Open charm measurement with HFT at 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.

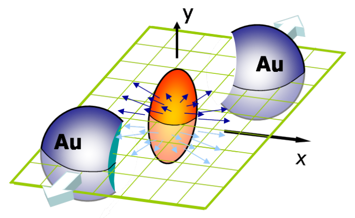

Figure 1: Illustration of non-central heavy ion collision. The spatial asymmetry of the interaction region creates an asymmetry in particle momentum distributions.

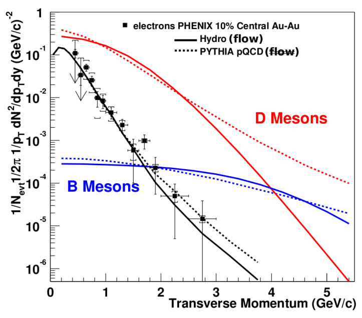

Figure 2: Extreme collective behavior scenarios (Pythia, hydro). Compared to difference in D and B meson spectra, electron spectrum provides less sensitivity to dynamics. Plot from [1], data from [2].

Charm quarks:
- produced early in the collision
- derive their mass from the Higgs field - 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.

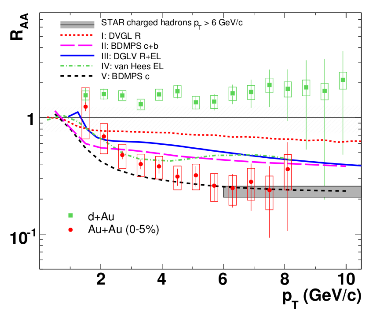

Figure 3: Nuclear modification factor of non-photonic electrons in central Au+Au collisions shows similar suppression as hadrons [3]. Relative contribution of charm and bottom is crucial to interpret the results.

To address these challenges, STAR needs to upgrade its tracking system. A proposed micro vertex detector - Heavy Flavor Tracker (HFT) - 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)
- **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

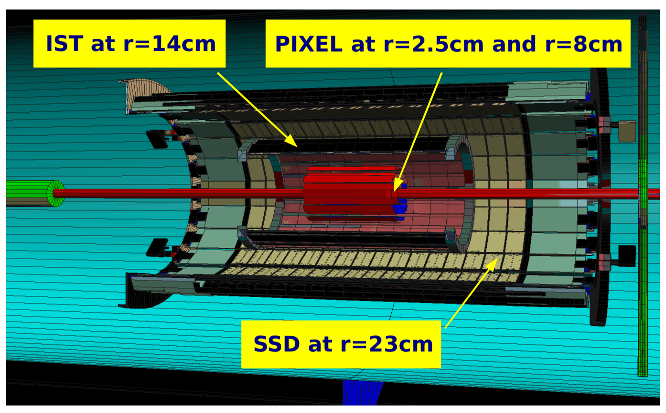

Figure 4: Subsystems of the HFT (PIXEL, IST - current design), with the existing SSD detector.

	current design		simulated design	
layer	r (cm)	Hit resolution (r-φ x z) (μm x μm)	r (cm)	Hit resolution (r-φ x z) (μm x μm)
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

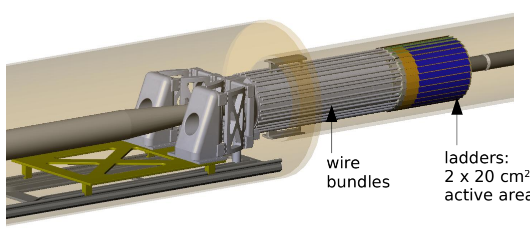

Figure 5: Design of PIXEL detector support structure, with ladders and wire bundles.

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 cm²) chip prototype MimoSTAR3 currently under testing
- analog readout
- 2 ms integration time

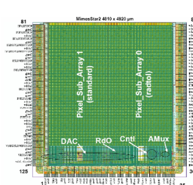

Figure 6: MimoSTAR2 chip, 128 x 128 pixels, 4 x 4 mm².

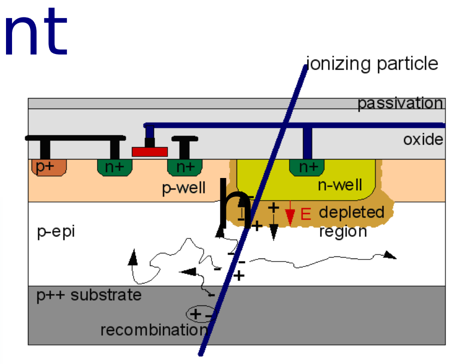

Figure 7: MAPS principle of operation: electrons created in the epitaxial layer thermally diffuse toward low potential n-well region.

Development and deployment plan

Phase 1 sensors:
- large area chips (2 x 2 cm²)
- 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
- 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

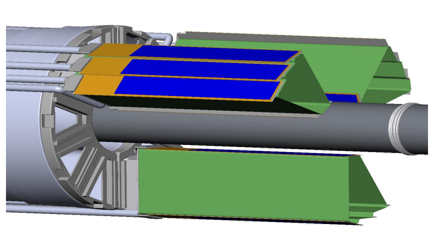

Figure 8: Detail of PIXEL detector patch design.

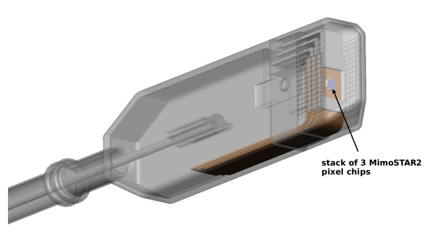

Figure 9: Prototype telescope with 3 MimoSTAR2 sensors.

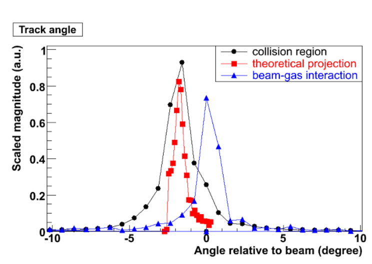

Figure 10: Tracks from the interaction diamond, registered by the telescope, increased width due to MCS in the beam pipe. Beam background observed.

Tracking performance

- 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.

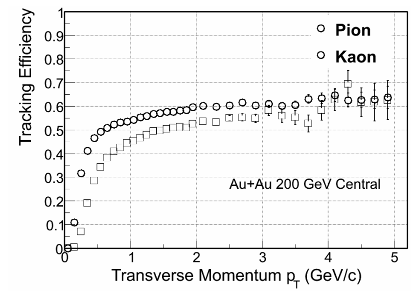

Figure 11: Reconstruction probability of pion and kaon tracks in $|\eta| < 1$ with correctly associated hits in both PIXEL layers.

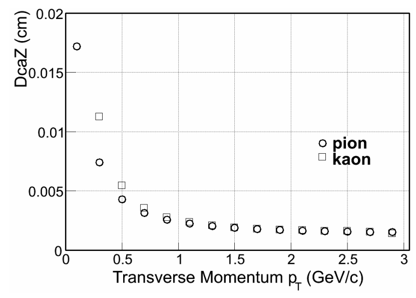

Figure 12: Pointing resolution in z-direction to event primary vertex for tracks with hits in both PIXEL layers.

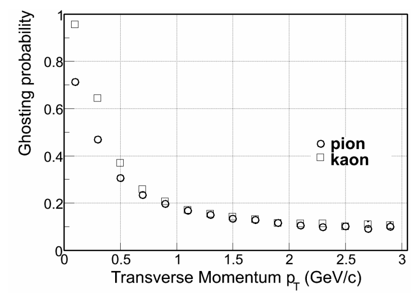

Figure 13: probability of wrong hit association (ghosting) in PIXEL layers. Highest contribution comes from pointing to PIXEL2 layer.

D^0 reconstruction

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

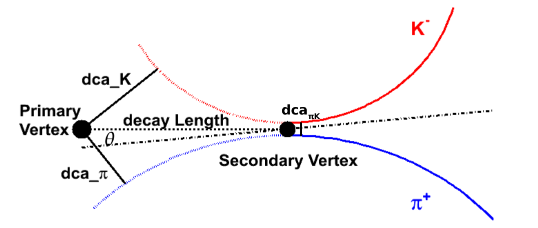

Figure 14: $D^0 \rightarrow K^- \pi^+$ decay topology.

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, $<p_T>$ = 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

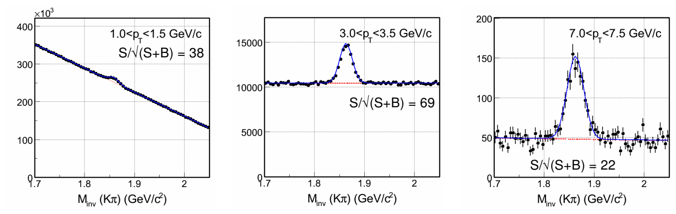

Figure 15: Estimated M_{inv} distributions from 100M central Au+Au events. Entries per 5 MeV/c².

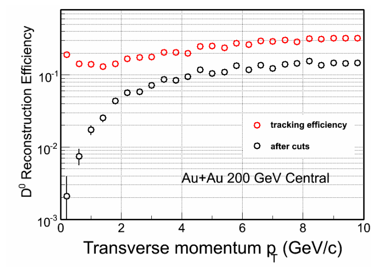

Figure 16: Efficiency to reconstruct D^0 decay daughters and D^0 (after applying cuts). For D^0 in $|\eta| < 1$.

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

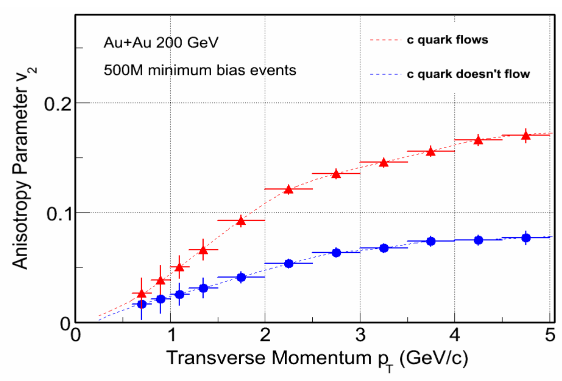

Figure 17: Two extreme scenarios for D^0 elliptic flow. Statistical errors correspond to 1 month of data taking.

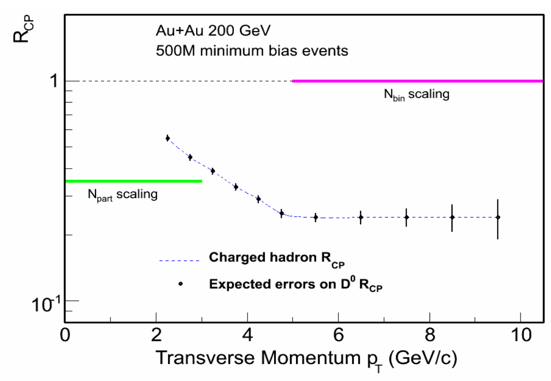

Figure 18: Estimated statistical errors of R_{CP} measurement (corresponding to 1 month of data taking). Expected D^0 yield in peripheral collisions at high p_T is scaled by $1/R_{CP}$ with respect to N_{bin} scaling.

HFT performance in high luminosity environment

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

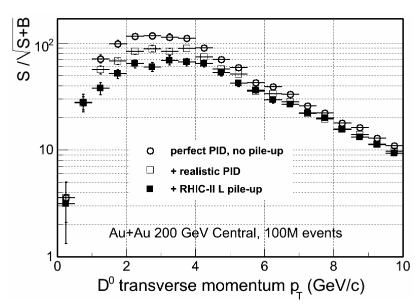

Figure 19: D^0 signal significance in central Au+Au events, under different assumptions.

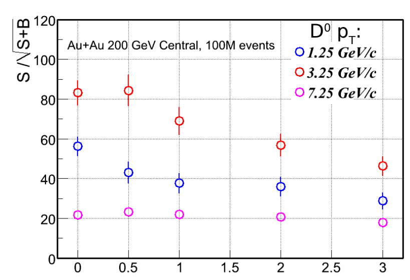

Figure 20: D^0 signal significance in three selected p_T bins, as a function of pile-up level (x-axis: 0 - no pile-up, 1 - RHIC-II luminosity).

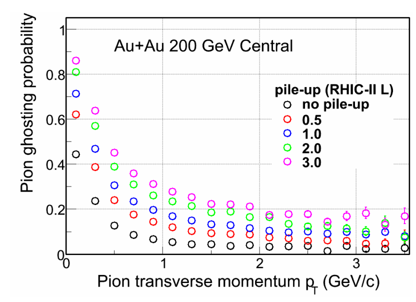

Figure 21: Probability of pion ghosting in PIXEL layers for different pile-up levels.

Conclusions

- 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 taking), will provide strong constraints on theory.
- MAPS telescope prototype has been successfully tested in STAR environment during 2007 Au+Au RHIC run.

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