International Conference on Technology and Instrumentation in Particle Physics, Beijing, People’s Republic of China

The tracking system at LHCb in Run 2: hardware alignment systems, online calibration, radiation tolerance and 4D tracking with timing

23/05/2017

Artur Ukleja
National Centre for Nuclear Research

on behalf of the LHCb Outer Tracker Group

Outline

Performance of the LHCb Outer Tracker in Run 1: JINST9 (2014) P01002
This talk covers preparation of paper for Run 2

- **Introduction**
  - ✧ LHC, LHCb and Outer Tracker – gaseous detector
- **Outer Tracker Performance**
  - ✧ Drift time and hit resolutions
  - ✧ The real time global t_0 calibration
  - ✧ Occupancies and hits efficiency
  - ✧ Noisy channels
  - ✧ Geometrical survey, optical alignment system RASNIK
  - ✧ Ageing
  - ✧ Timing of reconstructed physics objects
  - ✧ Flight time for pions and protons
- **Summary**

LHC and LHCb

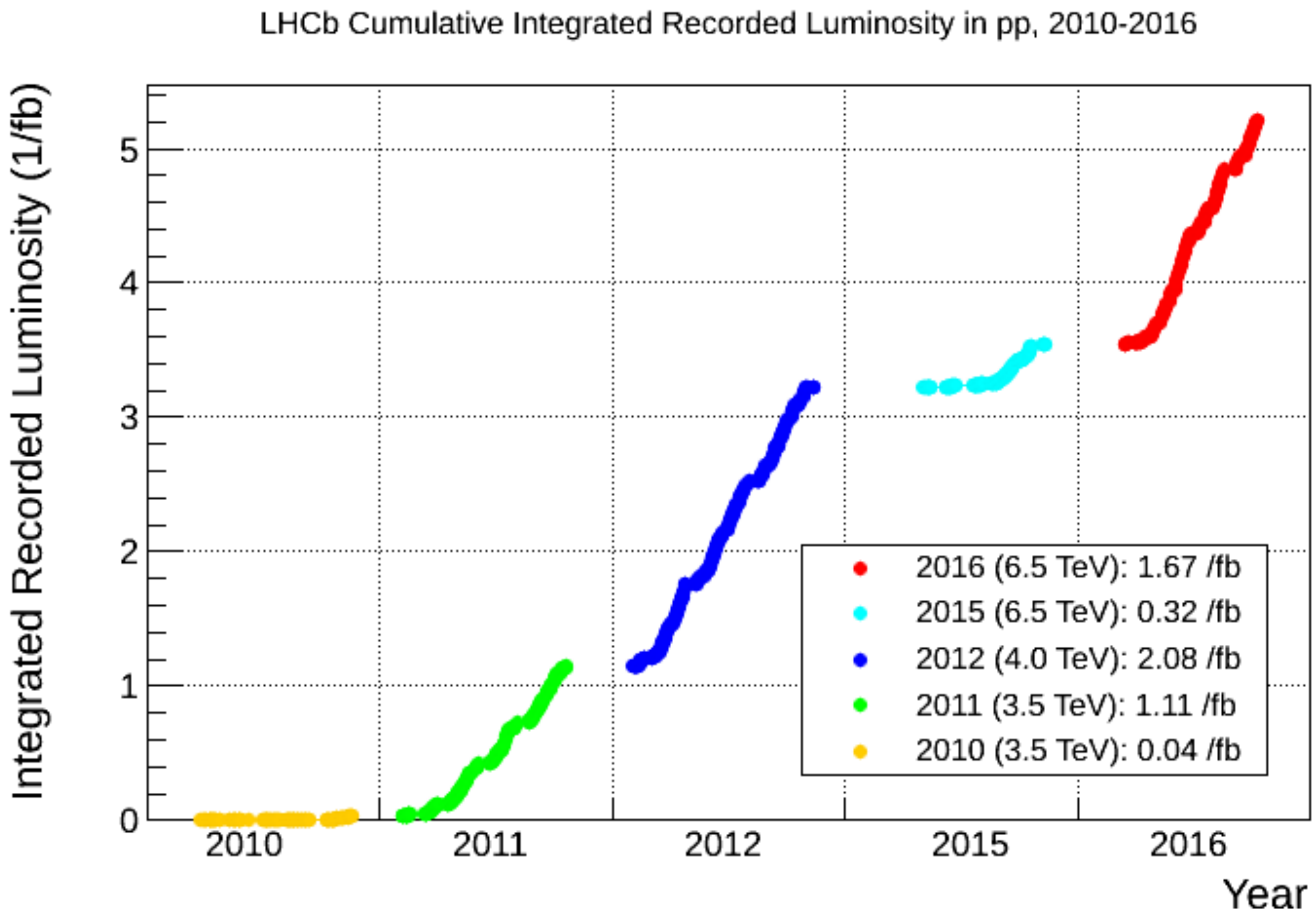
LHCb performance LHC Run 2

LHCb integrated Luminosity pp collisions 2010-2016

Run 1: 40/pb (2010)
1.1/fb (2011)
2.1/fb (2012)

Run 2: 0.3/fb (2015)
1.7/fb (2016)
?/fb (2017)

For each 1/fb:
~28k $B^0_s \rightarrow J/\psi(\mu\mu)\ \phi(K^+K^-)$
~2M $D^{*\pm} \rightarrow D^0(\rightarrow K^-K^+)\pi^\pm$

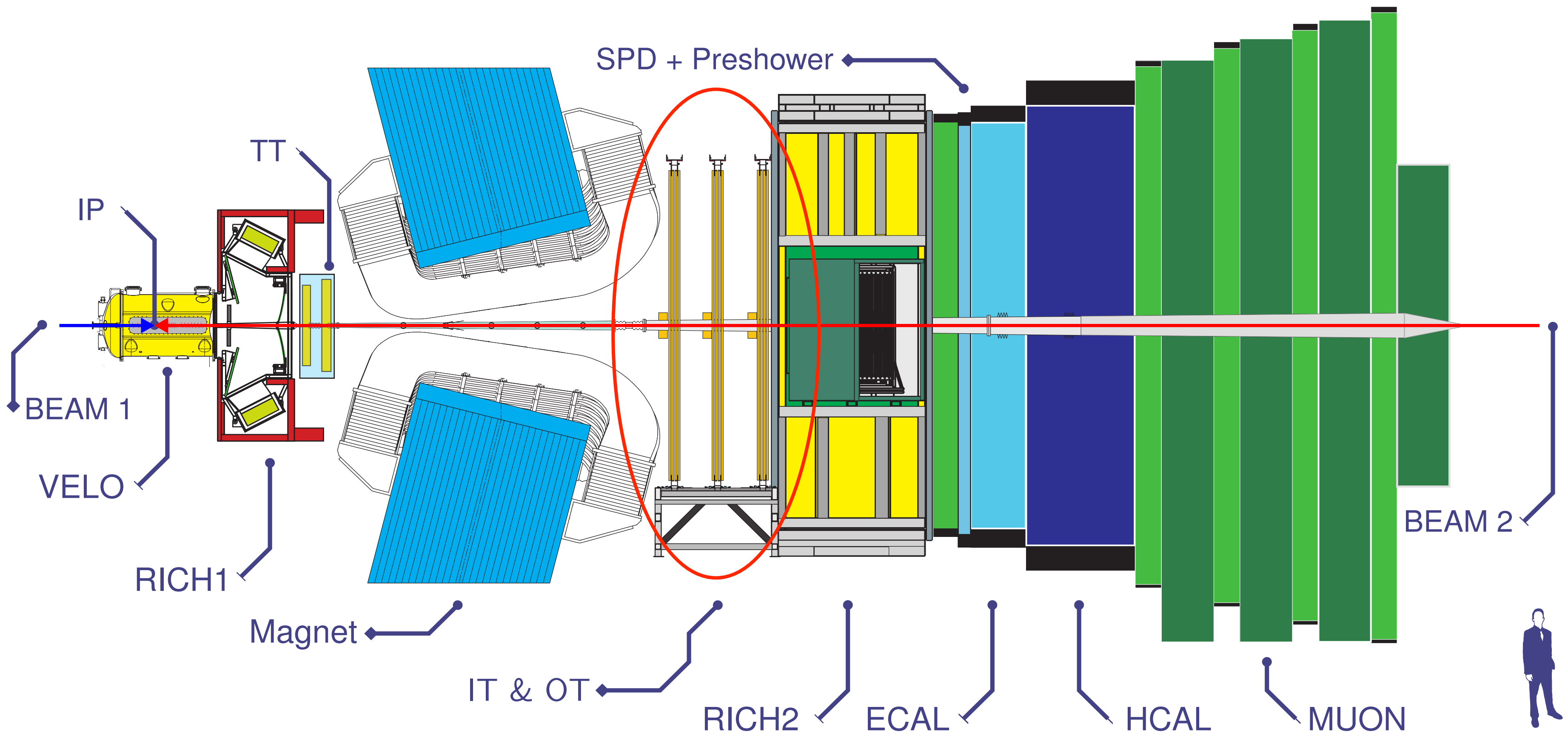


LHC is running now
Data for physics analysis in June 2017

The tracking system at LHCb

The single-arm forward spectrometer (a new concept for HEP experiments)
$10<\theta<300$ mrad ($2<\eta<5$)

JINST3(2008)S08005

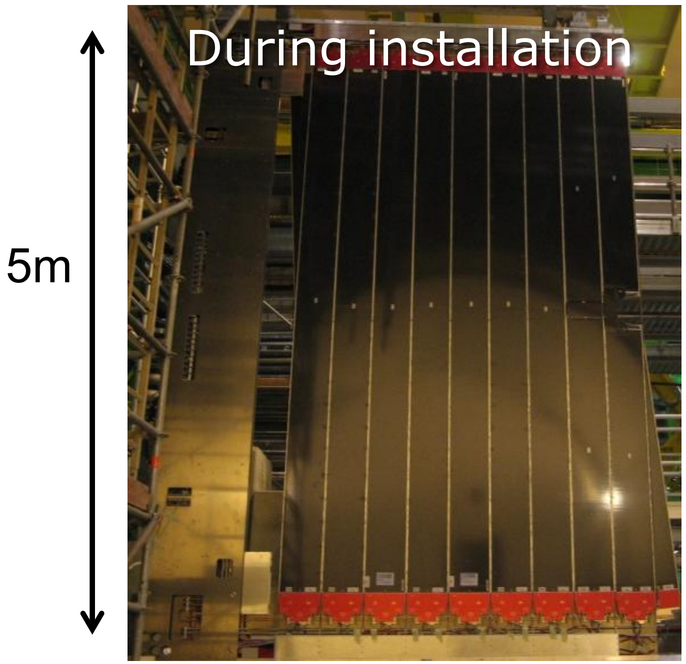


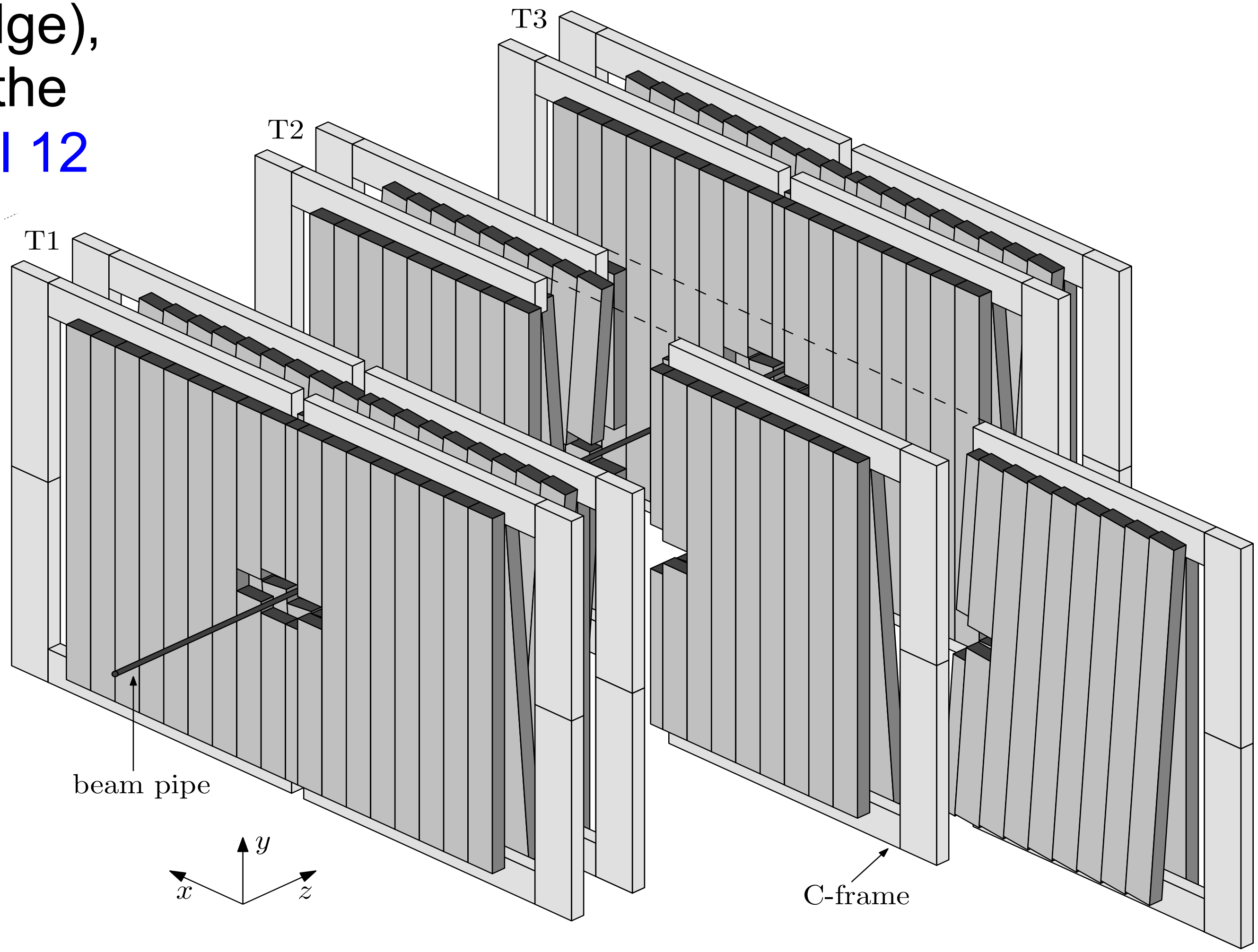
- VELO – precision primary and secondary vertex measurements, resolution of IP: 20 μm, decay lifetime resolution ~ 45 fs: 0.1 $\tau(D^0)$
- Excellent tracking resolution: $\Delta p/p$ = 0.4% at 5 GeV to 0.6% at 100 GeV

Outer Tracker

Outer Tracker

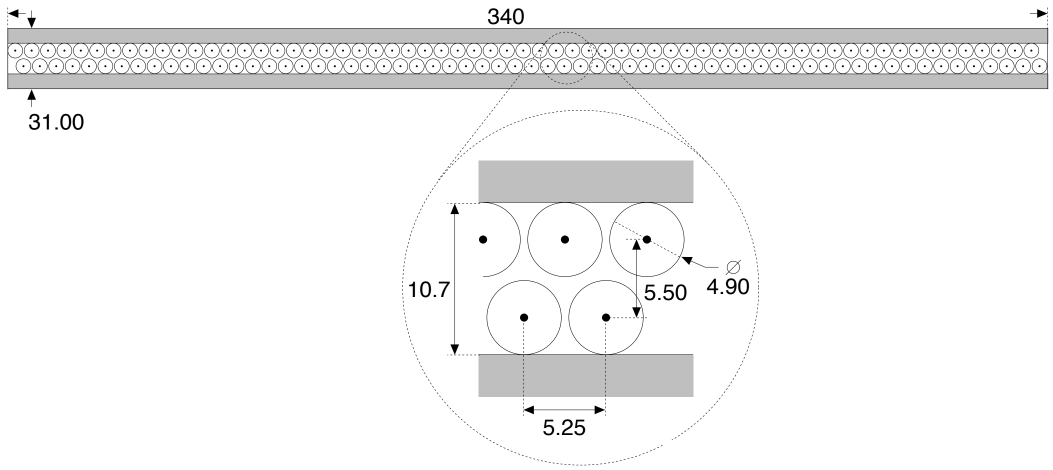
- Gaseous straw tube detector and covers an area of 5 x 6 m^2
- 12 double layers of straw tubes (3 stations, each station consists of 4 module layers)
- Each half station consists of two C-frames (independently movable units)
- The C-frames are sustained by a stainless steel structure (bridge), equipped with rails allowing the independent movement of all 12 C-frames

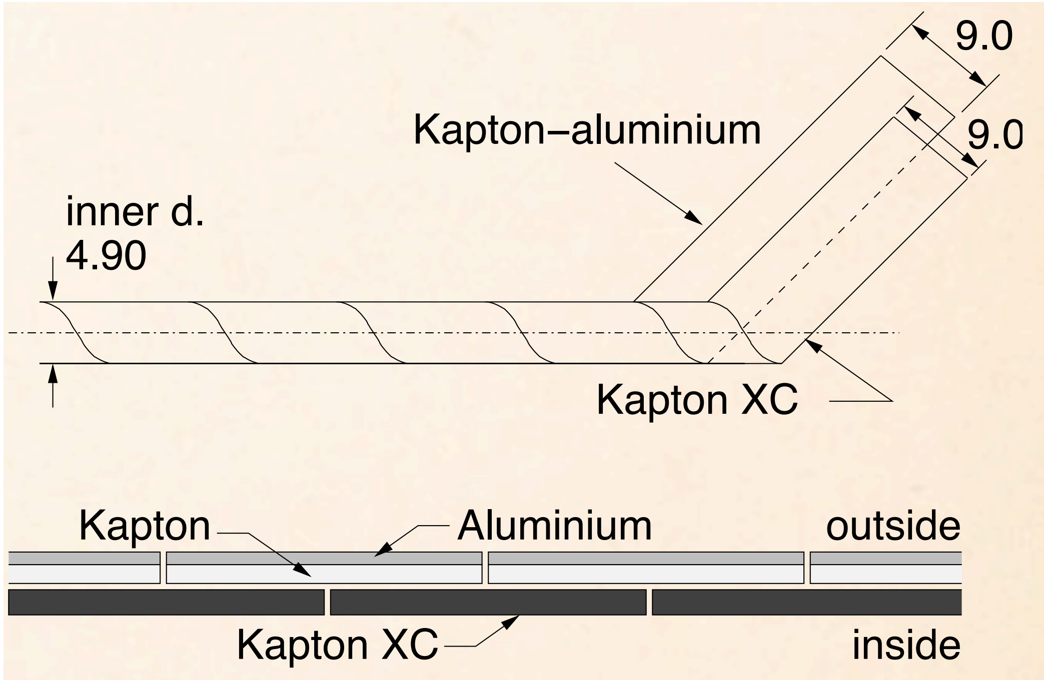




Outer Tracker Modules

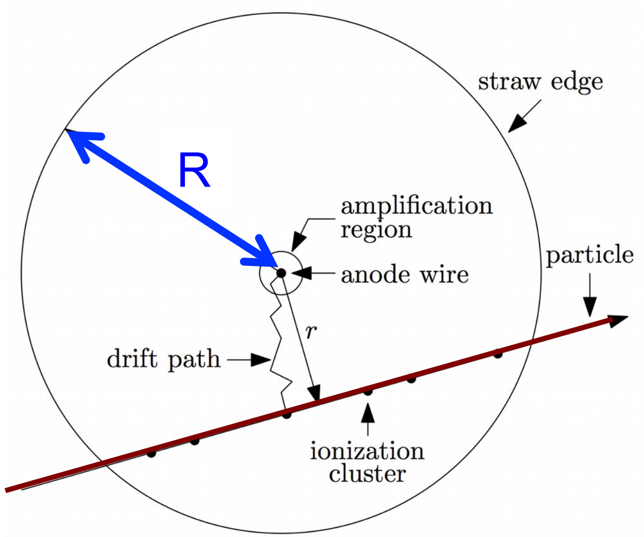
- Each module consists of 2 staggered straw tube monolayers
- Number of straws in monolayer: 64
- Total number of straws: 53760
- Inner diameter of straw tubes: 4.9mm
- Straw tube length: 2.4m
- Glue: Araldite Epoxy AY103-1
- Cathode: Kapton XC
- Anode: Gold+Tungsten (HV: +1550V)
- Gas: $Ar/CO_2/O_2$: 70/28.5/1.5 %

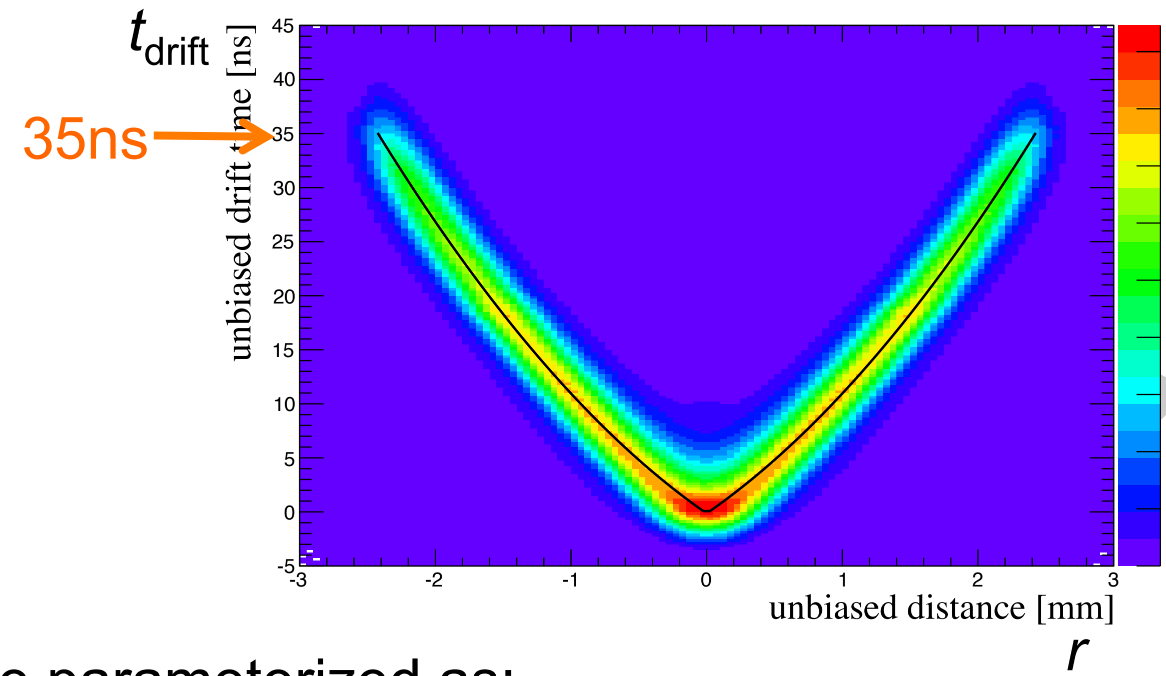




Distance drift time relation

- The position of the hits in the OT is determined by measuring the drift time to the wire of the ionisation clusters
- Distance drift time relation is calibrated on data by fitting the distribution of drift time as a function of the reconstructed distance of closest approach between the track and wire (r)





- Distance drift time relation can be parameterized as:

$$t_{\mathrm{drift}}(r) = (21.3\frac{|r|}{R} + 14.4\frac{|r|^2}{R^2})\mathrm{ns}$$

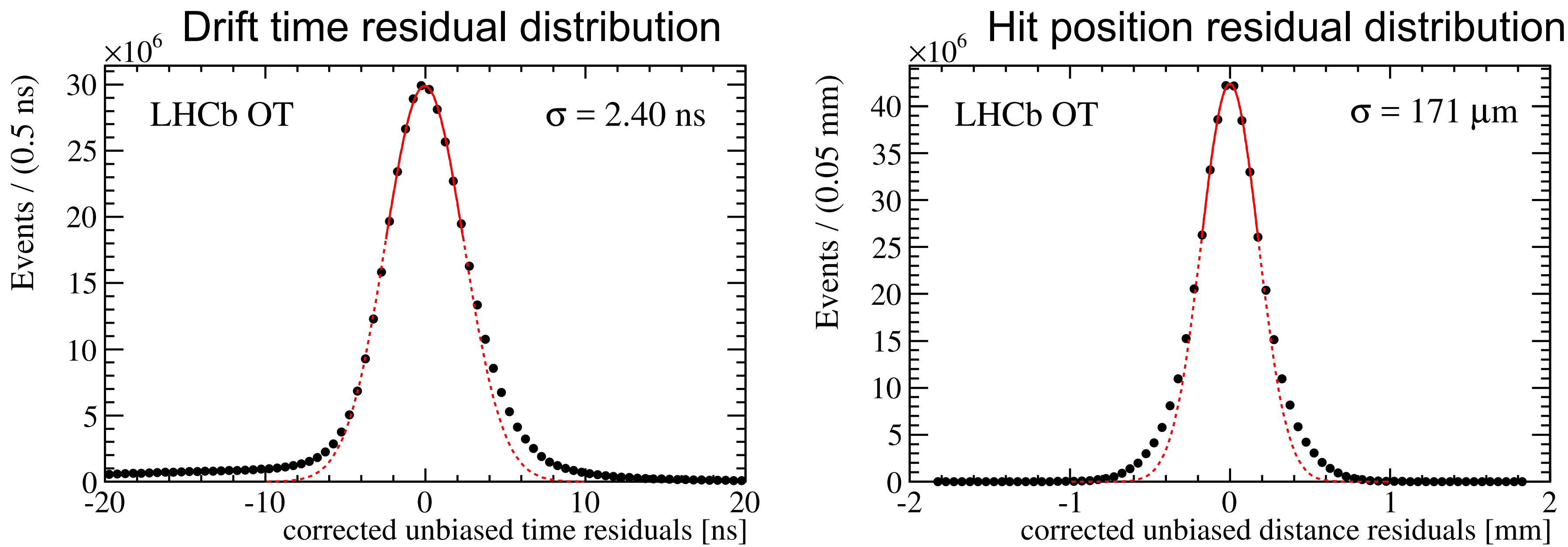
Radius of the straw: R=2.45mm

The relation is stable through the years

- Maximum drift time extracted from the parameterization is 35ns

Drift time and hit resolutions

- The resolution dependence on the distance from the wire is also extracted from the fit: $\sigma t_{\text{drift}}(r) = (2.25 + 0.3\frac{|r|}{R})\text{ns}$ Maximum σt = 2.55ns
- The average time and spatial resolution are determined by comparing the measured drift time and hit position in a straw to the values predicted by the track fit



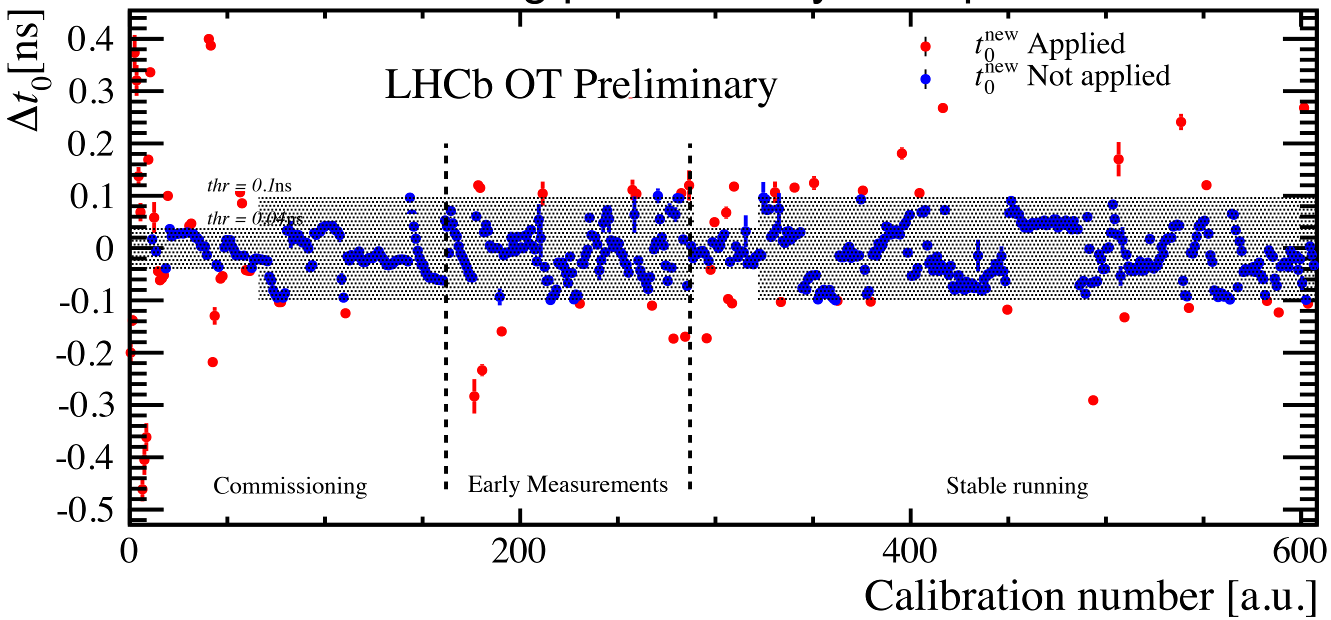
Due to a background contribution coming mainly from secondary hits, the residual distributions are fitted with a Gaussian function in a ±1σ range:

- The drift time residual distribution has a width of 2.4ns (in Run 1 was 3ns)
- The spatial resolution is 171µm (in Run 1 was 205µm)

Online calibration

- The drift time residuals distributions are used to perform the real time global t_0 calibration strategy
- The calibration algorithm produces a fit to the global drift time residuals distribution about every 15 minutes, in case of physics data
- The difference between the new t_0 calculated with the current calibration wrt. the previous t_0 is used
- The t_0 found exceeds a defined threshold (shadowed regions): 0.1ns (optimal, red points) or 0.04ns (during commissioning, smaller statistics)

Data taking period: 3July-14Sept.2015

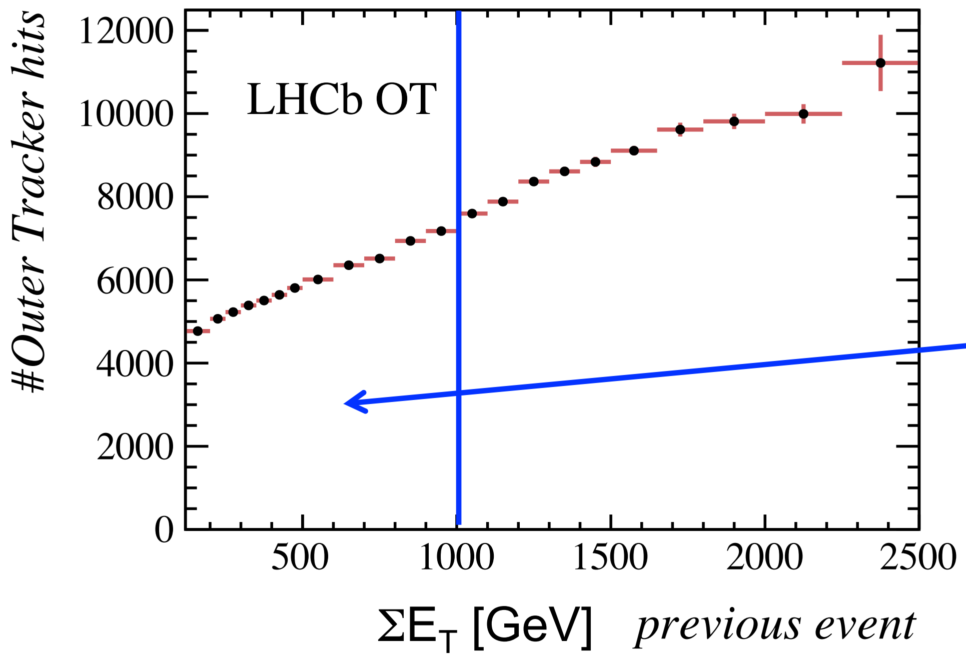


- If the t_0 is smaller than an upper limit, the last version of the global t_0 condition has been used (blue points)
- The above strategy allows for a time alignment of the OT time and LHCb clock better than 0.1ns

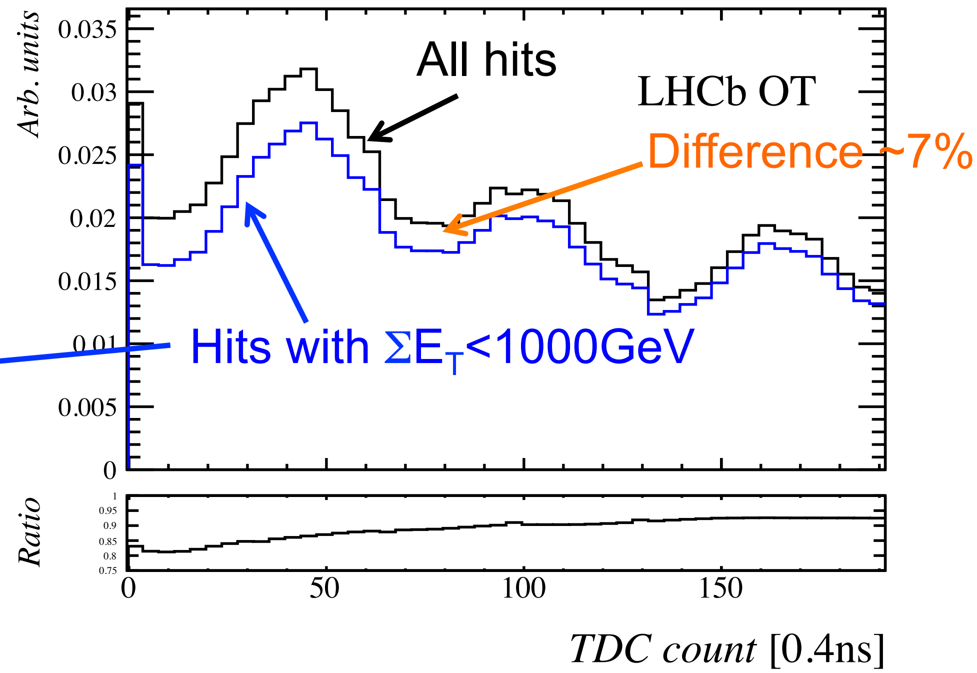
Occupancies and hits efficiency

To reduce the occupancy in good events we are vetoing on previous busy events

The average number of recorded hits in the OT as a function of the ΣE_T in the previous event in all calorimeter clusters



The recorded drift time spectrum for hits in the OT

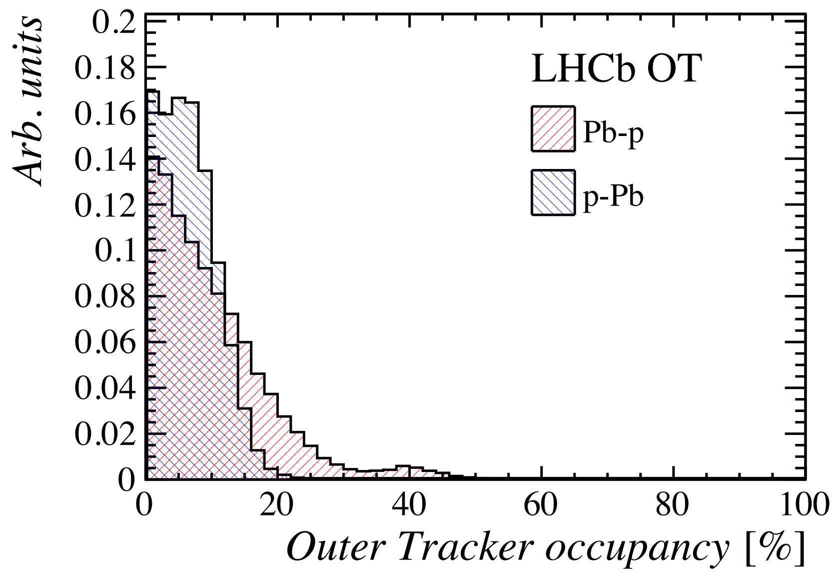


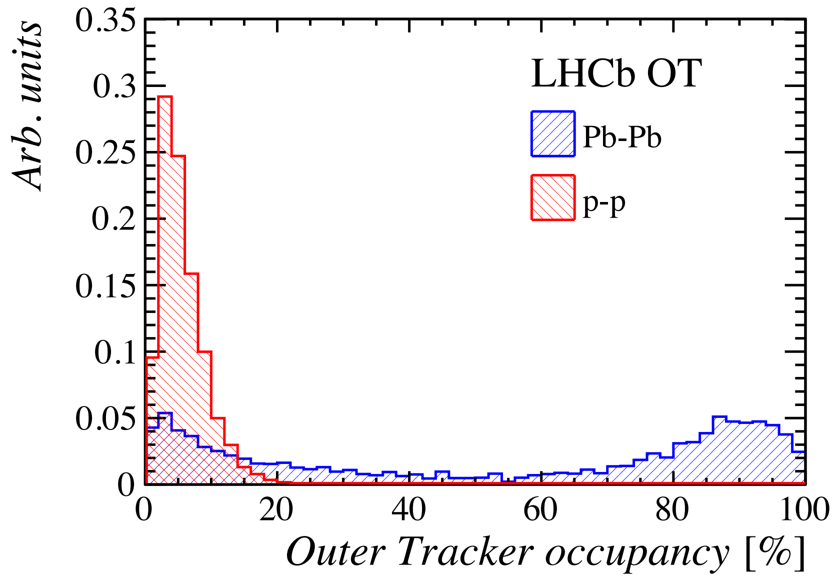
- The OT hits due to spill-over from the previous event:
  - if the previous event was empty then there are ~5000 hits
  - if the previous event was quite busy (ΣE_T<1000GeV) then the number of hits increases to ~7500 hits (limit in data acquisition)
- When only events with an upper limit ΣE_T<1000GeV (loss ~7% of the events), the effect on the drift time is mostly affected for lower drift times

Occupancies in p-Pb and Pb-Pb collisions

Mainly the LHC operates with p-p beams but there is also interesting part of physics in p-Pb and Pb-Pb collisions (one month a year)

The average number of recorded hits in minimum bias



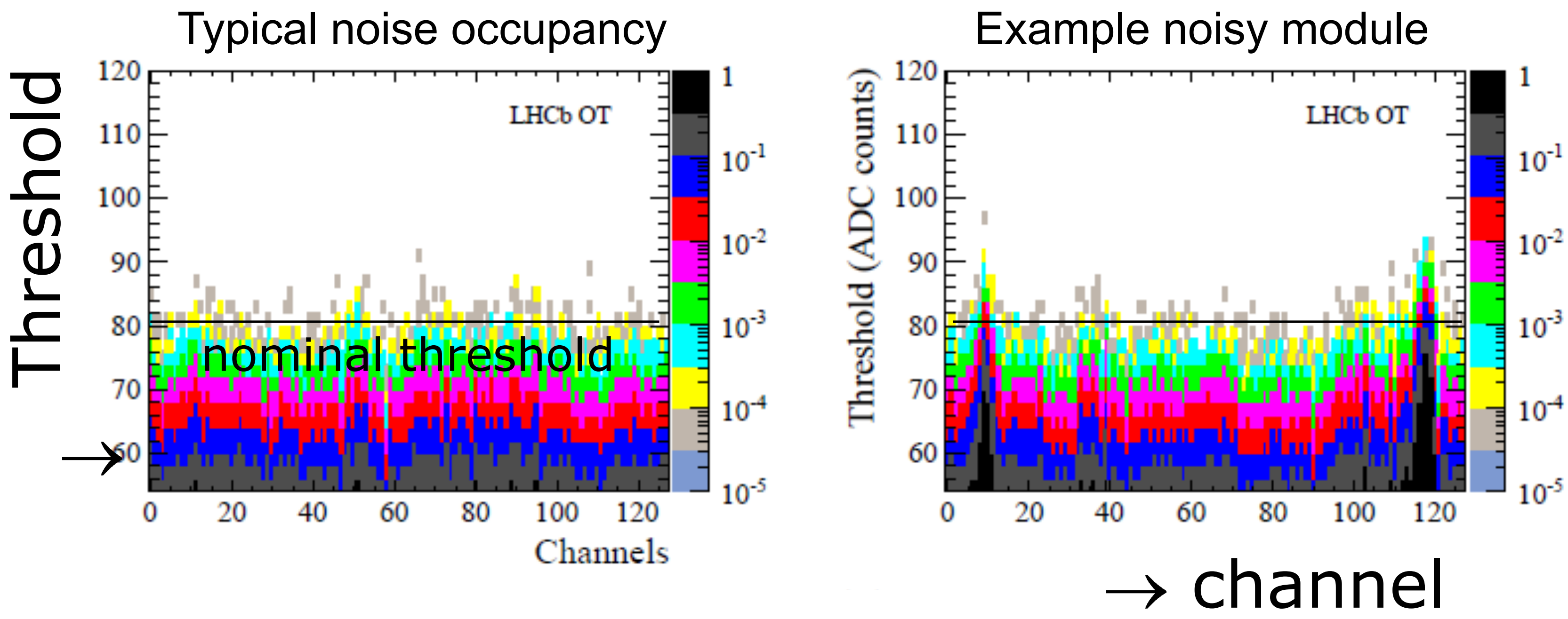


- The occupancy of the OT is significantly larger in Pb-Pb than in p-p collisions
- In p-p the occupancy is smaller than 20%
- In Pb-Pb the occupancy ups to 100%
    - offline not all events up to the highest OT occupancy are used, go up to a Pb-Pb centrality of ~60%
- In Pb-p the occupancy is smaller than 50%

Noisy channels

To identify channels that have an “abnormal” level of noise (dark pulses from the detector, bad FE-electronics shielding, or bad grounding) the hit occupancy is determined for increasing values of the amplifier threshold (nominal value is 800mV)

Measured in Run 1



- A noise occupancy at the level of 10^{-4} is observed at nominal threshold
- At the nominal threshold of 800mV only 0.2% of channels exhibited a noise occupancy larger than 0.1%
- Completely negligible for data taking in Run 2 as well

Geometrical survey

The correct spatial positioning of the modules is ensured in a few steps:

1) The design and construction of the OT detector guaranties a mechanical stability of 100μm in x and 500μm in z directions

2) By construction the anode wire is centered within 50μm with respect to the straw tube

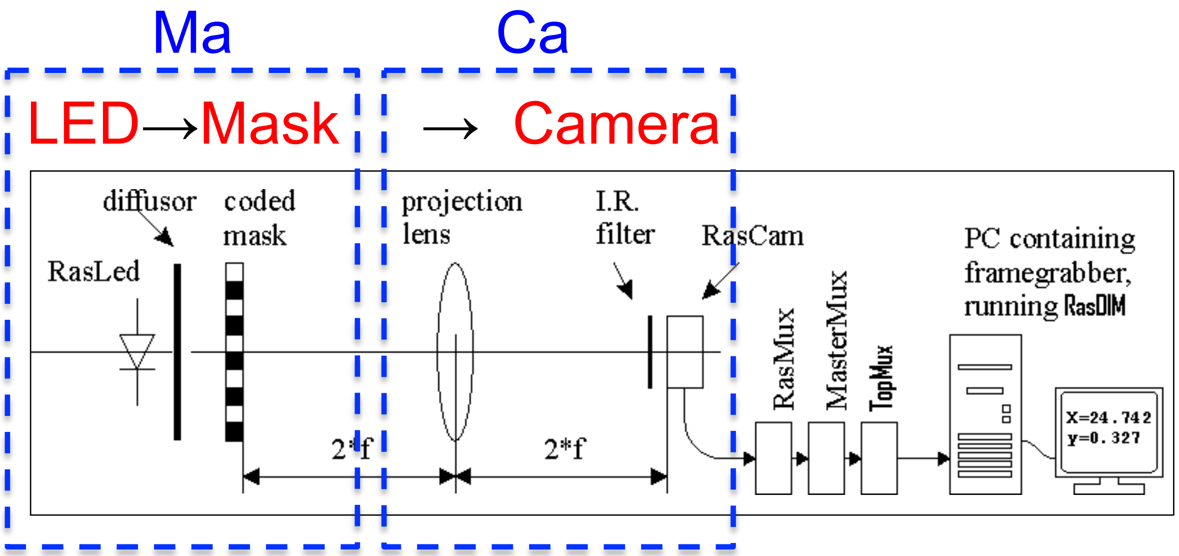
3) The modules are fixed to the C-frames at the top and the bottom, with tolerances below 50 μm

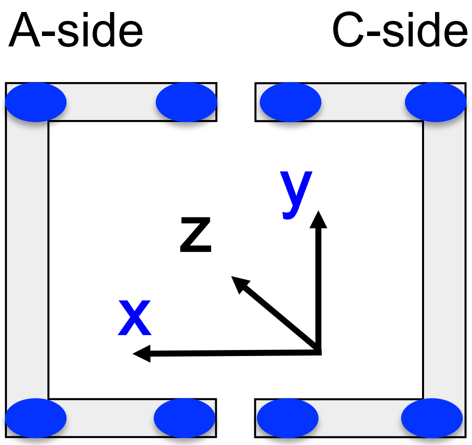
4) After installation, the position the four corners of the C-frames were adjusted within ±1mm of the nominal position

5) Finally, the positions of all modules are determining using dedicated optical alignment system RASNIK continuously (during breaks and data taking periods)

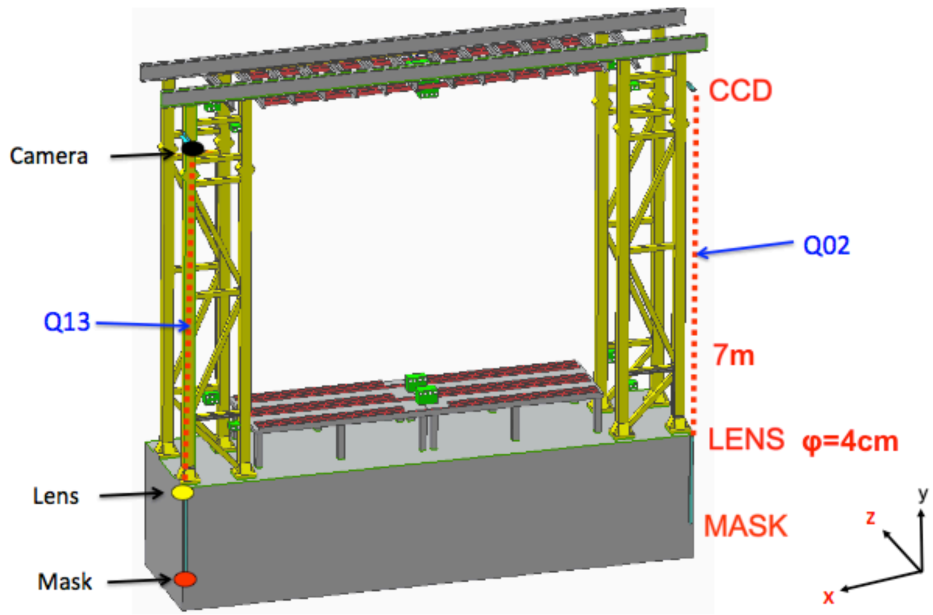
Mechanical stability

- An optical alignment system (RASNIK – Relative Alignment System of NIKHEF) measures relative displacements
- RASNIK measures relative movements of Ma vs Ca
- The lines are mounted on each corner of C-frames (3 stations * 2 pairs of frames * 8 lines per pair of frame = 48 lines)
- The resolution in perpendicular directions to the optical axis is better than 1 μm and in longitudinal direction is better than 150 μm.



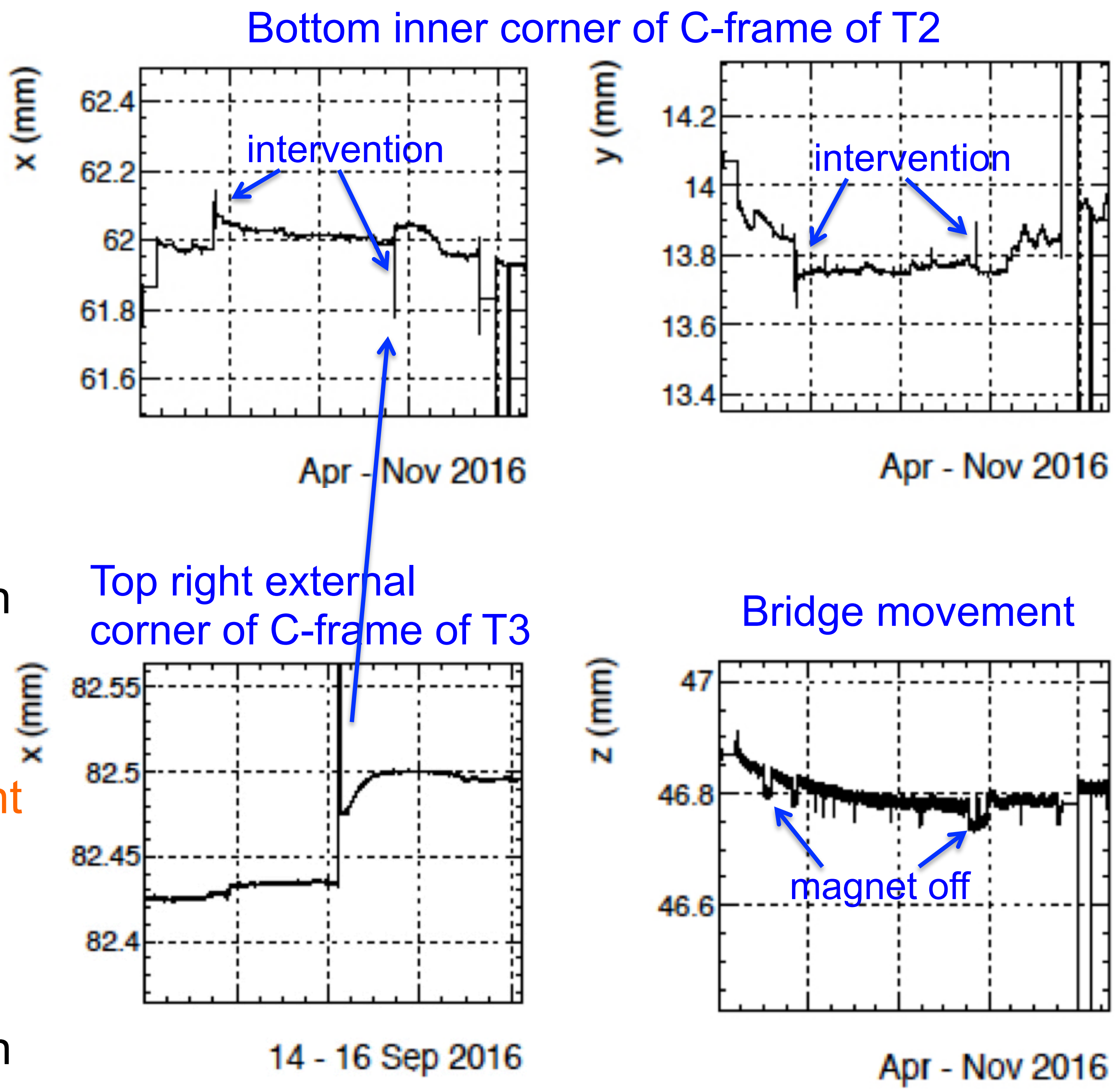


- The 2 lines measure movement of support bridge wrt. floor



The RASNIK results

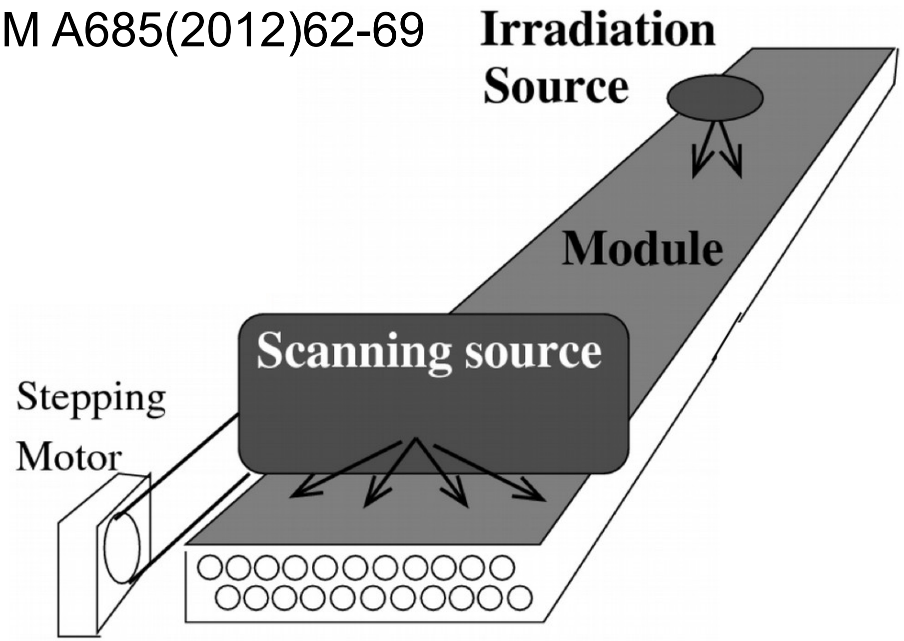
- The x and y positions of the bottom C-frames vary within ~200μm
- Precise RASNIK data for x positions of C-frames show how the OT mechanical system slowly attains the equilibrium state after interventions
- The intervention in T3 on C-side caused shifts ~70 μm in horizontal x
- The changes in z ~100 μm are caused by the movement of the bridge wrt. floor
- After switching on the magnet, the bridge moves back to the previous position



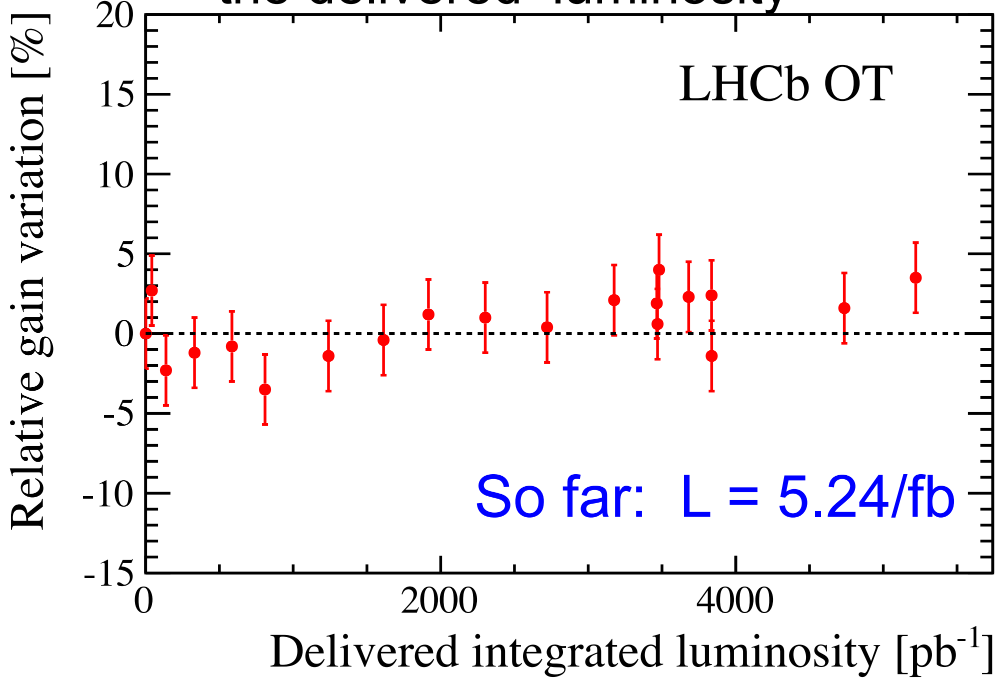
Measurement of ageing

- To deduce the relative gain over the years, dedicated runs take place (during LHC operations) in which the amplifier threshold is varied per layer
- The two ^{90}Sr source are used to measure gain, response to radioactive source for each straw channel for each position along Y

NIM A685(2012)62-69



Average gain as a function of the delivered luminosity

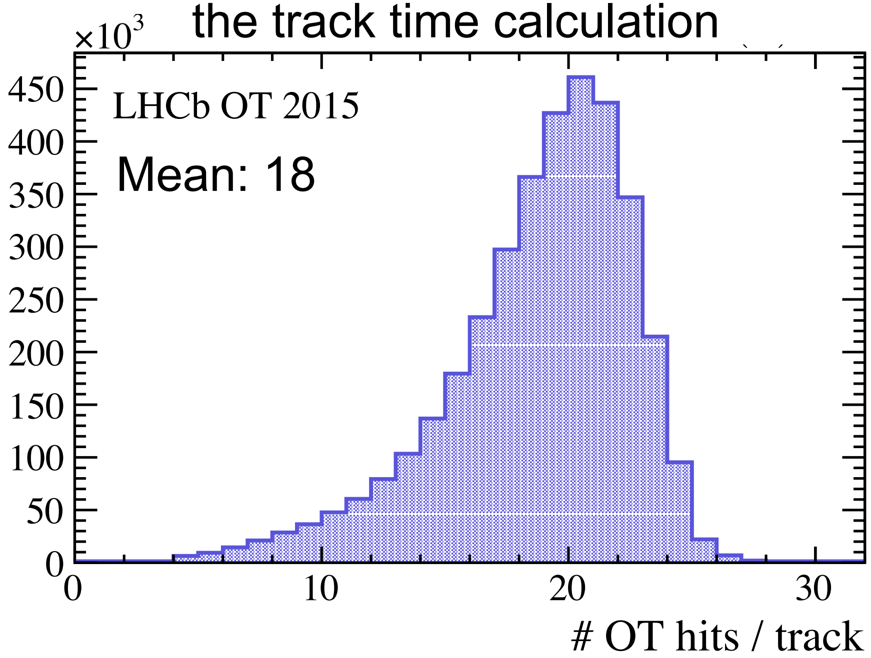


- Results are consistent with no sign of gain loss (vary within ±5%)
- Also the inner, outer and lower parts of the detector are analyzed separately; no different trends are observed for the different region of the detector

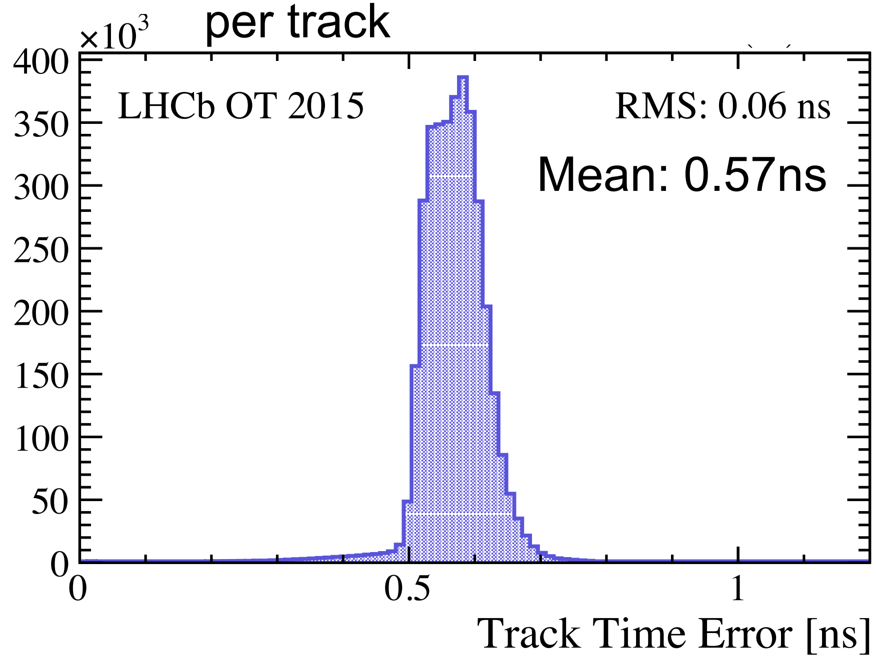
Timing of physics objects exploiting the OT

- A single track has multiple measurement points in the OT
- The mean number of hits per track lies at 18, with a long tail to the left

The number of hits per track for the track time calculation



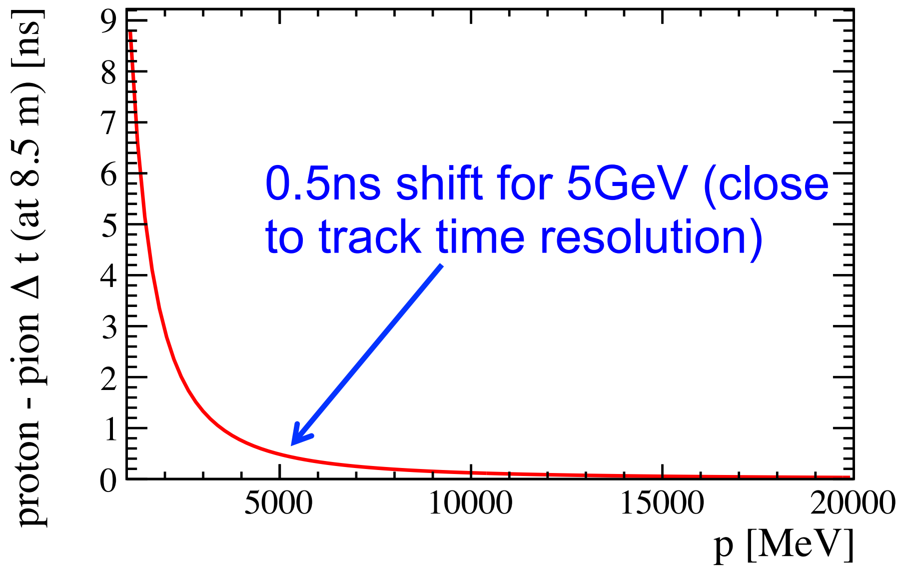
The uncertainty on the time per track



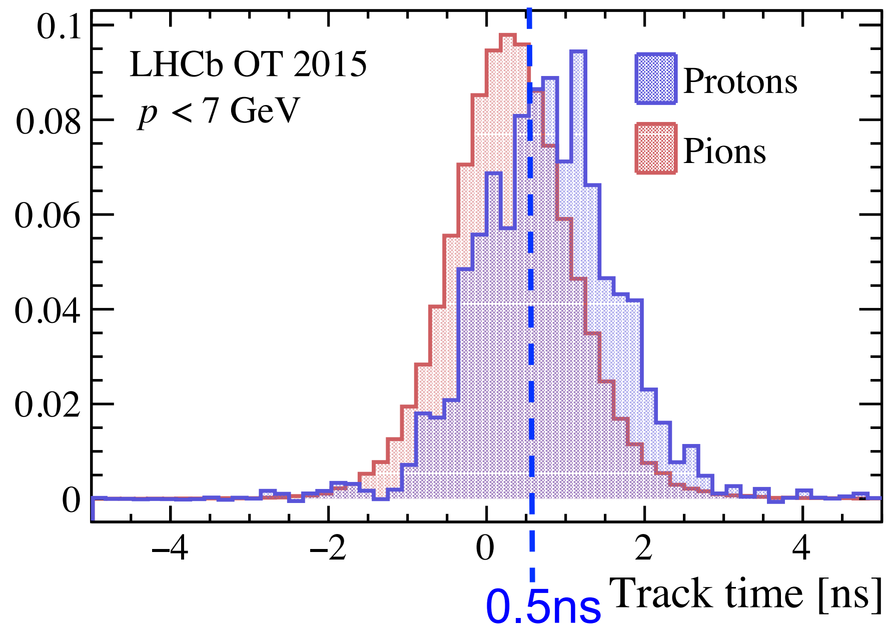
- For each point the drift time residuals are calculated
- The track time resolution is determined as the weighted sum of the errors on all individual drift time residuals and equals 0.57 ns

Flight time for pions and protons

- The velocity of particles created in pp can mostly approximated by the speed of light
- But heavy low momentum particles can velocity sufficiently lower than light and they have a significant shift in the arrival time
- For protons the shift in the arrival time is about 0.5 ns at 5 GeV from pions at the center of the OT (about 8.5 m)
- The difference (visible by eye) in the track time distributions between low momentum (p < 7 GeV) pions and protons can be used to help in identification of these particles



The distribution of track times in data with p < 7 GeV



Summary and conclusions

The performance of the OT LHCb detector was stable in the entire Run 2:

- Ageing is consistent with no gain loss within 5%
- Only 0.2% of channels exhibited a noise occupancy larger than 0.1% (completely negligible for data taking)
- An optical alignment system RASNIK measures that position of all modules are stable up to ±200μm
- High efficiency drift time (2.4ns) and spatial (171μm) resolutions

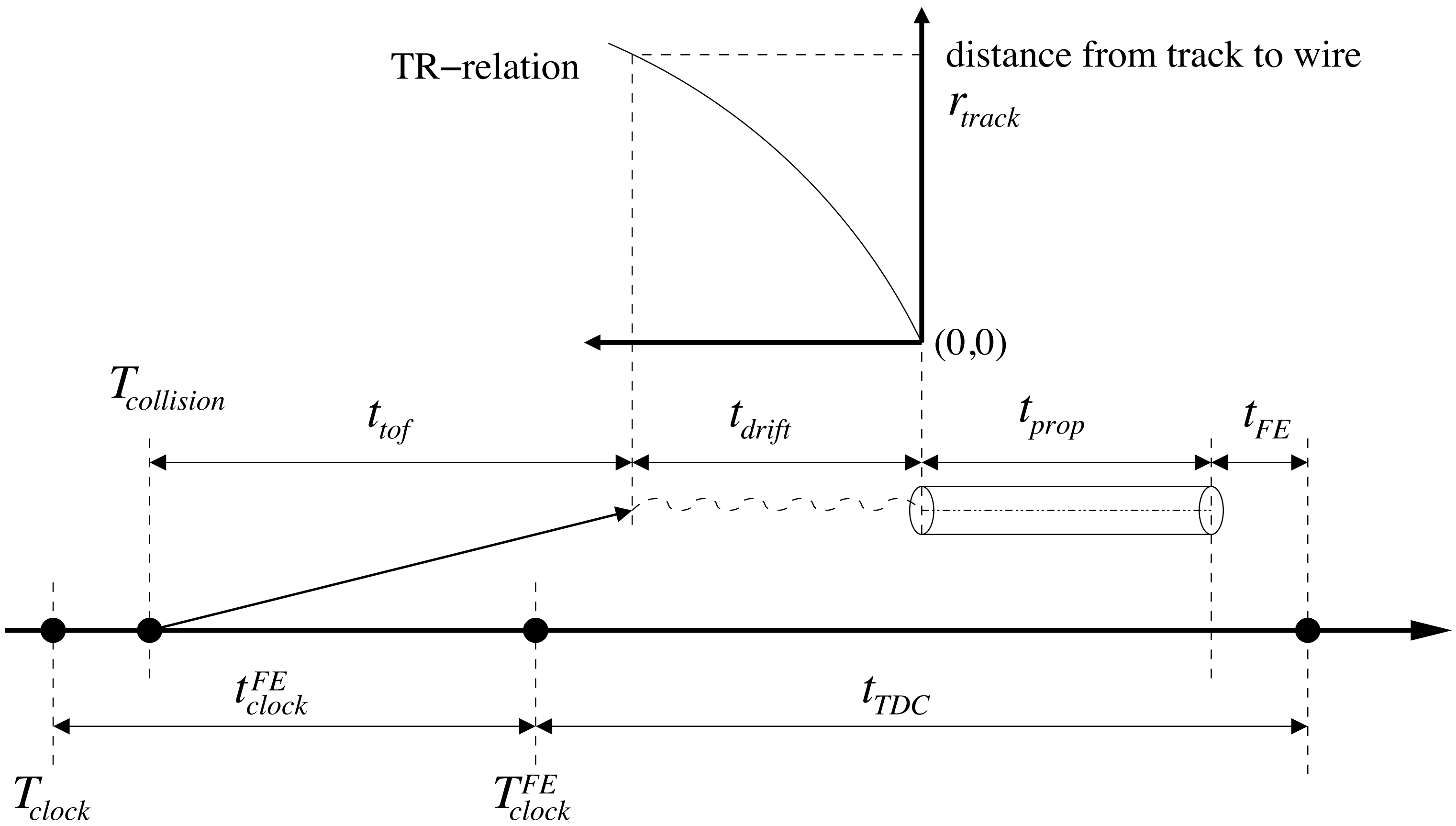
Future:

- LHC is running now and data for physics analysis in June 2017


BACK UP!

Distance drift time relation

The OT measures the arrival time with respect to LHC clock (T_{clock})



$T_{collision}$ the arrival time of the signal corresponds to the time of the pp collision

t_{tof} the time of flight of the particle

t_{drift} the drift time of the electrons in the straw

t_{prop} the propagation time of the signal along the wire to the readout electronics

t_{FE} the delay induced by the FE electronics

$$t_{\rm TDC} = (T_{\rm collision} - T^{\rm FE}_{\rm clock}) + t_{\rm tof} + t_{\rm drift} + t_{\rm prop} + t_{\rm FE}$$

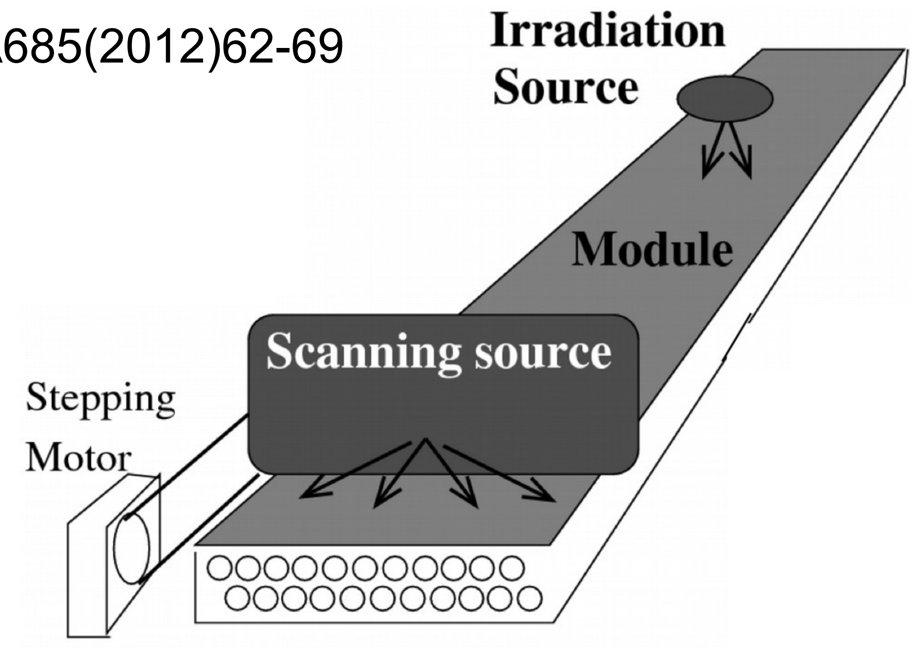
$$t_0 = t_{\rm FE} - t^{\rm FE}_{\rm clock}$$

$$t_{\rm clock} = T_{\rm collision} - T_{\rm clock}$$

$$t_{\rm TDC} = (T_{\rm collision} - T_{\rm clock}) + t_0 + t_{\rm tof} + t_{\rm drift} + t_{\rm prop}$$

Ageing – radiation tolerance

NIM A685(2012)62-69



- Using two ^{90}Sr source to measure gain
- Measure response to radioactive source for each straw channel for each position along Y
- Test at each technical stop of the LHC with irradiation source
- Short irradiation tests during technical stop
- No sign of aging within ±5%