Event anisotropy v_2 in Au + Au collisions at STAR

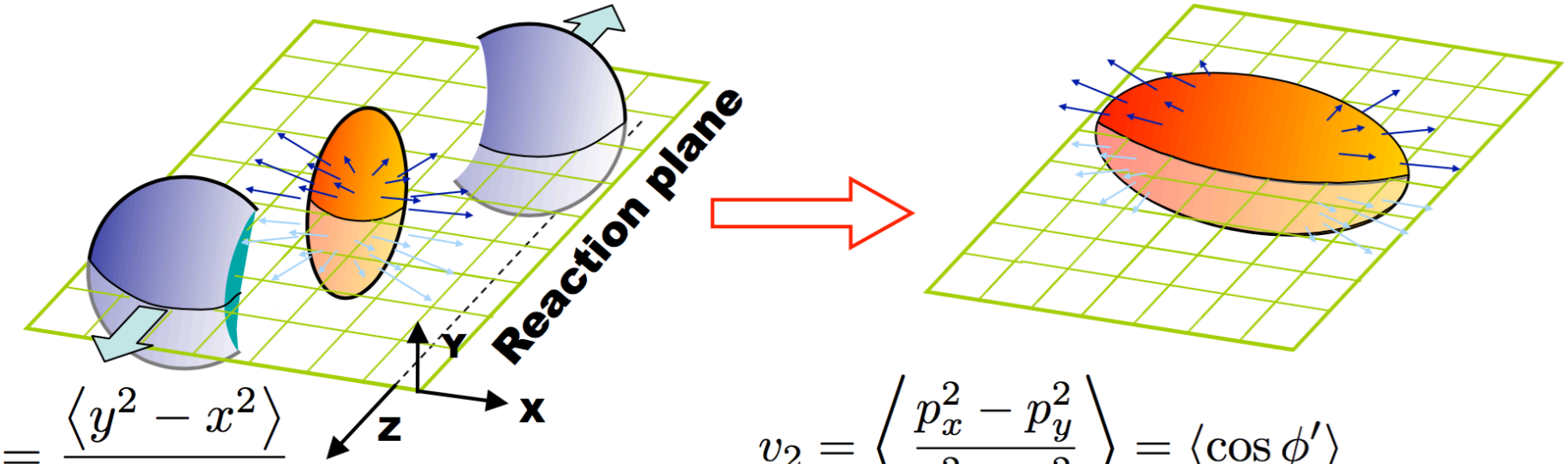
Shaowei Lan

Central China Normal University

Outline

- **Introduction**
- **STAR Detectors**
- **Results and Discussions**
- **Summary and Outlook**

Elliptic flow (v_2)



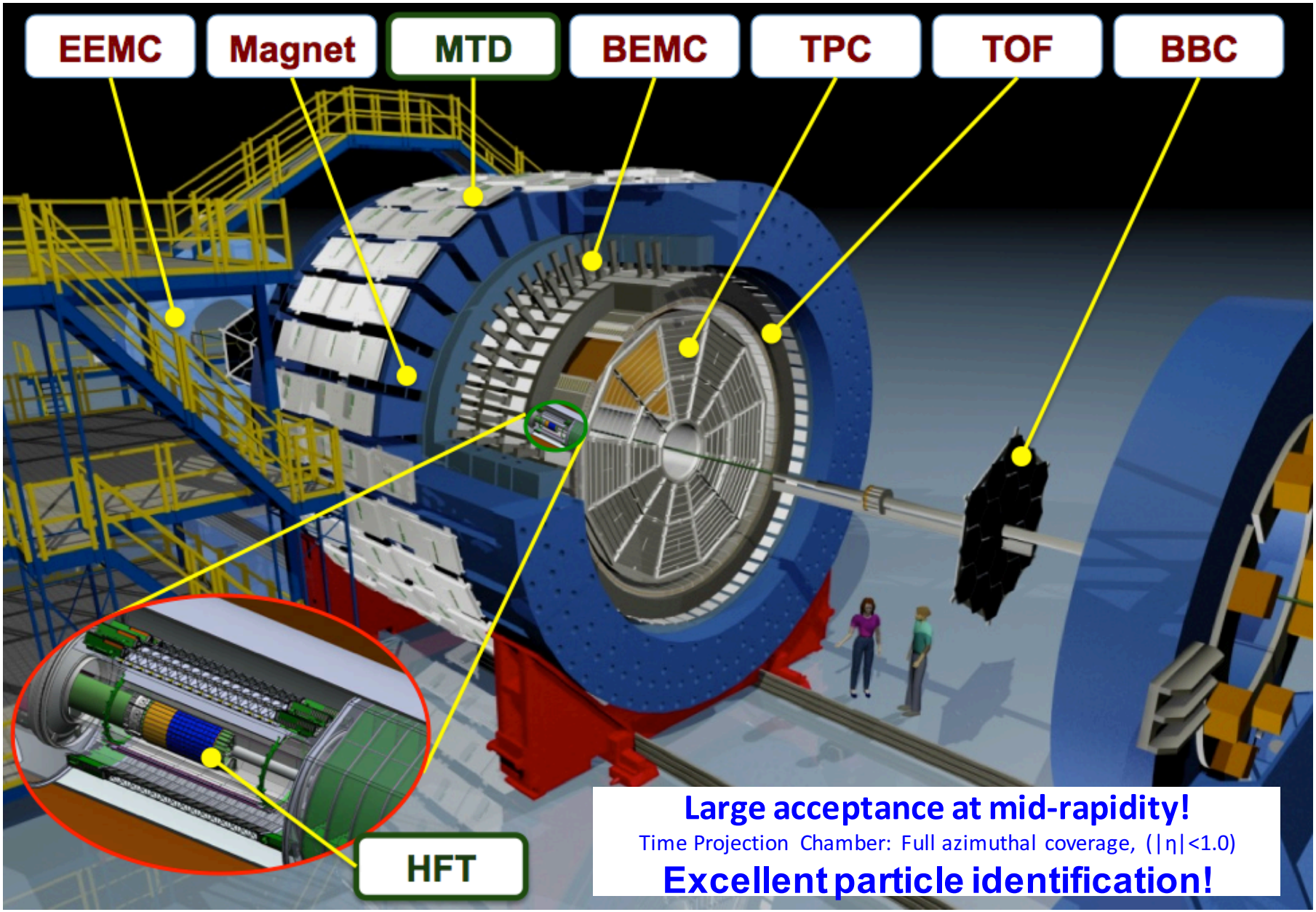
$$\varepsilon = \frac{\langle y^2 - x^2 \rangle}{\langle y^2 + x^2 \rangle}$$

$$v_2 = \left\langle \frac{p_x^2 - p_y^2}{p_x^2 + p_y^2} \right\rangle = \langle \cos \phi' \rangle$$

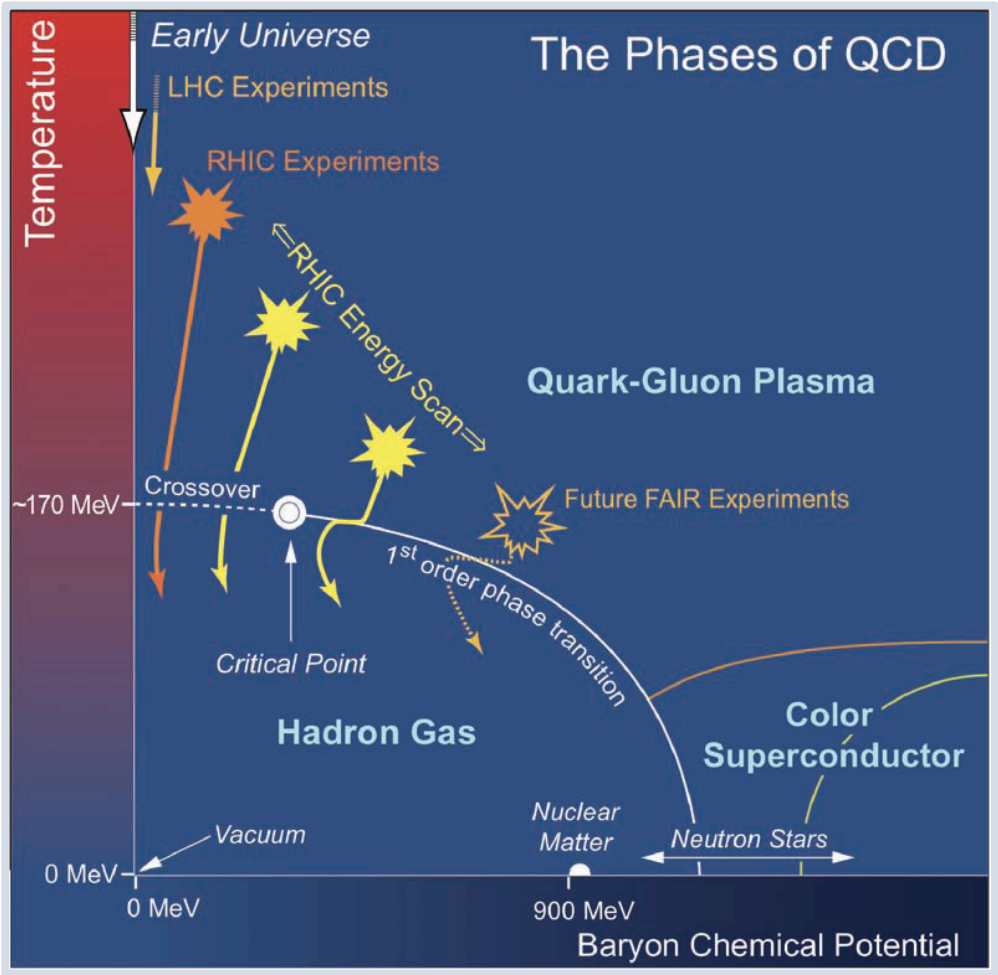
Initial geometry overlap (eccentricity) => finial momentum anisotropy (elliptic flow)

- ✓ Sensitive to the the early stage of heavy ion collisions
- ✓ Pressure gradient drives flow
- ➢ **Multi-strange hadrons and ϕ meson**:
  - *Less sensitive to late hadronic re-scatterings*
  - *Freeze-out earlier than other light hadrons*

STAR detectors



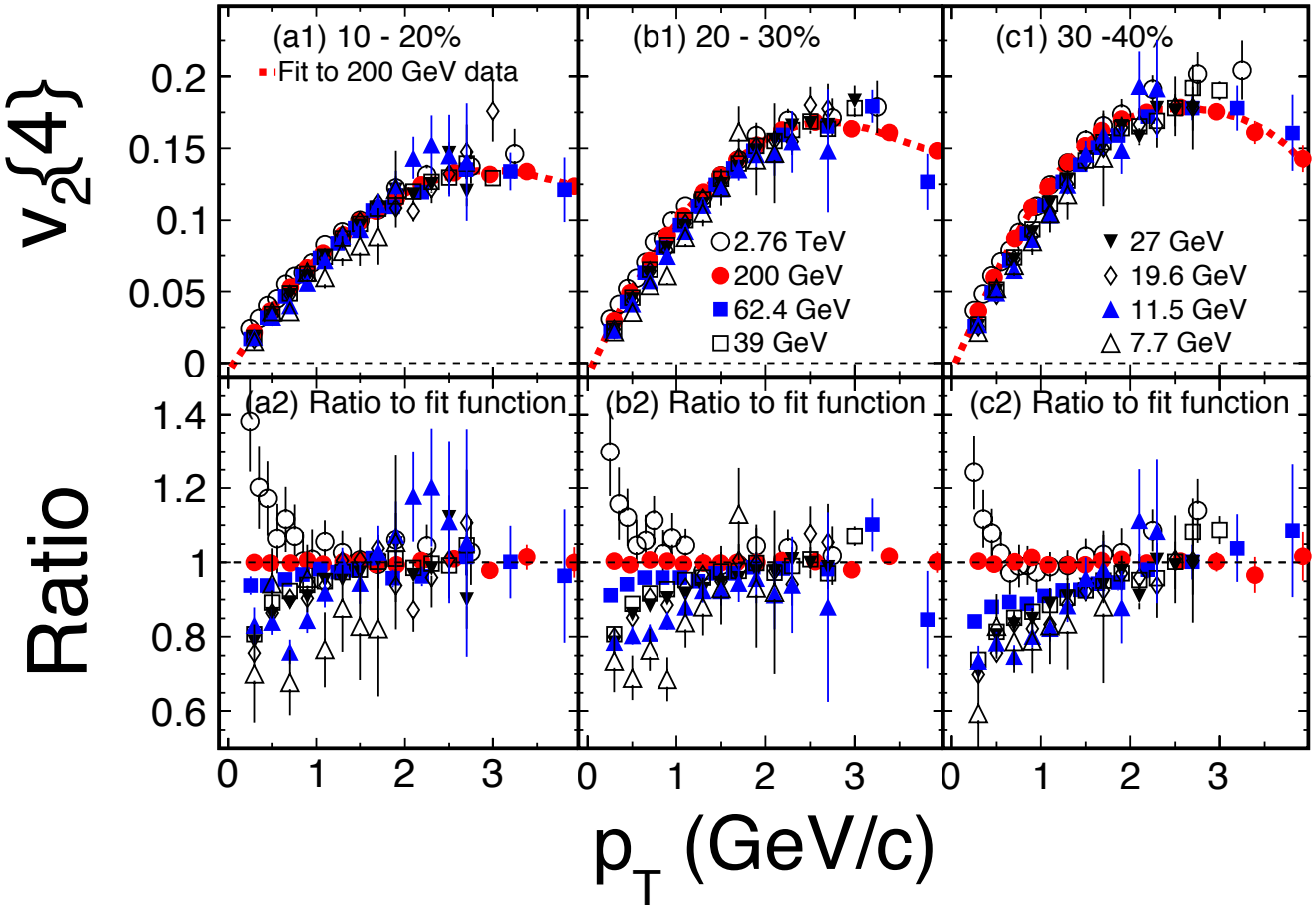
Beam Energy Scan I



$\sqrt{s_{NN}}$ (GeV)	Events (10^6)	Year
200	350	2010
62.4	67	2010
54.4	**1000**	**2017**
39	39	2010
27	70	2011
19.6	36	2011
14.5	20	2014
11.5	12	2010
7.7	4	2010

Explore the QCD phase structure!

Energy dependence v_2

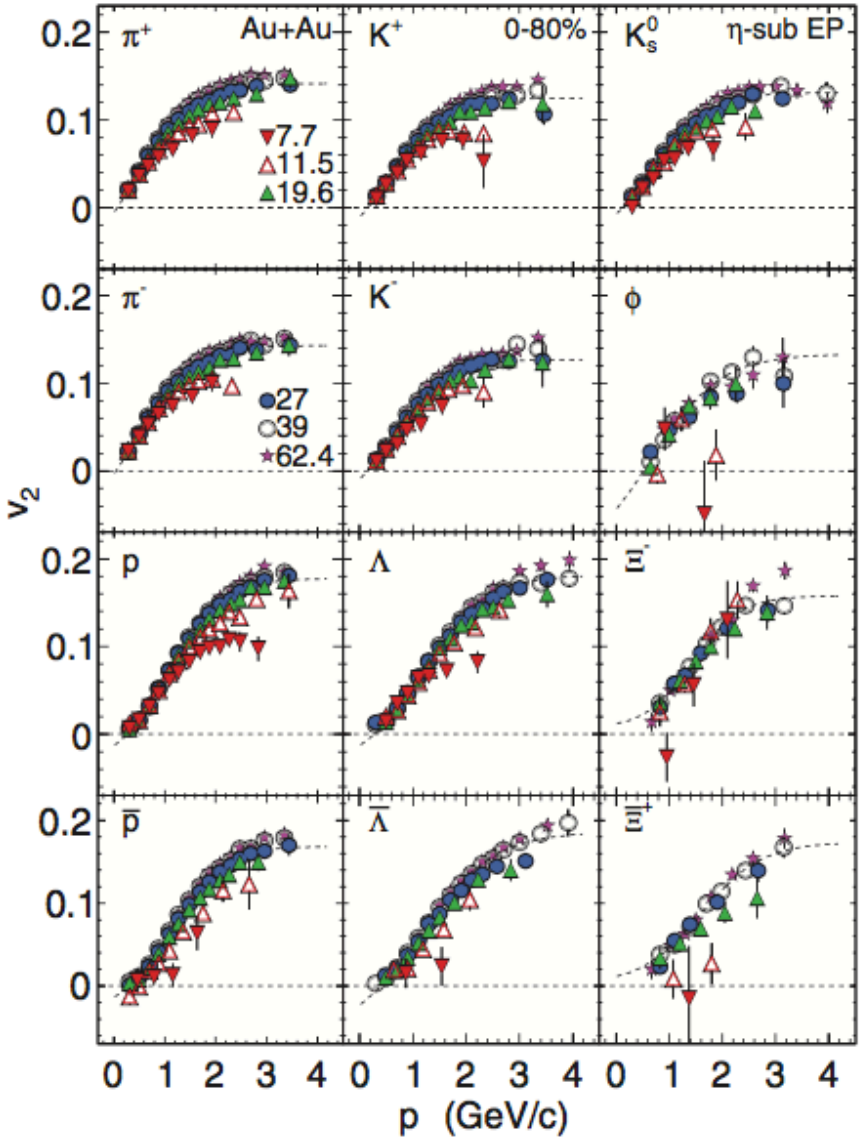


- **$v_2\{4\}$ results**
- Three centrality bins
- **Consistent $v_2(p_T)$ from 7.7 GeV to 2.76 TeV for $p_T > 2$ GeV/c**
- **$p_T < 2$GeV/*c***
- The v_2 values rise with increasing collision energy -> Large collectivity? Particle composition?

STAR: Phys. Rev. C 86 54908 (2012)

ALICE data: Phys. Rev. Lett. 105, 252302 (2010)

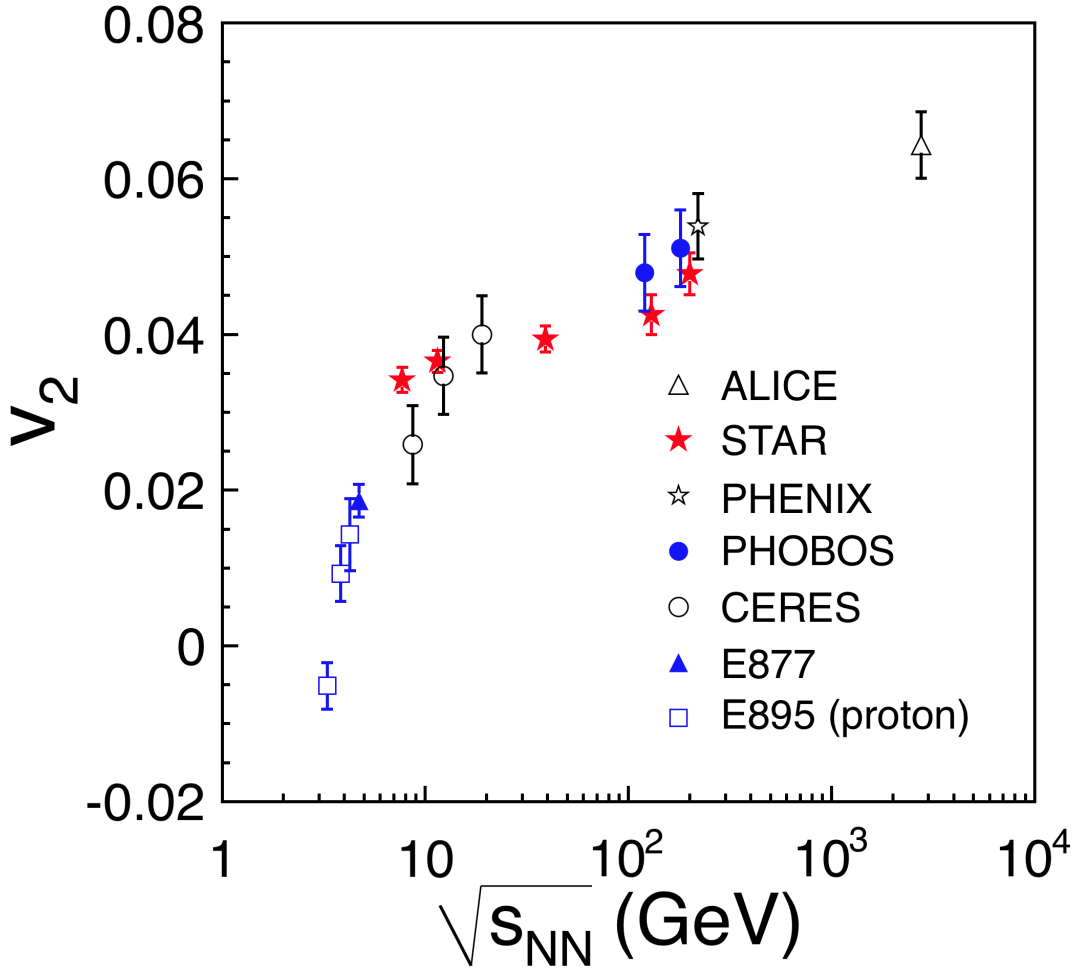
Energy dependence v_2



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

- **Similar $v_2(p_T)$ shape for PID at RHIC BES I energy.**

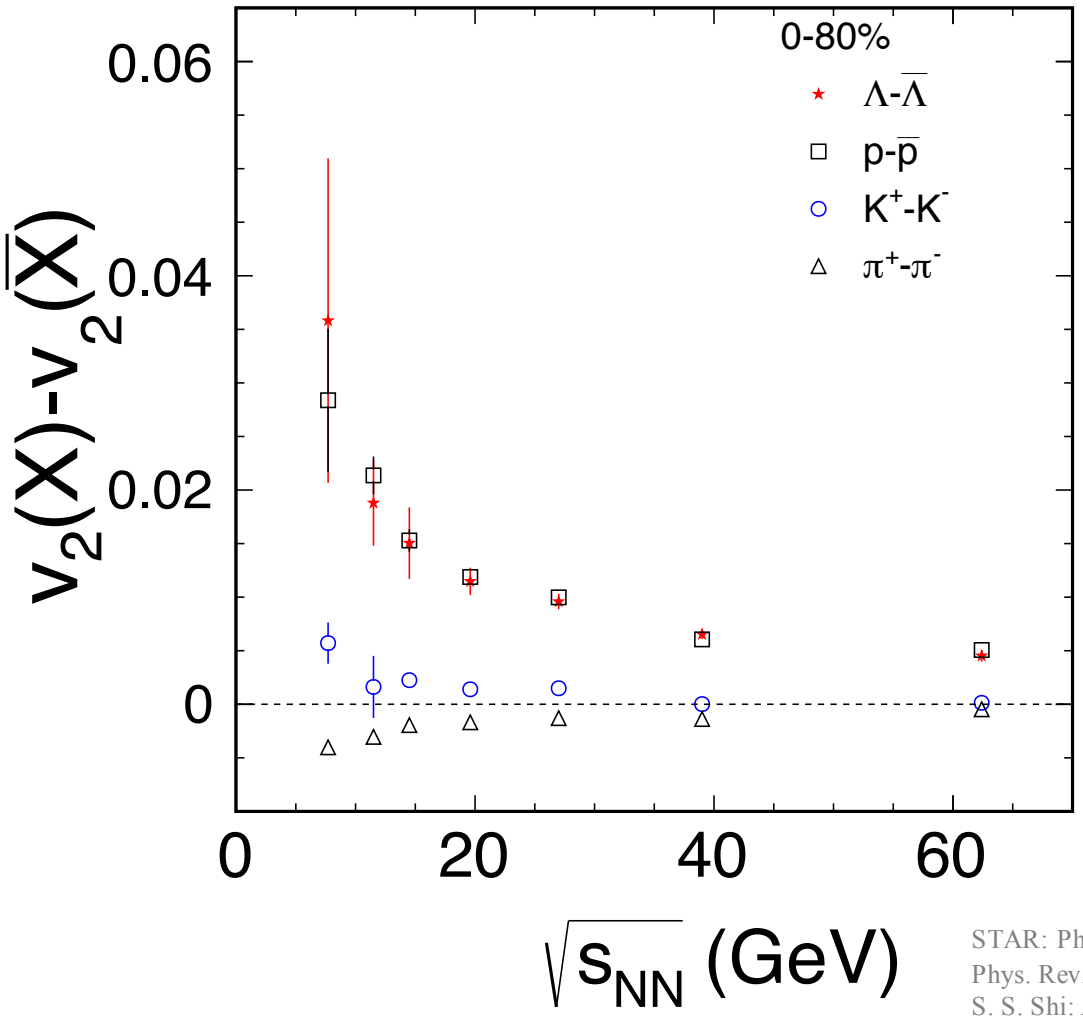
Energy dependence v_2



- **STAR, ALICE: $v_2\{4\}$ results**
  - Centrality: 20-30%
- **An increasing trend is observed for p_T integrated v_2 from AGS to LHC**
  - The rate of increase with collision energy is slower from 7.7 to 39 GeV compared to that between 3 to 7.7 GeV

ALICE: Phys. Rev. Lett. 105, 252302 (2010)
PHENIX: Phys. Rev.Lett. 98, 162301 (2007).
PHOBOS: Phys. Rev.Lett. 98, 242302 (2007).
CERES: Nucl. Phys. A 698, 253c (2002).
E877: Nucl. Phys. A 638, 3c(1998).
E895: Phys. Rev. Lett. 83, 1295 (1999).
STAR 130 and 200 GeV: Phys. Rev. C 66,873 034904 (2002); Phys. Rev. C 72,790 014904 (2005)

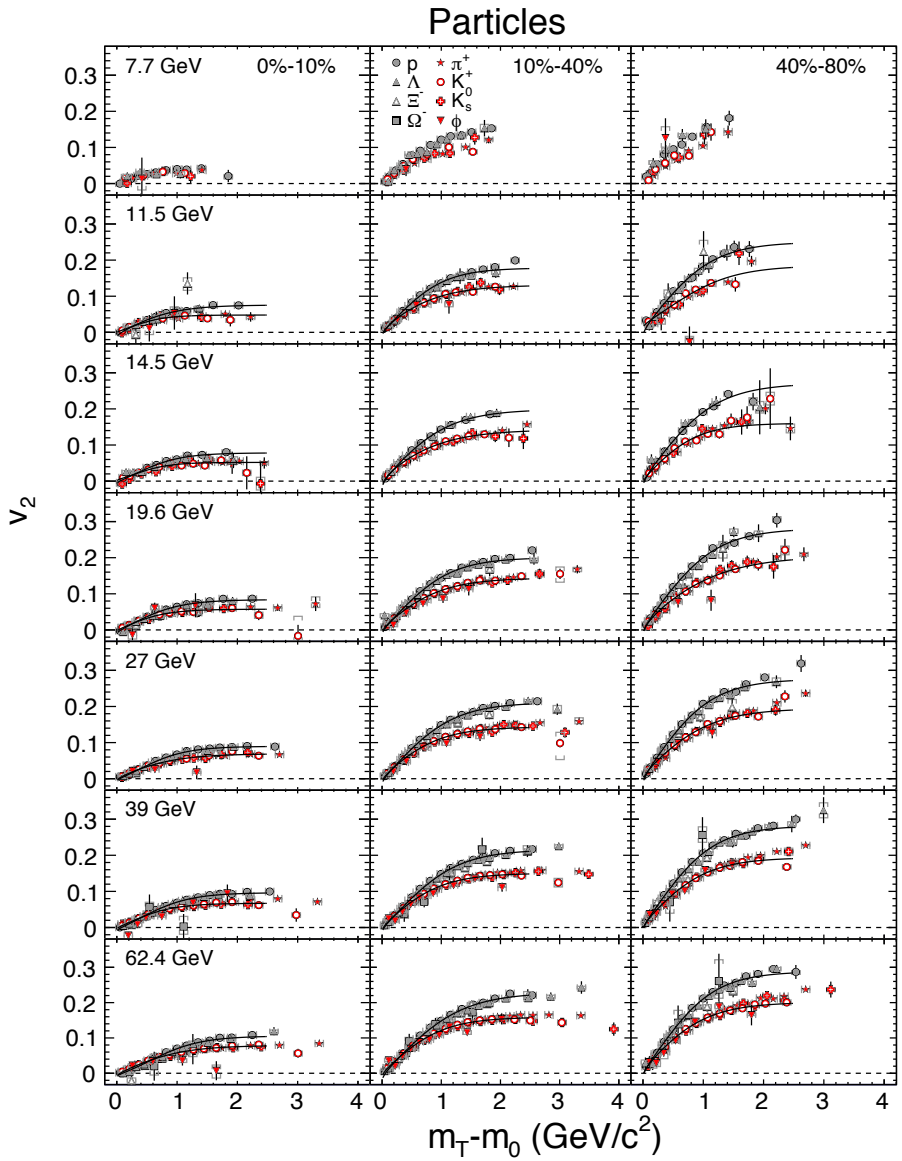
Particle vs. Anti-particle v_2



STAR: Phys. Rev. Lett. 110 (2013) 142301
Phys. Rev. C 93, 014907(2016)
S. S. Shi: Adv. High Energy Phys. 2016, 1987432 (2016)

- **Significant difference between baryon and anti-baryon v_2 is observed**

Baryon/Meson Separation

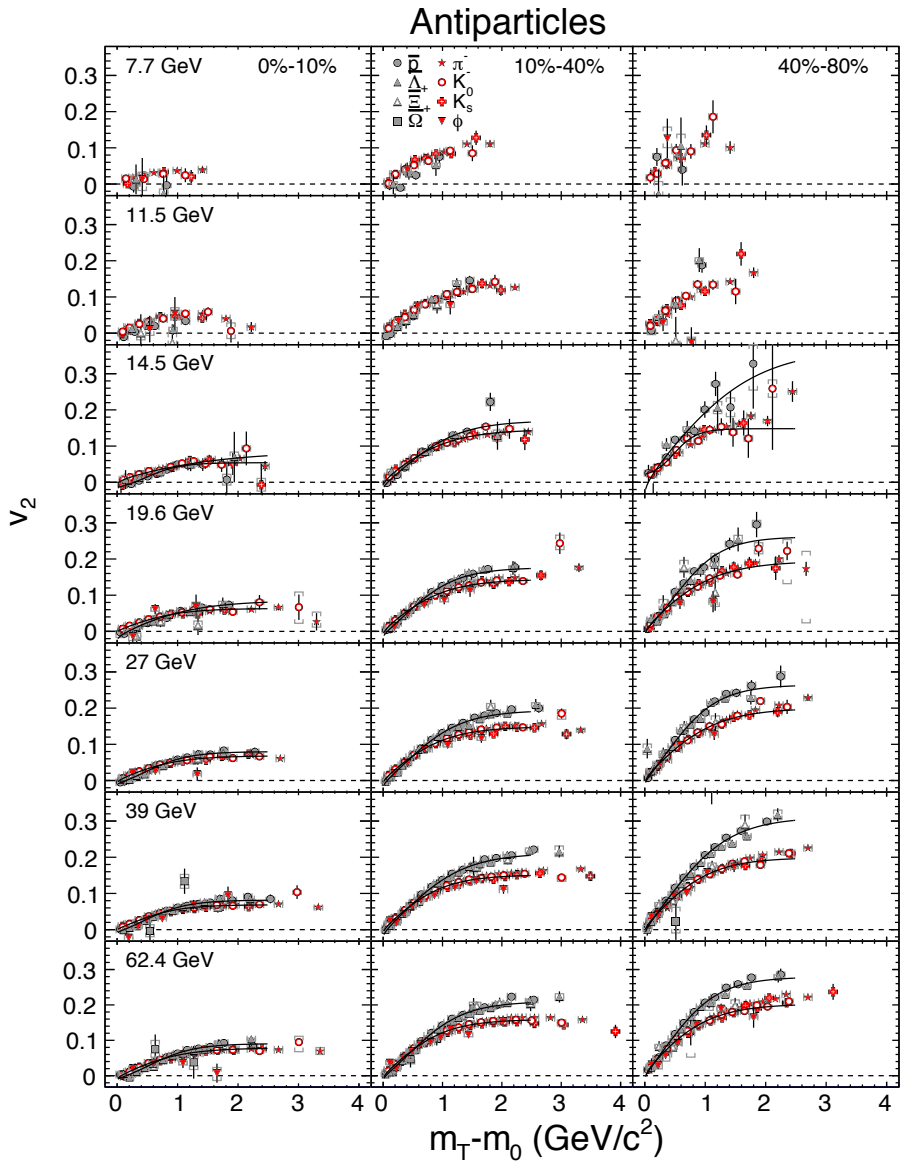


A splitting between baryons and mesons is observed at all energies except 7.7 GeV and all centralities.

At 7.7 GeV we are limited by the number of events.

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

Baryon/Meson Separation

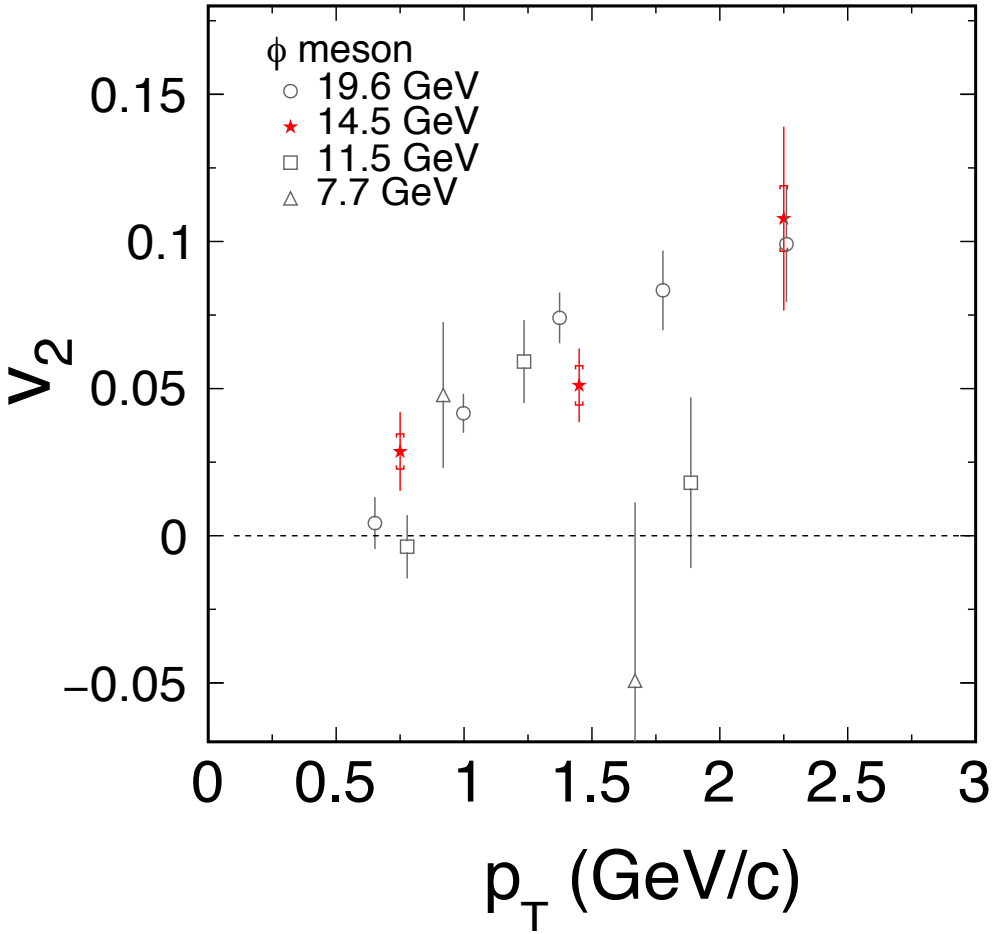


The splitting between baryons and mesons is observed significant for all energies above 14.5 GeV and also at 14.5 GeV for 40%–80%.

For these energies below 11.5 GeV, we are limited by the number of events.

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

ϕ Meson v_2

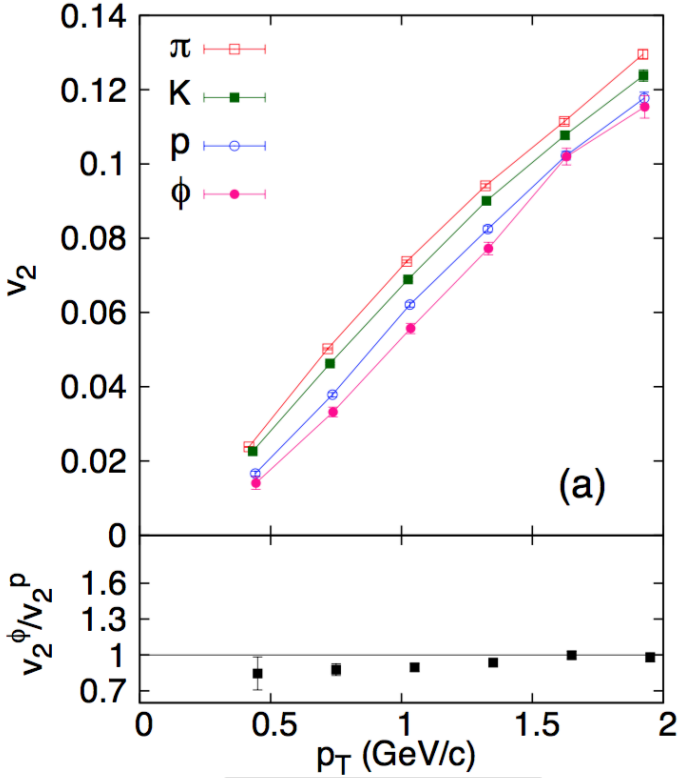


- **ϕ meson is less sensitive to late hadronic interactions**[1]
- **Sizable ϕ meson v_2: comparable to 19.6 GeV**
- **High statistics and more energies below 20 GeV needed!**

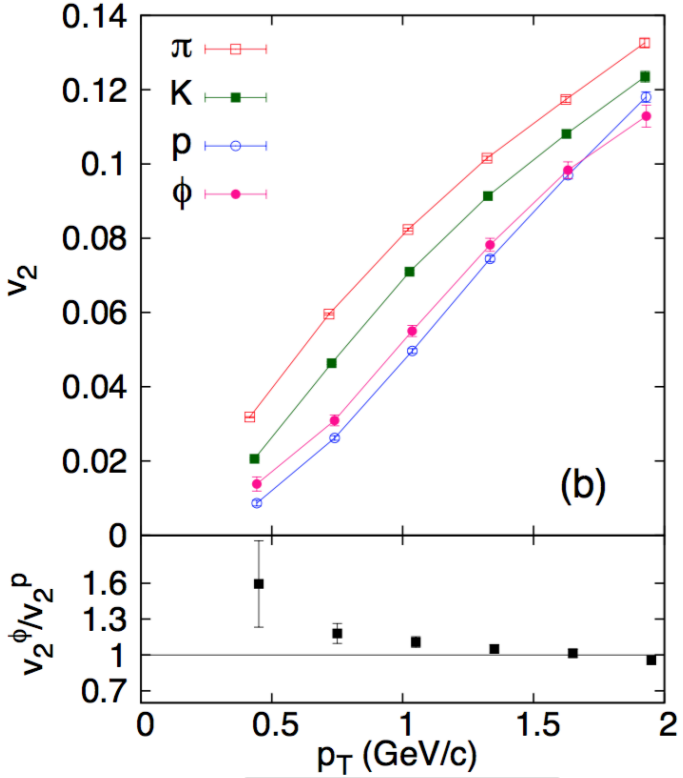
STAR: Phys. Rev. C 88, 014902(2013)
Phys. Rev. C 93, 014907(2016)
[1] STAR: Phys. Rev. Lett. 116, 062301(2016)

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

Model calculations: T. Hirano et al., ; PRC77, 044909 (2008), PRC92, 044907 (2015)



Before hadronic re-scattering



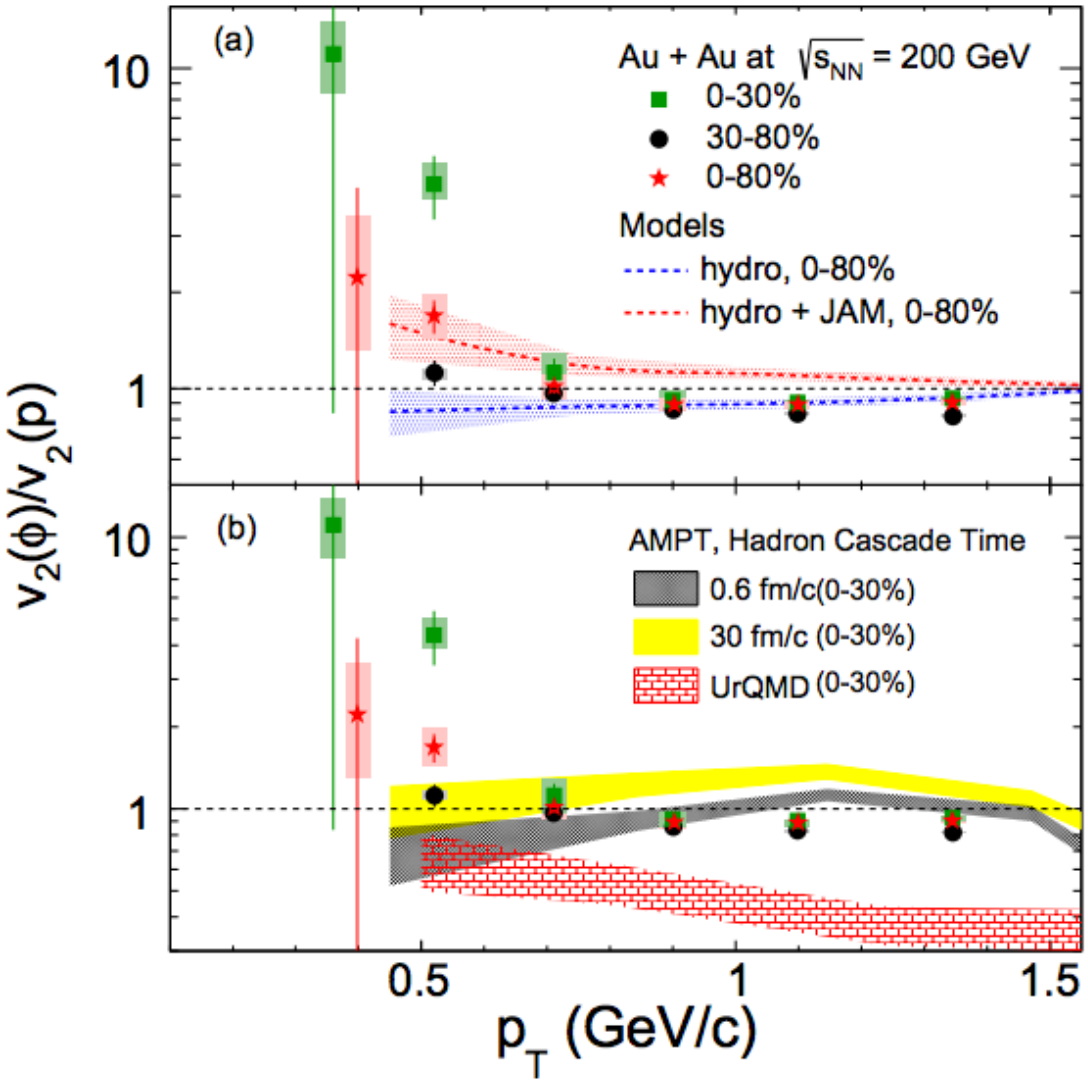
After hadronic re-scattering

- **Ideal hydro + hadron cascade (JAM)**
- **Small hadron cross section + hadronic re-scattering 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% ->**

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), PRC92, 044907 (2015)

Beam Energy Scan II

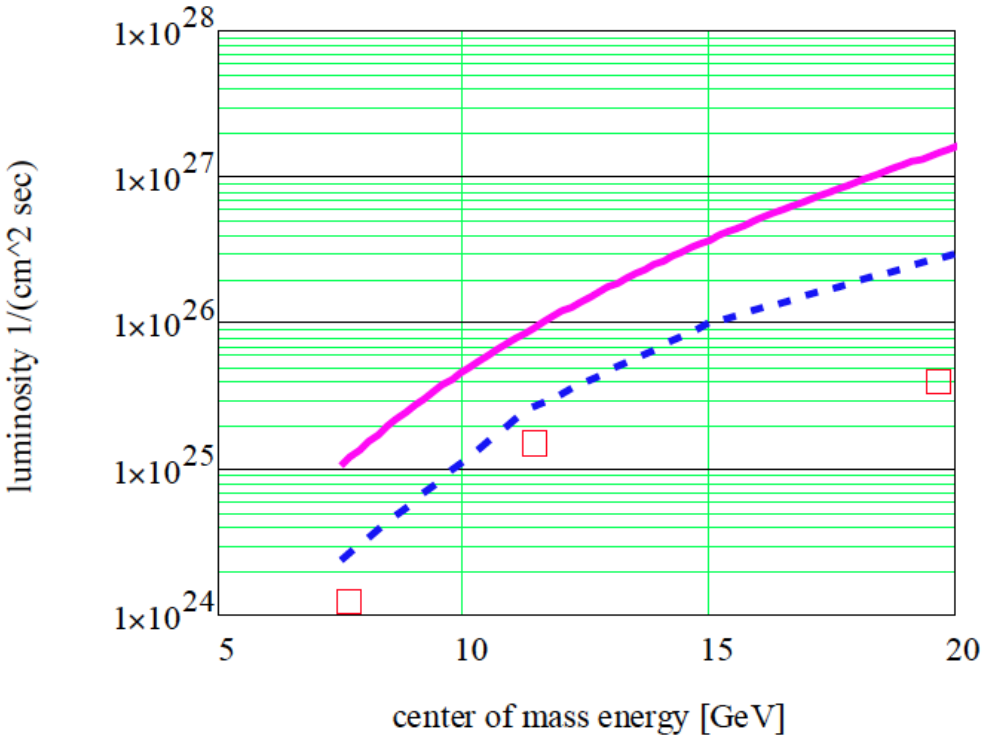
Electron cooling + longer beam bunches for BES II
factor 4-15 improvement in luminosity compared with BES I

Detector upgrade

- **Event Plane Detector**
  important for flow and fluctuation analyses
- **iTPC upgrade**
  increases TPC acceptance to ~1.7 in η; improves dE/dx resolution
- **ETOF upgrade**
  New charged hadron PID capabilities for 1.1<|η|<1.6

Fixed target program

extends STAR's physics reach to region of compressed baryonic matter



Summary

- **Particle vs. Anti-particle v_2**

  The difference increases with decreasing beam energy

- **Baryon and meson $v_2(p_T)$ separation has been observed**
- **Mass ordering break for ϕ meson and proton v_2**

  Indicates late hadronic interactions on proton v_2

- **ϕ meson and multi-strange hadron v_2 => study the QCD phase boundary**
- **BES II force on the $\sqrt{s_{NN}}$ < 20 GeV region.**

Thank you for your attention!