
Probe the QCD Phase Boundary with Elliptic Flow in Relativistic Heavy Ion Collisions at STAR

Shusu Shi
for the STAR collaboration

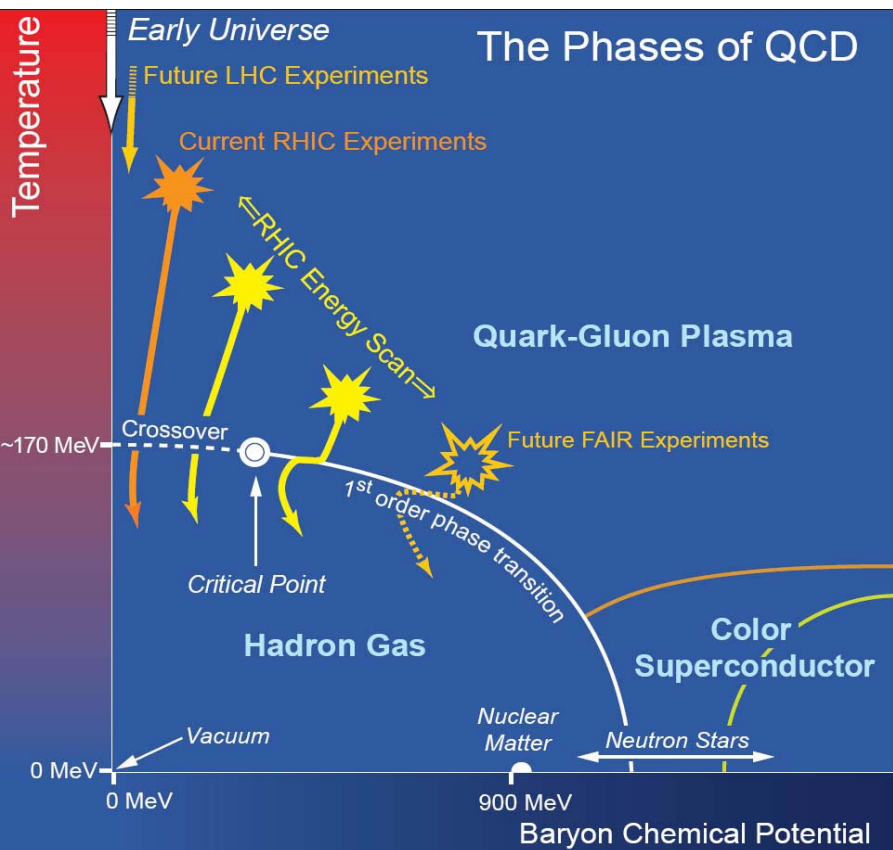
Central China Normal University

Outline

- **Introduction and Motivation**
- **STAR detector and Data analysis**
- **Results and Discussions**
 - v_2 method comparison
 - Energy dependence
 - Model comparison
 - v_2 of particles and anti-particles
 - NCQ scaling test
- **Summary**

Introduction

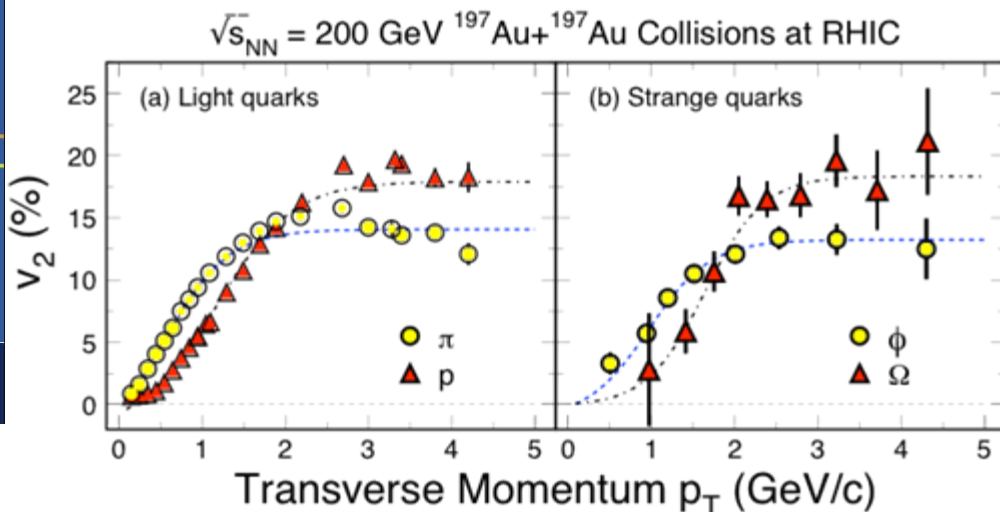
The RHIC Beam Energy Scan (BES)



➤ **BES Motivation**

- **Search for critical point**
- **Search for phase boundary**

Number of Constituent Quark scaling on v_2
partonic vs. hadronic degree of freedom (dof)

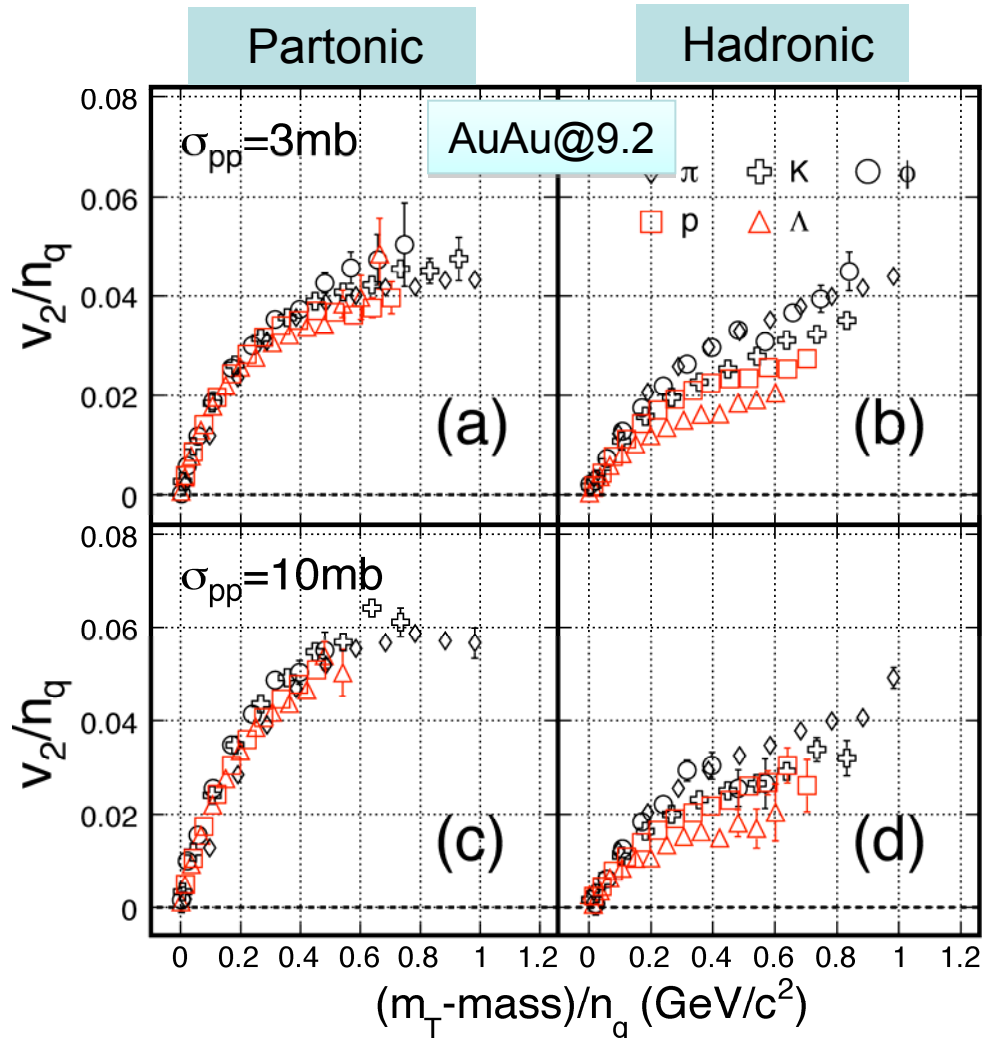


- Data Collected in 2010:**
- 7.7 GeV
 - 11.5 GeV
 - 39 GeV
- Data Collected in 2011:**
- 19.6 GeV
 - 27 GeV

STAR: PRL99, 112301 (2007)
NPA830:187c-190c(2009)
PHENIX: PRL98, 162301 (2007)

STAR Energy Dependence of NCQ Scaling

F. Liu, K.J. Wu, and N. Xu: J. Phys. G **37** 094029(2010)



AMPT model results:

- Scaling in v_2 : partonic dof dominant;
- No scaling in v_2 : hadronic dof dominant

=>

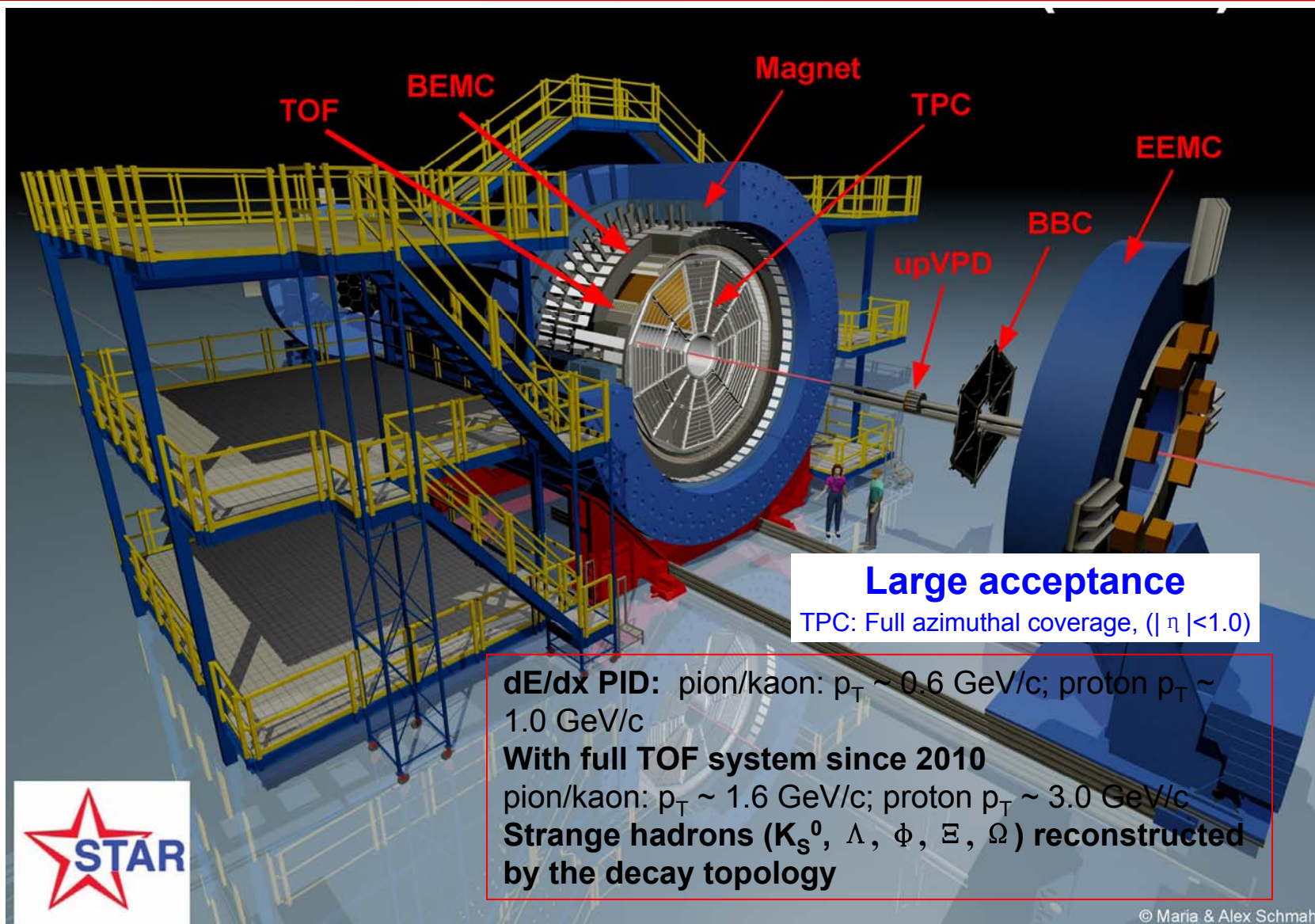
A tool to search for the possible phase boundary!

- The beam energy dependence of the partonic cross sections will not affect the v_2 scaling argument.

=>

Important for Beam Energy Scan program.

STAR Detectors



Large acceptance

TPC: Full azimuthal coverage, ($|\eta| < 1.0$)

dE/dx PID: pion/kaon: $p_T \sim 0.6$ GeV/c; proton $p_T \sim 1.0$ GeV/c

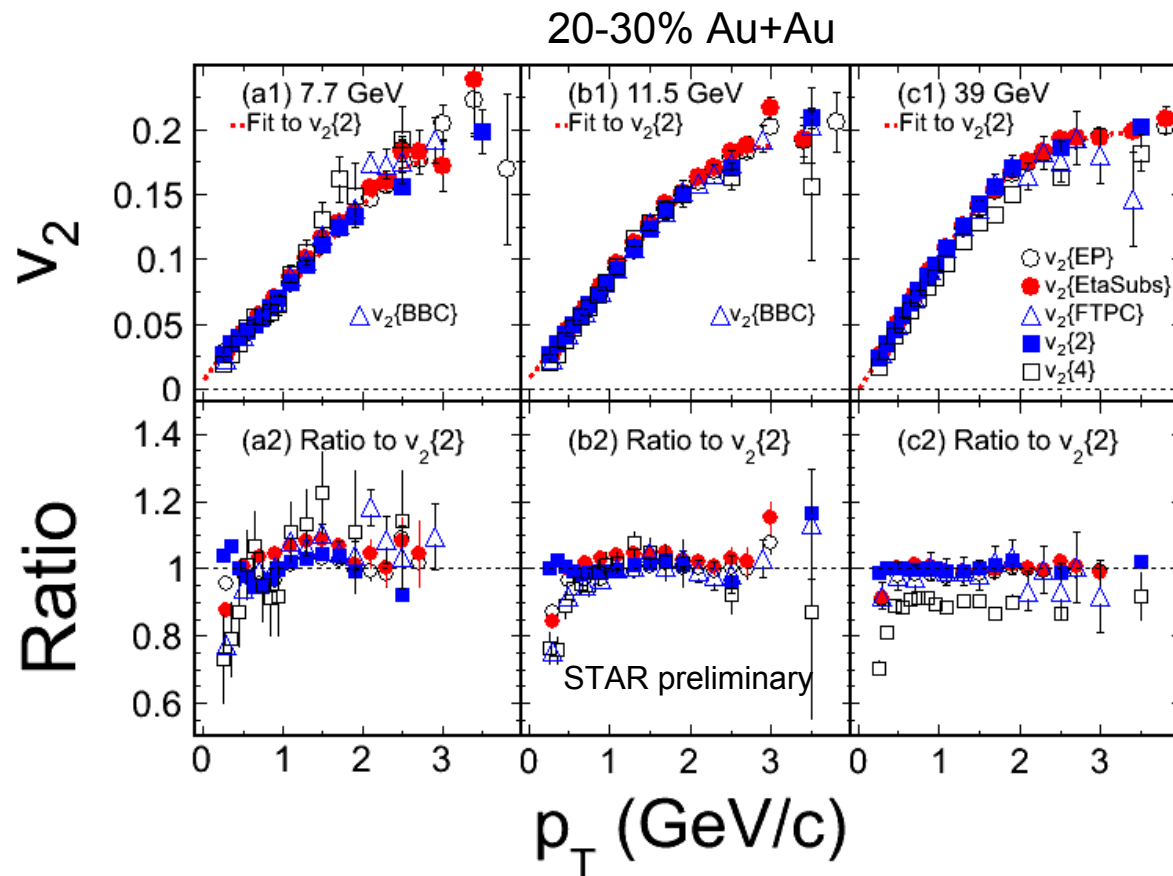
With full TOF system since 2010

pion/kaon: $p_T \sim 1.6$ GeV/c; proton $p_T \sim 3.0$ GeV/c

Strange hadrons (K_S^0 , Λ , ϕ , Ξ , Ω) reconstructed by the decay topology



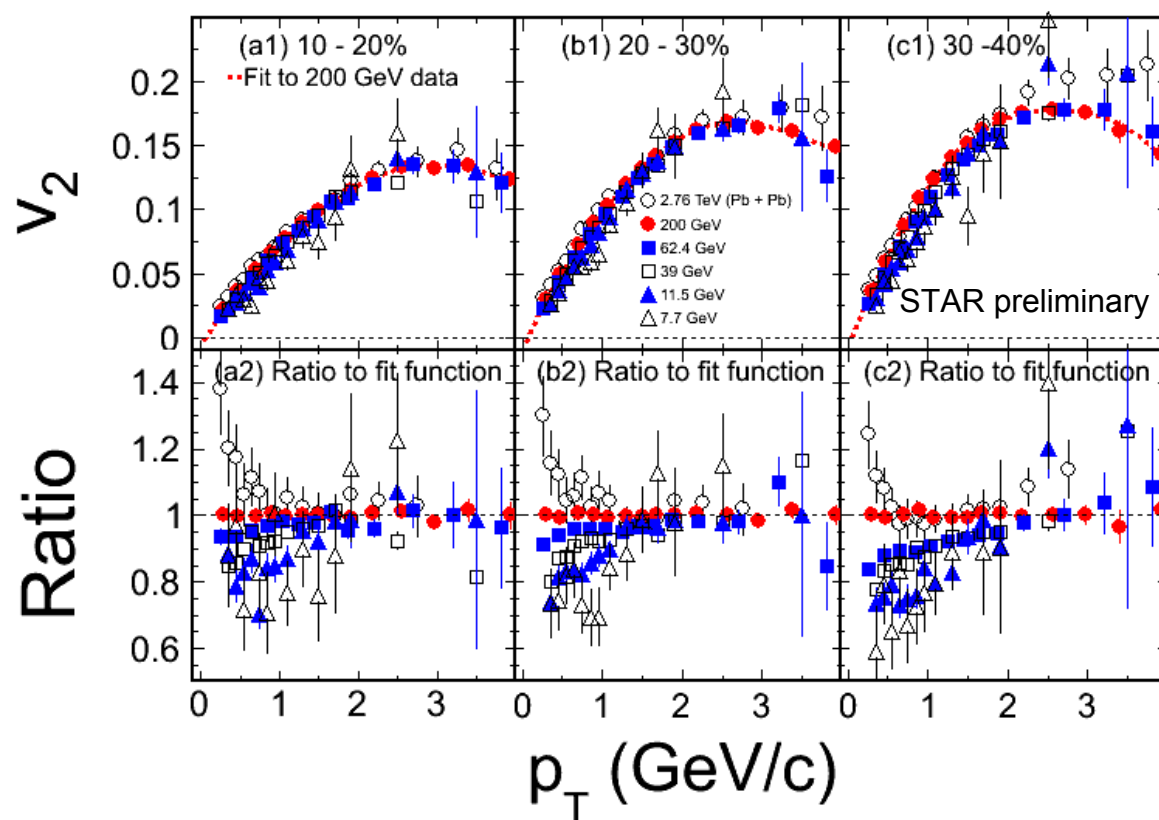
Method Comparison



➤ v_2 method

- Event Plane method
 - TPC EP ($|\eta| < 1.0$)
 - FTPC EP ($2.5 < |\eta| < 4.0$)
 - BBC EP ($3.8 < |\eta| < 5.2$)
 - Cumulant method
 - $v_2\{2\}$, $v_2\{4\}$
 - Different methods show different sensitivity to non-flow and fluctuations
- **The difference between $v_2\{2\}$ and $v_2\{4\}$ decreases with decrease in beam energy**
- non-flow and fluctuations

Energy Dependence

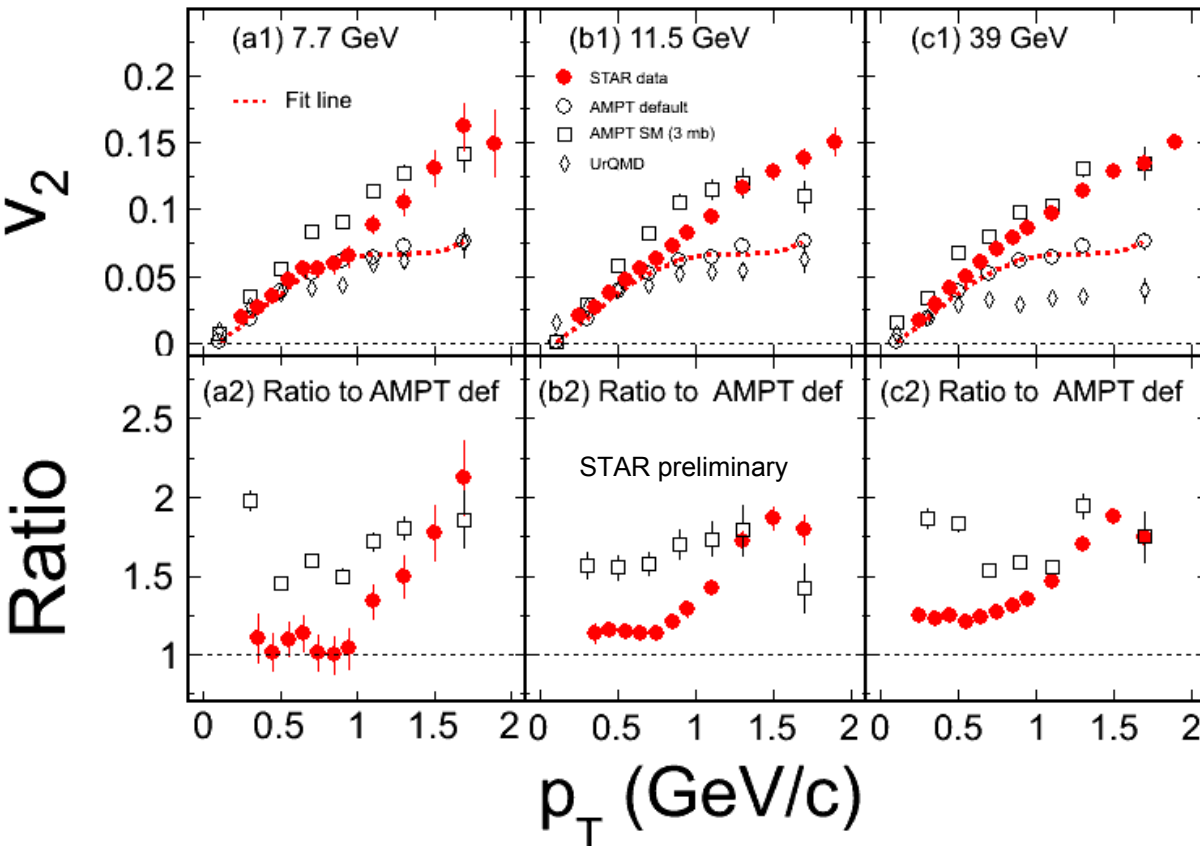


- **$v_2\{4\}$ results**
- Three centrality bins
- **The shape of $v_2(p_T)$ looks similar in all beam energies**
- **$p_T < 2\text{GeV}/c$**
- The v_2 values increase with increase in beam energy

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

Model Comparison

$v_2\{4\}$, 20-30% Au+Au

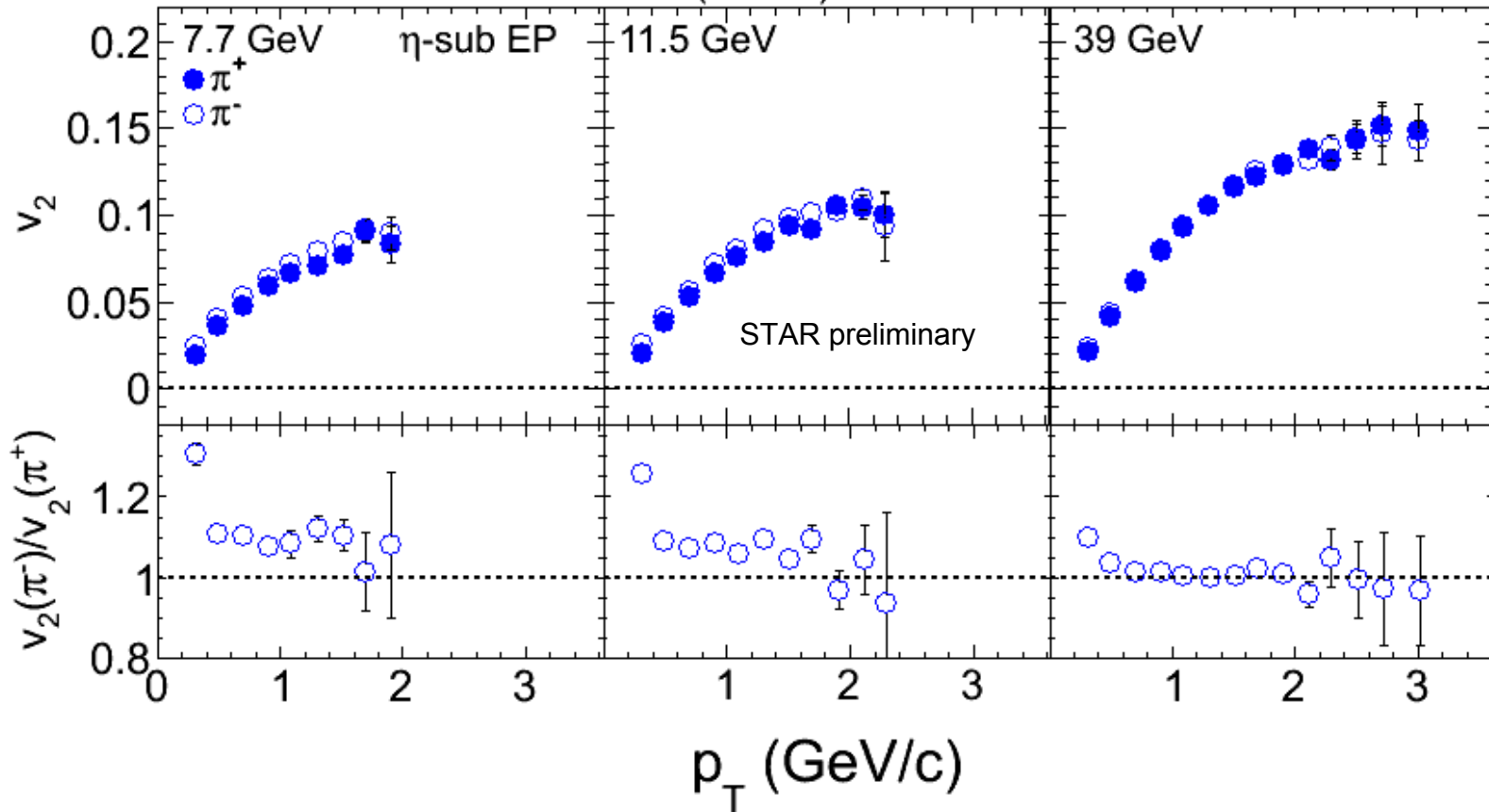


- The data at 11.5 and 39 GeV fall between UrQMD and AMPT model incorporating additional partonic interactions for partonic cross section of 3 mb.
- The AMPT default version and UrQMD explains the data at 7.7 GeV fairly well when $p_T < 1$ GeV/c
- The data is closer to the AMPT default and UrQMD models in the lower beam energy.

-> Hadronic interactions are more dominant in the lower beam energy

π^+ vs. π^-

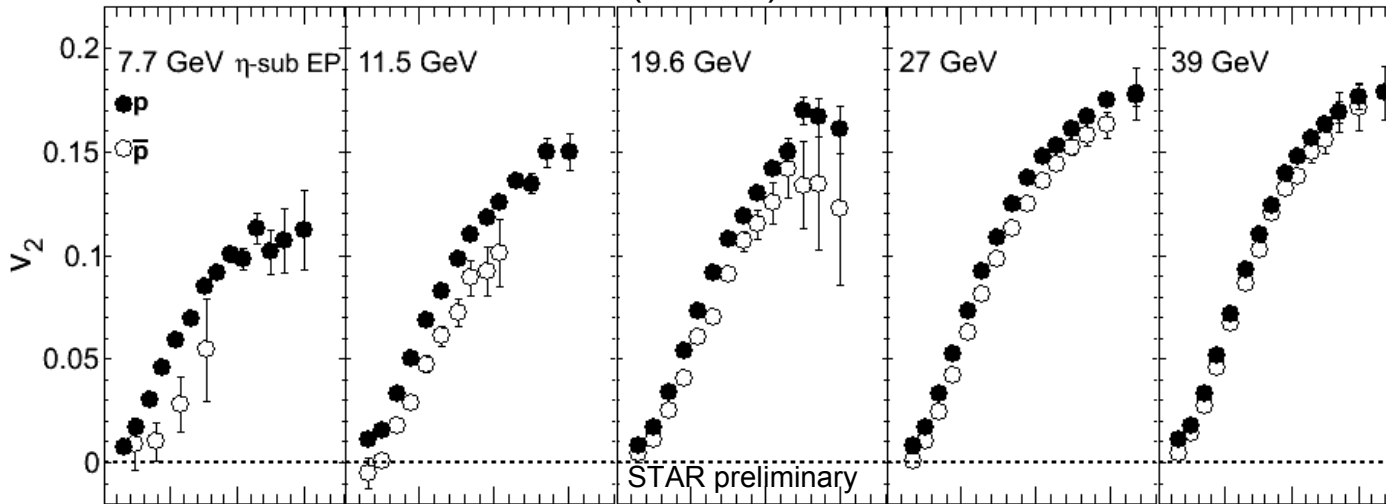
(0-80%) Au+Au



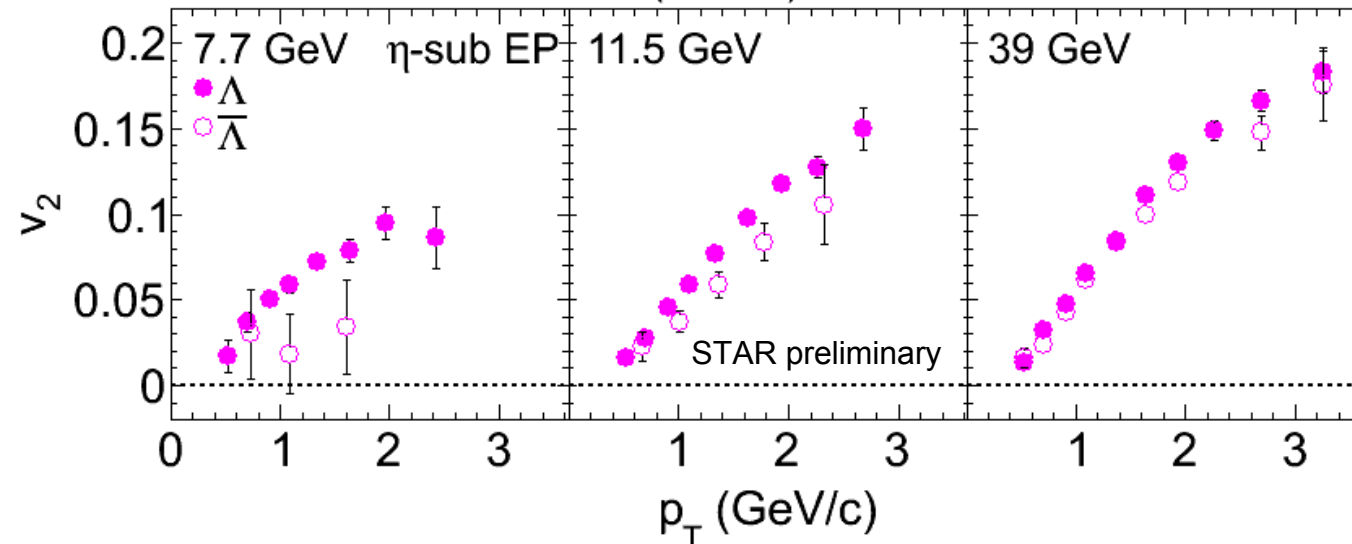
- $v_2(\pi^-) > v_2(\pi^+)$ in Au + Au collisions at 11.5 and 7.7 GeV
- Same magnitude of v_2 at 39 GeV

p (Λ) vs. Anti-p (Λ)

(0-80%) Au+Au



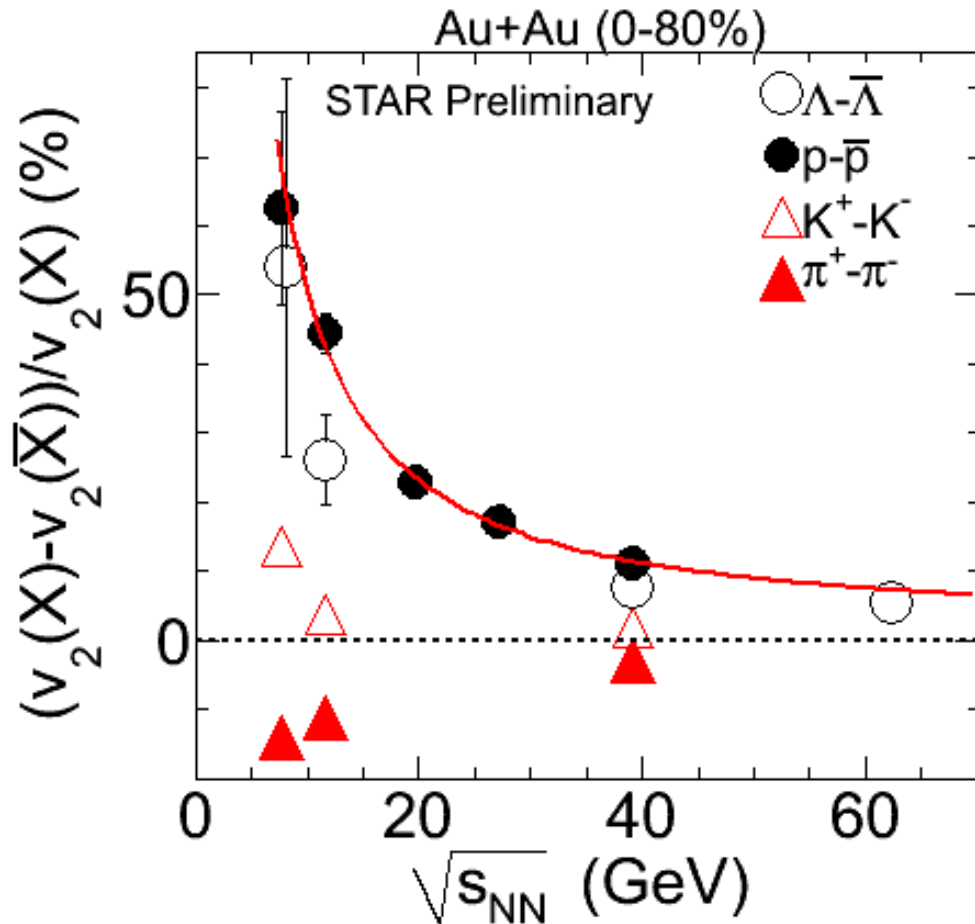
➤ $v_2(p) > v_2(\text{anti-p})$ at all energies, The difference is increasing as beam energy decreasing



➤ Similar trend observed for Λ and anti- Λ

Particles vs. Anti-particles

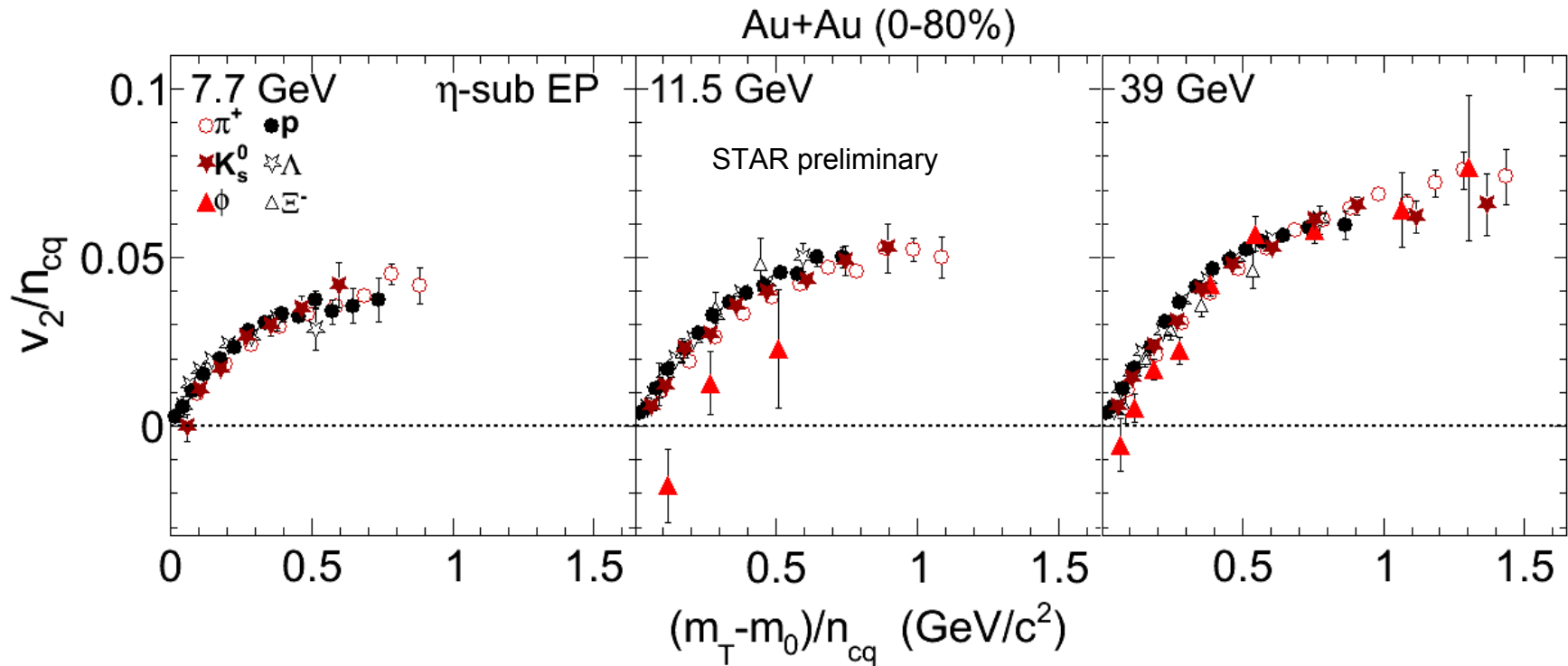
STAR AuAu@62.4: Phys.Rev.C75, 054906 (2007)



- **Beam energy ≥ 39 GeV**
 - Baryon and anti-baryon v_2 consistent within 10%
 - Almost no difference for meson
- v_2
- **Beam energy < 39 GeV**
 - The difference of baryon and anti-baryon v_2
 - *Increasing with decrease of beam energy*
 - $v_2(K^+) > v_2(K^-)$ at 7.7 GeV
 - $v_2(\pi^-) > v_2(\pi^+)$ at 7.7, 11.5 GeV
- **Possible explanation**
 - Baryon transport to mid-rapidity?
ref: arXiv:1107.3078
 - Absorption in hadronic environment?

The difference between particles and anti-particles is observed

NCQ Scaling Test: $m_T - m$



- Universal trend for most of particles
 - ϕ meson v_2 deviates from other particles in Au+Au@11.5 GeV:
Mean deviation from pion distribution: 0.02 ± 0.008 ($\rightarrow 2.6 \sigma$)
- Small or zero v_2 for ϕ meson \rightarrow without formation of partonic matter*
- Hadronic interactions are dominant when $\sqrt{s_{NN}} \leq 11.5$ GeV*

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

Summary

- The v_2 of charged hadron in the lower beam energy is closer to AMPT default and UrQMD models
Hadronic interactions are more dominant in lower beam energy
- The difference between particles and anti-particles increases with decrease of beam energy
- ϕ meson deviates the trend of other particles at 11.5 GeV: Mean deviation from pion distribution: 2.6σ
Hadronic interactions are dominant when $\sqrt{s_{NN}} \leq 11.5$ GeV

Outlook

- The v_2 of strange hadrons (K_S^0 , Λ , ϕ , Ξ , Ω) in Au+Au collisions at 19.6 and 27 GeV will come soon