中国科学技术大学
University of Science and Technology of China

STAR

Open Heavy Flavor Production at RHIC with the STAR Experiment

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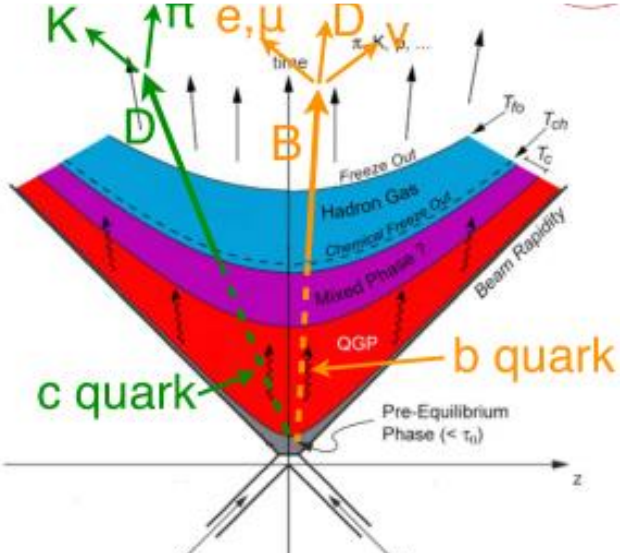
Second China LHC Physics Workshop (CLHCP 2016): 第2届中国LHC物理工作会议

Outline

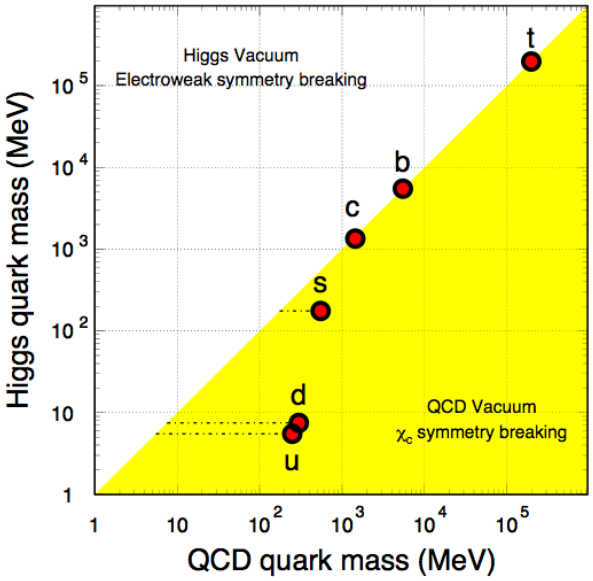
- **Motivation**
- **STAR experiment**
  - **HFT sub-system design and performance**
- **Heavy Flavor Measurements**
  - D^0 R_{AA}
  - D^0 v_2
  - D_s R_{AA}
  - D_s V_2
- **Outlook**
- **Summary**

Motivation

- Heavy quarks
  - produced mostly from initial hard parton scatterings at RHIC energies; exposed to the whole evolution of the QGP
  - total yield or mass not (significantly) altered within the QGP



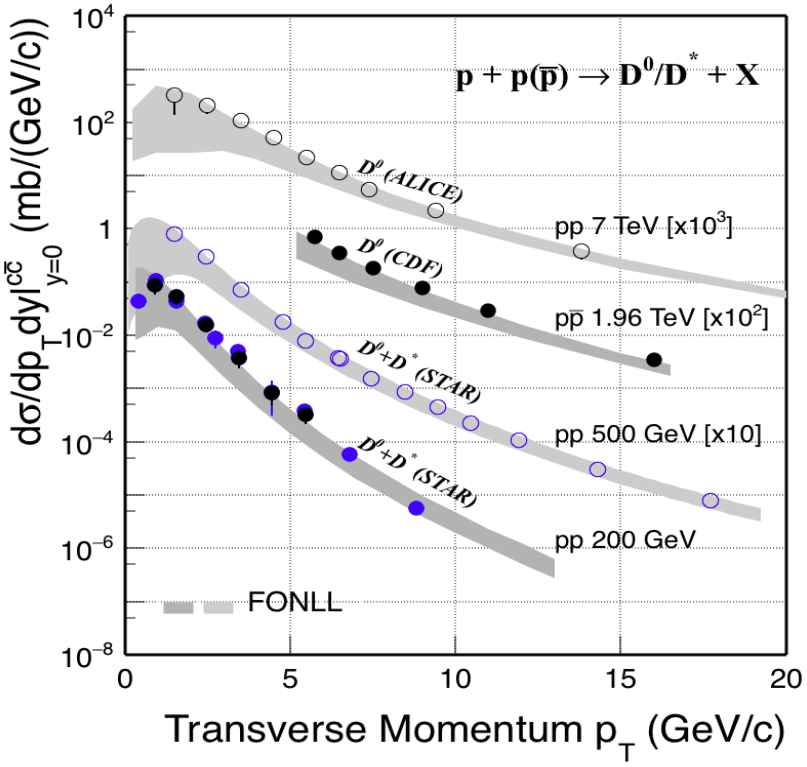
- Physics Interest
  - High p_T: test different energy loss mechanisms: radiative vs collisional
  - At low p_T: extract medium properties from motion of heavy quarks in medium e.g. diffusion coefficient

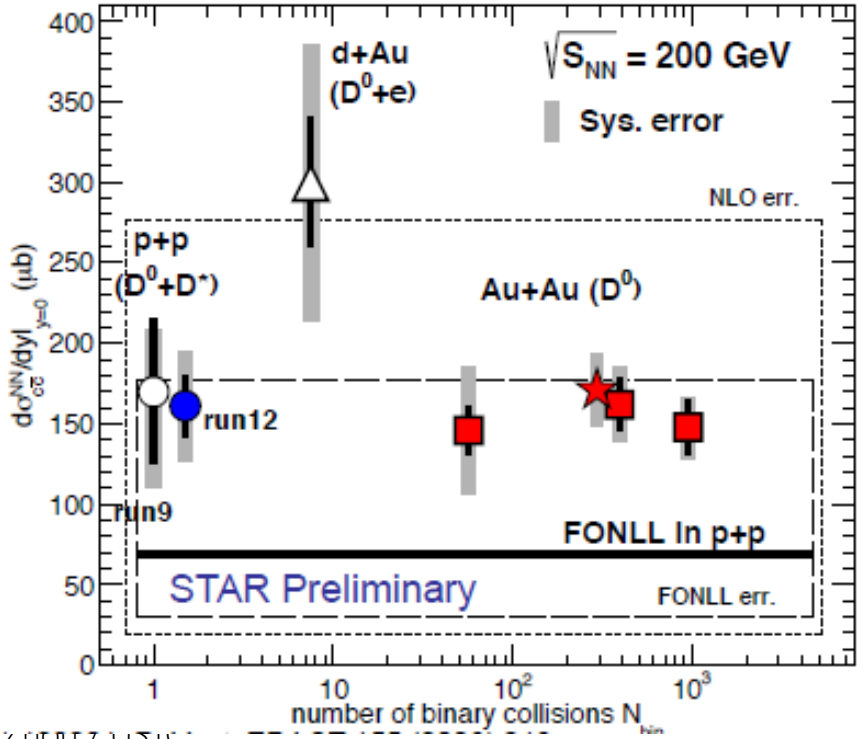


Open Charm production at RHIC

Heavy flavor quarks can serve as calibrated probes for the QGP at RHIC:

- production in p+p collisions are described by pQCD calculations
- produced mostly in the initial hard scatterings at RHIC energies
- has only a small contribution from gluon splitting





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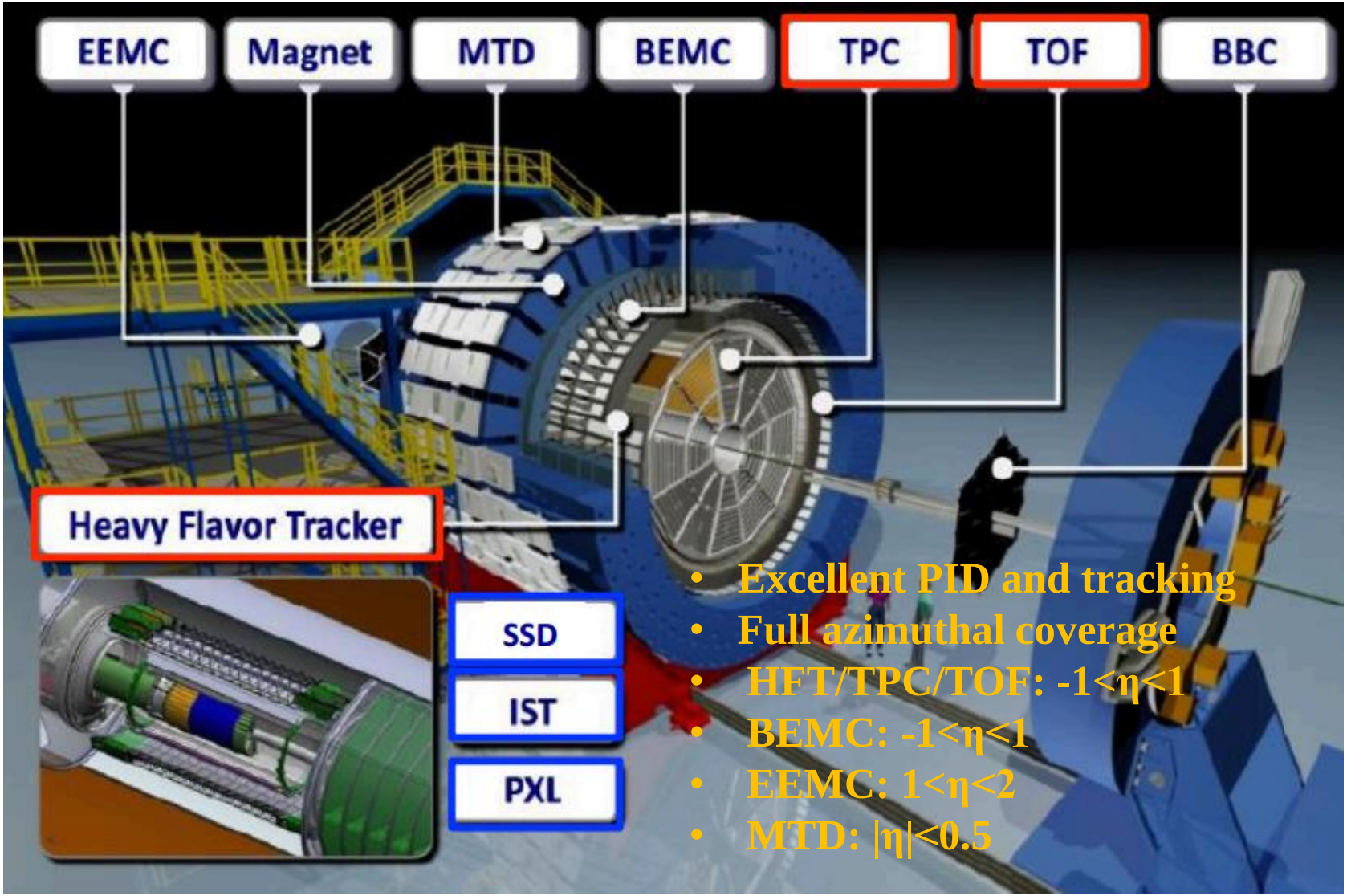
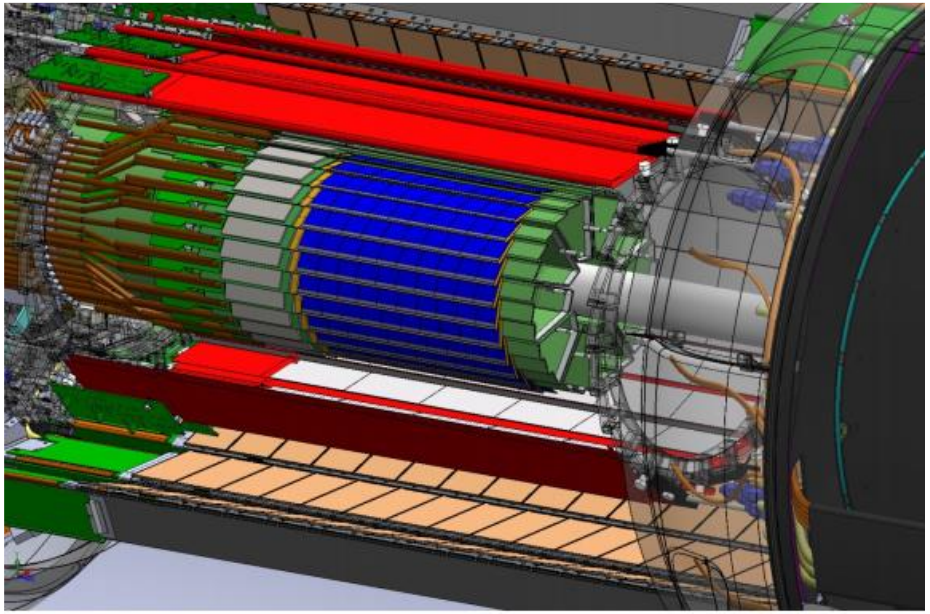
Experimental Setup



STAR Heavy Flavor Tracker



Pixel detector (PXL)

- two layers of thin Monolithic Active pixel Sensors with 356M 20.7x20.7μm pixels
- excellent DCA resolution for HF studies

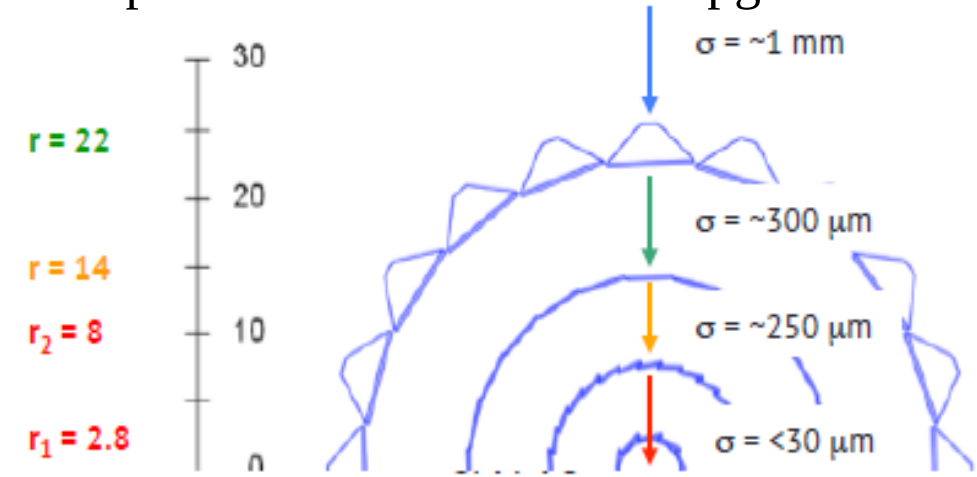
Intermediate Silicon Tracker (IST)

- one layer of fast readout single-sided double-metal silicon strip detector

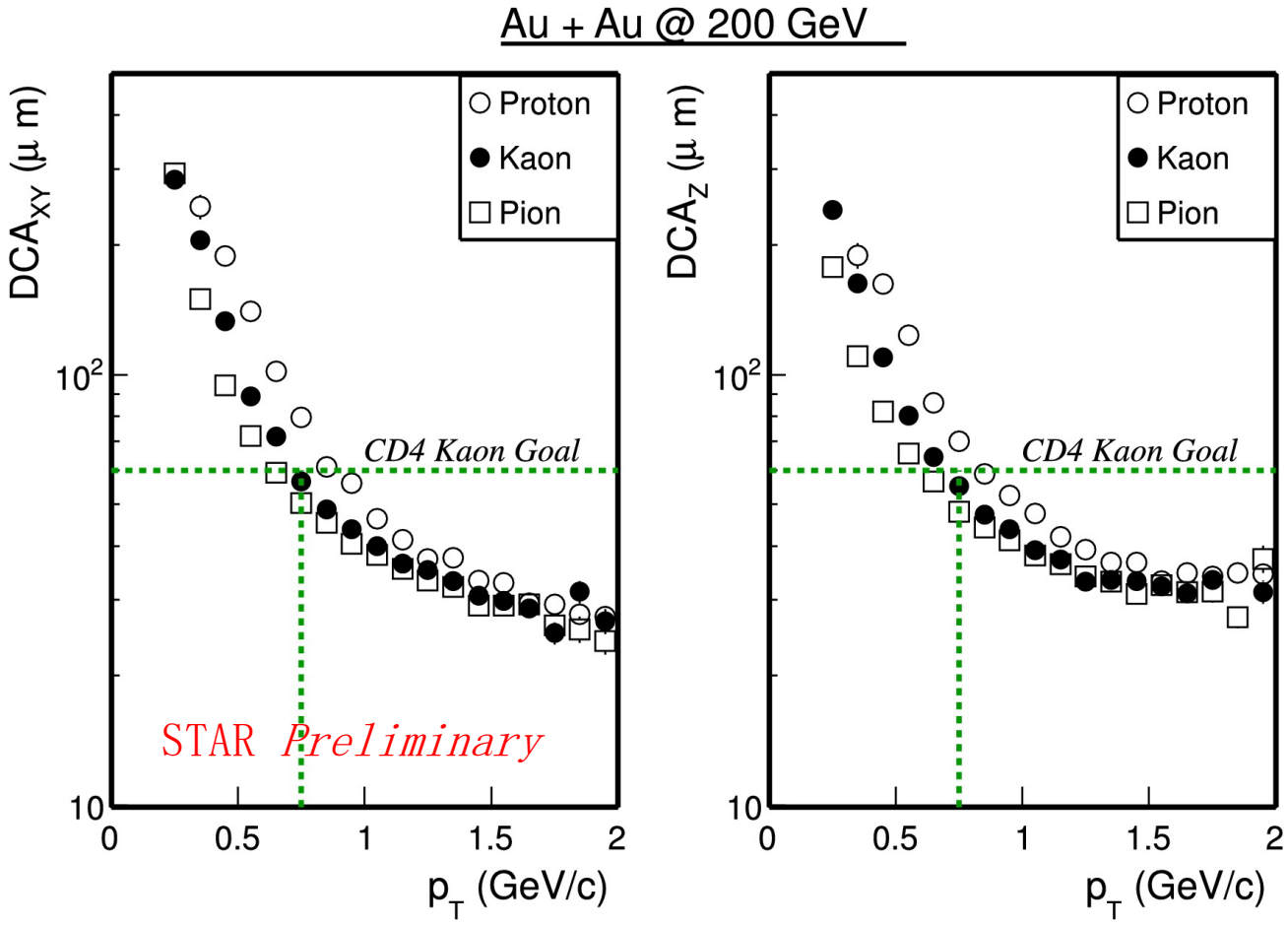
Silicon Strip Detector (SSD)

- existing one layer of double-sided silicon strip detector with electronic upgrade

Detector	Radius (cm)	Hit Resolution R/φ - Z (μm)	Radiation length
SSD	22	20 / 740	1% X_0
IST	14	170 / 1800	<1.5 %X_0
PXL	2.8/8	6 / 6	~0.4 %X_0



HFT performance



- Kaon track pointing resolution exceeds the requirement <55 μm at 750 MeV/c
- Pointing resolution in the region with Al-cables ~45 μm

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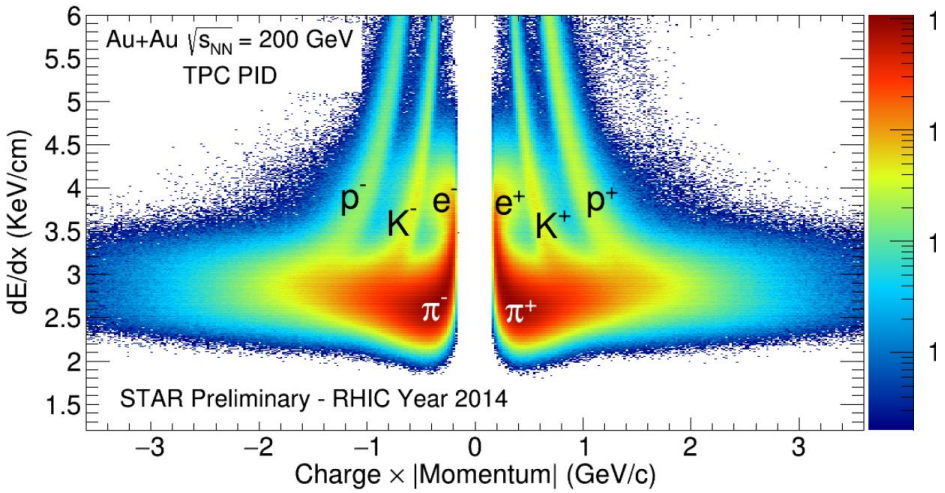
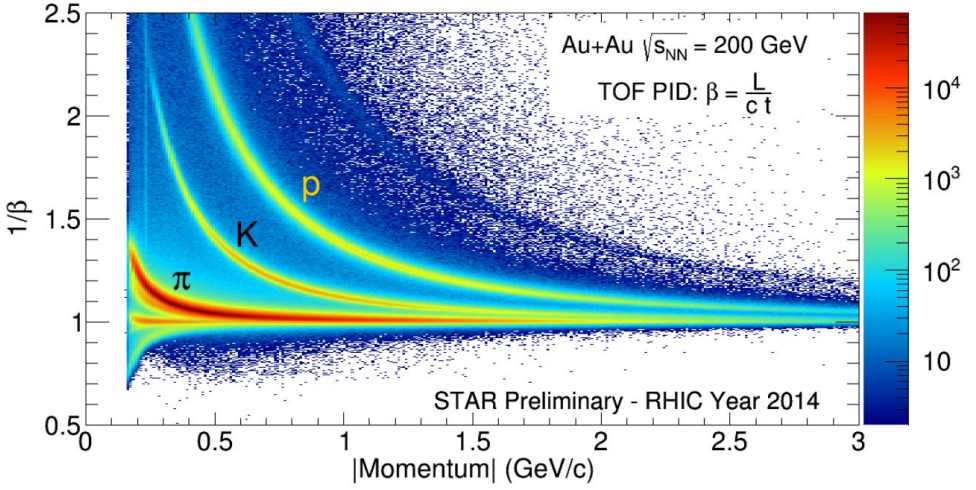
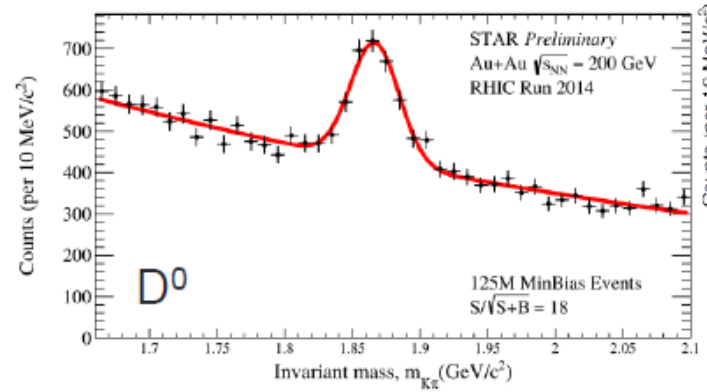
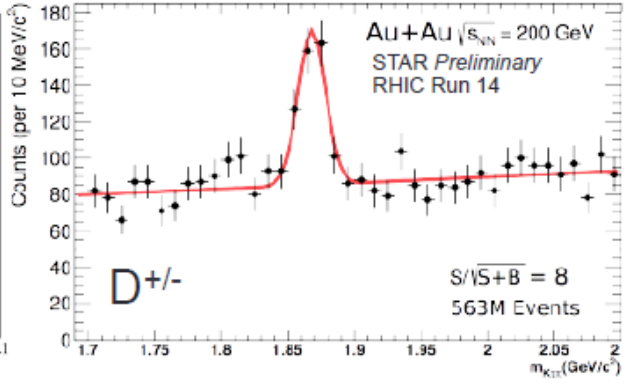
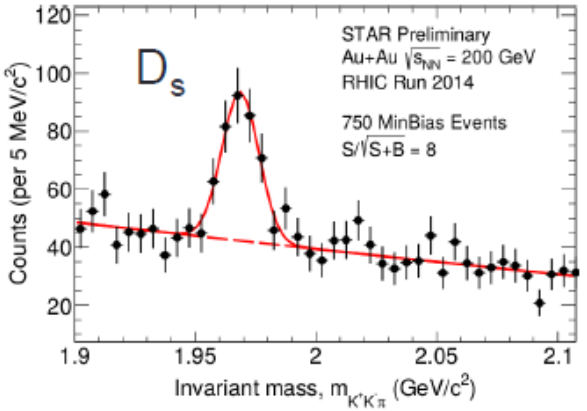
Particle Identification





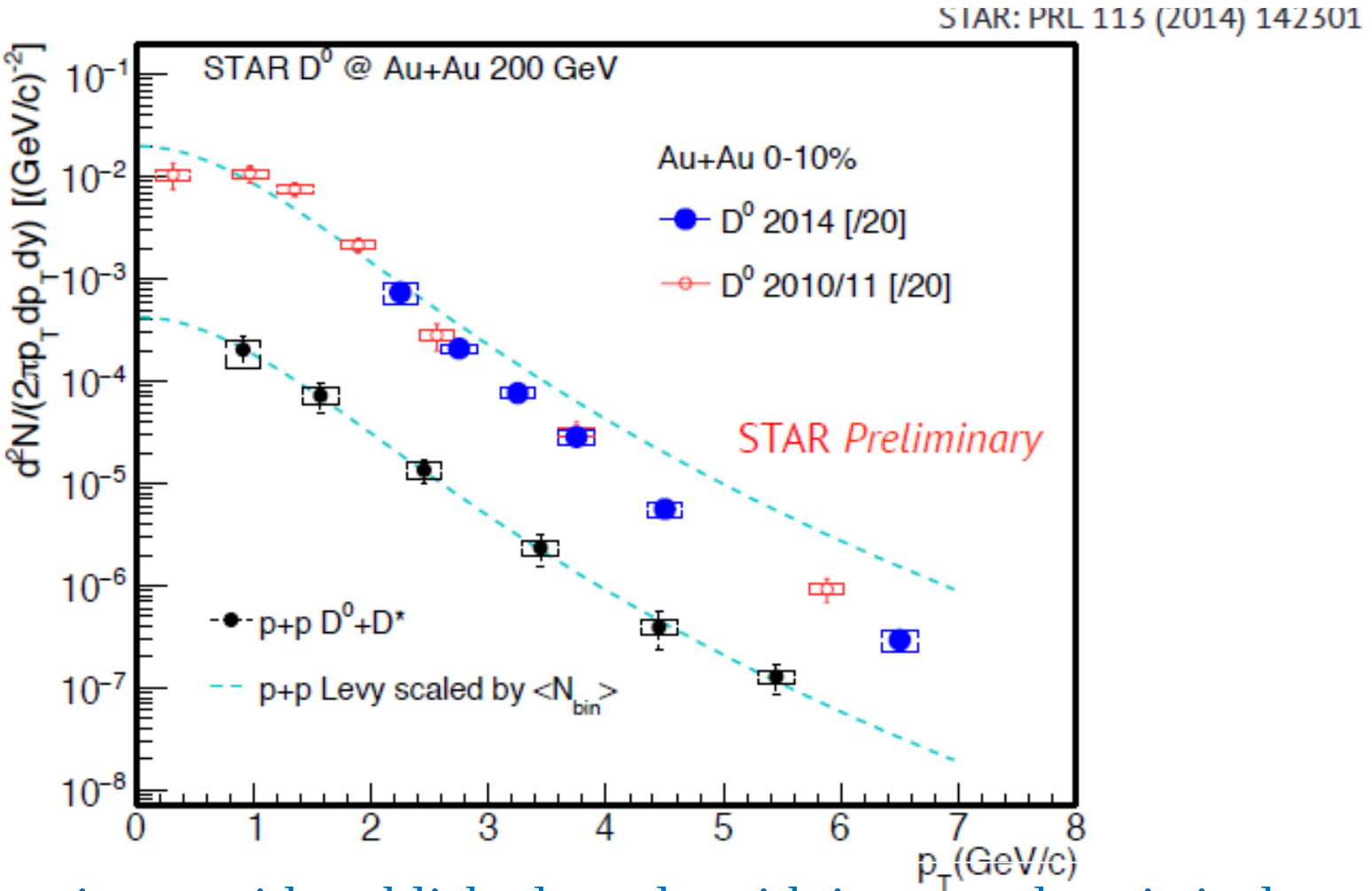






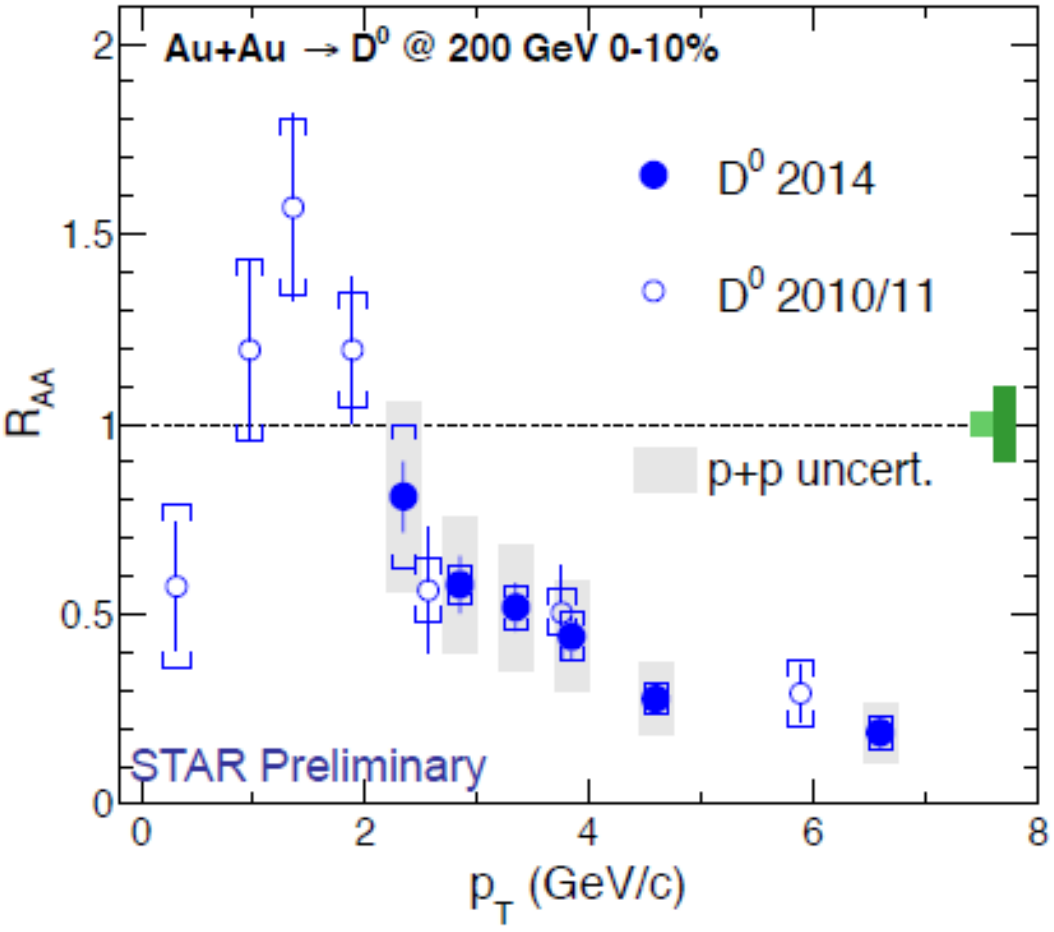
- Excellent long-lived hadron and electron identification
- Secondary vertex reconstruction with HFT → Full kinematic reconstruction of charmed hadron
- A factor of ~4 improvement in D0 significance by the HFT. First results on $D^{\pm}$ and Ds

New Results from HFT-D^0 Spectrum



- Consistent with published result, with improved statistical precision
- Finalizing systematic uncertainties for $p_T < 2$ GeV/c

New Results from HFT-D^0 R_{AA}



$$R_{AA} = \frac{dN_{AA}/dy}{N_{binary} \cdot dN_{pp}/dy}$$

- R_{AA}(D)>1 for pT~1.5 GeV/c

Charm coalescence with a radially flowing bulk medium

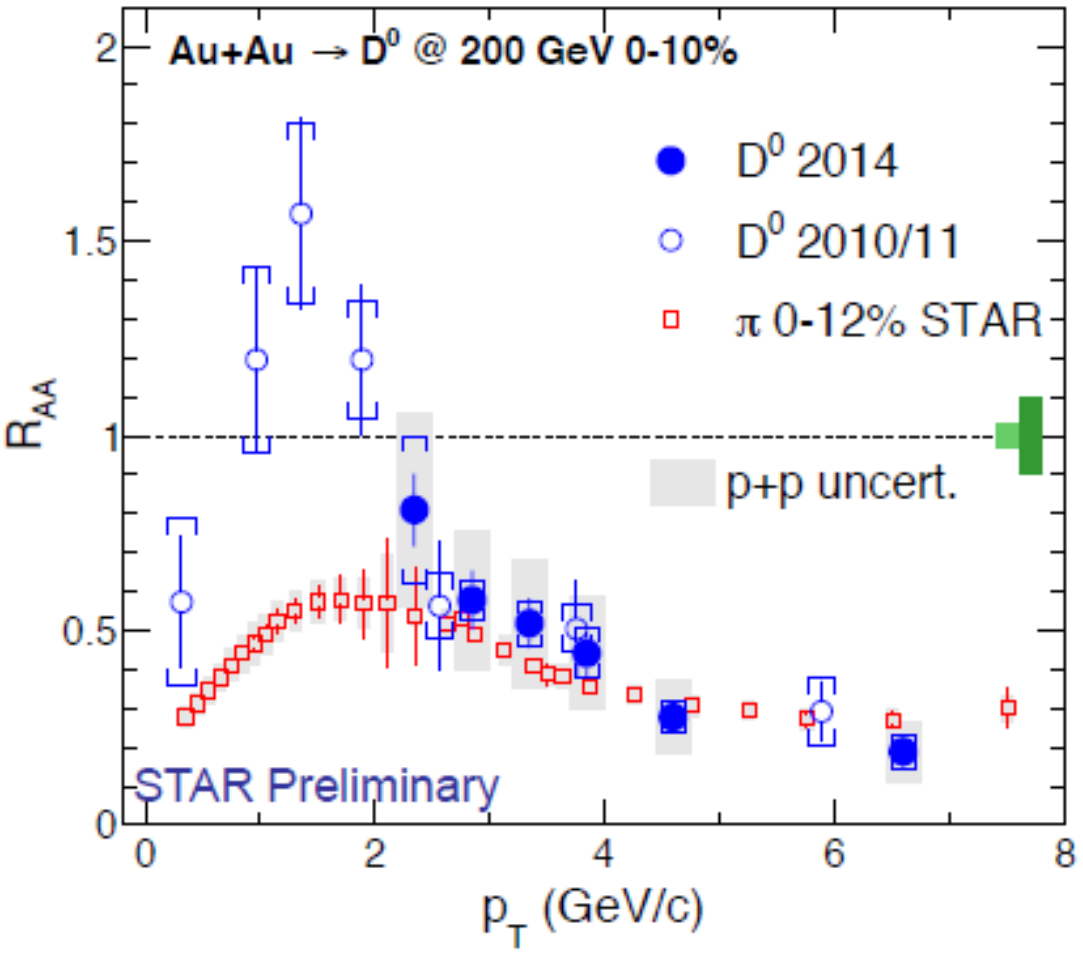
- High p_T: significant suppression in central Au+Au collisions.

Strong charm-medium interaction

- Improved Au+Au precision at high p_T thanks to the HFT.
- R_{AA} at low p_T with Run14 Au+Au and Run15 p+p HFT data are underway.

STAR D_0 2010/11: PRL 113 (2014) 142301

New Results from HFT-D^0 R_{AA}



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Charm coalescence with a radially flowing bulk medium

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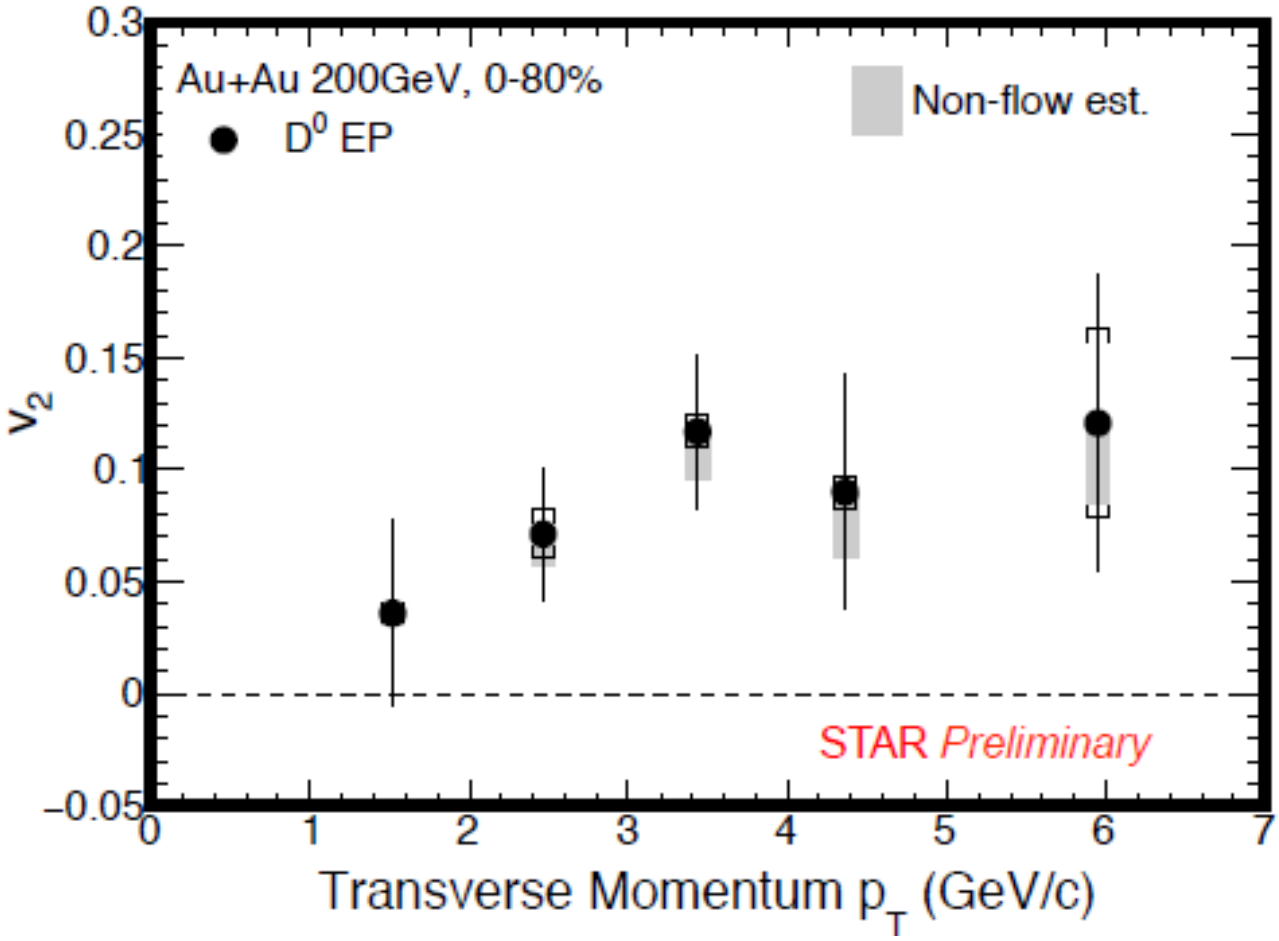
Strong charm-medium interaction

- R_{AA}(D) ~ R_{AA} (π) at p_T>4 GeV/c

Similar suppression for light partons and charm quarks at high pT

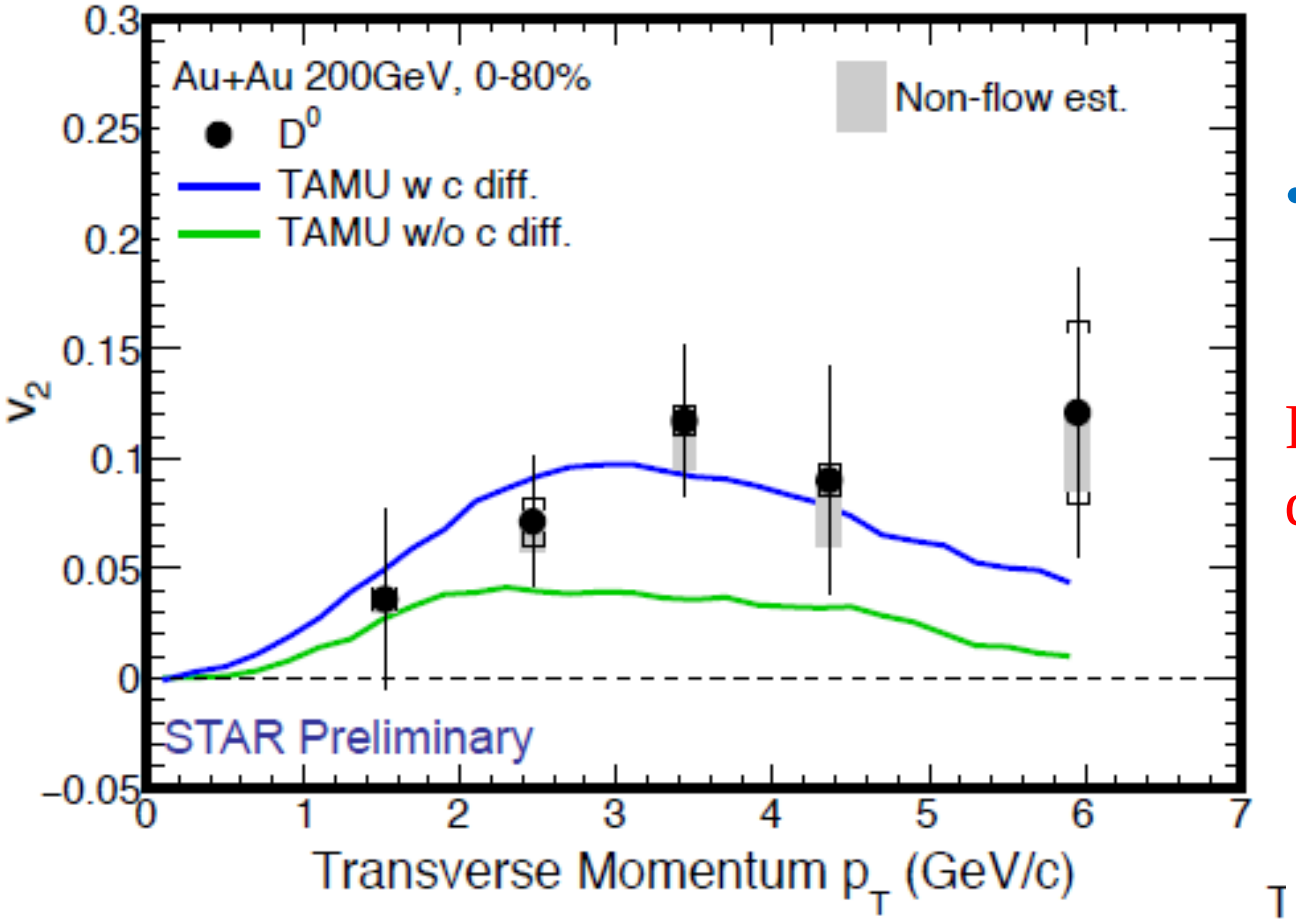
STAR D_0 2010/11: PRL 113 (2014) 142301
STAR π 0-12%: PLB 655 (2007) 104

New Results from HFT – D^0 V_2



- *D*0 azimuthal anisotropy significantly different from zero for $\boldsymbol{p_T}$ > 2 GeV/c
- B->D feed down is negligible at RHIC energies (<5% relative contribution)

New Results from HFT – D^0 V_2

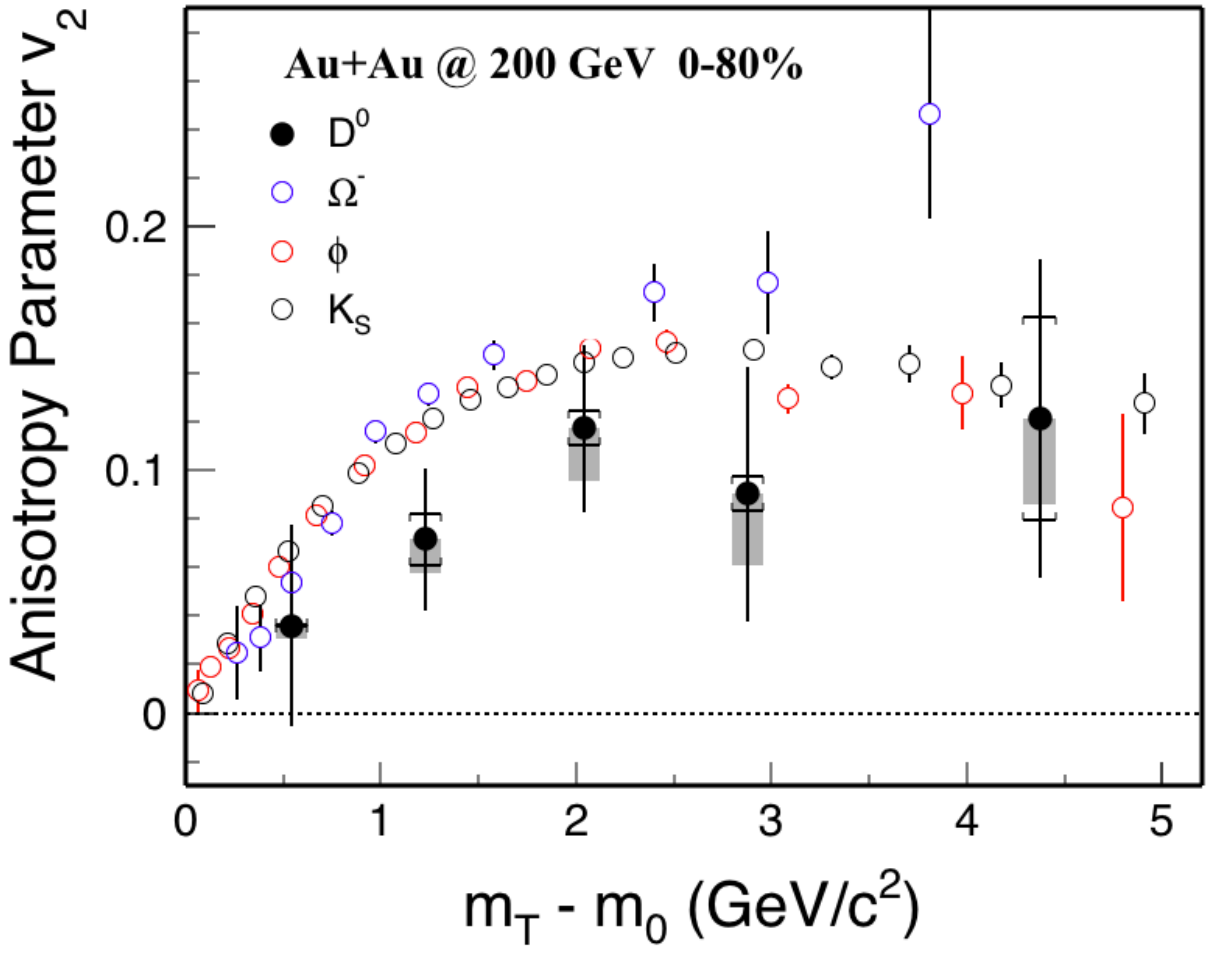


- Finite D_0 v_2 for p_T>1 GeV/c

Favors charm quark diffusion

Theory curves: latest calculations from private communications
TAMU: PRC 86 (2012) 014903, PRL 110 (2013) 112301

New Results from HFT – D^0 V_2



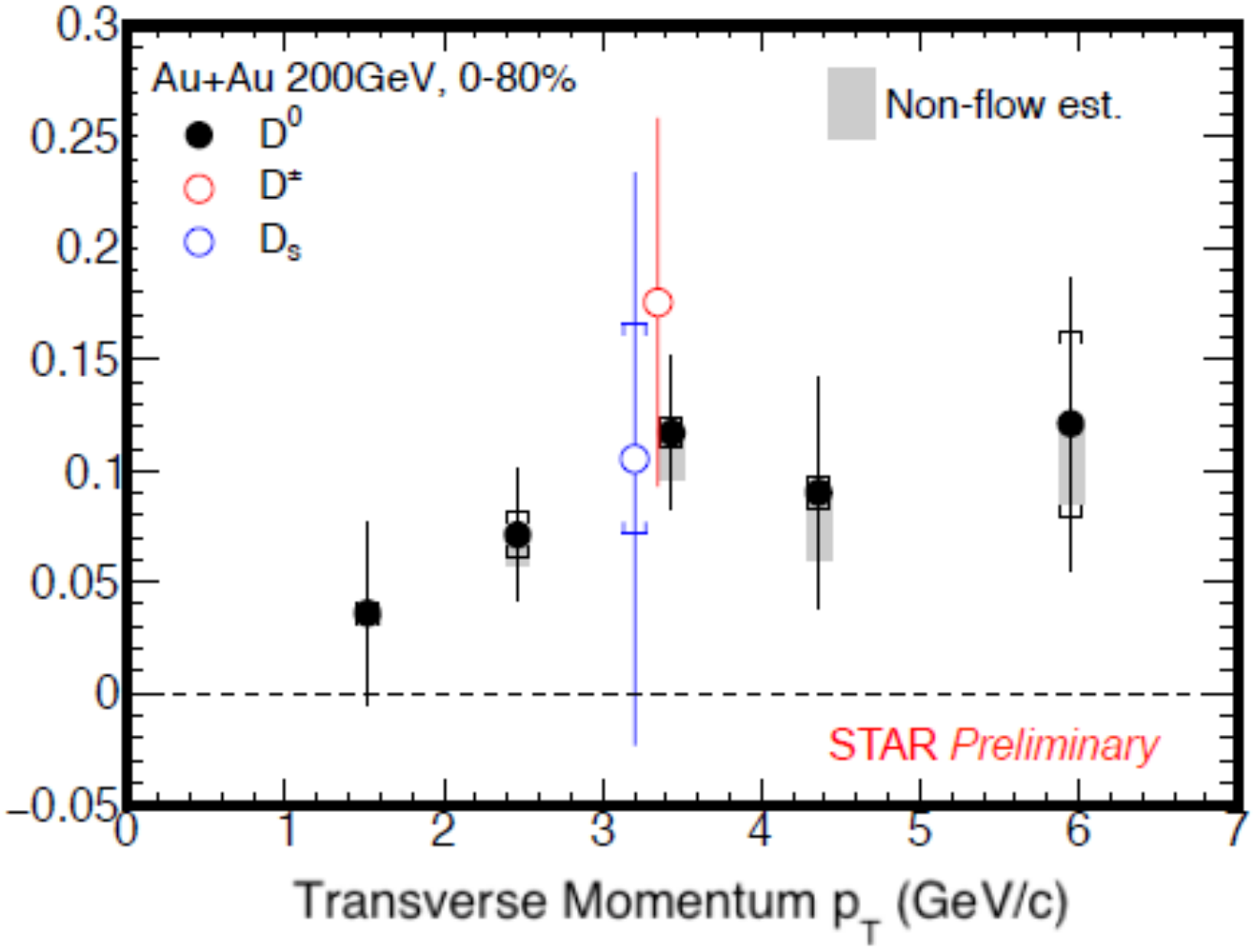
- Finite D_0 v_2 for p_T>1 GeV/c

Favors charm quark diffusion

- Lower than light hadron v_2

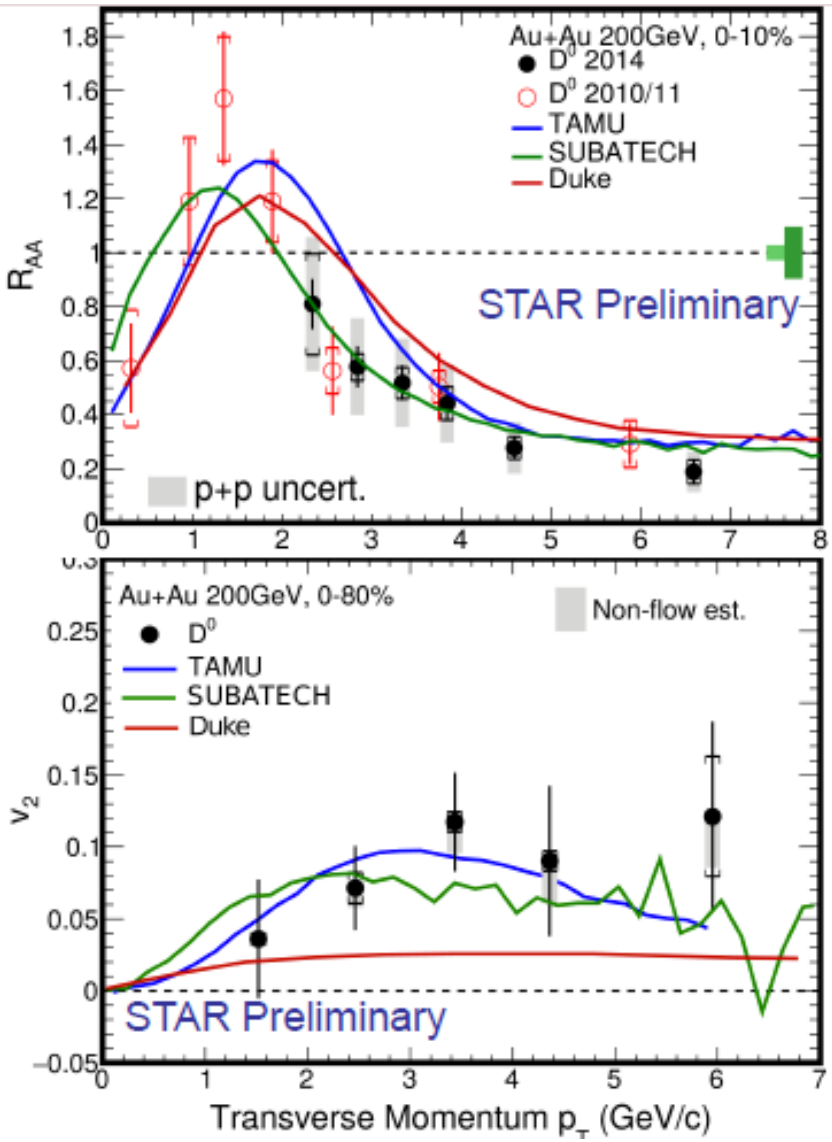
Indicates that charm quarks are not fully thermalized with the medium

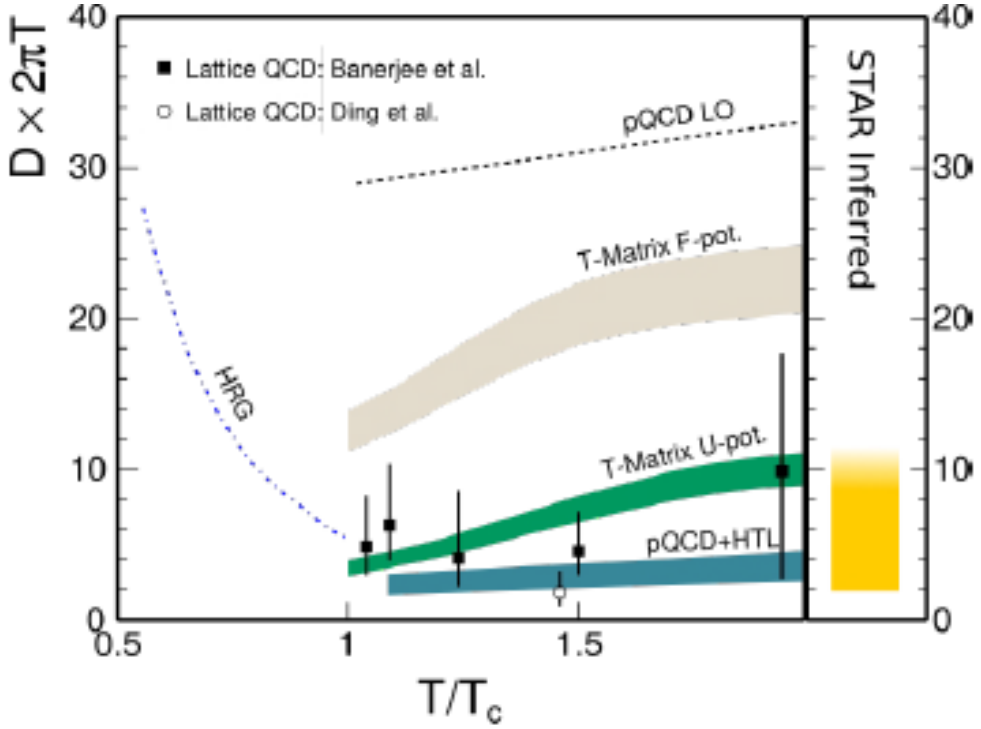
New Results from HFT – D meson V_2



- $D^{\pm}$ V_2 compatible with D^0 albeit within large error bars
- First measurement of $D_s V_2$ in heavy-ion experiment, limited statistics

Compare with Theory

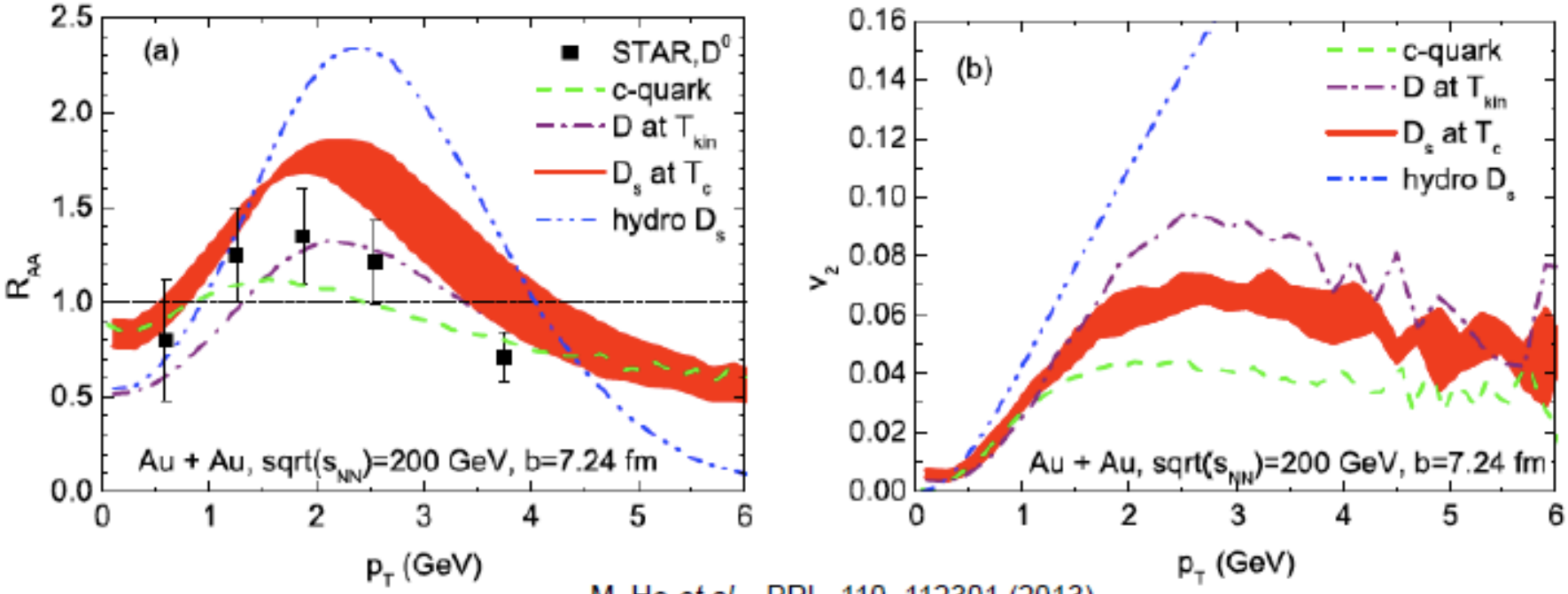




Models with charm diffusion coefficient of 2~10 describe STAR D^0 R_{AA} and v_2 results.

Lattice calculations are consistent with values inferred from data.

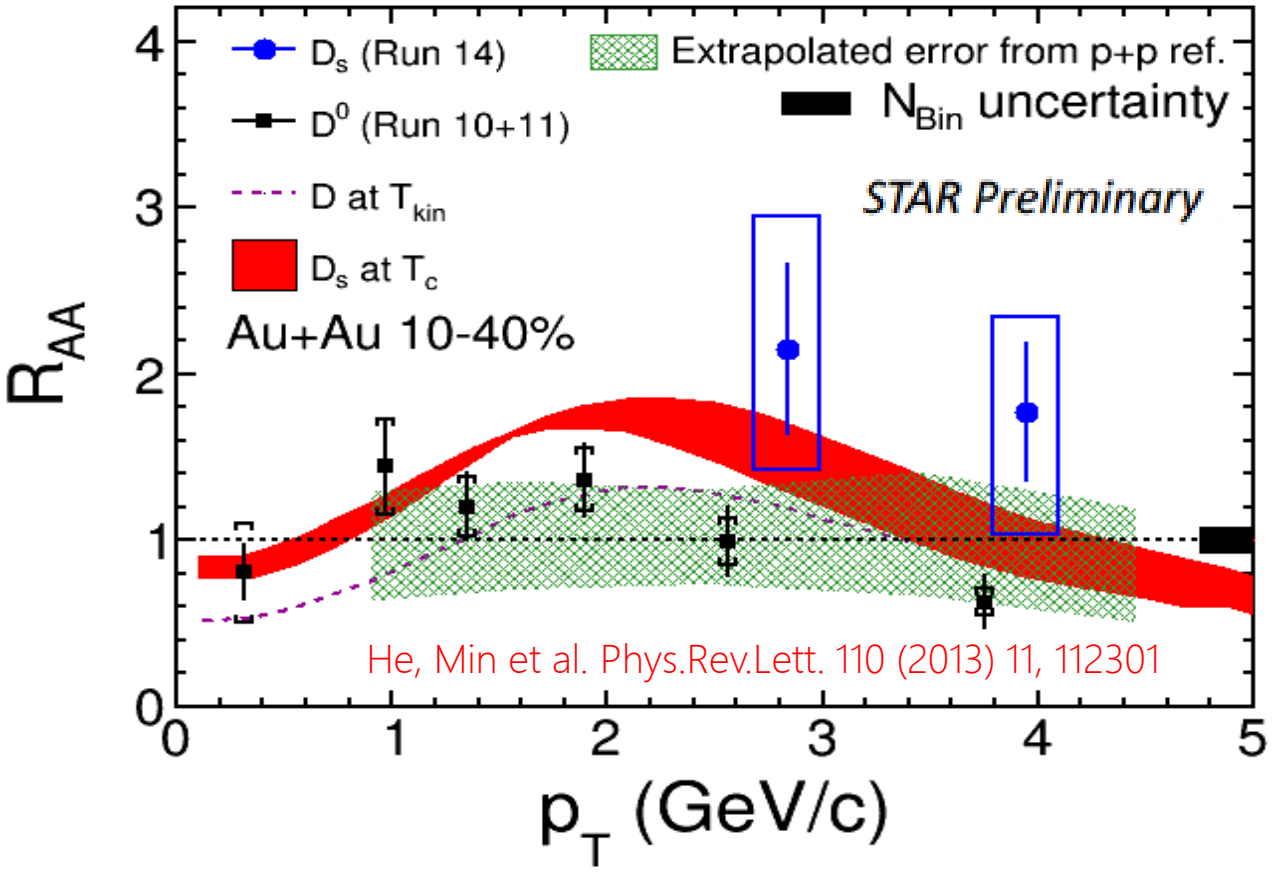
New Results from HFT – D_s



M. He *et al.*, PRL 110, 112301 (2013)

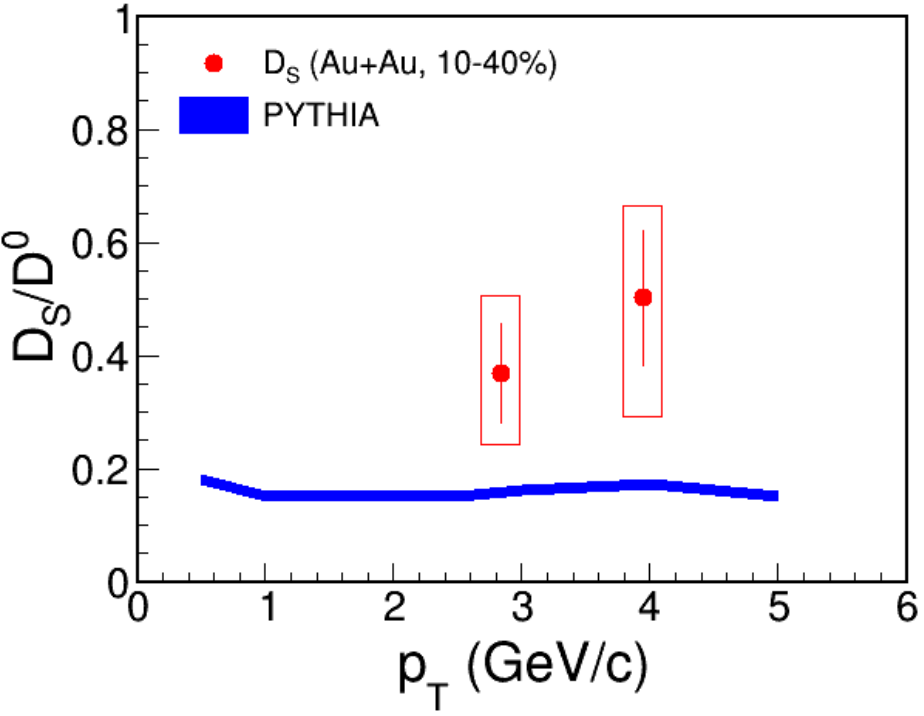
- Strangeness enhancement in heavy-ion collisions is expected to affect the yield of D_s: relative increase of D_s yield than D^0 predicted.
- Elliptic flow of $D_s < D^0$ is expected due to earlier freeze out of D_s.

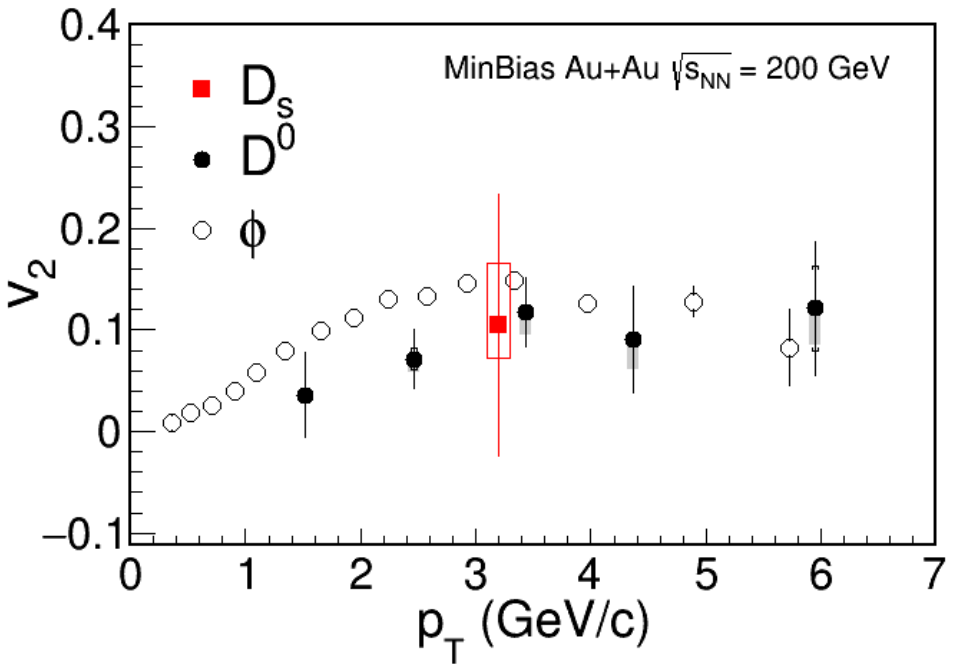
New Results from HFT - D_s R_{AA}



- Both D_s and D^0 R_{AA} are consistent with model calculations within uncertainty.
- Hint of enhancement in D_s meson production.

New Results from HFT - D_s





- The ratio of D_s/D^0 yield measured in Au+Au collisions is found to be higher than that in p+p collisions from PYTHIA
- First measurement of D_s v_2 in heavy-ion experiment. More data are needed to draw conclusion.

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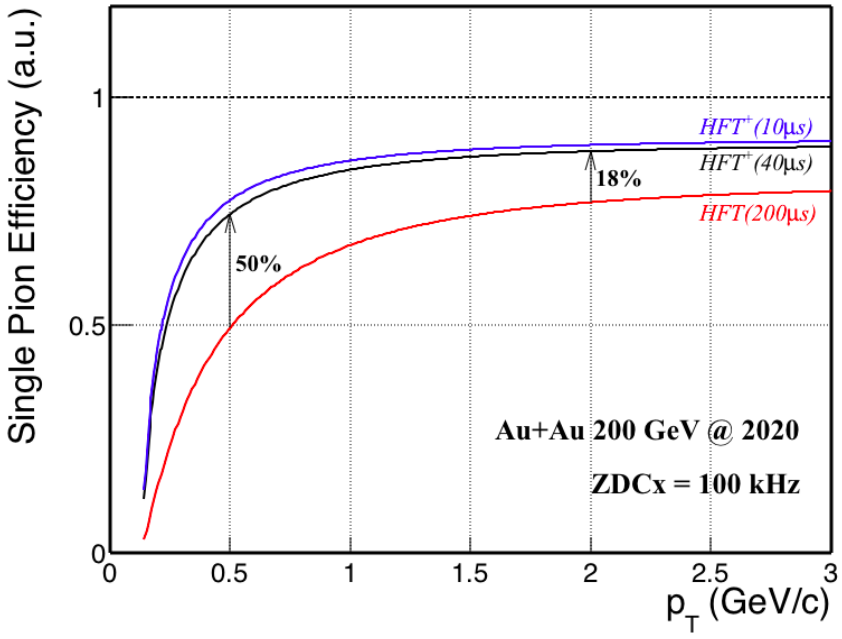
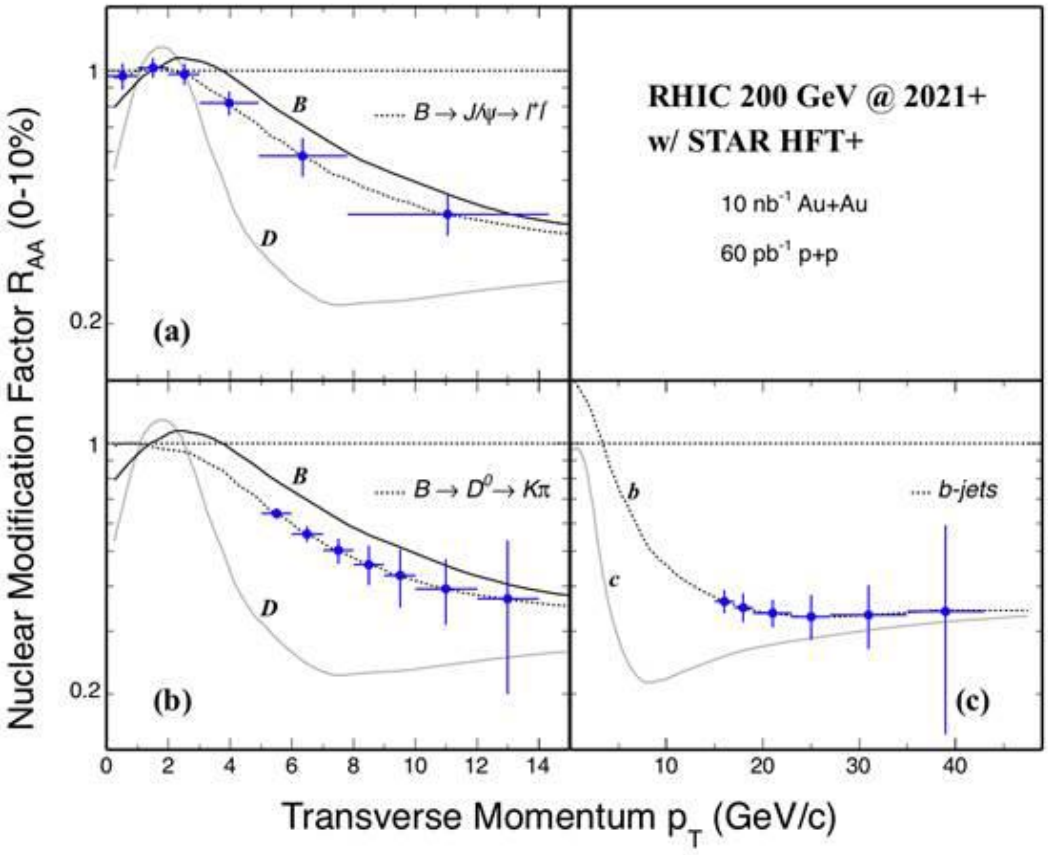
STAR Heavy Flavor II



HFT+ with Faster MAPS sensors

- integration time from ~185 μs to below 40 μs – less pile-up hits and thus better tracking efficiency
- use chips developed for ALICE ITS upgrade and existing HFT infrastructure – cost effective



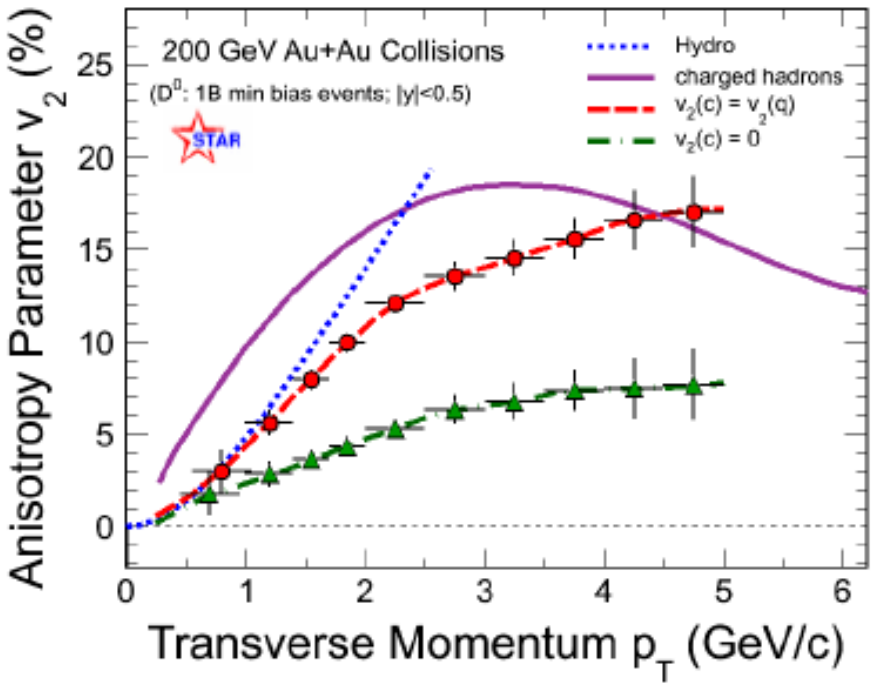
Projected R_{AA}(0-10%) stat. uncertainty for RHIC pp and AuAu running in 2021-22

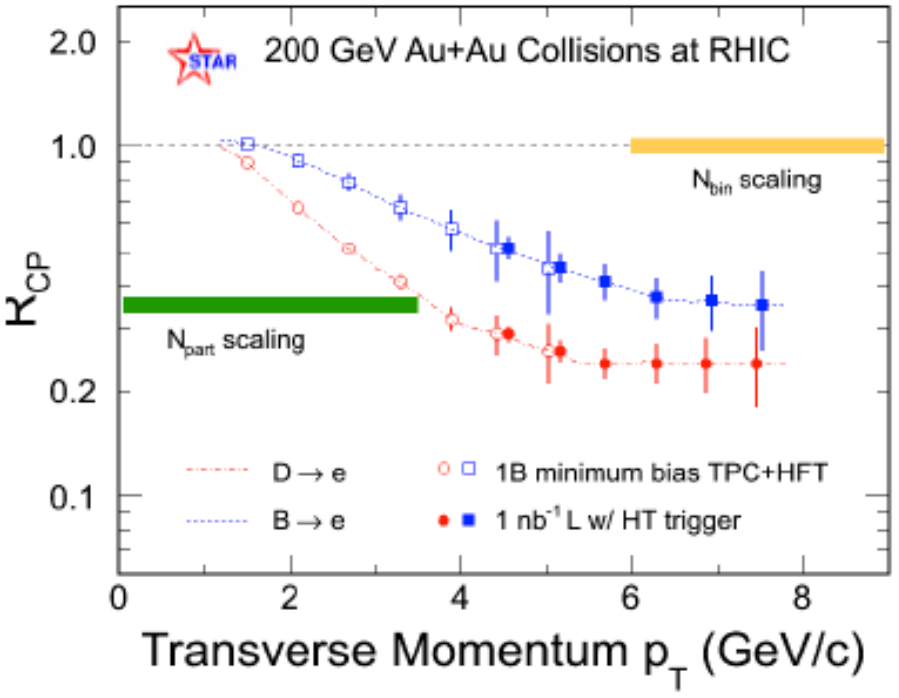
Summary

- The STAR HFT has been successfully installed and taking data in 2014-2016
- Presented first results of charmed meson R_{AA} and v_2 using the HFT
- D^0 R_{AA} and v_2 in Au+Au collisions: favor model calculation with charm quark diffusion, diffusion coefficient inferred from data consistent with Lattice QCD
- Looking forward to improved baseline from 2015 and statistics in year 2016
- A faster HFT+ has been planned in order to measure the bottom quark hadrons at the top RHIC energy

Backup

Heavy Flavor Tracker



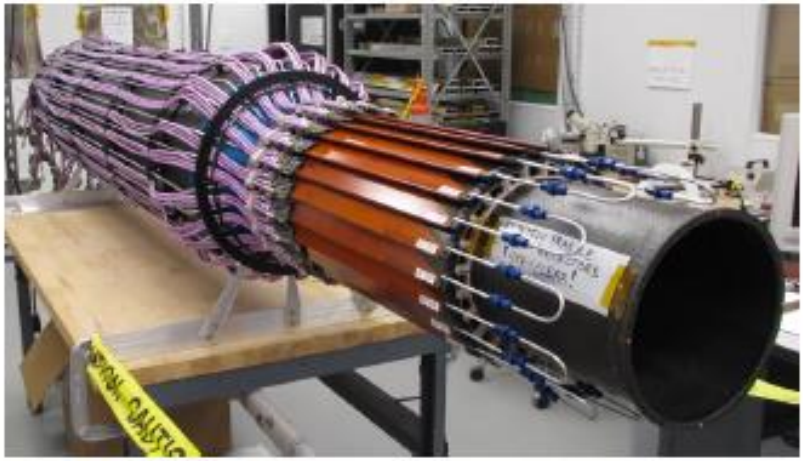


High precision R_{AA}, R_{pA}, v_2, correlations results for D mesons and HF leptons;
Unique at low p_T -> medium thermalization, total charm production

HFT sub-systems

Silicon Strip Detector (SSD)
- Double sided silicon strip modules with 95 μm pitch
- Existing detector with new faster electronics
- Radius: 22 cm – Length: ~106 cm

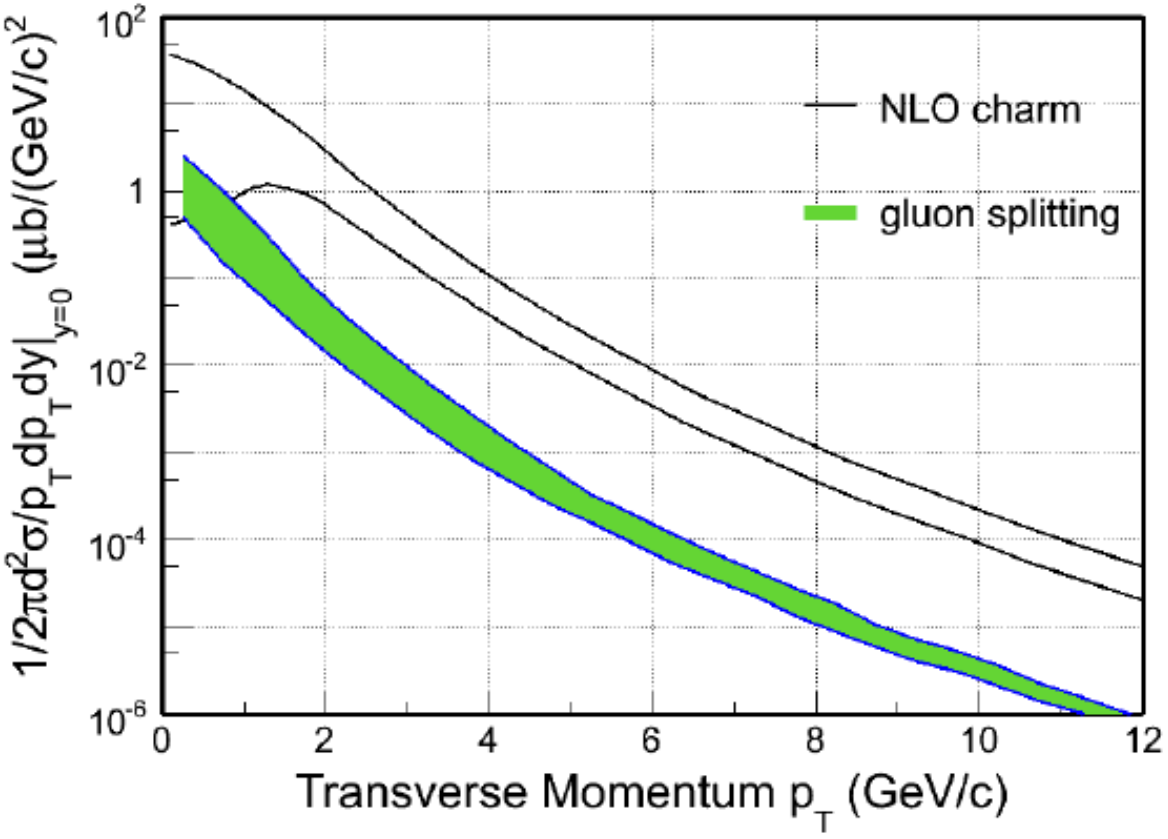
Intermediate Silicon Tracker (IST)
- Single sided double-metal silicon pad with 600 μm x 6 mm pitch
- Radius: 14 cm – Length: ~50 cm



PiXeL detector (PXL)
- *Monolithic Active Pixel Sensor* technology
- 20.7 μm pitch pixels
- Radius: 2.8 and 8 cm – Length: ~20 cm

First MAPS-based vertex detector at a collider experiment

Charm production at RHIC



Charm production in jets at p_T ~ 2-10 GeV/c has a small contribution from gluon splitting and is dominated by jets initiated by charm quarks

- Direct topological reconstruction through hadronic channels, for instance:

$$D^0(\overline{D^0}) \rightarrow K^{\mp}\pi^{\pm}$$

B.R. 3.9% $c\tau \sim 120\ \mu m$

- Greatly reduced combinatorial background (4 orders of magnitude)

- Topological cuts optimized using TMVA (Toolkit for Multivariate Analysis)