Electron and photon reconstruction in CMS

P. Vanlaer
IIHE - Université Libre de Bruxelles
for the CMS collaboration

First IPM Meeting on LHC Physics,
Isfahan, 20-24 April 2009

- Physics with electrons and photons
- The CMS electromagnetic calorimeter (ECAL)
- Calibration of the ECAL and energy corrections
- Electron reconstruction
- Electron selection
- Photon selection
- Trigger
- A few ECAL results

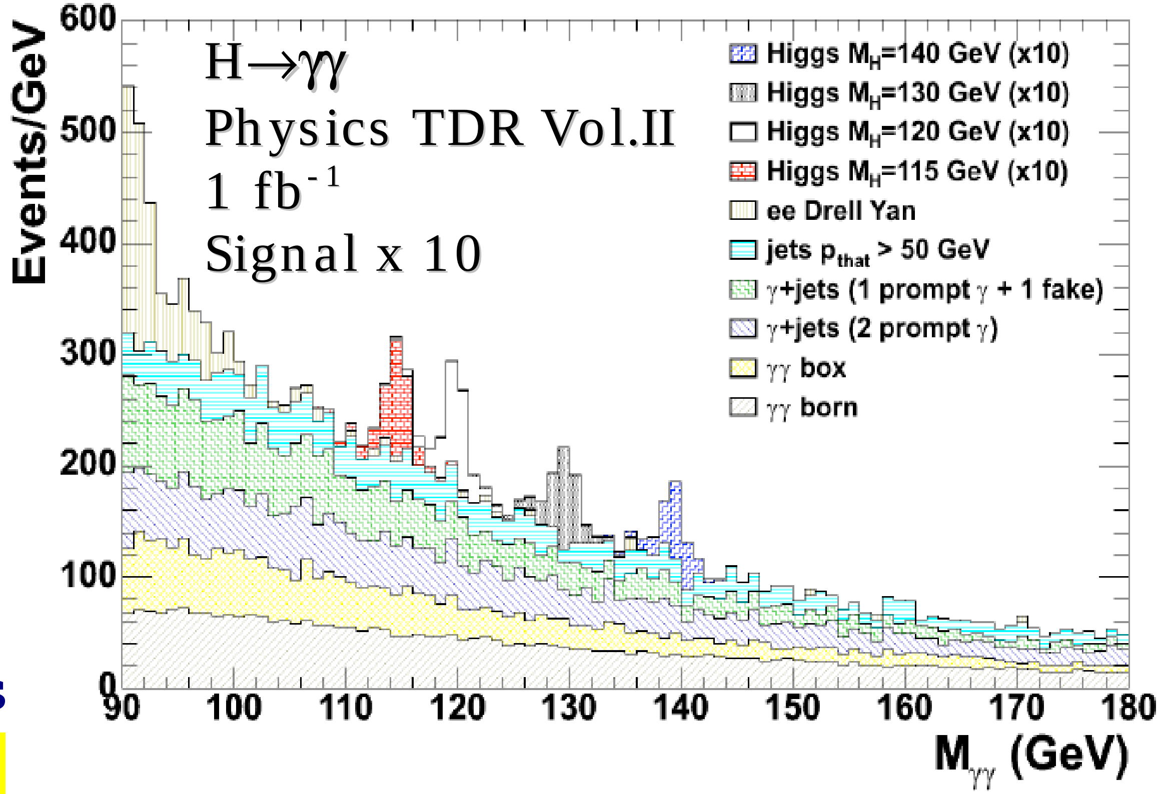
Physics with $e^{+/-}$ and γ

Higgs boson discovery
- $H\to\gamma\gamma$ (m_H < 140 GeV)
- $H\to ZZ^*\to e^+e^-e^+e^-$

New heavy bosons
- Zprime$\to e^+e^-$
- $G\to e^+e^-$, $G\to\gamma\gamma$

SuperSymmetry
- leptons+MET+jets

Electroweak, QCD
- $W\to e\nu$, $Z\to e^+e^-$, WZ, γ+jets



Main issues:
- Energy resolution
  - a narrow peak is more significant
- Jet background
  - σ(Jets, p_T > 100 GeV) : ~ 10μb,
  - 1000 evts/s at L= 10^{32} cm^{-2}s^{-1}
  - σ.BR($H\to\gamma\gamma$, $H\to 4l^{+/-}$) : O(10) fb

Electron and photon detection

Main interaction with matter at E > 10 MeV:

e: bremsstrahlung: $e+N \to e+\gamma+N$

γ: conversion into pair: $\gamma+N \to N+e^+e^-$

$\to$ cascade process

Electromagnetic shower

Radiation length X_0:

$$X_0 \approx \frac{716.4\, g\, cm^{-2}\, A}{Z(Z+1)\ln(287/\sqrt{Z})}$$

Jet rejection

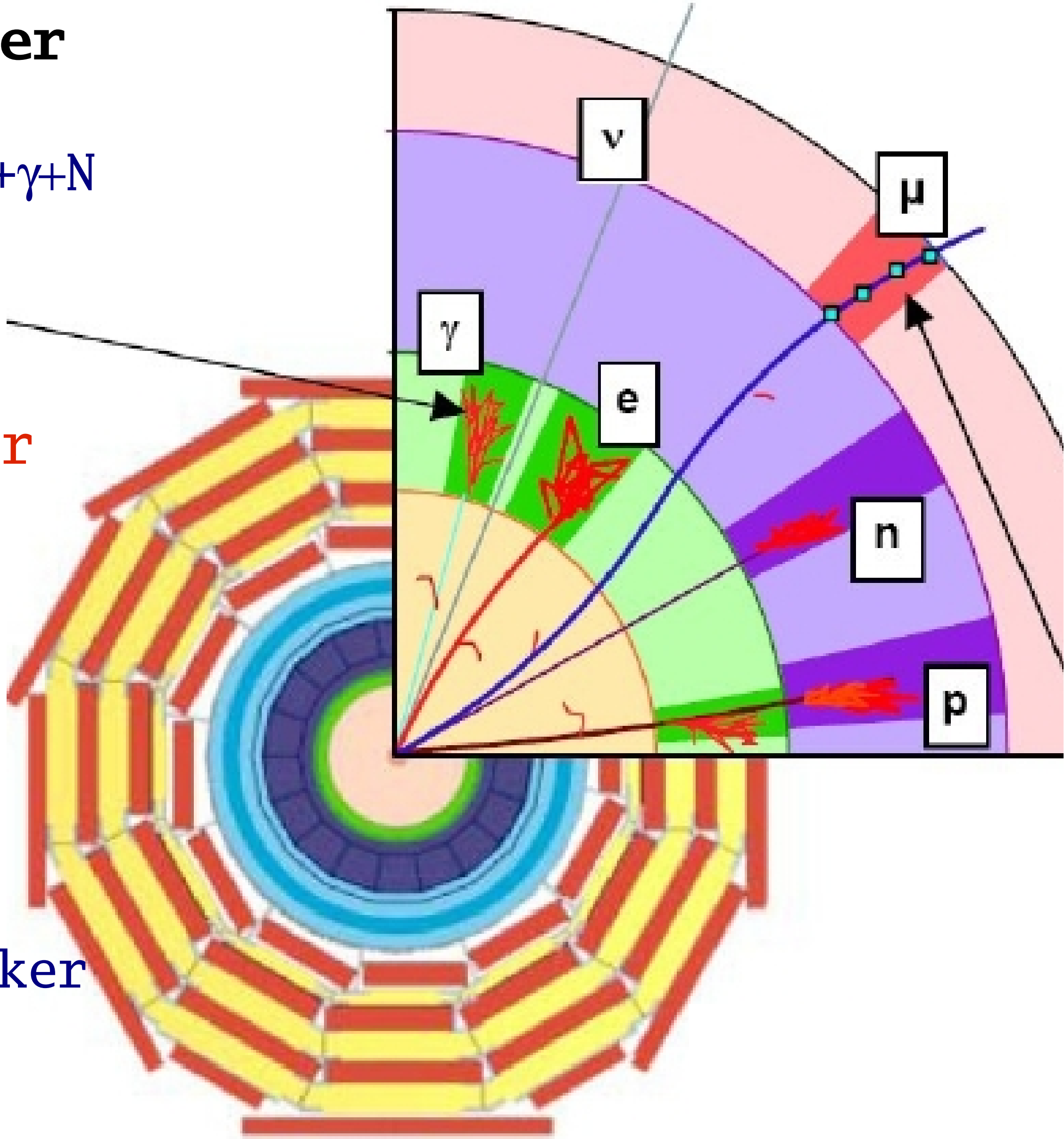
Energy fully contained in ECAL: small H/E

e: matching track in tracker

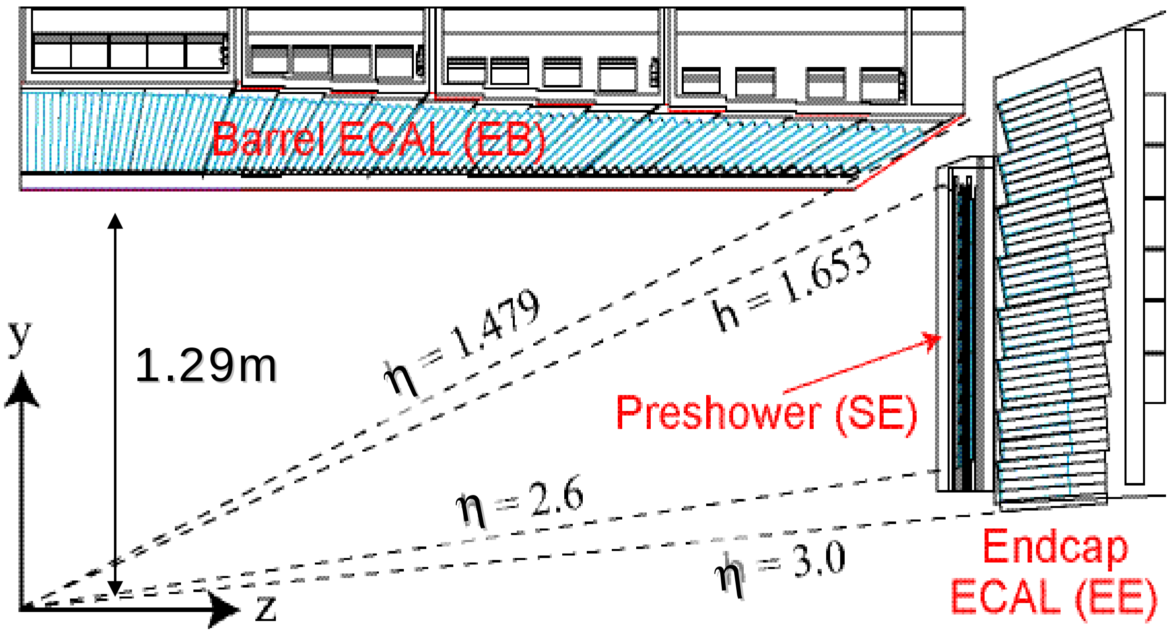
γ: "no track" in tracker

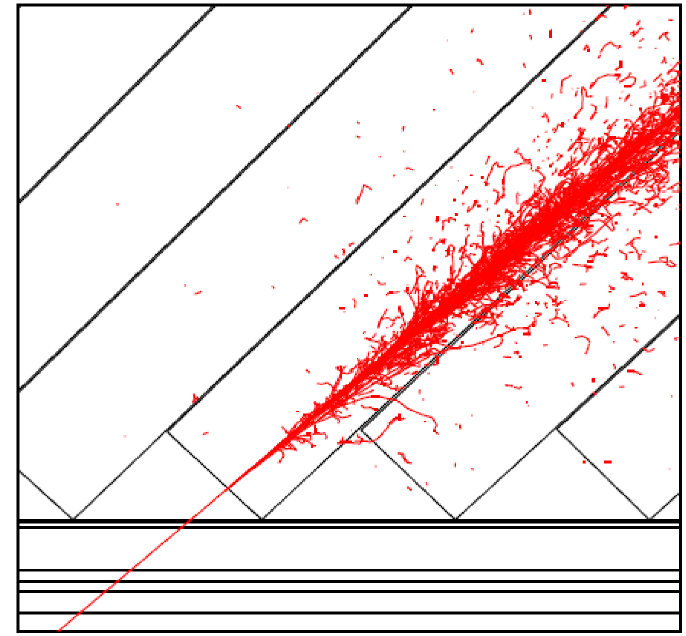
narrow shower

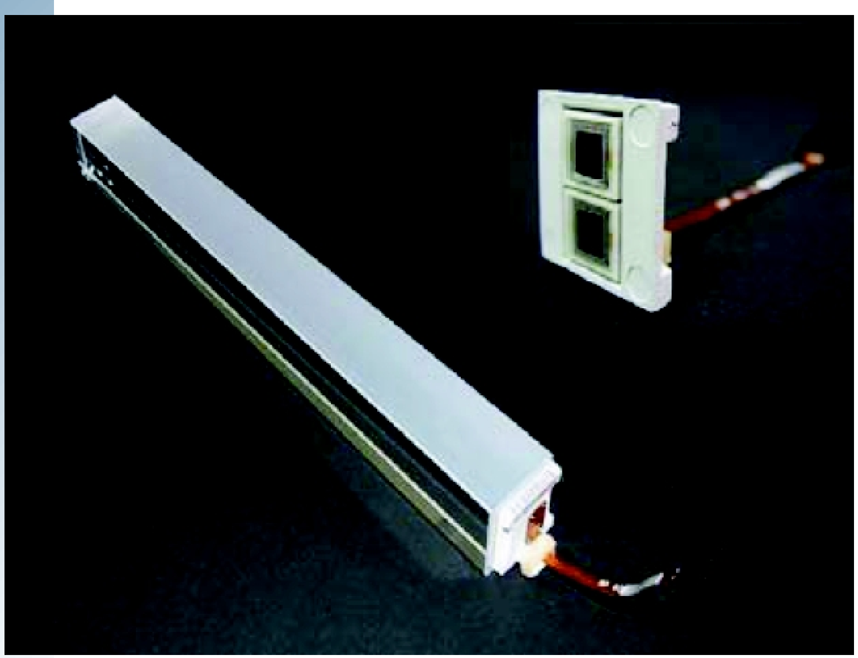
isolation



The CMS ECAL







$PbWO_4$ scintillating crystals

Radiation length X_0 = 0.89 cm

Moliere radius = 2.2 cm

Barrel (EB):

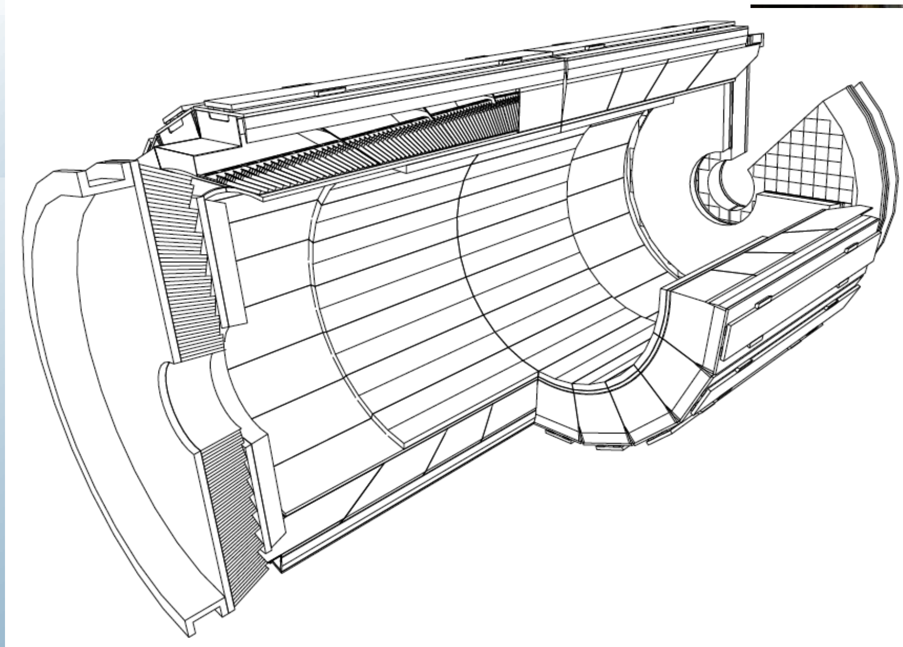
Front face dimensions: 0.0174×0.0174 in η×ϕ ($22 \times 22 mm^2$)

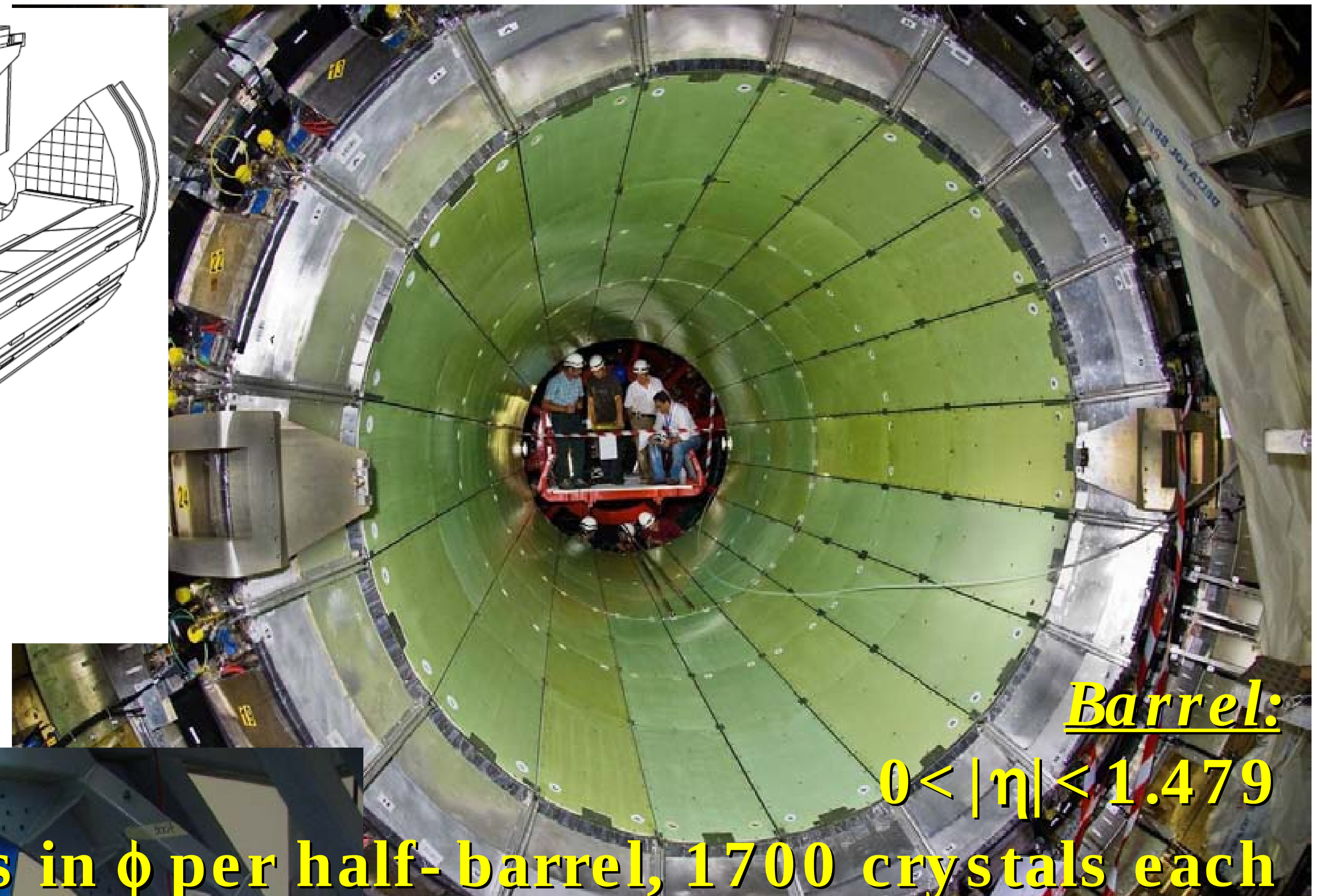
Crystal depth: $25.8X_0$ (230mm)

Endcaps (EE):

$29x29mm^2$ front face, $24.7X_0$

Preshower ($3X_0$)





Barrel:

0<|η|<1.479

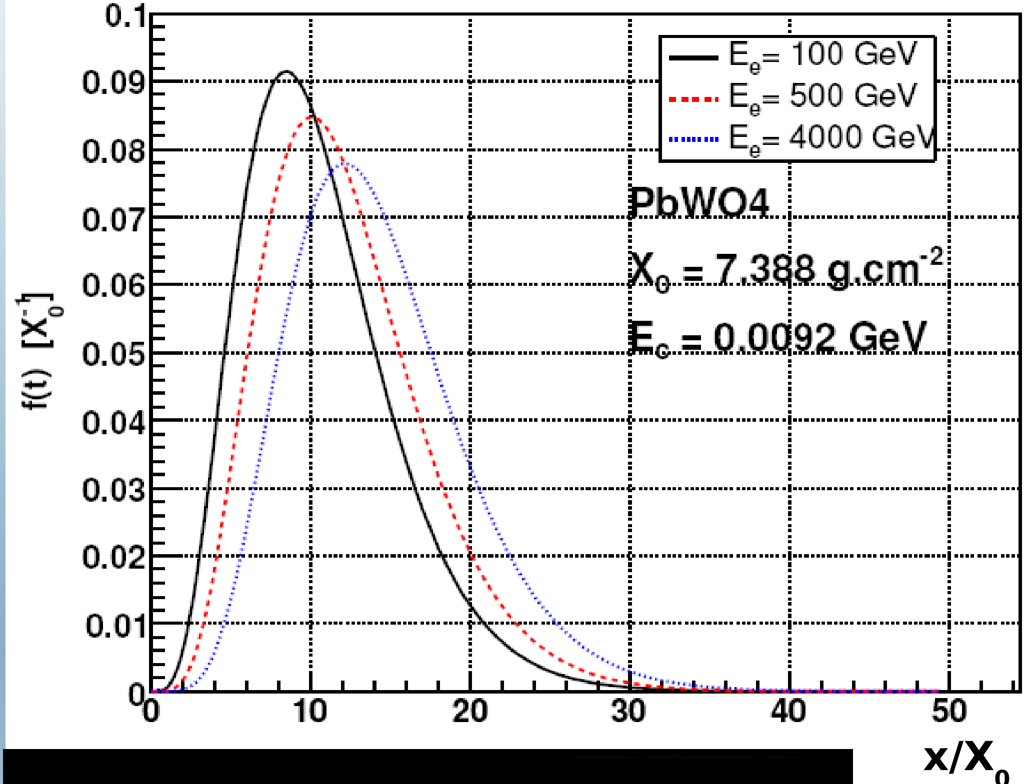
18 supermodules in ϕ per half-barrel, 1700 crystals each

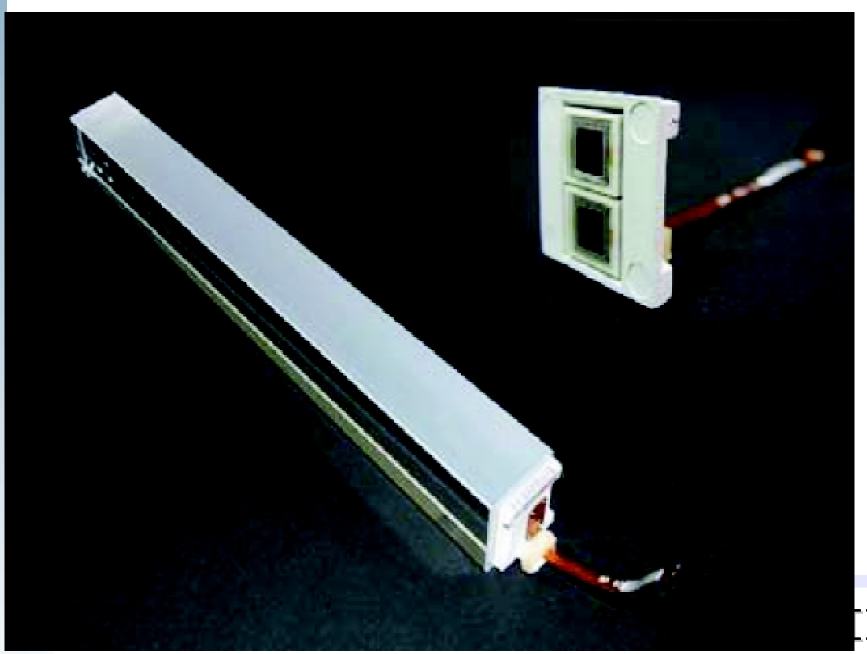
4 modules in η per supermodule

Endcaps:

1.479<|η|<3

4 Dees, 3662 crystals each grouped in 5x5 matrices (supercrystals)





EM shower containment

- ~fully contained in $26X_0$
- 5x5 crystal matrix contains 96.5% of energy of incident photon in EB

Readout of scintillation light:

- APD (barrel – gain~50)
- VPT (endcaps – gain~10)

Light yield:

- ~4.5 photoelectrons/MeV
- temperature-dependent
  - T° stability to 0.01°C
- bias voltage-dependent
  - V stability to 10mV

Crystal transparency:

- dose-rate-dependent
  - monitored by laser light to 0.2% level

Energy resolution

$$\left(\frac{\sigma}{E}\right)^2 = \left(\frac{S}{\sqrt{E}}\right)^2 + \left(\frac{N}{E}\right)^2 + C^2$$

Stochastic term (S)

photo-statistics

shower fluctuations

Noise term (N)

electronics noise

Constant term (C)

non-uniformity of response

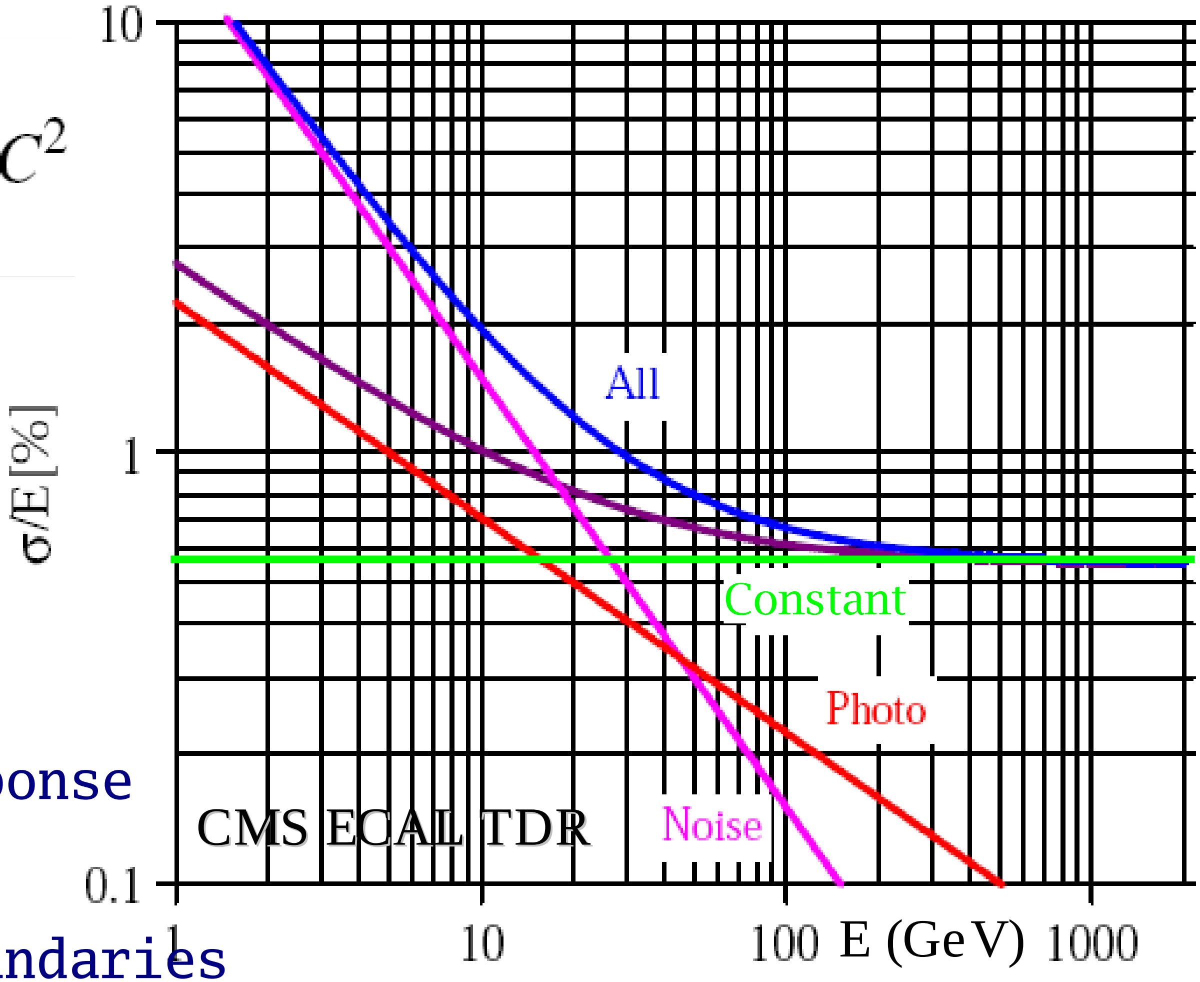
- between crystals
- with η
- across module boundaries
- across one crystal

main sources:

light yield RMS ~ 15%

VPT gain RMS ~ 25%

Channel intercalibration = main challenge



Design goal:

$S = 2.7\% * GeV^{0.5}$

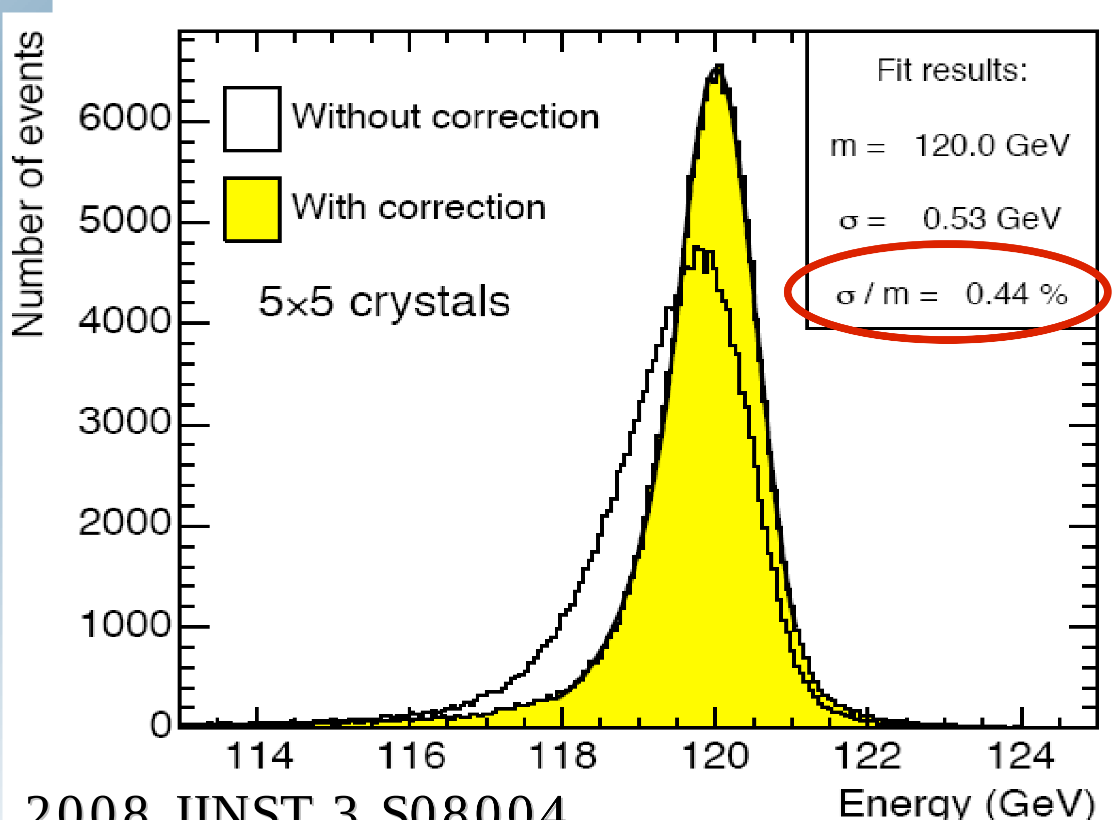
$N < 0.2 GeV$

$C = 0.55\%$

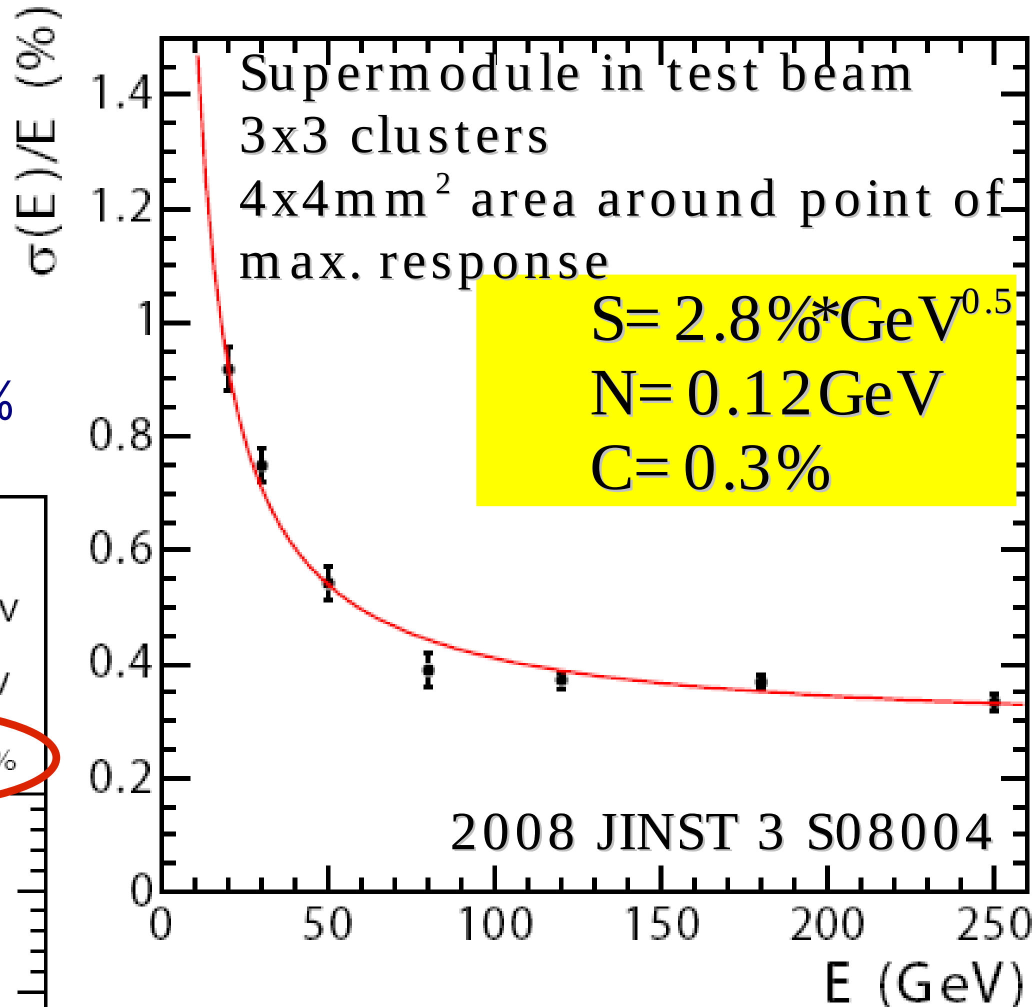
ECAL calibration

Pre-calibrations

- Light yield with ^{60}Co source
  - RMS: ~5% in EB
  - ~10% in EE
- Test beams for ¼ of barrel supermodules
  - intercalibration to 0.3%

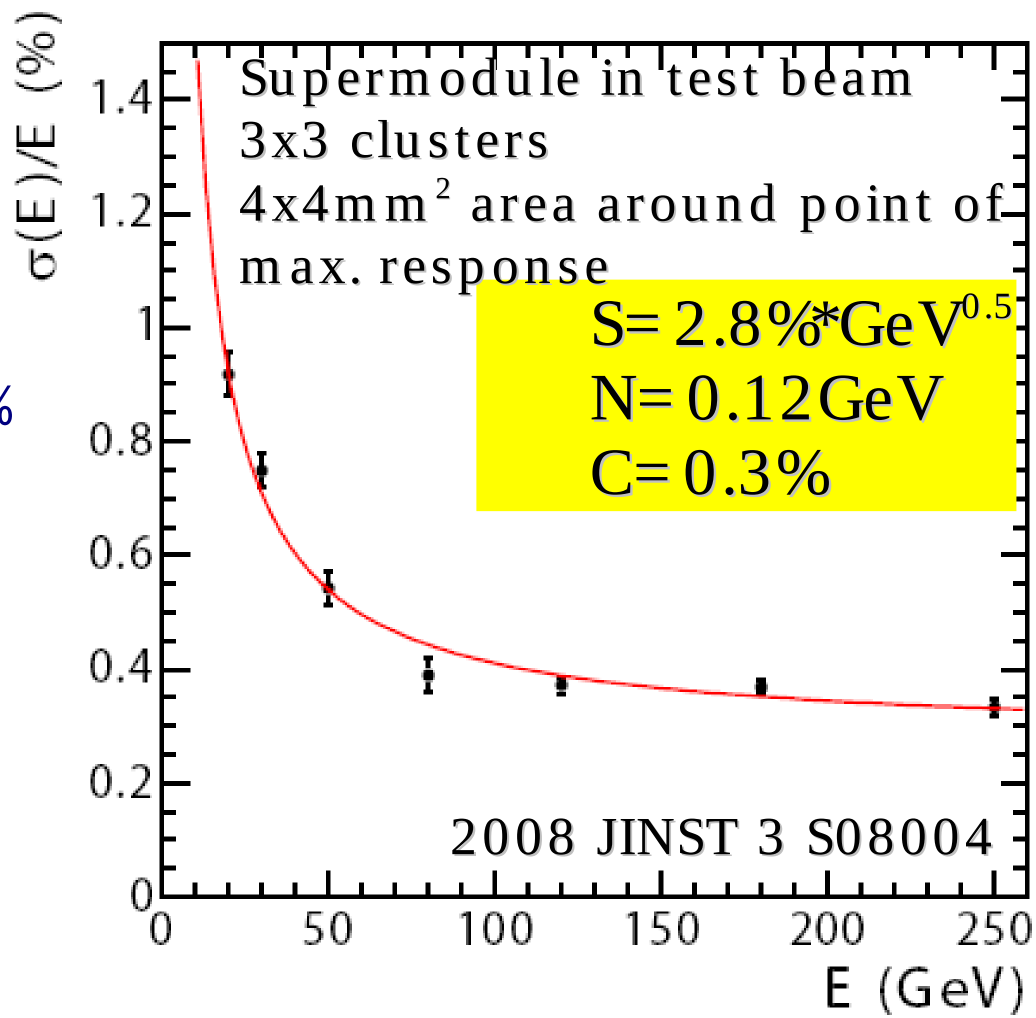


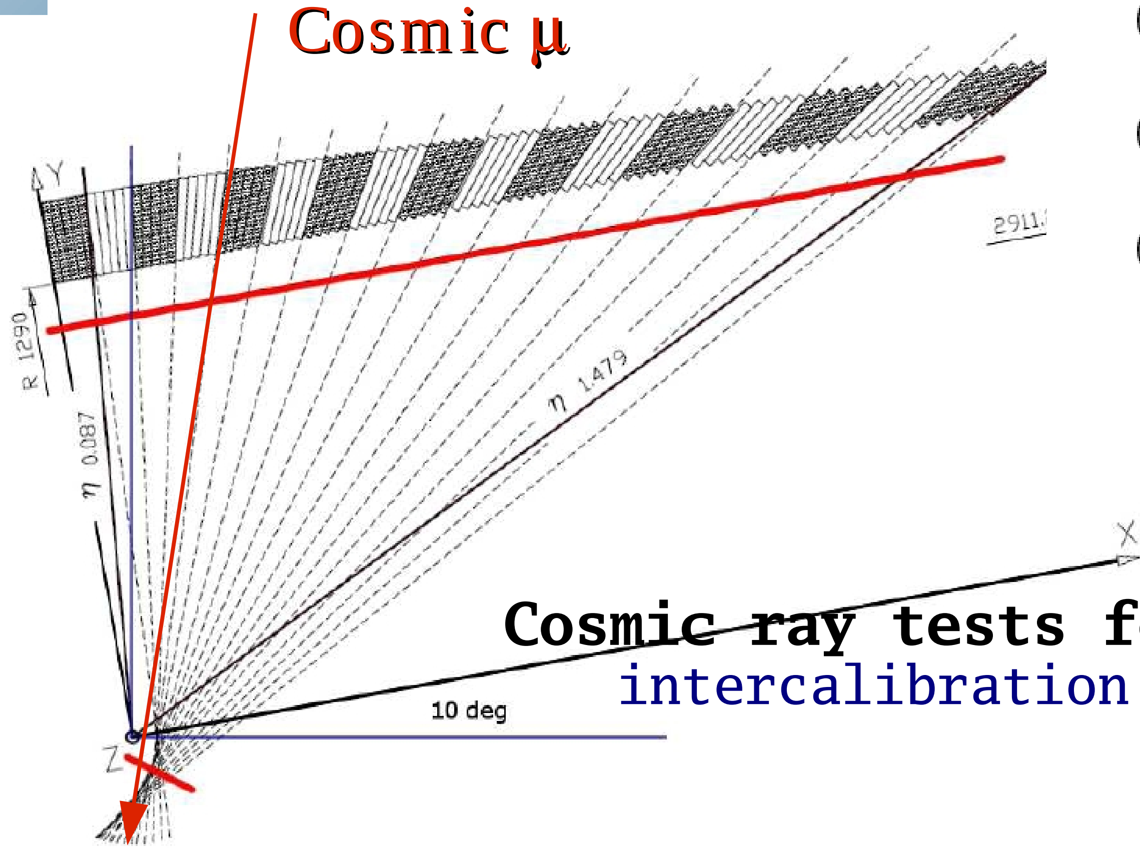
2008 JINST 3 S08004



Pre-calibrations

- Light yield with ^{60}Co source
  - RMS: ~5% in EB
  - ~10% in EE
- Test beams for ¼ of barrel supermodules
  - intercalibration to 0.3%





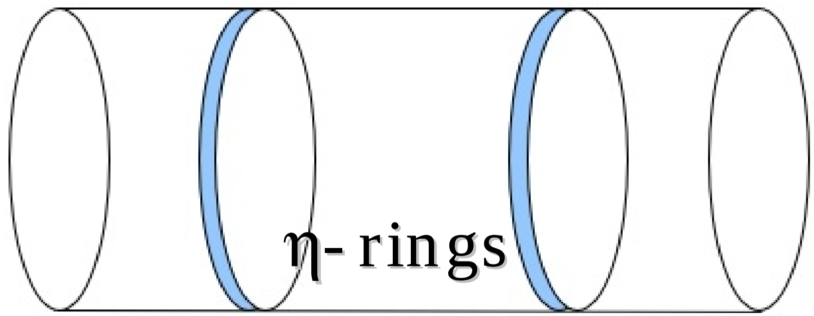
Cosmic ray tests for all barrel supermodules

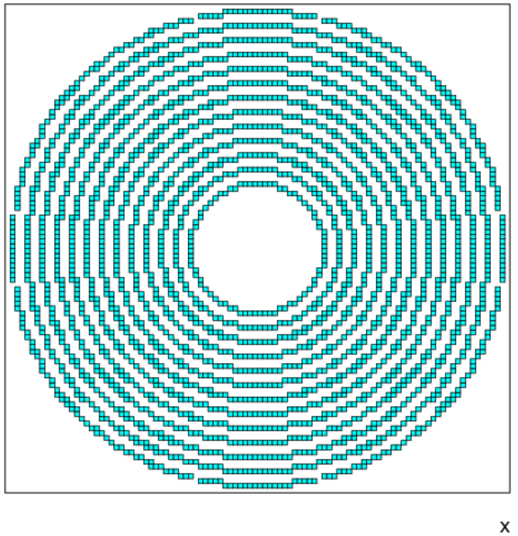
intercalibration to 1.4-2.2%

ECAL calibration

Intercalibration with LHC data

- ϕ-symmetry of average energy deposition

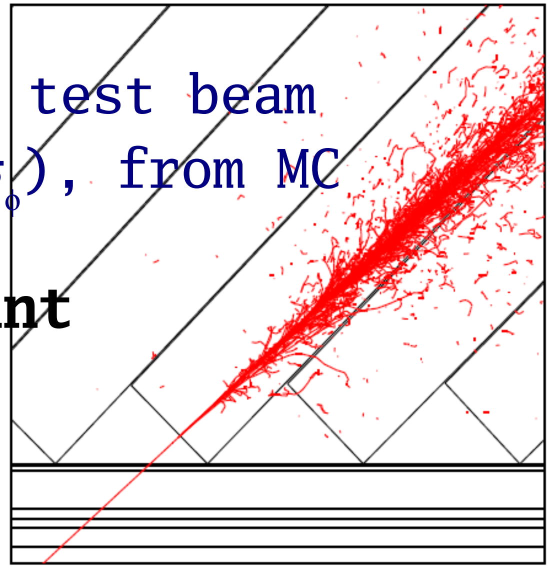




- π^0 and η invariant mass reconstruction
- E–p matching for electrons from $W \rightarrow e\nu$
  ~70,000 selected at 14 TeV per $10 pb^{-1}$

Energy corrections

- Lateral leakage correction $f_{5x5}(\eta)$, from test beam
- Bremsstrahlung-sensitive correction $f(\sigma_\phi)$, from MC
- Local containment correction...



Energy scale $f(\eta, E_T)$ from Z-mass constraint

- $Z \rightarrow ee$
  ~4,000 selected at 14 TeV per $10 pb^{-1}$
- $Z \rightarrow \mu\mu\gamma$
  pure photon sample

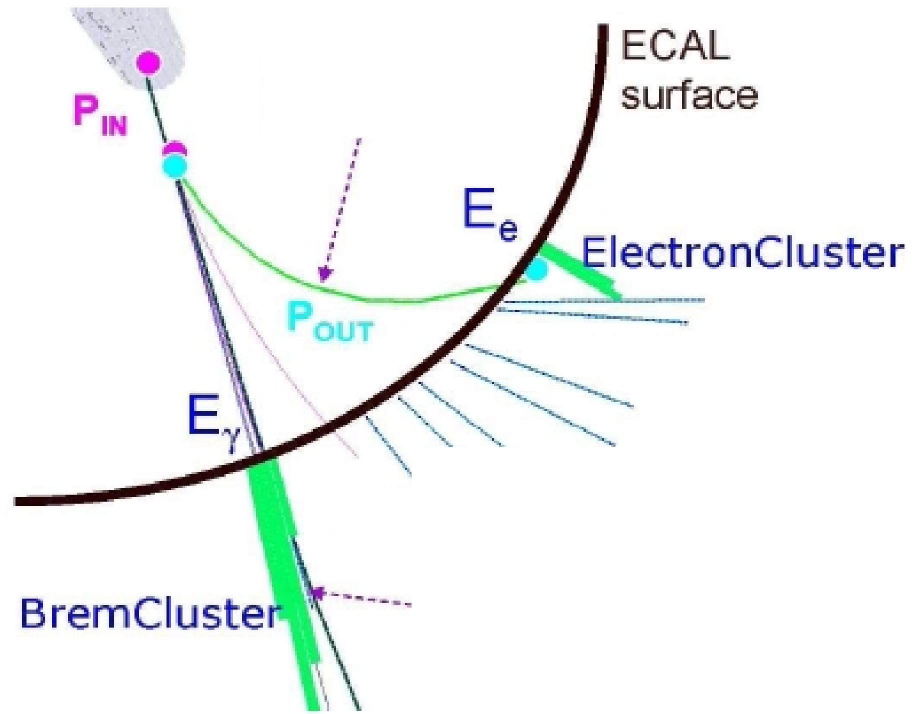
Energy reconstruction

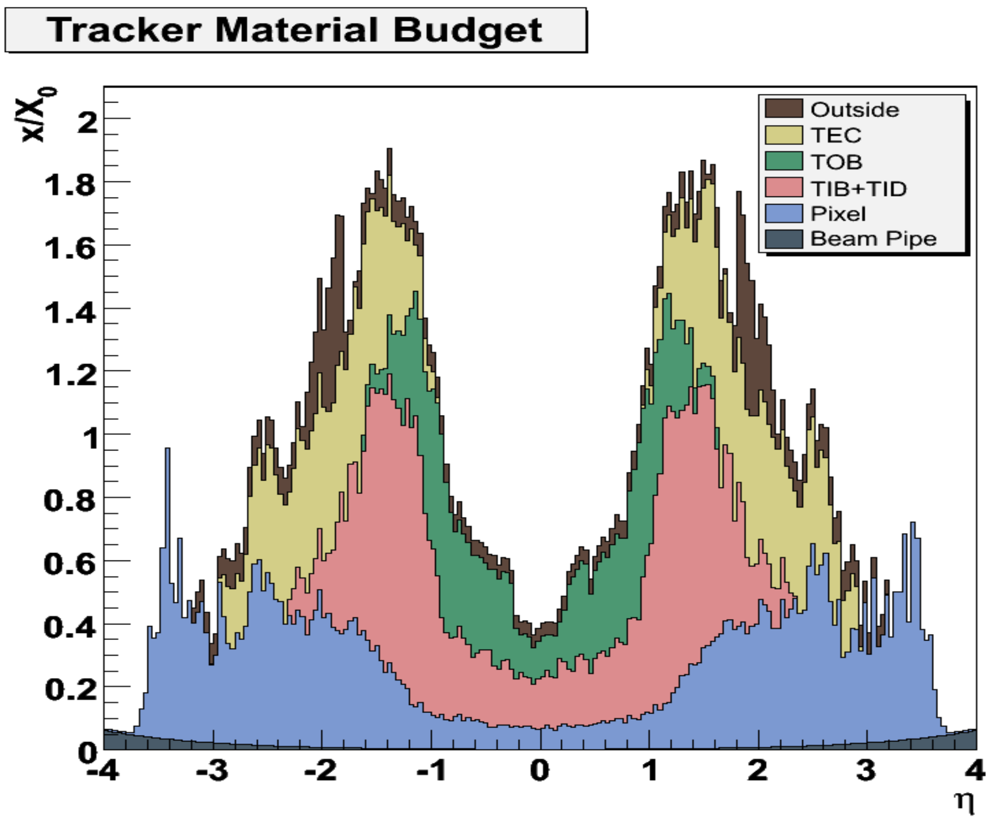
Reminder:

5x5 matrix contains 96.5% (97.5%) of unconverted photon energy in EB (EE)

Due to tracker material:

- electrons radiate on average ~70% of their energy in the tracker by bremsstrahlung
- photons have >50% probability to convert into e^+e^- pair
- energy spreads in ϕ due to B-field





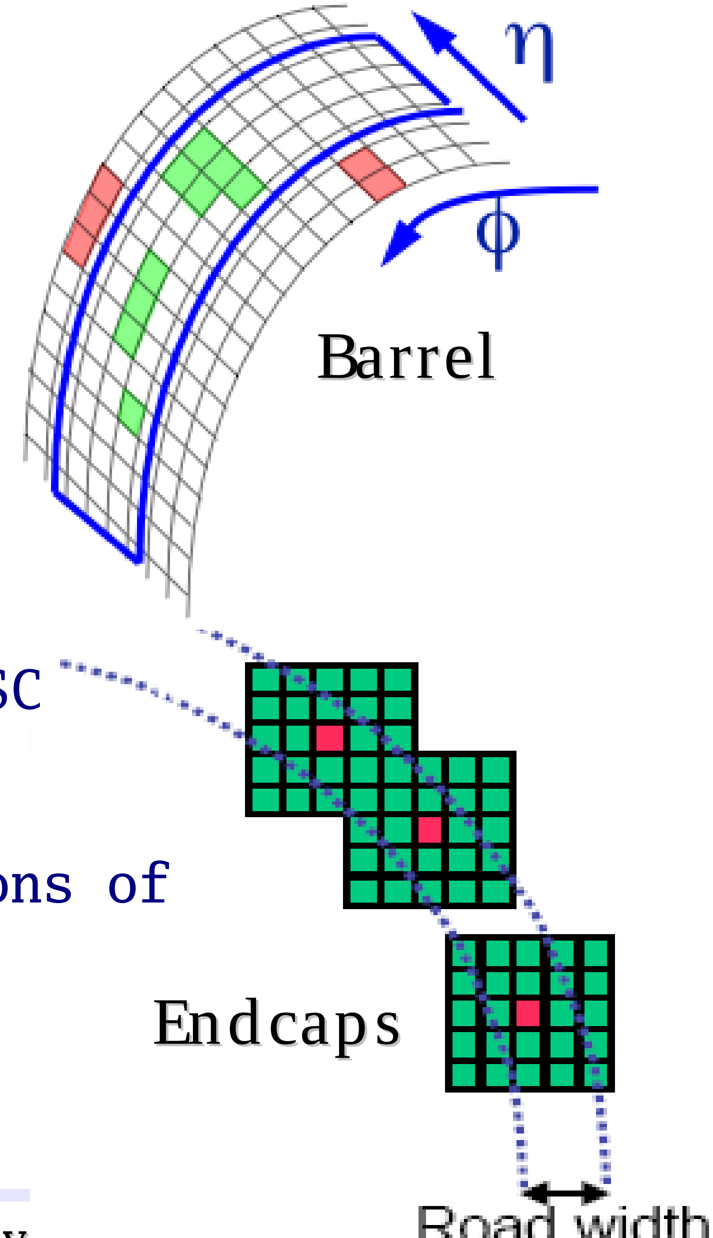
Energy reconstruction

SuperClusters (SC) aim at recovering energy of brem. photons (and conversion pairs)

In Barrel: “hybrid” algorithm

- search for highest E_T crystal
- make dominoes of narrow η-width (5 crystals)
- collect dominoes in long ϕ-road around seed (+/-17 crystals)

In Endcaps: “multi5x5” algorithm



Energy estimation:
sum of energy of all crystals in SC

Position determination:
energy-weighted average of positions of crystals in SC

$$x = \frac{\sum x_i \cdot W_i}{\sum W_i} \qquad W_i = W_0 + \log\left(\frac{E_i}{\sum E_j}\right)$$

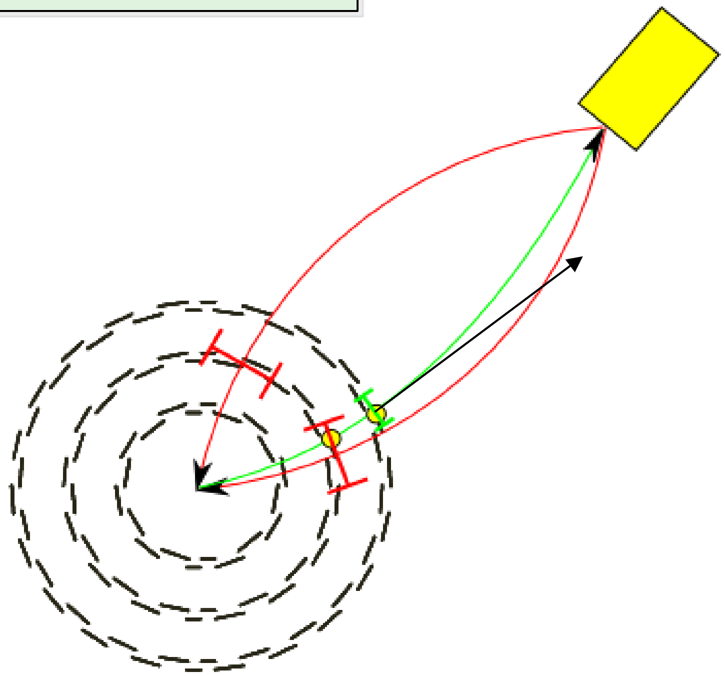
Electron reconstruction

SuperCluster

Trajectory Seed

→ Electron Seed → Electron TrackCandidate → Electron Gsf track → **GsfElectron**

Pre-selection → GsfElectron



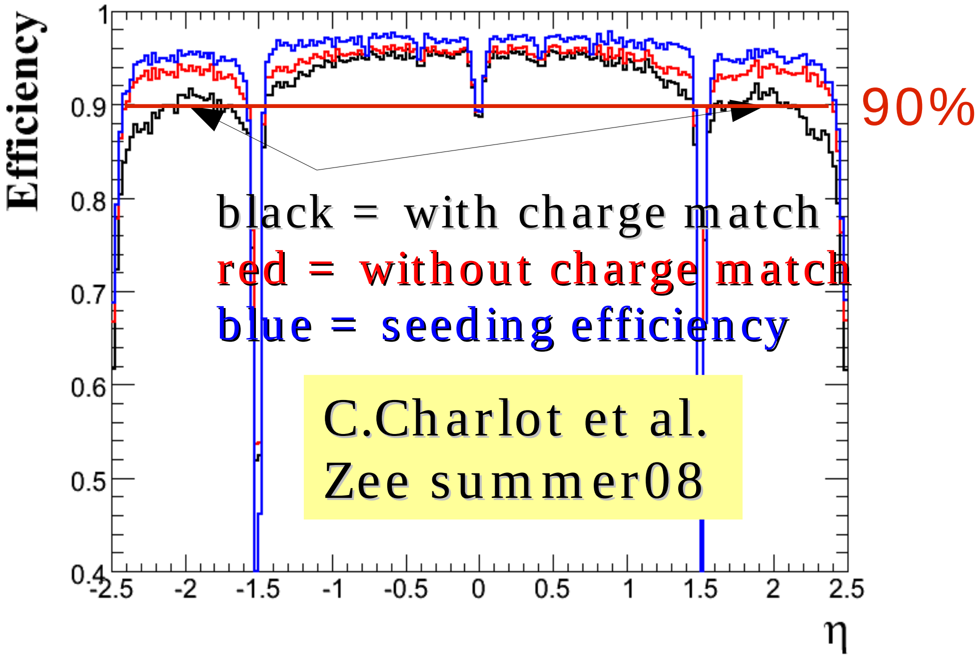
Track finding:

- CTF builder
- Electron loss modeling
- Loose χ^2 cut
- Reduced #candidates per layer

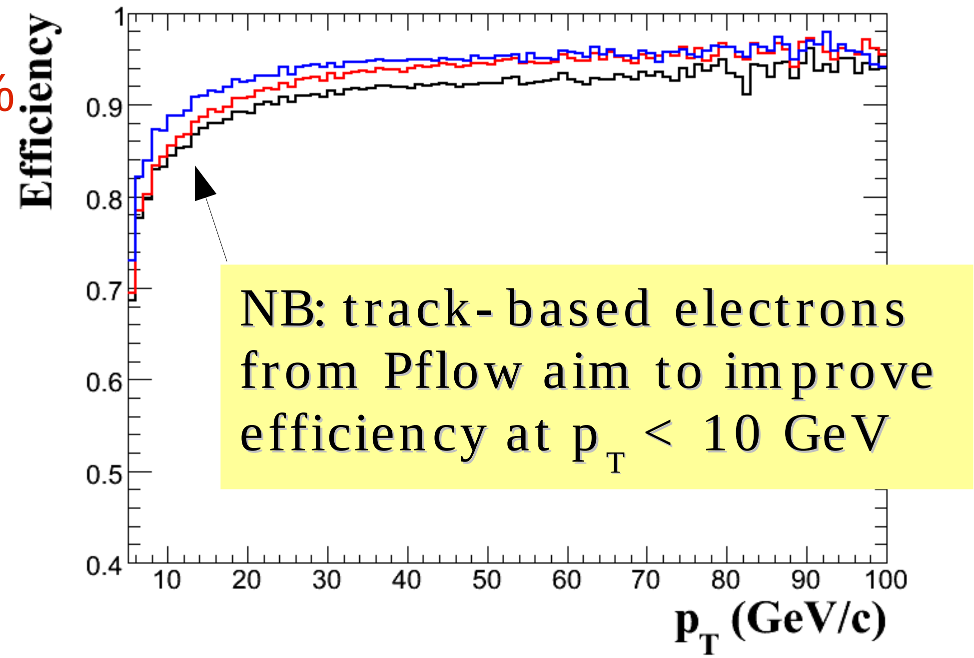
Gsf track fit:

- Electron loss modeling
- Mode of the gaussian mixture used for p_{ele}
- Brem fraction

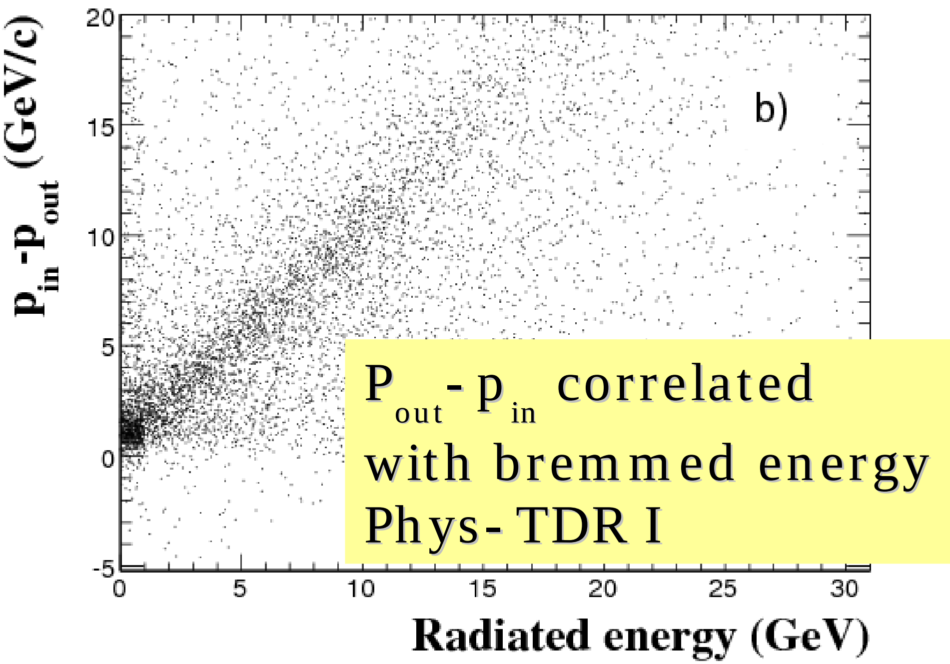
Performance



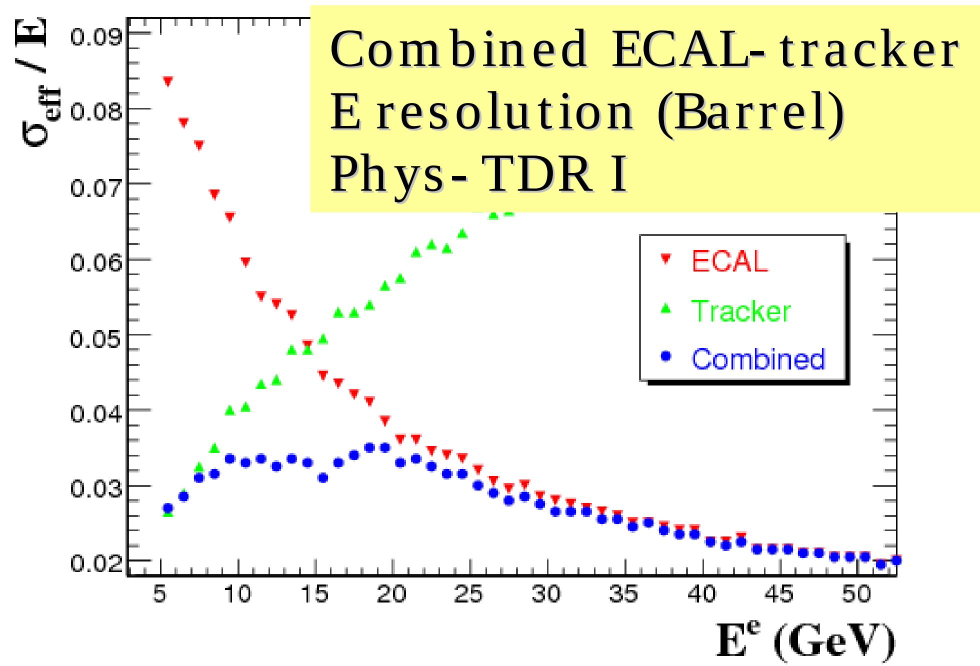
C.Charlot et al.
Zee summer08



NB: track-based electrons from Pflow aim to improve efficiency at $p_T < 10$ GeV



P_{out} - p_{in} correlated with bremmed energy
Phys-TDR I



Combined ECAL-tracker E resolution (Barrel)
Phys-TDR I

Electron identification

Reconstruction makes ~1 fake electron per jet event

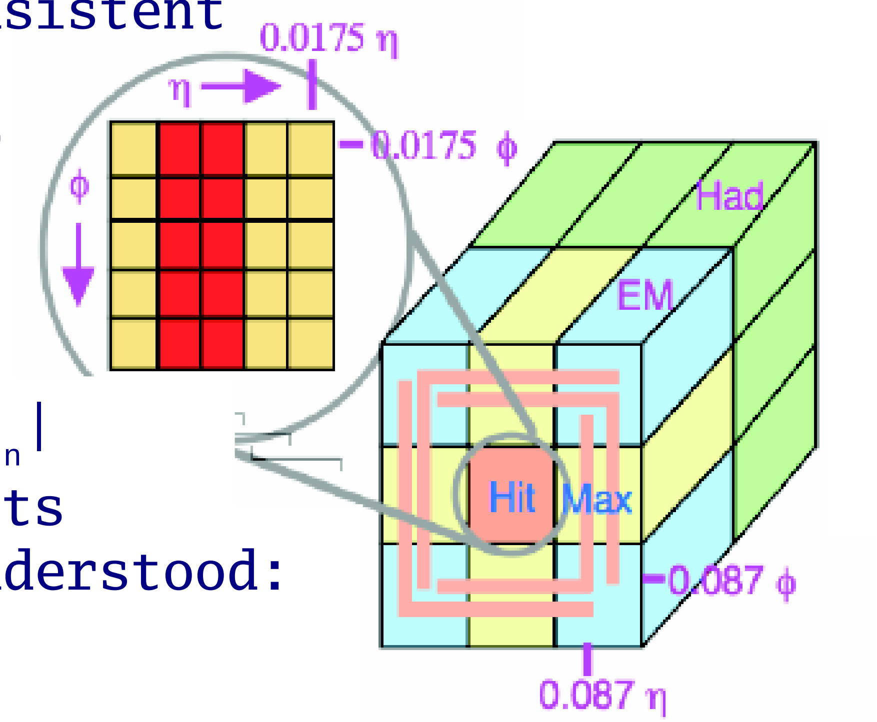
- Tuned for efficiency rather than for purity

Electron ID:

- Test if electron candidate is consistent with electron properties
- Reduce fake rate by factor ~10–50

At startup:

- Cuts on robust variables
  - H/E, shower width in η
  - track–SC matching $|\Delta\eta_{in}|$, $|\Delta\phi_{in}|$
  - loose and tight working points
- When electron tracking is well understood:
  - E_{SC}/p_{in}, $f_{brem}=(p_{in}-p_{out})p_{in}$
  - E_{seed}/p_{out}

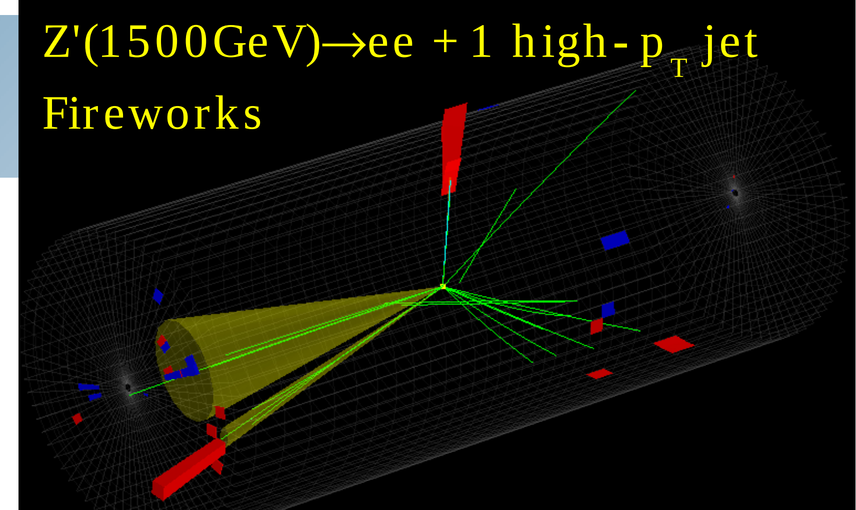


H/E, η-shape at trigger L1

Two multivariate methods also ready

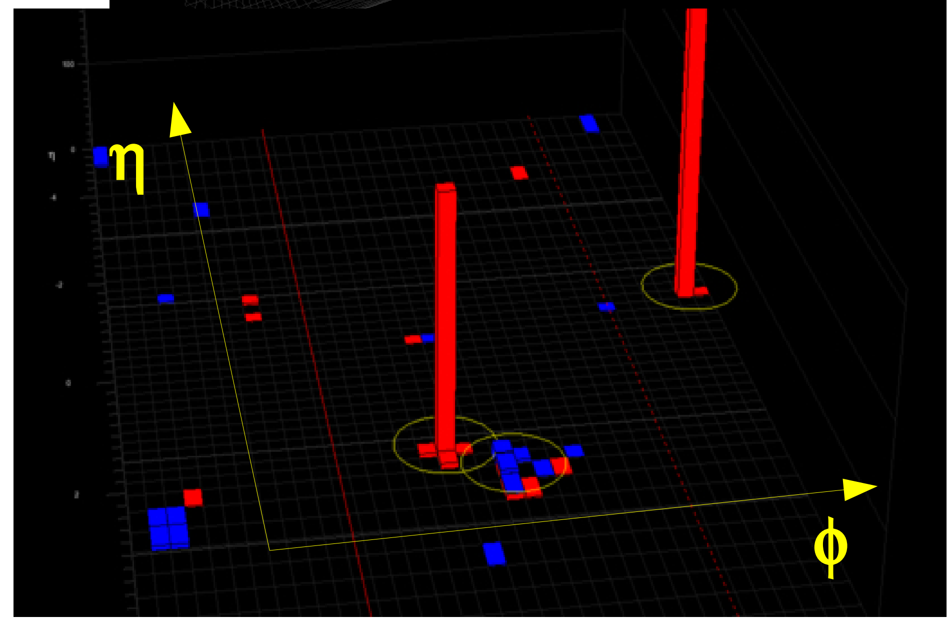
- Likelihood ratio, Neural net

Isolation



Fake $e^{+/-}$ are due to jets

- overlaps of $\pi^{+/-}$ and γ from π^0
- early conversion of γ from π^0 decay...

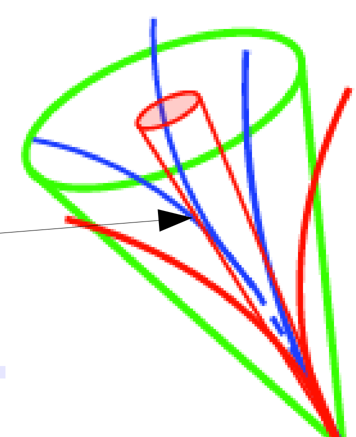


Not isolated: in cone of aperture $\Delta R=\sqrt{(\Delta\phi^2+\Delta\eta^2)}$ there are

- tracks from charged hadrons
- deposits in ECAL
  π^0, early hadron showers
- deposits in HCAL
  hadron showers

Cuts on ΣE_T of tracks, ECAL and HCAL deposits

- reject fakes (also factor ~100)
- keep isolated electrons
  NB: must remove electron track
  and energy from sums
  (veto cones)

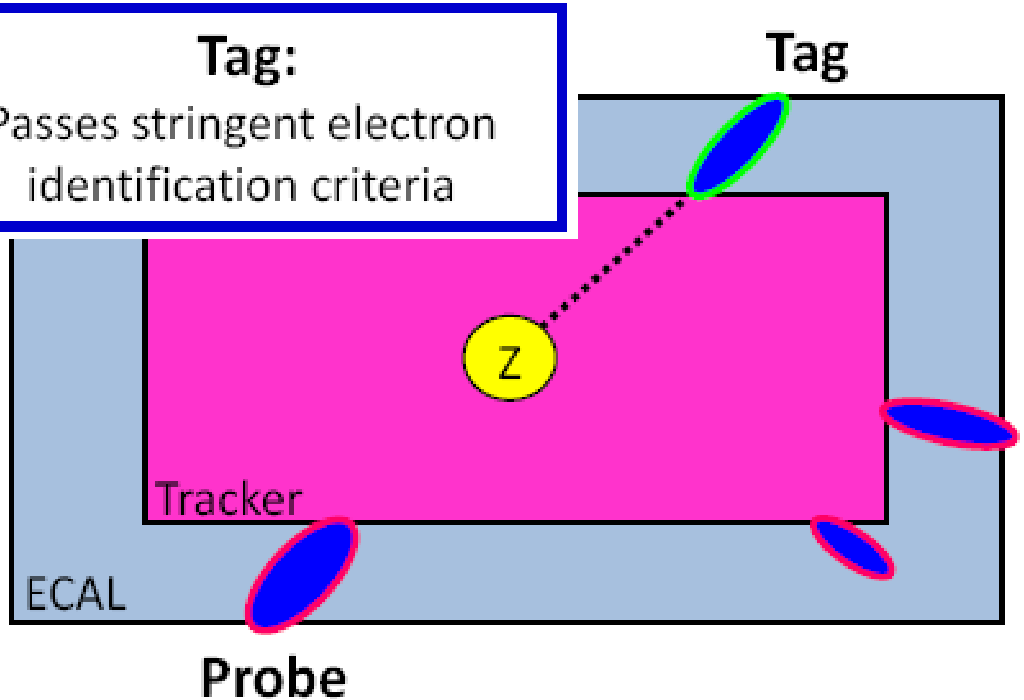


Efficiency measurement from data

Selection efficiencies need to be known e.g. for estimating cross-sections

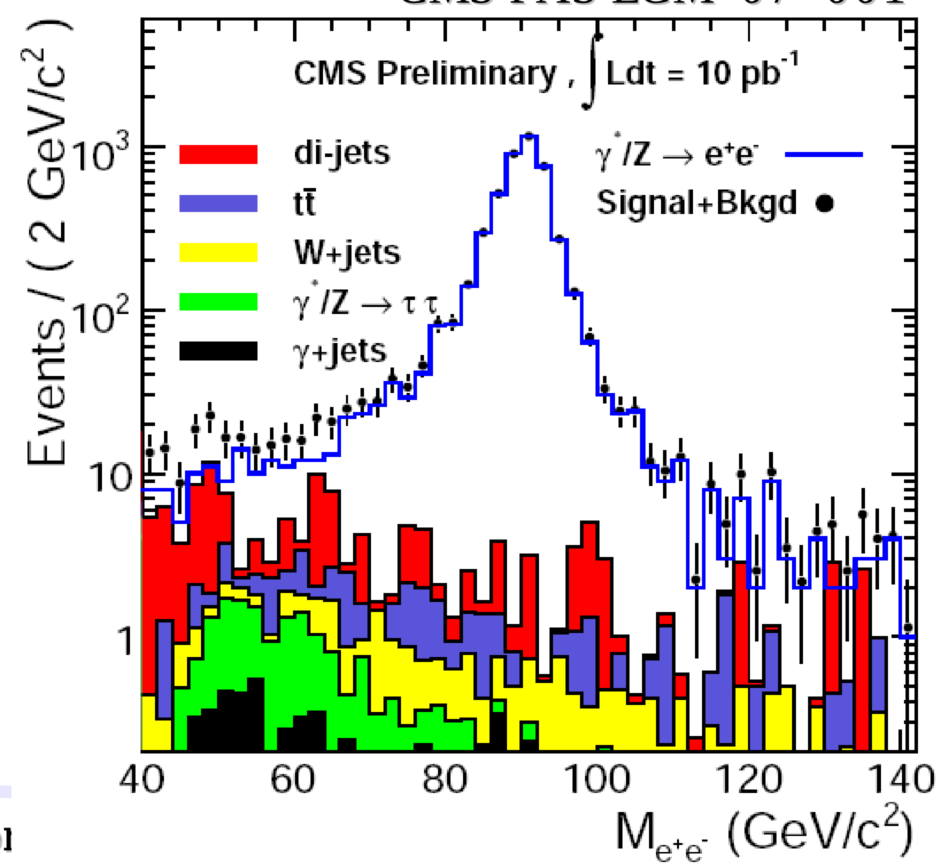
$Z \to e^+e^-$ provides large, pure sample of electrons that are unbiased wrt. the selection efficiency studied

Tag:
Passes stringent electron identification criteria



Probe:
Passes a set of identification criteria depending on the efficiency under study

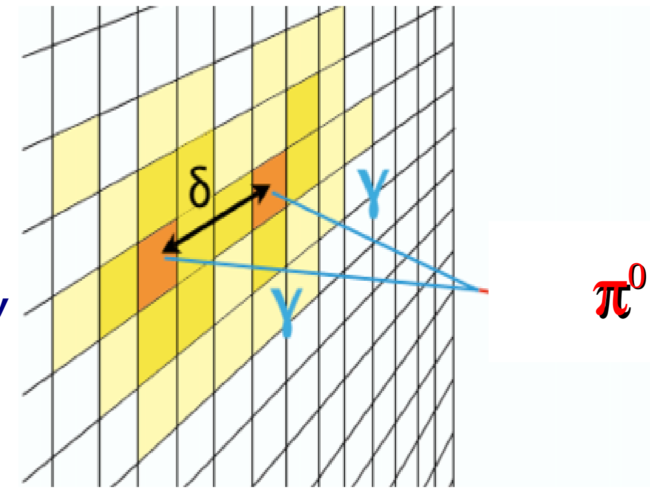
CMS PAS EWK-08-005
CMS PAS EGM-07-001



Photon selection

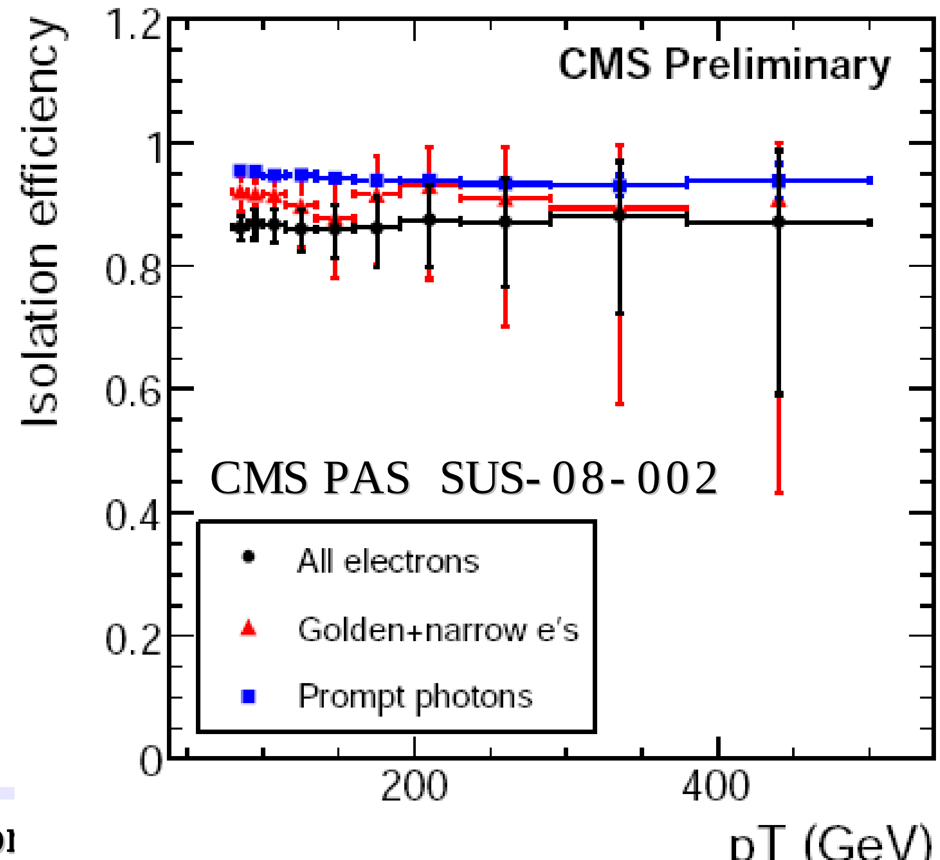
Variables used

- isolation
- shower shape
  - in particular $R_9 = E_{3x3}/E_{SC}$
  - • both a selection of unconverted γ
    - →better energy resolution
  - • and rejection of π^0



Validation from data

- $10pb^{-1}$: $Z \rightarrow e^+e^-$
  - apply γ selection on e
  - apply tag-and-probe method
- final-state photons from
  - $Z \rightarrow \mu^+\mu^-\gamma$
    - need ~$1fb^{-1}$ of data



Trigger

Cross-sections, event rates at 14 TeV, $L=10^{32}\ cm^{-2}s^{-1}$

Jets (q,g): ~10μb, 1000/s

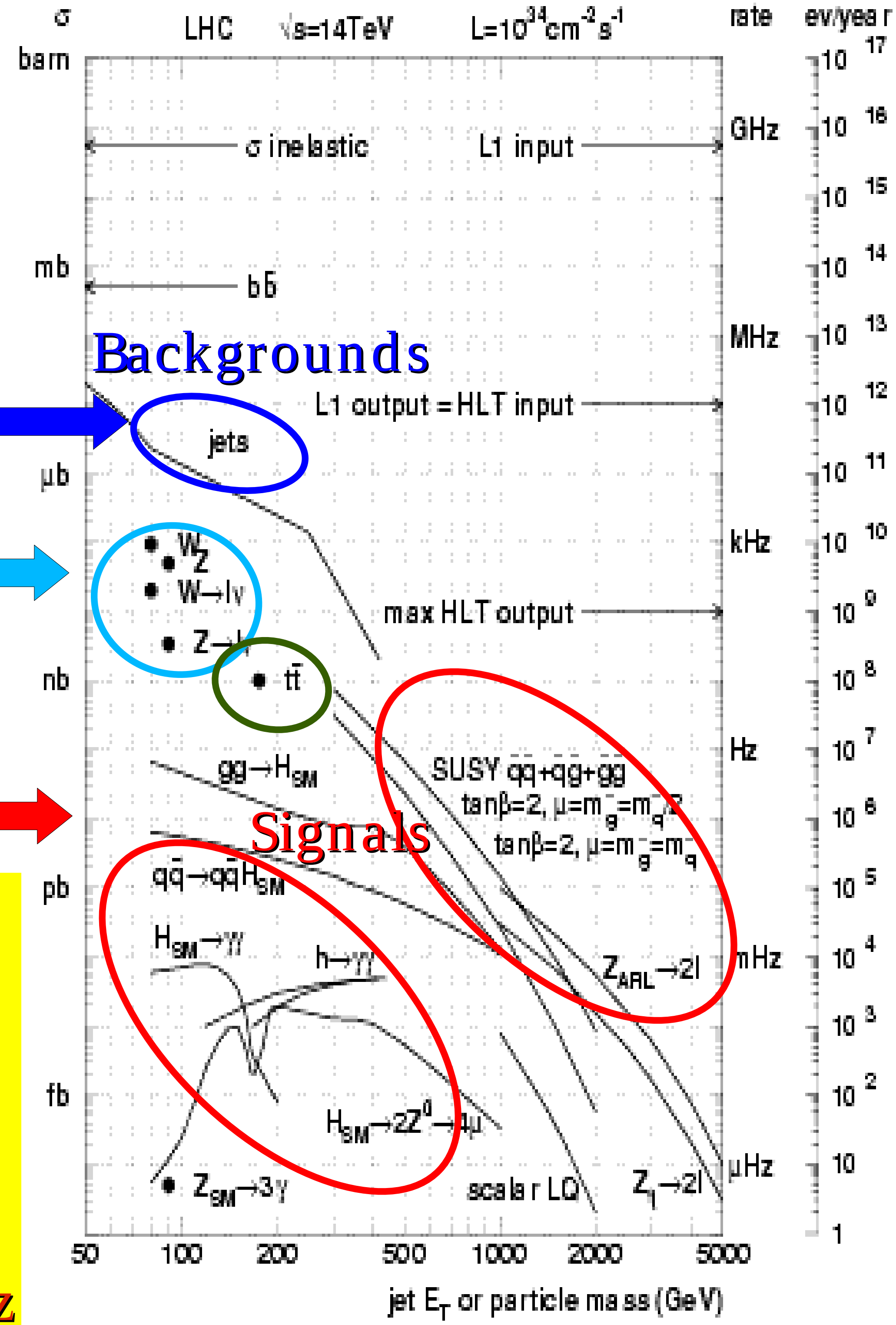
$W \to e\nu$: ~20 nb, 2/s

$Z \to e^+e^-$: ~2 nb, 0.2/s

SUSY (M~500 GeV): O(10) pb

Z'(M~1 TeV)$\to e^+e^-$: O(1) pb

$H \to 4l^{+/-}$: ~10 fb



Reduce rate at L1 by:

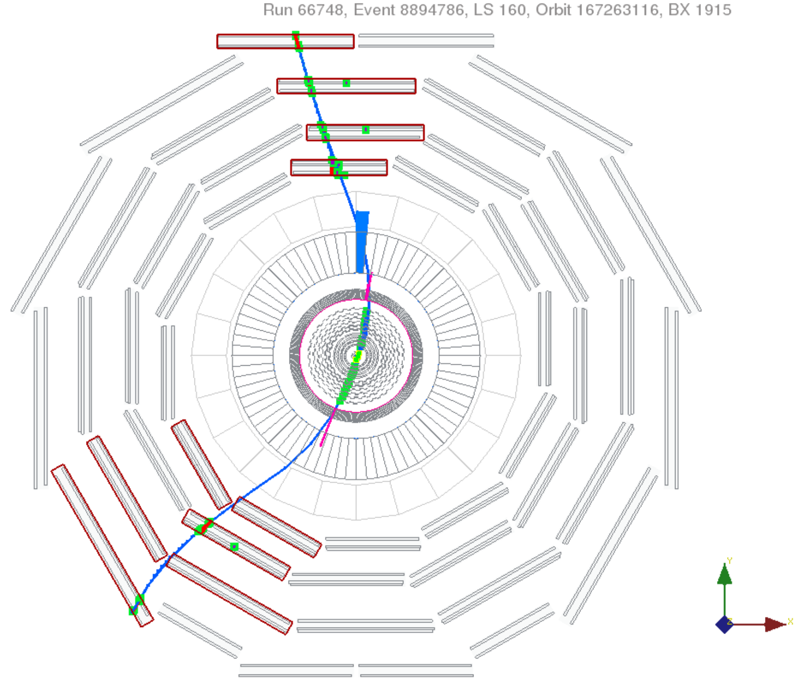
- E_T cut
- Shower shape cuts
- Isolation cuts

and in HLT farm by:

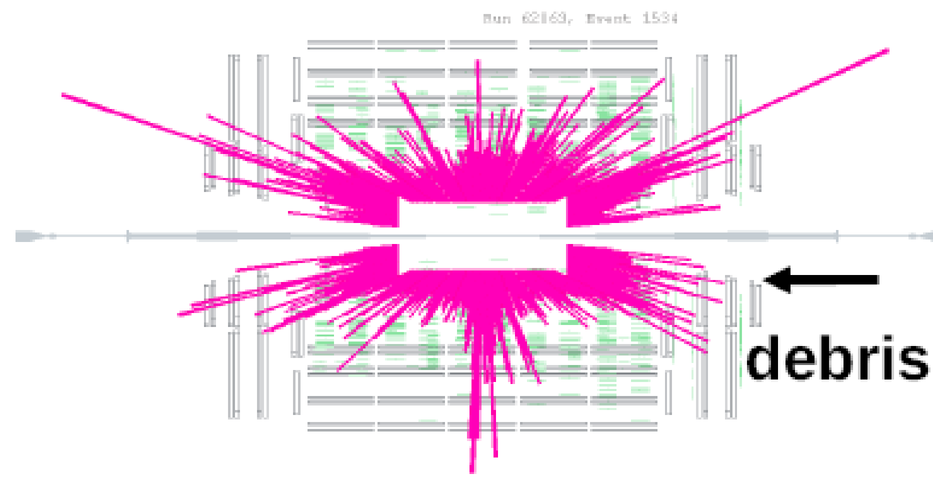
- Same + Track matching cuts

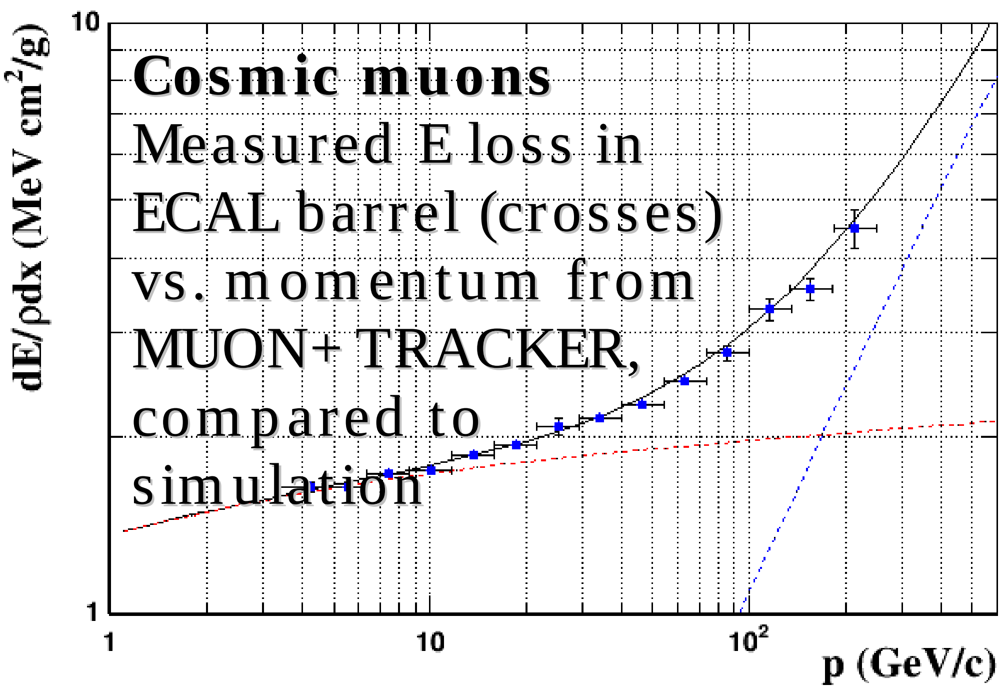
Final rate for EM triggers~ 20 Hz

Tests in cosmic rays and beam splashes

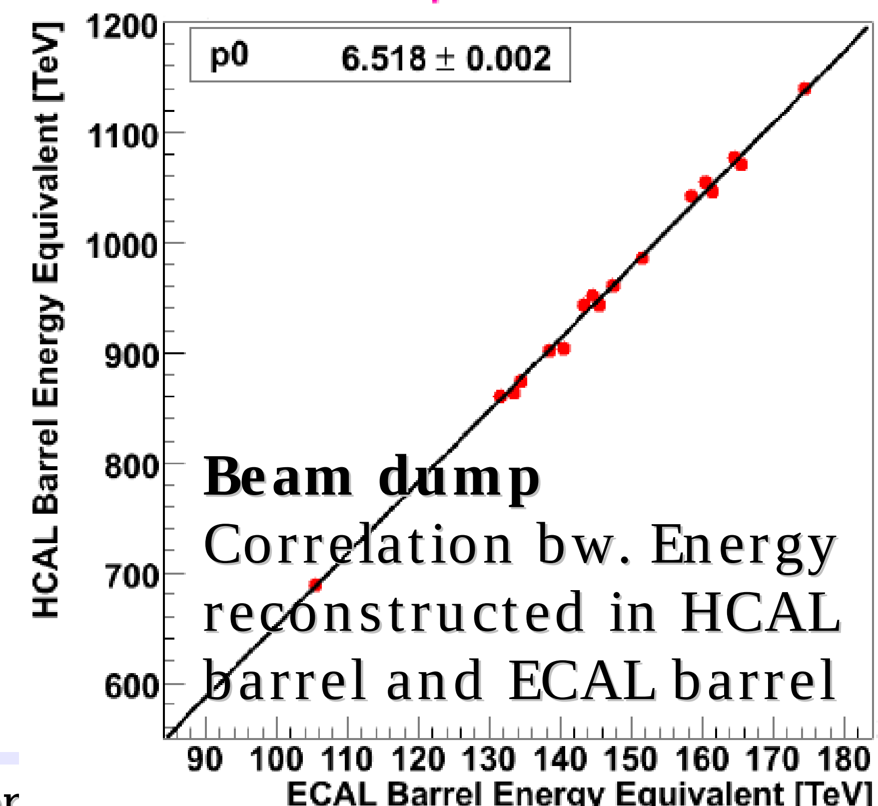


ECAL energy





Cosmic muons
Measured E loss in ECAL barrel (crosses) vs. momentum from MUON+ TRACKER, compared to simulation



Beam dump
Correlation bw. Energy reconstructed in HCAL barrel and ECAL barrel

Conclusions

We are in good shape for data taking

- CMS works beautifully
- Photon and electron reconstruction programs are in good shape

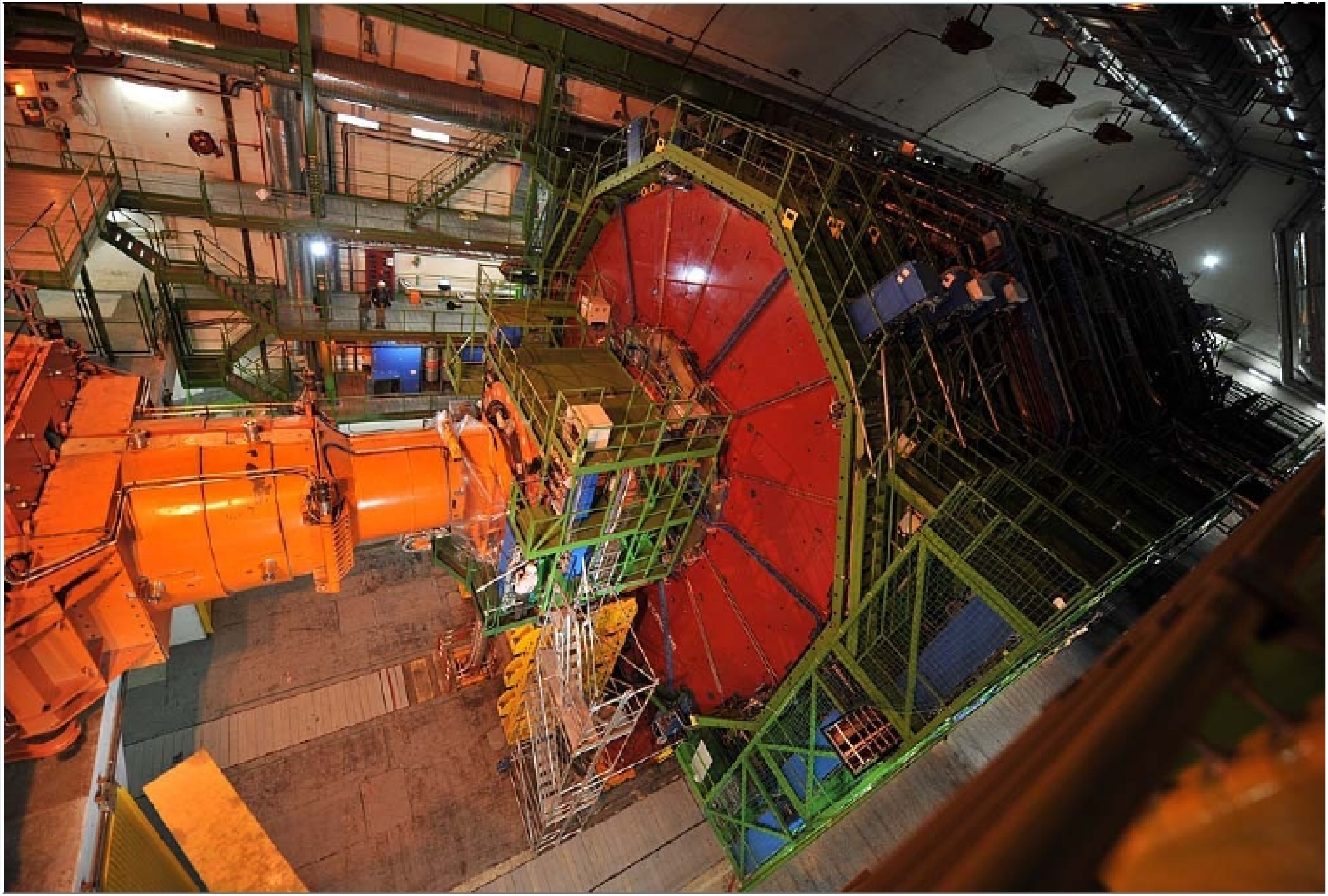
Main issues

- ECAL calibration with data
- Electron and photon triggers for luminosities beyond 10^{32} $cm^{-2}s^{-1}$
- Electron selection efficiency

Data-driven procedures in place

- Rely on $Z \rightarrow e^+e^-$ events
- Waiting for beam !

CMS closed – July 2008



Backup

Benchmark channels with electrons

H→ZZ*→e⁺e⁻e⁺e⁻

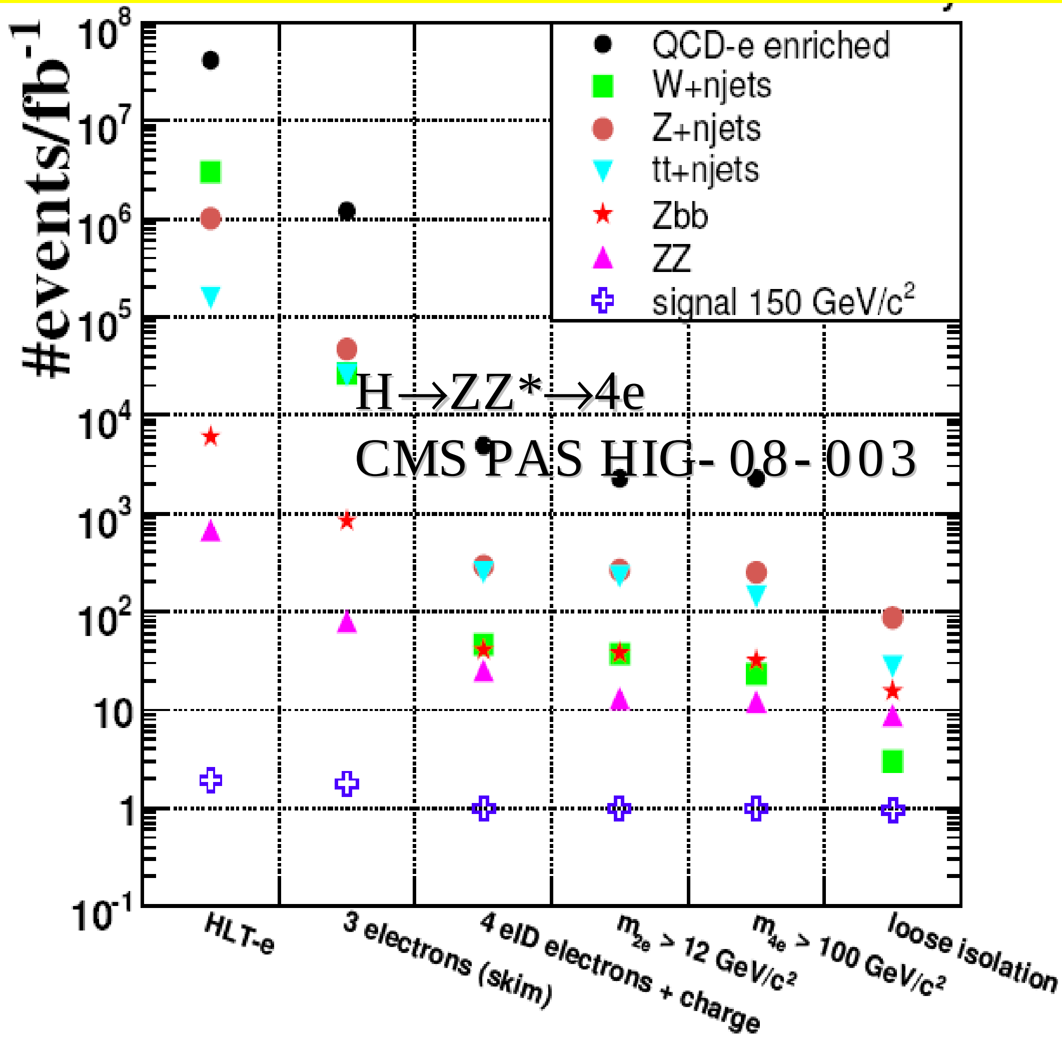
multi-leptons, low p_T

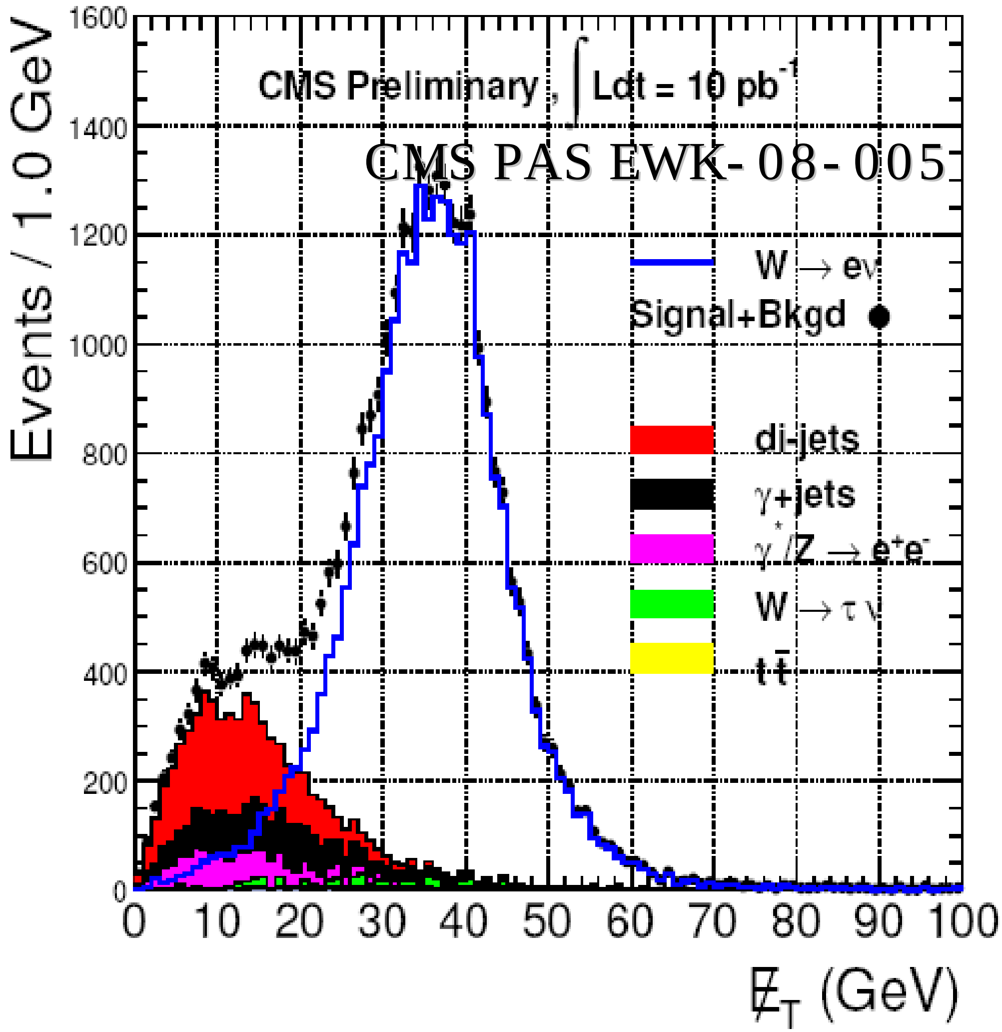
Standard candles

Drell-Yan process Z→ee, W→eν

Key detector parameters:

Efficient and pure electron reconstruction and identification





Signals and backgrounds

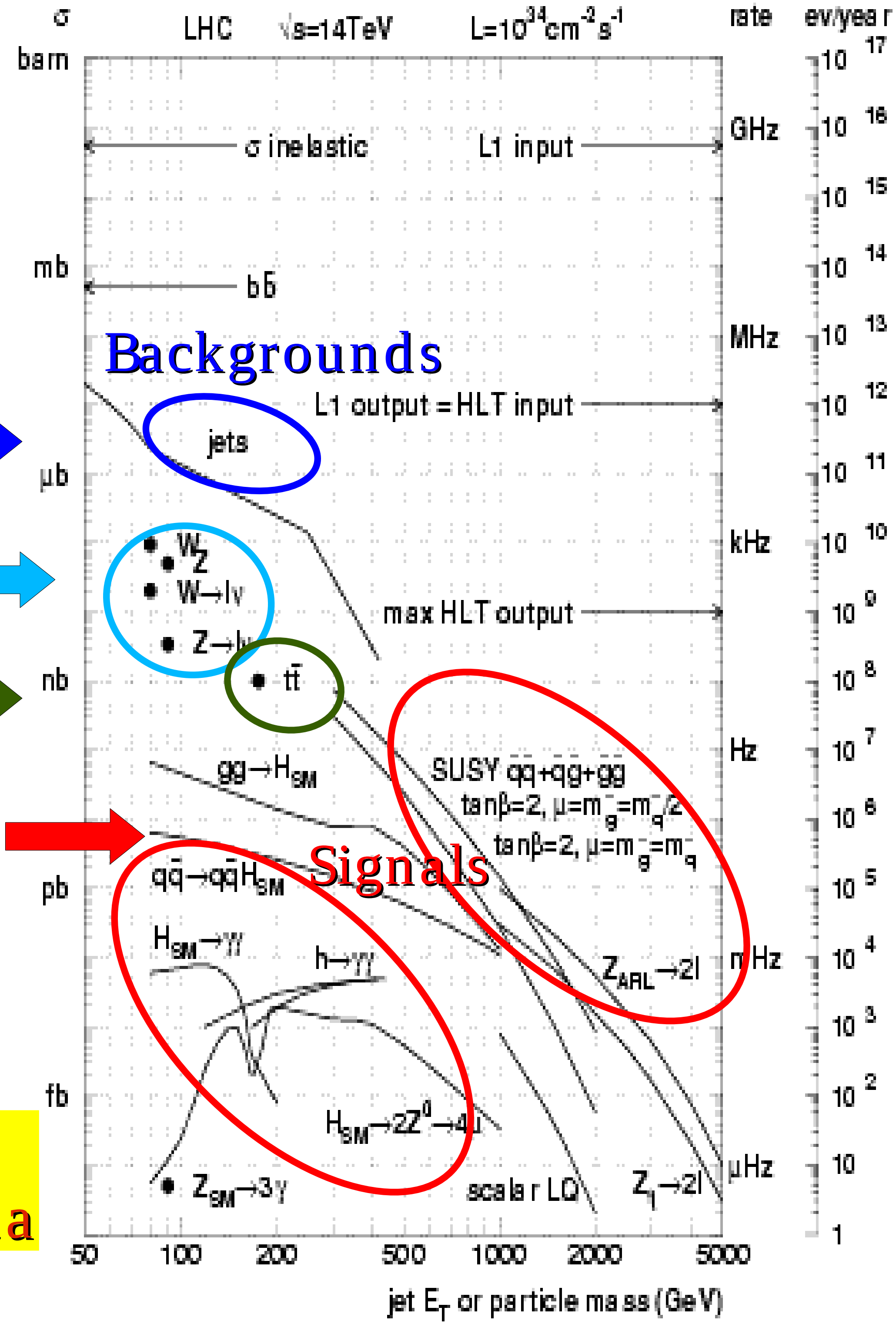
Cross-sections
at $\sqrt{s}$ = 14 TeV

Jets (q, g): ~μb

W→lν / Z→νν: ~20/12 nb
Z→l^+l^-: ~2 nb

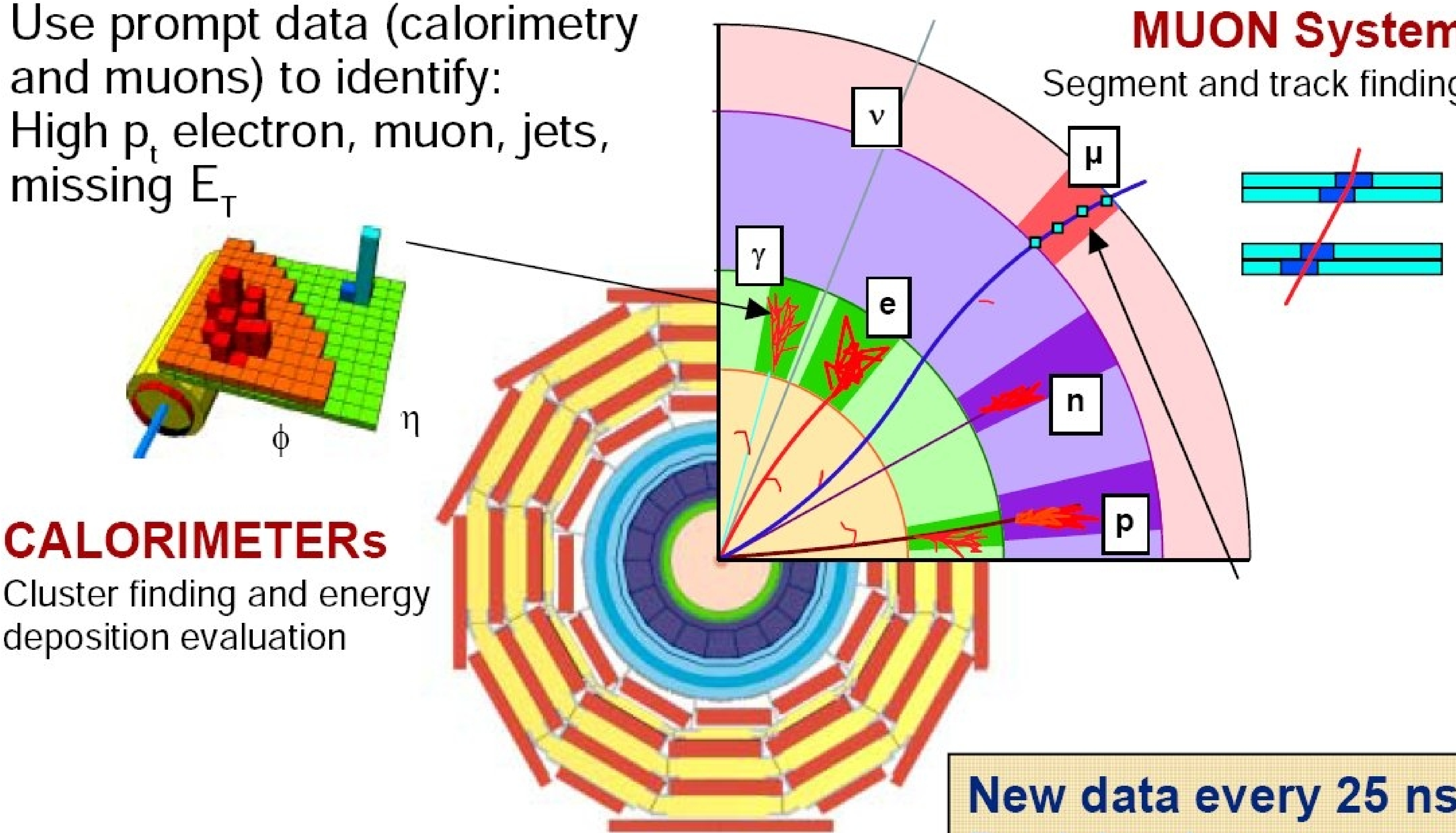
Top quark: ~1 nb

SUSY (M~500 GeV): ~10 pb
Z'(M~1 TeV)→l^+l^-: ~1 pb
steeply falling with M
H→4$l^{+/-}$: ~10 fb



- Selectivity 1,000 - 1,000,000
- Control background from data

Use prompt data (calorimetry and muons) to identify:
High p_t electron, muon, jets, missing E_T



New data every 25 ns
Decision latency ~ μs

Benchmark channel with electrons

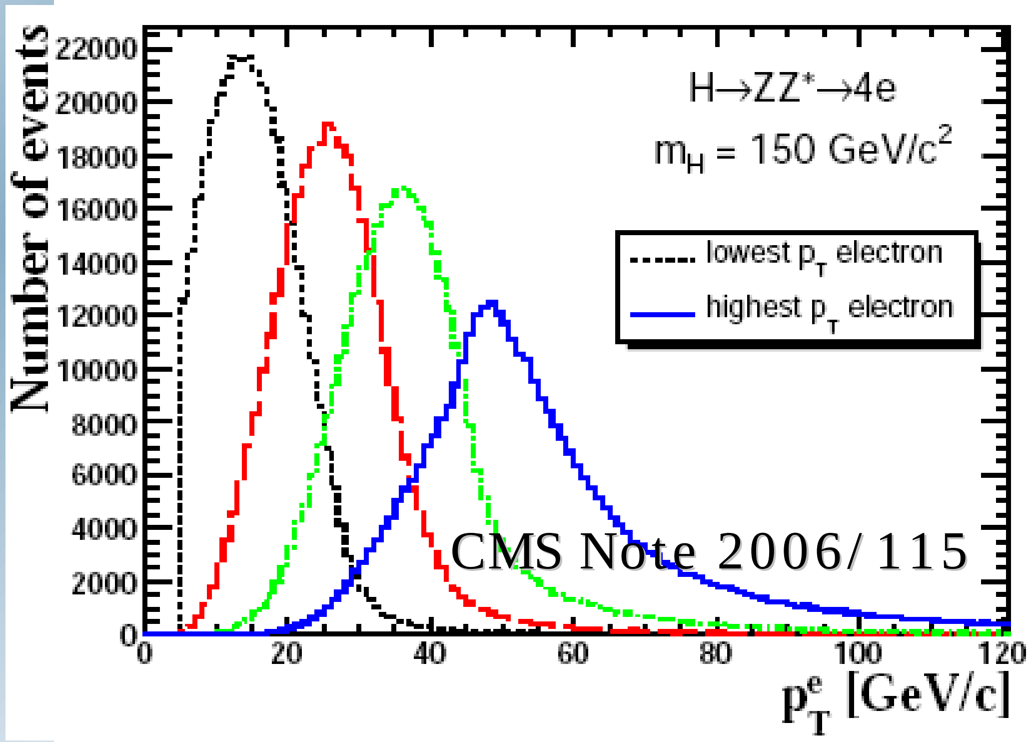
$H \rightarrow ZZ^* \rightarrow e^+e^-e^+e^-$

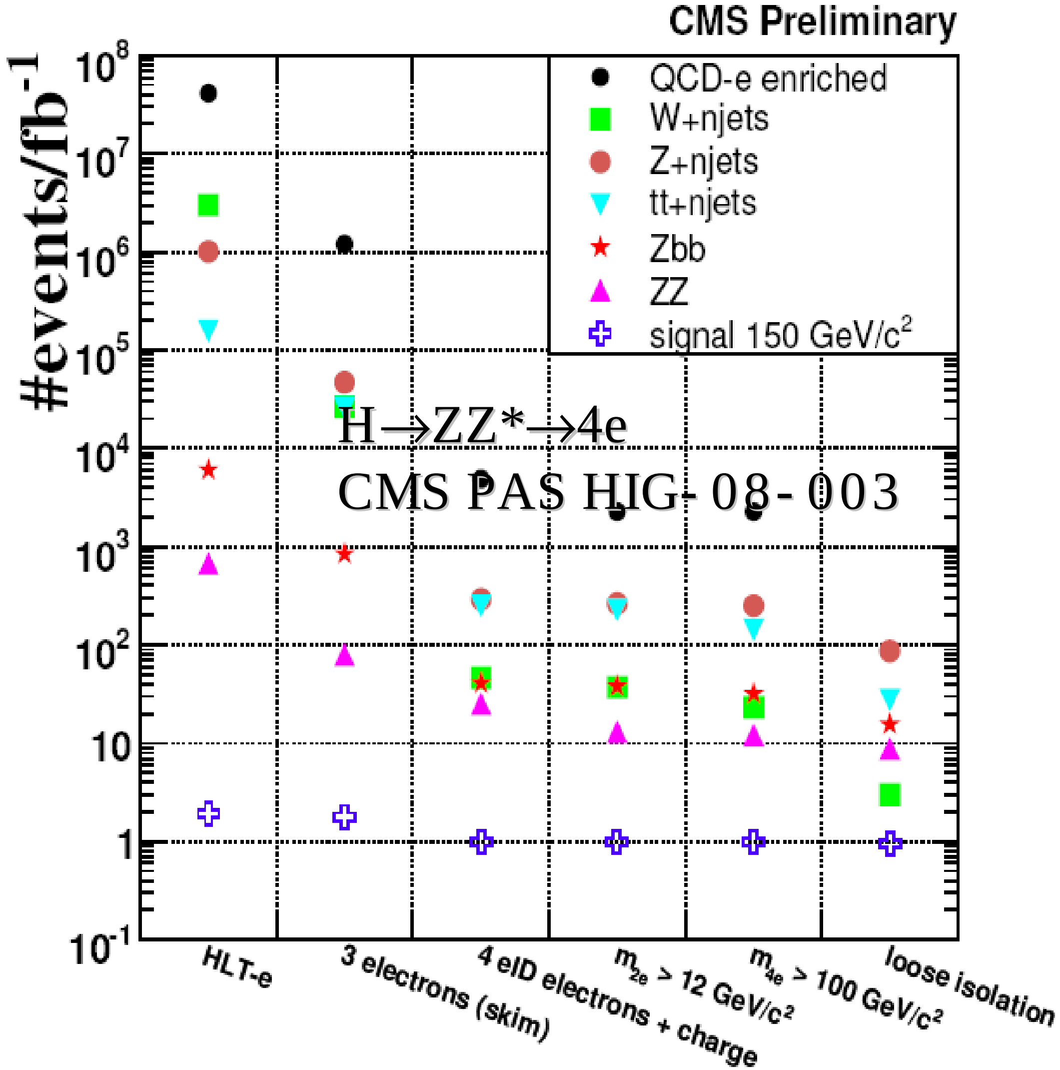
multi-leptons

low p_T

Key detector parameters:

Efficient and pure electron reconstruction and identification



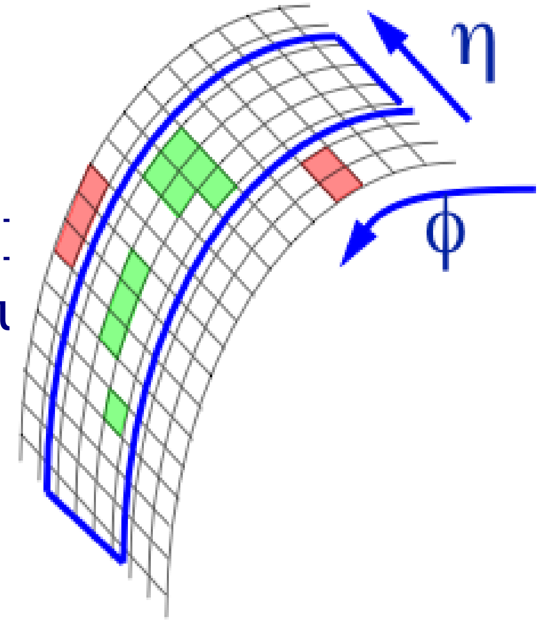


SuperClusters (SC)

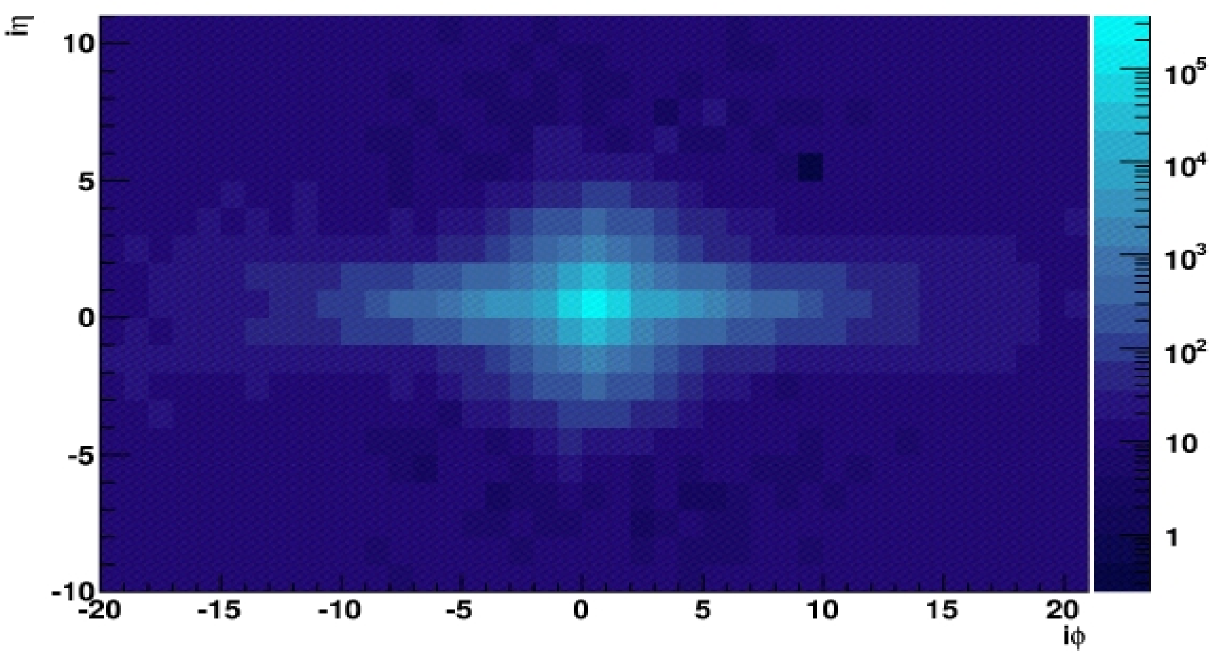
SuperClustering aims at recovering energy of brem. photons (and conversion pairs)

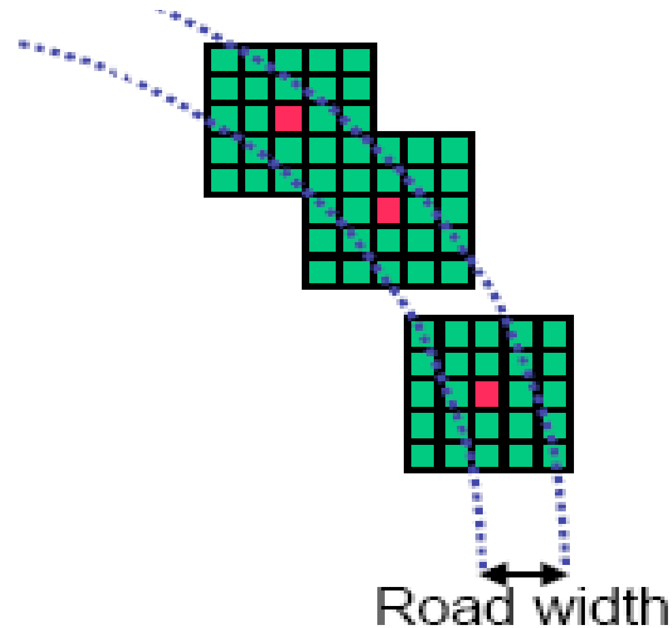
In Barrel: "hybrid" algorithm

- search for highest E_T crystal
- make dominoes of η-width = 5 crysta
- collect dominoes in wide φ-road arou crystals)



Average photon cluster in barrel (A.Askew)





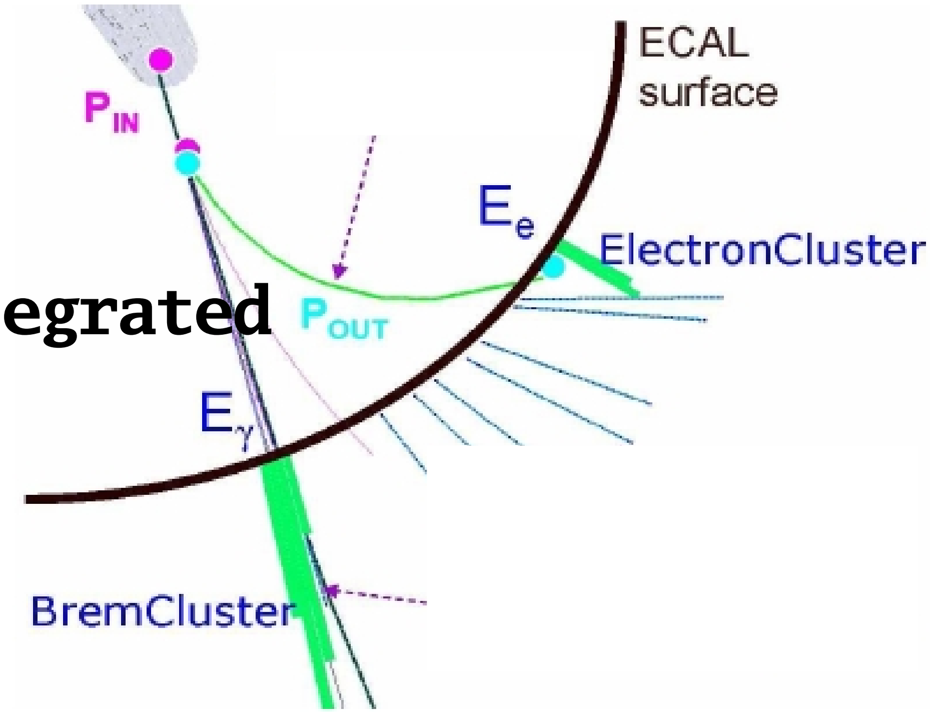
HC Phy

In Endcaps:

Track-based electrons

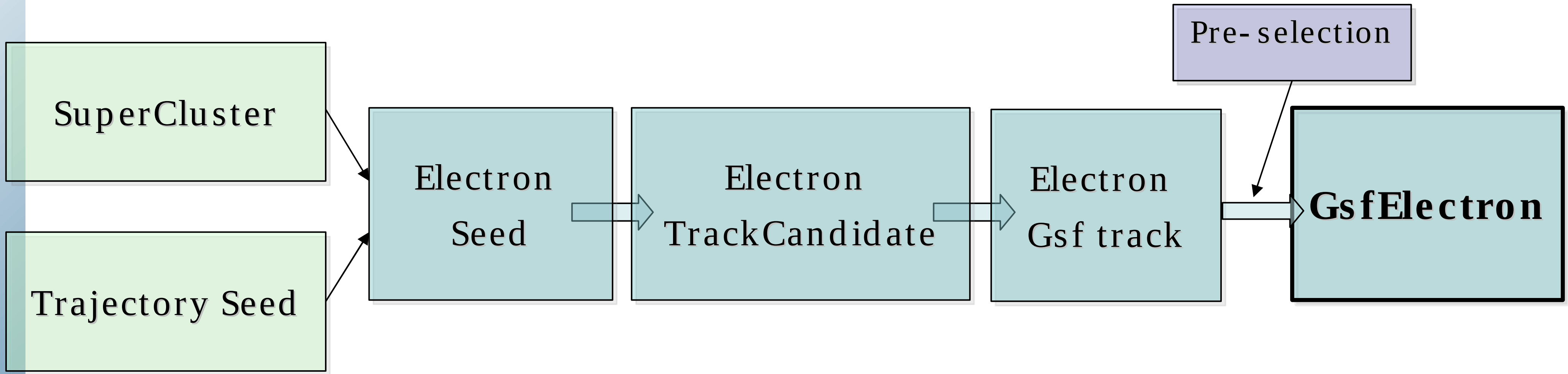
At low p_T (< 10 GeV)

- Low efficiency of main approach
  - split cluster, poor ET estimation
- Can trade more fakes and bad ET measurement for efficiency
- →Track-based approach from ParticleFlow:
  - 3 hits
  - very loose track-SC geometrical matching



Both electron lists being integrated in CMSSW31X

Electron reconstruction



Seeding:
- Track seeds
- SC driven pixel match filter
- E_T, H/E

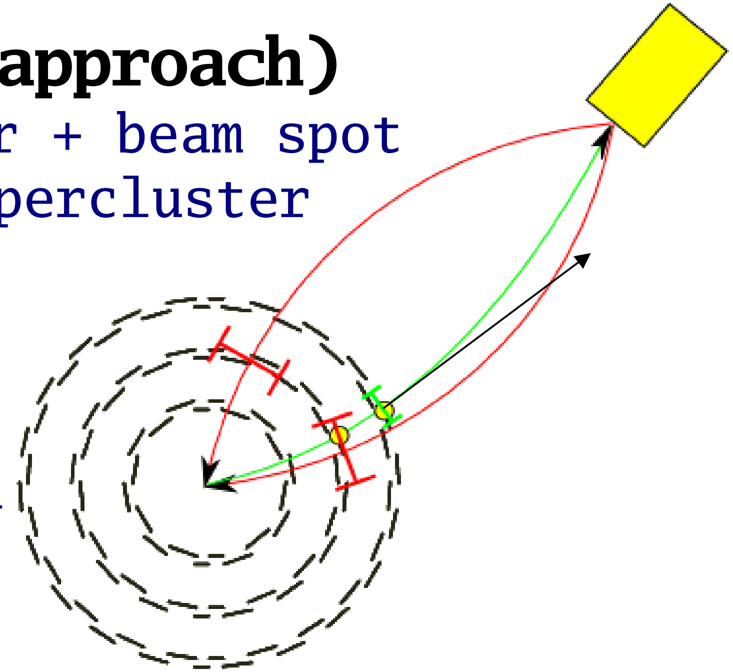
Track finding:
- CTF builder
- Electron loss modeling
- Loose χ^2 cut
- Reduced #candidates per layer

Gsf track fit:
- Electron loss modeling
- Mode of the gaussian mixture used for p_{ele}
- Brem fraction

Electron reconstruction

SuperCluster-driven seeding (main approach)

- Initial track segment = pixel hit pair + beam spot
  - curvature compatible with E_T of supercluster
- Both charge hypotheses considered



Track finding

- Bethe-Heitler energy loss
- Loose χ^2 cut on hits included in track
- Minimum 5 hits required

Track fitting

- Sum of Kalman filters to account for non-Gaussian tails
  - hence the name: Gaussian-Sum Filter electrons (GsfElectrons)

Pre-selection

- remove most obvious fake electrons
- $E_T > 4$ GeV
- Loose geometrical matching SC-track: $|\Delta\eta|<0.02$, $|\Delta\phi|<0.1$
- Shower length discriminant: $H/E < 0.2$