Measurement of *D*-meson azimuthal anisotropy in Au+Au 200GeV collisions at RHIC

Michael R. Lomnitz
Kent State University
Lawrence Berkeley National Laboratory

for the STAR Collaboration

2015 KOBE JAPAN

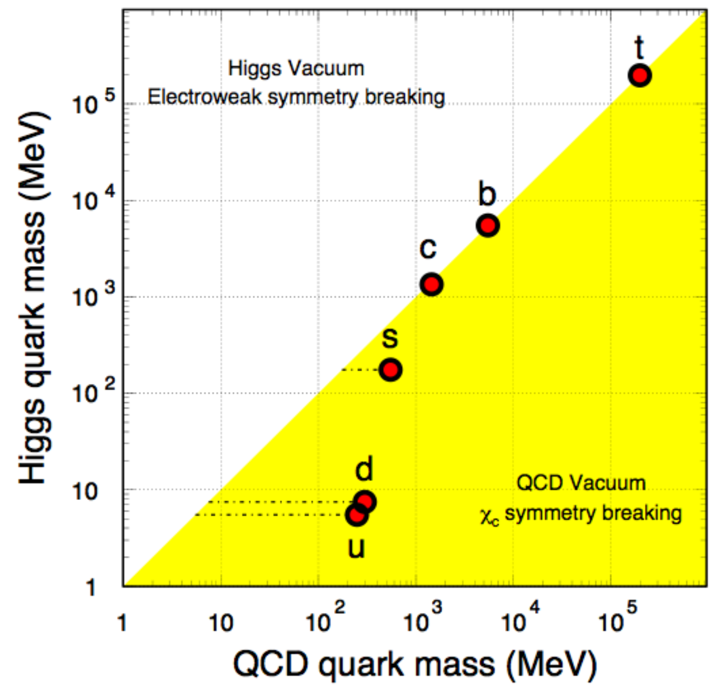
Motivation

Charm quarks:

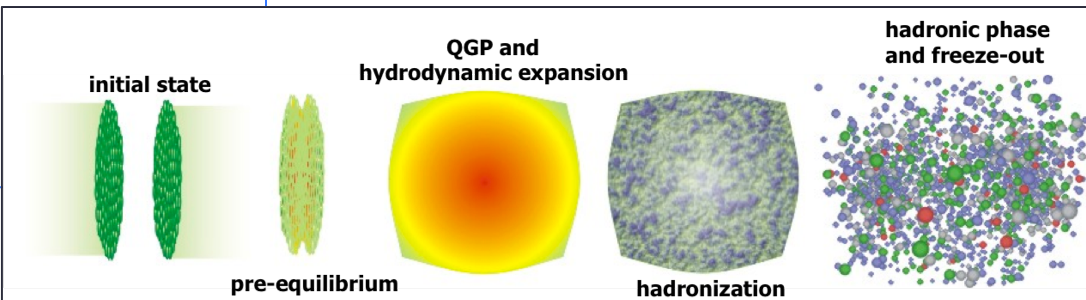
- Produced early in heavy ion collisions at RHIC, through hard scattering
- Experience the whole evolution of the system -> good probe for medium properties

Physics interest:

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



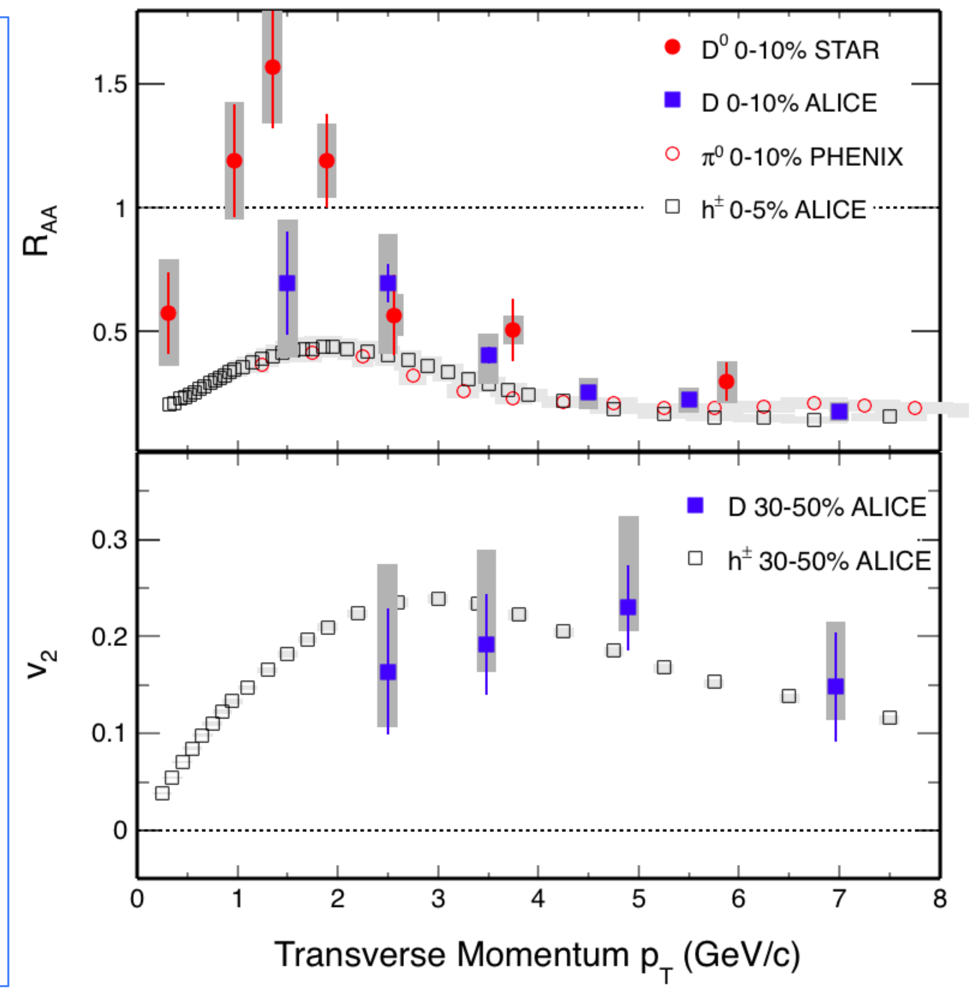
X. Zhu, *et al*, Phys. Lett. **B647**, 366(2007).



Recent developments and understanding

- RHIC and LHC: *D*-meson R_{AA} suppression at high p_T : strong charm-medium interactions
- D^0 v_2 LHC 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

For R_{AA} talk see G. Xie (Monday 15:10)



STAR:PRL 113 (2014) 142301
PHENIX:PRL 101 (2008) 232301
ALICE: PRL 111 (2013) 102301
arXiv:1509.06888 (2015)

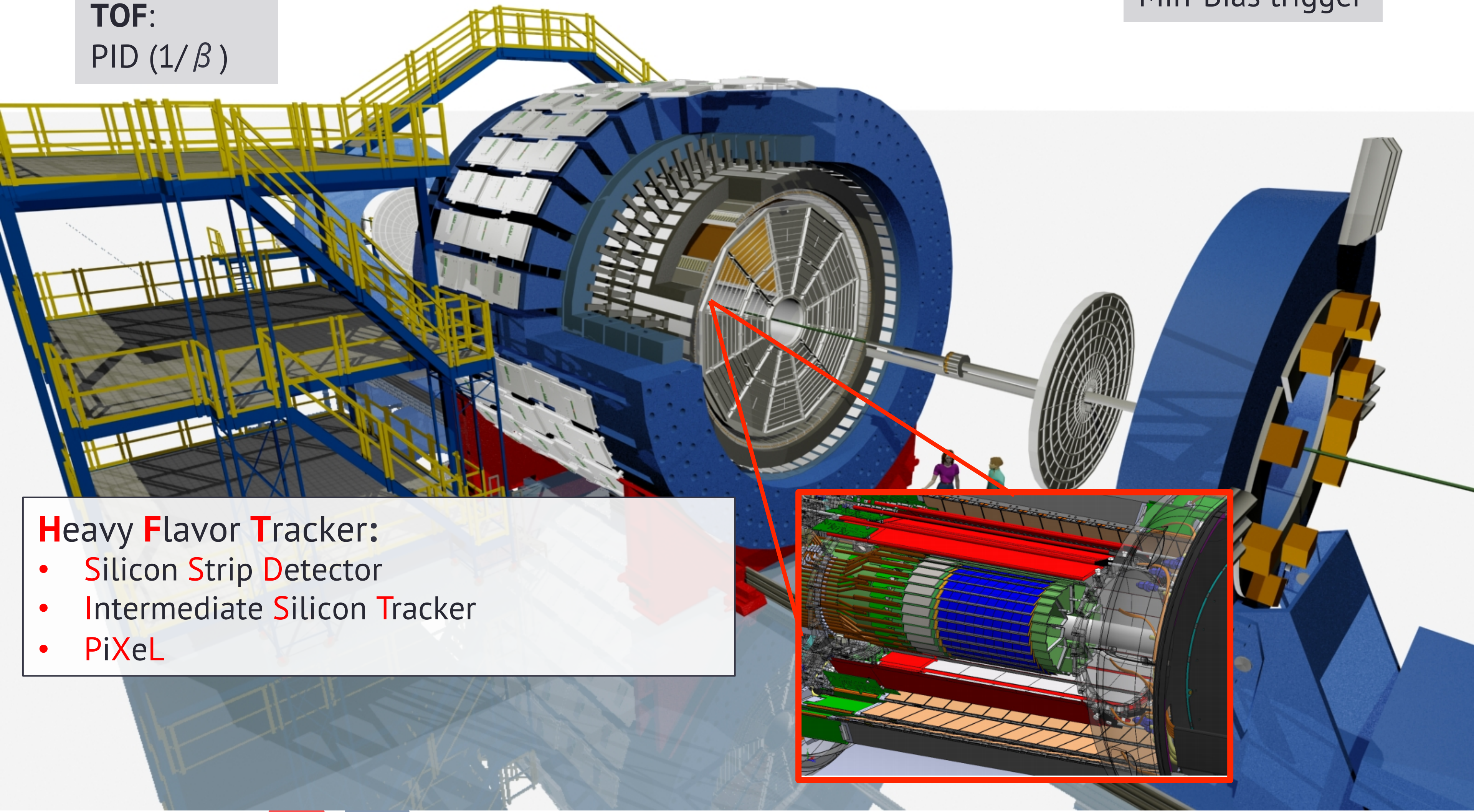
STAR experiment

TPC:
Tracking,
PID (dE/dx)

TOF:
PID ($1/\beta$)

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

VPD:
Min-Bias trigger



Heavy Flavor Tracker:
- Silicon Strip Detector
- Intermediate Silicon Tracker
- PiXeL

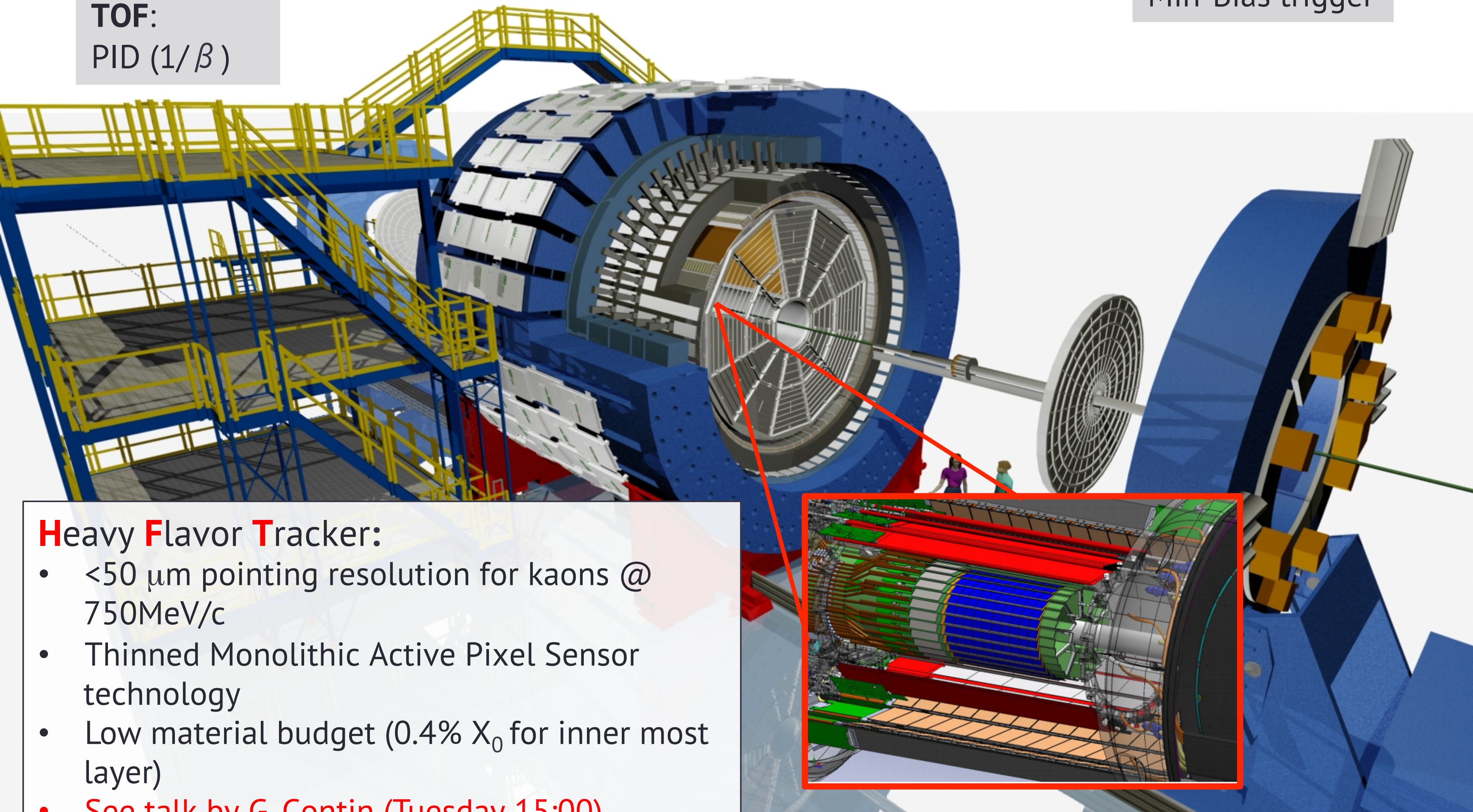
STAR experiment

TPC:
Tracking,
PID (dE/dx)

TOF:
PID ($1/\beta$)

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

VPD:
Min-Bias trigger



Heavy Flavor Tracker:

- <50 μm pointing resolution for kaons @ 750MeV/c
- Thinned Monolithic Active Pixel Sensor technology
- Low material budget (0.4% X_0 for inner most layer)
- See talk by G. Contin (Tuesday 15:00)

D^0 reconstruction

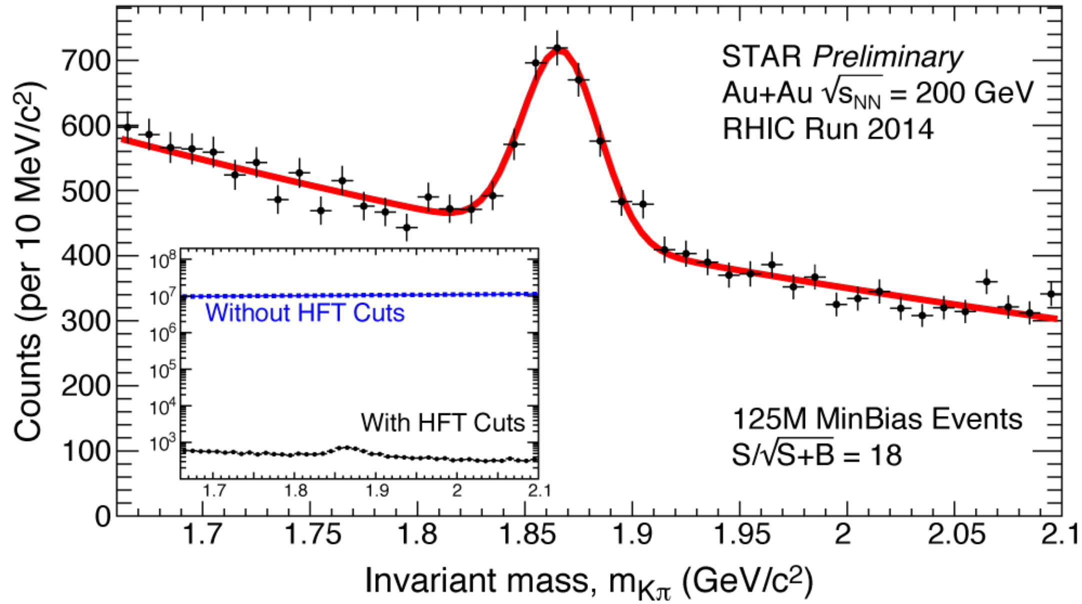
- Direct topological reconstruction through channel:

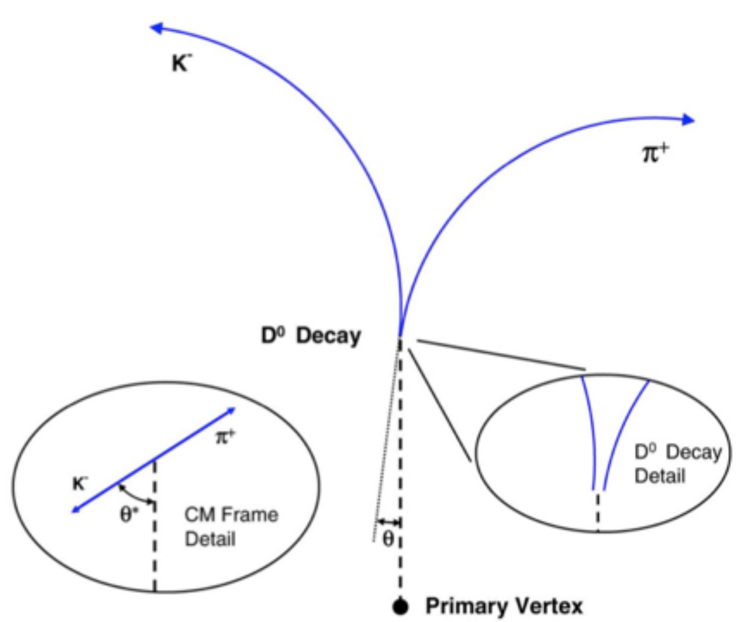
$$D^0(\overline{D^0}) \rightarrow K^{\mp}\pi^{\pm}$$

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

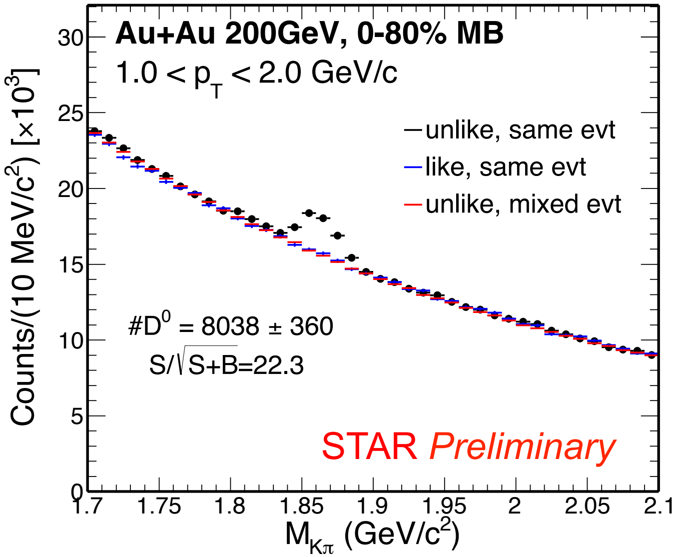
- Greatly reduced combinatorial background (4 orders of magnitude)

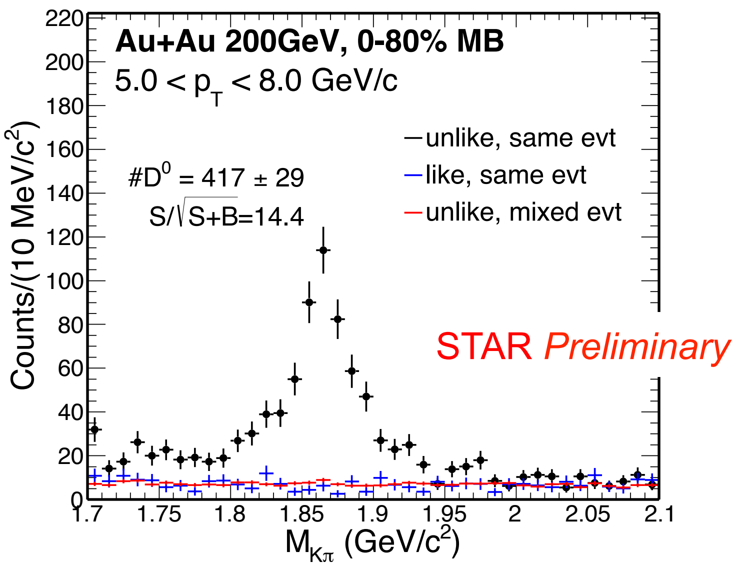
- Topological cuts optimized using TMVA (Toolkit for Multivariate Analysis)





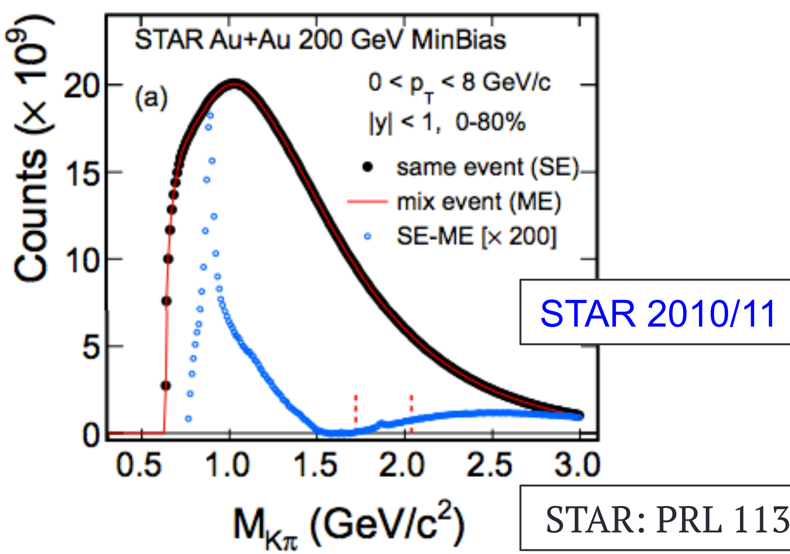
D^0 reconstruction using HFT





- 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
sig per billion events	13	51



STAR: PRL 113 (2014) 142301

v_2: Event plane method

- Event plane reconstructed using charged hadrons within STAR TPC acceptance (|η|<1)
- Corrected for detector acceptance
- Yields in ϕ−Ψ bins corrected for event plane resolution

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

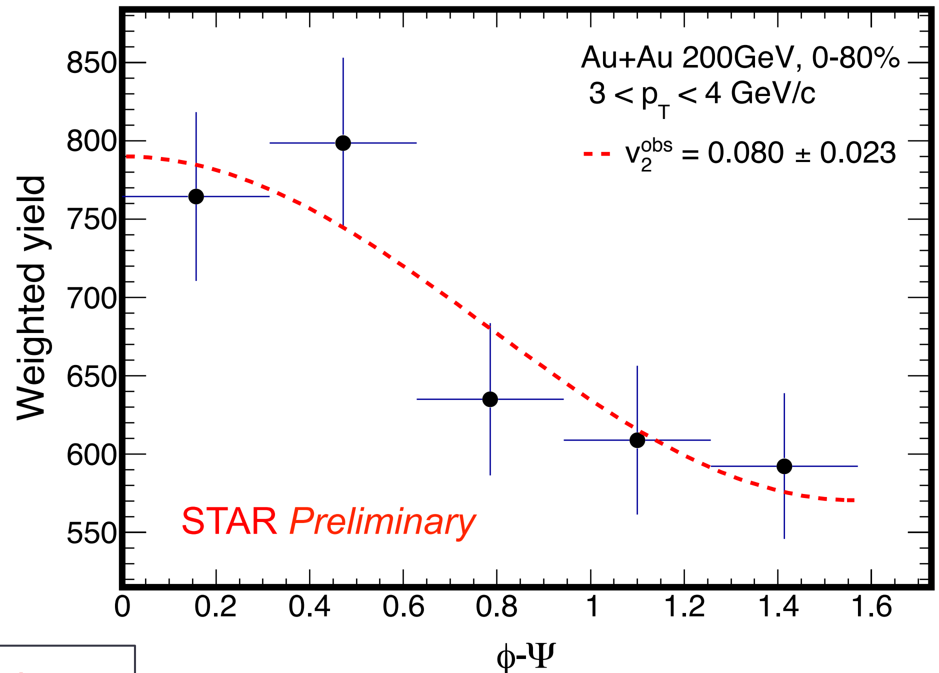
- Δη gap of ~0.15 used in event plane reconstruction

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

p+p

Au+Au

- Non-flow estimated from measured D-h correlations in p+p 200GeV



A.M. Poskanzer, et al. PRC 58 (1998) 1671
STAR: PRL 93 (2004) 252301

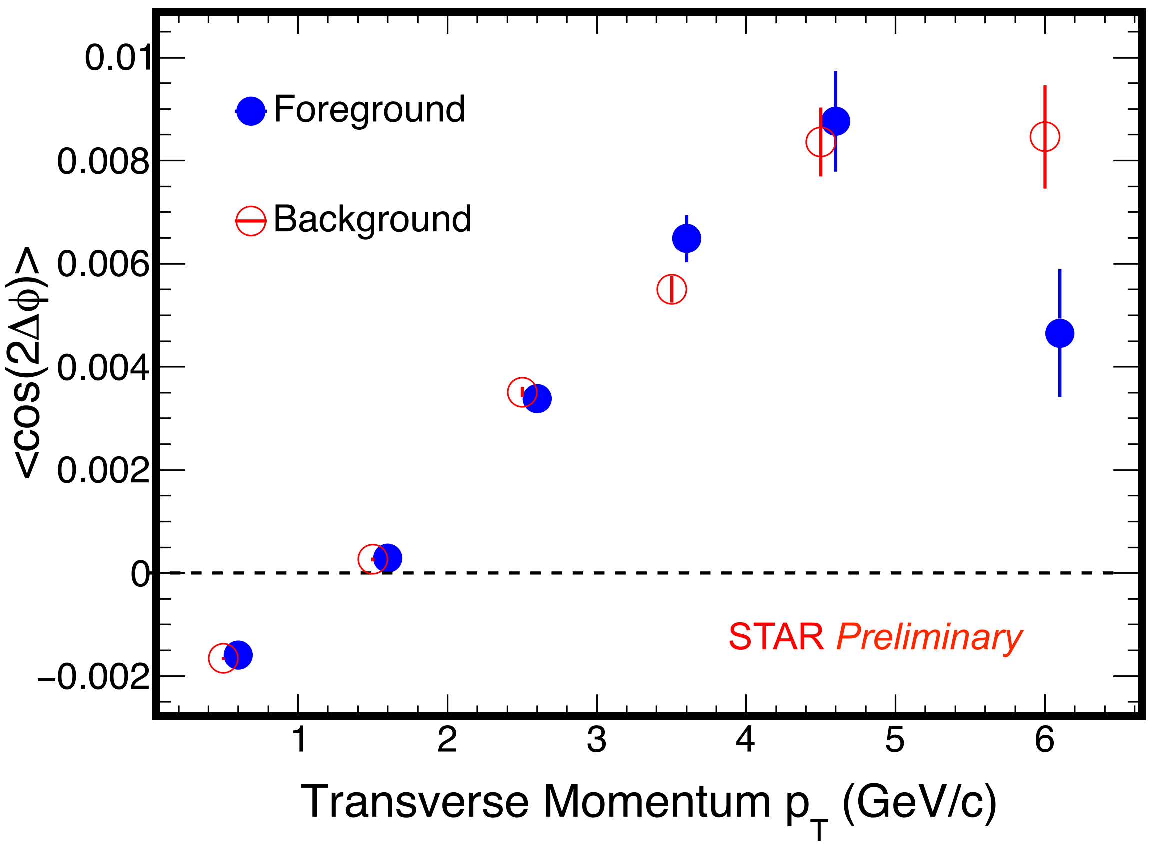
v_2: Two particle correlation

- 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



A.M. Poskanzer, et al. PRC 58 (1998) 1671

For details see poster by L. He (Exhibition space 4)

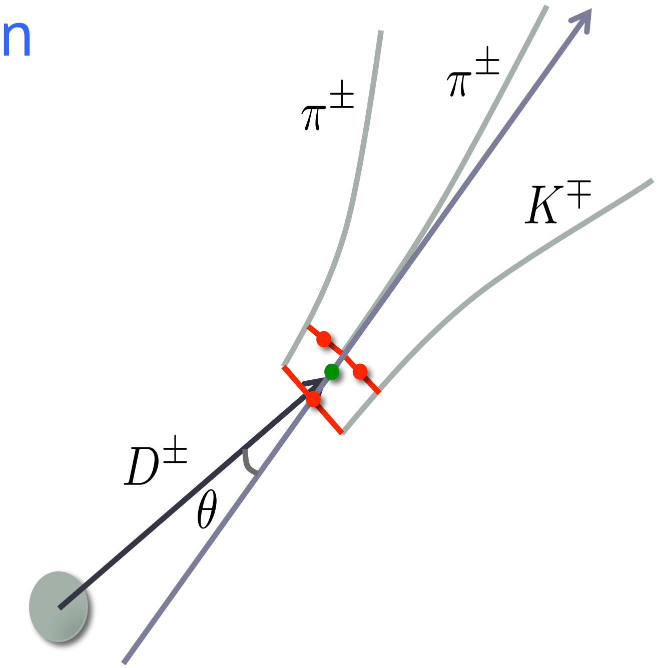
$D^{+/-}$ reconstruction

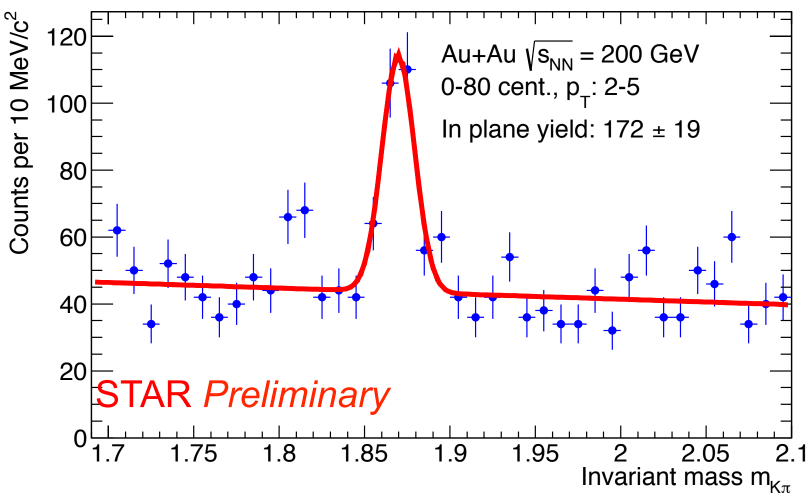
- Direct topological reconstruction through channel:

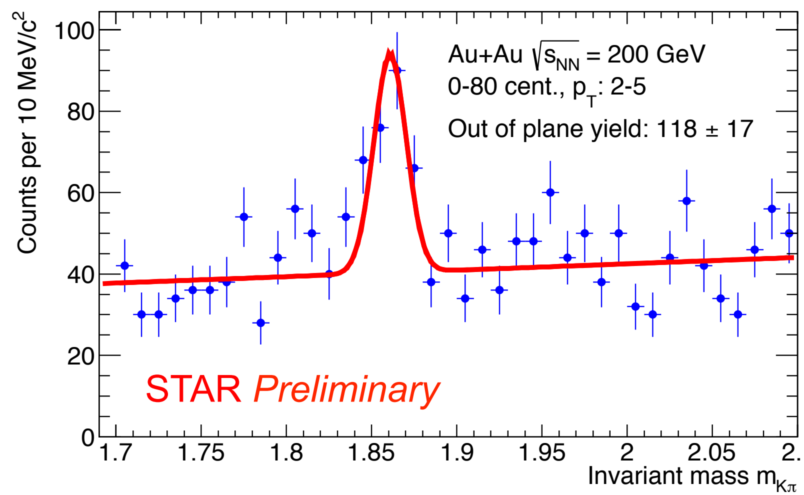
$$D^{\pm} \rightarrow K^{\mp} 2\pi^{\pm}$$

$$\text{B.R. } 9.1\% \quad c\tau \sim 300\ \mu m$$

- Yield in plane and out of plane obtained following event plane method

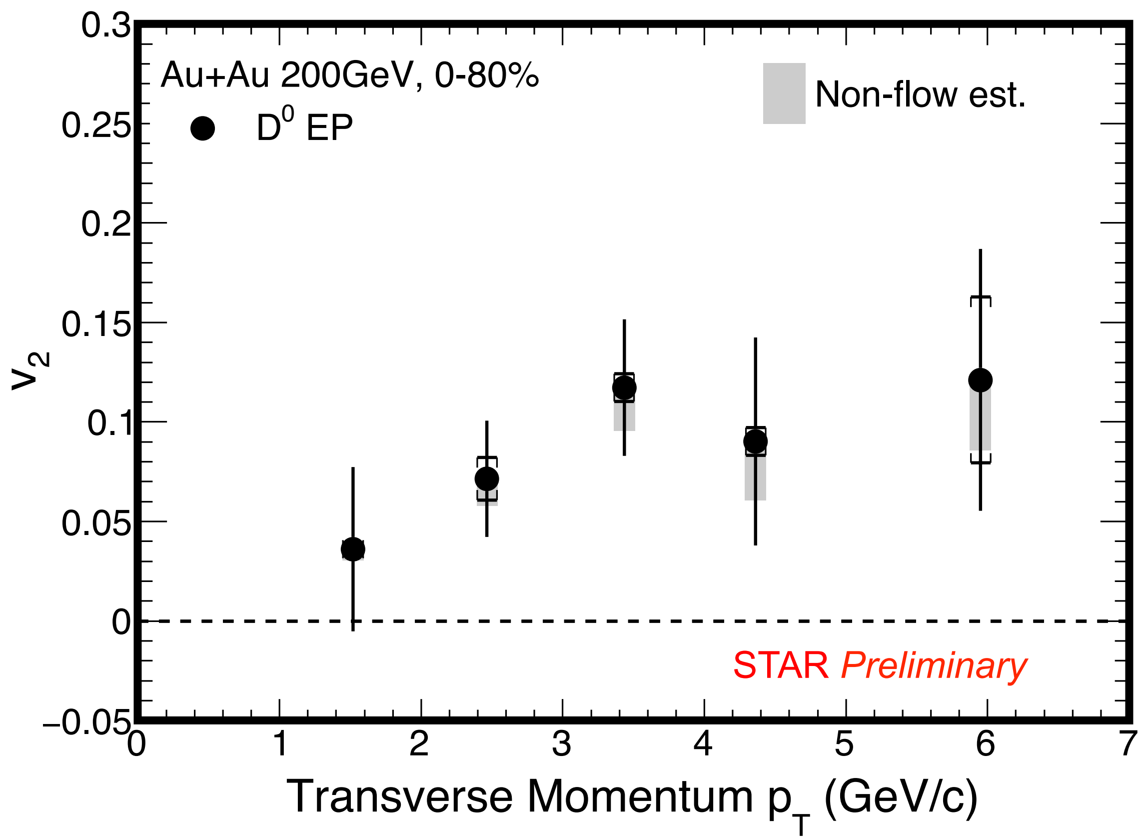






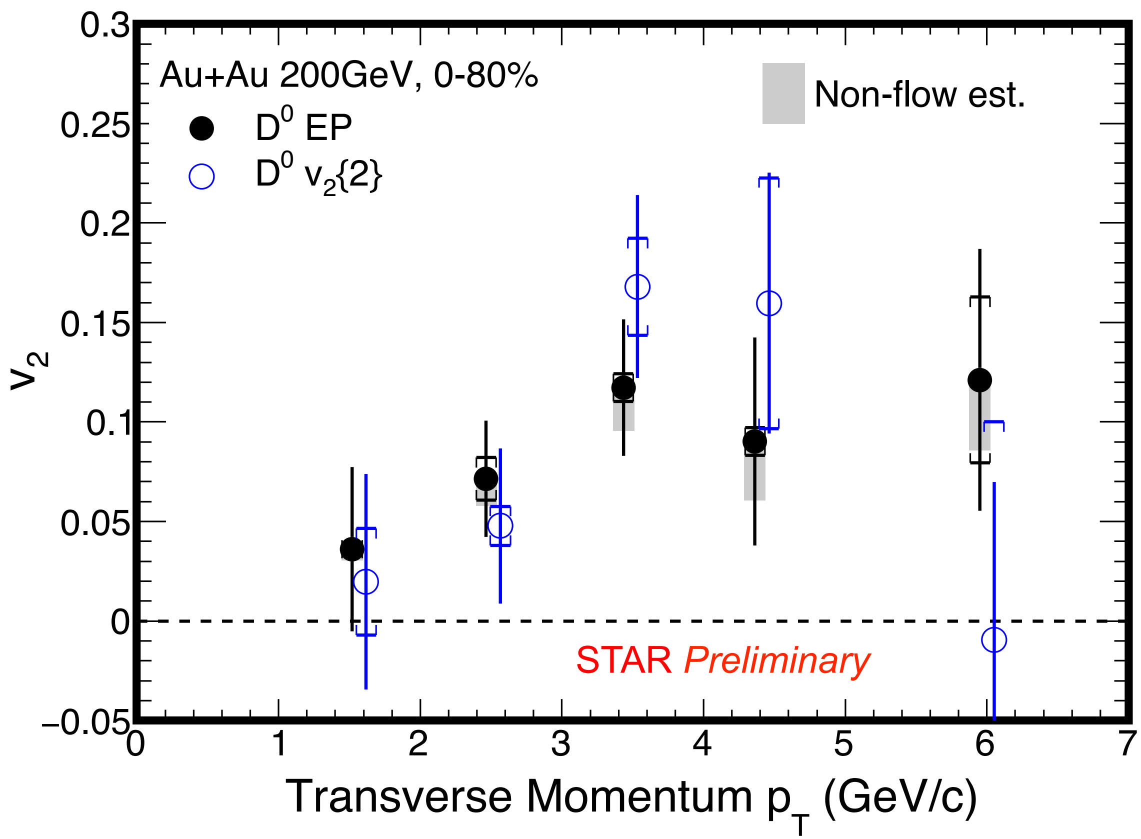
$D^{+/-}$ yield in and out of plane

D Meson v_2



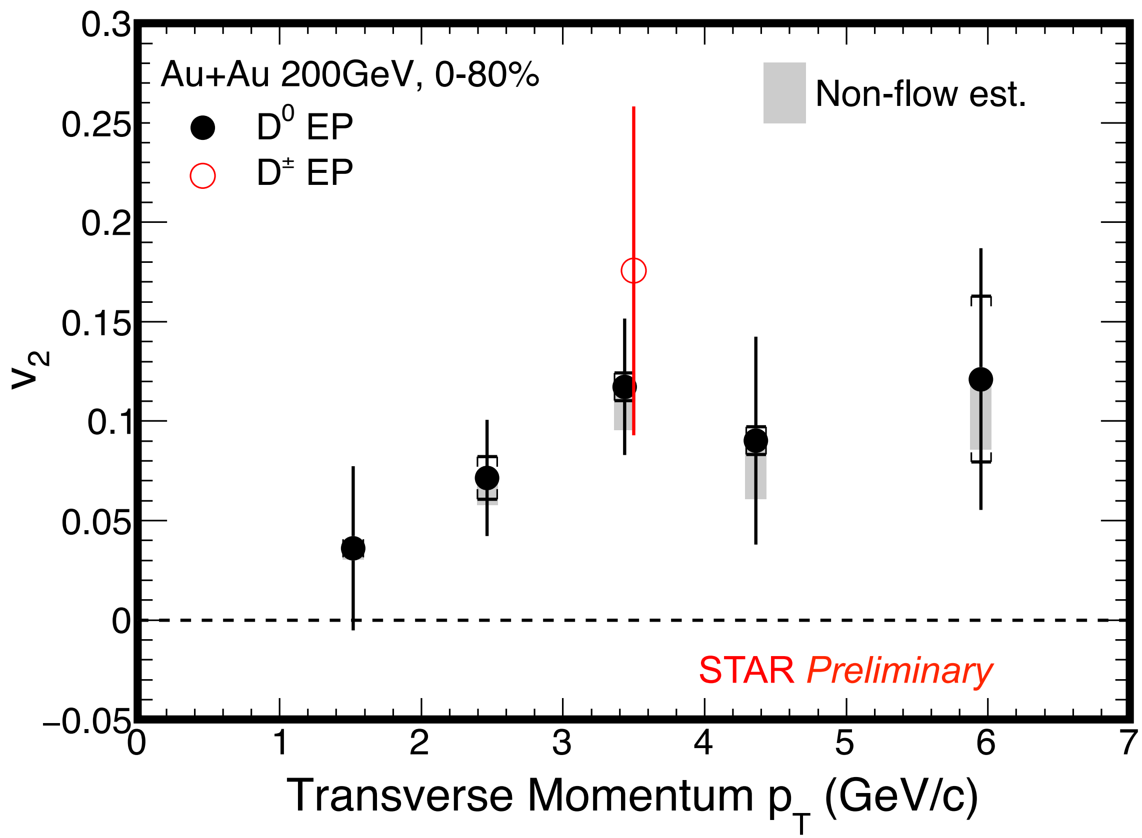
- *D^0* azimuthal anisotropy significantly different from zero for p_T > 2 GeV/c
  (χ^2/n.d.f. = 17.5/4)
- B->D feed down is negligible at RHIC energies (<5% relative contribution)

D Meson v_2



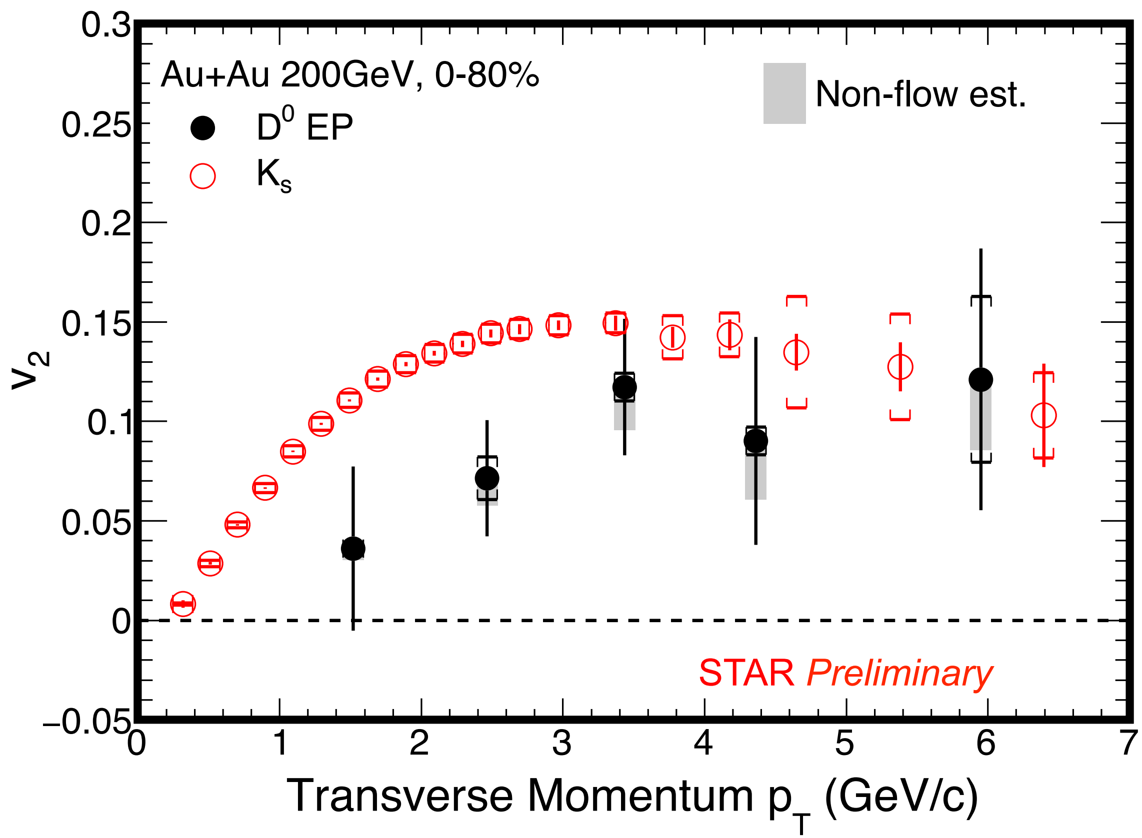
- Good agreement between EP and 2 PC methods within systematics

D Meson v_2



- $D^{+/-}$ v_2 compatible with D^0 albeit within large error bars

Comparison to experiment



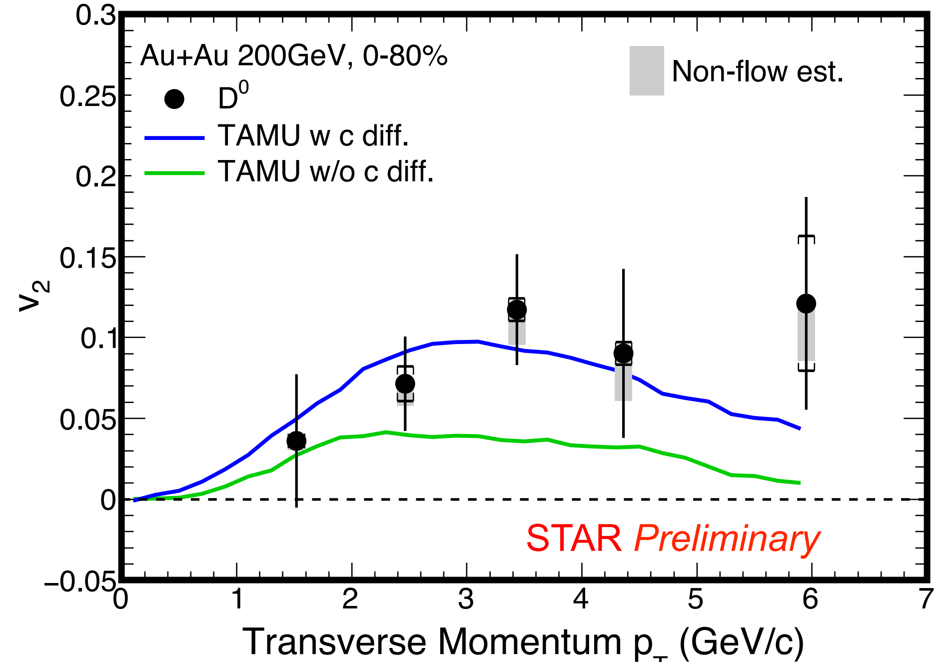
- D^0 v_2 is below light hadrons for $1 < p_T < 4$ GeV/c
  - (χ^2/n.d.f. = 9.6/3)

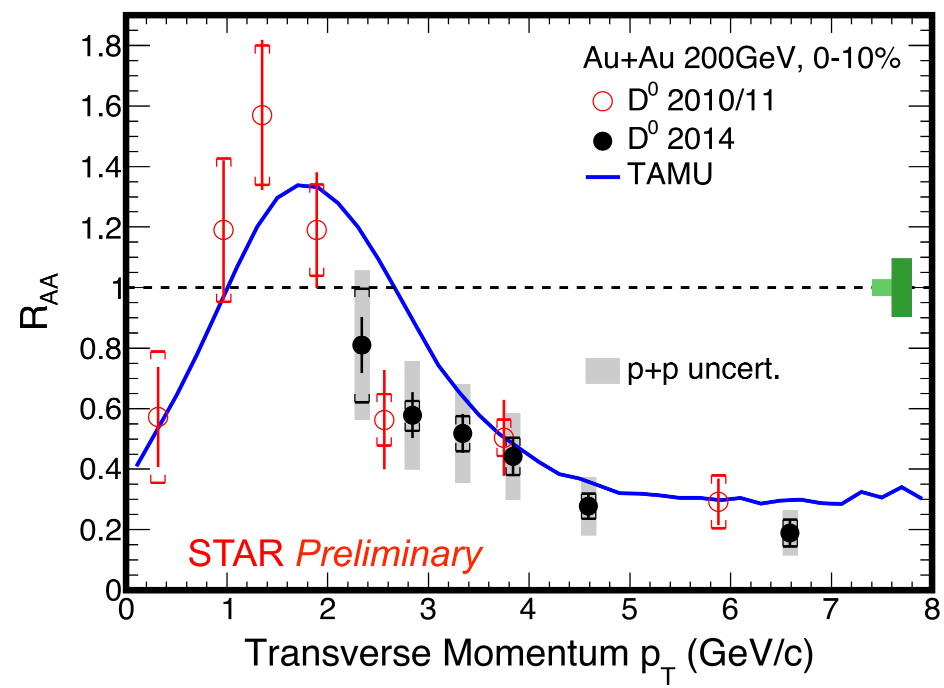
STAR:PRC 77 (2008) 54901

Model comparison: TAMU

- Full T-matrix treatment, non-perturbative model with internal energy potential
- Diffusion coefficient extracted from calculation $2\pi T \times D = 2\text{-}7$
- Good agreement with D^0 meson v_2 at low p_T, data favors model including c quark diffusion in the medium
  - (w/ c diff. χ^2/n.d.f. = 1.8/5)
  - (w/o c diff. χ^2/n.d.f. = 7.4/5)
  - *- χ^2 tests done to v_2*

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





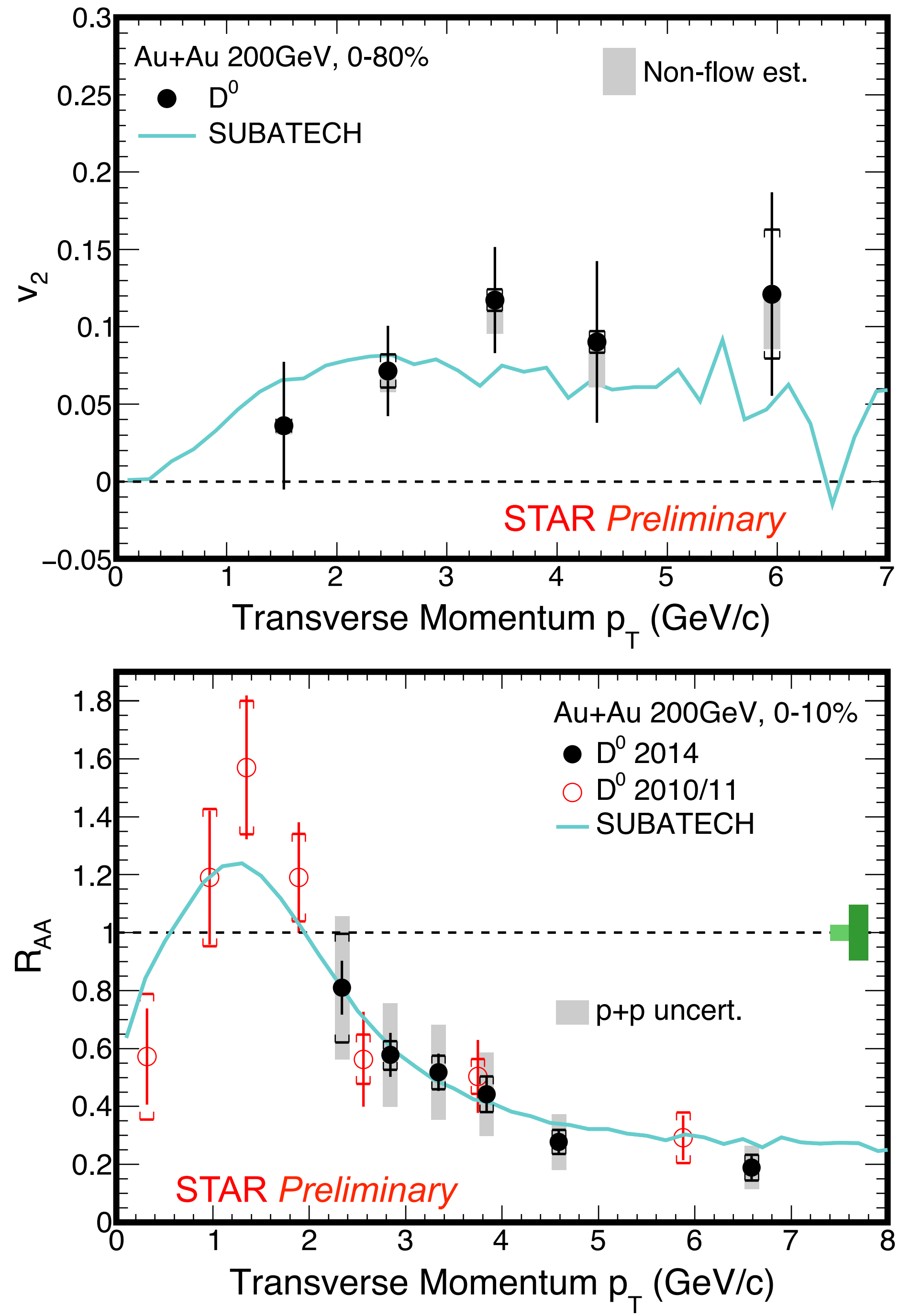
Model comparison: SUBATECH

- 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

  (χ^2/n.d.f. = 2.8/5)

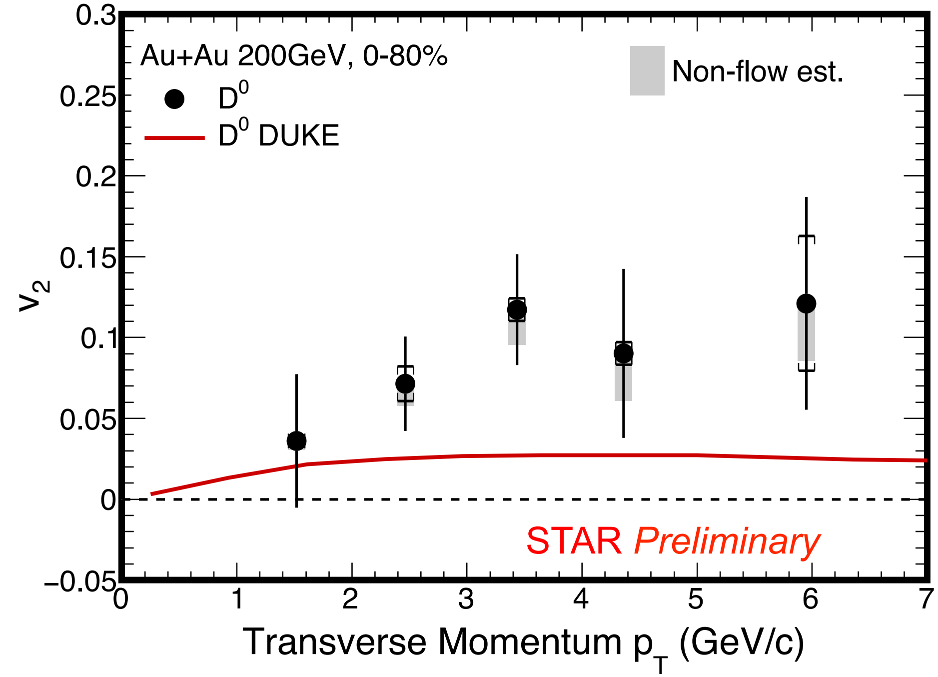
  - χ^2 tests done to v_2

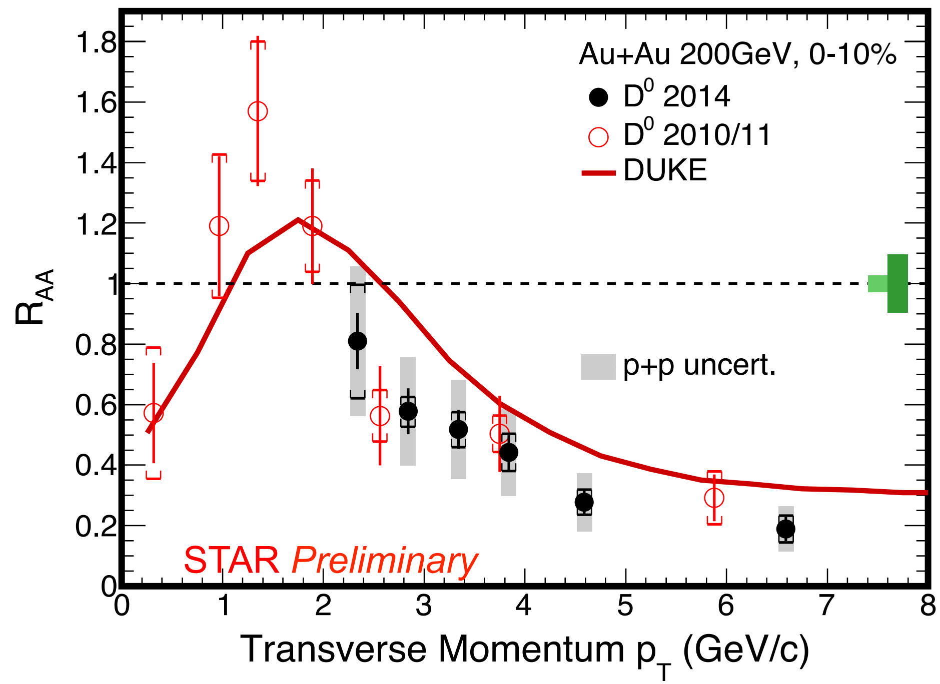
Theory: arXiv:1506.03981 (2015) & private comm.
STAR: PRL 113 (2014) 142301



Model comparison: Duke

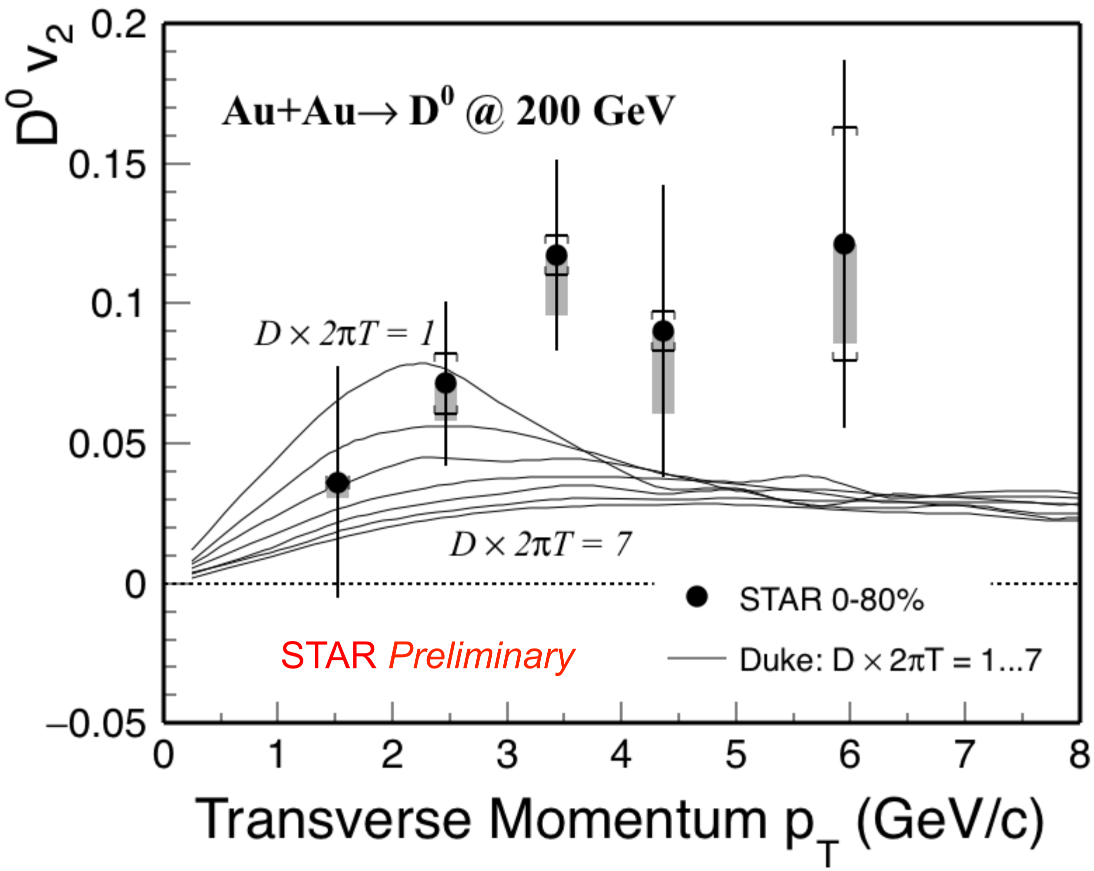
- Diffusion coefficient is a free parameter, fixed by fitting to R_{AA} at high p_T
- Input value for diffusion coefficient $2\pi T \times D = 7$ fixed to fit LHC results
- Model with $2\pi T \times D = 7$ doesn't describe the magnitude of v_2 in experimental data





Theory: arXiv:1505.01413 & private comm.
STAR: PRL 113 (2014) 142301

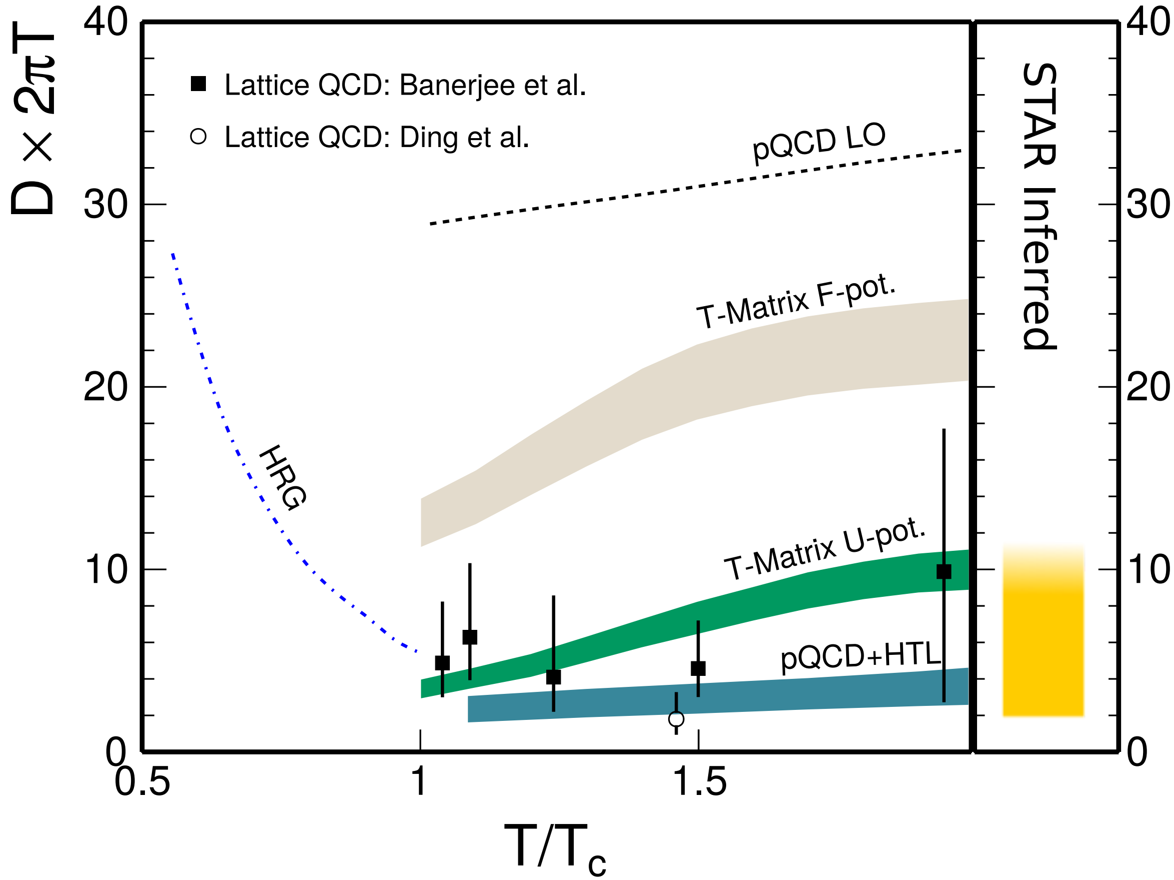
Charm diffusion coefficient



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

Theory: arXiv:1505.01413 & private comm.

Diffusion coefficient



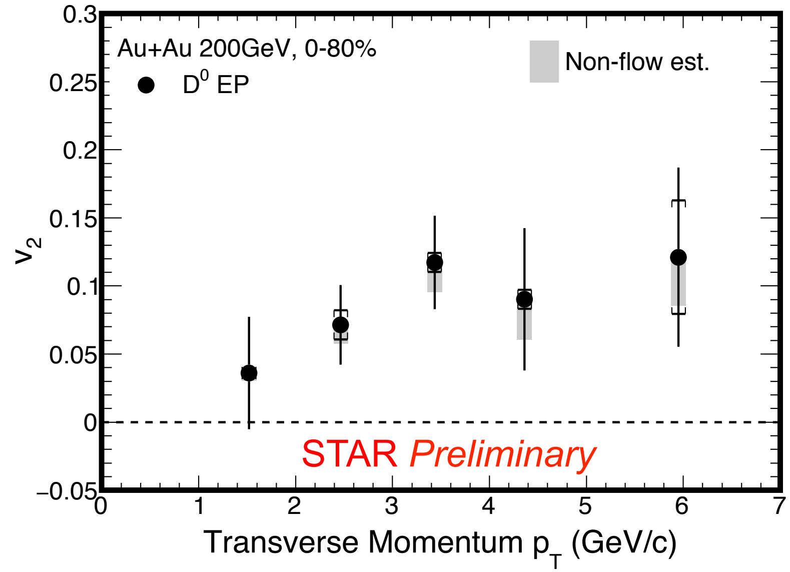
- Compatible with models predicting a value of diff. coefficient between 2 to ~10
- Lattice calculations, although with large uncertainties, are consistent with values inferred from data

Outlook

- Run 14:
  - Full statistics available soon
- Run 15:
  - Full aluminum cables for inner layer of PXL
  - p+p and p+A data sets with HFT
- Run 16:
  - Full aluminum cables for inner layer of PXL
  - Factor 2 -3 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
Future		
Run 16:		
	Au+Au	2 B

Summary

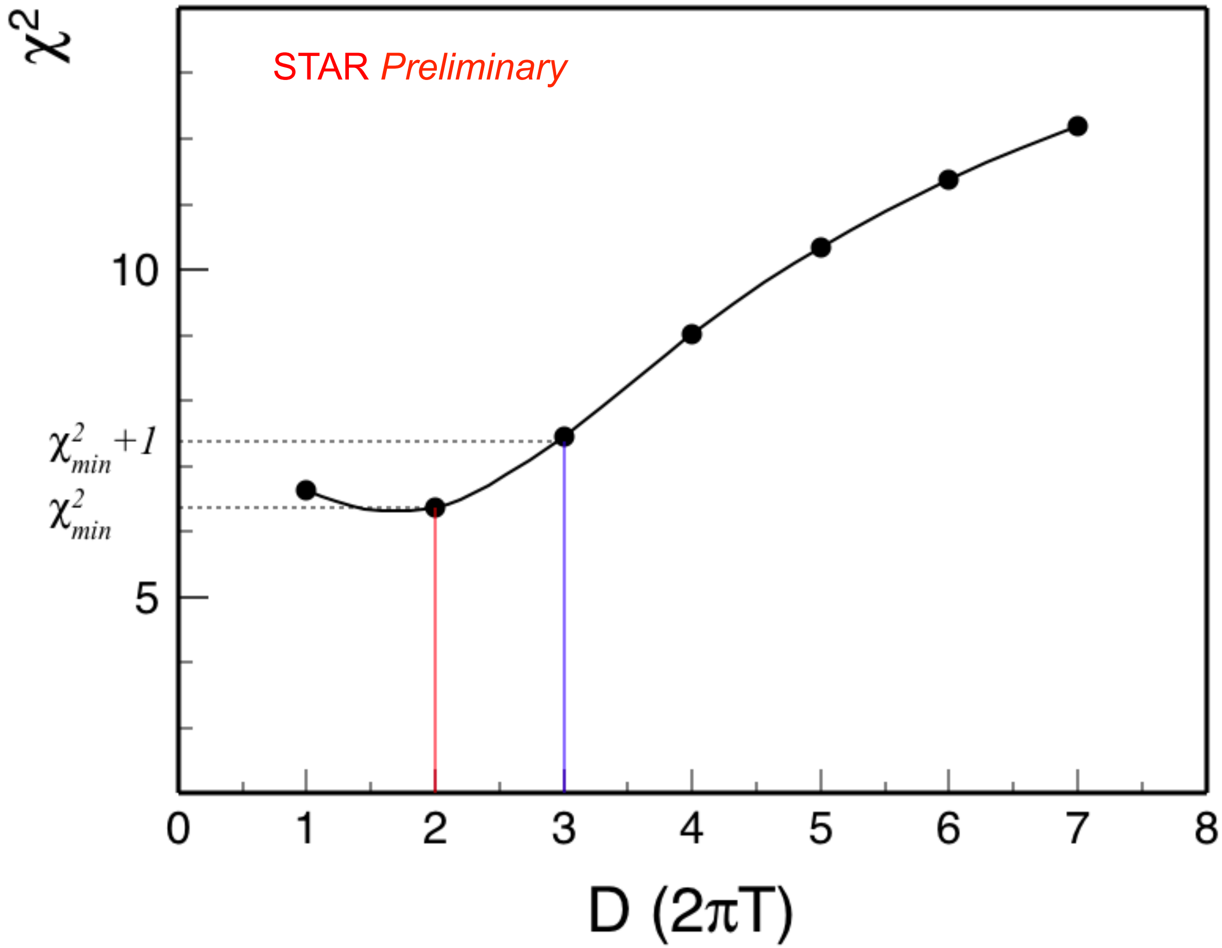


- D^0 v_2 is finite for $p_T > 2.0$ GeV/c
- D^0 v_2 lower than light hadrons for $1 < p_T < 4.0$ GeV/c
- Data favor model scenario where charm quarks flow
- D^0 v_2 and R_{AA} can be described simultaneously by models and are consistent with values of $2\pi TxD$ between 2 and ~10
- Looking forward to improved statistics in year 2016

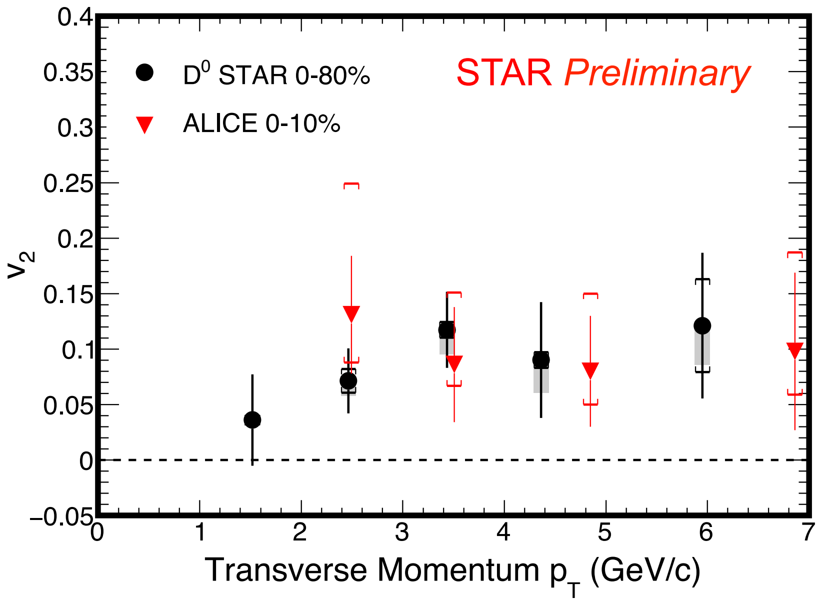
Thank you!

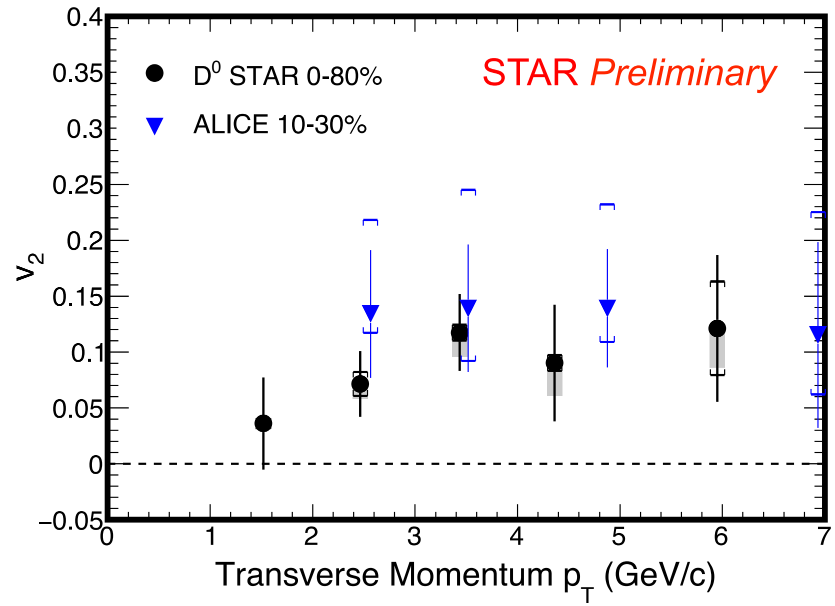
Back ups

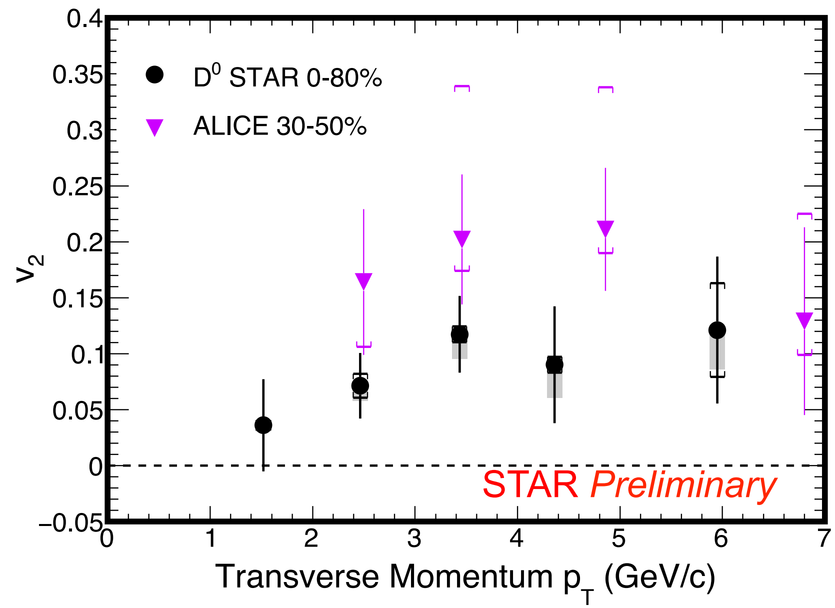
Diffusion Coefficient from DUKE



Comparison to ALICE







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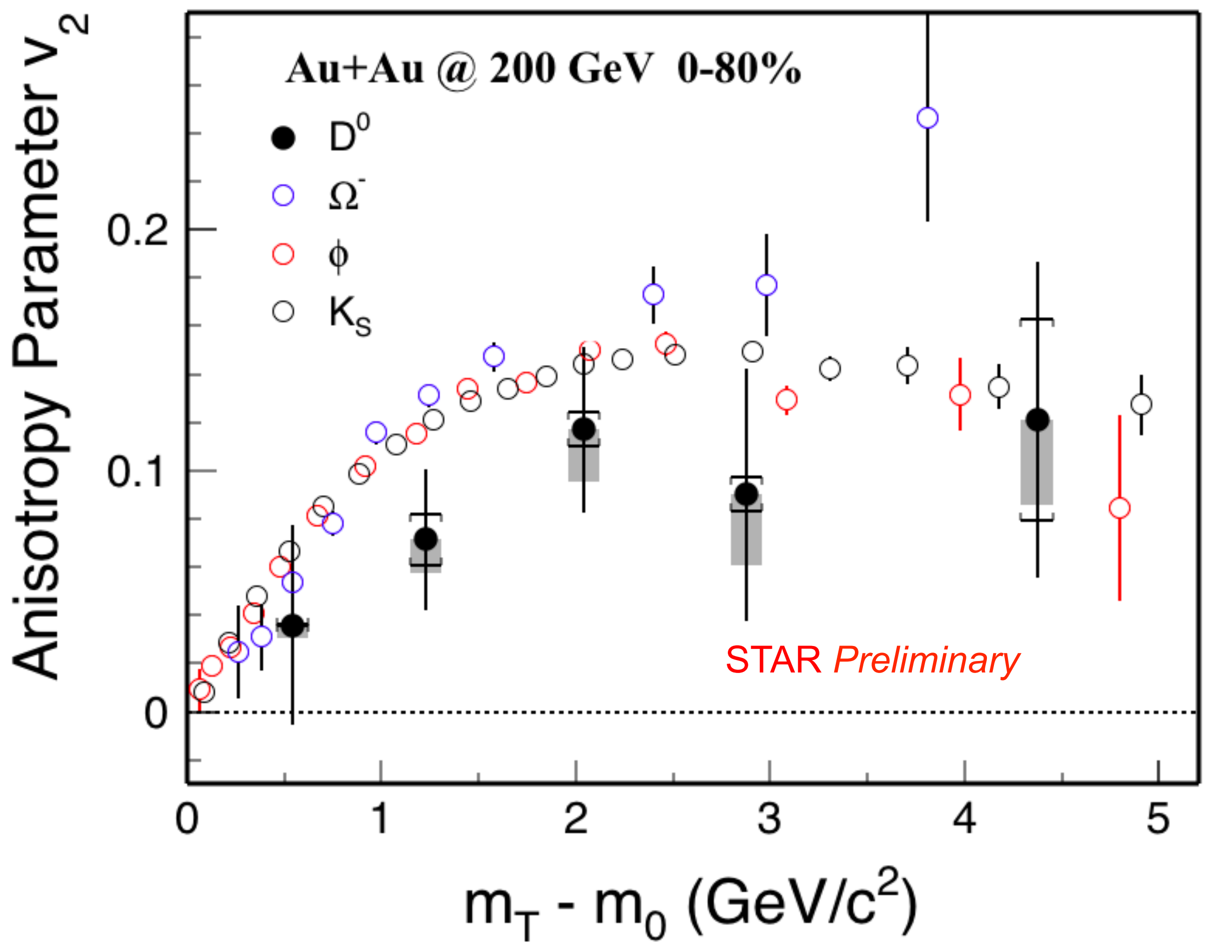
Mass Effect



Au+Au @ 200 GeV 0-80%
D0
Ω-
ϕ
KS
STAR Preliminary
Anisotropy Parameter v2
0.2
0.1
0
0
1
2
3
4
5
mT - m0 (GeV/c2)