Electron/Photon identification in ATLAS and CMS

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for CMS and ATLAS collaborations
Outline

- Physics motivation
- ATLAS and CMS detectors @LHC
- In situ calibration procedures
- Energy estimation
- Electron tracking
- Material budget effects
- $e$/jet and $\gamma/\pi^0$ separation
- Soft electrons
Physics motivations

- Higgs search
  - $H \rightarrow \gamma\gamma$
  - $H \rightarrow ZZ(\ast) \rightarrow 4e$
- BSM
  - TeV resonances
  - Also SUSY
    - Leptonic decays of charginos and neutralinos
- Many SM processes, top, $Z \rightarrow ee$, $W \rightarrow ev$
  - Backgrounds to new signals
  - Calibration processes
The CMS Detector

**Superconducting Coil**

**HCAL**
- Plastic scintillator/brass sandwich

**Calorimeters**
- ECAL: Scintillating PbWO4 crystals
  - 75848 Xtals
  - 36 supermodules
  - 4 dees
  - $|\eta|<2.6$

**Muon Barrel**
- Drift Tube
- Resistive Plate
- Cathode Strip Chambers

**Tracker**
- Pixel
  - 3 layers (barrel)
  - 2x2 disks (fwd)

**SST**
- >8 hits, depending on $\eta$
- $|\eta|<2.5$

**General Specifications**
- Total weight: 12,500 t
- Overall diameter: 15 m
- Overall length: 21.6 m
- Magnetic field: 4 Tesla

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CMS PbWO4 Calorimetry

**Energy resolution**

\[
\frac{\sigma(E)}{E} = \frac{2.8 \%}{\sqrt{E}} + \frac{124 \text{ MeV}}{E} \oplus 0.26 \%
\]

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- **0.6% at 50 GeV**
- **Resolution 3x3**
  \[\sigma/E = 0.39 \pm 0.01 \%\]
- **Resolution 5x5**
  \[\sigma/E = 0.42 \pm 0.01 \%\]
The ATLAS Detector

General requirements for the LArEM:
- $\sigma_E/E = 10\%/\sqrt{E} \pm 24.5\%/E \pm 0.7\%$
- linearity better than 0.5% up to 300 GeV
- shower direction with $s_q \sim 50$ mrad / $\sqrt{E}$
- fine granularity of 1$^{st}$ compartment
- shower shape measurement

| Layer   | Granularity ($\Delta\eta \times \Delta\varphi$) |
|---------|---------------------------------------------|
| Pre-sampler | 0.025 x 0.1 |
| Front    | 0.003 x 0.1 |
| Middle   | 0.025 x 0.025 |
| Back     | 0.05 x 0.025 |

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**ATLAS LAr calorimetry**

**Energy resolution**

- CTB 2004 (preliminary)
- Run 2102478
- $E_{\text{beam}} = 180$ GeV
- $\eta = 0.3$

**Calo TB 2001-2002**

- $10.0 \pm 0.1 \% /\sqrt{E} \pm 0.21 \pm 0.03 \%$

**Constant term**

- @245 GeV
- P13 production module, $\phi > 7$
- $\text{rms} \Rightarrow c_L = 0.45 \%$

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Intercalibration: phi symmetry

- **Startup scenario:** use single jet triggers
  - Previous study using min. bias events
  - Jets closer to the relevant energy scales
  - Reach 2-3% depending on eta
    - In only few hours assuming full trigger bandwidth allocated to phi symmetry calibration
  - To be complemented by a method to intercalibrate the phi rings
    - e.g. $Z \rightarrow ee$
    - Which therefore needs to run on less regions
  - Limited by the tracker material non uniformity in $\phi$
Intercalibration: $Z \rightarrow ee$

- Intercalibration of regions at start up using kinematical constraint
- Select low radiating electron pairs
  - Main difficulty
  - Efficiency of 5.6% for golden-golden $Z$'s
- 0.6% after $2fb^{-1}$ (CMS)
  - Starting from a mis-calibration between rings of 2% and within rings of 4%
    - As result of lab measurements and phi symmetry

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Intercalibration: $W \rightarrow e\nu$

- Intercalibrate in small regions
  - Use peak of $E/p$ to intercalibrate the regions
- Going from electron to photon will require MC
Cluster energy corrections

0.1%-0.2% spread from 10GeV to 1TeV over all \( \eta \)!

\[
E_{\text{rec}} = (a(E) + b(E))E_{PS} + c(E)(E_{PS}^{vis} \cdot E_{1}^{vis})^{0.5} + d(E) \sum_{i=1,3} E_{i}^{calo} \cdot (1 + f_{\text{leak}}(\text{depth})) \cdot f_{\text{brem}}(E) \cdot f_{\text{cell impact}}
\]

- E loss upstream of PS
- E loss
- PS and calo
- calo sampling fraction + lateral leakage E dependent
- Longitudinal leakage

Testbeam: Achieved better than 0.1 % over 20-180 GeV:
- done in one \( \eta \) position in a setup with less material than in ATLAS and no B field
- No Presampler for \( \eta > 1.8 \)

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Cluster corrections

\[ E_{\text{corr}} = E_{\text{sc}} \cdot F(N_{\text{cry}}) \cdot f(\eta) \]

\[ E_{\text{endcaps}} = E_{\text{presh}} + E_{\text{corr}} \]

Algorithmic corrections ultimately tuned on \( Z \rightarrow ee \) data

- \( F(N_{\text{cry}}) \): containment, ECAL only correction
- \( f(\eta) \): energy lost, residual \( \eta \) dependence, depending on track-cluster patterns (\( e \) classes)

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Electrons and photons starts with clusters in the ECAL

For electrons, associate the cluster with a track

Pixel match in CMS
  - Same algo for offline and HLT
  - Low $p_T$ algo starts with tracking

HLT 2.5

Full PIXEL detector

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CMS in-out GSF electron tracking

- Energy loss for electrons is highly non-gaussian
- Bethe-Heitler energy loss modeled by several gaussians
- Use most probable value of the components pdf instead of mean
- Meaningful momentum @ last point

**Graphs:**

- Hits collected up to the end

**Equation:**

\[ \text{brem fraction: } \left( \frac{p_{\text{in}} - p_{\text{out}}}{p_{\text{in}}} \right) \]

**Figures:**

- CMS
- 30 GeV

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E-scale corrections, e classes

- Different track-cluster patterns due to brems in tracker material
- E-scales corrections depend on classes
  - « golden electrons »
    - Good E/p and phi match
    - Low brems fraction
  - « big brems electrons »
    - Good E/P match
    - High brems fraction
  - « narrow electrons »
    - Good E/P match
    - Intermediate brems fraction
  - « showering electrons »
    - Bad E/P match, brems clusters
- Tuned using Z→ee data
  - Still MC needed for low p_T region

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Material from data

- Location from X-ray of the detector using conversions
- Amount from variables sensitive to material integral
  - E/p distribution
  - Use brem fraction from GSF
  - \( <X/X_0> \sim -\ln(1-f_{\text{brem}}) \)

~2% precision on X/X0

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Photon conversions

- ECAL driven inward seed/track finding
  - Followed by outward seed/track finding
- Pairs of opposite-charge tracks fitted to common vertex
  - Parameters refitted with vertex constraint
- Photon momentum from the tracks
  - Determines the primary interaction vertex

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Shower shape

LArEM beam test 2001-2002

Comparison between data and G4 standalone simulation

Longitudinal development

Lateral development

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**e⁻/jet separation using TRT**

- **Results from TB 2002 @20 GeV**

  - 20-GeV electrons
    - beam-test data
    - Monte-Carlo simulation

  - 20-GeV pions
    - beam-test data
    - Monte-Carlo simulation

- **Results from CTB2004 @9 GeV**

  - Preliminary

  - 90% electron efficiency
  - 2x10⁻² pion efficiency
  - (#energy than TB2002)

*Typical TR photon energy depositions in the TRT are 8-10 keV. Pions deposit about 2 keV.*
Isolation is a very powerful tool to reject jet backgrounds:
- Track based isolation
- Calorimeter isolation
- Combined isolation

**H → 4e signal** ($m_H = 150$)
Backgd: $t\bar{t}$ $p_T^{1,2,3,4} > 5$

**H → $\gamma\gamma$ signal** ($m_H = 120$)
Backgd: $\gamma + \text{jet}$ $p_T^{1} > 40$, $p_T^{2} > 15$

Rej $> 11$

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Electron identification

- Electromagnetic object from calo information
- Track matching ($\Delta\eta$, $\Delta\phi$), $E/p$
- Use of transition radiation (ATLAS)
- Isolation
- ID per class (CMS)
- Identification of conversions
\( \pi^0/\gamma \) separation

- Once isolation has been applied, only jet with little hadronic activity remains

Results from TB 2002 @50 GeV

Results from G4 full simulation

\[ R_{p0} \text{(data)} = 3.18 \pm 0.12 \text{ (stat)} \]
\[ R_{p0} \text{(MC)} = 3.29 \pm 0.10 \text{ (stat)} \]

\[ \varepsilon_{\gamma} = 90\% \]

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Electrons from b’s

- Reconstruction of electrons close to jet is difficult
  - Dedicated algorithm required
- ATLAS low $p_T$ algorithm:
  - Build cluster around extrapolated track
  - Calculate cluster properties
  - pdf and neural net for ID
- Performances on single tracks
- Soft $e^-$ b-tagging efficiency
  - ATLAS: 60% for R=150 (WH)
  - CMS: 60-70% above 10 GeV
    - miss rate ~1.5% (tt and QCD)

\[\begin{align*}
\text{ATLAS: } 60\% \text{ for } R=150 \text{ (WH)} \\
\text{CMS: } 60-70\% \text{ above } 10 \text{ GeV} \\
\text{miss rate } \sim 1.5\% \text{ (tt and QCD)}
\end{align*}\]
Electron and photon ID are essential ingredients for new physics at LHC

In situ calibration procedures are established

Material budget is a key issue
  - Impact the reconstruction efficiency
  - Degrades performances

Isolation is a very powerful tool

Final ID using shape and match variables

Dedicated algorithms needed for e- from b’s