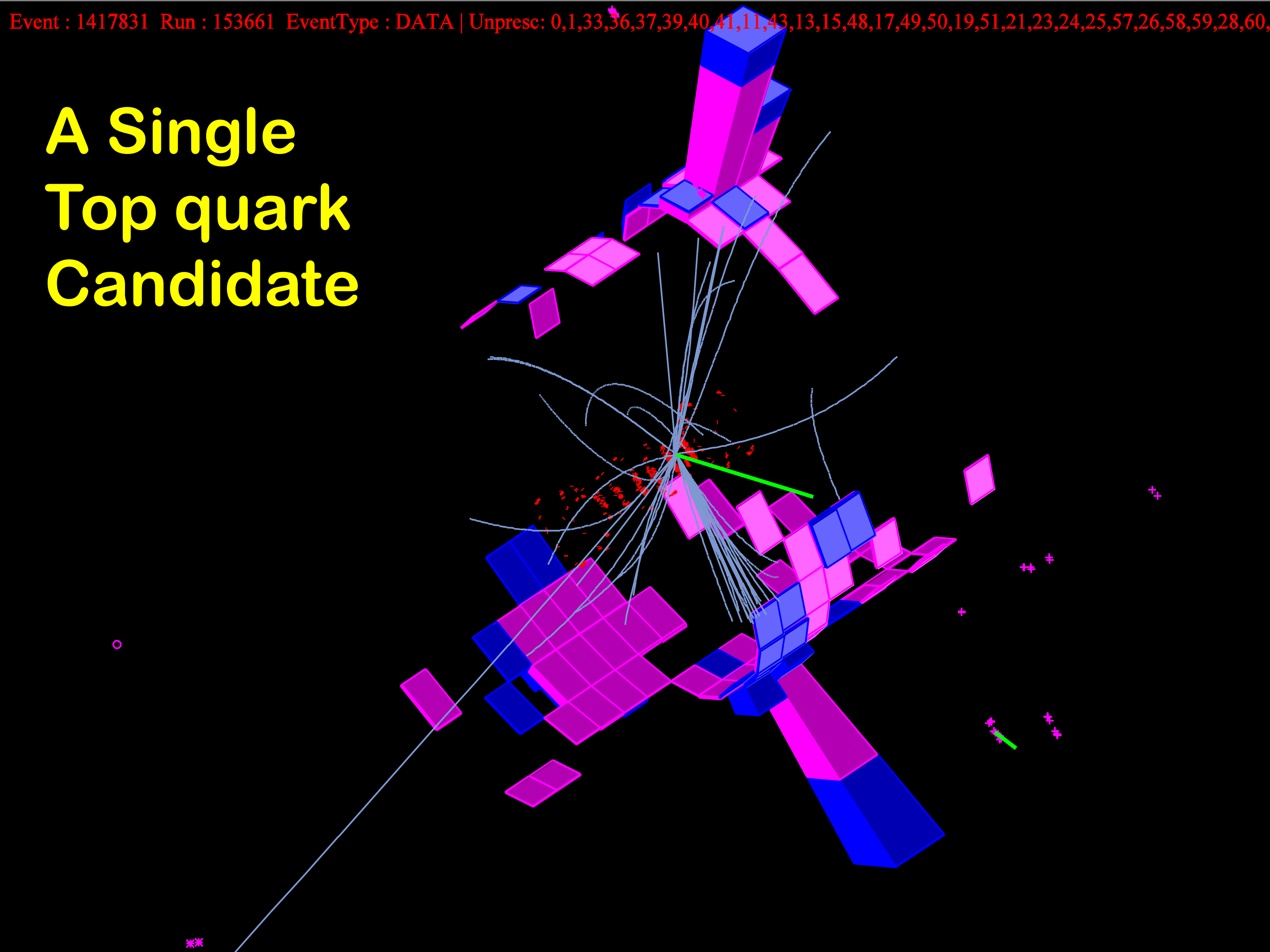
Basic principle is the **interaction of particles with matter**

- **Momentum/Charge Measurement:**
  - need to affect particle as little as possible
  - use dilute/thin absorber medium (gas, thin silicon wafers): Tracker
- **Energy Measurement:**
  - want to fully absorb particle
  - use thick absorber medium (lead, steel, uranium): Calorimeter

A detector cross-section, showing particle paths

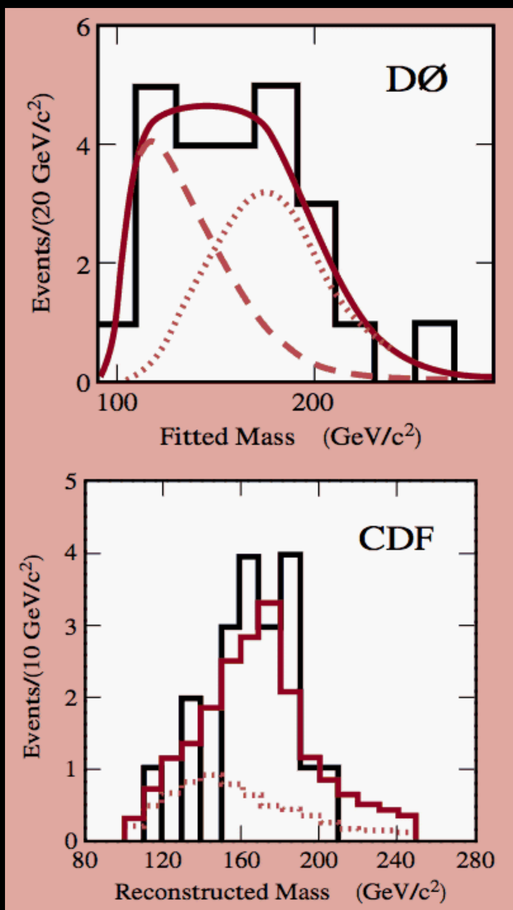


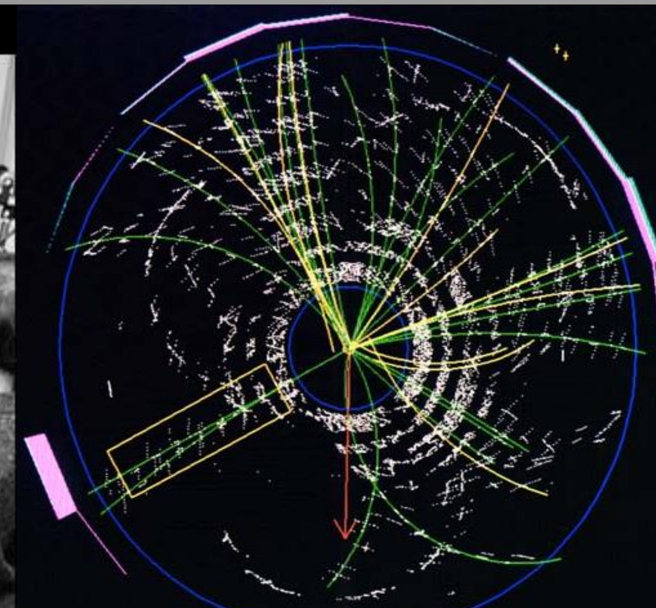
A Single Top quark Candidate

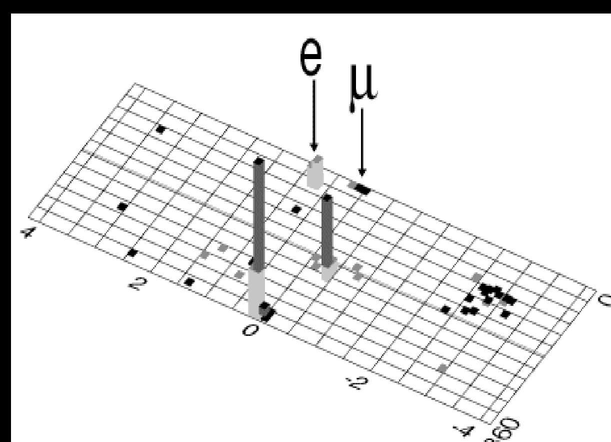


Top Quark Discovered!

1995

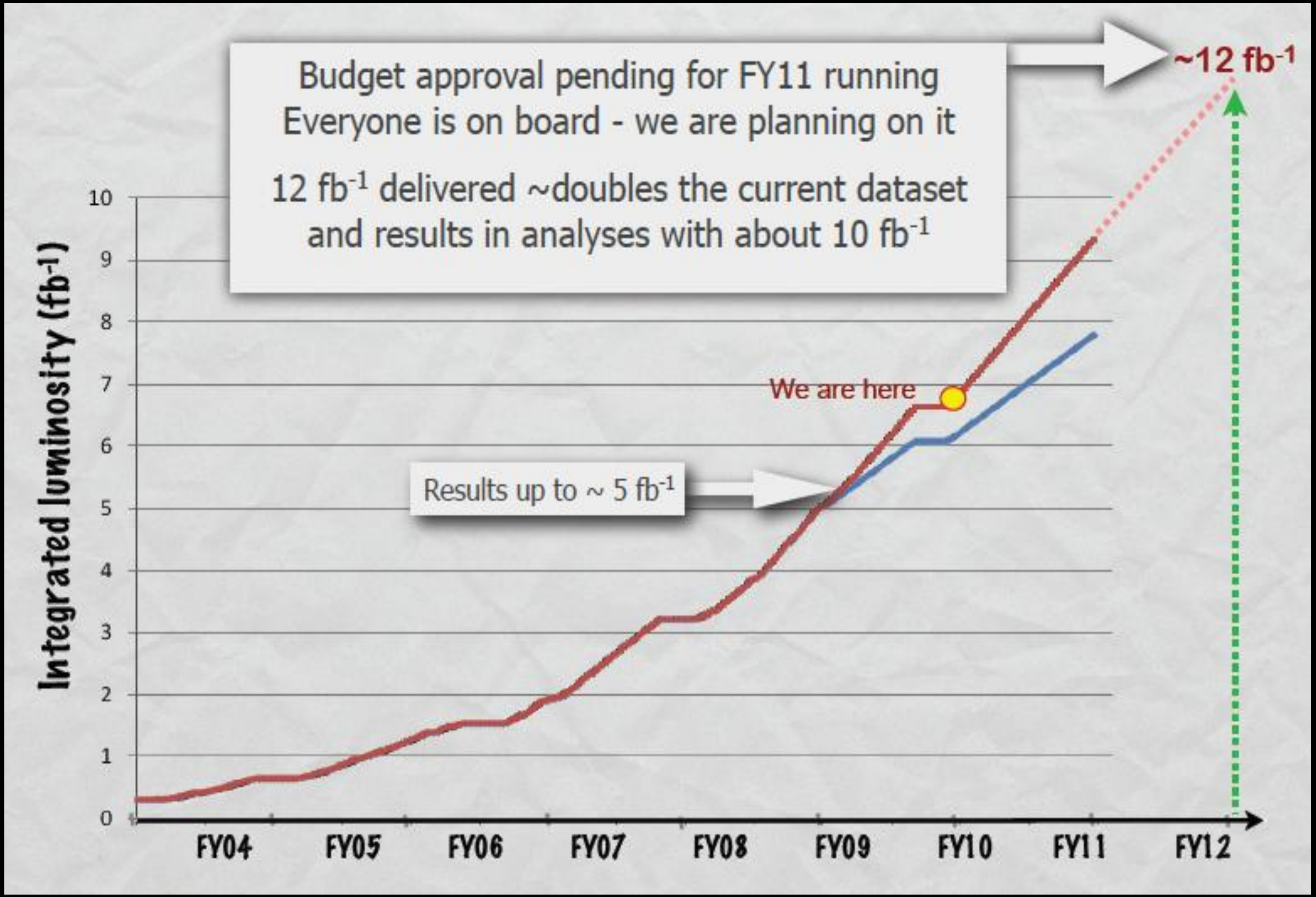






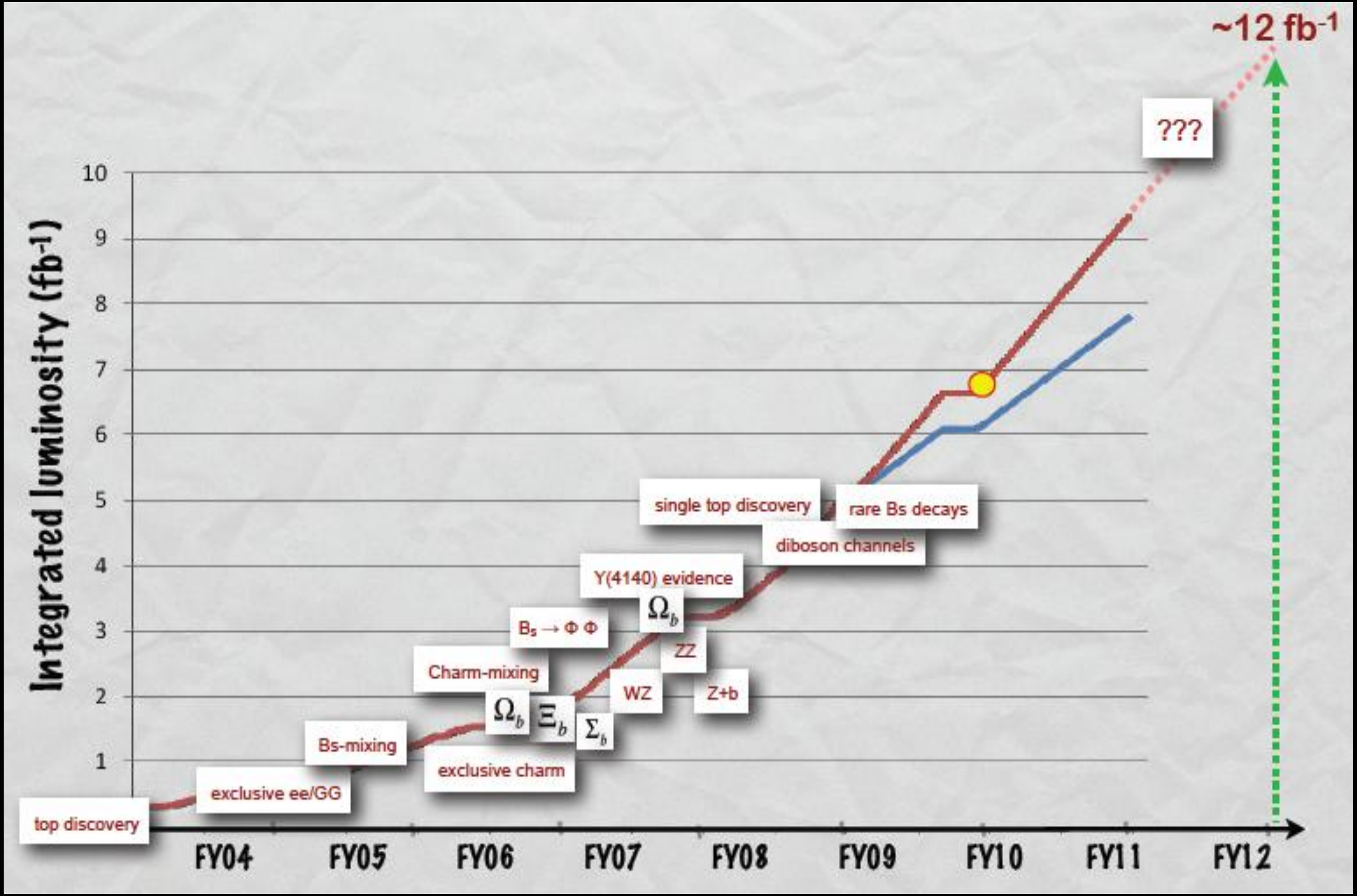
You Can Not make a Discovery with one Collision

It is a Statistical Process!

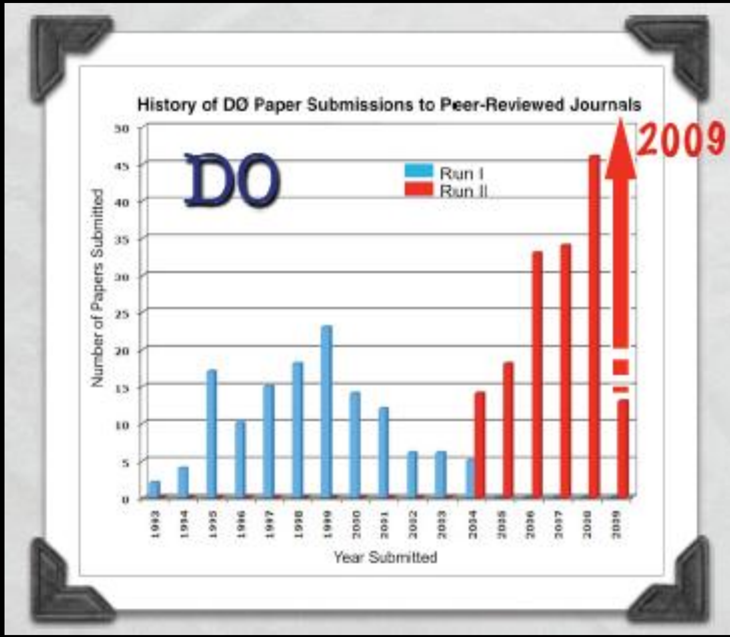


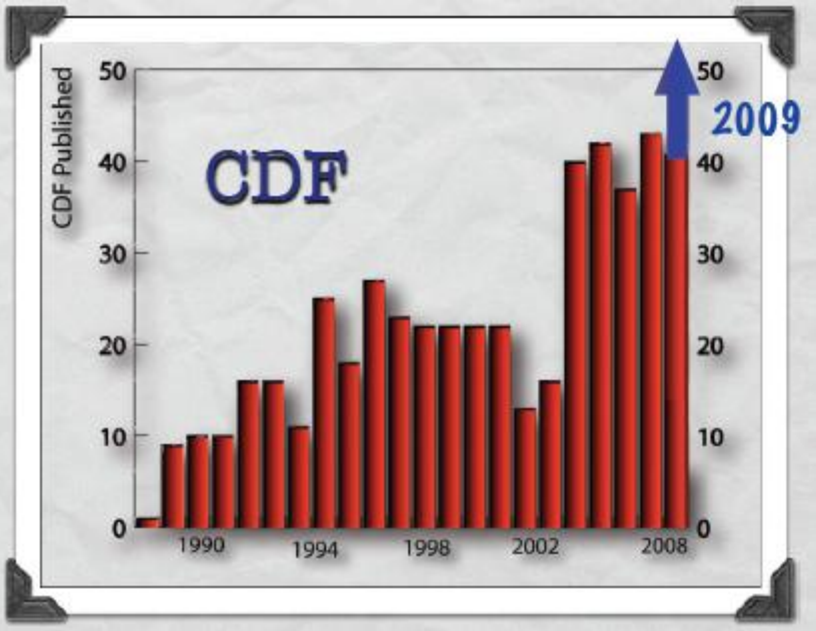
Today we have 70 times more data collected than we used to discover the top quark

New Physics Shows Up Throughout



Tevatron Physics Output





Tevatron Experiments publishing >100 papers/year

Over the last few years, ~60 PhD’s/year

Present >200 talks at conferences each year

The Tevatron Research Program

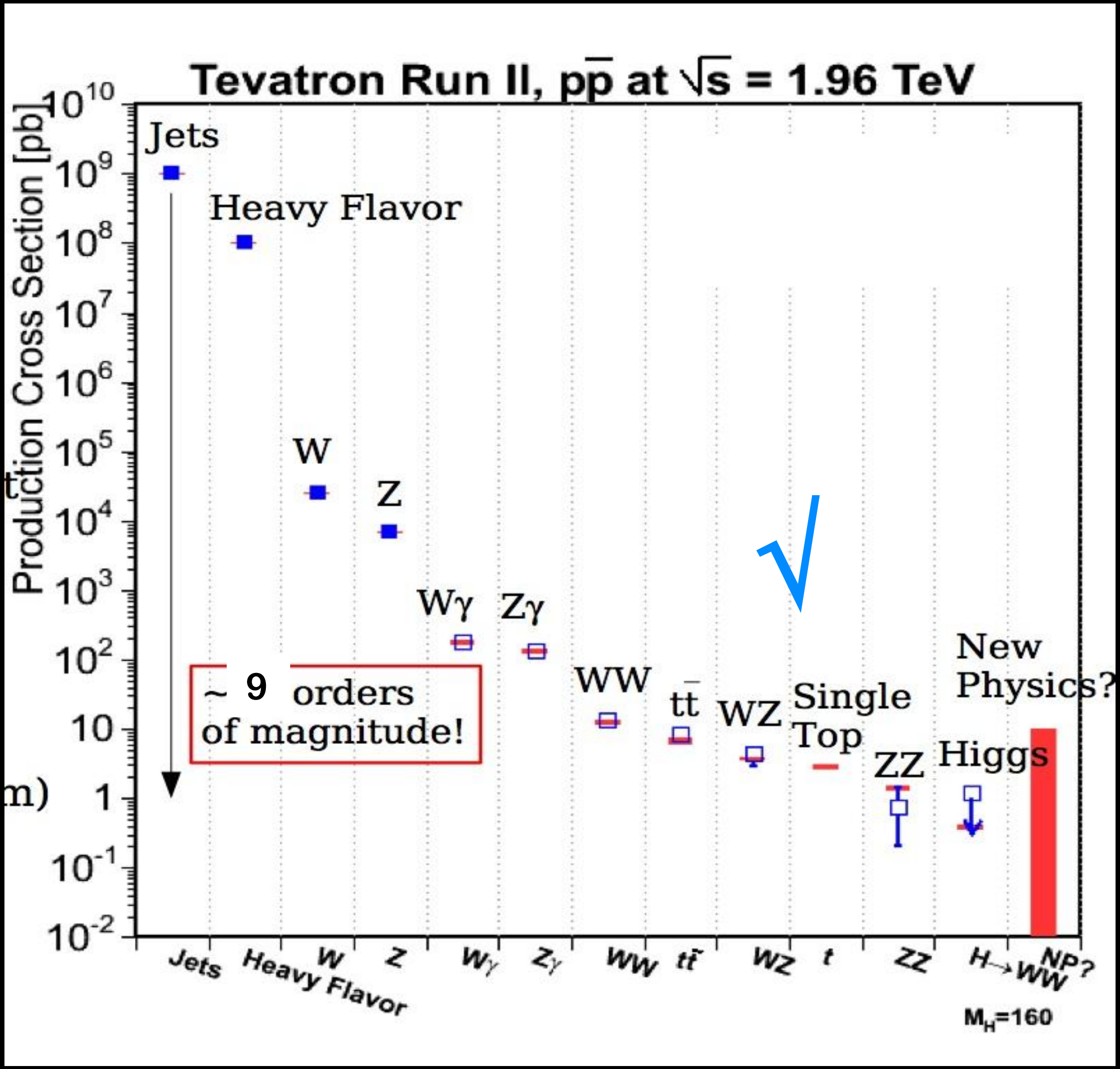
Precision, New Research Discoveries

- Mixing, CKM Constraints and CP Violation
- Heavy Flavor Spectroscopy
- New Heavy Baryon States
- Tests of Quantum Chromodynamics
- Precise measurement of Top-quark and W-boson Masses
- Top Quark Properties
- Di-Boson production and SM Gauge Couplings
- New Exclusive/Diffractive Processes

Unique Window into the unknown

- Searches for Supersymmetry, Extra Dimensions, Exotica
- Still at the Energy Frontier
  - Proobing the Terascale as the luminosity increases
- The Standard Model BEHHGK (Higgs) Boson is within reach!

A Roadmap to discovery…

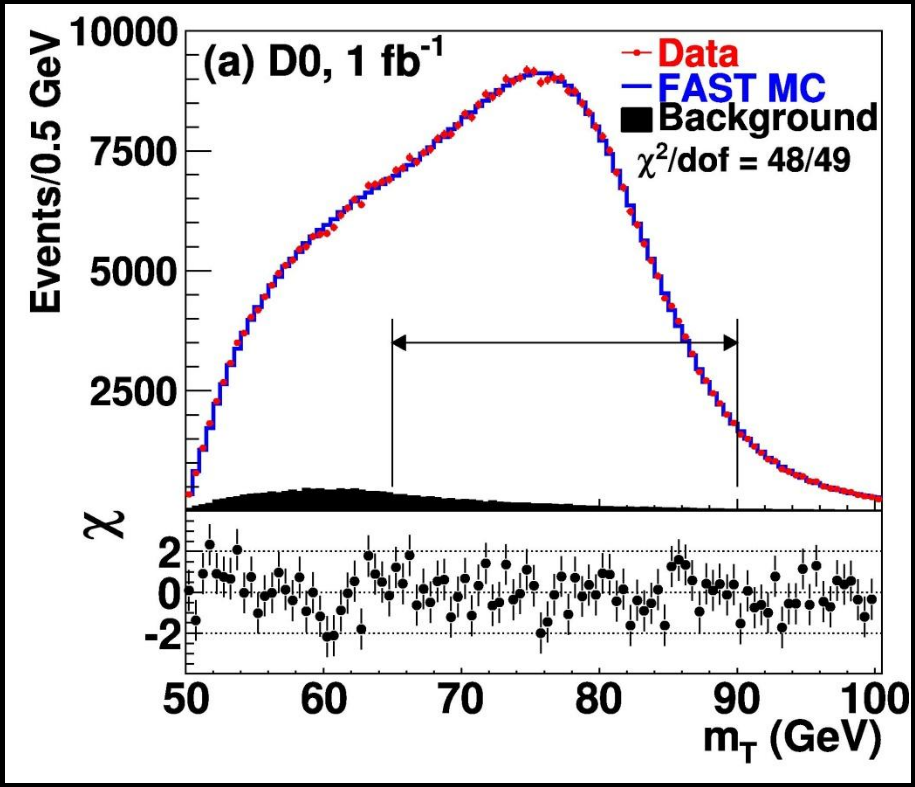


Harder to Produce

Harder to Observe

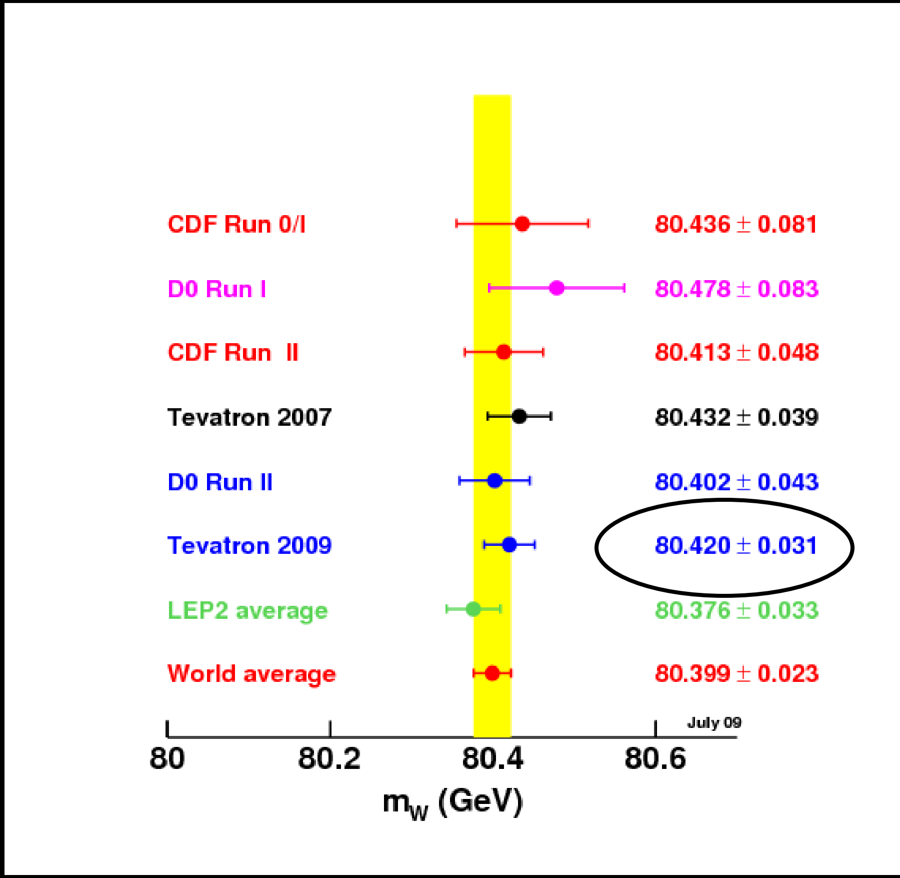
The road to the BEHHGK (Higgs)

W Mass Summary

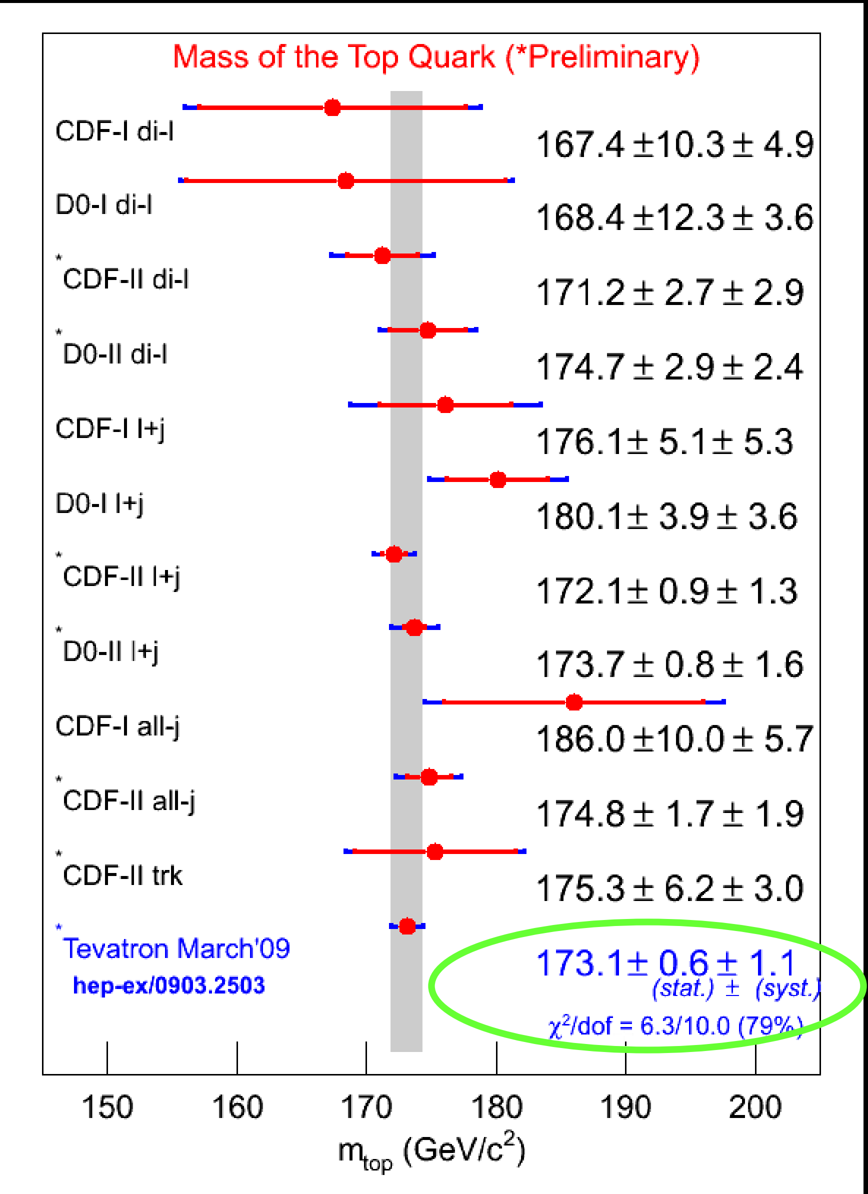


Tevatron has worlds best measurement

M_W = 80.399 ± 0.023 GeV



Summary of Top Mass



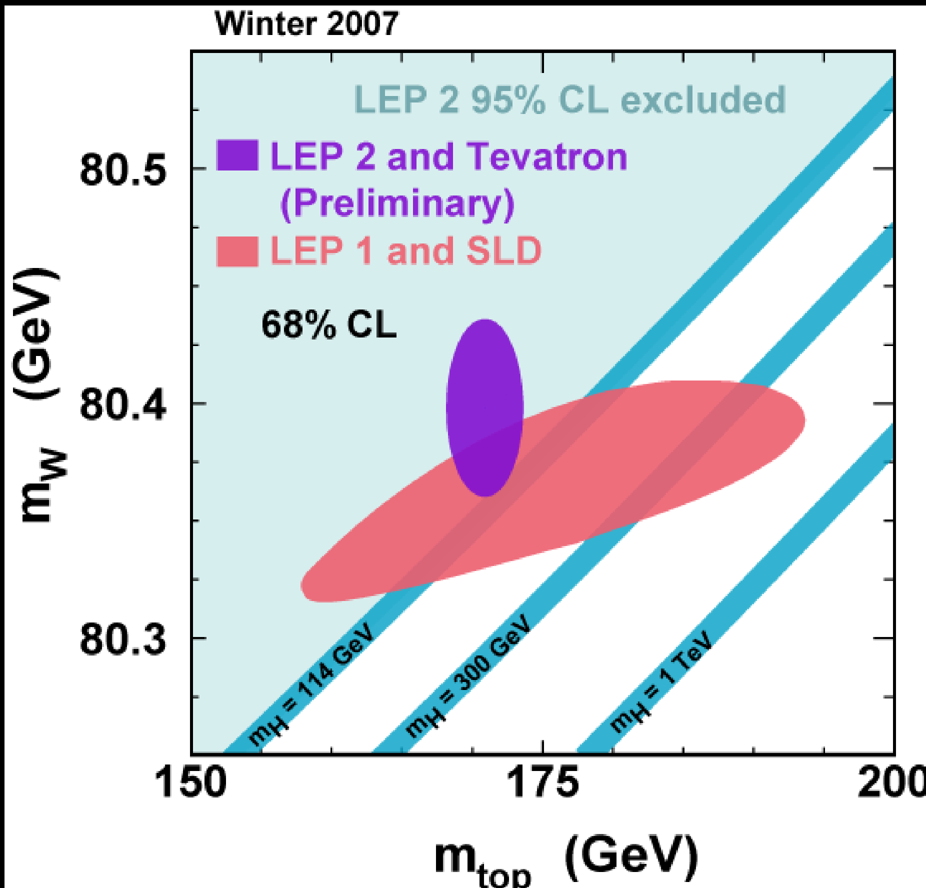
M_t = 173.1 ± 1.2 GeV

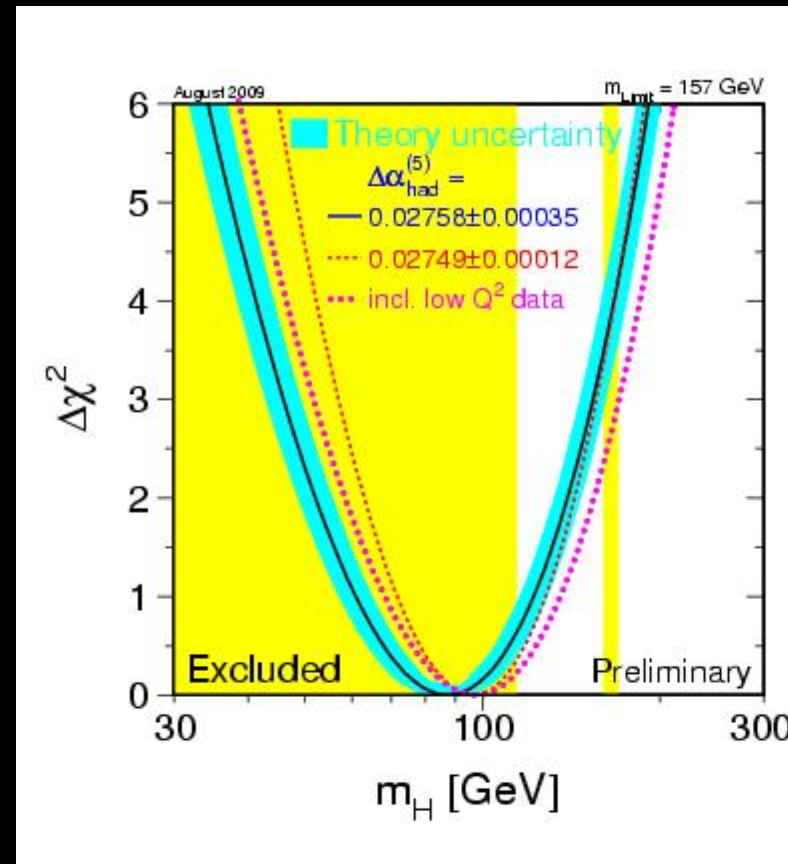
<1% Precision

We now know the mass of the top quark with better precision than any other quark!!!

15 short years from discovery to this….

Where is the BEHHGK (Higgs) Hiding?



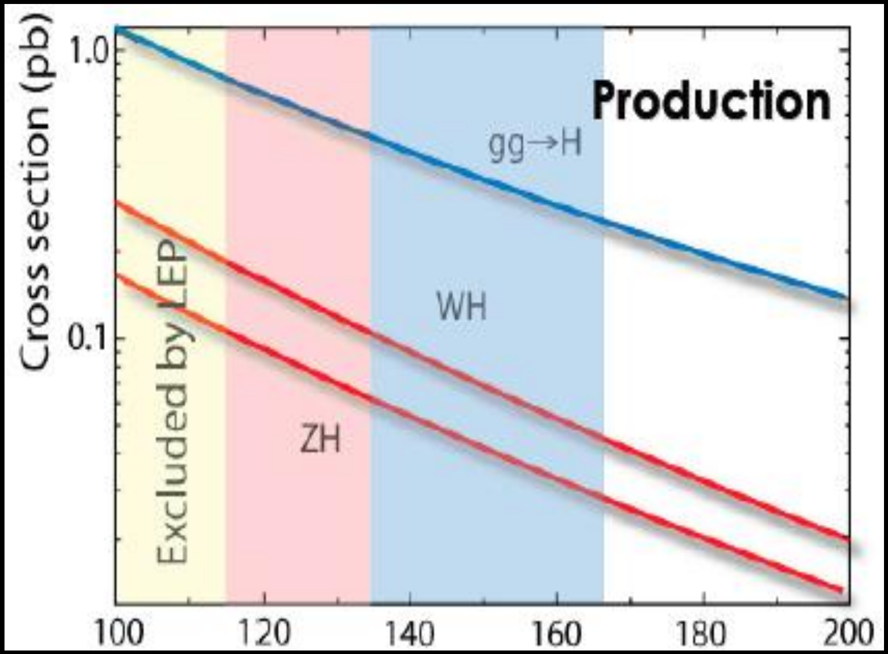


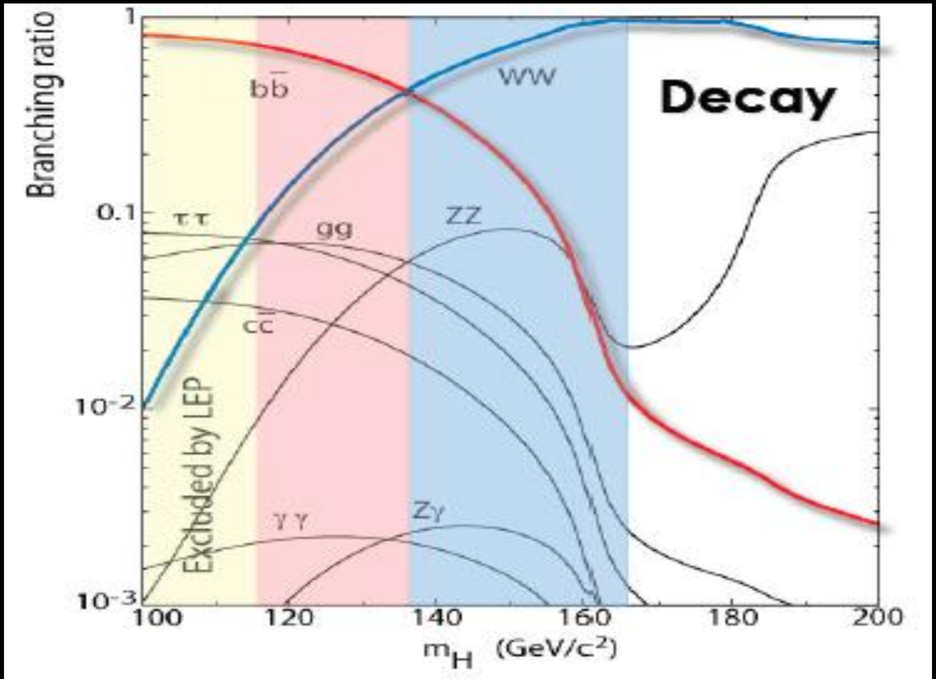
Mw vs Mtop

$M_H < 157$ GeV at 95% C.L.

Preferred $M_H - 87^{+35}_{-26}$ GeV

Higgs Production and Decay



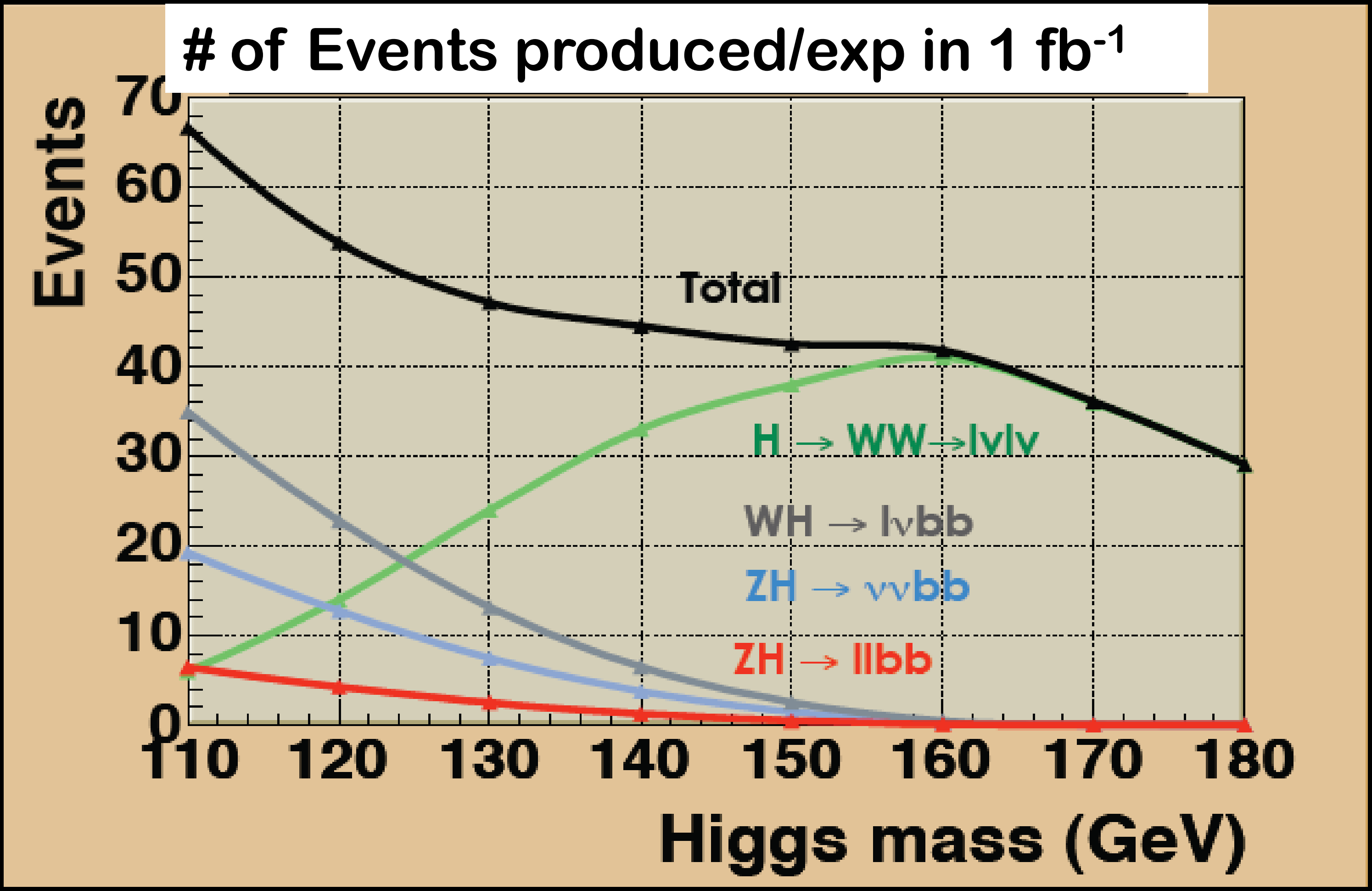


Higgs are produced in several diferent ways…

Higgs decay into different "final states" depending on the mass of the Higgs

To find it, we need to look at all these final decay states and combine the results

The Challenge



These are production numbers –
trigger, acceptance etc.not yet factored in…

Doing the Math…

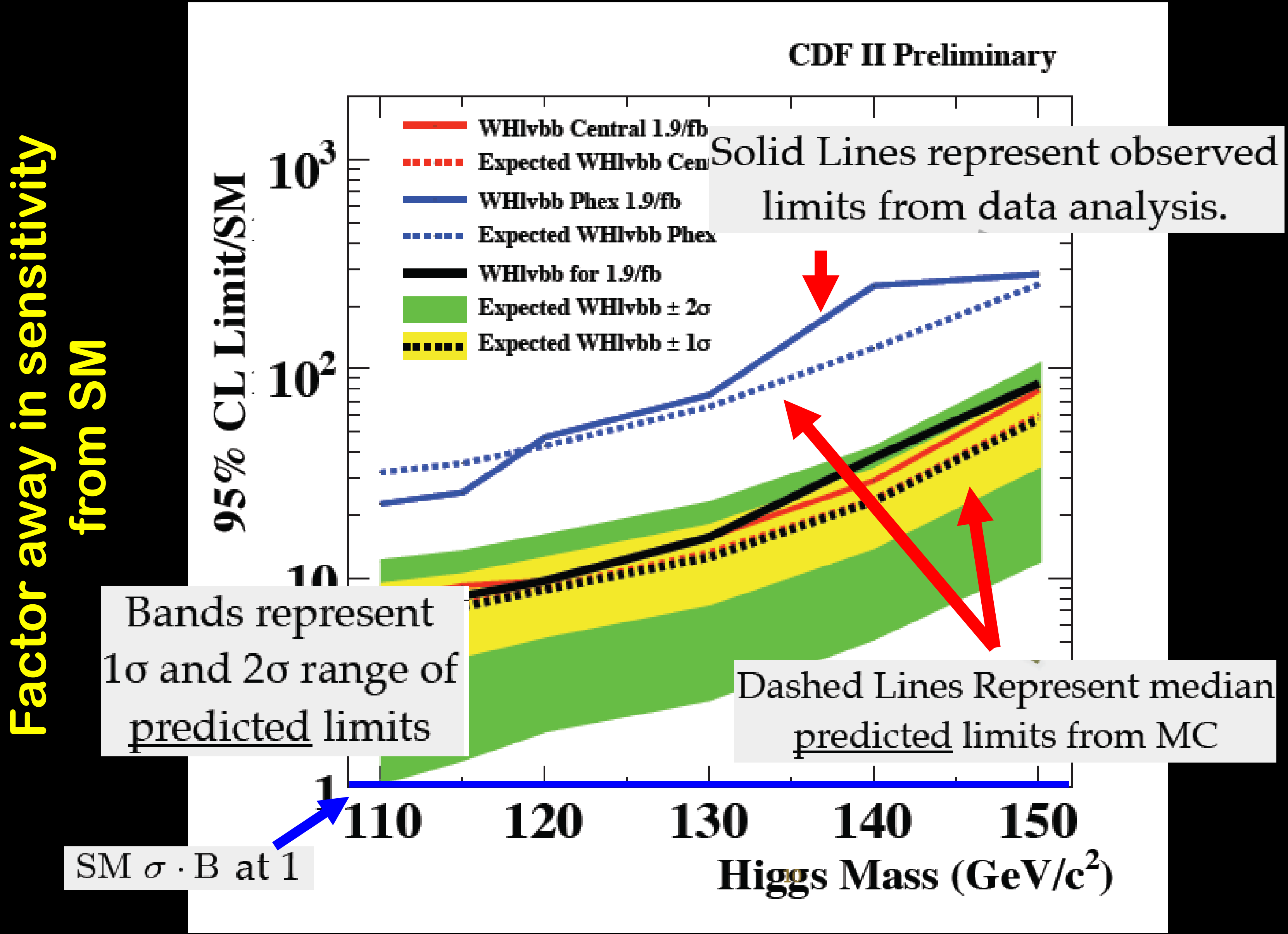
From the previos page…. we expect to make 40-60 Higgs events inside each detector for every 1/fb of data

We now have 6 /fb of data – so we expect to have made 250-350 BEHHGK (Higgs) candidates

If our efficiency for finding them is a few percent, we are trying locate a handful of events out of billions of collisons!

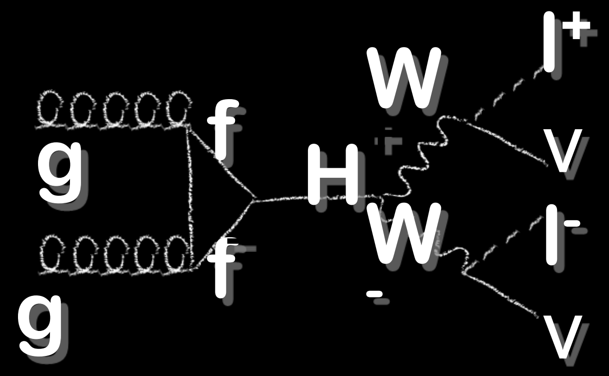
This is a Hard Way to Make a Living!!!

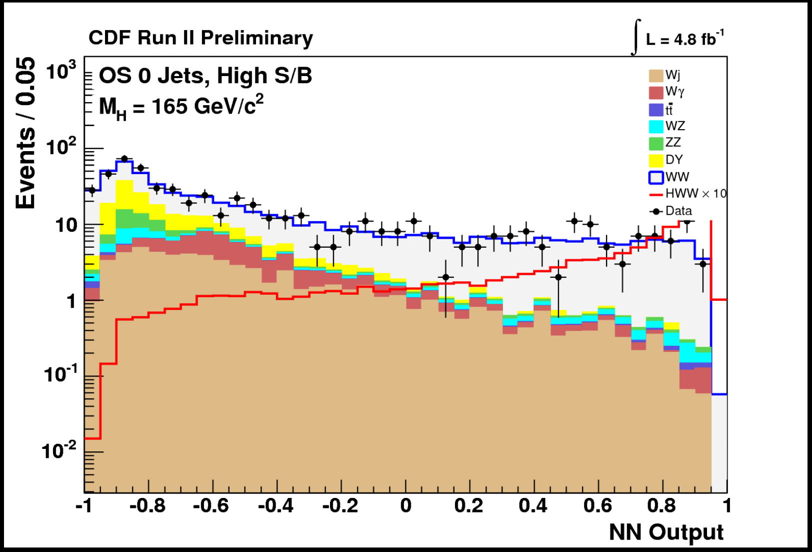
Decoding Limit Plots 101

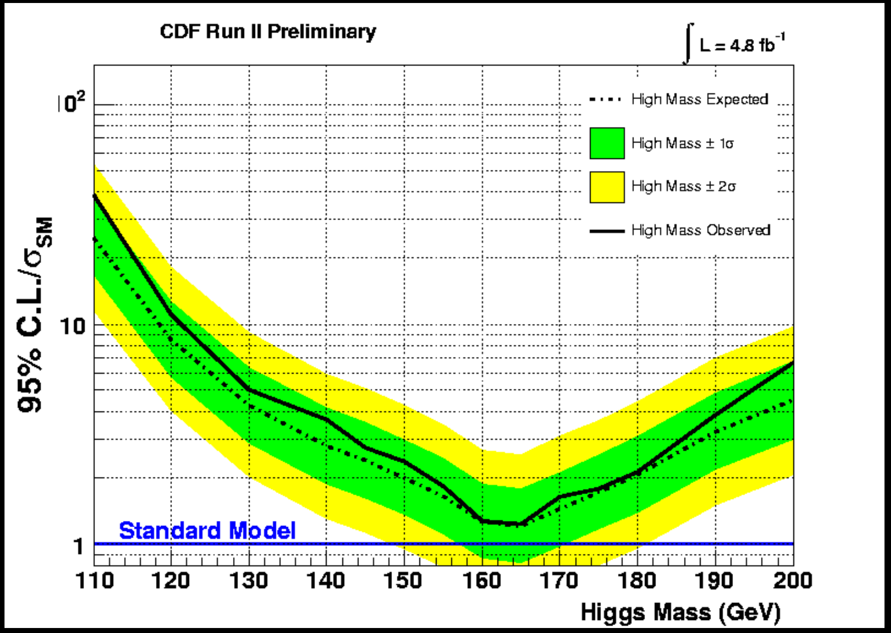


An Example -- Higgs →WW

- Signature: Two high pT leptons and Missing Energy
  - Primary backgrounds: WW and top in di-lepton decay channel
  - Key issue: Maximizing lepton acceptance
- Most sensitive Higgs search channel at the Tevatron

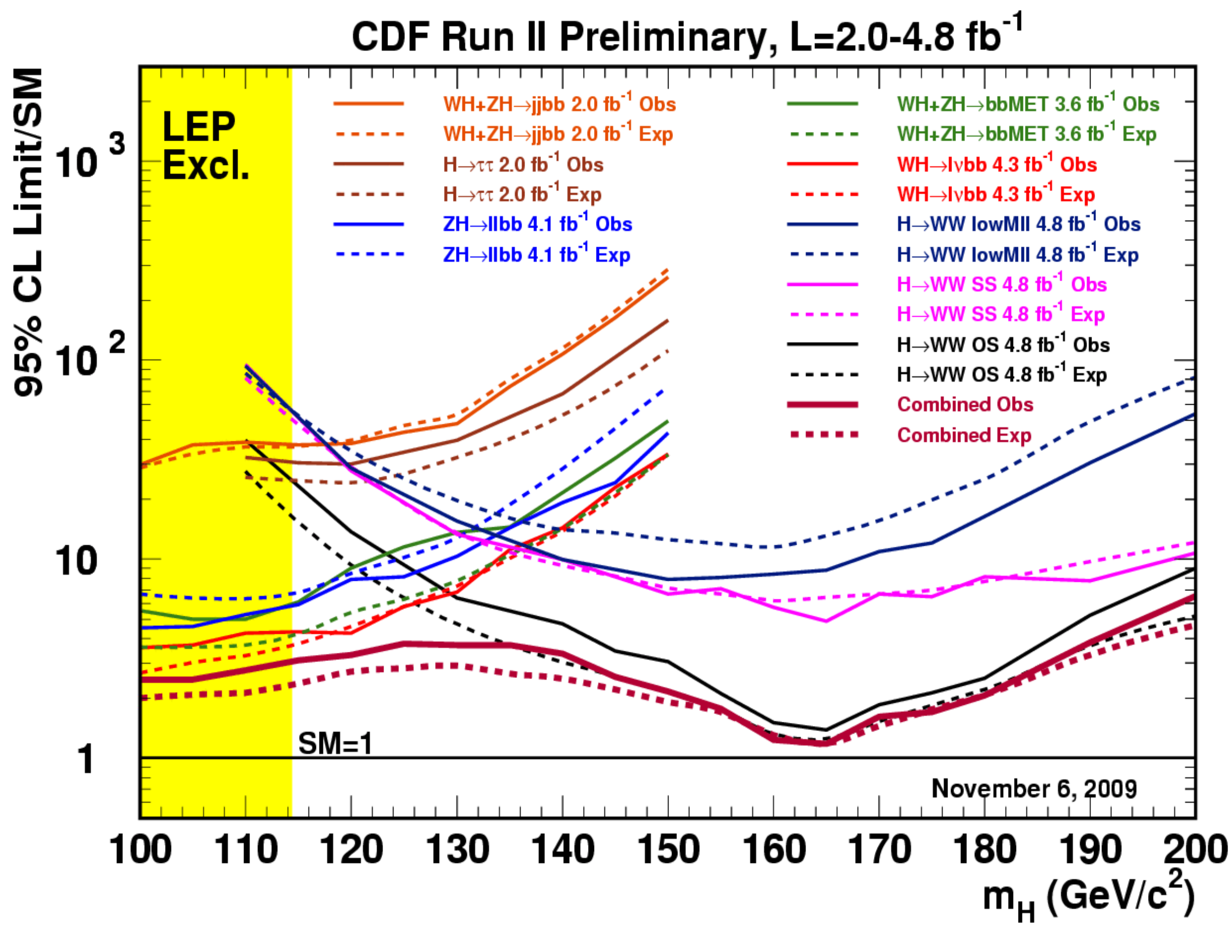






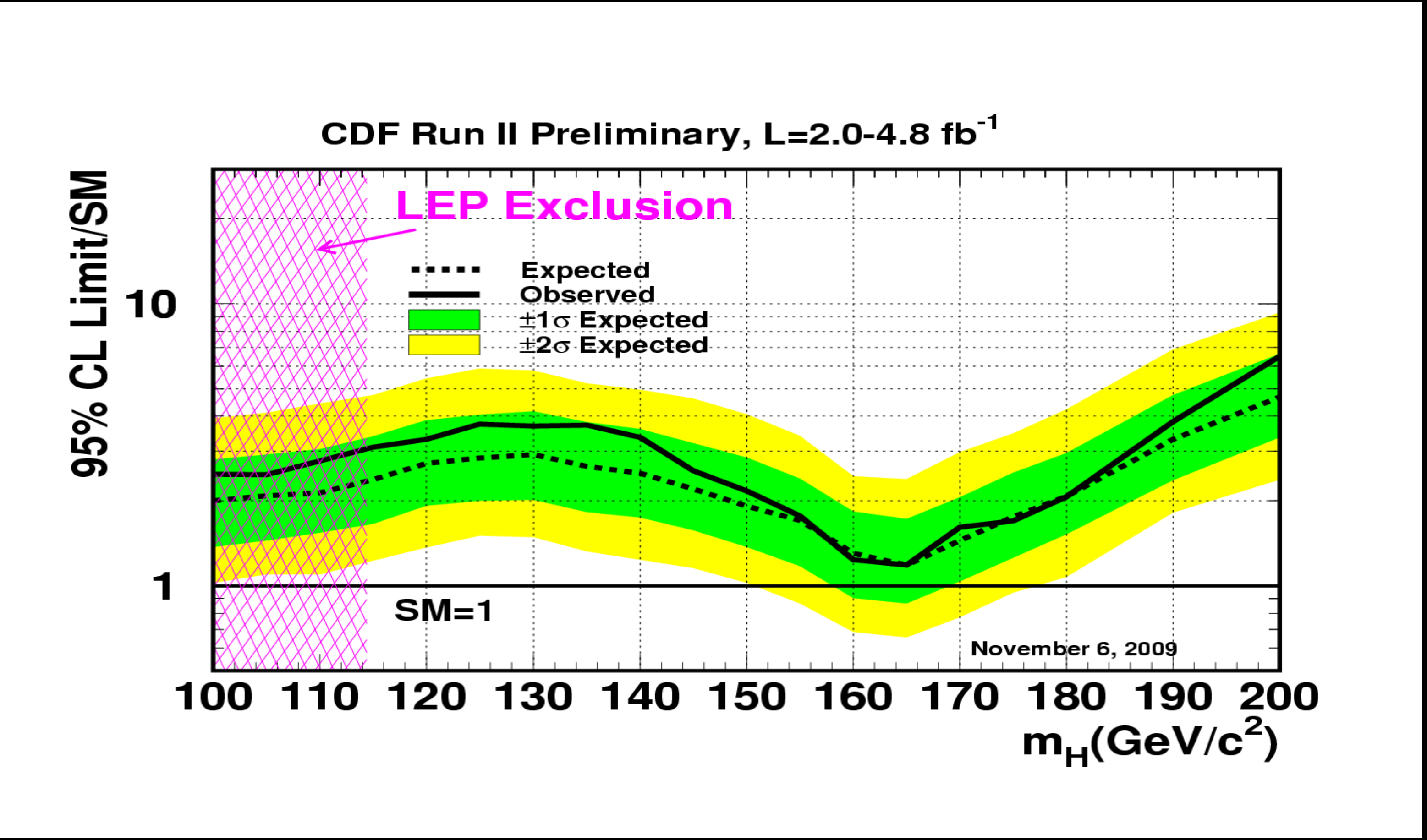
One Experiment's Channel Combination

Factor away in sensitivity
from SM



One Experiment's Channel Combination

Factor away in sensitivity from SM

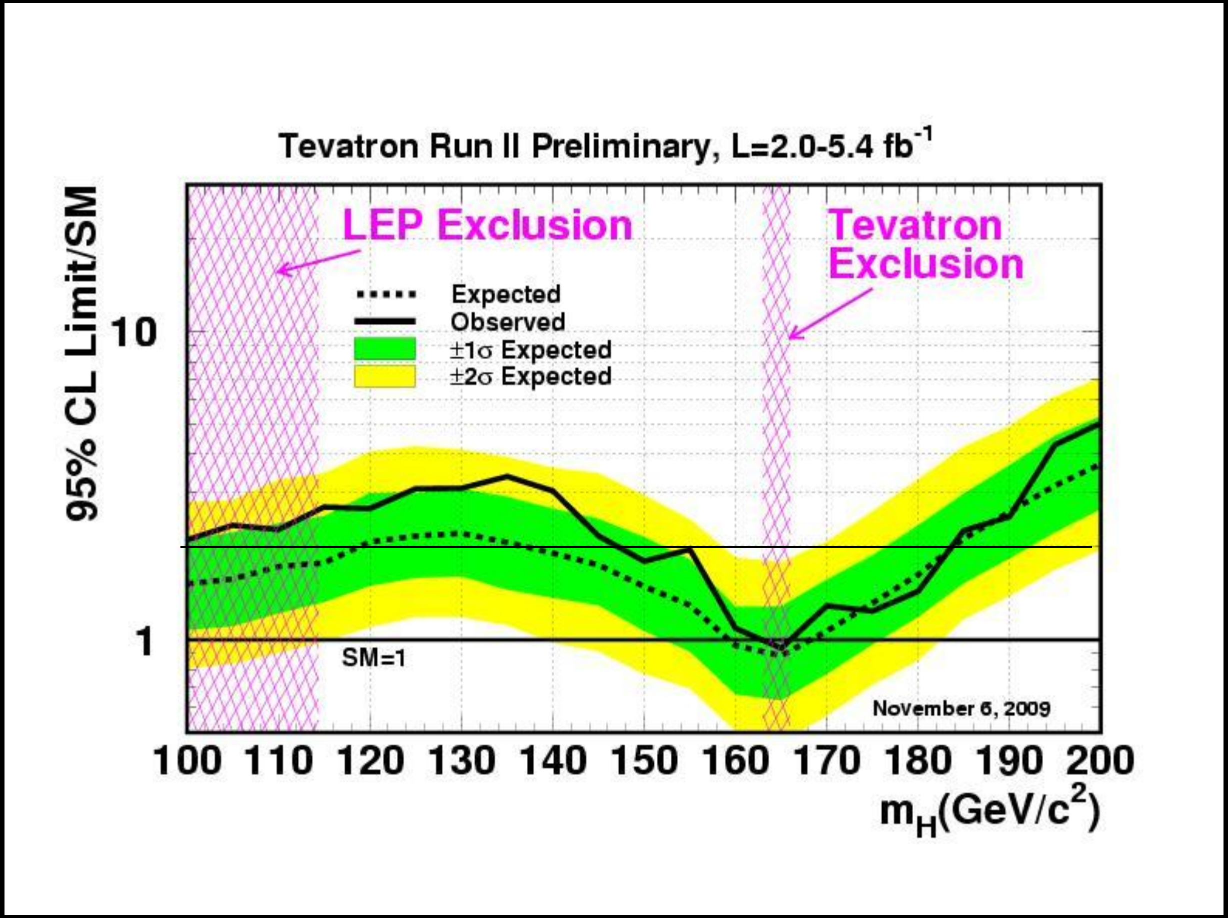


- Statistically combine channels
- Use a procedure to account for correlated uncertainties

Combine Experiments

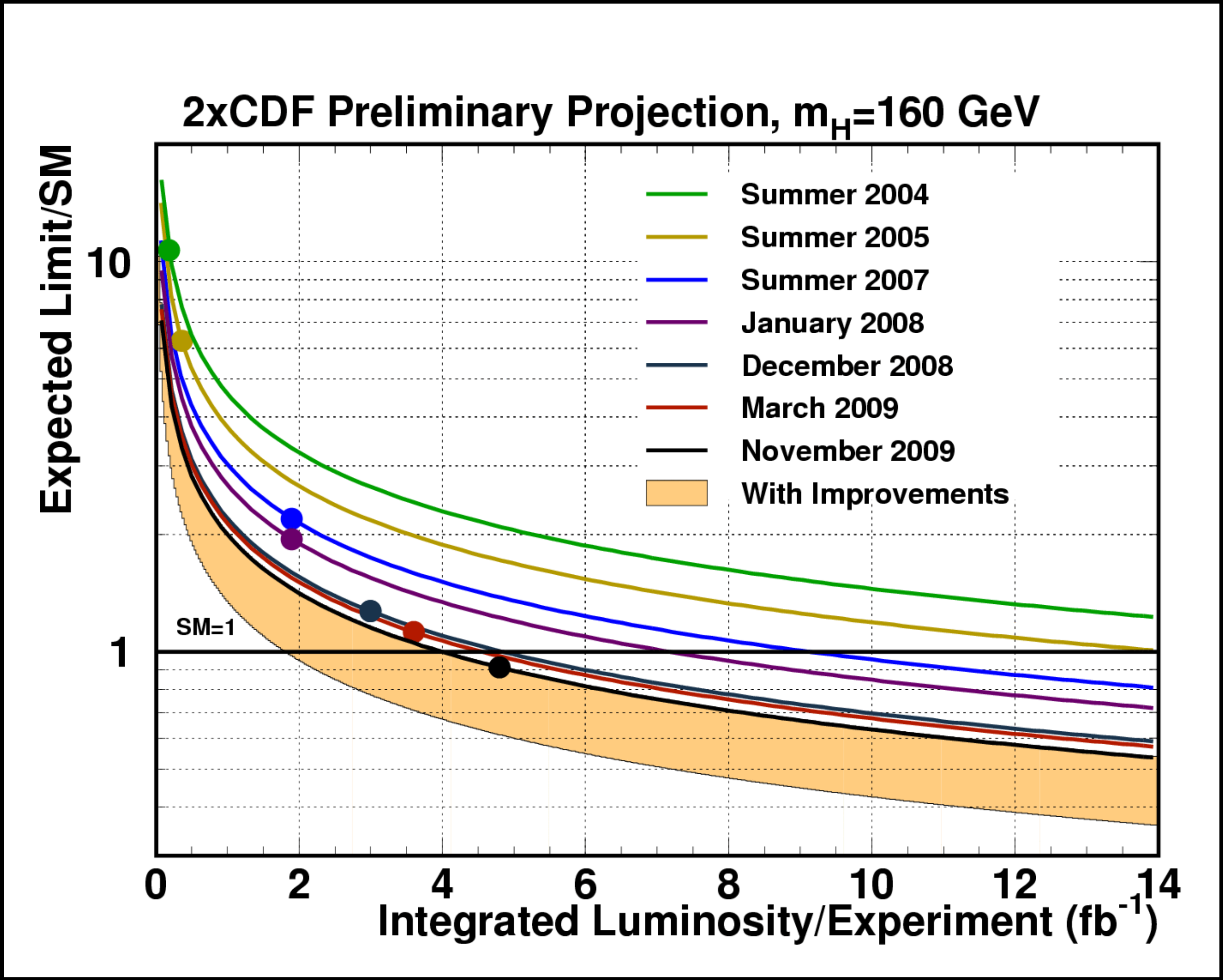
Neither experiment has sufficient power to span the entire mass range using the luminosity we expect to acquire in Run II

Factor away in sensitivity from SM



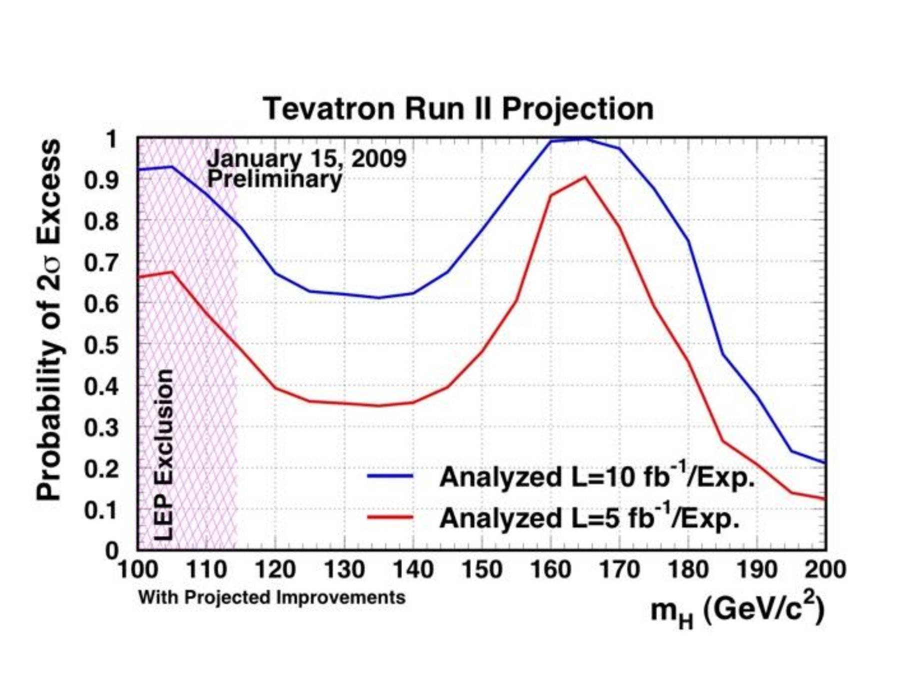
SM Higgs Excluded: m_H = 163-166 GeV

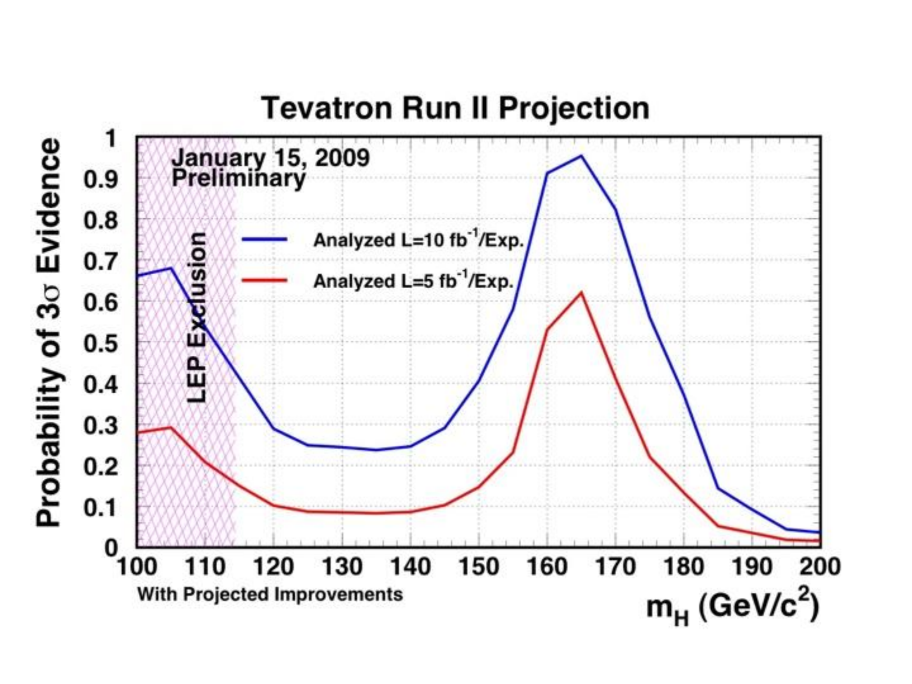
We are Making Steady Progress…



For a 160 GeV Higgs

How Well Can We Do???





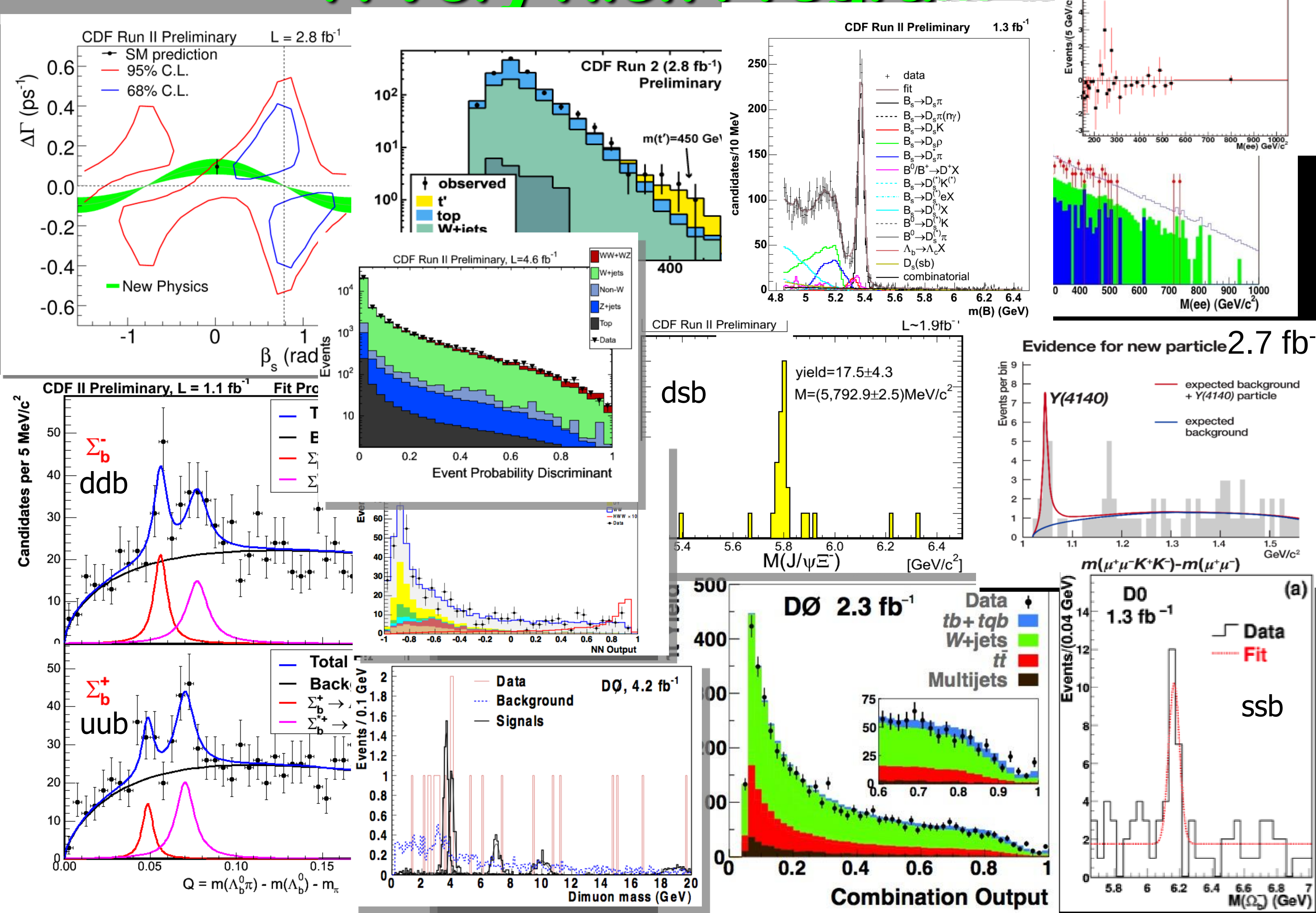
2σ 3σ

Projections with 5, 10 fb-1 data sets/experiment

We are Getting Serious!

Reaching for the Higgs Horizon

A Very Rich Program



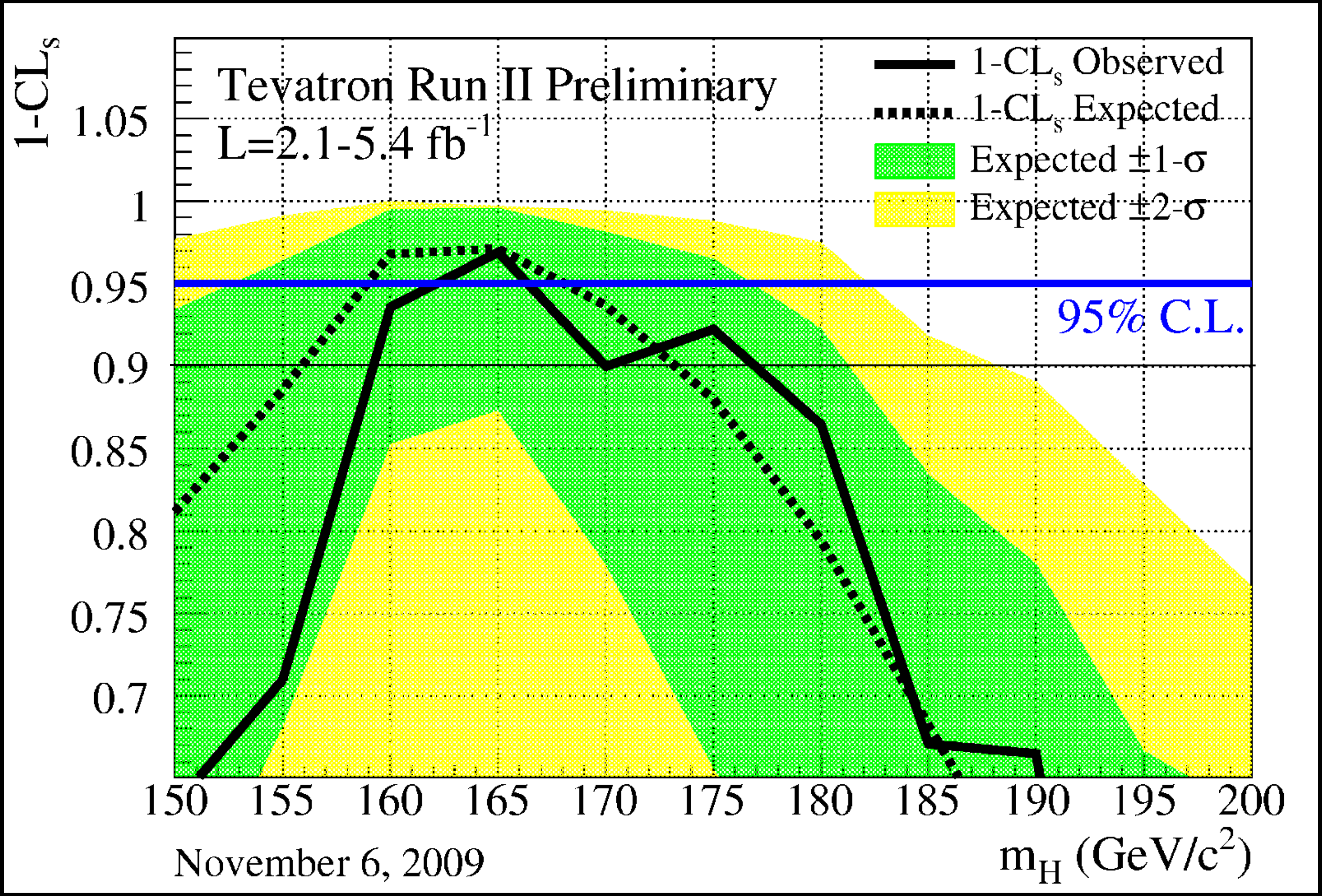
Conclusions

- High Energy Colliders provide physicists with a tool to explore the fundamental questions about nature
- The Tevatron has been remarkably successful from the discovery to the top quark, to the observation of B_s mixing to the remarkable precision measurements of the Top quark and W boson mass just to name a few
- Evidence for the Higgs is within reach and the Tevatron. Its going to be an exciting next couple of years !!!

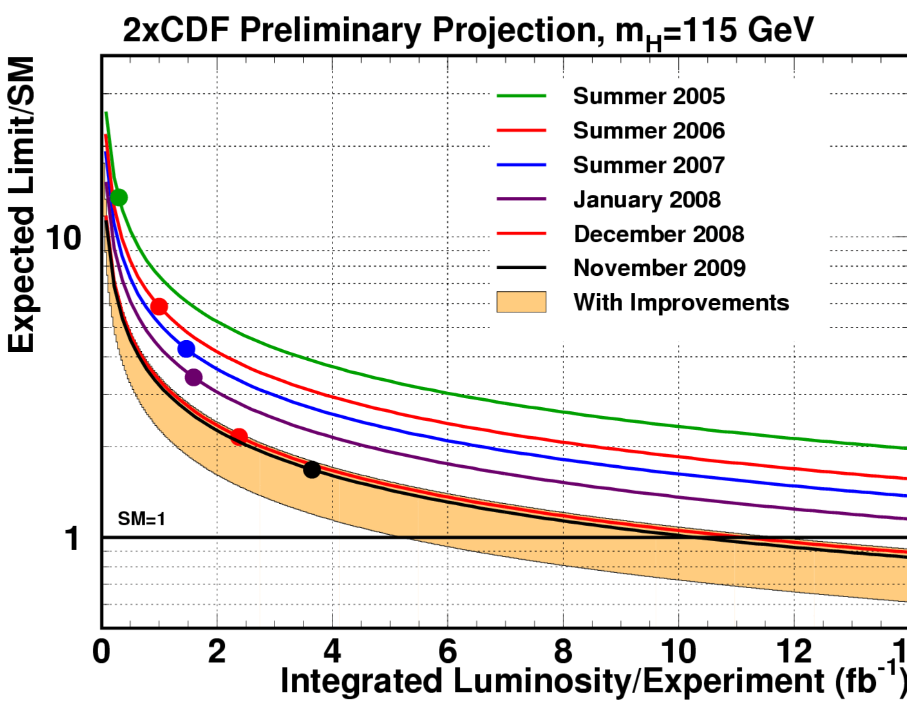
Backup

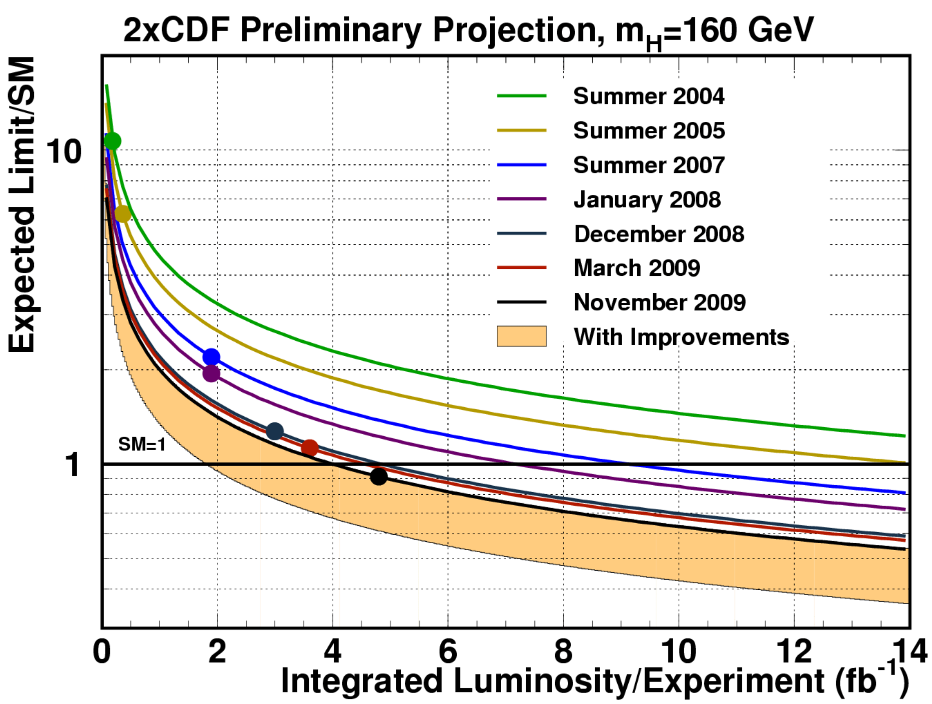
The Multistep Process

- Step 1 – select events using simple kinematic cuts (high pt lepton, missing energy, b jets in the event
- Step 2 – Make use of other distinguishing features
  - Fits to kinematic distributions
  - Multivariate techniques (neural nets) to make optimal use of the information in each event
- Step 3 -- Optimize
  - Improve triggering
  - Improve lepton acceptance
  - Improve background rejection
  - All of this is very hard pain staking work
- Step 4 – Combine efforts
  - Combine all the different decay channels together
  - Combine results from both experiments


1-CLs
Tevatron Run II Preliminary
L=2.1-5.4 fb-1
1-CLs Observed
1-CLs Expected
Expected ±1-σ
Expected ±2-σ
95% C.L.
1.05
1
0.95
0.9
0.85
0.8
0.75
0.7
150
155
160
165
170
175
180
185
190
195
200
November 6, 2009
mH (GeV/c2)

We are Making Steady Progress…





115 GeV

160 GeV