STAR Heavy Flavor Tracker

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for the STAR Collaboration

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Outline

- Physics motivation
- Design
    - Heavy Flavor Tracker
    - PiXeL detector
    - Monolithic Active Pixel Sensors
- Status and performance
    - Status
    - Efficiency
    - Survey and alignment
    - Hit residual and track DCA
- Summary

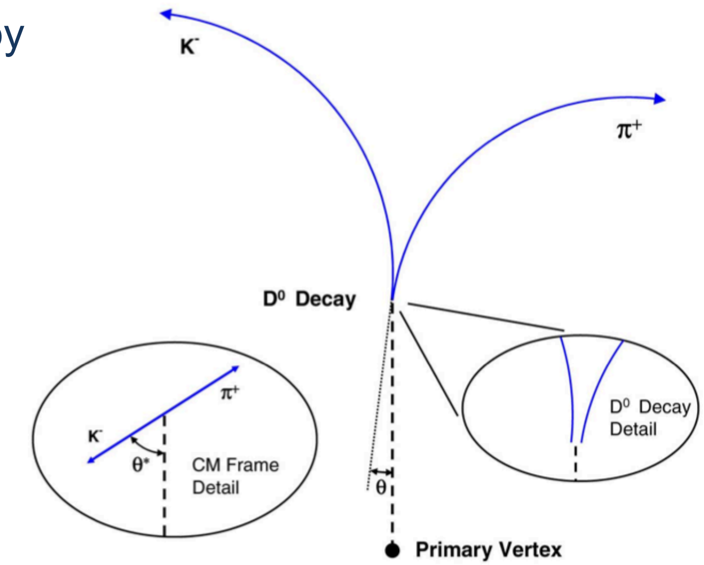
Physics Motivation

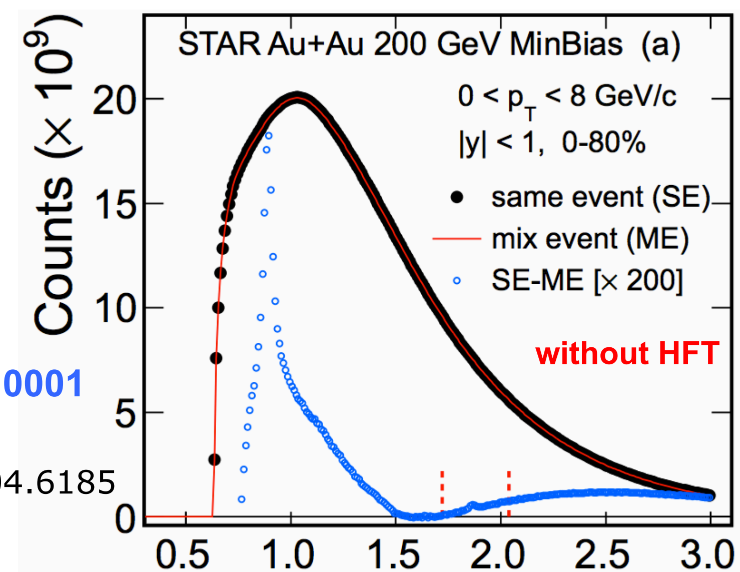
- Heavy flavor
  - $m_{b,c} >> T_C, \Lambda_{QCD}, m_{u,d,s}$
  - Produced early in initial hard scatterings
  - Total number conserved in system evolution at RHIC

  } Good probe to QGP
- However, it's also difficult to study heavy flavor quarks in experiments
  - Limited yield comparing with light flavor particles
  - Short lifetimes, large combinatorial background for direct reconstruction of open heavy flavor hadrons without displaced decay vertex reconstruction
  - Large kinematics smearing for studies with electrons from semi-leptonic decay
- A precision vertex detector will be an important tool to assess HF physics.

How Heavy Flavor Tracker Helps

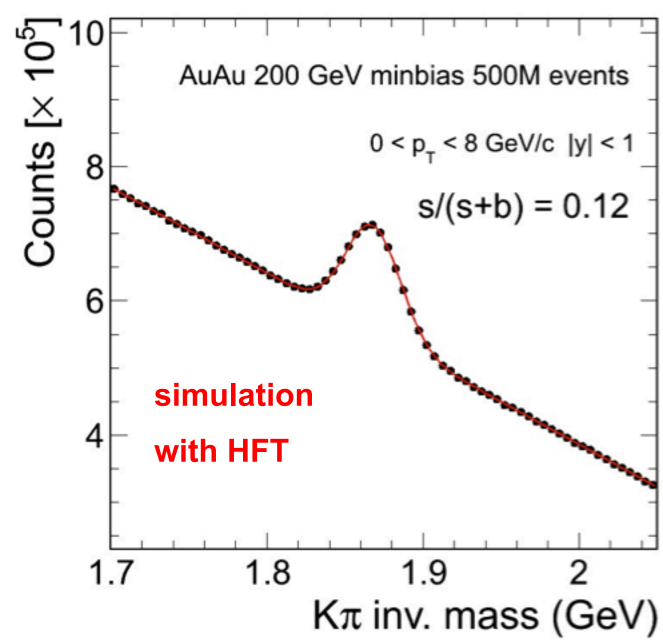
- HFT can be used to study heavy flavor production by reconstruction of displaced decay vertices
  - $D^0 \rightarrow K^- \pi^+$
    - BR = 3.83 %   cτ ~ 120 μm
  - $\Lambda_c^+ \rightarrow p K^- \pi^+$
    - BR = 5.0 %   cτ ~ 60 μm
  - B mesons → J/ψ + X or e + X
    - cτ ~ 500 μm



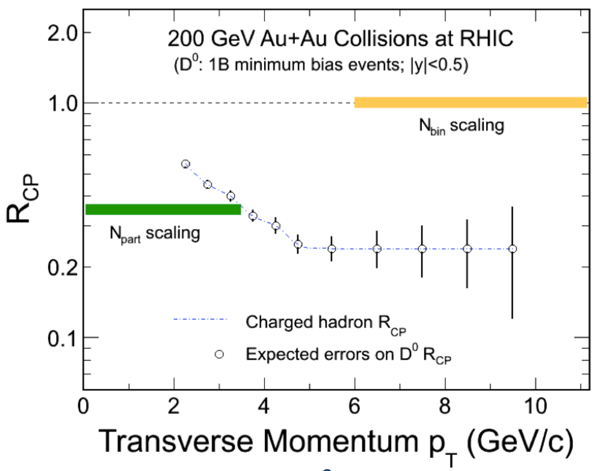


s/(s+b) = 0.0001

arXiv:1404.6185

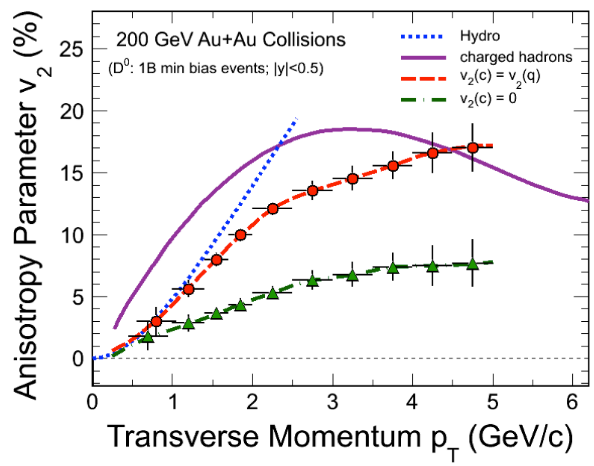


Examples of Physics with HFT

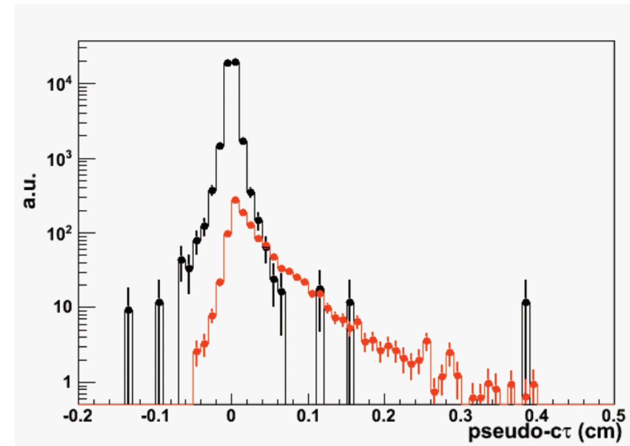


projection of D^0 R_{CP} with HFT

HFT CDR (STAR Note SN0600)



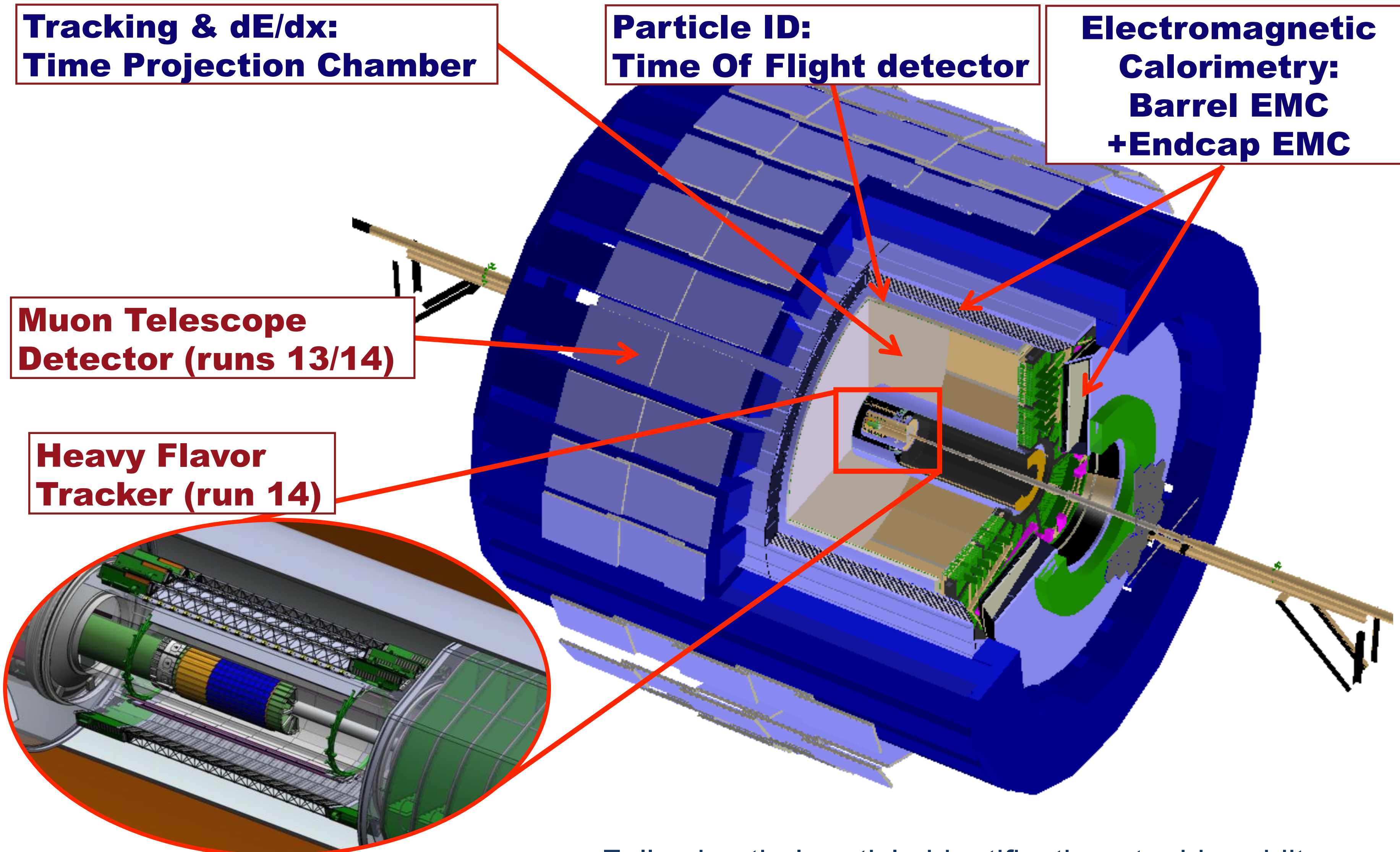
projection of D^0 v_2 with HFT



simulation of separating prompt and B decayed J/ψ with HFT

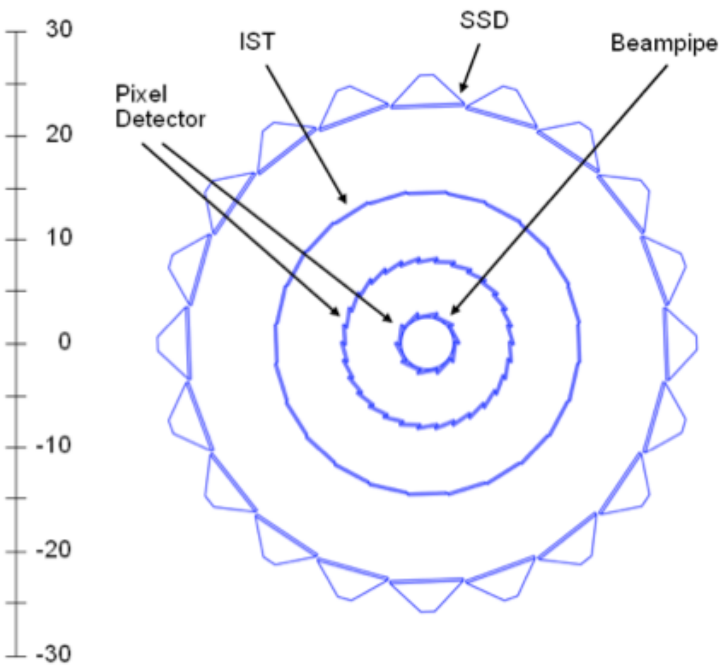
- Total charm yield → baseline for charmonium suppression & coalescence
- R_{CP}, R_{AA} → energy loss mechanism, QCD in dense medium
- Charm collectivity → degree of light flavor thermalization
- Low radiation length enables reconstruction of D^0 down to very low p_T, enabling more direct and precise measurement of total charm cross section and charm flow.
- Separating charm and beauty → probing the medium with heavy quarks with different masses

HFT in STAR



- Full azimuthal particle identification at mid-rapidity

HFT Design



Silicon Strip Detector:

existing detector with new faster electronics

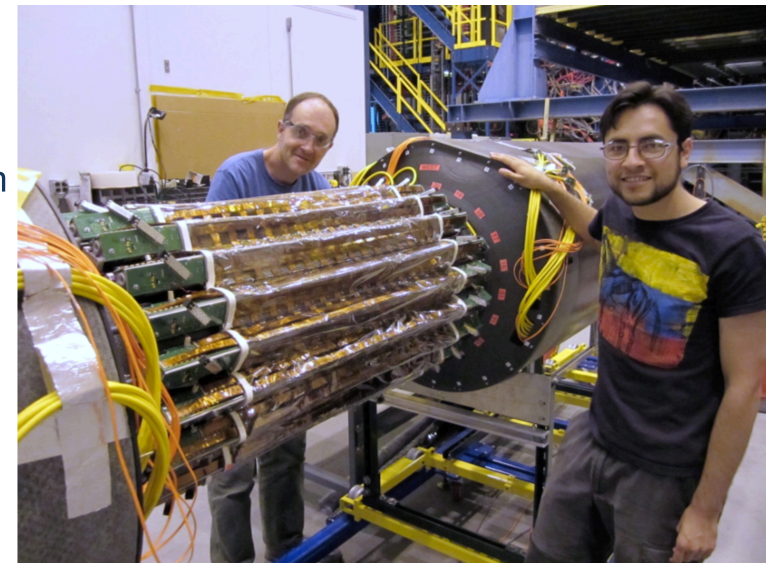
double sided silicon strip modules with 95 μm pitch

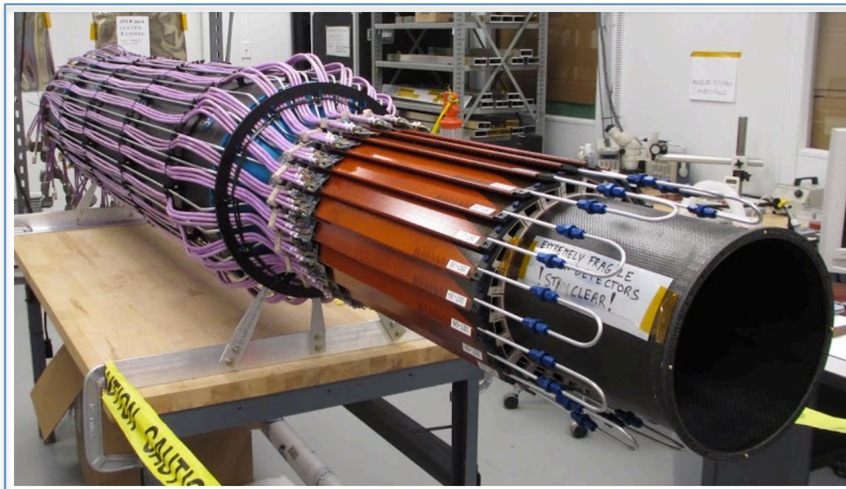
$\sigma_{r\text{-}\varphi}$: 20 μm

σ_z: 740 μm

radius: 22 cm

X/X_0: 1 %





Intermediate Silicon Tracker:

single-sided double-metal silicon pad

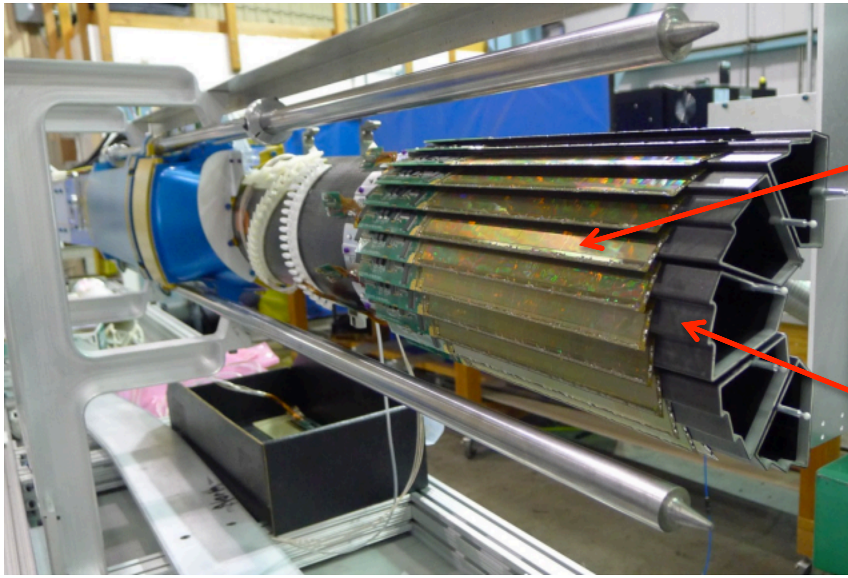
sensors with 600 μm × 6 mm pitch

$\sigma_{r\text{-}\varphi}$: 170 μm σ_z: 1800 μm

radius: 14 cm $X/X_0 < 1.5$ %

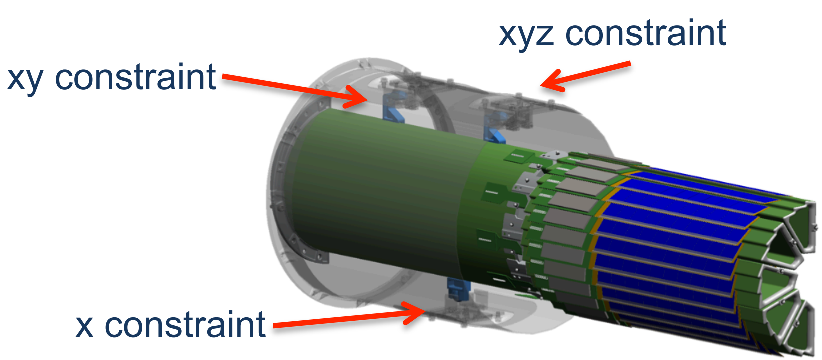
The task of SSD and IST is to connect the tracks from the TPC to PXL in a high hit density environment.

Pixel Detector Design



PIXEL detector

- 10 sectors * 4 ladders (1 inner + 3 outer) * 10 Monolithic Active Pixel Sensors (MAPS)
    - 20.7 μm pixel pitch
    - thinned down to 50 μm
    - used in a collider experiment for the first time
- light carbon fiber support
- radius:
    - 2.9 cm (inner)
    - 8.2 cm (outer)
- σ: $\sqrt{\left(20.7/\sqrt{12}\right)^2 + 5^2}$ = 7.8 μm (vibration)
- X/X_0: 0.4 % / layer
- 360 M pixels in total
- air cooled

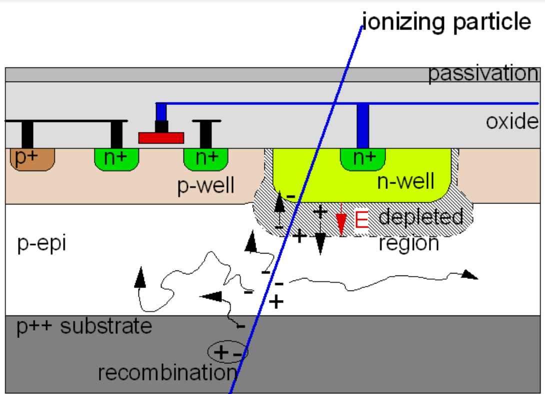


3 kinematic mounts locate the PXL half on the PXL supporting tube.

PXL insertion can be done in ~12 hours, by pushing PXL halves along rails and latching on kinematic mounts.

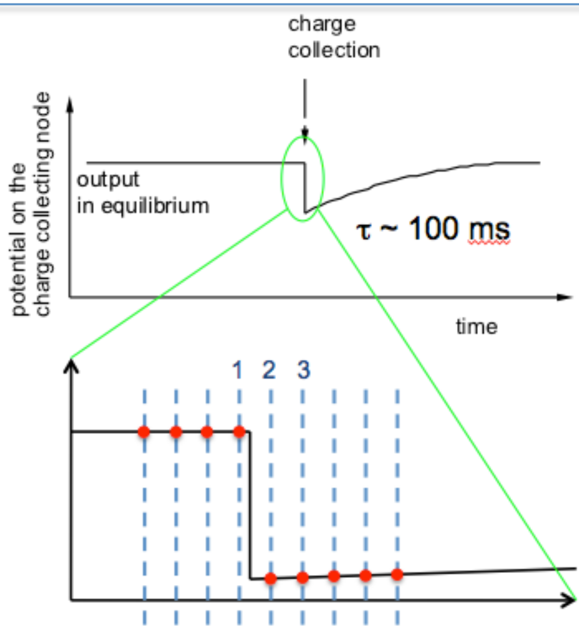
2 sets of PXL detectors and 40 spare ladders are made, to replace damaged detector units when needed.

Monolithic Active Pixel Sensors



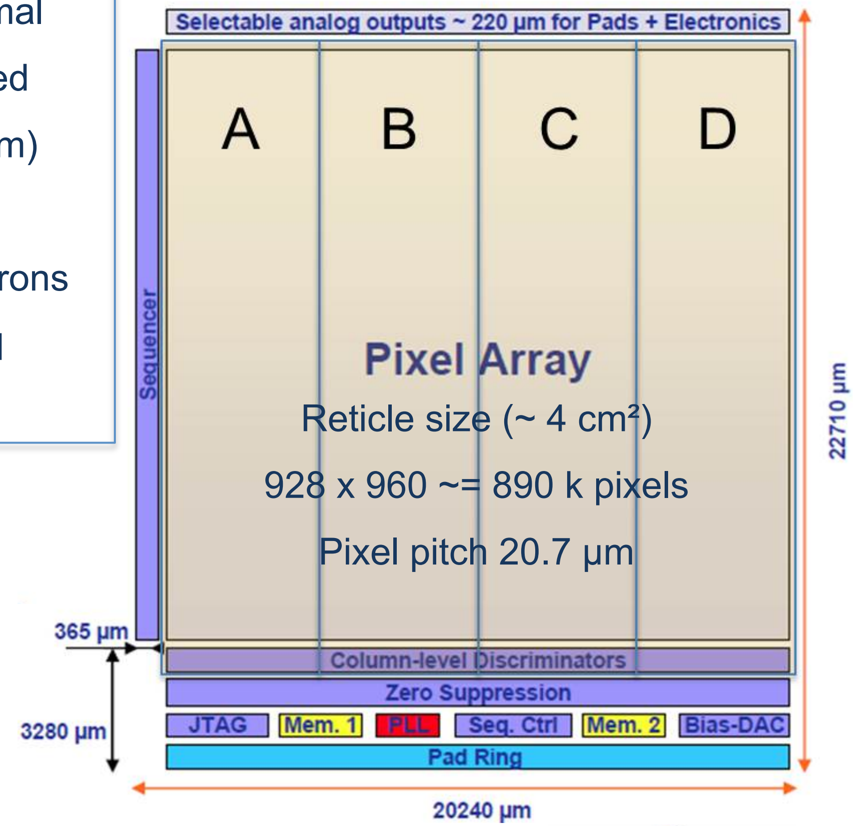
MAPS pixel cross-section (not to scale)

- signal mainly from thermal diffusion in the low-doped epitaxial layer (10~15 μm)
- 100 % fill-factor
- MIP signal < 1000 electrons
- collected in large E-field depleted region



(Sample 1 – Sample 2) > threshold => hit
(Sample 2 – Sample 3) < threshold => no hit

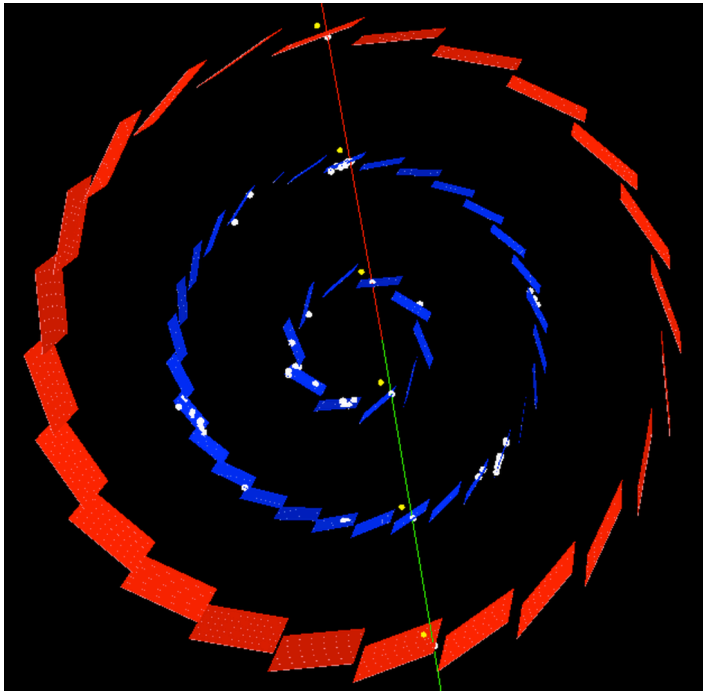
Correlated Double Sampling



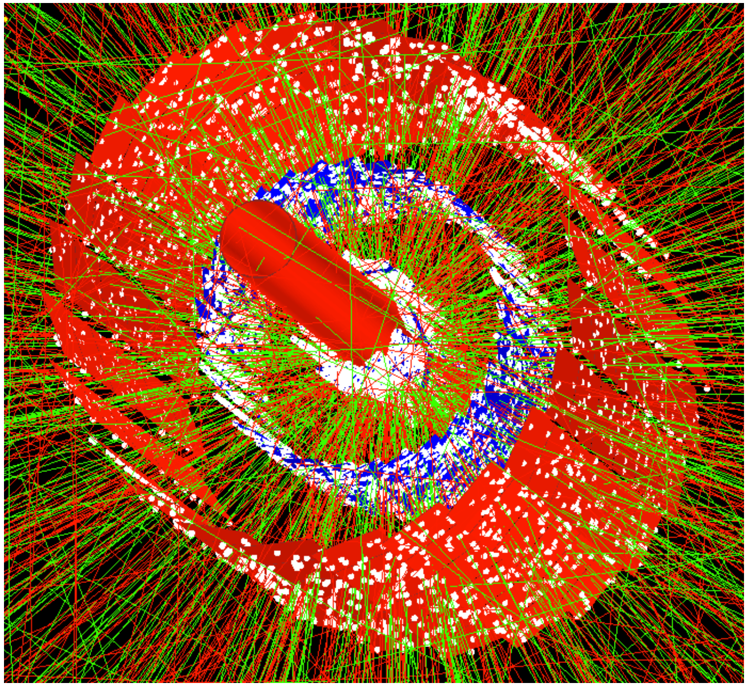
Developed by PICSEL group of IPHC-Strasbourg.
(Marc Winter et al.)

- standard commercial CMOS technology
- sensor and signal processing are integrated in the same silicon wafer
- discriminator & zero suppression in sensor, readout raw hits directly
- integration time 185.6 μs

HFT Status



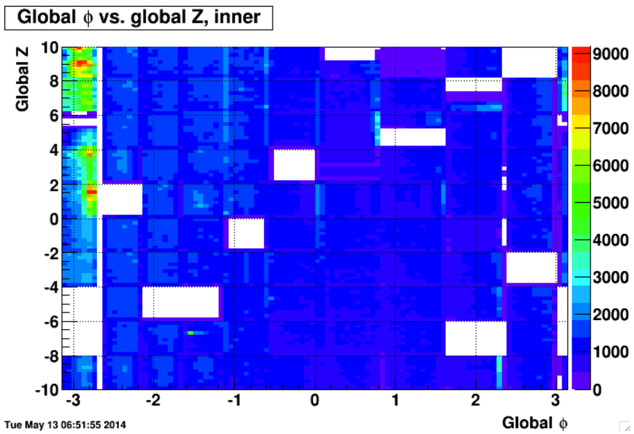
Cosmic event



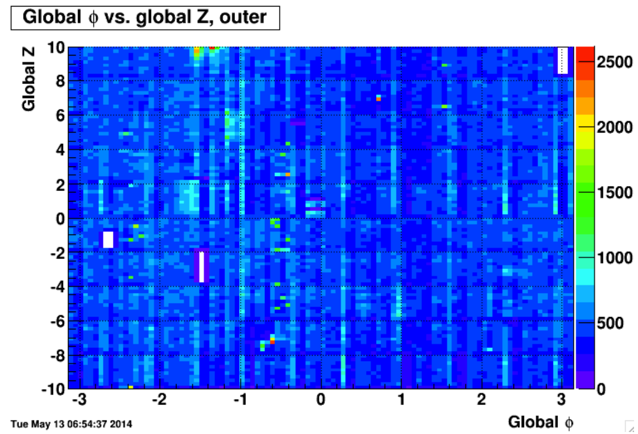
Au+Au 200 GeV event

- The **full** system has been installed ahead of RHIC 2014 running to take cosmic data for alignment (before Feb. 9 and whenever there is long time with no beam). We also tested 3 PXL sectors in Run-13.
- Some detector performance optimization was done during the 14.5 GeV Au+Au run (Feb. 14 ~ Mar. 11)
- 200 GeV Au+Au data taking with PXL and IST started in March 15. Collected ~1.2 Billion events.
- SSD commissioned later in the run – collected about 172 Million events.

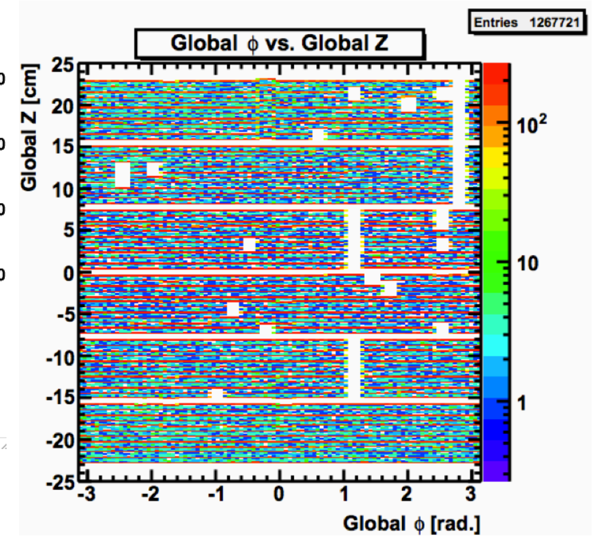
Damage and Remediation



Z vs. φ of hits in PXL inner layer



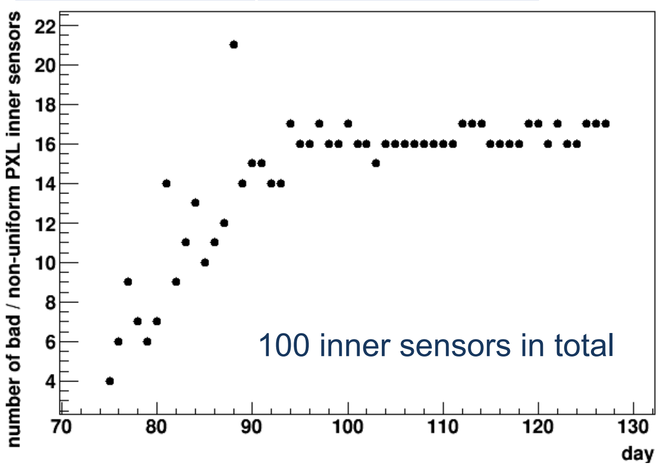
Z vs. φ of hits in PXL outer layer



Z vs. φ of IST hits

layer	inactive units
PXL inner	14 %
PXL outer	1 %
IST	4 %

Most PXL sensor damages appear to be radiation related damage possibly due to latch up in thinned sensors.

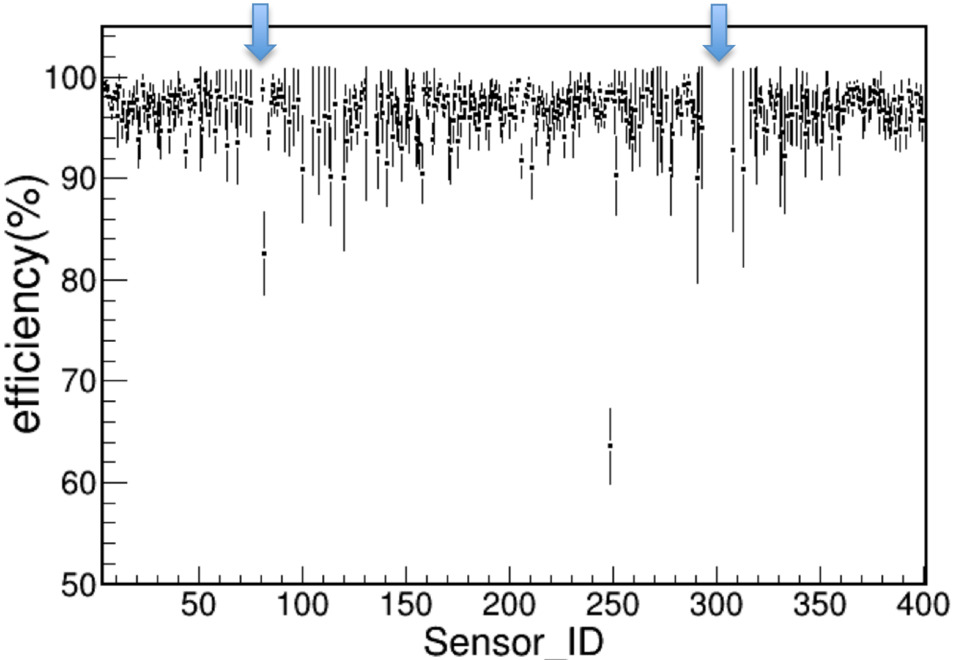


Minimal or no damage for > 1 month: our operational methods were successful at stopping or greatly reducing the rate of damage.

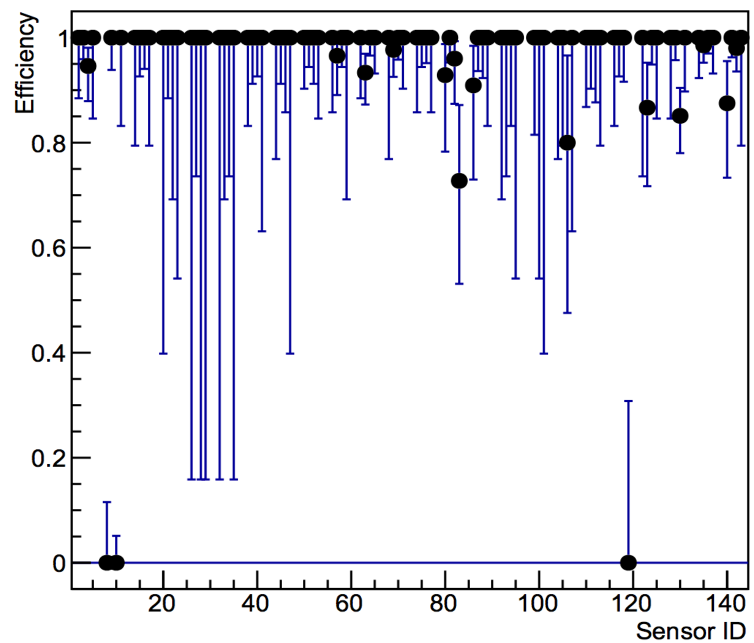
- PXL and IST are only turned on when collision rate < 55 kHz.
- the full PXL detector resets every 15 minutes
- Latch up thresholds changed from 400 mA to 120 mA above the measured operating current for each ladder

Efficiency

Low statistics of near horizontal cosmics



IST Efficiency from Cosmics Data



PXL sensor efficiency measured with cosmic ray:

hits / projection

- Before the detector response optimization and running with the beam
- **Average = 97.2 %**

IST efficiency measured with cosmic ray:

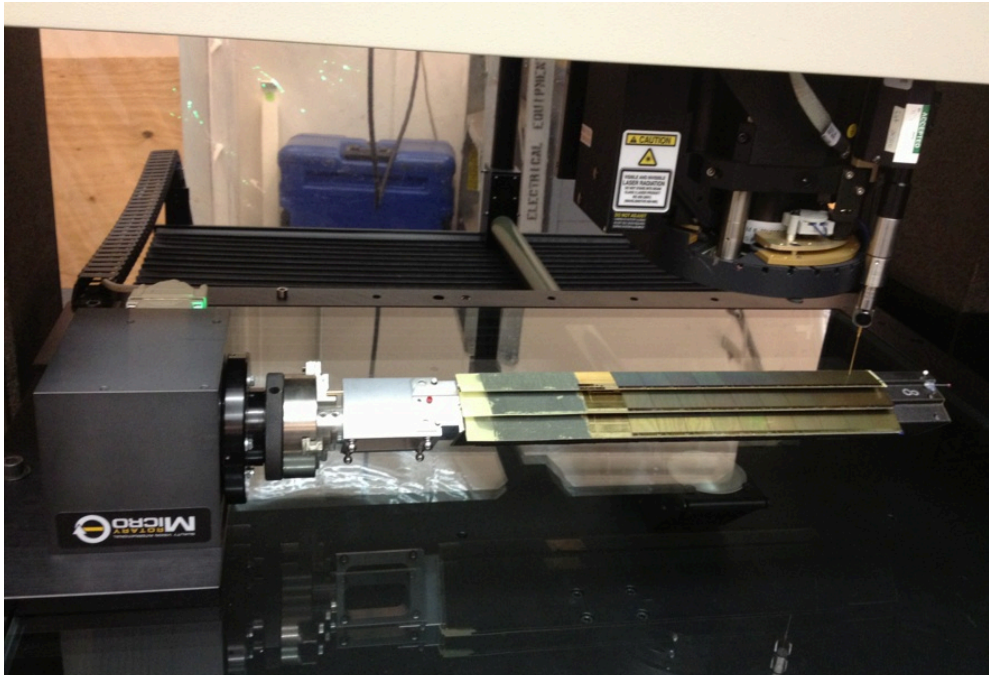
hits / projection

Average = 98.6 %

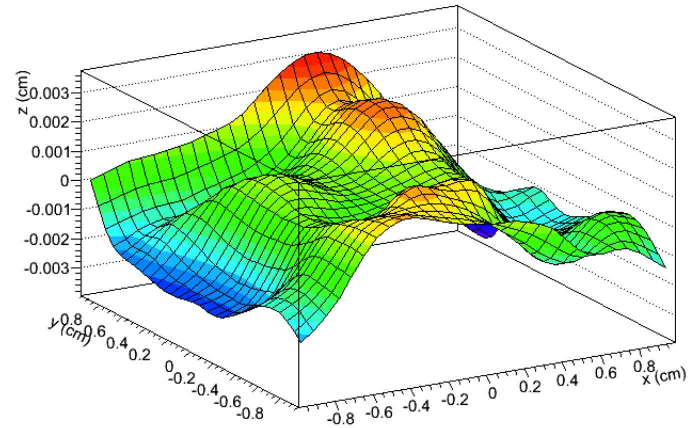
- Tuning for including HFT in tracking is going on…

STAR ☆

Survey and Alignment



Coordinate Measurement Machine is used to survey HFT detector parts.

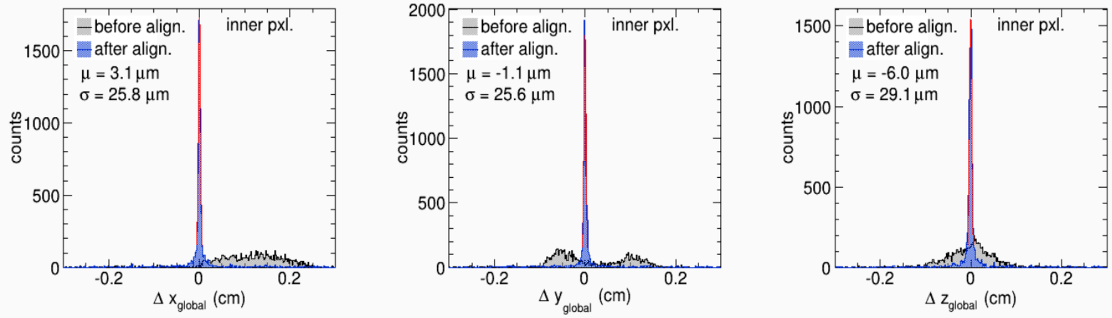


PXL sensor surface profile from survey

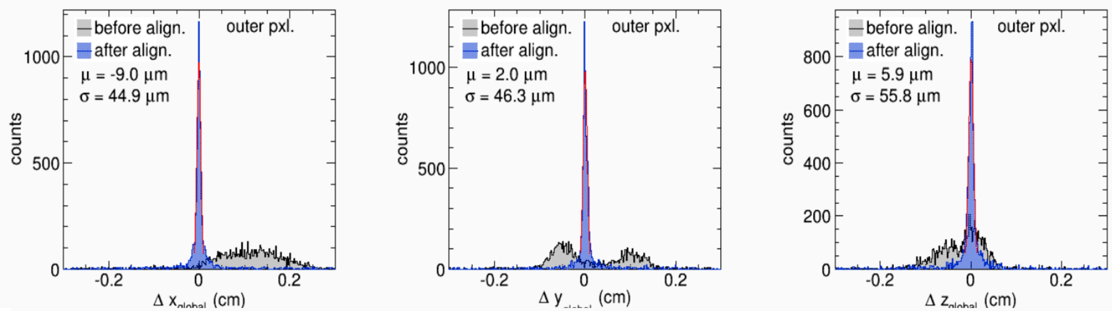
+- 30 μm > PXL hit error

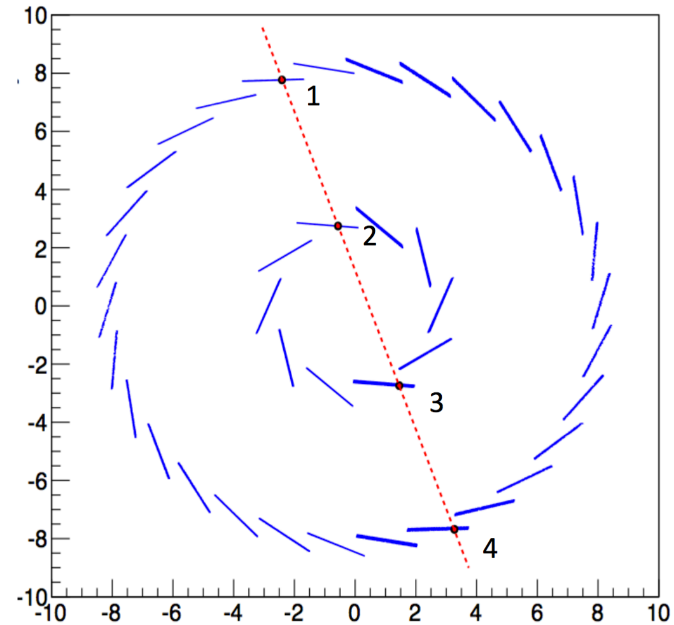
- Survey fixed sensor-on-ladder and ladders-on-sectors plus surface profiles (PXL)
- Repeatability/time dependences were found to be ~10 microns
- Similar work was done for SSD, IST
- Alignment fine tuned sector-on-half and half-to-half positioning in-situ
  - Self (relative) PXL alignment based on track projection and reconstructed vertex/sector analysis
- SSD/IST adjusted to PXL

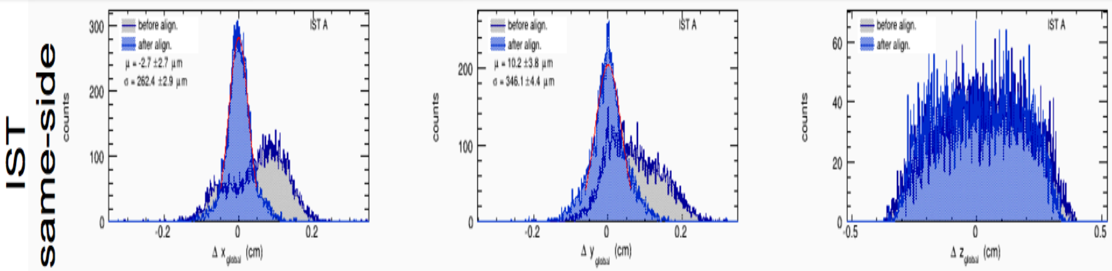
Survey and Alignment



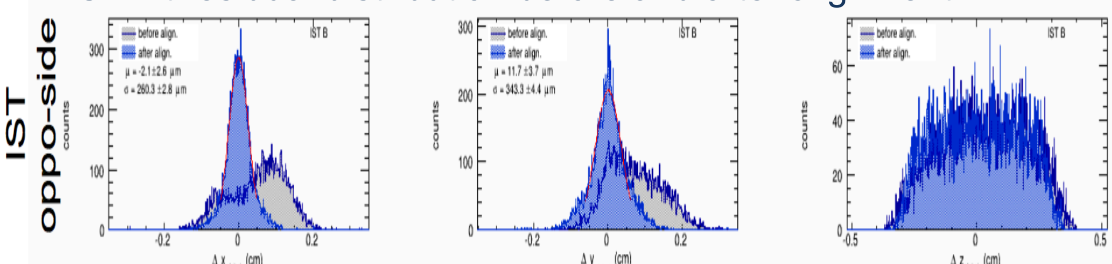
PXL hit residual distribution before and after alignment







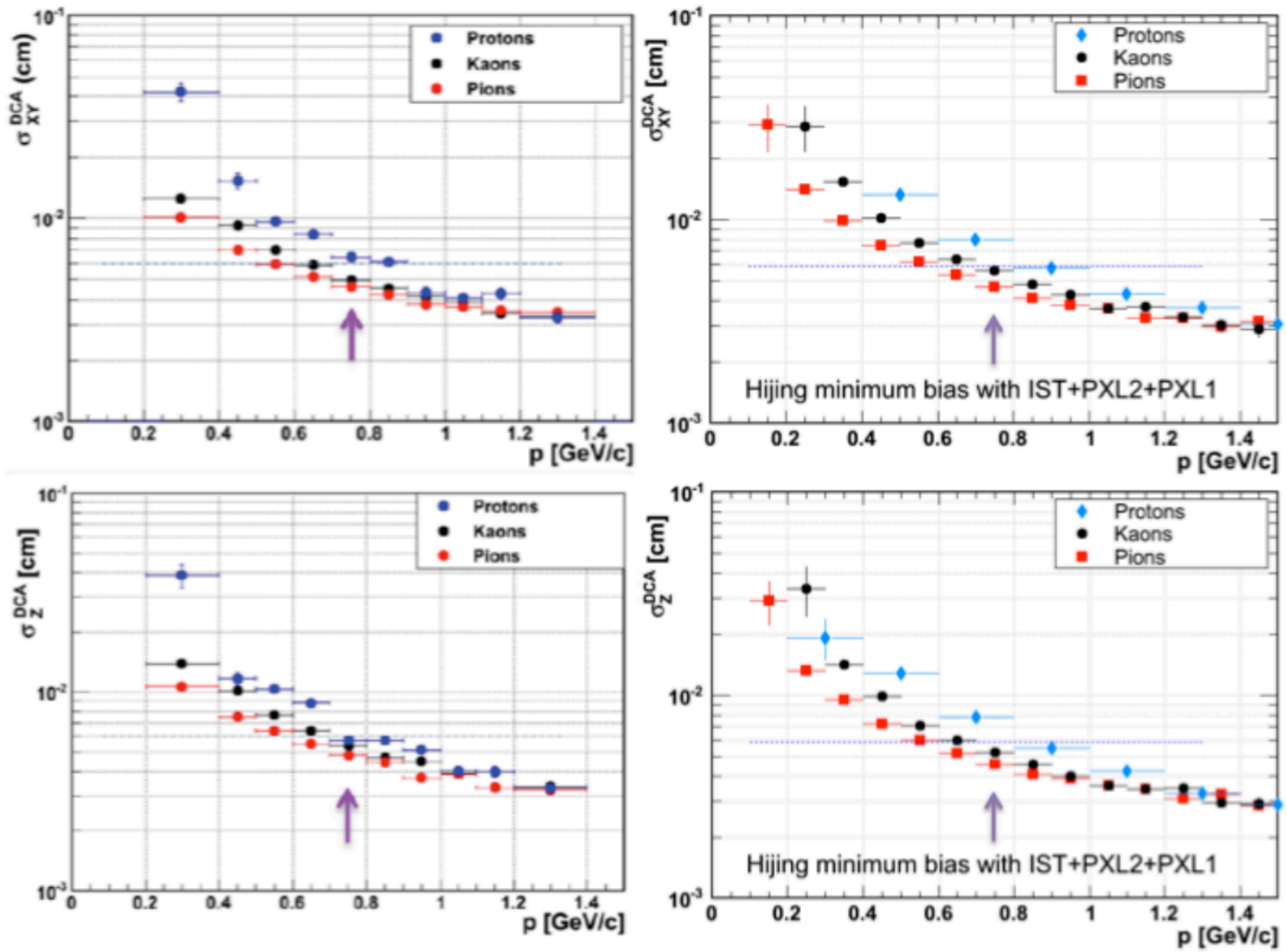
IST hit residual distribution before and after alignment



- Cosmic ray and Low Luminosity data are used to align and monitor different HFT detector parts
- Widths are compatible with expected extrapolation errors (hit resolution+MCS)

Track DCA

Measured | Simulated



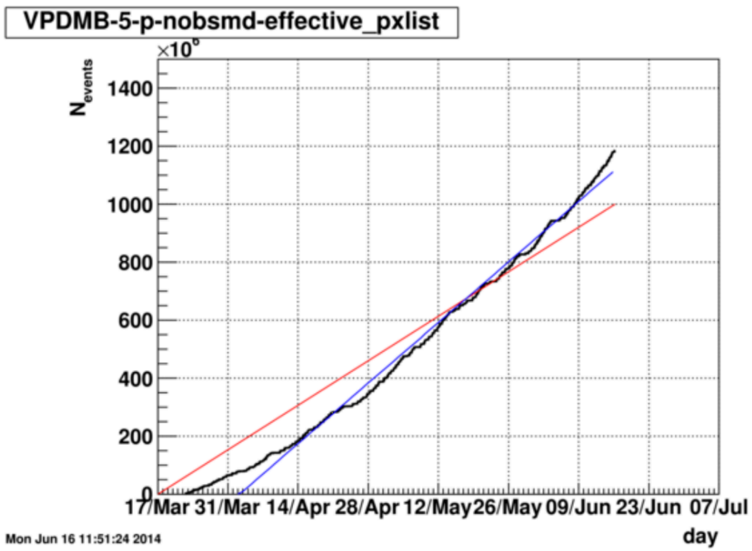
DCA resolution vs. momentum (averaged over phi) for pion, kaon and proton tracks with 1 IST hit + 2 PXL hits

~ 30 μm at high p_T

Achieved CD4 goal: <60 μm for kaon with p_T = 750 MeV/c

Summary

- STAR Heavy Flavor Tracker will enable or enhance many open heavy flavor measurements, by reconstructing open heavy flavor hadrons with displaced decay vertices.
- State-of-art MAPS technology is used for the first time in a collider experiment in the PXL detector.

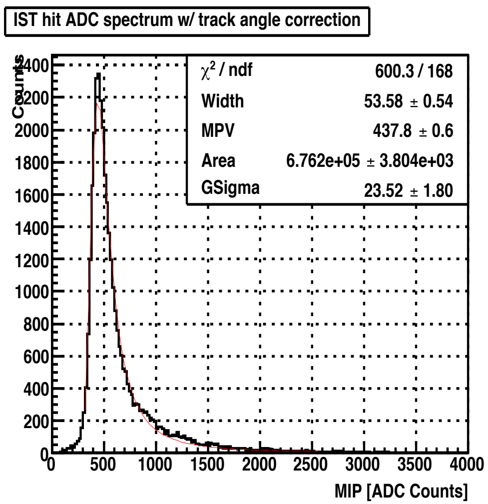


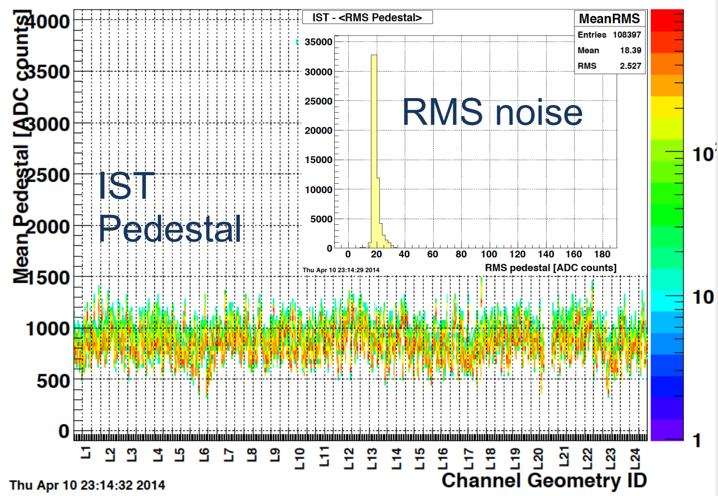
- All 3 sub-detectors (PXL, IST, SSD) were assembled and inserted into STAR before RHIC year 2014 running.
- With survey and preliminary alignment, we already achieved ~30 microns pointing resolution for high p_T tracks reconstructed with HFT hits.
- Data taking with PXL and IST reached our goal for Run-14. p+p 200 GeV and more Au +Au data will come in runs 15 & 16.
- New physics results with HFT will greatly enhance our understanding of QGP created at RHIC.

END

Extra Slides

Signal, Pedestal and Noise Scan





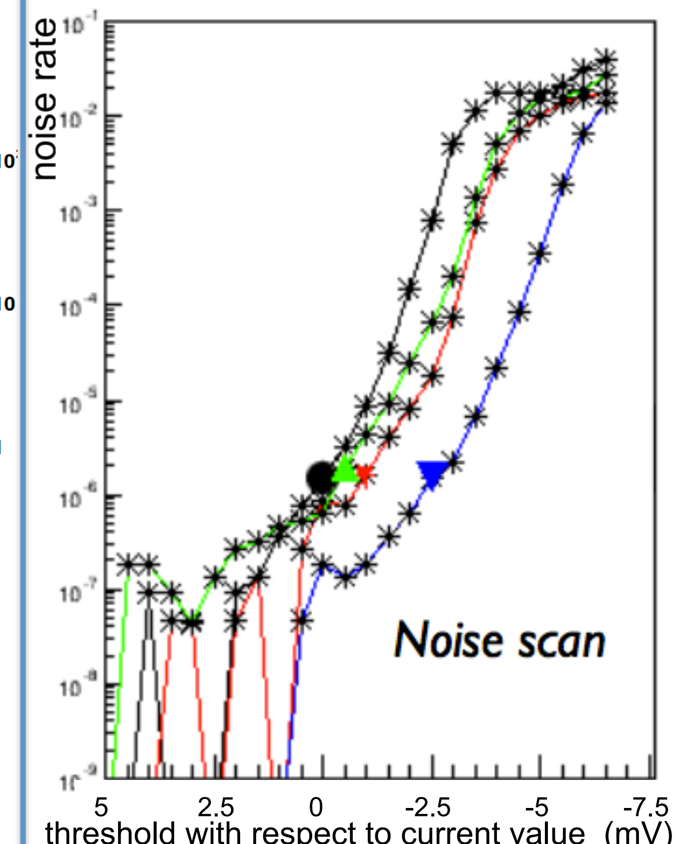
IST signal with MIP

MVP ~ 440 ADCs

- signal to noise ratio ~ 23

IST has stable pedestal and RMS level over all channels

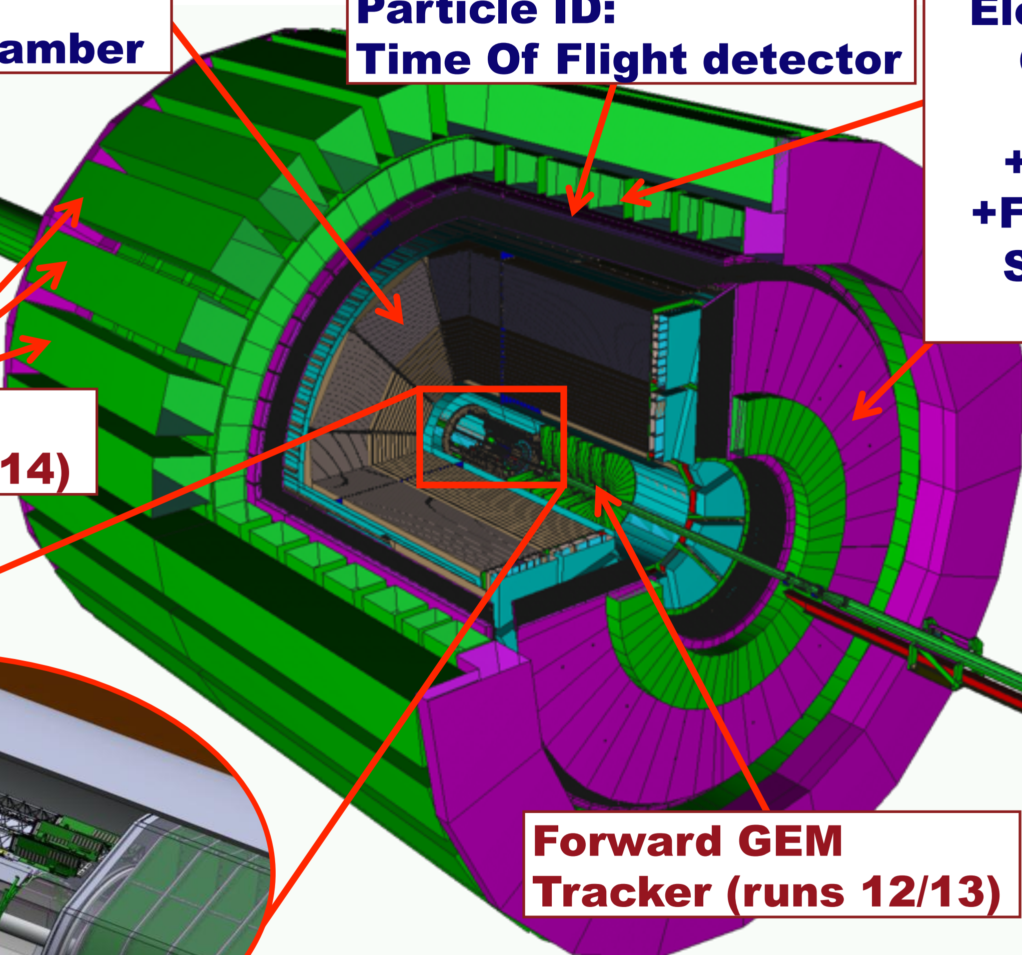
See details at poster M-30 by Yaping Wang

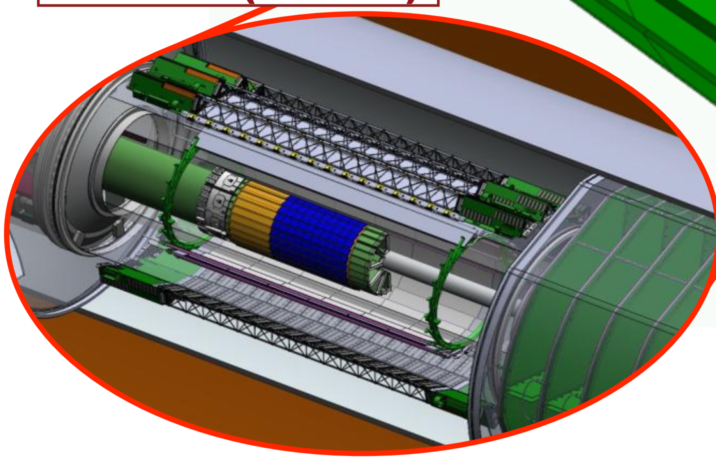


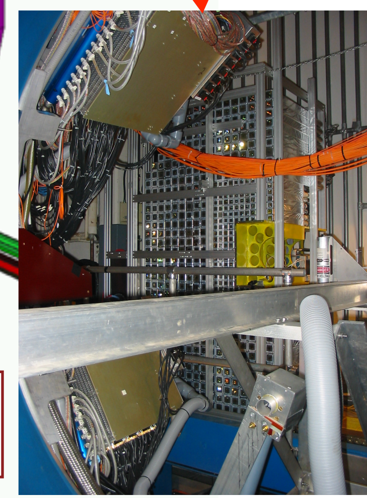
Optimize sub-array thresholds in a PXL sensor for noise rate = 2.e-6

- Noise data for PXL and pedestal data for IST and SSD are taken at least once per day without beam, to monitor PXL noise rate, hot pixels, and calibrate IST pedestal.

STAR Detector Overview

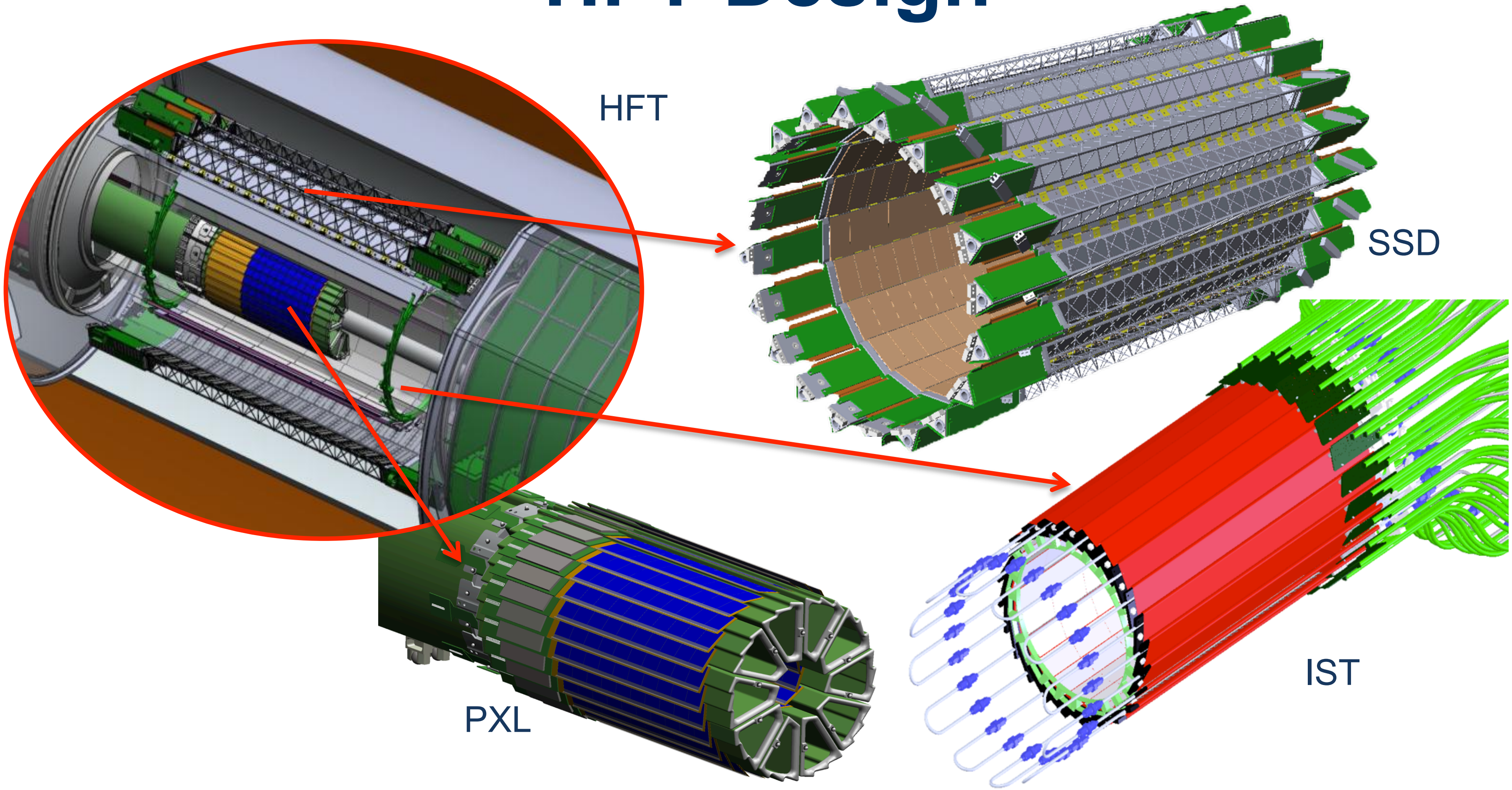






- Full azimuthal particle identification at middle rapidity

HFT Design

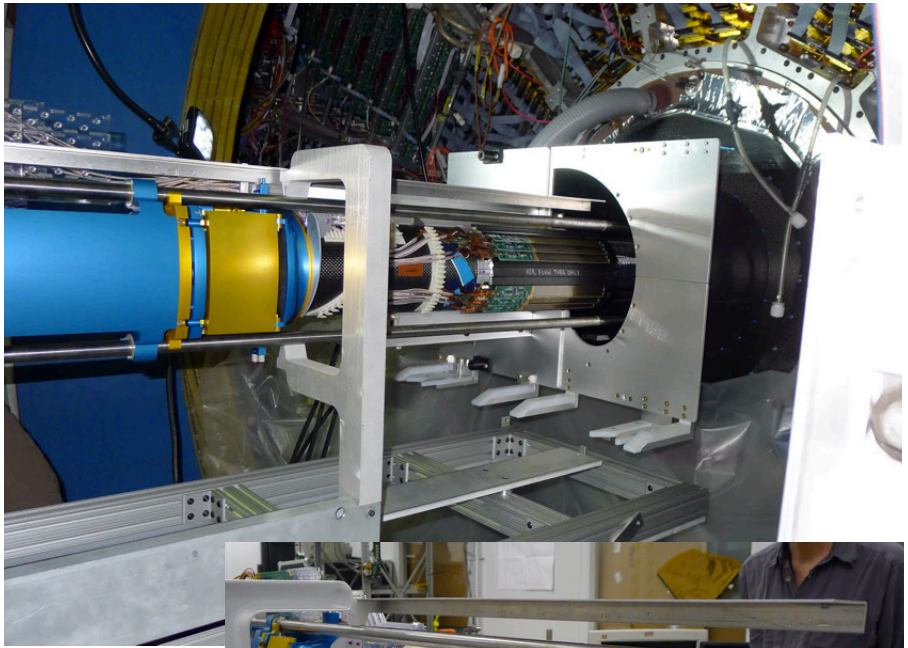


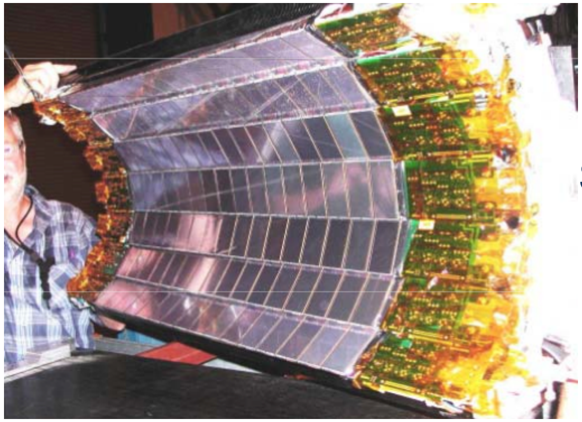
Sub detector	r (cm)	Sensitive units	$\sigma_{R-\varphi}$(μm)	σ_Z(μm)	X/X_0(%)
Silicon Strip Detector	22	2 side strips with 95 μm pitch	20	740	1
Intermediate Silicon Tracker	14	500 μm x 1cm strips	170	1800	<1.5
PIXEL	2.5/8	20 μm pixel pitch	12	12	0.4/layer

HFT Status

- Engineering run for PXL prototype (3 out of 10 sectors) finished
  - installed on May 8, 2013
    - within 12 hours
  - first PXL data in daq file on May 10
  - 78 M events taken with PXL
- full system to be installed in 2014

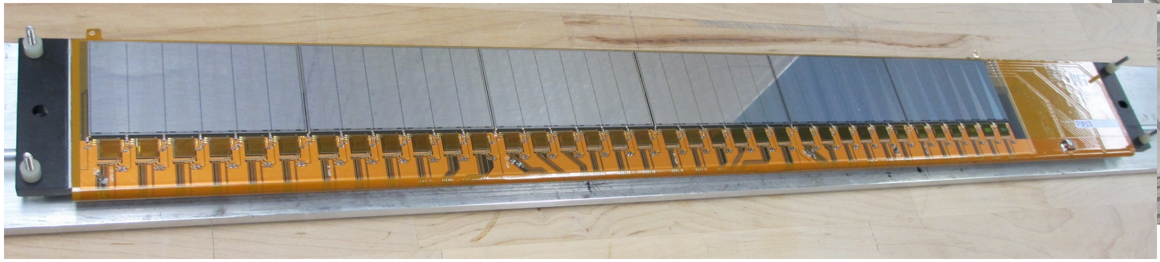
PXL prototype insertion

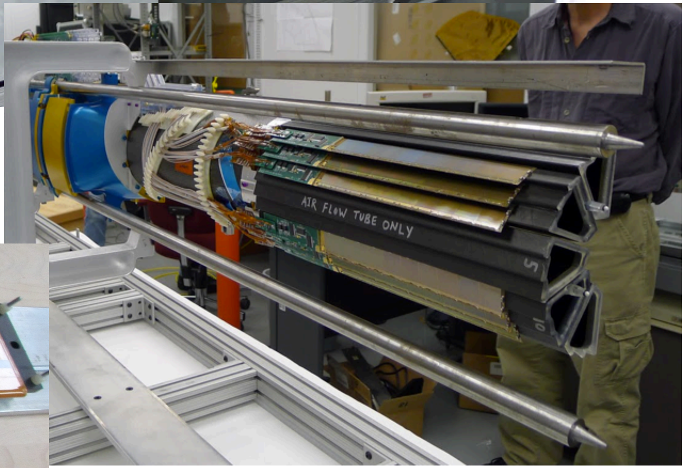




SSD part

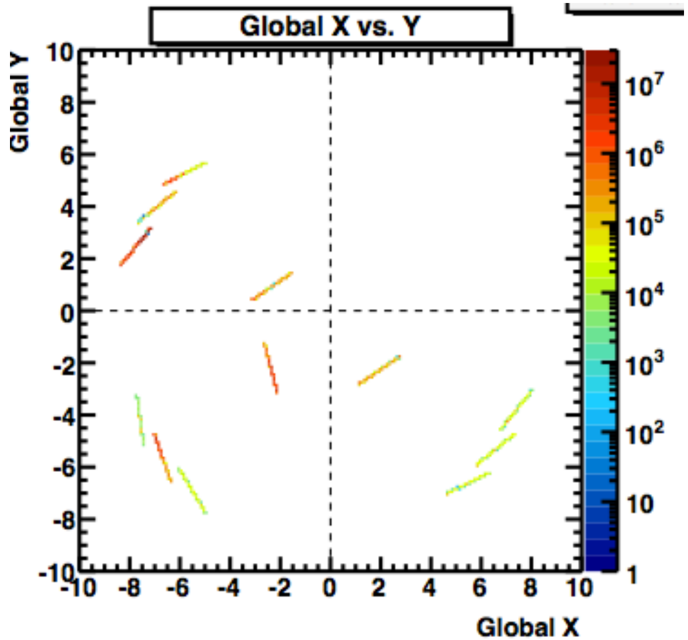
IST ladder

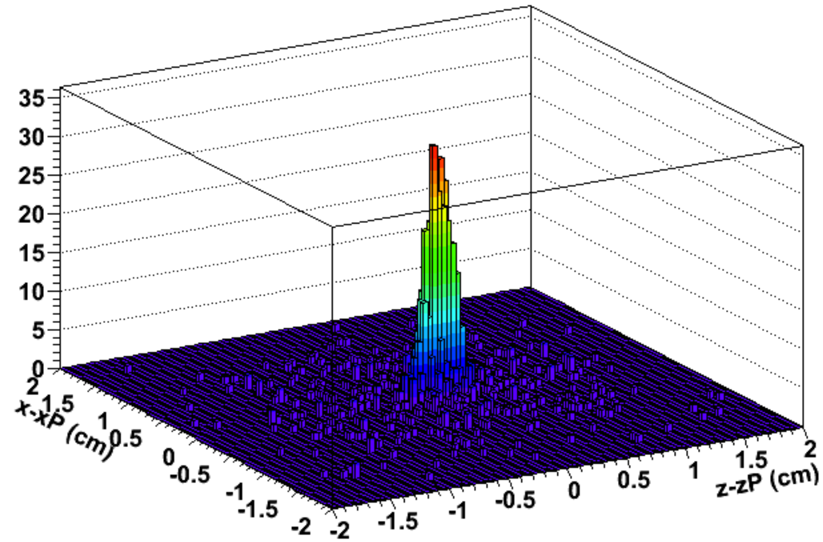




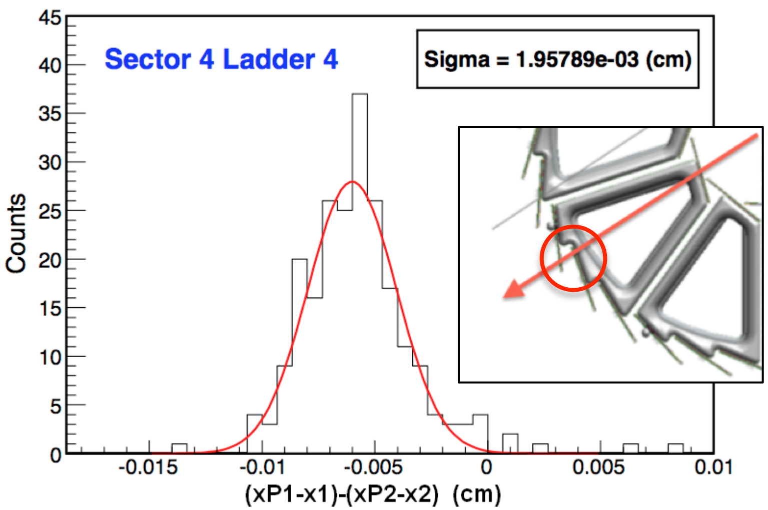
PXL prototype half

PXL Performance





- 2D correlation between measured pxl hit and TPC track projection on a sensor



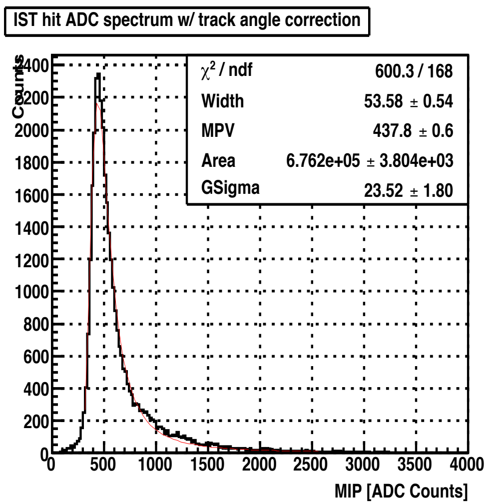
- Double difference of hit and track projection positions between 2 overlapping sensors
- Single sensor resolution = 20 / √2 = 14 microns
  ~ 12 microns resolution of designed goal

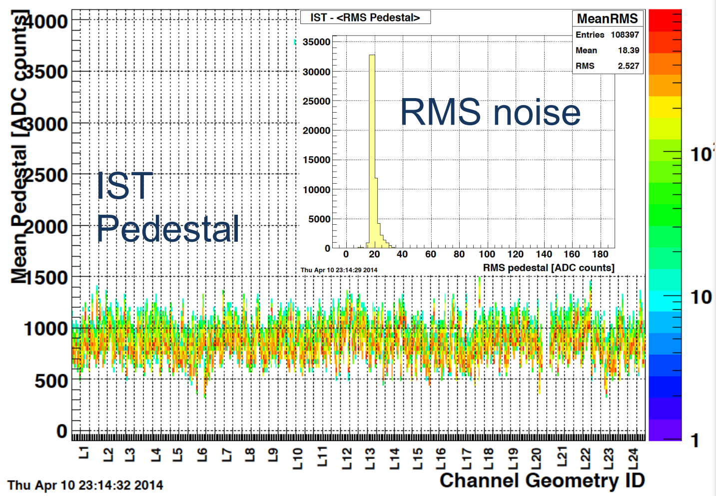
RHIC Run Plan

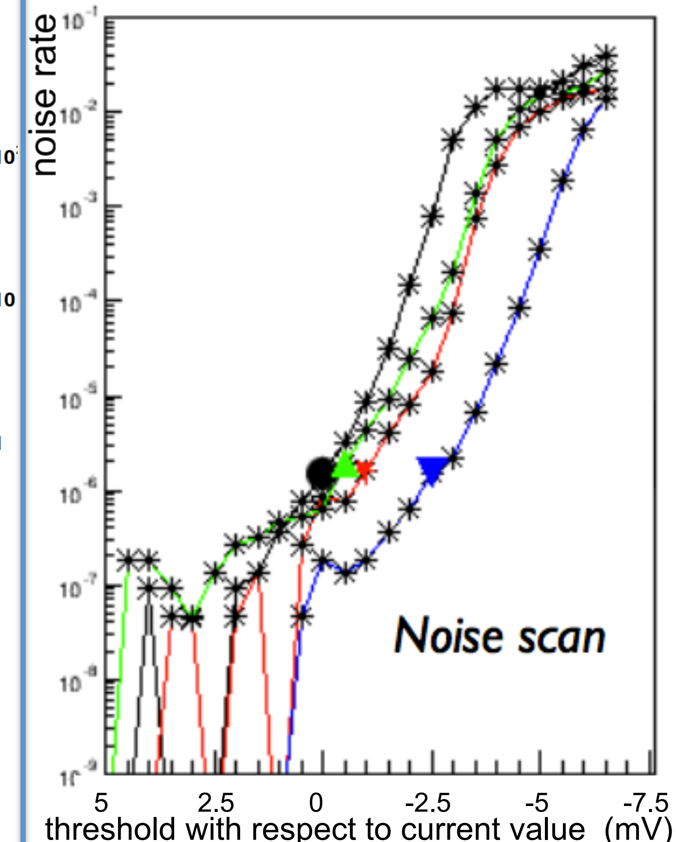
Run	Energy	Time	System	Goal
14[1]	$\sqrt{s_{NN}}$=200GeV	14-week	Au+Au	HFT & MTD heavy flavor measurements, $\mathcal{L}$=10 nb^{-1}, 1000M M.B.
	$\sqrt{s_{NN}}$=15GeV	3-week	Au+Au	1) Collect 150M M.B. events for CP search 2) Fixed-target data taking[3]
15[2]	$\sqrt{s_{NN}}$=200GeV	5-week	p+Au	Study saturation physics, pA-ridge and heavy ion reference, $\mathcal{L}$=300 nb^{-1}
	$\sqrt{s}$=200GeV	12-week	1) p+p	1) Heavy ion reference data $\mathcal{L}$=90 pb^{-1}, 500M M.B.
			2) transverse 6 weeks	2) Study transversity, Sivers effects $\mathcal{L}$=40 pb^{-1}, 60% pol.
			3) longitudinal 6 weeks	3) Study $\Delta g(x)$ $\mathcal{L}$=50 pb^{-1}, 60% pol.

- STAR Beam User Request, endorsed by RHIC PAC.
- Focus on 200 GeV AA, pA, and pp collisions for heavy ion programs with new upgrades.

Signal, Pedestal and Noise Scan







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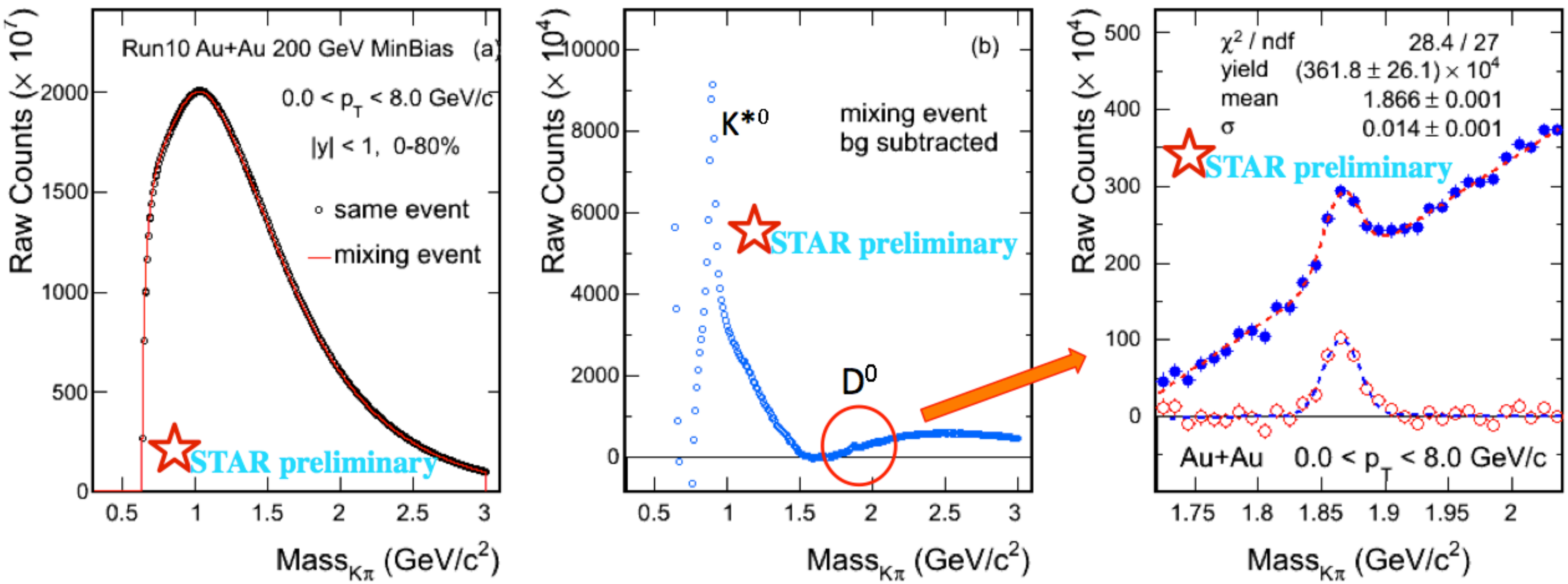
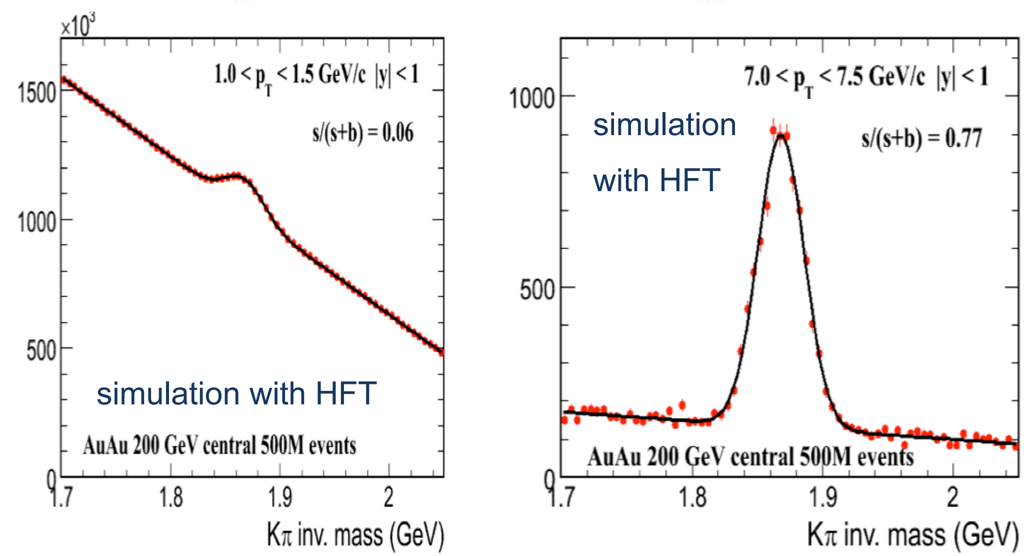
- Noise data for PXL and pedestal data for IST and SSD are taken at least once per day without beam, to monitor PXL noise rate, hot pixels, and calibrate IST pedestal.

Charm Yield, R_{CP} and R_{AA}



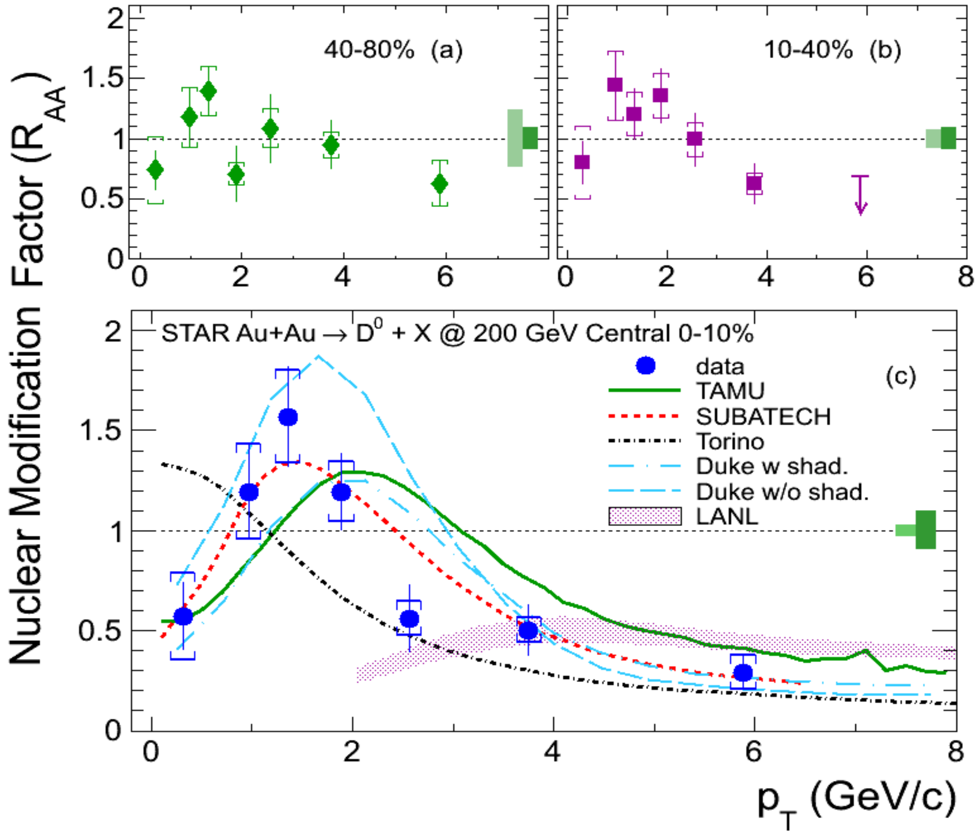
arXiv:1404.6185; subm. to PRL

- Large combinatorial background using primary tracks to reconstruct D^0
- Much better S/B ratio with displaced vertex from HFT



HFT CDR (STAR Note SN0600)

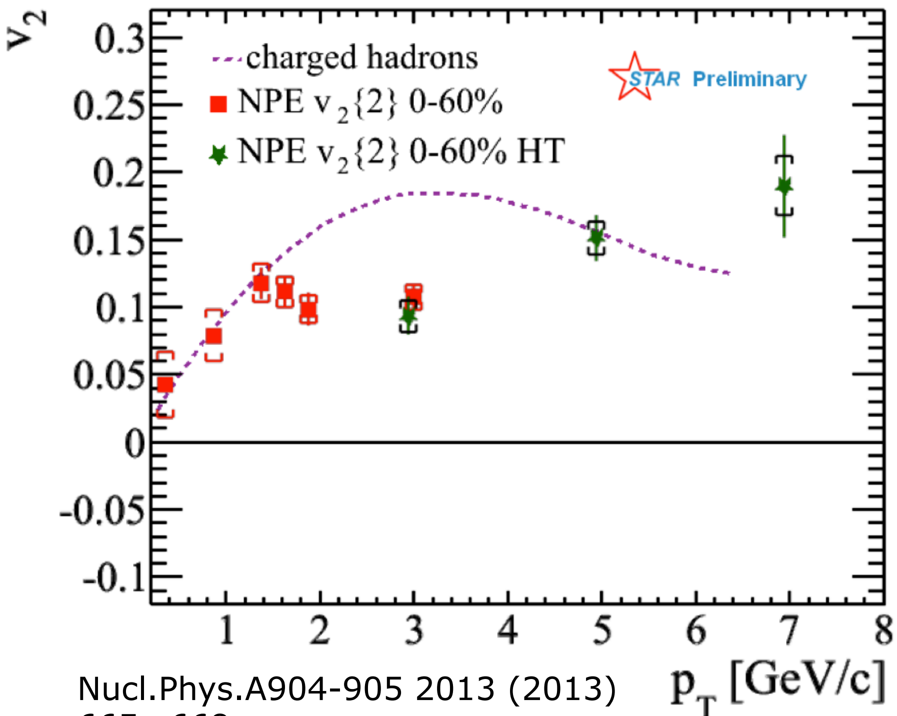
Charm Yield, R_{CP} and R_{AA}



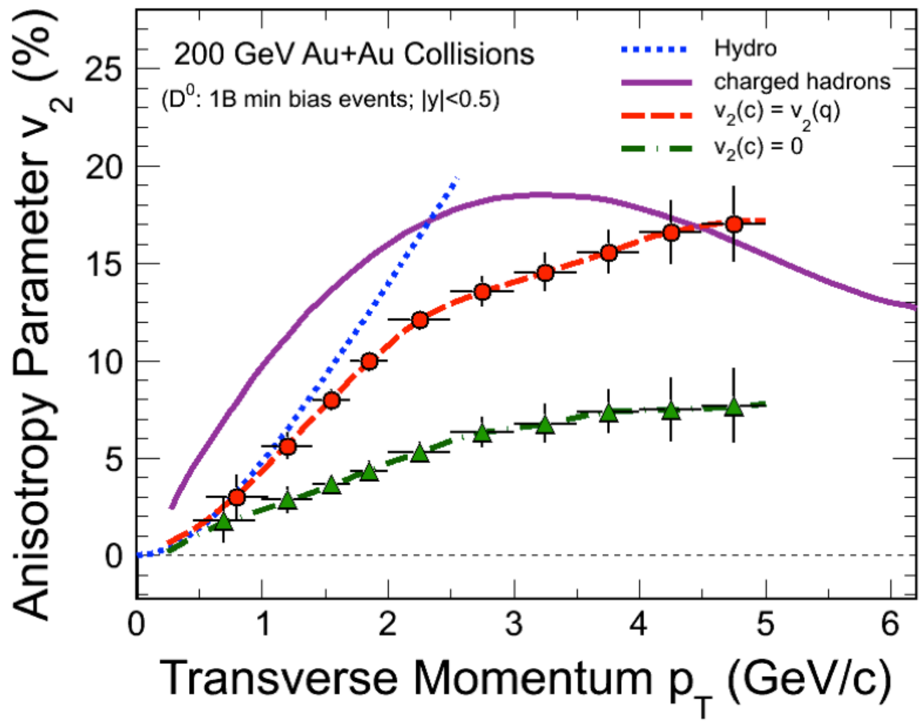
arXiv:1404.6185; subm. to PRL

- Total charm yield → base line for charmonium suppression & coalescence
- R_{CP}, R_{AA} → energy loss mechanism, QCD in dense medium

Charm Flow



Nucl.Phys.A904-905 2013 (2013) 665c-668c



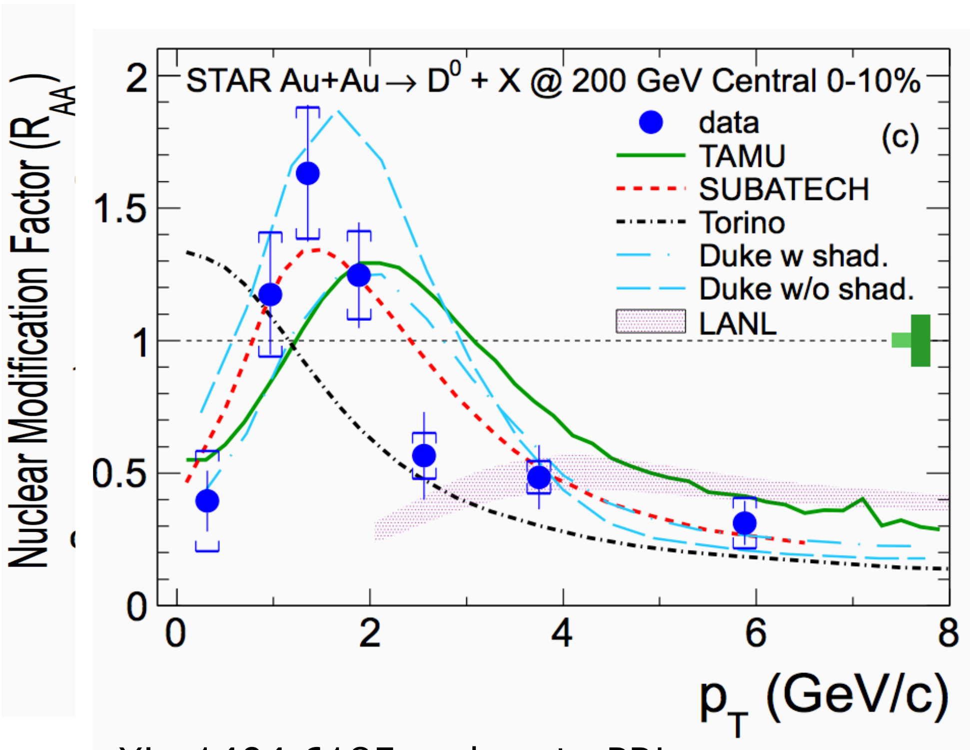
STAR projection with HFT

HFT CDR (STAR Note SN0600)

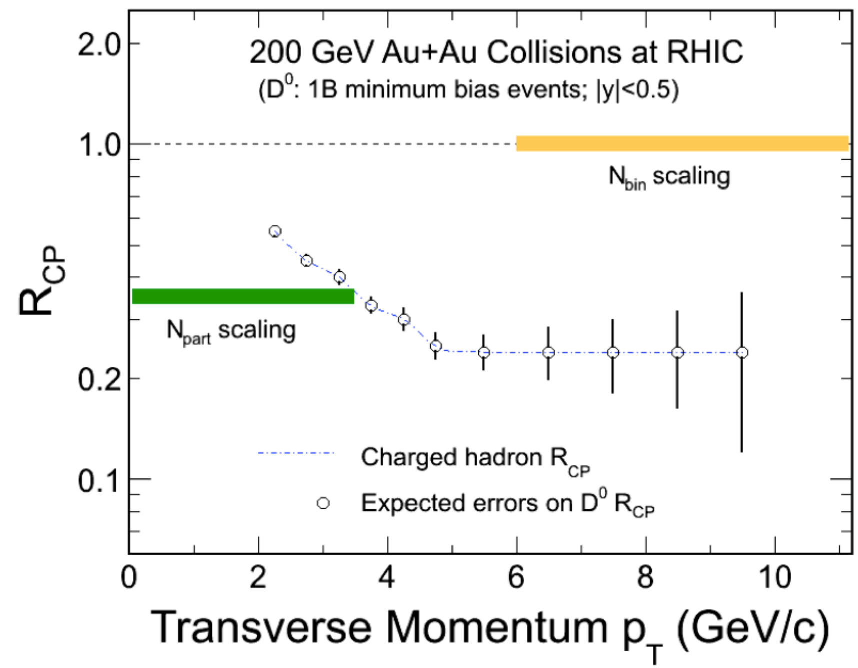
- Charm collectivity → light flavor thermalization?

- D^0 v_2 is a more direct measurement of charm flow than non-photonic electron v_2.
- With HFT STAR is able to measure D^0 v_2 at low p_T region, which is sensitive to charm flow.

Charm Yield, R_{CP} and R_{AA}



arXiv:1404.6185; subm. to PRL

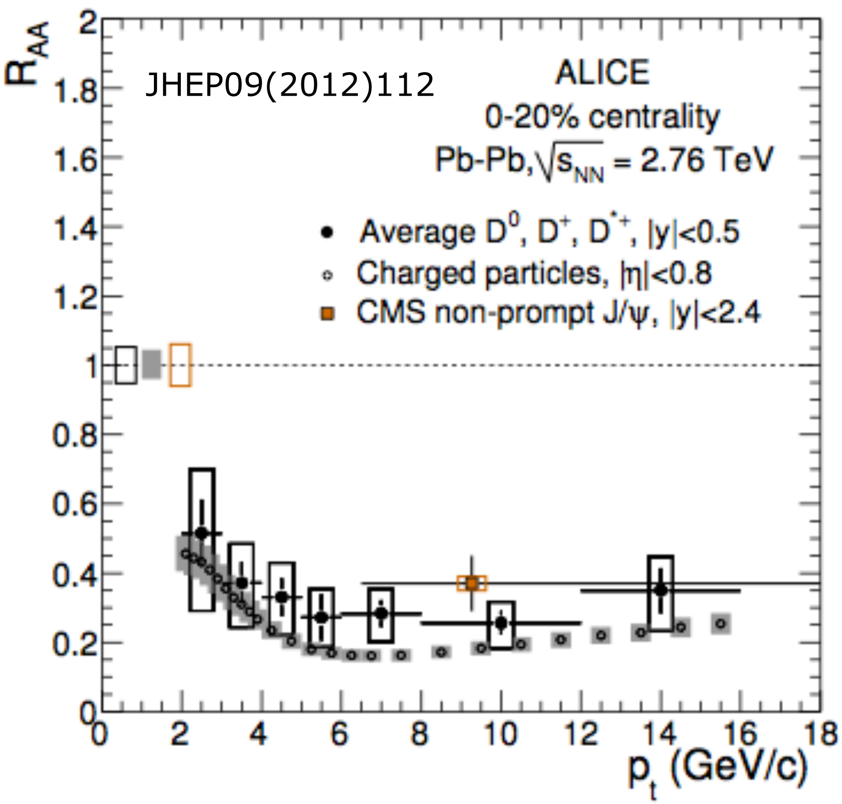


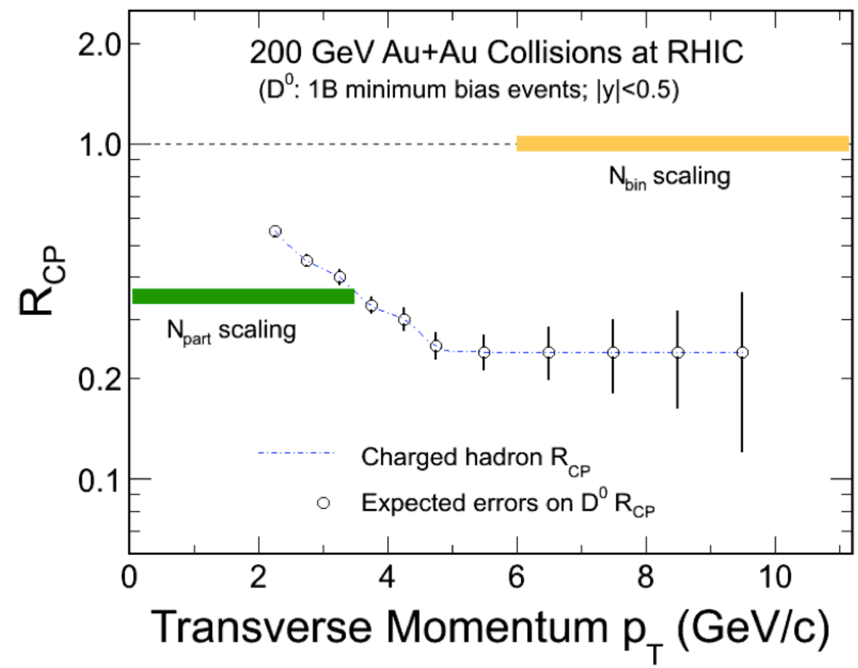
STAR projection with HFT

HFT CDR (STAR Note SN0600)

- Much better precision with HFT than current STAR measurement
- Low radiation length enable reconstruction of D^0 with p_T starting from ~0, enabling charm total cross section measurement.

Charm Yield, R_{CP} and R_{AA}

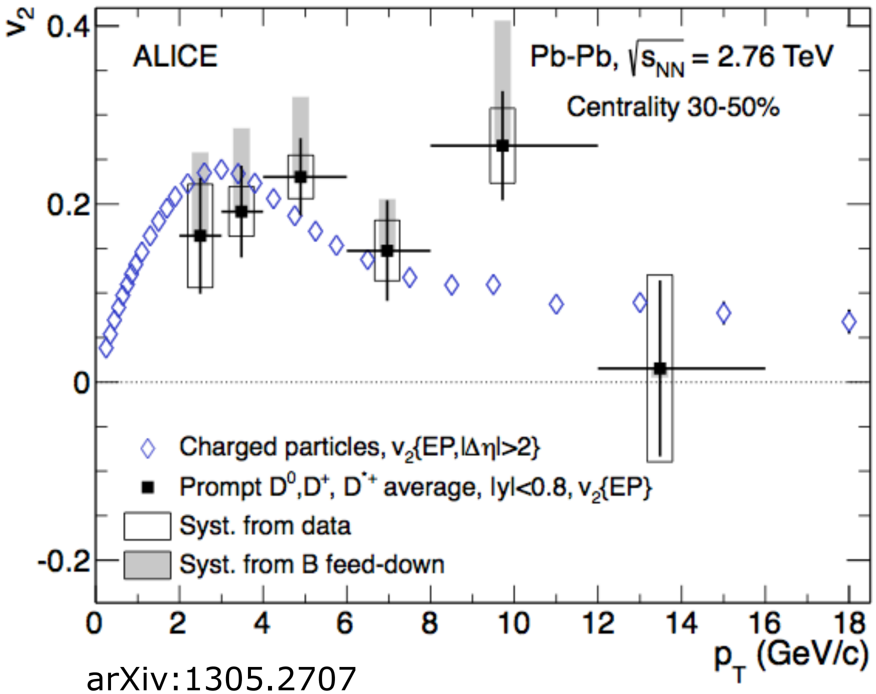




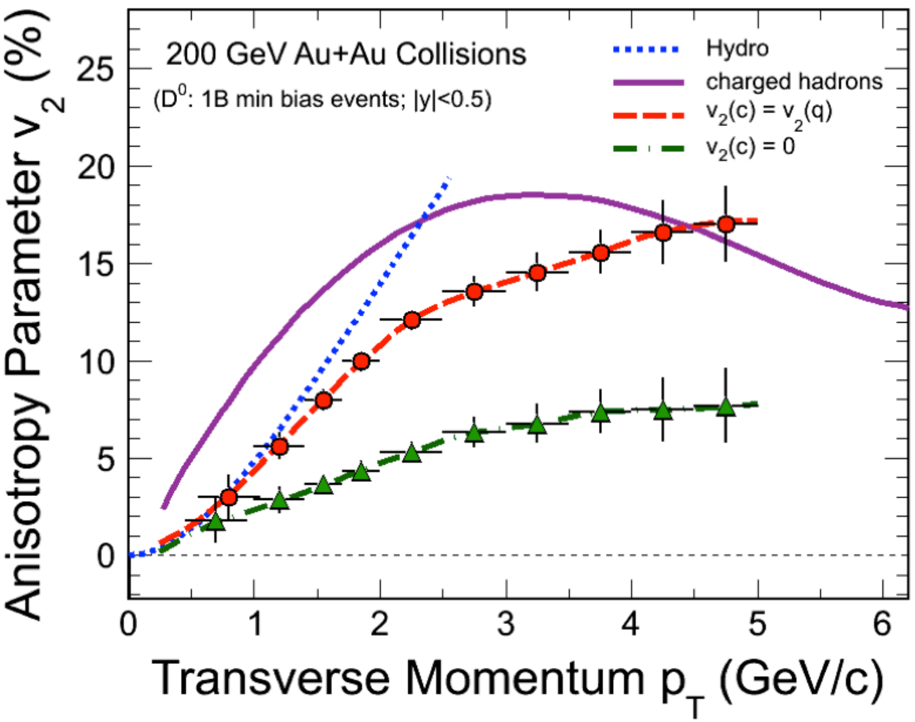
STAR projection with HFT

- Probe possible different medium property with different collision energy.

Charm Flow



arXiv:1305.2707
Phys. Rev. Lett. 111 (2013) 102301



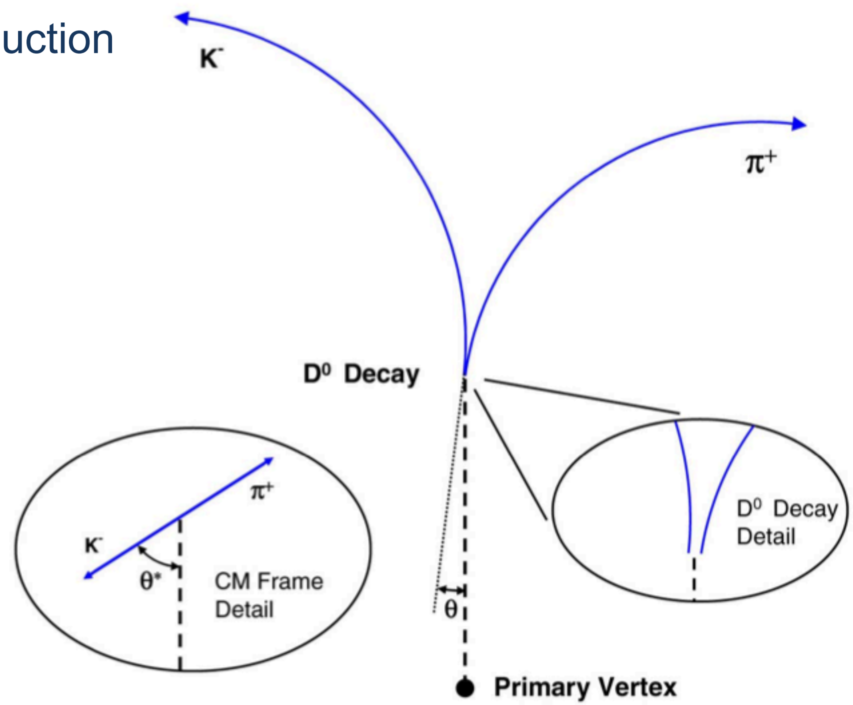
STAR projection with HFT

HFT CDR (STAR Note SN0600)

- Charm collectivity → light flavor thermalization?
- Measurements at both LHC and RHIC will explore the change of media properties with energy.

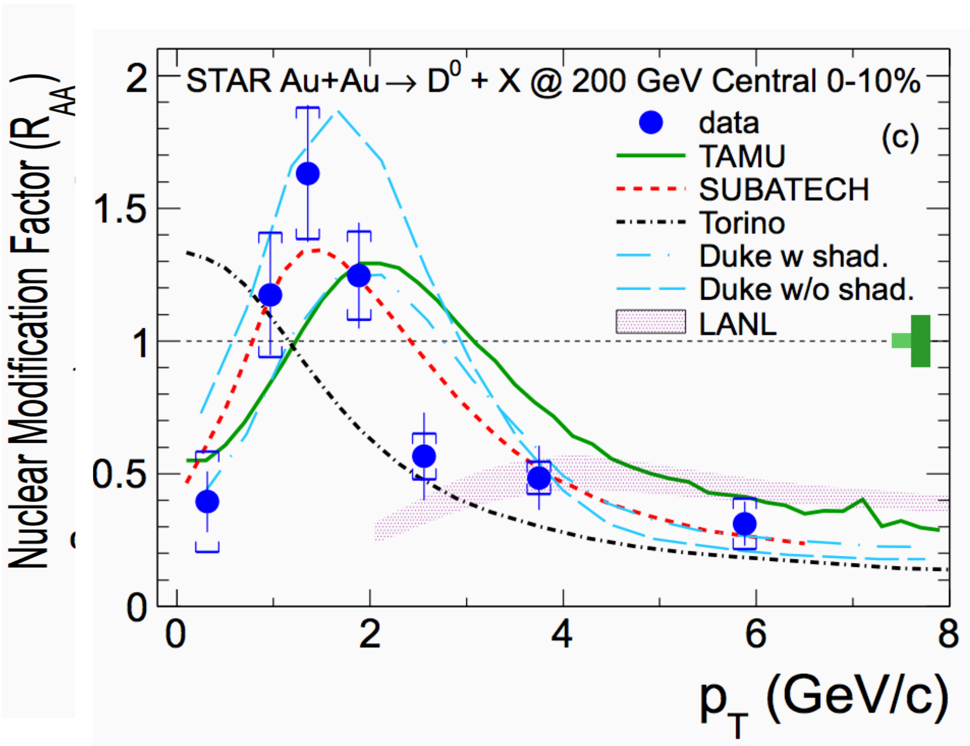
HFT Physics Motivation

- HFT can be used to study heavy flavor production by the measurement of displaced vertices
  - $D^0 \rightarrow K^- \pi^+$
    - BR = 3.83 % $c\tau \sim 120\ \mu m$
  - $\Lambda_c^+ \rightarrow p\, K^- \pi^+$
    - BR = 5.0 % $c\tau \sim 60\ \mu m$
  - B mesons → J/ψ + X or e + X
    - $c\tau \sim 500\ \mu m$



- Total charm yield → base line for charmonium suppression & coalescence
- R_{CP}, R_{AA} of charm and bottom → energy loss in QGP
- Charm (D^0) flow → thermalization?
- $c\bar{c}$ ($D^0 \overline{D^0}$) angular correlation → interaction with the medium
- Λ_c^+/D^0 → test coalescence model

Charm Yield, R_{CP} and R_{AA}



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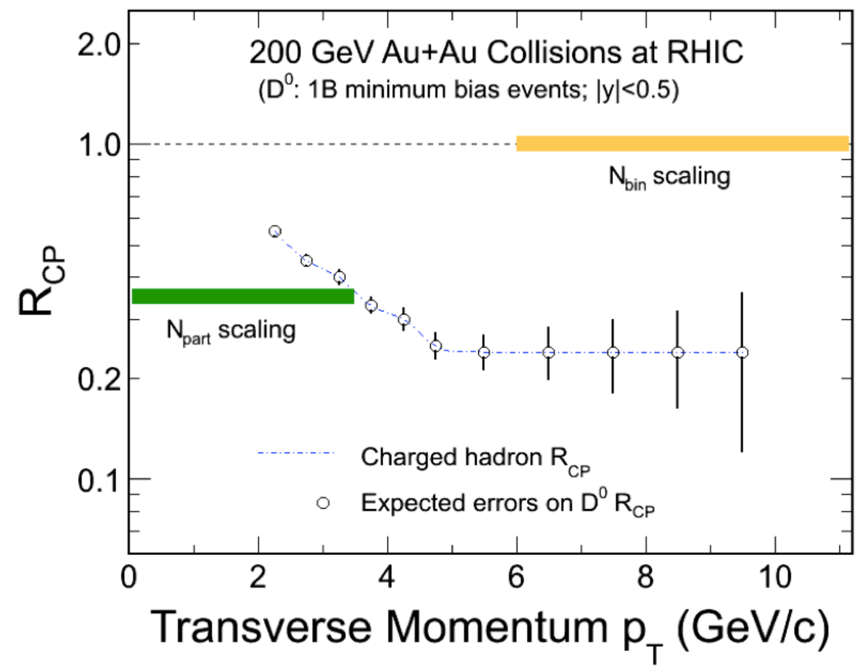

STAR projection with HFT

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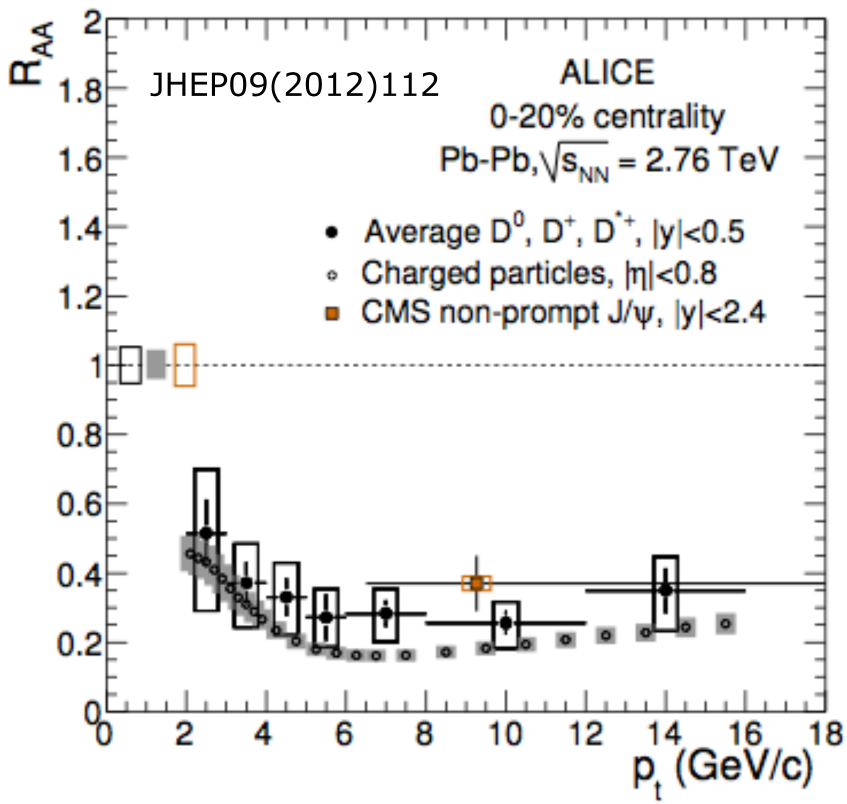
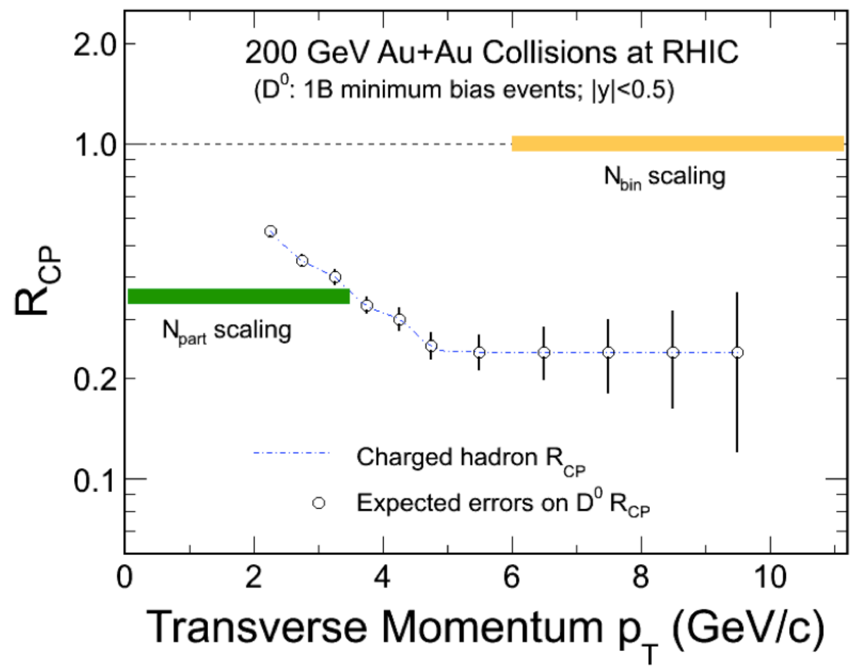
Charm Yield, R_{CP} and R_{AA}

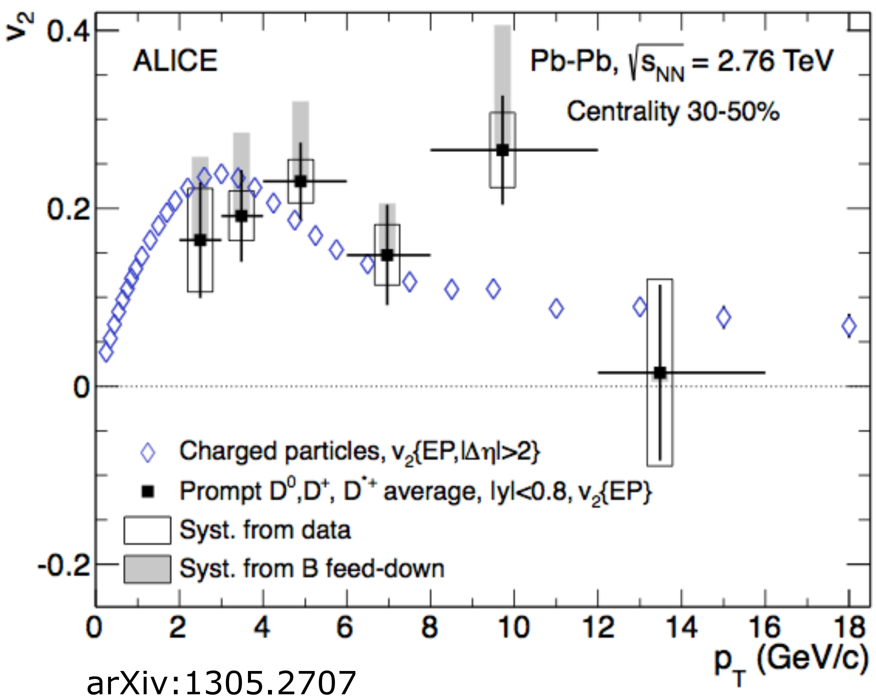




STAR projection with HFT

- Probe possible different medium property with different collision energy.

Charm Flow



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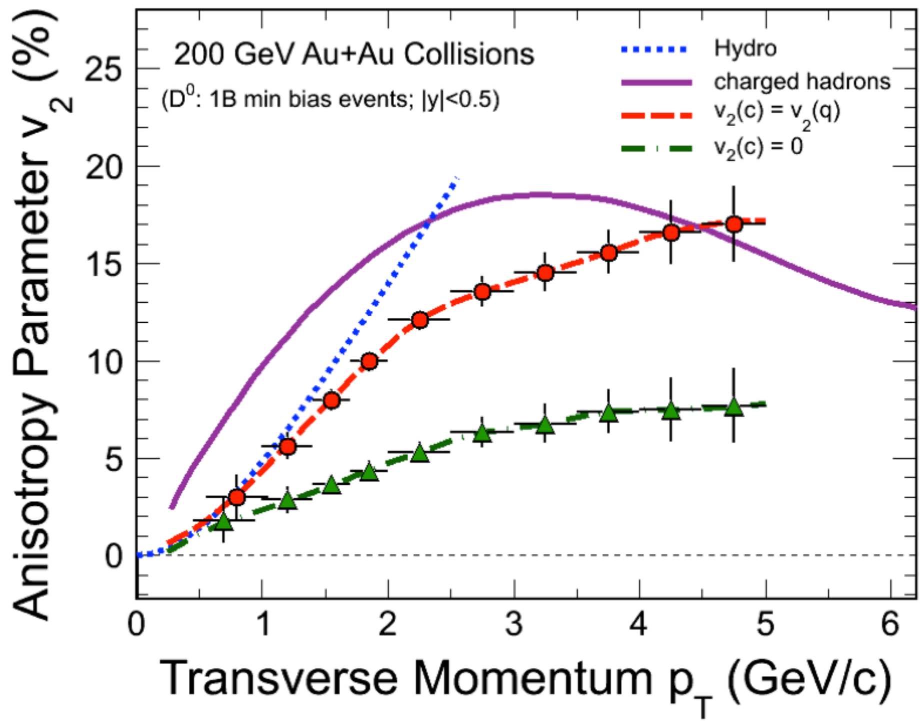

STAR projection with HFT
HFT CDR (STAR Note SN0600)

- Charm collectivity → light flavor thermalization?
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