Measurements of open-charm hadrons in heavy-ion collisions by the STAR Experiment

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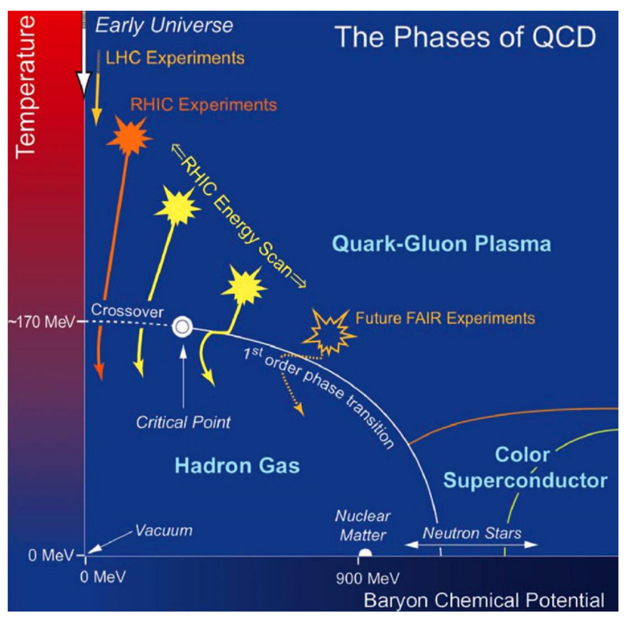
Abstract

Charm quarks are primarily produced at early stages of ultra-relativistic heavy-ion collisions and can therefore probe the Quark-Gluon Plasma (QGP) throughout its whole evolution. Transverse momentum spectra and azimuthal anisotropies of open-charm hadrons are commonly used to experimentally study the charm quark interaction with the QGP. Thanks to the precise vertex reconstruction provided by the Heavy Flavor Tracker (HFT), STAR is able to directly reconstruct $D^{\pm}$, D^0, $D_s^{\pm}$, and $\Lambda_c^{\pm}$ via their hadronic decay channels. The topological cuts for signal extraction are optimized using multivariate analysis and supervised machine learning techniques. In this poster, we show an overview of recent open charm results from the STAR experiment. In particular, the nuclear modification factors of open-charm mesons, together with $D_s^{\pm}/D^0$ and $\Lambda_c^{\pm}/D^0$ ratios as functions of transverse momentum and collision centrality are presented.

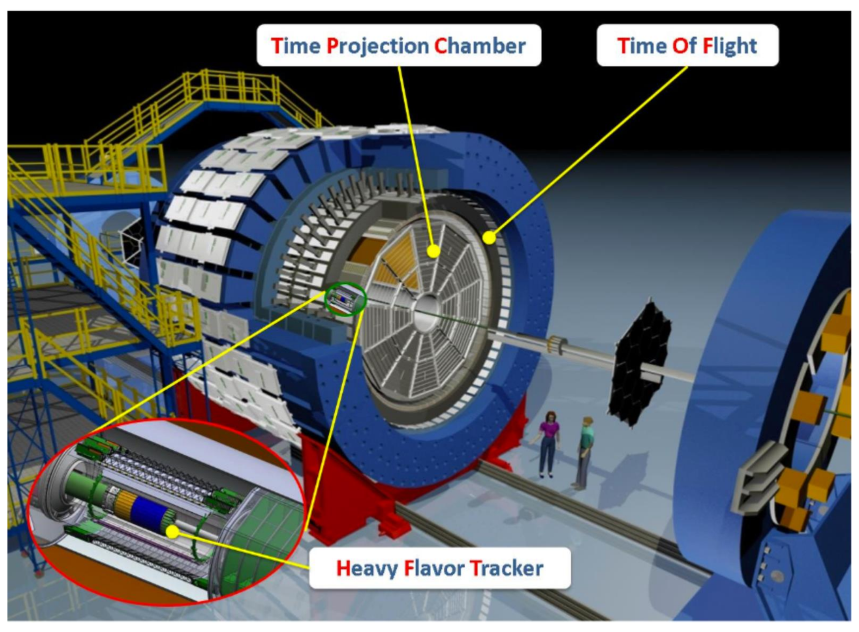
Physics Motivation

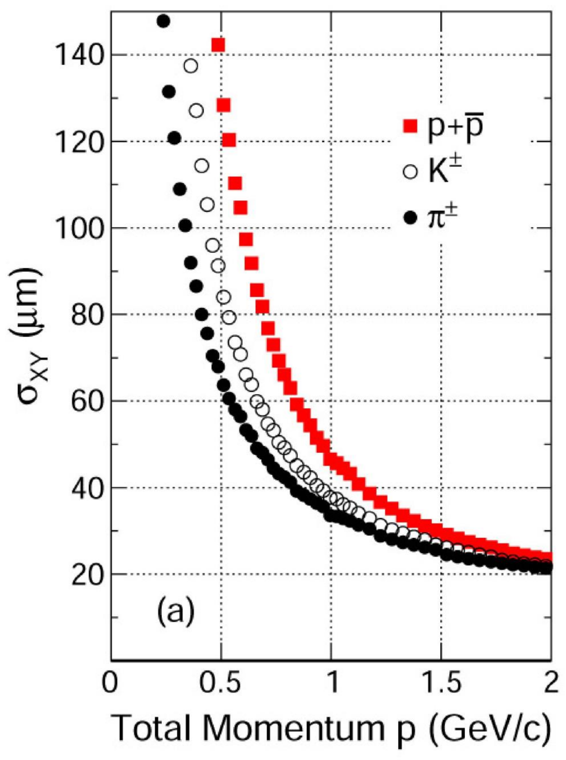
- Heavy-ion collisions are used to explore the phase diagram and properties of the nuclear matter.
- Charm quarks are created dominantly at early stages of A+A collisions at RHIC, before creation of the QGP fireball.
- Charm quarks lose energy and gain collective flow as they pass through and interact with the QGP medium
- They are an ideal probe of the QGP.



STAR Detector

- STAR is an experiment designed primarily to study properties of strongly-interacting matter and proton spin structure.
- **Time Projection Chamber** (TPC) and **Time Of Flight** (TOF)
  - Particle momentum (TPC) and identification (TPC and TOF)
- **Heavy Flavor Tracker** (HFT) is a 4-layer silicon detector used for precise topological reconstruction of heavy-flavor hadrons decays [1].
  - Pixel detectors – 2 layers, Strip detectors – 2 layers





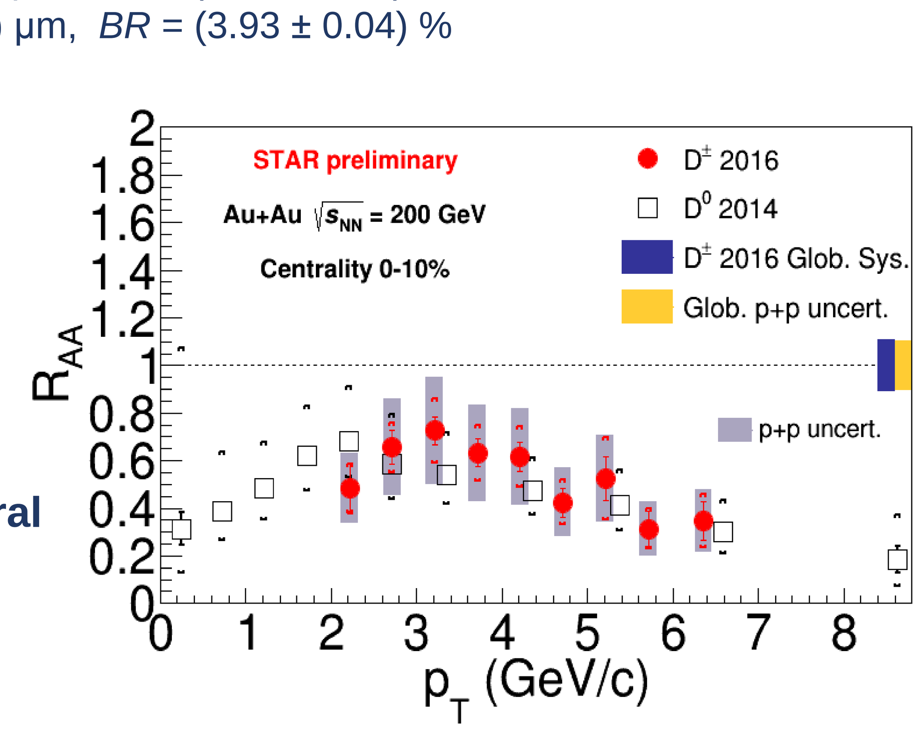
D^0 and $D^{\pm}$ Nuclear Modification Factor

- Decay channels used:
  - $D^+ \to K^-\pi^+\pi^+$ $c\tau = (311.8 \pm 2.1)$ μm, $BR = (8.98 \pm 0.28)$ %
  - $D^0 \to K^-\pi^+$ $c\tau = (122.9 \pm 0.4)$ μm, $BR = (3.93 \pm 0.04)$ %
- Nuclear modification factor:

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

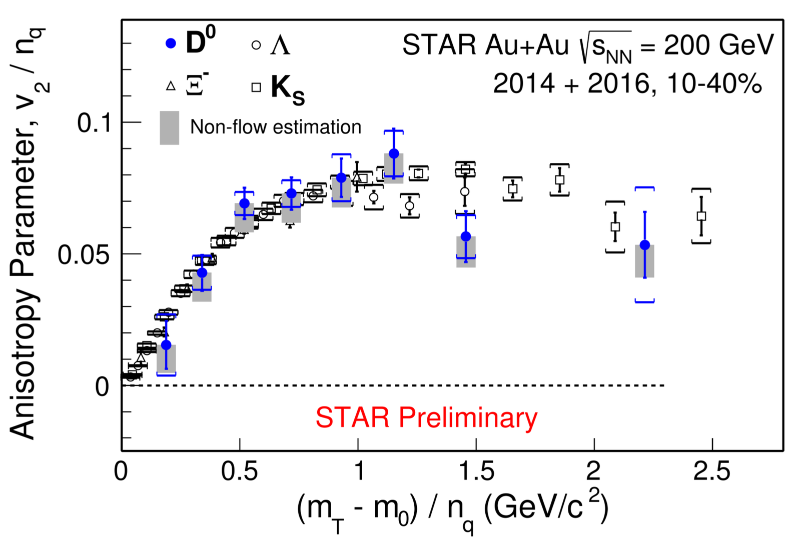
$\langle N_{coll}\rangle$ is the mean no. of binary collisions from Glauber model

- dN^{pp}/dp_T from combined D^0 and D^* measurement in 200 GeV p+p collisions [2].
- **$D^{\pm}$ and D^0 [3] suppressed in central Au+Au collisions.**
- Similar level of suppression for $D^{\pm}$ and D^0.



D^0 Elliptic Flow

- Large elliptic flow (v_2) of D^0
  - Comparable to that of light-flavor hadrons
- Charm quarks follow the Number of Constituent Quarks (NCQ) scaling
- **Suggests strong interactions of the charm quarks with the QGP and that charm quarks acquire similar flow as light flavor quarks**



D^0 Directed Flow

- Predicted contributions:
  - Hydrodynamics
    - Mismatch between the tilt of the bulk and the longitudinal density profile of charm quark production
    - Predicts significantly larger v_1 for charm hadrons than for light-flavor hadrons [4]
  - Initial EM field from passing spectators
    - May lead to opposite slopes for D^0 and $\overline{D^0}$ [5] with respect to rapidity
- First evidence of large directed flow (v_1) of D^0 and $\overline{D^0}$
  - Negative v_1 slope for both D^0 and $\overline{D^0}$ with respect to rapidity
  - **Approximately 20 times larger v_1 for D^0 than for kaons [6].**
  - Insufficient precision to conclude about the EM induced splitting

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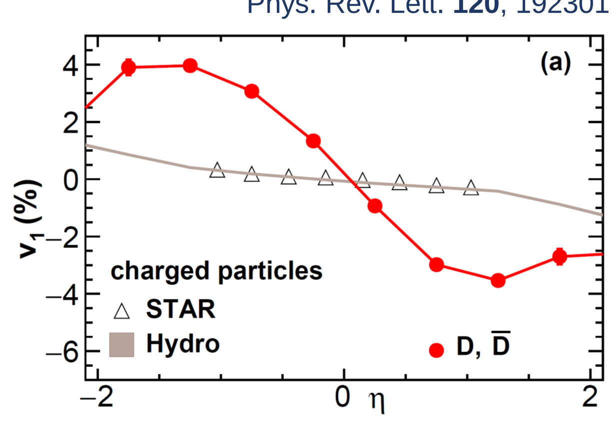
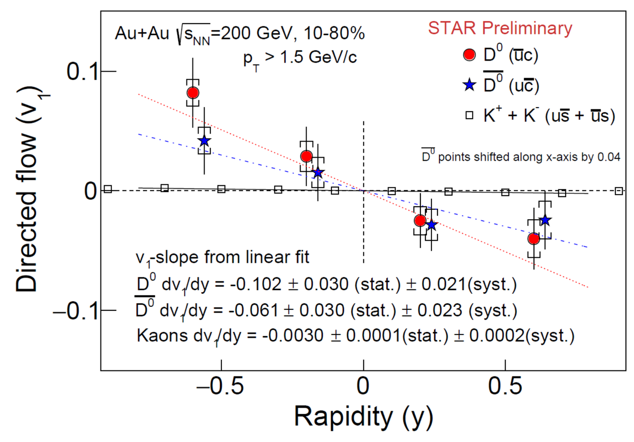




Open-charm Baryon/Meson Ratio

Decay channel used:

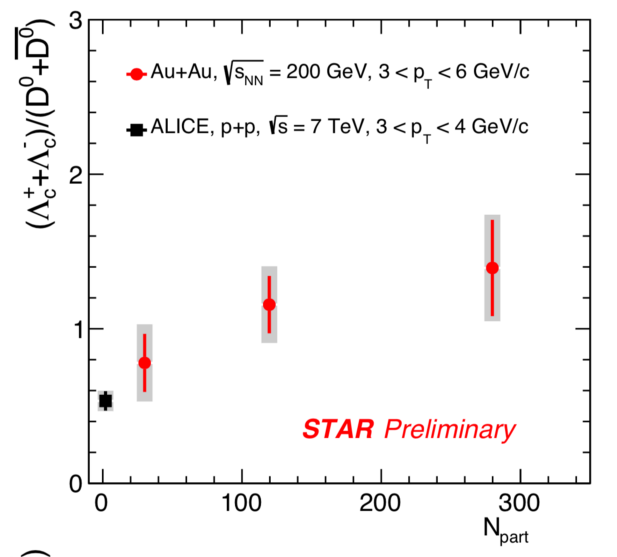
- $\Lambda_c^+ \to K^-\pi^+p$, $c\tau = (59.9 \pm 1.8)$ μm, $BR = (6.35 \pm 0.33)$ %

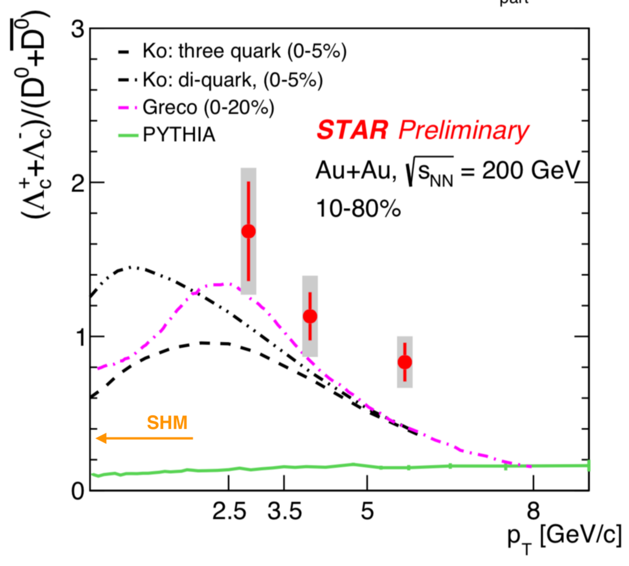
Centrality Dependence:

- Enhancement of the $\Lambda_c^{\pm}/D^0$ ratio increases towards central collisions
- The value in peripheral collisions is close to p+p measurement at $\sqrt{s} = 7$ TeV by ALICE [6]

Transverse momentum dependence:

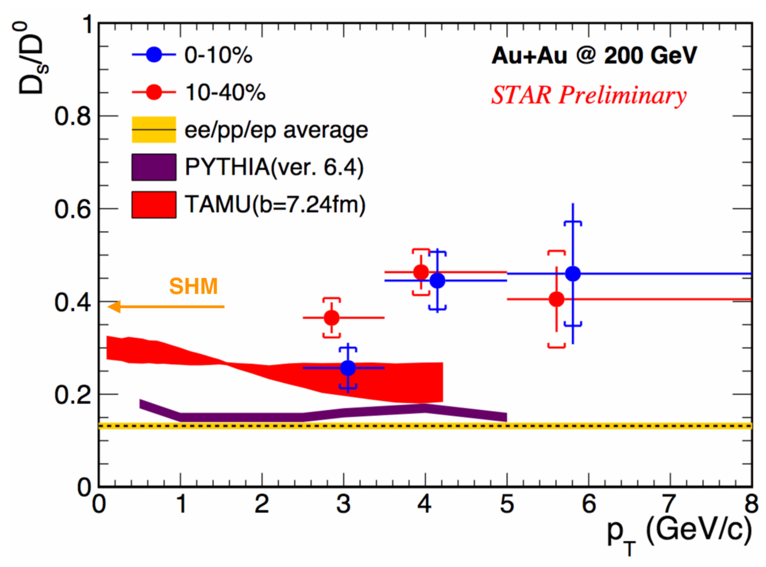
- Strong enhancement of the $\Lambda_c^{\pm}/D^0$ ratio compared to PYTHIA calculations
- Coalescence model calculations [7,8] closer to data
- Statistical Haronization Model (SHM) [9] underpredicts data
- **Λ_c/D^0 ratio shows significant enhancement in Au+Au collisions with respect to PYTHIA**





D_s/D^0 Enhancement

- Decay channel used:
  - $D_s^+ \to \phi\pi^+$, $\phi \to K^-K^+$, $c\tau = (149.9 \pm 2.1)$ μm $BR = (2.27 \pm 0.08)$ %
- Enhancement of D_s/D^0 ratio in Au+Au collisions with respect to PYTHIA and elementary collisions (ee/pp/ep) [10]
  - TAMU [11] underpredicts measurements
  - Reasonable agreement with the SHM [9]
- **D_s/D^0 is enhanced in Au+Au collisions possibly due to strangeness enhancement and coalescence hadronization**



Conclusion

- STAR has extensively studied production of open-charm hadrons in heavy-ion collisions.
- D^0 and $D^{\pm}$ mesons are significantly suppressed in central Au+Au collisions.
- D^0 mesons have large v_1 with negative slope.
- D^0 mesons have v_2 comparable to light-flavor hadrons and seem to follow the NCQ scaling.
- Λ_c/D^0 and D_s/D^0 enhancements in Au+Au collisions with respect to p+p collisions.

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