# Alignment tools

Silvia Borghi, **Chris Burr** and Chris Parkes
University of Manchester

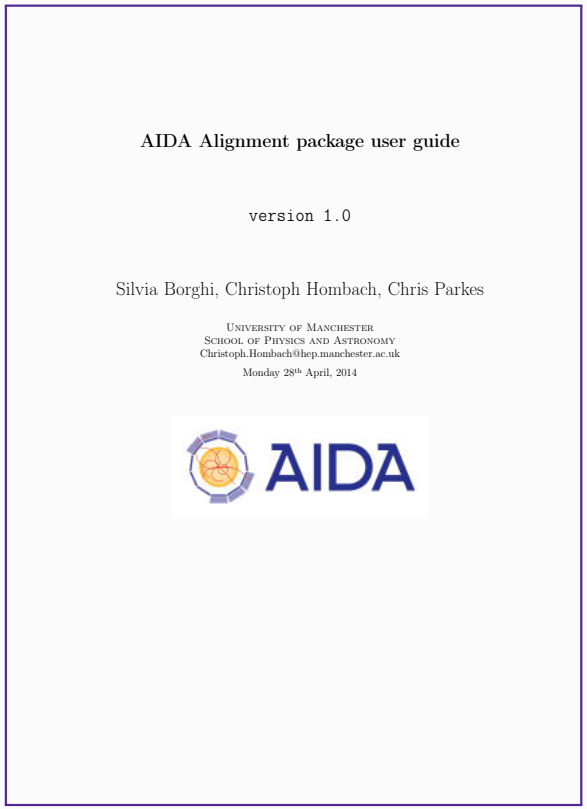
April 6, 2017


# Introduction

- Update on the alignment work within WP3
- Will be talking about:
  - Updates to the Bach alignment toolkit
  - Alignment support for the LHCb timepix3 telescope
  - Studies of the performance of the upgrade LHCb vertex locator

# Bach Alignment Toolkit

# Bach alignment toolkit



**AIDA Alignment package user guide**

version 1.0

Silvia Borghi, Christoph Hombach, Chris Parkes

University of Manchester
School of Physics and Astronomy
Christoph.Hombach@hep.manchester.ac.uk

Monday 28th April, 2014

AIDA

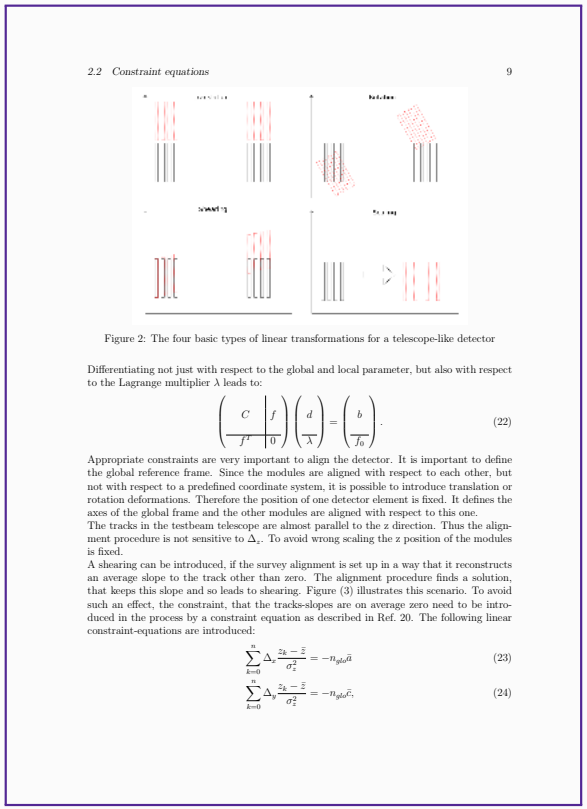






Figure 2: The four basic types of linear transformations for a telescope-like detector

Differentiating not just with respect to the global and local parameter, but also with respect to the Lagrange multiplier $\lambda$ leads to:

$$\left(\begin{array}{c|c} C & f \\ \hline f^t & 0 \end{array}\right)\left(\begin{array}{c} d \\ \hline \lambda \end{array}\right) = \left(\begin{array}{c} b \\ \hline f_0 \end{array}\right). \quad (22)$$

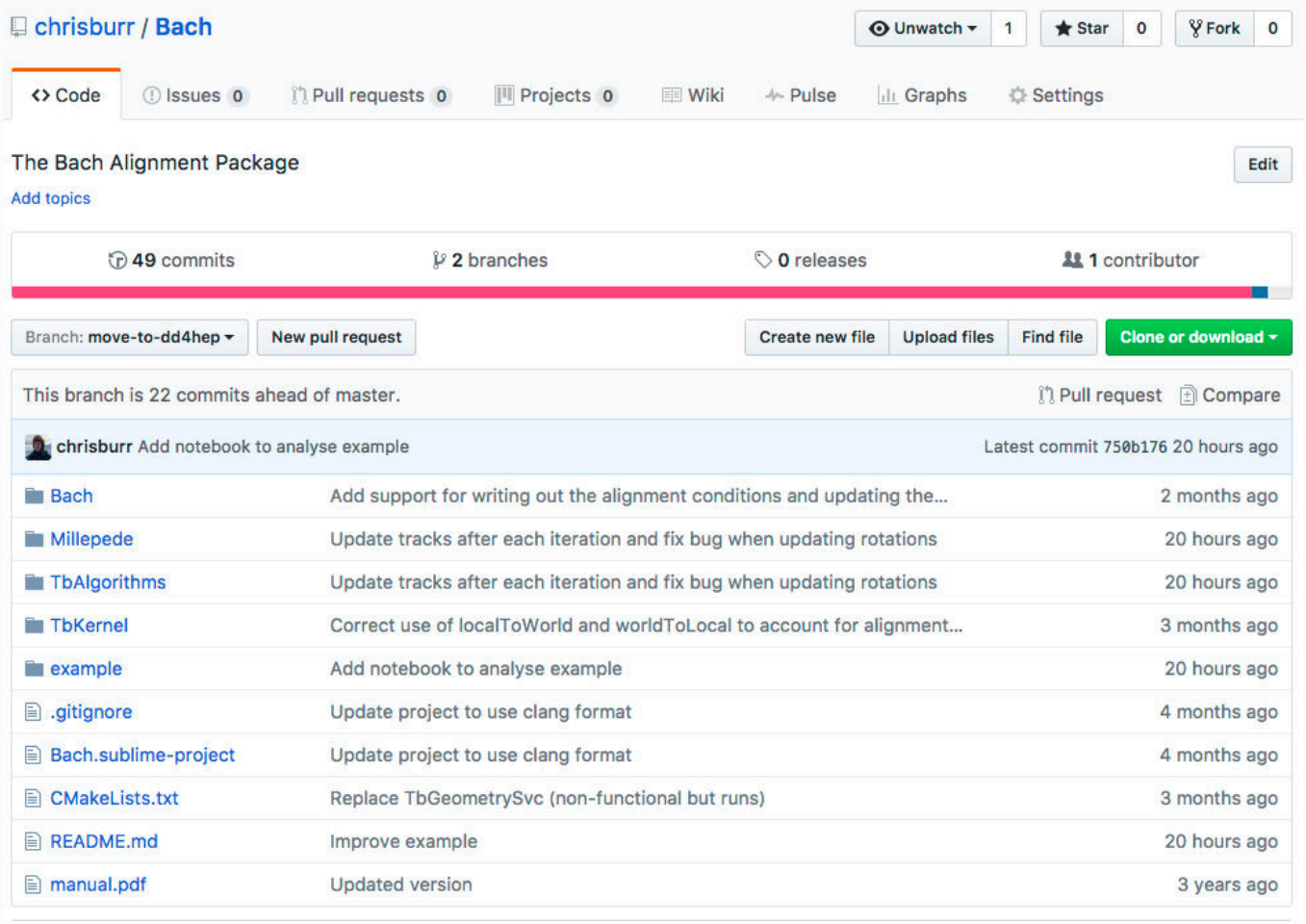
Appropriate constraints are very important to align the detector. It is important to define the global reference frame. Since the modules are aligned with respect to each other, but not with respect to a predefined coordinate system, it is possible to introduce translation or rotation deformations. Therefore the position of one detector element is fixed. It defines the axes of the global frame and the other modules are aligned with respect to this one.
The tracks in the testbeam telescope are almost parallel to the z direction. Thus the alignment procedure is not sensitive to $\Delta_z$. To avoid wrong scaling the z position of the modules is fixed.
A shearing can be introduced, if the survey alignment is set up in a way that it reconstructs an average slope to the track other than zero. The alignment procedure finds a solution, that keeps this slope and so leads to shearing. Figure (3) illustrates this scenario. To avoid such an effect, the constraint, that the tracks-slopes are on average zero need to be introduced in the process by a constraint equation as described in Ref. 20. The following linear constraint-equations are introduced:

$$\sum_{k=0}^{n} \Delta_x \frac{z_k - \bar{z}}{\sigma_z^2} = -n_{glo}\bar{a} \quad (23)$$

$$\sum_{k=0}^{n} \Delta_y \frac{z_k - \bar{z}}{\sigma_z^2} = -n_{glo}\bar{c}, \quad (24)$$

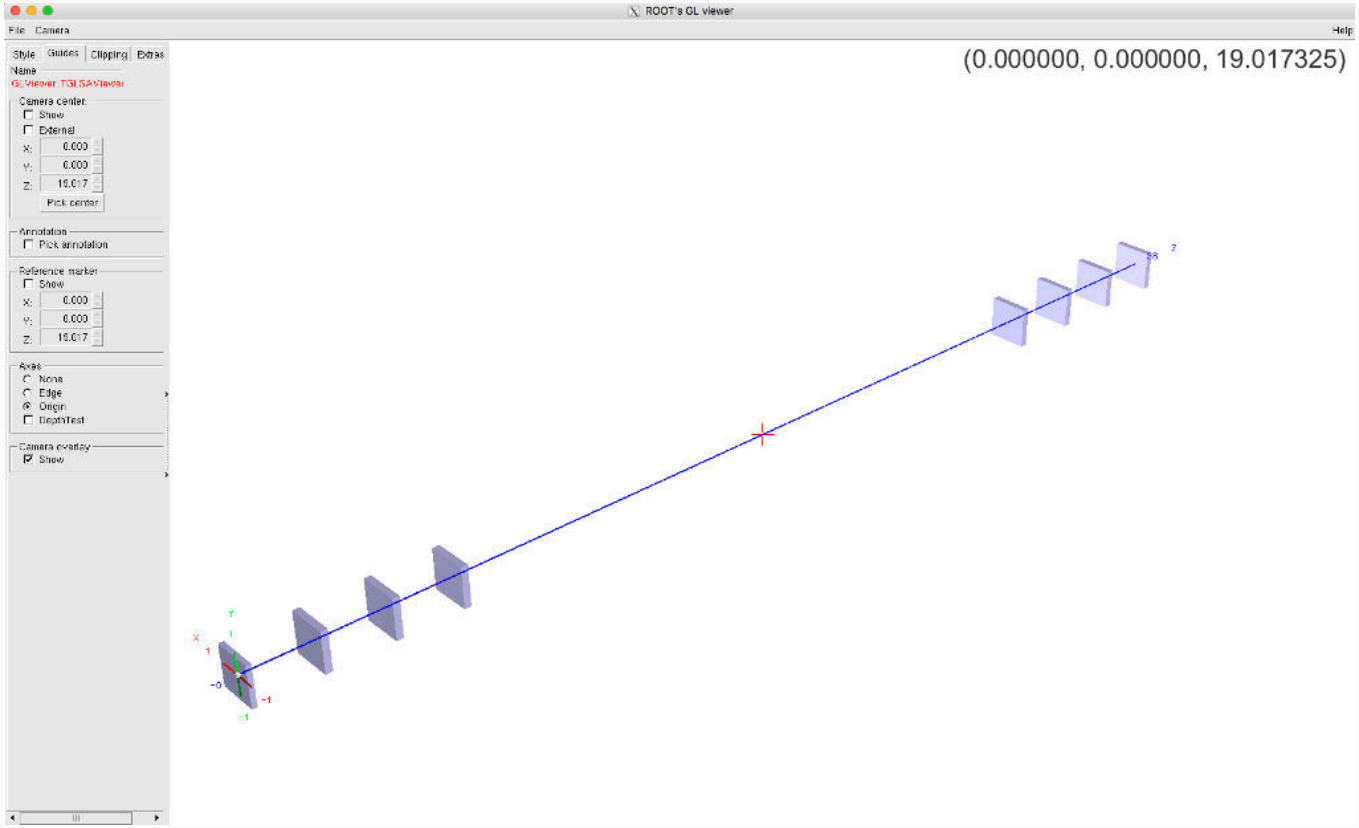
- Software package for aligning telescope like detectors
- Previously developed as part of the original AIDA project (Task 2.10)
- Has been used by:
  - LHCb timepix3 telescope
  - LHC beamgas vertex group
  - MICE (Muon Ionising Cooling Experiment)

# Changes to Bach




- Project source moved to GitHub (`https://github.com/chrisburr/Bach`)
- Build system modified to use CMake
- Replaced custom detector description with DD4hep

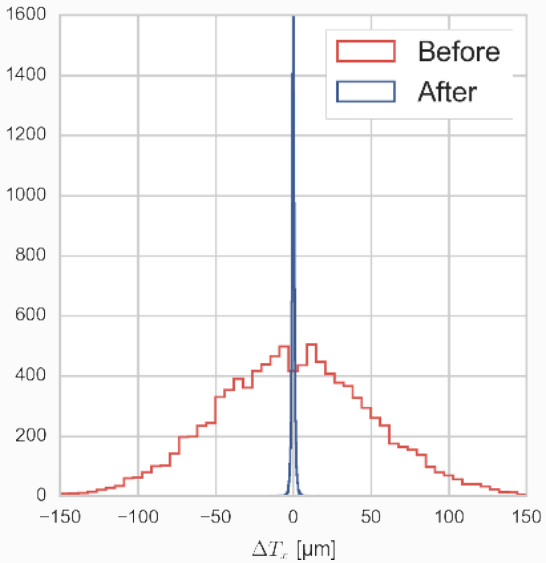
# LHCb timpix3 telescope

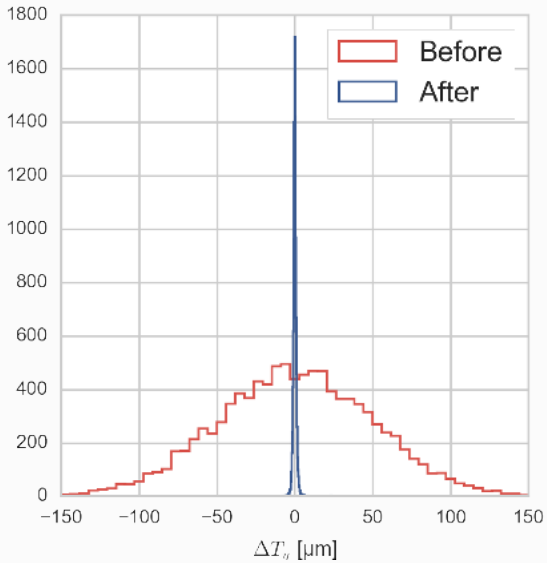


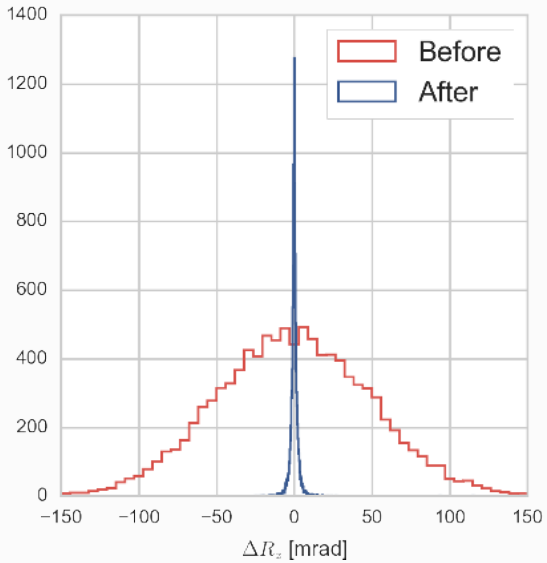

- Test geometry needed to perform validation studies
- Developed a DD4hep driver for a “LHCb timpix3 telescope” like geometry

# Validation

- Validation performed using toy studies and the new DD4hep driver
  - Generate 1000 events each with $\sim$ 25 tracks
  - Reconstruct data using a randomly misaligned detector
  - Align detector using BACH

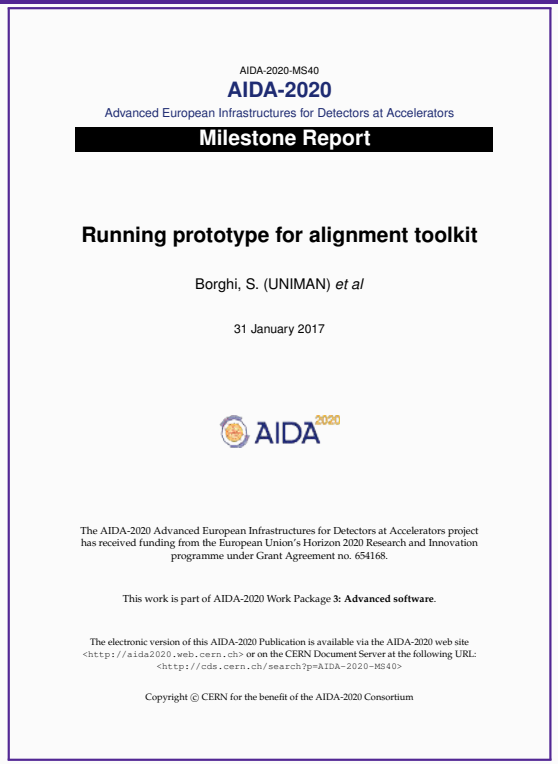



Alignment constants for plane 3 before and after alignment for 1000 different alignment scenarios

# Milestone 40



AIDA-2020-MS40

**AIDA-2020**

Advanced European Infrastructures for Detectors at Accelerators

**Milestone Report**

**Running prototype for alignment toolkit**

Borghi, S. (UNIMAN) *et al*

31 January 2017

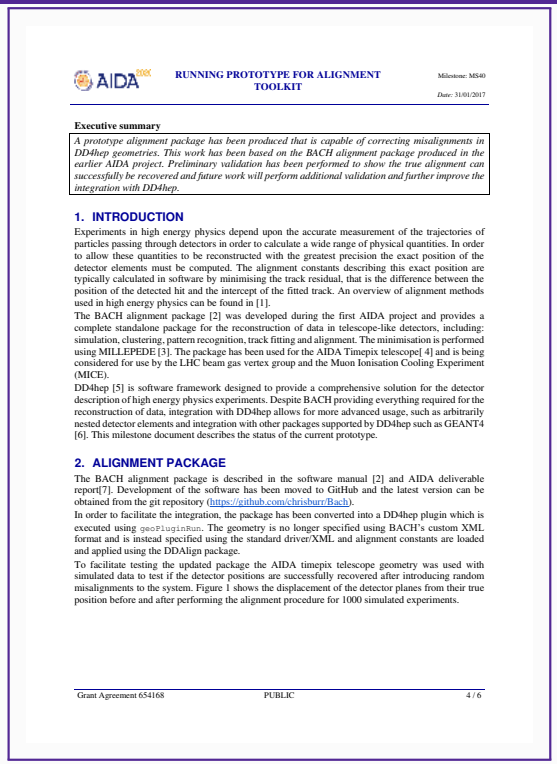
AIDA 2020

The AIDA-2020 Advanced European Infrastructures for Detectors at Accelerators project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement no. 654168.

This work is part of AIDA-2020 Work Package **3: Advanced software**.

The electronic version of this AIDA-2020 Publication is available via the AIDA-2020 web site <http://aida2020.web.cern.ch> or on the CERN Document Server at the following URL: <http://cds.cern.ch/search?p=AIDA-2020-MS40>

Copyright © CERN for the benefit of the AIDA-2020 Consortium



AIDA 2020

**RUNNING PROTOTYPE FOR ALIGNMENT TOOLKIT**

Milestone: MS40

*Date:* 31/01/2017

**Executive summary**

*A prototype alignment package has been produced that is capable of correcting misalignments in DD4hep geometries. This work has been based on the BACH alignment package produced in the earlier AIDA project. Preliminary validation has been performed to show the true alignment can successfully be recovered and future work will perform additional validation and further improve the integration with DD4hep.*

## 1. INTRODUCTION

Experiments in high energy physics depend upon the accurate measurement of the trajectories of particles passing through detectors in order to calculate a wide range of physical quantities. In order to allow these quantities to be reconstructed with the greatest precision the exact position of the detector elements must be computed. The alignment constants describing this exact position are typically calculated in software by minimising the track residual, that is the difference between the position of the detected hit and the intercept of the fitted track. An overview of alignment methods used in high energy physics can be found in [1].

The BACH alignment package [2] was developed during the first AIDA project and provides a complete standalone package for the reconstruction of data in telescope-like detectors, including: simulation, clustering, pattern recognition, track fitting and alignment. The minimisation is performed using MILLEPEDE [3]. The package has been used for the AIDA Timepix telescope[ 4] and is being considered for use by the LHC beam gas vertex group and the Muon Ionisation Cooling Experiment (MICE).

DD4hep [5] is software framework designed to provide a comprehensive solution for the detector description of high energy physics experiments. Despite BACH providing everything required for the reconstruction of data, integration with DD4hep allows for more advanced usage, such as arbitrarily nested detector elements and integration with other packages supported by DD4hep such as GEANT4 [6]. This milestone document describes the status of the current prototype.

## 2. ALIGNMENT PACKAGE

The BACH alignment package is described in the software manual [2] and AIDA deliverable report[7]. Development of the software has been moved to GitHub and the latest version can be obtained from the git repository (https://github.com/chrisburr/Bach).

In order to facilitate the integration, the package has been converted into a DD4hep plugin which is executed using `geoPluginRun`. The geometry is no longer specified using BACH's custom XML format and is instead specified using the standard driver/XML and alignment constants are loaded and applied using the DDAlign package.

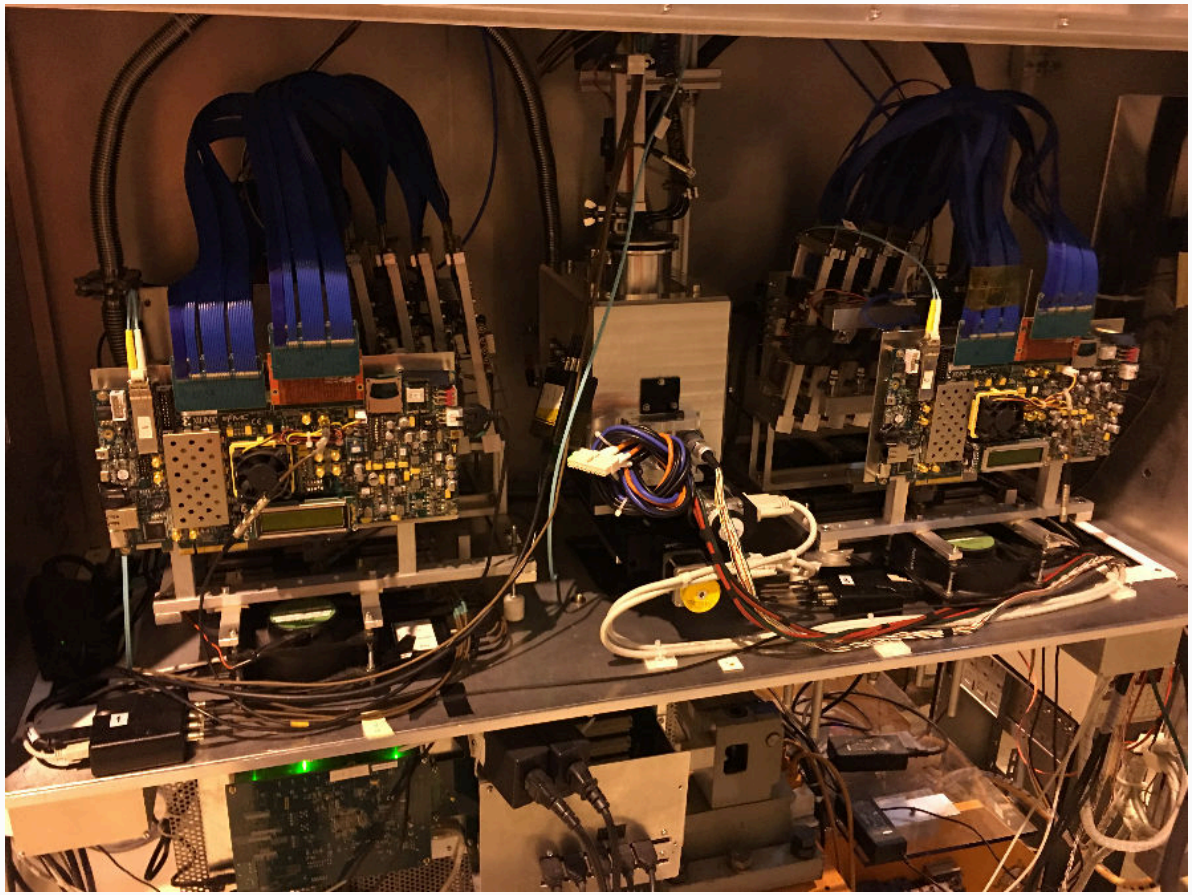
To facilitate testing the updated package the AIDA timepix telescope geometry was used with simulated data to test if the detector positions are successfully recovered after introducing random misalignments to the system. Figure 1 shows the displacement of the detector planes from their true position before and after performing the alignment procedure for 1000 simulated experiments.



- Milestone 40 was submitted on time at the end of January
  - "Running prototype for alignment toolkit"
- Since submission:
  - Bug preventing the alignment of rotations has been fixed
  - Alignment constants can now be read back using DD4hep
  - Multiple alignment iterations can now be used

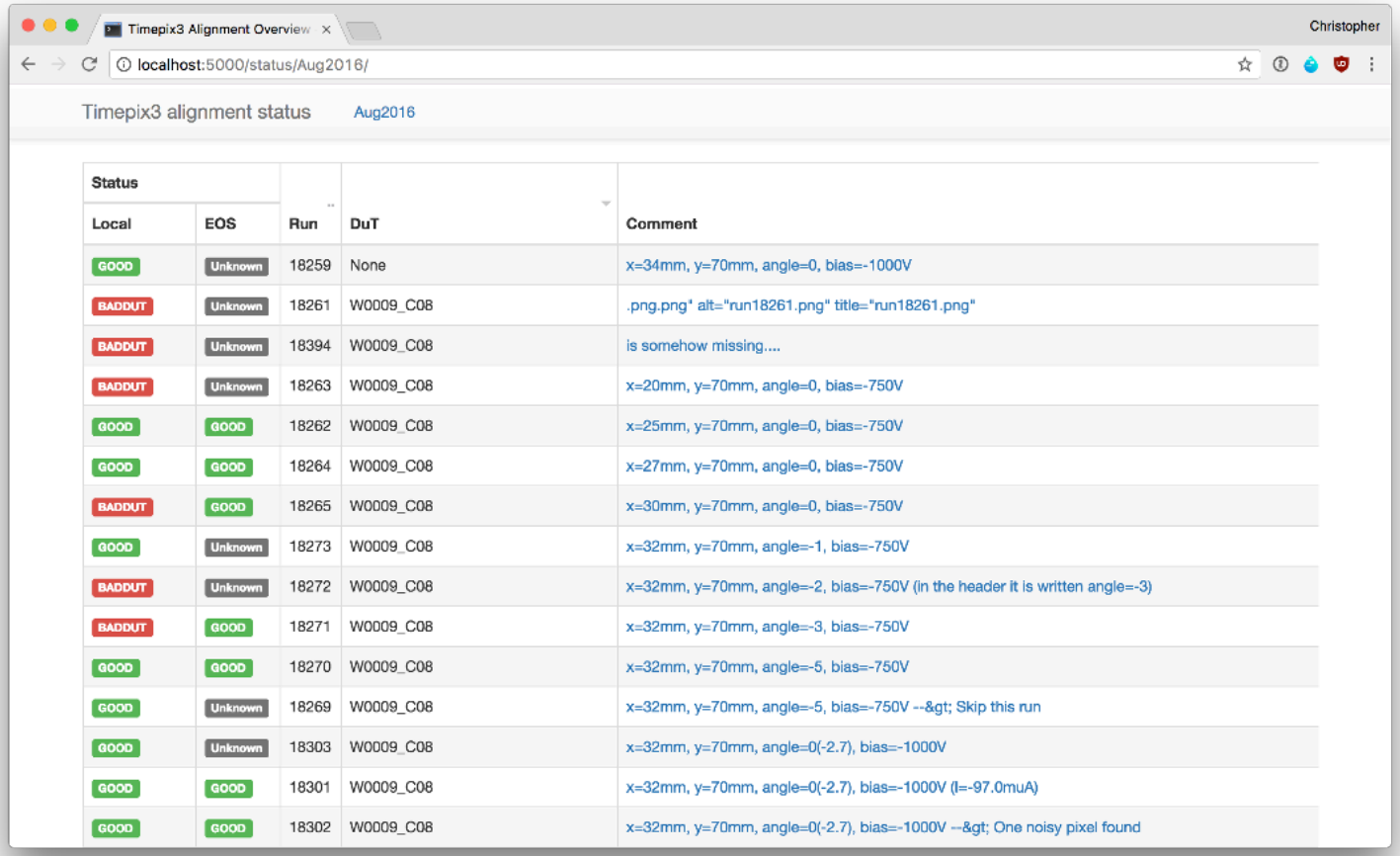
# Testbeam Alignment

# Timepix3 telescope



- Comprised of 8 timepix3 sensors
  - Each has a 256x256 grid of 55x55 µm pixels
  - Rotated by $\sim 9$ about $x/y$ to improve resolution/charge sharing
- 35 mm between each plane in each arm
- Remotely movable ($T_x/T_y/R_y$) DuT can be placed between the arms

# Testbeam Alignment



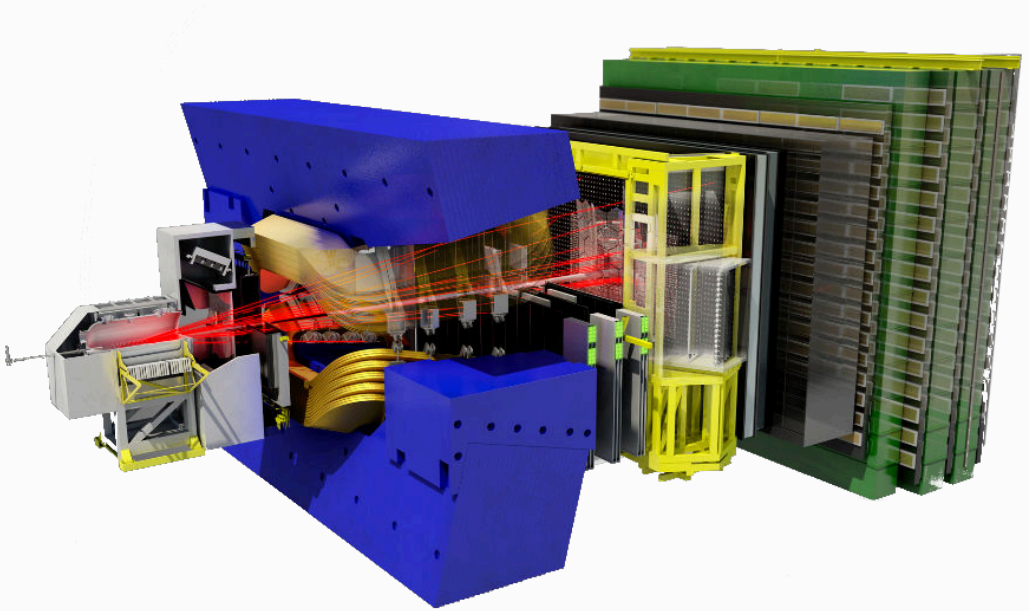

| Status | | | | |
|---|---|---|---|---|
| Local | EOS | Run | DuT | Comment |
| GOOD | Unknown | 18259 | None | x=34mm, y=70mm, angle=0, bias=-1000V |
| BADDUT | Unknown | 18261 | W0009_C08 | .png.png" alt="run18261.png" title="run18261.png" |
| BADDUT | Unknown | 18394 | W0009_C08 | is somehow missing.... |
| BADDUT | Unknown | 18263 | W0009_C08 | x=20mm, y=70mm, angle=0, bias=-750V |
| GOOD | GOOD | 18262 | W0009_C08 | x=25mm, y=70mm, angle=0, bias=-750V |
| GOOD | GOOD | 18264 | W0009_C08 | x=27mm, y=70mm, angle=0, bias=-750V |
| BADDUT | GOOD | 18265 | W0009_C08 | x=30mm, y=70mm, angle=0, bias=-750V |
| GOOD | Unknown | 18273 | W0009_C08 | x=32mm, y=70mm, angle=-1, bias=-750V |
| BADDUT | Unknown | 18272 | W0009_C08 | x=32mm, y=70mm, angle=-2, bias=-750V (in the header it is written angle=-3) |
| BADDUT | GOOD | 18271 | W0009_C08 | x=32mm, y=70mm, angle=-3, bias=-750V |
| GOOD | GOOD | 18270 | W0009_C08 | x=32mm, y=70mm, angle=-5, bias=-750V |
| GOOD | Unknown | 18269 | W0009_C08 | x=32mm, y=70mm, angle=-5, bias=-750V --> Skip this run |
| GOOD | Unknown | 18303 | W0009_C08 | x=32mm, y=70mm, angle=0(-2.7), bias=-1000V |
| GOOD | GOOD | 18301 | W0009_C08 | x=32mm, y=70mm, angle=0(-2.7), bias=-1000V (I=-97.0muA) |
| GOOD | GOOD | 18302 | W0009_C08 | x=32mm, y=70mm, angle=0(-2.7), bias=-1000V --> One noisy pixel found |

- Last year had 3 testbeam periods (May, August and November)
- 2240 separate runs taken and most have good alignments available
- Currently developing a web interface to easily view information about each run

# LHCb Vertex Locator

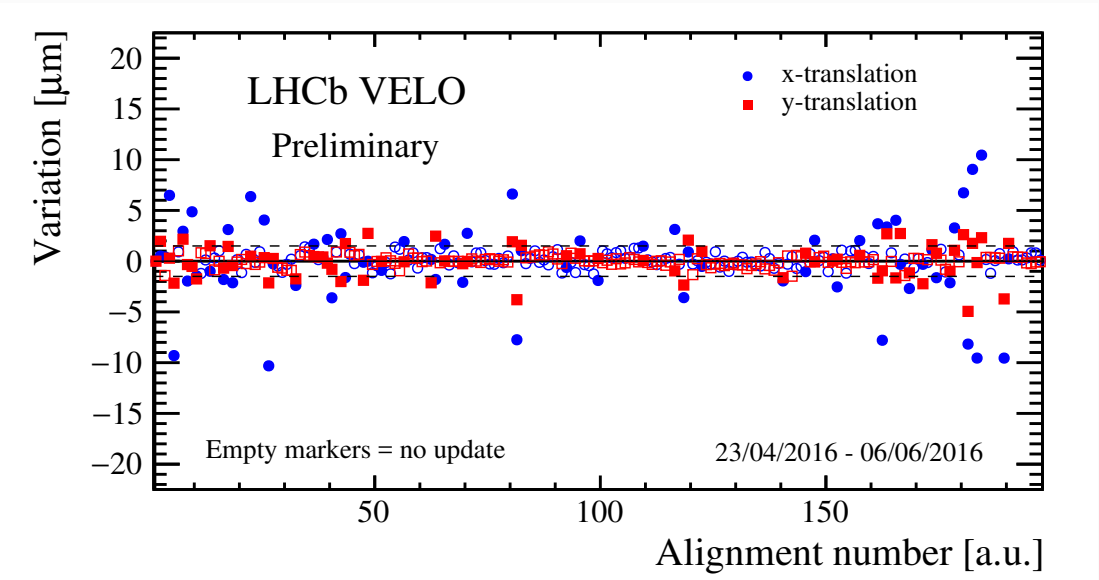
# Real time alignment and calibration

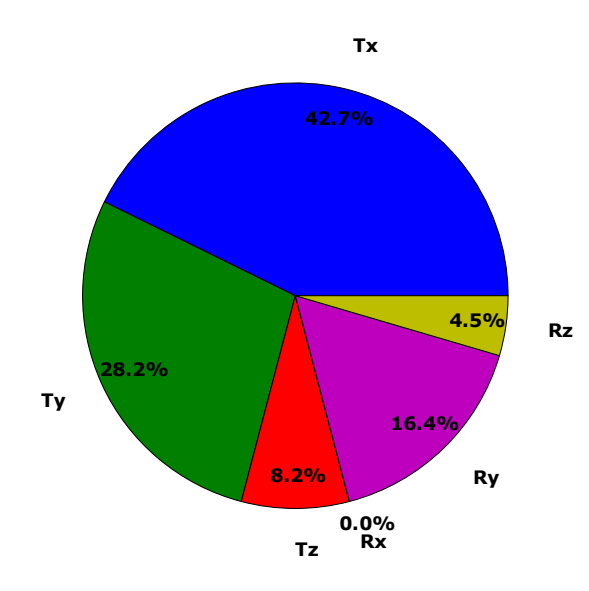
- In Run2, a novel real-time alignment procedure was developed at LHCb
- Alignment is evaluated within a few minutes for each fill and updated if needed
- Parallelised across $\sim$ 1700 nodes of the online farm
- The full aligned detector and the possibility to run the same reconstruction in the trigger allows to obtain the same online and offline performance



# Status in 2016

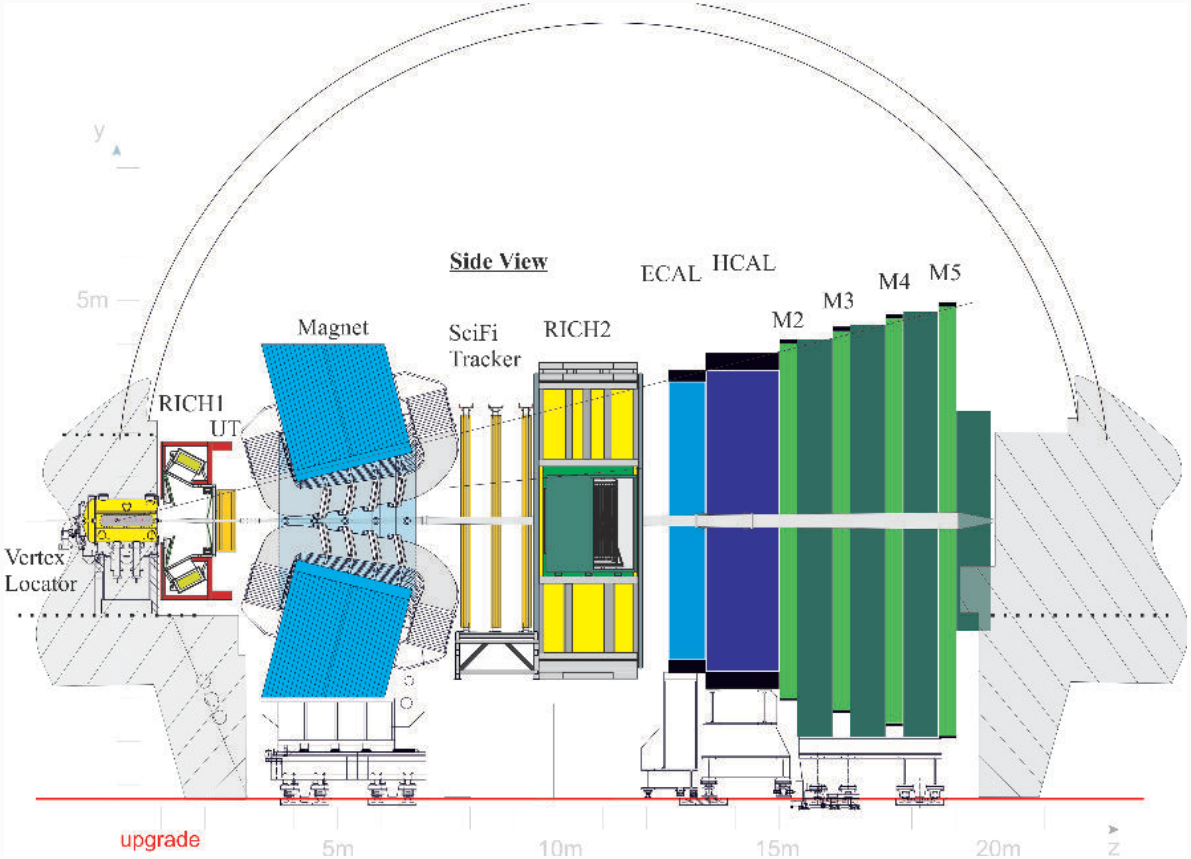
- Everything ran smoothly and with alignment fully automated
- Alignment parameters updated automatically if outside of tolerances
  - Every $\sim$ 3 fills on average for VELO
  - Every $\sim$ 10 fills on average for tracker



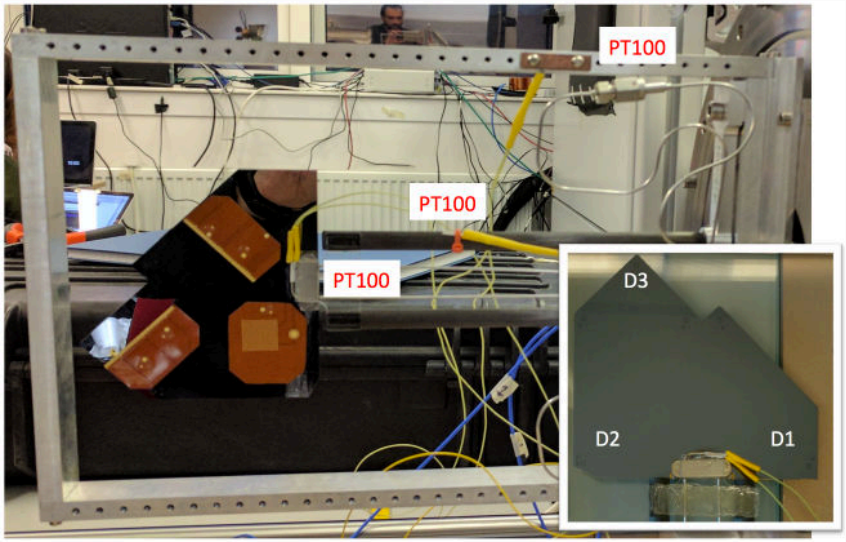
# LHCb Upgrade Vertex Locator

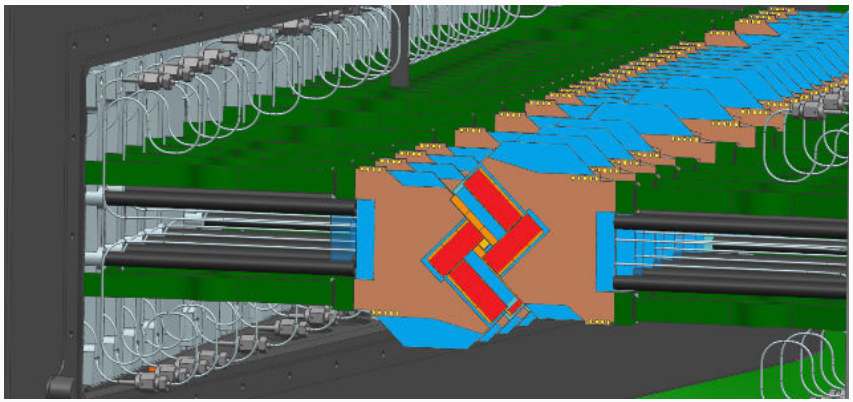
# LHCb Upgrade Vertex Locator




- Much of the LHCb detector will be replaced during LHC Long Shutdown 2 (2018)
  - Vertex locator
  - Tracking detectors
  - RICH - replacing photon detectors
  - All readout electronics

# LHCb Upgrade Vertex Locator

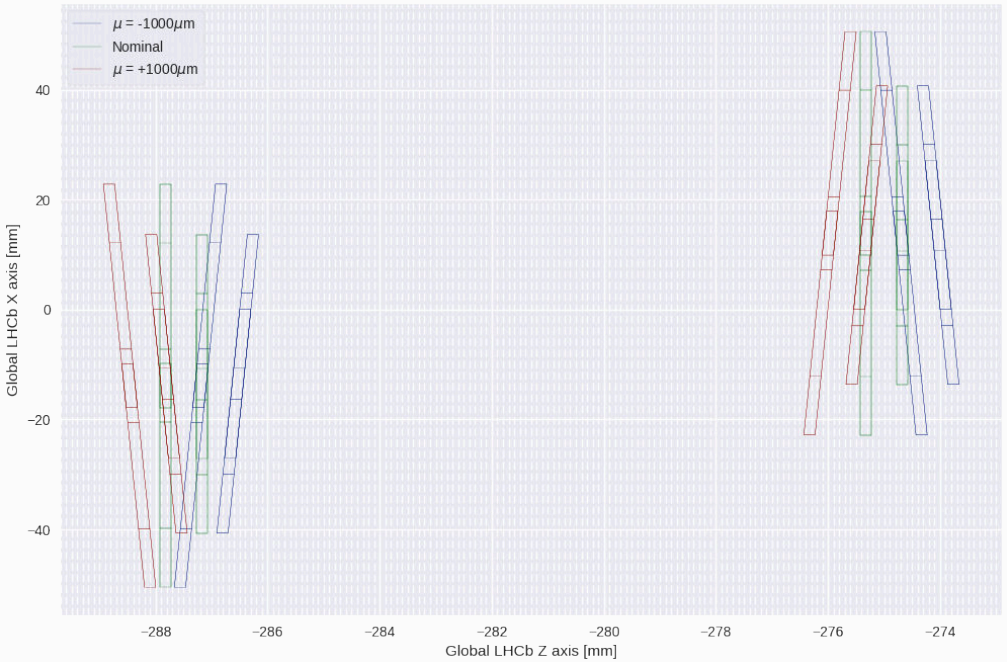


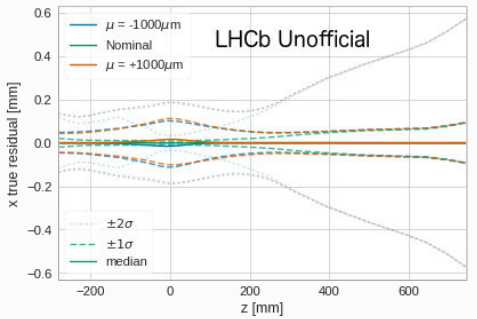
- 52 modules each containing silicon pixel detectors
- Split into two retractable halves
- Prototype modules have been found to rotate around $y$ when cooled
  - $\mathcal{O}(5\times)$ larger than the current tolerances

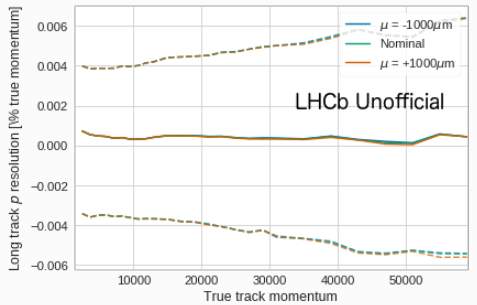
# Performance studies

- Studies under way using the full LHCb simulation and reconstruction
- Evaluating how much alignment can be used to correct for distortions
- Examining many potentially effected quantities:
  - Track and PV reconstruction
  - Momentum resolution
  - Tracking efficiency
  - Lifetime measurements




Extreme distortions for illustration



# Conclusions

- Bach is now integrated with DD4hep
- LHCb real-time alignment procedure run smoothly in 2016
  - no major changes required for 2017
- Will continue the support alignment of the timepix3 telescope
  - Several test beams planned for this year
  - First functional LHCb VP module prototype should be tested!
- LHCb upgrade vertex locator alignment work ongoing

Backup