Production of open-charm hadrons in Au+Au collisions at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV measured by the STAR experiment

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OUTLINE

INTRODUCTION

- Motivation for open-charm hadron measurements in heavy-ion collisions
- STAR detector
- Open-charm hadrons measurements with the HFT

RESULTS

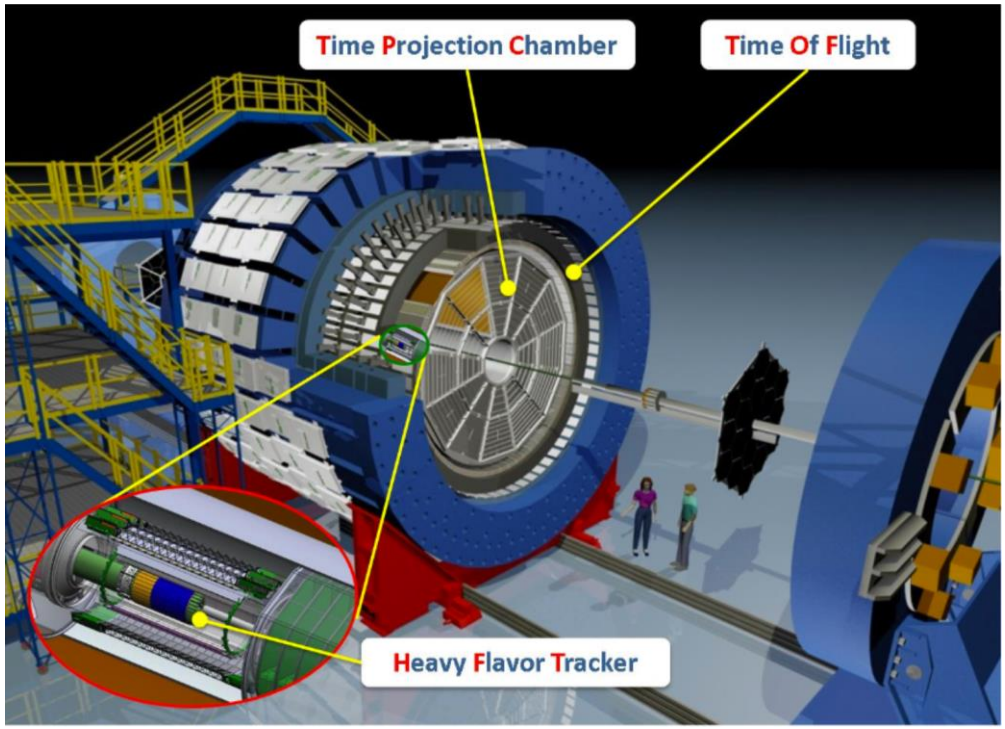
- $D^{\pm}$ and D^0 nuclear modification factor
- D^0 elliptic flow
- D^0 directed flow
- D_s/D^0 ratio
- Λ_c/D^0 ratio

PHYSICS MOTIVATION

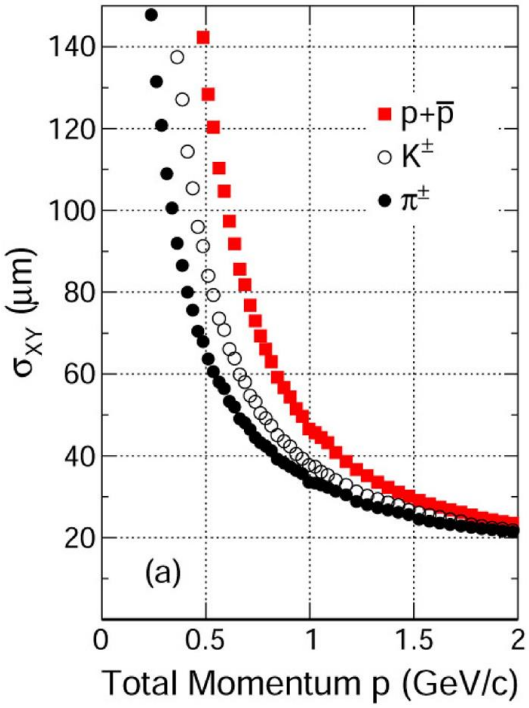
- At RHIC energies, charm and bottom quarks are produced predominantly through partonic hard scatterings at early stage of A+A collisions
  - They experience the whole evolution of the system which makes them an excellent probe of the QGP
  - Observed open-charm hadrons come primarily from initially produced charm quarks, small feedown from bottom decays
- Study of various open-charm hadron species in A+A collisions is essential for understanding the QGP properties as well as charm quark hadronization in the medium
  - **Energy loss in the medium**
    - **D^0, $D^{\pm}$ nuclear modification factor**
  - **Initial tilt of the bulk + initial electromagnetic field**
    - **D^0 directed flow**
  - **Heavy quark diffusion coefficient**
    - **D^0 elliptic flow**
  - **Hadronization**
    - **D_s, Λ_c production**

STAR DETECTOR

- **S**olenoidal **T**racker **At** **RHIC**
- **Heavy Flavor Tracker** (HFT, 2014–2016) is a 4-layer silicon detector
  - MAPS – 2 innermost layers, Strip detectors – 2 outer layers
- **Time Projection Chamber** (TPC) and **Time Of Flight** (TOF)
  - Particle momentum (TPC) and identification (TPC and TOF)



PRL 118 212301 (2017)



OPEN-CHARM MEASUREMENTS WITH THE HFT

- Decay channels used*:
  - $D^+ \rightarrow K^-\pi^+\pi^+$ $c\tau = (311.8 \pm 2.1)$ μm $BR = (8.98 \pm 0.28)$ %
  - $D^0 \rightarrow K^-\pi^+$ $c\tau = (122.9 \pm 0.4)$ μm $BR = (3.93 \pm 0.04)$ %
  - $D_s^+ \rightarrow \phi\pi^+, \phi \rightarrow K^-K^+$ $c\tau = (149.9 \pm 2.1)$ μm $BR = (2.27 \pm 0.08)$ %
  - $\Lambda_c^+ \rightarrow K^-\pi^+p$ $c\tau = (59.9 \pm 1.8)$ μm $BR = (6.35 \pm 0.33)$ %
  - *Charge conjugate particles are also measured
- The HFT allows direct topological reconstruction of open-charm hadrons through their hadronic decays
- STAR took data with the HFT in 2014 and 2016 for Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV
  - 2014: ~900M minimum-bias events
  - 2016: ~1.3B minimum-bias events

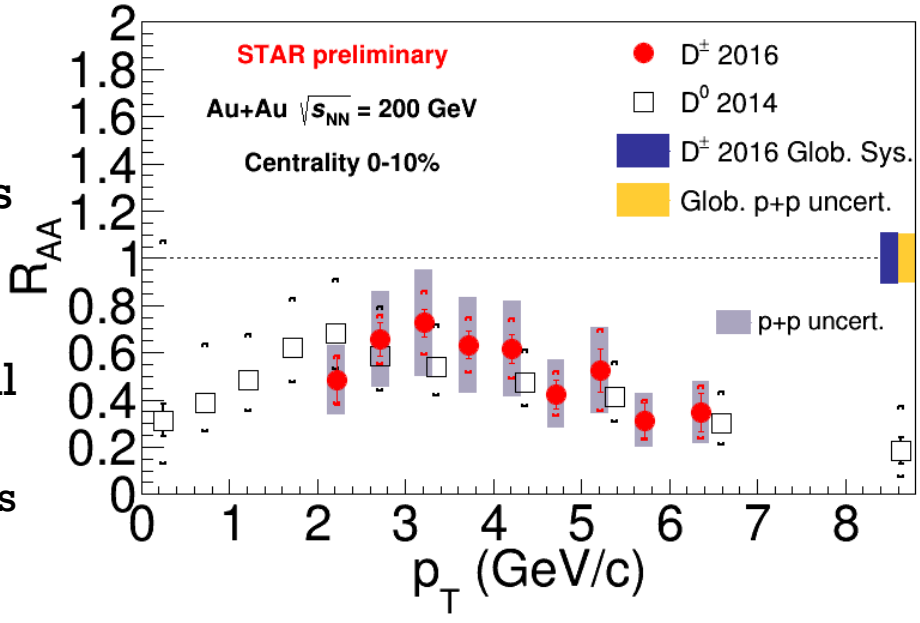
$D^{\pm}$ AND D^0 NUCLEAR MODIFICATION FACTOR

- Nuclear modification factor:

$$R_{AA}(p_T) = \frac{dN_D^{AA}/dp_T}{\langle N_{coll} \rangle \, dN_D^{pp}/dp_T}$$

- Reference: combined D^0 and D^* measurement in 200 GeV p+p collisions using 2009 data

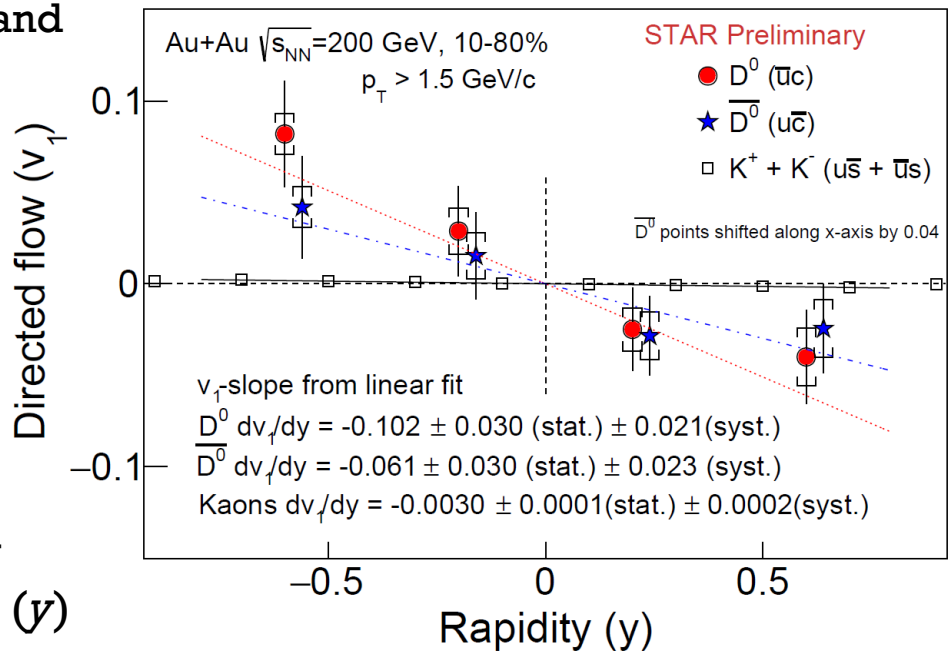
- High-p_T $D^{\pm}$ and D^0 suppressed in central Au+Au collisions
  - Strong interactions between charm quarks and the medium
  - Similar level of suppression for $D^{\pm}$ and D^0



D^0 DIRECTED FLOW

- Predicted contributions:
  - Hydrodynamics
    - Difference between the tilt of the bulk and the density profile of HF production
    - Larger slope of HF than light flavors
    - *Chatterjee, Bozek: Phys Rev Lett 120, 192301 (2018)*
  - Initial EM field from passing spectators
    - Predicted opposite slope for D^0 and $\overline{D^0}$
    - *Das et. al., Phys Lett B 768, 260 (2017)*

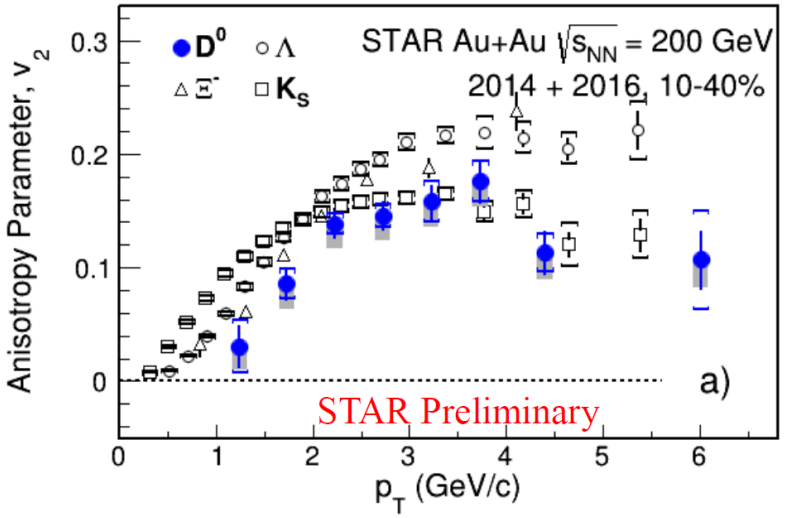
- First evidence of non-zero directed flow (v_1) of D^0 and $\overline{D^0}$ as a function of rapidity (y)
  - Negative v_1 slope for both D^0 and $\overline{D^0}$
  - Larger than for kaons
  - Insufficient precision to conclude about the EM induced splitting

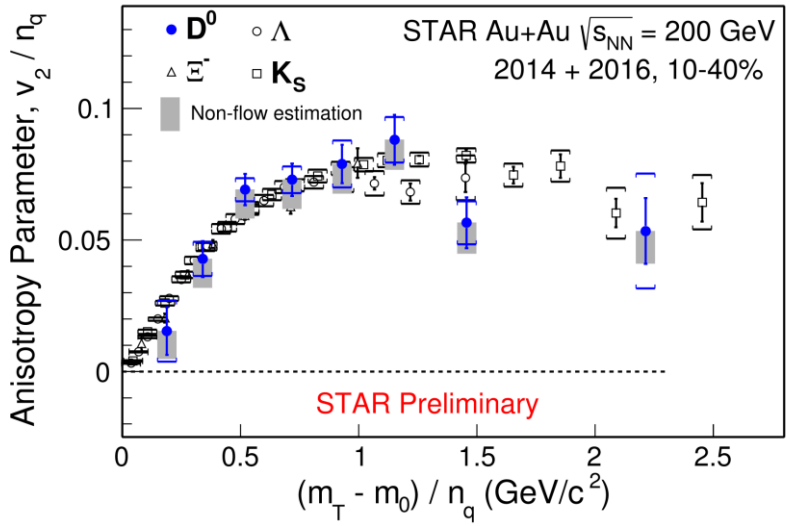


Kaons (STAR): PRL 120, 062301 (2018).

D^0 ELLIPTIC FLOW

- Non-zero elliptic flow (v_2) of D^0
  - Strong collective behavior of charm quarks
- As a function of p_T
  - Mass ordering for $p_T < 2$ GeV/c
  - Comparable to light mesons for $p_T > 2$ GeV/c
- As a function of $(m_T - m_0)/n_q$
  - Follows Number of Constituent Quarks (NCQ) scaling
- **Suggests that c quarks might have achieved thermal equilibrium with the QGP**

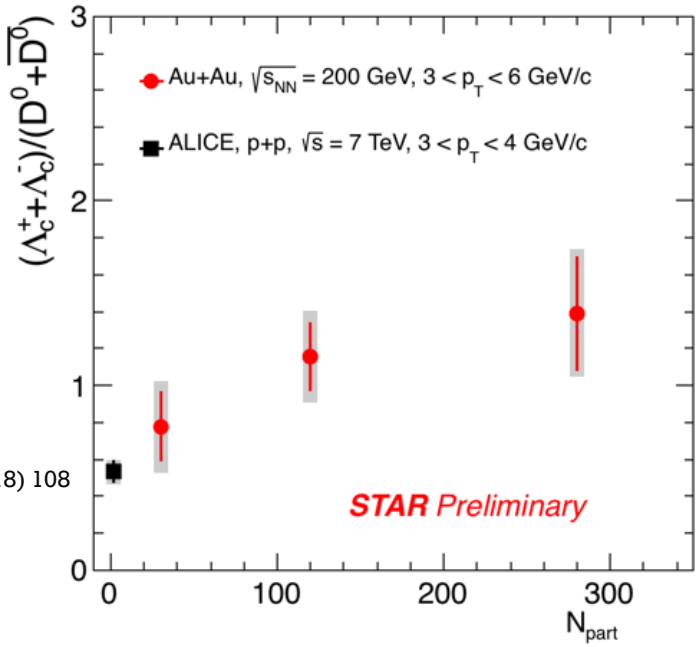




OPEN-CHARM BARYON/MESON RATIO

CENTRALITY DEPENDENCE

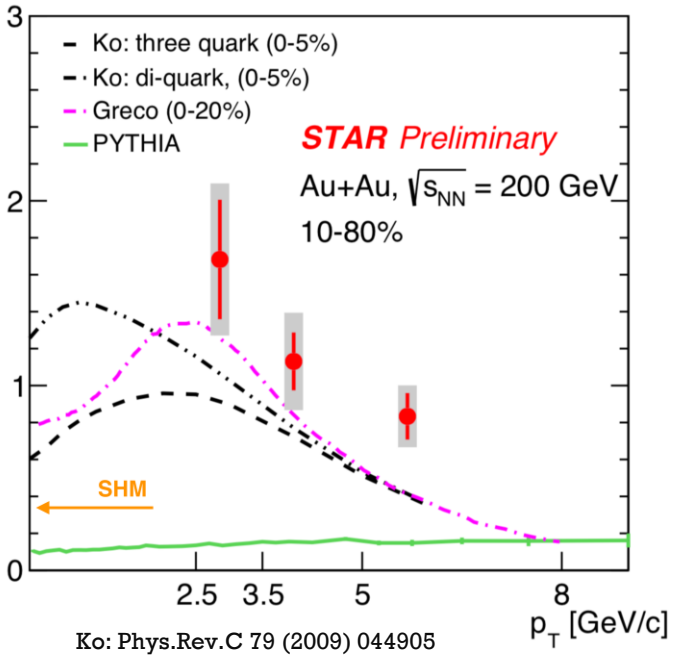
- Enhancement of the ratio increases towards central collisions
- The value in peripheral collisions is consistent with p+p measurement at $\sqrt{s} = 7$ TeV by ALICE



ALICE: JHEP 04 (2018) 108

p_T DEPENDENCE

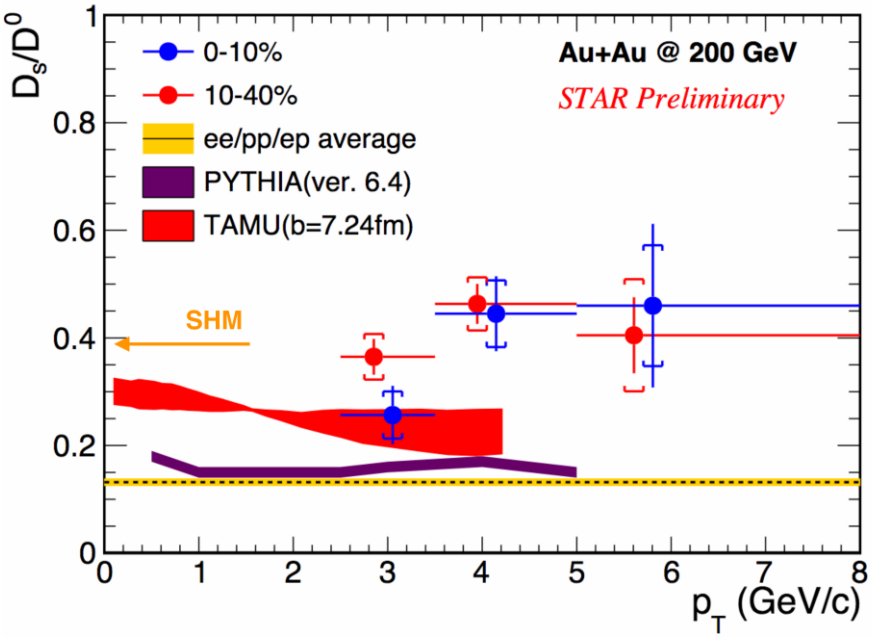
- Strong enhancement towards low p_T
- Coalescence models closer to data than PYTHIA
- SHM underpredicts data



Ko: Phys.Rev.C 79 (2009) 044905
Greco: Eur.Phys.J.C (2018) 78:348
SHM: Phys.Rev.C 79 (2009) 044905

D_s/D^0 ENHANCEMENT

- D_s/D^0 ratio as a function of p_T
- Enhancement of D_s/D^0 ratio in Au+Au collisions with respect to PYTHIA and elementary collisions (ee/pp/ep)
  - Strangeness enhancement
  - Coalescence hadronization
- Comparison to models:
  - TAMU underpredicts measurements
  - Reasonable agreement with SHM



ep/pp/ep avg: EPJ C 76, 397 (2016)
TAMU: PRL 110, 112301 (2013)
SHM: Phys.Rev.C 79 (2009) 044905

CONCLUSION

- STAR has extensively studied production of open-charm hadrons in heavy-ion collisions
  - Outstanding spatial resolution of the STAR HFT allows precise measurements of open-charm hadrons
  - Presented results provide significant constraints on model calculations
- D^0 and $D^{\pm}$ mesons are significantly suppressed in central Au+Au collisions
  - Important for understanding charm quark energy loss in the QGP
- D^0 mesons have larger v_1 slope than light-flavor mesons
  - Can probe initial tilt of the bulk
- D^0 mesons have v_2 comparable to light-flavor hadrons
  - c quarks are possibly in thermal equilibrium with the medium
- Λ_c/D^0 and D_s/D^0 enhancements in Au+Au collisions with respect to p+p collisions
  - Important for understanding hadronization process
  - Importance of coalescence

THANK YOU FOR ATTENTION

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