The Collider Detector at Fermilab

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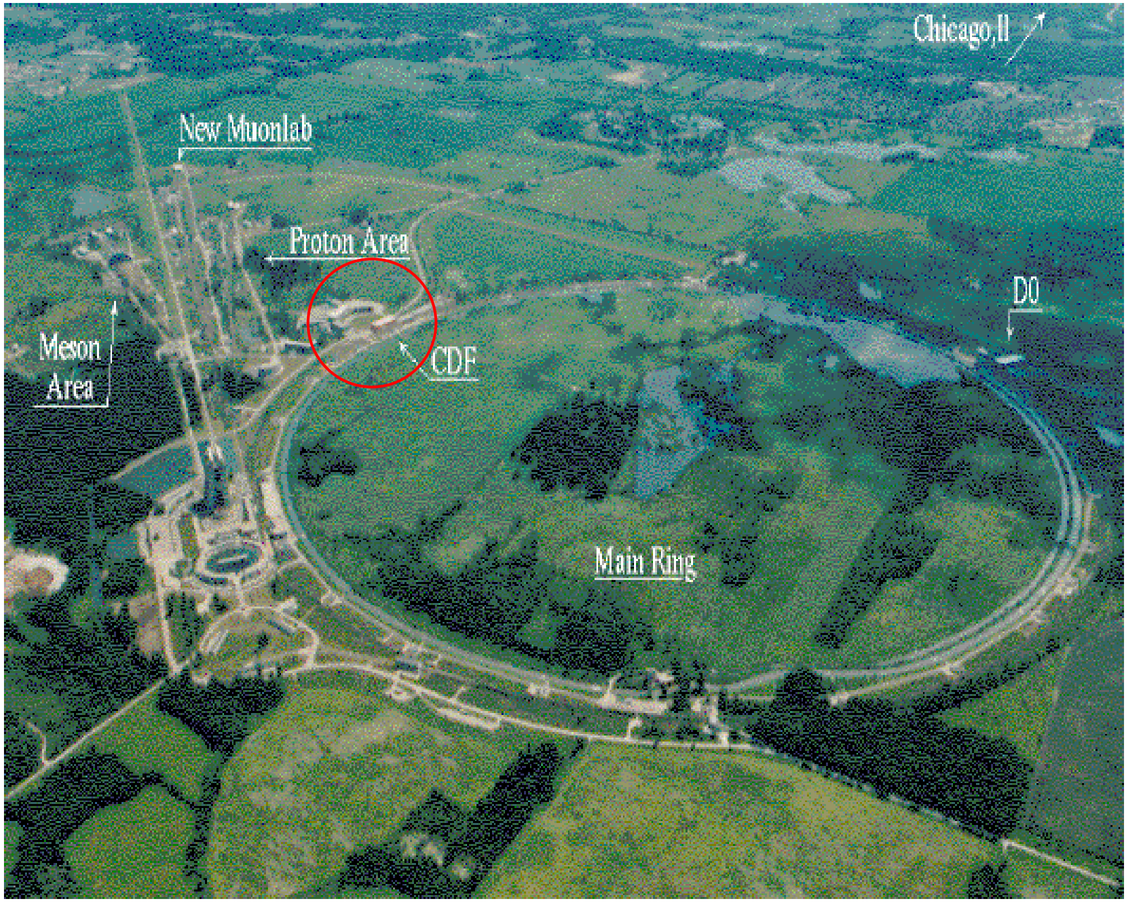
What is Fermilab?

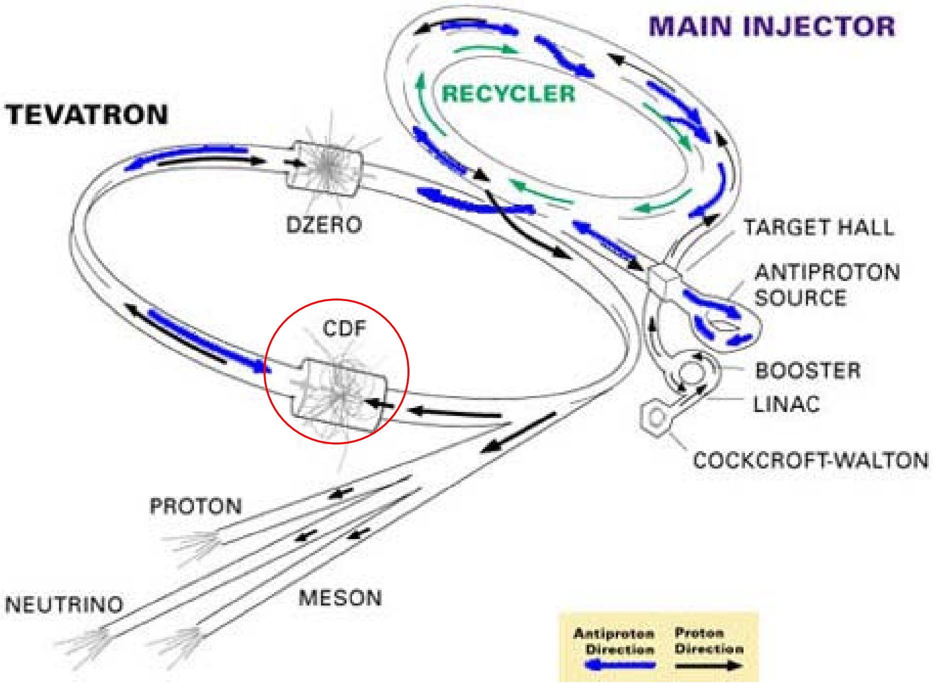


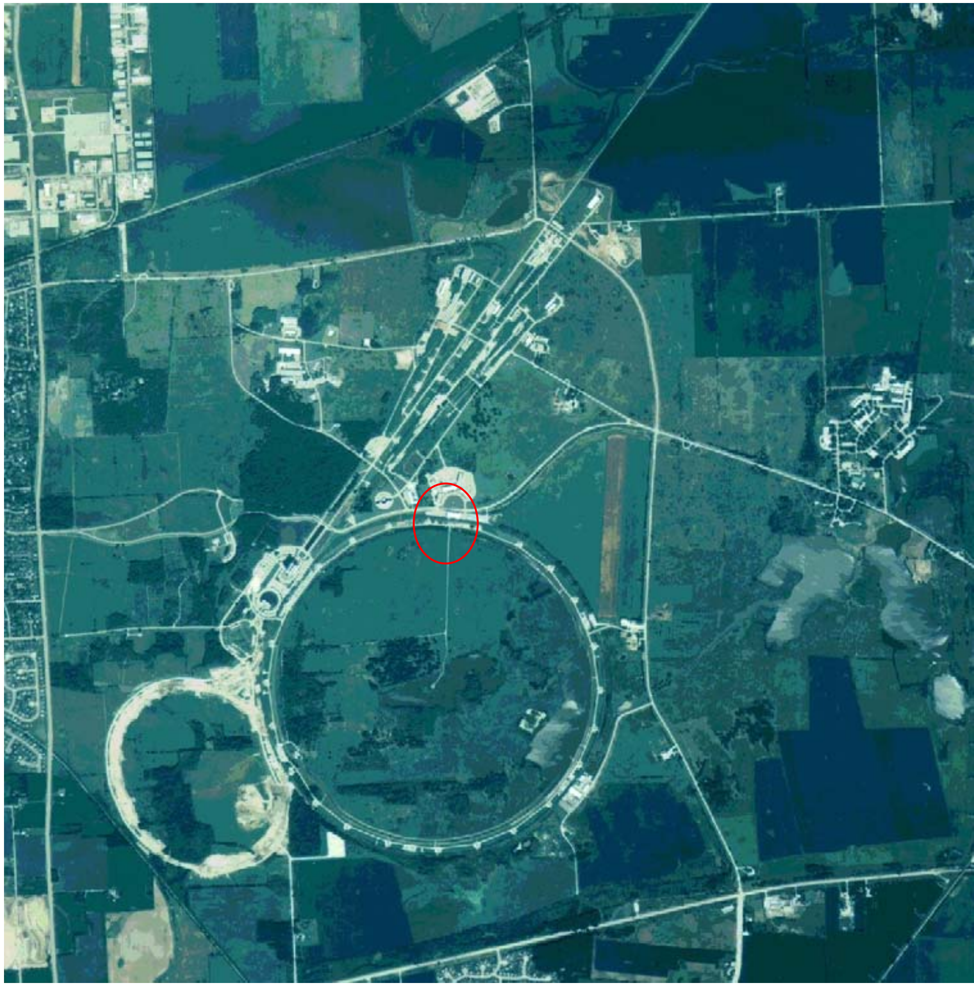
A "user" facility with the **Tevatron:**

4 mile ring with superconducting magnets.

- Collides protons with antiprotons.
- Energies up to 2 TRILLION eV achieved.

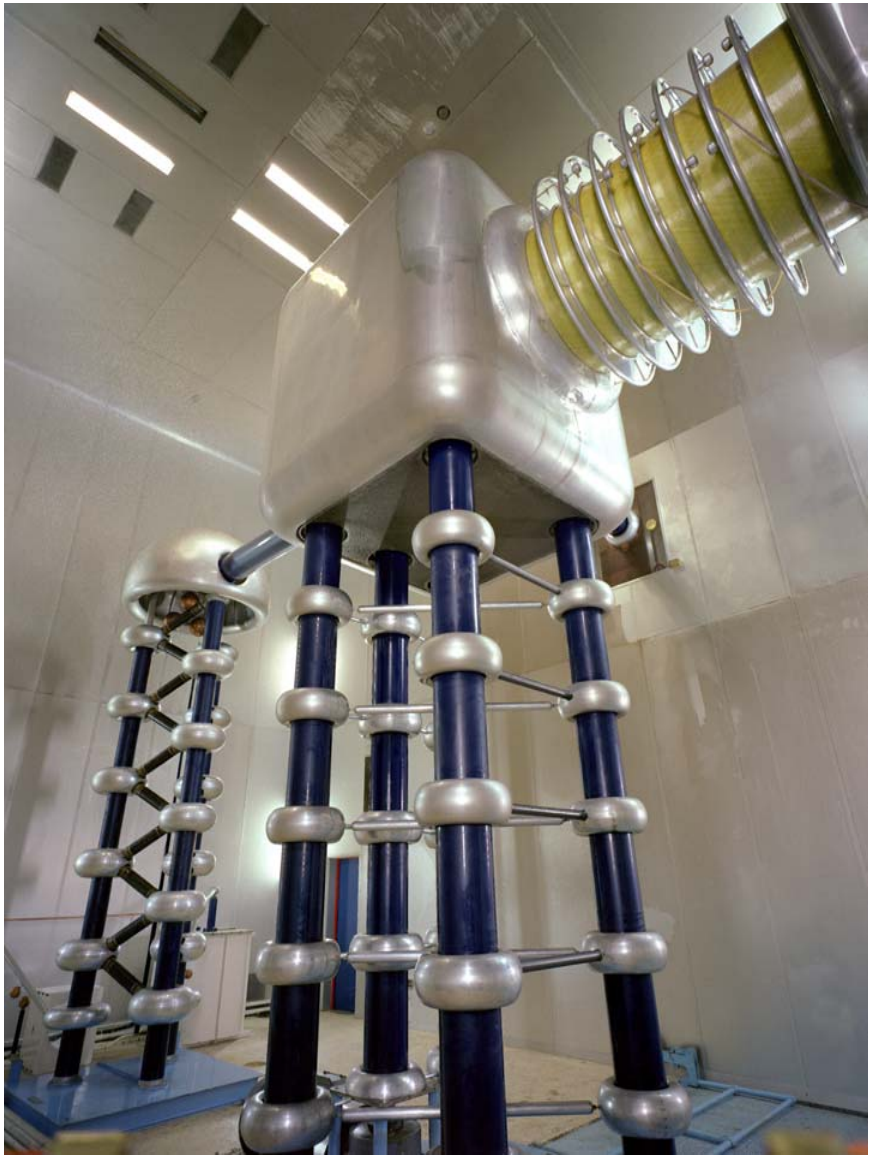
The Tevatron at Fermilab





- Many stages of boosting.
  - Note p-bar production.
- A “user” facility.
  - Fixed-target or collider.

The Cockroft-Walton and Linac
(where protons start out)



The Tevatron

The Tevatron in Numbers

	Run 1B	Run IIa	Run IIb
Energy/beam	900 GeV	1000 GeV	1000 GeV
Peak Luminosity	1.6×10^{31}	2.0×10^{32}	5.0×10^{32}
Number of bunches	6	36/108	~ 108
Bunch spacing	3500 nsec	396/132 nsec	132 nsec
Interactions/crossing	2.8	5.8/1.9	4.9
Run period	1992-96	2001-03	2004-07
Integral Luminosity	118 pb^{-1}	2 fb^{-1}	13 fb^{-1}

Note integral luminosity given in inverse **barns.** (10^{-28} m^2)

Some important numbers:

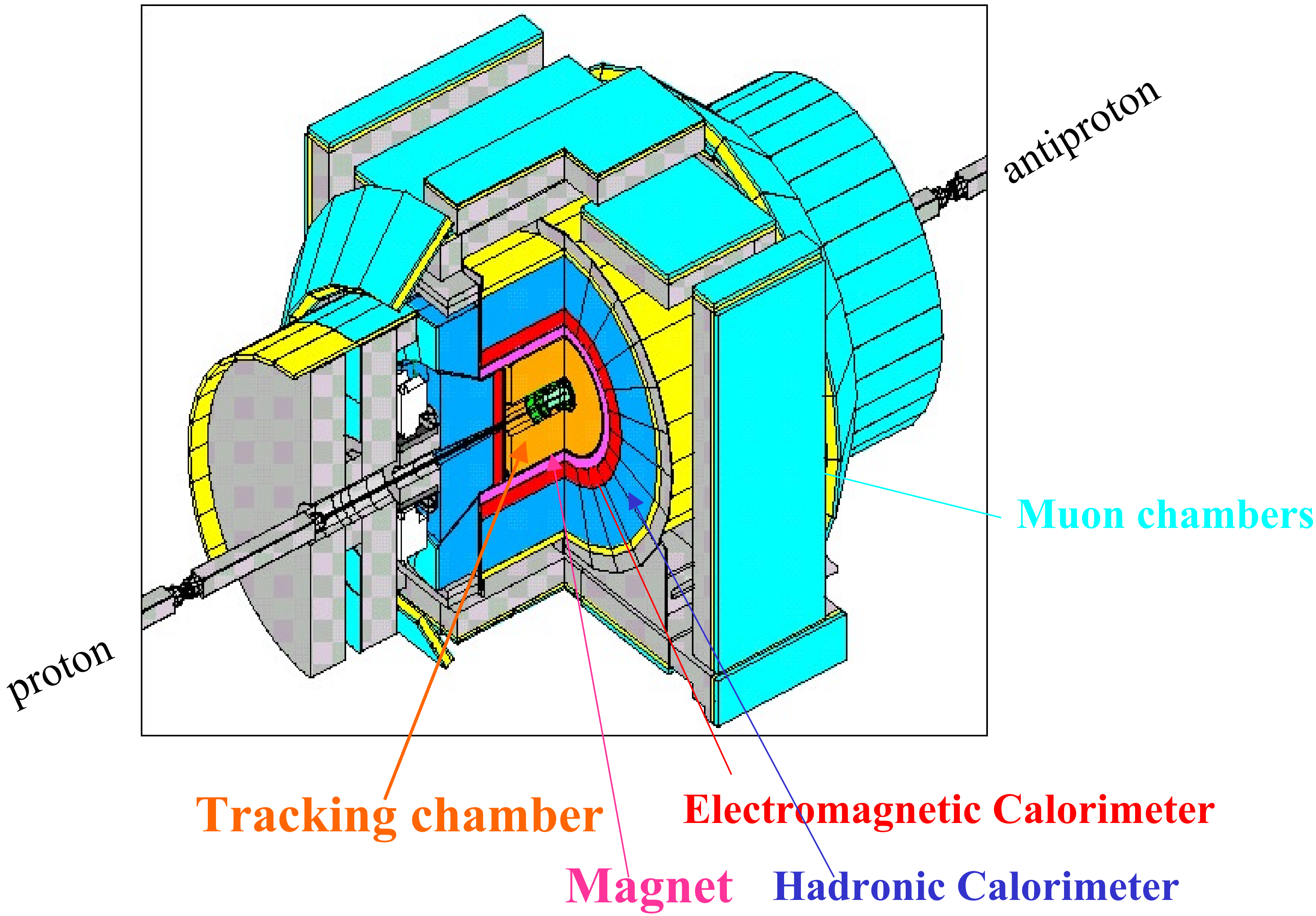
•$p\bar{p}$ total cross-section (2TeV) ~ 70mb.

•$p\bar{p}$-> W, (Z) boson production (2TeV) ~ 2.5 nb , (250 pb) *leptonic decay*.

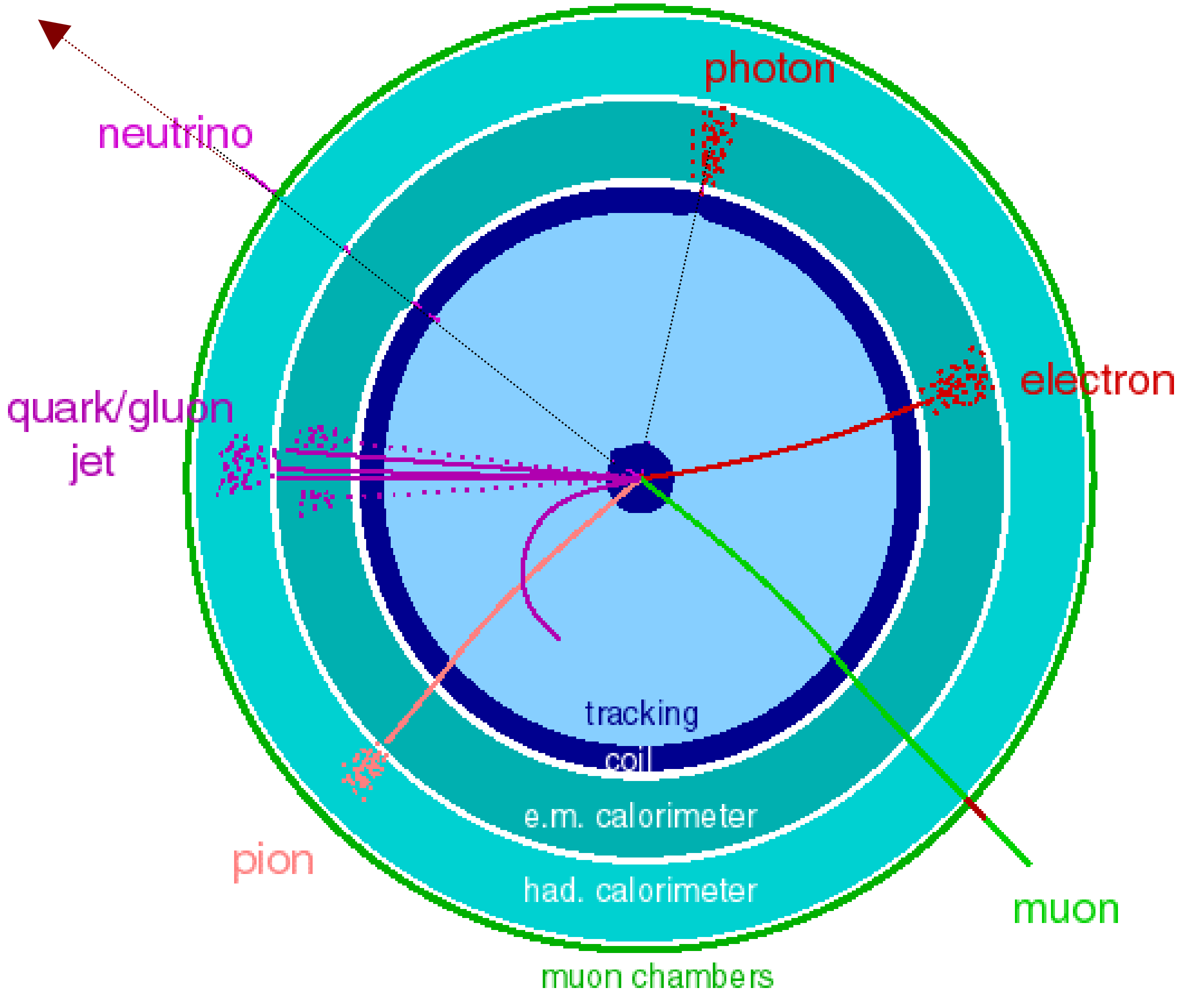
•$p\bar{p}$-> $t\,\bar{t}$ cross section (2TeV) ~ 5 pb.

•$p\bar{p}$-> Higgs +X cross section (2TeV) ~ few fb (?) ***depends on M_H.***

The CDF Collider Detector



Particle Identification
(basic)

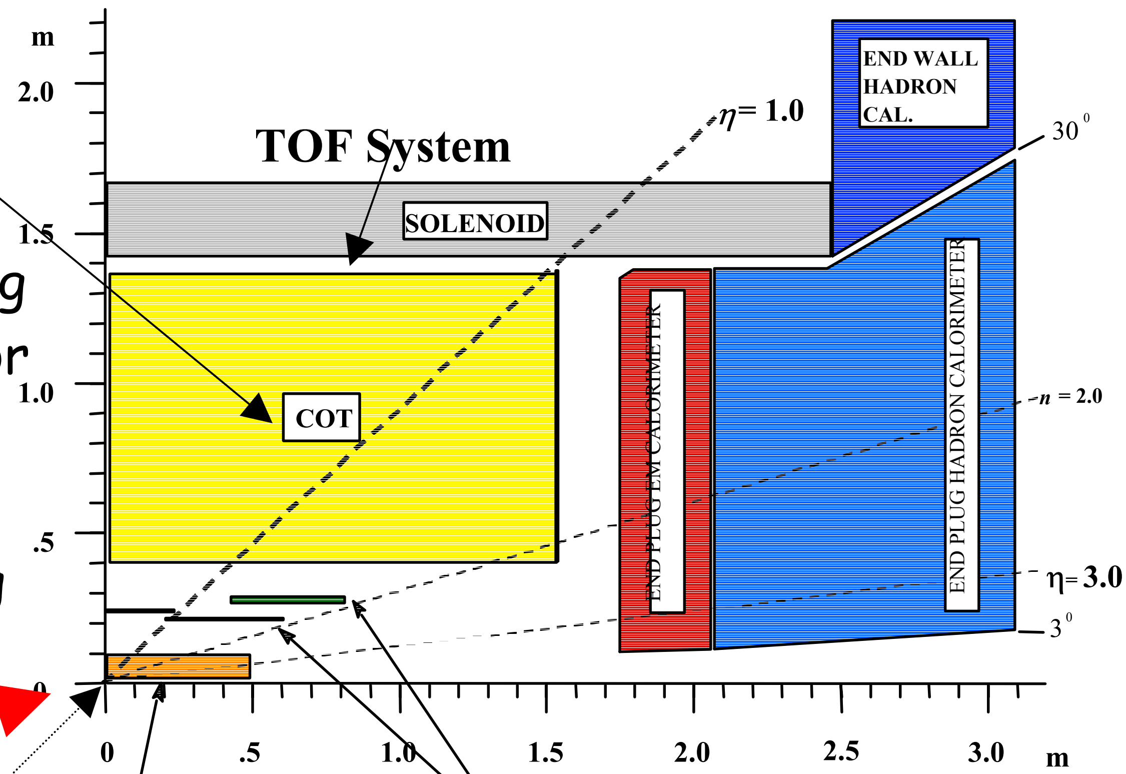


- Electron
  track, contained cluster, E/P~1
  γ, no track
- Hadron (p,π,K)
  track, extended (had) cluster
  n, no track
- Muon
  penetrating track
- Short lived (b)
  Displaced (mm) vertex.
- Weak, no charge (ν,LSP)
  Missing momentum

The CDF detector quarter view

wire drift chamber (96 hits)

- A new powerful <u>3D</u> tracking system and vertex detector covering |η| out to 2.0.
- A new scintillating tile plug calorimeter covering |η| out to 3.6.



Collisions happen here

Innermost Si on beampipe

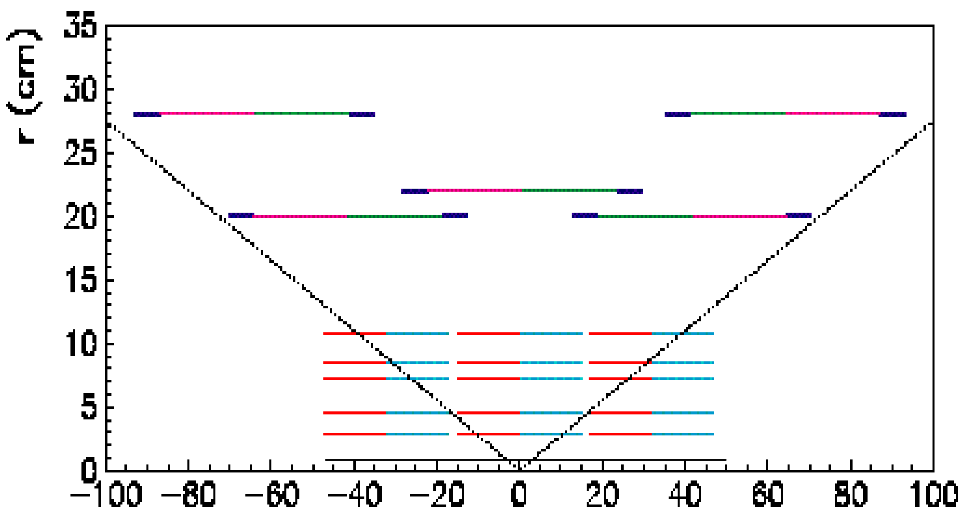
Inner silicon 6 layers

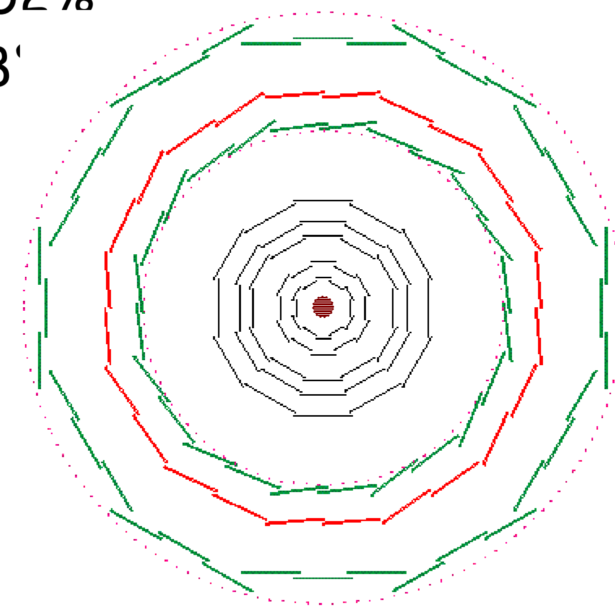
Intermediate silicon 1, 2 layers

Silicon Vertex Tracking

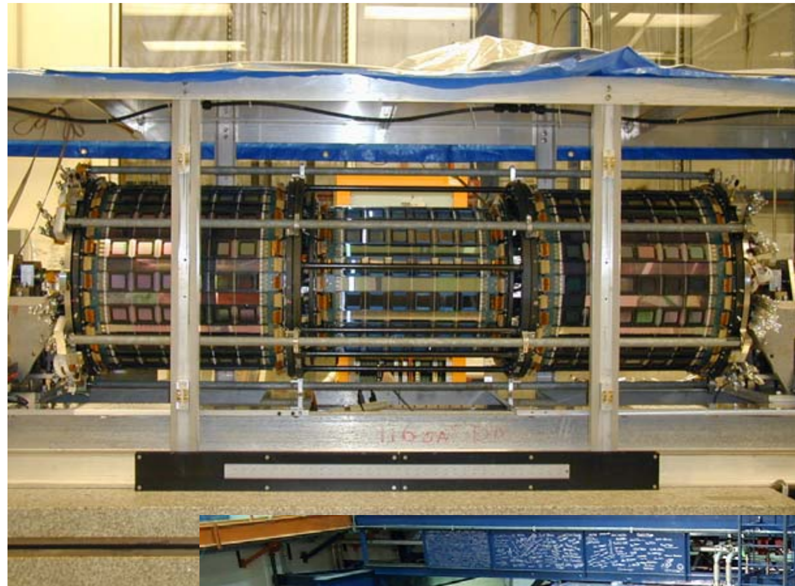
- The silicon strip detector is a stand-alone 3D tracking system
- Impact parameter resolution $\sigma_d = \sqrt{a^2 + (b/P_t)^2}$ (a =7μm, b =20-30μm)
- Increase in B tagging for $t\bar{t}$:

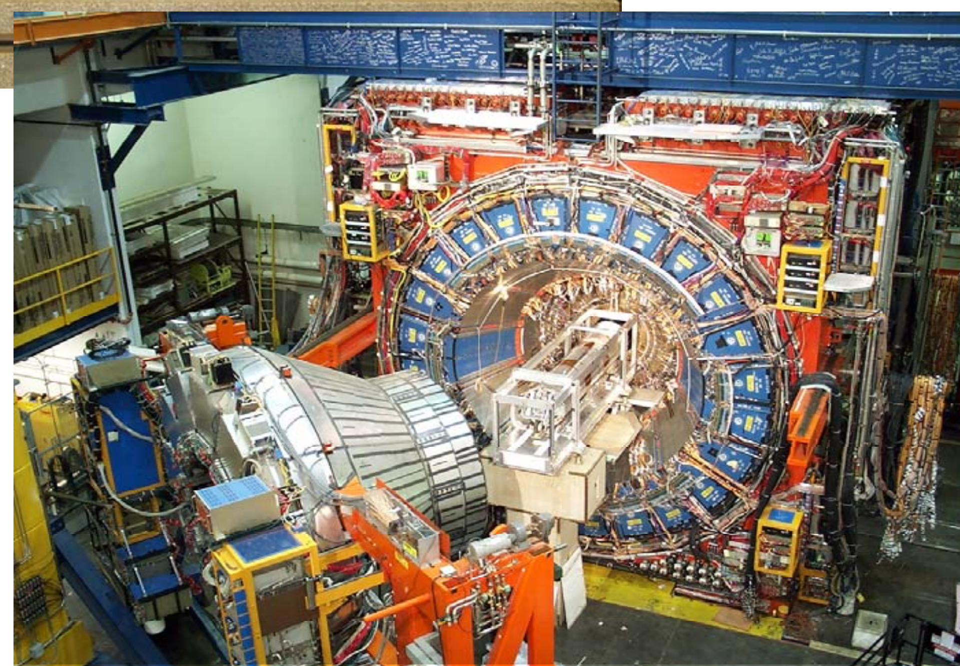
	Run I	Run II
single tag	25%	52%
double tag	8%	28



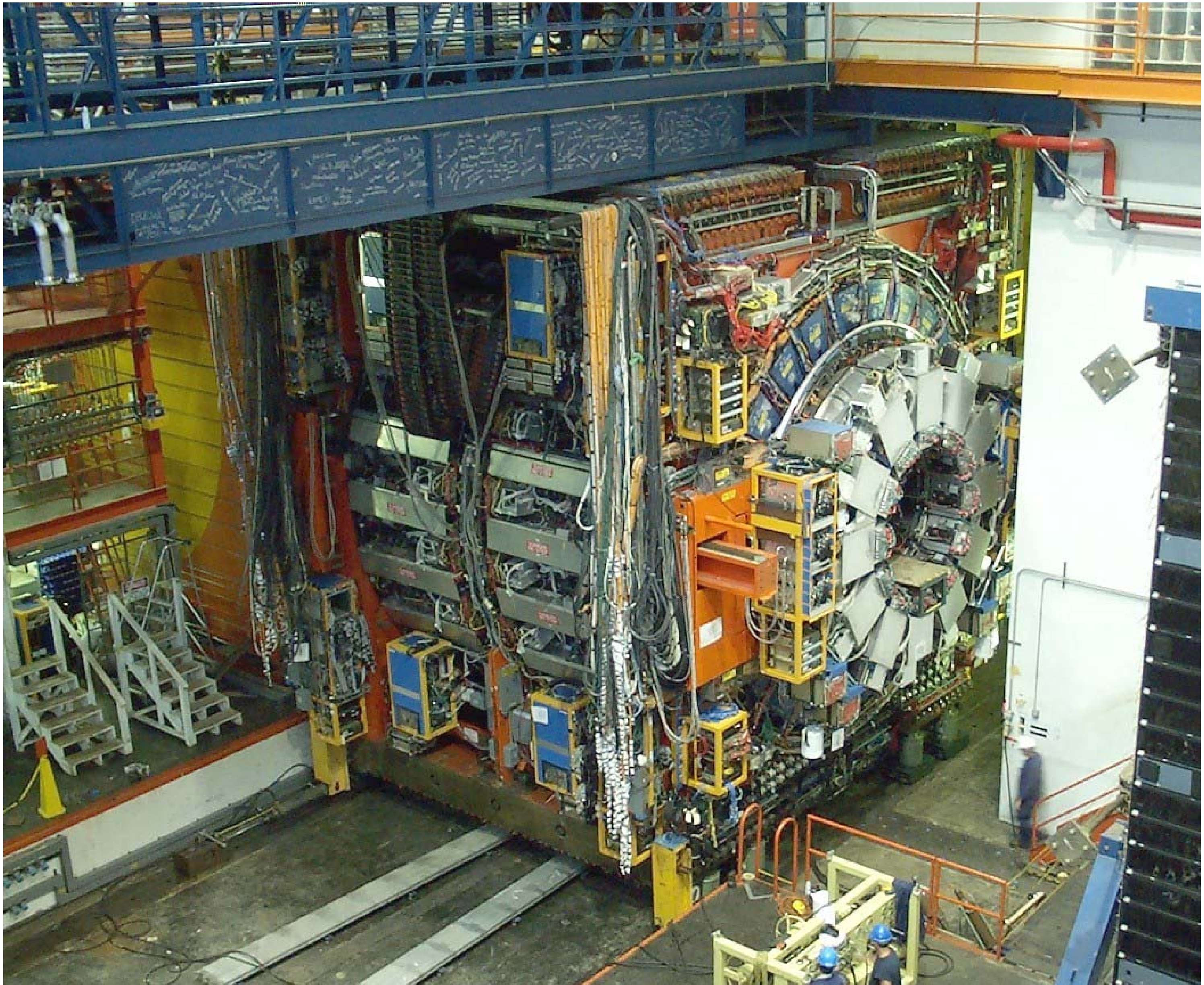


CDF Silicon Vertex Detector

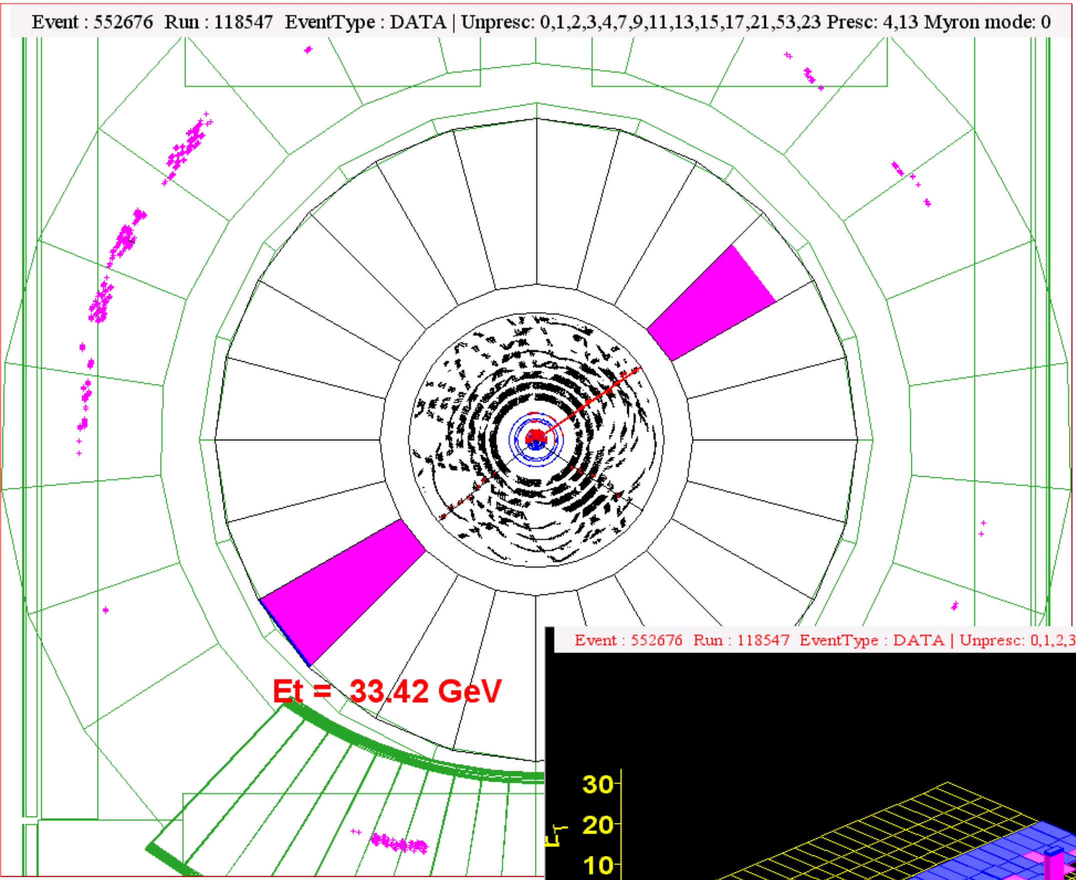




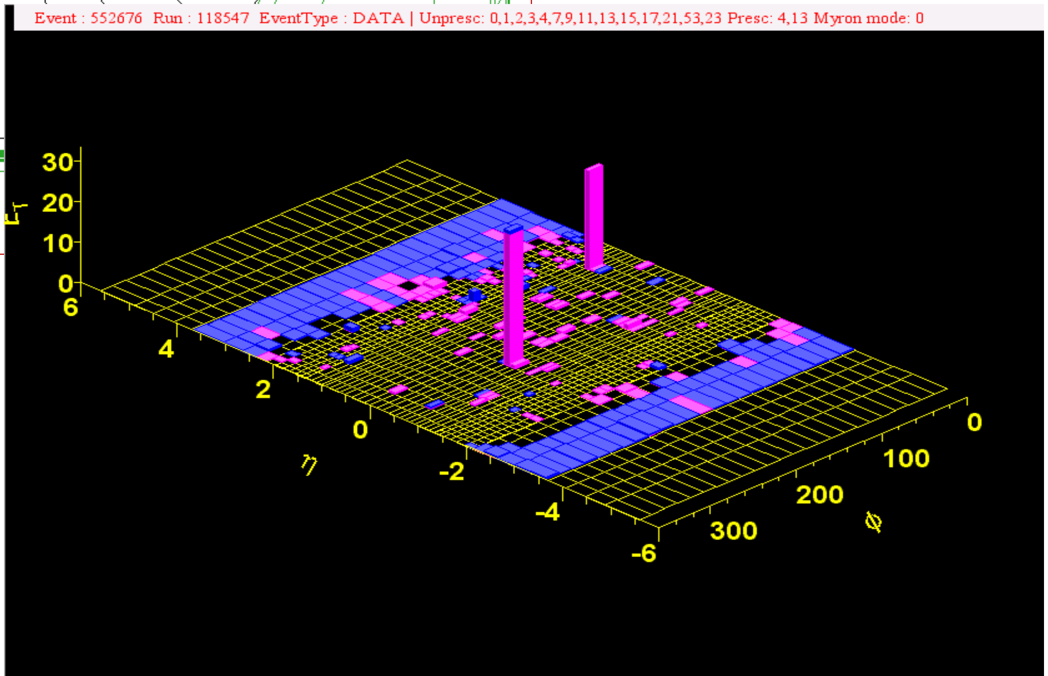
CDF Rolling into Collision Hall



Z decay to electrons

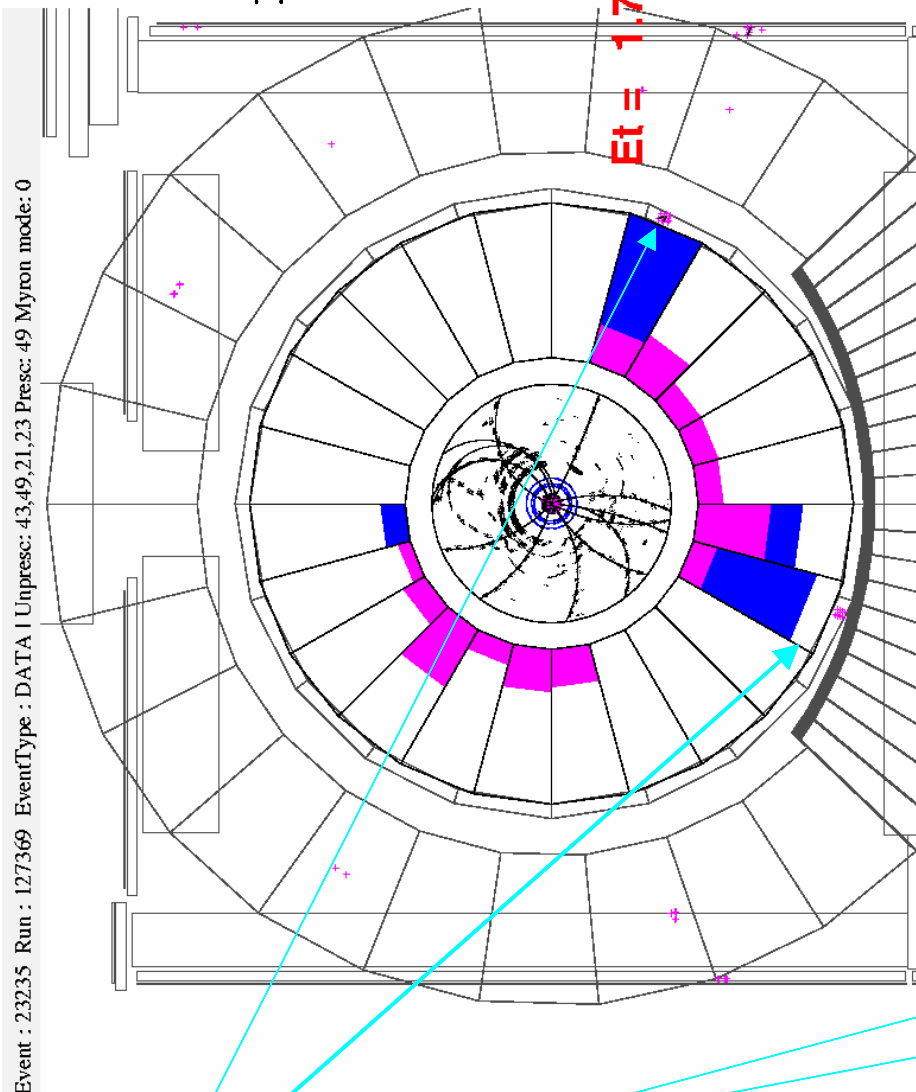


- **All energy contained in EM calorimeter.**
- **2 hard tracks.** ***Lots of soft ones.***
- **Electron ID?**
  - **EM energy: 36.97, 39.71 GeV**
  - **Had energy: 0.73, 0.0 GeV**
  - **P: 34.65, 61.57 GeV/c**

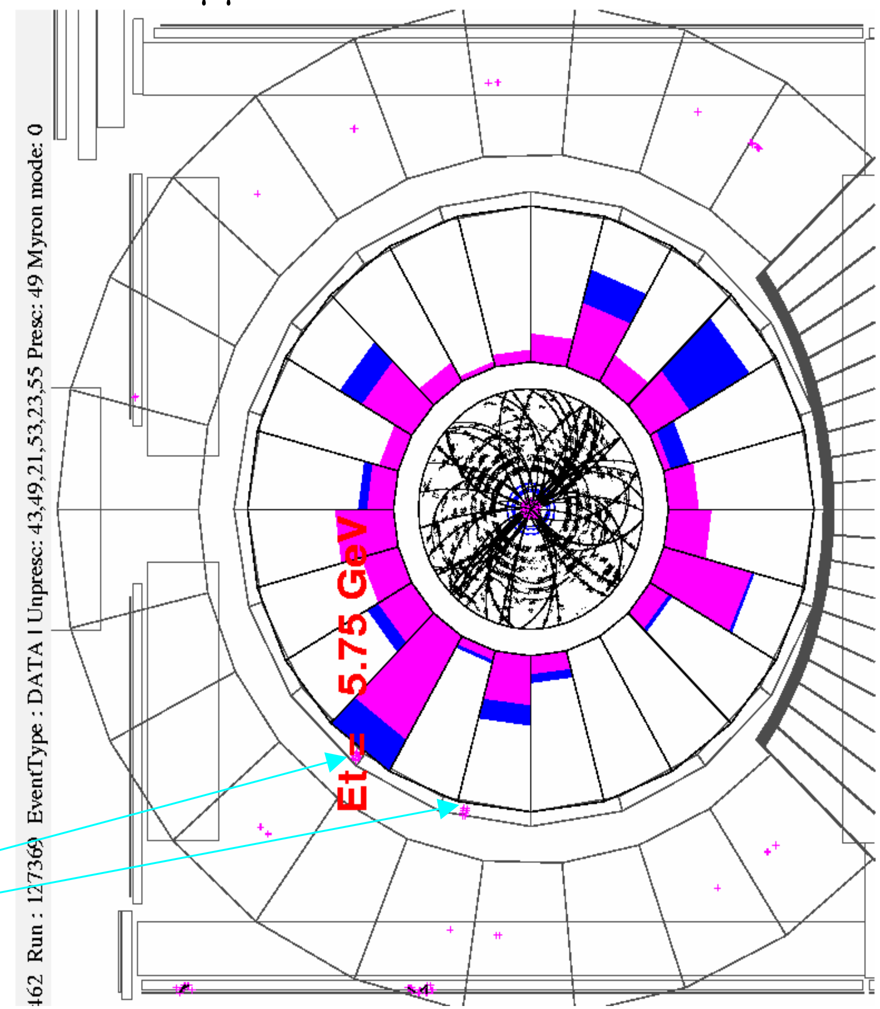


Jpsi to muons

$M_{\mu\mu}= 3.0507$

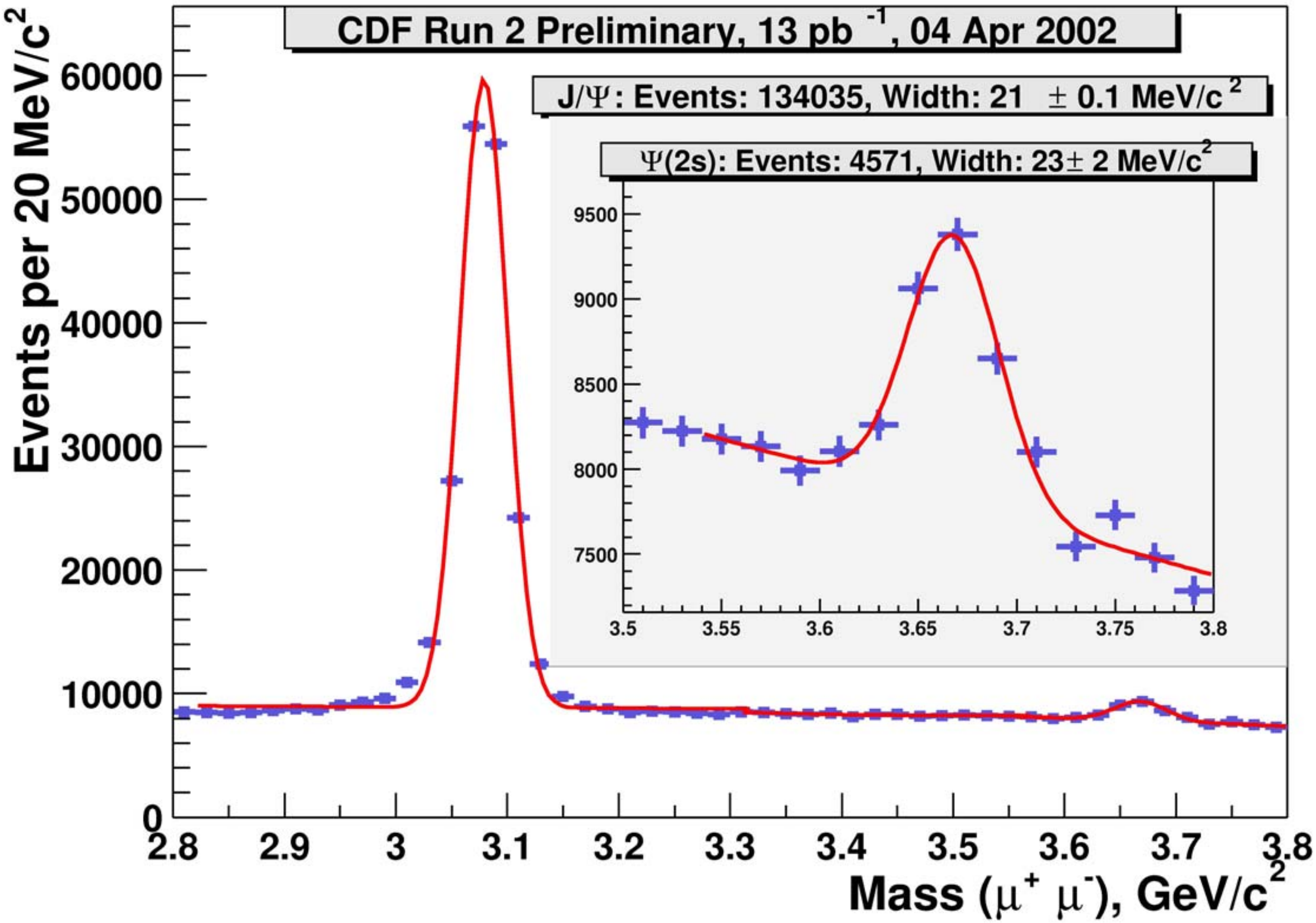


$M_{\mu\mu} = 3.0859$

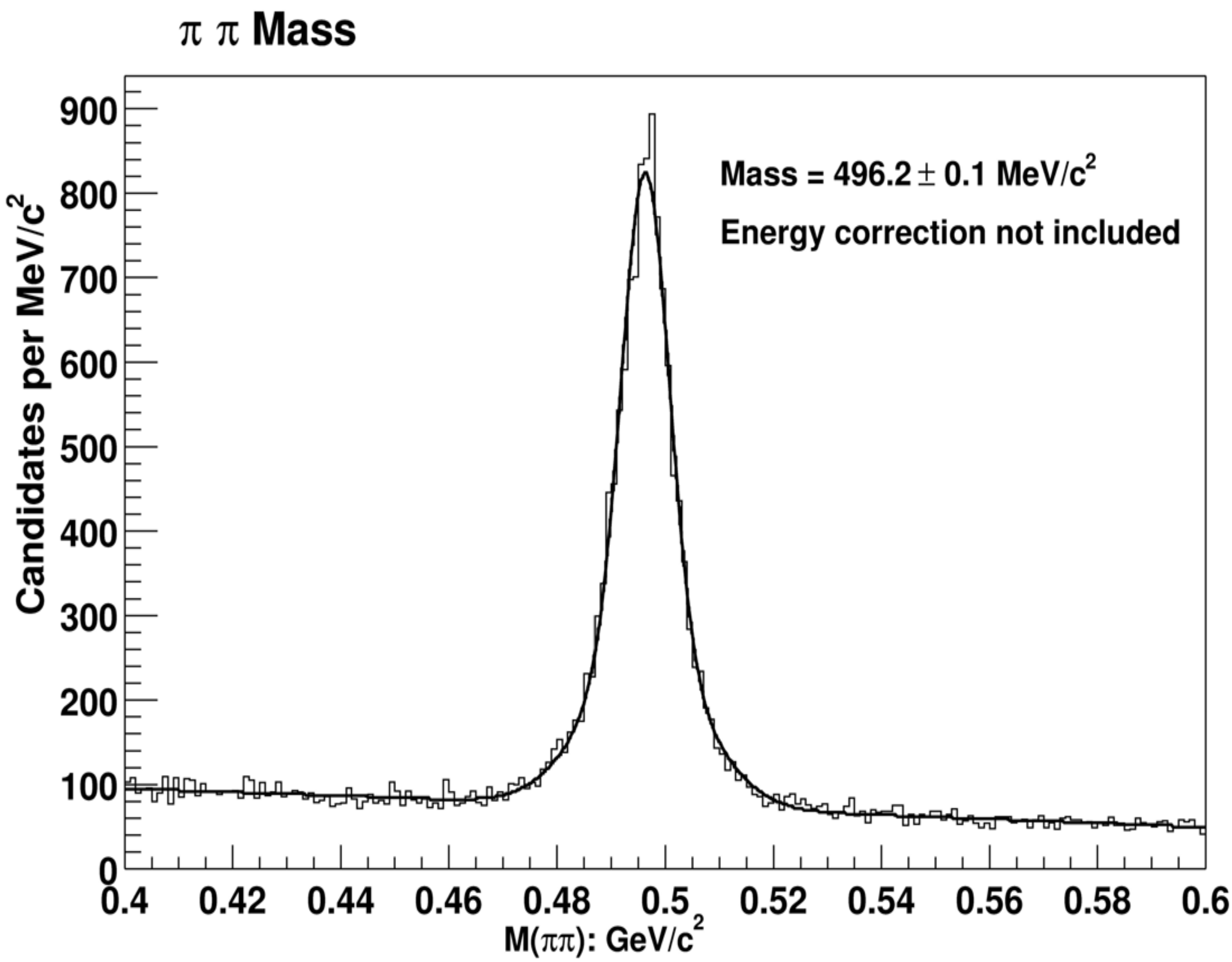


Muon hits

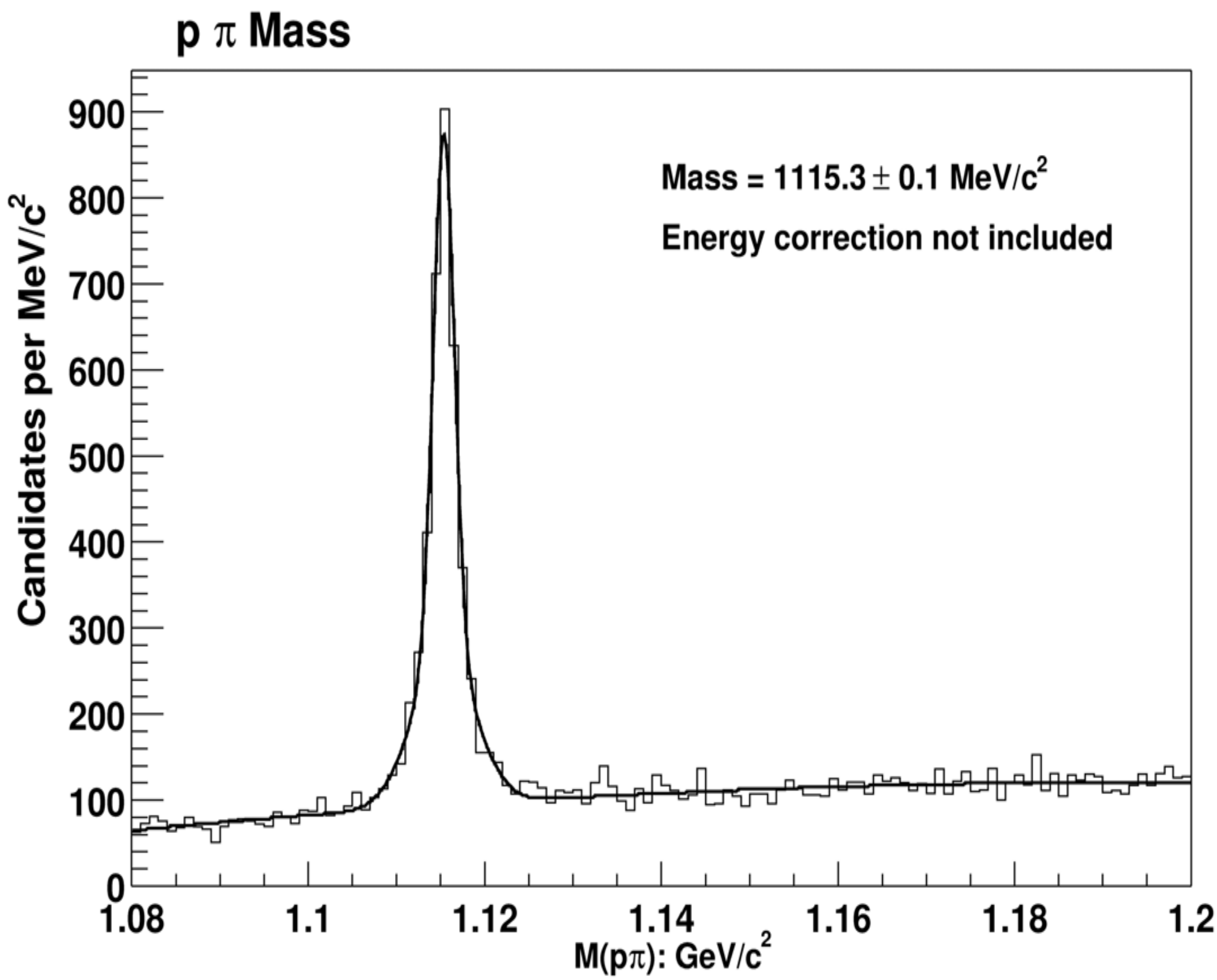
Jpsi to muons Mass



Kshort Mass


π π Mass
Mass = 496.2 ± 0.1 MeV/c²
Energy correction not included
Candidates per MeV/c²
0
100
200
300
400
500
600
700
800
900
0.4
0.42
0.44
0.46
0.48
0.5
0.52
0.54
0.56
0.58
0.6
M(ππ): GeV/c²

Lambda Mass


p π Mass
Mass = 1115.3 ± 0.1 MeV/c²
Energy correction not included
Candidates per MeV/c²
0
100
200
300
400
500
600
700
800
900
1.08
1.1
1.12
1.14
1.16
1.18
1.2
M(pπ): GeV/c²

B Meson Lifetime

B -> Jpsi

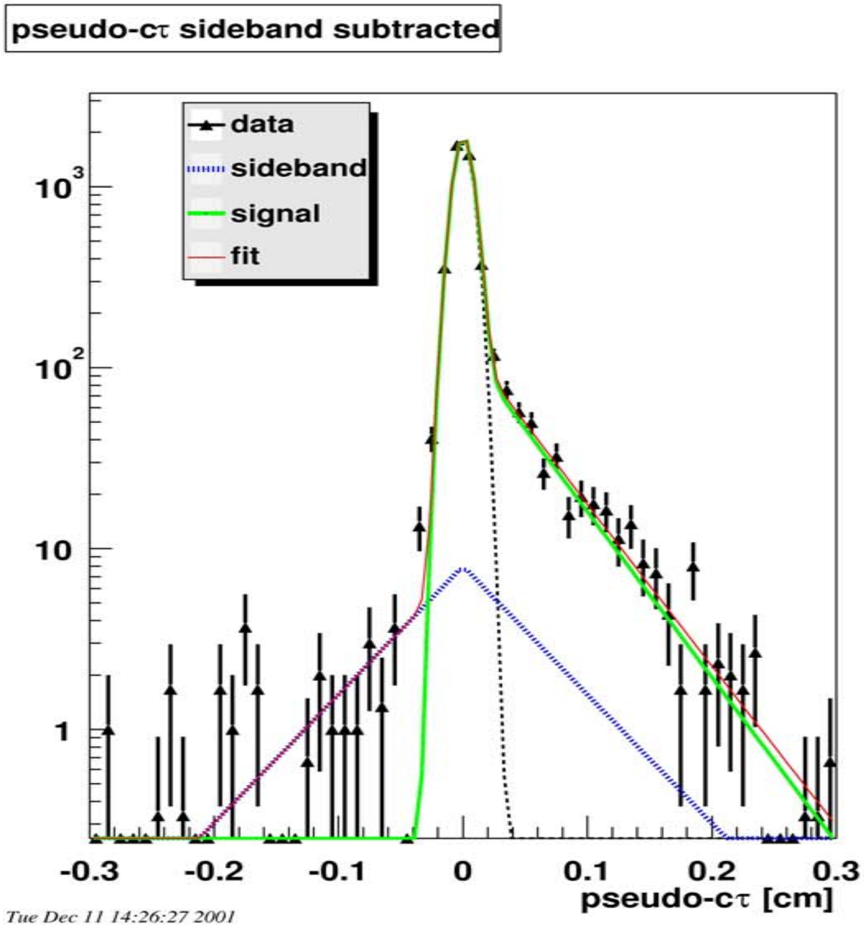
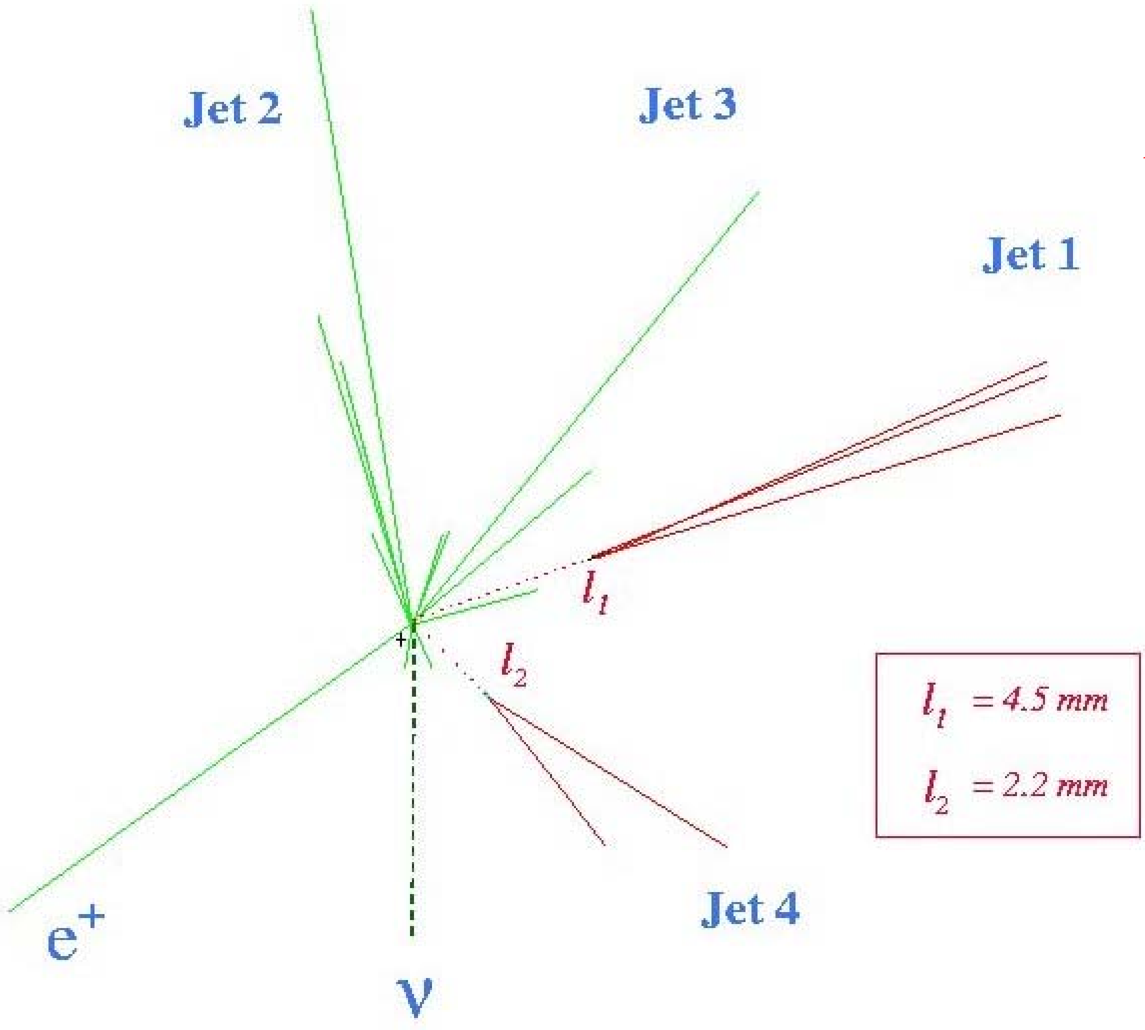


Figure 14: Sideband-subtracted J/ψ pseudo-$c\tau$ distribution.

Top Quark Event in Run 1



What happened?

pp-> t t

b W-> e ν

b W -> q q′ (jets)

Keep in mind:

W -> e, μ (+ ν) ~20%

B meson cτ ~ 500 μm

M_{top}^{Fit} = 170 ± 10 GeV/c^2

24 September, 1992
run #40758, event #44414

Basic Idea of Hadron Collider/Detector

- Collide hadrons at highest energy possible.
  - Cross-sections increase with energy.
- Highest collision rates possible.
- General purpose detector that detects and identifies:
  - Electrons, muons, photons, pions, (missing P).
  - Displaced vertices from B mesons.
- Look for final states with specific signatures.
  - Like Higgs. (SM or SUSY).
- Quick identification (in *trigger*) better than later (in analysis).

CDF Deadtimeless Trigger.

P P̄

132 ns -> 7.6 Mhz

L1

Calorimeter energy
Central Tracker (Pt,ϕ)
Muon stubs

50 kHz

L2

Cal Energy-track match
E/P, EM shower max
Silicon secondary vertex
Multi object triggers

300 Hz

L3

Farm of PC's running fast versions of Offline Code → more sophisticated selections

Mass Storage
(1 Pb in 2 years)

30 – 50 Hz

CDF Secondary Vertex Trigger

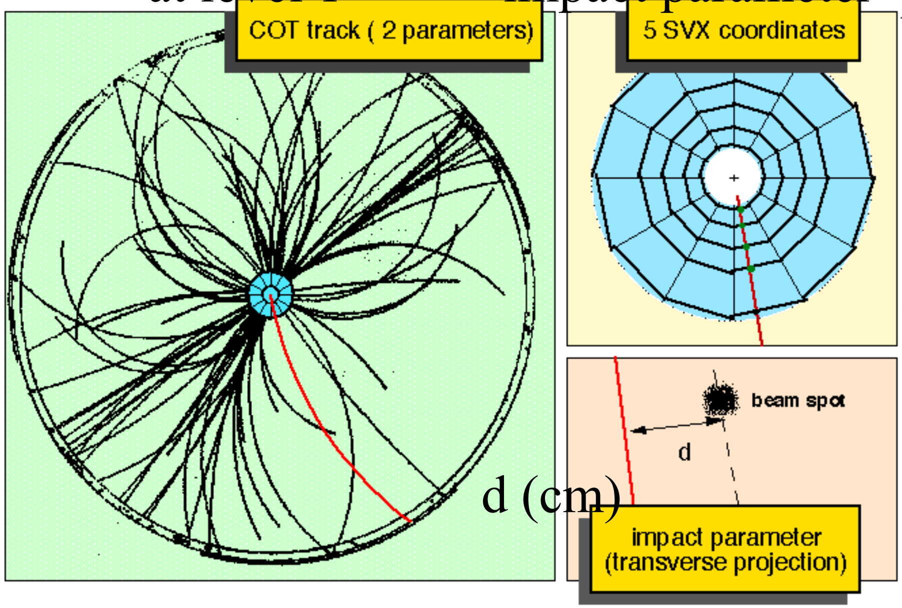
NEW for Run 2 -- level 2 impact parameter trigger

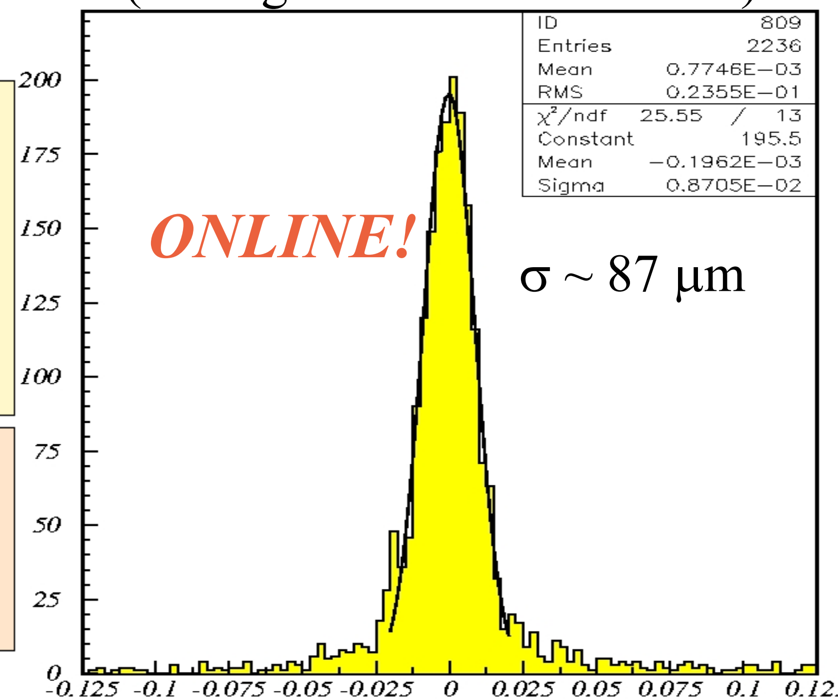
SVT Provides access to ***hadronic*** B decays

Data from commissioning run

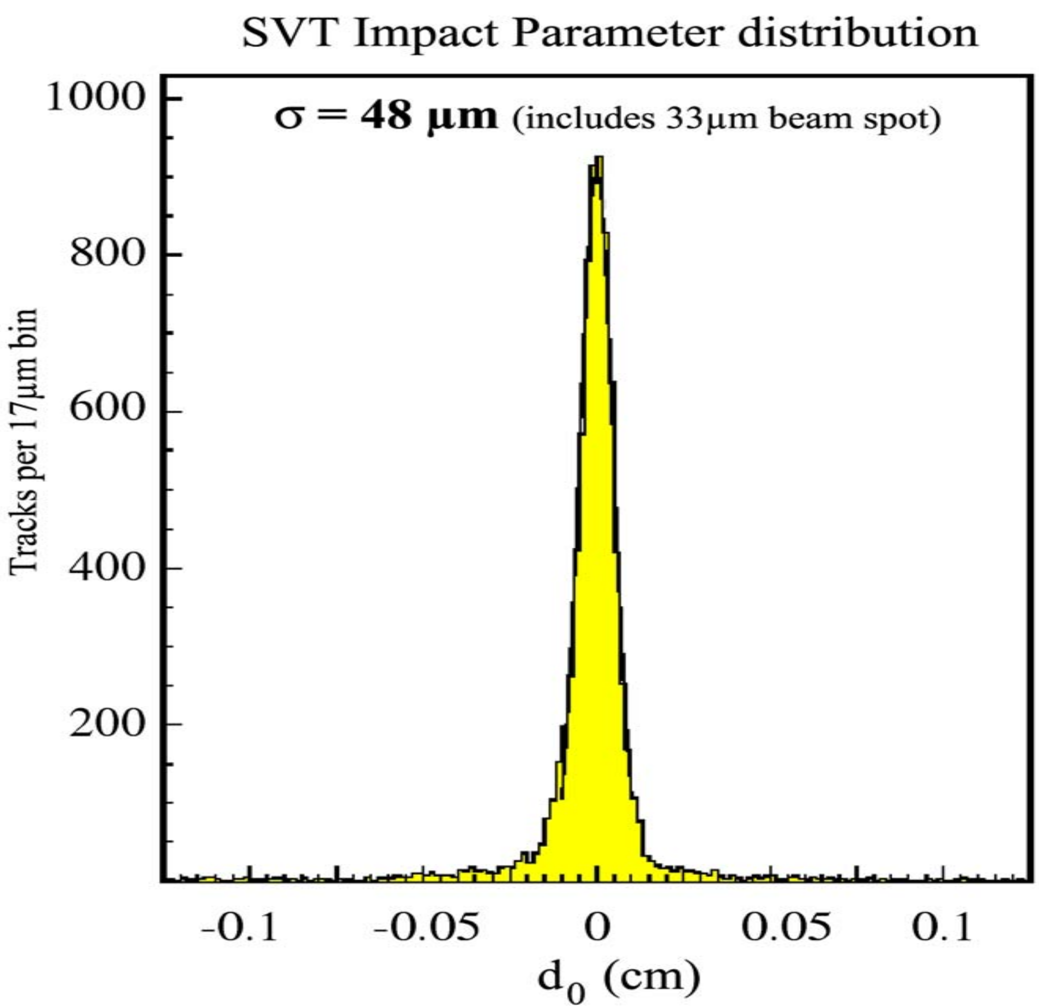
COT defines track at level 1 → SVX measures impact parameter

(no alignment or calibrations)





SVT Impact Parameter



In Run 1, b-quark decays were tagged by decays to leptons.

In Run 2, we hope to tag hadronic decays of B.

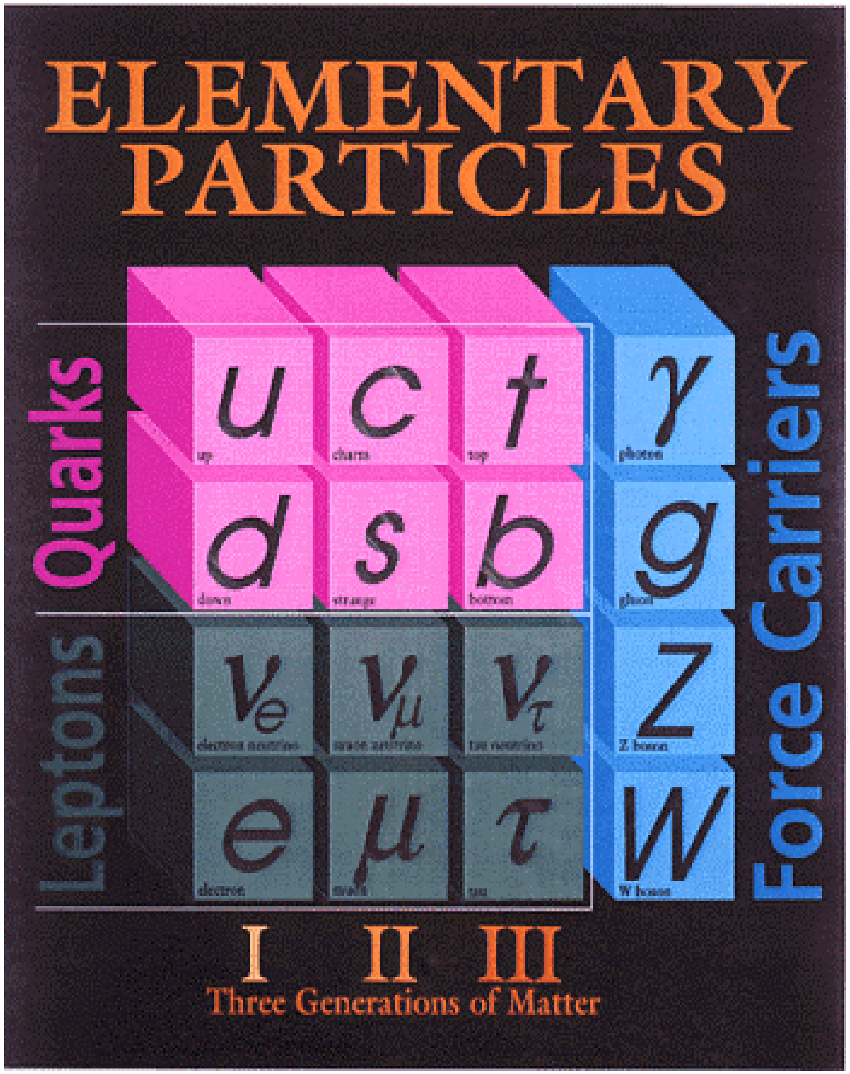
Approx 5x increase in B acceptance possible.

Physics Analyses

Sample of main results

- **QCD**
  - Properties of jets and photons
  - **Is there quark substructure?**
- **B**
  - **Bc discovery (The “last meson”)**
  - Lifetimes, mixing
  - **sin(2b) (CP violation in the B system)**
- **Top/Electroweak.**
  - **Top quark discovery**
  - Top mass, W mass
- **Searches for new particles (EXOTICS).**
  - Several limits set
    - ➔ **Z’, W’, SM/MSSM Higgs**
    - ➔ **SUSY, Technicolor, Leptoquarks**

Why do all this?



Isn't this good enough?

Go Back 100+ Years.

$$\nabla \cdot \vec{E} = \rho / \varepsilon_0$$

$$\nabla \cdot \vec{B} = 0$$

$$\nabla \times \vec{E} = -\frac{d\vec{B}}{dt}$$

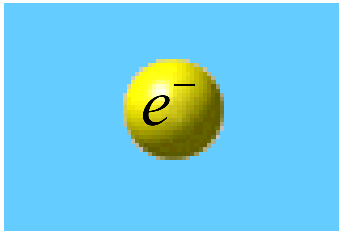
$$\nabla \times \vec{B} = \mu_0 \vec{j} + \varepsilon_0 \mu_0 \frac{d\vec{E}}{dt}$$

$$\vec{F} = q\left(\vec{E} + \vec{v} \times \vec{B}\right)$$

Isn't this good enough?

Even before QED, we knew that classical electrodynamics could not be the whole story . . .

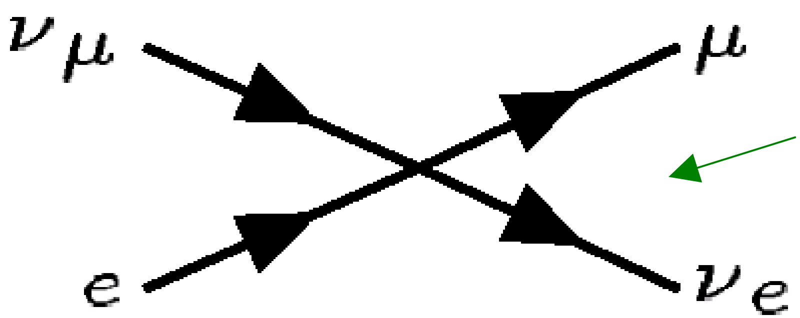
The classical theory predicts its own demise with an infinite electron self-energy



(This is a recurring and important theme)

Nonsensical predictions, and **solutions**

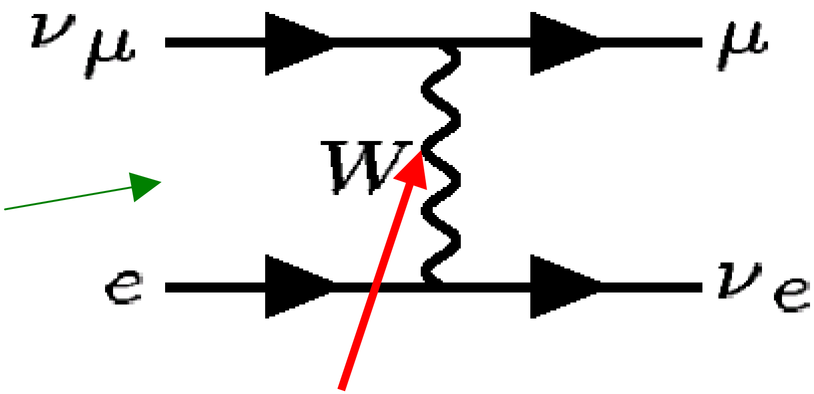
Fermi theory of the 1930's



This process violates unitarity at high energies. (Simple muon decay, for instance).

What do we do?

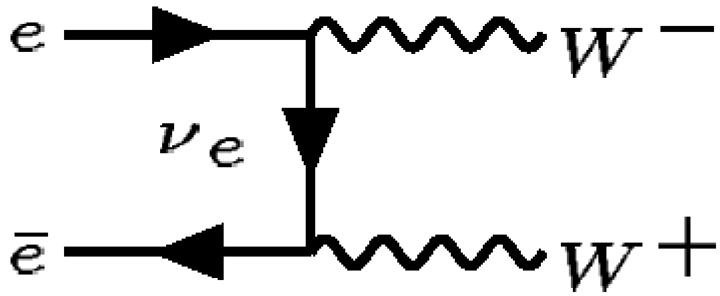
Modify the diagram to cancel the divergence.



Add the W boson

(observed at CERN in 1983)

Nonsensical predictions, and **solutions cont**.

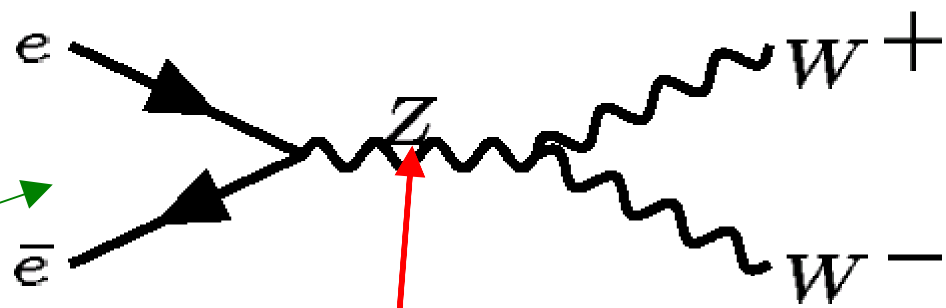


But now this process violates unitarity at high energies! (Simple

e+e- annihilation).

What do we do?

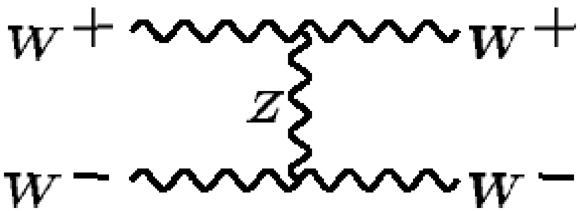
Introduce another diagram that cancels the divergence

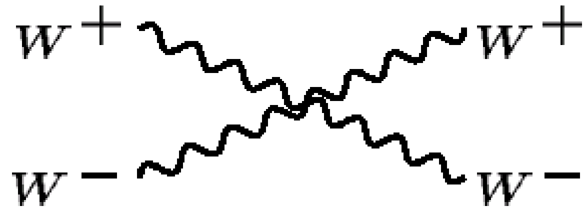


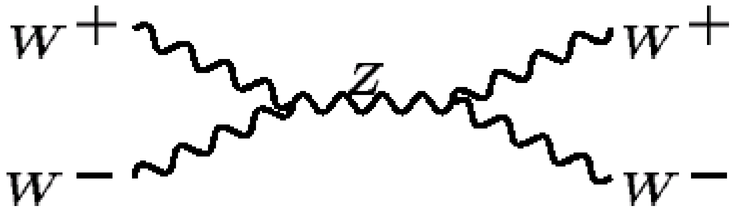
the Z boson

(also observed at CERN in 1983)

Nonsensical predictions, and **solutions cont 2.**



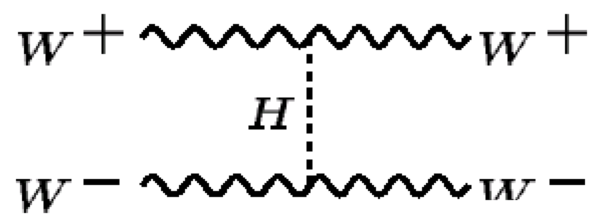


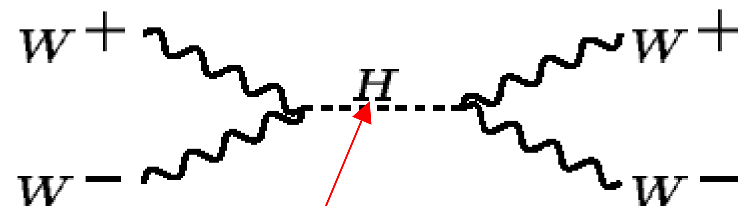


But now *these* processes violate unitarity at high energies! (not so simple W+W- scattering)

What do we do?

Introduce *other* diagrams to cancel the divergence



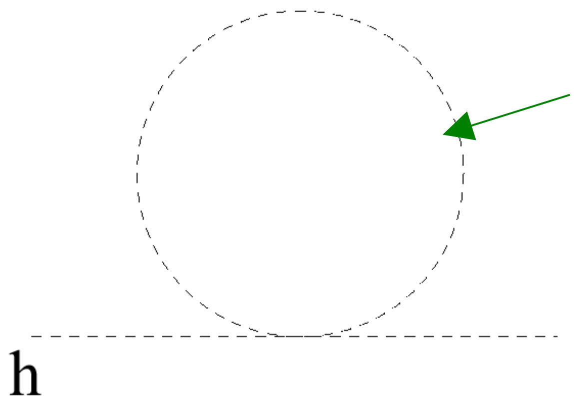


The **Higgs boson!**

Nonsense Predictions don't stop here!

Thus far we have <u>no direct evidence</u> for the Higgs boson*

but so what:



If the Higgs exists, this process violates unitarity at high energies ("fine-tuning" or "universe is size of basketball" problem)

What do we do?

Introduce other diagrams to cancel the divergence without fine-tuning →

- supersymmetry
- strong dynamics
- extra dimensions

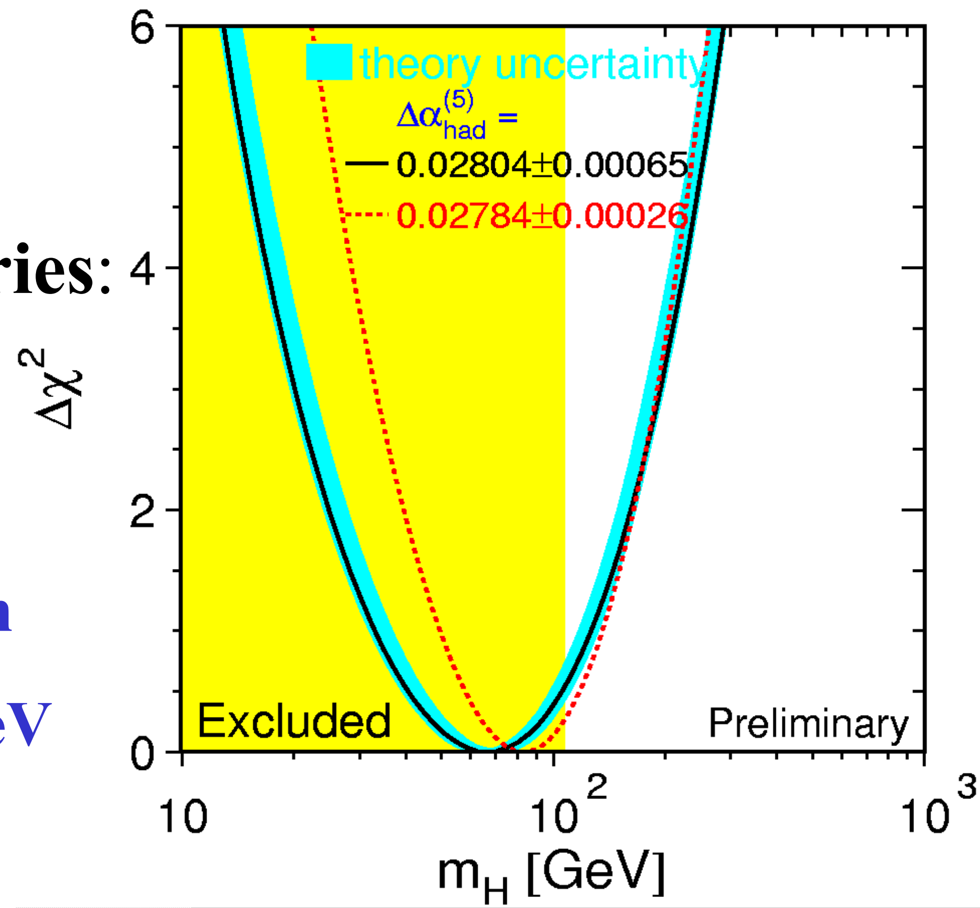
The Higgs Boson.

Even though we know the simple (Standard Model) Higgs Boson is not viable, it makes a good benchmark.

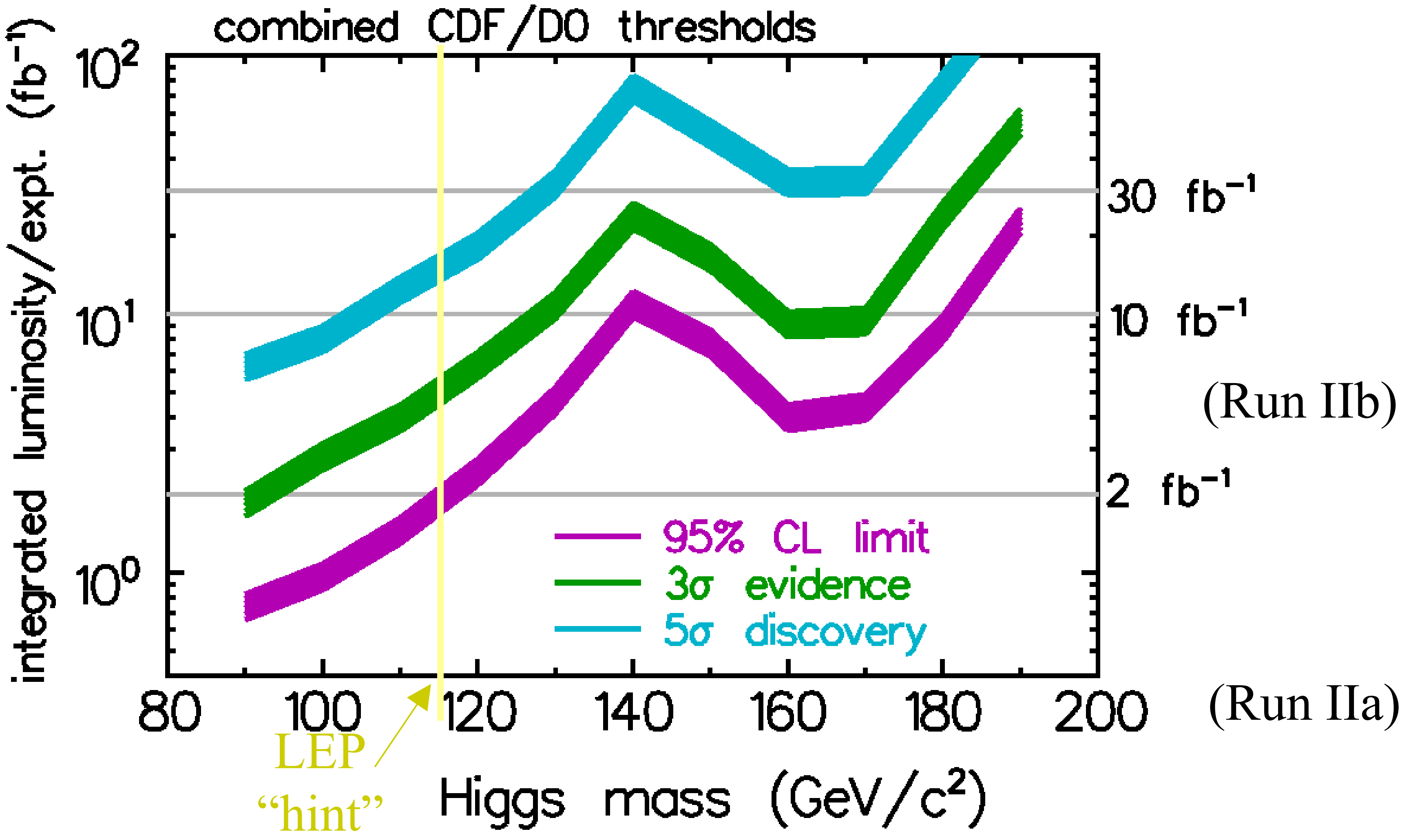
- **Weak Boson masses:** Mz, Mw.
- **Electroweak asymmetries**: $\sin^2\theta_w$
- **Top quark mass.**

If higgs exists, then

$113 < m_h < 170$ GeV



Higgs Discovery Potential



Luminosity is key

But you just said Higgs has problems…

The simple Higgs theory does have problems but it solves the many problems quite elegantly, so we are loath to throw it out entirely.

What do we hope/expect to find?
Whatever is responsible for EW symmetry breaking - obviously not SM Higgs - should be at M~ 150 GeV (see Steve Schnetzer's talk). These should be observable.

Possibilities at 1 TeV

Logically, the possible options now are:

a) A Higgs-like field does not exist
$\rightarrow \exists$ other interesting physics at $\approx$ 1 TeV

b) A Higgs-like field does exist

i) A parameter is tuned to 1 part in 10^{16}
$\rightarrow$ No need for new physics at $\approx$ 1 TeV

ii) The parameter is not tuned to 1 part in 10^{16}
$\rightarrow \exists$ other interesting physics at $\approx$ 1 TeV

Hence the excitement!

Conclusion

- CDF is a good general purpose detector.
  - Good tracking: electron, muon id.
  - Good vertex finding: b-tagging.
  - Smart trigger.
- We need this, since we cannot be certain of the signature of the new physics.
  - SM Higgs? SUSY? Technicolor? N-dim?
- Indirect indicators are encouraging.
- Watch this space!