Measurement of D^0 Meson Production and Azimuthal Anisotropy in Au+Au Collisions at $\sqrt{s_{NN}}$ = 200 GeV

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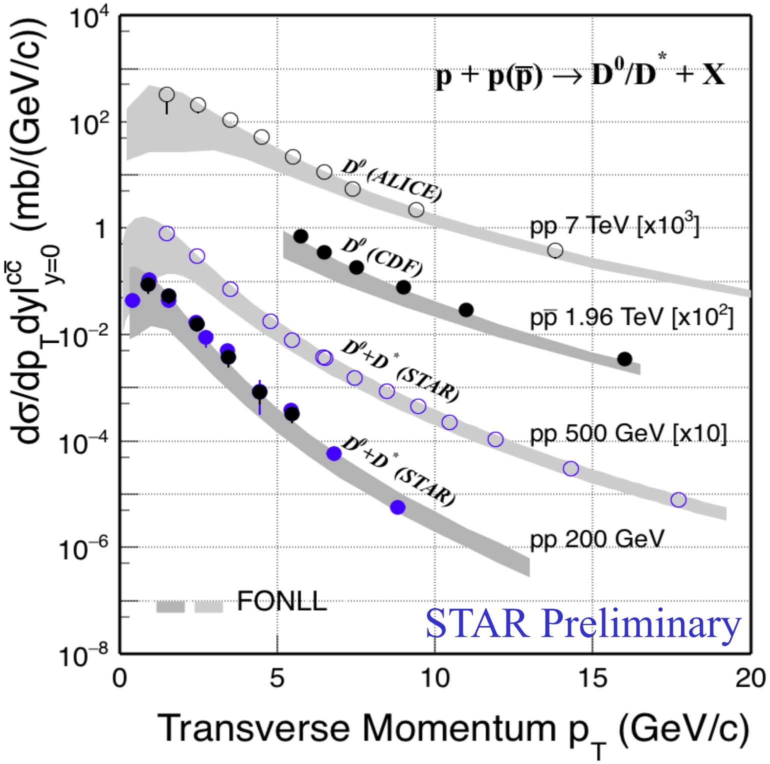
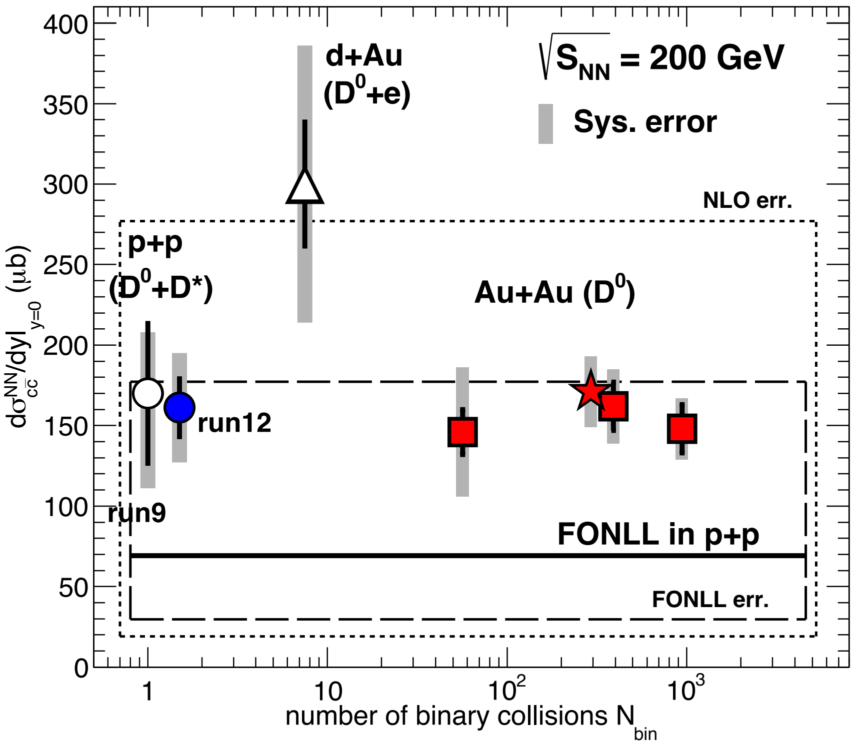
Motivation

Charm quarks: $m_c >> T_C, \Lambda_{QCD}, m_{u,d,s}\ \ T_{QGP(RHIC/LHC)}$

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



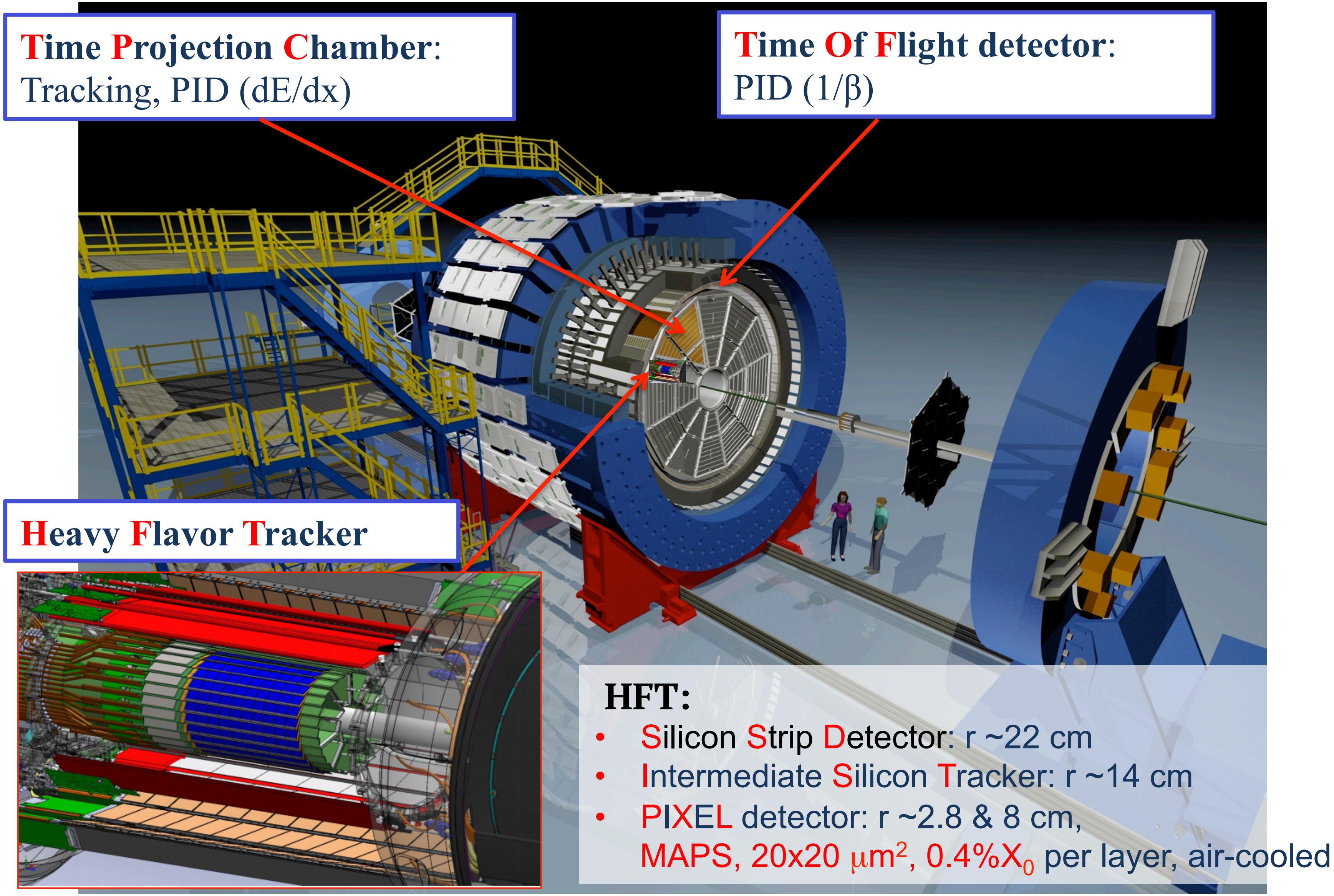


Perturbative QCD calculations (FONLL) are consistent with experimental data.

Charm cross section follows number of binary collisions scaling at RHIC.

STAR: PRD 86 (2012) 072013, NPA 931 (2014) 520, PRL 94 (2005) 62301, PRL 113 (2014) 142301. CDF: PRL 91 (2003) 241804. ALICE: JHEP01 (2012) 128. FONLL: PRL 95 (2005) 122001. NLO: Eur.Phys.J.ST 155 (2008) 213

STAR Detector



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

Time Of Flight detector:
PID ($1/\beta$)

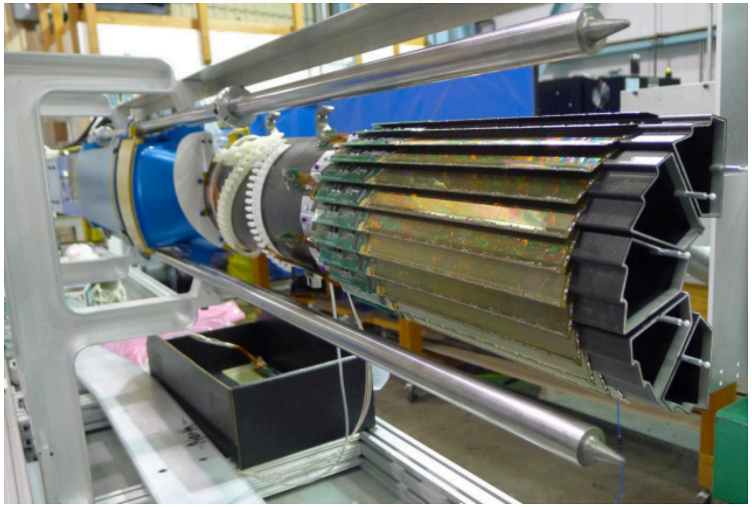
Heavy Flavor Tracker

HFT:

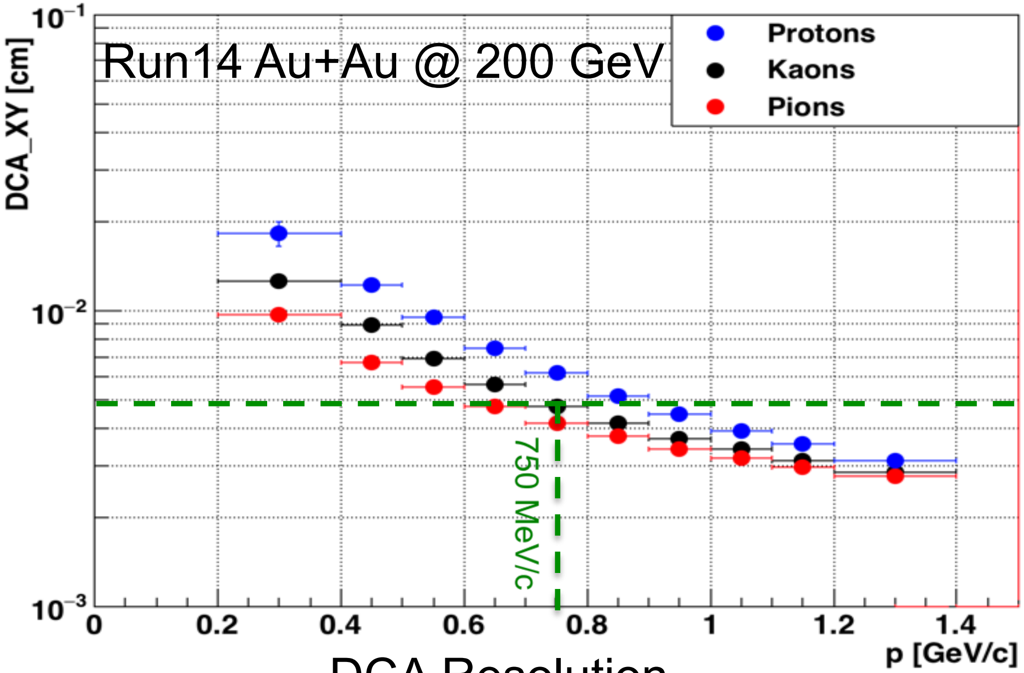
- Silicon Strip Detector: r ~22 cm
- Intermediate Silicon Tracker: r ~14 cm
- PIXEL detector: r ~2.8 & 8 cm,
  MAPS, 20x20 μm^2, 0.4%X_0 per layer, air-cooled

HFT Performance

Au+Au @ 200GeV Run 2014, with Heavy Flavor Tracker
~780M minimum bias events analyzed (out of 1.2B events recorded in 2014)



PIXEL detector



DCA Resolution

DCA (Distance of Closest Approach) resolution

- DCA resolution < 50 μm for Kaons at p = 750 MeV/c, and ~ 30 μm for p > 1.2 GeV/c, achieved from Run 2014 using Al-cables.
- With Al-cables for entire PXL in Run 2016, the overall pointing resolution will be better

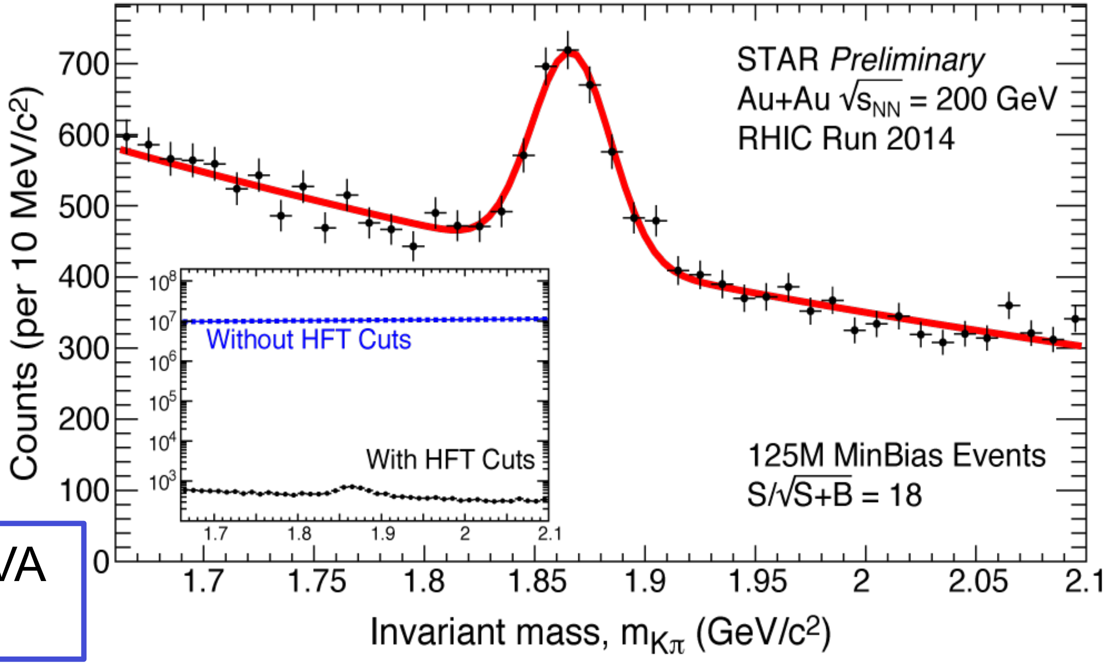
D^0 Meson Reconstruction

Direct topological reconstruction through hadronic channel:

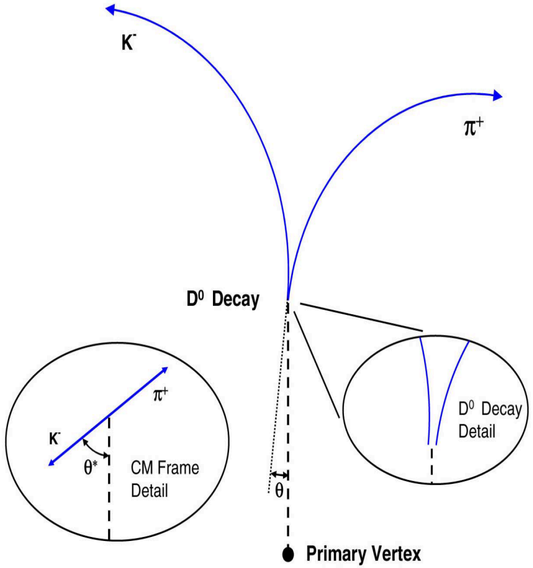
$$D^0(\overline{D^0}) \rightarrow K^{\mp}\pi^{\pm}(BR\ 3.89\%)$$

$$c\tau \approx 120\mu m$$

With HFT:
Greatly reduced combinatorial background

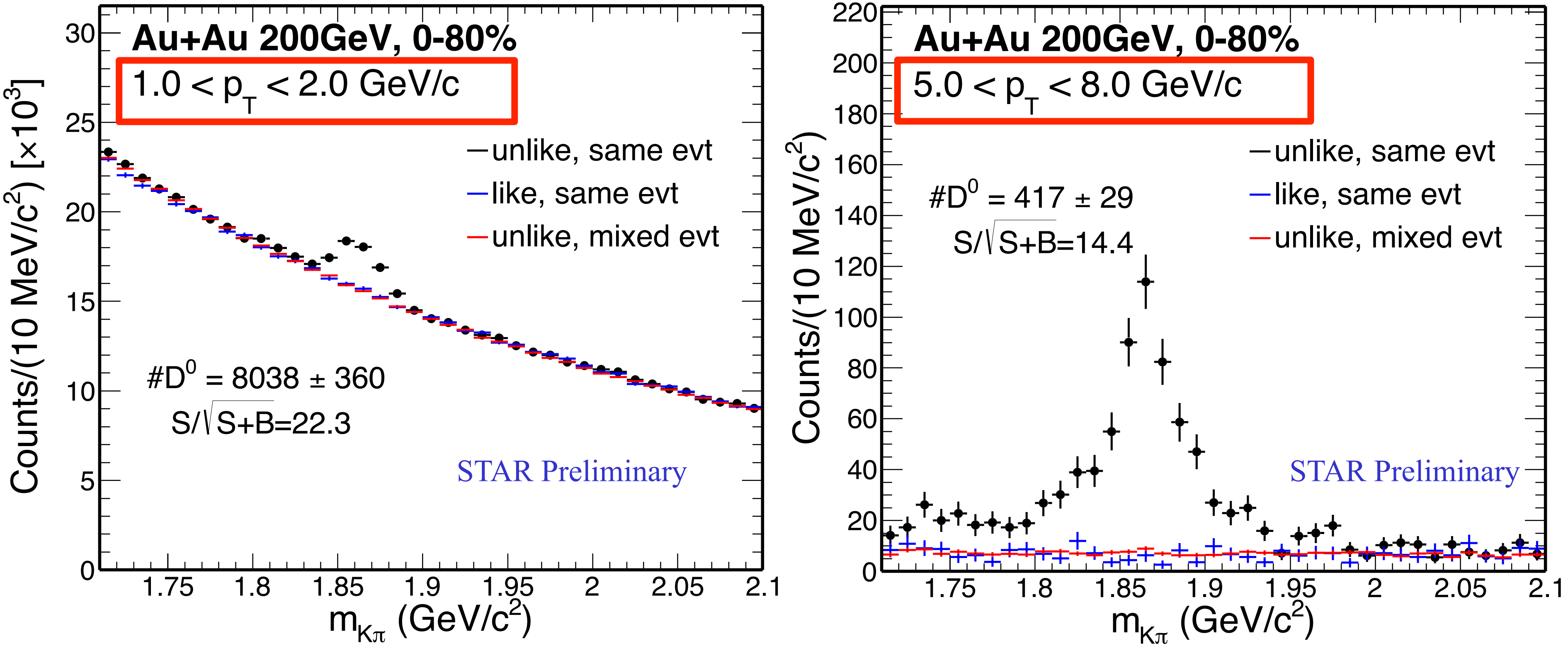


Topological cuts optimized by TMVA (Toolkit for Multi-Variate Analysis)



D^0	**w/o HFT**	**with HFT**
Year	2010 + 2011	2014
# Events (MB) analyzed	1.1 B	780M
Significance per billion events	13	51

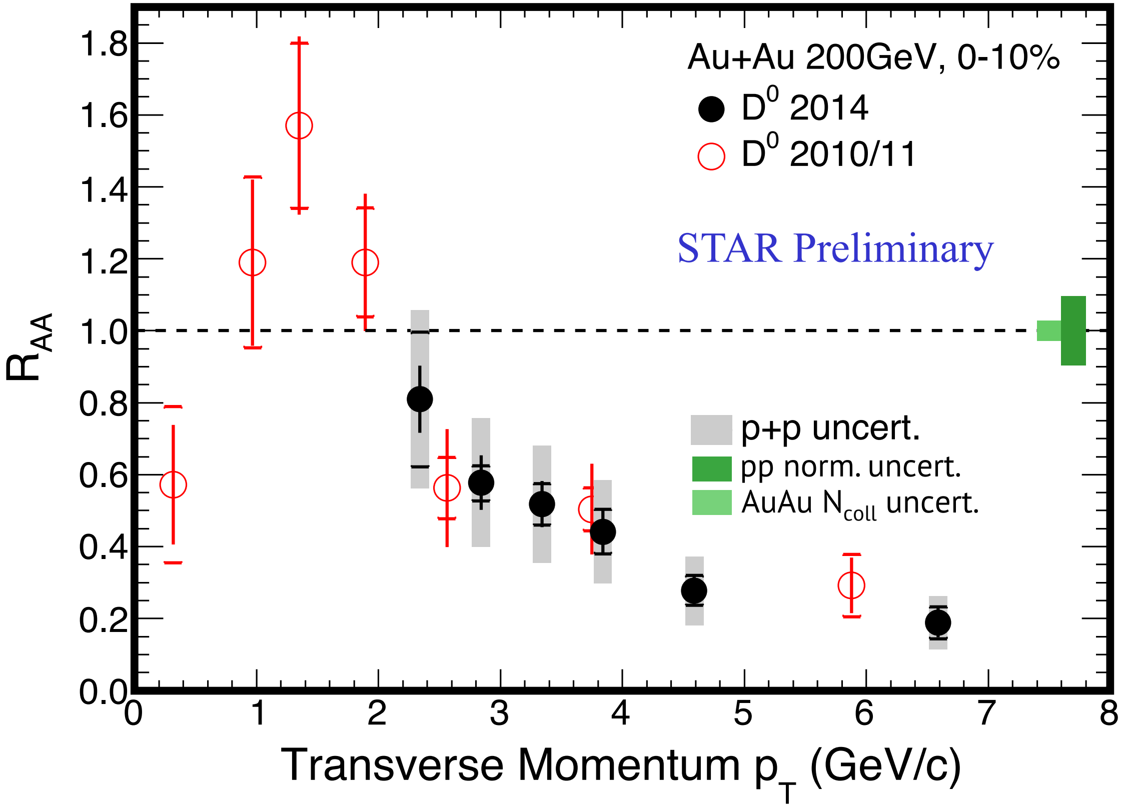
D^0 Meson Signal



- Clean D^0 signals reconstructed with significantly enhanced signal-to-background ratios with the HFT in a broad range of transverse momentum

D^0 Nuclear Modification Factors (R_{AA})

STAR: PRL 113 (2014) 142301



- High p_T: significant suppression in central Au+Au collisions. New results have improved precision.

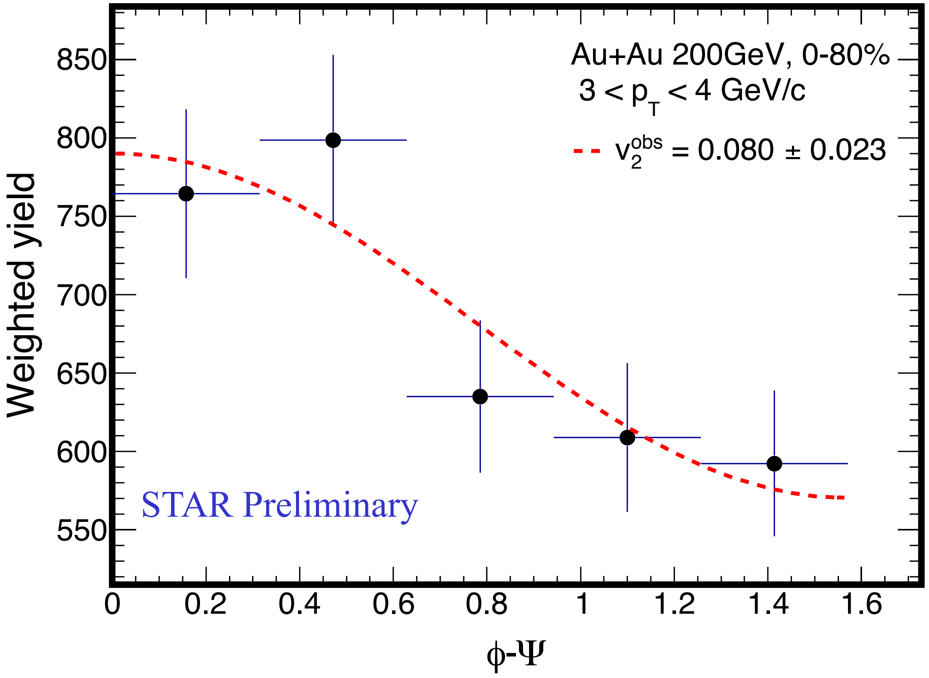
v_2: Event Plane Method

- Event plane reconstructed using charged hadrons within STAR TPC acceptance ($|\eta|<1$)
  - Hadrons within $|\Delta\eta| < 0.15$ around D^0 candidates removed from event plane reconstruction
- Corrected for detector acceptance and non-uniform efficiency
- Yields in ϕ-Ψ bins corrected for event plane resolution
- $v_2 = v_2^{obs} \times \left\langle \frac{1}{\text{E.P. Resolution}} \right\rangle$
- Non-flow contribution estimated from D-h correlations in p+p collisions at $\sqrt{s_{NN}}$ = 200 GeV

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

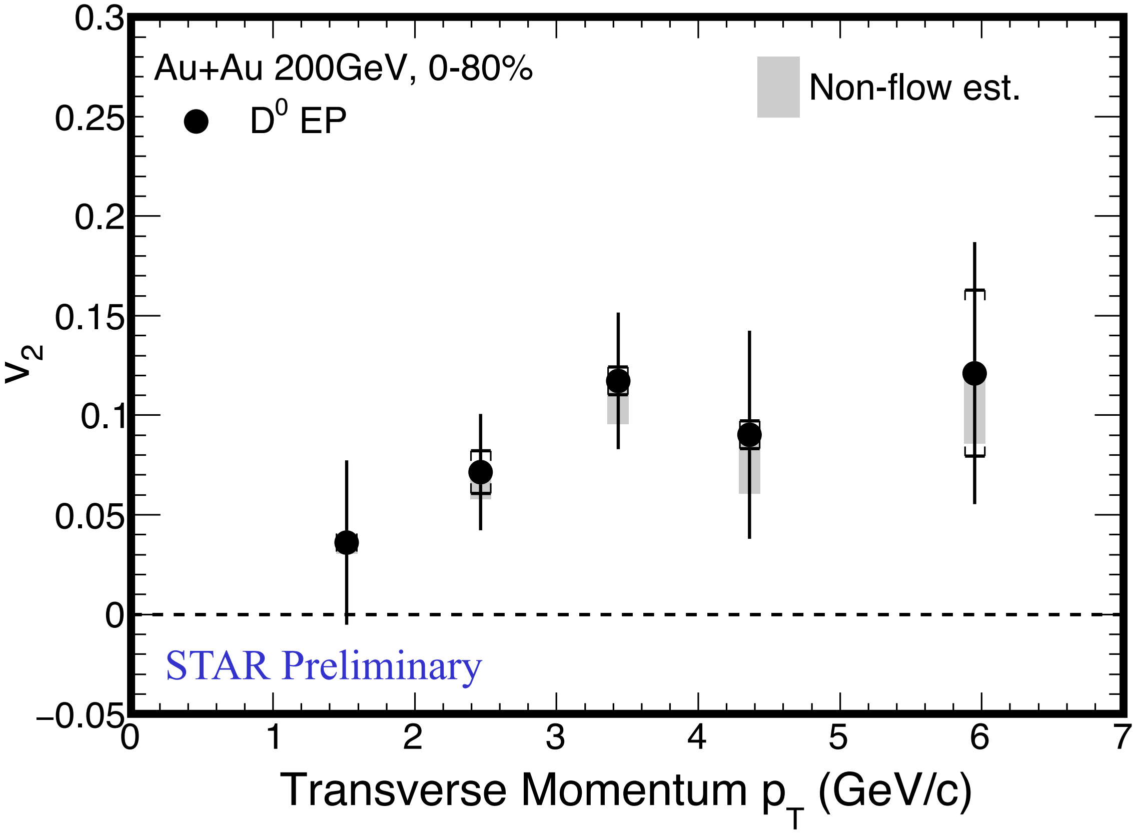
p+p

Au+Au



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

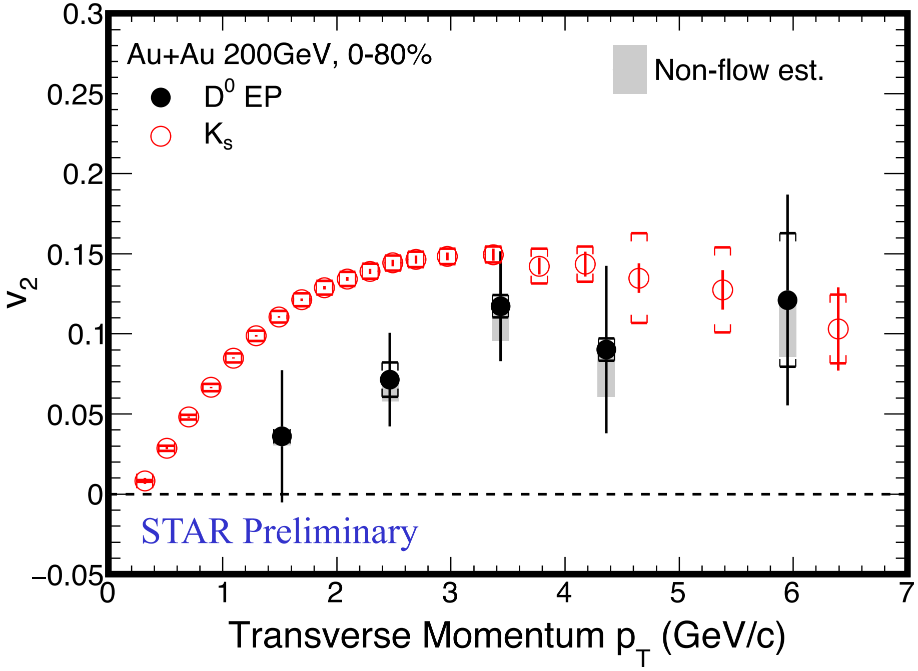
D^0 Meson v_2

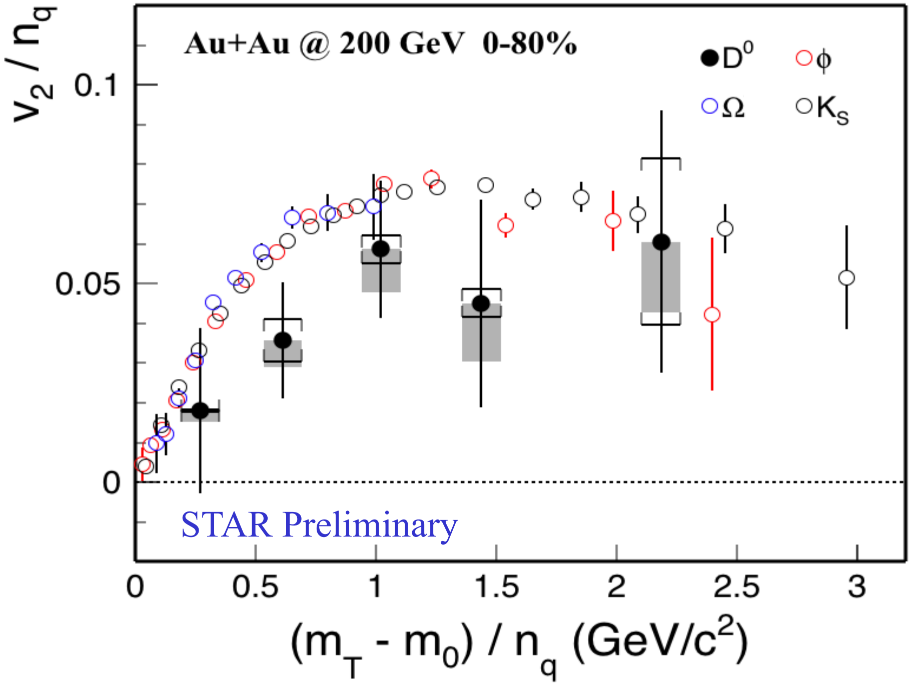


- D^0 v_2 significantly above zero for p_T > 2 GeV/c
- B->D feed down is negligible at RHIC energies (<5% relative contribution)

D^0 v_2 vs. Light Hadrons

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

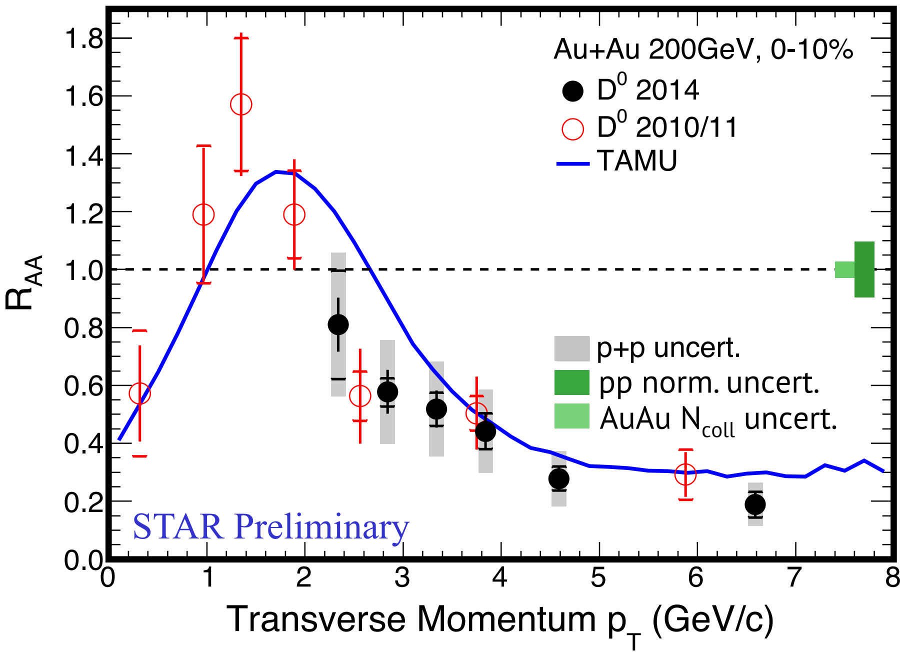


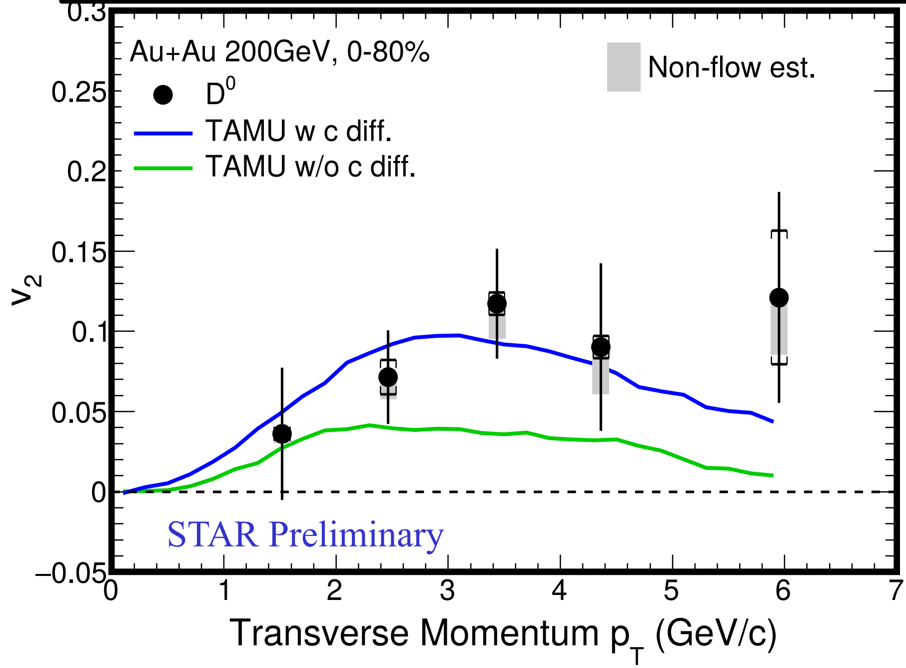


- D^0 v_2 is below light hadrons for $0.5 < (m_T-m_0)/n_q < 1.5$ GeV/c^2 in 0-80% centrality bin
- D^0 production is biased towards central collisions. Comparison in finer centrality bins is needed

Model Comparison: TAMU

STAR: PRL 113 (2014) 142301
A. Andronic arXiv:1506.03981(2015) &Private comm

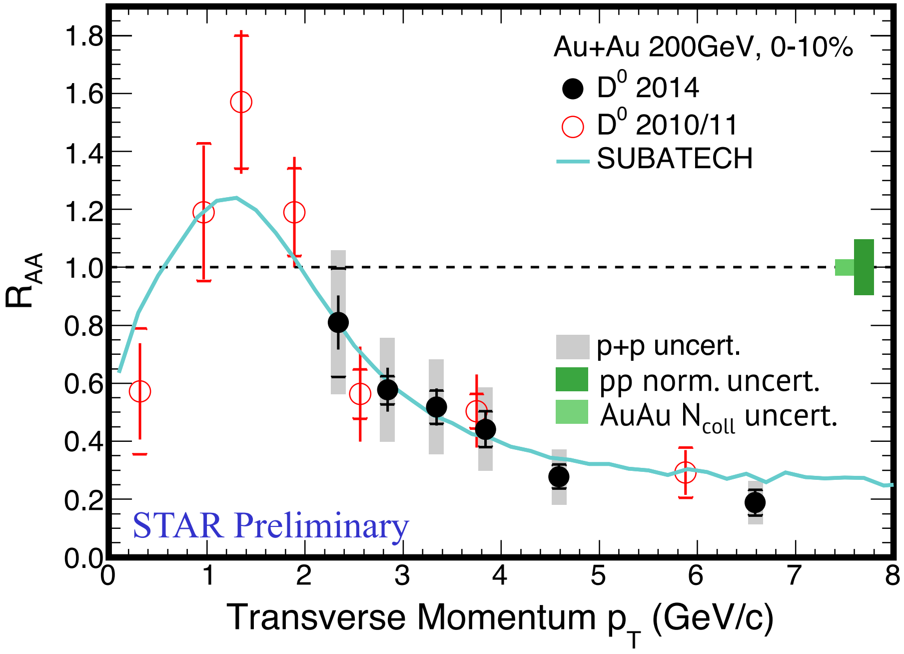


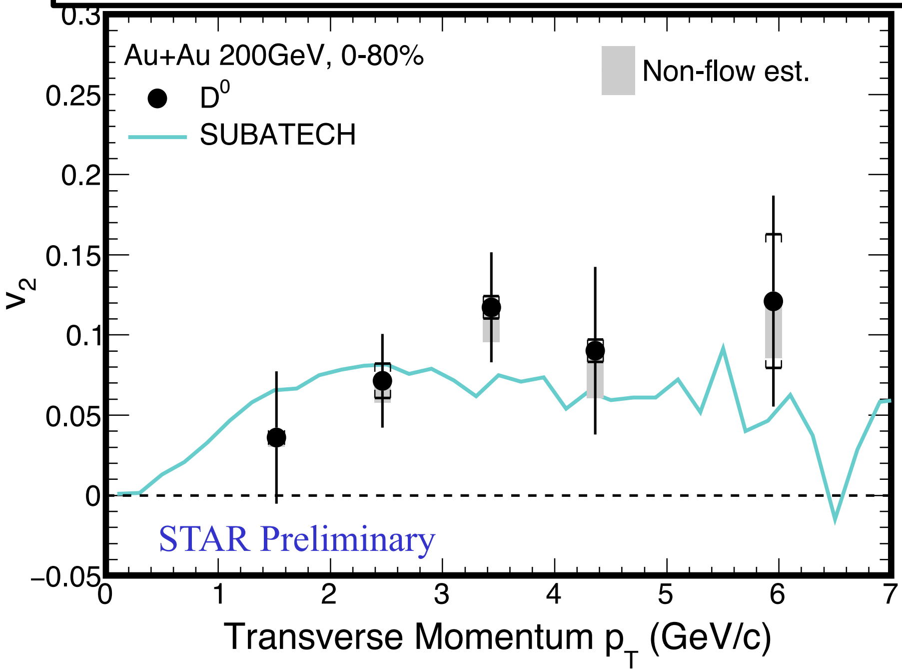


- Full T-matrix treatment, non-perturbative model with internal energy as heavy quark potential
- Diffusion coefficient extracted from calculation $2\pi T \times D = 3\text{-}11$
- Good agreement with D^0 meson v_2. Data favor model including charm-quark diffusion in the medium

Model Comparison: SUBATECH

STAR: PRL 113 (2014) 142301
A. Andronic arXiv:1506.03981(2015) &Private comm

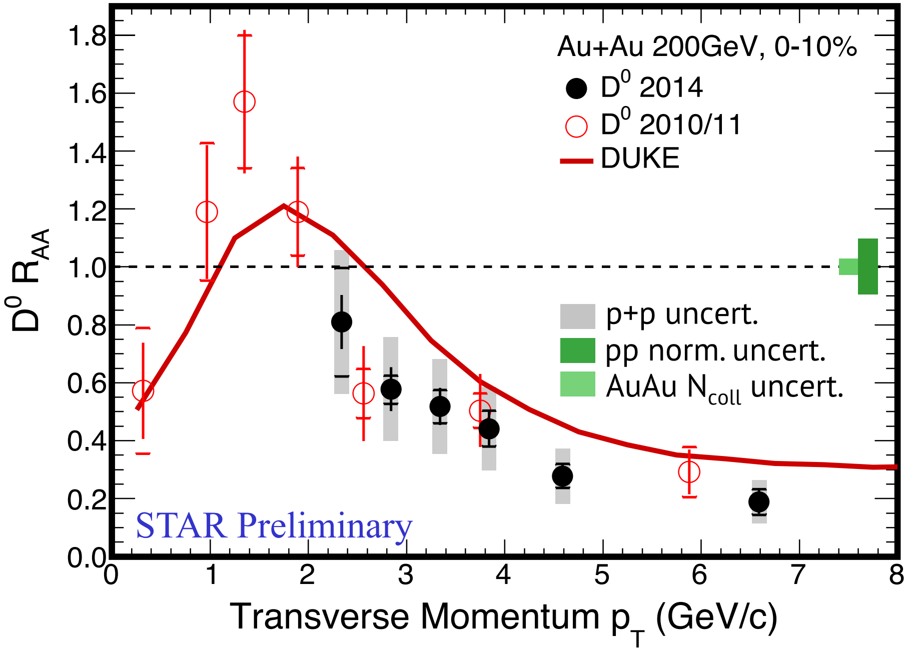


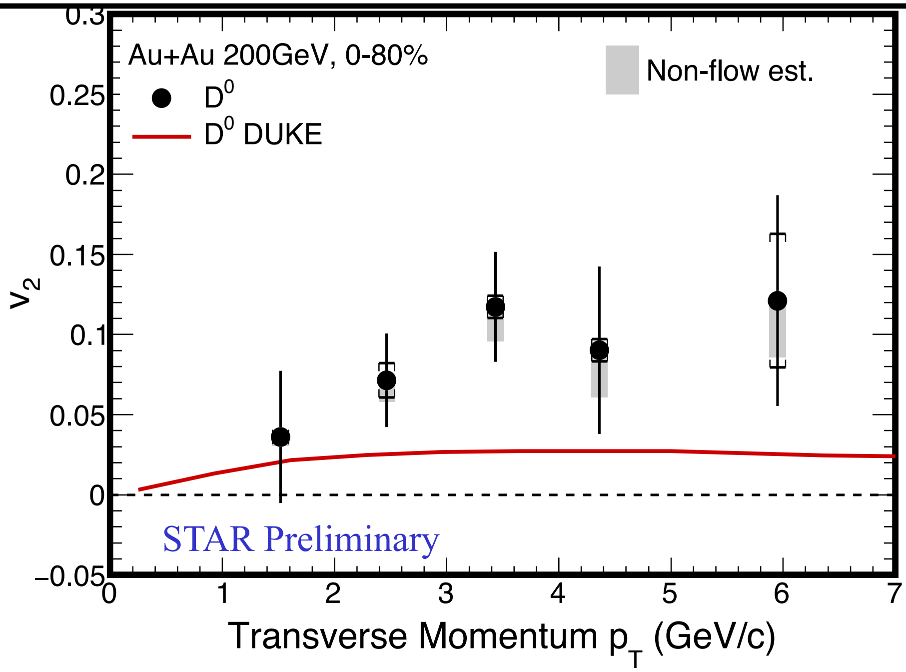


- MC@sHQ calculation with latest EPOS3 initial conditions
- Diffusion coefficient extracted from calculations $2\pi T \times D \sim 2\text{-}4$
- Good agreement between model and experiment data for both v_2 and R_{AA} in entire p_T range

Model Comparison: DUKE

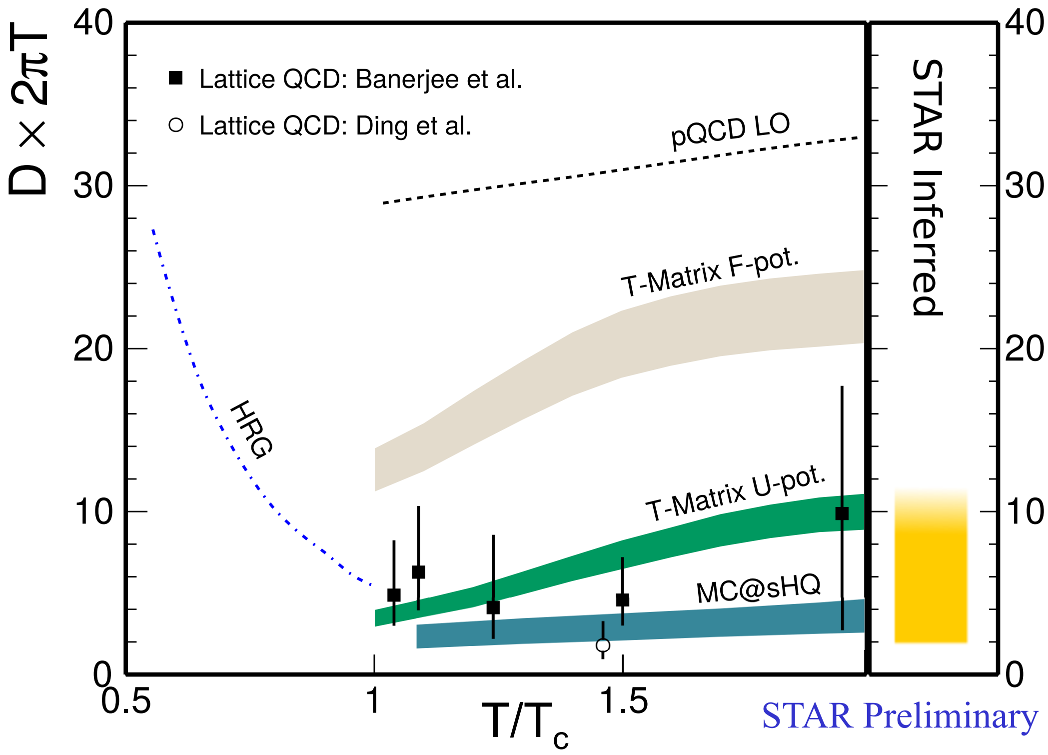
STAR: PRL 113 (2014) 142301. DUKE: PRC 92 (2015) 024907
A. Andronic arXiv:1506.03981(2015) &Private comm





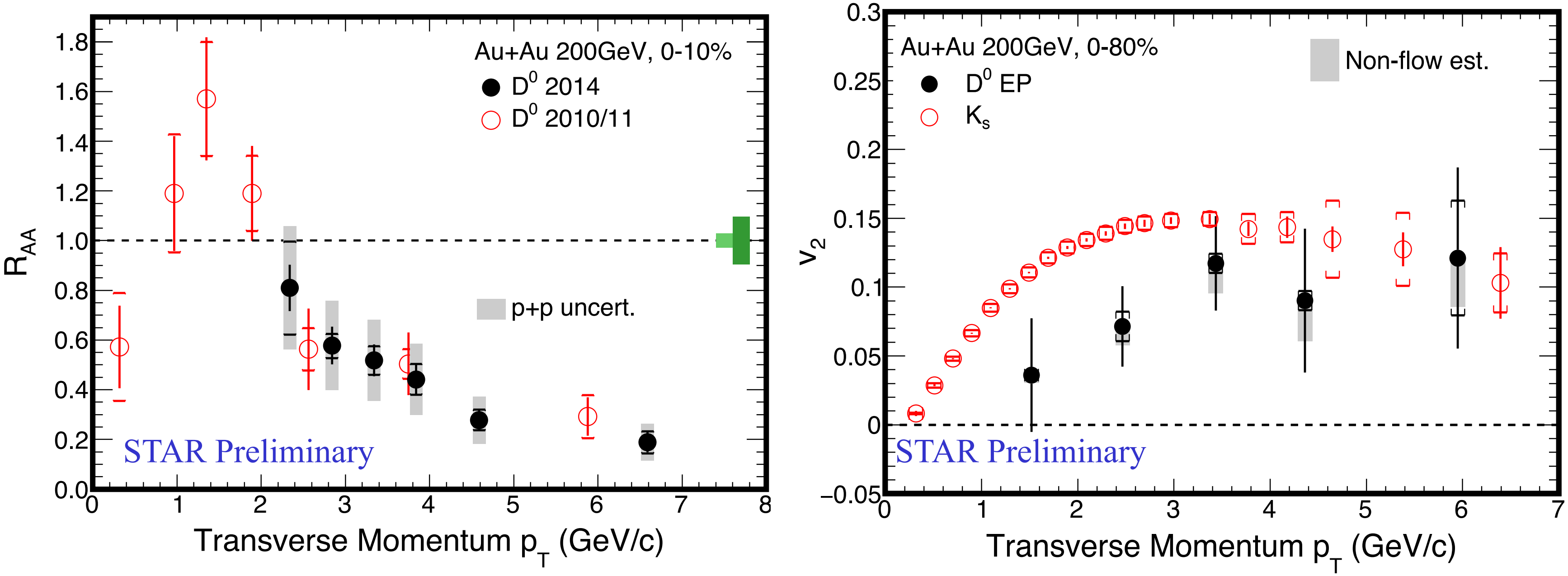
- Diffusion coefficient is a free parameter, and the input value here is fixed to be $2\pi T \times D = 7$ by fitting to LHC results
- Model underestimates v_2 in experimental data

Diffusion Coefficient



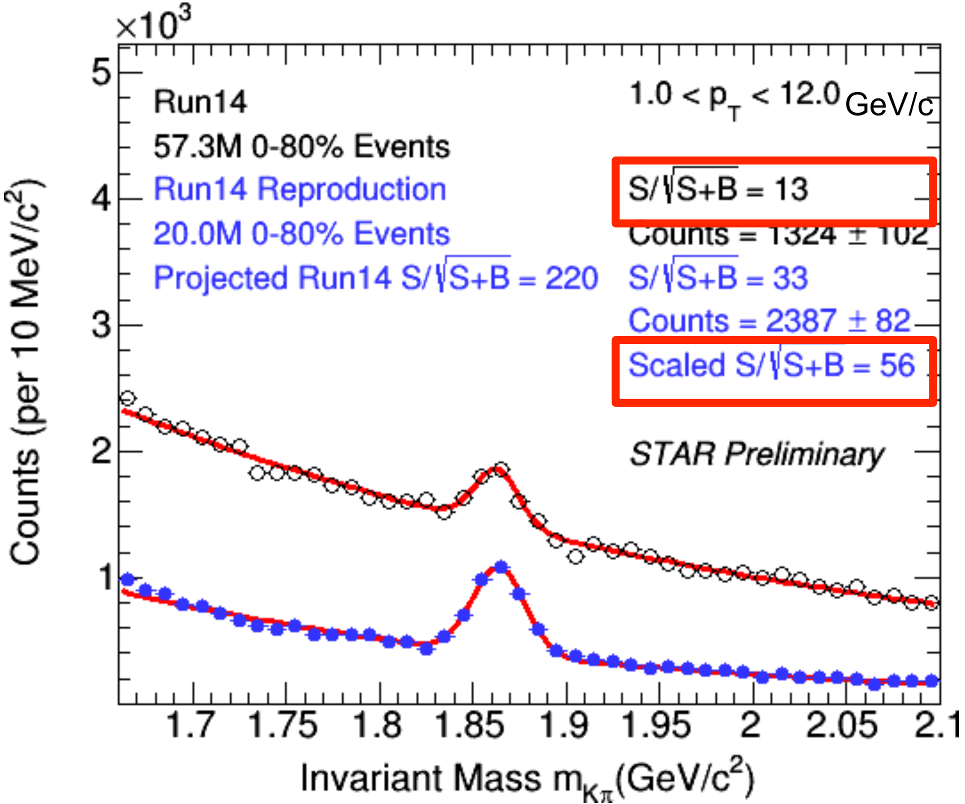
- D^0 v_2 and R_{AA} can be described by models with values of 2πTxD between 2 and ~12
- Lattice calculations, although with large uncertainties, are consistent with values inferred from data
- Differences between models need to be resolved

Summary



- First measurement of D^0 R_{AA} using STAR HFT.
- D^0 v_2 is finite and lower than that of light quarks for $1 < p_T < 4.0$ GeV/c in 0-80% centrality bin
- Data favor model where charm quarks flow
- D^0 v_2 and R_{AA} can be simultaneously described by models with values of $2\pi TxD$ between 2 and ~12, and differences between models need to be resolved

Outlook



- Run14: with improved HFT tracking efficiency after discovering and fixing a decoder issue in PXL offline reconstruction software, factor 2-4 improvement expected with reprocessed data, therefore measuring centrality dependence for v_2 is feasible
- Run16: with full Al-cables and 2B MB events, factor 2-3 further improvement, thus further improved precision for v_2 and first precise measurement for v_3 are expected.

Thank You

BackUp

References

Slide2 LEFT Plots -->
STAR: PRD 86 (2012) 072013,
NPA 931 (2014) 520
CDF: PRL 91 (2003) 241804
ALICE: JHEP01 (2012) 128
FONLL: PRL 95 (2005) 122001

Slide2, RIGHT Plots -->
STAR: PRL 94 (2005) 62301,
PRD 86 (2012) 072013,
PRL 113 (2014) 142301
FONLL: PRL 95 (2005) 122001
NLO: Eur.Phys.J.ST 155 (2008) 213

Slide3, Plots -->
STAR D0: PRL 113 (2014) 142301
PHENIX π0: PRL 101 (2008) 232301
ALICE D: PRL 111 (2013) 102301
ALICE D: JHEP 03 (2016) 081

Slide11 Plots →
STAR:PRC 77 (2008) 54901
PRL 116 (2016) 62301

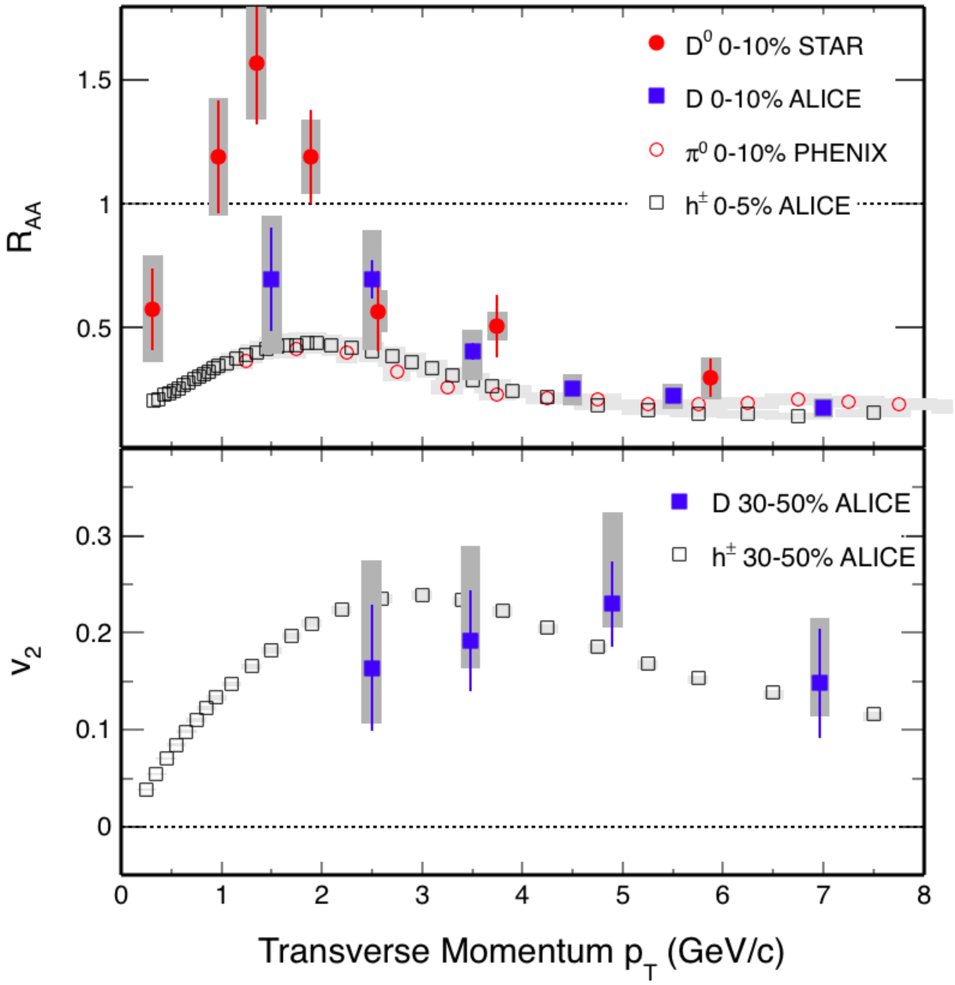
Slide12,13,14, Plots→
STAR: PRL 113 (2014) 142301
DUKE: PRC 92 (2015) 024907
A. Andronic arXiv:1506.03981(2015)
Private comm

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?

- Comparable suppression at high p_T
  - collisional and radiative ΔE
- Possibly different physics at low p_T
  - Initial parton distributions
    - x_T at 2 GeV/c ~ 10^{-2} (RHIC)
      ~ 10^{-3} (LHC)
  - “Cronin” effect
  - Charm quark flow
- R_{AA} can be understand as integral of v_2 for phi differencal
- Low p_T v_2 is especially sensitive to the partonic medium: scattering strength, transport properties

References in backup



Data-Driven Fast Simulation Package

D^0 efficiency = TPC tracking eff ⊗ HFT tracking eff ⊗ topological cuts

TPC tracking eff → Embedding

HFT tracking eff ⊗ topological cuts → Data- Driven simulation

Assumptions:

1)Factorization of tracking efficiency: $\frac{HFT}{MC} = \frac{HFT}{TPC} \times \frac{TPC}{MC}$

2) Spatial resolution of HFT is encoded in two variables: DCA_{XY} and DCA_Z (correlated)

3)Vertex resolution, which is possibly folded in the DCA resolution of single tracks and correlated, is a negligible, at least for semi-central to central events

4)The contribution of feed-down particles from secondary decays to DCA is negligible

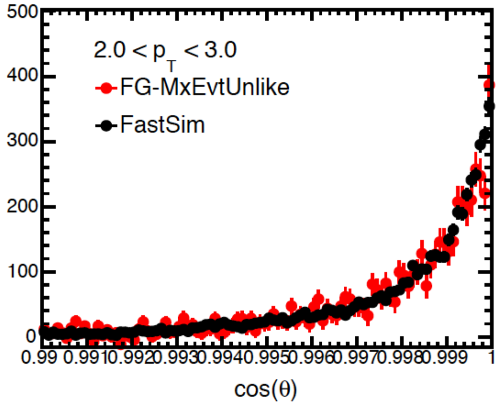
5) D^0 with mis-matched daughter tracks are removed by topological cuts

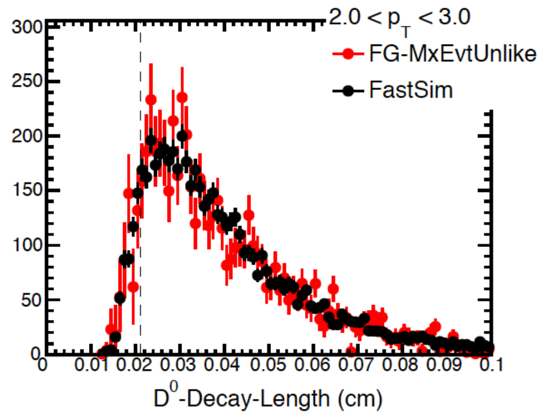
Ingredients:

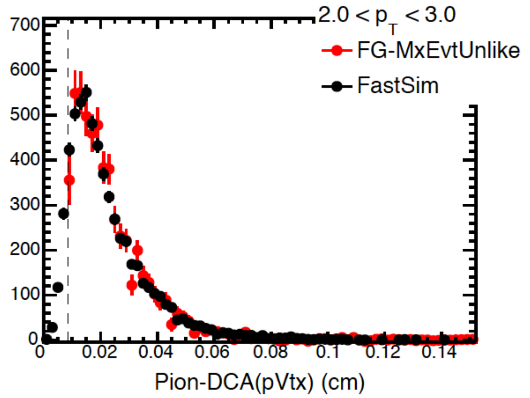
1) Extract Vz distributions from data (centrality dependent)
2) Extract ratio of HFT matched tracks to TPC tracks from data.
3) Extract DCAXY - DCAZ distributions from data.
4) Extract TPC efficiency and momentum resolution from embedding

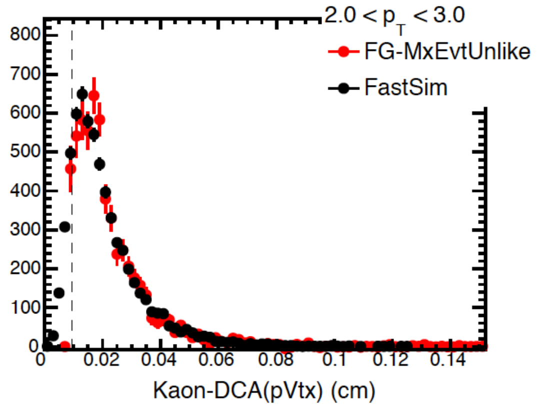
Our fast-simulator was validated by full GEANT simulation

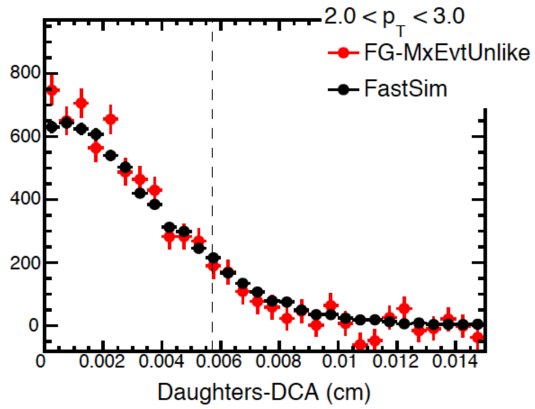
STAR ☆ Topology Distribution Comparison

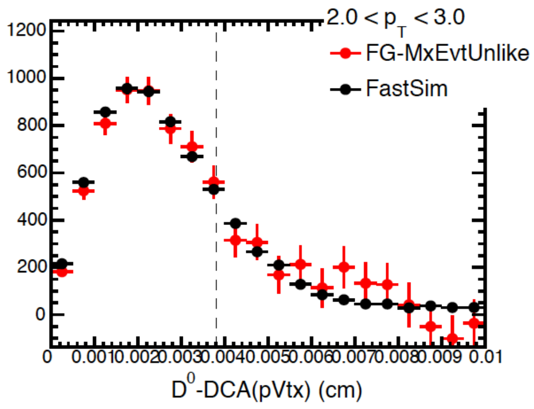








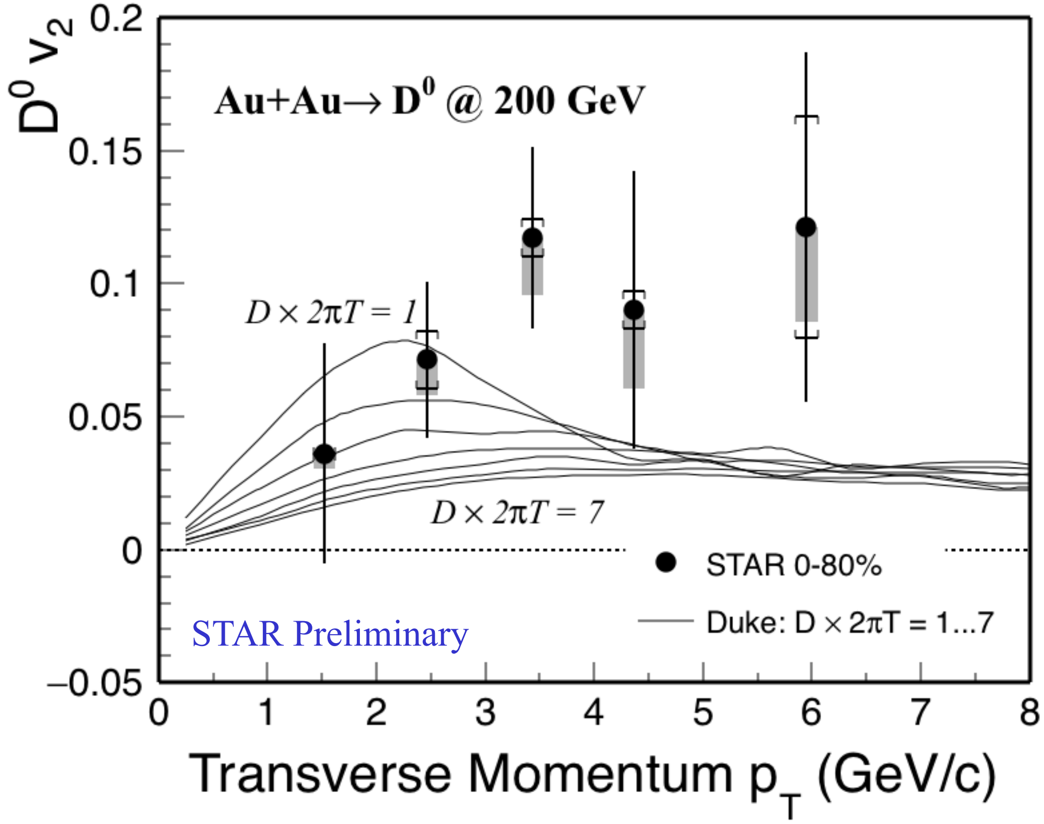




Our data-driven fast-simulation package can well describe our topology distribution

Charm Diffusion Coefficient Scan

Theory: arXiv:1505.01413 & private comm.



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