Performance results of the LHCb Silicon Tracker detector at the LHC

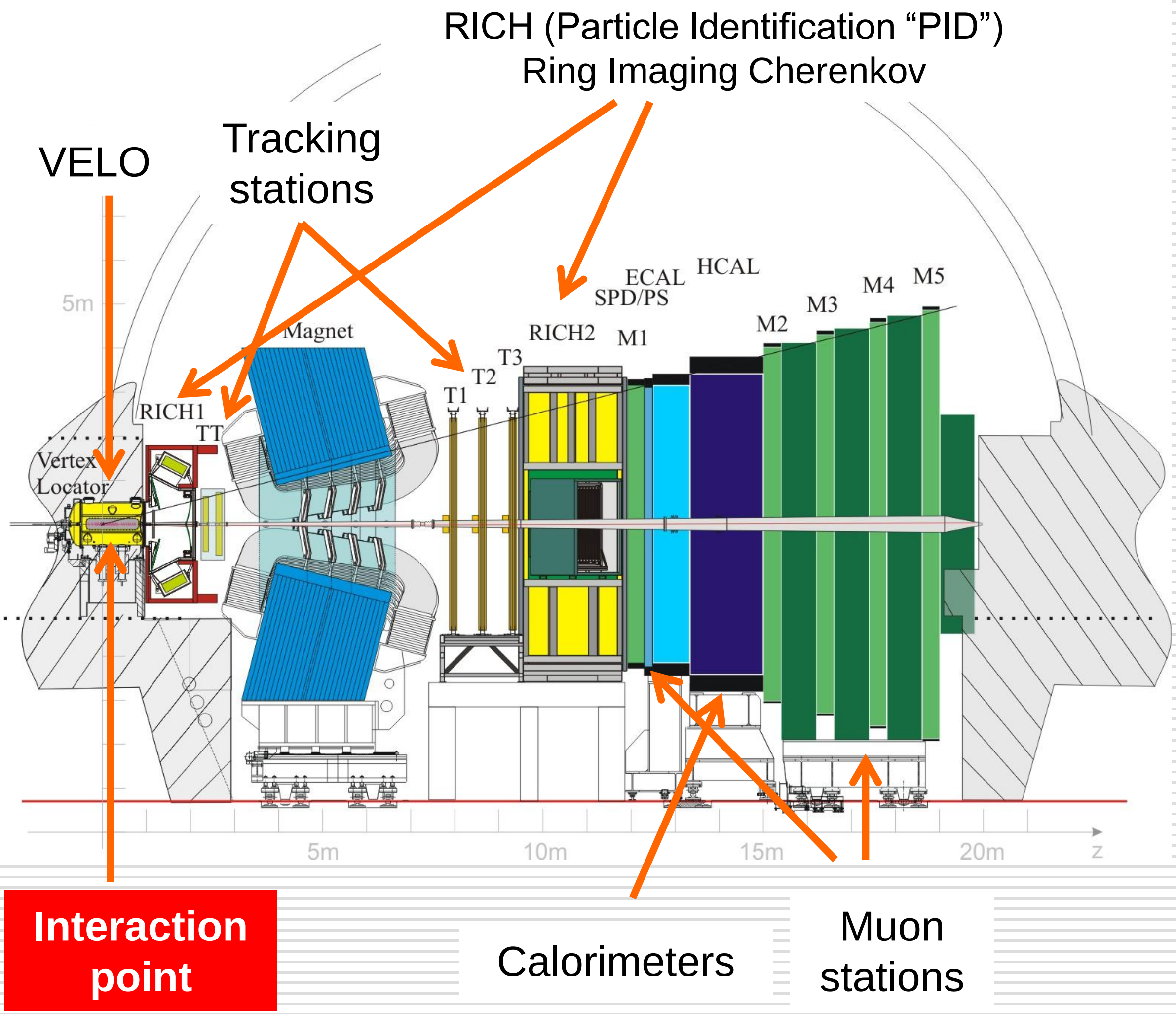
RD11 - 10th International Conference on Large Scale Applications and Radiation Hardness of Semiconductor Detectors, Firenze, Italia

Daniel Esperante on behalf of the LHCb Silicon Tracker Collaboration

Outline

- The Silicon Tracker project:
  - Consists of 2 subdetectors: the Inner Tracker (IT) and the Tracker Turicensis (TT)
  - A total of around 50 people has collaborated on it for all these years. Many are gone, some other are coming
- Contents:
  - Description of LHCb and the ST
  - Results about the detector performance: status, time and spatial alignment, resolution, S/N, efficiency, radiation damage and other results
  - Summary

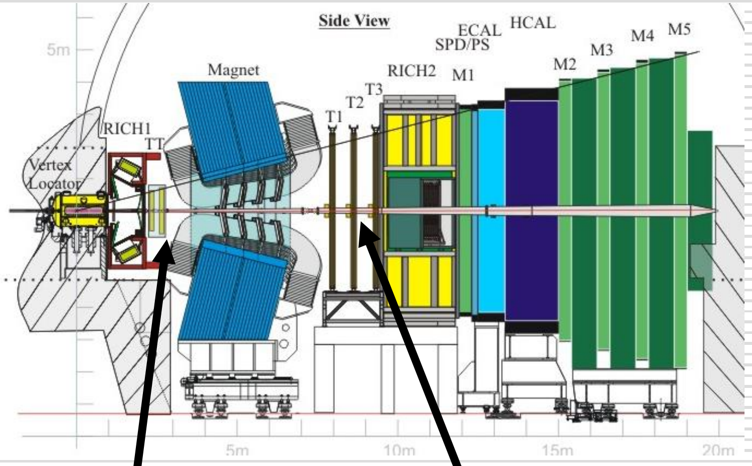
The LHCb experiment

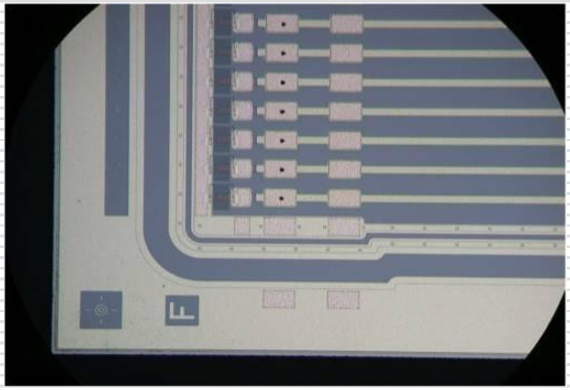


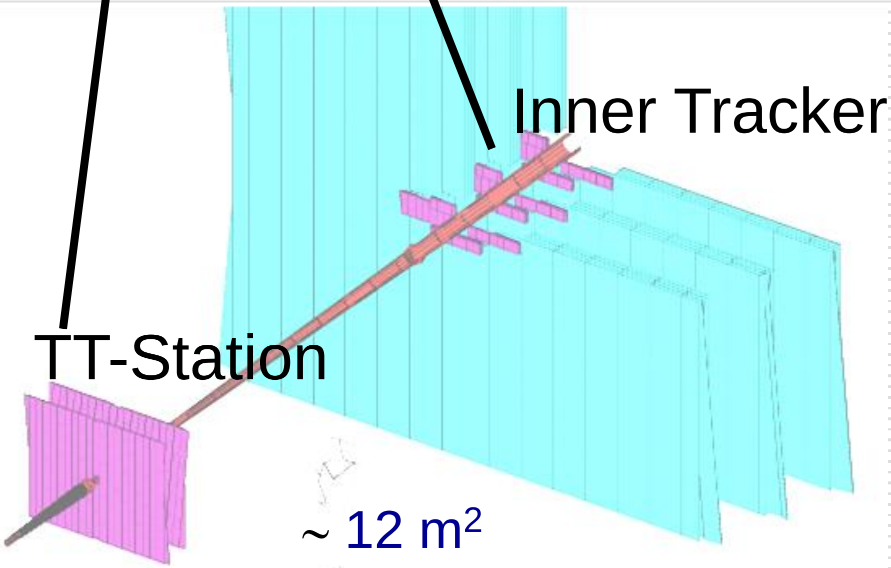
LHCb:

- Specialized B-Physics experiment:
  - Study B-meson decays/CP violation, NP
- Single arm forward spectrometer:
  - $b\bar{b}$ pairs are produced along the LHC beam axis
  - Acceptance:15-300(250) mrad
- Luminosity:
  - $2\cdot10^{32}$ cm^{-2}s^{-1} → 10^{12} $b\bar{b}$/year
- 1MHz readout rate

The LHCb Silicon Tracker







~ 12 m^2

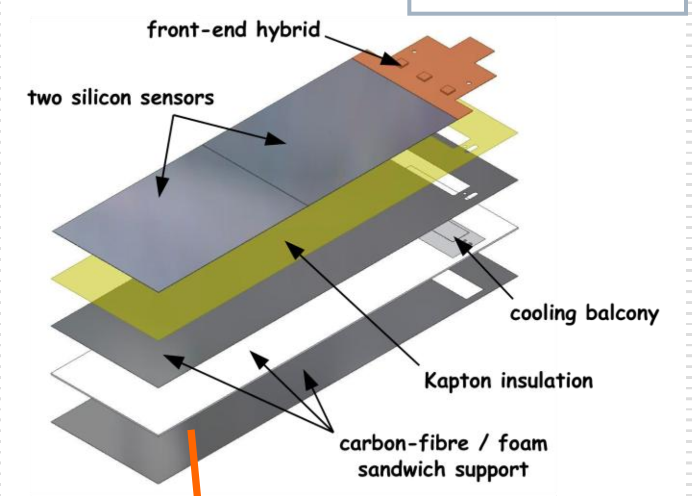
~ 272k RO channels

Silicon Sensors:

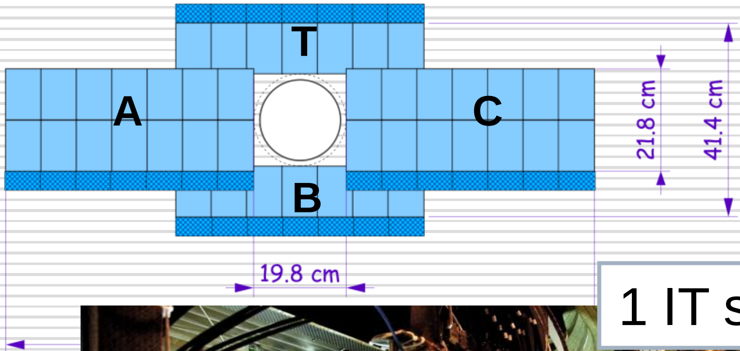
- p-n silicon strip sensors (HPK)
- 1-4 sensors bonded together → up to 37 cm long strips
- Radiation Dose:
  - IT: 5 x 10^{13} 1 MeV n/cm^2 eqv after 10 years
  - TT: 8 x 10^{13} 1 MeV n/cm^2 eqv after 10 years
- Operation @ ~ 0ºC

IT Layout

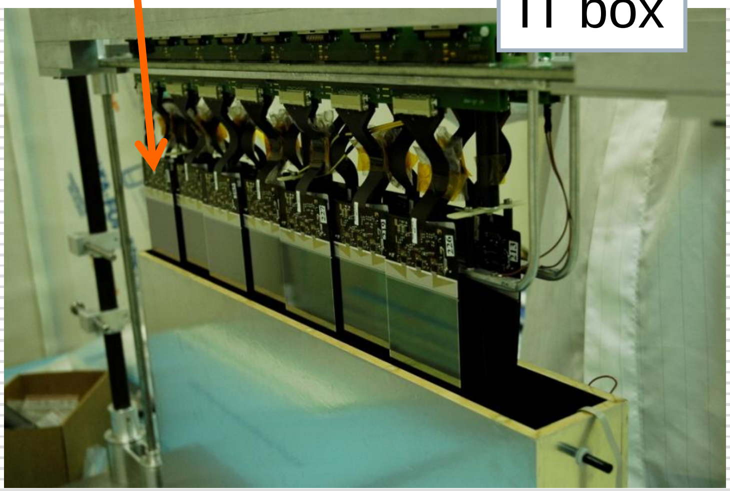
IT module



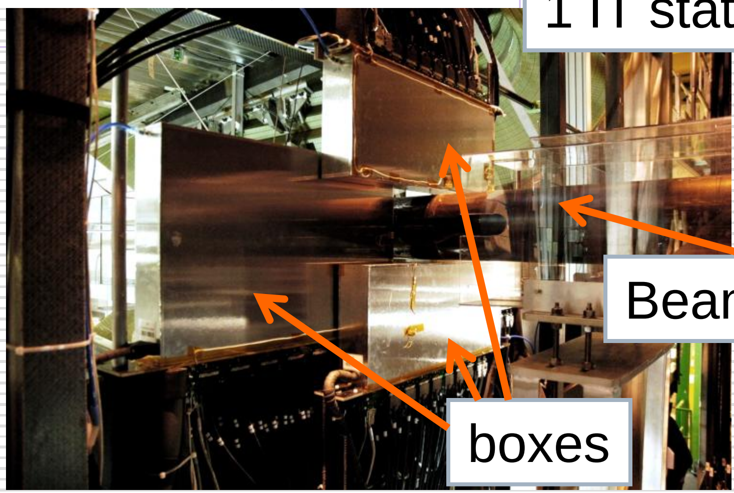
- 3 Stations with 4 Boxes
- Each box has 4 layers (0, +5º, -5º, 0)
- Thicknesses: 320 μm (1 sensor ladders), 410 μm (2 sensor ladders)
- 198 μm pitch, w/p = 0.25



IT box

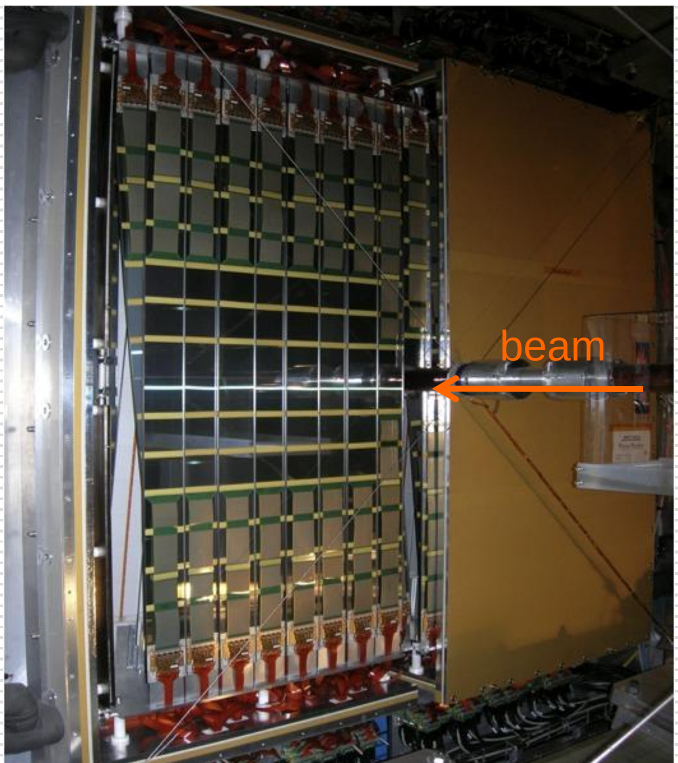


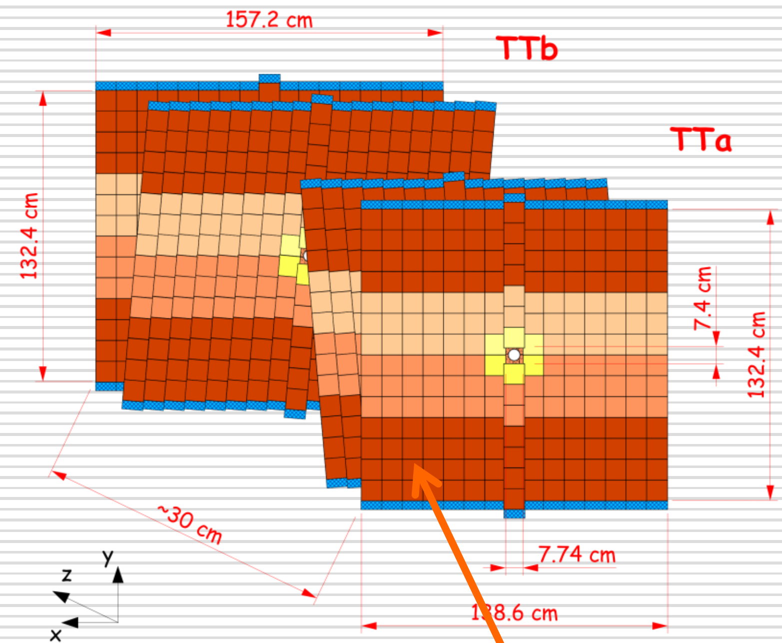
1 IT station

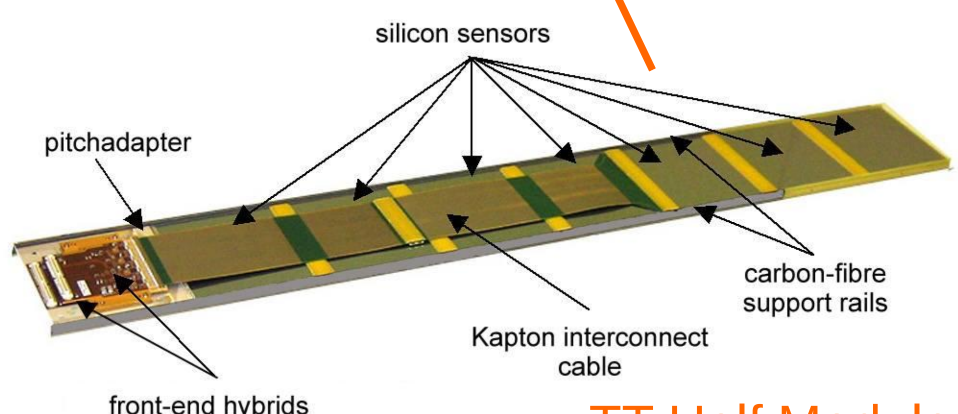


TT Layout

- 4 Layers (0, +5º, -5º, 0)
- 128 half-modules with 7 sensors
- 500 μm thickness
- 183 μm pitch, w/p = 0.25
- Sensor size: 96.4 x 94.4 mm



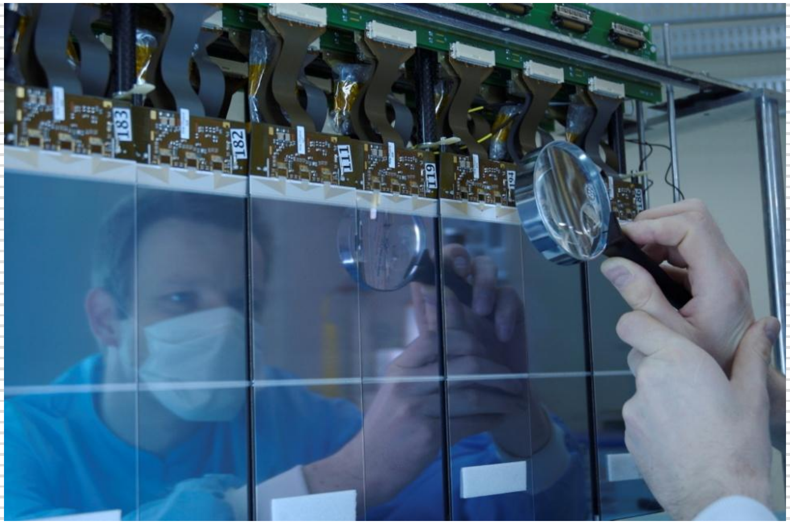


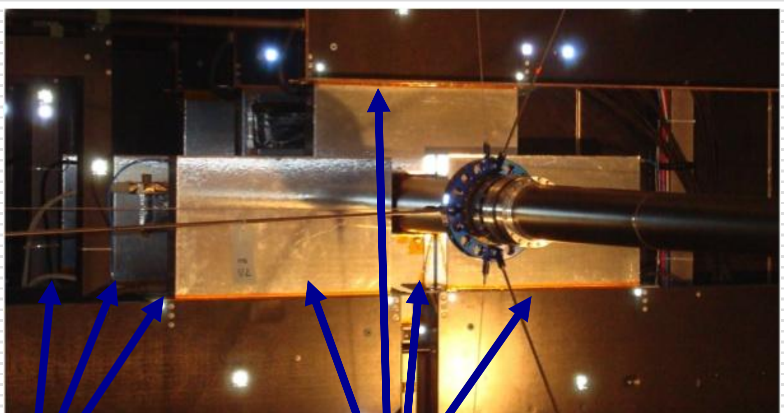


TT Half Module

Detector Installation

Inner Tracker



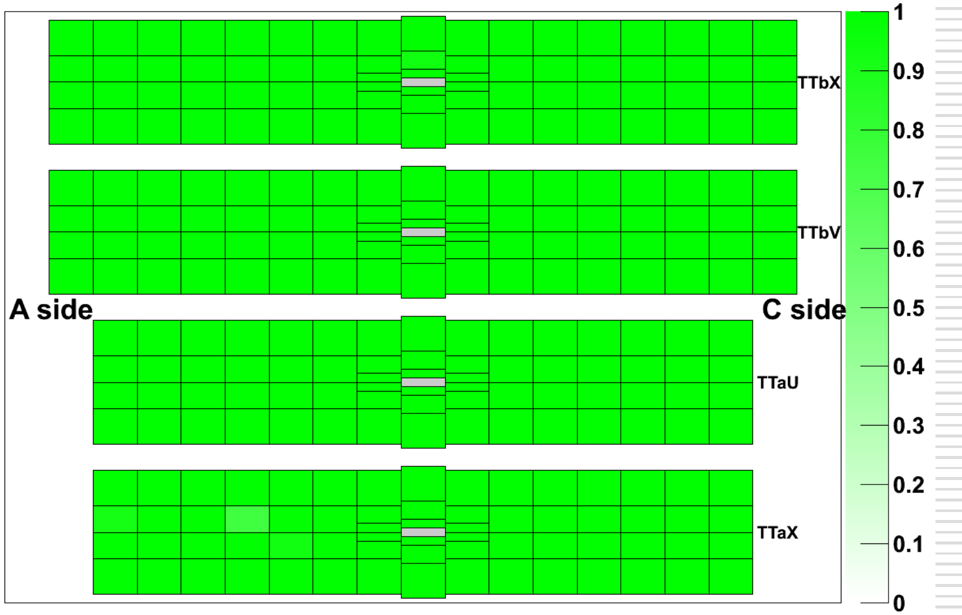


Tracker Turicensis

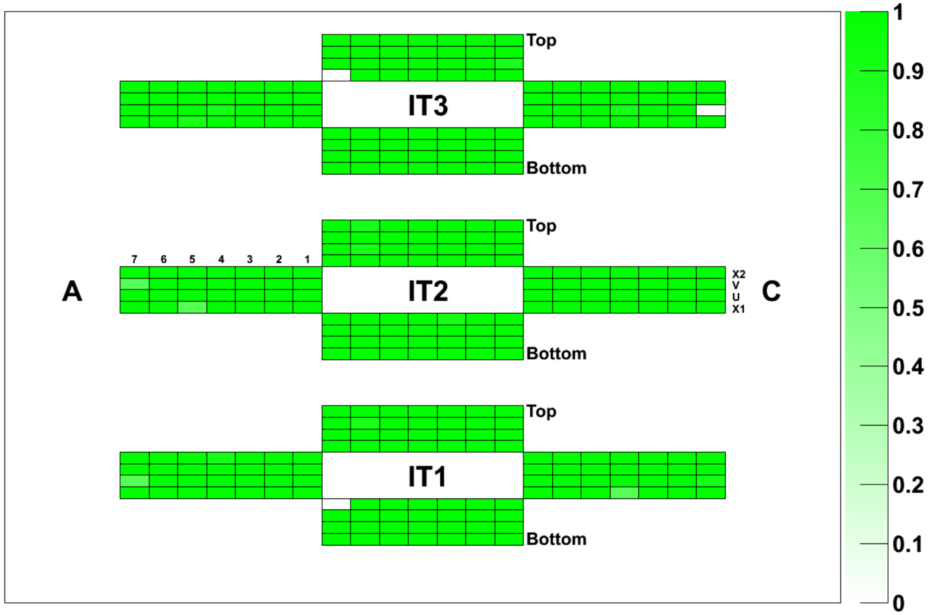
Detector status

Status by June 2011

Tracker Turicencis



Inner Tracker



99.7% working channels

- 2 ports disabled, 1 dead VCSEL, Digitizer board(s) to be replaced

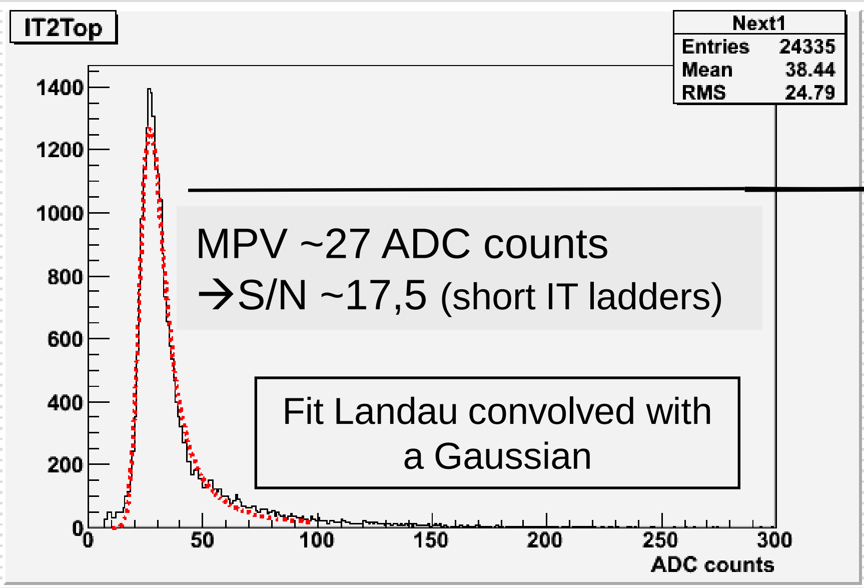
98.4% working channels

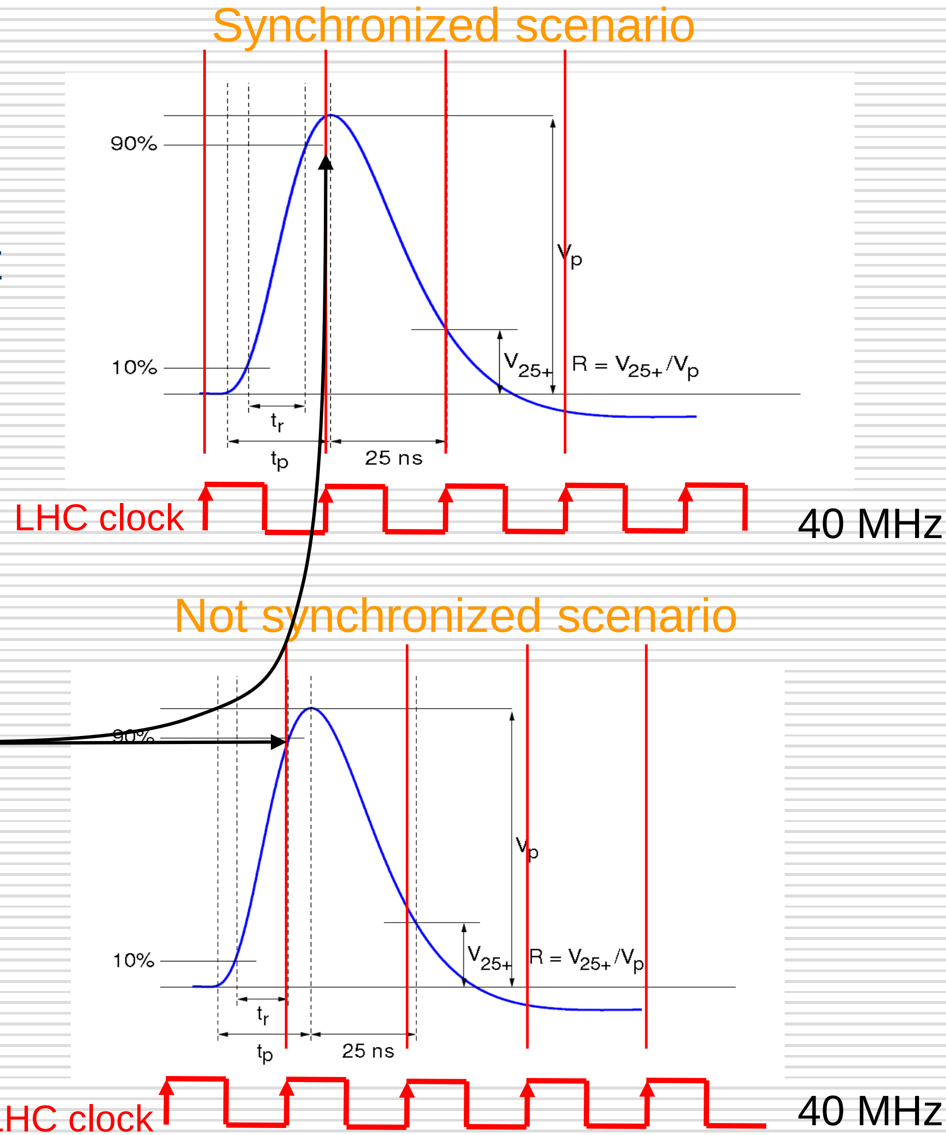
- 10 ports disabled, 2 modules are not configurable, 1 module with HV problem, 3 dead VCSELs

Noise cluster rate ~10^{-5} (with a S/N threshold of 5)

ST time alignment

- Signal sampling every 25 ns (40 MHz)
- Different cable lengths for different parts of the detector
- Different stations have different time of flight of particles
  - Need to adjust timing delays of individual detector elements
  - Timing delay scans (charge measurement vs clock delay)

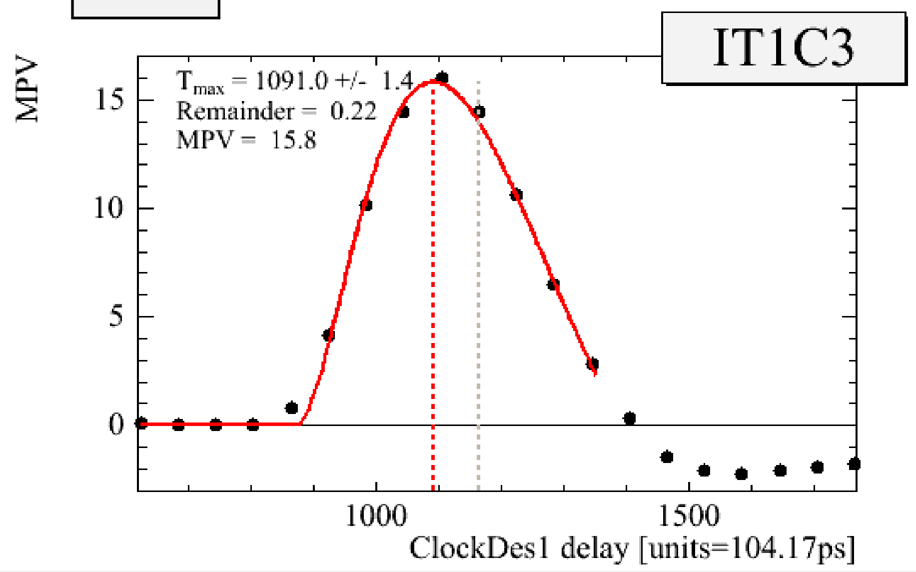




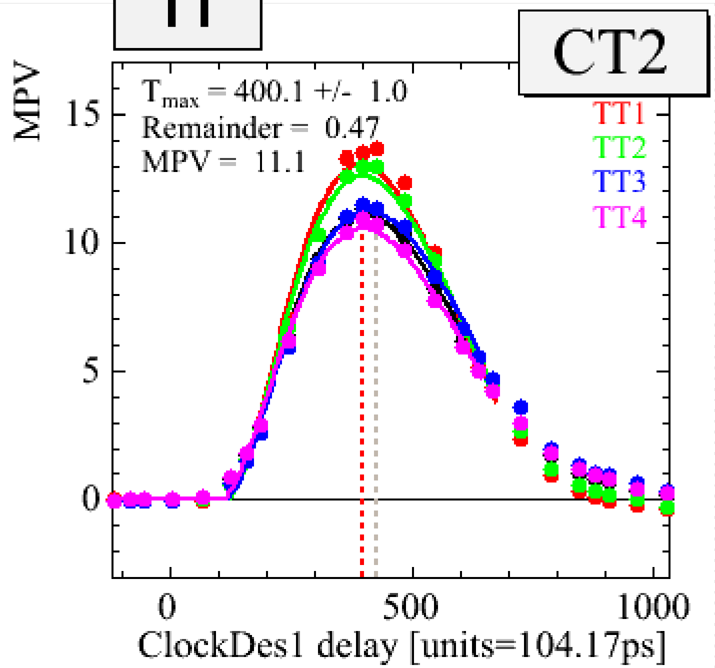
ST time alignment

- Time delay scans (collected charge vs sampling time)
- Sampling point tunable per Svce box

IT



TT

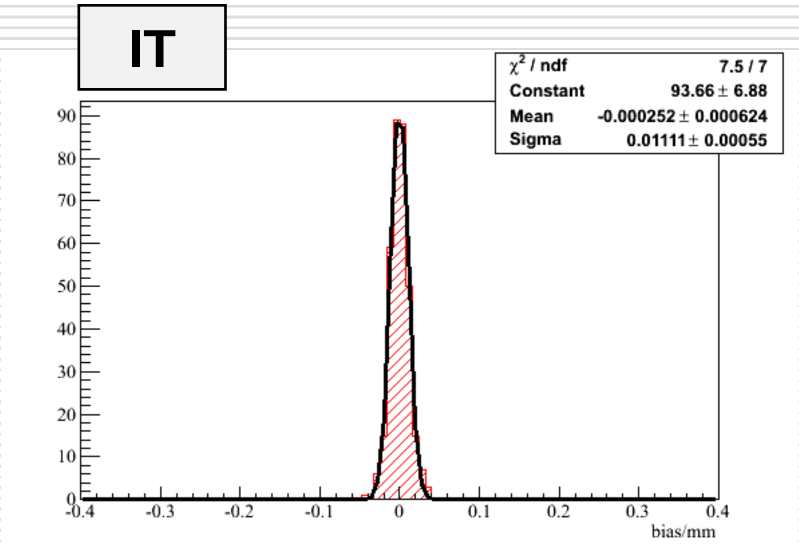


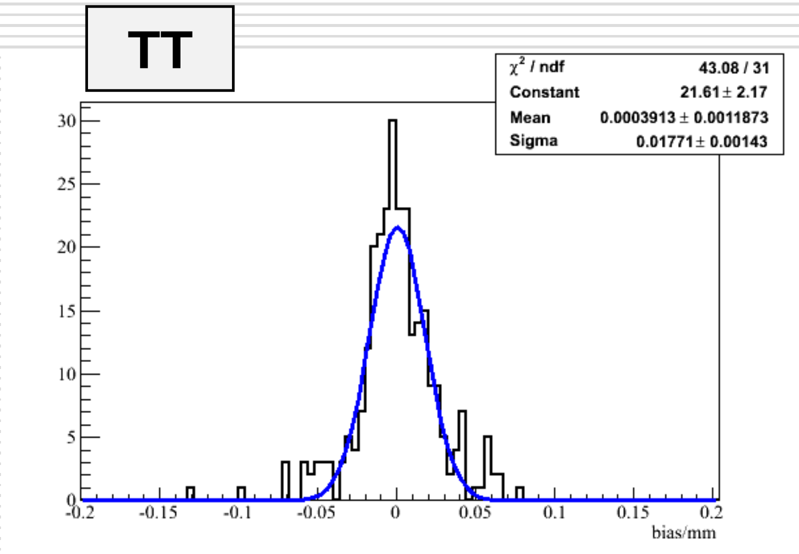
Detector internally time aligned with a resolution of ~1 ns

Spatial alignment

- Use “long tracks” (VeLo+T stations)
  - Additionally use standalone IT track reconstruction for IT alignment
- Global chi-2 minimization based on Kalman track fit residual (W. Hulsbergen, NIM A600, 471)
- Alignment precision evaluated by looking at the biases in the residual distributions for all sectors:
  - IT: ~11 µm
  - TT: ~18 µm

  - Work in progress, target 10 µm

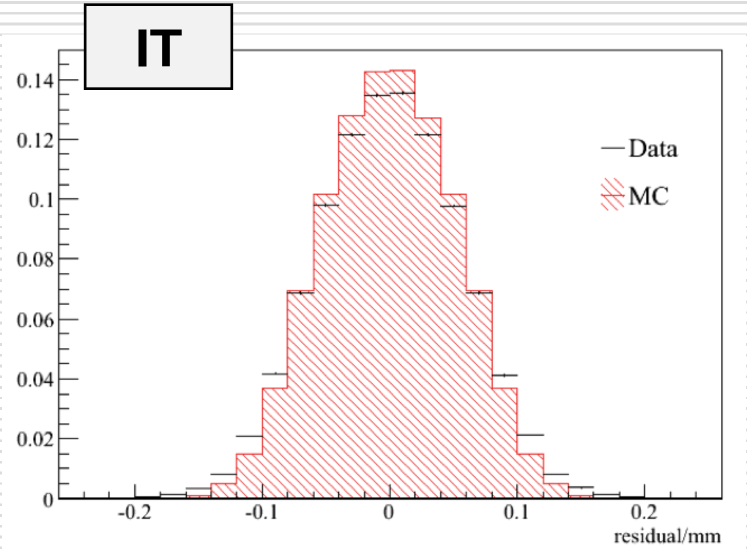


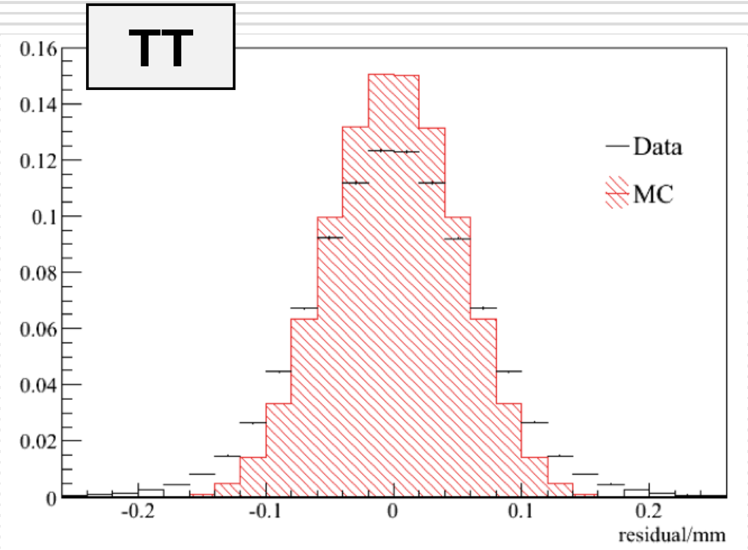


Hit resolution

- Hit resolution
  - IT : 58 µm, strip pitch 190 µm
  - TT : 62 µm, strip pitch 183 µm

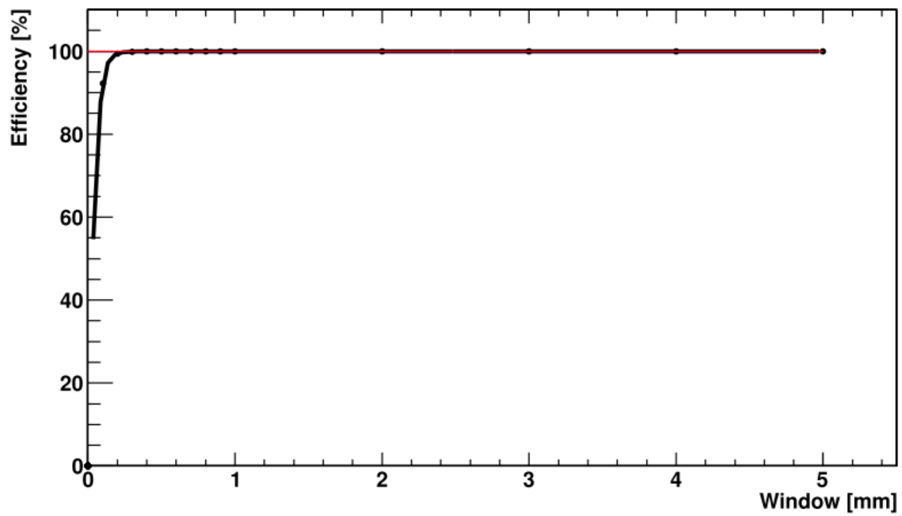
- The difference with respect to Monte Carlo due to:
  - Some difference in the gain
  - Status of the alignment



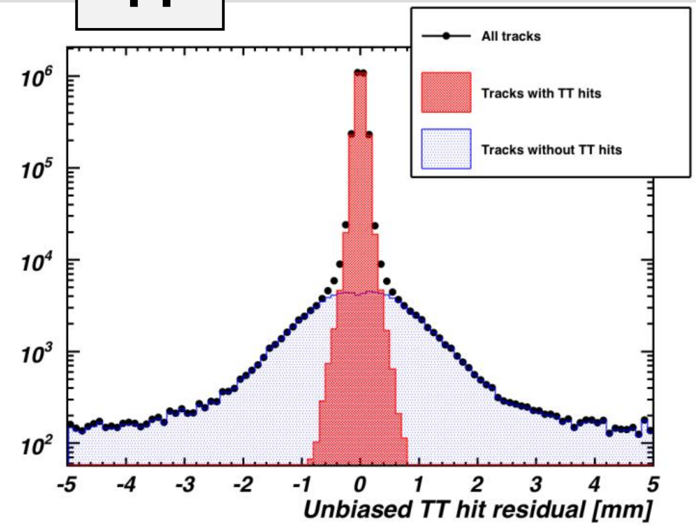


Hit efficiencies

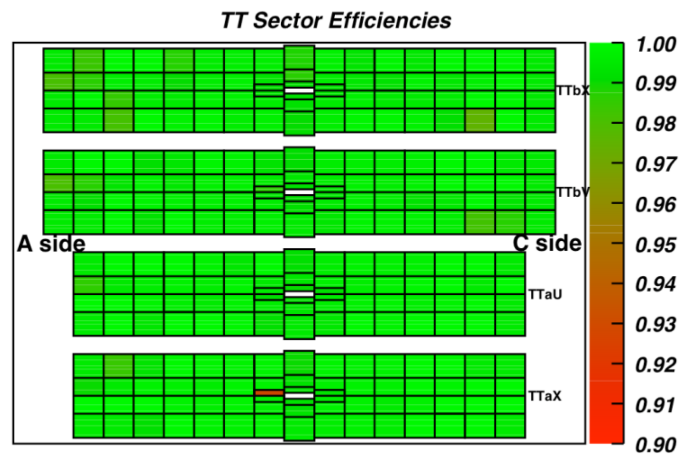
IT



TT

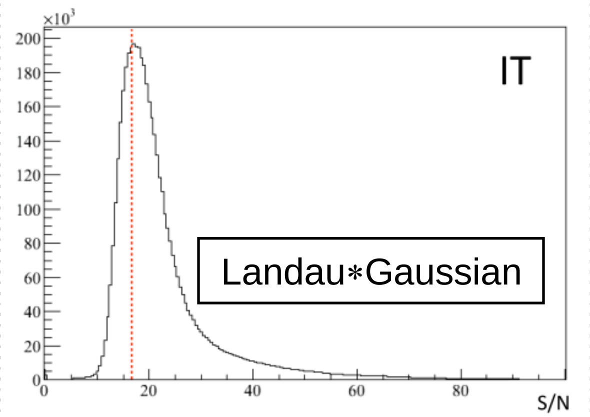


- Procedure:
  - Long tracks
  - High momentum, P > 10 GeV
  - Window around track (IT-1 mm, TT-2,5 mm)
    - TT hits are not required by the pattern recognition
  - Efficiency: (nr hits found)/(nr expected)
- Results:
  - IT: 99,7%
  - TT: 99,3%

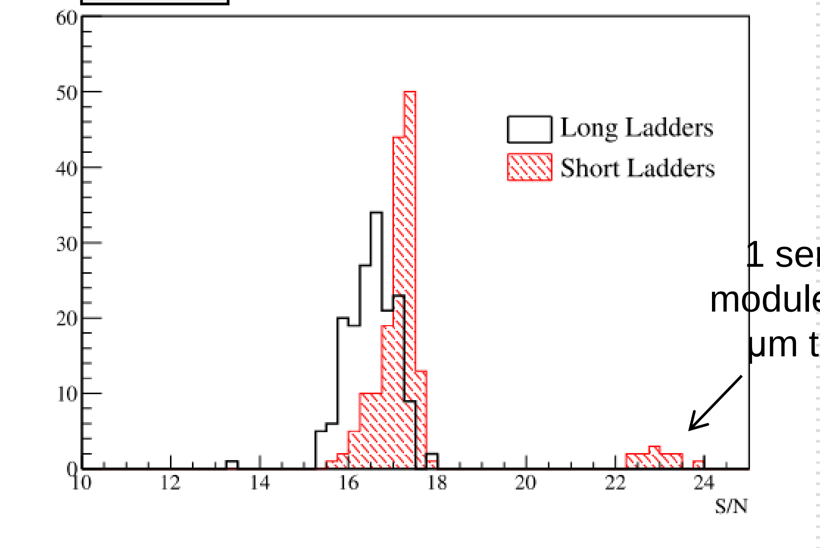


S/N performance

- Procedure:
  - Use clusters on reconstructed tracks (p > 5 GeV)
  - Fit a Landau convolved with a Gaussian and get MPV
- S/N results:
  - IT: 16,5 (long ladders) and 17,5 (short ladders)
  - TT: 12 - 15

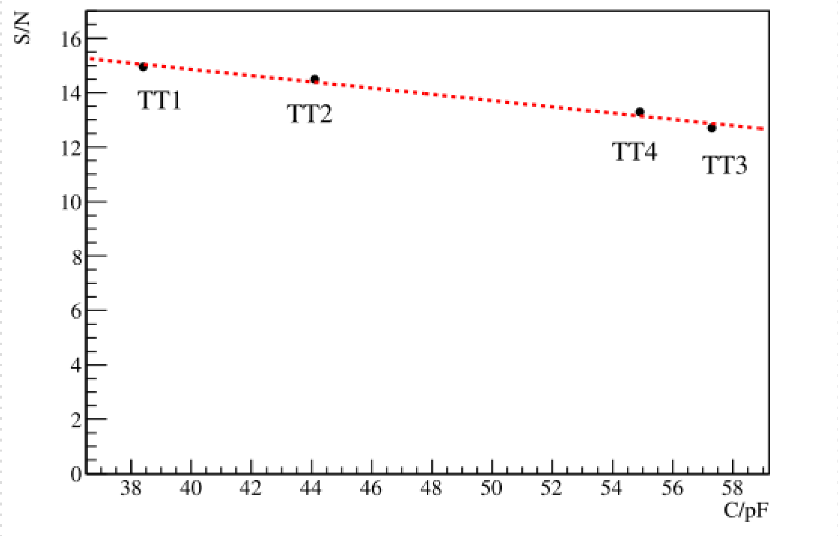


IT

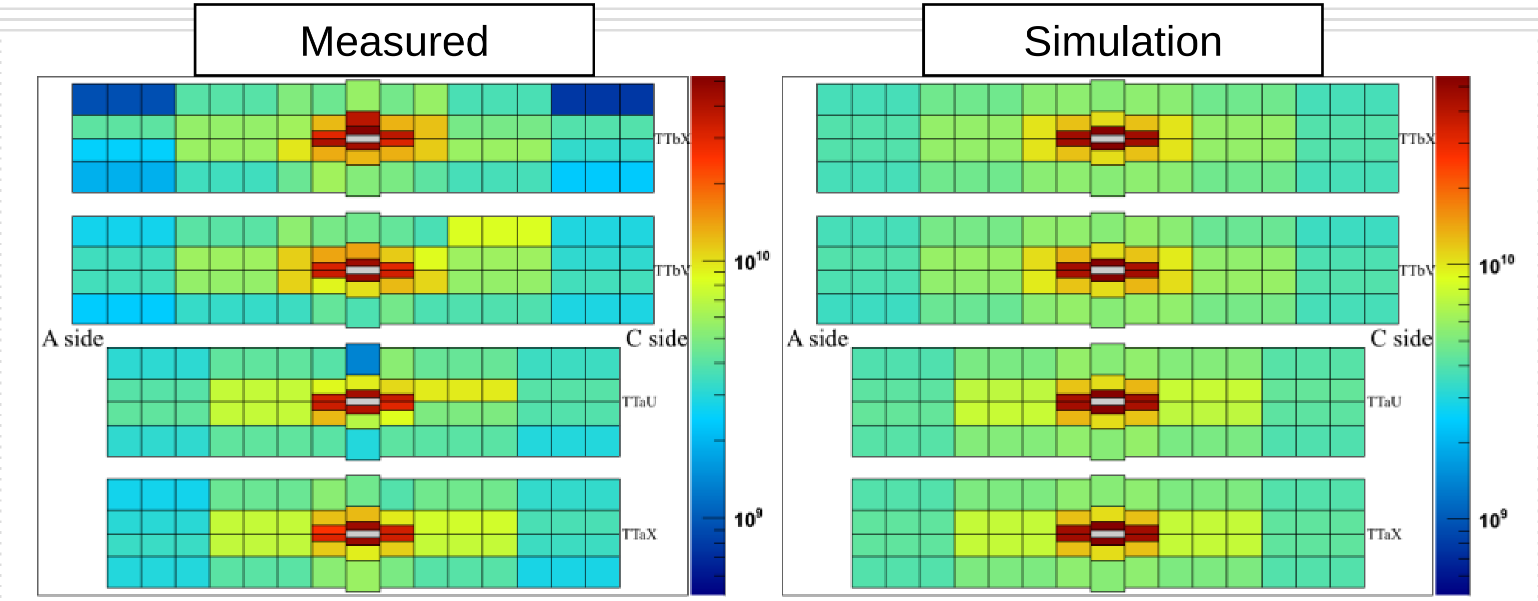


1 sensor modules 410 µm thick

TT

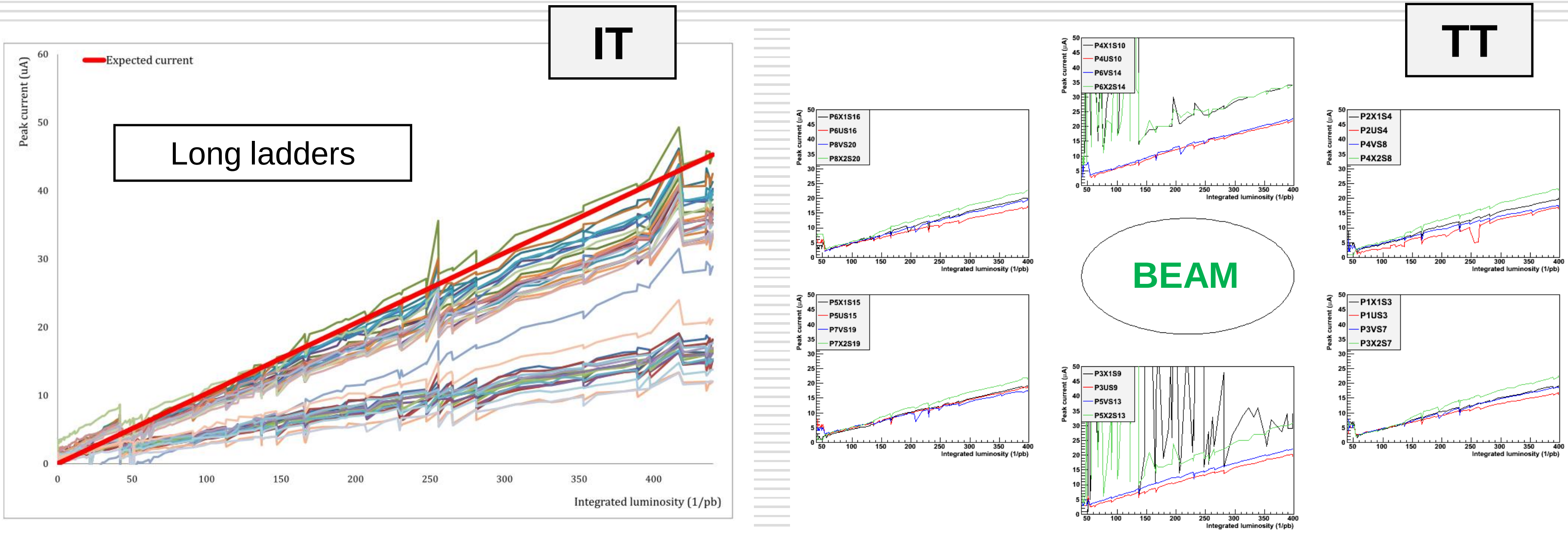


Radiation damage (preliminary)



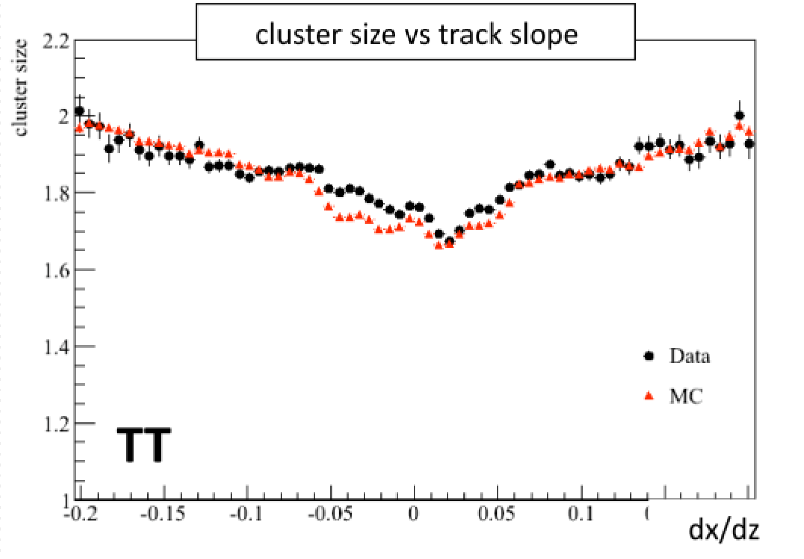
- 1 MeV-neutron equivalent radiation dose (log scale):
  - Left plot is our estimated 1 MeV equivalent
  - Right one is simulation in Fluka
- Method: monitor the radiation damages using the leakage current:
  - The damages are in agreement with predictions (next slide)
- Another method is to study the charge collection efficiency (ongoing)

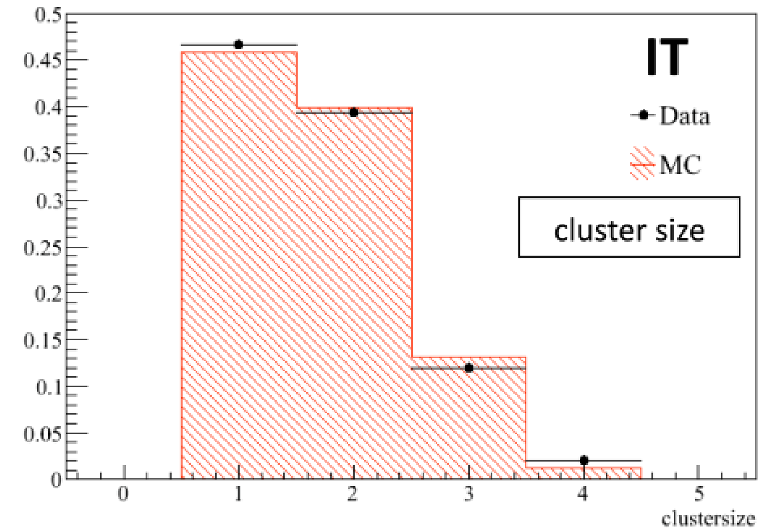
Radiation damage (preliminary)

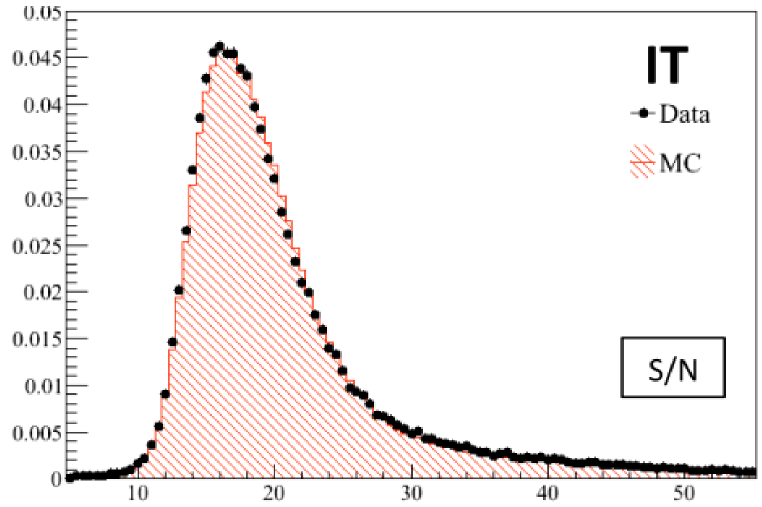


- According to the measured leakage current the damages are in agreement with "our" predictions:
  - ΔI(HV-partition)<800 μA
    - for Integrated lumi = 20 fb-1
  - Long ladder 22x8x0.041 cm3 (Boxes A,C)
    - ΔI (@10˚ C) = 0.141[μA*pb-1] * Integrated lumi [pb-1]
  - Short ladder 11x8x0.032 cm3 (Boxes T,B)
    - ΔI (@10˚ C) = 0.055[μA*pb-1] * Integrated lumi [pb-1]

Other agreements with MC







- Many effects measured:
  - Charge collection
  - Capacitive coupling
  - Gain
  - Radiation damage
- In good agreement with expectations/simulations

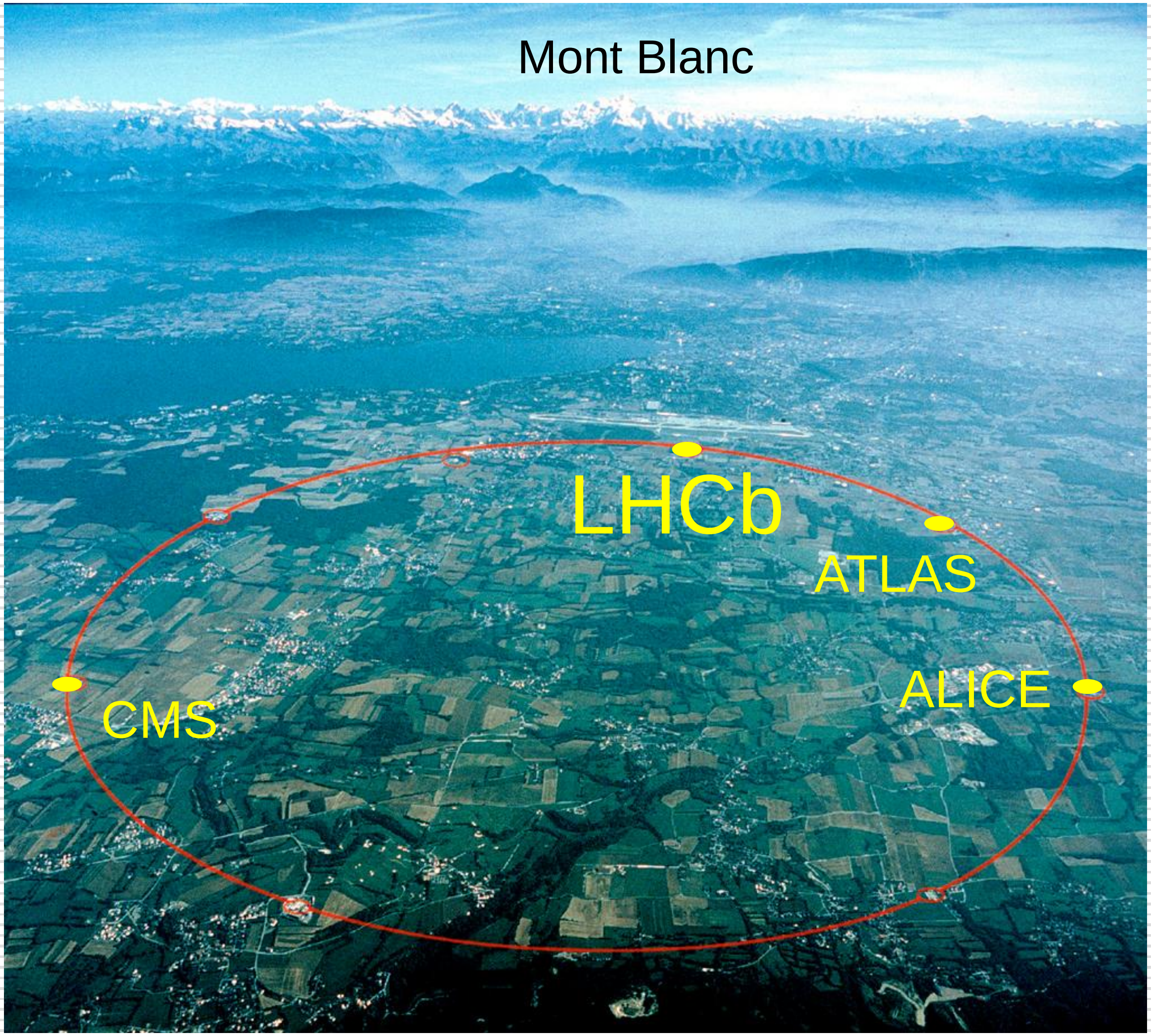
Summary

- The LHCb Silicon Tracker is a silicon strip detector for the high density particle region near the LHC beam pipe behind and in front of the bending magnet
- At the moment ~99% of the detector is fully operational
- Working within the expectations:
  - Time alignment good to 1 ns
  - Internal and global alignment: 17.7 μm (TT) and 11.1 μm (IT)
  - Hit efficiency using tracks determined to be 99.3 % (TT) and 99.7 % (IT)
  - Radiation damages compatible with predictions

The LHCb Silicon Tracker is performing well

Back-up slides

Introduction



LHC:

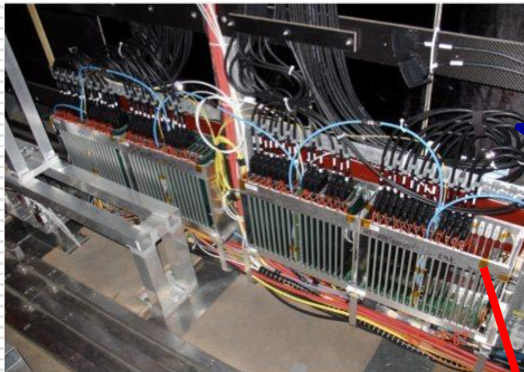
- 27 Km long
- pp@14 TeV
- 40 MHz pp collisions
- 4 major experiments at CERN:
  - ATLAS
  - ALICE
  - CMS
  - **LHCb**

Silicon Tracker requirements

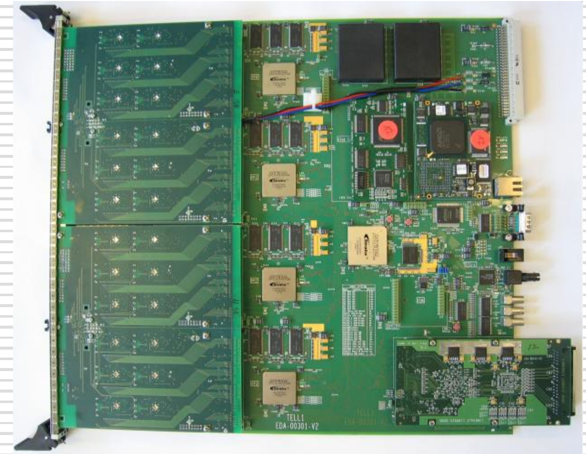
- ***Spatial resolution:*** simulation studies → **single-hit resolution of 50 µm** for IT and TT. Readout strip pitches of about 200 µm meet this requirement
- ***Hit occupancy*:** high particle densities close to the beam pipe → use different readout strip lengths to keep strip **occupancies at the level of a few percent**
- ***Signal shaping time:*** fast front-end amplifiers with a **shaping time of 25 ns** to avoid pile-up of events. Simulation studies → remainders @ 25 ns below 50% for the TT and 30% for the IT are acceptable for the track reconstruction
- ***The hit efficiency:*** test beam → hit efficiency decreases rapidly as the S/N ratio drops below 10:1. Detector designed such that a **S/N ratio in excess of 12:1**
- ***Radiation damage:*** silicon sensors designed to survive the lifetime of the experiment such that shot noise does not significantly deteriorate the S/N and the risk of thermal runaway due to leakage currents is avoided
- ***Material budget:*** the momentum resolution dominated by multiple scattering → keep material budget as small as possible. **TT** → FE electronics and mechanical supports outside of the LHCb acceptance. **IT (**located in active region of the OT) → significant design effort to keep the amount of material for mechanical supports and for the cooling of FE electronics as small as possible
- ***Number of channels*:** try to **reduce the overall cost** of the detector

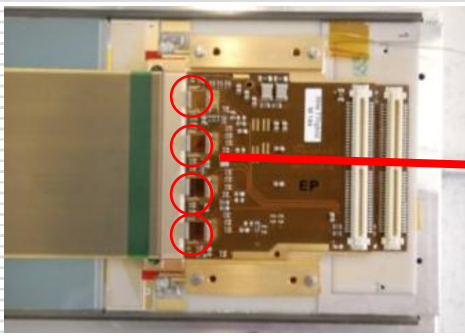
Read-out Electronics

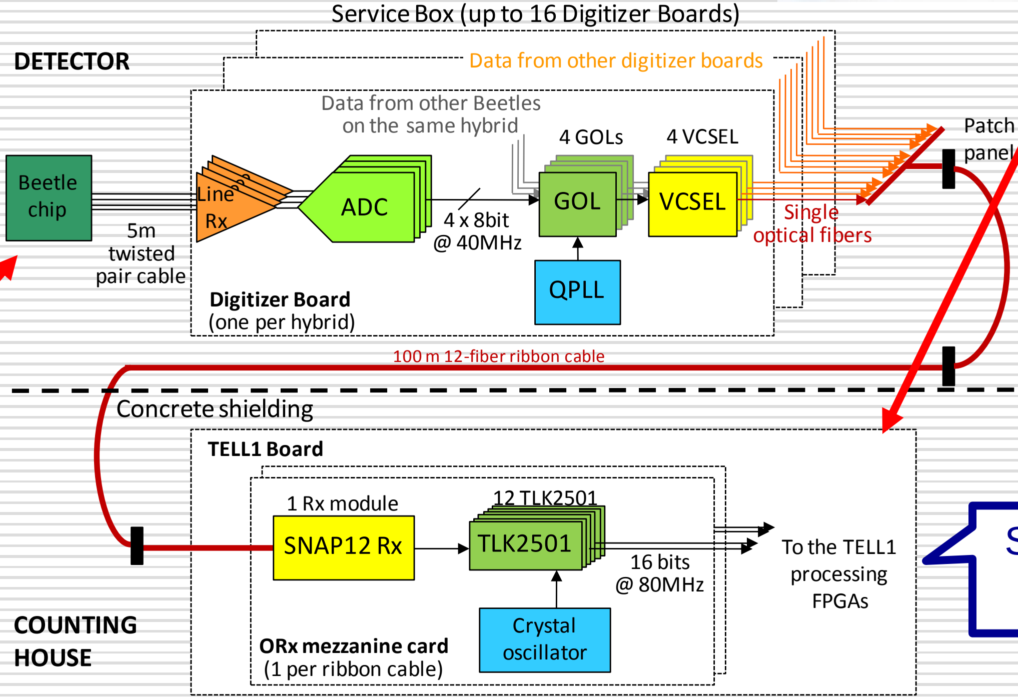
In detector
< 1 Mrad in
10yrs

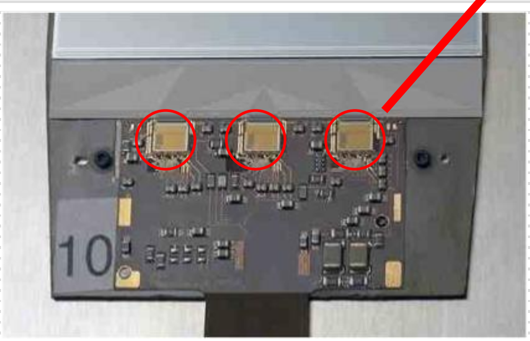


near
detector
~ 15krad
in 10 yrs





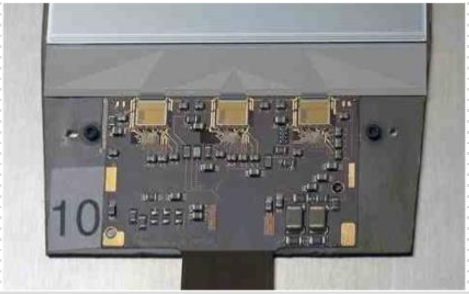




Safe environment
counting house

Read-out Electronics

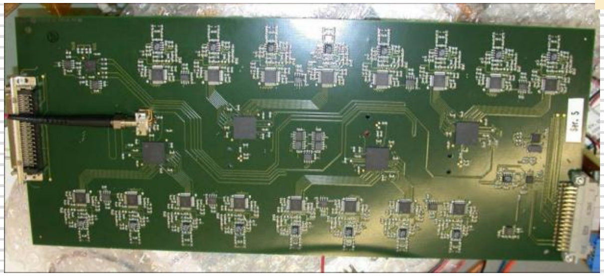
Hybrid



- 3 (4) Beetle readout chips IT(TT)
- 40 MHz, 128 channels multiplexed onto 4 output ports
- 1.1 MHz evt readout (analogue)
- Pipelined 160 bunch crossings

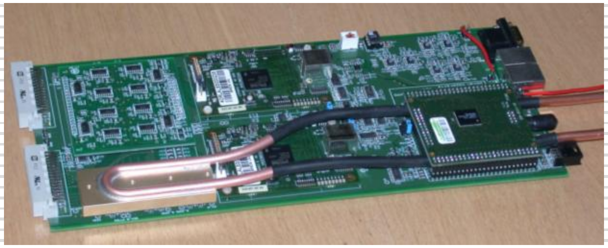
Service Box

Digitizer Board



- Beetle data digitization and optical transmission to TELL1

Control Board

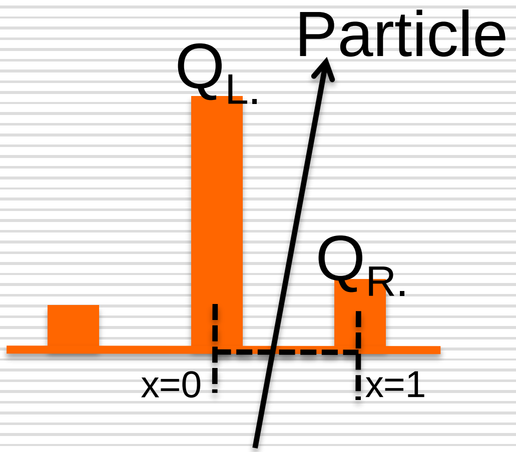


- Fast and slow control

TELL1

- Data deserialization, synchronization, real-time processing (pedestal and CM substr., and zero suppression) and data packaging

Intrinsic Charge Sharing

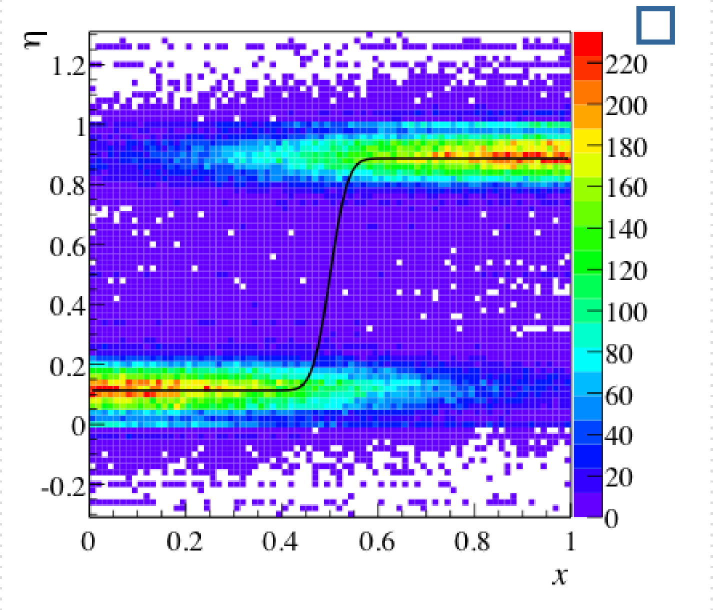


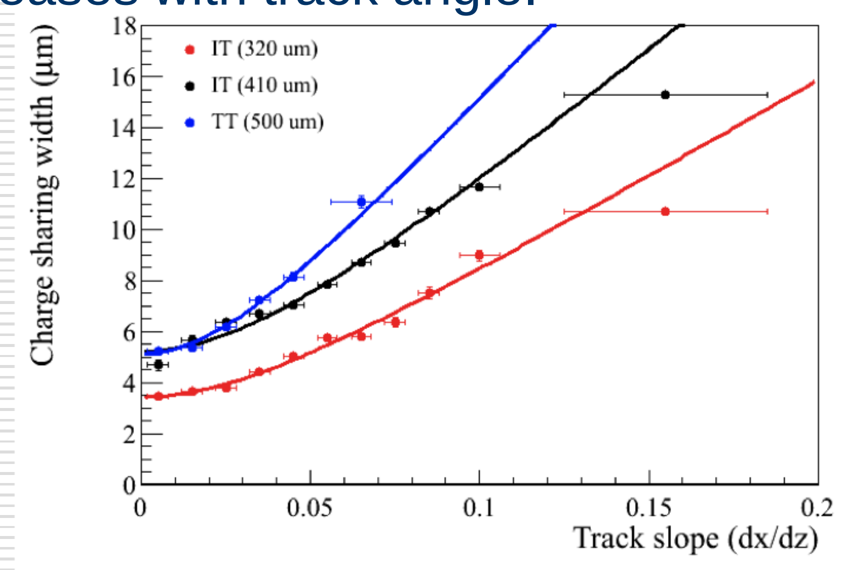
Method:

- Calculate cluster centre-of-gravity, η.
- Plot vs fractional position of track, x.
- Fit error function.
  - Sigma gives charge sharing width

Results:

- Width: 3.5 to 5.0 μm.
  - Expected 11 to 35 μm from previous measurements.
- Increases with track angle.





Leakage current and radiation flux

$$I(20^\circ\mathrm{C}) = \alpha \cdot \Phi \cdot V$$

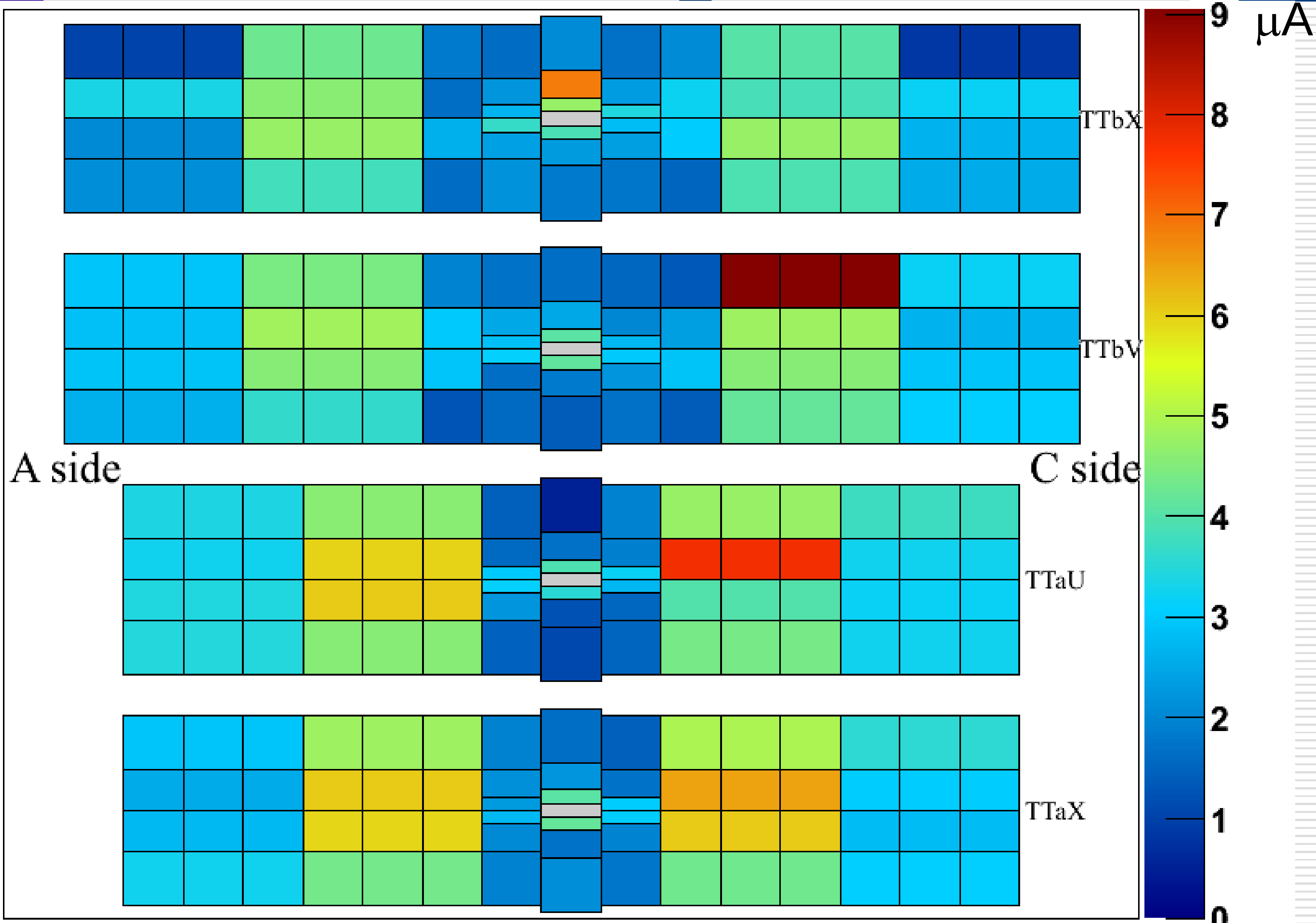
Flux (Φ)

Volume of the sensor(s) (V)

- For 1 MeV neutrons: $\alpha = 4 \times 10^{-17}\ \mathrm{A/(particle \cdot cm)}$
  - Taken from Frank's radiation note (LHCb-2004-070).
- Current doubles every 7 degrees of temperature increase.
  - Measured ambient temperature in TT box ~ 13 degrees.
  - Gives a factor 0.5 compared to 20° C.

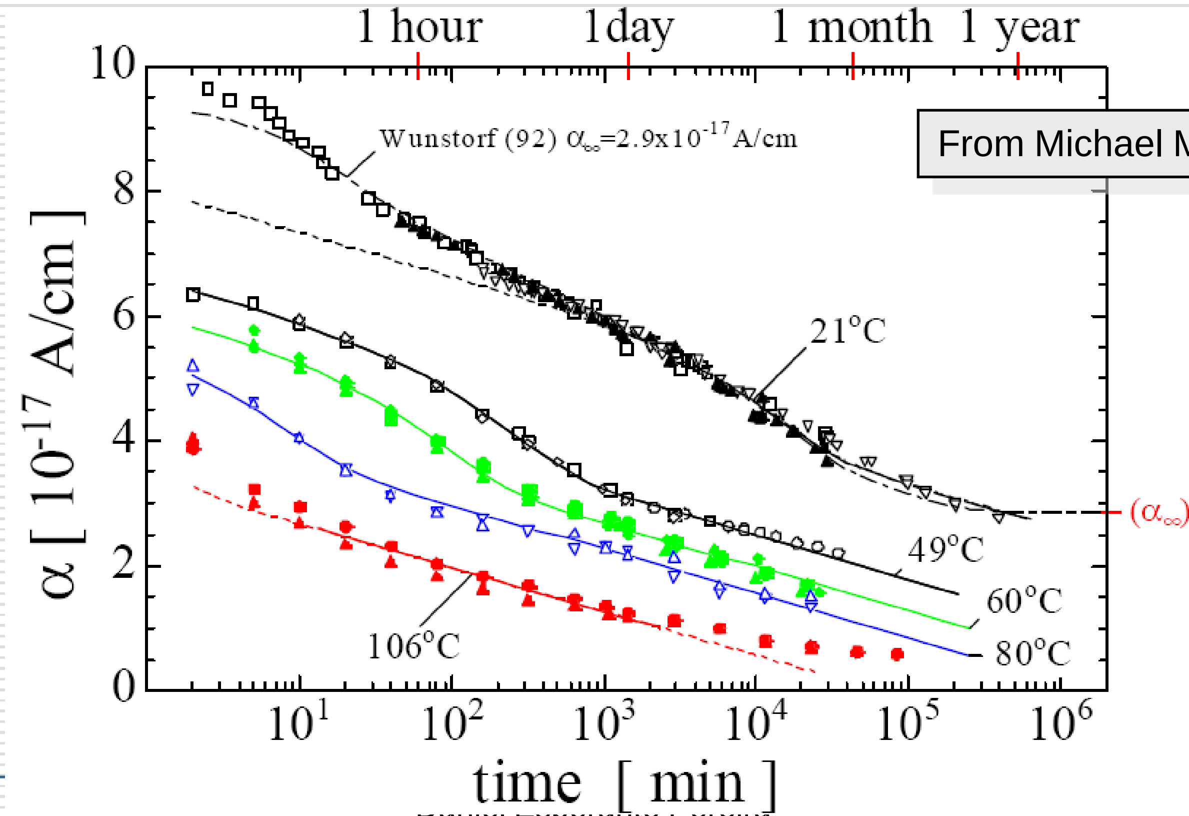
- Leakage currents retrieved from archived PVSS data points
- Used only time intervals when HV was on (300 or 350 V).

Increase in leakage current



What is alpha?

- PDG quotes a value of 3×10^{-17} for 1 MeV neutrons.
  - This is the number for after long annealing (>1 year) at room temperature.
- At 13 degrees assume some continuous annealing.
- Alpha of 4×10^{-17} does not seem to be a bad choice.
  - Maybe a bit low, hence measured flux might be overestimated (conservative).
- Ideally measure the leakage current at 20° C after 2 weeks c
  - Value



Hit efficiencies