Elliptic flow results from STAR

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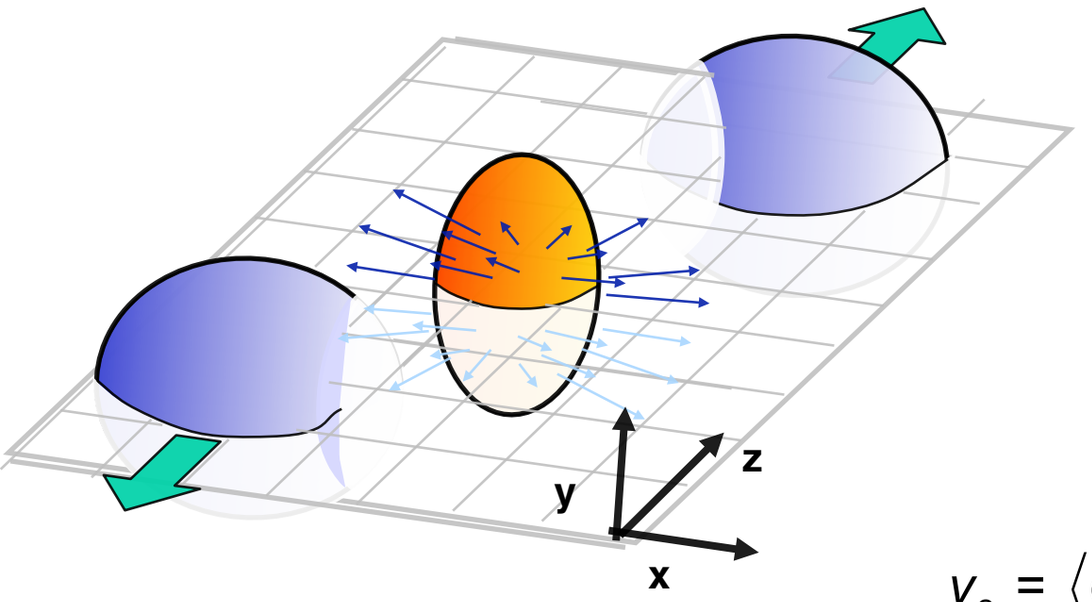
RHIC&AGS Users‘ Meeting - BNL - June 2010

Outline

1. Introduction.
2. The STAR experiment.
3. Search for signals in the energy and system size dependence of elliptic flow to study the phase diagram of strongly interacting matter
    a. Looking for signatures for the partonic degrees of freedom (PDoF)
    b. Phase transition (PT): Softest Point of the EoS
4. Summary and Conclusions.

Elliptic Flow



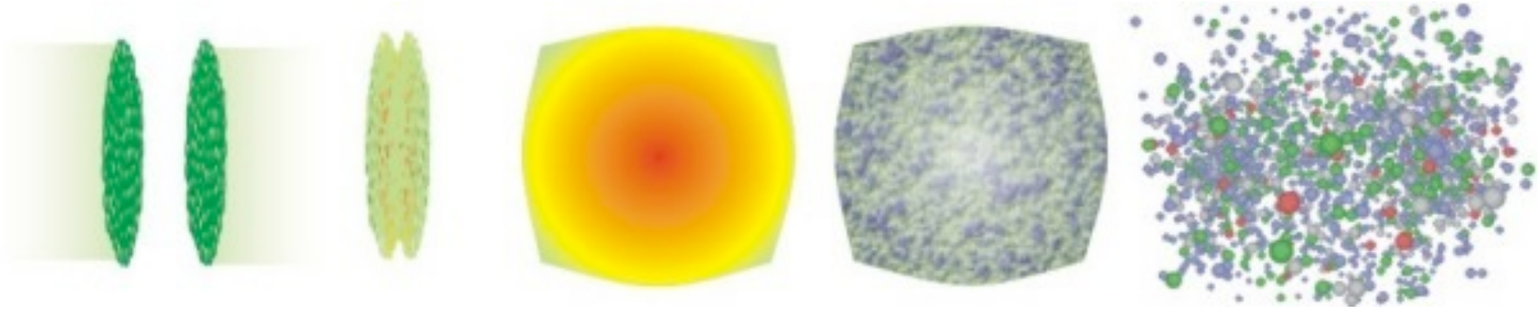
$$\varepsilon = \frac{\langle y^2 - x^2 \rangle}{\langle y^2 + x^2 \rangle}$$

$$v_2 = \langle \cos 2\phi \rangle, \; \phi = \tan^{-1}\left(\frac{p_y}{p_x}\right)$$

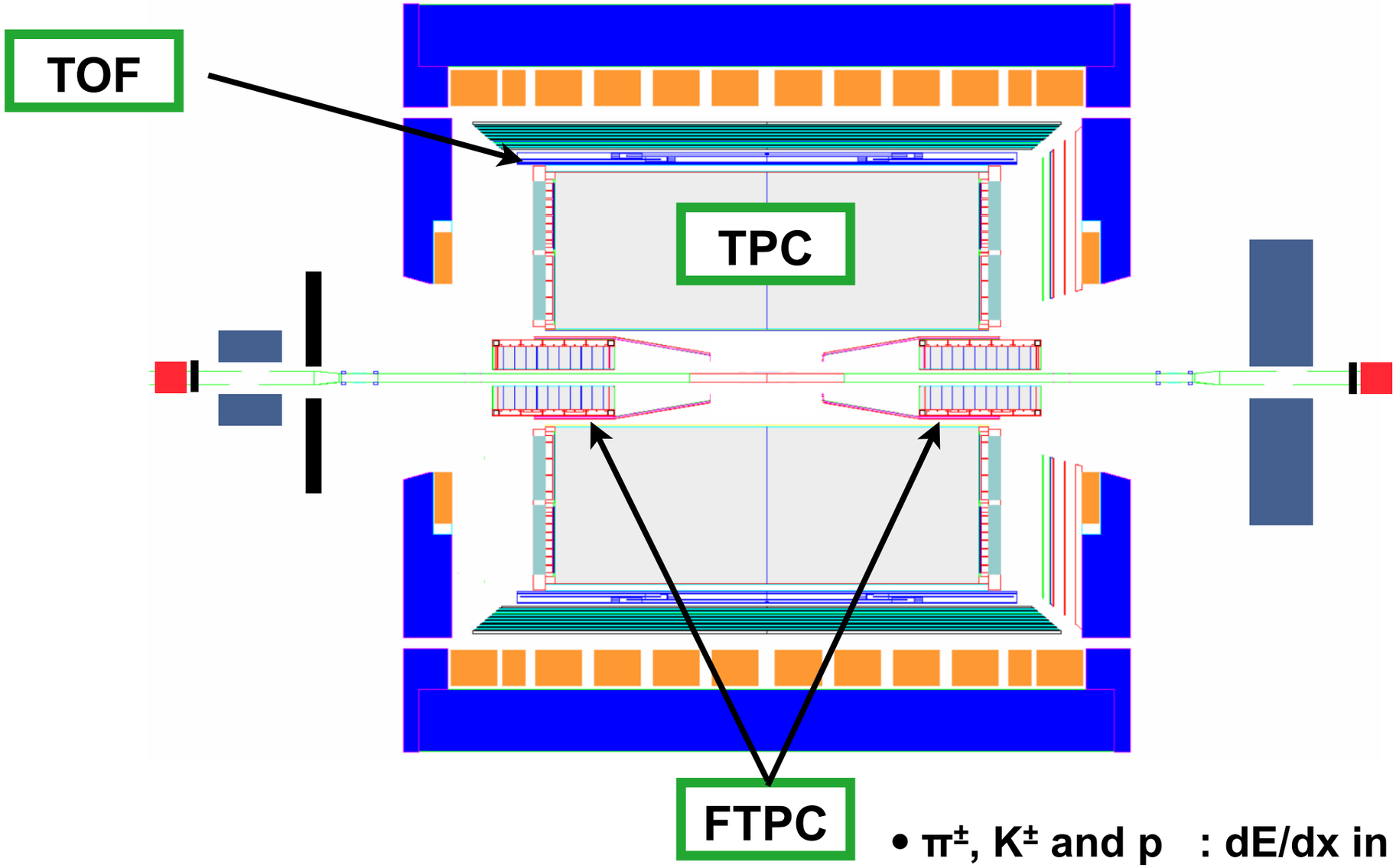
- **In non central collisions the coordinate space configuration is anisotropic, but the initial momentum distribution is isotropic.**
- **Interaction among constituents generate a pressure gradient which transforms the initial coordinate space anisotropy into the observed momentum space anisotropy → anisotropic flow**
- **Elliptic flow is sensitive to the early stage of collision dynamics.**

  ⇒ A unique hadronic probe of the early stage

Heavy Ion collision → Partonic phase → Hadronic phase



The STAR Experiment



- TPC: Q, $\vec{x}$, $\vec{p}$, dE/dx
- TOF: time of flight

STAR Ref.: K. H. Ackermann et al.: NIM A 499 (2003) 624

- $\pi^{\pm}$, $K^{\pm}$ and p : dE/dx in TPCs
- K^0_s, Λ, Ξ, Ω : decay topology + inv. mass. + dE/dx
- φ : inv. mass. + dE/dx

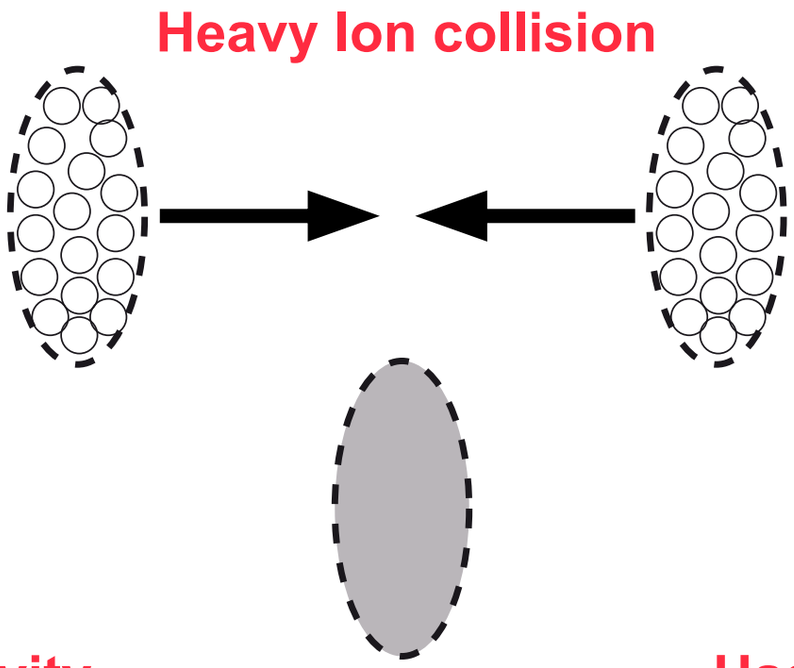
Scenarios for Partonic Matter and Phase Transition

a) Partonic degrees of freedom

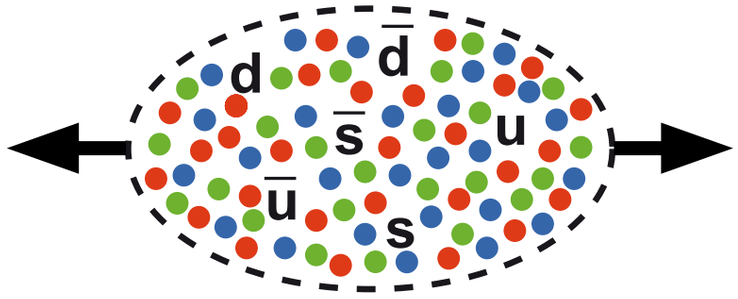
- Do we see partonic collectivity at top RHIC energies?
- Does ideal hydrodynamic work at RHIC energies?
- Is NQ scaling only a geometry effect?

b) Phase transition

Partonic Collectivity

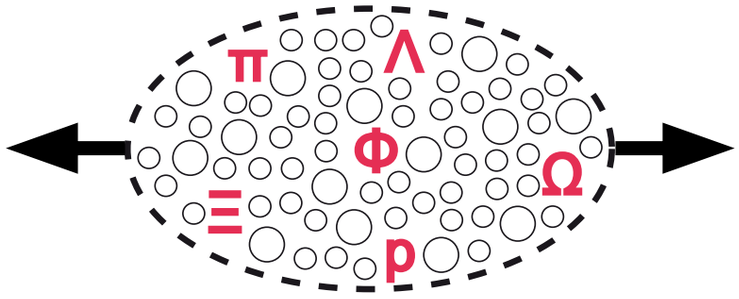


Partonic collectivity



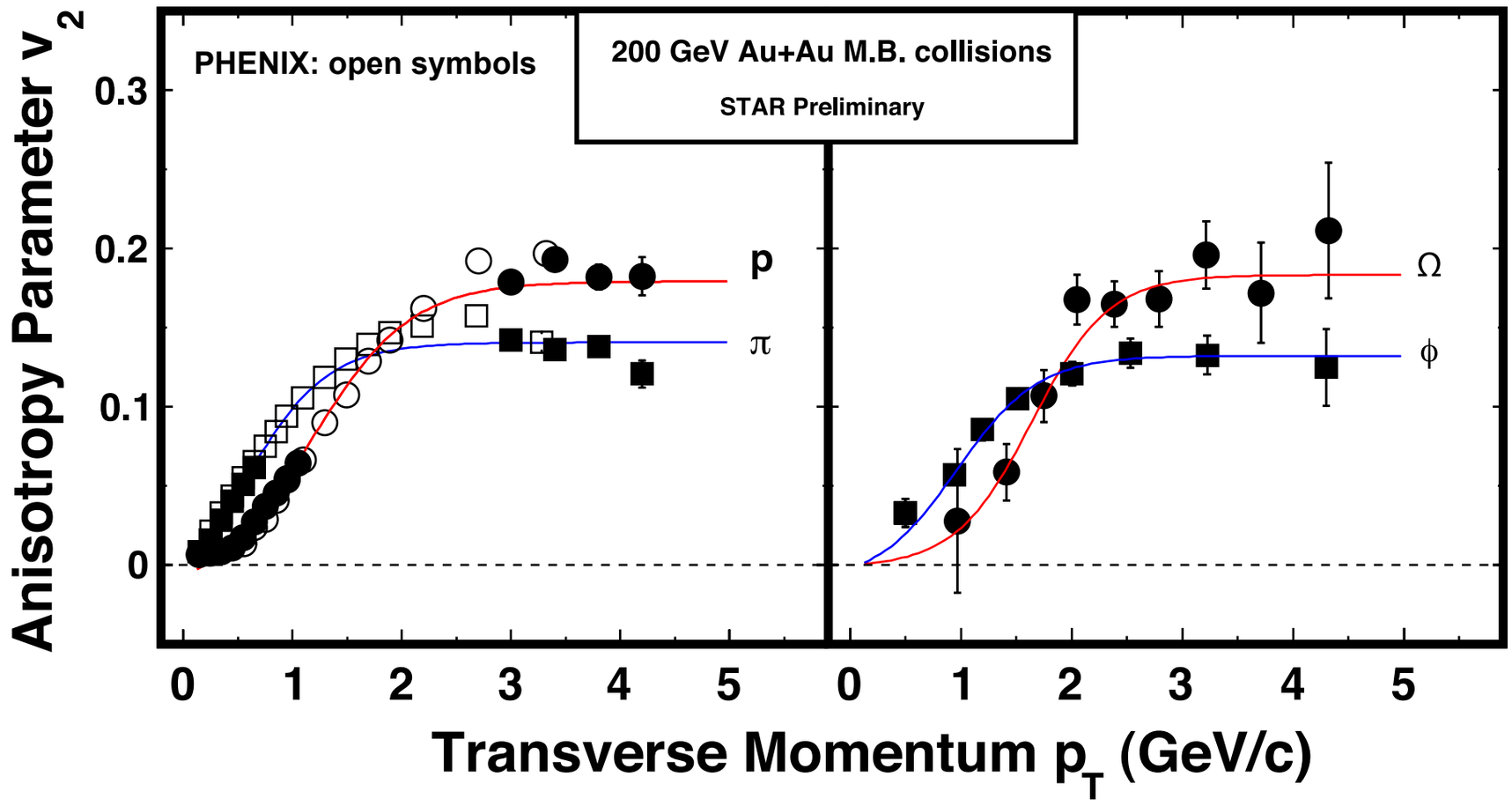
- Collectivity develops on the quark level and persists on the hadron level after hadronization.

Hadronic collectivity



- Collectivity develops on the hadronic level and will be different for every hadron species due to their cross-section.

Partonic Collectivity



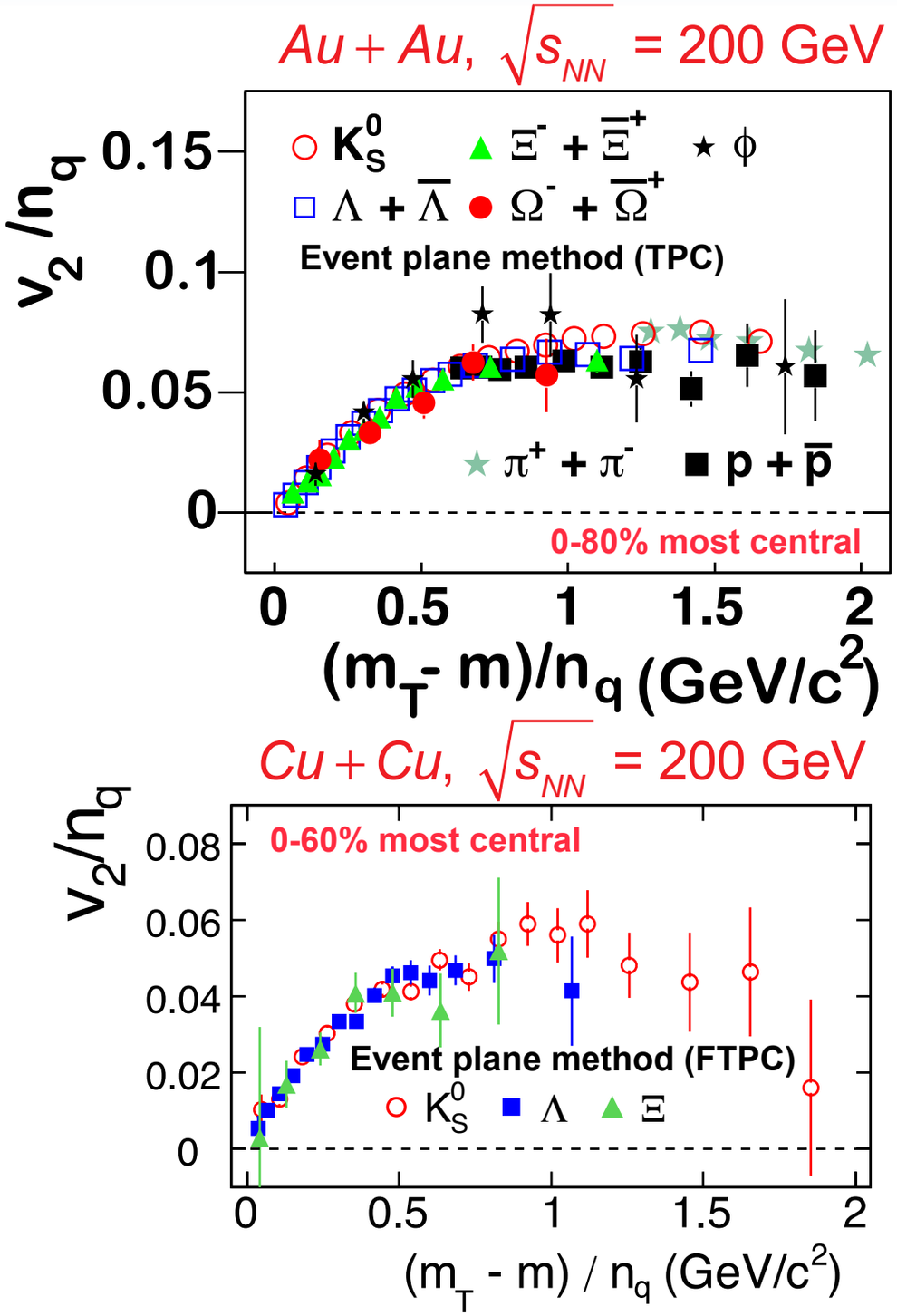
- At low p_t (≤ 2 GeV/c) hadronic mass ordering effect is visible.
- At high p_t (> 2 GeV/c) number of quarks ordering.

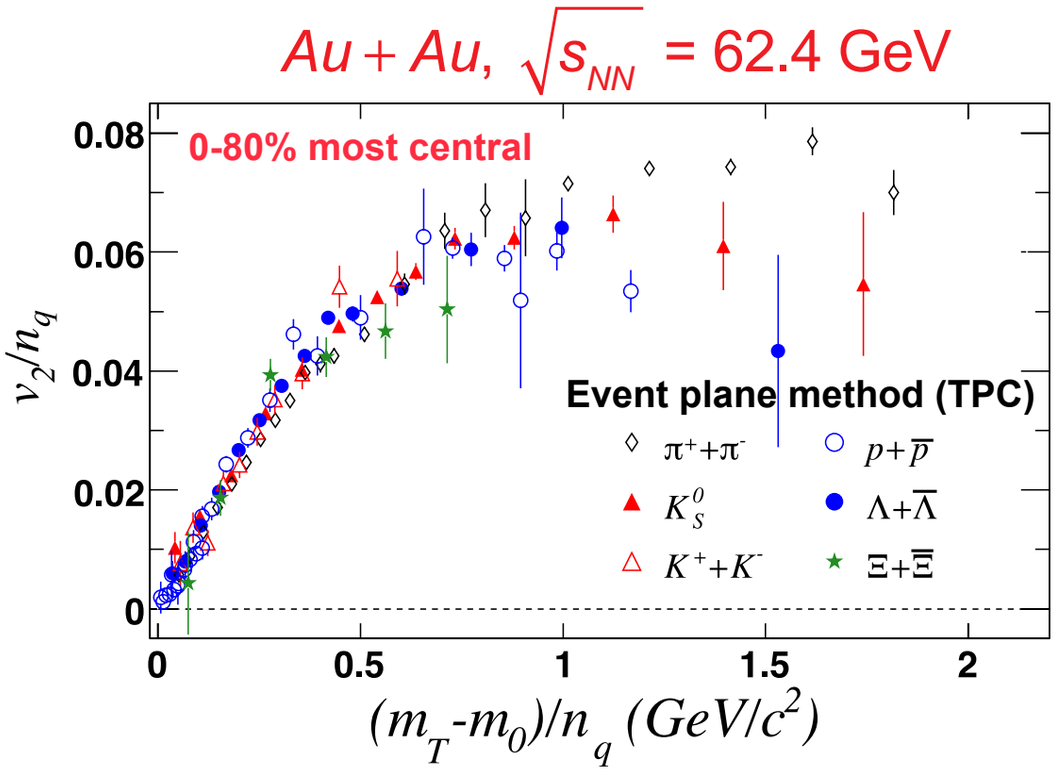
  ⇒ Collectivity develops at the partonic stage

STAR Ref.: S. Shi for the STAR Collaboration: NPA 830 (2009) 187

PHENIX: Issah and Tarenko, nucl-ex/0604011
NQ inspired fit: Dong et al., PLB 597 (2004) 328

Partonic Collectivity



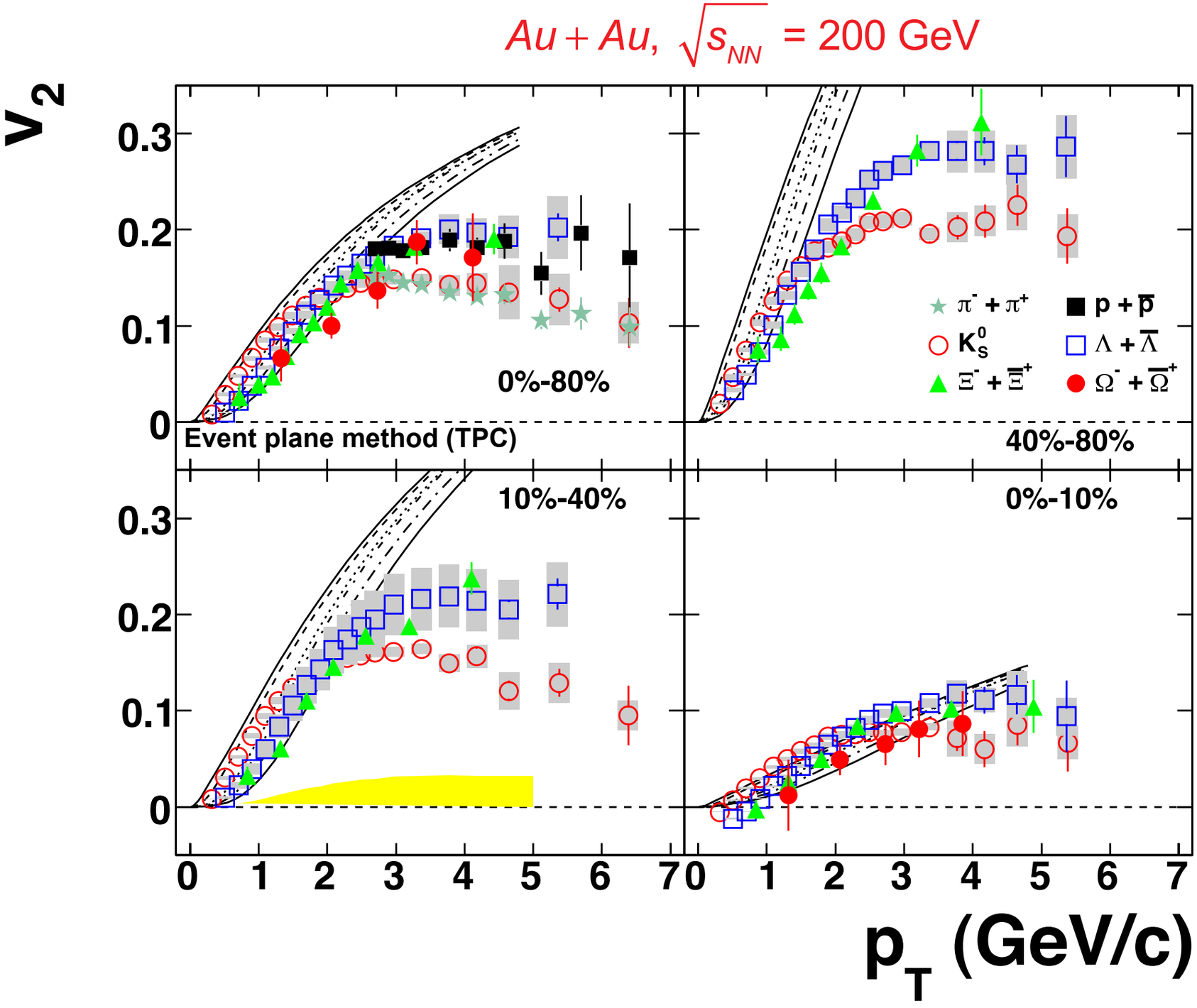


- v_2 of light and multi-strange hadrons are scaling by the number of quarks

  ⇒ also visible for Φ and Ω which indicates that the collectivity develops at the partonic level

STAR Ref.: B. I. Abelev et al.: PRC 75 (2007) 054906
B. I. Abelev et al.: PRC 99 (2007) 112301
B. I. Abelev et al.: PRC 77 (2008) 054901
B. I. Abelev et al.: PRC 81 (2010) 044902

Ideal Hydrodynamics



- **Ideal hydrodynamics fails to describe the data**
  - **Missing of v_2 fluctuations?**
  - **Viscosity (non-zero η/s)?**
  - **Incomplete thermalization?**

Huovinen et al.:ARNPS 56 (2006) 163
Huovinen priv. communication 2003, 2006

STAR Ref.: B. I. Abelev et al.: PRC 77 (2008) 054901

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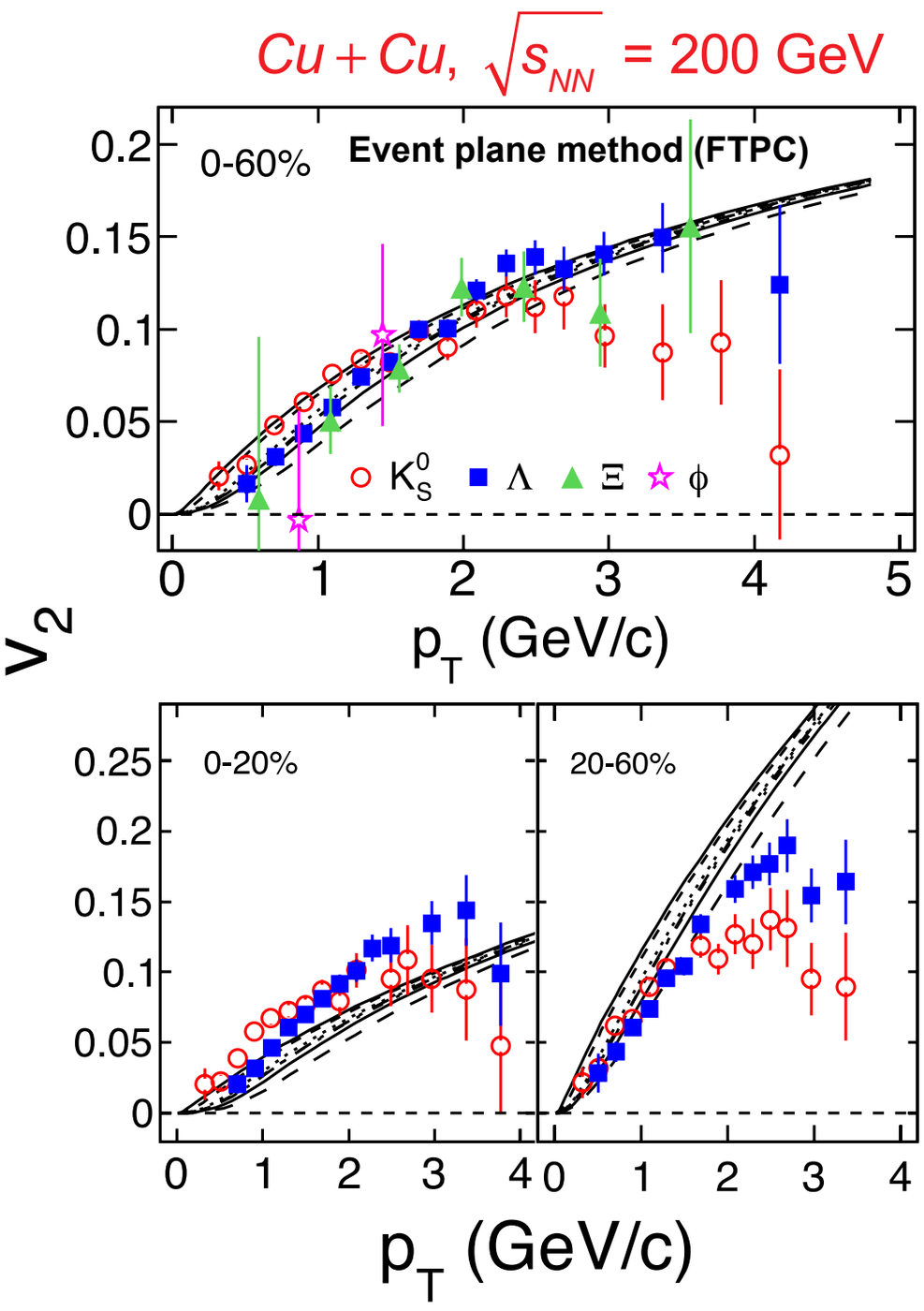

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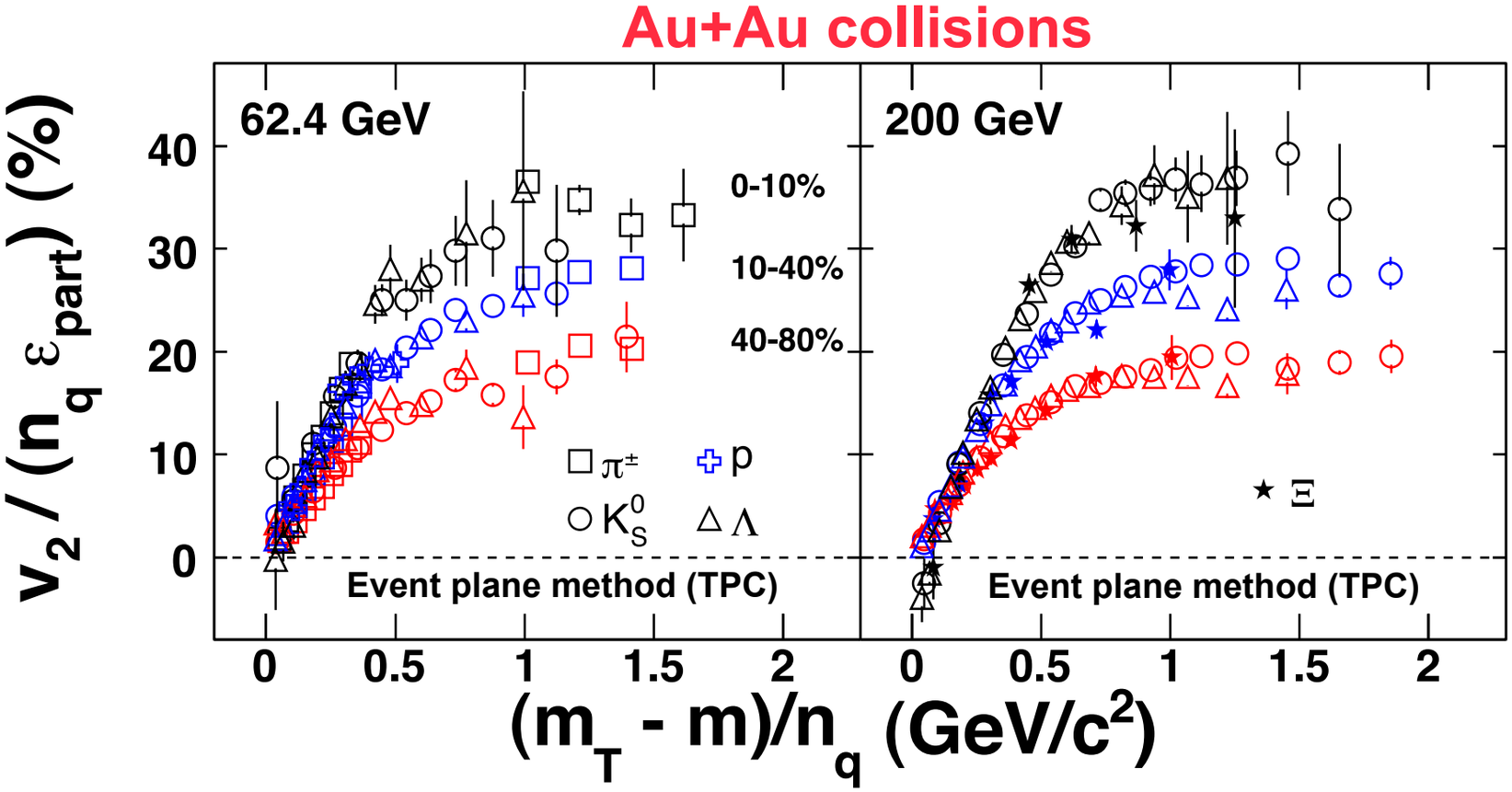
Centrality Dependence



- v_2 scaled by the eccentricity to remove initial geometry effects.
- No ε_{part} scaling is observed.
- v_2/ε_{part} is larger for central collisions compared to peripheral ones which indicates stronger collectivity in central collisions.

⇒ scaling by the number of quarks is visible for all centralities

STAR Ref.: B. I. Abelev et al.: PRC 77 (2008) 054901

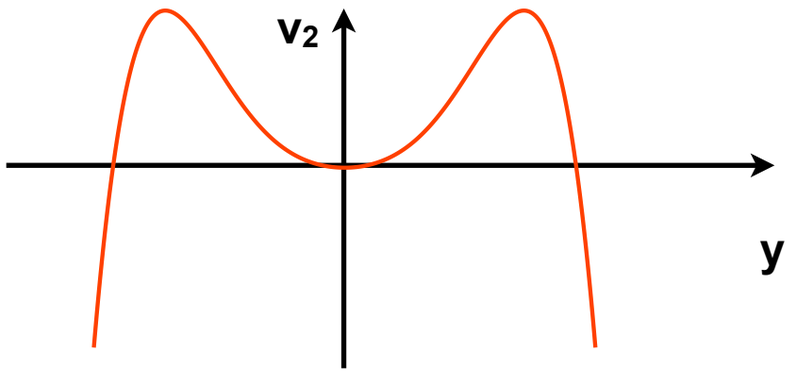
Scenarios for Partonic Matter and Phase Transition

a) Partonic degrees of freedom

b) Phase transition

- **Will we see a change of the EOS in the RHIC Beam Energy Scan (BES)?**

Signatures for a Phase Transition - BES Program



- At the phase transition from hadronic matter to quark-gluon plasma the EOS is softer in a mixed phase.
- This should be visible in a deep minimum of proton v2 at midrapidity known as softest point.

Stöcker:NPA 750 (2005) 121
Kolb et al.:PRC62 (2000) 054909

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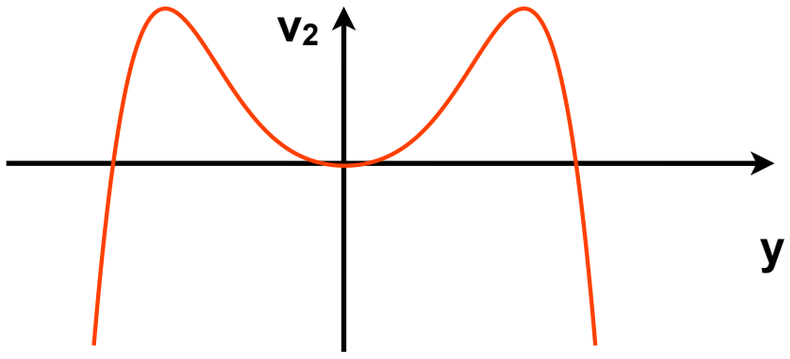
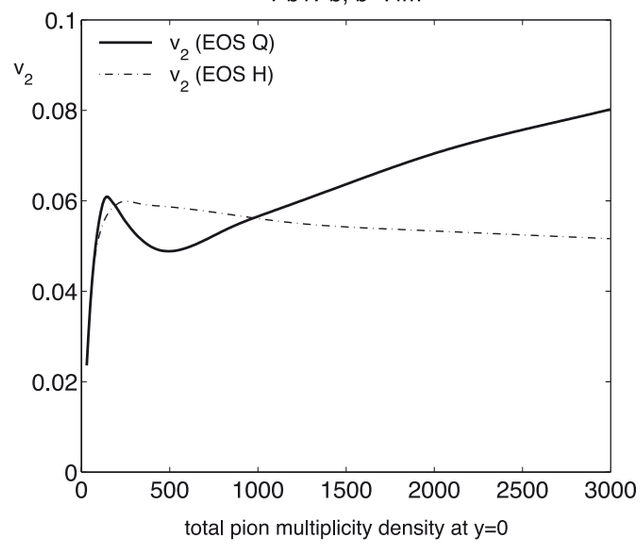


Pb+Pb, b=7fm



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- Hydro calculation shows a minimum for the elliptic flow when passing through a change of the EOS from hadronic matter to quark-gluon plasma.

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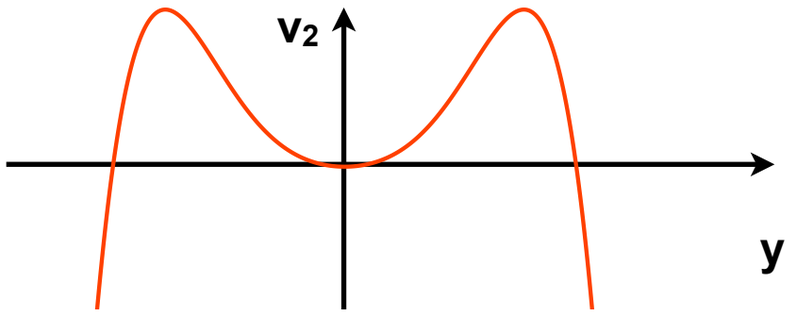

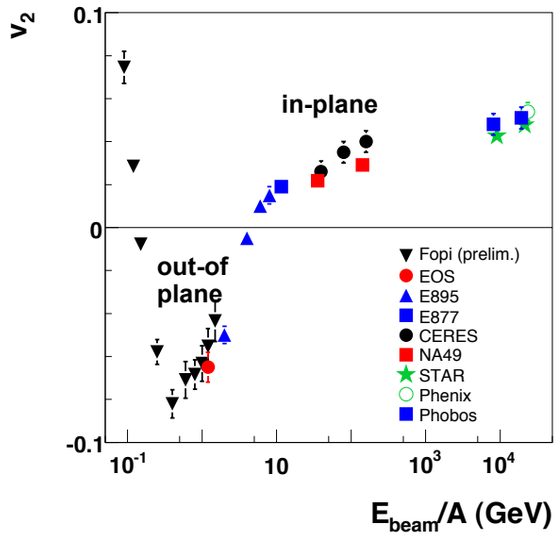

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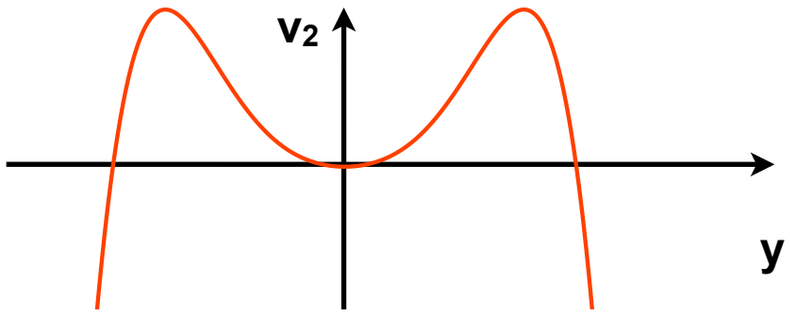

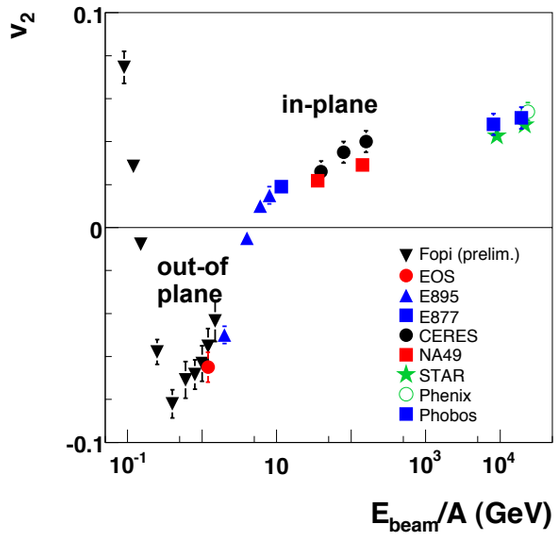

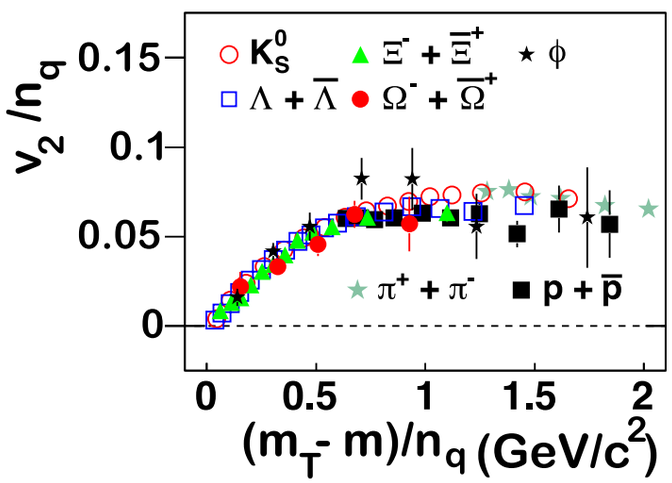

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- This should be visible in a deep minimum of proton v2 at midrapidity known as softest point.

- Hydro calculation shows a minimum for the elliptic flow when passing through a change of the EOS from hadronic matter to quark-gluon plasma.

- The breaking of v_2 number of quark scaling will indicate a transition from partonic to hadronic world.

  ⇒ Important to measure multi-strange particles especially Ω and ϕ v_2

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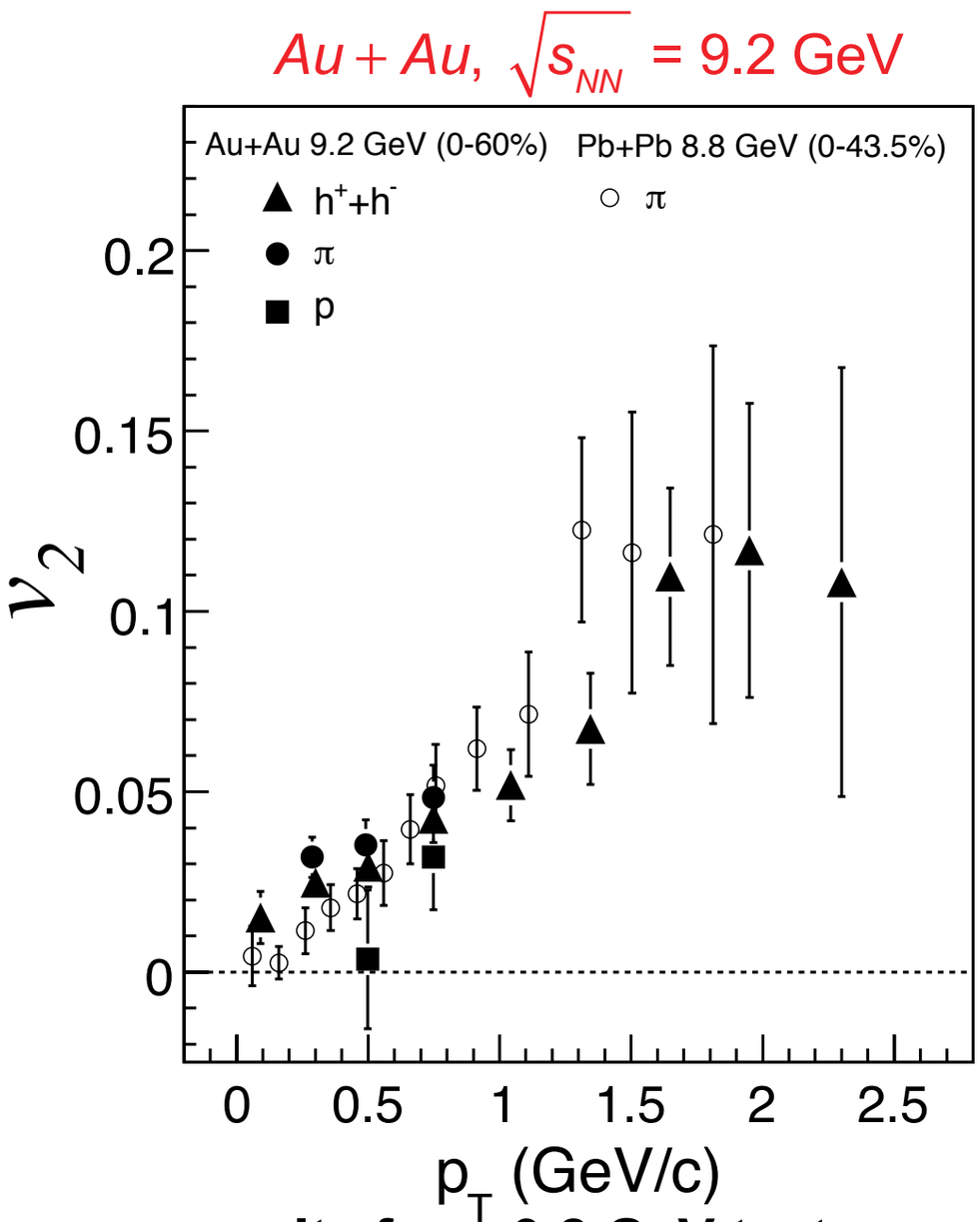
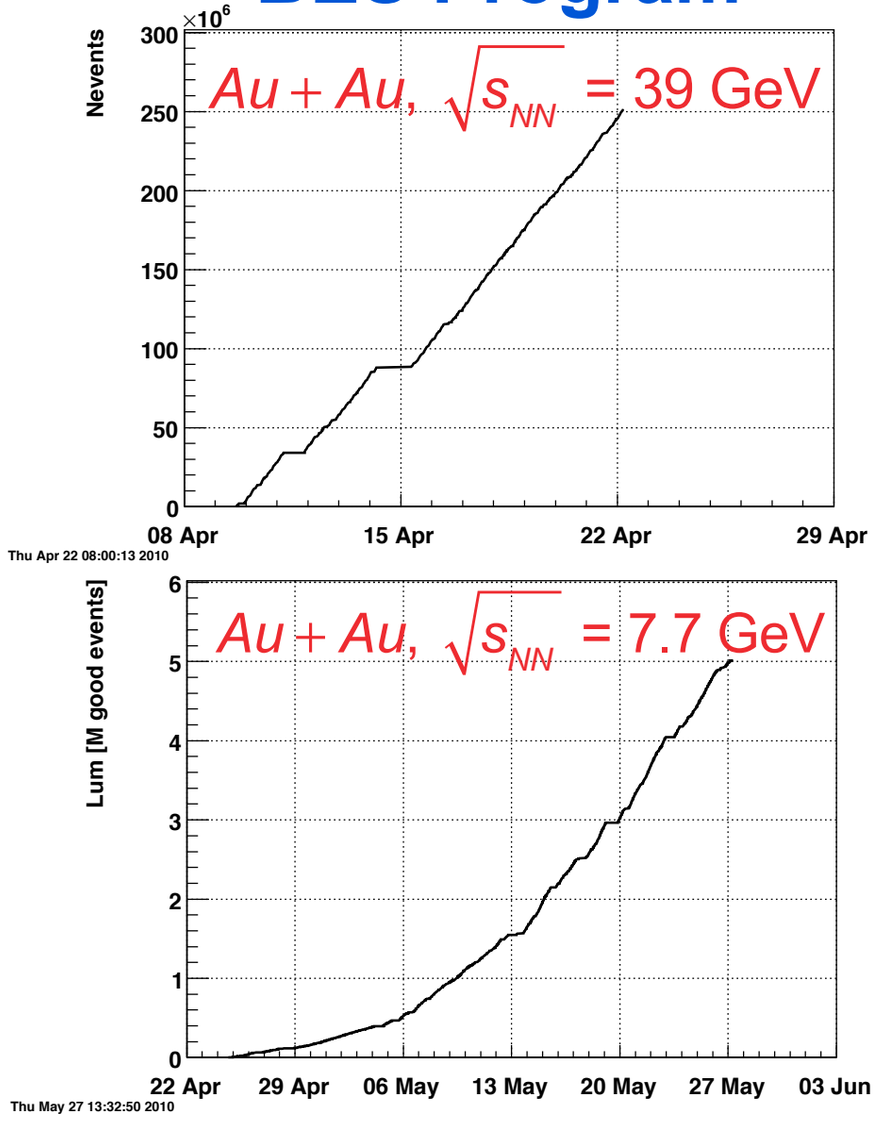
Signatures for a Phase Transition - BES Program



- **v_2 results from 9.2 GeV test run with 3k good events.**

BES Program



- **Analysis of v_2 results for charged and PID hadrons are ongoing.**

STAR Ref.: B. I. Abelev et al.: PRC 81 (2010) 024911 **Alt:PRC 68 (2003) 034903**

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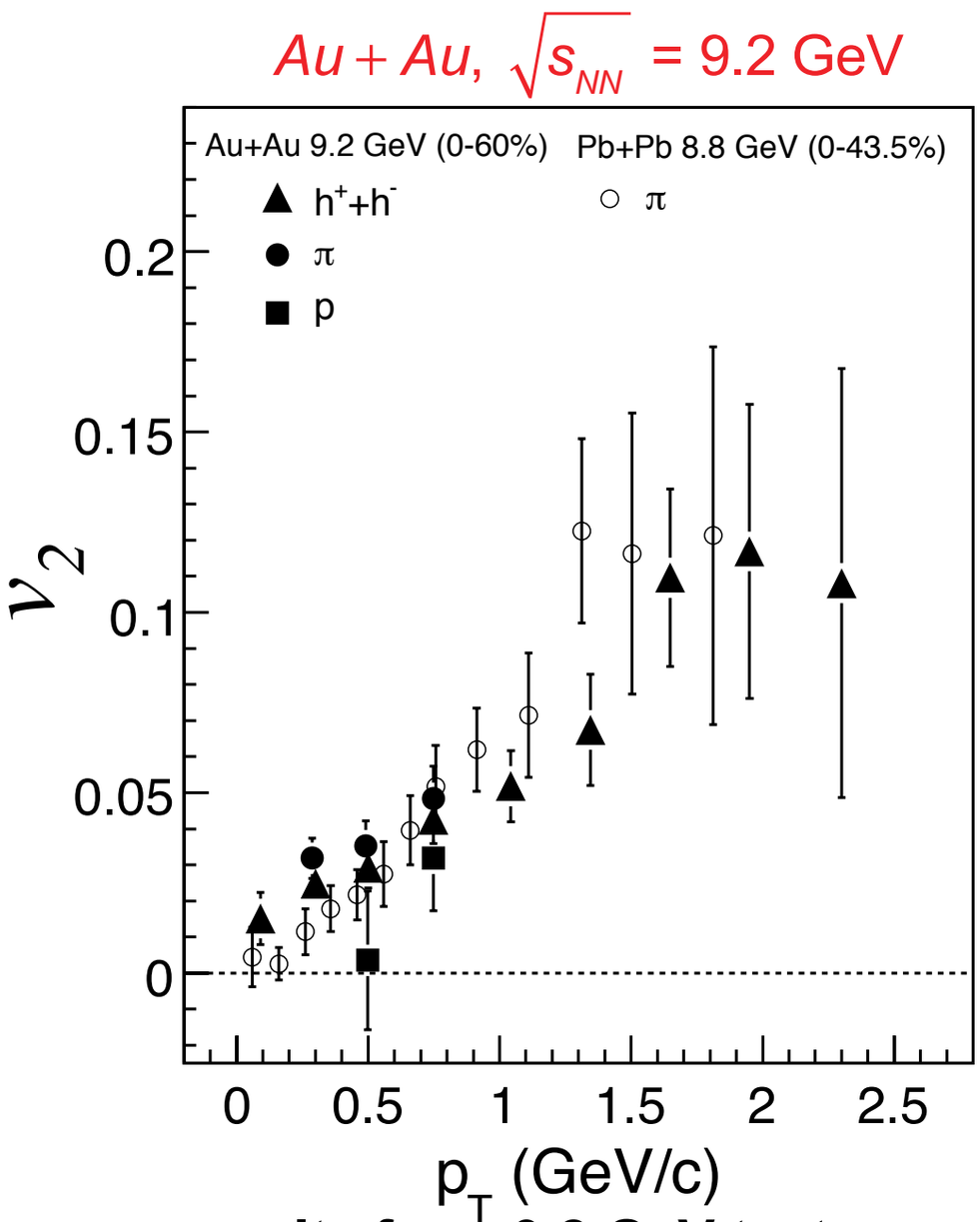

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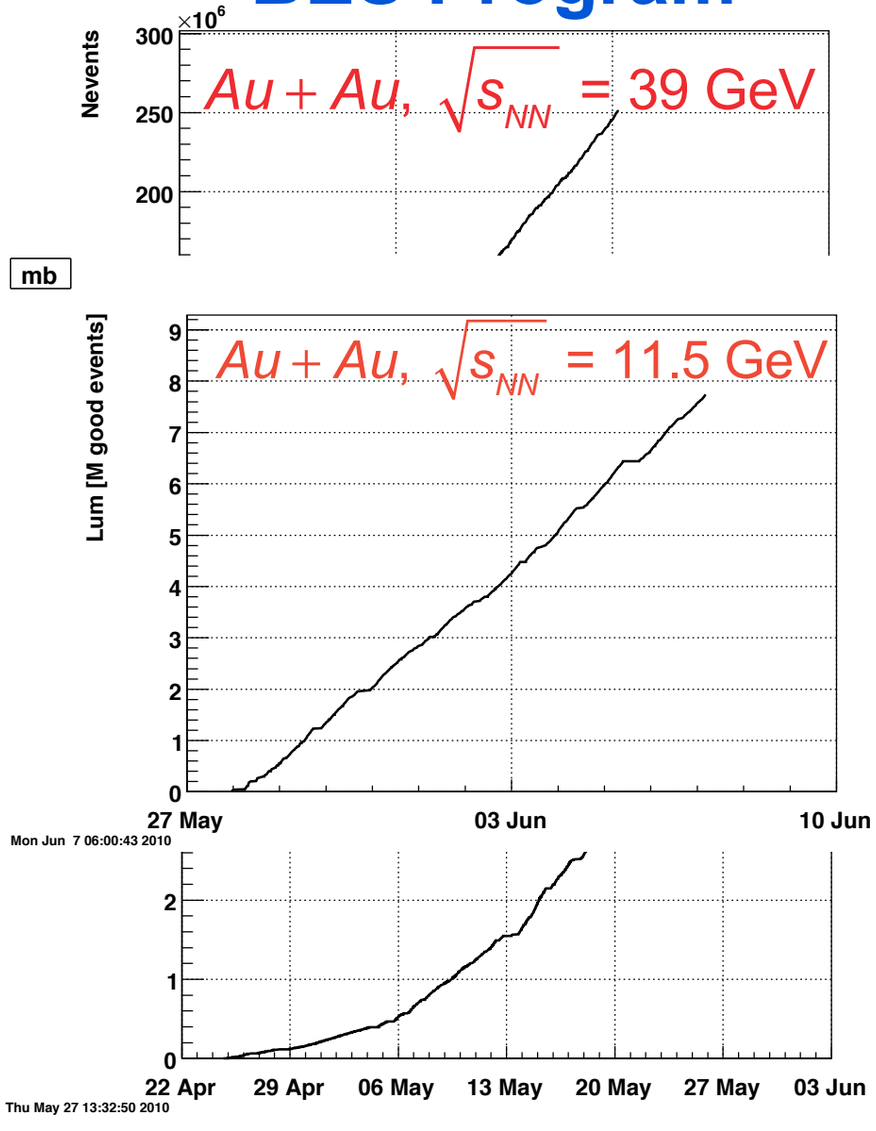

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Summary and Conclusions

a) Partonic degrees of freedom

- NQ scaling works for Au+Au $\sqrt{s_{NN}}$ = 62.4/200 GeV and Cu+Cu at $\sqrt{s_{NN}}$ = 200 GeV collisions.
- Ideal hydrodynamics fails to reproduce the data from Au+Au and Cu+Cu collisions.
- v_2/ε_{part} shows larger v_2 for central compared to periheral collisions

  ⇒ scaling by the number of quarks is visible for all centralities

b) Phase transition

- The EOS will be softer in a mixed phase. This should be visible:
  - Collapse of proton v_2 at midrapidity
  - Minimum of v_2 for charged particles when trespassing a change of the EOS
- v_2 NQ scaling will break in a hadronic scenario.

The End and
Thanks for
Your Attention