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

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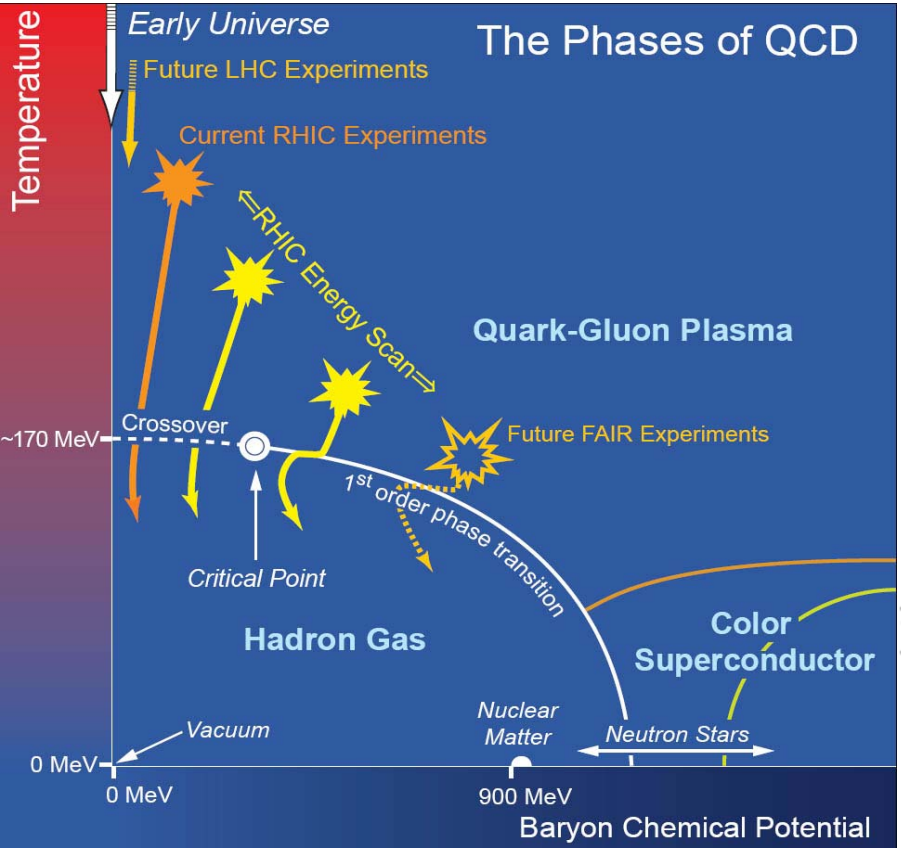
Outline

- **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

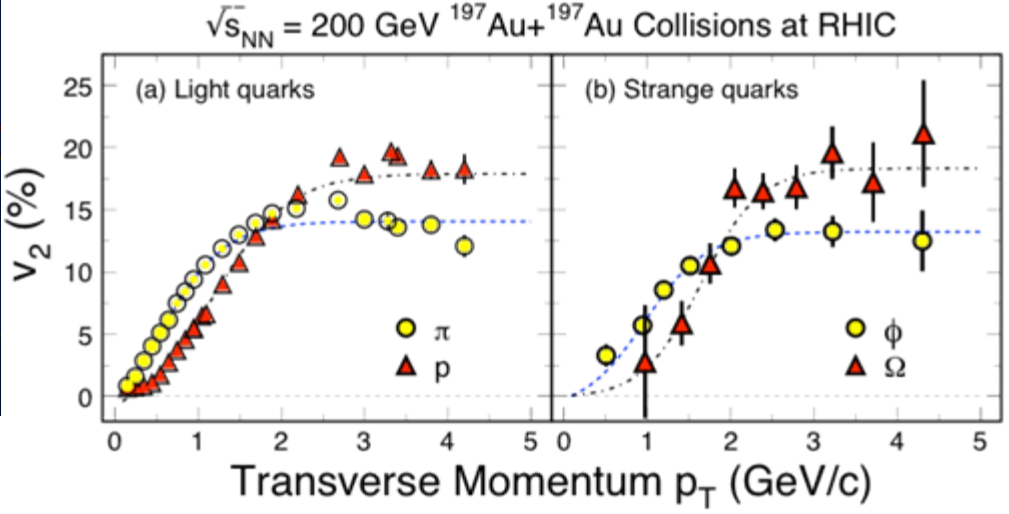
The RHIC Beam Energy Scan (BES)



- **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)



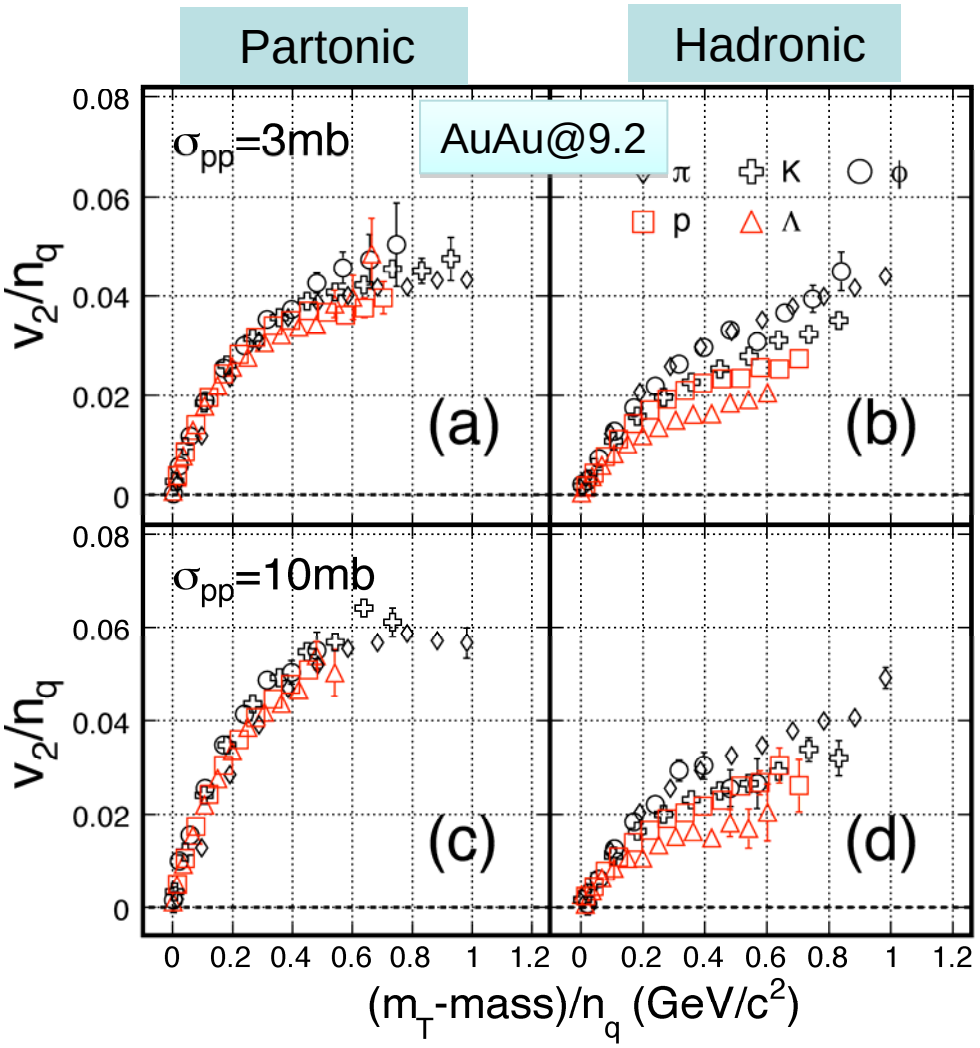
Data Collected in 2010:
- 7.7 GeV
- 11.5 GeV
- 39 GeV

Data Collected in 2011:
- 19.6 GeV
- 27 GeV

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

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

=>

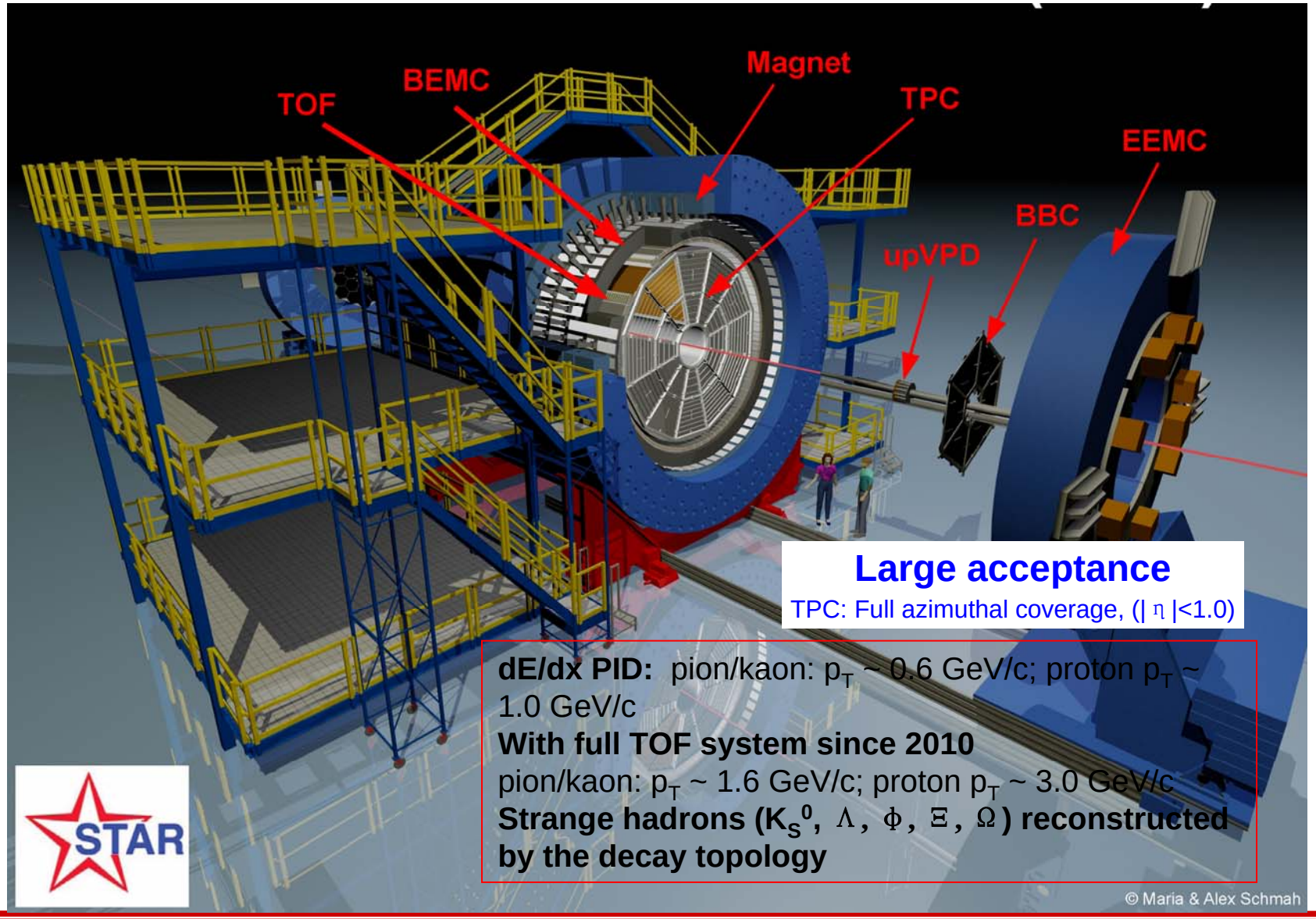
A tool to search for the possible phase boundary!

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

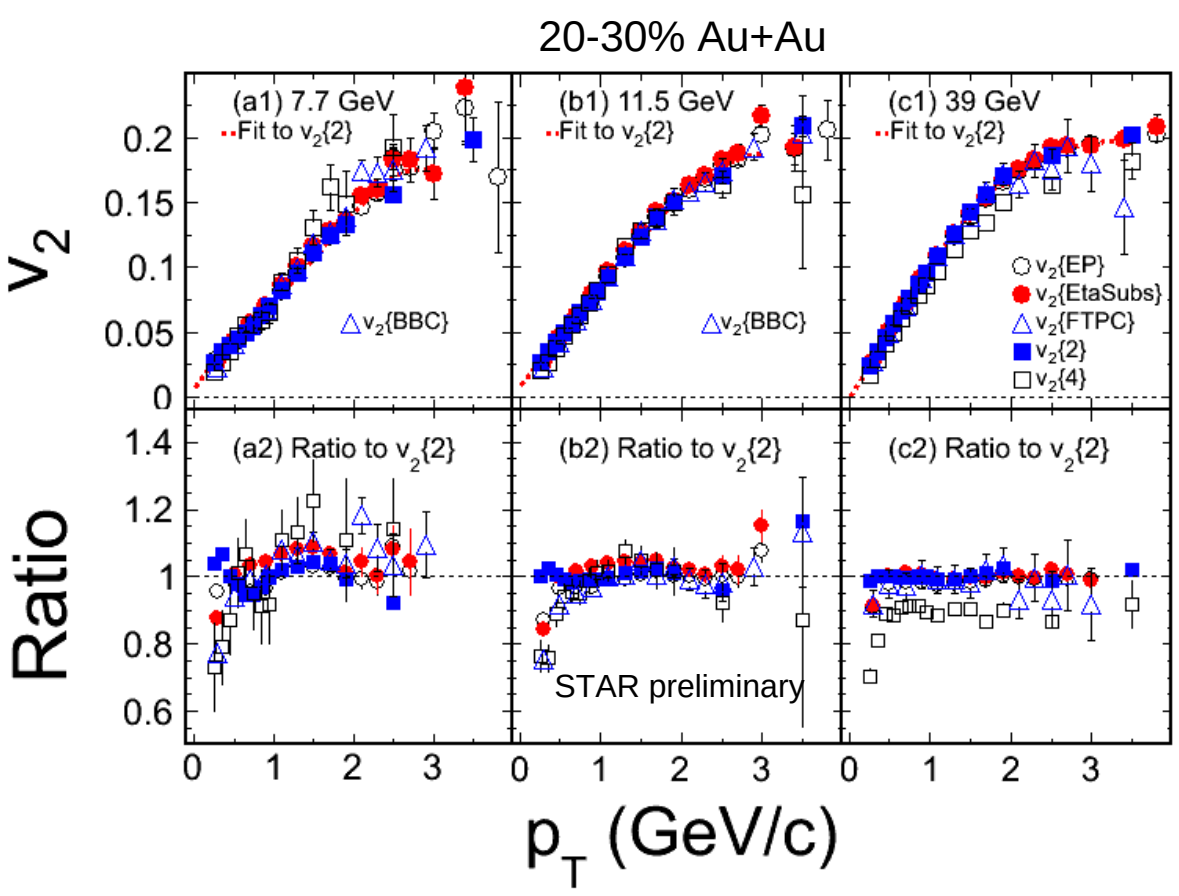
=>

Important for Beam Energy Scan program.

STAR Detectors

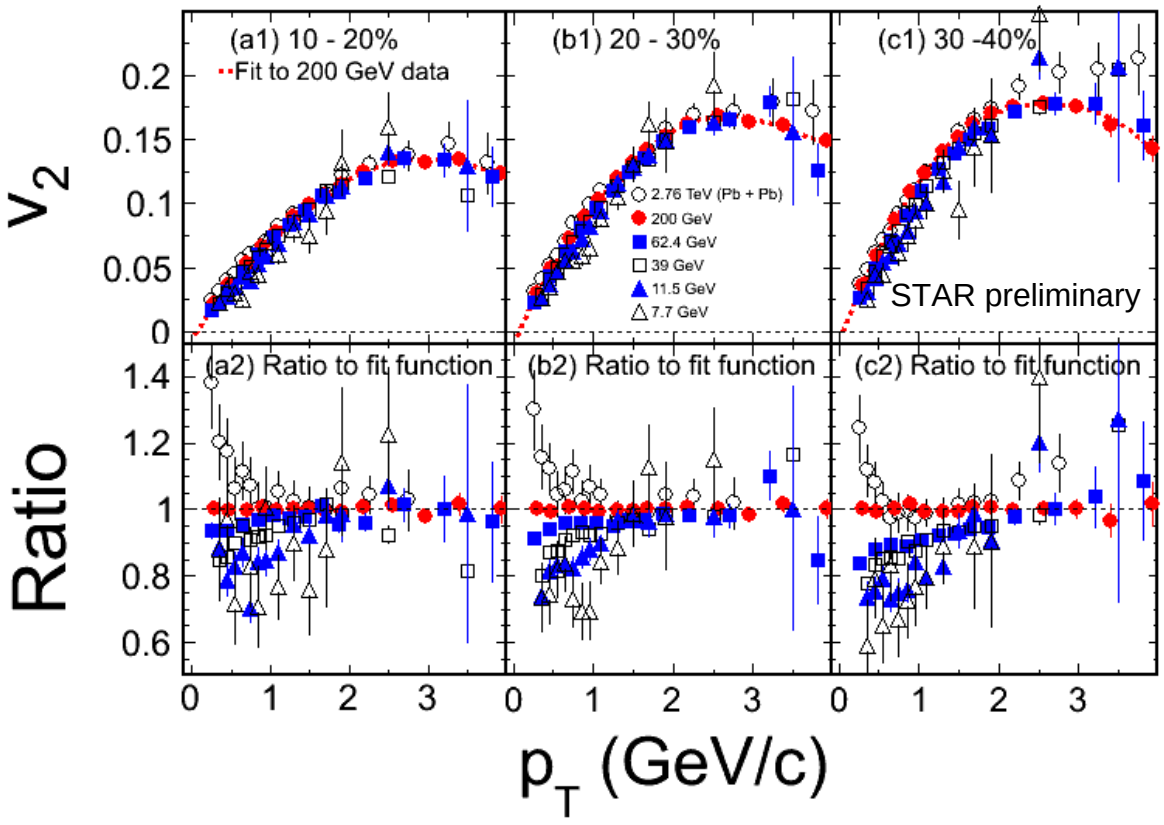


Method Comparison



- **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

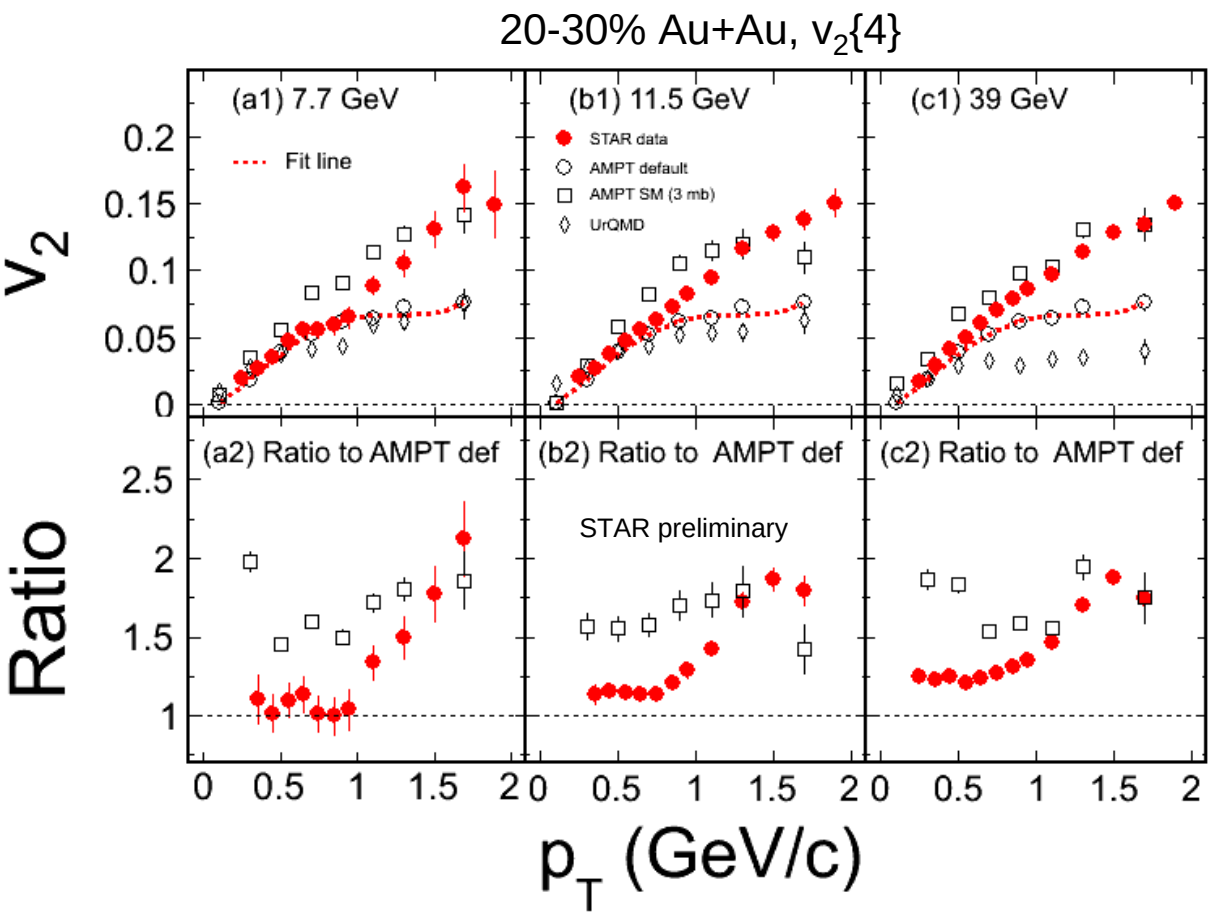
Energy Dependence



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

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

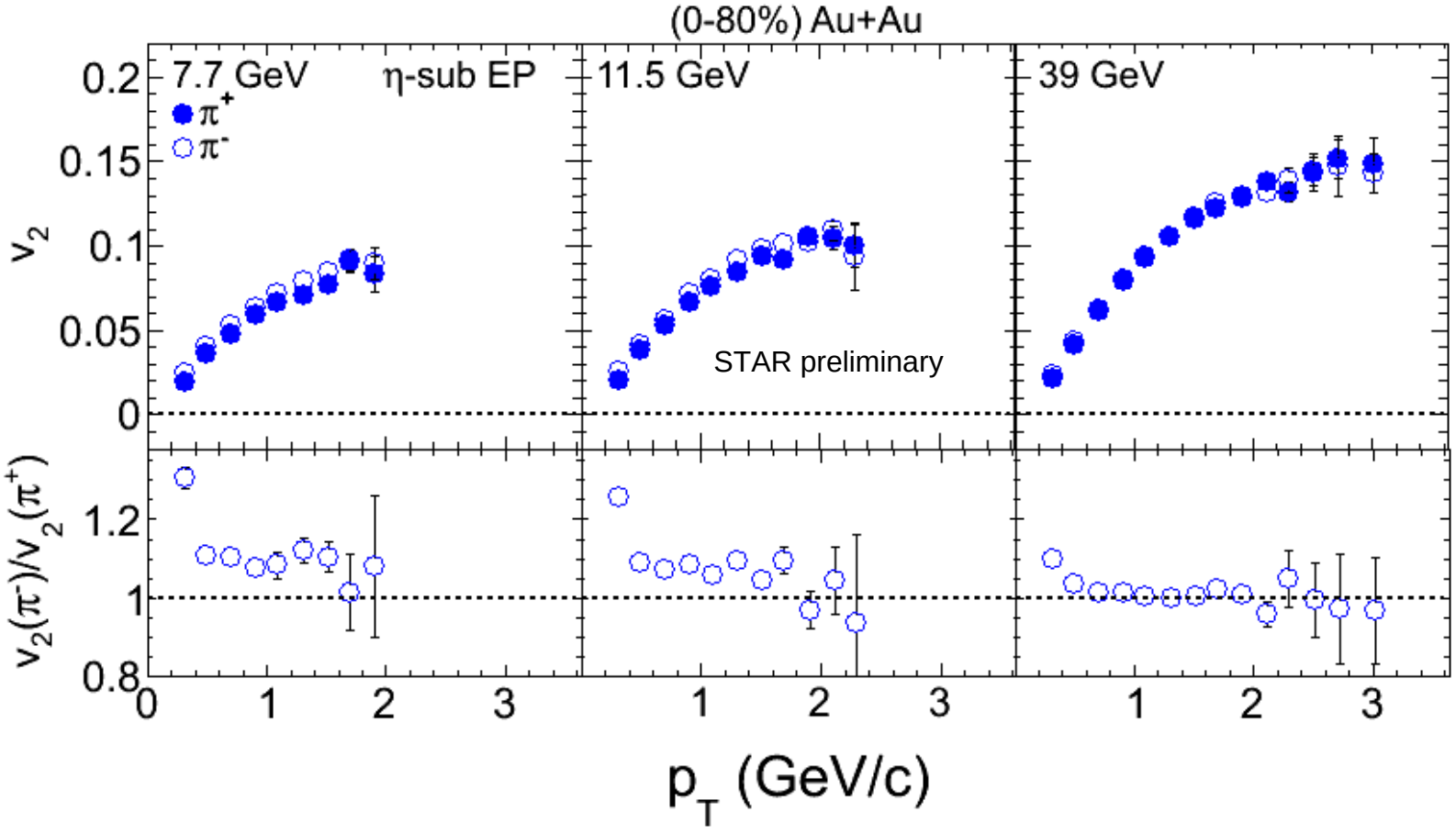
Model Comparison



- 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 pT < 1 GeV/c
- The data is closer to the AMPT default and UrQMD models in the lower beam energy.

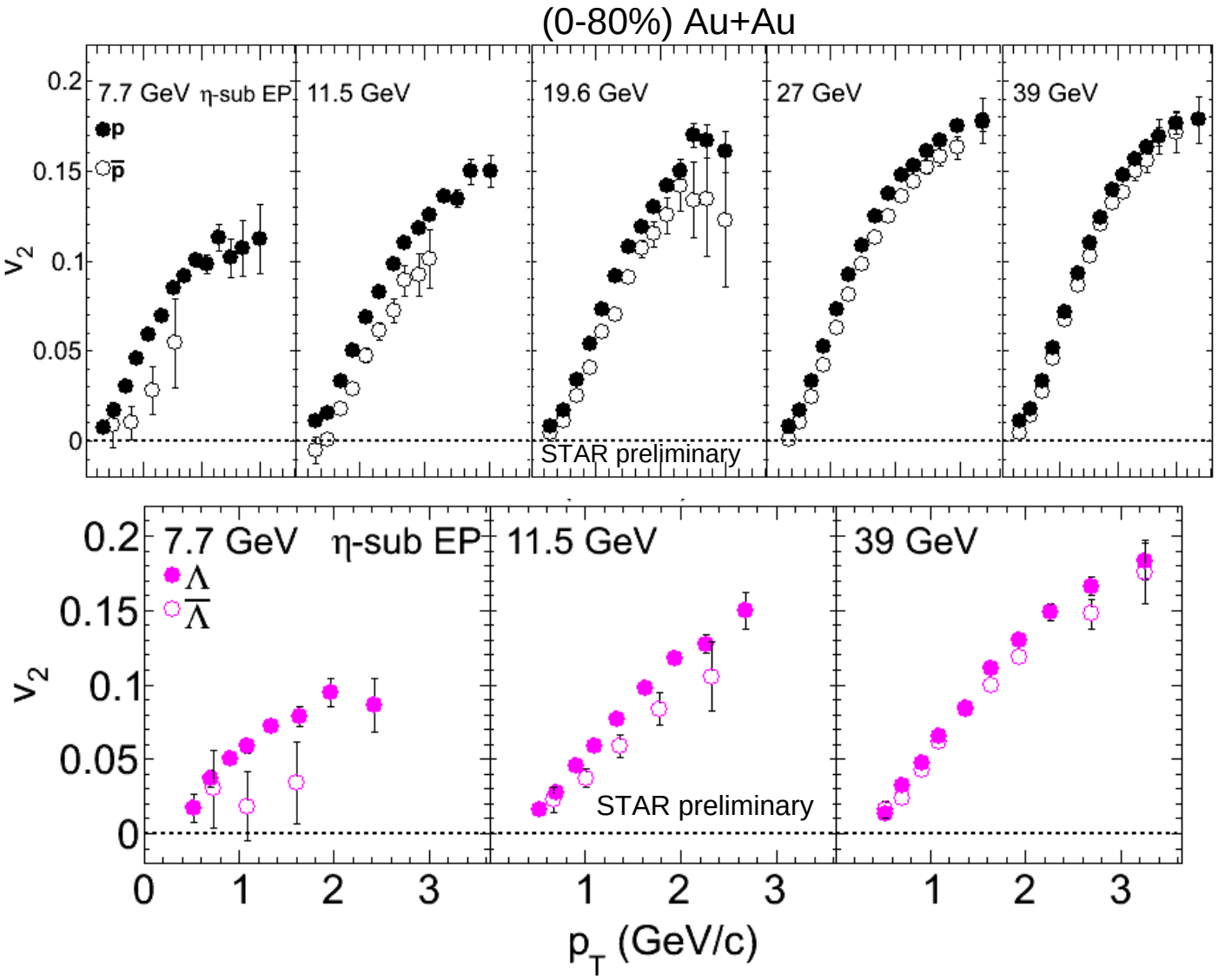
-> Hadronic interactions are more dominant in the lower beam energy

π^+ vs. π^-



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

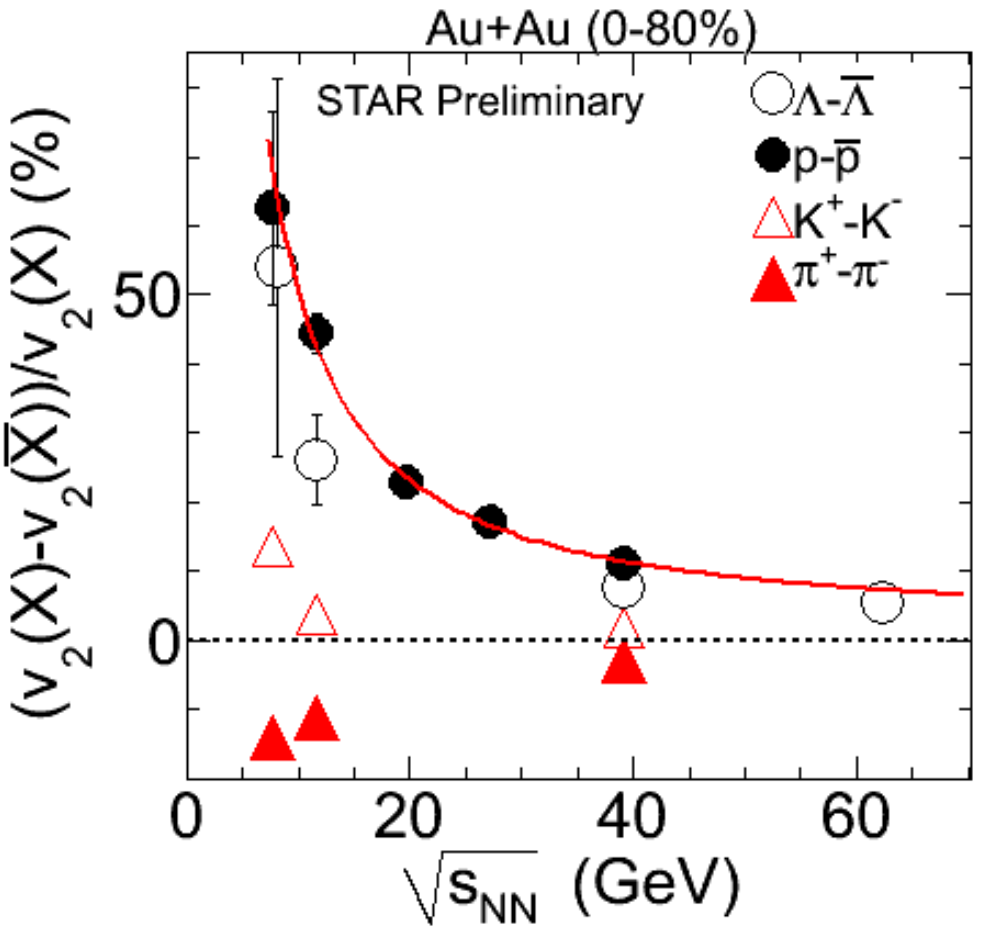
p (Λ) vs. Anti-p (Λ)



- $v_2(p) > v_2(\text{anti-p})$ at all energies, The difference is increasing as beam energy decreasing
- Similar trend observed for Λ and anti- Λ

Particles vs. Anti-particles

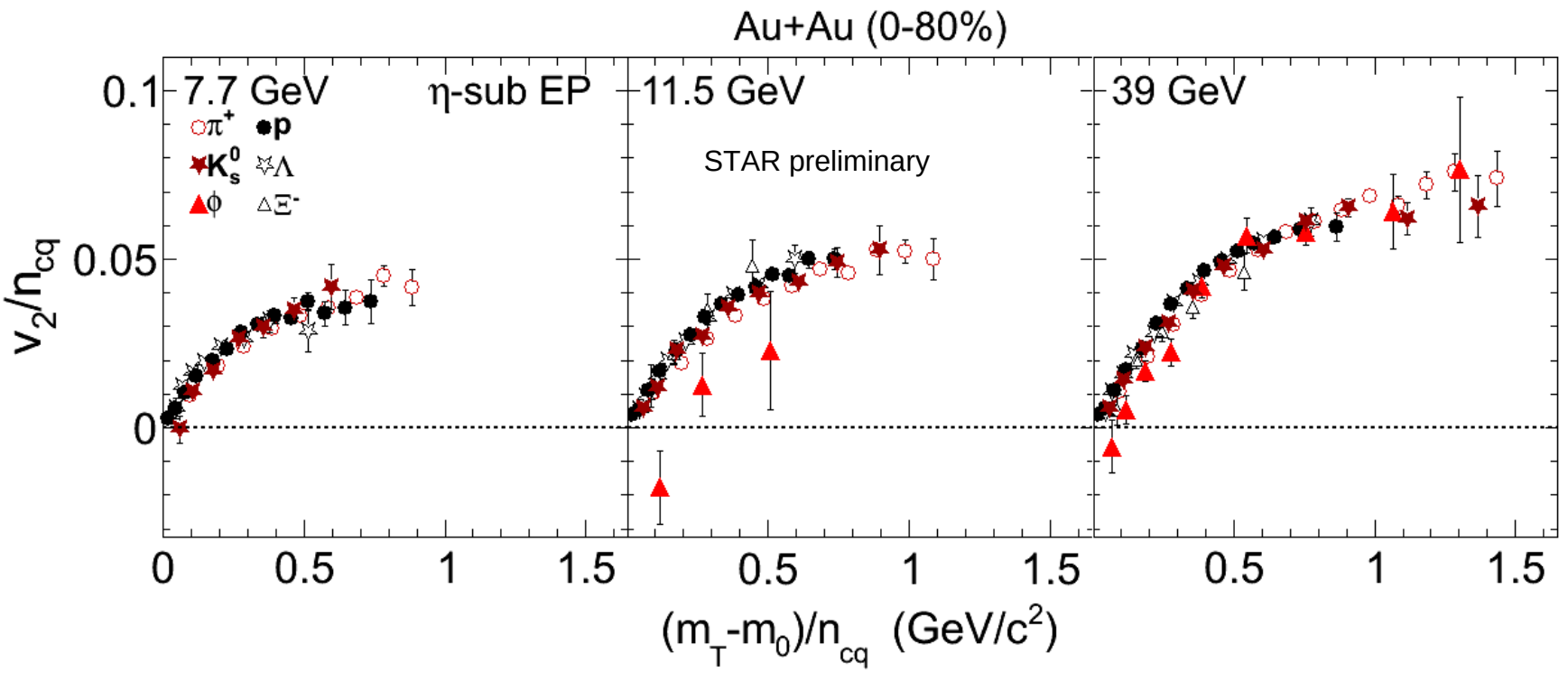
STAR AuAu@62.4: Phys.Rev.C75, 054906 (2007)



- ➢ **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 σ)

Small or zero v_2 for ϕ meson -> without formation of partonic matter
Hadronic interactions are dominant when $\sqrt{s_{NN}} \leqslant 11.5$ 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: 2.6 σ

  Hadronic interactions are dominant when $\sqrt{s_{NN}} \leqslant 11.5$ 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