ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Commissioning of the LHCb Silicon Tracker with the LHC injection tests

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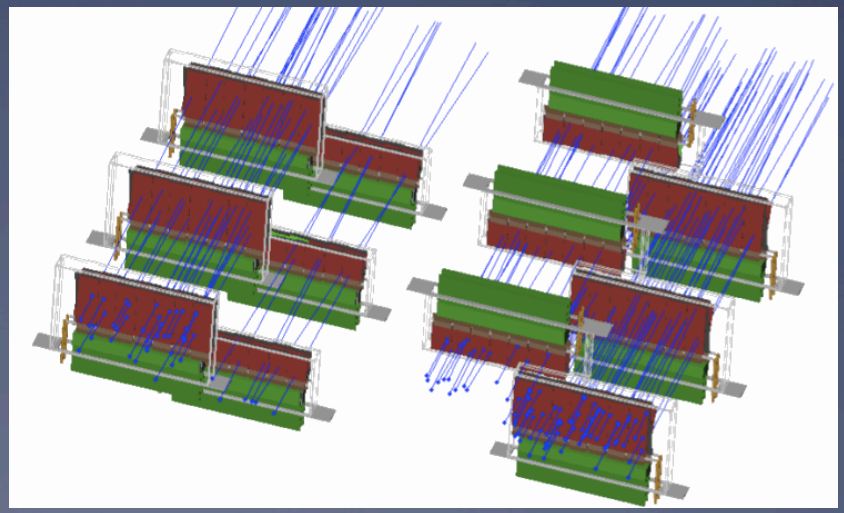

REAL DATA!

Outline

- The LHCb detector
  - The Silicon Tracker project
    - Inner Tracker
    - Tracker Turicensis
    - Status
- The LHC injection tests
- Time alignment
- Spatial alignment
- Summary

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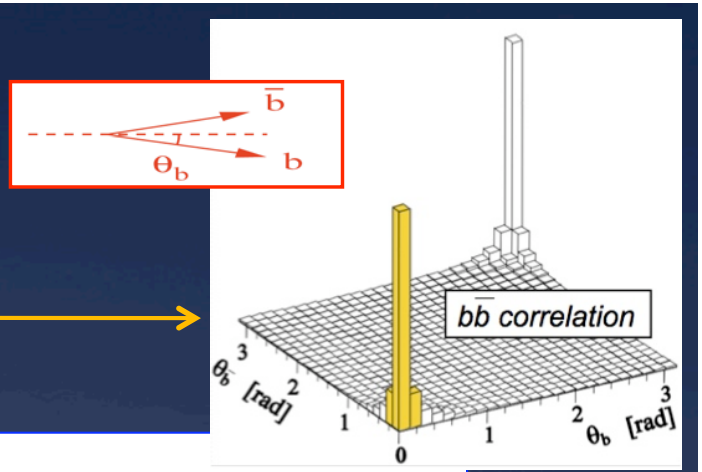
The LHCb detector

- Single-arm forward spectrometer dedicated to the study of *CP* violation and rare decays in the *b*-quark sector
- Peaked *b*-quark production at high η
- ~100 tracks/pp interaction, ~30 long tracks



RICH (Particle Identification « PID »)
Ring Imaging CHerenkov

Tracking stations

muon stations

Vertex Locator (VeLo)

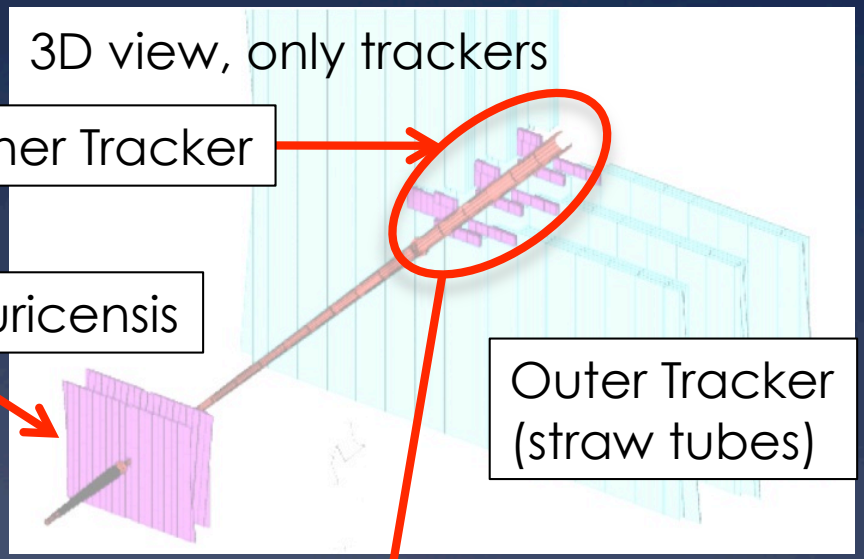
tracks

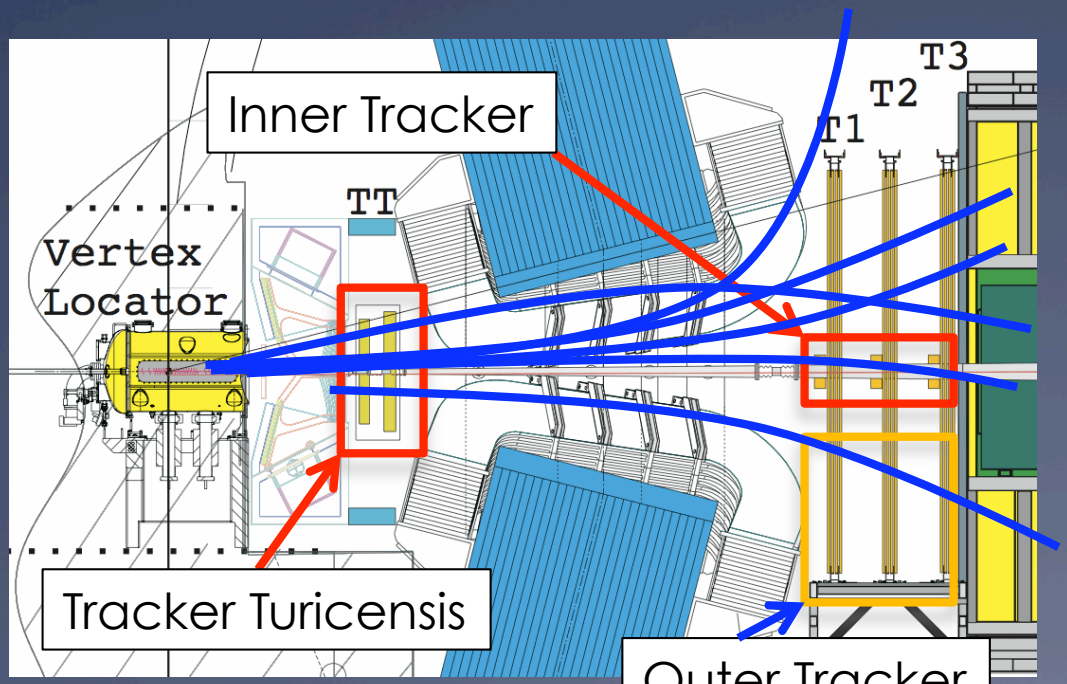
pp interaction

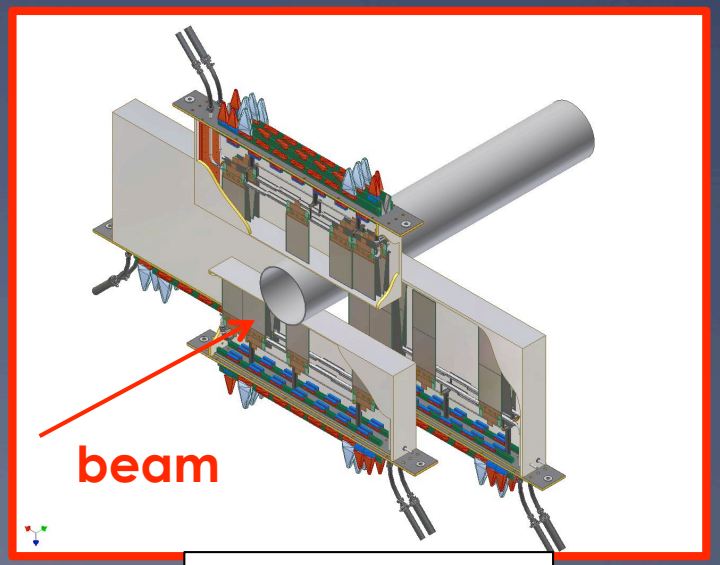
calorimeters

The Silicon Tracker Project

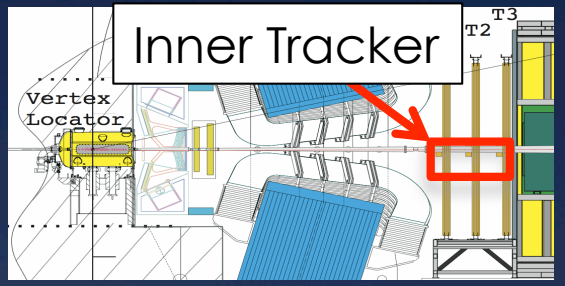
- Consists of:
  - Inner Tracker
  - Tracker Turicensis (« Turicum » means Zurich ...)
- Silicon microstrip technology
- In total 272'000 readout channels, covering an area of ~12m^2





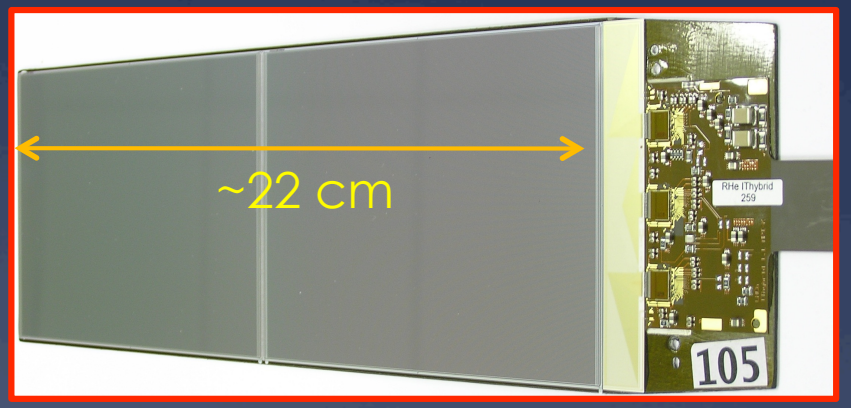


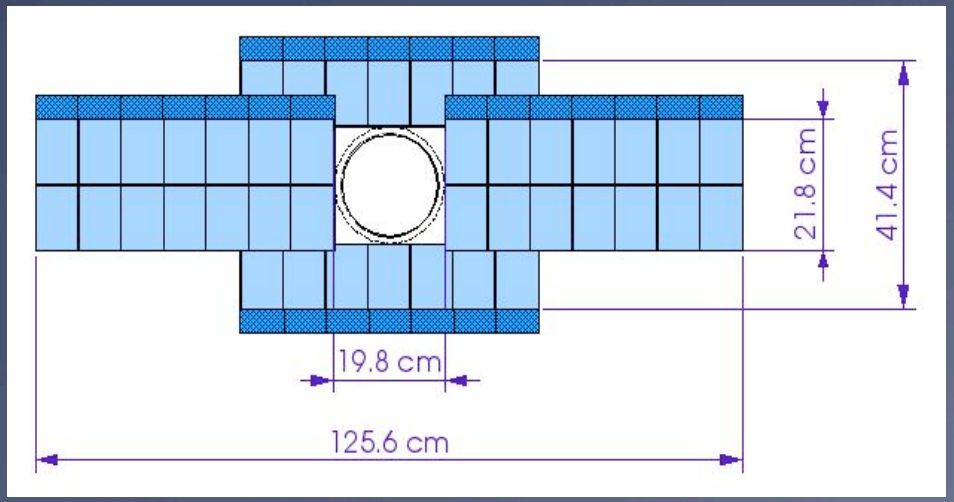
The Silicon Tracker Project
1: The Inner Tracker

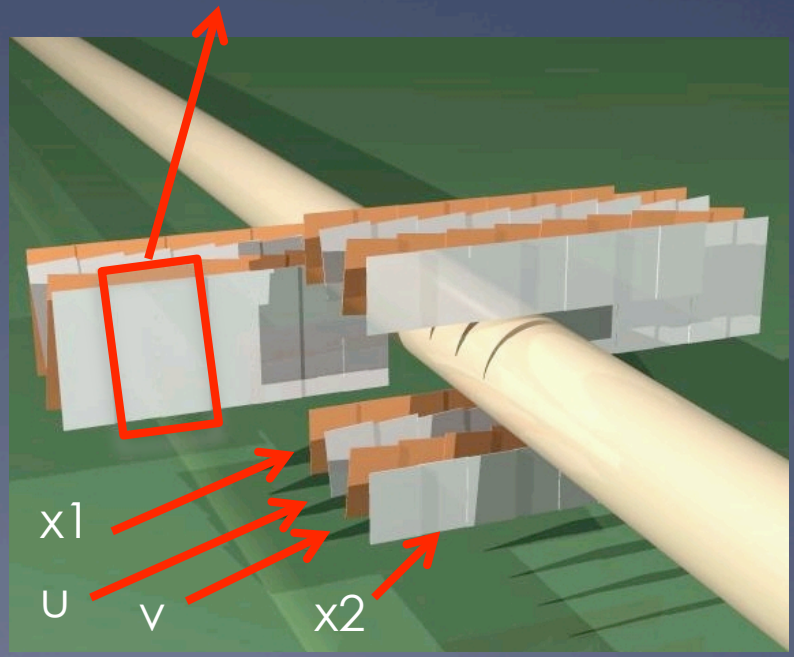


- 336 ladders of 320/410 μm thick silicon micro-strips (129k channels)
  - 1-sensor ladders (320μm) « short »
  - 2-sensors ladders (410μm) « long »
- 198 μm pitch
- 3 stations x 4 boxes x 4 layers
- Layers x1(0°), u(+5°), v(-5°), x2(0°) (stereo)
- Covers the **innermost part of the tracking stations after the magnet**
- **Large track density** (closest detector to the beam-pipe)

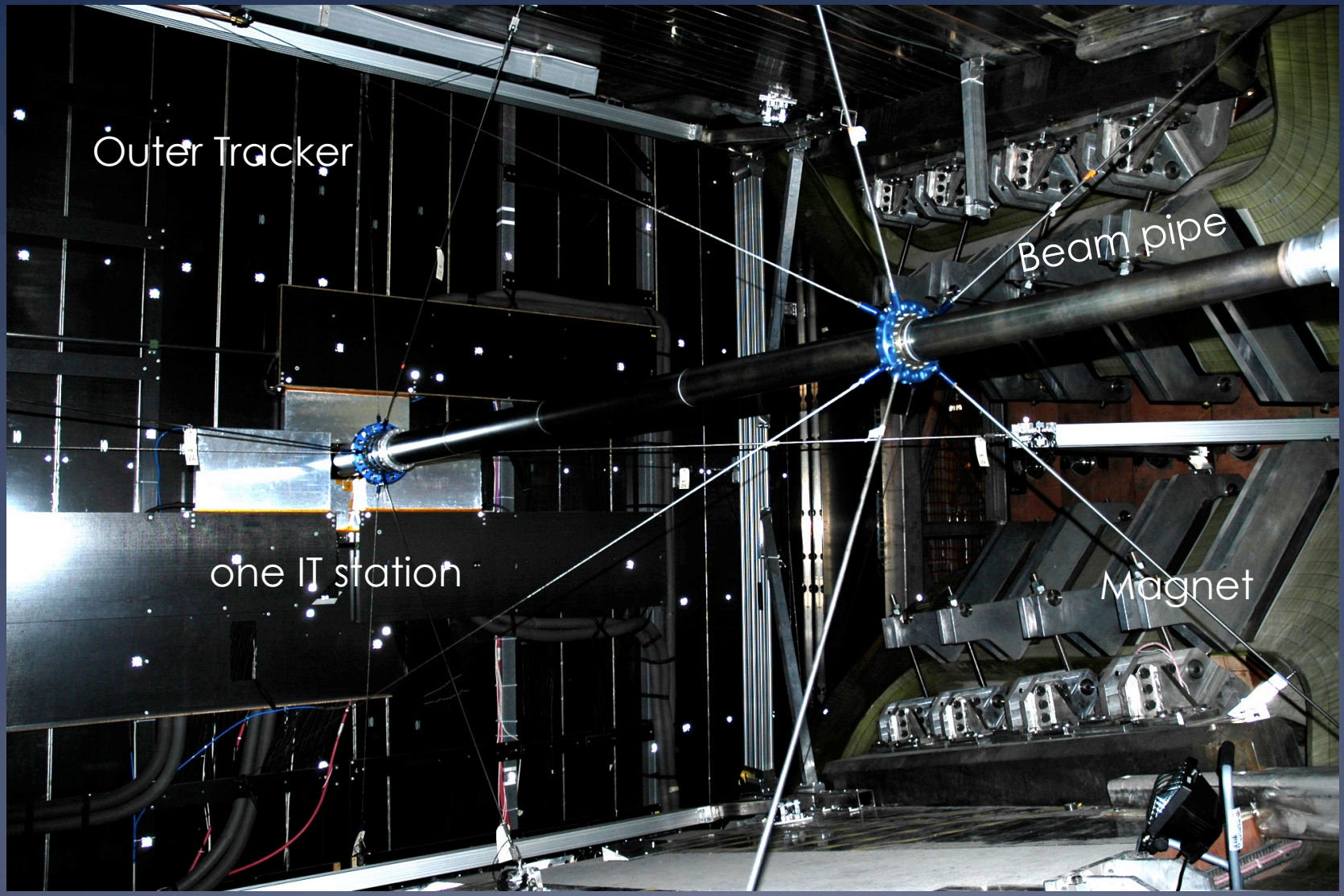
2-sensors ladder



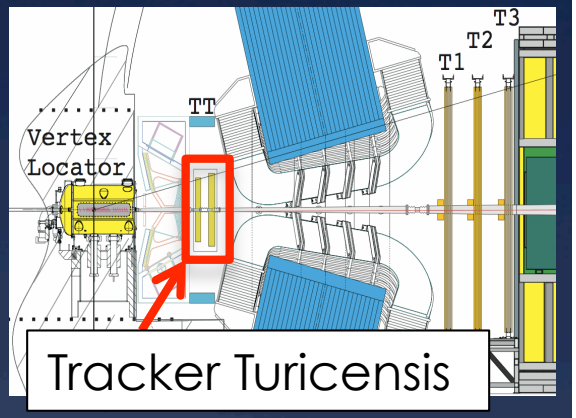




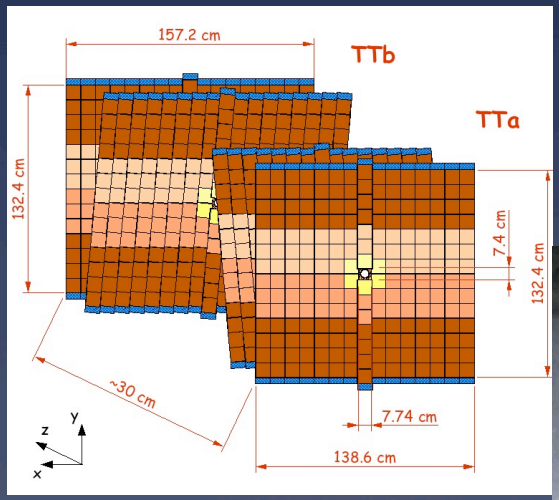
Inner Tracker picture

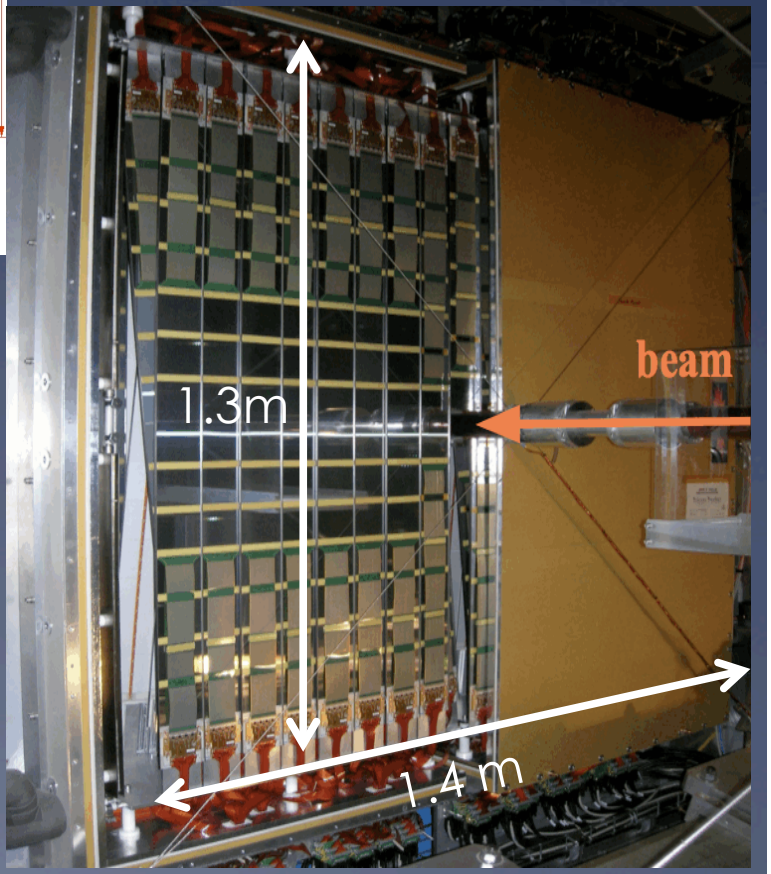


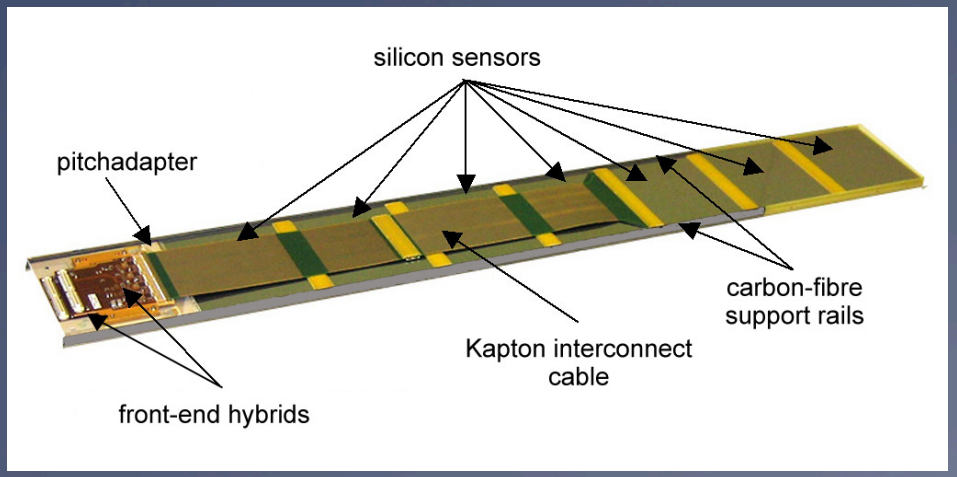
The Silicon Tracker Project 2: The Tracker Turicensis



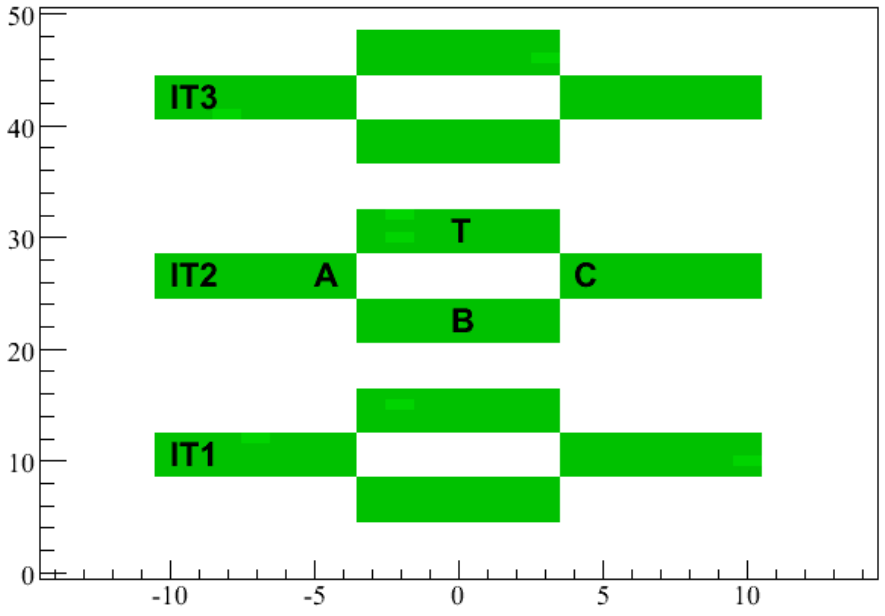
- 128 half-modules with 7 sensors, 500 μm thick
- 183 μm pitch
- 4 layers: x1(0°), u(+5°), v(-5°), x2(0°)
- 143k channels
- Covers the complete acceptance



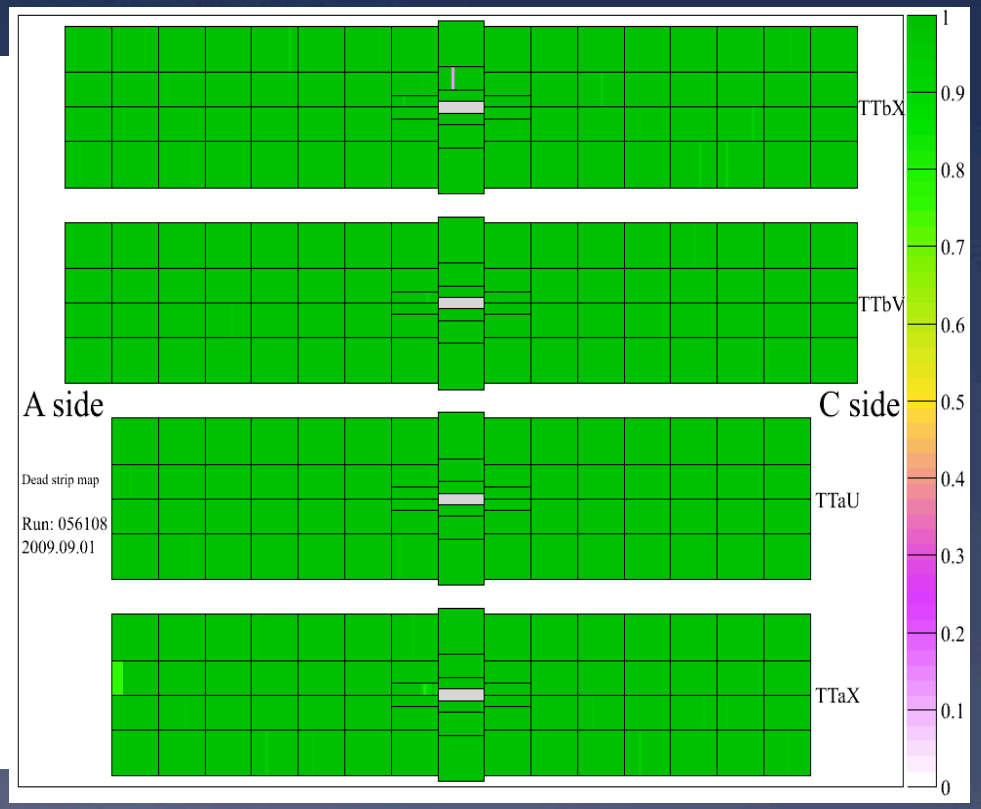




Hardware status



IT



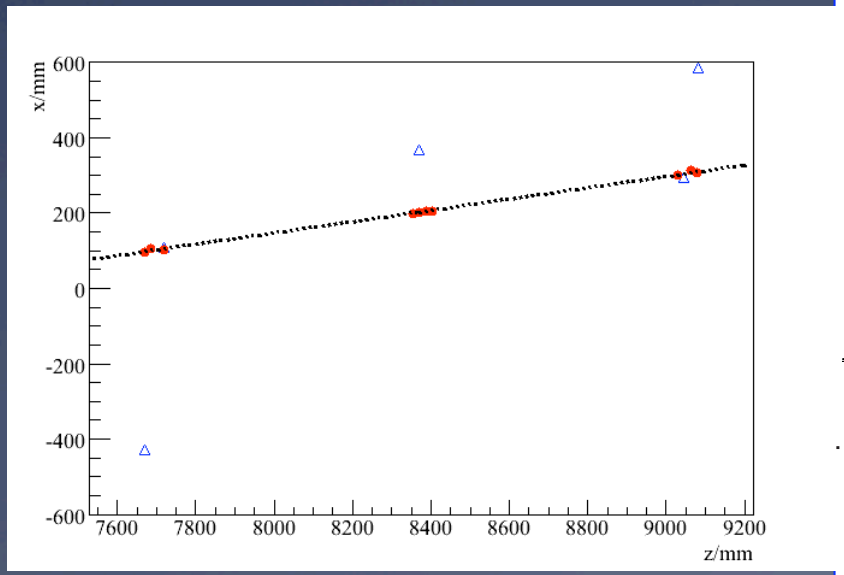
TT

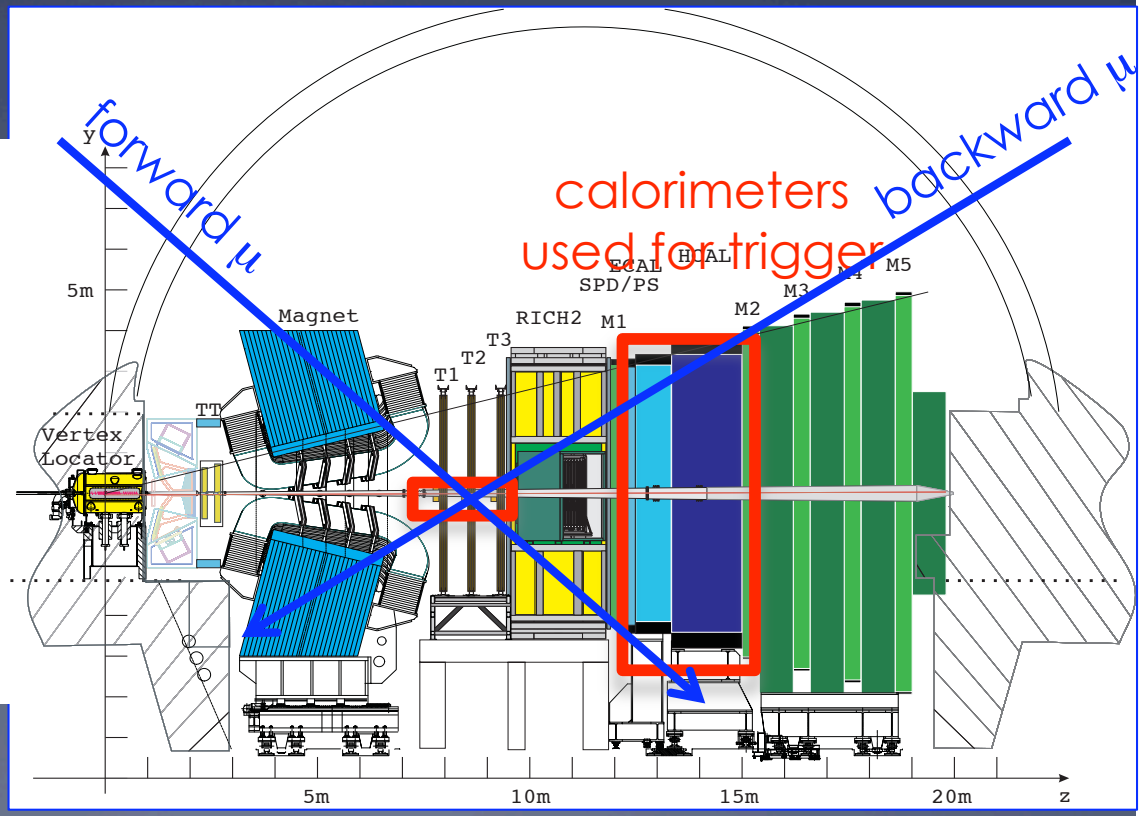
- IT: 99.7% of channels are functional
- TT: 99.7% (not a typo) of channels are functional

Cosmics: very first real data

- Very low rate (geometry)
  - ~1000 cosmics through 1 box in 2008, over 2.6 million Calo triggers (0.002 Hz)
  - 3 cosmics through 3 box in 2008 (6 x10^{-6} Hz)
- Not enough data for alignment
- But **first real data**, and rough timing set
- TT also a few (more distance to trigger)

one of the 3 cosmics through 3 IT boxes





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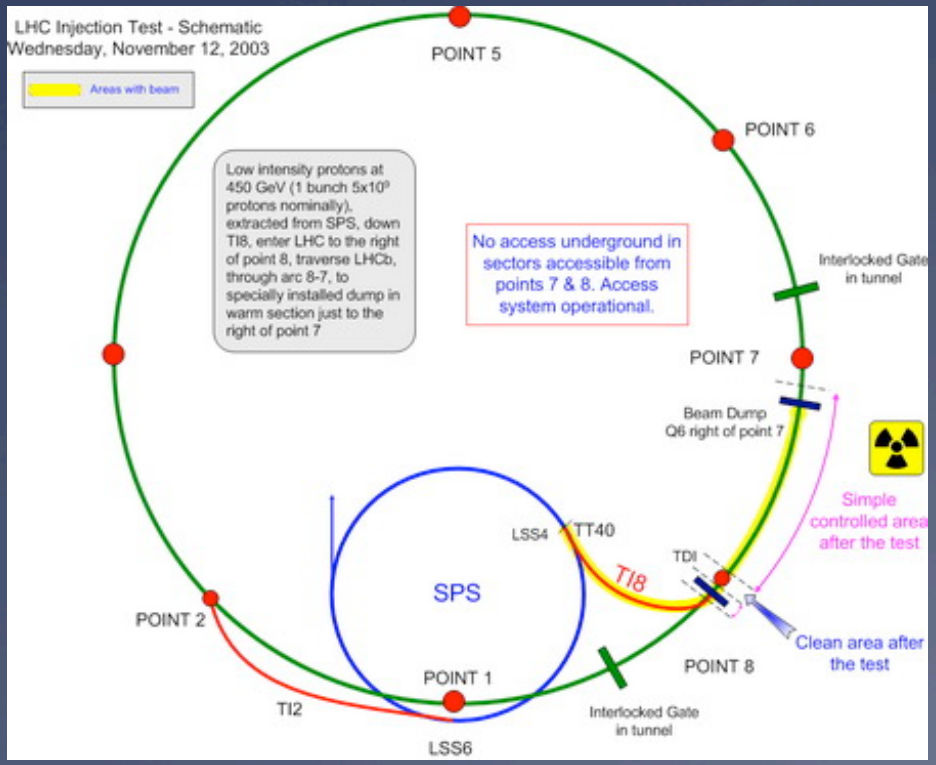
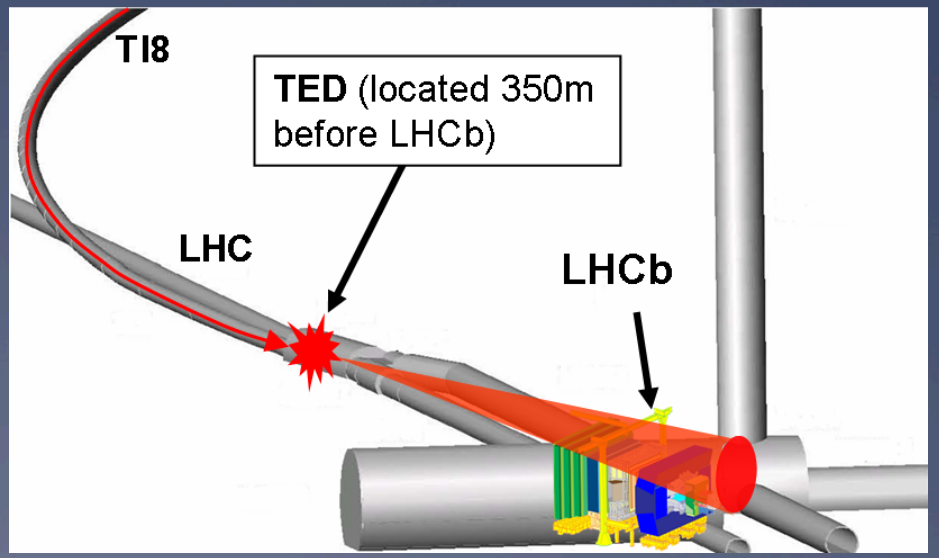
The LHC injection tests

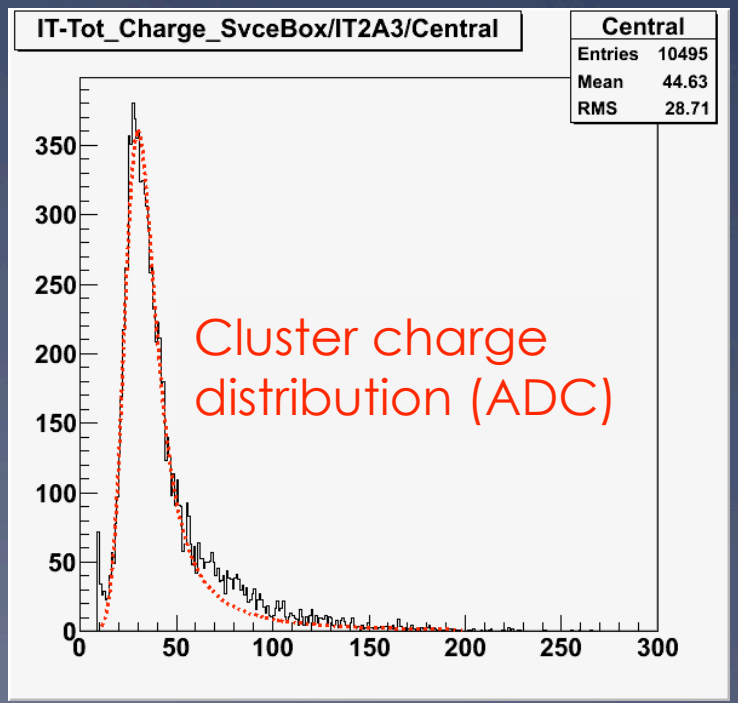
- In August and September 2008, and in June 2009 were performed injection tests, from the SPS line into the LHC.
- Bunches of ~ 2-5x10^9 protons were dumped to a beam stopper (TED) every 48 seconds
- LHCb detector is 350m downstream of the TED
- Splashes of particles were observed in our detector (wrong direction)
- Monte-Carlo indicates mainly ~10 GeV muons





The TED data

- Challenging environment (high occupancy):
  - ~5000 clusters for a typical event (6% strip occupancy in IT): **~10 times typical *B-meson* event**
- Data:
  - TED1 (21-22 August, 5-6 September 2008):
    - pulse-shape scans for timing
    - first tracks (~5300)
    - DAQ: ~6 hours≈450 TED shots
  - TED2 (6-7 june 2008):
    - pulse-shape scan again
    - final time-alignment
    - lots of tracks (~50'000)
    - DAQ: ~72 hours≈5300 TED shots



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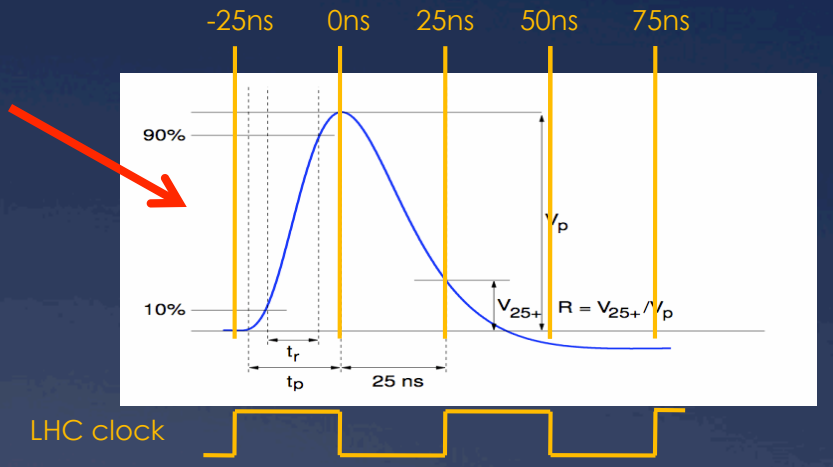
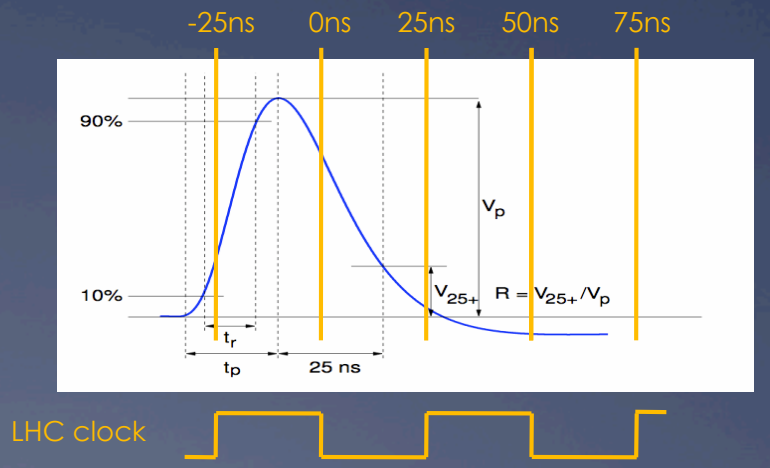
Time alignment

- Output signal from the RC-shaper
- Sample every 25 ns (LHC clock @20MHz)
- Synchronize **sampling time v.s. maximum signal**
- 2 types:
  - **Global timing:**
    - IT/TT trigger w.r.t global trigger
  - **Relative timing:** timing of a sub-part of our detector w.r.t. the global timing. It is due to:
    - time of flight
    - different cable lengths
    - different strip length (capacitance)



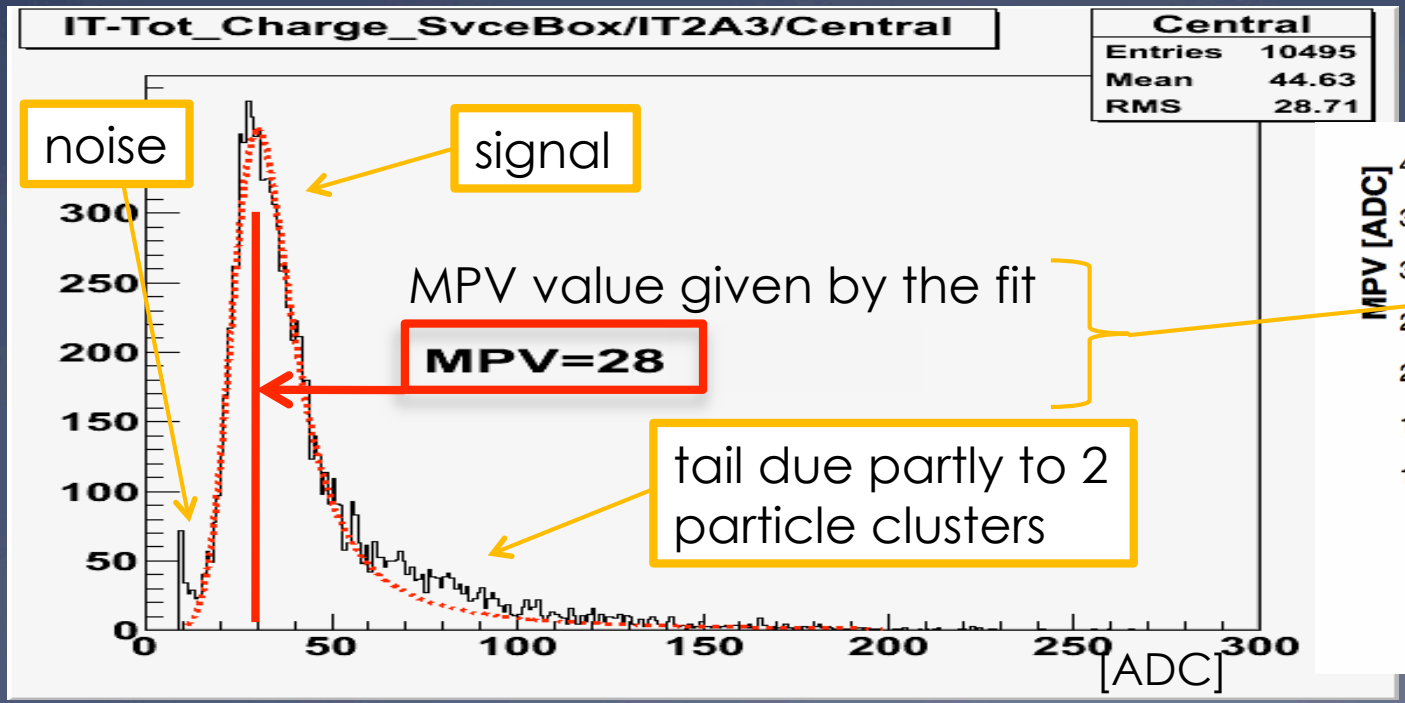
synchronized

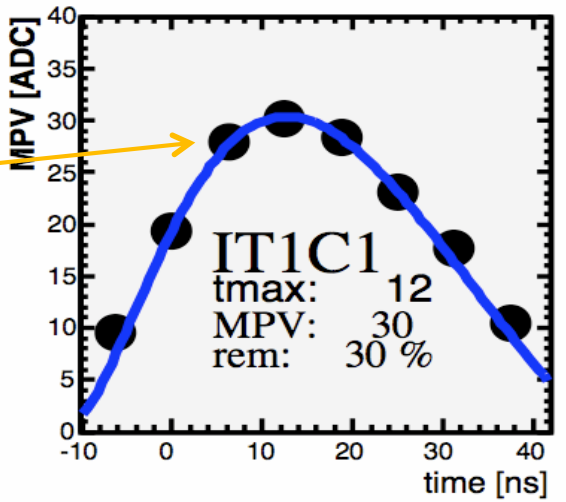


not synchronized

Timing: pulse-shape scans

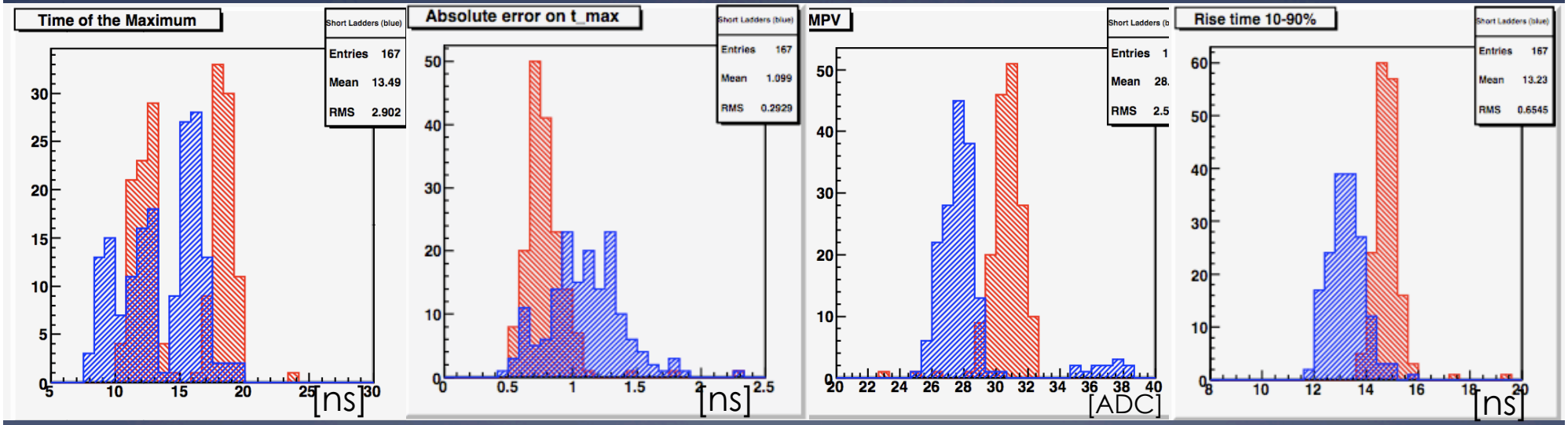
- Charge distribution for 10 GeV muons: **convolution of a Landau with a gaussian**
- Most Probable Value: (MPV) proportional to the signal
  ➔ **plot the MPV versus to get the maximum**
- Take 4 sets of data with ±5 sampling points
  ➔ Full window of 100ns with a sample every 6.5 ns.
- Do this for each cable lenght





Pulse-shape scans results (IT)

- Pulse-shape scans **are very precise**, and allowed to extract few signal parameters:
  - **time of the maximum**
  - rise-time: time to go from 10% of signal to 90%
  - value at the maximum
  - a few other parameters



time of the maximum

error on t_{max}

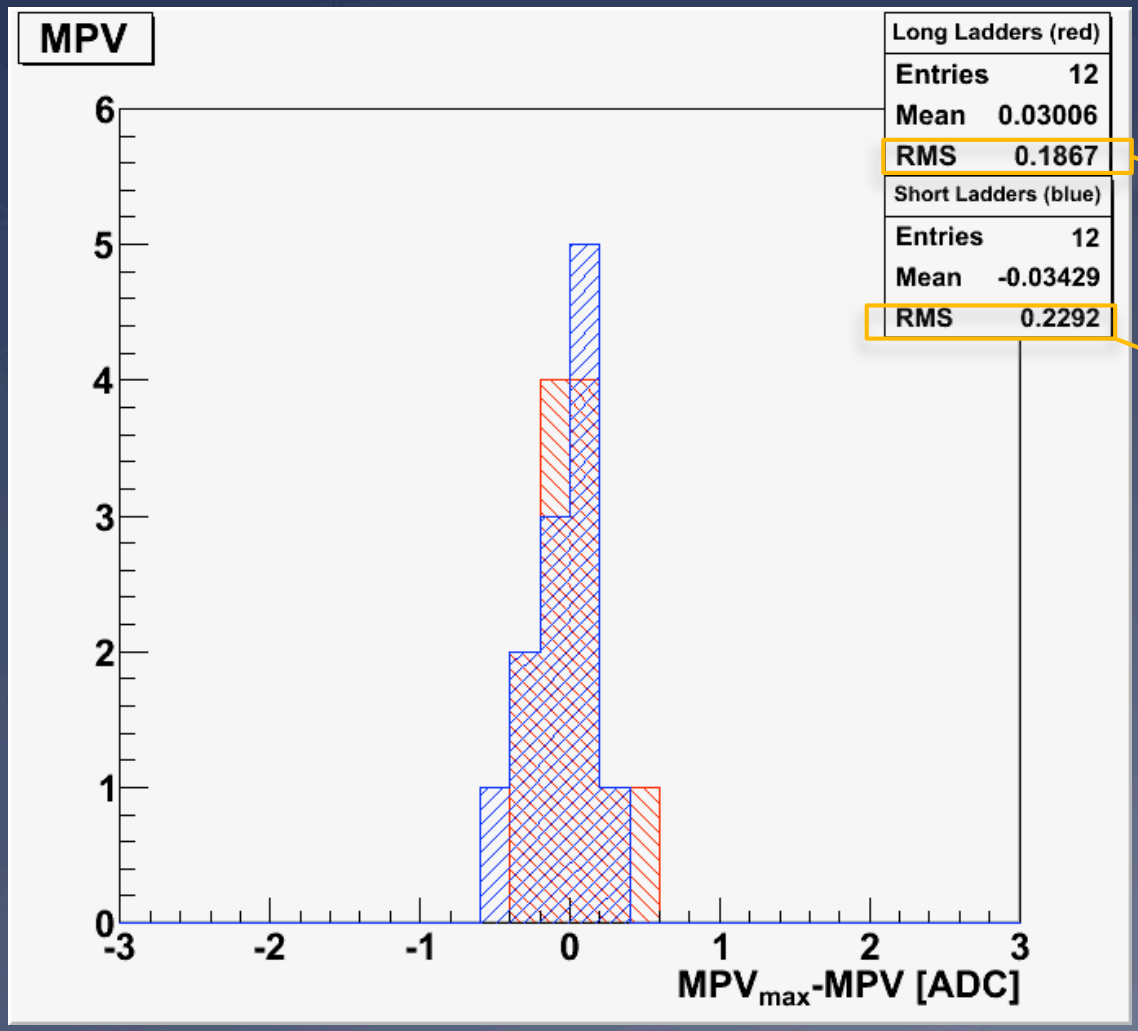
max MPV

rise-time

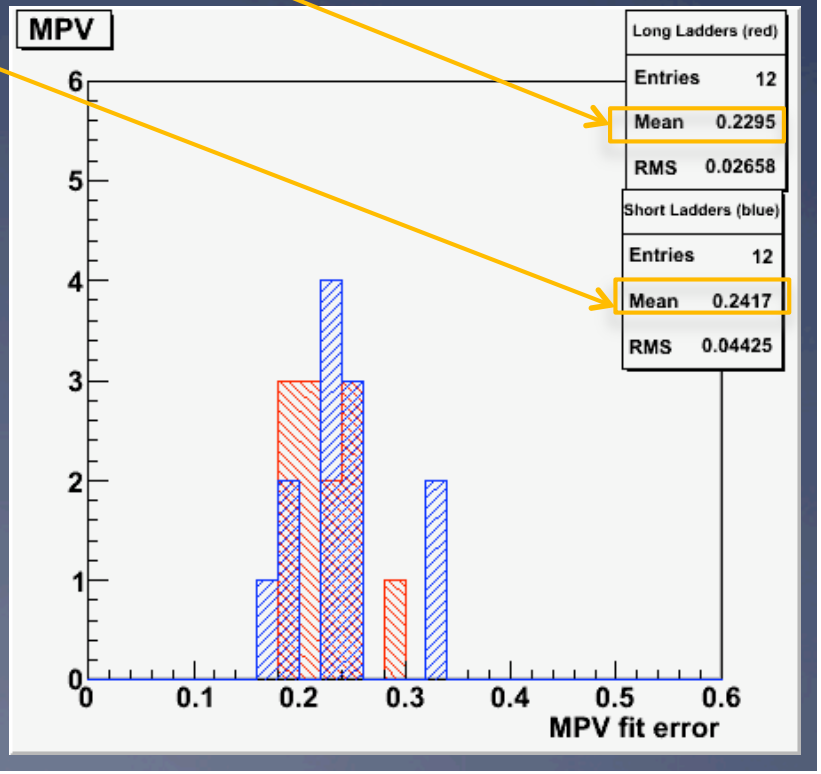
red: long ladders
blue: short ladders

Timing results (IT)

* X-check: plot the difference MPV(pulse-shape)-MPV(after alignment)



The error is **dominated by the error on the fitted MPV**, otherwise we would'nt have something centered at zero!



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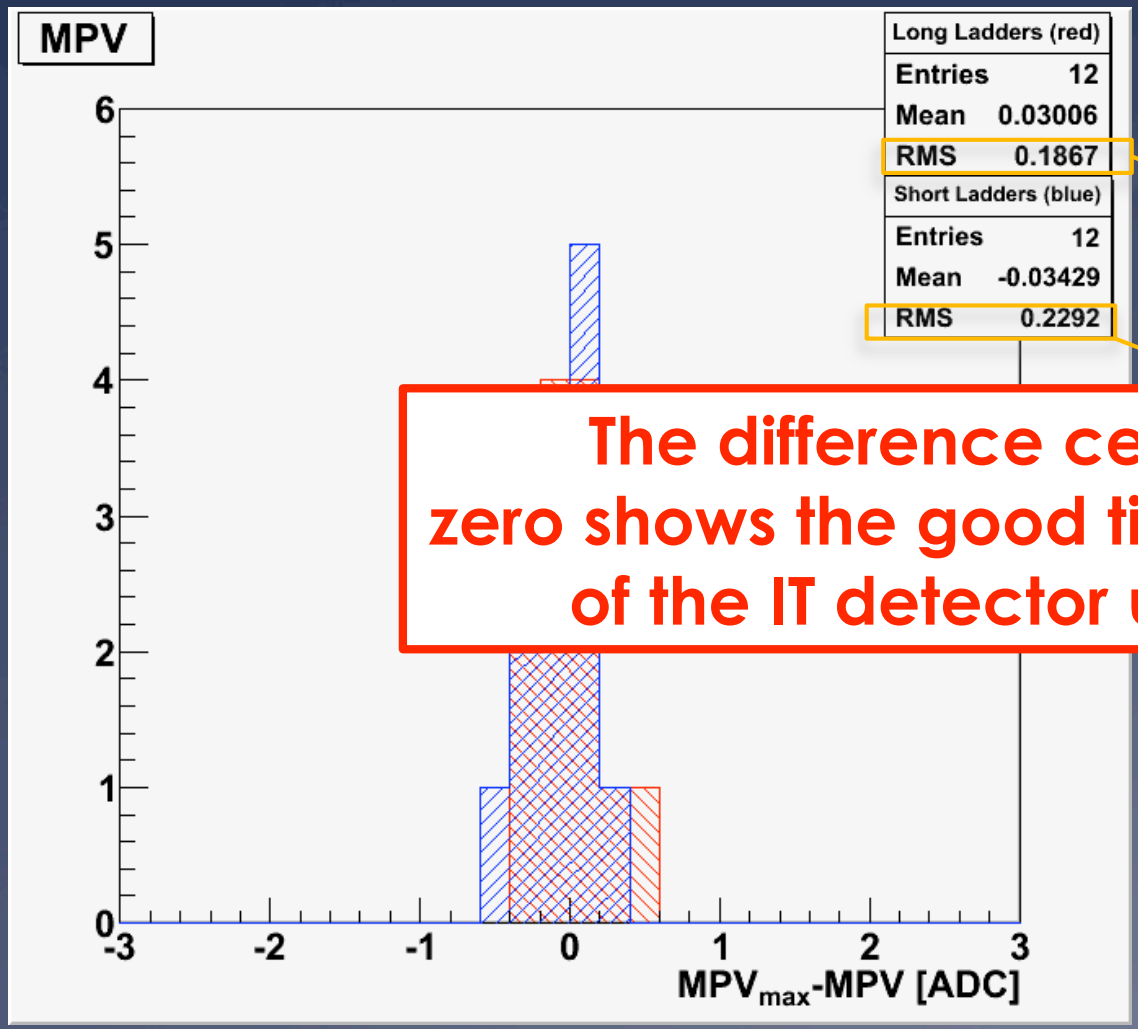

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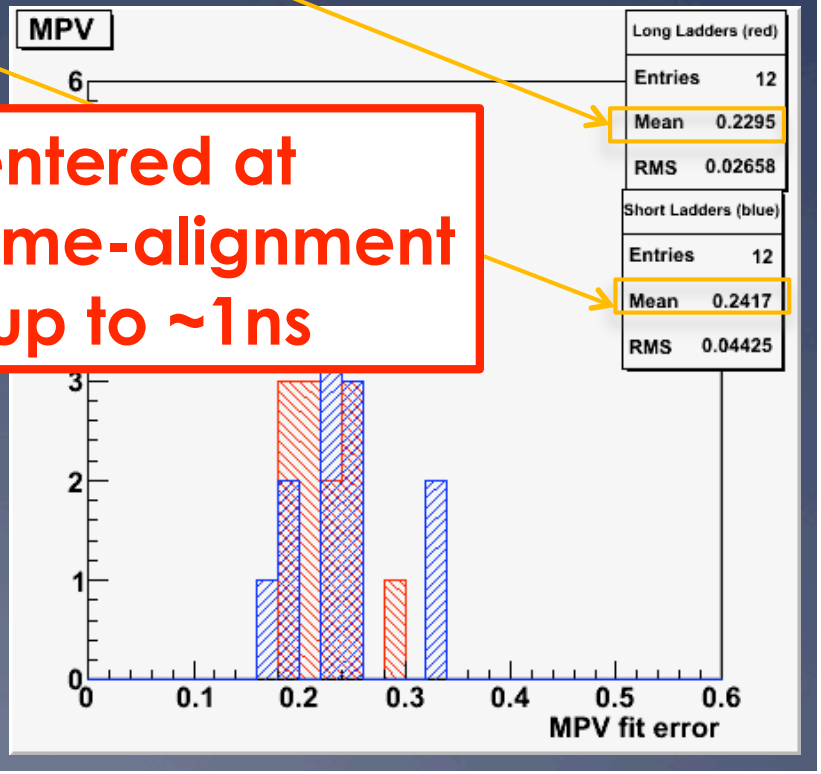
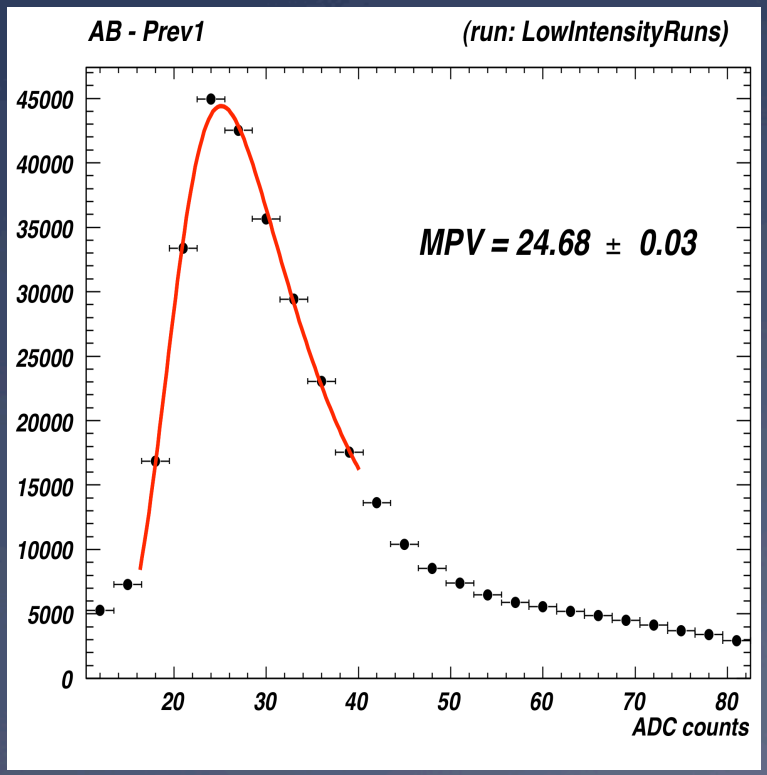
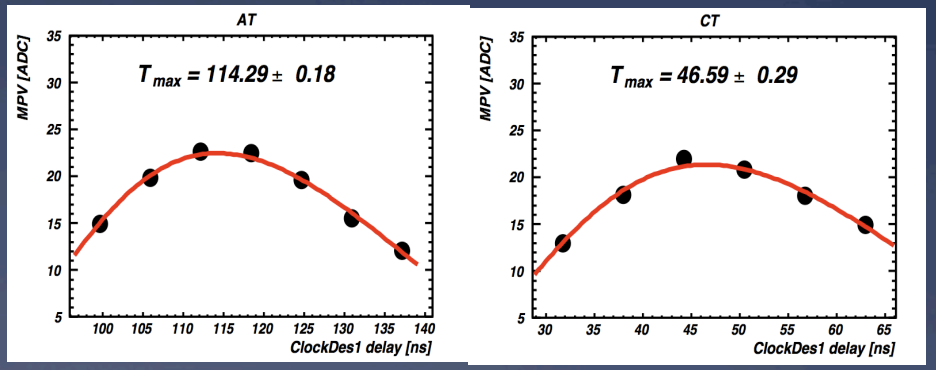


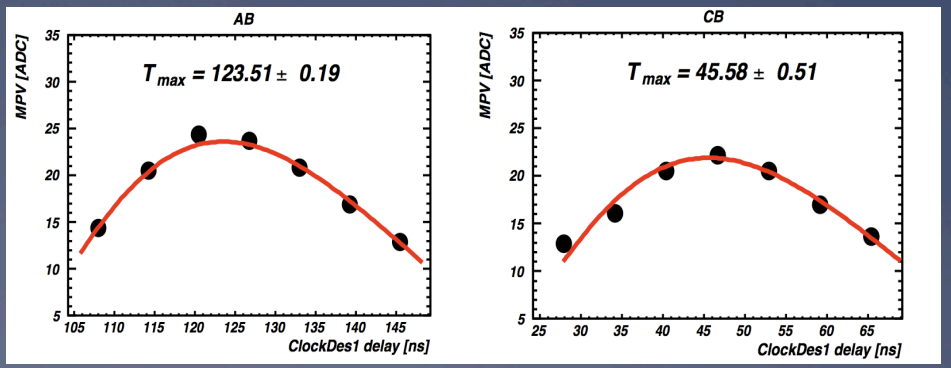
The difference centered at zero shows the good time-alignment of the IT detector up to ~1ns

TT time alignment

- Similar results for TT, do the time alignment per quadrant
- Precision also to 1 ns







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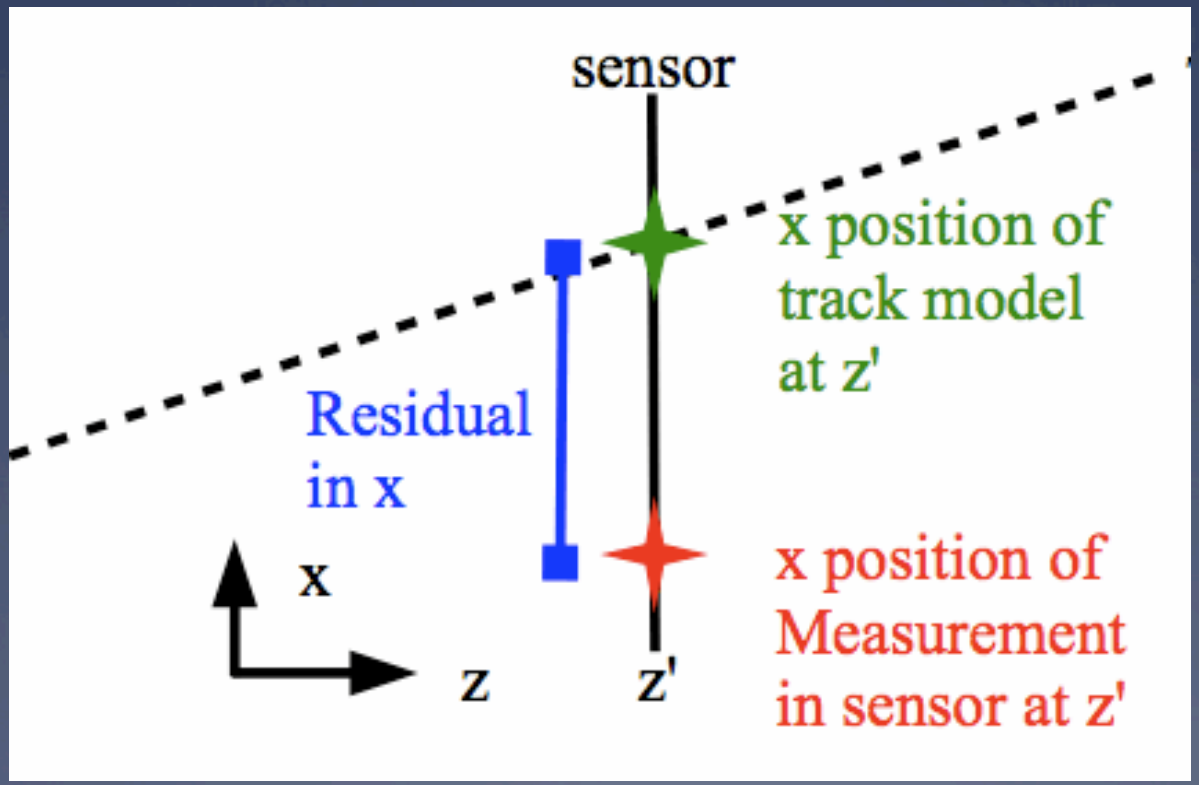
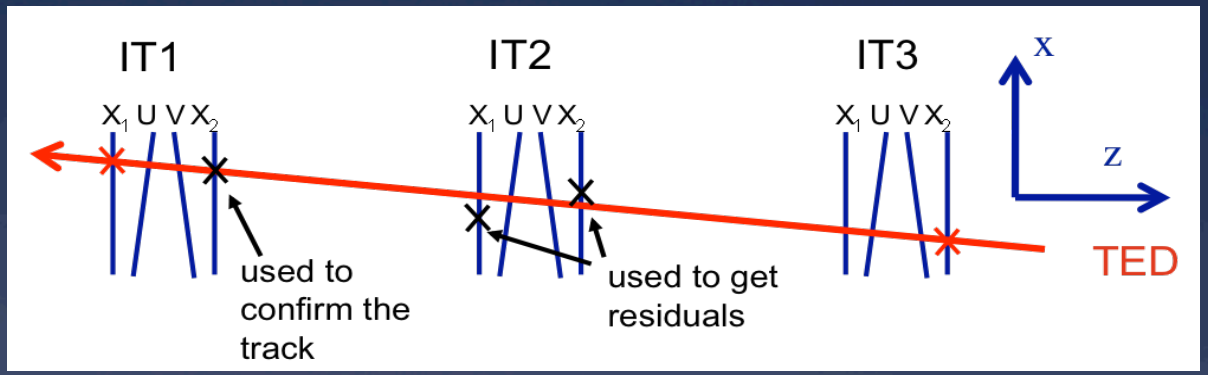
Tracking & space alignment (IT)

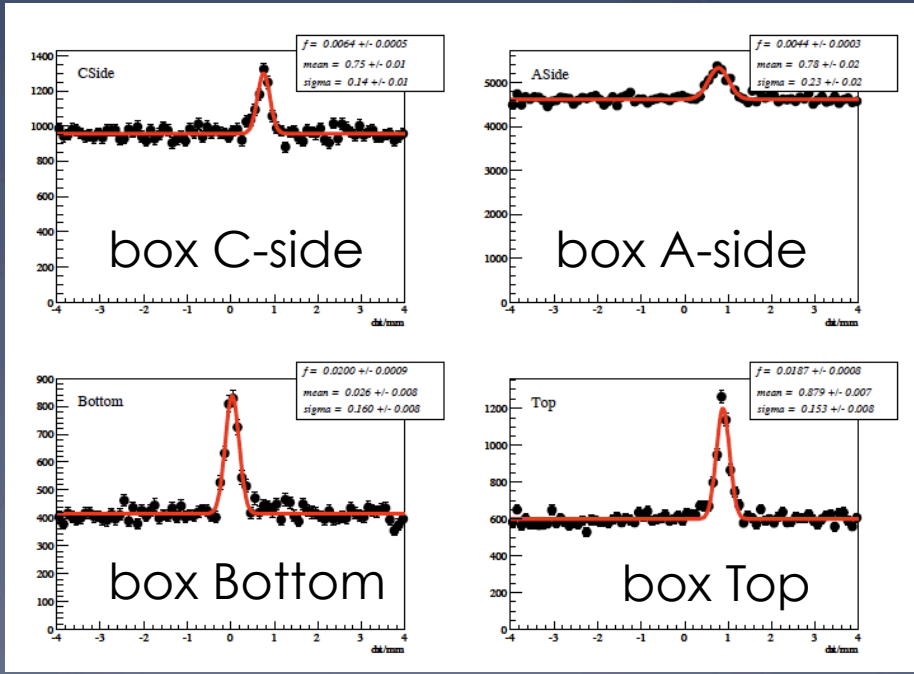
* General alignment procedure: **minimise difference between track model and actual position of the hit** (residuals)



Simple alignment (IT)

- Occupancy too high for standard alignment
  ➔ Box alignment with the histogramming technique, using survey results
- Draw a line between 1st layer of IT1 and 4th layer of IT3
- Require the line to points towards TED
- Get residuals in IT2
- **box ajusted to 700μm**



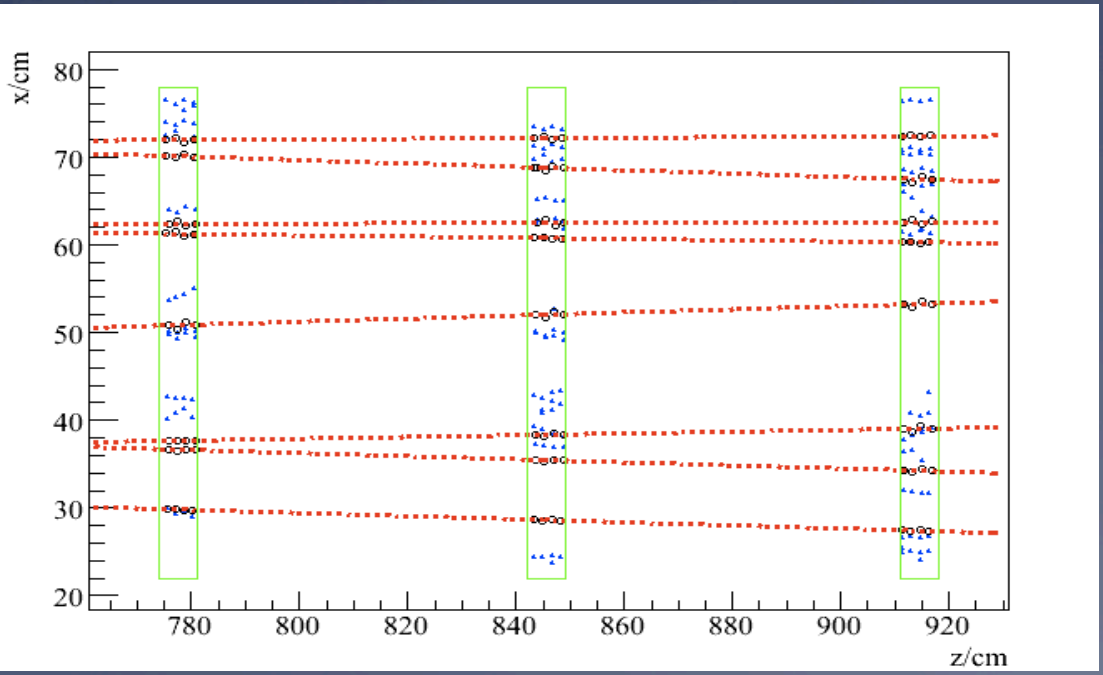


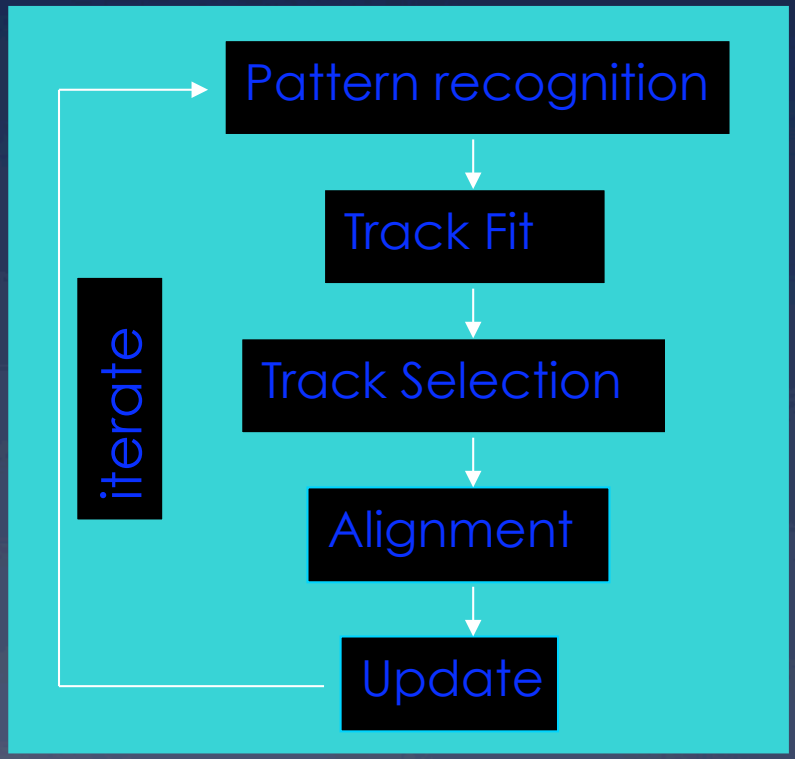
mean gives estimate of the box and ladder position in x

residuals in station 2

IT alignment

- Use TED runs with lowest occupancy
- Reconstruct tracks only in IT, and ask to point towards TED
- Alignment:
  - boxes in X, Y translations and Z rotations
  - layers in X translation and Z rotations
  - ladders in X translation
- Evolving χ^2 while iterating

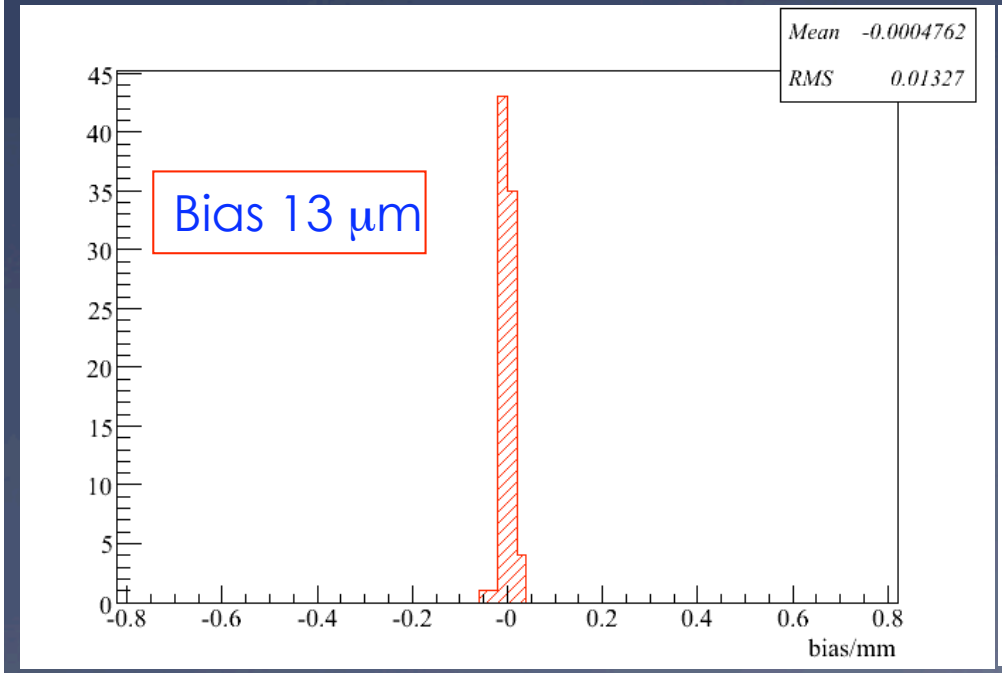


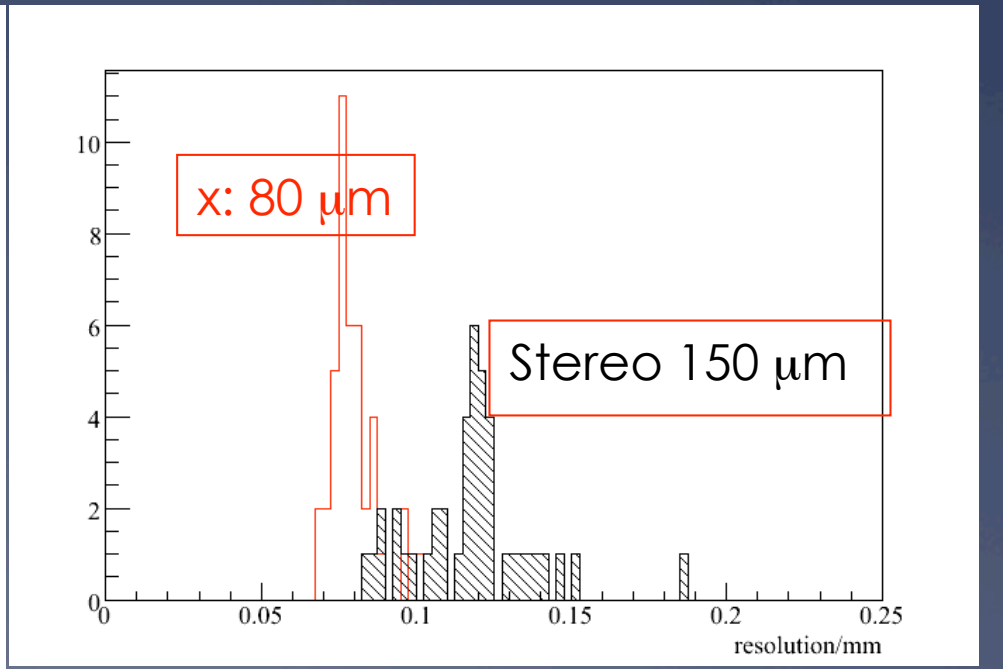


standalone IT tracks
low intensity event

IT alignment validation

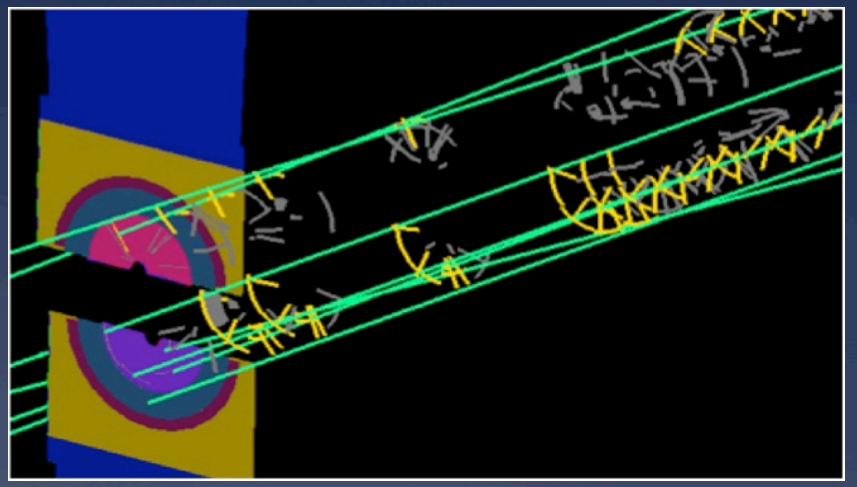
- Convergence after a few iterations
- **After alignment: ladder bias 13mm**
- **Resolution:**
  - **in x: 80mm**
  - **in stereo: 150 mm**



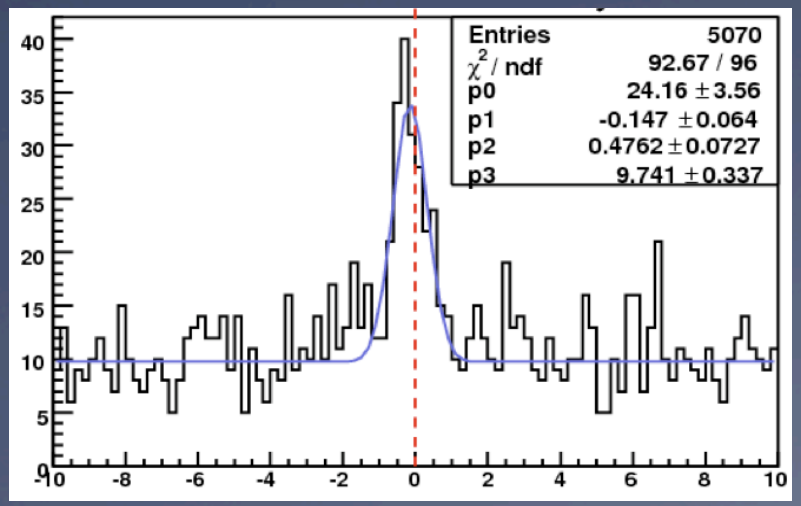


TT alignment

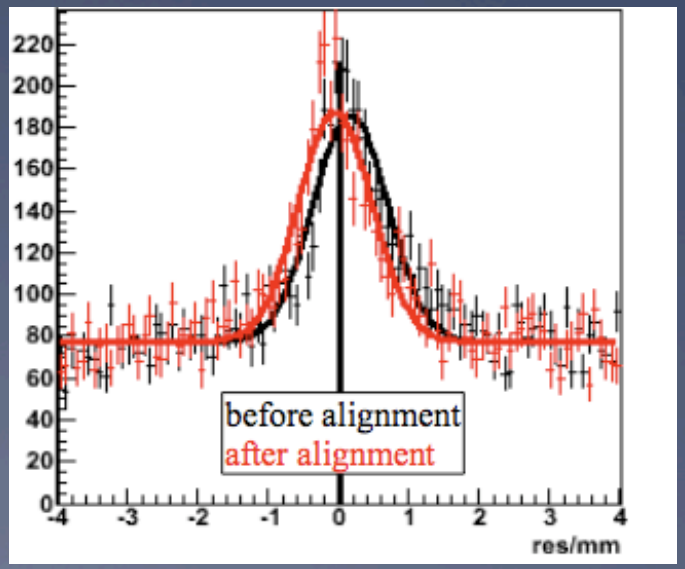
- Only 4 layers
  ➔ no stand-alone tracking possible
- Solution:
  - **extrapolate tracks from the VELO pointing to TED**
  - **Calculate residuals in TT**
- Parallel tracks (TED is 350m away), only small region of TT illuminated by VELO tracks



VELO TED tracks



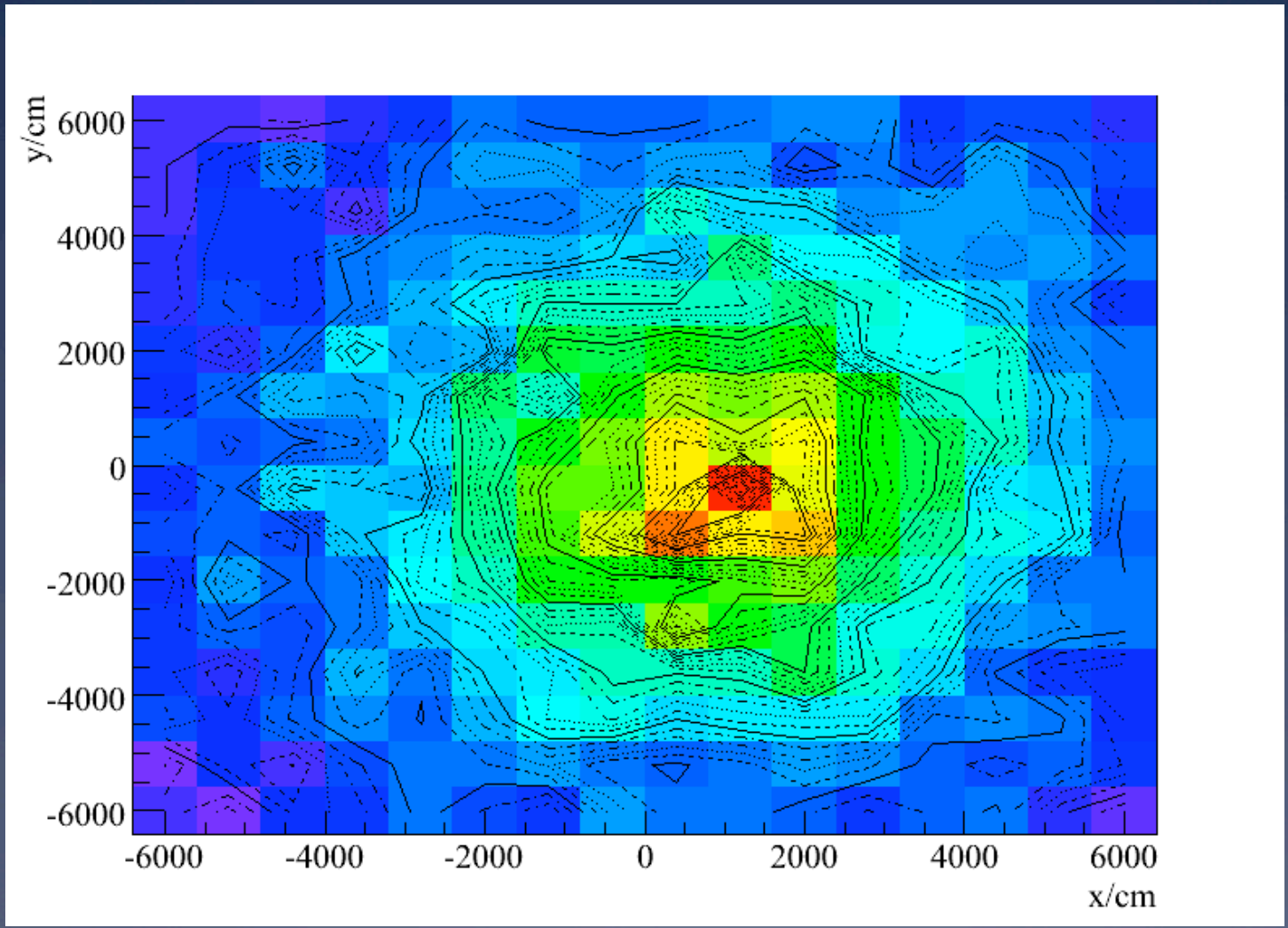
Residuals in TT



Summary

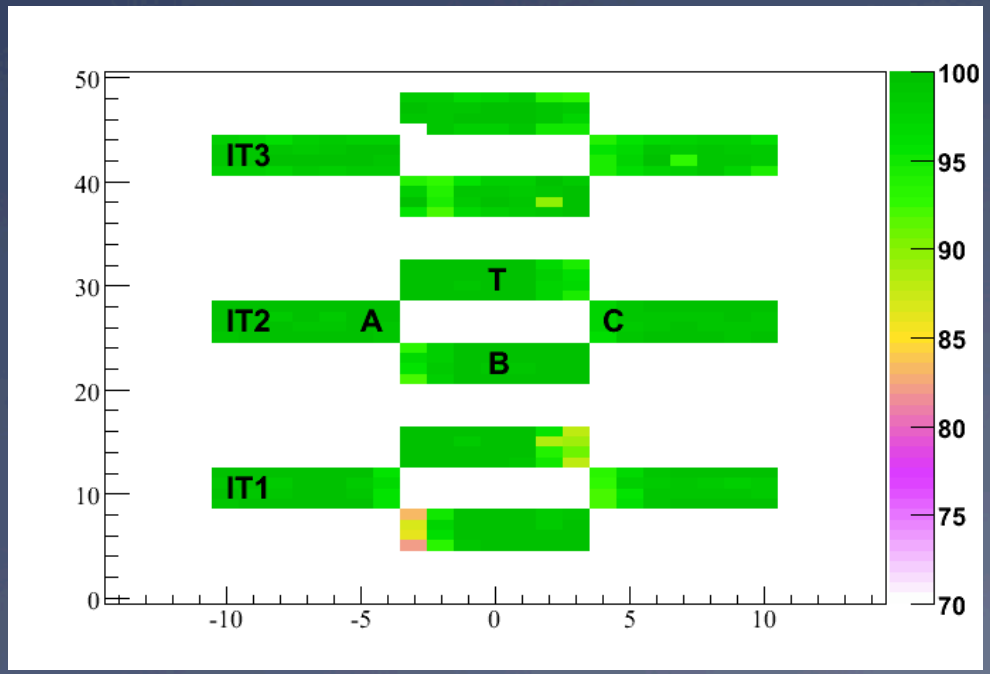
- The LHC TED injection tests were **golden data** for the Silicon Tracker:
  - **time alignment up to 1ns**
  - **space alignment up to 13 μm for IT**
  - partly space alignment for TT
- **First tracks were observed in the 3 tracking systems (VELO + IT + TT)**
- New TED runs ongoing in october
- **WE ARE READY FOR LHC BEAM DATA TAKING**

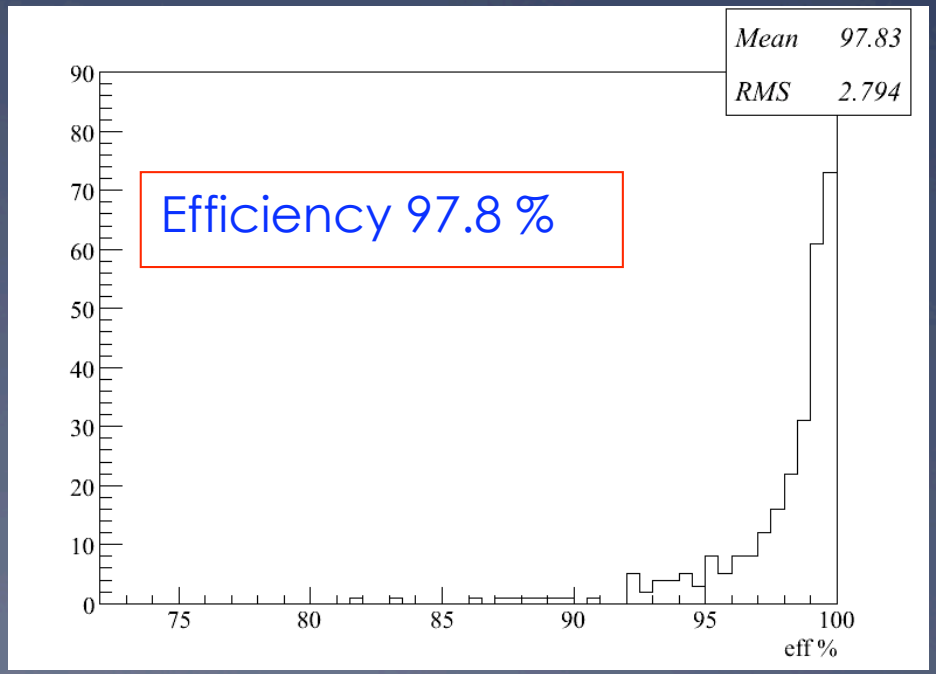
Backup: track x-y at TED z



Efficiency

- Use tracks to measure ladder efficiency
- Measured efficiency 97.8 %
- Inefficiencies dominated by modules close to detectors edge (alignment/acceptance problems) + known problem modules





Radiation damage

- Modest requirements
- Radiation Dose:
  - IT : 6 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 @ ~ 5°C

TT data