SQM2022

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Elliptic and triangular flow of (multi-)strange hadrons and ϕ mesons in BES-II energies at STAR

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Outline

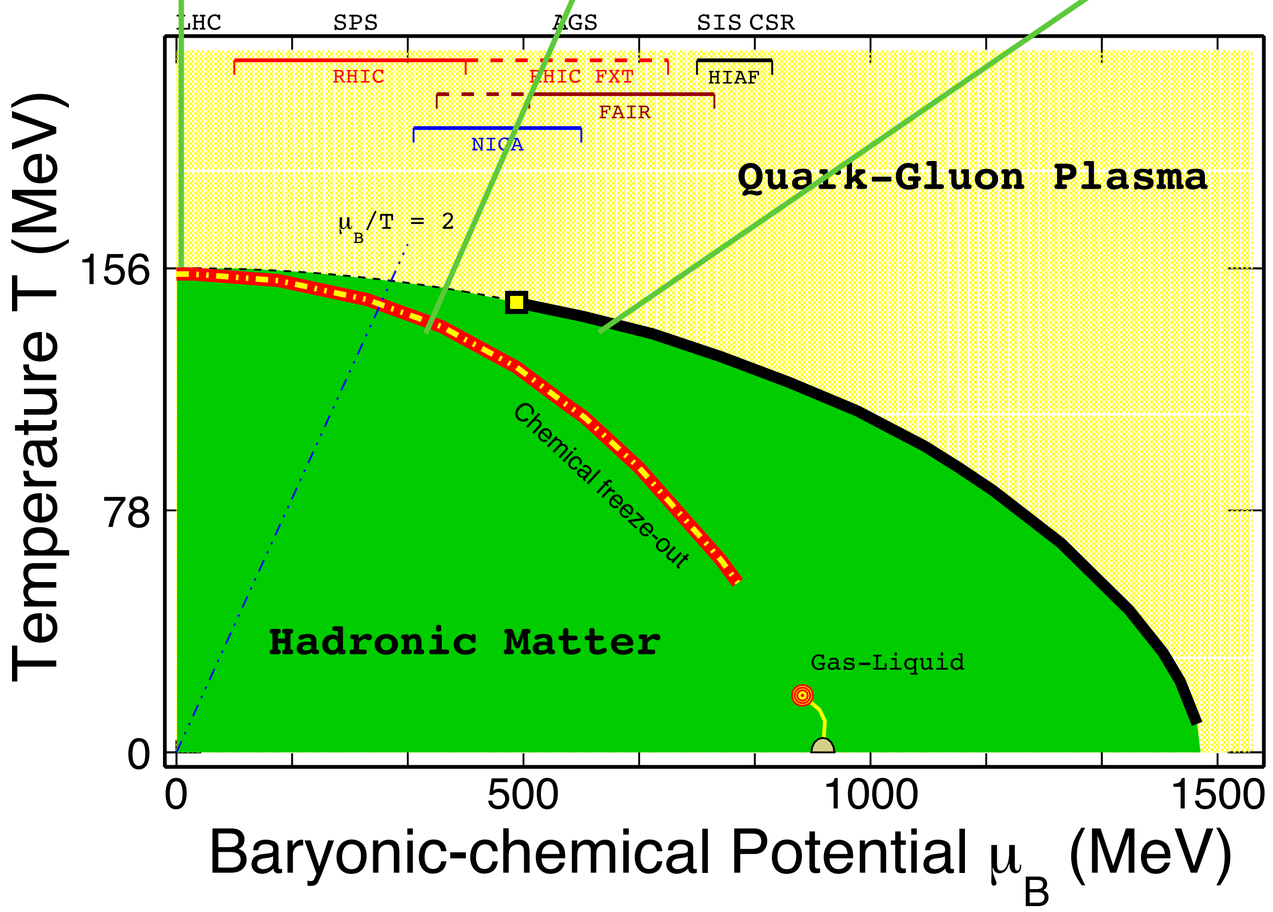
- Motivation
- Experimental Setup
- Analysis Method
- Results and Discussion
- Summary and Outlook

Motivation

LHC, RHIC 200 GeV
T_C

RHIC COL: 7.7-62.4 GeV
u_B: 73-420 MeV

RHIC FXT: 3.0-7.7 GeV
u_B: 420-750 MeV



- RHIC 200 GeV and LHC

  Small viscosity, high temperature

  Evidence of Quark-Gluon Plasma

- Beam energy scan program

  Search for Critical Point

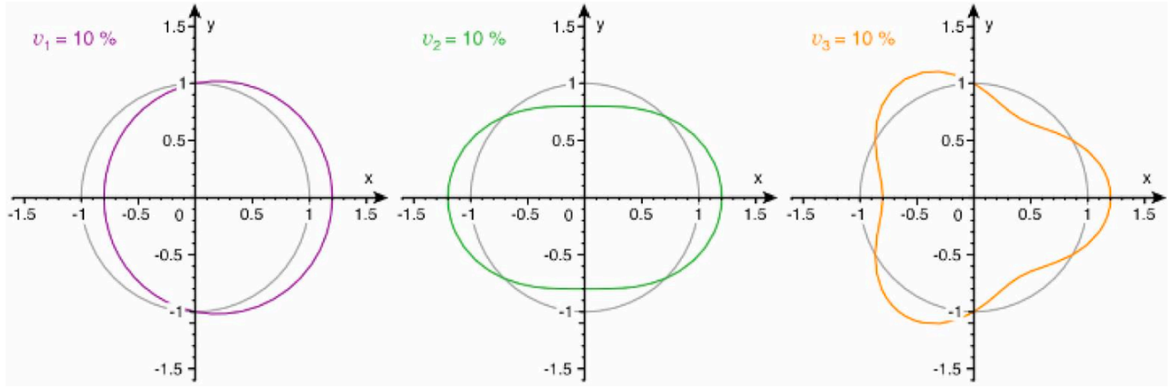
  Locate the first-order phase boundary

A. Bazavov et al., Phys. Rev. D 85, 054503 (2012); K. Fukushima and C. Sasaki, Prog. Part. Nucl. Phys, 72, 99 (2013)

Motivation

Heavy ion collisions: Initial spatial anisotropy → Pressure gradient → Anisotropic flow

$$E\frac{d^3N}{dp^3} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left(1 + \sum_1^\infty 2v_n \cos\left[n\left(\phi - \psi_{RP}\right)\right]\right)$$



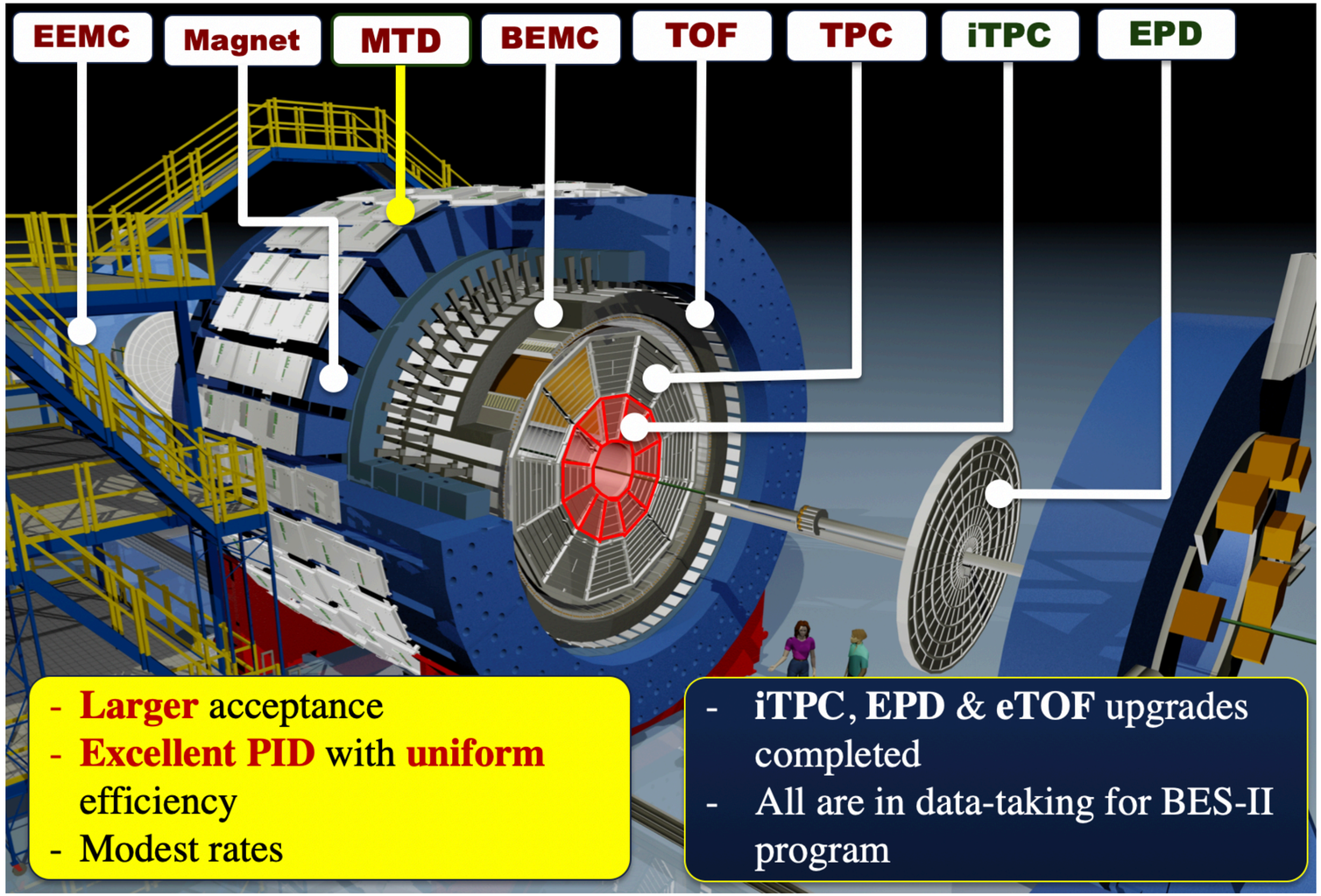
v_1: directed flow v_2: elliptic flow v_3: triangular flow

Self-quenching effect

- v_2 is sensitive to constituent interactions and degree of freedom
- v_3 is sensitive to event-by-event fluctuations in the overlap region
- ϕ-meson and strange hadrons less affected by the hadronic phase
  - Small hadronic interaction cross sections
  - Freeze-out earlier than other light hadrons

B. Mohanty, N. Xu, Journal of Physics G 36, 064022 (2009); M. Nasim et al. Physical Review C 87, 014903 (2013)

Experimental Setup



- The STAR Detector
  - Full 2π azimuthal coverage
  - Large acceptance at mid-rapidity
  - Excellent particle identification

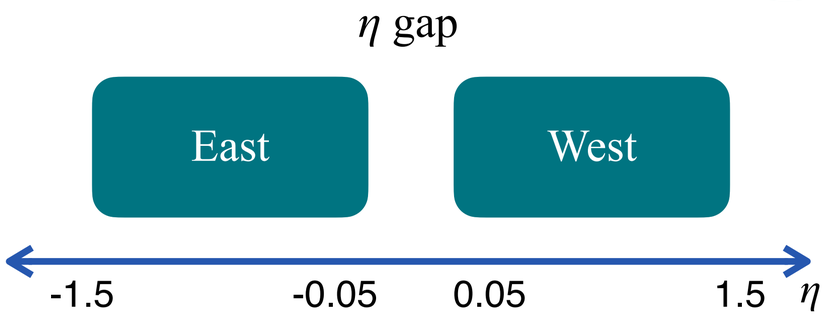
- Upgrade of inner-TPC
  - Better track quality
  - Larger acceptance ($|\eta| < 1.5$)

Event Plane Calculation

A. M. Poskanzer and S. A. Voloshin, Phys. Rev. C58, 1671 (1998)

- The n[th] harmonic event plane was calculated as:

$$\vec{Q} = \begin{pmatrix} Q_y \\ Q_x \end{pmatrix} = \begin{pmatrix} \sum_i w_i \sin(n\phi_i) \\ \sum_i w_i \cos(n\phi_i) \end{pmatrix} \qquad \Psi_n = \tan^{-1}\left(\frac{\sum_i w_i \sin\left(n\phi_i\right)}{\sum_i w_i \cos\left(n\phi_i\right)} \right) / n$$

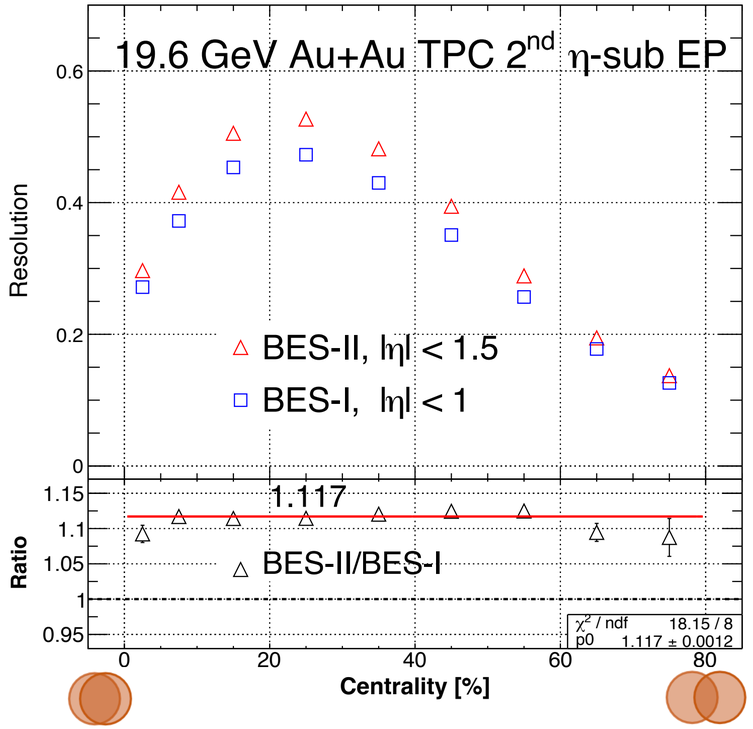


- Since finite multiplicity limits the estimation of the reaction plane, this will bring resolution:

$$R_n = \left\langle \cos\left[n\left(\Psi_{n,EP} - \Psi_{RP} \right) \right] \right\rangle \qquad R_{n,sub} = \sqrt{\left\langle \cos\left[n\left(\Psi_{n,east} - \Psi_{n,west} \right) \right] \right\rangle}$$

STAR detector upgrades and higher statistics:

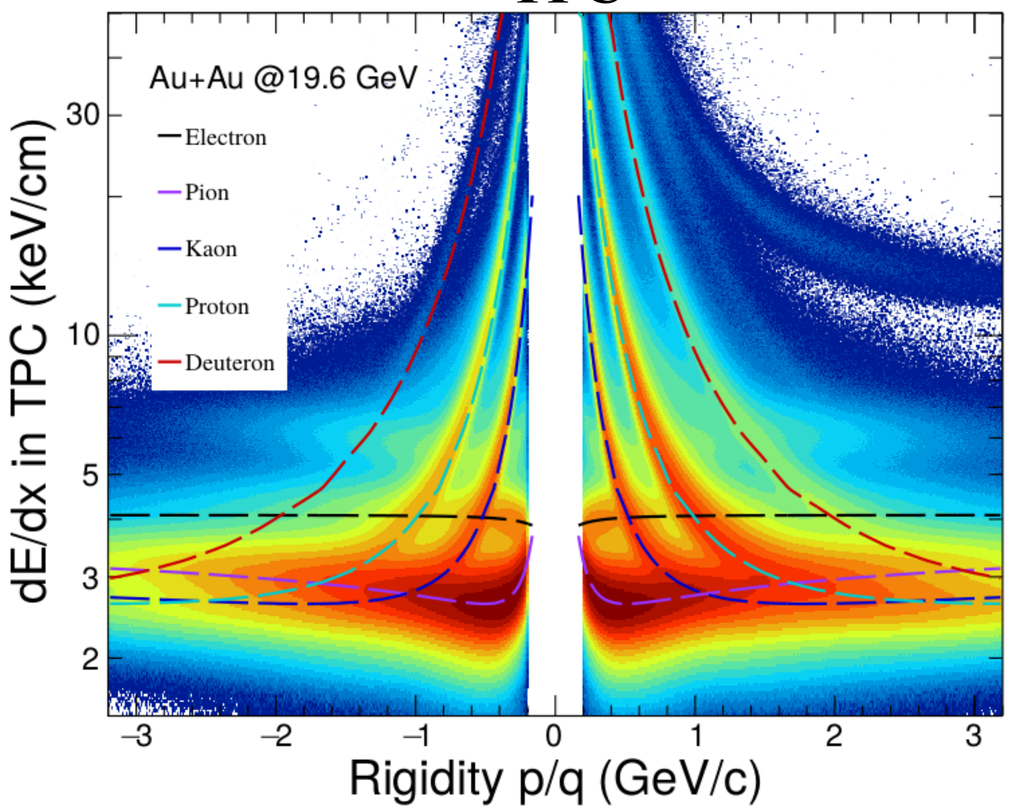
- 11% improvement of 2[nd] EP resolution
- Typical 3[rd] EP resolution achieved and first v_3 measurement



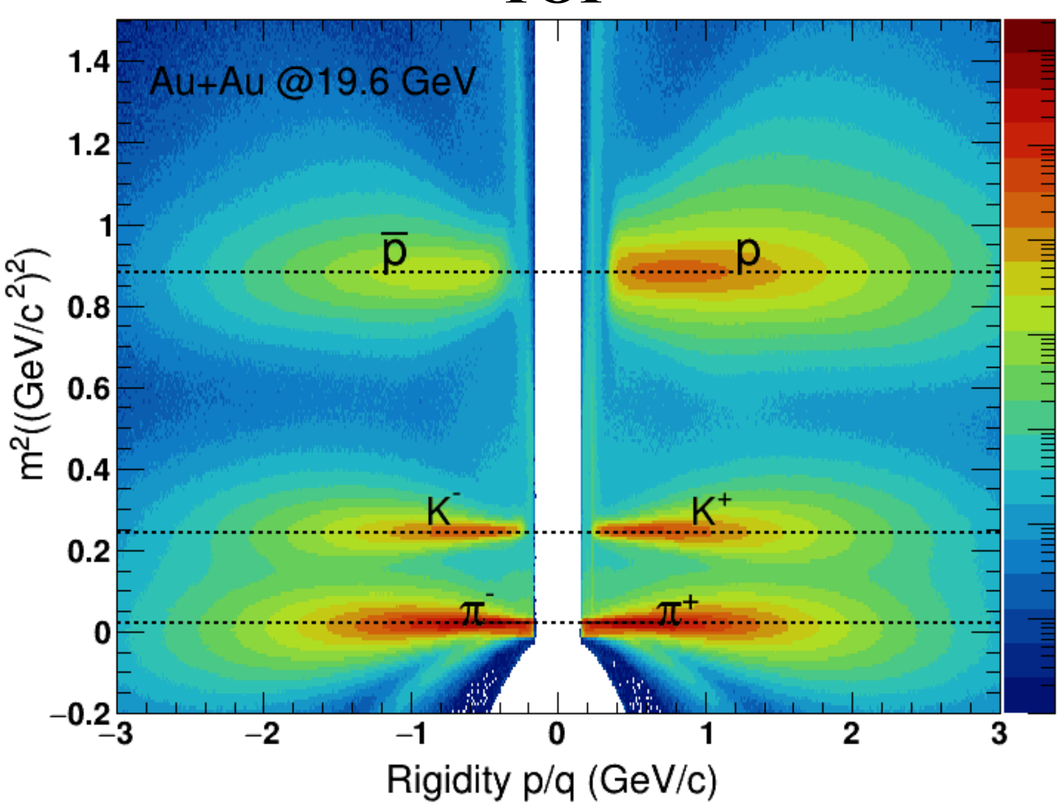
Prabhupada, 6/14 5:10 pm, POS-BLK-10

Particle Identification

TPC

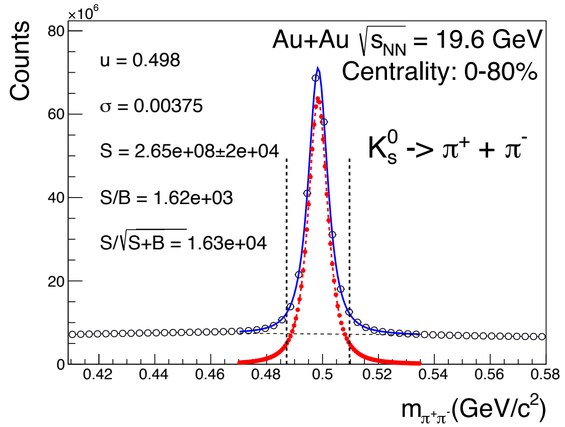


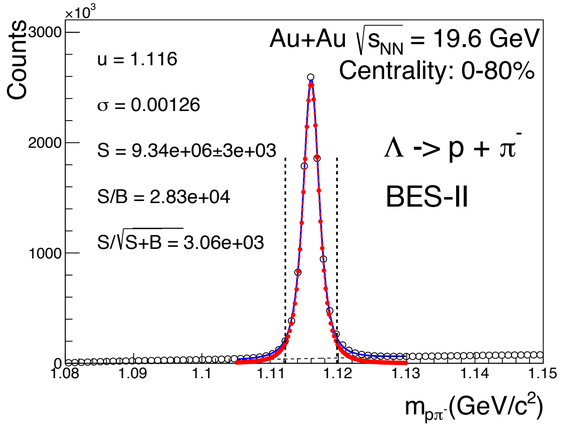
TOF

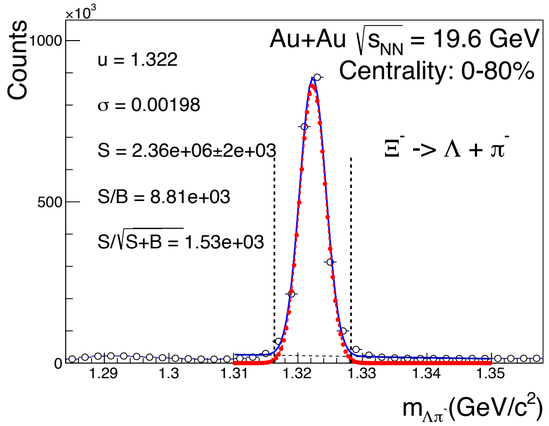


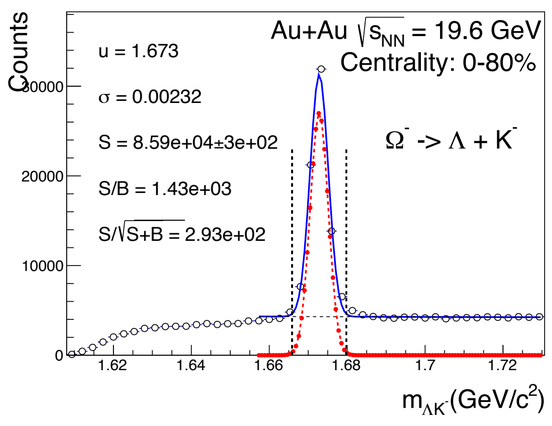
- Good particle identification capability based on TPC and TOF

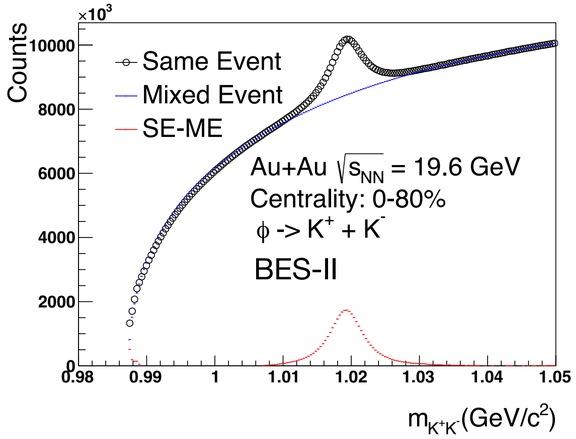
Decay Particle Reconstruction







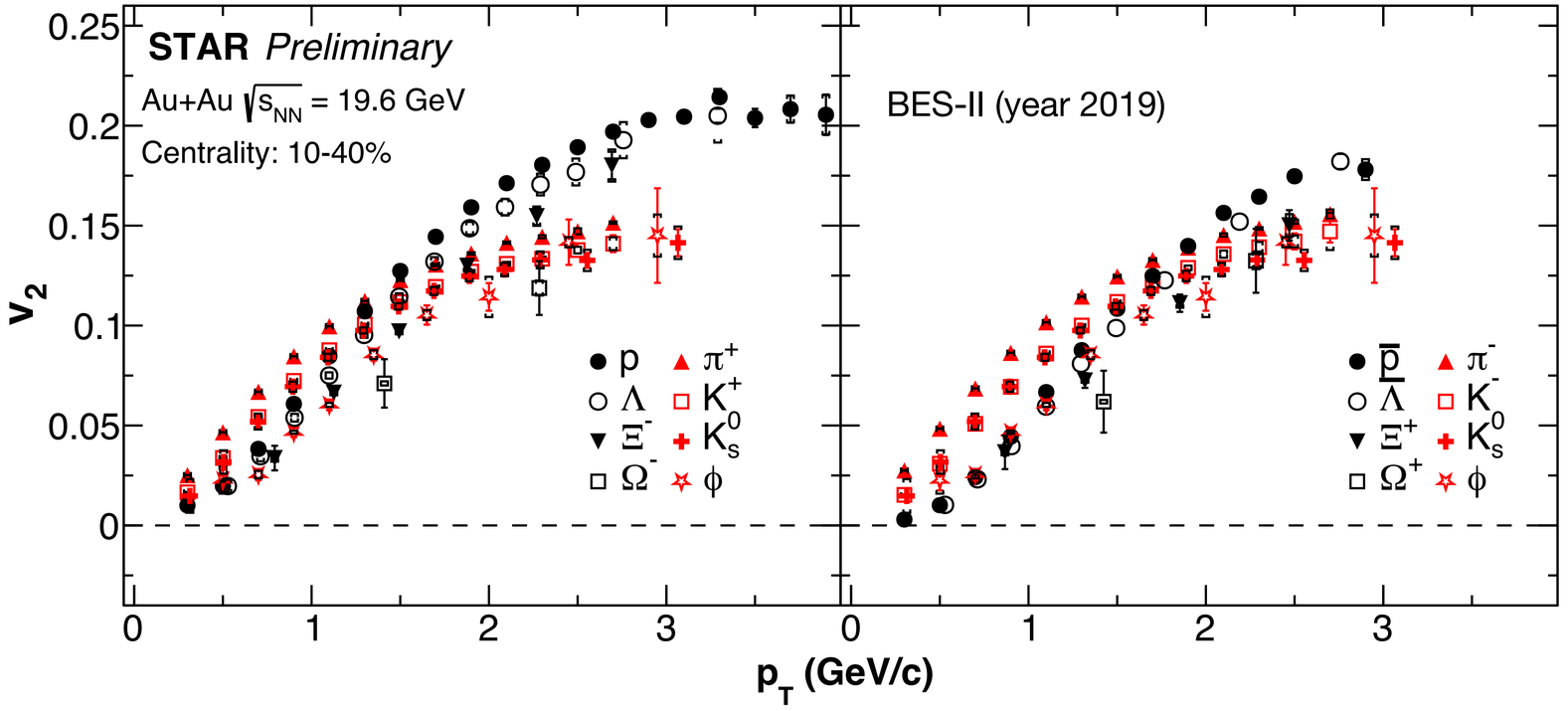




- K^0_s, Λ, $\bar{\Lambda}$, $\Xi^{\pm}$, $\Omega^{\pm}$ are reconstructed by KF particle package
  - background described by first order polynomial
- ϕ-mesons are reconstructed by K^+K^- channel
  - background estimated by using mixed event method

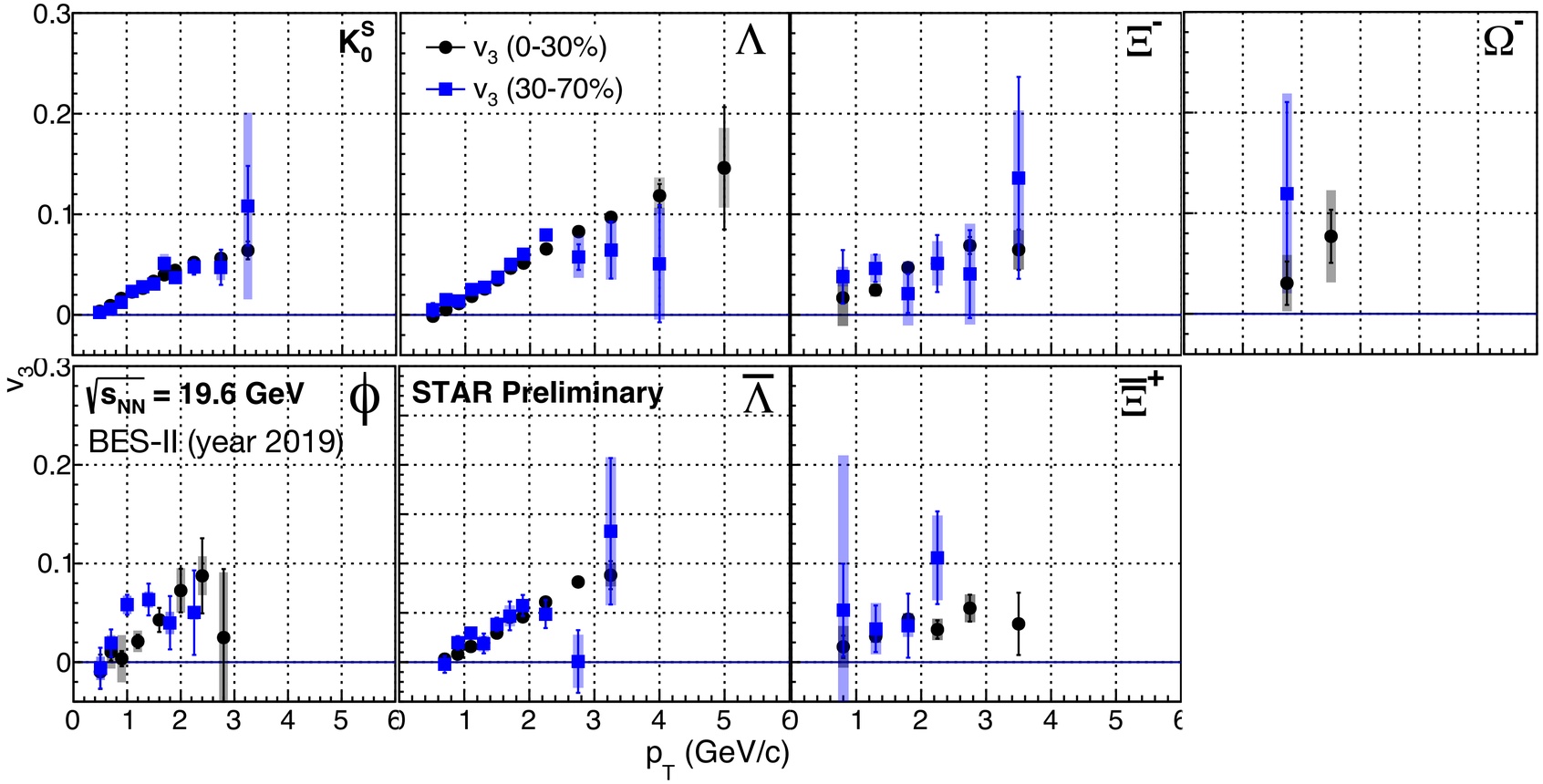
A. Banerjee, I. Kisel and M. Zyzak, Int. J. Mod. Phys. A 35, 2043003 (2020)

v_2 of Identified Particles



- Clear mass ordering of $v_2(p_T)$ when $p_T < 1.5$ GeV/c **radial flow**
- Particles grouped according to hadron type (baryon or meson) when $p_T > 1.5$ GeV/c **quark coalescence**

v_3 of Identified Particles

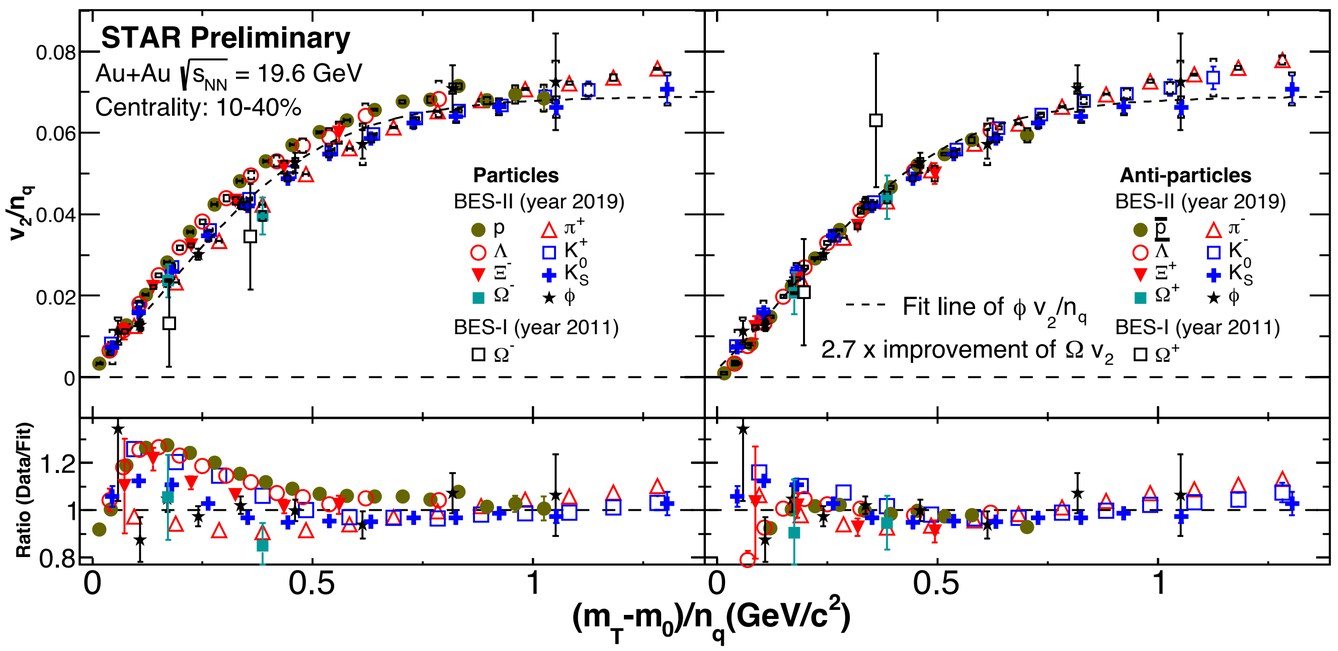


- Weak centrality dependence for v_3

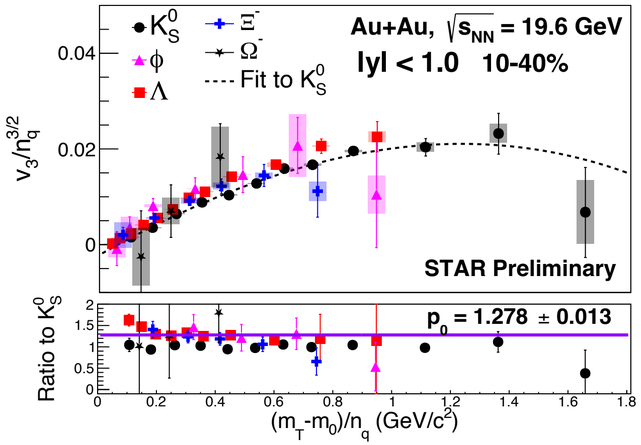
  Event-by-event fluctuation is the dominant source

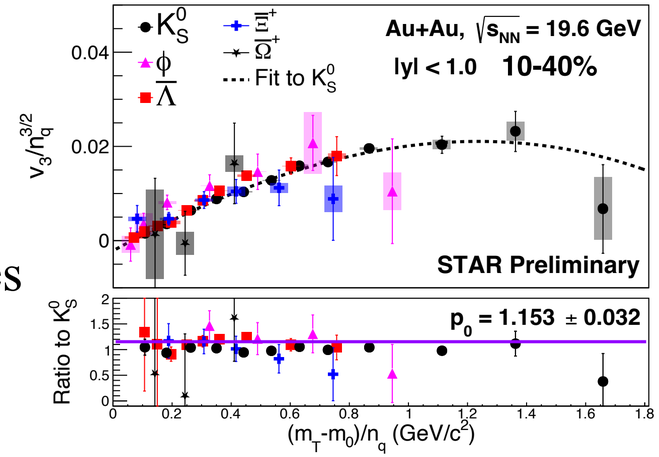
Test of NCQ Scaling at 19.6 GeV

NCQ scaling of v_2



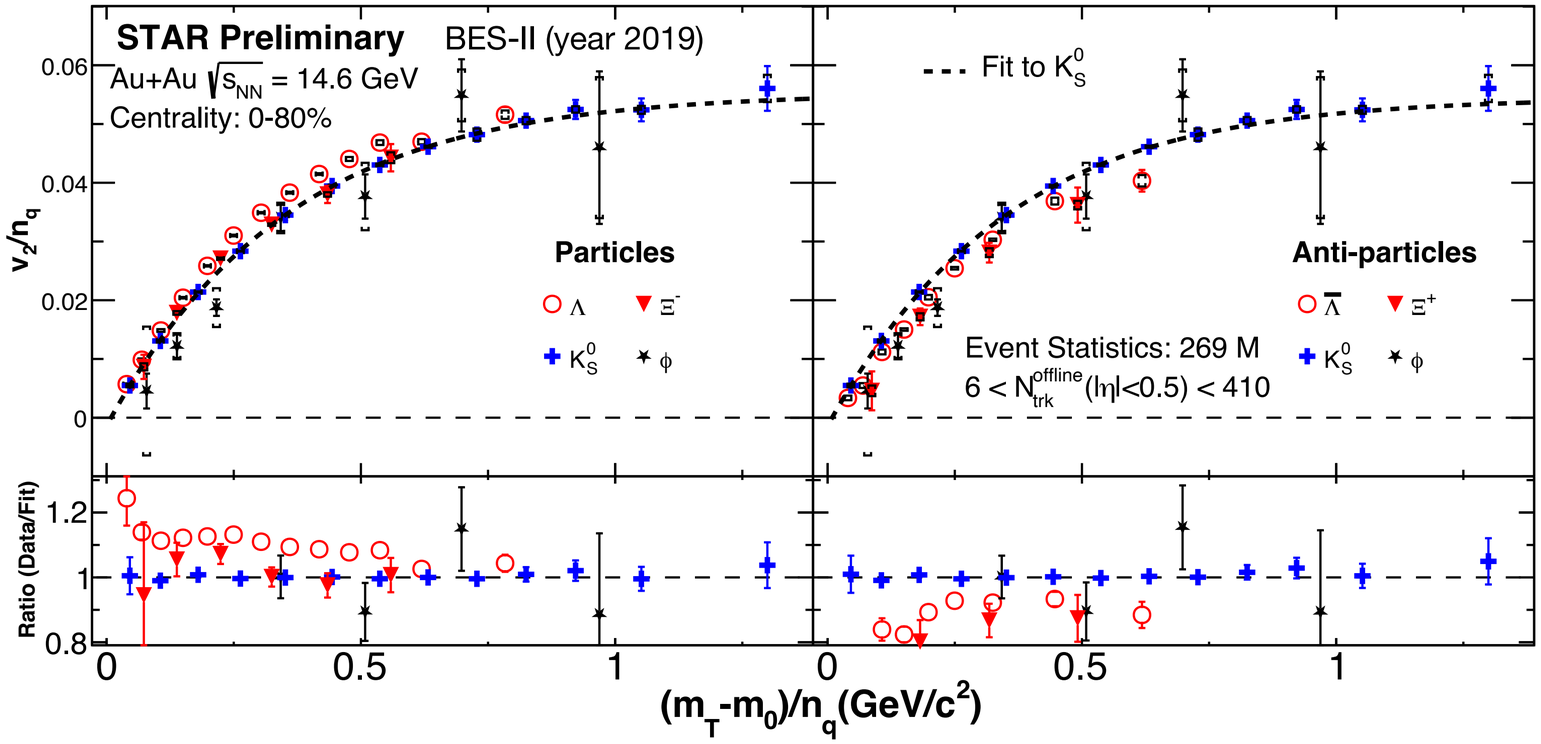
NCQ scaling of v_3





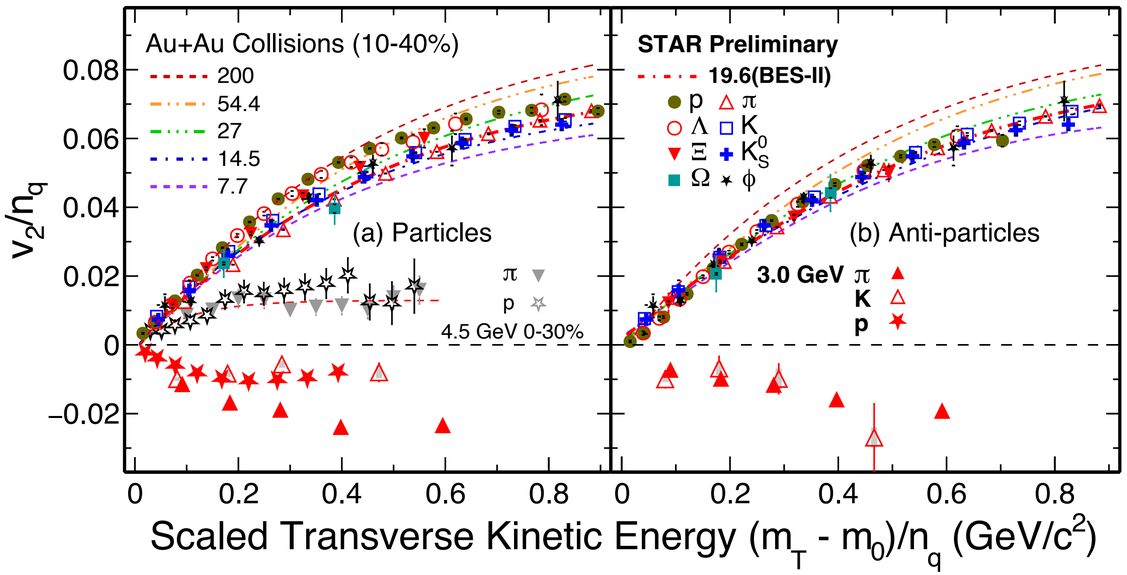
- NCQ scaling of v_2 (v_3) holds within 10(15)% for anti-particles, 20(30)% for particles
  quantify the NCQ scaling -> benefit from enhanced statistics of BES-II
  - Indicating the collective flow has been built up in the **partonic stage**
- NCQ scaling of anti-particles is better than particles: **produced vs. transported quarks**

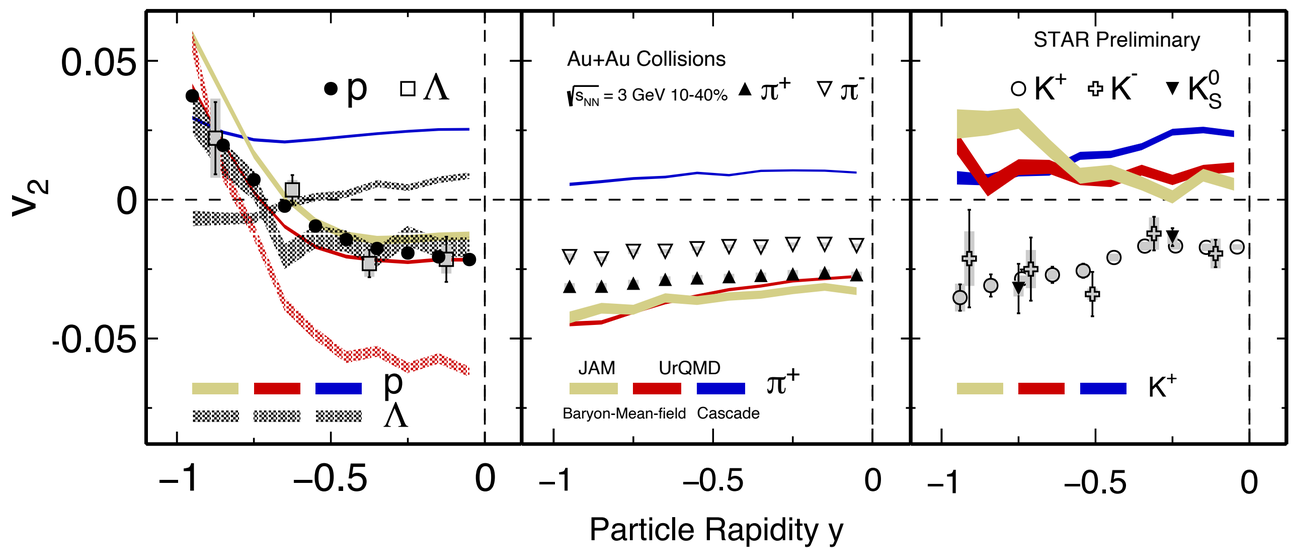
Test of NCQ Scaling at 14.6 GeV



- NCQ scaling holds at 20% level

v_2 results at 3 GeV





- At this energy, $\mu_B \sim 750$ MeV, high baryon density region
- The values of v_2 for all particles are negative, and the NCQ scaling is absent
- The data can be qualitatively reproduced by baryonic mean-field transport models

disappearance of partonic collectivity and likely dominated by baryonic interactions

M. S. Abdallah et al. (STAR): Phys. Lett. B 827, 137003 (2022)

Summary

- NCQ scaling of v_2 and v_3 holds well at 19.6 GeV
  - **Signature of partonic collectivity**
  - **Difference between transported and produced quarks**
- NCQ scaling is absent at 3 GeV
  - **Medium likely dominated by baryonic interactions**

Outlook

$\sqrt{s_{NN}}$(GeV)	μ_B(MeV)	Events	Date collected
19.6	206	478 M	2019
14.6	262	324 M	2019
11.5	316	235 M	2020
9.2	373	162 M	2020
7.7	422	101M+163 M	2021
6.2	487	118 M	2020
5.2	541	103 M	2020
4.5	589	108 M	2020
3.9	632	170 M	2020
3.5	666	116 M	2020
3.2	697	201 M	2019
3.0	721	2361 M	2021

Collider mode

Fixed target mode

- The data taking of BES-II has been finished, enhanced statistics, upgraded detectors
  - **Precise measurements of multi-strange hadron and ϕ meson v_n**
- Explore the QCD phase diagram with BES-II 3-20 GeV datasets

Thank you for your attention!