ϕ meson measurements at RHIC – KK decay channel
results from PHENIX and STAR

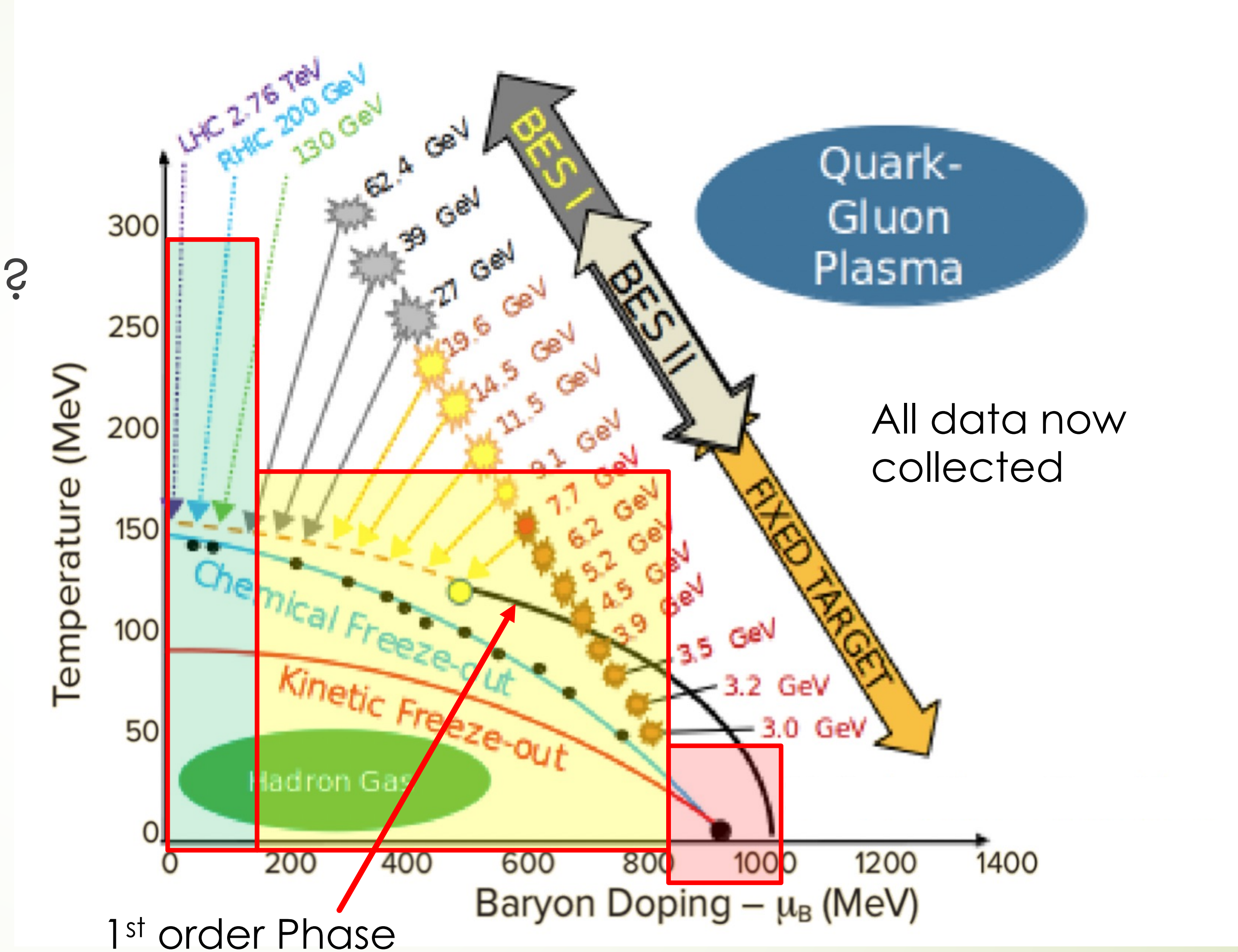
Richard Seto
University of CA, Riverside

Reimei Workshop

Feb. 22, 2022

Outline

- Why is the ϕ interesting?
- Masses and Widths
- Yields – simple systems
- Yields – AuAu at low $\sqrt{s}$
- Flow

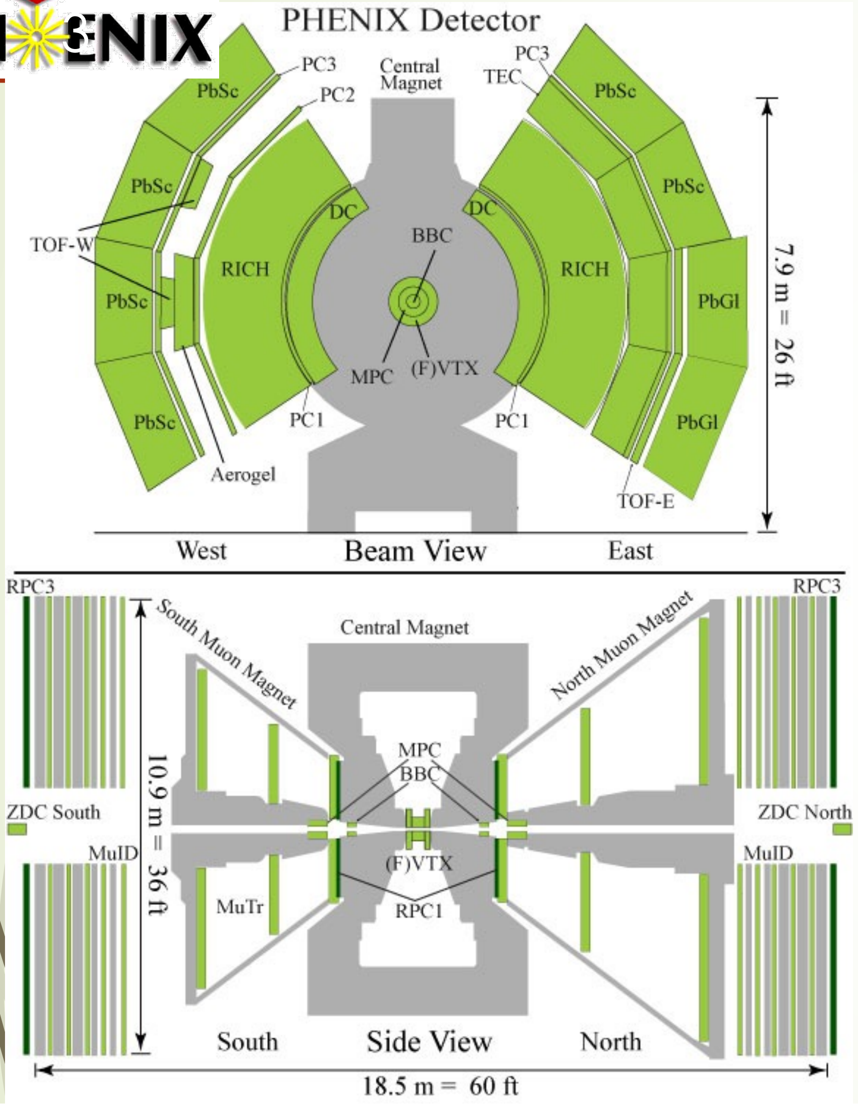


Guess: 1st order phase transition
~ 10-20 GeV CM

1st order Phase transition

- I will be looking at shaded yellow region
- Concentrate on ϕ

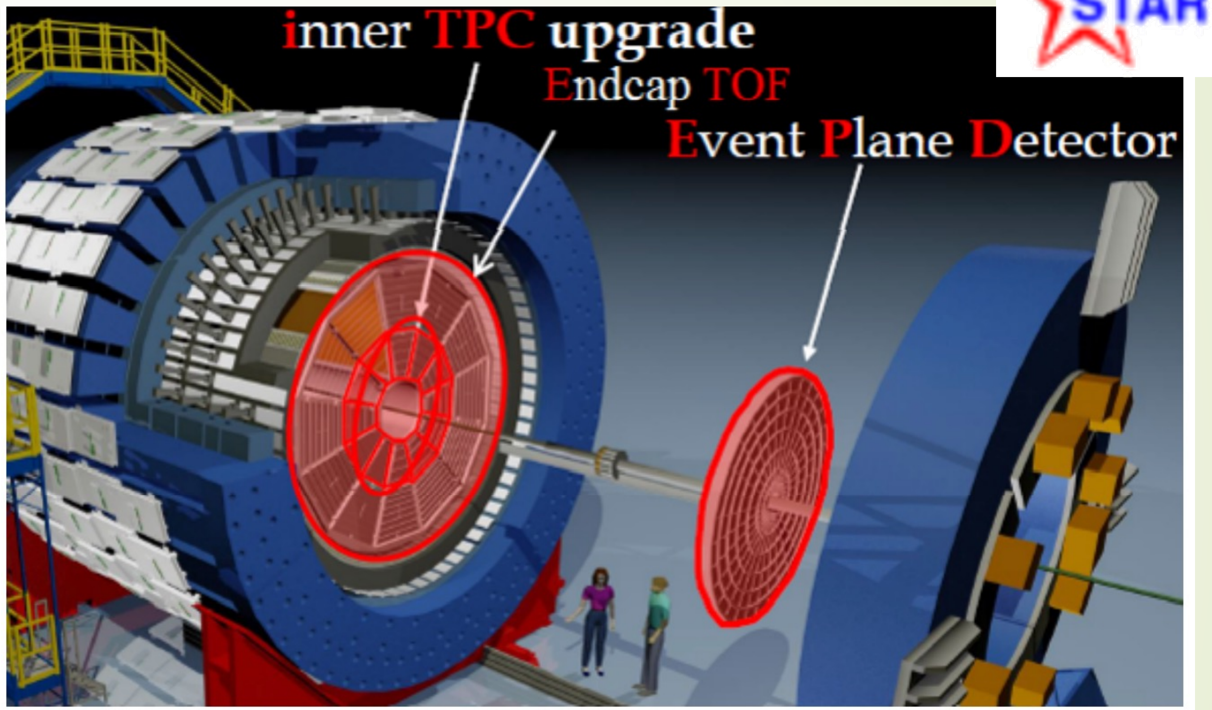
PHENIX and STAR



PHENIX

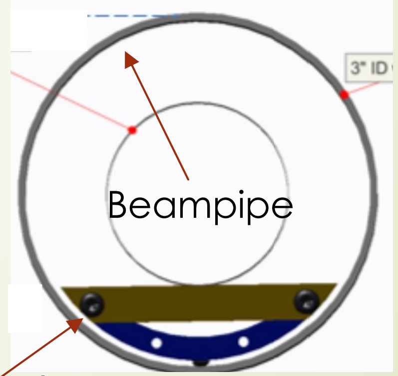
Completed data taking 2016 ➔ sPHENIX

STAR



Recent Upgrades

- Inner TPC $|\eta|$ extended to 1.5
- Event Plane Detector $2.1 < |\eta| < 5.1$
- eTOF $-1.6 < \eta < -1.1$
- Fixed Target (FXT) $\sqrt{s}$ 3-7.7 GeV CM



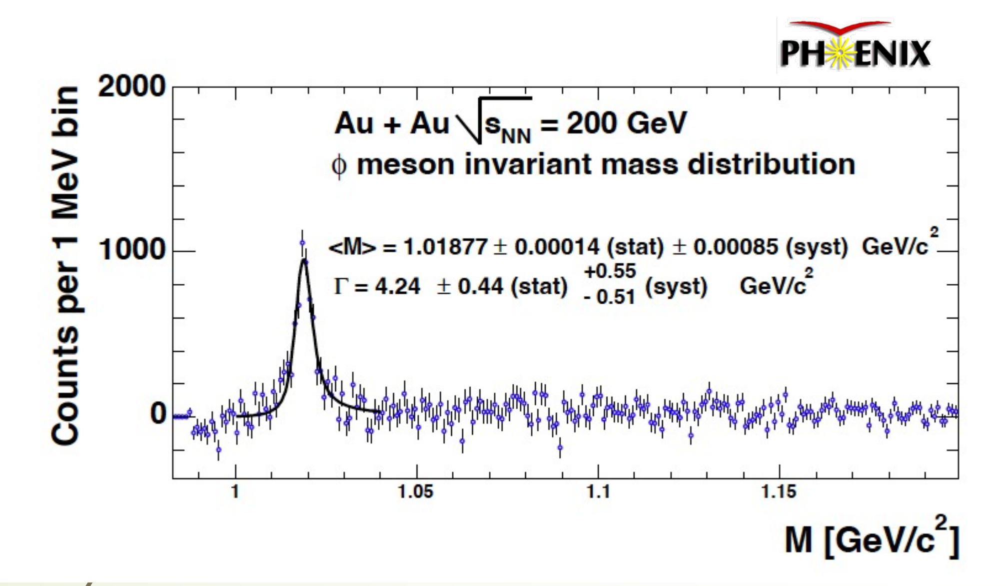
Fixed target

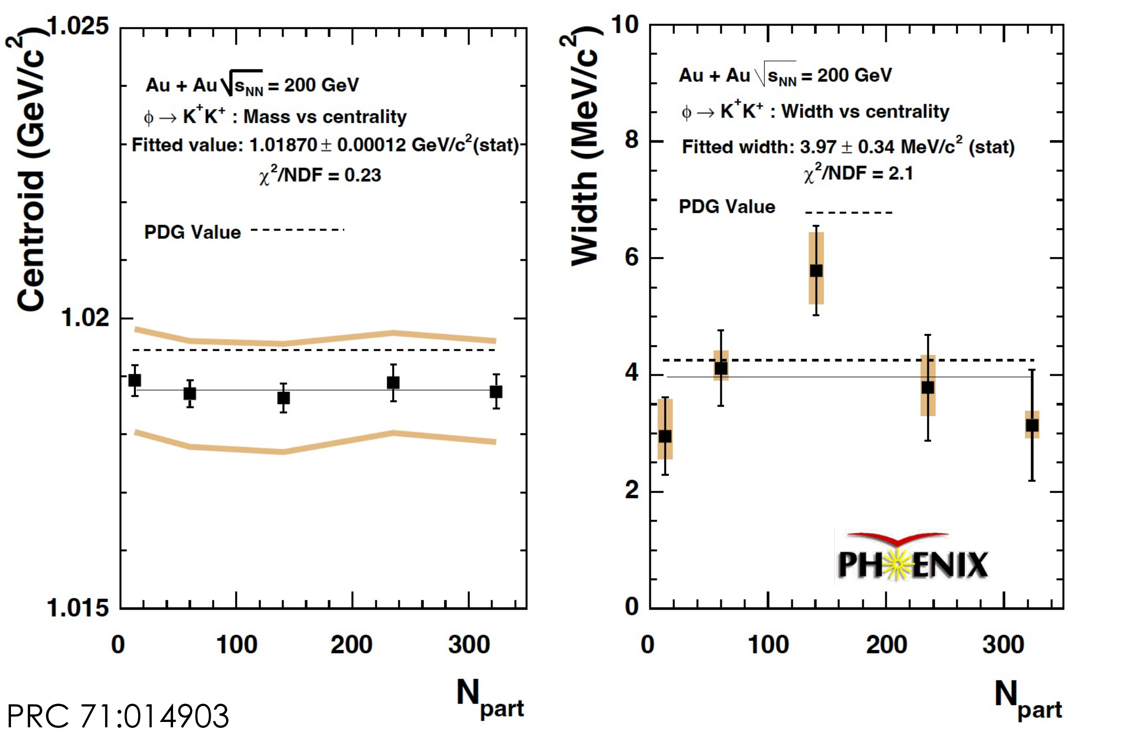
Why is the ϕ interesting in Nuclear Collisions?

- Lifetime ~ 45 fm "Short". Possibility of decay in medium to probe properties of particle in hot matter
- $s\bar{s}$ "strange" meson : produced quarks, but total strangeness=0
- Cross section with hadrons is small
- Meson but $m_\phi \sim m_p$

- Themes
  - Understanding the QGP and the initial conditions
  - Locating the Phase transition energy
  - Understanding the Phase transition and hadronic matter

Mass and Width in KK channel (200 GeV)





PRC 71:014903

Quark Gluon Plasma – Two transitions

- Deconfinement
- Restoration of Chiral Symmetry
  - ➔mass shift, broadening

Looking for High T effect (not high ρ_B)

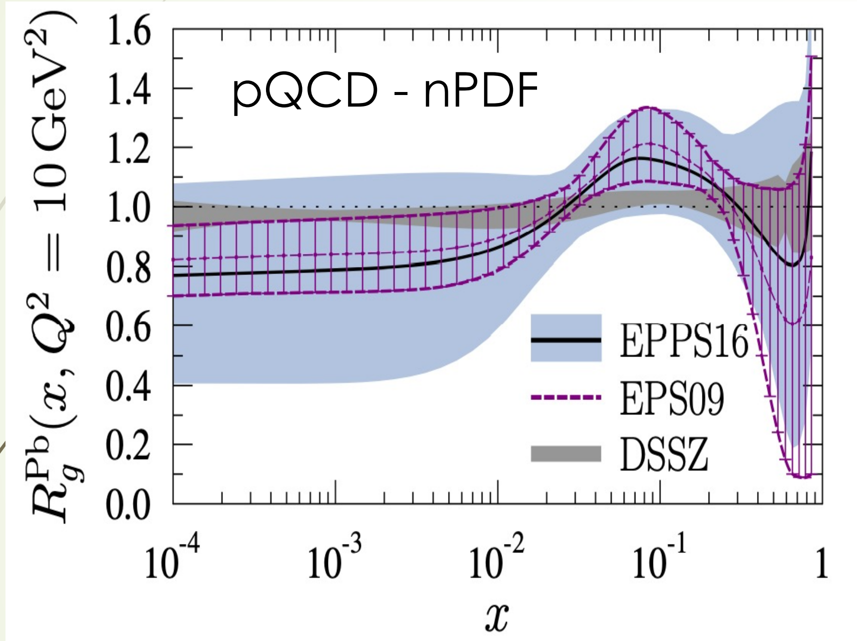
Looking at KK decay

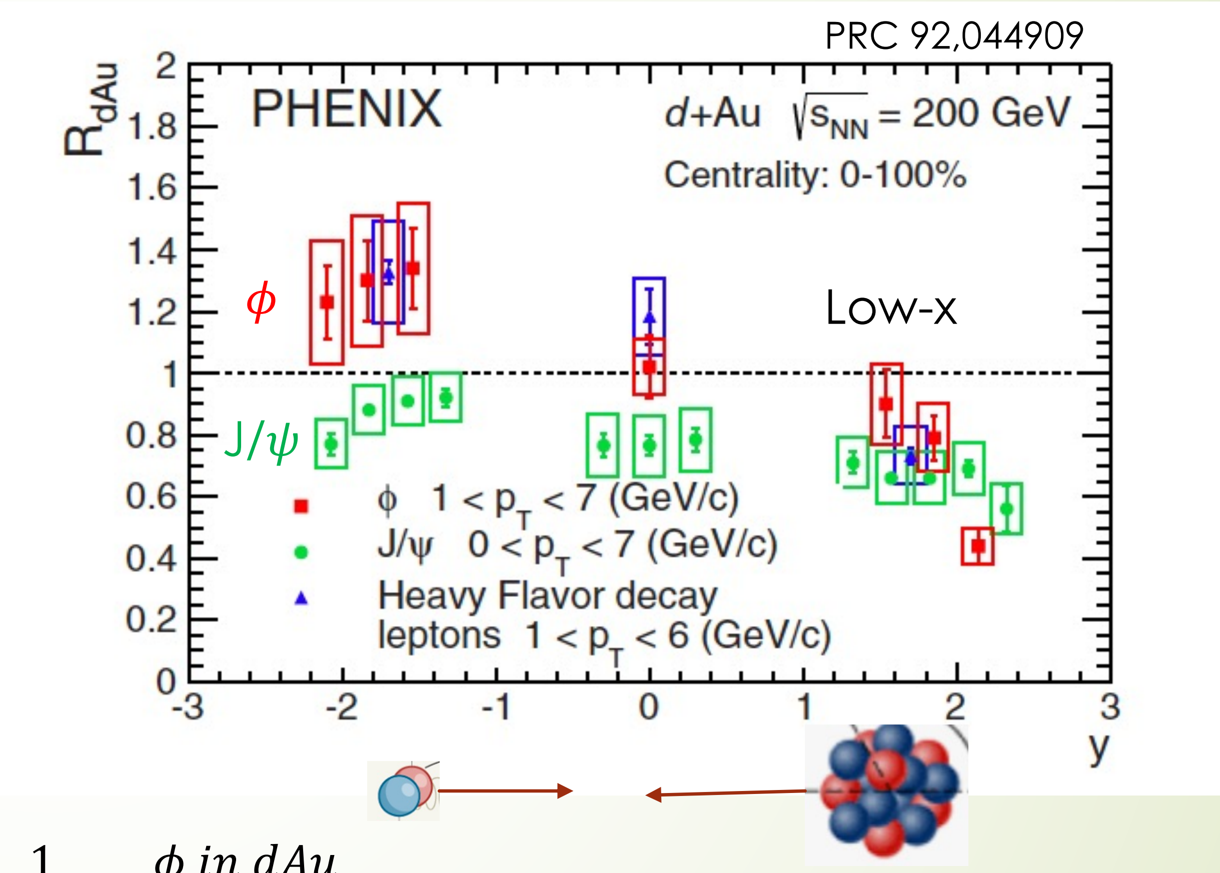
Most ϕ decay outside medium

K can reinteract in medium

➔No sign of mass shift or broadening With centrality

Cold Nuclear Matter: ϕ yields and suppression, d+Au 200 GeV CM





$$R_g^{Pb} = \frac{xG^{Pb}(x)}{A^{Pb}xG^{p}(x)}$$

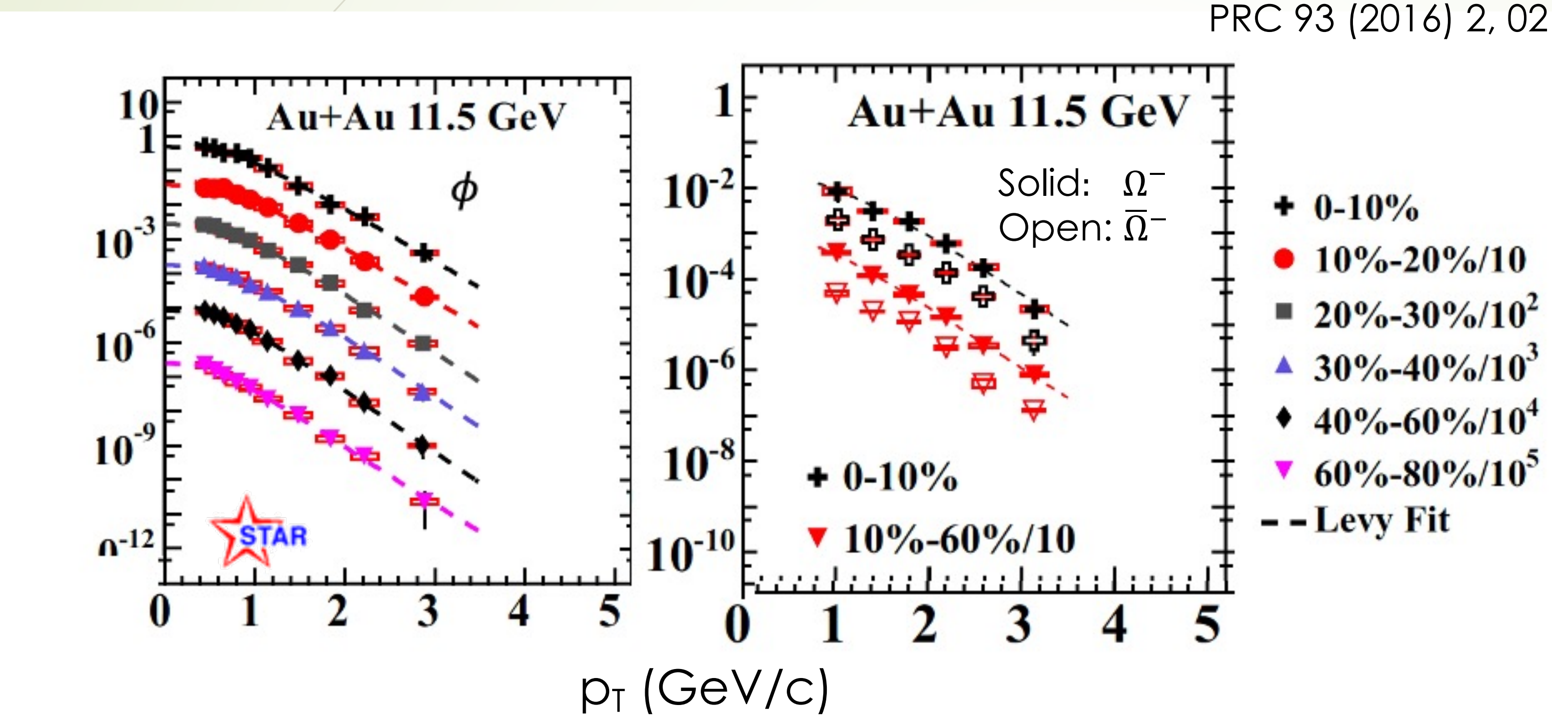
$$R_{\mathrm{dAu}} = \frac{1}{\langle n_{binary}\rangle}\frac{\phi\ in\ dAu}{\phi\ in\ pp}$$

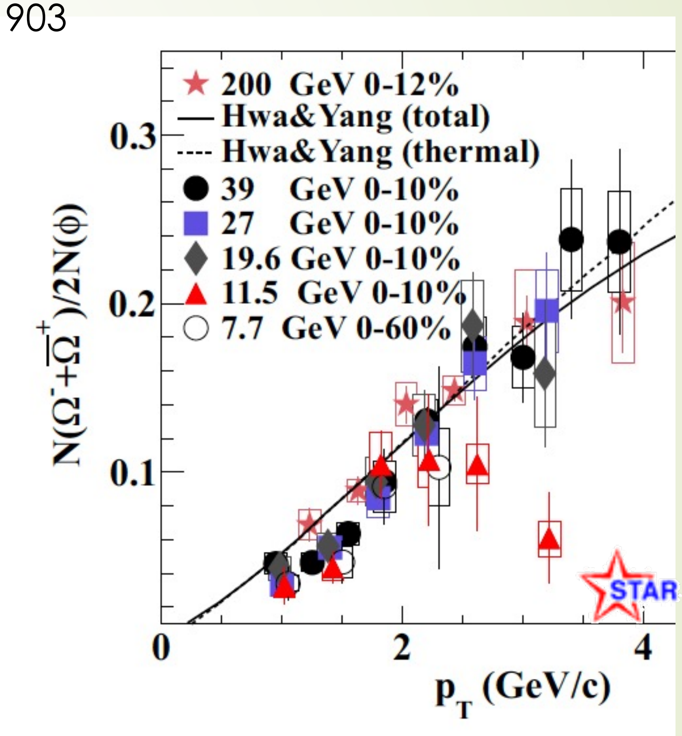
➔nPDF's can explain J/ψ at forward rapidity(fit now shown). ϕ behaves similarly
Whether hard of soft collisions governs ϕ production In this regime is an open question.

Yields Ω^{-}/ϕ – getting s quark distribution (10 GeV region)

BES I

PRC 93 (2016) 2, 021903





11.5 and 7.7 fall off
Trend line

Yields Ω^-/ϕ – getting s quark distribution

Assume coalescence
➔ use Ω/ϕ to get s quark p_T distribution

Phys.Rev.C 93 (2016) 2, 021903

$\Omega \sim f_s^3(p_T^s)$ $\phi \sim f_s(p_T^s)\, f_s^3(p_T^{\bar{s}})$ $s \sim \bar{s}$

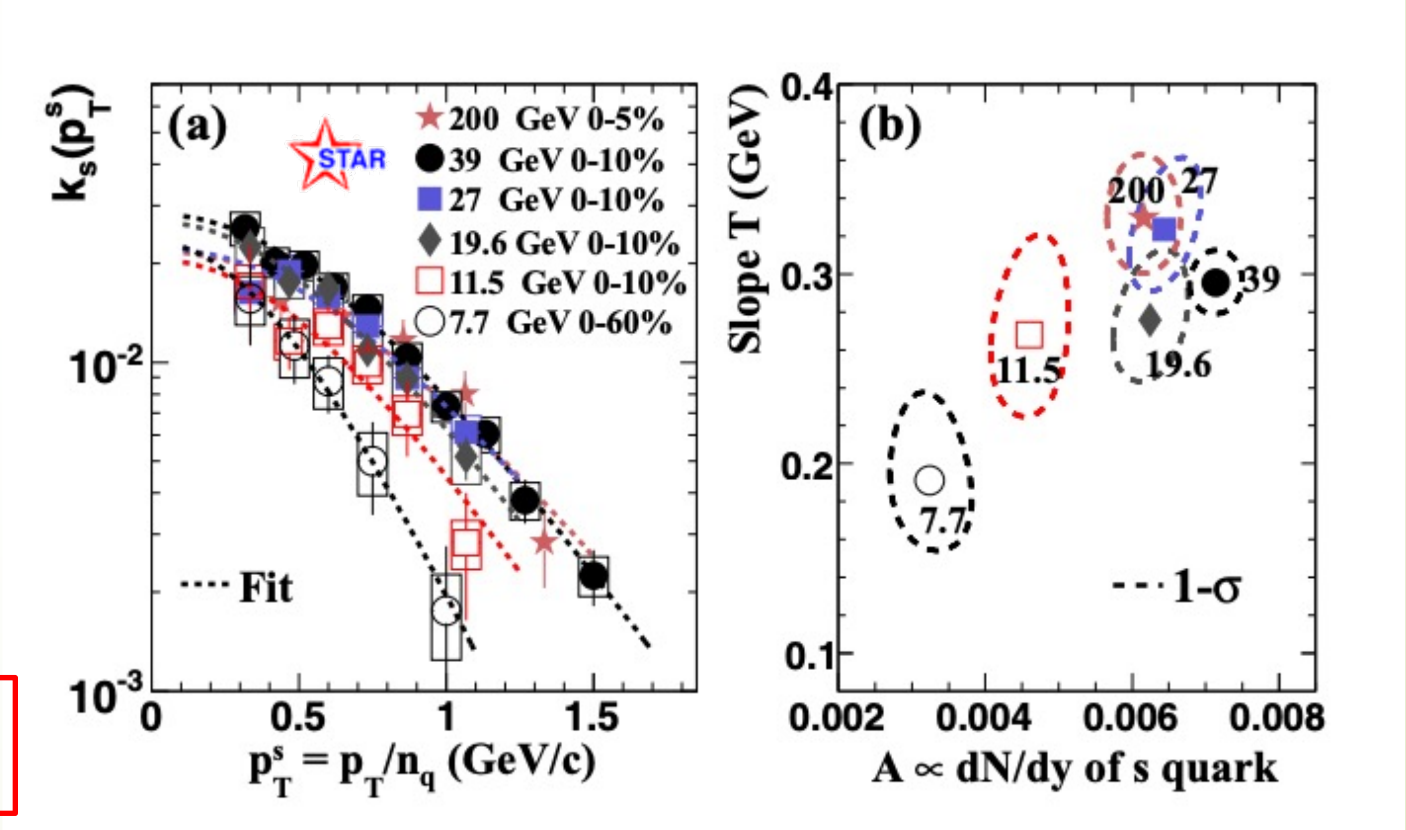
s quark distribution at hadronization ~

$$k_s(p_T^s) = \frac{N(\Omega^- + \overline{\Omega}^+)|_{p_T^{\Omega}=3p_T^s}}{2N(\phi)|_{p_T^{\phi}=2p_T^s}}$$

Fit to a Boltzmann*

11.5 and 7.7, lower T, and
lower s quark local density

➔ Change is underlying strange
Quark dynamics below 19.6 GeV



* Note: correction made for different Yield ratios of s and $\bar{s}$

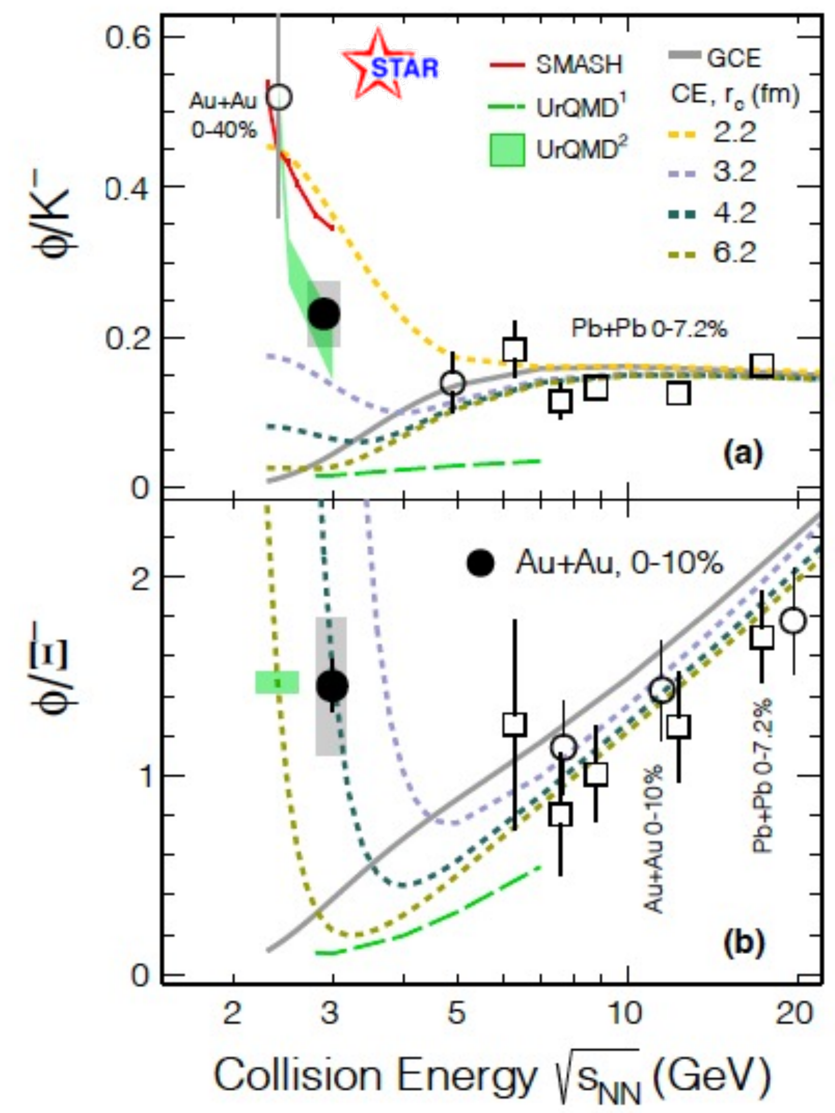
Yields ϕ /K$^-$ and ϕ /Ξ^- at 3 GeV: test of strangeness conservation

BES II

- strangeness conserved locally?
  - Thermal Models
    - GCE (Grand Canonical Ensemble)
    - CE (Canonical Ensemble)
      - ϕ /K$^-$ flat above ~ 5 GeV CM
      - Reduction in yields of non-zero strangeness as one goes to lower energy "Canonical suppression"
      - BUT not for ϕ ($s\bar{s}$)
- ϕ /K$^-$ and ϕ/Ξ^- – understand thermal properties of strange quarks
- Expect ϕ/K$^-$, ϕ/ Ξ^- to increase in CE treatment
- Model Calculations, r_C=strangeness correlation length

➔CE models favored at low energies
r_C ~2.7fm (ϕ/K$^-$) 4.2fm (ϕ/ Ξ^-)

arXiv/2108.00924



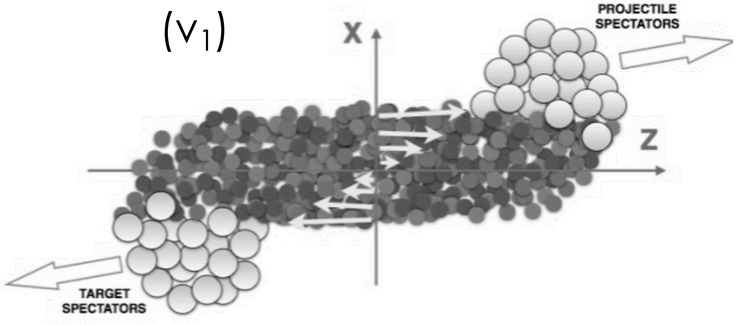
Flow

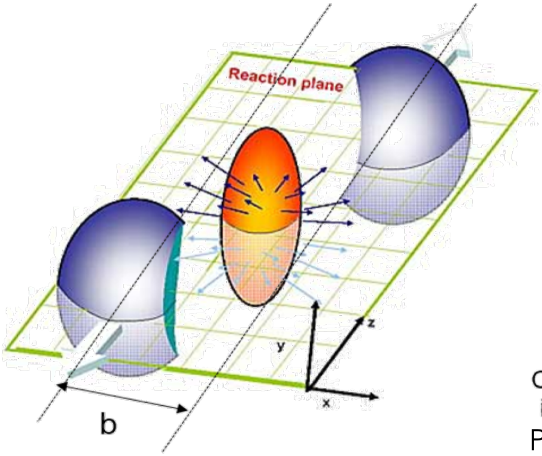
Geometry ➡ Flow(Collective effect) ➡ Hydrodynamics ➡ Fluid (the sQGP+η,ζ,...)

11

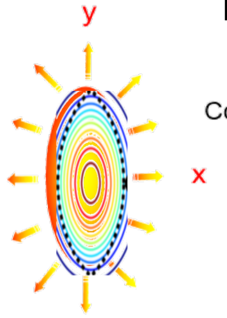
Flow generated in QGP phase reflects characteristics of QGP

Directed flow (v_1)





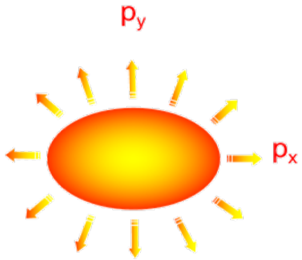
Elliptic flow (v_2)



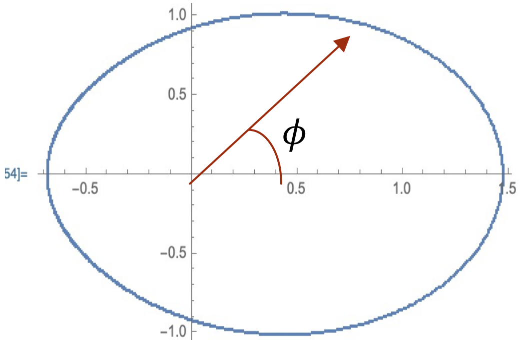
Coordinate space: initial asymmetry

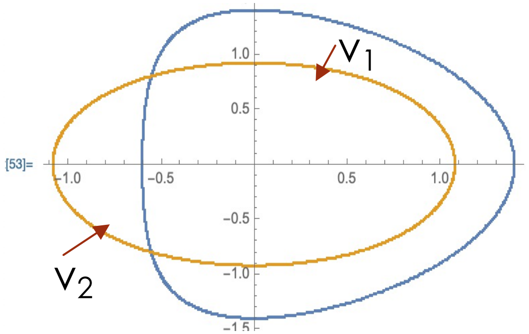
Pressure gradients

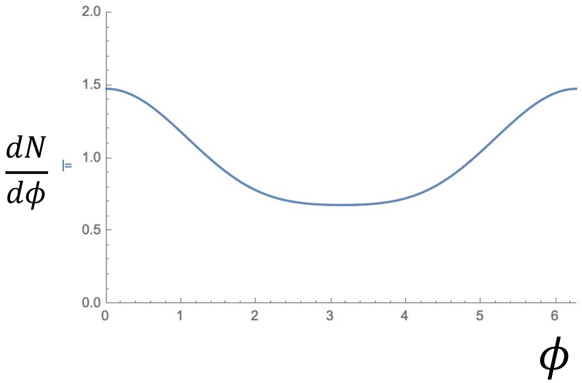
Collective interaction pressure

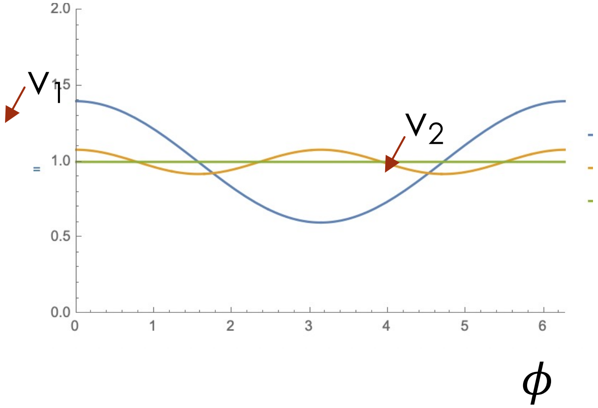


Momentum space: final asymmetry





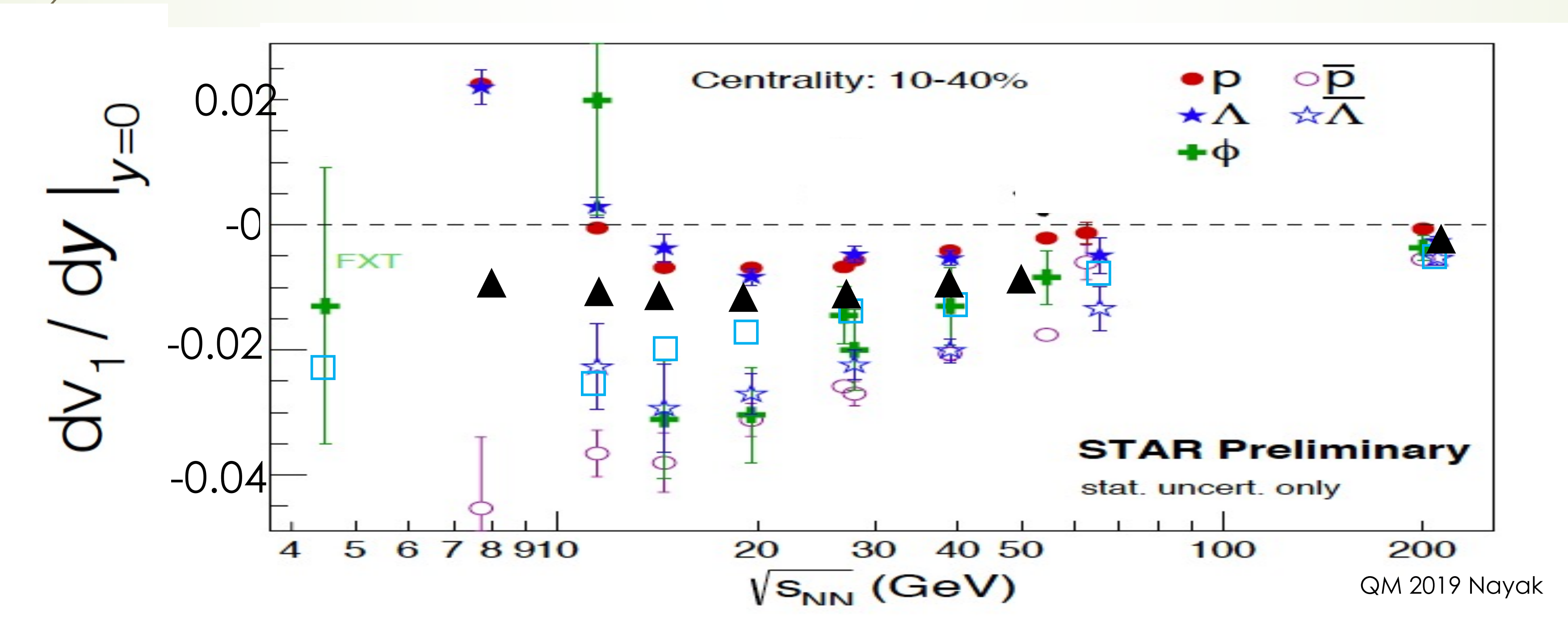




$$dN/d\phi \sim 1+2v_1(p_T)\cos(\phi)+2v_2(p_T)\cos(2\phi)+\ldots$$

Directed Flow: v1 (BES II)

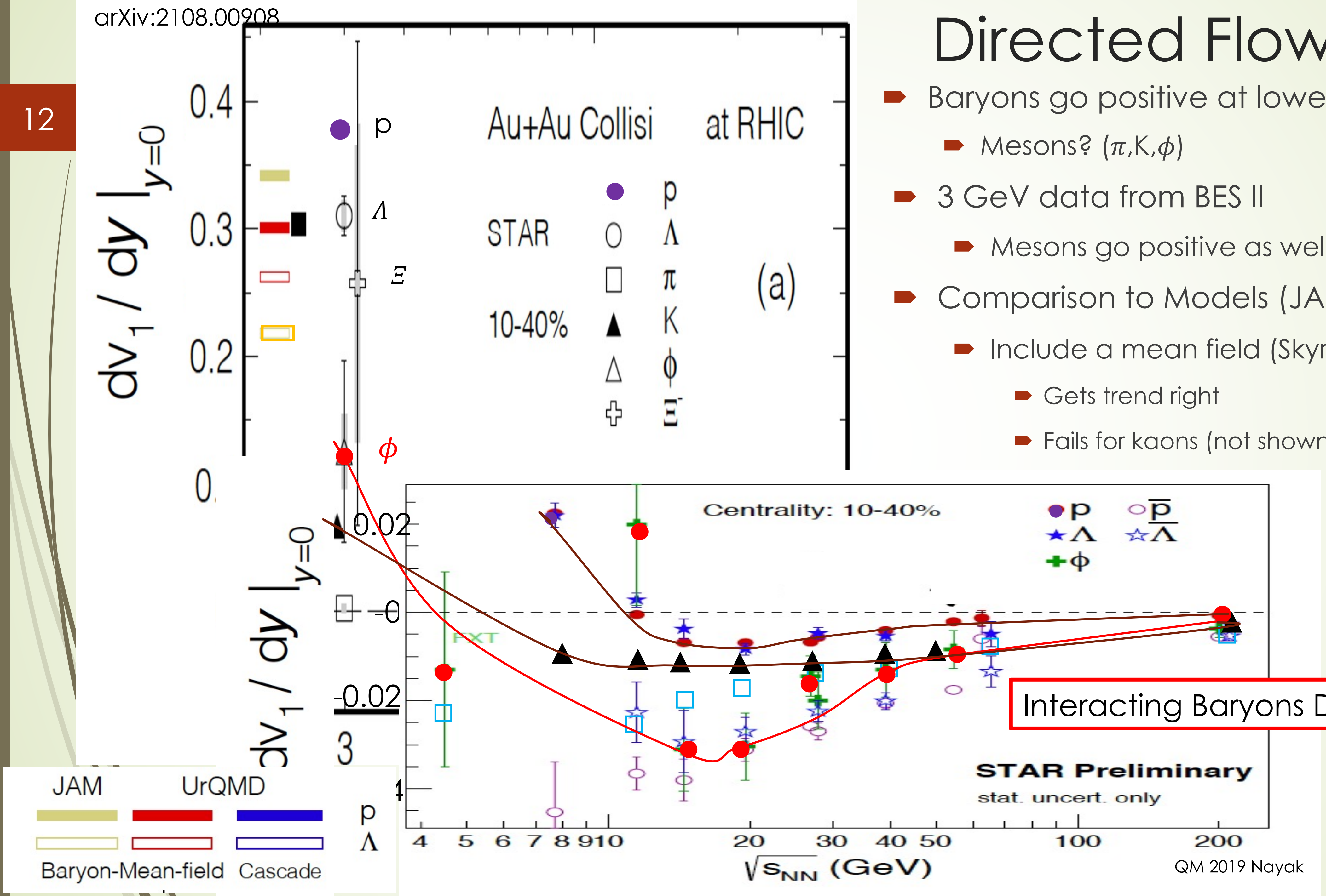
- Strength ~ dv_1/dy
- Minimum of net protons/kaons (e.g. $p - \bar{p}$) ~ 15 GeV CM
  - signature of softening of EOS i.e. 1st order phase transition?
  - Models include momentum dependent potentials ~ mimic 1st order phase transition
  - No model gets it right



QM 2019 Nayak

Directed Flow: v1 (BES II)

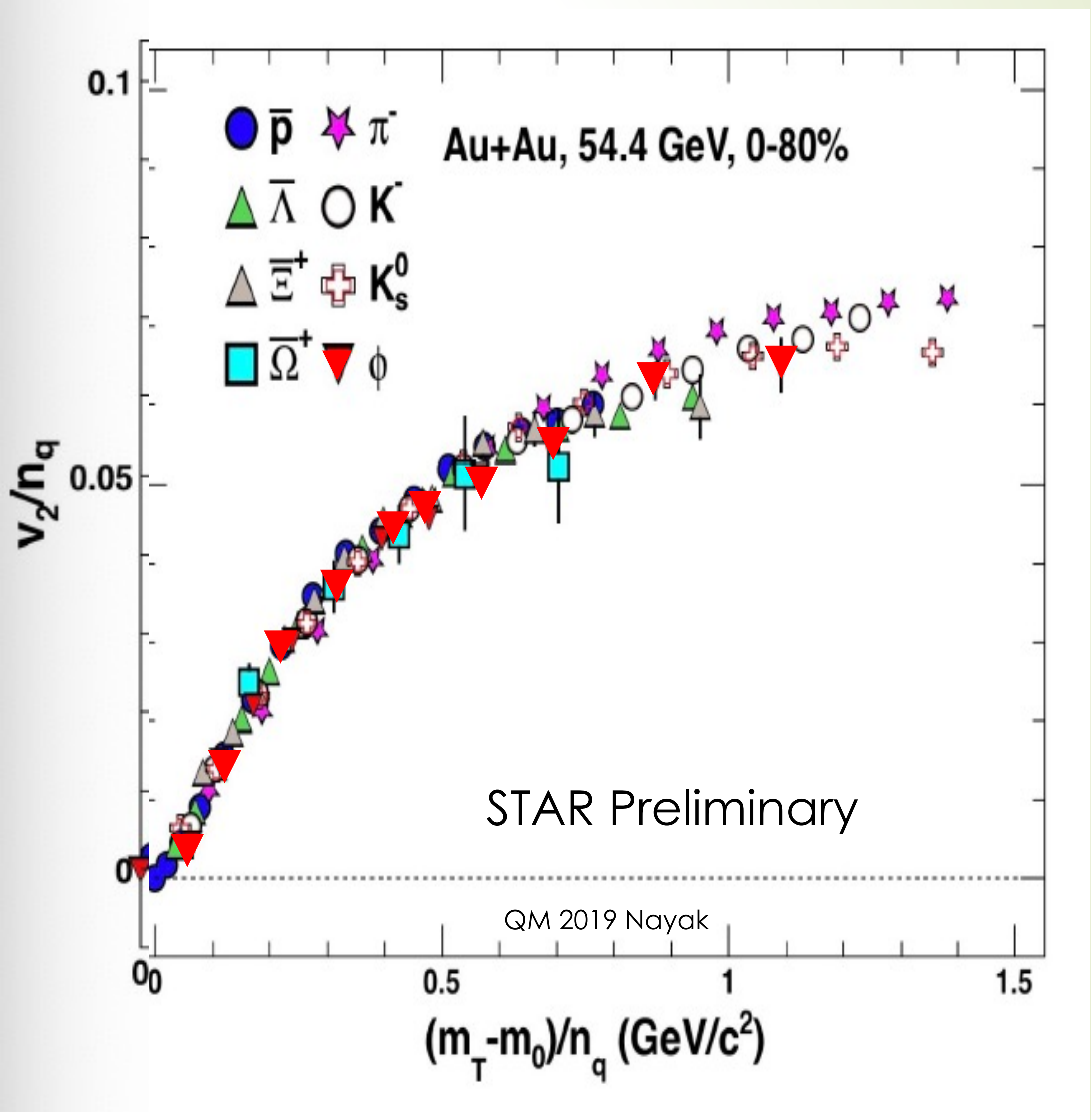
- Baryons go positive at lower energies
  - Mesons? (π,K,ϕ)
- 3 GeV data from BES II
  - Mesons go positive as well
- Comparison to Models (JAM, URQMD)
  - Include a mean field (Skyrme PE)
    - Gets trend right
    - Fails for kaons (not shown)



Interacting Baryons Dominate Physics

Elliptic flow (v_2) and n_q scaling

- In 2003: What governed flow?
  - Mesons and Baryons split
  - Hydro – the mass?
- ϕ a meson with mass of a baryon
  - Divide v_2 and m_T-m_0 by n_q
    - Mesons: $n_q = 2$ Baryons: $n_q = 3$
- ➔ Flow develops on partonic level. Particles form by quark coalescence



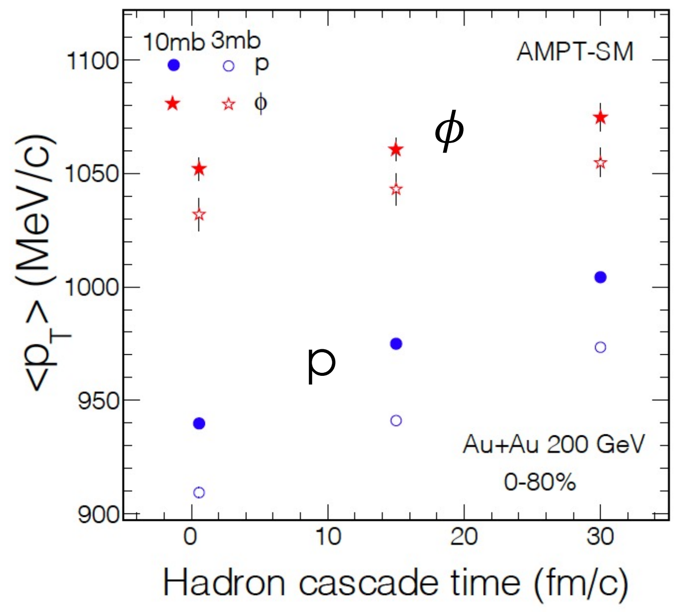
- Complications:
  - Flow is also developed in hadronic state (flow at very low energies)
  - Entropy conserved by soft gluons?

ϕ-hadron cross section

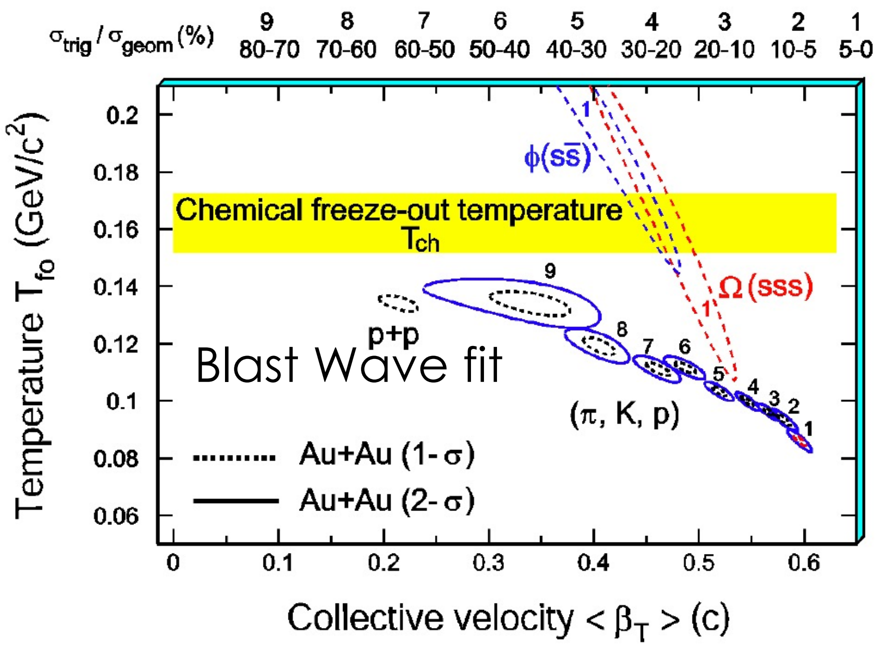
- Freezeout temperature, higher
- Scattering length small
  - e.g. $a_{\rho,\omega} \sim -0.45$, $a_{\phi} \sim -0.15$
  - Koike, Hayashigaki- *Prog.Theor.Phys. 98 (1997) 631-652*
- ϕ not sensitive to hadronic phase
  - reflects partonic phase

AMPT
Increase cascade time
~ proxy for increasing
hadronic interaction

PRC 87.014903

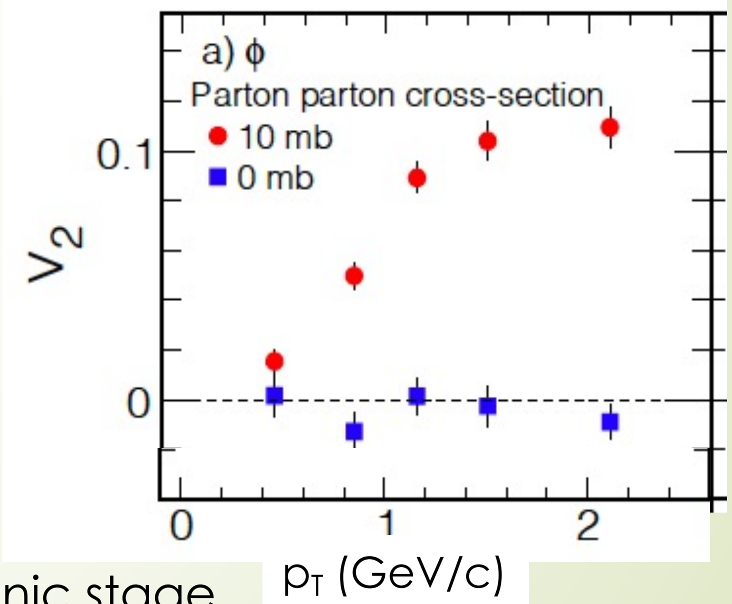


STAR Collaboration / Nuclear Physics A 757 (2005) 102–183



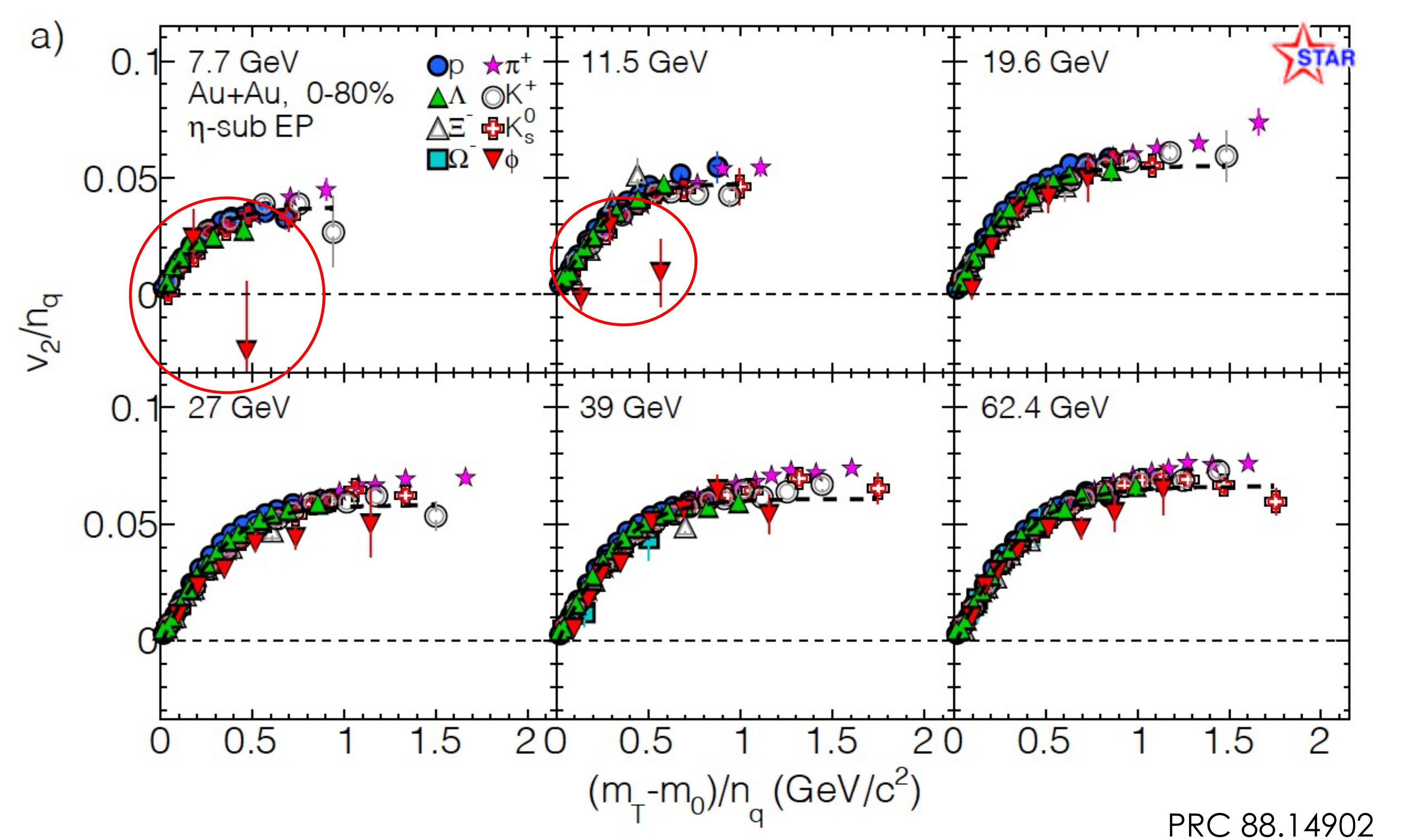
AMPT:
Turn off
partonic
scattering

PRC 87.014903



$\rightarrow \phi$ v_2 reflects partonic stage

ϕ Elliptic Flow (v_2): Status from BES I



PRC 88.14902

v_2 of ϕ from BES I below 19.6 GeV, not well measured due to lower statistics
BES II – increase statistics by more than an order of magnitude (data in hand)

Conclusions

- Results at 200 GeV
  - AuAu- ϕ mass and width – KK no modification
  - dAu – ϕ production suppressed in forward regions (low-x)
    - Consistent with pQCD picture of nPDF suppression at low-x
- BES I and II (AuAu)
  - Strange quark dynamics changing Quark matter ➔ hadronic matter below 19.6 GeV
  - CE treatment more appropriate at low energy ~ 3 GeV
  - Directed flow of mesons (ϕ and K) turns positive at low energy similar to baryons ~ 3 GeV
  - V_2 of ϕ mesons sensitive to flow of partonic state (measurement yet to come) – 14 GeV??
- Future for BES II: many more energies ~ 3 to 20 GeV, including much higher statistics at 3 GeV