Physics 214 UCSD/225a UCSB

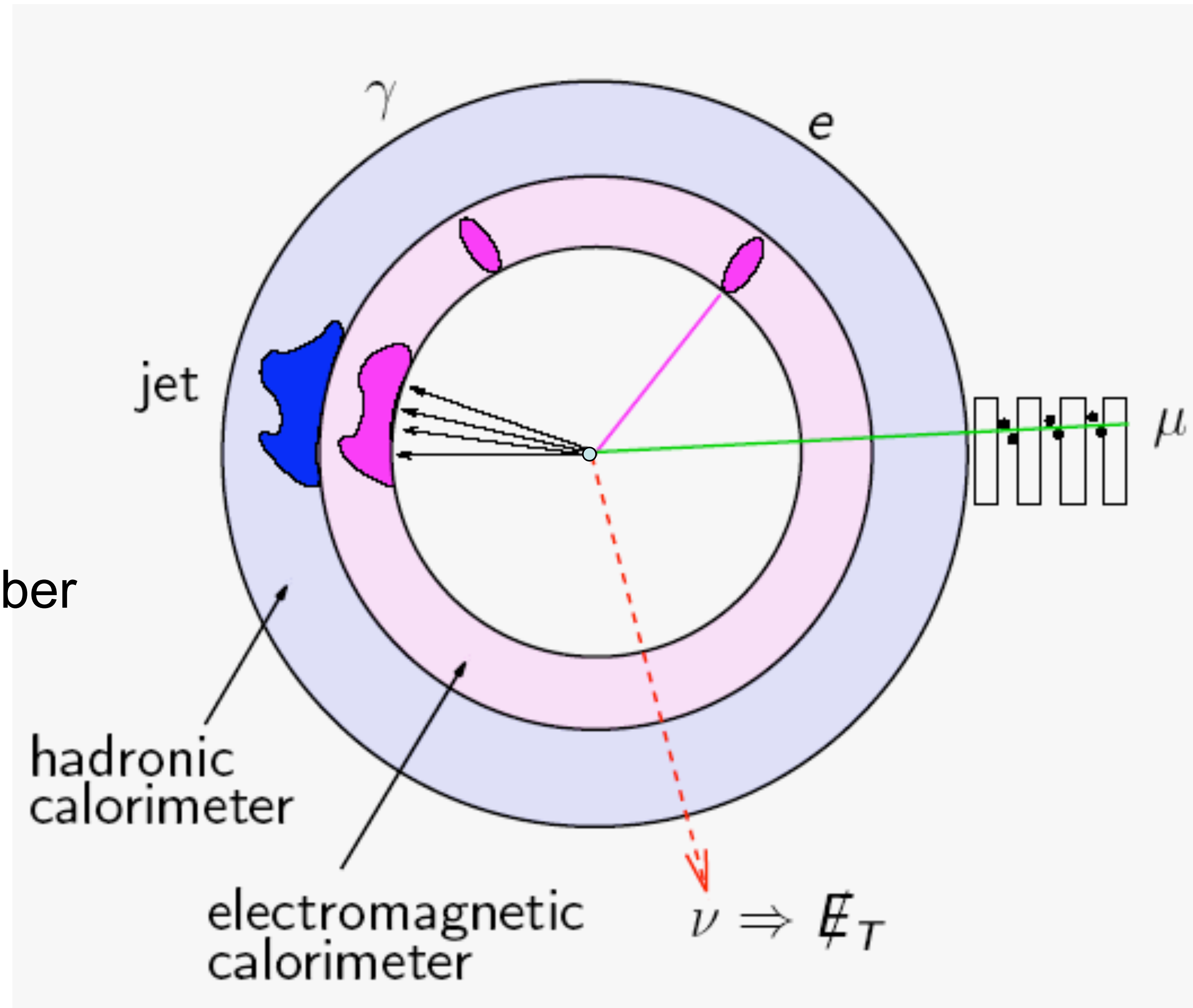
Lecture 4

- Collider Detectors
  - –Kleinknecht chapters:
    - •7. Momentum measurement
    - •6. Energy measurement

All modern collider detectors look alike

Increasing radius

- beampipe
- tracker
- ECAL
- solenoid
- HCAL
- Muon chamber



Tracking

- Zylindrical geometry of central tracking detector.
  - Charged particles leave energy in segmented detectors.
    - ⇒ Determines position at N radial layers
- Solenoidal field forces charged particles onto helical trajectory
  - Curvature measurement determines charged particle momentum:

$$R = P_T / (0.3B)$$

for R in meters, B in Tesla, P_T in GeV.

E.g. In 4Tesla field, a particle of 0.6GeV will curl in a tracking volume with radius 1m.

Limits to precision are given by:

1. Precision of each position measurement
   => more precision is better
2. Number of measurements => $1/\sqrt{N}$
   => more measurements is better
3. B field and lever arm => $1/BL^2$
   => larger field and larger radius is better
4. Multiple scattering => $1/\sqrt{X_0}$
   => less material is better

Momentum Resolution

Two contributions with different dependence on p_T

$$\frac{\sigma(p_T)}{p_T} = \frac{\sigma_{r\phi} p_T}{0.3BL^2}\sqrt{\frac{720}{N+4}}$$

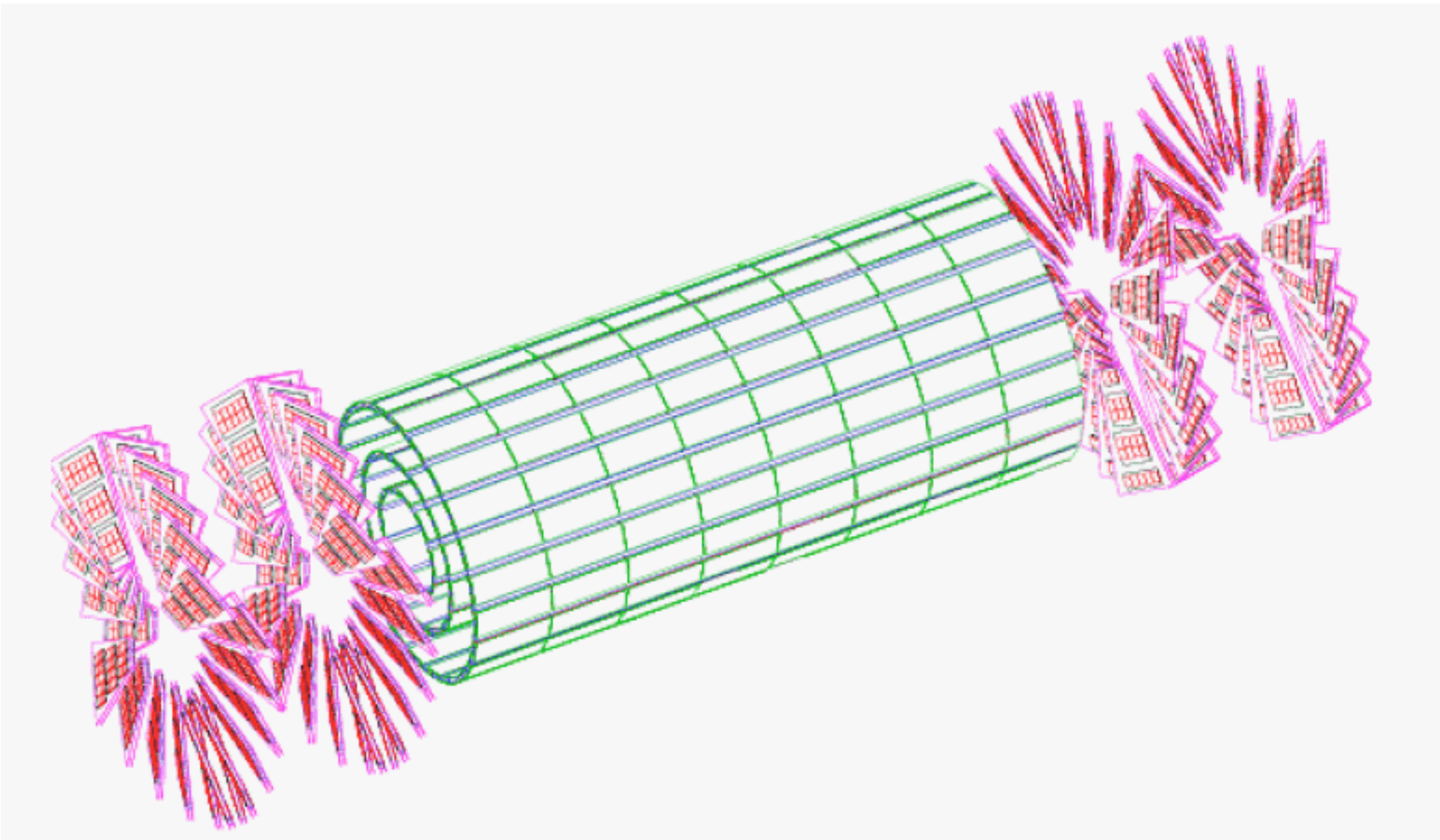
Device resolution

$$\frac{\sigma(p_T)}{p_T} = \frac{0.05}{BL}\sqrt{\frac{1.43L}{X_0}}$$

Multiple cattering

Small momentum tracks are dominated by multiple scattering.

Example CMS Tracker



CMS Tracker Z-view

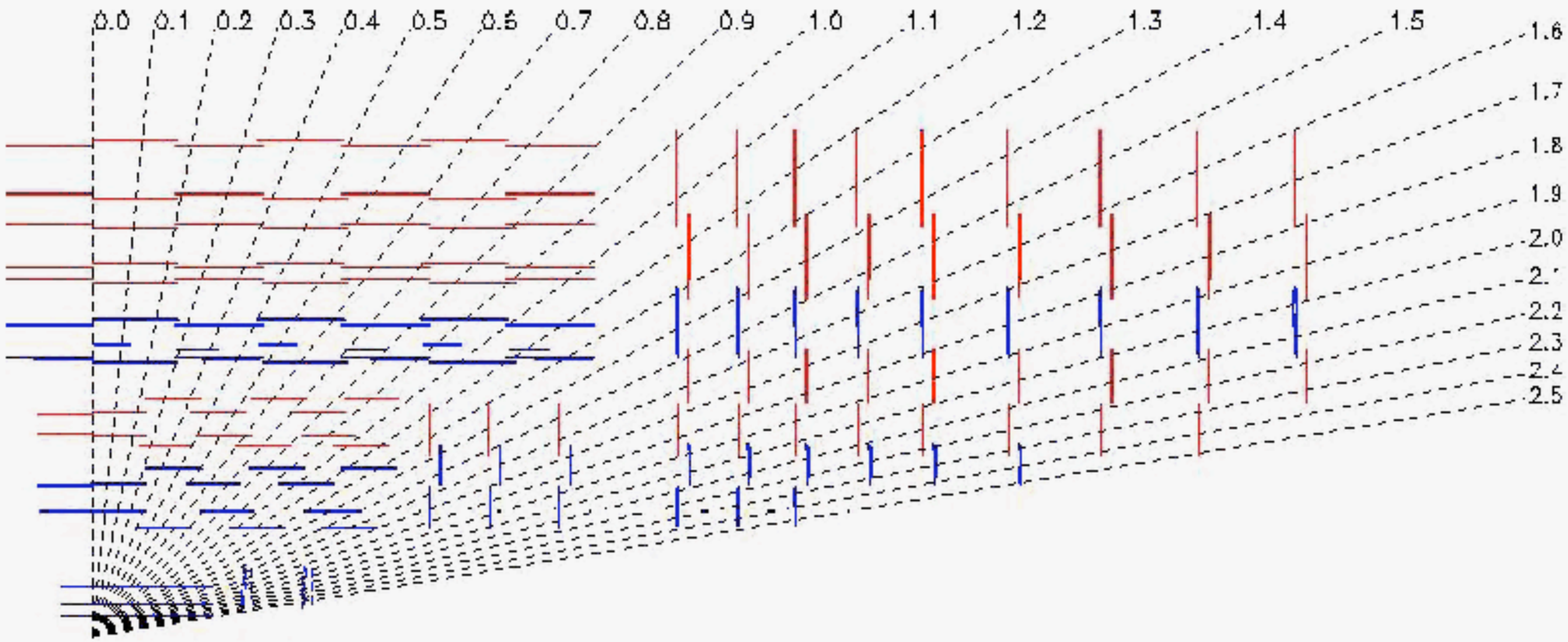
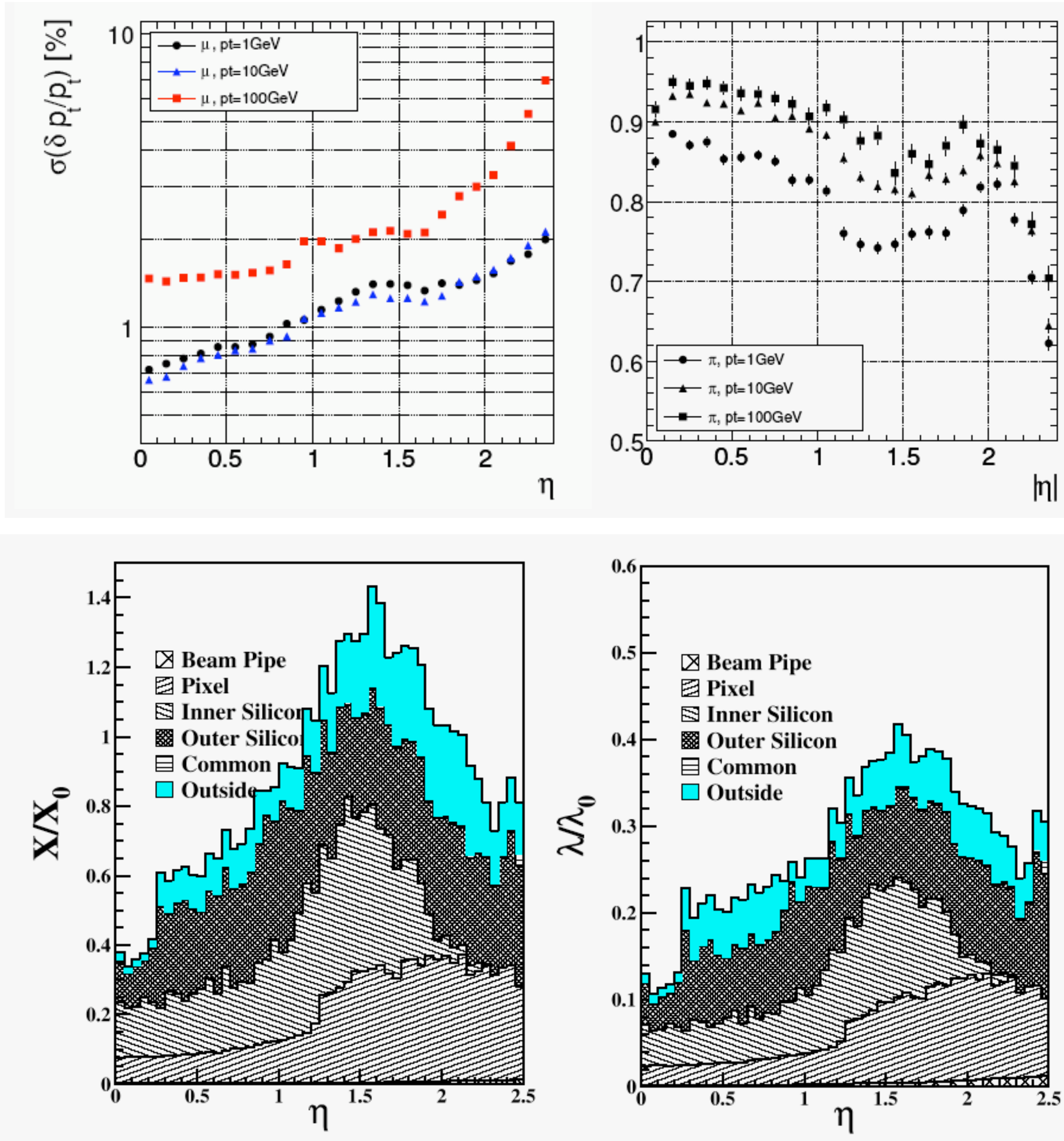


Figure 1.9: The tracker layout (1/4 of the z view).

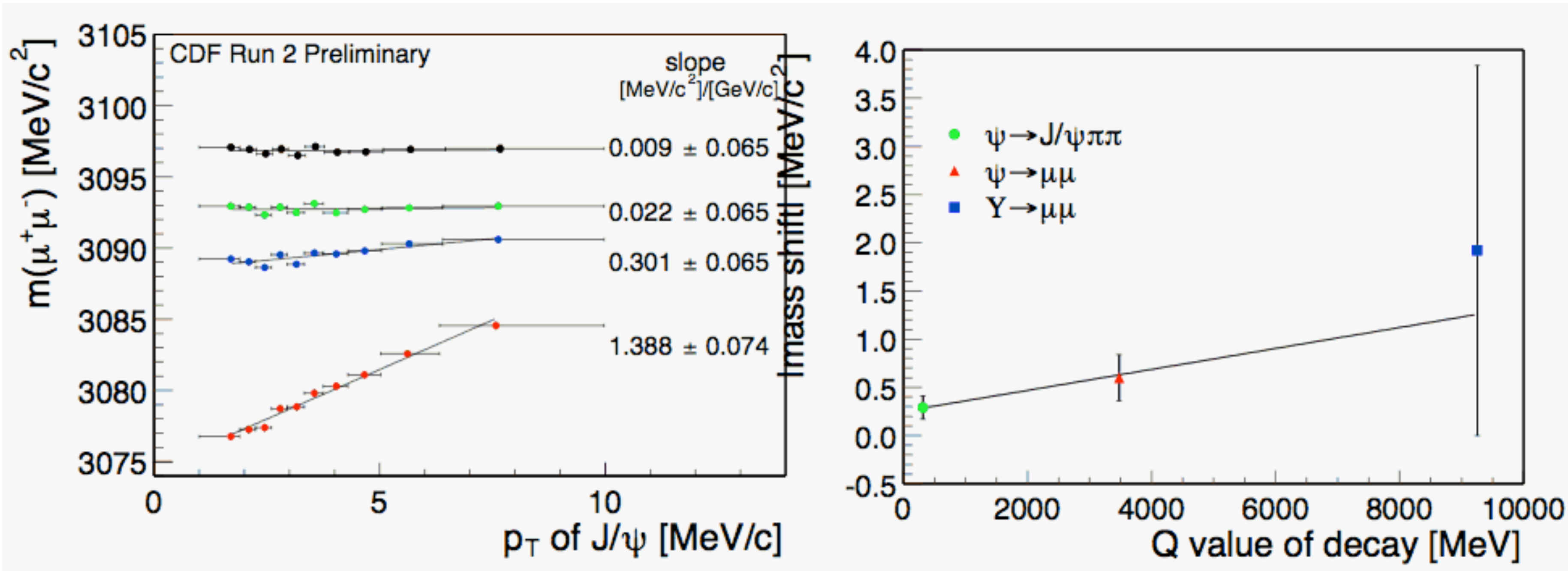
Limit to tracking due to material budget



Tracking Calibration

- Alignment of the detector
  - Use a variety of different sources to determine the “rigid body” location in space for all tracking detector elements.
  - Most important thing to get right early on.
  - Likely to be refined many times later.
- Material budget
  - Measured via conversions
  - Verified via impact on mass measurements
    - Energy loss affects p_T
    - p_T affects invariant mass reconstruction vs p_T
- B-field scale
  - Directly affects mass scale

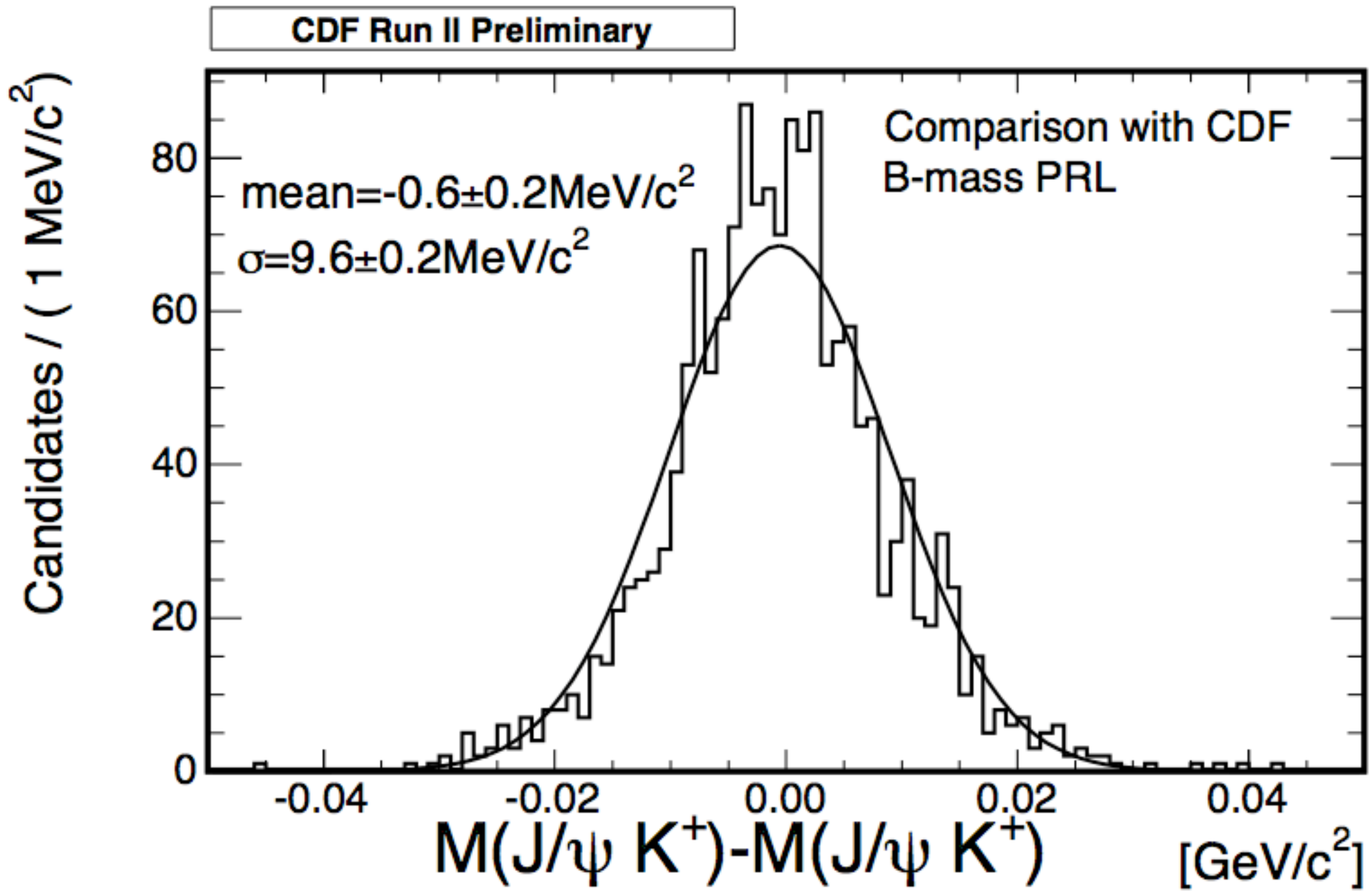
Example from CDF



$$\delta m = 1.09 \cdot 10^{-4} \cdot Q + 0.25[MeV]$$

(Phys.Rev.Lett.96:202001,2006.)

Recalibration example from CDF



0.41 (0.36) MeV stat. (syst.) precision published in 2005

Recalibration example from CLEO

- CLEO published the discovery of B+ decay to omega K+ in PRL in 1998.
- Then went through a recalibration of all the data. The signal went away.
- It took 7 more years until this decay was actually observed at Belle in 2002.
  - Actual BR now 1/3 of the first claim by CLEO.

Aside on Strength and Danger of analyses that exploit all of phase space.

ECAL

- Detects electrons and photons via energy deposited by electromagnetic showers.
  – Electrons and photons are completely contained in the ECAL.
  – ECAL needs to have sufficient radiation length X_0 to contain particles of the relevant energy scale.
- Energy resolution $\propto 1/\sqrt{E}$

Real detectors have also constant terms due to noise.

Example CMS ECAL

$$\left(\frac{\sigma}{E}\right)^2 = \left(\frac{0.04\sqrt{GeV}}{\sqrt{E}}\right)^2 + \left(\frac{124\,MeV}{E}\right)^2 + 0.003$$

- 1st term: statistical fluctuations
- 2nd term: electronic noise

These parameters were obtained from testbeam data.

Thoughts on photons vs electrons

- Electrons brems
  - ⇒energy loss deteriorates the resolution
- Photons convert
  - ⇒loss of efficiency and/or resolution
  - ⇒Unknown origin reduces resolution
    - ⇒Need to identify primary vertex
    - ⇒Need to choose primary vertex if multiple interactions per crossing

HCAL

- Only stable hadrons and muons reach the HCAL.
- Hadrons create hadronic showers via strong interactions, except that the length scale is determined by the nuclear absorption length λ, instead of the electromagnetic radiation length X_0 for obvious reason.
- Energy resolution $\propto 1/\sqrt{E}$
- 4T field in CMS may hurt jet resolution.
  - Attempting to do particle flow algorithm

Muon Detectors

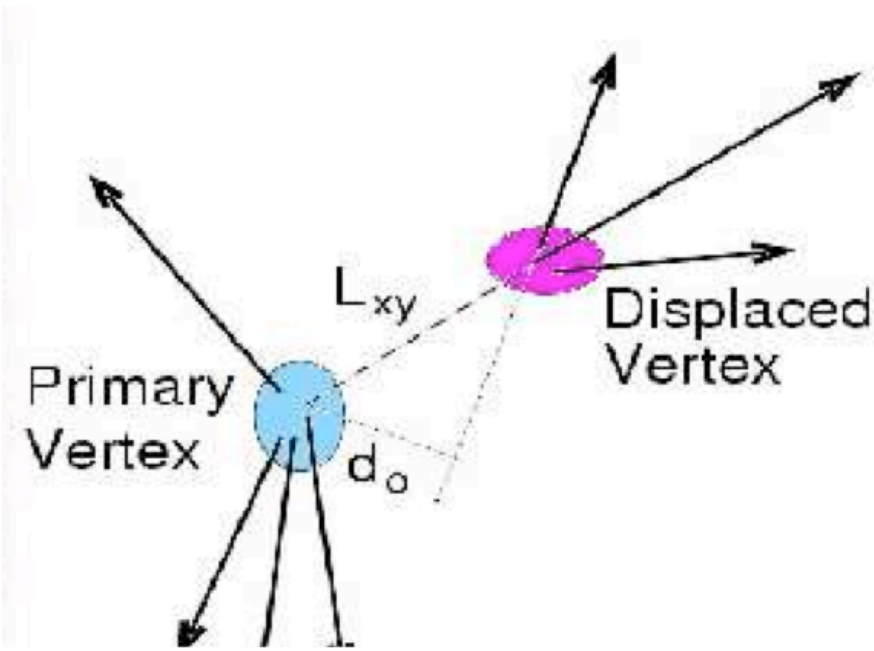
- Muons are minimum ionizing particles, i.e. small energy release, in all detectors.
- Thus the only particles that range through the HCAL.
- Muon detectors generally are another set of tracking chambers, interspersed with steal or iron absorbers to stop any hadrons that might have “punched through” the HCAL.

What do we need to detect?

- Momenta of all stable particles:
  - Charged: Pion, kaon, proton, electron, muon
  - Neutral: photon, K^0_s , neutron, K^0_L , ***neutrino***
- Particle identification for all of the above.
- "Unstable" particles:
  - Pizero
  - ***b-quark, c-quark, tau***
  - Gluon and light quarks
  - ***W,Z,Higgs***
  - … anything new we might discover …

Haven't told you how to detect the blue ones!
Three more "detection" concepts missing.

Lifetime tags

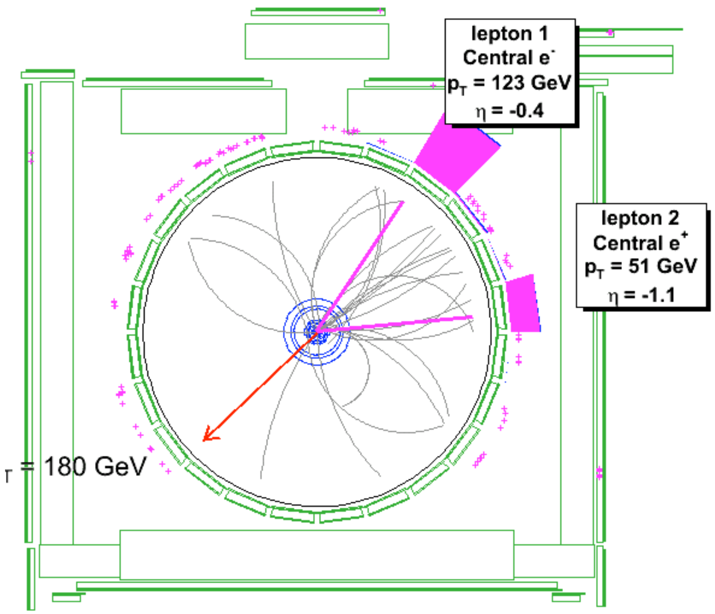


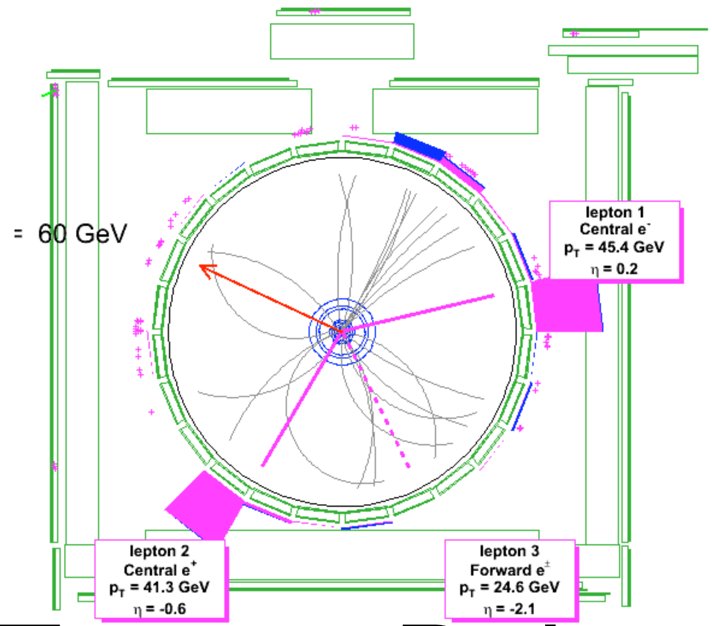
Weakly decaying particles
Have measurable flight distance:

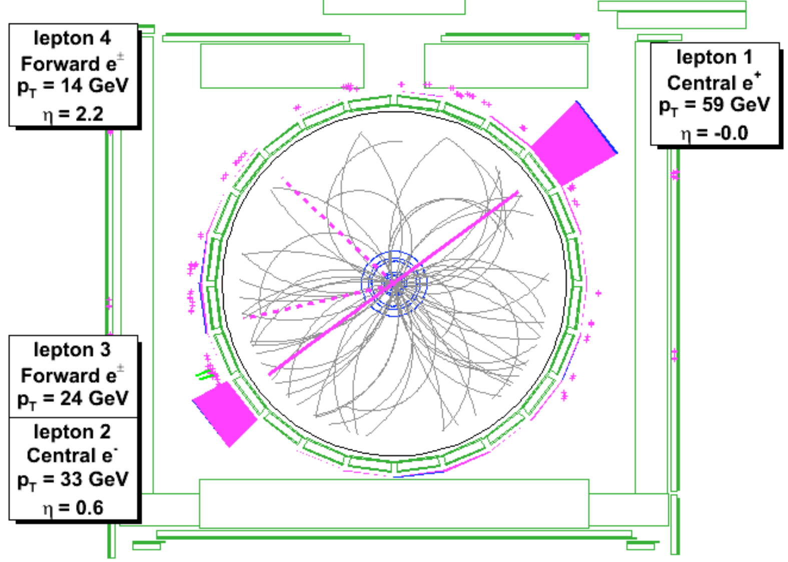
$$\langle L_{xy} \rangle = \beta\gamma c\tau$$

However, lifetime tags depend crucially on transverse momentum, e.g. on m_b not being too small compared to p_{track} .

Transverse Energy Balance

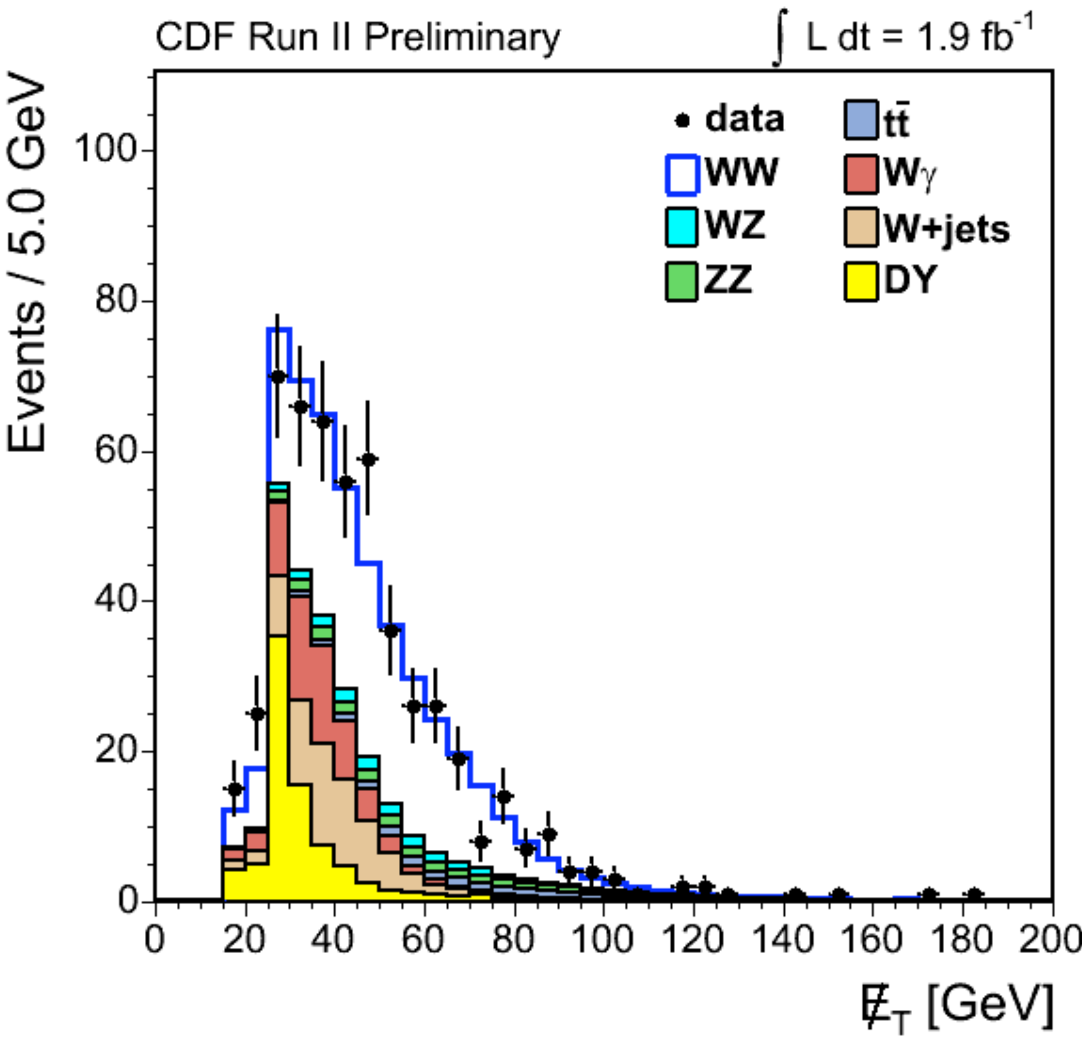






Used to find events with particles that interact very weakly with matter.

WW candidates at CDF



Both W's decay leptonically

Reconstruction via decay products.

Example: 1st Observation of WZ (CDF Fall 2006)

Use the fully leptonic decays of W and Z only.
Require consistency with Z mass
for opposite charge same flavor lepton pair.
Do not require W mass because of neutrino.
Id neutrino presence via MET.