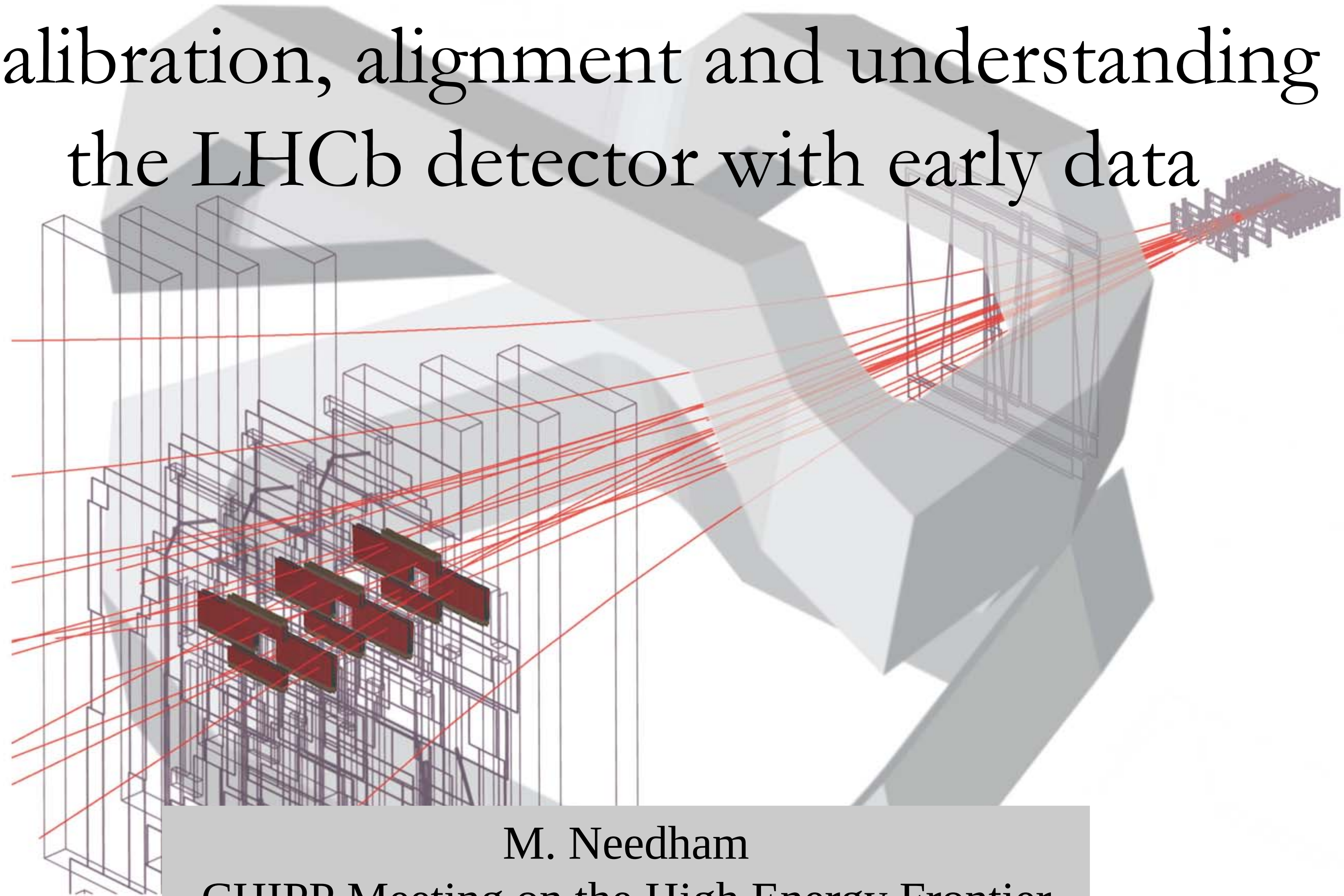
Calibration, alignment and understanding the LHCb detector with early data



M. Needham

CHIPP Meeting on the High Energy Frontier

1st September Zurich 2010

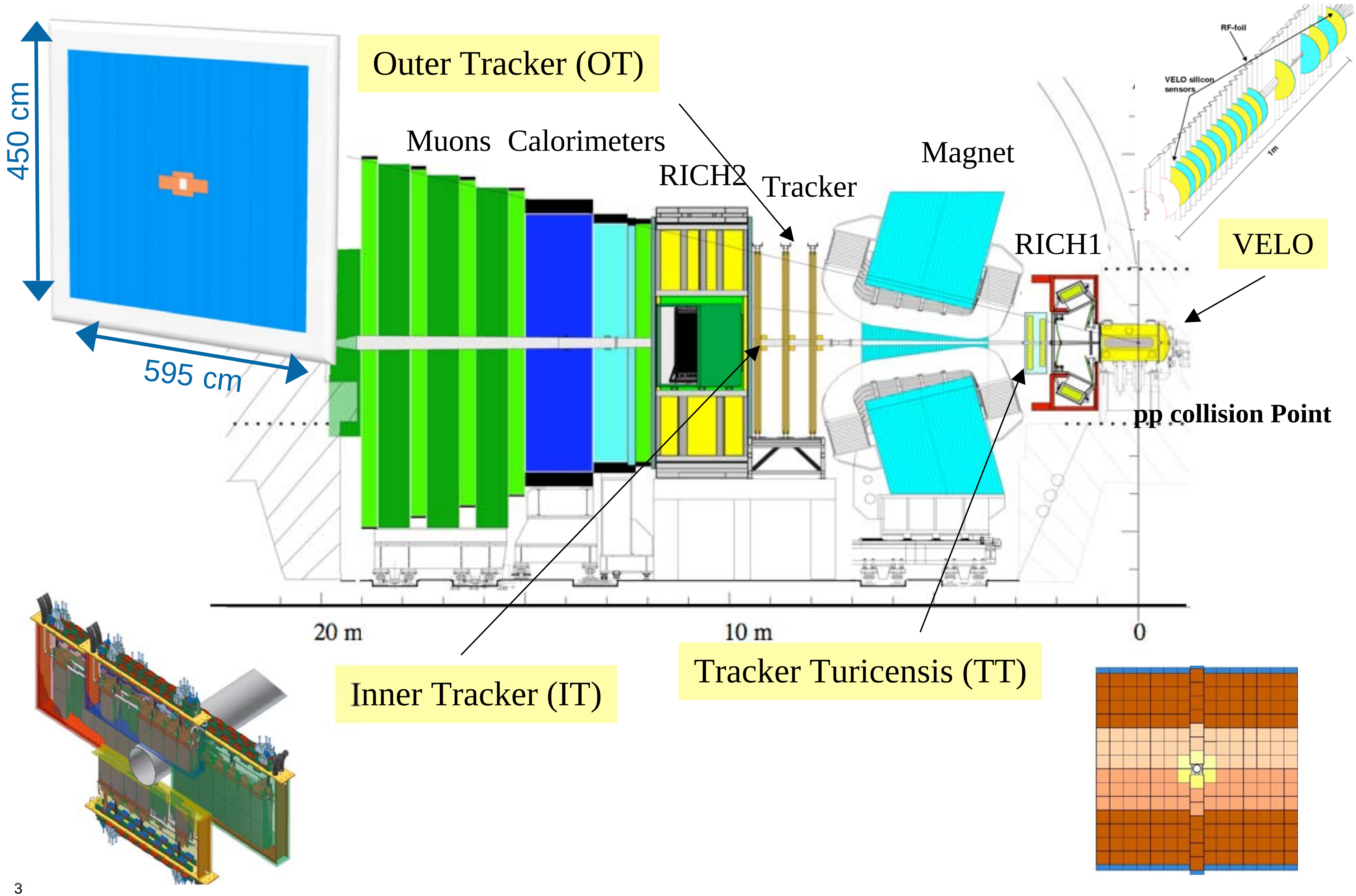
Outline

Swiss institutes are making an important contribution to the alignment and calibration of the LHCb tracking system

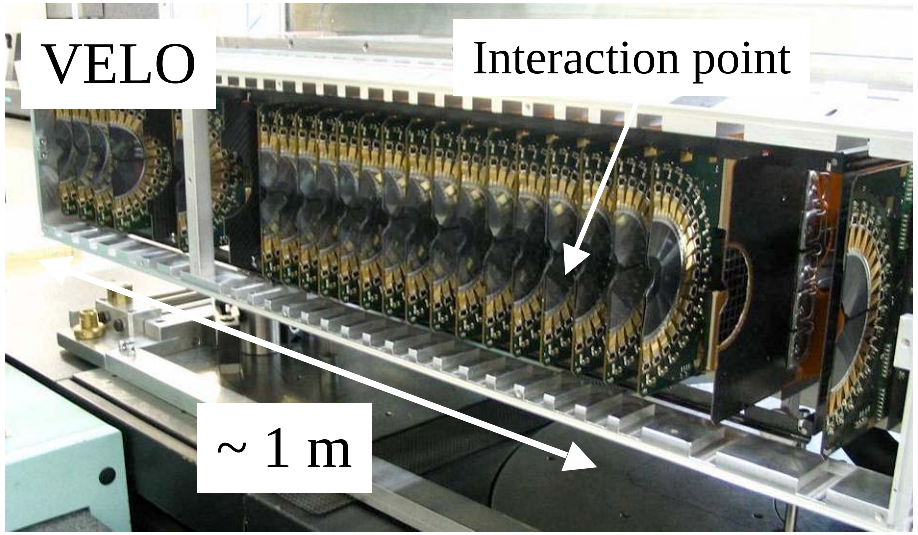
- Introduction to the LHCb tracker
- Alignment + performance (resolutions)
- Mass and momentum scale calibration

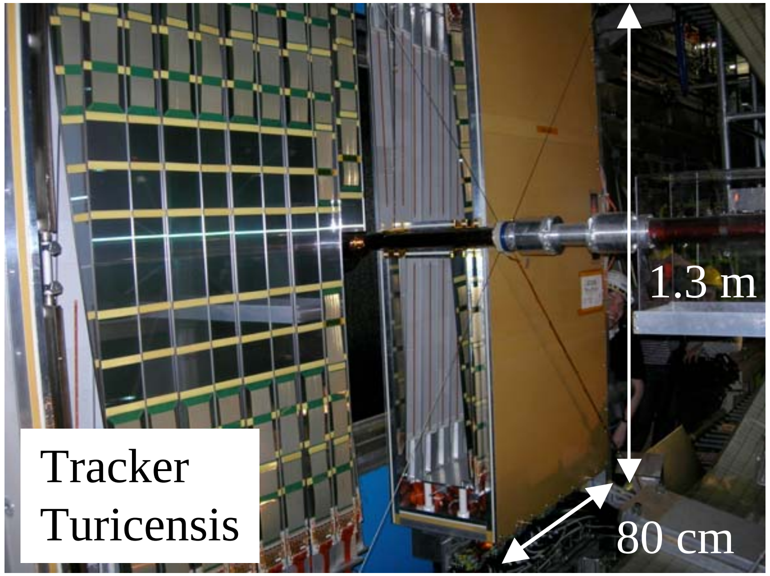
Alignment and detector understanding improving all the time, most results here pre-summer. Major update and improvements coming soon

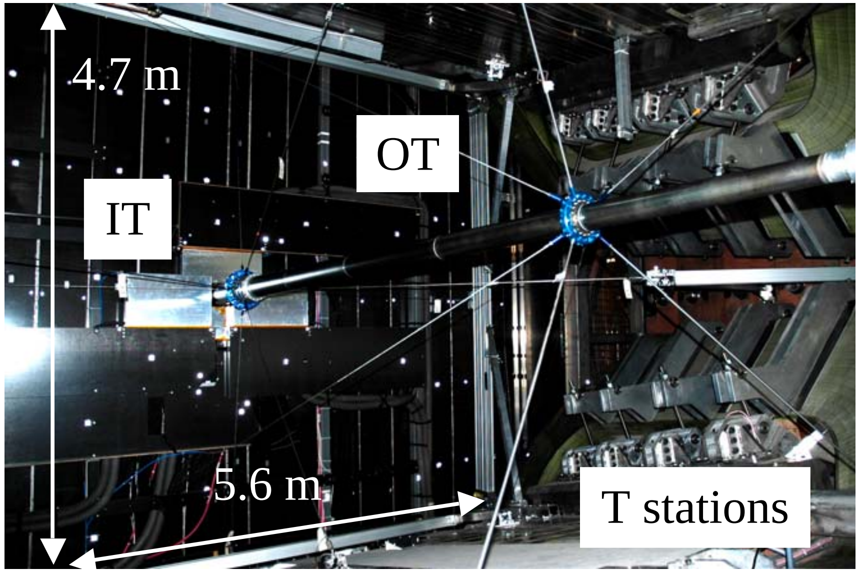
The LHCb Tracker

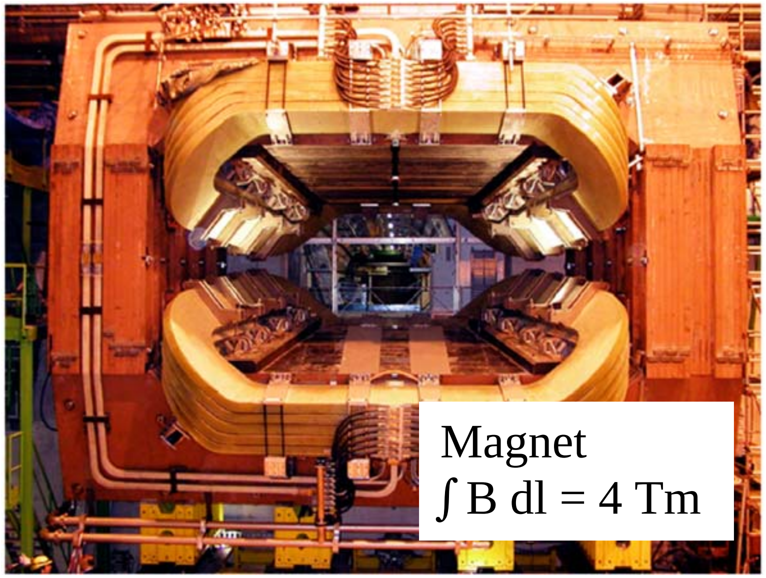


The LHCb Tracker





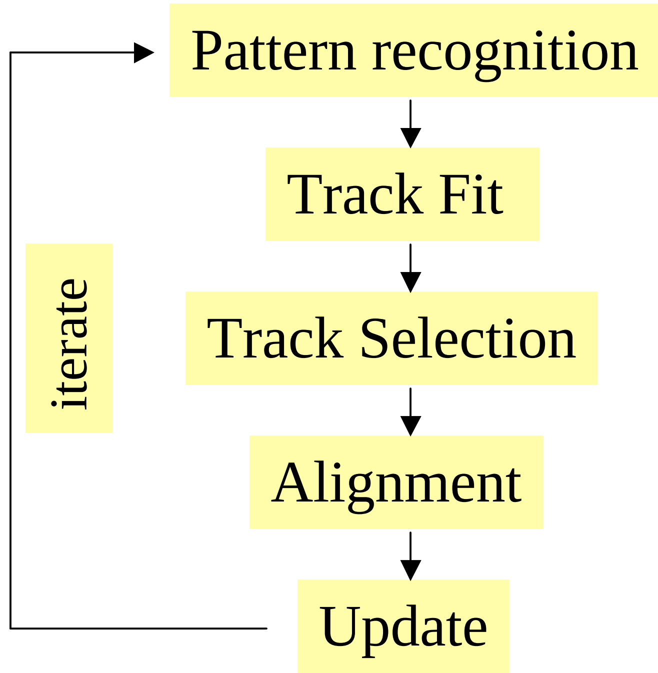




Alignment

LHCb Alignment framework

- Coupled to the LHCb Track model
- Based on closed form Kalman filter
  - W. Hulsbergen NIM A600:471-477,2009.
- Possible to iterate full reconstruction chain
- Used for both global + internal alignment
- Millepede used for crosschecks + Velo alignment



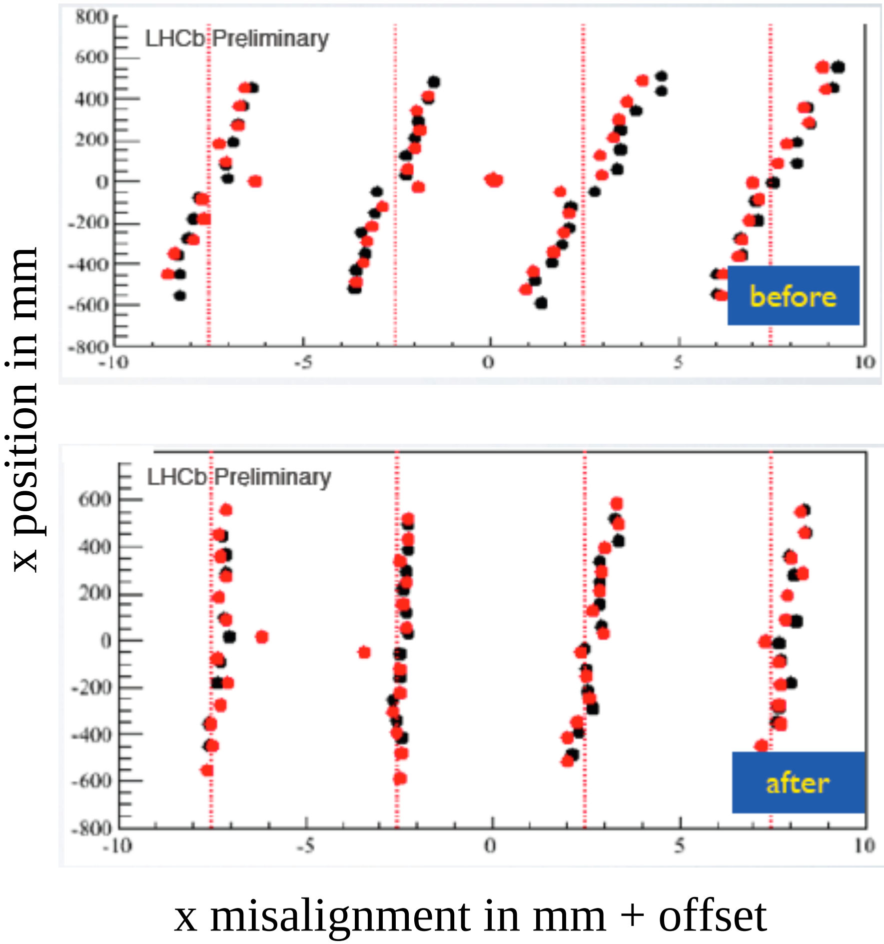
Validation:

- Size of movements: are they reasonable compared to survey ?
- Unbiased hit residuals: biases and obtained resolution
- Known mass of resonances, expected resolution from Monte Carlo/fitted mass error

(Not) Alignment

Toughest challenges encountered are not related to alignment but incorrect assumptions about the detector geometry

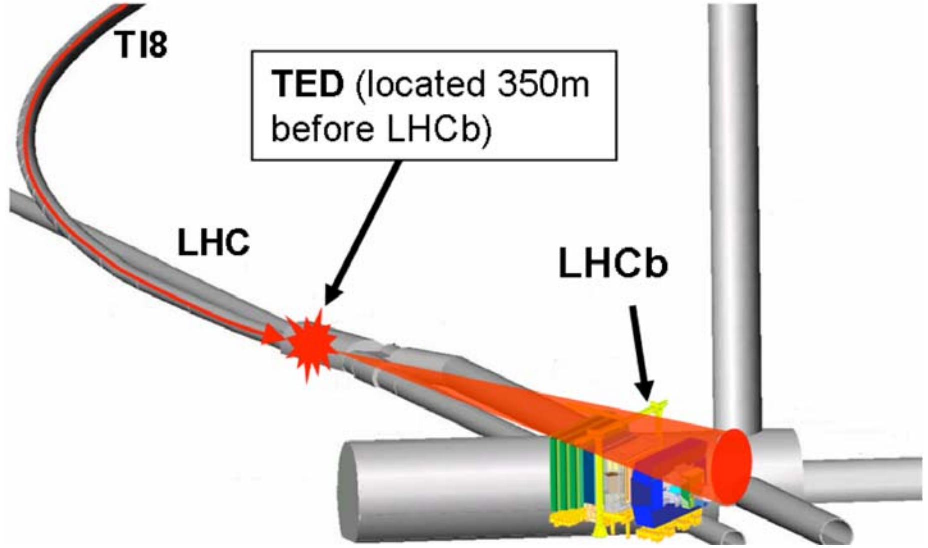
- Tracker measures x precisely
- Strong constraints from module overlaps
- Difficult to recover from wrong assumptions about geometry in x
- e.g. wrong TT pitch:
- 183.33 μm used instead of 183 μm
- Leads to x-scaling

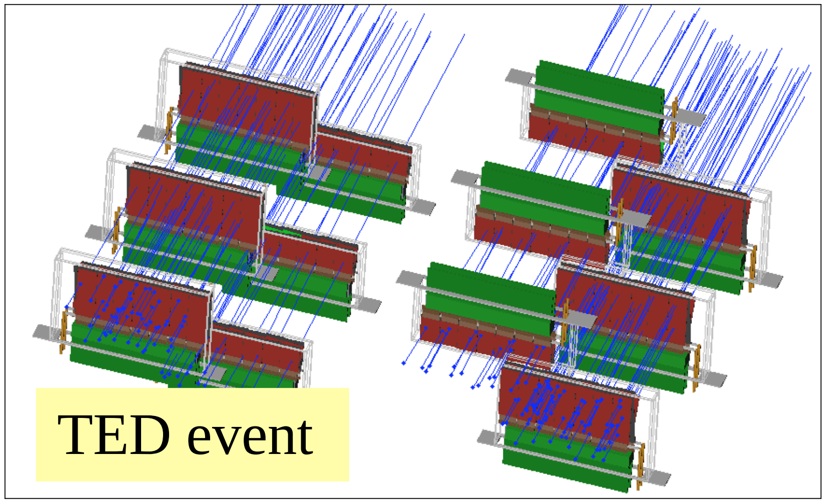


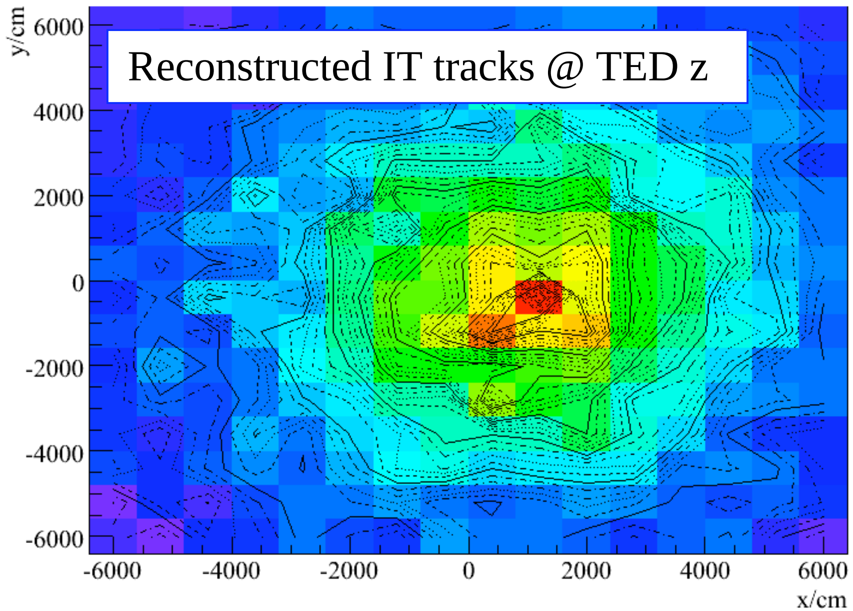
Before first collisions

2008/2009 TED runs

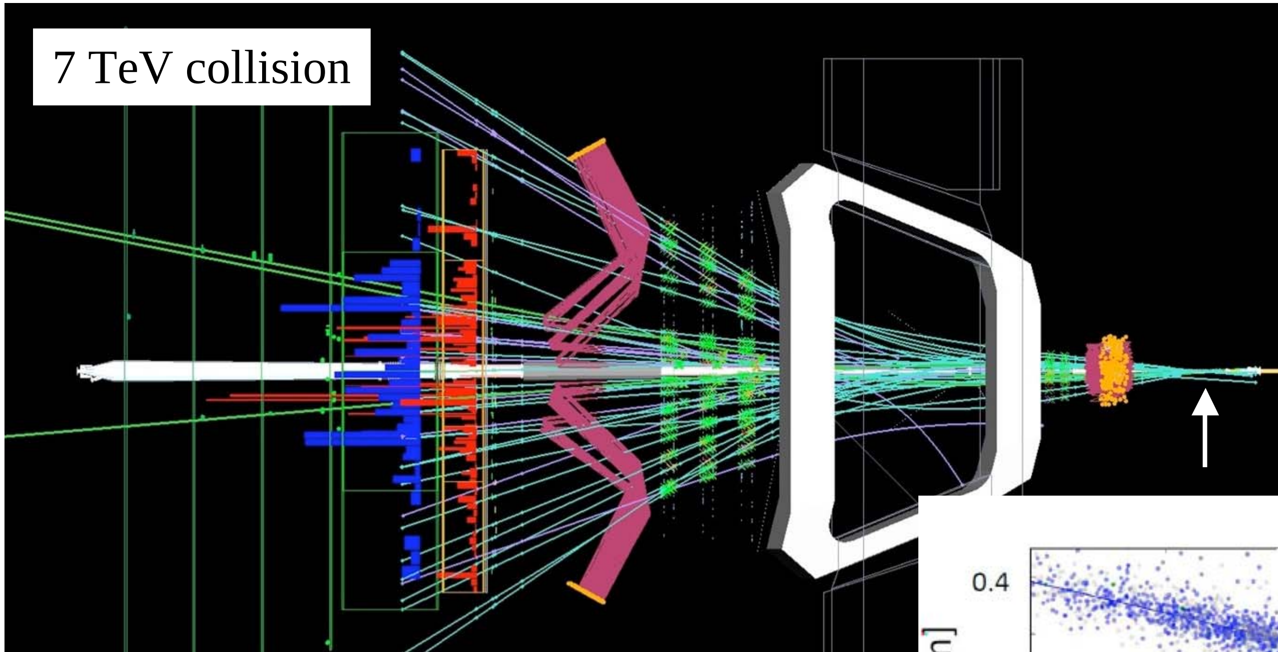
Spills of 5 ×10[9] protons dumped on a tungsten beam-stopper (the 'TED') 350 m downstream of LHCb.
First time/space alignment of VELO and Silicon Tracker performed

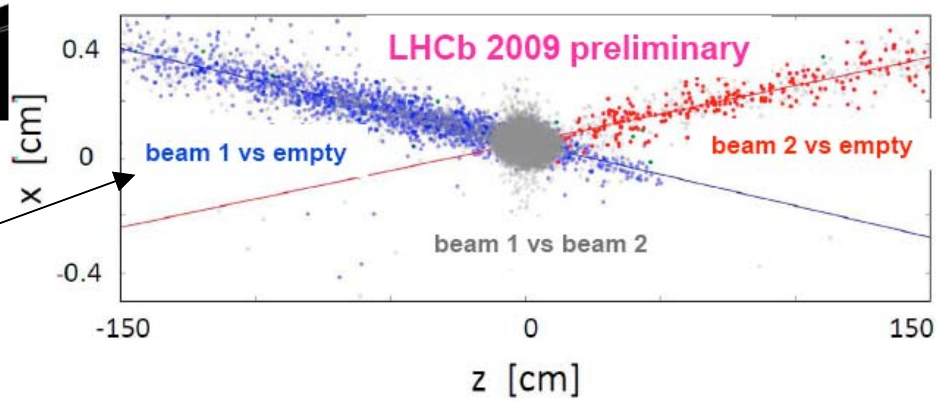






First collisions





900 GeV beam imaged with beam-gas interactions

Velo Performance

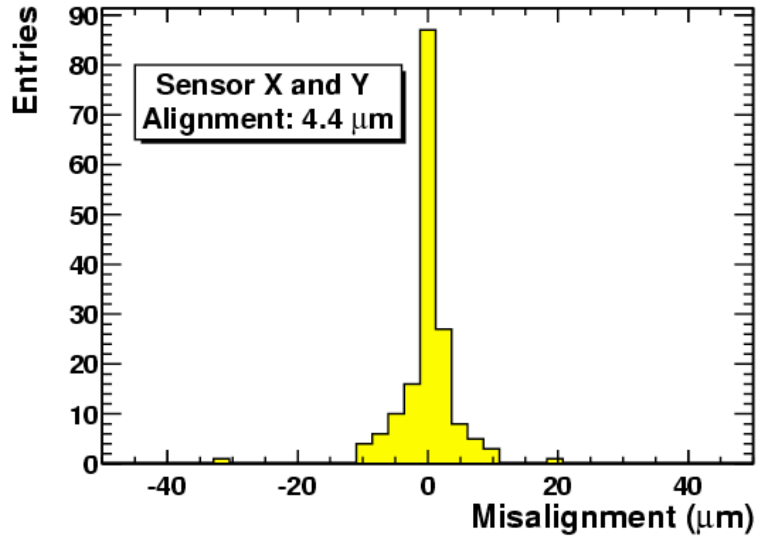
• Module and sensor alignment better than 5 μm: improvement to 2 μm soon

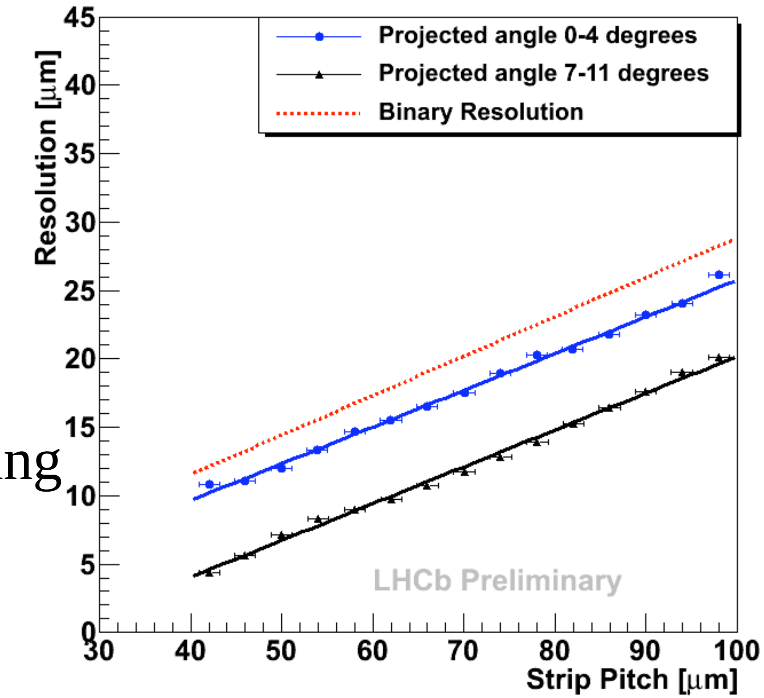
• Fill-to-Fill variation along (x,y) of relative alignment of two halves within (5 μm , 3 μm)

• Hit resolution as a fraction of strip pitch and projected angle

• Measured with hit residuals corrected for track uncertainty

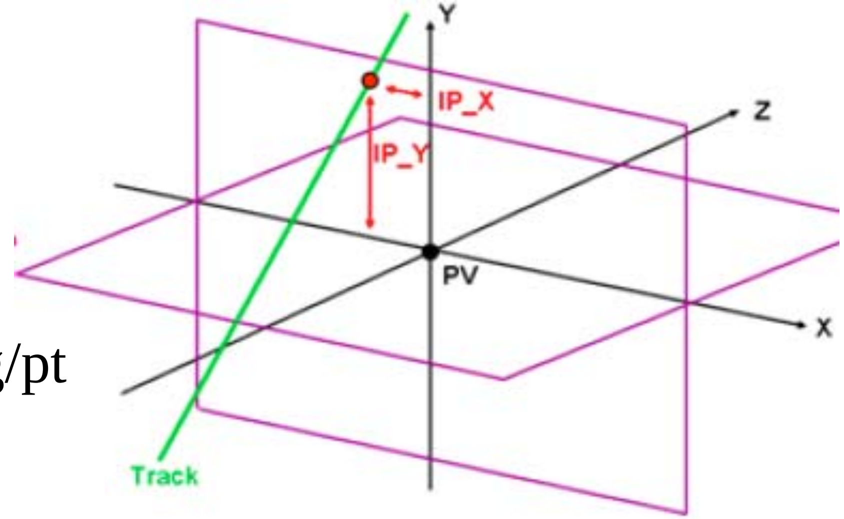
• Good agreement with Monte Carlo assuming module alignment is ~ 5 μm





Impact parameter resolution

Closest distance of approach of track to the beamline: Impact Parameter



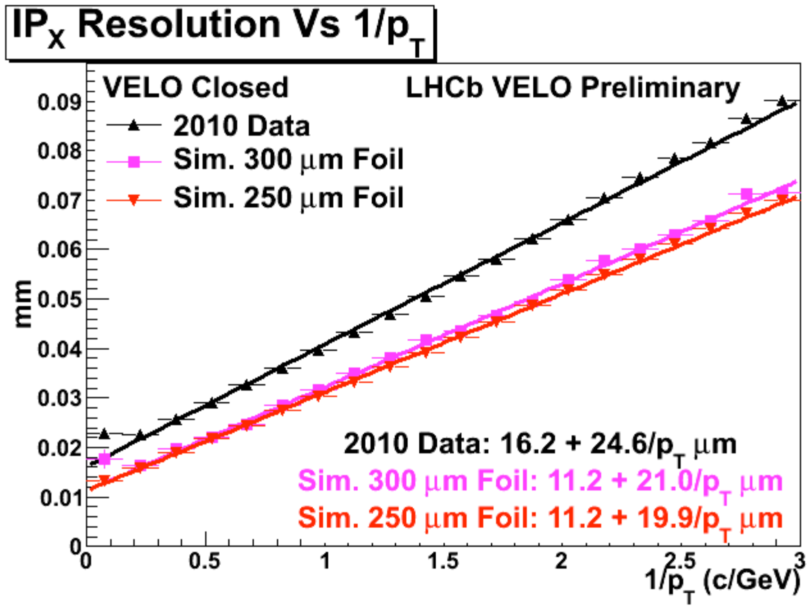
IP(3D) = hit resolution $\oplus$ multiple scattering/pt

Measure x and y component of IP

Assume track originates at primary interaction point

σ of the distribution is IP resolution

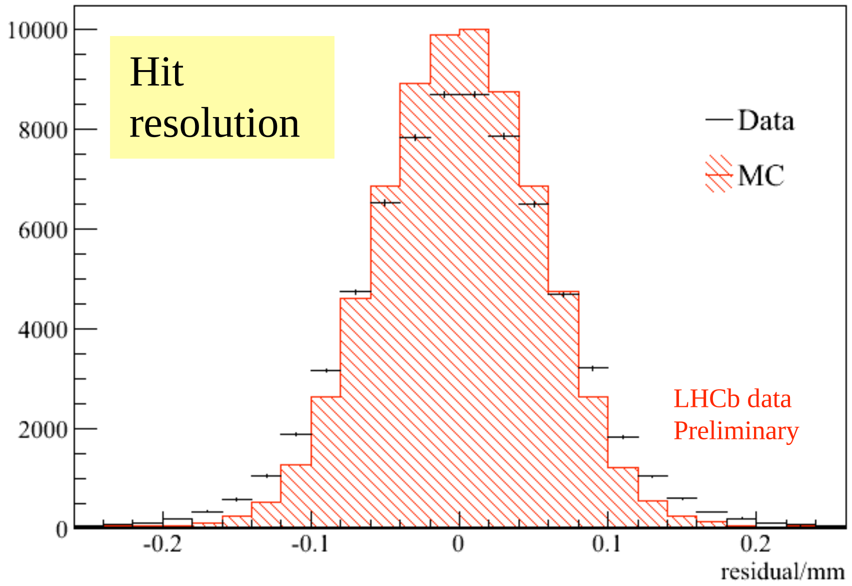
Lead to increase of RF foil thickness in MC from 250 to 300 μm

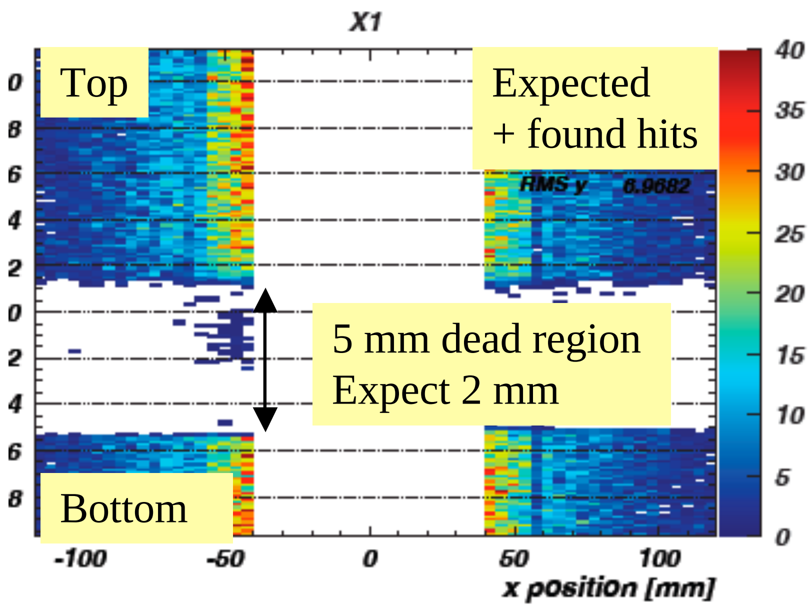


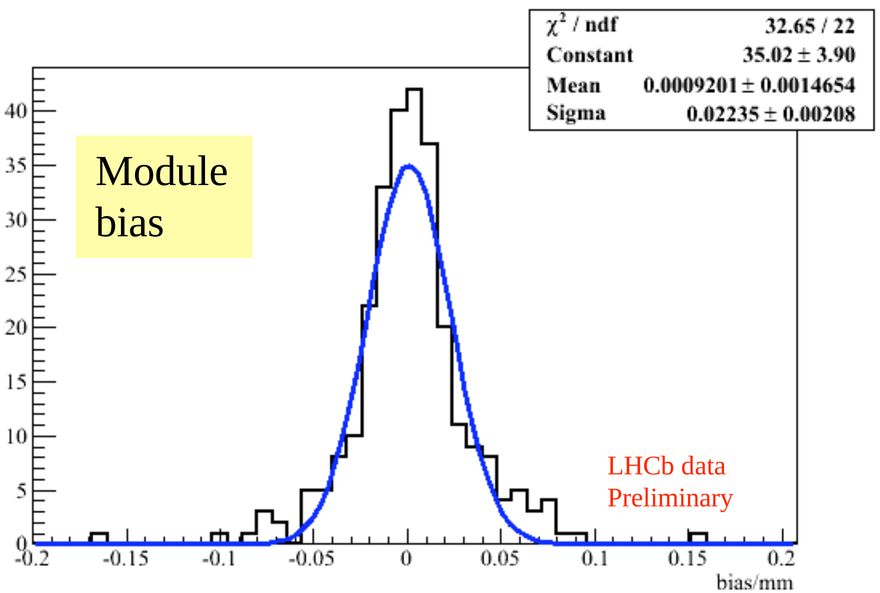
TT Performance

Study unbiased residuals unfolding track uncertainty

- Data ~ 55 μm, MC ~ 51 μm
- Module misalignments 24 μm, 15 μm soon
- Binary resolution ~ 52 μm,
- y positioning ~ 3 mm global inconsistancy



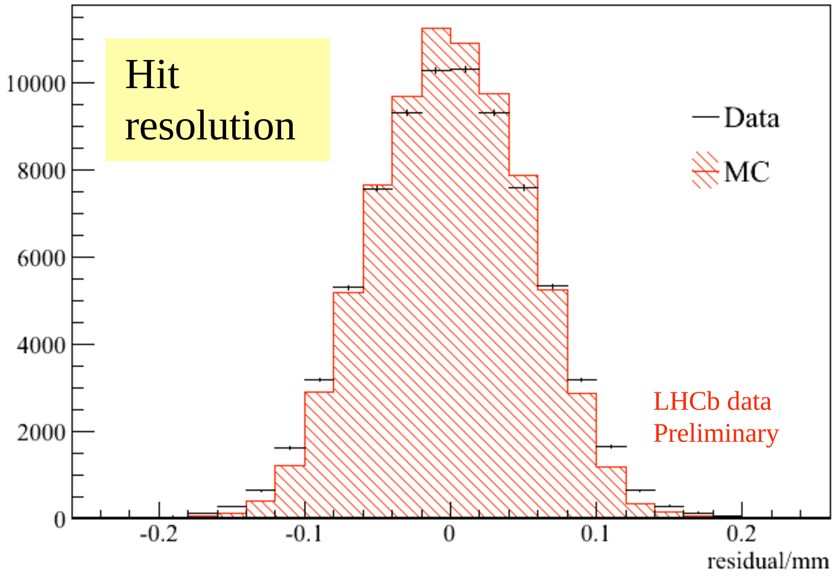


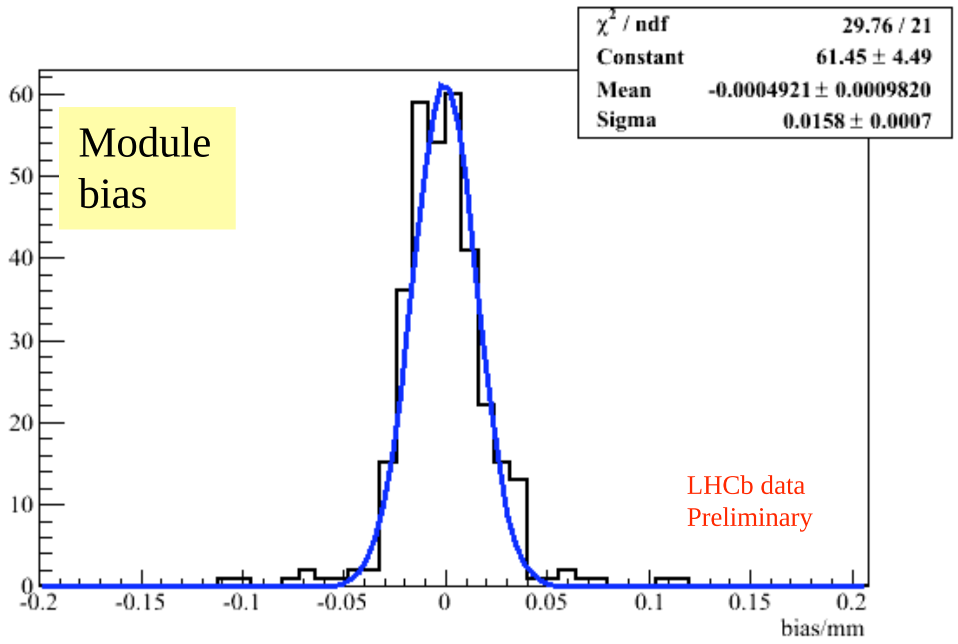


IT Performance

Study unbiased residuals unfolding track uncertainty

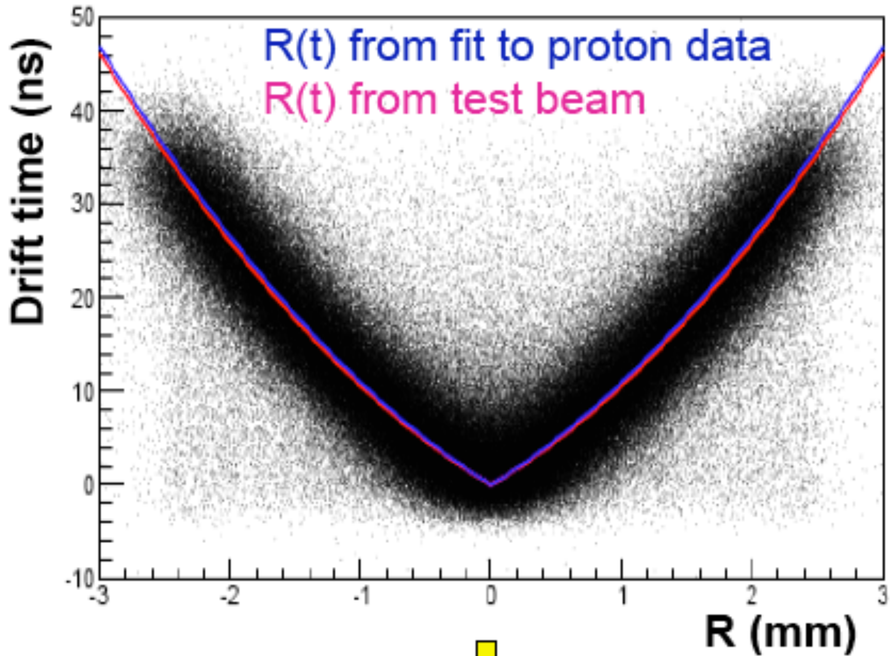
- Data ~ 55 μm , MC ~ 52 μm
- Module misalignments 16 μm, improvement to 10 μm soon
- Binary resolution ~ 57 μm
- y positioning ~ 1 mm global inconsistancy

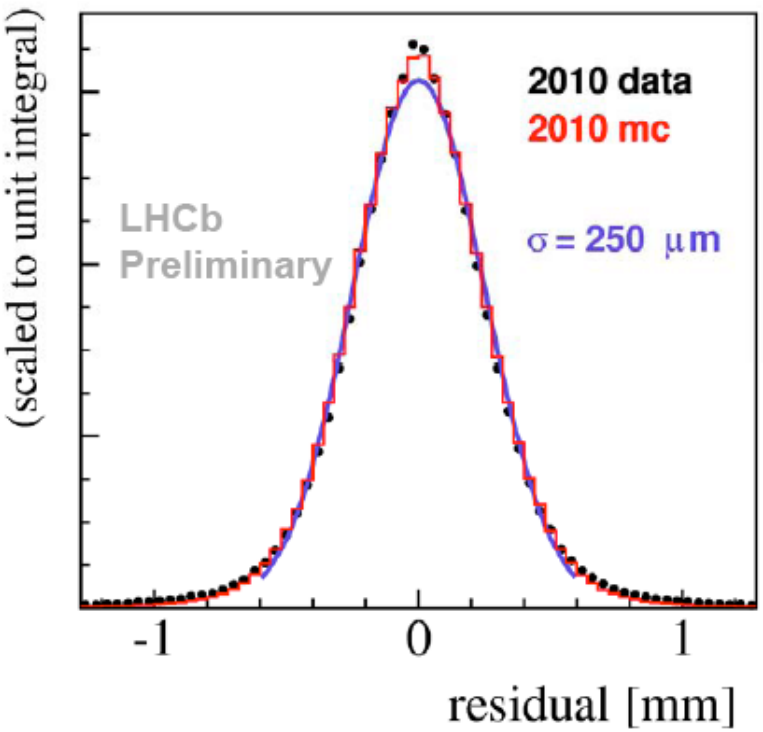


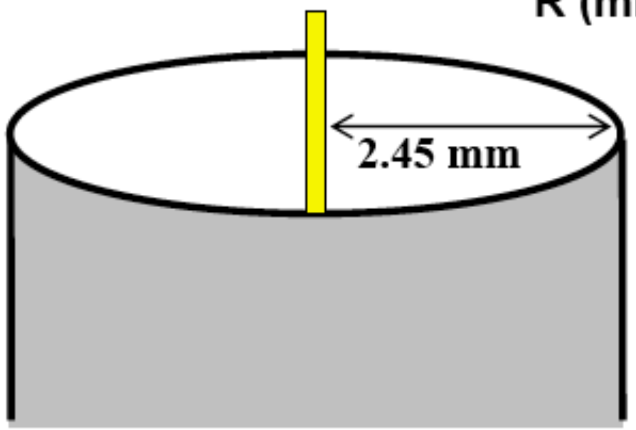


Outer Tracker Performance

- Space time relation consistant with testbeam
- Measured resolution 250 μm
- Expectation from testbeam 200 μm

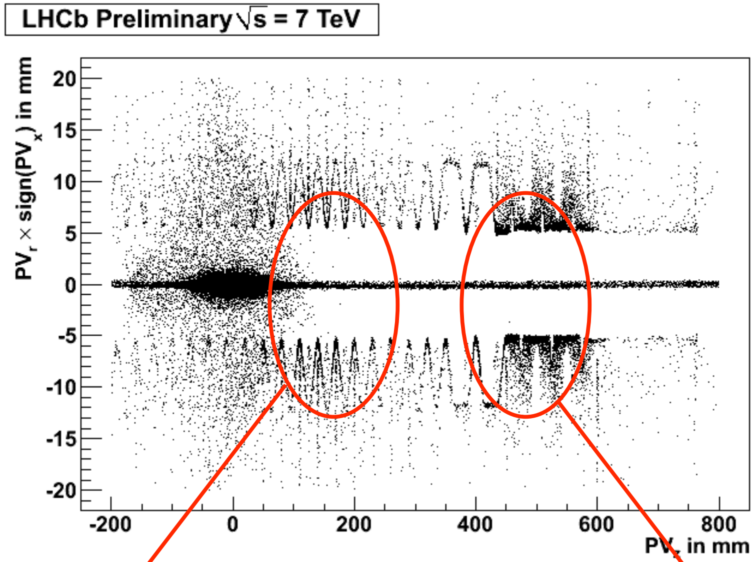


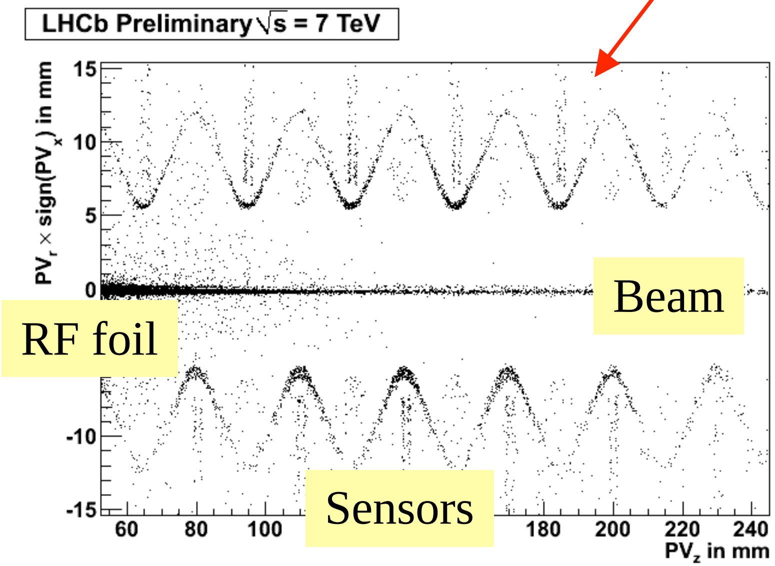


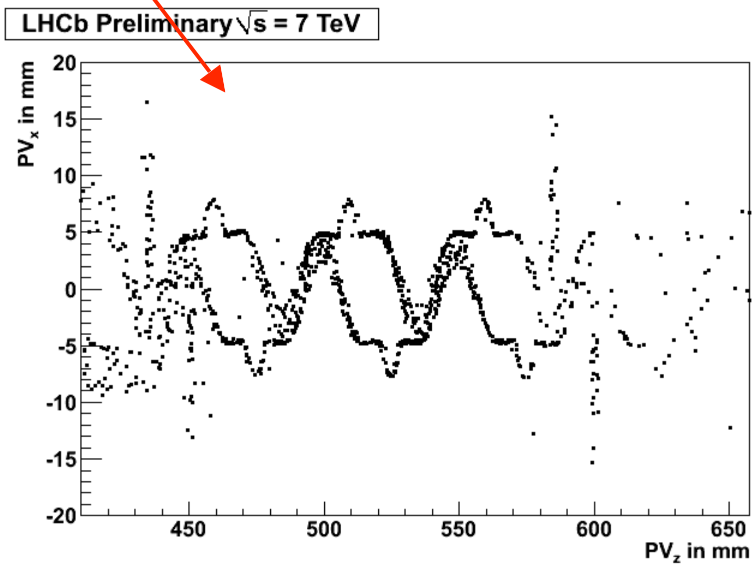


Mapping Material

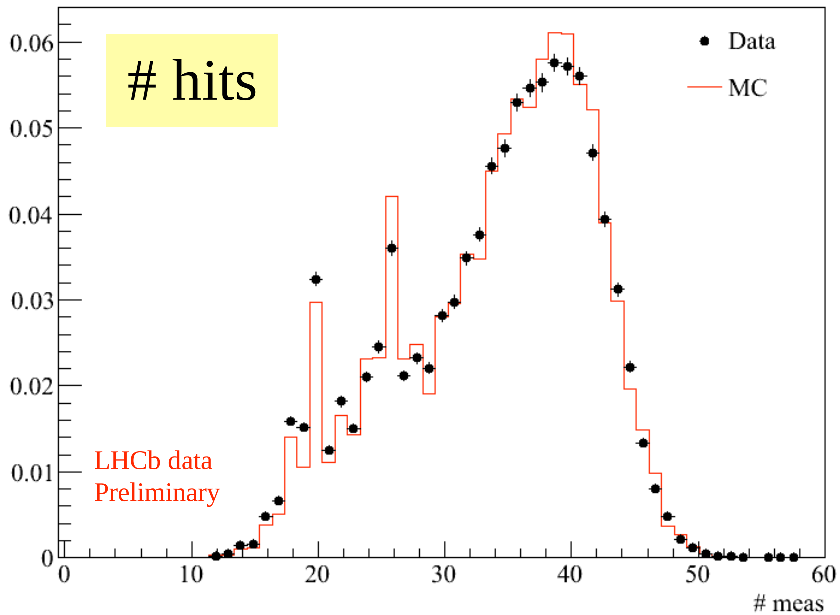
2.4 million vertices
20k from material
Interactions
≥3 tracks per vertex

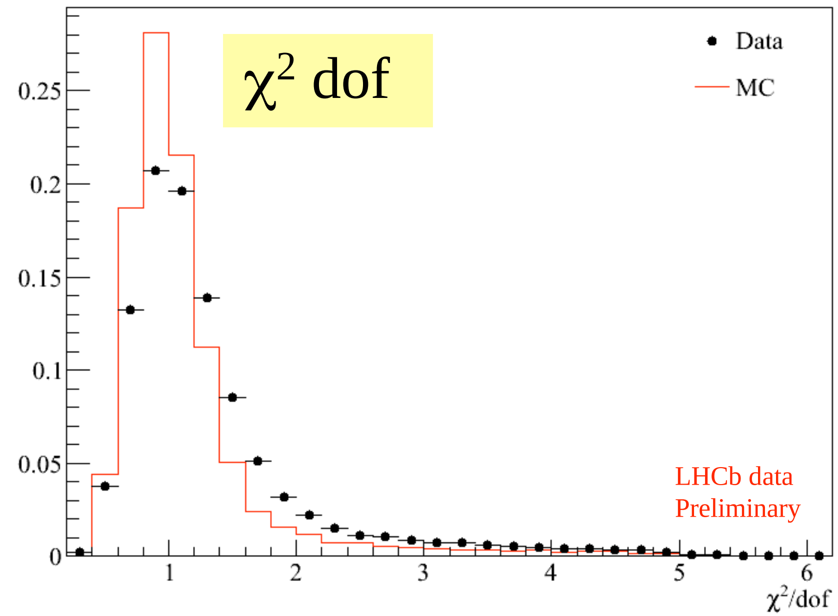


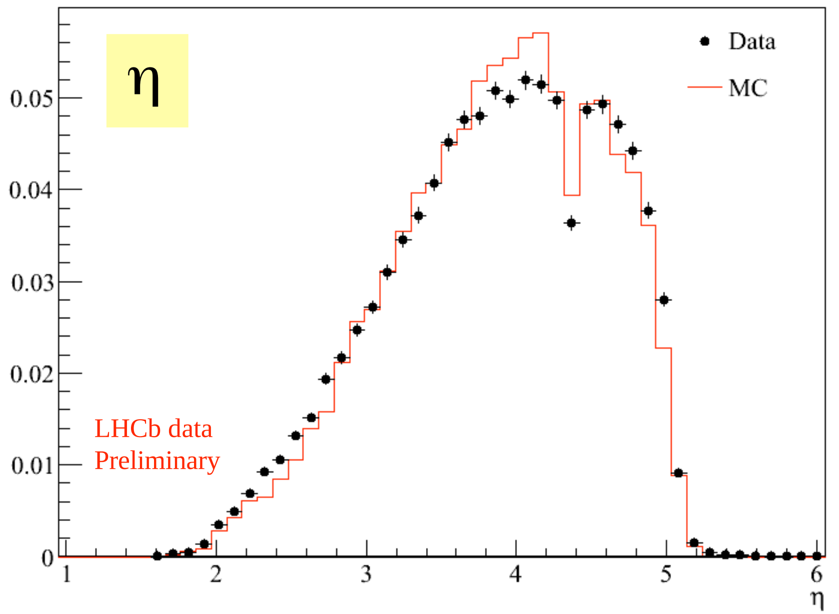


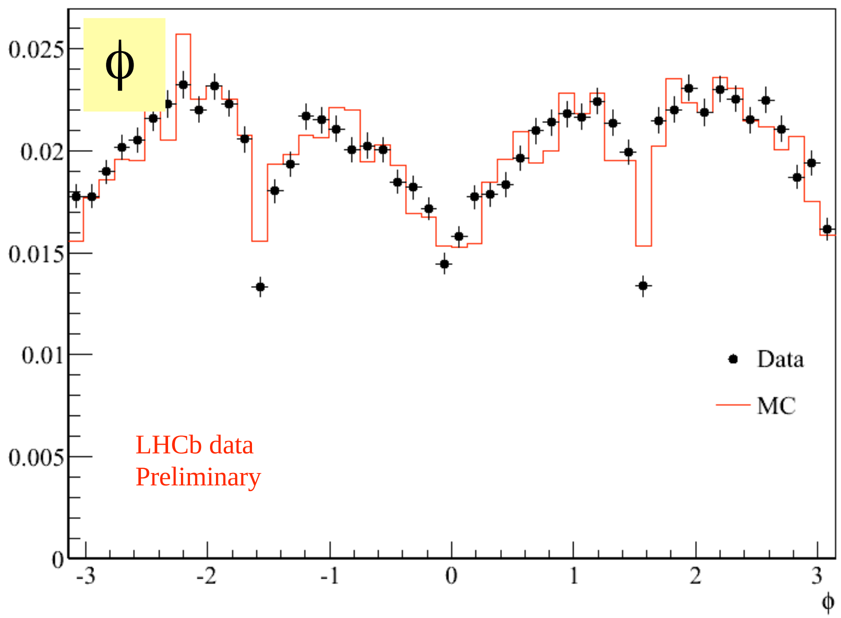


Data/MC comparison









Resonance Studies

Crucial test: mass and resolution of 2-body decays of known resonances

$$m^2_{d_1 d_2} = (E_1 + E_2)^2 - (\vec{p_1} + \vec{p_2}) \cdot (\vec{p_1} + \vec{p_2})$$

Mass bias + resolution depends on the daughter momenta and opening angle

K_s

J/ψ

Y

Opening angle dominated

Momentum dominated

Different resonances are dominated by different systematics

Resonance Studies

Material effects

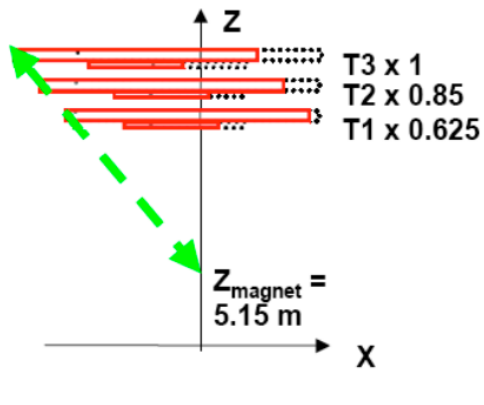
Energy loss: sqrt dependence on p and amount of material
Multiple scattering: degrades resolution, sqrt dependence on X_0

Field map: Cowboys + marines

Discrepancies between used field map + reality
Good discriminating variable angle between normal to decay plane and the field direction

Alignment Weak modes

e.g. q/p bias, visible if plot mass versus $p^+ - p^-$
'Fix': with J/ψ or magnet off data



Common X-translation with a scale factor in T

Resonance Studies

$$m_{d_1 d_2}^2 = (E_1 + E_2)^2 - (\vec{p_1} + \vec{p_2}) \cdot (\vec{p_1} + \vec{p_2})$$

Taylor Expansion

$$m(d_1) = m(d_2) \longrightarrow m_{d_1 d_2}^2 = m_d^2 R + 2 \cdot (p_1 p_2 - \vec{p_1} \cdot \vec{p_2})$$

$$R = 2 + \frac{p_1}{p_2} + \frac{p_2}{p_1}$$

Field Scaling $p' \longrightarrow \alpha \cdot p$

$$\Delta m = \alpha \cdot \frac{m_d^2 R - m_P^2}{m_P} \longrightarrow \Delta m = \alpha \cdot m_P.$$

$$m_d^2 R \ll m_P^2$$

K_s

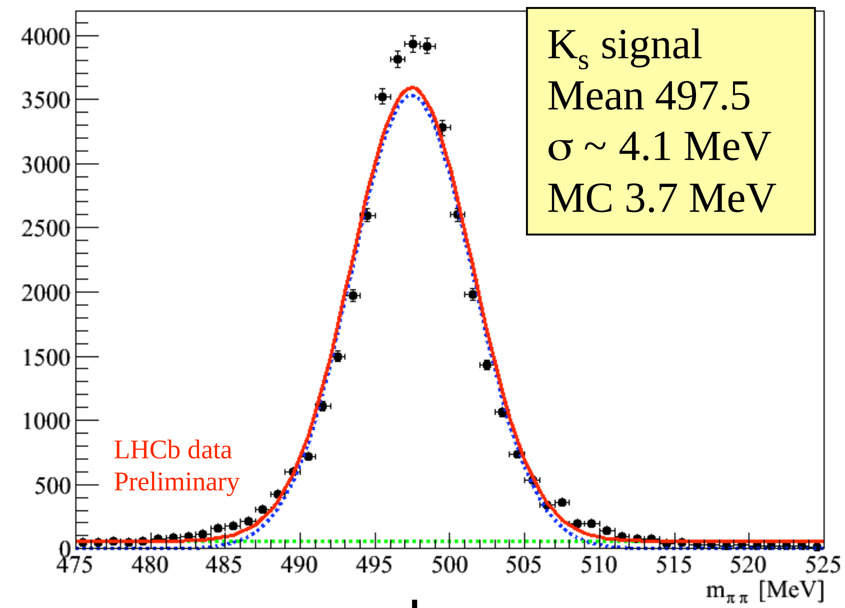
J/ψ

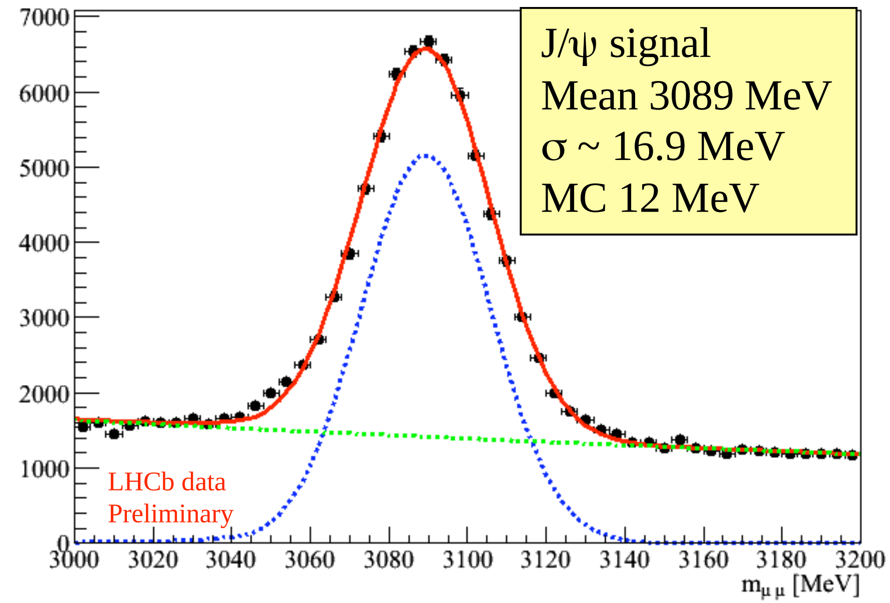
Energy loss $p \longrightarrow p' - \beta_{ion}$

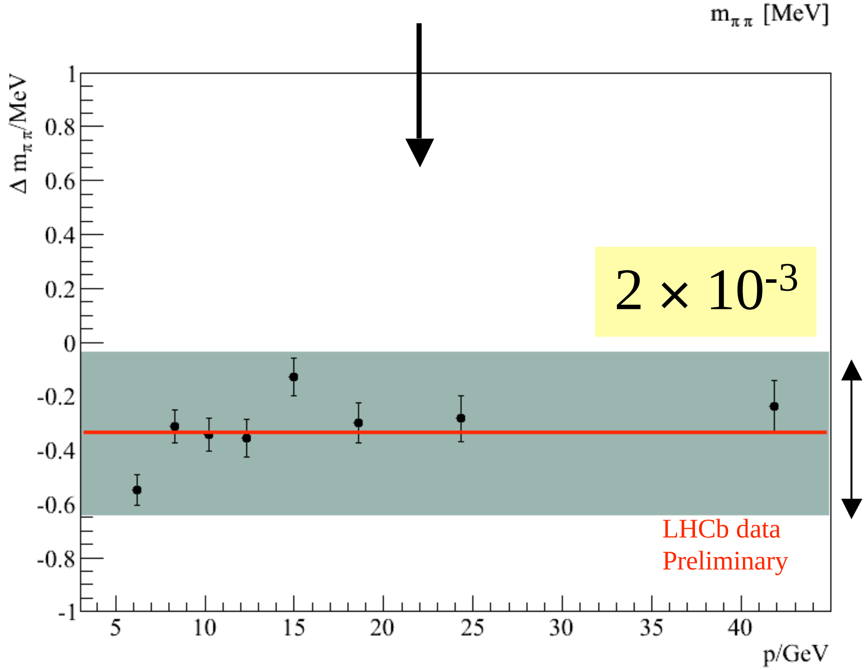
$$m_{d_1 d_2}^2 - m_P^2 = \beta_{ion} \cdot (p_1 + p_2) \cdot \theta^2$$

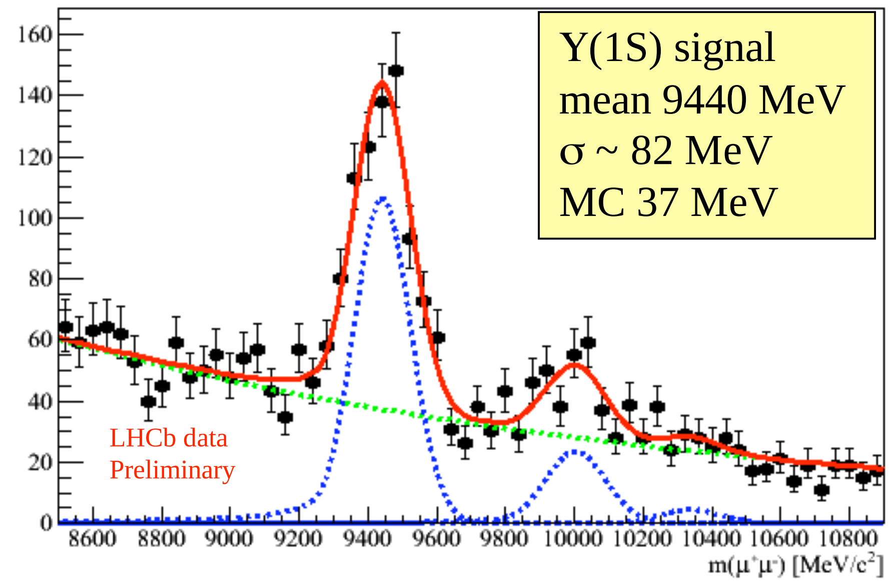
square root dependence on p

Mass Signals



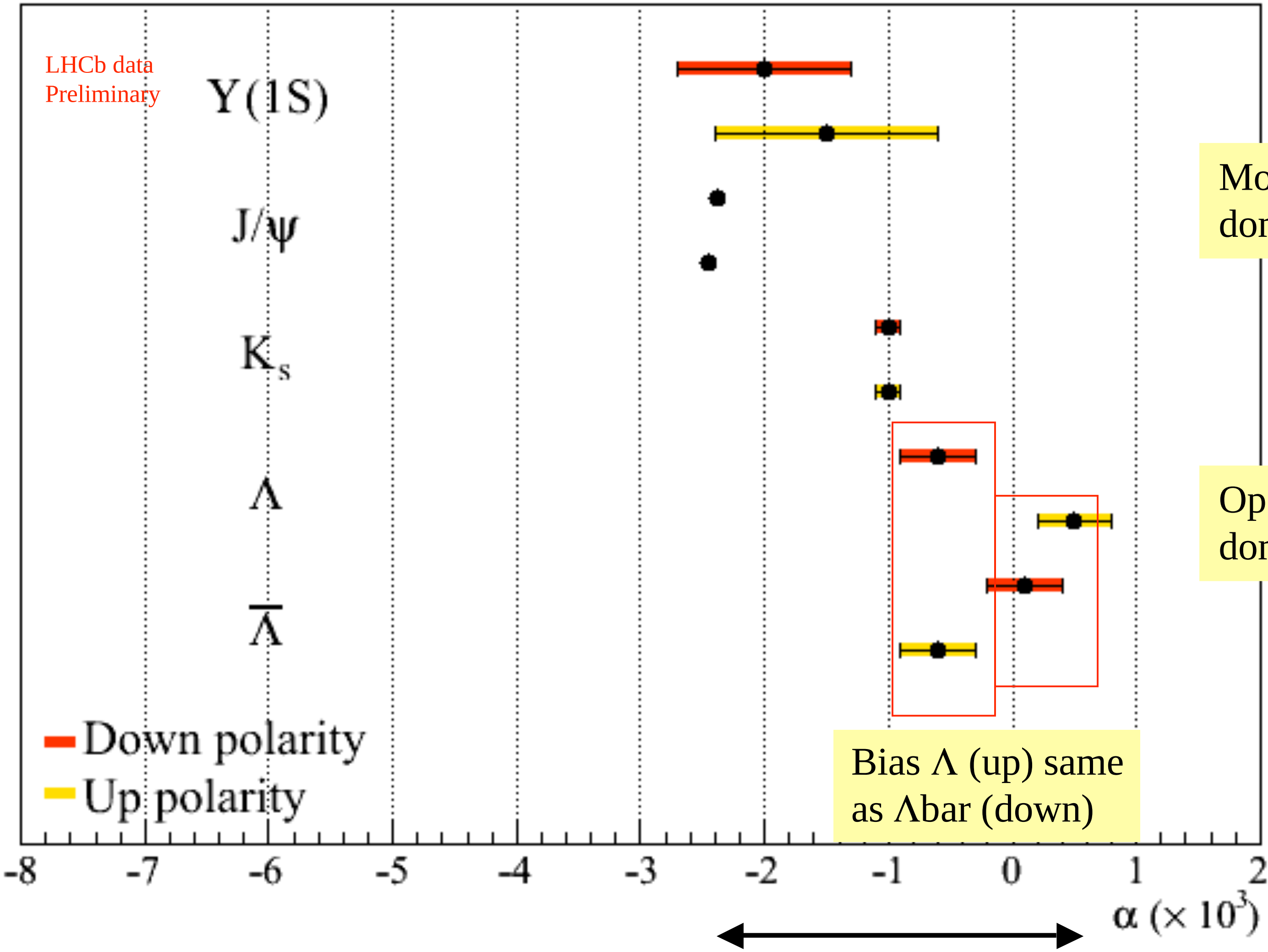






Momentum Scale

Tracks with VELO hits



Momentum dominated

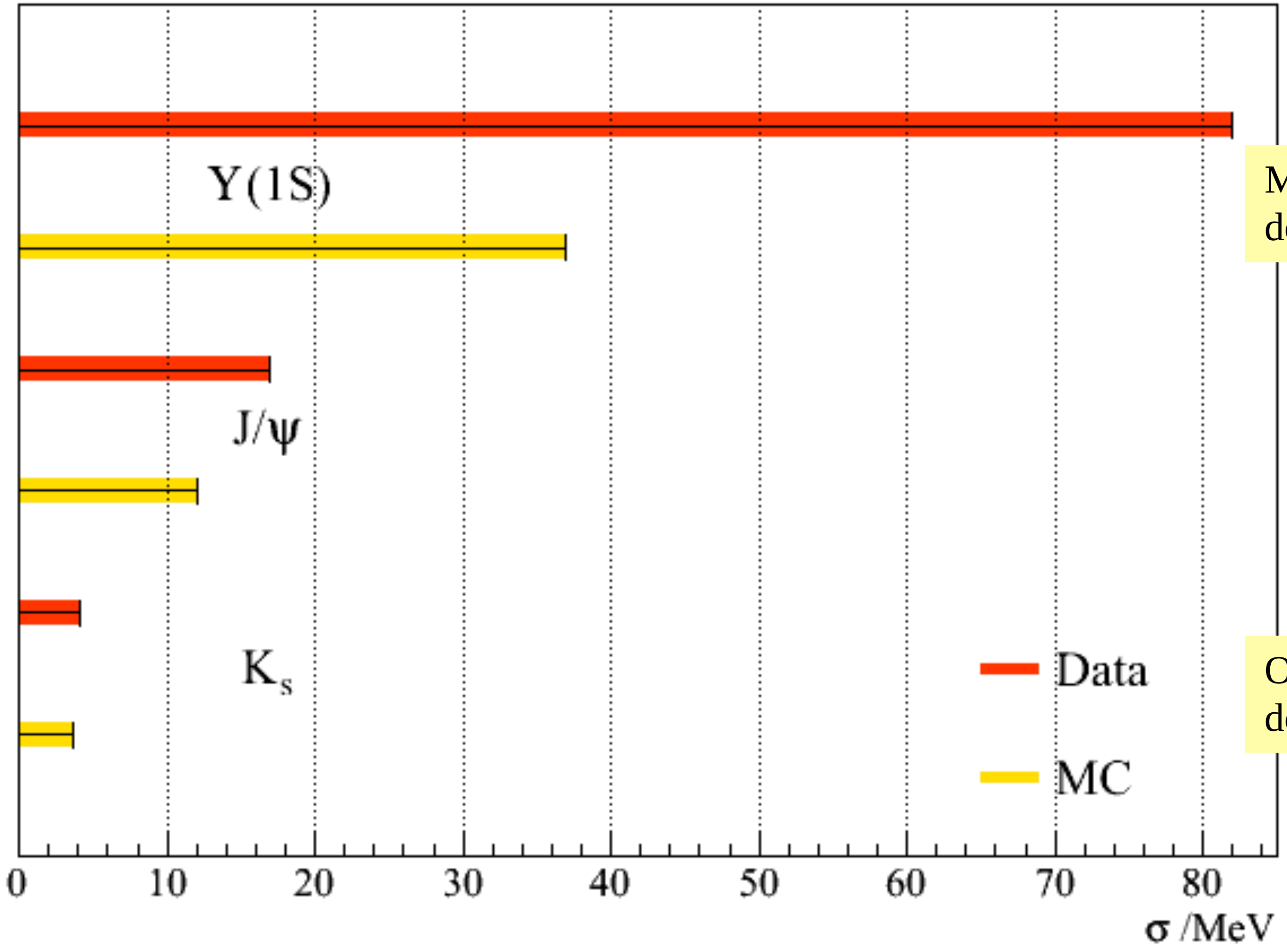
Opening angle dominated

Bias Λ (up) same as Λbar (down)

3 per mille

Mass Resolution

Comparison data/MC



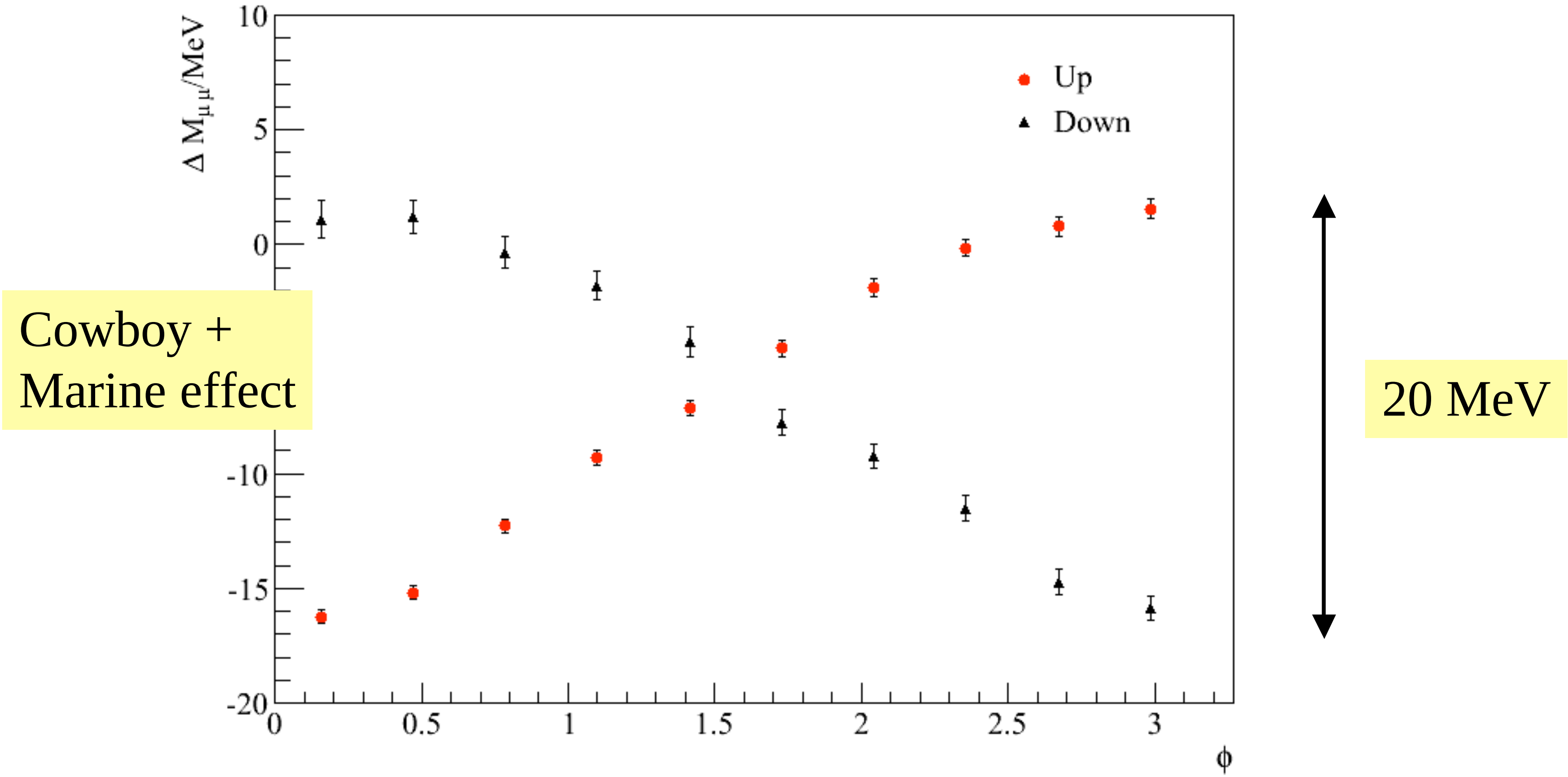
Momentum dominated

↓

Opening angle dominated

Cowboys and Marines

Study J/ψ mass resolution as a function of the angle between the decay plane and the y-axis (B field direction)



Origin of the effect unclear: seems to come from the alignment

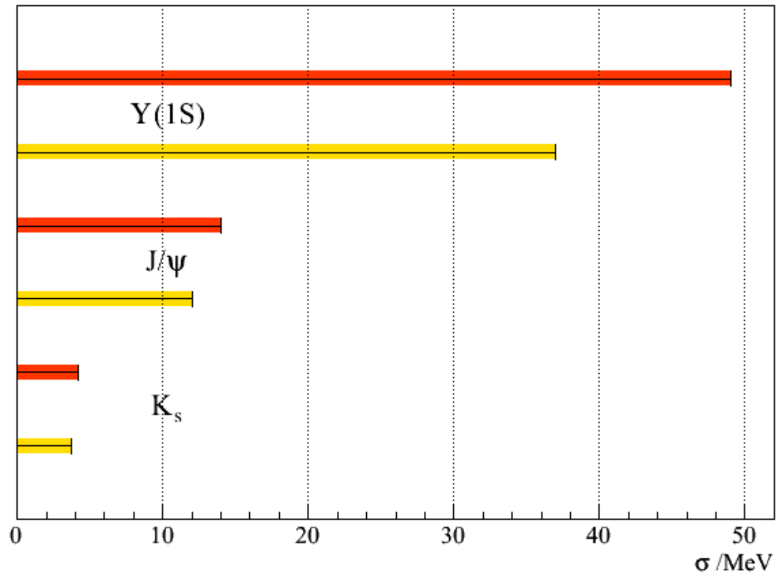
Work in progress

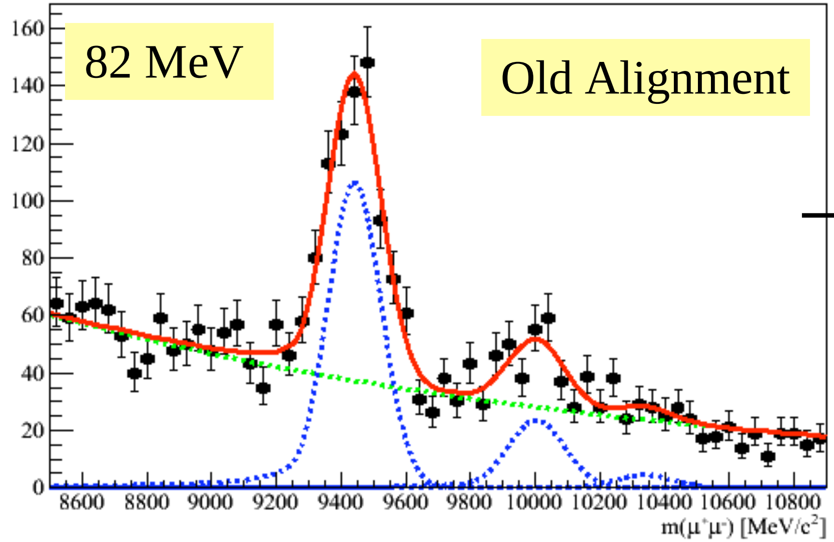
To remove Cowboy/Marine effect

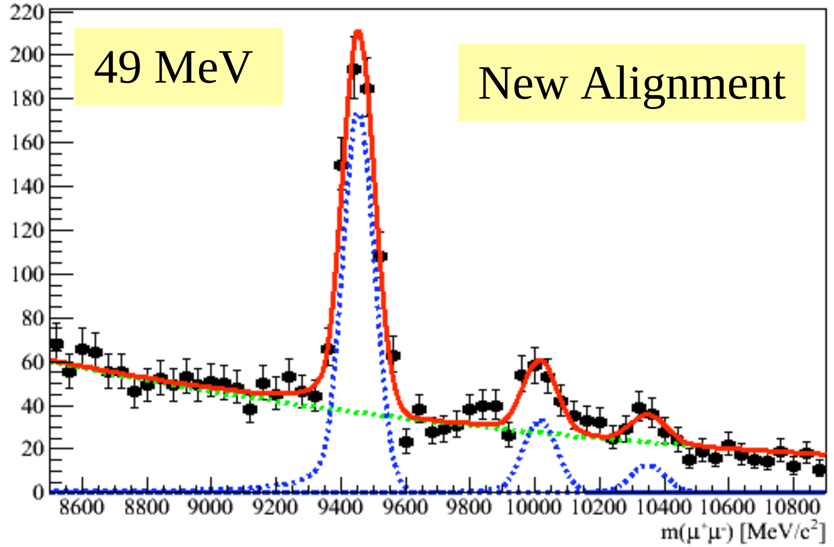
- J/ψ mass constraint in alignment
- Use only high p tracks in procedure

Good improvement in mass resolution

- Detector movements to be understood







Summary

LHCb have made a great start

- Alignment and calibration of tracking system already well understood
  - Helped by data taken during sychronization tests before first beam
- Close to achieving MC expectations for residuals , good data/MC agreement

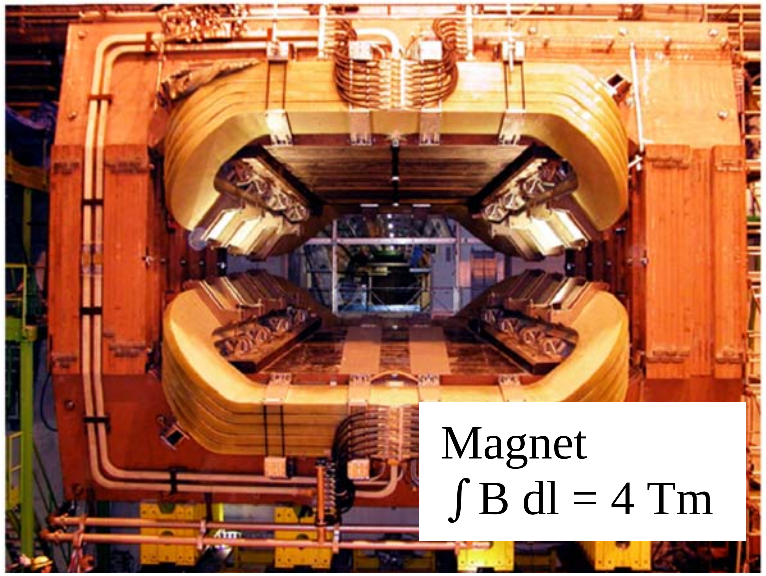
Mass and resonance studies

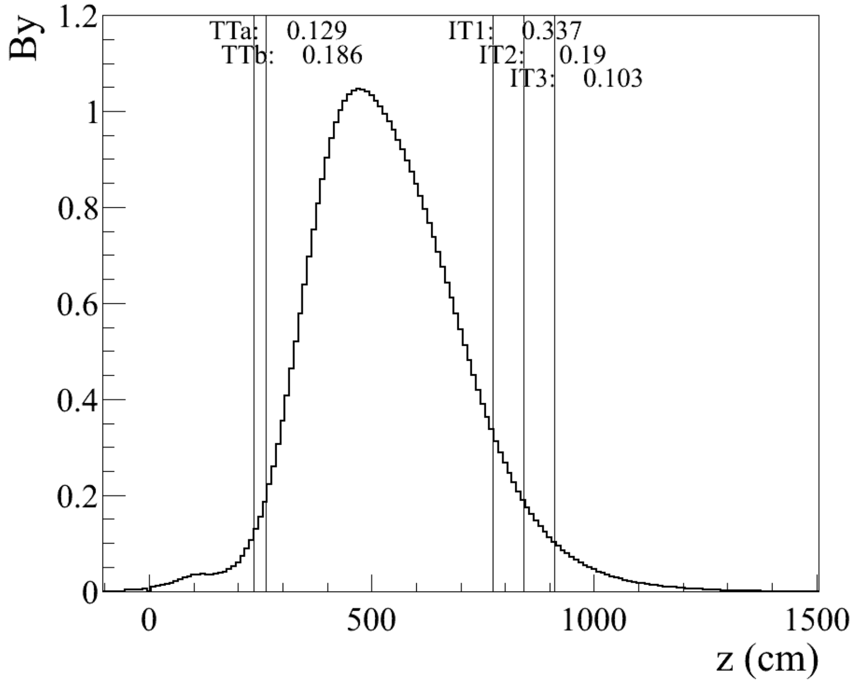
- Probe global rather than local consistancy of the alignment
- J/ψ shows clear evidence of cowboy/marine effect
  - 'Solved' by using J/ψ constraint in alignment
- Significant impact on ϒ resolution (82 to ~ 49 MeV)

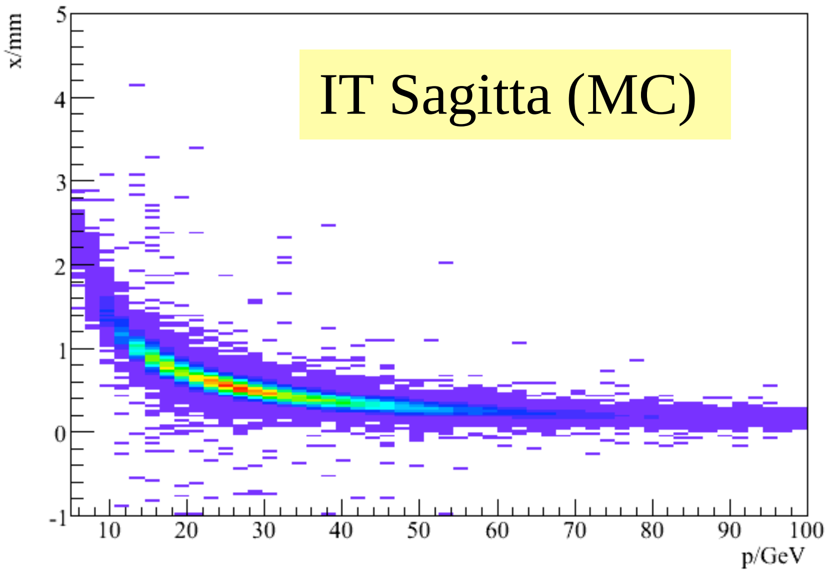
Studies to improve the alignment quality ongoing, improvement expected soon

Backup

The Magnet







Both TT and T stations sit in significant field

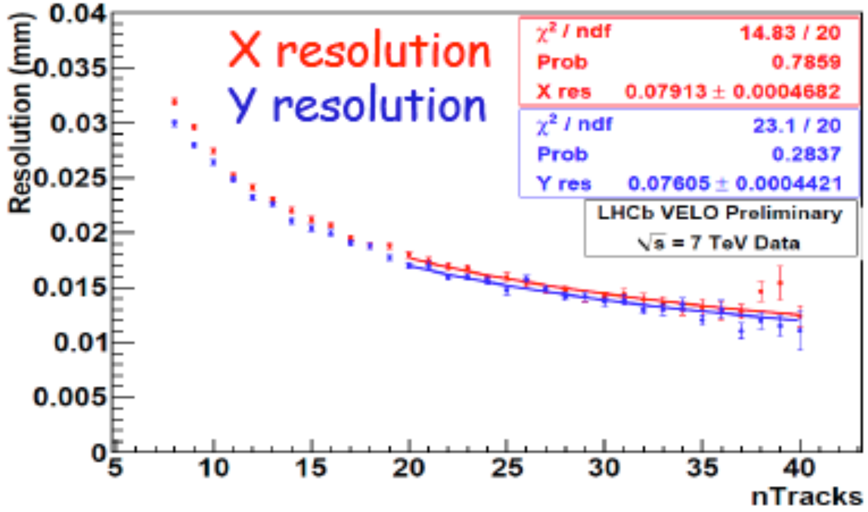
Particle trajectory is not a straight line

Complicates many things….

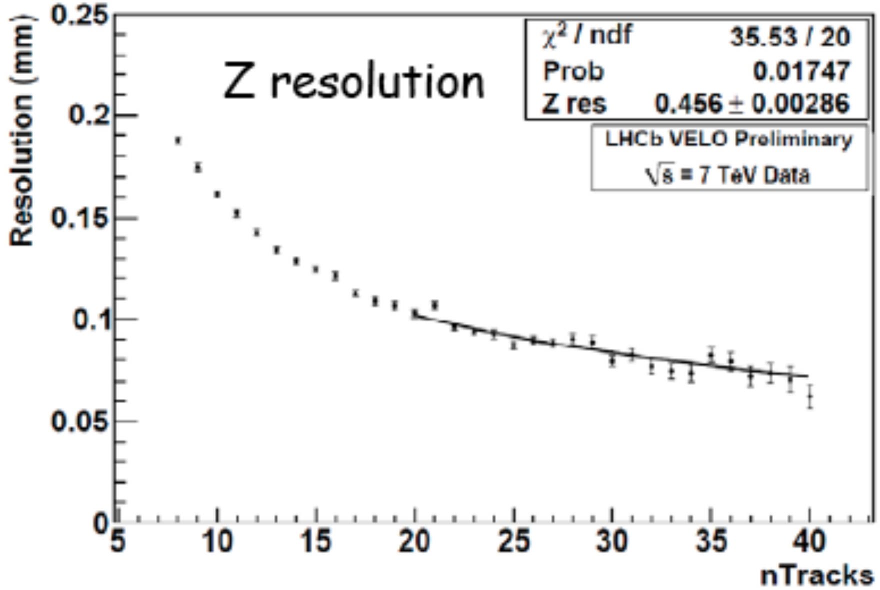
PV Resolution

Vertex Resolution

Measure resolution by splitting
Track sample in two
Compare split vertices of equal multiplicity
Method validated with MC



PV Resolution (x,y,z) with 25 tracks

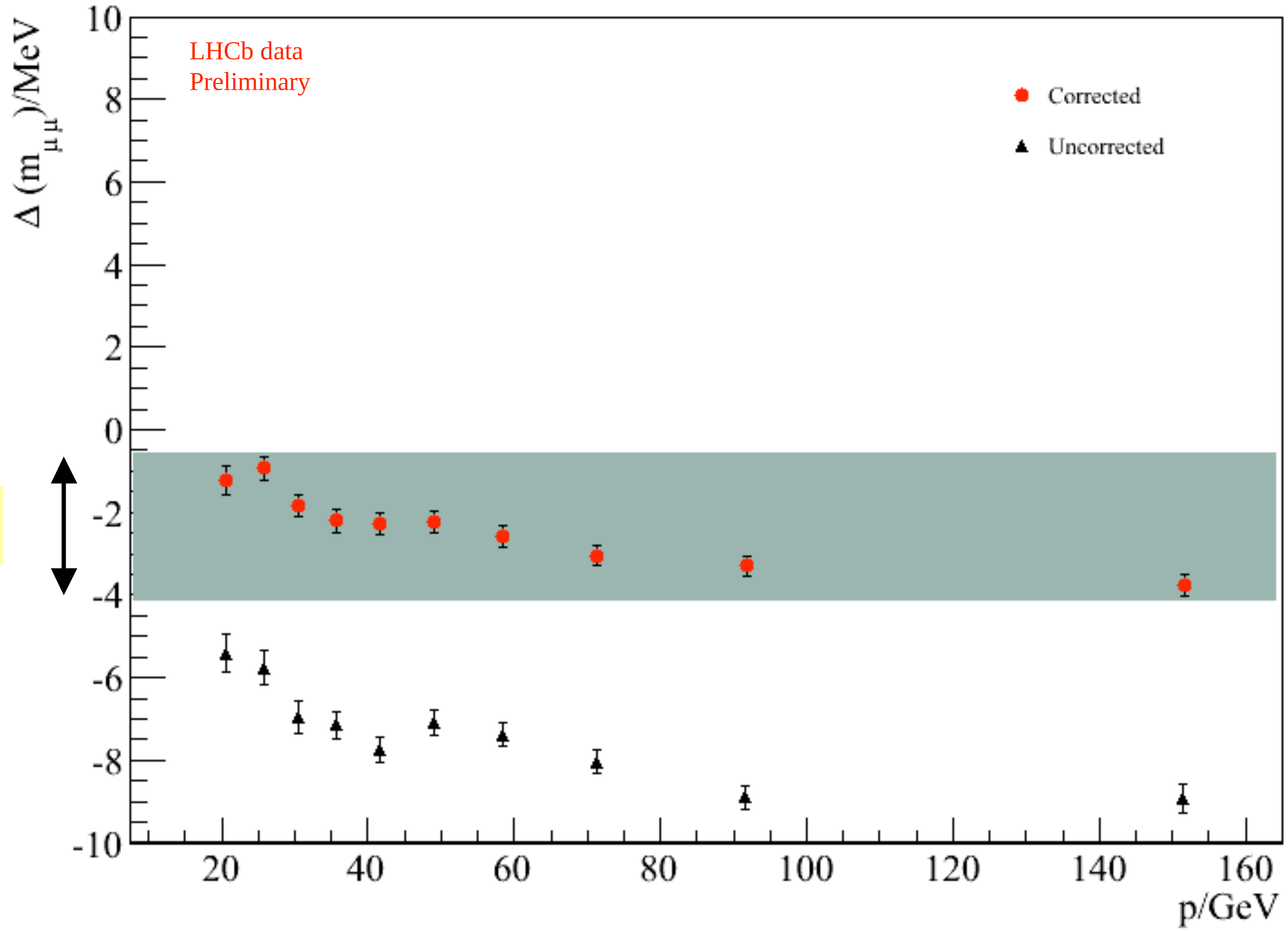


Data: (16, 15, 91) μm
MC (12, 11, 57) μm

Momentum Scale

Apply linear correction to the mass based on decay plane angle based on March-June data

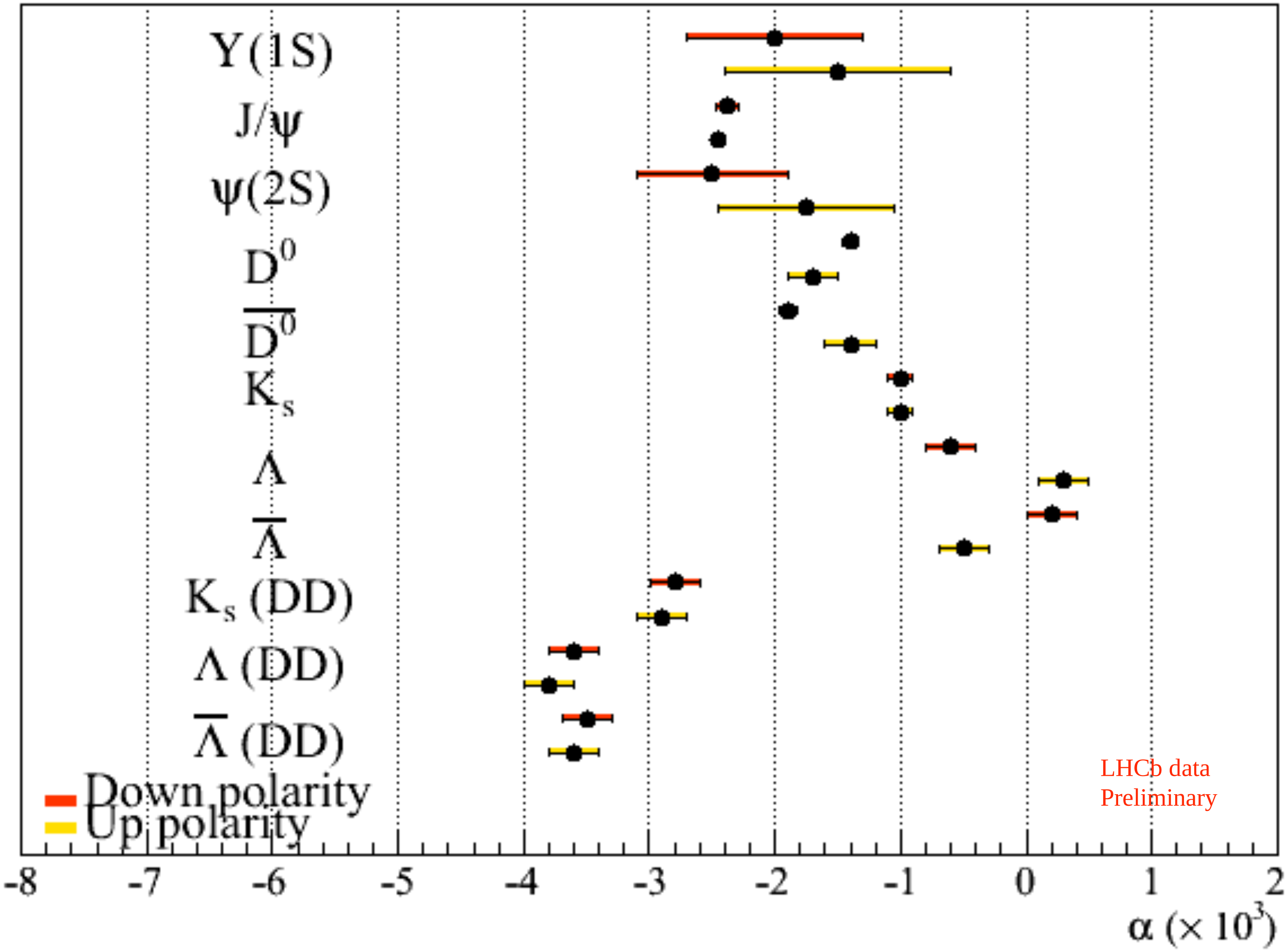
3.3 MeV



10^{-3}

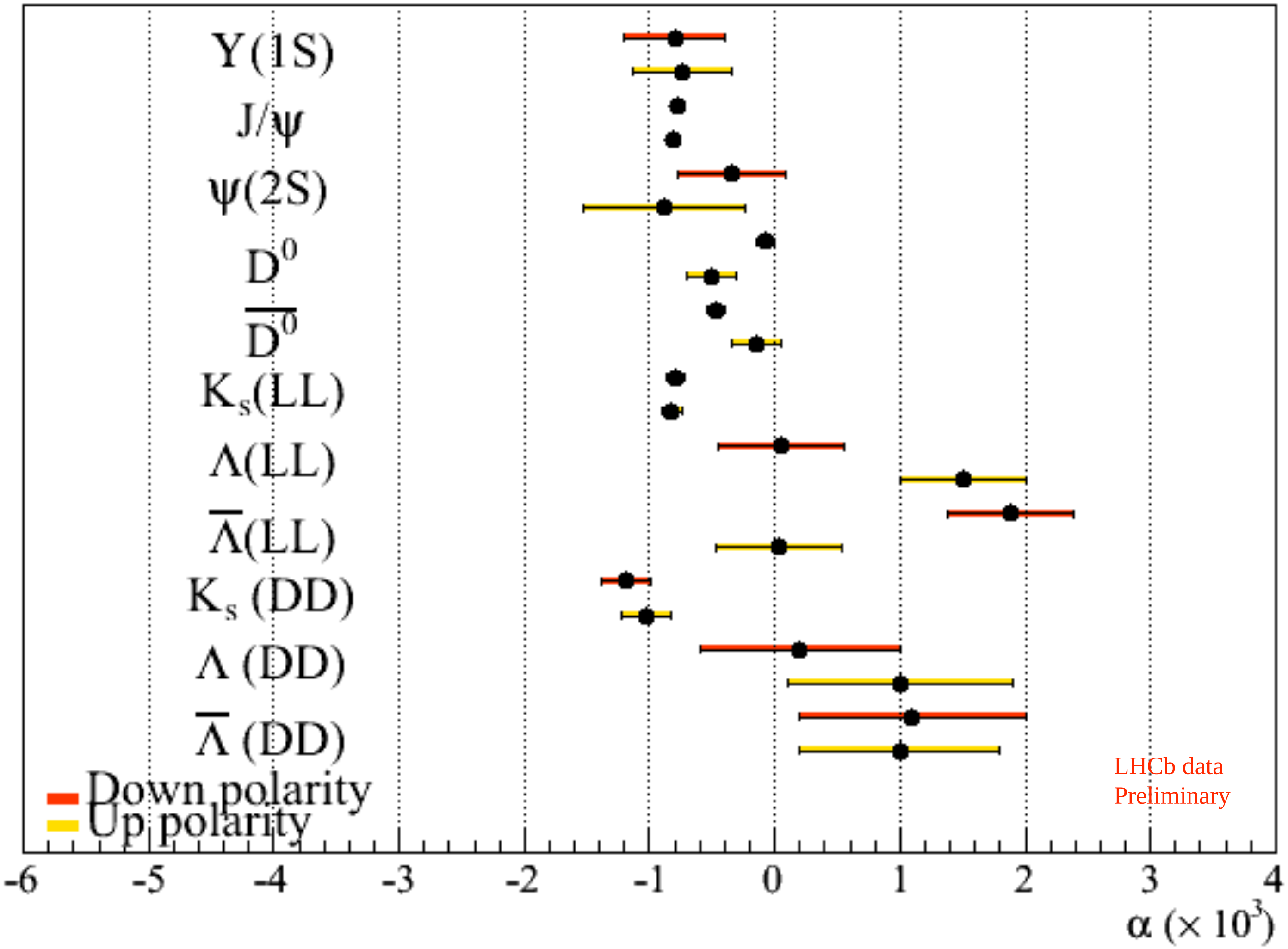
Momentum Scale

Old Alignment



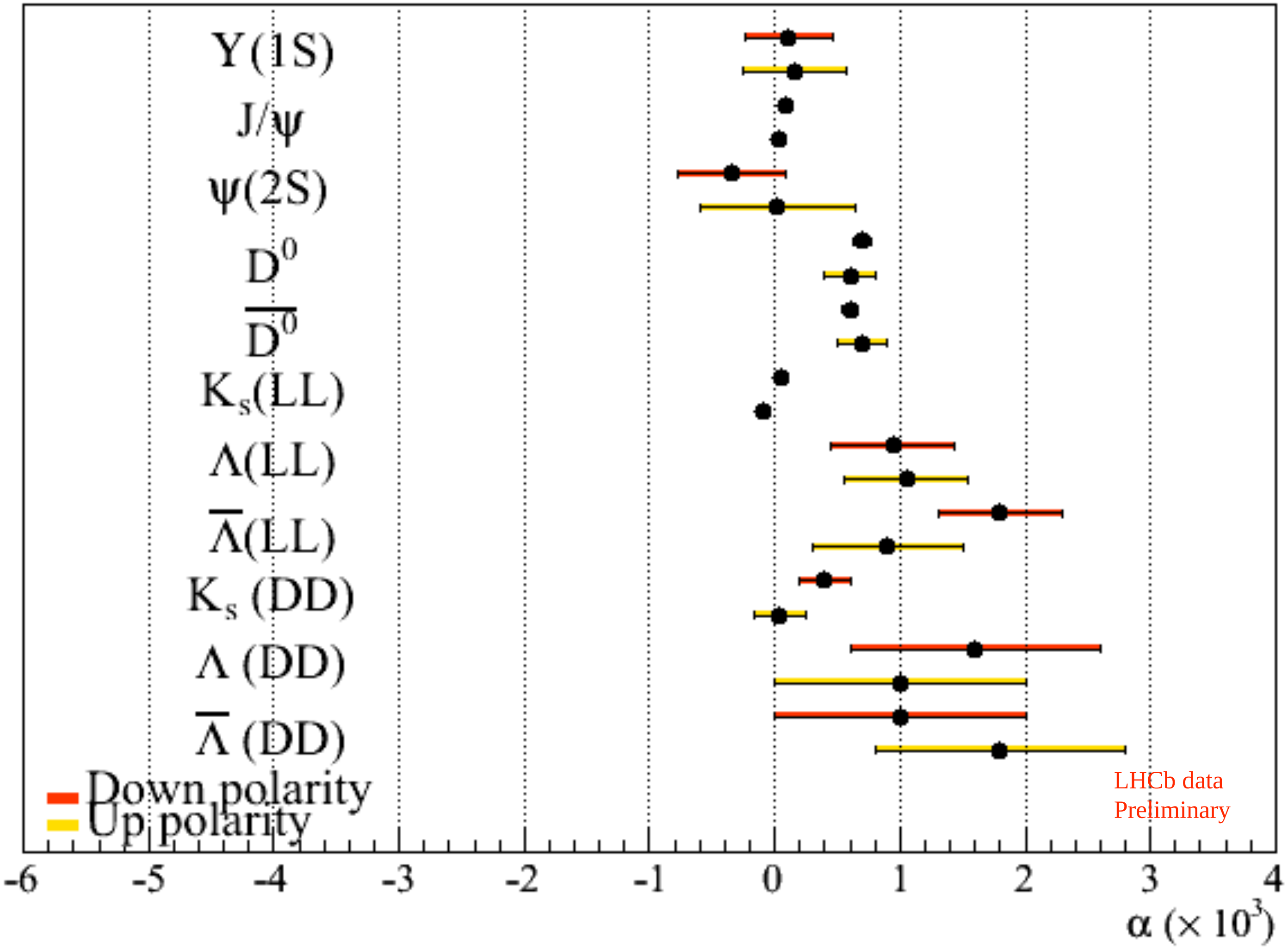
Momentum Scale

New Alignment

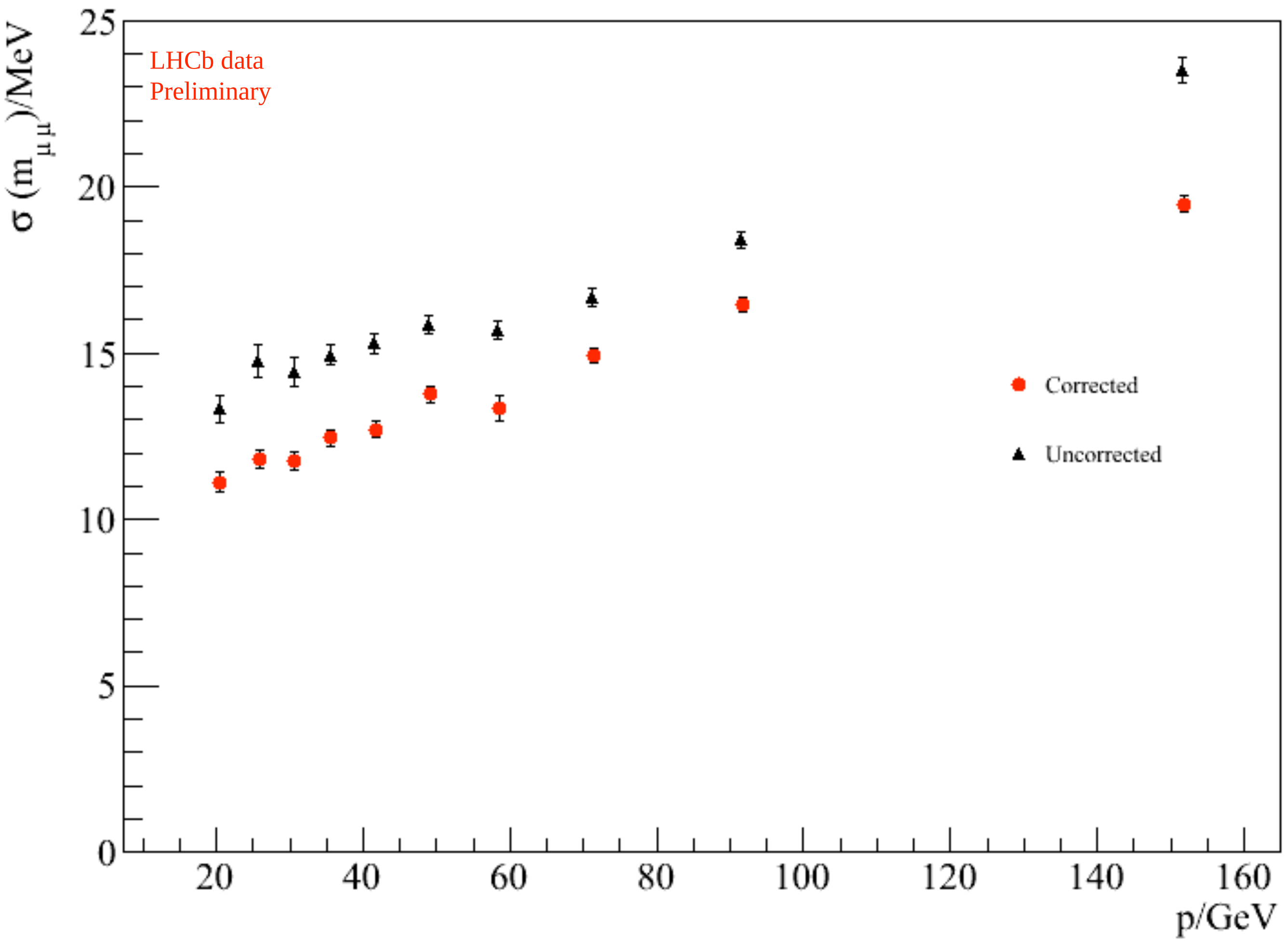


Momentum Scale

New New Alignment



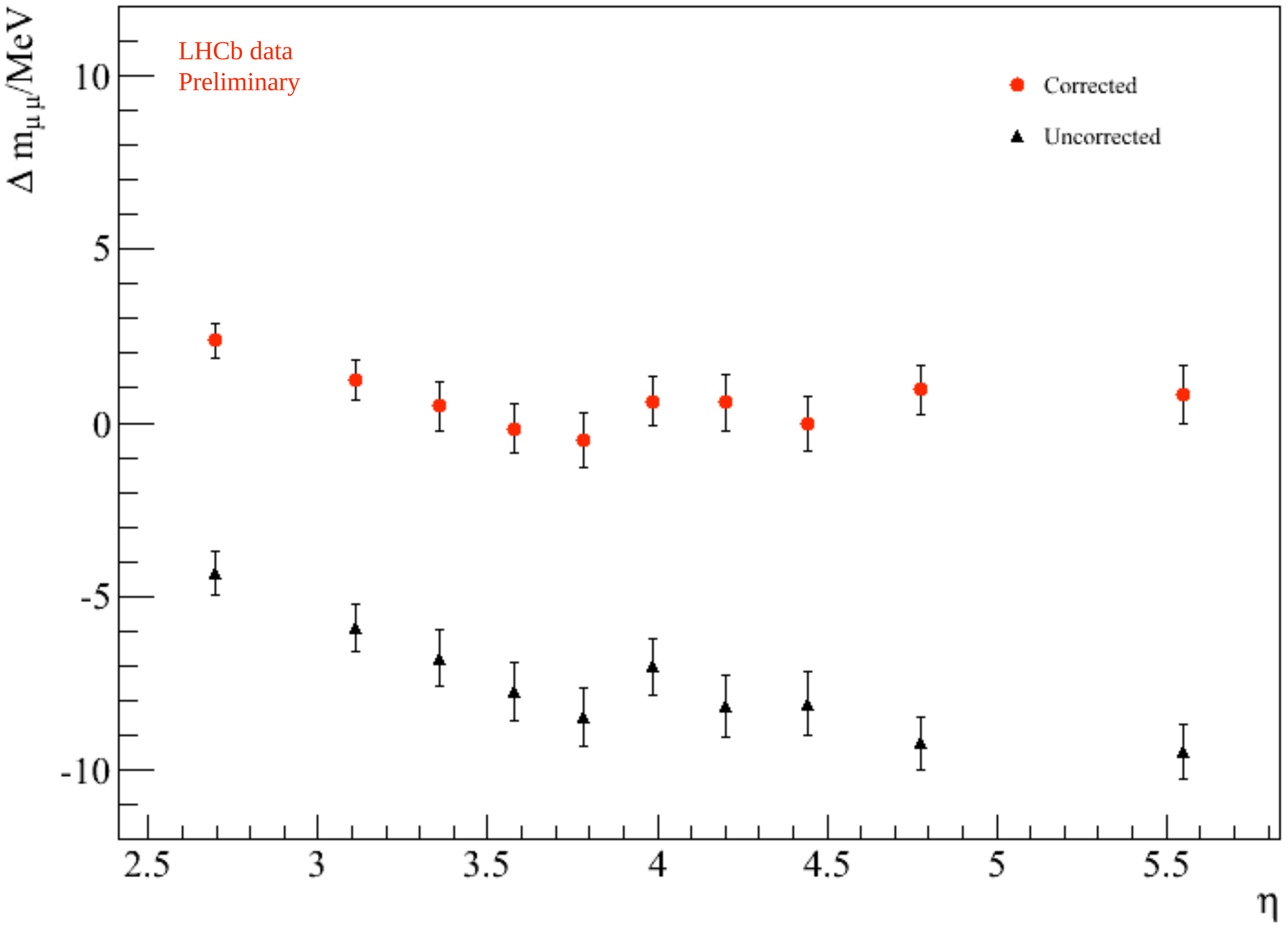
Momentum Scale



Mass resolution improved to 14 MeV, shape versus p look more reasonable

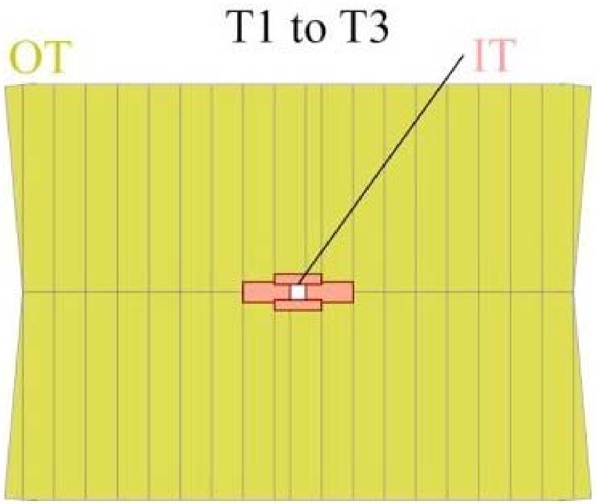
Momentum Scale

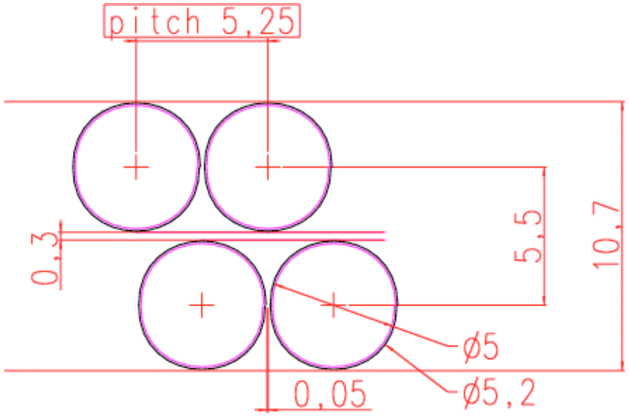
Bias versus pseudorapidity

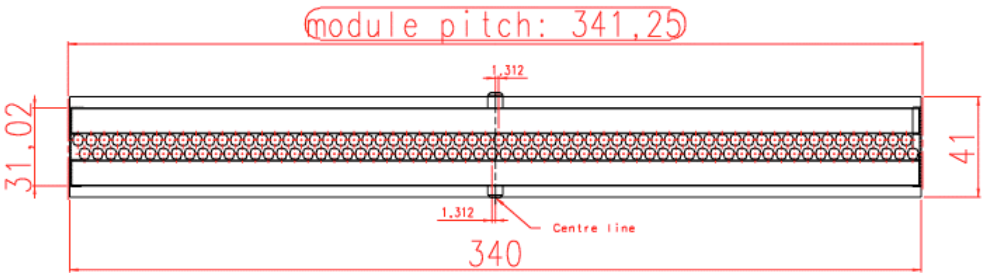


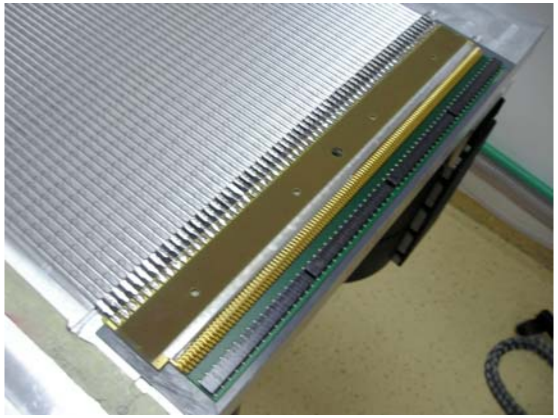
Outer Tracker

- Outer part of 3 stations after the magnet
- Each station 4 double planes of straw tubes
- Largest straws 4.7 m long with two sided readout
- Cell diameter 5 mm , pitch 5.25
- Straws made from Kapton XC with Al winding
- Gas Ar/CO_2/O_2 70/28.5/1.5
- ~ 3 % X_0 per station, 52k channels

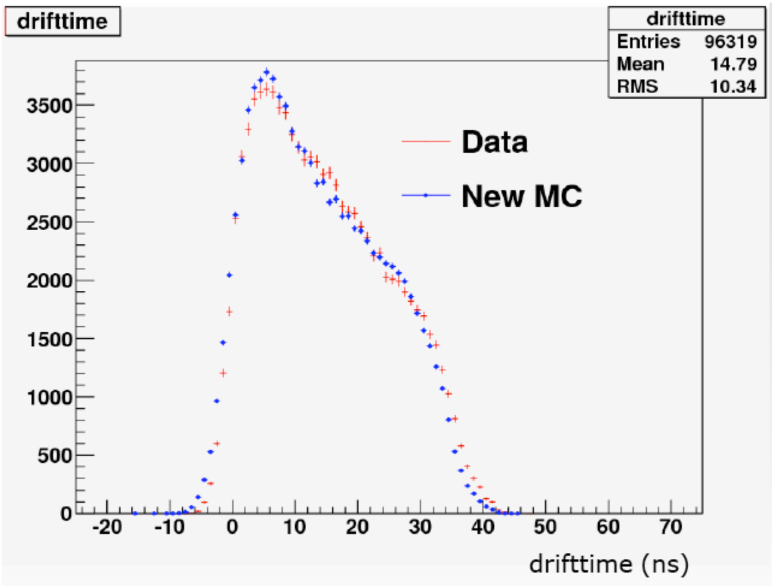


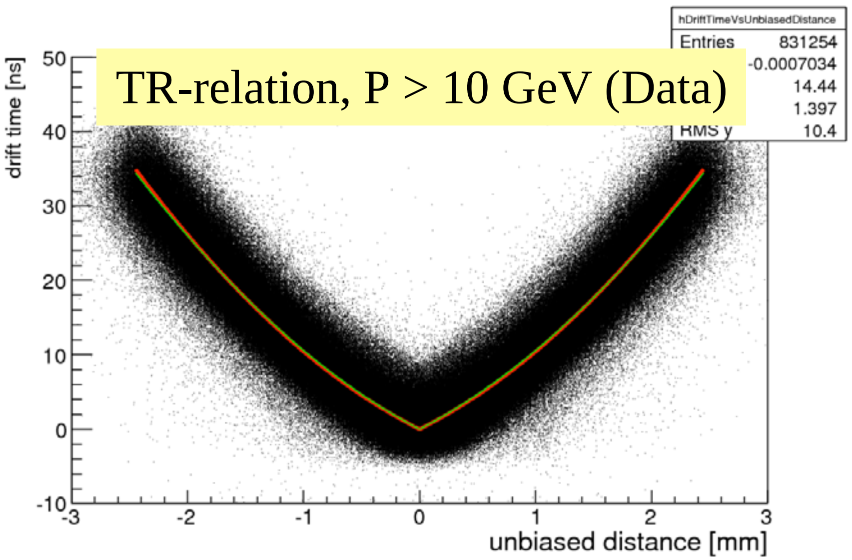






Outer Tracker





OT measures a drift time

Max drift time ~ 50 ns (read out 3 crossings)

TR relation to convert to unsigned distance to wire

Drift ambiguity solved by adding to track (Solution that minimizes drift distance)

Correction for propagation on wire

Detector resolution ~ 200 microns

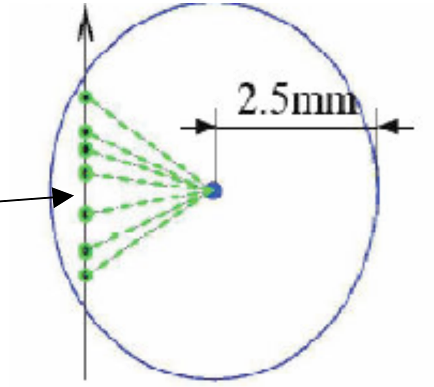
Outer Tracker

~ 19 hits track in OT acceptance , dead region around y = 0 cm

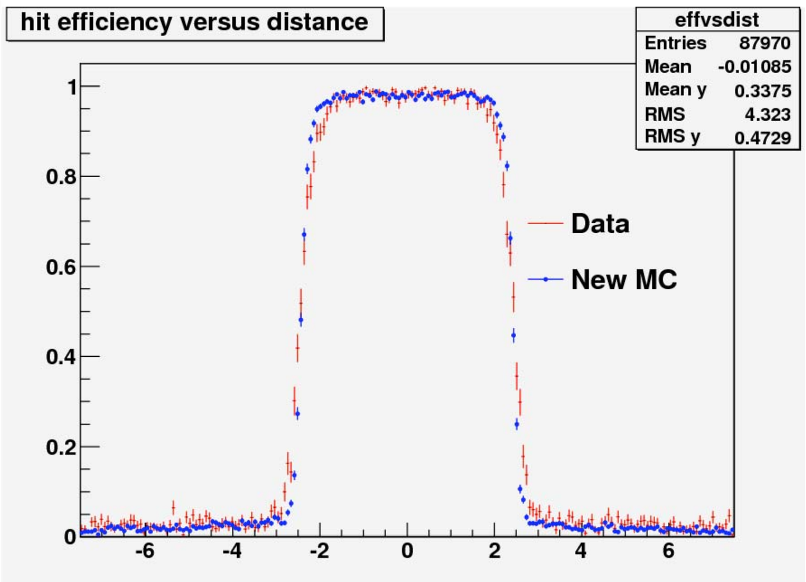
~ 1 % crosstalk

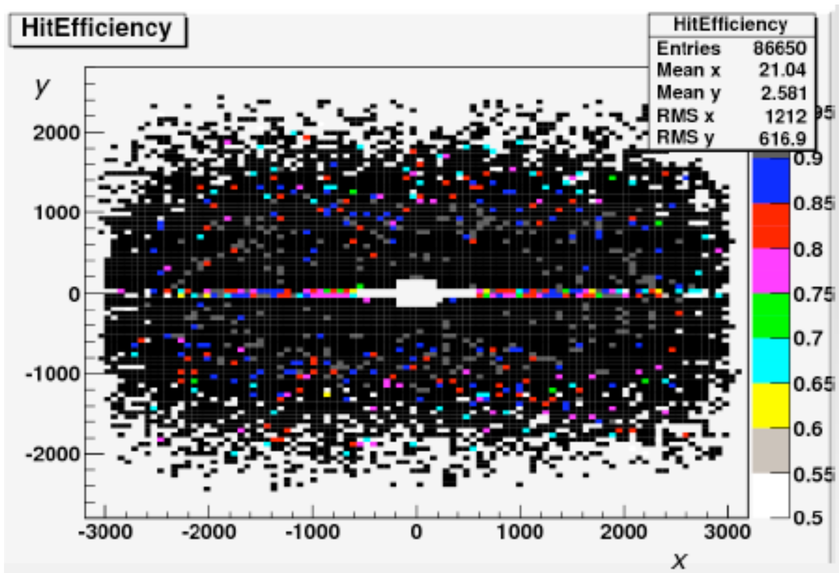
Efficiency parameterized by

$$\epsilon(l) = \eta_0(1 - e^{-\rho l}) \qquad l = 2\sqrt{r^2 - d^2}$$

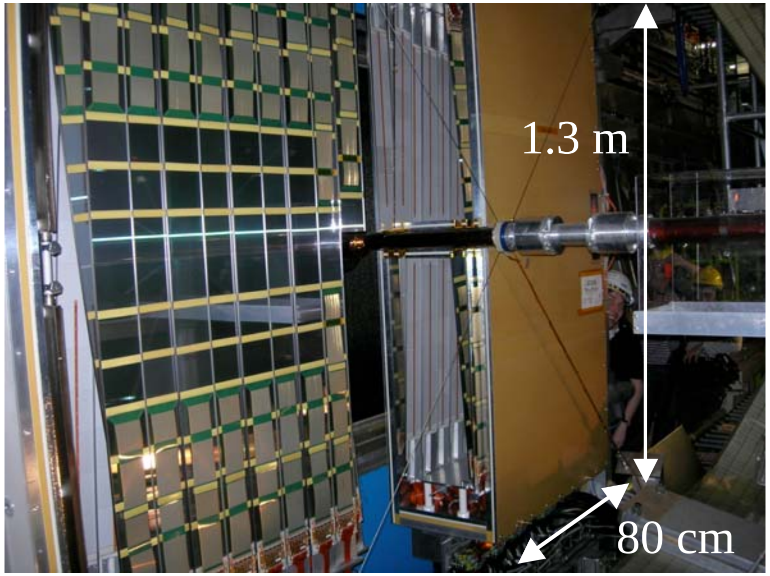


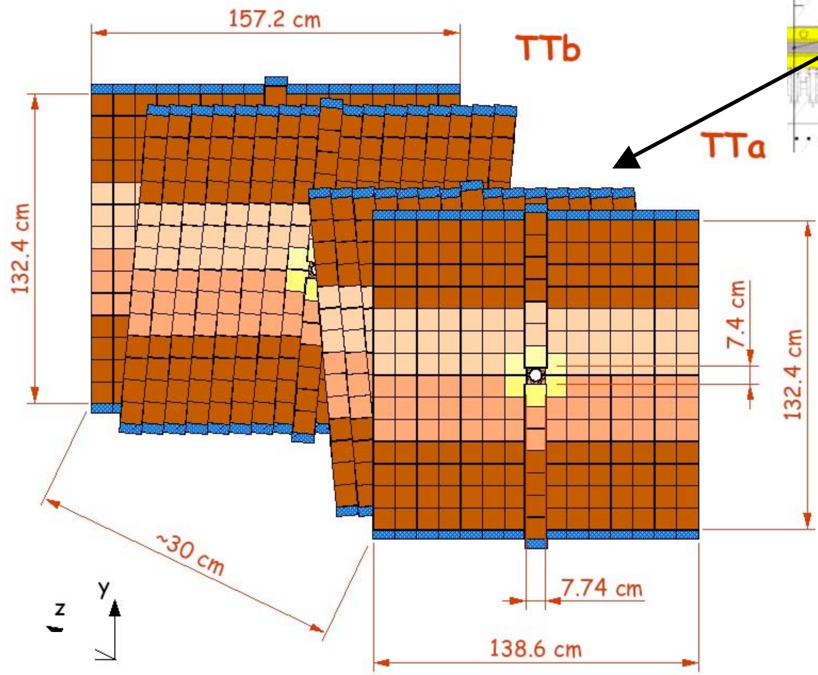
$\rho \sim 1.5$ / mm (no O_2)

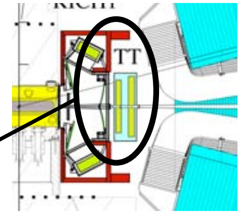


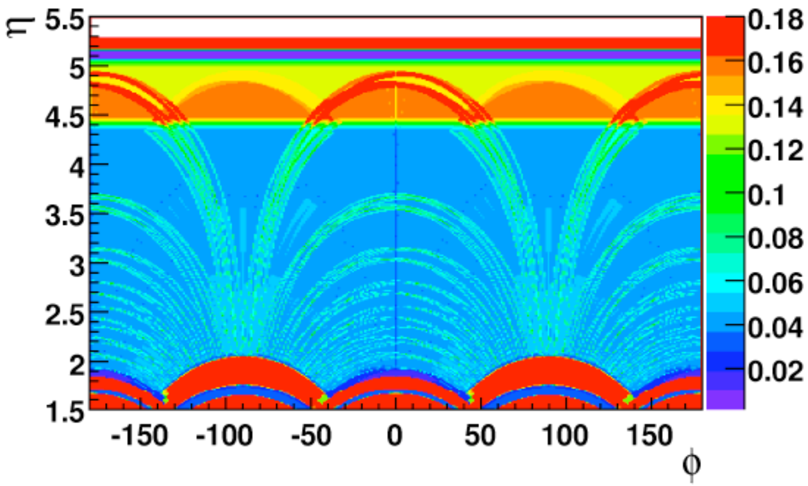


Tracker Turicensis





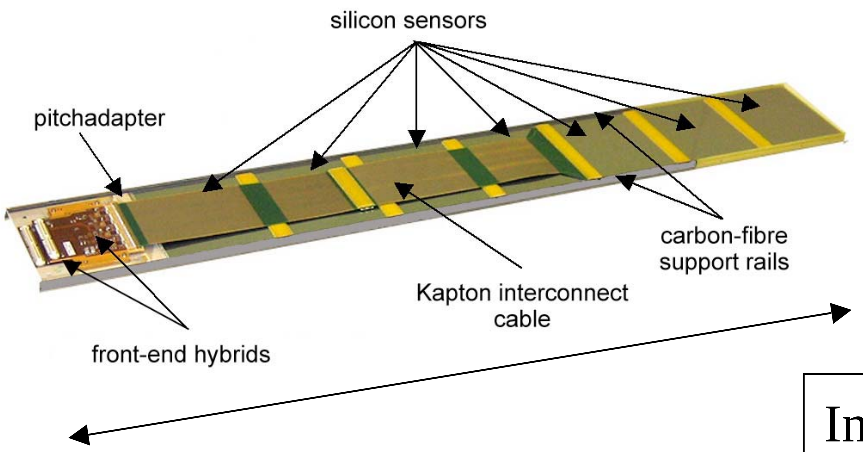




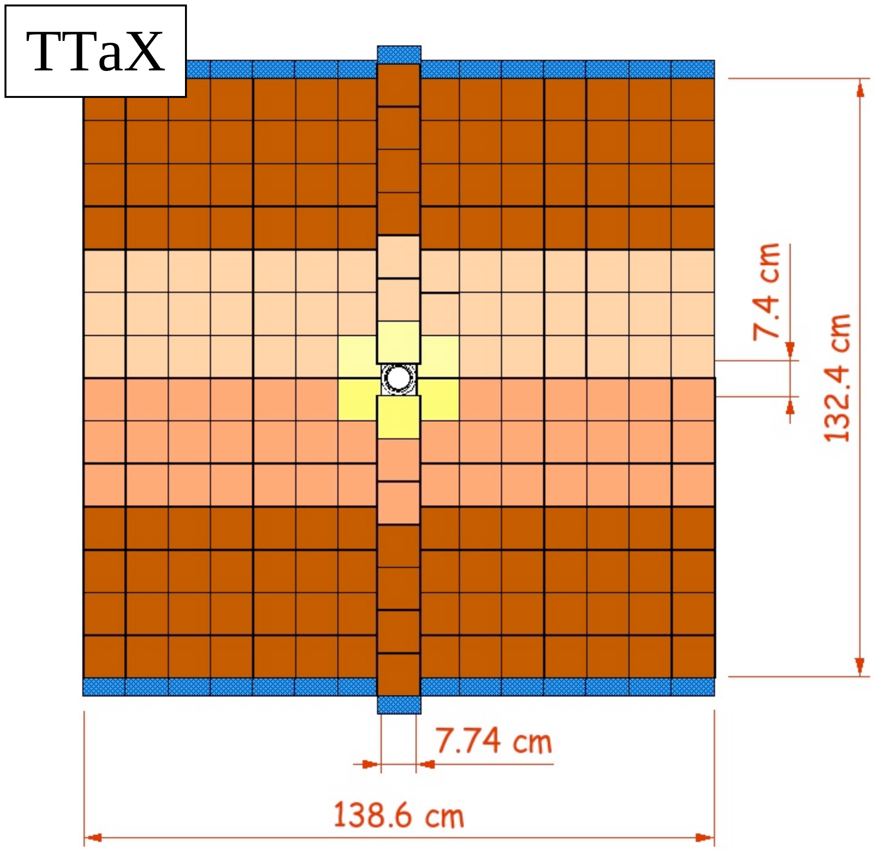
- 4 planes of Silicon (0°, +5°, -5°, 0°)
- Area of 8.2 m^2 covered ,
- 143 k readout channels
- 7 % radiation length

Tracker Turicensis

- 7-sensor ladders.
- 500 μm thick, 183 μm pitch sensors
- Strip lengths up to 37 cm,
- Capacitance 56 pF
- Long Kapton interconnects to take signal out



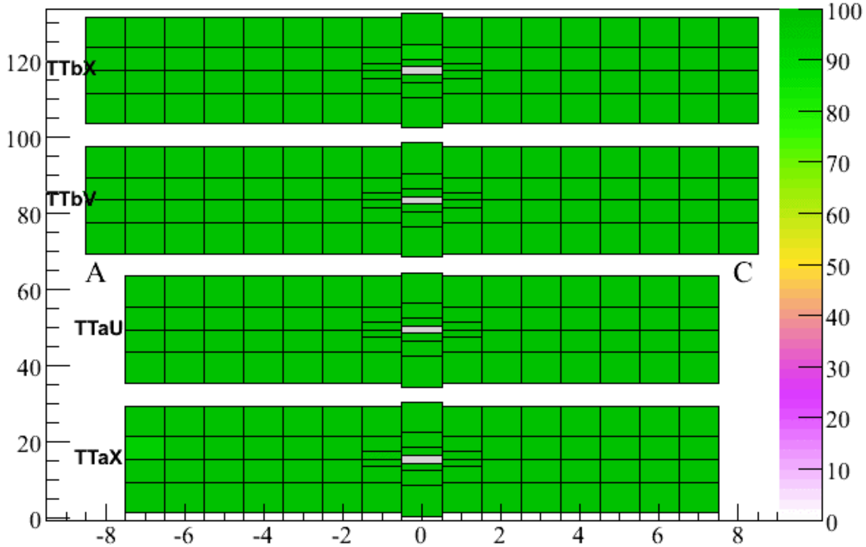
65 cm

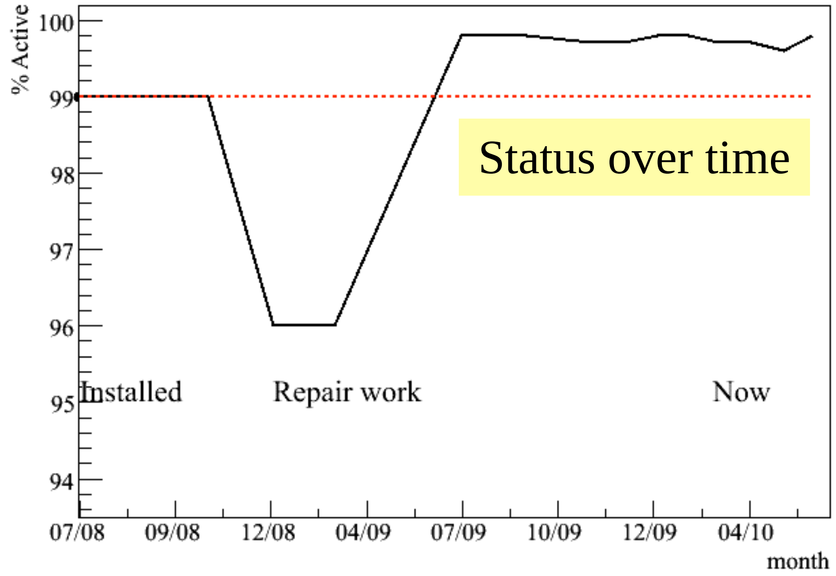


Inner part: High Occupancy 4-2-1 segmentation

Outer part: Low occupancy 4-3 segmention

TT Status





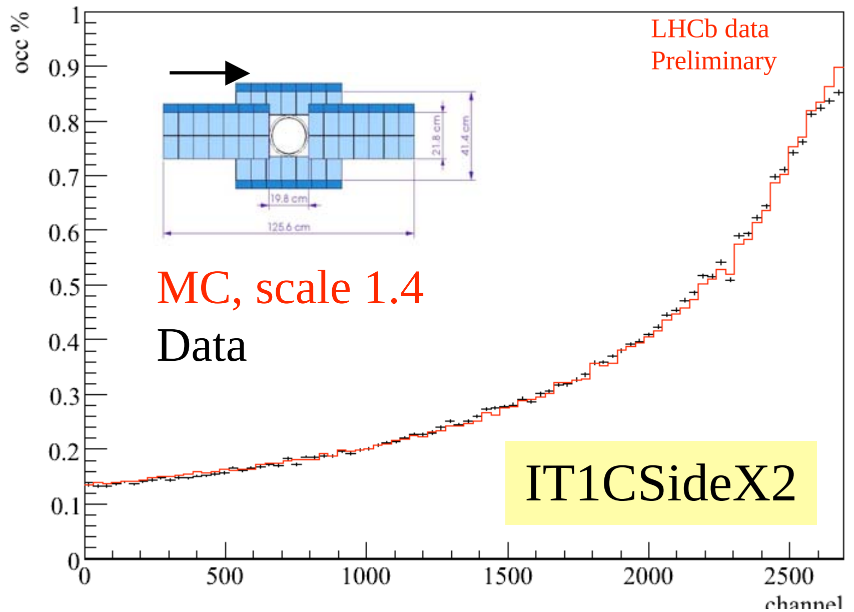
99.8 % of the detector functional

IT Performance

Occupancies in 7 TeV Min bias events with 1 reconstructed PV

TT 230 clusters/event (MC: 160)

Shapes well described



Detector efficiency measured to be

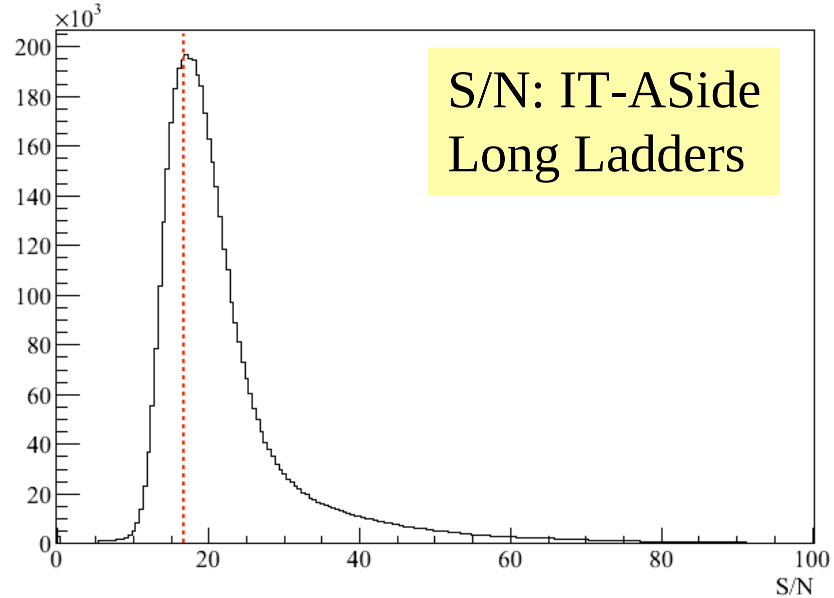
99.8 % (with tracks)

S/N 16-18

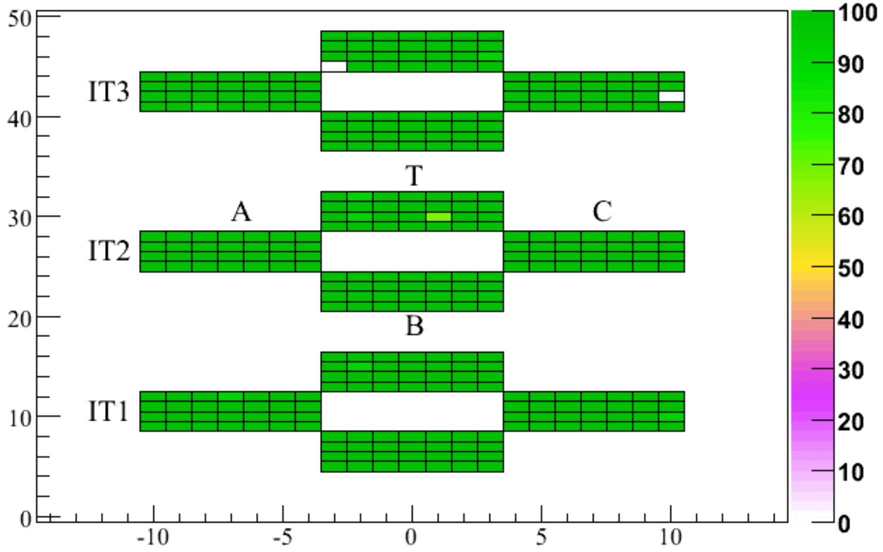
Noise rate 10^{-5}

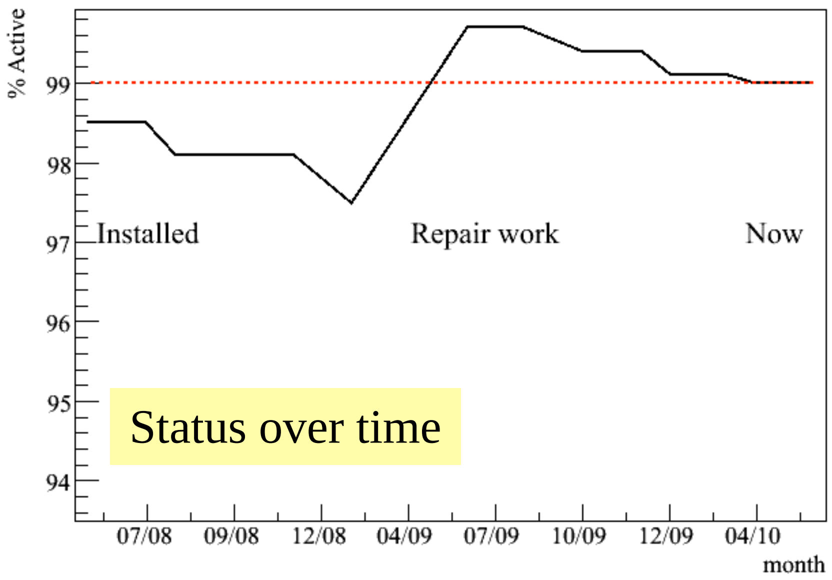
Resolution ~ 60 microns (MC 40)

(misalignments, …)



IT Status

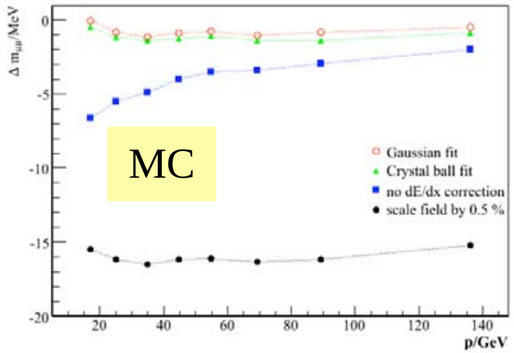




99 % of the detector functional

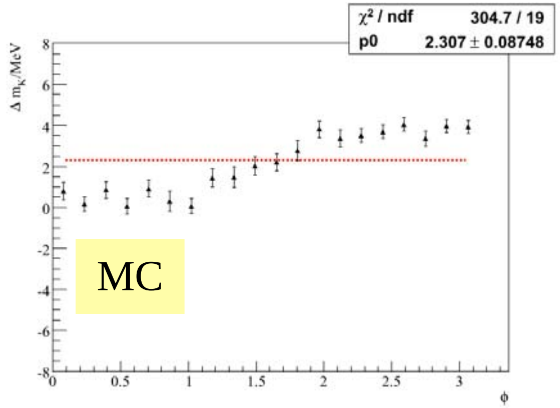
Resonance Studies

'Trivial' scaling



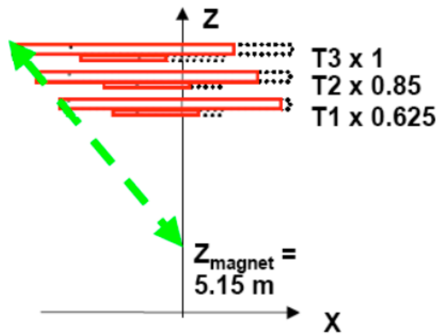
Overall scale factor: Mass offset (flat versus p)
Energy loss: sqrt dependence versus p

Field map: Cowboys + marines



Discrepancies between used field map + reality
Good discriminating variable angle between normal to decay plane and the field direction

Alignment Weak modes



e.g. q/p bias, visible if plot mass versus p+-p-
'Fix': with J/ψ or magnet off data

Common X-translation with a scale factor in T