Understanding the Alignment of LHCb's Scintillating Fibre Tracker

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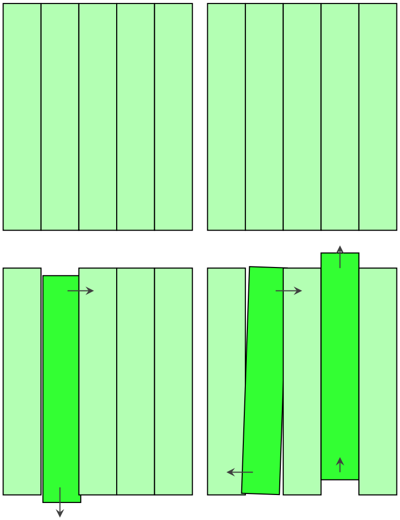
Overview

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

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

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

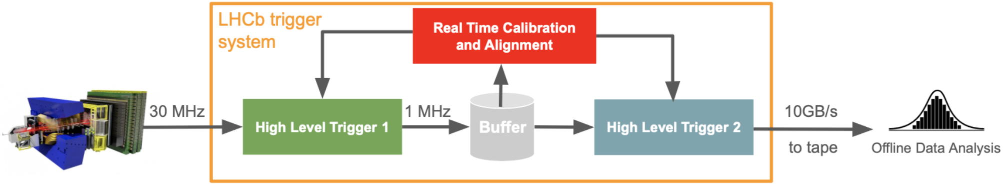
↓

Update alignment constants

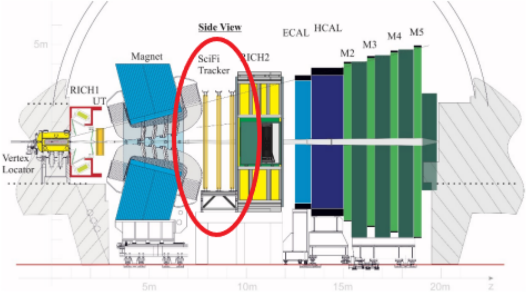
- Use survey information as starting point
- aligning the detector by minimizing the residuals of the track hits
- basically a χ^2 minimization problem with alignment parameters $\boldsymbol{\alpha}$
- Why Kalman Filter?
  - easily models material interactions as well as multiple scattering
- propagation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

Importance of alignments

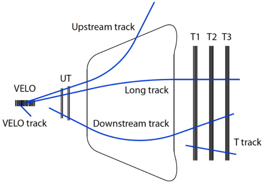
- Alignment is part of the LHCb trigger system
- Physics performance tied to alignment performance
- with optimal alignment:
  - → remove systematic biases for asymmetry measurements
  - best possible mass resolution



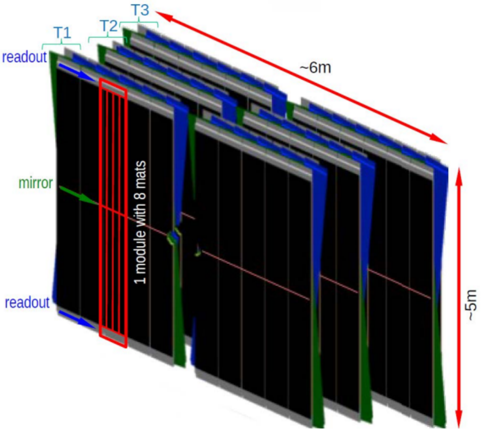
LHCb upgraded with the SciFi



- 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



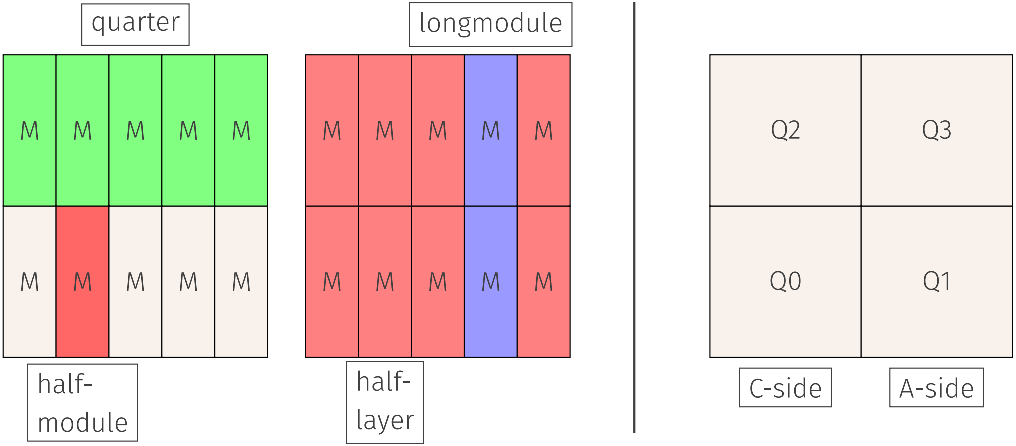
The Scintillating Fibre Tracker



- 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

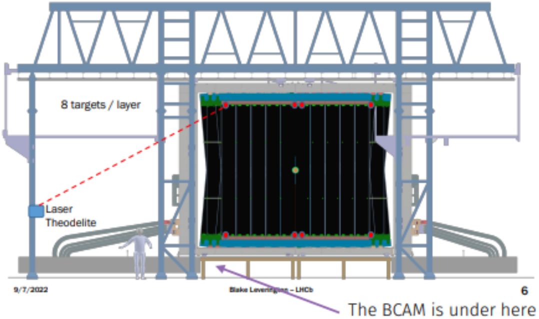
SciFi terminology

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



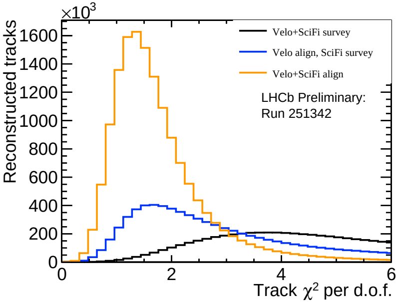
The survey: what is it and the different types

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



- 2022: photogrammetry (assembly hall)
  → not quite perfect
- 2023: cavern
- compare survey to simulation
- layer survey: coarse, survey layer positions
- module survey: keep track of each module

Alignment versions in use

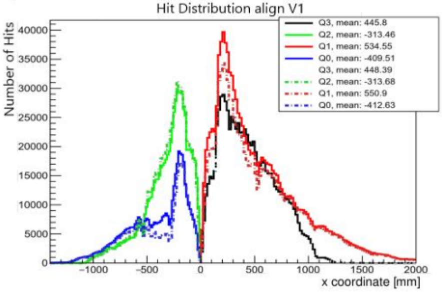


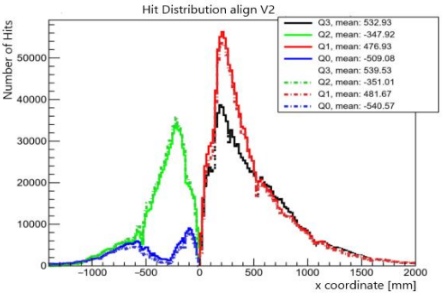
- V1: First ever alignments after upgrade
- Using first data sets
- Starting configyartion: long modules, Tx Rz

- V2: Imroved configuaration from V1
- half modules, Tx Rz, new time alignment

Hit distribution per quarter in V1 and V2 alignment

- A-side improved a lot in V2, losing some performance on C-side
- Performance discrepancies →quarter analysis
- $\chi 2$ per quarter →alignment performance per detector part
  - Scan quarters individually; find issues faster

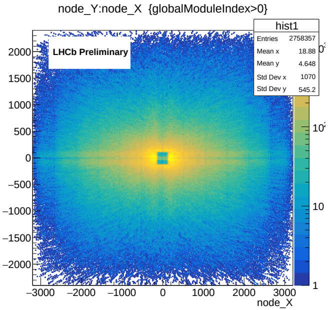


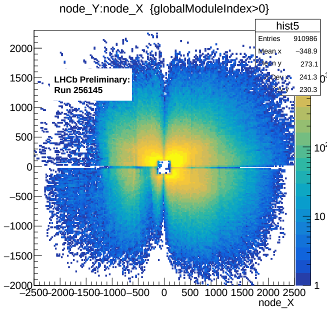


Track hits comparison of V2 and simulation

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

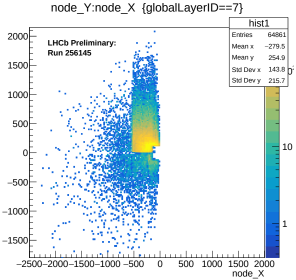
→ scan C-side quarters for possible issues in distinct layers

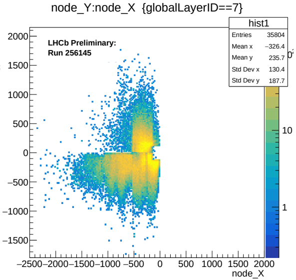


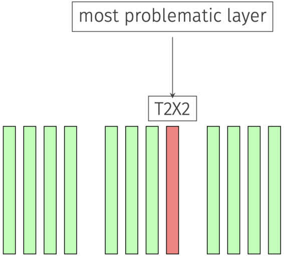


Improved Q0 positions in T2X2 layer with V2 alignment

- manual comparison of striking features in problematic layer
- Q0 too far out of alignment →less hits
- Manual scans + looser tracking config →Alignment V3







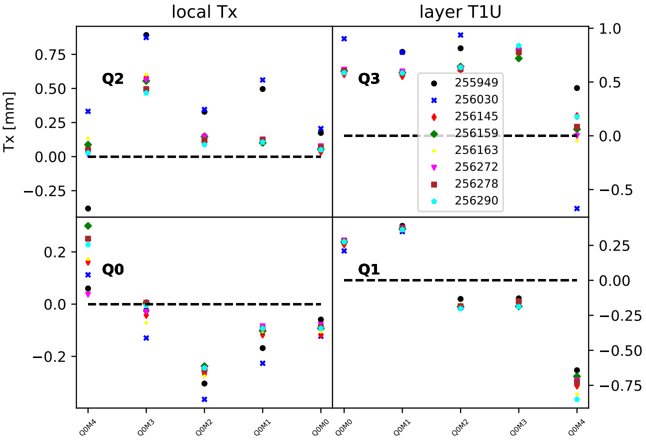
Stability tests on 2022 data

- **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?

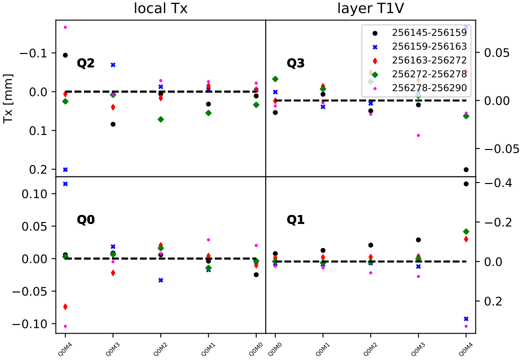
Module Positions in local half module frame

- Runs 255949 + 256030 problematic →issues known!
- Optimal fine timing implemented in 256145 (afterwards)
- Both magnet polarities comparable results



Reduced dataset: removed pre timing update runs

- comparison of module positions of 2 runs each
- Outer modules →low statistics →difficult for the alignment →large movement
- Inner modules: movement around $150\mu m$ allowed



stability tests: Conclusion

- Timing changes have big impact on module alignment
- 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.

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
    - 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

Backup: stability dataset

- 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