**Alignment methods for the Heavy Flavor Tracker (HFT) of the STAR experiment at RHIC**


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**Abstract**

We present an overview of three alignment procedures developed for the Heavy Flavor Tracker (HFT) of the STAR experiment at RHIC. The three methods are iterative minimization techniques and use as input the hit residual information from primary tracks reconstructed by the STAR TPC. One relies on a factorization of the alignment steps and uses histogramming techniques to improve the robustness of the minimization, while the other two use minimization algorithms applied to 2 track SDCA or residual $\chi^2$ distribution, a technique developed for the CMS detector[2]. The methods’ performance was extensively tested using simulations with mis-alignments. Here we present the basic elements of the methods, their estimated performance characteristics and also their application to data collected from a PXL prototype beam test in 2013 and cosmic data taking ahead of 2014 RHIC run.

**Introduction: the physics of HFT**

The studies of high-energy collisions at RHIC give insights about the nuclear matter at extreme temperatures and energy densities and describe the so-called Quark-Gluon Plasma. Investigation of particles produced during the initial phase of the collision (where hard interactions of incoming partons occurs) will then probe this state of matter [1,3].

Heavy quarks:
- Produced at the early stages of the collision through gluon fusion and the associated process.
- Not affected by the chiral symmetry breaking.
- Study of their energy loss through the medium as well as their collective flow during the initial phase of the collision (where hard interactions of incoming partons occurs)

To reach this goal, the STAR collaboration has installed a micro-vortex detector composed by:
- The existing SSD: a single layer of silicon strip detector located at a radius of 22 cm from the beam axis.
- PXL detector: Two layers at 2.5m and 8 cm from the beam axis of 18.4 cm x 18.4 cm Multilayer Active Pixel Sensors (MAPS) developed at Stanford by Marc Winter’s CMOS group with IPPC[3].
- IST: The Intermediate silicon tracker, a layer of single sided ladders. It is composed of 24 liquid cooled silicon strip detectors with associated hits in STAR, their positions in the global coordinate system must be known.
- The transformation from local to global coordinates is done in terms of a series of matrix multiplications using class TGeoHMatrix.

Alignment procedures and preliminary tests

To fully exploit the performance of PXL detector and the whole HFT detector, it is essential to characterize the geometrical placement of the different elements with as high precision as possible. The goal of alignment is to calculate a set of correction parameters that can be introduced to refine the geometry of a given element at any point in the full local to global transformation.

Alignment procedures were developed to refine and correct the geometries during commissioning. All three procedures are iterative minimization techniques using as input the hit residual information obtained from tracks:

**DCA Minimization**:
- Zero field cosmic data used for procedure are reconstructed as separate tracks in STAR.
- Tracks are projected from one side of PXL to the opposite.
- Several iterations using different minimization methods (SNRU

**PXL and IST alignment**

The alignment procedures were applied to correct geometry tables at several stages of full local to global transformation. Overall alignment strategy is to first align PXL detector and then align IST and SSD relative to PXL, and finally place the whole HFT within the TPC and STAR magnet.

**PXL Relative alignment**:
- Zero field cosmic data, obtained from runs during January and February 2014 were used for PXL relative alignment.
- Two hits on separate layers of a single sector of PXL were used to define tracks and project to the opposite side of the detector. Residuals were used for relative alignment between both PXL halves and then sectors.
- Results obtained both for half and full sector to sector alignments obtained through different procedures were all consistent to within tens of microns and less than a mrad and corroborated using histogramming method.

**Histogramming technique**:
- t-distribution fitting of alignment parameters with respect to the corresponding derivative matrix after minimizing background to give most likely deviations
- By straight line fitting, the slope and intercept give rotation or shift misalignment in global or local coordinates
- Relies on factorization of alignment steps but is more robust than other methods.

Three sectors of the PXL subsystem were tested in beam conditions during the RHIC run in 2013. Among the goals of the engineering run was the developing and testing of alignment procedures.

The $\chi^2$ and histogramming methods were tested in simulations using a series of blind tests where misalignments were introduced in the geometry and primary tracks from TPC alone were used as input.

Alignment was obtained with precision of the order of 20 microns and half a mrad.

Both procedures were also applied to the data obtained from special low luminosity runs with similar results.

**Alignment procedures**

Alignment procedures for the Heavy Flavor Tracker (HFT) of the STAR experiment at RHIC[1] use the following HITs:
- Two hits on separate layers of a single sector of PXL were used to define tracks and project to the opposite side of the detector. Residuals were used for relative alignment between both PXL halves and then sectors.
- Results obtained both for half and full sector to sector alignments obtained through different procedures were all consistent to within tens of microns and less than a mrad and corroborated using histogramming method.

**Alignment procedures**

Alignment procedures are focused on finding any corrections required to position IST relative to PXL.
- Using zero field cosmic data, straight line tracks with 2 or more hits in different layers of a single sector of PXL are projected outwards towards IST and the geometry tables for individual ladders were corrected.
- Once IST is aligned to PXL, cosmic tracks from the Time Projection Chamber (TPC) with field on were matched to hits in PXL and IST and used to align the whole of HFT with respect to TPC.

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**Summary**

- The HFT has been installed and taking data for 200 GeV Au+Au heavy ion collision.
- To fully take advantage of the intrinsically high resolution of the detector, it is necessary to accurately align the different subassemblies.
- Three alignment procedures were tested in simulations and used in real data taking.
- Preliminary pointing resolution is within design goals.