Physics at the High Energy Frontier

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Graduate Seminar
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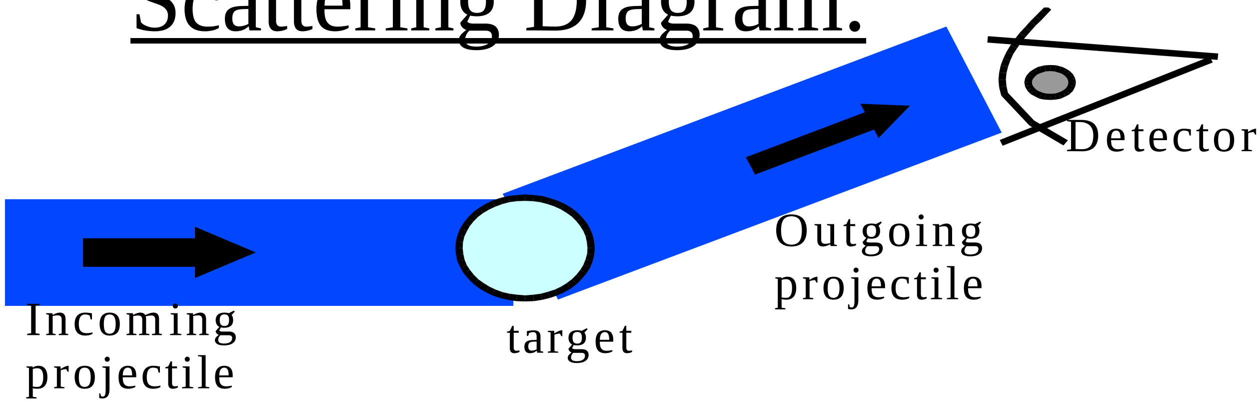
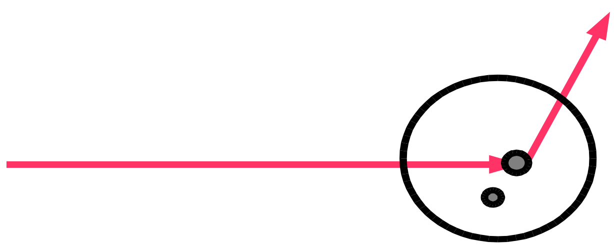
Scattering Diagram.



Low Resolution

Large wavelength, low energy, target looks like a big blob.



High resolution

Small wavelength, high energy, constituents of targets become visible

Scattering to find Structure of Matter

- To look at smaller things, go to higher energy projectiles. Need accelerators.
  - Atom is **1/ (10 billion)** meters. Need hard Xrays.
  - Nucleus is **1/ (100,000 billion) meters**. Need gamma rays.
  - Proton, neutron is **1/ (1 million-billion)** meters. Need cyclotrons.
  - Quarks are **pointlike** (as far as we know). Need massive, huge, mile long accelerators.
- **Caveat!** Simple scattering picture breaks down at higher energies.
  - Why? Antimatter!

What's Antimatter?

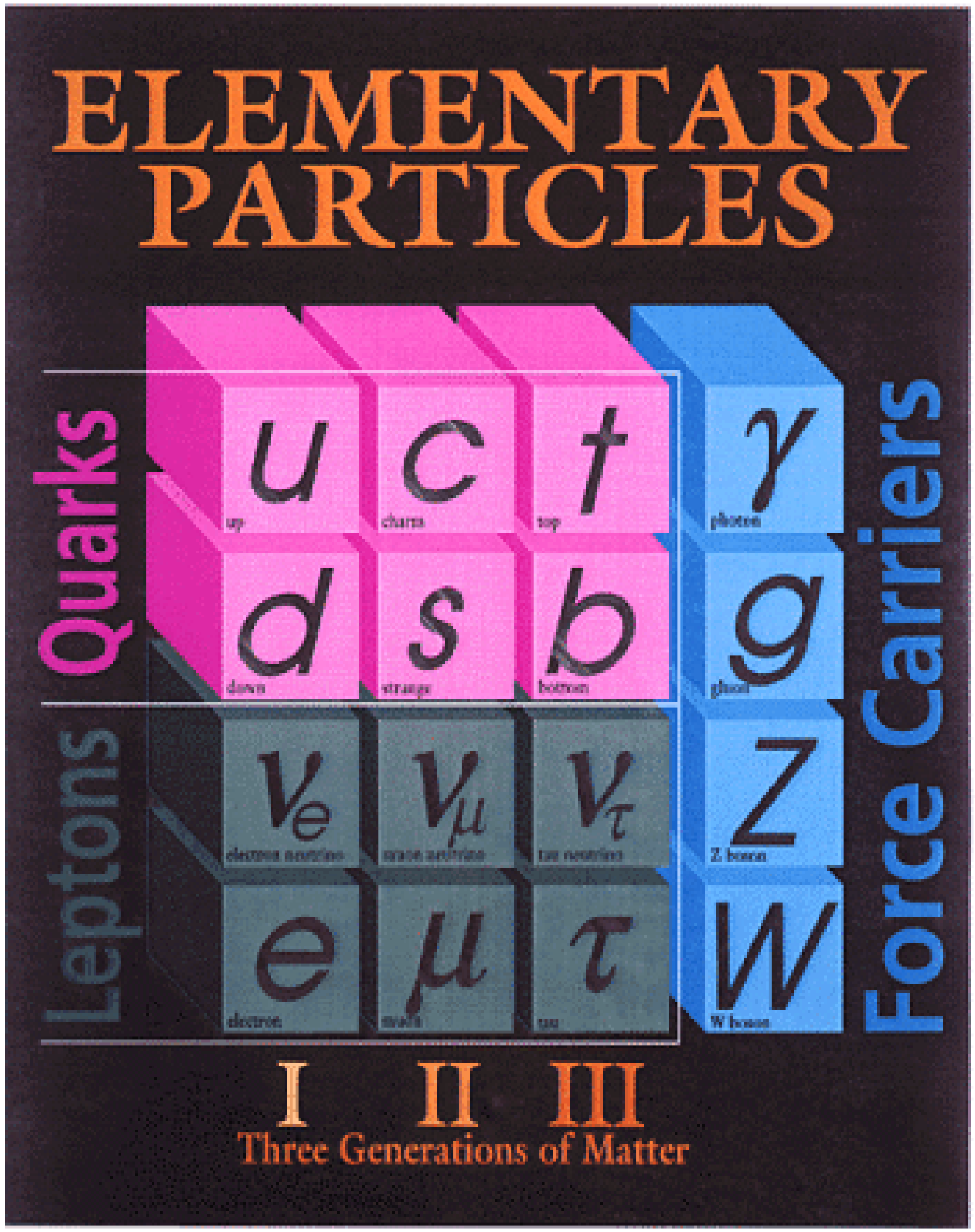
- As energies get higher, simple scattering picture (*projectile bouncing off target*) needs to be modified.
  - Projectile and target exchange forces through a *field particle (**boson**).*
  - Matter particles are ***fermions***. Forces are ***bosons***.
  - But: $E=mc^2$, so as E gets large, it can become a pair of particles matter + antimatter, $m + \bar{m}$. (Dirac).
- Creation of $m + \bar{m}$ pairs needs to be accounted for in scattering at larger energies, ***and becomes the main object!***

Status as of 2001

	Particles			Forces they feel: EM	Strong nuclear	Weak nuclear
Quarks	Up	Charm	Top	+2/3	yes!	yes
	Down	Strange	Bottom	-1/3	yes!	yes
Leptons	Electron	Muon	Tau	-1	no	yes
	e-neutrino	mu-neutrino	tau-neutrino	0	no	yes

Everything in the universe is made of the 1st generation particles.

Quarks bind together with the strong force to make familiar particles such as protons and neutrons.



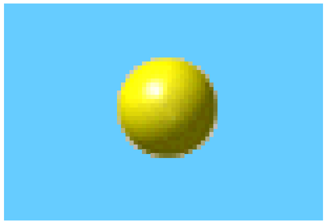
Isn’t this good enough?

Go back 100 years . . . Maxwell's Equations:

Isn't this good enough?

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

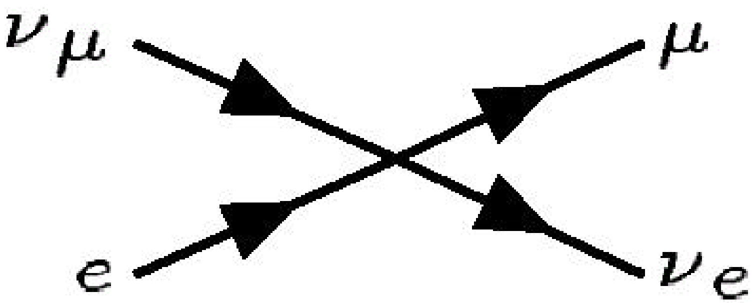
The classical theory predicts its own demise with an infinite electron self-energy



(This is a recurring and important theme)

Nonsensical predictions, and solutions

Fermi theory of the 1930's

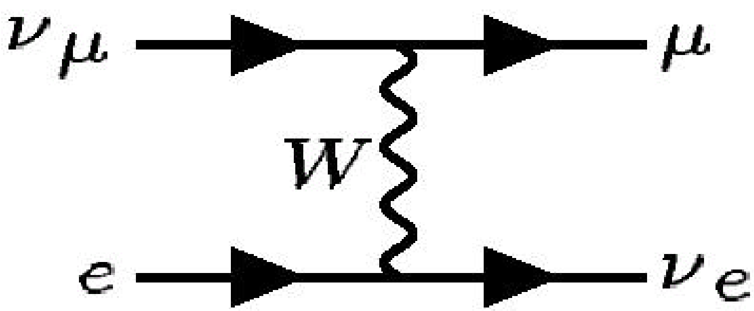


This process violates unitarity at high energies

What do we do?

Modify the diagram to cancel the divergence

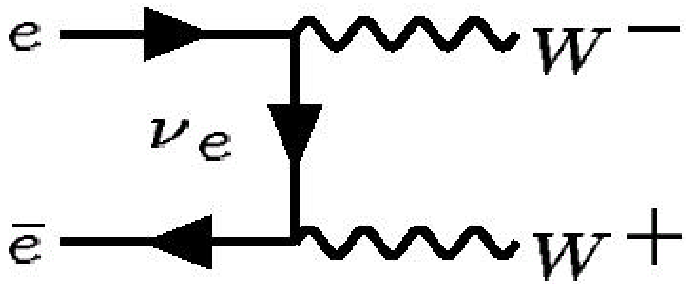
The *Glashow-Weinberg-Salaam* theory



the W boson

(observed at CERN in 1983)

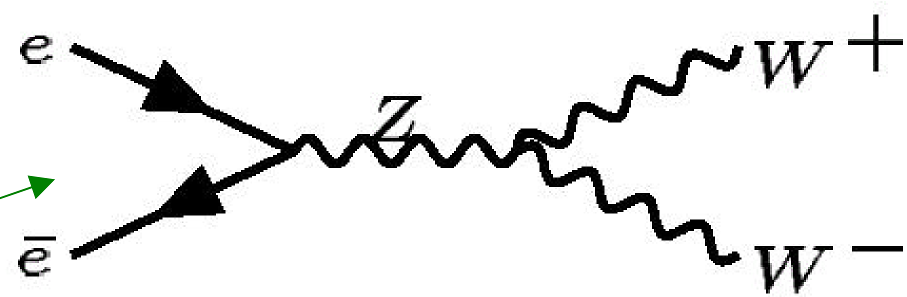
Nonsensical predictions, and solutions cont.



But now this process violates unitarity at high energies!

What do we do?

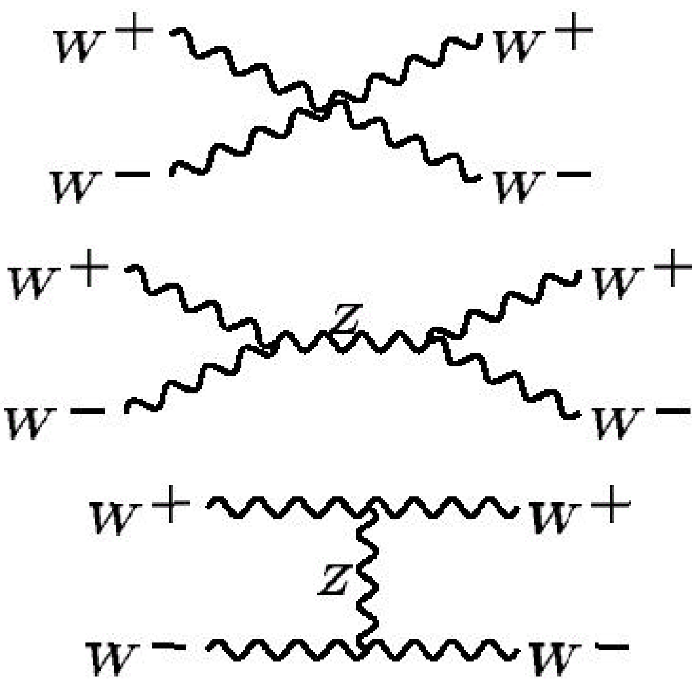
Introduce another diagram that cancels the divergence



the Z boson

(also observed at CERN in 1983)

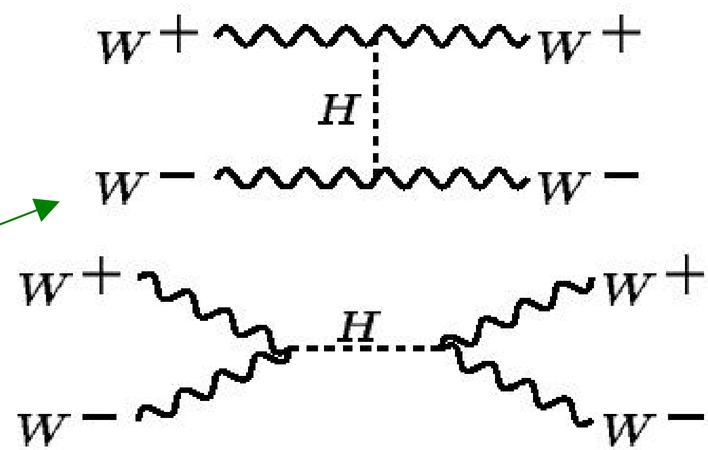
Nonsensical predictions, and solutions cont.



But now *these* processes violate unitarity at high energies!

What do we do?

Introduce *other* diagrams to cancel the divergence

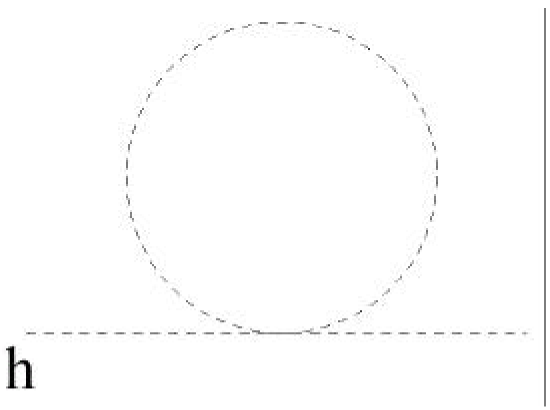


the Higgs boson

Unnatural predictions, and solutions

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

but let's keep going:



If the Higgs exists, this process violates unitarity at high energies unless a parameter is "unnaturally" fine-tuned ("fine-tuning problem")

What do we do?

Introduce other diagrams to cancel the divergence without fine-tuning

- supersymmetry
- strong dynamics
- extra dimensions

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}

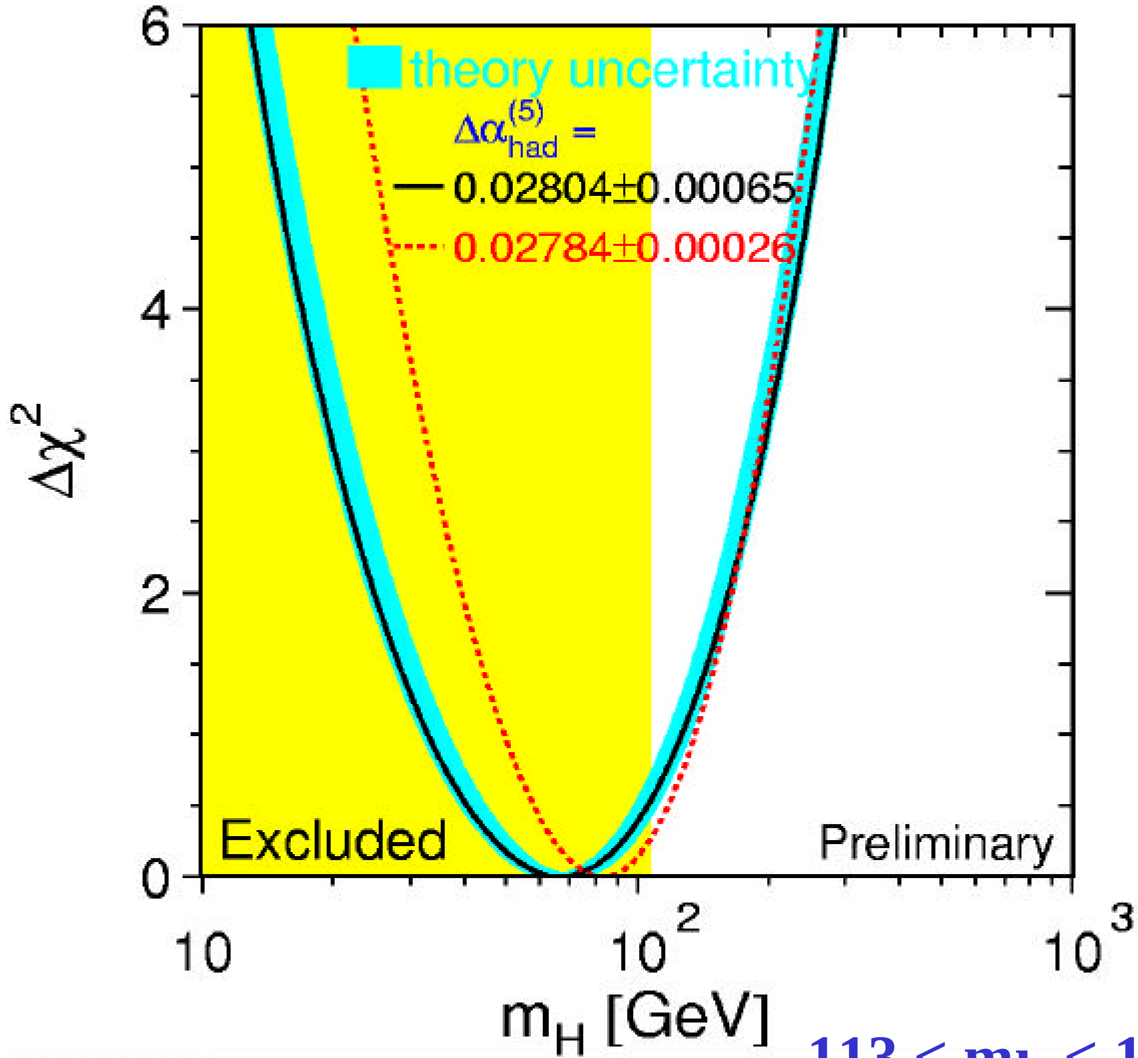
$\rightarrow$ No need for new physics at $\approx$ 1 TeV

ii) The parameter is not tuned to 1 part in 10^{16}

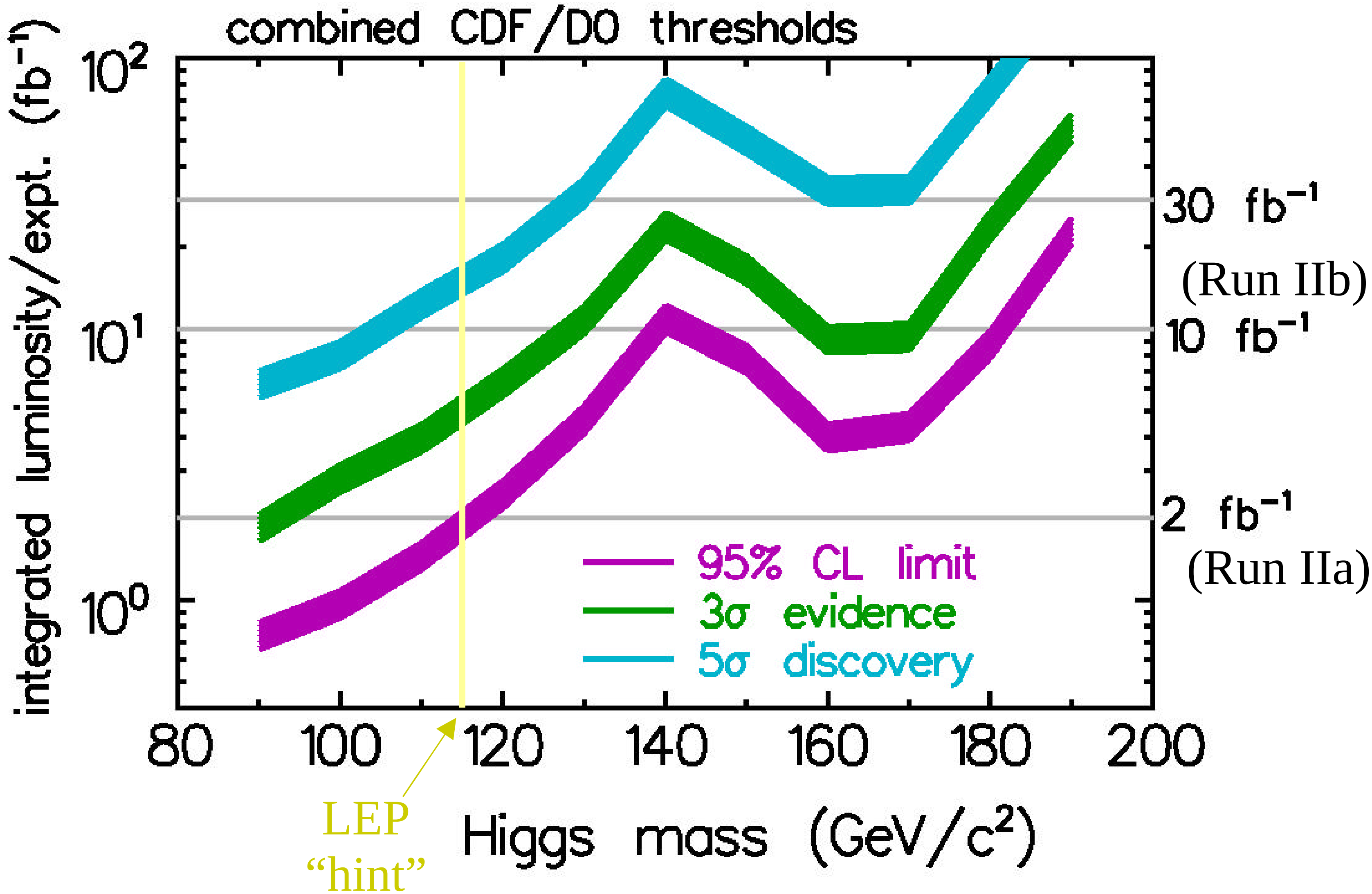
$\rightarrow \exists$ other interesting physics at $\approx$ 1 TeV

Hence the excitement!

If a Higgs particle exists, what is its mass?



$113 < m_h \lesssim 170$ GeV



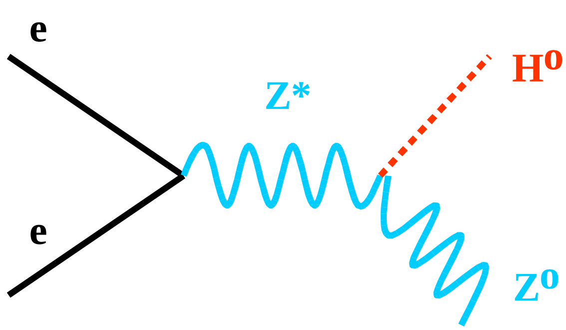
Luminosity is key

Hint of a Higgs?

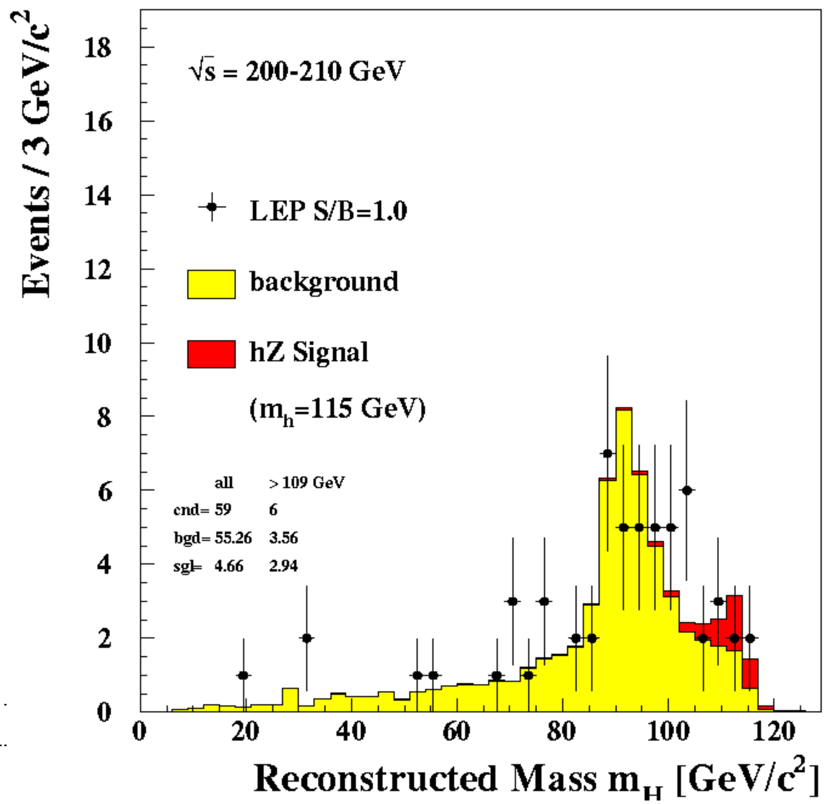
I personally don't think so, but...

m_H is completely unpredicted, but , once measured, the Higgs production cross section and couplings are set

Towards the end of their running, experiments at LEP (e^+e^- collider at = 200 GeV) have had the hint of a signal in the channel:



the Higgs, very fond of mass, wil decay to the most massive particles available, in this case

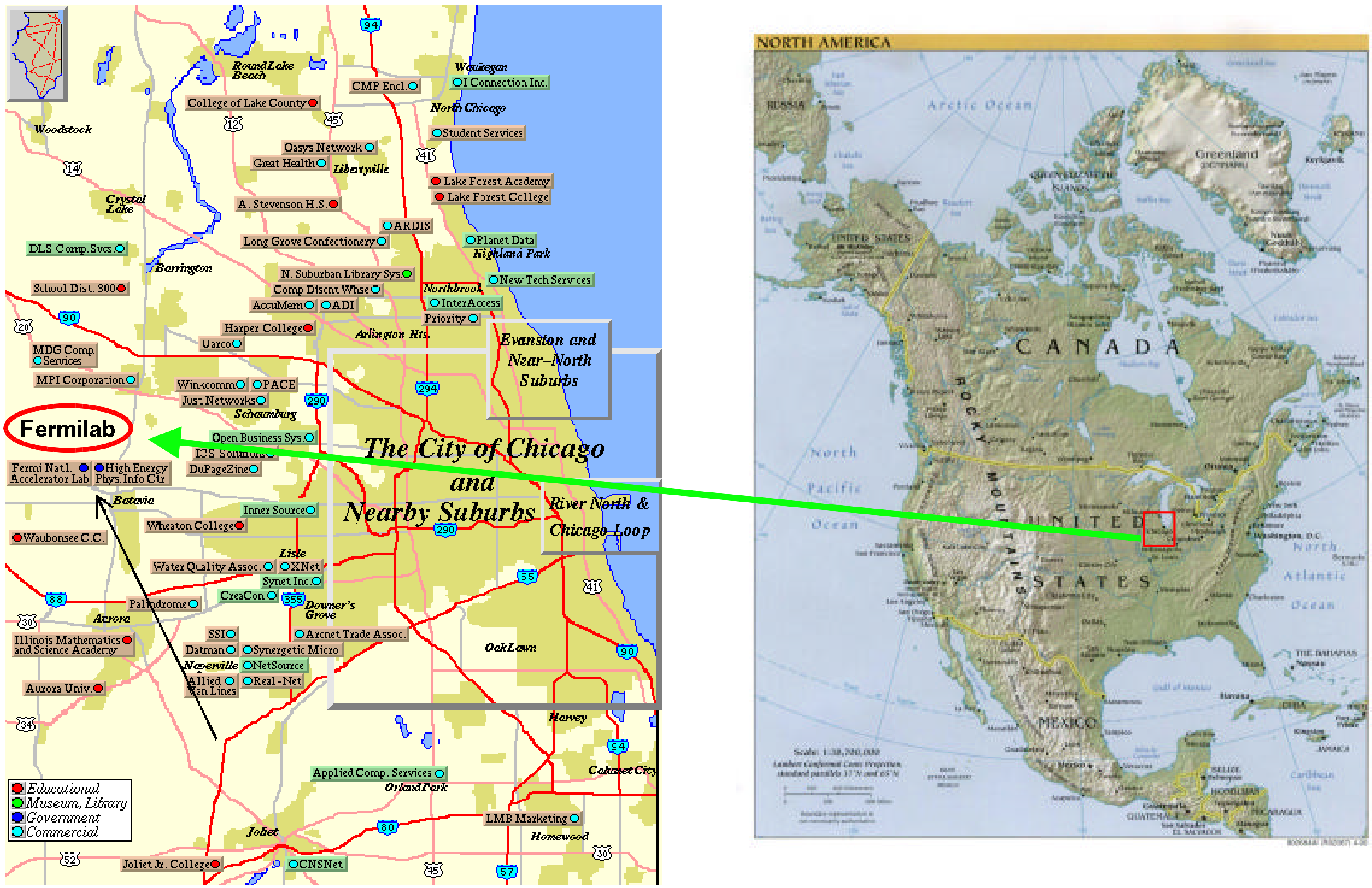


m_H~115 GeV, s<3

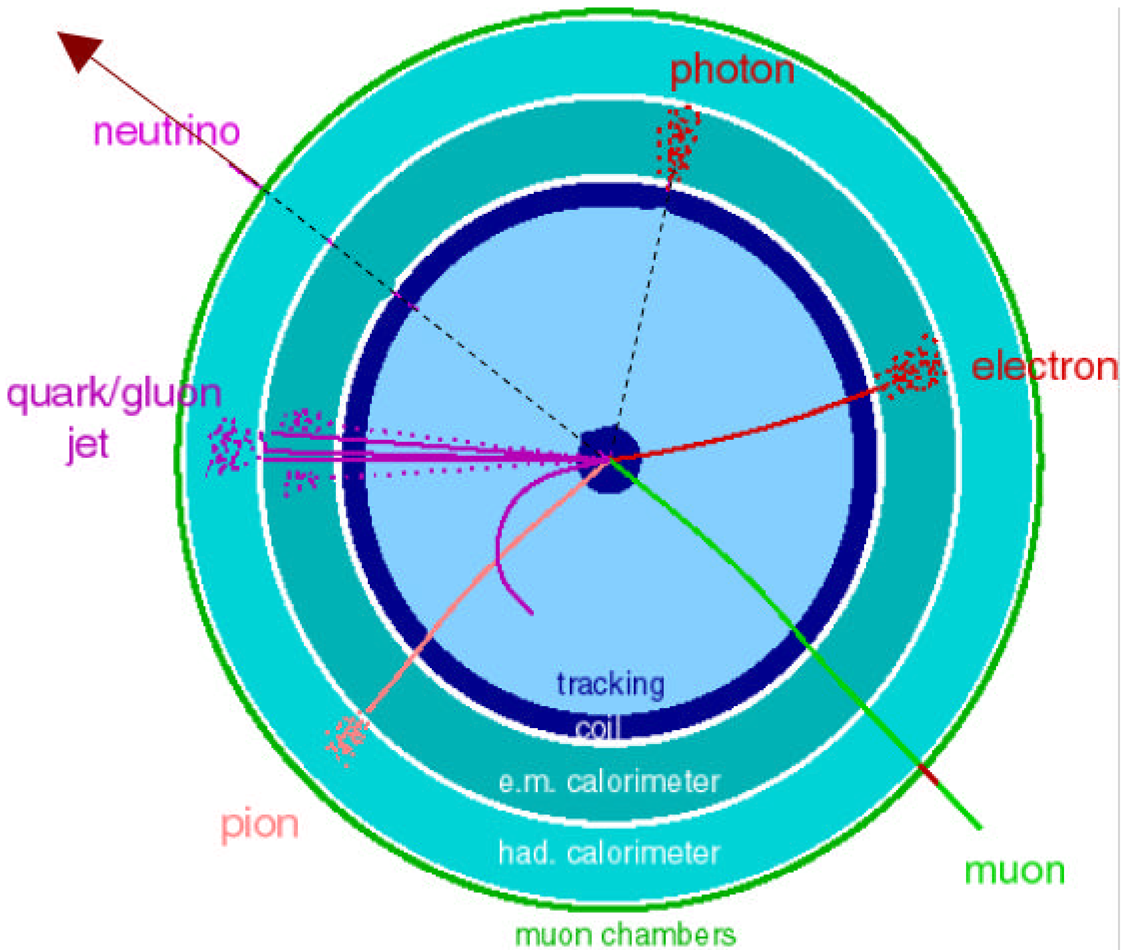
Standard Model in Run 2: Summary

- Precise measurement of masses (W, top) tests the SM and provides indirect information about the Higgs mass
- Many other quantities of interest, not mentioned here:
  - Angular distributions and polarizations
  - Multi-boson production properties
  - Single top production
- Direct search for the Higgs boson looks promising in Run 2 (run 2b in particular).
- B physics: the new laboratory for matter-antimatter asymmetry

Fermilab location

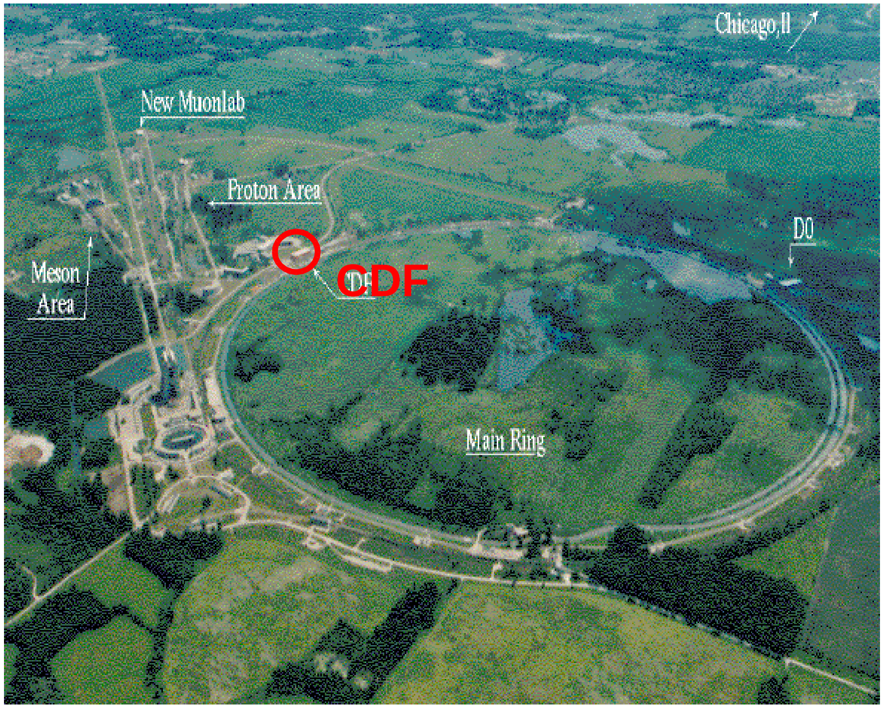


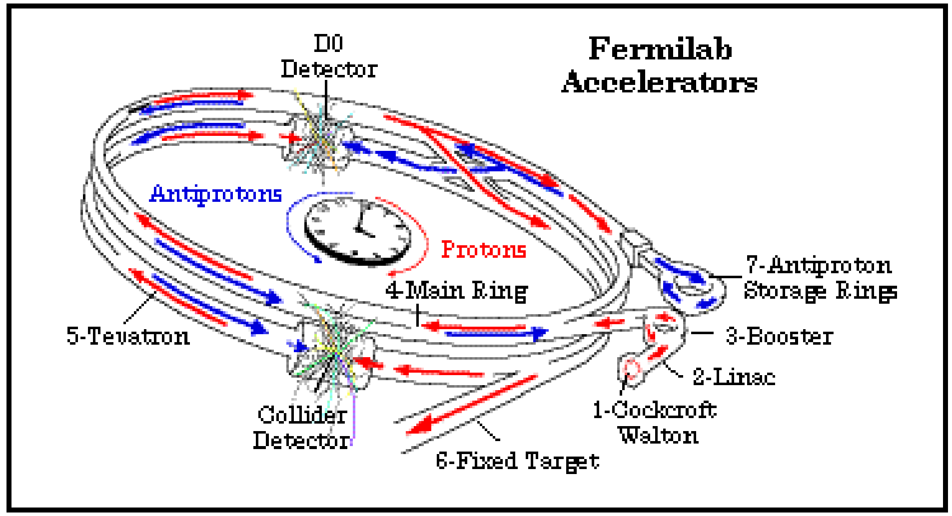
Collider Detector Basics

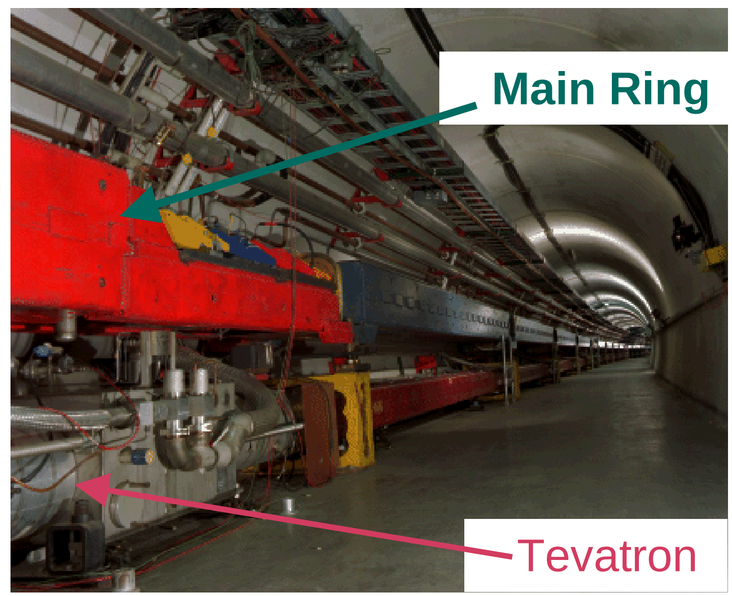


- Electron
  - track, contained cluster, E/P~1
  - γ, no track
- Hadron (p,π,K)
  - track, extended (had) cluster
  - n, no track
- Muon
  - penetrating track
- Short lived (b)
  Displaced (mm) vertex.
- Weak, no charge (ν,LSP)
  - Missing ET

The Tevatron during Run I

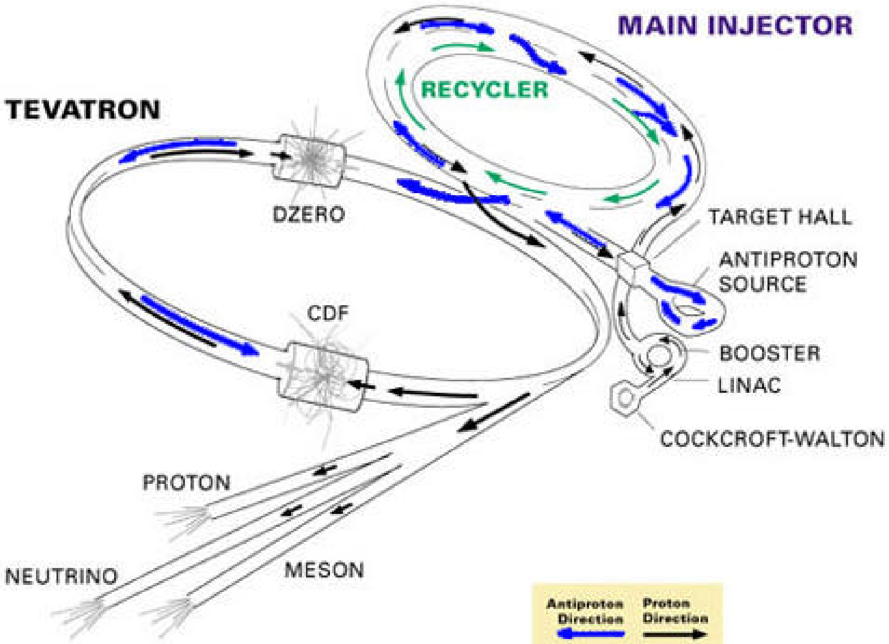


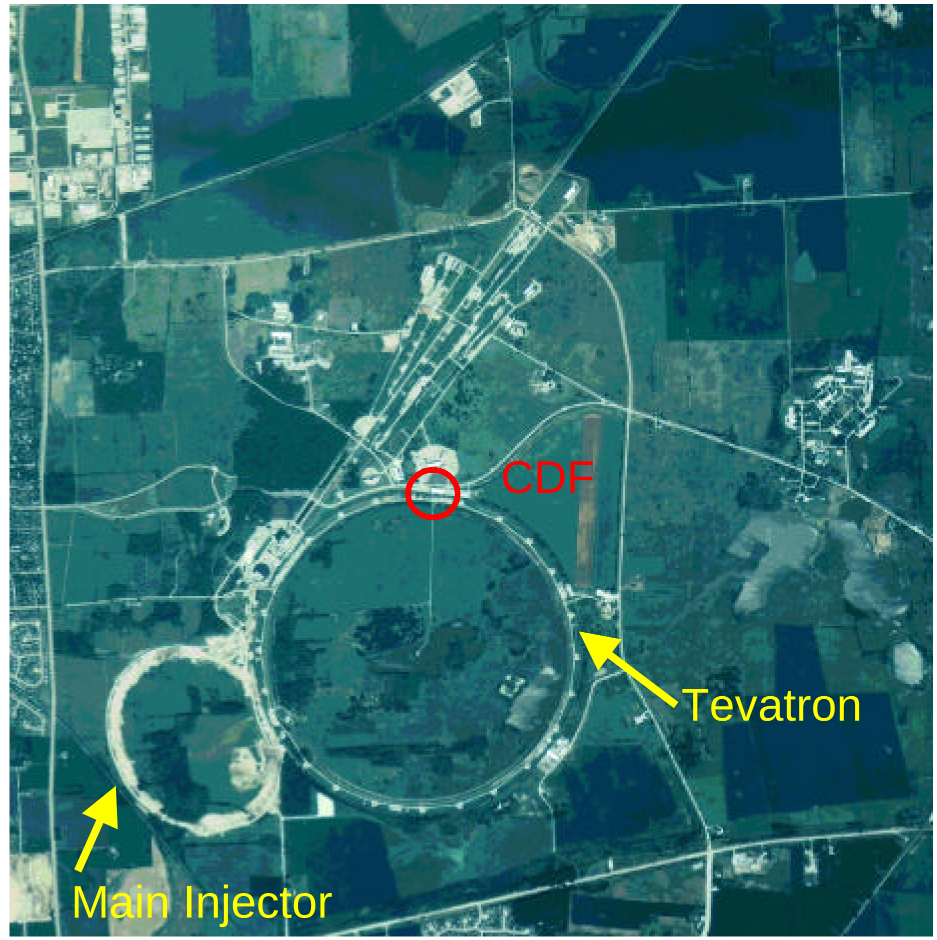




- 4 miles superconducting ring
- Proton – antiproton
- CM energy 1800 GeV
- Typical luminosity ~10^{30} - 10^{31}

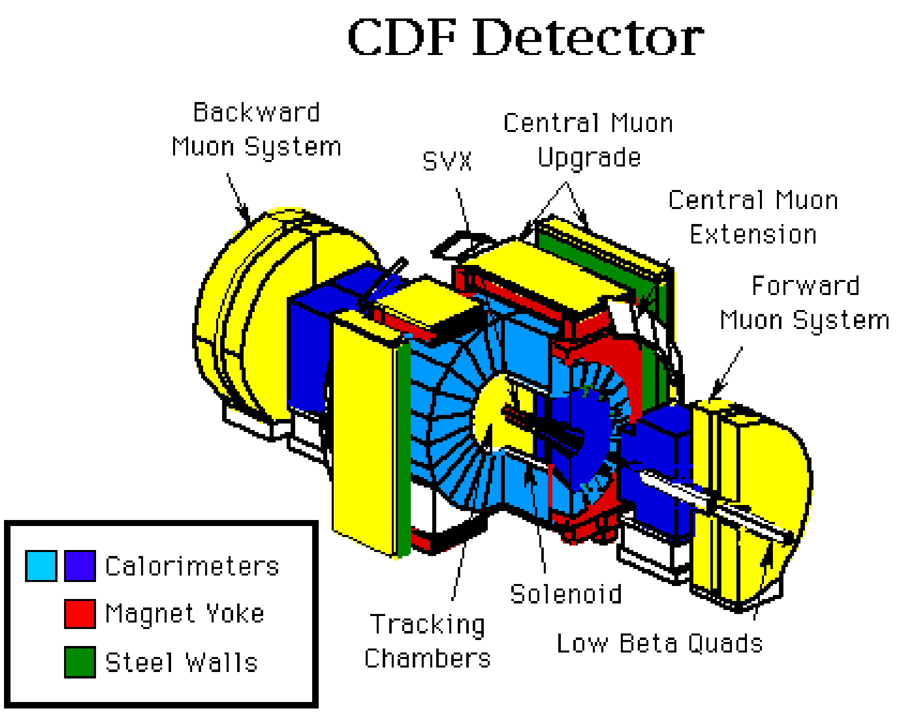
Tevatron Upgrade

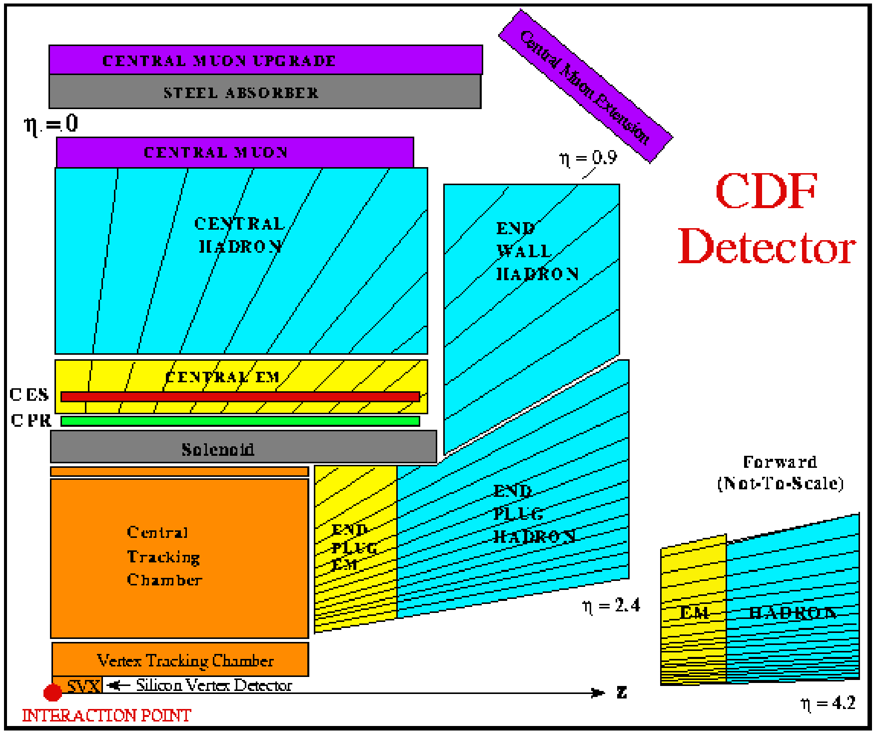




- New Main Injector:
  - Improve p-bar production
- Recycler ring:
  - Reuse p-bars!

CDF during Run I





- 4 layer Si strip detector: 60% acceptance, σ_D = 13 μm
- CTC large drift chamber: B=1.4 T, N_{axial} = 60, N_{stereo} = 24, $\Delta p_t/p_t < 0.001\, p_t$
- Projective towers calorimeters: ΔηxΔφ=0.1x0.3, lead/steel-scintillator(PWC)
- Central muon chambers: |η| < 1
- Forward calorimeters and muon up to η=4.2

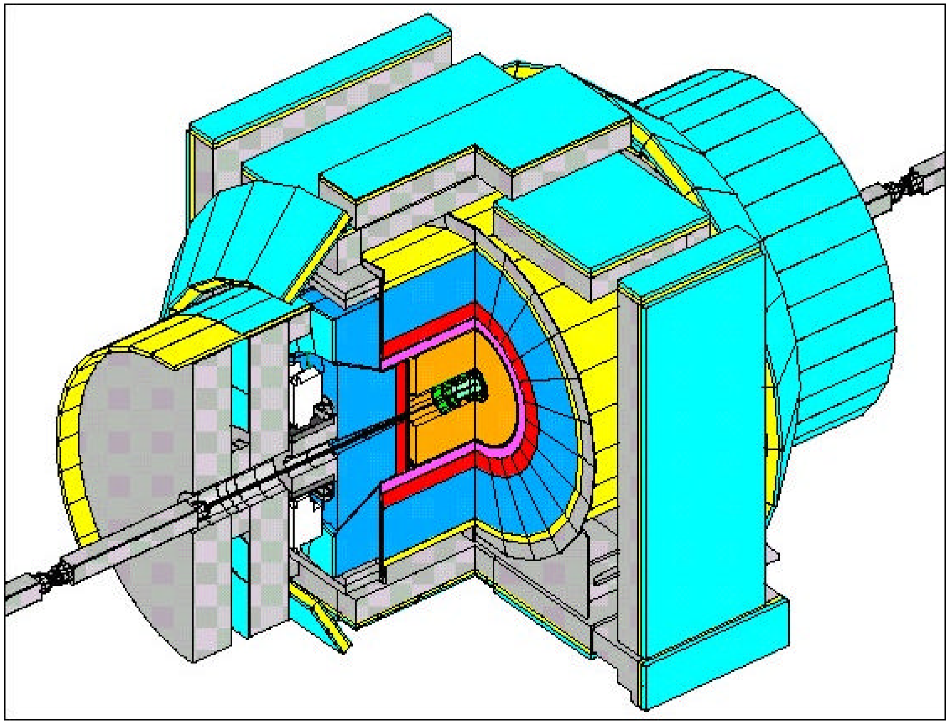
CDF II

- CDF II:
  - All front-end, DAQ and trigger replaced!!!

    New L1 tracking trigger

    New L2 secondary vertex trigger (Rm1)

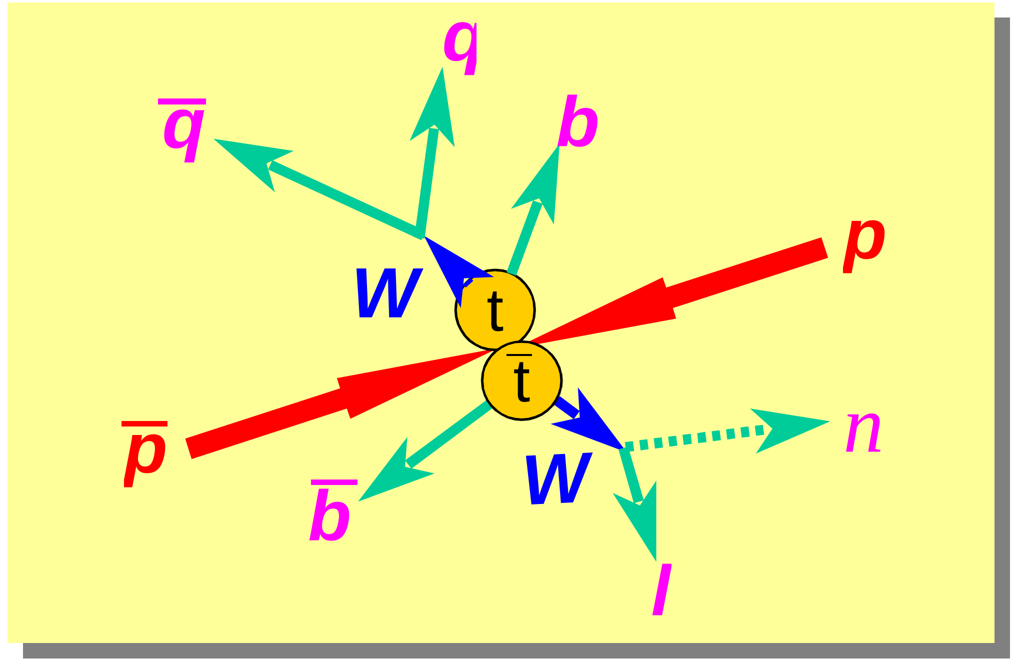
    New Time of Flight (Rm1)



- **New** Full acceptance 7(8) layer silicon system: $|\eta|<2$ coverage
- **New** COT drift chamber: B=1.4 T, $N_{axial} = 48$, $N_{stereo} = 48$, $\Delta p_t/p_t < 0.001\, p_t$
- **New** Plug calorimeter has smaller inner hole
- Central muon chambers up to $|\eta| < 1.5$ – **Some new**
- Forward calorimeters and muons removed

Top physics in Run 1

- Discovery in 1995



- Typical "usable" top event topologies:
  - $tt \rightarrow l\nu l\nu bb$ **di-lepton** 5% e+μ
  - $tt \rightarrow l\nu qqbb$ **lepton+jets** 30% e+μ
  - $tt \rightarrow qqqqbb$ **all hadronic** 45%

How does new detector help with physics?

Look at Run 1 **top** event (CDF)

What happened?

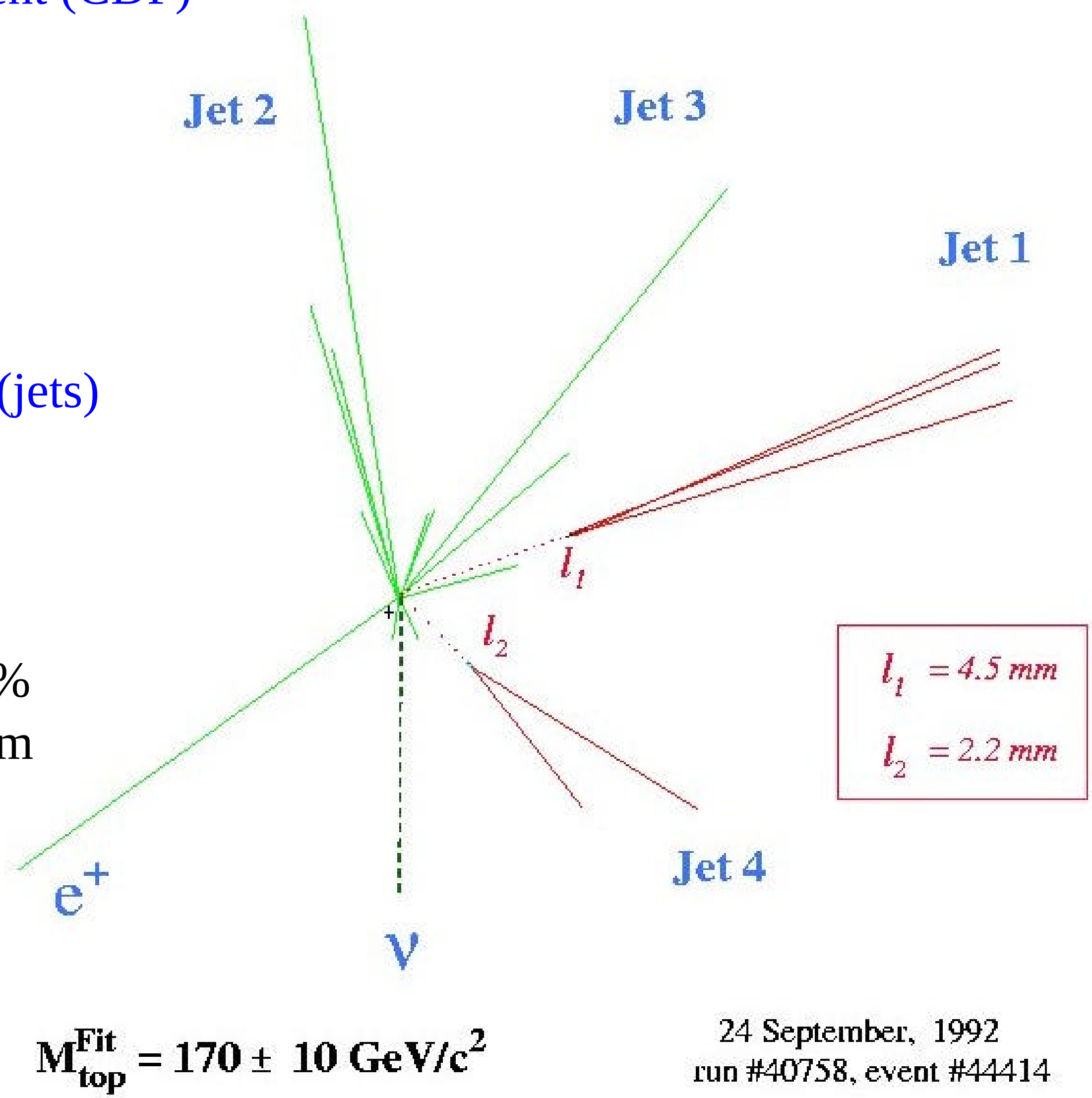
$\bar{p}p \rightarrow \bar{t}\,t$

- ▶ $b \;\; W^+ \rightarrow e^+\nu$
- ▶ $\bar{b} \;\; W^- \rightarrow q\,q'$ (jets)

Keep in mind:

W -> e, μ (+ ν) ~20%

B meson cτ ~ 500 μm



How does new detector help with physics?

Look at Run 1 **top** event (CDF).

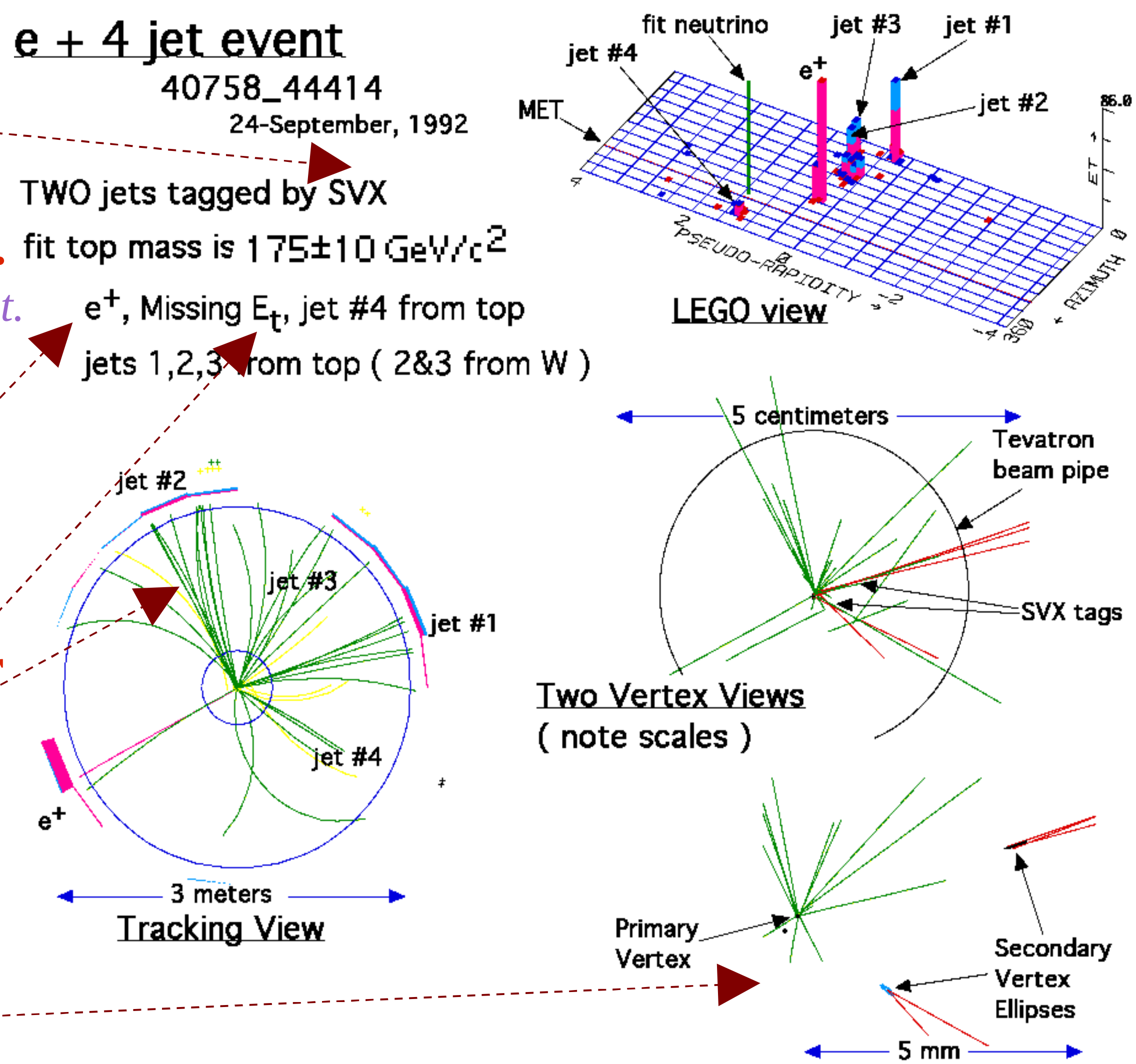
Better vertex detector,
3D-tracking, higher |h|
smaller s d => more b-tags.
May also be able to lower Pt cut.

Plug calorimeter, better e,
Better m coverage.

More hermetic calorimeter

TOF, Particle ID, find K?

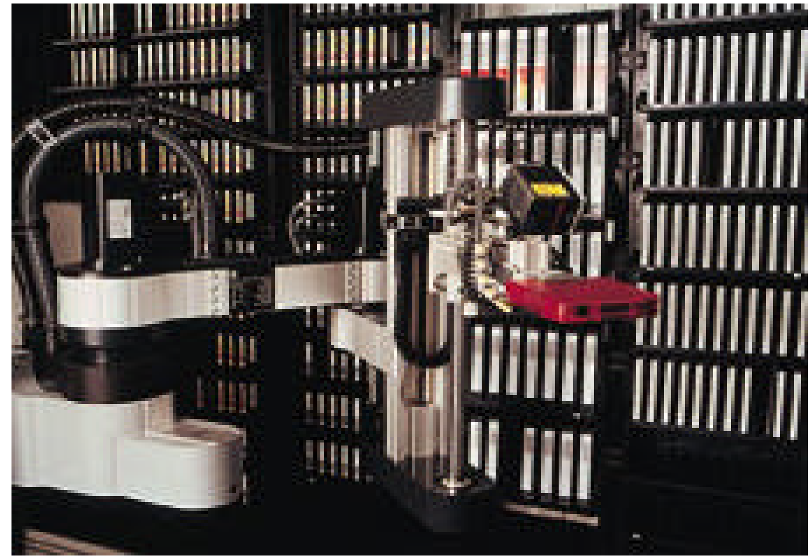
Vertex at L2 (SVT)
-> hadronic B decays.



Rutgers at

CDF

Data Handling
(1 Pb in 2 years)



Silicon
Vertex
Detector

What an Experimental High Energy Thesis Entails

- First year spent at Rutgers, taking courses, quals.
- Second year we send you to Fermilab.
  - CDF collaboration requirement: 1 year of "service".
  - Also, you pick a topic, join analysis group.
  - You participate in data taking, analysis with entire collaboration (physicists and students from many universities and labs around the world).
- After data is in the can, you return to Rutgers to write up the dissertation and defend.

Why Join the Rutgers CDF group?

- We are the largest university group at CDF.
  - Six full-time faculty members.
  - Three postdocs (currently interviewing for more).
  - Four committed graduate students, two tentative.
- We are in charge of important elements of the experiment.
  - Silicon detector management, calibrations.
  - Data Handling.
- We are building significant data analysis capability at Rutgers and at Fermilab.
  - 40-node Linux farm at RU, 8 to 10 at FNAL.
- Rutgers group has history of important physics results.
  - Main MSUSY result from CDF Run 1.
  - b-quark, tau-lepton tagging, Bc meson, jet analyses...