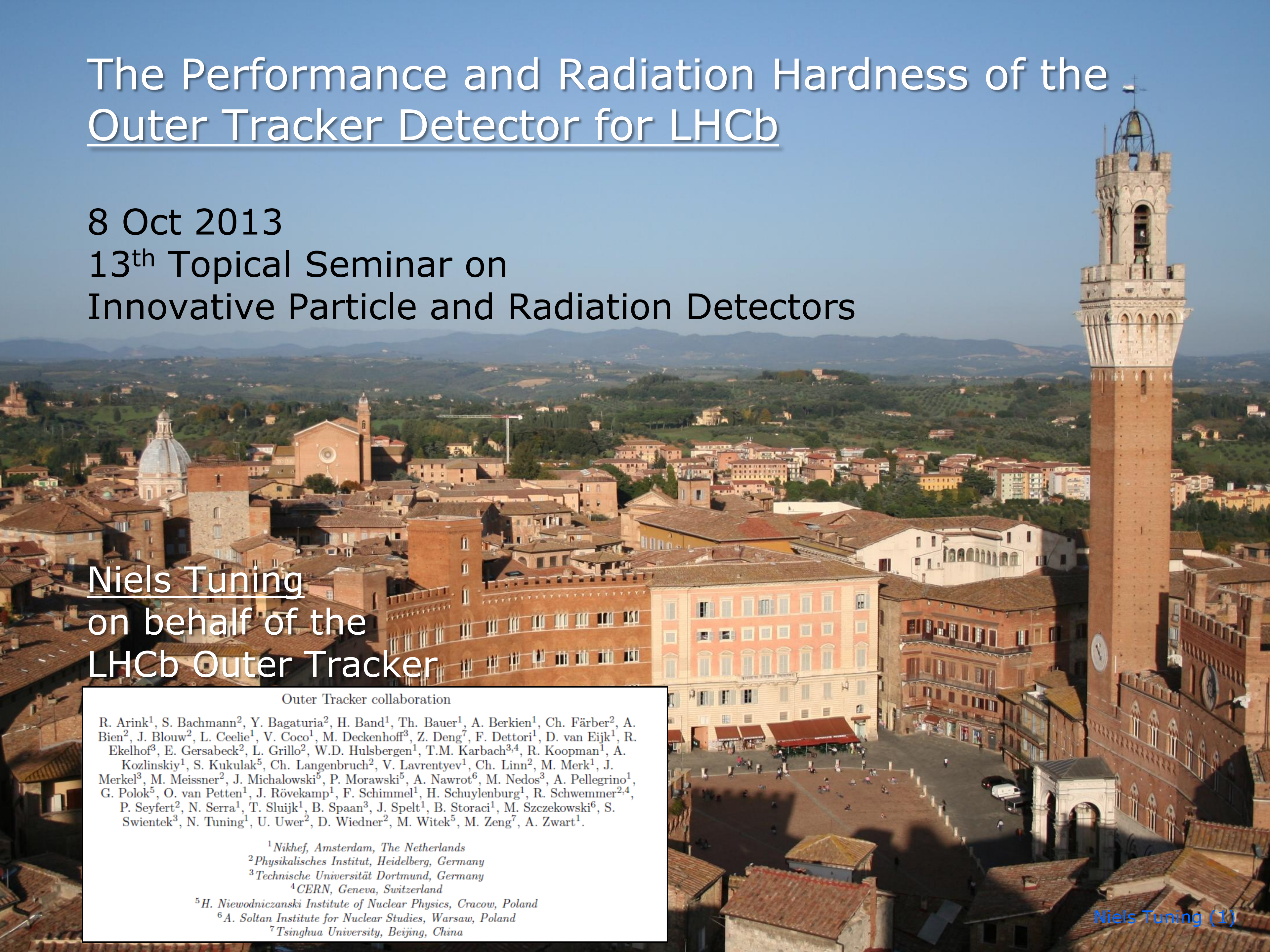


The Performance and Radiation Hardness of the Outer Tracker Detector for LHCb

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

Niels Tuning
on behalf of the
LHCb Outer Tracker

Outer Tracker collaboration

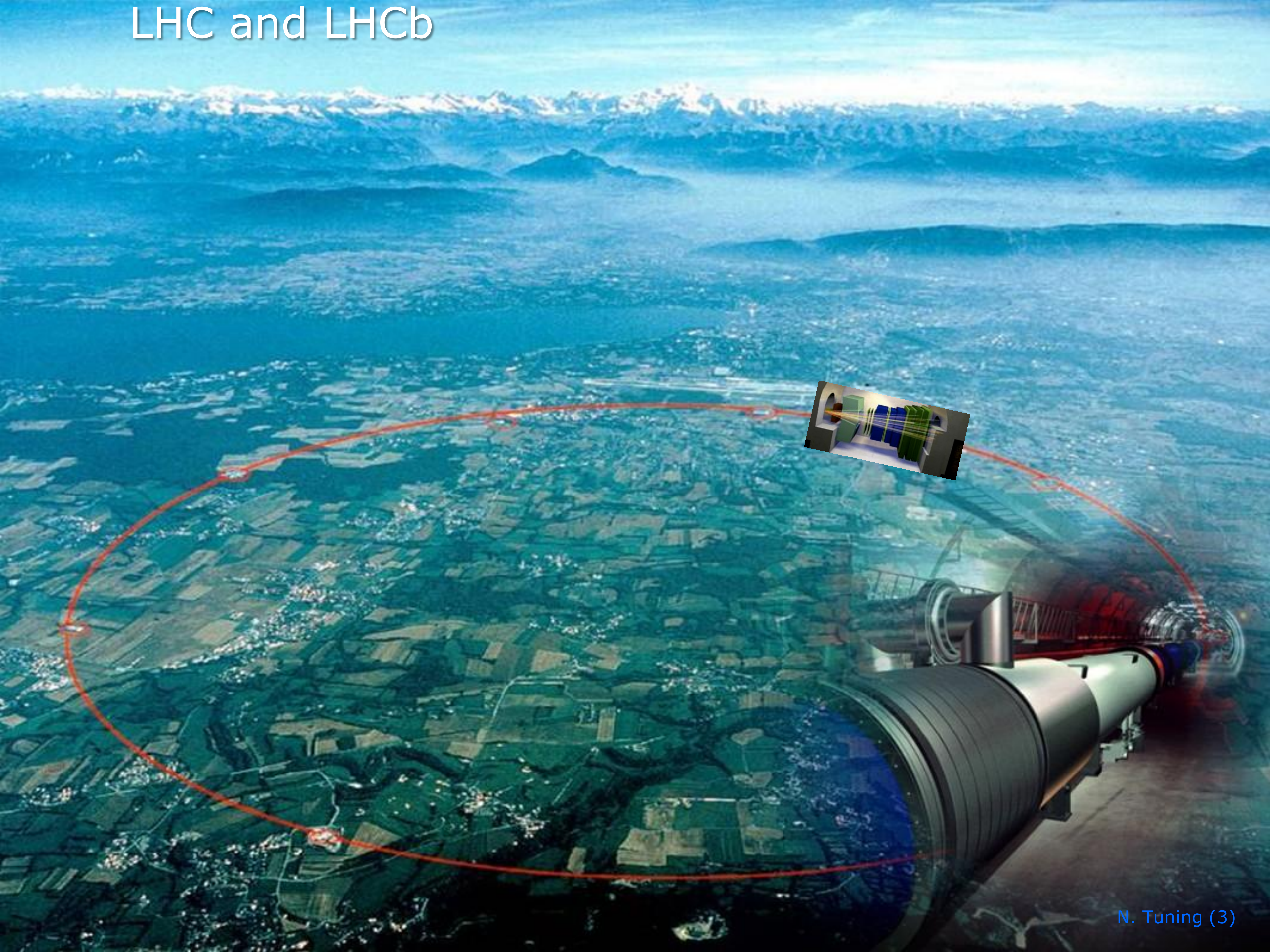
R. Arink[1], S. Bachmann[2], Y. Bagaturia[2], H. Band[1], Th. Bauer[1], A. Berkien[1], Ch. Färber[2], A. Bien[2], J. Blouw[2], L. Ceelie[1], V. Coco[1], M. Deckenhoff[3], Z. Deng[7], F. Dettori[1], D. van Eijk[1], R. Ekelhof[3], E. Gersabeck[2], L. Grillo[2], W.D. Hulsbergen[1], T.M. Karbach[3,4], R. Koopman[1], A. Kozlinskiy[1], S. Kukulak[5], Ch. Langenbruch[2], V. Lavrentyev[1], Ch. Linn[2], M. Merk[1], J. Merkel[3], M. Meissner[2], J. Michalowski[5], P. Morawski[5], A. Nawrot[6], M. Nedos[3], A. Pellegrino[1], G. Polok[5], O. van Petten[1], J. Rövekamp[1], F. Schimmel[1], H. Schuylenburg[1], R. Schwemmer[2,4], P. Seyfert[2], N. Serra[1], T. Sluijk[1], B. Spaan[3], J. Spelt[1], B. Storaci[1], M. Szczekowski[6], S. Swientek[3], N. Tuning[1], U. Uwer[2], D. Wiedner[2], M. Witek[5], M. Zeng[7], A. Zwart[1].

[1] *Nikhef, Amsterdam, The Netherlands*
[2] *Physikalisches Institut, Heidelberg, Germany*
[3] *Technische Universität Dortmund, Germany*
[4] *CERN, Geneva, Switzerland*
[5] *H. Niewodniczanski Institute of Nuclear Physics, Cracow, Poland*
[6] *A. Soltan Institute for Nuclear Studies, Warsaw, Poland*
[7] *Tsinghua University, Beijing, China*

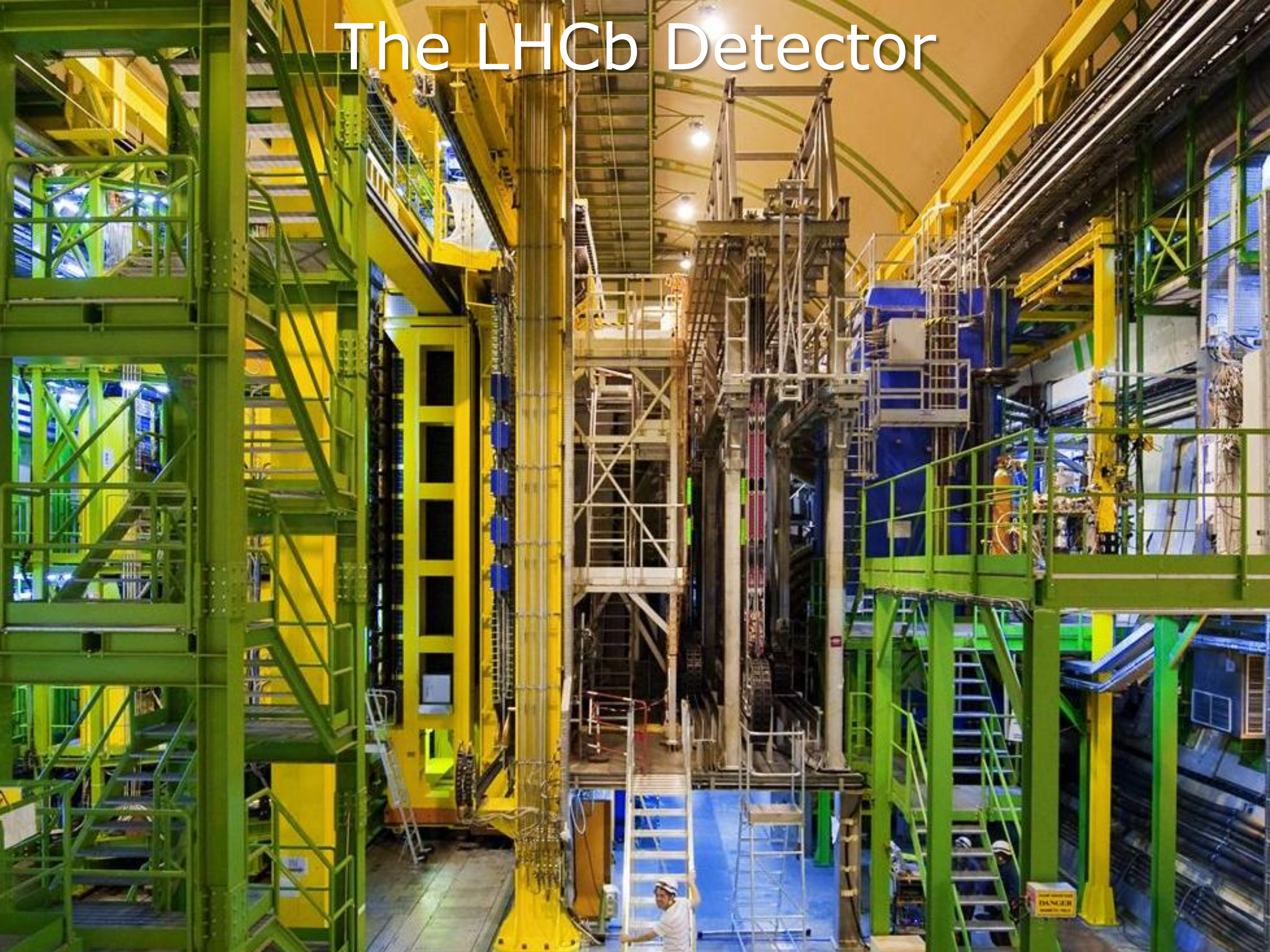
Outline

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

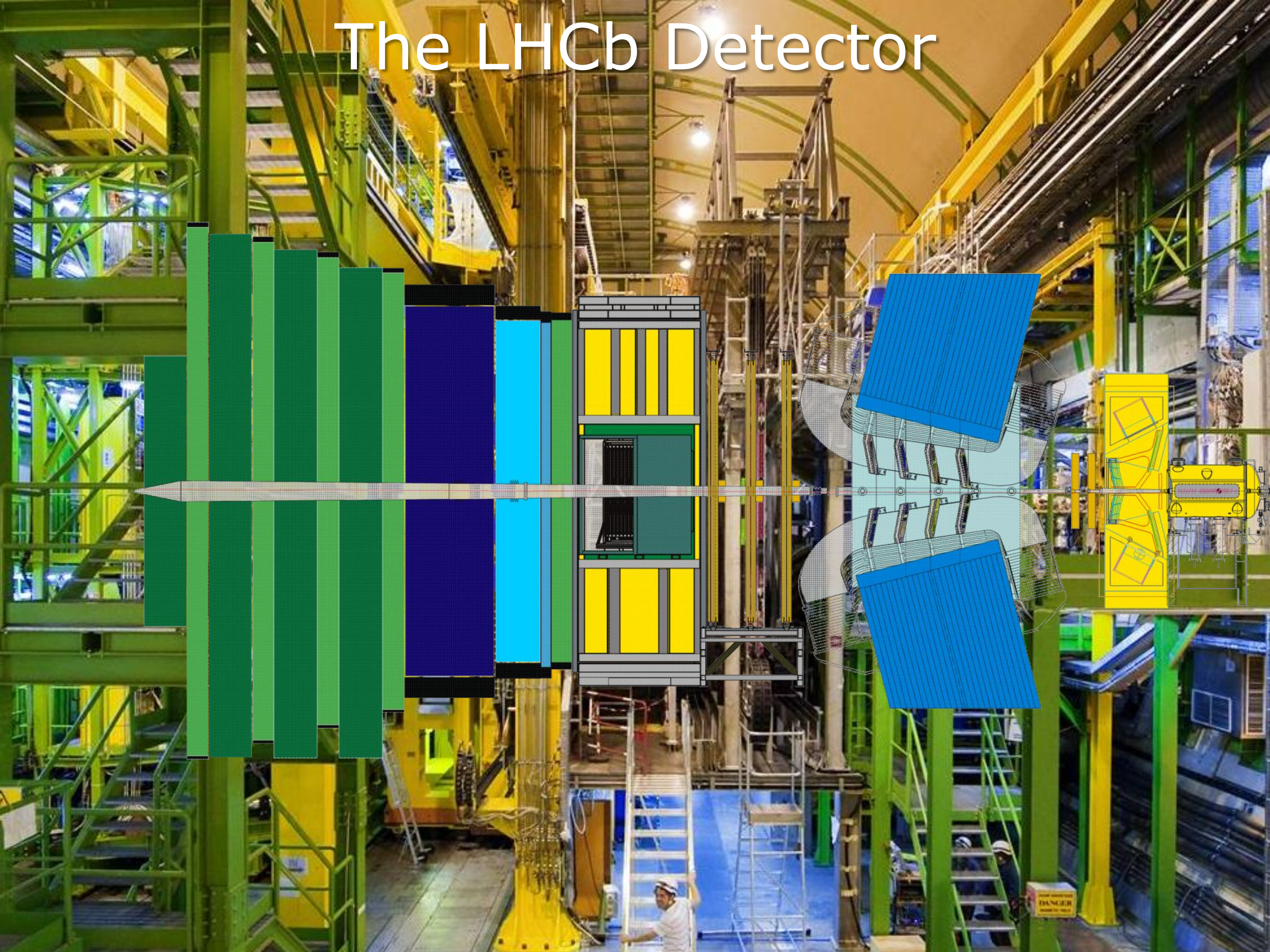
LHC and LHCb



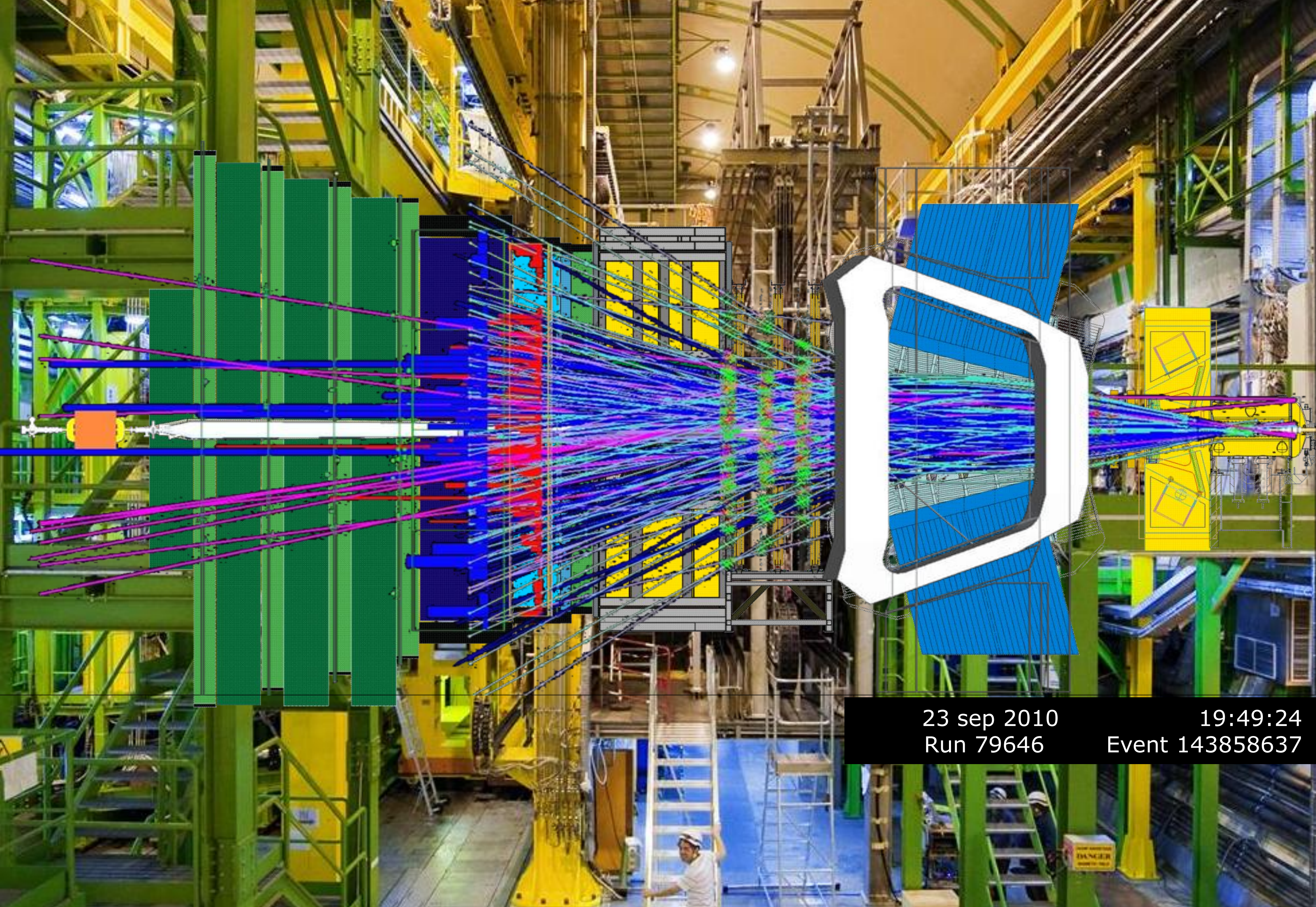
The LHCb Detector



The LHCb Detector



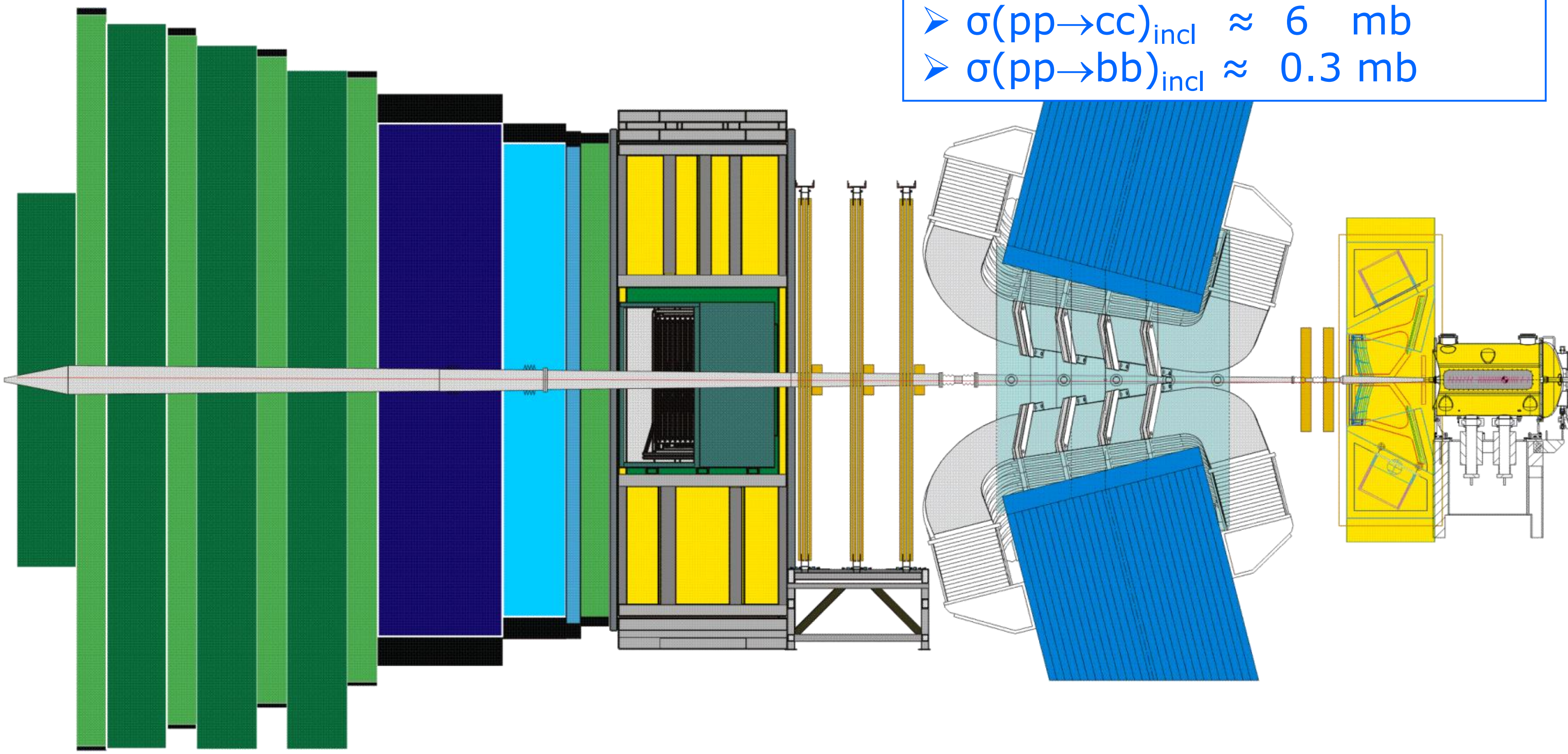
The LHCb Detector



The LHCb Detector

Forward arm spectrometer

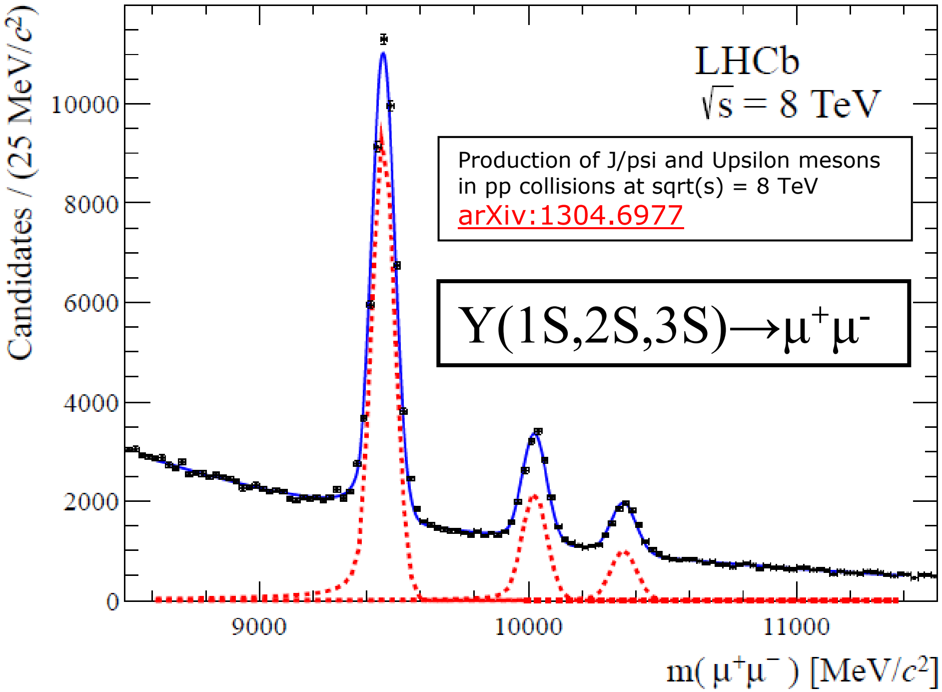
- $2<\eta<5$
- $\sigma(pp\rightarrow X)_{inel} \approx 60$ mb
- $\sigma(pp\rightarrow cc)_{incl} \approx 6$ mb
- $\sigma(pp\rightarrow bb)_{incl} \approx 0.3$ mb

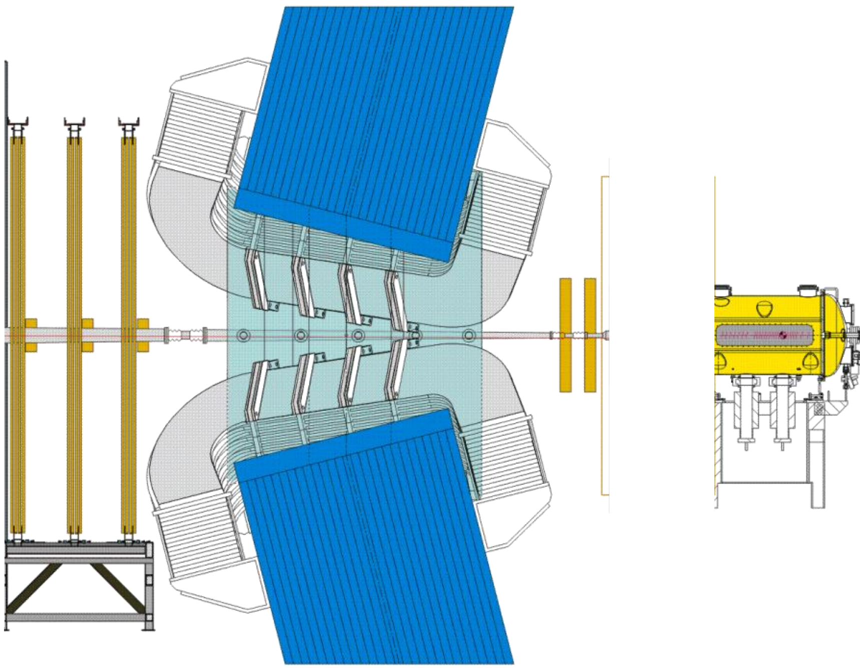


The LHCb Detector

Tracking: dp/p ~ 0.4-0.6%

Excellent mass resolution





The LHCb Detector

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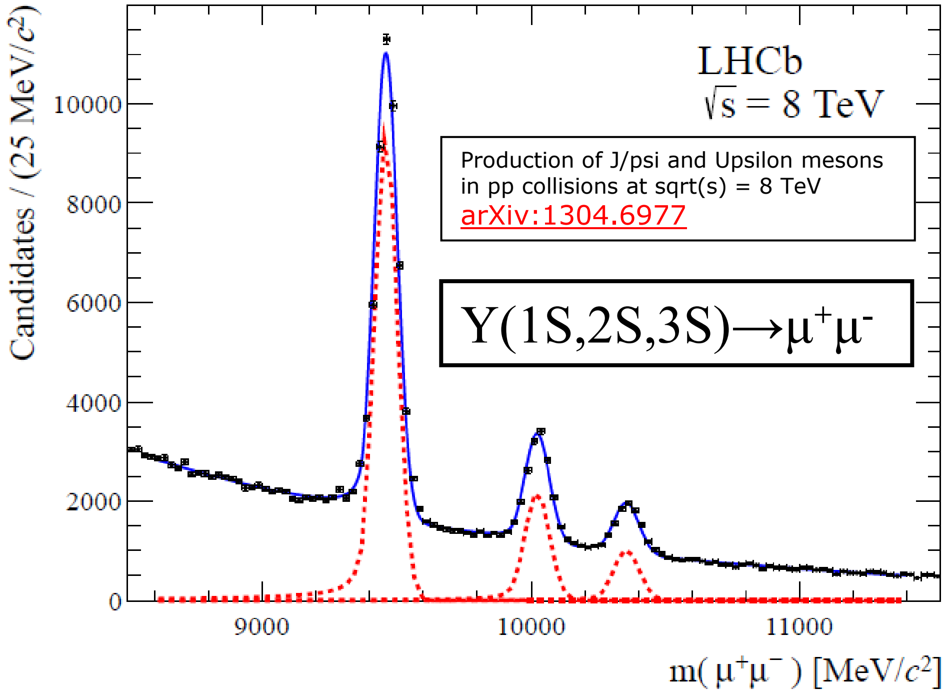
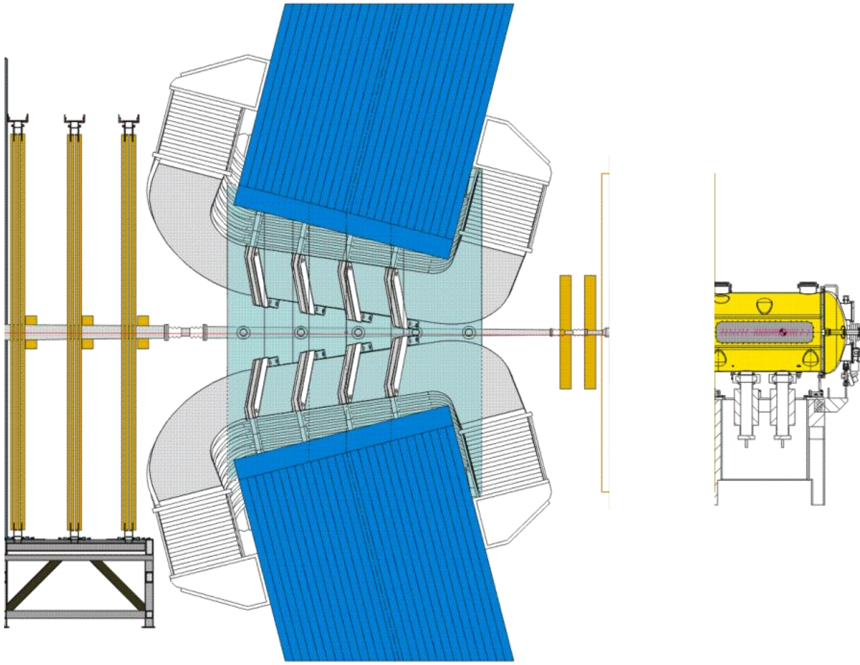


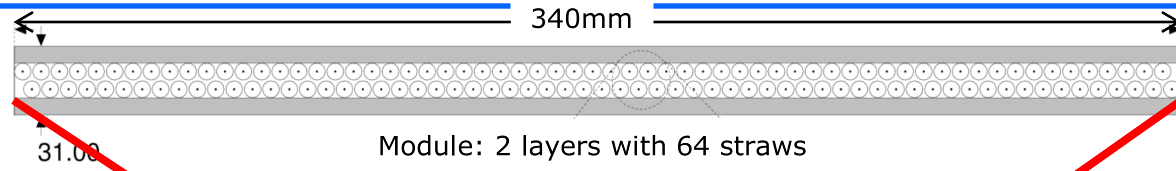


Other LHCb contributions (Yesterday, Monday 16:55)

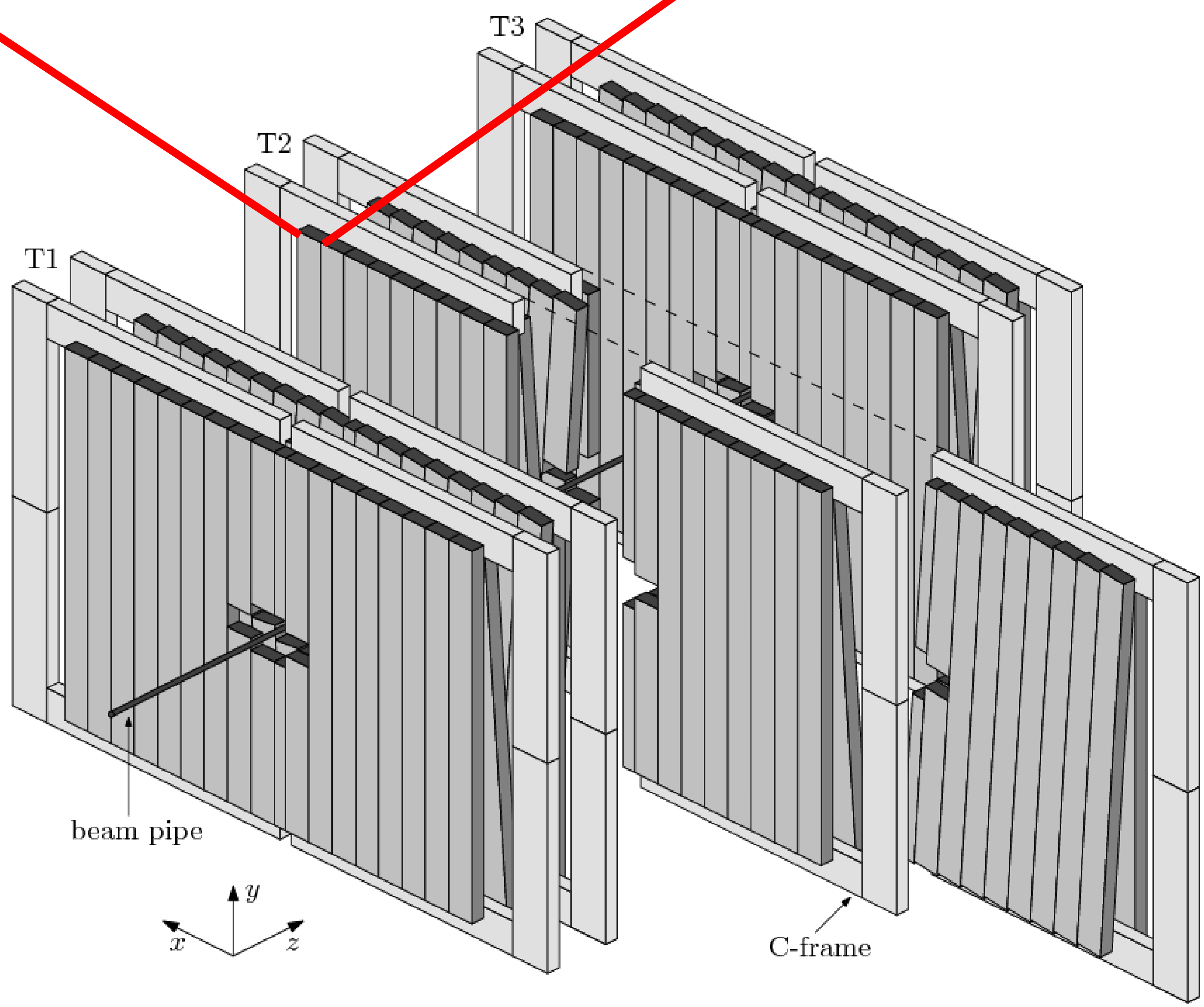
- Christian Elsasser — The LHCb Silicon Tracker
- Agnieszka Oblakowska — The LHCb Vertex Locator - Performance and Radiation Damage
- Kazu Akiba — The LHCb Vertex Locator - Upgrade Plans

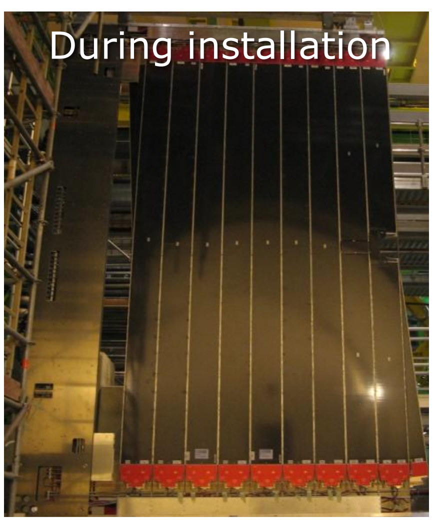
Outer Tracker

Outer Tracker

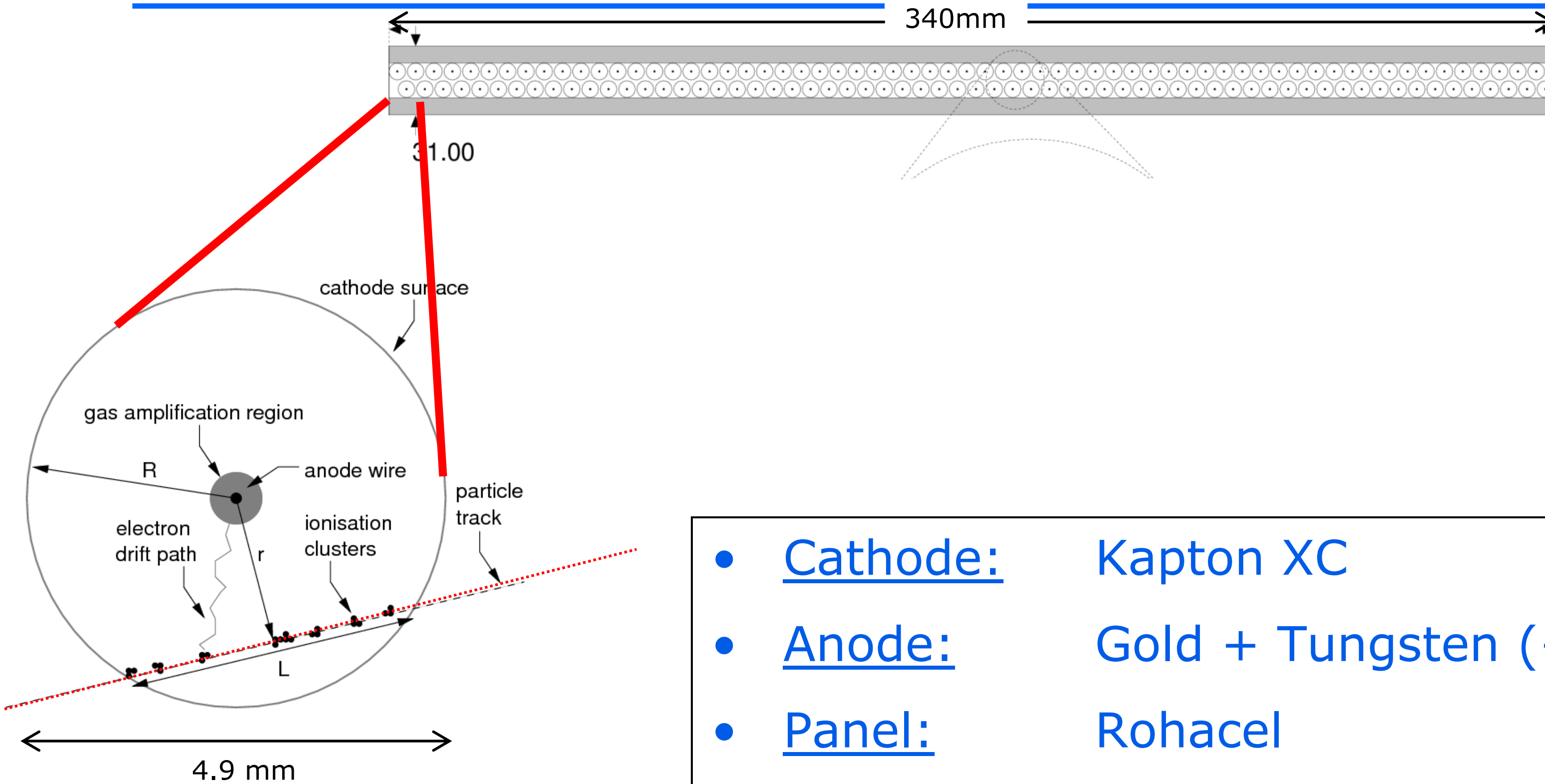


- 12 double layers
- 5 x 6 m^2
- 53760 channels



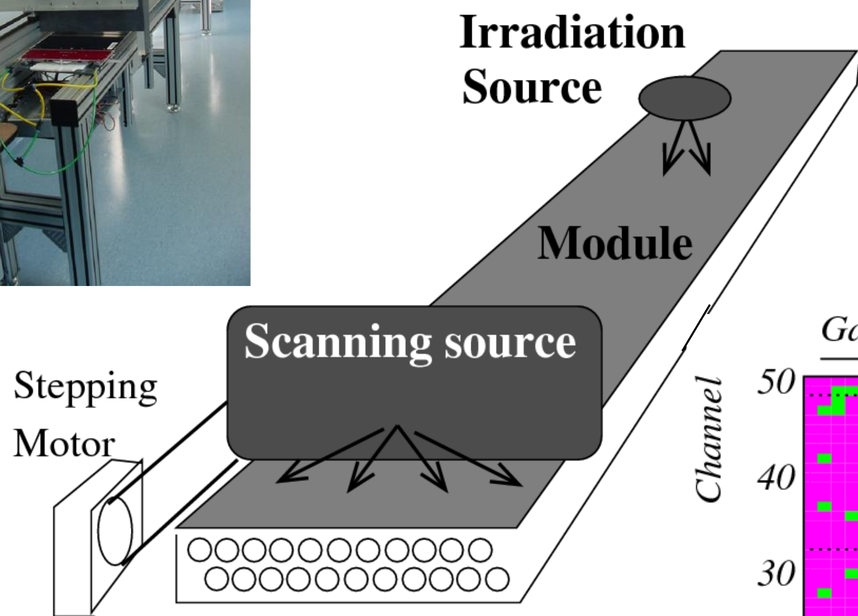


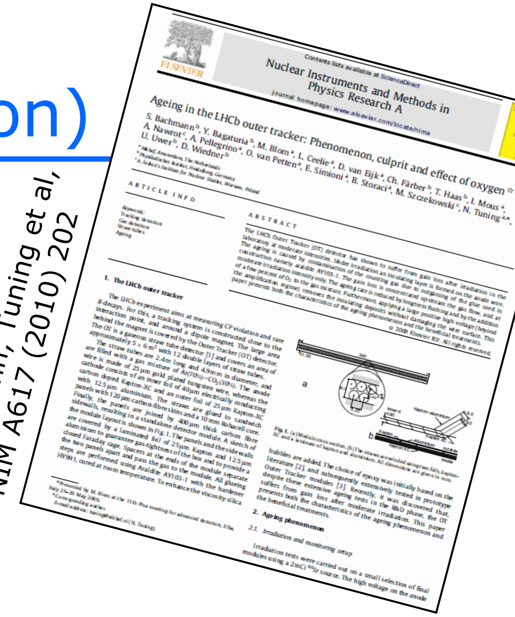
Outer Tracker



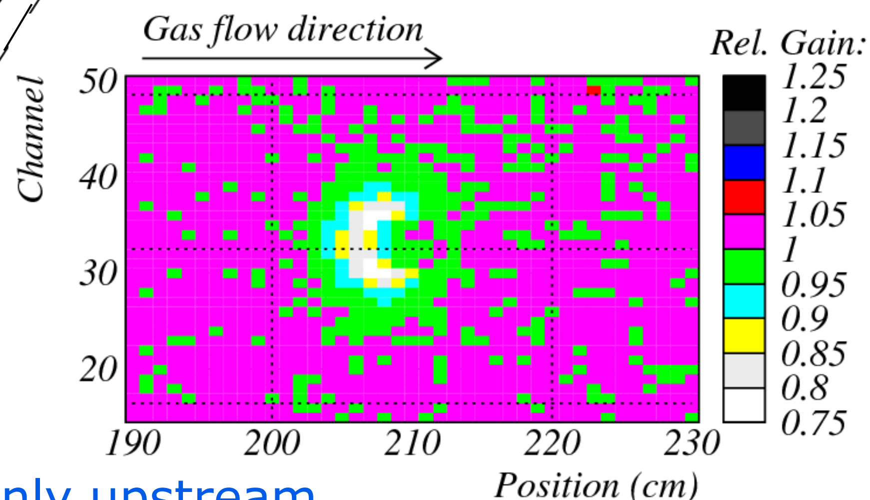
- Cathode: Kapton XC
- Anode: Gold + Tungsten (+1550 V)
- Panel: Rohacel
- Glue: Araldite Epoxy AY103
- Gas: $Ar/CO_2/O_2$: 70/28.5/1.5

Ageing: The saga - part I (phenomenon)



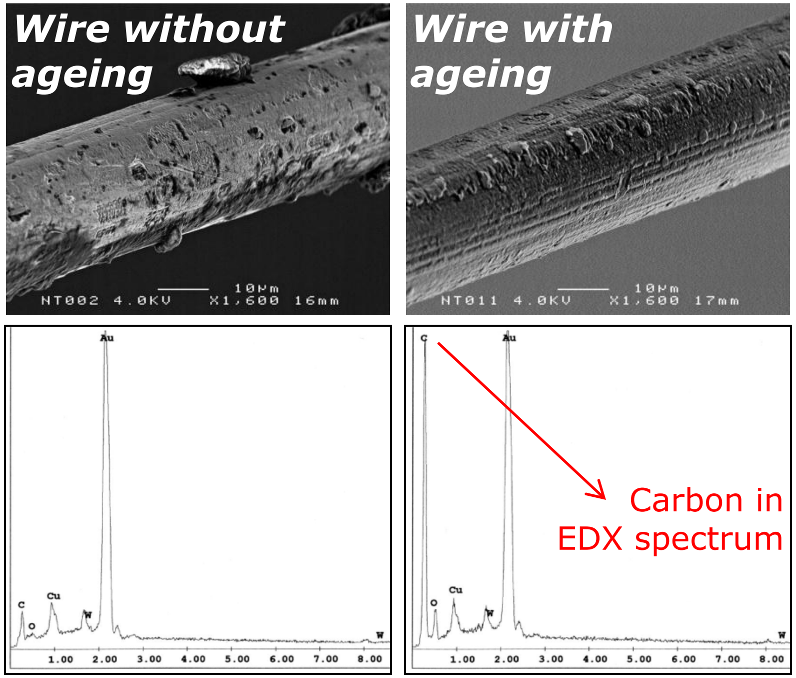


Bachmann, Tuning et al,
NIM A617 (2010) 202



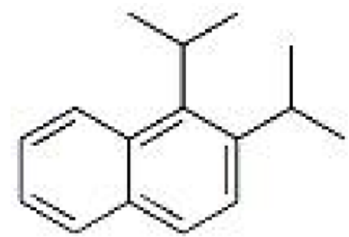
- **Remarkable:**
- No gain loss under source, only upstream
- Very rapid; -30% in 15 hours
- Not seen in R&D phase, despite extensive ageing tests

Ageing: The saga - part II (culprit)



Tuning et al,
NIM A656 (2011) 45

- **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

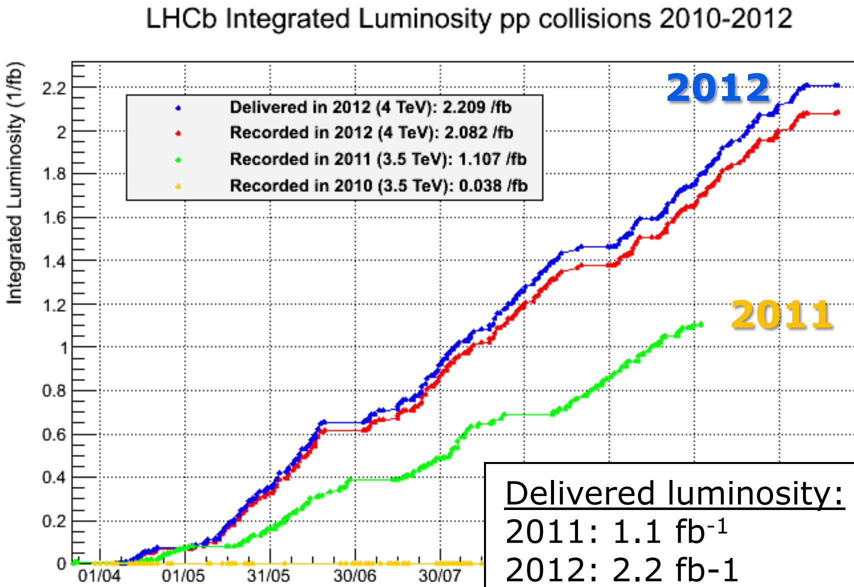
Outline

- 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

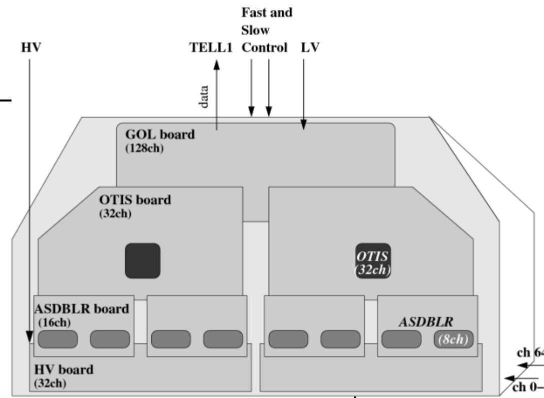


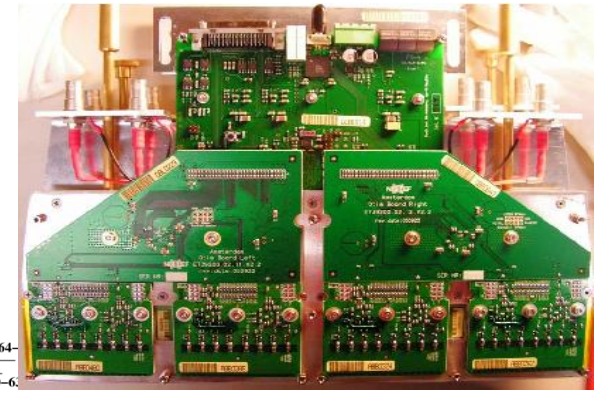
<u>Delivered luminosity:</u>
2011: 1.1 fb^{-1}
2012: 2.2 fb-1
(~10^7 s at 3.5×10^{32} $cm^{-2}s^{-1}$)

<u>Int. dose in hottest region:</u>
0.12 C/cm

OT Performance in LHC Run I - Readout

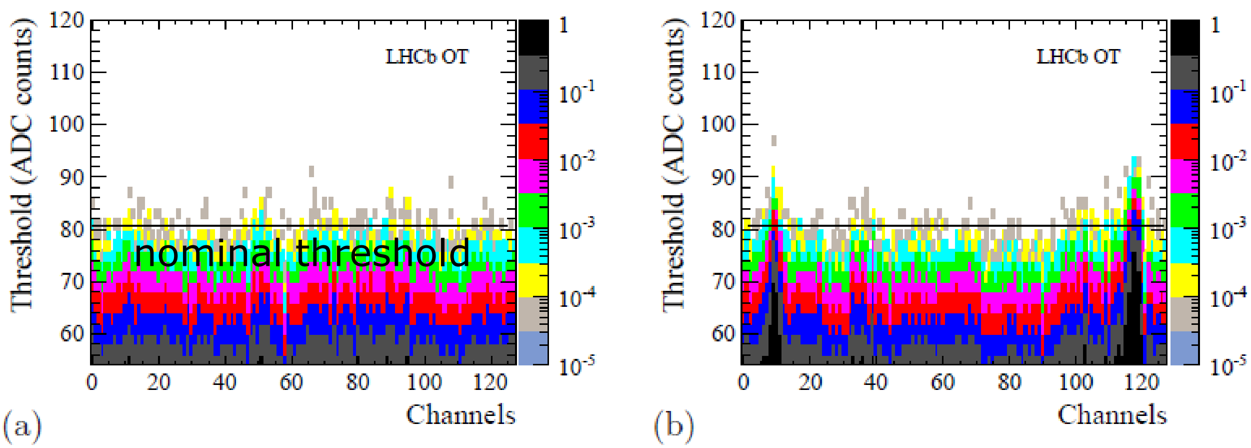
- Gas gain: ~ 5×10^4
- Analog signal: ~ 10^6 e^-
- ASD: Ampl, Shape, Discr.
- TDC: 0.4 ns stepsize
- Pipeline: 160 BX deep (= 4 μs)
- GOL: Upon L0 trigger, readout 3 BX





Detector module
2 x 64 straws

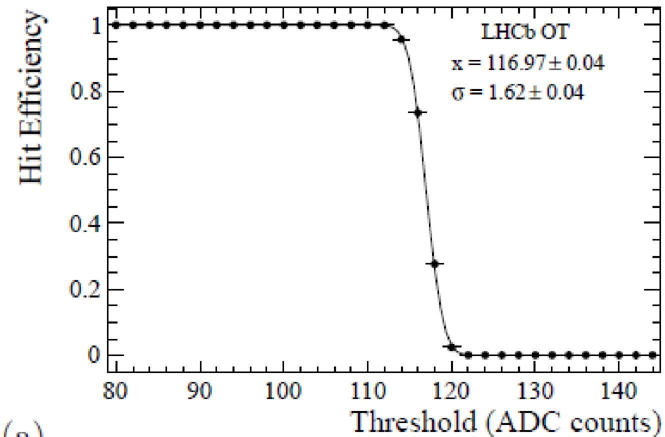
Example noisy module:



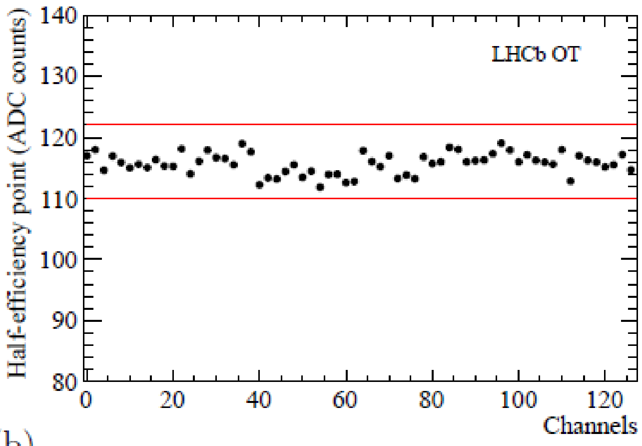
➢ **Noise level ~ 10^{-4}**

OT Performance in LHC Run I – Dead channels

- <u>During data taking</u>: use test pulses

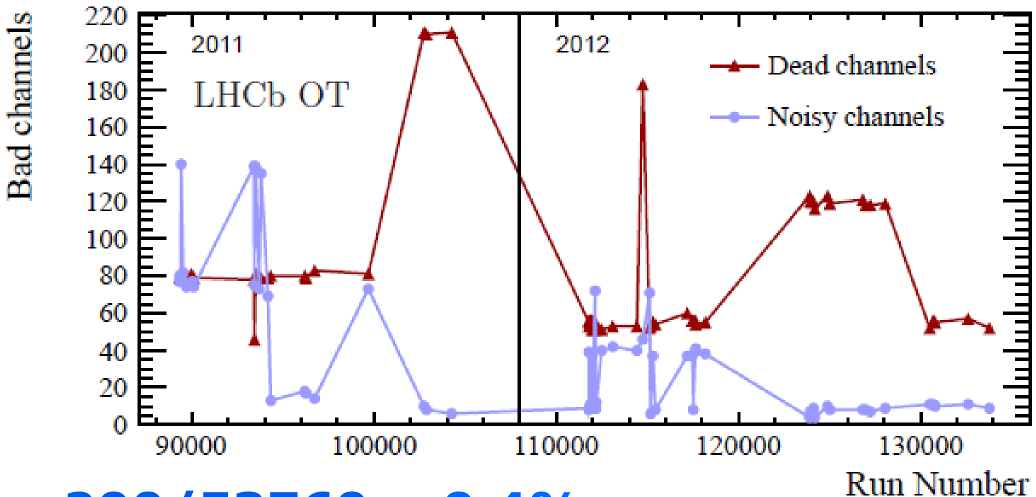


(a)



(b)

- <u>Offline</u>: find channels too few/many hits

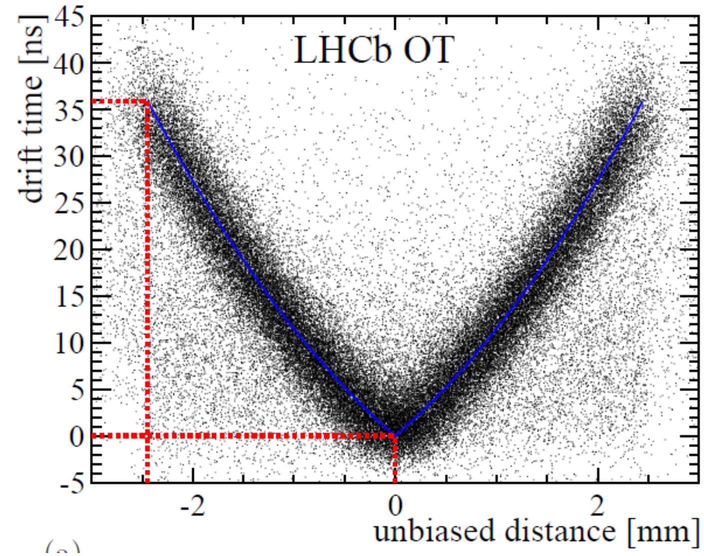


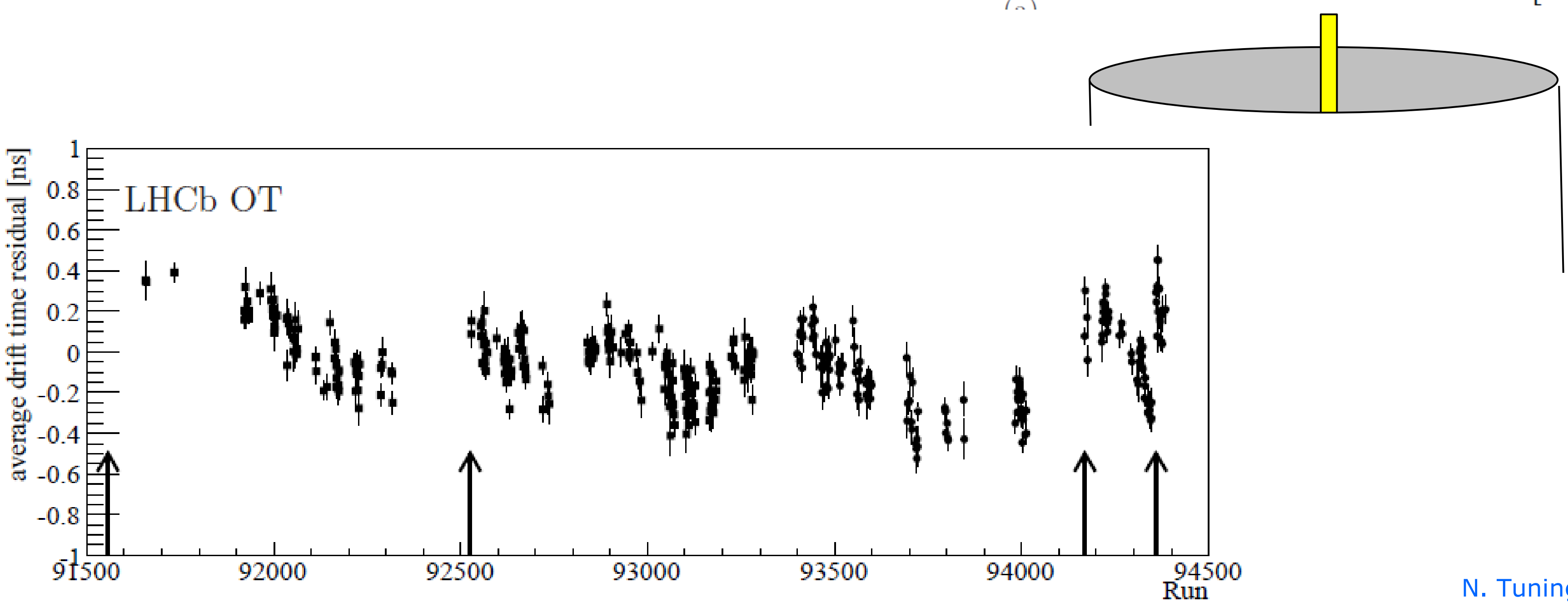
➢ **Noise/Dead channels: ~ 200/53760 = 0.4%**

OT Performance in LHC Run I – Calibration

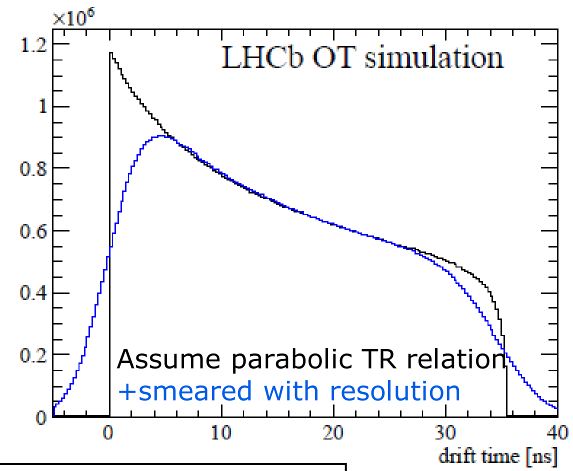
- Time calibration very stable
- Performed ~ 4x per year

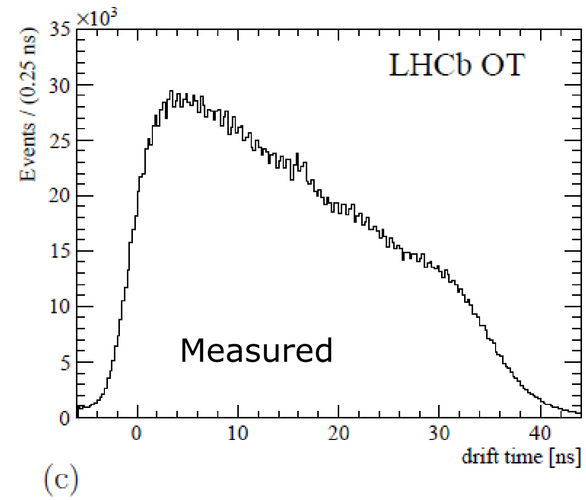
$$t_{\text{drift}}(r) = 20.5\,\text{ns} \cdot \frac{|r|}{R} + 14.85\,\text{ns} \cdot \frac{r^2}{R^2}$$



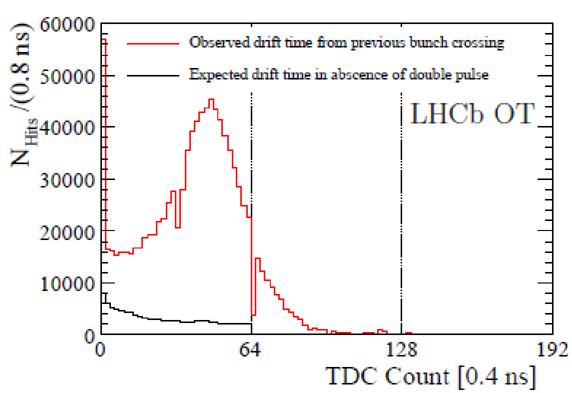


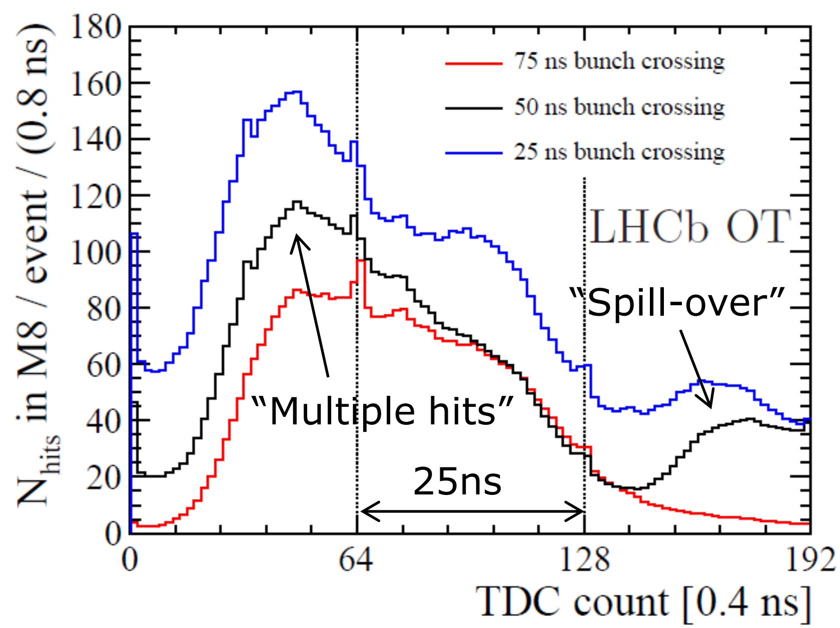
OT Performance in LHC Run I – Drift time spectrum





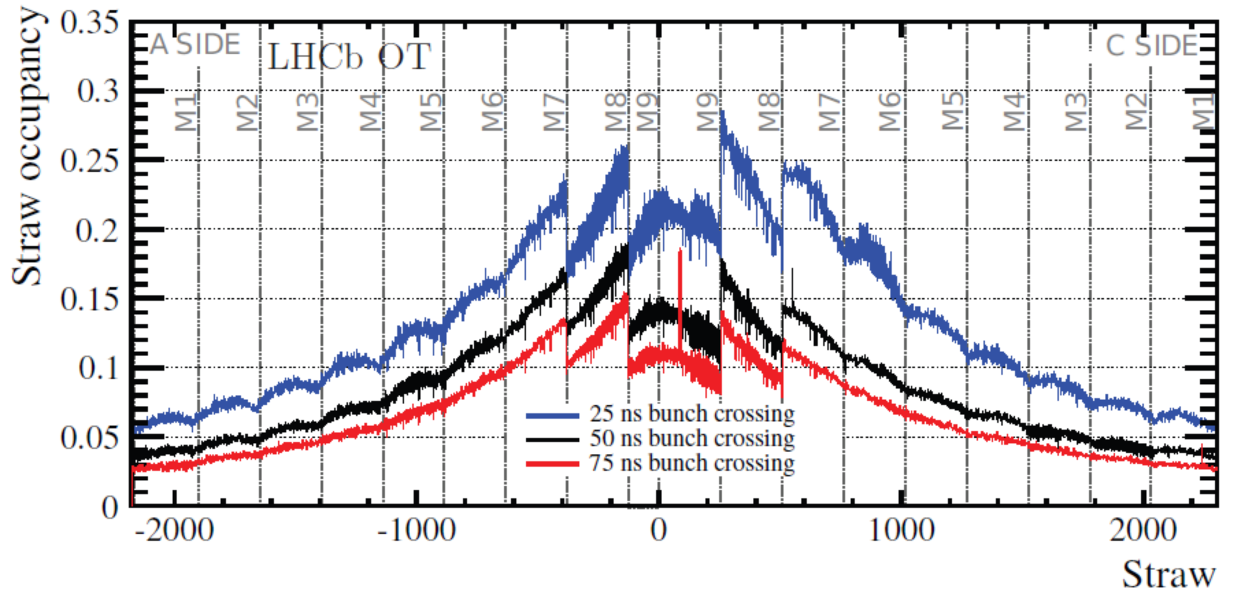
- Max. drift time ~35 ns
- Max. measured time ~50 ns
- Extra hits from:
  - “Spill-over hits”
  - “Multiple hits”

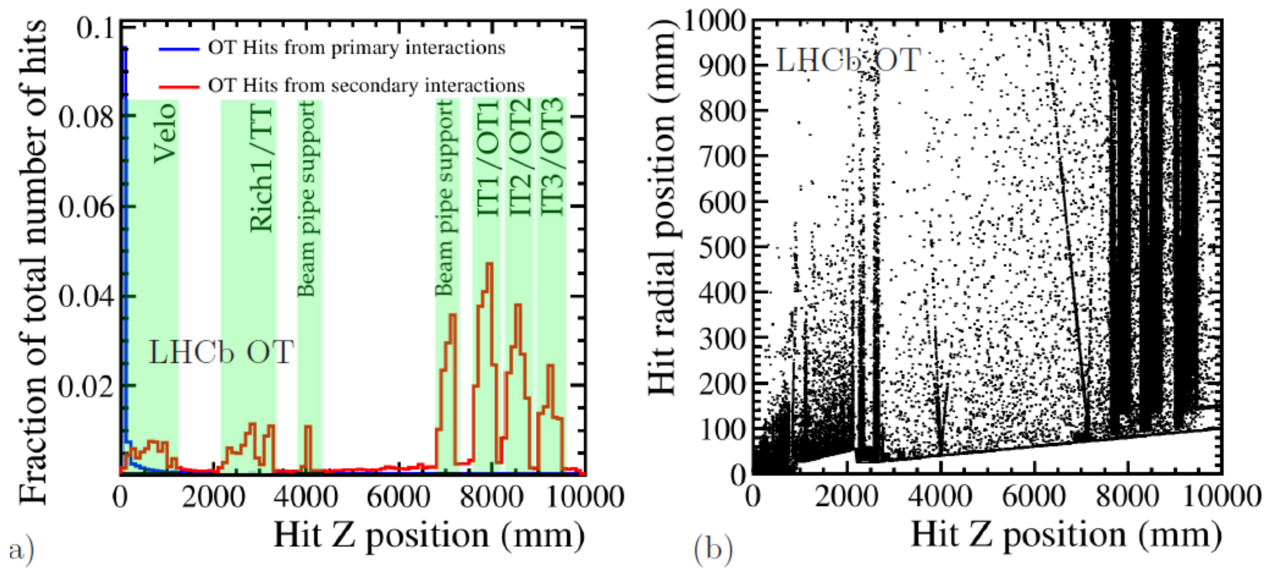




OT Performance in LHC Run I – Occupancy

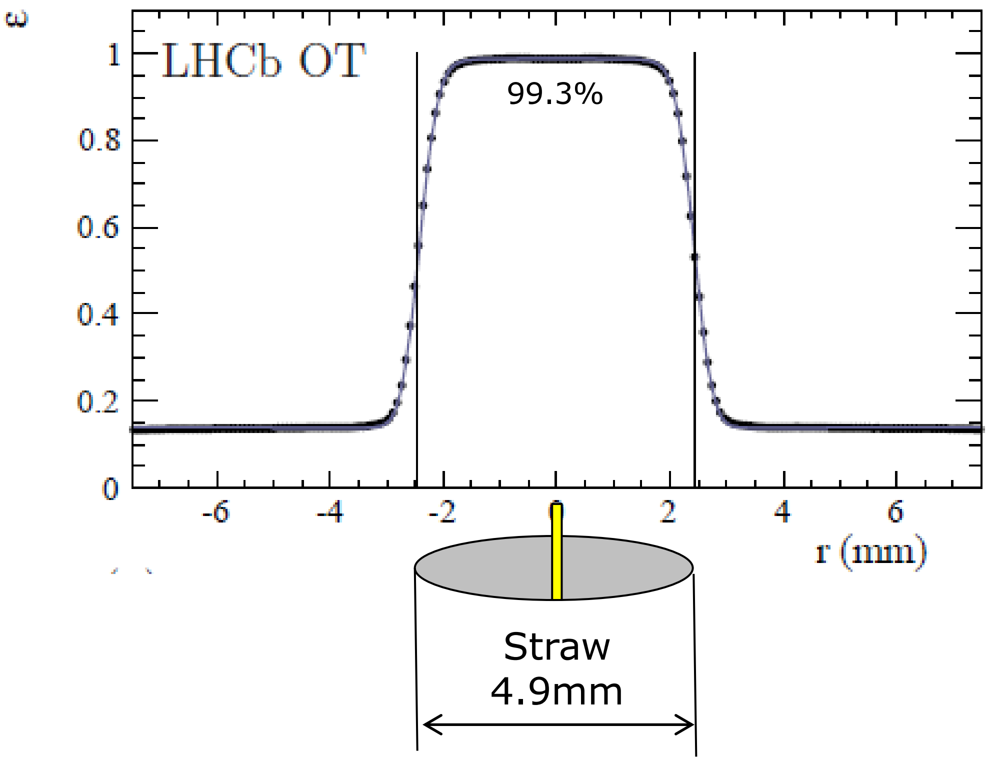
- Occupancy: 3% – 15%
- Large fraction from secondary interactions

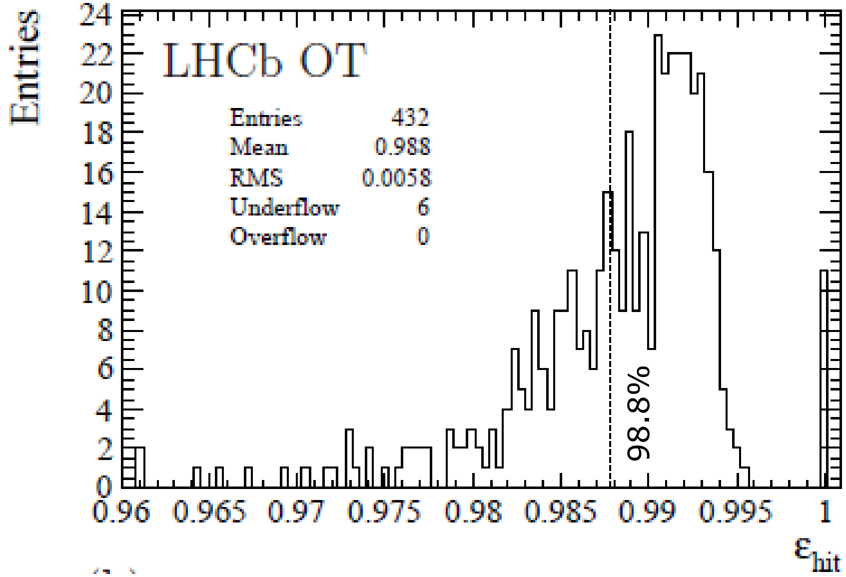




OT Performance in LHC Run I – Efficiency

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

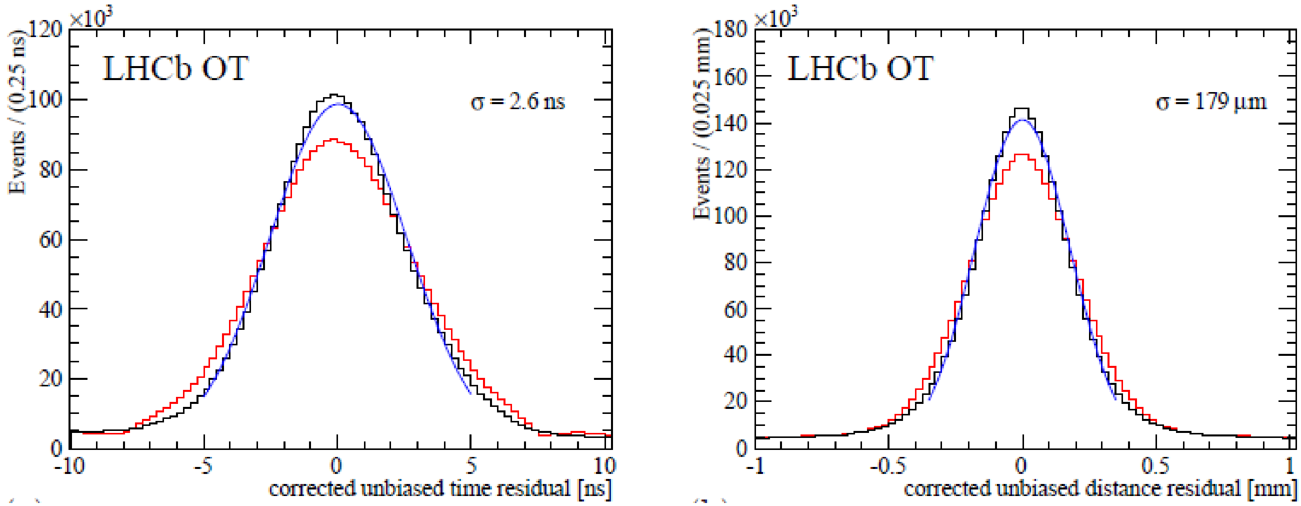




➢ **Single hit efficiency |r|<1.25mm: ~ 99.3%**

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



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

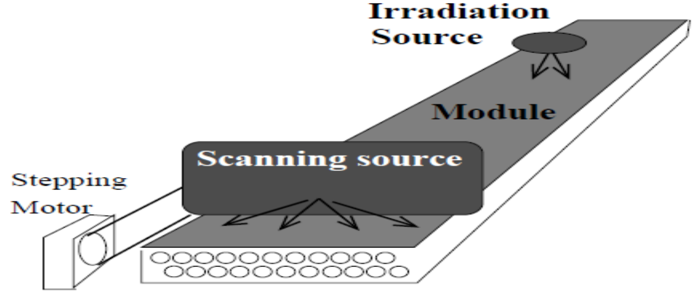
Outline

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

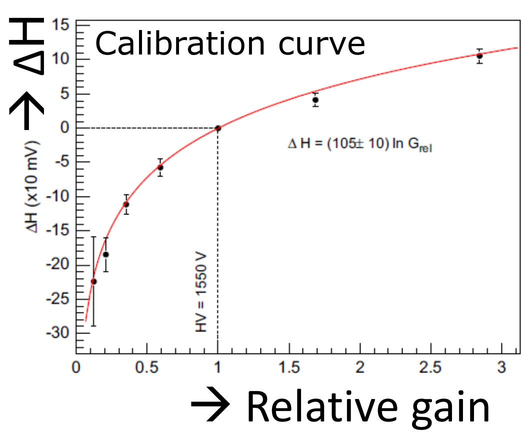
Radiation hardness

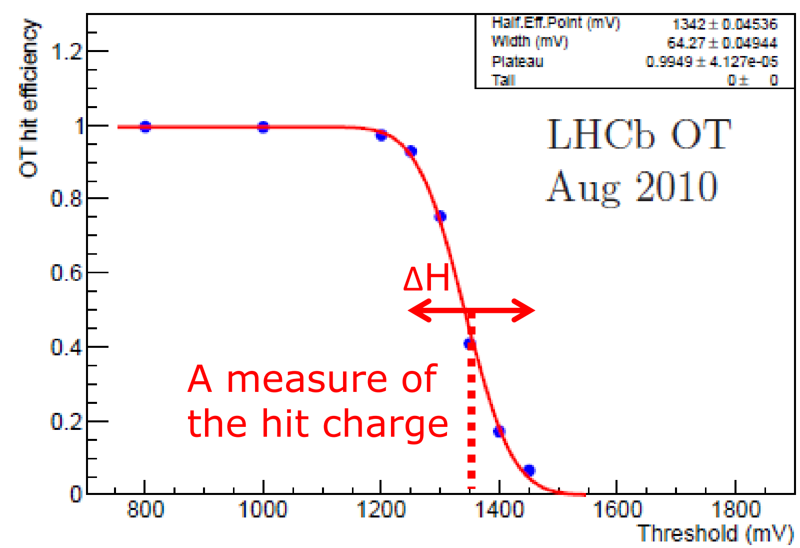
Two methods to monitor gain loss

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



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





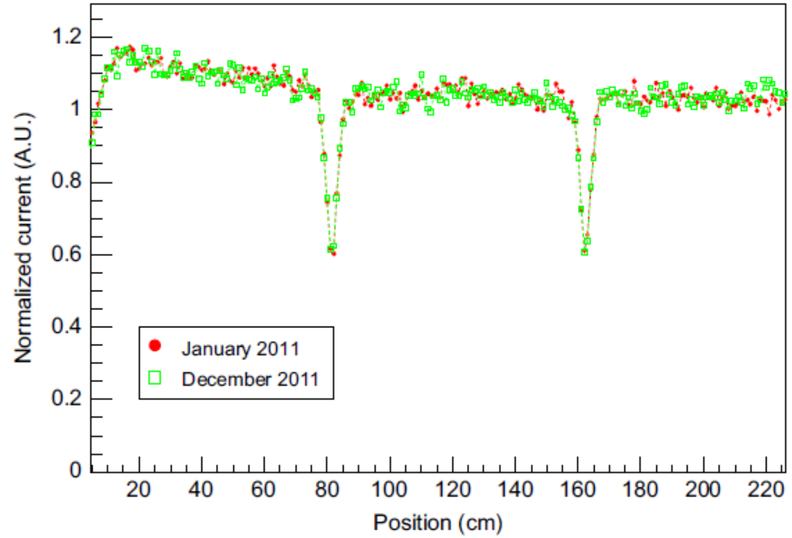
Radiation hardness

Van Eijk, Tuning et al, NIM A685 (2012) 62

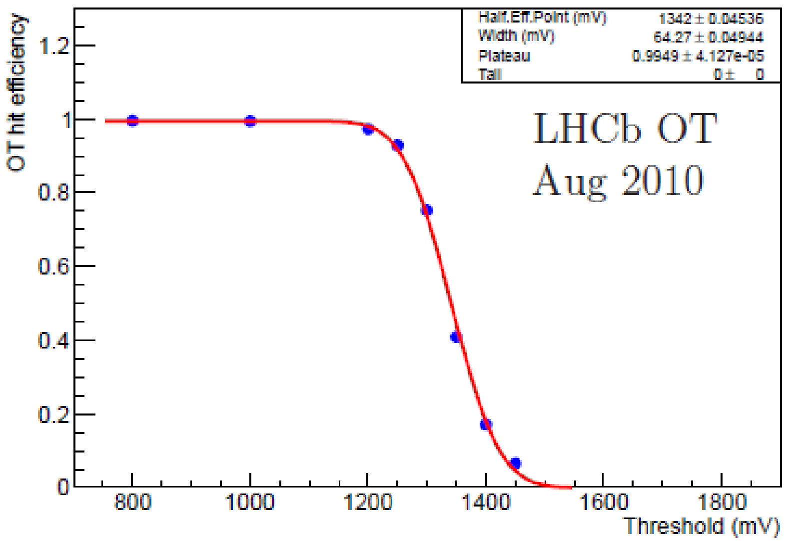
Two methods to monitor gain loss

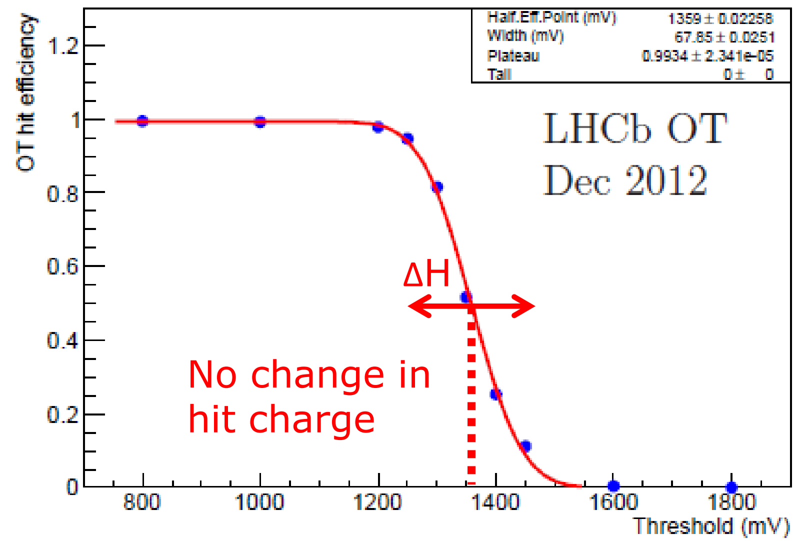
1) During technical stops

- No signs of gain loss



2) During LHC operation





Conclusions & Outlook

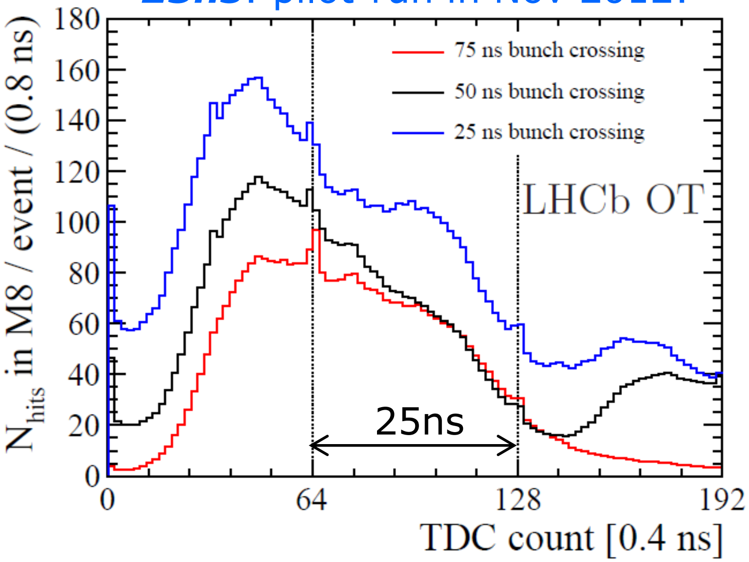
- Outer Tracker performed superbly in **run I**
  - Few dead or noisy channels
  - No irradiation effects observed
  - High hit efficiency (>99%) and resolution (~200 μm)

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

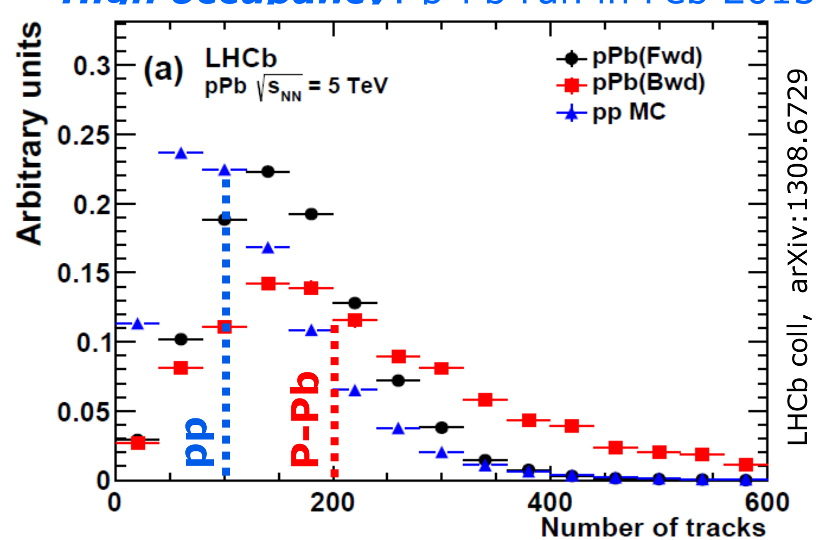
- Looking forward to **run II**
  - 2015
  - $\sqrt{s}$=13 TeV
  - 25 ns bunch spacing

- 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:



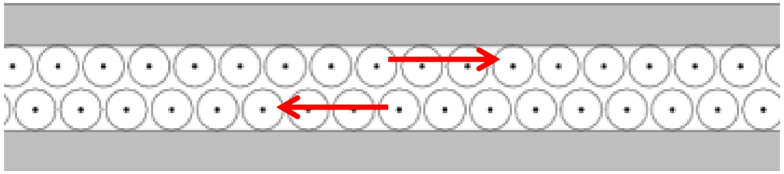
LHCb coll, arXiv:1308.6729

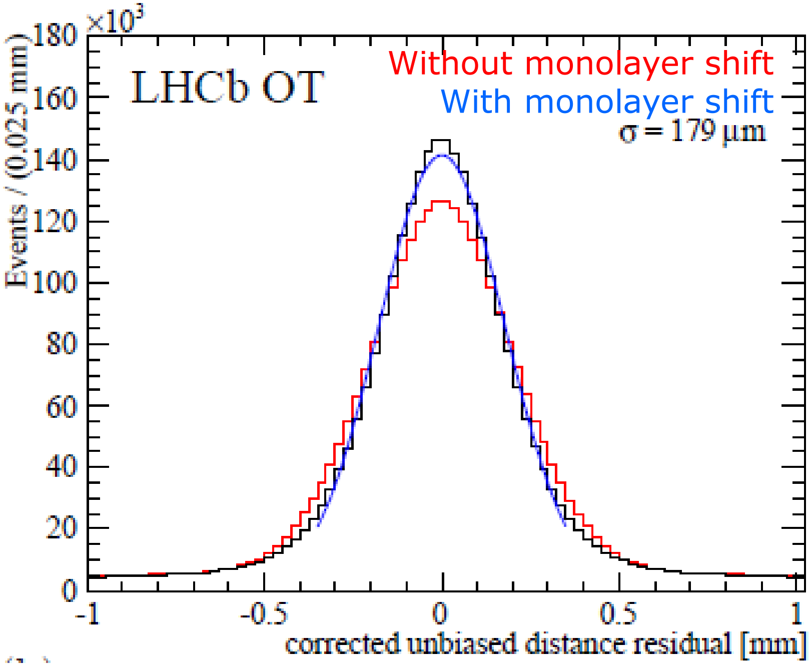
Backup: the nitty-gritty

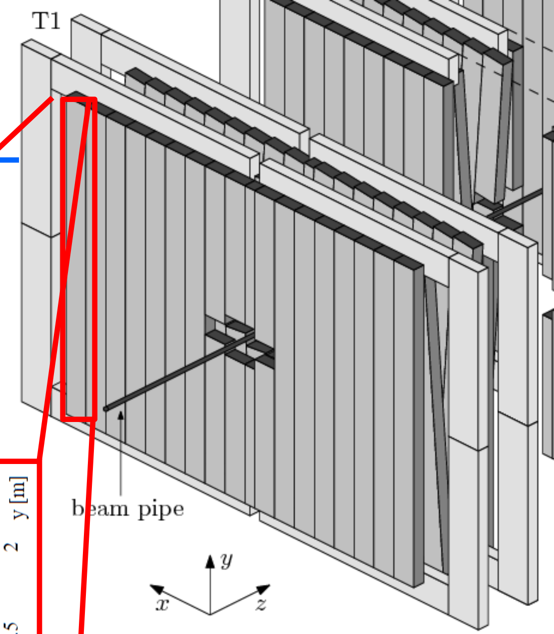
- Internal misalignments
- Effective ionization length
- Signal reflections: “*walk*” correction

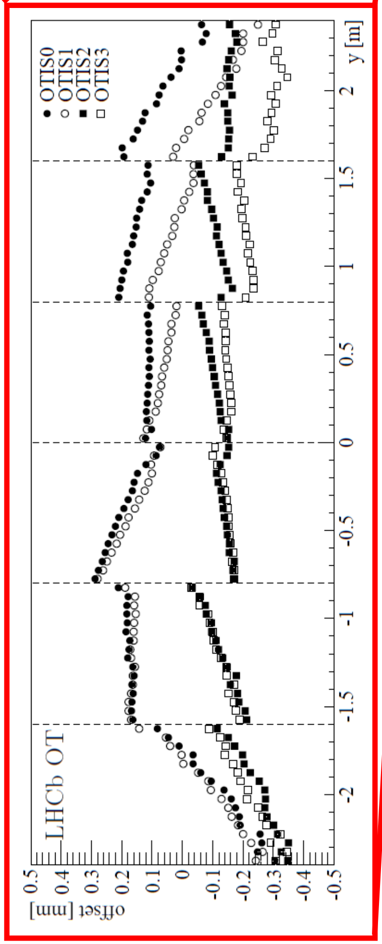
Internal module alignment

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









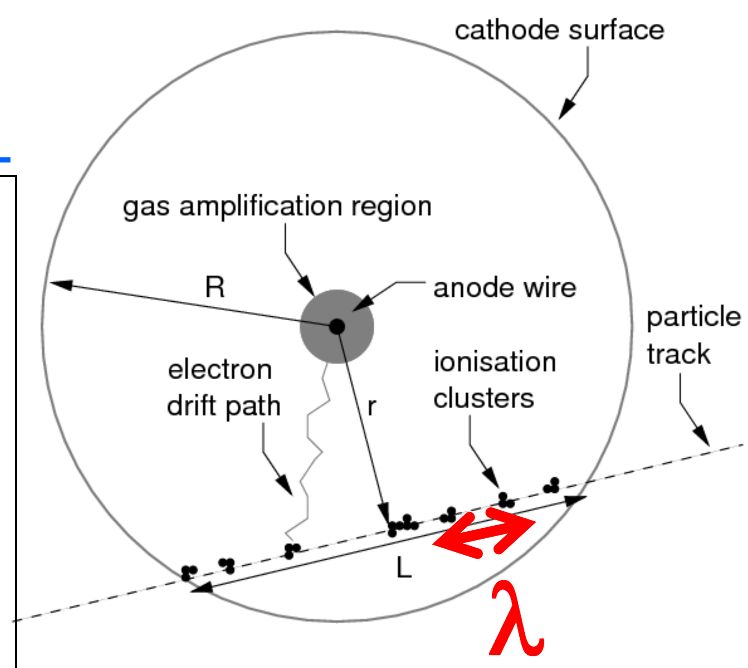
Ionization length

- Ionization length λ:

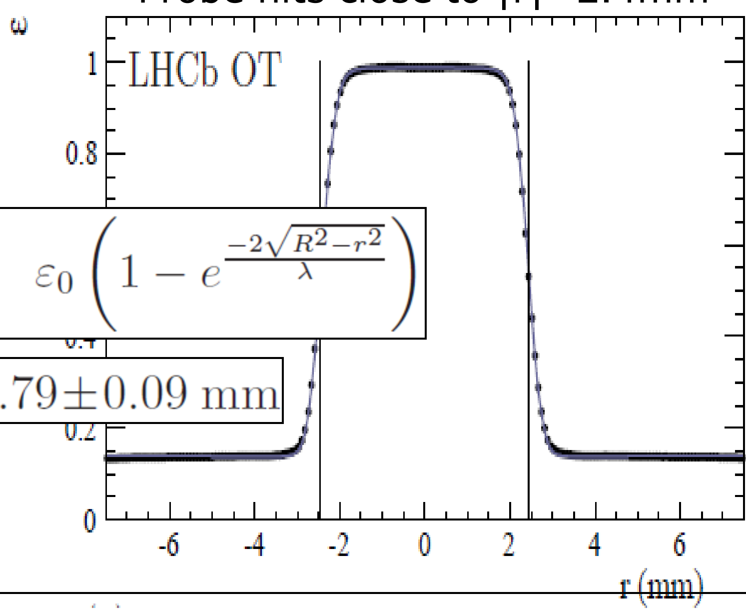
  average distance between clusters

- Measured *effective* λ in two ways:
  1) Efficiency profile: probes large |r|
  2) Drift time distribution: probes small |r|

  ➢ Disentangle effect of absorbtion



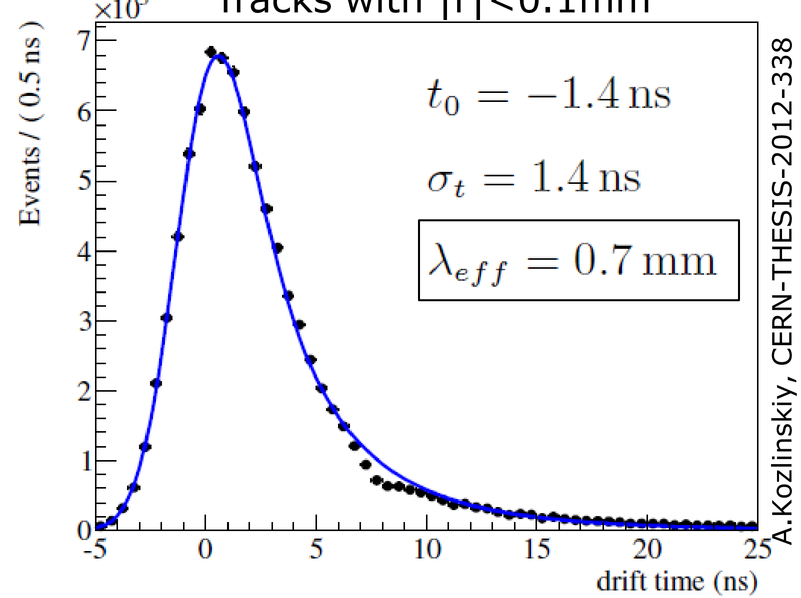
Probe hits close to |r|=2.4mm



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

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

Tracks with |r|<0.1mm



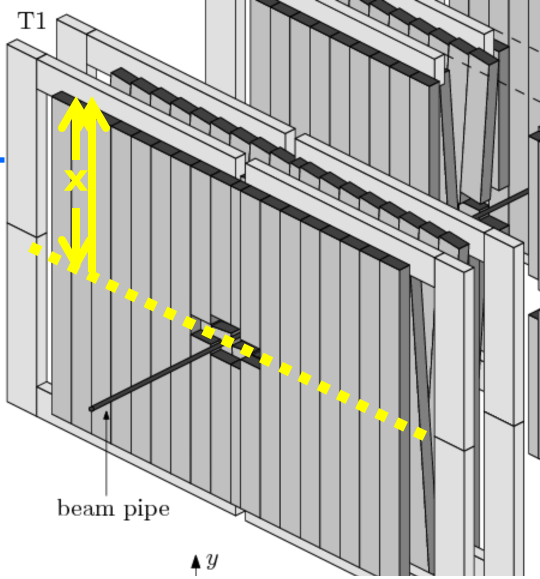
$$t_0 = -1.4 \text{ ns}$$

$$\sigma_t = 1.4 \text{ ns}$$

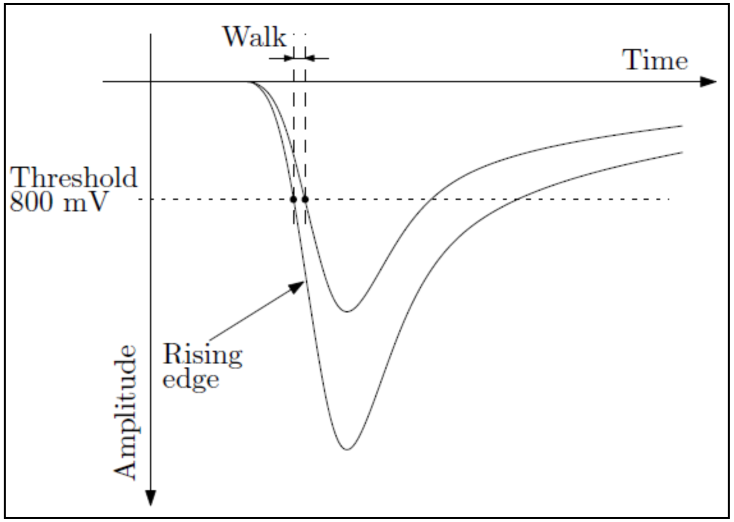
$$\lambda_{eff} = 0.7 \text{ mm}$$

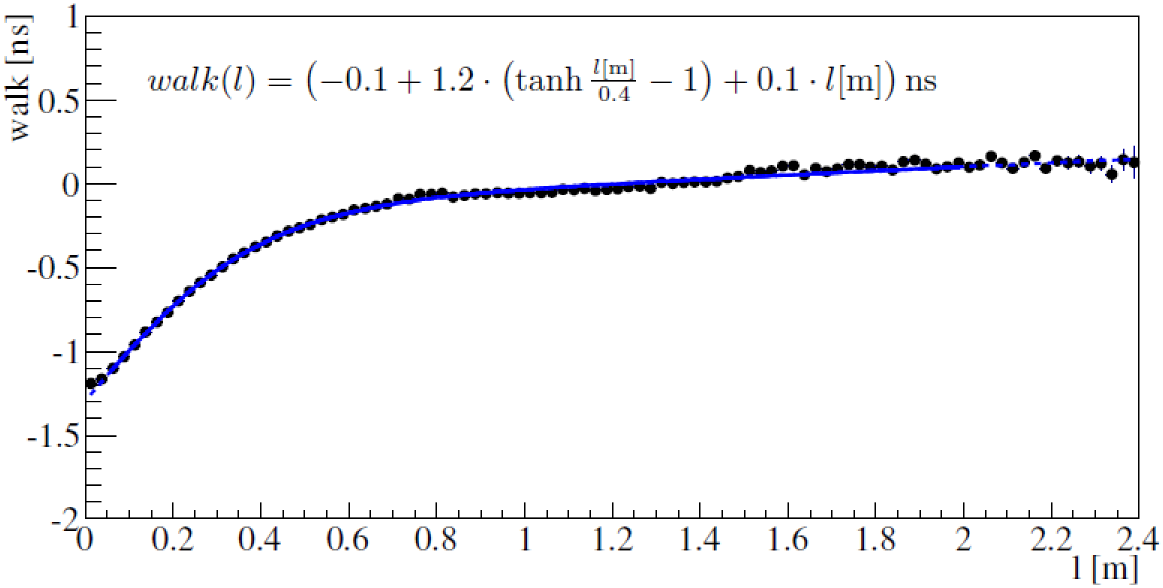
➢ **λ_{eff} 2x larger than nominal; not due to absorbtion**

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**