Measurements of $\Lambd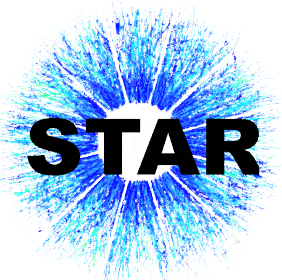a_c^\pm$, $D_s^\pm$, $D^{*\pm}$ and $D^0(\overline{D}^0)$ Production in Au+Au Collisions at $\sqrt{s_{NN}} = 200$ GeV at STAR

Guannan XIE（for the STAR Collaboration）

University of Illinois at Chicago

Sept. 30 – Oct. 5, 2018

Introduction

Heavy quarks: $m_{c/b} \gg \Lambda_{QCD}, T_{QGP(RHIC)}$

- Produced early in heavy-ion collisions through hard scatterings
- Experience the whole evolution of the system
  → good probe of medium properties, e.g. transport parameters
- Focus on charm production

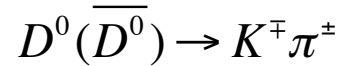Charm Flow: Liang He on 2nd Oct. Bottom production: Xiaolong Chen on 2nd Oct
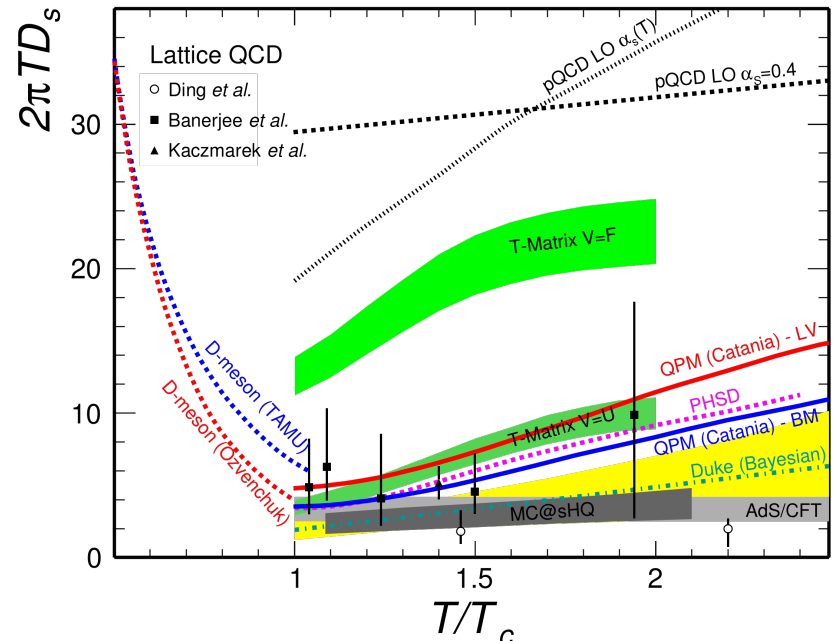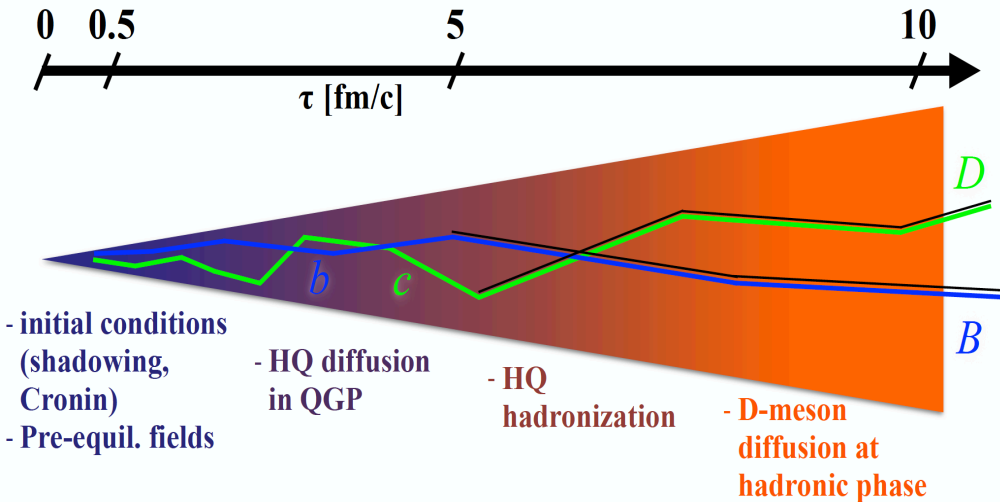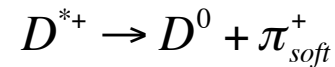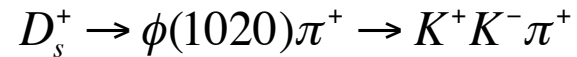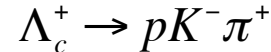

Y. Akiba etc. arXiv:1502.02730

Contents

- In medium energy loss
   - D^0 R_{AA}, R_{CP}

- Hadronization
   - Λ_c, D_s

- Total charm cross-section

- Possible medium effect of resonance production
   - $D^{*+/-}$

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

$$\Lambda_c^+ \to pK^-\pi^+$$

$$D_s^+ \to \phi(1020)\pi^+ \to K^+K^-\pi^+$$

$$D^{*+} \to D^0 + \pi^+_{soft}$$

STAR Detector

Time Projection Chamber:
Tracking, PID (dE/dx), $|\eta|<1$, $0<\phi<2\pi$

Time Of Flight detector:
PID ($1/\beta$), $|\eta|<1$, $0<\phi<2\pi$
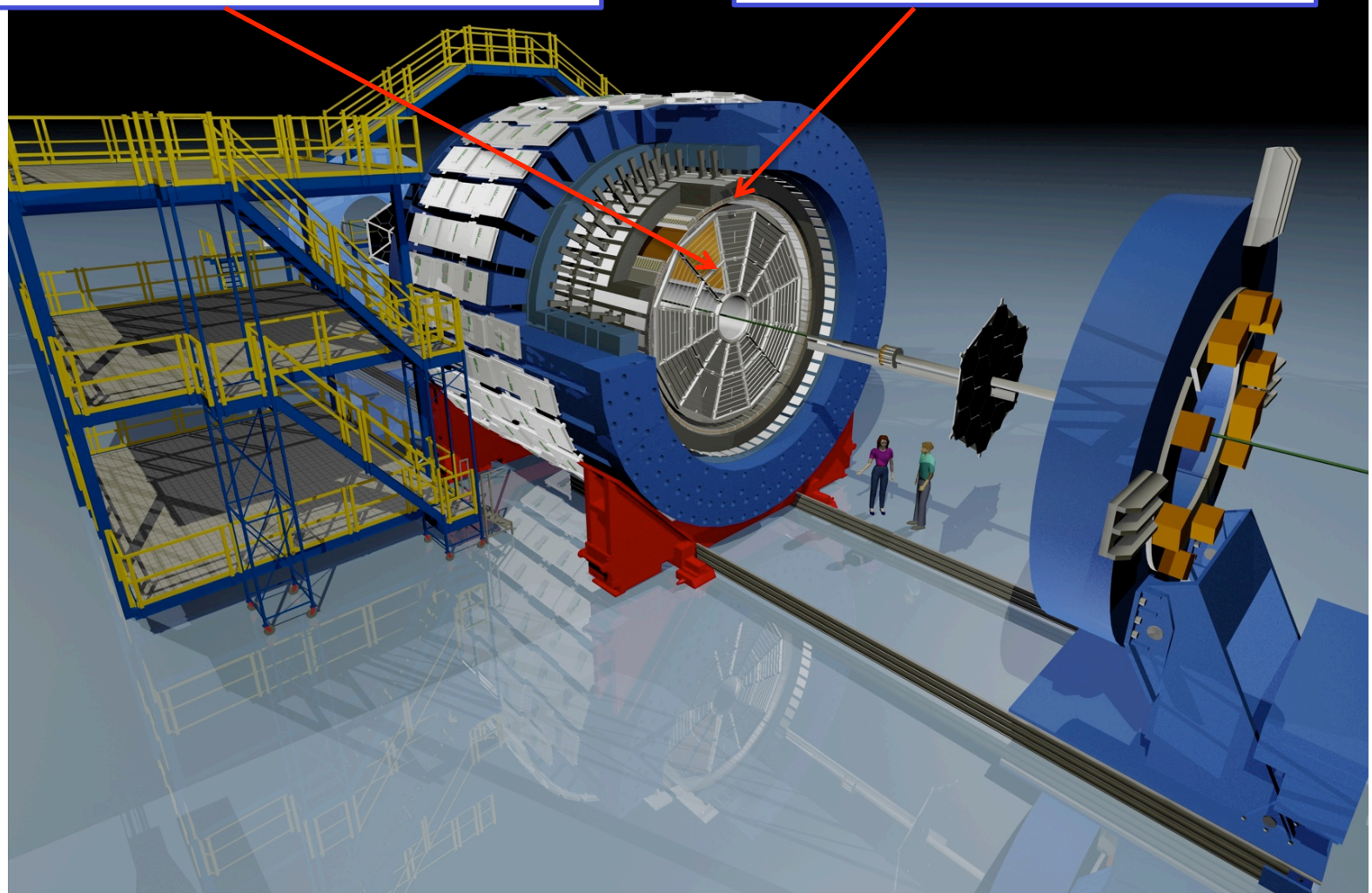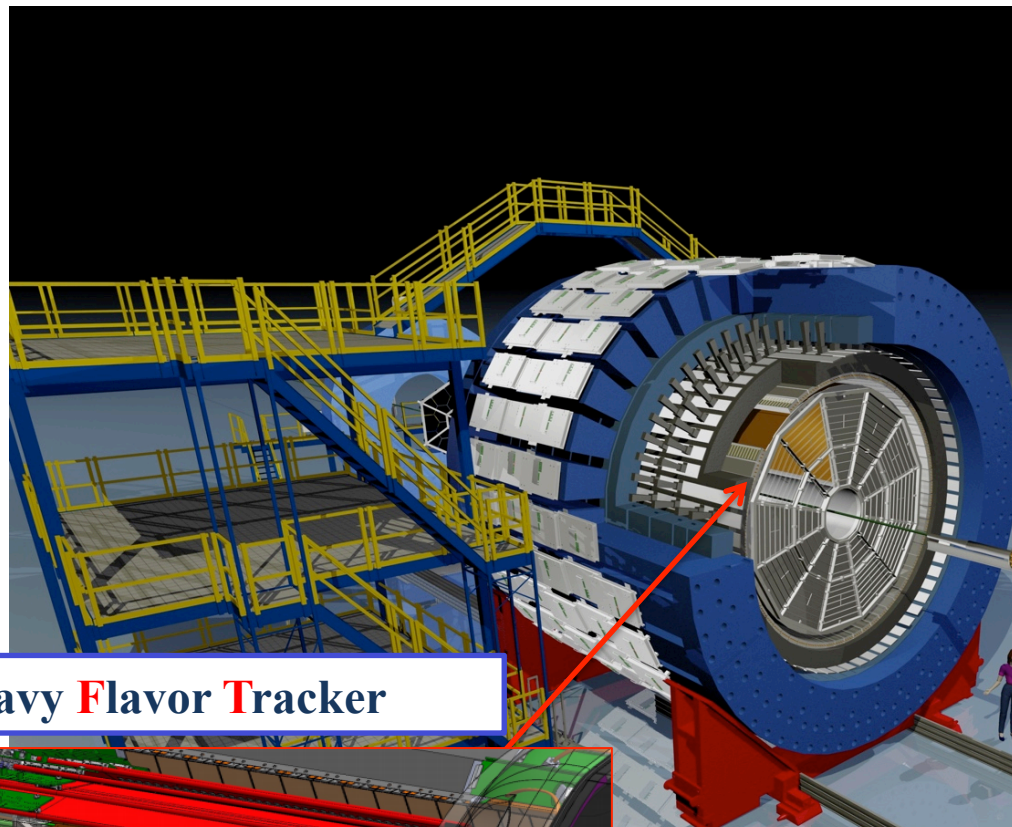
Heavy Flavor Tracker

Heavy Flavor Tracker

DCA$_{XY}$ Resolution
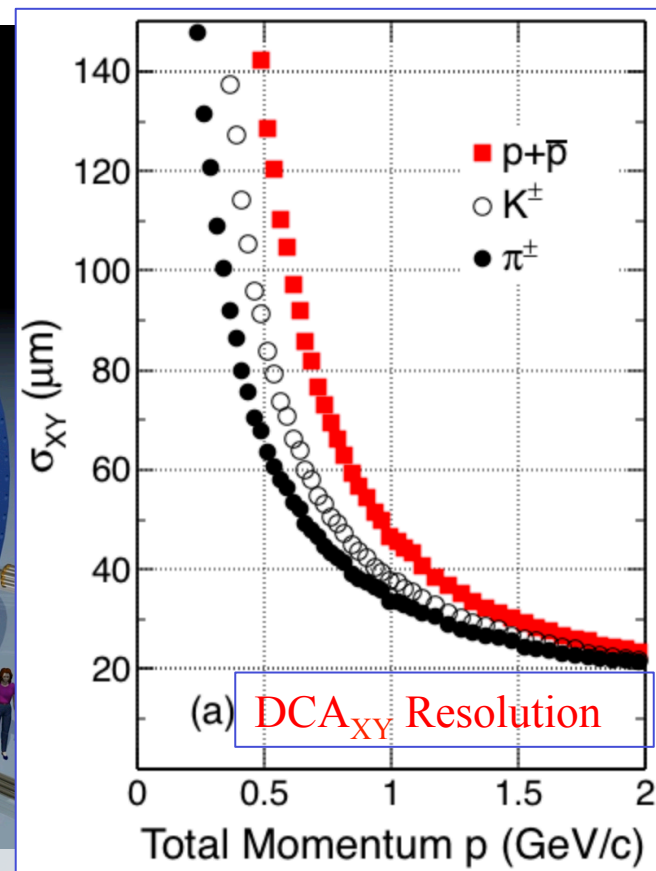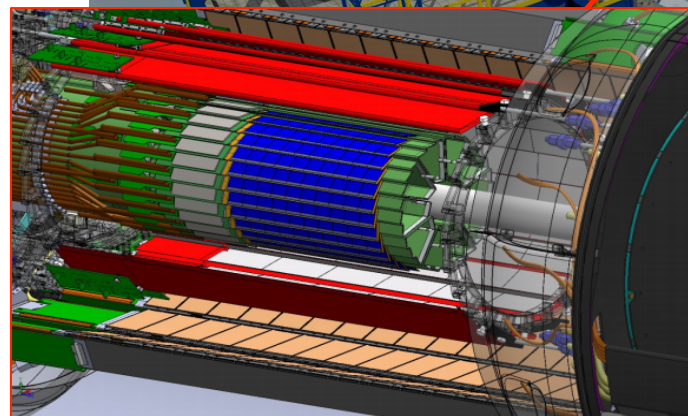
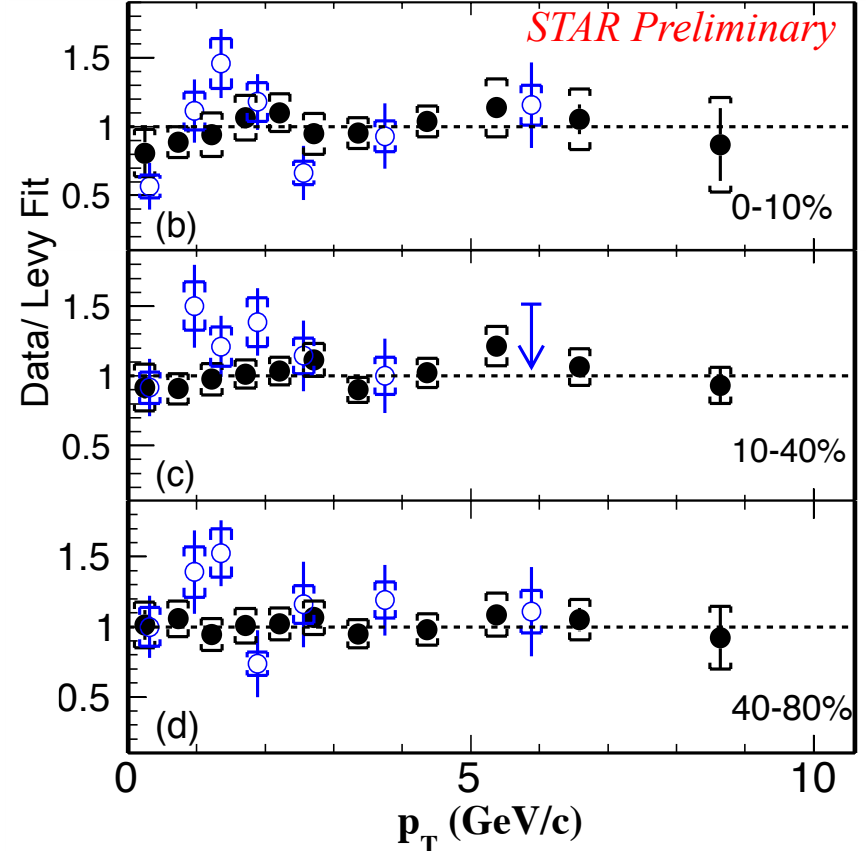**HFT:**
- Silicon Strip Detector: r ~22 cm
- Intermediate Silicon Tracker: r ~14 cm
- PIXEL detector: r ~2.8 & 8 cm,
  MAPS, 20.7x20.7 μm^2, 0.5%X_0 (2014)
  0.4%X_0 (2016) , air-cooled

D^0 p_T Spectra

- Precise measurements of D^0 spectra extended to low p_T and non-central collisions from 2014 data with HFT
- Results consistent with the re-analyzed 2010/11 TPC-only analysis
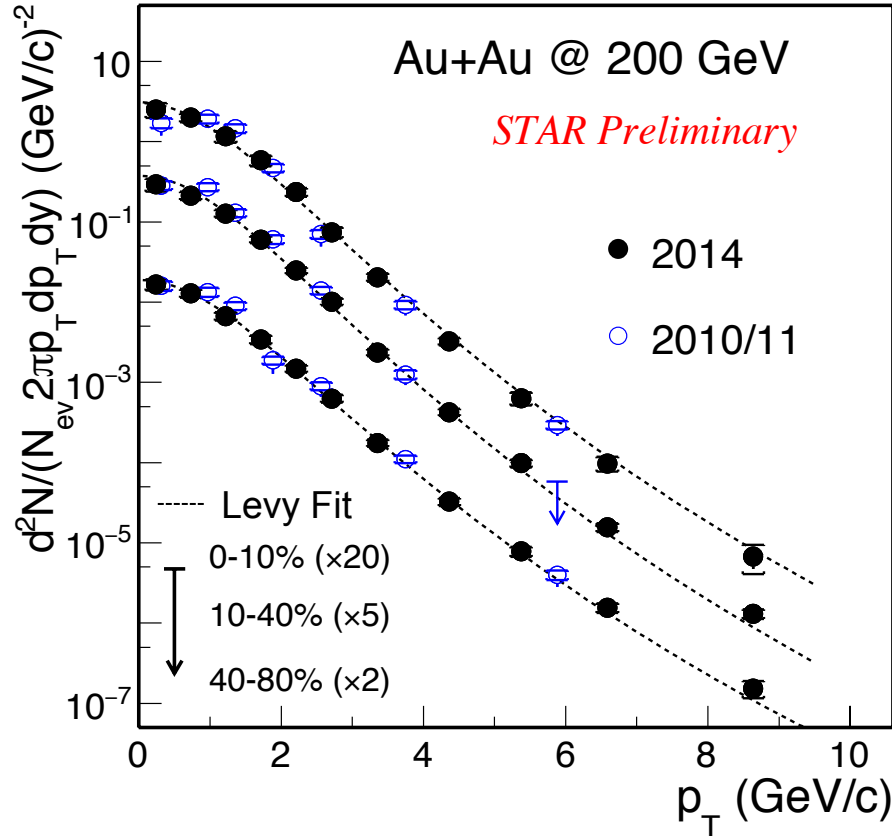
D^0 R_{AA}

- $R_{AA} < 1$ in the 0-10% centrality interval for all p_T
- Suppression at high p_T increases towards more central collisions
- Similar trend as D-mesons at LHC and high-p_T pions at RHIC
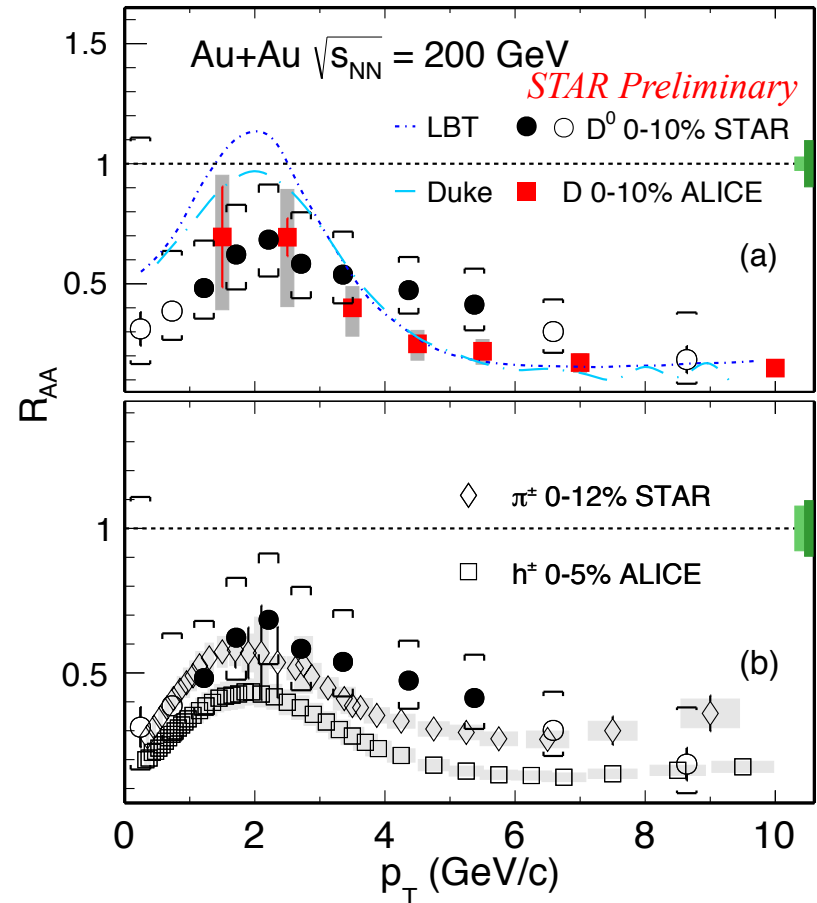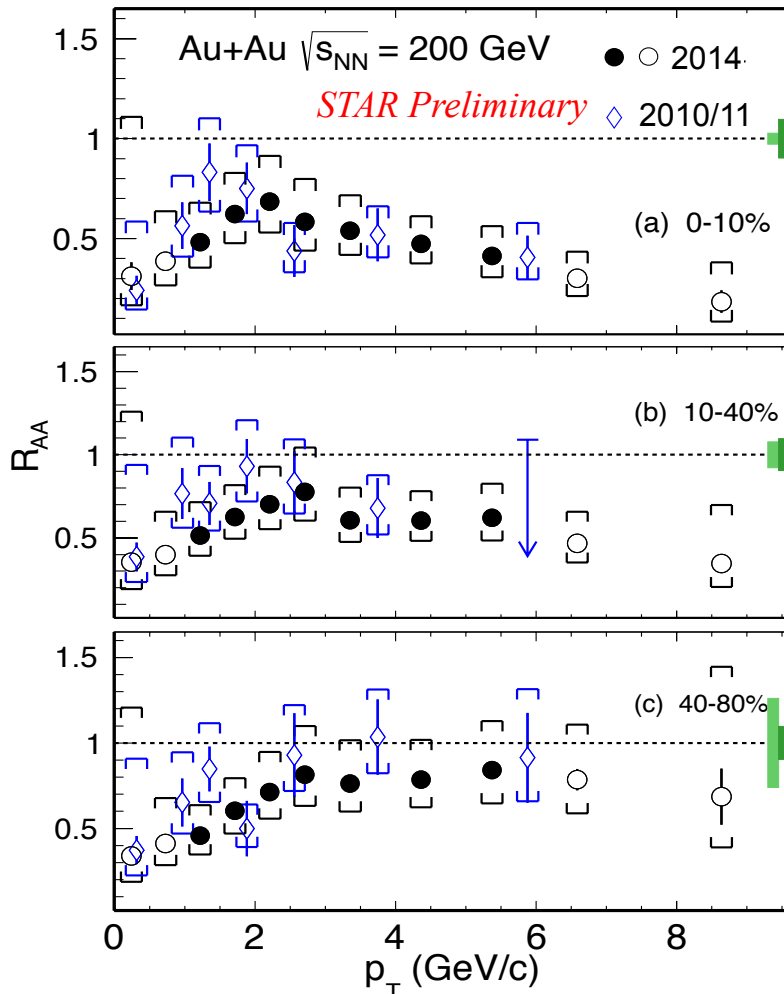
D^0 R_{CP} and $\overline{D}^0/D^0$ Ratio

- Significant suppression at high p_T .
- Reasonable agreement with theoretical calculations
- $\overline{D}^0/D^0$ ratio is larger than 1, possibly due to finite baryon density
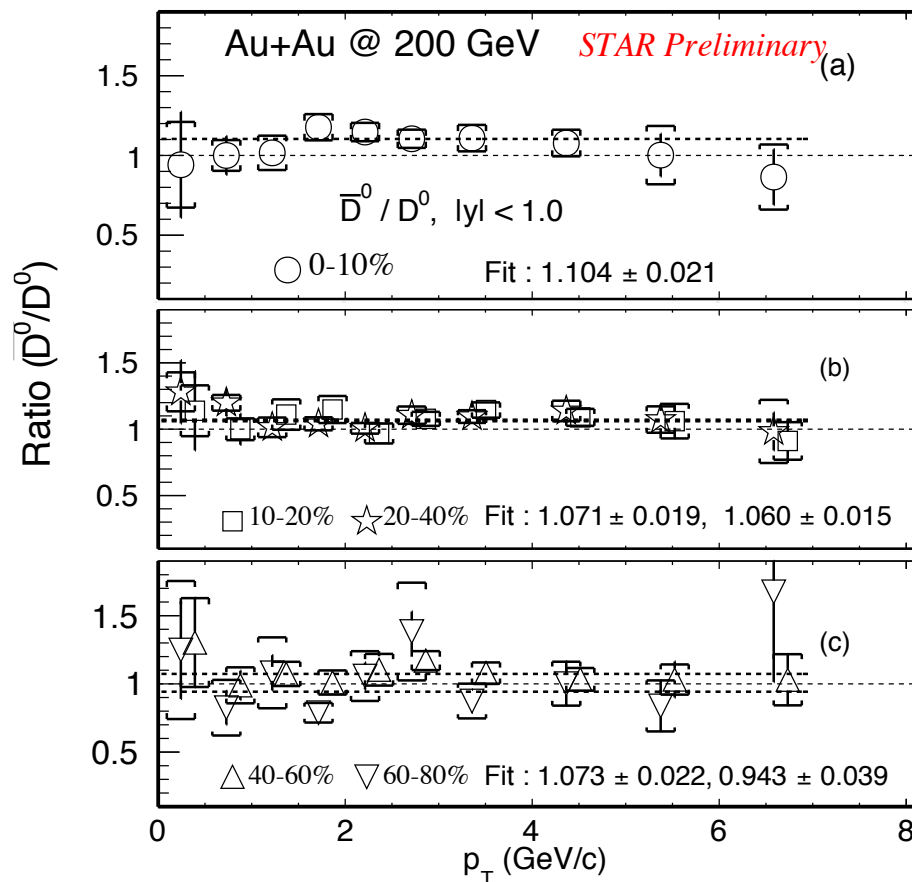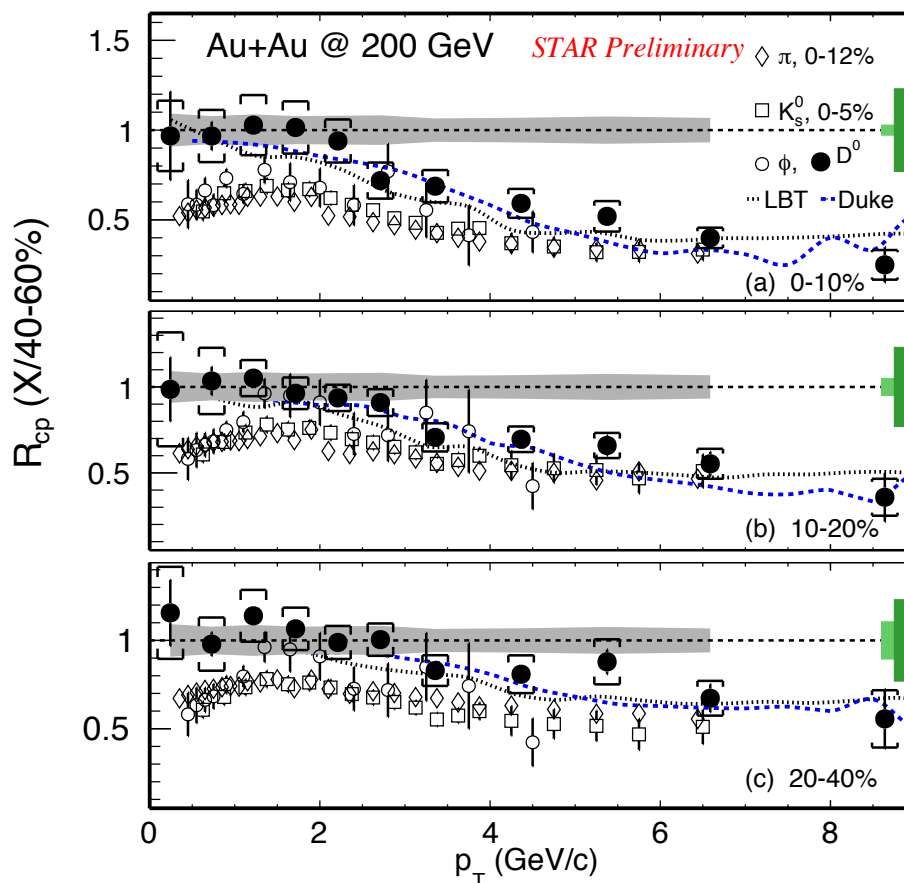
D^0 Cross-section and Blast Wave Fit

- p_T-integrated D^0 cross-section is nearly independent of centrality, and smaller than in p+p collisions. However, for $p_T > 4$ GeV/c it decreases towards central collisions.

- Blast Wave fits ($p_T < 5$ GeV/c) : suggests earlier freeze-out of D^0 compared to light flavor hadrons.
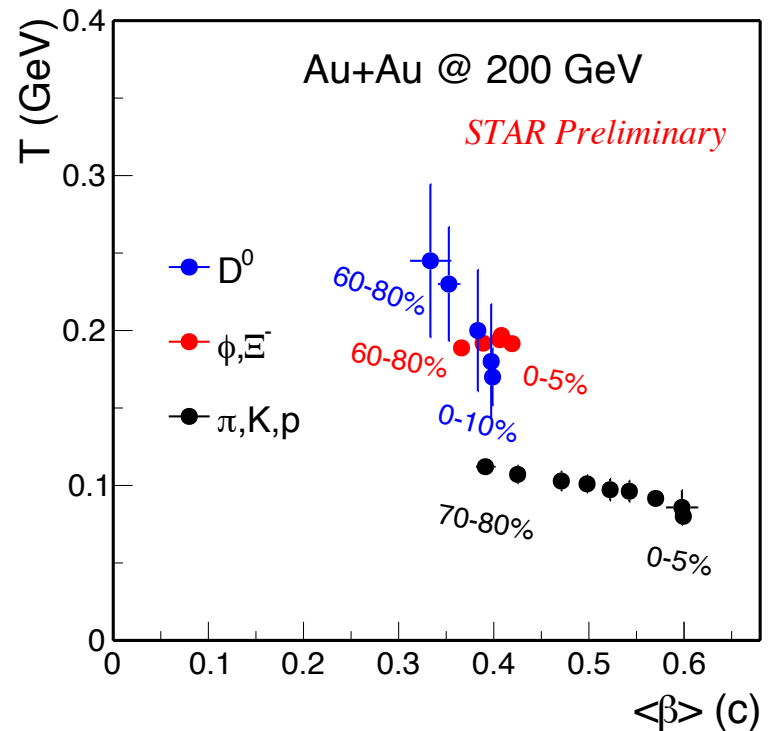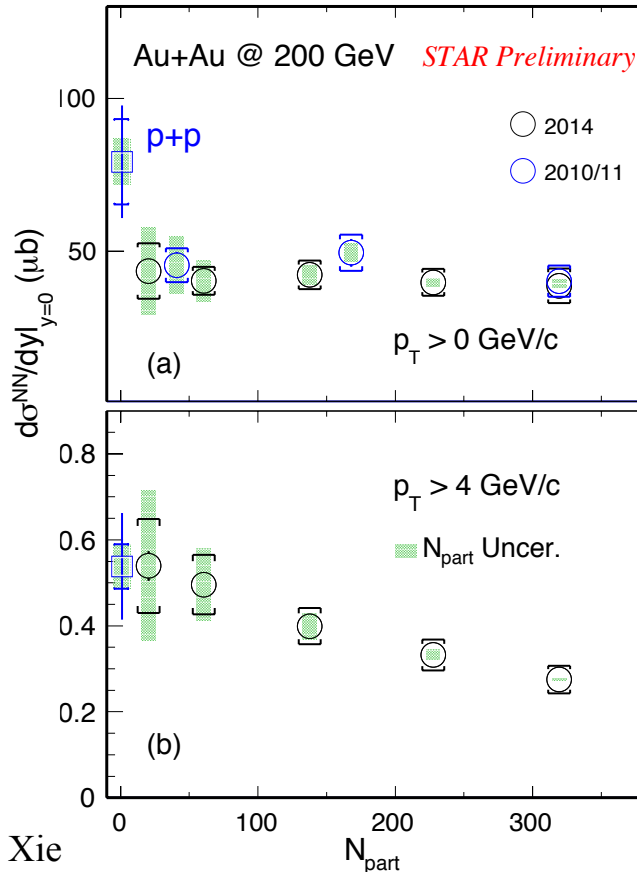
Λ_c and Heavy Quark Hadronization

- Strong enhancement of Λ_c/D^0 ratio seen in Au+Au collisions.
- Enhancement predicted from coalescence hadronization.
- Enhancements relative to PYTHIA also seen in p+p and p+Pb collisions at LHC.

QM17

Au+Au @ 200 GeV

$\dfrac{(\Lambda_c + \overline{\Lambda_c})}{(D^0 + \overline{D^0})}$

STAR Preliminary

Ko: di-quark

0-5%

10-60%

2014

Ko: three-quark

Λ_c / D^0

SHM

Greco (Λ_c/D)

PYTHIA

Transverse Momentum p_T (GeV/c)

Λ_c^+ / D^0

pp, $\sqrt{s}$ = 7 TeV

|y| < 0.5

- ALICE
- PYTHIA8 (Monash)
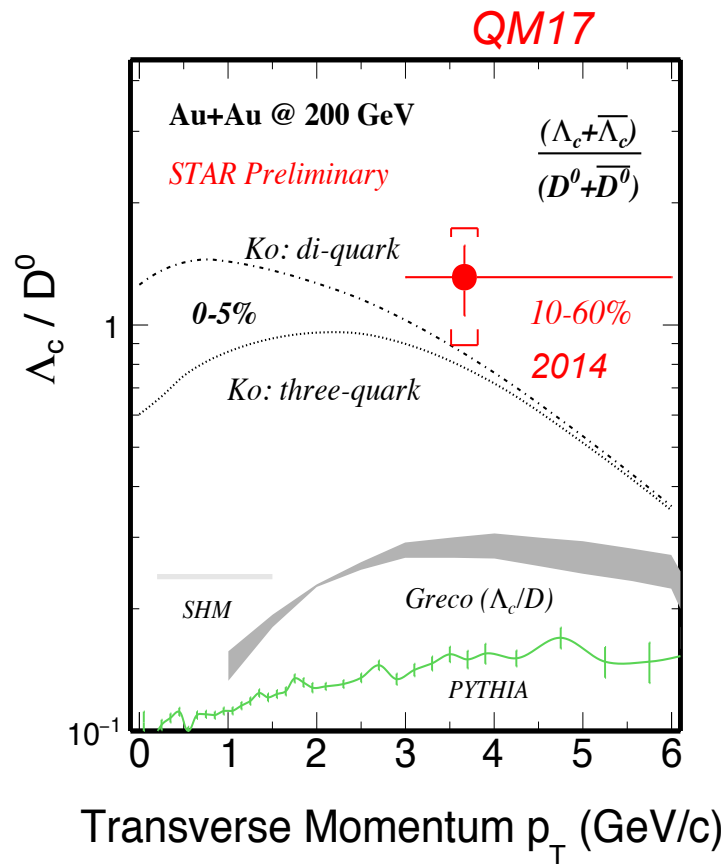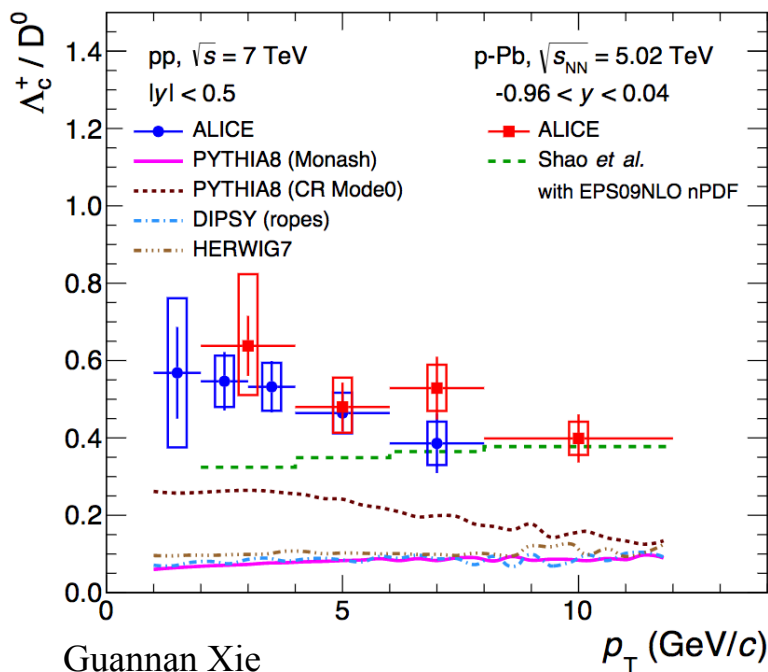- PYTHIA8 (CR Mode0)
- DIPSY (ropes)
- HERWIG7

p-Pb, $\sqrt{s_{NN}}$ = 5.02 TeV

-0.96 < y < 0.04

- ALICE
- Shao *et al.*
  with EPS09NLO nPDF

p_T (GeV/c)

Λ_c/D^0 in A+A
p_T and centrality dependence?

Ko: PRC 79 (2009) 044905. Greco: PRD 90 (2014) 054018
SHM: PRC 79 (2009) 044905. ALICE: arXiv:1712.09581

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Λ_c Reconstruction

- More than 50% improvement in signal significance with TMVA BDT
- Also new data from 2016
  - → Effectively 4x more data

2014 (Rectangular) *QM17*
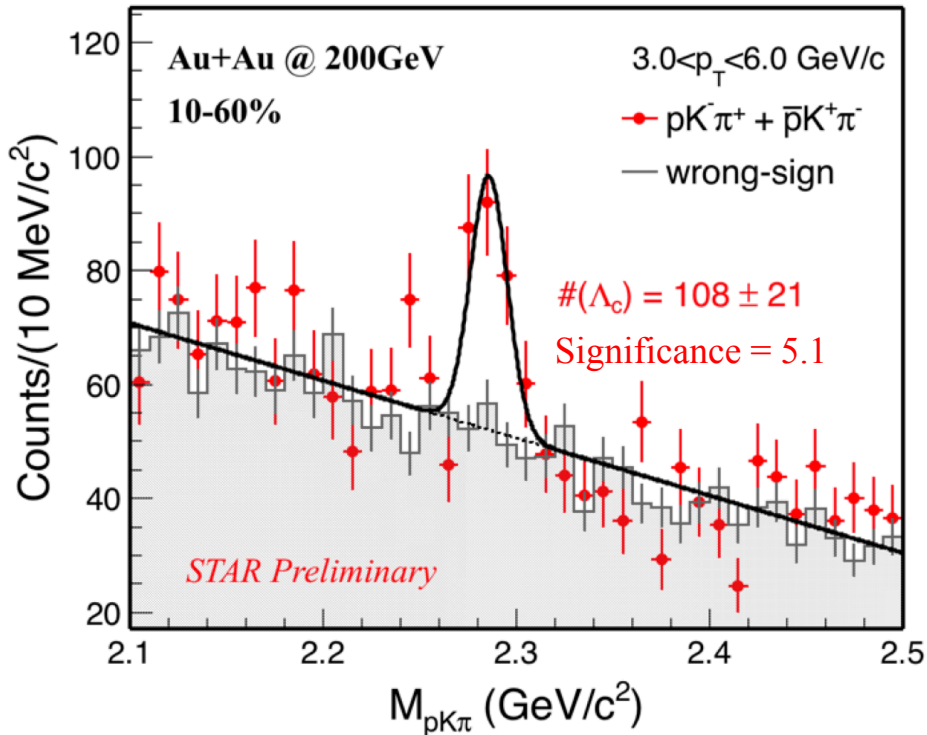
2014+2016 (BDT)
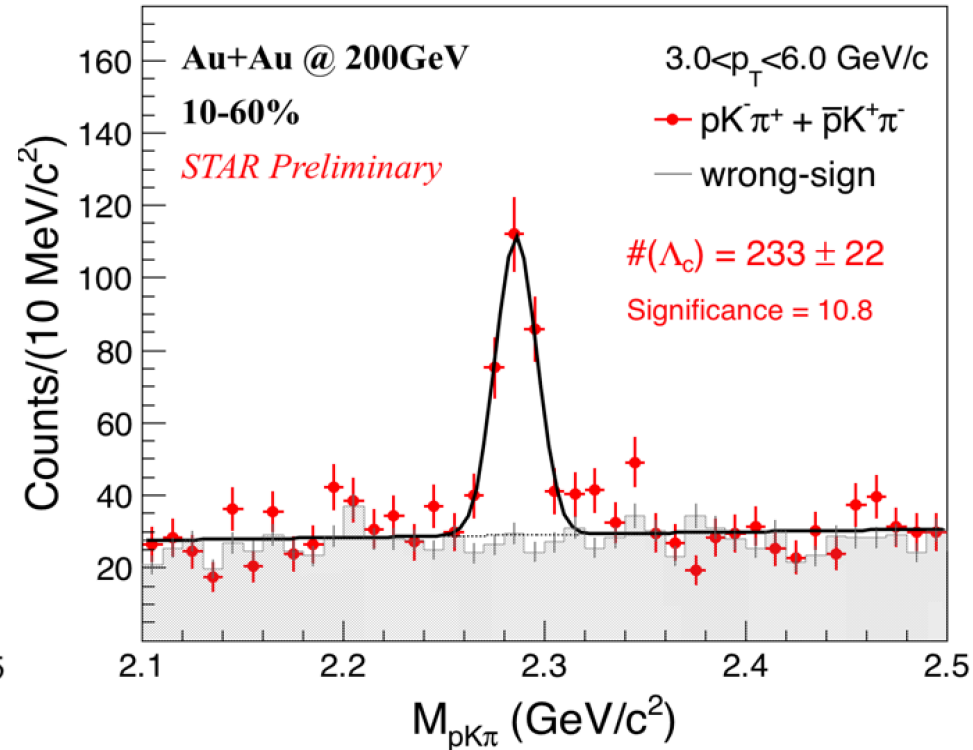
Λ_c/D^0 : p_T Dependence

- Significant enhancement of Λ_c/D^0 compared to PYTHIA/fragmentation baseline
- The Λ_c/D^0 ratio is comparable with light flavor baryon-to-meson ratios
- Consistent with charm quark hadronization via coalescence
  -- higher than model predictions, particularly at higher p_T
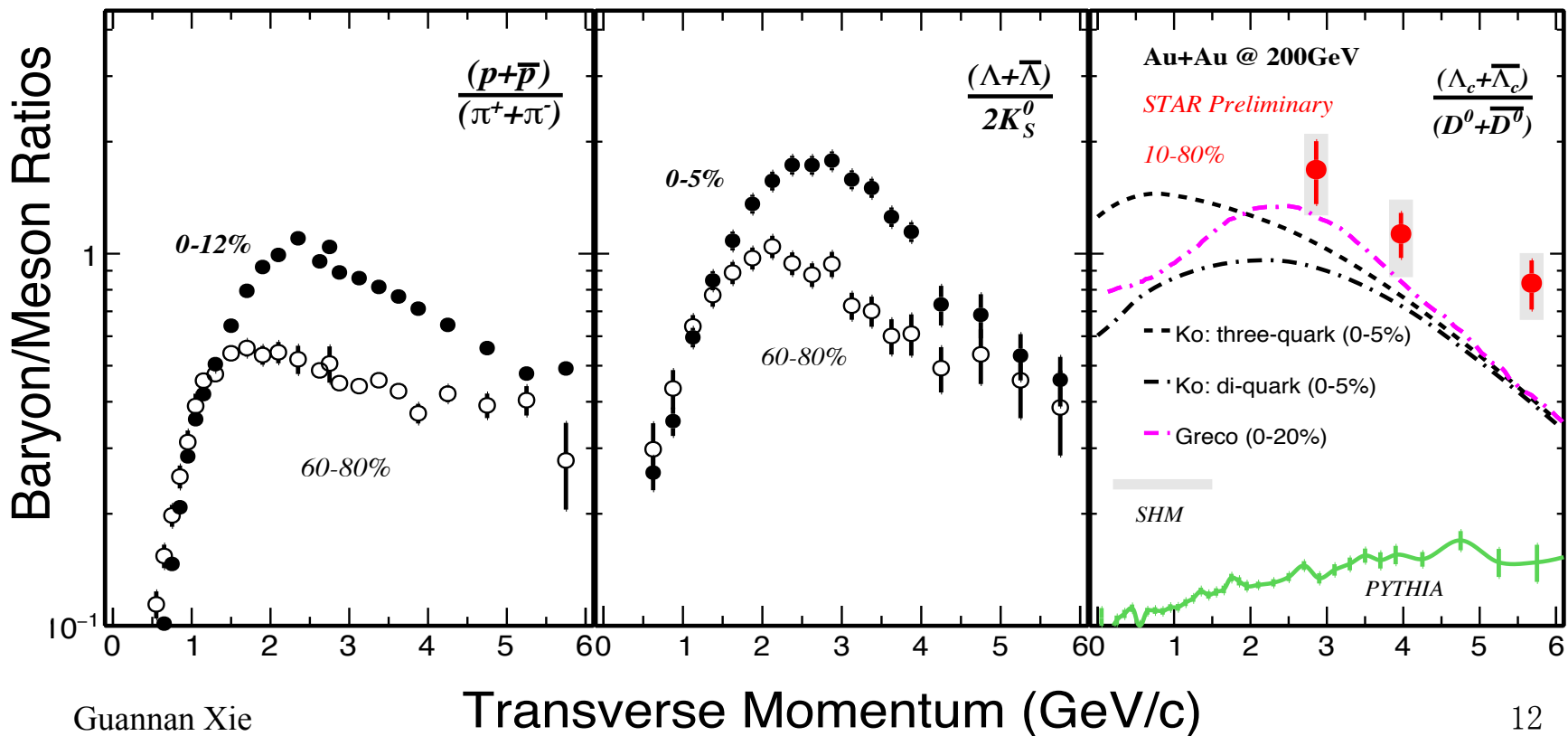
Λ_c/D^0 : Centrality Dependence

- Λ_c/D^0 ratio increases from peripheral to central collisions, indicative of hot medium effects
- Ratio for peripheral Au+Au comparable with p+p value at 7 TeV
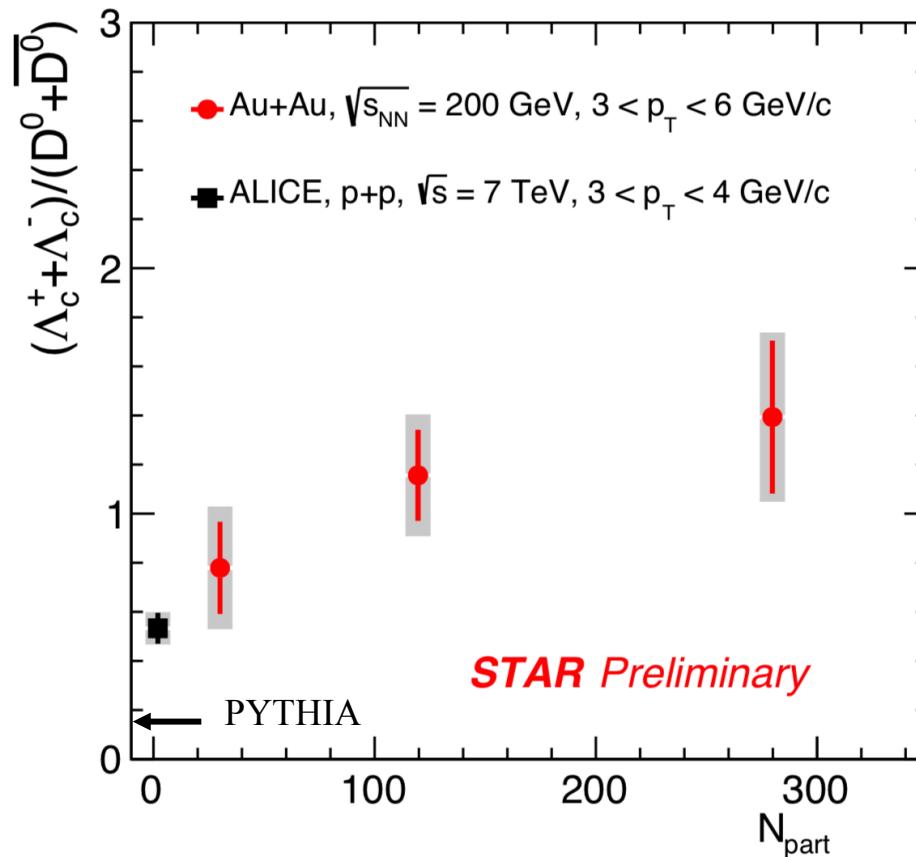
ALICE: JHEP 04 (2018) 108

D_s/D^0 Enhancement

- Strong D_s/D^0 enhancement observed in central A+A collisions w.r.t fragmentation baseline
  - Strangeness enhancement and coalescence hadronization
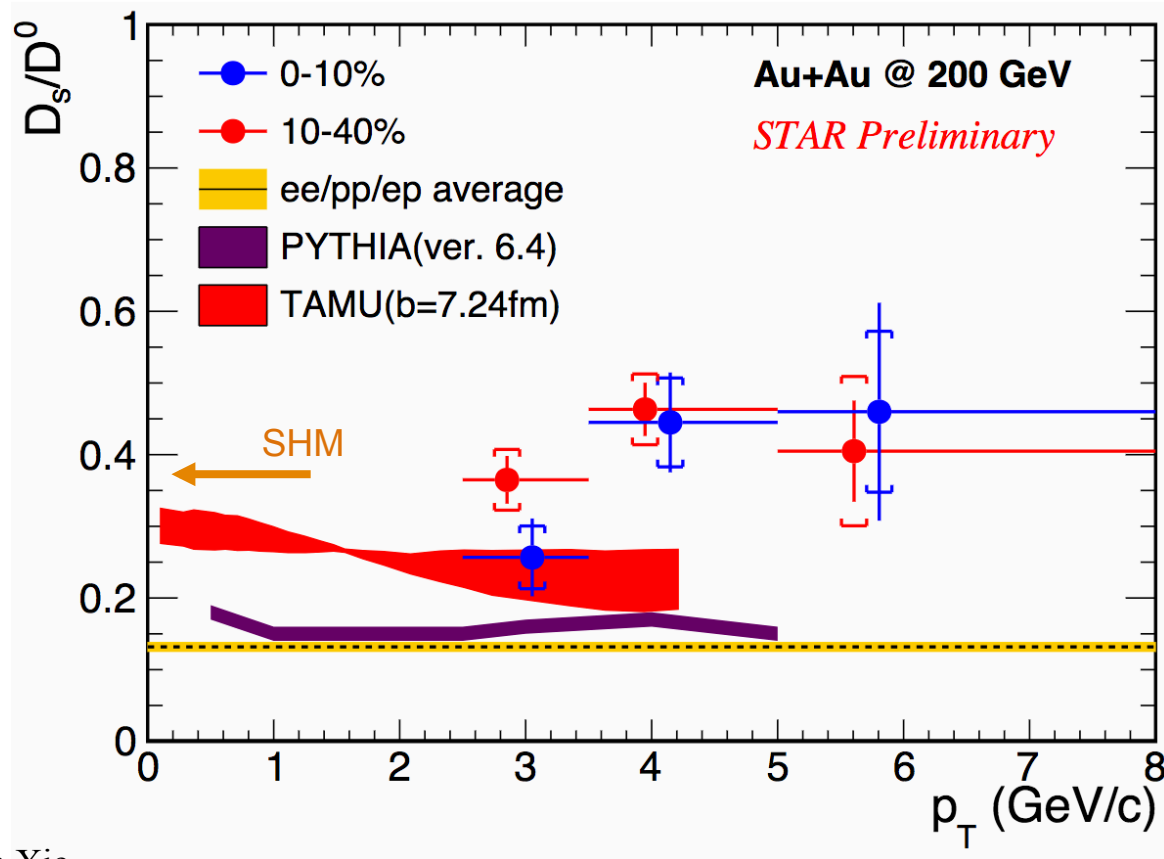- Enhancement is larger than model predictions, particularly at higher p_T

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Total Charm Cross-section

- Total charm cross-section is estimated from the various charm hadron measurements

-- D^0 yields are measured down to zero p_T

-- For $D^{+/-}$ and D_s, Levy fits to measured spectra are used for extrapolation.

-- For Λ_c, three model fits to data are used and differences are included in systematics

| Charm Hadron		Cross Section $d\sigma/dy$ (μb)
AuAu 200 GeV (10-40%)	D^0	41 ± 1 ± 5
	D^+	18 ± 1 ± 3
	D_s^+	15 ± 1 ± 5
	Λ_c^+	78 ± 13 ± 28 *
	Total	**152 ± 13 ± 29**
pp 200 GeV	**Total**	**130 ± 30 ± 26**

* derived using Λ_c^+ / D^0 **ratio in 10-80%**

- Total charm cross-section is consistent with p+p value within uncertainties, but redistributed among different charm hadron species

D*+ Production in Au+Au Collisions

- D*+ feeds down to D⁰ yields $D^{*+} \rightarrow D^0 + \pi^+_{soft}$
- Possible hot medium effects :
  - D*+ life time could become shorter in hot medium
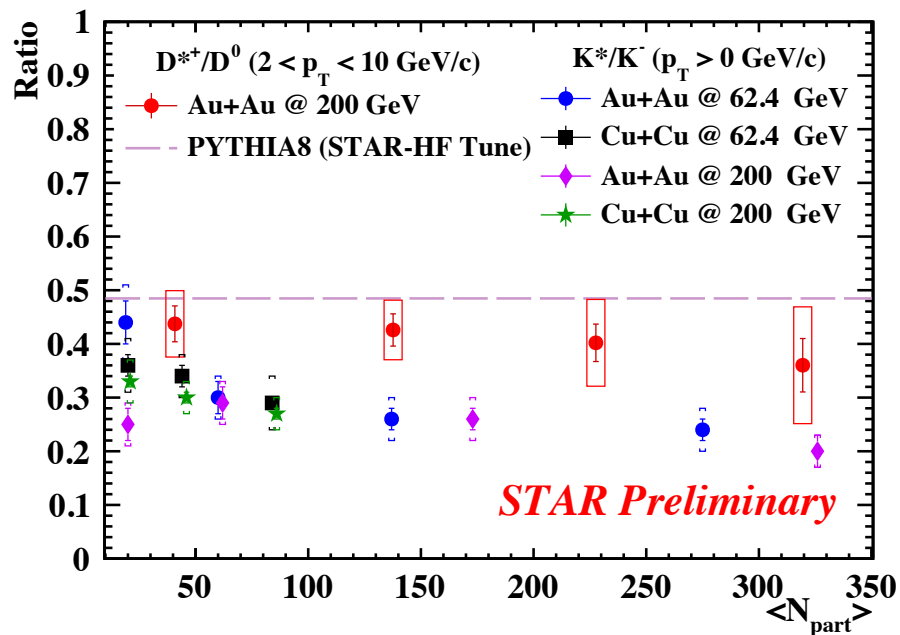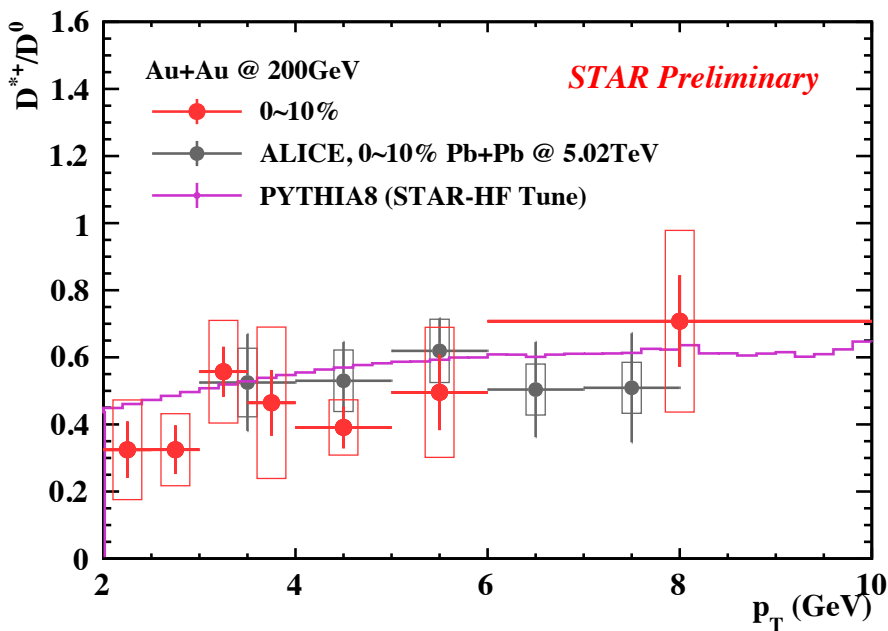 - Re-scattering can lead to loss of yield
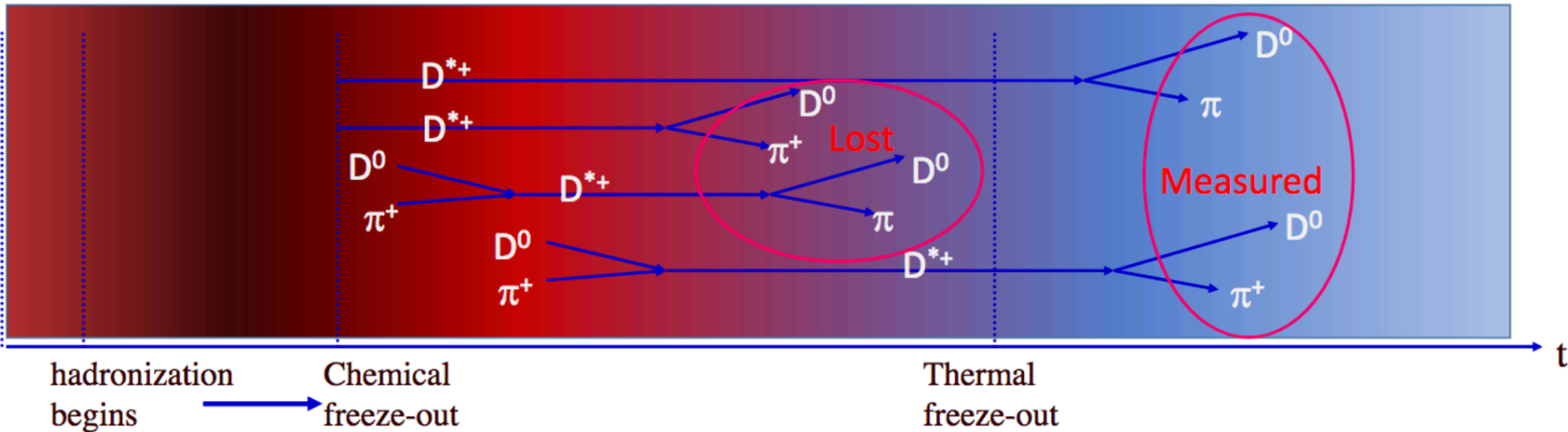
Shuai Y. F. Liu and Ralf Rapp. Phys. Rev. C 97 (2018) 034918.

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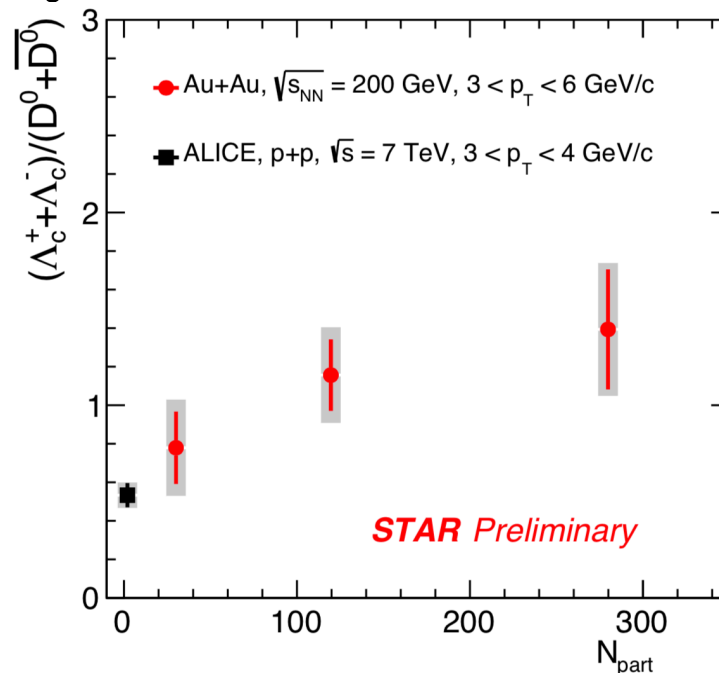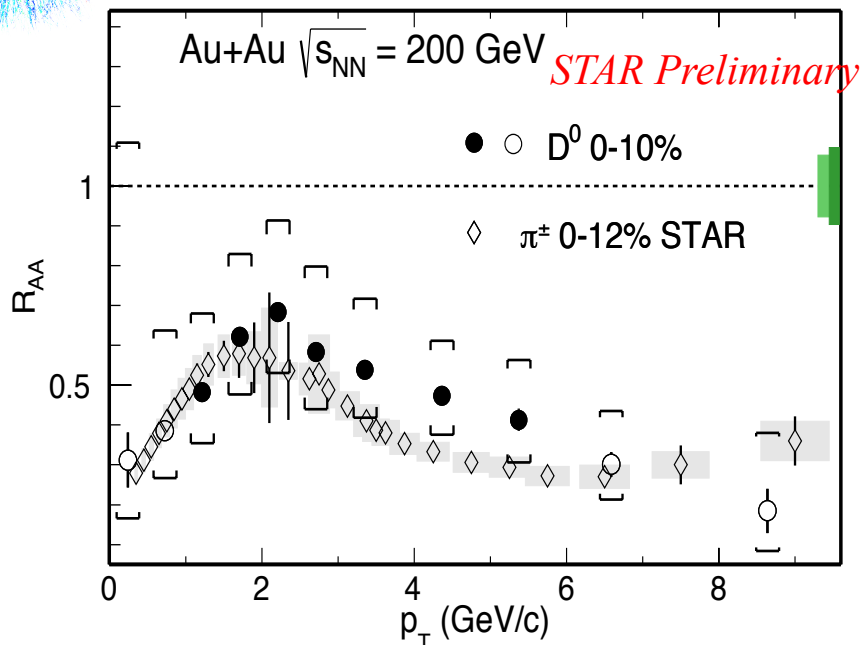# D^{*+}/D^0 Ratio in Au+Au Collisions

- D^{*+}/D^0 ratio in Au+Au collisions at 200 GeV is consistent with PYTHIA and with ALICE data at higher p_T.
- Ratio of the integrated yields shows no strong centrality dependence

K/K, Phys. Rev. C (2011) 84. 034909.*
ALICE Collaboration, arXiv:1804.09083.

Summary

- Strong modification of charm hadron spectra in A+A collisions. (D^0 R_{AA} & R_{CP}, D_s/D^0, Λ_c/D^0).
  -- total charm quark cross-section consistent with that in p+p, but redistributed
  -- substantial energy loss
  -- coalescence hadronization
- Next, measurement of bottom hadrons via various decay channels to test mass hierarchy of parton energy loss

Bottom production: Xiaolong Chen on 2nd Oct

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Back up

D^0 in AuAu (2010/2011 TPC Analysis) - I
# Erratum: PRL 113 (2014) 142301

1. Two mistakes were discovered in calculating TOF related efficiency corrections
   - Hybrid PID: algorithm inconsistently implemented in data analysis vs. efficiency calculation
   - a DCA_{xy} cut efficiency was included in the correction two times

2. p+p measurement: no issue discovered, but the p+p D^0 baseline used for R_{AA} is updated with latest knowledge of charm frag. ratios
   - considering the p_T dependence of $D*/D^0$ frag. ratio
   - latest world average of c->D^0 and c->$D*$ frag. ratios

   (D^0 at p_T<2 GeV/c + $D*$ at 2-6 GeV/c, *PRD 86 (2012) 072012*)
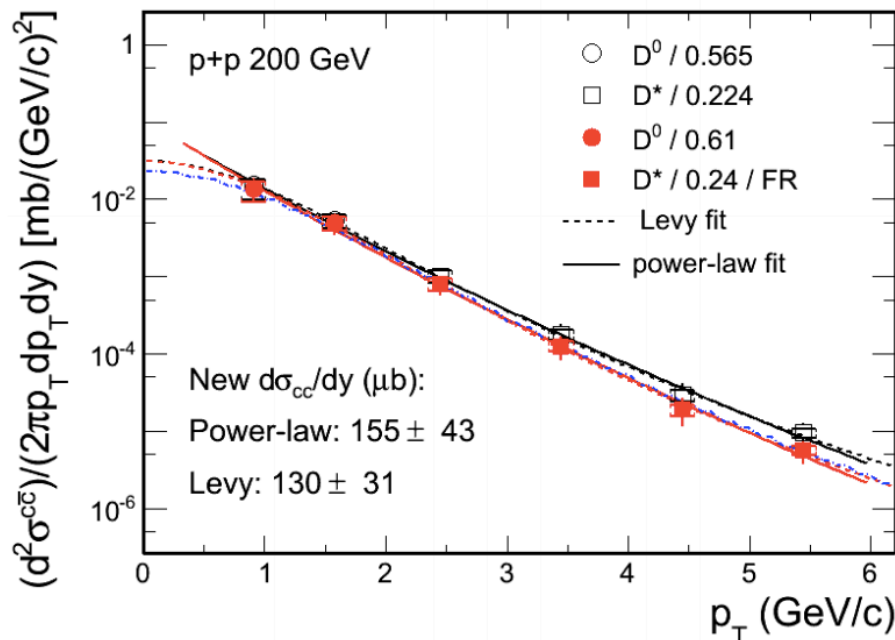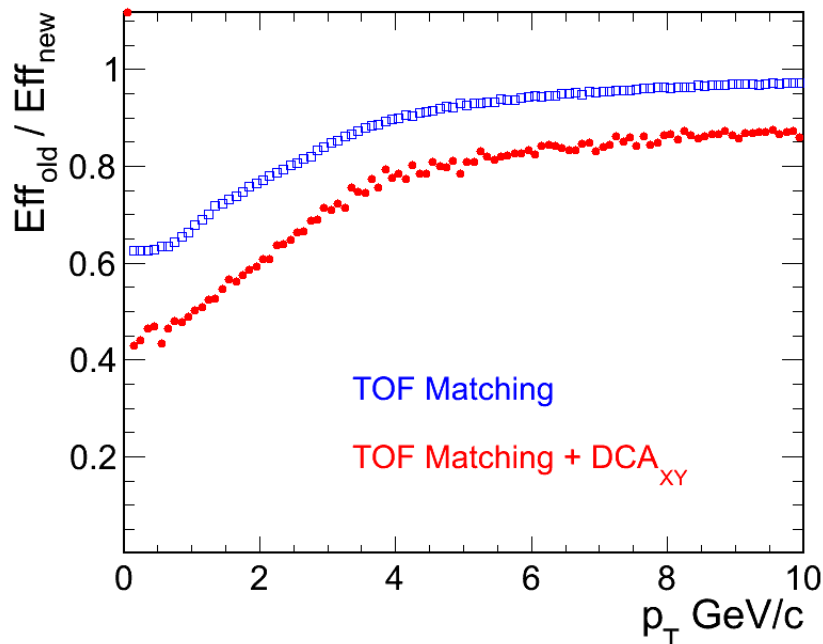
Topological Reconstruction
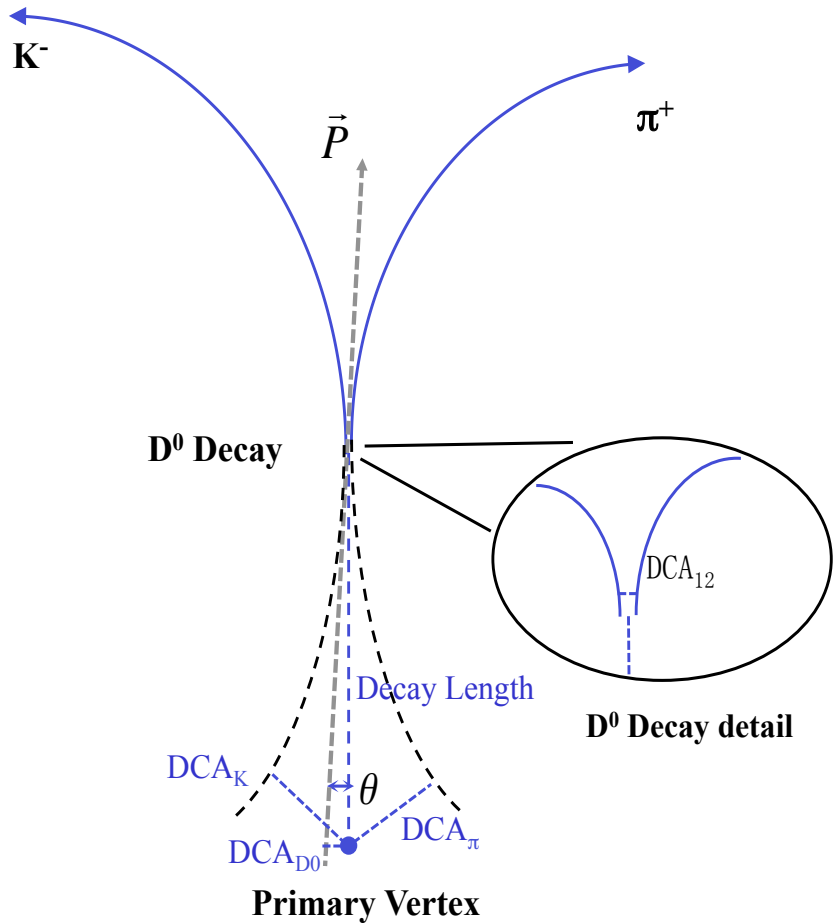
- Direct topological reconstruction through hadronic channels
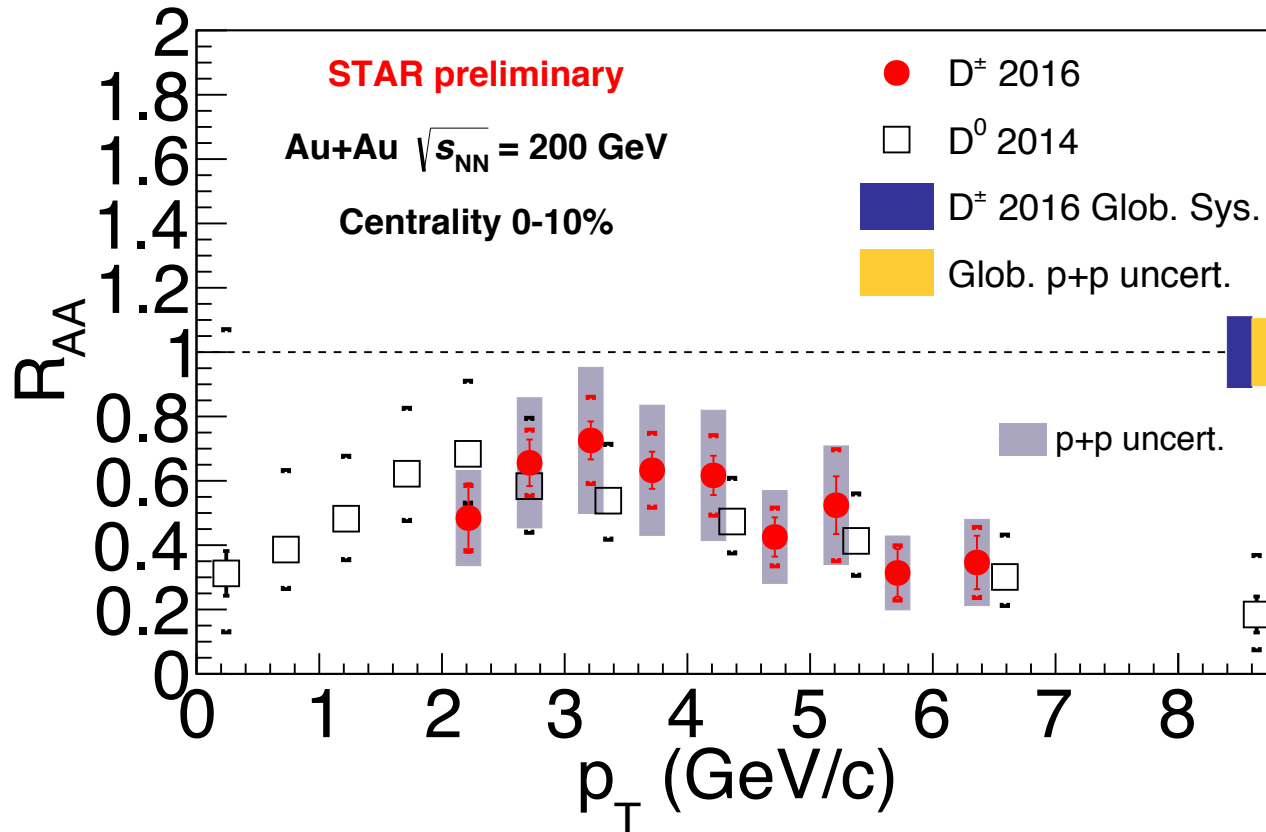
$$D^0(\overline{D^0}) \to K^{\mp}\pi^{\pm}$$
$$\Lambda_c^+ \to pK^-\pi^+$$
$$D_s^+ \to \phi(1020)\pi^+ \to K^+K^-\pi^+$$

- With HFT: greatly reduced combinatorial background

- Topological cuts optimized by TMVA (Toolkit for Multi Variate Analysis)
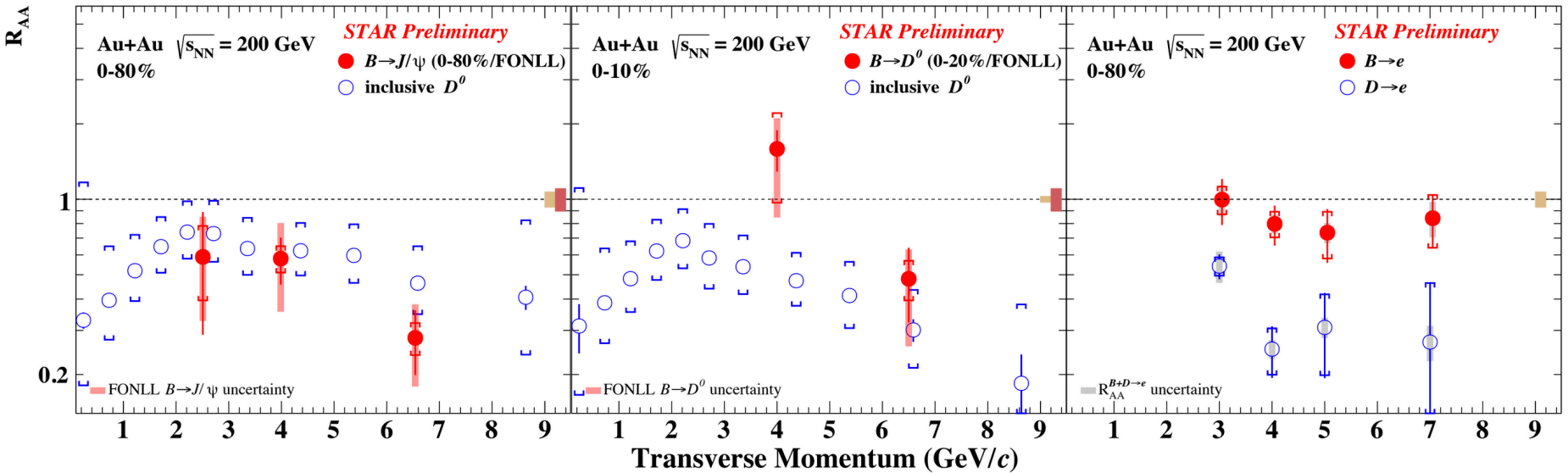
$D^{+/-}$ R_{AA}

- Similar suppression for D^0 and $D^{+/-}$
- Spectra measurement was important for the total charm cross-section

B Study from Non-prompt J/ψ & D⁰ & e

- Strong interaction of charm with the medium. How about bottom?
- Strong suppression for $B \to J/\psi$ and D^0 at high p_T.
- Indication of less suppression for $B \to e$ than $D \to e$ (~2 σ): consistent with $\Delta E_c > \Delta e_b$. Measurements with improved precision on the way

$$R_{AA}^{B \to J/\psi} = \frac{f_{Au+Au}^{B \to J/\psi}(data)}{f_{p+p}^{B \to J/\psi}(theory)} R_{AA}^{inc.\ J/\psi}(data)$$

$$R_{AA}^{B \to D^0} = \frac{1}{\langle N_{coll} \rangle} \frac{f_{Au+Au}^{B \to D^0} \times dN_{Au+Au}^{inc.\ D^0}/dp_T}{dN_{FONLL}^{B \to D^0}/dp_T}$$

$$R_{AA}^{B \to e} = \frac{f_{Au+Au}^{B \to e}(data)}{f_{p+p}^{B \to e}(data)} R_{AA}^{inc.\ e}(data)$$

$$R_{AA}^{D \to e} = \frac{1 - f_{Au+Au}^{B \to e}(data)}{1 - f_{p+p}^{B \to e}(data)} R_{AA}^{inc.\ e}(data)$$

R_{AA} references (data vs. theory) are different for comparisons. The decay kinematics needs to be unfolded for different channels.

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