Commissioning and Performance of the ATLAS Transition Radiation Tracker with First High Energy pp and Pb-Pb collisions at LHC

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Outline

• ATLAS and the LHC
• The Transition Radiation Tracker (TRT):
  • Design
  • Operation
  • Calibration
  • Performance
• Summary
Status of the LHC

- Synchronous collider of protons (40 MHz, 25 ns bunch spacing) and Pb ions
- First collisions in Nov. 2009, stable running in 2010, continuing to run in 2011
- Design instantaneous luminosity of $10^{34} \text{ cm}^{-2}\text{s}^{-1}$ with energy of 7 TeV per proton beam; currently running at $\sim 10^{33} \text{ cm}^{-2}\text{s}^{-1}$ (setting world records!) with 3.5 TeV per beam and 50 ns bunch spacing
- Delivered 48 pb$^{-1}$ of proton-proton collisions and 10 µb$^{-1}$ of Pb-Pb collisions in 2010
- Already delivered over 500 pb$^{-1}$ of pp collisions in 2011!
ATLAS

- Large multi-purpose particle detector
- Consists of several sub-detectors:
  - Muon Spectrometer (MS)
  - Liquid Argon and Scintillator Tile Calorimeters
  - Inner Detector (ID)
- Toroid magnets supply ~1.4 T field and ID solenoid provides 2 T field

- Inner Detector composed of two silicon trackers (Pixel & SCT) surrounded by straw tracker (TRT)
- ID provides tracking for charged particles with $p_T > 0.1$ GeV within $|\eta| < 2.5$; $\eta \equiv -\ln(\tan(\theta/2))$
- 6.2 million channels in the SCT and more than 80 million channels in the Pixels
TRT Design: The Straw

- Kapton straw (d = 4 mm) strung with gold plated tungsten anode wire (d = 31 µm)
- Reinforced with carbon-fiber for mechanical strength and thermal conductivity

- Filled with gas mixture of Xe/CO₂/O₂ (70%/27%/3%) chosen for stability and transition radiation absorption
- Works in proportional mode with the straw wall being held at -1.5 kV (wire at ground)

Straws in a prototype end-cap wheel
TRT Design

TRT Barrel

• ~53k 1.44 m straws arranged parallel to beam pipe covering $|\eta| < 1.0$

• Wire segmented in middle by glass bead to create a total of 106k readout channels (innermost straws have two beads with dead region in between to reduce occupancy)

• Polypropylene foam for transition radiation

TRT End-cap

• 39 cm straws arranged radially in 20 wheels (8 straw layers per wheel) covering 0.7 < $|\eta| < 2.0$

• ~120k readout channels per end-cap, one end-cap on each side of the barrel

• Polypropylene foils between wheels for transition radiation
**TRT Operations**

- For the 2010 run, the TRT provided good quality data with **100% efficiency** during LHC stable beams - one of two ATLAS sub-detectors!
- Due to:
  - Much work by TRT experts to keep the detector running smoothly
  - Automated processes to correct readout problems at runtime
  - Ability to run with nominal high voltage regardless of beam conditions
- Note: **98%** of the installed detector is currently being read out

<table>
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<th>Inner Tracking Detectors</th>
<th>Calorimeters</th>
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Luminosity weighted relative detector uptime and good quality data delivery during 2010 stable beams in pp collisions at $\sqrt{s} = 7$ TeV between March 30\textsuperscript{th} and October 31\textsuperscript{st} (in %). The inefficiencies in the LAr calorimeter will partially be recovered in the future.
Particle Detection

- Charged particle ionizes gas, closest ionization determines $T_{\text{Drift}}$
- Readout granularity of 3.119 ns (8 bins per bunch crossing), trigger reads out 3 bunch crossings (~75 ns)
- **Low threshold** - particle tracking
- **High threshold** - particle identification using transition radiation photons
$W\rightarrow ev$ Candidate

electron $p_T = 23$ GeV  \hspace{1cm} $E_T^{\text{miss}} = 31$ GeV

**ATLAS Experiment**

Underlying Event/Pileup

$W\rightarrow ev$ candidate in 7 TeV collisions

Run Number: 152777, Event Number: 3276028
Date: 2010–04–10 12:07:39 CEST
Calibration

- **Thresholds:**
  - Low thresholds equalized to 2% noise occupancy
  - High thresholds equalized for uniform response to electrons

- **Calibration (every 24 hours):**
  - “R-t” relation converts $T_{\text{drift}}$ to a measured drift radius
    - Depends on gas composition, temperature, magnetic field
  - Uniform, stable detector response: two R-t relations for barrel, one for each end-cap
  - “$T_0$” calibration (front end chip level)
    - Accounts for time of flight of particle, electronics delays, etc.
Position Resolution

- TRT provides on average **30 position measurements** with **118 (132) \( \mu \)m** resolution in the barrel (end-cap)

- Due to:
  - Alignment work, including a wire by wire alignment of the entire TRT (over 700k DoF!)
  - Calibration improvements, including drift time corrections for signal size

Mean Position Residual
Red/Blue == Misaligned!

\[ \text{Residual} = R_{\text{Drift}} - R_{\text{Track}} \]
Momentum Resolution

- **Significant improvement** in momentum resolution in the Inner Detector due to large number of hits and longer “lever arm”

- Z mass resolution in the Inner Detector also shows good performance, approaching that of the “ideal” Monte Carlo

\[
\frac{d\sigma}{dp} \times d
\]

\[
\begin{align*}
\int Ldt &= 42 \text{ pb}^{-1} \\
|\eta| &< 1.05 \\
\text{Inner Detector}
\end{align*}
\]

\[
\sigma = (2.36 \pm 0.07) \text{ GeV}
\]

\[
\begin{align*}
\text{Data 2010} \\
\sqrt{s} &= 7 \text{ TeV}
\end{align*}
\]

*ATLAS* Preliminary Cosmic ’08

*ATLAS* Preliminary
Transition Radiation

- **Transition radiation**: photon emitted by a charged particle when traversing the boundary between materials with different dielectric constants ($\varepsilon_1, \varepsilon_2$)

- Intensity of emission is a function of $\gamma = E/m$, $\theta \propto 1/\gamma$
  - Low photon emission probability per transition $\Rightarrow$ many transitions needed
    - Intensity eventually limited by saturation effects
  - Emitted energy $\propto (\varepsilon_1 - \varepsilon_2)$
    - Gas and plastic give photon energies of 5 to 30 keV

- Gas with high photon absorption (high Z) required - Xenon

- Discriminate electrons from hadrons based on number of **High Threshold** (HT) hits on a track
$W\rightarrow\text{ev}$ Candidate

TRT high threshold hits on track marked in red

Underlying Event/Pileup

Electron

Missing $E_T$
**Particle Identification**

- **TRT High Threshold hit fraction** provides electron/hadron discrimination from transition radiation for energies < 150 GeV.
- End-caps provide better HT fraction discrimination due to regular spacing of the radiator foils and also having more radiator.
- **Time over threshold** is sensitive to $\frac{\partial E}{\partial X}$ of charged particle, providing particle identification for momentum < 10 GeV.
Heavy Ion Performance

$Z \rightarrow e^+e^-$ candidate in Pb-Pb collisions
Heavy Ion Performance

- Provide a challenge for the TRT as detector occupancies for the most central collisions are > 90%
- Readout performed well due to lossless data compression and lower collision rate
- Allowed studies to optimize tracking in high occupancy environments
- Even in high occupancy events, TRT contributes to particle tracking
Summary

• The TRT:

• A straw tracker in the ATLAS Inner Detector which provides charged particle tracking and identification

• Smooth running with 100% data taking efficiency during LHC stable beams in 2010 and 2011

• Alignment and calibration procedures implemented and producing 118 (132) μm hit resolution in barrel (end-cap)

• Tracking improves momentum resolution and transition radiation detection improves electron identification

• Heavy ion collisions demonstrate readout and tracking capability in high occupancy environments
Backup
Hit Efficiency

- Hit Efficiency $\equiv \frac{\text{# of hits on track}}{\text{# of straws passed by track}}$
  (excluding first and last hit on track)
- Achieved a “plateau” hit efficiency of 94% in the central (± 1.3 mm) region of the straw
- Inefficiency at outer straw radius due to reconstruction effects and smaller signal size
- Excludes 2% of straws which are known to be inactive