Strangeness in Quark Matter, 18-24 September 2011, Cracow, Poland

Probing QCD phase diagram with ϕ meson production in STAR BES program

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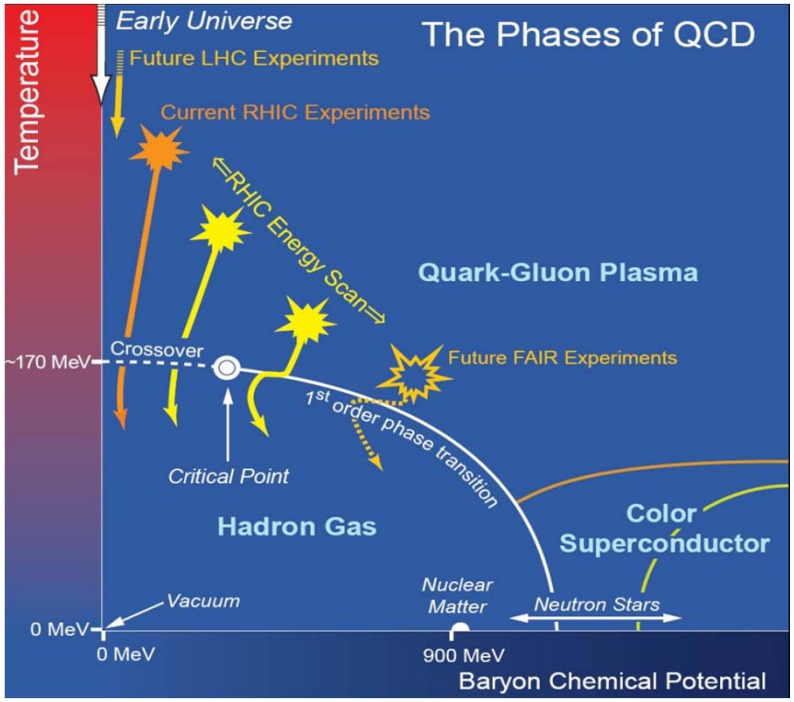
For the STAR Collaboration

- QCD phase transition and ϕ meson production
- Spectra and elliptic flow (v_2) results and discussions
- Summary and outlook

Motivation



- **Characterize different phases by the elliptic flow (v_2) of ϕ mesons**

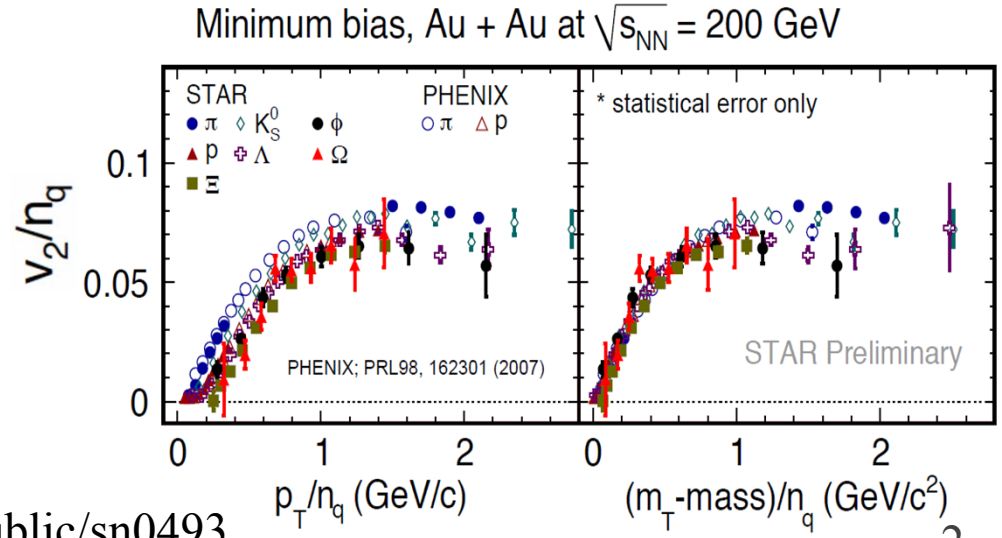
→ Partonic dominate: NCQ scaling, similar v_2 between light hadrons and ϕ mesons

→ Hadronic dominate: smaller v_2 of ϕ mesons due to its small hadronic cross sections

Beam Energy Scan at RHIC

Search for signals of phase boundary

Search for QCD critical point



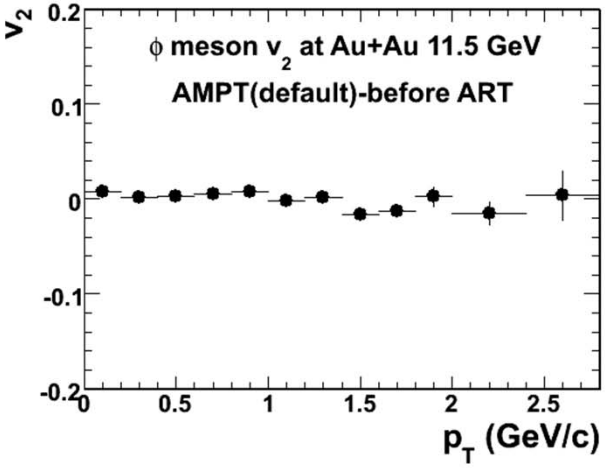
STAR, Phys. Rev. Lett. 92 (2004) 052302

STAR, Phys. Rev. Lett. 99 (2007) 112301

http://drupal.star.bnl.gov/STAR/starnotes/public/sn0493

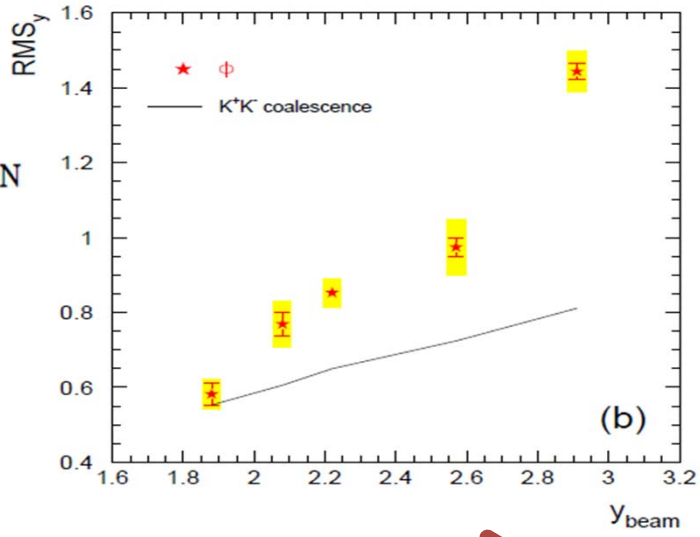
More about ϕ mesons……

- ✓**Hidden strangeness ($s\bar{s}$), small hadronic cross section**, less sensitive to hadronic scattering σ(ϕN) ~ 10 mb, cτ = 46 fm
- ✓K^+K^- is not the main production channel in our interested region
- ✓ϕ meson v_2 ~ 0, if only from string fragmentation, **may break NCQ scaling in hadronic dominated phase**
- ✓Deconfinement phase transition, copious strangeness production $s + \bar{s} \rightarrow \phi$, **strong yields enhancement**



$\sigma_{\rho N} \sim 3\ \sigma_{\phi N}$
$\sigma_{\pi N} \sim 2.6\ \sigma_{\phi N}$
$\sigma_{KN} \sim 2.1\ \sigma_{\phi N}$

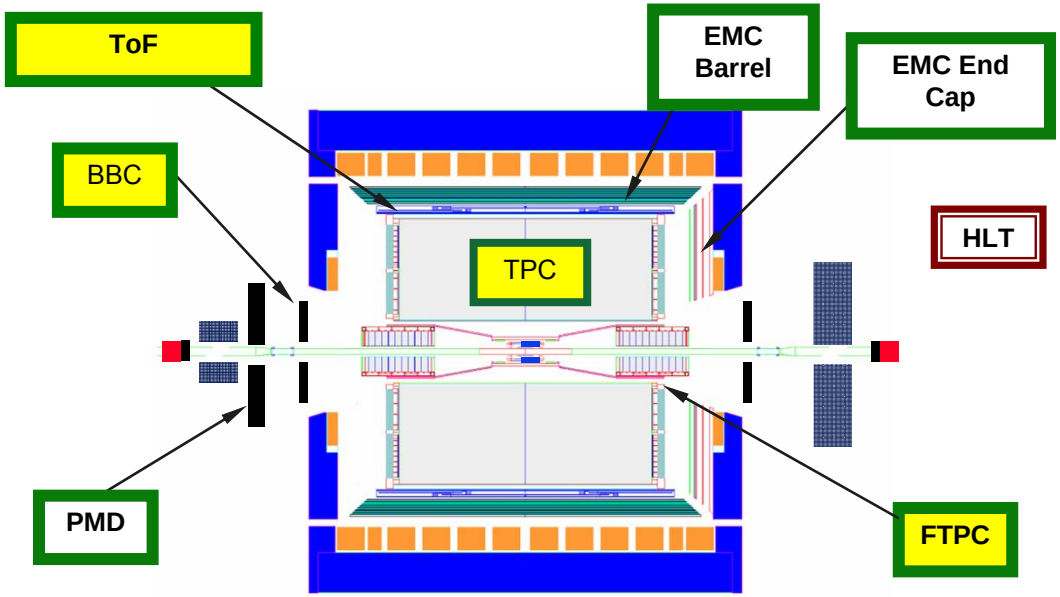
$\sigma_{\Lambda N} \sim 3.5\ \sigma_{\phi N}$
$\sigma_{NN} \sim 4\ \sigma_{\phi N}$

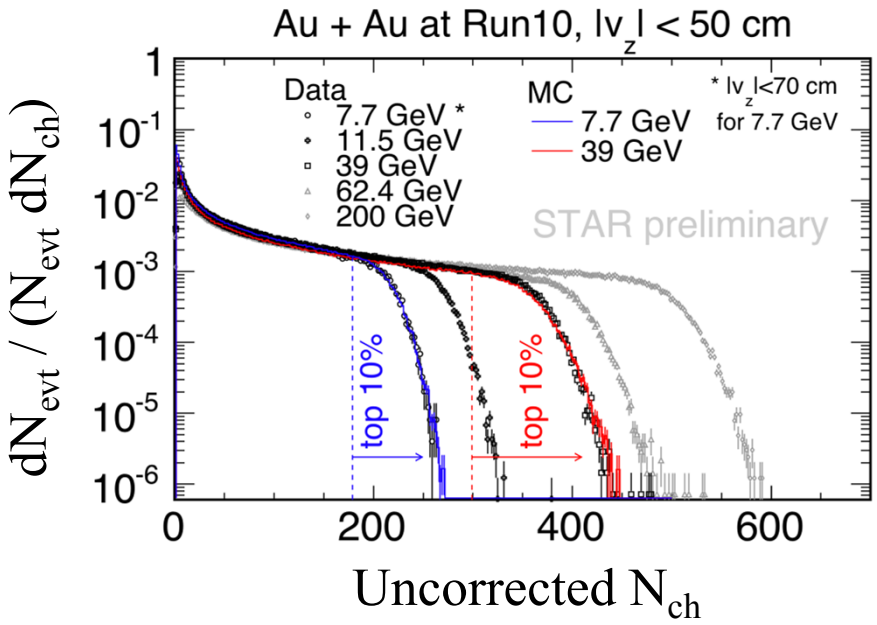


arXiv: nucl-th/0606044
NA49, Phys. Rev. C 78, 044907 (2008)
B. Mohanty and N. Xu, J. Phys. G 36, 064022 (2009)

$\sqrt{s_{NN}}$ (GeV) 6.3 → 17.3

Detector settings during STAR BES 2010-2011

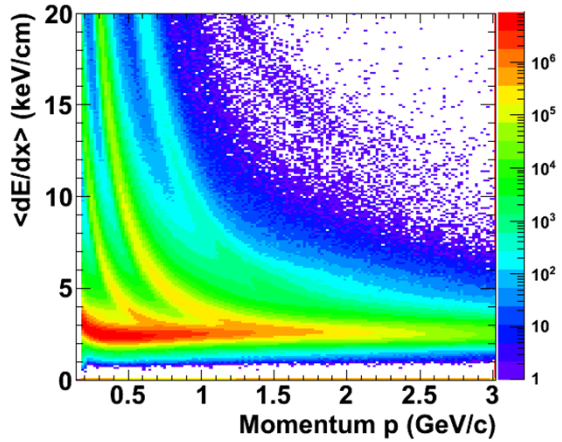


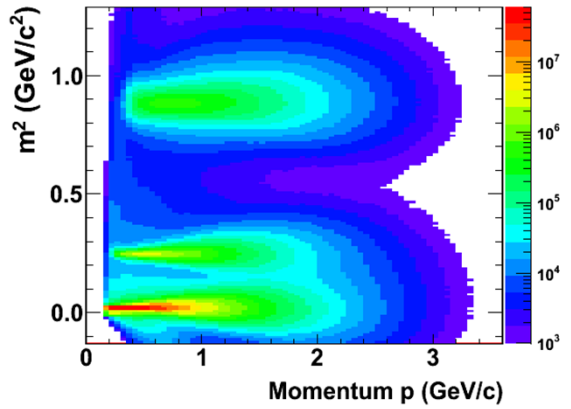


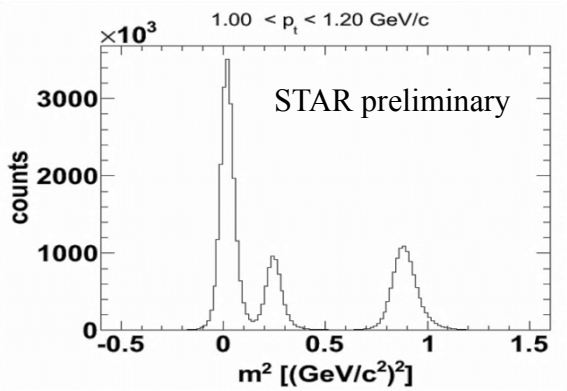
- Collisions: Au+Au
- The largest data set of heavy ion collisions in possible QCD phase transition region

$\sqrt{s_{NN}}$ (GeV)	Good MB events in Million
5.0	
7.7	~ 5
11.5	~ 12
19.6	~ 17
27	~ 37
39	~ 170
62.4	~ 143

Particle identification and v_2 analysis



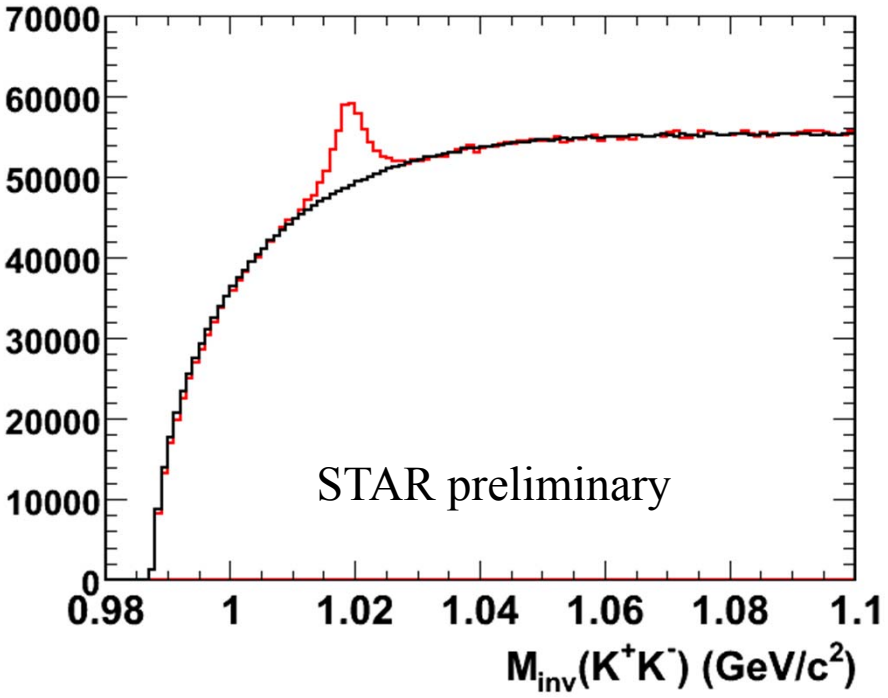


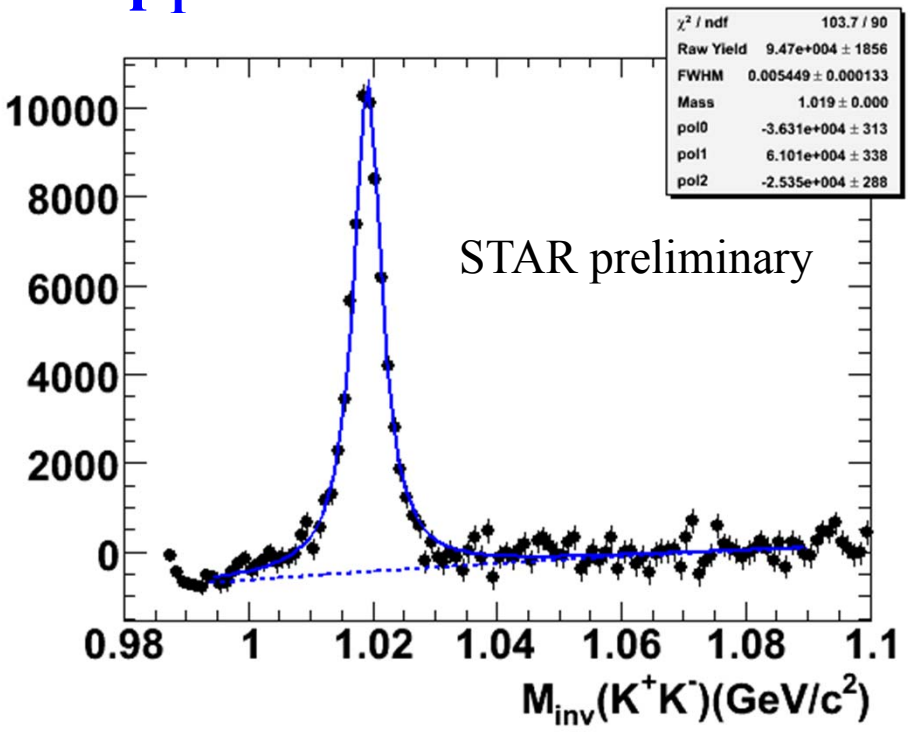


- **Time projection chamber (TPC)**
  full azimuth, $|\eta| < 1$
  dE/dx v.s. momentum
  secondary vertex finder for K^0_s, Λ
- **Barrel Time-Of-Flight (TOF)**
  full azimuth, $|\eta| < 1$
  Particle flight time
  Clean separation of K, π up to $p_T = 1.6$ GeV/c
- Collisions centrality from uncorrected $dN_{ch}/d\eta$ in $|\eta| < 0.5$
- $v_2 = < cos2(\varphi - \psi_2)/Res >$
- **TPC η-sub event plane for v_2 analysis**
  Non-flow effect reduced

$\phi \rightarrow K^+ + K^-$ reconstruction

Au+Au 7.7 GeV $0.3<p_T<1.2$ GeV/c

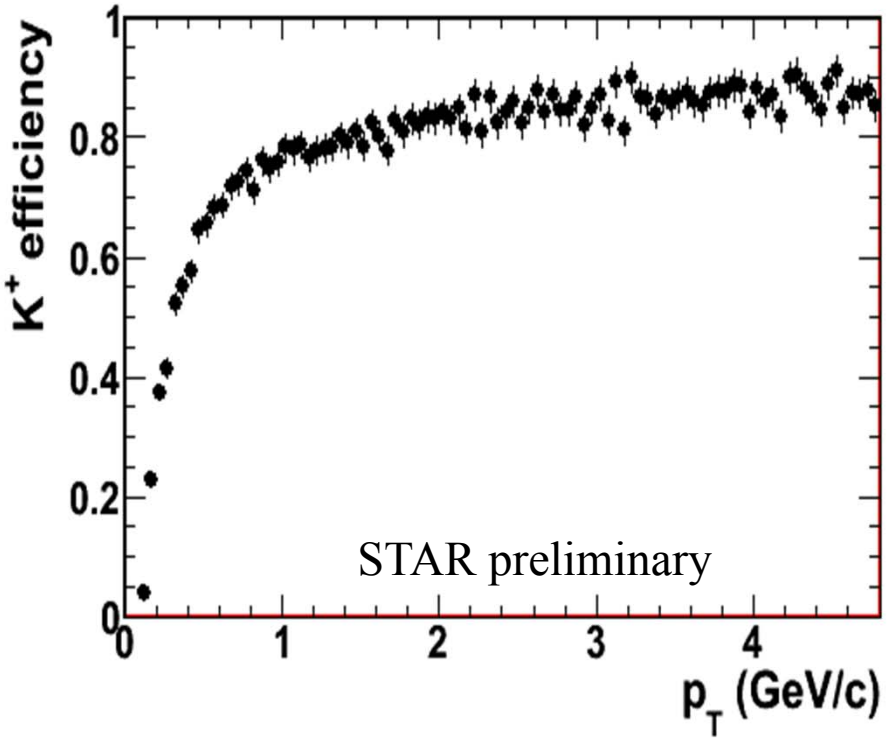


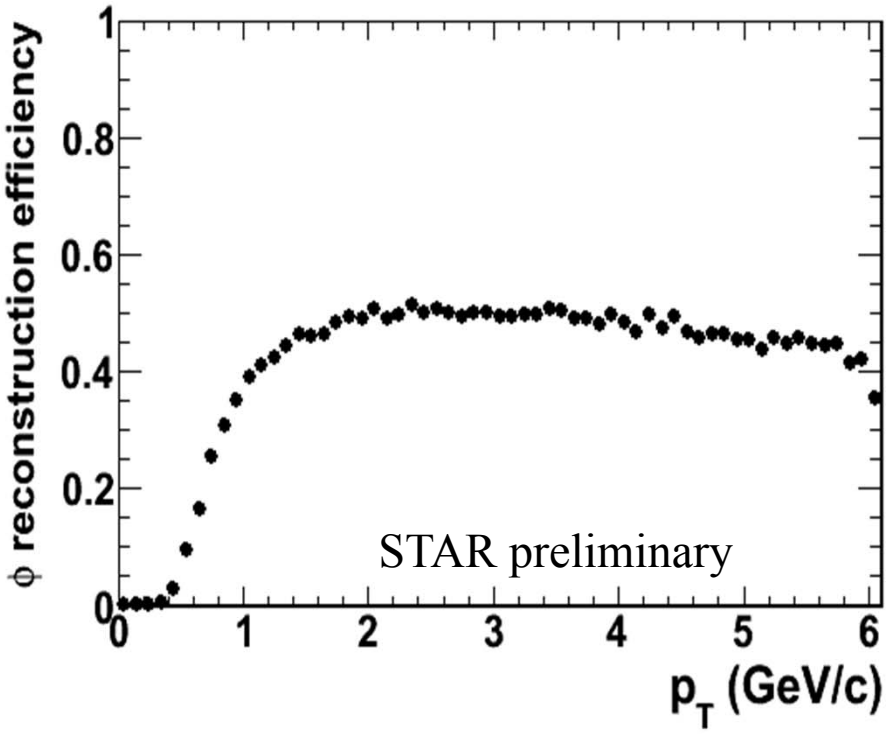


- TPC PID is used for spectra analysis, TPC+TOF PID is used for v_2 analysis
- **S/B of ϕ resonance significantly improved with additional TOF PID**

$\phi \rightarrow K^+ + K^-$ reconstruction efficiency

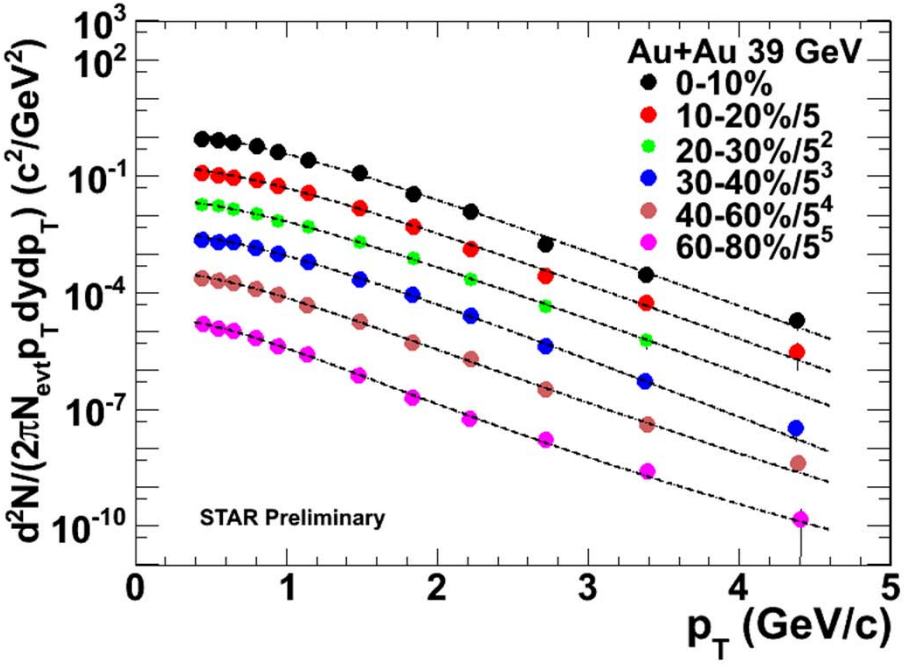
Au+Au 39 GeV 30-40%



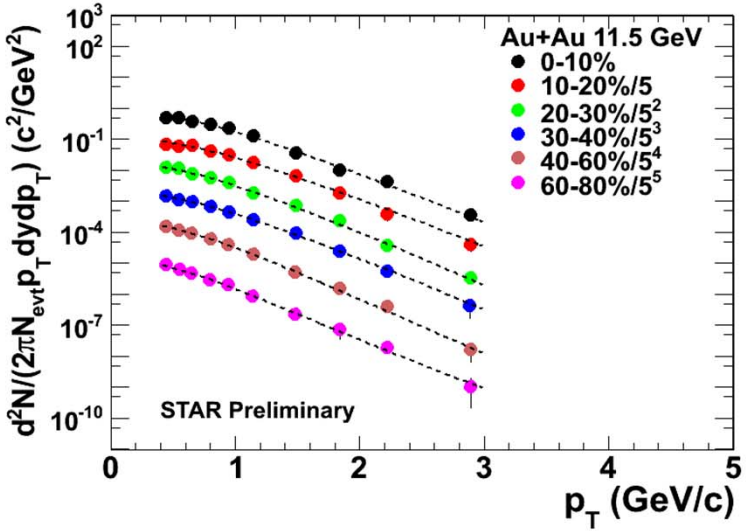


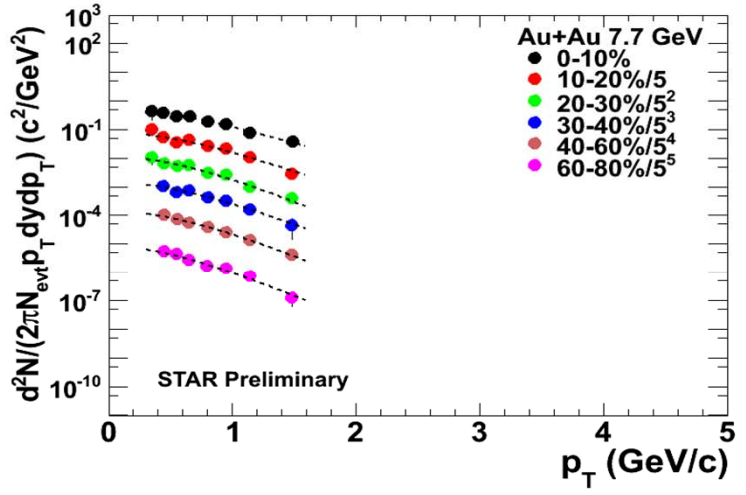
- **ϕ meson reconstruction efficiency is simulated from single kaon efficiency**

Spectra from $\phi \rightarrow K^+ + K^-$ decay channel



Statistical error only

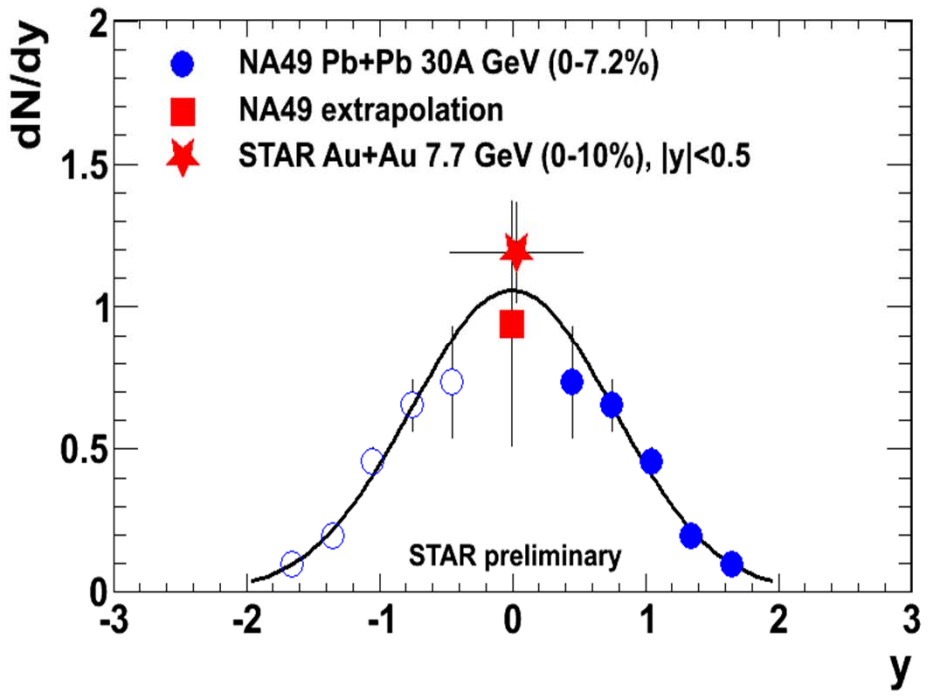


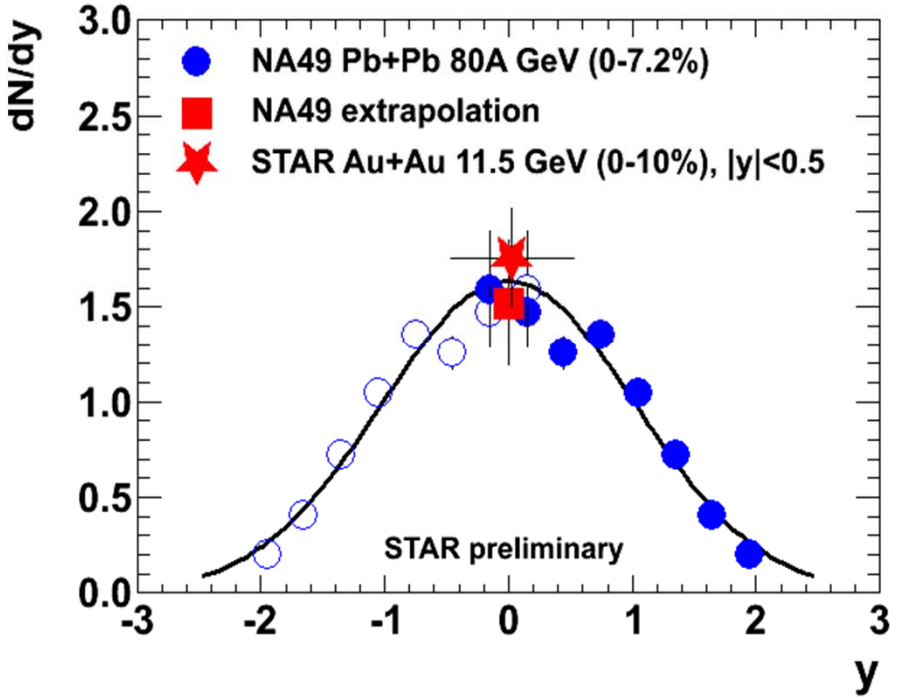


- **ϕ meson transverse momentum distribution could be well fitted by Levy function**

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

ϕ meson yields comparison

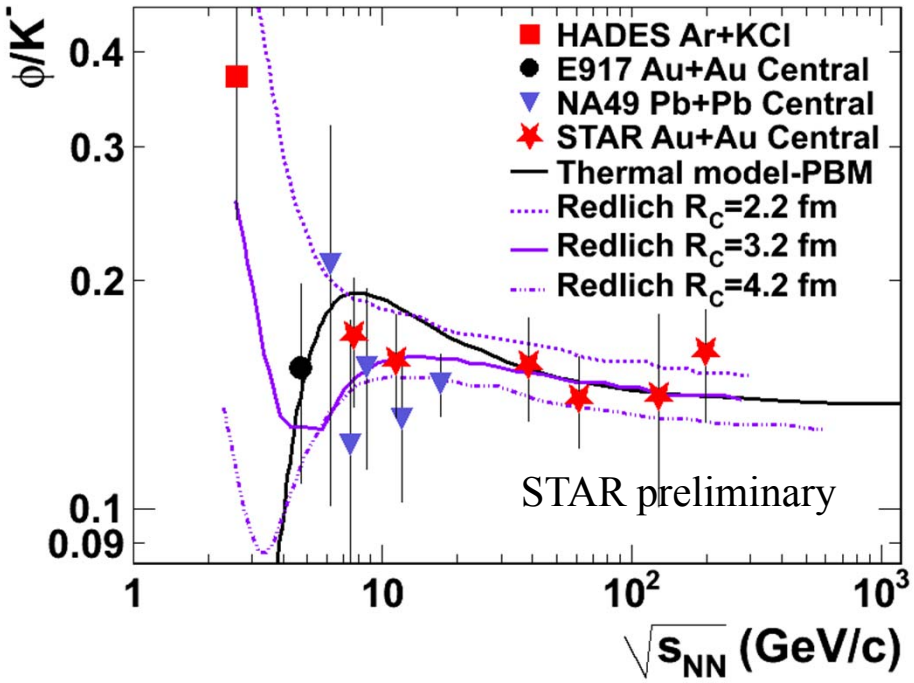


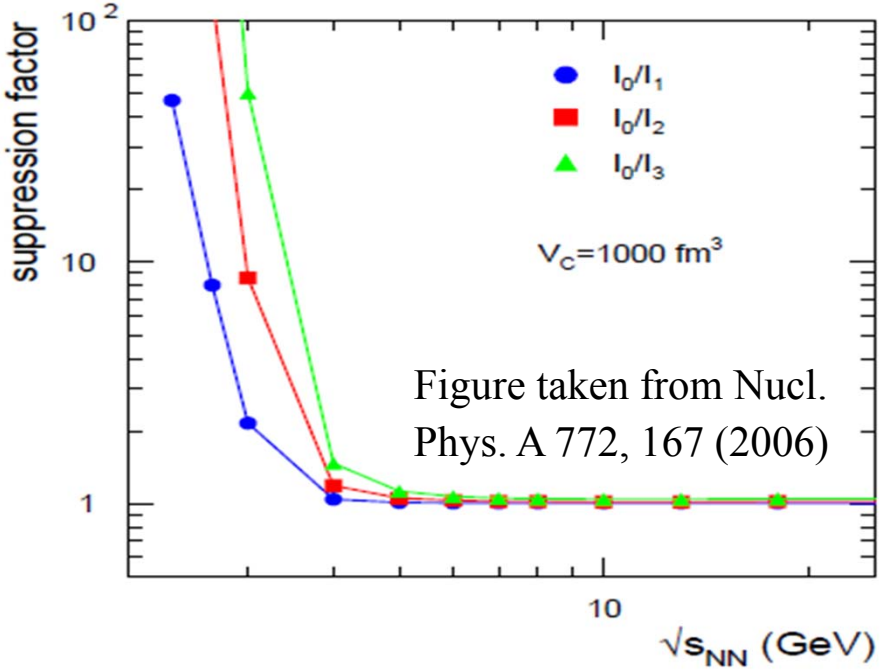


- NA49: 30A GeV ~ $\sqrt{s_{NN}}$ = 7.6 GeV, 80A GeV ~ $\sqrt{s_{NN}}$ = 12.3 GeV
- Consistent within error bars: statistical + systematical error

NA49, Phys. Rev. C 78, 044907 (2008)

ϕ/K^- ratio



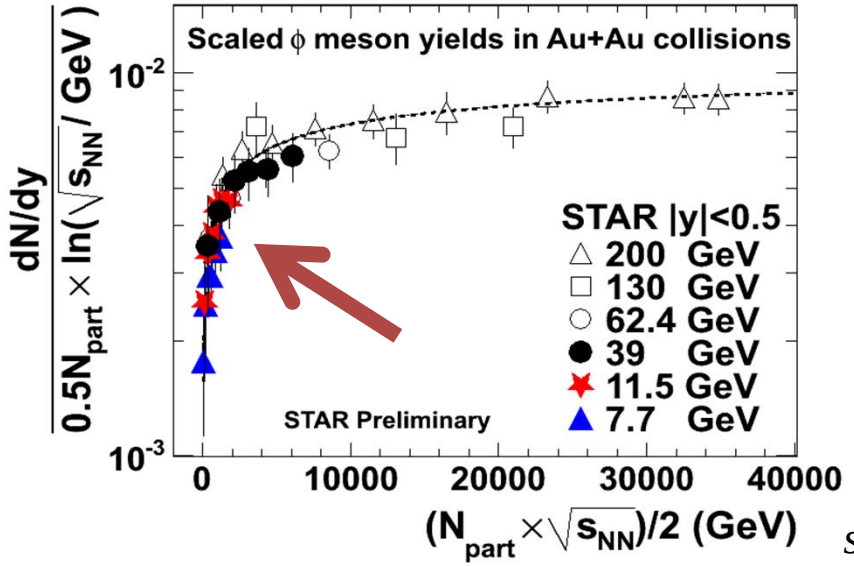


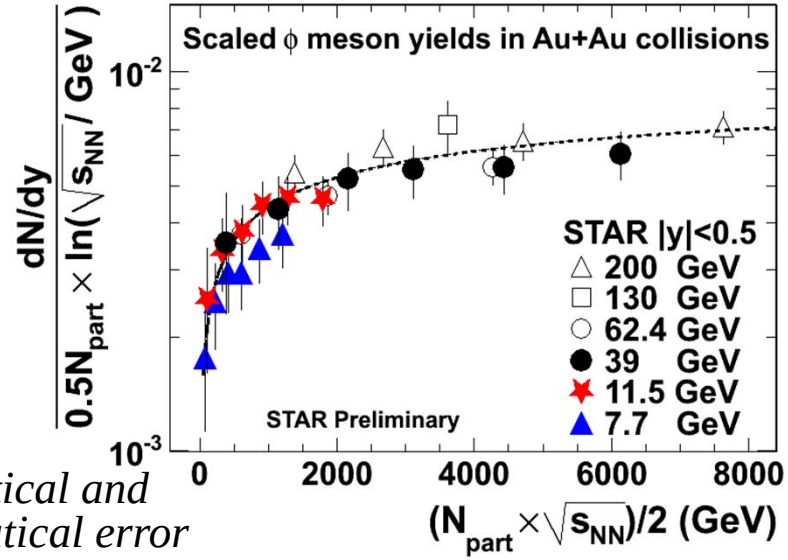
HADES: Phys. Rev. C 80, 025209 (2009) E917: Phys. Rev. C 69, 054901 (2004)
NA49: Phys. Rev. C 78, 044907 (2008) STAR 62.4, 130 & 200 GeV: Phys. Rev. C 79, 064903 (2009)
Thermal model-PBM: Nucl. Phys. A 772, 167 (2006)
Redlich model: Phys. Lett. B 603, 146 (2004)

Statistical + systematical error

- **ϕ/K^- ratio is sensitive to strangeness production mechanism**
- PBM model: canonical suppression, V_C = 1000 fm^3
- Redlich model: strangeness correlation length R_C: 2.2 – 4.2 fm
- The calculations with R_C: 2.2 – 4.2 fm agree with STAR data

Scaling behavior of ϕ meson yields

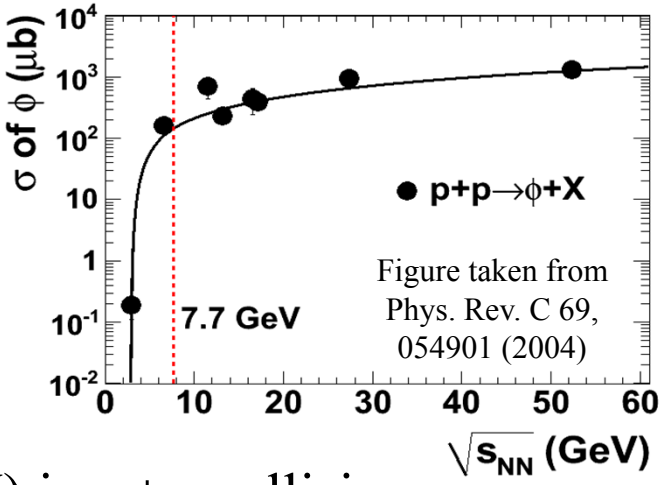




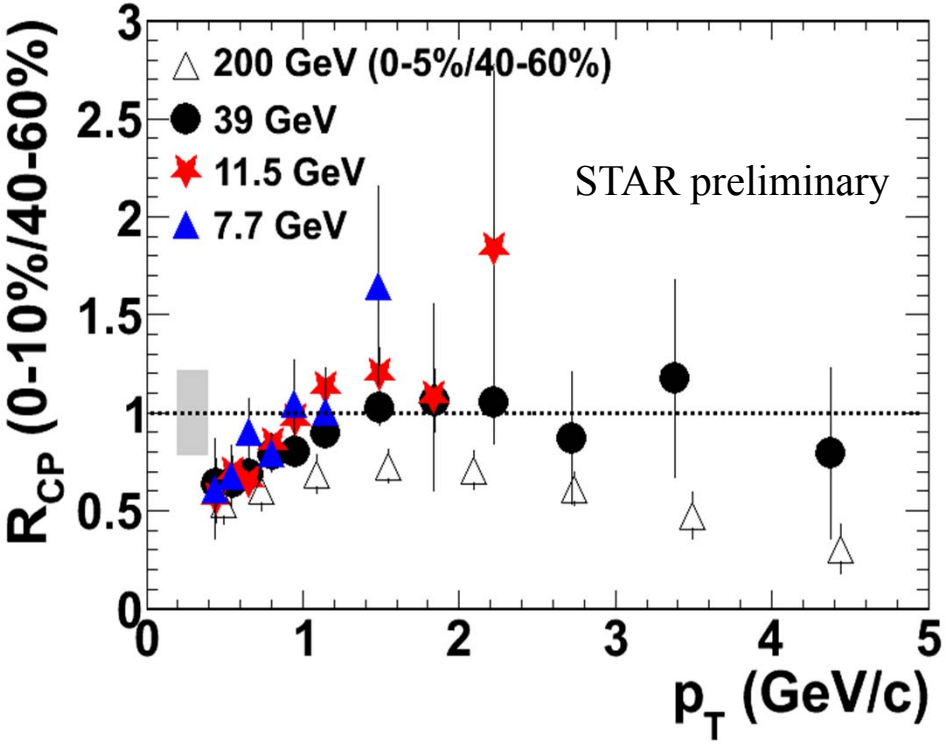
Statistical and systematical error

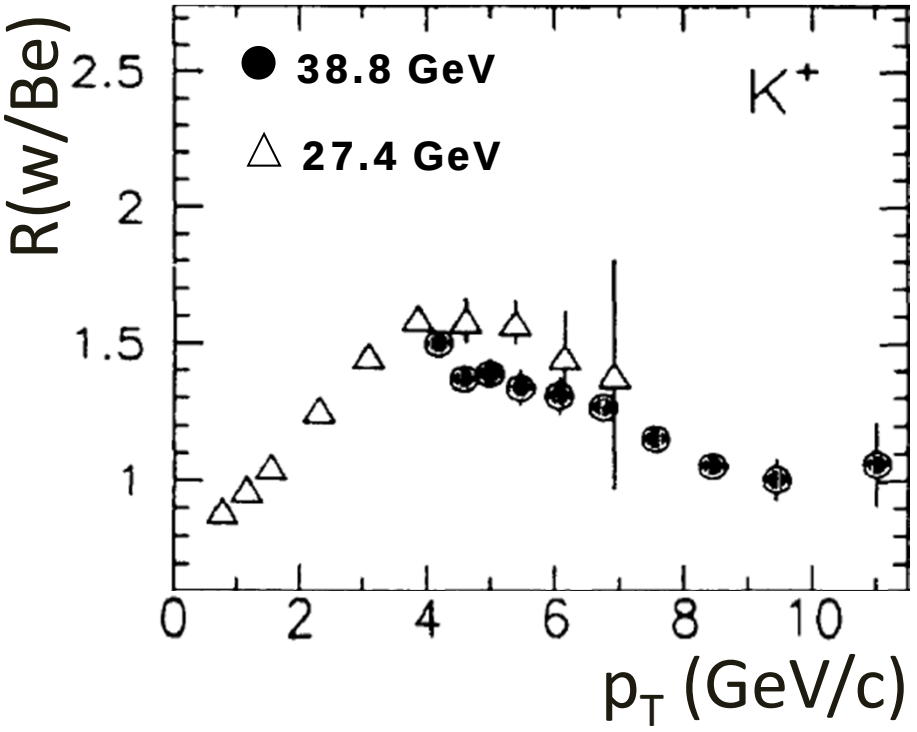
STAR 62.4, 130 & 200 GeV: Phys. Rev. C 79, 064903 (2009). ϕ cross section in pp are from Phys. Lett. B 491, 59 (2000), Phys. Rev. C 63, 024004 (2001), Phys. Lett. B 468, 7 (1999); ibid. 59, 88 (1975); ibid. 110, 326 (1982); Nucl. Phys. 186, 205 (1981); Z. Phys. C 9, 293 (1981).

- dN/dy scaled by $0.5N_{part} \times ln\sqrt{s_{NN}}$ v.s. $0.5N_{part} \times \sqrt{s_{NN}}$
- **A common curve for above energies and collision centralities**
- Strong increase in $0.5N_{part} \times \sqrt{s_{NN}} < 2000$
- **Threshold effect?** $\sqrt{s_{NN}}$ = 7.7 GeV is well above ϕ meson production threshold (2.896 GeV) in p+p collisions
- **Multi-stage process? deconfinement phase transition?**



ϕ meson nuclear modification factor (R_{CP})



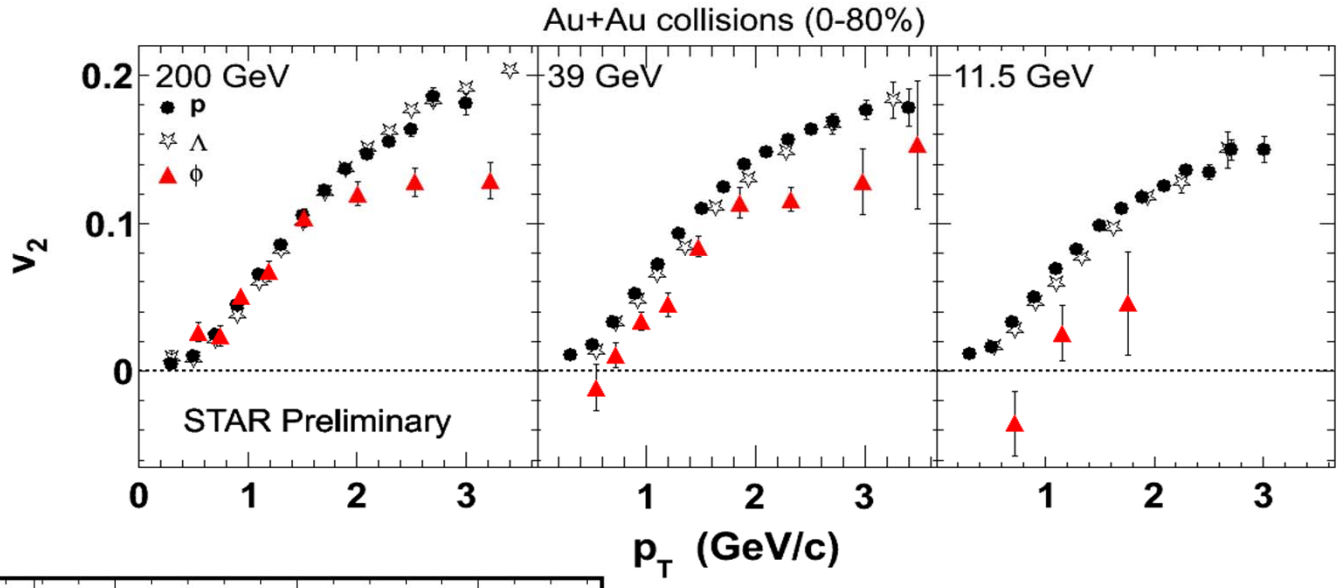


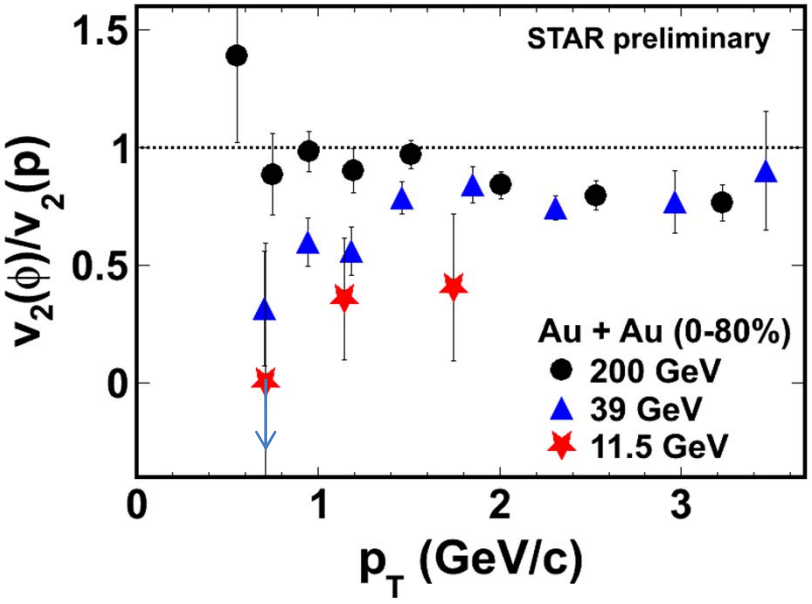
P. B Straub et al., Phys. Rev. Lett. 68, 452 (1992)

Grey band: normalization error on number of binary collisions Points: statistical error

- **R_{CP}(0-10%/40-60%) consistent with unity for p_T > 1 GeV/c at 39 GeV, no suppression**
- Interplay between Cronin effect (p_T broadening due to multiple scatterings) and parton energy loss?

ϕ meson v_2 v.s. p_T



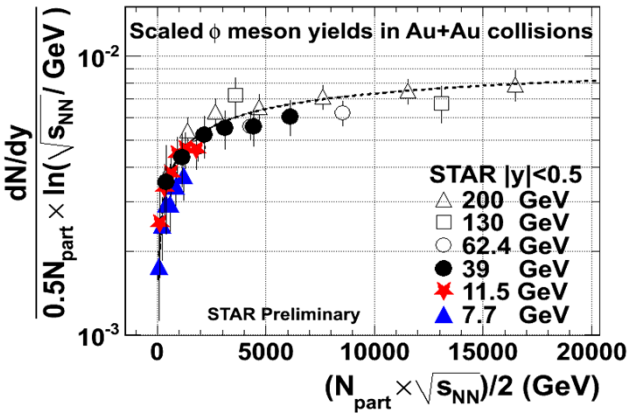


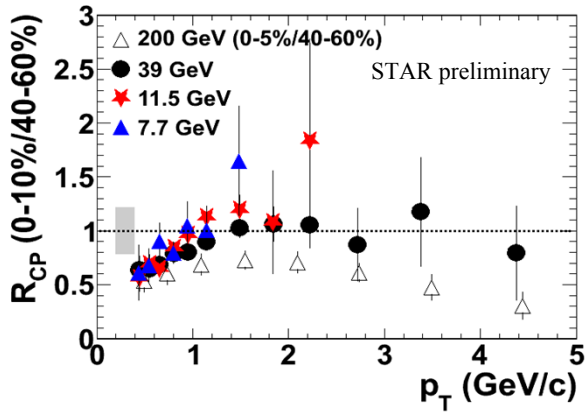
- Mass: proton ~ ϕ ~ Λ
- At low p_T, $v_2(\phi)/v_2(p)$ decreases with decreasing beam energies
  → **partonic collectivity becomes weaker**

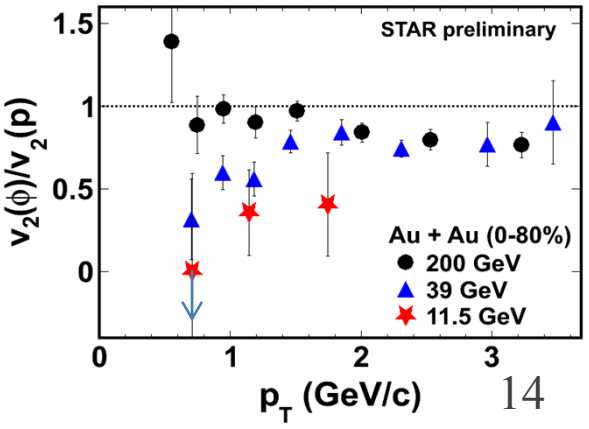
200 GeV: TPC full event plane; 11.5 and 39 GeV, TPC η-sub event plane; statistical error only

Summary and outlook

- STAR preliminary ϕ meson spectra and v_2 results in $\sqrt{s_{NN}}$ = 7.7, 11.5 and 39 GeV Au+Au collisions have been presented
- **Scaling behavior of ϕ meson yields in different collision energies and centralities.** Strong increase of scaled ϕ meson yields at $N_{part} \times \sqrt{s_{NN}}/2 < 2000$
- ϕ meson R_{CP}(0-10%/40-60%) consistent with unity at **39 GeV, no suppression**
- $v_2(\phi)/v_2(p)$ decreases with decreasing beam energies at low p_T → **partonic collectivity becomes weaker**
- Outlook: 19.6, 27 and 62.4 GeV data under analysis

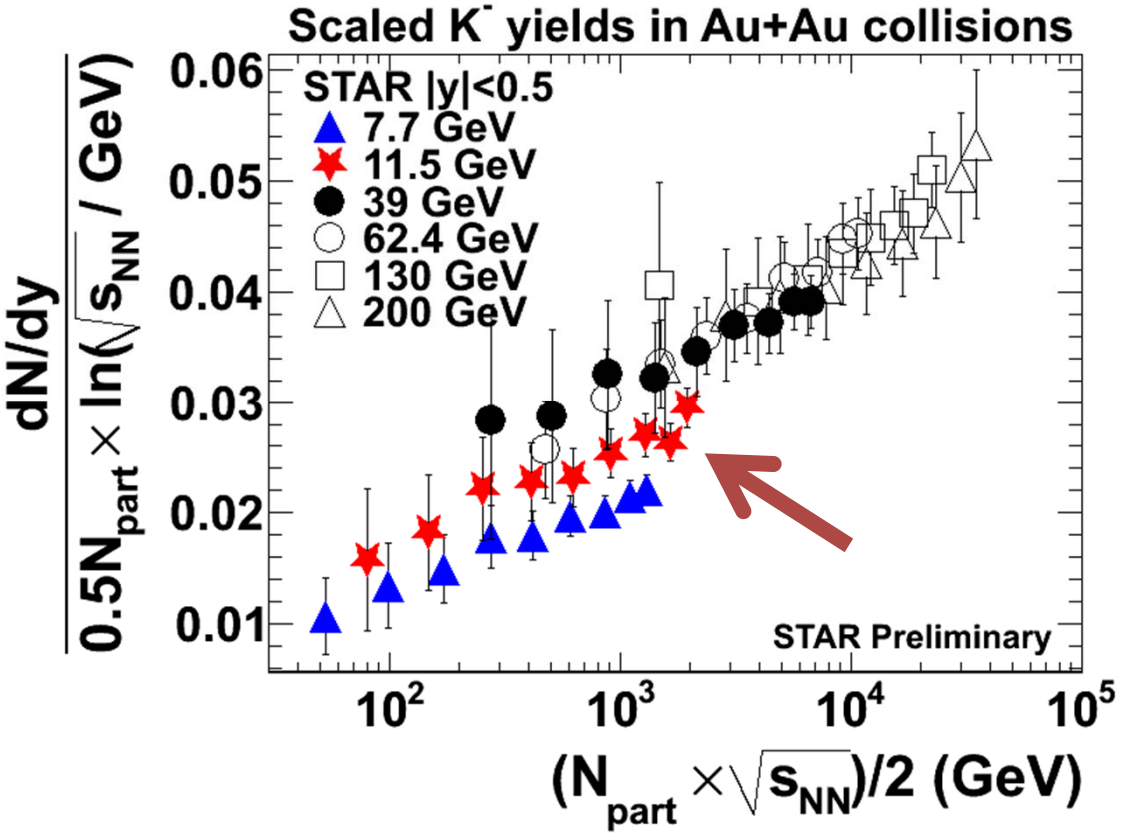






Backup

Scaled K^- yields

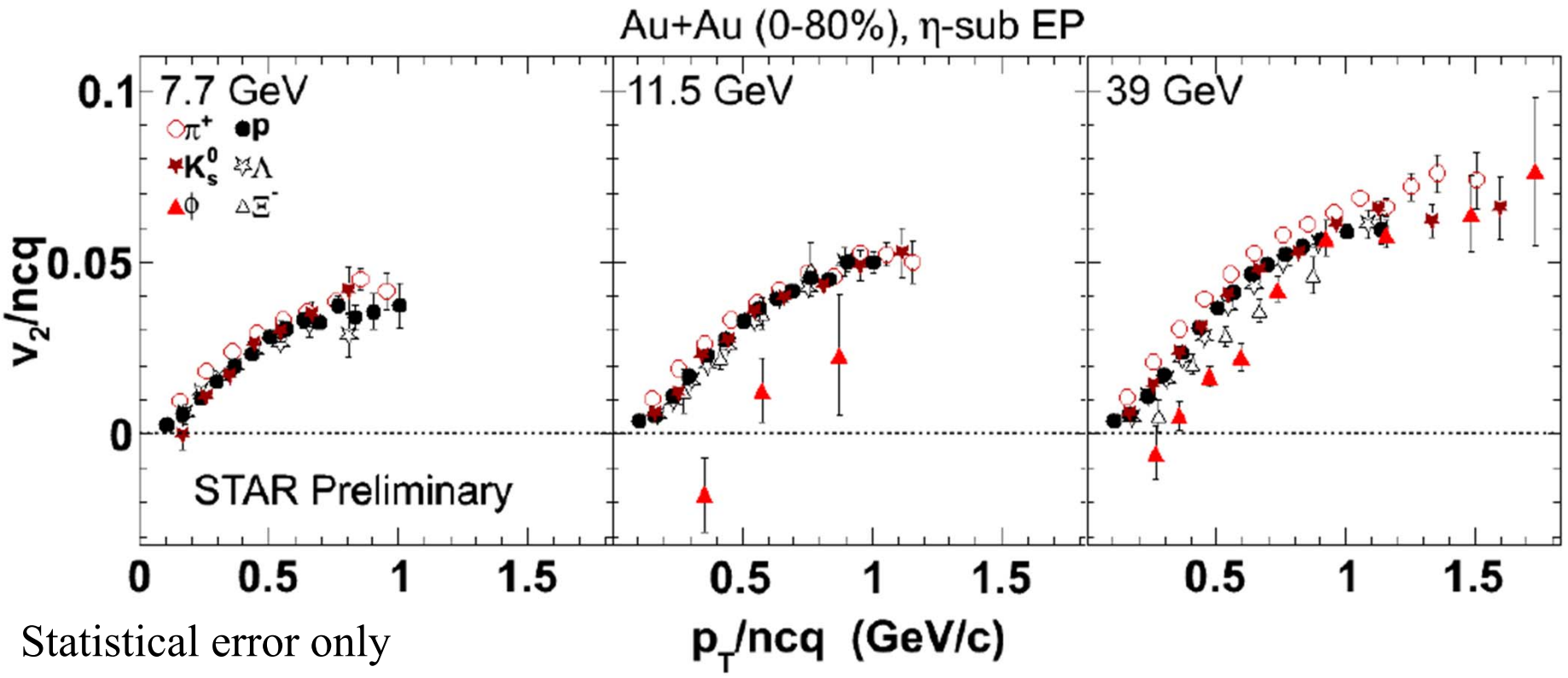


Statistical and systematical error

STAR 7.7, 11.5, 39 GeV data: Lokesh Kumar, Quark Matter 2011
STAR 62.4, 130, 200 GeV data, Phys. Rev. C 79, 034909 (2009)

- dN/dy scaled by $0.5N_{part} \times ln\sqrt{s_{NN}}$ v.s. $0.5N_{part} \times \sqrt{s_{NN}}$
- **A common curve for 39, 62.4, 200 GeV**
- Strong increase of scaled K^- yields from 7.7 GeV to 39 GeV in $0.5N_{part} \times \sqrt{s_{NN}} < 2000$
- **Threshold effect? multi-stage process? deconfinement phase transition?**

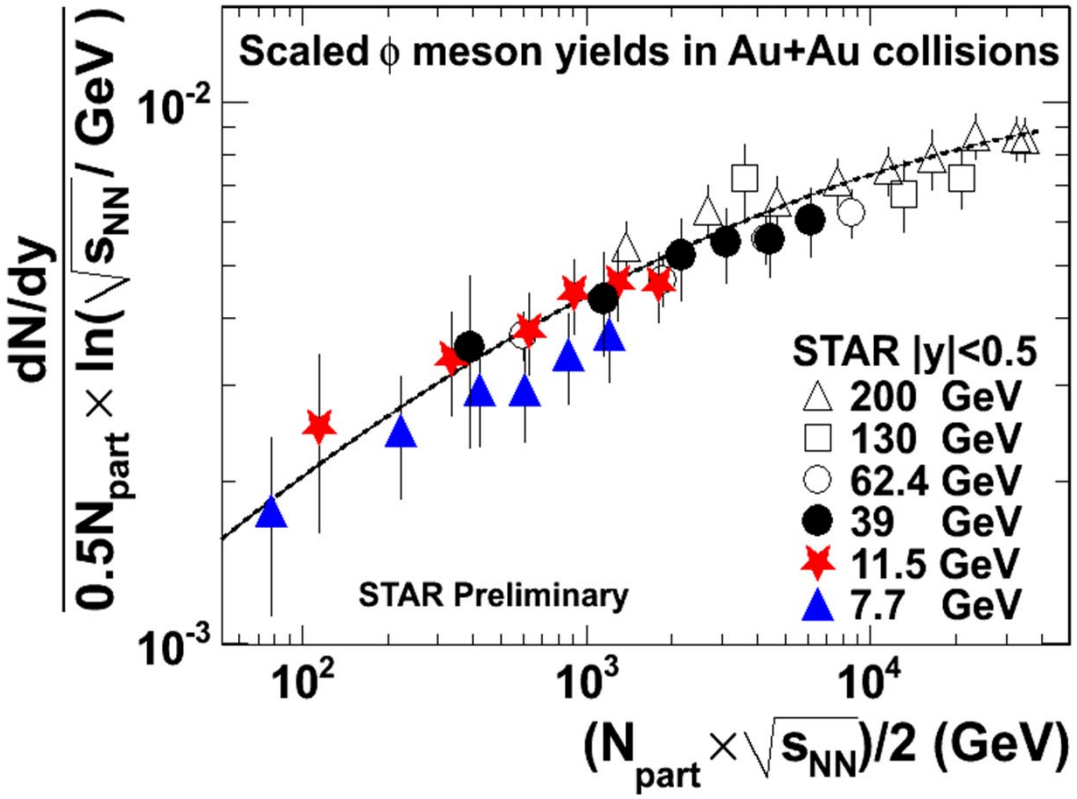
NCQ scaling — v_2/n_q v.s. p_T/n_q



Statistical error only

- π^+, K^0_S, p, Λ and Ξ^- approximately follow one common curve in the intermediate p_T range at 39 GeV
- **ϕ-mesons @ 39 GeV follow other hadrons at $p_T/ncq > 0.9$ GeV/c**

Scaling behavior of ϕ meson yields



- dN/dy scaled by $0.5N_{part} \times ln\sqrt{s_{NN}}$ v.s. $0.5N_{part} \times \sqrt{s_{NN}}$
- **A common curve for these energies and collision centralities**

Statistical and systematical error

STAR 62.4, 130 & 200 GeV: Phys. Rev. C 79, 064903 (2009)