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

Outer Tracker collaboration

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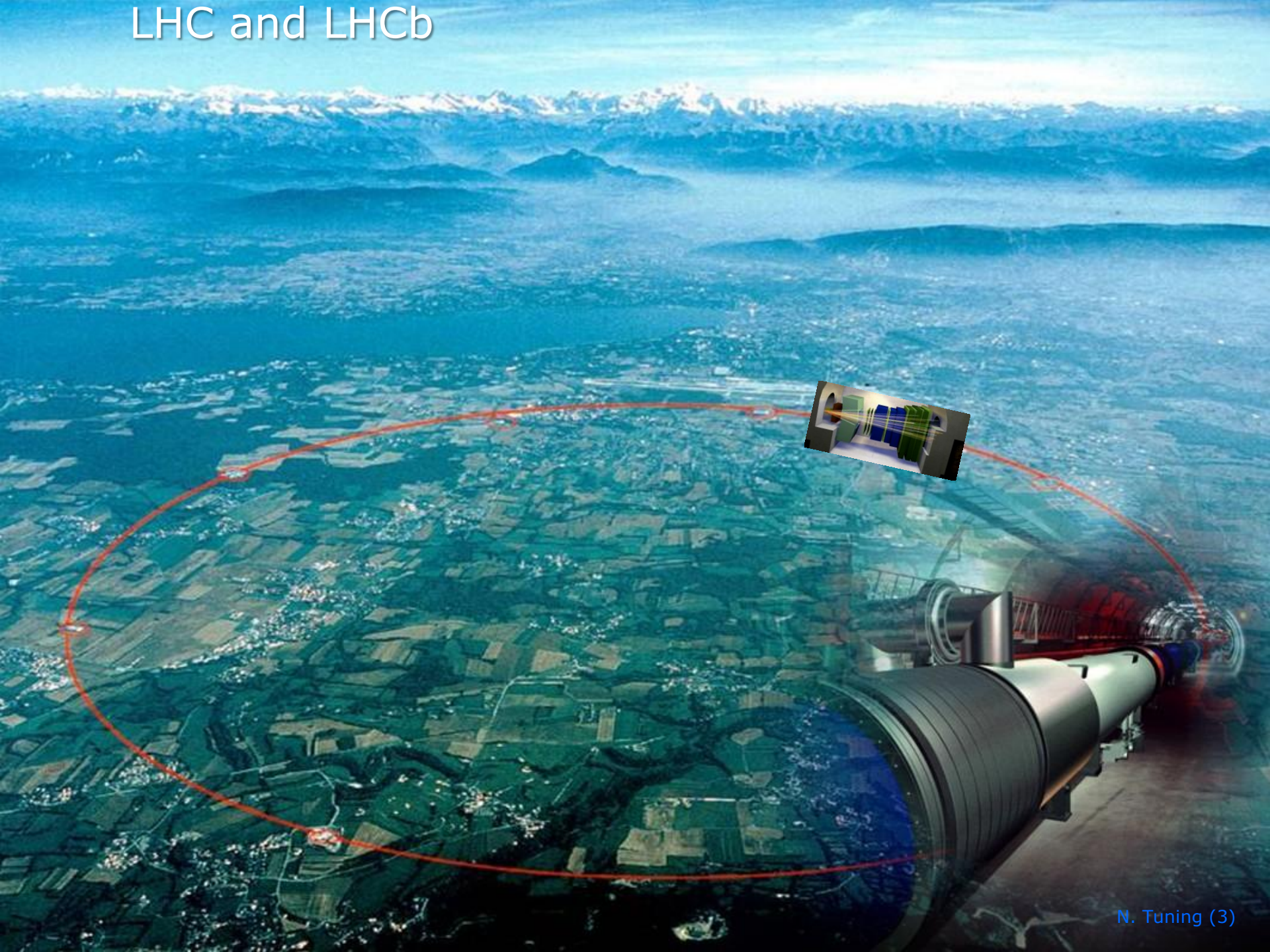
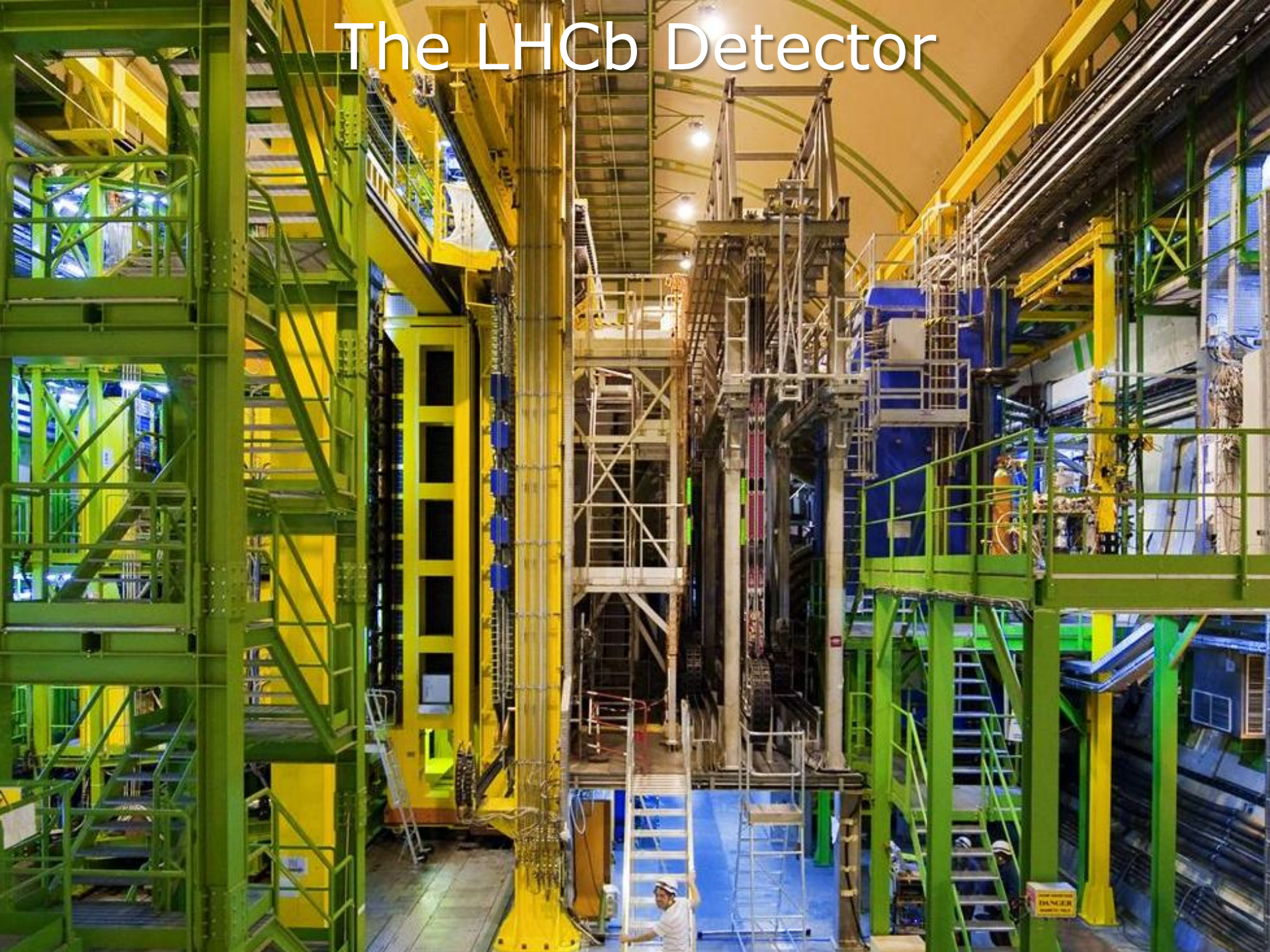
Outline

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

LHC and LHCb



The LHCb Detector



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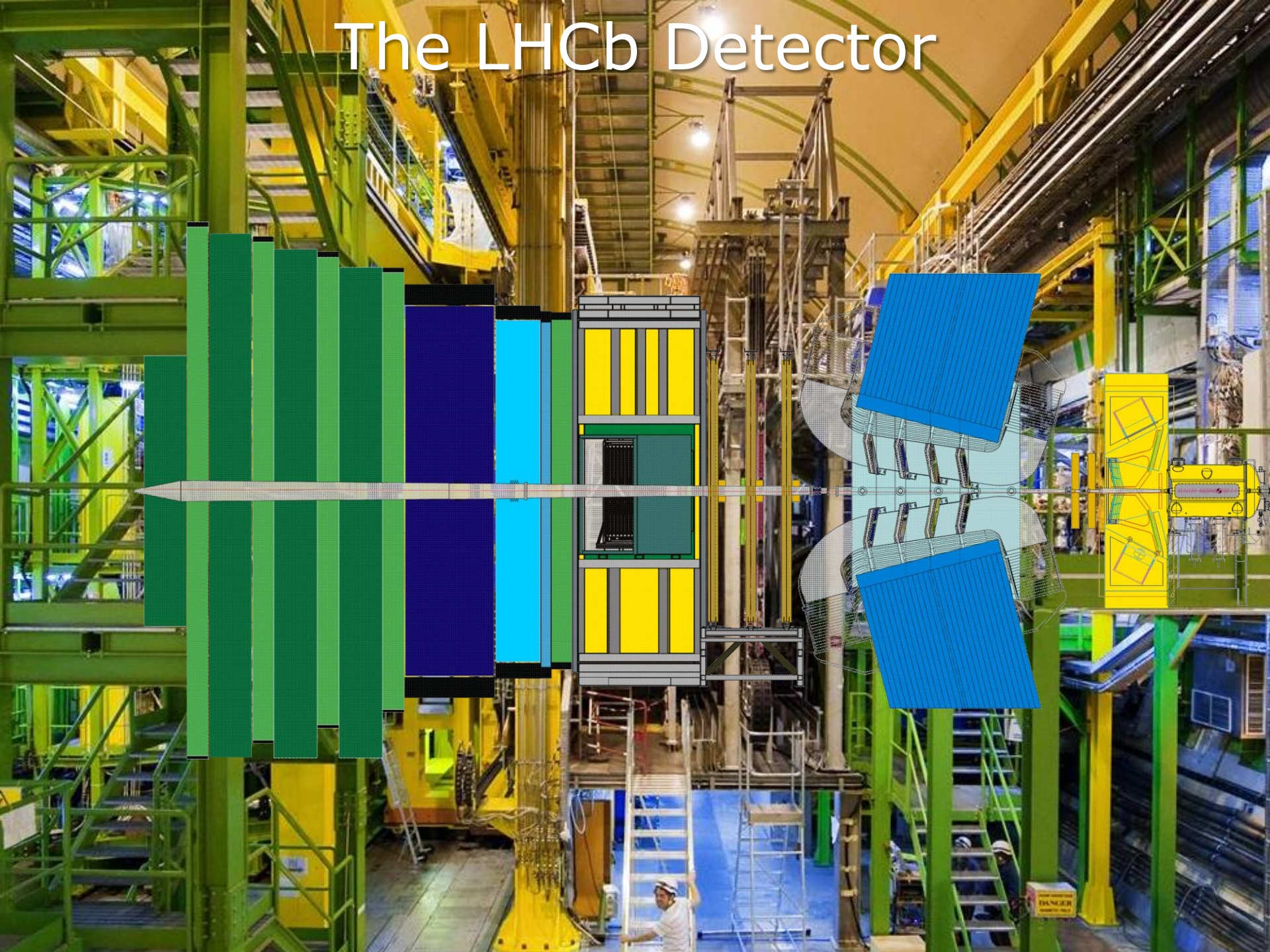
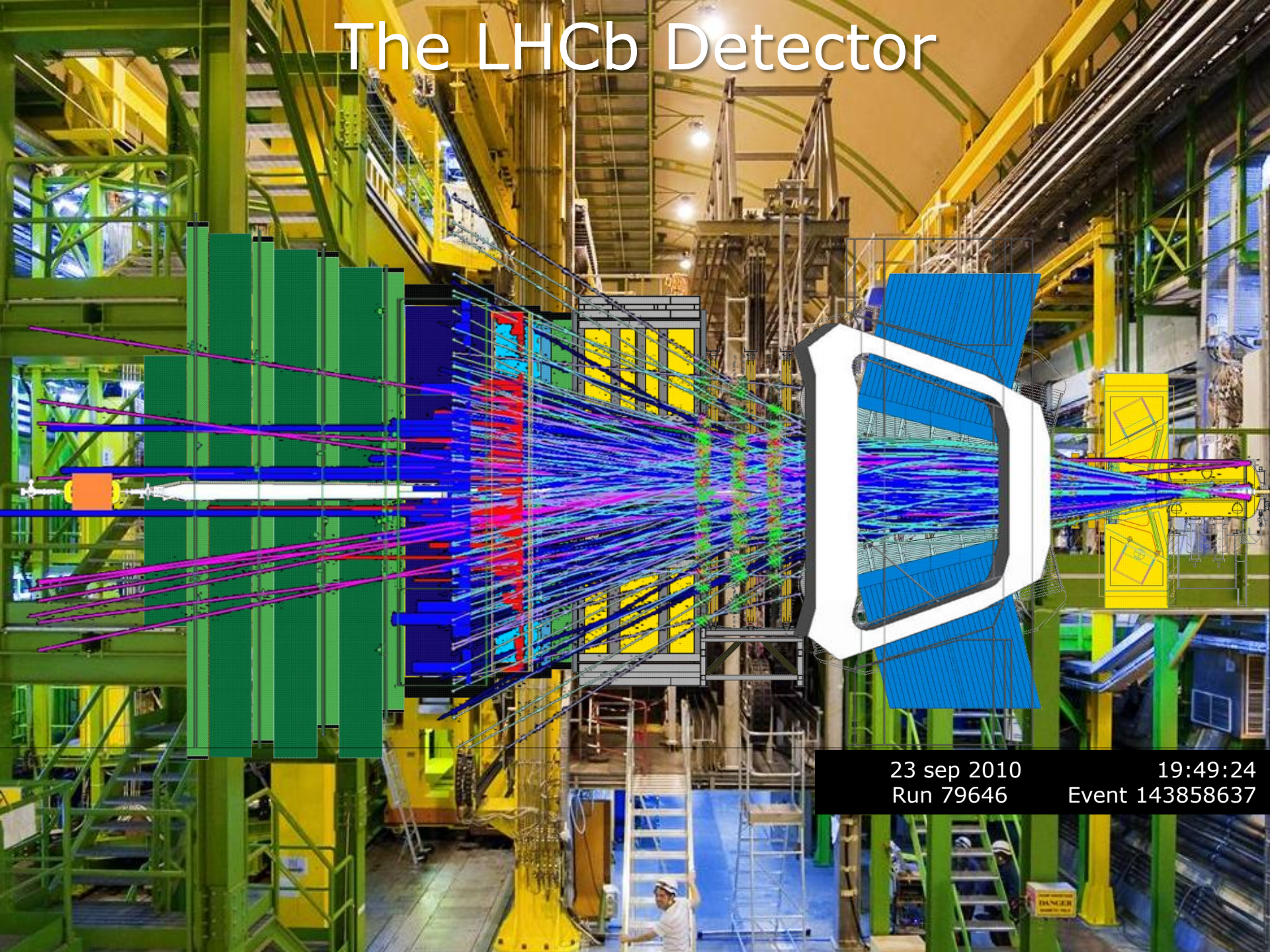
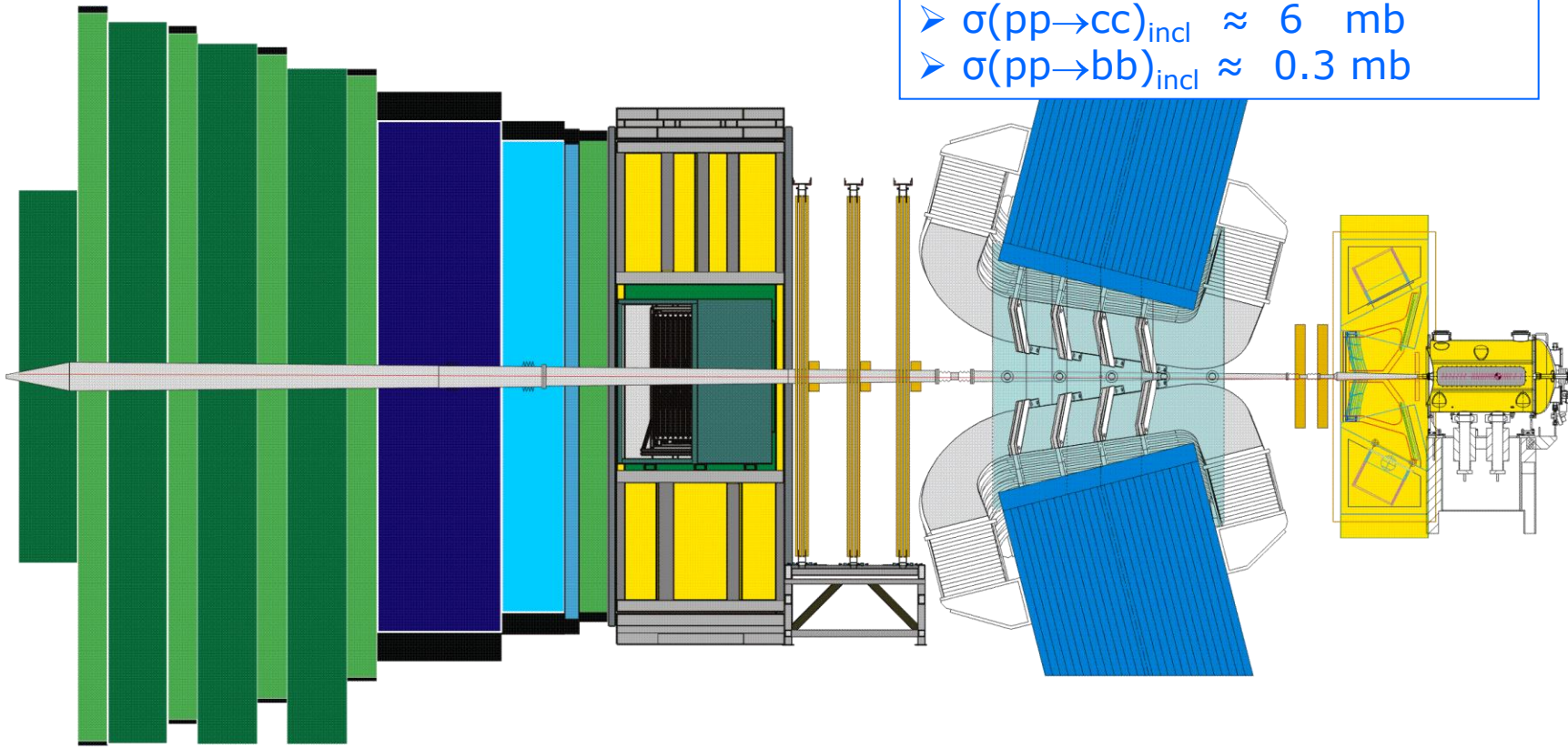


The LHCb Detector



The LHCb Detector

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



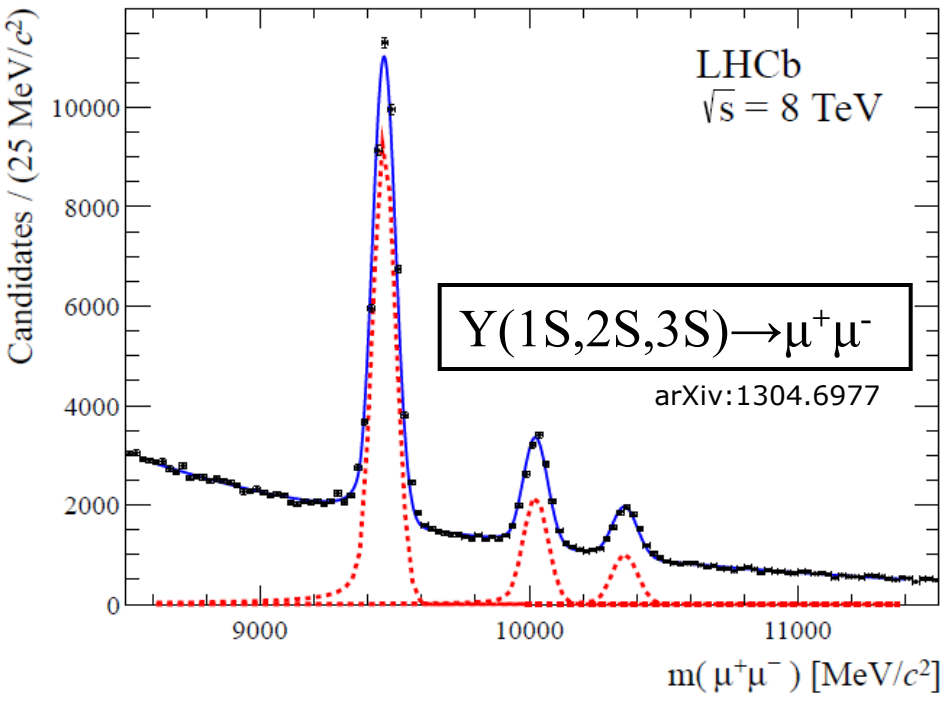
Other LHCb contributions (Yesterday, Monday 16:55)

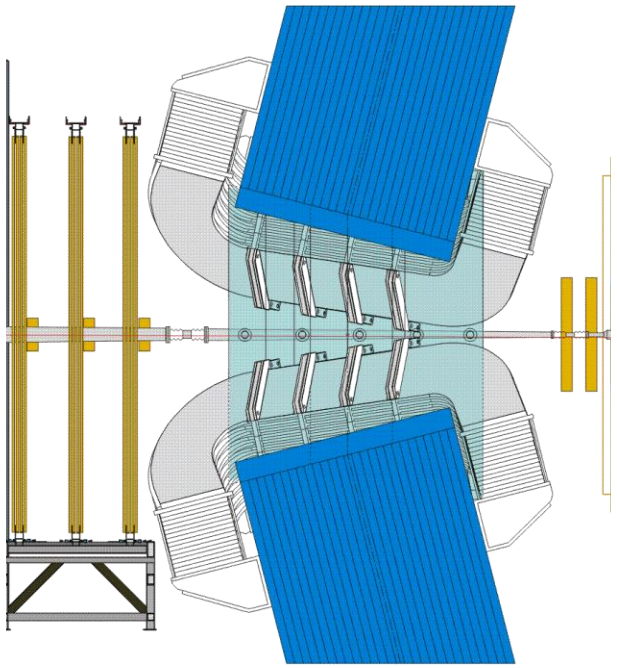
▪ Christian Elsasser	The LHCb Silicon Tracker
▪Agnieszka Oblakowska	The LHCb Vertex Locator - Performance and Radiation Damage
▪Kazu Akiba	The LHCb Vertex Locator - Upgrade Plans

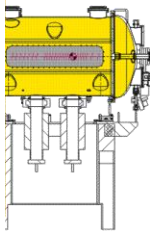
The LHCb Detector

Tracking: dp/p ~ 0.4-0.6%

Excellent mass resolution



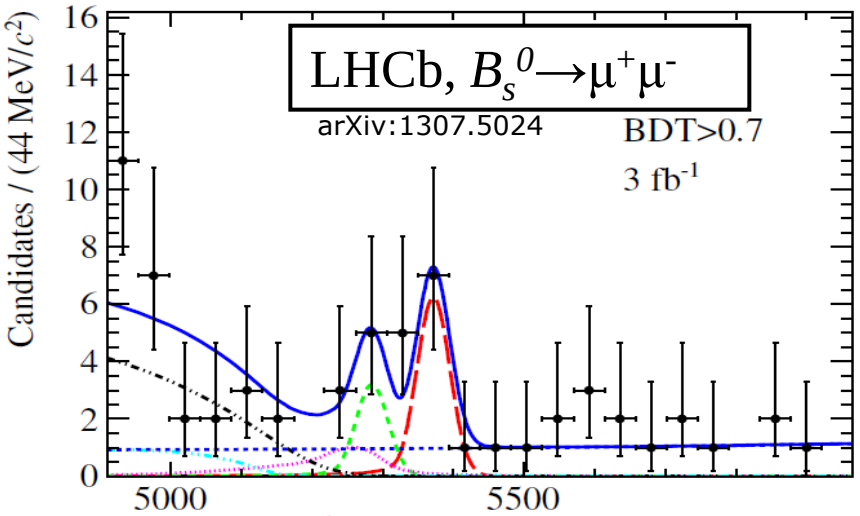


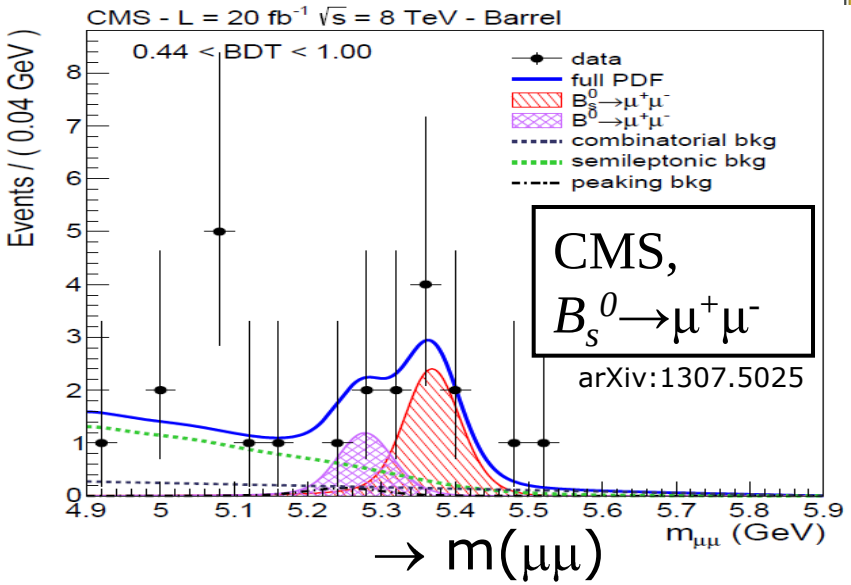


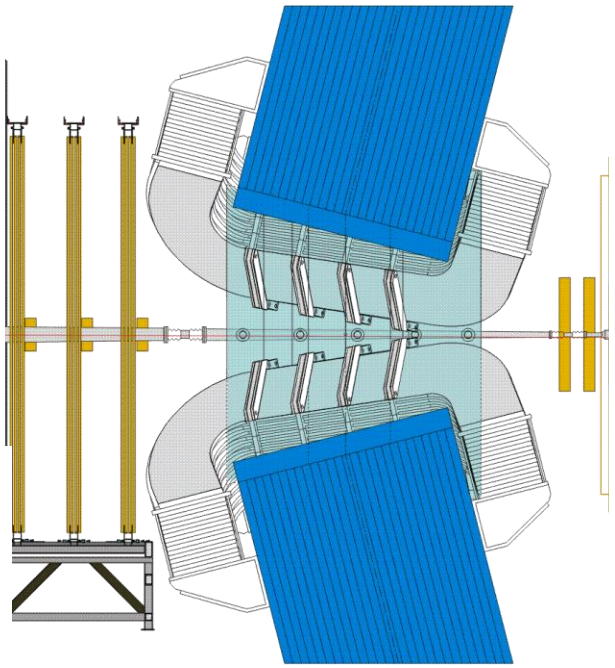
The LHCb Detector

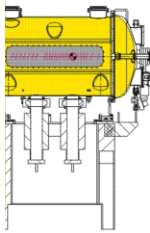
Tracking: dp/p ~ 0.4-0.6%

Excellent mass resolution



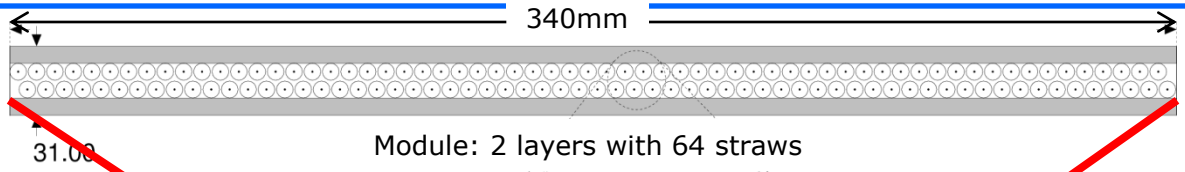




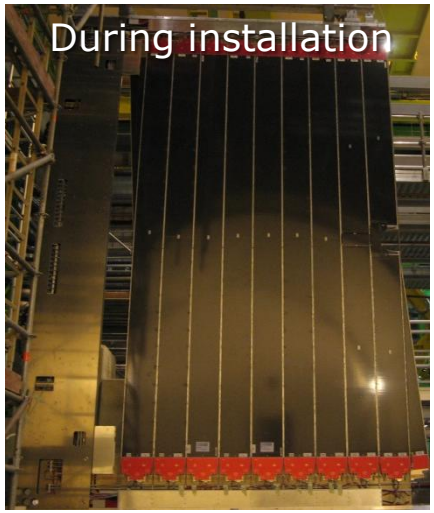


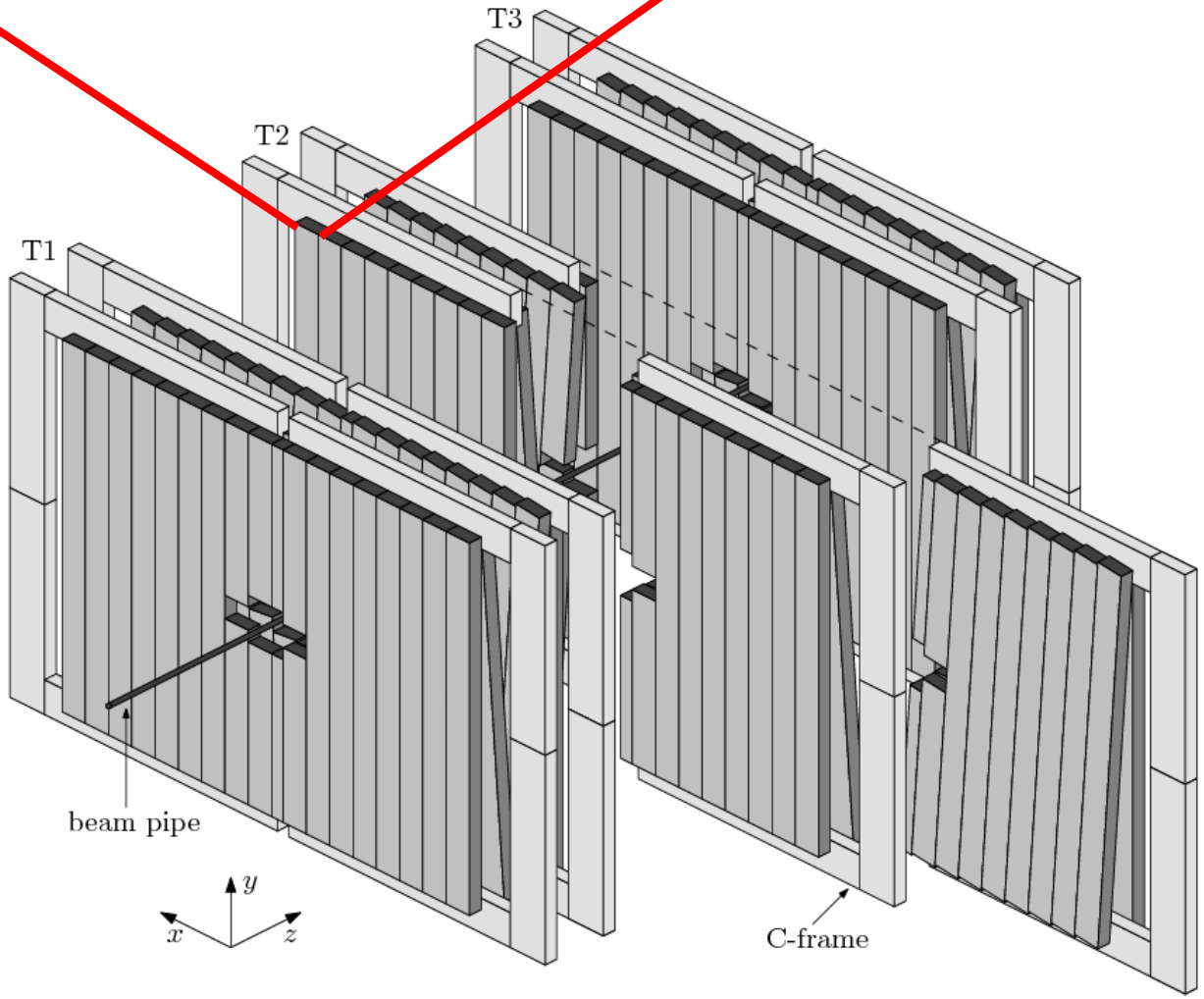
Outer Tracker

Outer Tracker

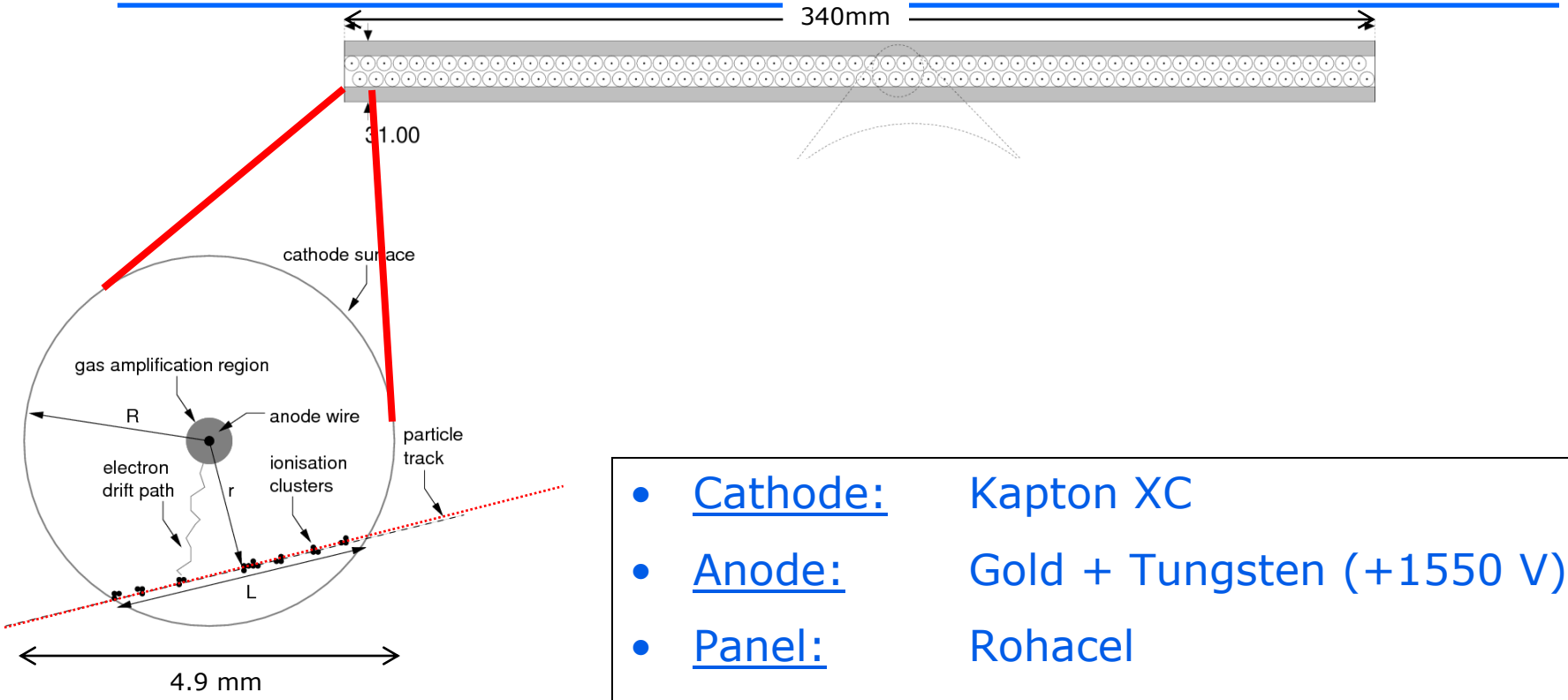


- 12 double layers
- 5 x 6 m^2
- 53760 channels



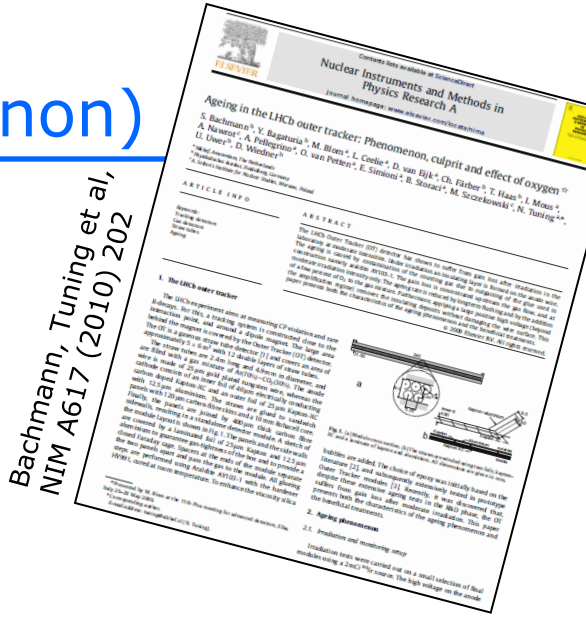


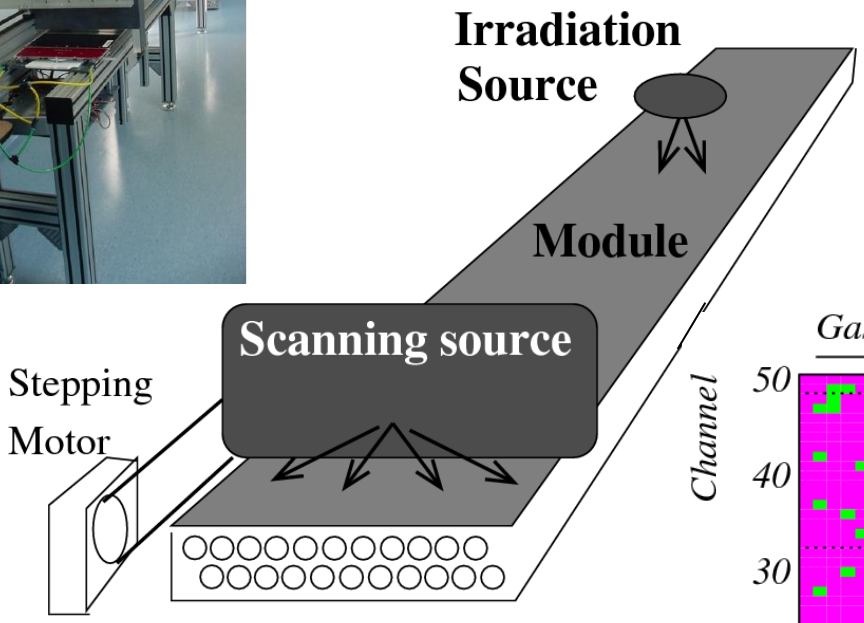
Outer Tracker

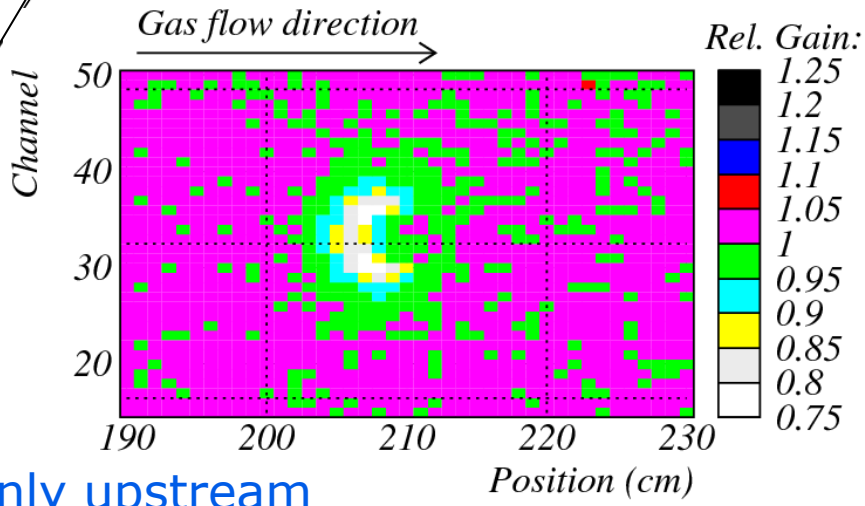


- Cathode: Kapton XC
- Anode: Gold + Tungsten (+1550 V)
- Panel: Rohacel
- Glue: Araldite Epoxy AY103
- Gas: $Ar/CO_2/O_2$: 70/28.5/1.5

Ageing: The saga - part I (phenomenon)

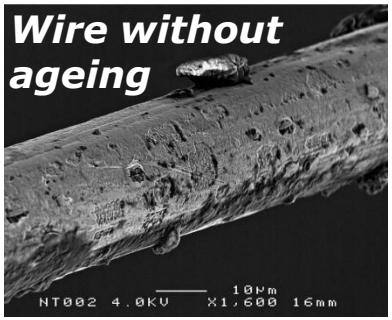


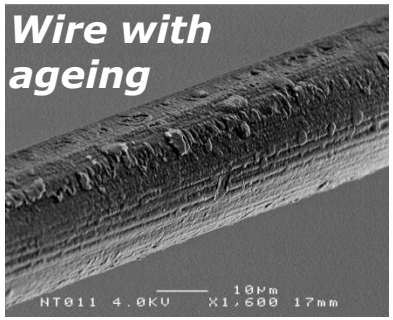


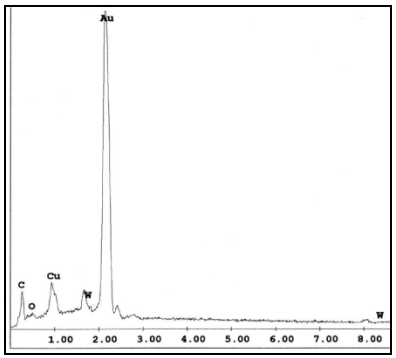


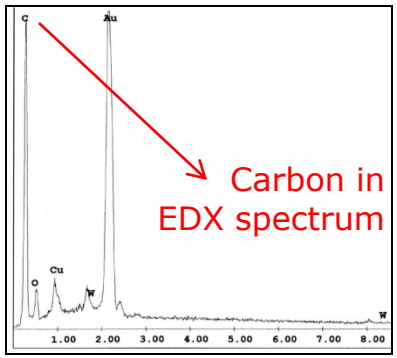
- **Remarkable:**
- No gain loss under source, only upstream
- Very rapid; -30% in 15 hours
- Not seen in R&D phase, despite extensive ageing tests

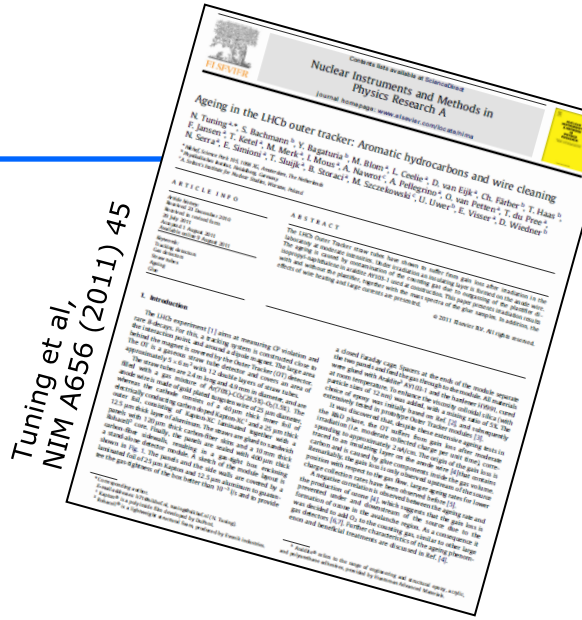
Ageing: The saga - part II (culprit)







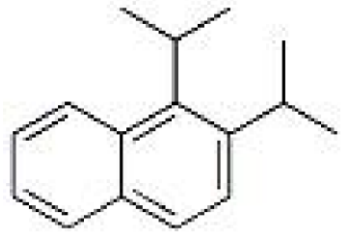



Tuning et al, NIM A656 (2011) 45

Nuclear Instruments and Methods in Physics Research A

Ageing in the LHCb outer tracker: Aromatic hydrocarbons and wire cleaning

- **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

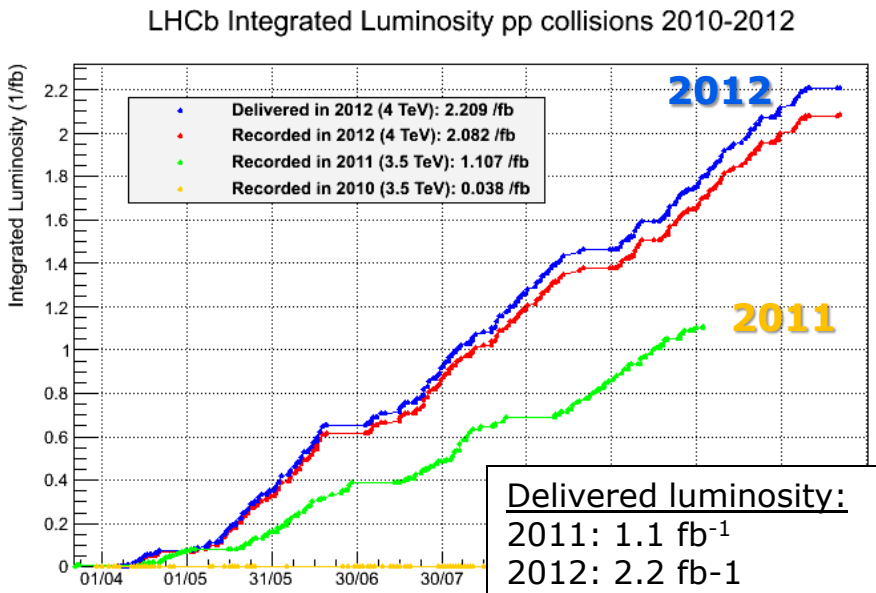
Outline

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

OT Performance in LHC Run I

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

- Radiation hardness

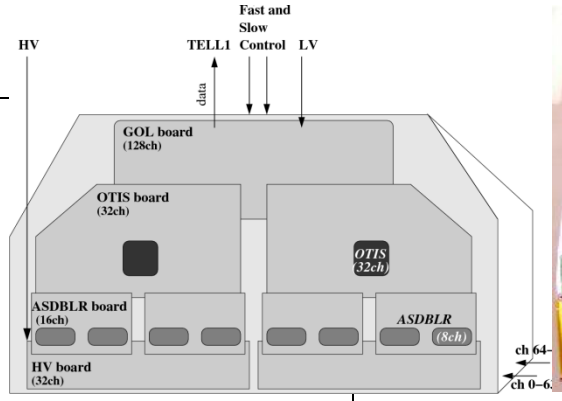


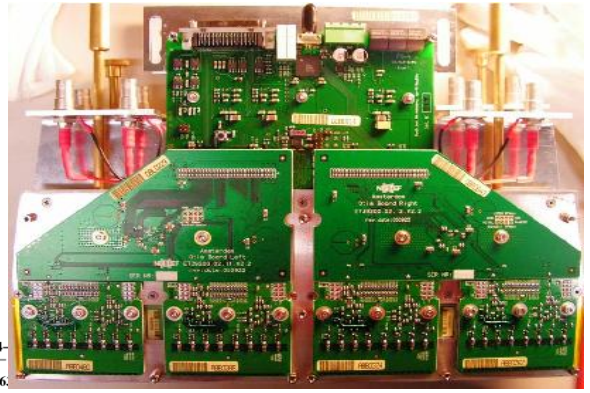
Delivered luminosity:
2011: 1.1 fb^{-1}
2012: 2.2 fb-1
(~10^7 s at 3.5x10^{32} $cm^{-2}s^{-1}$)

Int. dose in hottest region:
0.12 C/cm

OT Performance in LHC Run I - Readout

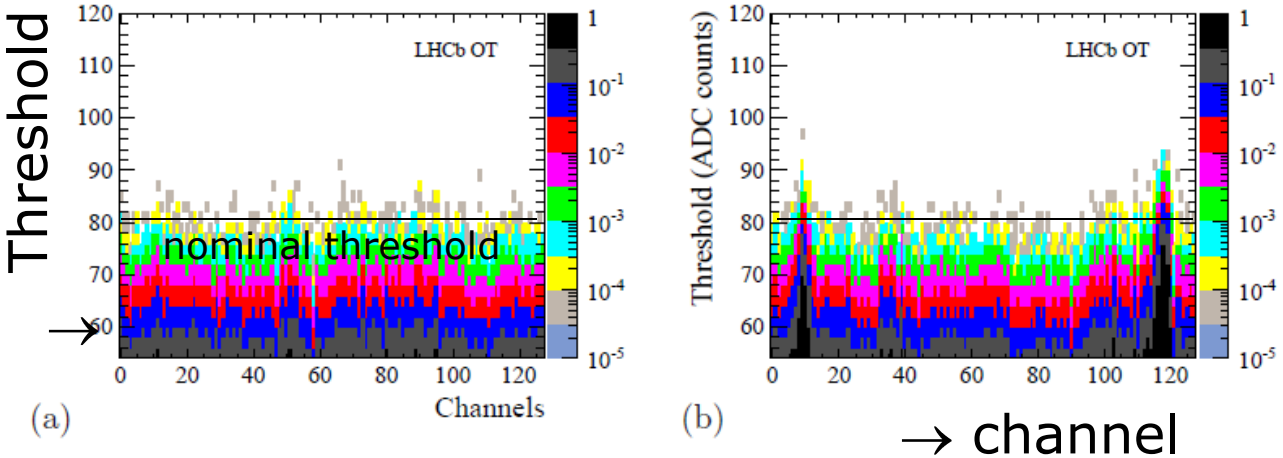
- Gas gain: ~ 5×10^4
- Analog signal: ~ 10^6 e^-
- ASD: Ampl, Shape, Discr.
- TDC: 0.4 ns stepsize
- Pipeline: 160 BX deep (= 4 μs)
- GOL: Upon L0 trigger, readout 3 BX





Detector module
2 x 64 straws

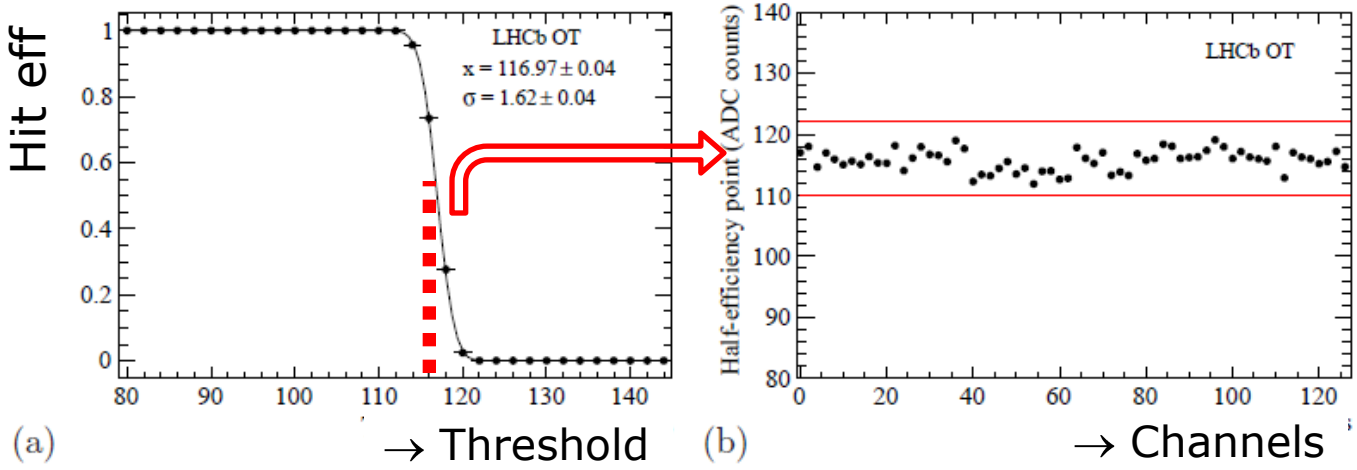
Example noisy module:



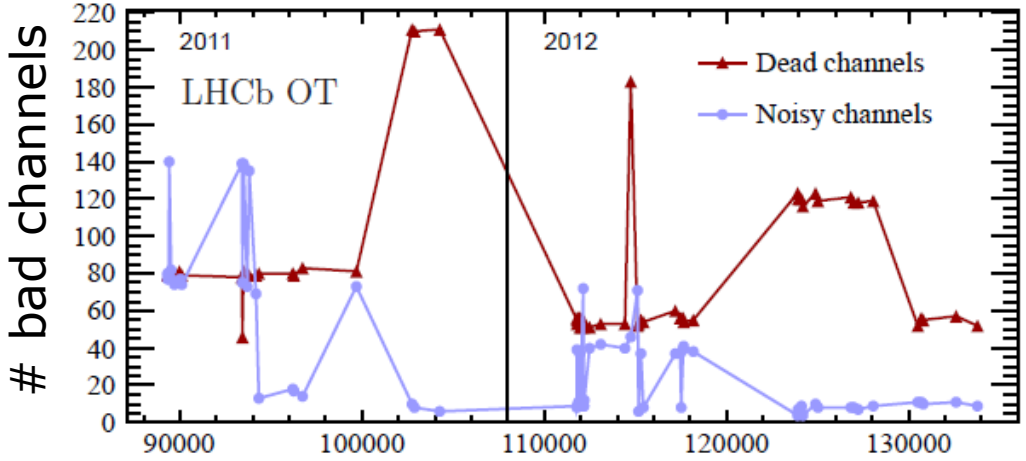
➢ **Noise level ~ 10^{-4}**

OT Performance in LHC Run I – Dead channels

- During data taking: use test pulses



- Offline: find channels too few/many hits

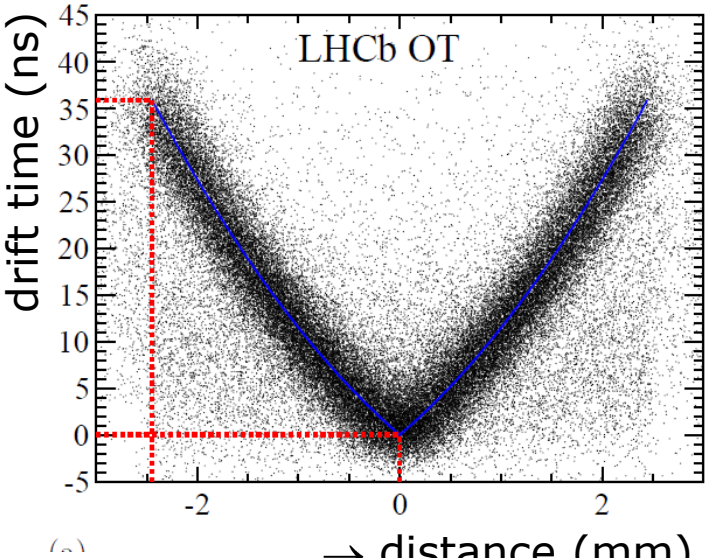


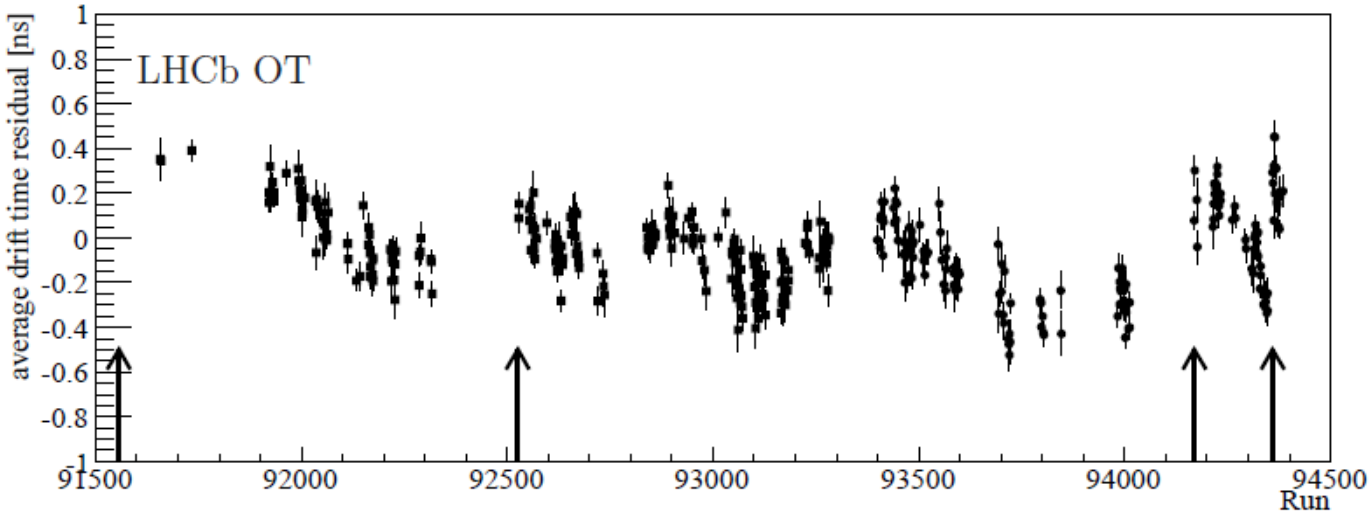
➢ **Noise/Dead channels: ~ 200/53760 = 0.4%**

OT Performance in LHC Run I – Calibration

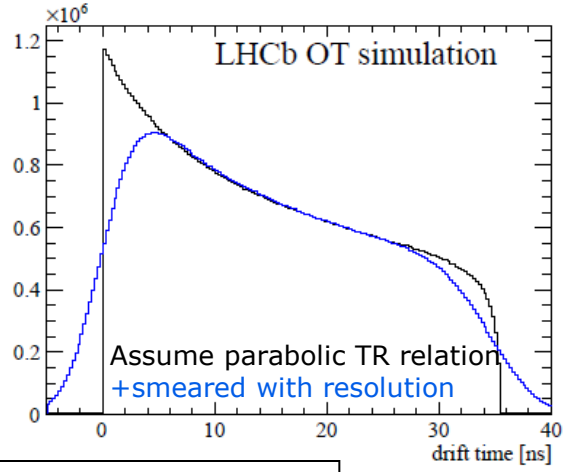
- Time calibration very stable
- Performed ~ 4x per year

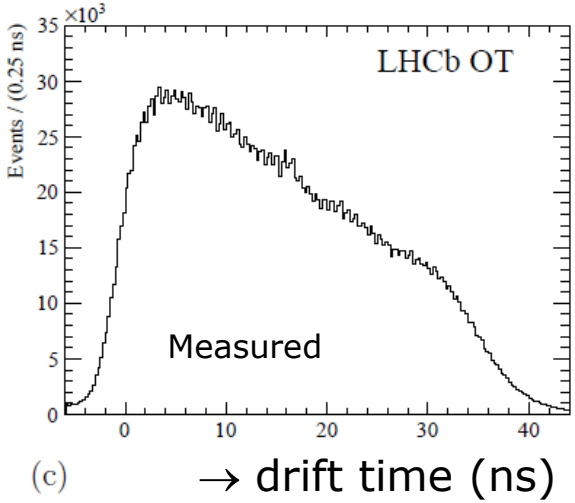
$$t_{\mathrm{drift}}(r) = 20.5\,\mathrm{ns} \cdot \frac{|r|}{R} + 14.85\,\mathrm{ns} \cdot \frac{r^2}{R^2}$$





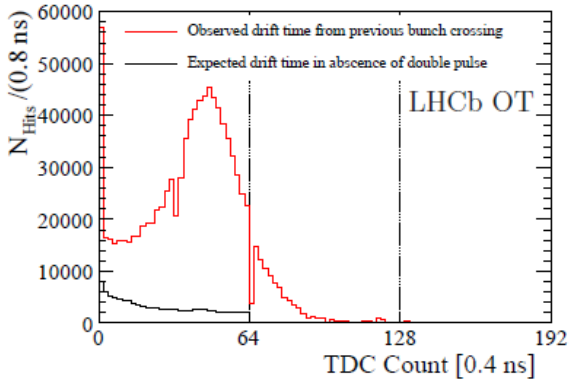
OT Performance in LHC Run I – Drift time spectrum

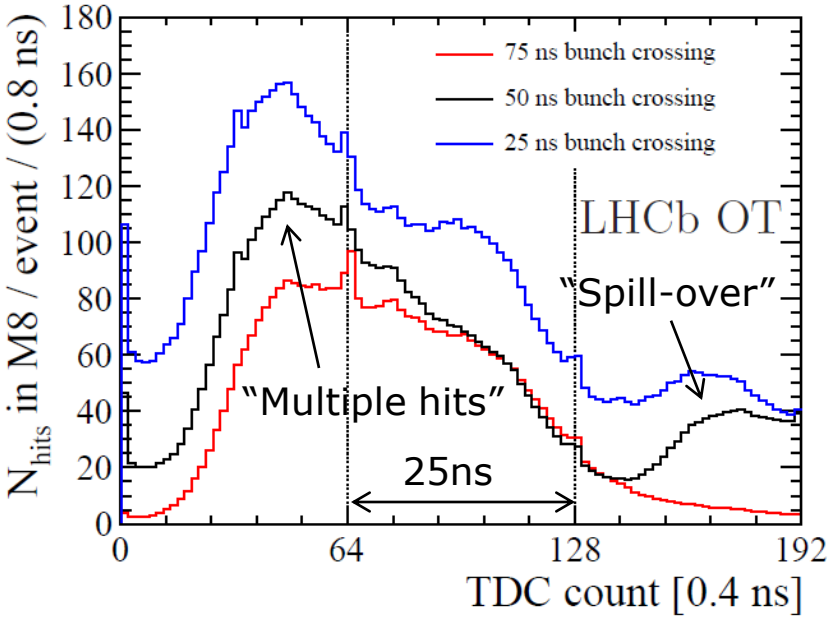




→ drift time (ns)

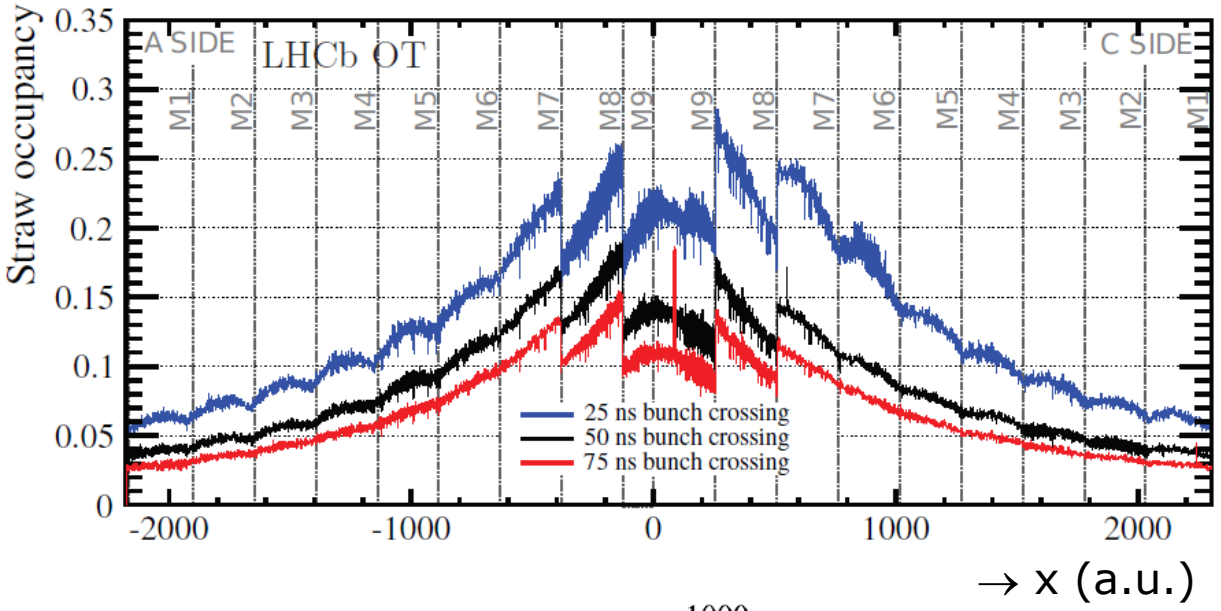
- Max. drift time ~35 ns
- Max. measured time ~50 ns
- Extra hits from:
  - "Spill-over hits"
  - "Multiple hits"

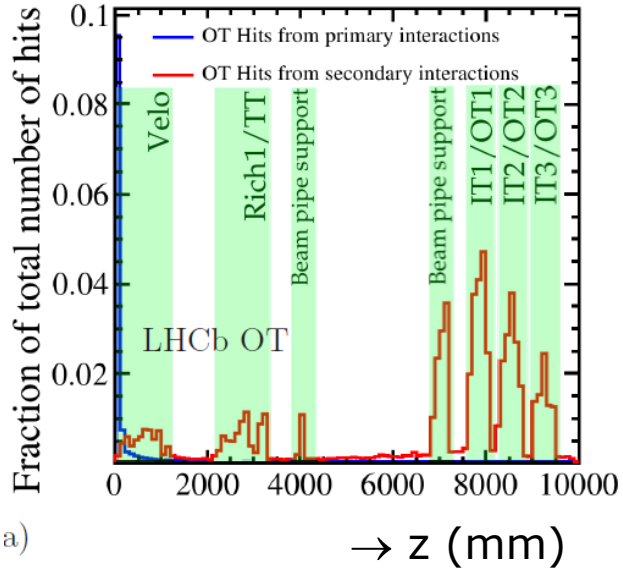


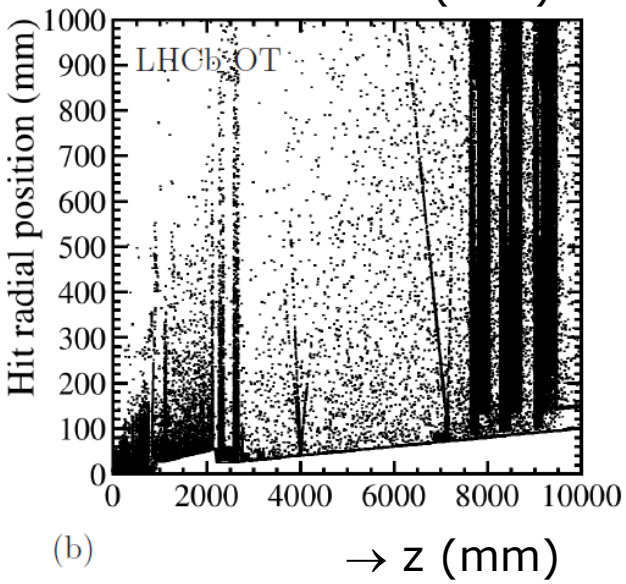


OT Performance in LHC Run I – Occupancy

- Occupancy: 3% – 15%
- Large fraction from secondary interactions

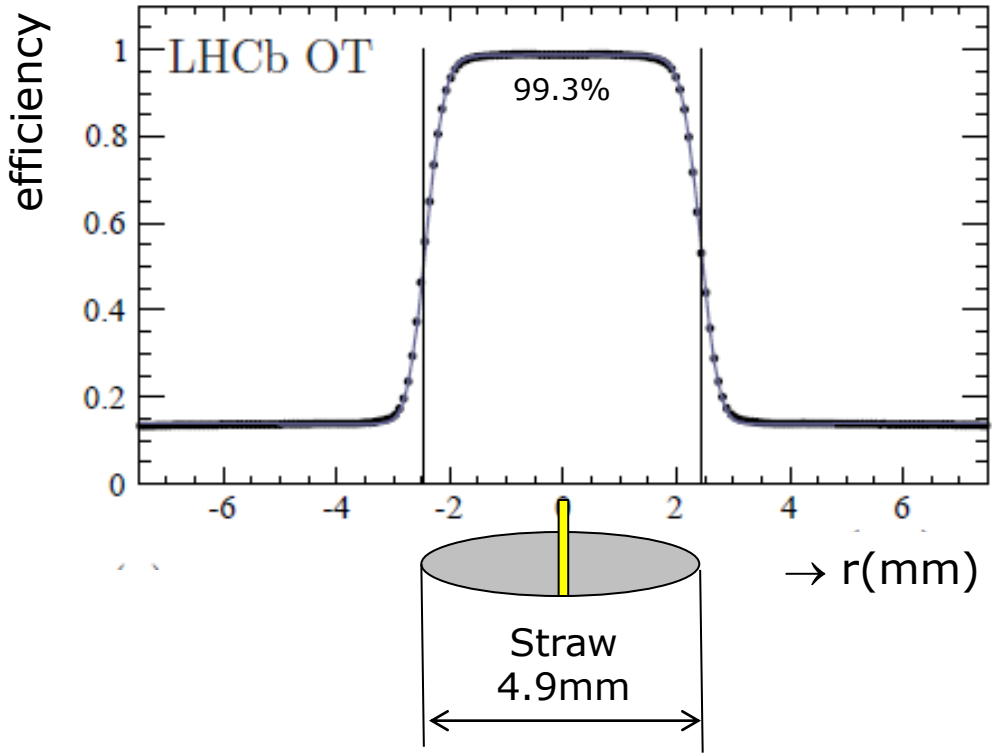


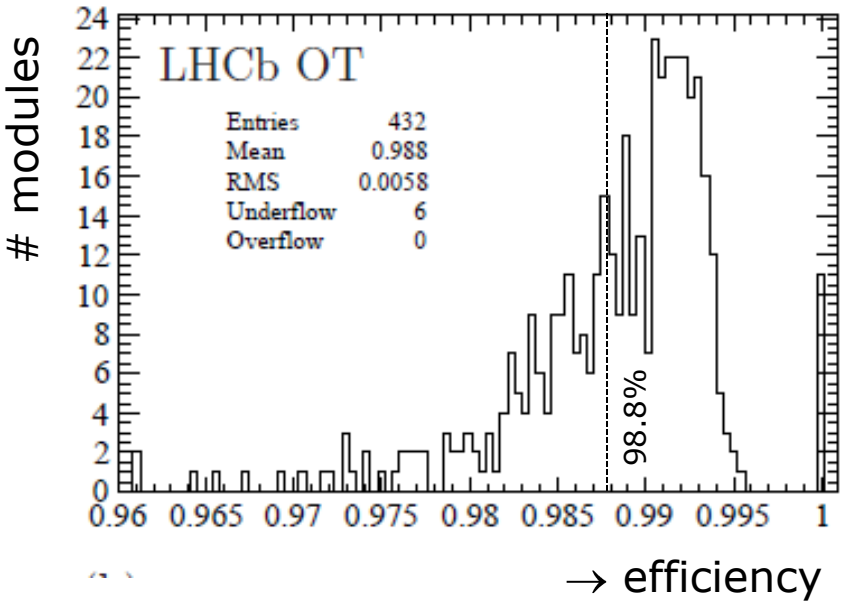




OT Performance in LHC Run I – Efficiency

- Efficiency to detect hit in center of cell |r|<1.25mm: ~ **99.3%**
- Average efficiency per module: ~ **98.8%**

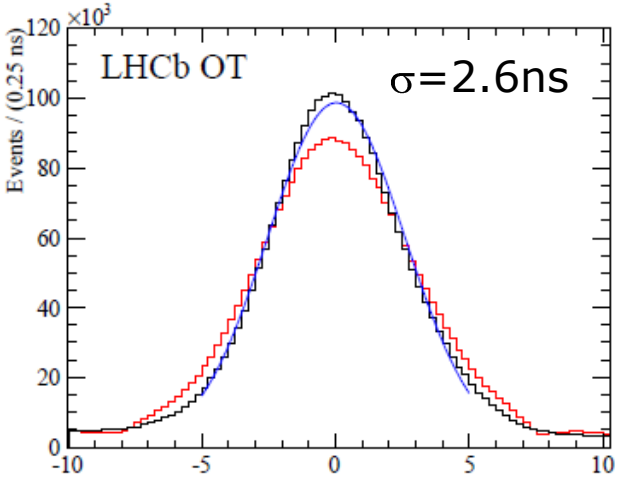




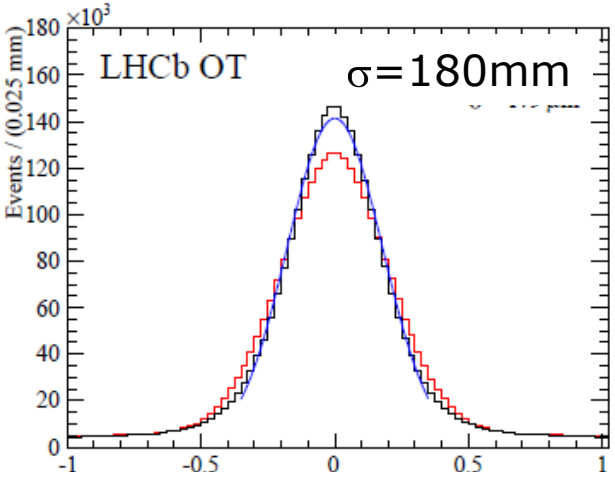
➢ **Single hit efficiency |r|<1.25mm: ~ 99.3%**

OT Performance in LHC Run I – Alignment/Resolution

- ➢ <u>Design specification: 200 μm</u>
- 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



→ time residual (ns)



→ distance residual (mm)

➢ **Internal alignment of mono-layers within a module improves resolution <u>210 → 180 μm</u>**

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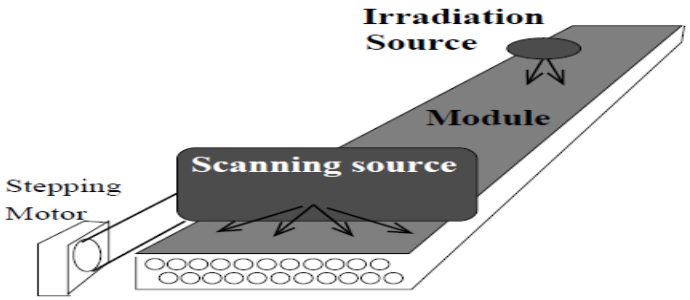
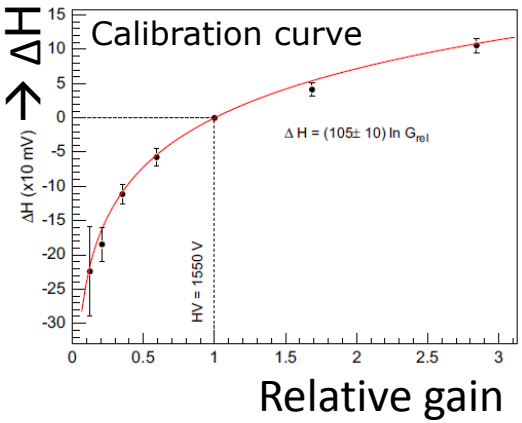
Radiation hardness

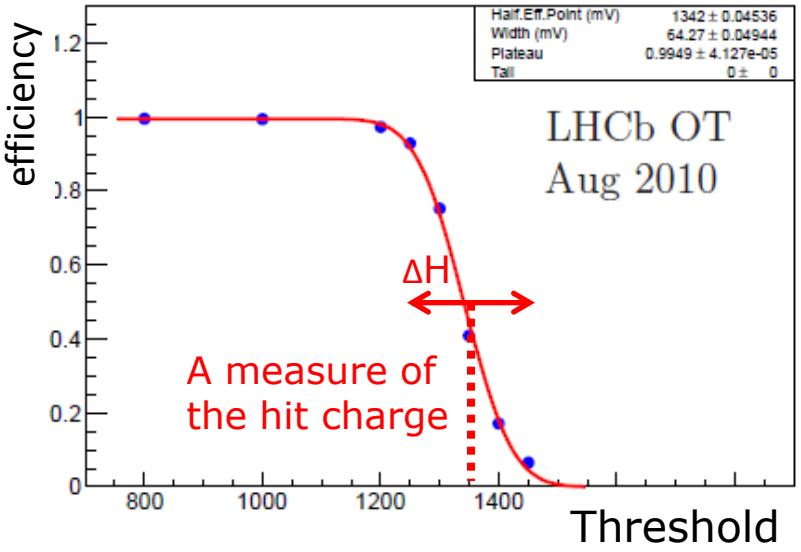
Two methods to monitor gain loss

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

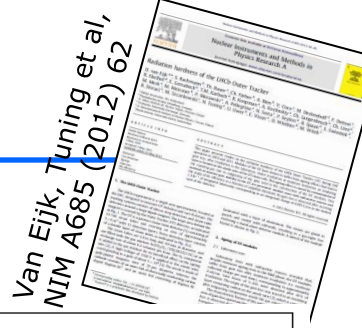


2) During LHC operation
   - Measure hit efficiency with tracks, at increasing amplifier threshold



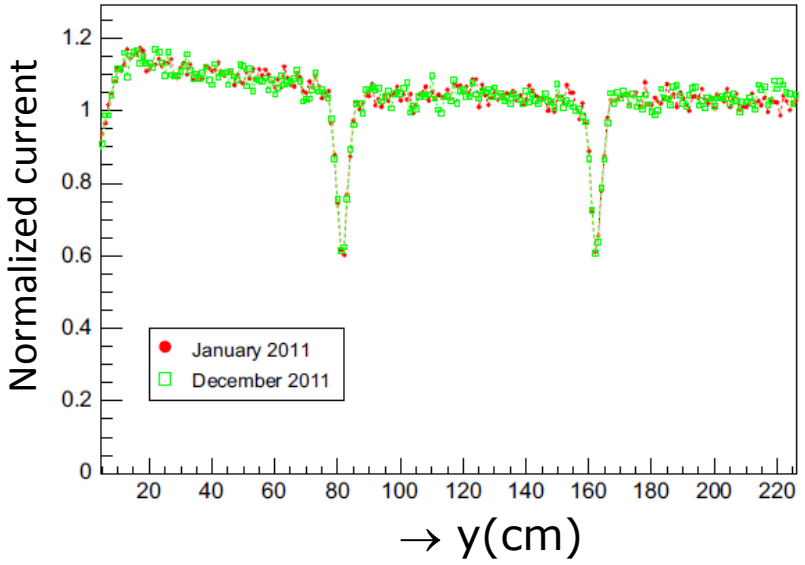


Radiation hardness

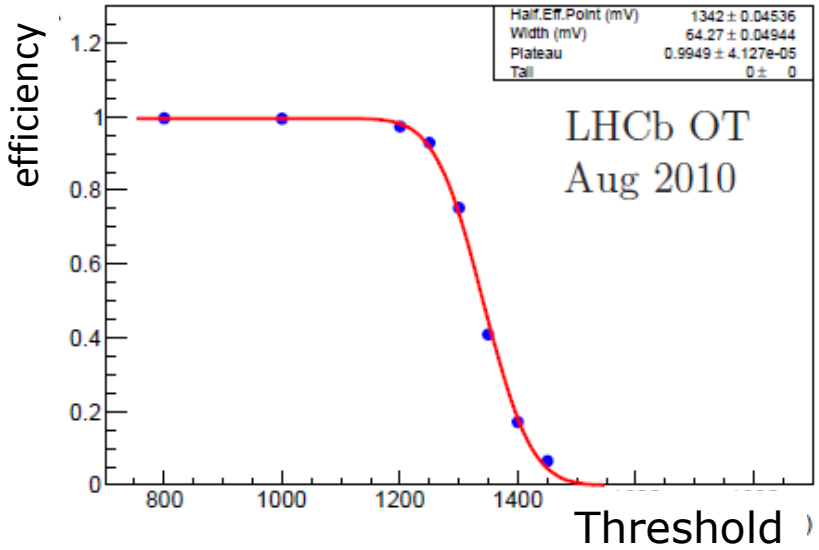


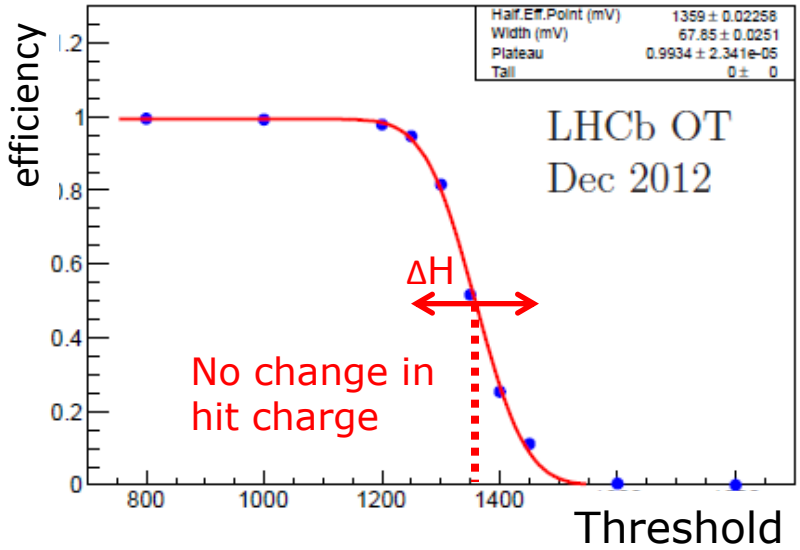
Two methods to monitor gain loss

1) During technical stops
   - ➢ No signs of gain loss



2) During LHC operation





Conclusions & Outlook

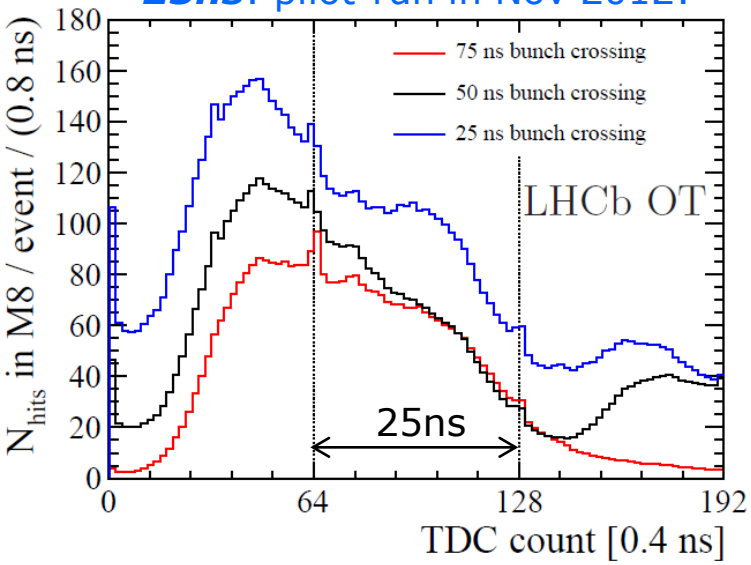
- Outer Tracker performed superbly in **run I**
  - Few dead or noisy channels
  - No irradiation effects observed
  - High hit efficiency (>99%) and resolution (~200 μm)

LHCb OT collaboration
LHCb-DT-2013-003,
to be published

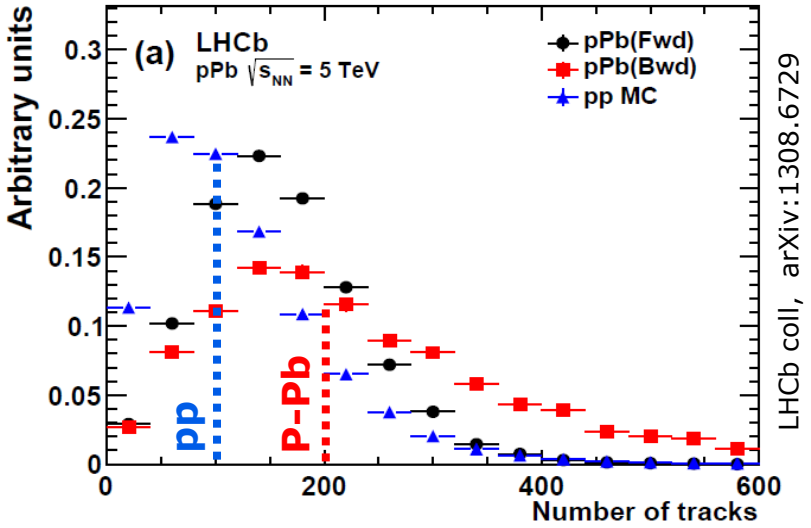
- Looking forward to **run II**
  - 2015
  - √s = 13 TeV
  - 25 ns bunch spacing

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

25ns: pilot-run in Nov 2012:



High occupancy: p-Pb run in Feb 2013:

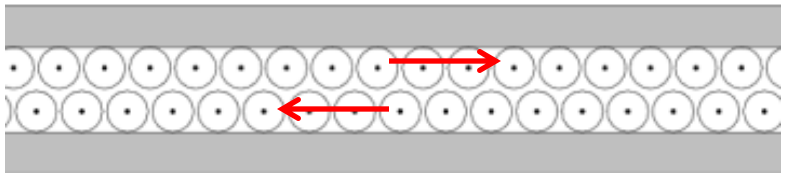


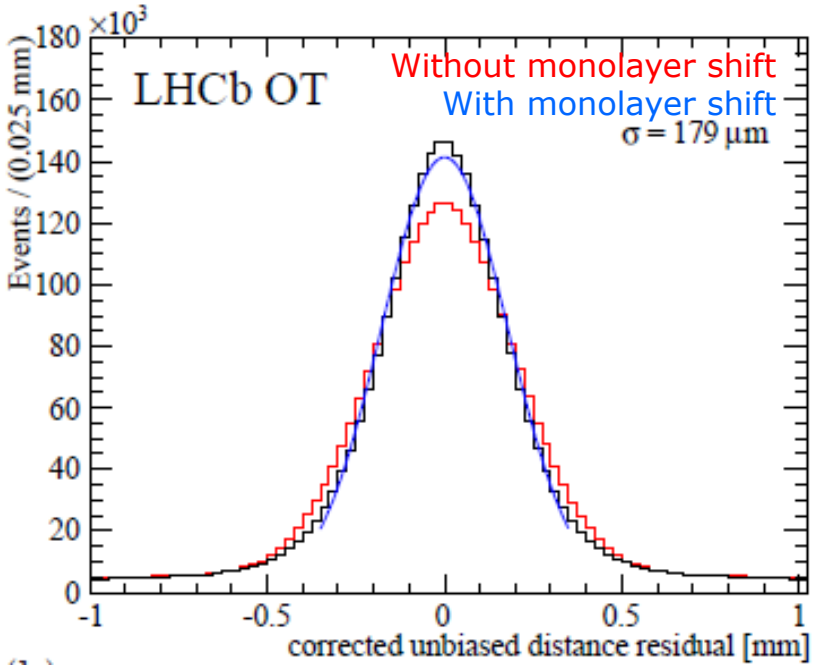
Backup: the nitty-gritty

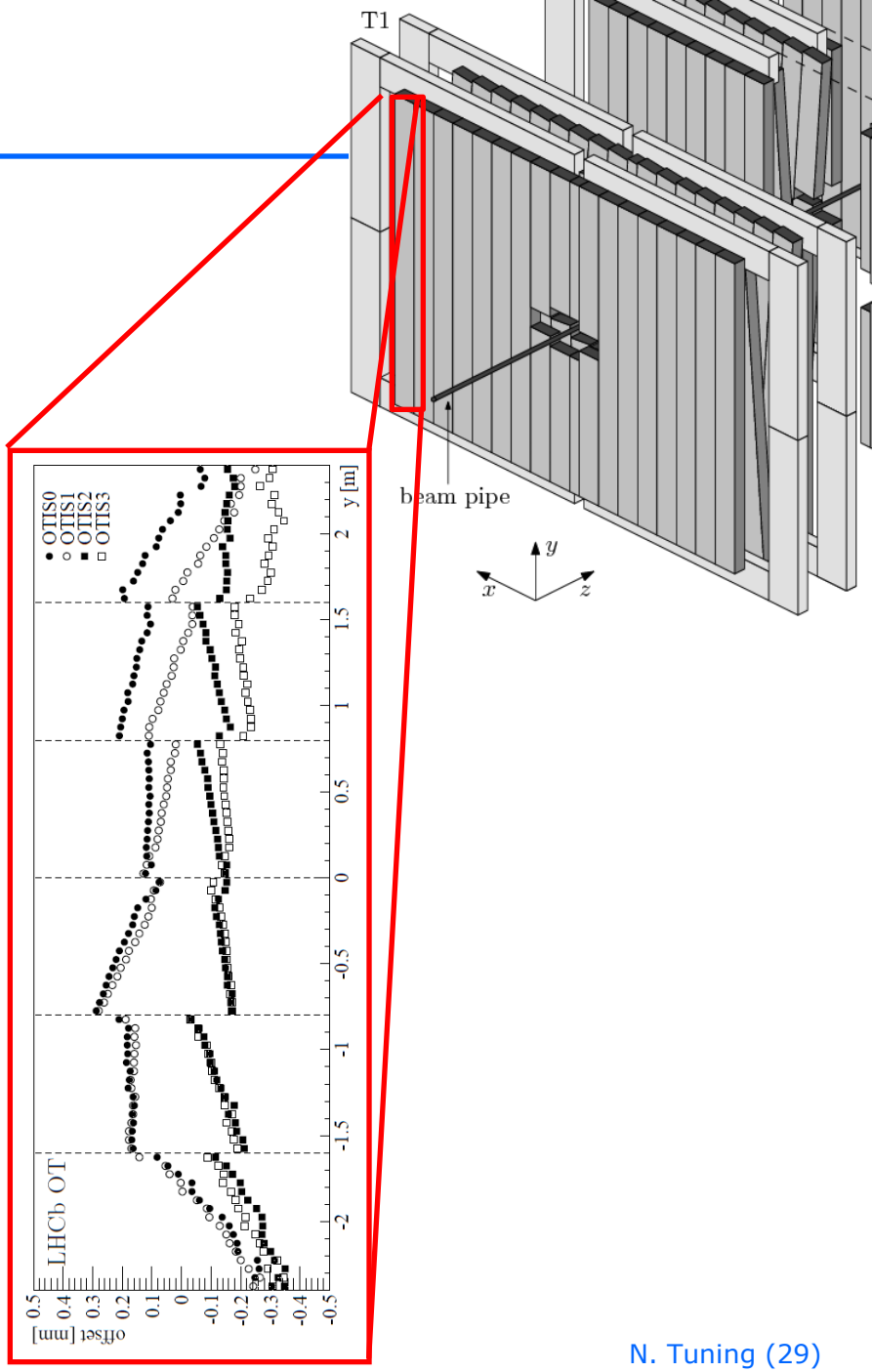
- Internal misalignments
- Effective ionization length
- Signal reflections: "*walk*" correction

Internal module alignment

- Recently improved alignment
- Relative shift of monolayers
- ➢ Resolution 210 → 179 µm







Ionization length

- Ionization length λ:

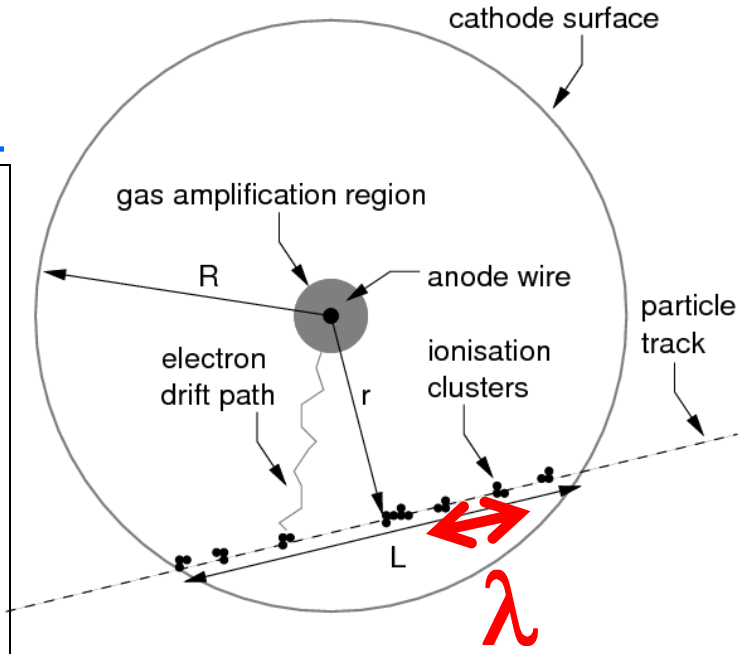
  average distance between clusters

- Measured *effective* λ in two ways:

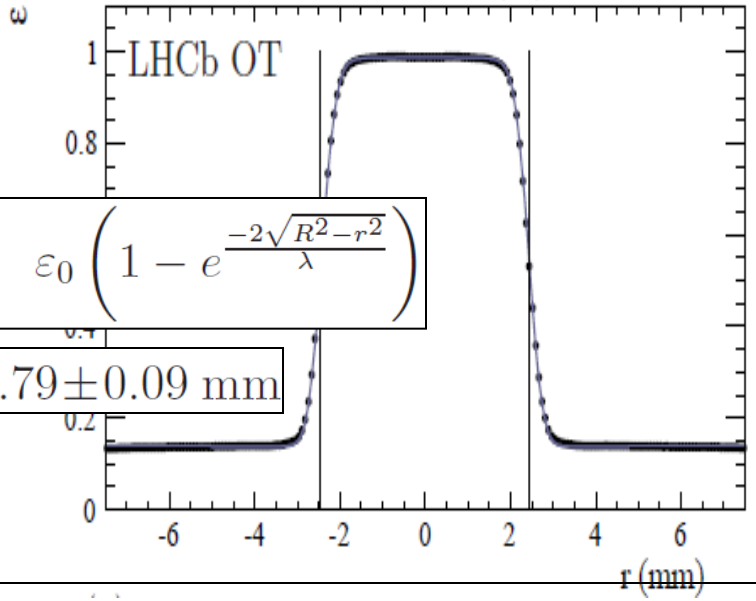
  1) Efficiency profile: probes large |r|

  2) Drift time distribution: probes small |r|

  ➢ Disentangle effect of absorbtion



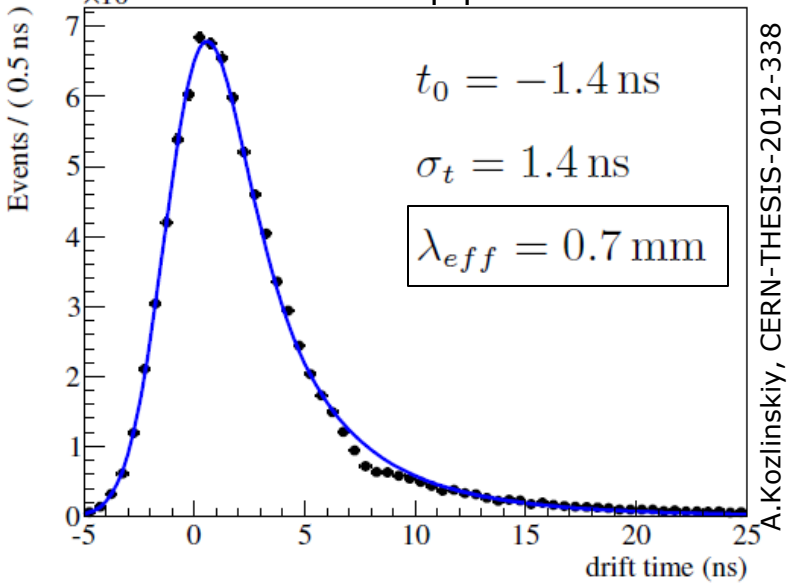
Probe hits close to |r|=2.4mm



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

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

Tracks with |r|<0.1mm



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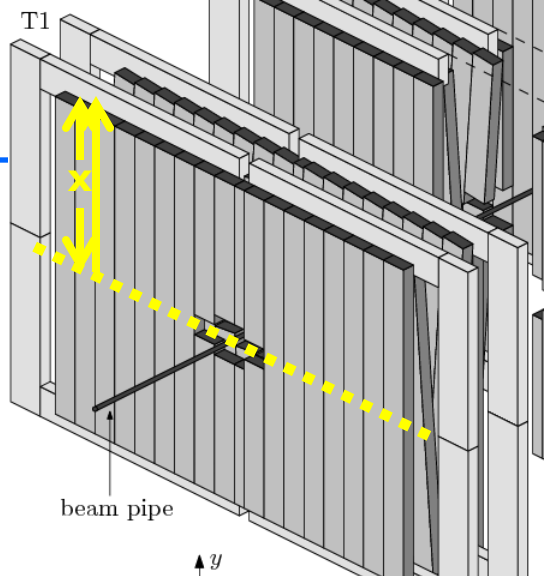
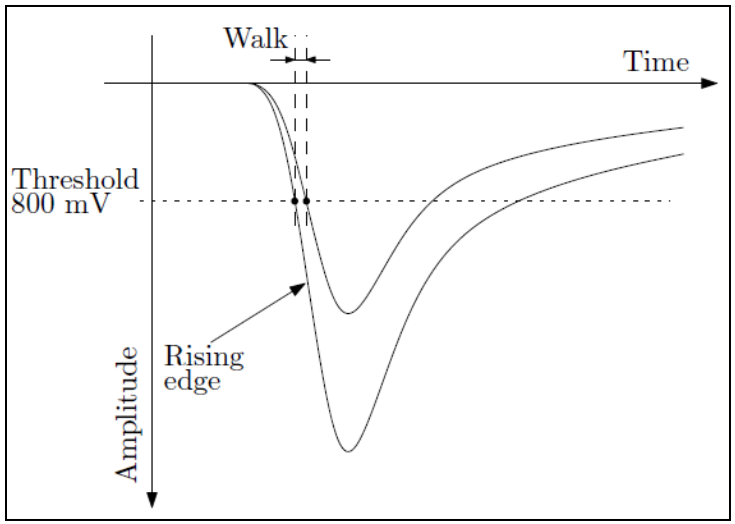
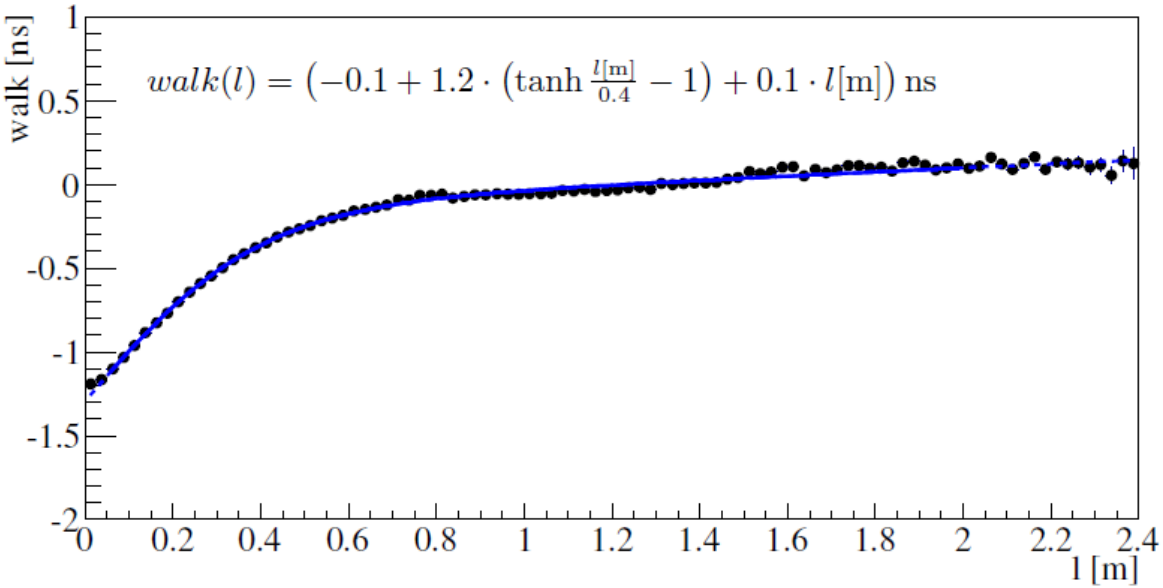
➢ λ_{eff} **2x larger than nominal; not due to absorbtion**

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**