The ATLAS TRT and its Performance at LHC

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Outline

- Introduction (LHC status)
- The ATLAS TRT
- Operation of the TRT
- Calibration of the TRT
- Particle Identification with TRT
- Performance of the TRT (*pp and Heavy Ion collisions*)
- Summary
ATLAS TRT and its Performance at LHC
LHC Status

- Design (for p-p collisions)
  - \( E_{CM} = 14 \text{ TeV} \)
  - Interaction rate \( f = 40 \text{ MHz} \)
    \( (T = 1/f = 25 \text{ ns bunch spacing}) \)
  - Luminosity \( L = 10^{34} \text{ cm}^{-2}\text{s}^{-1} \)

- Currently
  - running at \( L = 10^{33} \text{ cm}^{-2}\text{s}^{-1} \)
  - \( E_{CM} = 7 \text{ TeV} \)
  - \( T = 50 \text{ ns bunch spacing} \)
  - Delivered >1 fb\(^{-1}\) of p-p collisions
    and 10 \( \mu \text{b}^{-1}\) of Pb-Pb collisions

- Physics
  - *Standard Model has already been rediscovered*
ATLAS

- Large multi-purpose particle detector consisting of several sub-detectors:
  - Muon Spectrometer
  - Liquid Argon and Scintillator Tile Calorimeters
  - Inner Detector (ID) (for charged particle tracking and identification)

Toroid magnets: $B = 1.4$ T
ID solenoid: $B = 2.0$ T
ATLAS Inner Detector

ID is composed of

* two silicon trackers (Pixel & SCT)
* Transition Radiation Tracker (TRT)

Provides tracking information for charged particles with:

* $|\eta| < 2.5$
* $p_T > 0.5$ GeV

**Pixel: 80 M channels**

**SCT: 6.2 M channels**

Momentum Resolution:

$$\frac{\sigma(p_T)}{p_T} = 0.05\%p_T \oplus 1\%$$
ATLAS TRT

Physical Properties of TRT:
- is a gaseous detector.
- consists of straw tubes ($d = 4 \text{ mm}$) reinforced with carbon fibers and containing a $d = 31 \mu \text{m}$ gold plated tungsten wire in the center.
- The straw wall is at $-1.5 \text{ kV}$ while the wire is kept at ground.
- Filled with gas mixture of $\text{Xe/CO}_2/\text{O}_2$ (70%/27%/3%) chosen for stability and transition radiation performance

TRT provides:
- $p_T$ measurement over wide range
- electron identification
- long lever arm for continuous tracking ($\sim 30$ hits per track)
- hit precision of $\sim 130 \mu \text{m}$
ATLAS TRT

TRT Barrel
- 105088 readout channels
- 144 cm straws arranged parallel to beam pipe
- covers $|\eta| < 1.0$
- *Wires split in two, independent readout on both sides*

2 TRT End-caps
- 245760 readout channels
- 39 cm straws arranged radially in 20 wheels
- covers $0.7 < |\eta| < 2.0$
TRT Barrel

TRT End-cap
**ATLAS TRT Electronics**

***The TRT front-end electronics uses two thresholds***
- a low threshold (300 eV) for registering the passage of minimum ionizing particles
- a high threshold (6 keV) to flag the absorption of transition radiation X-rays.

***Front-End electronics consists of:***
- **ASDBLR** – Amplifier Shaper Discriminator Baseline Restorer
  => analog integrated circuit
- **DTMROC** – Digital Time Measurement Readout Chip
  => digital integrated circuit

**Total number of readout channels: 350848**
Particle Detection

- A charged particle ionizes gas
- Electrons drift to wire to produce signal (a few hundred of eV)
- LT: for particle tracking
- HT: for particle id
- ToT: for particle id

- Time resolution: 3.12 ns
- 8 bins per bunch crossing
- 75 ns read out per event
Calibration

- By design each straw measures a time which has to be converted into spatial coordinates.

- **R-t relation** converts $T_{drift}$ to a measured drift radius
  
  - Depends on external effects (*Magnetic Field, Temperature,..*)
  
  - For all TRT straws, One R-t relation is used for Barrel and one for end-cap
  
  - R-t calibration is performed regularly (every ~24h).

- **$T_0$ calibration** (Hardware level) depends on ToF, cable lengths, electronics delays.
Transition Radiation (TR)

TR: photon (soft X-ray) emitted by a charged particle when traversing the boundary between materials with different dielectric constants ($\varepsilon_1$, $\varepsilon_2$)

- Intensity: $I \propto \gamma = \frac{E}{m}$
- Emission angle: $\theta \propto \frac{1}{\gamma}$
- Emitted Energy: $E_{TR} \propto (\varepsilon_1 - \varepsilon_2)$

- Low photon emission probability per transition.
  => Many transitions needed

- Gas and plastic give photon energies 5 – 30 keV
- Gas with high photon absorption (high Z) required
  => Xenon based mixture

- Discriminate electrons from hadrons based on number of HT hits on a track
ATLAS TRT Performance
Particle Identification

- TRT High Threshold hit fraction defined by:
  \[ p \equiv \frac{\text{# of HT hits on tracks}}{\text{# of LT hits on tracks}} \]
  provides electron/hadron discrimination
  over the momentum range between 1 and 150 GeV/c

- Different number of radiators are used for barrel and end-cap
W→eγ candidate in 7 TeV collisions

\( p_T(e^+)=34 \text{ GeV} \)
\( \eta(e^+) = -0.42 \)
\( E_T^{\text{miss}} = 26 \text{ GeV} \)
\( M_T = 57 \text{ GeV} \)
Particle Identification

- Time Over Threshold (ToT) is sensitive to dE/dx of charged particle, allowing an independent method of particle identification.
Position Resolution

- TRT provides on average 30 position measurements with ~120(130) μm resolution in the Barrel(End-cap), surpassing design resolution!

Good alignment work, including a wire by wire alignment is done (700k DoF!)
Momentum Resolution

- With its long lever arm, the TRT significantly improves the momentum resolution compared to tracks reconstructed with silicon hits only.

**also**

- Z mass resolution in the ID shows good performance
- Good agreement data/MC
Straw Hit Efficiency

- TRT hit efficiency ~ 94% in the central region (1.3 mm) of the straw
- Dead channels excluded (~2%)
- Inefficiency at outer straw radius due to reconstruction effects and smaller signal size
- MC was tuned to 900 GeV agrees well with 7 TeV data
Heavy Ion Performance

- Several weeks of Heavy Ion running at the end of 2010

- Very challenging environment: occupancy > 90% (several thousands of tracks per event)

- Even in high occupancy, TRT provides useful tracking information
$Z\rightarrow e^+e^-$ candidate in Pb-Pb collisions
Summary

The TRT

- is an excellent detector improving ATLAS tracking with its long lever arm and the high number of hits per track
- provides particle identification
- runs with 100% data taking efficiency during LHC stable beams in 2010 and 2011
- alignment and calibration results in $\sim 120(130) \, \mu m$ hit resolution in Barrel(End-cap) which is better than the design expectations.
- improves the tracking measurements in HI collisions as well
- is ready for at least ten more years of LHC running
ACKNOWLEDGMENT

- Thanks to the many devoted TRT workers making the detector perfect.
References

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[3]. ATL-INDET-PROC-2010-040  J. D. Degenhardt

[4]. ATL-INDET-PROC-2010-043  R. Mashinistov

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[6]. ATL-INDET-SLIDE-2011-200  S. Schaepe
Backup Slides

A - T0 calibration

B - Particle ID and binomial distribution
A - T0 Calibration

In hardware, the timing of the readout window can only be tuned for single readout boards in fixed steps of 0.5 ns. Within a given board there is still a timing spread of up to 3 ns. For the desired resolution however a precision in the order of 100 ps has to be achieved. One of the main effects requiring offline calibration is illustrated in Fig. The timing signal is distributed to the different DTMROCs on a readout board serially resulting in a small offset between neighboring chips. Routinely the offset is measured for every straw in each run and a calibration is run on the level of single chips. Straws connected to one chip were found to show no major variations in timing. Experience shows that calibration constants have to be updated every few weeks. The main reasons for such frequent updates are linked to the slow drifts of the time reference provided by the LHC and replacements of single hardware components in the readout or triggering chain.
How a Straw Tube Measures Time

Cluster Arrival Time = Flight Time + Drift Time + Propagation Time
B - Particle Identification and Bin. Dist.

The use of HT is a statistical process \textit{>> binomial distribution}.

For \( N = 30 \) straws and \( p = 1 \) GeV/c
\[
\begin{align*}
P(e) &= 12\% \Rightarrow \langle n_{HT} \rangle = 3.6 \text{ hits} \\
P(\pi) &= 4\% \Rightarrow \langle n_{HT} \rangle = 1.2 \text{ hits}
\end{align*}
\]

For \( N = 30 \) straws and \( p = 10 \) GeV/c
\[
\begin{align*}
P(e) &= 20\% \Rightarrow \langle n_{HT} \rangle = 6.0 \text{ hits} \\
P(\pi) &= 4\% \Rightarrow \langle n_{HT} \rangle = 1.2 \text{ hits}
\end{align*}
\]

For \( N = 30 \) straws and \( p = 150 \) GeV/c
\[
\begin{align*}
P(e) &= 20\% \Rightarrow \langle n_{HT} \rangle = 6.0 \text{ hits} \\
P(\pi) &= 10\% \Rightarrow \langle n_{HT} \rangle = 3.0 \text{ hits}
\end{align*}
\]
Toy Simulation Results for N = 30 straw hits:

\[ p = 1 \text{ GeV/c} \]
- \( e \rightarrow \) ○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○○}
Test Beam vs 2010 Data and MC

ATLAS Preliminary
TRT barrel
- Data 2010 ($\sqrt{s} = 7$ TeV)
- Monte Carlo

$\chi^2/N_{d.o.f.} = 153.4/20$

$\gamma$ factor

Pion momentum [GeV]
Electron momentum [GeV]

Test Beam

Pion momentum [GeV]
Electron momentum [GeV]

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ATLAS TRT and its F