High precision track-based alignment of the tracking detector of the g-2 experiment

Gleb Lukicov

on behalf of the Fermilab Muon g-2 Collaboration

g.lukicov@ucl.ac.uk

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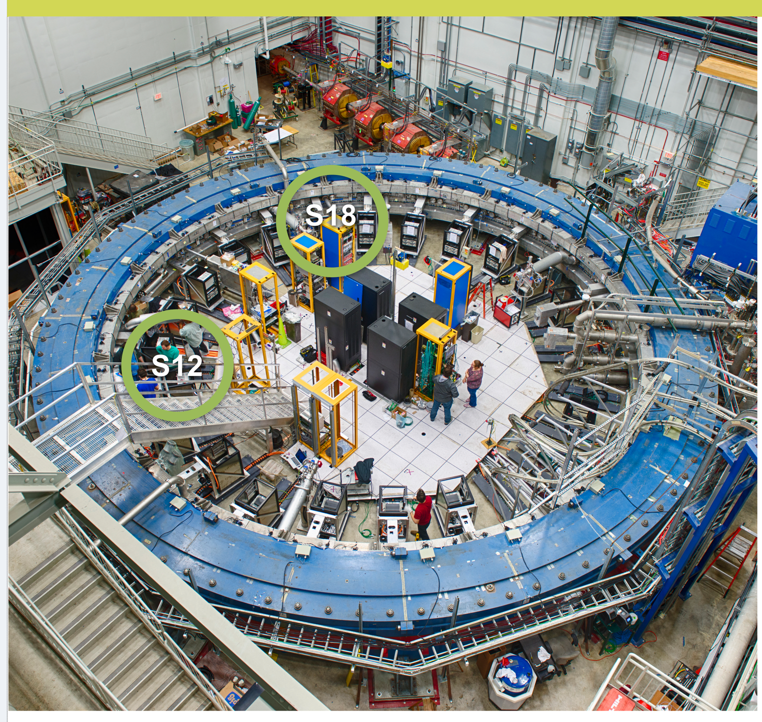
Introduction



The Fermilab g-2 experiment [1] will determine the anomalous magnetic moment, a_μ, of the positive muon to 140 *ppb* precision via a simultaneous measurement of the spin precision frequency and the magnetic field. The two tracking stations [2] help to reduce the systematic uncertainty on the a_μ via a non-destructive measurement of the beam profile [3].

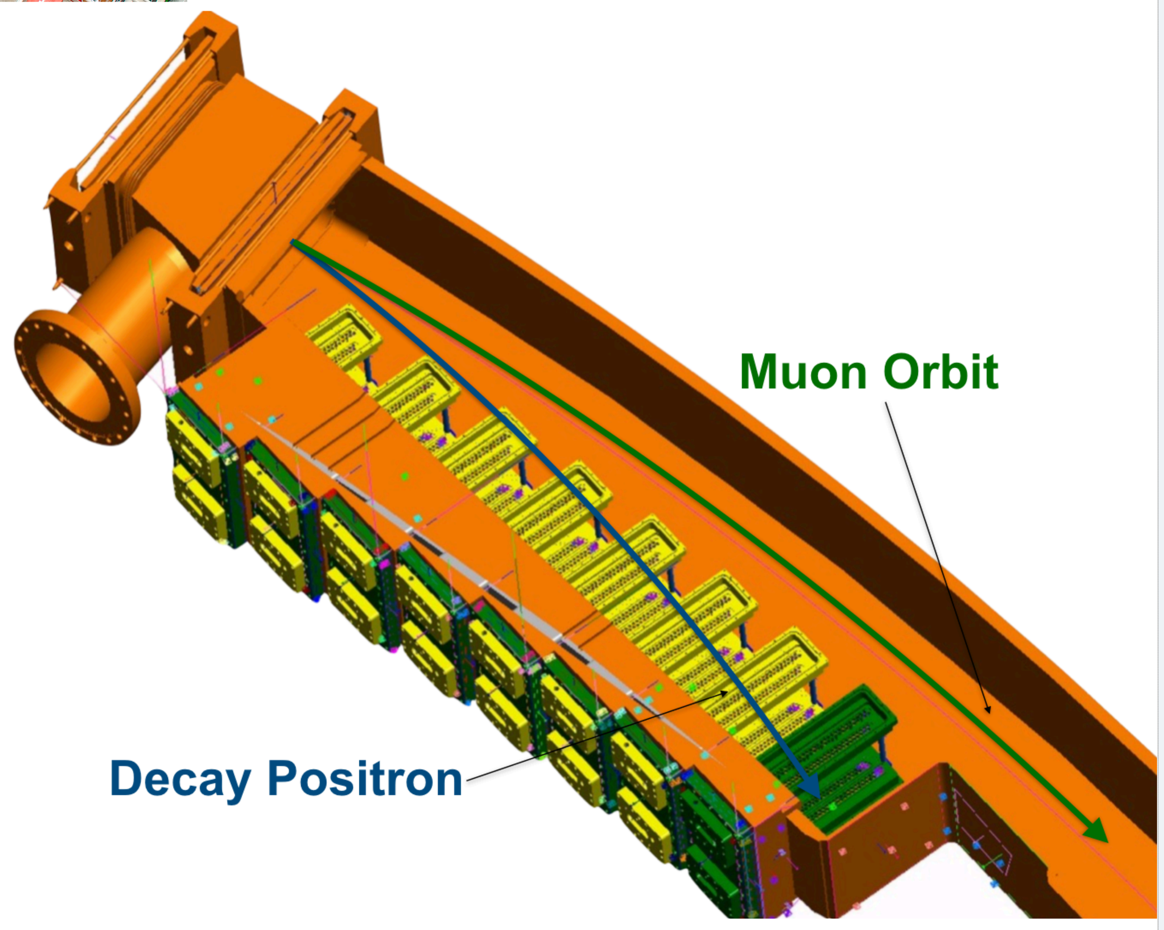


***Fig.1:** A tracker station consists of 8 modules that are placed inside a vacuum chamber.*

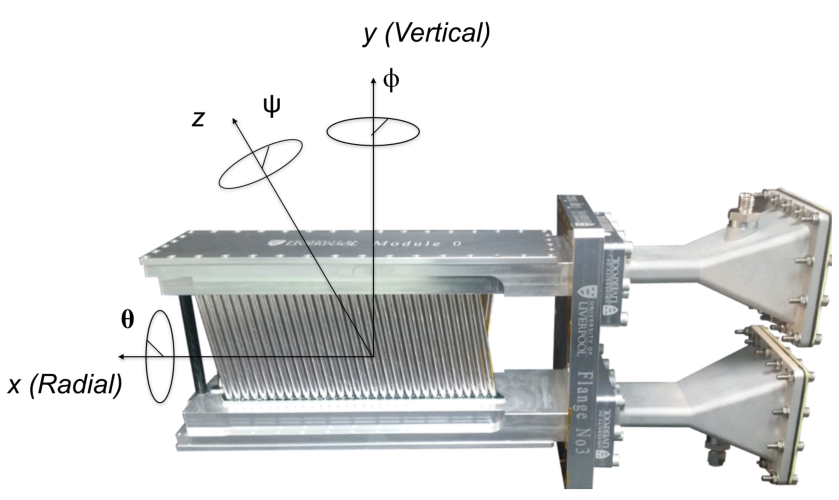


***Fig.2:** A single tracker module.*

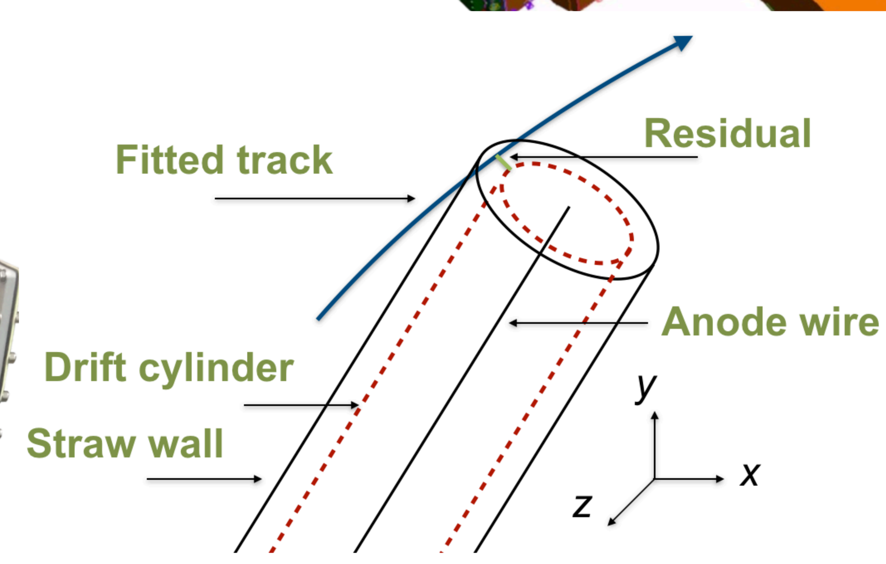


***Fig.3:** Definition of a residual in a straw.*

Motivation

The reconstructed beam distribution is affected by the absolute (external) alignment of a station, and the relative (internal) alignment of individual modules.

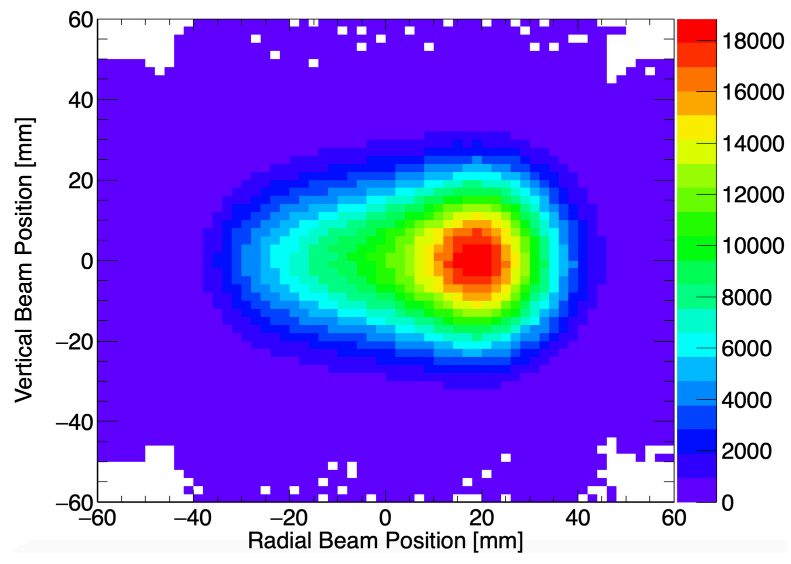


***Fig.4:** Muon beam profile as measured by the trackers.*

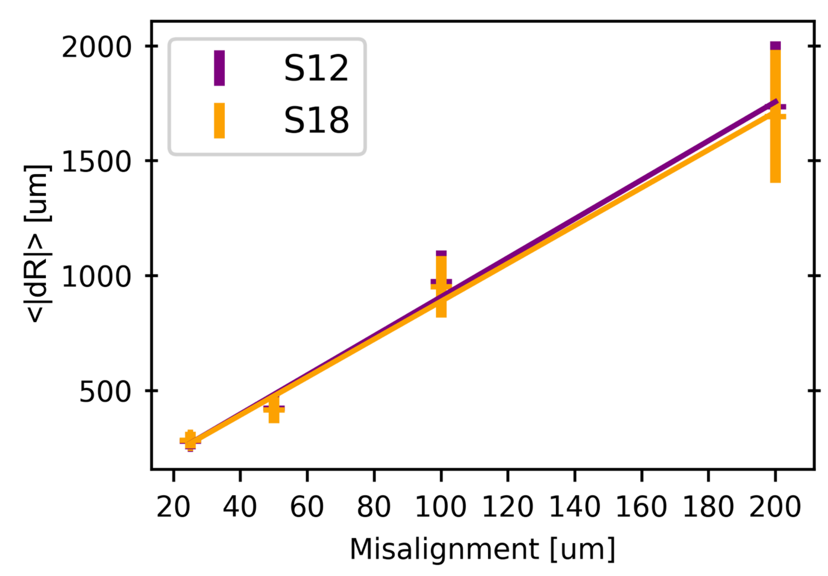


***Fig.5:** The response of the detector to an internal misalignment as a function of the change in the radial beam position.*

The alignment was implemented using the *Millepede II* [4] framework, which is a least squares fit solver that minimises the

$$\chi^2(\boldsymbol{a},\boldsymbol{b}) = \sum_{j}^{tracks}\sum_{i}^{hits}\frac{\left(r_{i,j}(\boldsymbol{a},\boldsymbol{b}_j)\right)^2}{(\sigma^{\text{det}})^2}, \quad (1)$$

where σ^{det} is the detector resolution and r is the residual, which is parameterised in terms of the alignment parameters (***a***) and track parameters (**b**).

Alignment Verification in Simulation

Simulation was used to test the alignment performance by comparison of the truth (input) misalignment with the alignment results from the *Millepede II.*

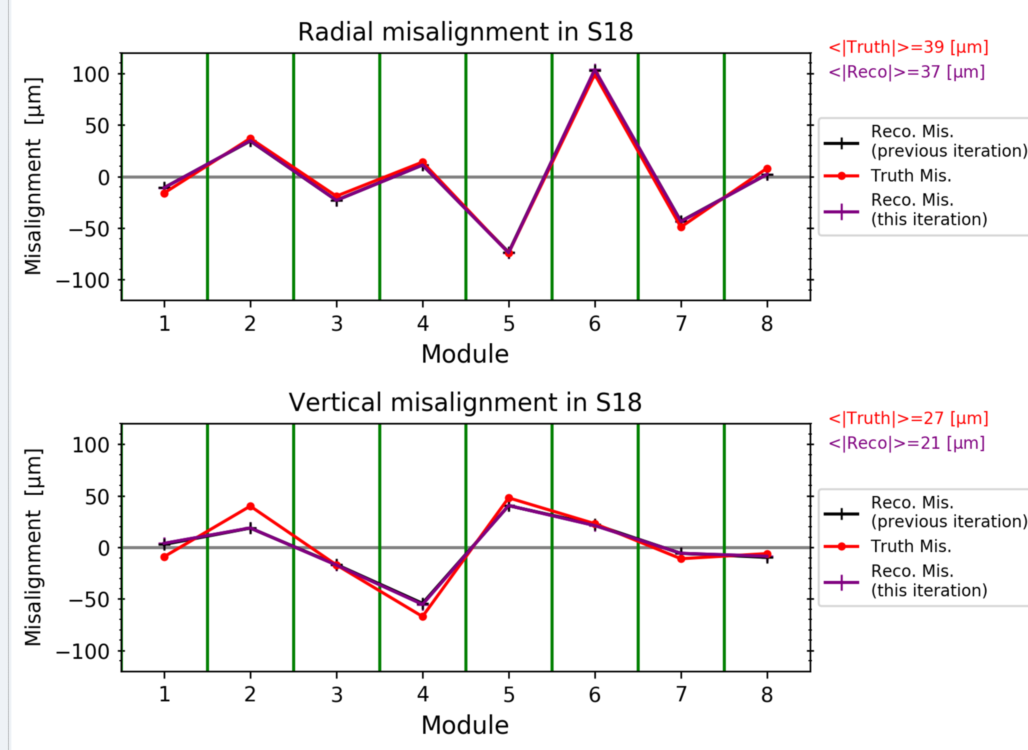


***Fig.6:** Simulation results with O(10^5 tracks) after 3 iterations. The truth misalignment is shown in red and the reconstructed misalignment in purple. Alignment convergence is reached within 2 μm and 10 μm radially and vertically, respectively.*

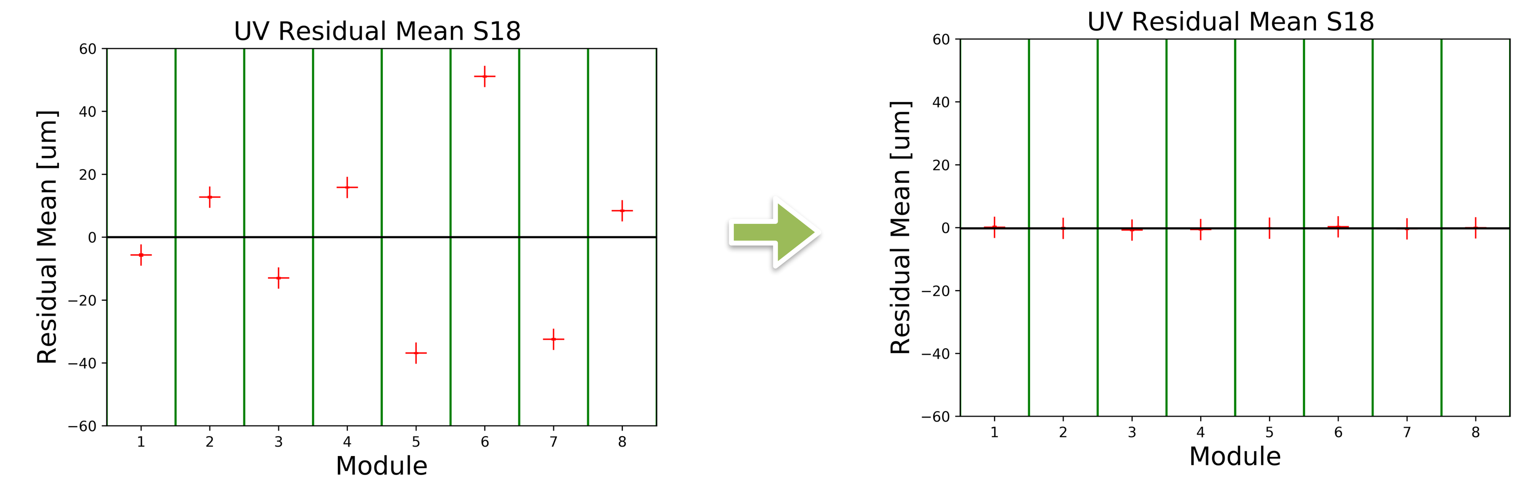


***Fig.7:** The mean value of the residual in one of the eight modules in a station before (left) and after (right) alignment with simulation.*

Alignment Results with Data

Preliminary alignment results were obtained with data from a single run (1 hour) with $O(10^5$ tracks). Alignment stability is reached after 3 iterations. For station 18, the absolute mean value of the recovered misalignment per module is 31 μm and 82 μm, radially and vertically respectively.

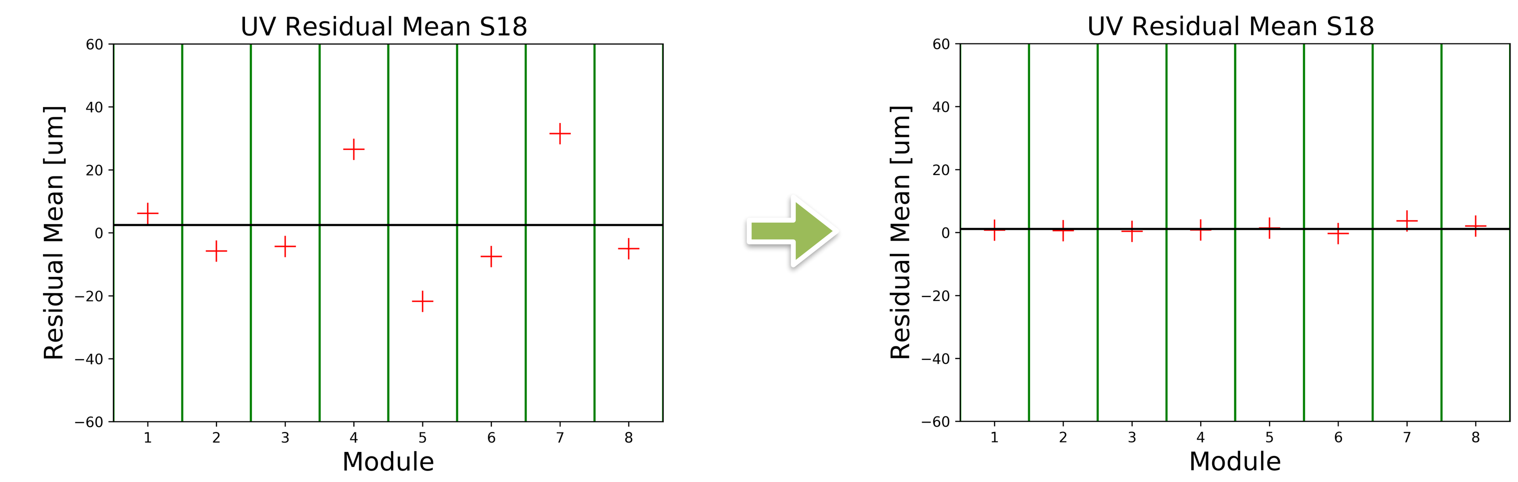


***Fig.8:** The mean value of the residual in one of the eight modules in a station before (left) and after (right) alignment with data.*

The number of reconstructed tracks has increased by 6% due to the position calibration from the alignment.

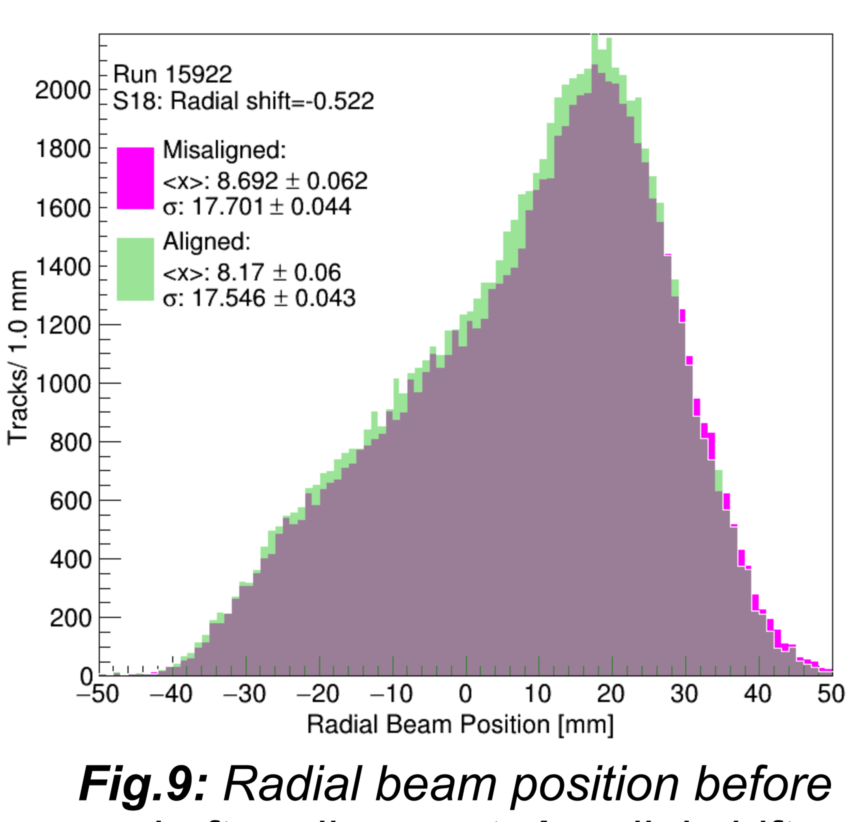


***Fig.9:** Radial beam position before and after alignment. A radial shift towards the centre of 522 μm was achieved.*

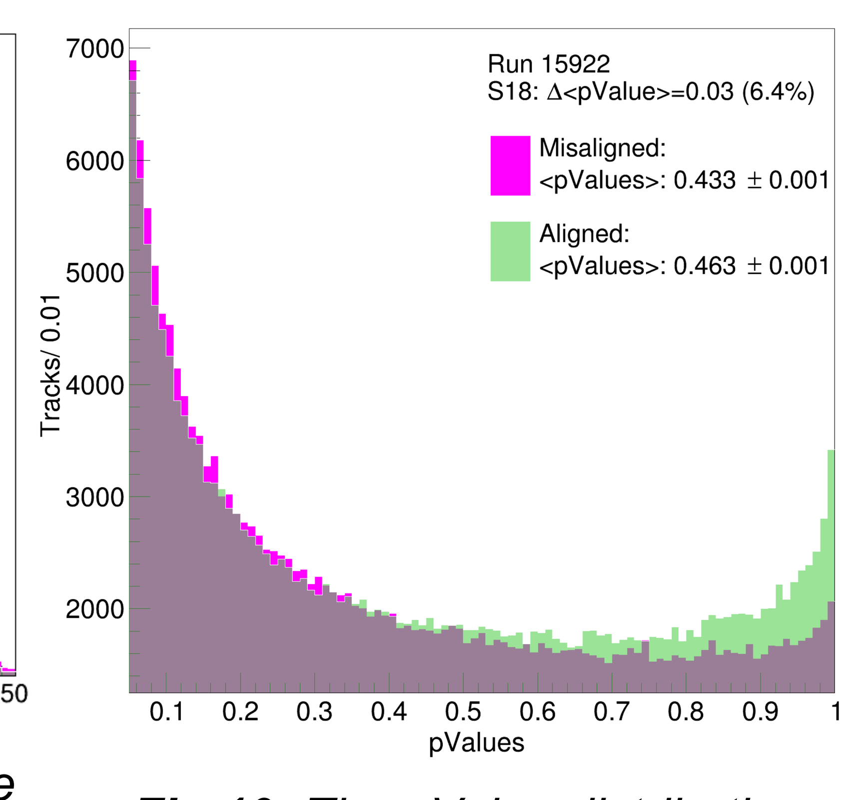


***Fig.10:** The pValue distribution before and after alignment.*

References:

[1] J. Grange et al., Muon (g-2) Technical Design Report, arXiv:1501.06858 (2015).

[2] T. Stuttard, PhD thesis, University College London (2017).

[3] S. Charity, PhD thesis, University of Liverpool (2018).

[4] V. Blobel, Nucl. Instrum. Methods A **5**, 556 (2006).

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