Measurement of D^0 elliptic and triangular flow in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV at RHIC

Michael R. Lomnitz
Kent State University
Lawrence Berkeley National Laboratory

for the STAR Collaboration

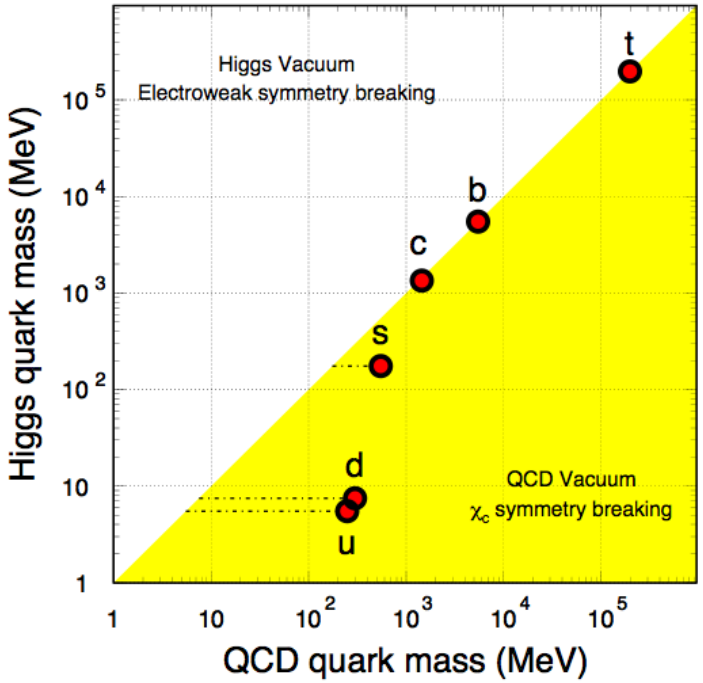
Motivation

Charm quarks:

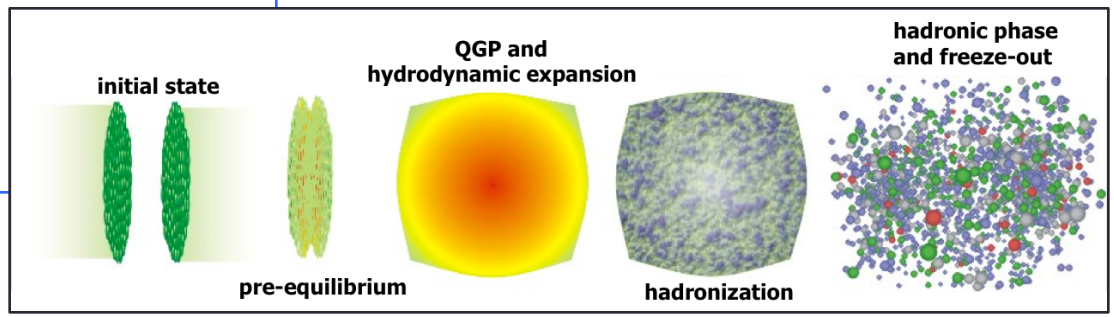
- Produced early in heavy ion collisions at RHIC, mostly through hard scattering
- Experience the whole evolution of the system -> good probe for medium properties

Physics interest:

- High p_T: test different energy loss mechanisms: radiative vs collisional
- Low p_T: extract medium properties from motion of heavy quarks in medium (Brownian motion), e.g. diffusion coefficient

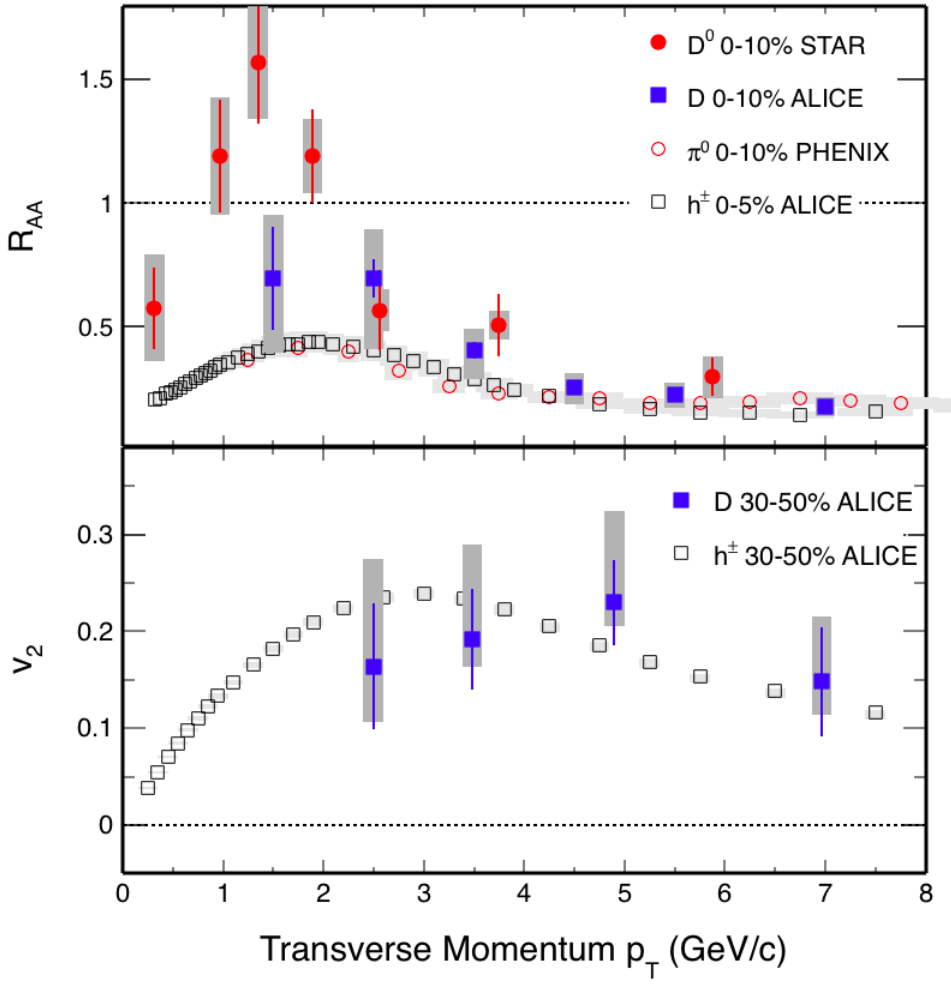


X. Zhu, *et al*, Phys. Lett. **B647**, 366(2007).



Recent developments and understanding

- RHIC and LHC: *D*-meson R_{AA} <<1 at high p_T -> strong charm-medium interactions
- LHC: D^0 v_2 results are compatible with light flavor v_2. Charm thermalized?
- v_2 and R_{AA} can be used simultaneously to constrain models
- What is occurring at low p_T at RHIC?
- Low p_T v_2 is especially sensitive to the partonic medium: scattering strength, transport properties



STAR D⁰: PRL 113 (2014) 142301
PHENIX π⁰: PRL 101 (2008) 232301
ALICE D: PRL 111 (2013) 102301
ALICE D: JHEP 03 (2016) 081

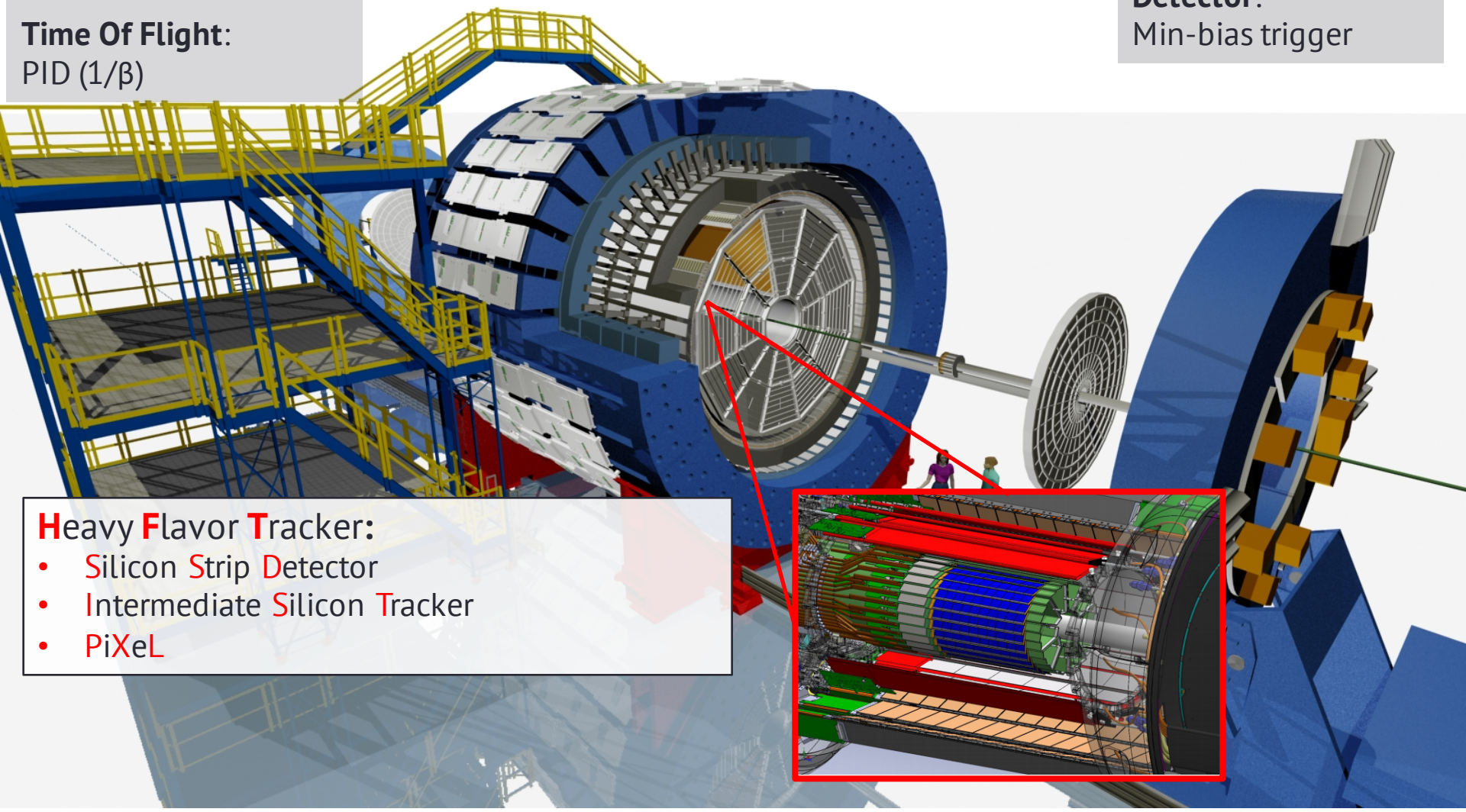
STAR experiment

Time Projection Chamber:
Tracking,
PID (dE/dx)

Time Of Flight:
PID (1/β)

$-1<\eta<1,\ 0\leqslant\varphi<2\pi$

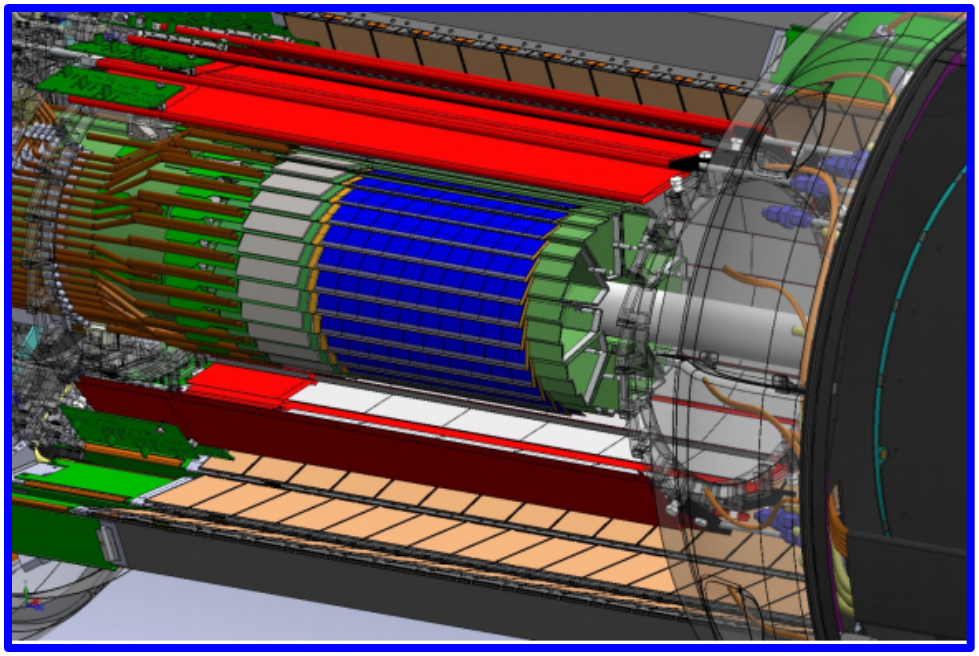
Vertex Position Detector:
Min-bias trigger



Heavy **F**lavor **T**racker:

- **S**ilicon **S**trip **D**etector
- **I**ntermediate **S**ilicon **T**racker
- **PiXeL**

STAR Heavy Flavor Tracker (HFT)

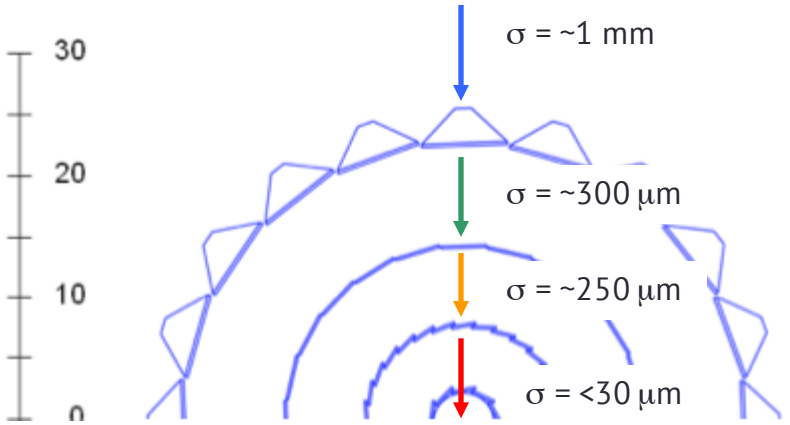


- Thinned Monolithic Active Pixel Sensor technology
- Low material budget
  - 0.49% X_0 for PXL Cu cables
  - 0.39% X_0 for PXL Al cables

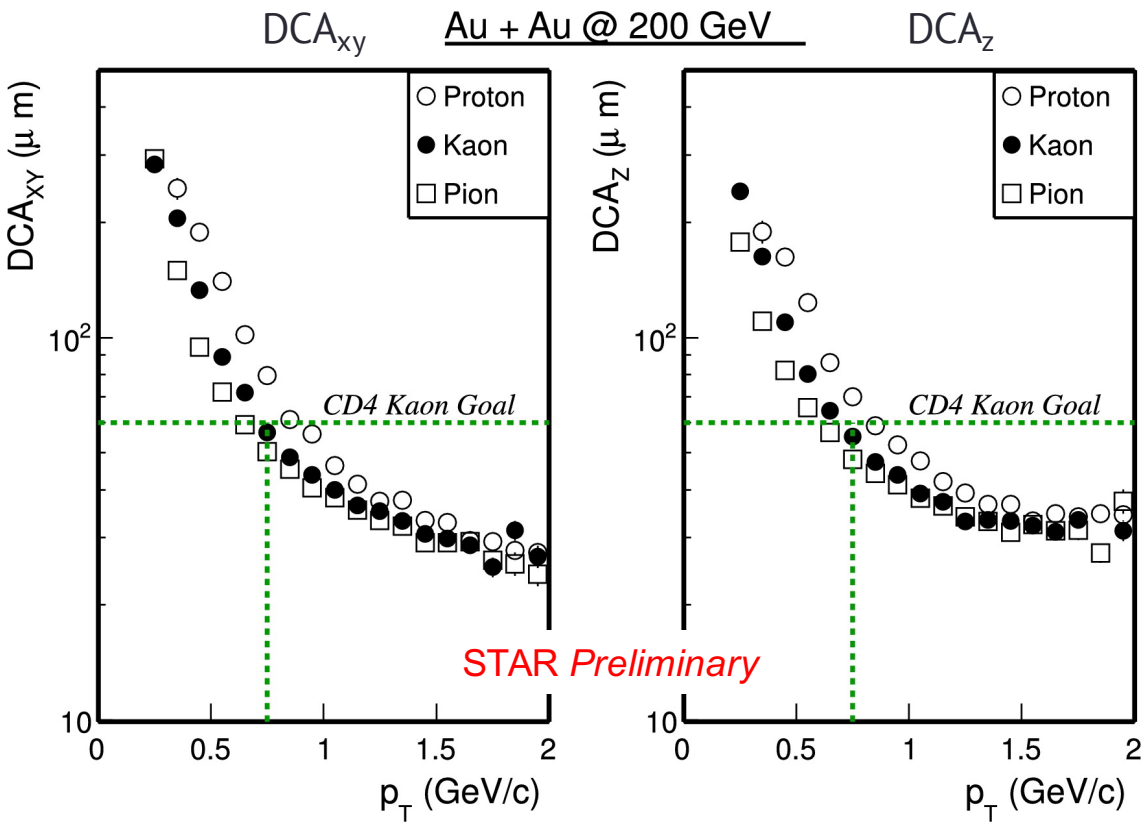
Acceptance coverage:
$-1 < \eta < 1$
$0 < \phi < 2\pi$

- SSD – Silicon Strip Detector
- IST – Intermediate Silicon Tracker
- PXL – Pixel Detector

Tracking inwards with gradually improved resolution:



HFT Performance vs design goals



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

D^0 reconstruction

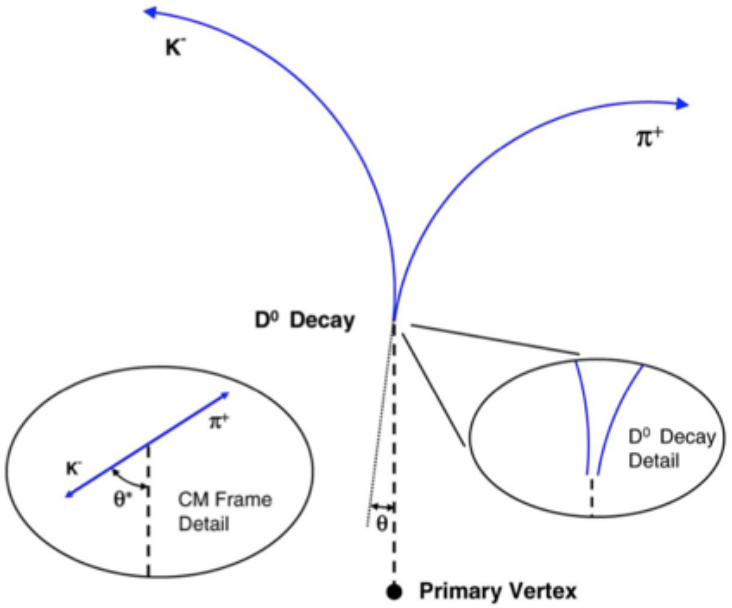
- Direct topological reconstruction through channel:

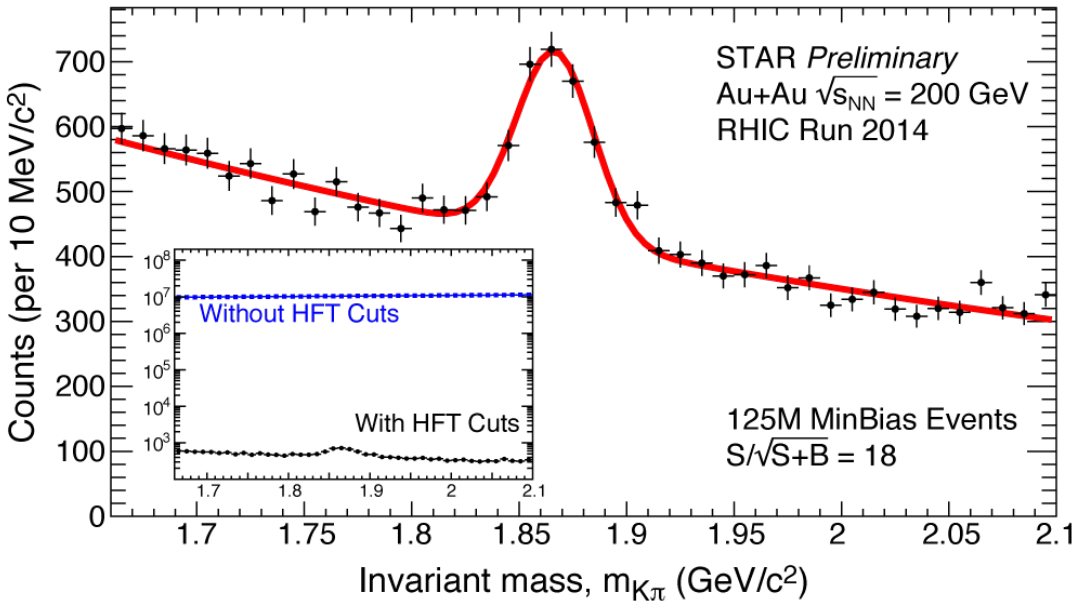
$$D^0(\overline{D^0}) \rightarrow K^{\mp}\pi^{\pm}$$

$$\text{B.R. } 3.9\% \quad c\tau \sim 120\ \mu m$$

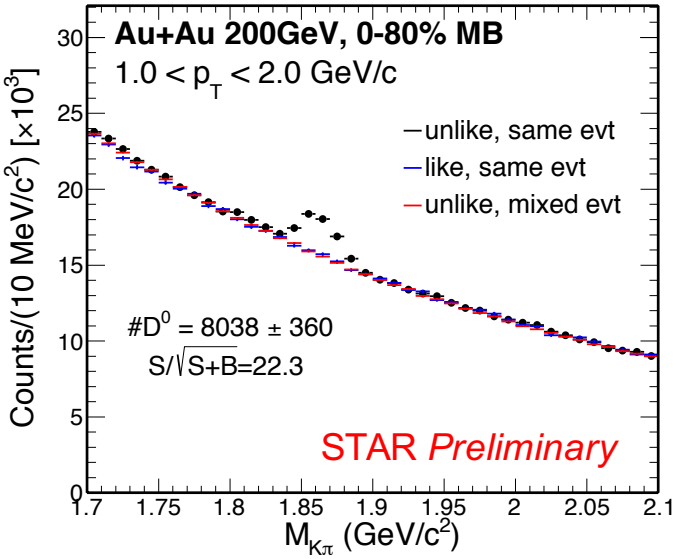
- Topological cuts optimized using TMVA (Toolkit for Multivariate Analysis)

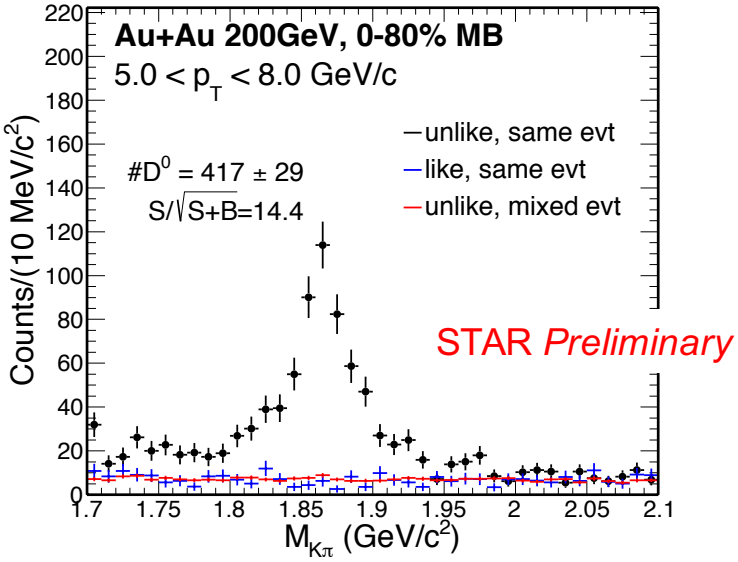
- Greatly reduced combinatorial background (4 orders of magnitude)





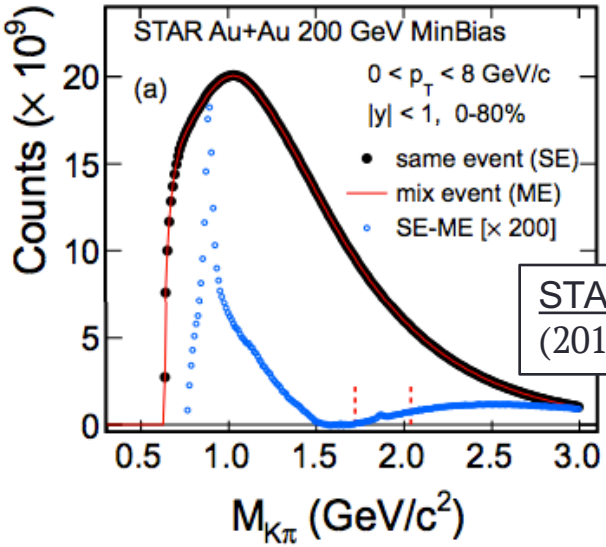
D^0 reconstruction using HFT





- Significance greatly enhanced compared to STAR previous, 2010+2011 results.

	w/o HFT	w HFT
	2010 + 2011	2014
# events(MB) analyzed	1.1 B	780 M
Significance per billion events	13	51



STAR 2010/11: PRL 113 (2014) 142301

v_2: event plane method

- Event plane reconstructed using charged hadrons within STAR TPC acceptance ($|\eta|<1$)
- Corrected for detector acceptance
- Yields in $\phi-\Psi$ bins corrected for event plane resolution

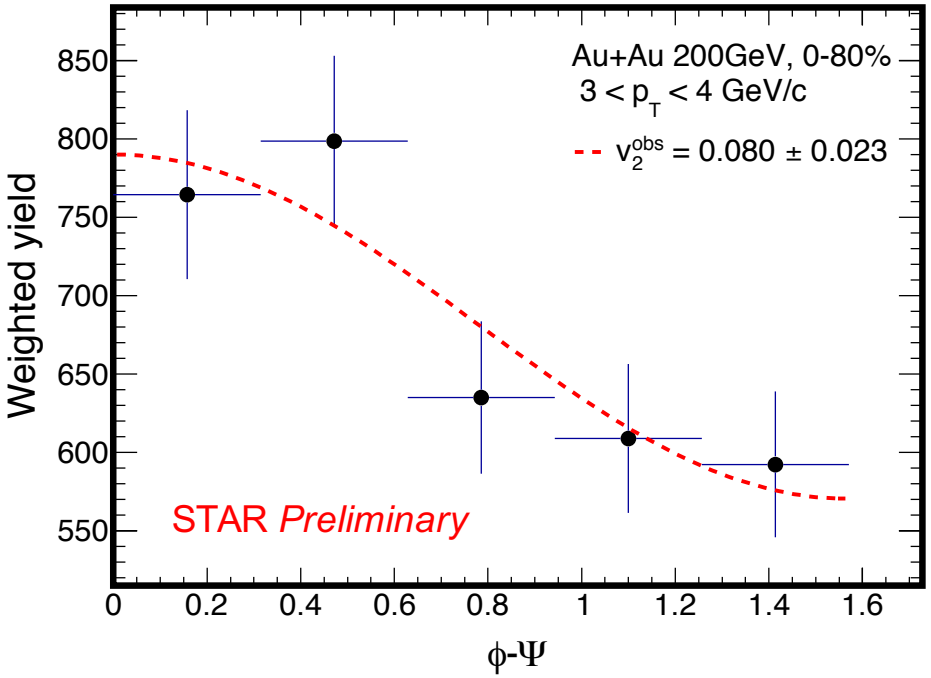
$$v_2 = v_2^{obs} \times \left\langle \frac{1}{\text{E.P. Resolution}} \right\rangle$$

- Hadrons $|\Delta\eta| < 0.15$ around D^0 candidates removed from event plane reconstruction
- Non-flow estimated from measured D-h correlations in p+p 200GeV

$$v_2^{nonFlow} = \frac{< \sum_h \cos(2(\phi_{D^0} - \phi_h)) >}{M v_2^h}$$

p+p

Au+Au



Methods for v_n: *A.M. Poskanzer* and *S.A. Voloshin*. PRC 58 (1998) 1671
Event plane resolution: *H. Masui* and *A. Schmah*
STAR: PRL 93 (2004) 252301

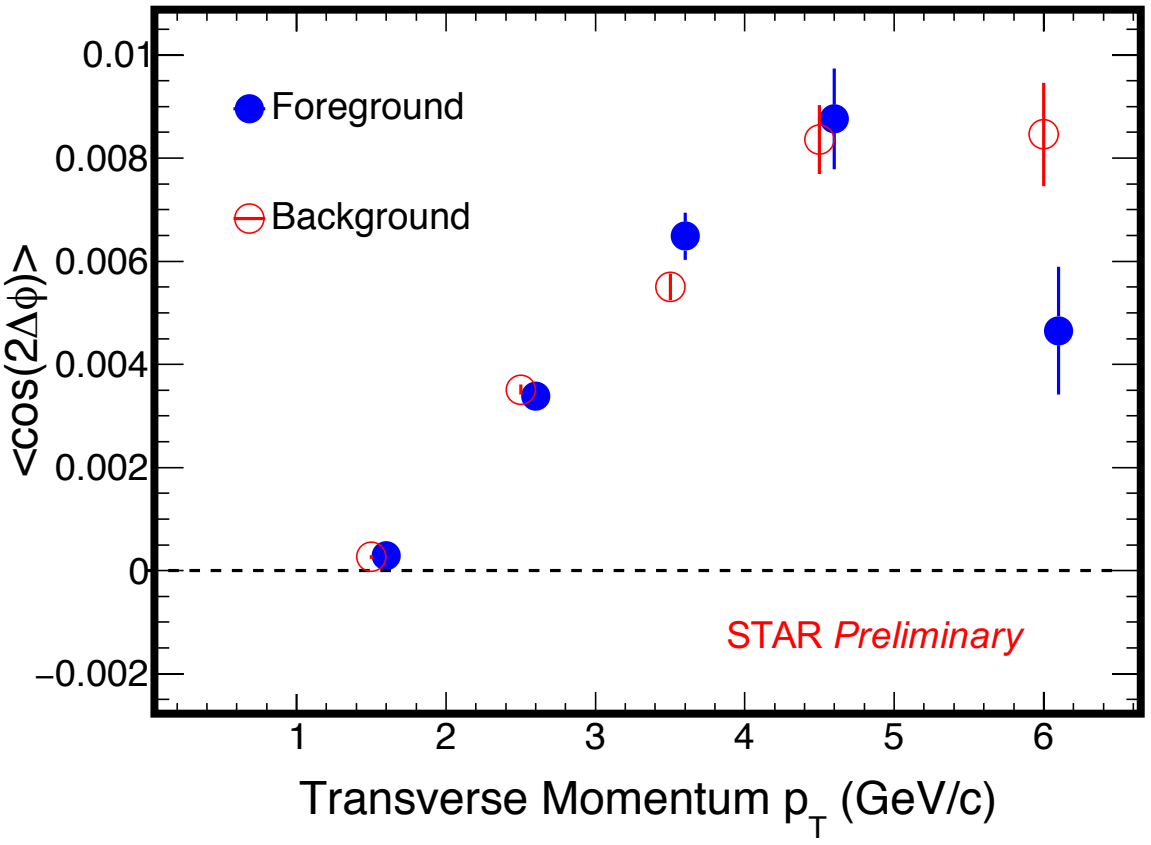
v_2: two particle correlation

- Event-by-event v_2 for foreground and background

$$< \cos(2\varphi_{h1} - 2\varphi_{h2}) >= (\nu_2^h)^2$$

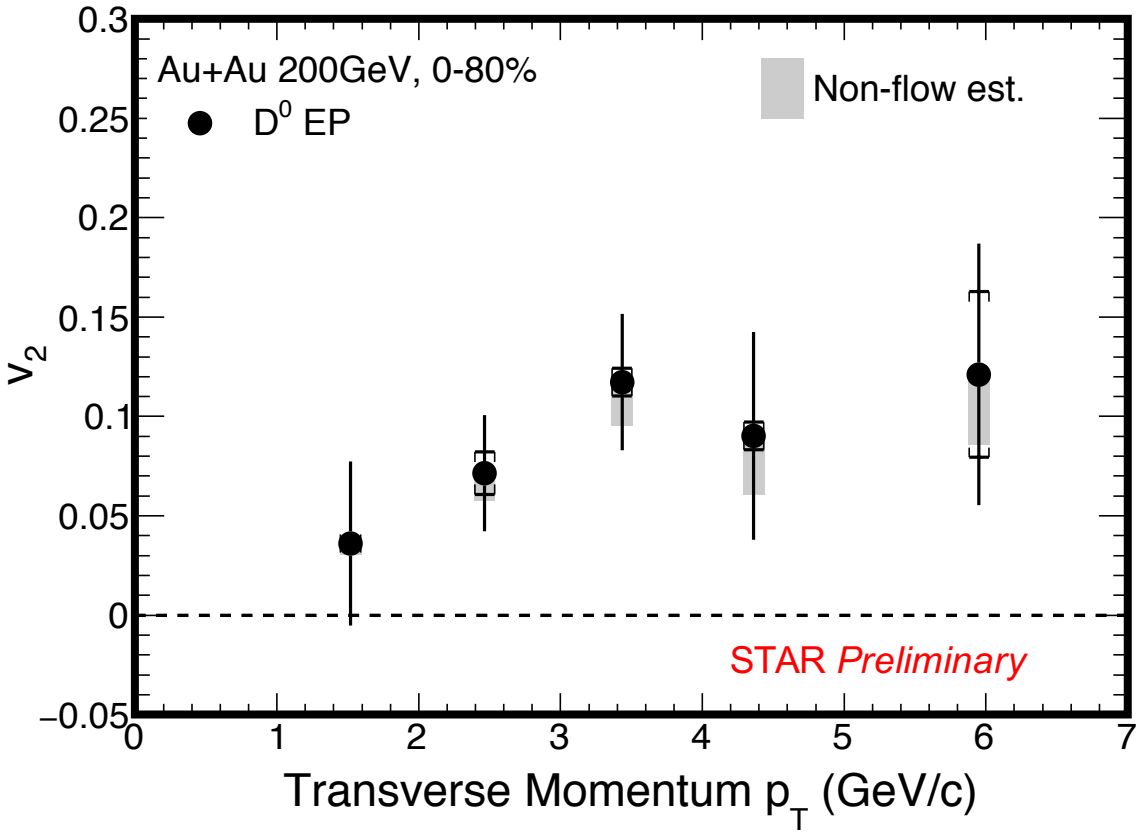
$$\nu_2^D = \frac{< \cos(2\varphi_D - 2\varphi_h) >}{\sqrt{< \cos(2\varphi_{h1} - 2\varphi_{h2}) >}}$$

- h_1 in $\eta < 0$, h_2 in $\eta > 0$
- Statistically subtract background from foreground to obtain D^0 v_2
- Corrected for detector acceptance



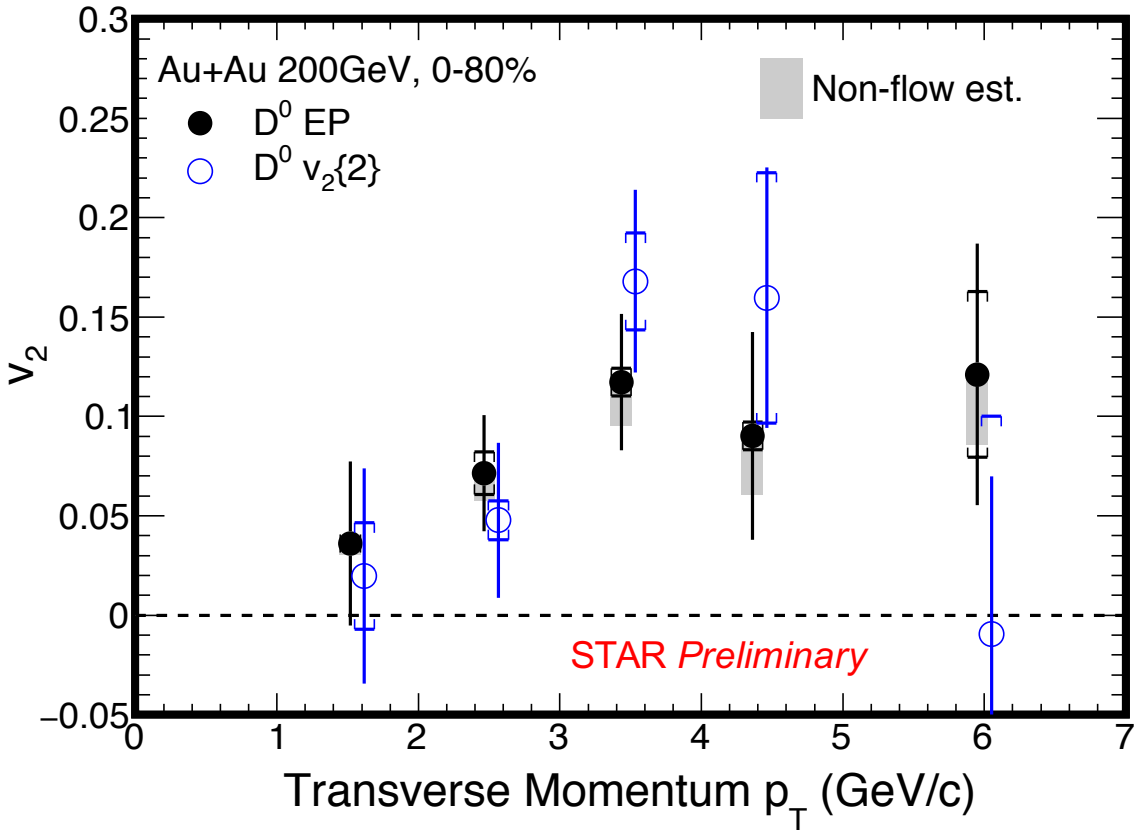
Methods for v_n: *A.M. Poskanzer* and *S.A. Voloshin.* PRC 58 (1998) 1671

D^0 meson v_2



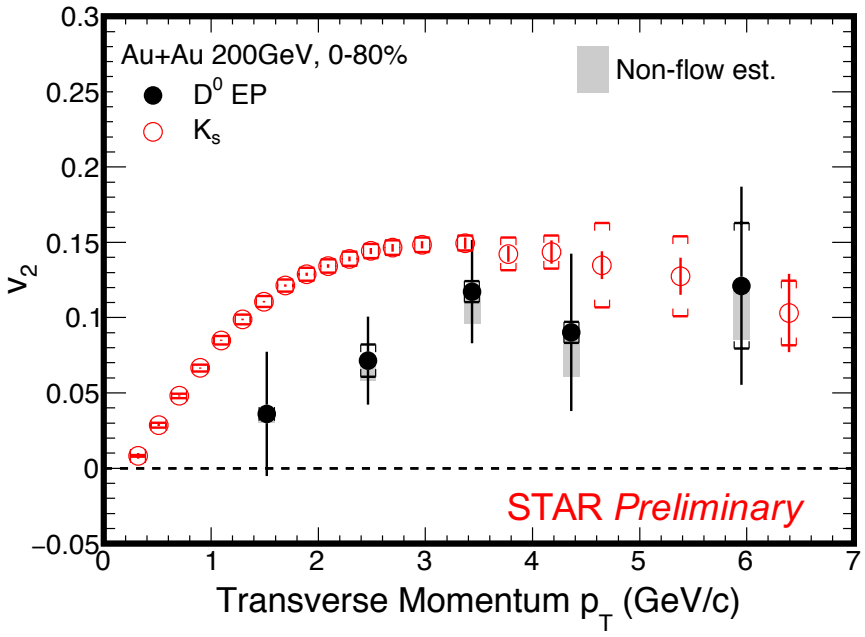
- D^0 v_2 significantly above zero for p_T > 2 GeV/c
- B->D feed down is negligible at RHIC energies (<5% relative contribution)

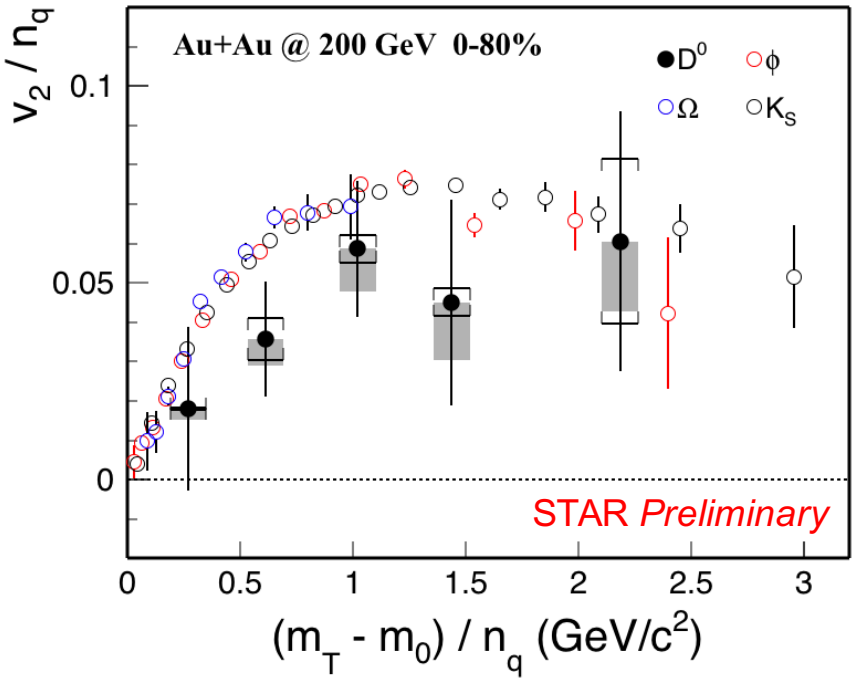
v_2 method comparison



- Good agreement between EP and 2 PC methods within uncertainties
- 2 PC systematics large, will focus on results from event plane method

Comparison to light quarks



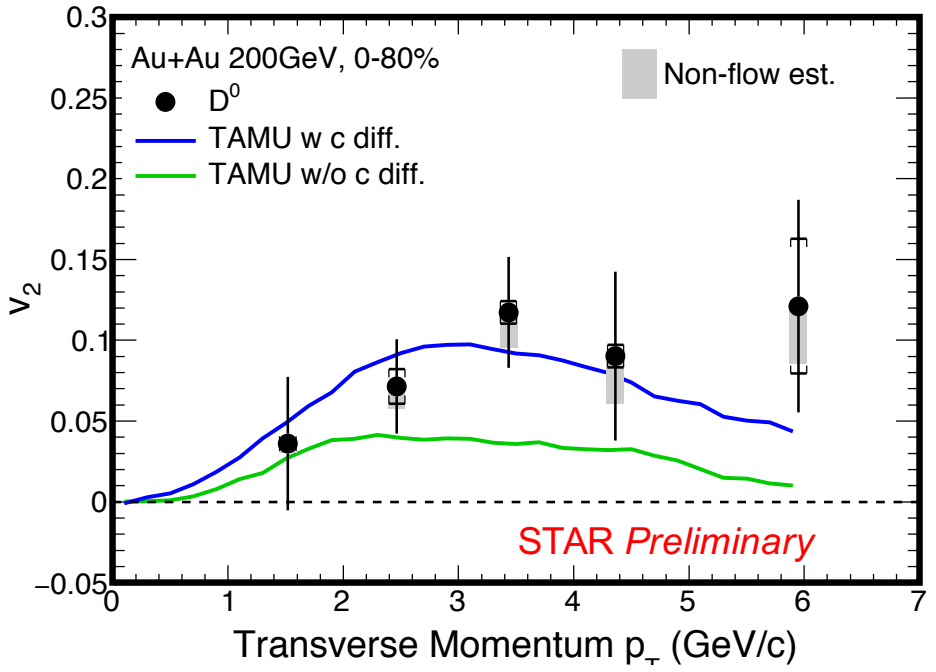


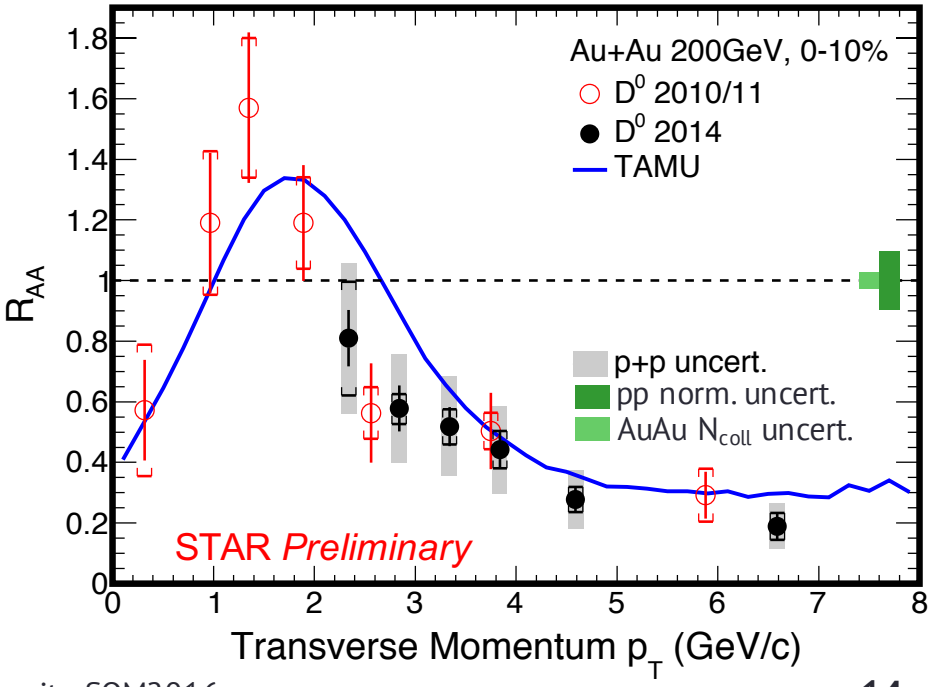
- D^0 v_2 is below light quarks for $0.5 < (m_T-m_0)/n_q < 1.5$ GeV/c
- Suggests something different than hydro

STAR:PRC 77 (2008) 54901
PRL 116 (2016) 62301

Model comparison: TAMU

- Full T-matrix treatment, non-perturbative model with internal energy potential
- Diffusion coefficient extracted from calculation $2\pi T \times D = 2\text{-}11$
- Good agreement with D^0 meson v_2 at low p_T. Data favors model including c quark diffusion in the medium

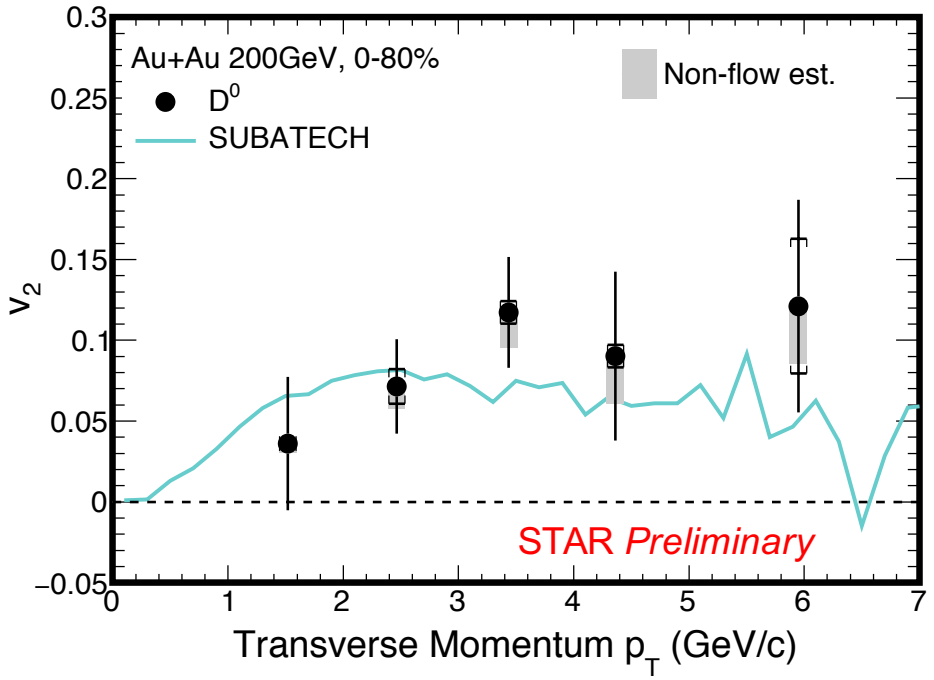


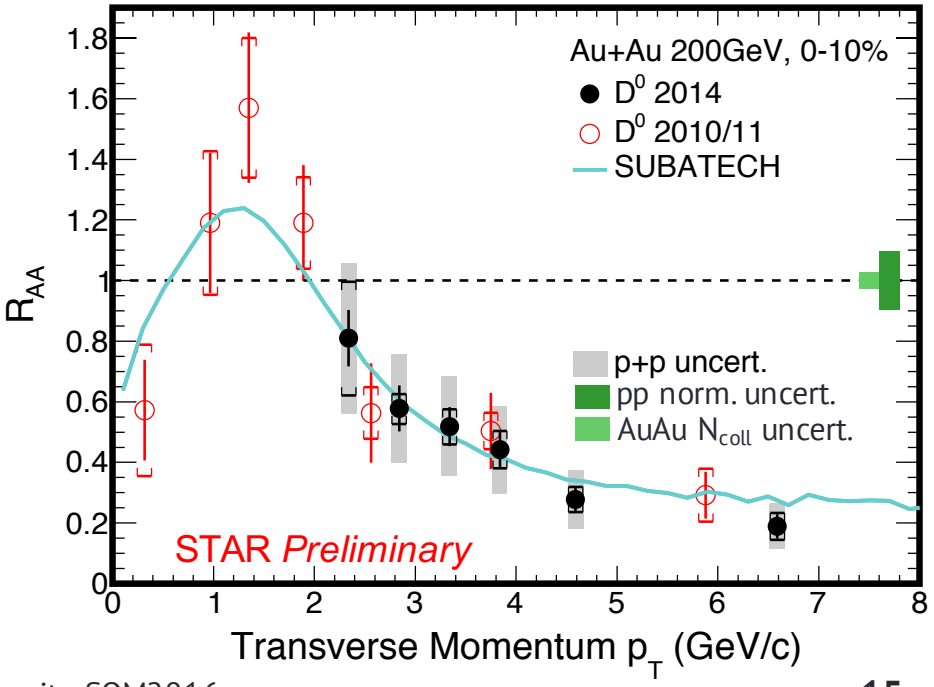


Theory: arXiv:1506.03981 (2015) & private comm.
STAR: PRL 113 (2014) 142301

Model comparison: SUBATECH

- pQCD+HTL calculation with latest EPOS3 initial conditions
- Diffusion coefficient extracted from calculations $2\pi T \times D \sim 2\text{-}4$
- Good agreement between model and experiment for both v_2 and R_{AA} in entire p_T range



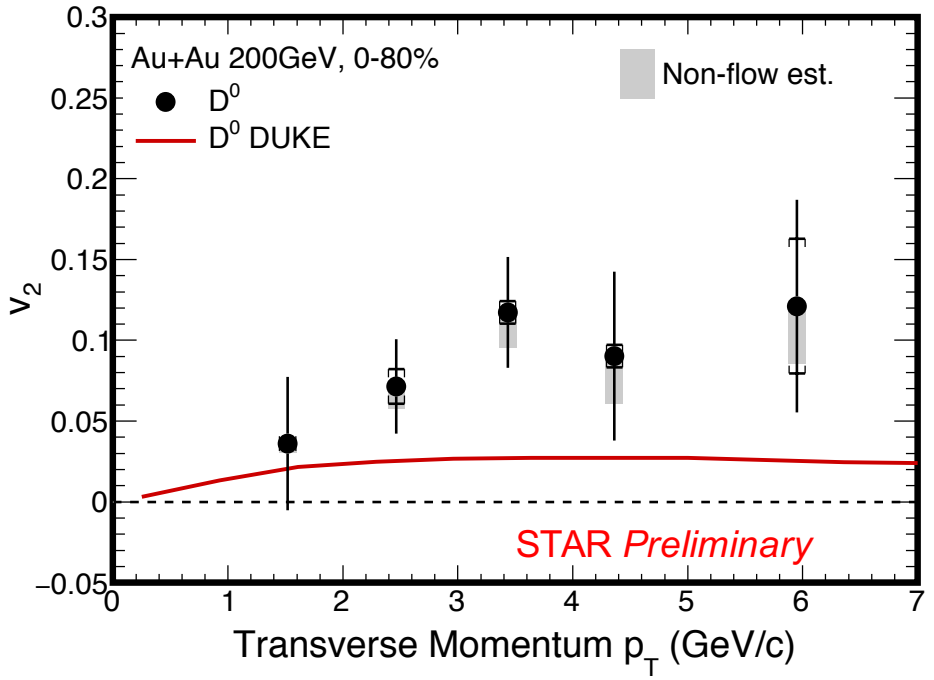


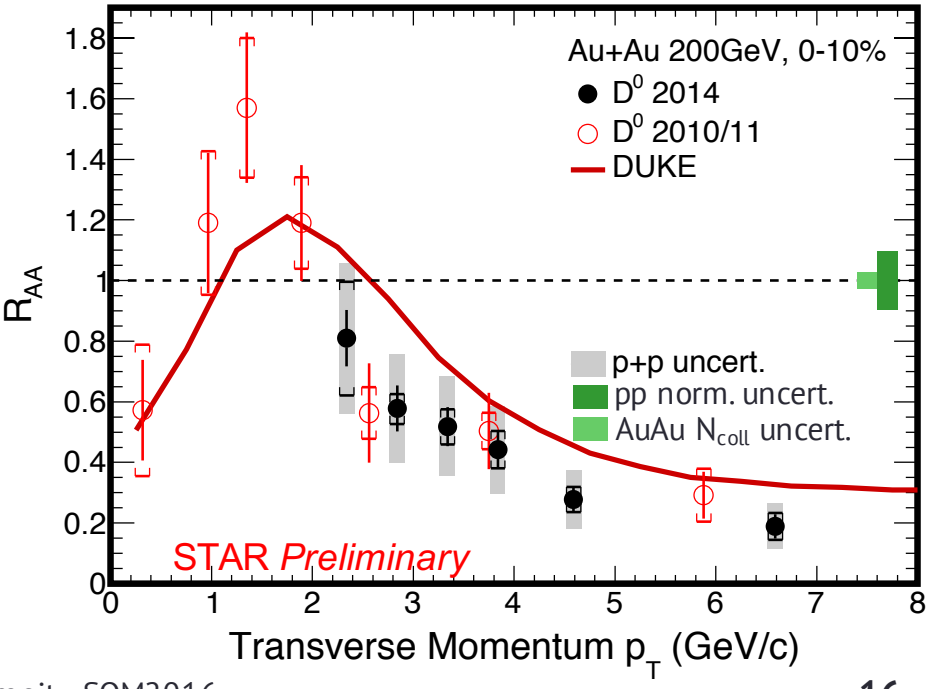
Theory: arXiv:1506.03981 (2015) & private comm.
STAR: PRL 113 (2014) 142301

Model comparison: Duke

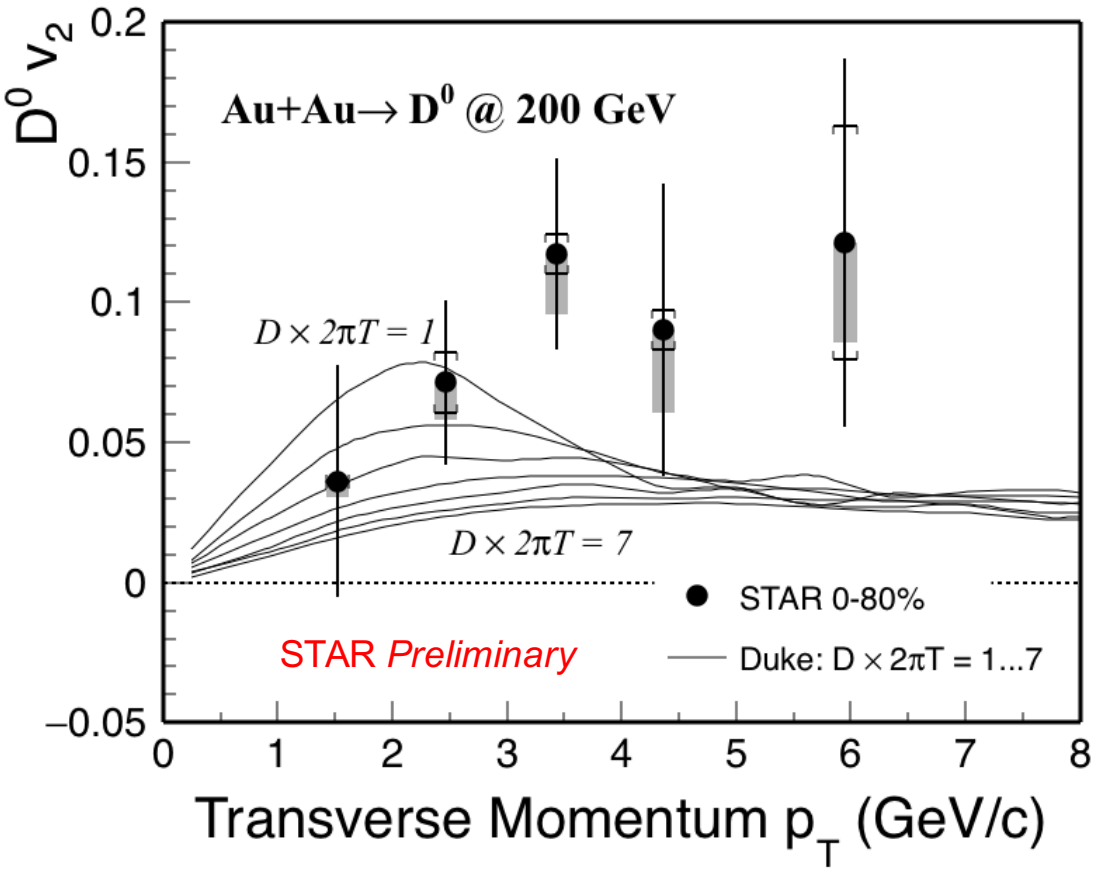
- Diffusion coefficient is a free parameter, fixed by fitting to R_{AA} at high p_T
- Input value for diffusion coefficient $2\pi T \times D = 7$ fixed to fit LHC results
- Model with $2\pi T \times D = 7$ doesn't describe the magnitude of v_2 in experimental data

Theory: PRC 92 (2015) 024907 & private comm.
STAR: PRL 113 (2014) 142301





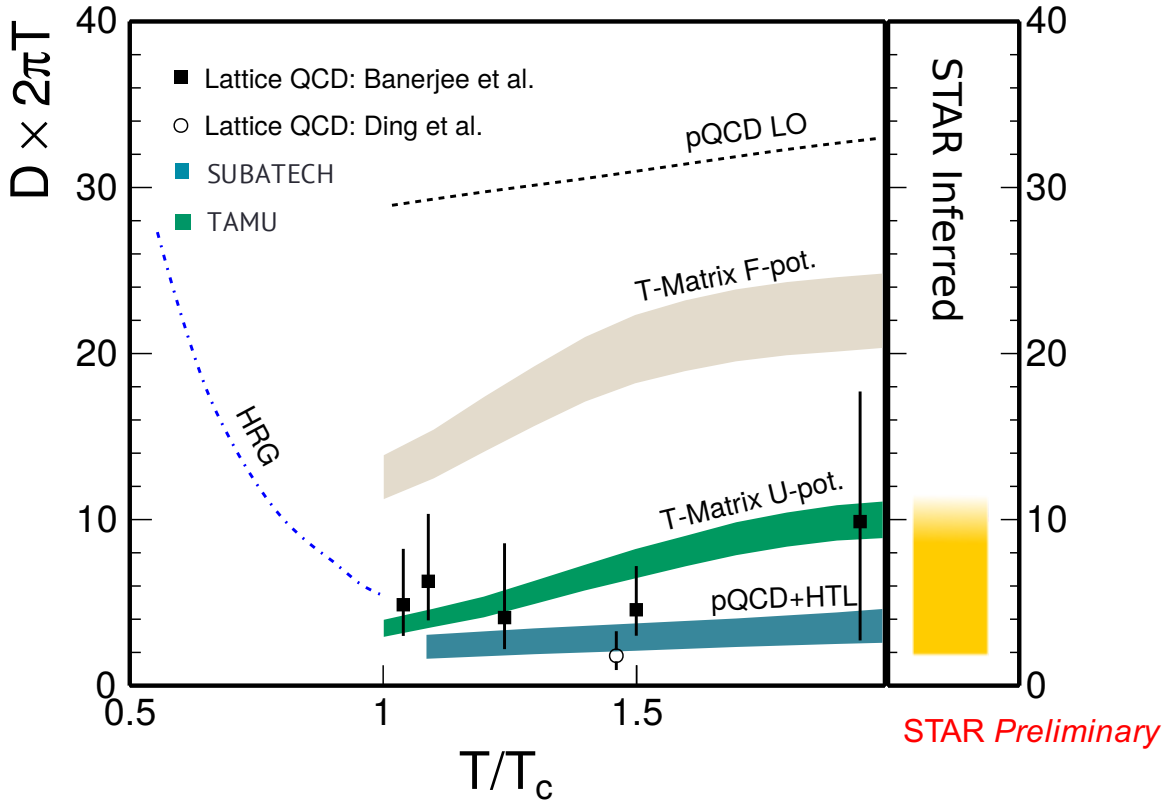
Charm diffusion coefficient scan



- Scan different values of the diffusion coefficient to find best agreement to data
- Best agreement for diffusion coefficient $2\pi T \times D$ = ~1 – 3
- This model seems to underestimate the data for p_T > 3 GeV/c

Theory: arXiv:1505.01413 & private comm.

Diffusion coefficient

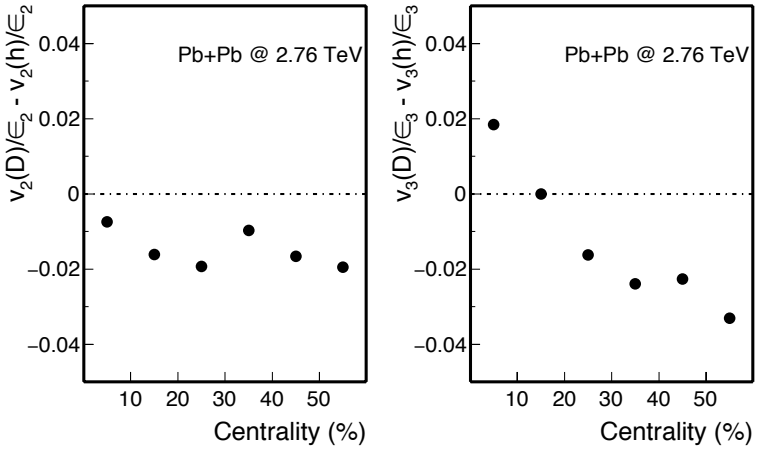


- Values for the diff. coefficient (left) extracted from models as a function of T/T_c and (right) inferred from comparison to STAR data
- Lattice calculations, although with large uncertainties, are consistent with values inferred from data

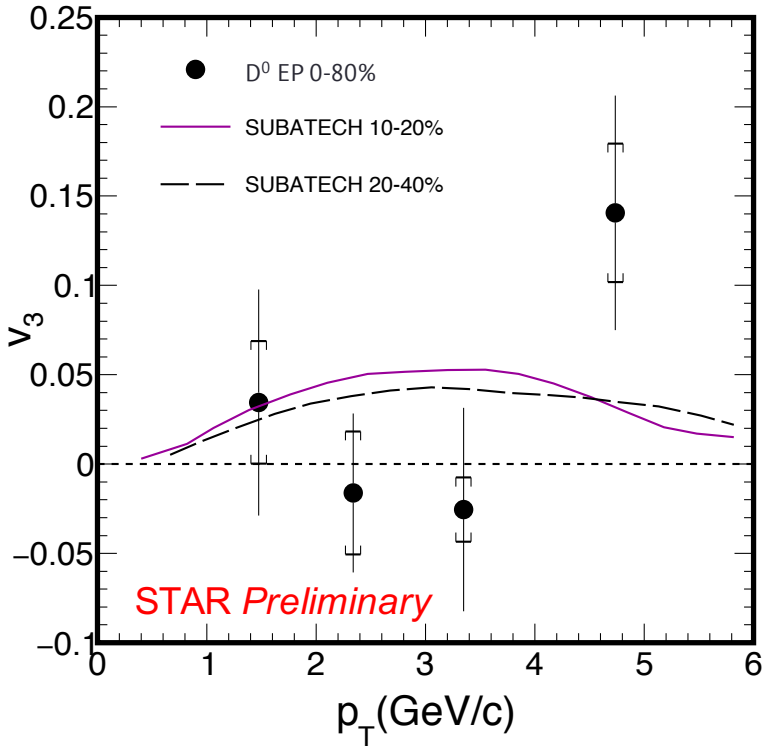
D^0 triangular flow

- Fluctuations in initial conditions and interactions with the medium could lead to a finite D^0 v_3
- Models suggest that a QGP with higher temperature/ larger volume will transfer more bulk flow to heavy quarks.
- This trend will be observable in the centrality dependence of v_3
- First measurement of D^0 v_3, current data uncertainties too large for any firm conclusions

Theory: PRC 91(2015) 014904 & private comm.

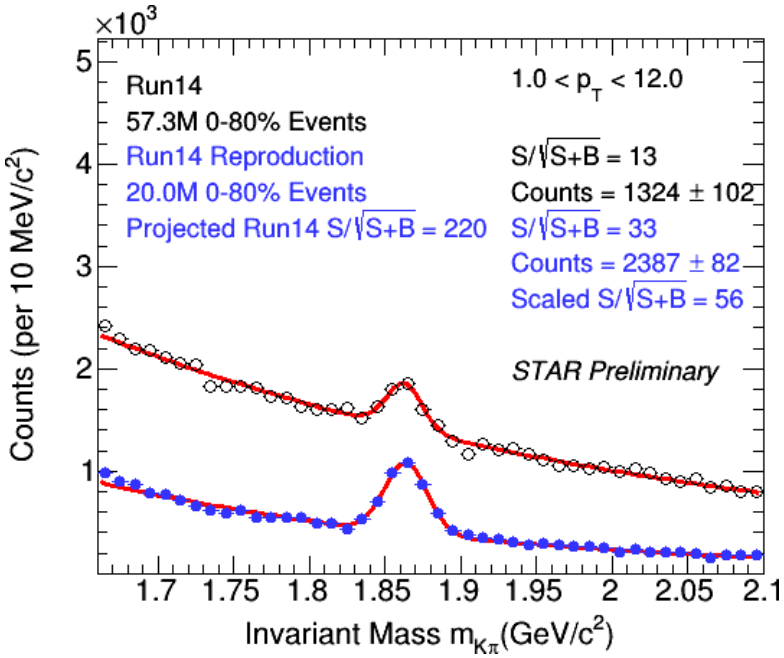


v_n/ε_n for different centralities in Pb+Pb @ 2.76 TeV



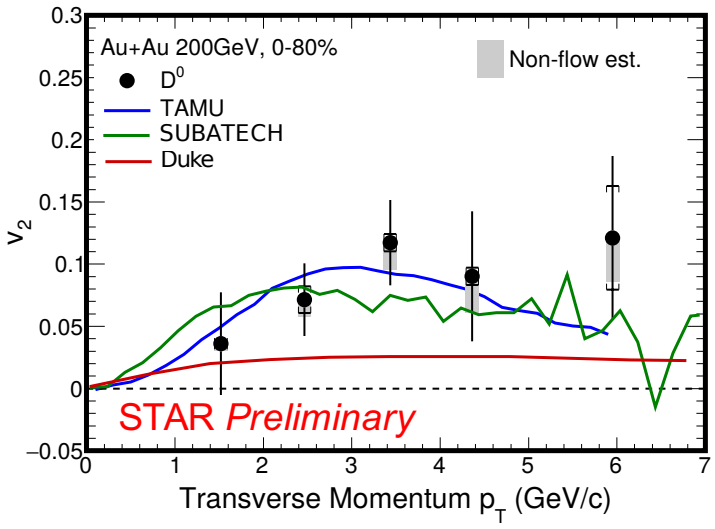
Outlook

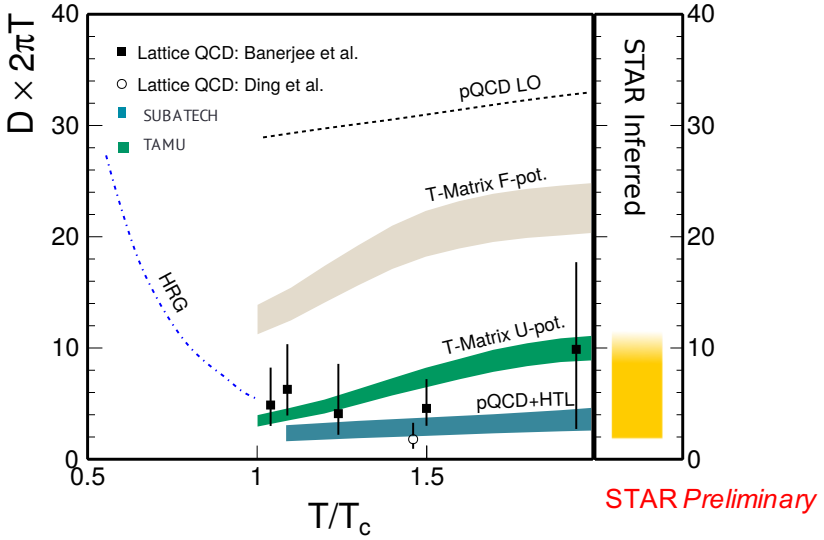
- Improved HFT tracking efficiency after discovering and fixing a decoder issue in PXL offline reconstruction
- Factor 2-4 improvement in D^0 significance expected with reprocessed data
- Preliminary results are consistent with the results obtained with the available re-processed sample
- Run 14:
  - Re-processed full statistics available soon
- Run 16:
  - Full aluminum cables for inner layer of PXL
  - Factor 2 -3 further improvement for D^0 significance @ 1 GeV -> centrality dependence for v_2



Year	System	Events(MB)
Run 14:		
	Au+Au	1.2 B
Run 15:		
	p+p	1 B
	p+Au	0.6 B
Run 16:		
	Au+Au	~2.0 B
	d+Au	~0.3 B

Summary



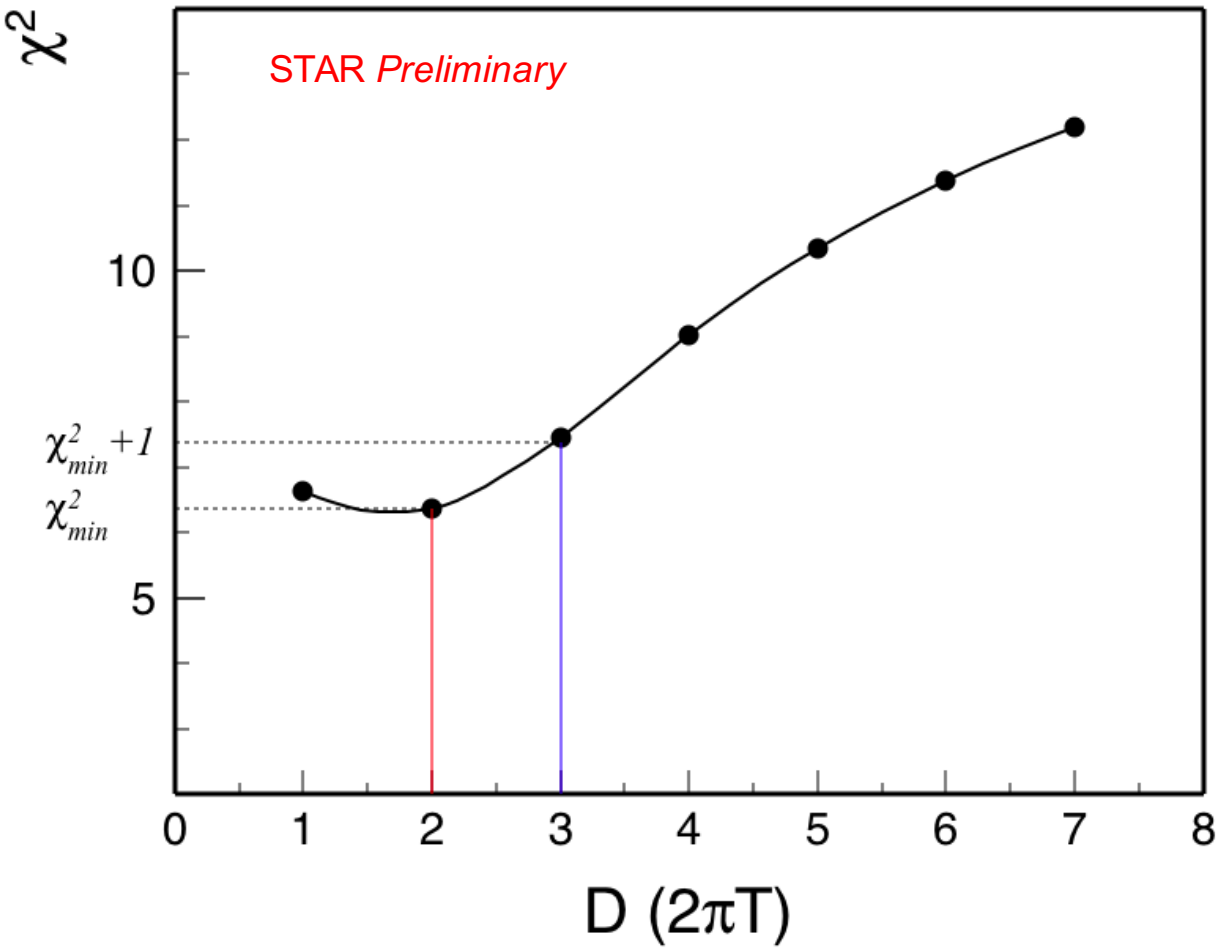


- D^0 v_2 is finite for $p_T > 2.0$ GeV/c and lower than that of light quarks for $1 < p_T < 4.0$ GeV/c
- First implementation of MAPS based vertex detector in a collider experiment
- Data favor model scenario where charm quarks flow
- D^0 v_2 and R_{AA} can be described simultaneously by models with values of 2πTxD between 2 and ~11
- Looking forward to improved significance from 2014 and statistics from year 2016

Thank you!

Back ups

Diffusion Coefficient from DUKE



Comparison to ALICE