Strangeness in STAR at RHIC

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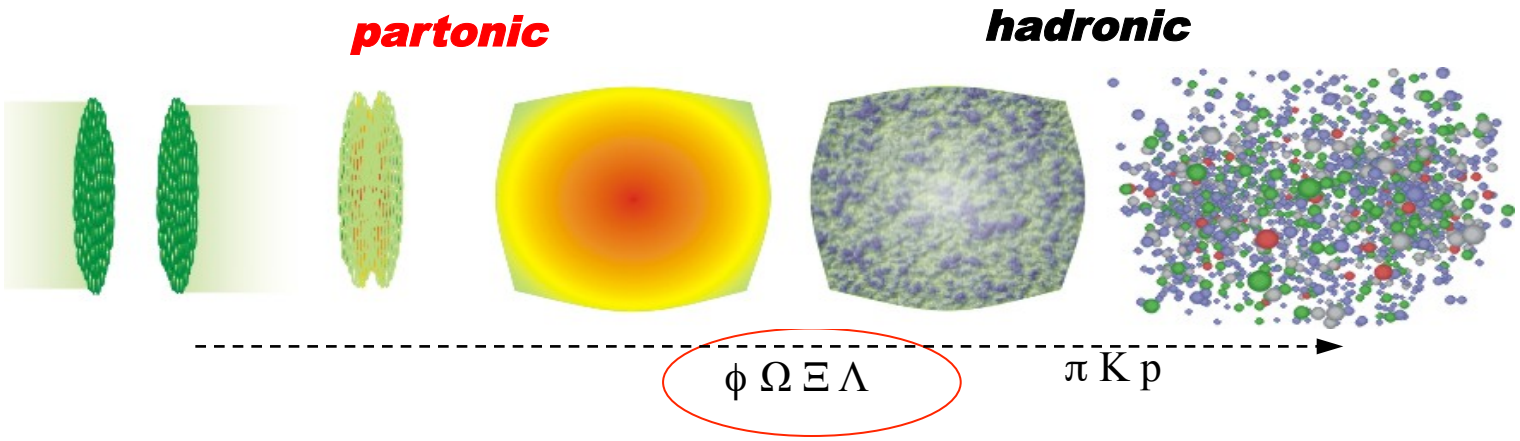
Outline

- Introduction
- Collectivity
  - Multi-strange hadron and ϕ meson v_2
  - Energy dependence of v_2
- Strangeness production
  - Nuclear modification factors R_{CP}
  - Baryon/meson ratio
- Summary

Strangeness



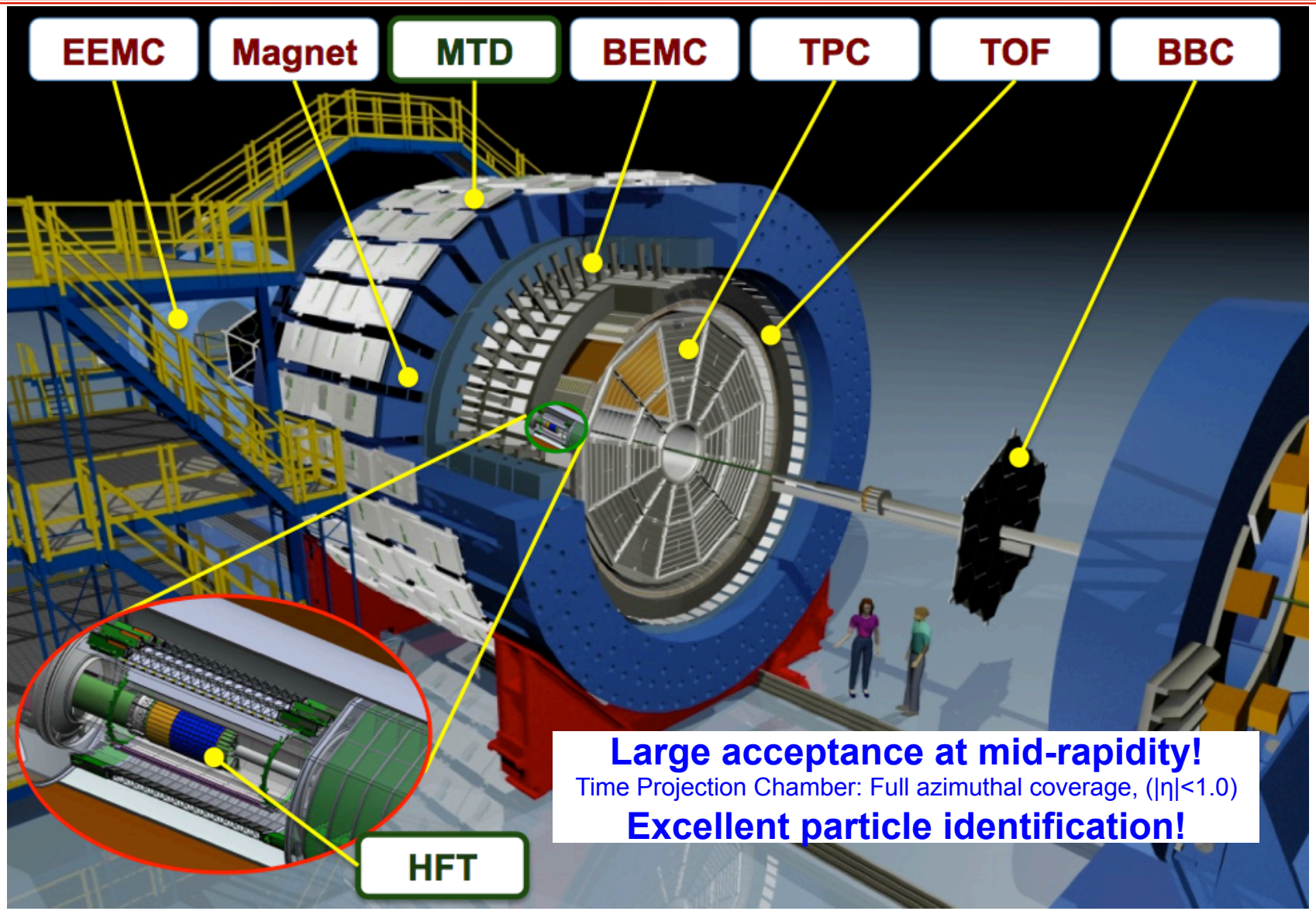
- **Strange, multi-strange hadrons and ϕ meson**
  Less sensitive to late hadronic interactions
- **Ω hyperons and ϕ meson**
  minimal distortion from decay feed-down

Good probe for QGP properties and QCD phase transition

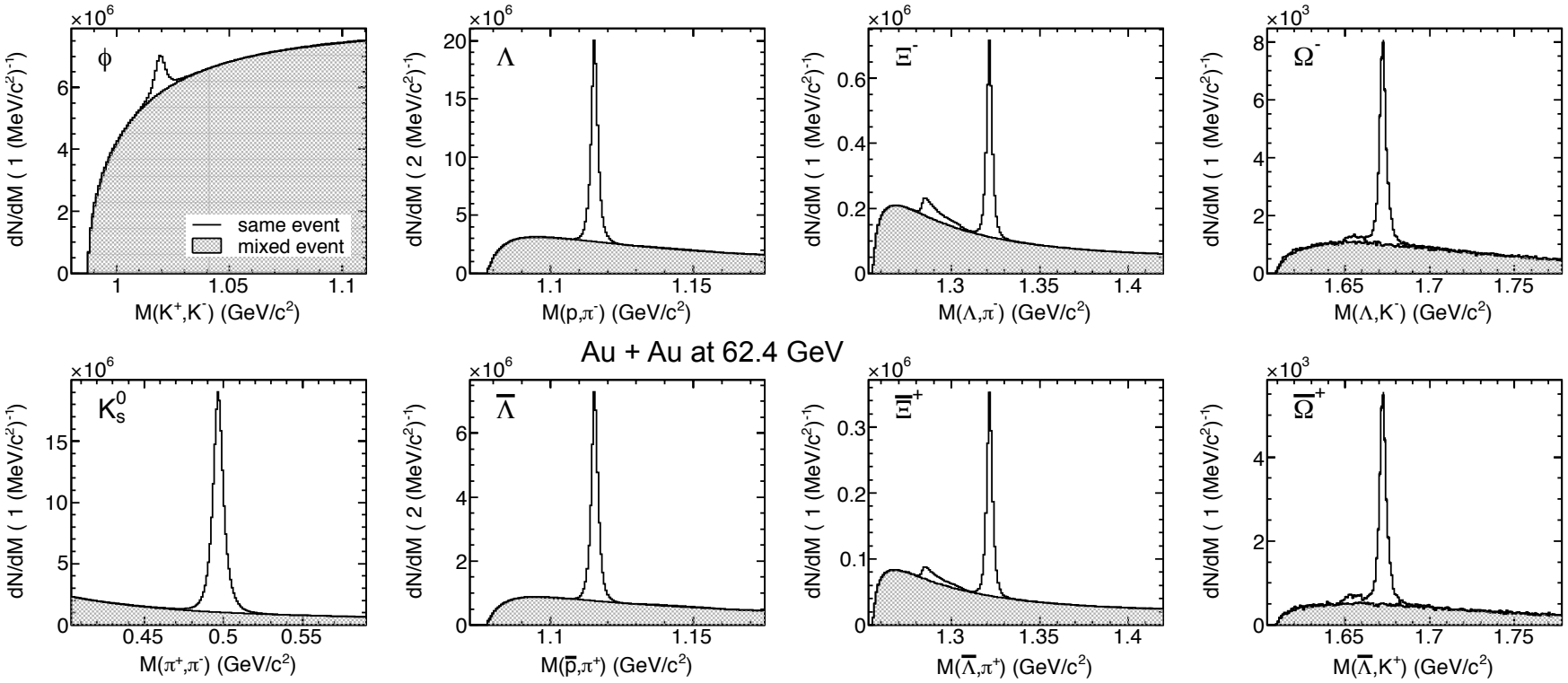
- ***Key observables***
- **Event anisotropy v_2**
  Collectivity
- **Nuclear modification factor**
  Partonic energy loss and recombination
- **Baryon/meson ratio**
  Parton recombination

STAR measurements at the beam energies of 7.7, 11.5, 14.5, 19.6, 27, 39, 62.4 and 200 GeV

STAR Detectors



Particle Identification

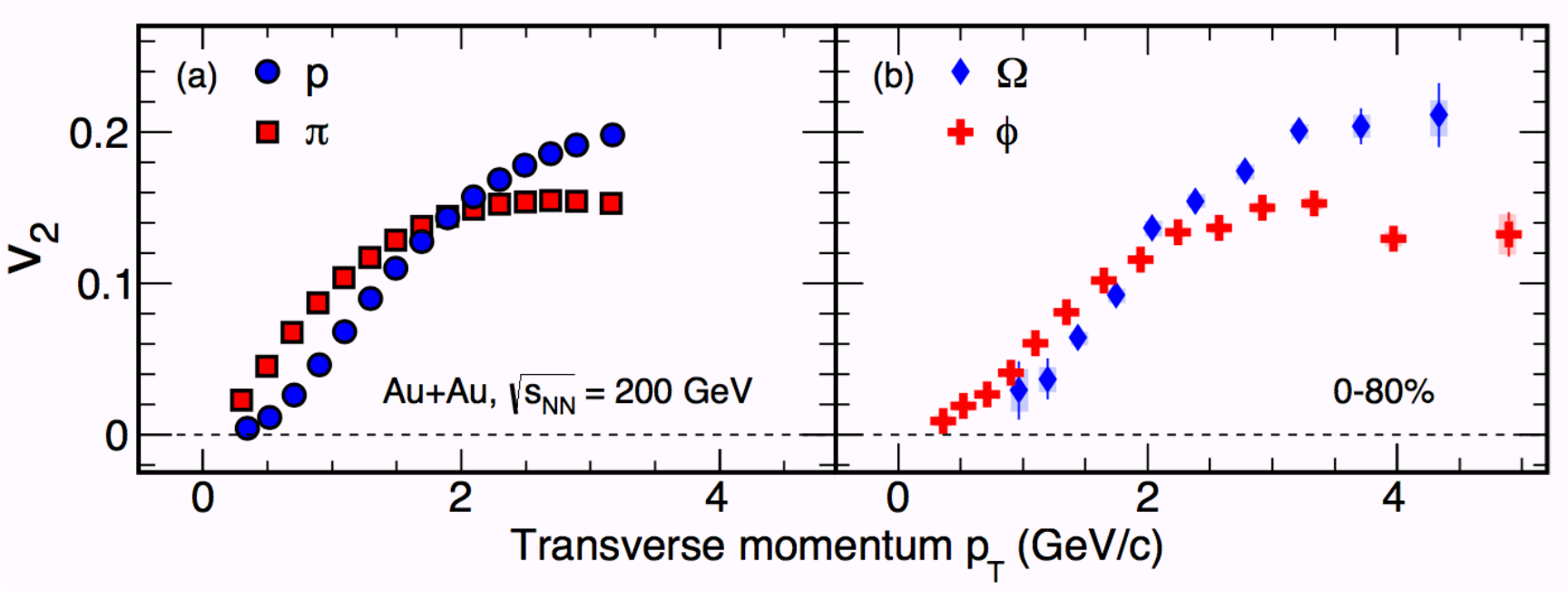


STAR: Phys. Rev. C 88, 014902 (2013)

- **Reconstruction techniques used**
- **ϕ mesons: invariant mass**
- **Weak decay particles (K_S^0, Λ, Ξ, Ω): secondary vertex + invariant mass**

Ω Baryon and ϕ Meson v_2

Ω and ϕ: good probes of early partonic stage of collision



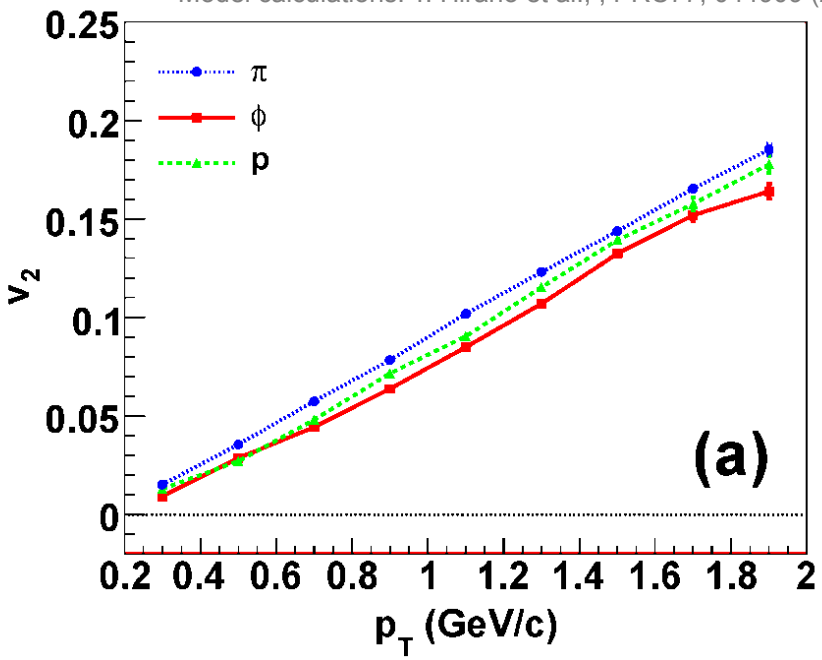
STAR: Phys. Rev. Lett.116, 062301 (2016)

- **Proton and pion v_2 compared with Ω baryon and ϕ meson v_2**
- **High precision data prove that Ω follows the baryon/meson splitting at intermediate p_T range, $2 < p_T < 5$ GeV/c . *First time!***

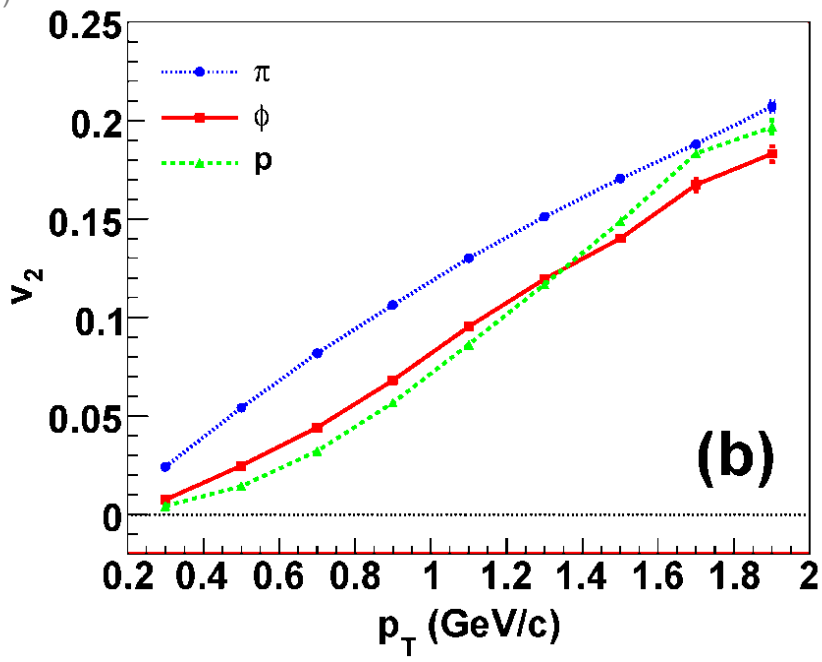
The major part of collectivity has been built-up at partonic stage!

$v_2(\phi)$ versus $v_2(p)$

Model calculations: T. Hirano et al., ; PRC77, 044909 (2008)



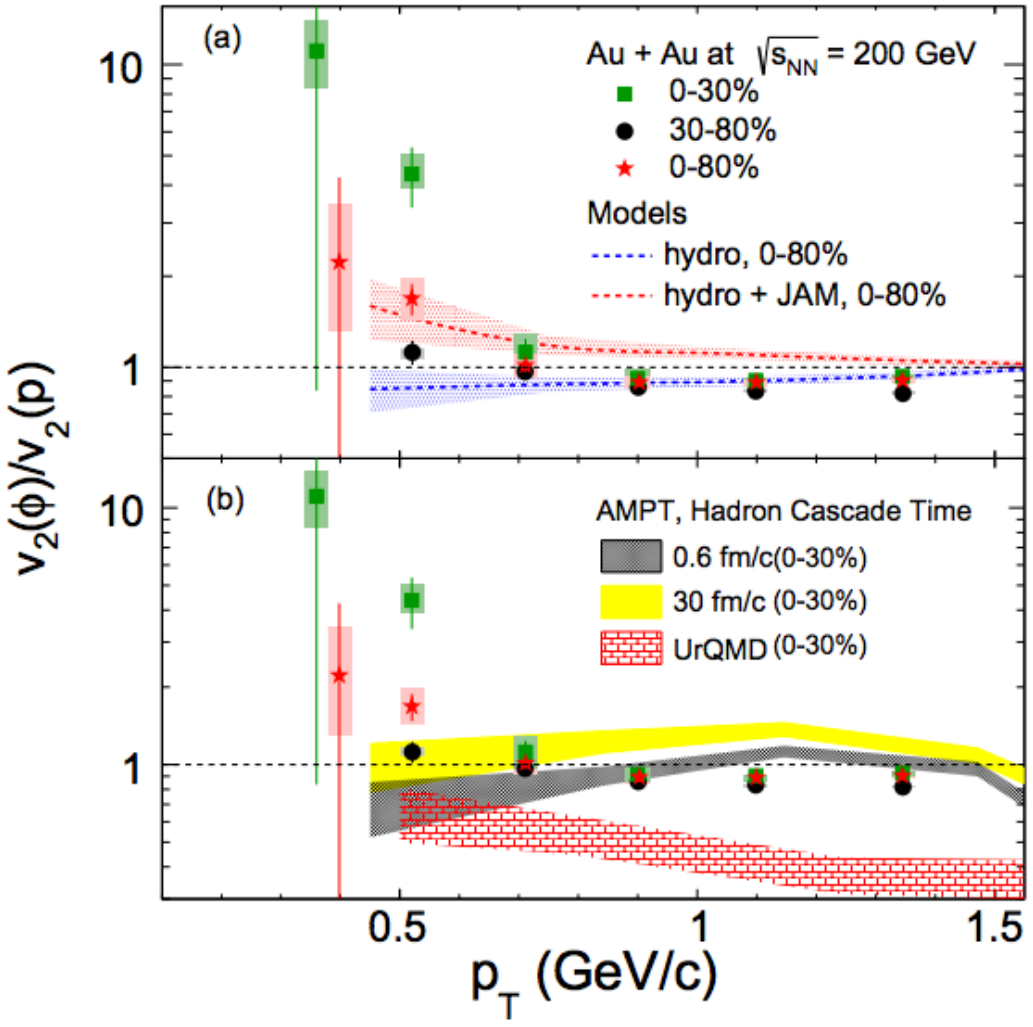
Before hadronic rescattering



After hadronic rescattering

- **Ideal hydro + hadron cascade (JAM)**
- **Small hadron cross section + hadronic rescattering effect on v_2**
  Mass ϕ > mass p ➔ $v_2(\phi) > v_2(p)$
  ➔ ***Break mass ordering for ϕ mesons and protons***

$v_2(\phi)$ versus $v_2(p)$



- **Model study indicates with increasing hadronic cascade time (more hadronic re-scattering), the $v_2(\phi)/v_2(p)$ ratio increases**

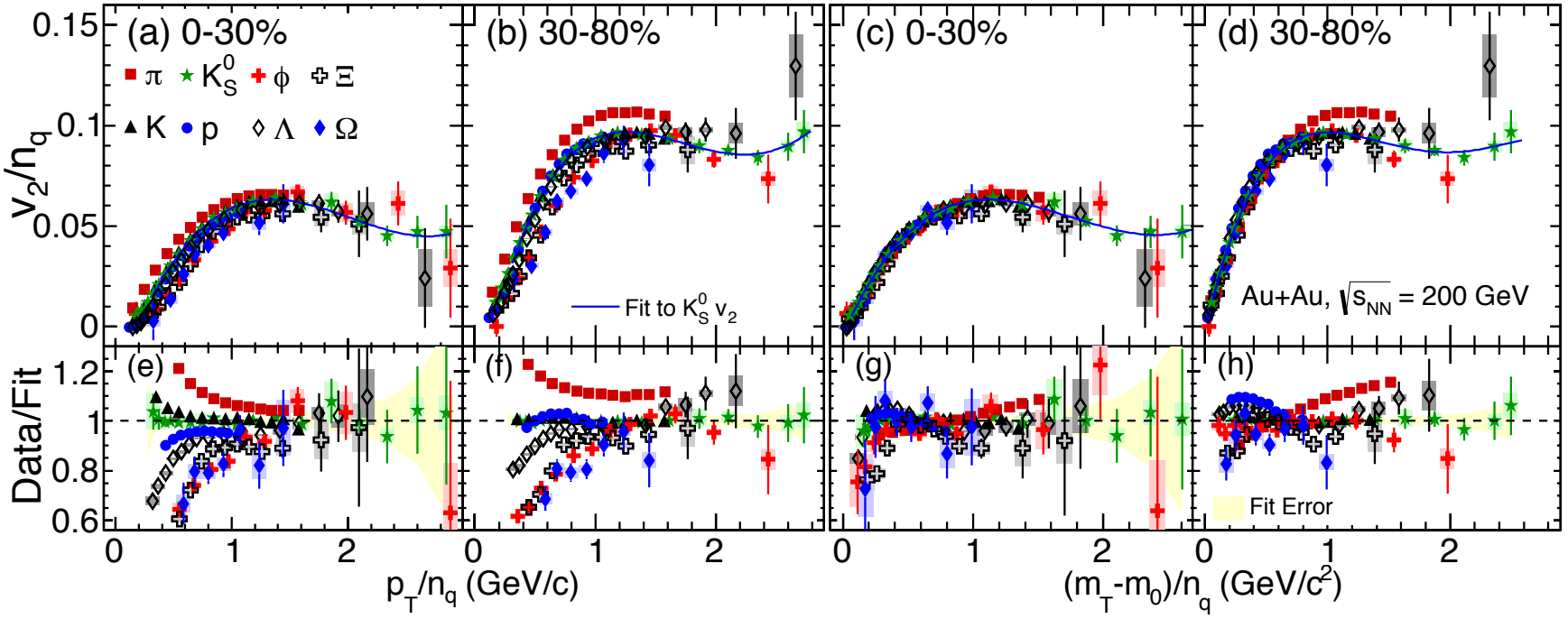
- **The ratio $v_2(\phi)/v_2(p)$ Is $4.35 \pm 0.98 \pm^{0.66}_{0.45}$ at p_T = 0.52 GeV/c in 0-30% ->**

Possibly due to the effect of late hadronic interactions on the proton v_2

STAR: Phys. Rev. Lett.116, 062301 (2016)
Model calculations: T. Hirano et al., ; PRC77, 044909 (2008)

NCQ Scaling - RHIC

Number of Constituent Quark Scaling



STAR: Phys. Rev. Lett.116, 062301 (2016)
ALICE: JHEP06(2015)190

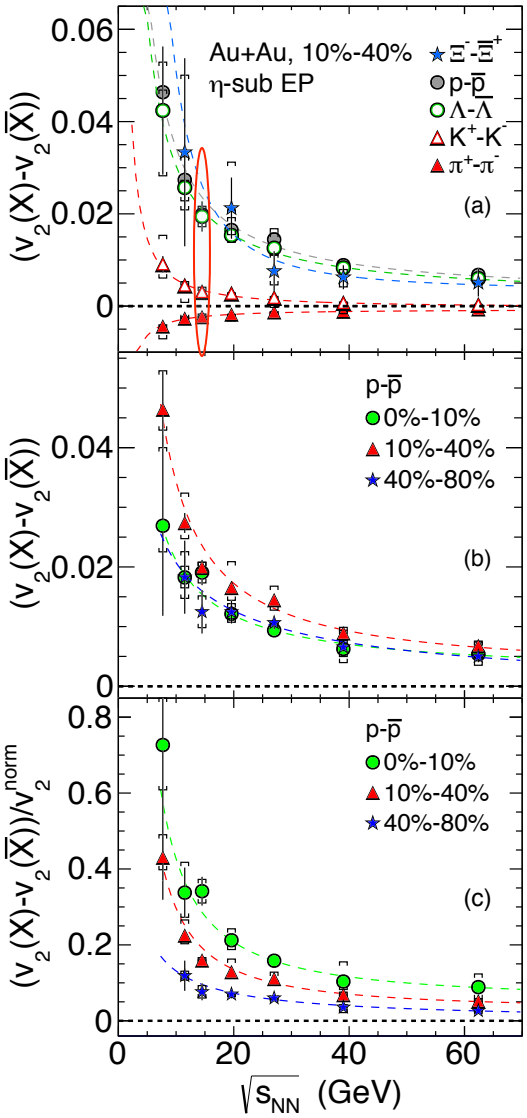
TABLE I. Deviation from the K^0_S fit line in the range $(m_T - m_0)/n_q > 0.8$ GeV/c^2 for 0-30% and 30-80% centrality.

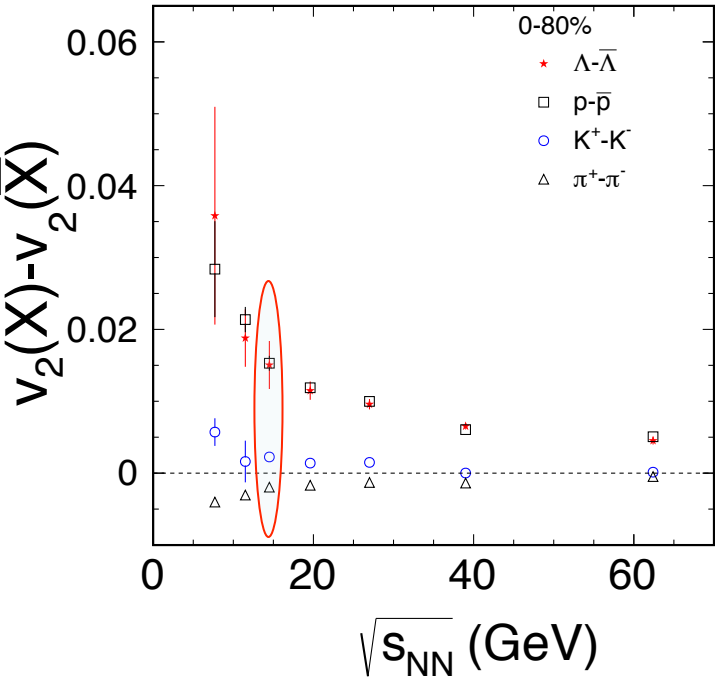
Particle	Deviation	
	0-30% centrality	30-80% centrality
ϕ	2.7±2.6(stat.)±1.8(sys.)%	1.2±1.3(stat.)±0.6(sys.)%
Λ	4.3±0.8(stat.)±0.2(sys.)%	1.5±0.7(stat.)±0.2(sys.)%
Ξ	11.3±2.3(stat.)±1.4(sys.)%	8.5±2.0(stat.)±0.5(sys.)%
Ω	10.1±8.4(stat.)±5.3(sys.)%	7.0±6.0(stat.)±1.5(sys.)%

RHIC: NCQ scaling holds within 10%

- LHC: The deviation from the NCQ scaling at the level of +/-20%
- Coalescence is the dominant hadronization mechanism at RHIC in the intermediate p_T range

Particle vs. Anti-particle v_2

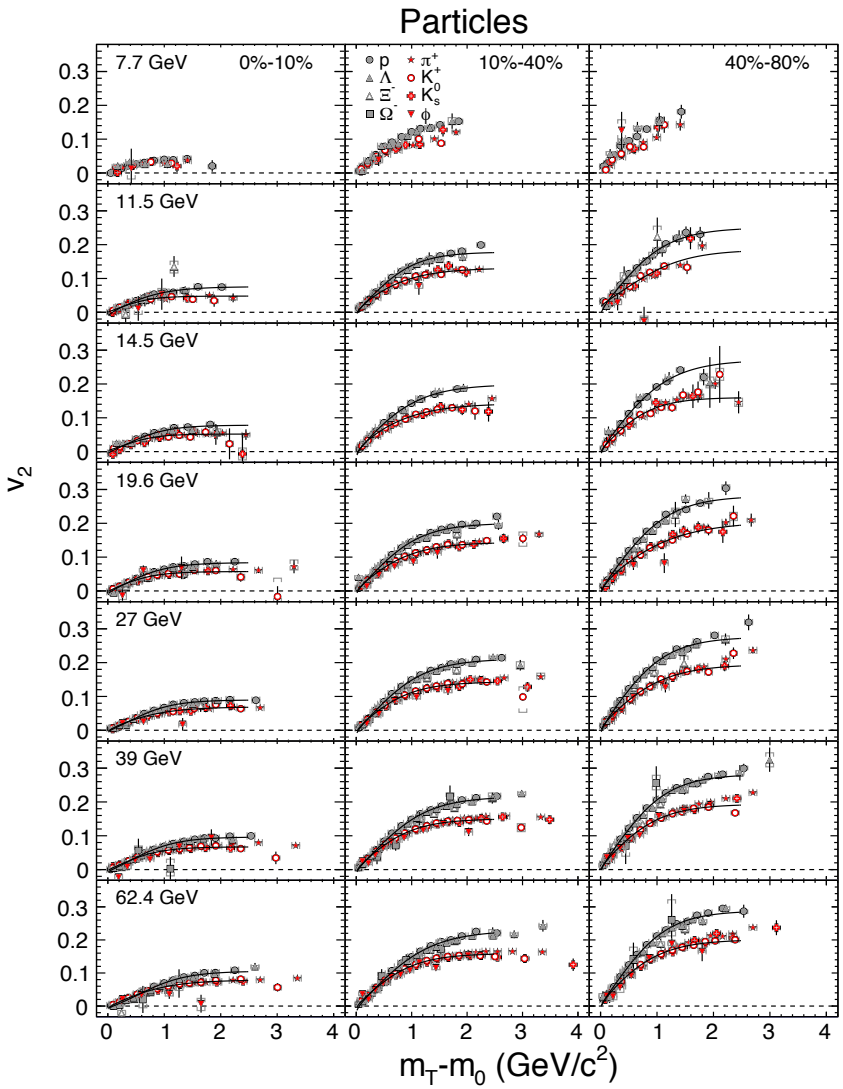




STAR: Phys. Rev. C 93, 014907(2016)

- **Significant difference of baryon and anti-baryon v_2 observed**
- **New data from 14.5 GeV fit the energy dependency curve**

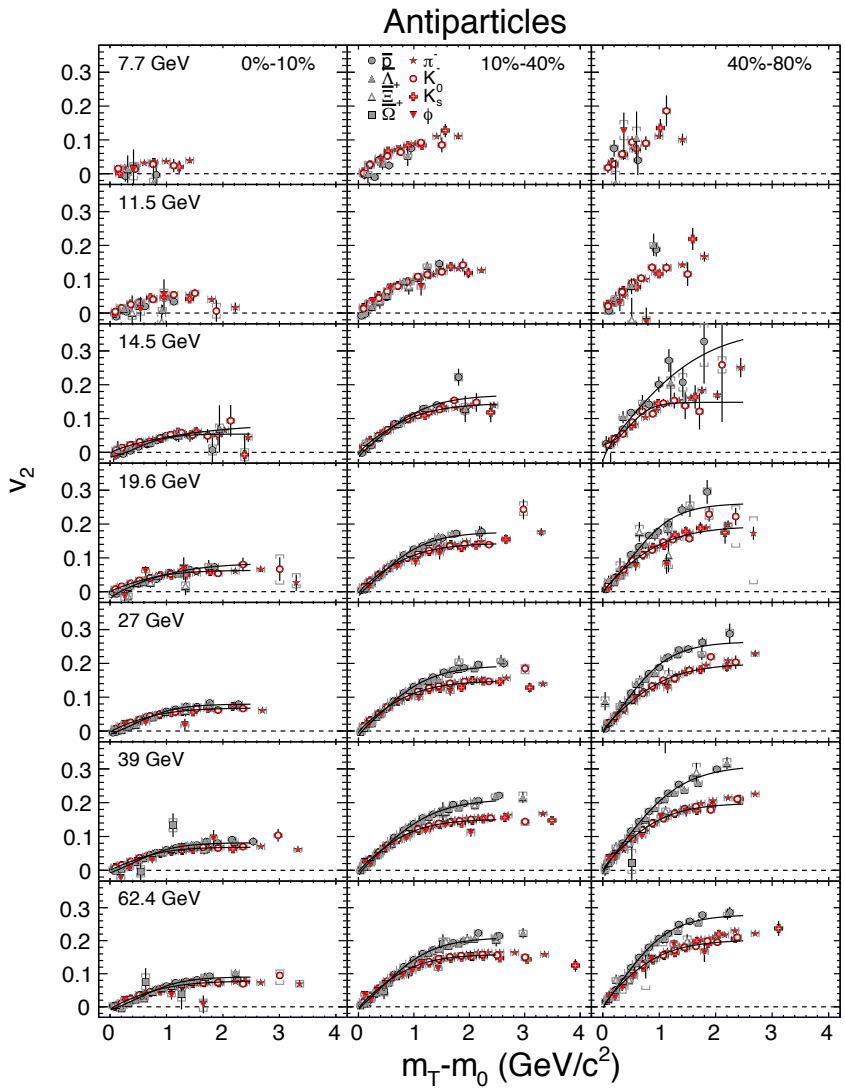
Baryon/Meson Separation



- **A splitting between baryons and mesons is observed at all energies except 7.7 GeV and all centralities.**
- **At 7.7 GeV we are limited by the number of events.**

STAR: Phys. Rev. C 93, 014907(2016)

Baryon/Meson Separation



- **The splitting between baryons and mesons is observed for all energies above 14.5 GeV and also at 14.5 GeV for 40–80%.**
- **For these energies below 11.5 GeV, we are limited by the number of events.**

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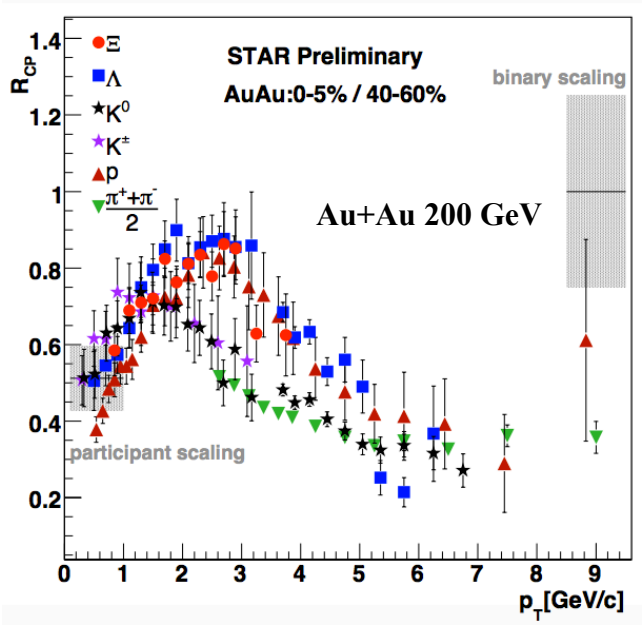
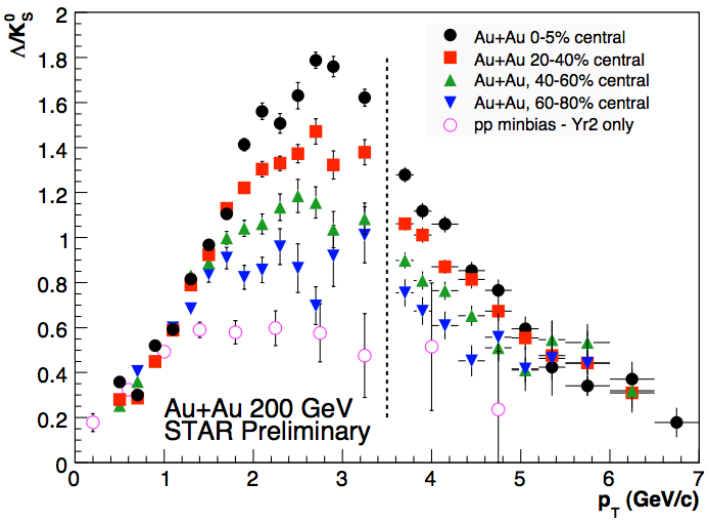
Strangeness Production





- Nuclear modification factors at Au+Au 200 GeV
  - Less than unity at high p_T
  - Baryon/meson follow different trends

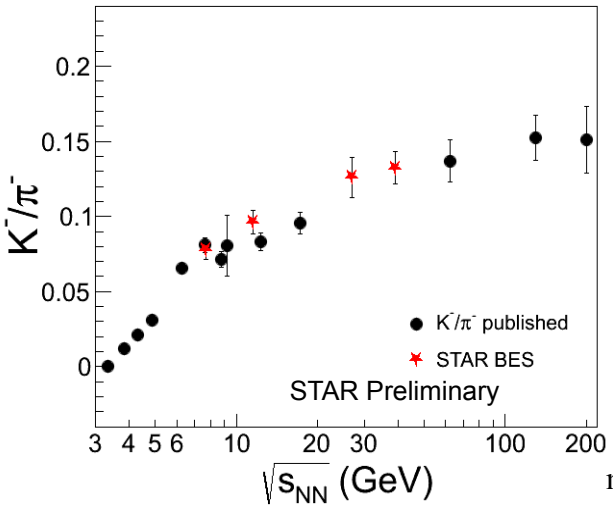
  -> Partonic energy loss and recombination
- Baryon/meson ratio at Au+Au 200 GeV
  - Baryon enhancement at intermediate p_T in central collisions

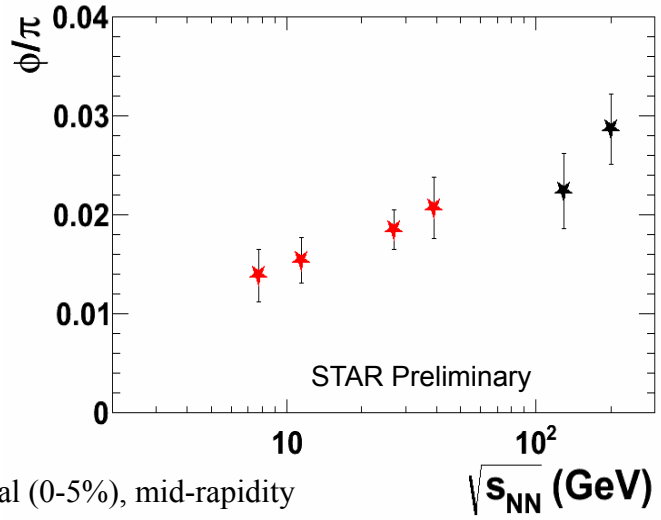
  -> Parton recombination

Strangeness is sensitive probe

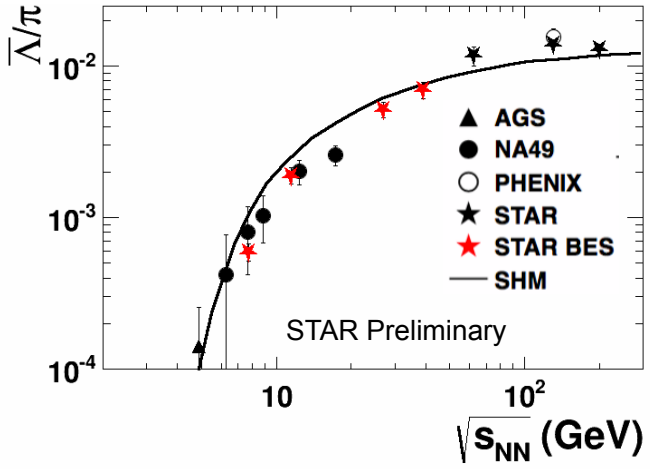
STAR: arXiv:1007.2613

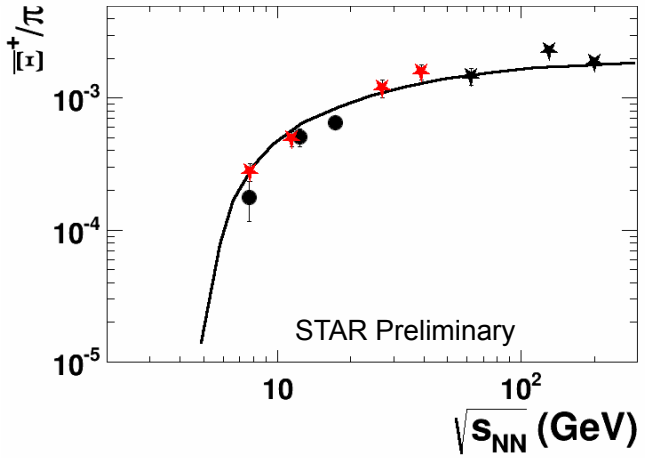
Strangeness Enhancement





most central (0-5%), mid-rapidity

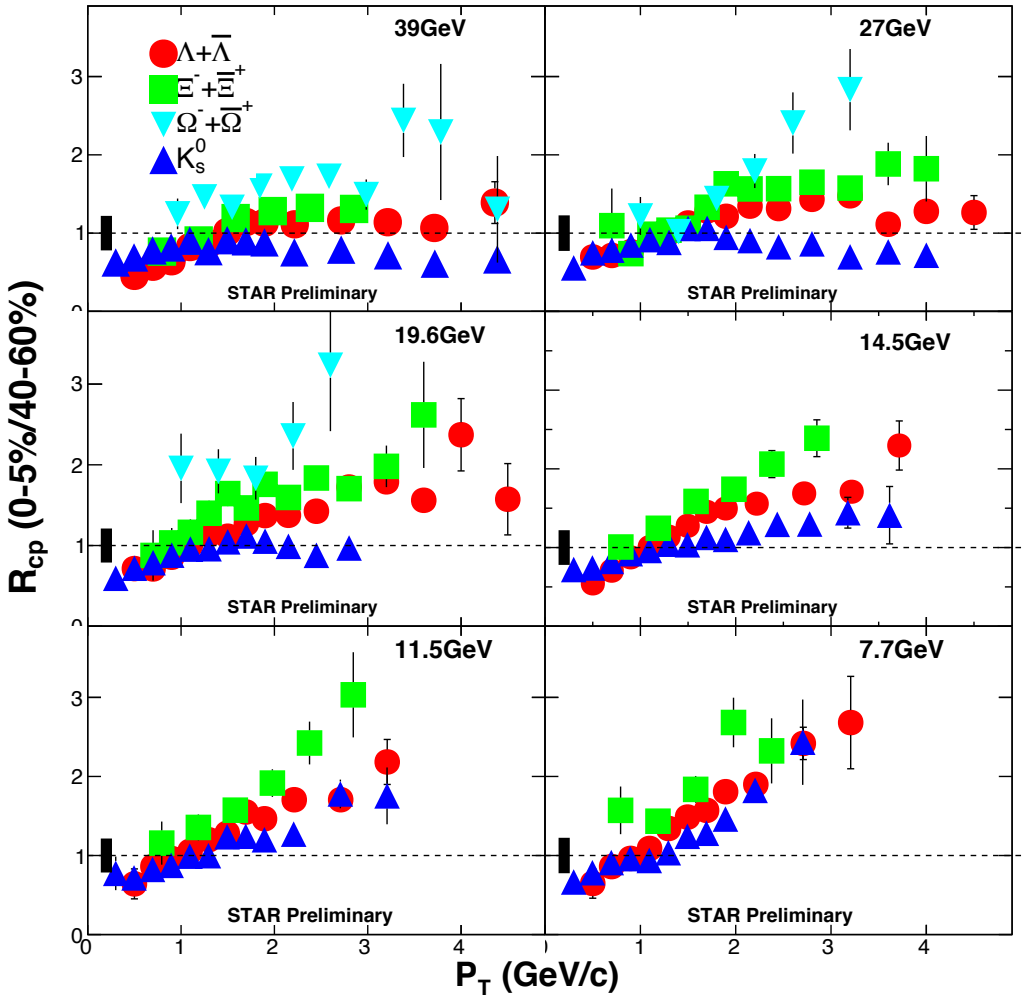




Statistical Hadron gas Model: A. Andronic et al., Nucl. Phys. A 772, 167 (2006)

- K^-, anti-Λ, anti-Ξ and ϕ yields increase significantly with respect to the pion yield as the beam energy increases

Nuclear Modification Factors

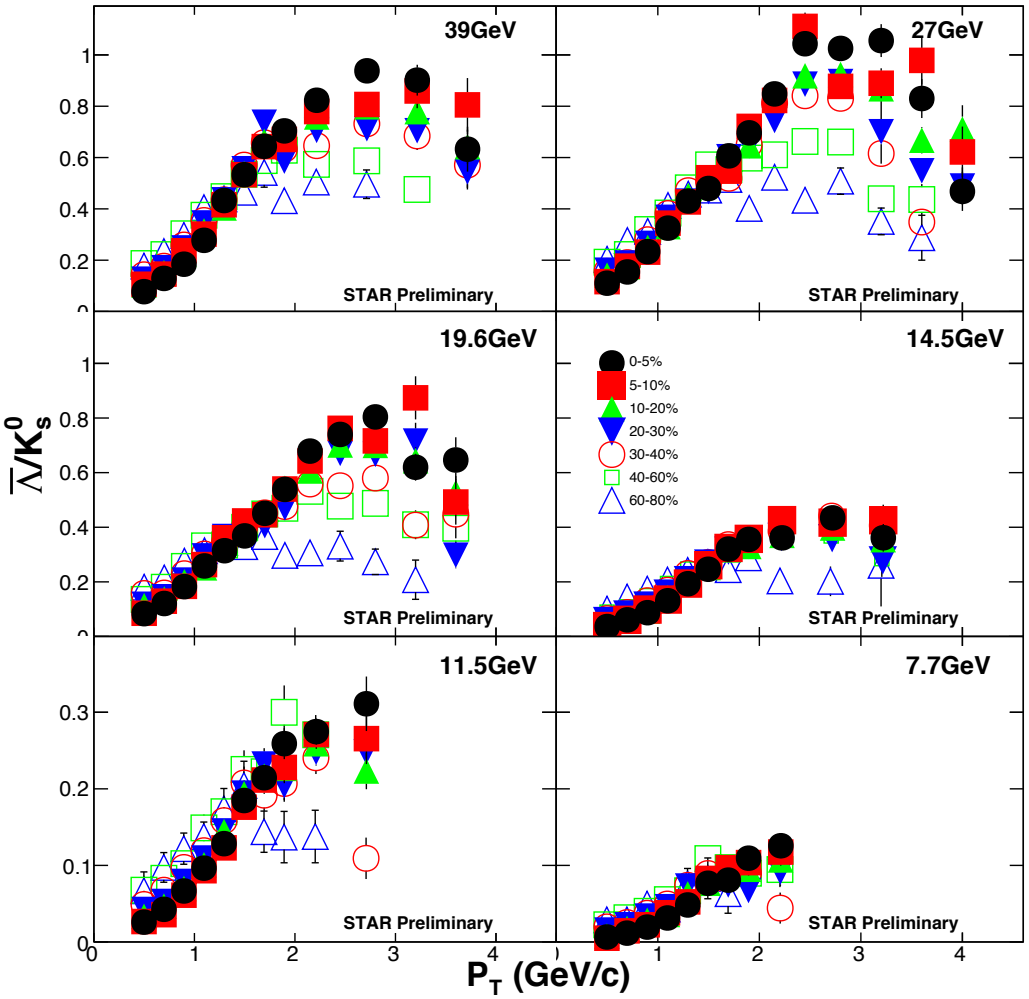


- K_S^0 R_{CP} increases with decreasing beam energies ->
  the partonic energy loss effect less important in lower beam energy
- The cold nuclear matter effect (Cronin effect) starts to take over at lower energies
- R_{CP} differences of particles becomes smaller at $\sqrt{s_{NN}} \leq$ 14.5 GeV -> indication of different properties of the system compared higher energies

$$R_{\mathrm{CP}}(p_T) = \frac{[d^2\sigma/(N_{\mathrm{bin}} p_T dp_T dy)]_{\mathrm{central}}}{[d^2\sigma/(N_{\mathrm{bin}} p_T dp_T dy)]_{\mathrm{peripheral}}}$$

Nuclear modification factor: partonic energy loss and recombination

$\overline{\Lambda}/K_S^0$ Ratio



- The separation of central (0-5%) and peripheral (40-60%) collisions in the ratio less obvious when collision energy ≤ 14.5 GeV: less baryon enhancement

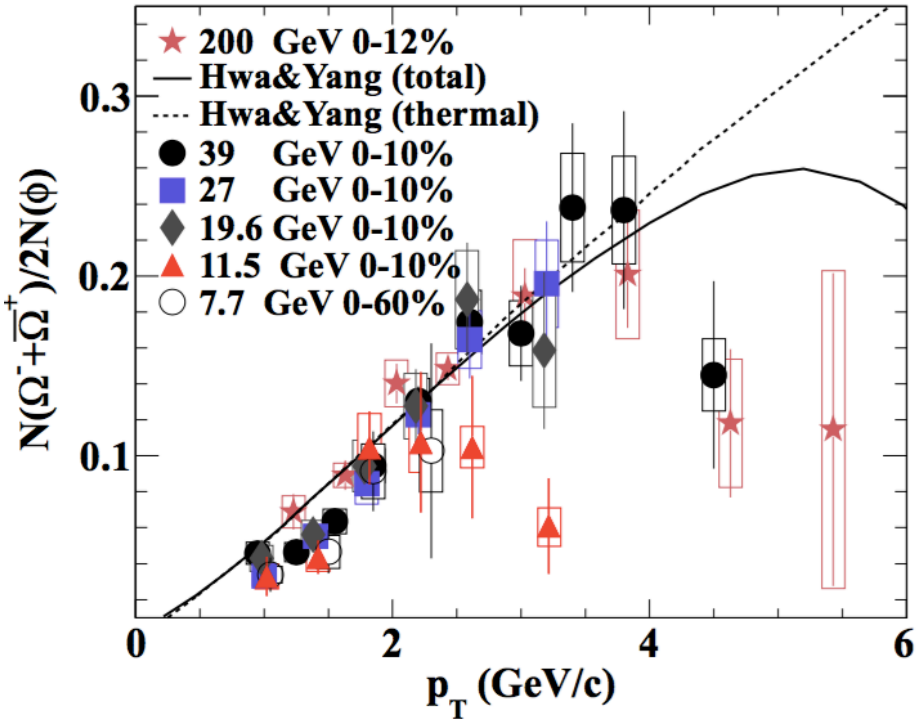
  ->

  possible change of medium property

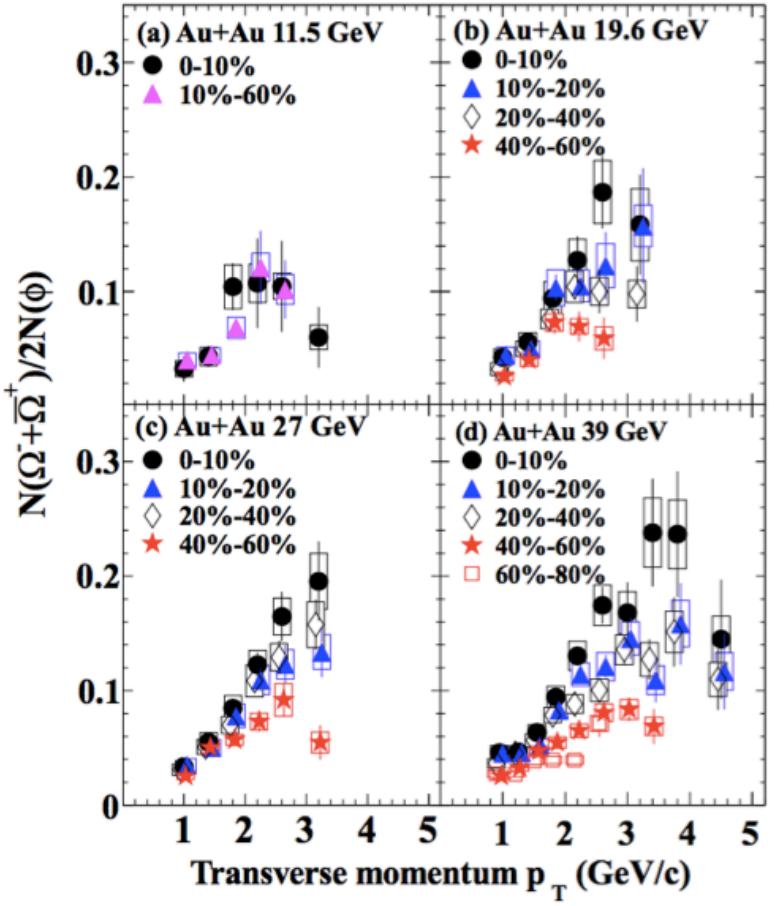
- Need more statistics at lower beam energies

Enhancement of baryon at intermediate pT in central collisions: parton recombination

Ω/ϕ Ratio

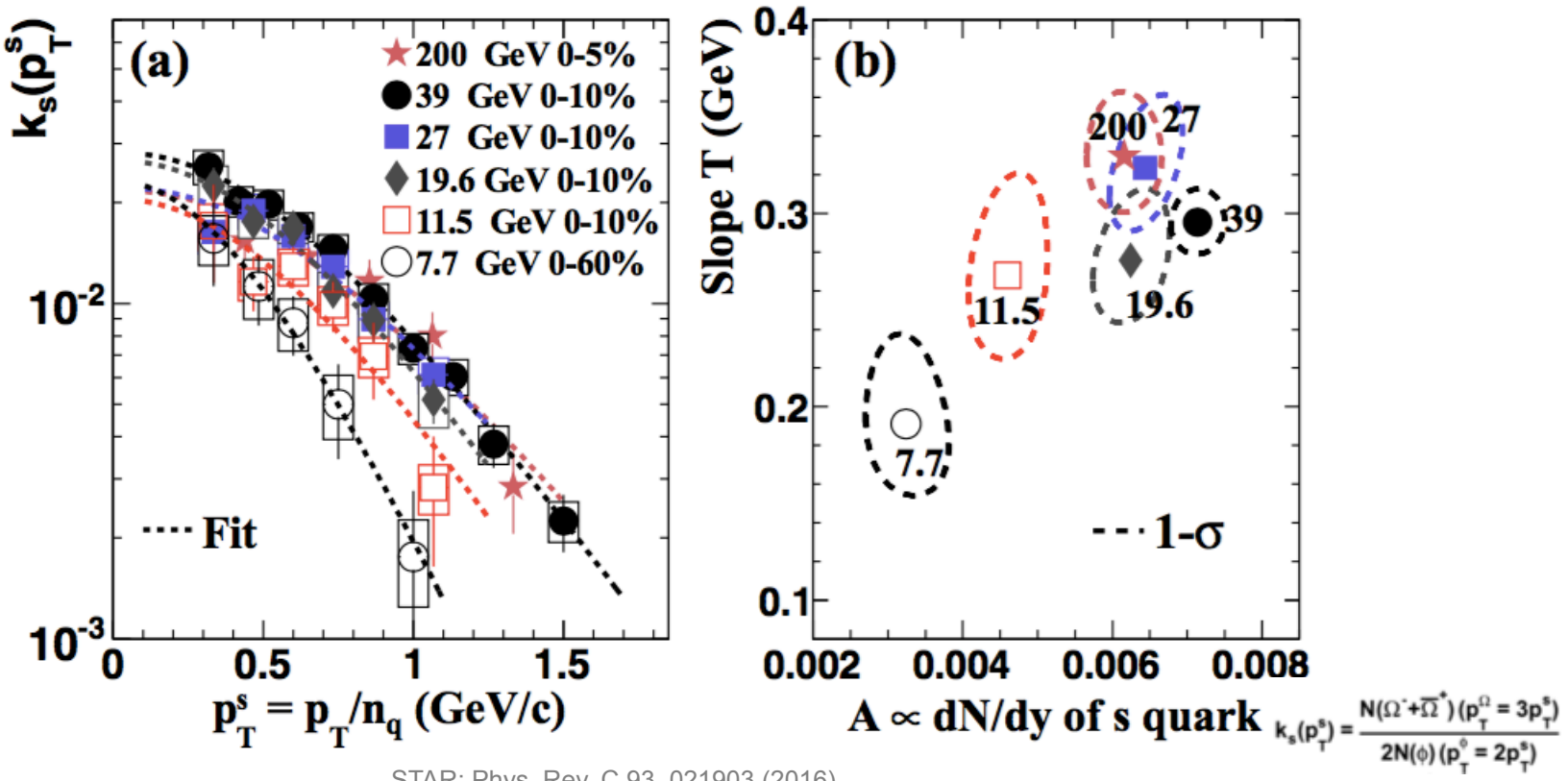


STAR: Phys. Rev. C 93, 021903 (2016)



- The ratios at 11.5 GeV seem to *deviate* from the trend observed at higher beam energies for p_T > 2.4 GeV/c
- 40%-60% peripheral < 0-10% central for 19.6, 27 and 39 GeV
- Need more statistics at lower beam energies

NCQ Scaled Ω/ϕ Ratio



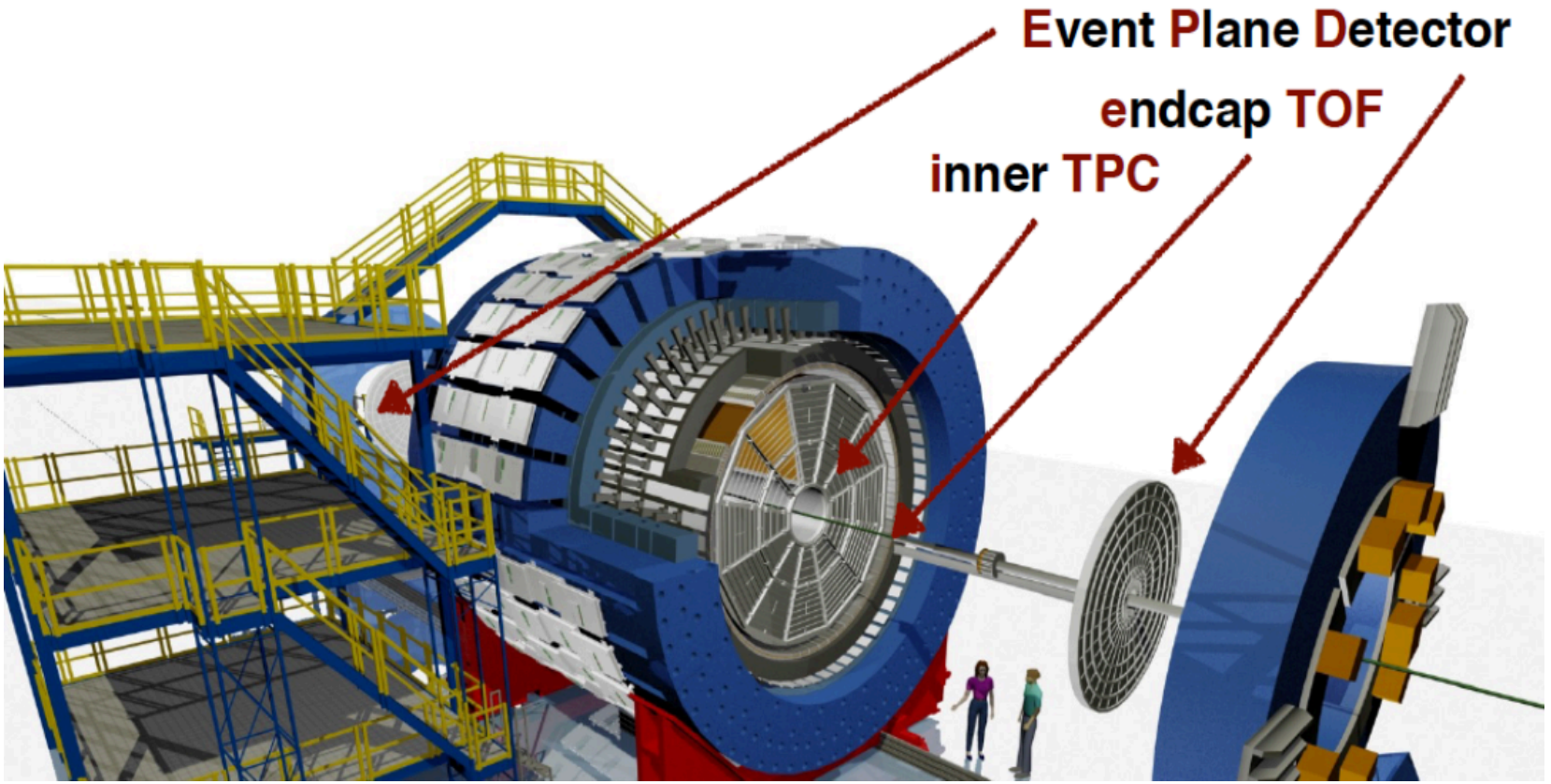
STAR: Phys. Rev. C 93, 021903 (2016)

- One single strange quark distribution describes both Ω and ϕ spectra-> quark coalescence production
- Slope (T) from Boltzmann fit changes at 7.7 GeV. *Centrality difference?*
- Decreasing *s* quark density below 19.6 GeV -> *Possible phase transition*

Summary

- **Multi-strange hadrons and ϕ meson v_2 ->**
  Partonic collectivity and coalescence hadronization
  ϕ mesons less sensitive to hadronic interactions
- **Energy dependence of v_2 ->**
  Further experimental investigations needed
- **R_{CP} increases with decreasing beam energies ->**
  Partonic energy loss effect less important
- **The separation of central/peripheral $\bar{\Lambda}/K_S^0$ less obvious below 19.6 GeV ->**
  Possible change of medium property
- **Decreasing s quark density below 19.6 GeV ->**
  Possible phase transition

Beam Energy Scan II



iTPC upgrade:

$-1 < \eta < 1$ ➡ $-1.5 < \eta < 1.5$;

p_T >125 MeV ➡ p_T > 60 MeV/*c*.

EPD upgrade:

Greatly improved Event Plane info; Alternative centrality definition

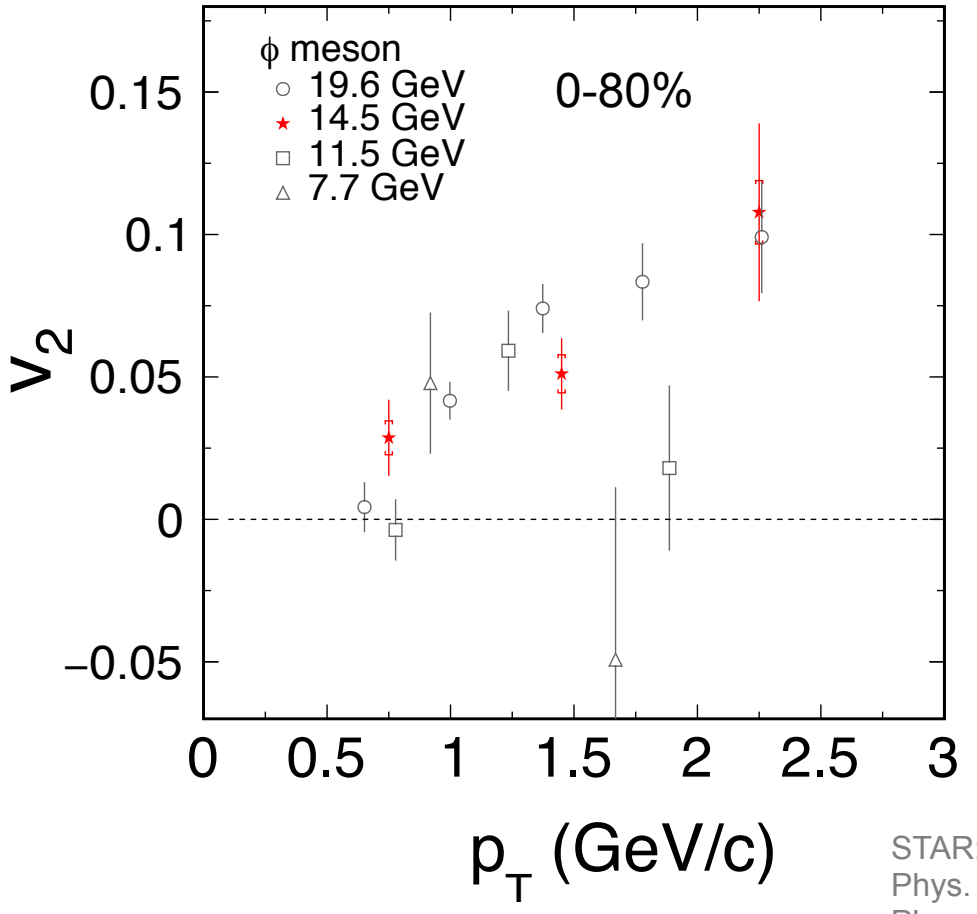
ETOF upgrade:

New charged hadron PID capabilities for $1.1<|\eta|<1.6$

Stay tuned for further experimental investigations with BES II focus on $\sqrt{s_{NN}} \leq 20$ GeV

Backup

ϕ Meson v_2



- **14.5 GeV: Sizable ϕ meson v_2, comparable to 19.6 GeV**
- **High statistics and more collision energies below 20 GeV needed!**

STAR:
Phys. Rev. C 93, 014907 (2016)
Phys. Rev. C 88, 014902 (2013)