

# STAR Heavy Flavor Tracker

Spiros Margetis (Kent State Univ.)  
for the STAR Collaboration

# Outline

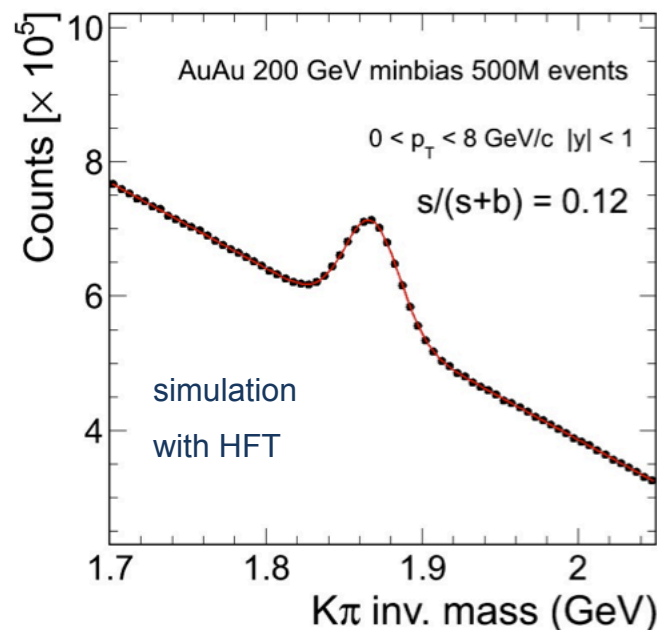
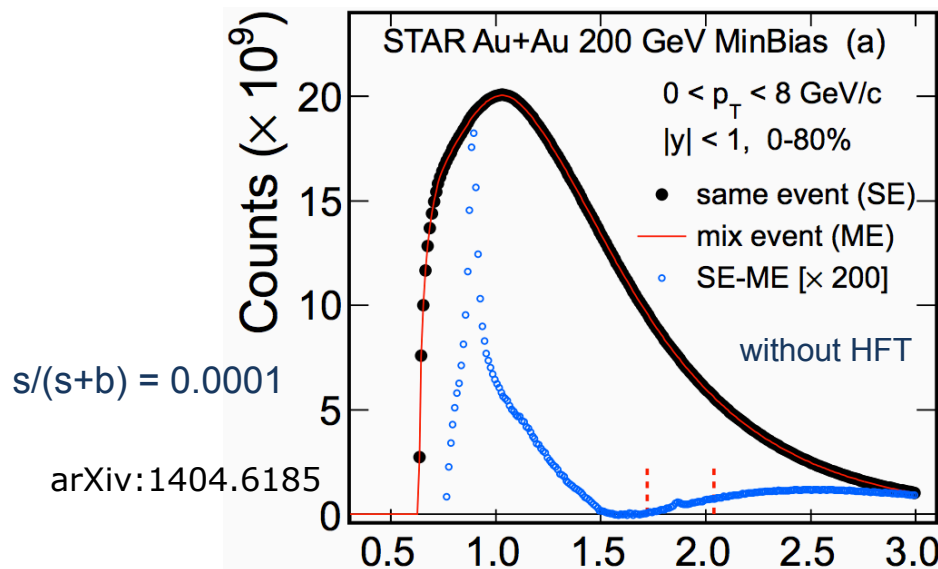
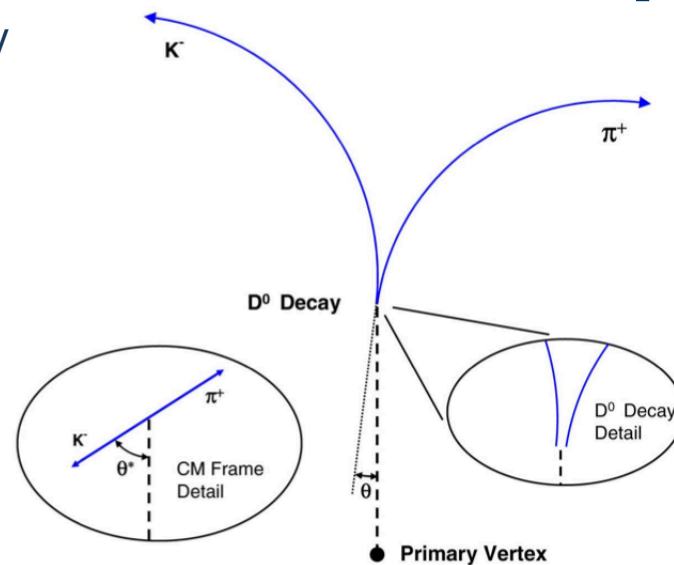
- Physics motivation
- Design
  - Heavy Flavor Tracker
  - PiXeL detector
  - Monolithic Active Pixel Sensors
- Status and performance
  - Status
  - Signal, pedestal and noise scan
  - Efficiency
  - Survey and alignment
  - Hit residual and track DCA
- Summary

# Physics Motivation

- Heavy flavor
    - $m_{b,c} \gg T_C, \Lambda_{\text{QCD}}, m_{u,d,s}$
    - 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.

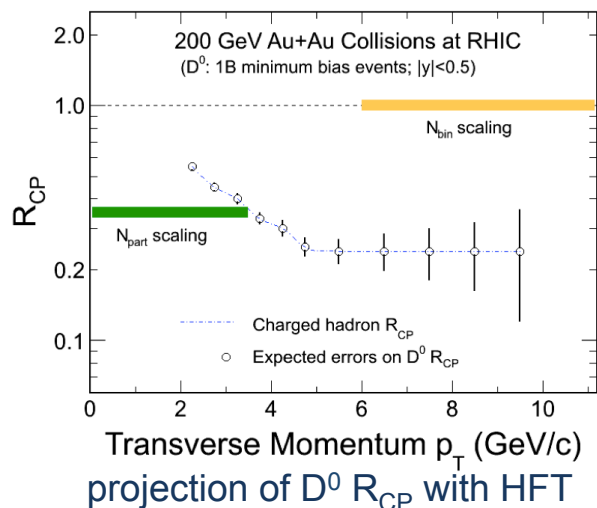
# How Heavy Flavor Tracker Helps

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

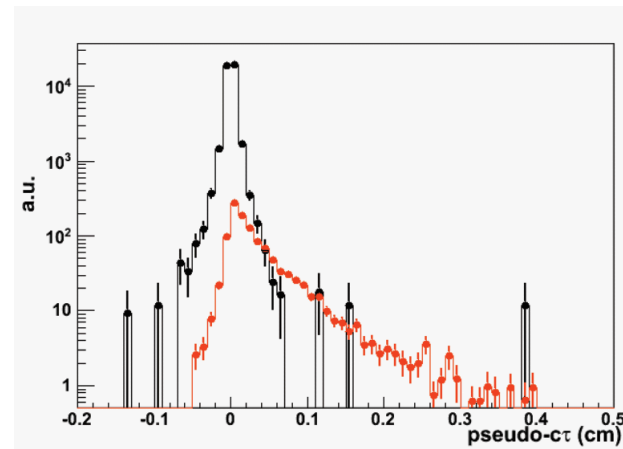
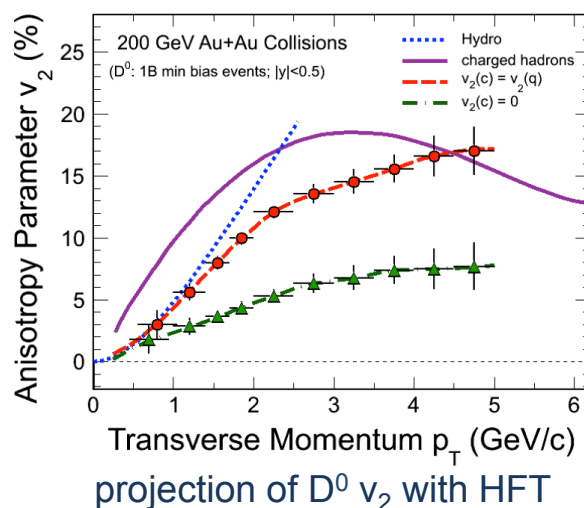




# Examples of Physics with HFT



HFT CDR (STAR Note SN0600)



simulation of separating prompt  
and B decayed  $J/\psi$  with HFT

- Total charm yield  $\longrightarrow$  baseline for charmonium suppression & coalescence
- $R_{CP}$ ,  $R_{AA}$   $\longrightarrow$  energy loss mechanism, QCD in dense medium
- Charm collectivity  $\longrightarrow$  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  $\longrightarrow$  probing the medium with heavy quarks with different masses

# HFT in STAR

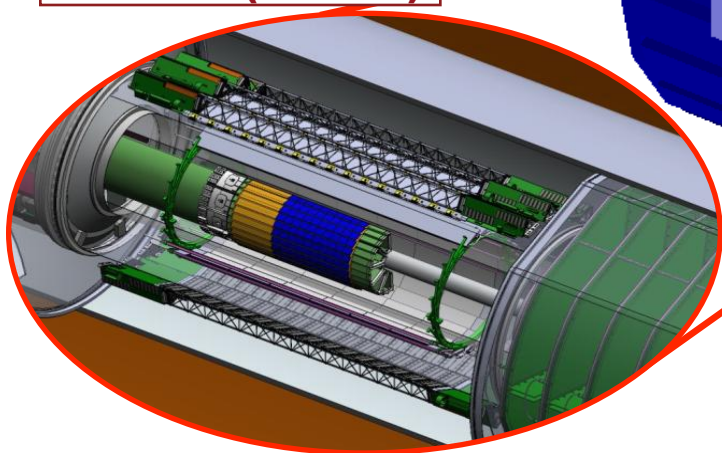
**Tracking &  $dE/dx$ :  
Time Projection Chamber**

**Particle ID:  
Time Of Flight detector**

**Electromagnetic  
Calorimetry:  
Barrel EMC  
+ Endcap EMC**

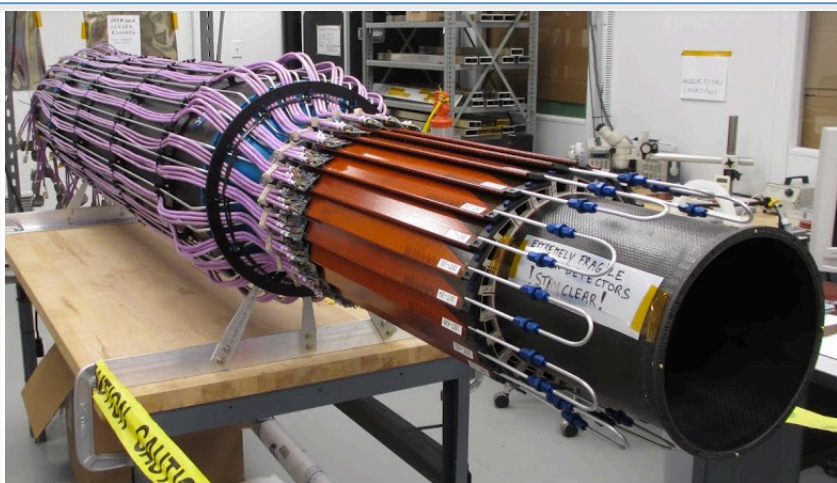
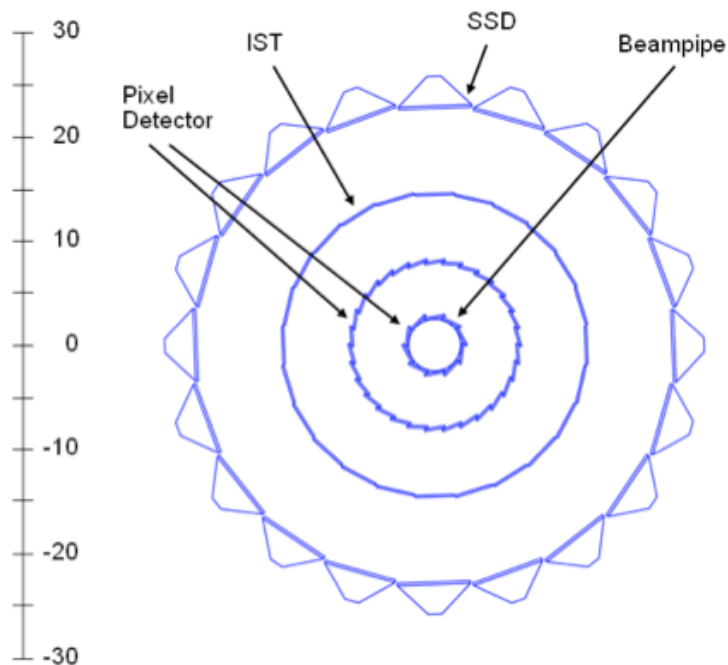
**Muon Telescope  
Detector (runs 13/14)**

**Heavy Flavor  
Tracker (run 14)**



- 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  $\mu\text{m}$  pitch

$\sigma_{r-\phi}$ : 20  $\mu\text{m}$

$\sigma_z$ : 740  $\mu\text{m}$

radius: 22 cm

$X/X_0$ : 1 %



## Intermediate Silicon Tracker:

single-sided double-metal silicon pad

sensors with 600  $\mu\text{m} \times 6 \text{ mm}$  pitch

$\sigma_{r-\phi}$ : 170  $\mu\text{m}$

$\sigma_z$ : 1800  $\mu\text{m}$

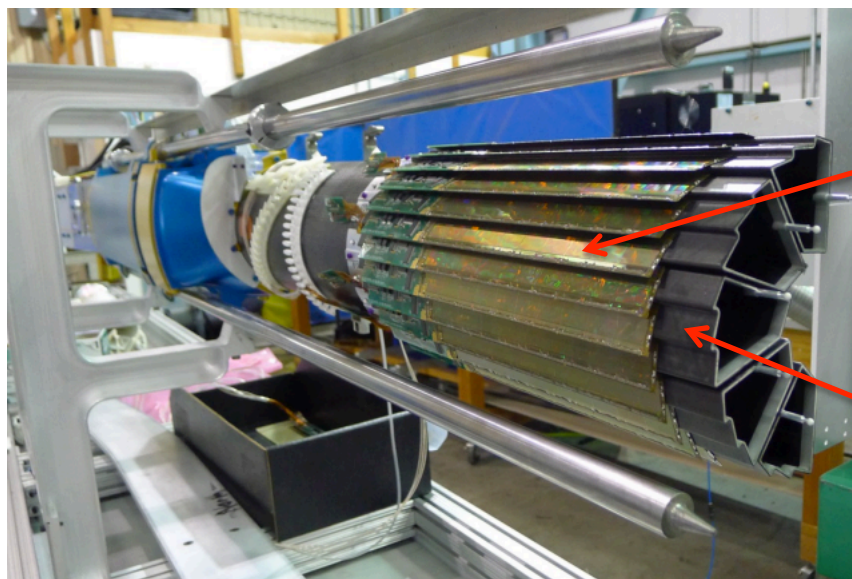
radius: 14 cm

$X/X_0 < 1.5 \%$

The task of SSD and IST is to guide the track from TPC to the innermost PXL detector with high hit density.



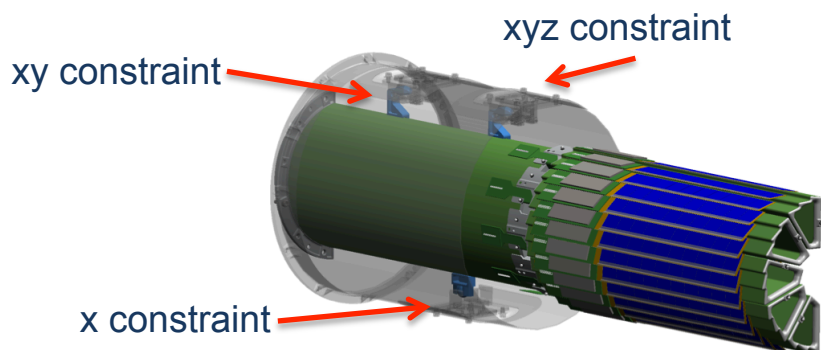
# Pixel Detector Design



PIXEL detector

- 10 sectors \* 4 ladders (1 inner + 3 outer) \* 10 Monolithic Active Pixel Sensors (MAPS)
  - 20.7  $\mu\text{m}$  pixel pitch
  - thinned down to 50  $\mu\text{m}$
  - used in a collider experiment for the first time
- light carbon fiber support
- radius:
  - 2.9 cm (inner)
  - 8.2 cm (outer)
- $\sigma$ :  $\sqrt{\left(20.7/\sqrt{12}\right)^2 + 5^2}$ 

= 7.8  $\mu\text{m}$  vibration
- $X/X_0$ : 0.4 % / layer
- 360 M pixels in total
- air cooled



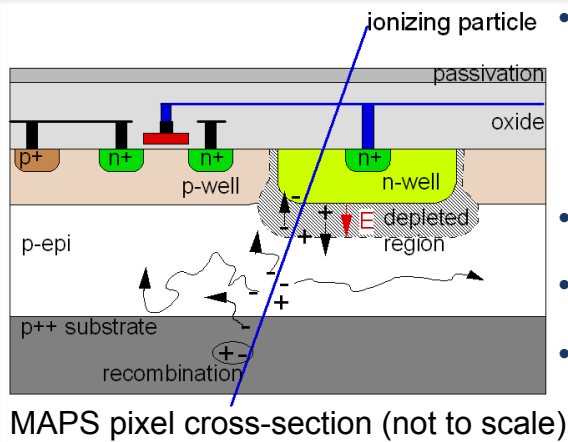
3 kinematic mounts locate the PXL half on the PXL supporting tube.

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

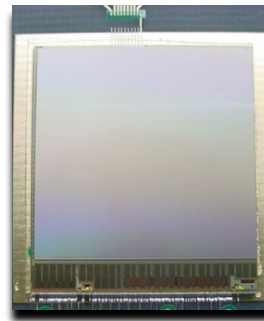
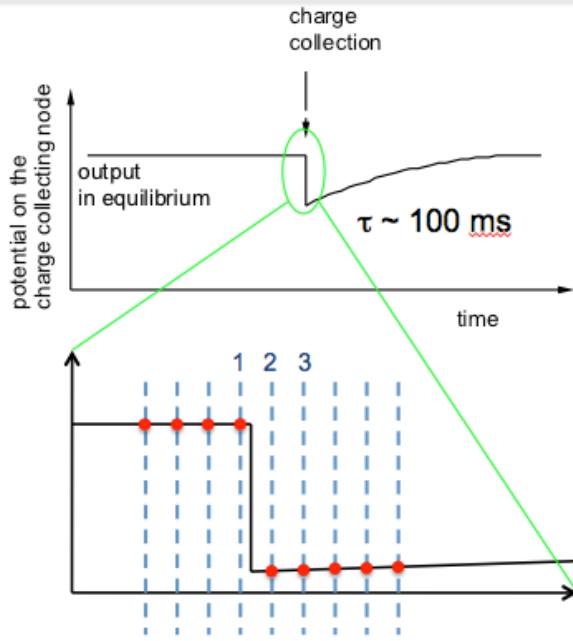
2 sets of PXL detectors and 40 spare ladders are made, to replace damaged detector units when needed.



# Monolithic Active Pixel Sensors

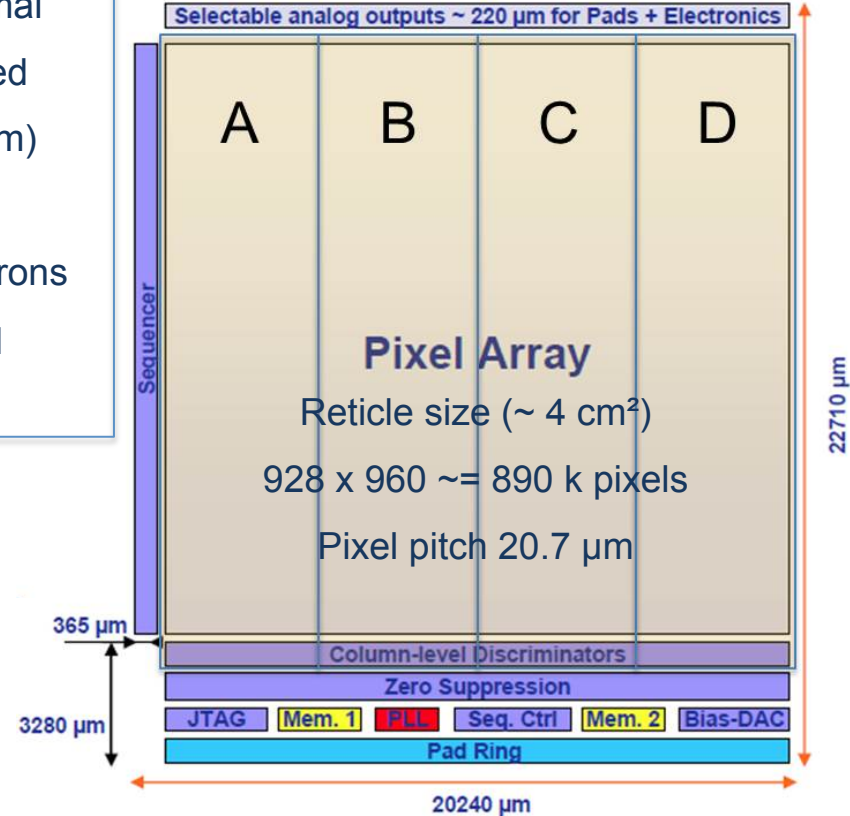


- signal mainly from thermal diffusion in the low-doped epitaxial layer (10~15  $\mu\text{m}$ )
- 100 % fill-factor
- MIP signal < 1000 electrons
- collected in large E-field depleted region

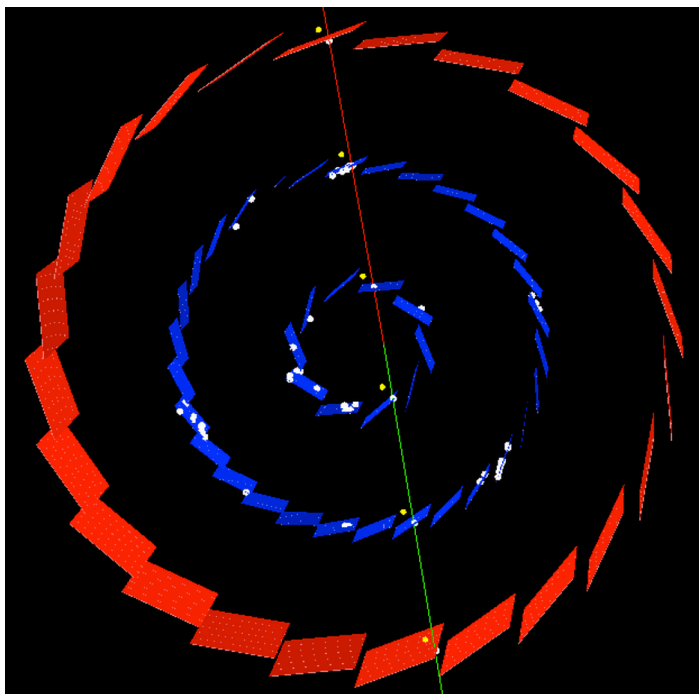


Developed by PICSEL group of IPHC-Strasbourg.  
(Marc Winter et al.)

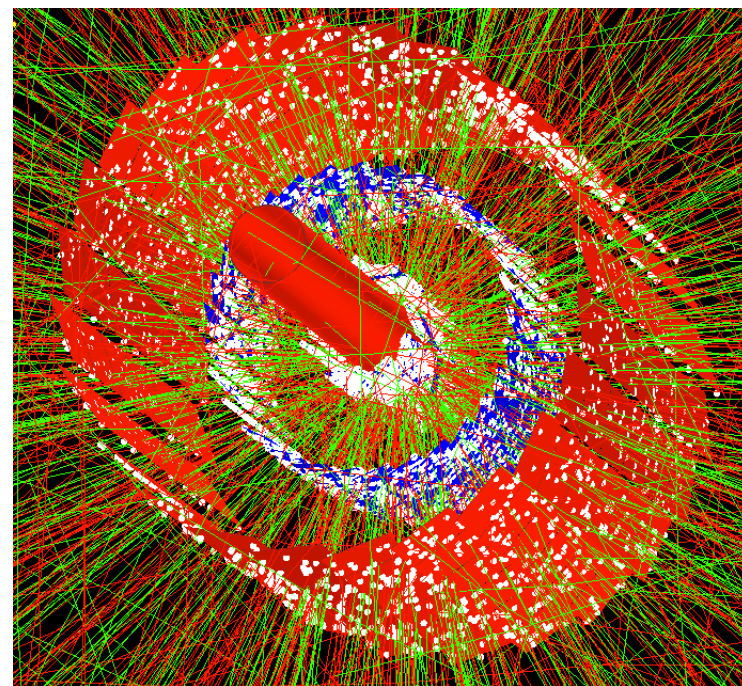
- standard commercial CMOS technology
- sensor and signal processing are integrated in the same silicon wafer
- discriminator & zero suppression in sensor, readout raw hits directly
- integration time 185.6  $\mu\text{s}$



# HFT Status



a cosmic event



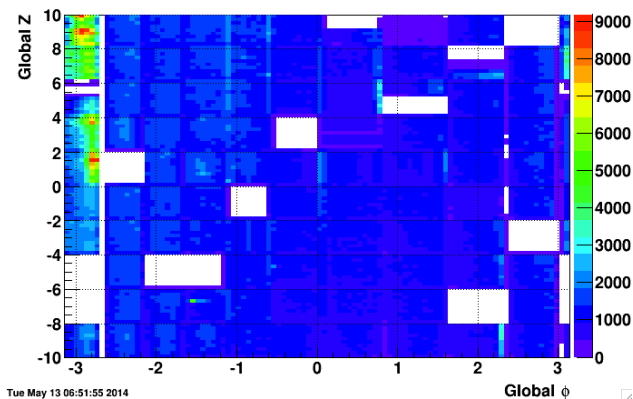
a Au+Au 200 GeV event

- 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 14.5 GeV Au+Au run (Feb. 14 ~ Mar. 11)
- 200 GeV Au+Au data taking with PXL and IST since March 15. Collected ~1.2 Billion events.
- SSD commissioned later in the run – collected about 172 Million events.



# Damage and Remediation

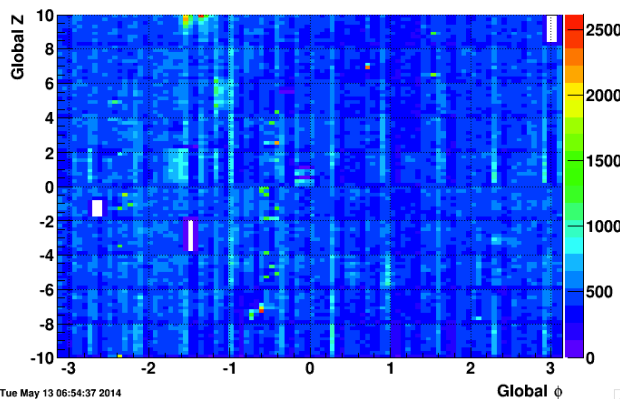
Global  $\phi$  vs. global Z, inner



Tue May 13 06:51:55 2014

Z vs.  $\phi$  of hits in PXL inner layer

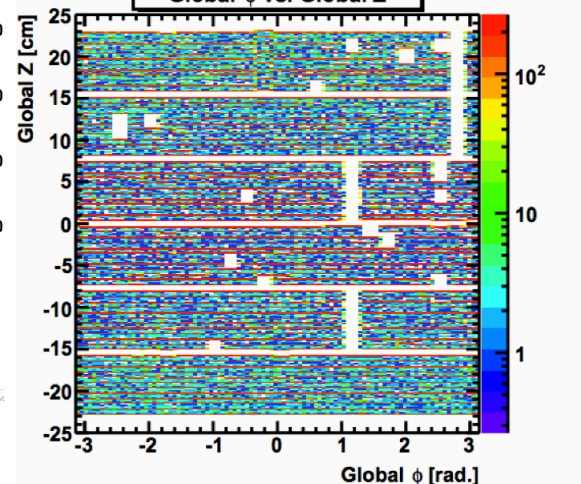
Global  $\phi$  vs. global Z, outer



Tue May 13 06:54:37 2014

Z vs.  $\phi$  of hits in PXL outer layer

Global  $\phi$  vs. Global Z



Entries 1267721

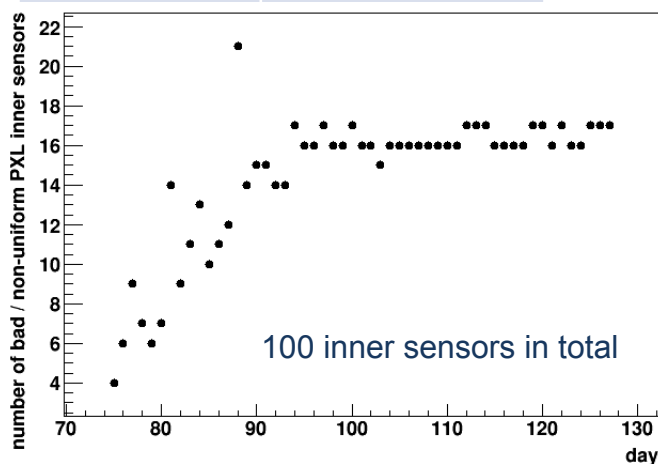
Z vs.  $\phi$  of IST hits

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.

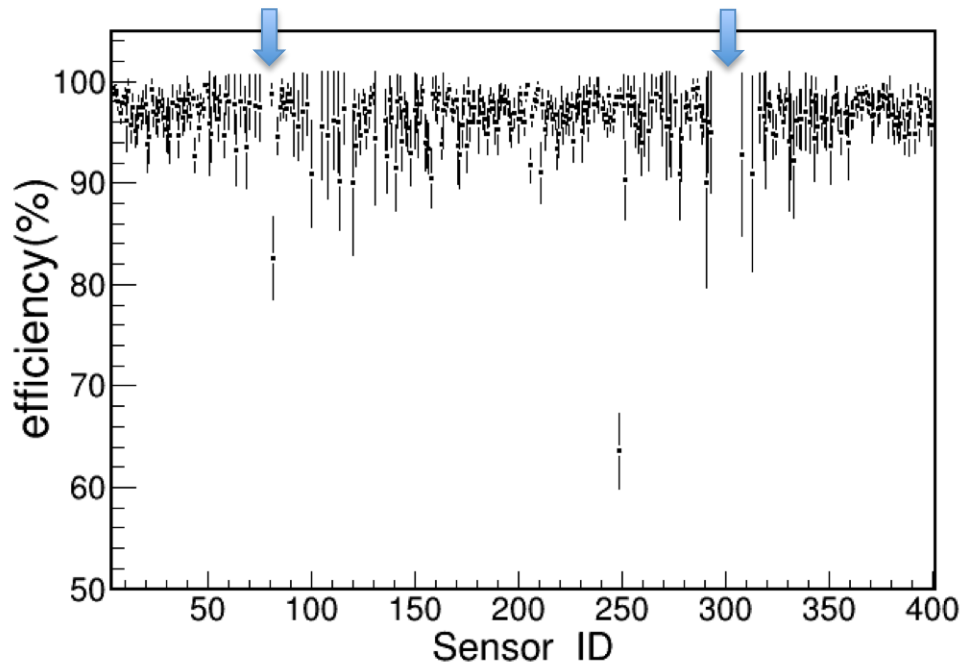
Minimal or no damage for > 1 month: our operational methods were successful at stopping or greatly reducing the rate of damage.

- 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 cosmic

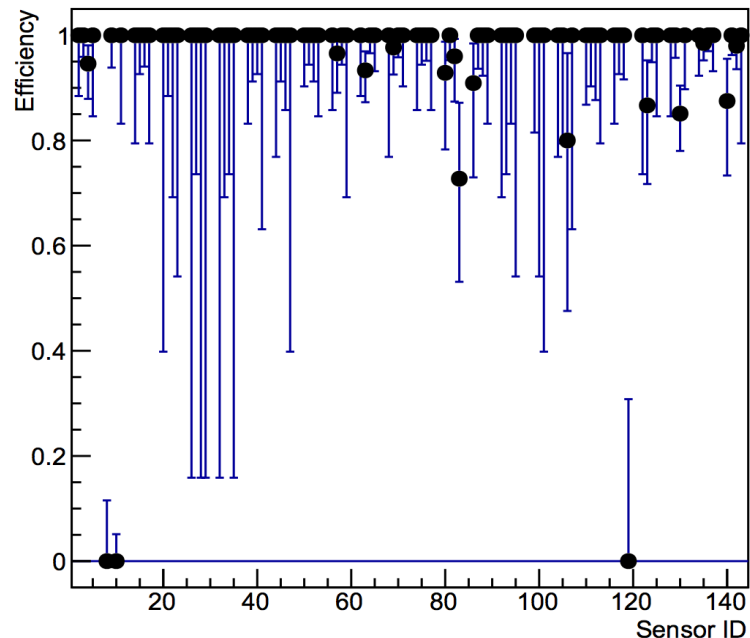


PXL sensor efficiency measured with cosmic ray:

hits / projection

- Before the detector response optimization and running with the beam
- **Average = 97.2 %**
- Tuning for including HFT in tracking is going on...

IST Efficiency from Cosmics Data



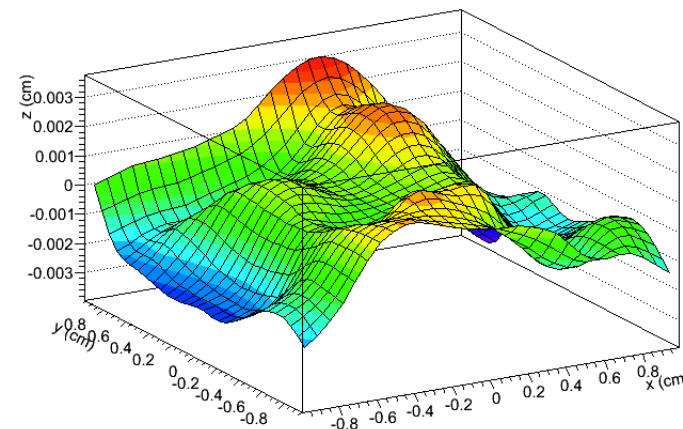
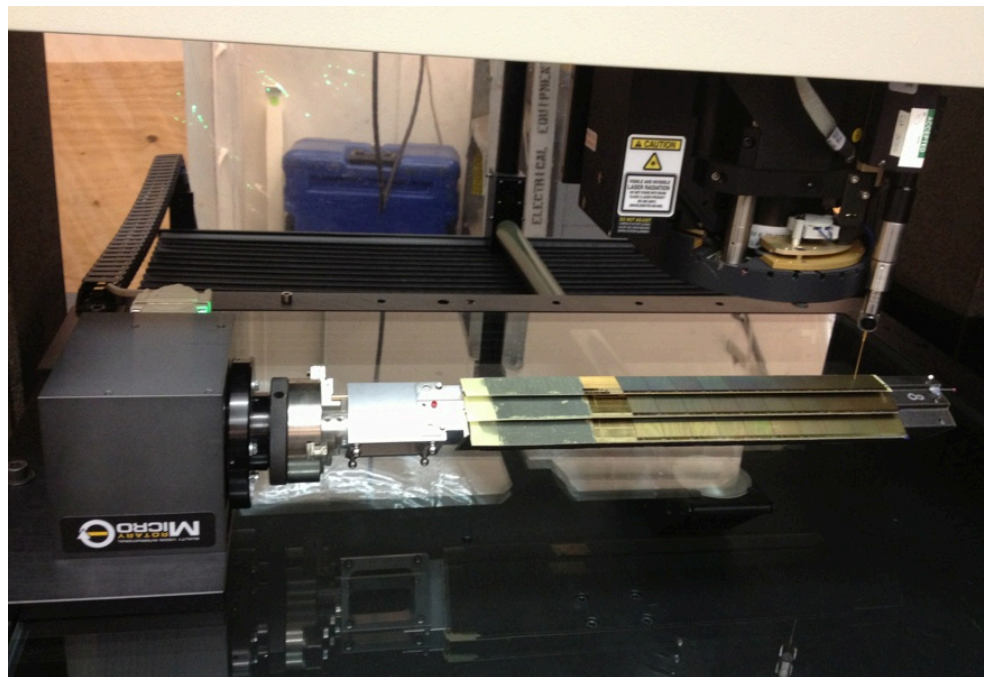
IST efficiency measured with cosmic ray:

hits / projection

**Average = 98.6 %**



# Survey and Alignment



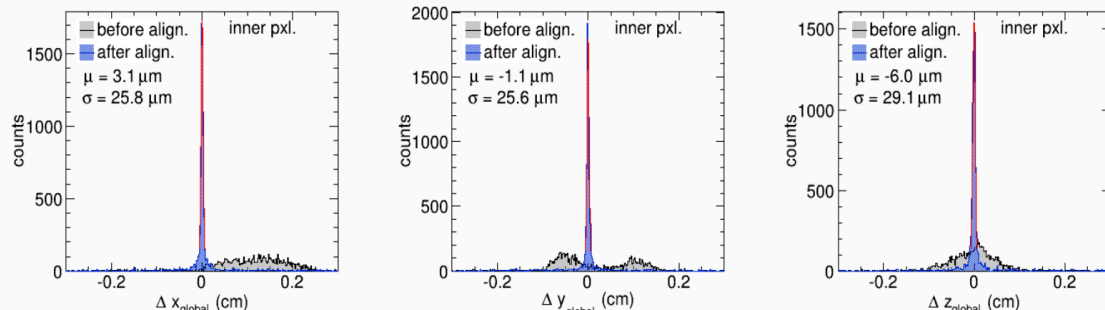
PXL sensor surface profile from survey

$\pm 30 \mu\text{m} > \text{PXL hit error}$

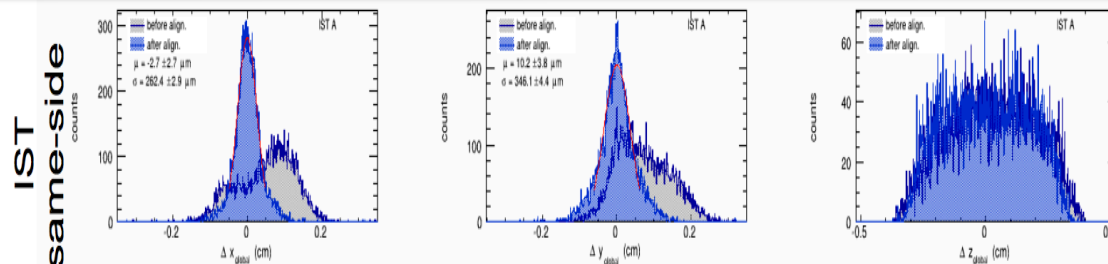
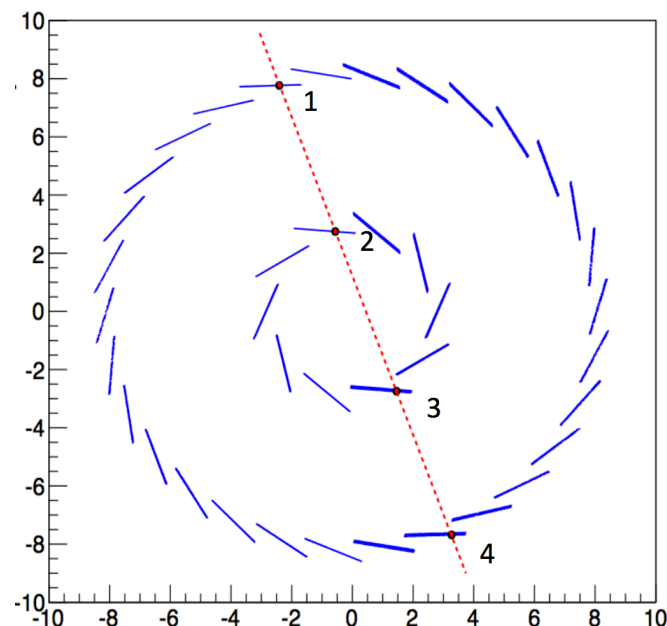
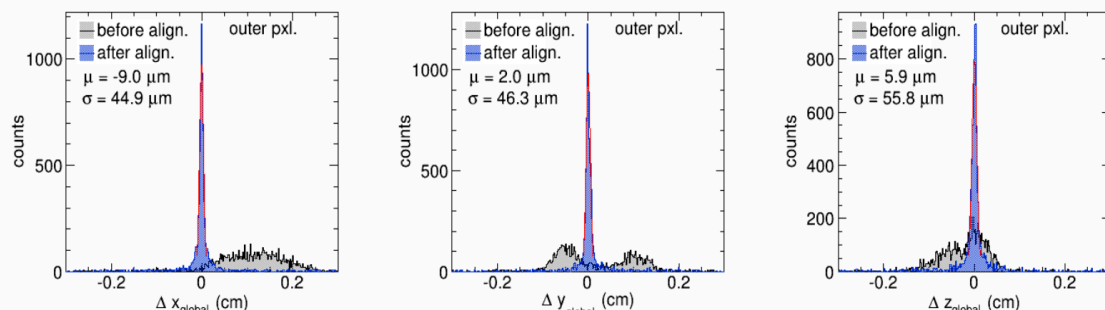
Coordinate Measurement Machine is used to survey HFT detector parts.

- Survey fixed sensor-on-ladder and ladders-on-sectors plus surface profiles (PXL)
- Repeatability/time dependences were found to be  $\sim 10$  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

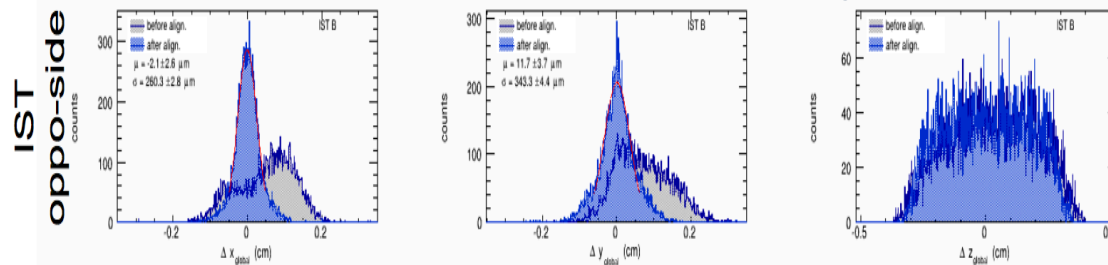
# Survey and Alignment



PXL hit residual distribution before and after alignment



IST hit residual distribution before and after alignment

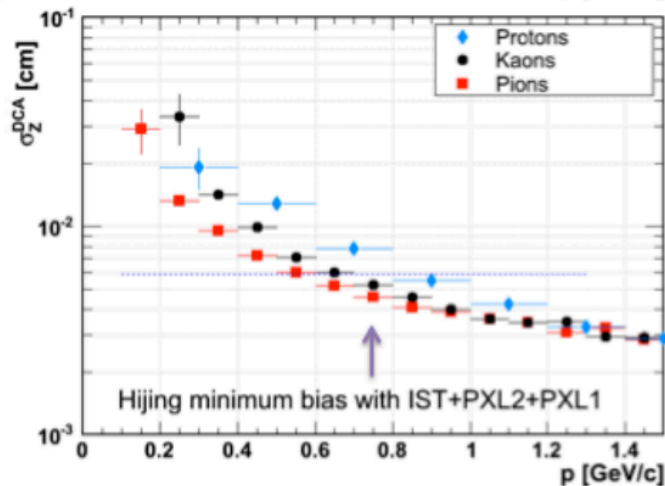
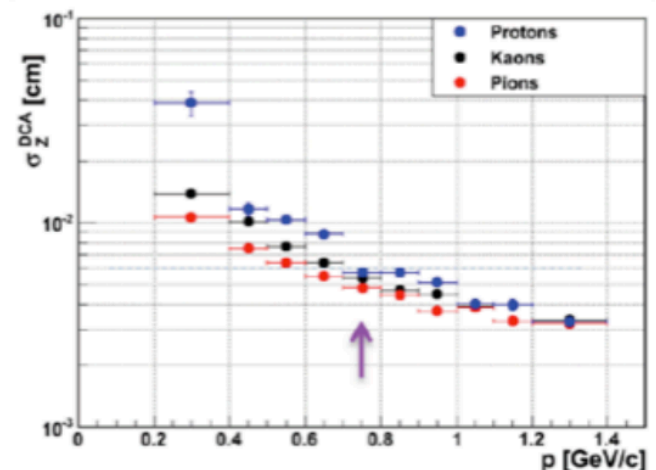
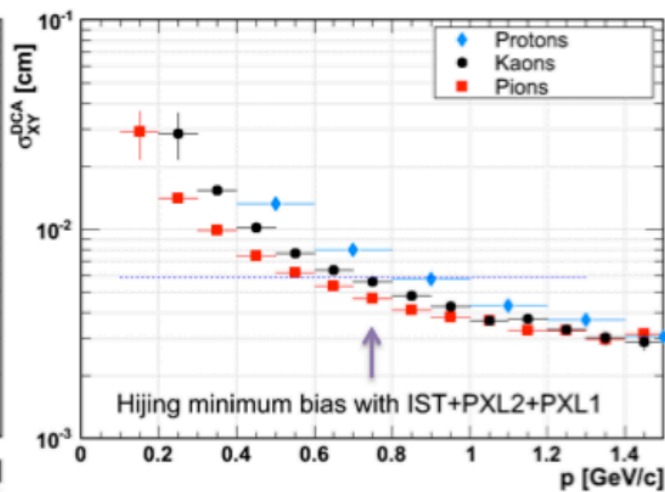
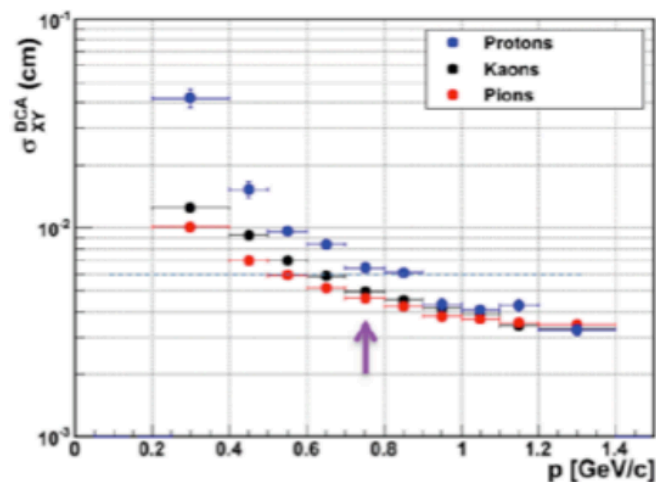


- Cosmic ray and Low Luminosity data are used to align and monitor different HFT detector parts
- Widths are compatible with expected extrapolation errors (hit resolution+MCS)

# Track DCA

Measured

Simulated

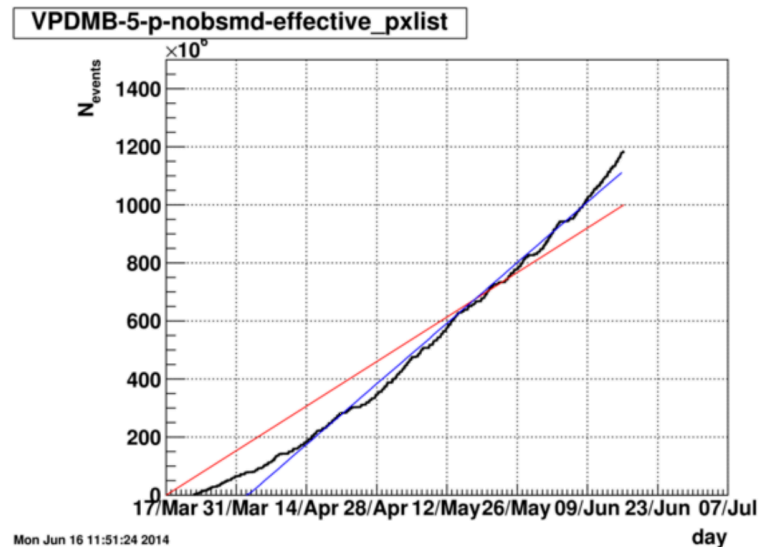


DCA resolution vs. momentum (averaged over phi) for pion, kaon and proton tracks with 1 IST hit + 2 PXL hits  
 $\sim 30 \mu\text{m}$  at high  $p_T$

Achieved CD4 goal:  $<60 \mu\text{m}$  for kaon with  $p_T = 750 \text{ MeV}/c$

# 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  $\sim 30$  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.

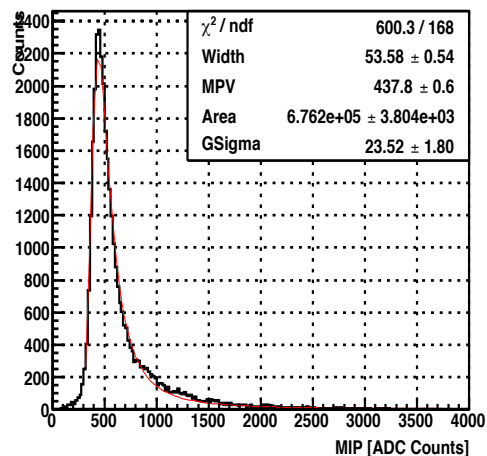


**END**

# Extra Slides

# STAR Signal, Pedestal and Noise Scan

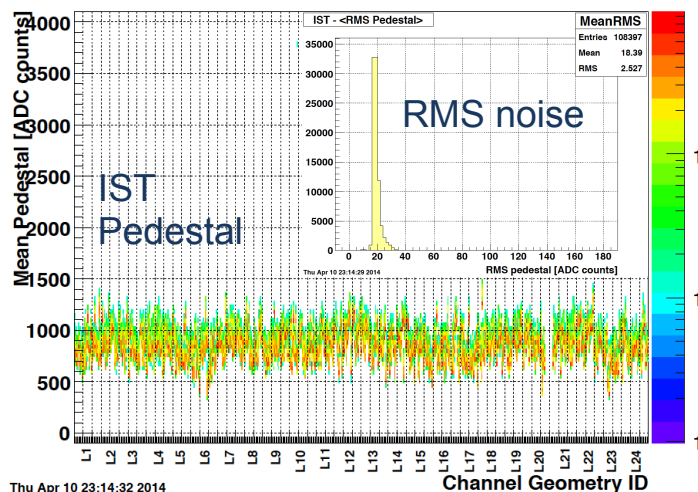
IST hit ADC spectrum w/ track angle correction



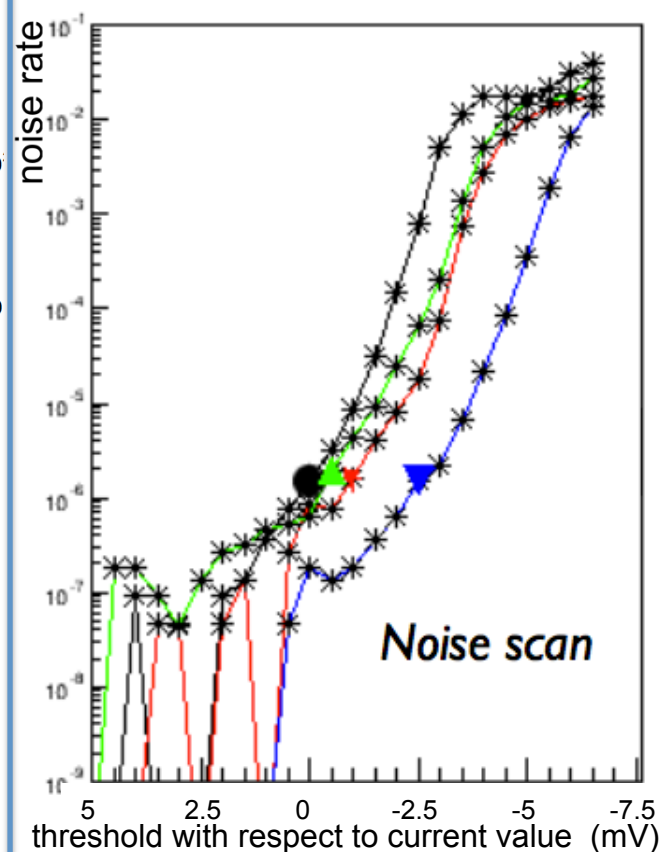
IST signal with MIP  
MVP ~ 440 ADCs

- signal to noise ratio ~ 23

See details at poster M-30 by Yaping Wang



IST has stable pedestal and RMS level  
over all channels



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

**Tracking & dE/dx:  
Time Projection Chamber**

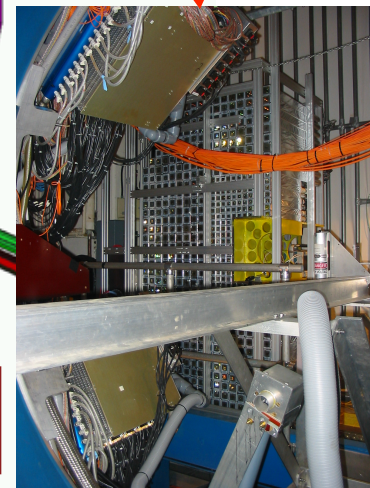
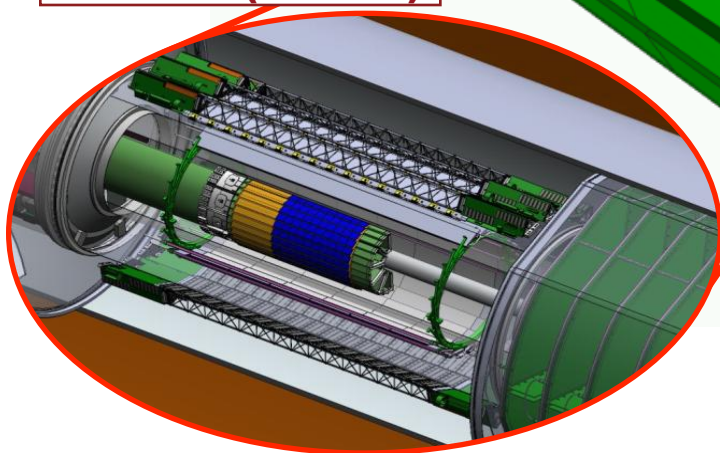
**Particle ID:  
Time Of Flight detector**

**Electromagnetic  
Calorimetry:  
Barrel EMC  
+ Endcap EMC  
+ Forward Meson  
Spectrometer  
( $-1 \leq \eta \leq 4$ )**

**Muon Telescope  
Detector (runs 13/14)**

**Heavy Flavor  
Tracker (run 14)**

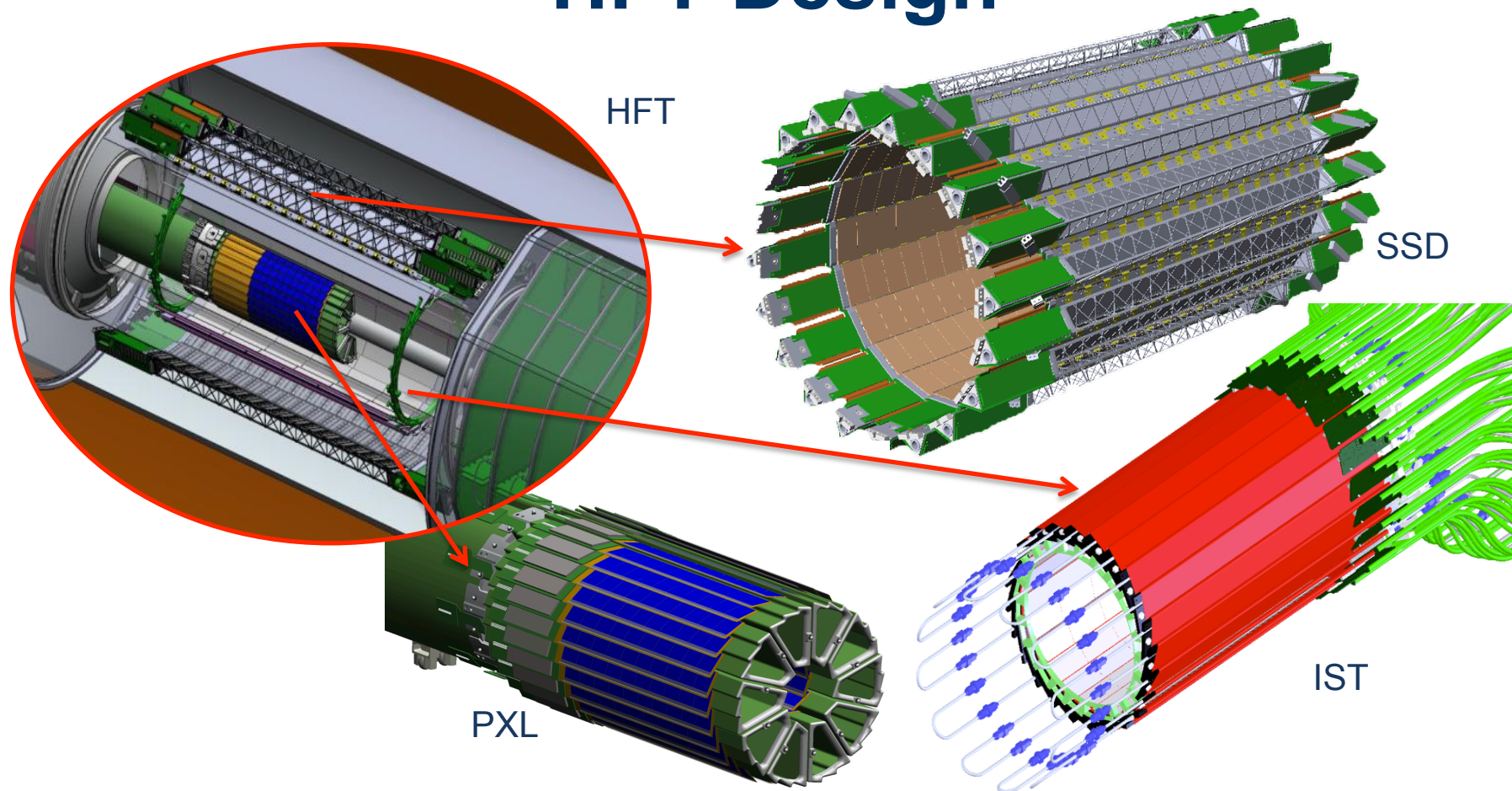
**Forward GEM  
Tracker (runs 12/13)**



- Full azimuthal particle identification at middle rapidity



# HFT Design

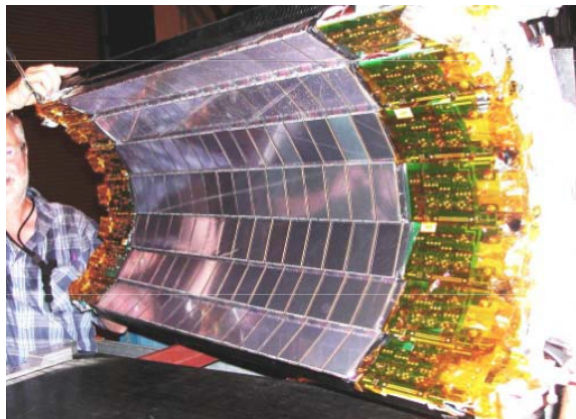
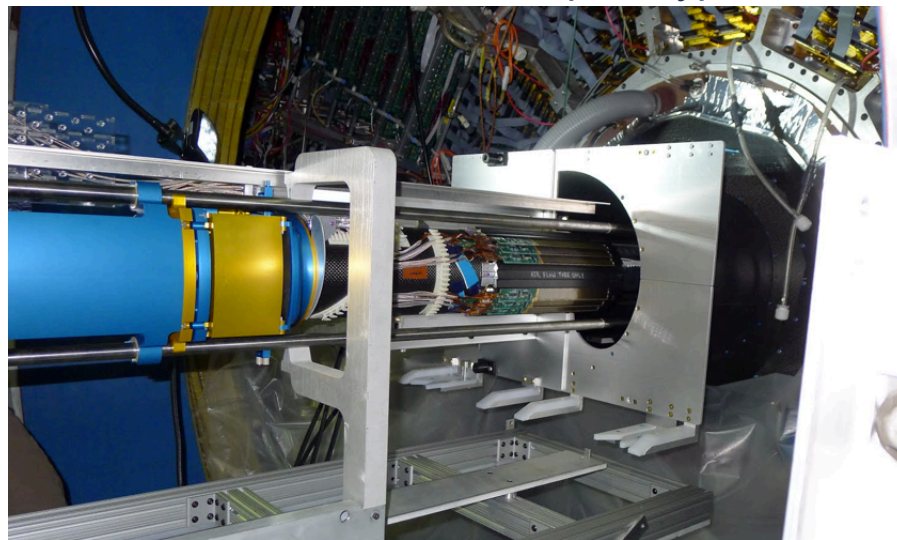


Sub detector	r (cm)	Sensitive units	$\sigma_{R-\phi}(\mu\text{m})$	$\sigma_z(\mu\text{m})$	$X/X_0(\%)$
Silicon Strip Detector	22	2 side strips with 95 $\mu\text{m}$ pitch	20	740	1
Intermediate Silicon Tracker	14	500 $\mu\text{m}$ x 1cm strips	170	1800	<1.5
PIXEL	2.5/8	20 $\mu\text{m}$ pixel pitch	12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

# HFT Status

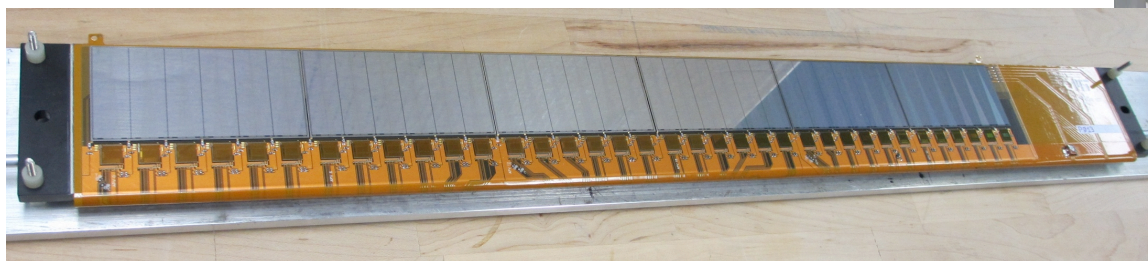
- Engineering run for PXL prototype (3 out of 10 sectors) finished
  - installed on May 8, 2013
    - within 12 hours
  - first PXL data in daq file on May 10
  - 78 M events taken with PXL
- full system to be installed in 2014

PXL prototype insertion



SSD part

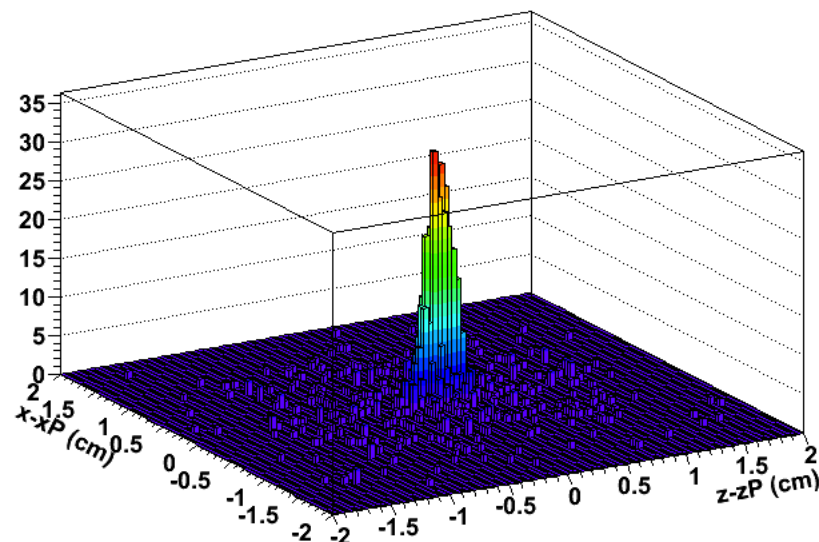
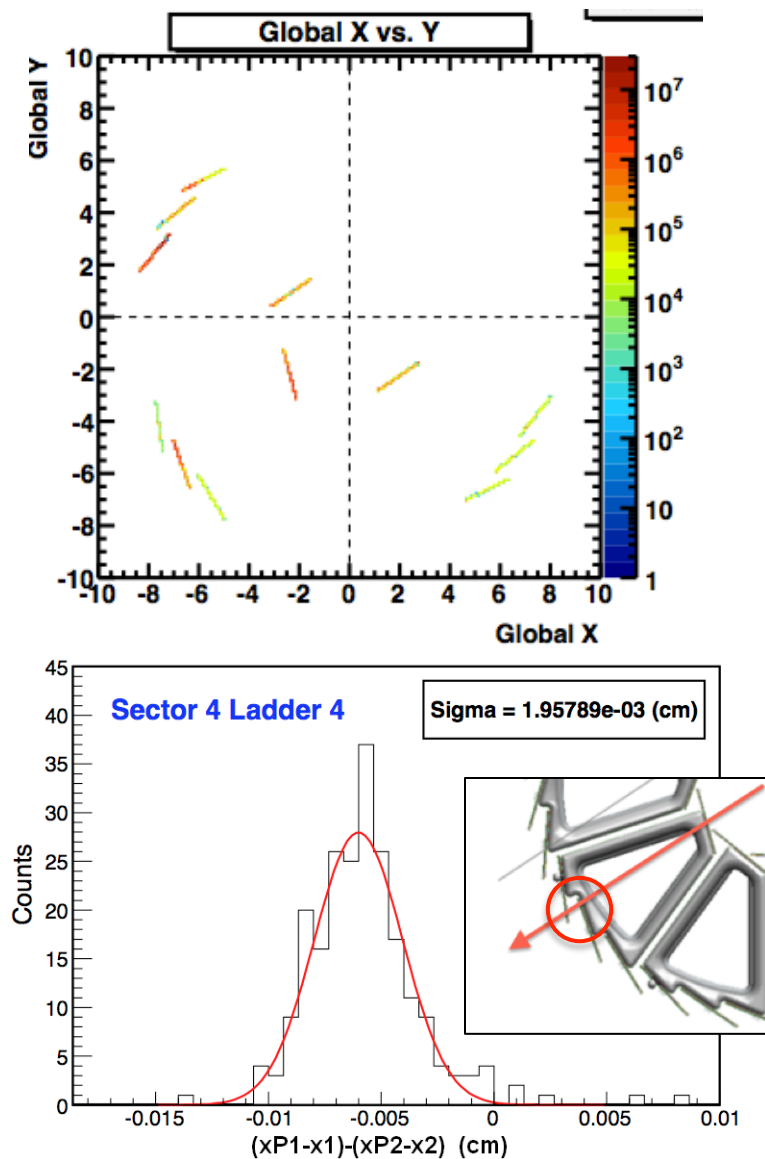
IST ladder



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 =  $20 / \sqrt{2} = 14$  microns  
~ 12 microns resolution of designed goal

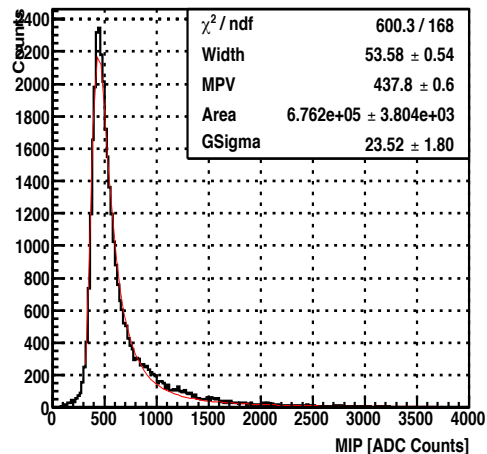
# RHIC Run Plan

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

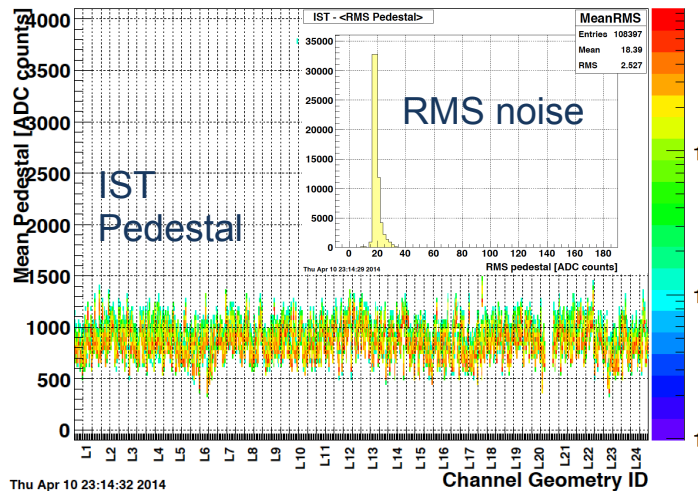
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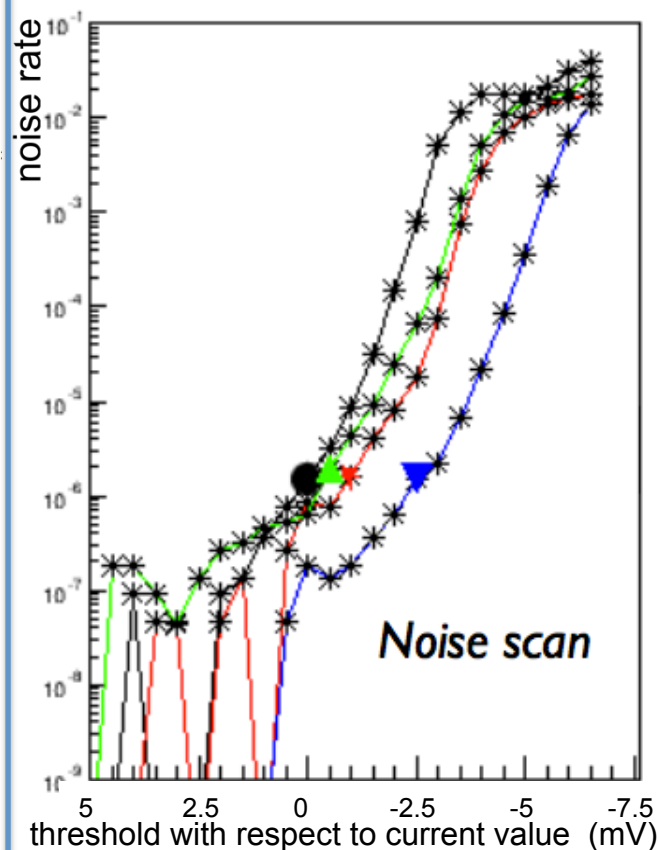
IST signal with MIP

MVP ~ 440 ADCs

- signal to noise ratio ~ 23



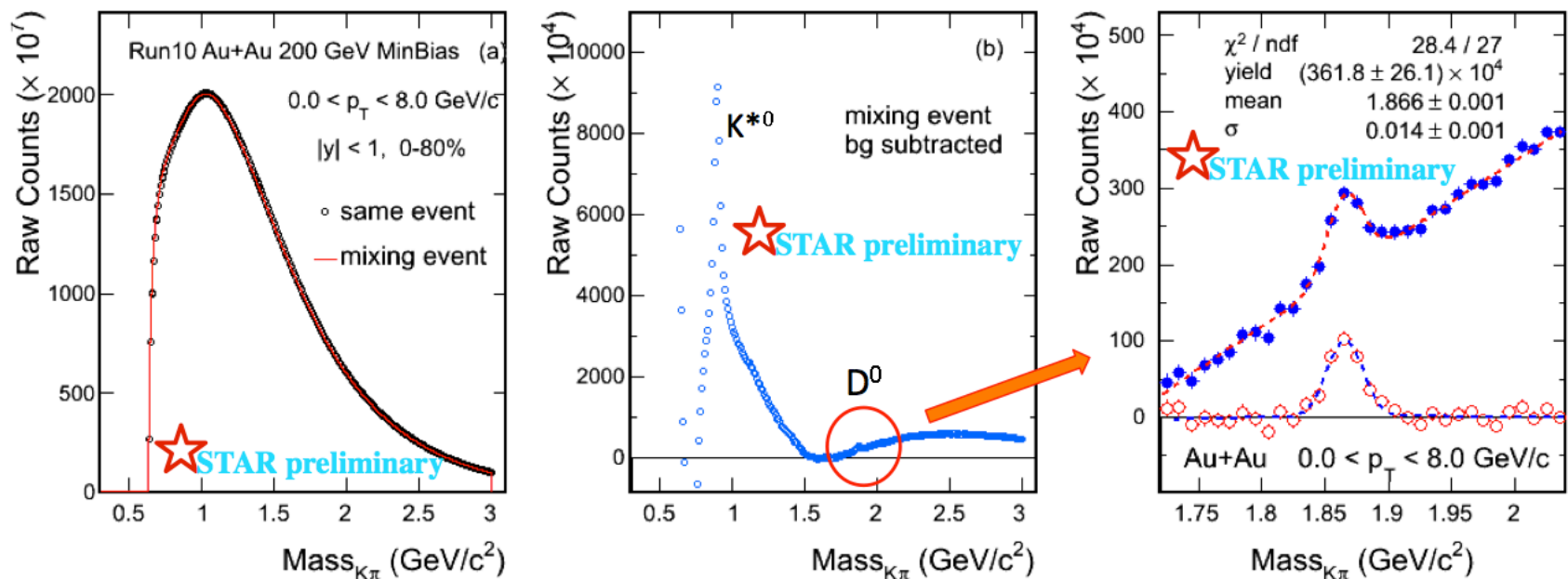
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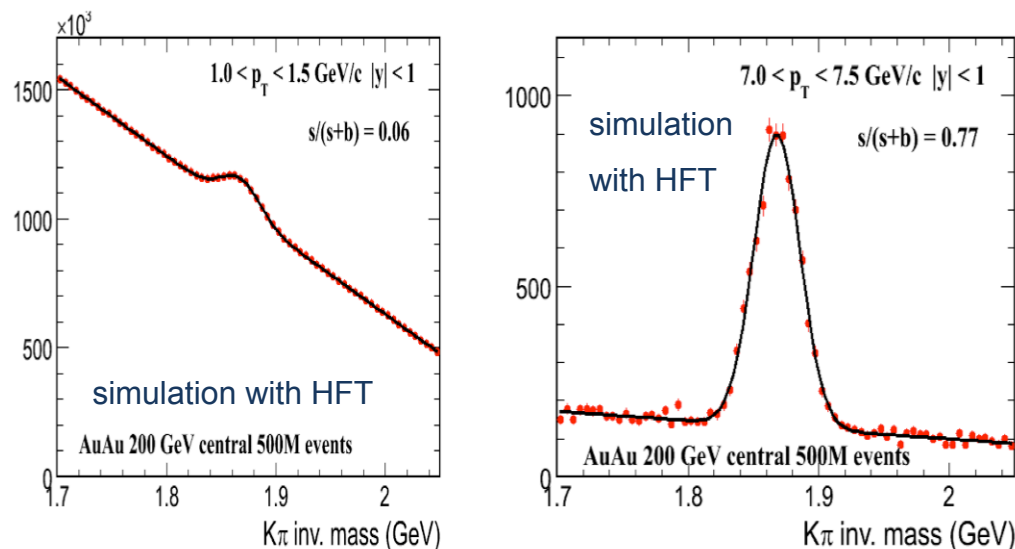
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# Charm Yield, $R_{CP}$ and $R_{AA}$

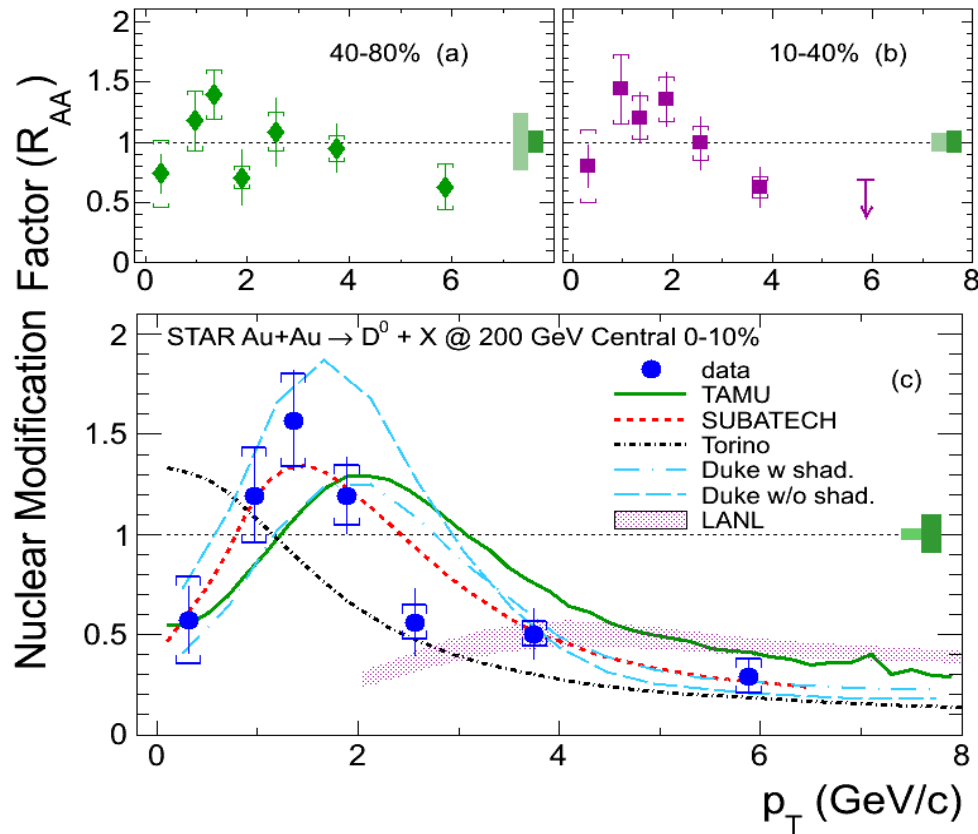


arXiv:1404.6185; subm. to PRL

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



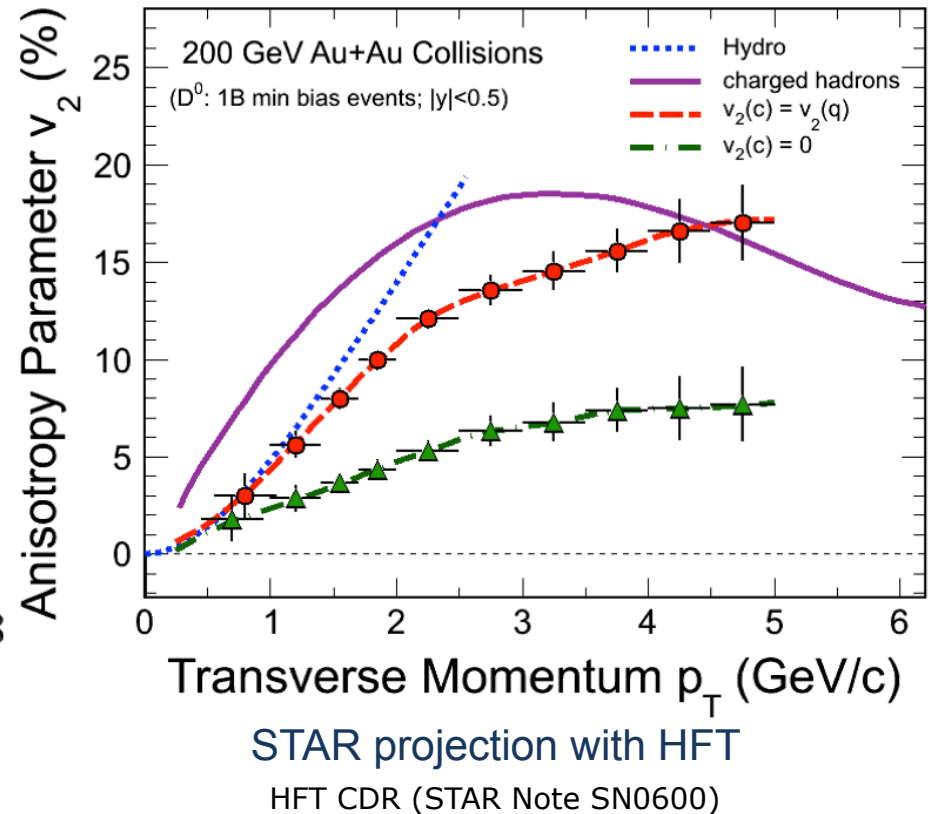
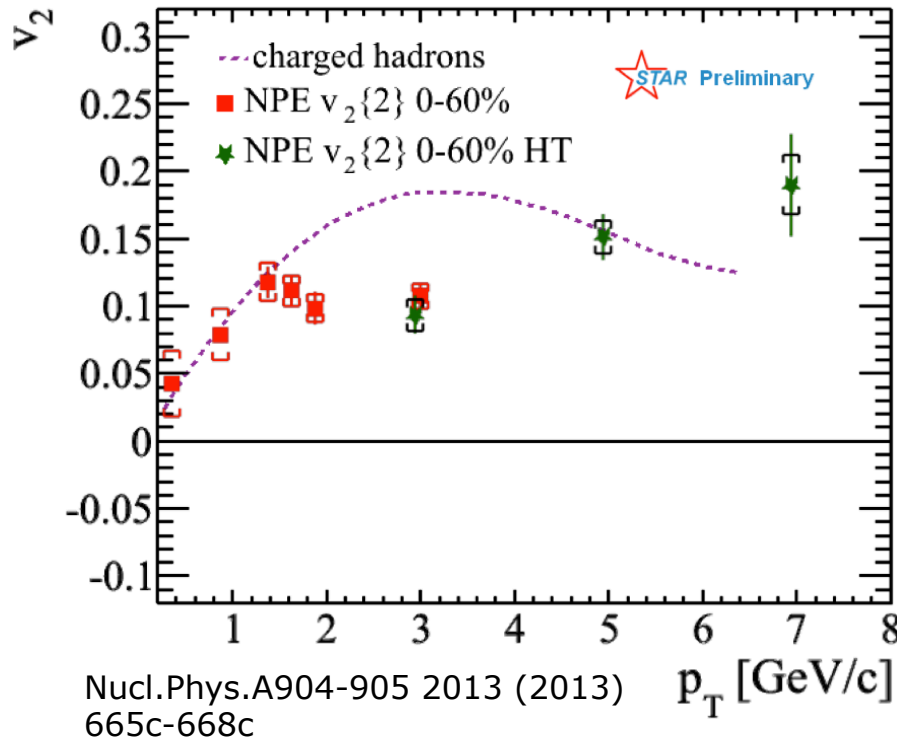
# Charm Yield, $R_{CP}$ and $R_{AA}$




arXiv:1404.6185; subm. to PRL

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

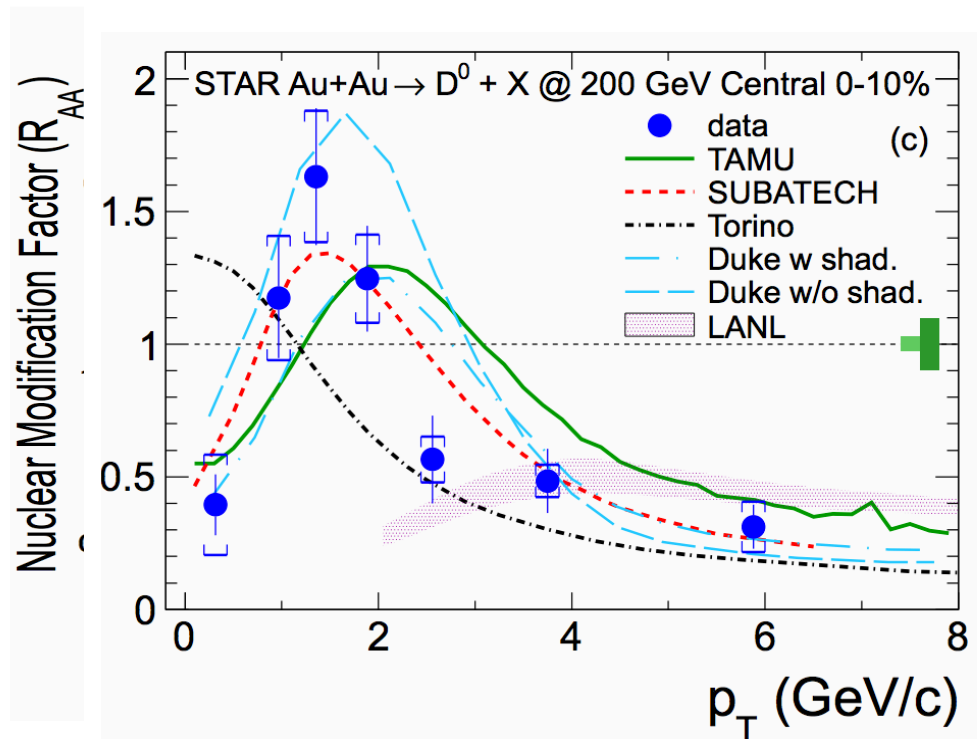
# Charm Flow



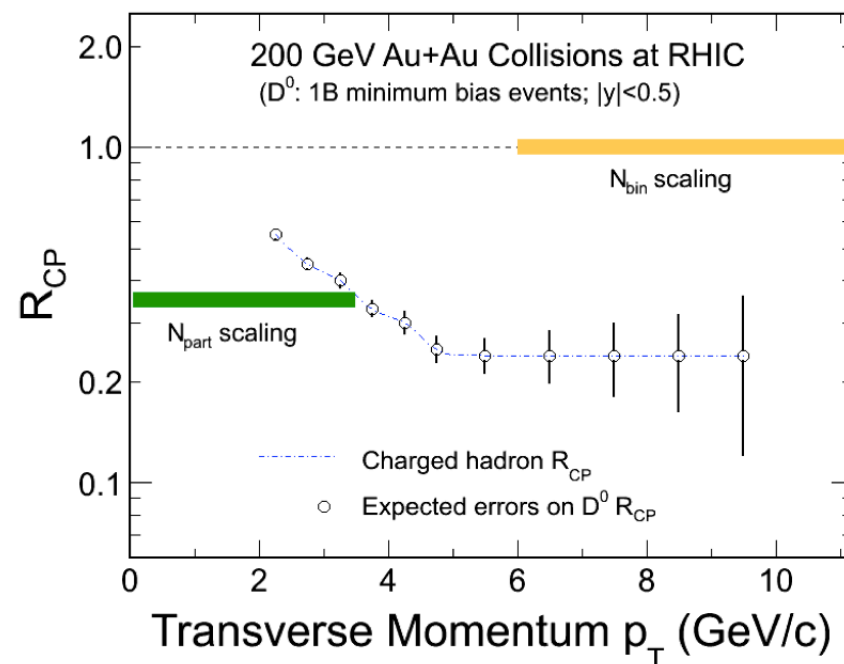
- Charm collectivity  light flavor thermalization?
- $D^0 v_2$  is a more direct measurement of charm flow than non-photonic electron  $v_2$ .
- With HFT STAR is able to measure  $D^0 v_2$  at low  $p_T$  region, which is sensitive to charm flow.



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



arXiv:1404.6185; subm. to PRL

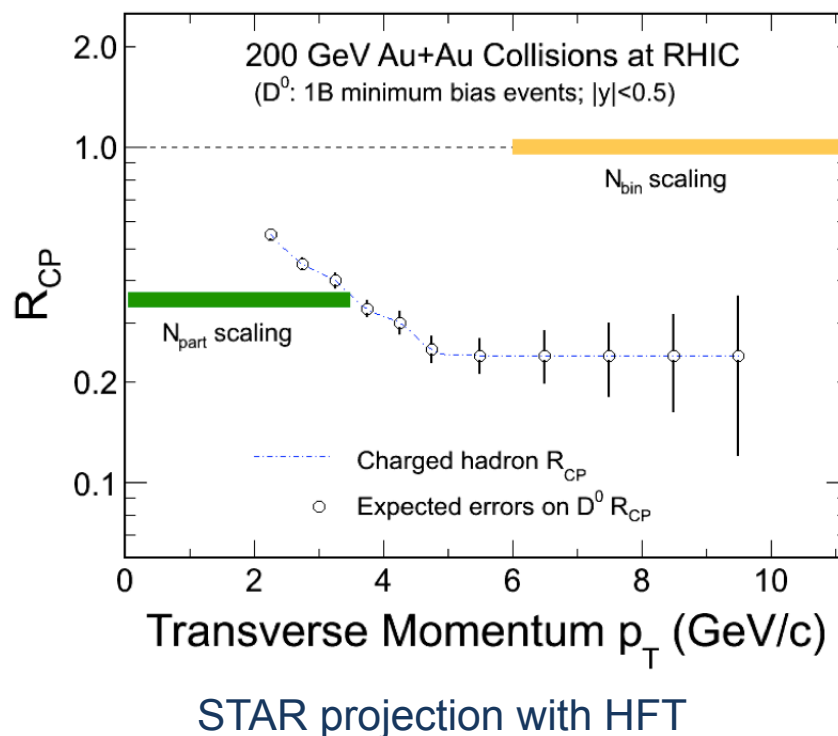
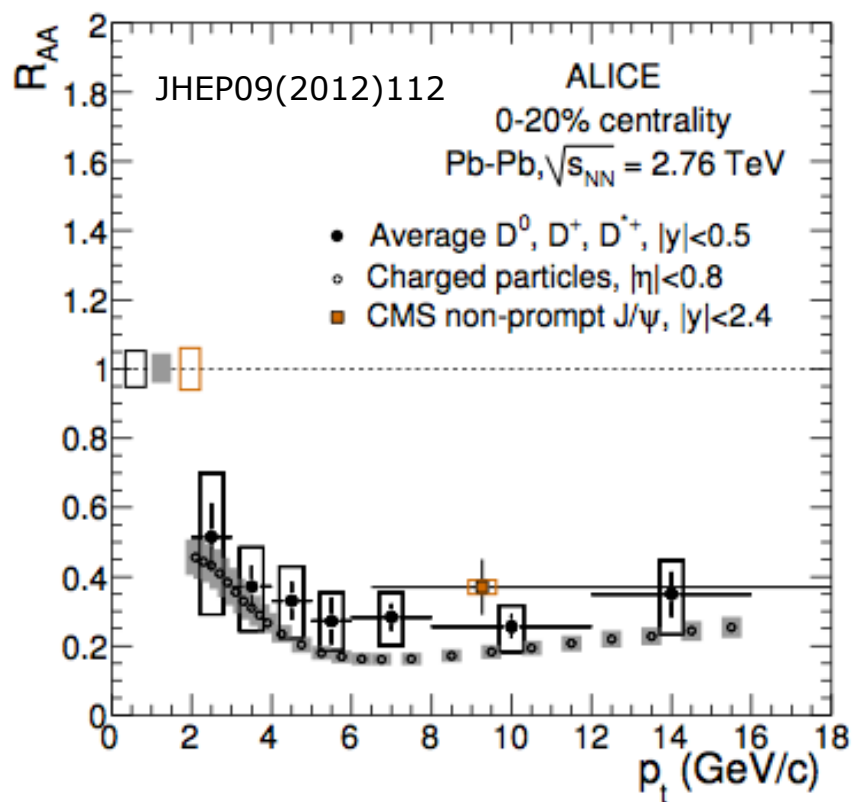


STAR projection with HFT

HFT CDR (STAR Note SN0600)

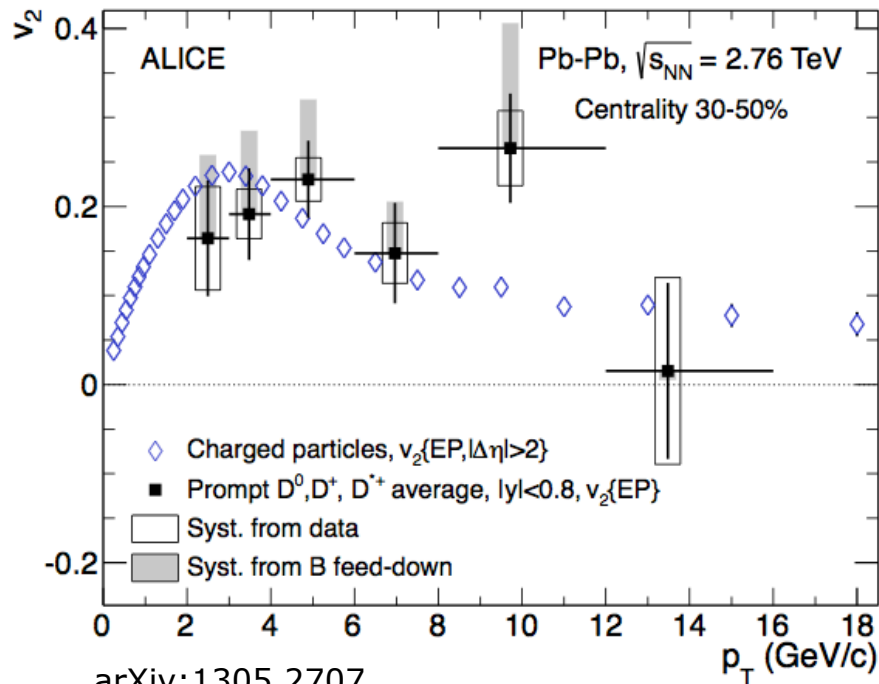
- Much better precision with HFT than current STAR measurement
- Low radiation length enable reconstruction of  $D^0$  with  $p_T$  starting from  $\sim 0$ , enabling charm total cross section measurement.

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



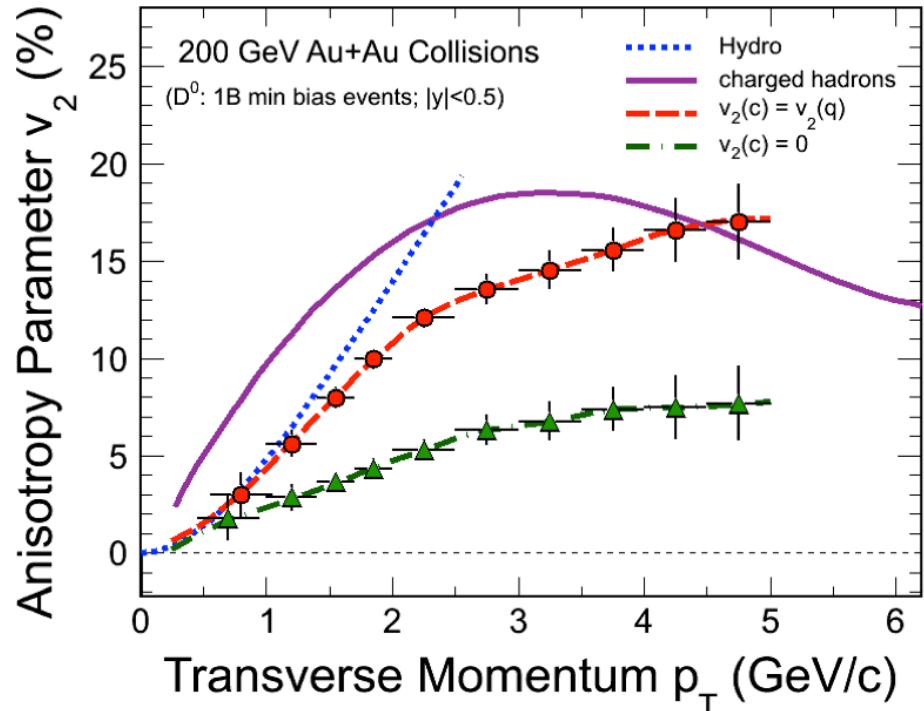
- Probe possible different medium property with different collision energy.

# Charm Flow



arXiv:1305.2707

Phys. Rev. Lett. 111 (2013) 102301



STAR projection with HFT

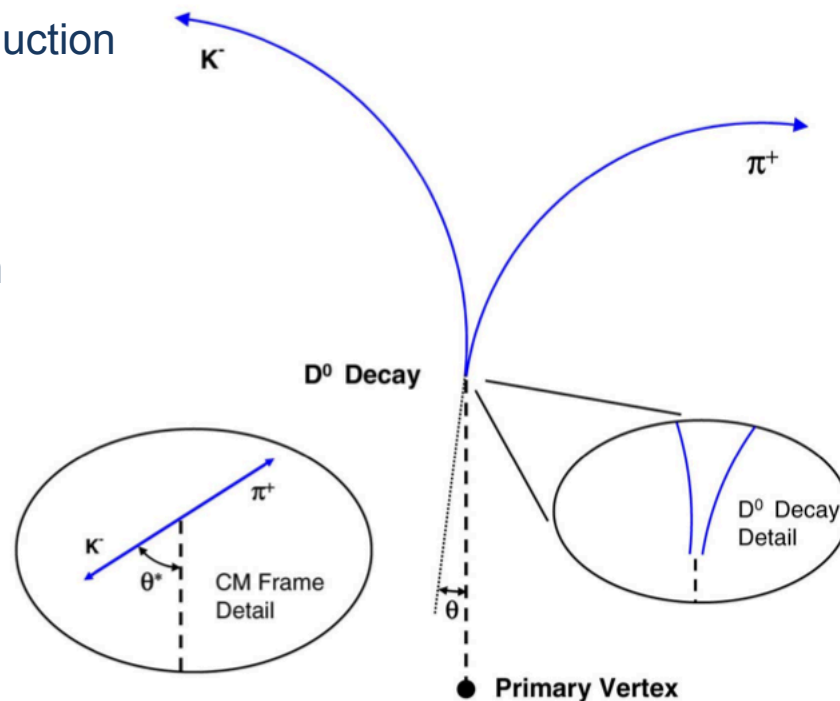
HFT CDR (STAR Note SN0600)

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

# HFT Physics Motivation

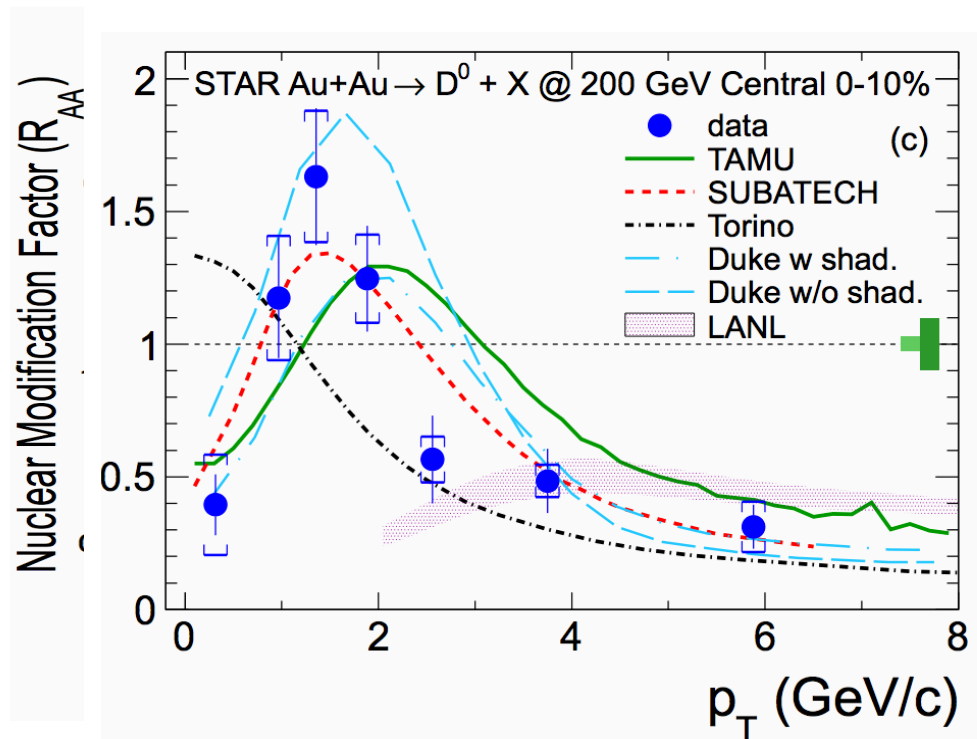
- HFT can be used to study heavy flavor production by the measurement of displaced vertices

- $D^0 \rightarrow K^- \pi^+$ 
  - BR = 3.83 %       $c\tau \sim 120 \mu\text{m}$
- $\Lambda_c^+ \rightarrow p K^- \pi^+$ 
  - BR = 5.0 %       $c\tau \sim 60 \mu\text{m}$
- B mesons  $\rightarrow J/\psi + X$  or  $e + X$ 
  - $c\tau \sim 500 \mu\text{m}$

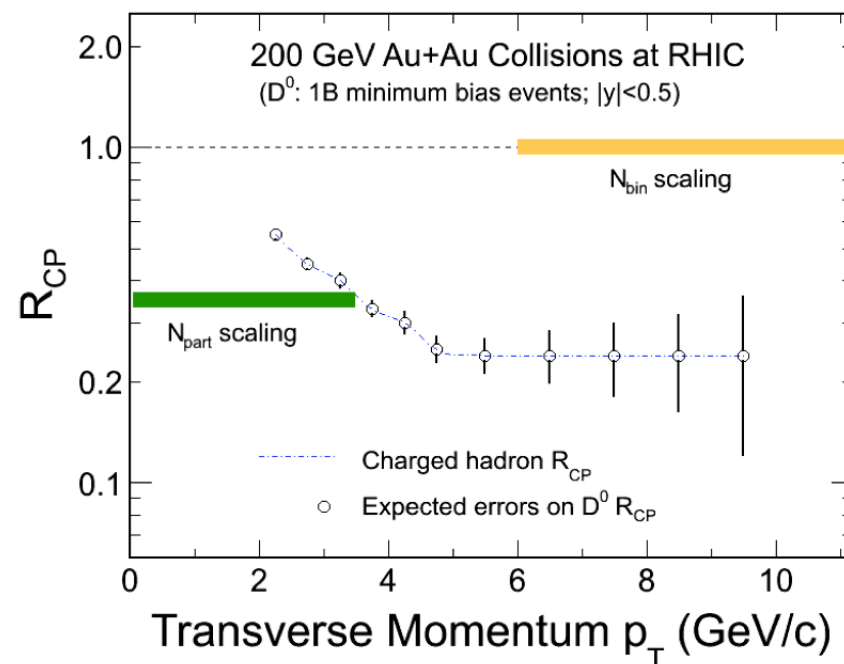


- Total charm yield  $\Rightarrow$  base line for charmonium suppression & coalescence
- $R_{CP}$ ,  $R_{AA}$  of charm and bottom  $\Rightarrow$  energy loss in QGP
- Charm ( $D^0$ ) flow  $\Rightarrow$  thermalization?
- $c\bar{c}$  ( $D^0\bar{D}^0$ ) angular correlation  $\Rightarrow$  interaction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

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



arXiv:1404.6185; subm. to PRL

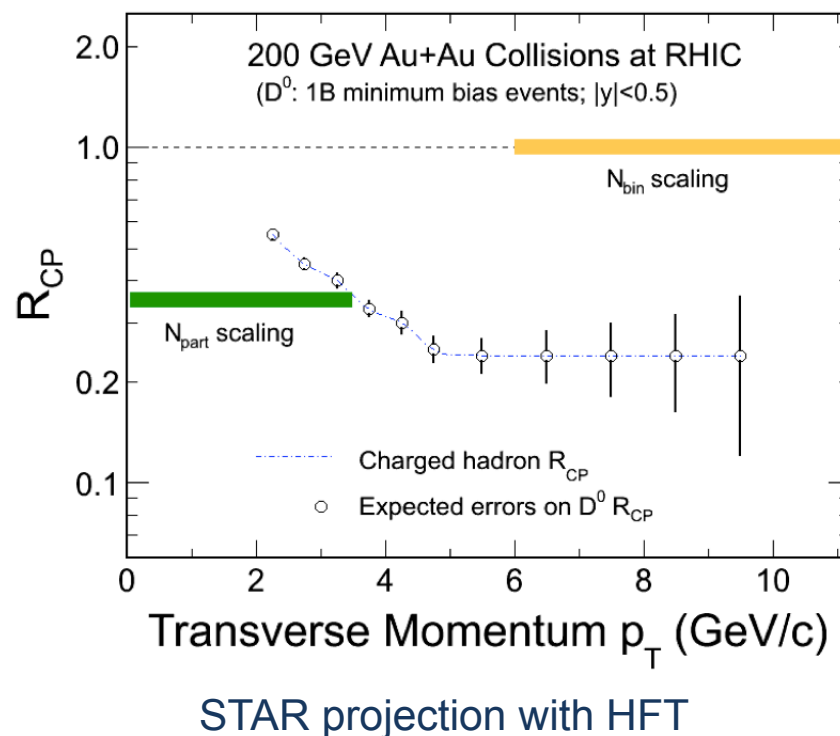
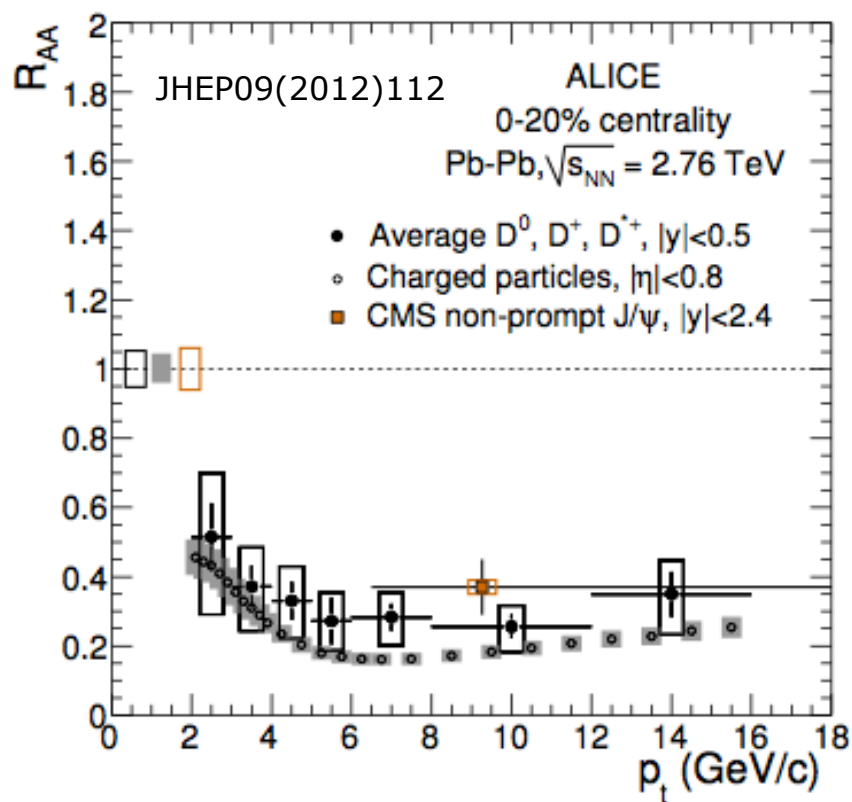


STAR projection with HFT

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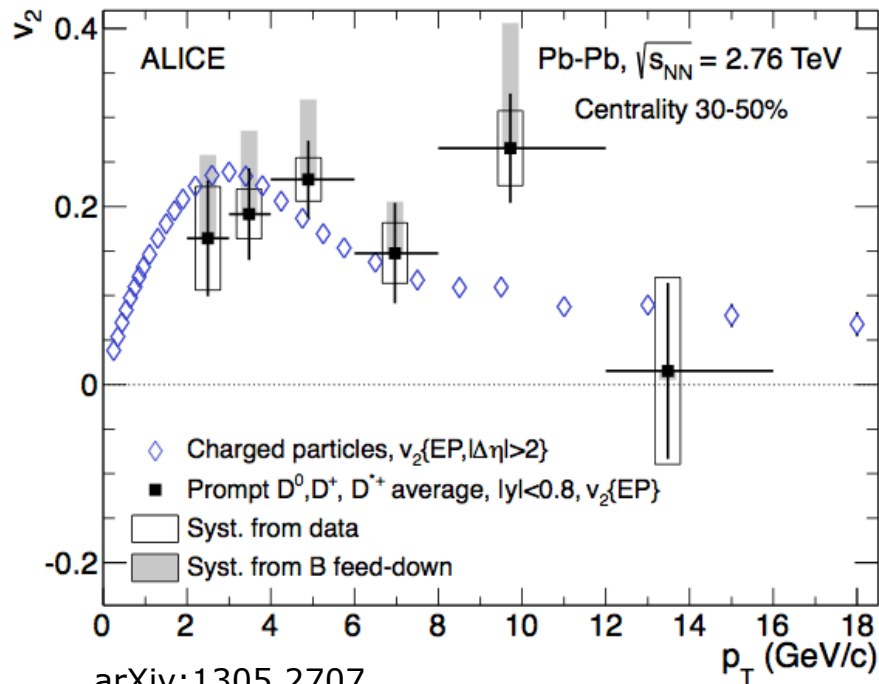
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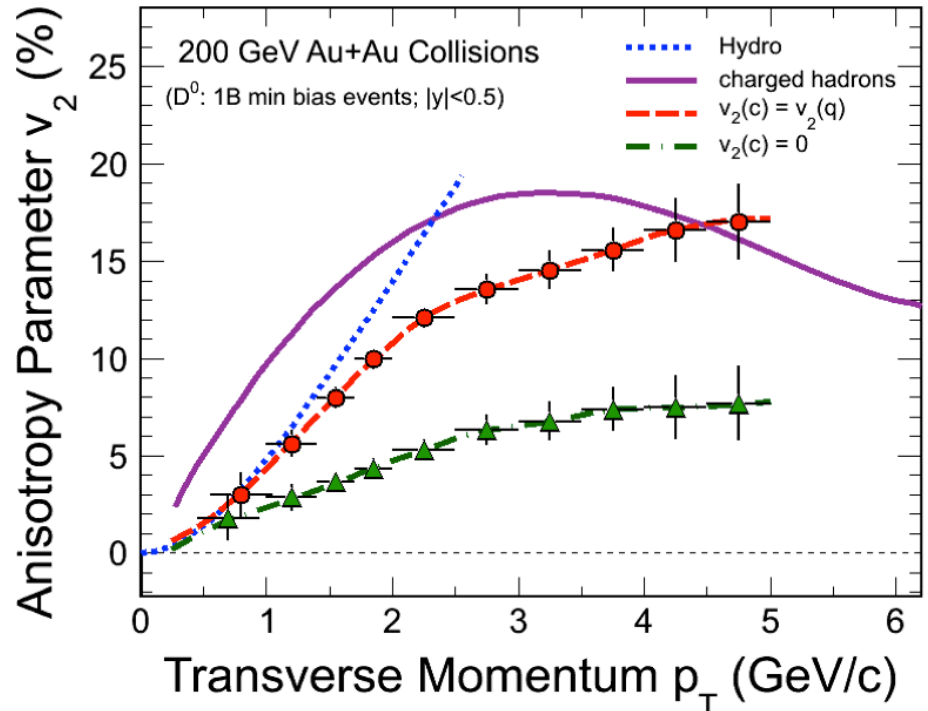
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STAR projection with HFT

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