Alignment tools

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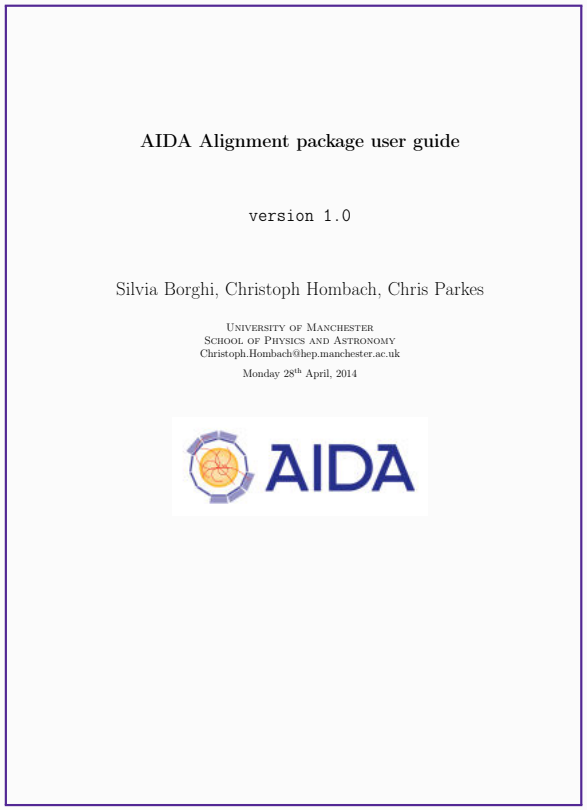
The University of Manchester

Introduction

- Update on the alignment work within WP3
- Will be talking about:
  - Updates to the Bach alignment toolkit
  - Alignment support for testbeams
  - Realtime alignment of LHCb
  - Testing the use of DD4hep for the LHCb upgrade

Bach Alignment Toolkit

Bach alignment toolkit



AIDA Alignment package user guide

version 1.0

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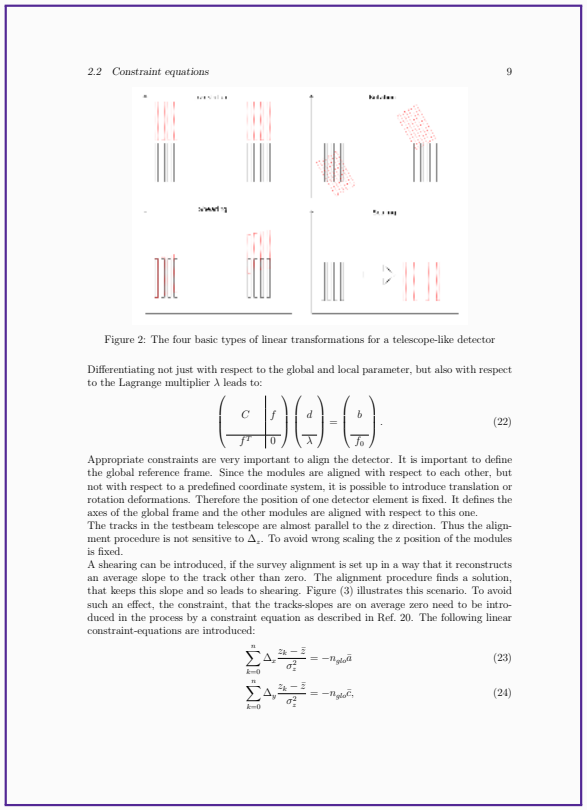


2.2 Constraint equations 9

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 λ leads to:

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

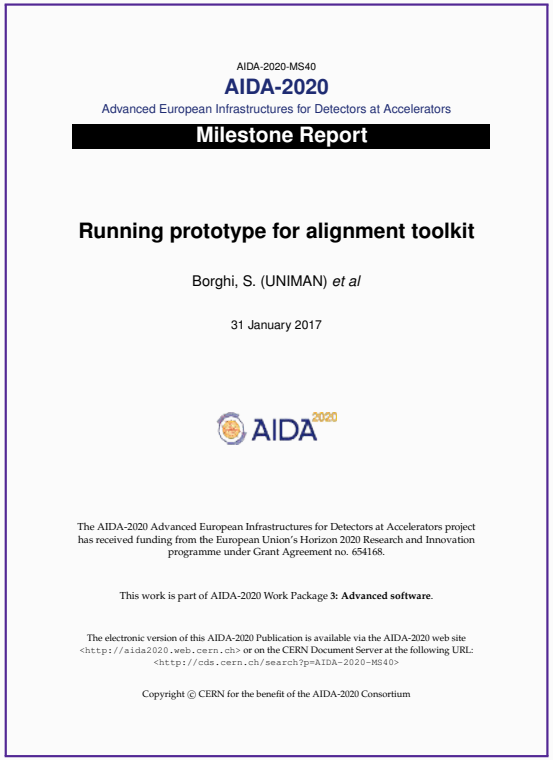
Appropriate constraints are very important to align the detector. It is important to define the global reference frame. Since the modules are aligned with respect to each other, but not with respect to a predefined coordinate system, it is possible to introduce translation or rotation deformations. Therefore 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 Δ_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:

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

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

- Software package for aligning telescope like detectors
- Previously developed as part of the original AIDA project (Task 2.10)

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

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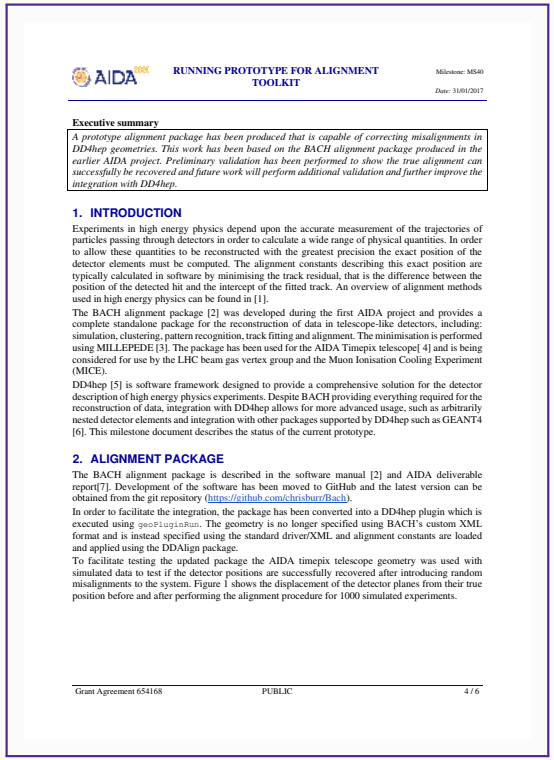

AIDA 2020 — RUNNING PROTOTYPE FOR ALIGNMENT TOOLKIT — Milestone: MS40 — Date: 31/01/2017

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.

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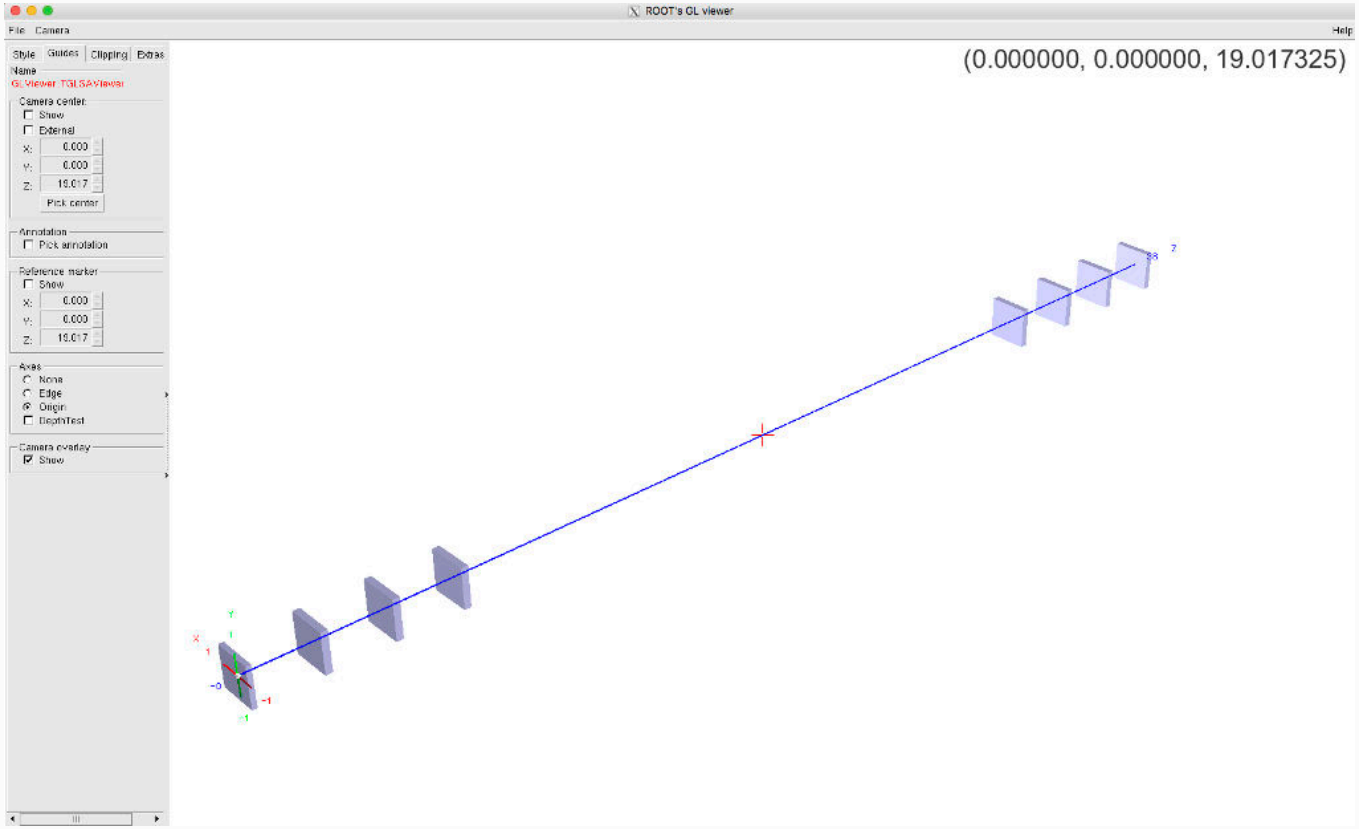
- Last year I showed changes that had been made for MS40
  - Move from custom geometry/conditions handling to DD4hep
  - Allows for much more complex geometries

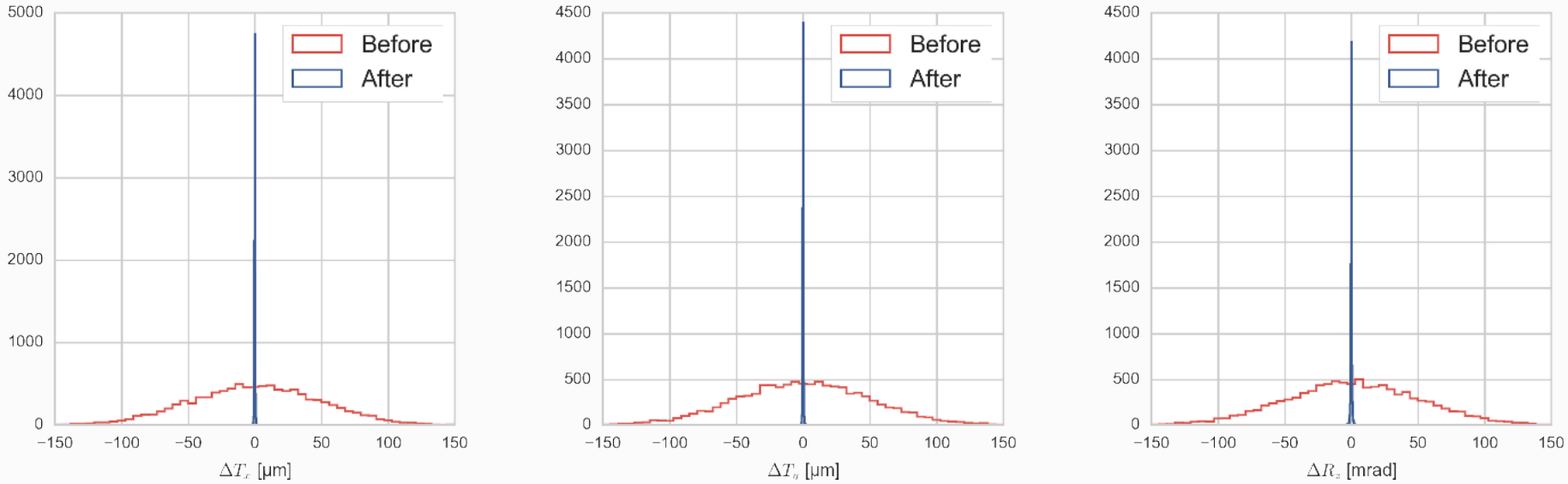
LHCb timpix3 telescope



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

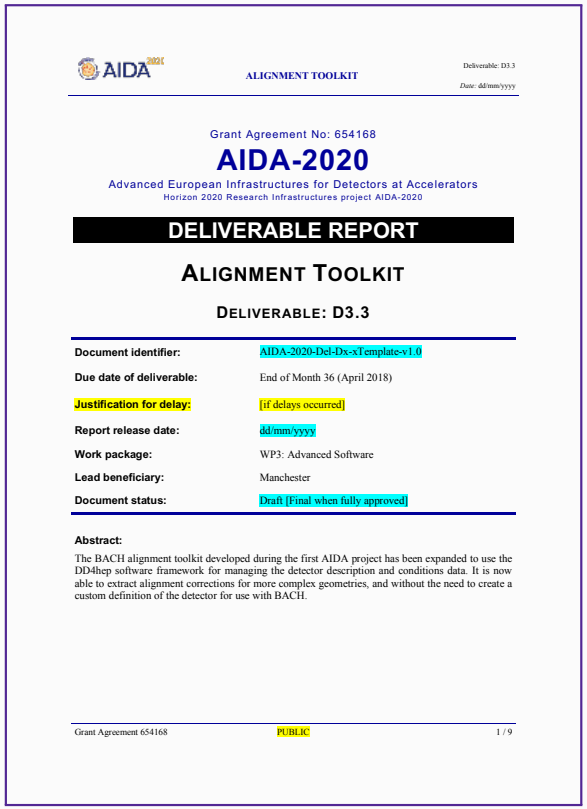
Validation

- 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 4 before and after alignment for 10 000 different alignment scenarios

Deliverable 3.3



AIDA 2020 ALIGNMENT TOOLKIT Deliverable: D3.3 Date: dd/mm/yyyy

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AIDA-2020

Advanced European Infrastructures for Detectors at Accelerators

Horizon 2020 Research Infrastructures project AIDA-2020

DELIVERABLE REPORT

ALIGNMENT TOOLKIT

DELIVERABLE: D3.3

Document identifier:	AIDA-2020-Del-Dx-xTemplate-v1.0
Due date of deliverable:	End of Month 36 (April 2018)
Justification for delay:	[if delays occurred]
Report release date:	dd/mm/yyyy
Work package:	WP3: Advanced Software
Lead beneficiary:	Manchester
Document status:	Draft [Final when fully approved]

Abstract:

The BACH alignment toolkit developed during the first AIDA project has been expanded to use the DD4hep software framework for managing the detector description and conditions data. It is now able to extract alignment corrections for more complex geometries, and without the need to create a custom definition of the detector for use with BACH.

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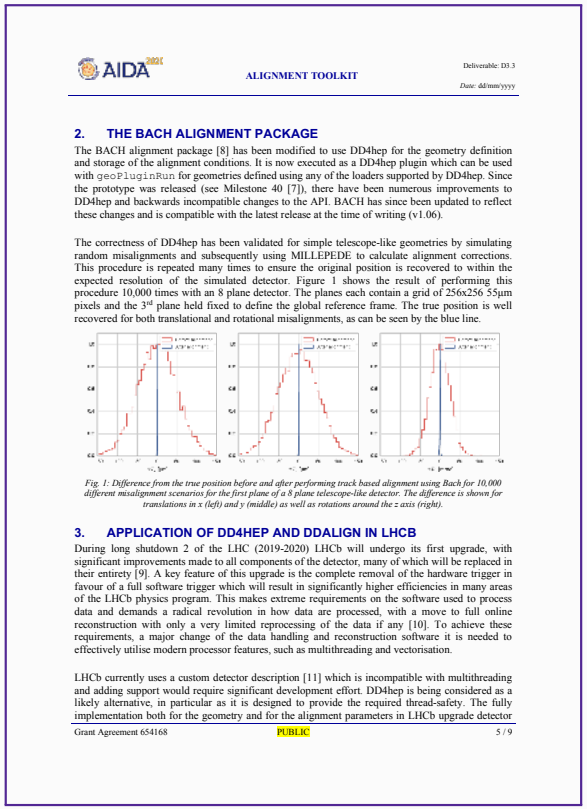

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2. THE BACH ALIGNMENT PACKAGE

The BACH alignment package [8] has been modified to use DD4hep for the geometry definition and storage of the alignment conditions. It is now executed as a DD4hep plugin which can be used with `geoPluginRun` for geometries defined using any of the loaders supported by DD4hep. Since the prototype was released (see Milestone 40 [7]), there have been numerous improvements to DD4hep and backwards incompatible changes to the API. BACH has since been updated to reflect these changes and is compatible with the latest release at the time of writing (v1.06).

The correctness of DD4hep has been validated for simple telescope-like geometries by simulating random misalignments and subsequently using MILLEPEDE to calculate alignment corrections. This procedure is repeated many times to ensure the original position is recovered to within the expected resolution of the simulated detector. Figure 1 shows the result of performing this procedure 10,000 times with an 8 plane detector. The planes each contain a grid of 256x256 55μm pixels and the 3rd plane held fixed to define the global reference frame. The true position is well recovered for both translational and rotational misalignments, as can be seen by the blue line.

Fig. 1: Difference from the true position before and after performing track based alignment using Bach for 10,000 different misalignment scenarios for the first plane of a 8 plane telescope-like detector. The difference is shown for translations in x (left) and y (middle) as well as rotations around the z axis (right).

3. APPLICATION OF DD4HEP AND DDALIGN IN LHCB

During long shutdown 2 of the LHC (2019-2020) LHCb will undergo its first upgrade, with significant improvements made to all components of the detector, many of which will be replaced in their entirety [9]. A key feature of this upgrade is the complete removal of the hardware trigger in favour of a full software trigger which will result in significantly higher efficiencies in many areas of the LHCb physics program. This makes extreme requirements on the software used to process data and demands a radical revolution in how data are processed, with a move to full online reconstruction with only a very limited reprocessing of the data if any [10]. To achieve these requirements, a major change of the data handling and reconstruction software it is needed to effectively utilise modern processor features, such as multithreading and vectorisation.

LHCb currently uses a custom detector description [11] which is incompatible with multithreading and adding support would require significant development effort. DD4hep is being considered as a likely alternative, in particular as it is designed to provide the required thread-safety. The fully implementation both for the geometry and for the alignment parameters in LHCb upgrade detector

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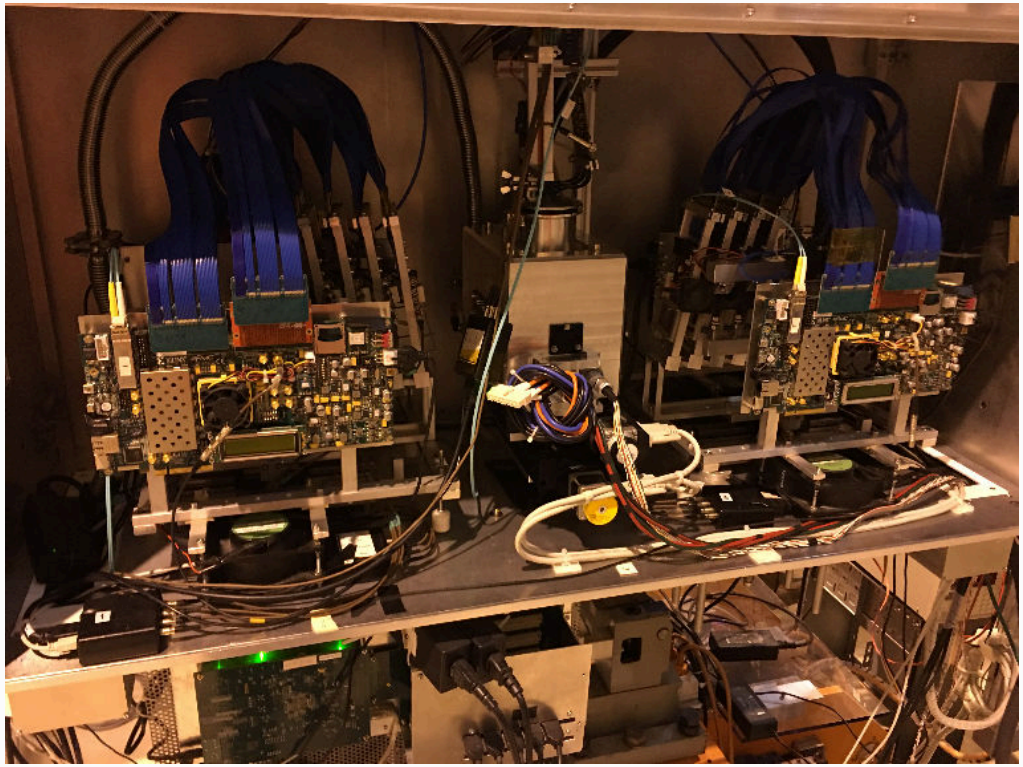
- Since MS40 there have been many changes:
  - Updated to reflect major changes in the DD4hep API
  - Add the ability to load the computed alignment conditions
  - Various important bugfixes

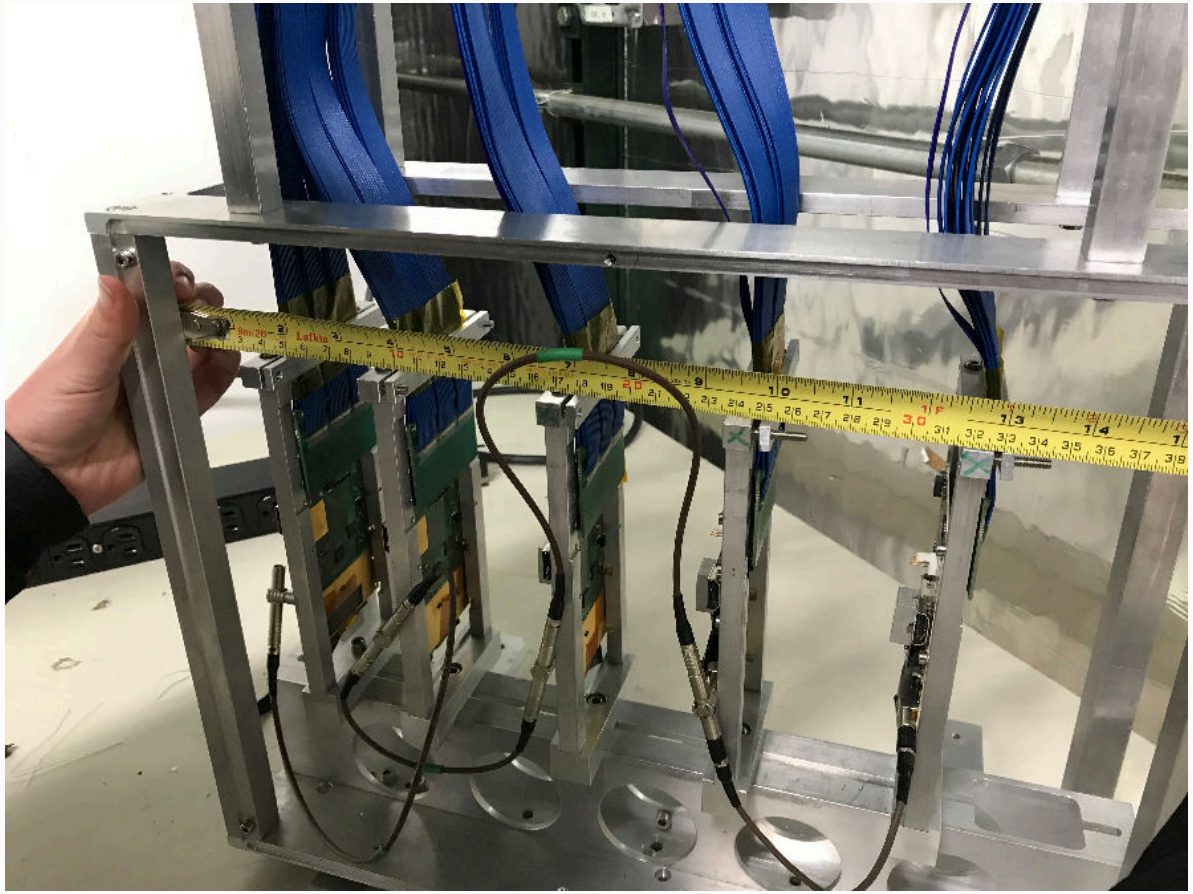
Testbeam Alignment

Timepix3 telescope



- Comprised of 8 timepix3 sensors
  - Each has a 256x256 grid of 55x55 µm pixels
  - Rotated by ~ 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
- Support provided for alignment and data taking

Velopix telescope at Fermilab

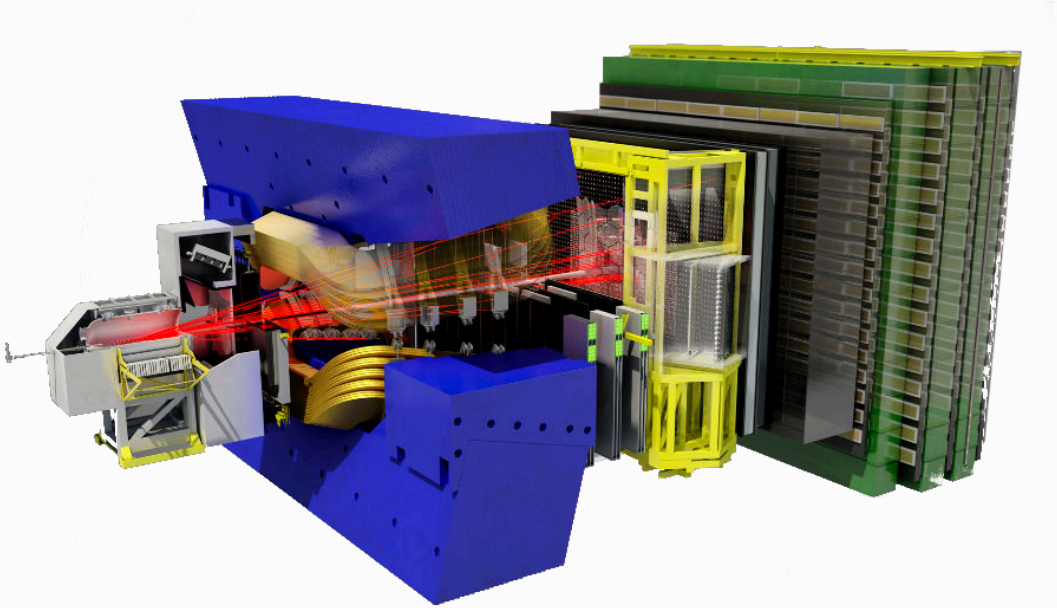


- Comprised of 4 velopix sensors (+ 1 DuT)
  - Each has a 256x256 grid of 55x55 µm pixels
- Used for tests at Fermilab with higher rates than available at CERN

LHCb Vertex Locator

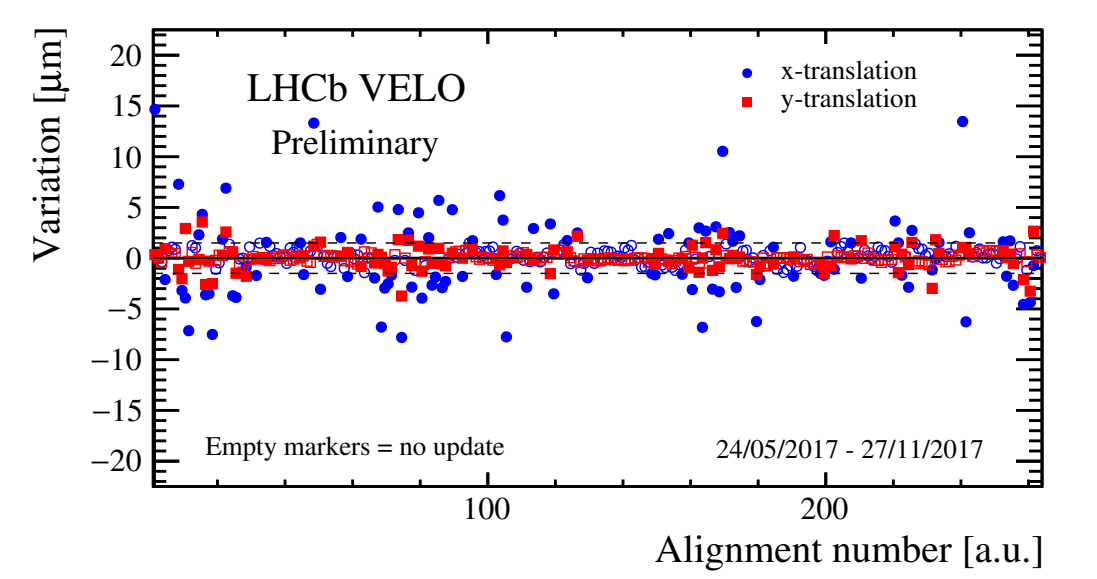
Real time alignment and calibration

- 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



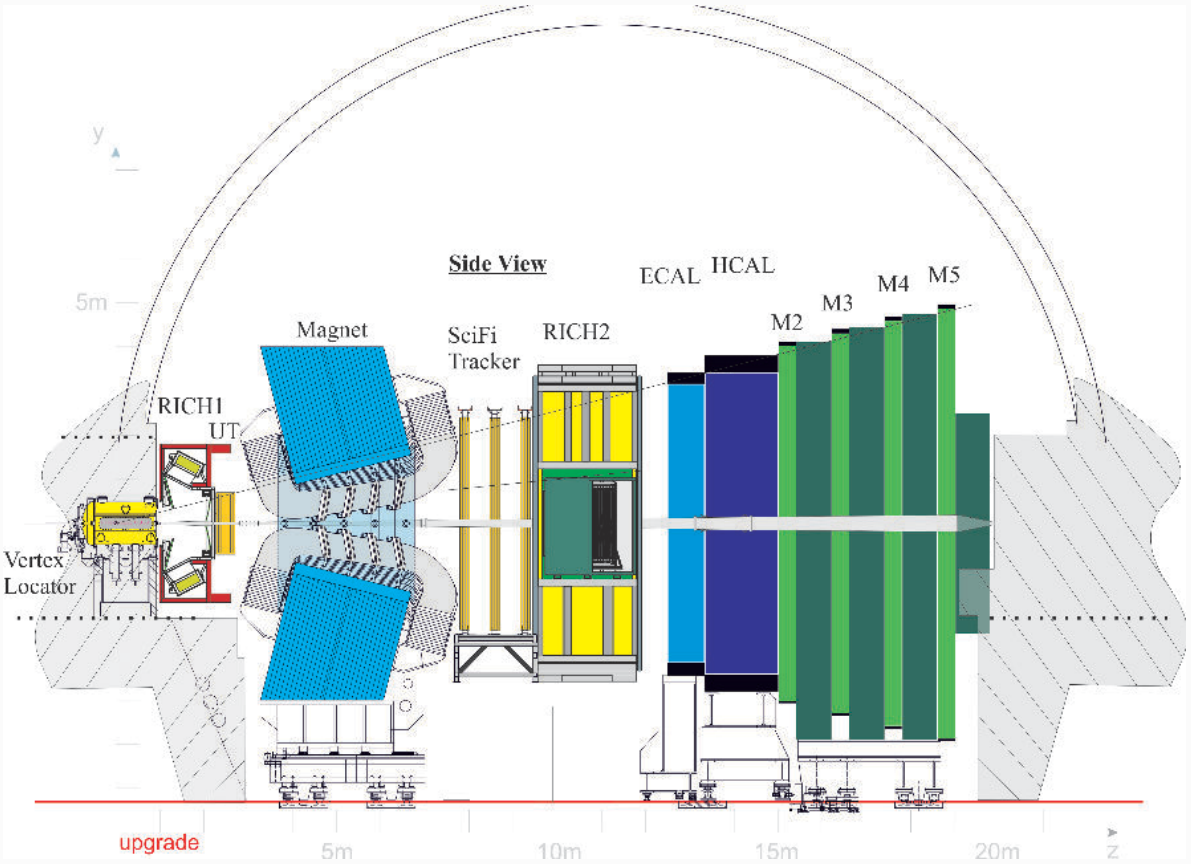
Status in 2017

- 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



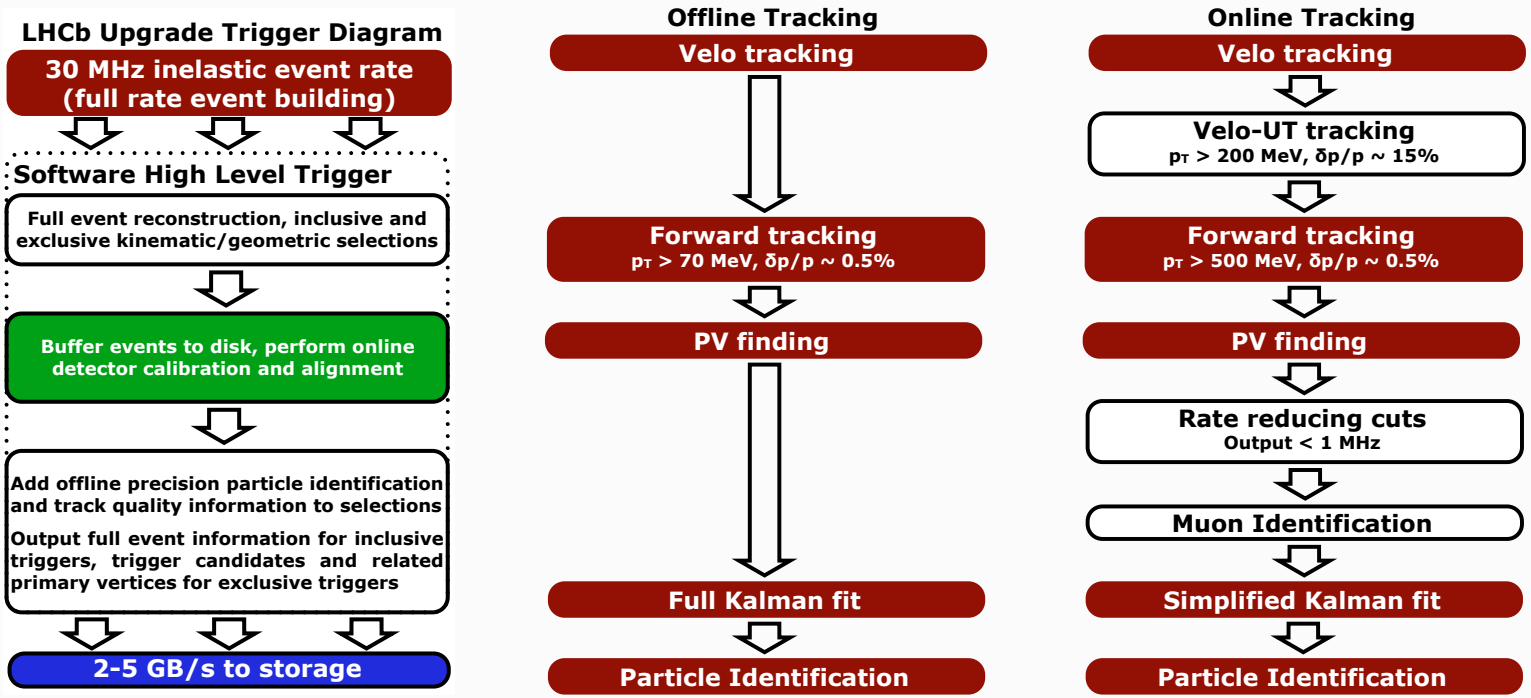
LHCb Upgrade

LHCb Upgrade



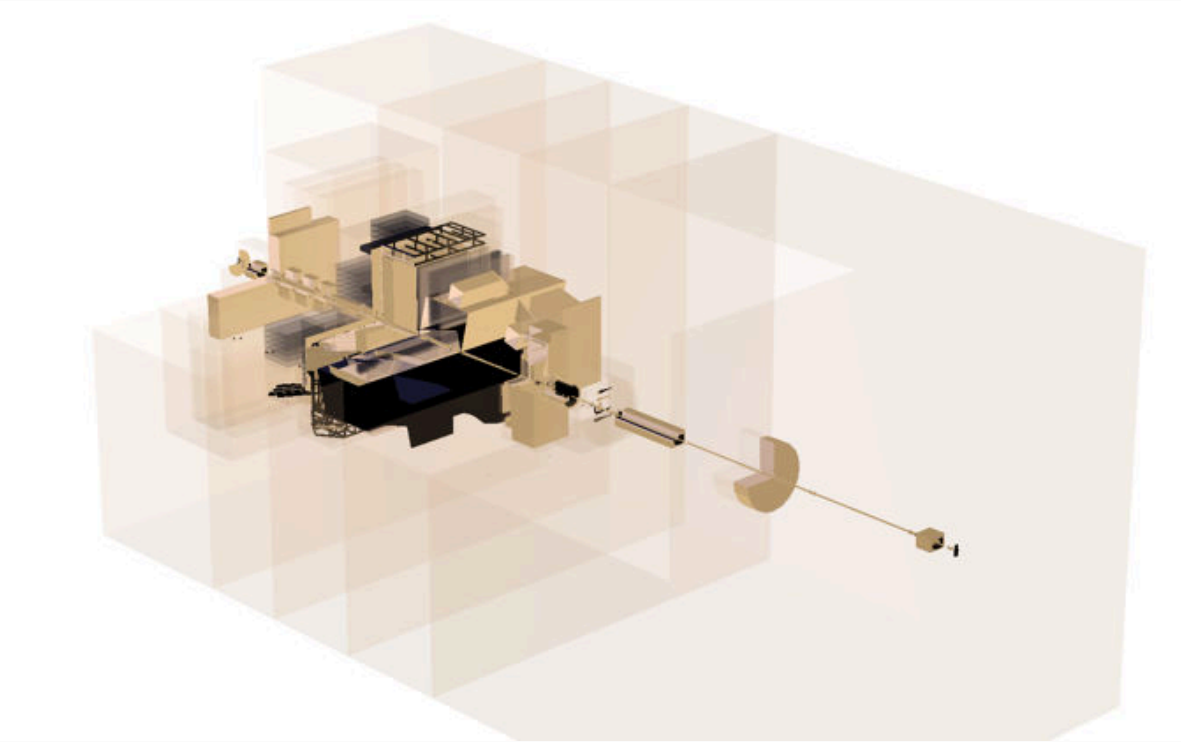
- Much of the LHCb detector will be replaced during LHC Long Shutdown 2 (2018)
  - Vertex locator
  - Tracking detectors
  - RICH - replacing photon detectors
  - All readout electronics

LHCb Upgrade Trigger



- The LHCb upgrade will use an all software trigger
  - Extremely challenging to reconstruct all 30 MHz of incoming events
  - Requires effective use of multithreading to be financially viable
  - Current geometry/conditions software for LHCb is old and unmaintained
  - Can DD4hep provide an alternative?

Using DD4hep in LHCb



- Investigating the feasibility of using DD4hep for conditions/alignment
- Performing direct comparisons between the current and DD4hep-based geometry
- Working towards running alignment procedure with both geometries:
  - Geometry XML modified for use with both the current software and DD4hep
  - Transport service to compute radiation length between points
- Very complex nested structure - already found/fixed DD4hep bugs
- First application of DD4hep for an existing large scale experiment

Conclusions

- Bach is now integrated with DD4hep and updated to support the latest changes
- LHCb real-time alignment procedure continues to run smoothly
- Will continue the support alignment of the timepix3 telescope
- Investigating the use of DD4hep for alignment/conditions in the LHCb upgrade
    - The decision for if DD4hep will be used will be made during summer

Any questions?