Recent elliptic flow measurements at RHIC

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Moriond QCD and High Energy Interactions,
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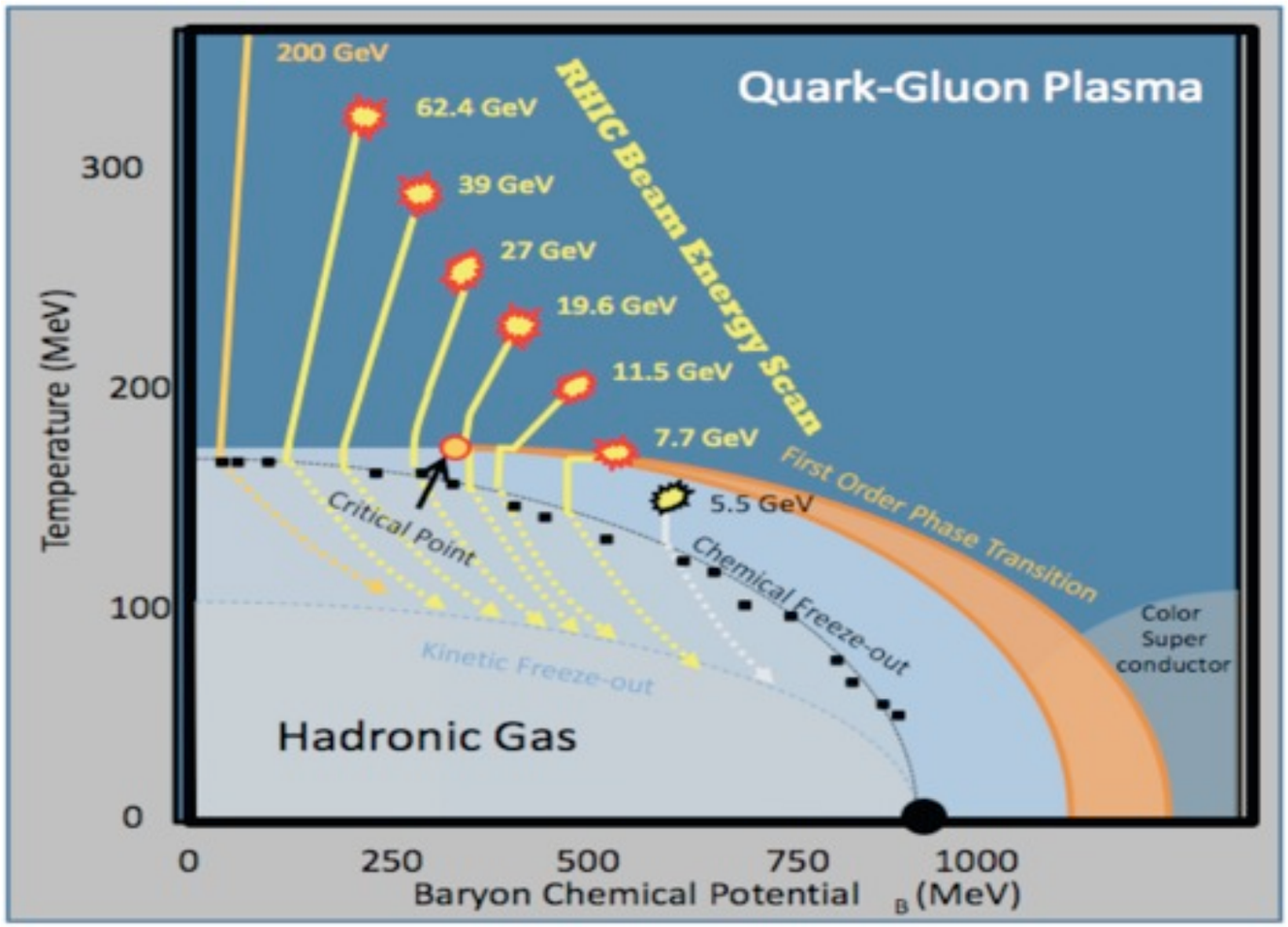
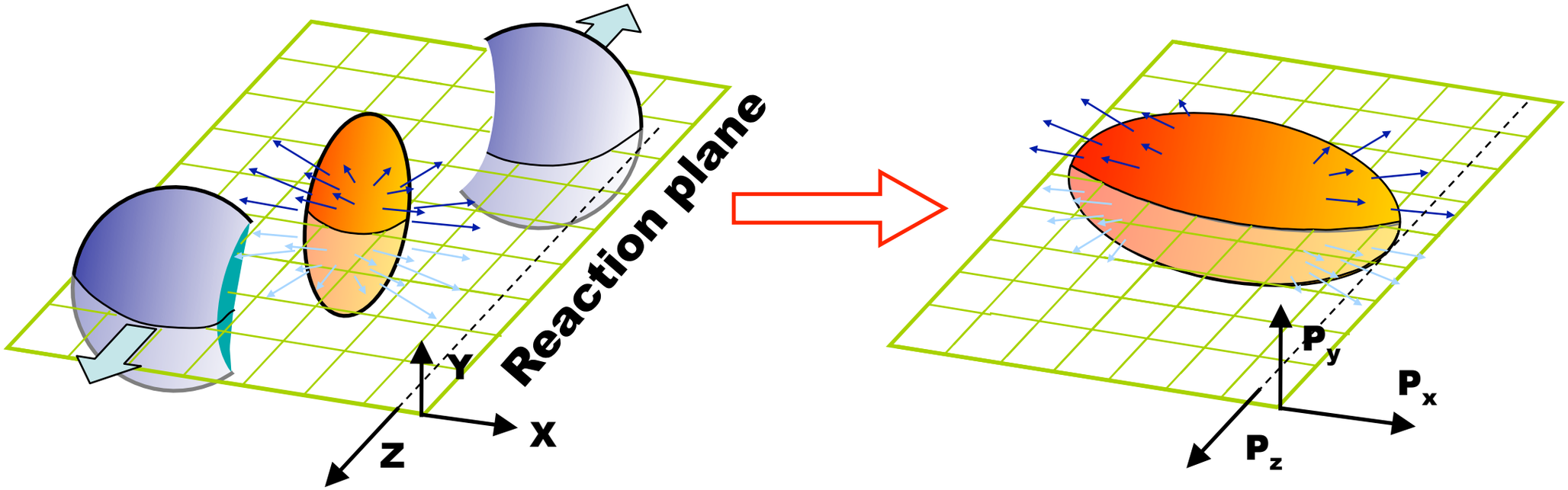
Outline

- Introduction
- What have we learned in Au + Au collisions at $\sqrt{s_{NN}}$ = 200 GeV ?
- Latest elliptic flow (v_2) results from RHIC Beam Energy Scan
- Conclusions and outlook



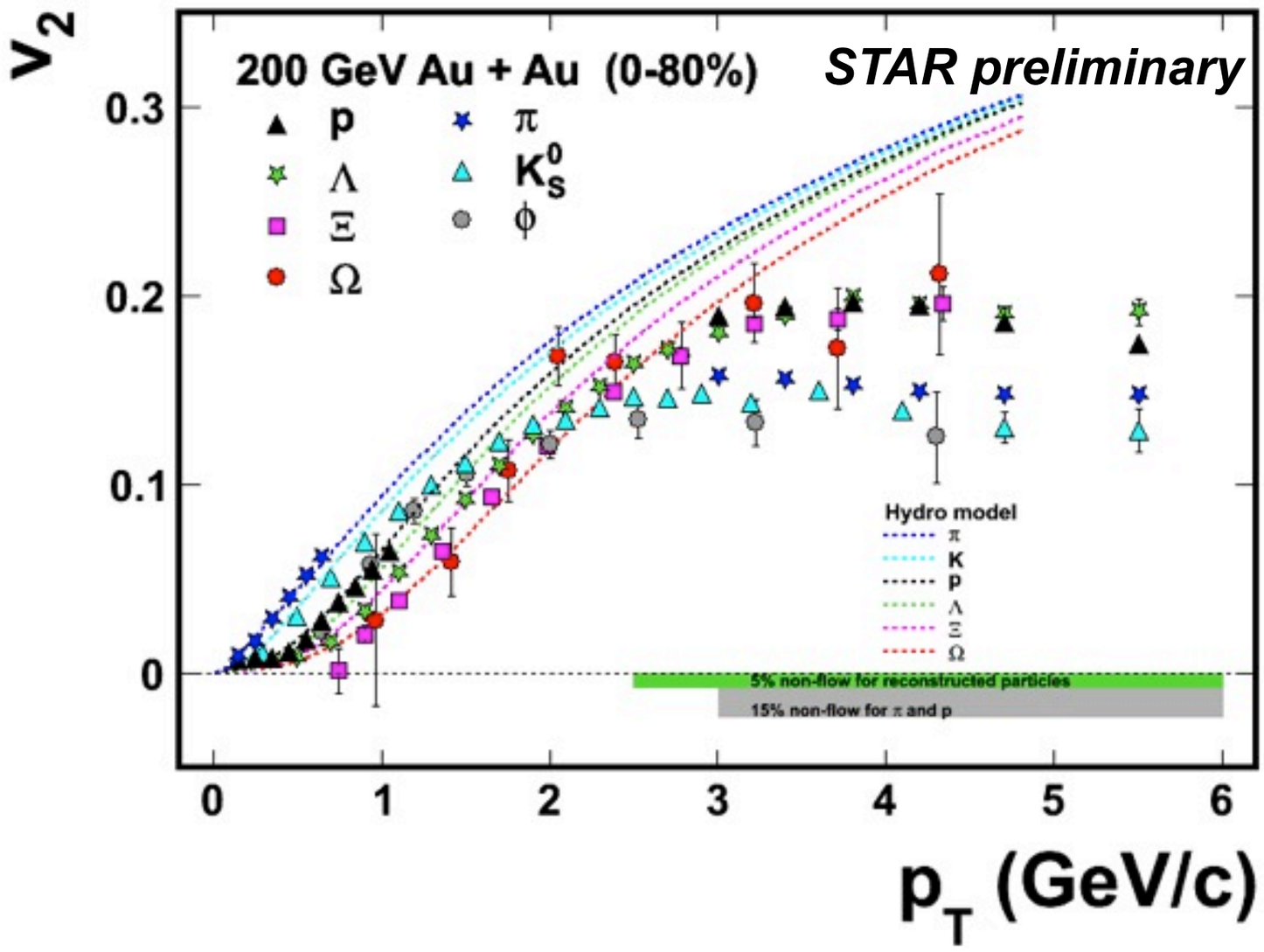
Elliptic flow
probe to the early collisions dynamics



$$\frac{dN}{d(\phi-\Psi)} \propto 1 + 2v_1\cos(\phi-\Psi) + \boxed{2v_2\cos(2\phi-2\Psi)} + \ldots$$

- Initial spatial anisotropy → final momentum anisotropy
  - degrees of interactions, Equation Of State, degrees of freedom, transport coefficients, ...
- Characterized by v_2 of Fourier expansion of azimuthal particle distribution with respect to the reaction plane

What have we learned ?



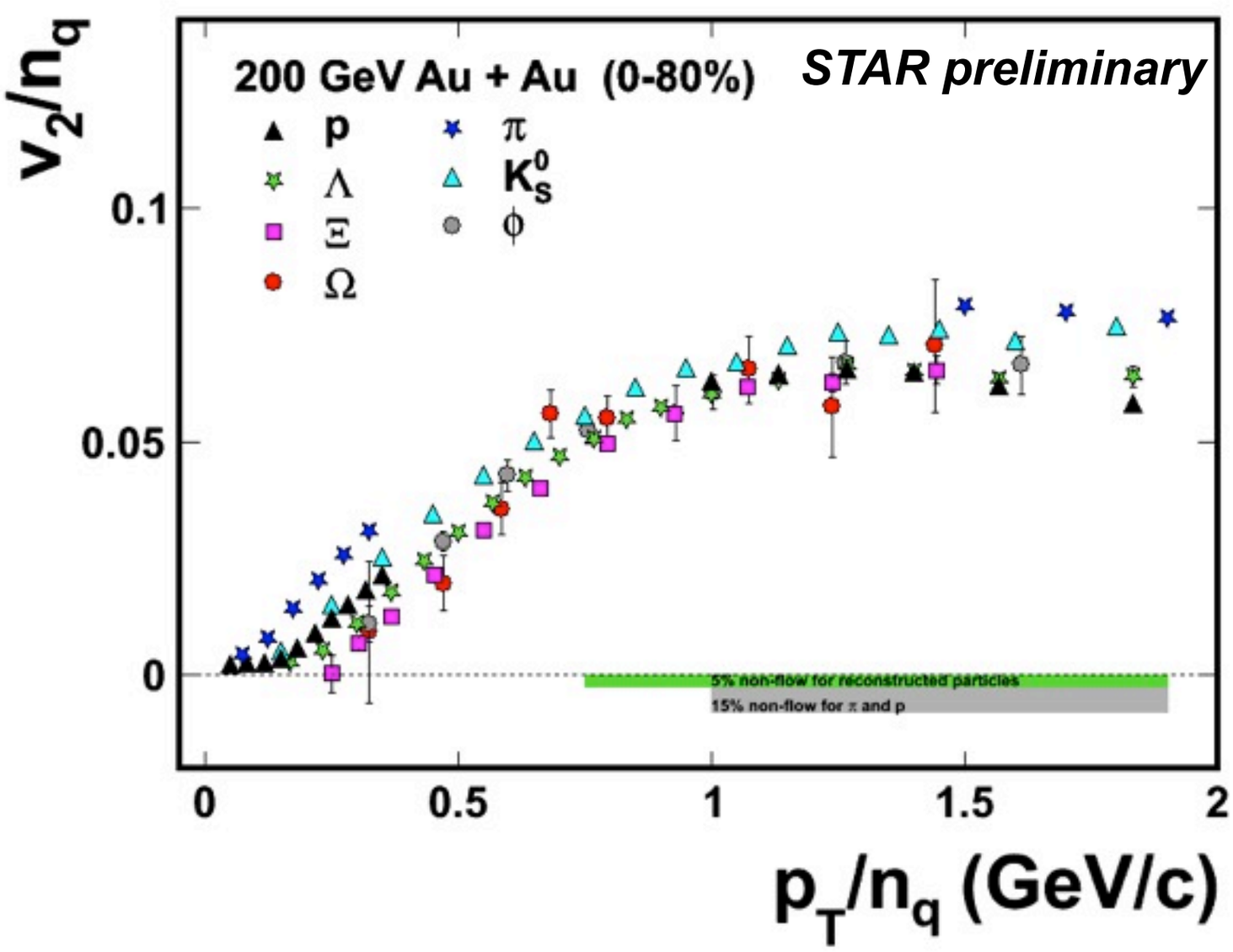
STAR
QM2009

$$\frac{v_2^h(p_T)}{n_q} \approx v_2^q(p_T/n_q)$$

Quark coalescence/recombination
*D. Molnar and S. A. Voloshin PRL **91**, 092301 (2003)*
*V. Greco, C. M. Ko and P. Levai PRC **68**, 034904 (2003)*
*R. J. Fries, B. Muller, C. Nonaka and S. A. Bass PRC **68**, 044902 (2003)*
*J. Jia and C. Zhang PRC **75**, 031901(R) (2007) ....*

- Mass ordering at low p_T → strong radial expansion

What have we learned ?



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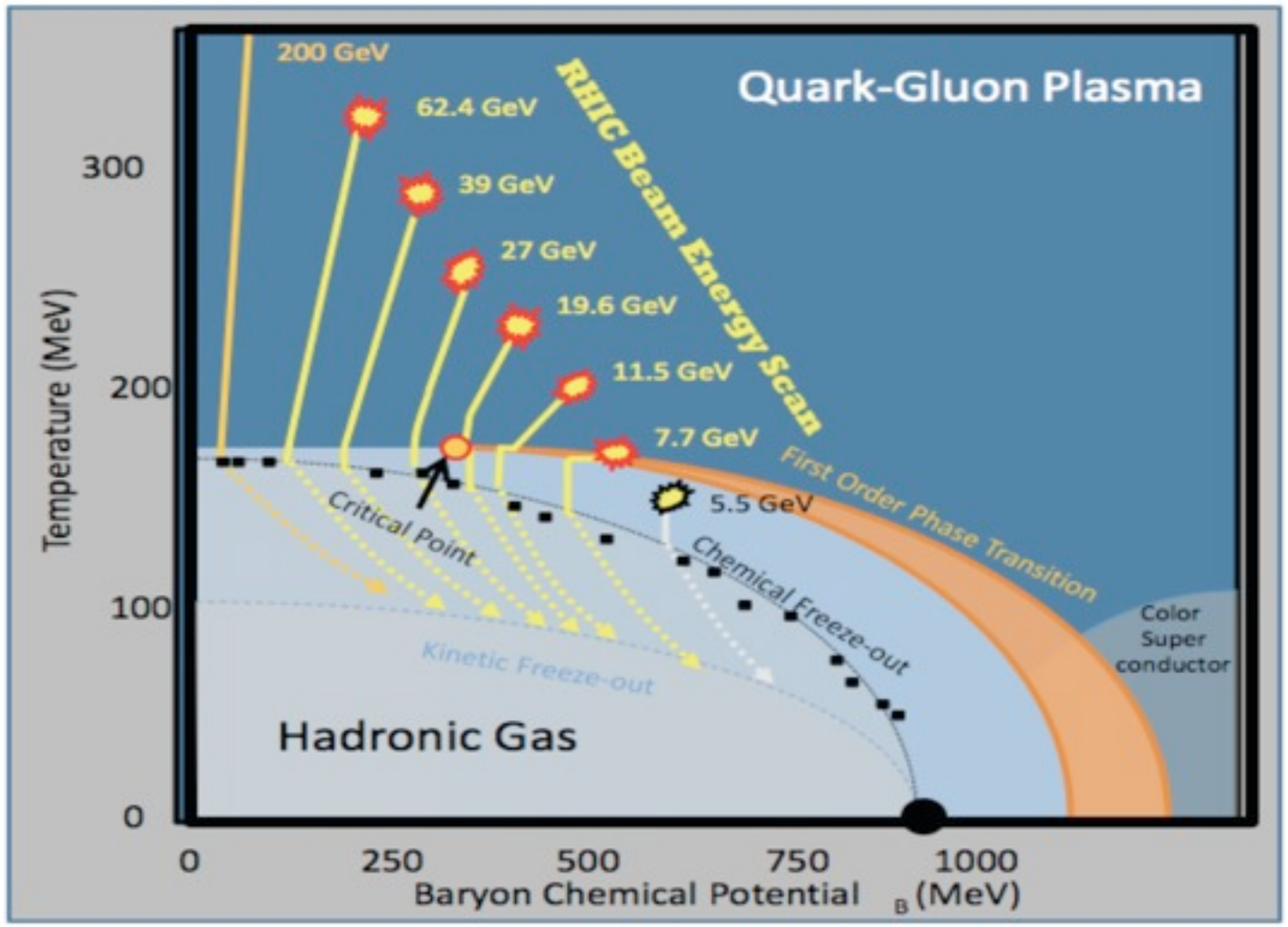
- Mass ordering at low p_T → strong radial expansion
- Number of constituent quark (NCQ) scaling of v_2

➡ Indication of partonic phase

RHIC Beam Energy Scan



- Two main goals
  - Signals of phase boundary
  - Critical point search
- How ?
  - Disappearance of QGP signals
  - Critical point induced fluctuations
- 6 different energies in year 2010 and 2011
  - 7.7, 11.5, 39 and 62.4 GeV (2010)
  - 19.6 and 27 GeV (2011)

    - Took 130 and 200 GeV in previous years

RHIC Beam Energy Scan

- What would be expected from v_2 measurements if hadron phase is dominant ?
  1. Break down of NCQ scaling
  2. Small ϕ meson v_2 due to smaller hadronic cross section of ϕ meson than that of other hadrons*
  3. ...

** B. Mohanty and N. Xu, J. Phys. G**36**, 064022 (2009)*

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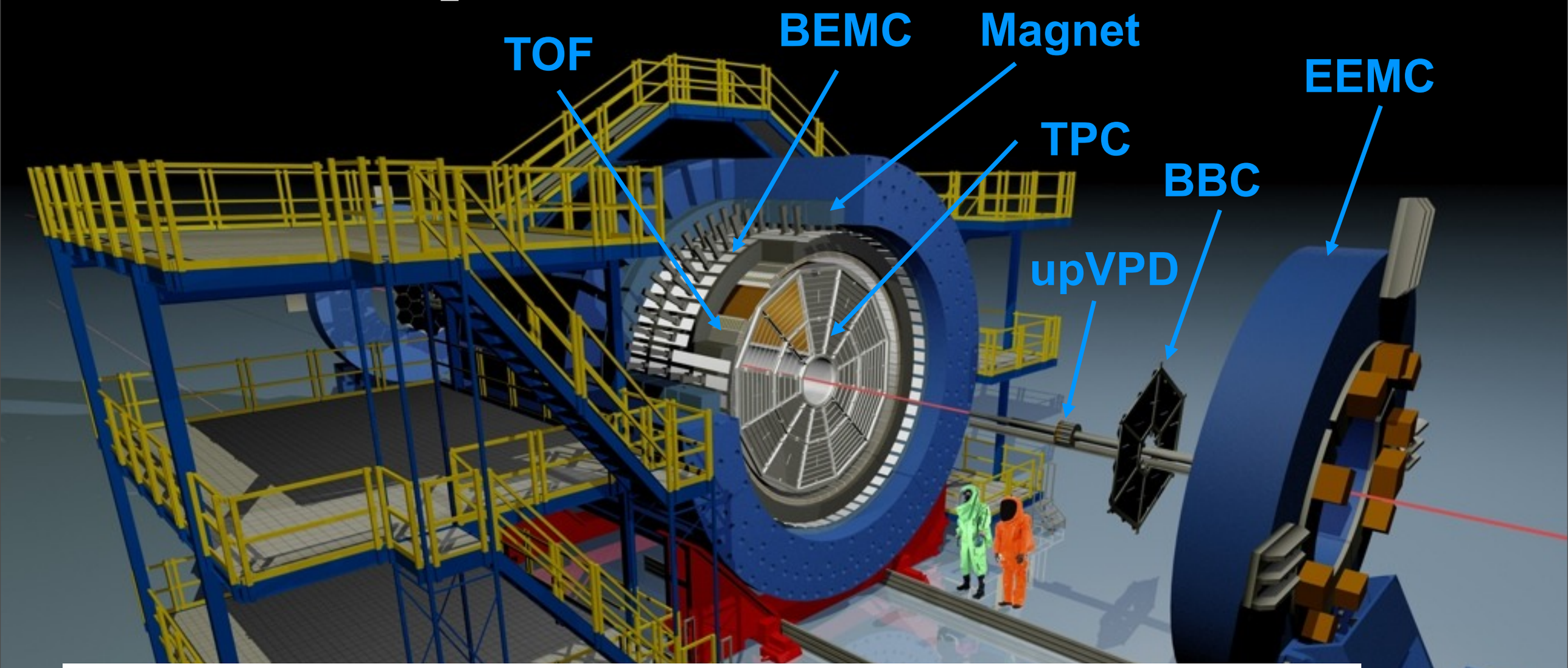
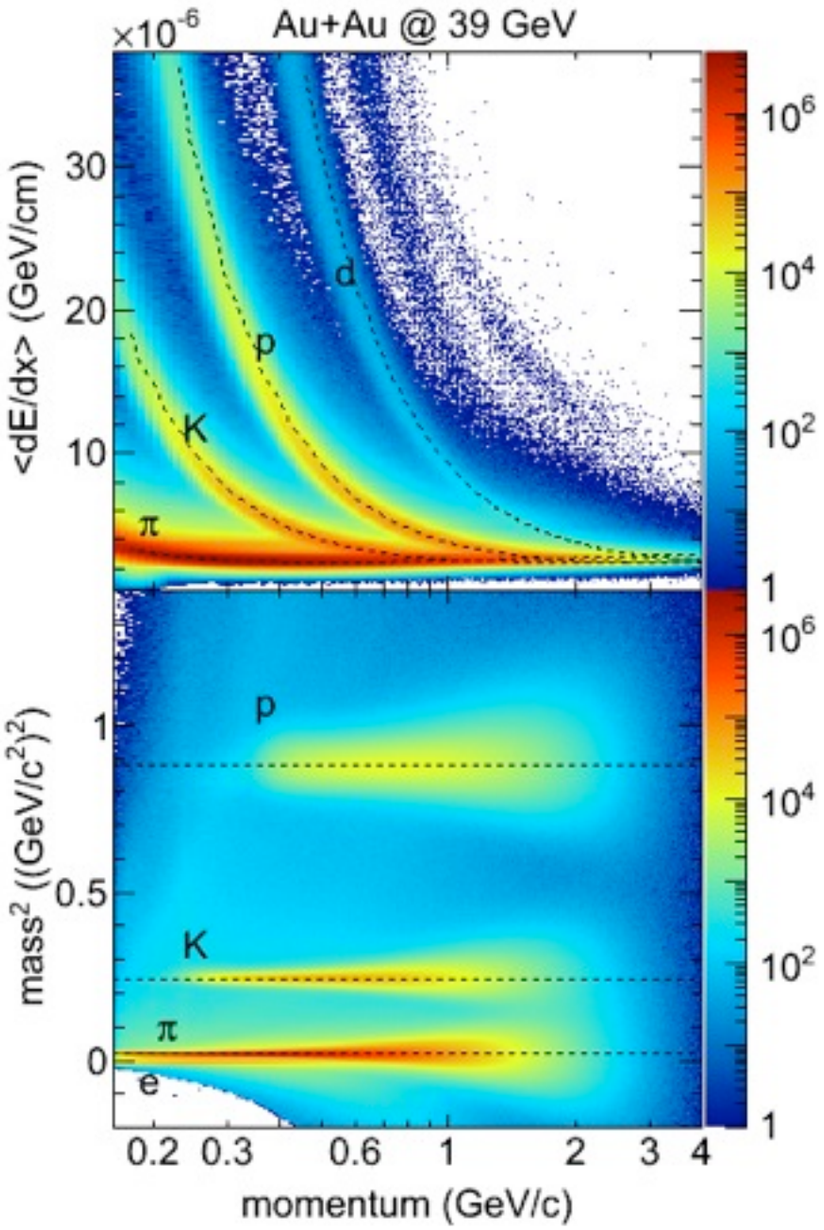
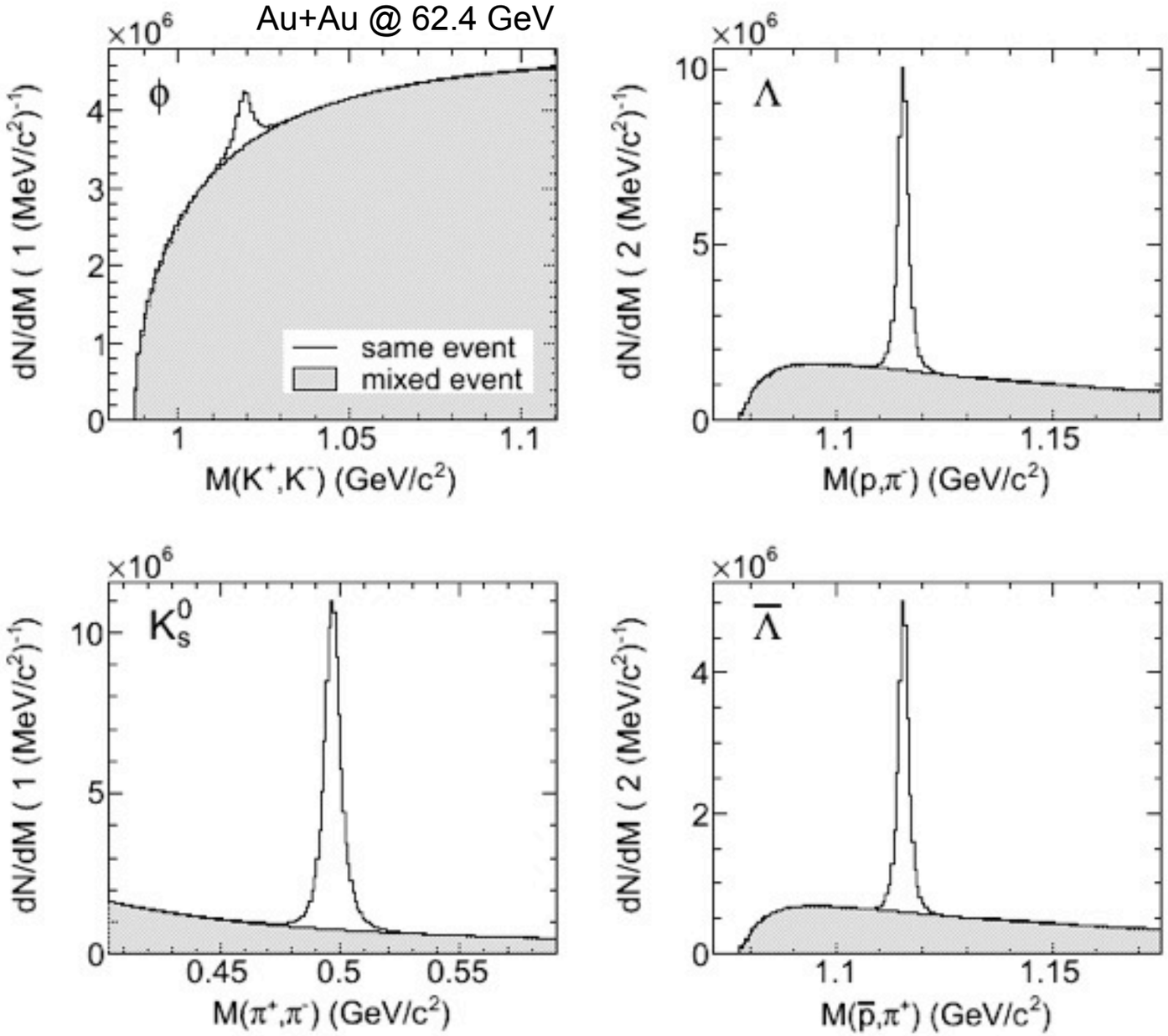
STAR experiment



- Time Projection Chamber (TPC)
  - Full azimuth, $|\eta| < 1$
- Full barrel Time-Of-Flight
  - Extend p_T reach for π, K and p, improve S/B for V_0's

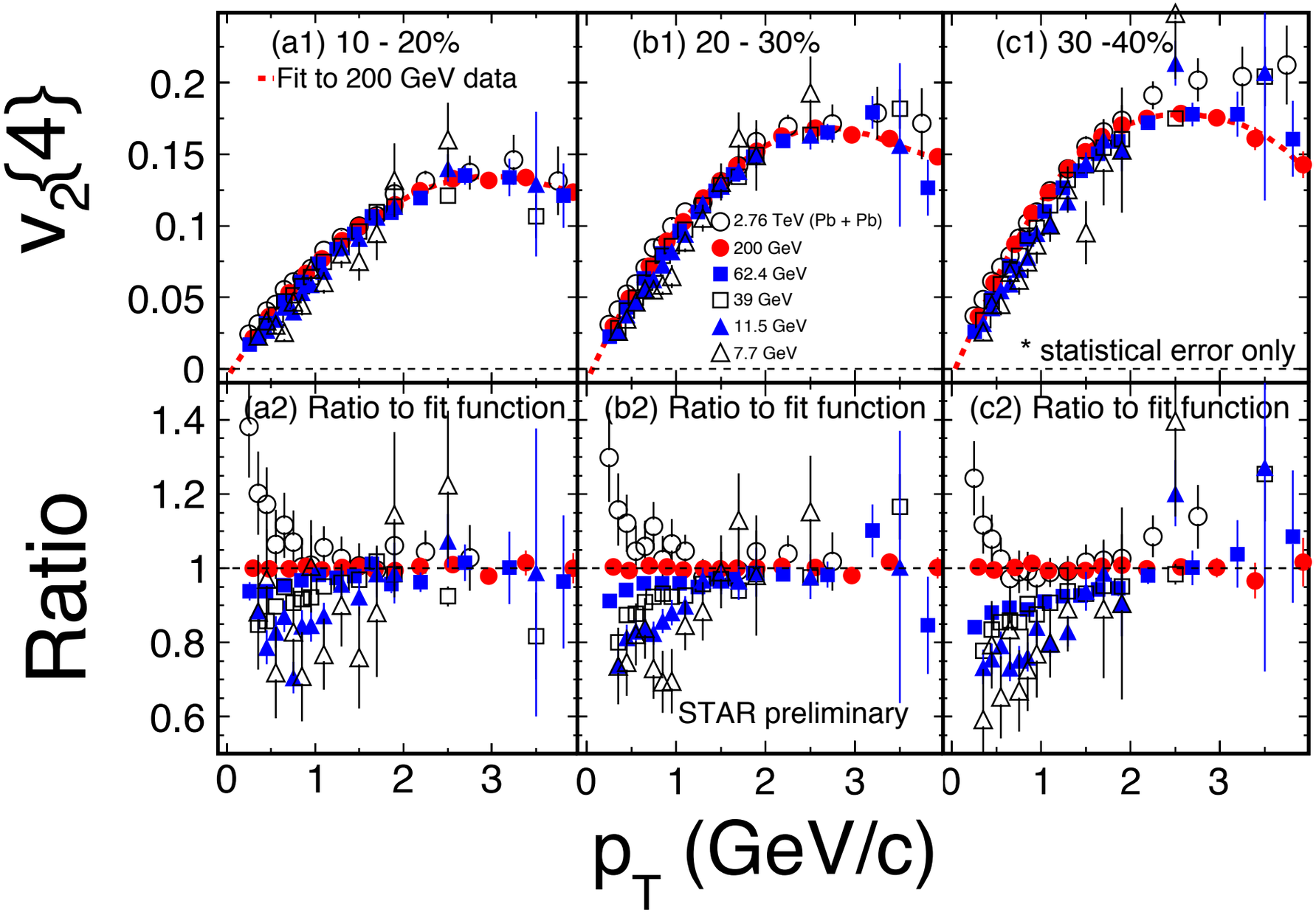
Particle identification at STAR





- dE/dx + TOF: π, K, p and $\phi \rightarrow K^+K^-$ (invariant mass)
- Secondary vertex + invariant mass: K^0_S, Λ (Ξ, Ω)

Charged hadrons



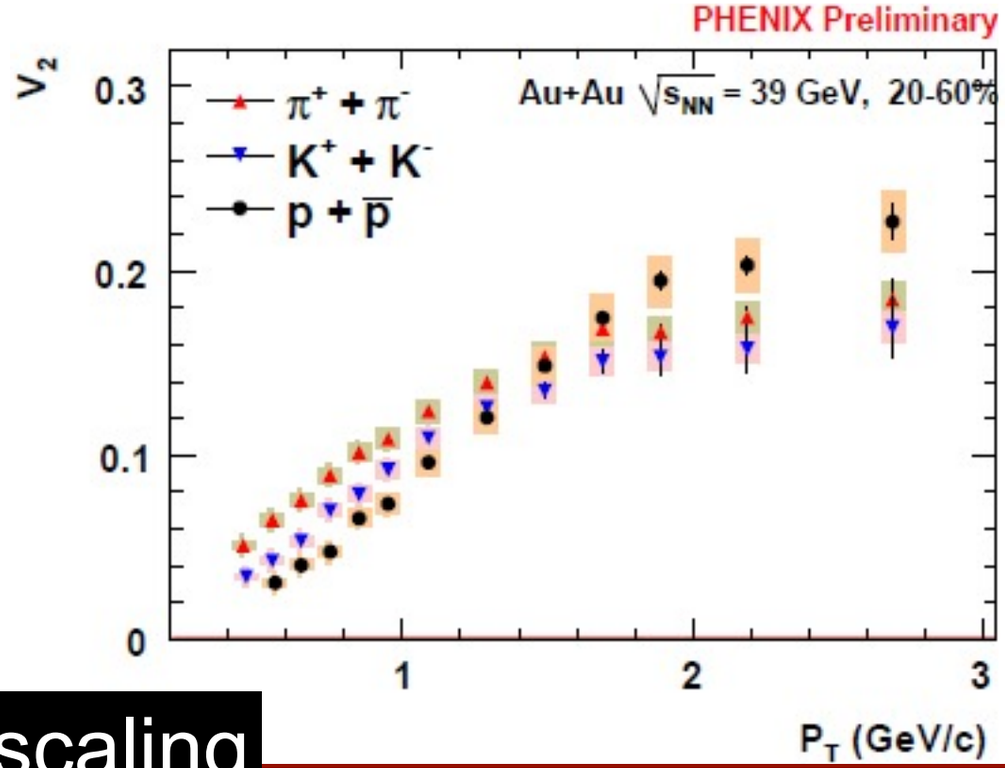
STAR QM2011, CPOD2011

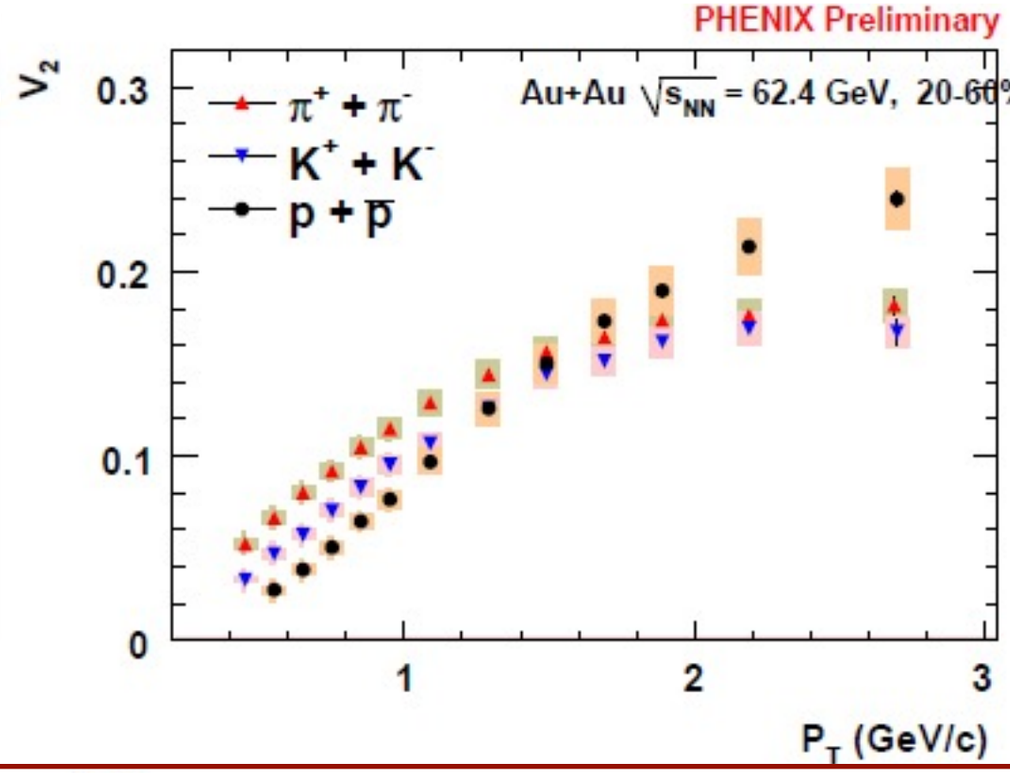
- Similar v_2 for p_T > 2 GeV/c from 7.7 GeV to 2.76 TeV
- 20-40% difference in p_T < 2 GeV/c
  - Different particle compositions ?

*62.4 GeV: STAR **PRC75**, 054906 (2007)*
*200 GeV: STAR **PRC77**, 054901 (2008)*
2.76 TeV in Pb+Pb:
*ALICE **PRL105**, 252302 (2010)*

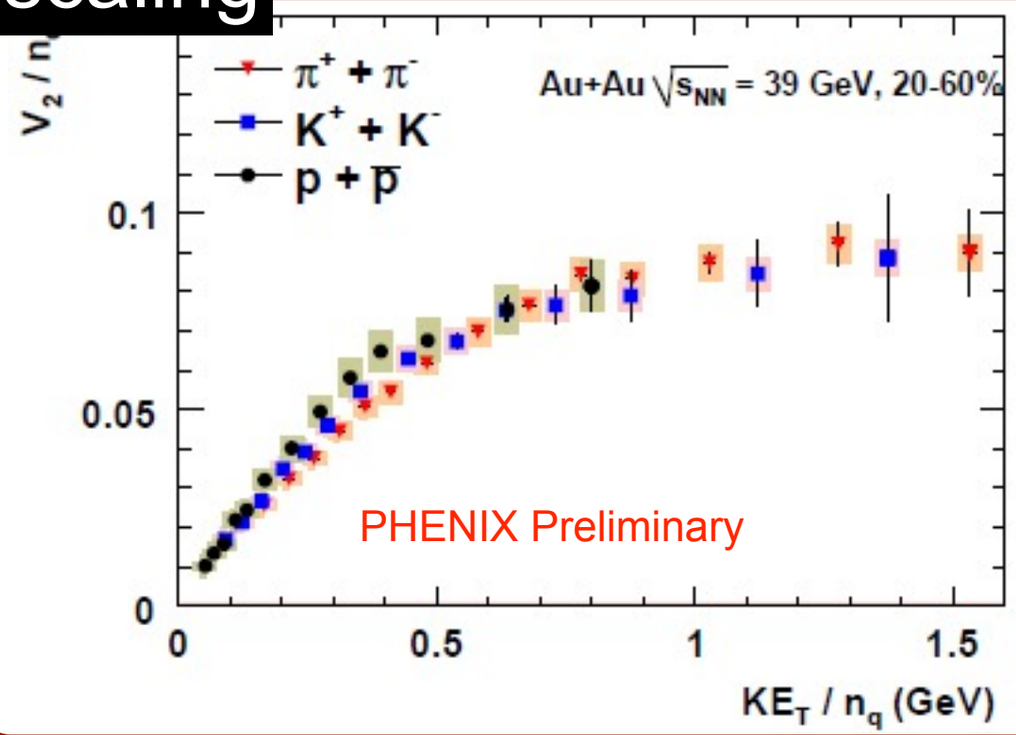
PHENIX identified hadrons

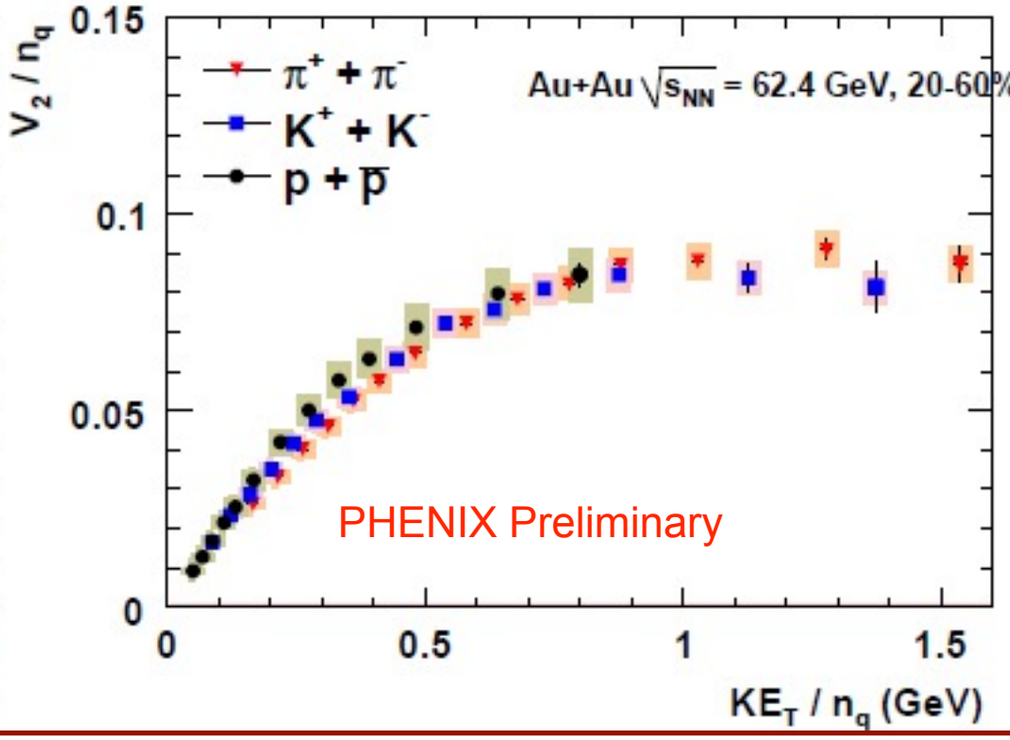
PHENIX
QM2011





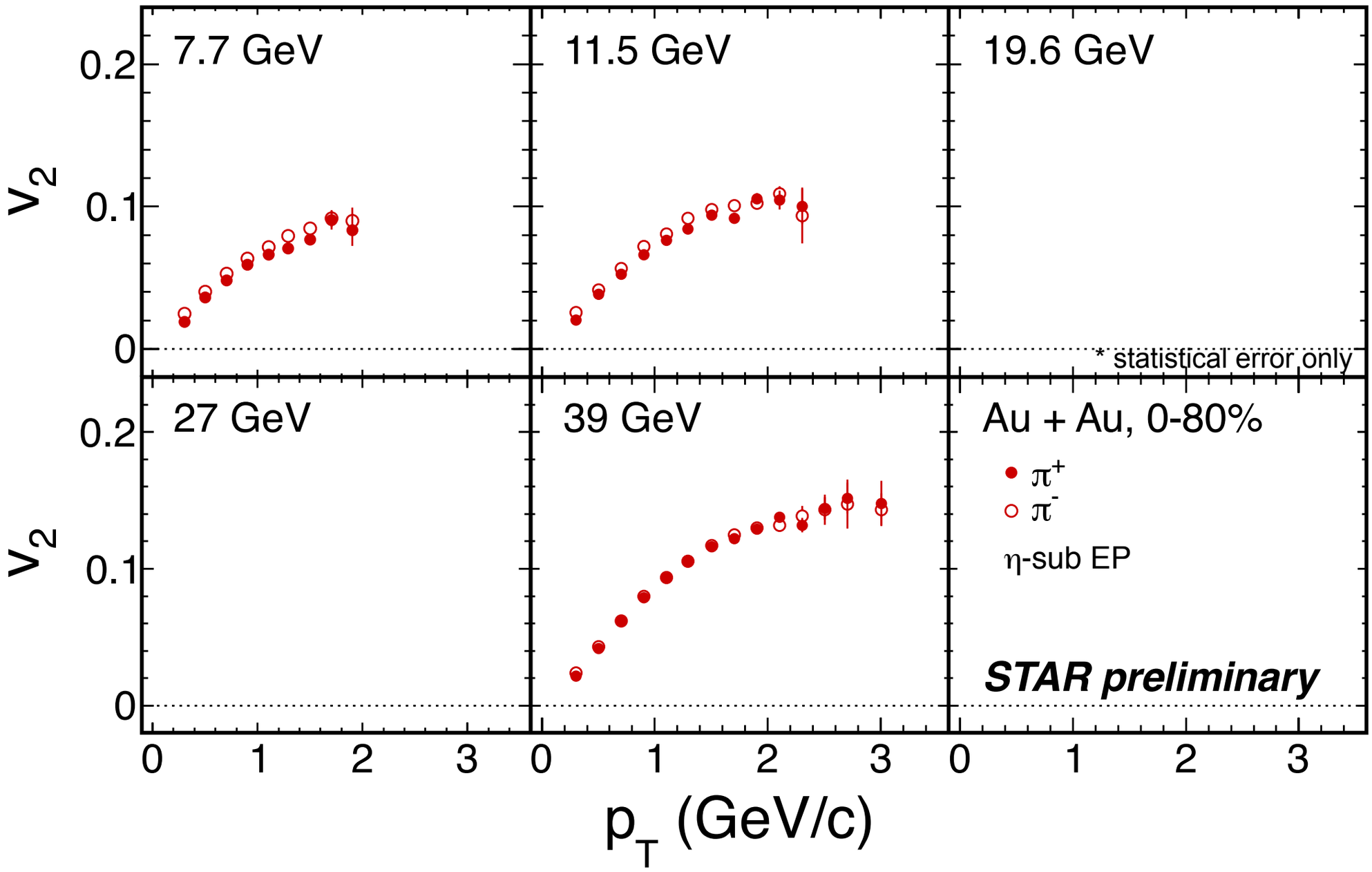
NCQ scaling





- Generally scales; small discrepancies at ~ 0.4 GeV/c^2

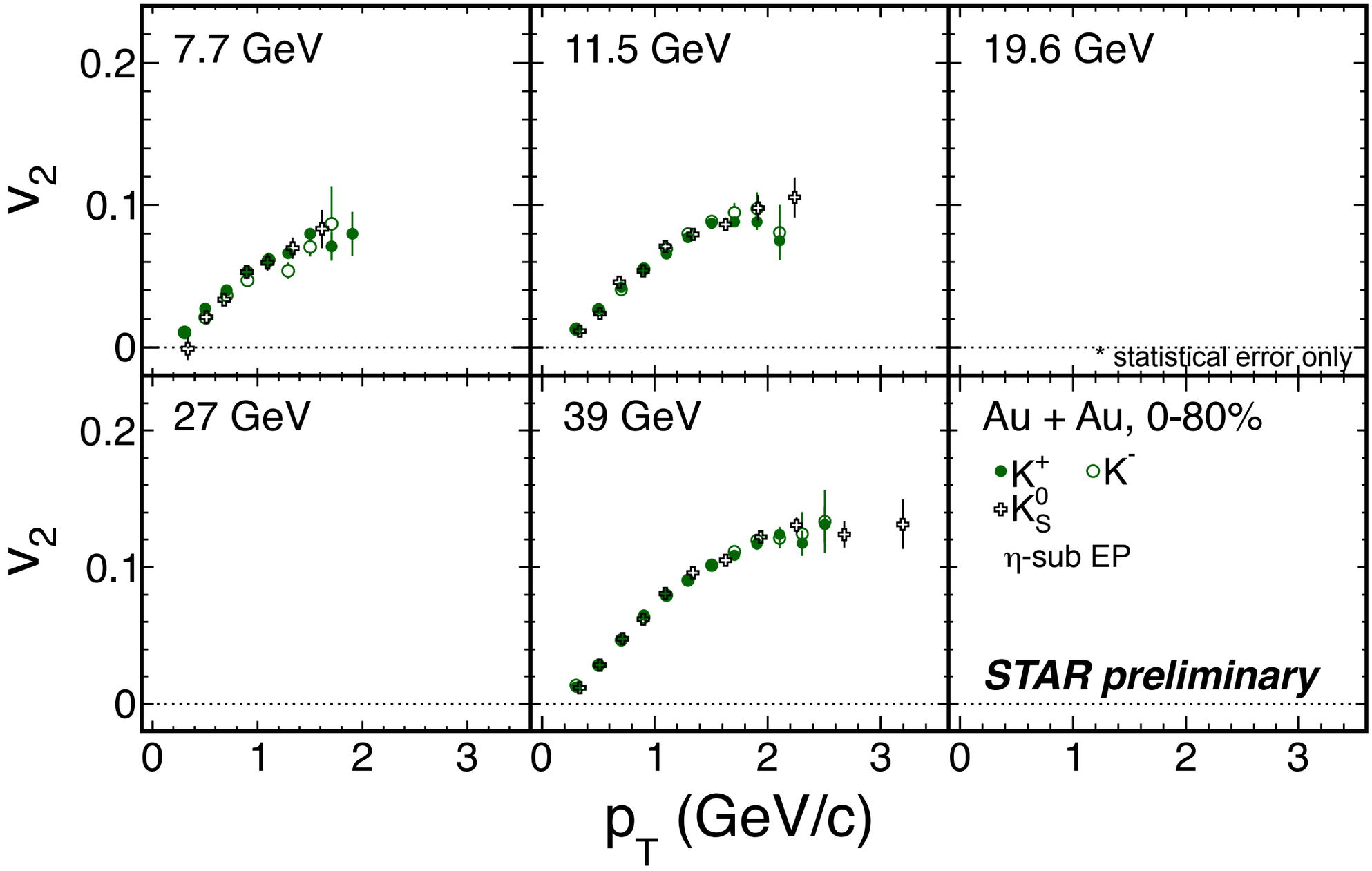
STAR identified hadrons



STAR
CPOD2011

- Difference of $v_2(p_T)$ between particle and anti-particles
  - Difference increases in lower energies

STAR identified hadrons



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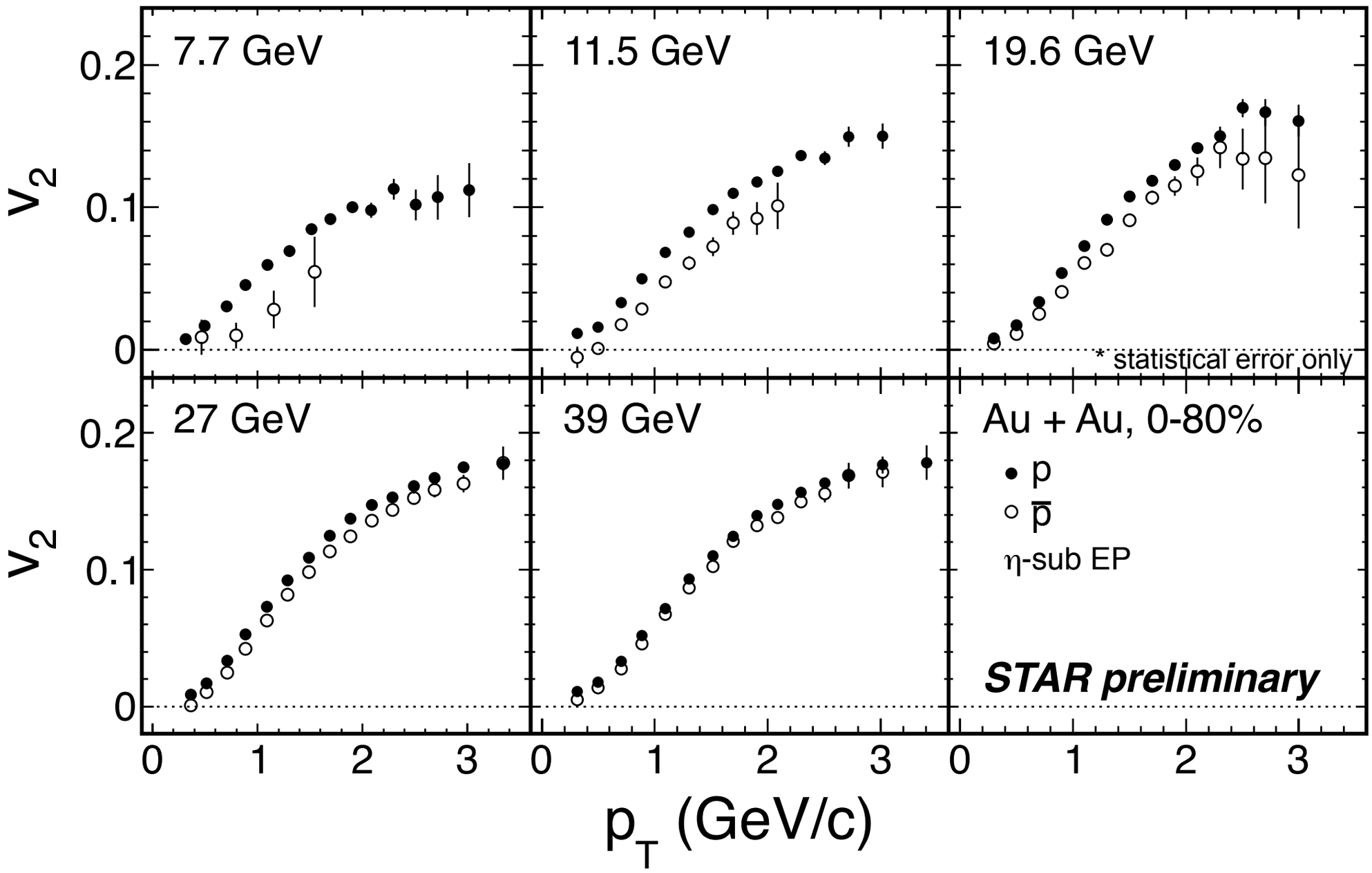

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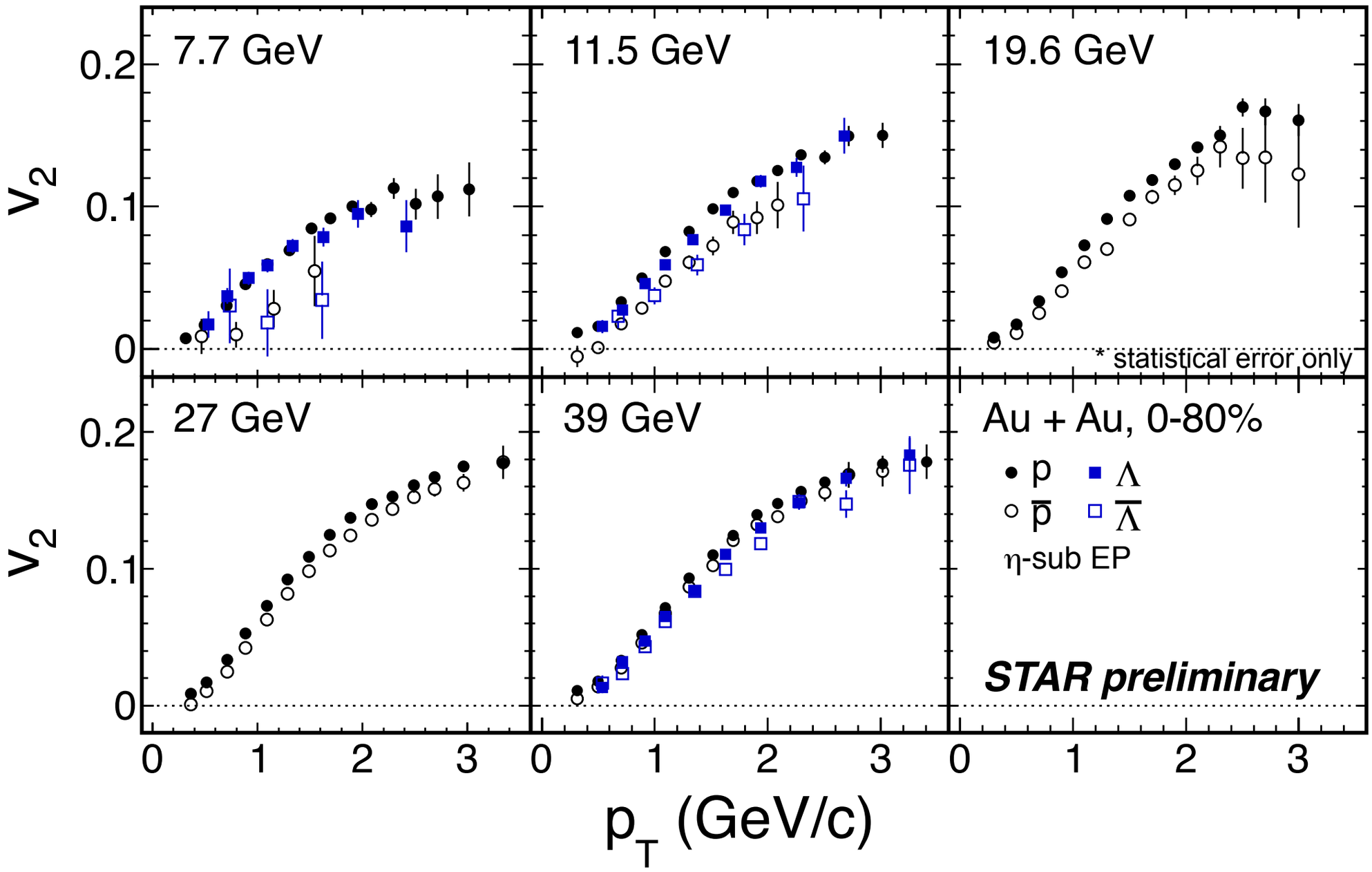

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CPOD2011

- Difference of $v_2(p_T)$ between particle and anti-particles
  - Difference increases in lower energies
  - Significant difference for baryons

Particles vs Anti-particles

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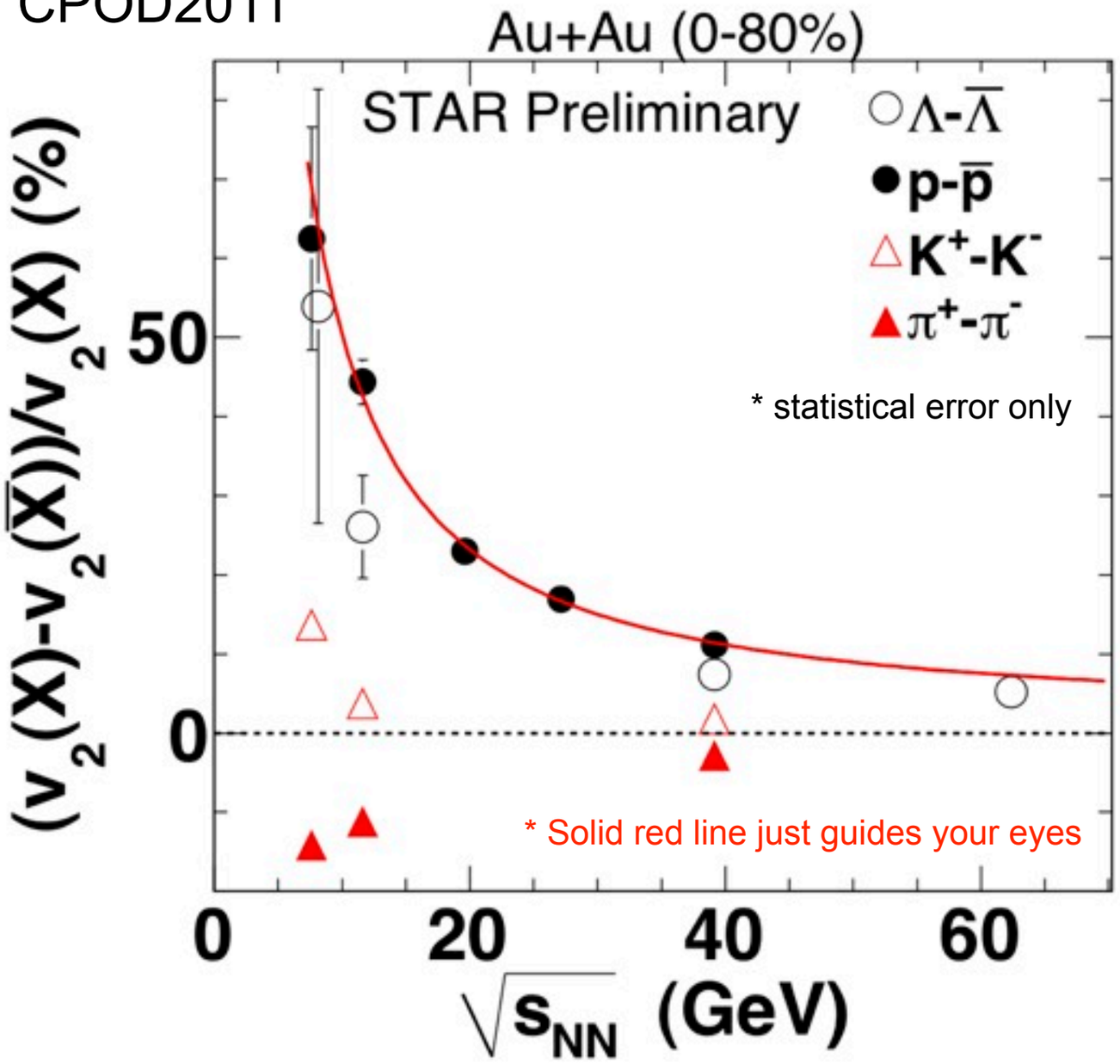
CPOD2011



Λ at 62.4 GeV: STAR ***PRC75***, 054906 (2007)

- v_2 is different between particles and anti-particles
  - Break down of NCQ scaling
- Relative difference increases with decreasing beam energy

➡ Dominance of hadronic phase ?

- Baryon transport* ?Hadronic potential** ? ...

** J. C. Dunlop et al., **PRC84**, 044914 (2011)*
*** J. Xu et al., arXiv:1201.3391 [nucl-th]*

ϕ meson v_2

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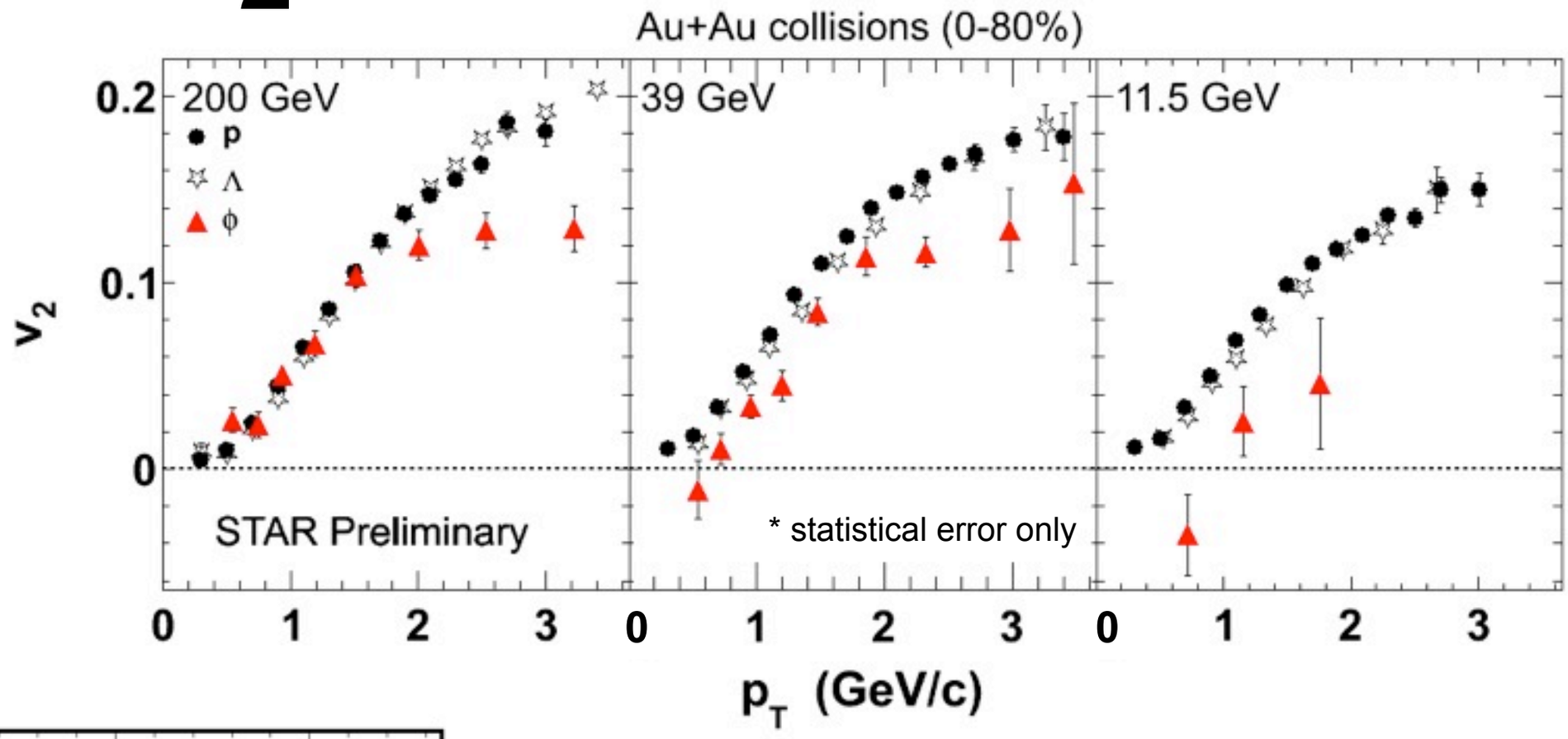
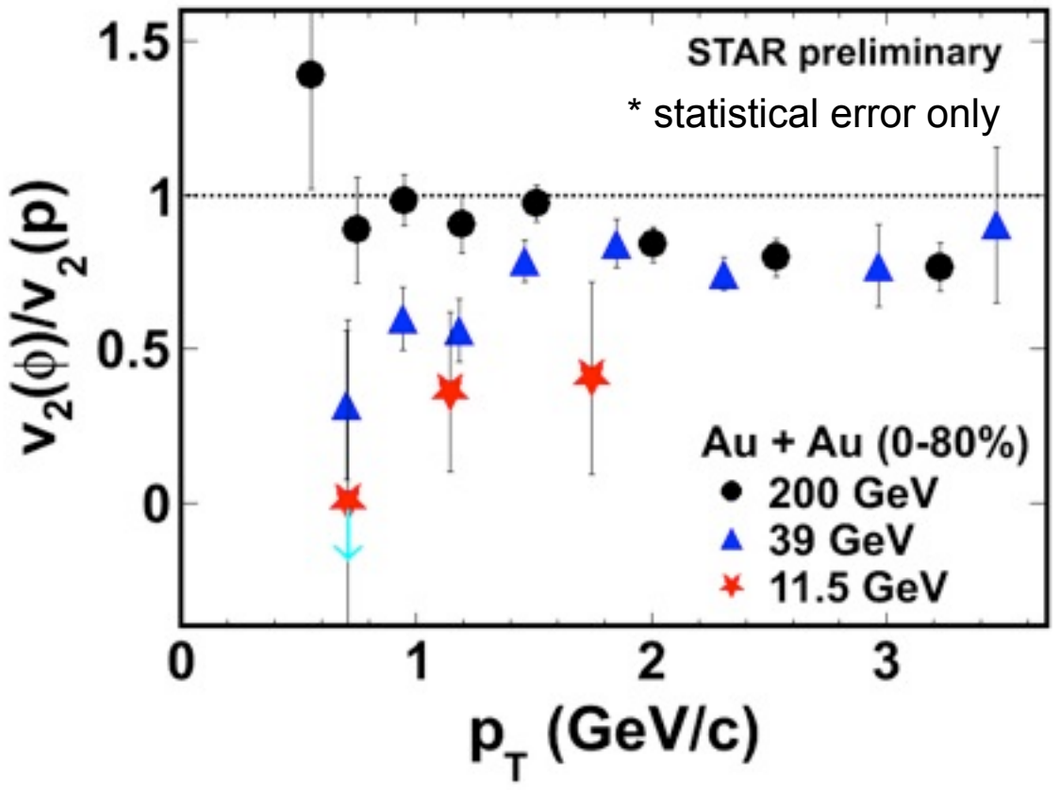
CPOD2011





- At low p_T, $v_2(\phi)/v_2(p)$ decreases with decreasing beam energies
  - small or zero v_2 for ϕ mesons predicted without partonic matter*

➡ Dominance of hadronic phase ?

** B. Mohanty and N. Xu, J. Phys. G**36**, 064022 (2009)*

Conclusions and outlook

- Charged hadrons
  - Consistent $v_2(p_T)$ from 7.7 GeV to 2.76 TeV for p_T > 2 GeV/c
  - 20-40% difference for p_T < 2 GeV/c → particle compositions ?

- Hadronic phase might be dominant at lower energies
  - Relative difference of v_2 between particles and anti-particles increase with decreasing the $\sqrt{s_{NN}}$

➡ NCQ scaling broken between particles and anti-particles

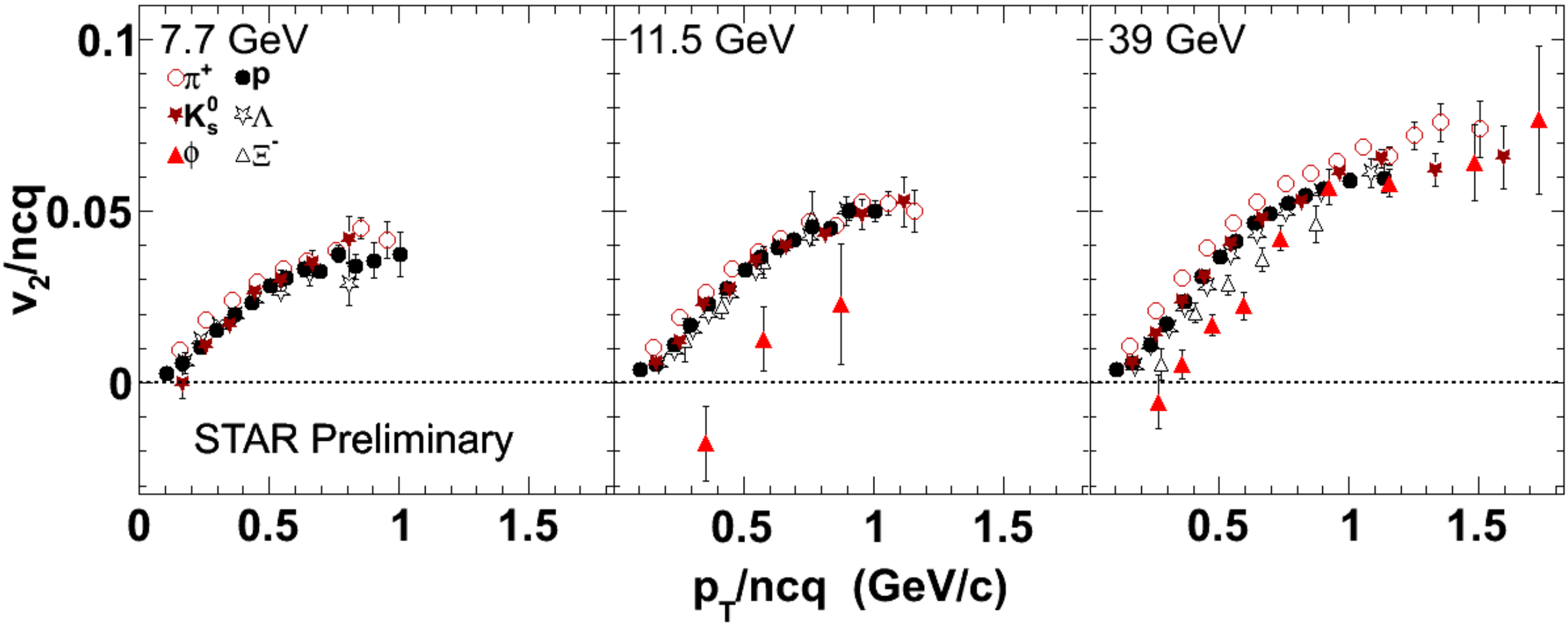
  - $v_2(\phi)/v_2(p)$ decreases with decreasing beam energies at low p_T

- Results at 19.6, 27 and 62.4 GeV are in preparation

Back up

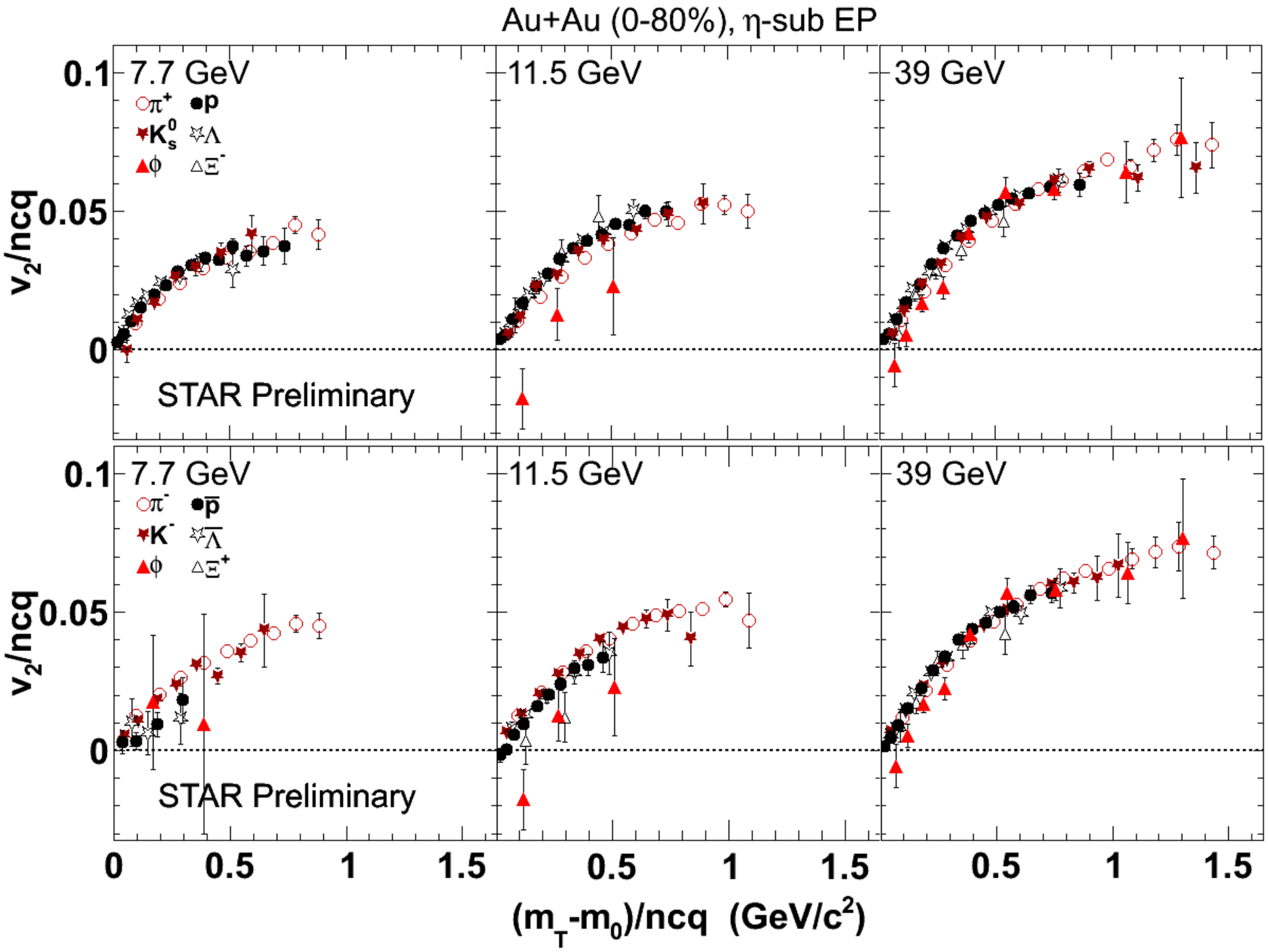
NCQ scaling test; $v_2(p_T)$

STAR
QM2011



- Result in p_T/n_{cq} > 1 GeV/c at 39 GeV looks similar to 200 GeV
- Only ϕ meson deviates from other hadrons. Rest of particles follow the scaling

Scaling test; $v_2(m_T-m_0)$ Particles vs anti-particles



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