中国科学技术大学博士学位论文开题报告

Measurements of inclusive D^0-meson production in isobar collisions at $\sqrt{s_{NN}} = 200$ GeV

Yuan Su (苏源)   BA21004043

Dept. of Modern Physics

Major: Particle and Nuclear Physics

PhD Supervisor: Yifei Zhang

Jul. 20th, 2023

Outline

- Motivation and STAR Experiment
- Energy loss
  - Measurements of D^0 p_T spectra and R_{AA} in isobar collisions at $\sqrt{s_{NN}} = 200$ at RHIC
- Collectivity （检查$\widetilde{v_2}$的分辨率修正及3 GeV以上信号提取）
  - Measurement of D^0 elliptic flow v_2 at mid-rapidity in isobar collisions
- Research plan
- Summary

Outline

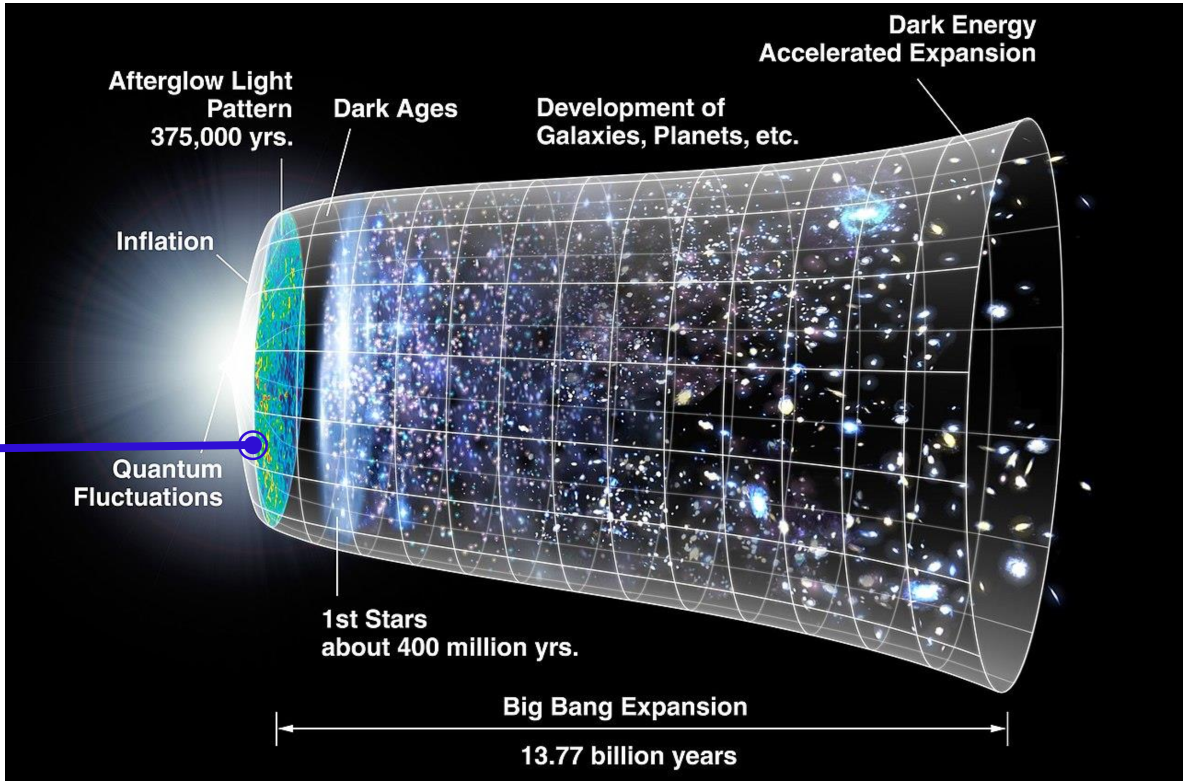
- Motivation and STAR Experiment
- Energy loss
  - Measurements of D^0 p_T spectra and R_{AA} in isobar collisions at $\sqrt{s_{NN}} = 200$ at RHIC
- Collectivity
  - Measurement of D^0 elliptic flow v_2 at mid-rapidity in isobar collisions
- Research plan
- Summary

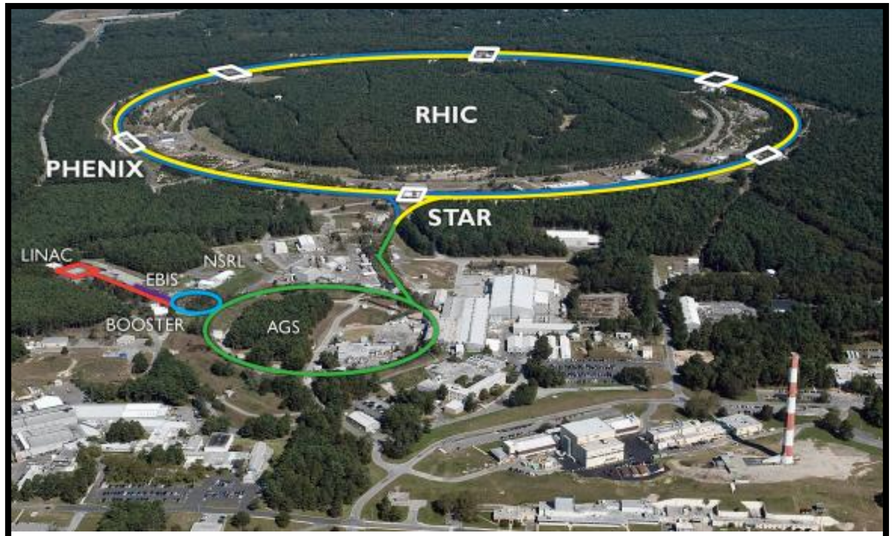
Relativistic Heavy Ion Collision

Energies involved in the Quark epoch are **directly accessible** in RHIC ("Little" Big Bang)

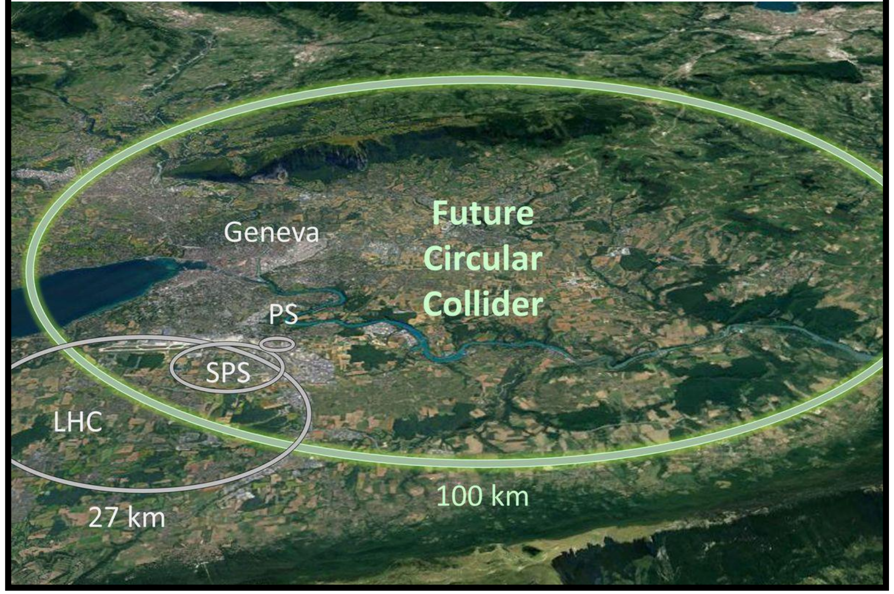
The early universe

T_c~**150-180 MeV**



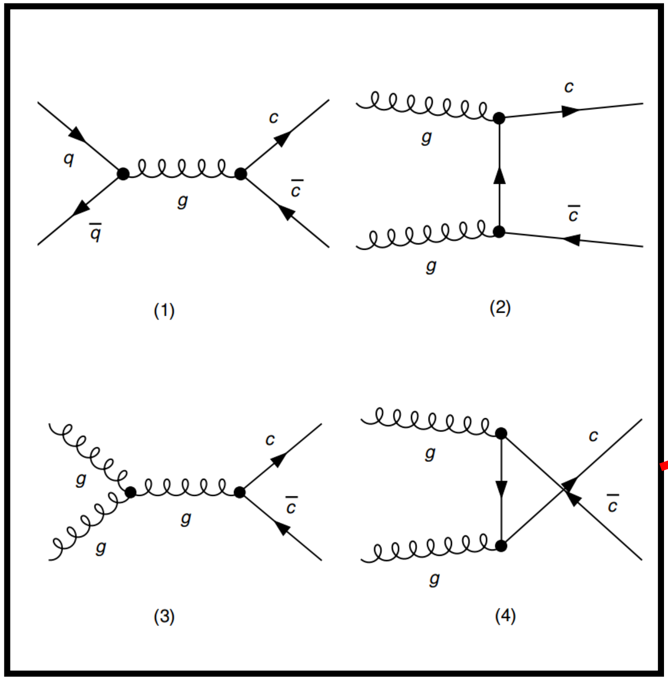


only two operating heavy-ion colliders

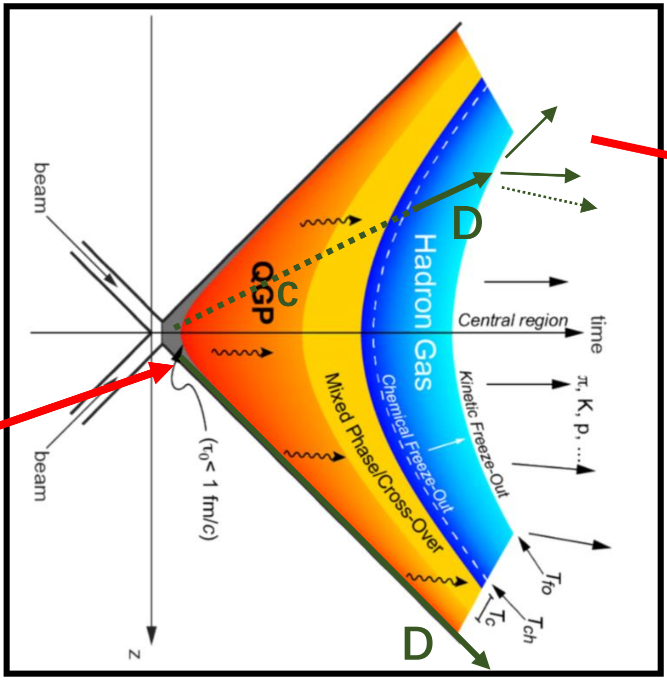


- **QGP is the hottest (~10^{12} K), smallest, and the most perfect fluid (0.08~0.2 $\hbar/k_B$) in nature!**
  - Jets, Heavy flavor energy loss, Flows ···
- Hypernuclei(${}^{4}_{\Lambda}H$, ${}^{4}_{\Lambda}He$) binding energies are one of the key ingredients needed to understand the composition of the neutron stars.
- Initial electromagnetic field ($|\vec{B}|$~10^{15} T) provide an opportunity to test QED under extreme conditions.

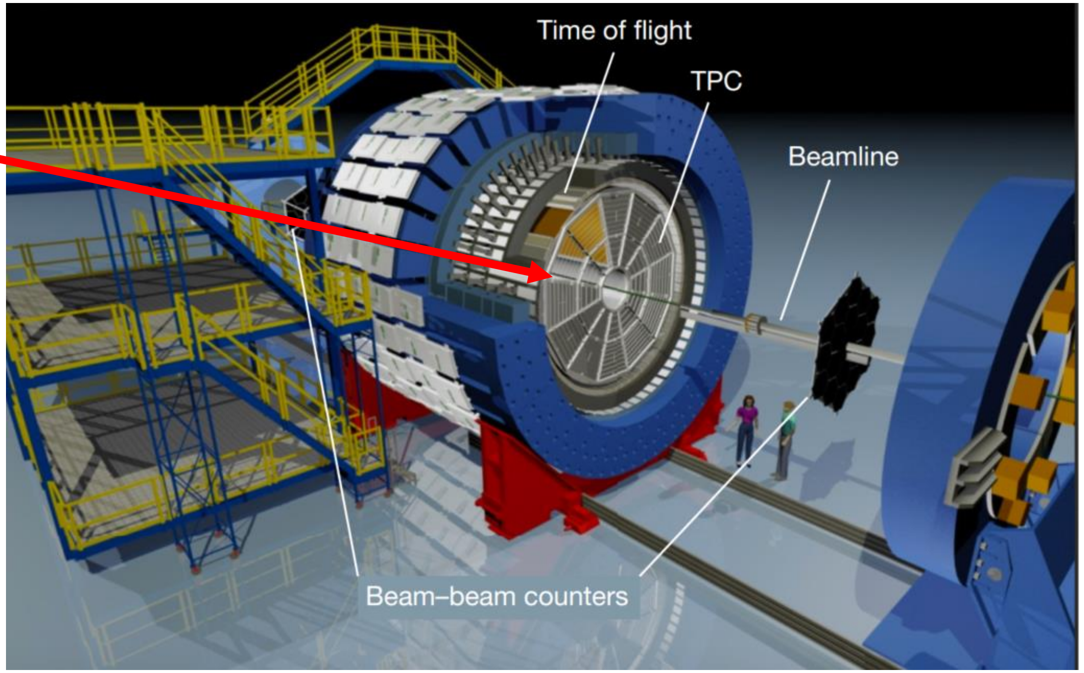
Open heavy-flavour produciton



< 1 fm/c, initial partonic hard scattering



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

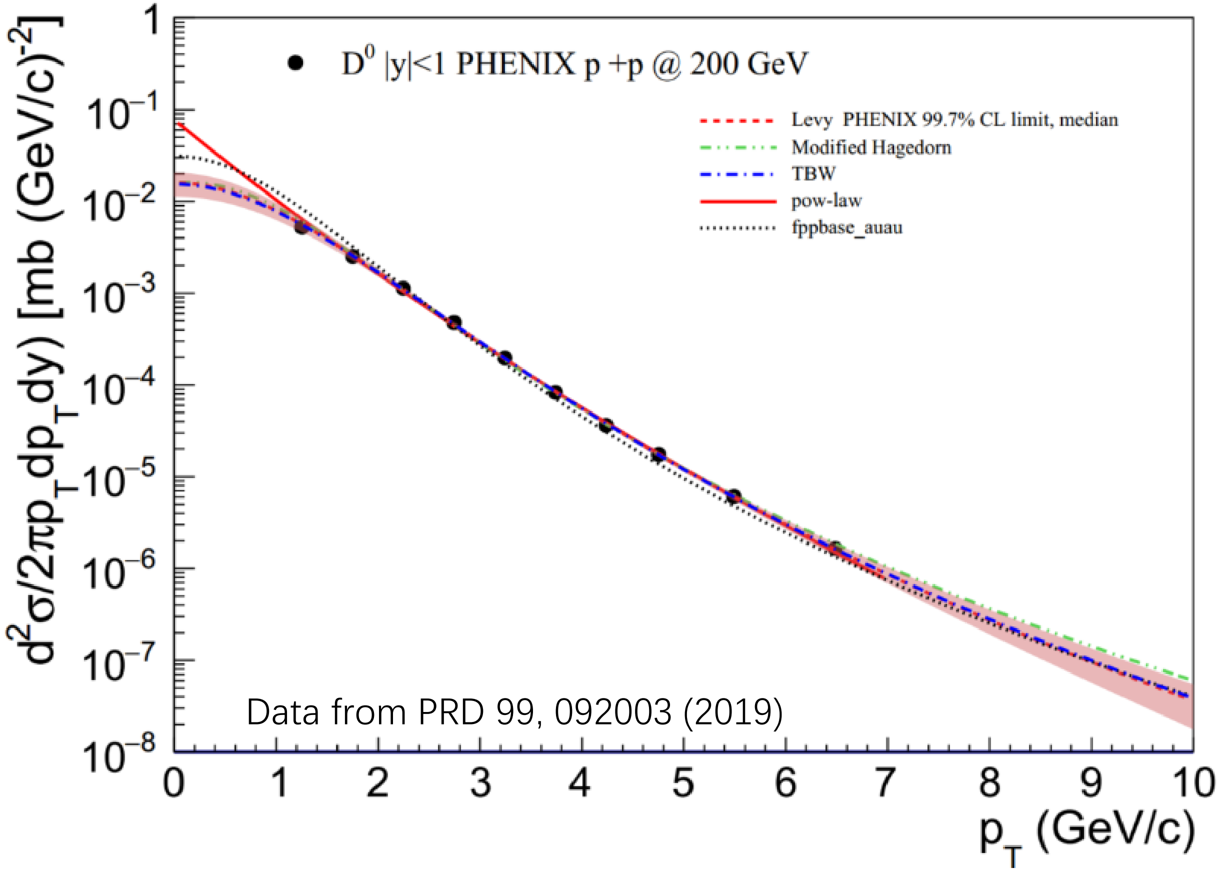


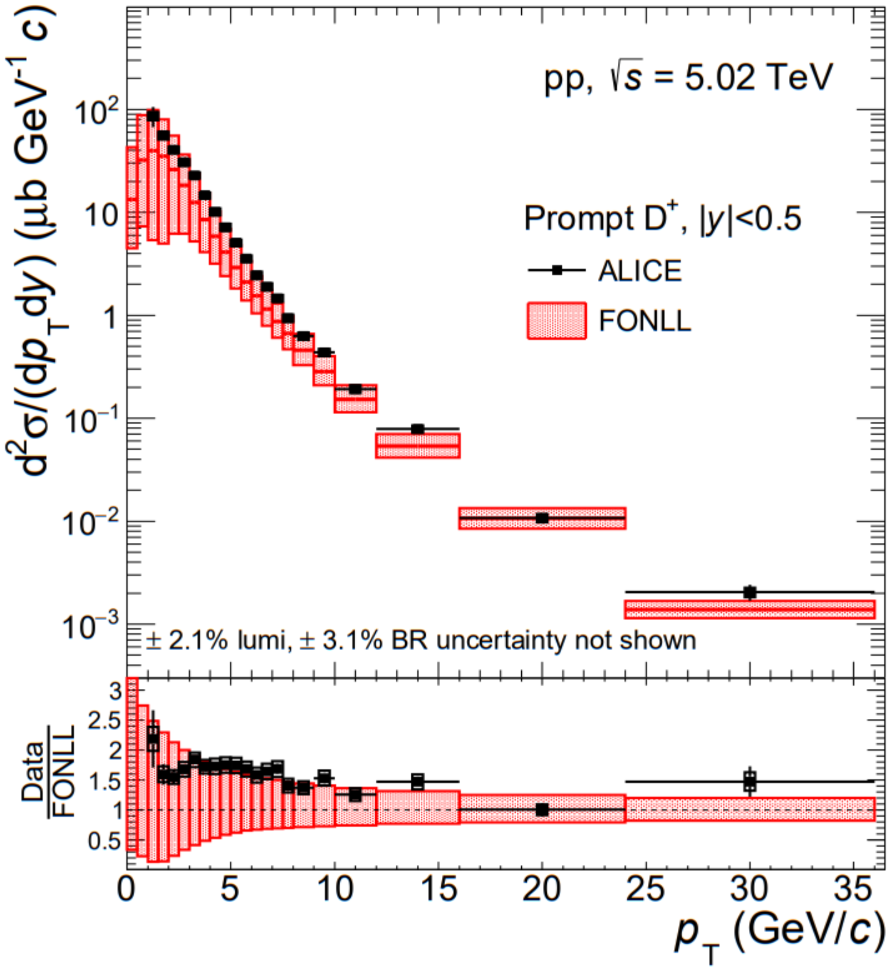
~ 350 μm, vertex resolution with more than 1000 tracks, by TPC; the precise 1/β extends PID power, TOF

Open heavy-flavour production plays **a unique role** in heavy-ion physics:

- Production restricted to **early collision stages (mainly gluon fusion)** and **retain a "memory"** of their evolution through the QGP
- 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 θ < m_Q/E_Q)
  - Collisional energy loss (**Brownian motion**)
- Heavy quarks **retain their flavour and mass identity**; can be "tagged" by the measurement of heavy-flavour hadrons

D^0 production cross section in p+p collisions



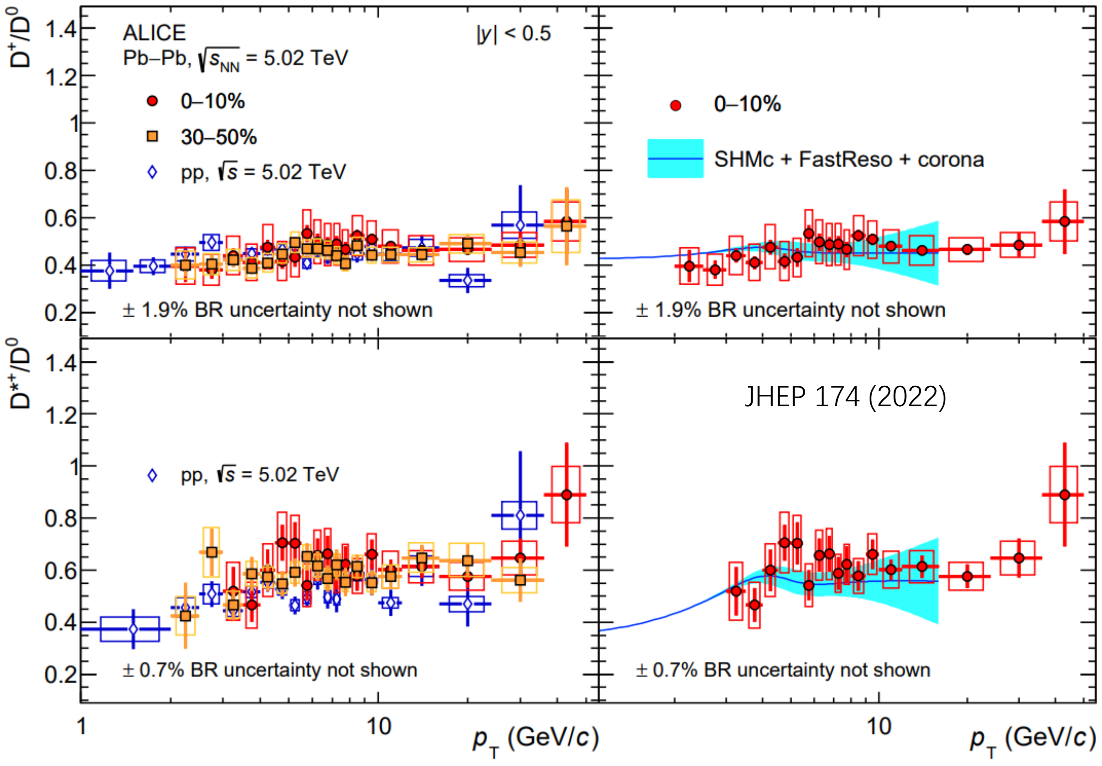


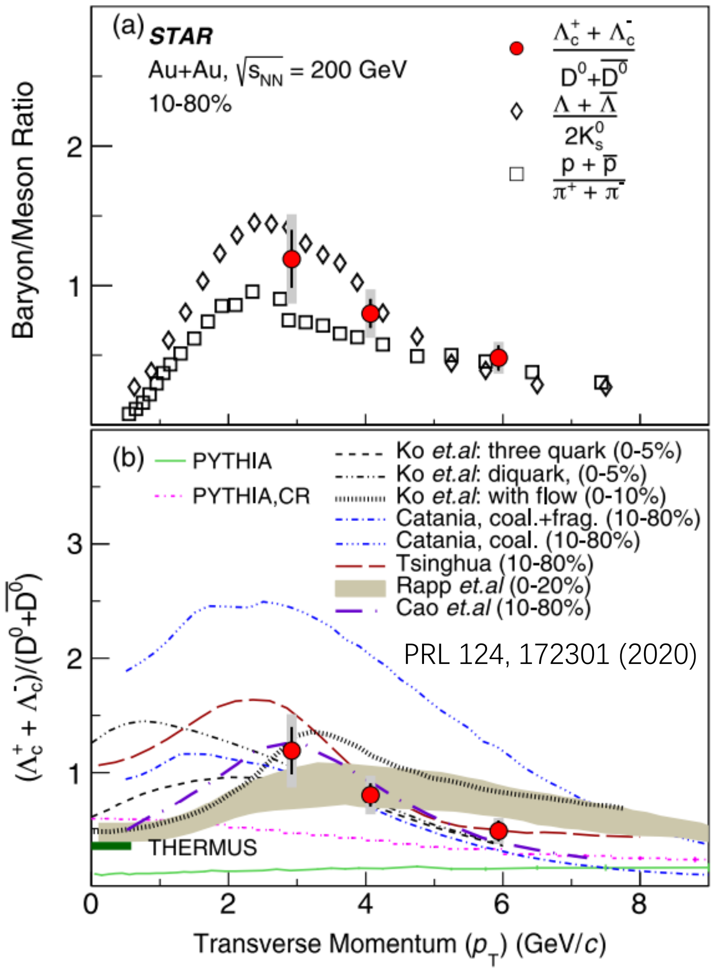
EPJC 79, 388 (2019)

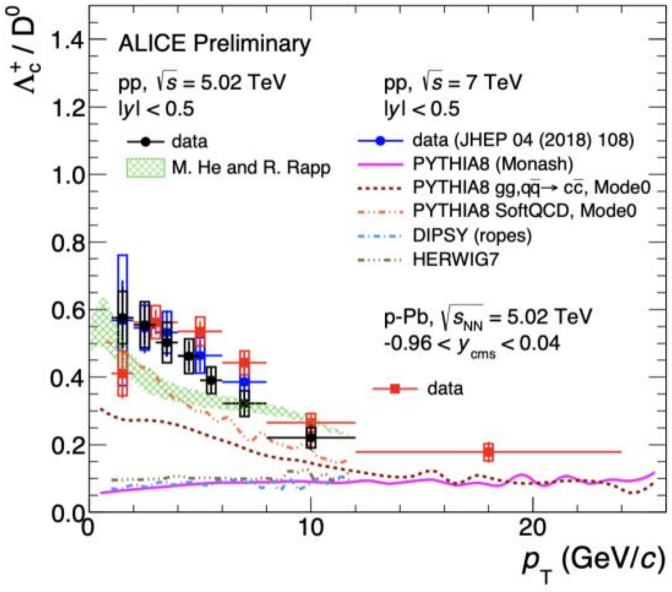
- pQCD calculations in p+p collisions, convolution
  - the parton distribution functions (PDFs) of the incoming protons
  - the partonic scattering cross section
  - the fragmentation function

- Measured down to $p_T = 0$ in central collisions
- provide important constraints to pQCD calculations and to low-x gluon PDFs
- Represent an essential reference for the study of effects induced by cold and hot strongly-interacting matter

Particle specie ratios in pp, p-Pb, Au-Au and Pb-Pb





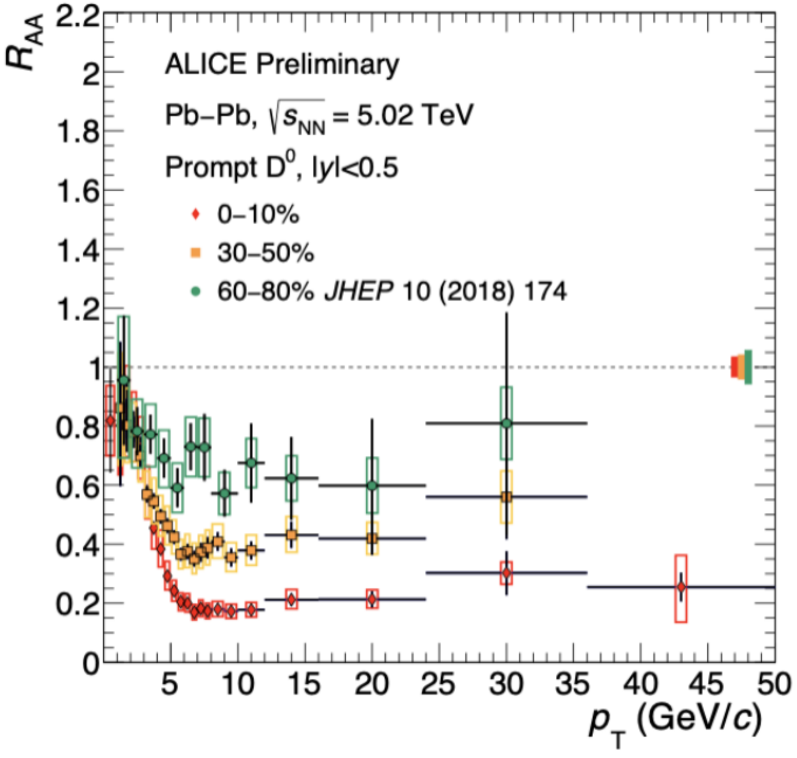


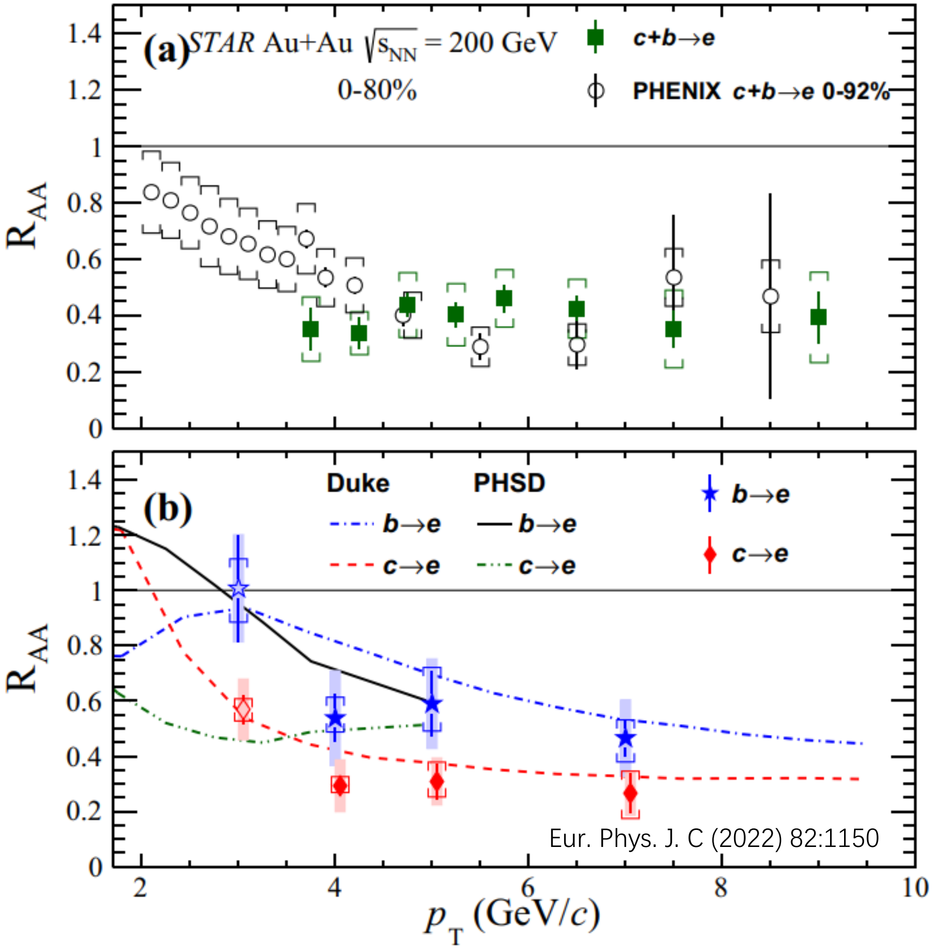
Journal of Physics 1602 (2020) 012031

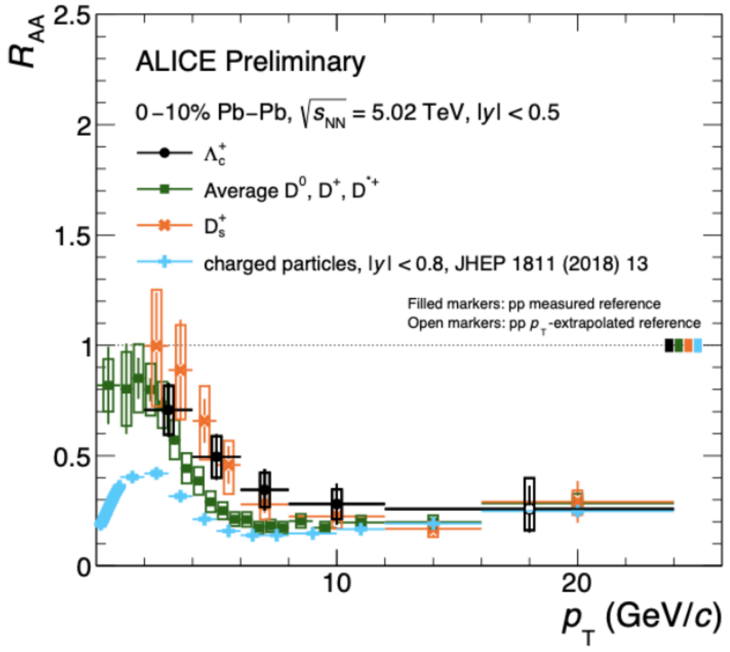
- Relative abundances
  - fragmentation fractions
  - hadronisation scenario (independent on system and energy)
- Universality of the fragmentation fractions for charm can not be ruled out in the meson sector.

- Λ_c/D^0 yield ratio is comparable to the baryon-to-meson ratios for light and strange-flavor hadrons
- Baryons contribute significantly to the total charm cross section
- Fragmentation fractions of charm quarks are non-universal

Energy loss mechanisms and Mass ordering







- Measured down to $p_T = 0$ in central collisions
- A large suppression is observed at low-intermediate p_T, and it is larger for the most central class
- Bottom decay electron R_{AA} to be significantly higher than those of charm-decay electrons
- $R_{AA}(\text{gluons, u, d}) < R_{AA}(\text{c}) < R_{AA}(\text{b})$

Outline

- Motivation and STAR Experiment
- Energy loss
  - Measurements of D^0 p_T spectra and R_{AA} in isobar collisions at $\sqrt{s_{NN}} = 200$ at RHIC
- Collectivity
  - Measurement of D^0 elliptic flow v_2 at mid-rapidity in isobar collisions
- Research plan
- Summary

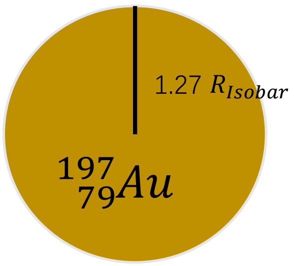
Energy loss in the QGP medium

- Nuclear modification factor

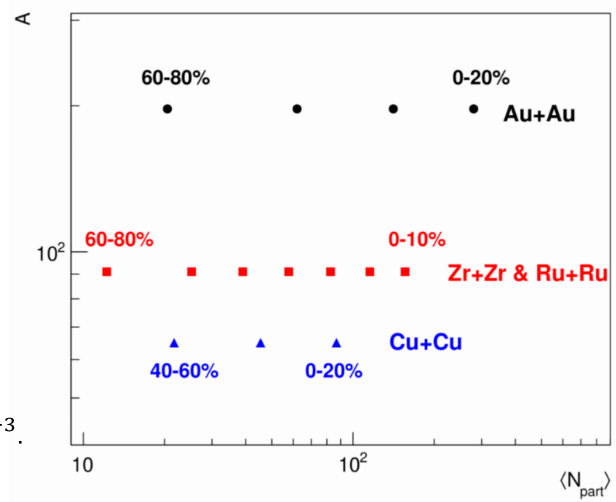
$$R_{AA} = \frac{d^2N_{AA}^{D^0}/dp_T dy}{< T_{AA} > d^2\sigma^{PP}/dp_T dy} = \frac{\sigma_{inel}^{NN} d^2N_{AA}^{D^0}/dp_T dy}{< N_{coll} > d^2\sigma^{PP}/dp_T dy}$$

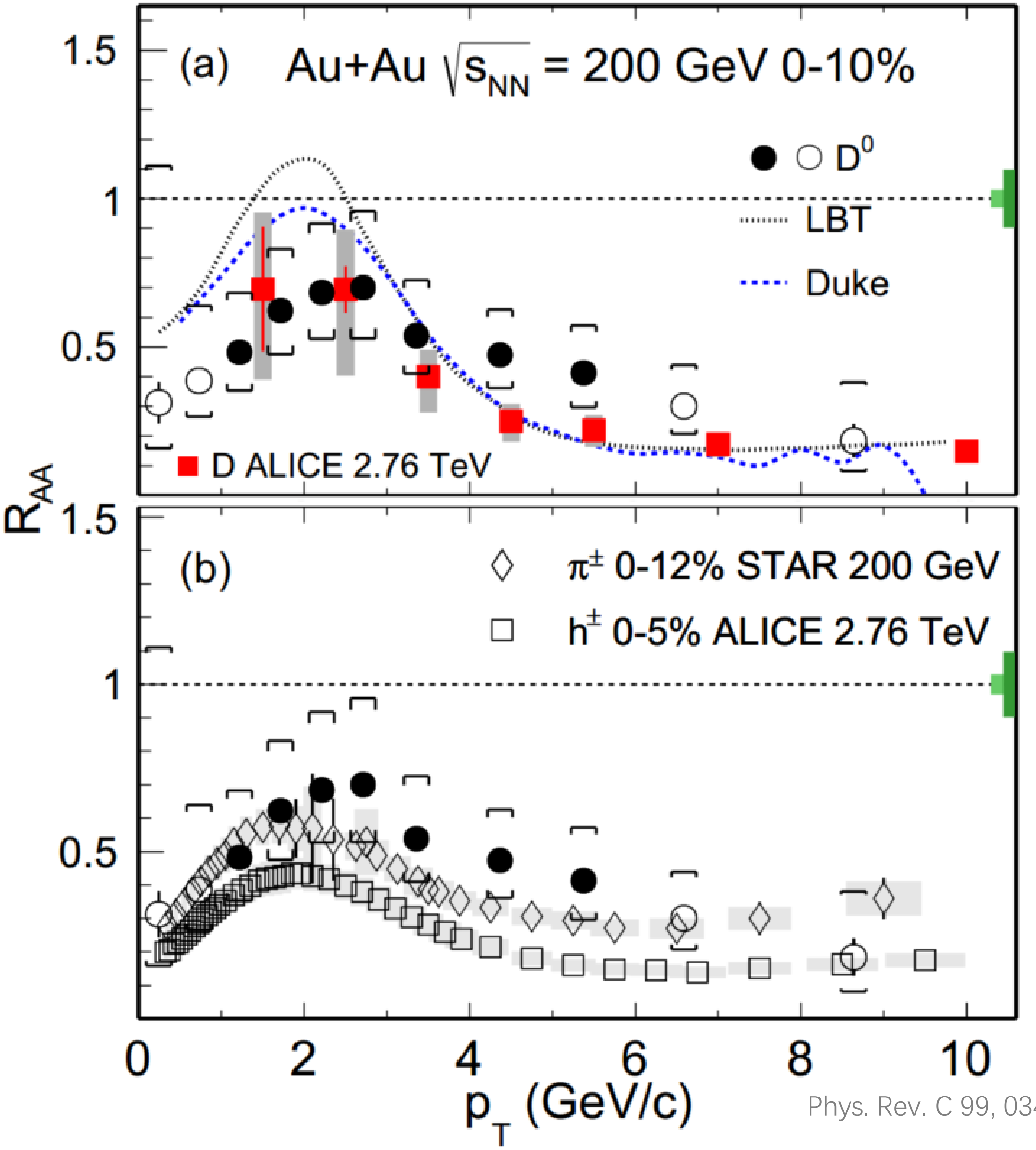
$$R_{CP} = \frac{d^2N}{N_{bin}\, dp_T\, dy}\Big|_{central} \Big/ \frac{d^2N}{N_{bin}\, dp_T\, dy}\Big|_{peripheral}$$

- Suppression level comparable to that of light hadrons in 0-10%
- A significant energy loss of charm quarks in isobar collisions?
- The N_{bin}-scale effect of the D^0 p_T spectra between isobar and Au-Au collisions?



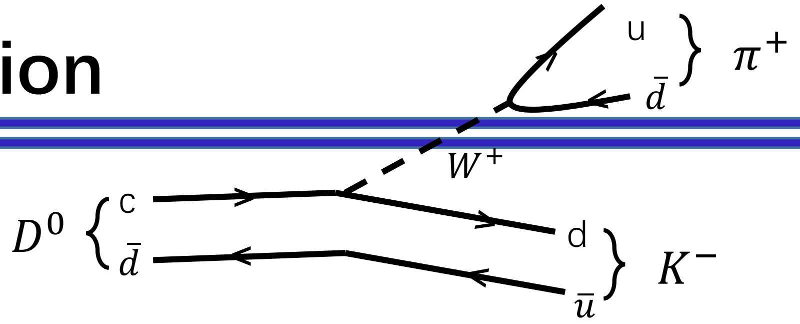
$R = R_0(A)^{1/3}, R_0 = 1.3\ Fermi$
The mass density for nucleus is $2.04 * 10^{17}$ kg·m^{-3}.



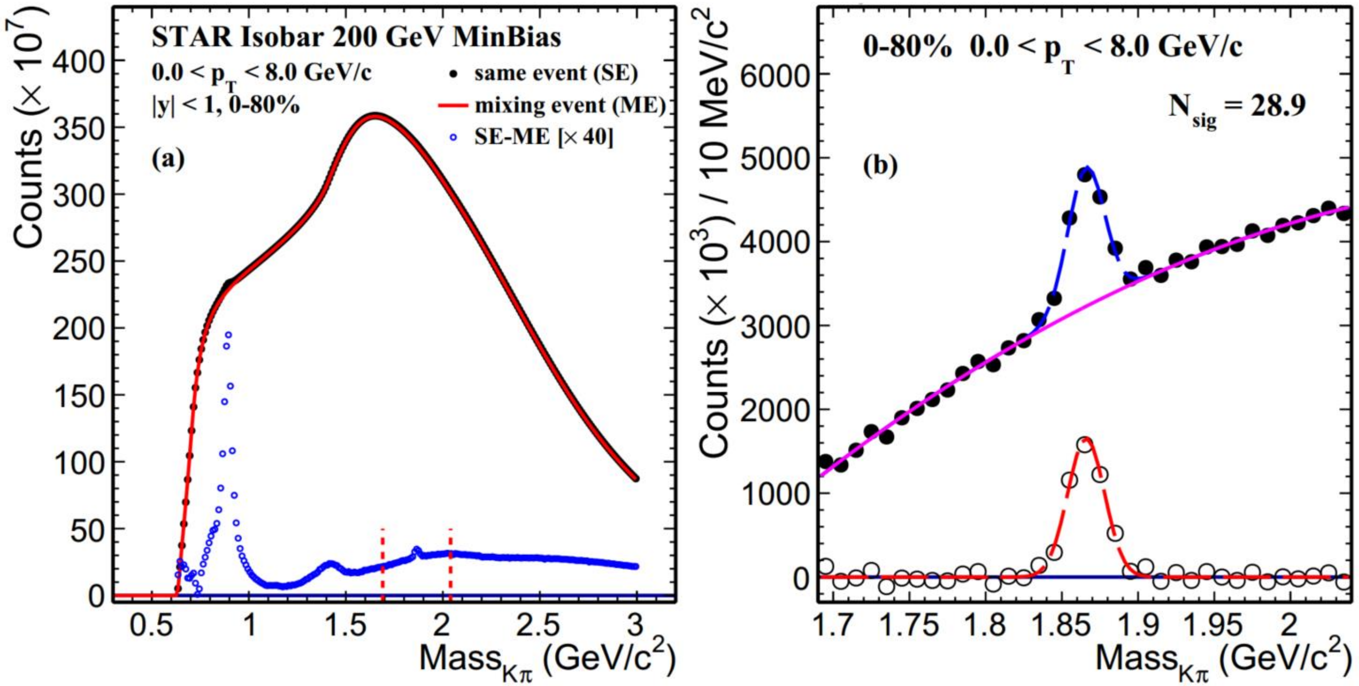


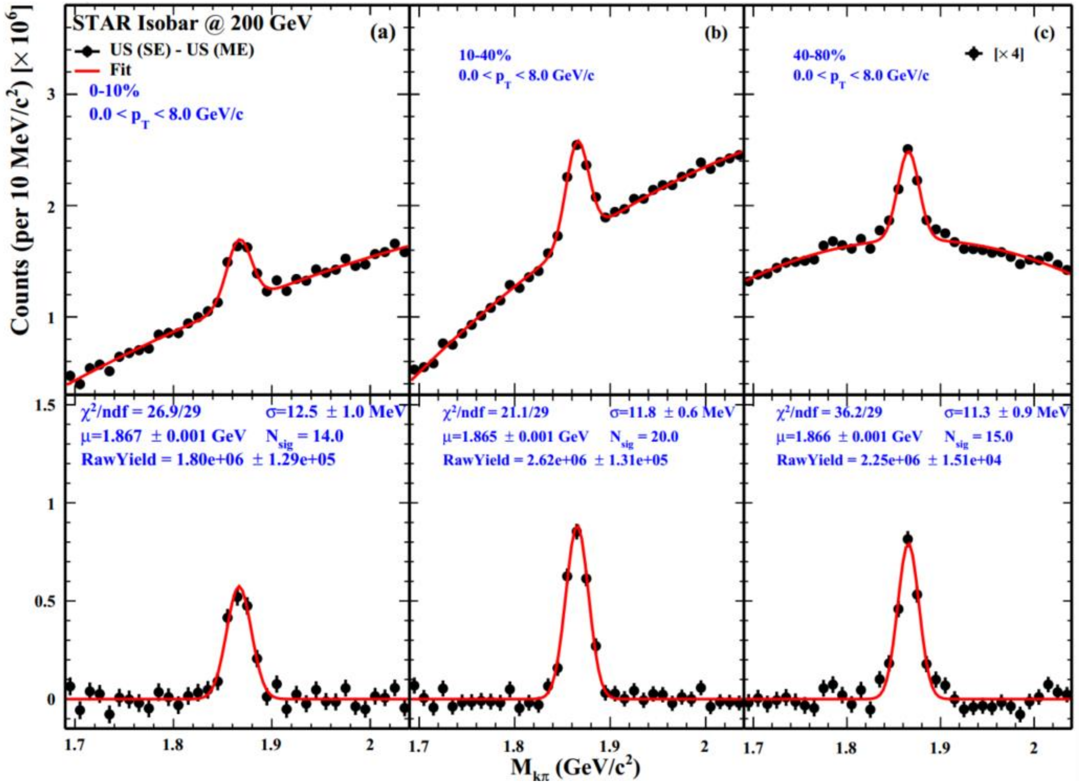
Phys. Rev. C 99, 034908

D^0 signal reconstruction



hadronic modes: $D^0 \rightarrow K^- + \pi^+$; $\overline{D}^0 \rightarrow K^+ + \pi^-$ (Γ_i/Γ ~ 3.95%)





- The K, π invariant mass distribution with centrality 0-80% and p_T range 0-8 GeV/c at midrapidity.
- The mix-event method can well reproduce the combination background (solid red line).

- D^0 signal at 0-10% (a), 10-40% (b), 40-80% (c) centrality bins with transverse momentum range 0-8 GeV/c at midrapidity.

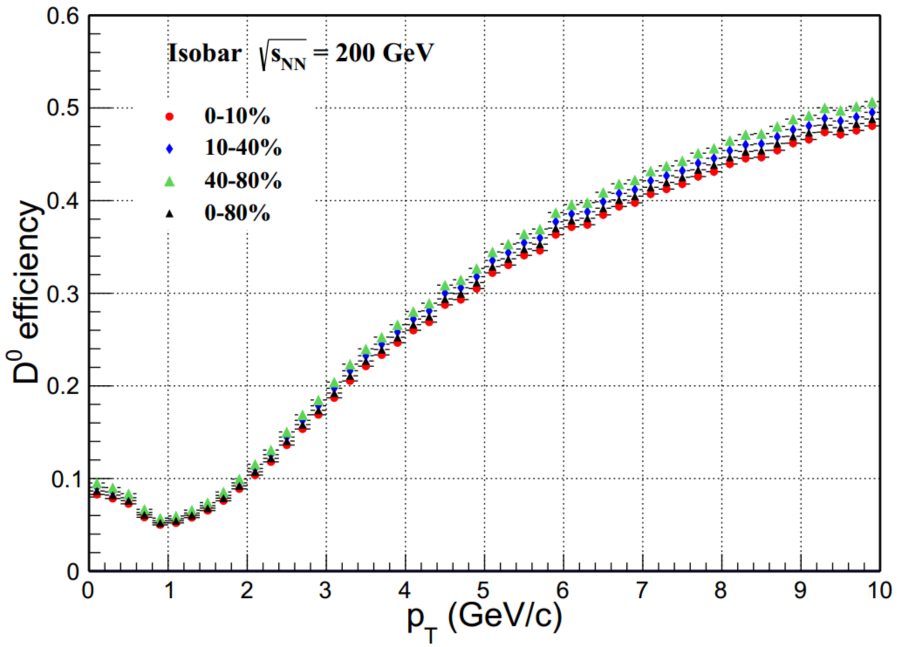
Efficiency correction procedures

$$\frac{d^2 N}{2\pi p_T dp_T dy} = \frac{\Delta N^{raw}/\epsilon_{D^0}^{reco}/2}{2\pi p_T \Delta p_T \Delta y \times N_{events} \times B.R.}$$

$$\epsilon_{D^0}^{reco} = \epsilon_{Accept} \times \epsilon_{TPC} \times \epsilon_{PID}$$

$$\epsilon_{PID} = \epsilon_{n\sigma_X} \cdot \epsilon_{TOF} \cdot \epsilon_{n\sigma_X^{TOF}} + \epsilon_{n\sigma_X} \cdot (1 - \epsilon_{TOF})$$

- ΔN^{raw} : the raw yield measured in the bin $\Delta p_T \Delta y$;
- $\epsilon_{Accept} \times \epsilon_{TPC}$: TPC acceptance and tracking efficiency (embedding);
- ϵ_{PID} : particle identification efficiency (data, K_s^0, ϕ, Λ^0).



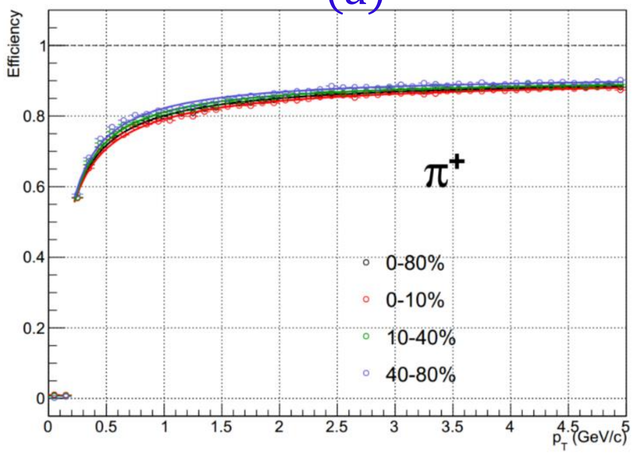
◉ D^0 efficiency as a function of D^0 transverse momentum at different centrality bins.

◉ (a) TPC tracking efficiency for Pion

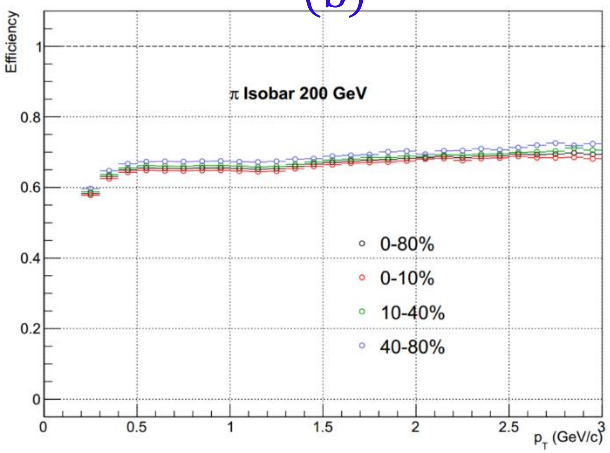
◉ (b) TOF matching efficiency for Pion

◉ (c) Pion TPC PID efficiency (black circles) and TOF PID efficiency (red circles)

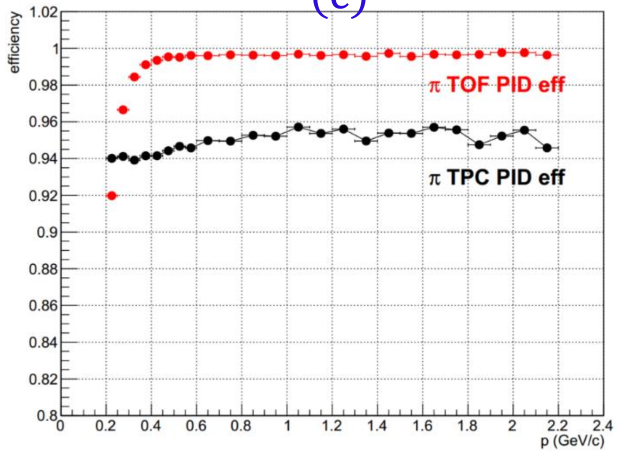
(a)



(b)



(c)



Systematic uncertainties

- Signal extraction
  - The difference between the fitting and counting methods (1.69, 2.04) GeV/c^2;
  - The order of polynomial function to depict the residual background (Pol3);
  - Signal fit range (1.73, 2.00) GeV/c^2;
  - p_T cut variation for daughter particles;
  - Mix-event like-sign normalization factor

- TPC tracking
  - DCA: 2cm (default);
  - nHitsFit: 20 (default)
- PID cuts 3%
- B.R. 0.5%
- p + p inelastic scattering cross section 8%

Systematic uncertainties in D^0 analysis

		0-10%	10-40%	40-80%	Correlation in pT
spectra	Raw yield	11.3-19.6%	10.0-14.0%	8.3-11.2 %	uncorrelated
	Double counting	0.7%	0.8%	0.9%	uncorrelated
	PID	3%	3%	3%	Largely correlated
	TPC	2-6%	2-6%	2-6%	Largely correlated
	B.R.	0.5%	0.5%	0.5%	global
R_{AA}	<Nbin>	1.6%	0.6%	0.4%	global
	ppbase	20.6-71.8%	20.6-71.8%	20.6-71.8%	partially correlated
Rcp (/40-80%)		0-10%		10-40%	
	Raw yield	13.6-20.7%		12.4-16.5 %	uncorrelated
	B.R.	0		0	global
	TPC	0		0	Largely correlated
Integrated cross section		pt>0		pt >4 GeV/c	
	Total	12.7-15.8%		12.0-15.2 %	

p_T Spectra and Integrated yields

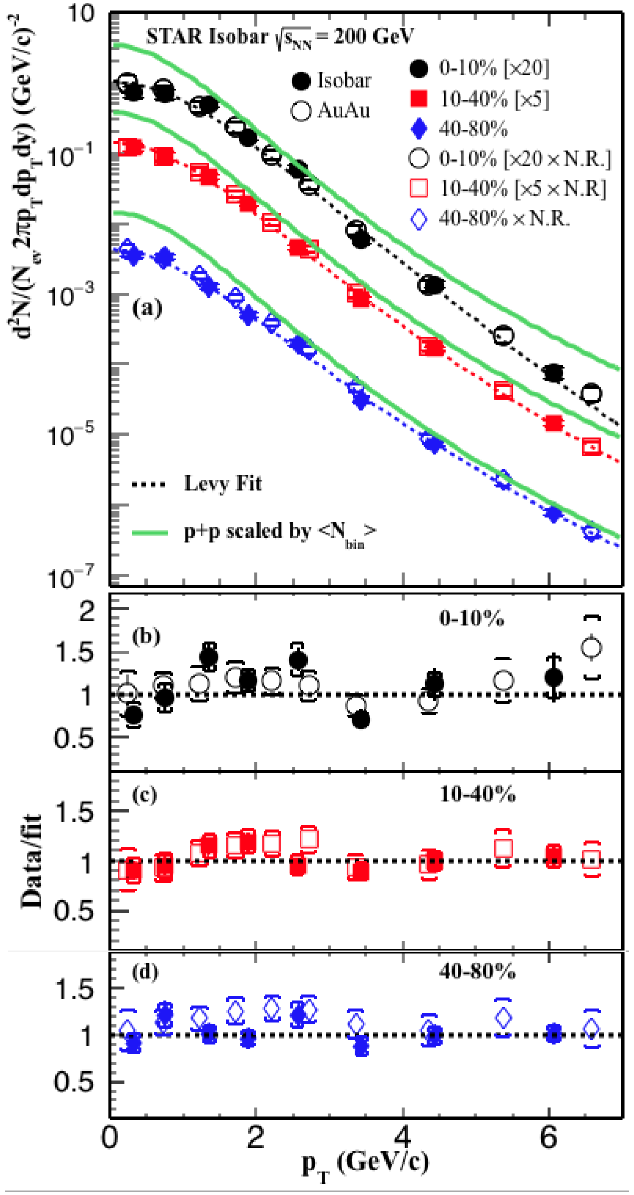
$$E\frac{d^3N}{d\boldsymbol{p}^3} = \frac{d^3N}{p_T dp_T dy d\phi} = \frac{d^2N}{2\pi p_T dp_T dy}$$

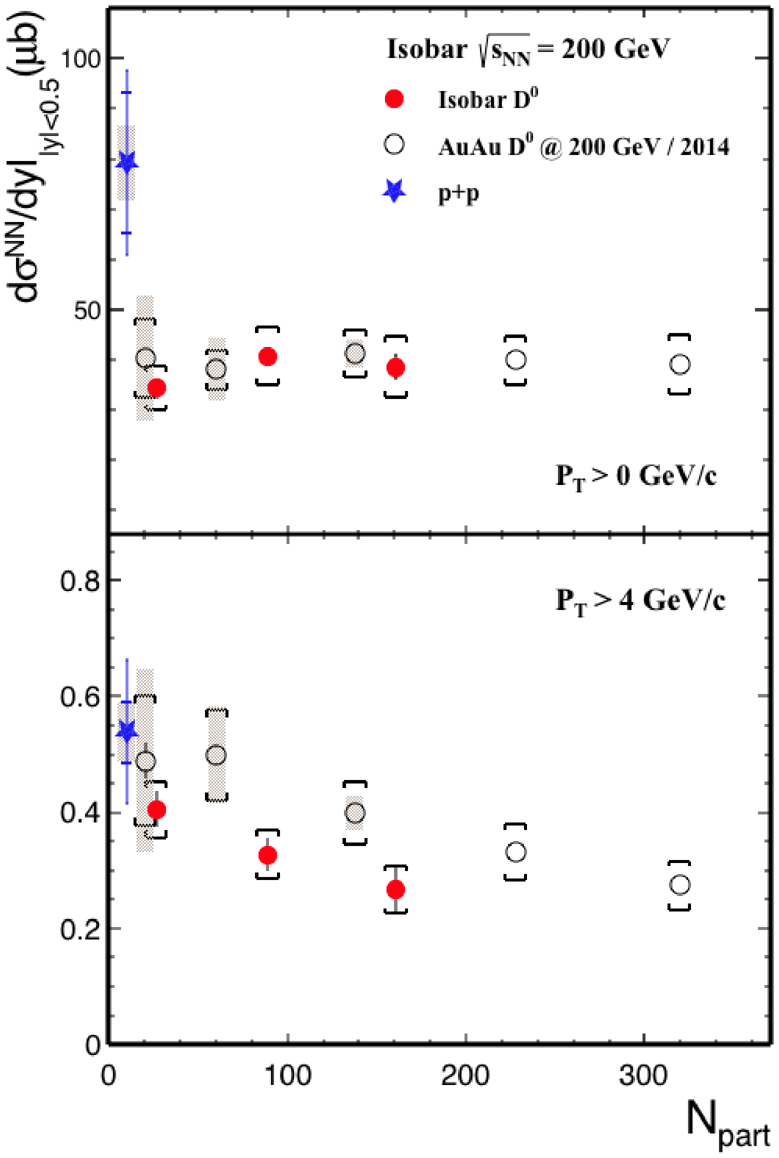
$$\frac{d^2\,N}{2\pi p_T dp_T dy} = \frac{\Delta N^{raw}/\epsilon_{D^0}^{tot}/2}{2\pi p_T \Delta p_T \Delta y \times N_{events} \times B.R.} = \frac{\Delta N_{D^0}^{AA}}{2\pi p_T \Delta p_T \Delta y} = E\frac{d^3\sigma_{D^0}^{AA}}{d\boldsymbol{p}^3}$$

- D^0 invariant yields at mid-rapidity (|y|<1) vs. transverse momentum for different centrality classes in isobar (solid) and Au + Au (open) collisions at $\sqrt{s_{NN}}$ = 200 GeV.

- D^0 integrated corss sections per nucleon-nucleon collision in isobar.

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

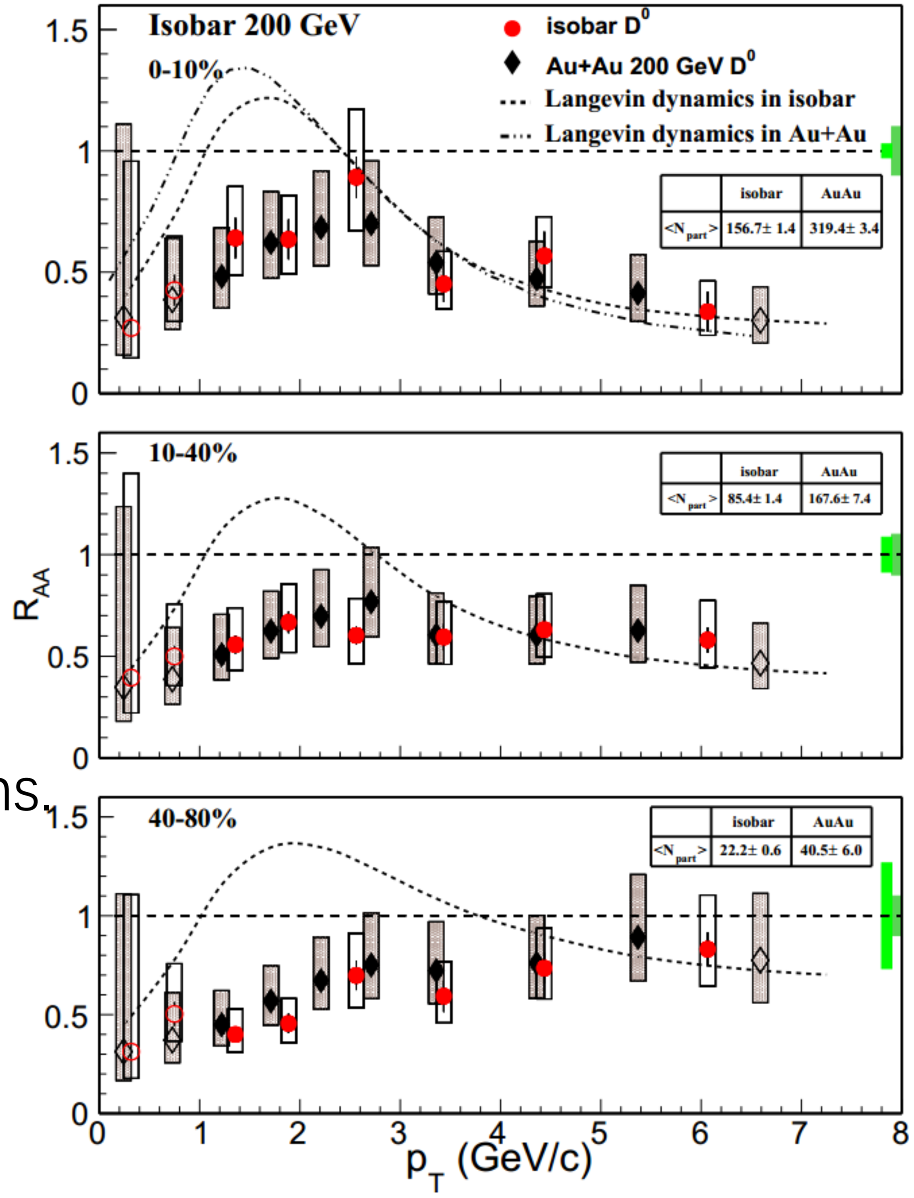


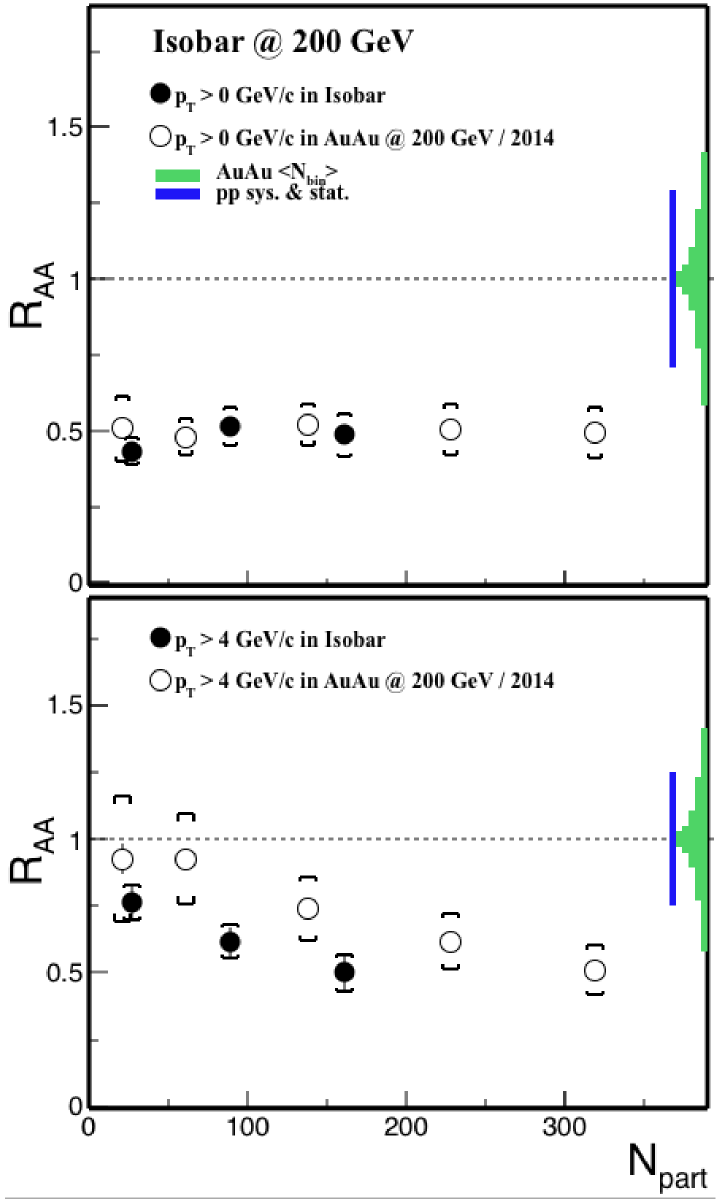


R_{AA} and R_{AA} vs. N_{part}

- D^0 R_{AA} for different centrality classes in isobar collisions compared to that of Au + Au results.

- D^0 integrated R_{AA} vs. $\langle N_{part} \rangle$ for $p_T > 0$ and $p_T > 4$ GeV/c in isobar and Au + Au collisions.

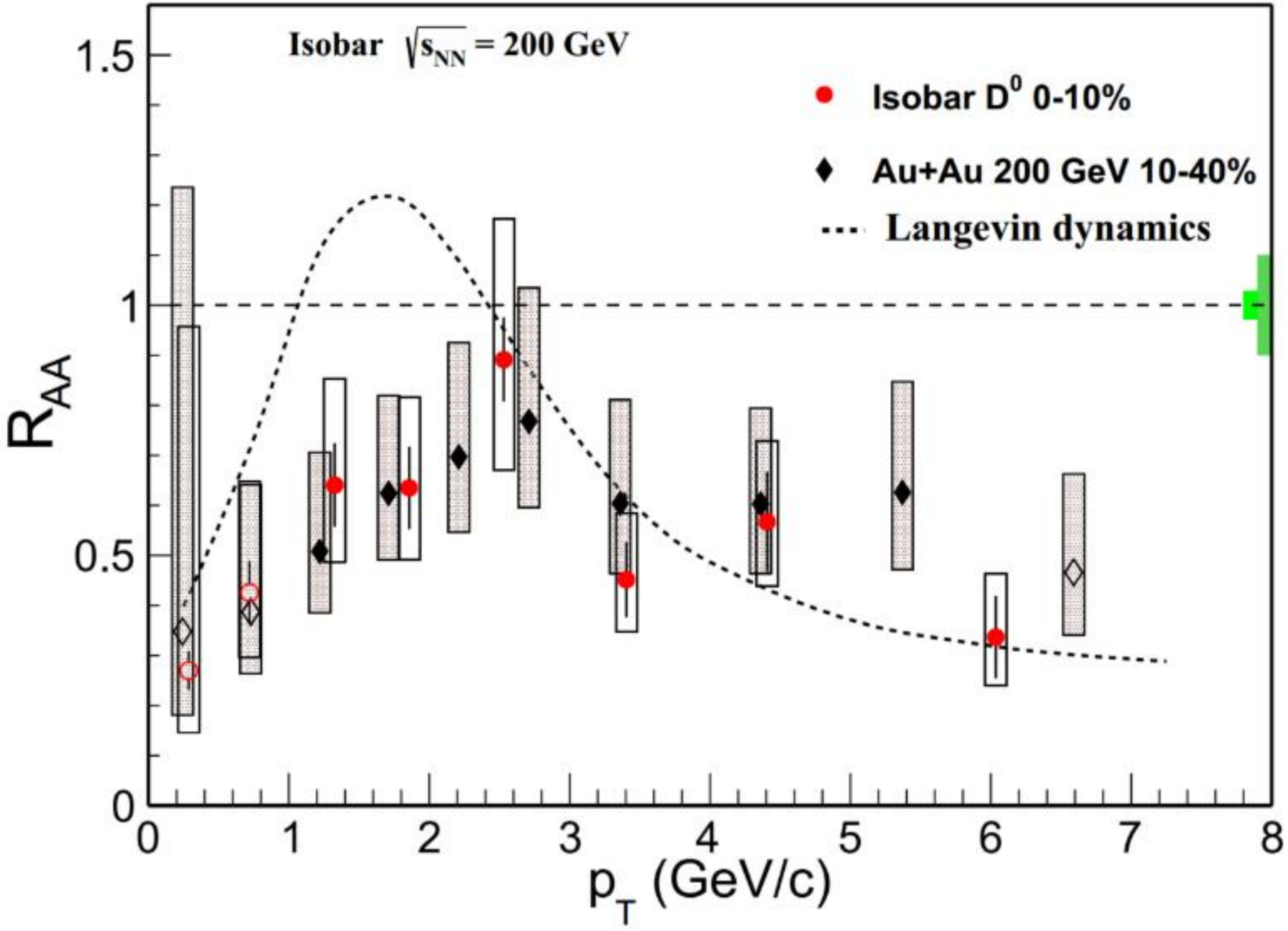




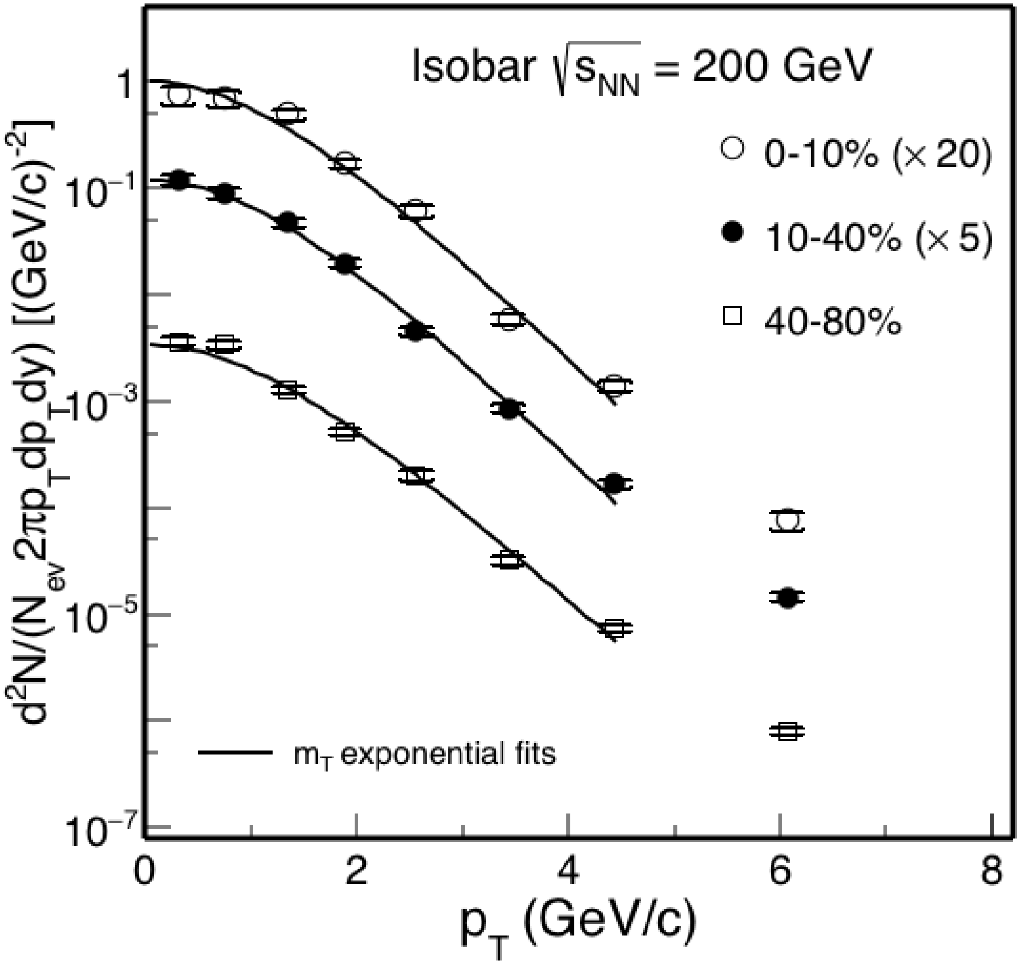
R_{AA} vs. p_T with similary $\langle N_{part} \rangle$

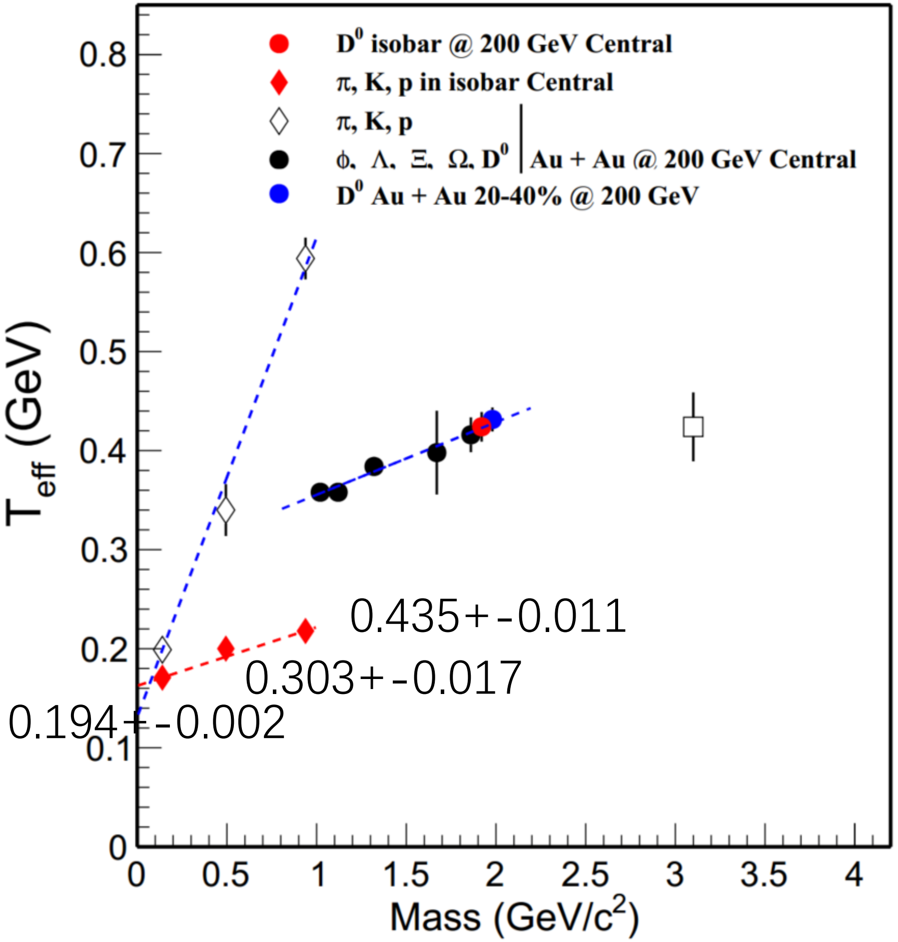
- D^0 R_{AA} for 0-10% in isobar collisions compared to that of Au + Au results for 10-40%.

- Due to the large uncertainty of the D^0 p_T spectrum in p + p collisions at $\sqrt{s_{NN}} = 200\ GeV$, more precise measurements are needed to determine whether the D^0 R_{AA} in isobar collisions agrees with that in Au + Au collisions at the same centrality or $\langle N_{part} \rangle$.



m_T Spectra and Collectivity

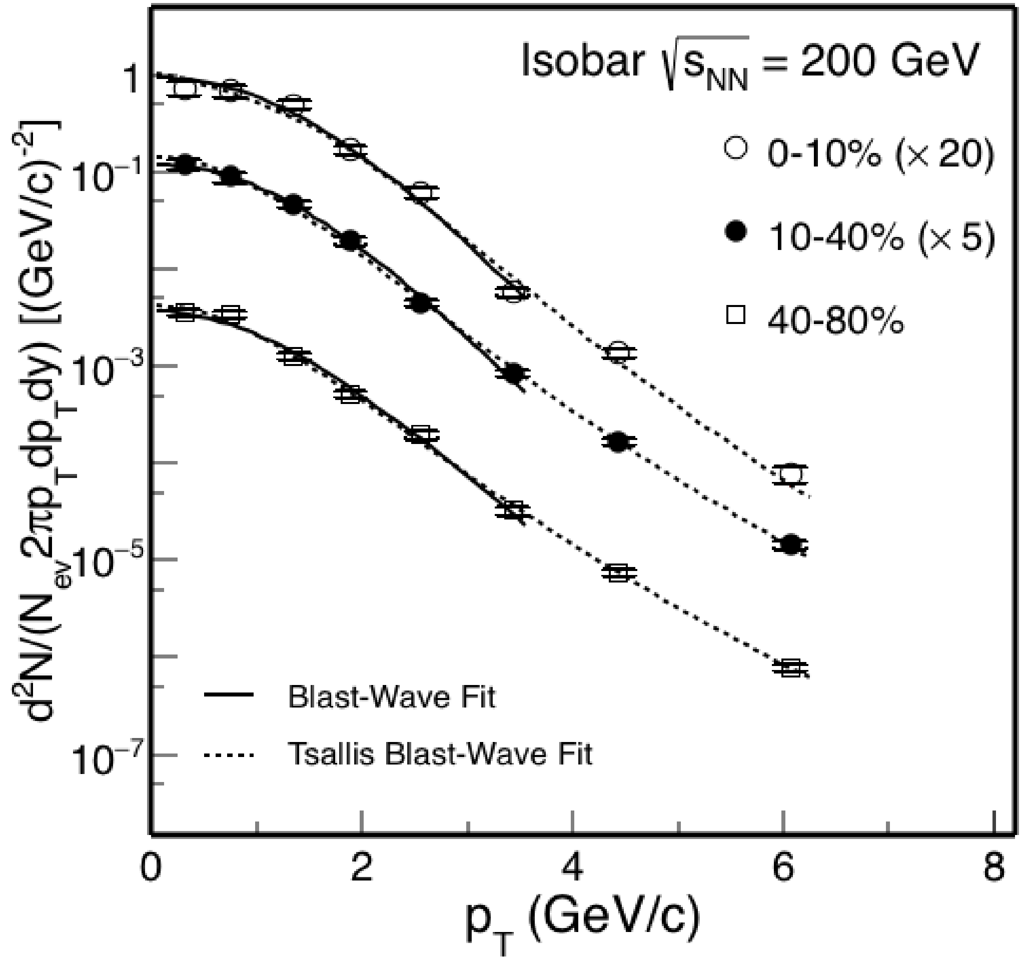


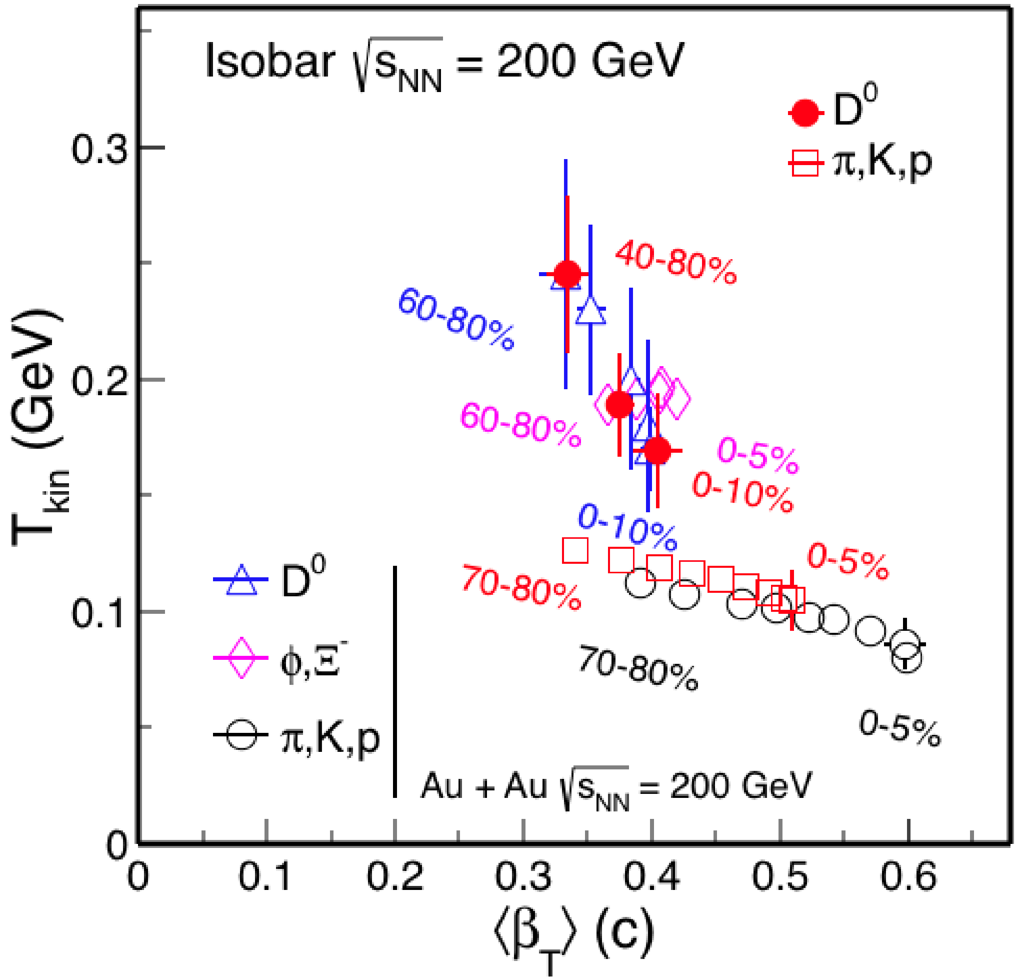


system	hadron	T_{eff}
isobar	π	0.176±0.001
	K	0.203±0.005
	p	0.218±0.001
	D^0	0.424±0.015
AuAu	π	0.199±0.002
	K	0.340±0.026
	p	0.594±0.020
	D^0	0.416±0.018
	D^0 (20-40%)	0.431±0.012

- D^0 invariant yield at mid−rapidity (|y|<1) vs. p_T for different centrality bins fitted with m_T distribution.
- T_{eff} for D^0 in central isobar collisions is consistent with that of Au + Au results. The red rhombus from left to right show the fit results of π, K, and proton in isobar collisions respectively.

Blast – Wave Fits





- D^0 invariant yield at mid−rapidity(|y|<1) vs. p_T for different centrality bins fitted with blast-wave function.
- D^0 freeze out temperature in isobar collisions are consistent with that of in Au + Au collisions for the same centrality. The open red circles from left to right shows the result of fitting π, K, and proton simultaneously from peripheral to central collisons.
- The average flow velocity increases with central collision, and (q −1) is also found to be close to zero.

Tsallis blast-wave model fits parameters to D^0 p_T-differential spectra in isobar collisions.

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

Summary — D^0 p_T spectra and R_{AA}

- D^0-meson productions are firstly measured at mid-rapidity (|y| < 1) in 200 GeV isobar collisions
- The number of binary collisions scale effect of D^0 production cross section between isobar and Au + Au collisions is observed
- The strong suppression of D^0 nuclear modification factor R_{AA} is observed for p_T > 3 GeV/c in central isobar collisions, demonstrating that charm quarks suffer significant energy loss in the QGP. Consistent with that in Au+Au collisions with similar multiplicities.
- No significant systematic dependence of D^0 kinetic freeze-out properties in central collisions between isobar and Au + Au collisions within uncertainties is observed.

Outline

- Motivation and STAR Experiment
- Energy loss
  - Measurements of D^0 p_T spectra and R_{AA} in isobar collisions at $\sqrt{s_{NN}} = 200$ at RHIC
- Collectivity
  - Measurement of D^0 elliptic flow v_2 at mid-rapidity in isobar collisions
- Research plan
- Summary

Collective flow in heavy-ion collisions

Acceleration of collective flow

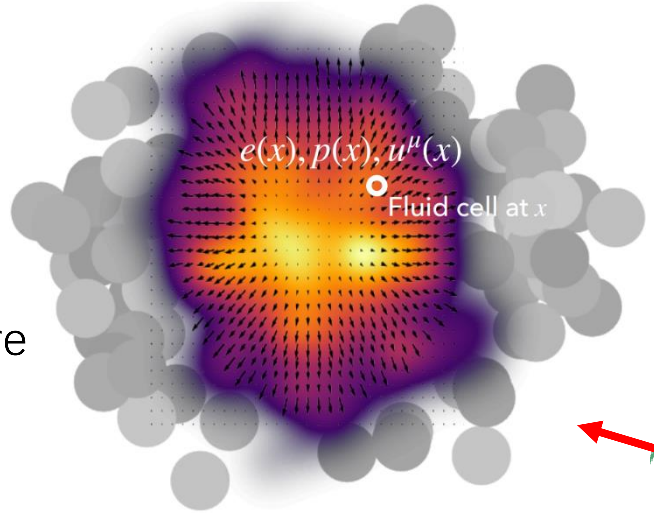
$$u^{\nu}\partial_{\nu}u^{\rho} = \frac{\Delta^{\rho\nu}\partial_{\nu}P}{e+P}$$ Euler equation

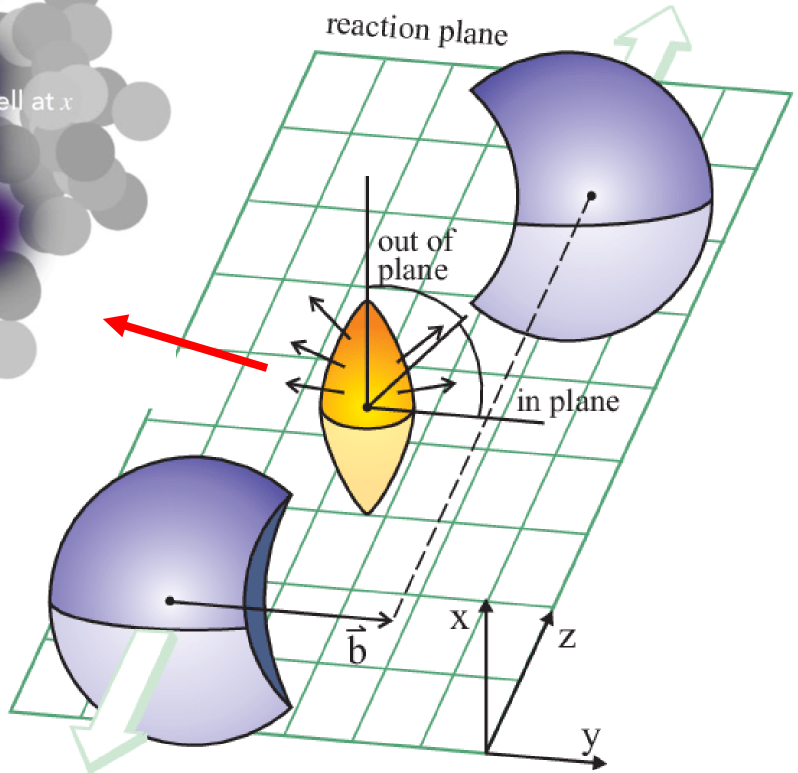
$$\partial_t u^i = \frac{\partial^i P}{e+P}$$

$\partial^i P$ → Spatial gradient of pressure

$e+P$ → inertia of fluid

$\partial_t u^i$ → flow acceleration



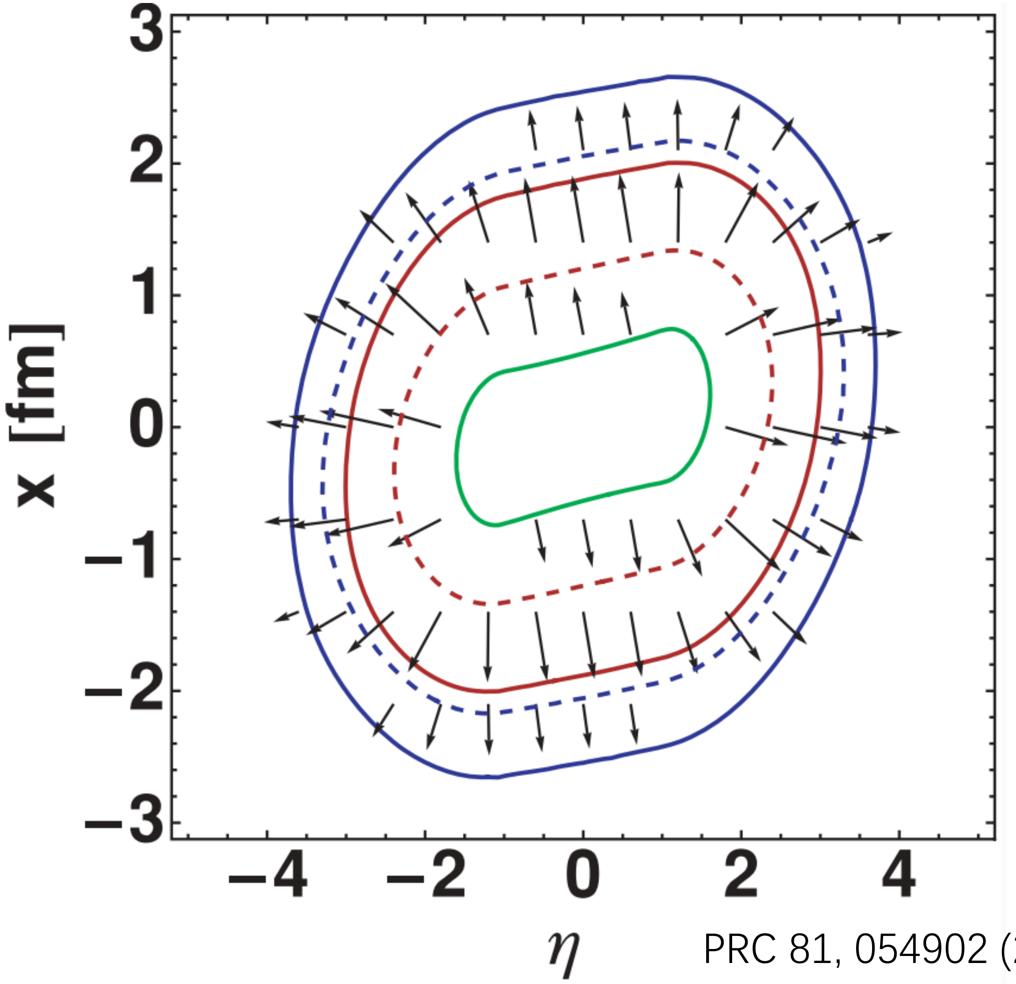


Pressure gradients drive the hydrodynamic expansion **Anisotropic flow & Anti-flow**

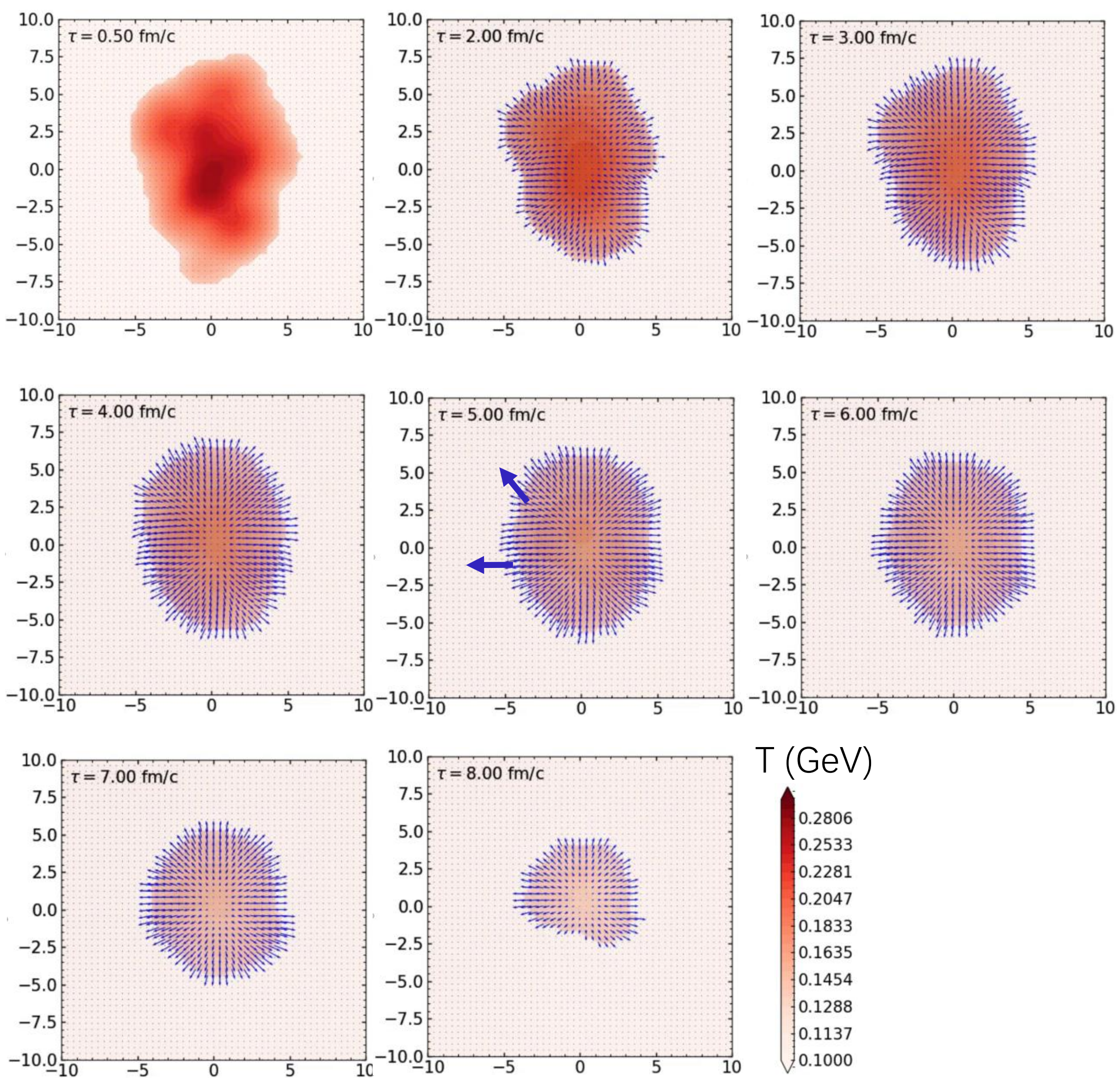
In-plane flow (direct flow) and Radial flow

- The tilted initial condition has a smooth tilted pressure gradient that gives a negative-directed flow
- Angle-averaged anisotropic flow

In-plane flow and Out-of-plane flow profile

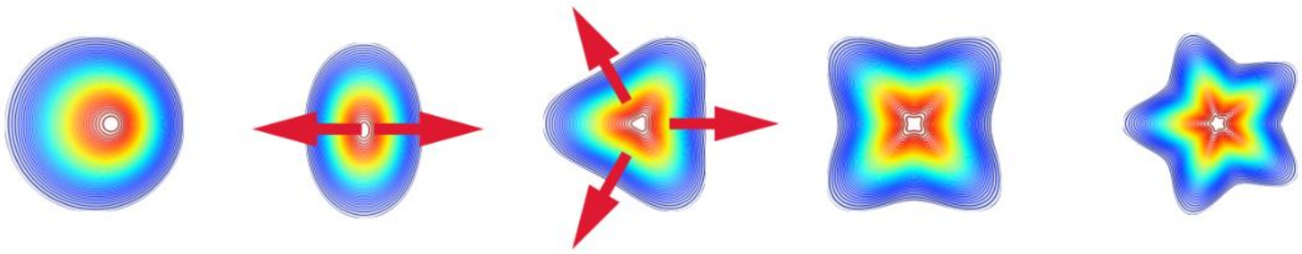


PRC 81, 054902 (2010)

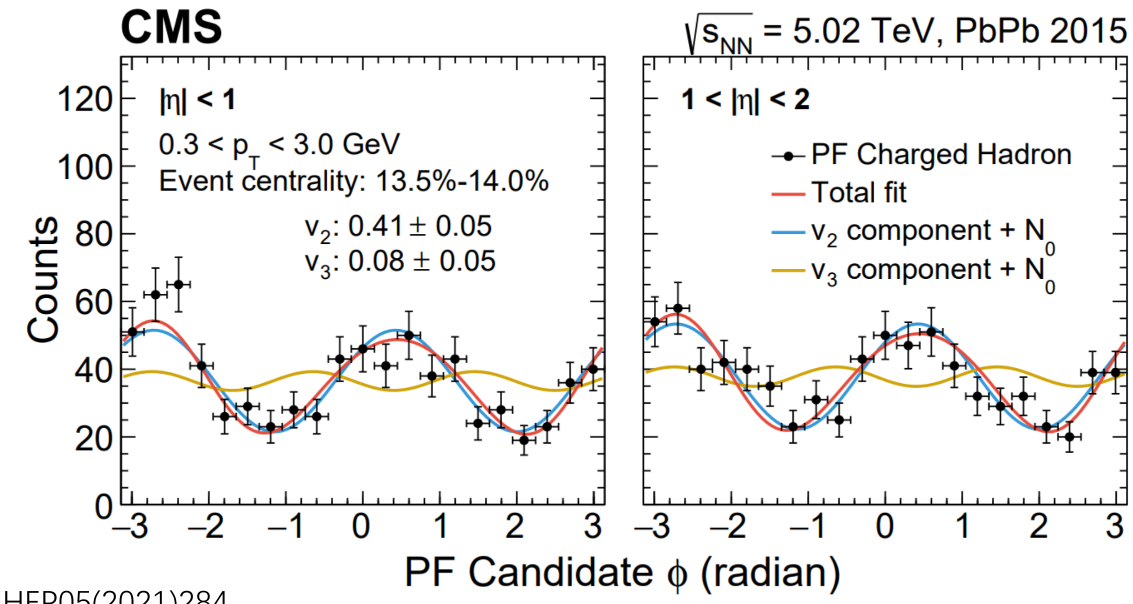


- A tilt of the initial source in the x-η plane for direct flow
- Animation for T and flow velocity in 200 GeV AuAu collisions for 20-30%

Anisotropic flow



initial fluctuating geometric deformation can be decomposed into spatial eccentricities



CMS, JHEP05(2021)284

Initial spatial eccentricities

$$\epsilon_n = \sqrt{\frac{\langle r^n \cos n\phi\rangle^2 + \langle r^n \sin n\phi\rangle^2}{\langle r^n\rangle^2}}$$

Average over energy density

ϵ_2 ellipticity, ϵ_3 triangularity, …

$$\frac{dN}{d\phi} = \frac{N}{2\pi}\left(1 + 2\sum_{n=1}^{\infty} v_n \cos[n(\phi - \Psi_n)]\right)$$

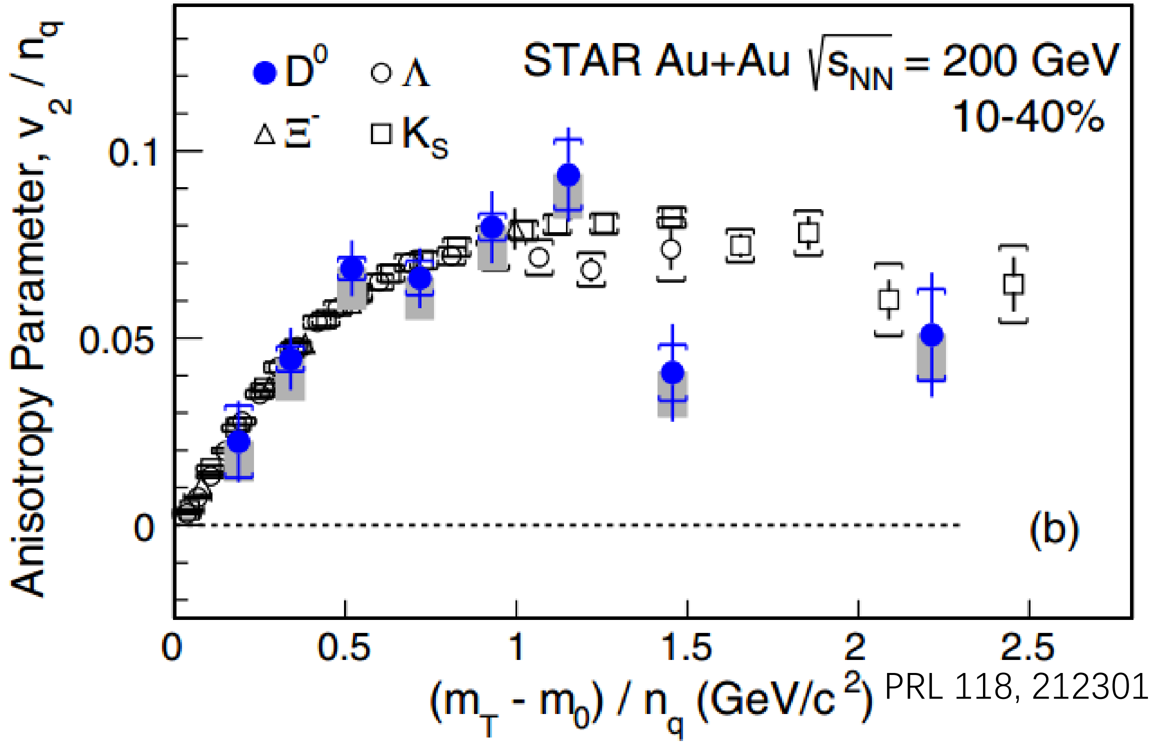
$$v_2 = \langle \cos[2(\phi - \Psi_2)]\rangle$$

average over azimuthal distribution

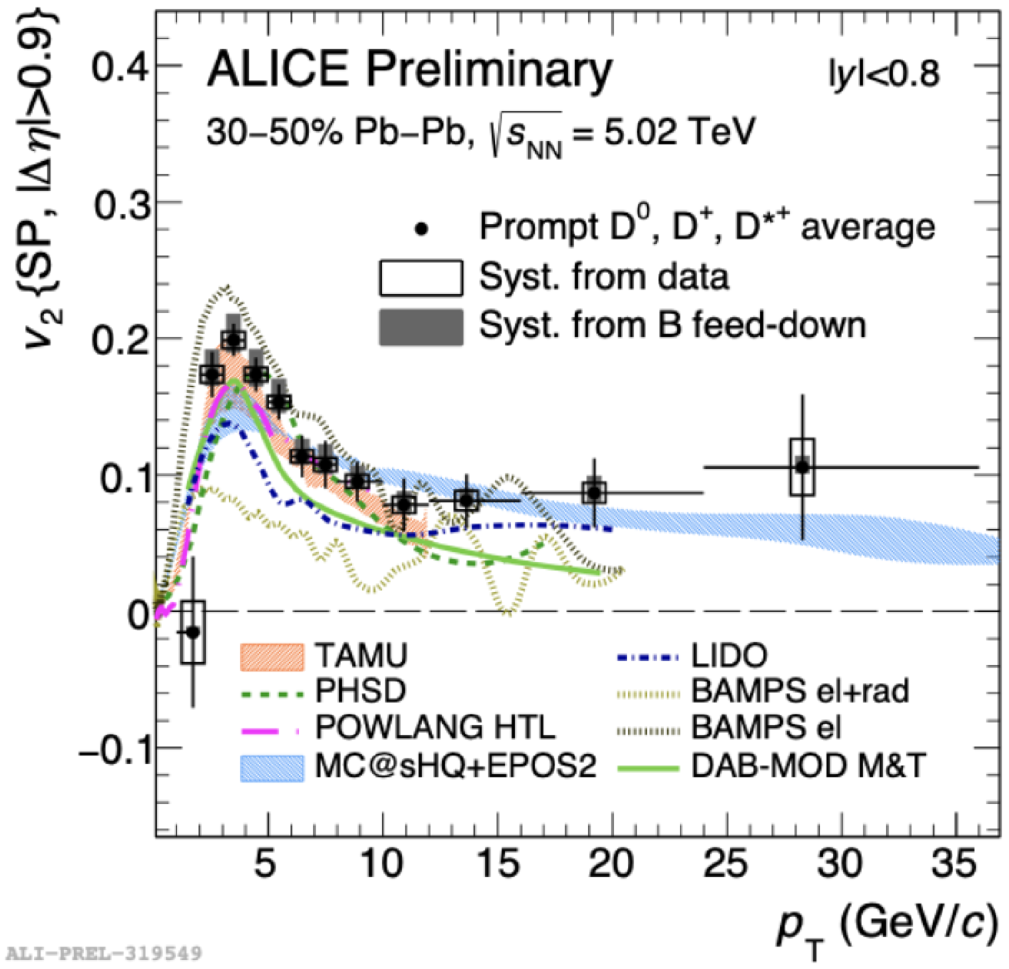
v_2 elliptic flow, v_3 triangular flow, …

v_2 is dominant and quantifies the azimuthal anisothropy

v_2 of open charm hadrons



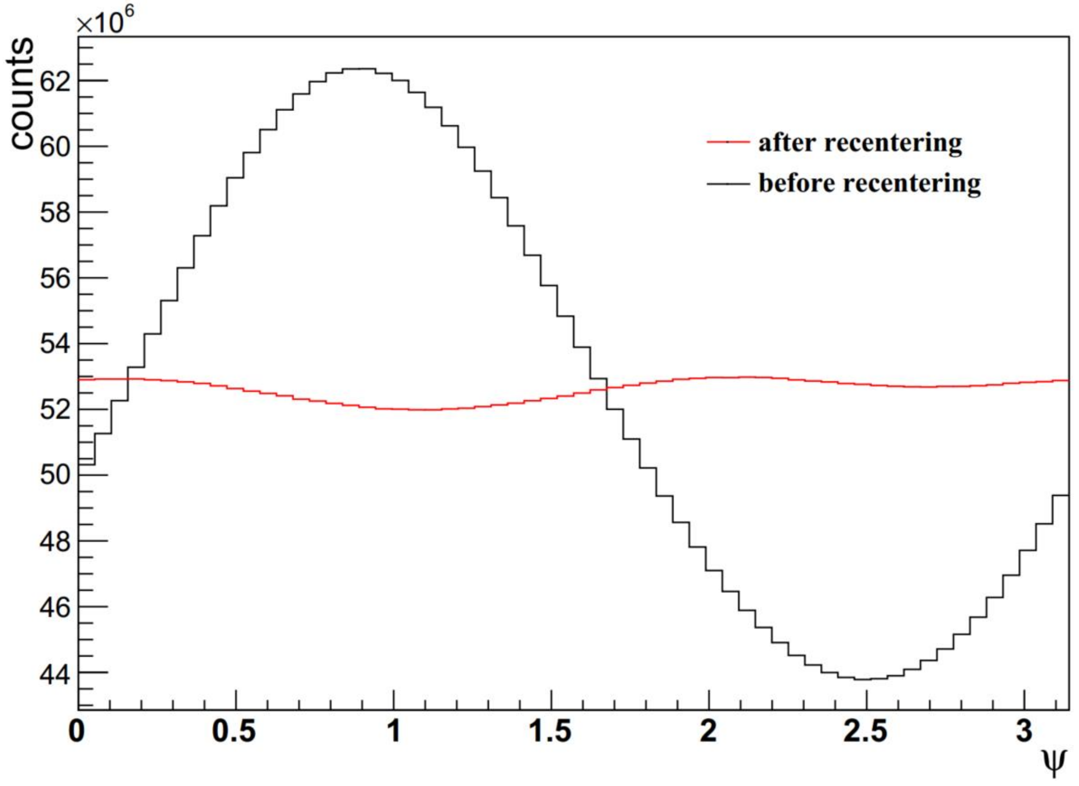
PRL 118, 212301 (2017)



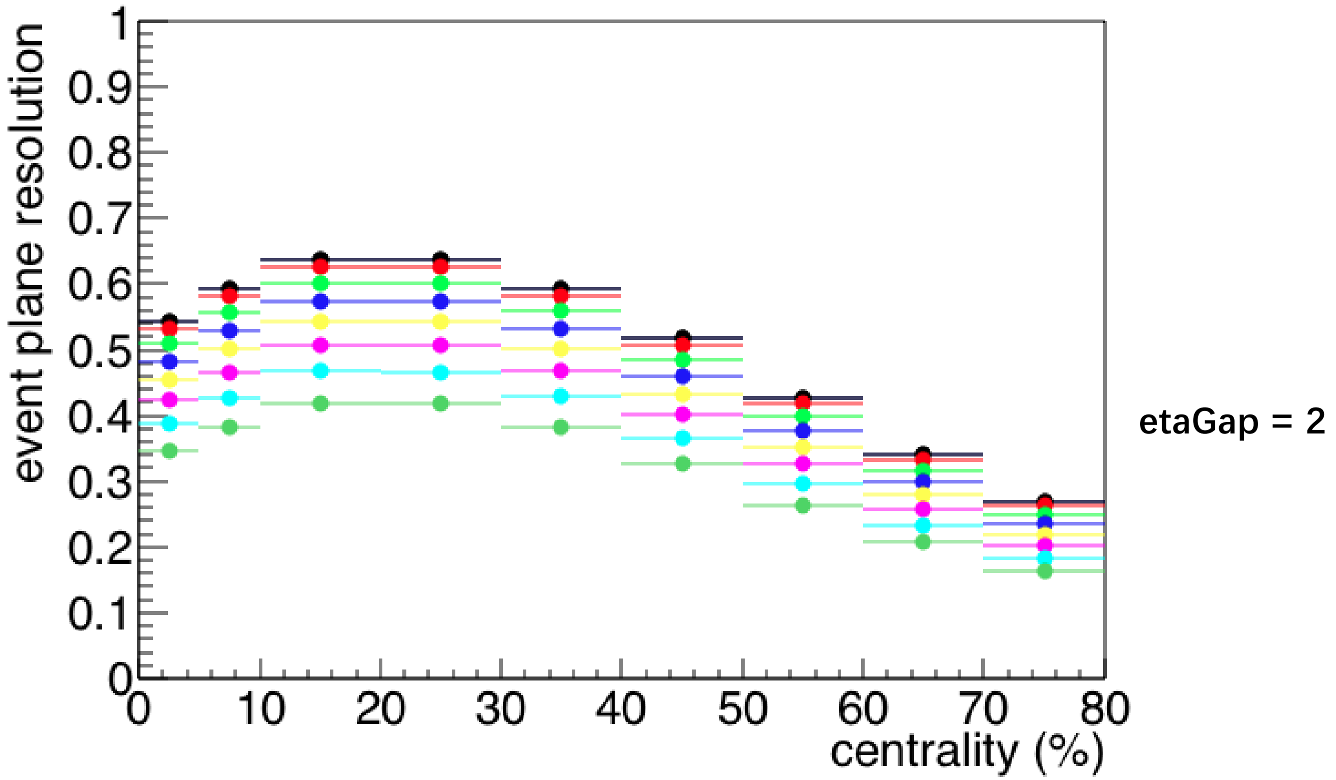
- A strong collective behavior and may be close to thermal equilibrium in 200 GeV Au+Au collisions.
- Charm quarks largely thermalise in the QGP

A expected smaller hot nuclei systems in Isobar, so v_2 depends on the system?
Charm quark gets thermalized in Isobar like in Au-Au at 200 GeV?

Event plane method to measure D^0 v_2

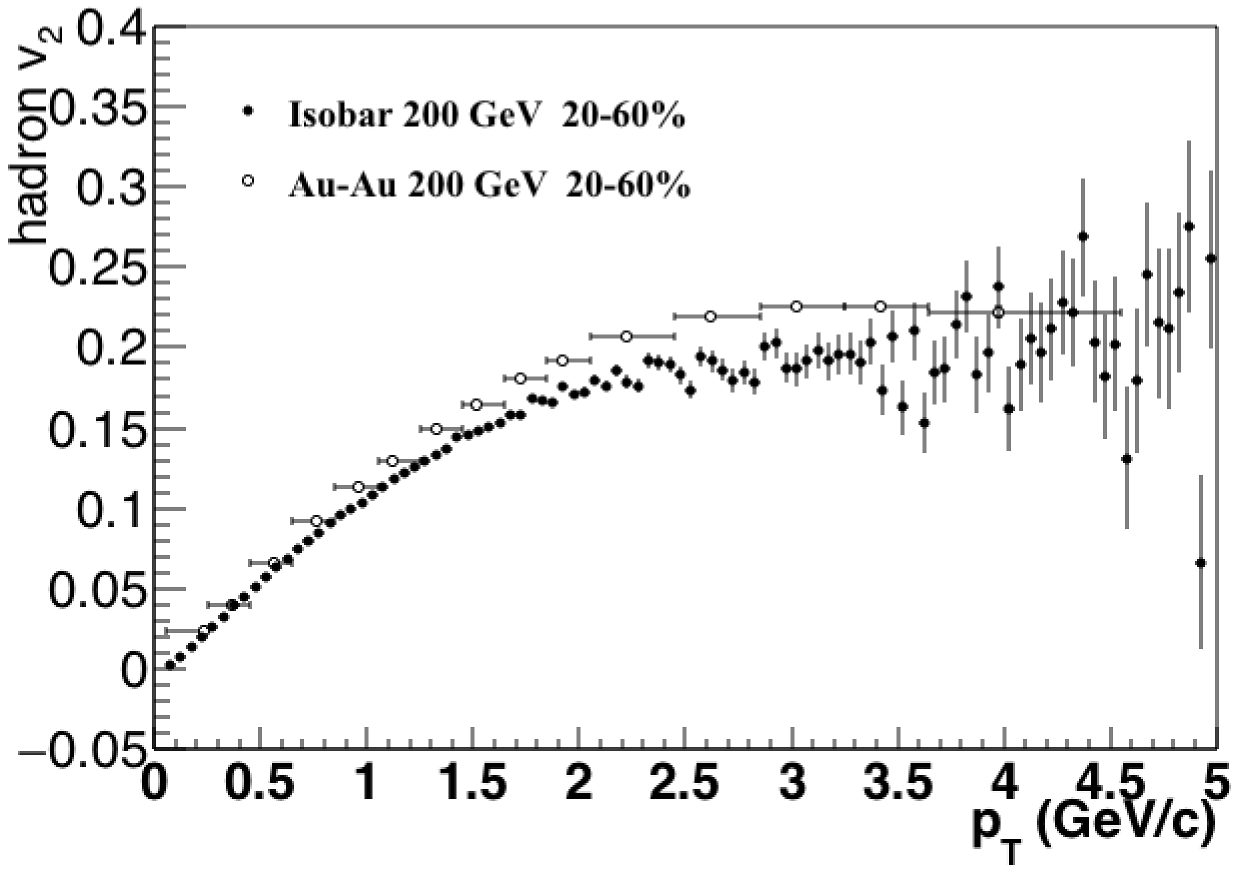


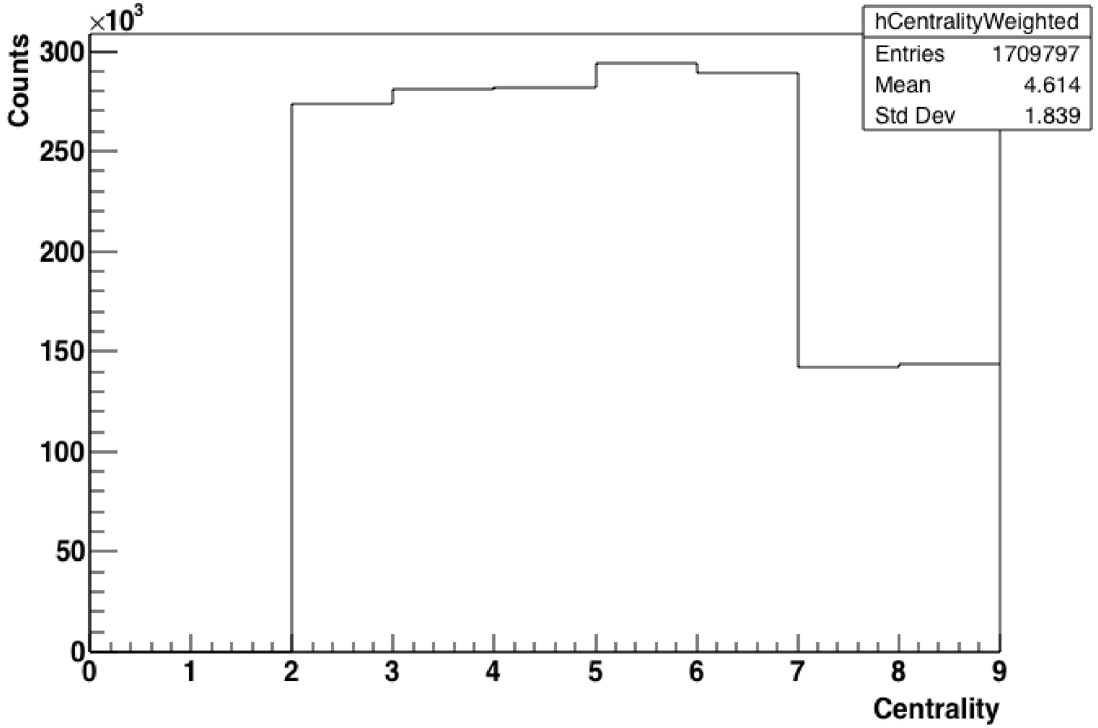
- Event plane reconstruction and recentering



- The different color markers represent different number of rejected 0.1 η bins around the D^0 candidate: black: 0; red: 1; light green: 3; blue: 5...dark green: 13

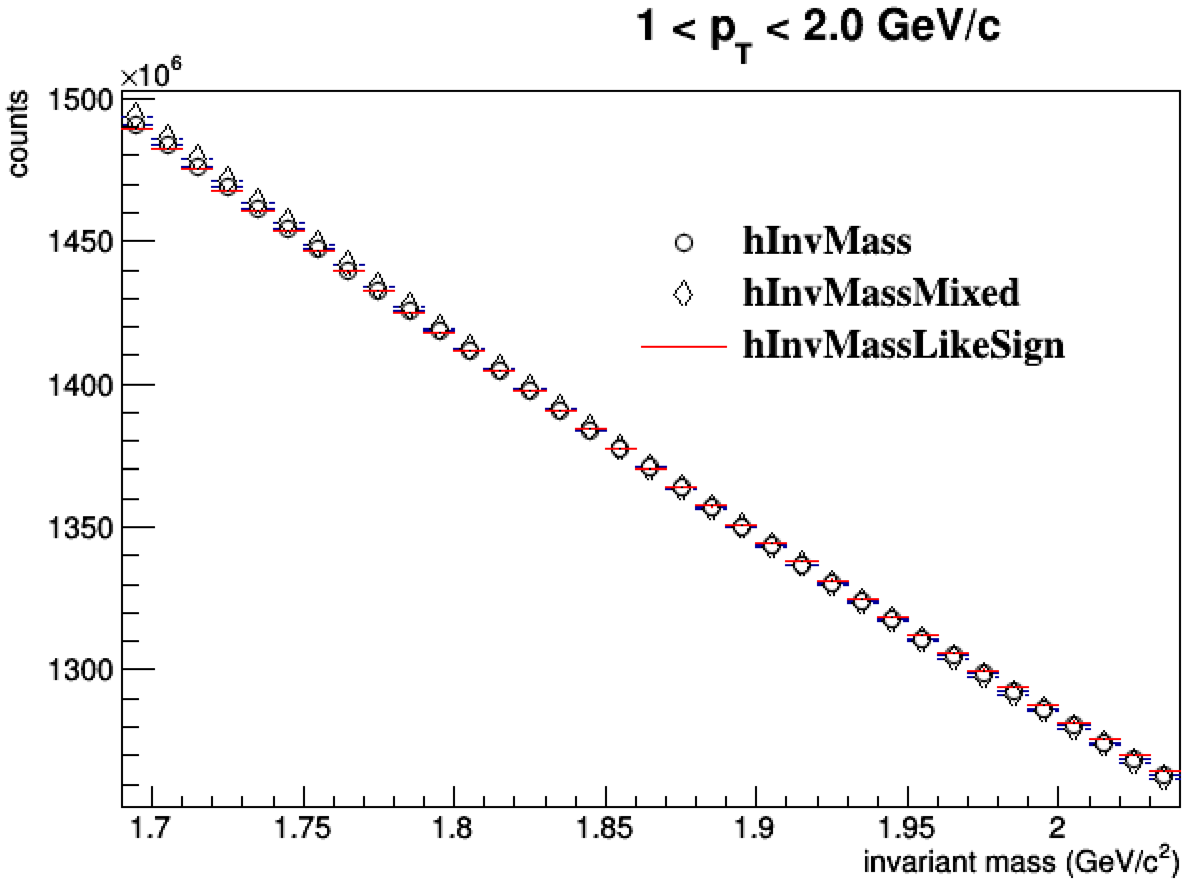
Hadron v_2 in isobar

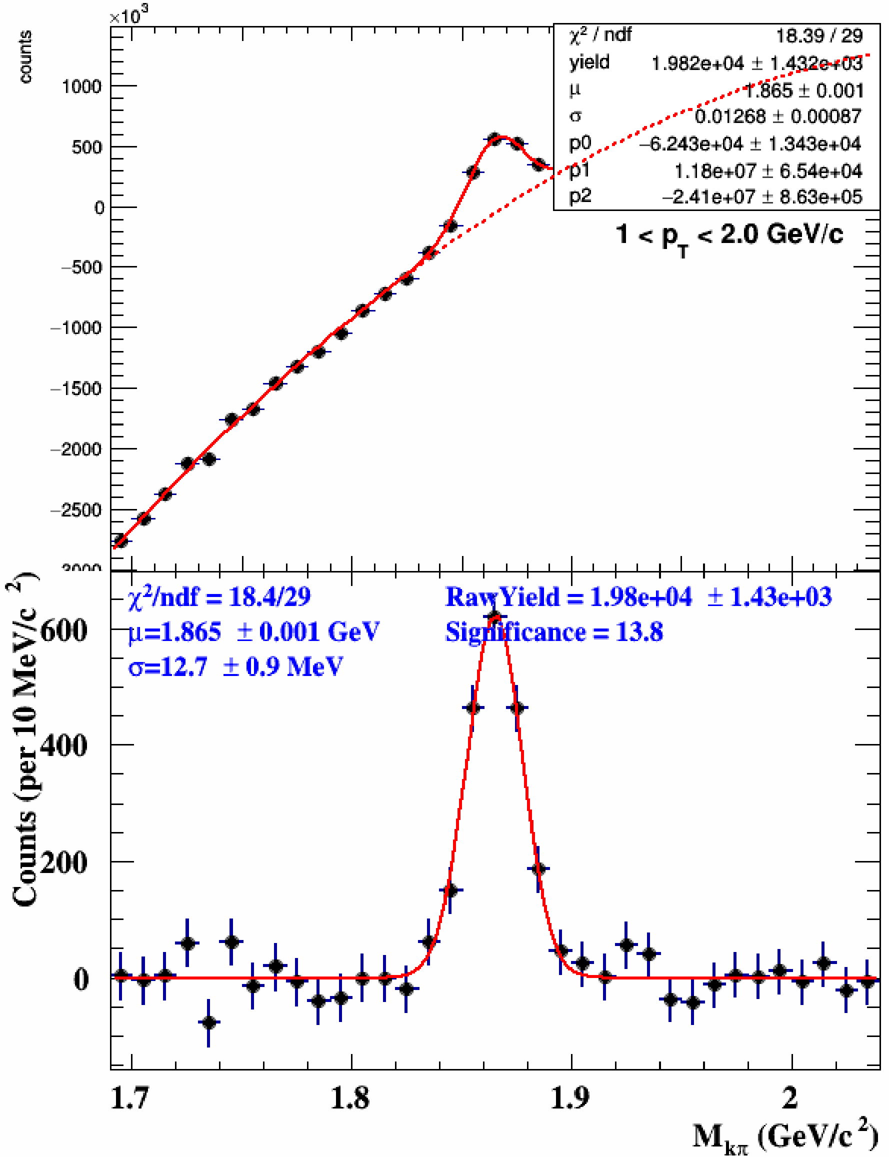




- Less than 1.7 M events are used to provide analysis method check;
- A more precise comparison is needed with measured hadron v_2 result in Isobar.

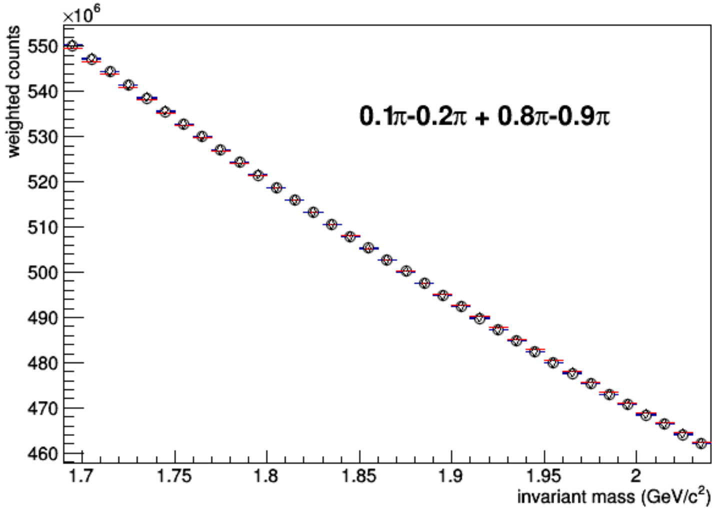
D^0 signal reconstruction

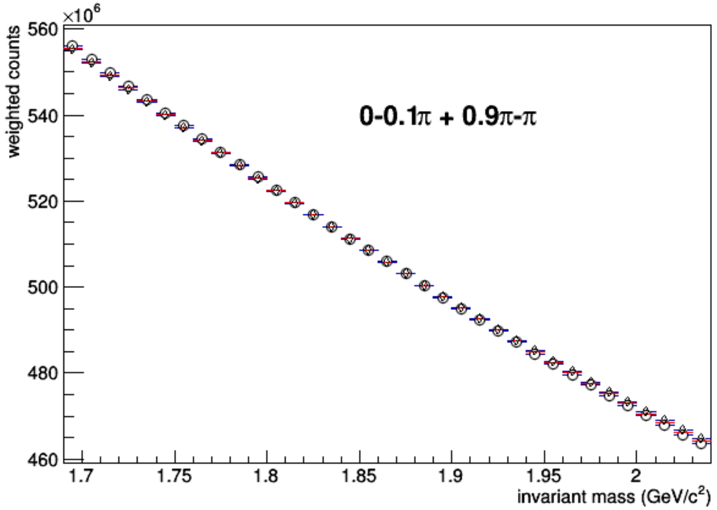


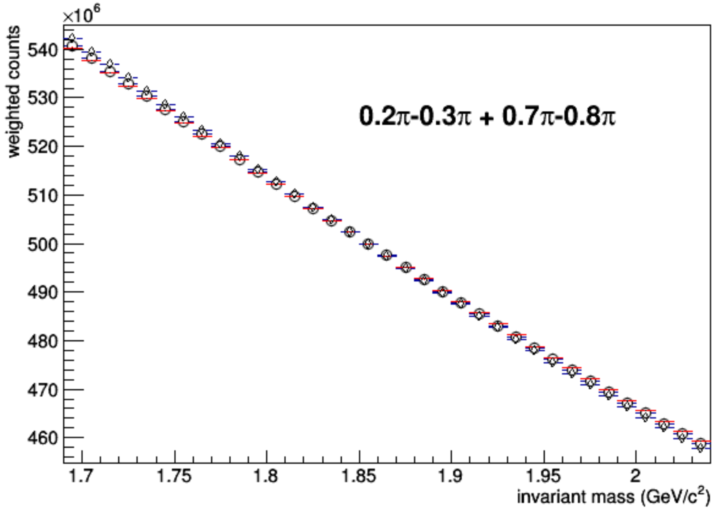


- Total D^0 signal at $1.0 < p_T < 2.0$ GeV/c

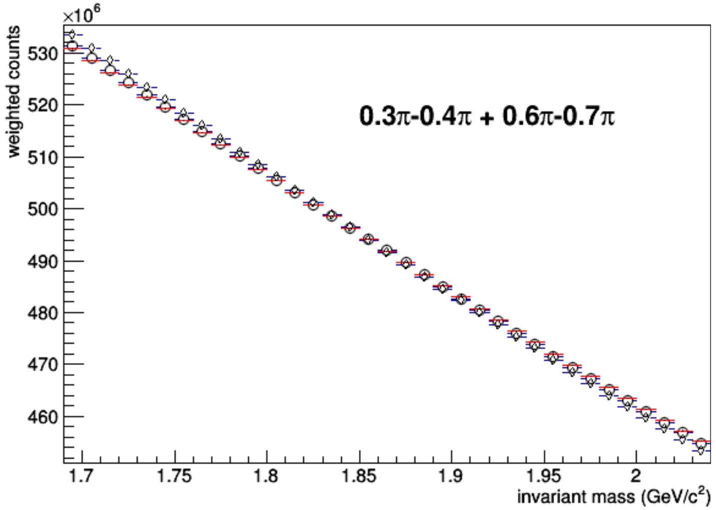
D^0 signal reconstruction

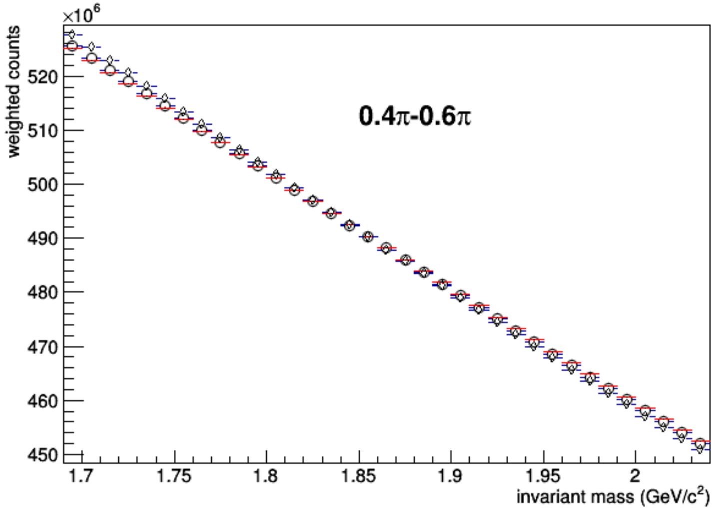




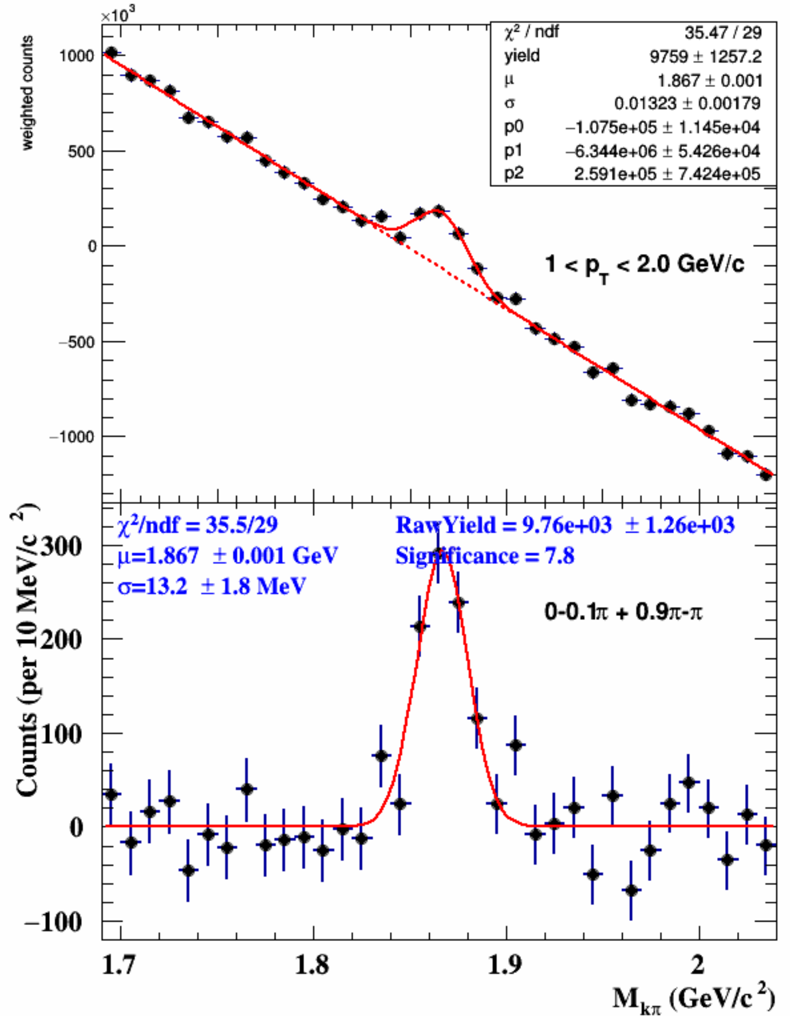


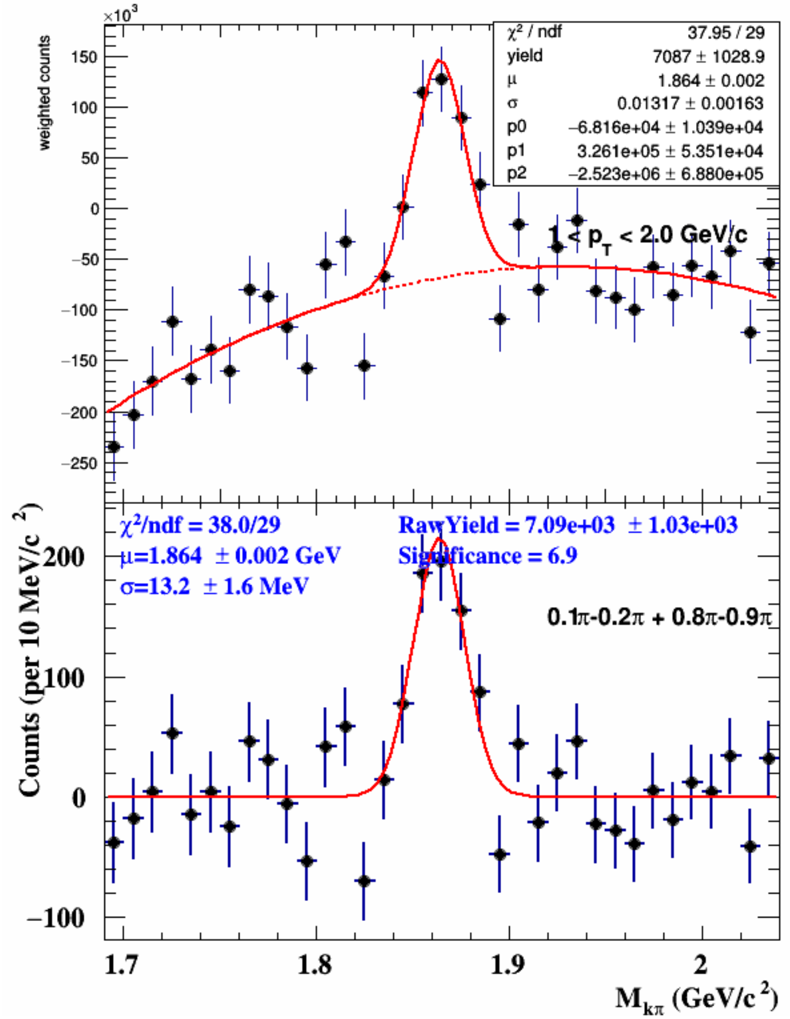
- Different (φ-ψ) bin D^0 signal at $1.0 < p_T < 2.0$ GeV/c

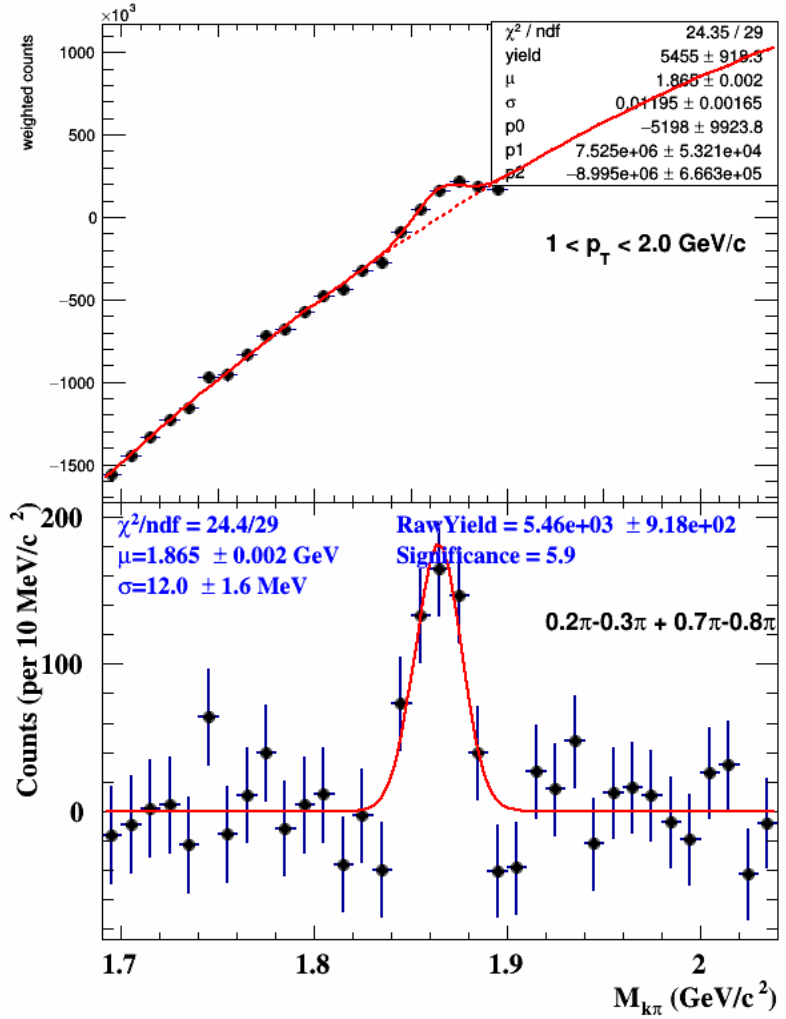




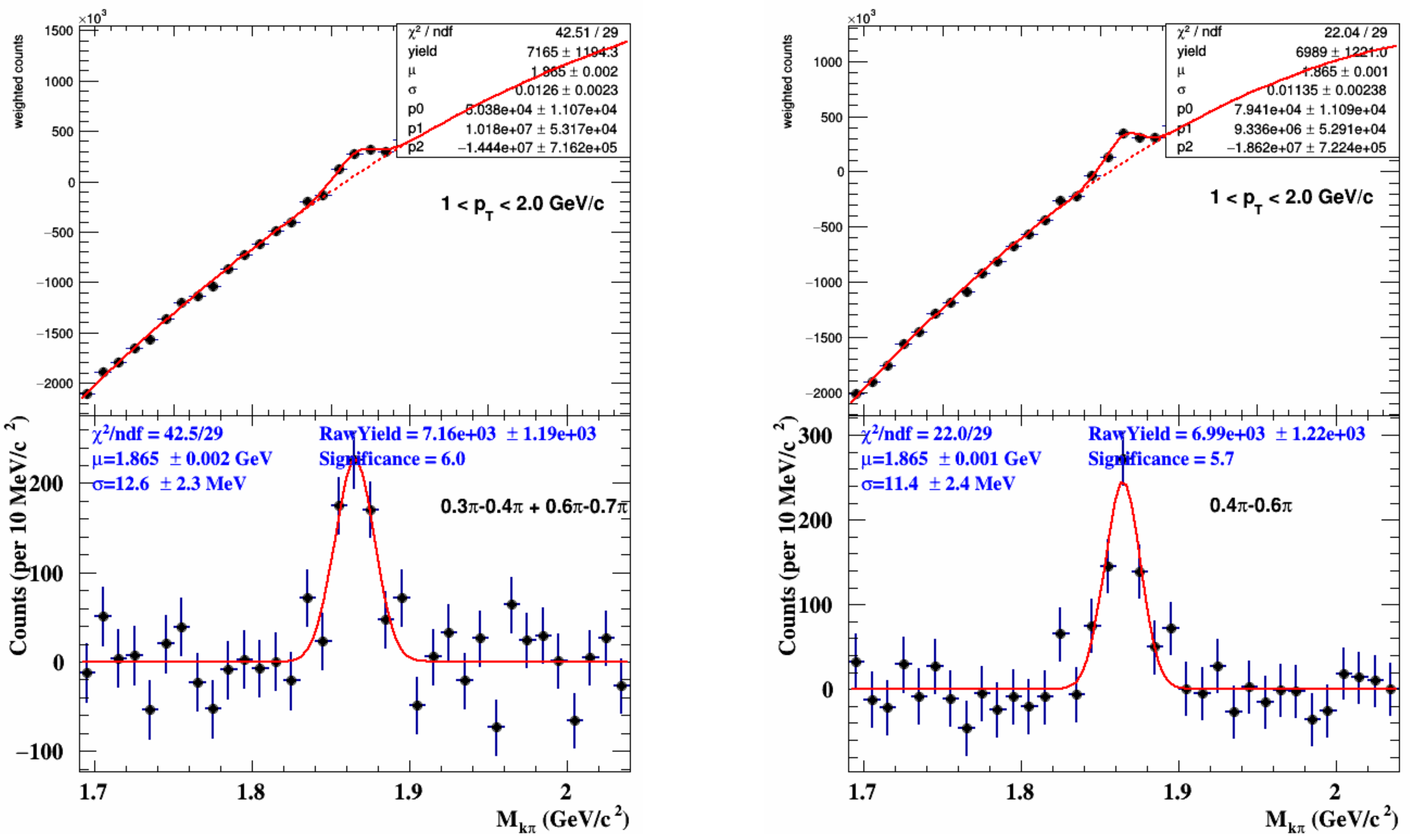
D^0 signal reconstruction



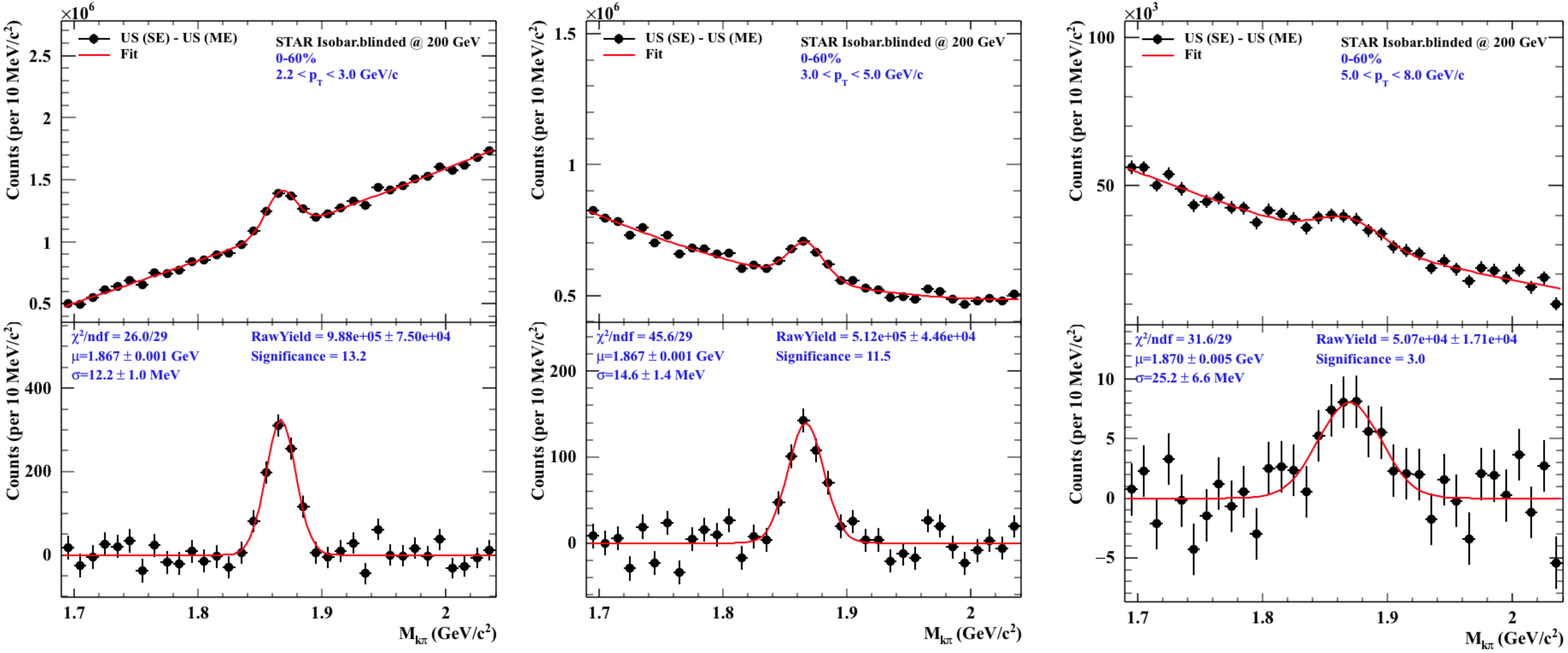




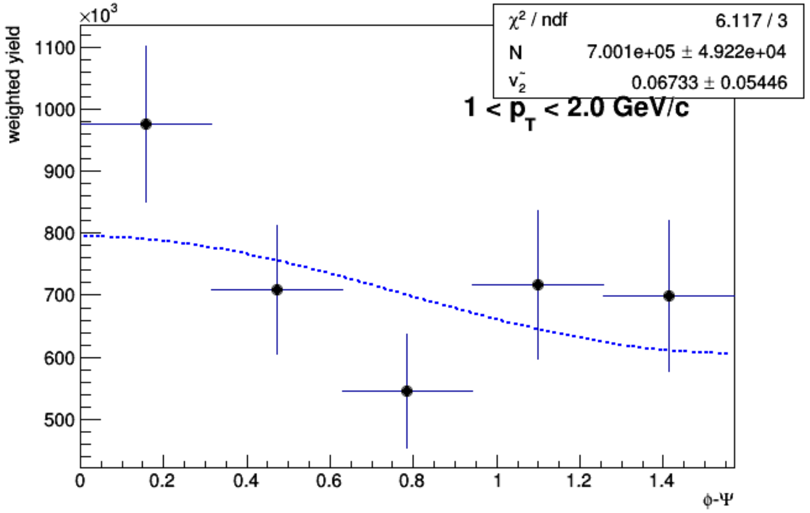
D^0 signal reconstruction



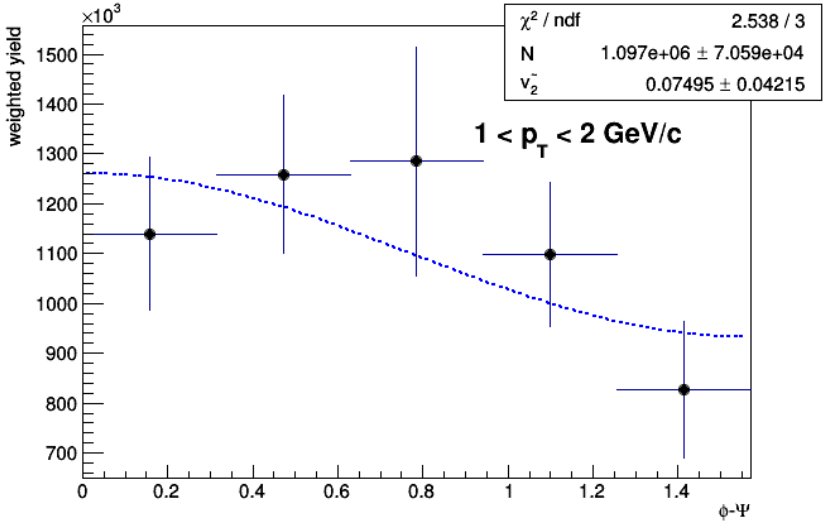
D^0 production at different p_T bin（0-60%）



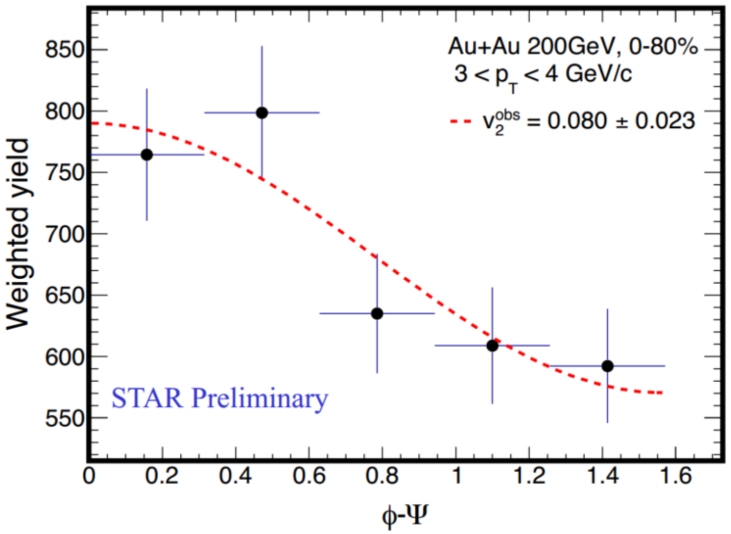
v_2 correction



Now (0-80%)



Before cuts (0-60%)

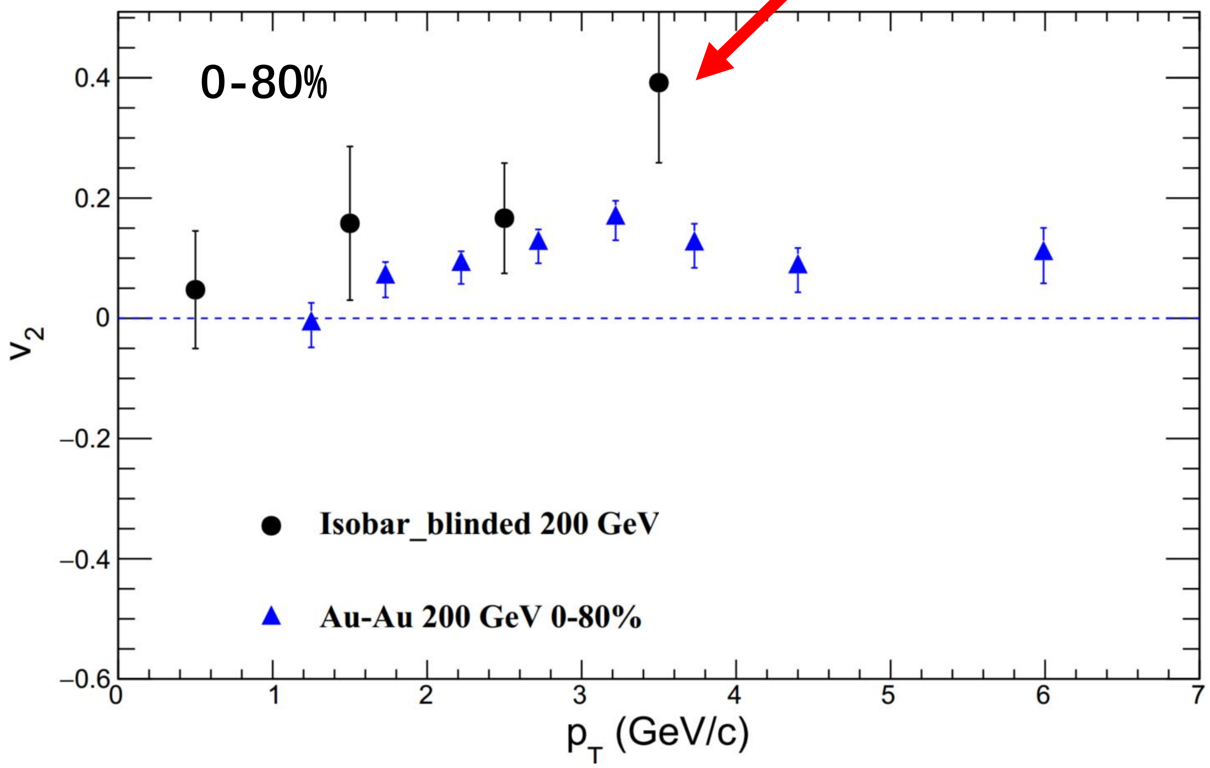


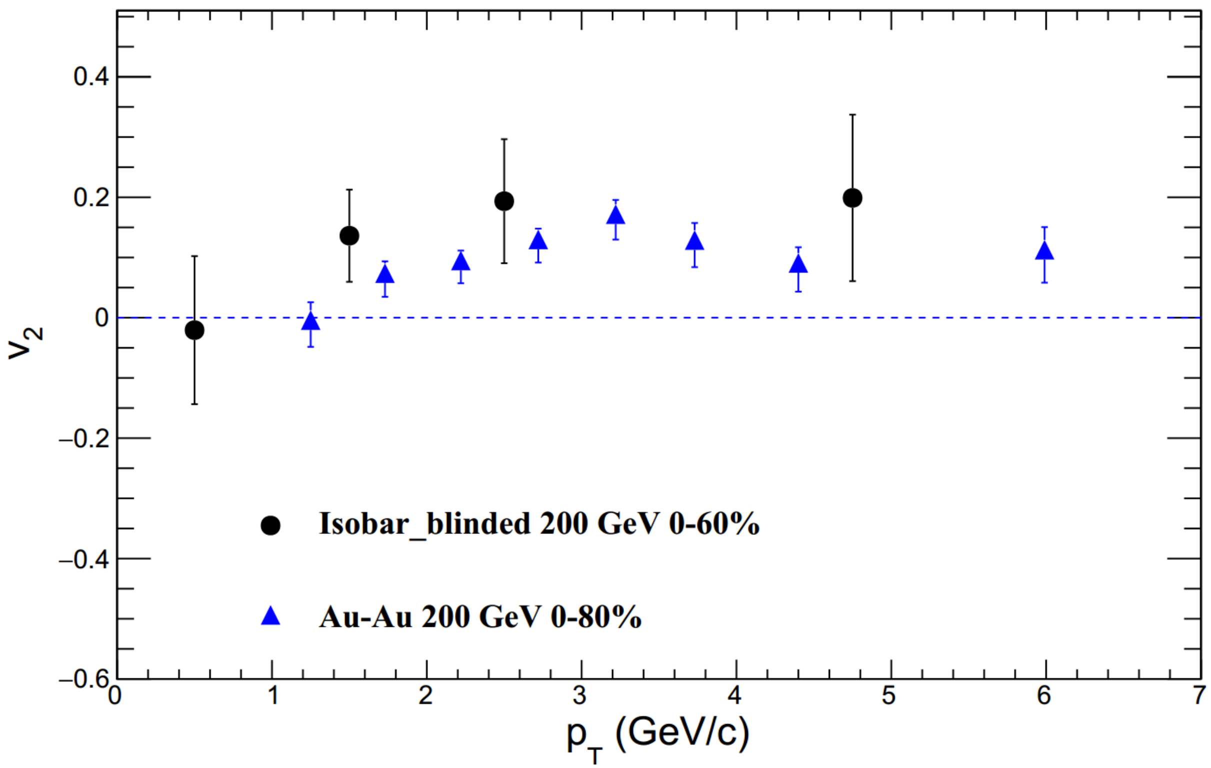
Guannan Xie Hard Probe 2016, Wuhan, China

$$N(1 + 2\tilde{v_2} cos(2(\phi - \Psi)))$$

- A scale of $\Delta/\sin\Delta$ = 1.01664 is done to correct for finite bin width $\Delta = 0.1\pi$;
- The $\widetilde{v_2}$ is divided by <1/R>, weighted by the D^0 yield, to get physics v_2.

D^0 v_2 in isobar collisions at $\sqrt{s_{NN}} = 200$ GeV





- Non-zero D^0 v_2 in medium p_T is observed (检查第二步修正)

Outline

- Motivation and STAR Experiment
- Energy loss
  - Measurements of D^0 p_T spectra and R_{AA} in isobar collisions at $\sqrt{s_{NN}} = 200$ at RHIC
- Collectivity
  - Measurement of D^0 elliptic flow v_2 at mid-rapidity in isobar collisions
- Research plan
- Summary

Research Plan

- Jul. — Nov. 2023: Pass PWG review for D^0 p_T spectra and R_{AA};
- Nov. — Jun. 2024: Finalize physical result for D^0 v_2;
- Jun. — Dec. 2024: Finalize collaboration review and write Ph.D thesis;
- Dec. — May. 2025: Prepare the Ph.D dissertation defense and paper publication

Outline

- Motivation and STAR Experiment
- Energy loss
  - Measurements of D^0 p_T spectra and R_{AA} in isobar collisions at $\sqrt{s_{NN}} = 200$ at RHIC
- Collectivity
  - Measurement of D^0 elliptic flow v_2 at mid-rapidity in isobar collisions
- Research plan
- Summary

Summary

D^0 p_T spectra and R_{AA}

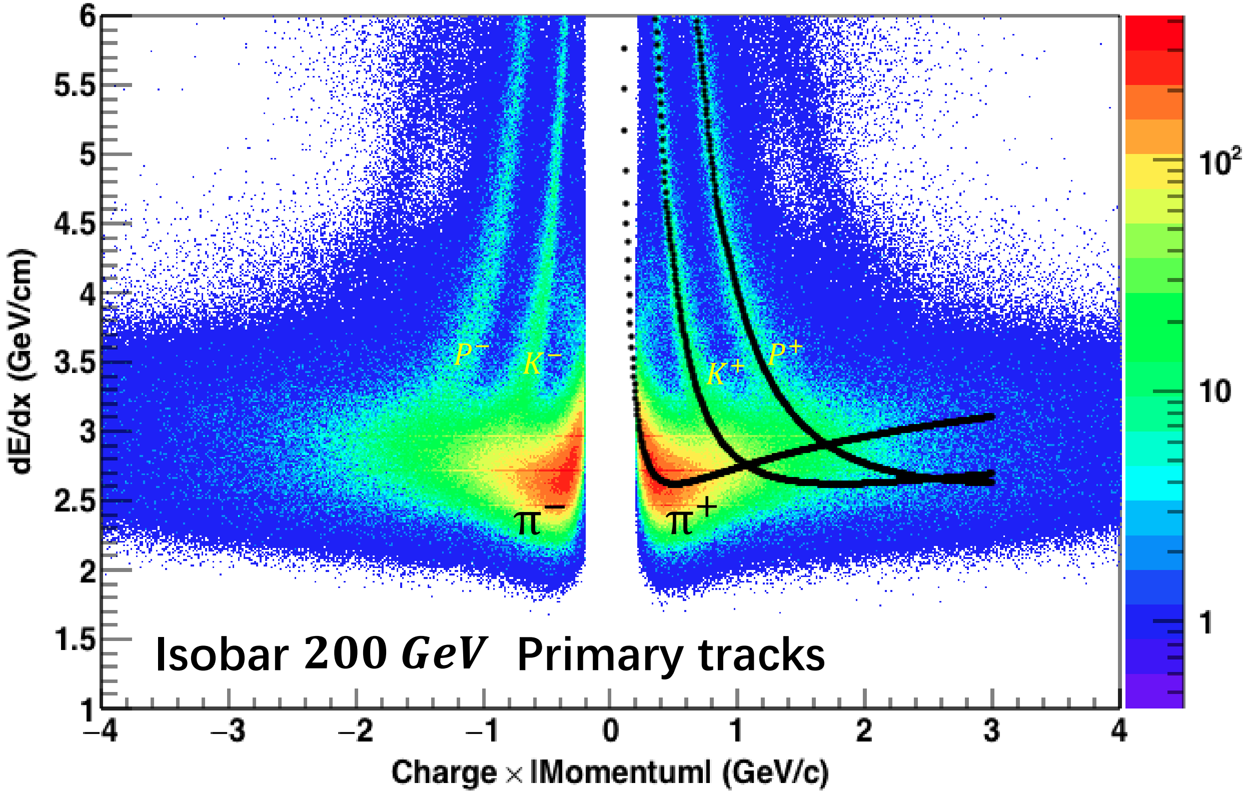
- D^0-meson productions are firstly measured at mid-rapidity (|y| < 1) in 200 GeV isobar collisions
- The number of binary collisions scale effect of D^0 production cross section between isobar and Au + Au collisions is observed
- The strong suppression of D^0 nuclear modification factor R_{AA} is observed for p_T > 3 GeV/c in central isobar collisions, demonstrating that charm quarks suffer significant energy loss in the QGP. Consistent with that in Au+Au collisions with similar multiplicities.
- No significant systematic dependence of D^0 kinetic freeze-out properties in central collisions between isobar and Au + Au collisions within uncertainties is observed.

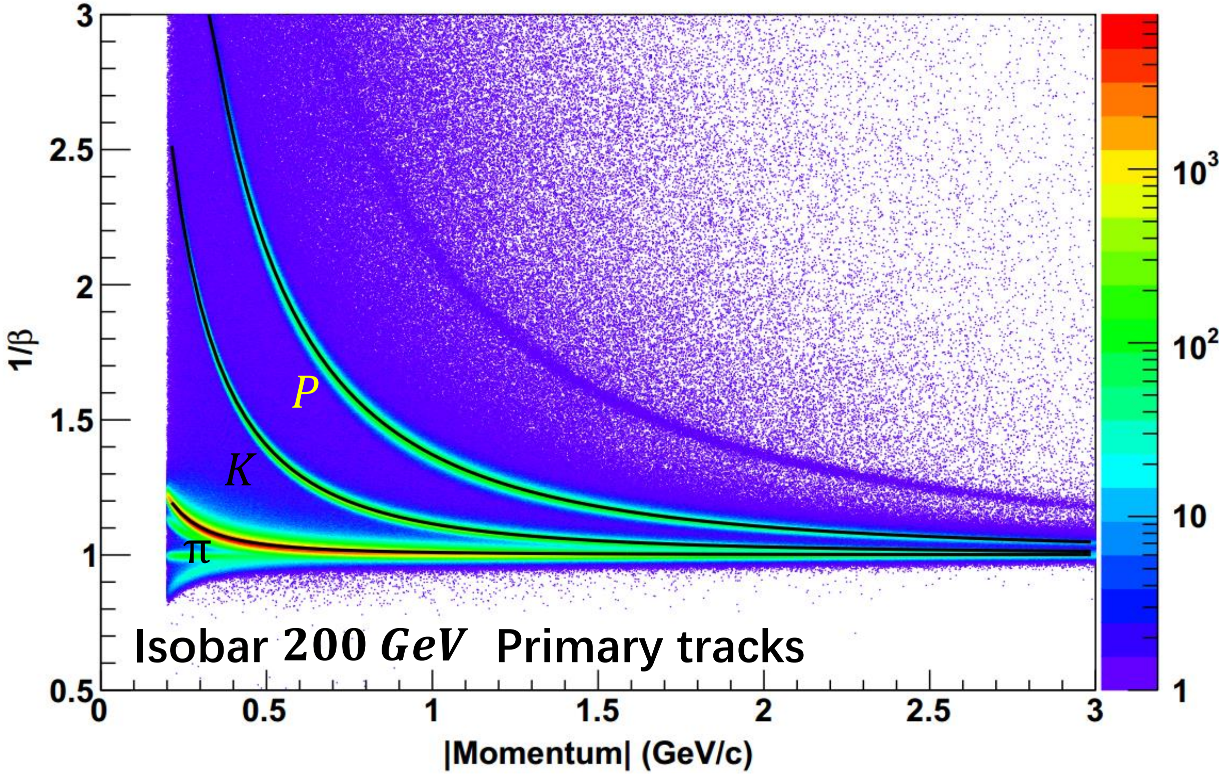
Non-zero D^0 v_2 is observed

Thank you!

Backup

dE/dx & 1/β

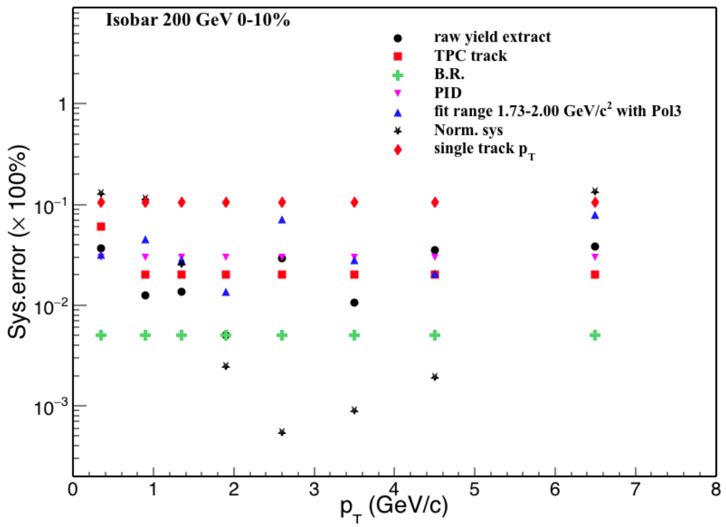


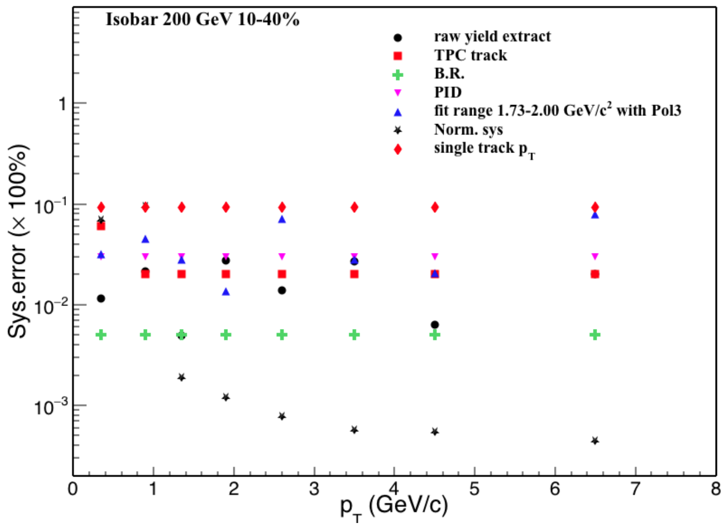


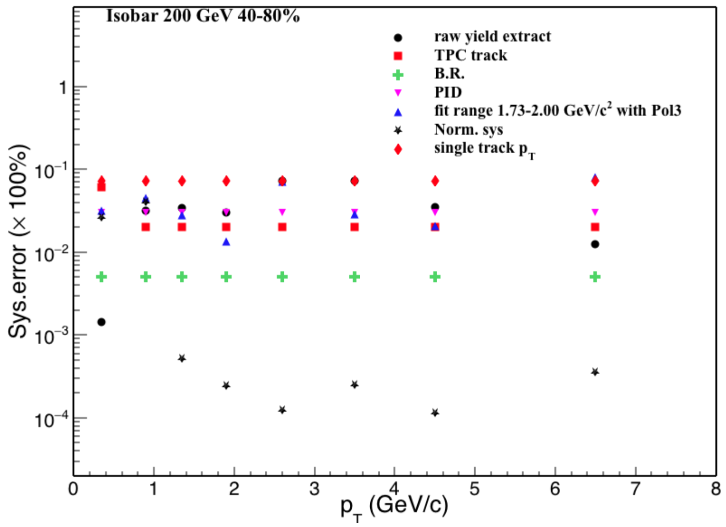
- Black points show the expected values
- Black curves show the expected values

Systematic uncertainties – spectra and R_{AA}

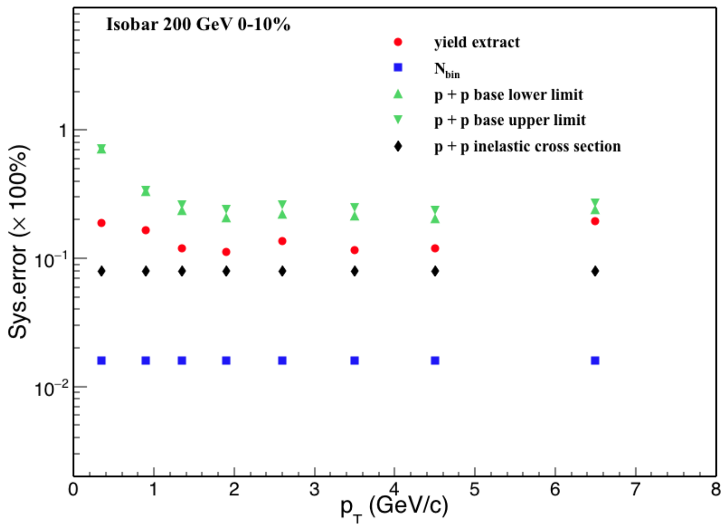
- D^0 spectra （0-10%, 10-40% & 40-80%)

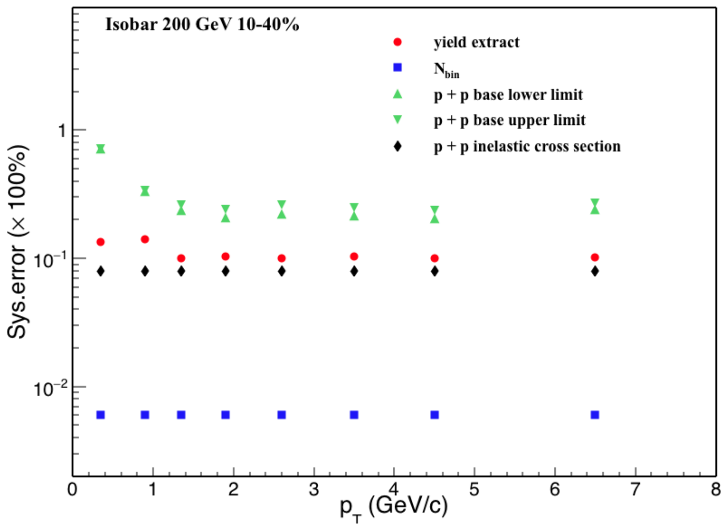


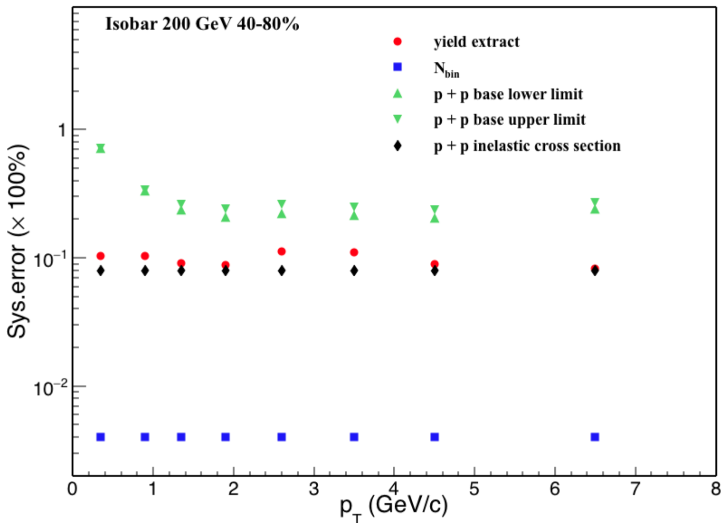




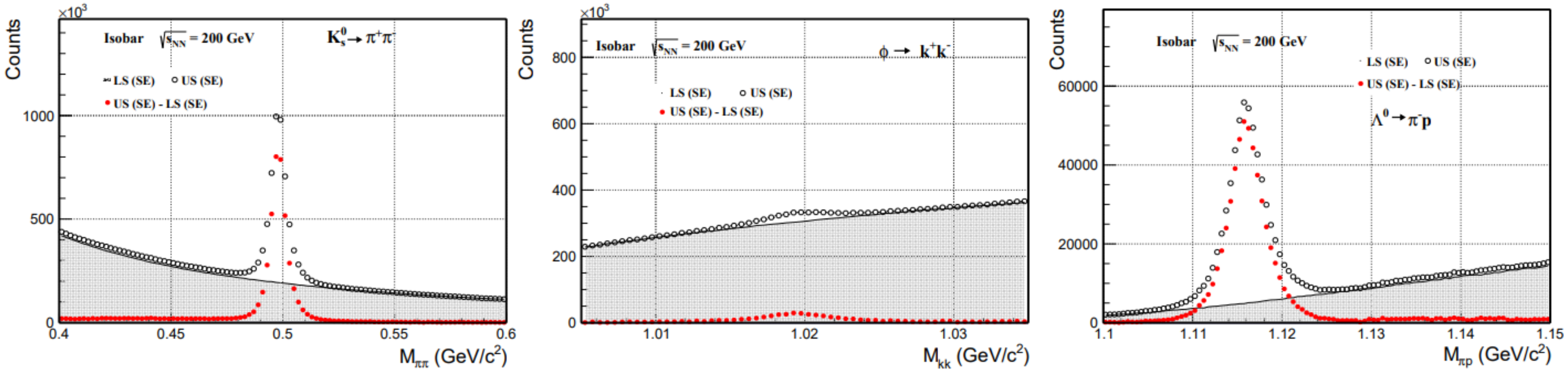
- D^0 R_{AA} （0-10%, 10-40% & 40-80%)





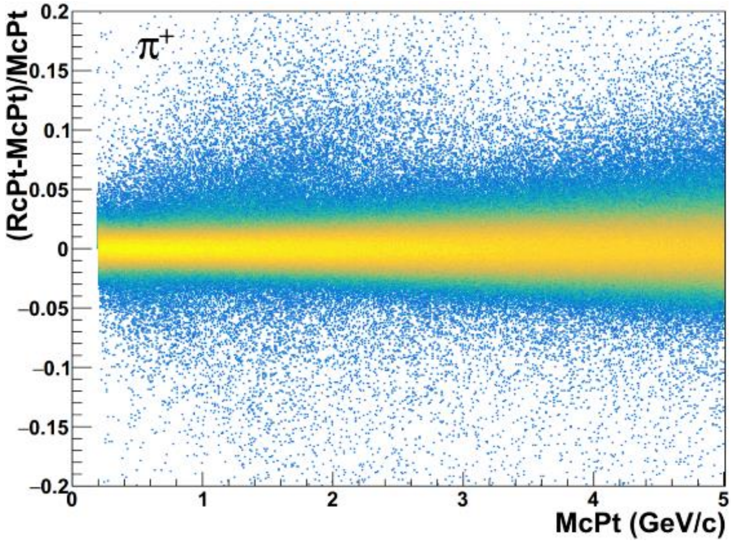


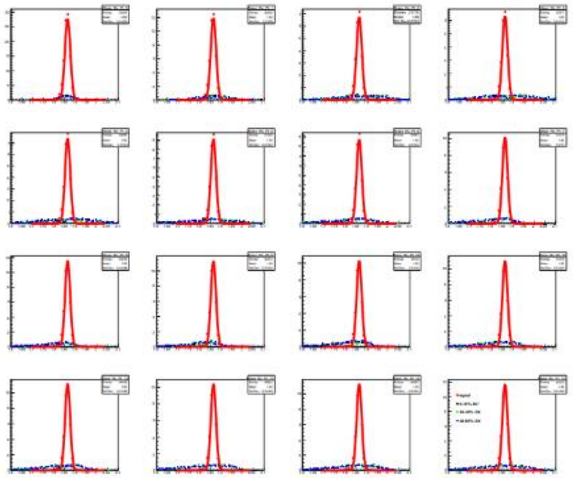
Double counting



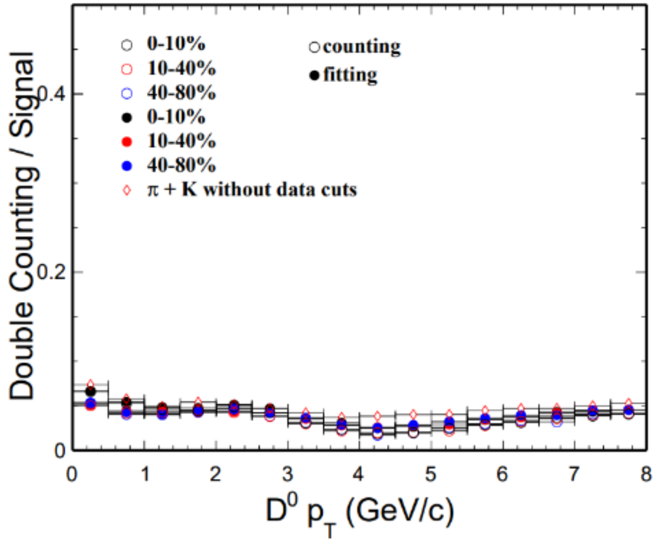
(a) (b) (c)

Fig. Invariant mass distributions for $K_s^0 \to \pi^+\pi^-$ (a), $\phi \to K^+K^-$ (b) and $\Lambda^0 \to \pi^- p$ (c) hadronic decay channel to select pure π, K, and proton sample.

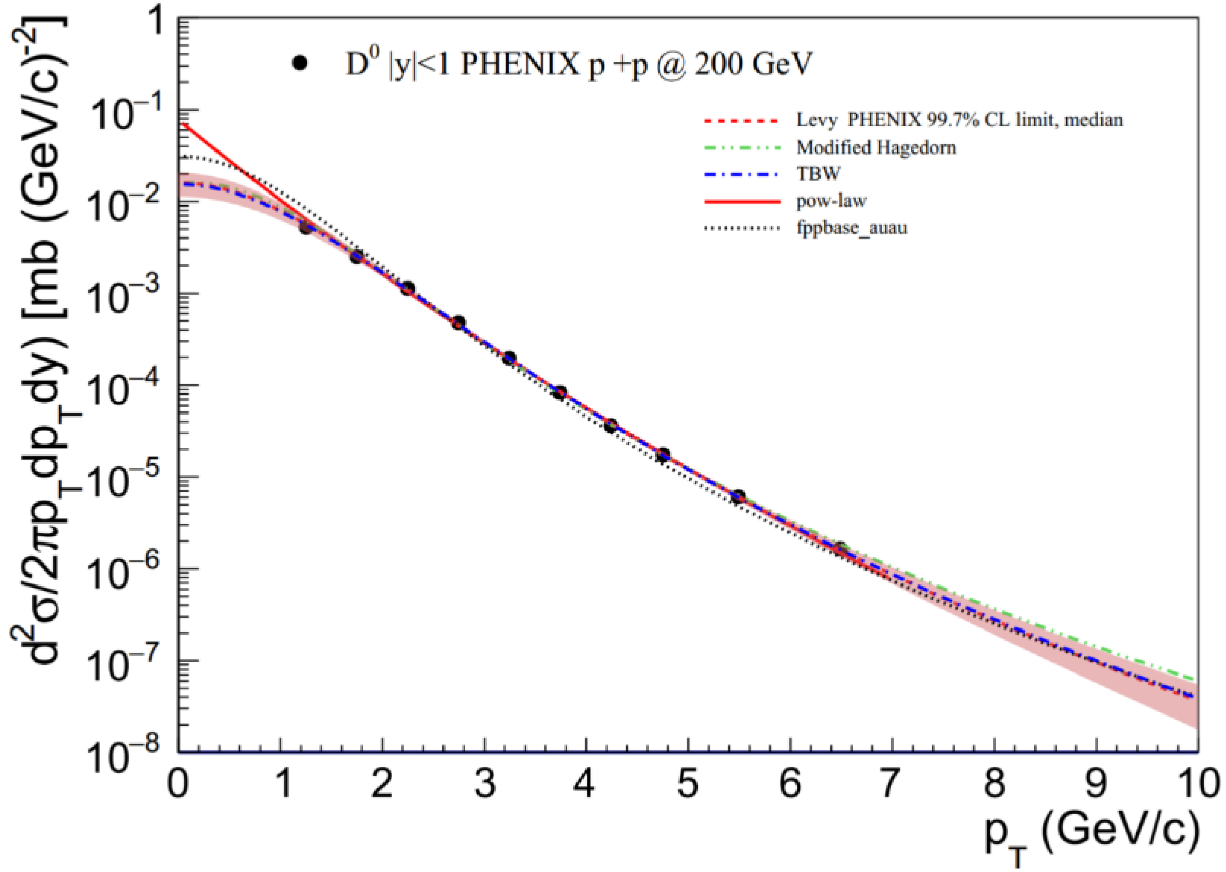


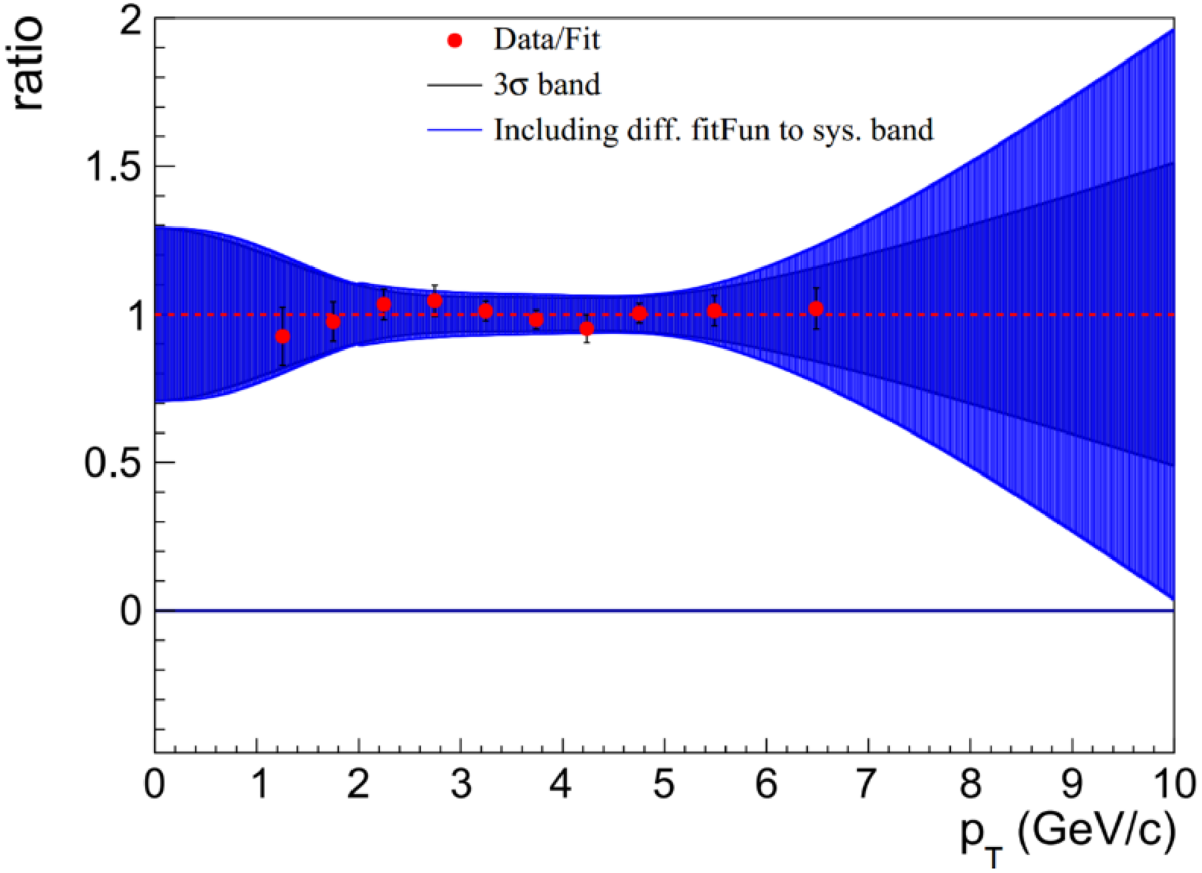


Invariant mass distributions of K, π from momentum smearing (red points) and doubly misidentification (bottom colored boxes). The red line is the fit to the smeared signal between 1.69 and 2.04 GeV/c^2. From top left to bottom right show the distributions in p_T bins: 0-0.5 GeV/c, 0.5-1.0 GeV/c, ..., 7.5-8.0 GeV/c.



Technical details: p+p baseline cross check





Technical details: Formulas

Spectra

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

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

Nuclear modification factor

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

$$R_{cp} = \frac{Y(0-10\%)/< N_{coll\_0-10} >}{Y(40-80\%)/< N_{coll\_40-80} >}$$

$< T_{AA} > \times \sigma_{inel}^{NN} = < N_{coll} >$ 42 mb

Systematic uncertainties for integrated D^0 cross section

$$\frac{d\sigma_{D^0}^{NN}}{dy}\Big|_{y=0} = \frac{dN_{D^0}^{AA}}{dy}\Big|_{y=0} \times \frac{\sigma_{inel}^{pp}}{< N_{bin} >} \quad 3$$

1

$$\frac{dN_{D^0}^{AA}}{dy}\Big|_{y=0} = \frac{(\Delta N^{raw} - D.C)/\epsilon_{D^0}^{tot}/2}{\Delta y \times N_{events} \times B.R.} \quad 2$$

Open Charm Hadron	Constitution
D^0	$c\bar{u}$
D^+	$c\bar{d}$
D_s^+	$c\bar{s}$
Λ_c^+	udc

Levy func

$$\frac{A(n-1)(n-2)}{nT(nT + m_0(n-2))} \times (1 + \frac{m_T - m_0}{nT})^{-n}$$

m_T Spectra

$$\frac{d^2N}{2\pi p_T dp_T dy} = \frac{d^2N}{2\pi m_T dm_T dy} = \frac{dN/dy}{2\pi T_{\text{eff}}(m_0 + T_{\text{eff}})} e^{-(m_T - m_0)/T_{\text{eff}}}$$

Blast-Wave func

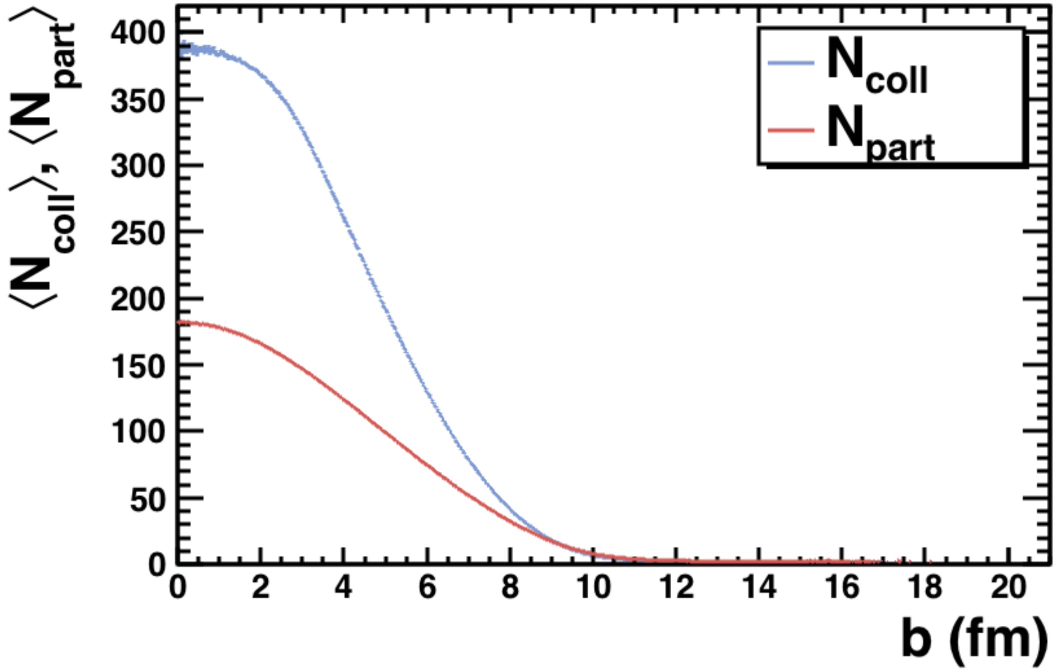
$$E\frac{d^3N}{dp^3} \propto \int_0^R r dr m_T I_0\left(\frac{p_T \sinh(\rho)}{T_{\text{kin}}}\right) K_1\left(\frac{m_T \cosh(\rho)}{T_{\text{kin}}}\right)$$

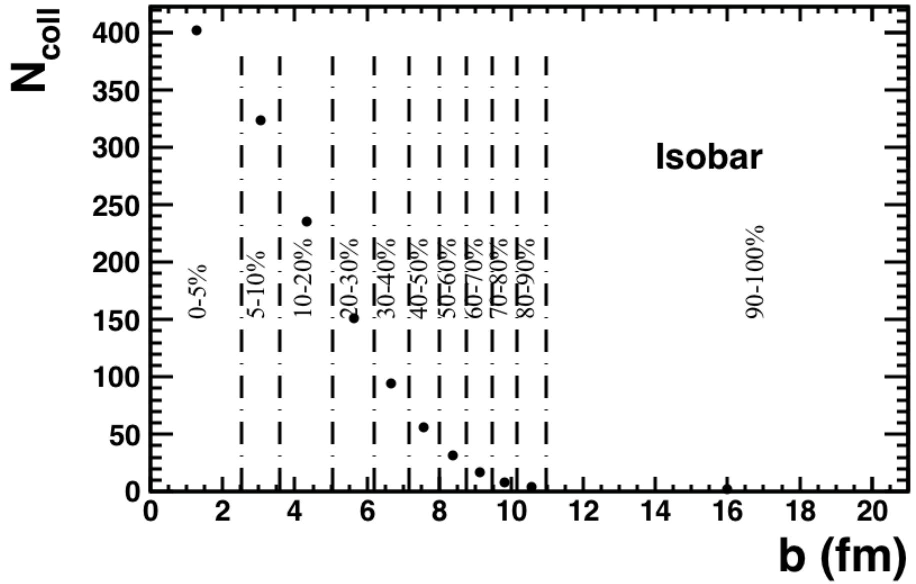
$$E\frac{d^3N}{dp^3} \propto m_T \int_{-Y}^{+Y} \cosh(y) dy \int_{-\pi}^{+\pi} d\phi \int_0^R r dr$$
$$\left(1 + \frac{q-1}{T_{\text{kin}}}(m_T \cosh(y)\cosh(\rho) - p_T \sinh(\rho)\cos(\phi))\right)^{-\frac{1}{q-1}}$$

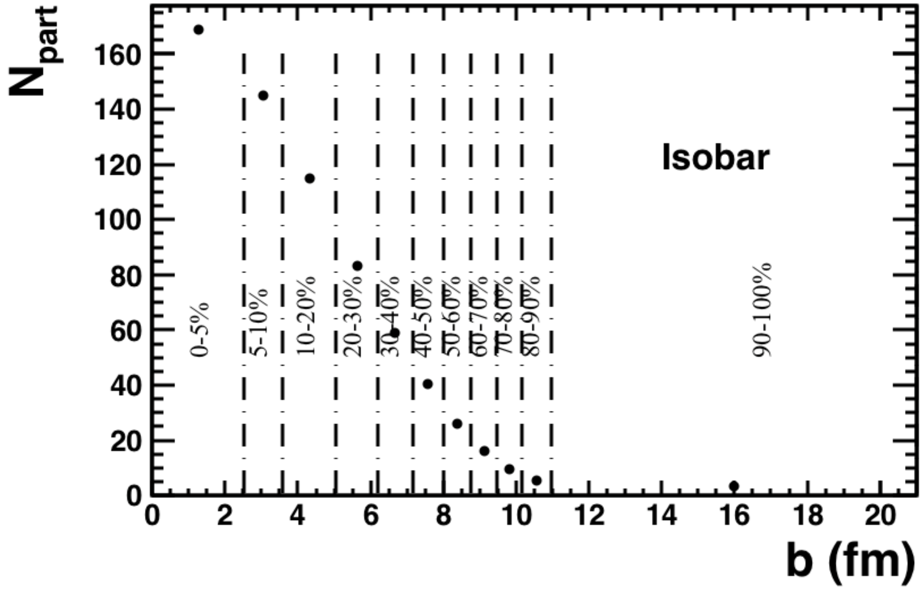
Glauber model simulation

R=5.02 fm a=0.46 fm

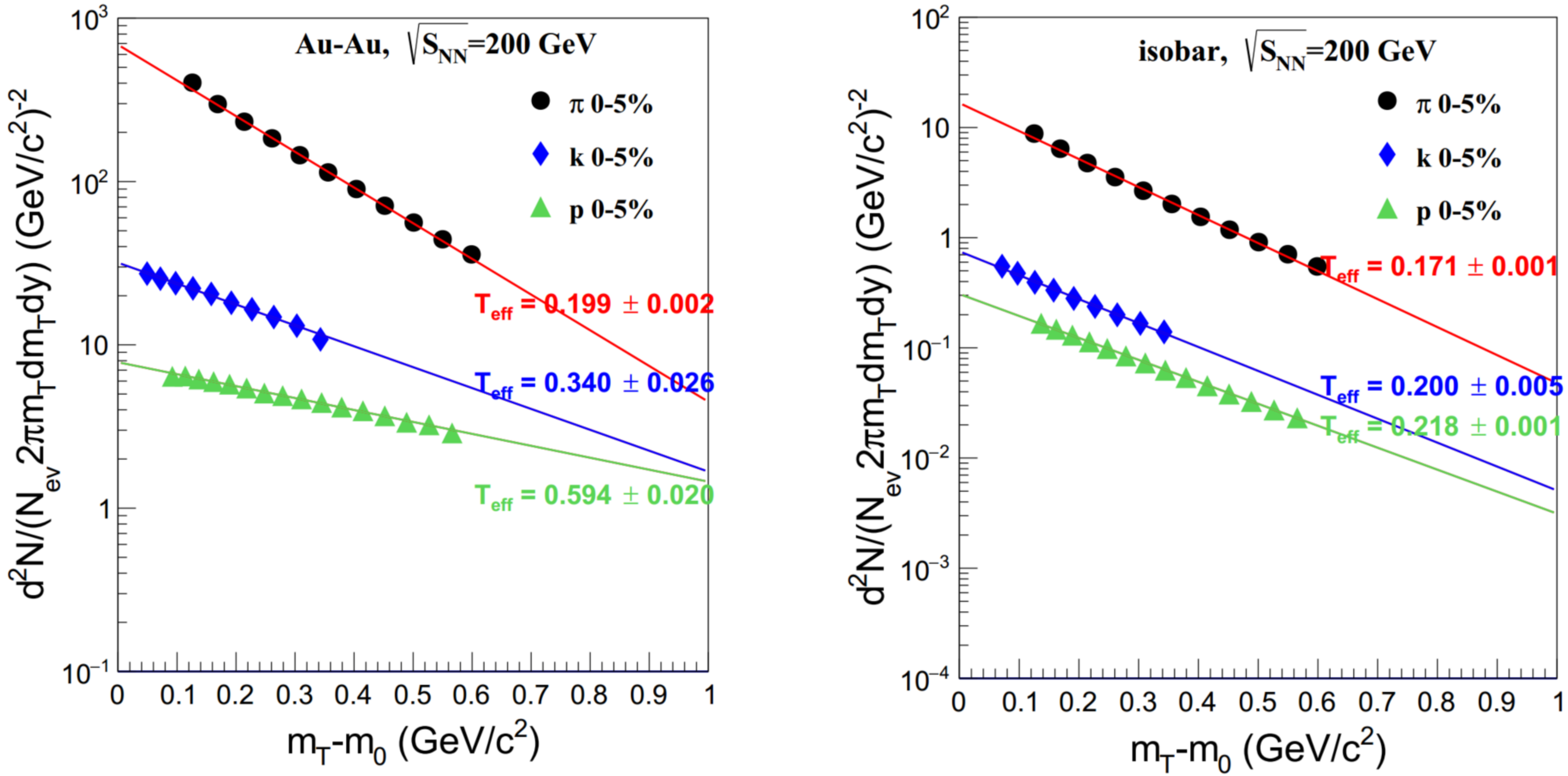
$\sigma_{inel}^{NN} = 42\, mb$







m_T-spectra fit details



- m_T-spectra fit details for Au + Au (left) and isobar (right).