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Understanding the Alignment of LHCb's Scintillating Fibre Tracker

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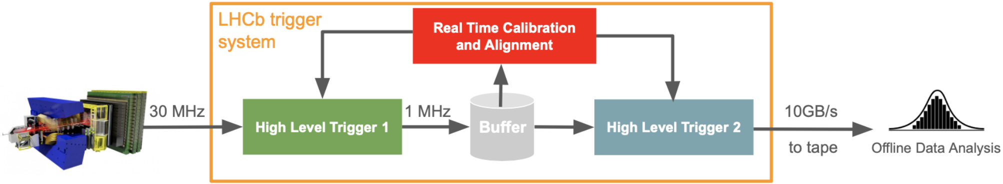
Overview

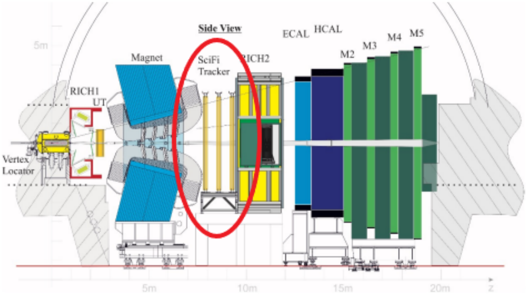
- The SciFi Detector Upgrade
- Importance of the SciFi and Alignment
- Understanding first alignments on 2022 data
- Stability measurements on 2022 data
- Joint constraints for SciFi modules

Importance of alignments

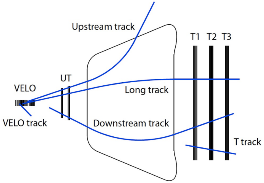
- Alignment is part of the LHCb trigger system
- Physics performance tied to alignment performance
- with optimal alignment:
    - → remove systematic biases for asymmetry measurements
    - best possible mass resolution



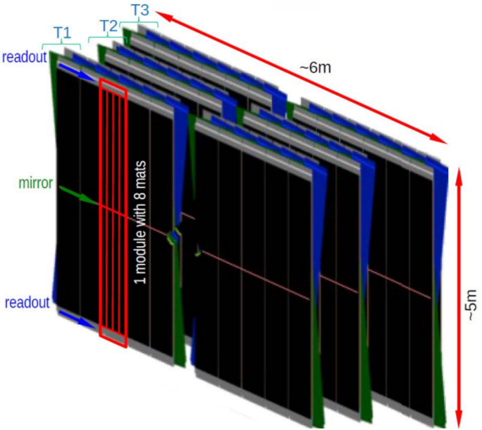
LHCb upgraded with the SciFi



- Consists of 3 stations: T1, T2, T3
- 4 layers per station: X1, U, V, X2
- replaces former IT and OT to cope with the increased instantaneous luminosity
- crucial part of tracking system



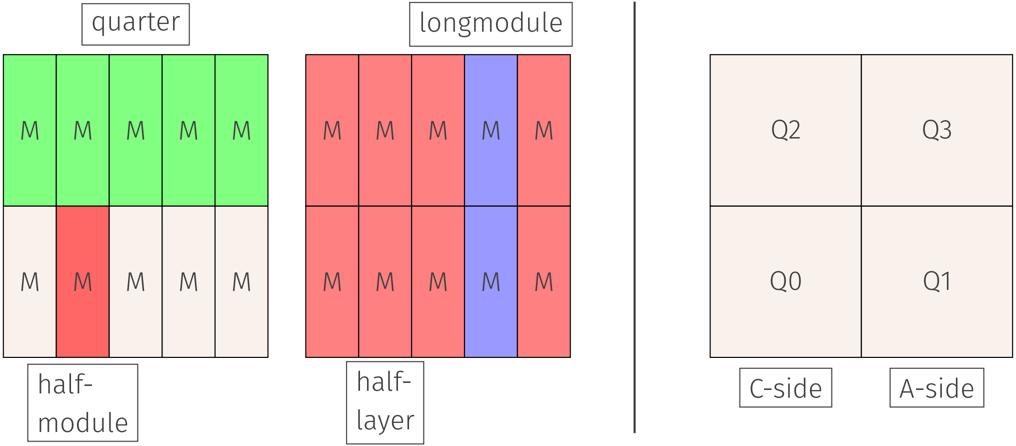
The Scintillating Fibre Tracker



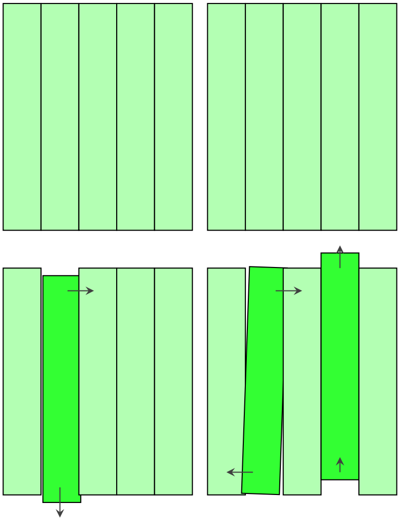
- Front two stations have 5 modules per side
- Back station has 6 modules on each side
- U, V layers have a **∓5 deg** stereo angle respectively
- → used for determining y-position of tracks by comparing hitposition at different angles

SciFi terminology

layers are divided into two halves commonly labeled as A-side and C-side



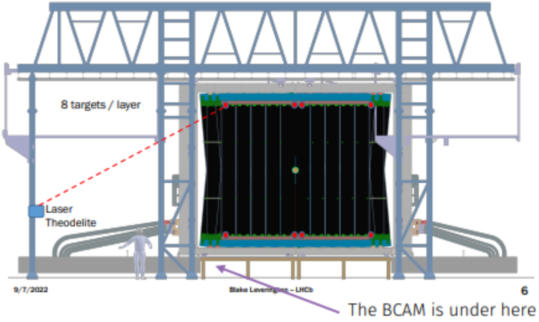
What is Alignment and why do we need it?



- top: ideal detector, bottom: physical detector
- Surveys are used to find the rotation and position of each detector component
- Are used as starting positions for software alignment
- Building tracks accurately requires positions in reconstruction to be as similar as possible to real positions

The survey: what is it and the different types

- measure distance of some points on the detector with a laser



- 2022: photogrammetry was recorded in assembly hall → not quite perfect
- 2023: photogrammetry will be recorded in cavern
- relative angles and positions between points are compared to simulation
- layer survey: performed in the cavern on the layer in the front in closed state (both halves together)
- module survey: performed inside assembly hall using reflective stickers keeping track of all positions

Alignment: track fits with the Kalman Filter

measurement m

track model h

$$r_i = m_i - h_i(x, \alpha)$$

$$\chi^2 = r^T V^{-1} r$$

covariance matrix V

Track fit with Kalman filter

↓

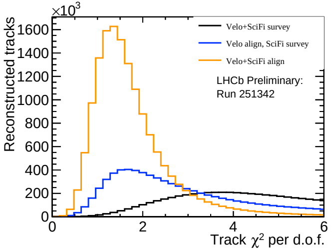
Alignment

↓

Update alignment constants

- Use survey information as starting point
- aligning the detector by minimizing the residuals of the track hits
- basically a χ^2 minimization problem with alignment parameters α
- Why Kalman Filter?
  - easily models material interactions as well as multiple scattering
- propagation of nodes, minimization, smooth error sizes by back propagation

Alignment versions in use



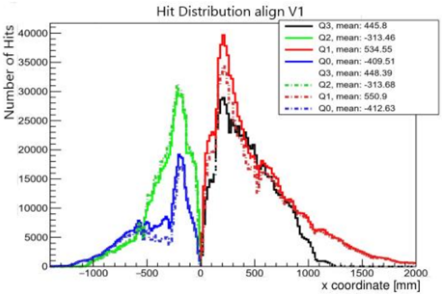
- V1: First ever SciFi alignments for the upgraded LHCb detector
- Using early tracks from comissioning
- use full length modules
- alignable degrees of freedom: Tx Rz (x translation, rotation around z →beam pipe axis)

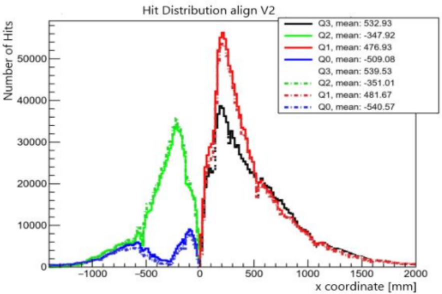
- V2: Updated alignment version with what we learned from V1
- aligned using half modules
- uses newest time alignment

Hit distribution per quarter in V1 and V2 alignment

- Improvements to V2 visible on A-side, losing some performance on C-side
- Alignment performance difference in each quarter → seperately analyse quarters!
- $\chi 2$ per quarter can provide more insights about alignment performance in each detector part

- analysis of each quarter seperately makes finding possible issues easier

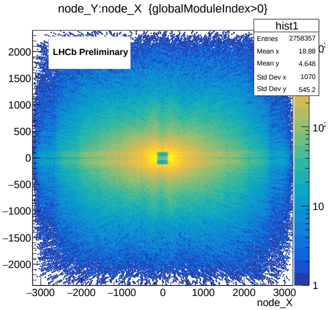


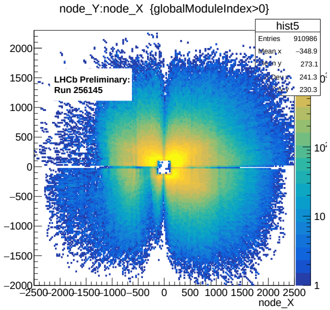


Track hits comparison of V2 and simulation

- Simulation: hits on **reconstructed** tracks fill whole detector
- data: filling tracks into A-side → good!

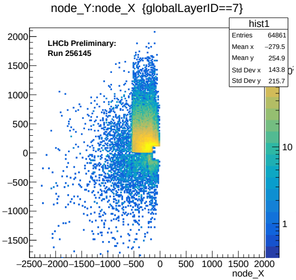
→ scan C-side quarters for possible issues in distinct layers

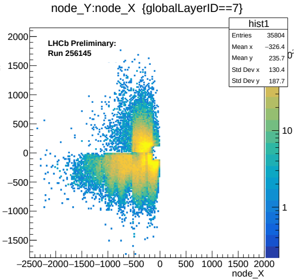


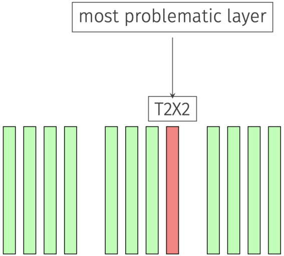


New Q0 positions in T2X2 layer

- Changes based on V2 alignment positions
- compare T2X2 constants to layers with good hit coverage →look for irregularities
- positions: translations relative to the nominal position for each module
- V2 alignment has only few tracks in Q0 because parts of the SciFi are too far out of alignment
- combining the manual scanning with a looser configuration →Alignment V3







Stability tests on 2022 data

- **How much does the SciFi move between runs?**
- **Does the magnet polarity impact playa role in the alignment?**

- Run an alignment for each of the runs on the list
- Sort the runs in ascending run number
- Compare the difference in module position for each run to the next
- Where are the modules in the local frame in all runs?

Dataset and Alignment setup

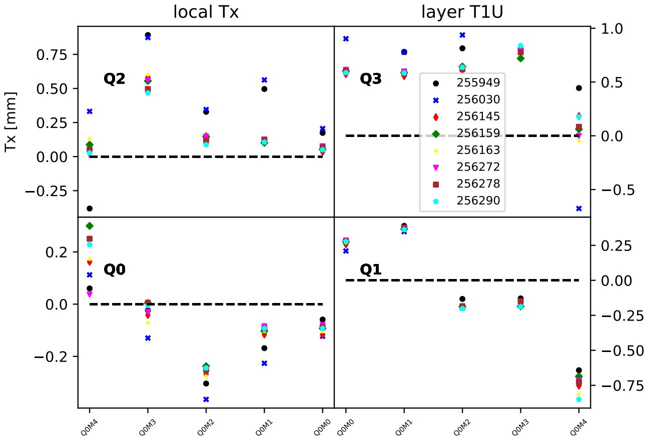
- Dataset contains magnet-up and magnet-down samples from 2022 labeled as "good" from EMTF
- Good: > 90% of datalinks are good
- Includes runs from fills: 8489, 8491, 8496

List of randomly chosen runs: 255949, 256030, 256145, 256159, 256163, 256272, 256278, 256290

- V3 Alignment from tag (loose tracking, half module alignment TxTz + Mat alignment, back layer fixed) from conditions database

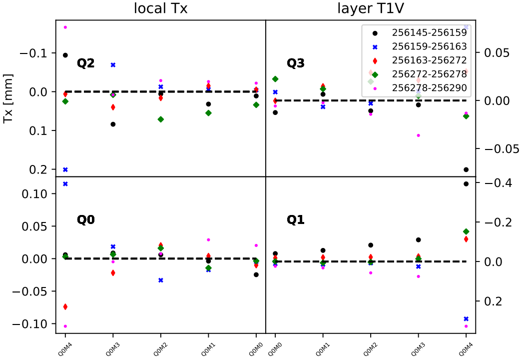
Module Positions in local half module frame

- Runs 255949 + 256030 were from fill 8489
- Optimal fine timing implemented in 256145 (afterwards)
- Positions of other runs compatible
- magUp: 256272, 256278, 256290
- magDown: 255949, 256030, 256145, 256159, 256163



Reduced dataset: removed pre timing update runs

- again: compare module positions of 2 runs but remove first 2 runs from input (different fine timing)
- Without the fine timing changes the largest movement is at max around **400μm** at most outer modules
- M4, M5 often < 1000 events (difficult for the alignment) →large movement,
- M0-M3: movement around **150μm**



stability tests: Conclusion

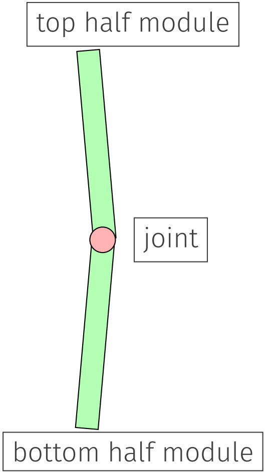
- Impactful changes like timing induces an observed movement up to 0.8mm in some cases
- The change in module position from run to run is at maximum **150μm** for the modules M0 →M3 in Tx

→only if there are no big changes between runs

- M4 moves at max **400μm** in this case
- there is no visible difference between magUp and magDown polarity
- With good SciFi timing, variation of 200 μm expected.
- A possible choice of an automatic update would be if variations of > 200 μm occur.

Joints constraints for SciFi module alignment

- Long SciFi modules: slight "banana shape"
- Half modules + joints reproduce the real shape
- Joints are implemented in the alignment by using a survey constraint (MR!368)
- it constrains parameters of 2 alignables A and B to each other with $\chi^2 = (p_A - p_B)^T V^{-1} (p_A - p_B)$
- p_A, p_B: set of parameters for half modules
- use common frame (local half modules)
- Uncertainties taken from diagonal covariance matrix →how realistic? →tuning needed
- No existing survey available for joints; tuning needed to control their χ^2



Tuning procedure

- Instead of one χ^2 $\rightarrow$look at χ^2 for joint parameters (Tx, Ty, Tz, Rx, Ry, Rz)
- Tune Uncertainties by running an alignment for each change to the respective parameter uncertainty until roughly χ^2 / DoF = 1
- make sure not to run into local minimum

- Procedure evaluated with 2023 data (run 269045, warm SciFi) and master from conditions database
- Using the alignment master

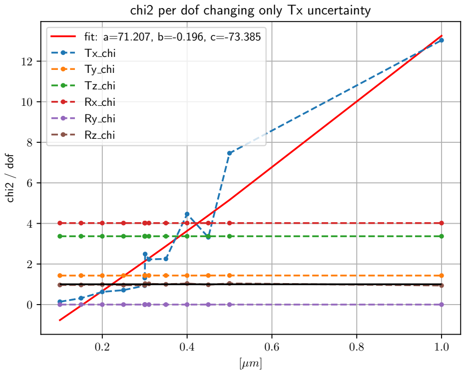
```
elements = Alignables()
elements.FTHalfModules("TxRz")

surveyconstraints = SurveyConstraints()
surveyconstraints.FT(addHalfModuleJoints=True)

constraints = []
constraints.append("BackFramesFixed : FT/T3/X2/HL.*/M. : Tx Rz")
```

Tuning of uncertainty: Tx

intersection: **0.22μm** (fit), **0.3μm** (measurement)

Initial errors:

- Tx,Ty,Tz [μm]: 1 1 1
- Rx,Ry,Rz [mrad]: 0.2 0.2 0.2
- Vary Tx uncertainty (starting at 1 μm) →run alignment →calculate χ^2/DoF values, keep other parameters at nominal!
  →Tx = **1μm** has $\chi^2 \approx$ **13**, perform a scan in a range of uncertainties to find the intersection χ^2/DoF = **1** (black line)

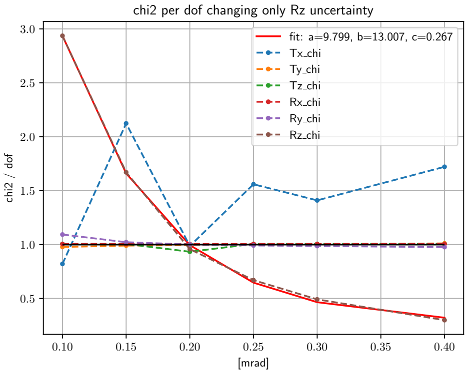


Tuning of uncertainty: Rz

intersection: **0.22μm** (fit), **0.3μm** (measurement)

Initial errors:

- In the last step Rz was tuned
- intersection at 0.2 mrad was already correctly set from nominal
- All parameters show good behaviour at chosen uncertainty
- final tunded uncertainties [μm, mrad]: 0.3 1.2 1.9 0.4 0.00000044 0.2



Summary

- Source of complications: SciFi parts too far out of alignment to be correctly updated, corrected now with new alignment version and photogrammetry
- Adapt module positions by hand: working procedure for singular low-efficiency modules
- stability tests show no substantial difference in alignment quality from magnet polarity
- sufficient statistics: **150μm** movement; rerun manually if this is exceeded
- Looser particle selection →more events, residuals comparable to strict selection, better D0 mass peak
- tuned parameters for loose selection [μm,mrad]: 0.0074 1.2 1.9 0.4 0.00044 0.22
- What does that mean for the joint constraint?
    - Constraint is mainly influenced by **Rx** and **Tz** →logical since this is the bending direction
    - **Tx** (left-to-right movement) is basically fixed since it has no impact on the constraint, same for **Ry** (rotation around vertical axis)

Backup

Loose Tracking config and D0 selection

```python
###############################################################################
# (c) Copyright 2022 CERN for the benefit of the LHCb Collaboration           #
#                                                                             #
# This software is distributed under the terms of the GNU General Public      #
# Licence version 3 (GPL Version 3), copied verbatim in the file "COPYING".   #
#                                                                             #
# In applying this licence, CERN does not waive the privileges and immunities #
# granted to it by virtue of its status as an Intergovernmental Organization  #
# or submit itself to any jurisdiction.                                       #
###############################################################################
from PyConf.Algorithms import (PrForwardTrackingVelo, PrMatchNN)
from Moore import options, run_reconstruction
from RecoConf.standalone import standalone_hlt2_light_reco_without_UT
from RecoConf.hlt2_tracking import (
    make_PrKalmanFilter_noUT_tracks,
    make_TrackBestTrackCreator_tracks,
)
from RecoConf.early_data import (
    get_loose_PrForwardTrackingVelo_params,
    get_loose_PrMatchNN_params,
    get_loose_PrKalmanFilter_params,
    get_loose_TrackBestTrackCreator_params,
)
with PrForwardTrackingVelo.bind(**get_loose_PrForwardTrackingVelo_params()), \
     PrMatchNN.bind(**get_loose_PrMatchNN_params()), \
     make_PrKalmanFilter_noUT_tracks.bind(**get_loose_PrKalmanFilter_params()), \
     make_TrackBestTrackCreator_tracks.bind(**get_loose_TrackBestTrackCreator_params()):
    run_reconstruction(options, standalone_hlt2_light_reco_without_UT)
```

pt_{min} = 800 MeV

pion, kaon required to have min pt and

IPCut = 60 μm

mass hypothesis [1760 MeV, 1960 MeV]

vertex χ^2 < 10