Alignment of the LHCb tracking system

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EPFL - LPHE

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Outline

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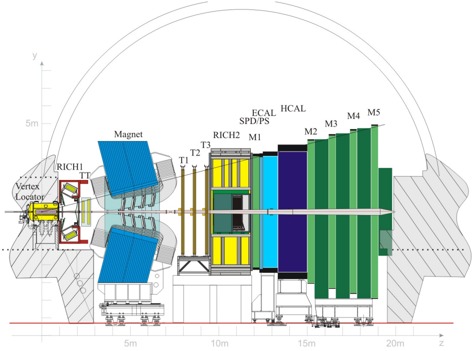
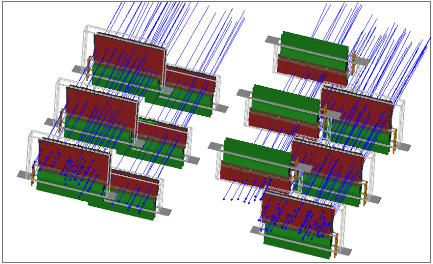
- Internal VELO alignment
  - Presentation
  - Features
  - Performance
- Global alignment
  - Presentation
  - Features
  - Performance
- Summary



What is software alignment ?

- All tracking subdetectors have been surveyed after assembly and installation
- Real tracks are used to know the position of the elements with an even higher precision
  - This is called software alignment



Software alignment using tracks fitted with a Kalman filter

Sample of selected good quality tracks

- χ^2 calculated from track fit residuals
- The χ^2 also gets a contribution from survey residuals
- Algorithm to minimize χ^2 as a function of alignment parameters

$$\chi^2 = \sum_{hits\ i} \left(\frac{m_i - h_i(x)}{\sigma_i} \right)^2$$

m $\rightarrow$ measurement, σ $\rightarrow$ measurement error

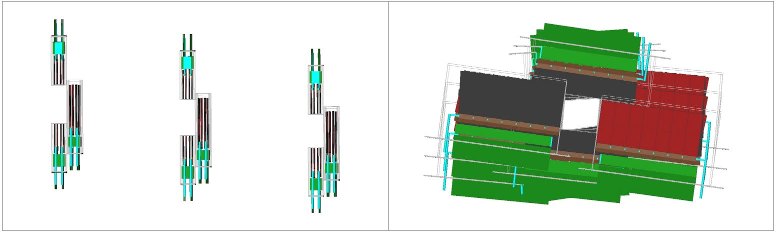
x $\rightarrow$ track parameters, usually 5

h $\rightarrow$ measurement model

$$0 \equiv \frac{d\chi^2}{dx}$$

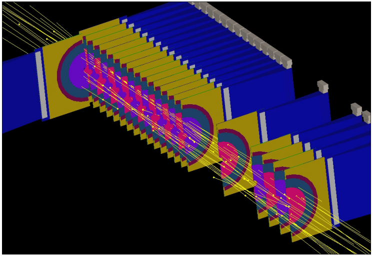
*W. Hulsbergen, The global covariance matrix of tracks fitted with a Kalman filter and an application in detector alignment, Nucl. Instr. and Meth. A, 600 (2009), p. 471.

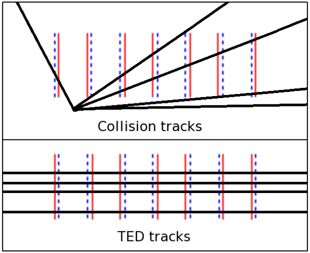
Degrees of freedom and weak modes



- Chose degrees of freedom (alignment variables)
  - translations and rotations
- Degrees of freedom are differently chosen at all levels
  - whole detector, layer, sensor, etc.
- Low sensitivity for certain degrees: weak modes
  - eg. translations along beam axis, scaling, shearing, ...

Data for alignment - find the best constraints



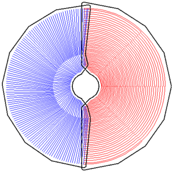


Different type of data giving different constraints

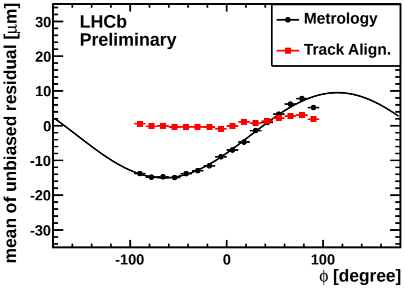
- Tracks from TED runs (collisions far away from the detector) and proton-beam gas collisions
  $\rightarrow$ small angle tracks
- Collisions - happening within the VELO
  $\rightarrow$ various angle tracks

Also very important constraints

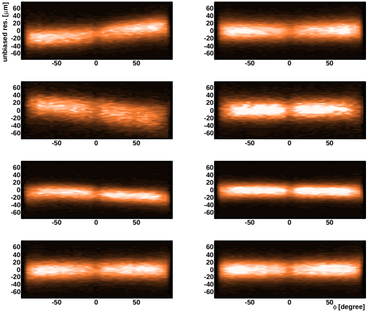
- Overlaps between subdetectors (eg. IT and OT)
- Overlaps between sensors within a subdetector



VELO fully closed
(stable beam)



R sensor number 38

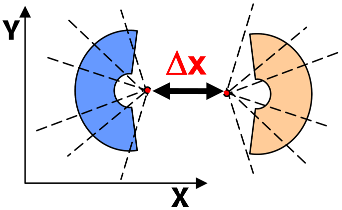


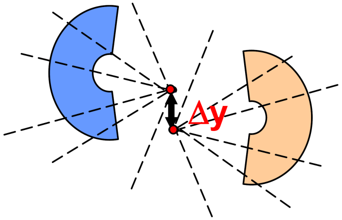
Metrology (left) / Alignmnent (right)

$$\text{res.}(R) = -\Delta x cos\phi_{track} + \Delta y sin\phi_{track}$$
$$\text{res.}(\phi) = \Delta x sin\phi_{track} + \Delta y cos\phi_{track} + \Delta\gamma r_{track}$$

- Initially used Millepede alignment starting from metrology
- Now χ^2 minimization of Kalman fit residuals
- Work on Z (beam axis) position ongoing (low sensitivity due to weak modes) - for the moment use metrology

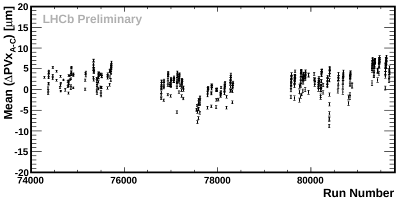
VELO alignment and primary vertices





PV left-right method

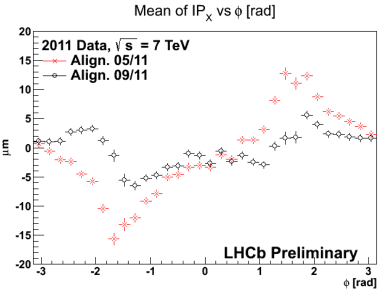
- Compute primary vertex with each half of the detector
- Calculate average distance between left and right PVs → two half misalignment

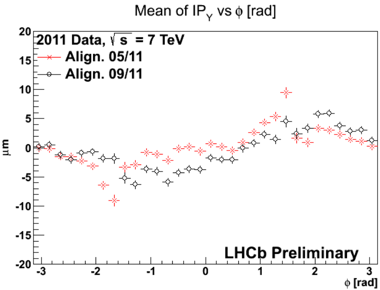


Also done in the software alignment

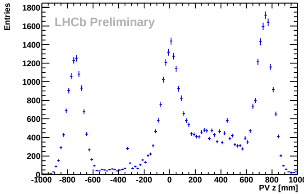
- Use particularly primary vertices to align the VELO halves
- Add overlap tracks to “link“ the two halves

VELO alignment with beam-gas events

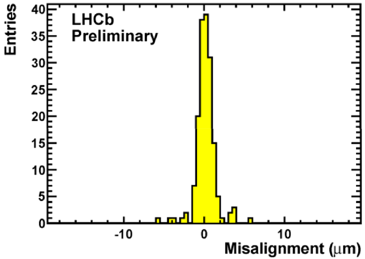




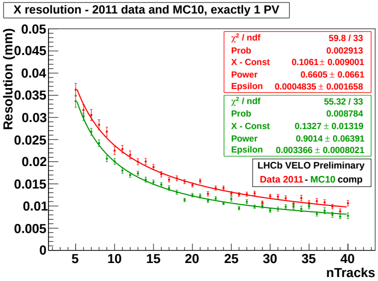
- Main goal: reduce Rz weak mode
- Use beam-gas selection (including standard collisions and satellite collisions at ±700 mm around the nominal collision point)
  - In these events: take tracks which cross many sensors (many tracks from the satellite collisions cross the full VELO)
  - Align for all degrees of freedom
  - Validate with collision data

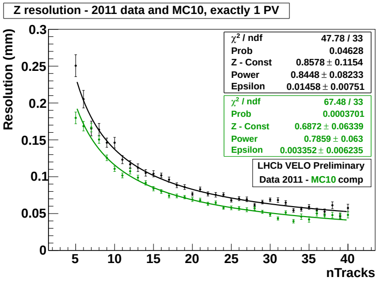


VELO alignment performance



- Sensor alignment better than 4 μm
- PV resolution (x,y,z) with 25 tracks:
  - Data (13.0, 12.5, 68.5) μm
  - MC (10.7, 10.9, 58.1) μm
- Still room for improvement

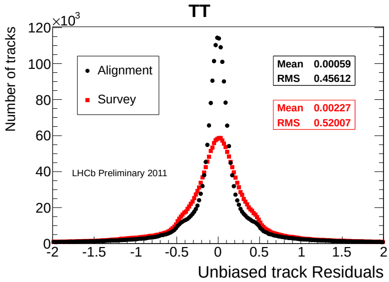


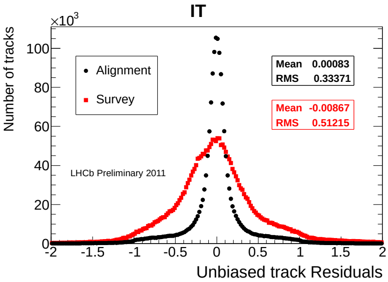


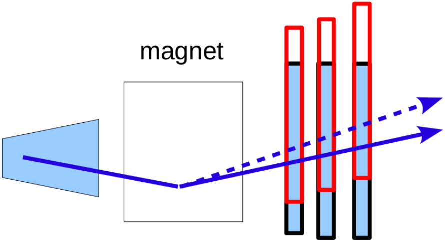
Global alignment

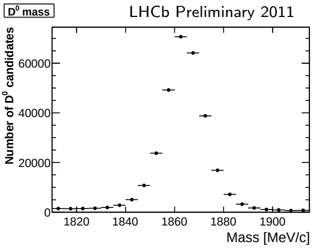
- TT, IT and OT are aligned by χ^2 minimization all at once
- Mostly tracks crossing the whole detector are chosen
- Additional kinematic cuts are applied
  - high momentum, high angle, good quality, etc.
- Some elements stay fixed along Z to survey constants
  - Whole TT subdetector
  - Two layers in OT

  $\rightarrow$ constrain the global position of IT and OT





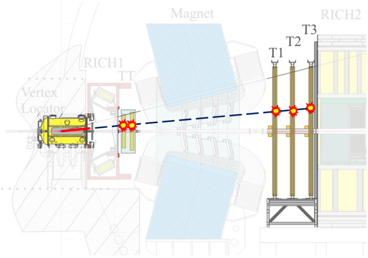


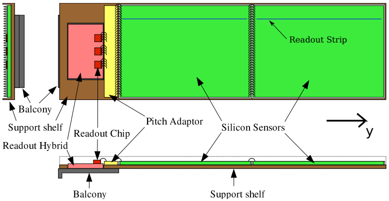


Weak mode: shearing with respect to magnet axis. Therefore mass constrained alignment (J/Psi or D0)

- Take $J/\psi \rightarrow \mu\mu$ or $D^0 \rightarrow K\pi$ daughter tracks
- Fix their origin vertex
- Fix the invariant mass to known J/ψ or D^0 mass respectively
- Compute the new tracks + residuals which go into the χ^2 minimization

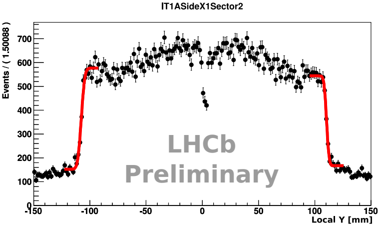
Global alignment - Y alignment



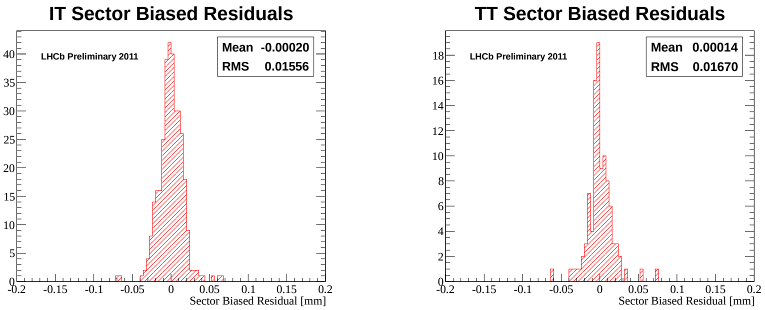


IT and TT Y alignment method

- Extrapolate VELO tracks to IT or TT in events without magnetic field
- Search for corresponding hits
- Find gaps and edges in their Y distribution



Global alignment performance



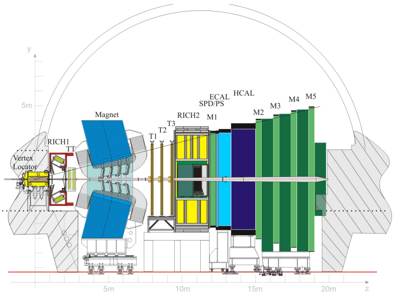
- Alignment precision can be evaluated by residual bias
  - IT Misalignment 15.6 μm
  - TT Misalignment 16.7 μm
- Even small errors in geometry implementation found by alignment
- Here also room for improvement

Summary

- Alignment not sensitive to all degrees of freedom, eg. Z position often fixed to survey constants
- Various methods to improve alignment - counter some weak-modes
  - Align VELO with primary vertices and overlap tracks
  - Use TED and beam-gas events and satellite collisions
  - Use masses of known particles as constraint
  - Extrapolate tracks from data without magnetic field
- Silicon strip detectors: sensor position known with a precision of
  - 4 μm for VELO
  - 15.6 μm for IT
  - 16.7 μm for TT

BACKUP SLIDES

The LHCb tracking system



- VErtex LOcator (VELO)
  - Silicon strip detector, closest to the collision point
- Tracker Turicensis (TT)
  - Silicon strip detector, between the VELO and the magnet
- Inner Tracker (IT)
  - Silicon strip detector, after the magnet, covering the innermost part
- Outer Tracker (OT)
  - Straw tube drift chambers, after the magnet, covering the outer part