Measurement of $D^{\pm}$ meson production in Au+Au collisions at $\sqrt{s_{NN}}$=200 GeV with the STAR experiment

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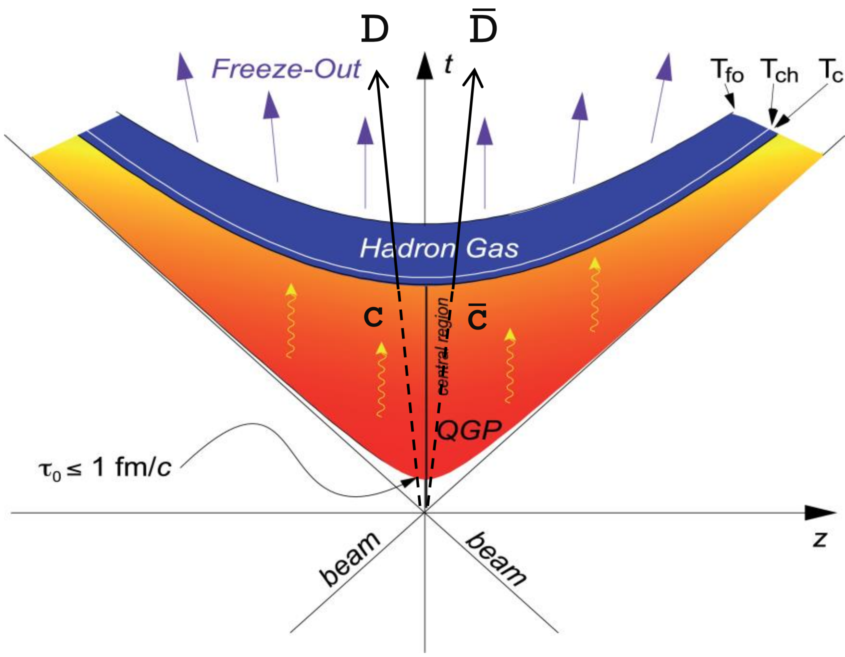
PHYSICS MOTIVATION

- **Quark-Gluon Plasma** (QGP) can be studied using relativistic heavy-ion collisions
- At RHIC energies, **charm quarks** are produced predominantly through hard partonic scatterings at **early stage** of Au+Au collisions
  - They experience **the whole evolution of the medium**
- **Charm quark energy loss** in the medium can be studied by measurement of open-charm meson nuclear **modification factor R_{AA}**



D^0 NUCLEAR MODIFICATION FACTOR

- Nuclear modification factor:

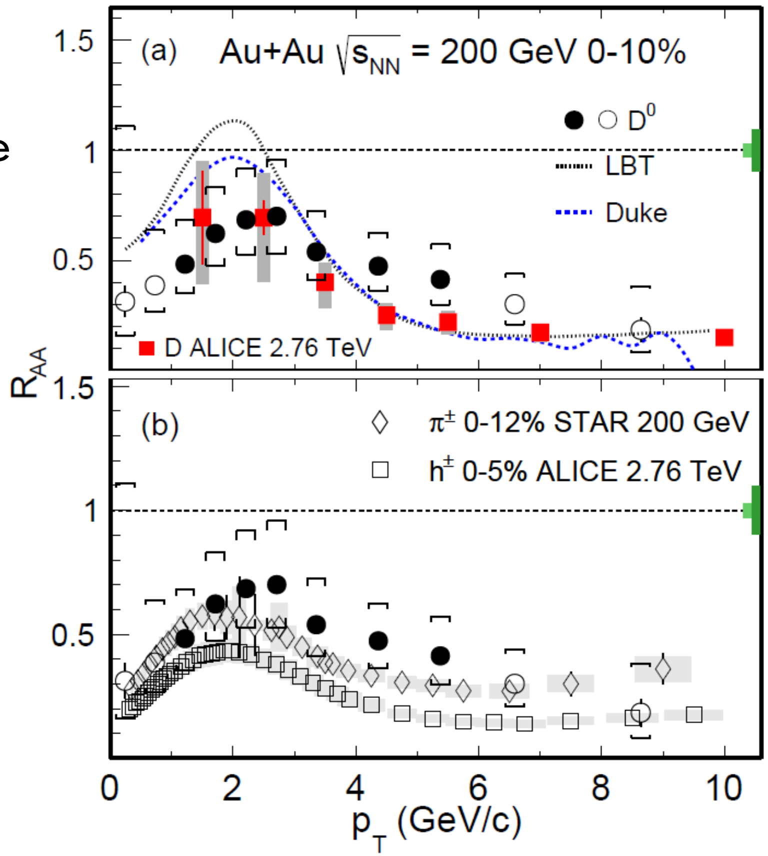
$$R_{AA}(p_T) = \frac{dN_D^{AA}/dp_T}{\langle N_{coll}\rangle\, dN_D^{pp}/dp_T}$$

- D^0 mesons suppressed in central Au+Au collisions
  - Strong interactions between charm quarks and the medium
  - Suppression of D^0 mesons comparable to light flavor hadrons at RHIC and D mesons at LHC
  - Reproduced by models incorporating both radiative and collisional energy losses, and collective flow

- **Measurement of $D^{\pm}$ is complementary to that of D^0**
  - **Independent cross-check of the D^0 measurement**
  - **Important contribution to total charm cross-section**
  - **Three-body decay, larger decay length than D^0**

D^0 (STAR): Phys. Rev. C 99, 034908, (2019).
$\pi^{\pm}$ (STAR): Phys. Lett. B 655, 104, (2007).
D (ALICE): JHEP 03, 081, (2016).
$h^{\pm}$ (ALICE): Phys. Lett. B 720, 52, (2013).

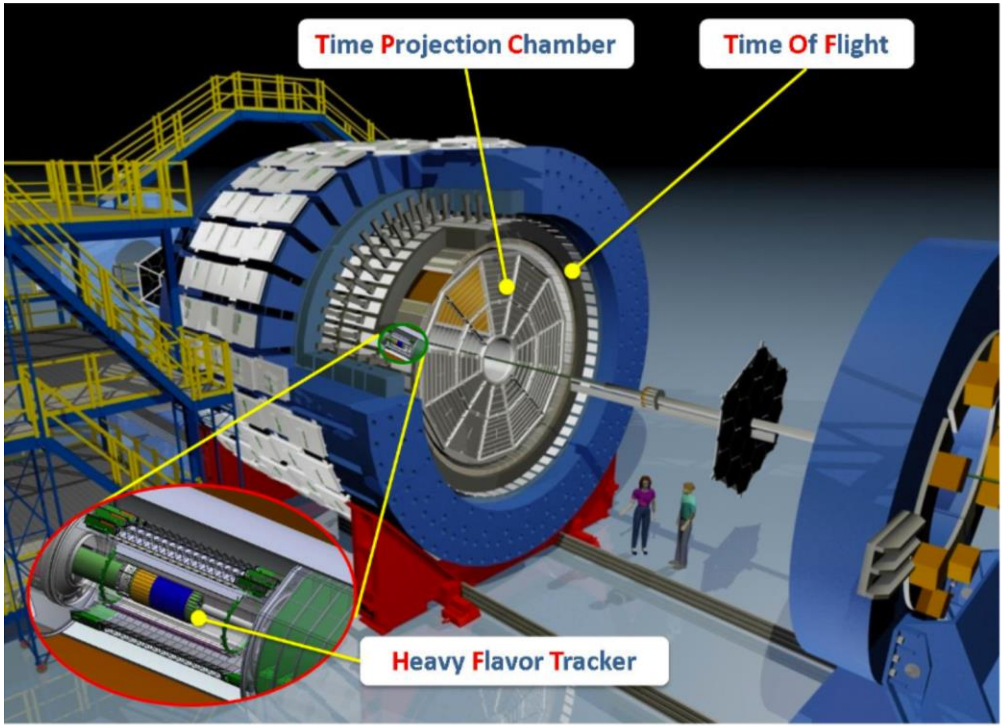
LBT (S. Cao *et al.*): Phys. Rev. C 94, 014909, (2016).
Duke (Y. Xu *et al.*): Phys. Rev. C 97, 014907, (2018).

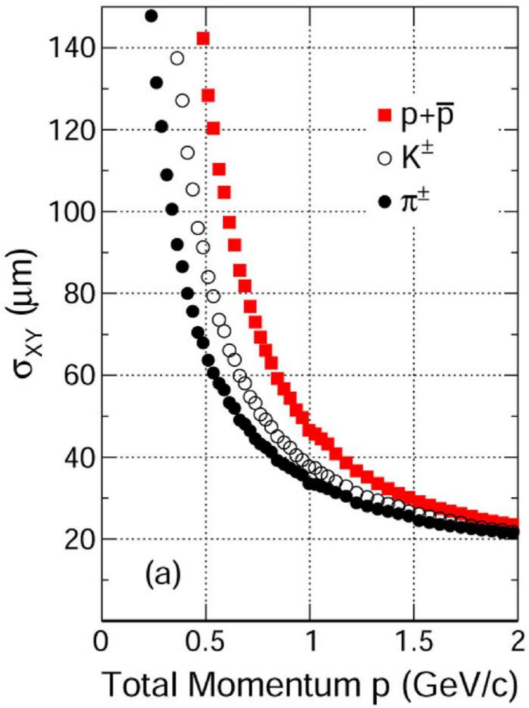


STAR DETECTOR

- **S**olenoidal **T**racker **A**t **R**HIC
- **H**eavy **F**lavor **T**racker (HFT, 2014–2016) is a 4-layer silicon detector
  - MAPS – 2 innermost layers (PXL1, PXL2), Strip detectors – 2 outer layers (IST, SSD)
- **T**ime **P**rojection **C**hamber (TPC) and **T**ime **O**f **F**light (TOF)
  - Particle momentum (TPC) and identification (TPC and TOF)

STAR: PRL 118, 212301, (2017)



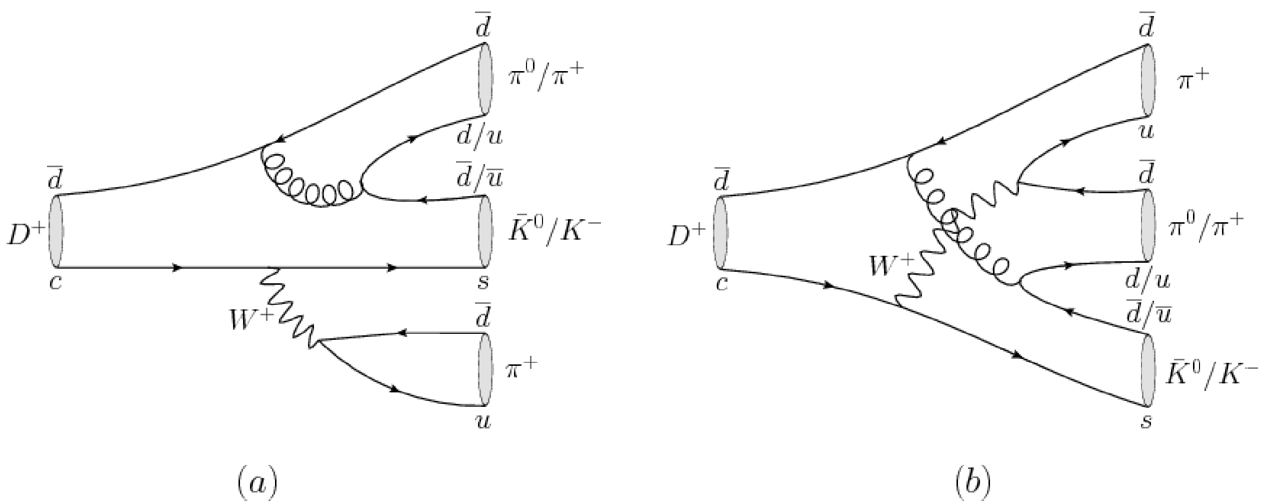


D$^\pm$ MEASUREMENTS WITH THE HFT

- Data used in this analysis are from 2014 and 2016 for Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV

- Total of ca. 2.3B good minimum bias events after event selection

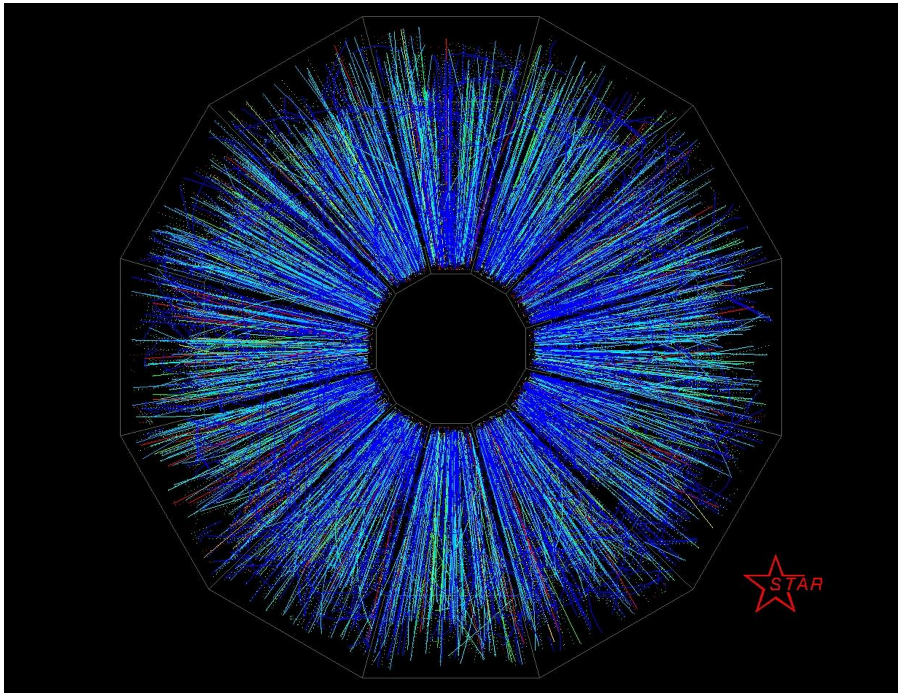
- The HFT allows direct topological reconstruction of D$^\pm$ mesons through their hadronic decay
  - $D^\pm \rightarrow K^\mp \pi^\pm \pi^\pm$ $\quad$ $c\tau = (311.8 \pm 2.1)\ \mu m$ $\quad$ $BR = (8.98 \pm 0.28)\ \%$



F. Niecknig, B. Kubis: JHEP 1510, 142, (2015)

EVENT AND TRACK SELECTION, PID

- **Event selection**
  - Position of primary vertex along the beam axis
- **Track selection**
  - Low p_T cut – suppresses combinatorial background from low-p_T particles
  - $|\eta| < 1$ – detector acceptance
  - Minimum number of hits in the TPC for each track – good track quality
  - At least three hits in HFT, one in PXL1, one in PXL2 and at least one in IST or SSD
- **Particle identification (PID)**
  - TPC – energy loss of charged particles in the TPC gas
  - TOF – velocity of the charged particles
- **Topological selection criteria**
  - Possible only with use of the HFT
  - Constrain topology of the reconstructed secondary vertex
  - Suppress combinatorial background
  - Optimized using TMVA



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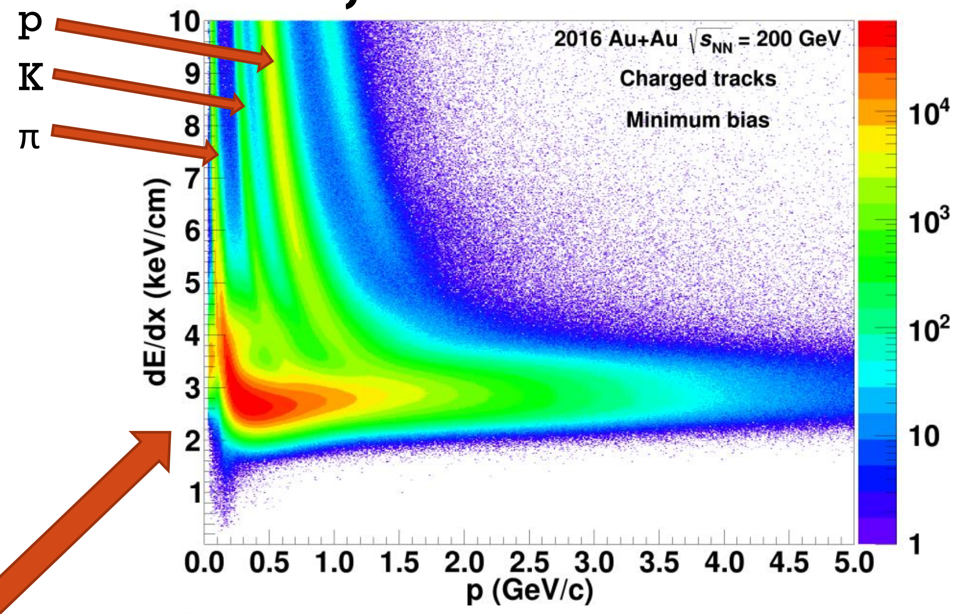

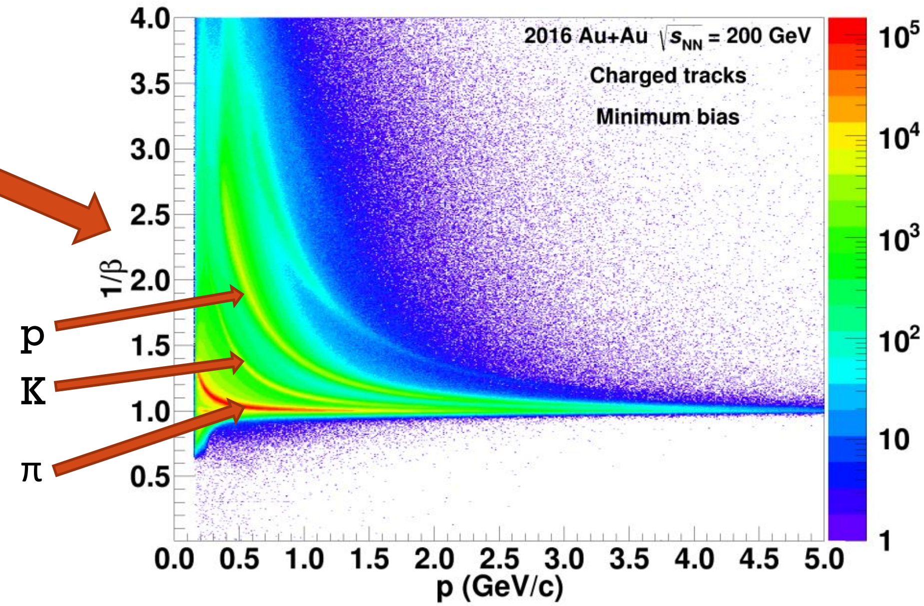

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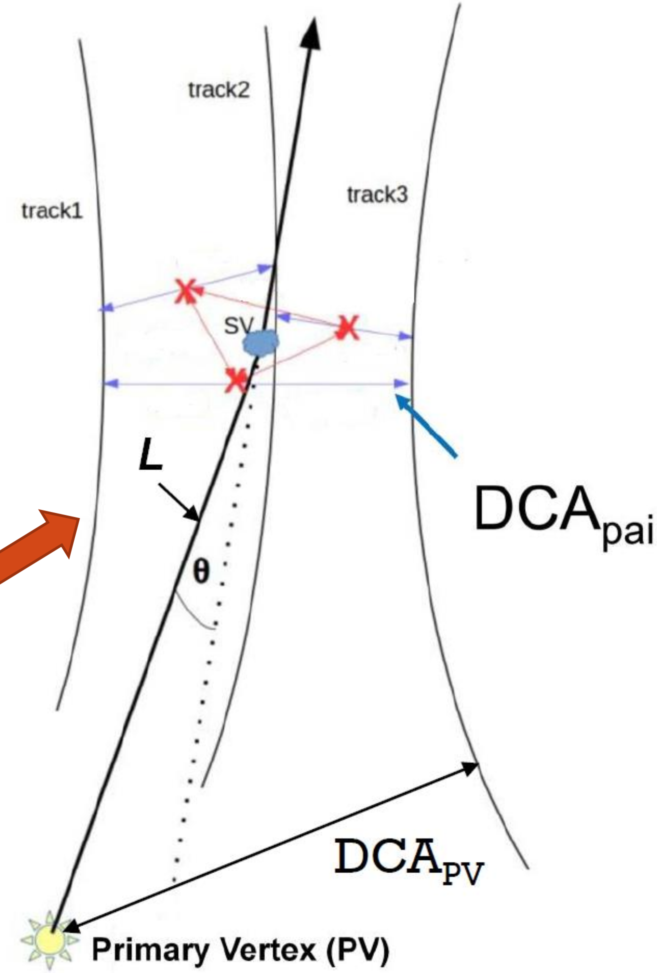
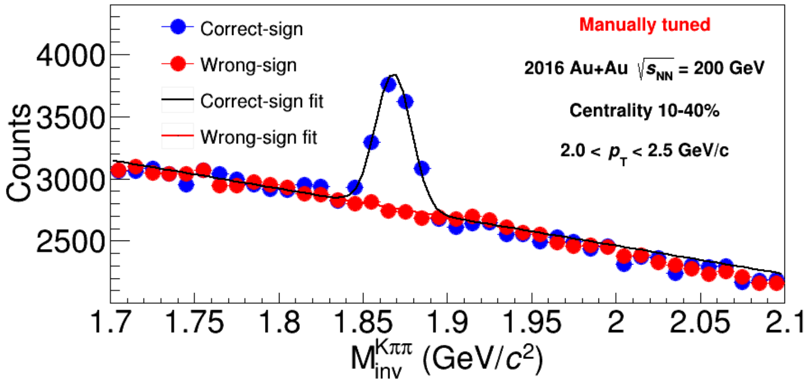
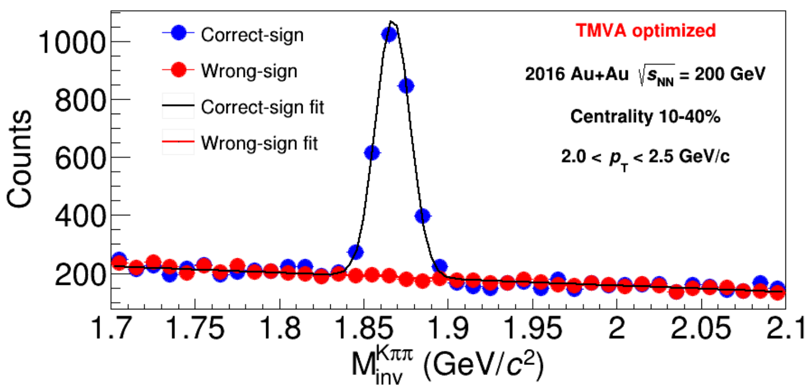
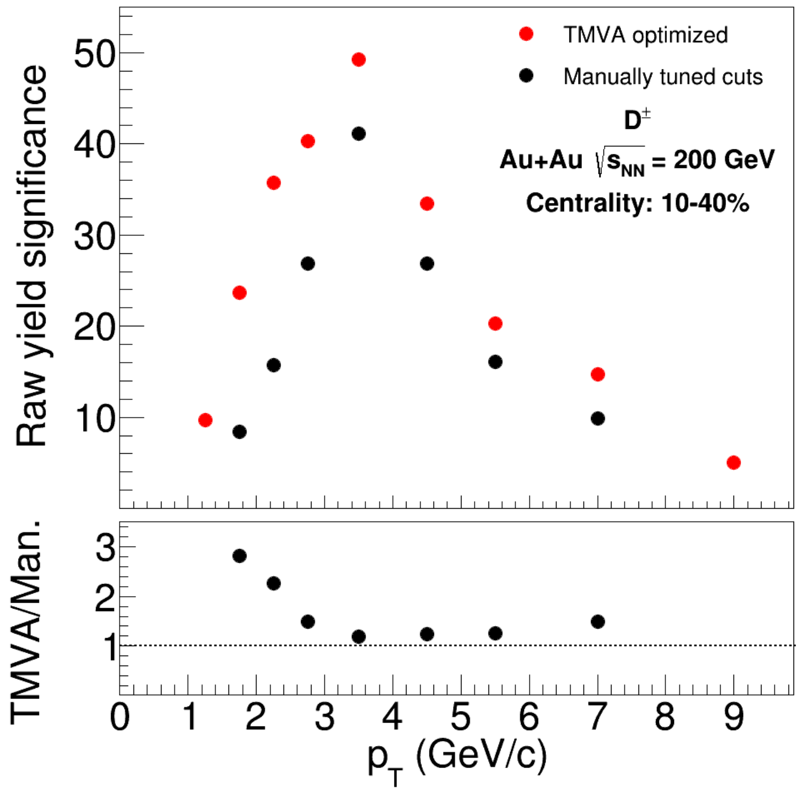


D± RAW YIELD EXTRACTION

- Raw yield extracted from invariant mass spectra of Kππ triplets
  - Significant background suppression with TMVA optimization of the topological selection criteria
  - Improved signal significance







$D^{\pm}$ INVARIANT SPECTRUM

- Invariant yield is calculated according to:

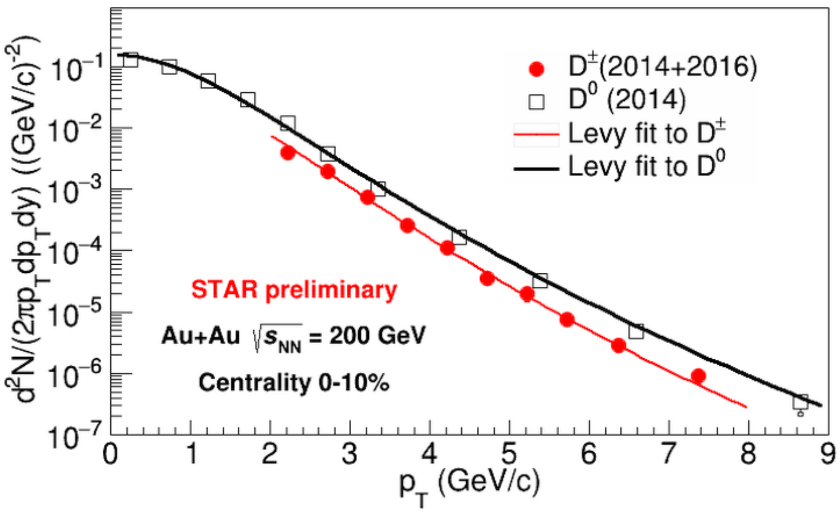
$$\frac{\mathrm{d}^2 N}{2\pi p_{\mathrm{T}}\,\mathrm{d}p_{\mathrm{T}}\mathrm{d}y} = \frac{Y_{\mathrm{raw}}}{2\,\pi\,N_{\mathrm{evt}}\,BR\,p_{\mathrm{T}}\Delta p_{\mathrm{T}}\Delta y\,\varepsilon(p_{\mathrm{T}})}$$

- Y_{raw} = raw yield, N_{evt} = number of events, BR = branching ratio, $\varepsilon(p_{\mathrm{T}})$ = total $D^{\pm}$ reconstruction efficiency

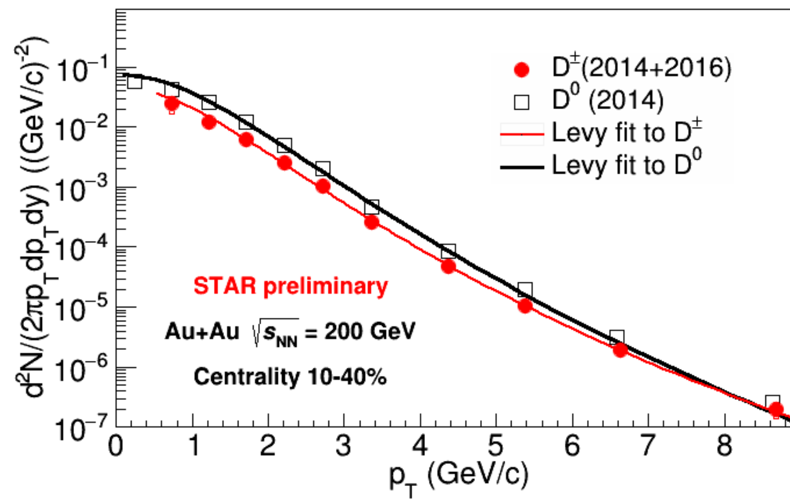
- **Collision centrality classes: 0-10%, 10-40%, 40-80%**
  - Determined from charged track multiplicity in TPC matched to Glauber model simulation

$D^{\pm}$ INVARIANT SPECTRUM

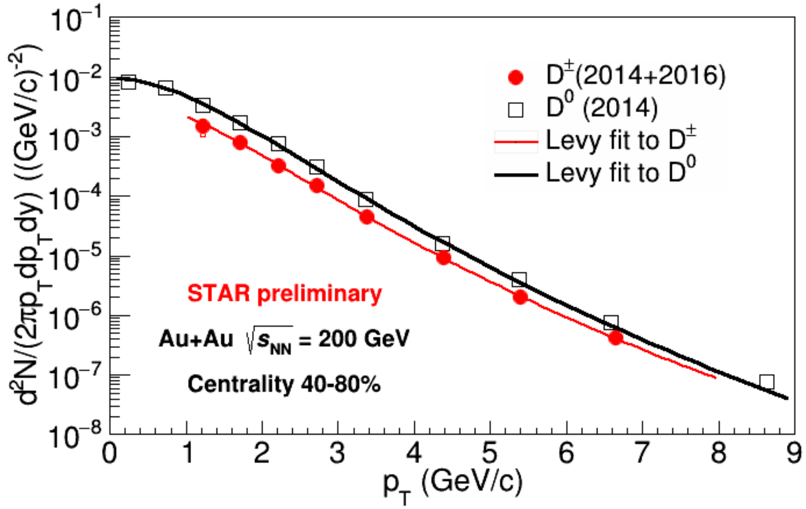
0-10%



10-40%



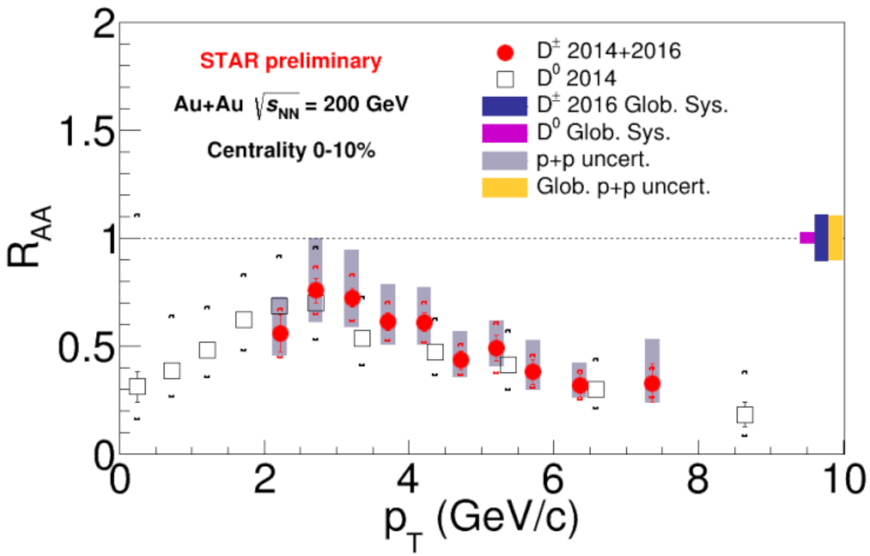
40-80%

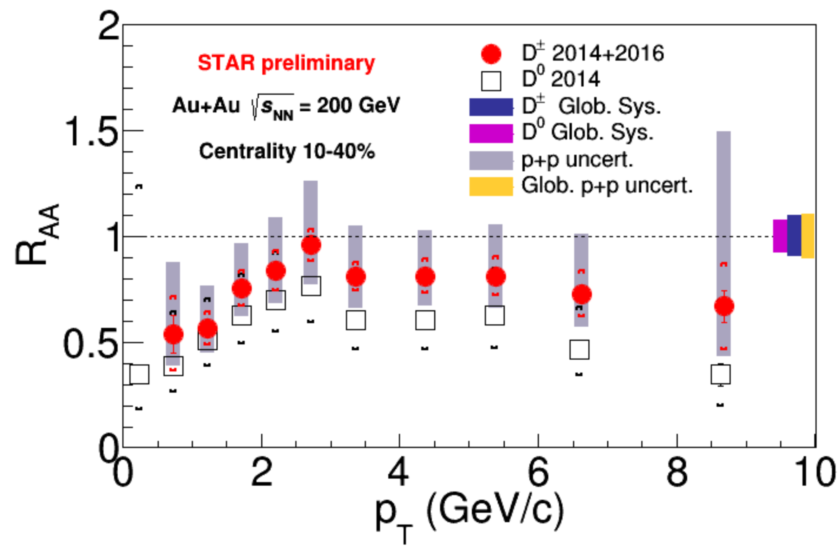


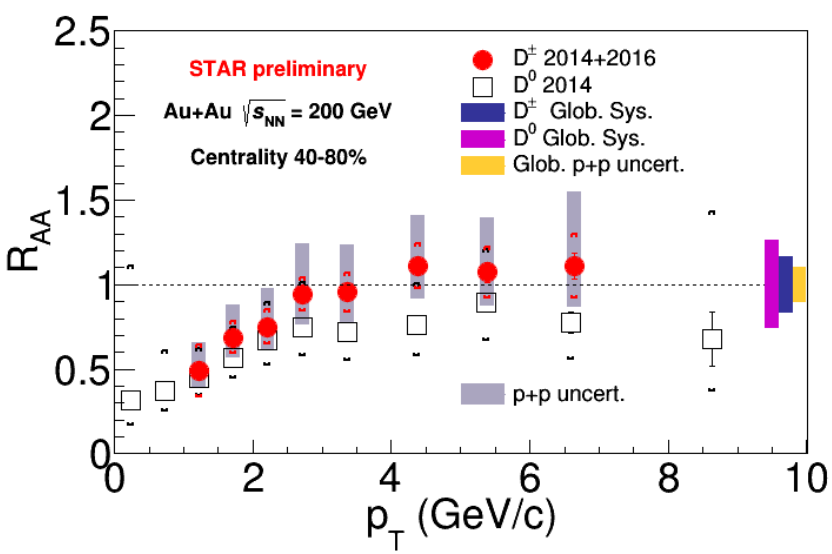
D^0 (STAR): Phys. Rev. C 99, 034908, (2019).

- Invariant spectra of $D^{\pm}$ and D^0 mesons measured in Au+Au collisions at $\sqrt{s_{NN}}$=200 GeV
- Spectra are fitted by Levy function
- The $D^{\pm}$ results help to constrain the total open charm cross-section and for better understanding of charm quark hadrochemistry in Au+Au collisions

$D^{\pm}$ NUCLEAR MODIFICATION FACTOR





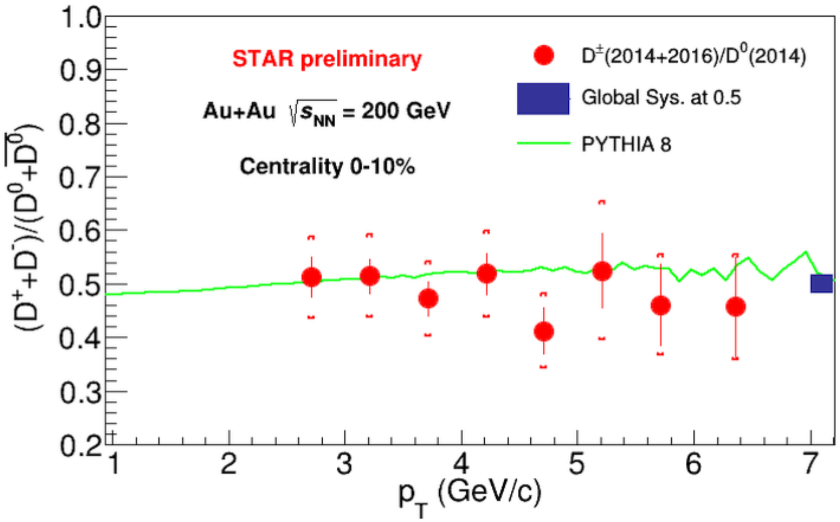


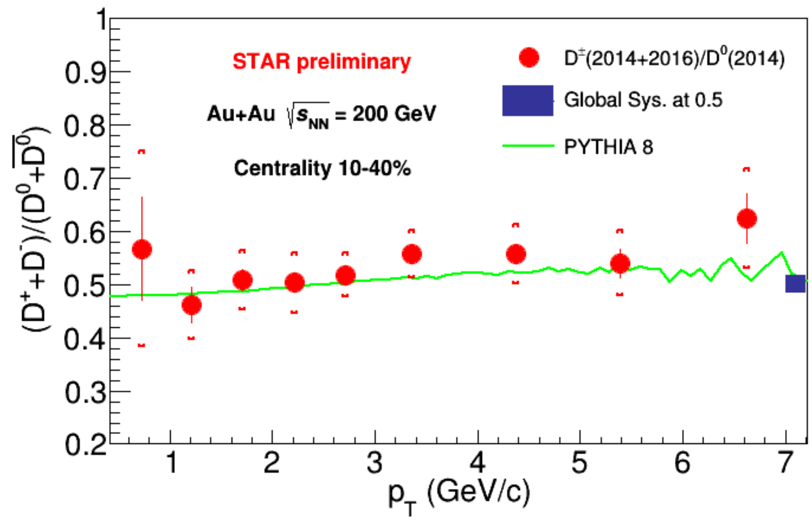
- Reference: combined D^0 and D* measurement in 200 GeV p+p collisions using 2009 data
- Similar level of suppression and centrality dependence for $D^{\pm}$ and D^0
- High-p_T $D^{\pm}$ and D^0 suppressed in central Au+Au collisions
  - Strong interactions between charm quarks and the medium

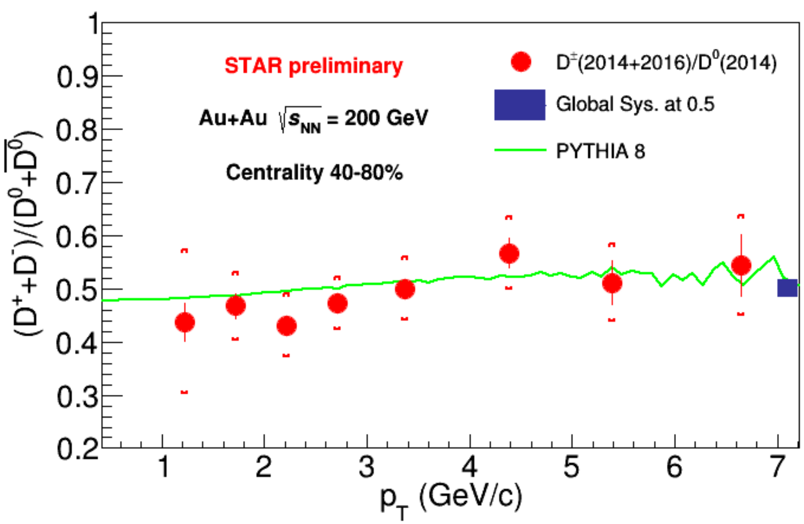
p+p reference (STAR): Phys. Rev. D 86, 072013, (2012)

D^0 (STAR): Phys. Rev. C 99, 034908, (2019).

$D^{\pm}/D^0$ YIELD RATIO







- The $D^{\pm}/D^0$ yield ratio is compared to PYTHIA 8 calculation
  - Good agreement in all Au+Au centrality classes

- No modification of the $D^{\pm}/D^0$ yield ratio compared to PYTHIA

CONCLUSION

- STAR has extensively studied production of open-charm mesons in Au+Au collisions at $\sqrt{s_{\mathrm{NN}}}$=200 GeV utilizing the Heavy-Flavor Tracker

- The HFT allows direct topological reconstruction of hadronic decays of open-charm mesons

- $D^{\pm}$ invariant spectrum measured for three centrality classes of Au+Au collisions
  - 0-10%, 10-40%, 40-80%

- $D^{\pm}$ nuclear modification factor is consistent with that of D^0
  - D^0 and $D^{\pm}$ mesons are significantly suppressed at high-p_{T} in central Au+Au collisions
  - Charm quarks interact strongly with the QGP

- $D^{\pm}/D^0$ yield ratio
  - Agrees with PYTHIA 8 calculation

THANK YOU FOR ATTENTION

Acknowledgement: This research is funded by the project LTT18002 of the Ministry of Education, Youth, and Sport of the Czech Republic

16 BACKUP

EVENT AND TRACK SELECTION, PID

- Example of analysis cuts for $D^{\pm}$ reconstruction using the HFT
- Event selection
  - Position of primary vertex along the beam axis
- Track selection
  - p_T – suppresses combinatorial background from low-p_T particles
  - nHitsFit – large number of TPC hits used for track reconstruction to ensure good track quality
  - Hit in at least three layers of the HFT
- PID: HFT+TPC+(TOF)
  - Hybrid TOF = use TOF only for tracks with valid TOF information
- Topological selection criteria
  - Possible only with use of the HFT
  - Constrain topology of the reconstructed secondary vertex
  - Suppress combinatorial background
  - Optimization using the TMVA

Event selection		$\lvert V_z \rvert < 6$ cm
		$\lvert V_z - V_{z(VPD)} \rvert < 3$ cm
Track selection		$p_T > 300$ MeV/c (500 MeV/c)
		$\lvert \eta \rvert < 1$
		nHitsFit > 20
		nHitsFit/nHitsMax > 0.52
		HFT track = PXL1+PXL2+(IST or SSD)
PID cuts	TPC	$\lvert n\sigma_{\pi} \rvert < 3$
		$\lvert n\sigma_{K} \rvert < 2$
	Hybrid TOF	$\lvert 1/\beta - 1/\beta_{\pi} \rvert < 0.03$
		$\lvert 1/\beta - 1/\beta_{K} \rvert < 0.03$
Topological selection criteria		DCA_{pair}
		$L_{D\pm}$
		$\cos(\theta)$
		$DCA_{\pi\text{-}PV}$
		$DCA_{K\text{-}PV}$