# Preparing for Physics with Electrons and Photons @ LHC

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# Outline

- Tevatron experience with EM ID
  - ID principles and challenges
- Transition to LHC and new challenges
  - Even bigger pressure: If the new physics is just beyond Tevatron reach, time to discovery would be the time to accumulate data – it will be the time to understand detectors: discovery timing can be crucial to the future of HEP
  - increased tracker material
  - more ambitious precision goals
- Measurements of ID Efficiency / Scales / Resolutions
  - $Z \to ee$, $Z \to \mu\mu\gamma$ (+ W, $J/\psi$, $\Upsilon$, etc... )
- Try out algorithms at Tevatron
  - gives at least qualitive picture
- Summary

# EM ID @ Tevatron

- Electrons
  - Two principal backgrounds: jets and photons
  - Two reconstructions paths
    - start with calorimeter
    - start with tracker
- Photons
  - Backgrounds from jets and electrons
  - reconstruction starts with calorimeter
- Calorimeter based reconstruction is essentially the same for electrons and photons
  - although the cut values may not be
  - separation between electrons and photons happens on the basis of whether or not there is a "matching track"
- Electrons reconstructed with track based algorithm are identified in a way somewhat similar to the calorimeter based
  - optimized for finding electrons in jets

# EM ID @ Tevatron

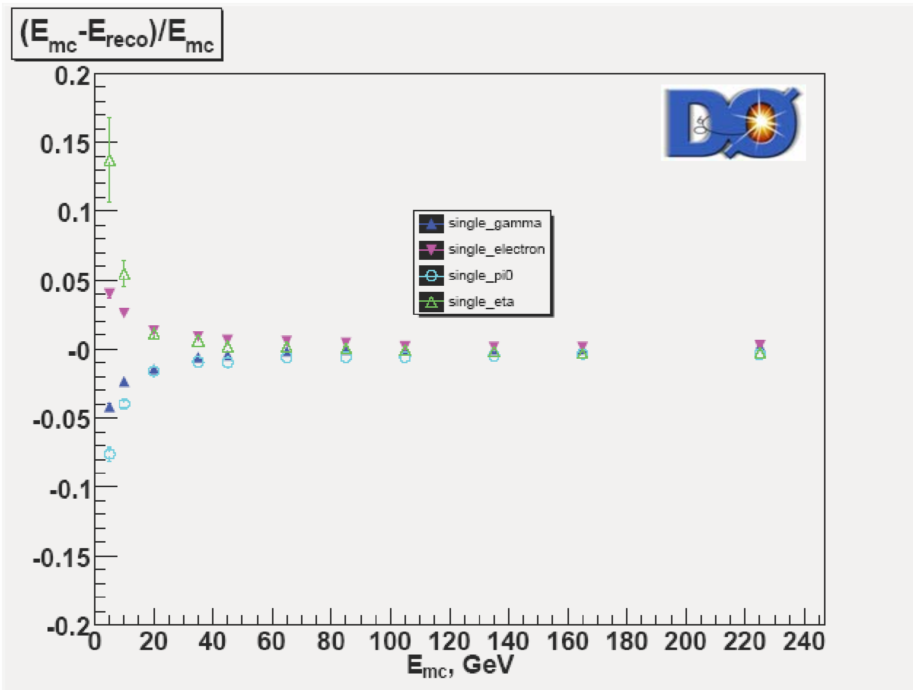
- CDF and DØ have conceptually mature algorithms
  - clusters with small had. fraction:
    - CDF: had/EM < 0.055 + 0.00045·$E^{\gamma}$
    - DØ: EM/(EM+had) > 0.9
  - isolation in calorimeter and tracker
    - can be absolute or relative to photon energy
    - CDF's track isolation: $\Sigma|p_T| < 2$ GeV + 0.005·$E_T^{\gamma}$
    - DØ calorimeter isolation: EM(0.2) / (EM(0.4)+had(0.4)) < 0.15
  - shower shape consistent with EM object
    - CDF: use shower max. chamber information
    - DØ: use fine segmentation of calorimeter (both longitudinal and transverse)
- Electrons v.s. photons: charged track pointing to the cluster
  - various definitions of "pointing"
  - DØ also has hit counts in roads to pick lost electron tracks
- At start-up: "vanilla" definitions with simple cuts
- Plethora of multivariate discriminators later in the run

# Challenges @ Tevatron

- Tuning MC is hard. Biggest problem seems to be in the material before the calorimeter (tracker & infrastructure)
  - mechanical drafts are slow to propagate to GEANT
  - as-built detector is not the same as as-drafted
- Conversions (photon efficiency, electron background)
  - hard to determine probability of
    - correct material budget
    - reconstruction of two tracks very close in space
  - probabilities to reconstruct tracks from conversion seem to be correlated
  - but the probability is relatively small
    - with LHC detectors the problem is going to be worse
- At Tevatron, there is no clean source of isolated high $E_T$ photons to test the MC predictions
  - Have to rely on MC to describe difference between electrons and muons
  - At LHC, one can use radiative Z decays! (this idea was born in the first Tev4LHC workshop)

# EM ID @ Tevatron

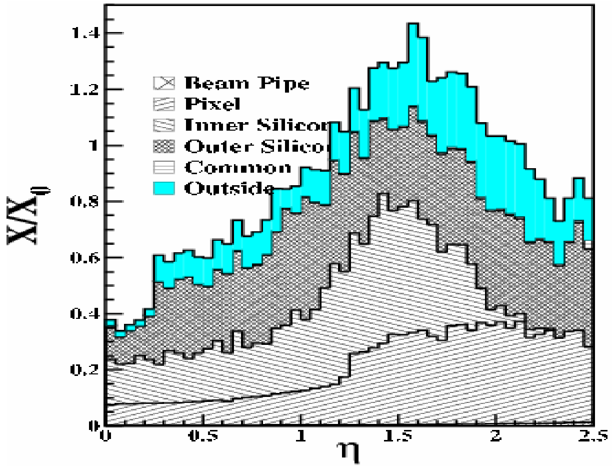
- Example of difficulties:
  - energy scales for electrons and photons are different
  - Two reasons: **containment** and **material**
  - LHC detectors have more material in the tracker




- energy scale depends on ID cuts
  - Smaller effect at DØ, but dominant at CMS

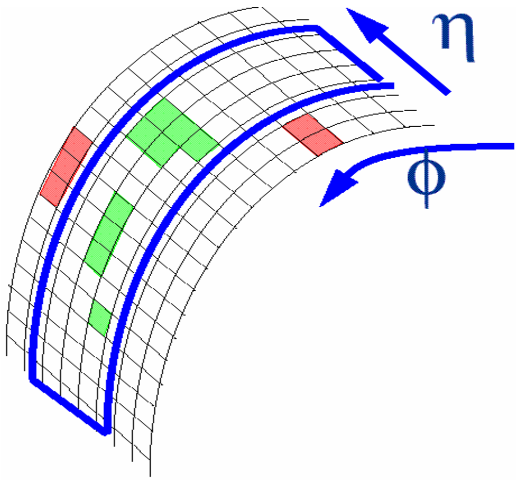
# EMID at CMS

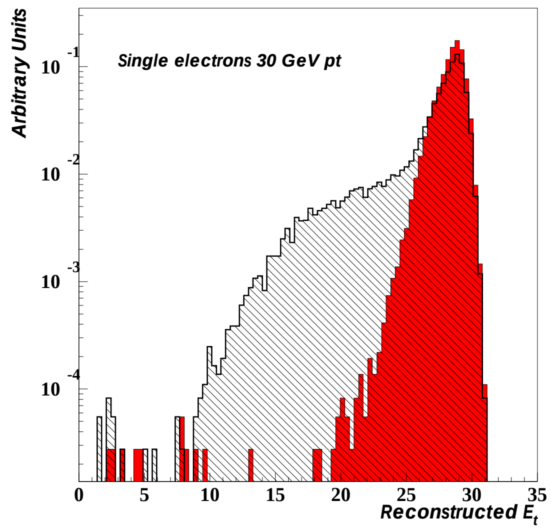
- Lead Tungstate crystals
  - $\Delta\varphi\times\Delta\eta$ ~ 0.02×0.02
- Up to 1.5 $X_0$ of material in front of the ECAL




## "Super" cluster Reconstruction:

- find bumps in calorimeter
- cluster the bumps
- approximate window size $\Delta\varphi\times\Delta\eta$ ~ 0.8×0.06




Note:

ATLAS'es material is only a little smaller

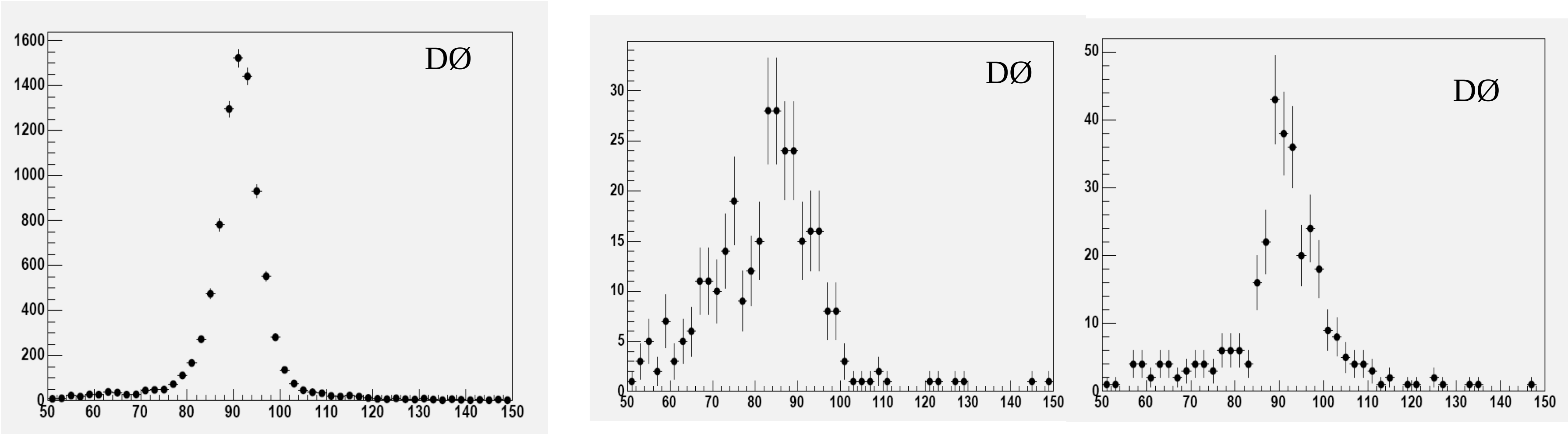
# "Brem recovery" at DØ

- The brem recovery algorithm can be checked with real data!

all di-electron events

di-electron events with identified brem

before correction　　after correction




Mee (GeV)　　Mee (GeV)　　Mee (GeV)

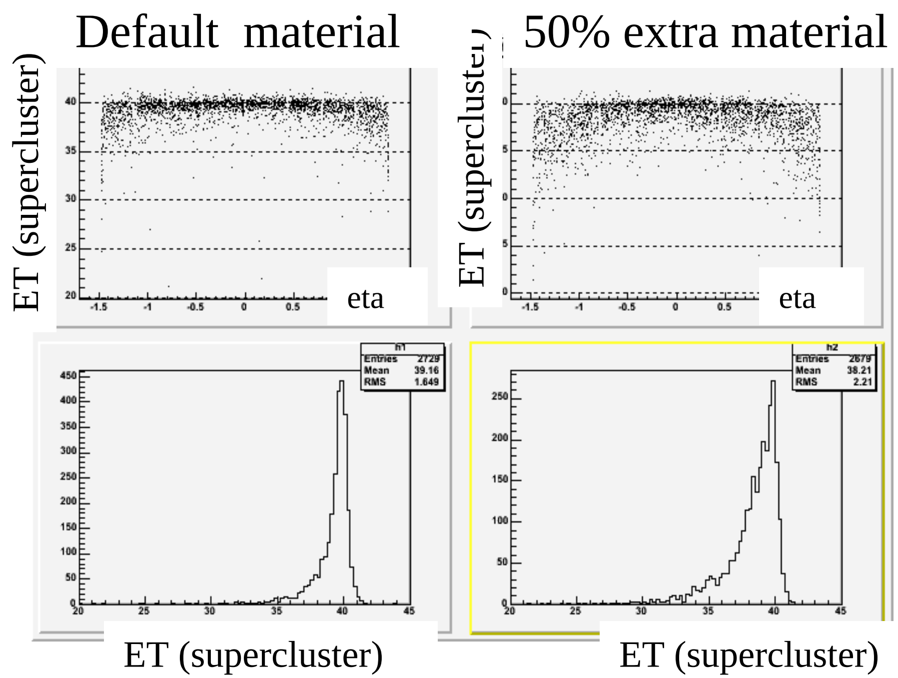
- Unfortunately, collecting all the energy of all brems is not enough to recover the resolution @ CMS
  - brems convert and electrons from conversion curl in the magnetic field
  - not all the energy reaches the calorimeter

# Tracker Material

- All previous experiments tried hard to implement correct material in MC and all miss by a factor of 1.5 to 2
  - Most recent examples - Run2 of Tevatron: DØ missed factor of 2, CDF (their third silicon!) missed 50%

Effect of 50% more material for 40 GeV electrons in CMS barrel:

- energy scale changes
- resolution worsens
- efficiency of ID cuts decreases




<u>e's and γ's propagate differently</u>

- electron continuously looses energy via Bremsstrahlung
- photons propagate intact until the first conversion
- Energy scales are non-linear, different for e and γ and depend on detector region (both rapidity and azimuth) – measuring amount of material *in situ* is needed

# Two-Pronged Attack

systematic studies how extra material affects electron and photon reconstruction and developing methods for measuring material *in situ*

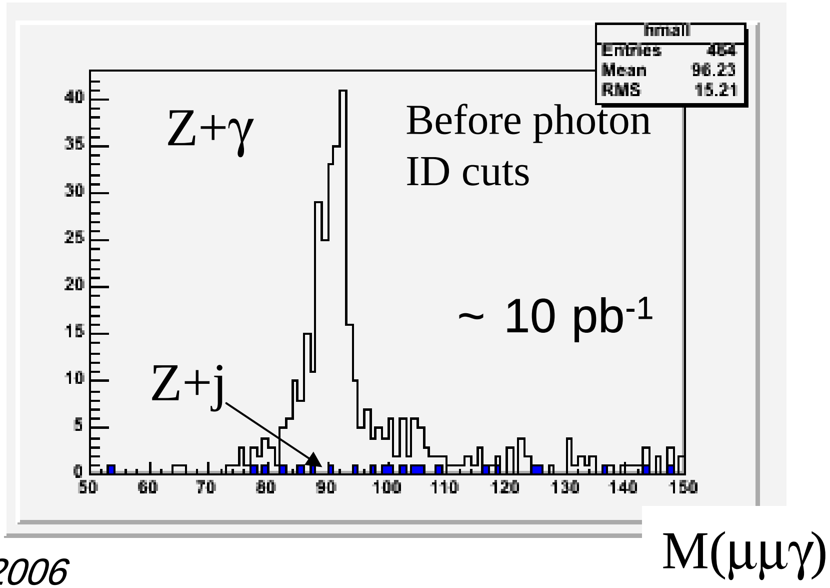
development of tools to measure true efficiency/resolution/energy scale of electrons and photons using data

# Material Measurement

- Not only the total material – spatial distribution too
  - material close to IP is more dangerous (magnetic field!)
- Total material can be measured in several ways
  - Mass v.s. pT for resonances decaying into MIPs (like $J/\psi \to \mu\mu$)
  - $p_T$(end)/$p_T$(begin) of electron tracks (special fitting algorithm exists that allows for large $p_T$ changes)
- Spatial distribution
  - counting converted photons
- Main problem
  - Know efficiency of conversion reconstruction v.s. R – it is not very likely to be described by the MC
  - In other experiments (CDF, DØ) outer tracker is "lighter", so electrons can be tracked relatively easily, but in CMS tracker gets heavier with radius

# Measuring Efficiencies/Scales/Resolutions

- While material in MC is tuned – measure everything!
- Algorithms for efficiency/fake rate measurements in data
  - $Z \to ee$ for electrons - similar to the way it was done at Tevatron
  - $Z \to \mu\mu\gamma$ for photons – too hard at Tevatron, but possible at LHC!!
  - still need MC to extrapolate to, for example, extrapolate to different momentum range
  - study possible biases, precision, etc...




Extract:

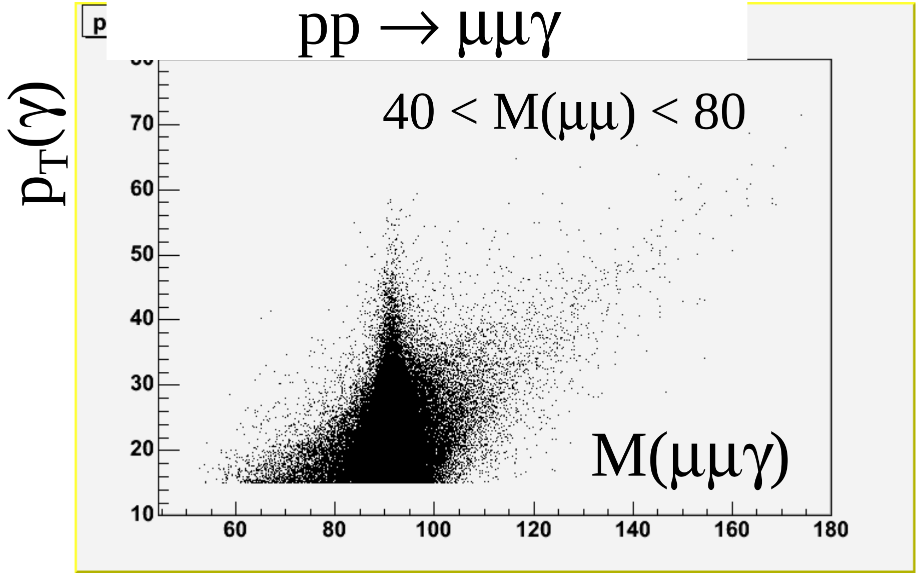
photon ID cuts efficiency

photon energy scale

Prepare software tools to do this kind of analysis quickly upon startup

# Examples of Biases

- Instrumental
  - correlation between objects: i.e. if in some fraction of the cases, a wrong crossing is read out for the tracker
- Fiducial
  - in DØ electron identification is more efficient for events with PV close to zero. Requiring a well-identified “tag” in Z→ee biases the PV distribution and therefore the efficiency can be overestimated
- Physical
  - kinematic cuts bias peak position and shape (both because of physics and resolution effects)



# Summary

- Experience gained at Tevatron is very valuable for LHC
- The LHC Physics Center (LPC) is an excellent opportunity to transfer it to LHC (at least CMS), and in a way that allows for a transfer of technical stuff in addition to ideas
- At start-up, the pressure to produce physics results is enormous, while detector does not work as MC says it should
  - short term strategy: measure all you need in data, use MC only for corrections, make sure you can make discovery fast
  - long term strategy: reconcile data and MC which would allow use of sophisticated algorithms, re-tune all algorithms if needed, etc...
  - hard to balance the two, need a good plan on collaboration management level!!

# ATLAS Inner Detector Material