Lepton Identification and Trigger Decision at Atlas Experiment

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Outline

◊ Introduction
◊ Leptons (e/mu/tau)
  – Leptonic signatures at LHC
  – Reconstruction/Identification
  – In-situ calibration using early data
◊ Trigger
  – Trigger system overview
  – Menus at low luminosity run
◊ Summary
Leptons
Introduction

◊ Leptons:
  – Leptonic signatures are clean.
    • Easy to trigger and select.
    • Suppression of physics (QCD) and non-physics backgrounds.
    • Excellent for calibration and alignment of the detector.
  – Thus primary channels of LHC discoveries are leptonic.

◊ We summarize;
  – lepton reconstruction, identification and predicted performances at the ATLAS detector,
  and also give our perspectives of;
  – In-situ calibration using early data and expected performances
  – They are sufficient for early discoveries??
Leptonic signatures

Physics shopping list w/ leptonic signatures

• Standard Model Higgs
  – $H \rightarrow ZZ \rightarrow llll$
  – $H \rightarrow WW \rightarrow l\nu l\nu$
  – $qqH \rightarrow q\tau\tau$ (one or both $\tau \rightarrow l\nu l\nu$)

• MSSM Higgs
  – $gg \rightarrow bbH(A), H(A) \rightarrow \tau\tau, \mu\mu$

• Doubly Charged Higgs
  – $H^{\pm\pm} \rightarrow W^{\pm}W^{\pm} \rightarrow l^{\pm}l^{\pm}\nu\nu$

• Massive Vector Bosons (KK, Gravitons, etc.)
  – $Z', G \rightarrow ll$
  – $Z', G \rightarrow WW \rightarrow l\nu l\nu$
  – $W' \rightarrow l\nu$ or $WZ$

• SUSY
  – $g \rightarrow q\tilde{l}$
  – $\tilde{q}_L \rightarrow q\tilde{\chi}_{2}\rightarrow q\tilde{\nu}_R \rightarrow q\nu\tilde{\chi}_{1}$

◊ GMSB ($\tilde{\chi}_1^0 \rightarrow \tilde{G} \gamma \tilde{\nu}_R \rightarrow \tilde{G} l$)
  – $\tilde{\chi}_2^0 \rightarrow \tilde{l}_R \rightarrow l l\tilde{\nu}_1 \rightarrow l l\tilde{G} \gamma$

◊ Right-Handed W
  – $W_R \rightarrow l + N \rightarrow l + ljj$

◊ Excited & Heavy Leptons
  – $pp \rightarrow l l' \rightarrow l lZ \rightarrow l + ljj$ (resonances)
  – $gg \rightarrow Z, Z' \rightarrow LL \rightarrow lZ + lZ \rightarrow ljj + ljj$

◊ Etc.
  – SM precision measurements, e.g.
**ATLAS (A Toroidal Lhc ApparatuS)**

“Small” 2T Solenoid for Tracking

3 Large Toroids for Muon Spectroscopy
- High BL$^2$ for Standalone Measurements

**Muon Spectrometer**
- Precision: MDT, CSC
- Trigger: RPC, TGC
- Excellent acceptance at poles

**Calorimetry**
- Lateral & Longitudinal Segmentation
- FCAL only 4.9m from IP

**Inner Tracking (Pixel, SCT, TRT)**
- Pixels: 50$\mu$m (r-φ) x 400$\mu$m (z)
- $\Delta p/p$ (1 GeV) = 0.013, 0.02 ($\eta=0,2.5$)
- $\Delta p/p$ (100 GeV) = 0.038, 0.11
- TRT for e/π identification
**Calorimeter Parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer Dimensions (r / z)</td>
<td>2.25m / ±6.65m (ECAL)</td>
</tr>
<tr>
<td></td>
<td>4.25m / ±6.10m (HCAL)</td>
</tr>
<tr>
<td>Coverage ((\eta))</td>
<td>±3.2 (ECAL, HCAL)</td>
</tr>
<tr>
<td></td>
<td>±4.9 (FCAL)</td>
</tr>
<tr>
<td>ECAL Technology</td>
<td>Presampler</td>
</tr>
<tr>
<td></td>
<td>Pb / LAr (Liquid Argon)</td>
</tr>
<tr>
<td></td>
<td>Accordion (190,000)</td>
</tr>
<tr>
<td>HCAL Technology</td>
<td>Fe / Scintillator (10,000)</td>
</tr>
<tr>
<td></td>
<td>Cu / LAr (HEC)</td>
</tr>
<tr>
<td></td>
<td>Cu / W / LAr (FCAL)</td>
</tr>
<tr>
<td>Samplings</td>
<td>1 + 3 + 3 (Barrel)</td>
</tr>
<tr>
<td></td>
<td>(1) + 3 + 4 (Endcap)</td>
</tr>
<tr>
<td></td>
<td>3 + 3 (Forward)</td>
</tr>
<tr>
<td>Material</td>
<td>24 (X_0) - 26 (X_0) (ECAL)</td>
</tr>
<tr>
<td></td>
<td>11 (\lambda) (HCAL)</td>
</tr>
<tr>
<td>Resolution ((\eta / \phi))</td>
<td>0.025 / 0.025 mrad (ECAL)</td>
</tr>
<tr>
<td></td>
<td>0.100 / 0.100 mrad (HCAL)</td>
</tr>
</tbody>
</table>
Basic detector performance

<table>
<thead>
<tr>
<th>Tracking</th>
<th>( \eta = 0 )</th>
<th>( \eta \approx 2.5 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \delta p/p ) at ( p_T = 1 ) GeV</td>
<td>1.3%</td>
<td>2.0%</td>
</tr>
<tr>
<td>( \delta p/p ) at ( p_T = 100 ) GeV</td>
<td>3.8%</td>
<td>11.0%</td>
</tr>
<tr>
<td>( \varepsilon ) (pions) at ( p_T = 1 ) GeV</td>
<td>84.0%</td>
<td></td>
</tr>
<tr>
<td>( \varepsilon ) (electrons) at ( p_T = 5 ) GeV</td>
<td>90.0%</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Calorimeter</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>ECAL ( \delta E/E ) (100 GeV Photons)</td>
<td>1 - 1.5%</td>
</tr>
<tr>
<td>ECAL ( \delta E/E ) (50 GeV Electrons)</td>
<td>1.3 - 2.3%</td>
</tr>
<tr>
<td>ECAL+HCAL Stochastic Term</td>
<td>55% / \sqrt{E}</td>
</tr>
<tr>
<td>ECAL+HCAL Constant Term</td>
<td>2.3%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Muon Spectrometer</th>
<th>Standalone</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \eta = 0 )</td>
<td>( \eta \approx 2 )</td>
<td>( \eta = 0 )</td>
</tr>
<tr>
<td>( \delta p/p ) at ( p = 10 ) GeV</td>
<td>3.9%</td>
<td>6.4%</td>
</tr>
<tr>
<td>( \delta p/p ) at ( p = 100 ) GeV</td>
<td>3.1%</td>
<td>3.1%</td>
</tr>
<tr>
<td>( \delta p/p ) at ( p = 1000 ) GeV</td>
<td>10.5%</td>
<td>4.6%</td>
</tr>
</tbody>
</table>
Electron: reconstruction

1. Build clusters from ECAL cells
2. Correct for geometry effects
3. Correct for cell saturation
4. Match clusters to tracks
5. Correction for bremsstrahlung
6. Require isolation
7. (kinematic cuts for analysis)
Electron: performance

Predicted performances from MC simulation

- The drop in efficiency is visible at:
  - gap region between the barrel and endcap calorimeters
  - low pt, mainly due to the loss of discrimination power of the shower shape cuts.
In-situ calibration using $Z \rightarrow ee$ (1)

◊ Robust analysis at early stage
  – No track info. needed
  – Key tool for commissioning of electron reconstruction and ID.
◊ Correct the residual non-uniformity under $Z$ mass constraint.
  – $\sim 30,000$ events of $Z \rightarrow ee$ enough to achieve a response uniformity of 0.7%
In-situ calibration using $Z \rightarrow ee$ (2)

Tag and probe method to determine efficiencies:
- “tag” electron: well identified electron on one side
- “probe” electron: track/EM cluster on the other side

Single electron trigger provides unbiased probes. Agrees with the predicted performances.

~2% accuracy with 100pb$^{-1}$

<table>
<thead>
<tr>
<th>$\eta$ range</th>
<th>15.00−25.00</th>
<th>25.00−40.00</th>
<th>40.00−70.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00−0.80</td>
<td>83.60±2.35±3.76</td>
<td>89.75±0.68±0.69</td>
<td>92.63±0.53±0.23</td>
</tr>
<tr>
<td>0.80−1.37</td>
<td>75.60±2.76±6.13</td>
<td>87.64±0.91±0.58</td>
<td>90.86±0.77±0.33</td>
</tr>
<tr>
<td>1.52−1.80</td>
<td>71.93±4.38±4.04</td>
<td>76.90±1.85±1.77</td>
<td>83.58±1.89±0.59</td>
</tr>
<tr>
<td>1.80−2.40</td>
<td>78.05±2.73±4.75</td>
<td>79.24±1.38±1.36</td>
<td>82.50±1.37±0.79</td>
</tr>
</tbody>
</table>
Muon: reconstruction

1. Build segments in muon stations
2. Build tracks from hits or segments
3. Correct for $E_{\text{loss}}$ & multiple scattering
4. Match inner tracks (or calorimeter hits)
5. Combine statistically or re-fit
Muon: performance

◊ Predicted performance from ttbar MC.
◊ Efficiency is fairly flat for pt between 10 and 100 GeV/c.
◊ Efficiency loss at eta=0.0, 1.2 due to the poor detector coverage.
First peaks of di-muon resonances

◊ Statistics for 1pb⁻¹ (@10^{31})
  – Assuming 30% accelerator + detector efficiency
◊ Possible studies are
  – First sanity check
  – ID(tracker) alignment
    • <100micron
  – Low pt muon scale

◊ Z \rightarrow \mu\mu for 100pb⁻¹
  – Detector efficiencies
  – Scales for higher-pt muons
**Tau: reconstruction**

1. Search for localized energy deposits in calorimeters
2. Require hadronic energy
3. Match with 1 or 3 tracks in cone
4. Remove photon conversion tracks
5. Require isolation in calorimeters
6. Require small jet mass

Hadronic tau decay (tau jet)

- 1 prong (49.5\%):
  \[ \tau \rightarrow \nu_\tau + \pi^{+/-} + n(\pi^0) \]

- 3 prong (15.2\%):
  \[ \tau \rightarrow \nu_\tau + 3\pi^{+/-} + n(\pi^0) \]
In-situ calibration of tau

◊ $Z \rightarrow \tau \tau (\ell \ell)$
  
  - Visible mass of tau pairs with an integrated $L$ of 100pb$^{-1}$ after subtracting the SS events from the OS.
  
  - Visible mass can be reconstructed with an error of <1%, tau scale can therefore be determined with an accuracy of a few %. 

March 28-29, 2008
## Summary of start-up and ultimate performances for leptons

<table>
<thead>
<tr>
<th></th>
<th>Start-up (~100pb⁻¹)</th>
<th>Ultimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>EM energy uniformity</td>
<td>&lt;2%</td>
<td>0.7%</td>
</tr>
<tr>
<td>Electron energy scale</td>
<td>~2%</td>
<td>0.02%</td>
</tr>
<tr>
<td>ID alignment</td>
<td>50-100 micron</td>
<td>&lt;10 micron</td>
</tr>
<tr>
<td>Muon system alignment</td>
<td>&lt;200 micron</td>
<td>30 micron</td>
</tr>
<tr>
<td>Muon momentum scale</td>
<td>~1%</td>
<td>0.02%</td>
</tr>
<tr>
<td>Tau momentum scale</td>
<td>~2%</td>
<td>---</td>
</tr>
</tbody>
</table>

**Integrated lumi.**

- **1pb⁻¹**
- **100pb⁻¹**
- **1fb⁻¹**

- Early discovery with leptonic signature? (SUSY, massive bosons...)
- Detector efficiencies, in-situ calibration for leptons
- Commissioning, alignment, low-pt lepton

**Cannot achieve ultimate performances, but do not need for early discoveries (<1fb⁻¹)**

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Trigger
Trigger: introduction

- At nominal high (low) luminosity, on average ~23 (2.3) minimum bias events superimposed on any rare discovery signal
  - 25 ns bunch crossing
  - Minimum bias rate ~7x10^8 (7x10^7) Hz
- ~1000 (100) low-pt tracks per event!
- Moreover, due to finite detector response time, out-of-time pile-up from different bunch crossings
  - Need “time stamp” to distinguish events
- Trigger system should be very fast and extremely selective:
  - 40 MHz input and O(100 Hz) “on tape” (100 events/s)
  - Selection at the <10^{-4}/10^9 = 10^{-13} level, with virtually zero dead-time!
Trigger System Overview

• Level 1:
  – Hardware based: Calo + Muon
  – Latency 2.5 $\mu$s
  – Output rate $\sim 37$kHz (75k)

• Level 2: $\sim 500$ farm nodes
  – “Regions of Interest” (RoI) to guide reconstruction
  – Custom algorithms
  – Average execution time $\sim 40$ ms
  – Output rate up to $\sim 1$kHz (2k)

• Event Builder: $\sim 100$ farm nodes

• Event Filter (EF): $\sim 1600$ farm nodes
  – Seeded by level 2
  – Access to full built event
  – Offline algorithms
  – Average execution time $\sim 4$ s
  – Output rate up to $\sim 200$ Hz

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Trigger menu at start-up \((L \sim 10^{31}\text{cm}^{-2}\text{s}^{-1})\)

<table>
<thead>
<tr>
<th>Unprescaled items</th>
<th>(rate in Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>e10_tight</td>
<td>21.9±1.49</td>
</tr>
<tr>
<td>e12</td>
<td>19.3±1.4</td>
</tr>
<tr>
<td>g20</td>
<td>6.62±0.82</td>
</tr>
<tr>
<td>2e5</td>
<td>6.72±0.83</td>
</tr>
<tr>
<td>2g10</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>mu10</td>
<td>18.7±1.38</td>
</tr>
<tr>
<td>2mu4</td>
<td>2.34±0.49</td>
</tr>
<tr>
<td>J120 (L1 only)</td>
<td>8.65±0.94</td>
</tr>
<tr>
<td>4J23 (L1 only)</td>
<td>6.92±0.84</td>
</tr>
<tr>
<td>FJ120 (L1 only)</td>
<td>0.92±0.31</td>
</tr>
<tr>
<td>J3E40 (L1 only)</td>
<td>0.1±0.1</td>
</tr>
<tr>
<td>2FJ35 (L1 only)</td>
<td>1.73±0.42</td>
</tr>
<tr>
<td>2b23_3L1J23</td>
<td>2.65±0.52</td>
</tr>
<tr>
<td>xe70 (L1 only)</td>
<td>0.2±0.14</td>
</tr>
<tr>
<td>te650 (L1 only)</td>
<td>0.31±0.18</td>
</tr>
</tbody>
</table>

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### Trigger menu at $L \sim 10^{32} \text{cm}^{-2}\text{s}^{-1}$

Unprescaled items (very preliminary) (rate in Hz)

<table>
<thead>
<tr>
<th>Item</th>
<th>Rate</th>
<th>Item</th>
<th>Rate</th>
<th>Item</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>e15i</td>
<td>54.1±7.4</td>
<td>e20_g20</td>
<td>0</td>
<td>0</td>
<td>tau100</td>
</tr>
<tr>
<td>e20_tight</td>
<td>19.4±4.4</td>
<td>e10_mu6</td>
<td>5.1±2.3</td>
<td>0</td>
<td>tau35i_xe40</td>
</tr>
<tr>
<td>g25_L32</td>
<td>19.4±4.4</td>
<td>e10_xe30</td>
<td>7.14±2.7</td>
<td>0</td>
<td>tau25i_e15i</td>
</tr>
<tr>
<td>2e15</td>
<td>&lt;1</td>
<td>e20_xe15</td>
<td>22.4±4.8</td>
<td>0</td>
<td>tau25i_mu10</td>
</tr>
<tr>
<td>2g20</td>
<td>&lt;1</td>
<td>g20_xe15</td>
<td>24.5±5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>mu15_xe15</td>
<td>26.5±5.2</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>mu20</td>
<td>19.4±4.4</td>
<td></td>
<td></td>
<td></td>
<td>tau20i_j120</td>
</tr>
<tr>
<td>mu4_mu6</td>
<td>4.3±3.8</td>
<td>j70_xe30</td>
<td></td>
<td>99±10</td>
<td>tau25i_b35</td>
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<tr>
<td>J120</td>
<td>85.7±9.3</td>
<td>2j42_xe30</td>
<td>64.3±8.1</td>
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<td>tau15i_b23_j42</td>
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<td>JE340</td>
<td>1.02±1</td>
<td>4j23_e15i</td>
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<td>2FJ70</td>
<td>&lt;1</td>
<td>4j2_xe30_e15i</td>
<td>1.02±1</td>
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<tr>
<td>2b35_3L1J35</td>
<td>3.06±1.8</td>
<td>j42_xe30_mu15</td>
<td>4.08±2</td>
<td>0</td>
<td>trk20i_calib</td>
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<tr>
<td>3b18_4L1J18</td>
<td>1.02±1</td>
<td></td>
<td></td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>xe70</td>
<td>2.04±1.4</td>
<td>Bmu4mu4</td>
<td>7.14±2.7</td>
<td>0</td>
<td>MBTS</td>
</tr>
<tr>
<td>te650</td>
<td>3.06±1.8</td>
<td>mu4_Brunumu</td>
<td>16.3±4.1</td>
<td>0</td>
<td>Random</td>
</tr>
<tr>
<td></td>
<td></td>
<td>mu4_Jpsimumu</td>
<td>16.3±4.1</td>
<td>0</td>
<td>SpacePoints</td>
</tr>
</tbody>
</table>

Not yet for $10^{33}$

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In-situ measurement of trigger efficiency(1)

◊ At design low luminosity ($10^{33}$ cm$^{-2}$s$^{-1}$), L1 rates do not allow to go below ~20GeV for the single and ~12GeV for the double electron signatures. Physics/Detector studies dominated by W and Z.
In-situ measurement of trigger efficiency(2)

Z→ee example:
- Select events accepted by single e trigger (e15, e15i, e25, e25i) → TAG
- Events with 2 electrons. Build inv. mass & keep only those with inv. mass close to Z peak.
- For this selection, check how many times the 2nd electron also triggered (2e15, 2e15i, 2e25, 2e25i) → probe

Tag and probe method still works for trigger efficiency measurements.
Triggers for inclusive SUSY searches

◊ Early SUSY searches will focus on inclusive signatures of:
  – Multiple jets
  – Large missing ET
  – Leptons

◊ To minimize biases and systematic effects, we should keep trigger selection criteria as simple as possible.
  – Due to its rich phenomenology, triggering SUSY events is easy in principle.

◊ We estimate Etmiss trigger takes time to get established and Etmiss is often crucial for signal selection (instrumental effects);
  – de-emphasize Etmiss trigger and loosen lepton selection are better choice in early days??

◊ Lepton triggers could be robust and urgent issue is

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Summary

◊ Data is coming this year and leptons play an important role for early physics at LHC.
  – Detector alignment will be performed with e/mu using very early data (\(\sim 1\text{pb}^{-1}\)).
  – pt scales of leptons are determined with an accuracy of \(\sim 2\%\) in the first 100pb\(^{-1}\)
  ➔ Satisfactory performances for early discoveries.

◊ Trigger menu at start-up (10\(^{31}\)) is well tuned and close to final.
  – Menus for 10\(^{32}\) and 10\(^{33}\) are presently under study.
◊ Tag and probe method works for determination of lepton trigger efficiencies.
◊ Also need in-situ measurements of jet/XE trigger efficiencies