Experimental Particle Physics PHYS6011

Putting it all together

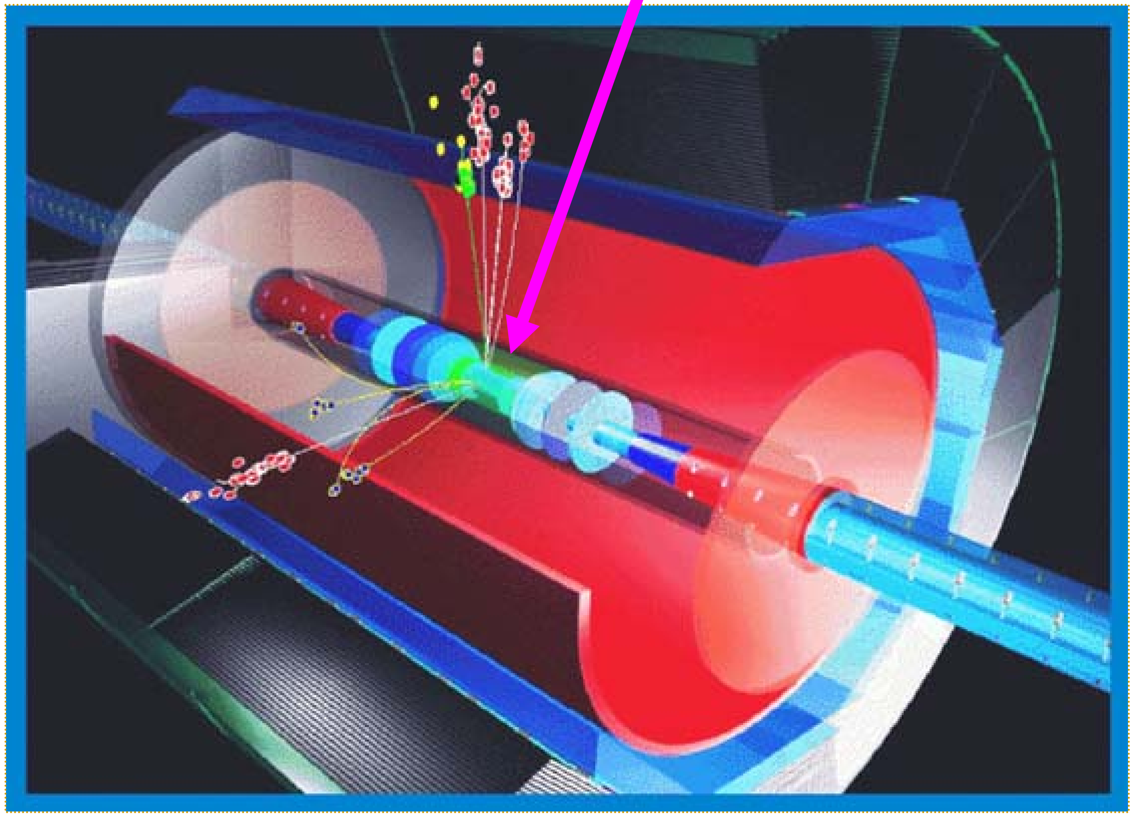
Lecture 4

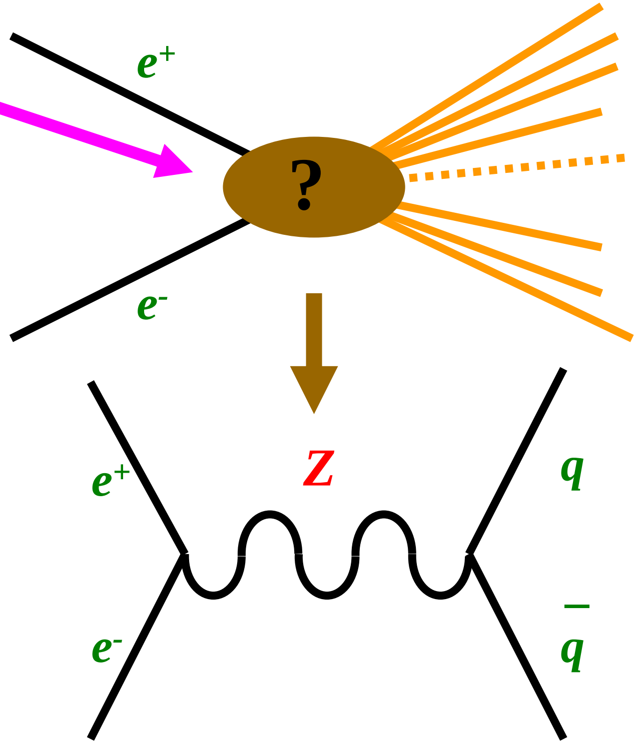
Collider Experiments

- So far:
  - Accelerators and colliders
  - Particle interactions
  - Types of detectors
- *Combine them to do physics…*
- Example: CDF at the Tevatron
  1. Proton-antiproton collisions
  2. Fermilab and the Tevatron
  3. CDF and DØ
  4. Identifying particles
  5. Identifying physics processes
     - Top production
     - Higgs Production

Reconstructing Collisions

What happened here?



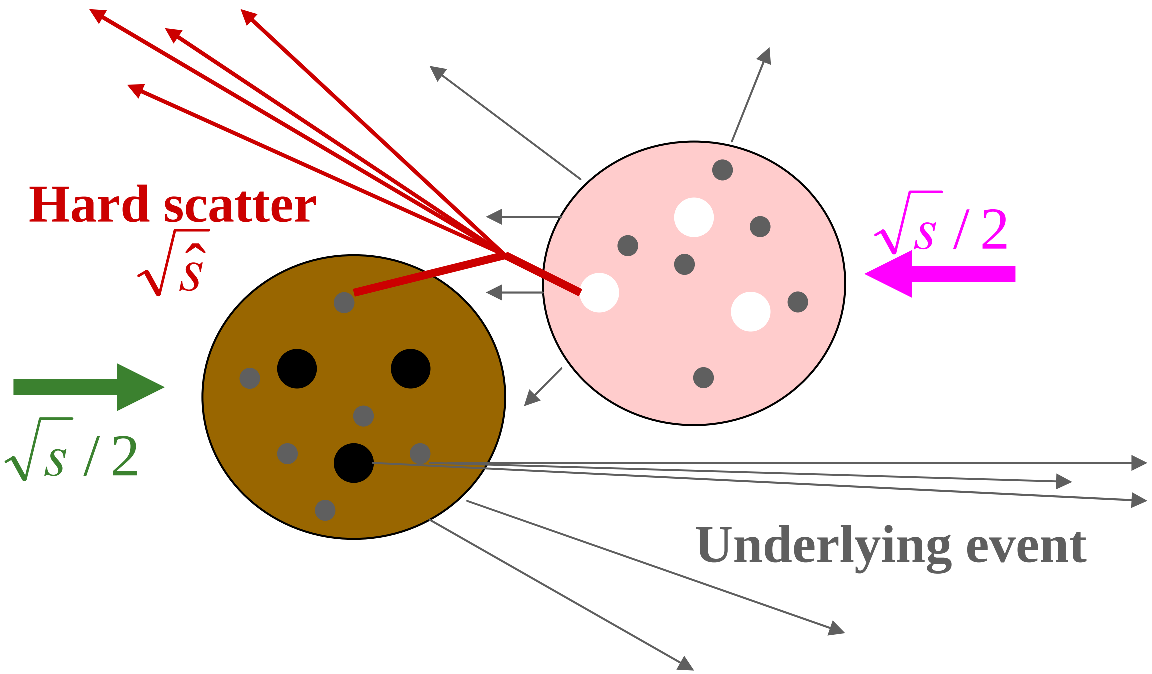


or something more exotic.....

- **extract maximum information from outgoing particles**

Proton-Antiproton Collisions

- Protons are composite objects: valence & sea quarks; gluons
- Really *parton-parton* collisions



- Underlying event:
  - Most lost at low angles
  - Some in detector
- p_z unknown
- Extra detector hits
- Initial partons unknown
- Huge total cross section *(10s of mb)*

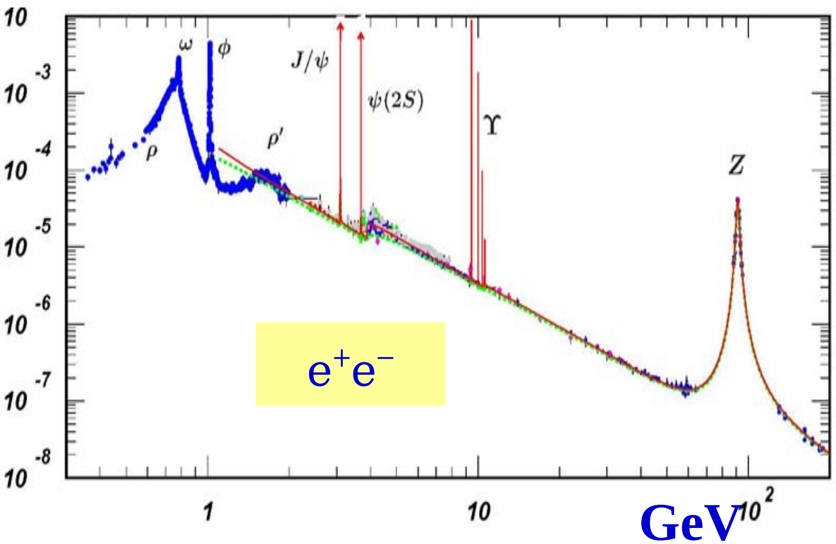
1 mb = 10^{-27} cm^2

Cross-Sections

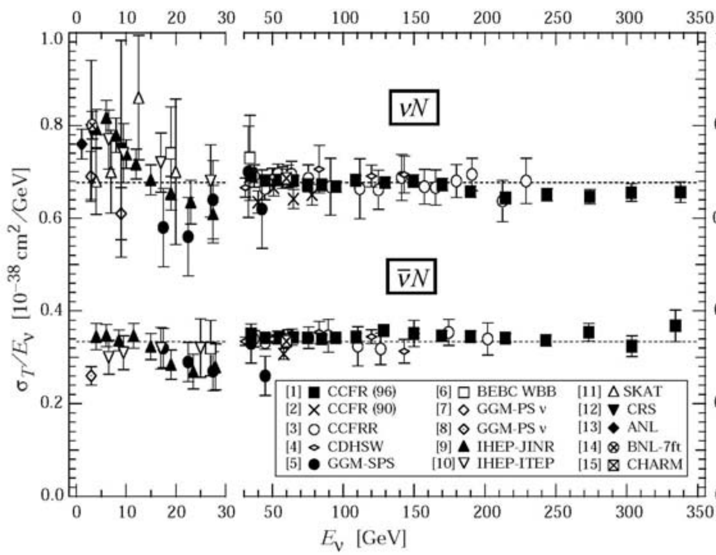
1 mb = 10^{-27} cm^2

1 fb = 10^{-39} cm^2

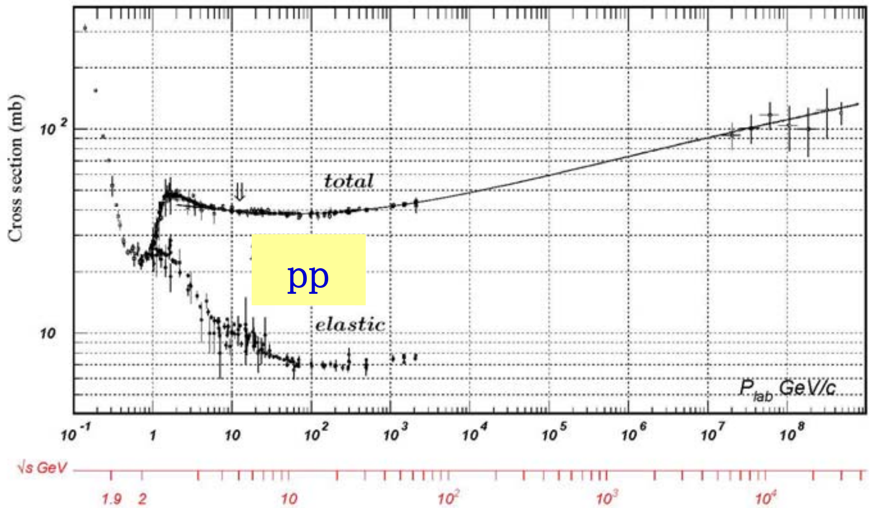
pb



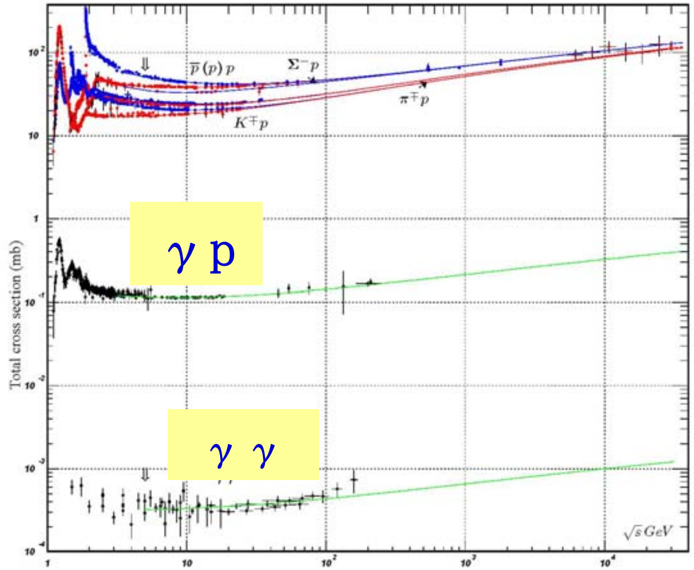
GeV



mb



mb



GeV

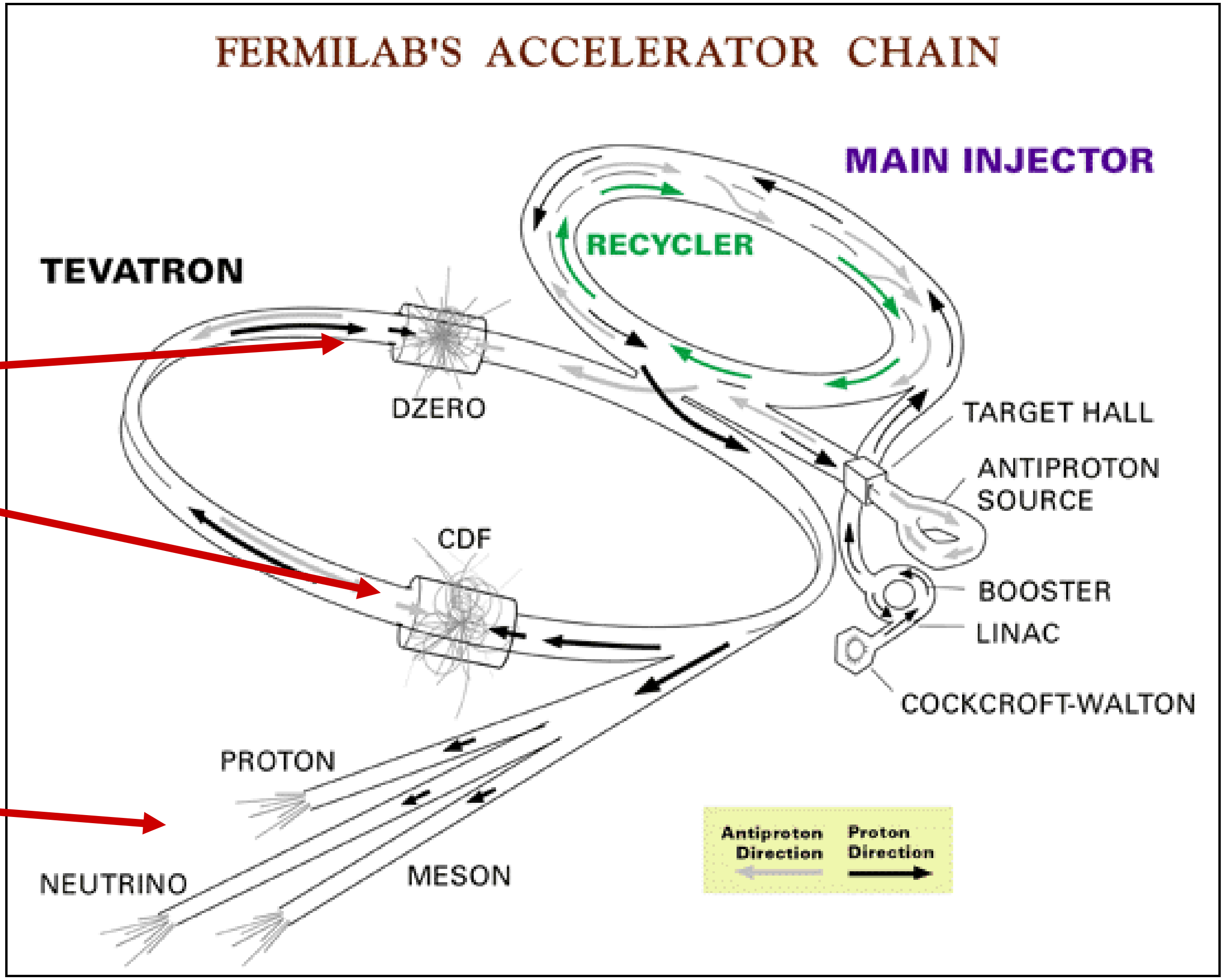
Fermilab

- 30 miles west of Chicago
- 10 square miles
- Started operating in 1972
- Major discoveries
  - 1977 Bottom quark
  - 1995 Top quark
  - 1999 Direct CP Violation
  - 2000 Tau Neutrino
  - 2006 B_s Oscillation
  - 2009 Higgs Exclusion Limits

Fermilab Accelerators

Collider Experiments

Fixed target beams



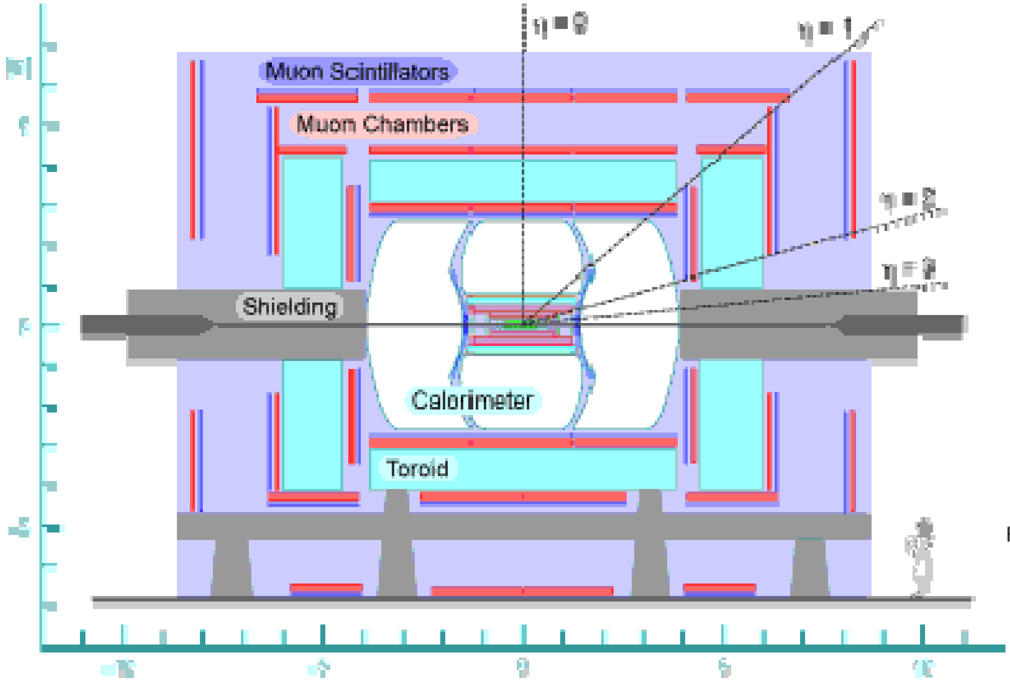
The Tevatron Run II

- Upgraded for 2001
- $\sqrt{s}$ = 1.96 TeV
- proton-antiproton collisions

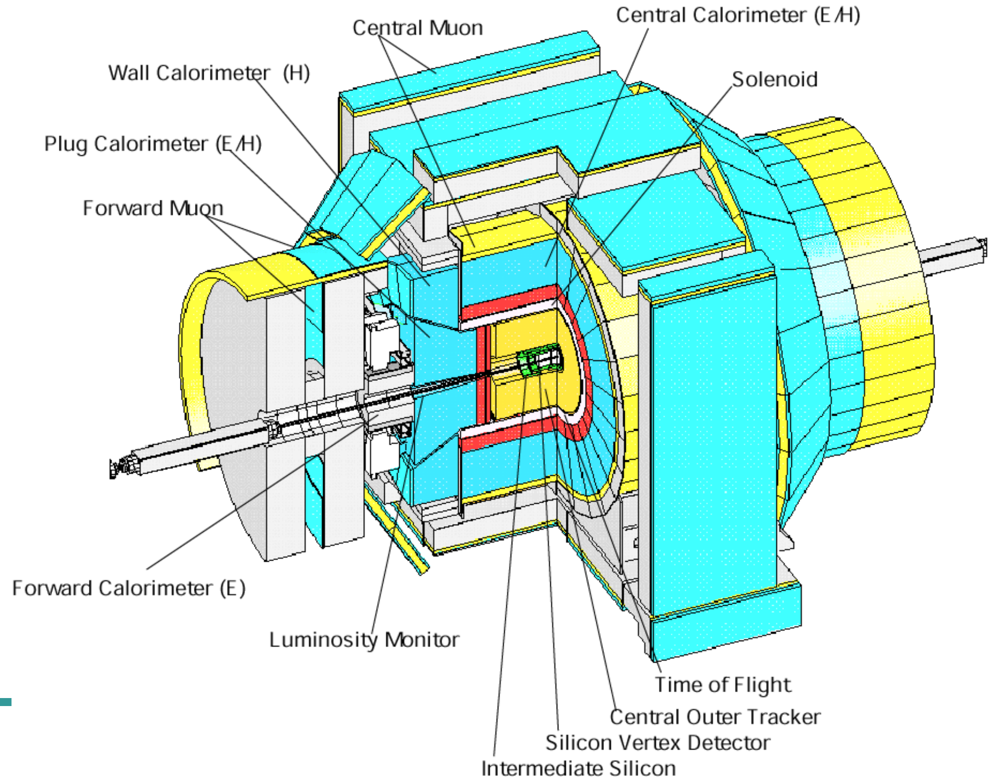
- 36 bunches
- 396 ns bunch crossing
- L ~ 10^{32} $cm^{-2}s^{-1}$
  - *3 interactions per crossing*
- 6.5 fb^{-1} by 2009

The Experiments

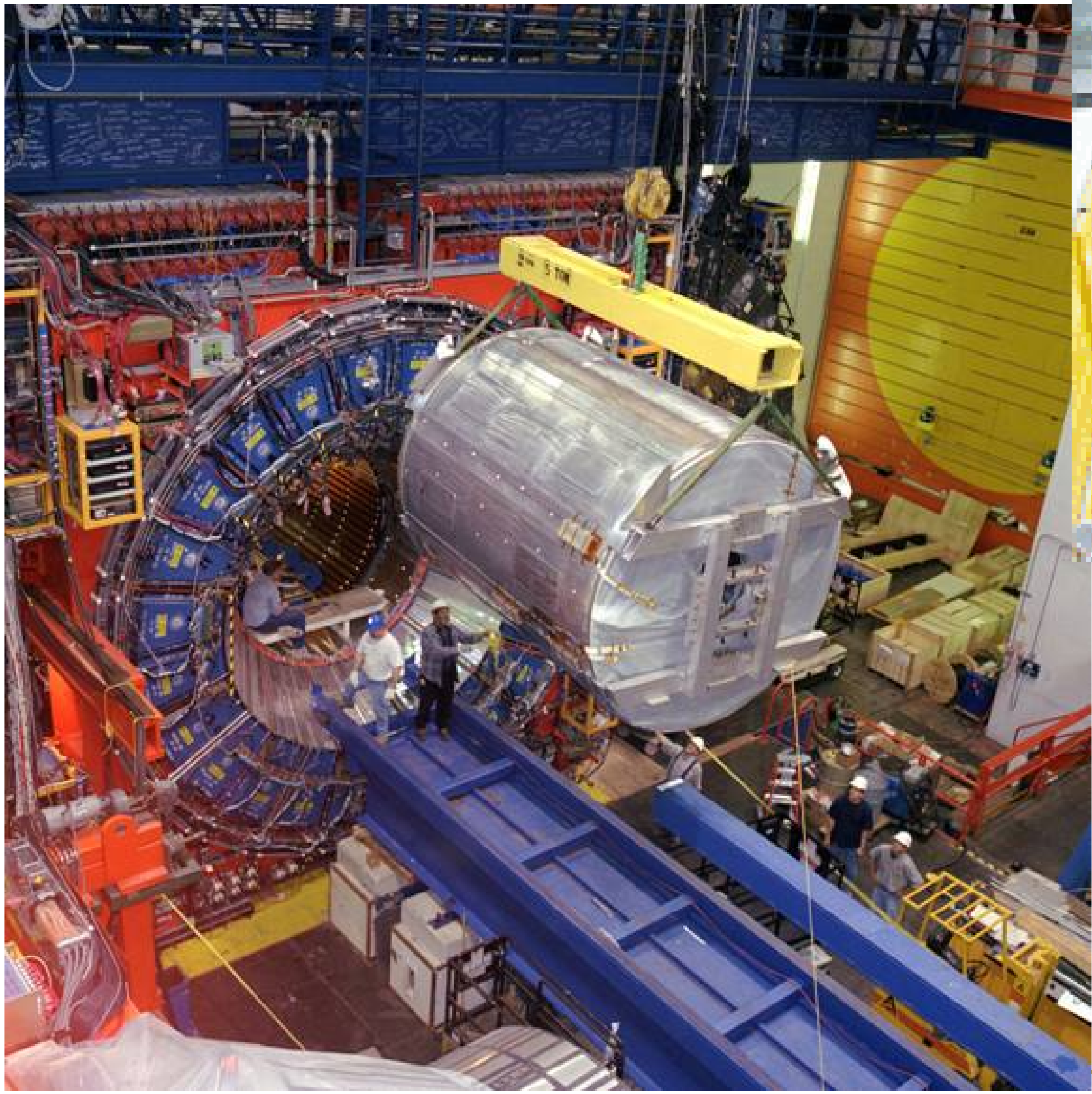
DØ - optimised for calorimetry

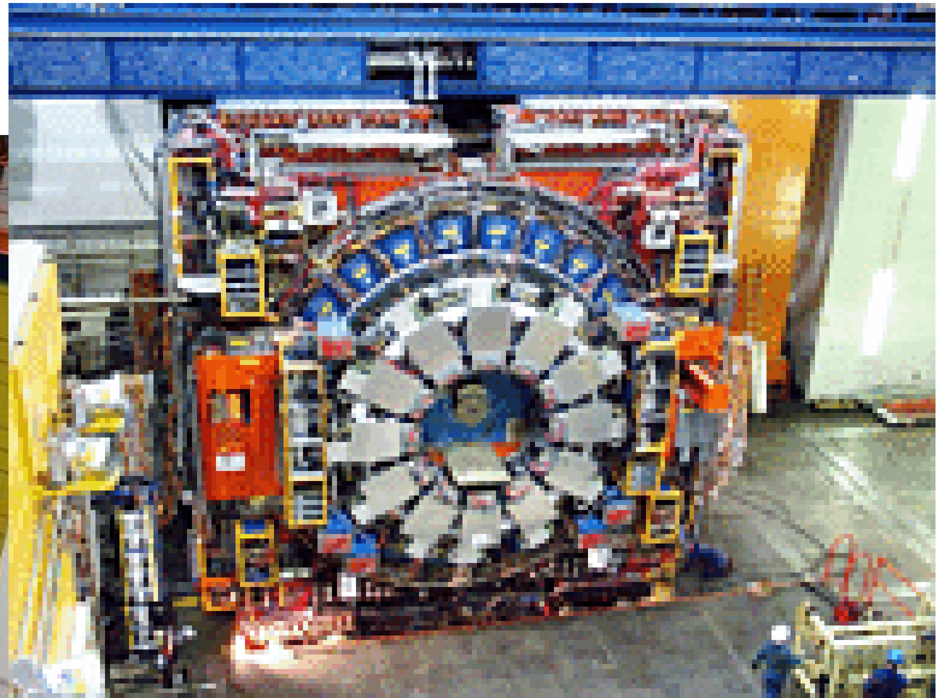


CDF - optimised for tracking



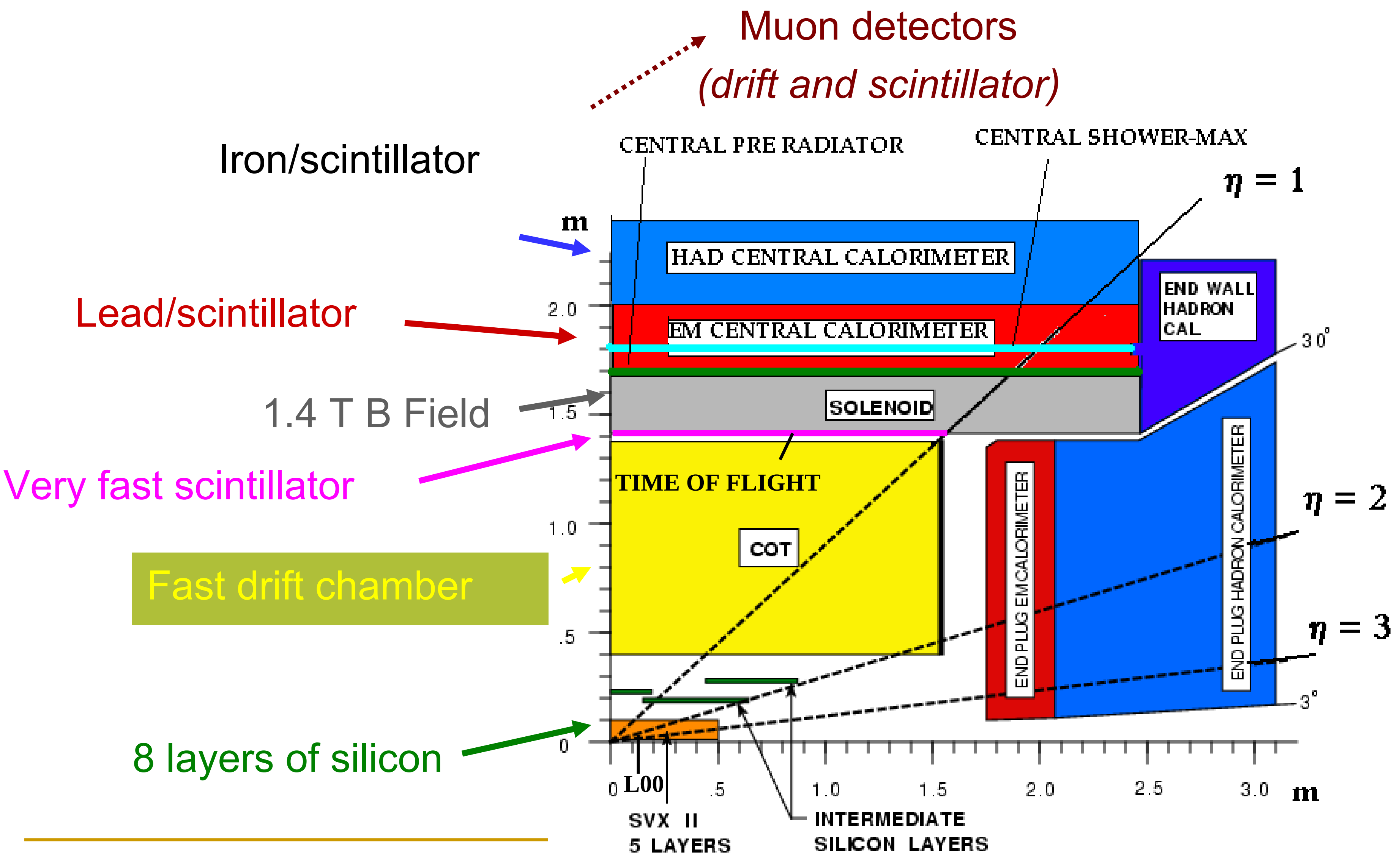
CDF





- 2001Upgrade
  - Higher luminosity
  - Newer technology

CDF Components



Trigger and DAQ

A million channels at 2.5 MHz

DAQ

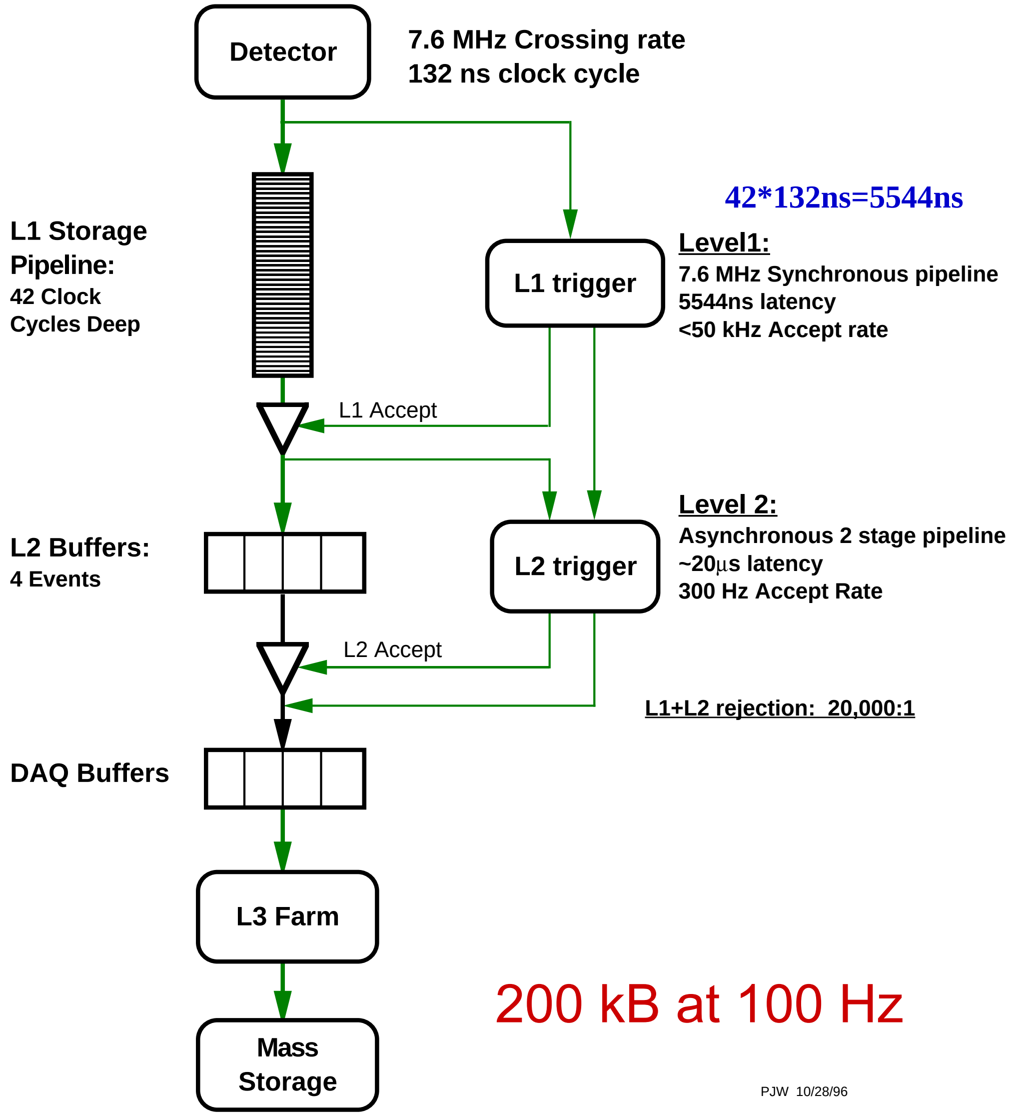
- Data AcQuisition
- Processing
- Storage

Keywords:

- Pipeline
- Latency
- Buffer
- Trigger Rate

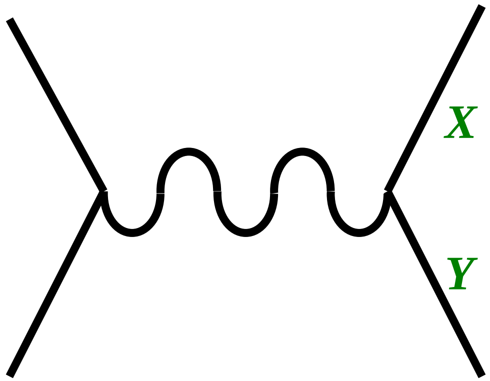
Trigger Inputs:

- Number of tracks
- Energy Clusters
- Particle Type



Feynman Level

- Hard process with final state X and Y



Directly observe X and Y if:		If not:
Long-lived (>picosecond)	→	Reconstruct from decay products
Interact with detectors	→	Reconstructed from "missing" transverse momentum p_T
Not confined (e.g. not a quark)	→	Produce jets

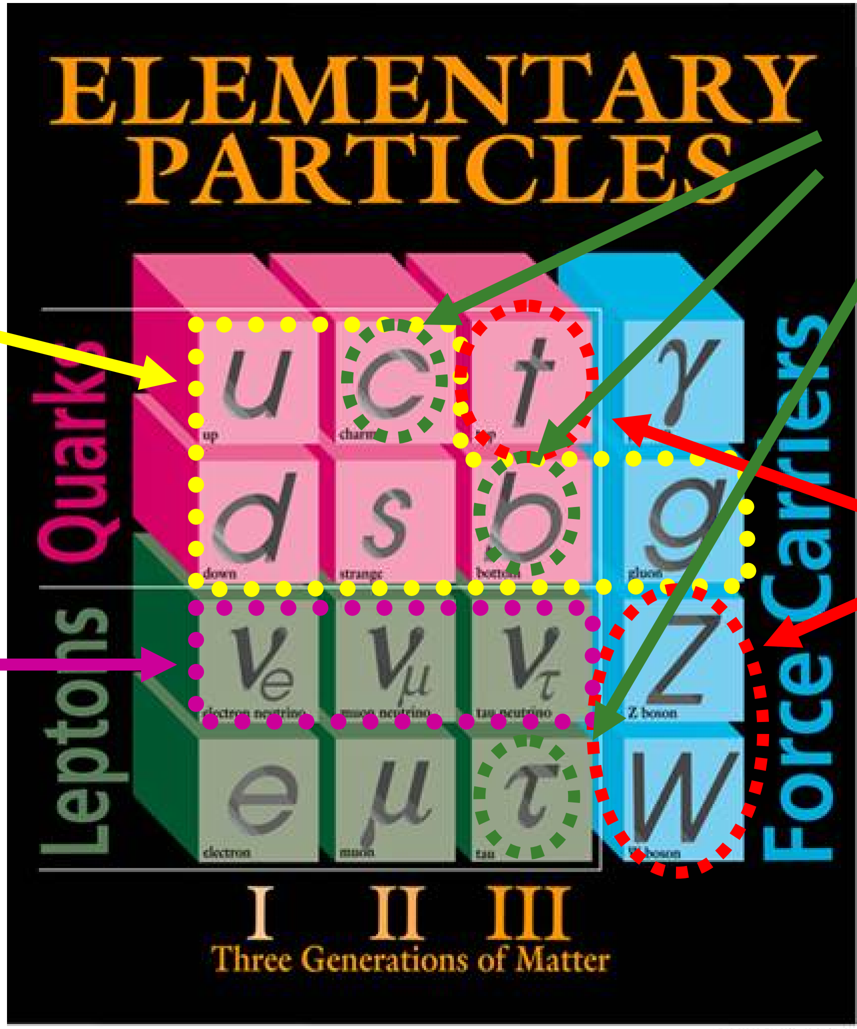
Standard Model Particles

Lifetime ~ ps

Confined

Short lived

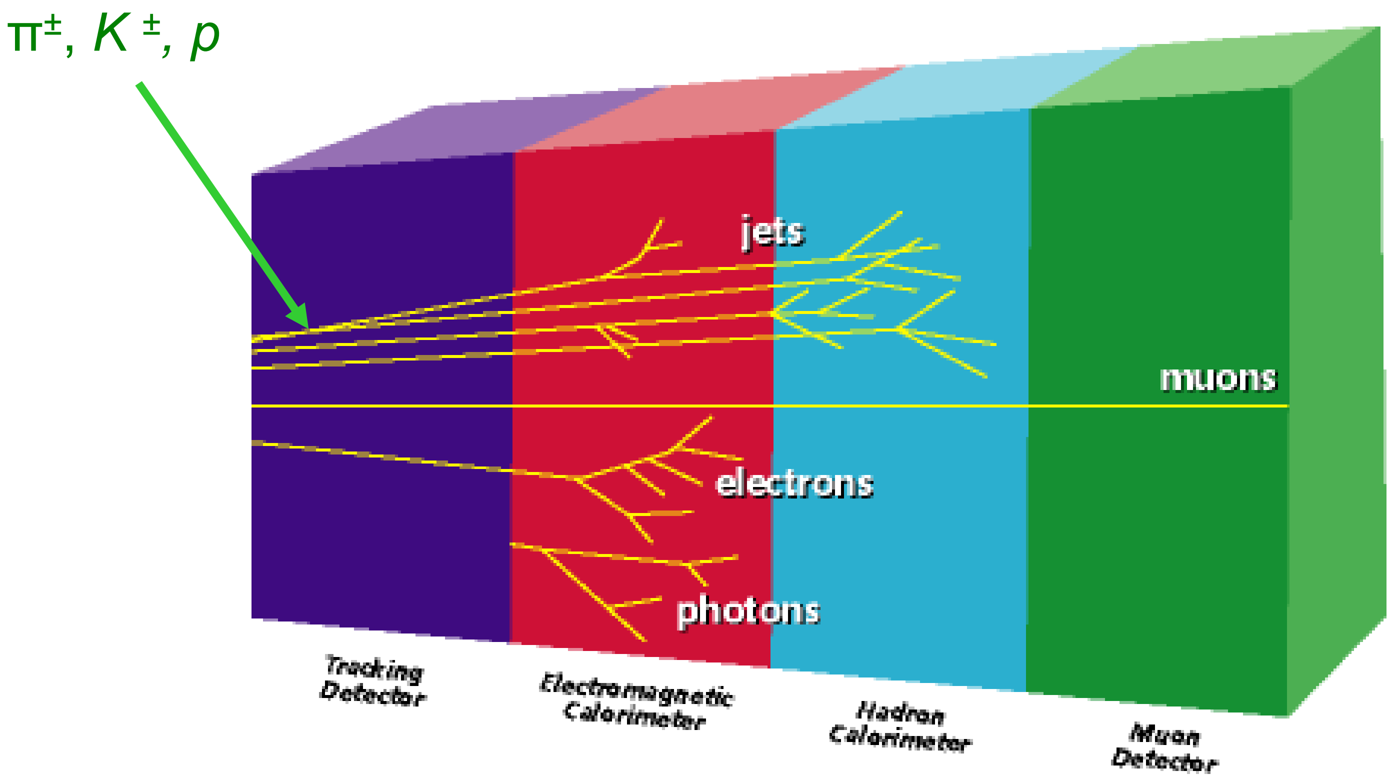
Non interacting



Fermilab 95-759

Particles Signatures

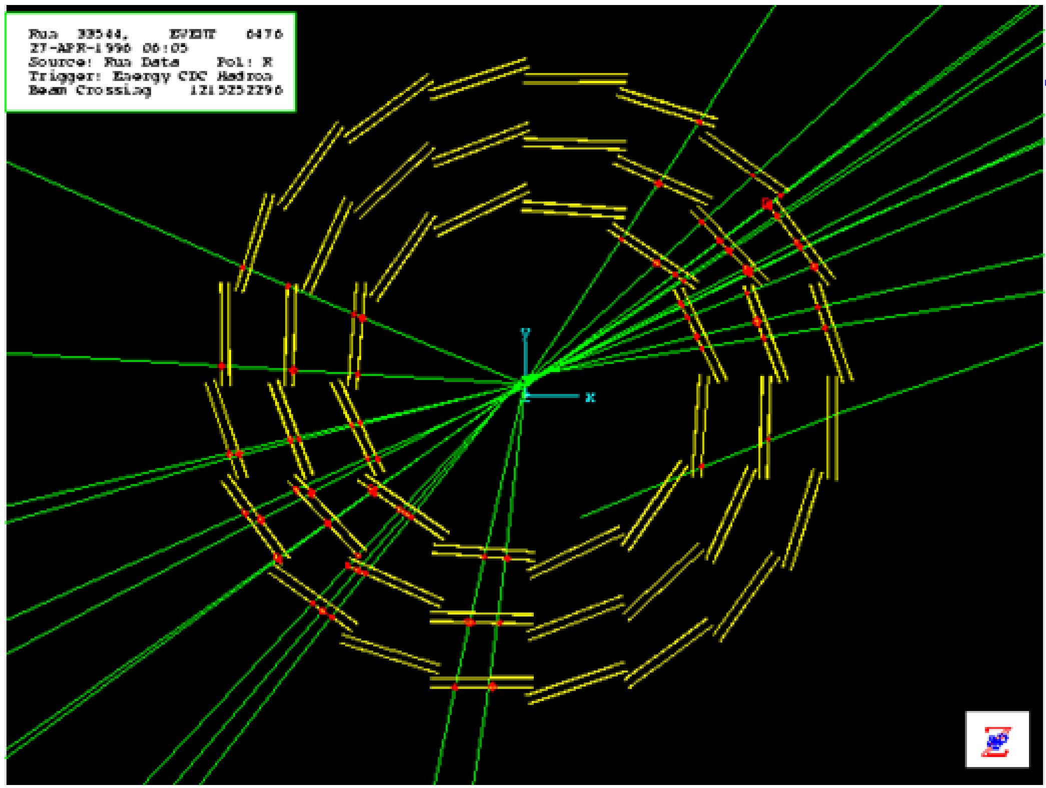
- Electron, photons, muons and jets

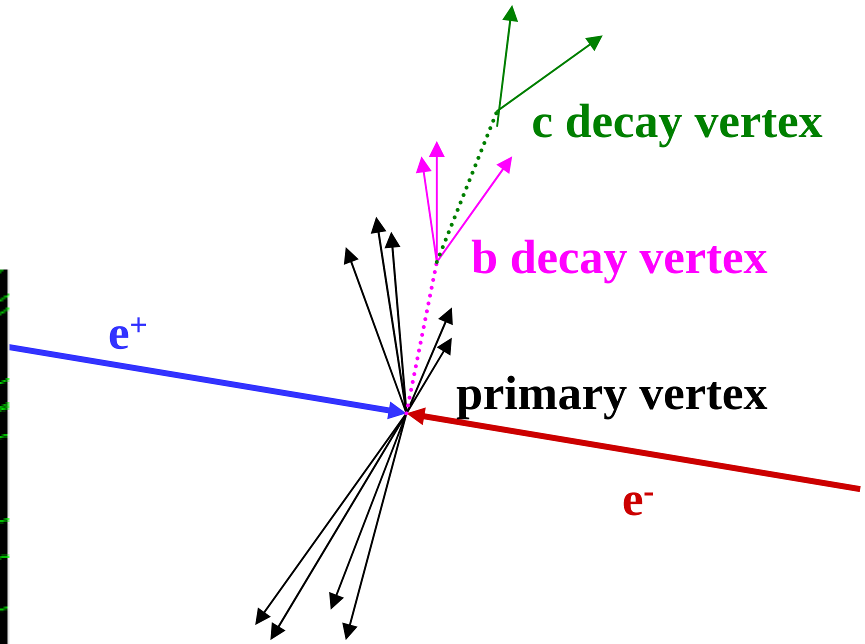


- Tau lepton ID depends on decay mode

Vertex Tagging

- *b-quark, c-quark,* τ-lepton will travel a few mm then decay





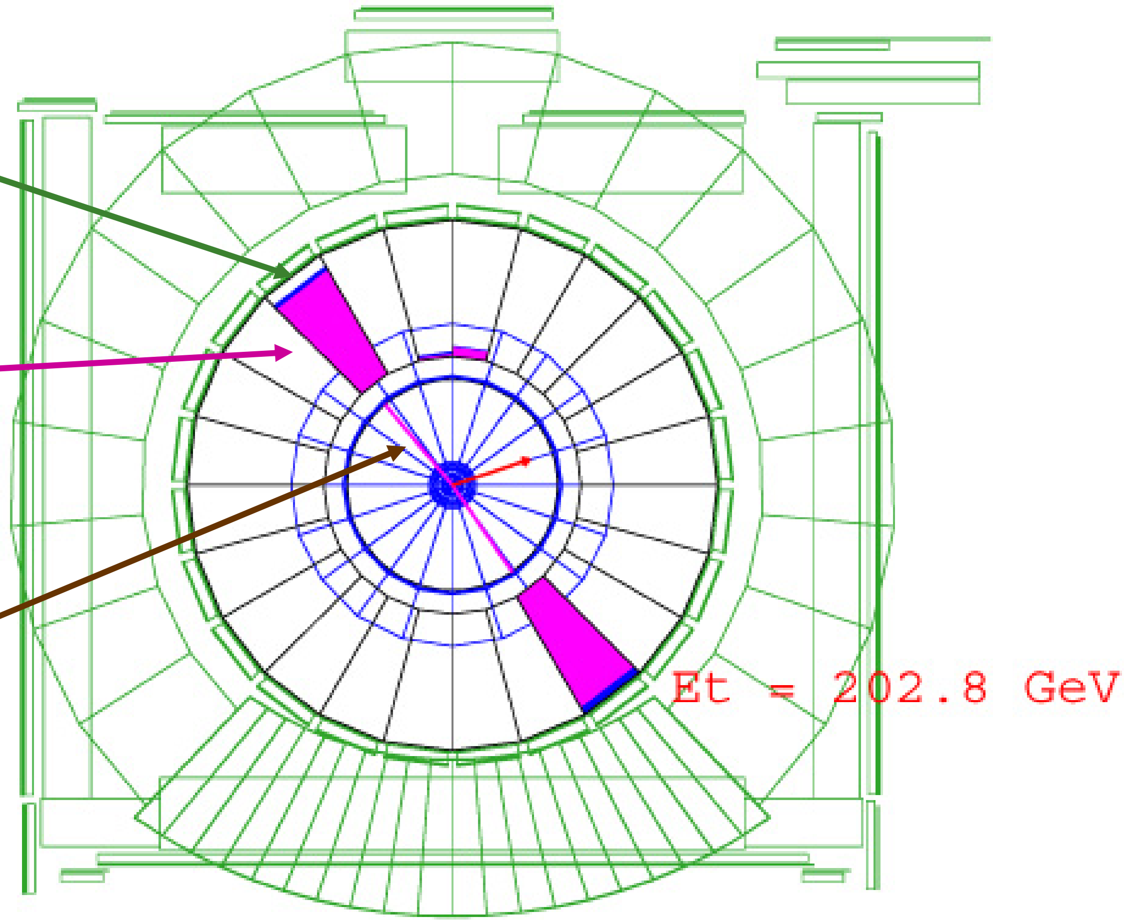
- Precise tracking shows "displaced vertices"
- Easiest for *b* hadrons

Signatures: Two Electron Event

Small hadronic energy

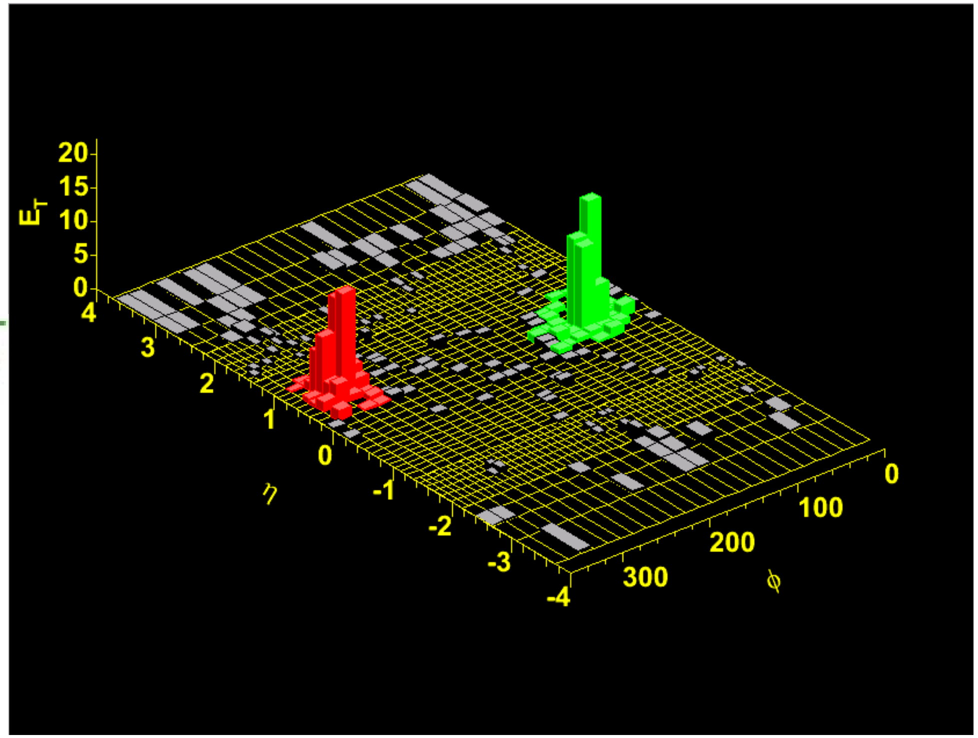
Large EM energy

High momentum track

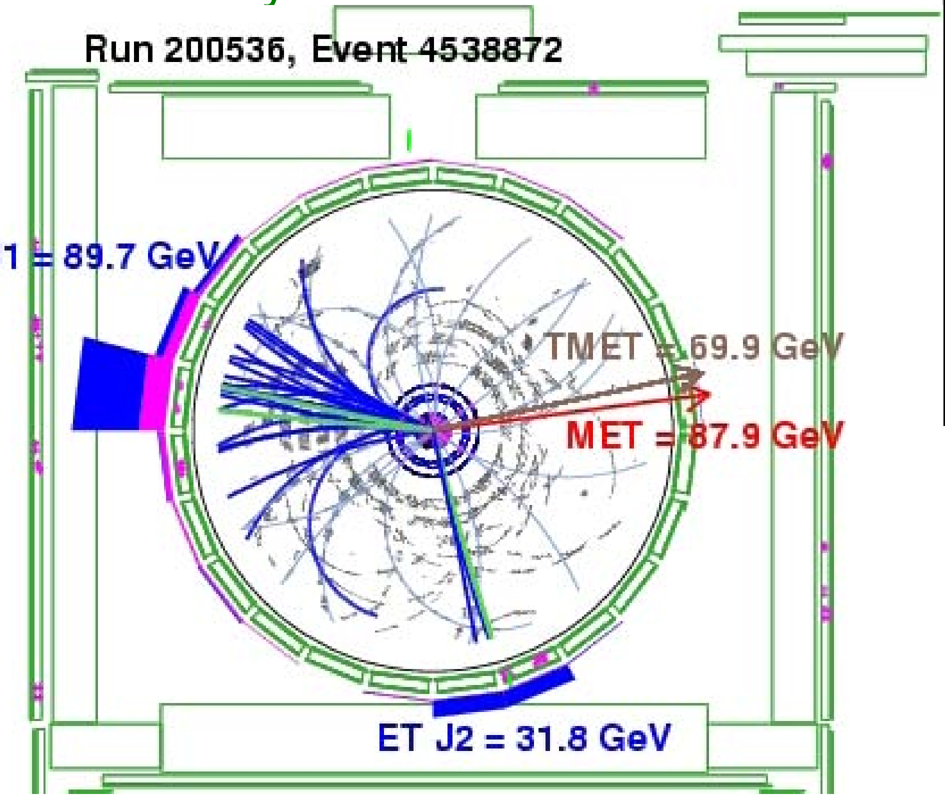


- Tracks and energies below a threshold not shown!

Signatures: Dijet + Missing Energy Trigger



- Two jets
  - energy in EM and hadron
  - many tracks



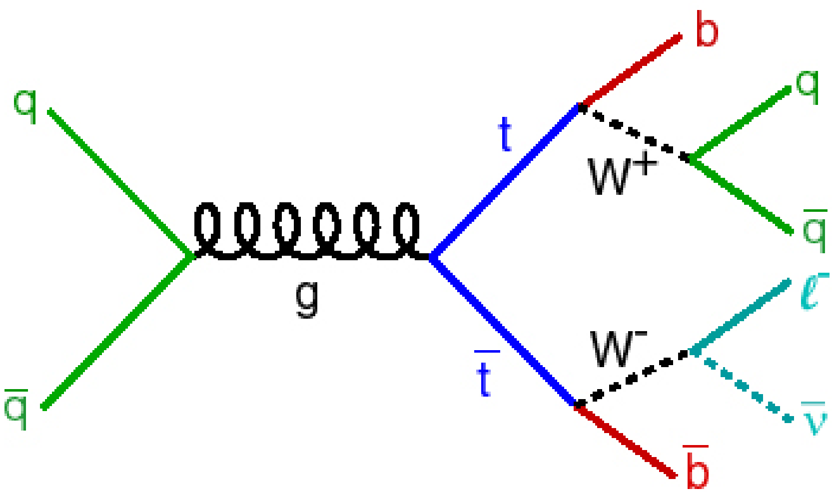
Alternate view of calorimeter

- p_T not balanced
  - *undetected particles*

Finding Top Quarks

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

- Top quark discovered at CDF and DØ in 1995
- Need to identify top pair production:
  - Br ($t \rightarrow bW^+$) ≈ 100%
  - Br ($W \rightarrow qq$) ≈ 70%
  - Br ($W \rightarrow l\nu$) ≈ 10% per *lepton*

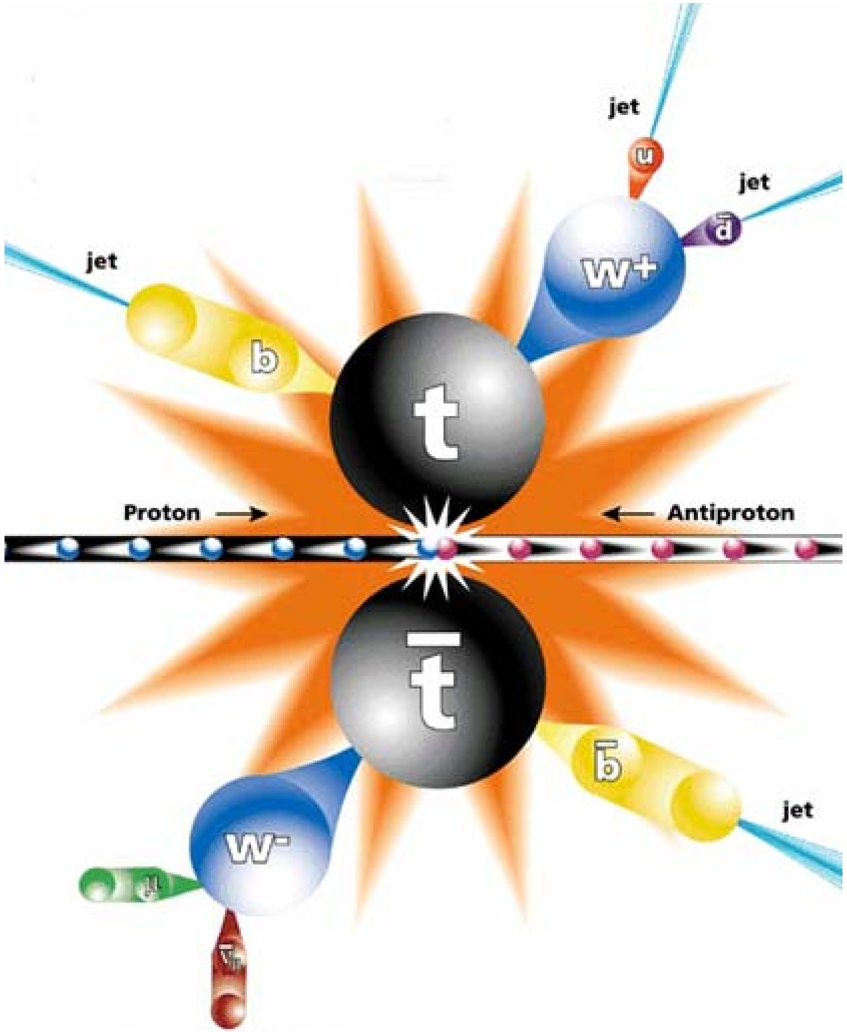


- Semileptonic channel
  - l^- is electron or muon
  - l^- easy to identify
  - only one neutrino
  - q is a “light jet” from a u,d,s quark.

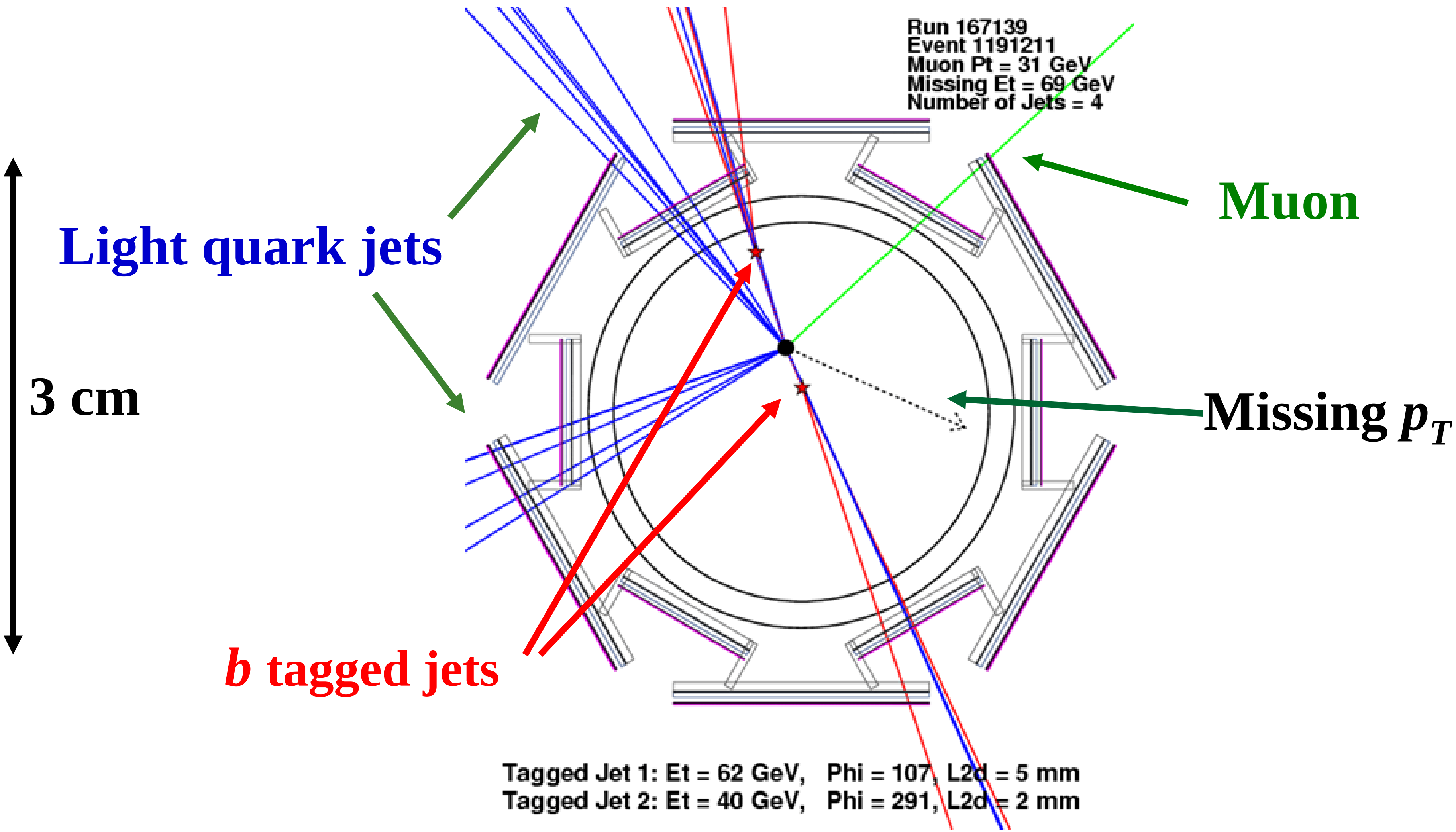
  NB may be higher order effects

Top Pair Production

- Electron or muon 20% of the time
- Signature:
  - 2 light quark jets
  - 2 bottom jets
  - One electron or muon
  - Missing transverse momentum (because of the neutrino)
- Extras:
  - Underlying event
  - Higher order processes
  - Multiple interactions



Top Event


Run 167139
Event 1191211
Muon Pt = 31 GeV
Missing Et = 69 GeV
Number of Jets = 4
Light quark jets
Muon
3 cm
Missing p_T
b tagged jets
Tagged Jet 1: Et = 62 GeV, Phi = 107, L2d = 5 mm
Tagged Jet 2: Et = 40 GeV, Phi = 291, L2d = 2 mm

Next Time...

Finding the Higgs and writing your first paper