Z(\rightarrow ee) + \gamma Candidate

Electrons & photons simulation in ATLAS

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On behalf of the ATLAS collaboration

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The ATLAS electromagnetic calorimeter

Lead/LAr EM calorimeter divided in 3 longitudinal compartments + Pre-sampler in front

- Good energy resolution:
  \[ \sigma(E)/E = a/E + b/\sqrt{E} + c \] (with \( a \sim 0.3 \text{ GeV}, b \sim 10\%, c \sim 0.7\% \))
- Good angular resolution:
  \[ \sigma(\Phi) \sim 10^{-3} \text{ rad} \]
  \[ \sigma(\eta) \sim 5 \times 10^{-4} \text{ rad} \]

<table>
<thead>
<tr>
<th>Layer</th>
<th>Granularity ( \Delta \eta \times \Delta \phi )</th>
<th>Radiation length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-sampler</td>
<td>0.025 x 0.1</td>
<td></td>
</tr>
<tr>
<td>Strips</td>
<td>0.003 x 0.1</td>
<td>4.3 ( X_0 )</td>
</tr>
<tr>
<td>Middle</td>
<td>0.025 x 0.025</td>
<td>16 ( X_0 )</td>
</tr>
<tr>
<td>Back</td>
<td>0.05 x 0.025</td>
<td>2 ( X_0 )</td>
</tr>
</tbody>
</table>
Electromagnetic objects in ATLAS

- In ATLAS an electron or a photon candidate is defined as a cluster of cells in the calorimeters representing the energy deposit to which we can associate tracks reconstructed in the inner detector.

- Sliding window algorithm to reconstruct the energy deposits:

- The identification of such objects is then based on:
  - The shower shape in the calorimeter
  - Track quality (number of hits, direction wrt the cluster,...)
  - Transition radiation (TRT “high threshold hits”)
  - $E/p$
Reminder: test beam tests

- The commissioning of the electron and photon performance has started well before the collisions and the simulation had been compared to
  - Test beam
Reminder: cosmic data (muons)

- The commissioning of the electron and photon performance has started well before the collisions and the simulation had been compared to
  - Test beam
  - Cosmics : selection of muons
    - Check of the visible energy in the calo
    - Adjustment of the calorimeter response
    - Improvement of the inner detector-calor alignment

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![Graph showing the performance of the calorimeter with cosmic muons](image)

**ATLAS**

- 2011 data after alignment
- Nominal geometry
- W/Z → eν/e+e- MC

**ATLAS Preliminary**

- EM BARREL LAYER 2

- 2008 Cosmic muons
- Data
- Cosmic MC
- dE/dx, $\bar{p} = 4.01$ GeV

**ATLAS**

- Landau MPV [MeV]
- Data/MC energy scaling factor 0.99
- 1x3 clusters

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06 octobre 2011

Olivier Arnaez - ATLAS electrons and photons simulation
Reminder: cosmic data (photons)

- The commissioning of the electron and photon performance has started well before the collisions and the simulation had been compared to
  - Test beam
  - Cosmics: selection of muon large bremsstrahlung energy deposit in the calorimeter

Very good agreement in energy, direction, energy loss of the cosmic muons (even below ~100 meters of rock) and energy deposits
Reminder: cosmic data (electrons)

- The commissioning of the electron and photon performance has started well before the collisions and the simulation had been compared to:
  - Test beam
  - Cosmics: selection of muon large bremsstrahlung energy deposit in the calorimeter and ionisation electron candidates but also high energy $\delta$-rays

First electrons observed in the ATLAS detector!
Points of interest for simulation

- Even if well-probed on the test beam and cosmic data, the simulation is still a crucial element in ATLAS physics analyses since not all electron and photon performance can be measured on collisions data.

- Key points for the simulation of electron and photon shower shapes:
  - Geant4 physics/tracking
  - Geometry description of the sub-detectors
  - Conversion of energy loss in calorimeters to visible energy
  - Upstream material
  - Cross-talk (not part of the actual “simulation” process)

- Identification also strongly relies on inner detector:
  - Amount of transition radiation
  - Track extrapolation (ID alignment, calo-ID alignment, scattering,...)

  see Markus Jungst’s talk
Energy calibration

- One reason why the simulation is sensitive to the knowledge of material is the energy calibration scheme.

- As the initial energy does not fully deposit within the electron/photon cluster, it is important to correct the cells energy sum to improve the energy scale and resolution.

- Our calibration procedure is based on calibration hits:
  - Store all GEANT4 energy deposits (in active, inactive material or escaping).
  - Parametrize the energy leaks (outside the cluster, in the dead material,...) in function of the position, the energy and the shower depth using this simulation.

- Of course this calibration is strongly dependent on the knowledge of the upstream material, this is why we need to map it.
Upstream material using conversions (1)

- The fraction of photons which convert being related to the radiation length through the formula
  \[ \frac{X}{X_0} = -\frac{9}{7} \ln(1 - F_{\text{conv}}) \]

  The radiation length (and thus the amount of material at a given distance) can be measured in collision data using the conversions

- Those are selected by reconstructing conversion vertices associated to two tracks pointing to the interaction point (|z| < 20 mm) passing some identification requirements from the TRT (high transition radiation)

- The quality of the vertexing is insured by requiring
  \[ D - R_1 - R_2 > 0 \text{ and } \chi^2 < 2.5 \]
Upstream material using conversions (2)

- The three pixel and the first two SCT layers are clearly visible.

- Overall there is a good agreement between the data and the simulation.

- However, some improvements on the geometry were required.

- Radial resolution in photon conversions is approximately 5 mm (opening angle between outgoing electron-positron pair close to zero)
Upstream material using hadronic interactions (1)

- While conversions measure the radiation length, the interaction length can be probed using secondary hadronic interactions.

- Low energy primary hadrons (<p>~4 GeV) interact with material → large opening angles
  - excellent spatial resolution (200-300 μm in R and z for radii < 100mm 
    ~1 mm at larger radii)

- Selection based on non diffractive events with large track multiplicity at primary vertices, but using only those not pointing to them (secondaries)

- Data are compared to PYTHIA6 (AMBT1 tune) simulated through GEANT4, corrected for a slight difference (~5-7%) in number of primary tracks. MC is needed for taking into account the strong R- and z-dependences of the secondary track reconstruction efficiency.
Upstream material using hadronic interactions (2)

- Uncertainty on modelling of hadronic interactions in GEANT4 controlled by studying the vertex yield in a control region
  - Using the Be part of the beam pipe (well-known composition, size and location)
  - → reasonable agreement

- New versions of the simulation have incorporated these results on the material mapping
Impact on energy scale and resolution

- Precision on material mapping good enough for the calibration aspects (energy scale and resolution) but could also have some impacts on the identification discriminant distributions.

![Graph showing relative energy scale difference between MC and data vs E](image)

**ATLAS** preliminary
Data 2010, $\sqrt{s}=7$ TeV
$\int Ldt=40$ pb$^{-1}$

Relative energy scale difference between MC and data vs E

0$<|\eta|<0.6$

![Histograms showing distribution of $N_{\pi^0}$ vs $m_{\gamma\gamma}$](image)

**ATLAS** Preliminary

- Data ($\pi^0$)
- MC ($\pi^0$)

0$<|\eta|<2.37$

![Histograms showing distribution of $N_{\pi^0}$ vs $m_{\gamma\gamma}$](image)

**ATLAS** Preliminary

- Data ($\pi^0$)
- MC ($\pi^0$)

4.2$<|\eta|<4.8$
Shower shape discriminant variables

- The shower shape in the calorimeter allows for the rejection of a large fraction of background ($O(1000)$).

- Benefiting from the thin granularity and the segmentation of the calorimeter, ATLAS defined a few variables illustrating the shower width in eta/phi and its longitudinal extension.

- Even if the agreement is fairly good, the simulation does not perfectly predict the key distributions for the lateral development.

- This has been observed during the test beam, the cosmics, and the collisions data-taking.
LAr absorber simulation

- We have tracked down that a large part of the disagreement was due to an improper simulation of the EM calorimeter absorber.

- Real absorber is a sandwich Iron-Glue-Lead-Glue-Iron but it was described as a blended material made of Lead, Iron and Glue.

- Running the detailed simulation costs an CPU time increase (30-60% for EM showers) but significantly improved the agreement.

- Have checked impacts of cross-talk, material, geometry (accordion, sagging,...), misalignment,... Unfortunately, yet no good explanation for the remaining discrepancies.
Impact of other aspects of simulation

- To select the electrons, we usually cut on many variables and correct the MC predictions by data/MC scale factors measured using T&P-based methods.

- Certain regions exhibit higher efficiencies in data than in MC. The reasons are understood and a large part of the effect is due to the transition radiation modelling resulting in a higher probability for an $e^\pm$ to have high-energy TRT hits.

- Tuning ongoing.
Conclusion

- This talk focused on the slightly imperfect aspects of our Monte Carlo but the ATLAS simulation is actually doing a very good job!

- The few discrepancies we have noticed between Monte Carlo and data have generally been tracked down to simulation imperfections (GEANT4 absorbers modelling, amount of transition radiation,...)

- Other issues are being improved with time and statistics (today using $O(4M)$ W, $O(1M)$ Z and $O(70k)$ J/Psi probes)...

![Graph showing total integrated luminosity over time]