# Open charm measurements with an HFT in STAR

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## Charm at RHIC

The goals of RHIC are identification and study of the properties of matter with partonic degrees of freedom. Previous studies have identified partonic collectivity, but have not yet demonstrated thermalization of the created matter. The study of heavy quark collectivity may allow us to address this issue.

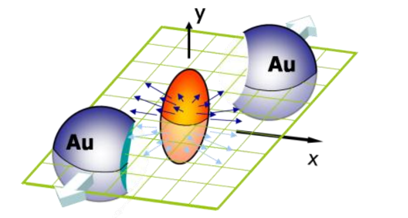

**Figure 1:** Illustration of non-central heavy ion collision. The spatial asymmetry of the interaction region creates an asymmetry in particle momentum distributions.

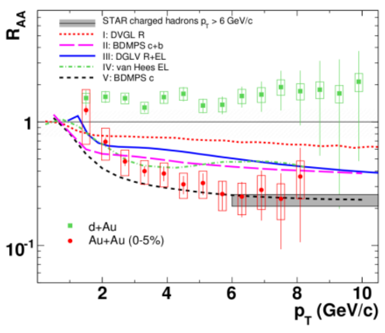

**Figure 2:** Nuclear modification factor of non-photonic electrons in central Au+Au collisions shows similar suppression as hadrons [1]. Knowledge of relative contribution of charm and bottom is crucial to interpret the results.

Charm quarks:

- produced early in the collision
- derive their mass from the Higgs field and stay massive even during chiral symmetry restoration
- their collectivity tests medium thermalization
- charm quark energy loss directly probes QCD medium at high temperature

**Need for direct reconstruction of open charm hadrons.**

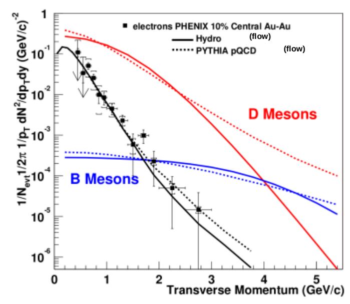

**Figure 3:** Extreme collective behavior scenarios (Pythia, hydro). Compared to difference in D and B meson spectra, electron spectrum provides less sensitivity to dynamics [2,3].

To address these challenges, STAR needs to upgrade its tracking system. A proposed micro vertex detector , the Heavy Flavor Tracker (HFT, [4]), will reconstruct displaced decay vertices of open charm hadrons.

## Heavy Flavor Tracker design

- 2 layers of PIXEL detector + 1 layer of IST (Intermediate Silicon Tracker) + 1 layer SSD (Silicon Strip Detector)
- **PIXEL**: measurement of open charm hadrons down to $p_T$ = 0.5 GeV/c requires low material budget – MAPS (Monolithic Active Pixel Sensors)
- **IST**: fast detector between PIXEL and the existing SSD detector to cope with high luminosity at RHIC-II and long integration time of PIXEL
- design was improved for better hit matching and lower mass budget, not fully simulated yet

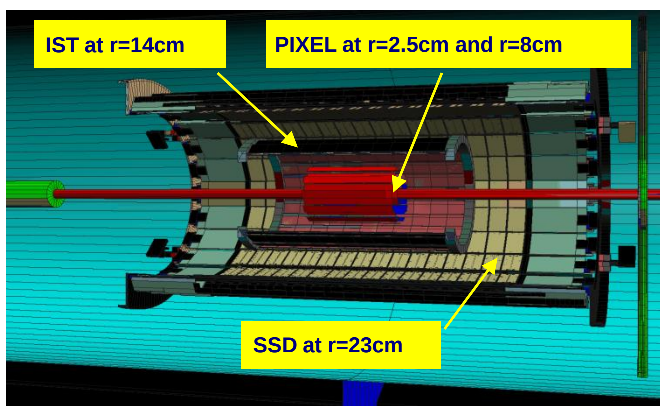


**Figure 4:** Subsystems of the HFT (PIXEL, IST - current design), with the existing SSD detector.

| | current design | | simulated design | |
|---|---|---|---|---|
| layer | r (cm) | Hit resolution ($r$-$\varphi$ x $z$) ($\mu m$ x $\mu m$) | r (cm) | Hit resolution ($r$-$\varphi$ x $z$) ($\mu m$ x $\mu m$) |
| SSD | 23 | 30 x 699 | 23 | 30 x 699 |
| IST2-B | - | - | 17 | 17 x 12000 |
| IST2-A | - | - | 17 | 12000 x 17 |
| IST1 | 14 | 115 x 2900 | 12 | 17 x 5500 |
| PIXEL2 | 8 | 9 x 9 | 7 | 9 x 9 |
| PIXEL1 | 2.5 | 9 x 9 | 2.5 | 9 x 9 |

**Table 1:** Hit position resolution of SSD + HFT layers for the two design versions. IST2 (simulated design) has two layers (A,B) with crossed strips.

Support structure of the PIXEL detector:

- low mass budget
- repeatable positioning with ~ 10 µm accuracy

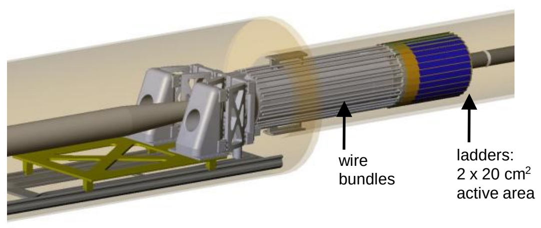


**Figure 5:** Design of PIXEL detector support structure, with ladders and wire bundles.

## PIXEL detector development

MAPS chip prototypes:

- 30 µm pixel pitch, ~ 15 µm thick active region
- modified diode design for improved radiation tolerance successfully tested (MimoSTAR2)
- large ( ~ 1 x 2 cm$^2$) chip prototype MimoSTAR3 currently under testing
- analog readout
- 2 ms integration time

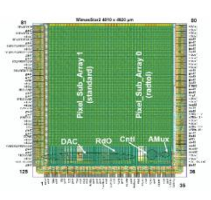

**Figure 6:** MimoSTAR2 chip, 128 x 128 pixels, 4 x 4 mm$^2$.

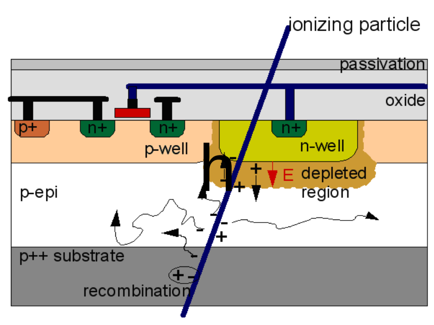


**Figure 7:** MAPS principle of operation: electrons created in the epitaxial layer thermally diffuse toward low potential n-well region.

Development and deployment plan

Phase 1 sensors:

- large area chips (2 x 2 cm$^2$)
- thinned to 50 µm, 0.28% $X_0$ including support
- digital readout and on-chip CDS
- 640 µs integration time
- build detector patch (~ 30% of full acceptance)

Ultimate sensors:

- on-chip cluster finding (data sparsification)
- < 200 µs integration time

MAPS telescope prototype test [5]

- telescope with 3 MimoSTAR2 chips placed inside STAR during 2007 Au+Au 200 GeV RHIC run
- located 150 cm from the interaction point, 5 cm below the beam pipe
- chip readout and integration with STAR trigger successfully tested

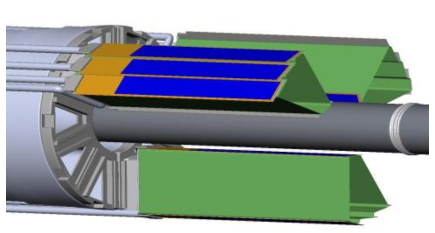

**Figure 8:** Detail of PIXEL detector patch design.

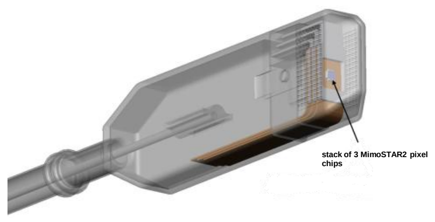

**Figure 9:** Prototype telescope with 3 MimoSTAR2 sensors.

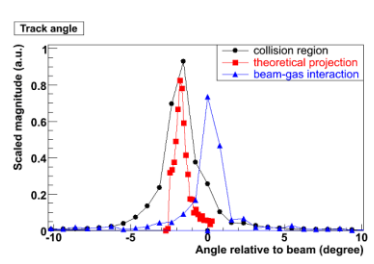

**Figure 10:** Tracks from the interaction diamond, registered by the telescope, increased width due to MCS in the beam pipe. Beam background observed.

## Tracking performance

- Hand calculations & simulation with full STAR geometry and tracking
- assuming RHIC-II luminosity: 80 kHz minimum bias collision rate
- $D^0$ embedded into HIJING central Au+Au events
- investigation of pile-up effects in PIXEL due to 200 µs integration time and high luminosity – addition of pseudo-random hits to PIXEL layers
- no pile-up in IST, SSD (fast detectors)

| | simulated design | |
|---|---|---|
| layer | central collision hit density (cm$^{-2}$) | RHIC-II pile-up hit density (cm$^{-2}$) |
| SSD | 0.21 | - |
| IST2-B | 0.38 | - |
| IST2-A | 0.38 | - |
| IST1 | 0.77 | - |
| PIXEL2 | 2.3 | 6.0 |
| PIXEL1 | 17.8 | 43 |

**Table 2:** Estimated hit densities (cm$^{-2}$) at detector center ($|\eta|$ = 0). Pile-up for RHIC-II luminosity is calculated assuming primary vertex diamond $\sigma_{PV}$ = 15 cm.

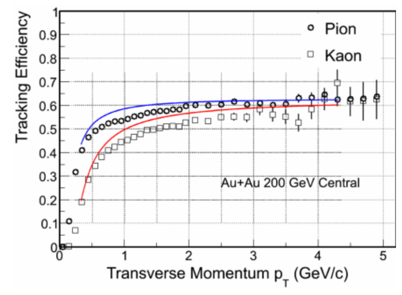

**Figure 11:** Reconstruction probability of pion and kaon tracks in $|\eta|$ < 1 with correct hit association in both PIXEL layers.

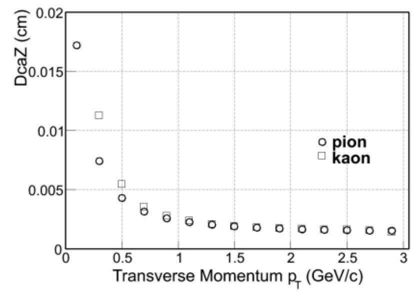

**Figure 12:** Pointing resolution in z-direction to event primary vertex for tracks with hits in both PIXEL layers.

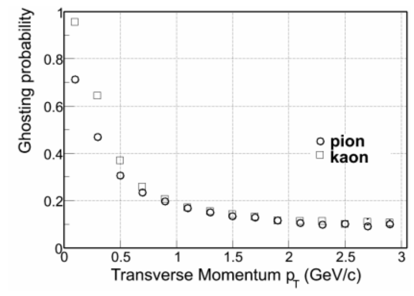

**Figure 13:** Probability of wrong hit association (ghosting) in PIXEL layers. Highest contribution comes from pointing to PIXEL2 layer.

## $D^0$ reconstruction

- $D^0 \to K^- \pi^+$, B.R. 3.8%; cτ = 123 µm
- decay daughters reconstructed requiring hits in both PIXEL layers

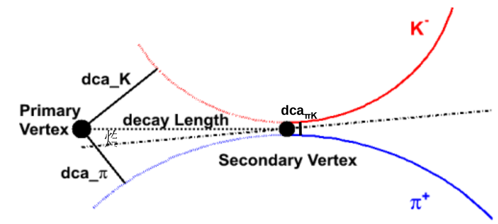


**Figure 14:** $D^0 \to K^- \pi^+$ decay topology.

Assumptions:

- perfect K-π separation for tracks with $p_T$ < 1.6 GeV/c (Time Of Flight detector)
- no PID for tracks with $p_T$ > 1.6 GeV/c
- $N_{bin}$ scaling for $D^0$ yields
- p+p $D^0$ yield: dN/dy = 0.002
- $D^0$ $p_T$ spectrum for central Au+Au: power-law, $\langle p_T \rangle$ = 1.0 GeV/c and n = 11

**$D^0$ reconstruction cuts:**

- $dca_{\pi K}$ < 100 µm
- dca_π, dca_K > 50 µm
- cos(θ) > 0.98
- 1.83 < $M_{inv}$(GeV/c$^2$) < 1.90

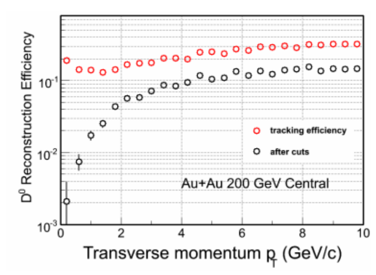

**Figure 16:** Efficiency to reconstruct $D^0$ decay daughters and $D^0$ (after applying cuts) for $D^0$ in $|\eta|$ < 1.

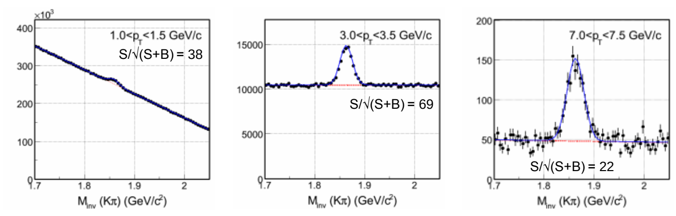

**Figure 15:** Estimated $M_{inv}$ distributions from 100M central Au+Au events. Entries per 5 MeV/c$^2$.

**Key measurements from 1 month of data taking at RHIC-II**

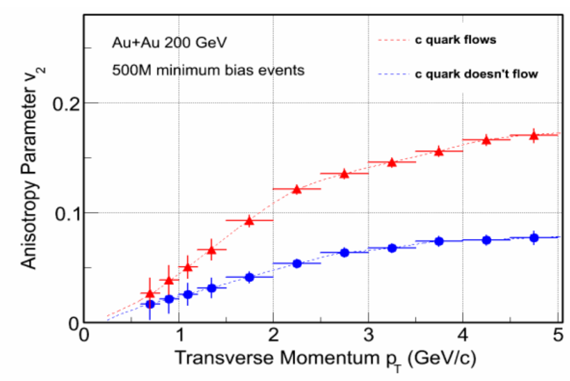

**Figure 17:** Two extreme scenarios for $D^0$ elliptic flow. Statistical errors correspond to 1 month of data taking.

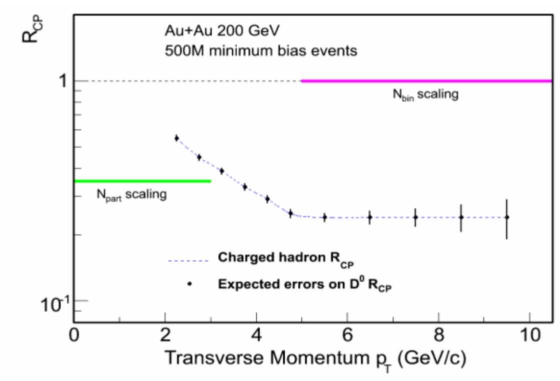

**Figure 18:** Estimated statistical errors of $R_{CP}$ measurement (corresponding to 1 month of data taking). Expected $D^0$ yield in peripheral collisions at high $p_T$ is scaled by $1/R_{CP}$ with respect to $N_{bin}$ scaling.

## HFT performance - high luminosity environment

Furthermore, we have studied $D^0$ reconstruction for different levels of pile-up hit densities in PIXEL detector.

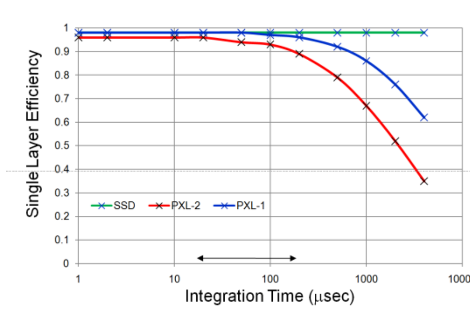

**Figure 19:** The performance of the intermediate tracking depends on the integration time of the PXL chip
P(good association) = 1/(1+S) if $S = 2\pi\, \sigma_x \sigma_y \rho$

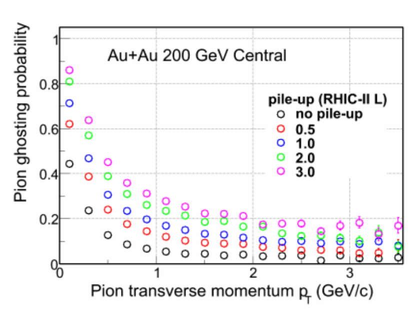

**Figure 20:** Probability of pion ghosting in PIXEL layers for different pile-up levels.

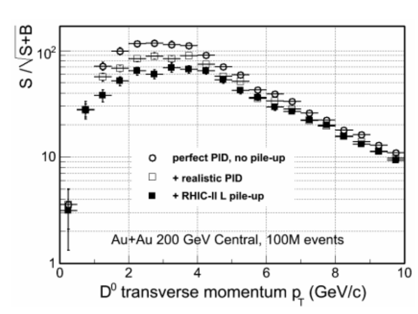

**Figure 21:** $D^0$ signal significance in central Au+Au events, under different assumptions.

## Conclusions

- The STAR HFT will perform topological reconstruction of open charm hadrons even in central Au+Au collisions at RHIC-II luminosities.
- $R_{CP}$ and $v_2$ measurements using 500M minimum bias events (one month of data) will provide strong constraints on theory.
- MAPS telescope prototype has been successfully tested in STAR environment during 2007 Au+Au RHIC run.

**With thanks to:**

E. Anderssen[7], J. Baudot[5], D. Beavis[1], M. Bystersky[4], R. Cendejas[2], C. Chasman[1], R. Debbe[1], X. Dong[7], L. Greiner[7], A. Hirsch[8], H. Huang[2], C. Hu-Guo[5], J. Joseph[3], J. Kapitan[4], D. Keane[3], J. Kelsey[6], V. Kushpil[4], J.H. Lee[1], M.J. Levine[1], S. Margetis[3], H.S. Matis[7], R. Milner[6], S. Morgan[7], M. Plesko[6], R. Redwine[6], H.G. Ritter[7], A. Rose[7], V. Rykov[3], S. Sakai[2], A. Shabetai[5], E. Sichtermann[7], F. Simon[6], R.P. Singh[7], B. Srivastava[8], T. Stezelberger[7], M. Sumbera[4], X. Sun[7], B. Surrow[6], M. Szelezniak[5], J.H. Thomas[7], V. Tram[7], G. Van Nieuwenhuizen[6], F. Videbaek[1], C. Vu[7], F. Wang[8], C. Whitten[2], H.H. Wieman[7], M. Winter[5], W. Xie[8], N. Xu[7], Z. Xu[1], W.M. Zhang[3]

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[5] M. A. Szelezniak *et al.*, Small-scale readout system prototype for the STAR PIXEL detector (IEEE NSS 2007 Conference Record Vol. 2 1474-1481 (2007), 10.1109/NSSMIC.2007.4437278).

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“Characterization of the QGP with Heavy Quarks”, Bad Honnef, 2008