Study of bulk properties through ϕ-meson in Au+Au collisions at high μ_B using the PHSD model

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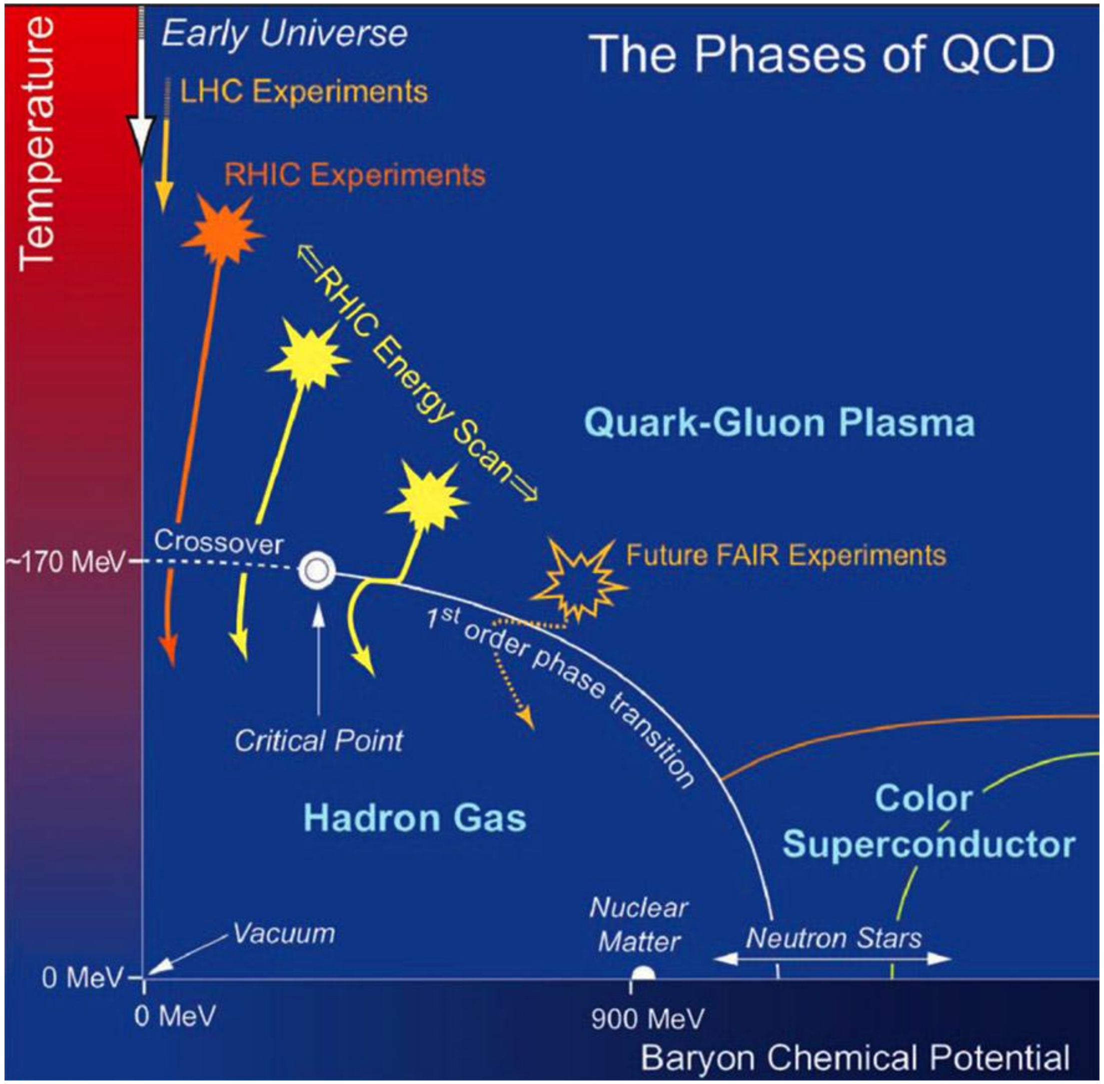
Motivation

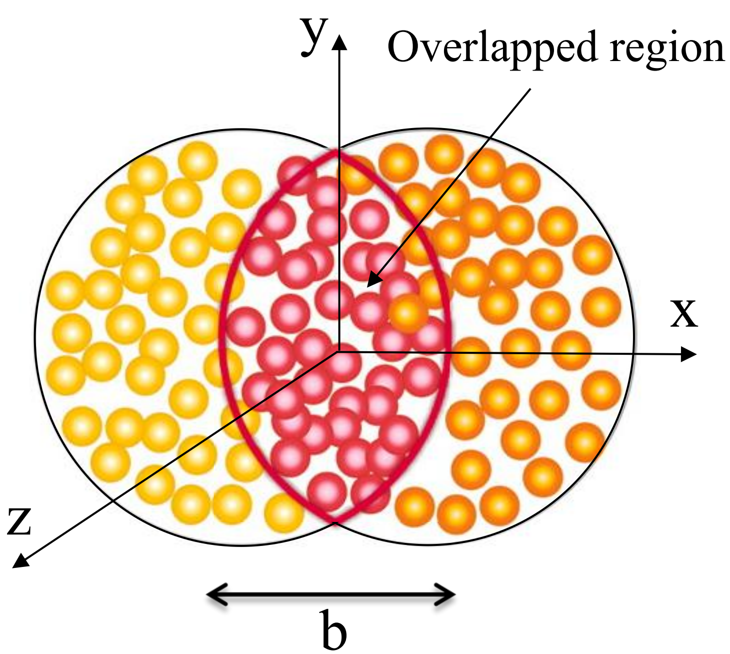


Conjectured QCD Phase diagram

STAR White Paper II
https://drupal.star.bnl.gov/STAR/starnotes/public/sn0598

- Primary goals of the relativistic heavy-ion collisions is to study quark-gluon plasma (QGP) and the QCD phase diagram.
- QCD phase diagram can be explored by varying baryon chemical potential and temperature through varying beam energy.
- Study nuclear matter at finite μ_B and look for onset of de-confinement phase boundary and critical point.
- Properties of the QCD matter can be probed through bulk observables such as particle spectra and collective flow.

Collective Flow

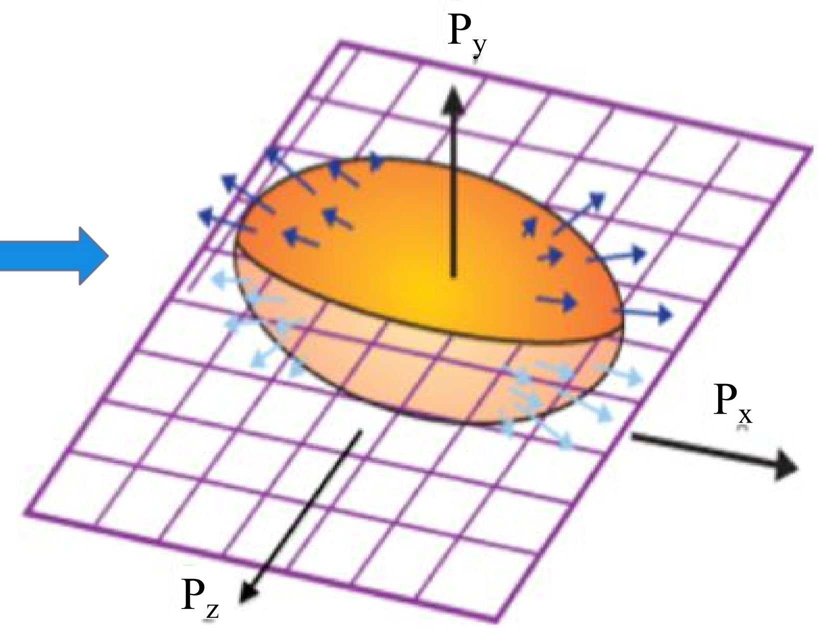


Interactions

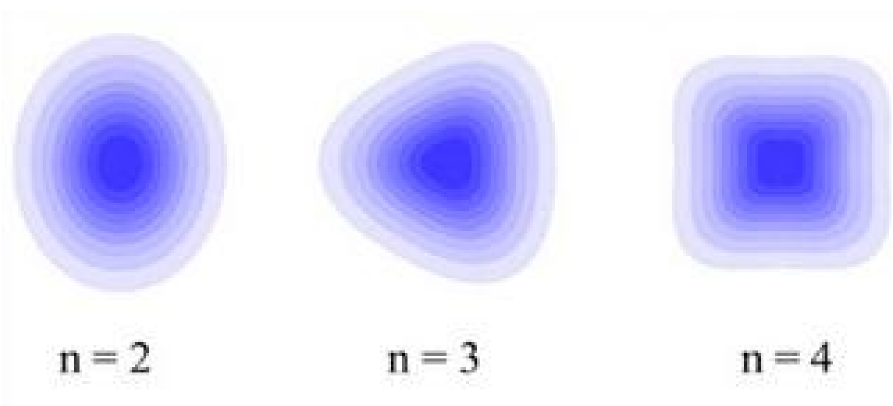
↓

Pressure(P)

$$y > x \rightarrow \frac{\partial P}{\partial x} > \frac{\partial P}{\partial y}$$



Different flow harmonics



Elliptic flow (v_2)

Momentum space anisotropy in the azimuthal angle distribution of produced particles with respect to the reaction plane.

- **Sensitive to initial conditions of collisions**
- **Sensitive to transport properties (η/s) of system**
- **Probe for the particle production mechanism (e.g. quark coalescence)**

- P. Klob, U. W. Heinz, Nucl. Phys. A715, (2003) 653c

Motivation: φ-meson

φ-meson:

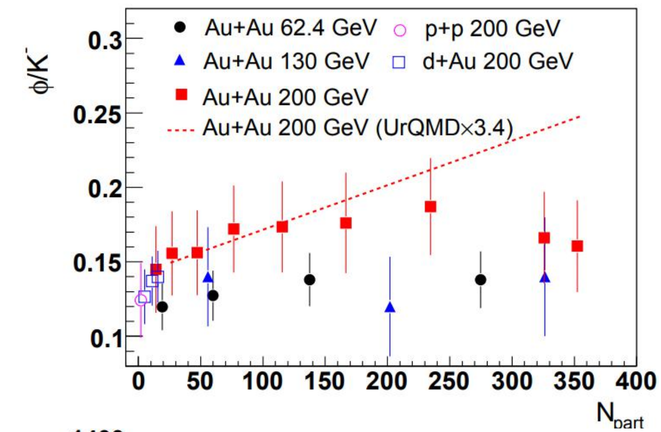
- Meson of mass 1.019 GeV comparable to baryons (p & Λ)
- Produced by coalescence of $s\bar{s}$ quarks not $K^+ + K^-$
- Small hadronic interaction cross-section $\sigma_{\varphi-h} \ll \sigma_{h-h}$

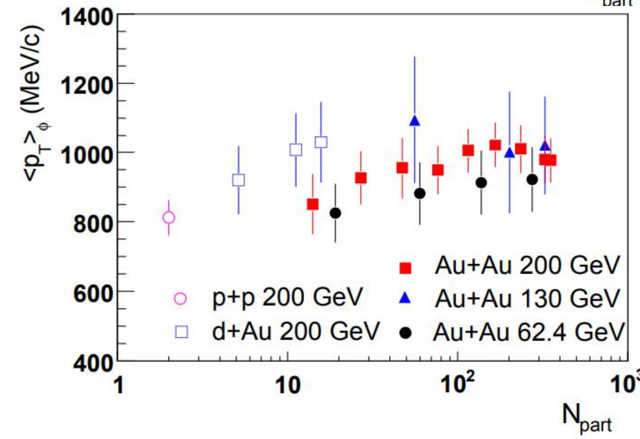
φ-meson production:

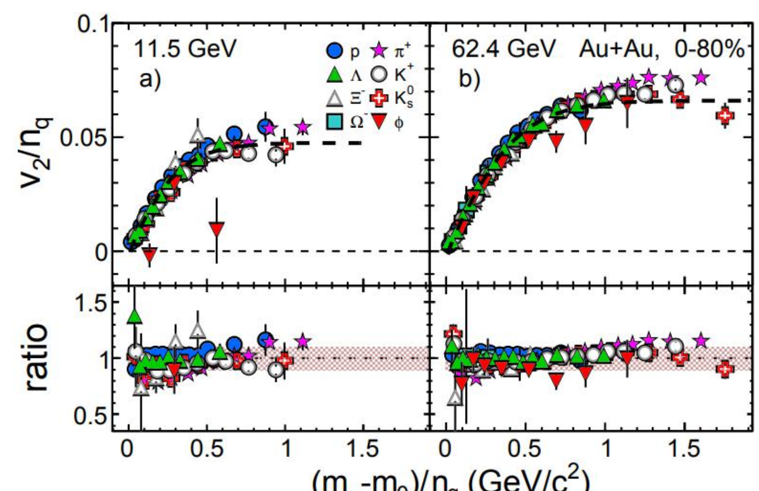
- Evolution of centrality dependence of φ-meson $<p_T>$ at $\sqrt{s_{NN}} = 200$ GeV suggest that it decoupled early

φ-meson flow:

- Partonic dominate: similar ellitpic flow (v_2) between light hadrons and φ-mesons and number of consitituent quark (NCQ) scaling
- Hadronic dominate: smaller v_2 of φ-mesons due to its small hadronic ross sections







- B. I. Abelev et al. (STAR), Phys. Rev. C 79, 064903 (2009)
- L. Adamczyk et al. (STAR), Phys. Rev. C 88, 014902 (2013)

PHSD model Information

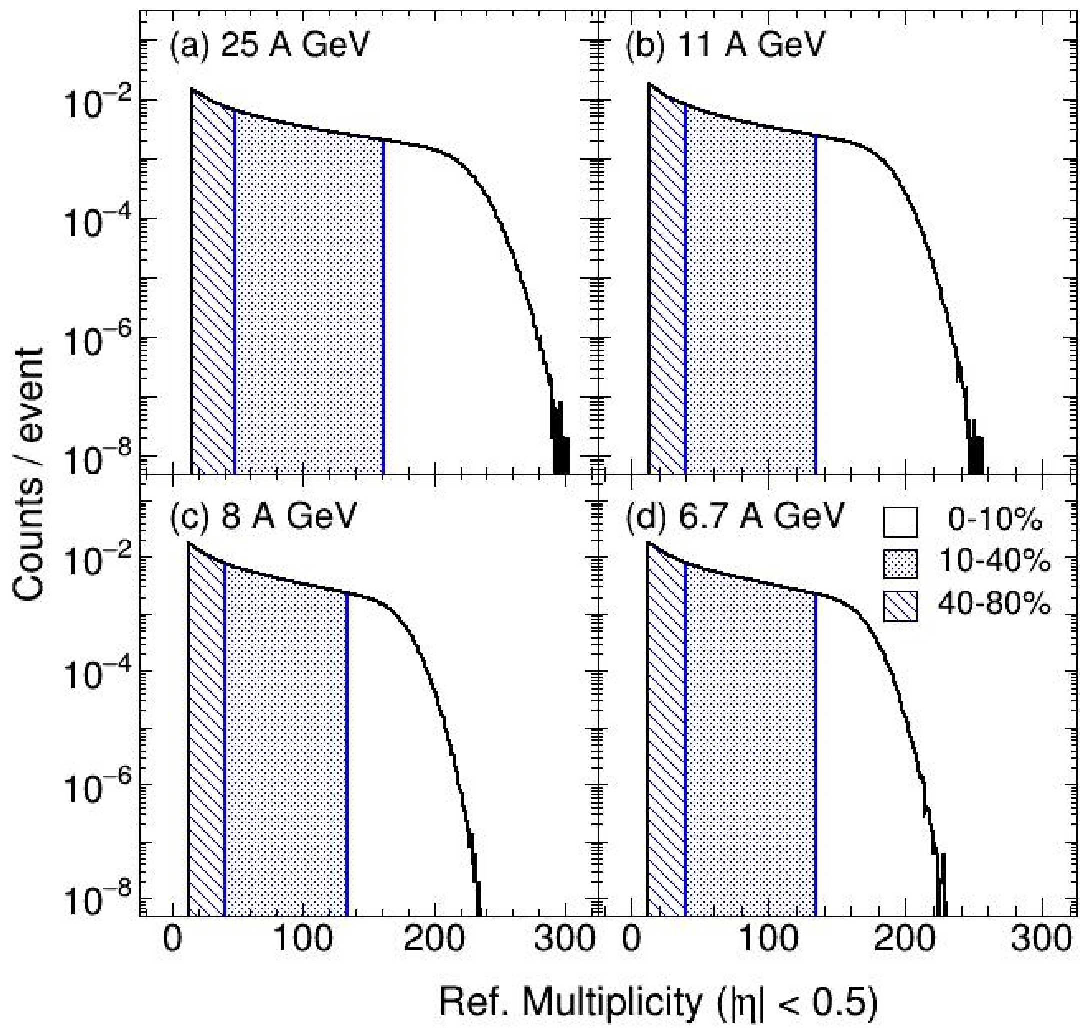
Model Name	Beam Energy	No. of Events	Impact Parameter	NUM (parallel ensembles) / ISUBS (runs)	Final Time
PHSD Model version 4.1-2021-11-01	E_{lab} = 6.7 A to 25 A GeV	50 Million	0-15 fm (Random MC)	50 / 250	500 fm/c

Centrality selection:

- Based on reference multiplicity (N_{ch} in $|\eta| < 0.5$) in the PHSD model similar to that of in the experimental measurements

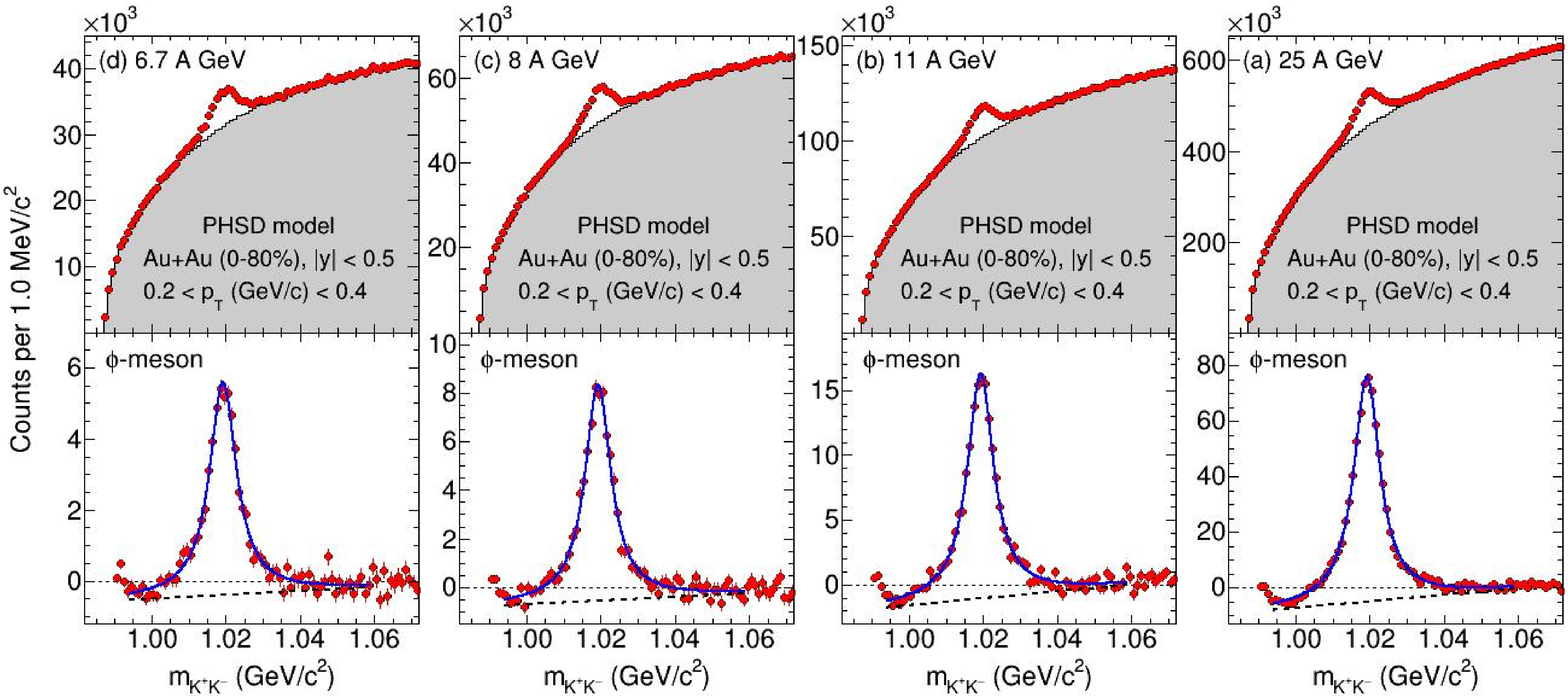
Particle selection (event plane):

- $|y| < 1.0$
- $0.2 < p_T < 2.0$ GeV/c



- W. Cassing and E.L. Bratkovskaya, Phys. Rev. C 78, 034919 (2008);
- W. Cassing and E.L. Bratkovskaya, Nucl. Phys. A 831, 215-242 (2009)

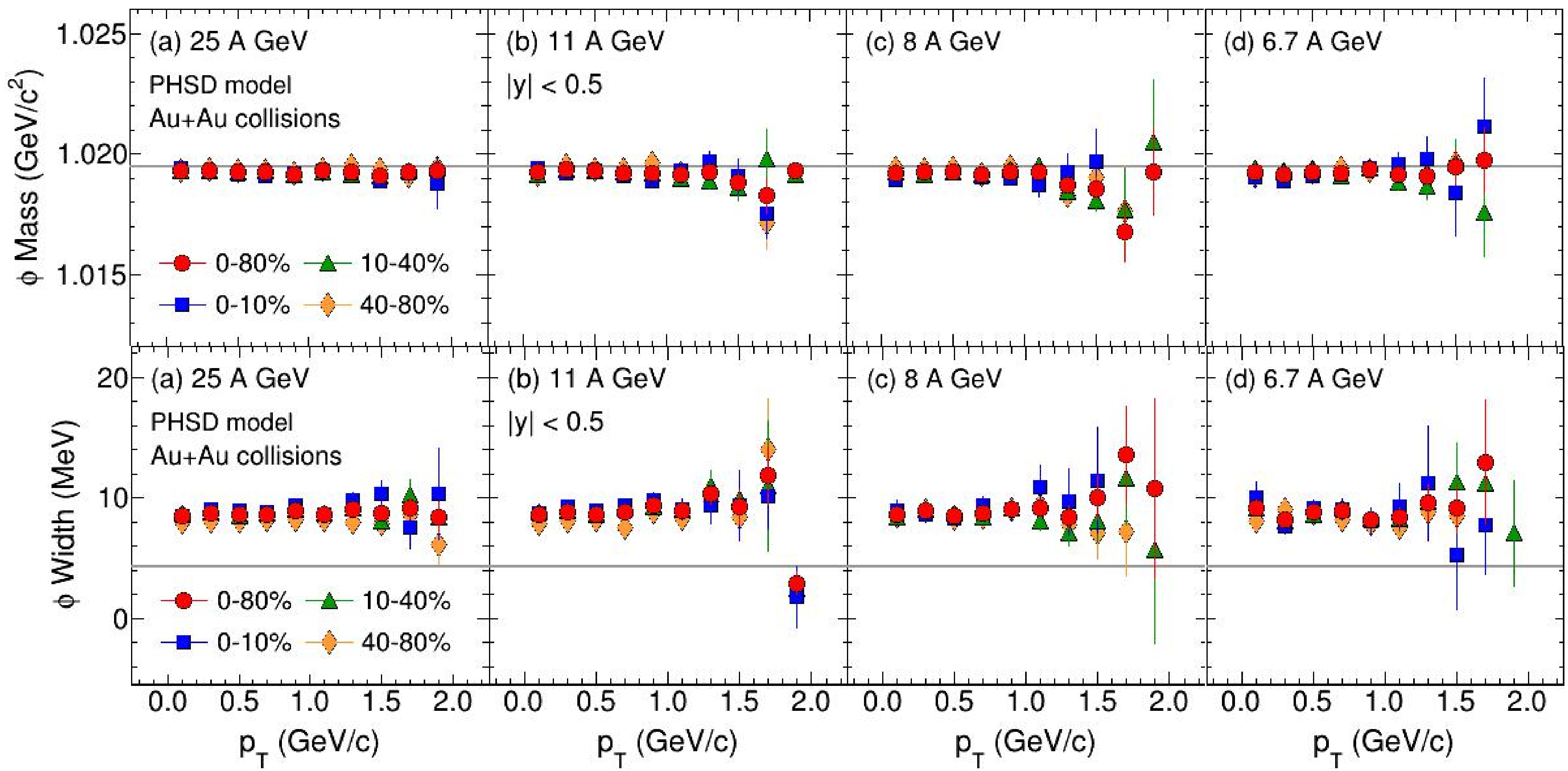
φ-meson reconstruction



- φ-meson reconstructed using invariant mass technique (hadronic decay: BR 49.1% $\varphi \rightarrow K^+ K^-$)
- Combinatorial background reconstructed using like-sign method ($K^+ K^+$ and $K^- K^-$)
- Yield extracted using Breit-Wigner + polynomial function fit

- S. Navas et al. (Particle Data Group), Phys. Rev. D 110, 030001 (2024)

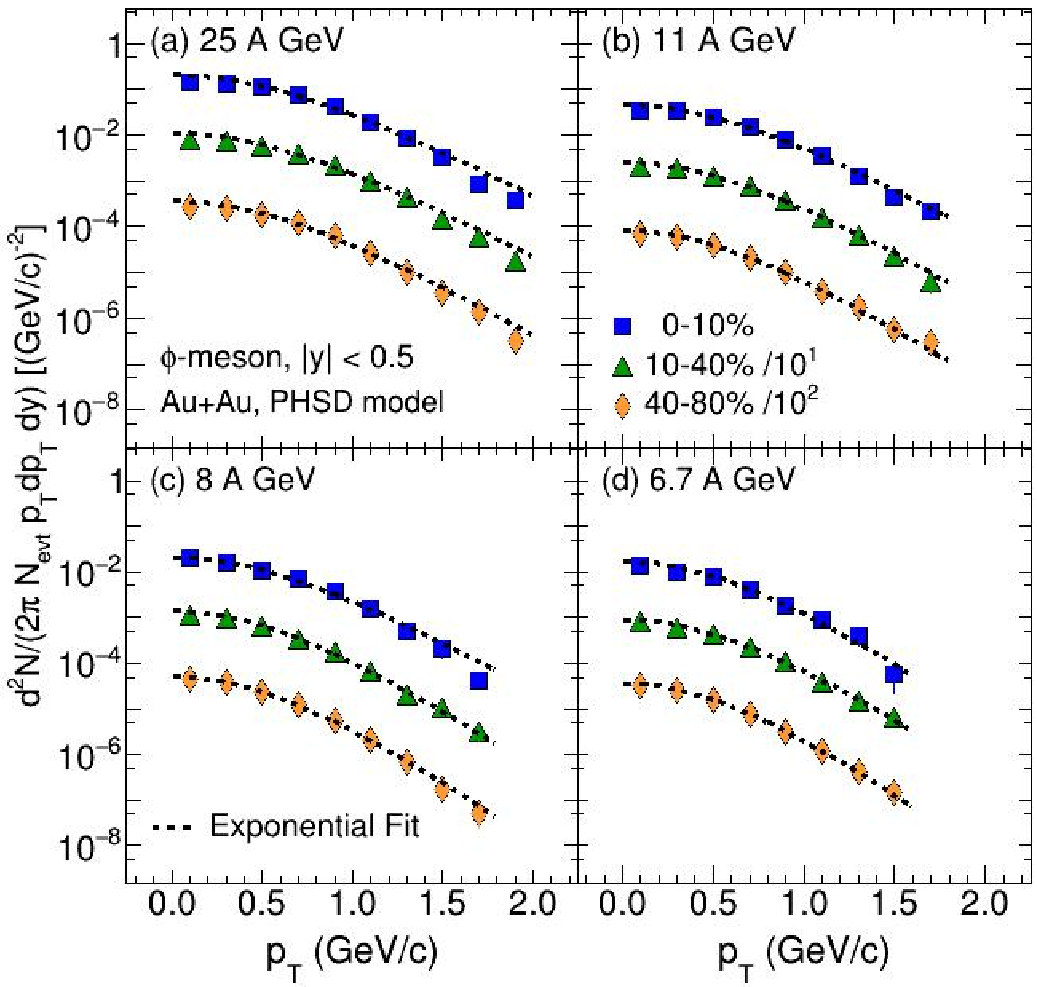
φ-meson mass and width

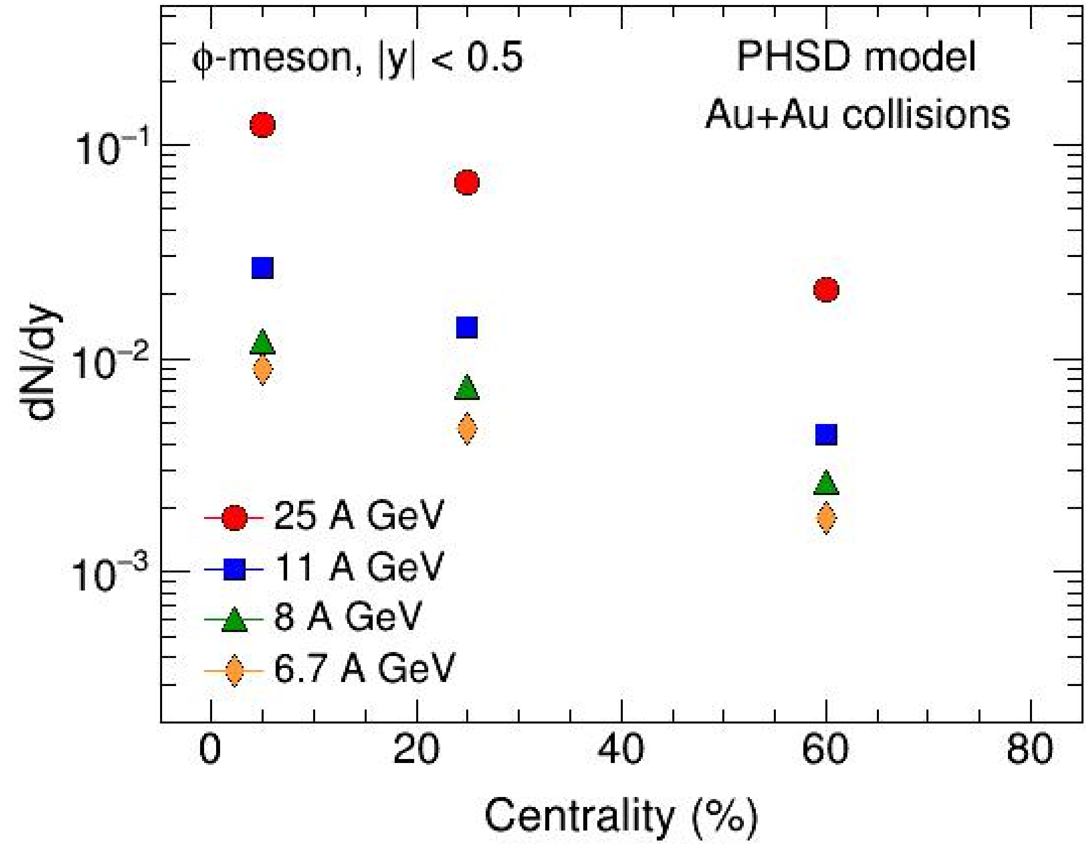


- Mass and width of φ-meson are consistent with the particle data group for all centrality classes and beam energies

- S. Navas et al. (Particle Data Group), Phys. Rev. D 110, 030001 (2024)

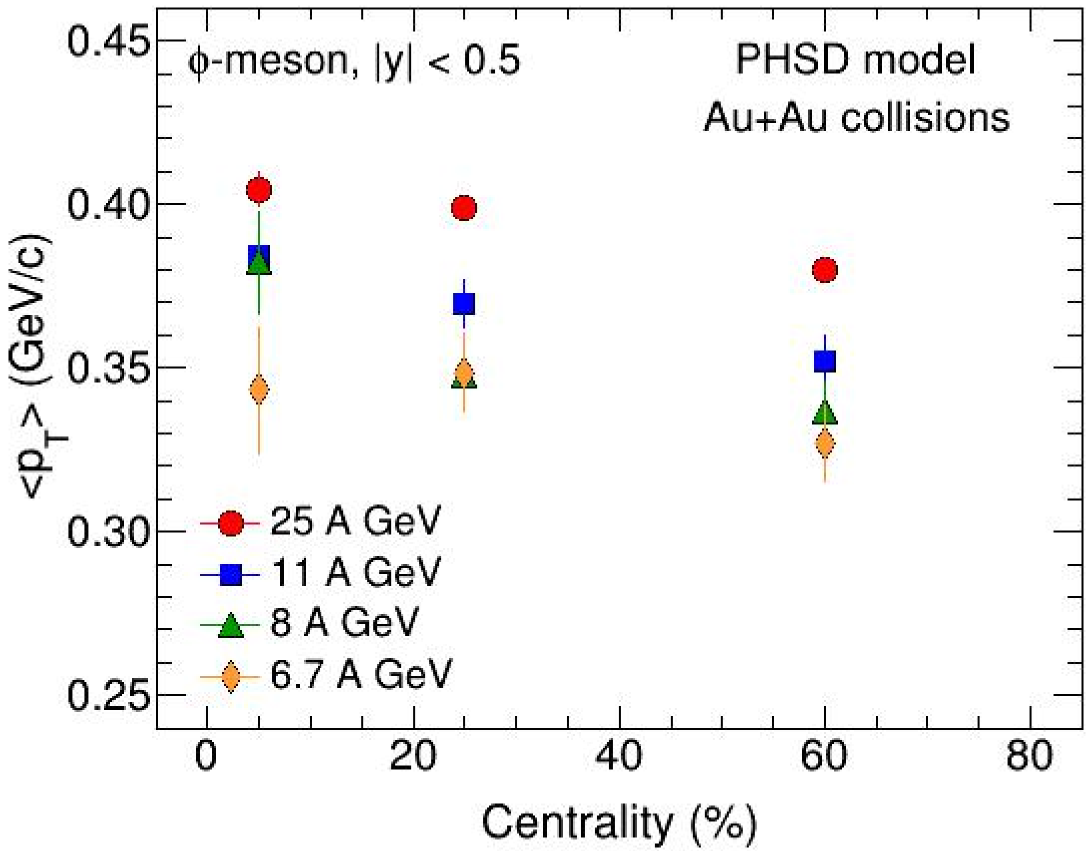
Transverse momentum (p_T) spectra

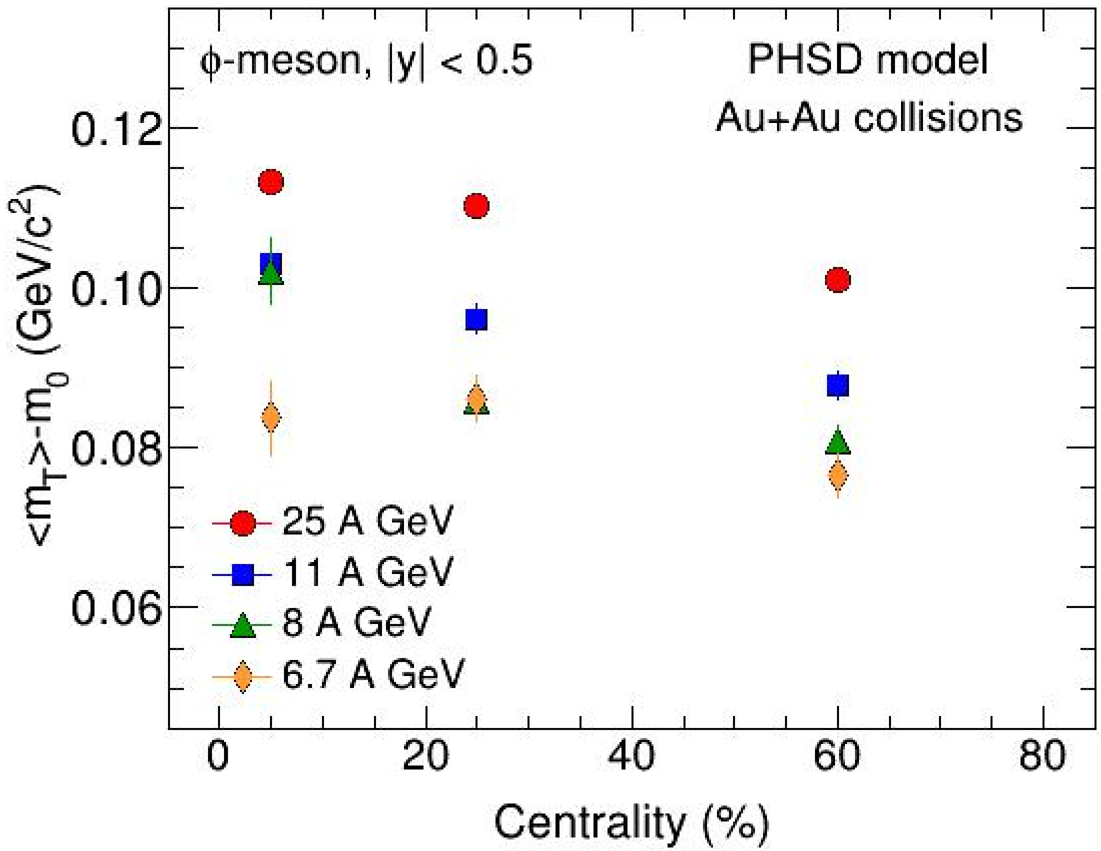




- The p_T-spectra of φ-meson well described by exponential function fit in the measured p_T range
- Invariant yield of φ-meson at mid-rapidity (|y| < 0.5) shows centrality and energy dependence
  - Indicating increase in φ-meson production with centrality

Average transverse momentum $\langle p_T \rangle$





- $\langle p_T \rangle$ and $\langle m_T \rangle - m_0$ of φ-meson increases with the increasing centrality at a given beam energy
  - ► Indicating gradual development of collective motion with the increasing medium volume

Flow analysis method

- **Single particle distribution:**

$$E\frac{d^3N}{dp^3} = E\frac{d^2N}{2\pi p_T dp_T d\eta}\left[1 + 2\sum_{n=1}^{\infty} v_n(p_T,\eta)\cos\{n(\phi - \Psi_n)\}\right]$$

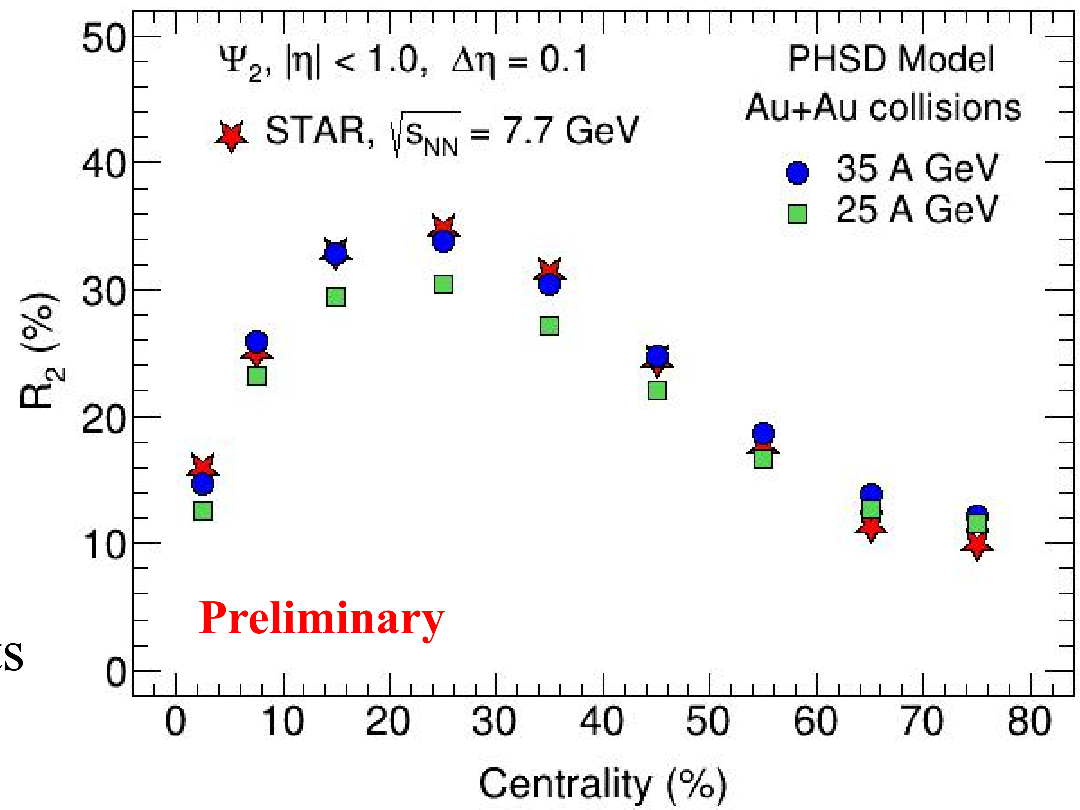
anisotropic flow $v_n = \langle\cos[n(\phi - \Psi_n)]\rangle$, Ψ_n = n[th]-order reaction plane angle

- **η-sub event plane method**

$$\Psi_n = \frac{1}{n}\tan^{-1}\left(\frac{\sum_{i=1}^{M} w_i \sin(n\phi_i)}{\sum_{i=1}^{M} w_i \cos(n\phi_i)}\right)$$

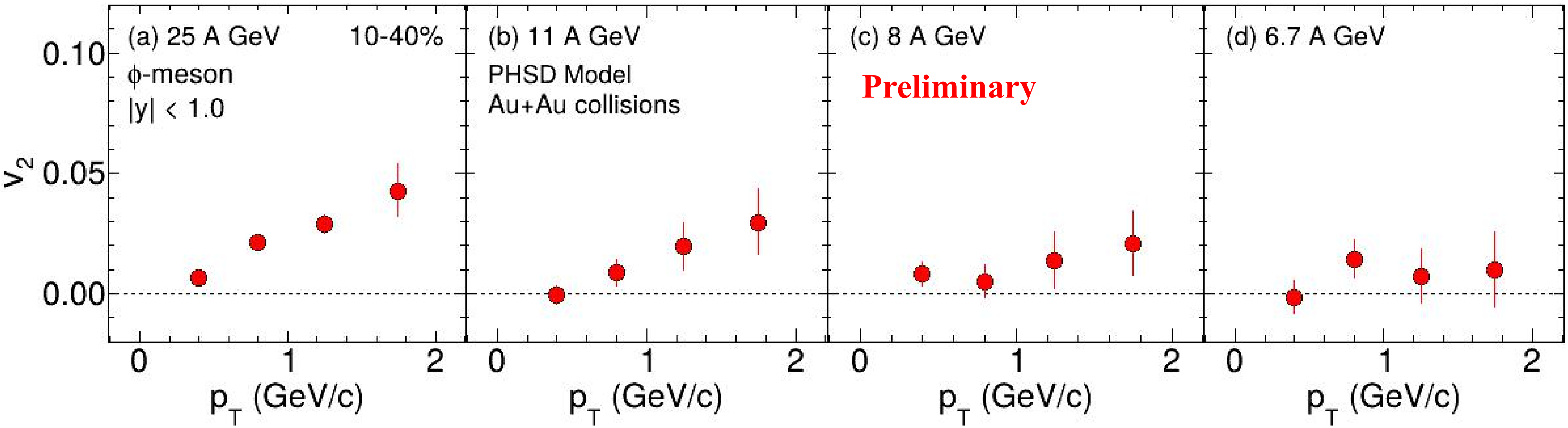
$$R_n = \sqrt{\langle\cos[n(\Psi_n^A - \Psi_n^B)]\rangle}$$

Event plane angle calculated in two sub-events A ($0.05 < \eta < 1.0$) and B ($-1.0 < \eta < -0.05$).



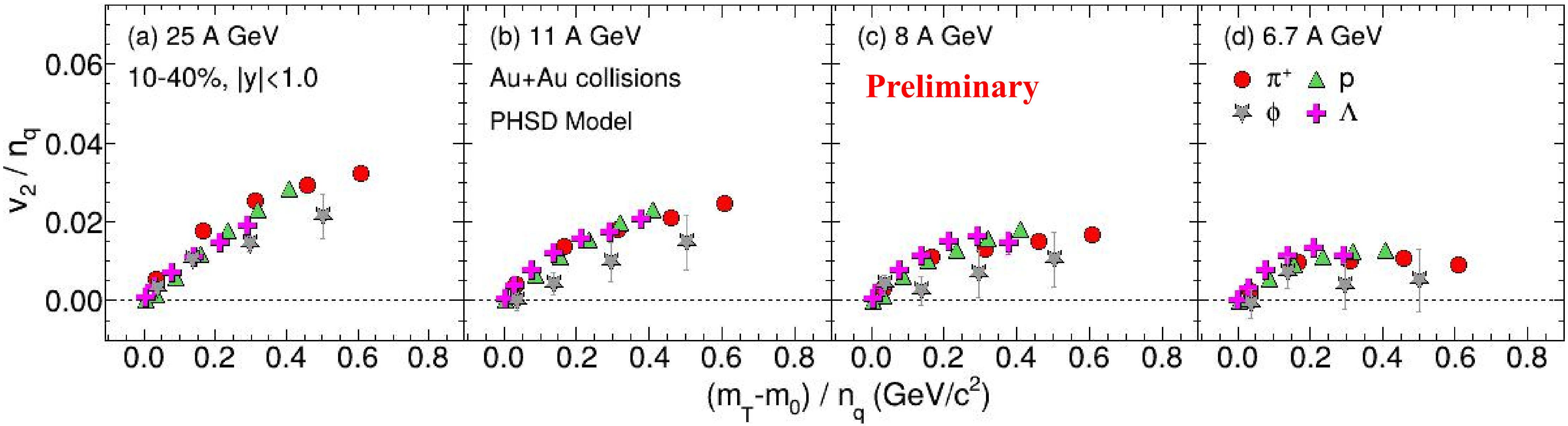
- A.M. Poskanzer & S.A. Voloshin, Phys.Rev. C 58 (1998)
- L. Adamczyk et al. (STAR), Phys. Rev. C 88, 014902 (2013)

φ-meson elliptic flow



- φ-meson v_2 (p_T) at mid-rapidity (|y| < 1.0) in Au+Au collisions at E_{lab} = 25 A - 6.7 A GeV from the PHSD model
- Magnitude of φ-meson v_2 decreases with lower beam energies
  - ► Indicating gradual increase of the hadronic dominante interactions

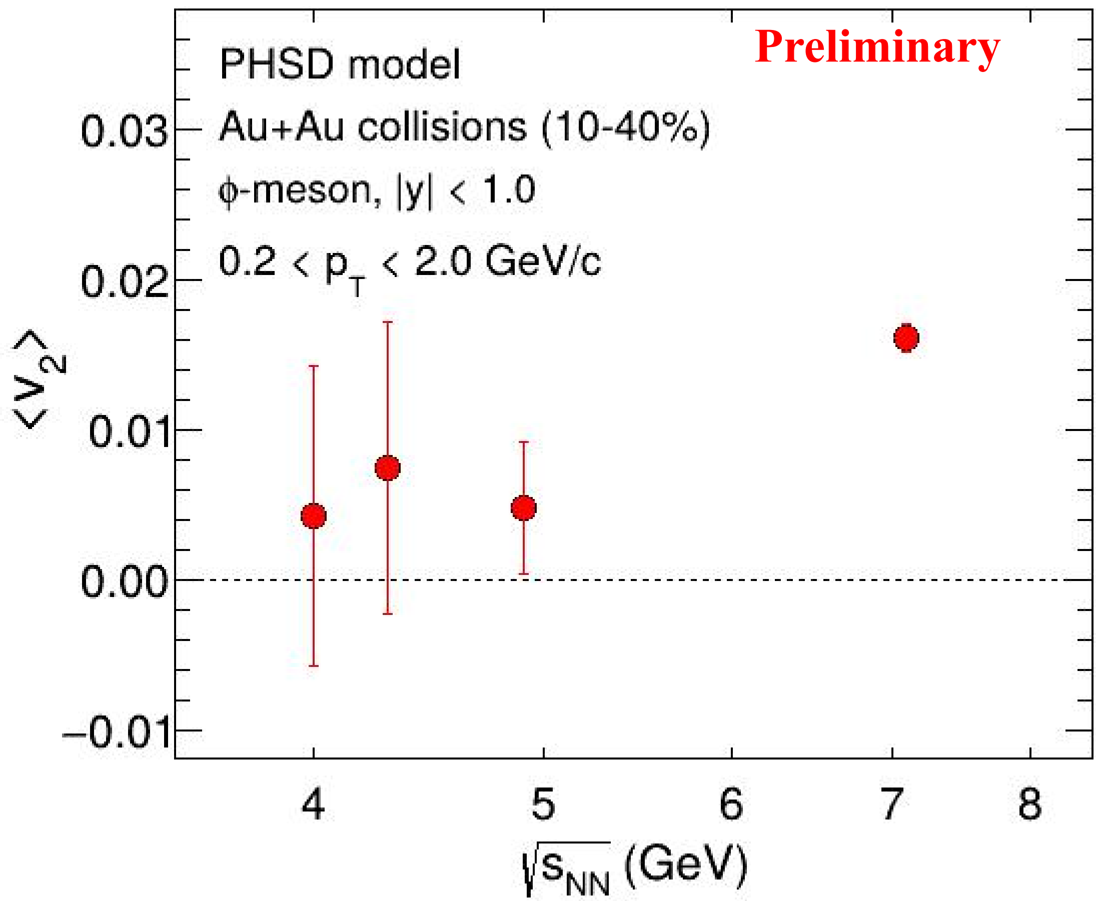
NCQ scaling



- φ-meson v_2 seems to break the NCQ scaling at lower beam energy
  - ► Suggesting medicum dominated by hadronic interactions

- B. Towseef et al., arXiv:2407.05722 (2024)

φ-meson v_2 vs. beam energy



- φ-meson integrated $\langle v_2 \rangle$ vs. center of mass energy in 10-40% central Au+Au collisions from the PHSD model $\langle v_2 \rangle$ decreases with decrease in beam energy
  - ► Likely due to the hadronic dominated medium in the PHSD model at low beam energies

Summary

- Transversme momentum spectra, invariant yield, $<p_T>$ and $<m_T>-m_0$ of φ-meson at $|y| < 0.5$ presented in Au+Au collisions at E_{lab} = 25 A to 6.7 A GeV using the PHSD model.

- Ellitpic flow v_2 of φ-meson at $|y| < 1.0$ presented in Au+Au collisions at E_{lab} = 25 A to 6.7 A GeV using the PHSD model.

- Invariant yield (dN/dy), $<p_T>$ and $<m_T>-m_0$ of φ-meson show centrality and energy dependence

Indicating gradual development of collective motion in the PHSD model

- Magnitude of φ-meson v_2 decreases with lower beam energies
- φ-meson v_2 seems to break the NCQ scaling at lower beam energy

Indicating gradual increase of the hadronic dominante medium in the PHSD model

Thank you for your attention!