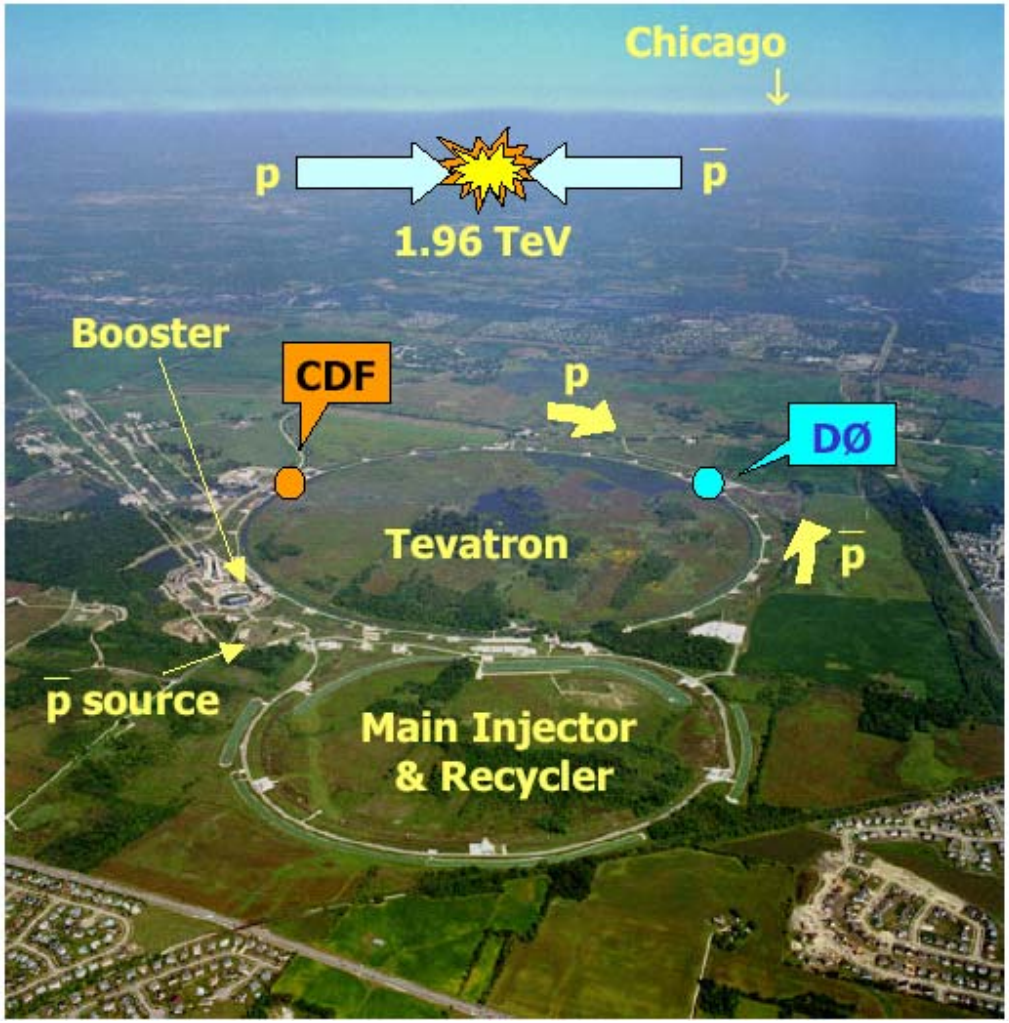
Electron, Muon and Photon ID at the Tevatron



For the CDF and D0 Collaborations

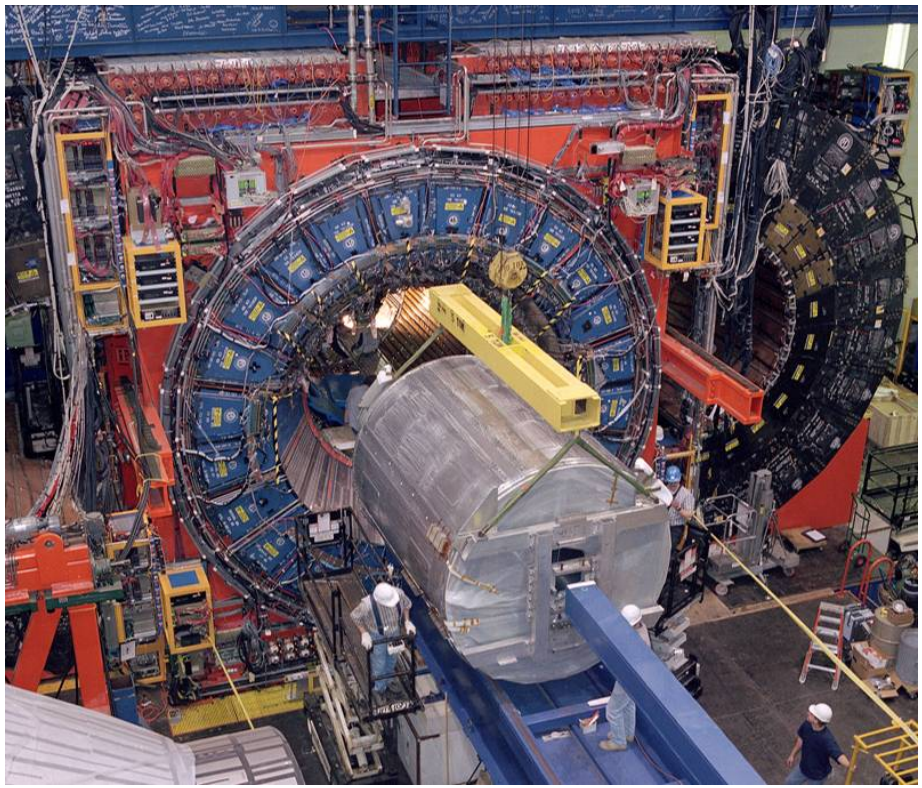
Xiaojian Zhang
University of Illinois,
Urbana-Champaign

Outline

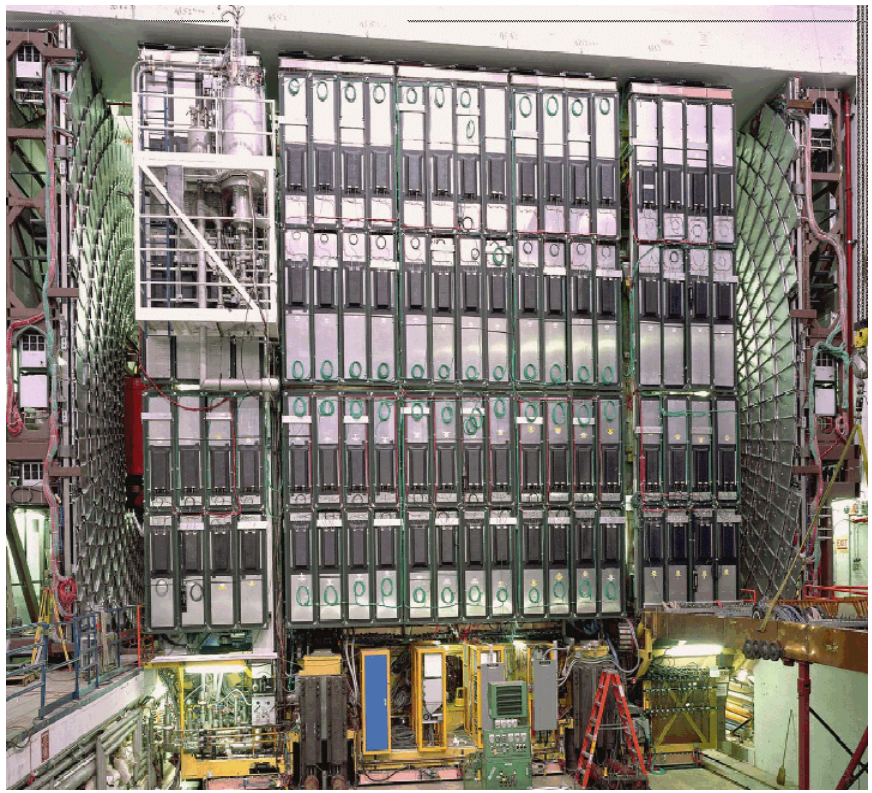
1. CDF & D0 Detectors
2. Lepton/γ Identification
3. ID efficiency
4. Fake Rate
5. Detector Calibration
6. Summary

Detector pictures

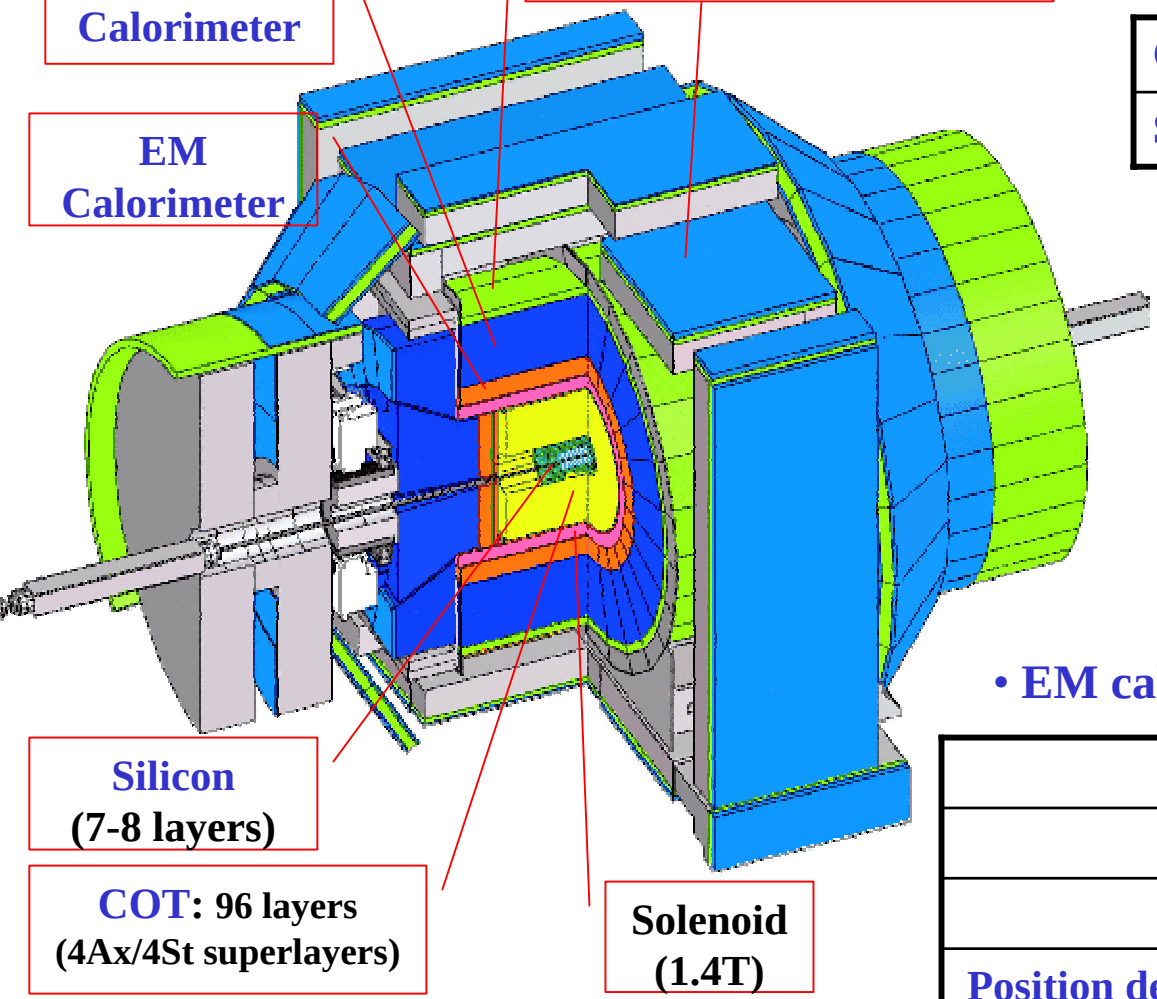
CDF



D0



CDF detector



• Tracking system

Central tracker	$\|\eta\| \leq 1.0$, R ~1.4m
Si tracker	$\|\eta\| \leq 2.0$

$$\eta = -\ln(\tan\frac{\theta}{2})$$

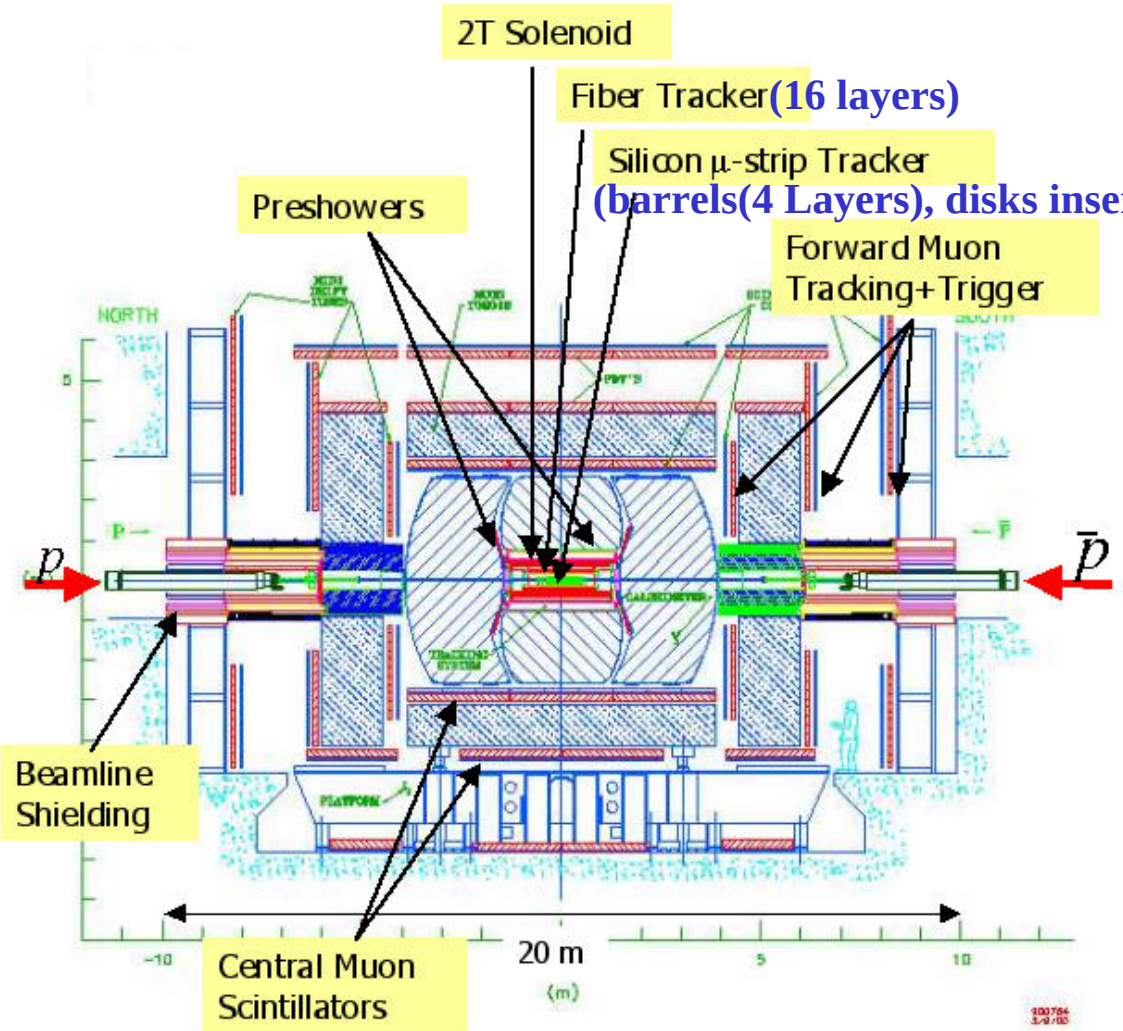
• Muon system

Drift chamber/ Scintillator
$\|\eta\| \leq 1.5$ (CMU/CMP, CMX, BMU)
# of layers: 4/4, 8, 4

• EM calorimeter

Scintillator/lead
0.11×0.26(η×ϕ)
~20 radiation length
Position detector(Strip and wires) at shower max

D0 detector



• **Tracking system**

Central tracker	$\|\eta\| \leq 1.7$, R ~0.5m
Si tracker	$\|\eta\| \leq 3.0$

• **Muon system**

Drift tube/ Scintillator
$\|\eta\| \leq 2$ (central & forward)
3 layers of tubes(3-4 planes/layer)
Toroid between layer 1 and 2

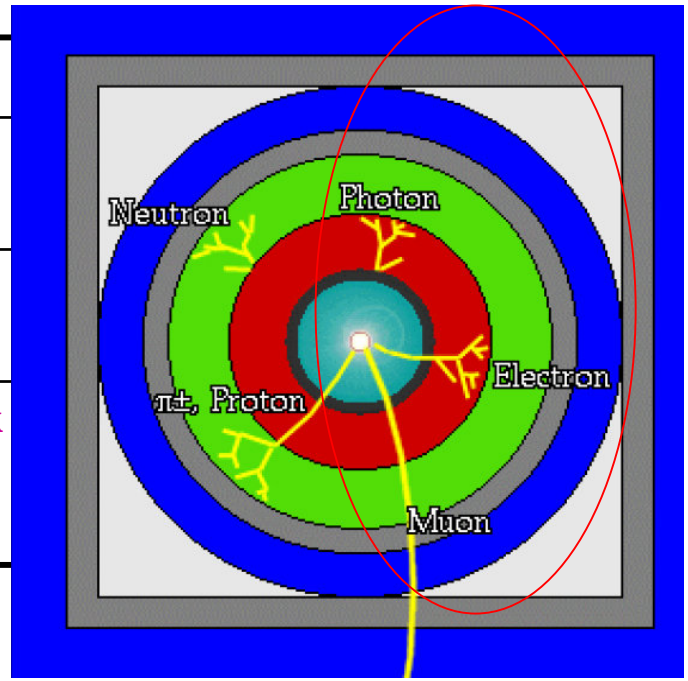
• **EM calorimeter**

Liquid Argon/Uranium
0.1×0.1 (η×ϕ)
~20 radiation length
Preshow: Scintillating strips
Shower max:3rd layer (0.05 × 0.05)

Identify e/μ/γ

- Extremely important for the Tevatron experiments
  - ✓ used in most analyses: top, EWK, Higgs, New Physics
- Identified by using the interaction with materials

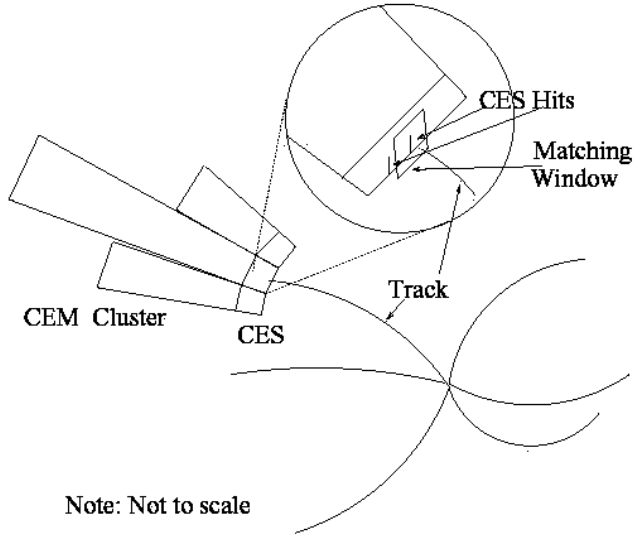
	Characteristics	Identification
Electron	Mainly bremsstrahlung	Calorimeter cluster+track
Muon	Minimum E loss	Muon stub hits+track
photon	E loss though conversion	Calorimeter cluster+No track matching

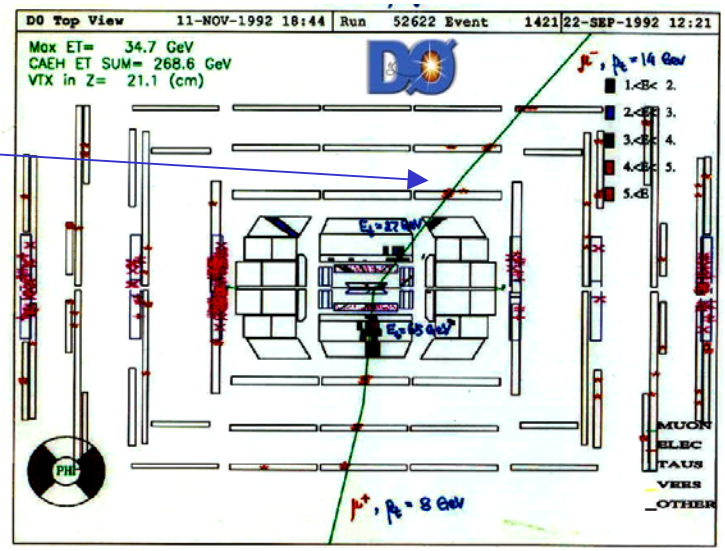


- Goal
  - High ID efficiency
    - ✓Get more events of interests.
  - Low fake rate
    - ✓ Improve the sensitivity of findings.

e/μ/γ Reconstruction

- **Electron**
  - ✓ Fired EM tower
  - ✓ Extrapolate track to the tower
    - ✓ Reversed order in FWD region
  - ✓ Apply ID cuts (discussed next…)
- **Muon**
  - ✓ Muon stub
  - ✓ Match to track
  - ✓ Low energy deposition in Calorimeter
- **Photon**
  - ✓ same as electron but vetoing associated track

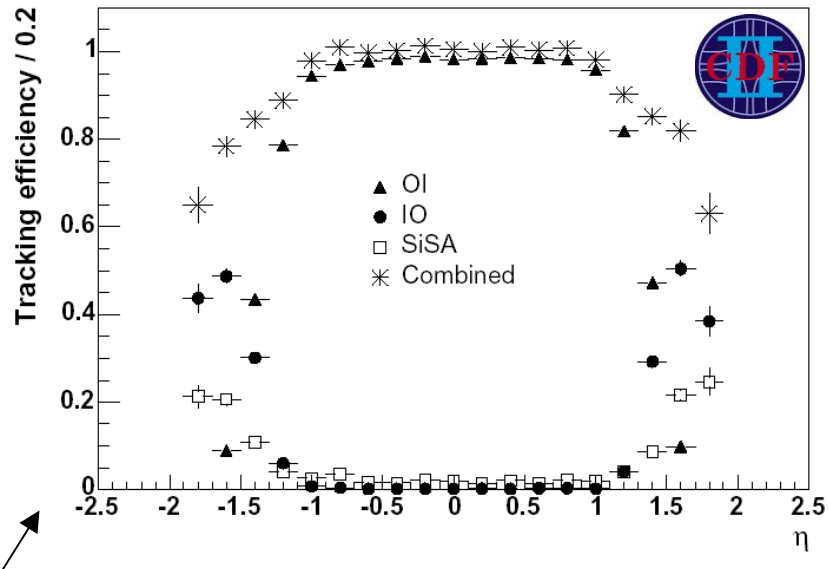


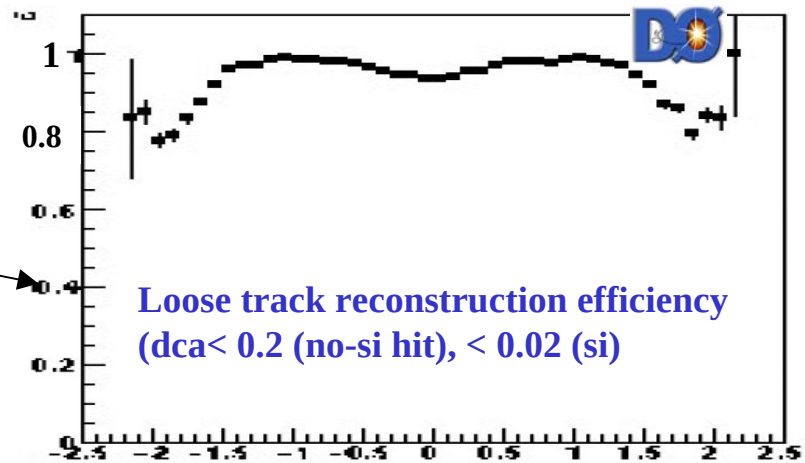


ID requirements

- **Basic cut:**
  - ✓ Fiducial
  - ✓ Muon: impact parameter, cosmic veto
  - ✓ Eletron: conversion removal
- **Isolation cut**
  - ✓ iso: E_T(surrounding cone)/E_T(e/γ)
  - ✓ Geometry cut
- **ID cuts**
  - ✓ Quality cuts, e.g.
  - ✓ e: Lshr, strip χ2 in shower max detector
  - ✓ μ: E_{EM}, E_{HAD}
  - ✓ track matching, need good tracking ε

    e.g. > 99% for CDF central



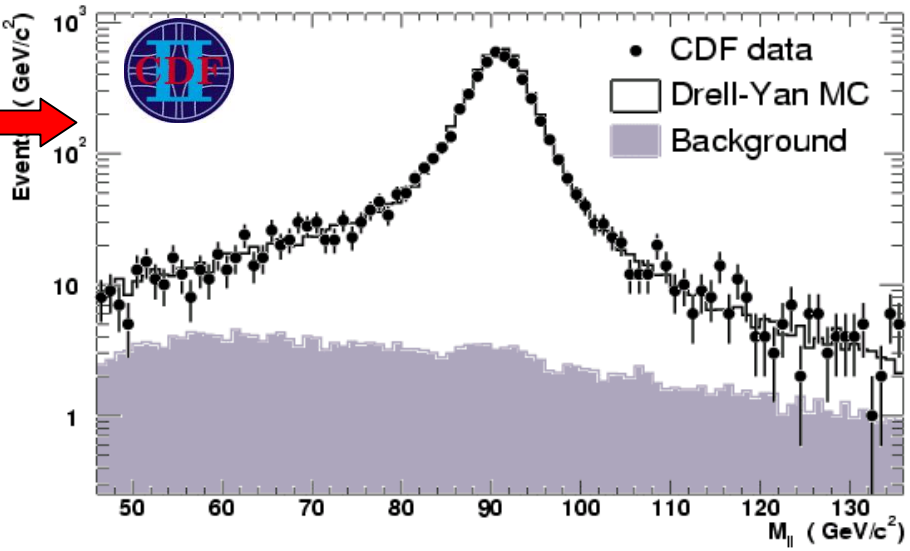


Selecting ID Cuts

- Vary among analyses, depending on
  - ✓Components of signal & background
- Two cut categories for e
  - ✓ **Tight cuts:** lower fake rate
    - ❖ when background is a concern.
  - ✓ **Loose cuts:** higher ID efficiency
    - ❖ when more signals are desired

Mode	ee	$e\mu$
WW	$12.82 \pm 0.06 \pm 1.06$	$28.82 \pm 0.09 \pm 2.39$
Drell-Yan	$4.83 \pm 0.52 \pm 1.26$	$3.56 \pm 0.43 \pm 0.93$
$t\bar{t}$	$0.05 \pm 0.01 \pm 0.01$	$0.11 \pm 0.01 \pm 0.01$
$WZ + ZZ$	$3.62 \pm 0.02 \pm 0.36$	$0.93 \pm 0.01 \pm 0.09$
$W\gamma$	$3.57 \pm 0.12 \pm 0.71$	$3.25 \pm 0.10 \pm 0.65$
W+jets	$2.96 \pm 0.23 \pm 0.71$	$6.69 \pm 0.41 \pm 1.98$

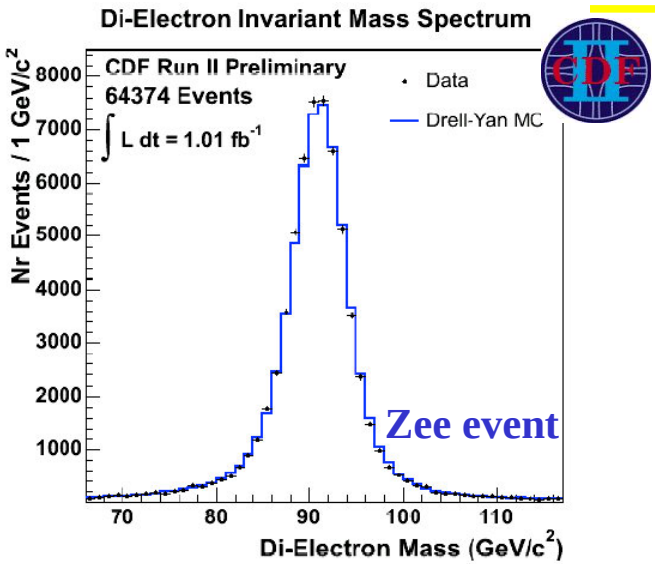
Fake is the major background in WW cross-section measurement

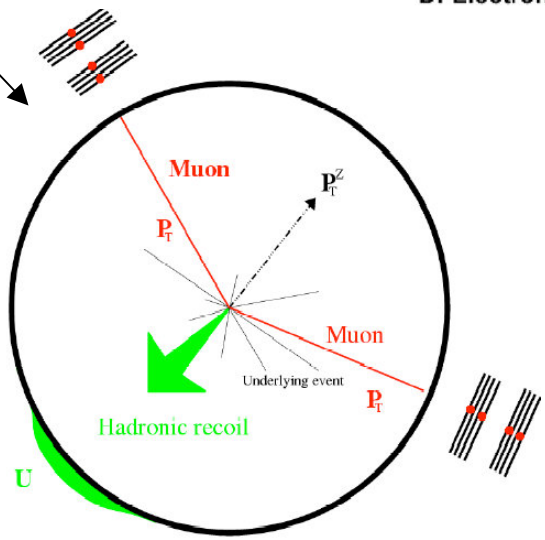


Fake as background is just a small fraction in The Z+bjet cross-section measurement

Measure the ID efficiencies

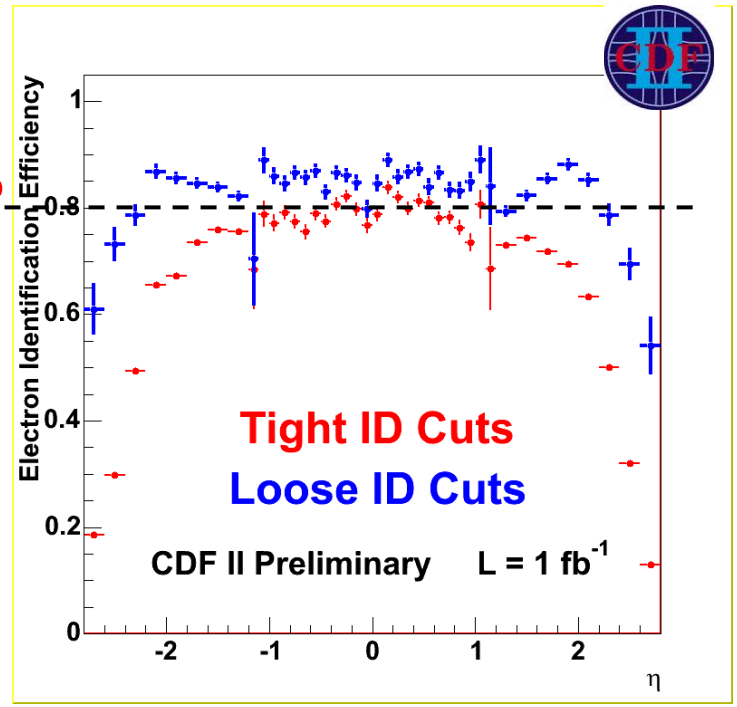
- **Resonance samples** (decay to di-e, di-μ)
  - ✓ Z, Upsilon, J/ψ (full pT spectrum)
  - ✓ Put "tight" ID cut on the triggered leg
  - ✓ Use the other leg as a probe
- **DY process**
  - ✓ Isolation study for the low E_T e
  - ✓ Selecting back-to-back electrons
- **Backgrounds**
  - ✓ Backgrounds under mass peak
  - ✓ bbbar, ccbar, jet fakes in DY
  - ✓ Remove converted electrons
- **Special treatment for photon**





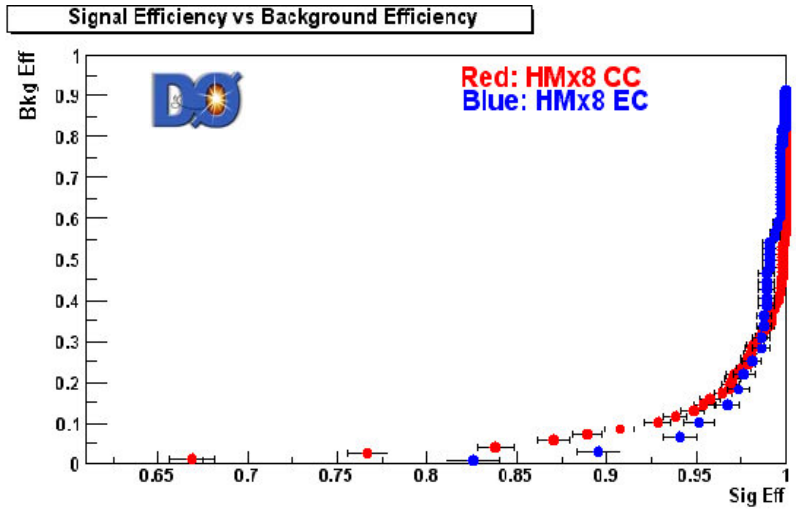
High PT electron ID Efficiency (I)

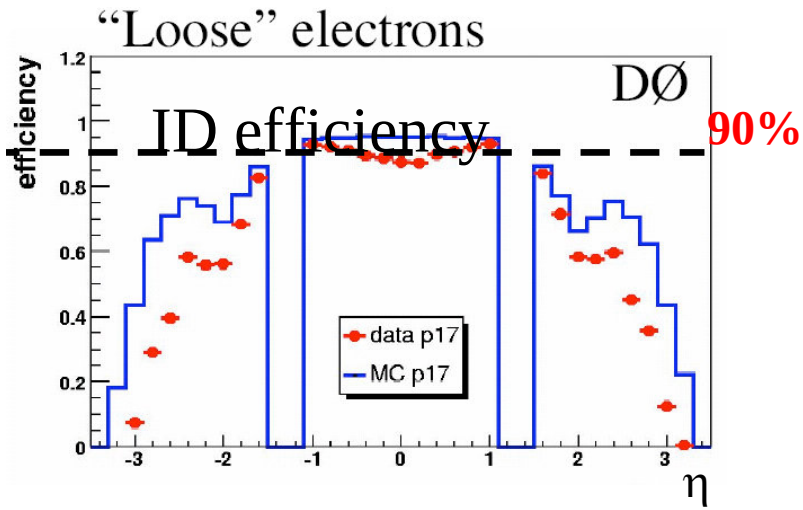
- Zee events from high pt e triggered dataset (Et > 18 GeV)
- ID cuts at CDF
  - ✓ Iso ≤ 0.1
  - ✓ E_{HAD}/E_{EM} : <0.055+(0.00045×E)
  - ✓ Lshr ≤ 0.2
  - ✓ E/P: ≤ 2 (pT<50 GeV)
  - ✓ Track matching (ΔX*q, ΔZ)
- Background subtractions
  - ✓ Veto converted electrons
  - ✓ Remove combinatorial backgrounds
    - ➢ Same sign method for the central e
    - ➢ Side band method in forward region (due to large charge fake rate)



High PT Electron ID Efficiency (II)

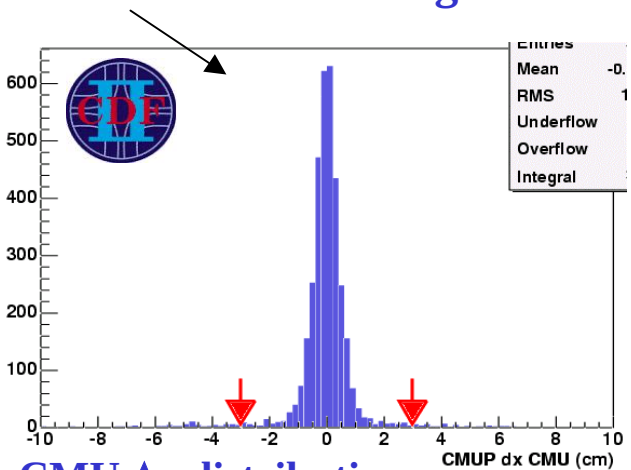
- **Likelihood method at D0**
  - ✓ Pre-selection: Iso < 0.15
- **Parameters in likelihood function**
  - ✓ H-Matrix: (longitudinal & lateral shape)
    - ✓ χ^2 based on 8 parameters
  - ✓ f_{EM}
  - ✓ EM-track matching χ^2 (3D)
  - ✓ ET/pT
  - ✓ Impact parameter
  - ✓ Distance in R to 2nd closest track to cluster
- **Other advanced technique:**
  - Neural Network: fairly confident of control samples



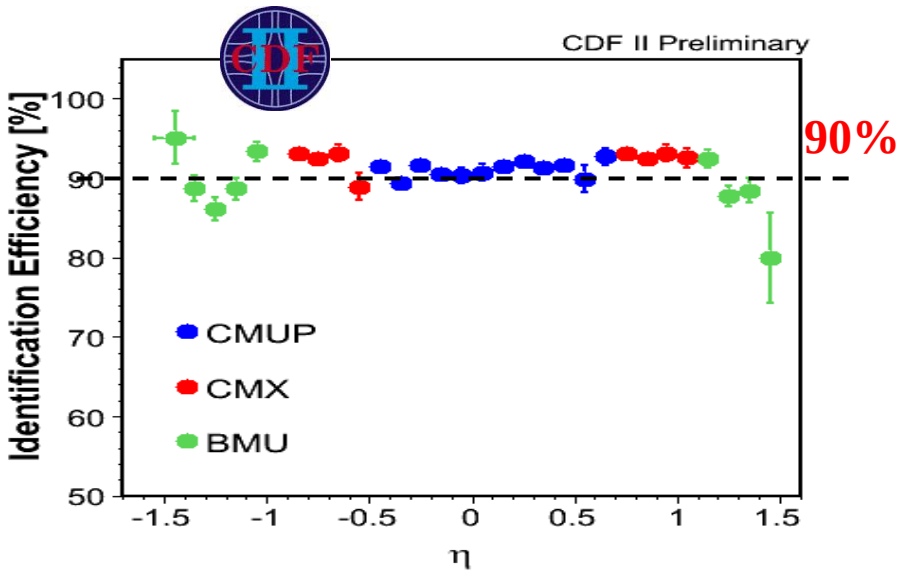


High PT Muon ID

- Zμμ events from high pT μ triggered sample
  - ✓ Very pure sample
  - ✓ No bgd subtraction needed
- ID cuts
  - ✓ Iso < 0.1 (better to be pT dependent)
  - ✓ E_{EM} < 2+max(0,(p-100)*0.0115)
  - ✓ E_{HAD} < 6+max(0,(p-100)*0.0280)
  - ✓ Δx from track matching

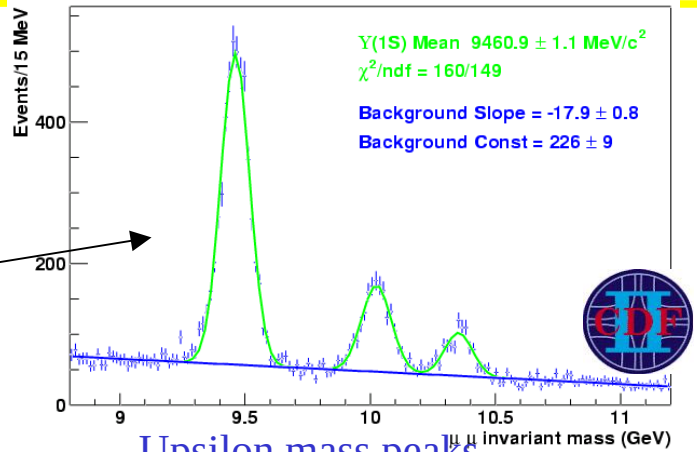


CMU Δx distribution

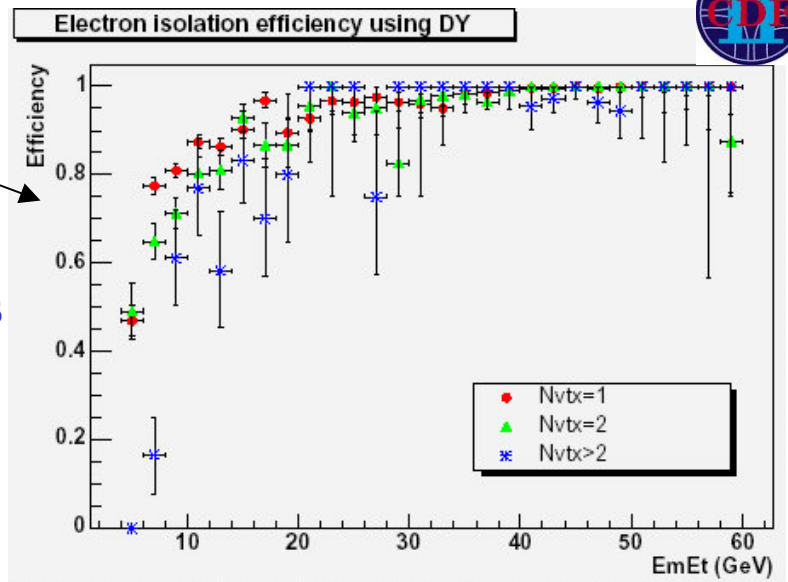


Low and Medium E_T Electron/muon ID

- Similar cuts with a few changes
  - ✓ E.g. for muon: Had_E < 3.5+pT/8
- ID efficiency
  - ✓ Inclusive e/mu data (> 8 GeV)
  - ✓ Reconstruct J/ψ, Upsilon
  - ✓ Non-triggered leg as probe
- Isolation efficiency of electron
  - ✓ Di-electron triggered data
  - ✓ Select DY events, cut on
    - ✓ Δϕ: separated di-electrons/di-mu
    - ✓ M_{ee} : always from resonance peak
  - ✓ One probe leg, the tag leg passes all ID cuts

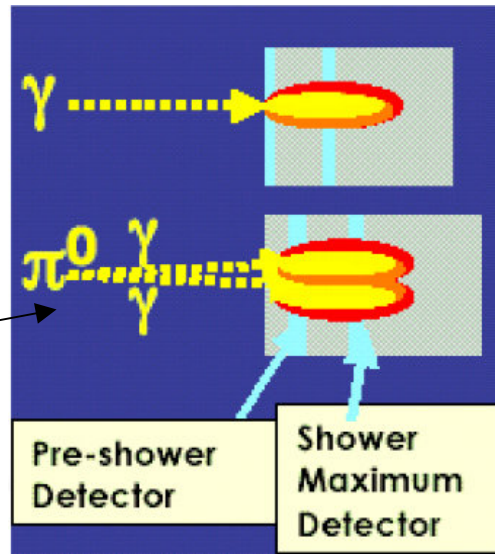


Upsilon mass peaks



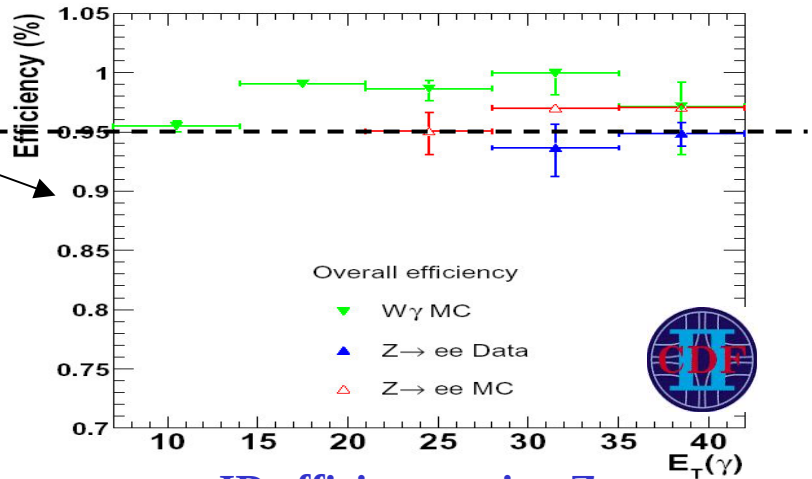
Photon ID

- **ID Efficiency**
  - ✓ **Strategy: use e to simulate photon**
    - **Same E_{HAD}/E_{EM} cut, etc**
  - ✓ **# tracks in cone: N3D ≤ 1 (pT<1+0.005*Et)**
  - ✓ **Track iso cone: ΣpT(trks) < 2+0.005*Et**
  - ✓ **Cut on 2nd CES cluster energy**
  - ✓ **Samples for the study**
    - ✓ **conversion : medium pT**
    - ✓ **Zee : high pT**



- **Isolation efficiency**
  - ✓ **Need special treatment**
  - ✓ **Discussed in next slide…**

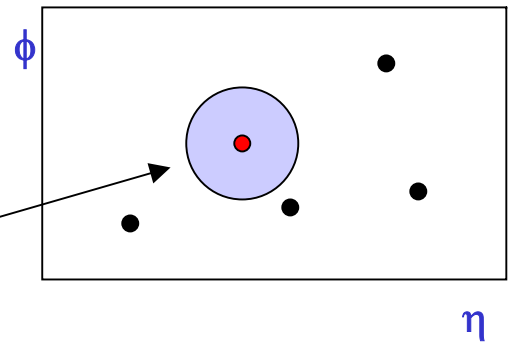
95%



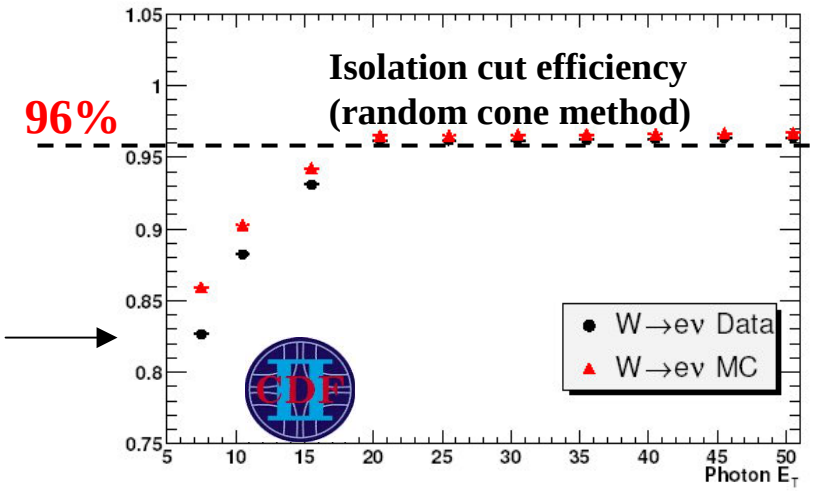
γ-ID efficiency using Zee events.

Photon Isolation Efficiency

- **Difficult to get pure photon sample**
  - ✓Resonance sample π^0, η -> $\gamma\gamma$ are not good:
    - either too soft or two γs very close to each other
  - ✓Sample selection needs iso pre-requirement on γ



- **One approach used at CDF:**
  - ✓"Random Cone Method"
  - ✓Throw random cone in η-ϕ space in an event
  - ✓ assume a virtual γ in the cone
  - ✓ randomly assign Et to the virtual photon
  - ✓ Apply isolation cut to the cone
    - $Et(\Delta R=0.4)/Et(\gamma) < 0.1$
  - ✓ Measured in Weν, minbias, jet20 sample

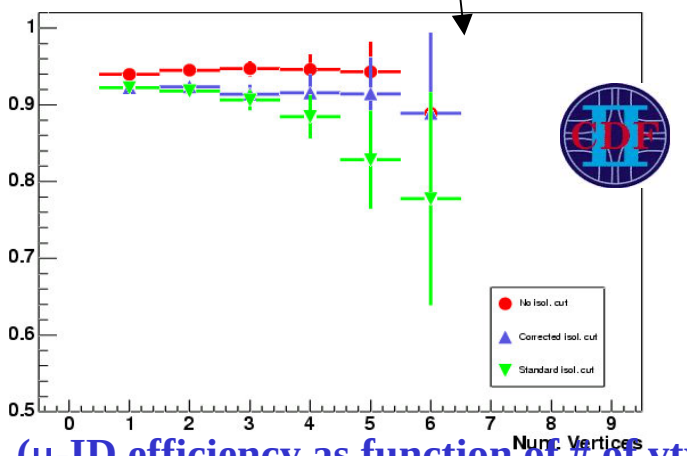


Luminosity Dependence

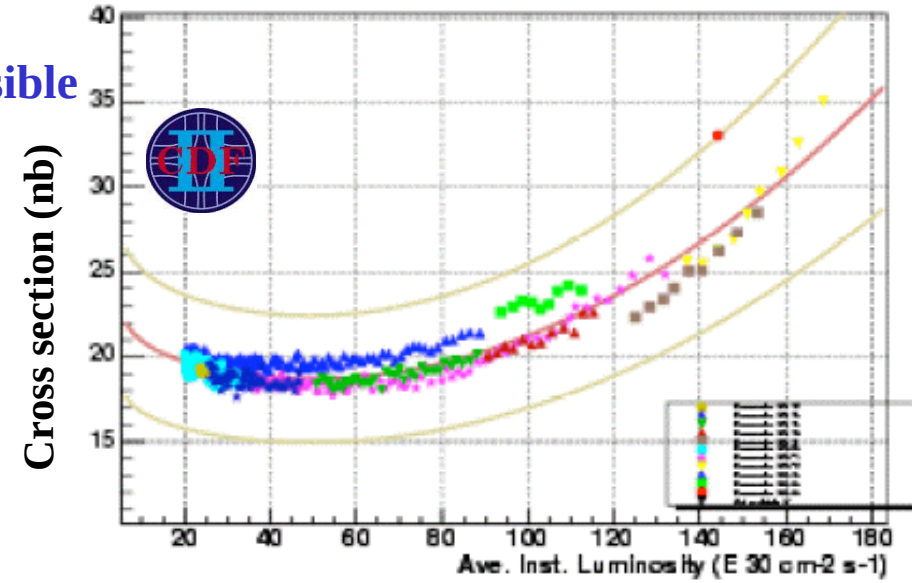
- As Tevatron increases the instantaneous luminosity
  - ✓ More vertices in each event, affect ID ε
    e.g. worse isolation efficiency
  - ✓ Have to deal with the increased trigger rate too
- Some work in the list
  - ✓ CDF is studying the corrected isolation cut

$$(E_T^{isol.} - 0.35 \cdot (N_{vtx} - 1))/P_T < 0.1$$

  - ✓ Save the backup triggers as much as possible



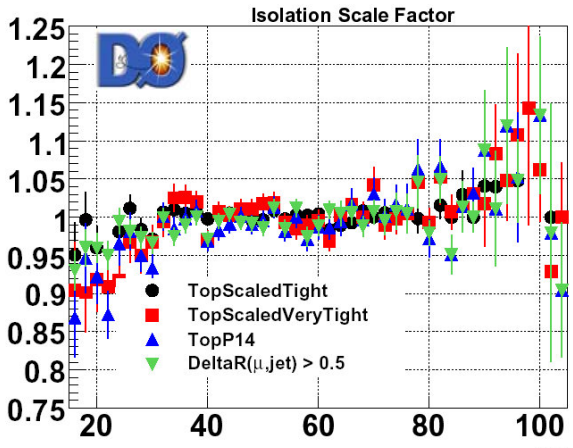
(μ-ID efficiency as function of # of vtx blue points is after the correction.)



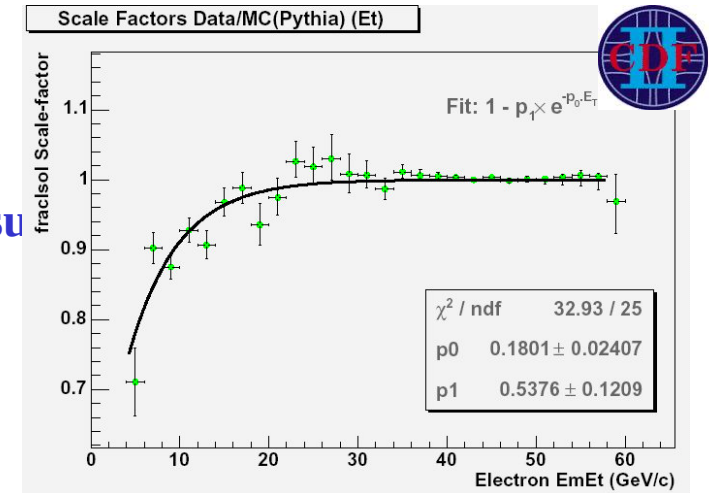
L2_jet40 trigger rate vs instantaneous luminosity

Scale Factors

- Scale factor: $S = \varepsilon_{DATA}/\varepsilon_{MC}$
  - ✓Take into account of the difference between MC and DATA
- Apply to MC predicted number
  - ✓ Acceptance
  - ✓ # of background events
- If there is dependence (e.g. Et)
  - ✓ provide fit function and convolute
- Minimize the error of scale factor
  - ✓ error on the scale factor enters final analysis resu
  - ✓ e.g. 6-8% in ttbar cross-section



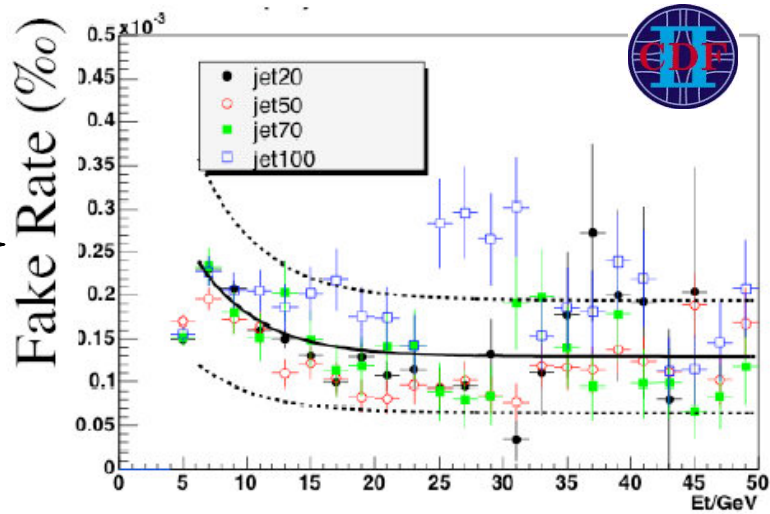
(Muon isolation scale factor)



(the dependence of scale factor on Et)

Fake Electron/Muon

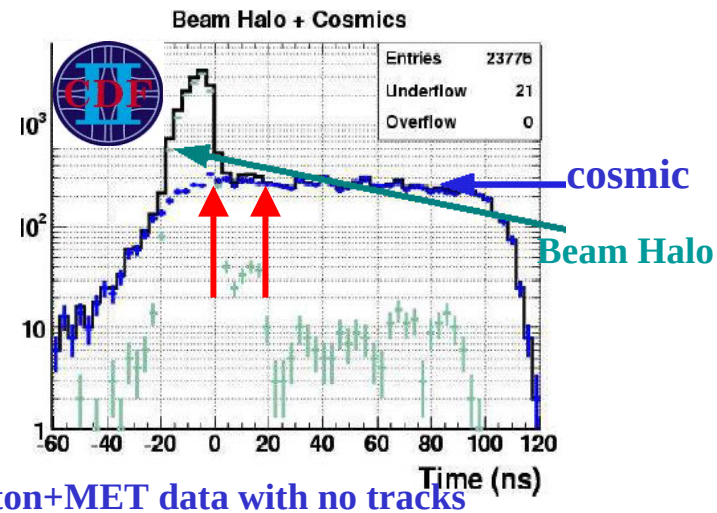
- **Fake is the main source of background for analyses using low Et leptons**
  - ✓**Fake lepton/γ mainly from jets containing π/η/κ**
  - ✓**Other sources: conversion, CalEM penetration, DIF, etc**
- **Fake rates**
  - ✓ **Measured in jet samples (j20, j50, etc)**
  - ✓ **Electron**
    - **~1(5) in 10,000 tight(loose) jets**
  - ✓ **Muon**
    - **~ 2 - 6 per 1000 tracks, depending on p_T**



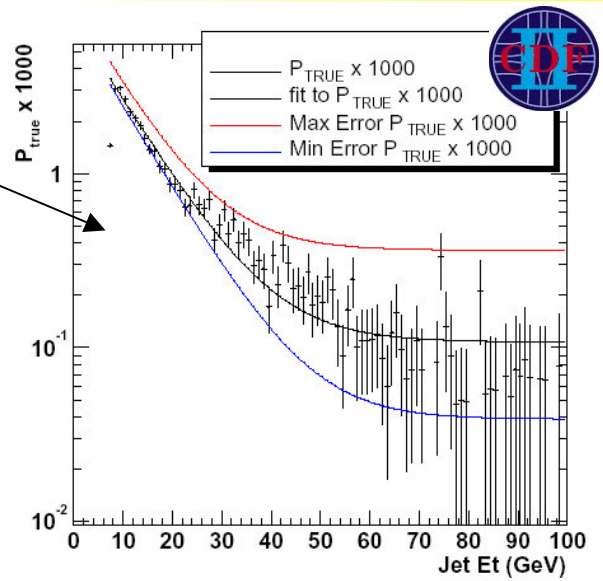
- **Low fake rate leads to precision measurement**
  - ✓ **Fake leptons cause major systematic error in WW cross-section**
    - ✓ **contribute 70% of the error to the acceptance value**

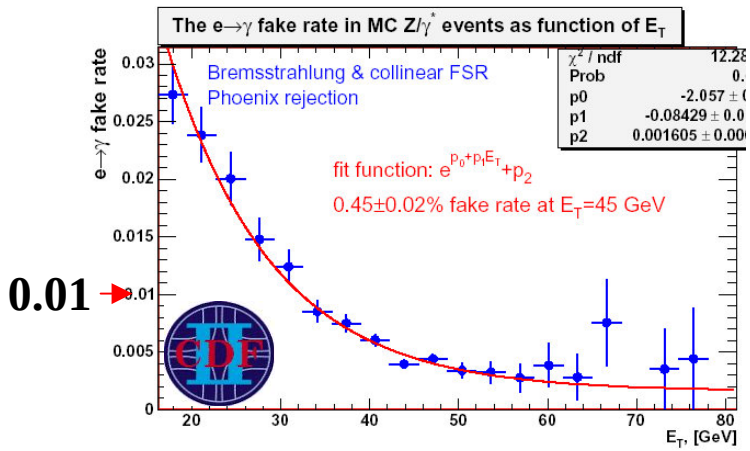
Fake Photon

- **Fake sources**
  - ✓ Jet fakes photon (1 – 10 per 10,000 jet)
  - ✓ Electron fakes photon
    (Fake rate largely depends on Et)
  - ✓ Cosmic rays
  - ✓ Beam halo dominates fakes in FWD region
- **Reject cosmic and beam halo**
  - ✓ Use EM timing system
    Real photon has timing variable from 0-20 ns



Photon+MET data with no tracks

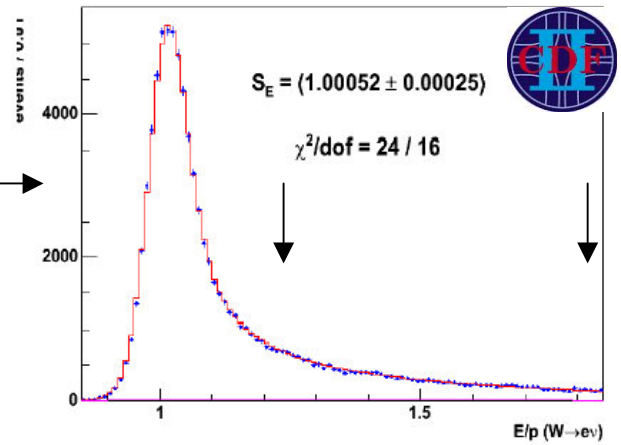




0.01

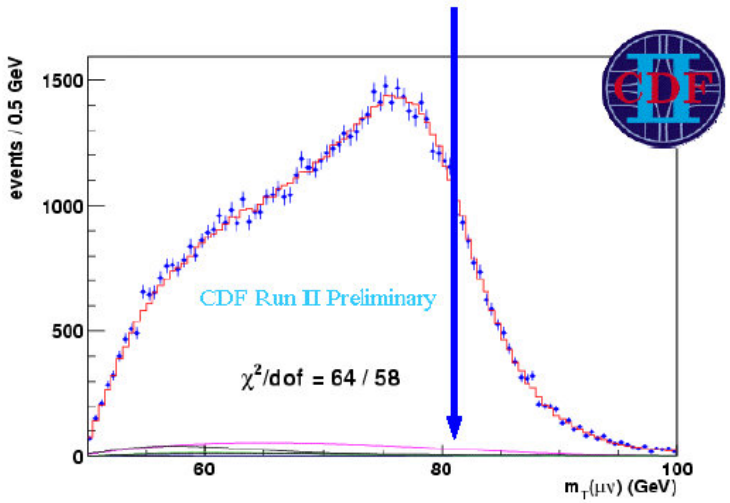
Calibration

- **Momentum scale**
  - ✓ Understand materials in tracking volume
  - ✓ Utilize radiative tail of E/P from electrons



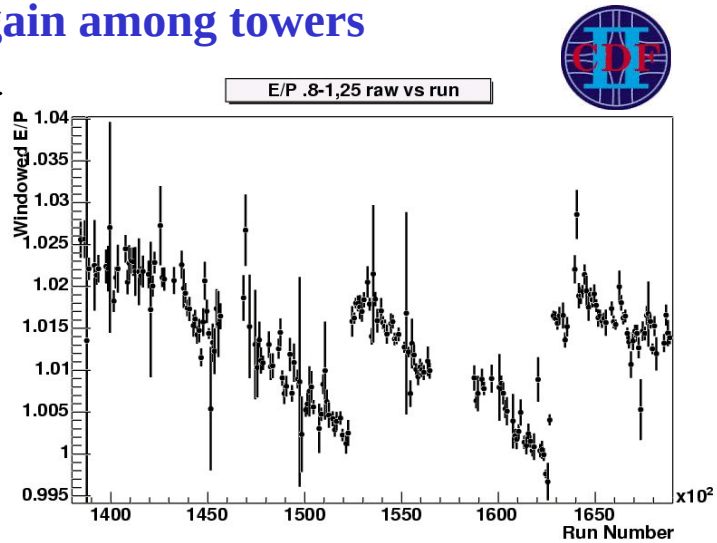
- **Energy Calibration**
  - ✓ Absolute energy scale from W → eν events
  - ✓ Energy resolution (Use Z peak)

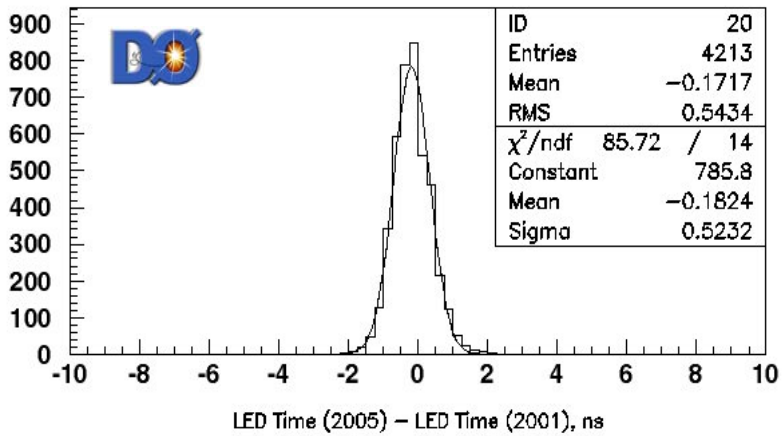
- **Most important for the W mass measurement**



Calibration monitoring

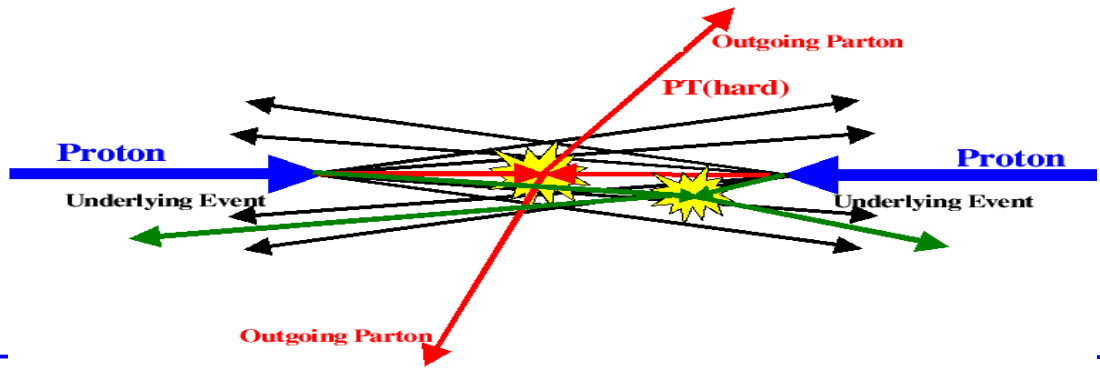
- **Calorimeter system**
  - ✓ Gain of PMT can change: causing non-uniform gain among towers
  - ✓ Fine tuning CEM tower using E/P peak
- **Muon system**
  - ✓ Timing shift in the scintillator detector
  - ✓ Gain change in the drift chamber
- **Monitoring continues over the duration of RunII**





Summary

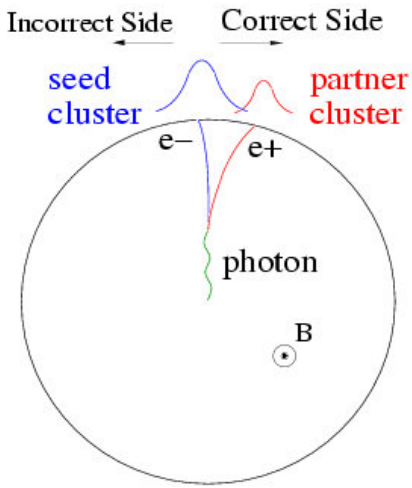
- **Lepton ID is very important in collider physics**
  - ✓ The identification method is well established at Tevatron experiments
  - ✓ Important to understand detector material
  - ✓ Deal with the effects from extra minbias events
  - ✓ Improvements in working progress (likelihood, Neural Net)
- **ID efficiency**
  - ✓ **80% - 90%** (lower in the forward region)
- **Fake rate:**
  - ✓ **1 in 1,000 –10,000** (depending on E_T/P_T)
- **Valuable experience for the coming LHC experiments.**



Backup slides

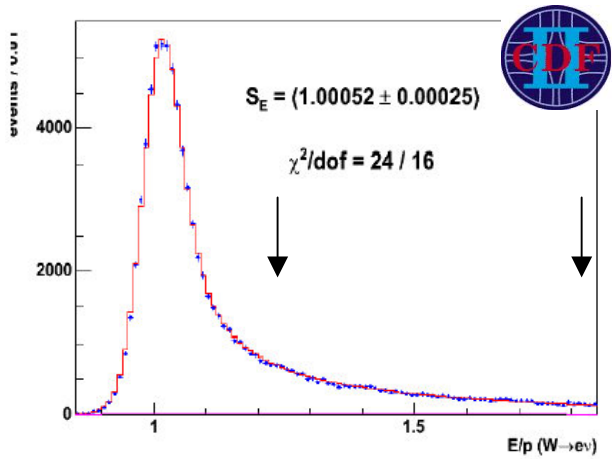
Fake Electron

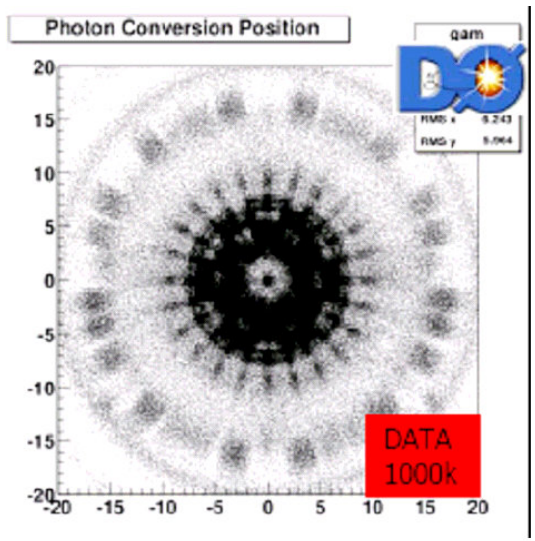
- **Fake definition**
  - denominator: # of jets
  - numerator: pass electron ID cuts
  - measured in jet samples (j20, j50, j70, j100)
- **Identify conversion and removal**
  - ✓ CES cluster at "correct side", 2 phi wedge away
  - ✓ close distance between the two tracks in transverse plane
    - ✓ Dxy < 0.1/0.2 (tight/loose)
  - ✓ close distance in z of the two cluster
    - ✓ $\Delta\cot(\theta) < 0.02/0.04$
  - ✓ removal efficiency: ~70% - 85% depending on cuts

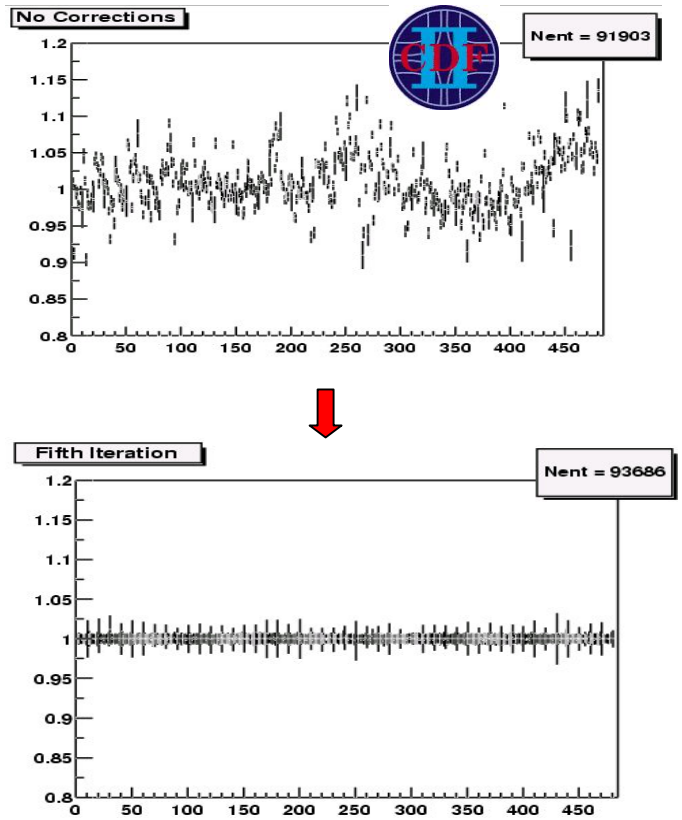


More on Momentum scale

- **Momentum scale**
  - ✓ Understand materials in tracking volume
  - ✓ Utilize radiative tail of E/P from electrons
  - ✓ Gives average material distribtion
  - ✓ Use muon track to estimate type of material
  - ✓ X-ray detector w/ gamma conversion





More on Energy Calibration

- **Obtain uniform gain among towers**
  - ✓ 8 GeV inclusive electron data
  - ✓ mean of windowed E/P (0.8-1.25)
  - ✓ Set online correction factor tower by tower
  - ✓ Offline correction factor similarly (much less fluctuation)
- **W → eν events**
  - ✓ Absolute energy scale
- **Finally calibrated with Zee peak**
  - ✓ Energy resolution (width)
  - ✓ cross-check of energy scale (mass)