The Performance and Radiation Hardness of the Outer Tracker Detector for LHCb

8 Oct 2013
13th Topical Seminar on Innovative Particle and Radiation Detectors

Niels Tuning on behalf of the LHCb Outer Tracker
Outline

- LHCb and the Outer Tracker
- Ageing: the saga
- OT performance in LHC run I
- Radiation hardness
- Outlook
LHC and LHCb
The LHCb Detector
The LHCb Detector
The LHCb Detector
The LHCb Detector

Forward arm spectrometer
- $2 < \eta < 5$
- $\sigma(pp \rightarrow X)_{\text{inel}} \approx 60 \text{ mb}$
- $\sigma(pp \rightarrow cc)_{\text{incl}} \approx 6 \text{ mb}$
- $\sigma(pp \rightarrow bb)_{\text{incl}} \approx 0.3 \text{ mb}$

Other LHCb contributions (Yesterday, Monday 16:55)
- Christian Elsasser: The LHCb Silicon Tracker
- Agnieszka Oblakowska: The LHCb Vertex Locator - Performance and Radiation Damage
- Kazu Akiba: The LHCb Vertex Locator - Upgrade Plans
The LHCb Detector

Excellent mass resolution

LHCb
$\sqrt{s} = 8$ TeV

$Y(1S, 2S, 3S) \rightarrow \mu^+ \mu^-$

arXiv:1304.6977

Tracking: $dp/p \sim 0.4$-$0.6\%$
The LHCb Detector

Excellent mass resolution

LHCb, $B_s^0 \rightarrow \mu^+\mu^-$

arXiv:1307.5024

CMS, $B_s^0 \rightarrow \mu^+\mu^-$

arXiv:1307.5025

Tracking: $dp/p \sim 0.4-0.6\%$
Outer Tracker

N. Tuning (10/27)
Outer Tracker

- 12 double layers
- 5 x 6 m²
- 53760 channels
• **Cathode:** Kapton XC
• **Anode:** Gold + Tungsten (+1550 V)
• **Panel:** Rohacel
• **Glue:** Araldite Epoxy AY103
• **Gas:** Ar/CO₂/O₂ : 70/28.5/1.5
Ageing: The saga - part I (phenomenon)

- Remarkable:
  - No gain loss under source, only upstream
  - Very rapid; -30% in 15 hours
  - Not seen in R&D phase, despite extensive ageing tests
Ageing: The saga - part II (culprit)

Wire without ageing

Wire with ageing

Carbon in EDX spectrum

➢ **Cause:**
- Manufacturer changed plastifier: AY103 → AY103-1
- Culprit: di-isopropyl-naphthalene

➢ **Good news:**
- Oxygen slows ageing (increase of ozone)
- Large dark currents cures gain loss
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OT Performance in LHC Run I

- Readout (Noise)
- Dead channels
- Calibration
- Drift time
- Occupancy
- Efficiency
- Alignment, resolution
- Radiation hardness

Delivered luminosity:
2011: 1.1 fb\(^{-1}\)
2012: 2.2 fb\(^{-1}\)
(\sim 10^7\,\text{s at }3.5\times10^{32}\,\text{cm}^{-2}\text{s}^{-1})

Int. dose in hottest region: 0.12 C/cm
OT Performance in LHC Run I - Readout

- **Gas gain**: \(~ 5 \times 10^4\)
- **Analog signal**: \(~ 10^6 \text{ e}^-\)
- **ASD**: Ampl, Shape, Discr.
- **TDC**: 0.4 ns stepsize
- **Pipeline**: 160 BX deep (= 4 \(\mu\)s)
- **GOL**: Upon L0 trigger, readout 3 BX

**Example noisy module:**

- **Threshold**
  - **Channels**: 0 to 120
  - **Threshold (ADC counts)**: 0 to 120
  - **Nominal threshold**

**Noise level**: \(~ 10^{-4}\)
OT Performance in LHC Run I – Dead channels

- **During data taking**: use test pulses

- **Offline**: find channels too few/many hits

  - Noise/Dead channels: $\sim \frac{200}{53760} = 0.4\%$
OT Performance in LHC Run I – Calibration

- Time calibration very stable
- Performed ~ 4x per year

\[ t_{\text{drift}}(r) = 20.5 \text{ ns} \cdot \frac{|r|}{R} + 14.85 \text{ ns} \cdot \frac{r^2}{R^2} \]
• Max. drift time \( \sim 35 \text{ ns} \)
• Max. measured time \( \sim 50 \text{ ns} \)
• Extra hits from:
  - "Spill-over hits"
  - "Multiple hits"
OT Performance in LHC Run I – Occupancy

- Occupancy: 3% – 15%
- Large fraction from secondary interactions
OT Performance in LHC Run I – Efficiency

- Efficiency to detect hit in center of cell \(|r| < 1.25\text{mm}\): \(\sim 99.3\%\)
- Average efficiency per module: \(\sim 98.8\%\)

- Single hit efficiency \(|r| < 1.25\text{mm}\): \(\sim 99.3\%\)
OT Performance in LHC Run I – Alignment/Resolution

- Design specification: 200 μm
  - Straws accurately positioned in module ±50 μm
  - Module hung with accuracy of ±50 μm (are modules straight?)
  - Frames positioned within ±1 mm
  - Optical survey ±0.2 mm
  - Final alignment with tracks

- Internal alignment of mono-layers within a module improves resolution 210 → 180 μm
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Radiation hardness

Two methods to monitor gain loss

1) During technical stops
   - $^{90}$Sr scans to measure detector response

2) During LHC operation
   - Measure hit efficiency with tracks, at increasing amplifier threshold
Radiation hardness

Two methods to monitor gain loss

1) During technical stops
   - No signs of gain loss

2) During LHC operation
   - No change in hit charge
   - No change in detector response
   - Threshold efficiency

 normalized current

\[ \Delta H \]

LHCb OT
Aug 2010

LHCb OT
Dec 2012
Conclusions & Outlook

- Outer Tracker performed superbly in **run I**
  - Few dead or noisy channels
  - No irradiation effects observed
  - High hit efficiency (>99%) and resolution (~200 μm)

- Looking forward to **run II**
  - 2015
  - √s = 13 TeV
  - 25 ns bunch spacing

- Tracker for **run III** to be decided
  - 2020
  - \( L = 2 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1} \)
  - Occupancy too high for present OT

25ns: pilot-run in Nov 2012:

**High occupancy**: p-Pb run in Feb 2013:
Backup: the nitty-gritty

- Internal misalignments
- Effective ionization length
- Signal reflections: “walk” correction
Internal module alignment

- Recently improved alignment
- Relative shift of monolayers

- Resolution 210 → 179 µm
Ionization length

- **Ionization length** $\lambda$: average distance between clusters
- **Measured effective** $\lambda$ in two ways:
  1) Efficiency profile: probes large $|r|$ 
  2) Drift time distribution: probes small $|r|$ 
  - Disentangle effect of absorption

$\varepsilon(r) = \varepsilon_0 \left(1 - e^{-2\sqrt{R^2 - r^2}/\lambda}\right)$

$\langle \lambda \rangle = 0.79 \pm 0.09$ mm

- $\lambda_{\text{eff}}$ is 2x larger than nominal; not due to absorption

$\lambda_{\text{eff}} = 0.7$ mm

$\sigma_t = 1.4$ ns

$t_0 = -1.4$ ns

Tracks with $|r| < 0.1$ mm
**Signal reflections; walk correction**

- Signal is reflected at center
- Hits close to center, get larger amplitude
- Larger amplitude, earlier time: **“walk”**

![Diagram showing signal reflections and walk correction](image)

**Time correction as function of vertical position**

\[ \text{walk}(l) = (-0.1 + 1.2 \cdot (\tanh \frac{l}{0.4} - 1) + 0.1 \cdot l) \text{ ns} \]