SQM 2013, Birmingham, UK

Probing the QCD Phase diagram with the

Measurement of ϕ-meson Production and Elliptic Flow in Heavy-Ion Collisions at STAR

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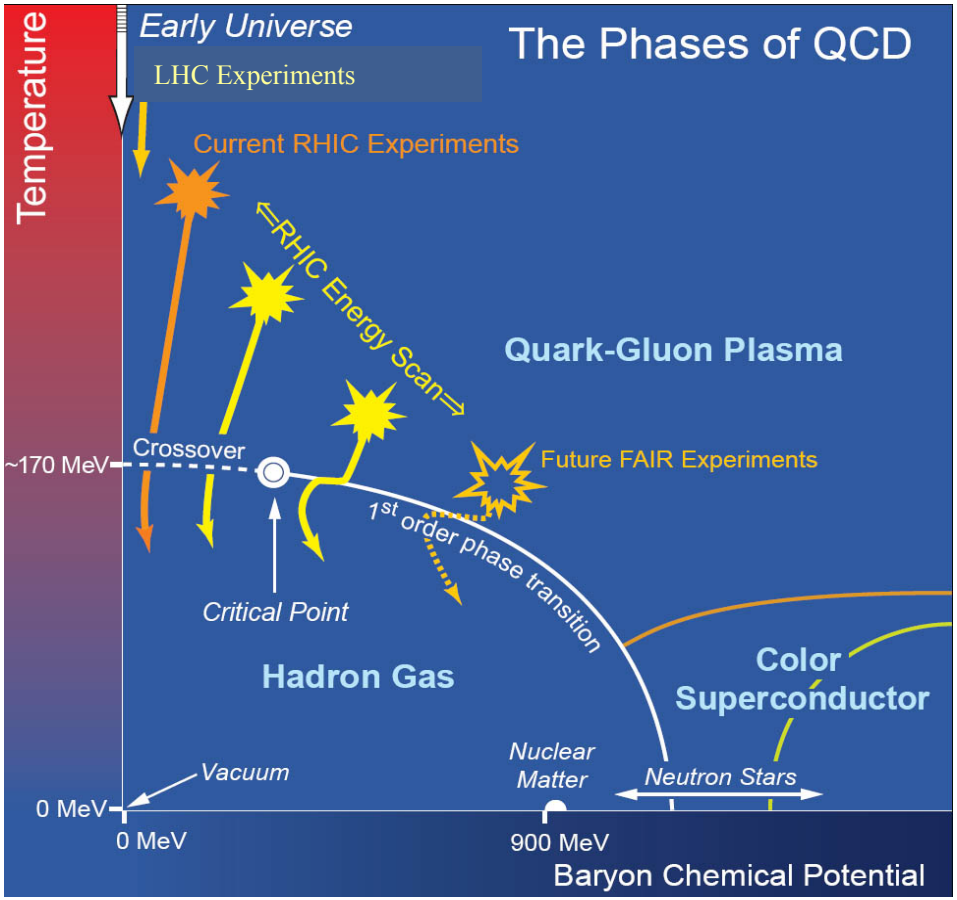
Outline

- Motivation
  - Beam Energy Scan at RHIC
  - ϕ-meson as a clean probe for onset of deconfinement
- The STAR experiment
- Results
  - p_T-spectra, R_{cp}, $N(\Omega)/N(\phi)$
  - Elliptic flow: $v_2(\phi)/v_2(p)$, NCQ scaling
- Summary

Motivation

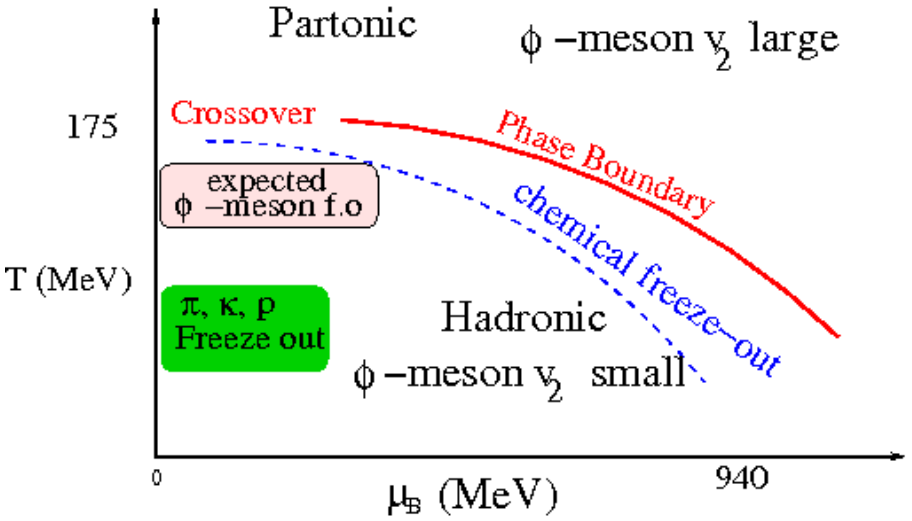
The RHIC Beam Energy Scan (BES)



- **BES Motivations**
- **Search for phase boundary**
- **Search for Critical point**

- **Observables of de-confinement**
  - **a) Strange hadron dynamics**
    $N(\Omega)/N(\phi)$ **and** $R_{CP}(\phi)$
  - **b) Strange hadron collectivity**
    Elliptic flow (v_2) **of** ϕ

ϕ−meson : A clean probe



- ✓ mass: proton ~ $\phi(s\bar{s})$ ~ Λ
- ✓ ϕ: meson, proton & Λ: baryon
- ✓ $s+\bar{s} \rightarrow \phi$ not $K^+ + K^- \rightarrow \phi$
- ✓ **small hadronic cross section**

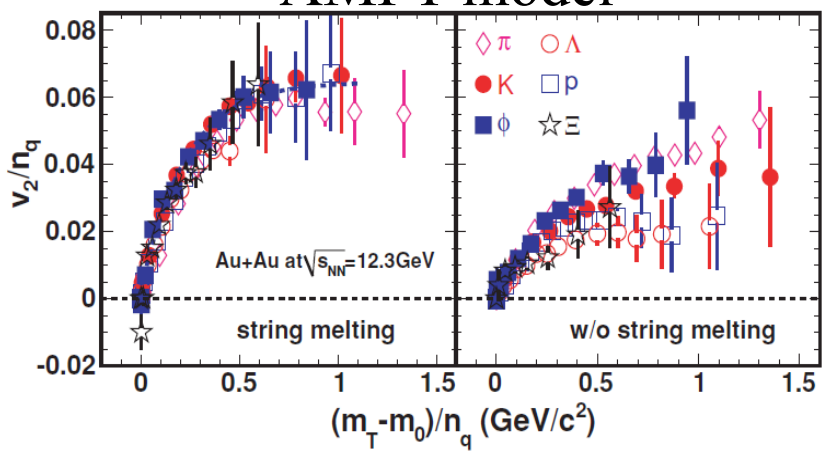
$\sigma_{\phi\text{-hadron}} << \sigma_{p\text{-}\pi,\ \pi\text{-}\pi}$

In the hadronic case, no number-of-quark scaling and the value of ϕ meson v_2 is expected to be small

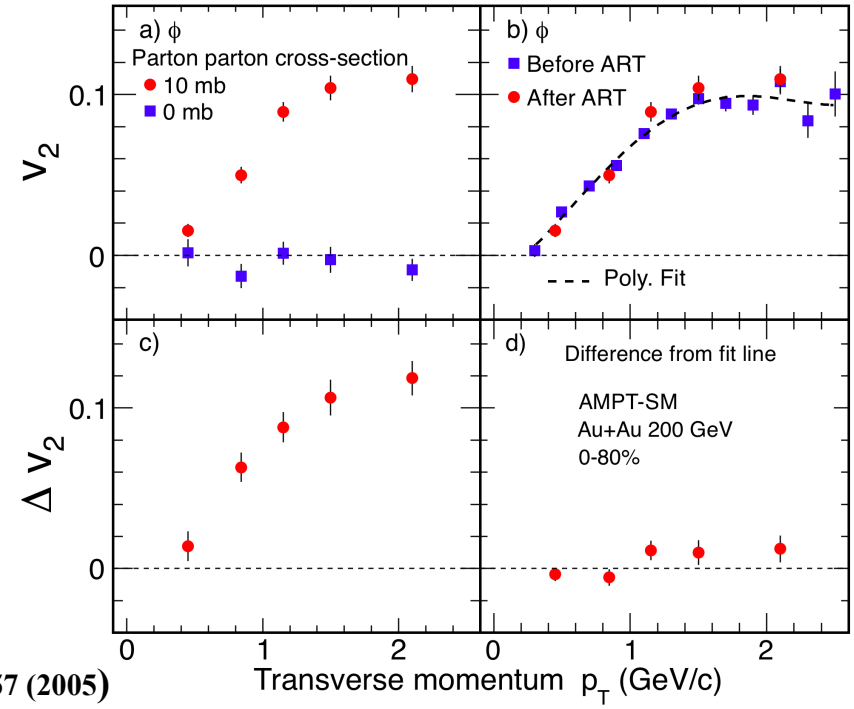
J. Phys. G 36, 064022 (2009)

STAR Collaboration : Nuclear Physics A 757 (2005)

AMPT model

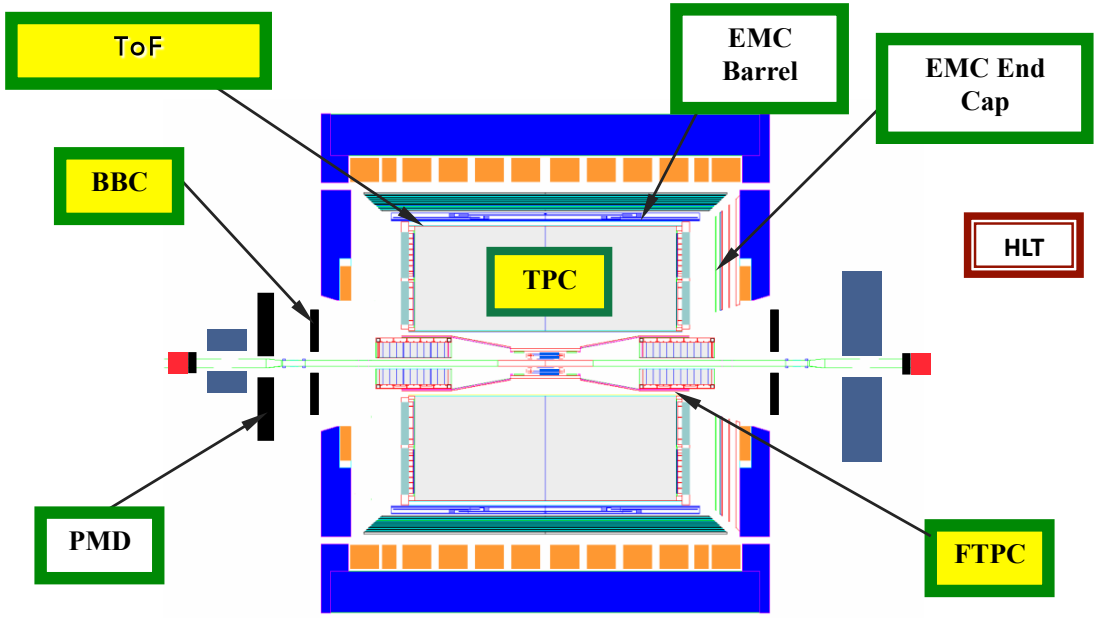


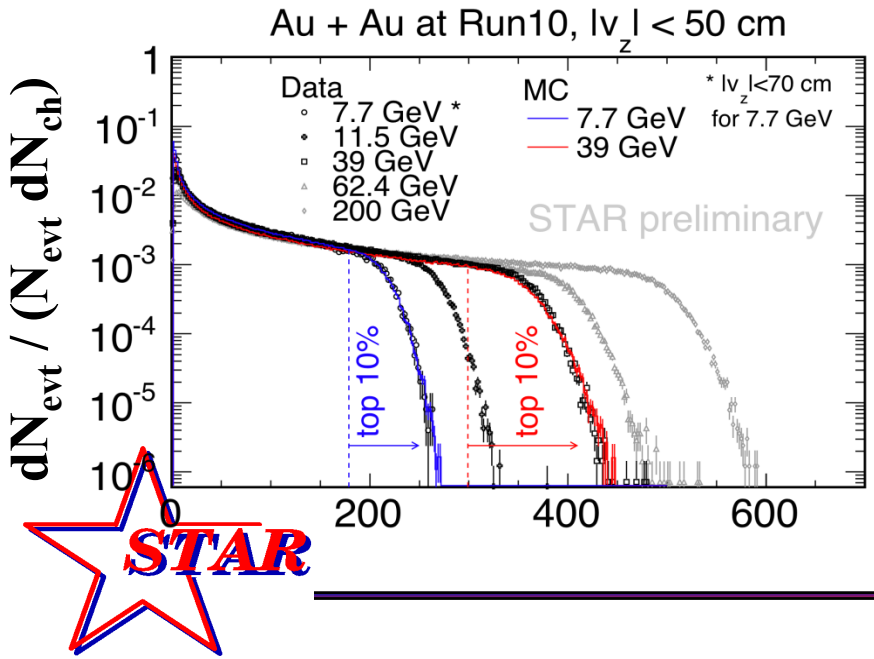
Phys. Rev. C 79, 067901 (2009)



Phys. Rev. C 87, 014903 (2013)

The STAR Experiment at RHIC

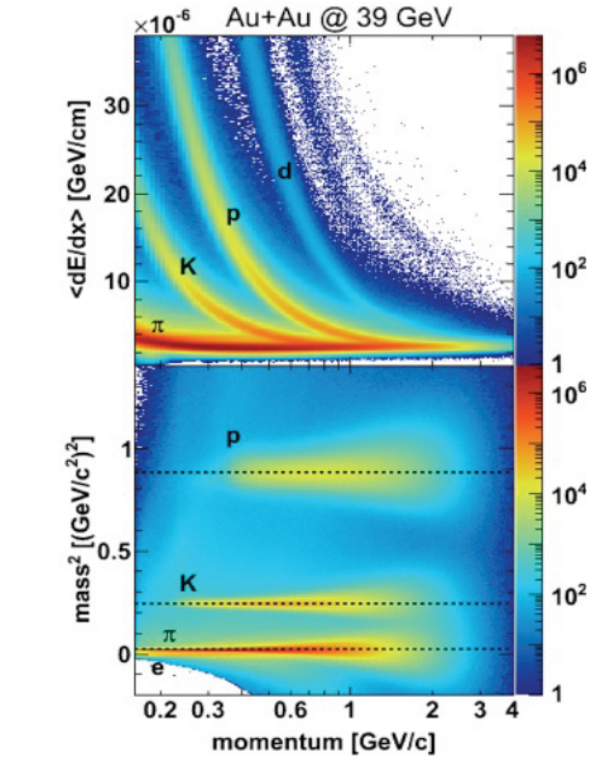


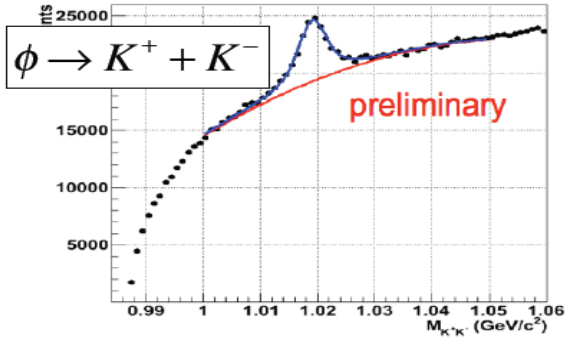


- Collisions: Au+Au
- Collisions centrality from uncorrected $dN_{ch}/d\eta$ in $|\eta| < 0.5$

$\sqrt{s_{NN}}$ (GeV)	Good MB events in Million
7.7	~ 4 M
11.5	~ 12 M
19.6	~ 36 M
27	~ 70 M
39	~ 130 M
62.4	~ 67 M
200	~ 240 M

Particle identification and v_2 measurement method



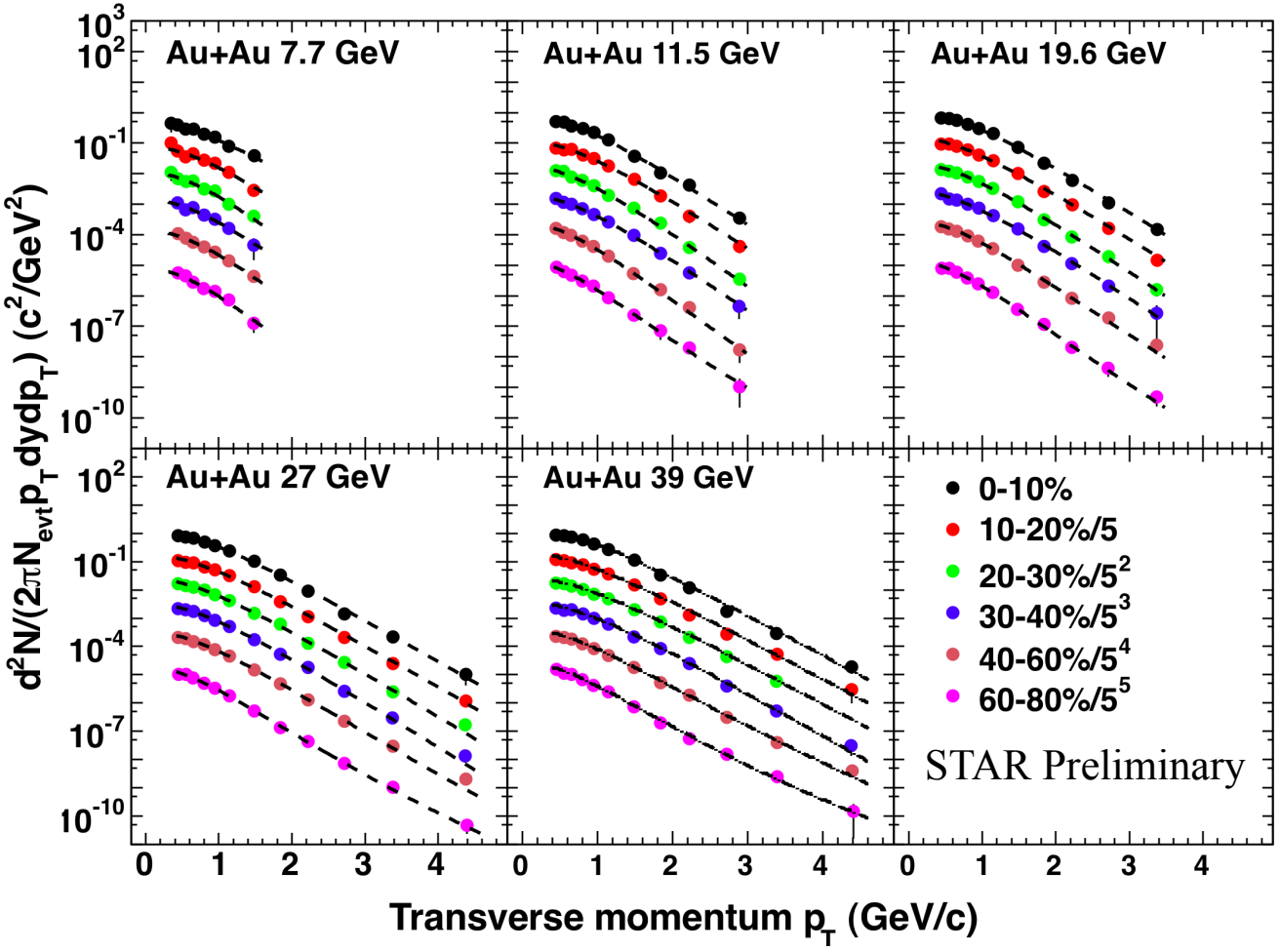


- **Time projection chamber (TPC)**
  full azimuth, $|\eta| < 1$
  dE/dx v.s. momentum
- **Barrel Time-Of-Flight (TOF)**
  full azimuth, **$|\eta| < 0.9$**
  Particle flight time
  Clean separation of K, π up to $p_T = 1.6$ GeV/c
- $v_2 = < cos2(\varphi - \psi_2)/Res >$
- **TPC η-sub event plane for v_2 analysis**
  Non-flow effect reduced

- TPC particle identification (PID) is used for spectra analysis, TPC+TOF PID is used for v_2 analysis

η-sub event plane method: STAR, Phys. Rev. C 77, 054901 (2008)

ϕ-meson p_T spectra

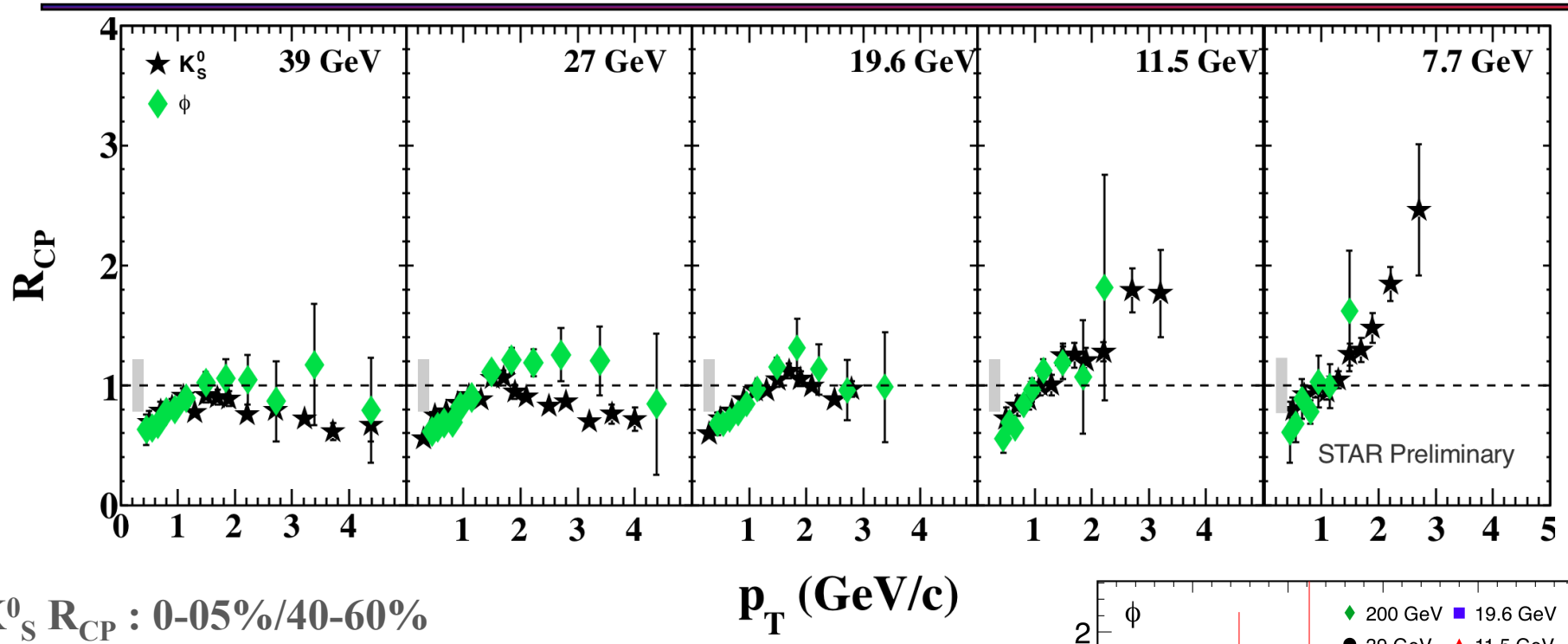


Statistical error

- ϕ meson transverse momentum distribution can be well described by a Levy function

$$\frac{1}{2\pi p_T}\frac{d^2N}{dp_T dy} = dN/dy\frac{(n-1)(n-2)}{2\pi nT(nT+m(n-2))}(1+\frac{\sqrt{p_T^2+m^2}-m}{nT})^{-n}$$

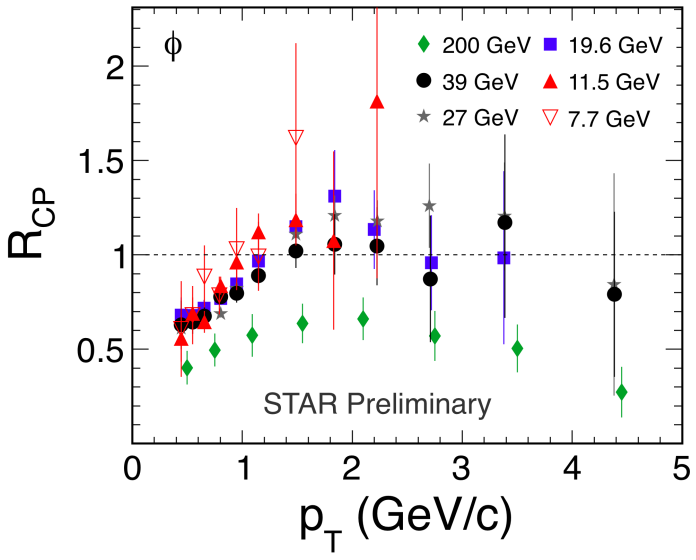
Nuclear Modification Factor (R_{cp})



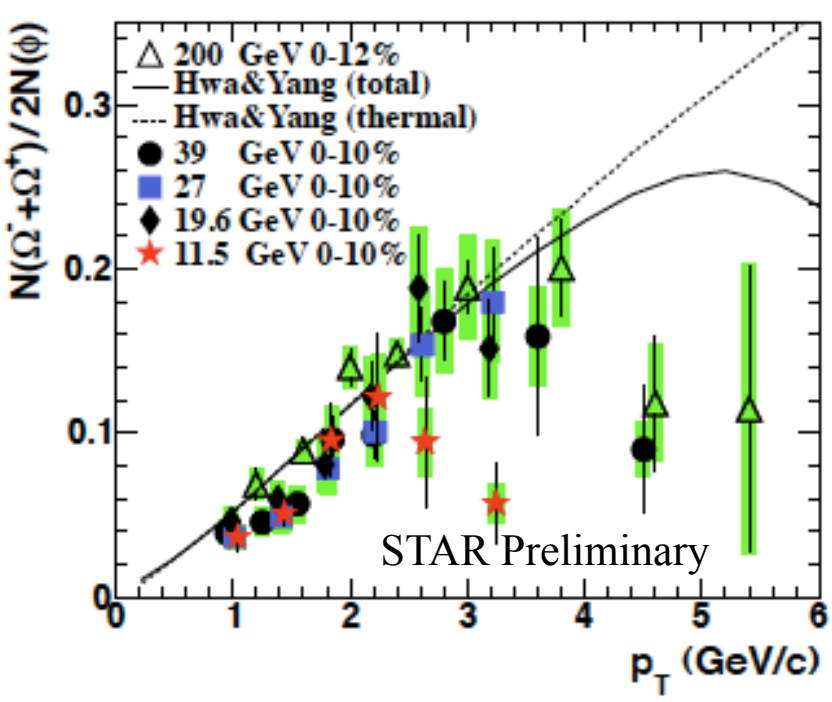
K^0_S R_{CP} : 0-05%/40-60%

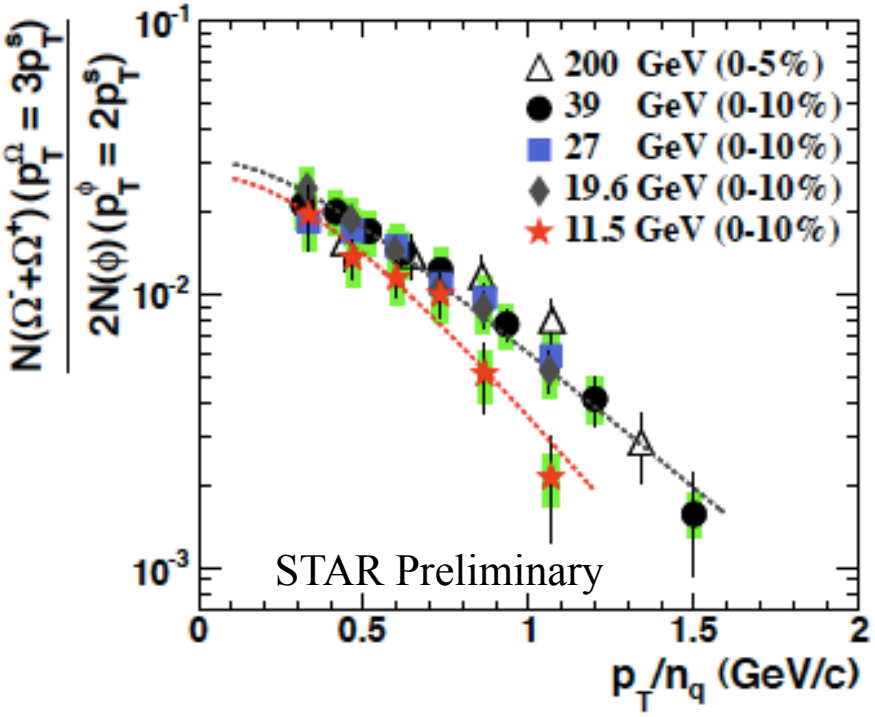
φ R_{CP}: 0-10%/40-60% and 0-05%/40-60% for 200 GeV

- φ-meson $R_{CP} \geq 1$ at intermediate p_T for $\sqrt{s_{NN}} \leq 39$ GeV.



Strange Quark Dynamics





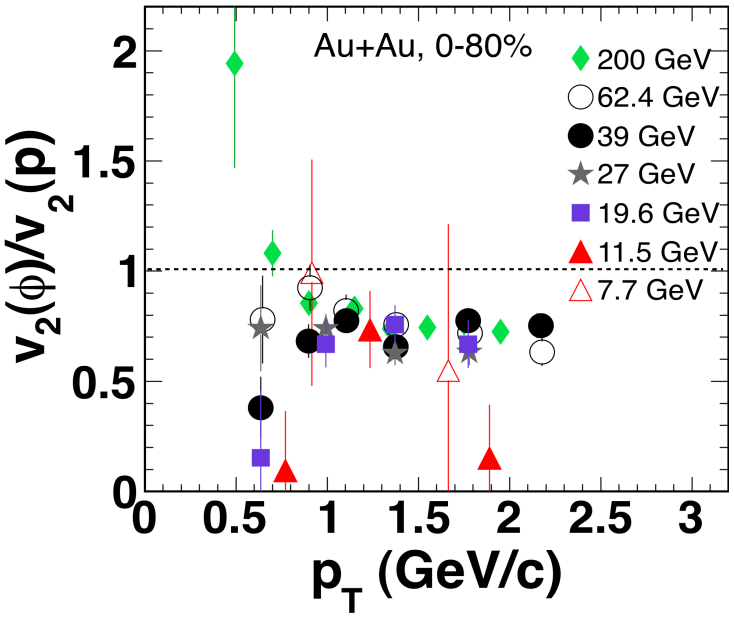
- **Intermediate p_T Ω/ϕ ratios: Indication of separation between ≥ 19.6 and 11.5 GeV.**
  The χ^2/ndf for deviation between 11.5 and 19.6 GeV is ~ 8.3/2 for $p_T > 2.4$ GeV/c.

- **Derived strange quark p_T distributions show a trend of separation between ≥ 19.6 and 11.5 GeV.**

Change of particle production mechanism ?

Hwa & Yang, Phys. Rev. C 75, 054904 (2007), Phys. Rev. C 78, 034907 (2008).

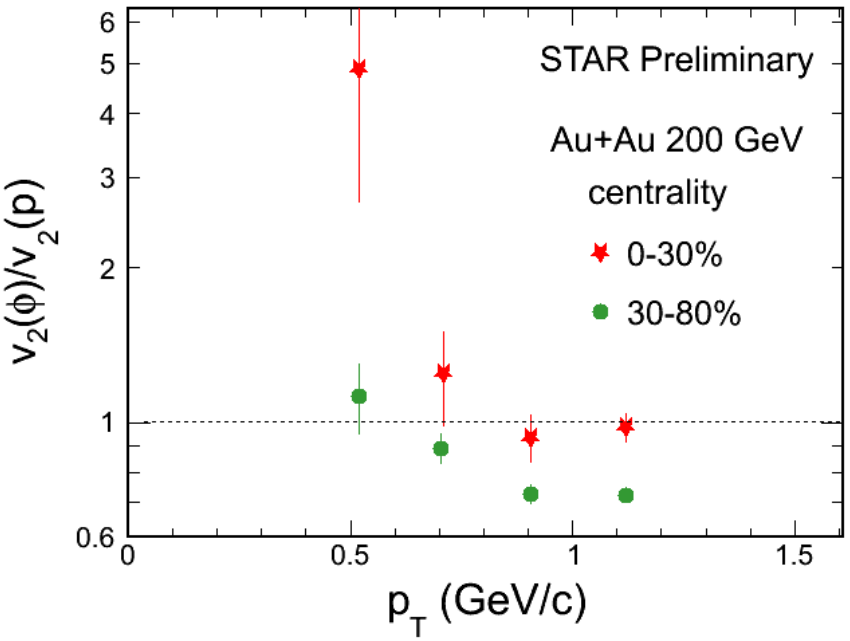
$v_2(\phi)$ vs. $v_2(p)$

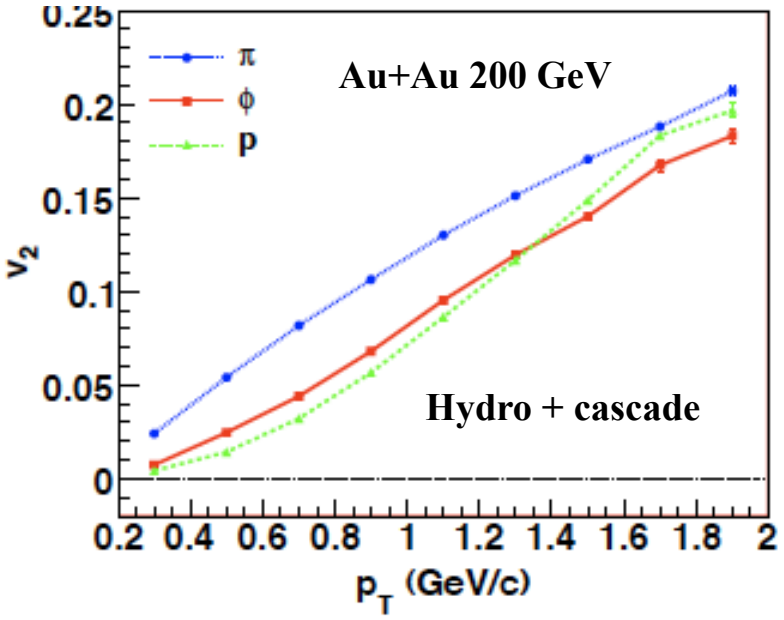


- **Mass: proton ~ ϕ**
- **At low p_T, $v_2(\phi)/v_2(p)$ decreases with decreasing beam energies**
  → Indicating less partonic collectivity with decreasing beam energy.

STAR Collaboration: arXiv: Phys. Rev. C 88, 014902 (2013) and Phys. Rev. Lett. 110, 142301 (2013). Phys. Rev C 87, 014903 (2013)

$v_2(\phi)$ vs. $v_2(p)$





Phys. Rev. C 77, 044909 (2008)

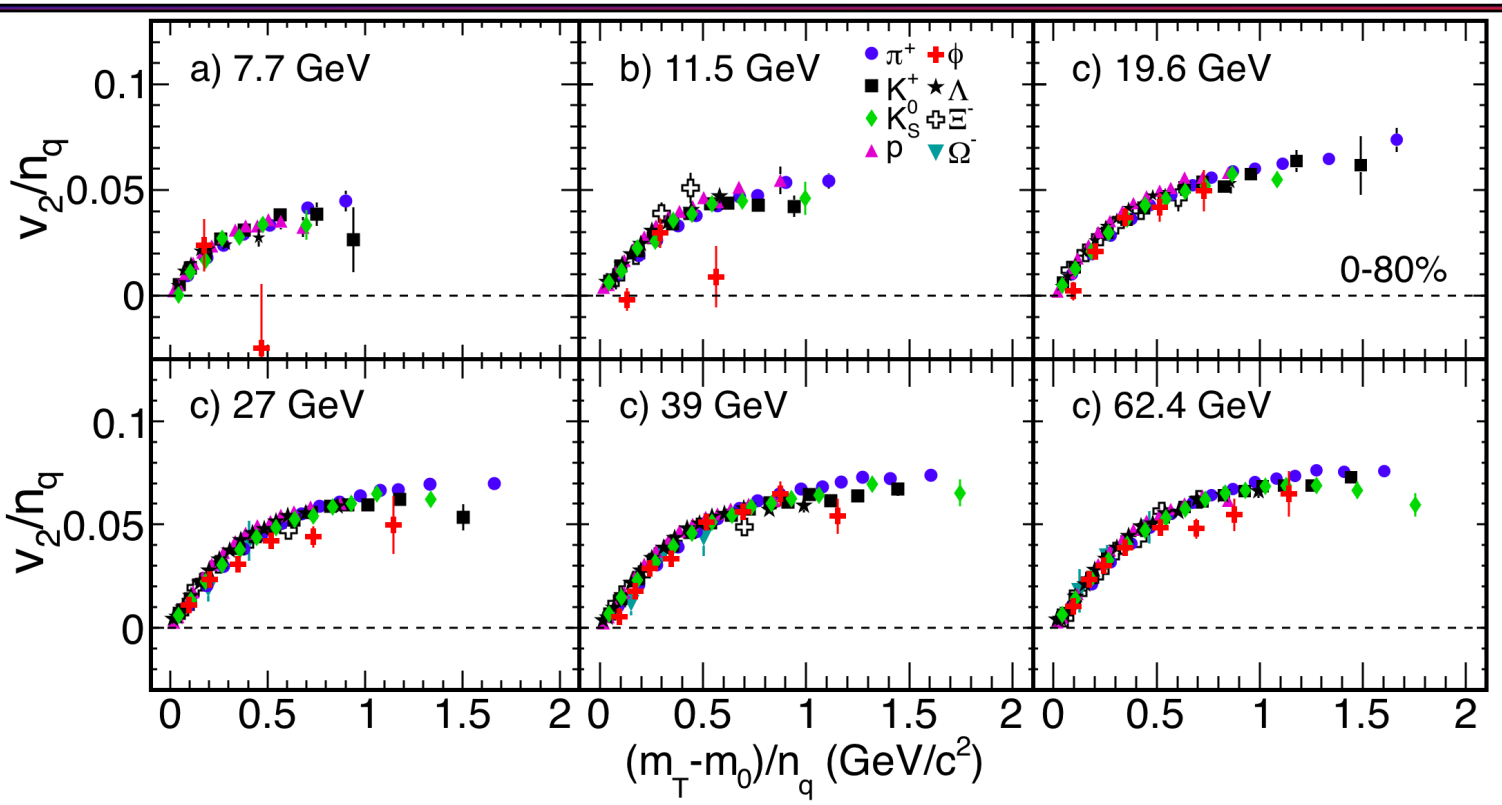
- **Mass: proton ~ φ**
- **At low p_T, $v_2(\phi)/v_2(p)$ decreases with decreasing beam energies**
  → Indicating less partonic collectivity with decreasing beam energy.

- **Au+Au , $\sqrt{s_{NN}}$ = 200 GeV**
- **At low p_T, $v_2(\phi)/v_2(p) > 1.0$**

→ proton v_2 possibly affected by hadronic re-scattering.

STAR Collaboration: arXiv: Phys. Rev. C 88, 014902 (2013) and Phys. Rev. Lett. 110, 142301 (2013). Phys. Rev C 87, 014903 (2013)

NCQ scaling: ϕ-meson v_2



Statistical error only

- **ϕ meson v_2 deviates from other particles ~ 2σ at the highest p_T data in 7.7 and 11.5 GeV collisions.**
  → Small or zero v_2 for ϕ meson implies hadronic interactions are more important at lower energies.

More data for 7.7 and 11.5 GeV are needed for clear conclusion.

Ref: B. Mohanty and N. Xu: J. Phys. G 36, 064022(2009) and Md. Nasim, B. Mohanty, N. Xu , Phys. Rev C 87, 014903 (2013)
STAR Collaboration: Phys. Rev. C 88, 014902 (2013) and Phys. Rev. Lett. 110, 142301 (2013)

Summary

- **STAR preliminary ϕ meson spectra and elliptic flow in Au+Au collisions at $\sqrt{s_{NN}}$= 7.7 - 200 GeV have been presented.**

- **ϕ-meson $R_{CP} \geq 1$ at intermediate p_T for $\sqrt{s_{NN}} \leq 39$ GeV.**

- **Intermediate p_T Ω/ϕ ratios and derived strange quark p_T distribution show a indication of separation between $\geq$ 19.6 GeV and 11.5 GeV.**

  → *May suggests change of production mechanism.*

- **At low p_T, $v_2(\phi)/v_2(p)$ decreases with decreasing beam energies.**

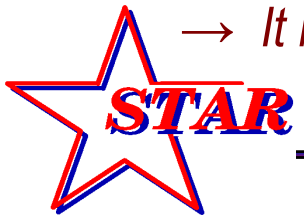
  → Indicating less partonic collectivity with decreasing beam energy.

  Top RHIC Energy ($\sqrt{s_{NN}}$ =200GeV): **At low p_T, $v_2(\phi)/v_2(p) > 1.0$.**

  → *Could be the effect of hadronic re-scattering.*

- **ϕ-meson v_2 deviates from other particles ~ 2σ at the highest p_T data in 7.7 and 11.5 GeV collisions.**

  → *It may indicate hadronic interactions are more important at lower energies.*



Back-up


STAR