

How to commission a detector & its reconstruction

some examples from LHCb history

RTA Workshop, 24.07.2019

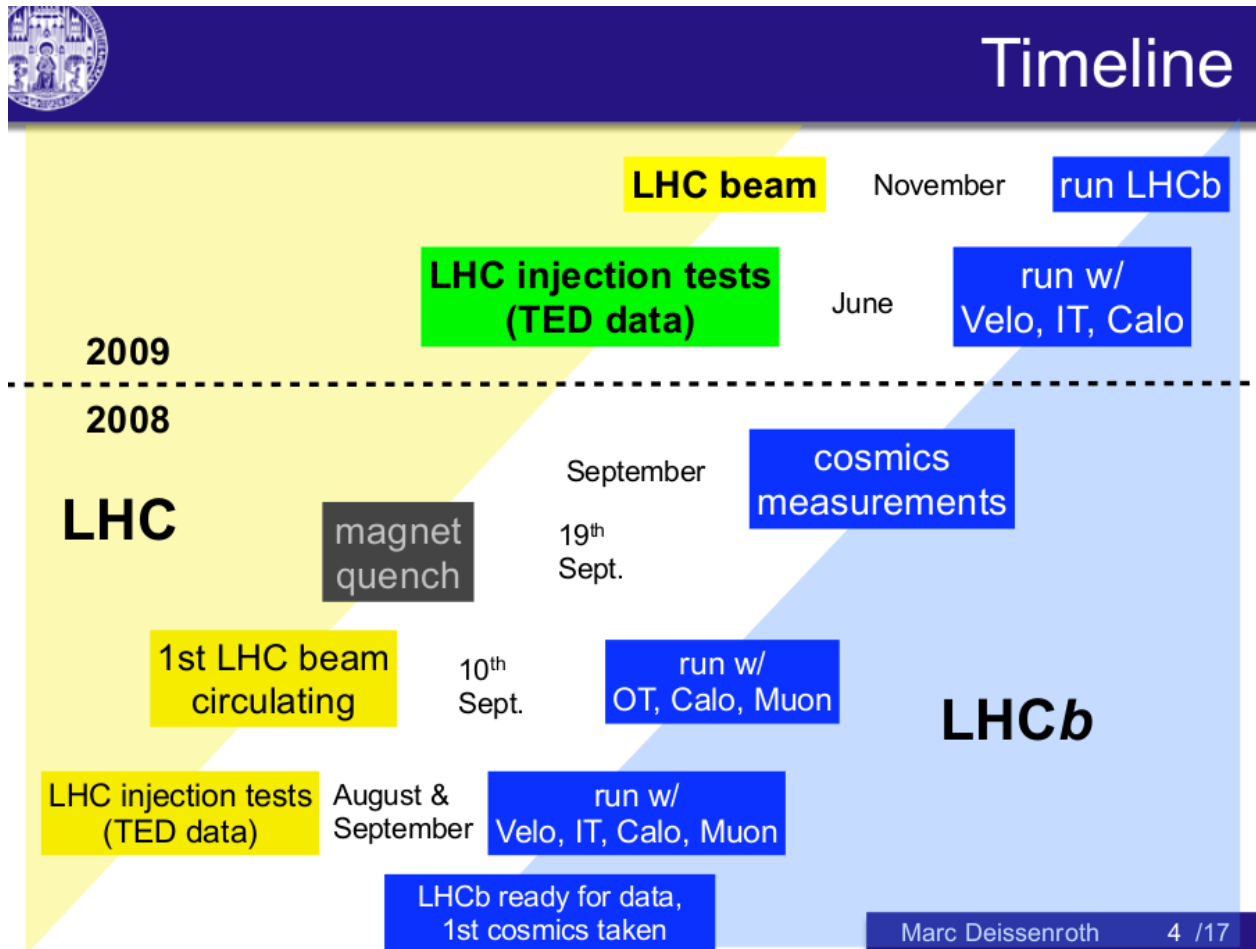
Stephanie Hansmann-Menzemer

Physikalisches Institut, Heidelberg

with known or unknown help from Marc Deissenroth, Wouter Hulsbergen, Matt Needham, Marco Gersabeck, Silvia Borghi, Abraham Gallas, Christian Linn, ...

Timescale

A lot of commissioning work started before the start of LHC 11/2009

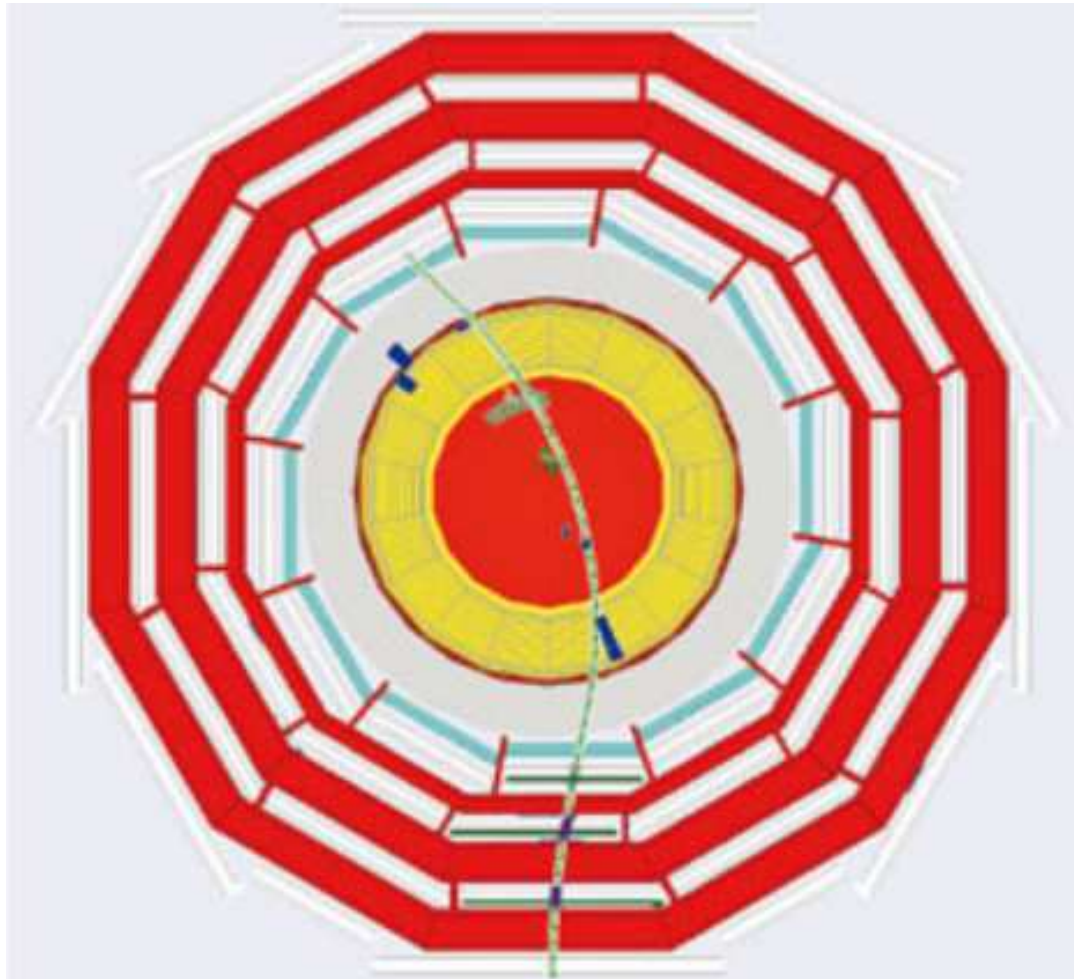


Cosmics and TED data very valuable – extra year was very beneficial for LHCb

Hopefully we have not to rush into high lumi physics data taking too fast.

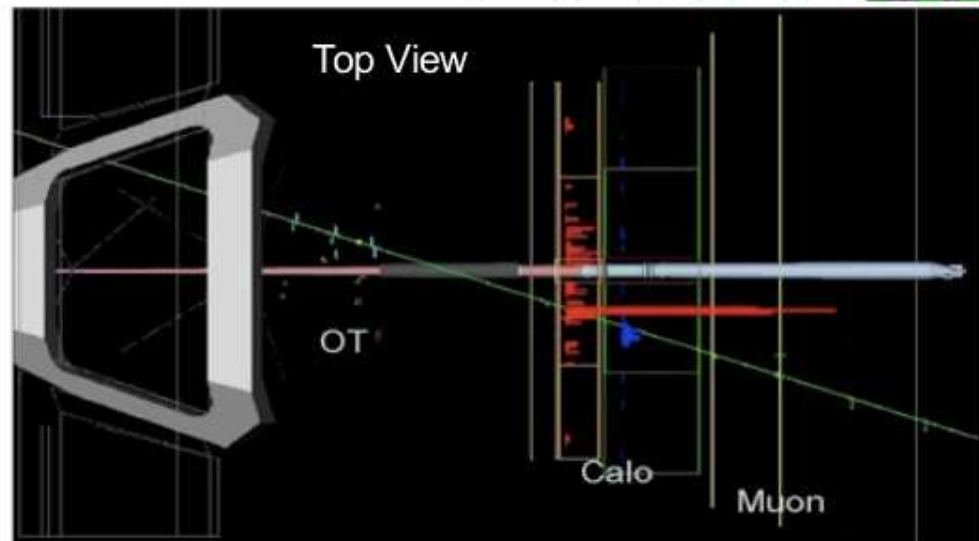
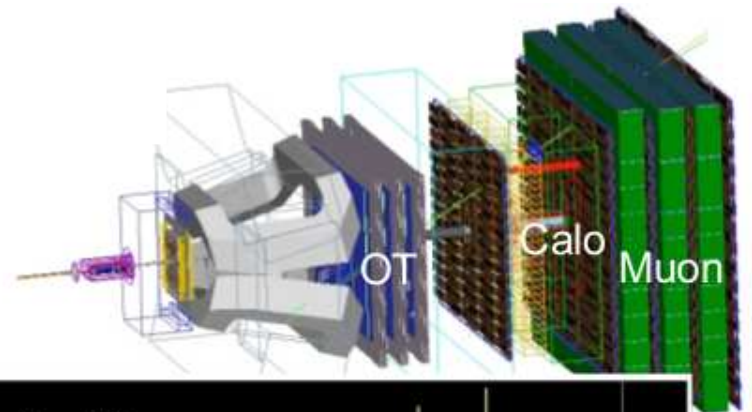
Commissioning with cosmics

- ▶ ATLAS & CMS were showing wonderful alignment results using cosmics
- ▶ With and without B-field, very valuable tracks connecting detector halves which are otherwise hard to align relative to each other



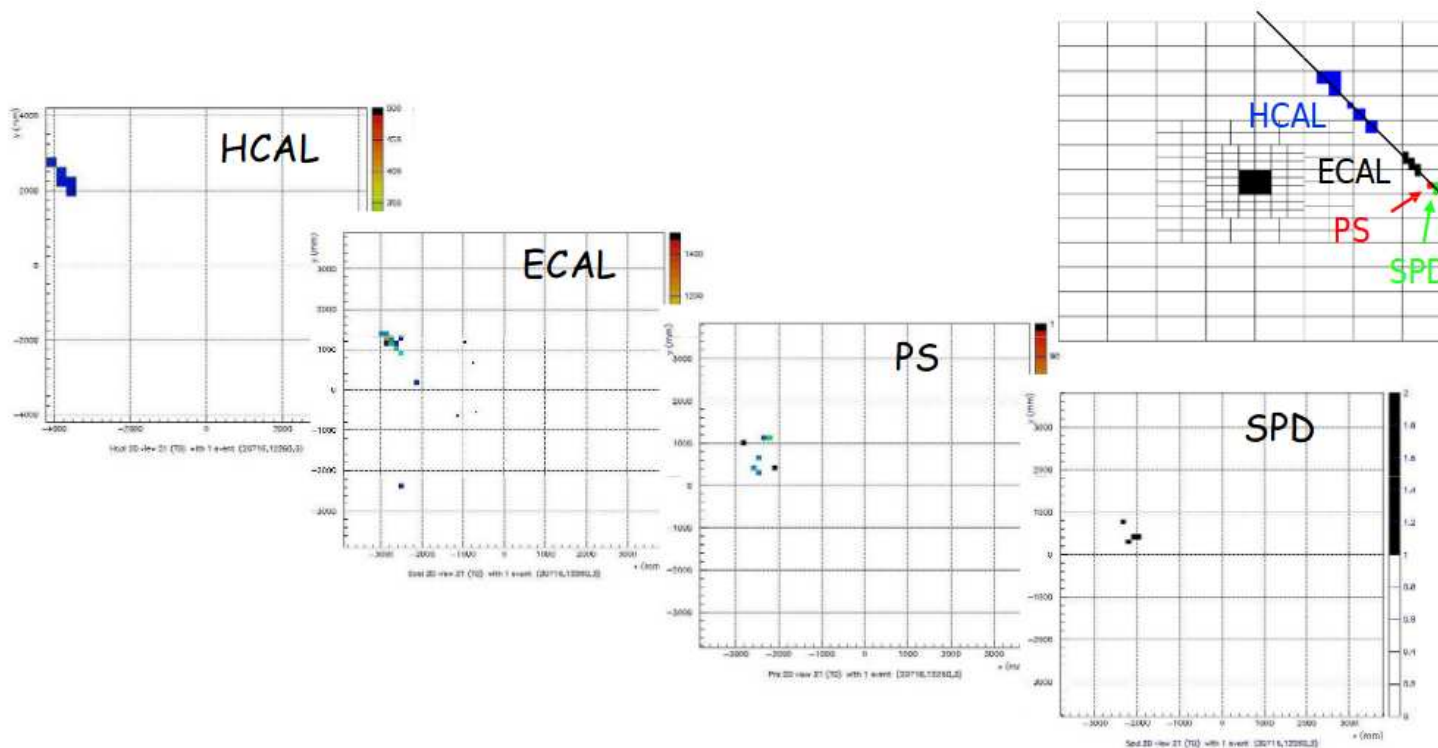
Commissioning with cosmics

- ▶ LHCb geometry not suitable for measuring cosmics, only useful for large area detectors
- ▶ events triggered with ECal/HCal & Muon
- ▶ trigger rate ~ 1 Hz
3 million events (2007-2009)
- ▶ no velo/ almost no TT
→ no momentum info
- ▶ extreme track slopes
(large clusters)
- ▶ cosmics used for time and spatial alignment of sub-detectors

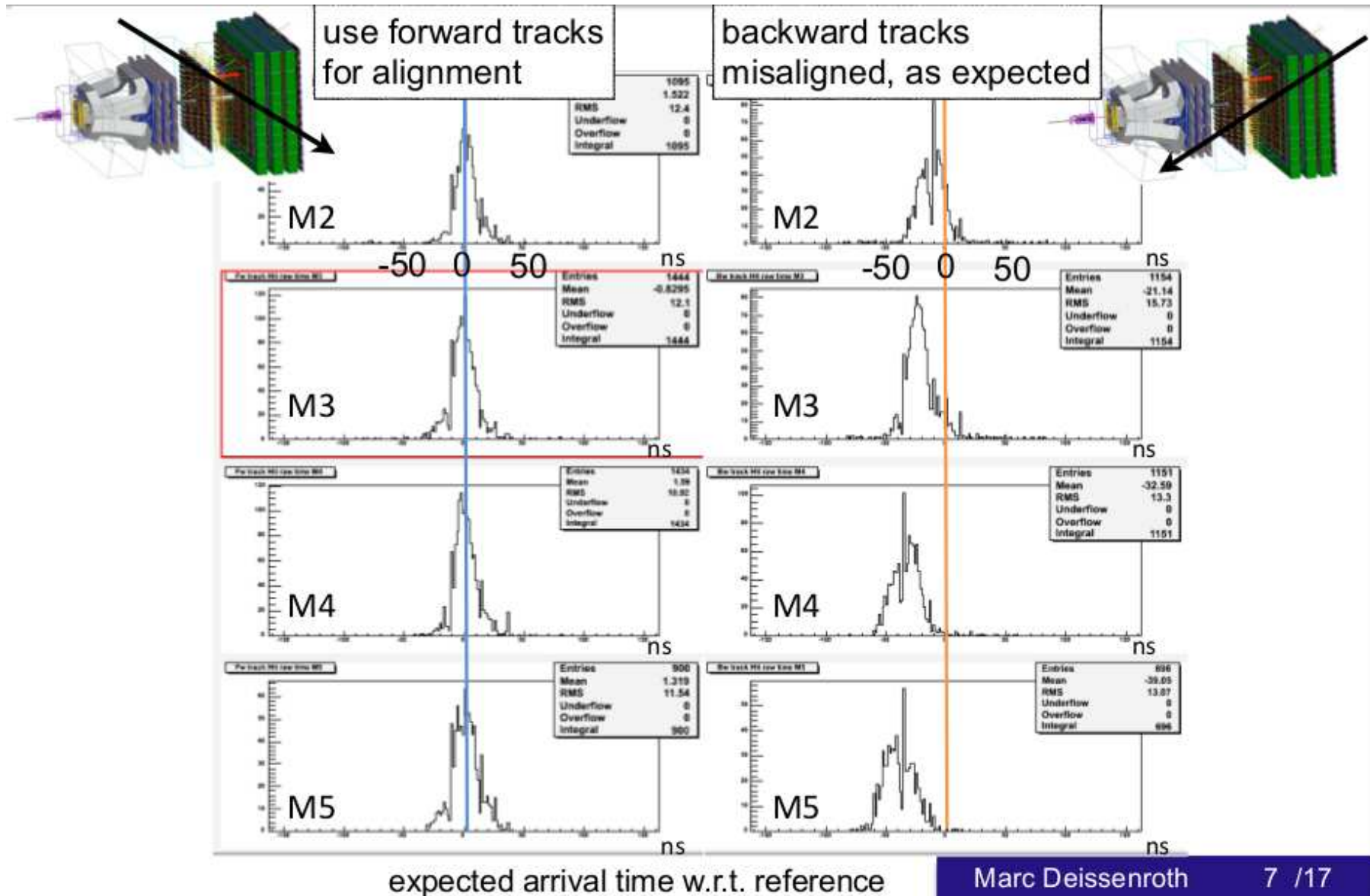


Calorimeter

- ▶ detect 15 consecutive bunches (normally 5: Prev2, Prev1, current, Next1, Next2)
usefull for relative time alignment of different sub-detector
- ▶ use tracks in the calorimeter to test efficiencies of PreShower and SPD
- ▶ test channel mapping in the software
a lot of crucial detector-software debugging, which would be hard in a busy environment



Time alignment of Muon Stations



Marc Deissenroth

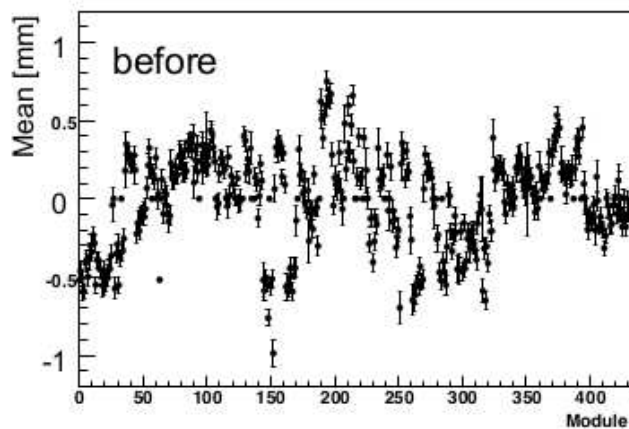
7 / 17

Spatial alignment of Outer Tracker

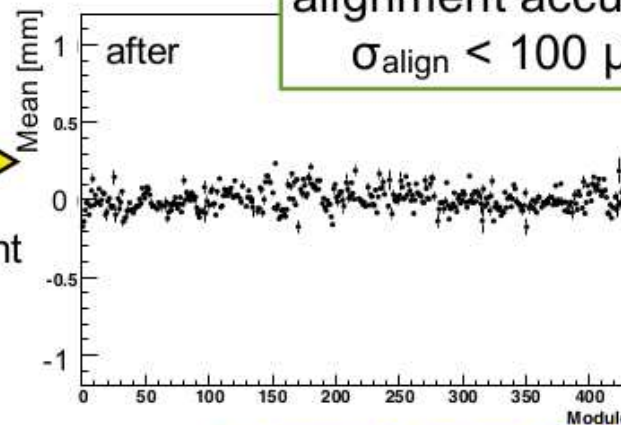
Dedicated OT seeding algorithm required to deal with angles, large clusters, non-calibrated drifttimes and large χ^2 .

Residual misalignment of 0.5mm after surveil expected for SciFi as well.

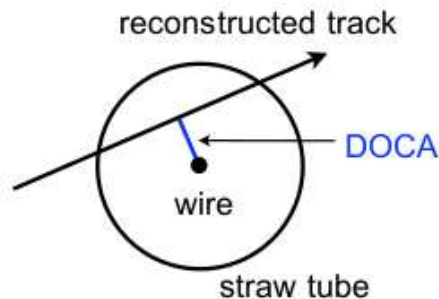
- global χ^2 minimization method for alignment
- cross check with mean of track residuals:



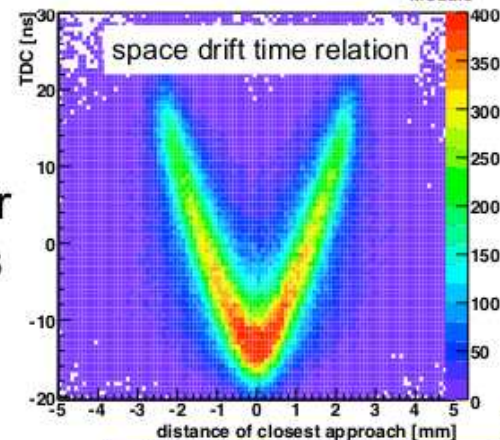
alignment



alignment accuracy:
 $\sigma_{\text{align}} < 100 \mu\text{m}$



- OT drift cells: V-shaped space drift time relation for aligned detector, as expected

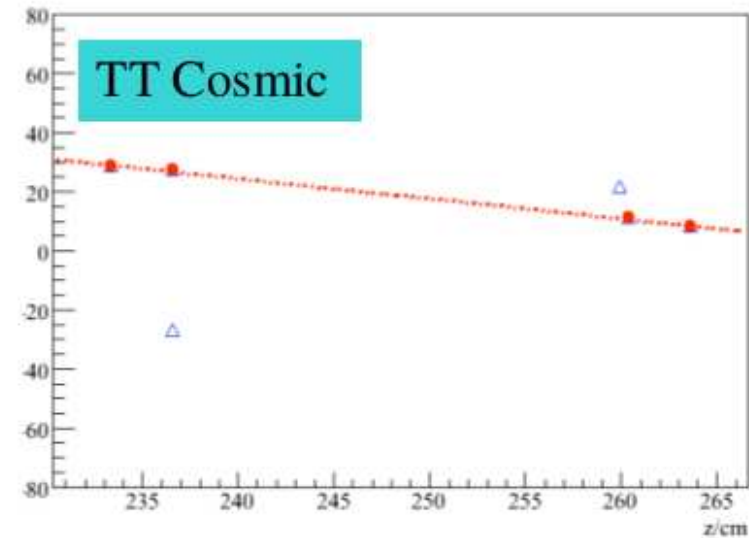
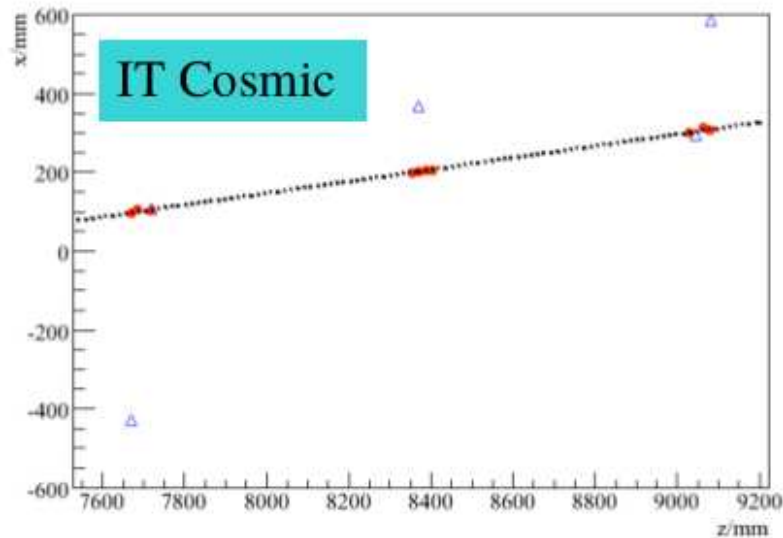


Commissioning with Comics (IT, TT)



Commissioning with Cosmics

Low rate of cosmics due to the forward geometry of LHCb



IT 2008 cosmic running

2.6 million calorimeter triggers

3 cosmics going through 3 IT boxes

~ 1000 through 1 IT box

First signals + coarse timing

TT 2009 cosmic running

Few cosmics 2008 (trigger is far away)

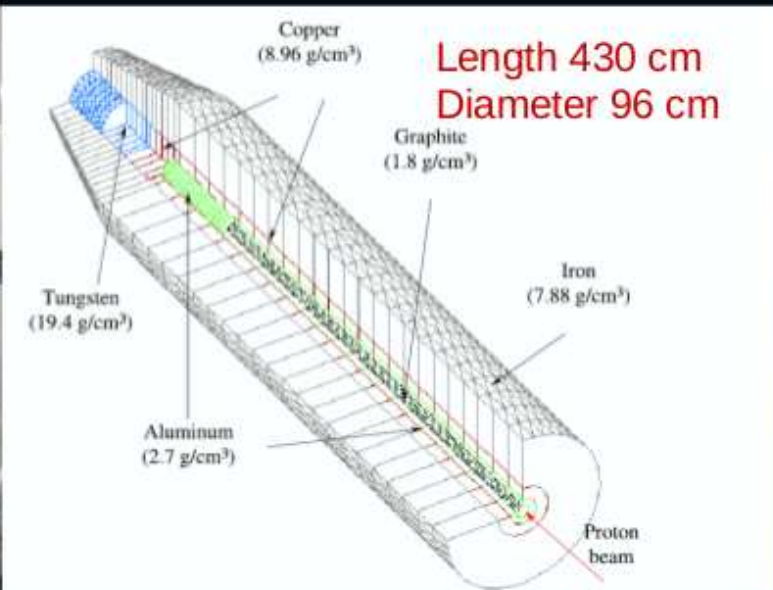
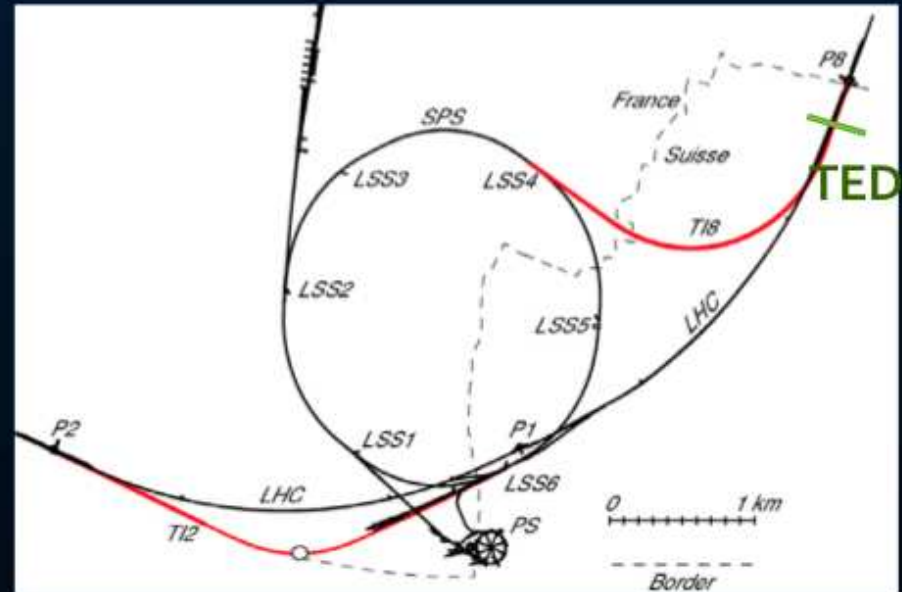
Scintillator trigger close to RICH1

First coincidences (TT/RICH)

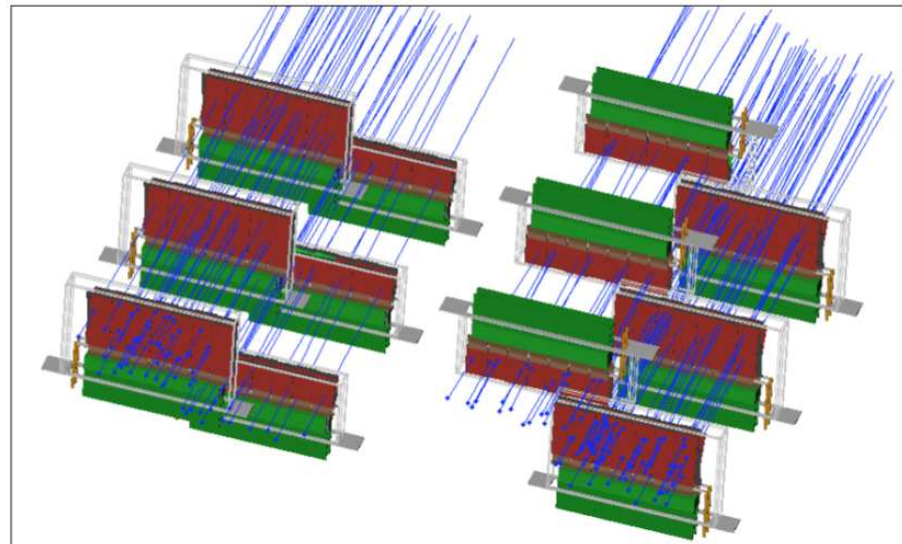
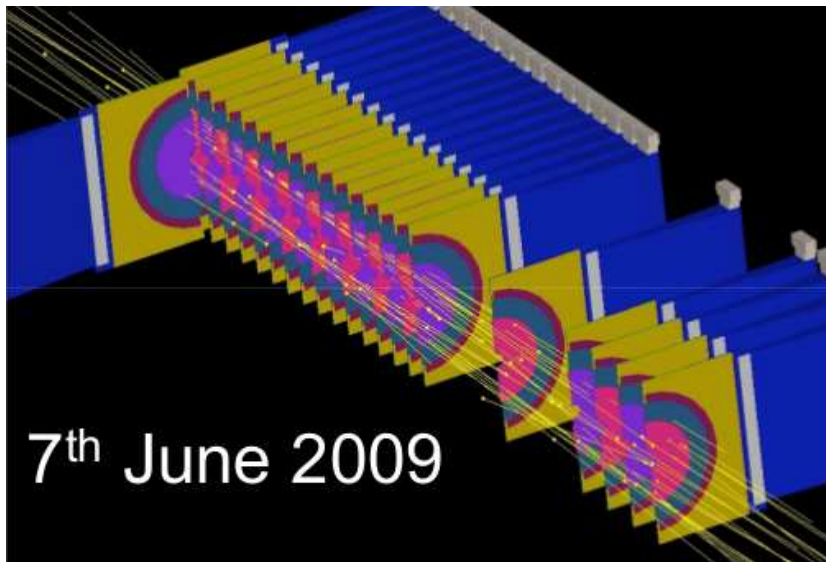
LHC synchronization test

in August and September 2008

- Beam 2 dumped on injection line beam stopper (TED)
- Beam
 - 1 shot each 48 seconds
 - About $5 \cdot 10^9$ protons per shot
- TED is an absorber at the end of the injection line
 - 4m tungsten, copper, aluminium, graphite rod in a 1m diameter iron casing
 - 340m before LHCb along beam 2
 - 8 mrad horizontally and 12 mrad vertically from LHCb beam axis



- ▶ Spray of ~ 10 GeV muons in the detector (no B-field), occupancy (for IT) 10 \times higher than in normal running, almost perpendicular to the planes
- ▶ Wealth of data (50k tracks in IT) from 3 days of data taking in June 2009



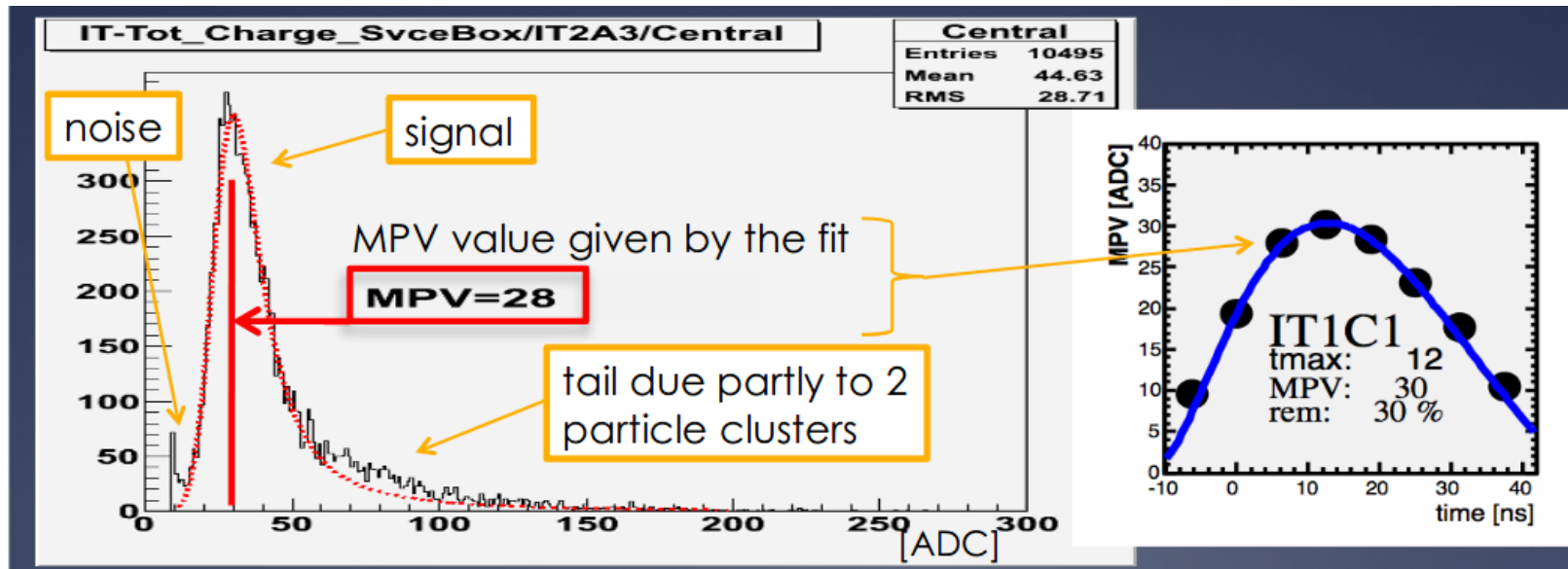
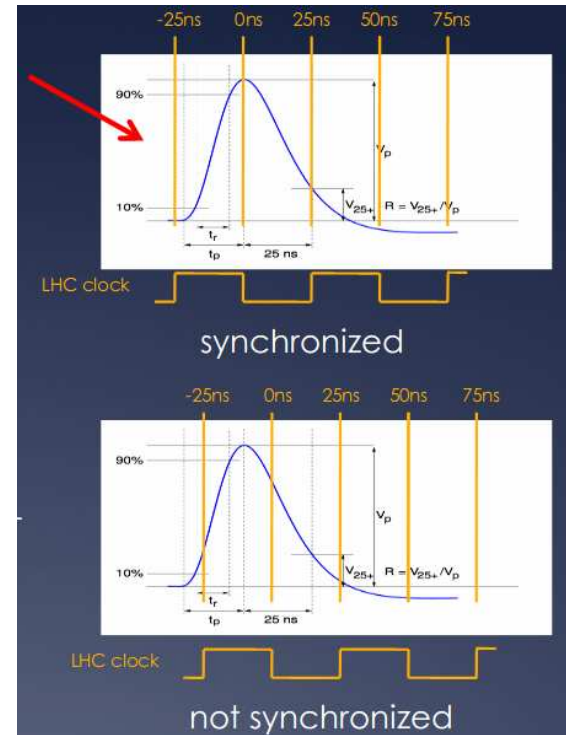
(IT was in open position, in general detectors have been in very different positions during commissioning phase)

ST Time Alignment

time differences between stations due to different cable lengths and different ToF per station

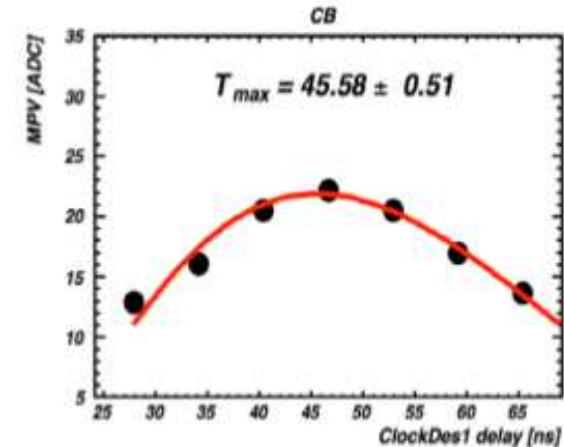
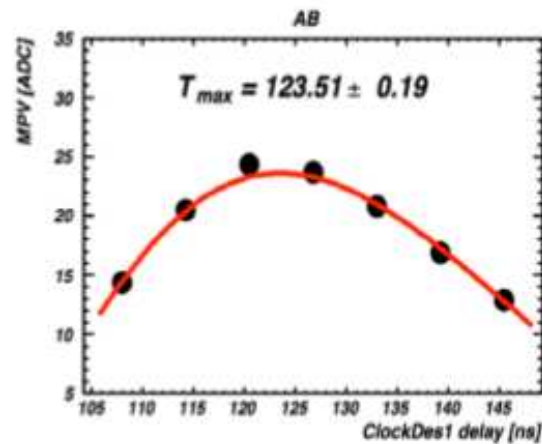
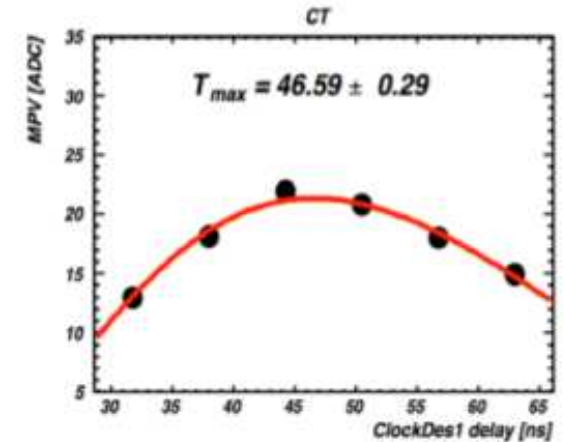
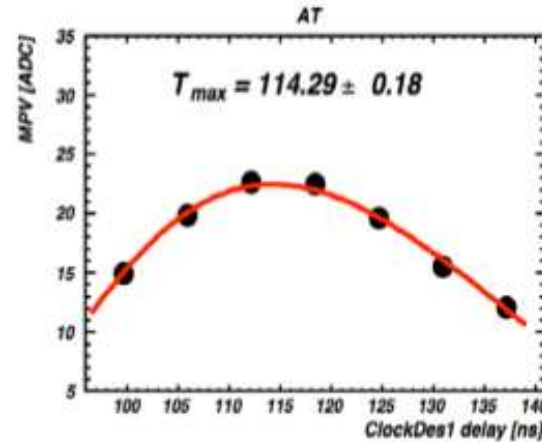
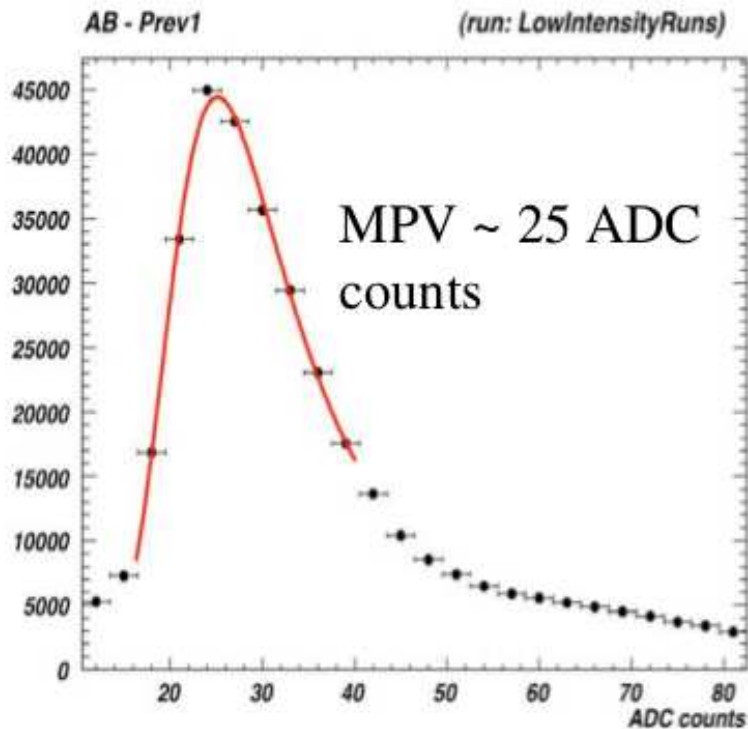
Synchronize sampling time vs. max signal.

Just loop over all clusters, no pattern recognition needed.



TT Time Alignment

Adjust timing delays of four quadrants of TT
Plot signal versus sampling time

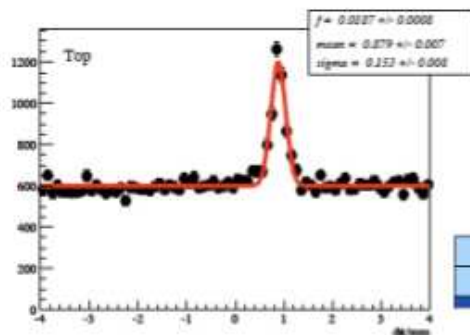
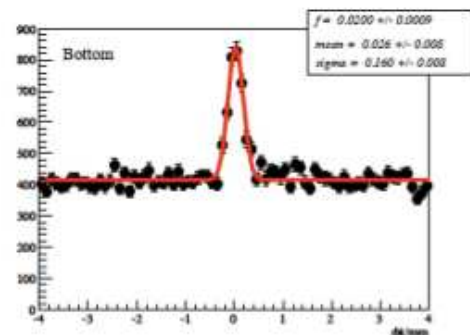
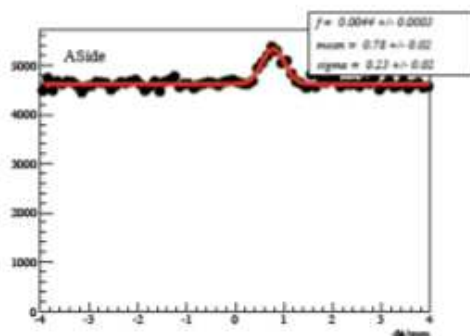
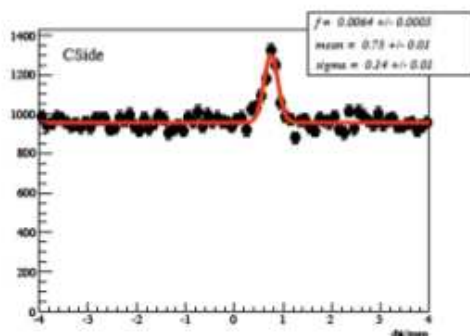
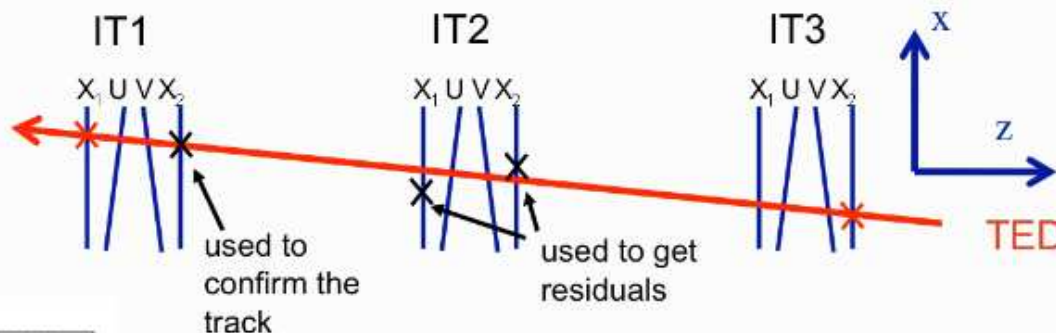


Scanning sampling time →

Internal time alignment of IT and TT better than 1ns after calibration.

“TED events”: occupancy too high for standard track finding.

Survey → Pre-Alignment → Alignment



Simple pre-alignment tracking

- Draw a line with hit in 1st layer of IT1 and 4th layer of IT3
- Line should point towards TED
- Confirm track with another hit in IT1 or IT3
- Residuals in IT2

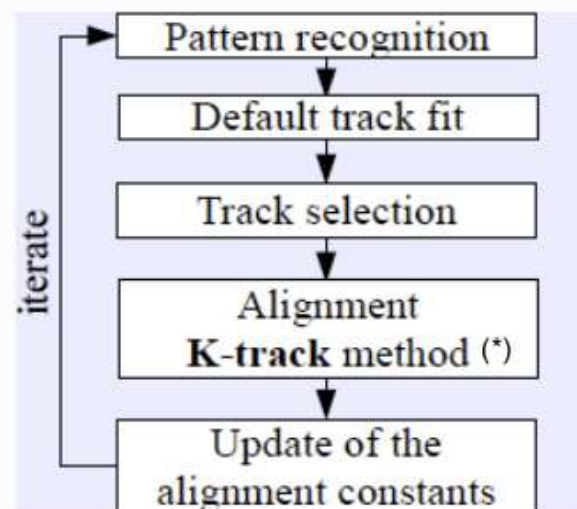
Survey

- Box photogrammetry (~ 1-2 mm)
- Layer survey (~ 50 μm)
 - Only x layer surveyed
- Ladder survey (precision: ~ 50 μm)
 - Only x ladders surveyed

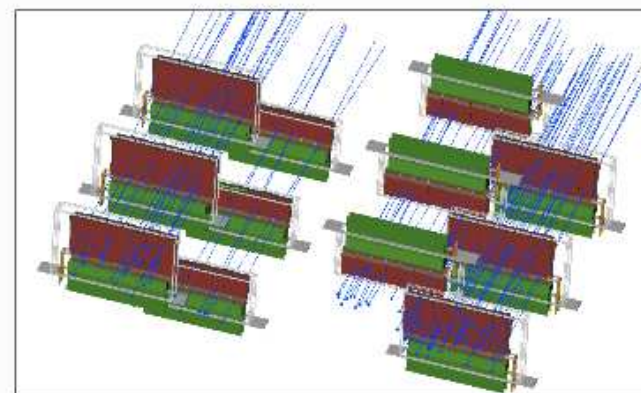
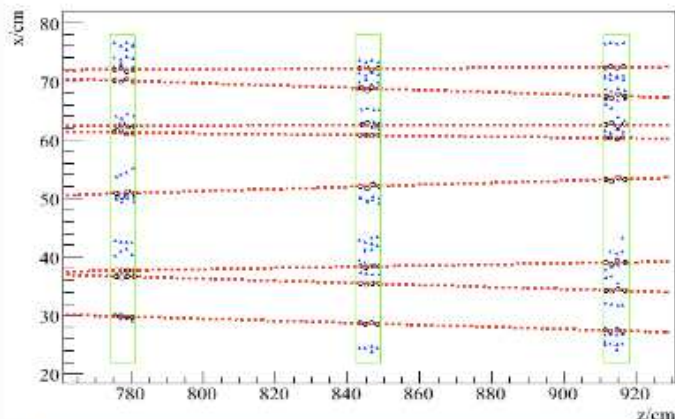
Estimate of x position of the IT2 station boxes

Alignment:

- Use TED runs with lowest occupancy
- Standalone IT reconstruction pointing towards TED
- Alignment of:
 1. Boxes in X, Y translation and Z rotations
 2. Layers in X translation and Z rotation
 3. Ladders in X translation



- Strategy: Evolving χ^2 / dof of reconstructed IT tracks for track selection with iteration
- Ladders were aligned to $\sim 20 \mu\text{m}$ precision with 2008 TED data. Will improve in 2009 TED



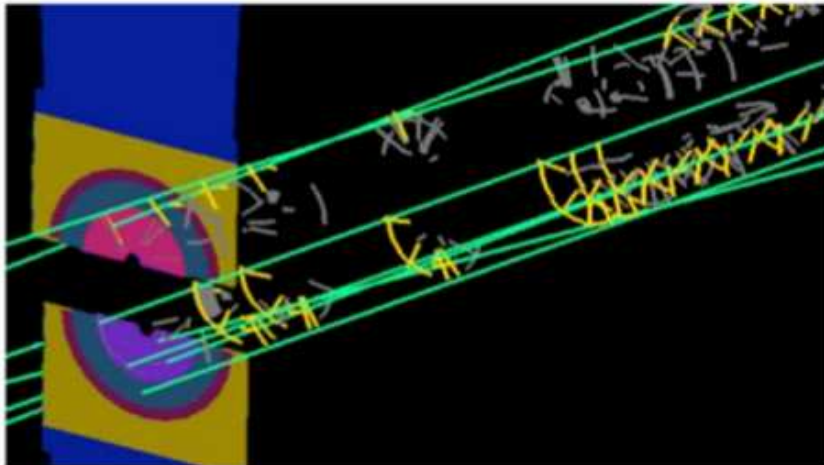
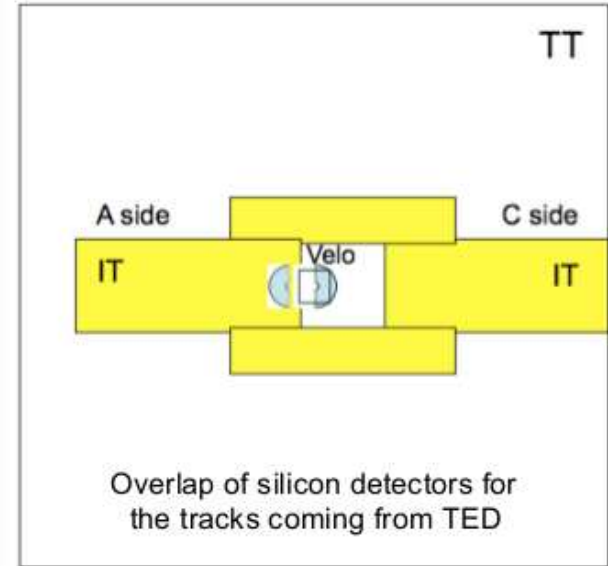
(*) NIM A600: 471-477, 2009

“TED” events

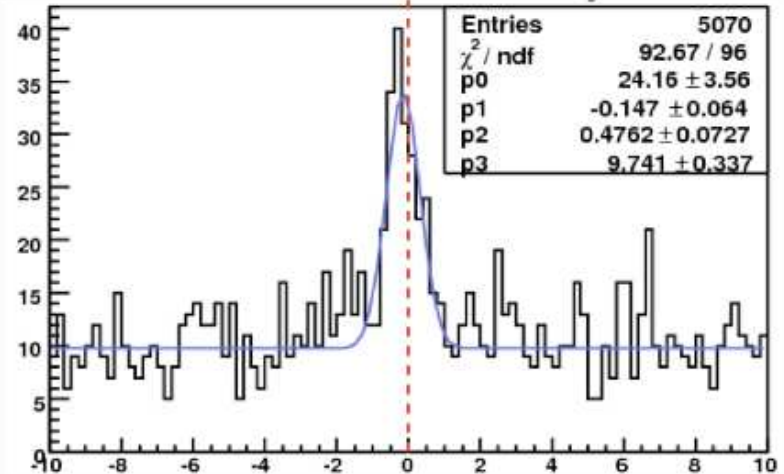
- No standalone TT track reconstruction, TT has only 4 layers (X,U,V,X)
- Track candidates from the VELO extrapolated to the TT:
 - Search for hits in the TT (min 3 hits in 4 layers)
- VELO acceptance very limited -> small region of TT illuminated by VELO tracks around beam pipe -> no individual module alignment
- Survey → Align full station in x and y rotation

Survey: Full station (500 μm) Module support (50 μm) Sensor metrology assembly (10 μm)

2008 TED run



Extrapolate VELO Track candidates



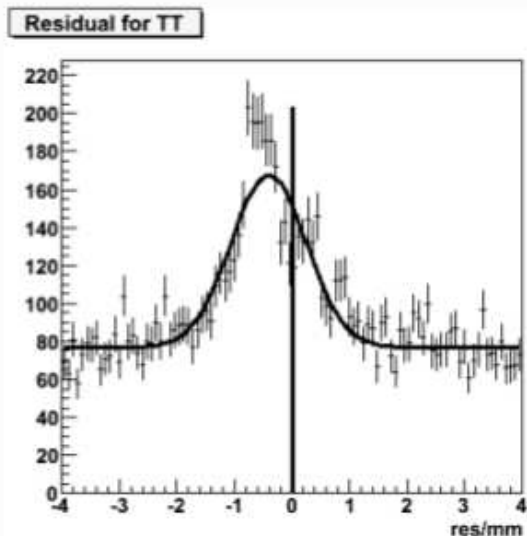
Residuals in TT (TT a/U)

Residuals of TT hits to extrapolated VELO tracks

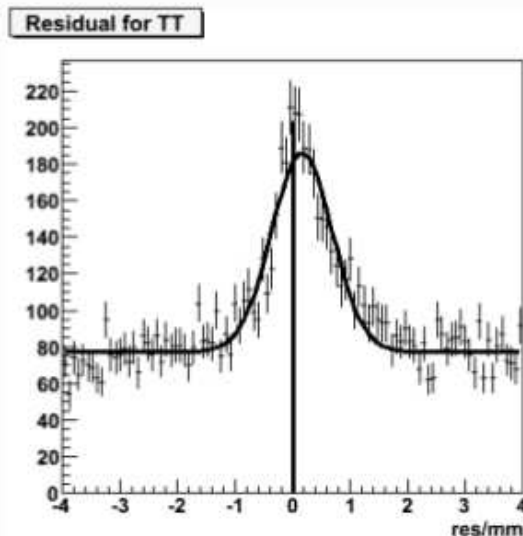
Nominal

Survey

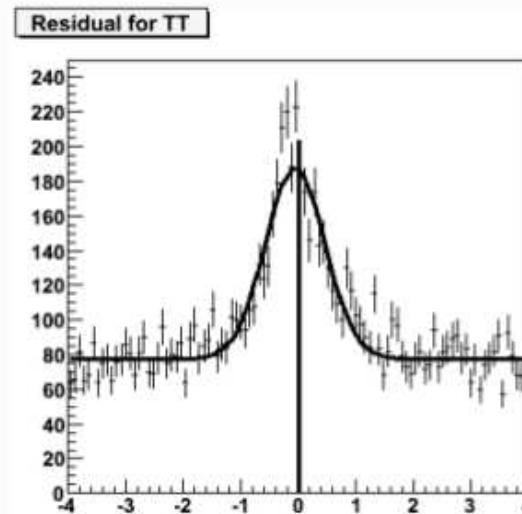
Aligned



Mean: -0.404 mm
Width: 0.655 mm

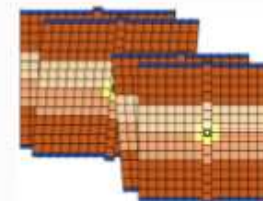


Mean: 0.162 mm
Width: 0.526 mm



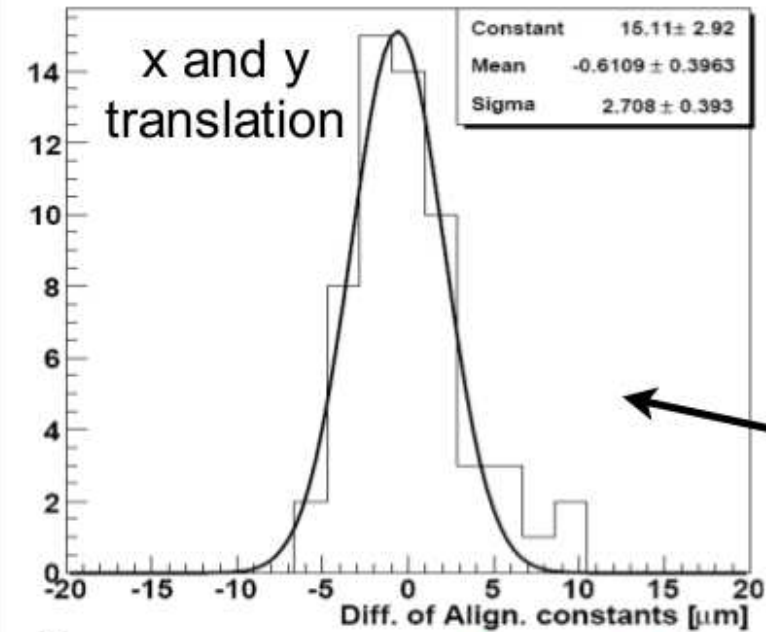
Mean: -0.053 mm
Width: 0.519 mm

Only alignment of full station

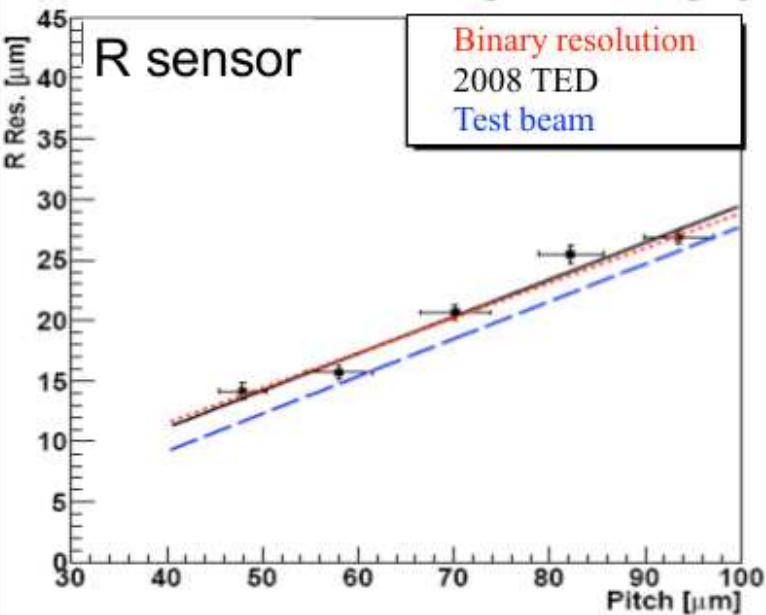




Vertex Locator alignment (TED)



- align Velo with data from TED run 1 and run 2 in 2008
- plot difference of constants

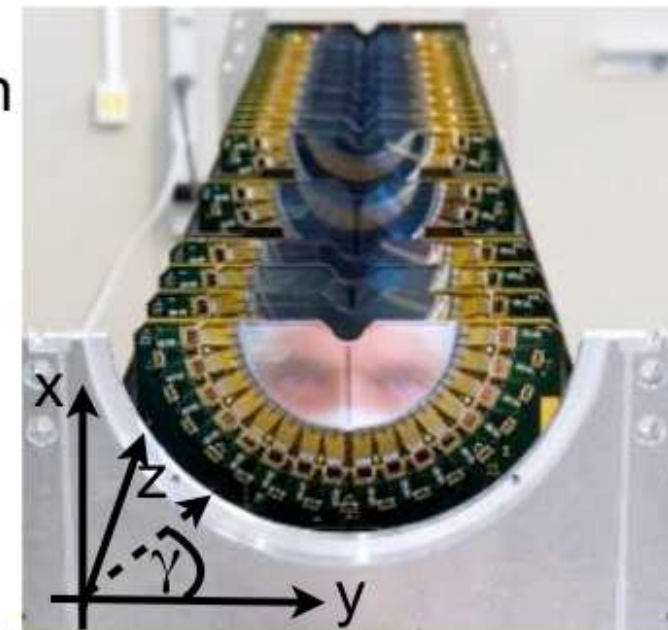


- TED data resolution matches binary resolution
(Test beam data with optimal threshold settings)

Module alignment accuracy

x and y translation:
 $5 \mu\text{m}$

z rotation (γ):
 $200 \mu\text{rad}$

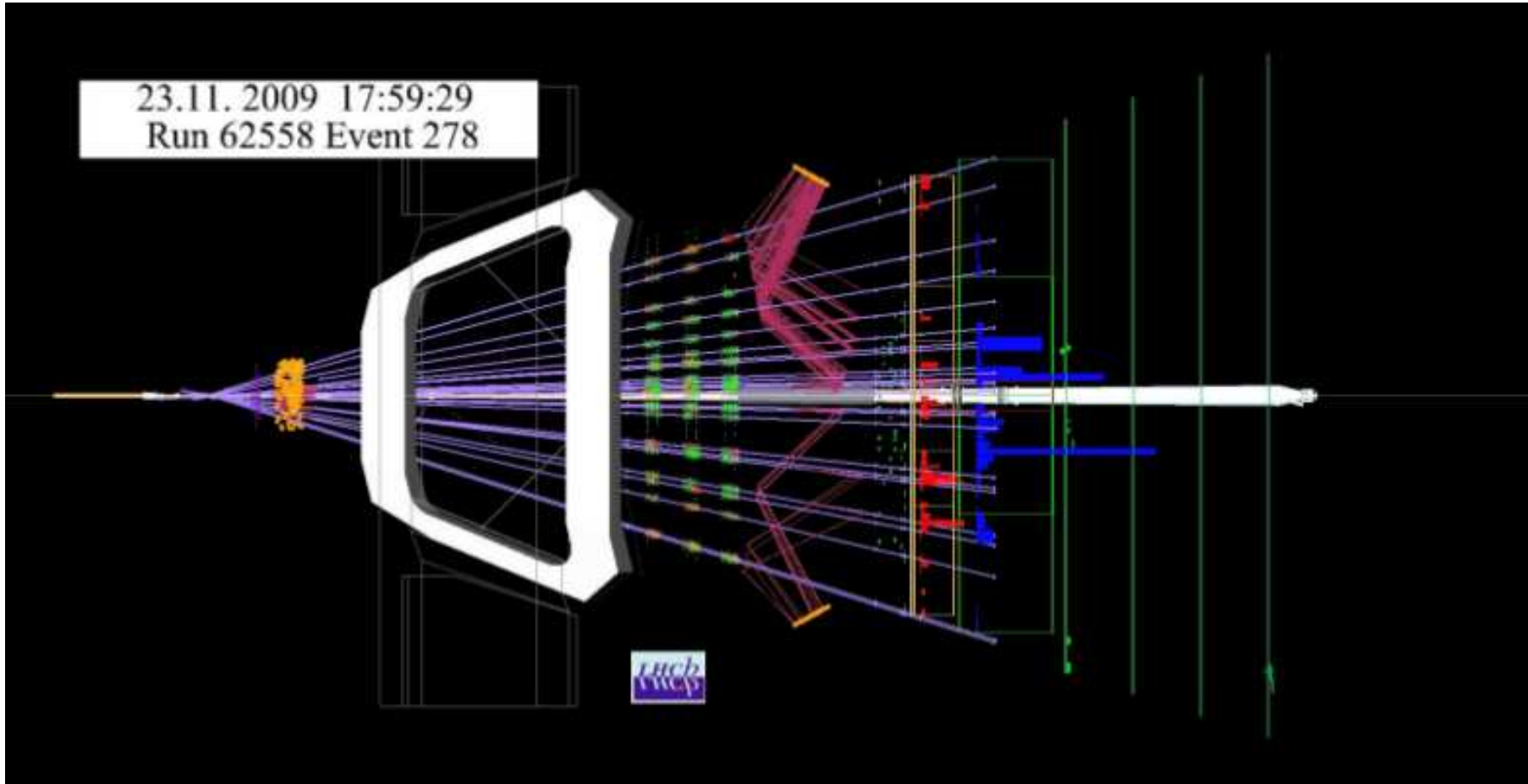


Summary of pre-beam commissioning

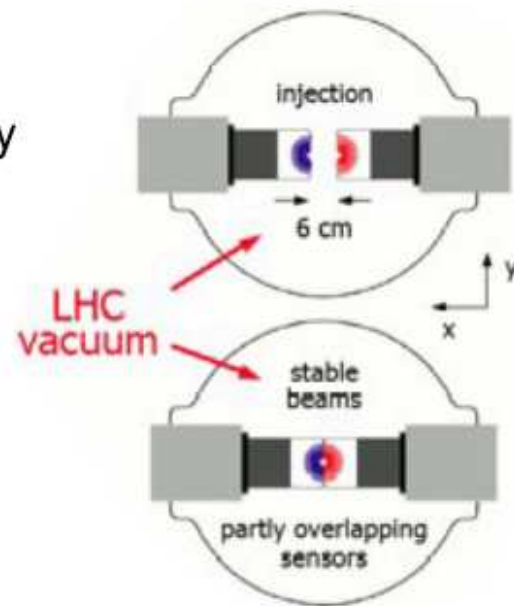
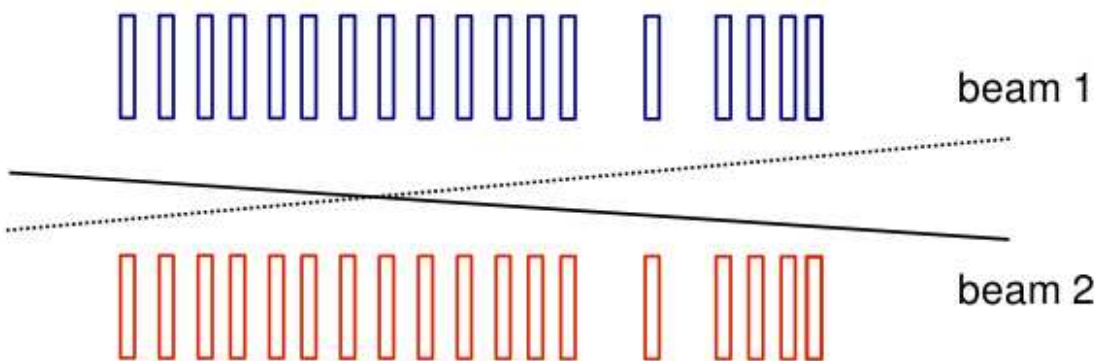
- ▶ need to be able to trigger with simple triggers on special type of events (depending which detector component is available at this time)
- ▶ need to be able to adapt/rewrite algorithms flexible (only one sub-detector component, different slopes, no B-field, no pointing back to the PV, different occupancies, ...)
- ▶ flexible code and well trained people needed to put their hands in the code
- ▶ very usefull data, complementary to beam data (no B-field, low occpancy, detector (partially) open, parallel tracks (binary resolution), all about 10 GeV
- ▶ very much hope to get some of this data in 2020
there will be huge pressure to show results on this data

With a hand full of events the detectore was in pace up to $\pm 10\text{-}20\%$ of the expected performance at the start of pp collisions

Finally first pp collisions



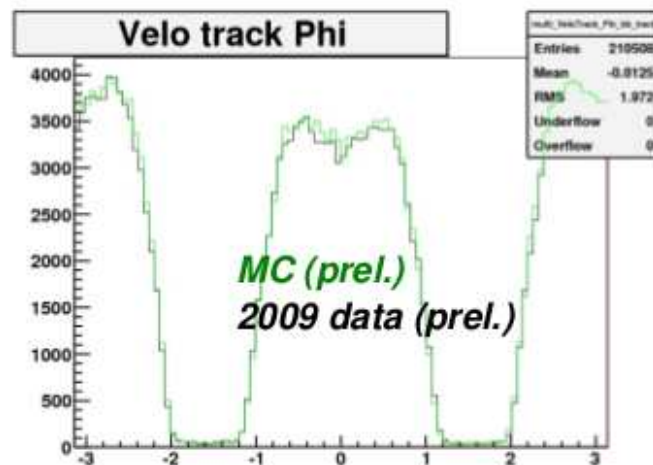
- LHCb vertex detector consists of two movable halves
- to correct for di-pole, angle of beams depends on energy



➔ velo can only be safely closed if $E_{\text{beam}} > 2\text{TeV}$

➔ at 450+450 GeV

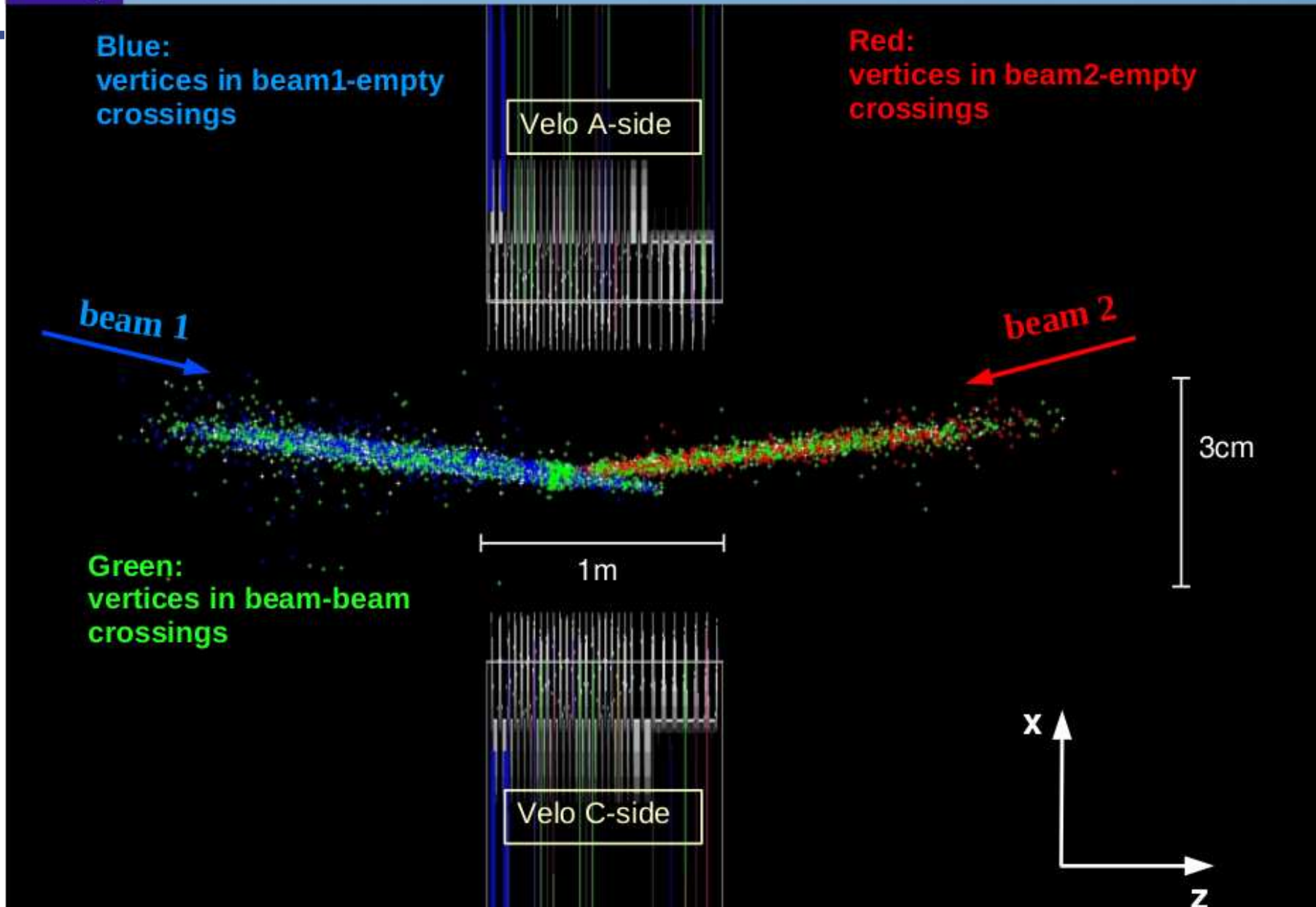
- reduced phi acceptance
- poorer vertex resolution (but in agreement with expectation)



Moriond EW 2010 – W. Hulsbergen (Nikhef)

Early measurements mainly based on downstream tracks.

How to measure downstream tracking efficiency without tag tracks in the velo?

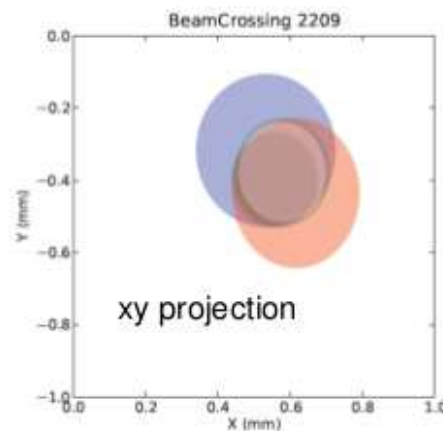
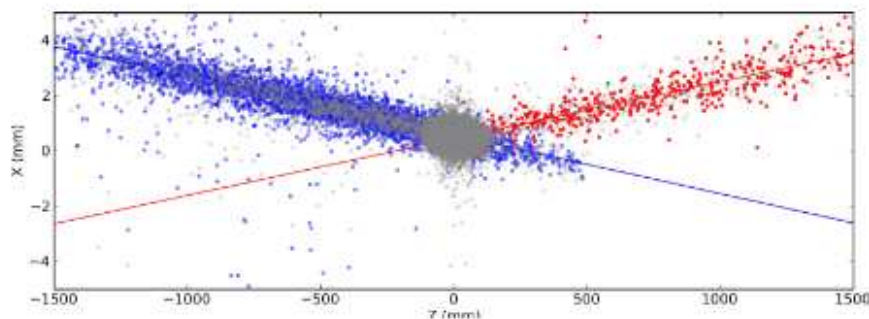
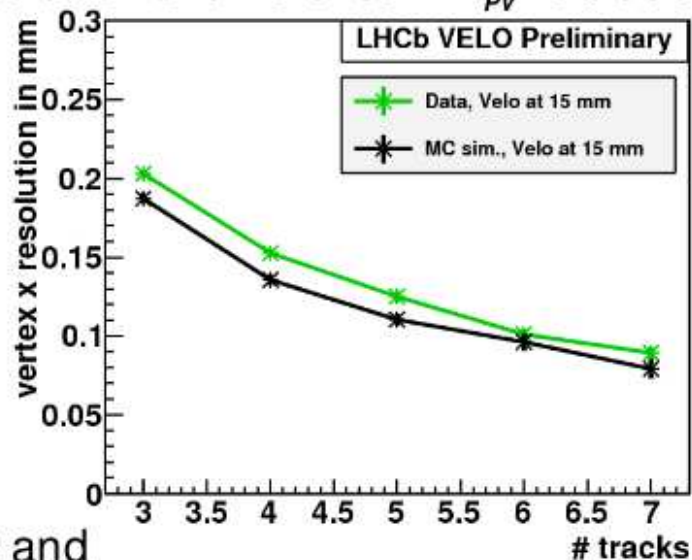


no constraints to origin of the tracks in the velo pattern recognition

- vertex resolution measurement
 - in each event, randomly split track set in 2
 - reconstruct PV with both sets
 - estimate resolution from difference
- ➔ within 10% of expectation from MC

- excellent PV resolution allows to measure size and position of both beams
 - feedback for LHC (e.g. VdM scan)
 - allows direct measurement of luminosity at LHCb

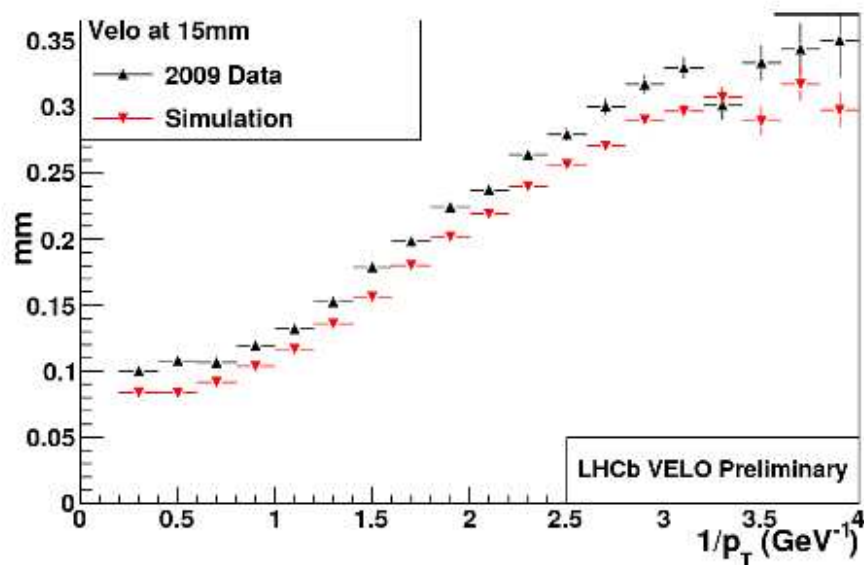
resolution of difference in x_{PV} vs # tracks



See also YSF: P. Hopchev,
"Luminosity measurement at LHCb"

- good impact parameter crucial for prompt background rejection
 - performance also representative for proper time resolution
- in LHCb usually presented as function of $1/p_T$:

resolution of distance of track to PV versus $1/p_T$



note: VELO *open*

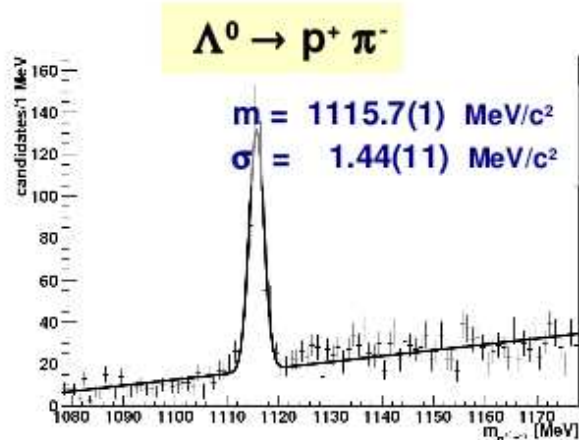
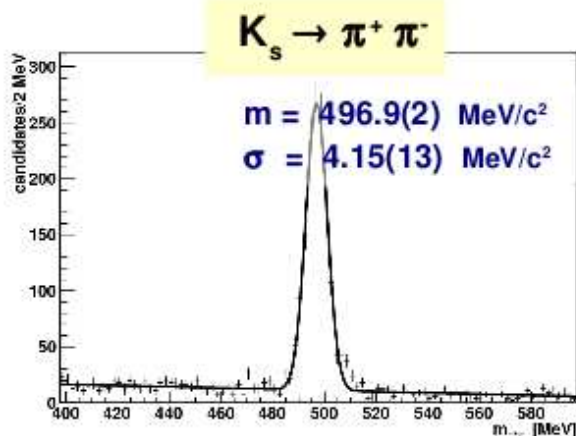


factor ~2 improvement with VELO *closed*

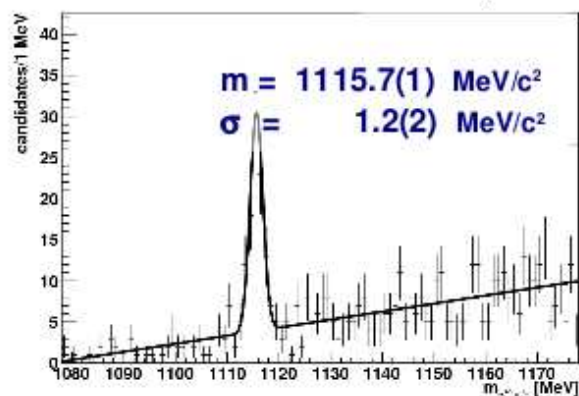
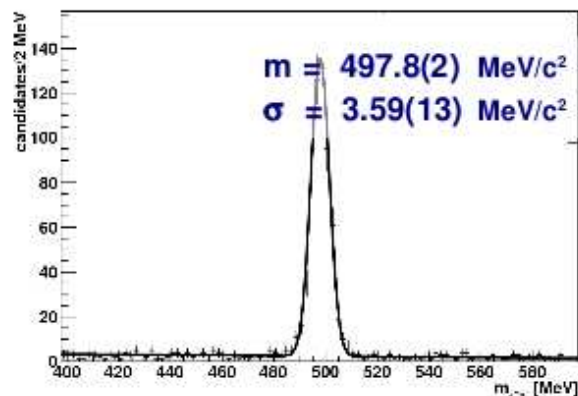
- IP resolution within ~20% of expectation
 - more than sufficient for trigger and physics analysis
 - improvement expected with better alignment

→ true for selections
not true to resolve B_s mixing

- spectrometer performance estimated from mass resolution of V0 signals



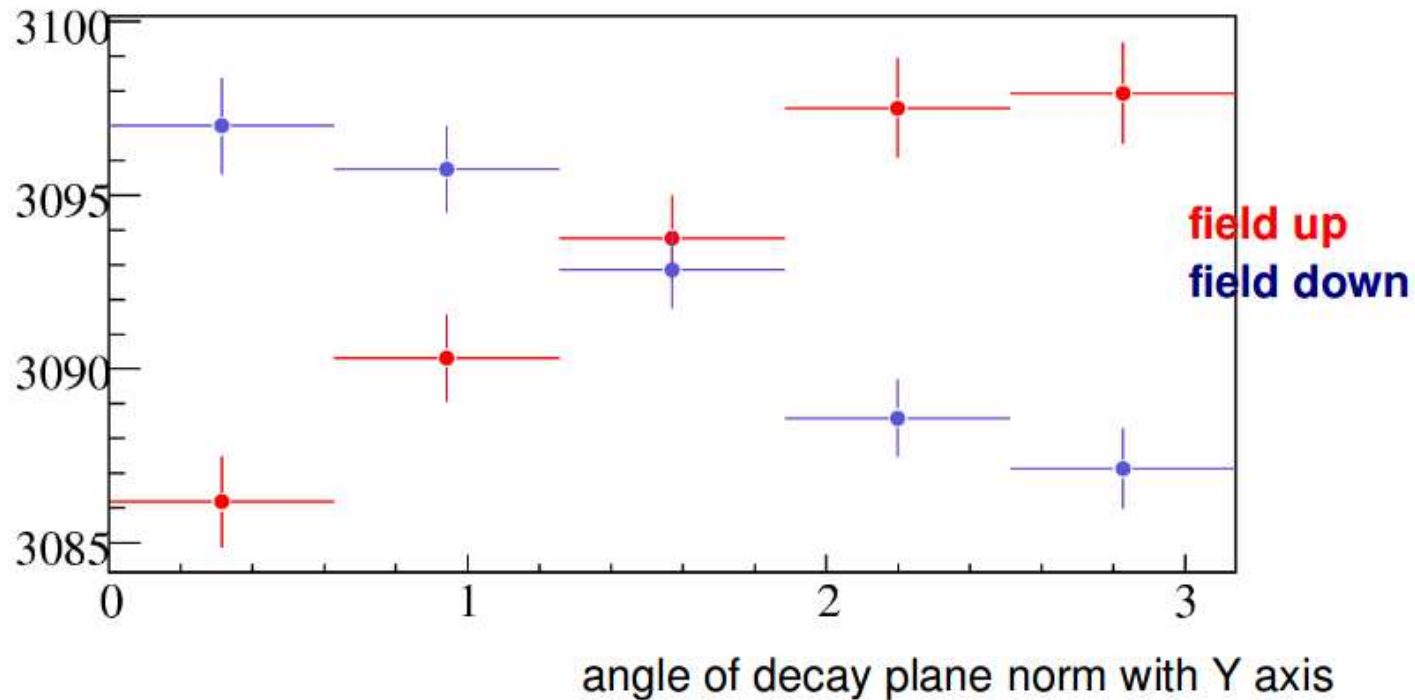
*LHCb 2009 data
(preliminary)*



*LHCb 2009 MC
(preliminary)*

- momentum resolution about 20% worse than in simulation
 - analysis of spectrometer alignment in full swing
 - expect significant improvement once we have collected large $J/\psi \rightarrow \mu\mu$ sample

Status June 2010:

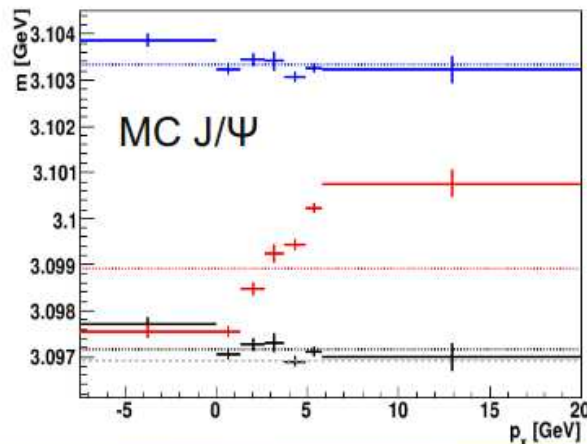
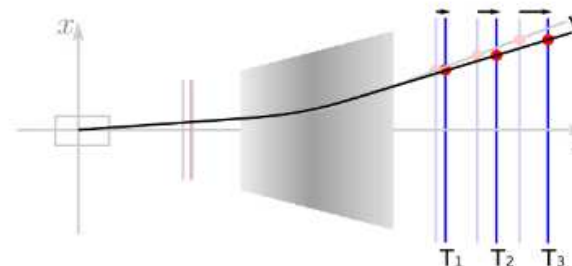
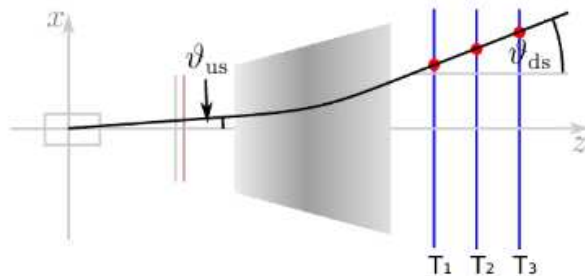


- note: the angle tells you whether you are dealing with 'sailors' or 'cowboys'!
- next step
 - use this in alignment (already tried, actually)
 - understand why alignment doesn't fix it ...

How can we distinguish between B-field scaling and z scaling?

→ discriminating variable: $\Delta p_{x; ds} = p_{x; ds}^+ - p_{x; ds}^-$ (Marco Rothley)

$\Delta p_{x; ds}$: downstream momentum in x-direction obtained from a track state after magnet



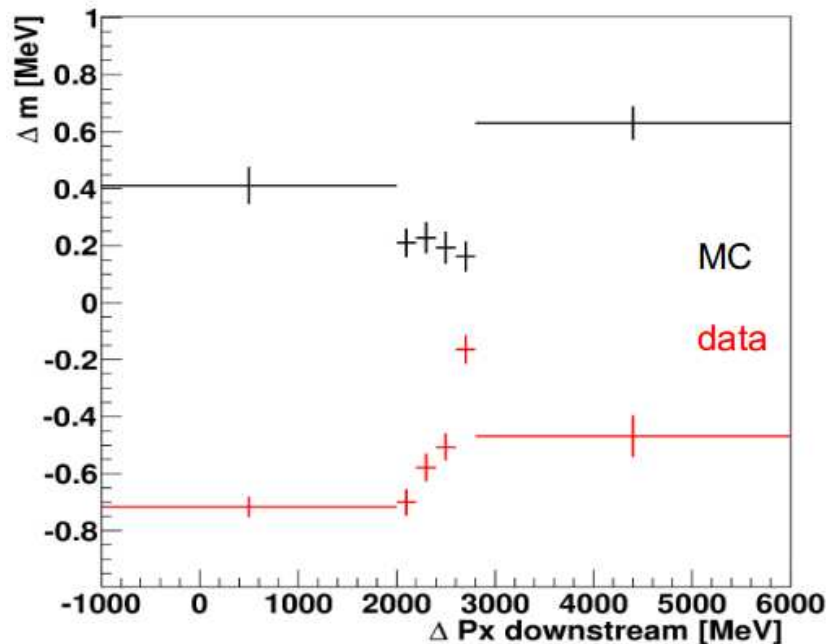
B-field scaling: global offset

z scaling: K_s with large Δp_x are more affected

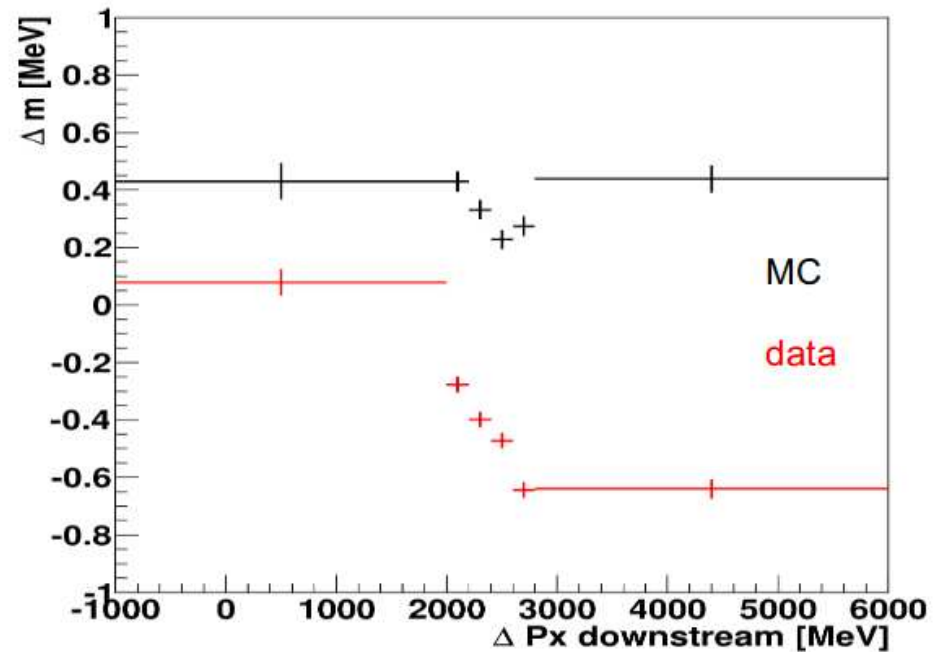
no scaling



downstream



long tracks



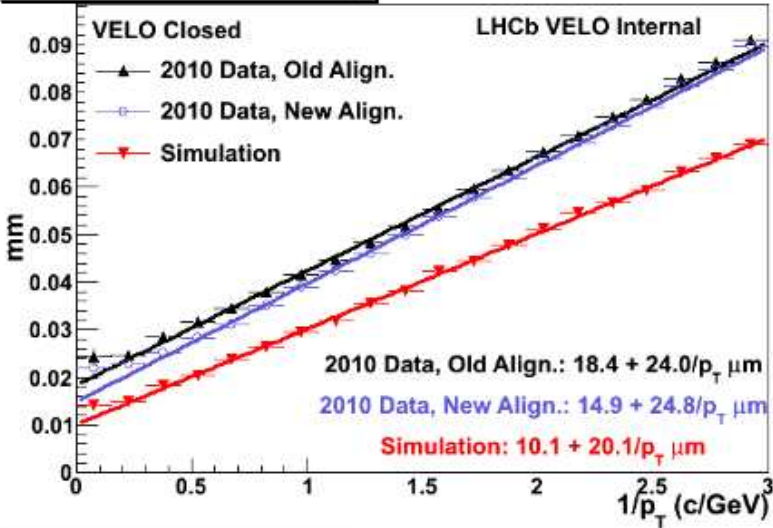
- MC almost flat, clearly not the case for data
- differences in shape for downstream and long tracks
 - probing different z scales: Velo – TStations, TT – TStations, TStations internally

IP resolution

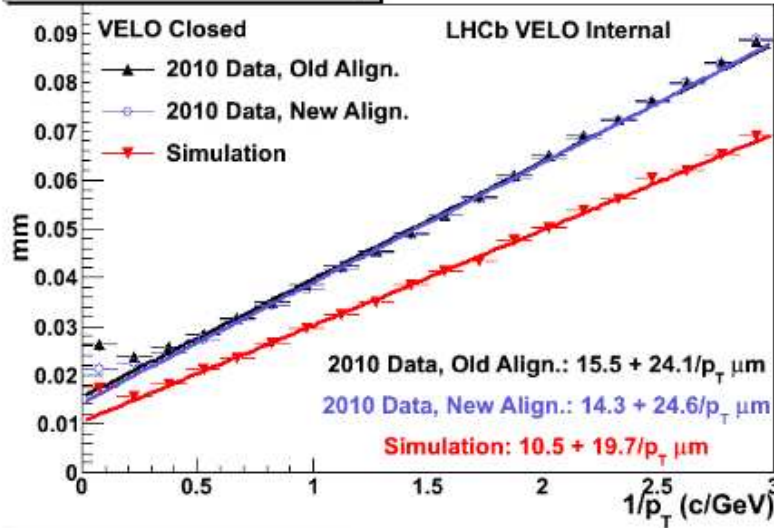


Effects of Improved Alignment

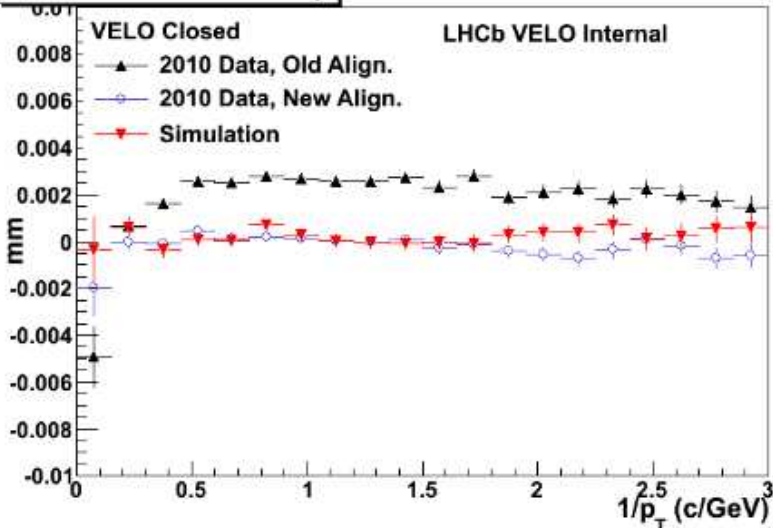
IP_x Resolution Vs 1/p_T



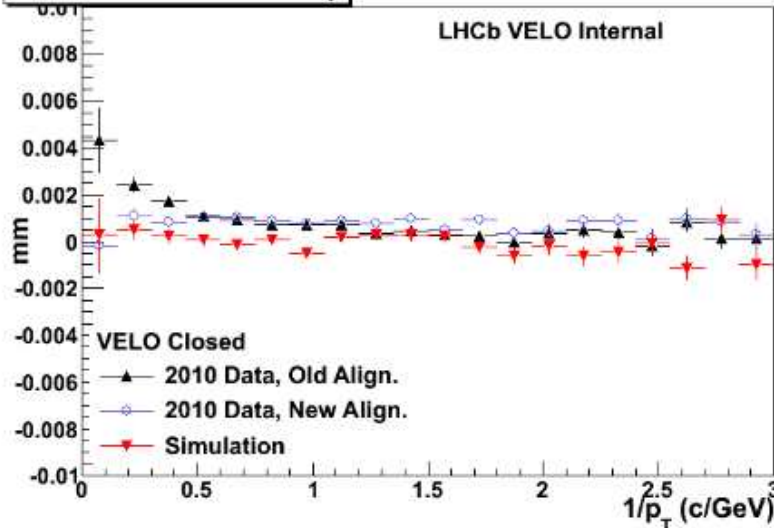
IP_y Resolution Vs 1/p_T



Mean of IP_x Vs 1/p_T



Mean of IP_y Vs 1/p_T



Weak modes

Most of the problems didn't had one single reason.

B field map was measured (at a few spots) with open not with closed detector rest extrapolated from simulation → new map brought some improvements

Very little crossing tracks in neighbouring modules.

→ heavily rely on good initial positions from survey to not run in local minima

→ new survey parameters contributed to improvements

Survey are often taken in open position and different reference frame than the geometry DB used for reconstruction, a lot of communication and common work of software and detector people needed to translate them properly.

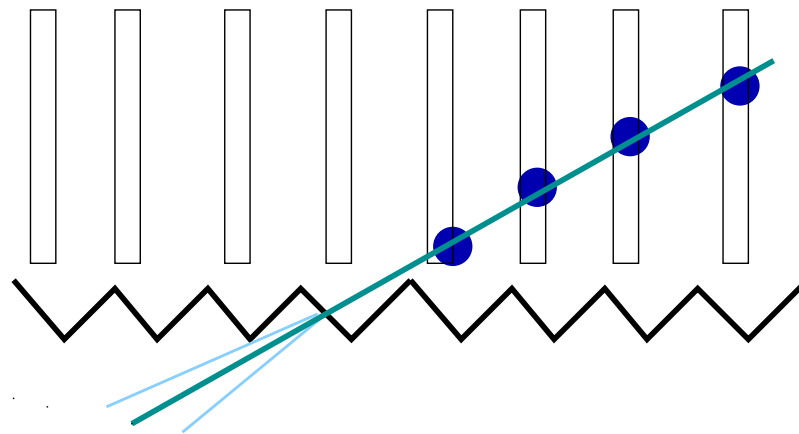
Included B field on and B field off data (including TED data = high momentum tracks) and resonances to alignment.

To get within 10-20% of simulation is relatively easy, then the hard work starts.

Surveil matter distribution (not only total matter content of subdetectors)

Describe matter distribution properly in the simulation

e.g. RF foil:

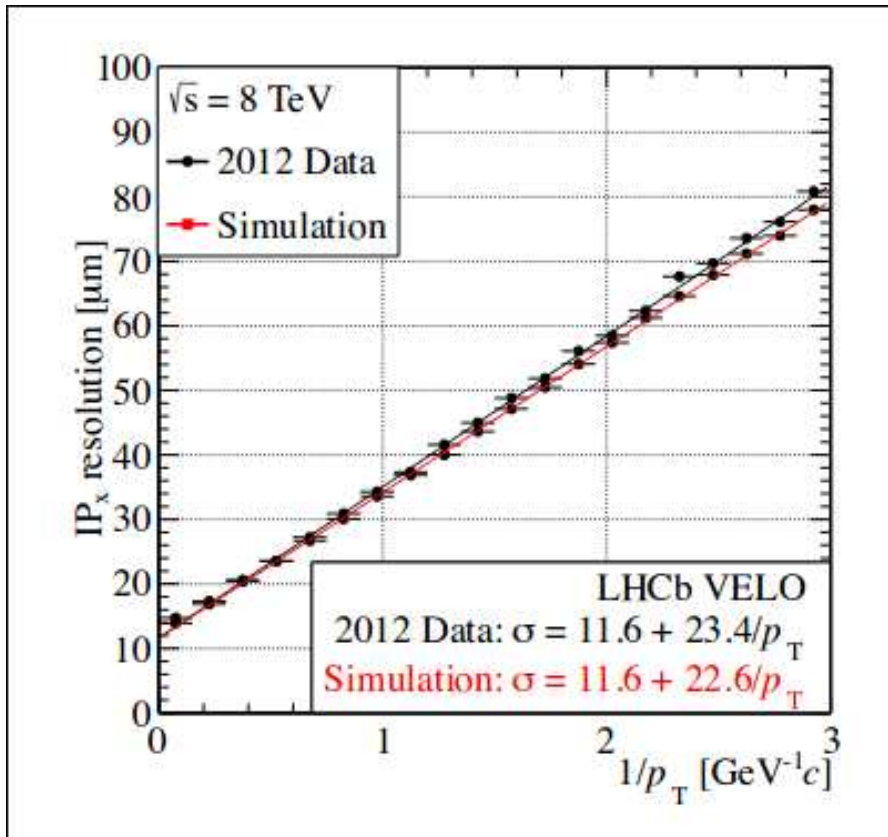


Shape of RF foil was wrongly modelled

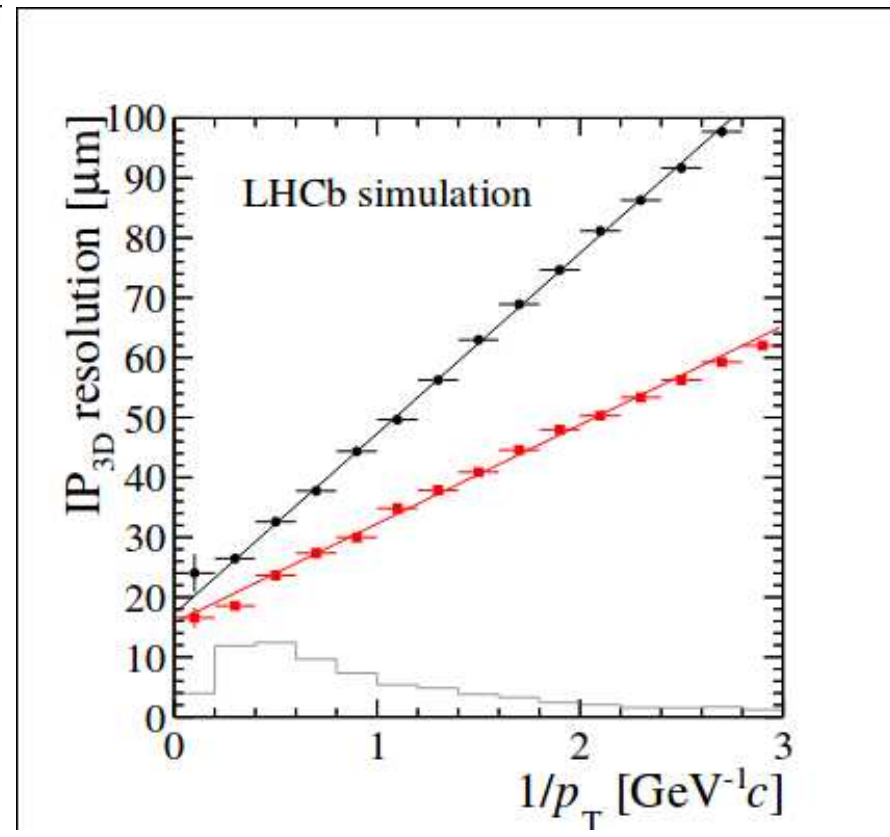
Slight difference in the curvature, changed the amount of material traversed in average and the position of the scattering → simulation was too optimistic

Current vs. Upgrade

Since 2012 very good agreement between data and Monte Carlo:



current data current simulation



current upgrade simulation

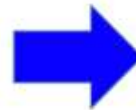
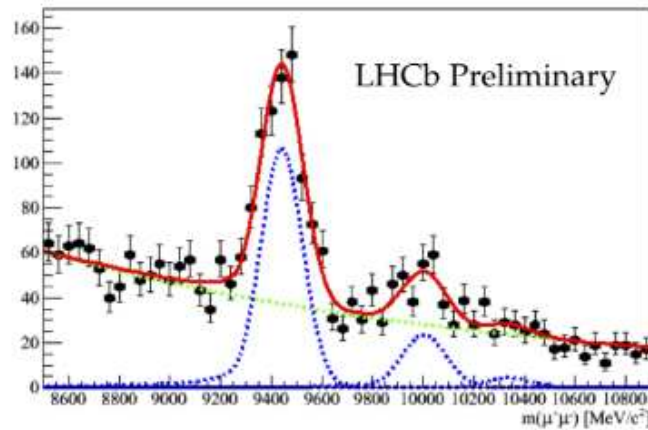
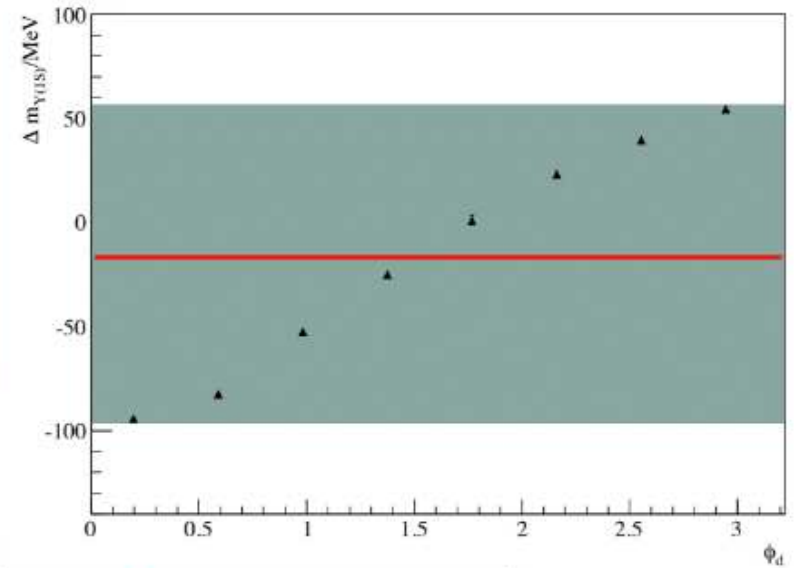
It will be tough to be in 2021 out of the box better with the upgrade detector compared to the current one.

Impact of mass constraints

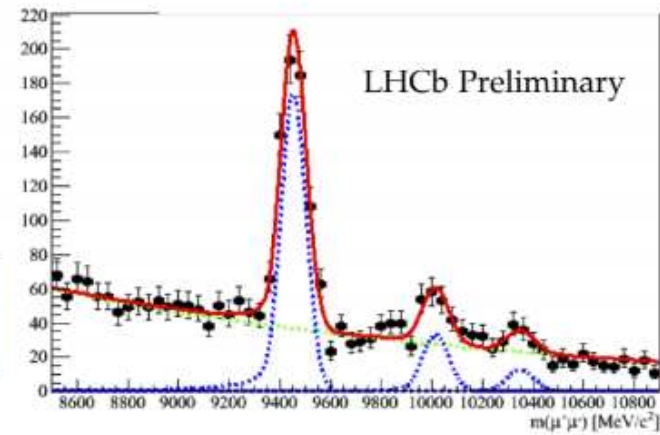
First versions of LHCb alignment in 2010 showed large variations in masses versus kinematics: Variations so big they degraded the resolution

e.g. angle between decay plane and field

Studies of mass identified problem and allowed to fix

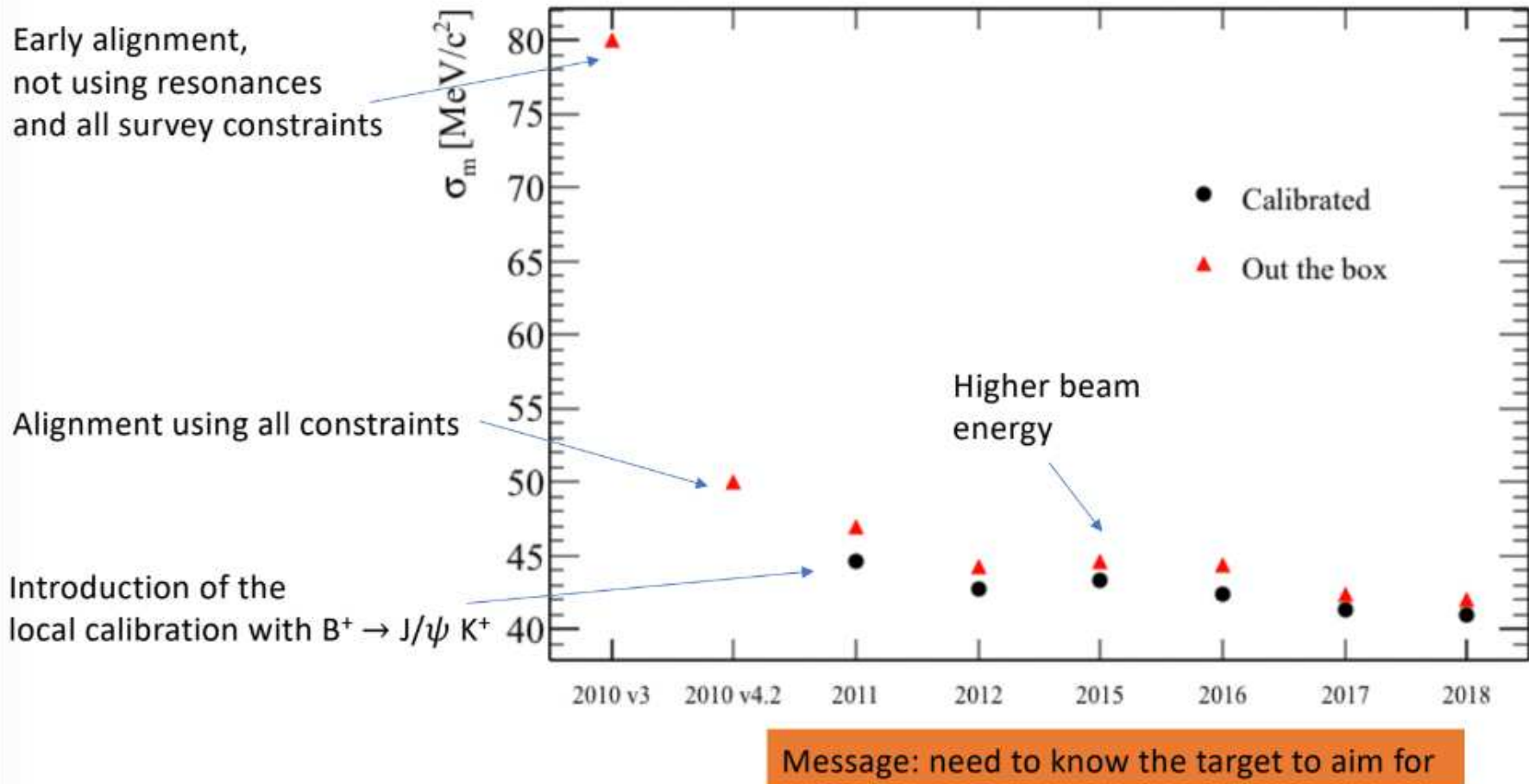


Better alignment



(see talk from Matt in RTA general meeting)

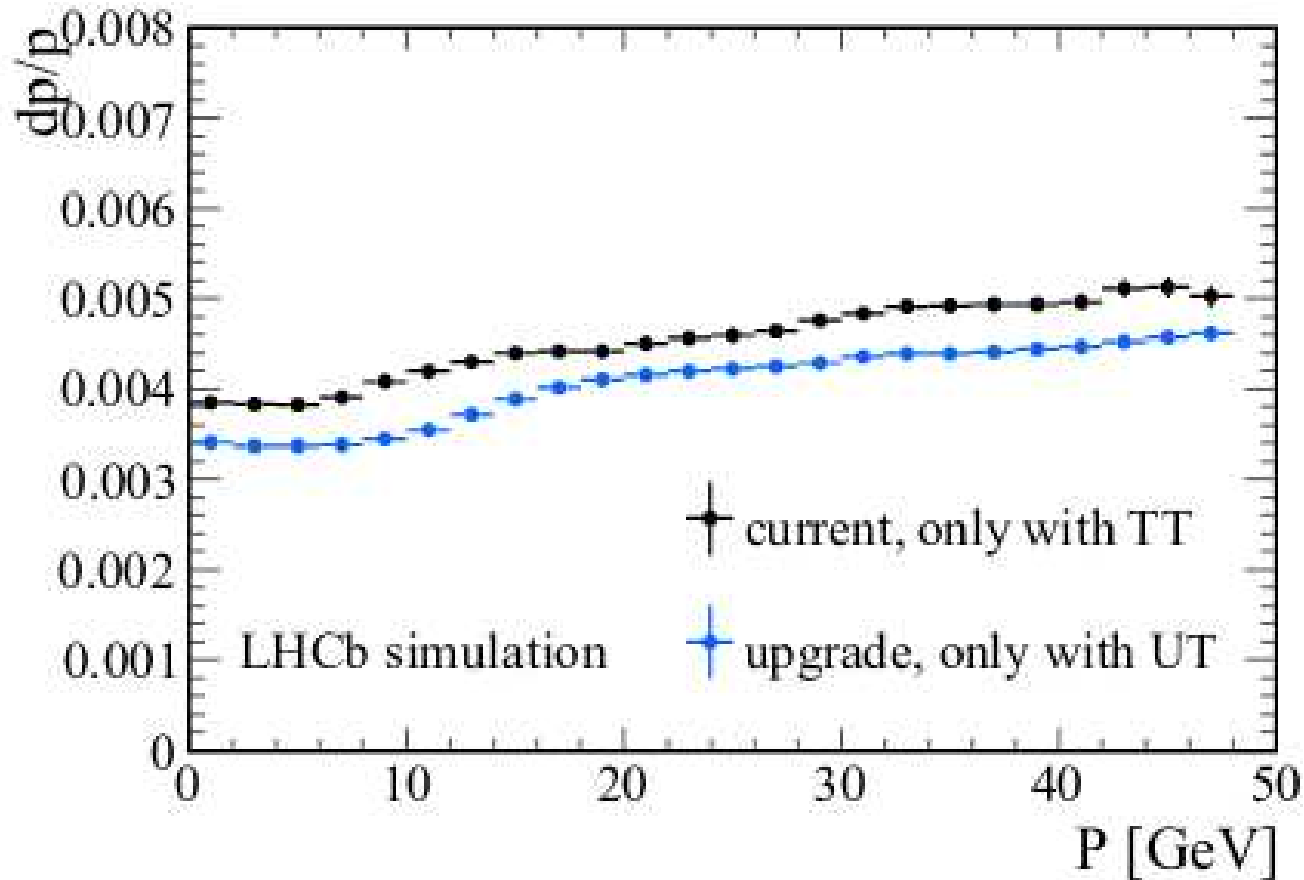
Mass resolution



mass resolution in MC: 37 MeV

(see talk from Matt in RTA general meeting)

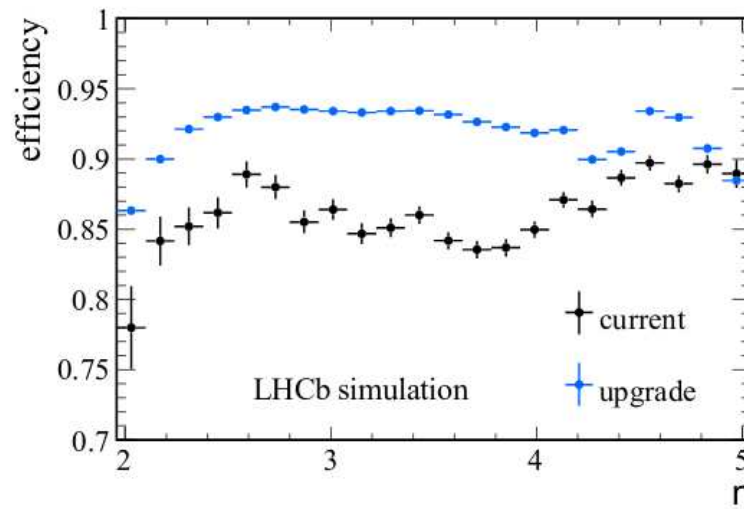
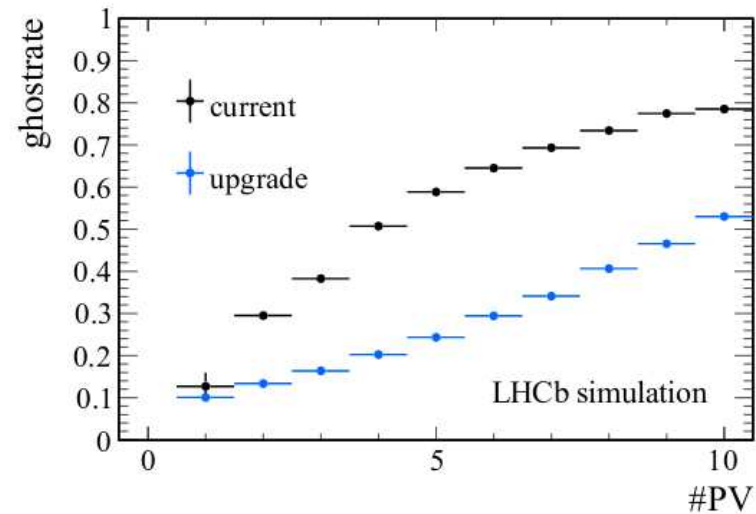
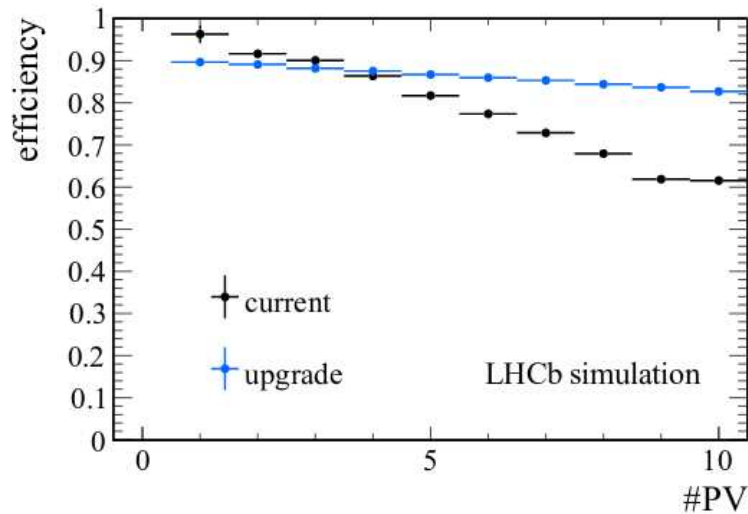
Momentum resolution



We expect 10% improvements in momentum resolution in the ideal upgrade detector compared to the current one from simulation [from Tracker TDR, 2014].

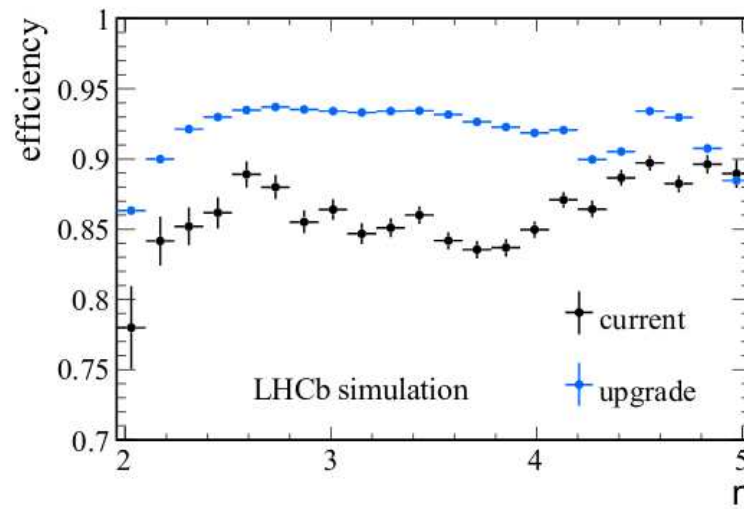
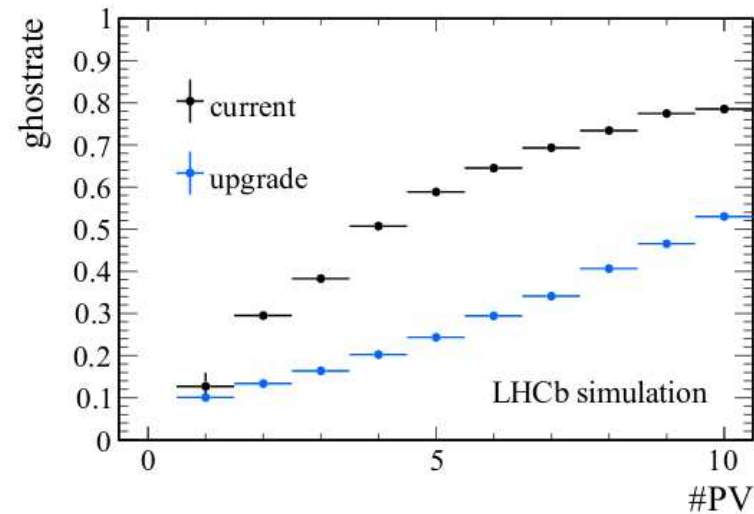
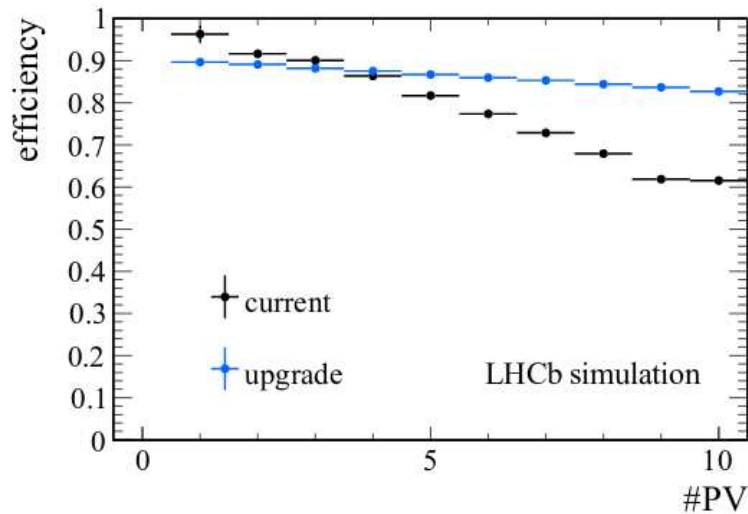
Current vs. Upgrade

If we compare Forward tracking of current and upgrade detector for a sample $\nu = 7.6$ the upgrade detector does better :-).



Current vs. Upgrade

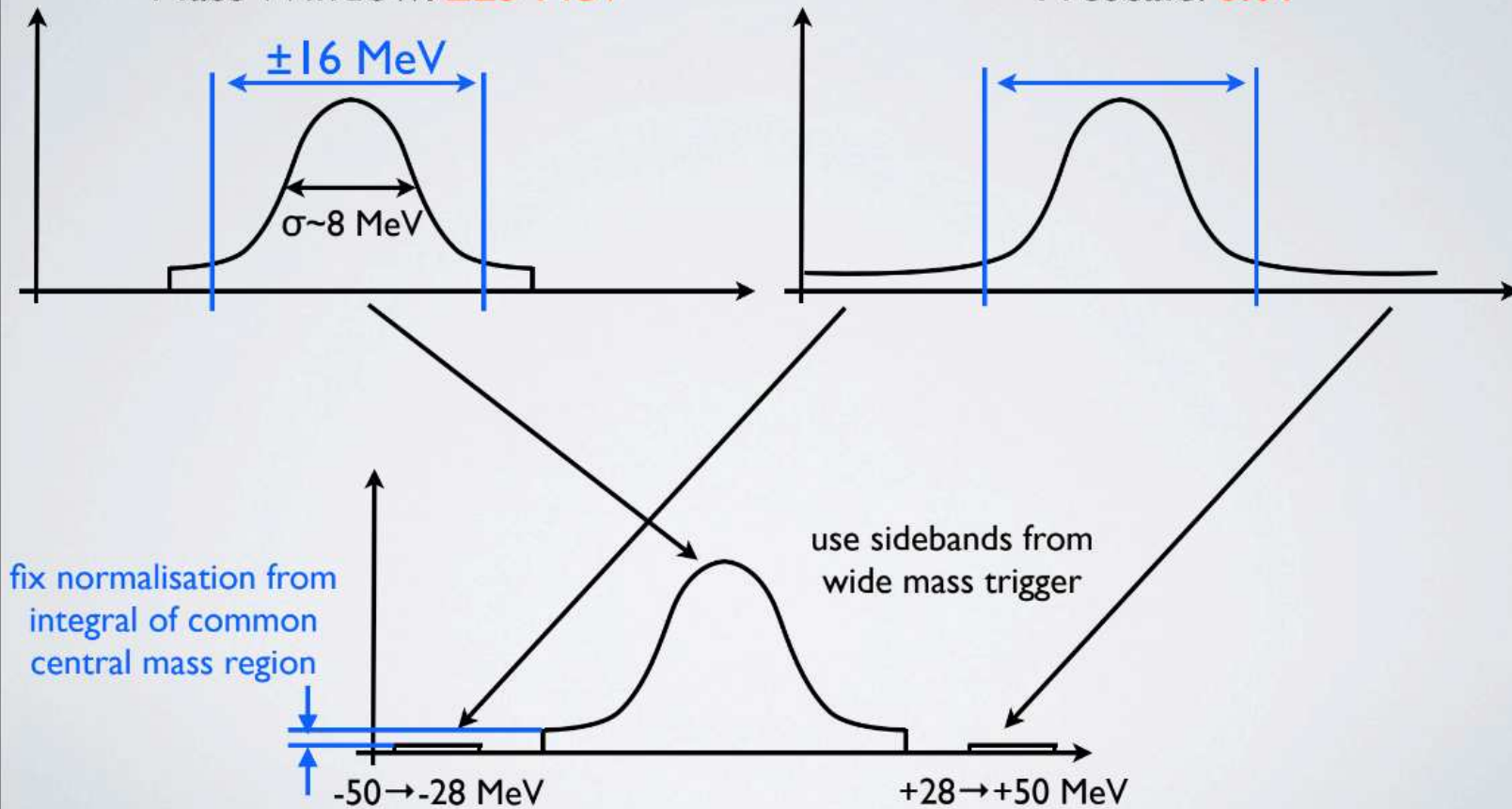
If we compare current detector at $\nu=2$ with upgrade detector at $\nu = 7.6$, the upgrade will do significantly worse :-). input from Velo is actually better



MASS WINDOWS

Hlt2CharmOSTF2Body
Mass Window: ± 25 MeV

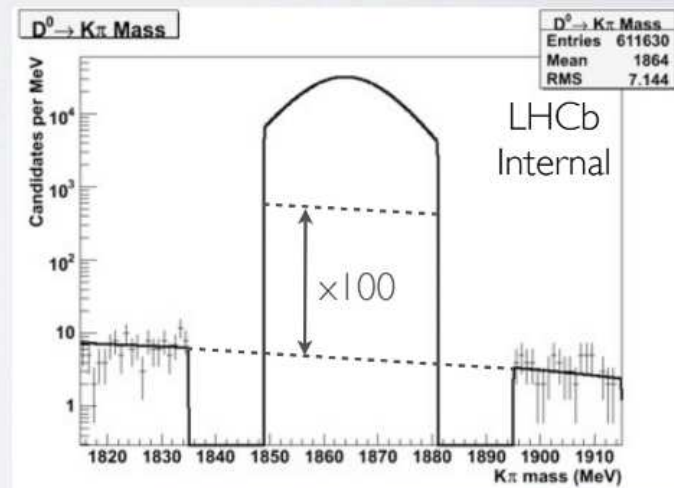
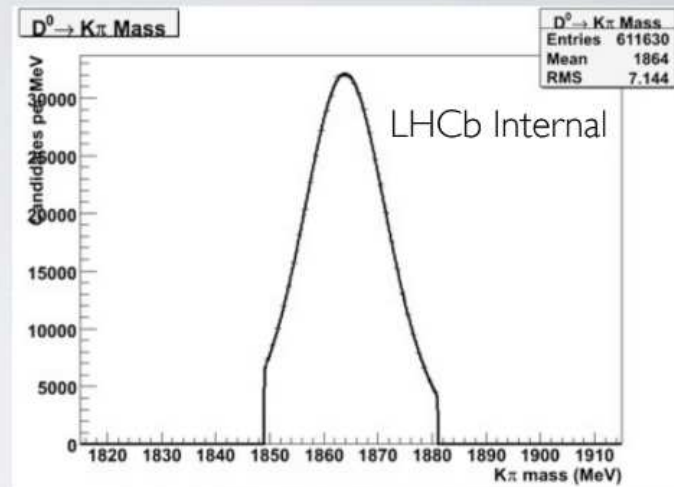
Hlt2CharmOSTF2BodyWideMass
Prescale: 0.01



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MASS FIT IN PRACTICE

- Use central region from signal trigger, side bands from wide mass trigger
- Background shape constrained from side bands, scale factor from integral of data samples in common central region
- Amount of pure background events to constrain fit models very small
→ room for improvement



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Our disadvantage:

- ▶ Less time for commissioning before the start of pp collisions
- ▶ For good or bad we will likely/hopefully get faster high luminosity running
- ▶ Experts of the pattern recognition algorithms must contribute to the commissioning
- ▶ Expectations very high due to the excellent performance of LHCb Run 1+2

Our advantage:

- ▶ Have a lot of (fancy) data-driven tools we can reuse from Run 1+2 (tag & probe for tracking efficiencies and PID calibration, ...), it is however **critical to understand the data** first to be able to use them
- ▶ **We will have more data, but likely with lower quality ...**