University of Glasgow
Experimental Particle Physics

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On behalf of the LHCb Collaboration

LHC Detector Alignment Workshop
CERN, 16 June 2009

Impact of misalignments on beauty Physics at LHCb

Random misalignments

Residual misalignments

Weak modes

- competing effects: B field

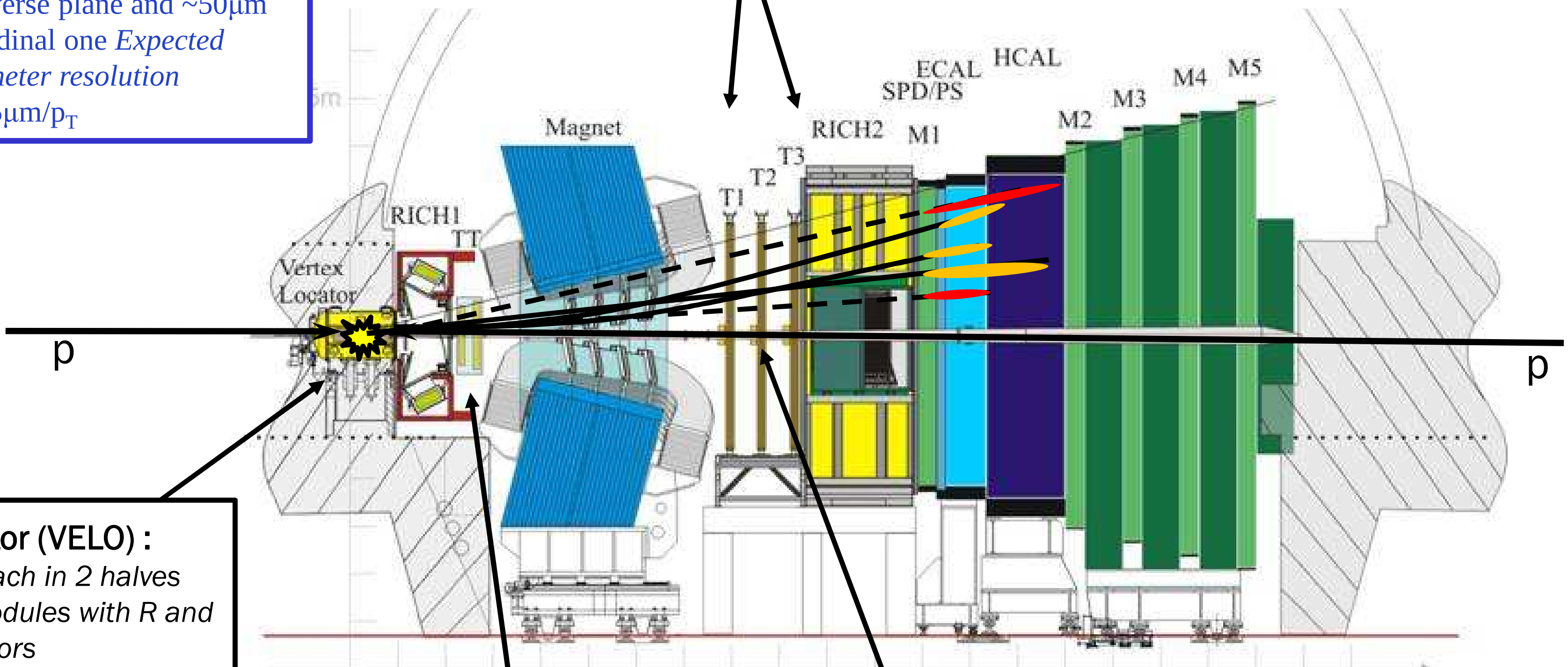
LHCb tracking detectors in short

See also the talks by:
Marc Deissenroth
Christophe Salzmann

Tracking:
Expected tracking resolution
$\delta p/p$=0.35% to 0.55%

Vertexing:
Expected primary vertex resolution
~10μm transverse plane and ~50μm in the longitudinal one *Expected Impact parameter resolution*
σ_{IP}=14μm+35μm/p_T

Outer Tracker (OT) :
3 stations, each divided in 2 halves
Each station contain 4 layers of modules
Modules made of gaseous straw tubes



Vertex Locator (VELO) :
21 stations, each in 2 halves
Each of 21 modules with R and Φ silicon sensors

Tracker Turicensis (TT) :
2-station silicon detector
Each station with 2 layers

Inner Tracker (IT) :
3 stations, each made of 4 boxes
Each box has 4 layers of silicon micro-strips

Random misalignments

- Systematic study of effect of (random) misalignments purely based on their size
- Does not involve any assumptions on quality of metrology or alignment software

Study procedure

Goal of study

Study effects of misaligned tracking system on measurements of $B \to hh'$ decays

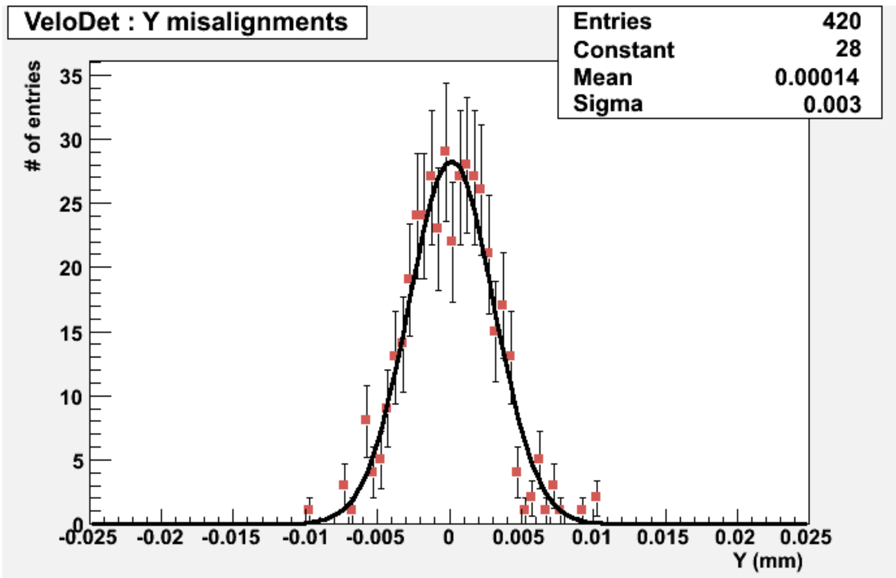
$\Rightarrow B \to hh'$ mode important / interesting:

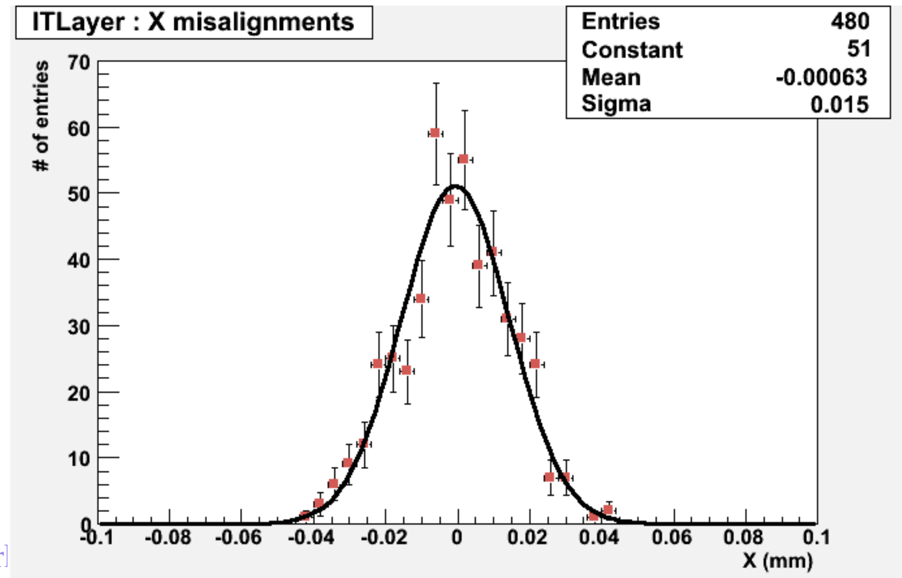
- new physics sensitive extraction of CKM angle g (h=π,K)
- calibration channel for e.g. $B_s \to \mu\mu$ mode
- decay rather affected by misalignments given high momentum of B-daughers

- Create random misalignments for VELO sensors/modules and IT and OT layers
- Choose scale (Gaussian sigma) to be ~1/3 of the detector's single hit resolution (called "1σ")
- Generate 10 sets of "1σ" misalignments and apply each to 2k $B \to \pi\pi$ events
  ($\Rightarrow$ 20k sample suppressing potentially "friendly" or "catastrophic" misalignment sets)
- Likewise, create similar sets with misalignment scales increased by factors of 3 (3σ) and 5 (5σ)
- Misalignments applied at reconstruction level to events generated with perfect geometry

Scales for the 1σ misalignment set

SUB-DETECTOR	Translations (μm)			Rotations (mrad)		
	Δ_x	Δ_y	Δ_z	R_x	R_y	R_z
VELO sensor VELO module	3	3	10	1.00	1.00	0.20
IT layer	15	15	50	0.10	0.10	0.10
OT layer	50	0	100	0.05	0.05	0.05





Intermezzo: the B $\rightarrow$ hh analysis cuts

Selection cuts consist of various requirements:

- **Particle identification:**

  K-π separation based on PID likelihood difference ($\Delta \ln \mathcal{L}_{K\pi}$)

- **Topological:**

  clear separation of primary vertex and B-decay vertex

  B-daughters impact parameter (IP) and B-decay length significance

- **Kinematic:**

  minimal B-candidate and B-daughters transverse momentum

- **Vertexing:**

  χ^2 of vertex fit to B-daughters

- **Mass:**

  mass window cut on invariant mass of B-daughters

Impact of VELO misalignments (1/4) – no IT/OT misalign.

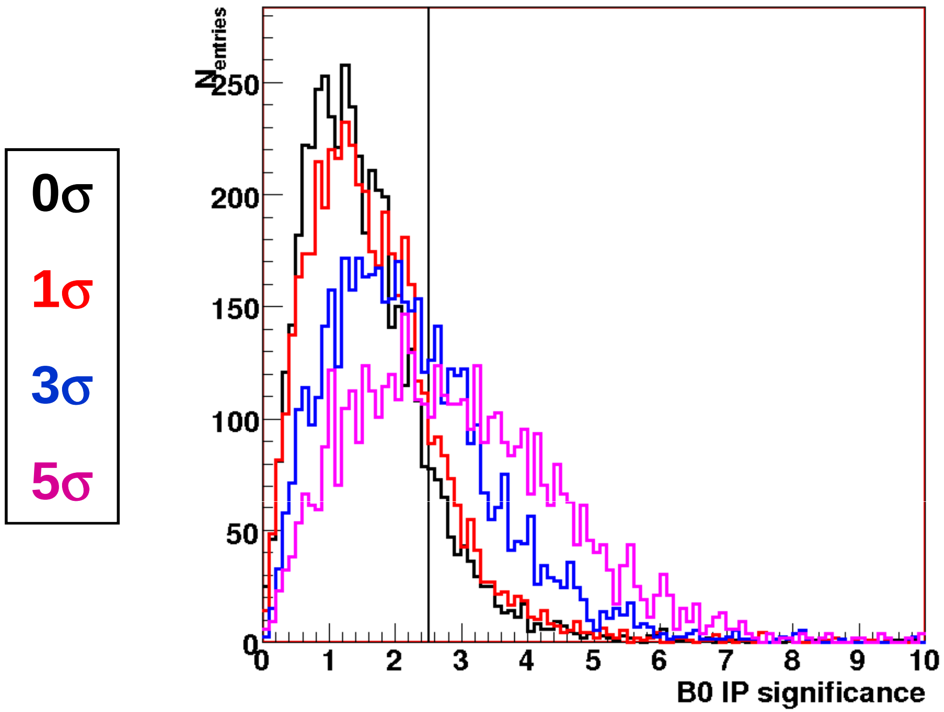
- **Selected event numbers and pattern recognition efficiencies *after* standard B $\rightarrow$ hh selection**

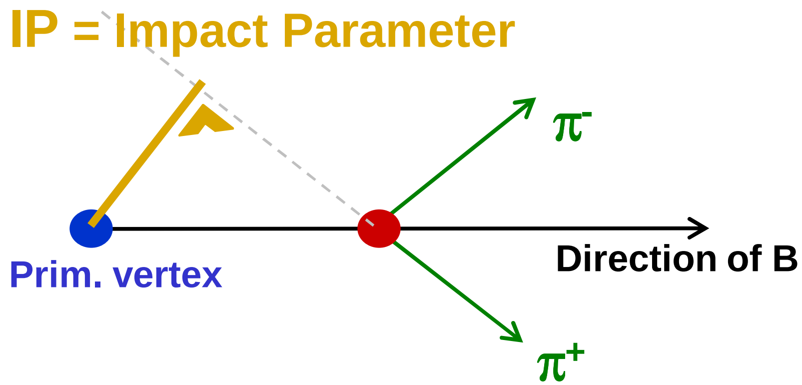
Pattern recognition for "long" tracks, i.e. tracks traversing the whole of LHCb

	$N_{\text{selected B}}$	$\varepsilon_{\text{PatternReco}}$ (%)
0σ	4229	85.9
1σ	3904	85.6
3σ	2241	83.1
5σ	1106	80.1

- Effect on tracking is small-ish
- Very significant loss of events, has to come from the selection itself …
  - ⇒ misalignments have serious impact on some selection variables
  - ⇒ systematic check of all of them …

Impact of VELO misalignments (2/4)





- ❑ Biggest effect comes from tight upper cut on the B-candidate IP significance, IPS < 2.5
- ❑ Additional effect on lower IPS cut of B-daughters
- ❑ Also χ^2 of B-vertex fit is rather affected

$IPS=IP/\sigma_{IP}$

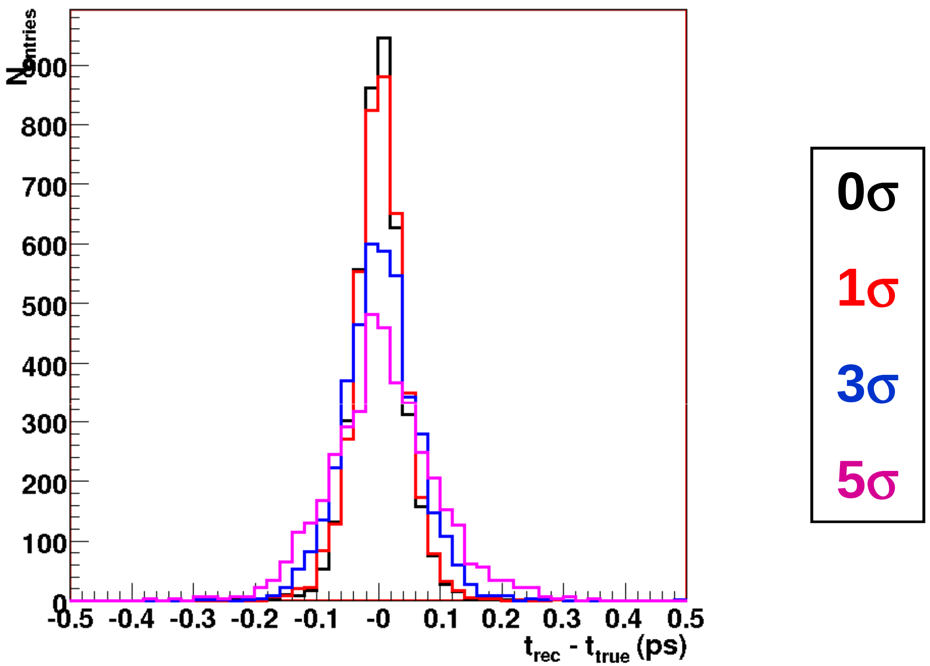
Impact of VELO misalignments (3/4)

❖ **Propertime resolution *after* standard B → hh selection**

- crucial in time-dependent CP violation measurements

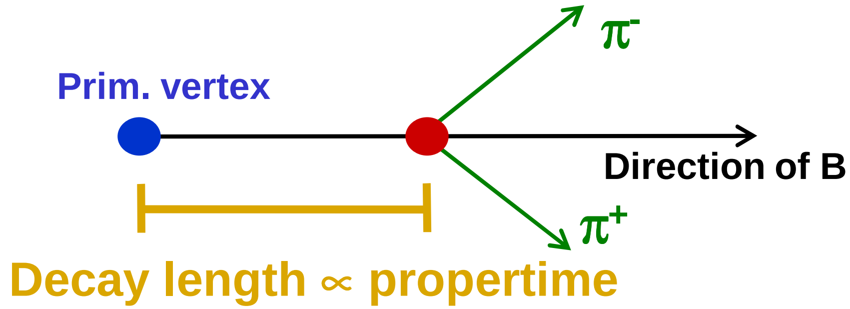
	τ resolution (fs)
0σ	37.7
1σ	39.4
3σ	58.1
5σ	82.0

(sigma of Gaussian fit)



2^{nd} order effects:

- ❑ **B-daughters momentum resolution: 0.50 → 0.52 %**
- ❑ **B mass resolution: 22.5 → 23.5 MeV**



Impact of VELO misalignments (4/4)

- Primary vertex and B-decay vertex resolutions in selected $B \to hh$ events

Resolution	Primary vertex (μm)		B-decay vertex (μm)	
	x/y	z	x/y	z
0σ	9	41	14	147
1σ	10	48	15	155
3σ	16	81	21	226
5σ	25	147	29	262

Impact of IT and OT misalignments – no VELO misalign.

- Effect on tracking is small
- Loss of events much smaller compared to the VELO case (~4% in the extreme 5σ case)

❖ Momentum and mass resolutions *after* standard B → hh selection

	p resolution (%)
0σ	0.50
1σ	0.50
3σ	0.54
5σ	0.59

	Mass resolution (MeV)
0σ	22.5
1σ	22.6
3σ	23.4
5σ	25.8

- p dominated by multiple scattering, not single-hit resolution
- at most of order 10% effect

Impact of combined VELO, IT and OT misalignments (1/2)

- **Selected event numbers, PR efficiencies and resolutions *after* standard B $\rightarrow$ hh selection**

	$N_{selected\ B}$	$\varepsilon_{PatternReco}$ (%)	τ res. (fs)	*p* res. (%)	Mass res. (MeV)
0σ	4229	85.9	37.7	0.50	22.5
1σ	3892	85.6	40.9	0.50	22.3
3σ	2086	83.3	58.0	0.56	25.1
5σ	1040	78.5	78.6	0.63	25.5

$\Rightarrow$ **Effects are roughly the combined effects of VELO and IT+OT misalignments**

If software alignment is of order or better than "1σ" we are in business!

Impact of combined VELO, IT and OT misalignments (2/2)

RESOLUTION	Affected by VELO misalignments	Affected by T misalignments
B-daughters momentum	no	yes
B mass	no	yes
B vertex	yes	no
B Impact Parameter	yes	no
B propertime	yes	no

no = very small/negligible effect

yes = significant effect

Residual misalignments

- ❑ **Study of remaining misalignment effects after application of alignment algorithms**
- ❑ **Identify potential problems/biases of alignment procedure**

Study procedure

- Sample: 20k minimum bias events reconstructed with the nominal geometry

- Tracks refitted using a misaligned geometry database for IT & OT:
  - translations in x applied to IT boxes, IT&OT layers, and IT ladders individually (x=measurement direction) following a flat distribution with widths:

(408 degrees of freedom to align for)

Detector		DoF	Amplitude
IT	boxes	TX [mm]	1.0
	layers	TX [mm]	0.1
	ladders	TX [mm]	0.05 (*)
OT layers		TX [mm]	1.0
		RZ [mrad]	0.15

- Alignment procedure based on the minimisation of the tracks χ^2 using Kalman filter fitted tracks

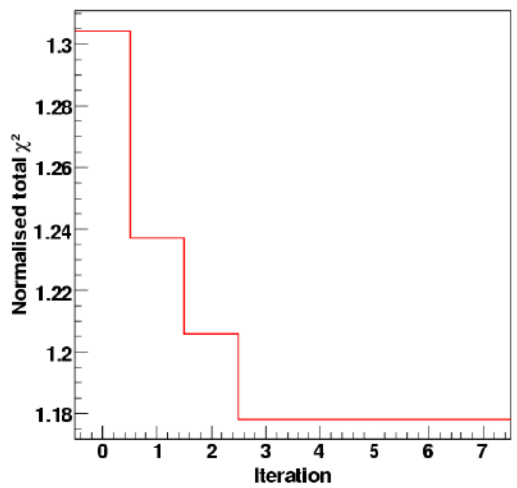
- Translations in y and z, and rotations in y, are not aligned for as χ^2 of tracks not very sensitive to these movements

Results at end of alignment process

See also the talk by
Christophe Salzmann

- The overall alignment of all IT & OT degrees of freedom followed an iterative procedure

  - 3 iterations are typically needed:



- E.g., after alignment, the distribution of residual misalignments for the IT has a Gaussian width ~20% the IT resolution (=60μm)

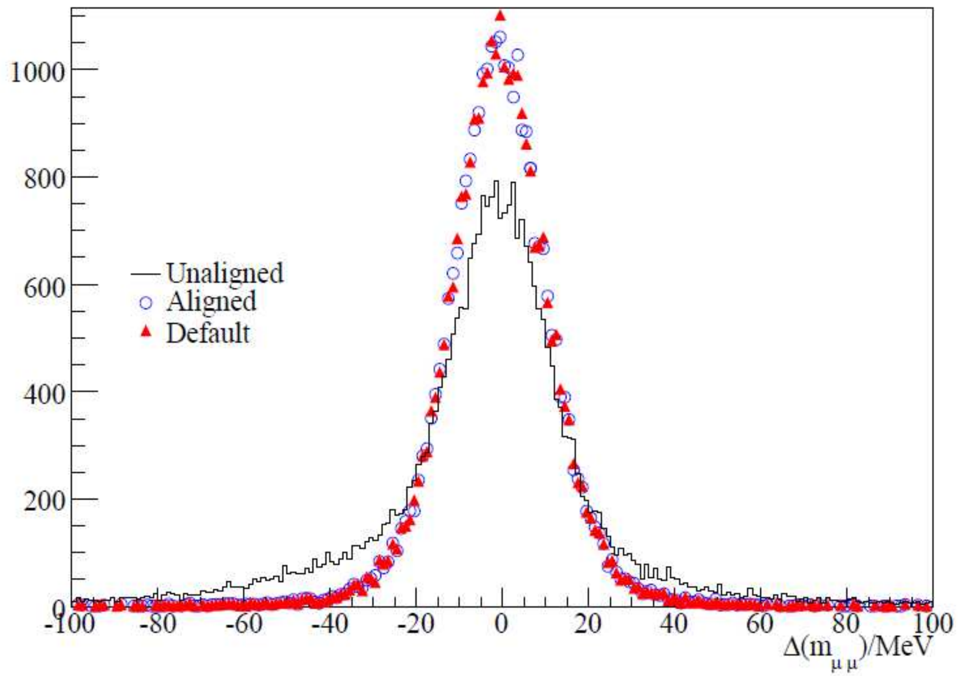
- After alignment, some weak modes may still be present

… but what is the impact on the physics studies?

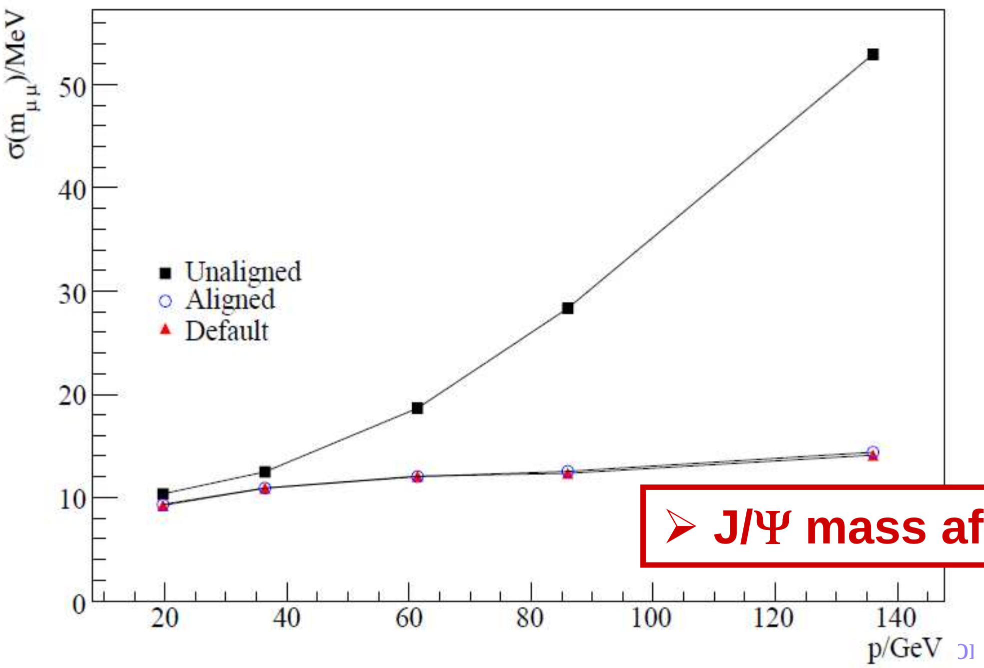
Effect on 2-body decays

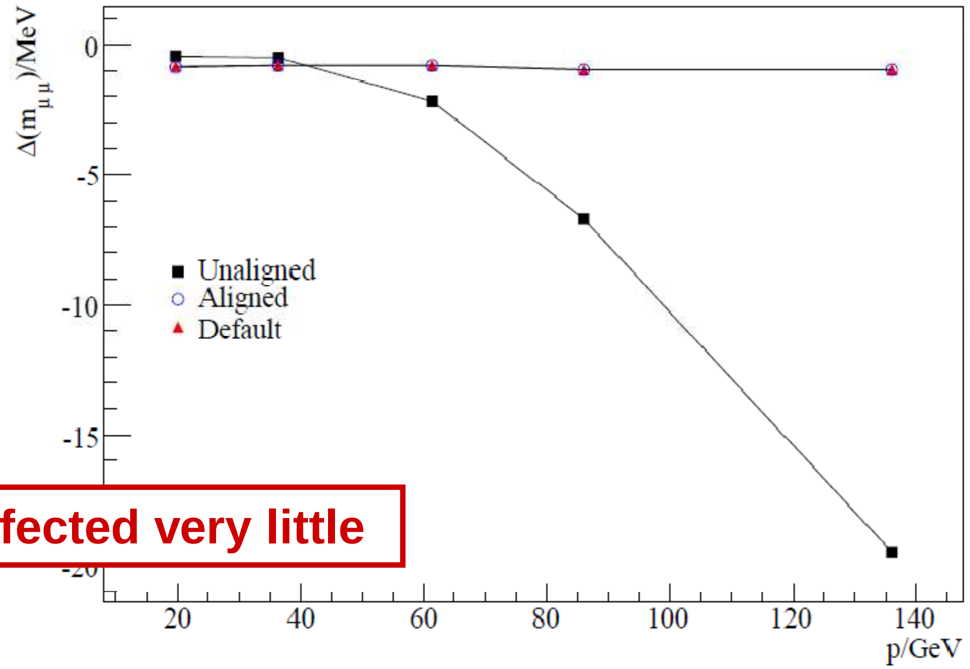
Comparison:

- Default: ideal geometry
- Unaligned sample: before alignment
- Aligned sample: after alignment job



Sample of $J/\Psi \rightarrow \mu\mu$ events





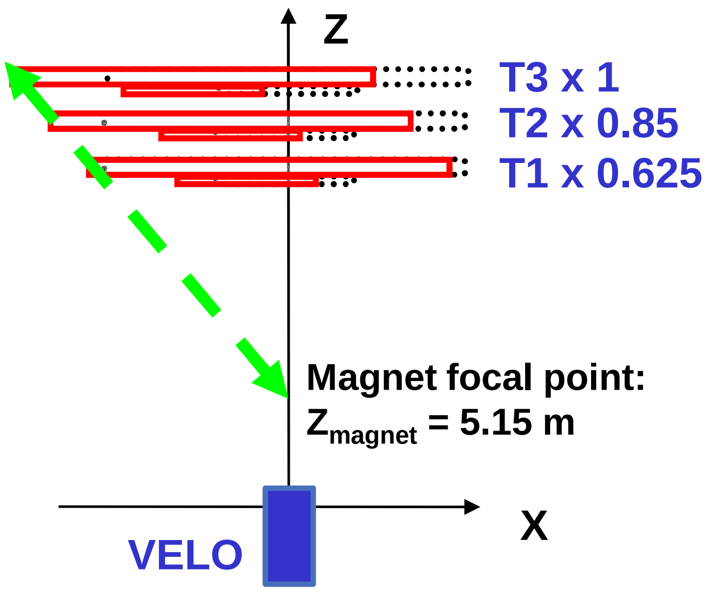
➢ J/Ψ mass affected very little

Weak modes

- Weak modes are linear combinations of alignment parameters that are insensitive to the alignment procedure
- Constraints are typically applied to avoid problems

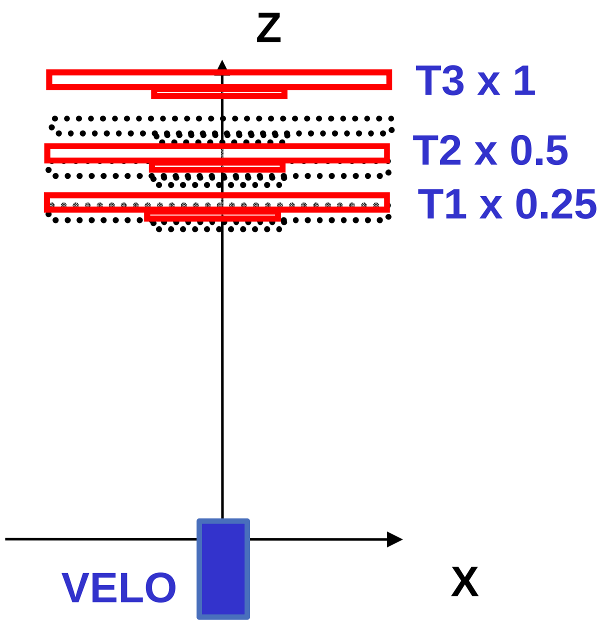
T-stations weak modes

- 2 T-stations weak modes identified, relevant to *p* determination:
  - have no significant effect on the track fit χ^2



X-shearing (IT & OT)
with a scale factor on Z

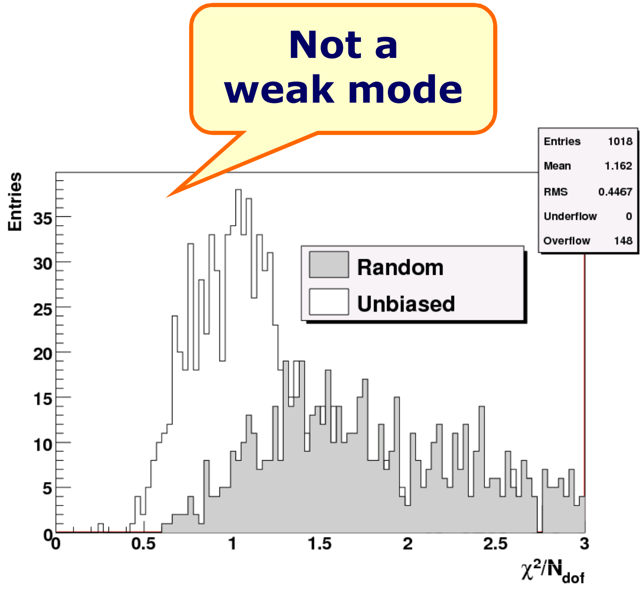
(e.g. 500 µm @ T3 → 425 µm @ T2 & 312 µm @ T1)



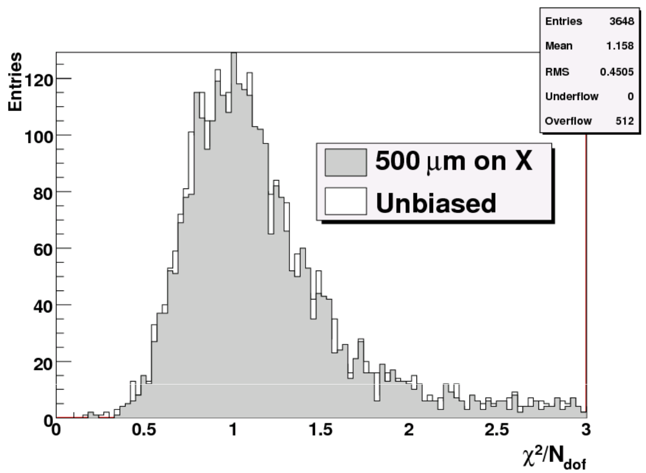
Z-scaling (IT & OT)
with a scale factor on Z

(e.g. 500 µm @ T3 → 425 µm @ T2 & 312 µm @ T1)

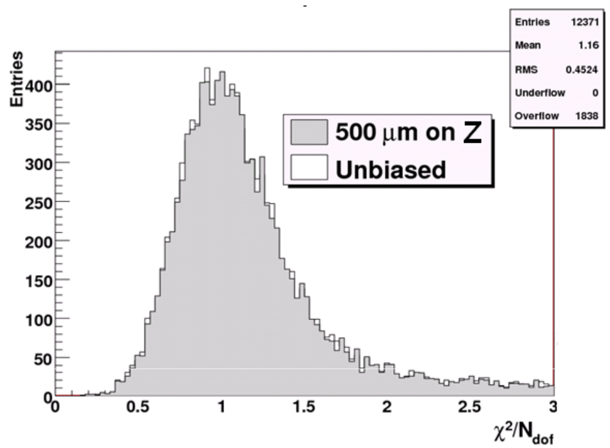
How weak are these weak modes?



Random misalignment of OT and IT of 500 microns



X-shearing with a scale factor of IT and OT



Z-scaling with a scale factor of IT and OT

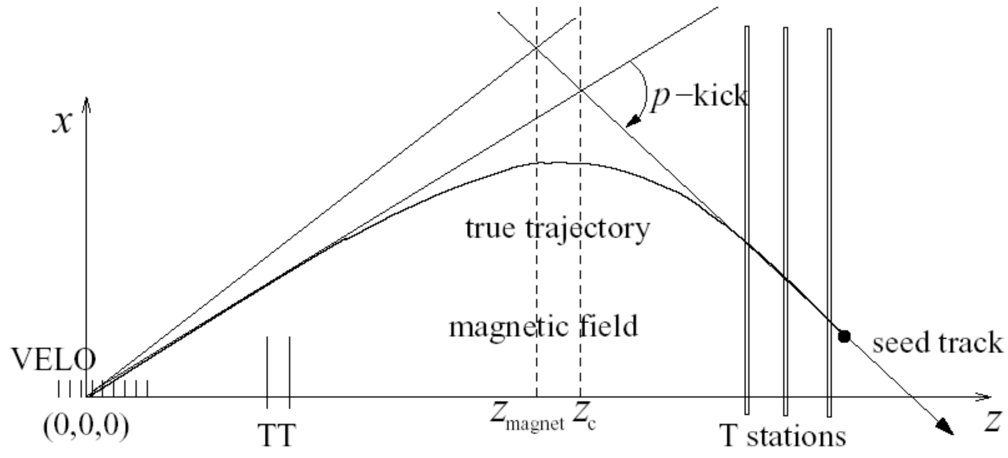
- **Very weak!**
  - **- no impact on the track χ^2 !**
  - **- reconstruction efficiency unchanged**

Momentum and mass - parametrisation

How we measure the momentum?

$$\omega = q/p$$

$$\Delta t_x \approx \frac{q}{\sqrt{p_x^2+p_z^2}} \int B_y dz = \omega I_B$$



Generic bias parametrisation:

$$\omega' = \omega_0 + \Delta\omega + \omega_0 \delta\alpha$$

Δω: x-shearing

$$p' \approx \frac{I_B q}{\omega_0 + \Delta\omega}$$

$$m'^2 \approx [1 + (p_1 - p_2)\Delta\omega] m^2$$

$$m' \approx \left[1 + \frac{(p_1 - p_2)}{2}\Delta\omega\right] m$$

δα: z-scaling

$$p' \approx \frac{I_B q}{\omega_0 (1+\delta\alpha)}$$

$$m' \approx (1+\delta\alpha) m$$

Magnetic Field scale:

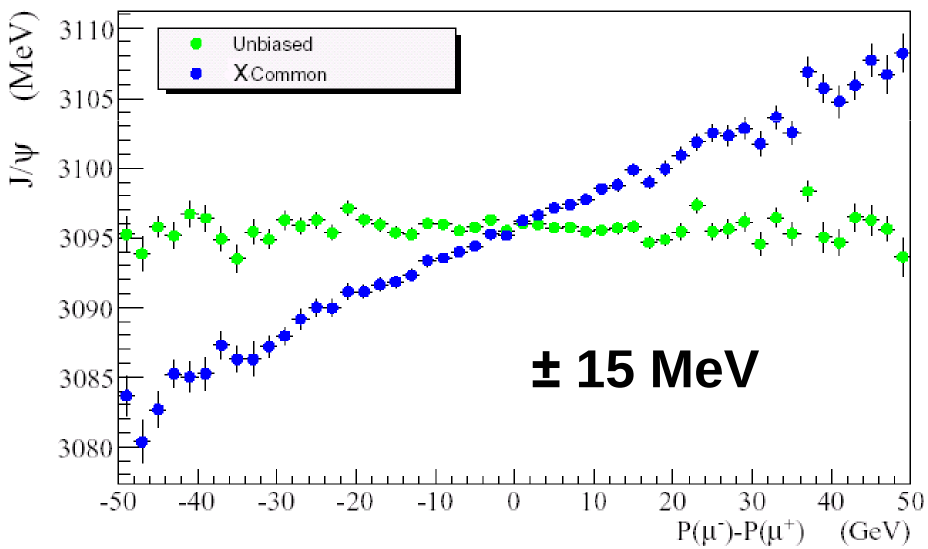
$$I_B' \approx (1+\delta k) I_B$$

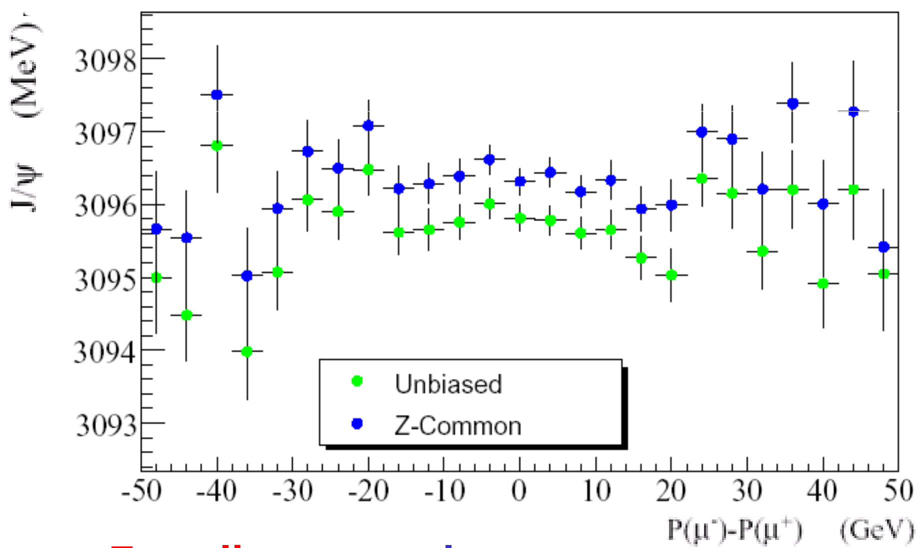
$$m' \approx (1+\delta k) m$$

Effect on mass of 2-body decays (1/2)

➢ **Bias on the mass after alignment:**
- One can use several 2-body decays
  $K_s \rightarrow \pi\pi$, $J/\psi \rightarrow \mu\mu$, $B_d \rightarrow \pi\pi$
  and plot the mass versus the momentum difference of the daughters

Example with 40 000 J/Ψ





X-shearing example (J/ψ):

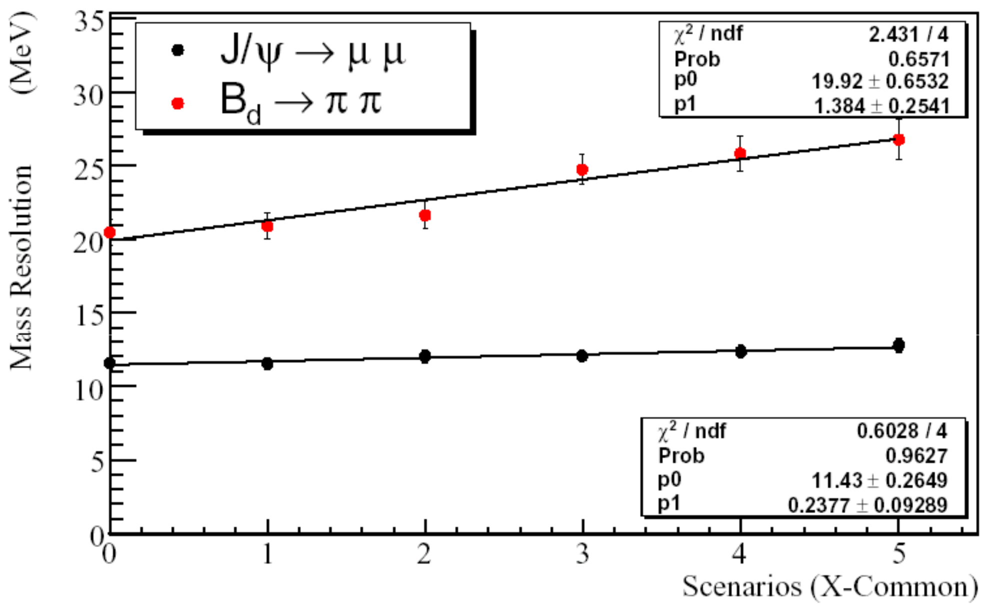
(500 μm; 425 μm; 312 μm;) = (T3,T2,T1)

Z-scaling example:

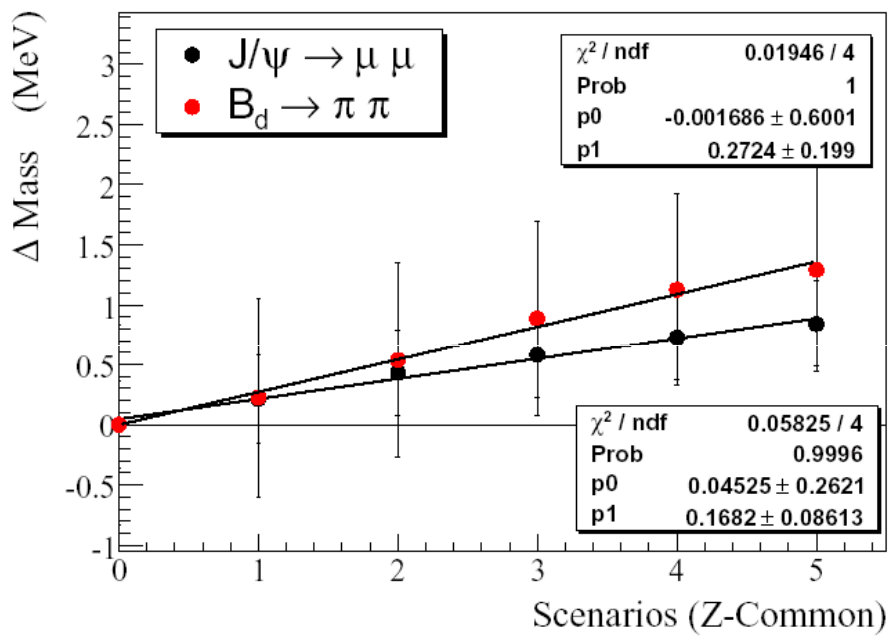
(500 μm; 250 μm; 125 μm;) = (T3,T2,T1)

Effect on mass of 2-body decays (2/2)

X-shearing with a scale factor of IT and OT



Z-scaling with a scale factor of IT and OT



- **For the B_d the mass resolution is rather sensitive**
  - because of high momentum of B-daughters

Weak modes and B-field

$$\Delta t_x \approx \frac{q}{\sqrt{p_x^2+p_z^2}} \int B_y dz = \omega I_B$$

Magnetic Field scale:

$$I_B^{'} \approx (1+\delta k) I_B$$

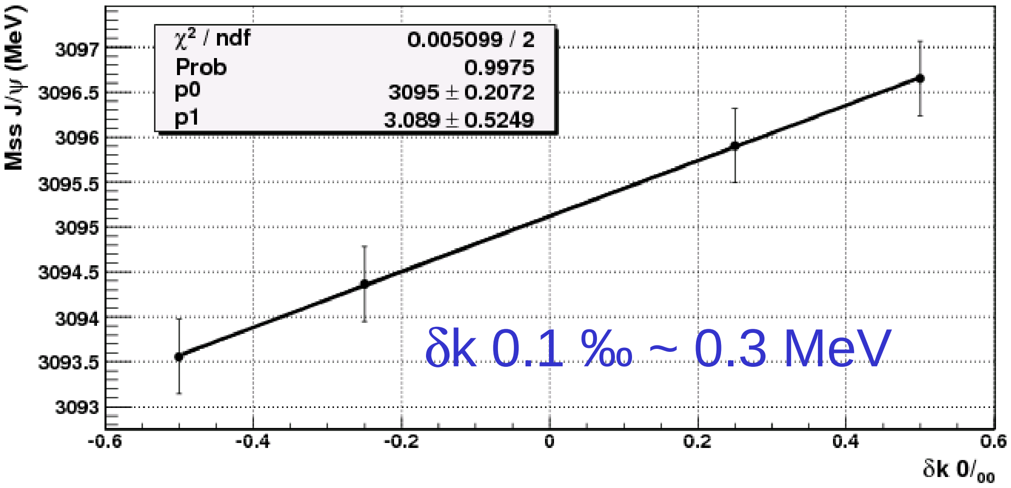
$$m' \approx (1+\delta k) m$$

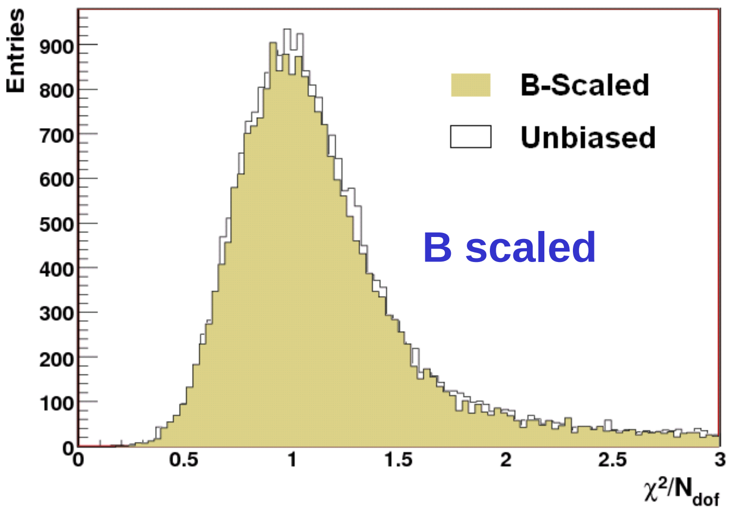
… to compare with z-scaling:

$$m' \approx (1+\delta\alpha) m$$

- **T-stations Z-scaling induces a mass bias identical to rescaling the B field**

- **LHCb B-field map known to 0.3 ‰**





Conclusions

- LHCb has studied the impact of tracking stations misalignments on the physics performance under various perspectives:
  s
  - random and residual misalignments, weak modes

- Results are rather reassuring and give confidence that we can deal with the expected misalignments:
  - B-event selection particularly sensitive to VELO misalignments, but the latter are well under control
  - momentum and mass determination not very much affected by size of expected misalignments

References

- LHCb 2008-012:
  Impact of misalignments on the analysis of B decays
- LHCb 2008-065:
  First studies of T-station alignment with simulated data
- LHCb 2008-066:
  Alignment of LHCb tracking stations with tracks fitted with a Kalman filter
- Eduard Simioni, PhD Thesis, to be published

Back-up slides

LHCb

Forward spectrometer

Acceptance: $1.8 < \eta < 4.9$

Luminosity: $2 \bullet 10^{32}\ cm^{-2}\ s^{-1}$

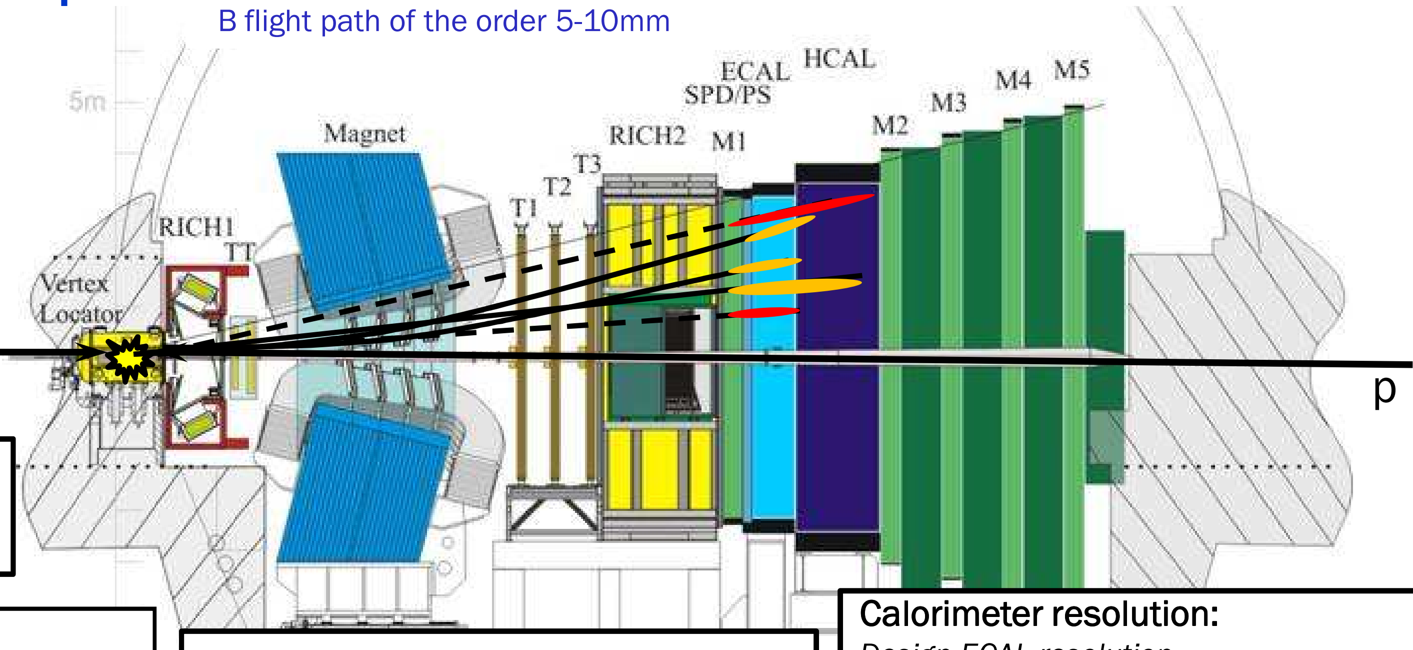
Nr of B's / $2fb^{-1}$ (nominal year)**:** 10^{12}

Detector: excellent tracking
excellent PID

Reconstruction:
- muons: easy
- hadronic tracks: fine
- electrons: OK
- π^0's: OK, though difficult
- neutrinos: no

Mission statement

- **Search for new physics probing the flavour structure of the SM**
- **Study CP violation and rare decays in the B-meson sector**



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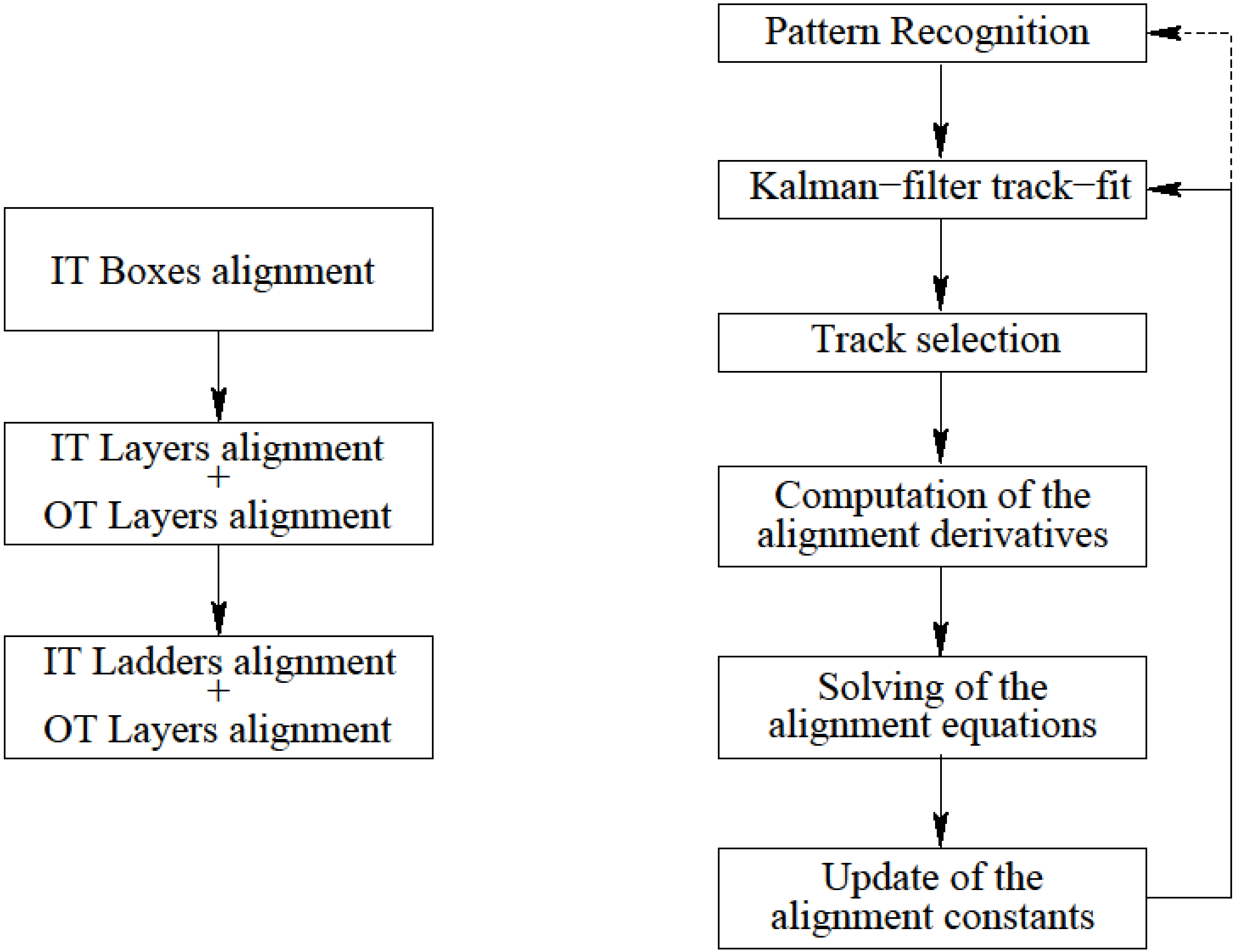
Expected tracking resolution
$\delta p/p$=0.35% to 0.55%

Vertexing:
Expected primary vertex resolution
~10µm transverse plane and
~50µm in the longitudinal one
Expected Impact parameter
resolution σ_{IP}=14µm+35µm/p_T

RICH performance:
Cherenkov angle resolution 0.6-1.8 mrad
Particle identification in p range 1-100 GeV
π, K ID efficiency > 90%, misID<~10%

Calorimeter resolution:
Design ECAL resolution
$\sigma(E)/E = 10\%\sqrt{E} + 1\%$ (E in GeV)
HCAL resolution from test-beam data
$\sigma(E)/E = (69\pm5)\%\sqrt{E} + (9\pm2)\%$ (E in GeV)

IT & OT alignment procedure

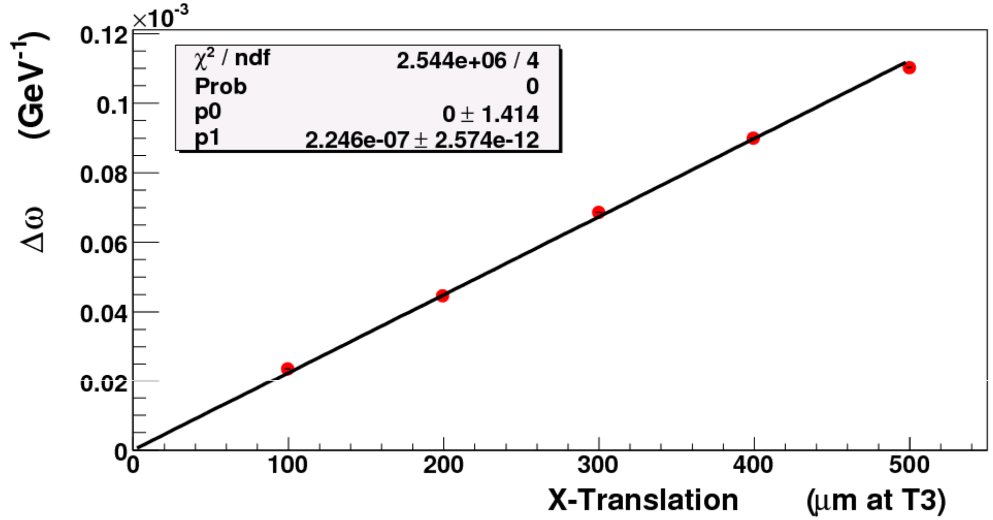


Effect on reconstructed ω

- Reconstruction of high momentum & clean tracks with ideal/misaligned geometry
  $\Rightarrow$ 2D distribution of ω - ω_0 versus ω

$$\omega = q / p$$

e.g. 500 μm in x
$\Rightarrow$ absolute shift of ~10^{-4} GeV^{-1}
on the reconstructed ω



e.g. 500 μm in z
$\Rightarrow$ ~0.15‰ error
on reconstructed ω