Elliptic Flow Measurements in Heavy-Ion Collisions at RHIC-STAR

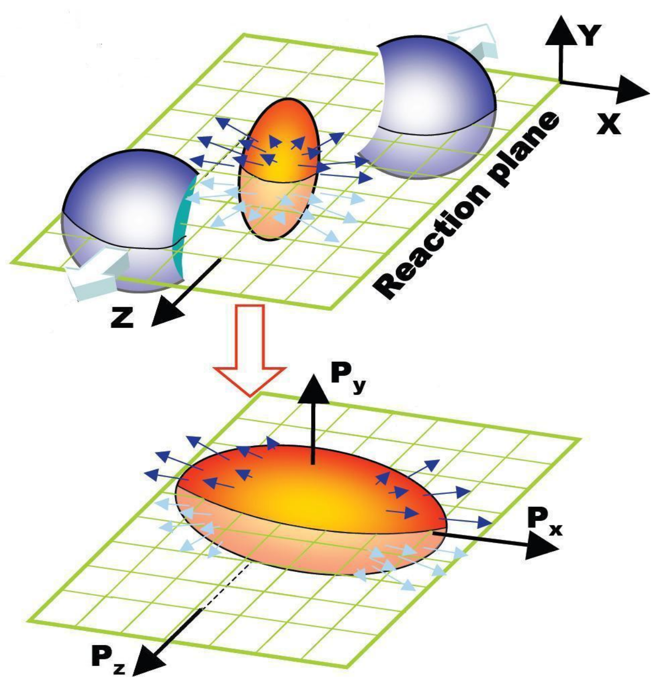
Shusu Shi 施梳苏

Central China Normal University
华中师范大学

Outline

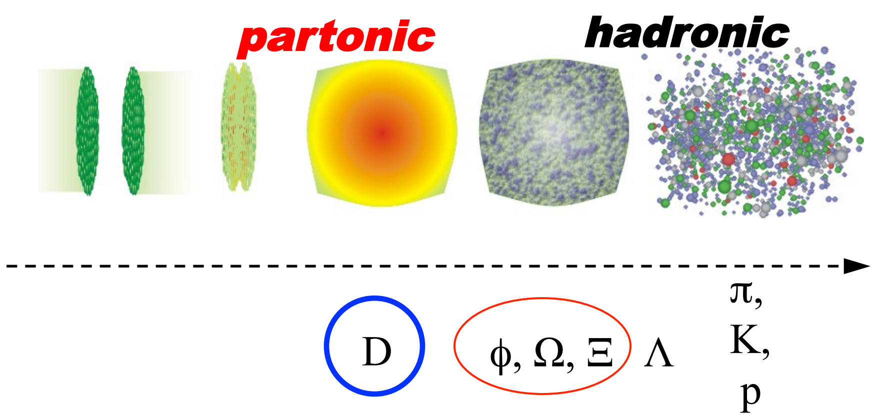
- Introduction
- Multi-strange hadron and ϕ meson flow
- Heavy flavor flow
- Number of constitute quark scaling
- Beam energy scan
- Summary

Elliptic Flow (v_2)

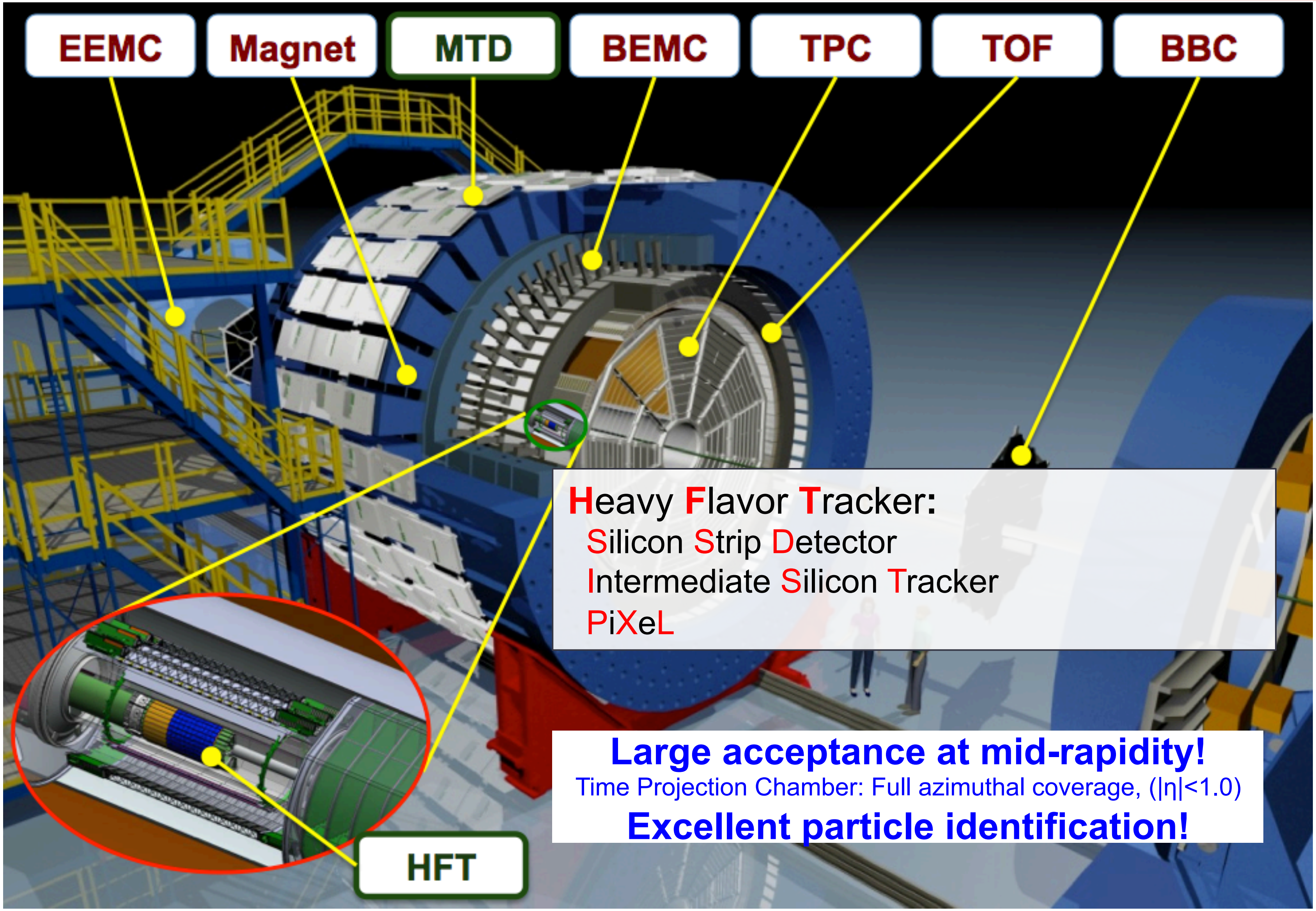


$$\varepsilon = \frac{< y^2 - x^2 >}{< y^2 + x^2 >} \Rightarrow v_2 =< \cos 2\varphi >, \quad \varphi = \tan^{-1}(\frac{p_y}{p_x})$$

- **Elliptic flow =>**
- Initial spatial anisotropy ε->
  Final momentum anisotropy v_2
  ➔ Interactions among constituents
- Self-quenching with time
  - Sensitive to the early stage of the system evolution
- **Multi-strange hadrons and ϕ meson**
  Less sensitive to late hadronic interactions
- **Heavy flavor flow**
  Extract medium properties from motion of heavy quarks in medium



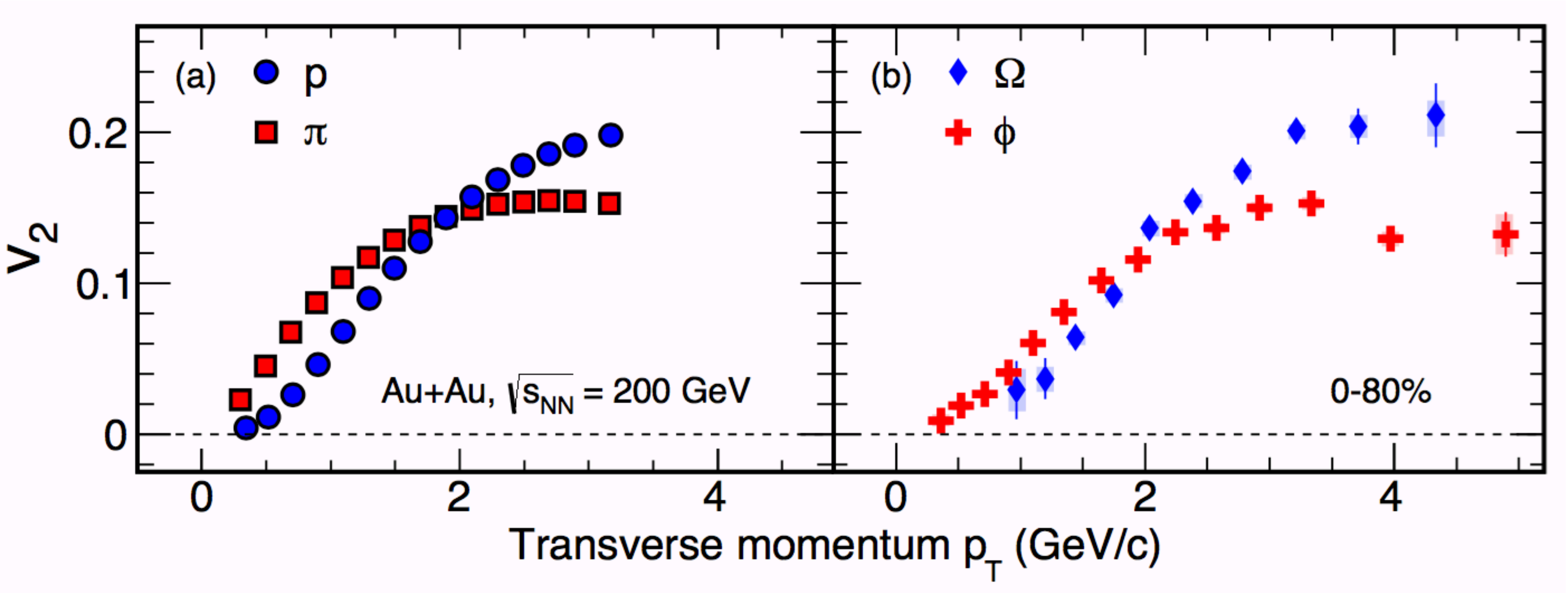
STAR Detectors



Heavy Flavor Tracker:
Silicon Strip Detector
Intermediate Silicon Tracker
PiXeL

Large acceptance at mid-rapidity!
Time Projection Chamber: Full azimuthal coverage, (|η|<1.0)
Excellent particle identification!

Partonic Collectivity

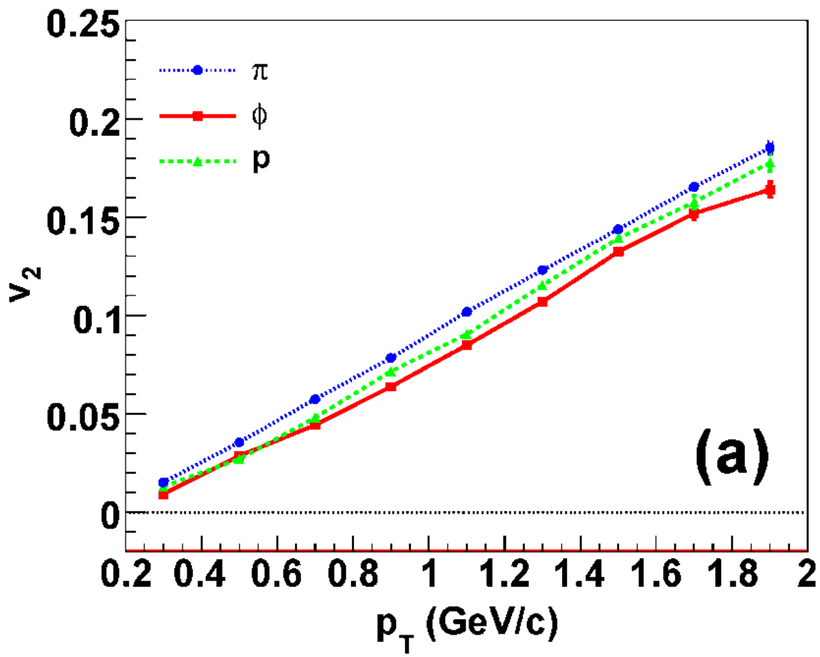


STAR: SQM2015, Phys. Rev. Lett.116, 062301 (2016)

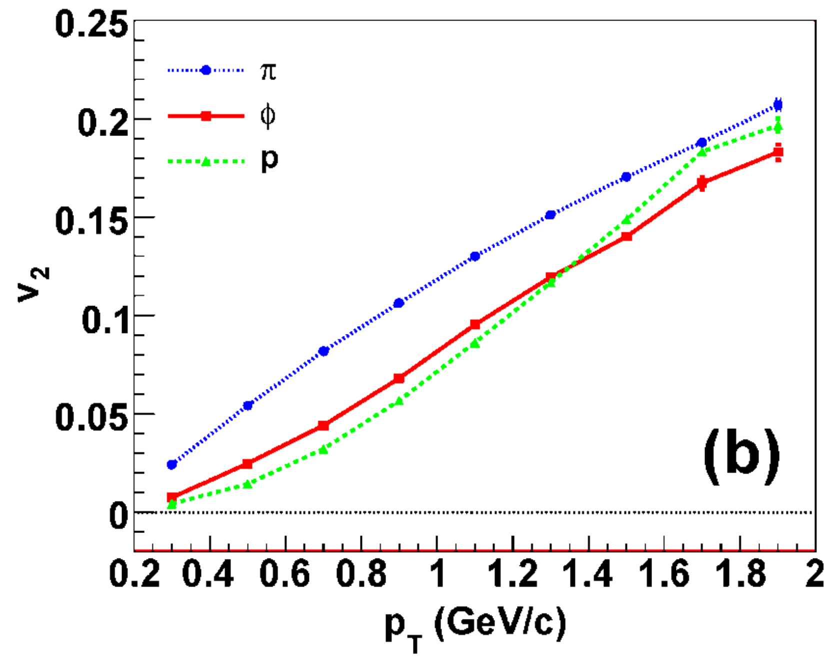
- **Mass ordering when p_T < 2 GeV/c**
- **Baryon/meson splitting when 2 < p_T < 5 GeV/c**

  High precision data prove that Ω follows the baryon/meson splitting.
  First time!

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



Before hadronic rescattering



After hadronic rescattering

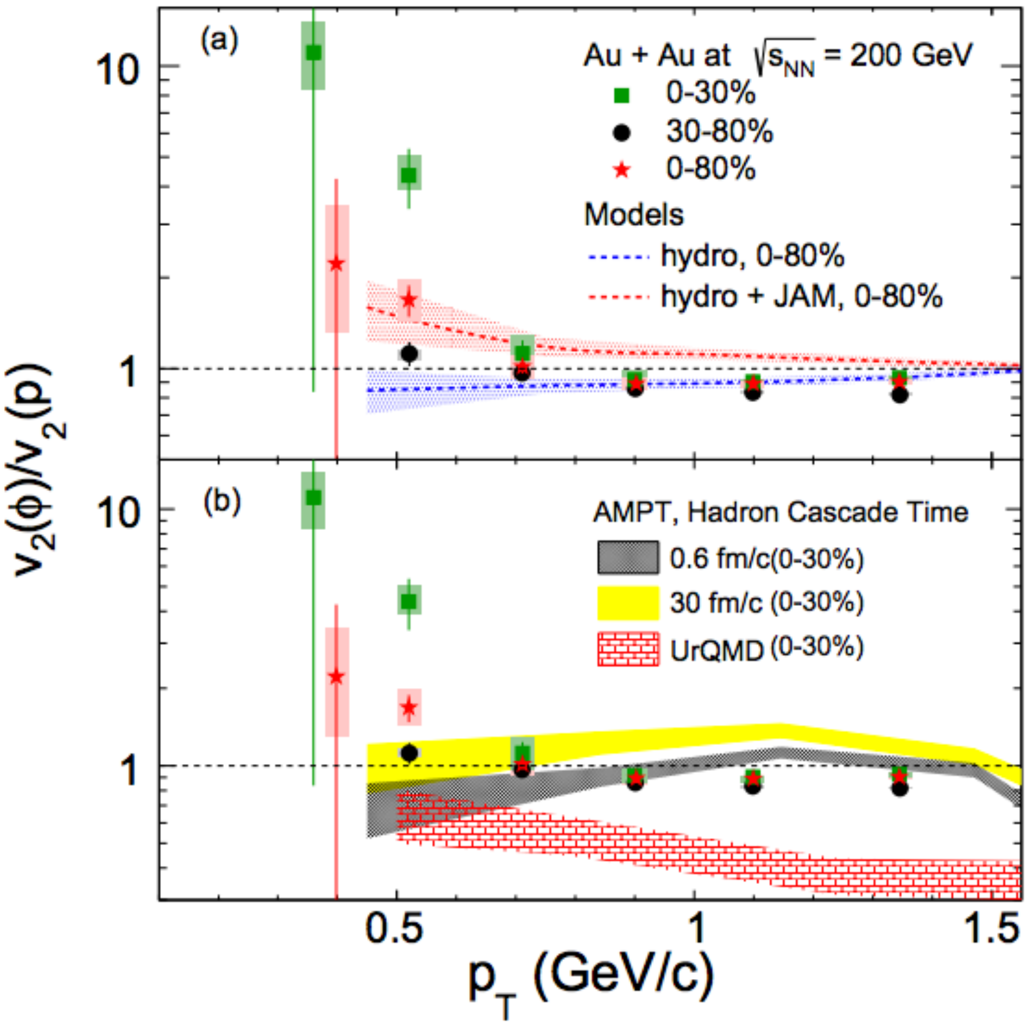
T. Hirano et al., ; PRC77, 044909 (2008)

- **Ideal hydro + hadron cascade**
- **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 $v_2(p)$

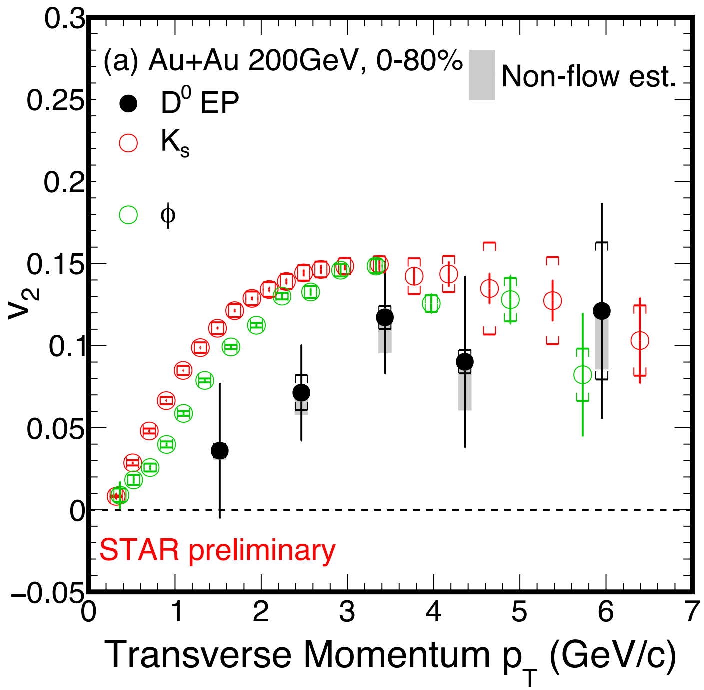


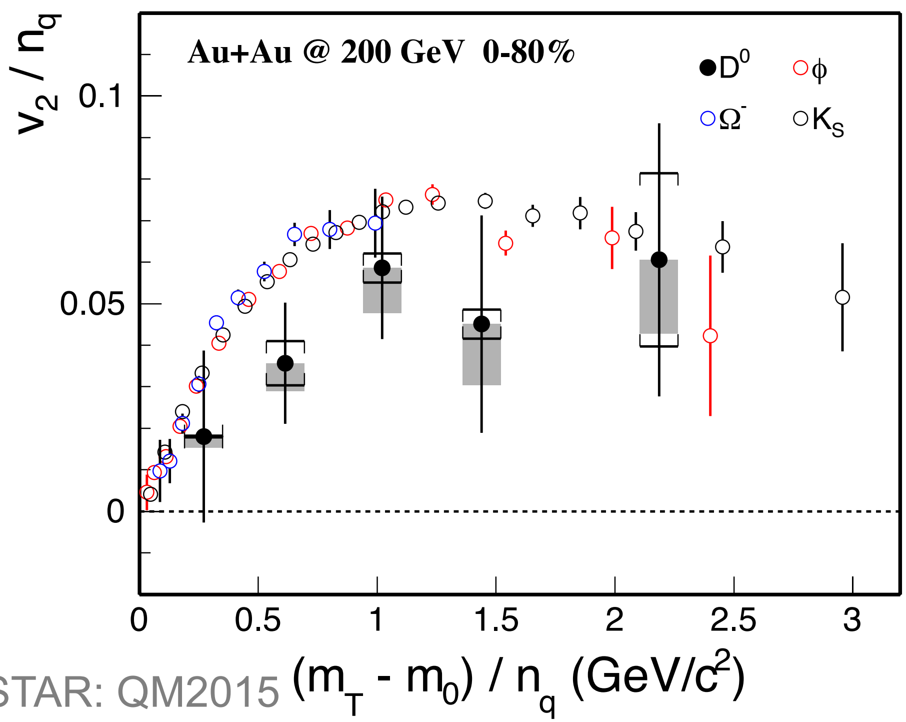
- **Model study indicates with increasing hadronic cascade time (more hadronic re-scattering), the $v_2(\phi)/v_2(p)$ ratio increases**

- **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: SQM2015, Phys. Rev. Lett.116, 062301 (2016)

D Meson v_2 at RHIC





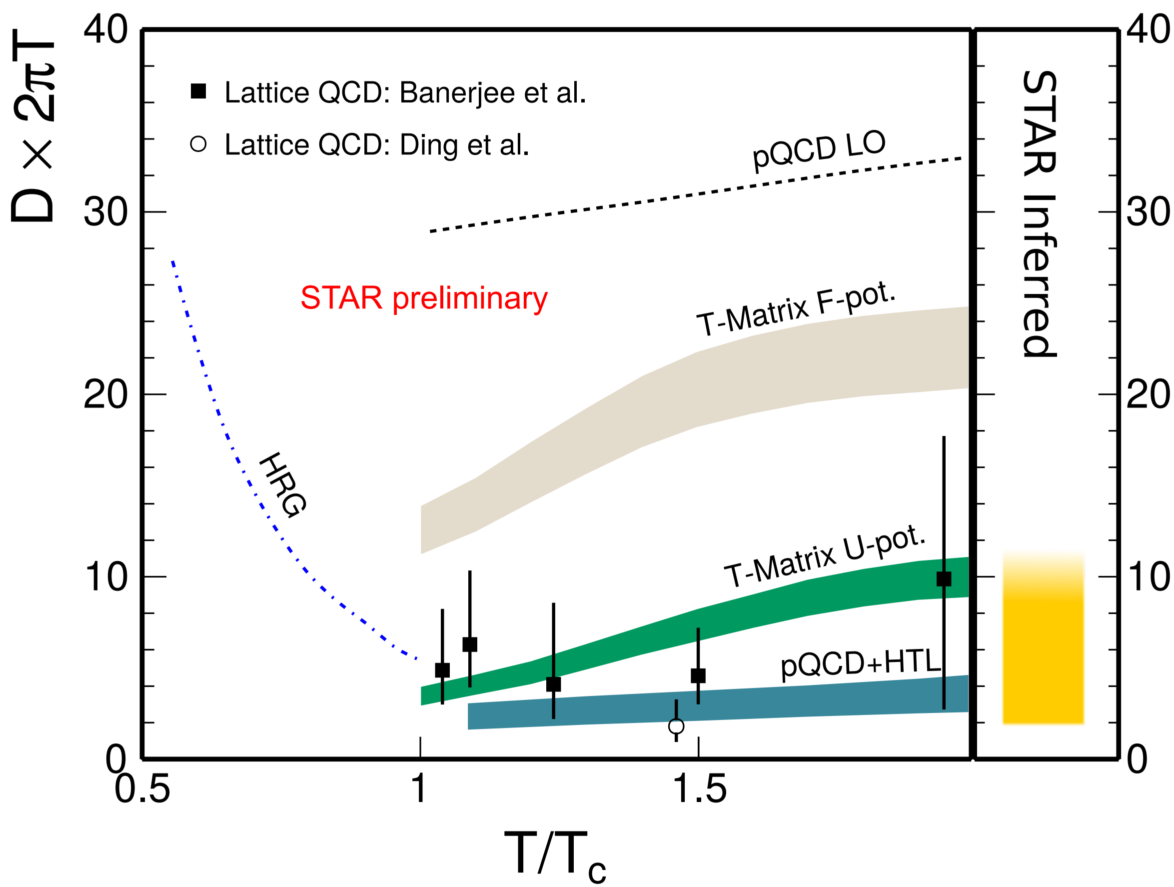
STAR: QM2015

- **Finite charm hadron v_2 at p_T > 2 GeV/c**
- **$v_2(D) < v_2(K_S, \phi)$ at p_T < 3 GeV/c**
- **v_2/n_q vs. $(m_T-m_0)/n_q$: indication of D meson lower than K_S, ϕ, Ω**

Thank Heavy Flavor Tracker!

Charm quarks flow; smaller collectivity than light flavor

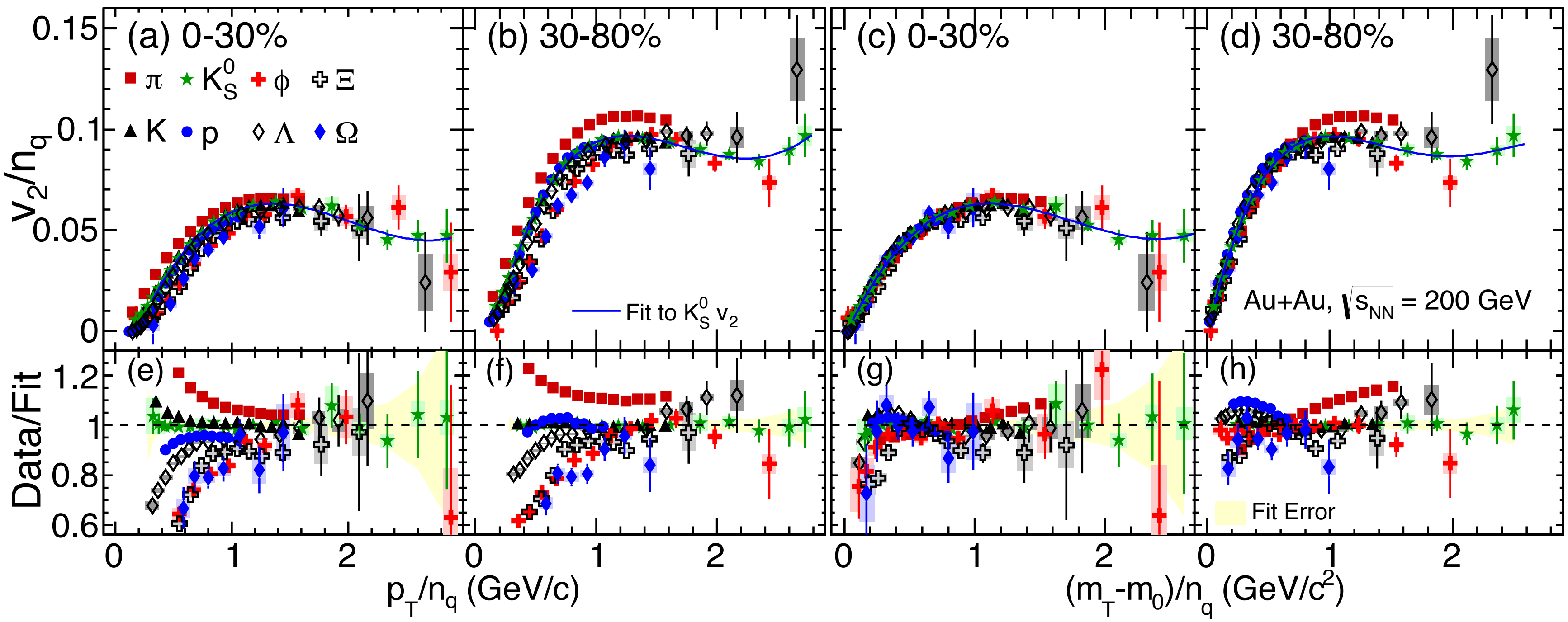
Diffusion Coefficient



The hot QCD white paper: arXiv:1502.02730v1; STAR: QM2015

- **Compatible with models predicting a value of diff. coefficient between 2 -10**
- **Lattice calculations are consistent with values inferred from data**

NCQ Scaling - RHIC



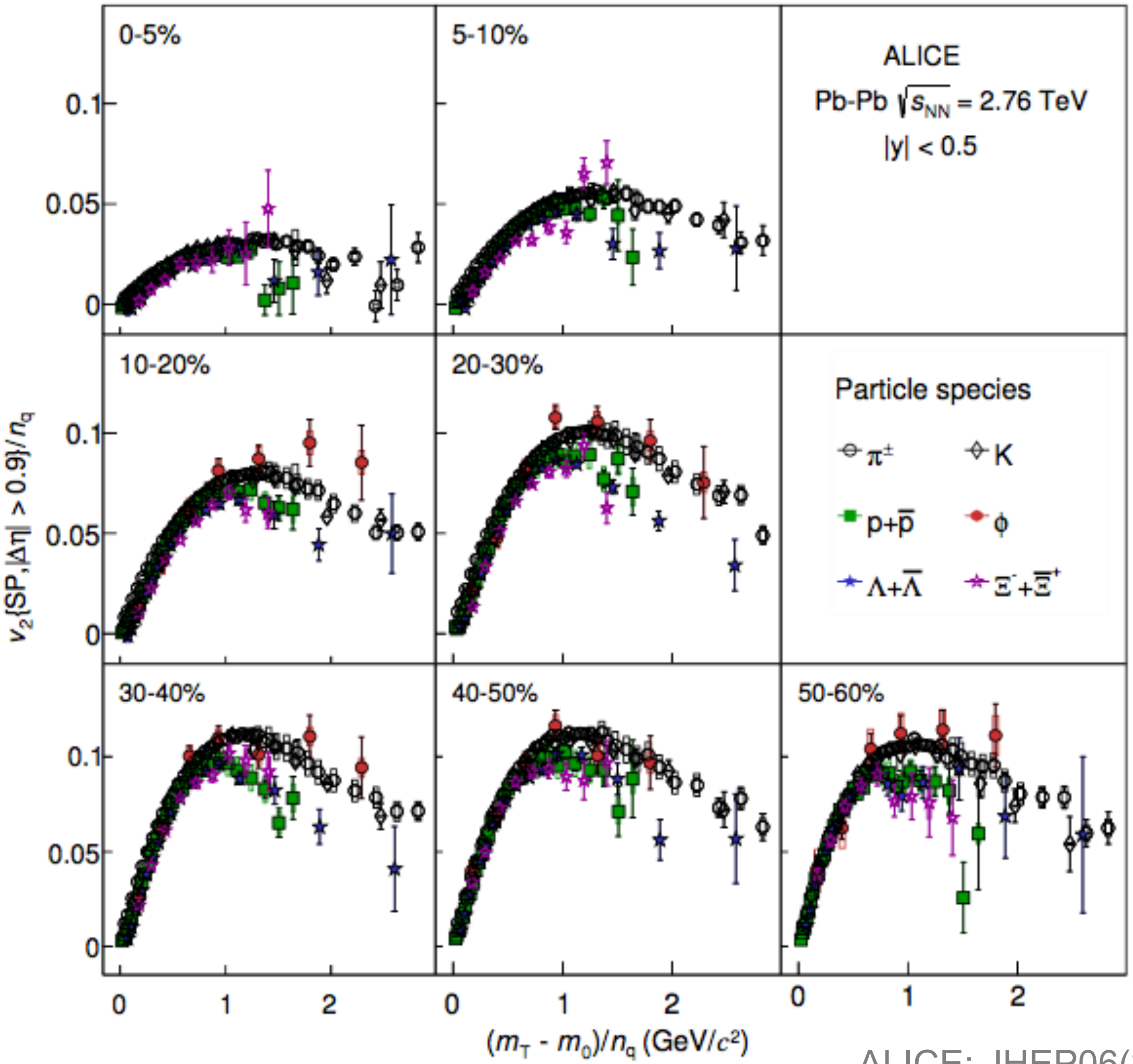
STAR: SQM2015, Phys. Rev. Lett.116, 062301 (2016)

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.)%

- **NCQ scaling holds within 10%**

NCQ Scaling - LHC



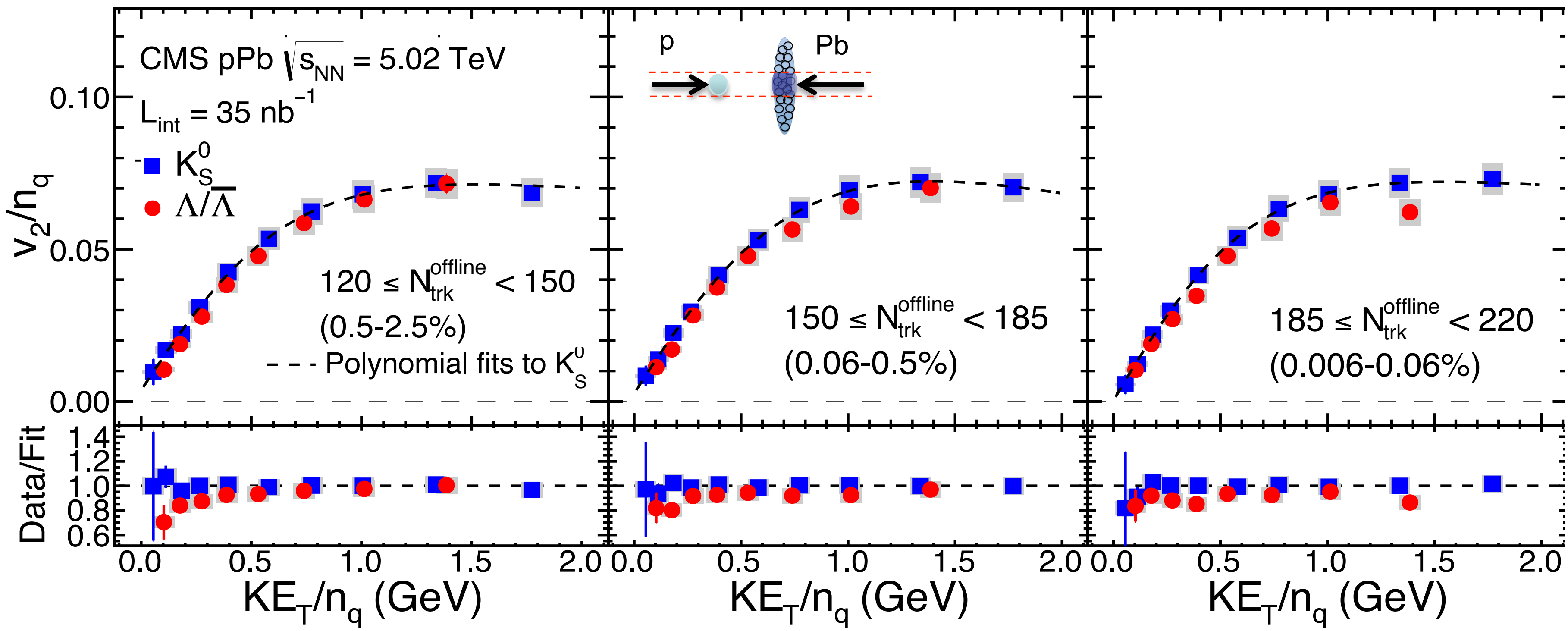
ALICE: JHEP06(2015)190

- The deviation from the NCQ scaling at the level of +/-20%

- Better NCQ scaling at RHIC -> indicates coalescence is the dominant hadronization mechanism at RHIC in the intermediate p_T range

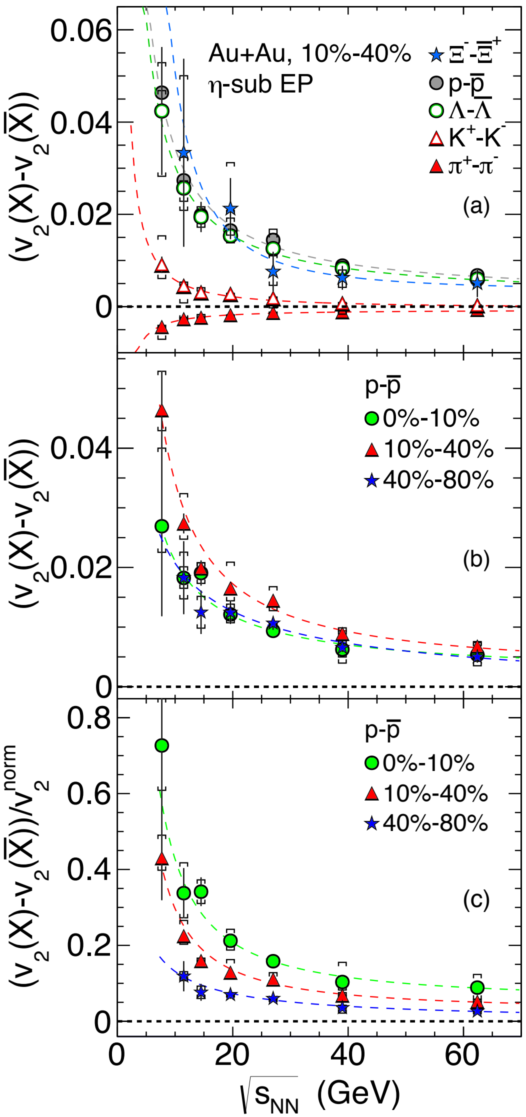
NCQ Scaling - pPb

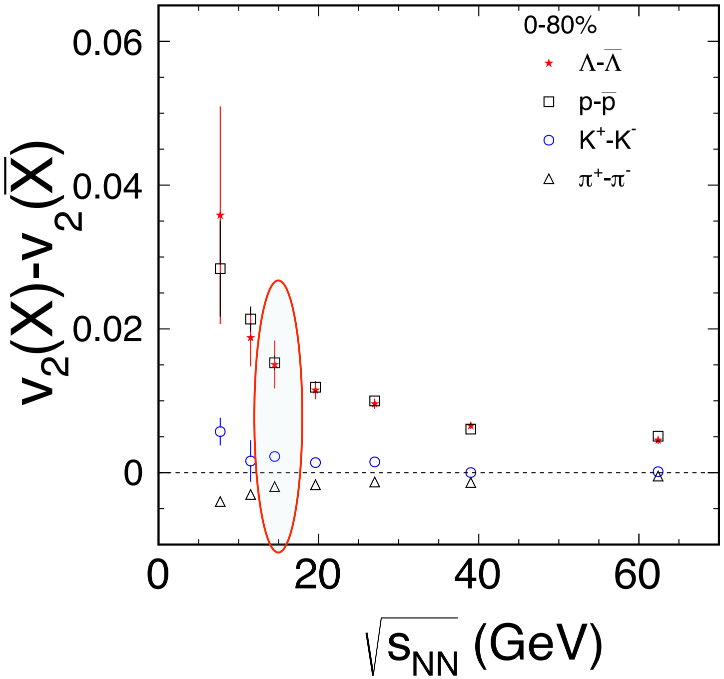
CMS: SQM2015, PLB 742 (2015) 200



- NCQ scaling observed for K_S^0 and Λ v_2
- Partonic collectivity at small colliding system?

Particle vs. Anti-particle v_2

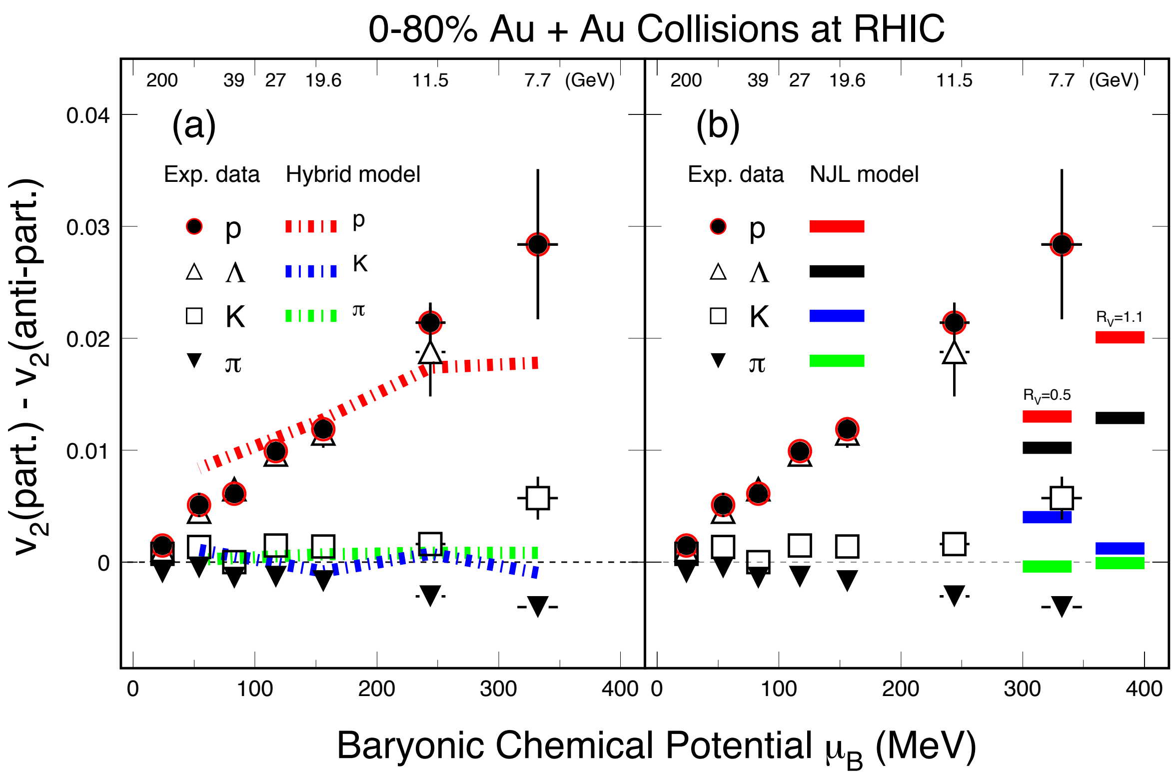




STAR: Phys. Rev. C 93, 014907(2016)

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

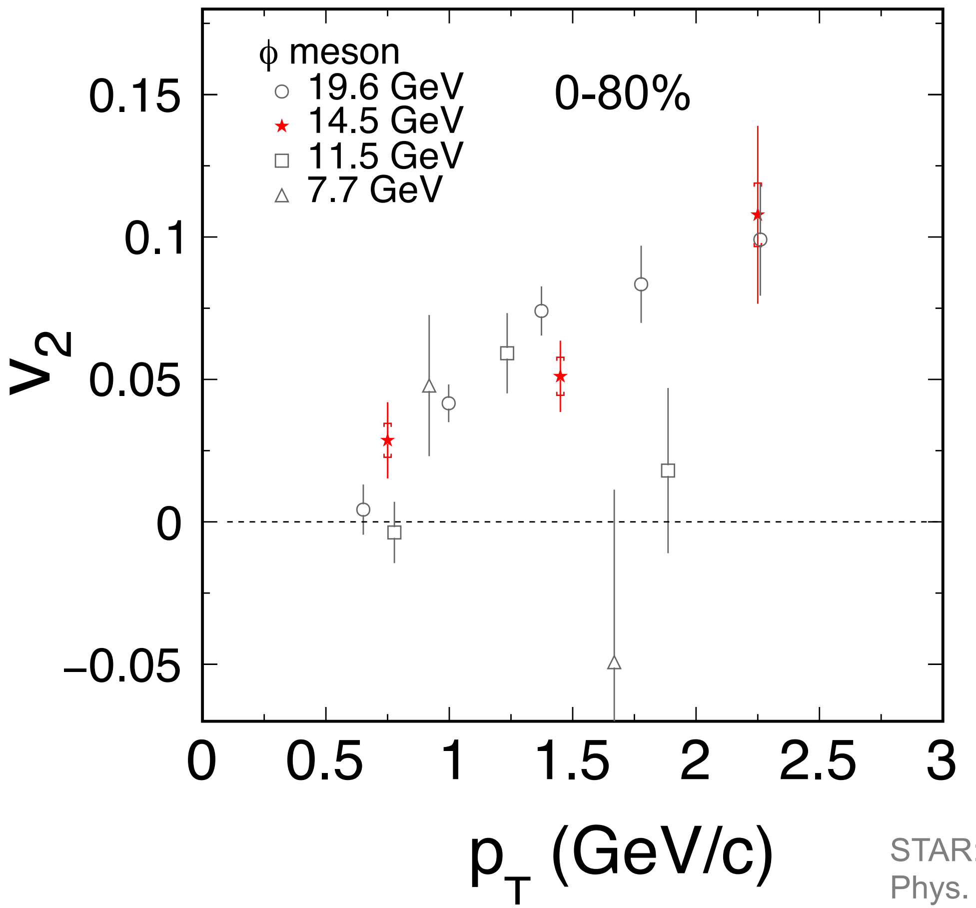
Particle vs. Anti-particle v_2



- **The difference between particles and anti-particles increases with decreasing beam energy – NCQ scaling breaks**
- **Model comparison**
  - Hydro + Transport (UrQMD): consistent with baryon data
  - Nambu-Jona-Lasino (NJL) model (partonic + hadronic potential): hadron splitting consistent

J. Steinheimer, V. Koch, and M. Bleicher PRC86, 44902(2013); J. Xu, et al., PRL112, 012301(2014)

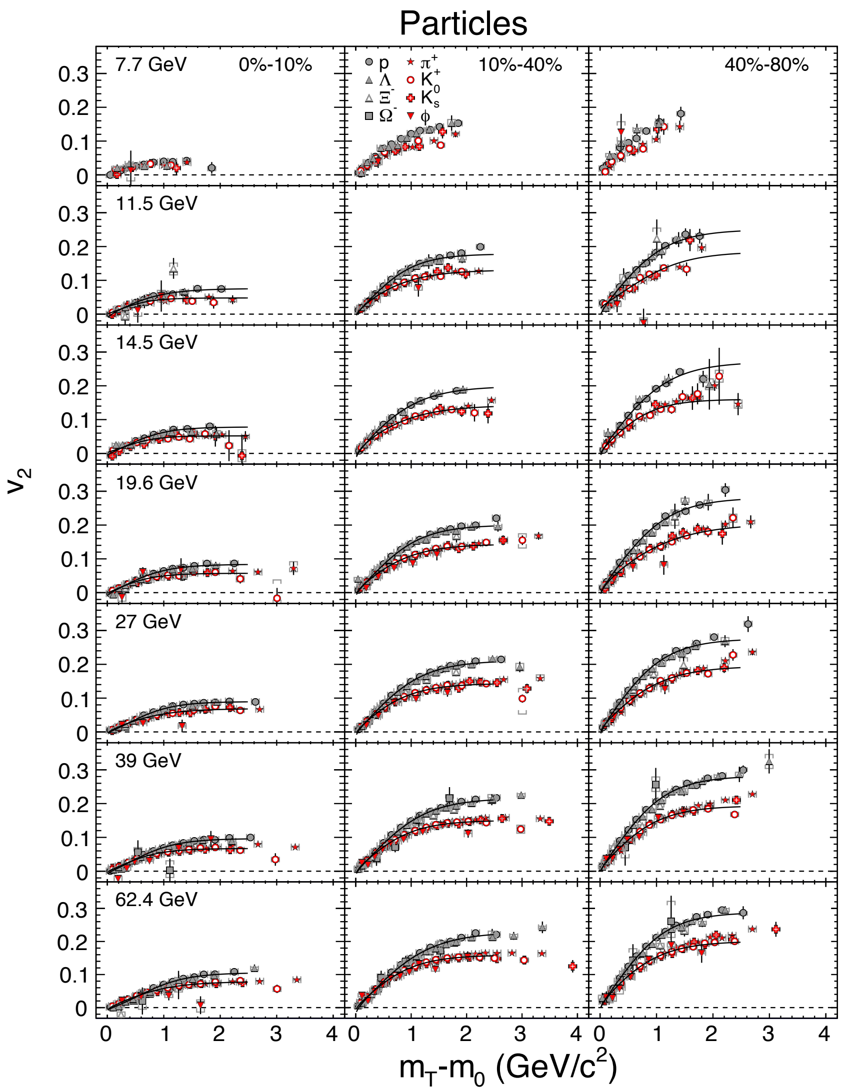
ϕ Meson v_2



- **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)

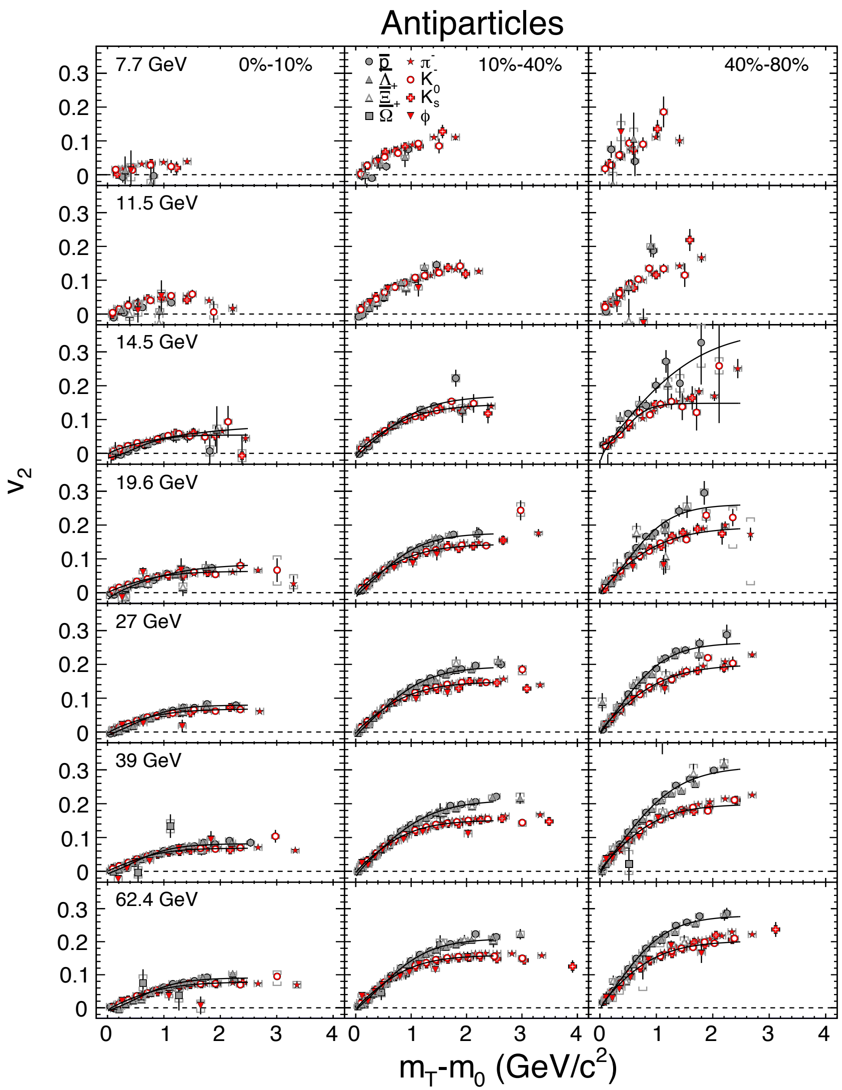
Baryon/Meson Separation



- 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.**

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

Summary

- **Multi-strange hadron v_2 ->**
  Partonic collectivity
- **D meson v_2->**
  Charm quarks flow
  Inferred diffusion coefficient between 2 - 12
- **NCQ scaling->**
  Hadronization mechanism
- **Beam Energy Scan program->**
  Explore the QCD phase structure
  Stay tuned for BES II