Electron Detection at CMS

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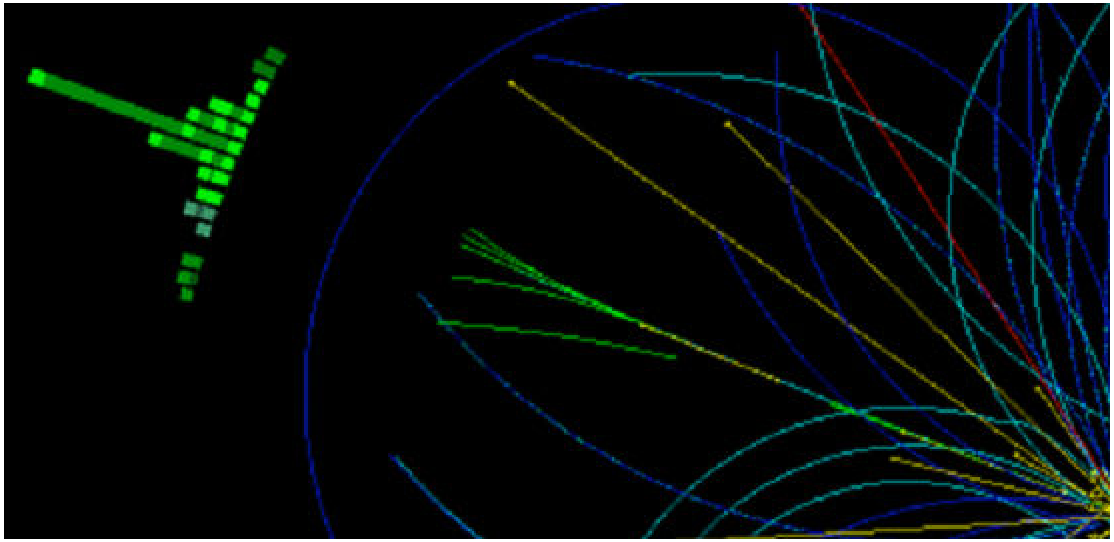


- Offline reconstruction
- ID and isolation criteria
- Triggering
- Efficiency and backgrounds

The CMS Electron Challenge

- Historically, high PT physics with electrons has enjoyed analysis sensitivity equal to or better than muons (taus a distant third)

- The LHC/CMS environment has given muons the upper hand:
  - Muons exploit the high field and precise silicon tracking of CMS without suffering from the high detector mass
  - Low misid rate for hadrons due to hermetic inner detectors with high hadronic absorption length
  - Redundant and overlapping muon chambers provide good background rejection and high efficiency for triggering

- Electrons shower frequently within the high mass tracker, suffer large backgrounds from jet misid, and cannot exploit tracking as well as muons do for triggering

- The Electron Challenge: use more specialized methods to restore parity with muons (and exceed them in some places)

The Egamma Physics Object Group

- Conveners: Chris Seez (Imperial) and Paolo Meridiani (CERN)

- Charge: study, develop, characterize and validate the tools to **identify and reconstruct electrons and photons** using all the information available from the CMS detector

- Meetings: “Week 1” Mondays at 7:30am FNAL time.

- Twiki: https://twiki.cern.ch/twiki/bin/view/CMS/EgammaPOG

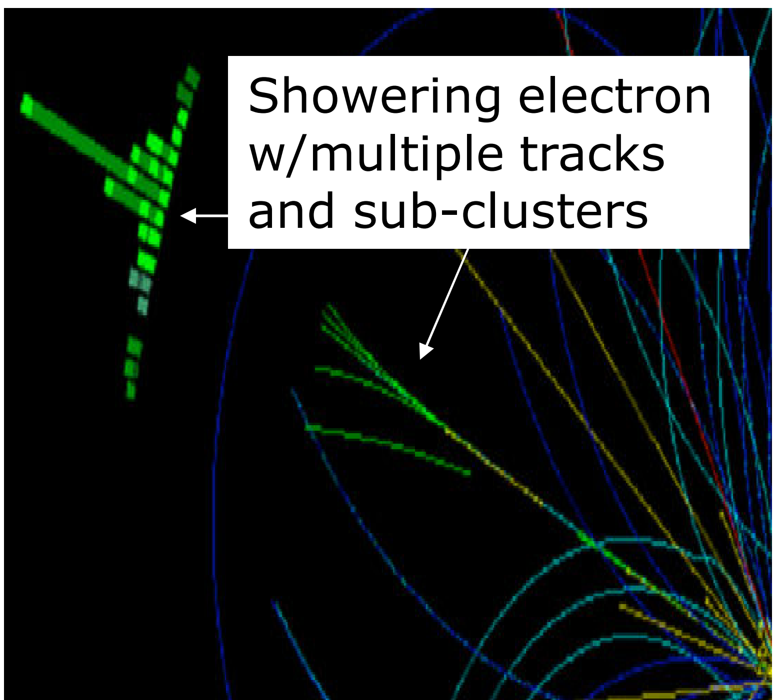
- LPC/USCMS contacts:
    - For POG projects : Jeffrey Berryhill (FNAL), Colin Jessop (UND), Yuri Gershstein (Rutgers), Marat Gataullin (Caltech)

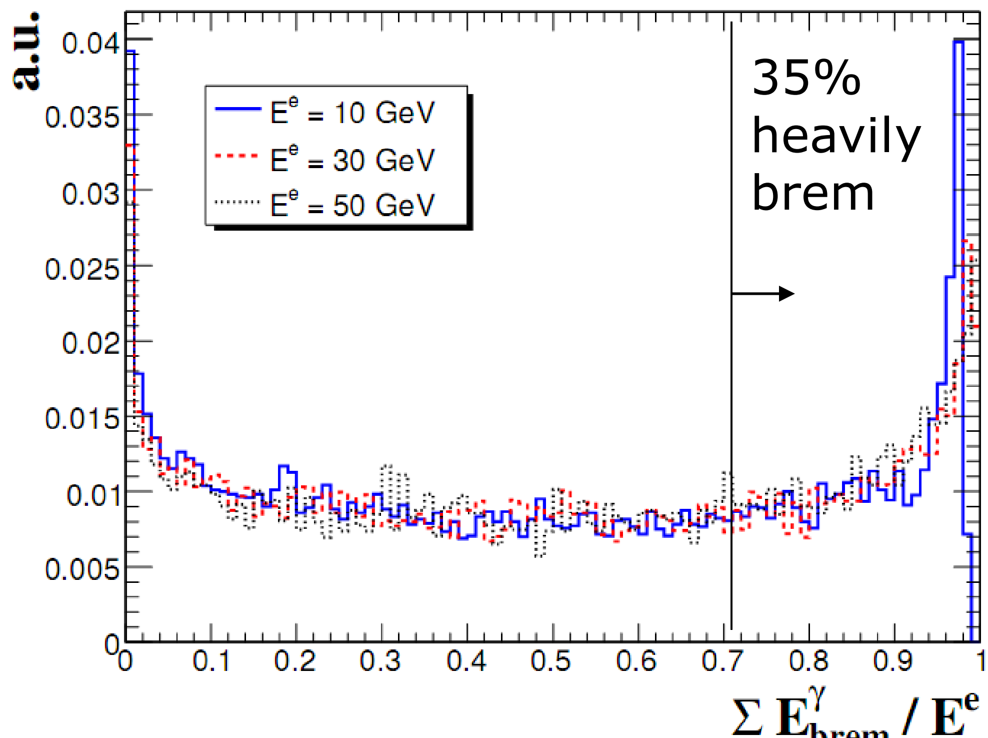
    - For PAG projects: LPC Photon, Dilepton, and Lepton+Jets groups

Electron Reconstruction

- Naïve concept: electron = ECAL energy cluster with a single charged track of comparable energy pointing at it

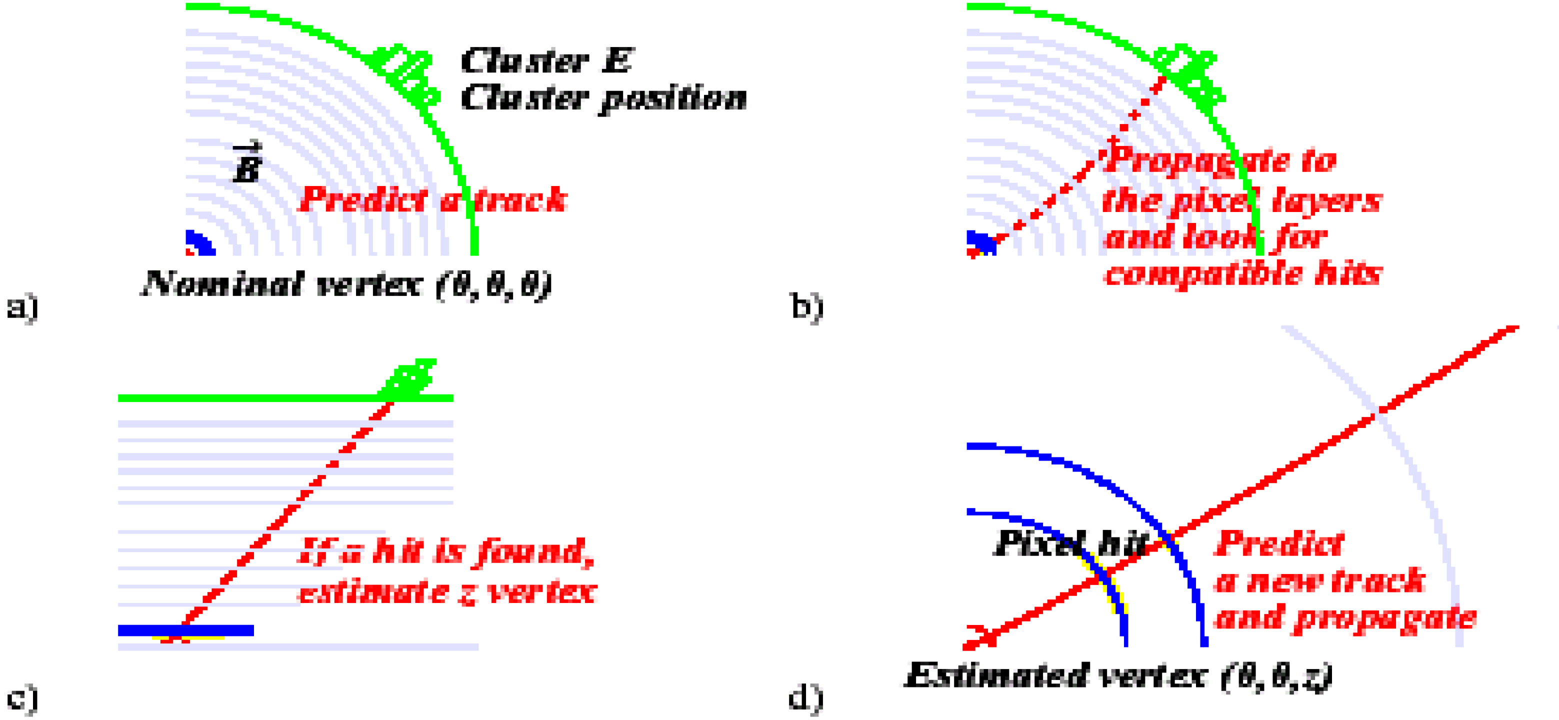
- At CMS: electrons frequently initiate an EM shower in the tracking system (= 0.4 to 1.4 X_0), complicating both clustering and tracking





The CMS “GSF Electron” Reconstruction Algorithm

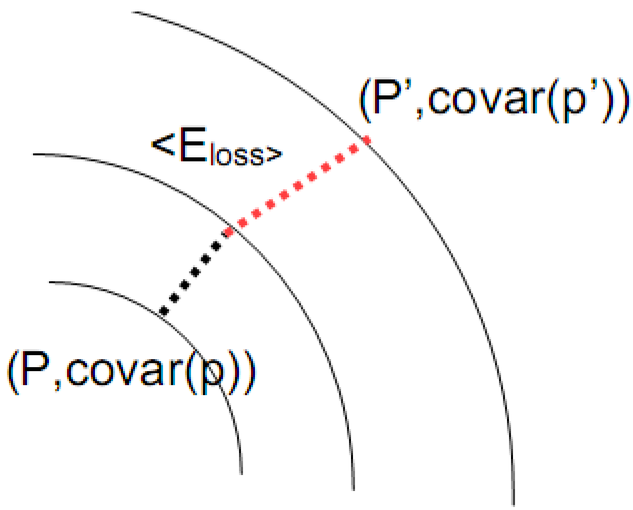
1. Find cluster-of-clusters = “**Superclusters**” , use primary vertex & SC centroid to define a search road
2. **Pixel seeding**: look for 2-3 compatible hits in the road, build a candidate hit list from **inside to outside**
3. Fit trajectories using GSF algorithm with hit lists, keep the best one(s)
4. Correct electron energy for losses



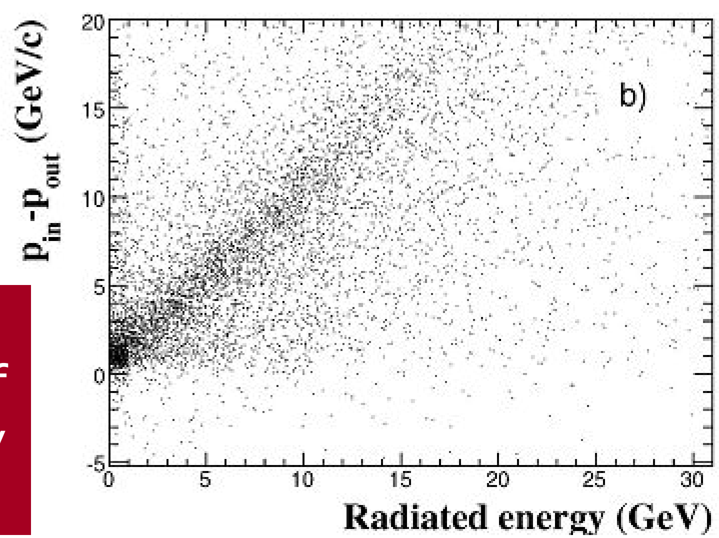
GSF = Gaussian Sum Filter

Gaussian Sum Filter = an extended Kalman filter tracking technique, which takes into account the effect of the interaction of the tracker material with a particle on its trajectory

At each layer of material, re-estimate window to look for the next track hit based on Bethe-Heitler energy loss formula (approximated by a sum of gaussians). Resulting GSF fit on candidate hits has track parameters varying vs. R.



Compare P_{in}-P_{out} (tracks) with E_{brem} (ECAL)



unbiased estimator of total energy loss!

Electron ID and nomenclature

With this R-varying GSF trajectory, we can now sensibly define matching variables between the GSF track and the associated supercluster:

E_{SC} : Supercluster energy

P_{IN} : GSF trk momentum at R=0

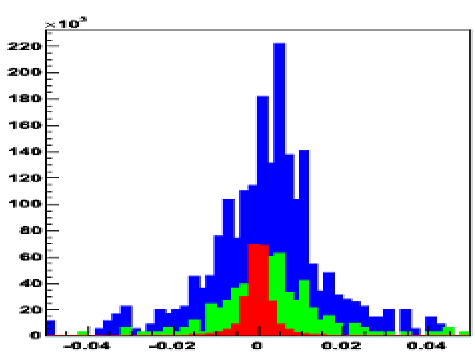
Eseed : Supercluster seed energy

P_{OUT} : GSF trk momentum at R = last track layer

f(brem): (Pin – Pout)/Pin “electron brem fraction”

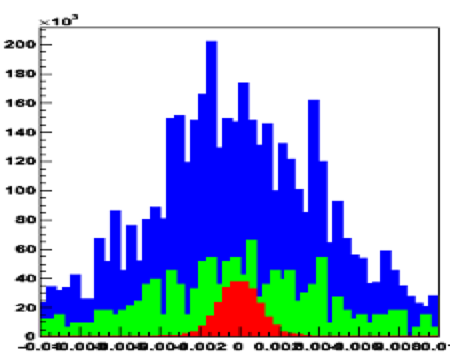
Delta phi_in : match between SC phi and extrapolation of Pin trajectory
Delta eta_in : “ “ eta “ “

Δφ IN



Z electrons

QCD dijets



Δη IN

Electron ID nomenclature

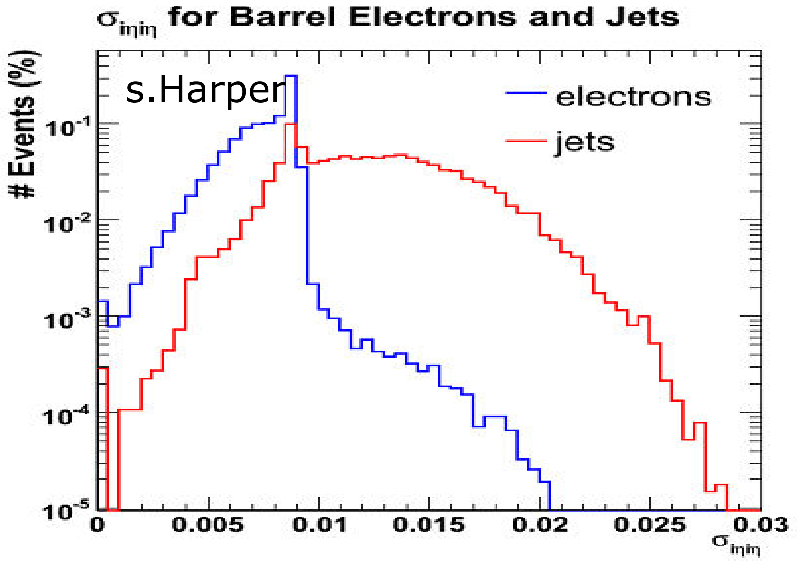
Electron shower shape variables
exploiting the finely segmented ECAL

H/E : Hcal tower energy behind seed cluster/ seed cluster energy

Sigma_eta,eta
(also phi,phi and phi,eta):

$$\sigma_{\eta\eta}^2 = \frac{\sum_i^{5x5} w_i \left(\eta_i - \bar{\eta}_{5x5}\right)^2}{\sum_i^{5x5} w_i} \qquad w_i = 4.2 + \ln E_i / E_{5x5}$$

Sigma9/Sigma25:
3X3 xtal energy/5X5 xtal energy centered on seed xtal

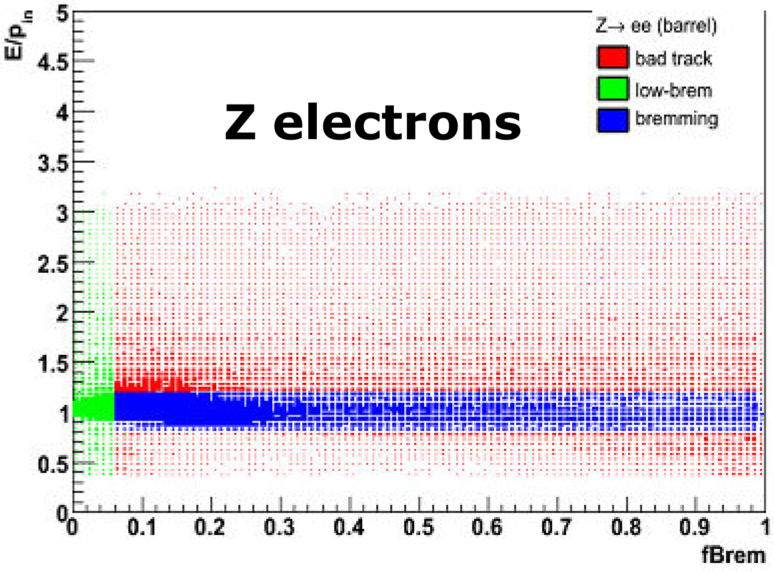


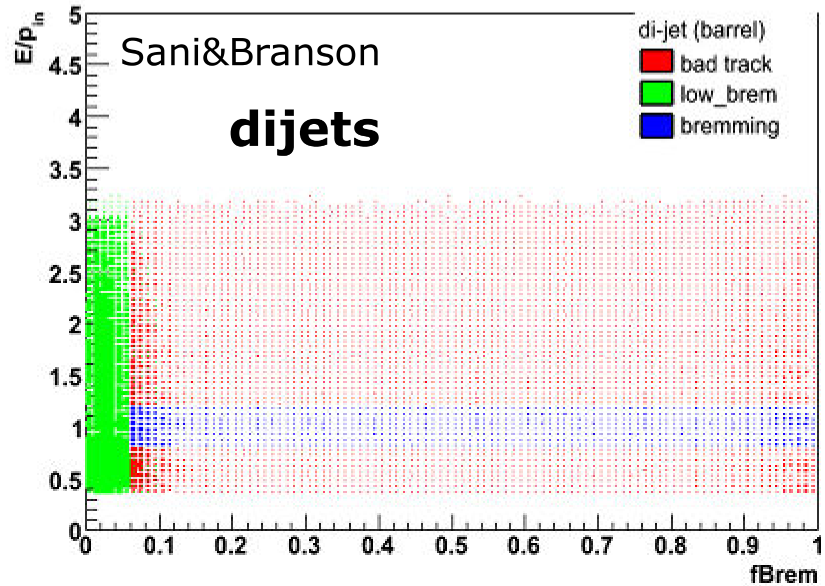
Early Electron ID Strategies

Fixed threshold ("robust"): uniform rectangular cuts on $\sigma\eta\eta$, $\Delta\phi$ IN, $\Delta\eta$ IN, and H/E, for EB and EE separately

2006 TDR "classes": subdivide GSF electrons into classes based on fBrem and cluster characteristics ("Golden", "Showering", "Big Brem", "Narrow"), tune several rectangular cuts class-wise for EB and EE

2007 UCSD "categories": Identify regions of similar S/B in E/pIN vs fBrem plane ("bremming", "low-brem", "bad track"), tune cuts (4 robust cuts + E/p) category-wise for EB and EE





Electron Isolation

Three varieties of imperfectly correlated critieria for rejecting electron-like objects originating from jets:

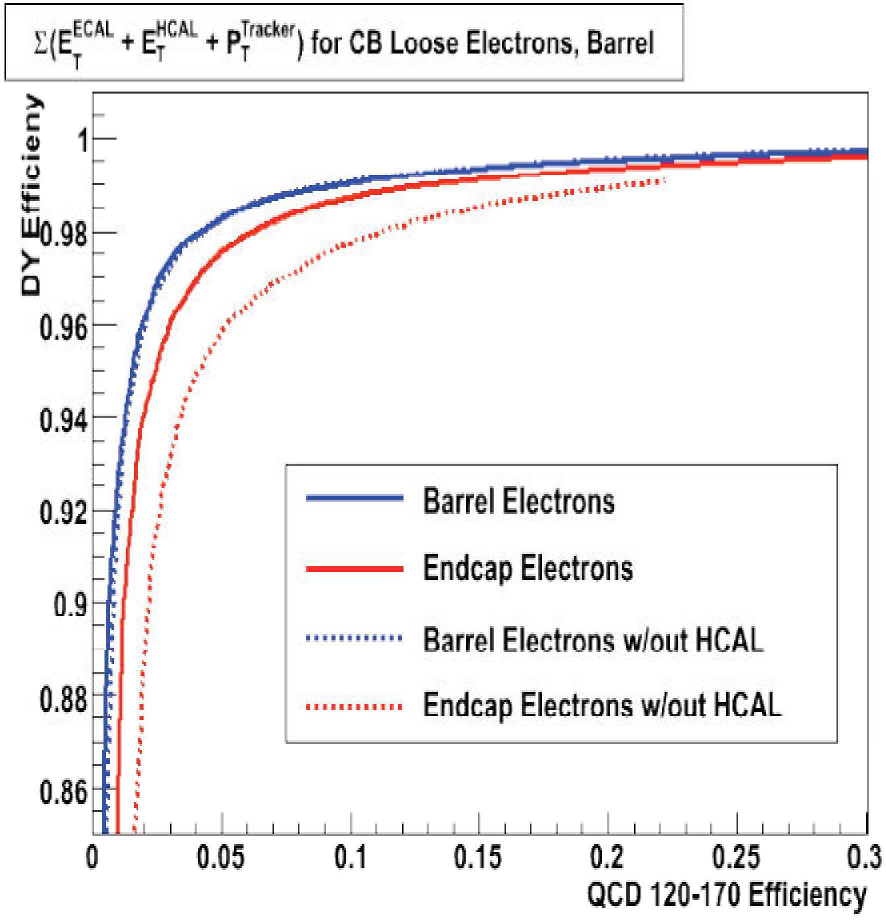
ECAL isolation: relative amount of ECAL "RecHit" energy in a cone about the electron trajectory, minus the electron "footprint"

HCAL isolation: relative amount of HCAL tower energy in a cone about the electron trajectory

Track Isolation: relative amount of track PT in an annular cone about the electron trajectory

Cut on all three-separately, or use a poor man's Fisher discriminant = ECAL Iso + HCAL Iso + Track Iso

M.LeBourgeois



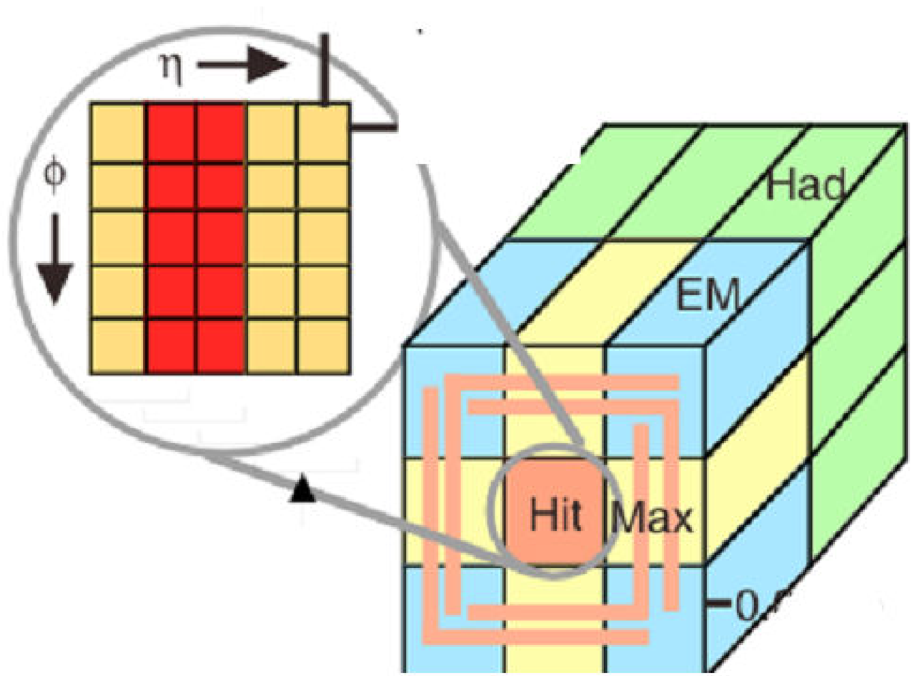
Electron L1 Trigger Reconstruction

No tracking in L1, just ECAL & HCAL
(electron = photon)
ECAL trigger subdivided into
trigger towers of 5X5 xtals

EM clusters are searched for in
each 3X3 tower array,
electron ET is center tower
+ Max ET neighbor

Nonisolated:
H/E cut on hit tower
Fine grain cut: 90% of hit tower energy
in two eta strips

Isolated: all 9 towers pass H/E and FG
≥ 1 "quiet corner" of 5 towers



4 best isolated and 4 best nonisolated clusters forwarded to L1 decision

Electron HLT Reconstruction

Common to e/γ

- L1 seeds
- Ecal regional unpacking and SCs
- η–φ matching of SC with L1 candidates firing the L1 seeds
- E_T cut

Offline-like Superclustering to recover full ET resolution and get good pixel seeding

Specific to electrons

- Electron Hcal isolation
- Pixel seeding
- Electron track reconstruction
- Electron track isolation ($\Sigma p_T / P_T^{ele}$)

Pixel seeding tighter than offline

Track reconstruction is the most expensive step so it is saved for last

https://twiki.cern.ch/twiki/bin/view/CMS/SWGuideEgammaHLT

8E29 Menu

Primary unprescaled trigger for high PT analysis is a PHOTON (i.e. ECAL cluster) trigger

HLT_Photon15_L1R	L1_SingleEG8
HLT_Photon15_TrackIso_L1R	L1_SingleEG8
HLT_Photon15_LooseEcalIso_L1R	L1_SingleEG8
HLT_Photon20_L1R	L1_SingleEG8

Meanwhile we experiment with HLT tracking needed for higher lumi…

Electron triggers

HLT path	L1 seeds
HLT_Ele10_LW_L1R	L1_SingleEG5
HLT_Ele10_LW_EleId_L1R	L1_SingleEG5
HLT_Ele15_LW_L1R	L1_SingleEG8
HLT_Ele15_SC10_LW_L1R	L1_SingleEG8
HLT_Ele20_LW_L1R	L1_SingleEG8
HLT_DoubleEle5_SW_L1R	L1_DoubleEG5
HLT_DoublePhoton5_eeRes_L1R	L1_SingleEG8 OR L1_DoubleEG5
HLT_DoublePhoton5_Jpsi_L1R	L1_SingleEG8 OR L1_DoubleEG5
HLT_DoublePhoton5_Upsilon_L1R	L1_SingleEG8 OR L1_DoubleEG5

1E31 Menu Physics Triggers

HLT_Ele15_SW_LooseTrackIso_L1R

HLT_Ele15_SW_EleId_L1R

HLT_Ele20_SW_L1R

HLT_DoubleEle10_SW_L1R

HLT_Photon25_L1R

HLT_DoublePhoton15_L1R

HLT_DoublePhoton15_VeryLooseEcalIso_L1R

Pixel matching and other background rejection required at 15 GeV

Unprescaled photon trigger increases to 25 GeV

At higher lumi, more and tighter cuts must be added to contain high background rate!

Electron Performance

Electron efficiency and jet fake rates will ultimately be evaluated and judged by performance on collision data

Standard-candles and other pure-ish electron samples to be collected and efficiency measured vs. any relevant dependent variables (ET, eta)

For ET = 5-20 GeV, use quarkonium decays, conversions, or whatever else can be found ? In progress.

For ET = 20-60 GeV use copious sample of Z decays to electron pairs

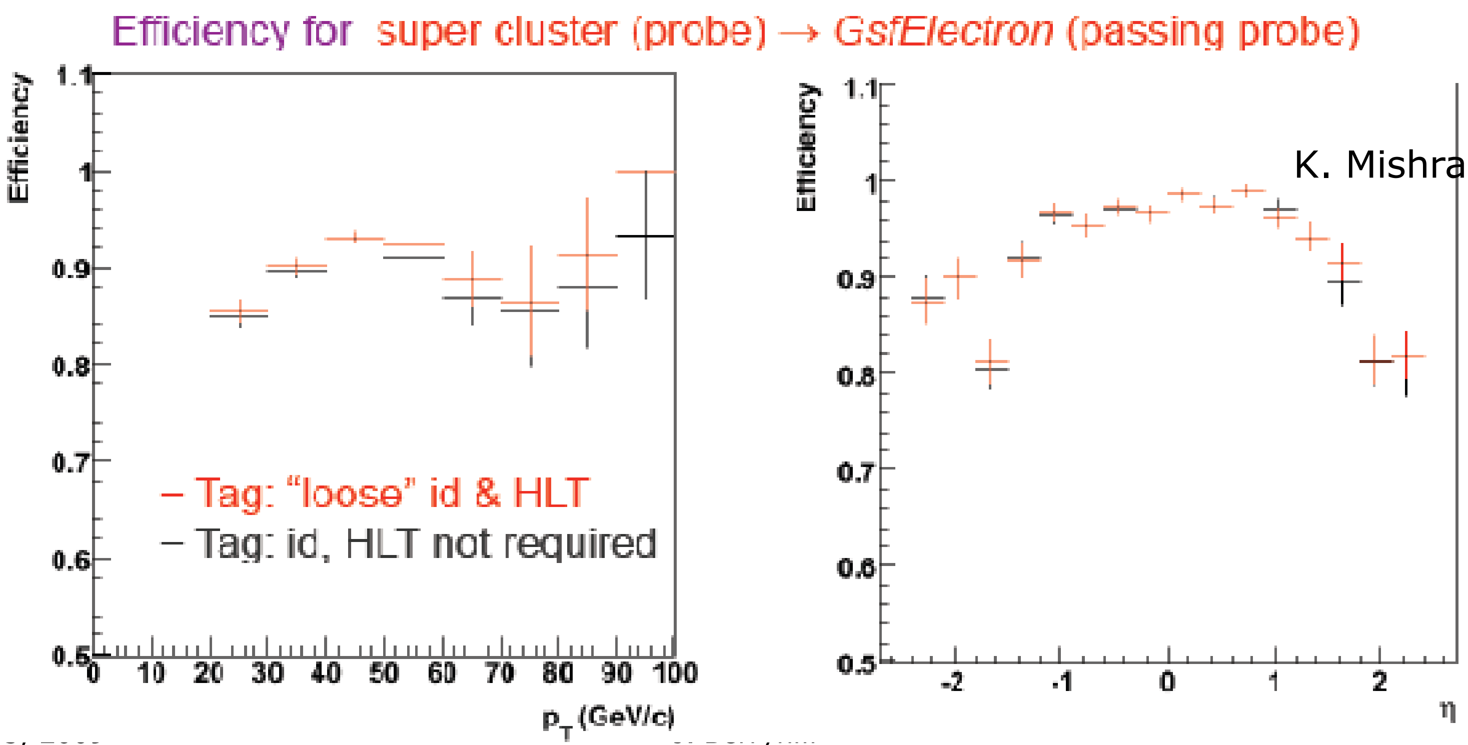
For very high ET electrons, use high-mass DY (“leapfrog method”)

Jet samples are also being defined to compute “fake-rates” for benchmarking selection or explicitly computing backgrounds

Electron Efficiency

"Tag and Probe" methodology systematized to produce configurable set of efficiency measurements in Z decays (or possibly also Jpsi/Upsilon) with configurable selection (PhysicsTools/TagAndProbe).

See tutorial Tuesday.



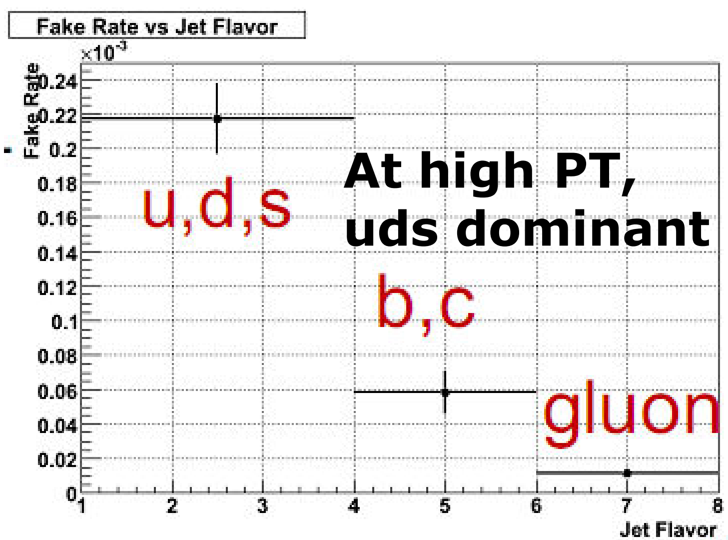
https://twiki.cern.ch/twiki/bin/view/CMS/ElectronTagAndProbe

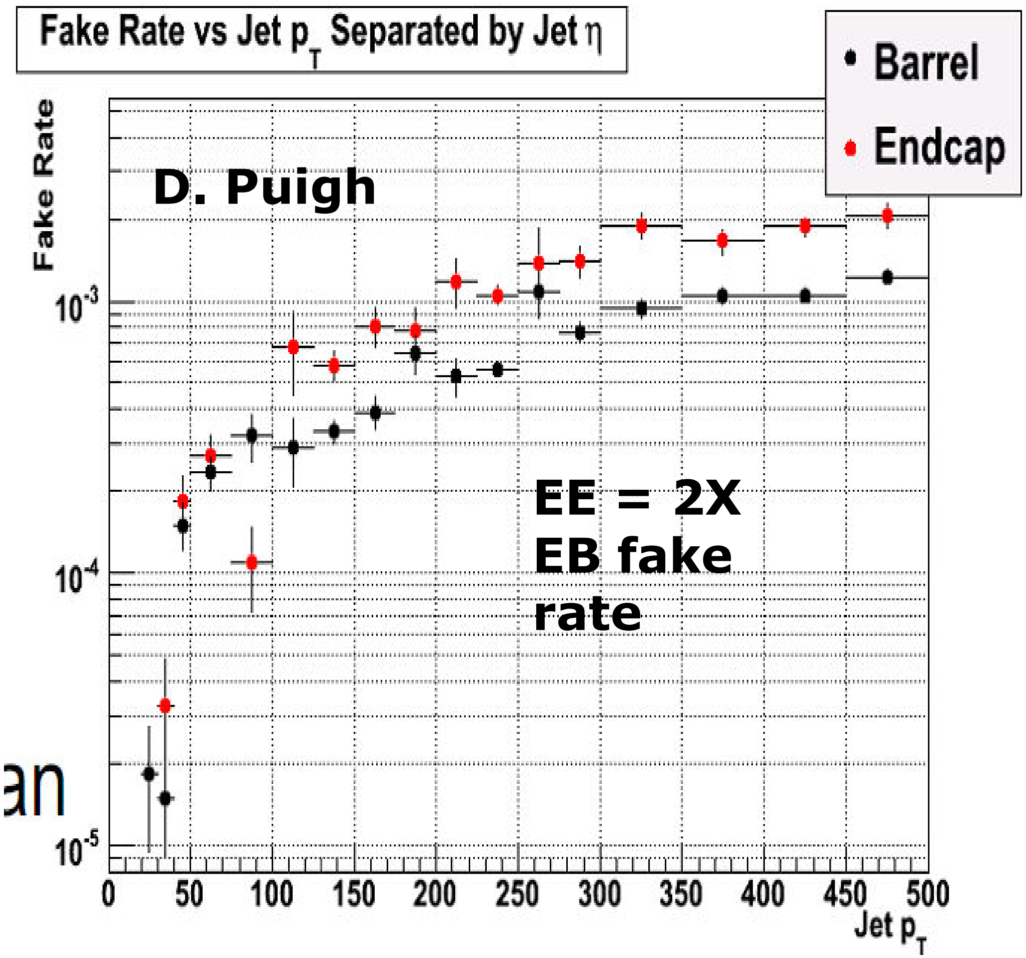
Electron Fake Rate

Fake rate per jet is 10^{-3} to 10^{-4},

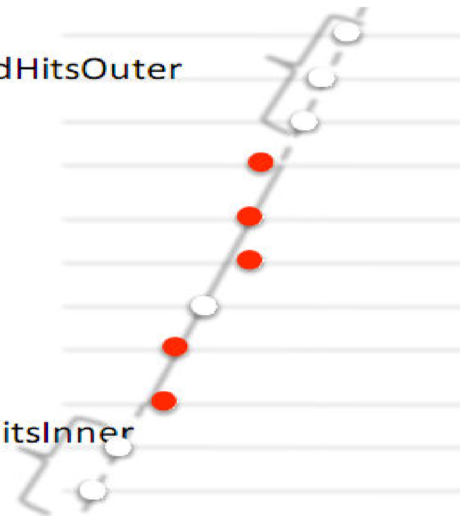
Strongly eID, PT, eta, and parton flavor dependent

Appropriate samples to map these in data under development





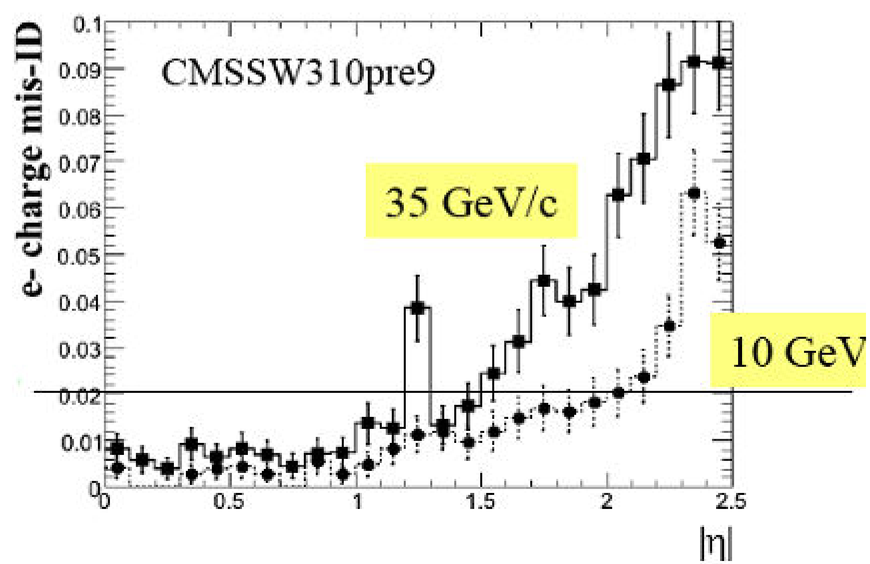
Conversions, Charge Misid



Y. Tu

Photon conversions a significant background source! Hit structure of GSF track to be exploited for conversion rejection (select on number of expected hits).

EE electrons have large charge misid (~few %)! Exploit more tracking data to reduce it.

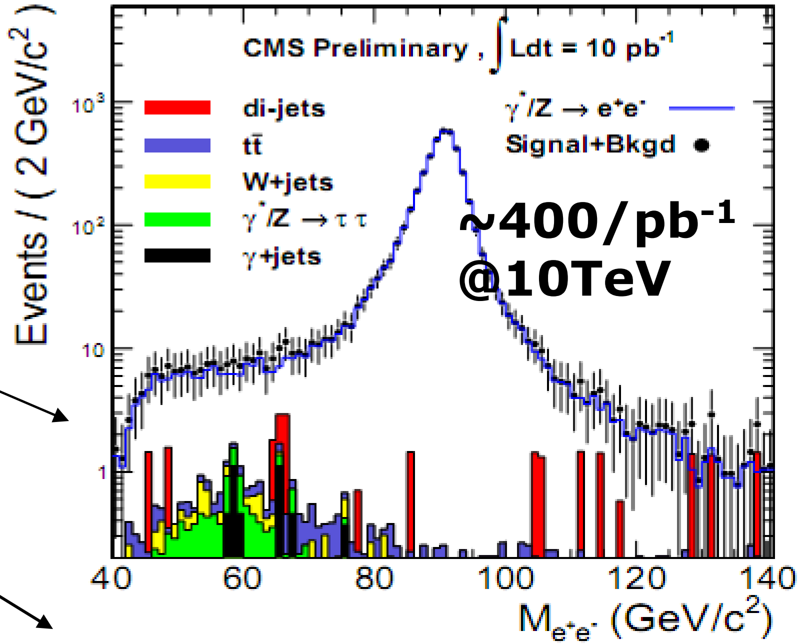


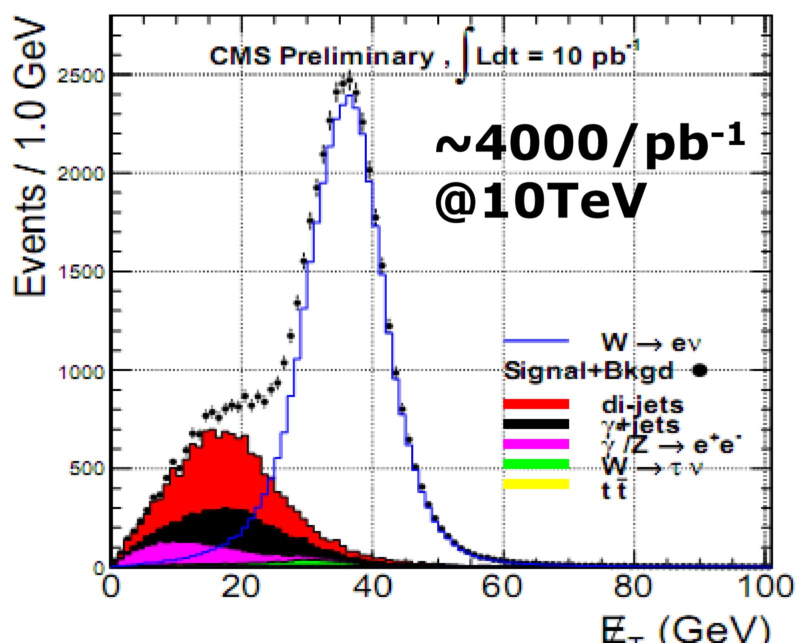
Selection for Early Analysis

At least two operating points for electron selection at startup:

1. Loose selection for Z (very low background! Now superior to Z to mumu)

2. Tight selection for W





1a. Very high-energy electrons have a very loose selection (Z' search)

2a. Something in between Z and W optimal for top, SUSY, W+jets (TBD)

If W and Z early physics is of interest to you, please consult LPC Dilepton group (V.Halyo & Y.Maravin) and CMS EWK electron subgroup (J.Berryhill & G.Daskalakis)

Not enough time to talk about

HF electron reconstruction: use short and long fibers of HF to discriminate electrons from hadrons. Good for extending acceptance of multi-lepton analyses.

Si strip-seeded electrons: use Si strips instead of just pixels to seed GSF tracking

Likelihood, neural-net, and other multivariate approaches: once we understand the simple cut-based selection, this is the next step

Particle-flow electrons: technique to find electrons in jets, use for b-tagging, low PT electron analysis, or improving jet energy estimate. Recently merged with GSFElectron collection for 3XY.

Conclusions

Now is a great time to get involved in electron studies:

Electron reconstruction at CMS is challenging, but we are armed with excellent tracking and ECAL detectors which have yet to be fully exploited. There is definitely room for improvement and introduction of new ideas.

Some sophisticated techniques have been deployed in simulation studies, but our experience with real-life electron reconstruction is very limited. Studies of the first collision data will be an excellent learning opportunity for us all.

Electron studies are directly associated with early publication opportunities in analysis, for both standard candles (W, Z) and searches (Z').