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

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on behalf of the LHCb Outer Tracker

Outer Tracker collaboration

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

Excellent mass resolution

Production of J/ψ and Upsilon mesons in pp collisions at $\sqrt{s} = 8$ TeV

arXiv:1304.6977

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

Excellent mass resolution

Production of J/psi and Upsilon mesons in pp collisions at \(\sqrt{s} = 8\) TeV

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Y(1S,2S,3S)→μ⁺μ⁻

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]
Outer Tracker

- 12 double layers
- 5 x 6 m²
- 53760 channels
Outer Tracker

- **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: \textit{AY103 \rightarrow AY103-1}
- Culprit: \textit{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\(^{-1}\)
(~10\(^7\) s at 3.5\times10^{32}\) cm\(^{-2}\)s\(^{-1}\)

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

- **Gas gain**: $\sim 5 \times 10^4$
- **Analog signal**: $\sim 10^6$ 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:**

- **Noise level**: $\sim 10^{-4}$
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

\[ t_{\text{drift}}(r) = 20.5 \text{ ns} \cdot \frac{|r|}{R} + 14.85 \text{ ns} \cdot \frac{r^2}{R^2} \]
OT Performance in LHC Run I – Drift time spectrum

- Max. drift time $\sim 35$ ns
- Max. measured time $\sim 50$ 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
   - $^{90}\text{Sr}$ 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
   - Known effect: 'wirelocators'
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
  - $\sqrt{s}=13$ TeV
  - 25 ns bunch spacing

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

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**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

Without monolayer shift
With monolayer shift
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

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

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

$\langle \lambda \rangle = 0.79 \pm 0.09 \text{ mm}$

- Tracks with $|r| < 0.1 \text{ mm}$
  - \( t_0 = -1.4 \text{ ns} \)
  - $\sigma_t = 1.4 \text{ ns} \)
  - $\lambda_{\text{eff}} = 0.7 \text{ mm}$
Signal reflections; walk correction

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

➢ Time correction as function of vertical position