Experience with LHCb Alignment Software on First Data

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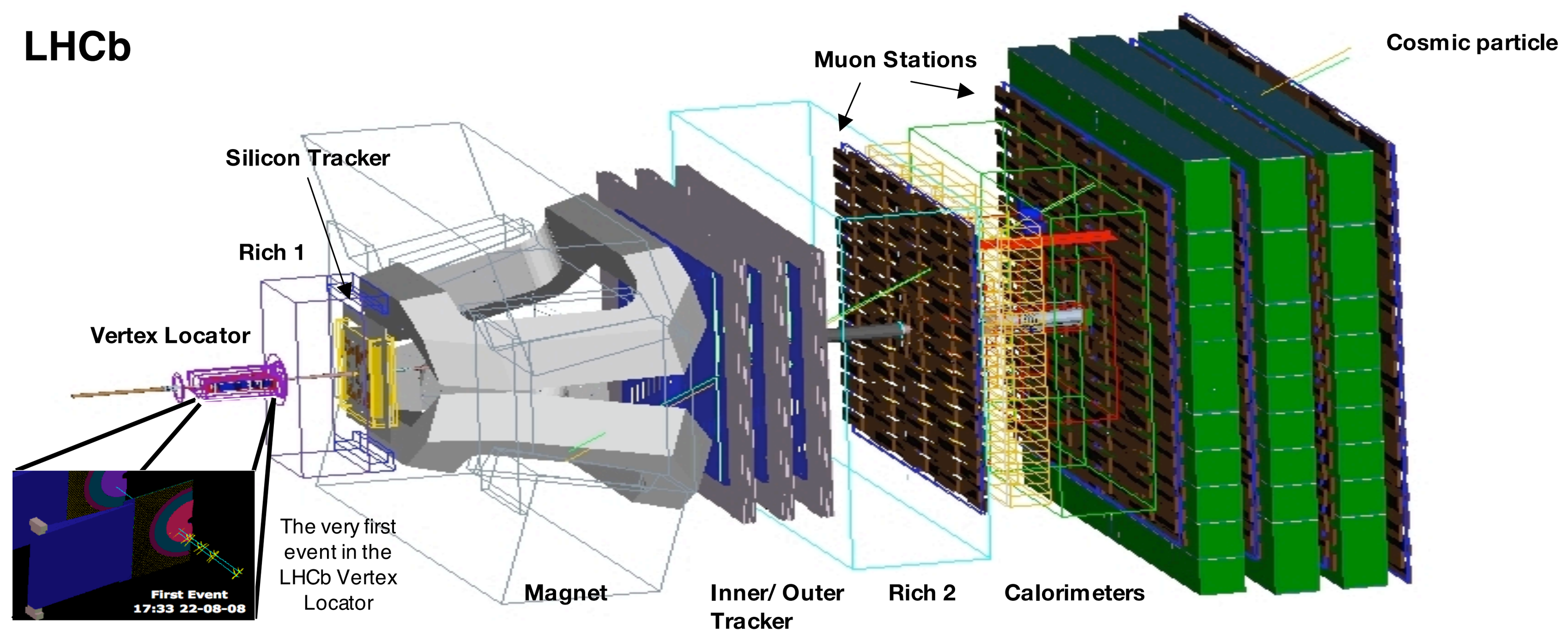
LHCb



LHCb Alignment Strategy

The LHCb detector is designed to study B meson decays with very high precision. Such precision measurements can only be achieved with a well calibrated and aligned spectrometer. For that, a very accurate determination of the relative position of the subdetectors to each other (global alignment), as well as an internal alignment of components of the subdetectors (local alignment) is necessary. A global alignment can only be achieved with tracks traversing the whole detector, whereas the local alignment requires tracks in the concerning subdetector. Here we present results obtained with data of cosmic muons and beam stopped events (TED), allowing the internal alignment of various subdetectors. The **Vertex Locator** and the **Inner Tracker** are calibrated using TED data, the large **Outer Tracker** and the **Muon Stations** collected a significant amount of muons from cosmic showers.

Alignment Formalism

Alignment of LHCb is challenging:	$O(1000)$ **parameters** to determine	$O(10^3)$-$O(10^6)$ **tracks** for precise alignment	**Robust and fast** algorithms required

1. Robust track fit using χ^2 minimization, written in matrix form with $\mathbf{L}(n{\times}n)$

$$\mathbf{L}\,\vec{a} = \vec{b} \qquad \text{with } \vec{a}: \text{track parameters; } \vec{b}: \text{measurements}$$

2. Assume ν tracks: build (N+ν·n)-matrix with track and alignment parameter information

$$\begin{pmatrix} \sum\Gamma_i & \cdots & M_i & \cdots \\ \vdots & \ddots & 0 & 0 \\ M_i^T & 0 & L_i & 0 \\ \vdots & 0 & 0 & \ddots \end{pmatrix} \begin{pmatrix} \vec{\alpha} \\ \vdots \\ \vec{a}_i \\ \vdots \end{pmatrix} = \begin{pmatrix} \sum\vec{\beta}_i \\ \vdots \\ \vec{b}_i \\ \vdots \end{pmatrix}$$

$\vec{\alpha}$: alignment constants (size N)
Γ: symmetric N×N matrix
$\vec{\beta}$: global measurements

3. Reduce to (N×N)- matrix and solve for alignment constants

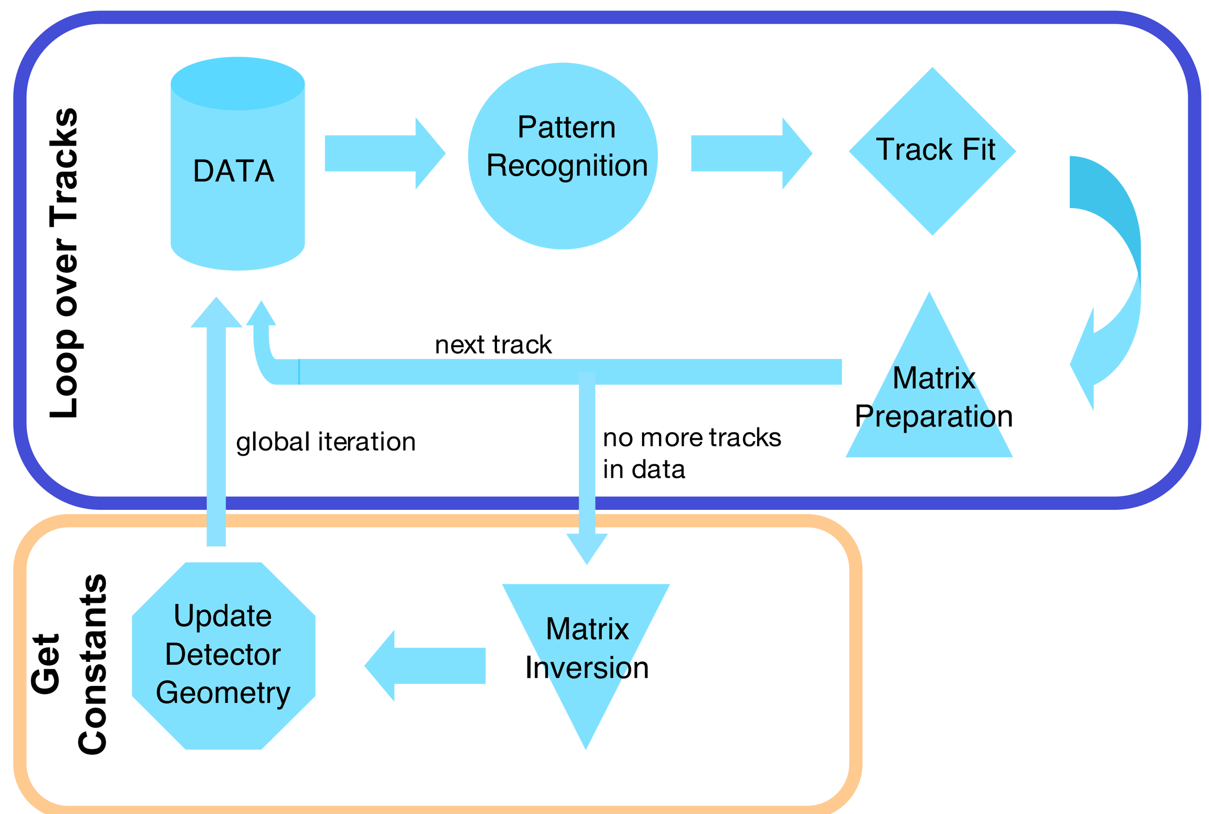
$$\left.\begin{aligned} \Gamma' &= \Gamma - \textstyle\sum_i M_i L_i^{-1} M_i^T \\ \vec{\beta}' &= \vec{\beta} - \textstyle\sum_i M_i (L_i^{-1}\vec{b}_i) = \vec{\beta} - \sum_i M_i(\vec{a}_i) \end{aligned}\right\} \quad \Gamma'\vec{\alpha} = \vec{\beta}'$$

Different implementations used in LHCb
- Millipede [1] formalism for internal alignment of VELO, IT, OT
- Implementation using tracks fitted with LHCb's standard track fit (Kalman filter [2]). Can be applied for local or global alignment*

*(See poster „Alignment of the LHCb detector with Kalman fitted tracks" by Jan Amoraal)

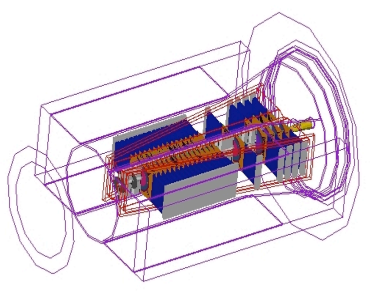
Alignment Process

The processing of an allignment run inside the LHCb software framework is shown on the right. First the global matrix is filled with information of all tracks and alignable detector components, second the matrix is inverted and the alignment constants are obtained. In case of nonlinear degrees of freedoms one has to evaluate the data again after a first iteration. This is due to the linearization of the system of equation which is necessary to solve the problem with the presented formalism.



[1] V. Blobel, *Linear Least Square Fit with a Large Number of Parameters*, http://www.desy.de/~blobel/wwmille.html
[2] R.E. Kalman, *A new approach to linear filtering and prediction problems*, Trans. ASME J. Bas. Eng. **D82** (1960) 35

Vertex Locator Alignment



The LHCb Vertex Locator (VELO) plays a crucial role in the high level trigger, the track and the vertex reconstruction. An accurate determination of primary and secondary vertices is mandatory to achieve an excellent lifetime resolution of the B mesons.
The presented results for the alignment of the LHCb Vertex Locator (VELO) are obtained using an algorihtm based on the Millepede [1] formalism.

- 2 halves, each with 21 silicon modules
- module with R and Φ sensors, pitch: 40-100 μm
- sensor thickness: 300 μm
- 172k readout channels
- retractable detector halves (accuracy 10 μm)

The task of the alignment:

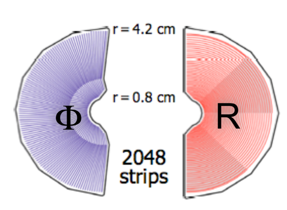
- number of alignable objects : 84
- total alignment parameters : 504

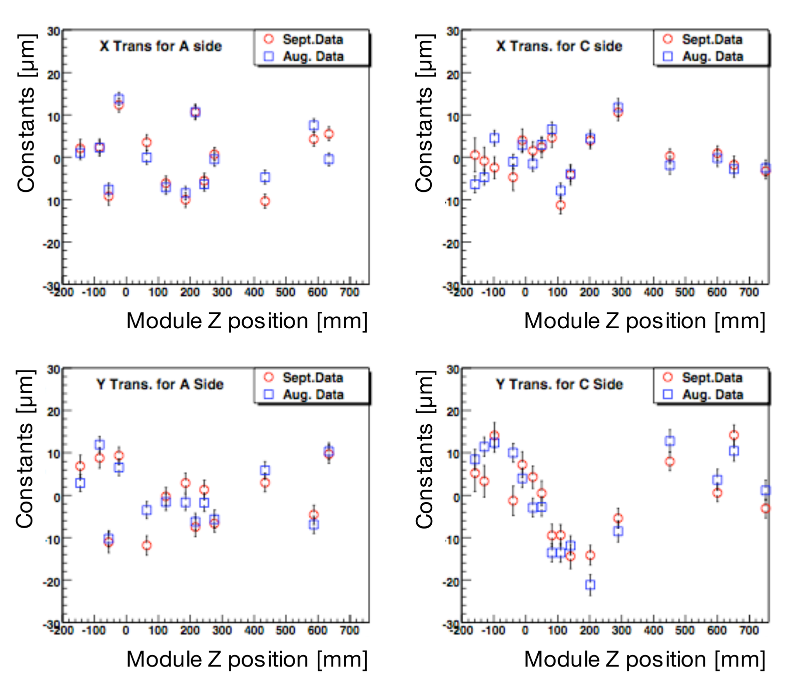
Data for alignment:

- 1400 tracks from TED data: muons produced by dumping protons on a beam stop
- survey

Module positions for different data

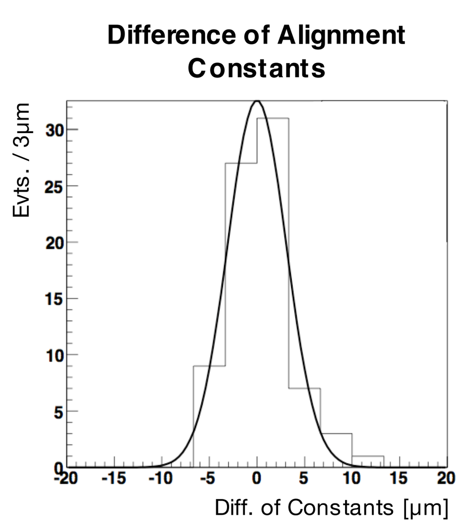
The proton beam in the LHC was dumped two times in 2008 (August & September) at a position beneficial for the VELO to take data. This data is used to determine the positione of the modules with the software alignment.





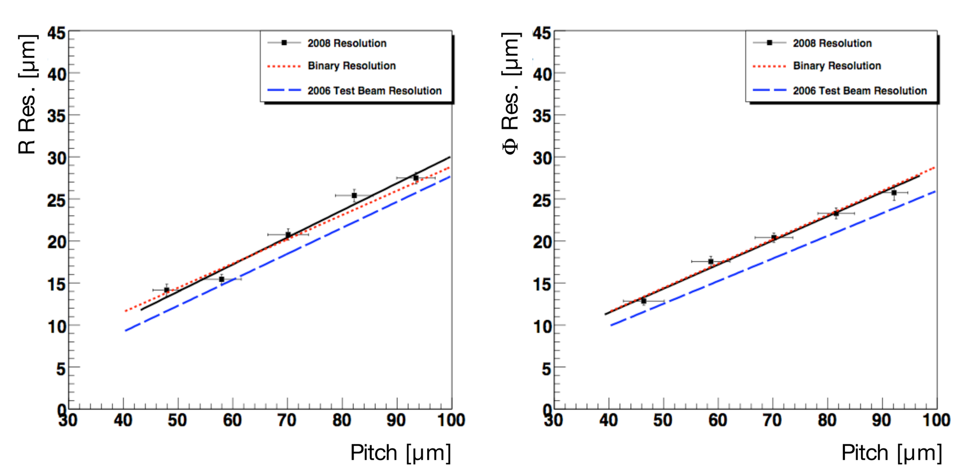
Misalignments in X and Y direction for the TED data from August and September. A side and C side denote the left and the right halves of the VELO.

The modules are in a stable position and the software gives reproducible output for the two runs.



Width of the distribution : 3 μm; alignment constants obtained in August and September are in very well agreement !

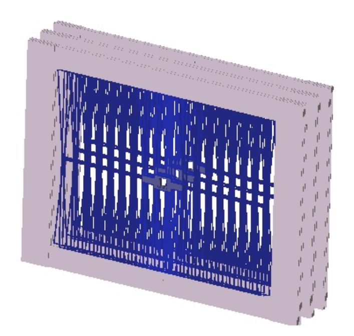
The track residuals in the R and Φ sensors



The resolution obtained from the TED data matches the binary resolution. This is expected because ca. 90% of the used clusters are one strip clusters.

The 2006 Test Beam Resolution will be reached after optimization of the DAQ (calibrate thresholds for each strip) and the time alignment for all sensors.

Outer Tracker Alignment



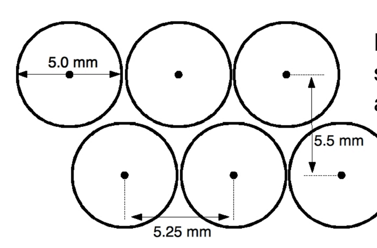
The Outer Tracker alignment is done twice with two independent algorithms. Thus a cross-check of the results and a comparison of the algorithms' performances is obtained.

The task of the alignment:

- area covered by detector : 27m²
- number of alignable objects : 432
- total alignment parameters : 2592
- magnetic field : yes

Data for alignment:

- 20k tracks from cosmic particles

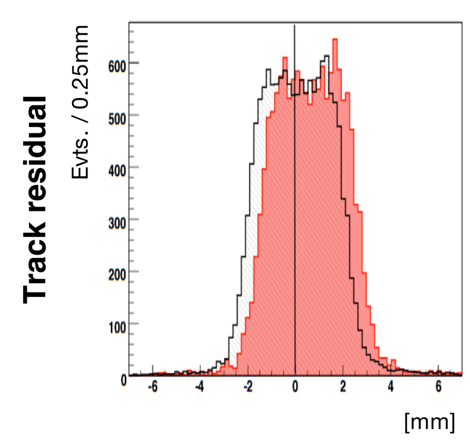


Double layer structure of an OT module

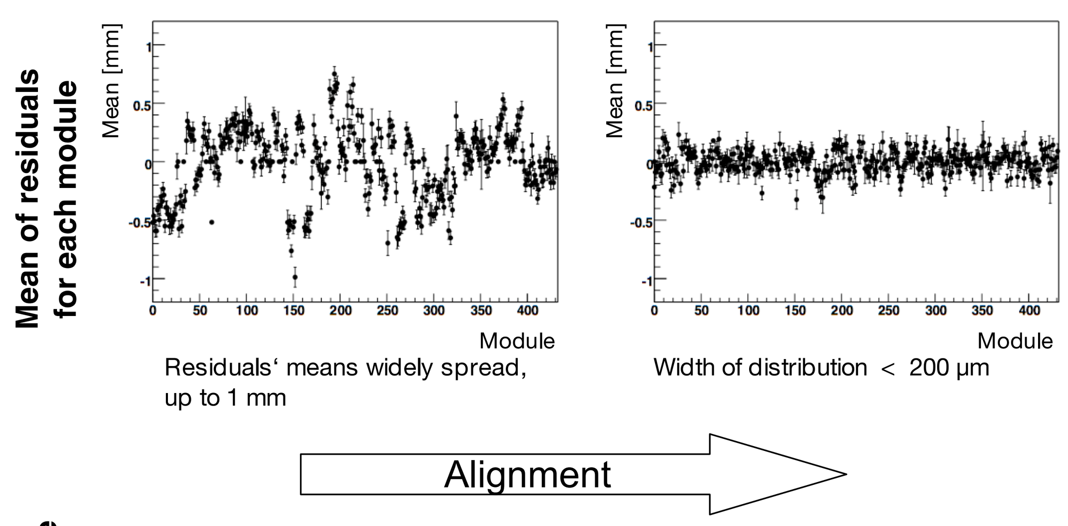
- straw tube technology
- 3 stations , 4 layers each (X , + 5° ,- 5° ,X)
- 432 modules (2.5m) glued together pairwise to 5m long modules
- 55k readout channels
- pitch: 5 mm
- resolution: 200 μm

Track residuals and detector calibration

With the data collected a successful alignment was done for 216 modules with reasonable statistics. The detector was adjusted in the main measurement direction X and in the rotation around the Z axis.

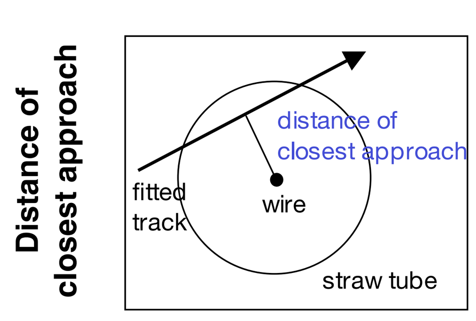


Before (red) and after (black) alignment; the width equals the expected resolution without drifttime information

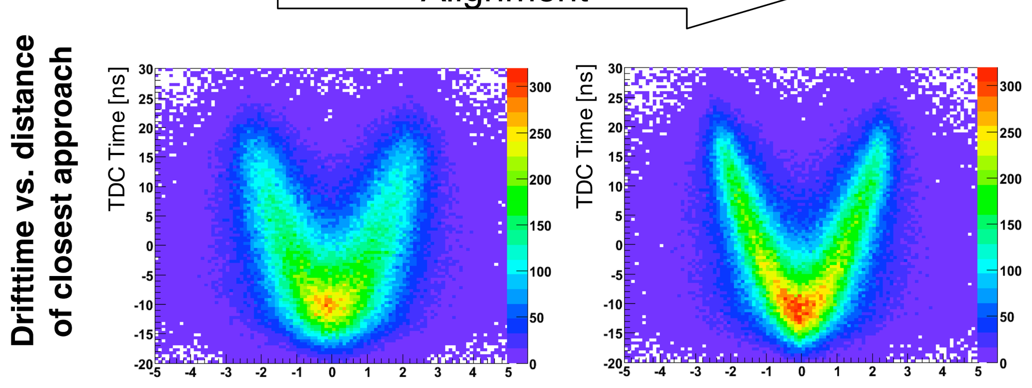


Residuals' means widely spread, up to 1 mm

Width of distribution < 200 μm



The OT has to be calibrated in order to get the correct correlation between the drifttime and the particle's flight path through the straw

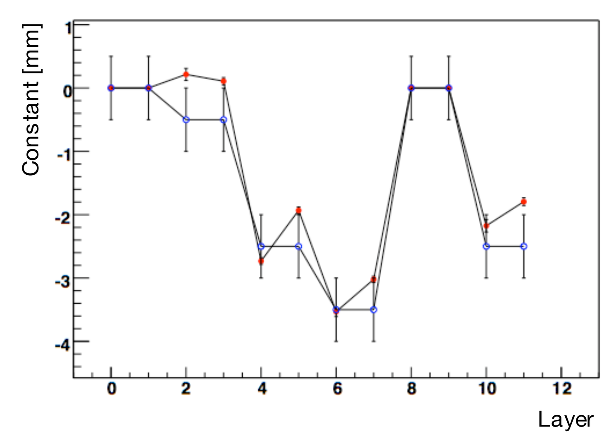


Smeared out function without alignment

With alignment: clearly V-shaped function, as expected

Survey vs. software alignment

Alignment of the Outer Tracker layers and comparison of the alignment parameters with survey data. The software alignment results are in very good agreement with the survey data!



Comparison of OT layers' z position:
Blue points: survey data
Red points : software alignment