Understanding the Alignment of LHCb's Scintillating Fibre Tracker

Nils Breer, Biljana Mitreska, Sophie Hollitt, Johannes Albrecht

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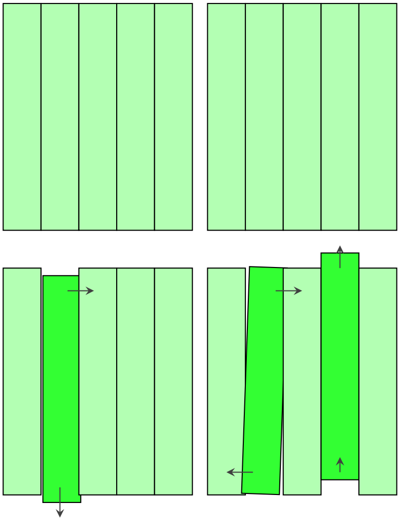
Maria Laach high energy physics school, Siegen

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
- →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

$$r_i = \overset{\text{measurement } m}{m_i} - \overset{\text{track model } h}{h_i(x,\alpha)}$$

$$\chi^2 = r^T \underset{\text{covariance matrix } V}{V^{-1}} r$$

Track fit with Kalman filter

↓

Alignment

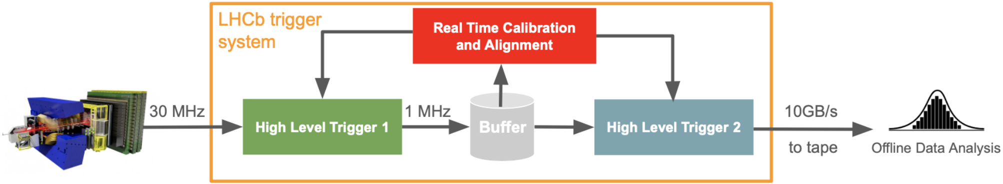
↓

Update alignment constants

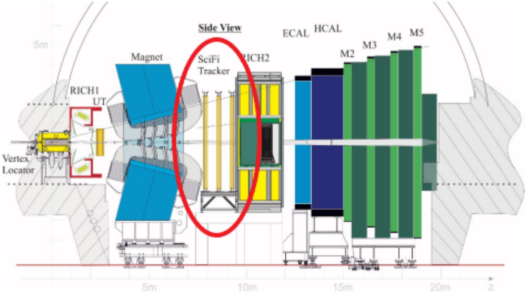
- Starting positions: positions from laser scans of detector objects (survey)
- Alignment: χ^2 minimization of track residuals
- Add measurements one-by-one to fit
- Prediction of next measurement →minimize residuals →redo until track complete
- Why Kalman Filter?
    - easily models material interactions as well as multiple scattering

Importance of alignments

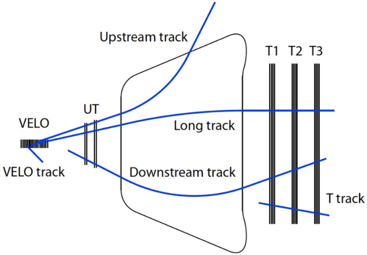
- Alignment is part of the LHCb trigger system
- Physics performance tied to alignment performance
- with optimal alignment:
  - → remove systematic biases for asymmetry measurements
  - Best possible mass resolution



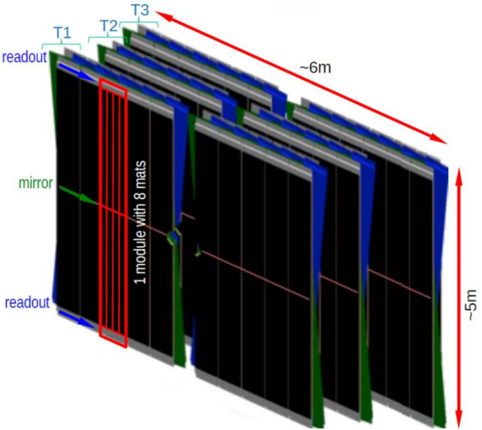
LHCb upgraded with the SciFi



- 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



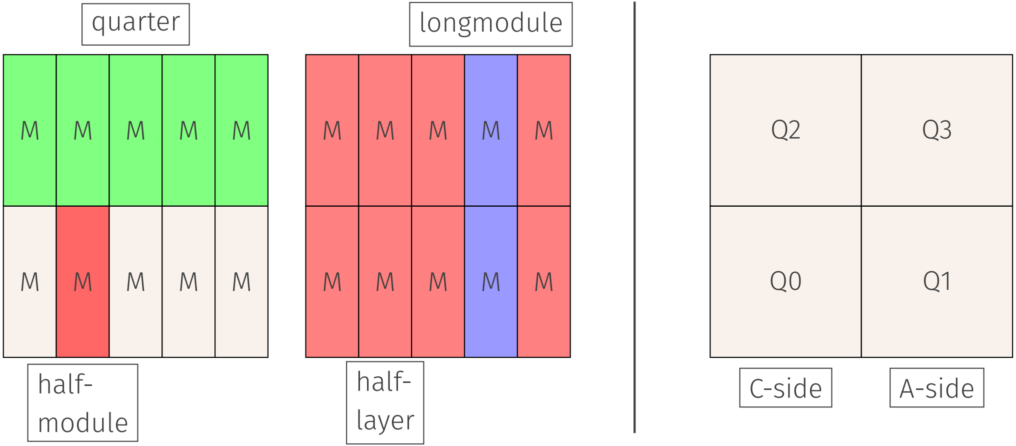
The Scintillating Fibre Tracker



- 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

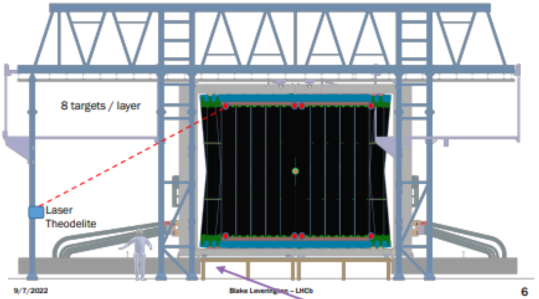
SciFi terminology

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



The survey: what is it and the different types

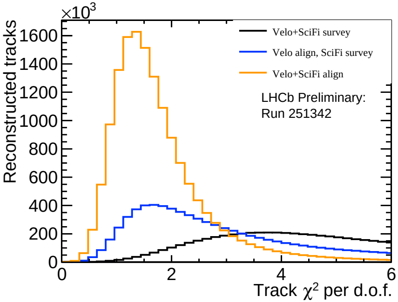
- Measure distance of some points on the detector with a laser



The BCAM is under here

- Layer survey: find corners of layers
- Module survey: reflective stickers, calculate module plane
- Compare survey to simulation

Alignment versions development in 2022



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

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

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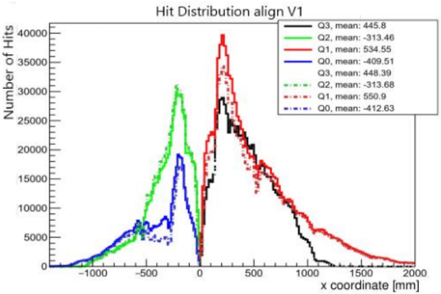
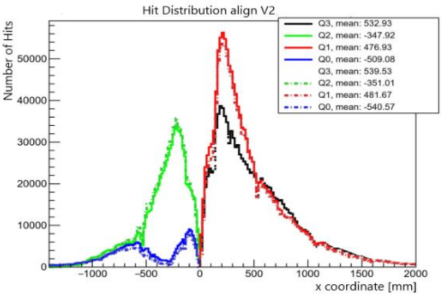
Hit distribution per quarter in V1 and V2 alignment on 2022 data

- V1 → V2: A-side better, C-side loosing some performance
- Performance discrepancies →quarter analysis
- $\chi 2$ per quarter →alignment performance per detector part
- Expectation for good alignment: symmetry and exponential hit distribution

- Scan quarters individually; find issues faster

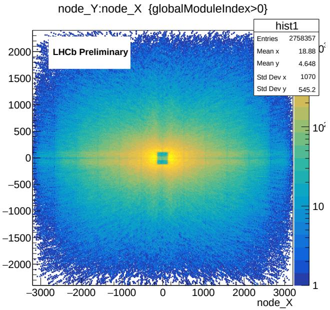


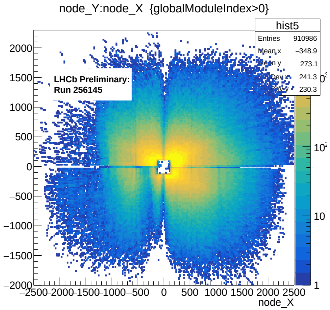


Track hits comparison of V2 and simulation

- Simulation: hits on **reconstructed** tracks fill whole detector
- A-side Track hits good!

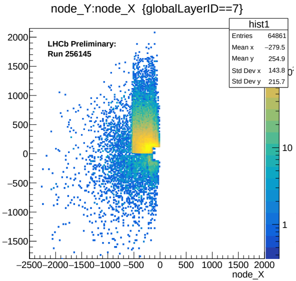
→ Scan C-side quarters for possible issues in distinct layers

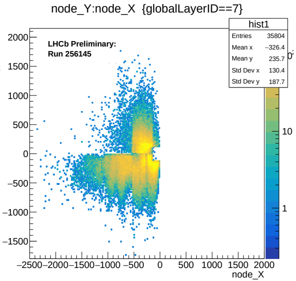


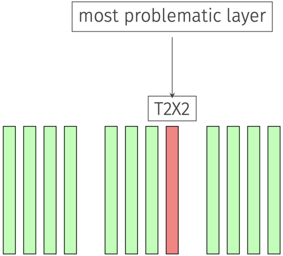


Improved Q0 positions in T2X2 layer with V2 alignment

- Compare good vs. poor performing layers
- Q0(bottom left quarter) modules too far out of alignment →less tracks reconstructed in these objects
- Fix manually and rerun alignment







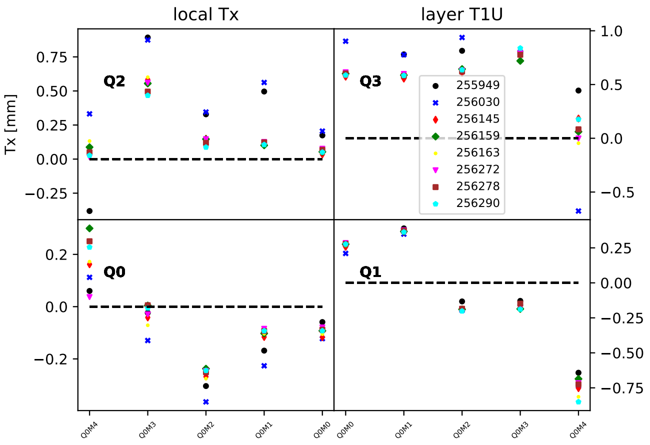
Stability tests on 2022 data

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

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

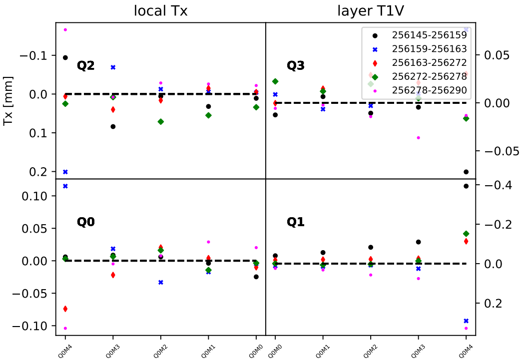
Module Positions in local half module frame

- 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
- Upper limit of module movement: **150μm**
- $\rightarrow$manually update
- Magnet polarity no major impact
- 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
- Correct 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: $150\mu m$ movement; rerun manually if this is exceeded

Backup

Loose Tracking config and D0 selection

```
###############################################################################
# (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