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

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RHIC relativistic heavy ion collider

Abstract

We present an overview of three alignment procedures developed for the Heavy Flavor Tracker[1] (HFT), the new silicon vertex detector of 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 either to 2 track 3D DCA or residual χ^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].

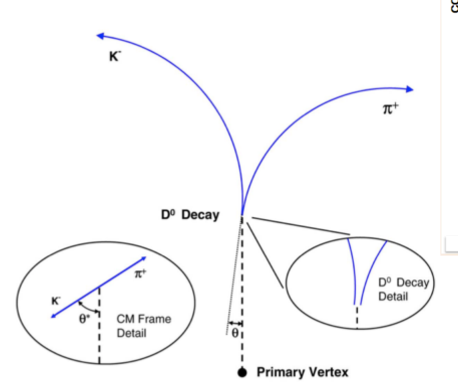
Heavy quarks :

- Produced at the early stages of the collision through gluon fusion and q-qbar annihilation.
- Not affected by the chiral symmetry breaking.
- Study of their energy loss through the medium as well as their collective flow.

$\Rightarrow$ sensitive probe to test medium characteristics (thermalization).

- HFT designed to detect heavy flavor through direct topological reconstruction of displaced vertices to greatly reduce the combinatorial background $\Rightarrow$ need track pointing resolution of ~60μm

Figure 1: Illustration of D^0 production and subsequent decay at a secondary (displaced) vertex.



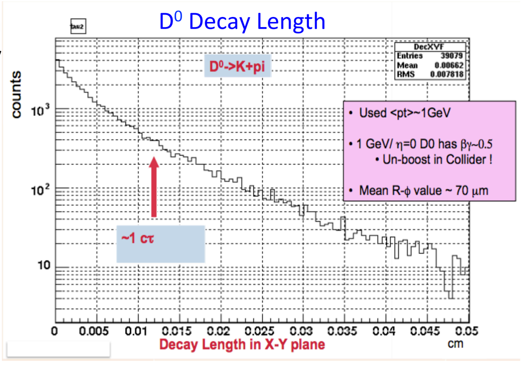


Figure 2: D^0 decay length in XY plane, Average value of 70μm sets requirements for HFT system.

• D^0	$\rightarrow K^- \pi^+$	BR = 3.83 %	$c\tau$ ~ 120 µm
• Λ_c^+	$\rightarrow p K^- \pi^+$	BR = 5.0 %	$c\tau$ ~ 60 µm
• B mesons	$\rightarrow J/\psi + X$ or $e + X$		$c\tau$ ~ 500 µm

Technical design and geometry

To reach this goal, the STAR collaboration has installed a micro-vertex detector composed by :

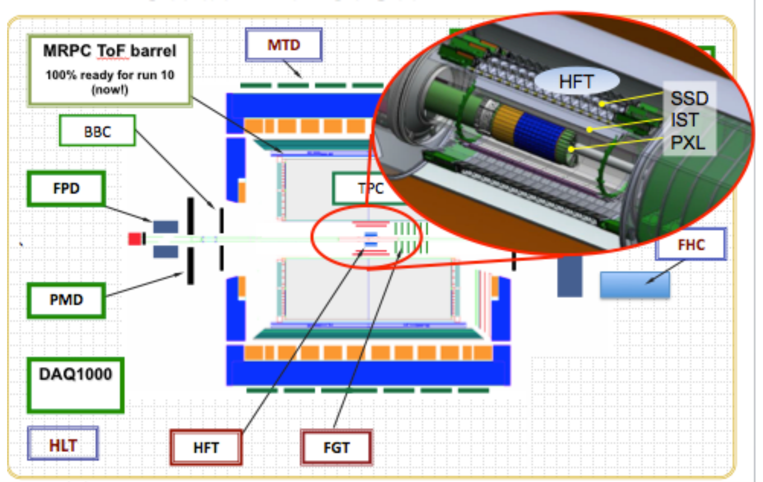


Figure 3: (left) Top view of STAR detector ; (right) oblique view of the HFT showing the beam pipe surrounded by the 4 layers of silicon detectors.

- 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 2.5cm and 8 cm from the beam axis of 18.4 μm x 18.4 μm Monolithic Active Pixel Sensors (MAPS) developed at Starsburg by Marc Winter's CMOS group with IPHC[3].

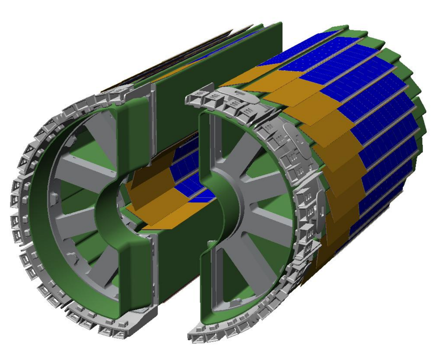


Figure 4: Configuration of the 2 PXL layers ; (bottom)

- IST : The Intermediate silicon tracker, a layer of single sided strips : it guides tracks from the SSD through PXL detector. It is composed of 24 liquid cooled ladders equipped with 6 silicon strip-pad sensors

- To use reconstructed 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:

$$\begin{pmatrix} x_G \\ y_G \\ z_G \\ 1 \end{pmatrix} = \begin{bmatrix} \hat{d}_x & \hat{n}_x & \hat{t}_x & d_x \\ \hat{d}_y & \hat{n}_y & \hat{t}_y & d_y \\ \hat{d}_z & \hat{n}_z & \hat{t}_z & d_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{pmatrix} x_L \\ y_L \\ z_L \\ 1 \end{pmatrix}$$

$$x_G^i = R \cdot x_L^i + T^i$$

$$x_G = \left(\hat{d}_x \cdot x_L + \hat{n}_x \cdot y_L + \hat{t}_x \cdot z_L\right) + d_x$$

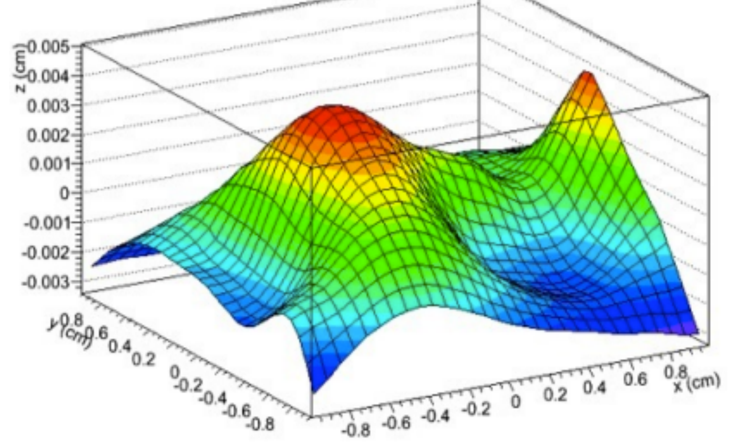


Figure 5: Thin plate spline method applied to correct for deviations from a plane in PXL ladders. Survey work done at Lawrence Berkeley National Lab.

- Thorough survey of detectors and mounting structure was used for initial geometry. Alignment was then applied to refine these tables
- Full transformation is obtained by multiplying successive matrices, for example for PXL the whole chain is as follows

PXLInGlobal=Tpc2Magnet*IDS2Tpc*PXL2IDS*DShell2PXL*Sector2DShell*(PxlInSector)

PxlInSector=Ladder2Sector*Sensor2Ladder*Pxl2Sensor

Alignment procedures and preliminary tests

To fully exploit the high resolution 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 is possible.
The goal of alignment is to calculate a set of six correction parameters that can be introduced to refine the geometry of a given element at any point in the full local to global transformation.
With this in mind three different alignment procedures were developed to refine and corroborate the geometries during commissioning. All three procedures are iterative minimization techniques using as input the hit residuals obtained from tracks:

DCA Minimization:
- Zero field cosmic data used for procedure are reconstructed as 2 separate tracks in STAR.
- Tracks are projected from one side of PXL to the opposite. Procedure minimizes hit-track 3D DCA .
- Several iterations using different minimization methods (GNU GSL minimizer).

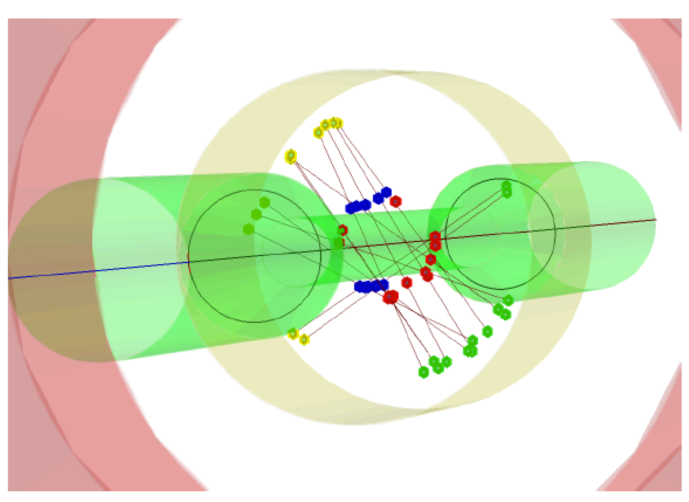


Figure 6: 3D display of matched hits used in DCA minimization in zero field alignment. Straight lines used with 4 PXL hits: 2 outer (green & yellow) 2 inner (red & blue).

Hits and Impact points (HIP) minimization:
- Follows procedure developed for CMS detector[2], algorithm is designed to align co-moving objects, e.g. sectors.
- Uses as input the hit residuals, i.e. the difference between hits and track projection.
- Generalized χ^2 minimization in terms of 6 parameters per sensor.

Histogramming technique:
- Y Slice fitting of misalignment 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.

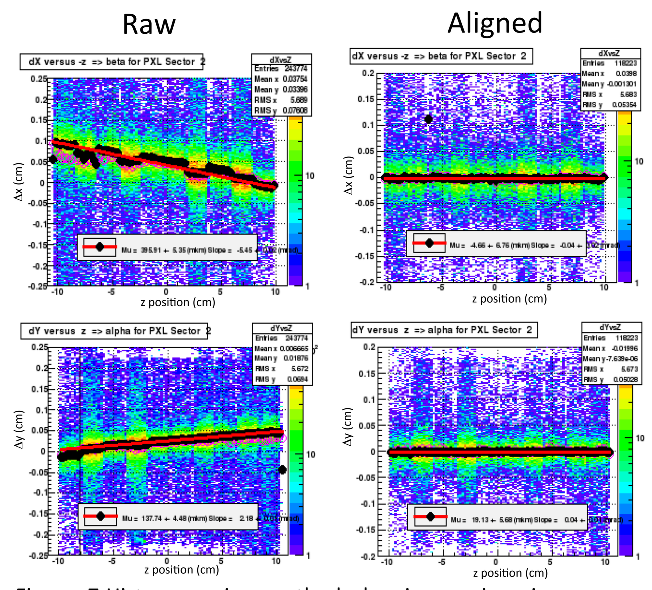


Figure 7: Histogramming method showing engineering run p-p 500GeV/c data before (left) and after (right) alignment.

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 χ^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.
Misalignment were obtained with precisions 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.

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 to half and 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.

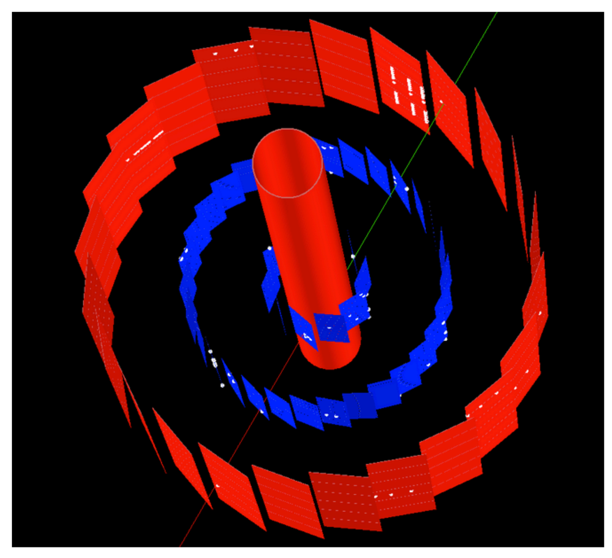
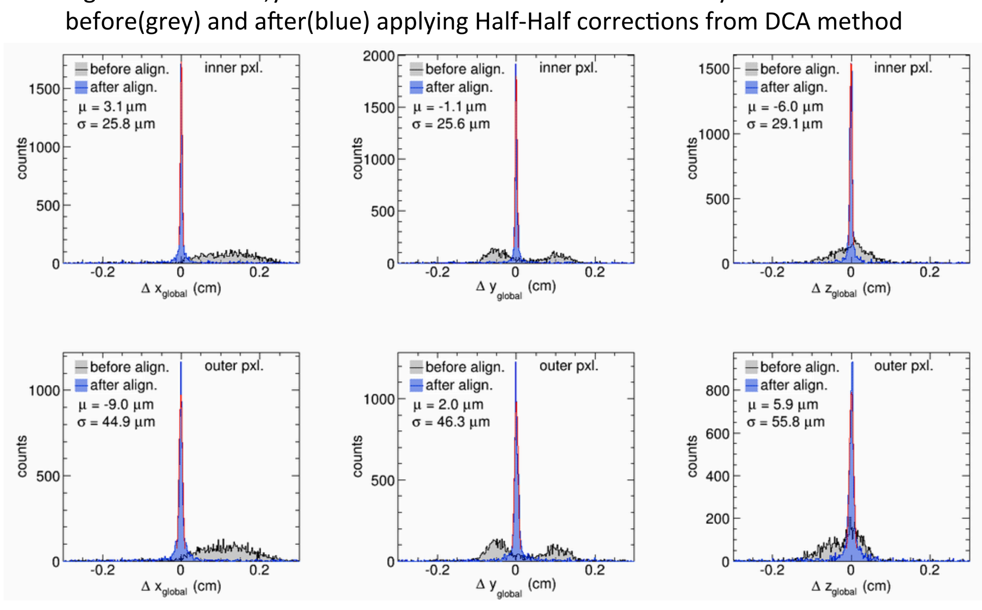


Figure 8: Event display showing a single cosmic track with associated hits in 2 sectors of PXL and 2 IST ladders.

Figure 9: Global x,y and z residuals for inner and outer layer of PXL detector before(grey) and after(blue) applying Half-Half corrections from DCA method



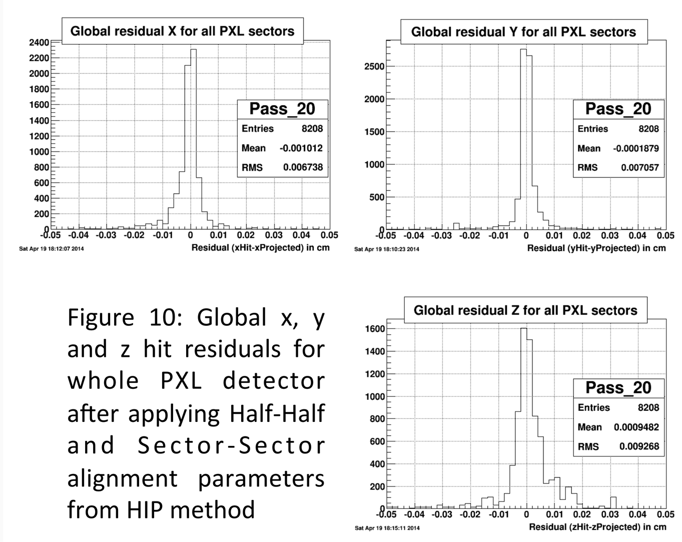


Figure 10: Global x, y and z hit residuals for whole PXL detector after applying Half-Half and Sector-Sector alignment parameters from HIP method

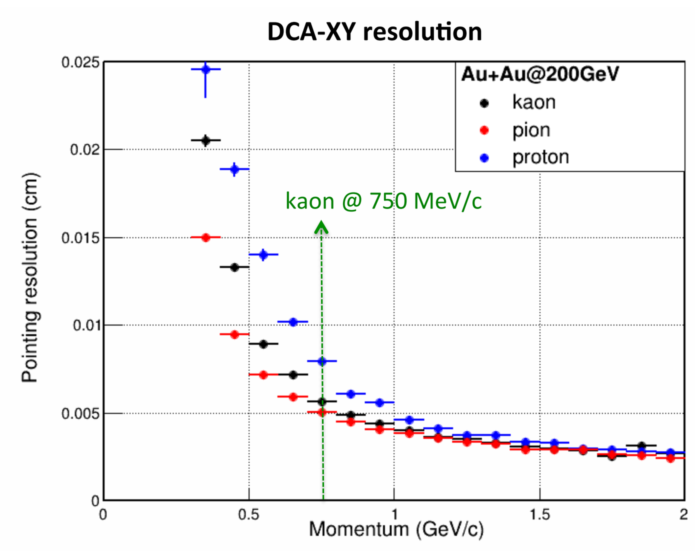


Figure 11: Track DCA-XY resolution with preliminary alignment using IST and PXL. Below requirement of 60μm for 750 MeV/c kaons. Time Of Flight and TPC used for particucle identification.

Once PXL is aligned the 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.
- Preliminary estimates on HFT performance after alignment are within physics and design goals. Further refinement is ongoing.

Summary

- The HFT has been installed in STAR 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.

[1]:HFT proposal: http://rnc.lbl.gov/~wieman/hft_final_submission_version.pdf
[2]:V. Karimaki et. al., CMS note 2006/018, T*he HIP algorithm for track based alignment and its application to the CMS detector*.
[3]:L. Greiner et al., Nuclear Instruments and Methods in Physics research section A, vol. 650 issue 1, *A MAPS based vertex detector for the STAR experiment at RHIC*
[4] Y.V. Fisyak et al., J. Phys. Conf. Series, 119(2008) 032017, Overview of the inner silicon detector alignment procedure and techniques in RHIC/STAR experiment

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