Exciting Physics at the Tevatron

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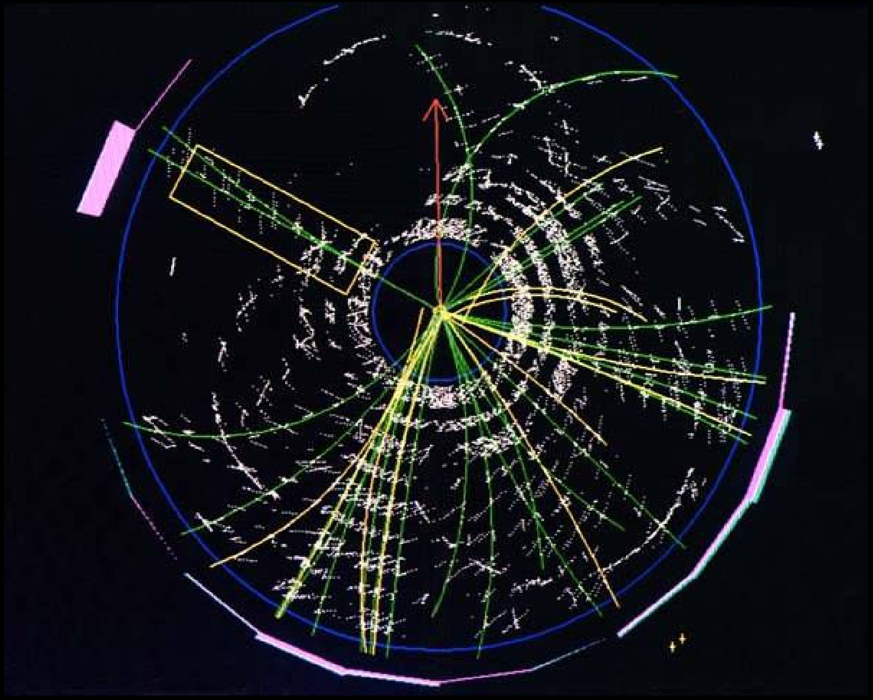
Fermi National Accelerator Laboratory

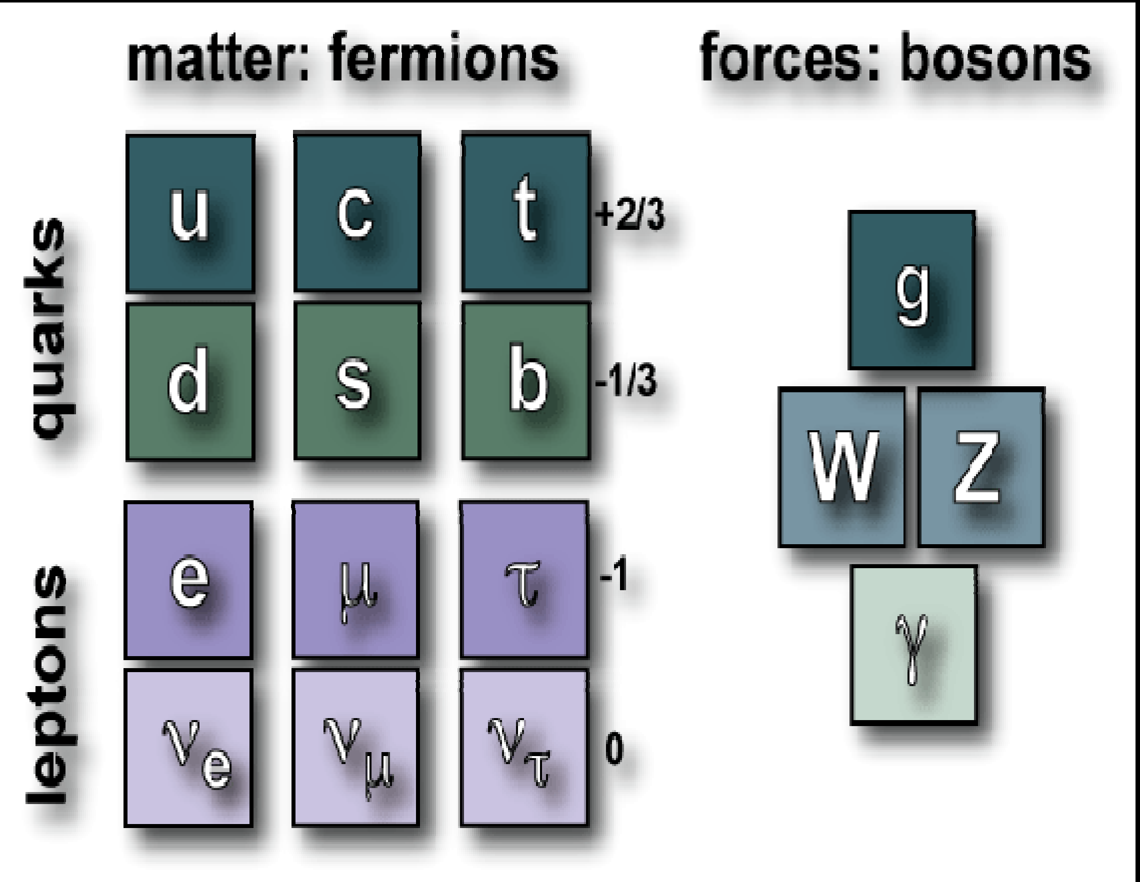


The Big Picture!

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

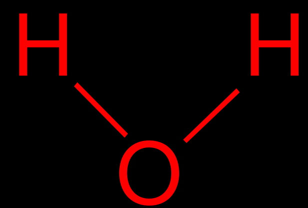
- Each particle has its own anti particle
- Quarks have fractional charge!
- SM provides a good description of particles and their interactions
- Extensively tested

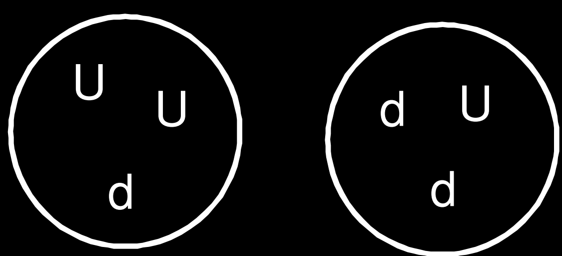
Periodic Table of the Particles



An example – Water!

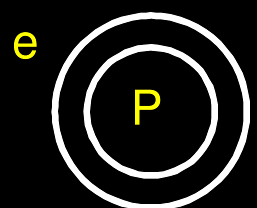
- H_20



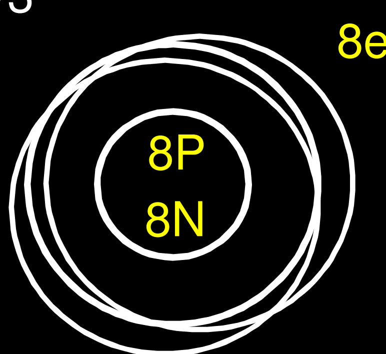


Proton
2/3+2/3-1/3

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



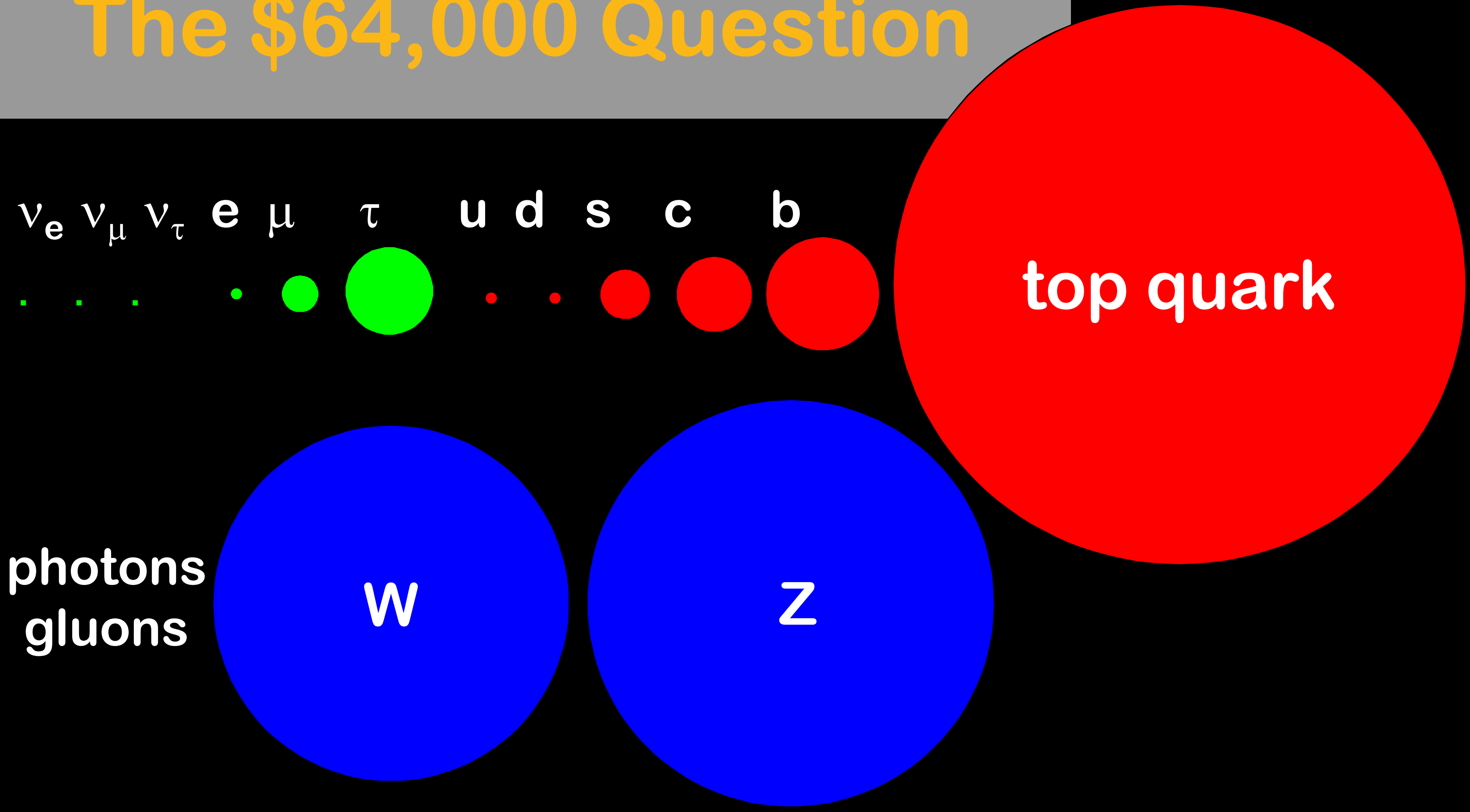
Hydrogen



Oxygen

H_2O ➡ 28 Up Quarks
26 down quarks
10 electrons

The $64,000 Question



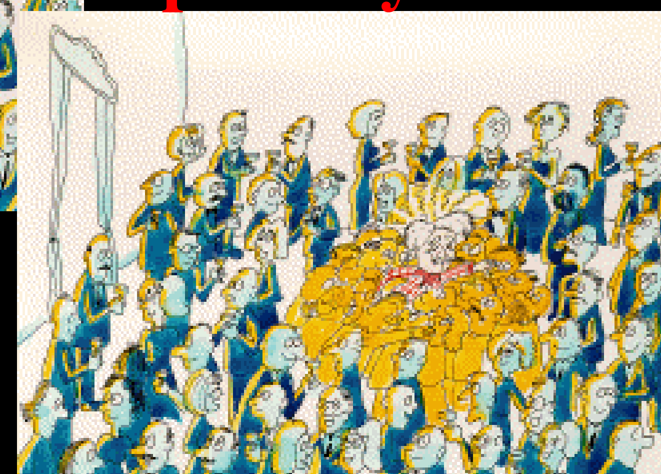
Why is top so heavy?

"Why are there so many particles?"

"Where does mass come from?"

Enter the Higgs Mechanism

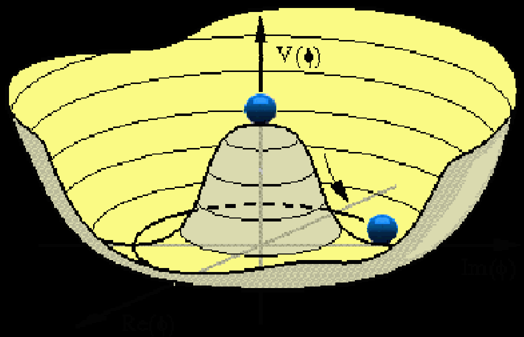
Popularity $\propto$ Mass



Analogy by Prof. David Miller
University College of London

The Solution:

- 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 Higgs boson
- Finding the BEHHGK boson
  - Means Higgs field exists
    - Means we confirm our theory for the origin of mass

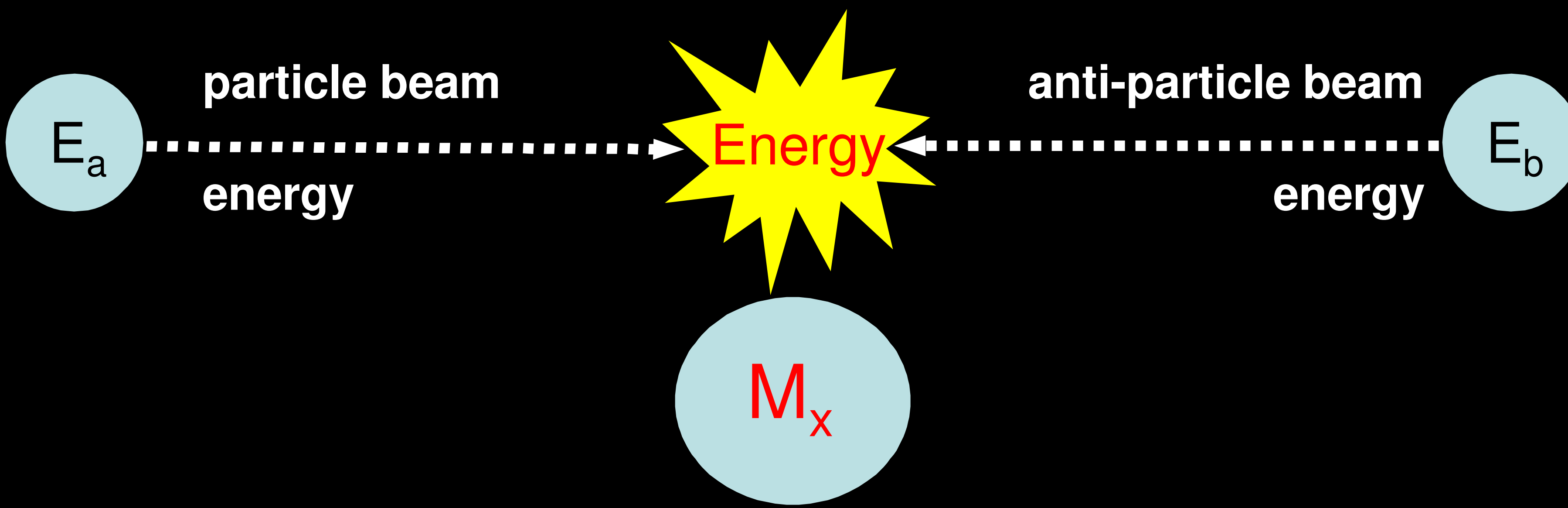
How does one search for the Higgs boson?

(or anything else for that matter)

Making Particle X

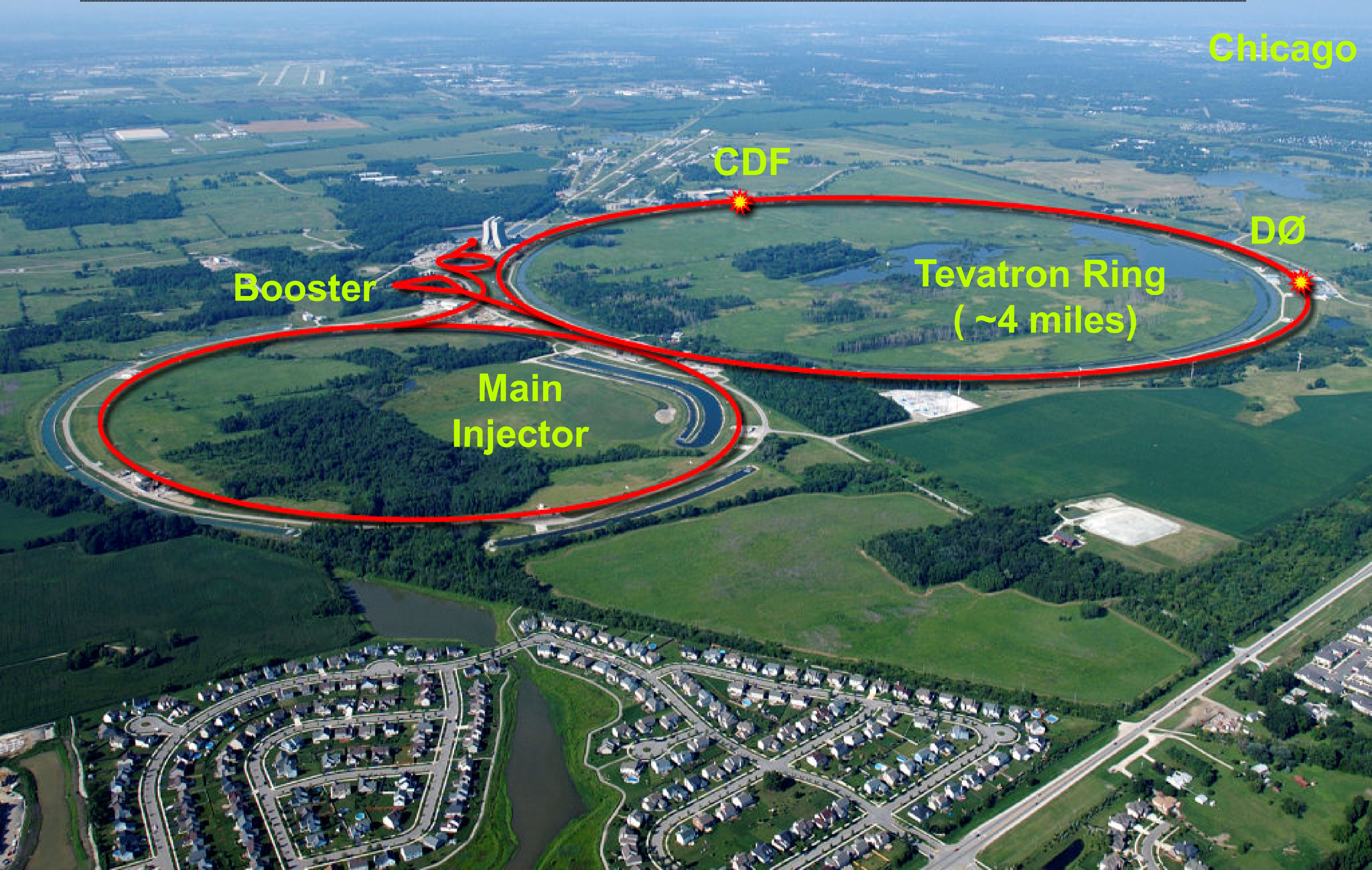
Thanks to Einstein we know that a high energy collision of particle A and B can result in the creation of particle X

$$E = mc^2$$



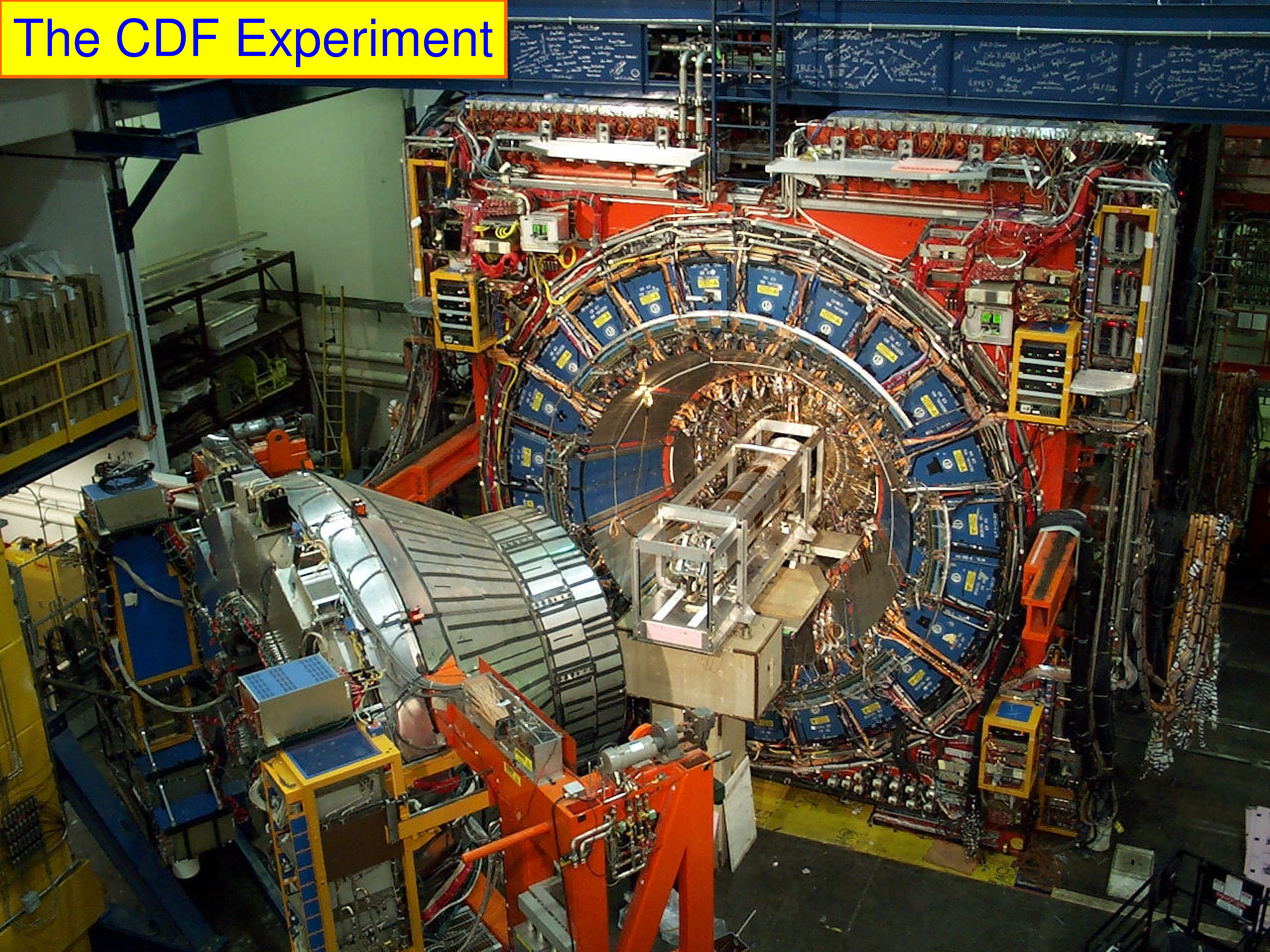
As long as $E_a + E_b >> M_x c^2$

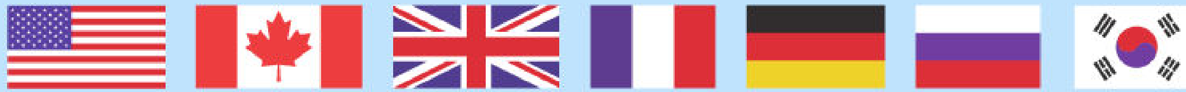
America's Most Powerful Accelerator: Fermilab's Tevatron

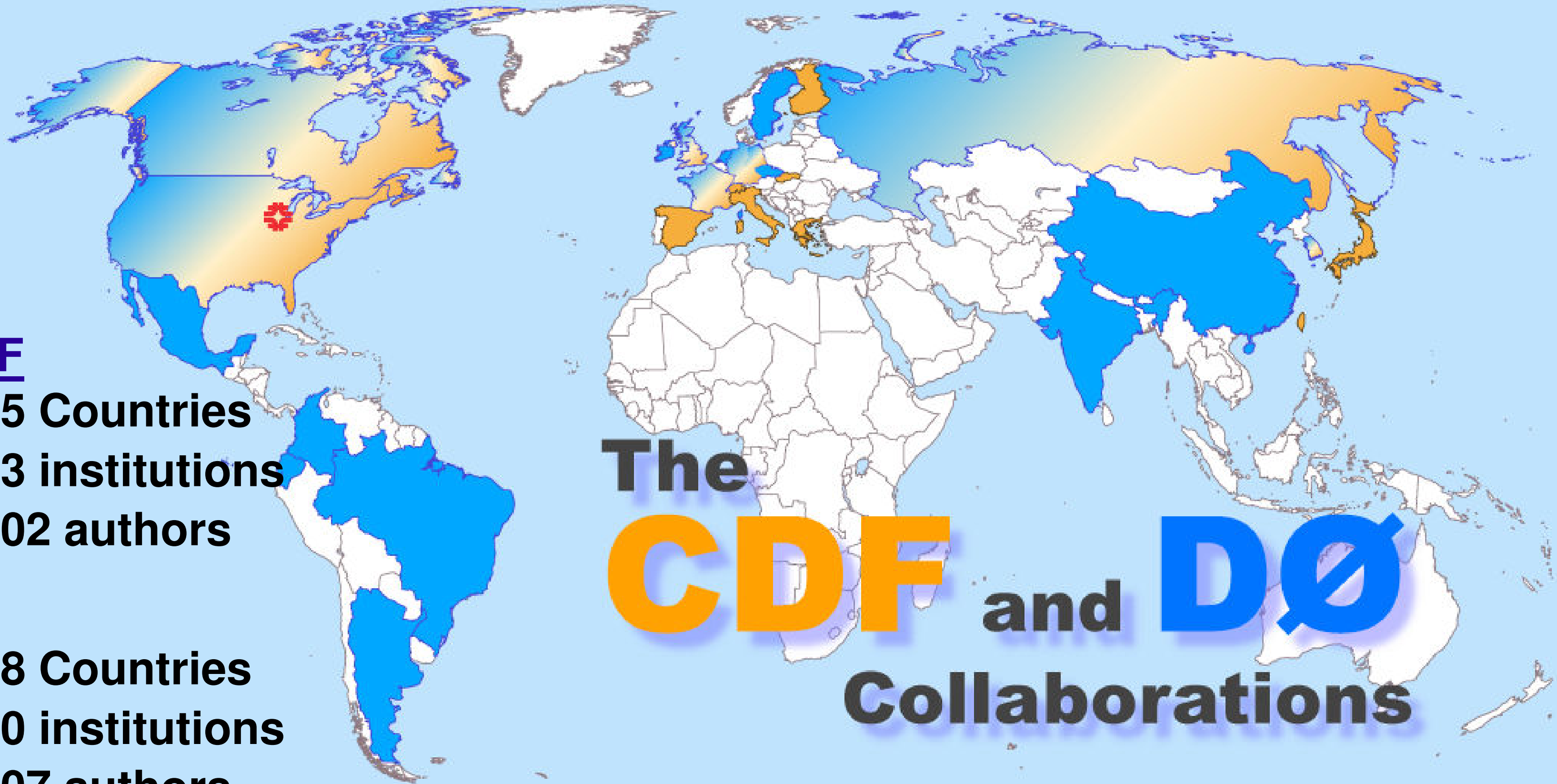


The D0 Experiment

The CDF Experiment



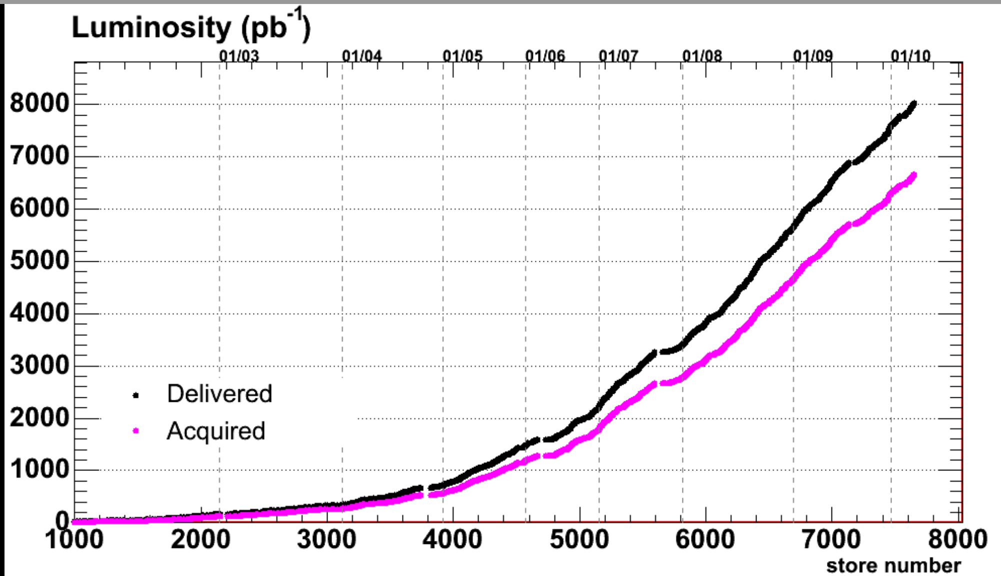




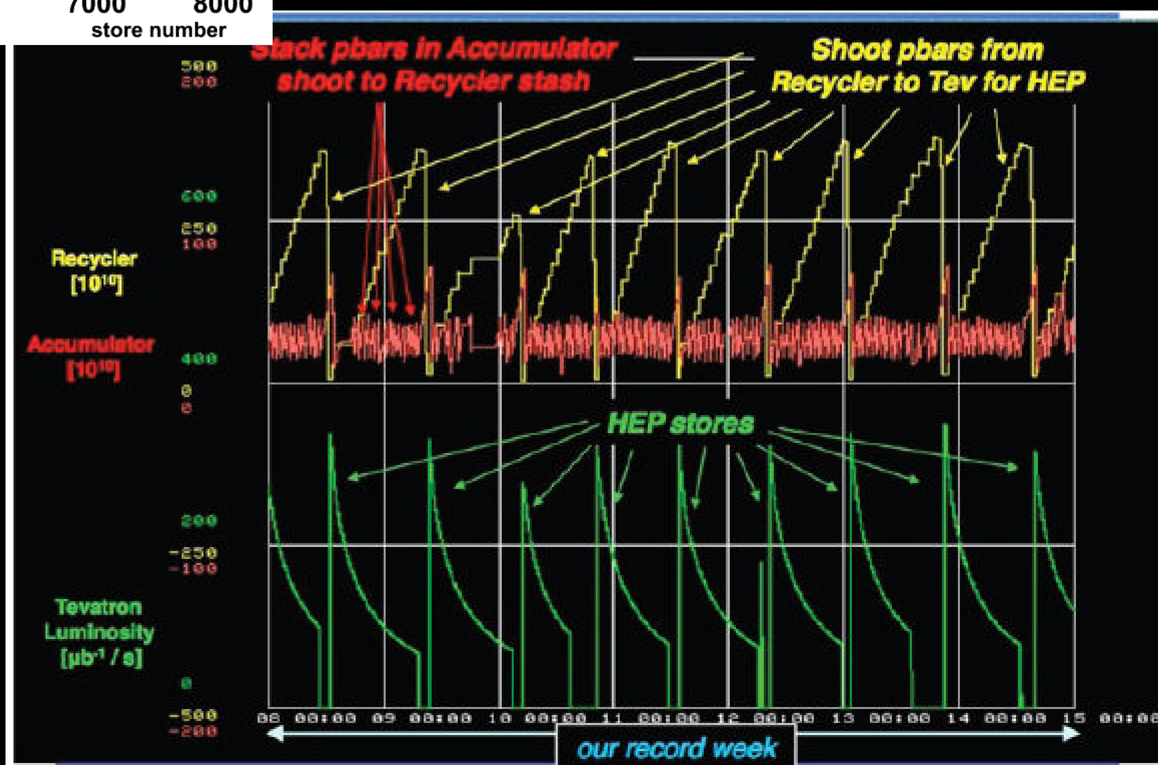
CDF
- ♦ 15 Countries
- ♦ 63 institutions
- ♦ 602 authors

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

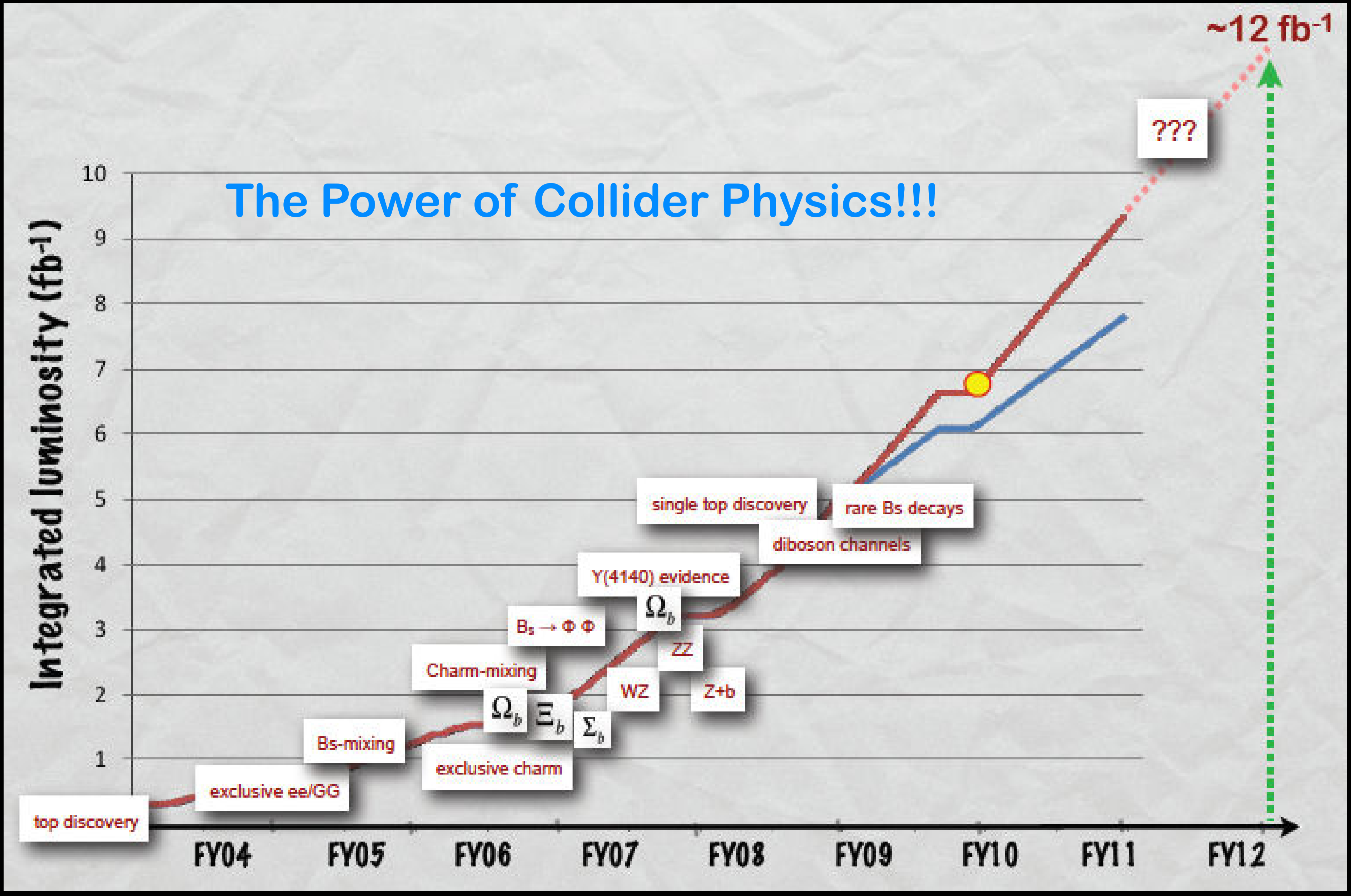
Tevatron Performance



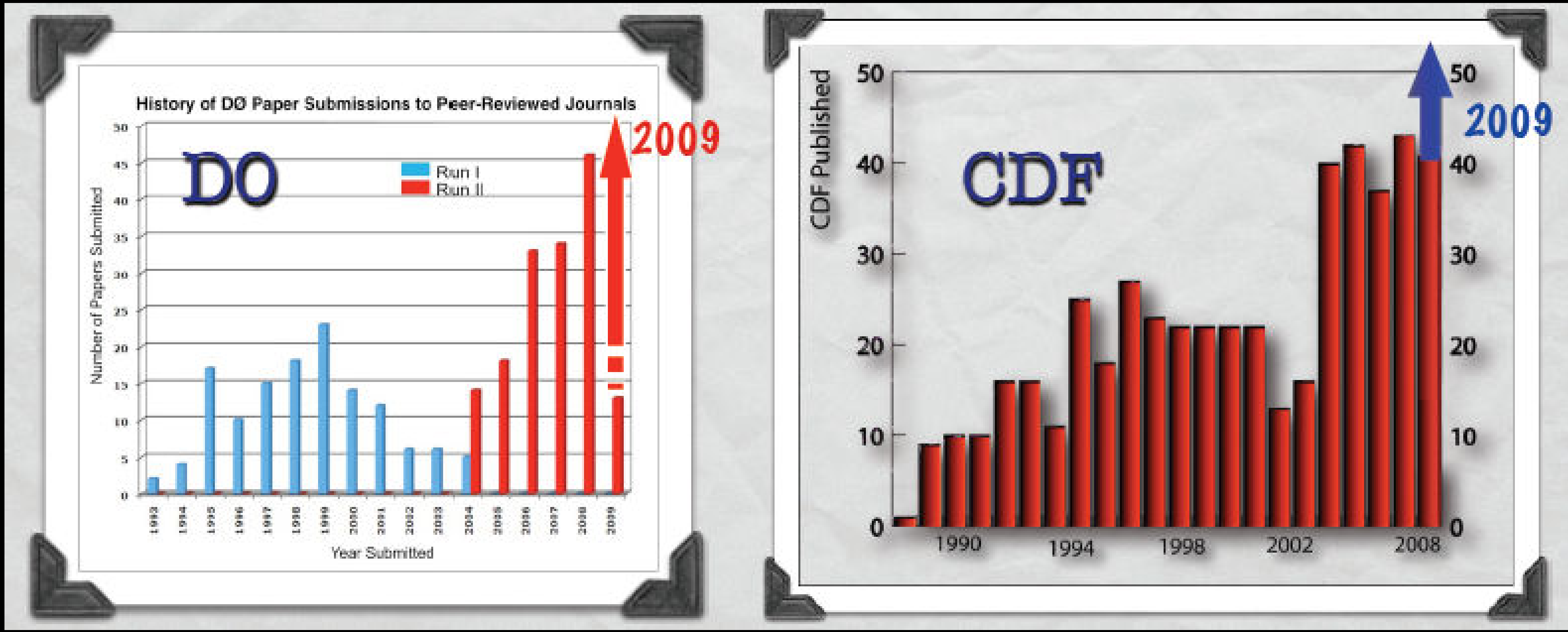
- Stores routinely come in at >300e32
- 60 – 70 pb delivered/week is typical
- Expect >2fb/year



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

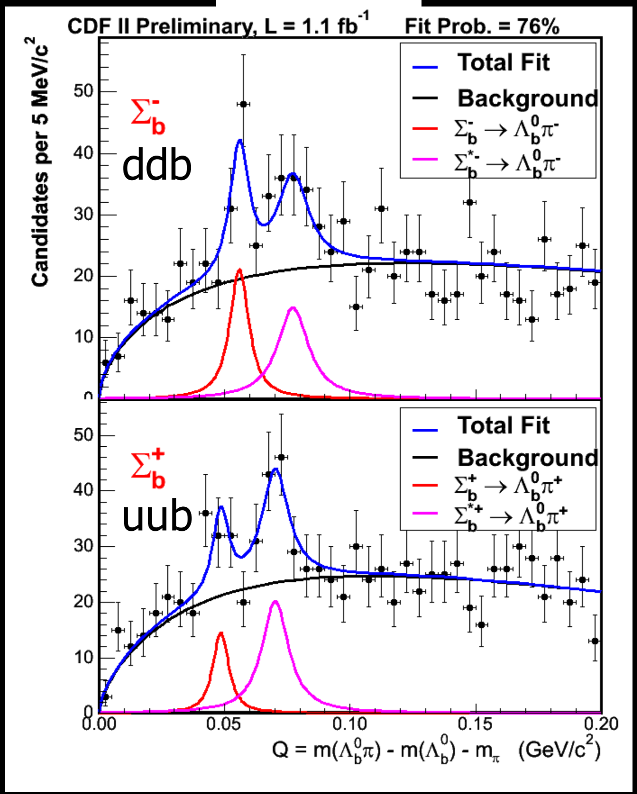
- Mixing, CKM Constraints and CP Violation
- Heavy Flavor Spectroscopy
- New Heavy Baryon States
- Tests of Quantum Chromodynamics
- Precise measurement of Top-quark and W-boson Masses
- Top Quark Properties
- Di-Boson production and SM Gauge Couplings
- New Exclusive/Diffractive Processes

Unique Window into the unknown

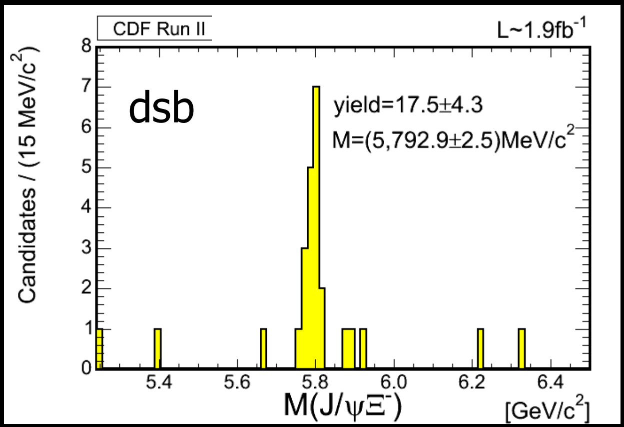
- Searches for Supersymmetry, Extra Dimensions, Exotica
- Still at the Energy Frontier
  - Proobing the Terascale as the luminosity increases
- The Standard Model BEHHGK (Higgs) Boson is within reach!

Observation of new heavy baryons

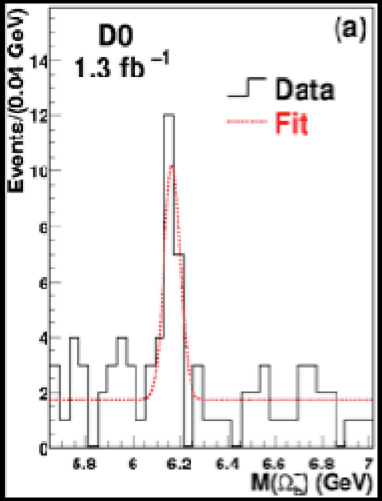
Σ_b

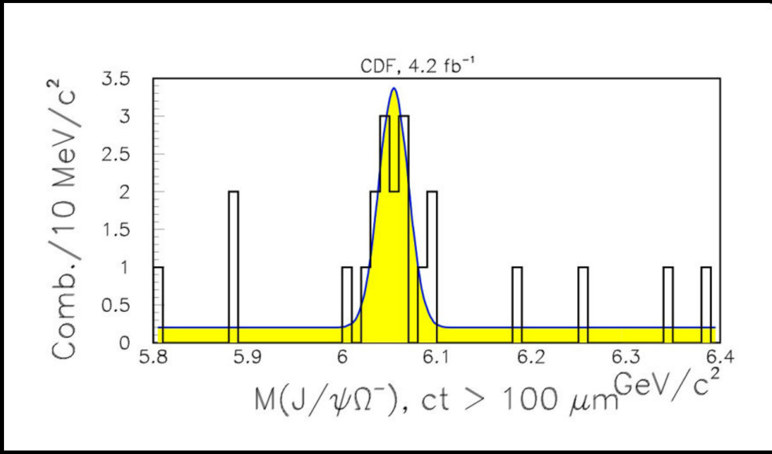


Ξ_b



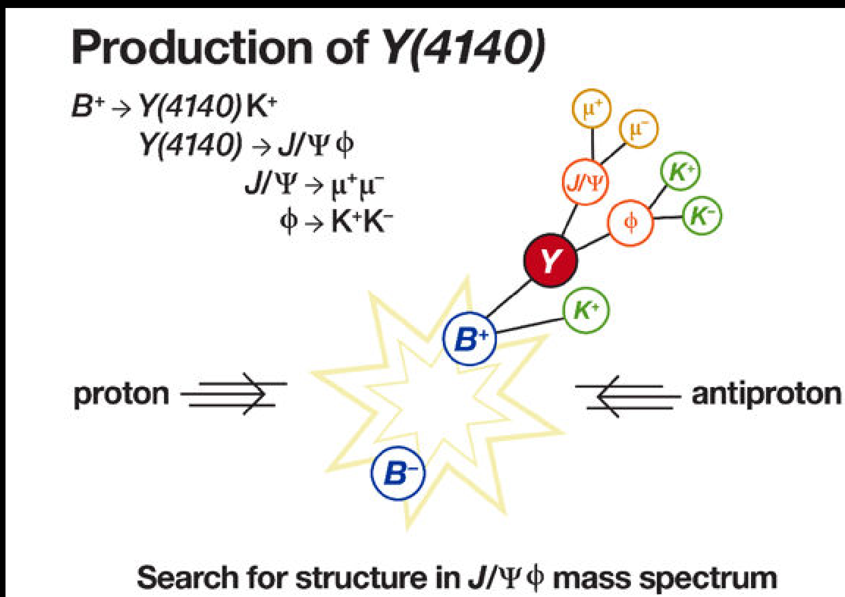
Ω_b

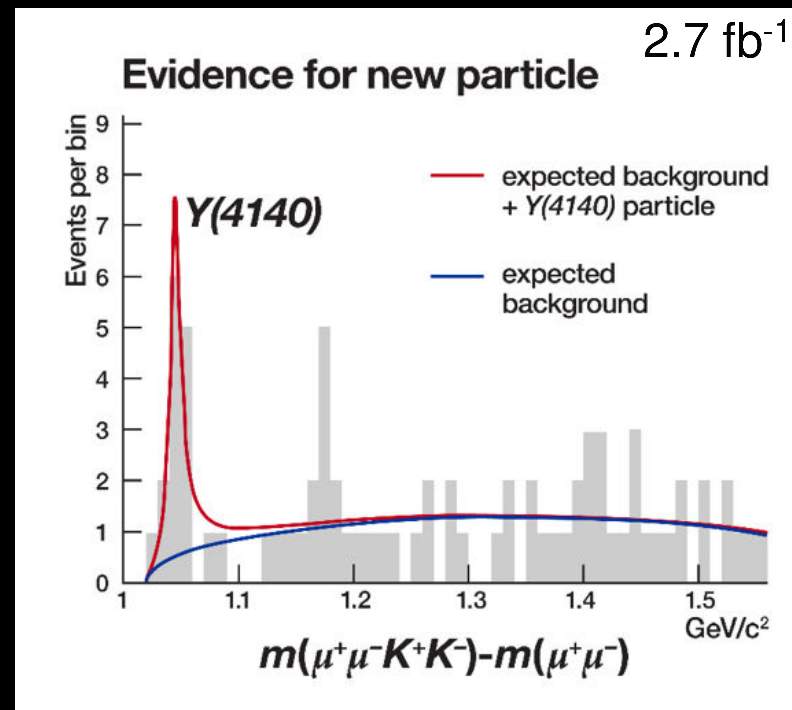




With more data : emergence of a new particle

Y(4140) unknown composition





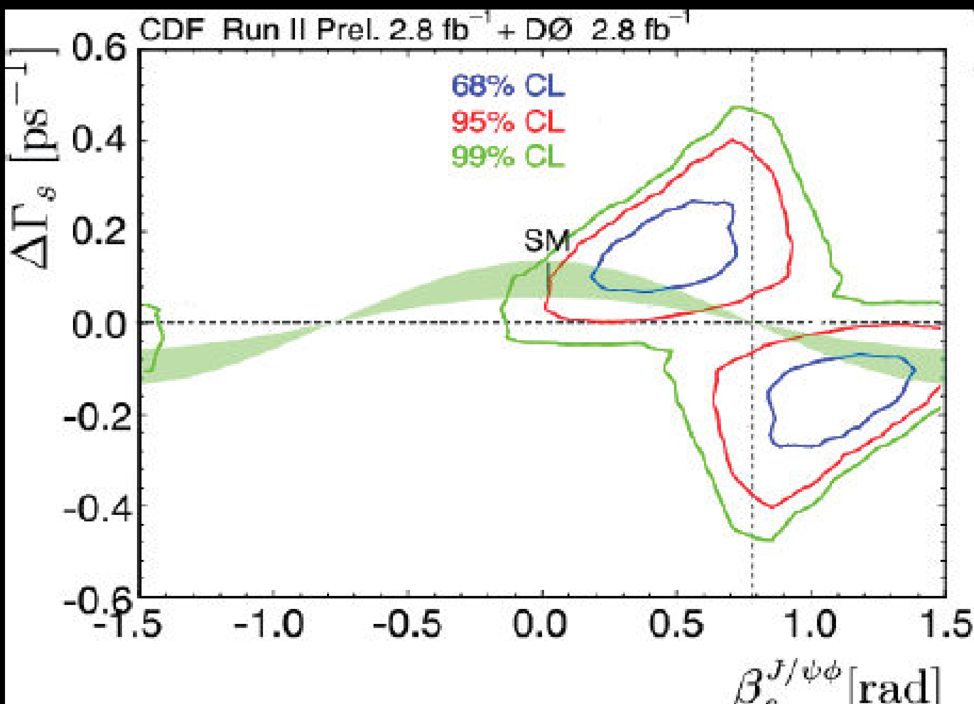
2009

These new discoveries yield a few events/fb^{-1} ==> new areas of research @ 10 fb^{-1}

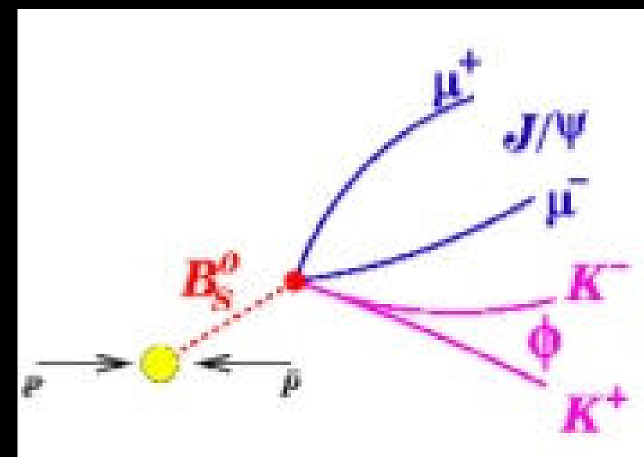
Precision: CPV in β_s

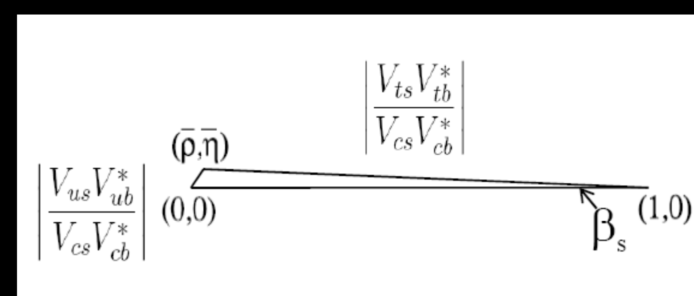
Both CDF and D0 measure the CP Violating Parameter β_s in B_s in $J/\psi\phi$ with 2.8/fb

$$B_s \to J/\psi\,\varphi$$



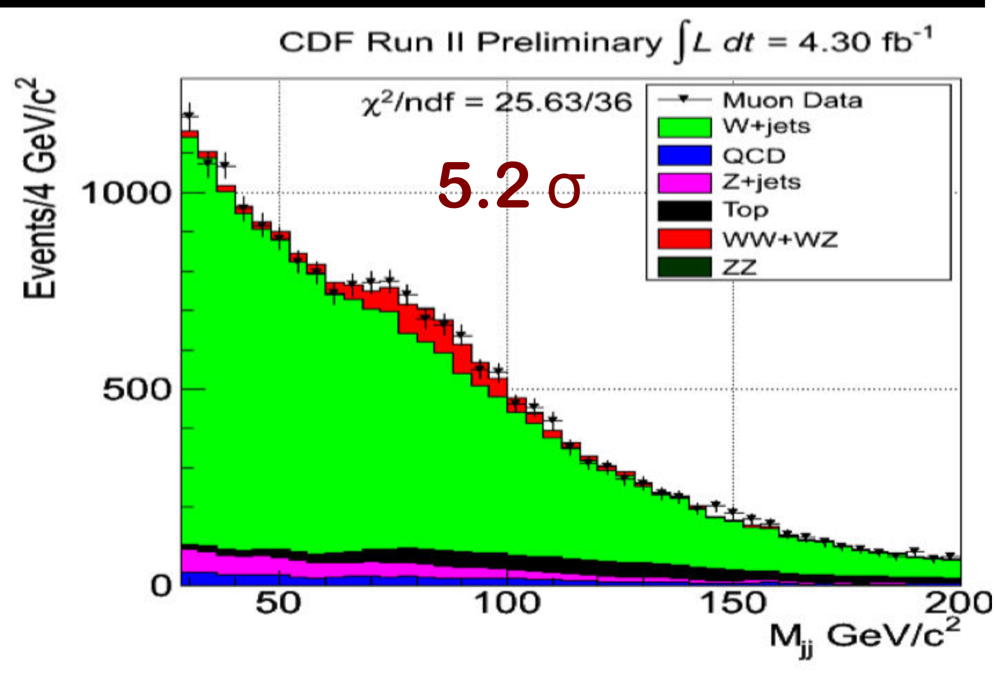
2.1-sigma from SM Prediction

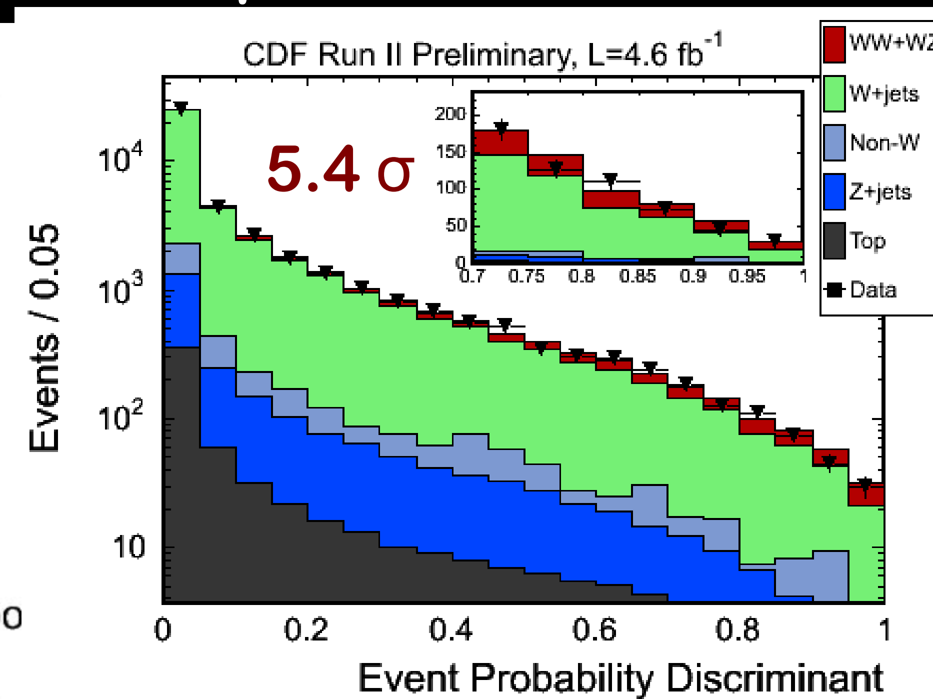




Di-bosons

- WW/WZ lepton + Jets observations
- Using m_{jj} and matrix element techniques with 4.3-4.6fb^{-1}

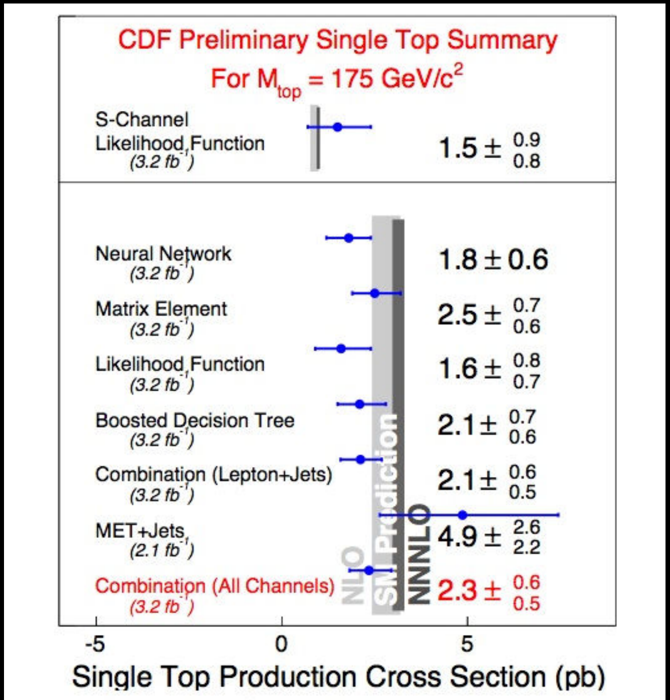


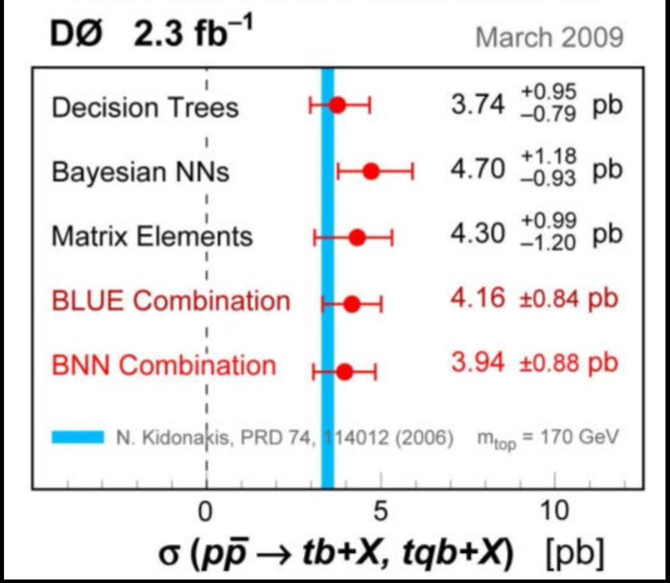


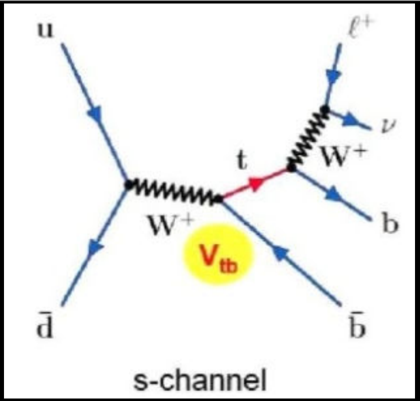
$\sigma = 18.1 \pm 3.3_{stat} \pm 2.5_{sys}$

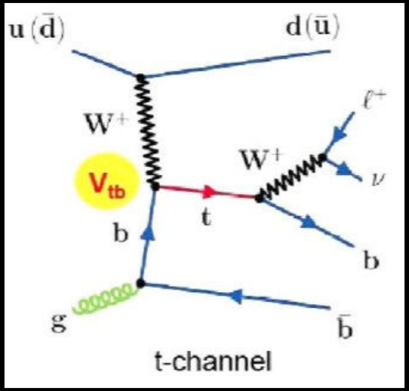
$\sigma = 16.5 +3.3-3.0 \pm 3.5_{sys}$

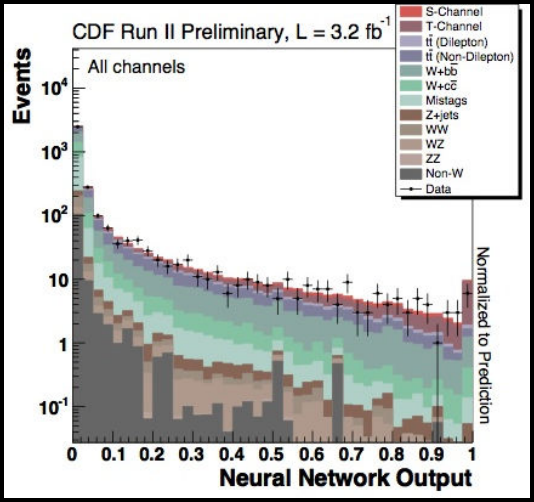
Recent discovery: single top







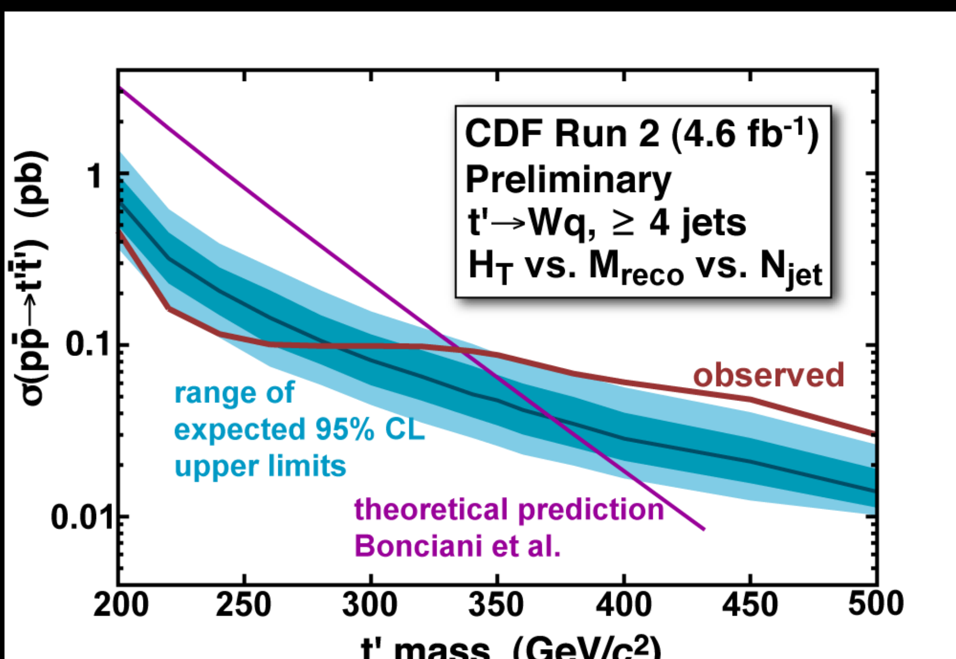


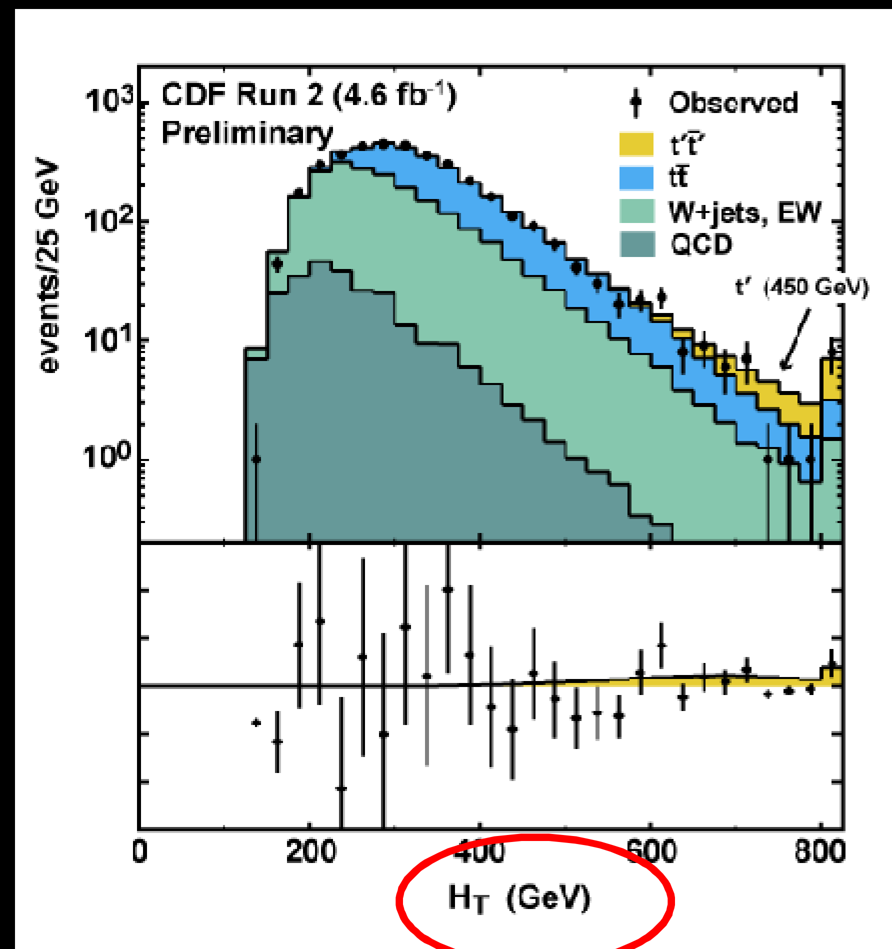


- <u>Single Top Physics Program</u>
  - Test s vs t [new physics]
  - Vtb [precision]
  - Lifetime [new physics]

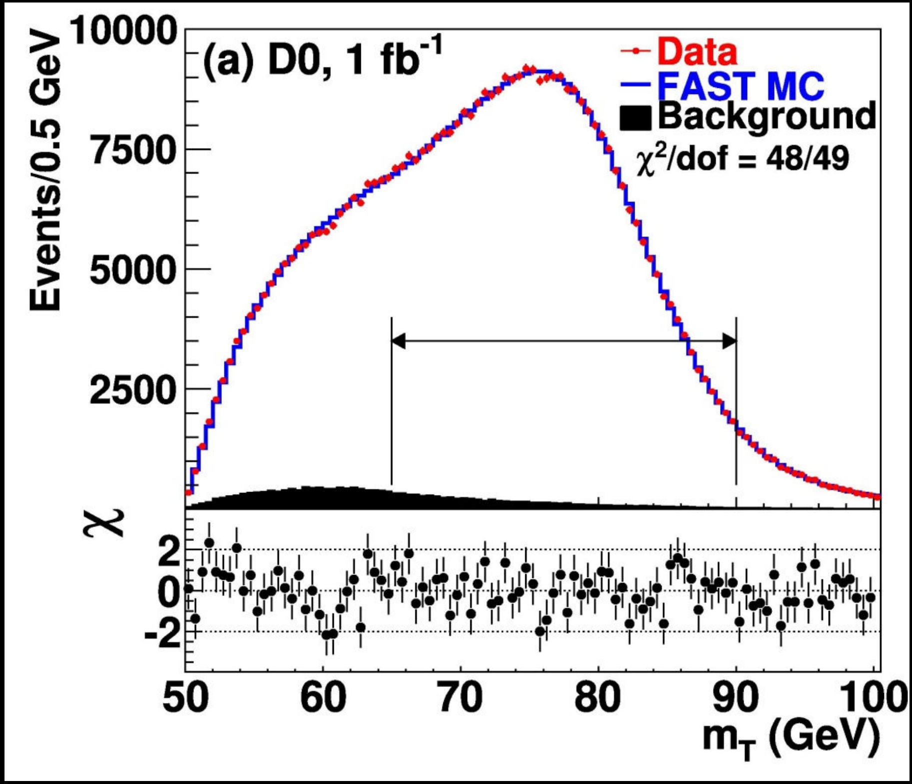
t' Search

- Search for heavy top t' → Wq
  - Leptons +Jets events with 4.6/fb
  - Reconstruct mass of t' and search in H_T and $m_{t'}$
  - May occur in little Higgs, forth generation, …



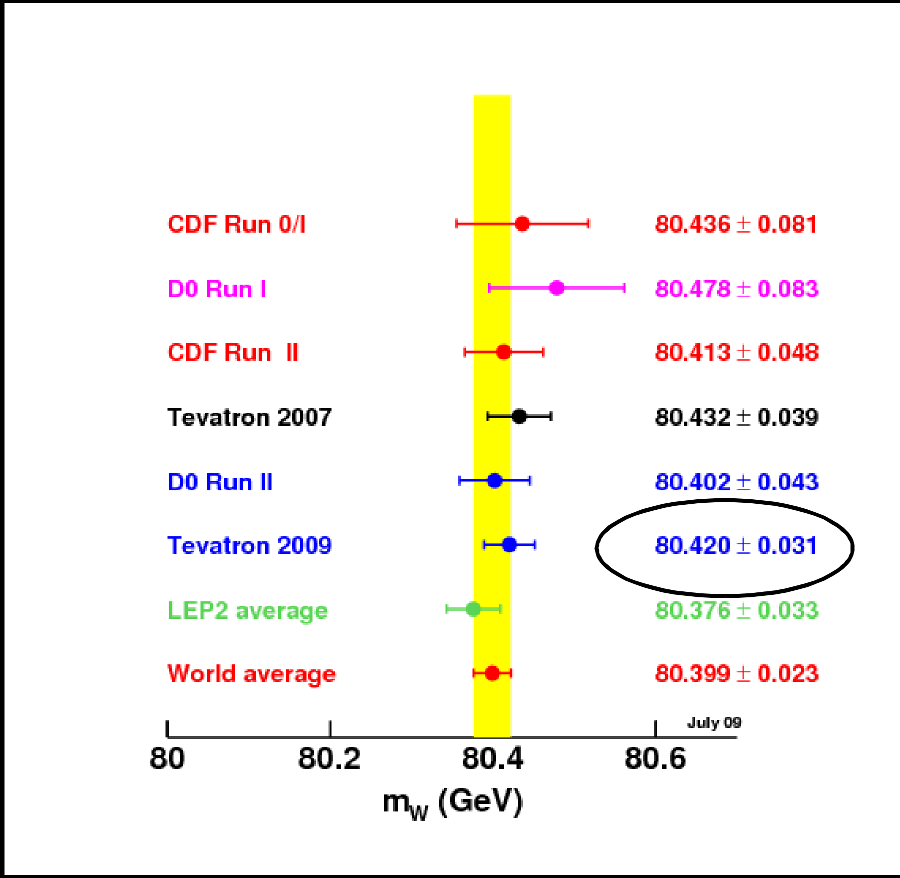


W Mass Summary

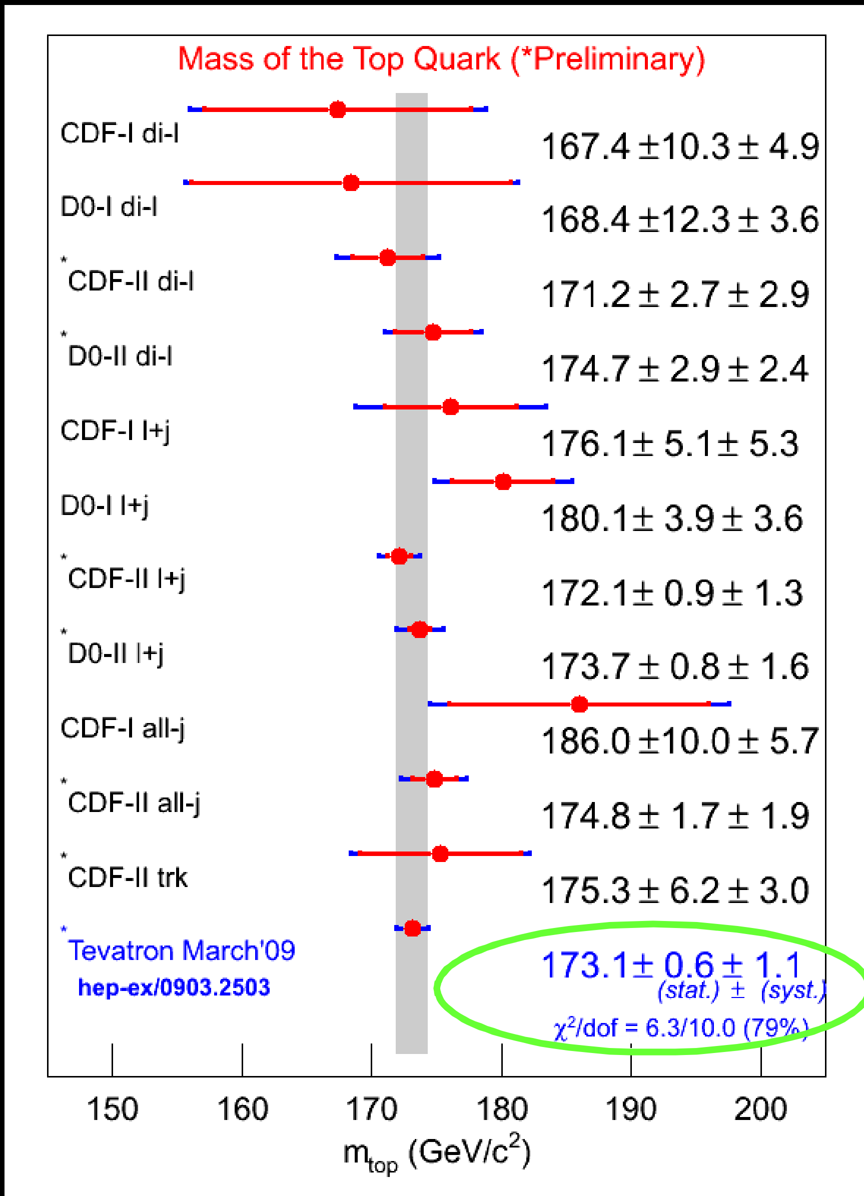


Tevatron has worlds best measurement

$M_W = 80.399 \pm 0.023$ GeV



Summary of Top Mass



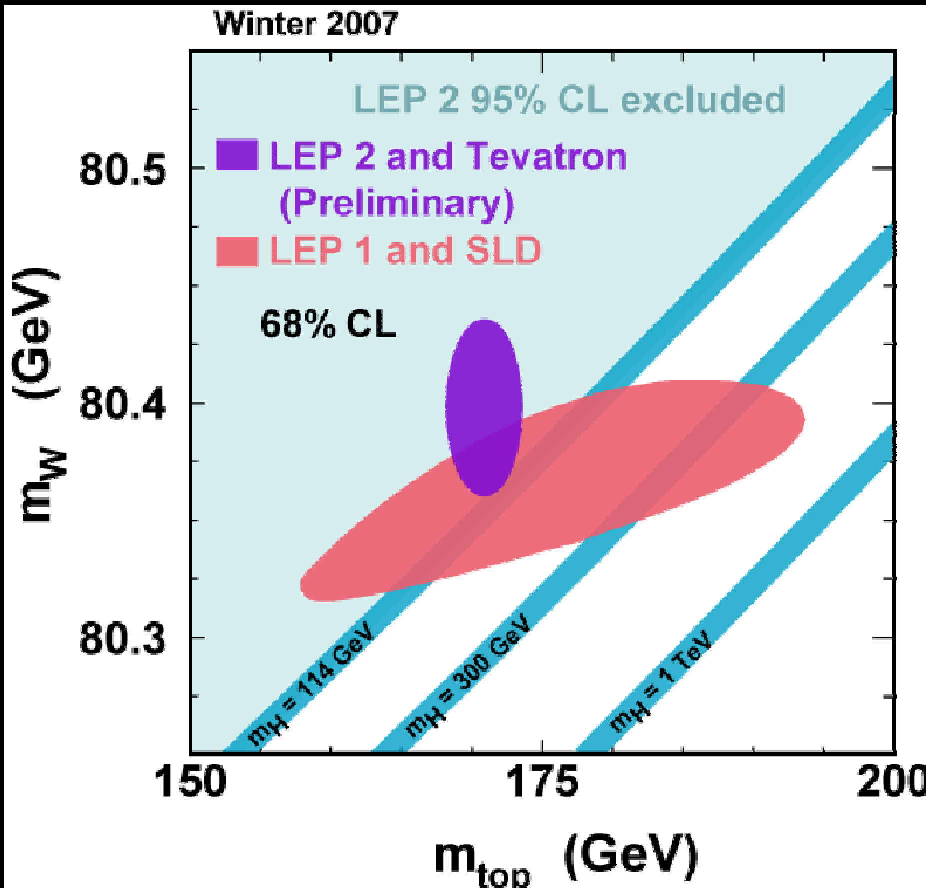
$M_t = 173.1 \pm 1.2$ GeV

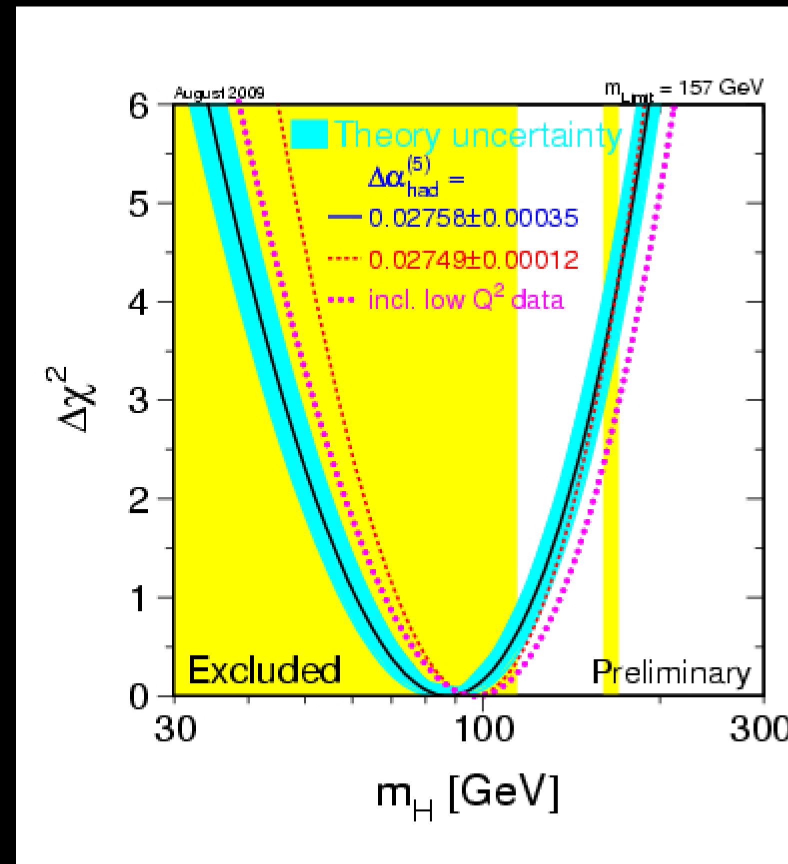
<1% Precision

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 Higgs Hiding?



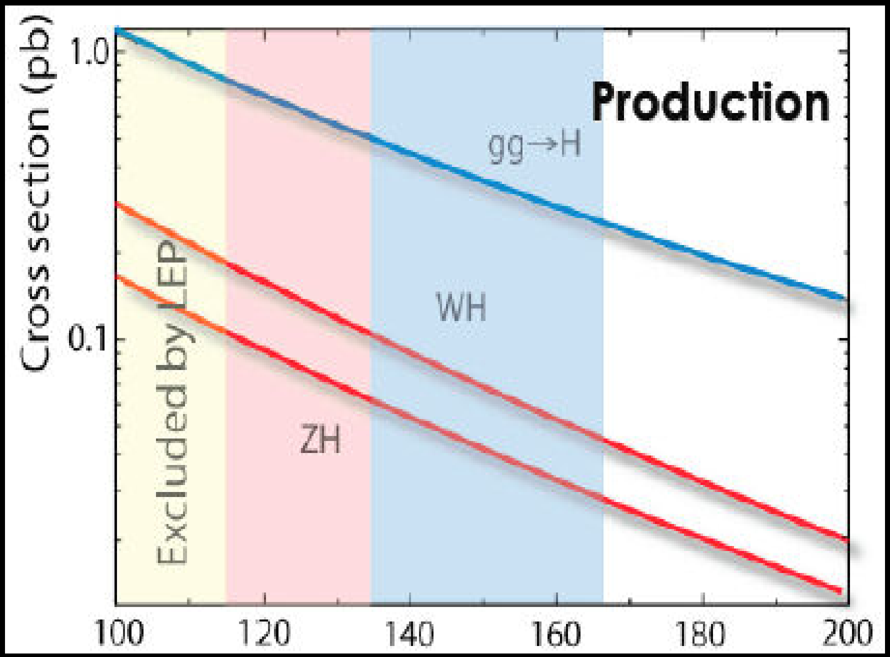


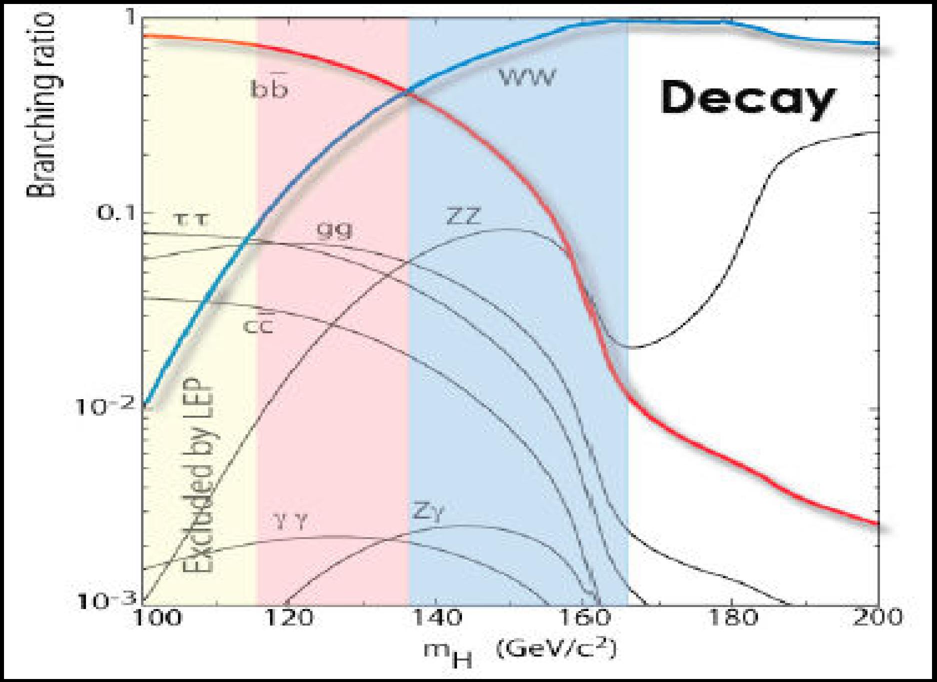
Mw vs Mtop

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

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

Higgs Production and Decay



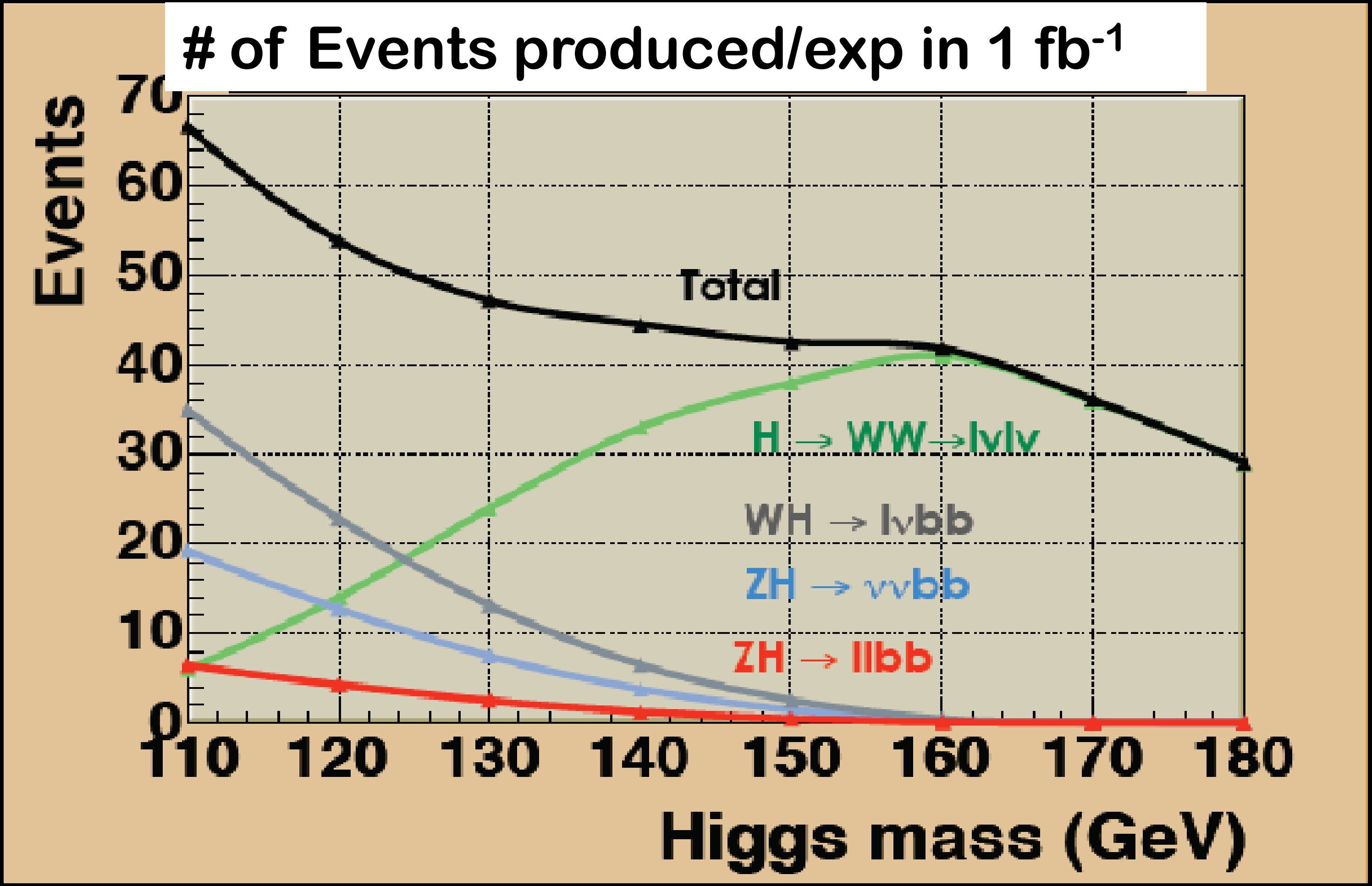


Higgs are produced in several diferent ways…

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

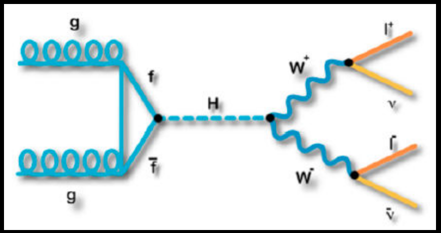
The Challenge

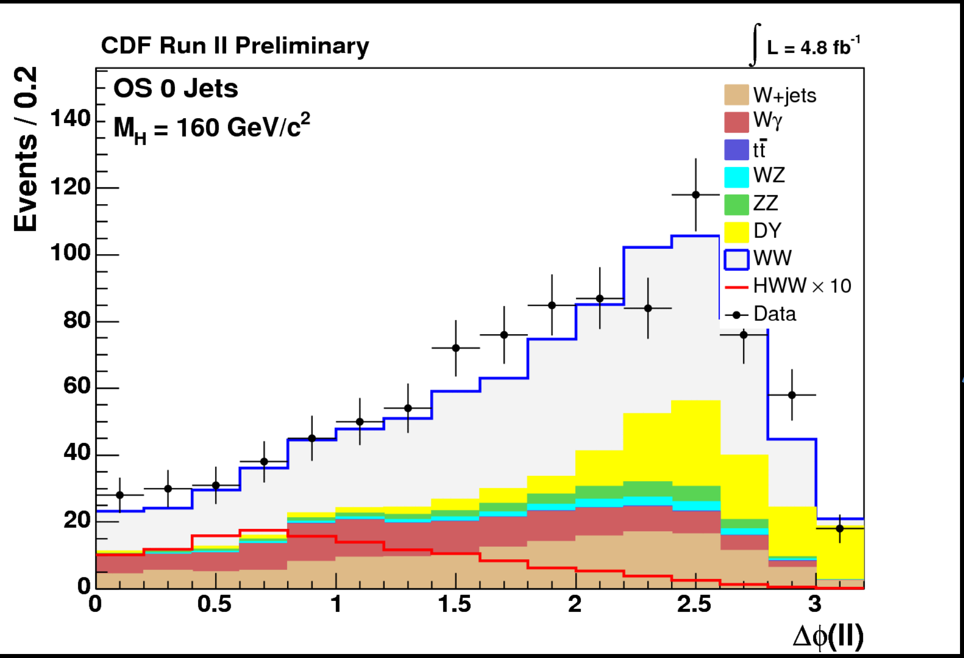


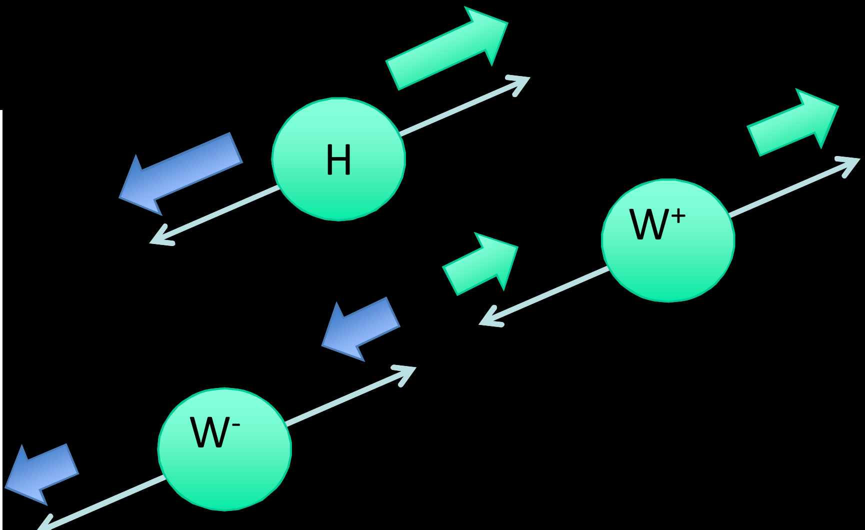
These are production numbers –
trigger, acceptance etc.not yet factored in…

SM Higgs: H→WW (High Mass Channel)

- $H \to WW \to l\nu l\nu$ - signature: Two high p_T leptons and MET
  - Primary backgrounds: WW and top in di-lepton decay channel
  - Key issue: Maximizing signal acceptance
  - Excellent physics based discriminants
- Most sensitive Higgs search channel at the Tevatron

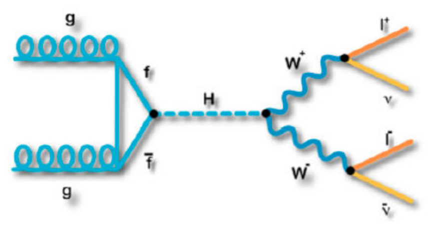




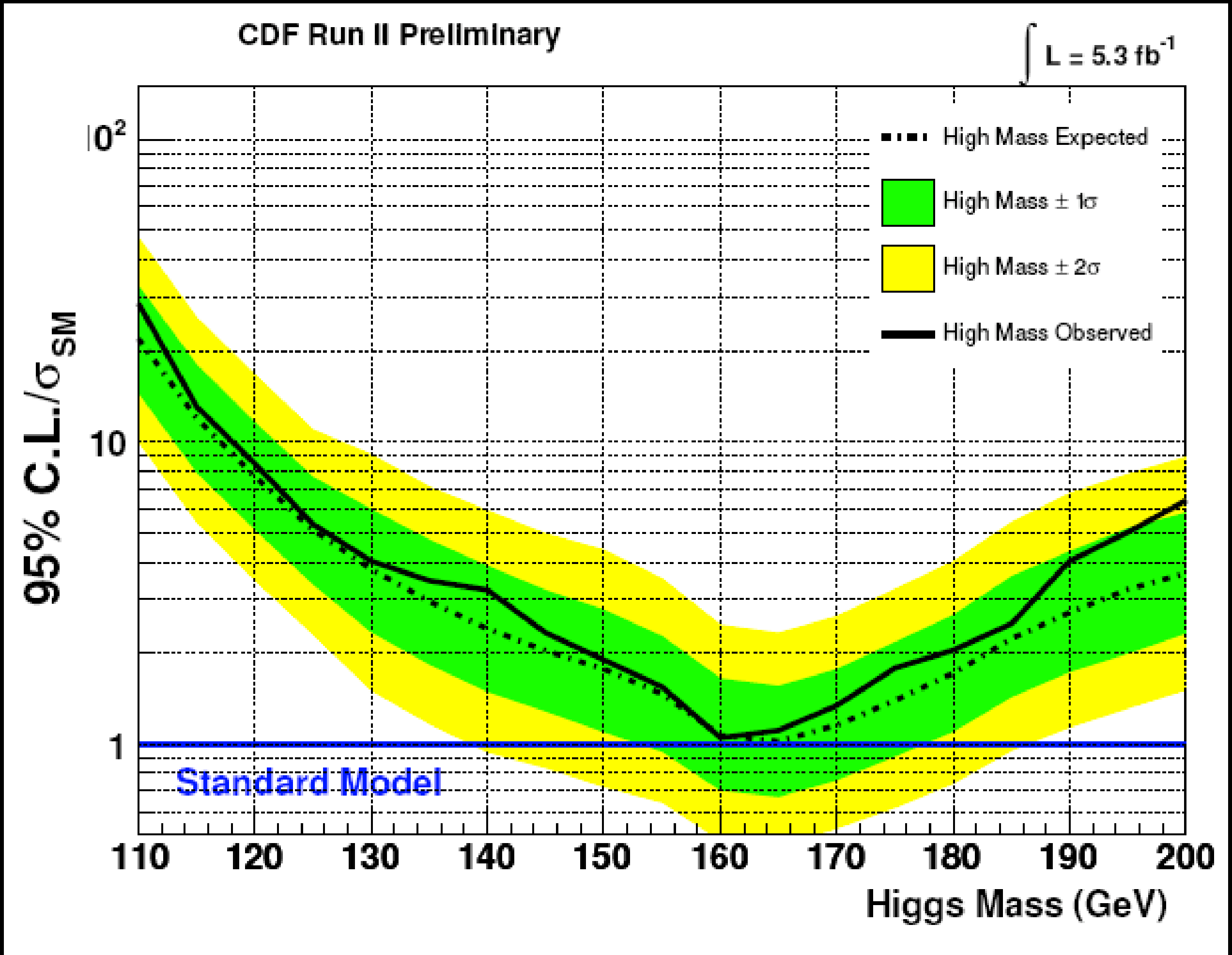


Spin correlation: Charged leptons go in the same direction

CDF H→WW Result



36 Higgs Events!

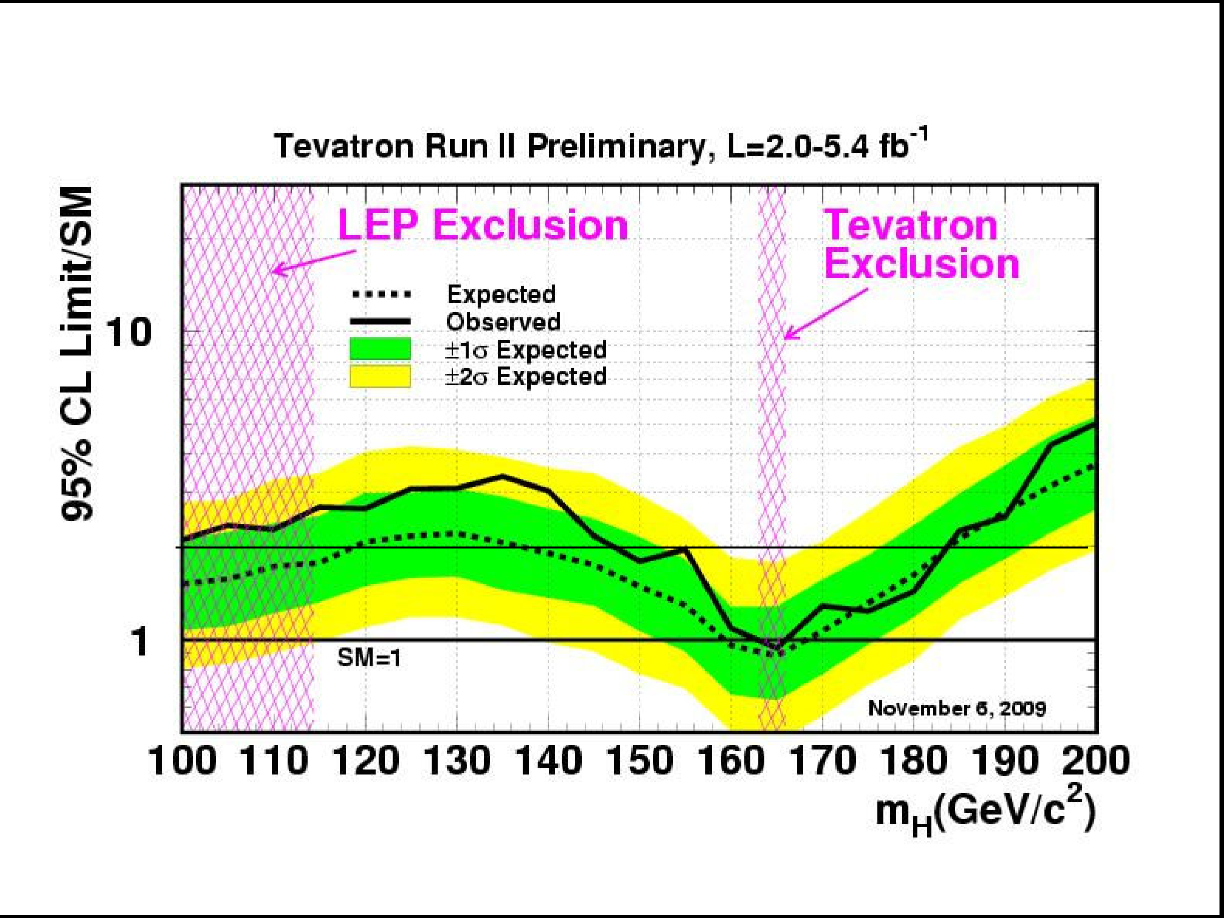


Exp. 1.07 @ 160 GeV, 1.02 @ 165 GeV

Combine Experiments

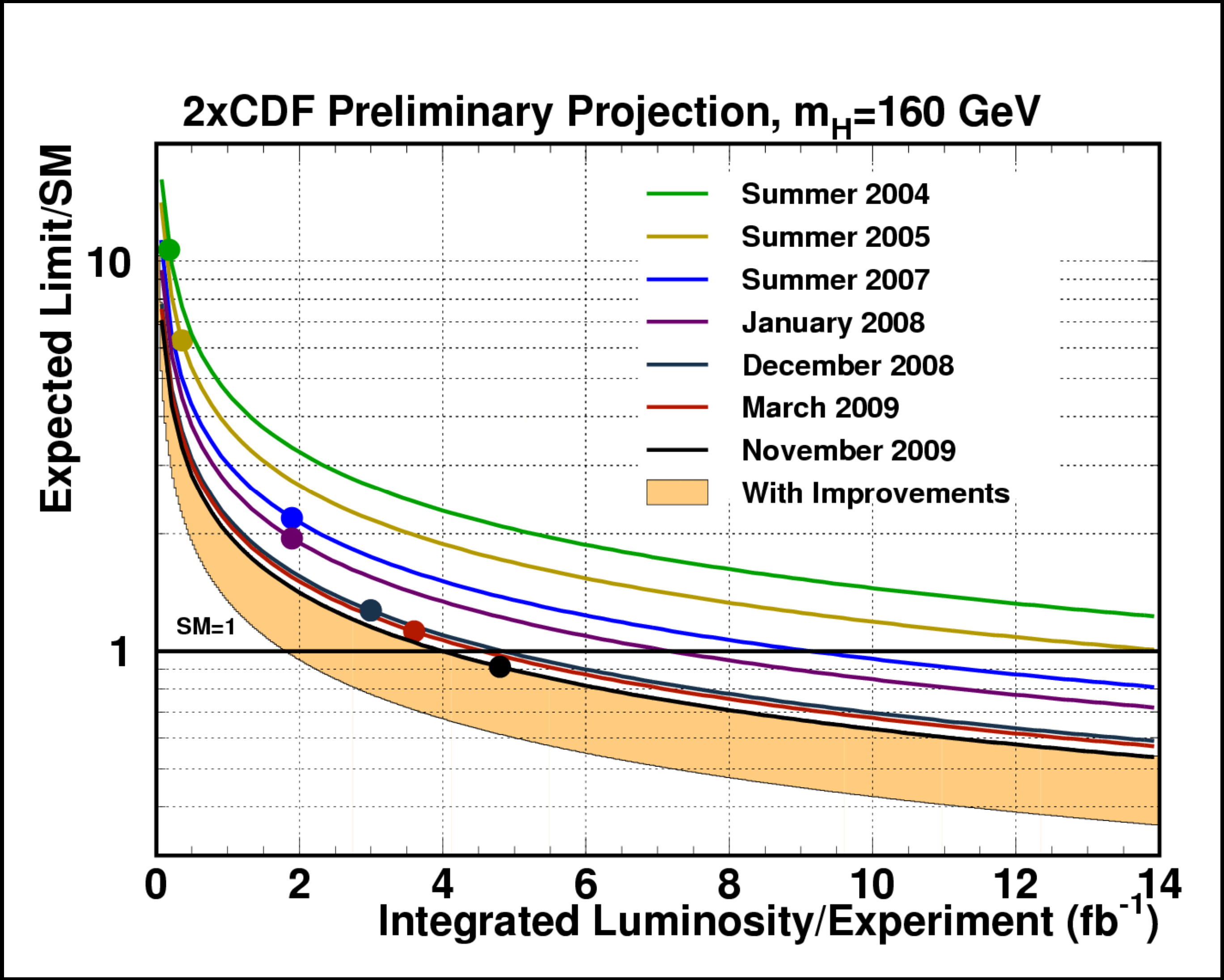
Neither experiment has sufficient power to span the entire mass range using the luminosity we expect to acquire in Run II

Factor away in sensitivity from SM



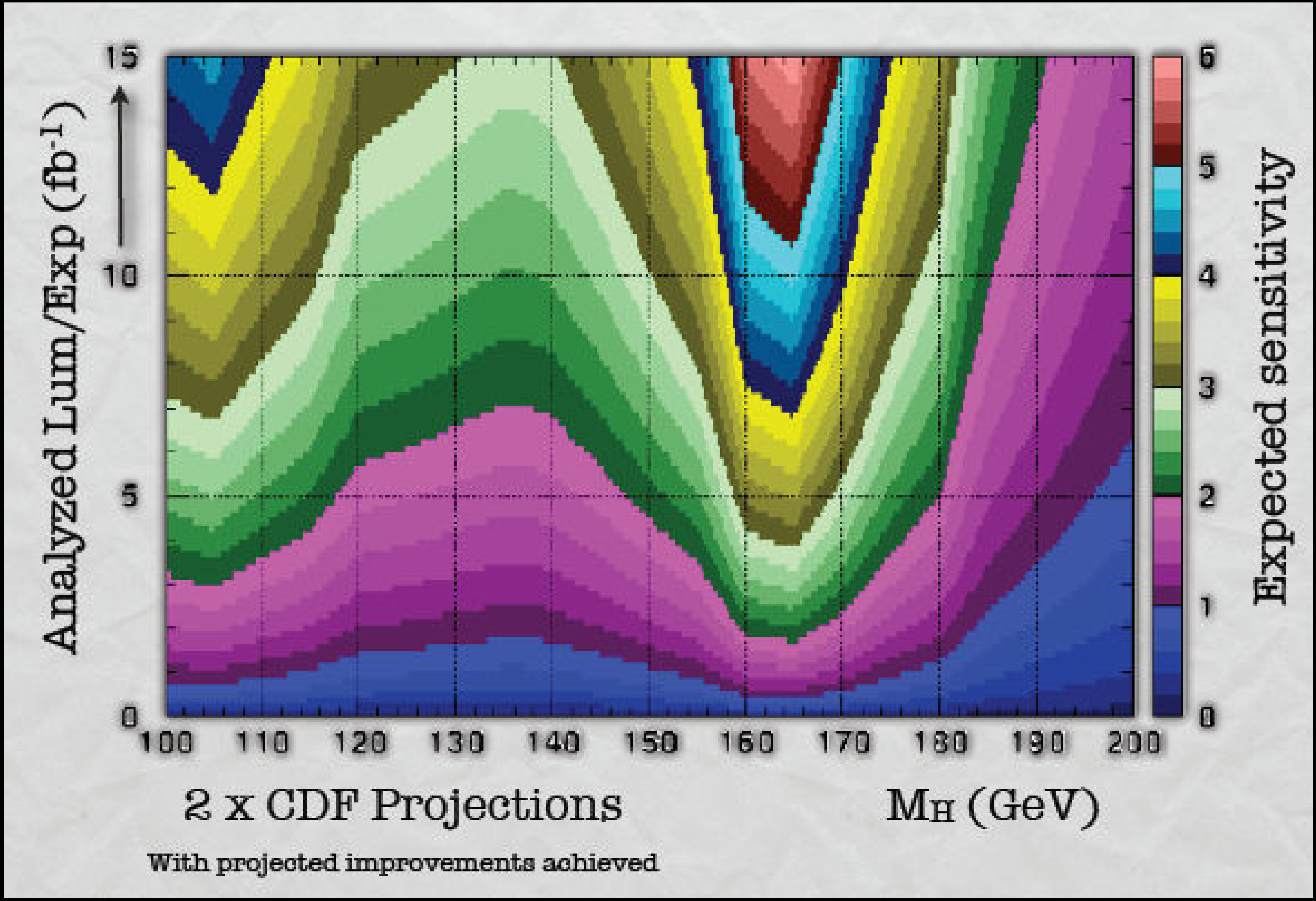
SM Higgs Excluded: m_H = 163-166 GeV

We are Making Steady Progress…



For a 160 GeV Higgs

How Well Can We Do?



Conclusions

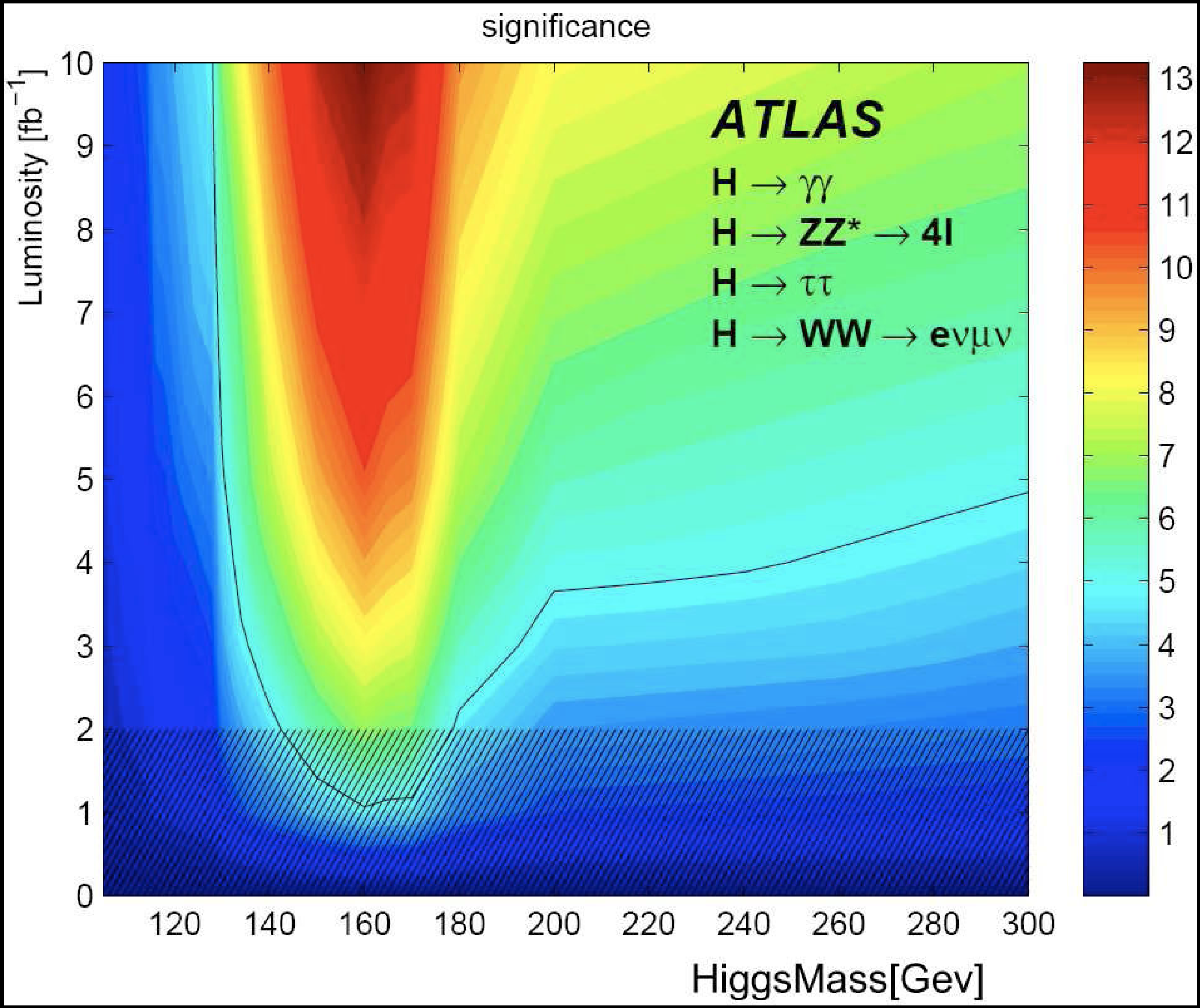
- High Energy Colliders provide physicists with a tool to explore the fundamental questions about nature
- The Tevatron has been remarkably successful from the discovery to the top quark, to the observation of B_s mixing to the remarkable precision measurements of the Top quark and W boson mass just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

Shameless Plug

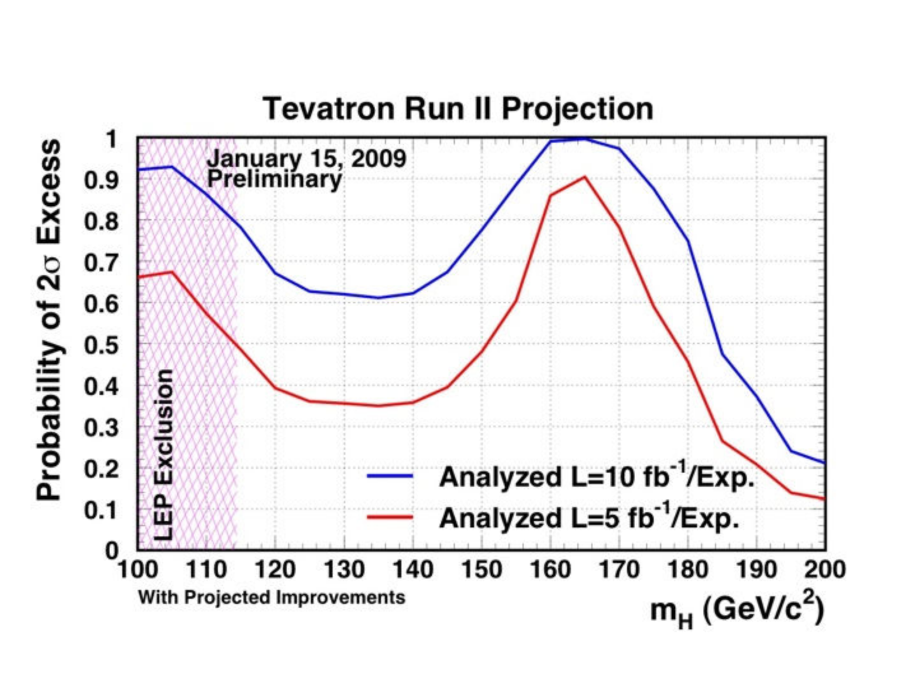
- The tevatron experiments are welcoming help
- CDF would love help in analyzing its data sample
- “service requirements” are very low (read none)
- The plan is to run through 2011 – though we would like to run it longer given the LHC plan

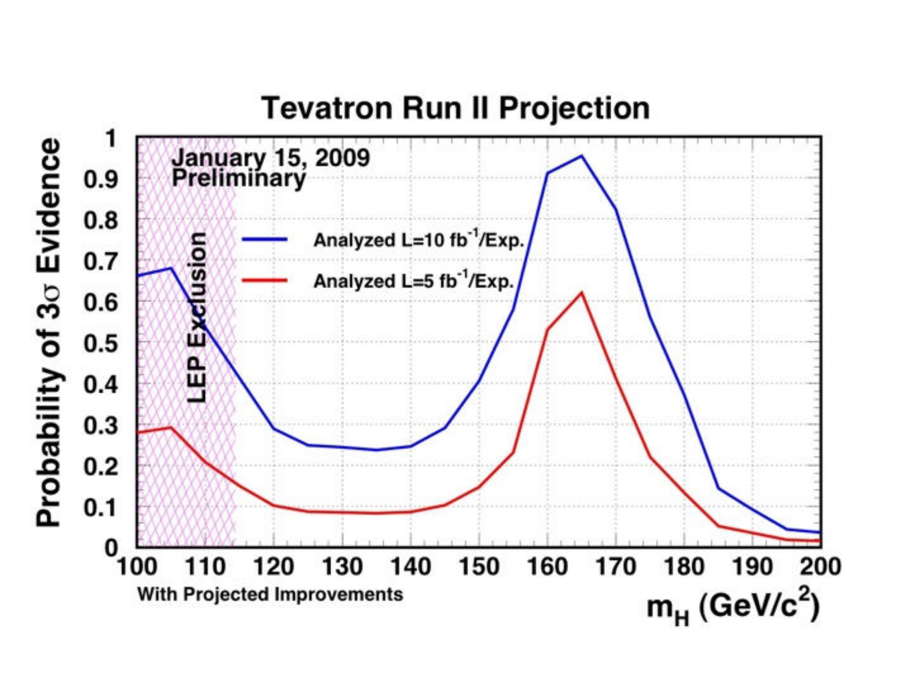
Backup

ATLAS Sensitivity at 14 TeV



How Well Can We Do???

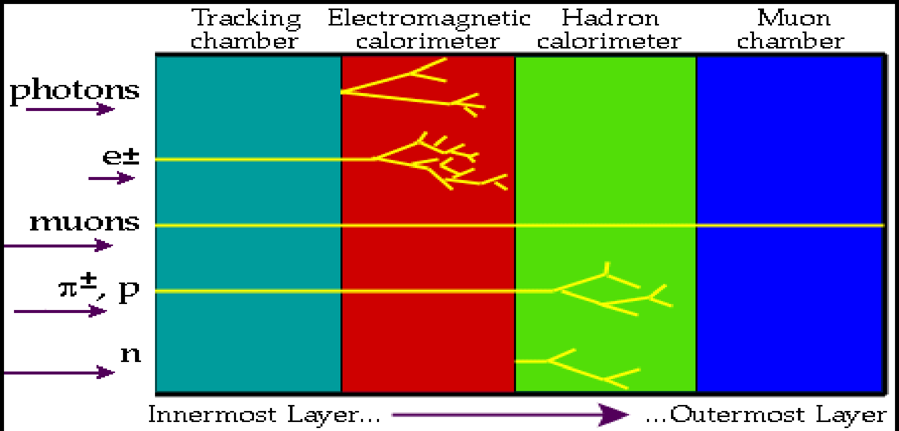


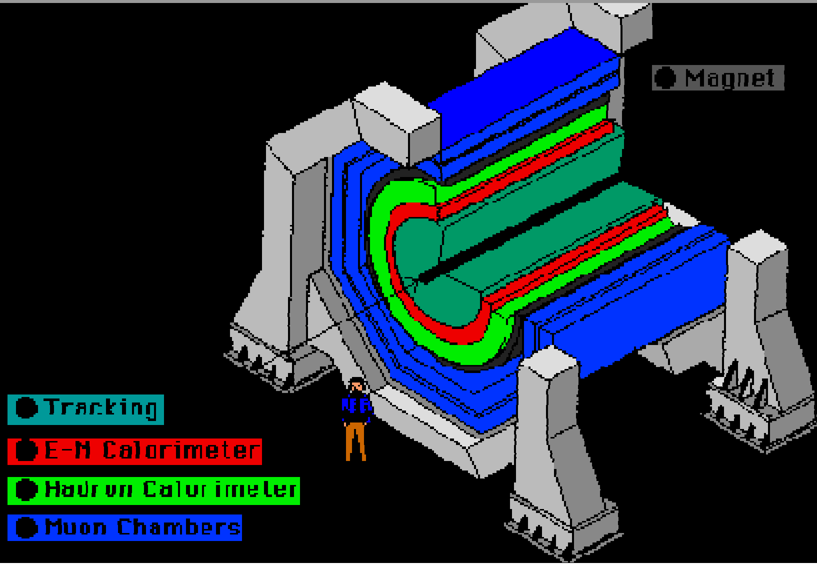


2 σ 3 σ

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

Principle of a Collider Detector

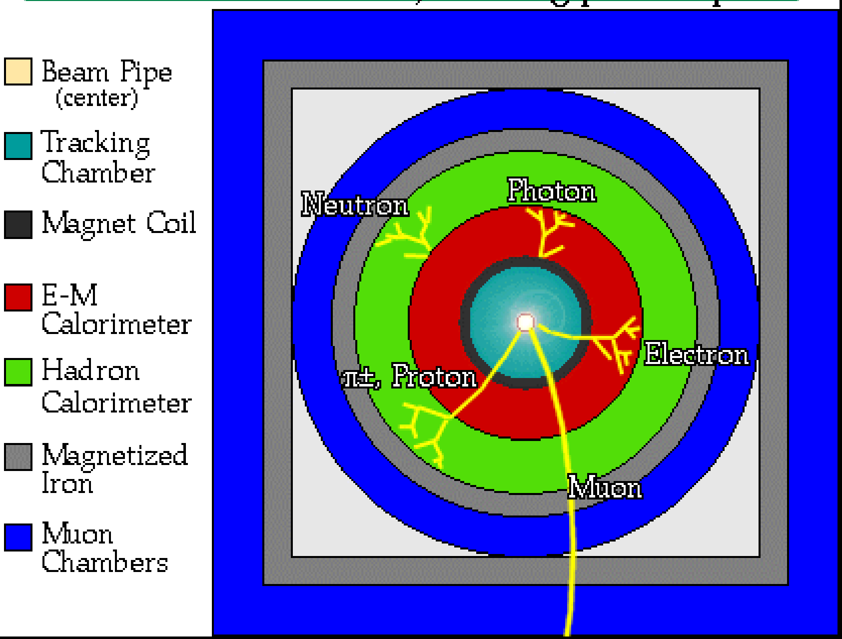


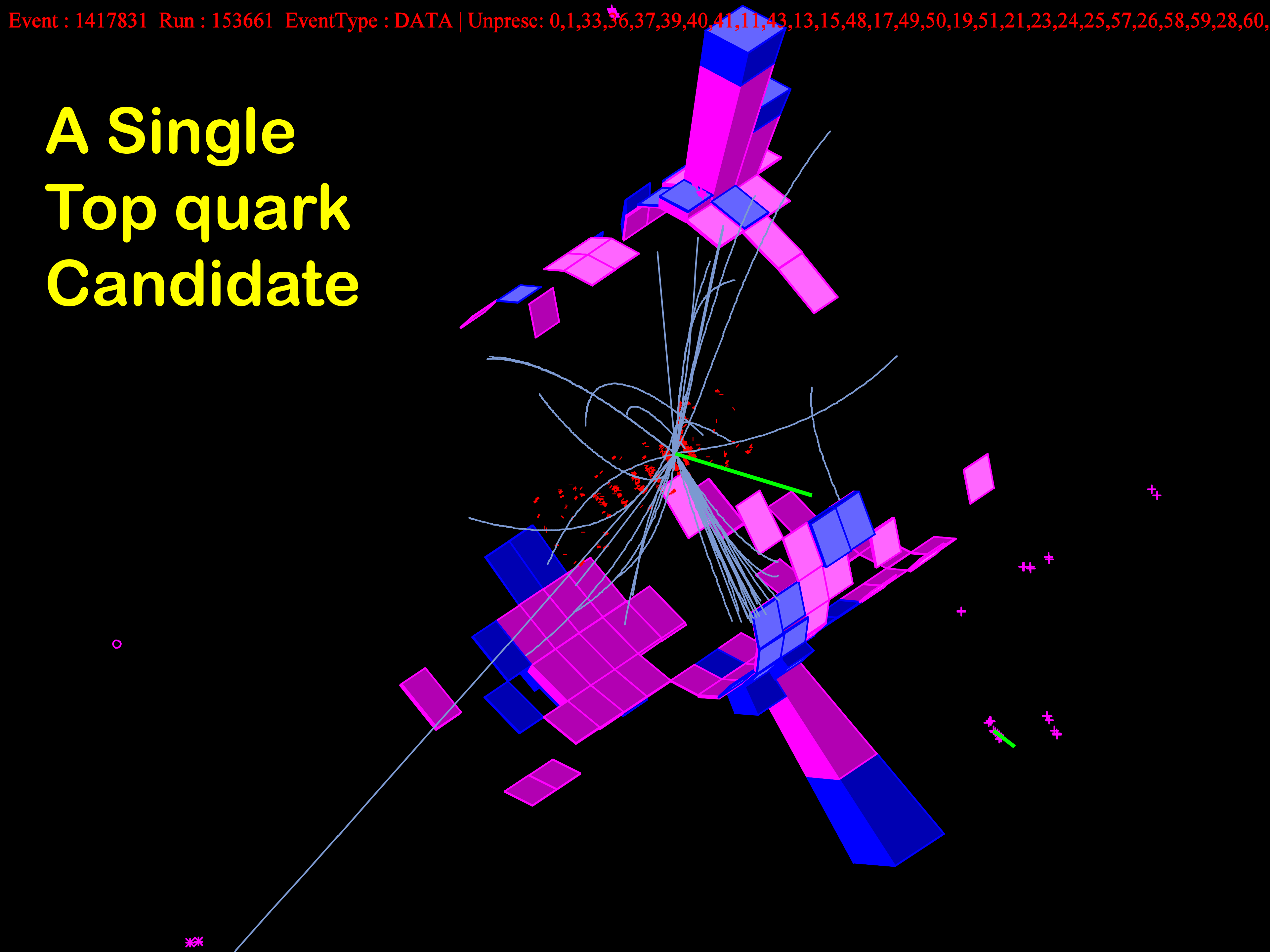


Basic principle is the interaction of particles with matter

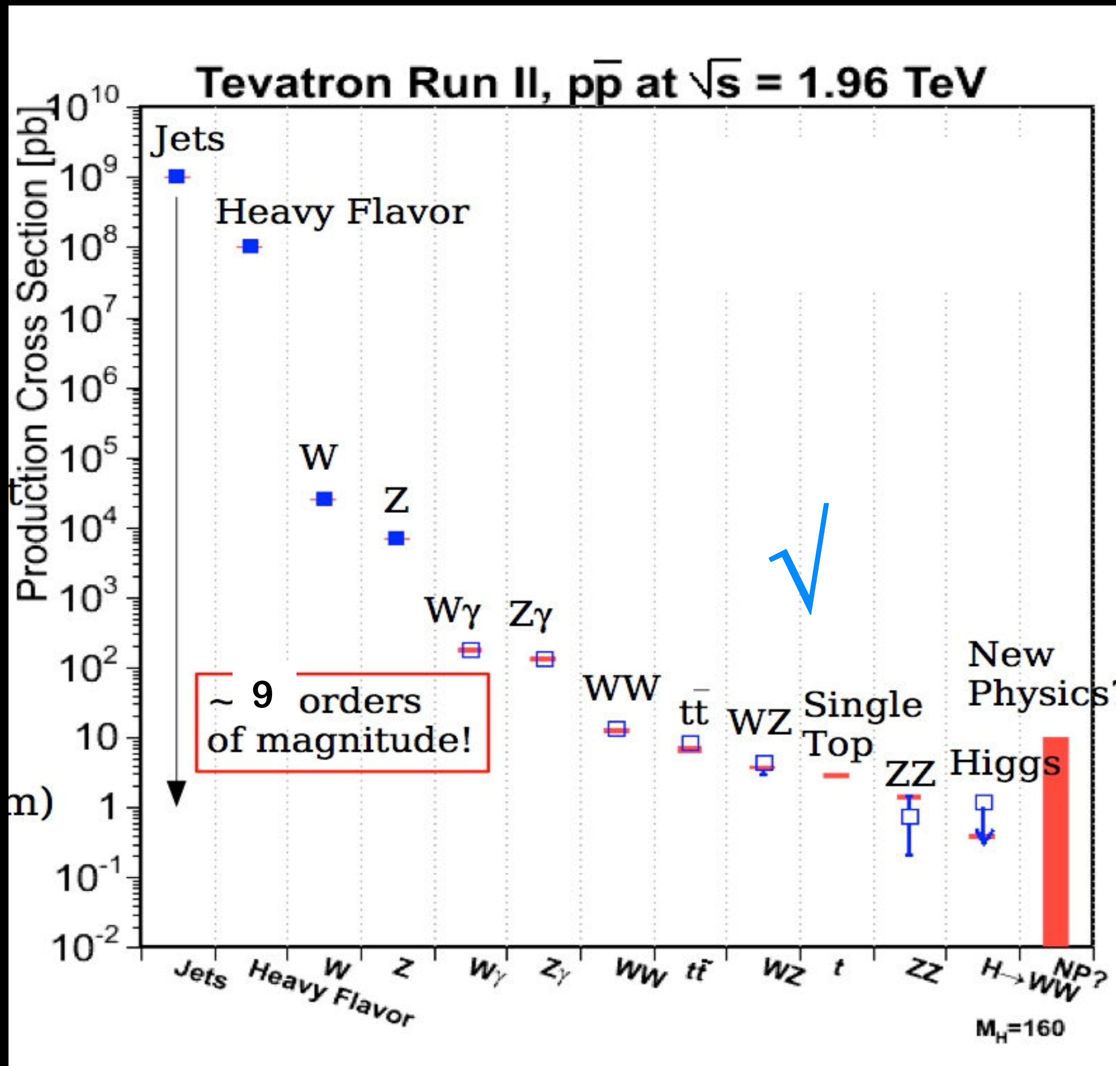
- Momentum/Charge Measurement:
  - need to affect particle as little as possible
  - use dilute/thin absorber medium (gas, thin silicon wafers): Tracker
- Energy Measurement:
  - want to fully absorb particle
  - use thick absorber medium (lead, steel, uranium): Calorimeter

A detector cross-section, showing particle paths




Event : 1417831 Run : 153661 EventType : DATA | Unpresc: 0,1,33,36,37,39,40,41,11,43,13,15,48,17,49,50,19,51,21,23,24,25,57,26,58,59,28,60,
A Single
Top quark
Candidate

A Roadmap to discovery…



Harder to Produce

Harder to Observe