Measurements of Charm Quark Interaction with the QGP in Heavy-Ion collisions at STAR

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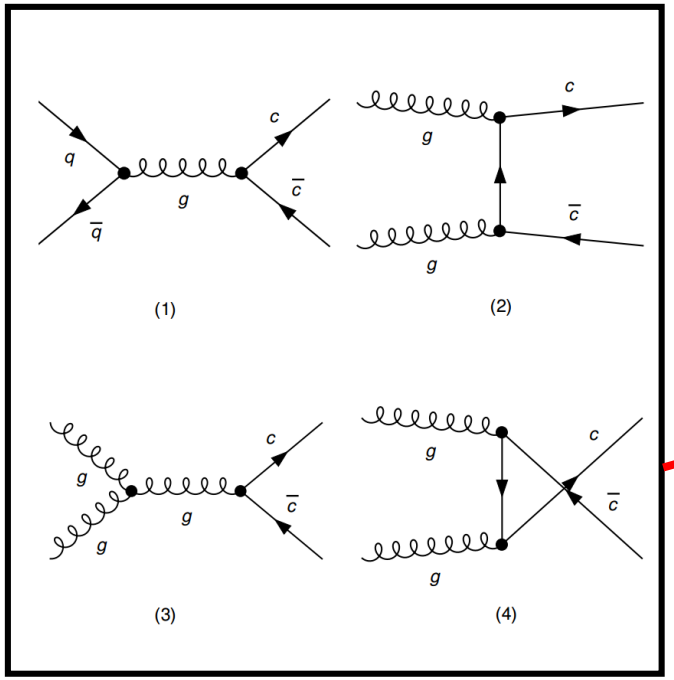
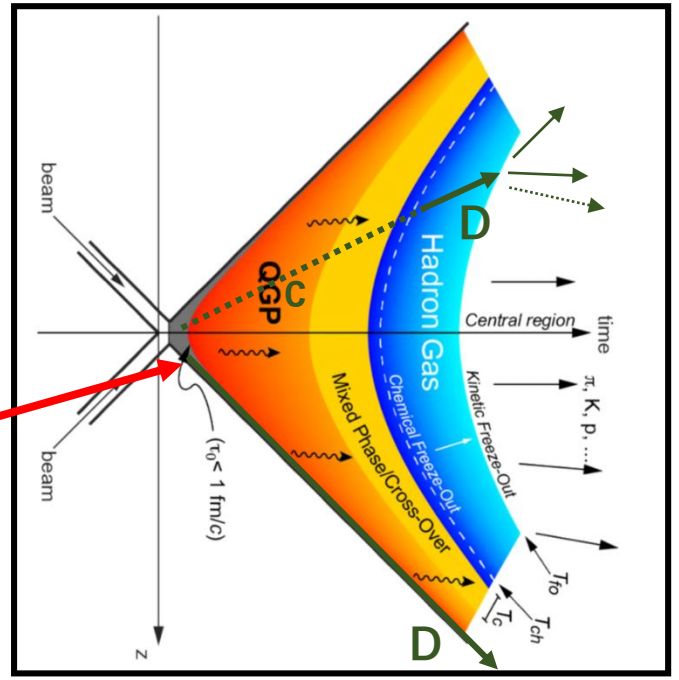
Supported in part by
U.S. DEPARTMENT OF ENERGY | Office of Science

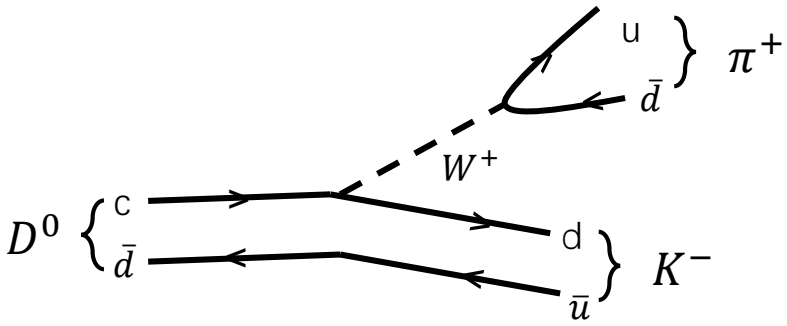
Open heavy-flavour produciton



< 1 fm/c, initial partonic hard scattering



$m_c > \Lambda_{QCD}$, an ideal probe with a high probability of penetrating QGP



Γ_i/Γ ~ 3.9%

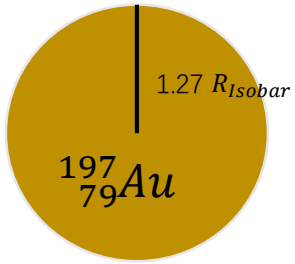
Open heavy-flavour production offers **a unique insight** into heavy-ion physics:

- Production is essentially restricted to **initial hard scatterings** (mainly gluon fusion) and **carry a "memory"** of the interaction history with sQGP
- Consistent with the theoretical calculation (**pQCD in p+p collisions**) and partons have energy loss in the medium
  - Gluon radiation (dead cone effect; suppressed at $\theta < m_Q/E_Q$)
  - Collisional energy loss (**Brownian motion**)
- The **nuclear modification factor** R_{AA} of heavy hadrons can be used to measure the nuclear effect

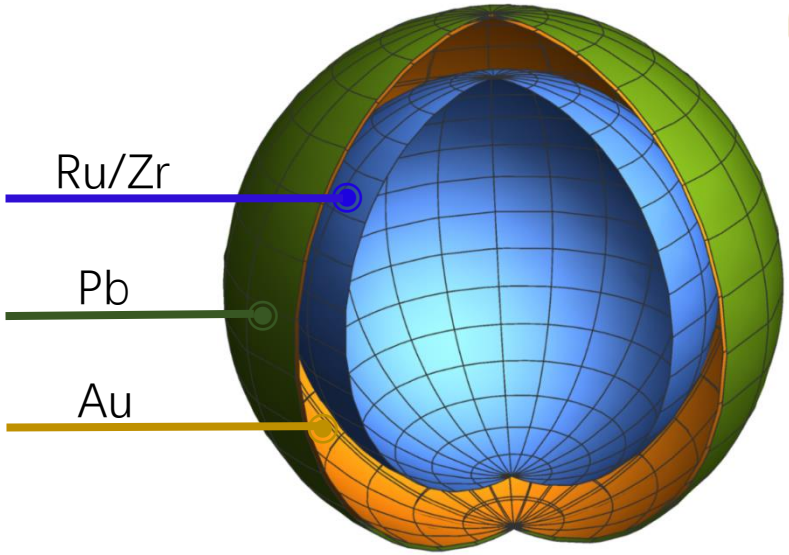
$$R_{AA} = \frac{\sigma_{inel}^{NN} d^2 N_{AA}^{D^0}/dp_T dy}{< N_{coll} > d^2\sigma^{PP}/dp_T dy}$$

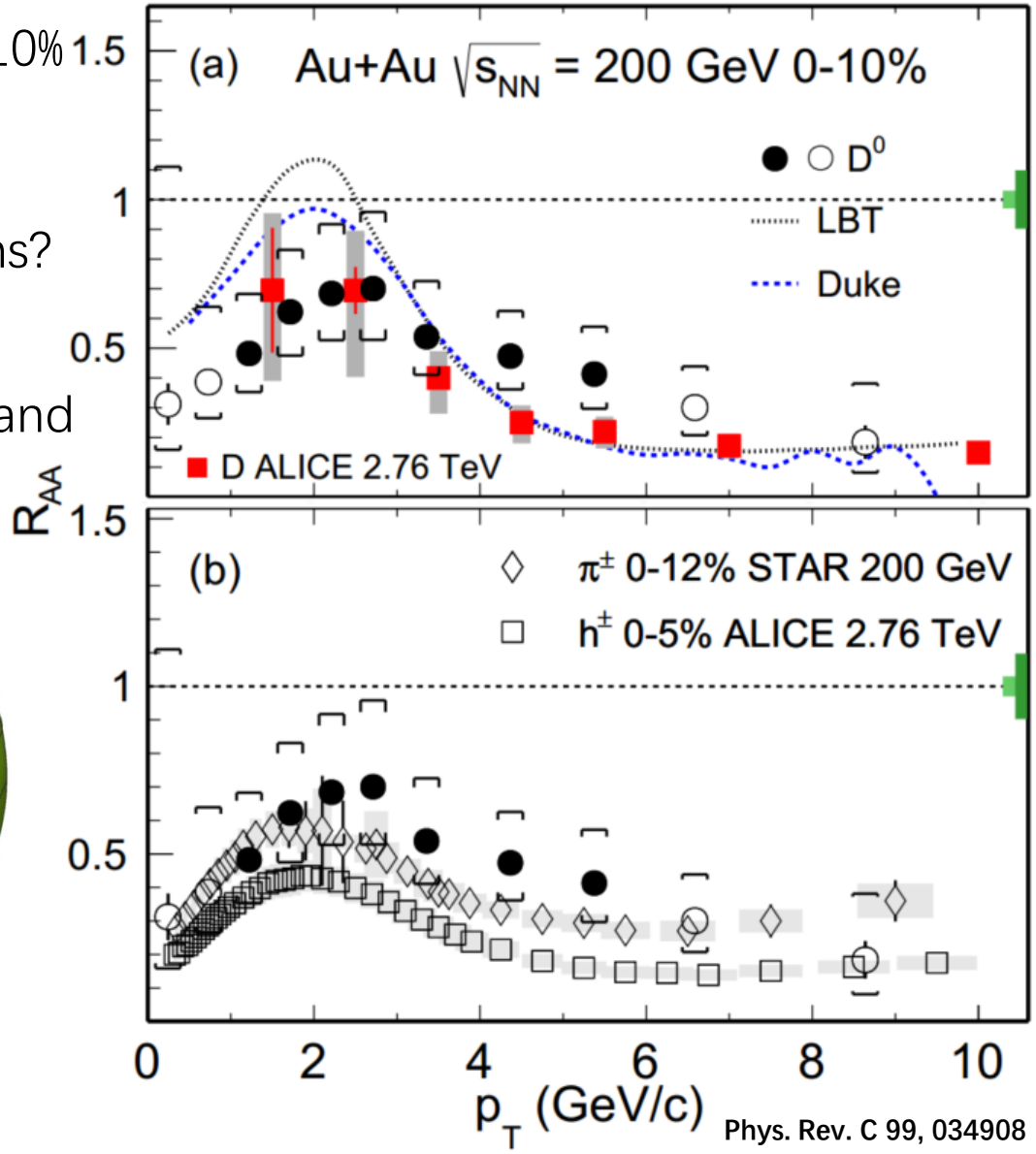
D^0 R_{AA} in Au+Au and Pb+Pb collisions

- Suppression level comparable to that of light hadrons in 0-10%
- Similar suppression in both Au+Au and Pb+Pb
- A **significant energy loss** of charm quarks in isobar collisions? ($^{96}_{40}Zr + ^{96}_{40}Zr$, 3.91 nb^{-1}; $^{96}_{44}Ru + ^{96}_{44}Ru$, 4.00 nb^{-1})
- The **N_{bin}-scale effect** of the D^0 p_T spectra between isobar and Au-Au collisions?



$R = R_0(A)^{1/3}, R_0 = 1.3\ Fermi$
$\rho_{M\_A} = 2.04 * 10_{17}\ \mathrm{kg \cdot m^{-3}}$





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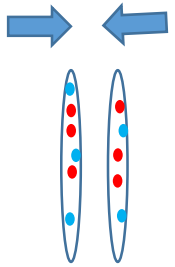
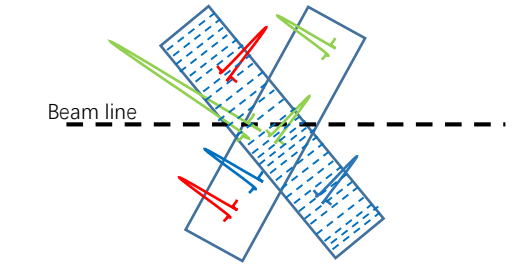
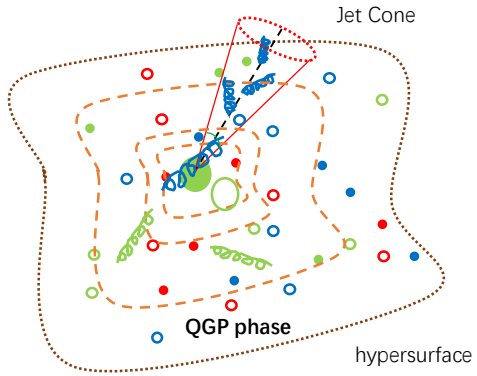
Note: Deformation nuclei may need to be considered

Charm jets tagged with D^0 mesons

- D^0 tagged Jets probe the strongly interacting QCD medium
  - Provide **more details** of charm production processes, and test the contribution from higher-order pQCD calculations
  - Interactions between jets and the QCD medium set **additional constraints** on the charm energy loss mechanism and the medium properties







System evolution

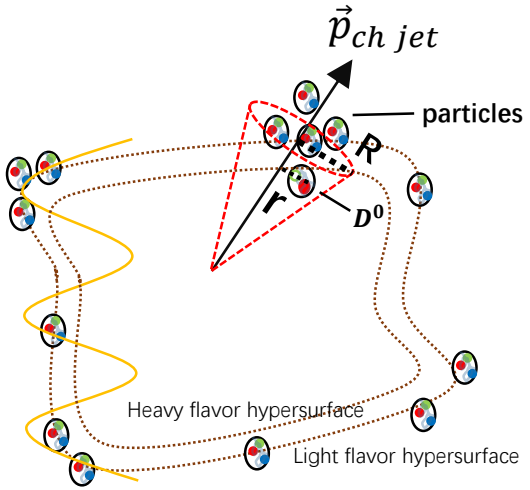
- Nuclear modifcation factors R_{cp} as a function of $p_{T,jet}$ and z

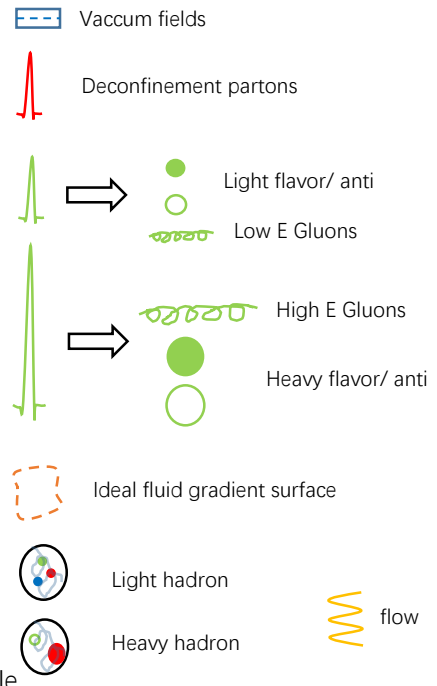
$$z = \vec{p}_{T,D^0} \cdot \hat{p}_{T,jet} / |\vec{p}_{T,jet}|$$

  - reduction of jet energy, “jet quenching”
  - insight into the charm-quark fragmentation

- Study the internal structure of these tagged jets by radial distribution of the D^0 mesons in jets

$$\frac{1}{N_{jet}^{D^0}} \frac{dN_{jet}^{D^0}}{dr} = \frac{1}{N_{jet}^{D^0}} \frac{\Delta N_{jet}^{D^0}}{\Delta r}$$



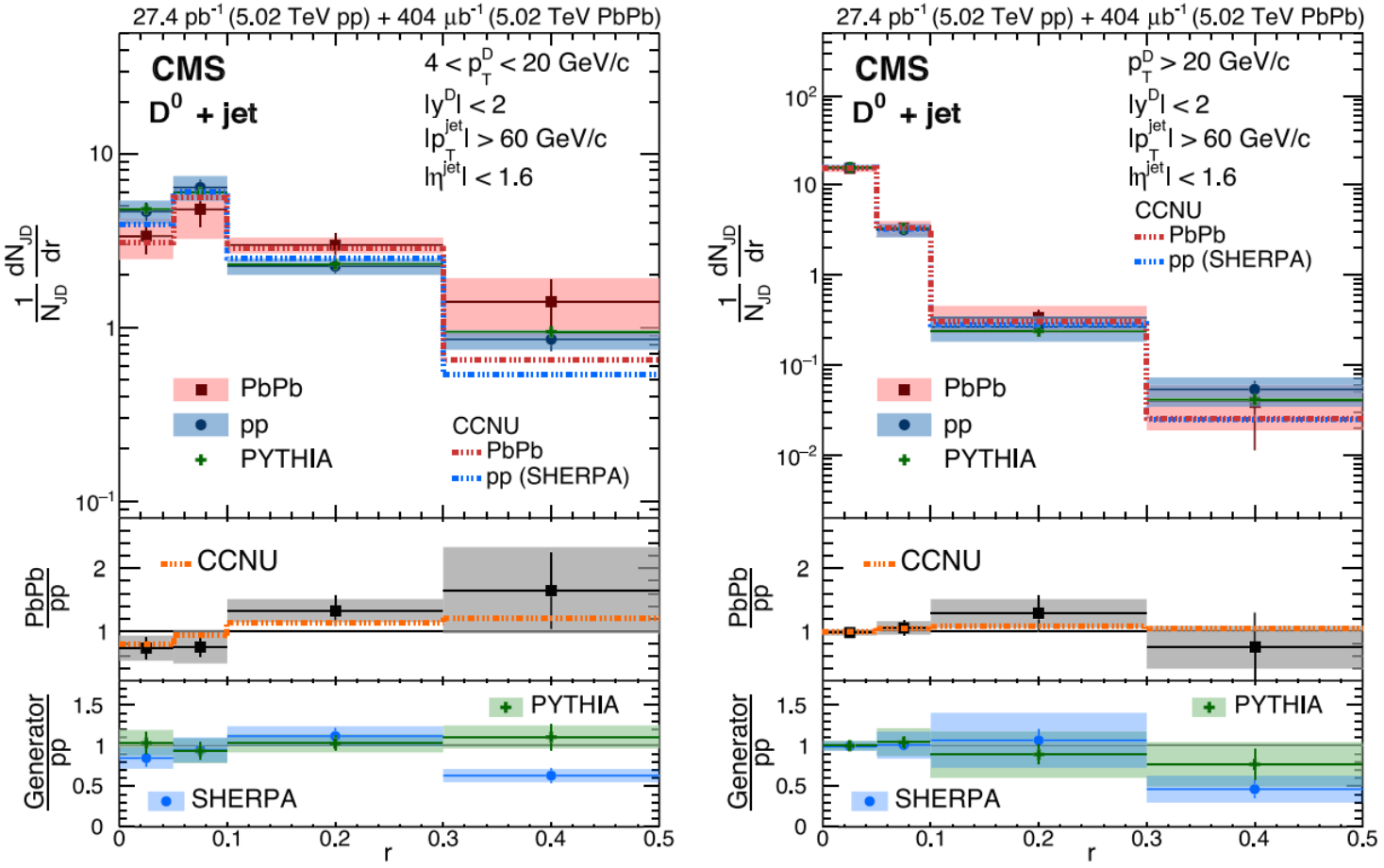


Measurements

Note: Chemical and Kinetic freeze-out need extra consideration;
The QCD physics is mainly considered.
The size of the parton is indicated, and it is actually a point particle.

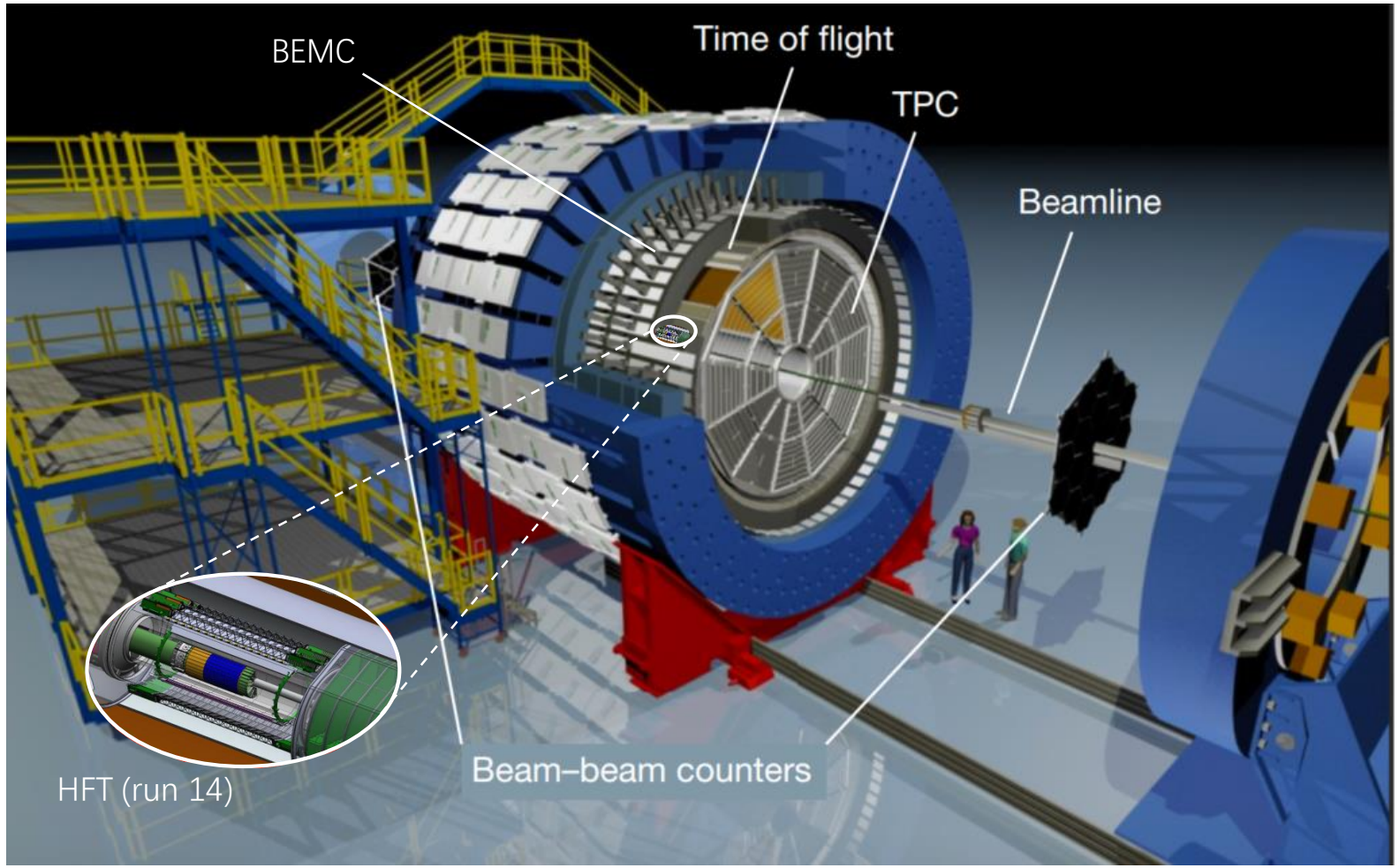
Charm jets tagged with D^0 mesons

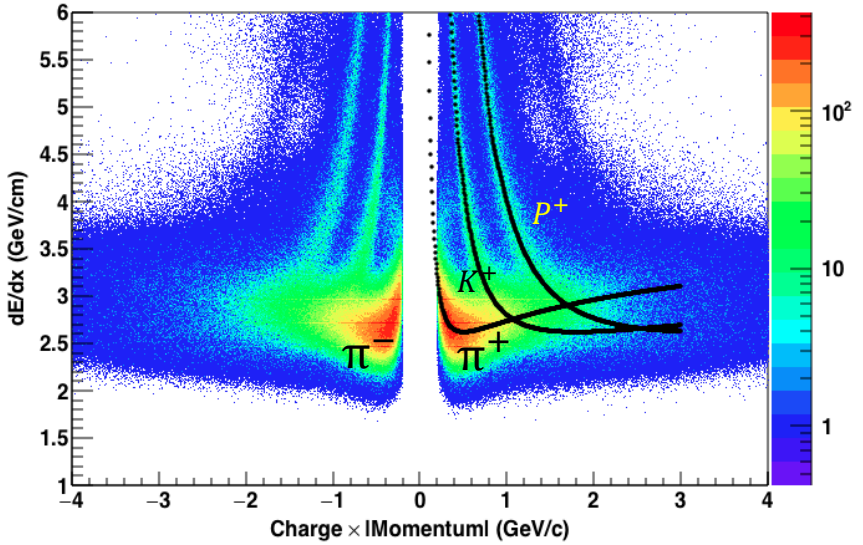
- Low p_T D^0 mesons appear to be diffused in the presence of QGP at LHC
- A **similar diffusion** of charm quarks at lower p_T in Au+Au collisions?
- A **significant suppression** of D^0 meson tagged jet yield with lower D^0 kinematics?

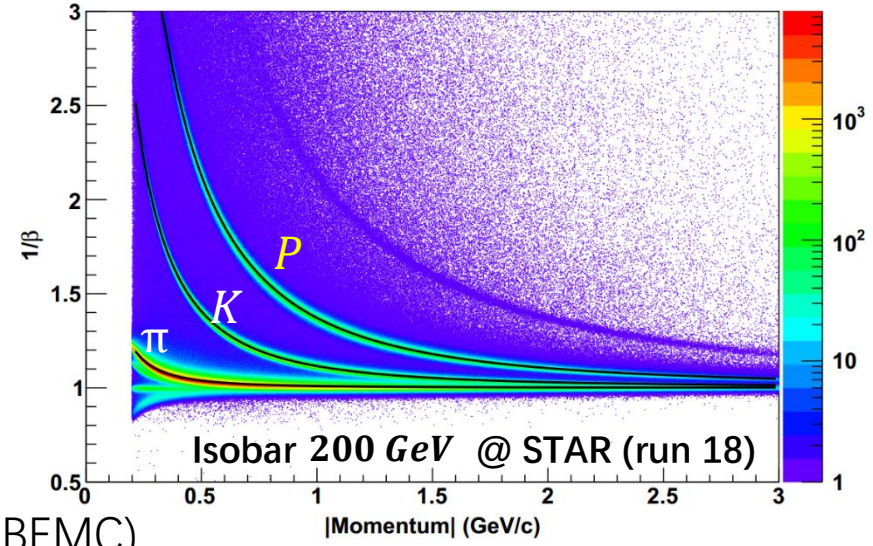


PRL 125, 102001 (2020)

STAR Experiment

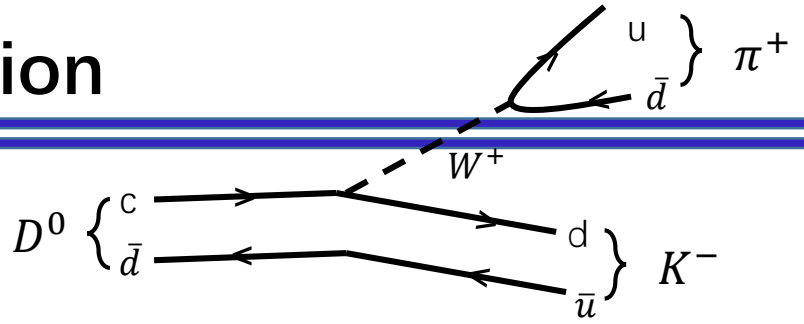




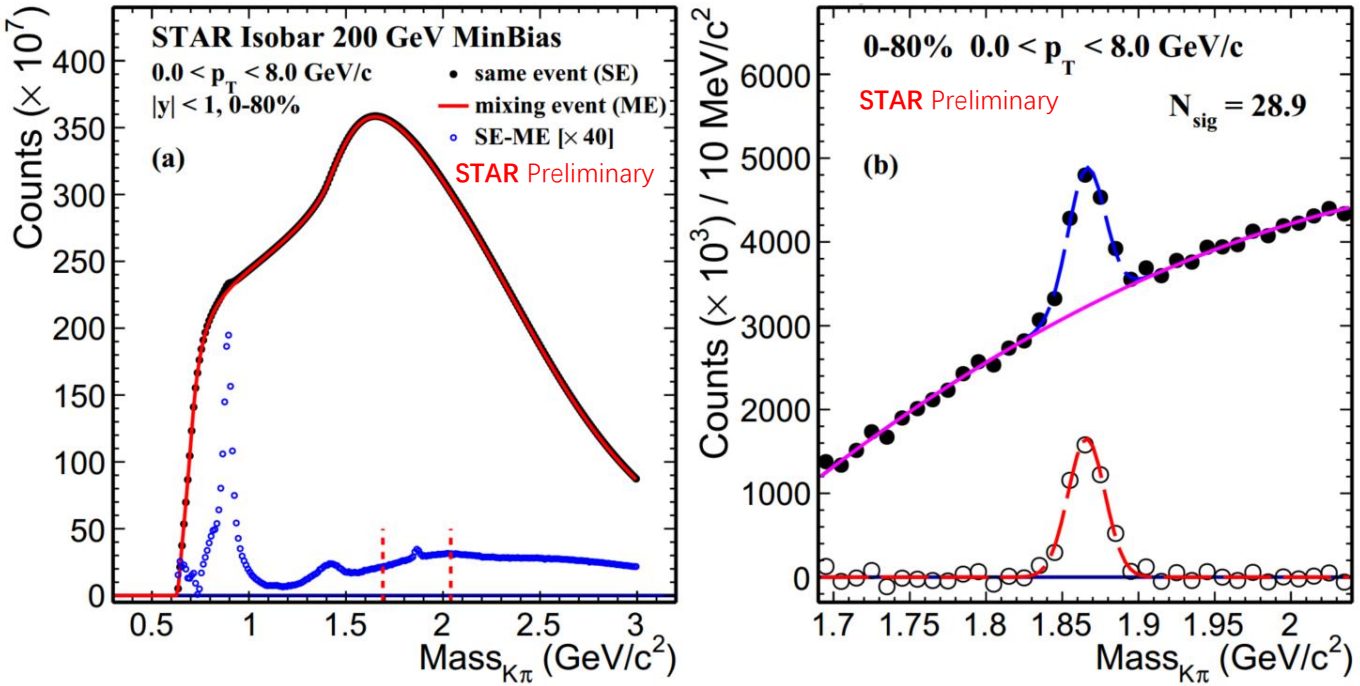


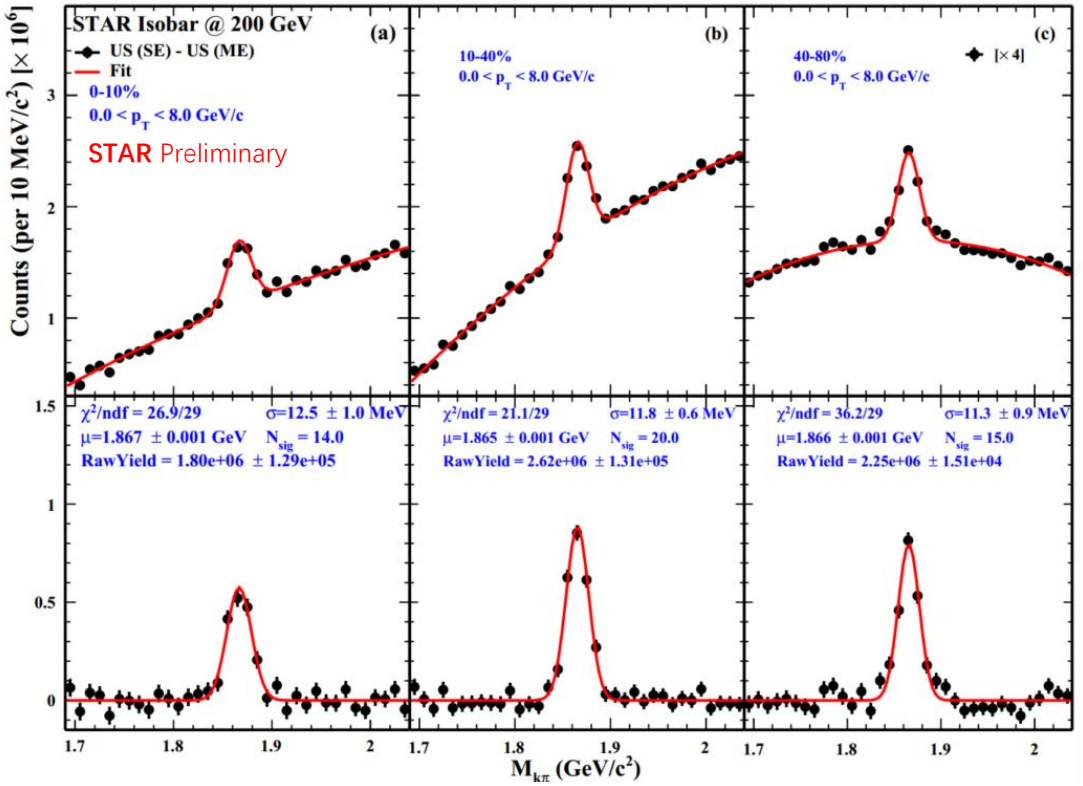
- Time Projection Chamber (TPC)
  ~ 350 μm, vertex resolution with more than 1000 tracks
- Time Of Flight detector (TOF)
  the precise 1/β extends PID power
- Heavy Flavor Tracker (HFT)
  ~ 30 μm, adding PXL hits into TPC track
- Barrel Electromagnetic Calorimeter (BEMC)
  measures neutral component of energy in jets

D^0 signal reconstruction



hadronic modes: $D^0 \rightarrow K^- + \pi^+; \bar{D}^0 \rightarrow K^+ + \pi^-$ ($\Gamma_i/\Gamma \sim 3.9\%$)





- The signal is extracted via an invariant-mass analysis
- The mix-event method can well reproduce the combination background
- Signal signifcance enables us to study the dependence of D^0 yields on centrality and transverse momentum

p_T Spectra and Integrated yields

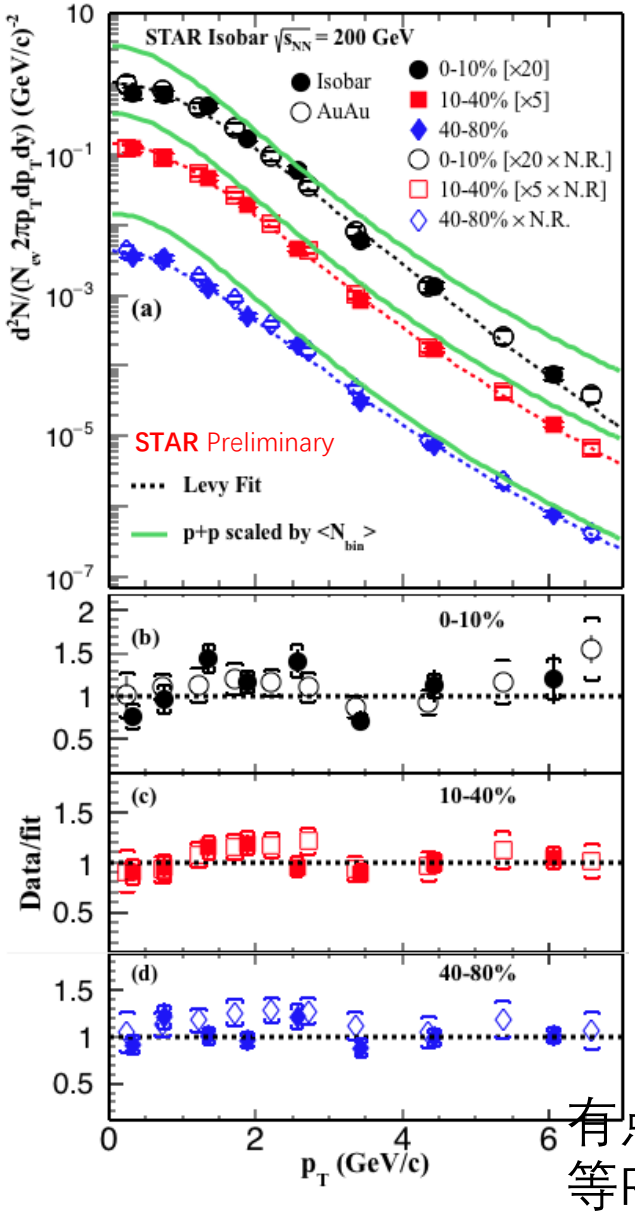
$$E\frac{d^3N}{d\boldsymbol{p}^3} = \frac{d^3N}{p_T dp_T dy d\phi} = \frac{d^2N}{2\pi p_T dp_T dy}$$

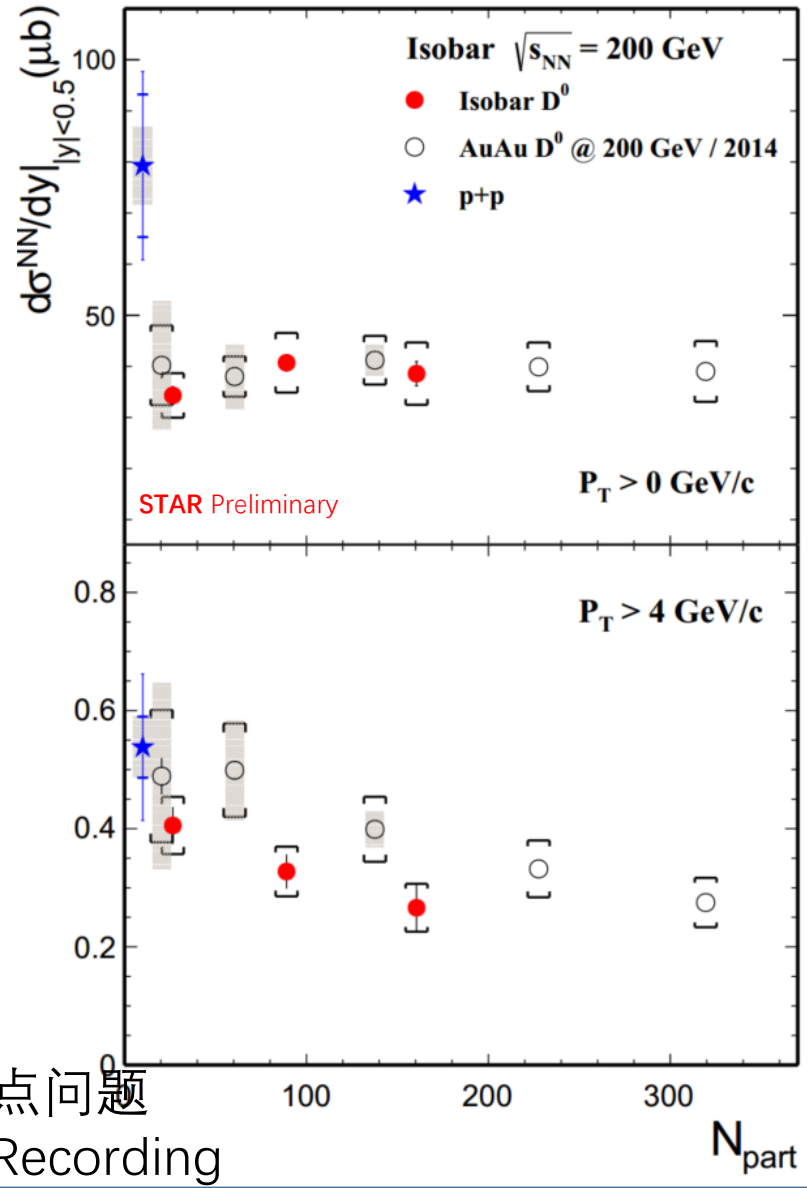
$$\frac{d^2N}{2\pi p_T dp_T dy} = \frac{\Delta N^{raw}/\epsilon_{D^0}^{tot}/2}{2\pi p_T \Delta p_T \Delta y \times N_{events} \times B.R.} = \frac{\Delta N_{D^0}^{AA}}{2\pi p_T \Delta p_T \Delta y} = E\frac{d^3\sigma_{D^0}^{AA}}{d\boldsymbol{p}^3}$$

- D^0 production cross section follows number of binary collisions scaling, indicating charm quarks are mostly produced via initial hard scatterings

$$\frac{d\sigma_{D^0}^{NN}}{dy}|_{y=0} = \frac{dN_{D^0}^{AA}}{dy}|_{y=0} \times \frac{\sigma_{inel}^{pp}}{< N_{bin} >}$$

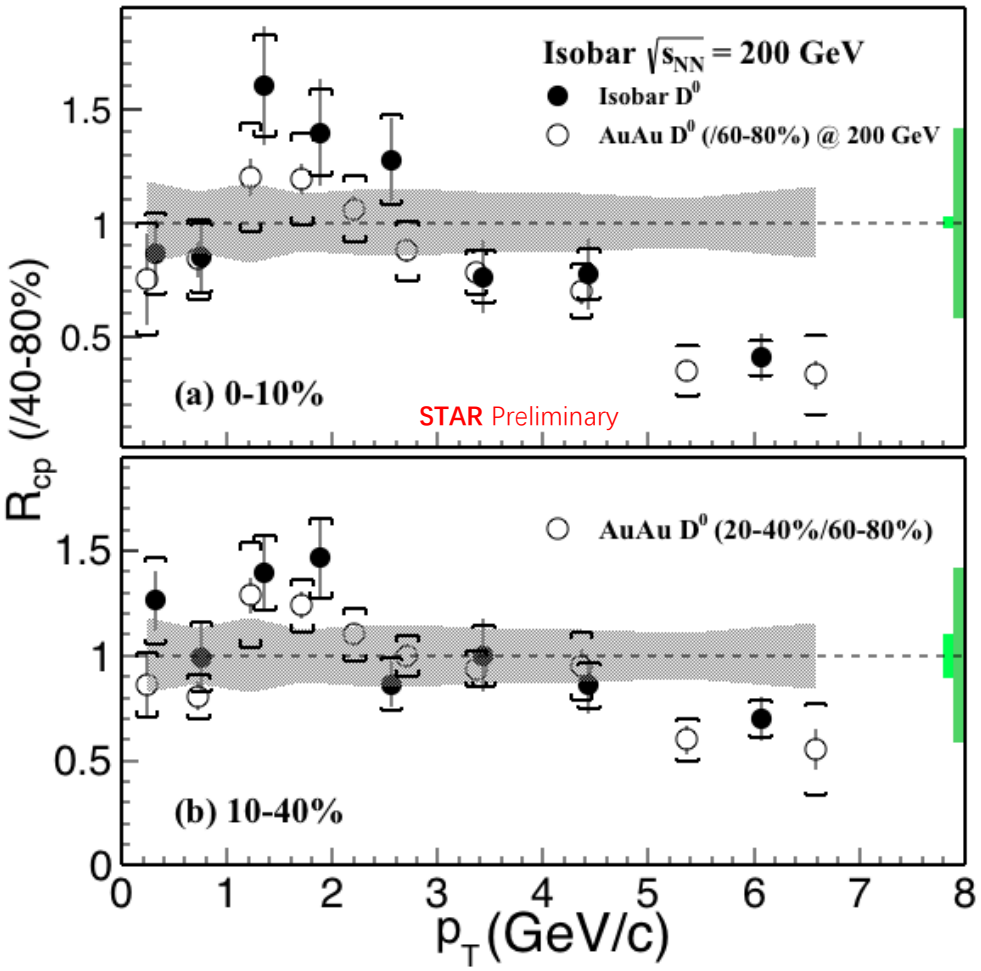
- $d\sigma^{NN}/dy$ VS p_T is consistent with results in Au+Au collisions with similar $\langle N_{part} \rangle$
- For $p_T > 4\ GeV/c$, $d\sigma^{NN}/dy$ decreases with $\langle N_{part} \rangle$ at RHIC energy

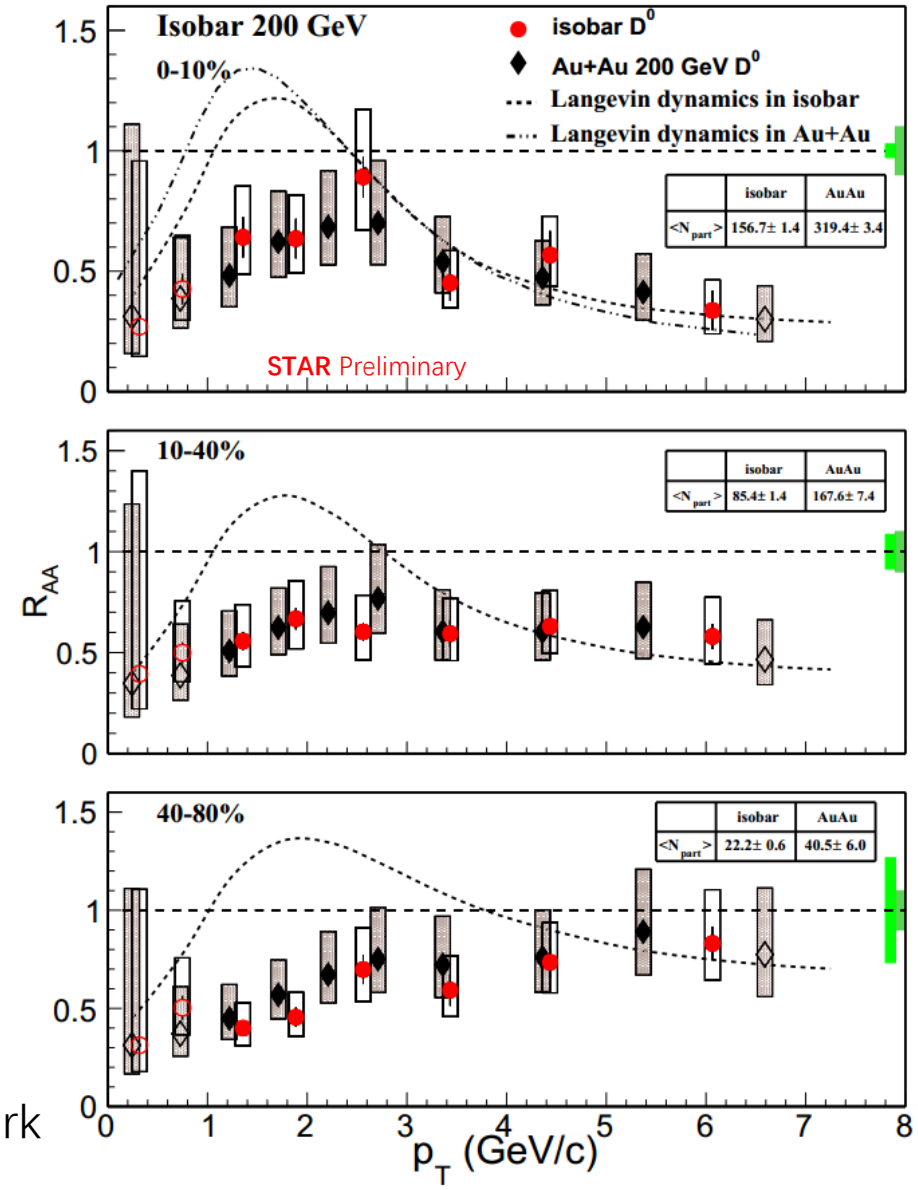




有点问题
等Recording

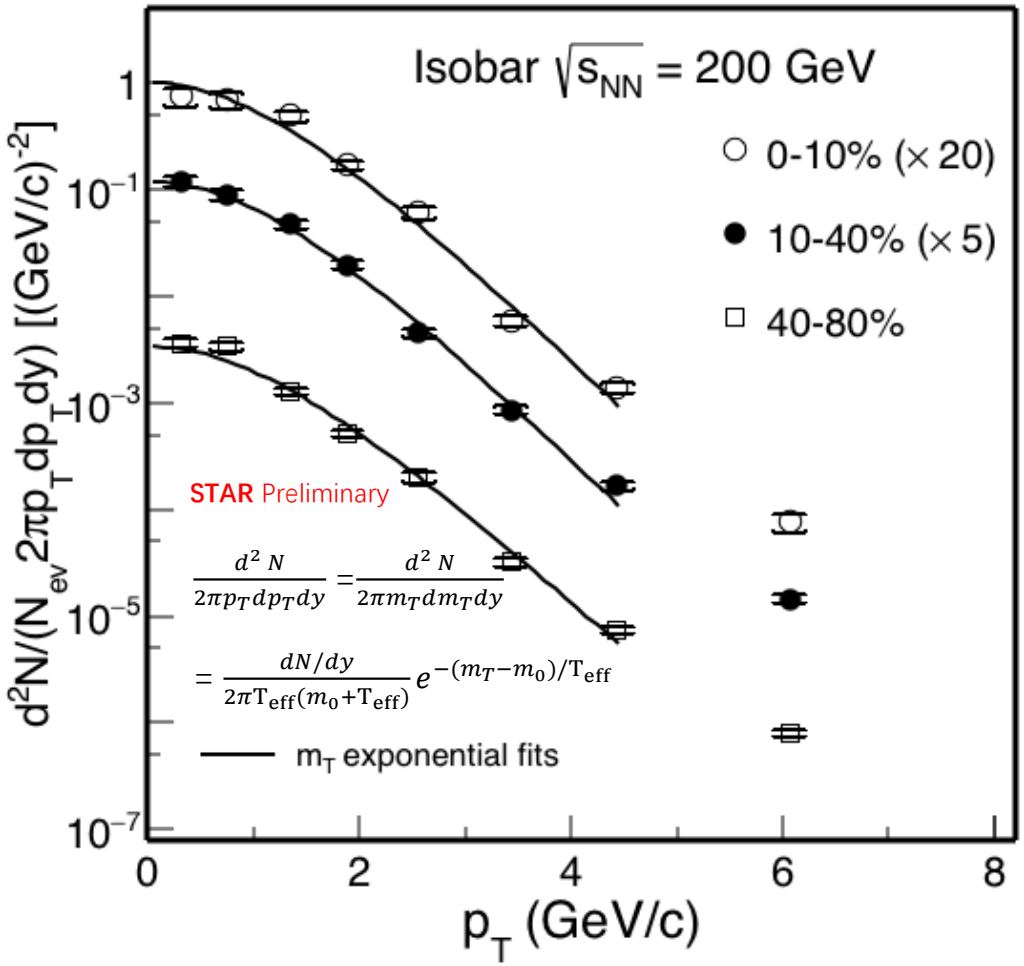
R_{AA} and $R_{\rm cp}$ vs. p_T

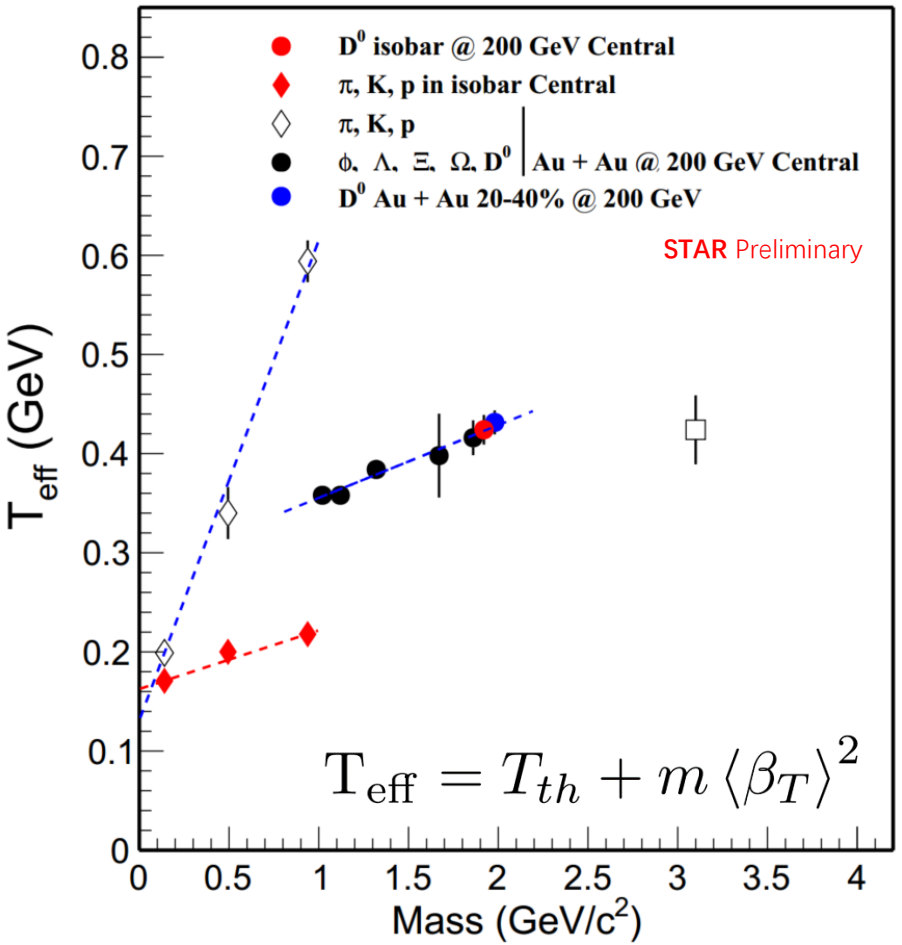




- D^0 R_{CP} and R_{AA} suppression observed at high p_T in central collisions
- Theoretical models that include collisional energy loss and charm-quark hadronization describe the suppression

m_T Spectra and Collectivity

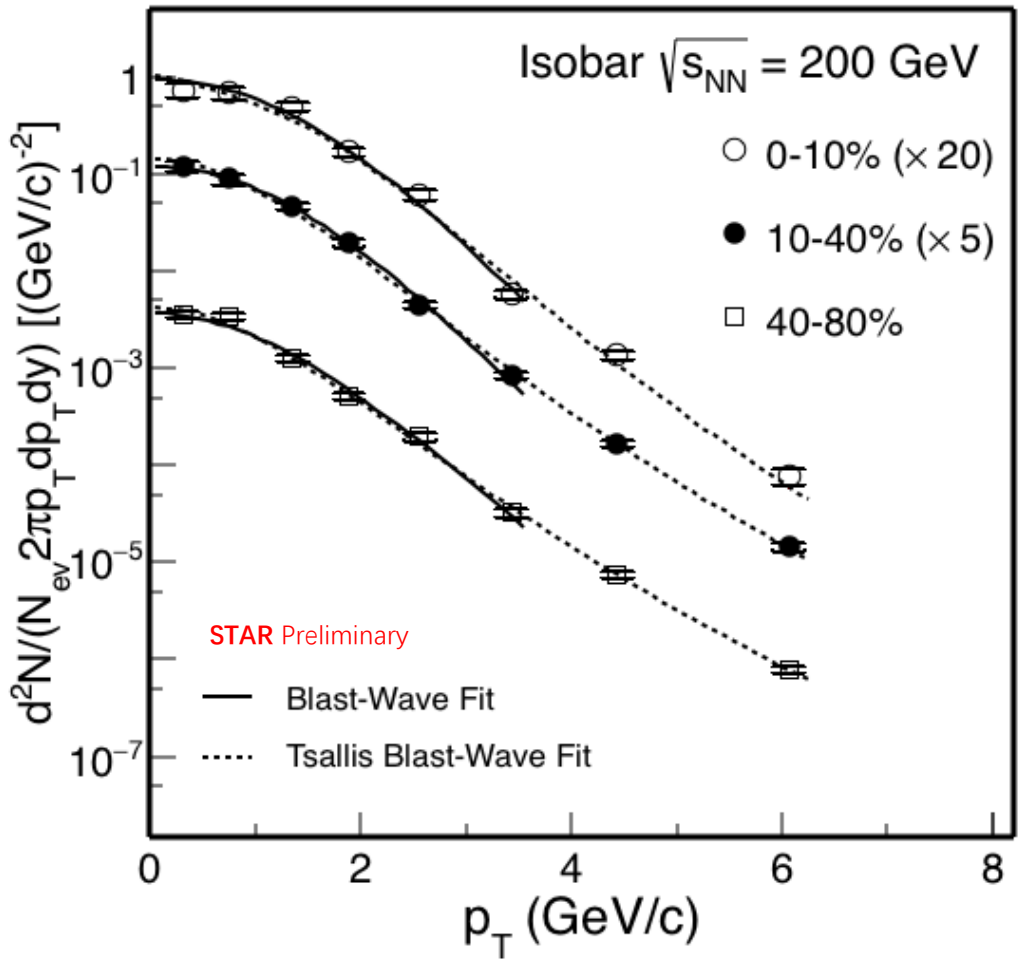


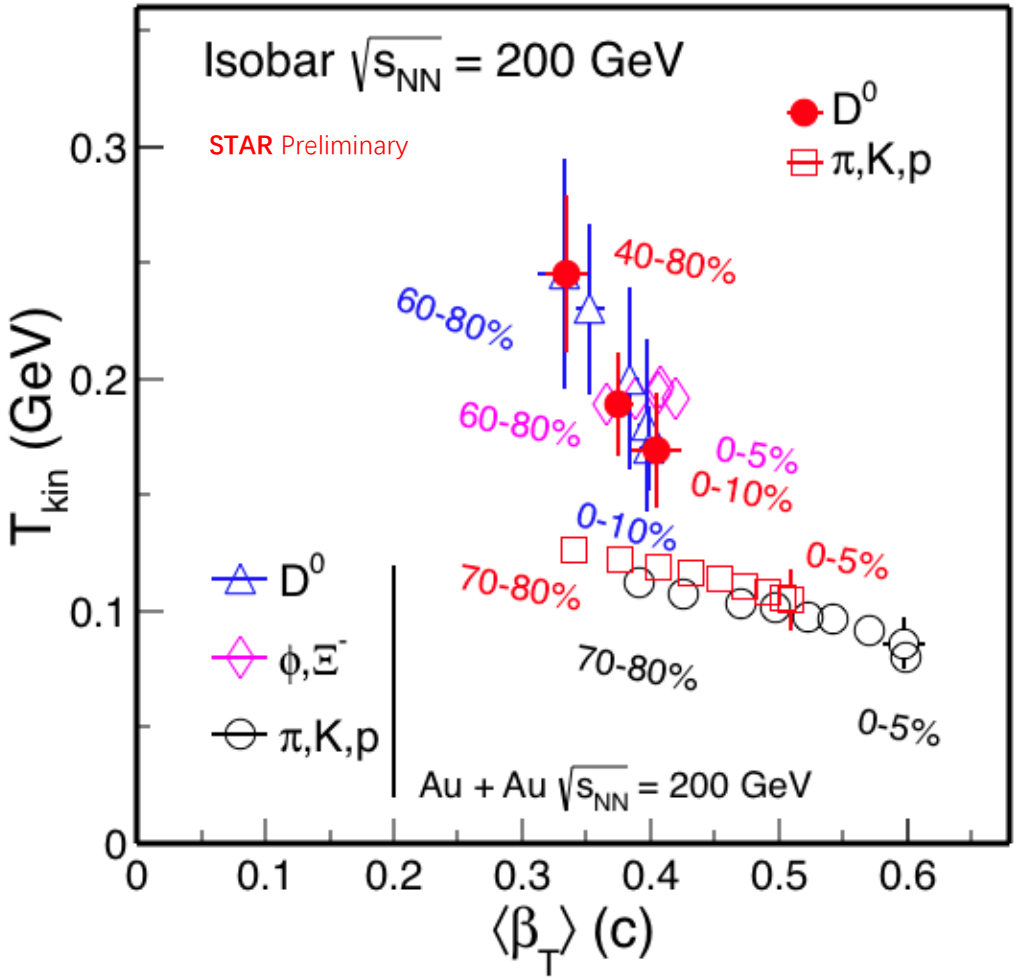


system	hadron	T_{eff}
isobar	π	0.176±0.001
	K	0.203±0.005
	p	0.218±0.001
	D^0	0.424±0.015
AuAu	π	0.199±0.002
	K	0.340±0.026
	p	0.594±0.020
	D^0	0.416±0.018
	D^0 (20-40%)	0.431±0.012

- D^0 T_{eff} is consistent with result in Au+Au collisions with similar $\langle N_{part} \rangle$ at the same collision energy
- Less radial collectivity with respect to light hadrons, which radial velocity may dependent on collision system

Blast – Wave Fits



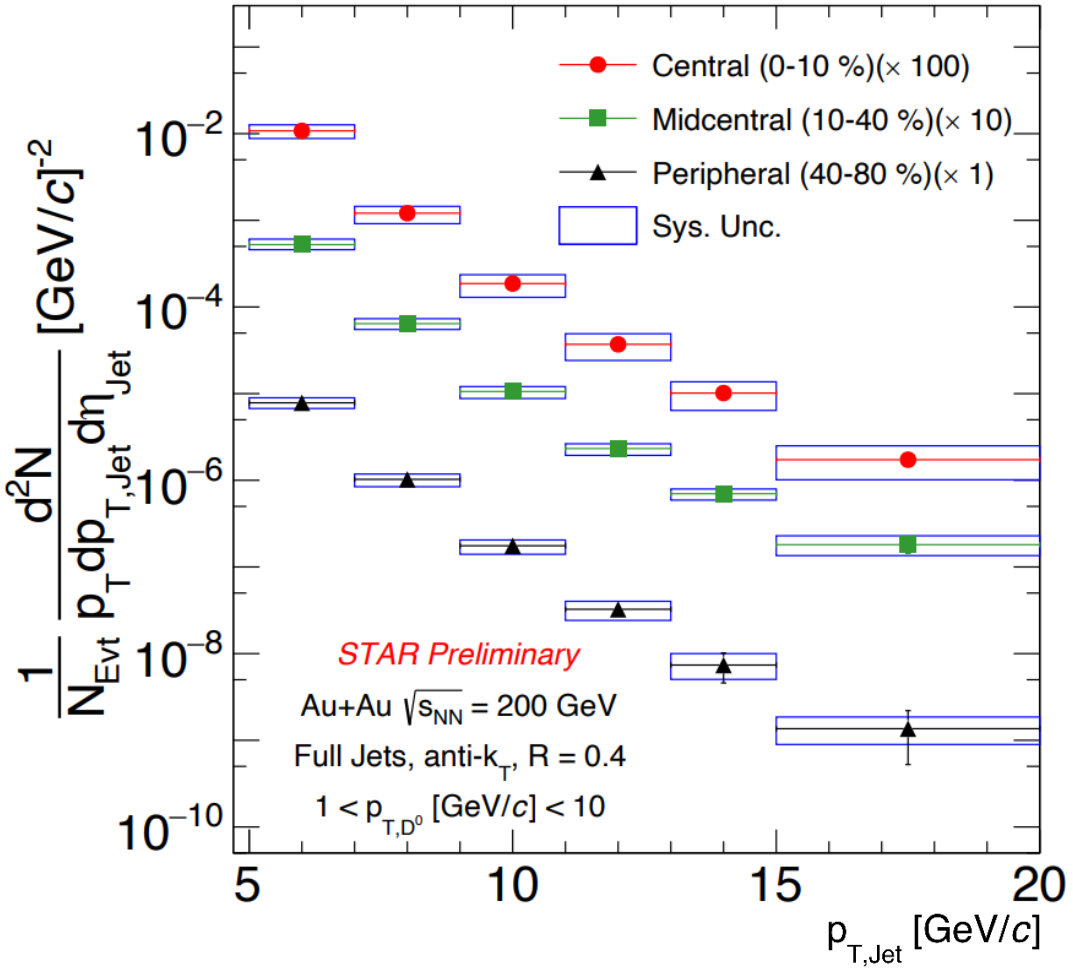


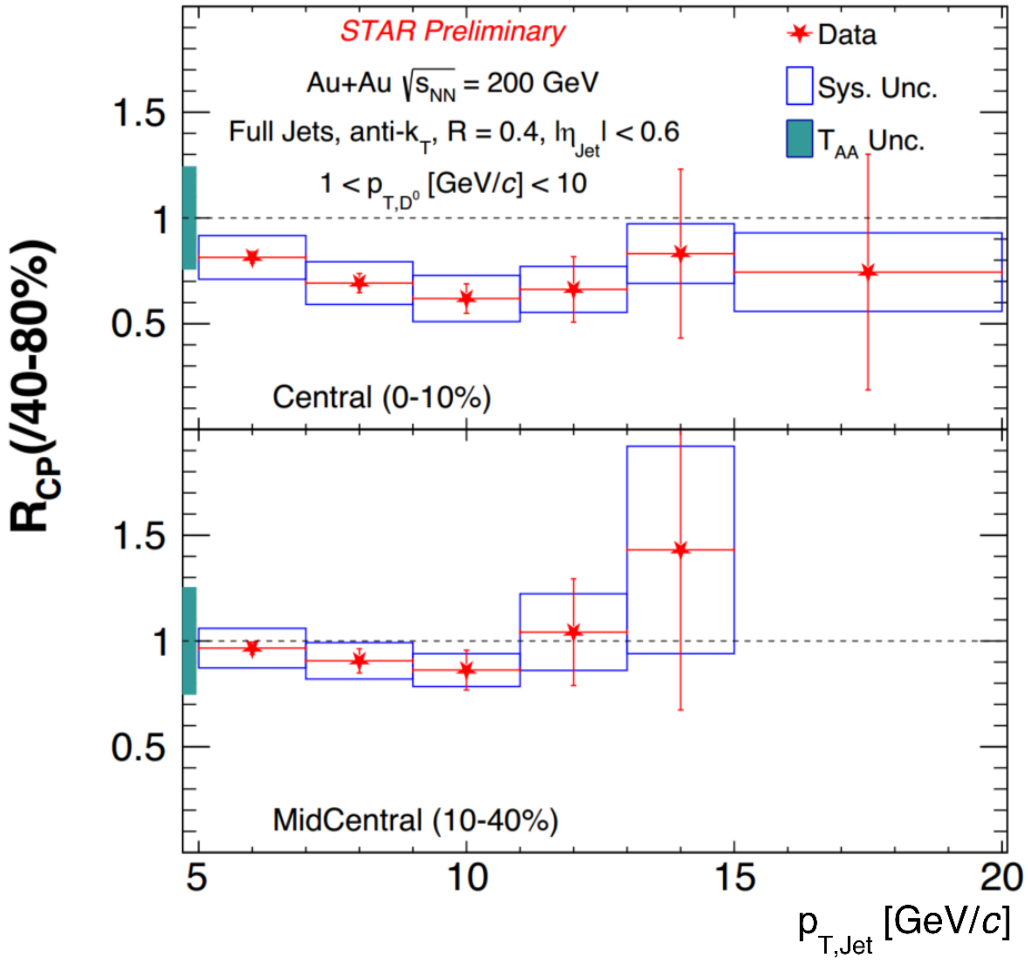
- T_{kin} decreases with centrality while ⟨β_T⟩ has the opposite trend
- The average flow velocity increases with central collision, and (q −1) is found to be close to zero

TBW fit parameters

Centrality	$\langle\beta_T\rangle$(c)	$q-1$
0-10%	0.282±0.018	0.070±0.007
10-40%	0.207±0.030	0.080±0.007
40-80%	0.189±0.031	0.089±0.005

D^0 tagged jet production in Au+Au collisons





有点问题
3页
Backup

- D^0 tagged jet p_T spectra for lower D^0 kinematics $1 < p_{T,D^0} < 10\ GeV/c$
- Hint of suppression of D^0 meson tagged jet yield in central collisions

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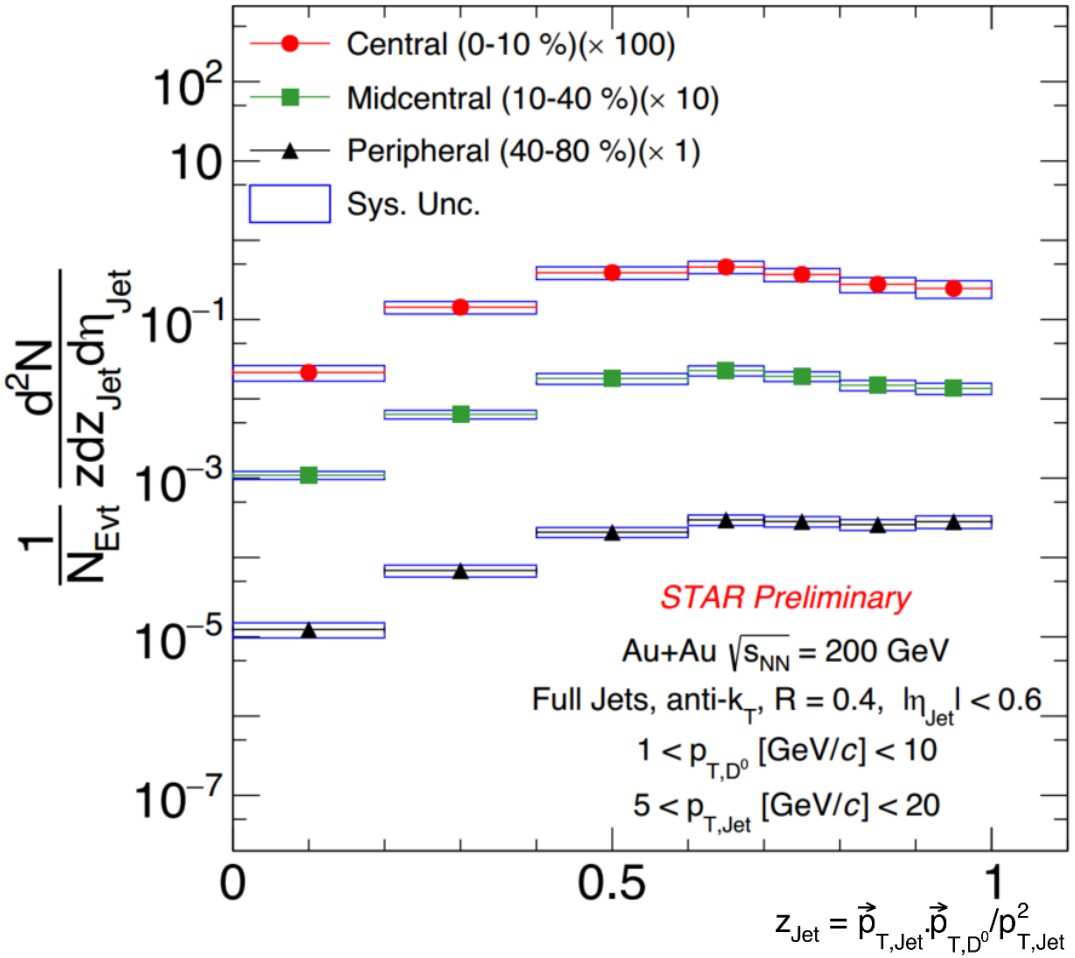
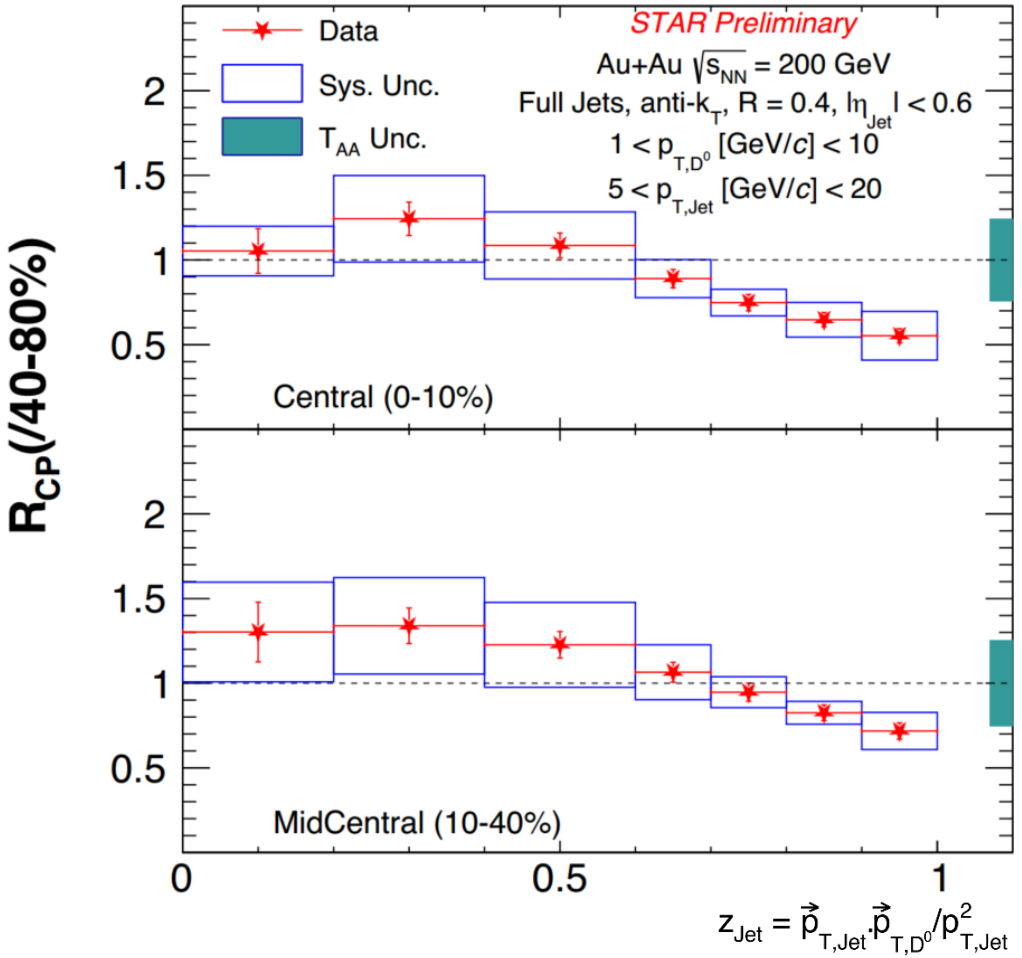
R_{cp} vs. $p_{T,Jet}$ and z_{Jet}





- D^0 tagged jet differential yield as a function of momentum fraction z
- Hard fragmented charm jets show signs of suppression, soft fragmented jets have R_{cp} consistent with 1.

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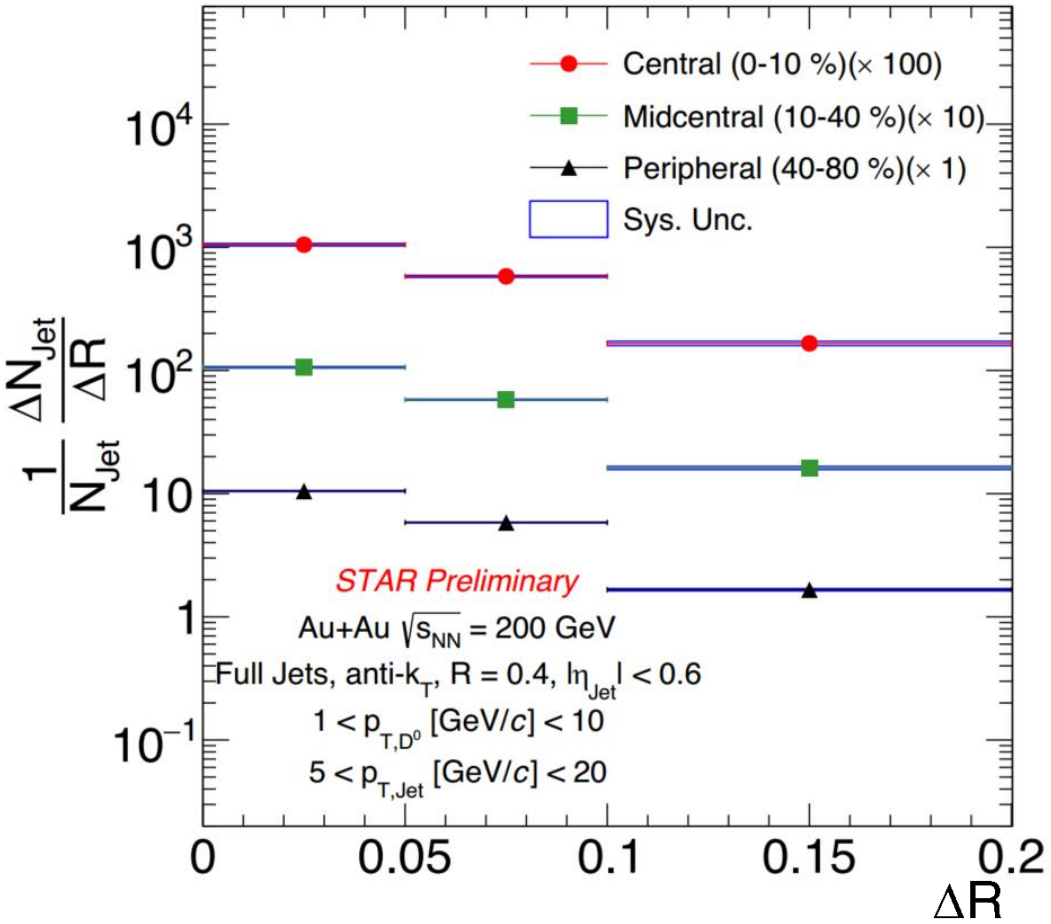
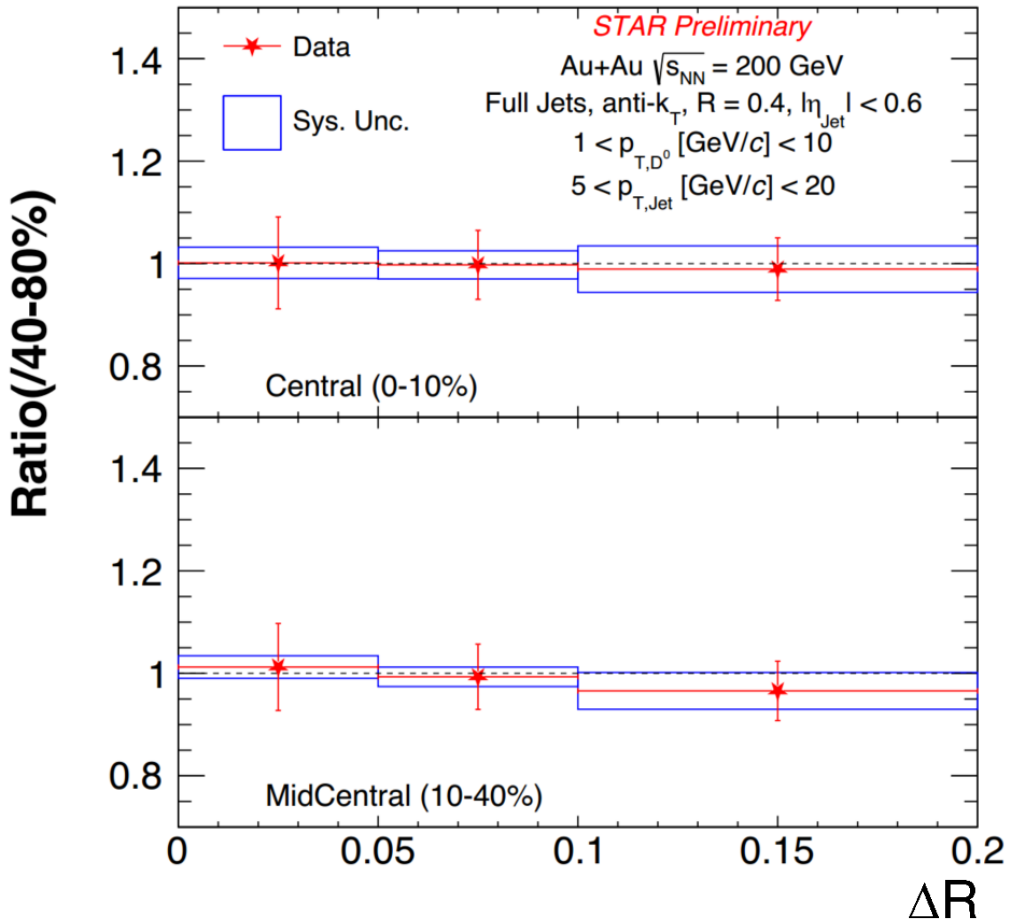
Radial profile of D^0 Mesons jets





- Ratio of radial profile in central and peripheral consistent with 1, no hint of D^0 meson diffusion with current precision （有点不同）
- D^0-tagged jet measurement for R_{AA} and the ratio of radial profile will be explored using high-statistics p+p data in 2024

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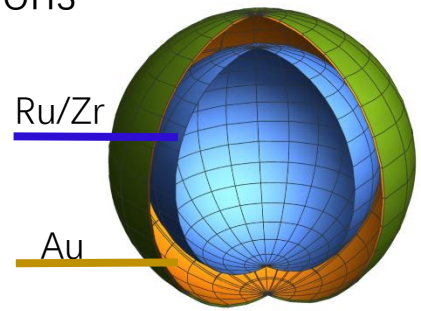
Summary

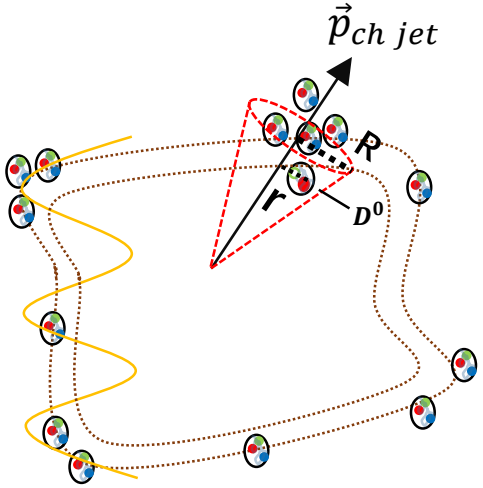
D^0 p_T spectra and R_{AA} in isobar collisions at STAR

- Detailed yield of D^0 are measured in isobar 200 GeV, and a significant suppression R_{AA} observed at p_T > 3 GeV/c in central collisions
- D^0 production cross section follows binary collisions scaling between isobar and Au + Au collisions
- No significant systematic dependence of D^0 kinetic freeze-out properties in central collisions between isobar and Au + Au collisions within uncertainties is observed.



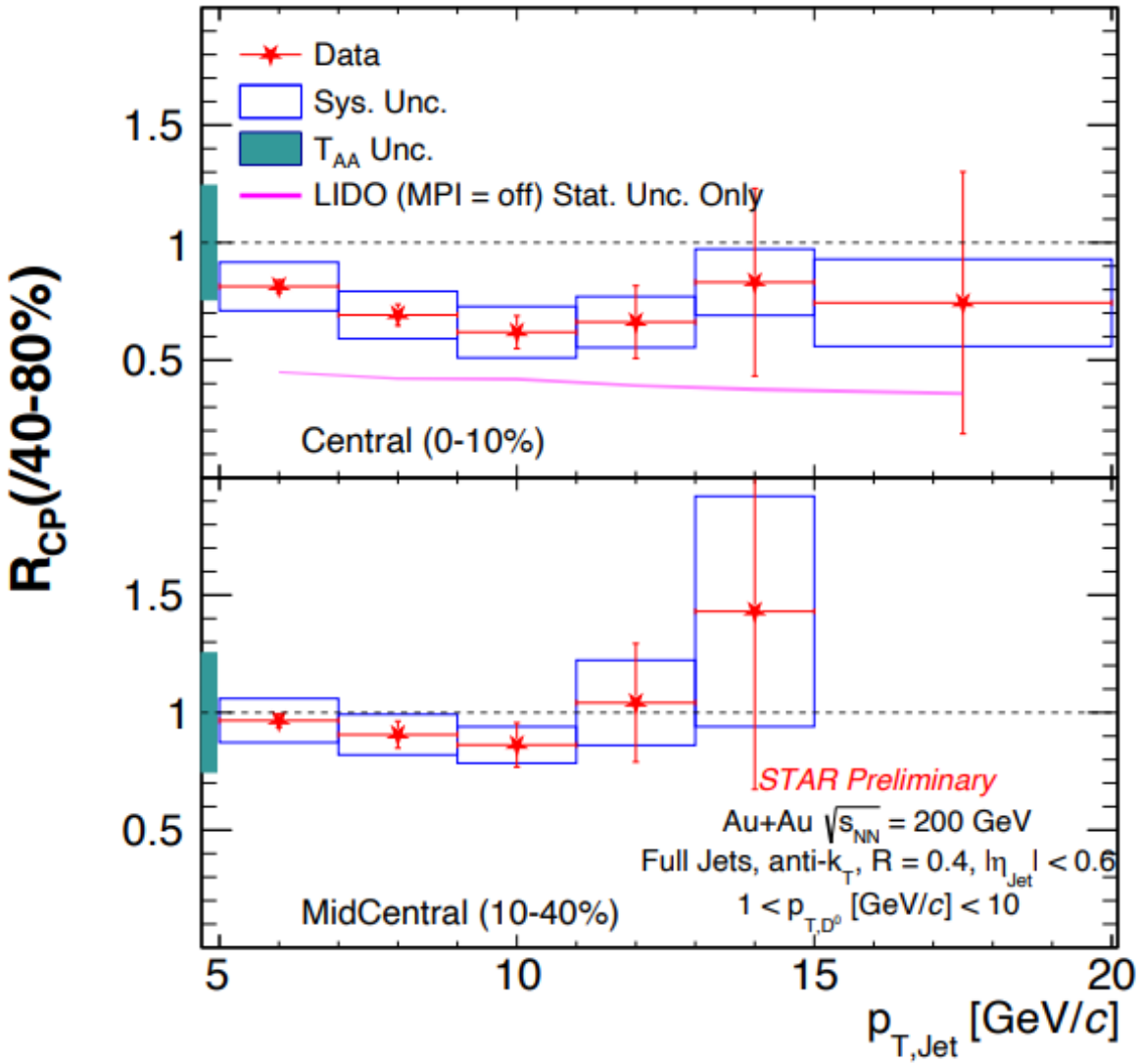
D^0 tagged jets in Au+Au collisons at STAR

- D^0 tagged jet yields VS p_T and z measured for $1 < p_{T,D^0} < 10\ GeV/c$ at RHIC energies
- Hint of suppression of D^0 meson tagged jet yield in central collisions
- The ratios of the D^0 meson radial distributions are consistent with unity within uncertainties, indicating that no significant diffusion of charm quarks with respect to the jet axis in Au+Au collisions



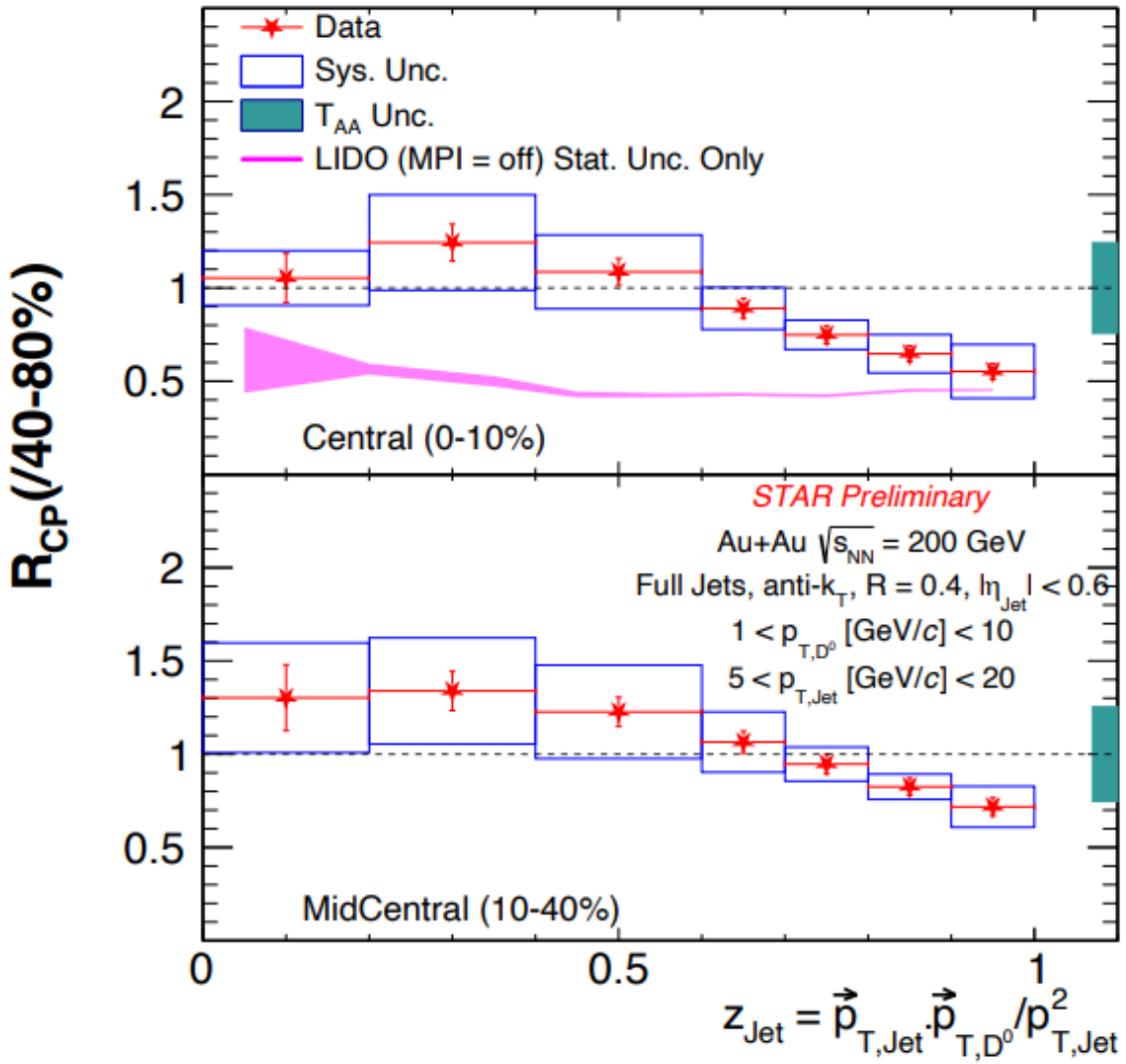
Backup

Technical details: Formulas



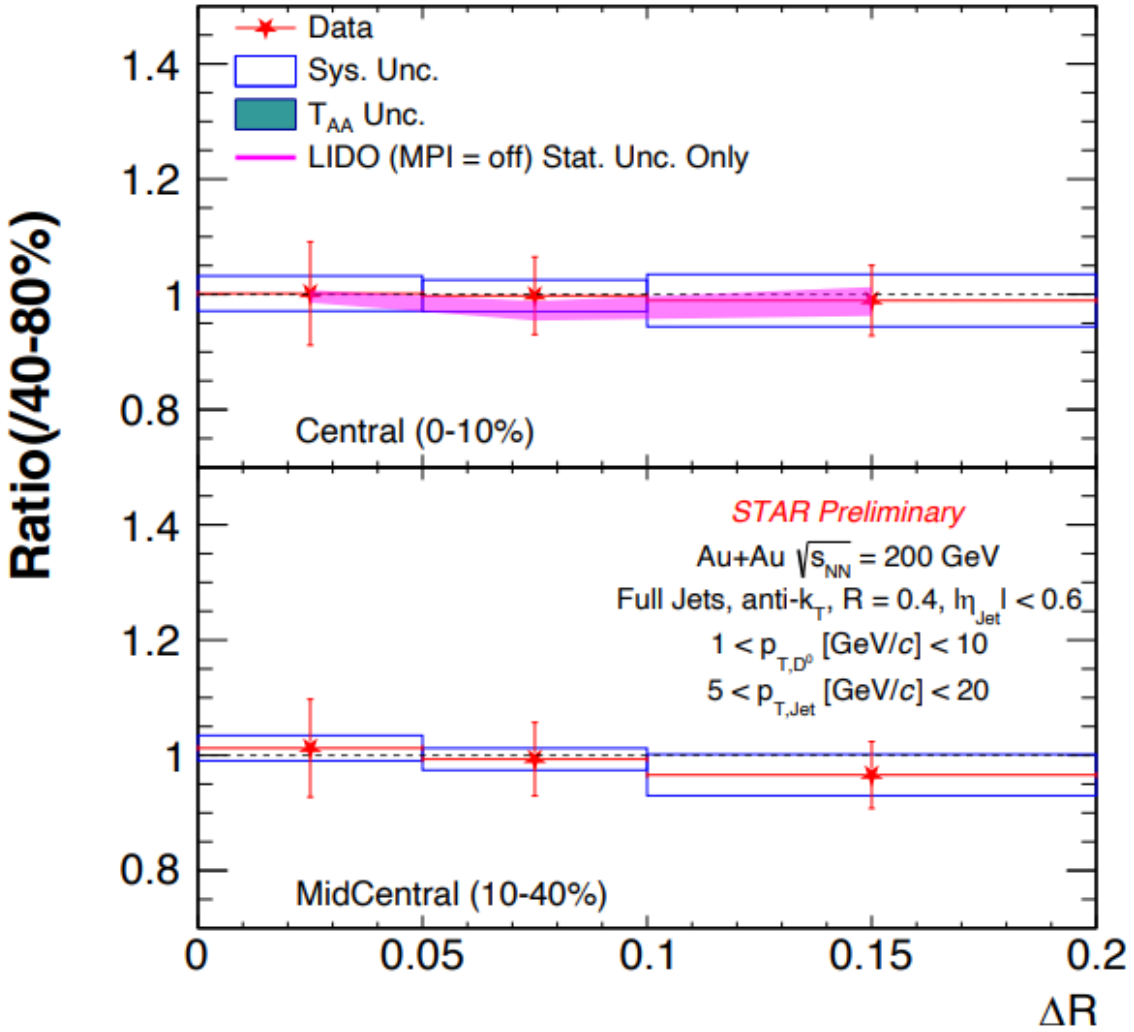
Hint of suppression of D^0 meson tagged jet yield in central collisions

Technical details: Formulas



Hard fragmented charm jets show signs of suppression, soft fragmented jets have RCP consistent with 1.

Technical details: Formulas



LIDO, Phys. Rev. C 98, 034004

Ratio of radial profile in central and peripheral consistent with 1, no hint of D^0 meson diffusion