High-p_T Isolated Electrons & Photons at the Tevatron Collider Experiments

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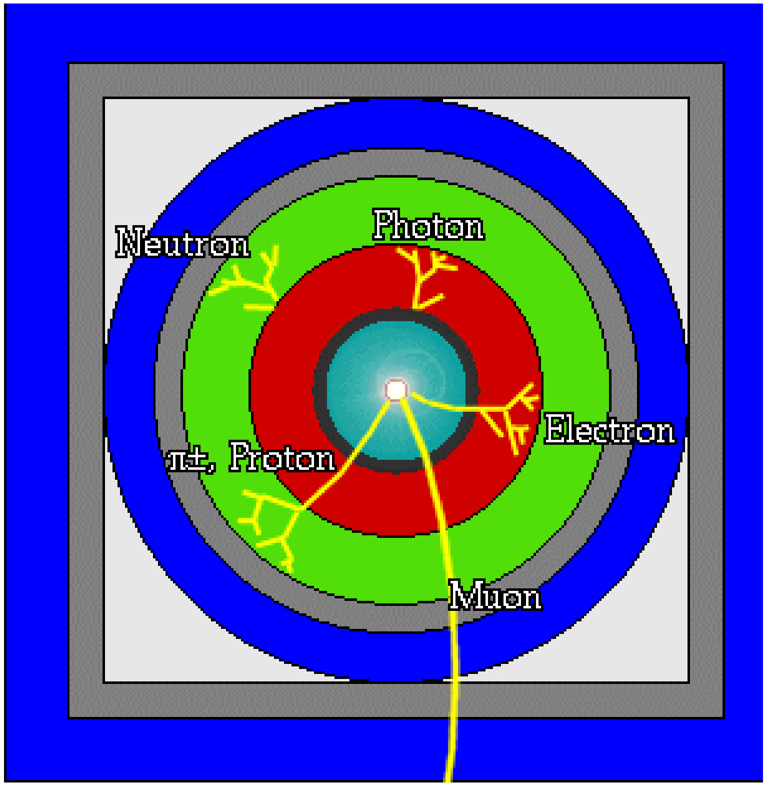
Outline

1. CDF & D0 Detectors
2. Electron & Photon ID
3. Calibrating the Detector
4. Analysis Tools

Detecting electrons and photons

- Electrons lose energy through bremsstrahlung and photons through e^+e^- pair production
  - ➔ **Energy loss proportional to atomic number of absorber**
    - Use high Z material as EM absorber (lead, uranium, etc.)
  - ➔ **Have single (e) or no track (γ)**
- Easy to separate from jets
  - ➔ **Important for triggering**
- Used in most analyses at hadron colliders
  - ➔ **EWK, top, New Physics, some b**



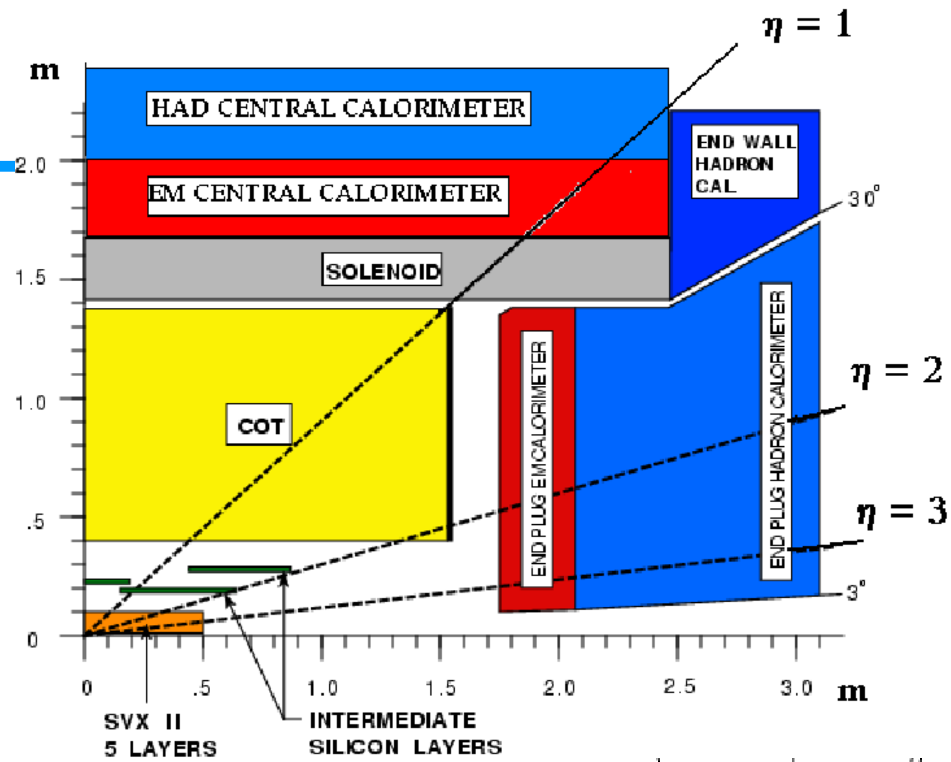
CDF detector

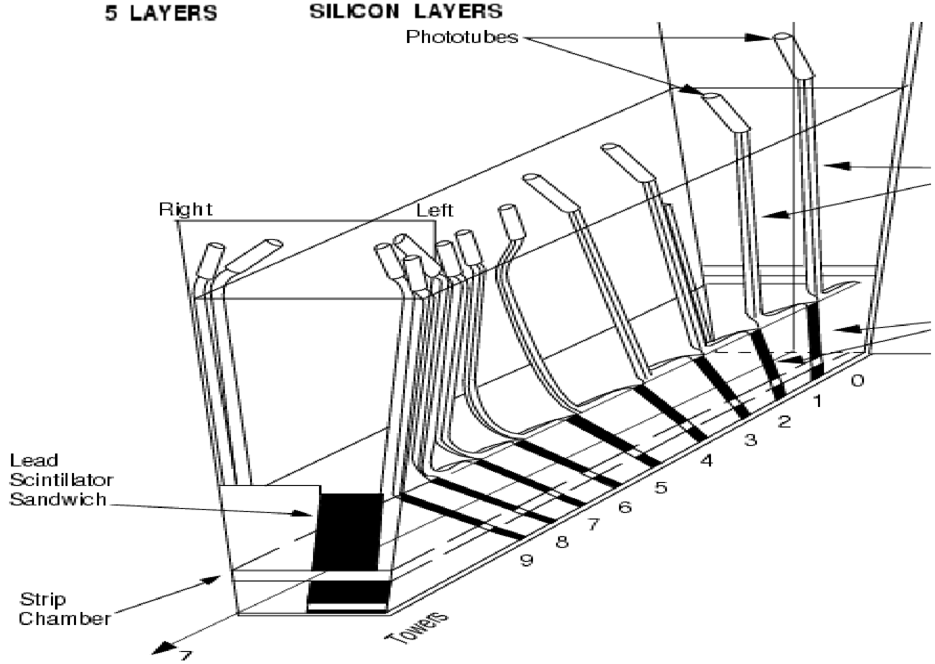
- Tracking specs

B Field	1.4 T
Outer radius	~1.3m
N measurements	96 + 7-8 Si

- EM Calorimeter specs

Technology	Scintillator / Pb
$\eta-\phi$ segmentation	0.1 x 0.25
Lateral Segmentation	2: EM & HAD
Depth	~20 X_0
Preshower	Scintillating Pads
Shower Max	Strips & Wires (pitch 1.5 – 2cm)





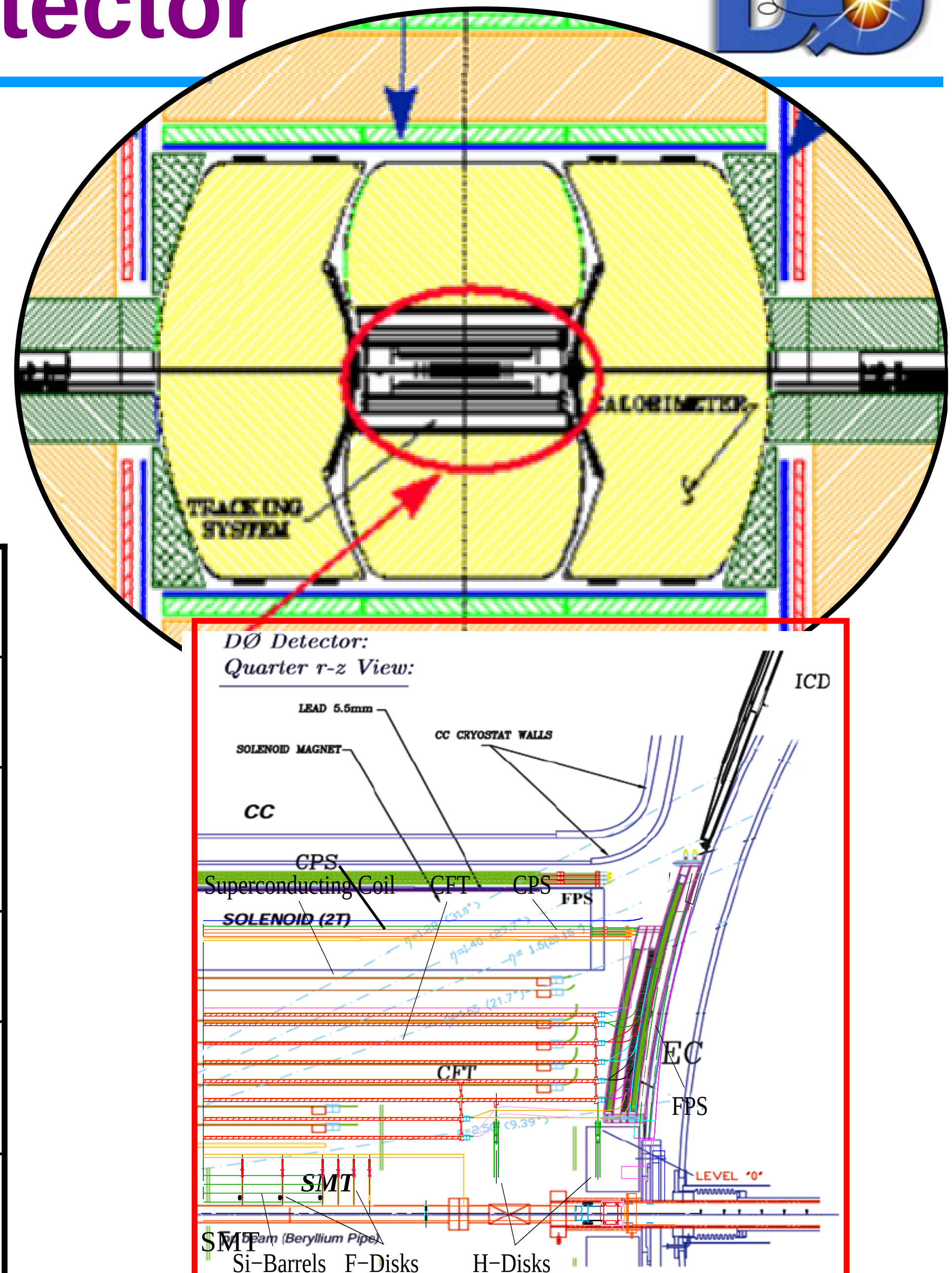
DØ Detector

- Tracking specs

B Field	2.0T
Outer radius	~0.5m
N measurements	16 + 3-4 Si

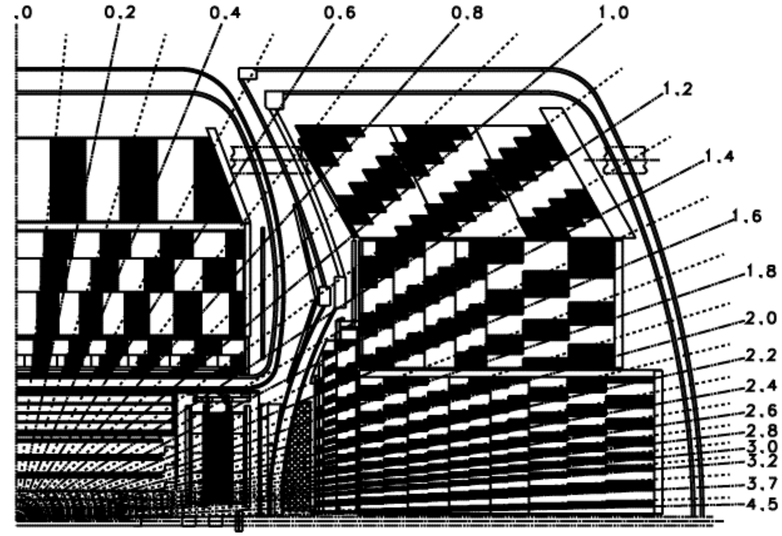
- EM Calorimeter specs

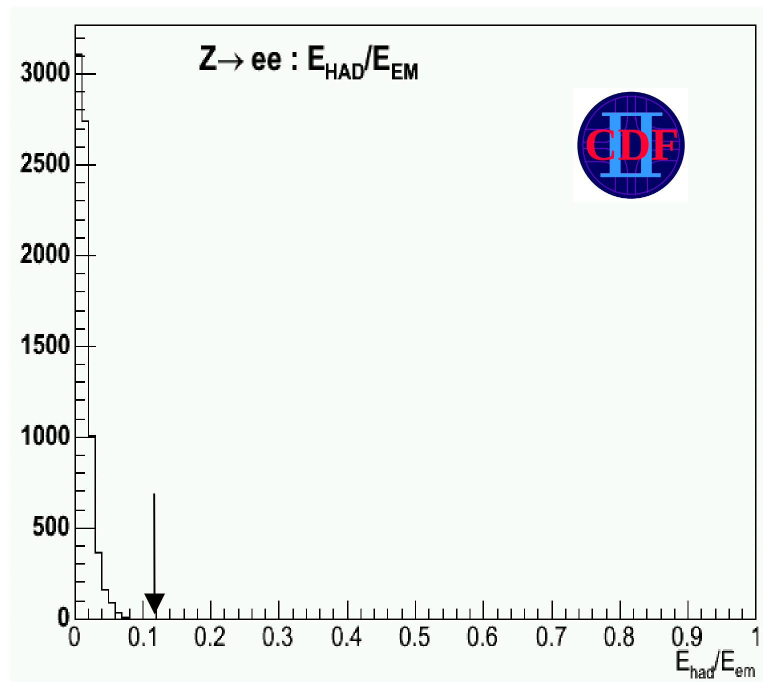
Technology	LAr / Ur
$\eta-\phi$ segmentation	0.1 x 0.1
Lateral Segmentation	9/8 layers (first 4:EM)
Depth	~20 X_0
Preshower	Scintillating Strips
Shower Max	3rd Layer (0.05 x 0.05)



ID: Electromagnetic Clusters

- Calorimeter towers projective nominal collision point
- Cal. Towers clustered into
  - ➔ $\Delta\eta - \Delta\phi \sim$ **0.2x0.2**
- e/γ shower contained in EM calorimeter
  - ➔ $$\frac{EM}{EM + HAD} > 0.9$$
- Associate tracks and SMX clusters



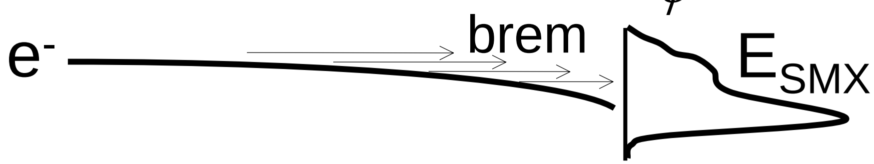


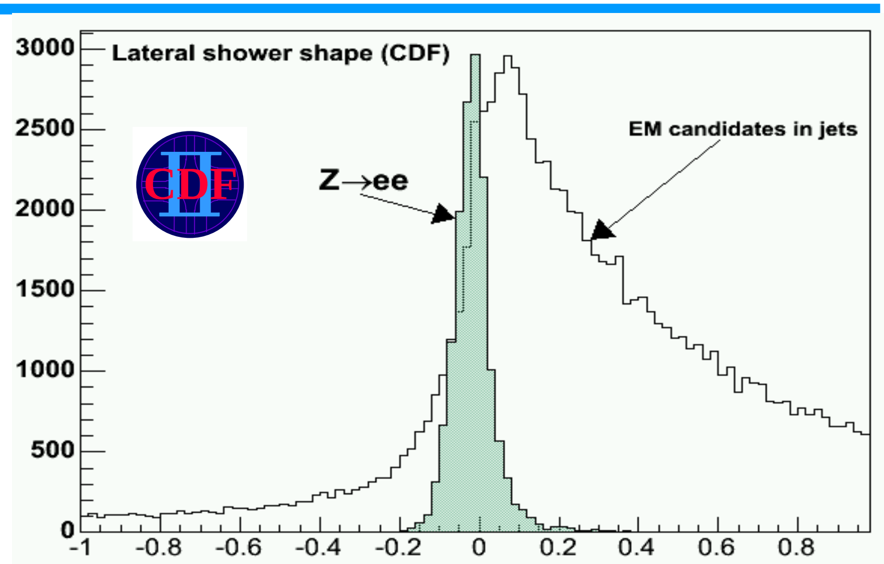
ID: Shower Profile

- CDF: Calorimeter and SMX
  - ➔ **Profile in adjacent cal. towers in z**

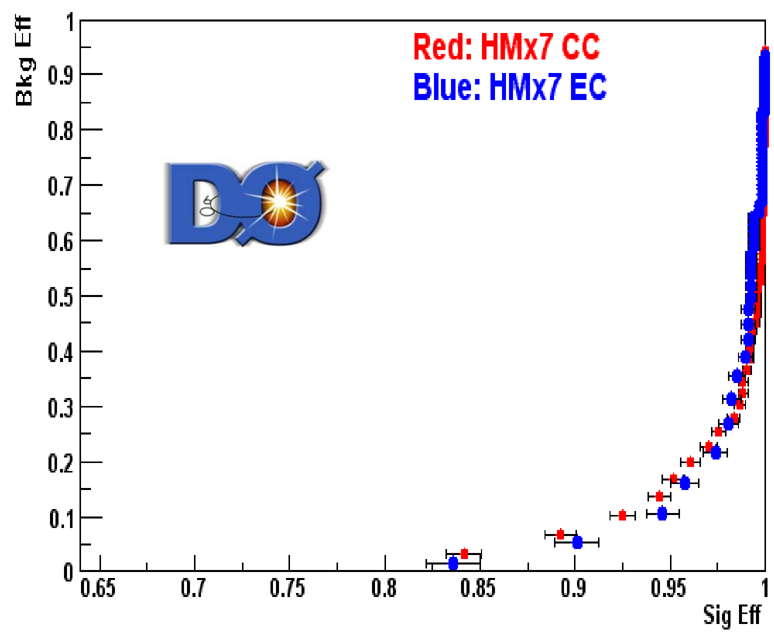
$$Lshr = 0.14 \cdot \sum \frac{E_i - E_{pred}}{\sigma_{E_i}}$$

  - ➔ **χ^2-type variables using SMX**
    - ➢ Not used for e, especially in $\hat{\phi}$



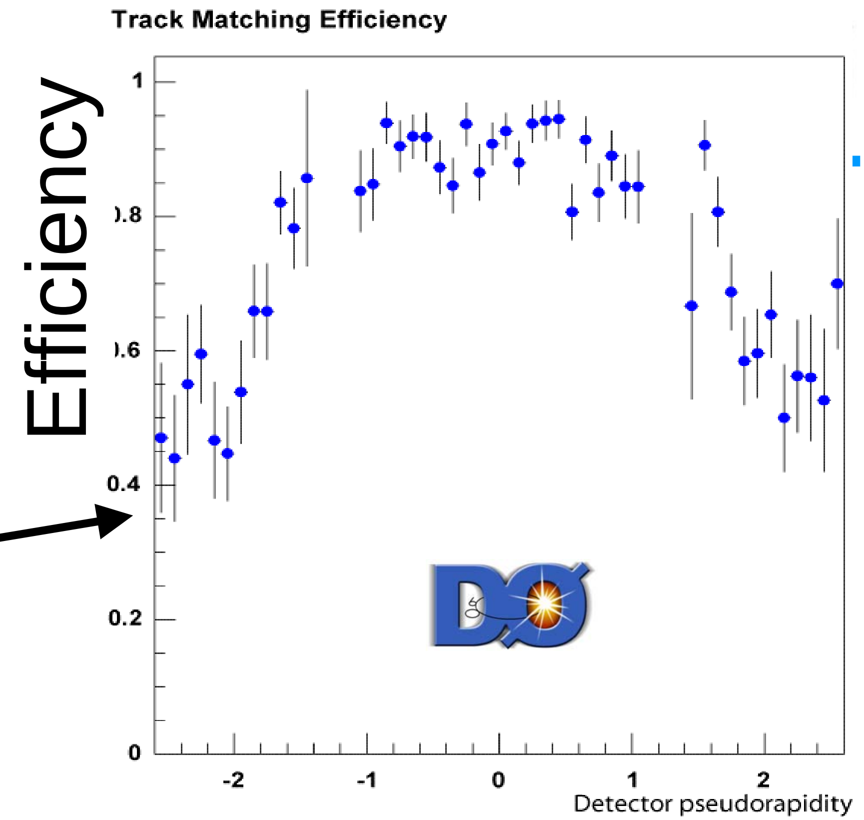


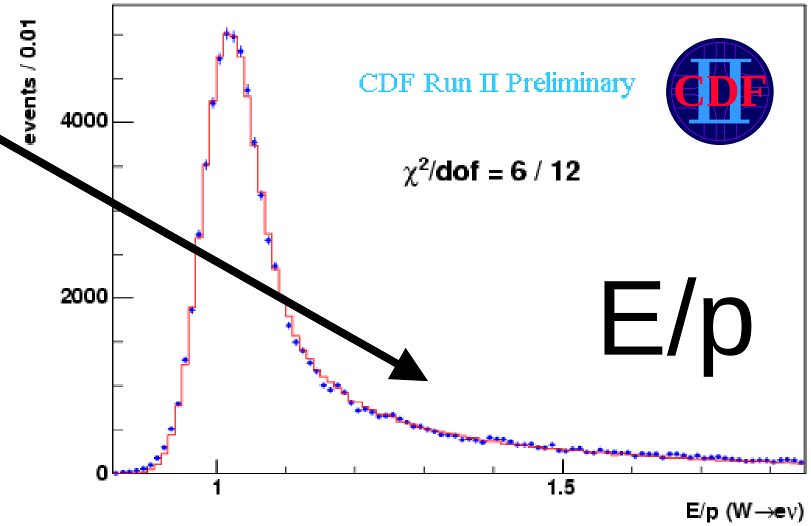
- D∅: "H-matrix" – measurement in 5 layers calculate χ^2 of shower using 7 or 8 variables
  - ➔ **Layer energy fractions**
  - ➔ **Lateral shower widths**
- **D∅ and CDF use different denominator for Background rejection
  - ➔ **CDF's rate is per generic jets**
  - ➔ **D∅'s rate is per loose EM cluster**



ID: Tracking

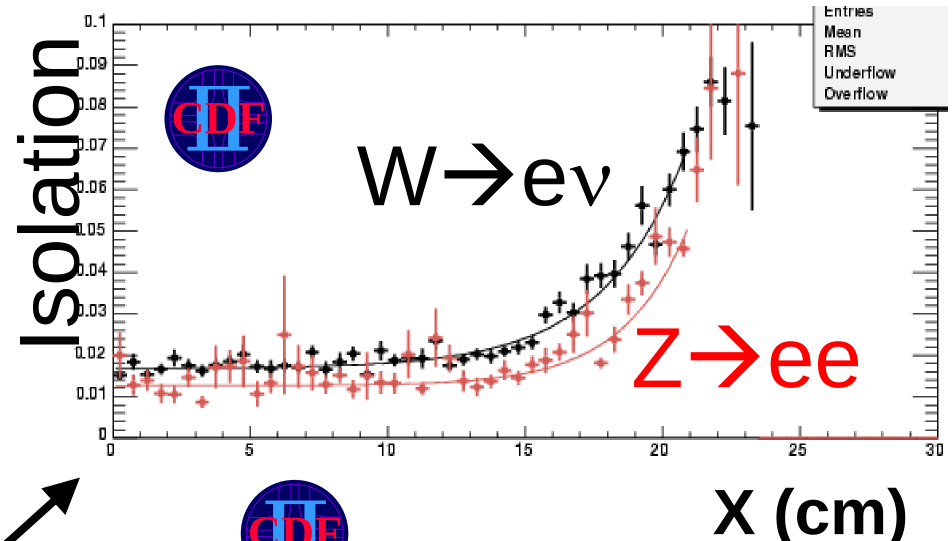
- Tracking important part of electron/photon ID
- Requiring or vetoing a high p_T track reduces background by x10
- Tracking more difficult in forward regions
- Very sensitive to the amount of material
  - ➔ **Radiation reduces track p_T**
  - ➔ **Converted photons are lost**
  - ➔ **Uncertainty in acceptance dominated early W/Z cross section mesurements**
    - 5.5% X_0 uncertainty in material gave a 4.7% uncertainty in the acceptance for Z→ee

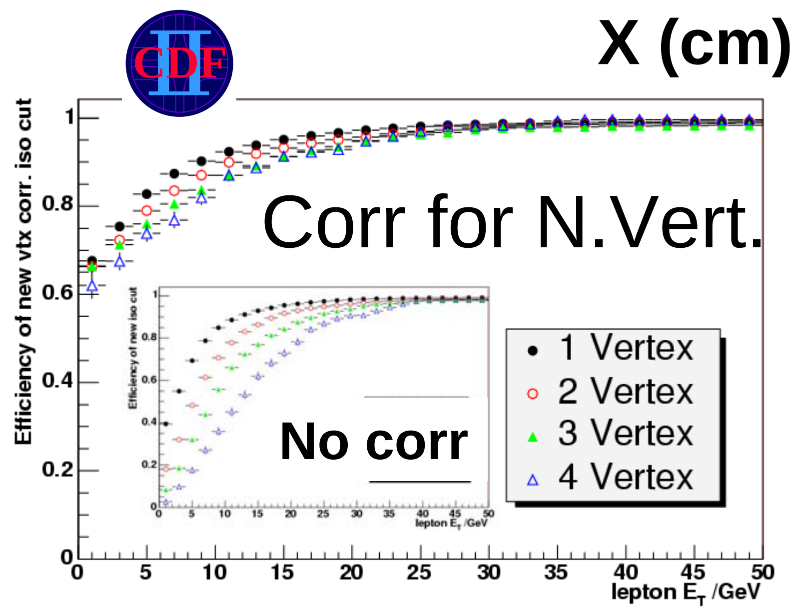




ID: Isolation

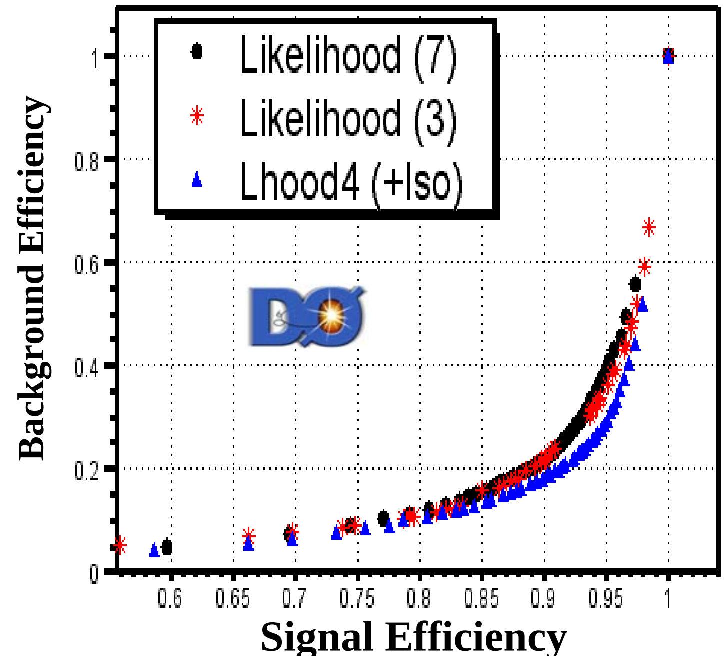
- Isolation is really an event topology cut
- Very good at rejecting jets faking electrons
- Both D∅ and CDF make similar cuts
  - ➔ **CDF: Iso(R<0.4)/E_T(e/γ)**
  - ➔ **D∅: Iso(R=0.2-0.4)/E_T(R<0.4)**
- CDF sensitive to energy leakage and brems that fall outside of cluster
- Both experiments sensitive to extra interactions

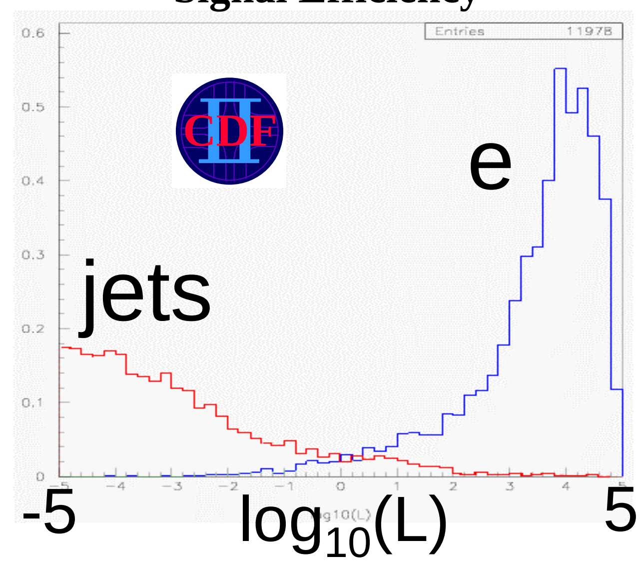




Advanced Techniques

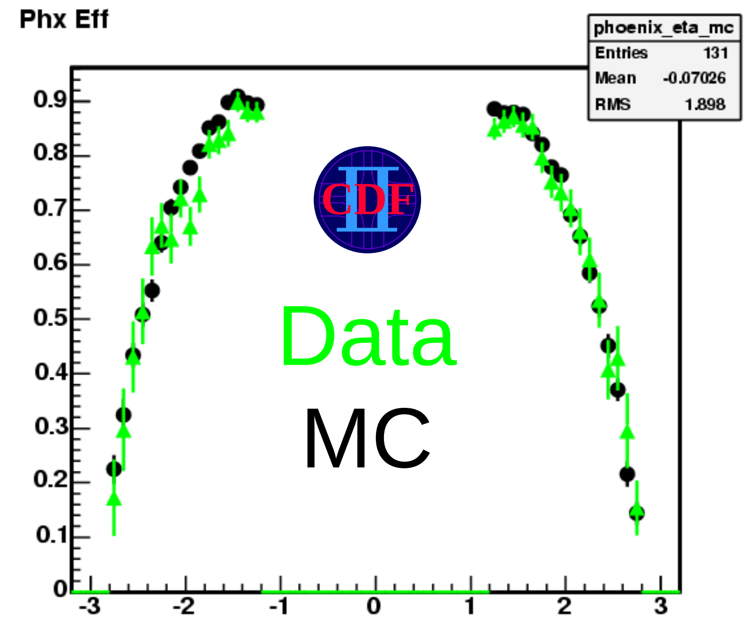
- Likelihoods and NN
  - ➔ **Can improve both efficiency and rejection**
- Many DØ analyses use likelihood
  - ➔ **Combines EMF, Iso, H-Matrix, Track Iso…**
- Only a few high-p_T CDF analyses use a Likelihood for e/γ ID
  - ➔ **Improves Eff. ~5% and reduces Bkg. ~40%!**
  - ➔ **Studies with NN show x2 improvement in bkgd reduction!**
- Must be fairly confident of control samples
  - ➔ **Need stability and understand correlations**

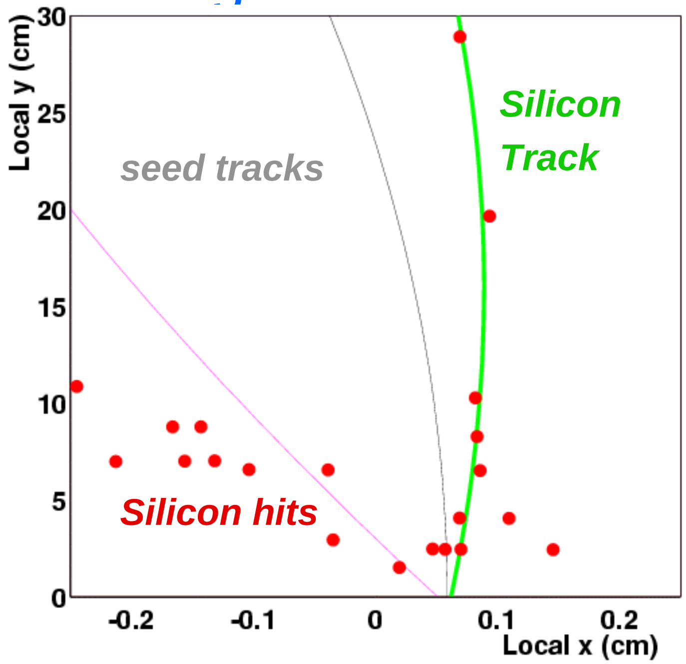


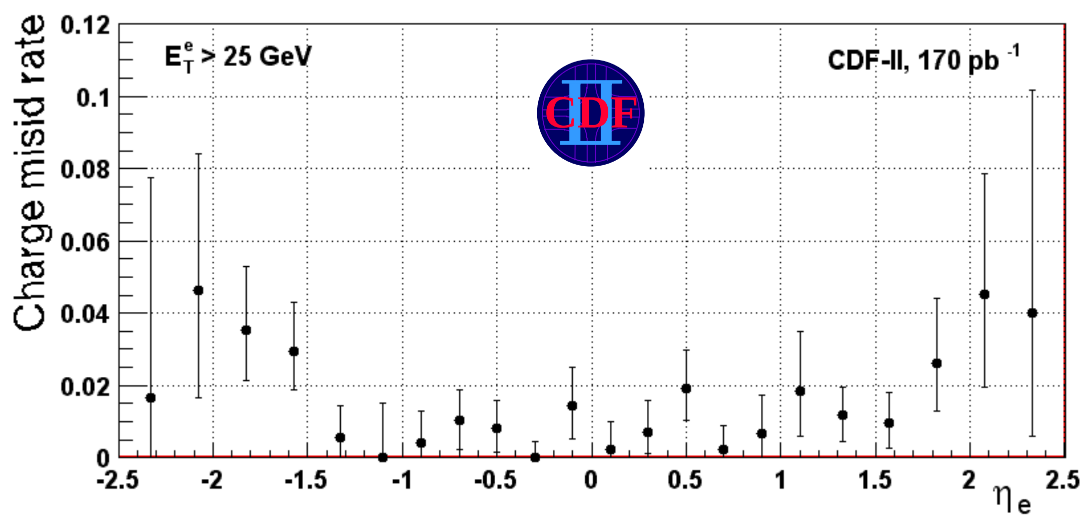


Calorimeter-seeded tracking

- Define two seed tracks
  - ➔ SMX shower (σ~1mm)
  - ➔ Event vertex (σ~0.1mm)
  - ➔ EM energy for curvature
  - ➔ Si hits that give good fit
- D∅ : reject photon backgrounds

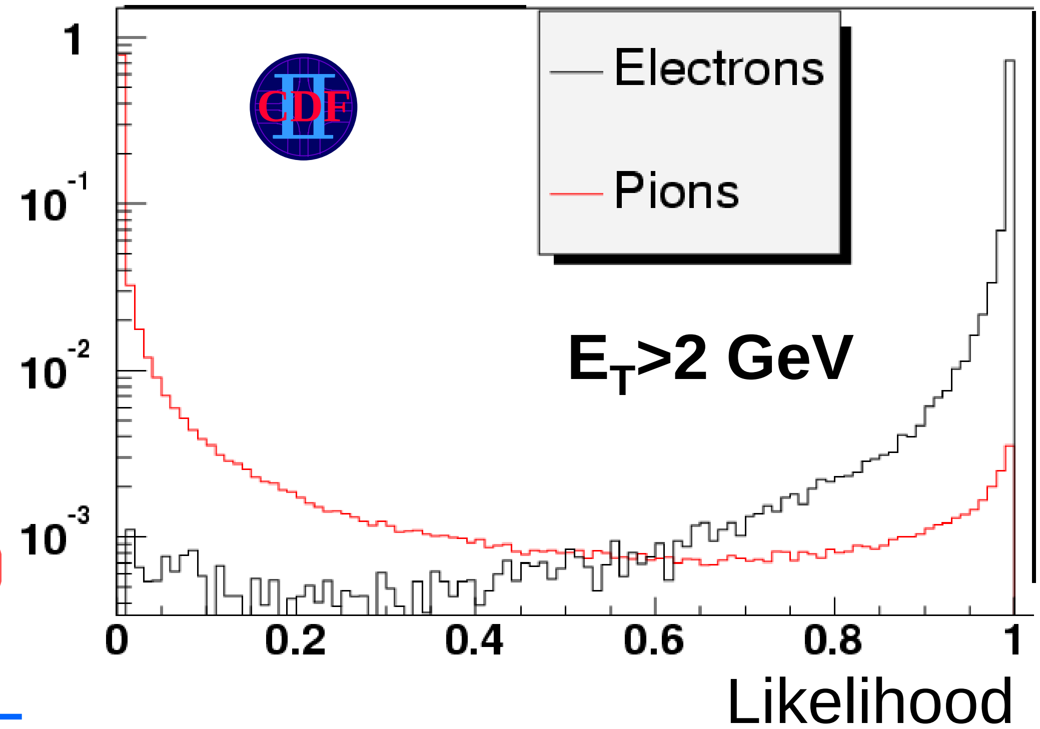






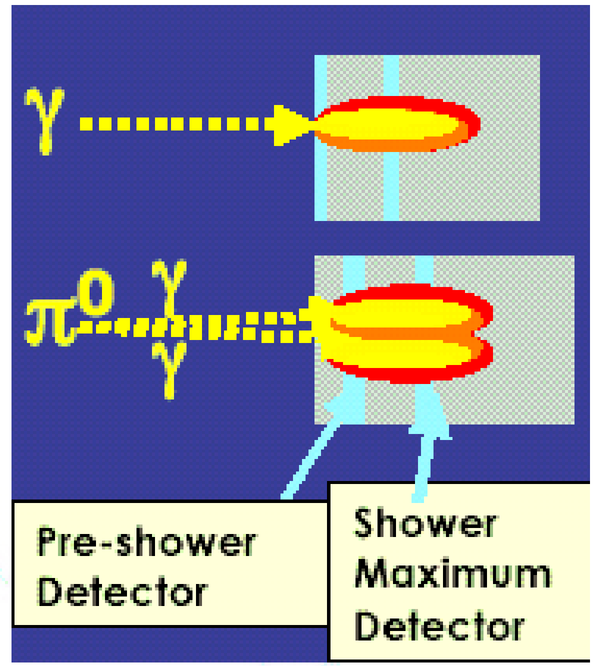
Looking for e in b-jets

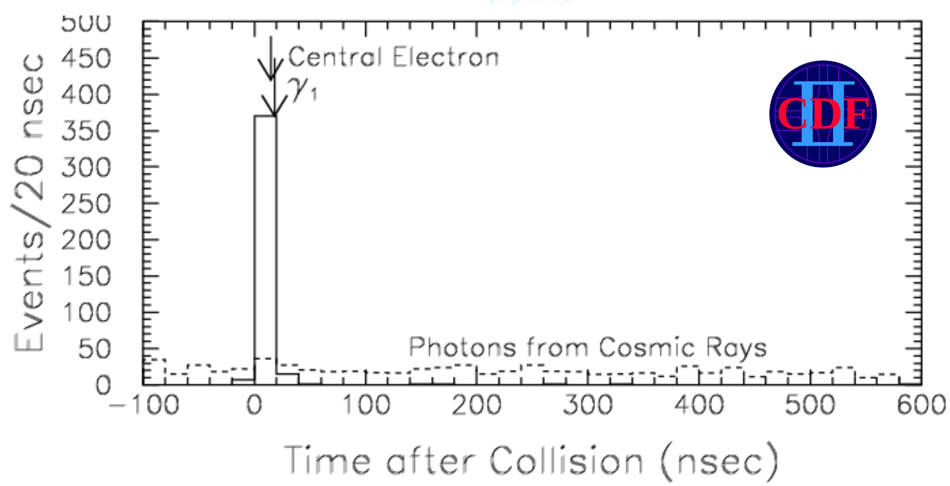
- More local variables
- Cal: 2 tower clusters
  - ➔ **Seeded by track**
  - ➔ **E/P and Had/Em**
- SMX:
  - ➔ **χ^2 of shwr profile**
  - ➔ **$q*\Delta X/\sigma$ (track – SMX)**
  - ➔ **Wire pulse height**
- CPR: $\sin\theta$ corrected E
- COT:dE/dx
- Track isolation
- Variable PDF's make likelihood



Differences for photon ID

- Track veto
  - ➔ $\leq$1 track with p_T<1GeV
  - ➔ $\Sigma p_T(R=0.4)$<2 GeV
  - ➔ Both scale with energy
- Shower shape better than electrons
  - ➔ No brems
  - ➔ Use SMX χ^2
- No 2nd SMX cluster
  - ➔ Works well: E_T < 40 GeV
- Reject beam halo and cosmics
  - ➔ EM timing important for photon + $\not\!\!E_T$ final states





Trigger strategy: Signal

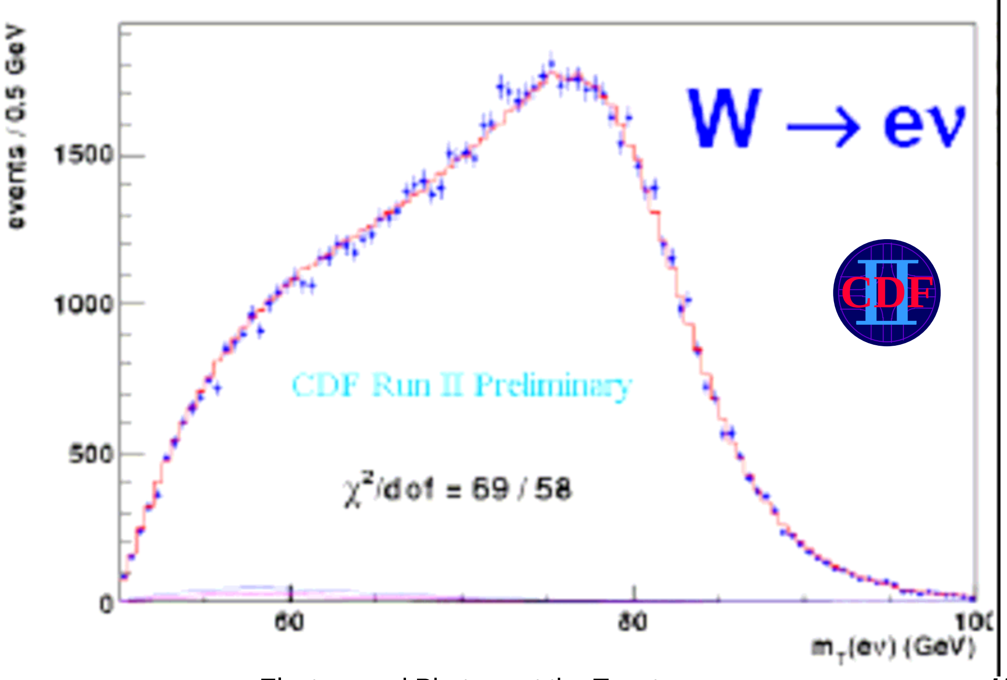
- Both experiments use a 3 level trigger
  - ➔ **L1 very basic objects, single tower and track thresholds, and combinations**
  - ➔ **L2 has calorimeter clusters, and some basic variables: EMF, Isolation, SMX**
  - ➔ **L3 close to full reconstruction**
- CDF:
  - ➔ **L1: EM tower with matching track**
  - ➔ **L2: higher E_T EM cluster with matching track**
    - ➢ Lower E_T use SMX
  - ➔ **L3: offline electron with very loose ID**
- D∅:
  - ➔ **L1: 1 or 2 EM towers**
    - ➢ has track capability
  - ➔ **L2: EM Cluster**
  - ➔ **L3: offline electron with very loose ID**

Trigger strategy: Backup

- Need to measure and monitor detector performance
- "W/Z-notrack":EM Cluster +
  - ➔ **Require $\not{E}_T$ or second EM Cluster**
  - ➔ **Check tracking**
- 8 GeV electrons
  - ➔ **Used for calibrating calorimeter**
- W/Z triggers with analysis kinematic cuts, but no ID cuts
  - ➔ **Check electron/photon ID**
- Many backup triggers with prescales to understand trigger cuts at each level

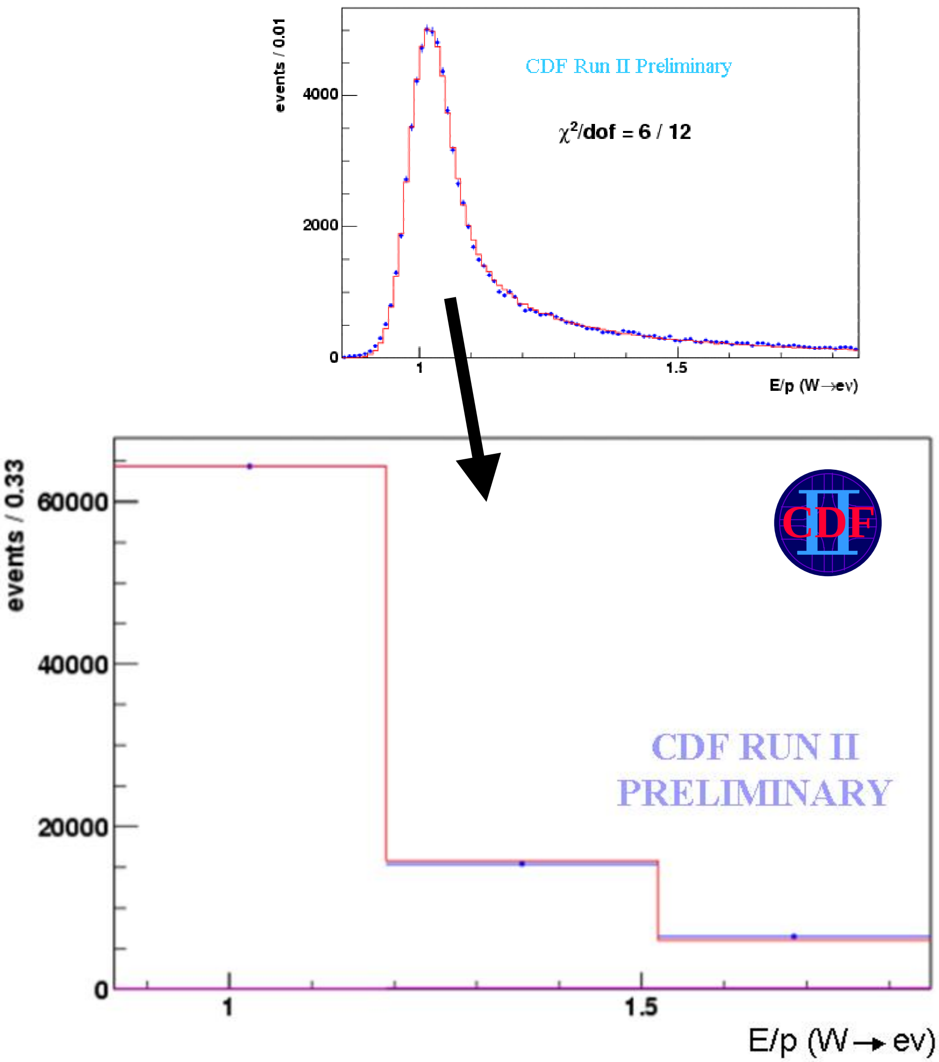
Calibrations

- Outline
  - ➔ Calorimeter energy
  - ➔ Material in tracking volume
- Most important for EWK precision measurements
  - ➔ e.g. : m_W → See Mark Lancaster's talk



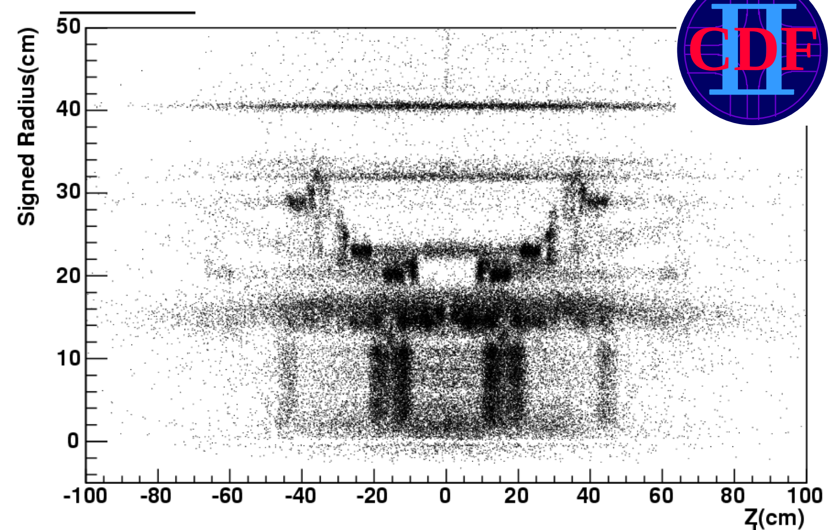
Material from E/P

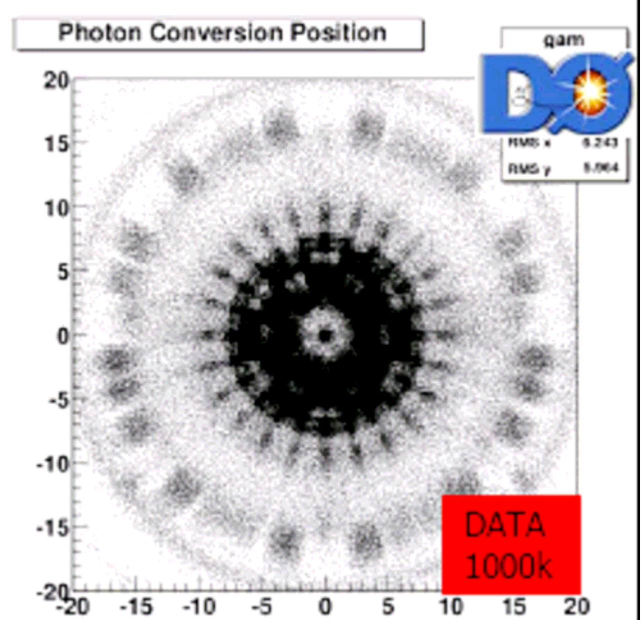
- Use radiative tail of E/P to measure material
- Gives average material
- Can be combined with energy-loss measurements of muons (J/ψ) to give roughly type of material
  - ➔ **CDF discovered it was missing Copper cables this way**



Material: X-raying the detector

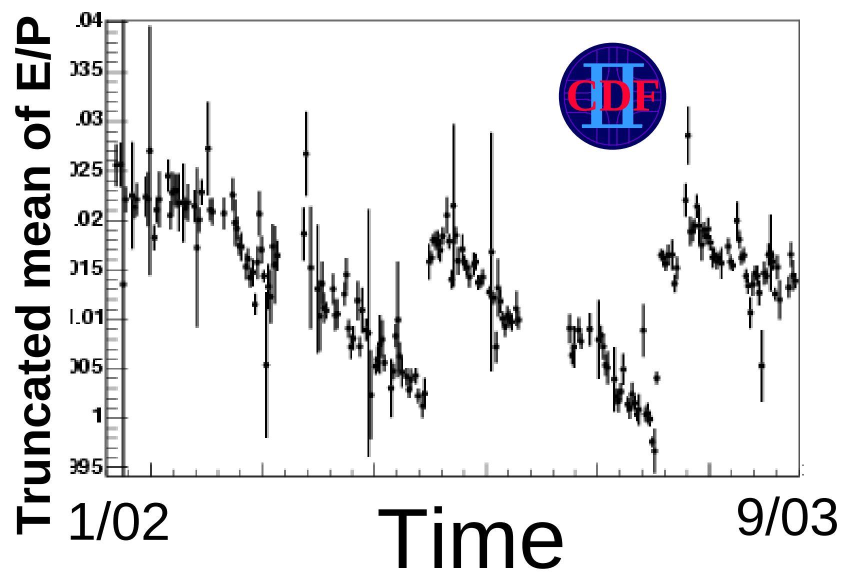
- Conversions can indicate location of material in detector
  - ➔ **Normalized to inner cylinder of tracking chamber**
  - ➔ **Overall normalization difficult**
    - ➢ Acceptance and efficiency depend on r
- Useful to find missing (or misplaced!) pieces



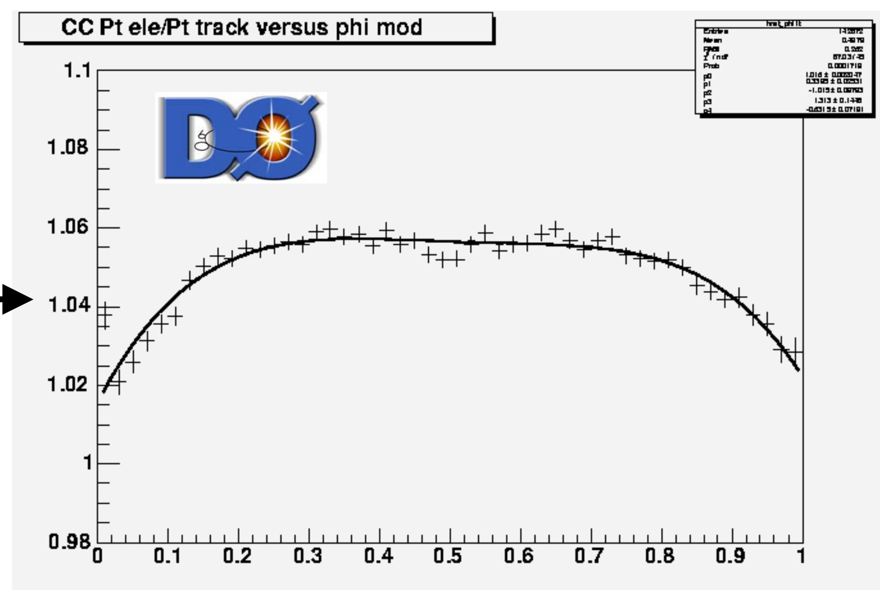


Energy calibrations I

- CDF makes heavy use of E/P peak for calibrations
- Time-dependent
  - ➔ **Scintillator and PMT aging**
  - ➔ **Measured with 8 GeV electrons**



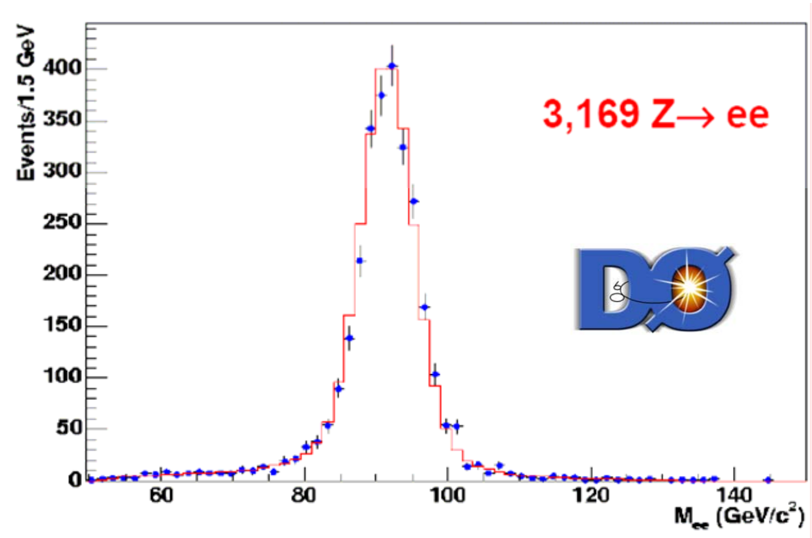
- Tower Face
  - ➔ **CDF:Taken from test-beam data checked with E/P in W➔eν events**
  - ➔ **D0: From data**

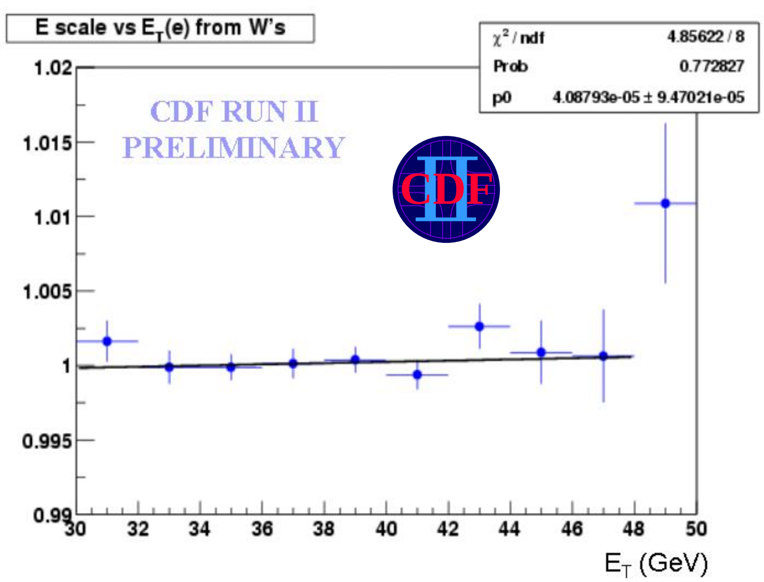


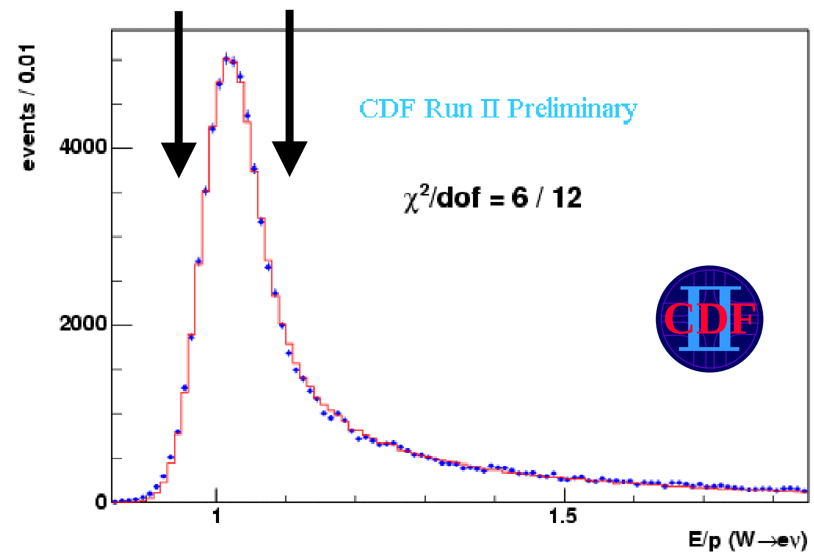
- Tower to Tower
  - ➔ **Measured with 8 GeV electrons**

Energy calibrations II

- Generally calibrated to Z→ee resonance
- E/P can give another handle
  - ➔ **Track momentum scale is measured with muons from J/ψ, ϒ, and Z→μμ**

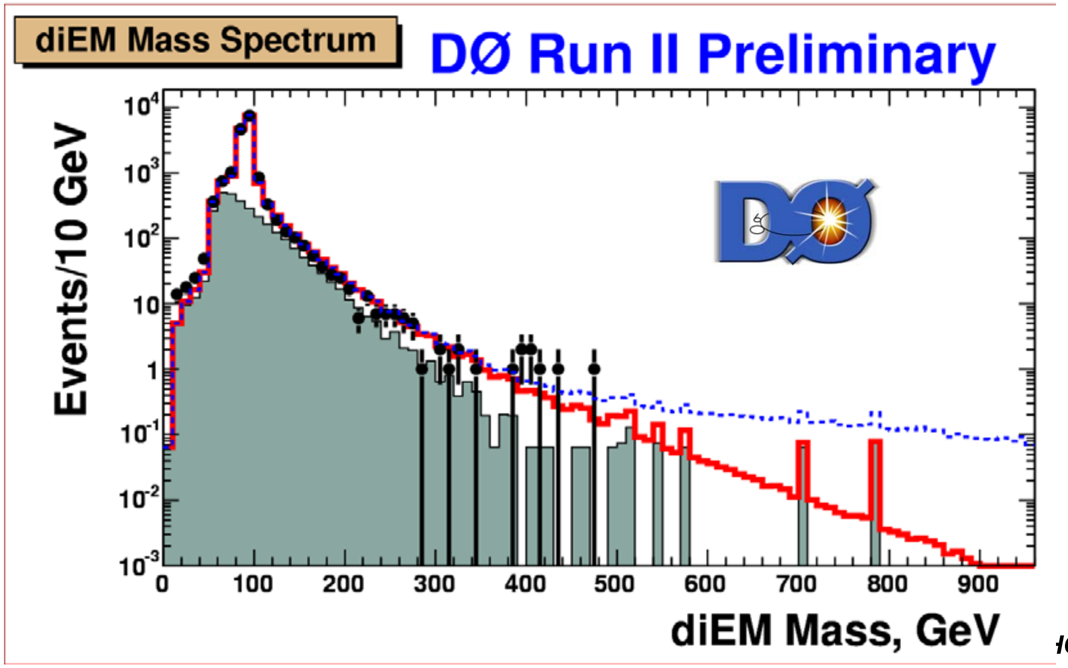






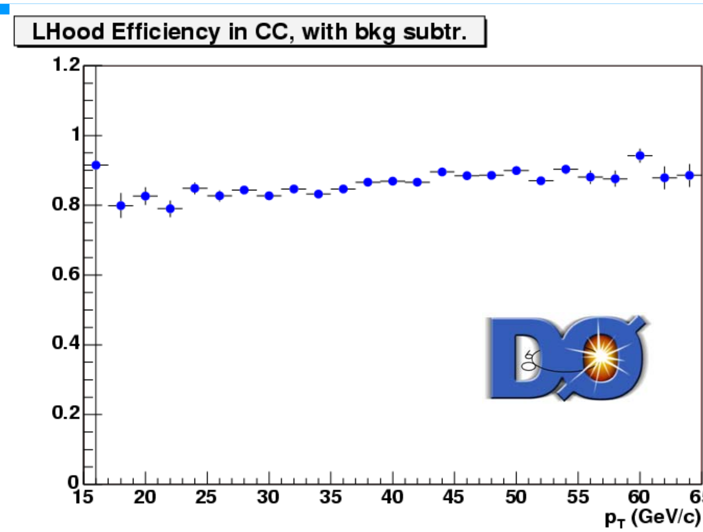
Analysis Tools

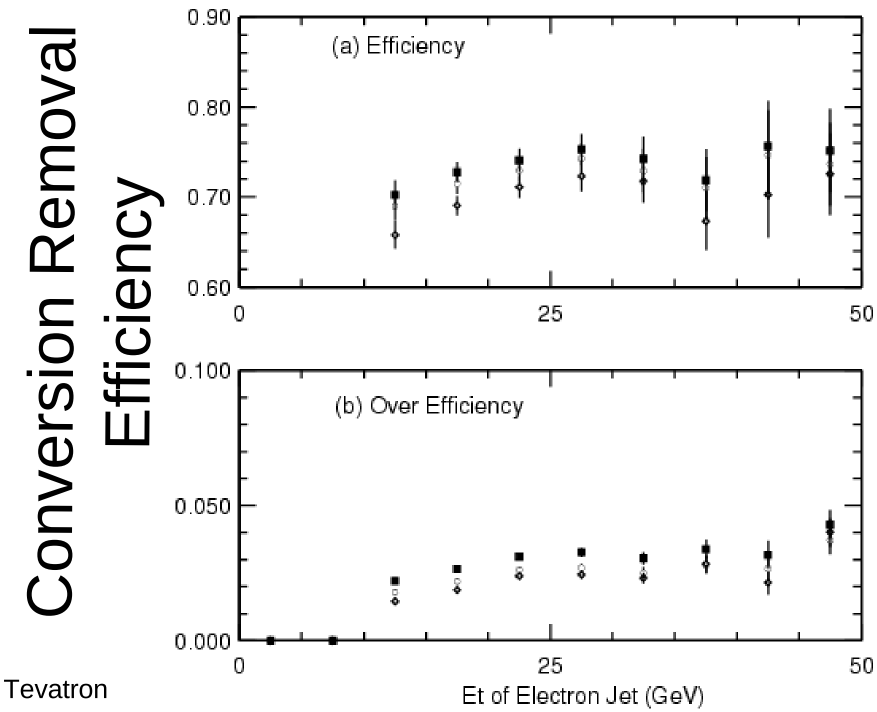
- Outline
  - ➔ **Electron and Photon ID efficiency**
  - ➔ **Electron and Photon fake rates**
- Important for all measurements
  - ➔ **e.g. : search for Extra Dimensions**
    - ➢ See Heather Gerberich's talk



Electron ID efficiency

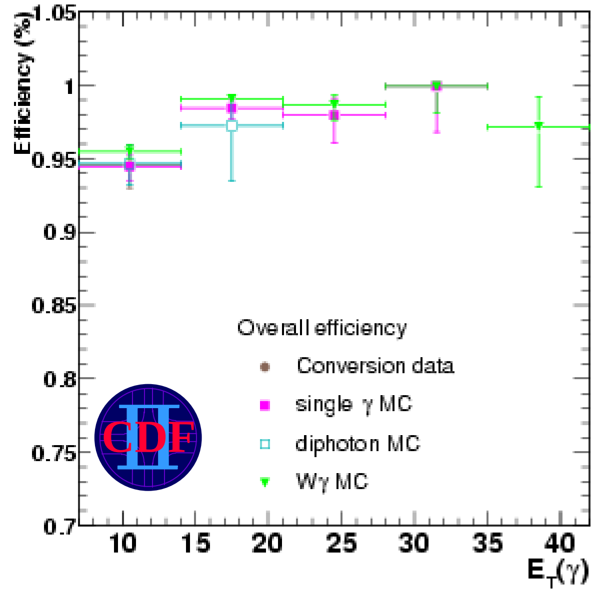
- Measure in Z→ee decays
  - ➔ **Select one tight electon and second EM cluster**
- Several quality classes
  - ➔ **Depends on analysis**
  - ➔ **80-95% efficient**
  - ➔ **Flat in most variables**
  - ➔ **Uncertainties < 1%**
- Very small corrections for background, and biases
  - ➔ **Very robust**
- Conversion removal
  - ➔ **Sensitive to material**
  - ➔ **Removes ~73% conversions and ~2.3% real electrons**
    - ➢ Inefficiency is ~5% without trident removal

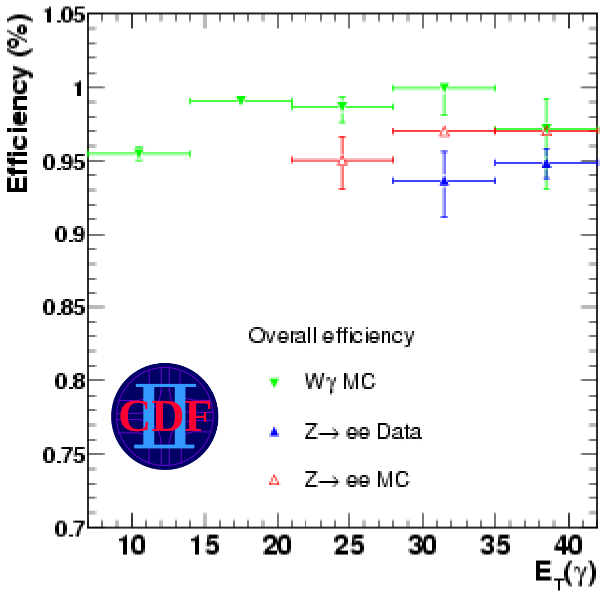




Photon ID efficiency

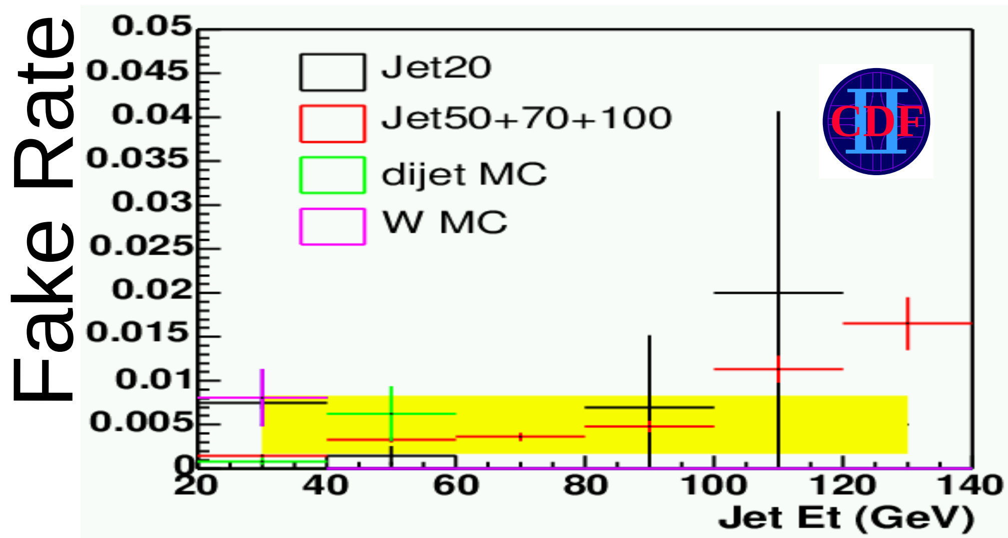
- No nice diphoton resonance
- Start from Z→ee
  - ➔ **Standard electron for 1st leg**
  - ➔ **Make a tight E/P cut on 2nd leg (minimize brems)**
  - ➔ **Gives efficiency for isolation and shower-shape variables**
  - ➔ **Account for backgrounds and “tridents”**
- Conversion Rate in Simulation tuned to data
  - ➔ **Knowledge of material important**

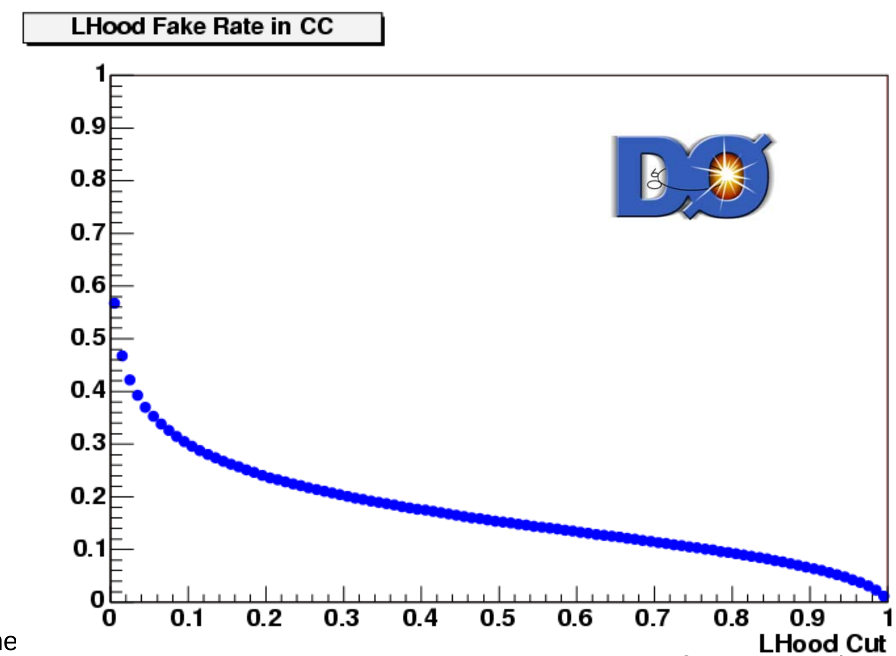




Background Estimation: e

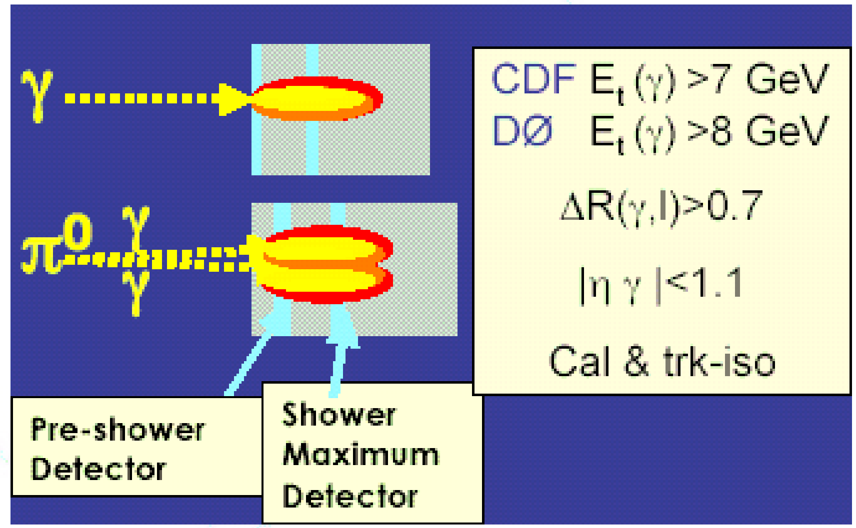
- Sources:
  - ➔ **b decays semi-leptonically**
  - ➔ **π^0 & $\pi^\pm$ give EM and track**
  - ➔ **Photon conversions**
  - ➔ **Composition depends on cuts**
- Fake rates are common way to measure backgrounds
  - ➔ **Measure rate of jets and electrons in jet triggered events**
  - ➔ **Apply to sample with signal topology with jet instead of electron**
- Generally, jet background is small, but has large uncertainty (~25-50%)
  - ➔ **Absolute rates ~ 10^{-3}-10^{-4}**

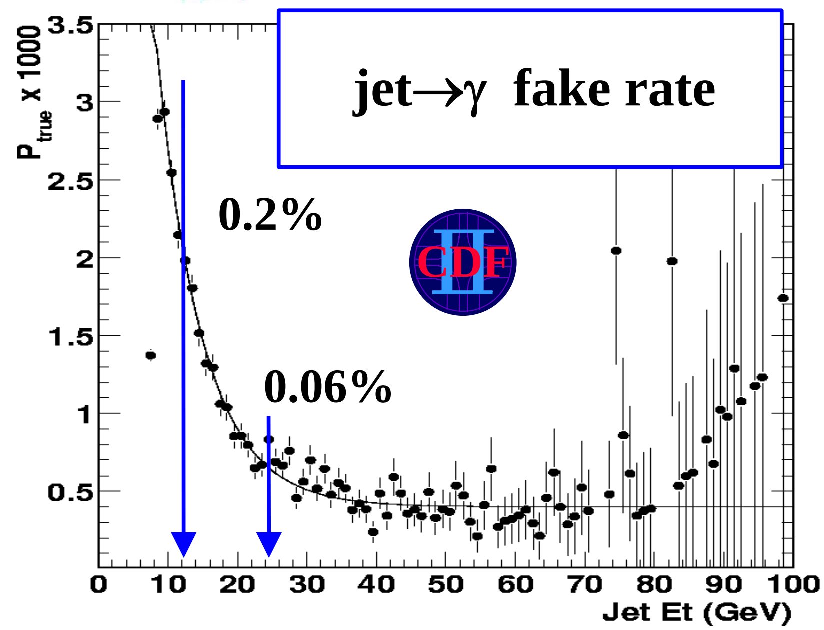




Background Estimation: γ

- Major Source
  - ➔ $\pi^0 \rightarrow \gamma\gamma$
- Fake rate measured in similar way to electrons
  - ➔ **Prompt photons need to be removed**
  - ➔ **Rates from different jet samples are compared for systematic**
  - ➔ **If jets are E_T-ordered, find rate is different for 1^{st}, 2^{nd}, and lower E_T jets**
- Rates ~ 5×10^{-4} for high E_T





Summary: Main Issues

- Calibrating the detector
  - ➔ **Important for measurements like W mass and other precision EW measurements**
- Understand material in detector
  - ➔ **Directly impacts photon and electron detector acceptance**
  - ➔ **Degrades many electron ID variables**
    - ➢ Shower profile, isolation-type variables, track momenta cuts, conversion removal
- Instantaneous luminosity
  - ➔ **Degrades performance of Isolation and had/em type cuts**
- Our pre-data simulations greatly underestimated both occupancy and material effects

Conclusions

- Electrons and photons are among the strongest handles we have at hadron colliders
  - ➔**Trigger and identification well established**
  - ➔**Improvements are always being worked on**
- Identification efficiencies are 80-90%, while jet fake rates are 10^{-3}-10^{-4}
- Knowledge of the material and the impact of multiple interactions important, especially at future LHC experiments