Search for Partonic EoS in High-Energy Nuclear Collisions

Selected Topics on Collective Dynamics

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Many Thanks to the Conference Organizers

"I cannot choose the best. The best chooses me." -- Rabindranath Tagore

Outline*

1) Introduction

2) Multi-particle correlations and the ridge at RHIC

3) Event anisotropy

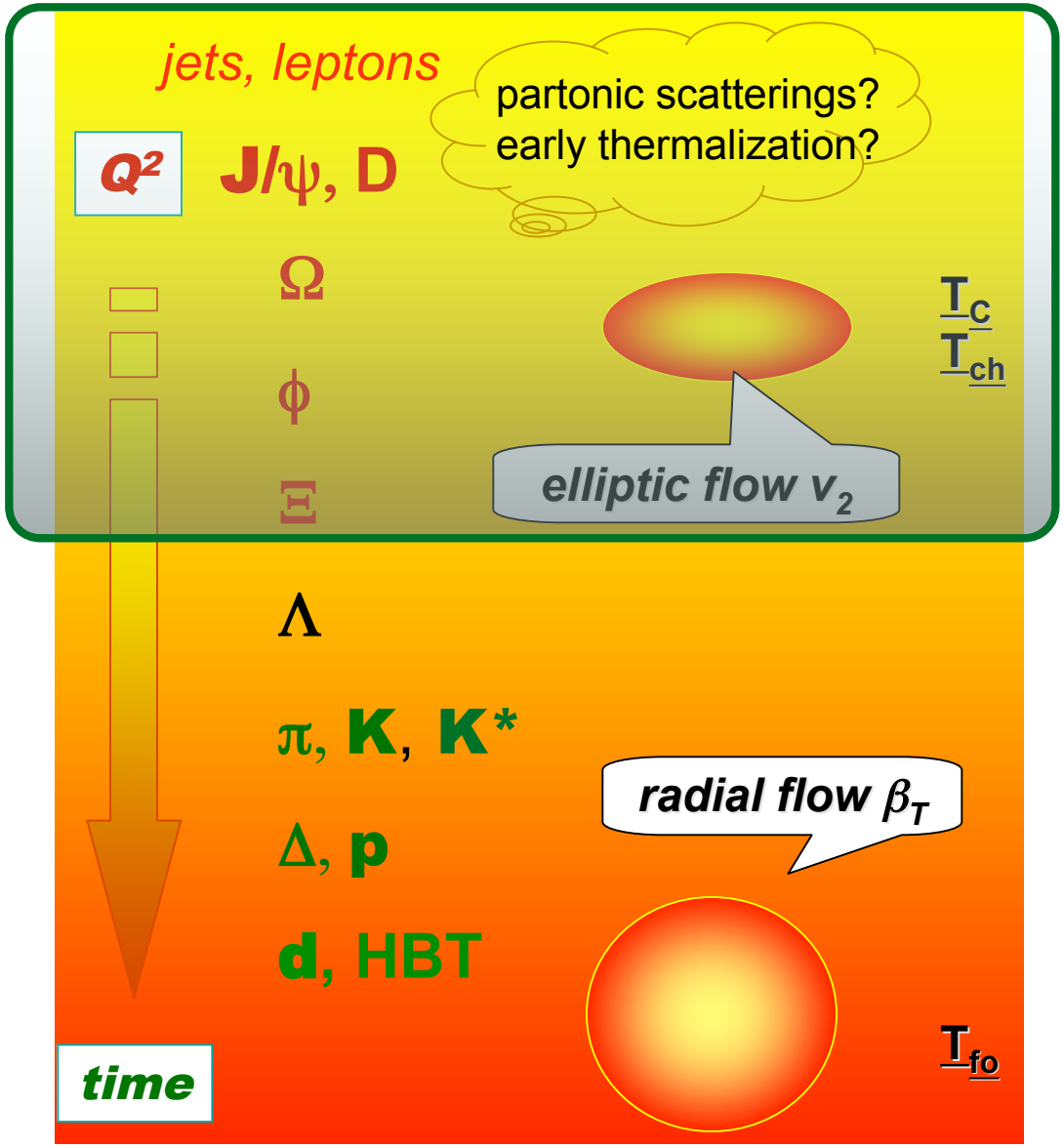
* Most of the materials are from parallel and poster sessions.

High-Energy Nuclear Collisions

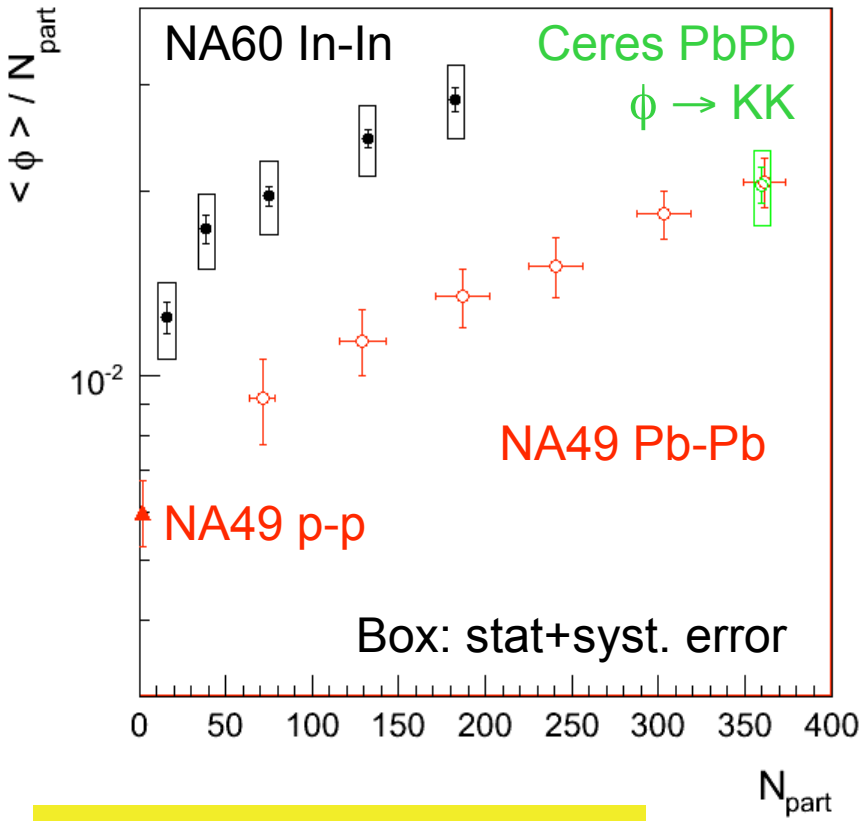
Initial Condition
- initial scatterings
- baryon transfer
- E_T production
- parton dof

System Evolves
- parton interaction
- parton/hadron expansion

Bulk Freeze-out
- hadron dof
- interactions stop



New ϕ Puzzle from SPS



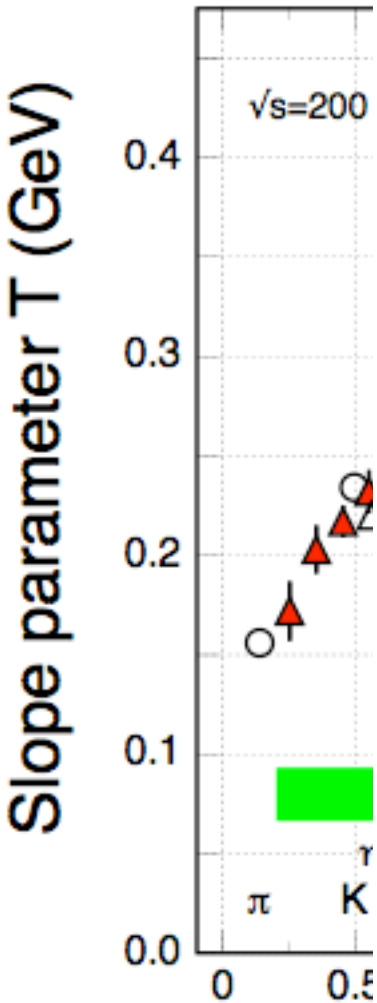
NA60 vs NA49 (full phase space): Also $\phi \rightarrow \mu\mu$ in In-In higher than NA49 yield (like NA50).

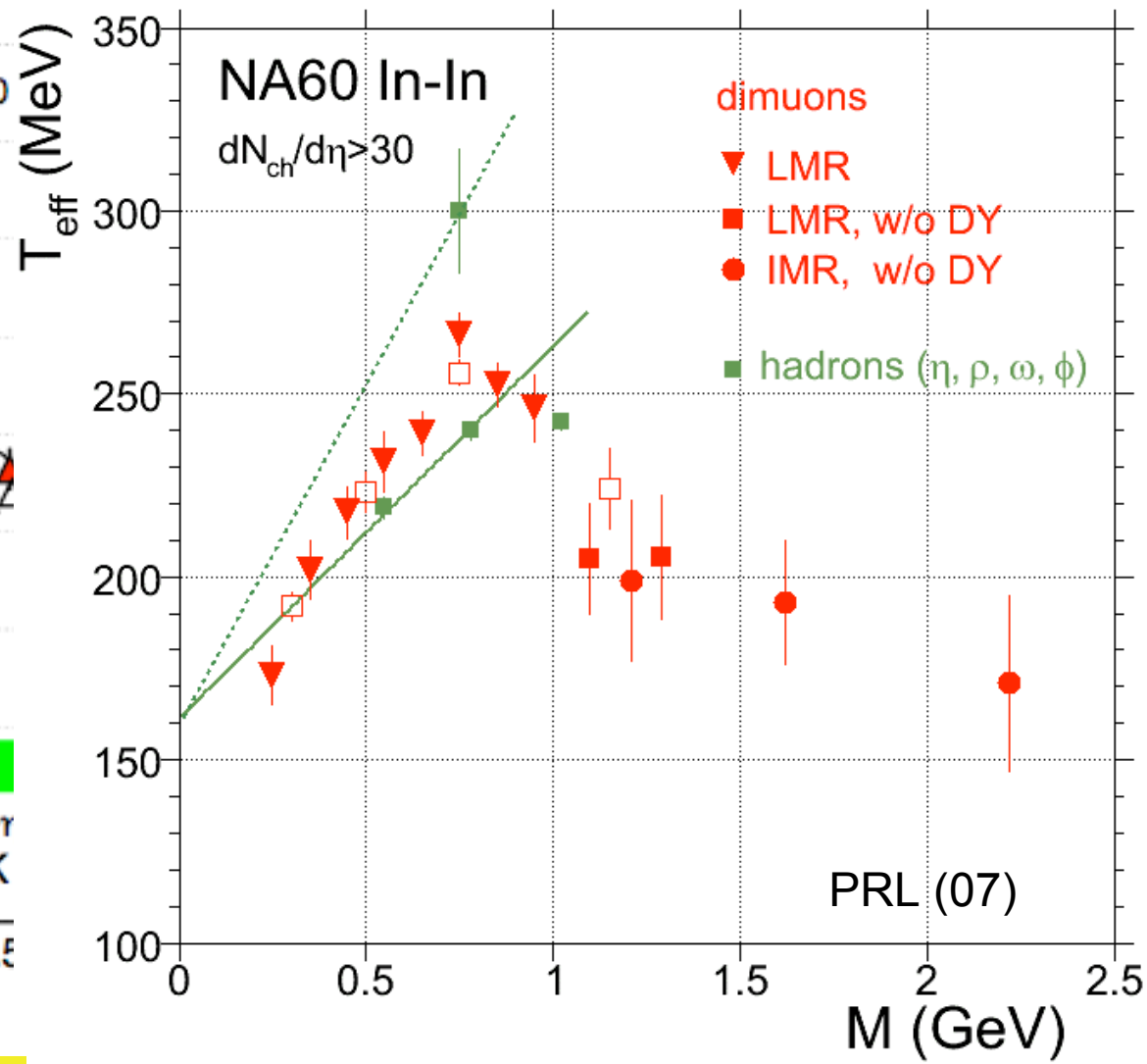
Looking forward to the NA60 $\phi \rightarrow KK$ results from In-In collisions.

Parallel: F. Arleo; D. Jouan

"Difference in $\phi \rightarrow \mu\mu$ and $\phi \rightarrow KK$ yields seems confirmed - related to a real physics mechanism (kaon absorption)?"

Direct Radiation from the Matter





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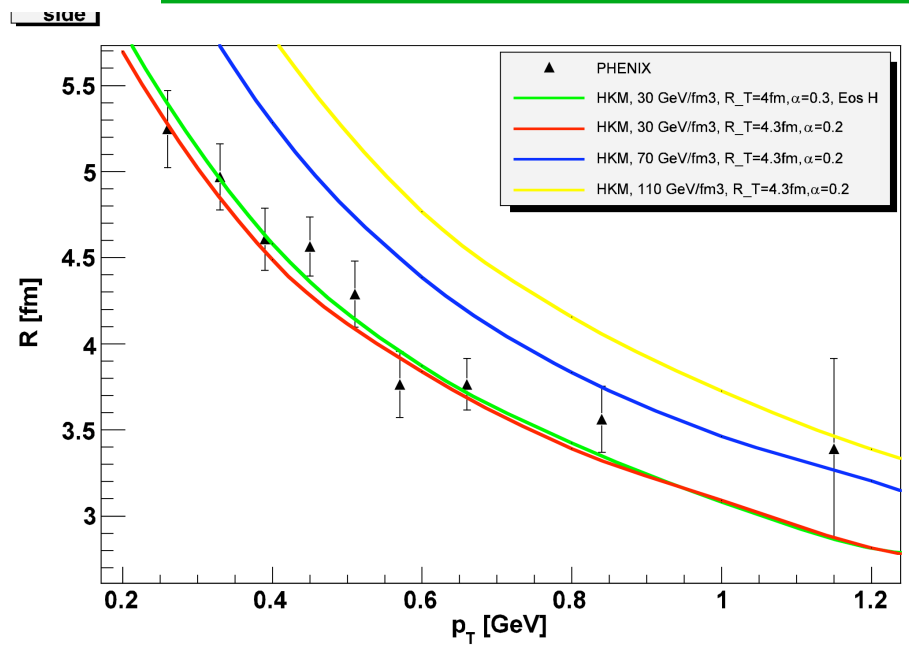
: source of
1.5 GeV

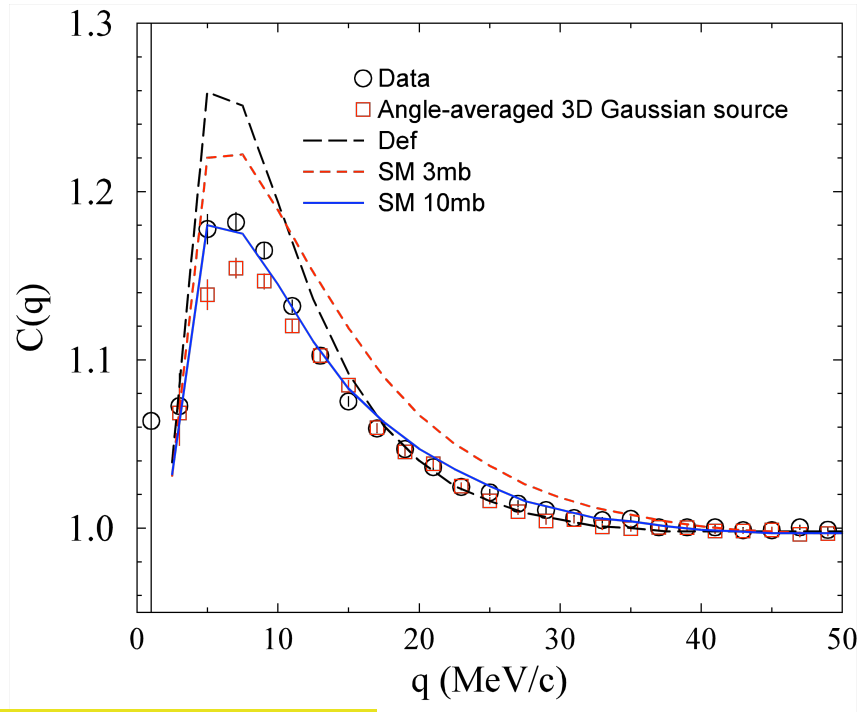
LHC:
crease with

S. Damjanovic

HBT - Forgotten Corner (?)



Parallel: Yu.M. Sinyukov



Parallel: Z.W. Lin

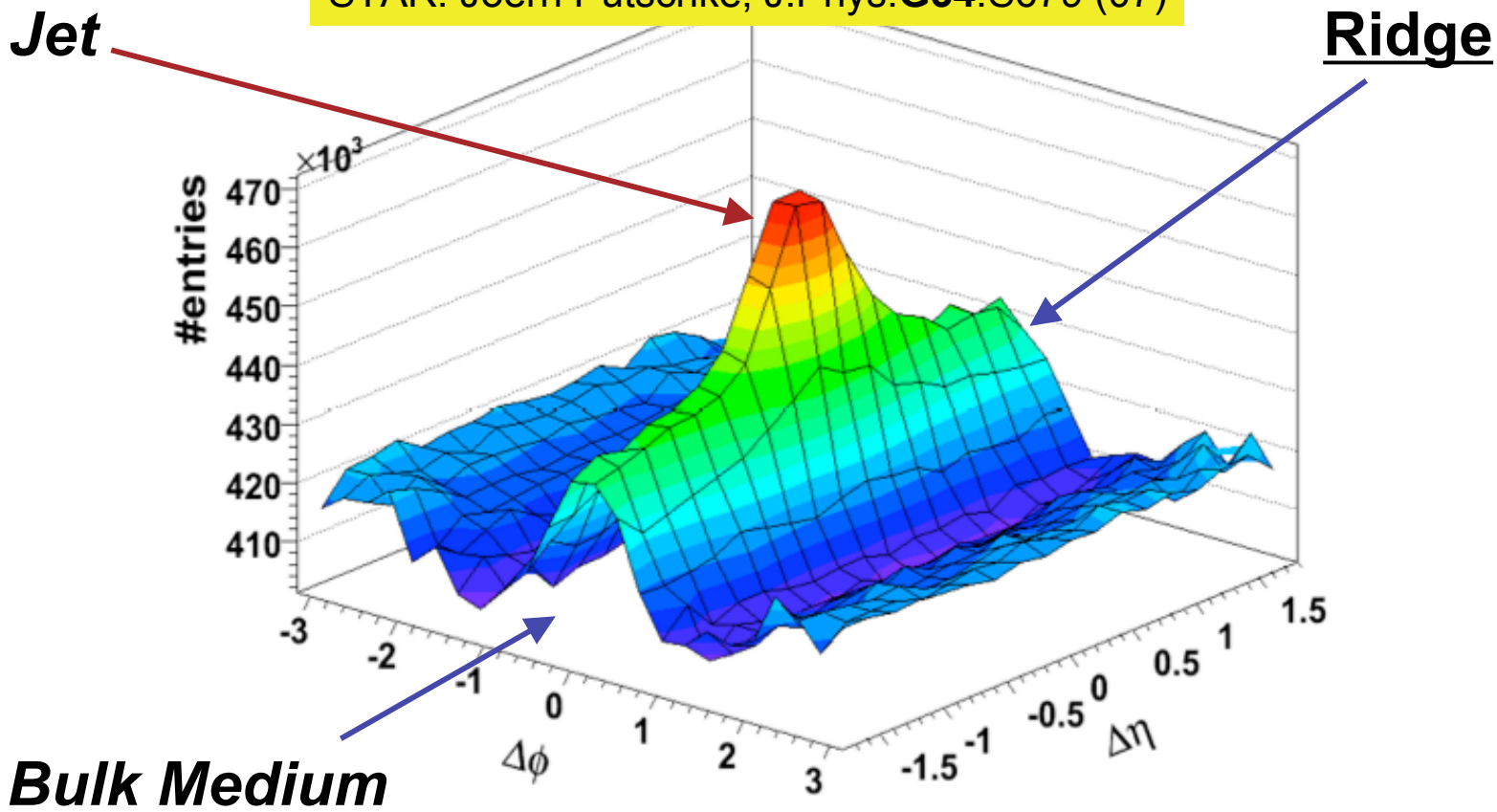
- Hydro Kinetic approach
- Consistent with R_{out}/R_{side} data
- **Initial velocity develops at pre-thermal stage**
- CGC initial condition, sensitive to EoS

- AMPT compared with PHENIX data
- **Sensitive to partonic stage (SM)**
- R_{out} does not work

Parallel: R. Lacey; D. Cebra

The Ridge from RHIC

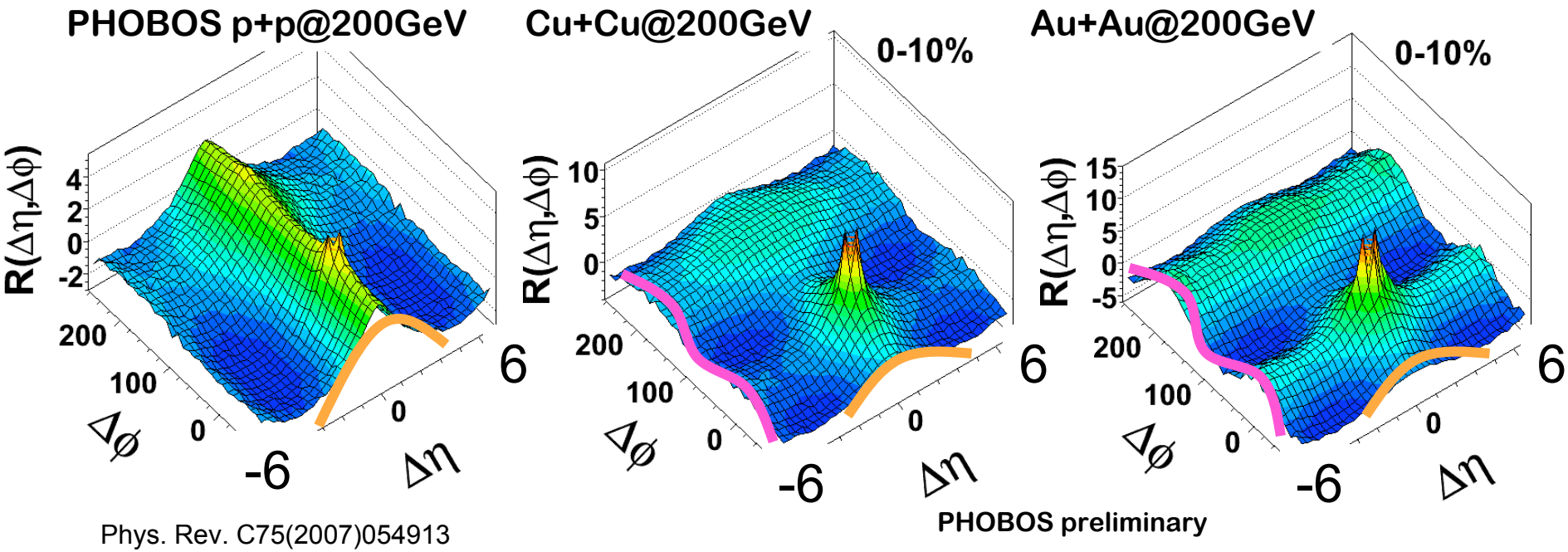
STAR: Joern Putschke, J.Phys.**G34**:S679 (07)



Rich underlying physics: jet, bulk, jet-medium interaction, medium responses,…

N. Armesto et al.; R. Hwa; A. Majumder, et al.; E. Suryak; S. Voloshin; C.Y. Wong

Two-particle Correlations in Cu+Cu and Au+Au Collisions

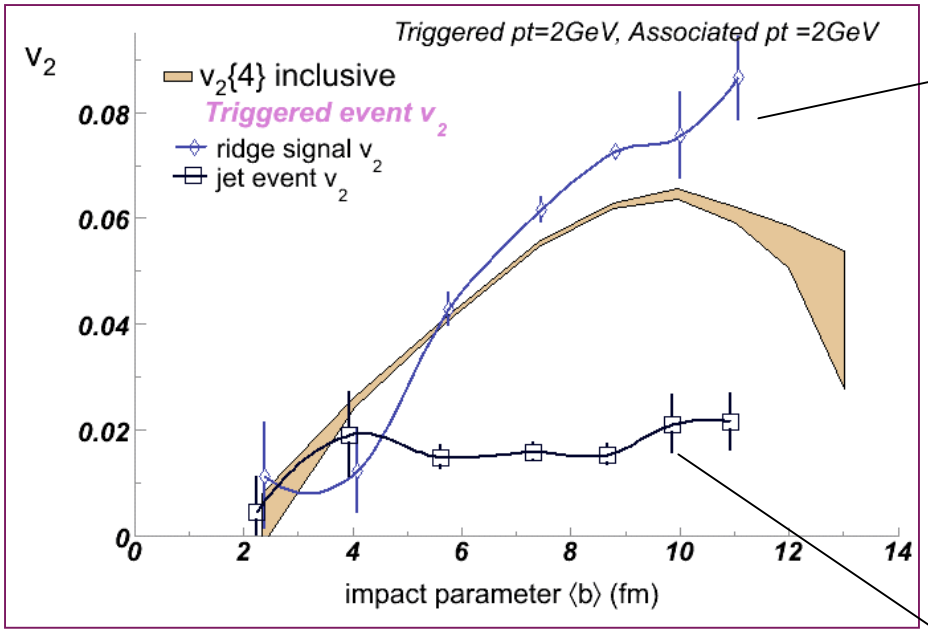


Phys. Rev. C75(2007)054913

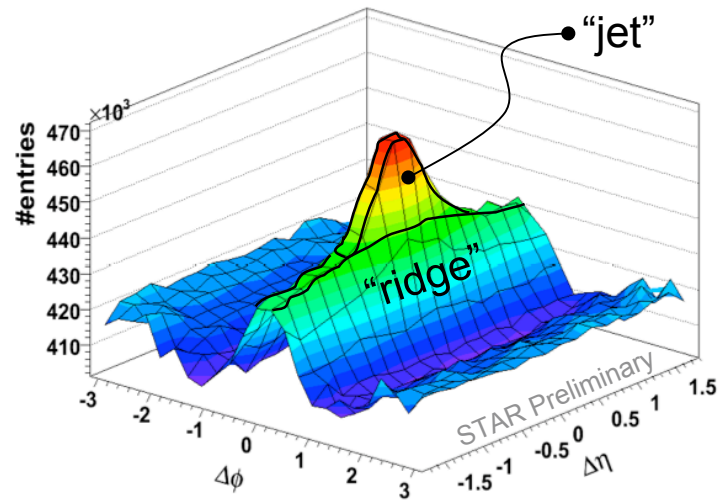
Parallel: W. Li

1) Short range cluster-like structure in A+A as in p+p.
2) Elliptic flow over large range of $\Delta\eta$ in A+A collisions.

Different Event Classes (?)



'ridge' event

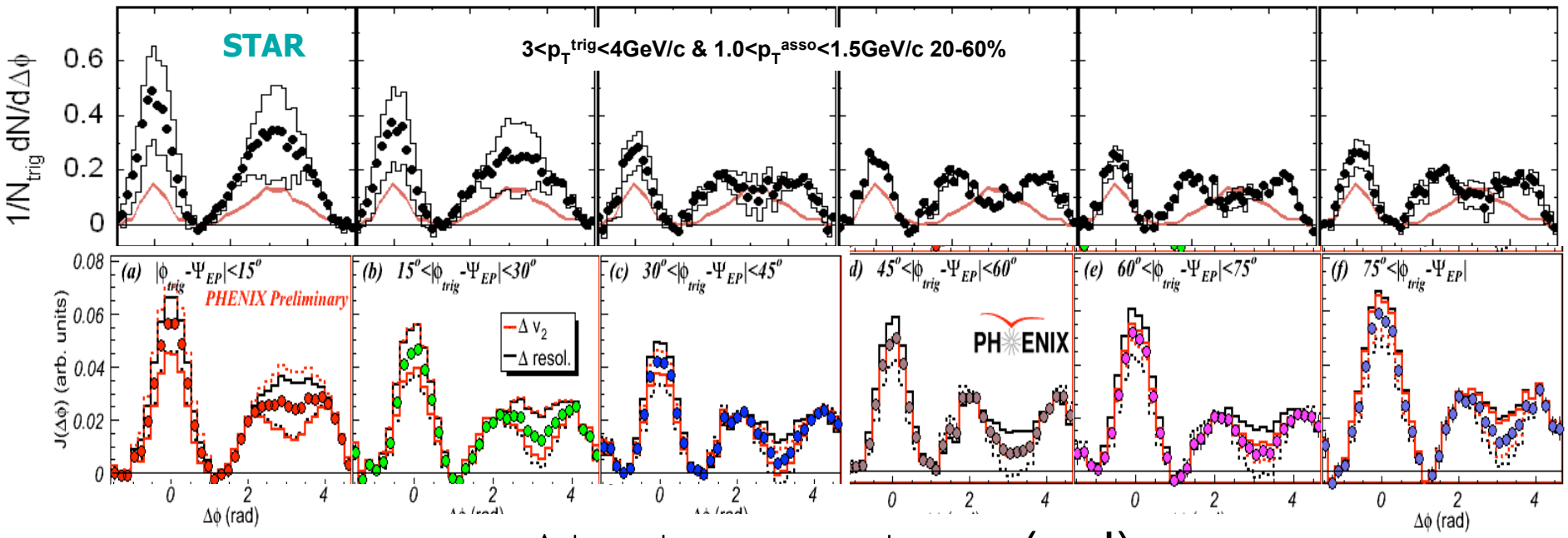


'jet' event

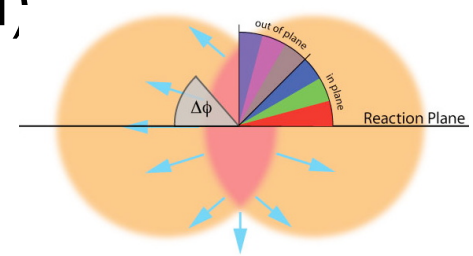
Parallel: Paul Sorense; B. Alver
Poster: Navneet Kumar Pruthi

1) 'jet' events' v_2: small, independent of centrality
2) 'Ridge' events v_2: similar to bulk

Reaction Plane Dependence



$\Delta\phi = \phi_{associate} - \phi_{trigger}$ (rad)

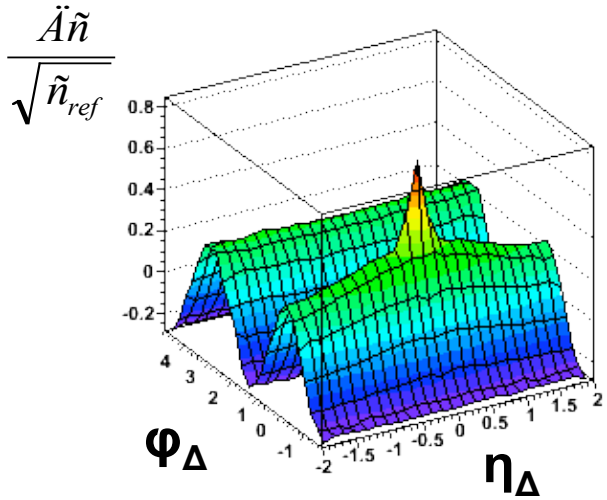


Parallel: M. McCumber; O. Catu; H. Pei
A. Feng; O. Barannikova; A. Adare

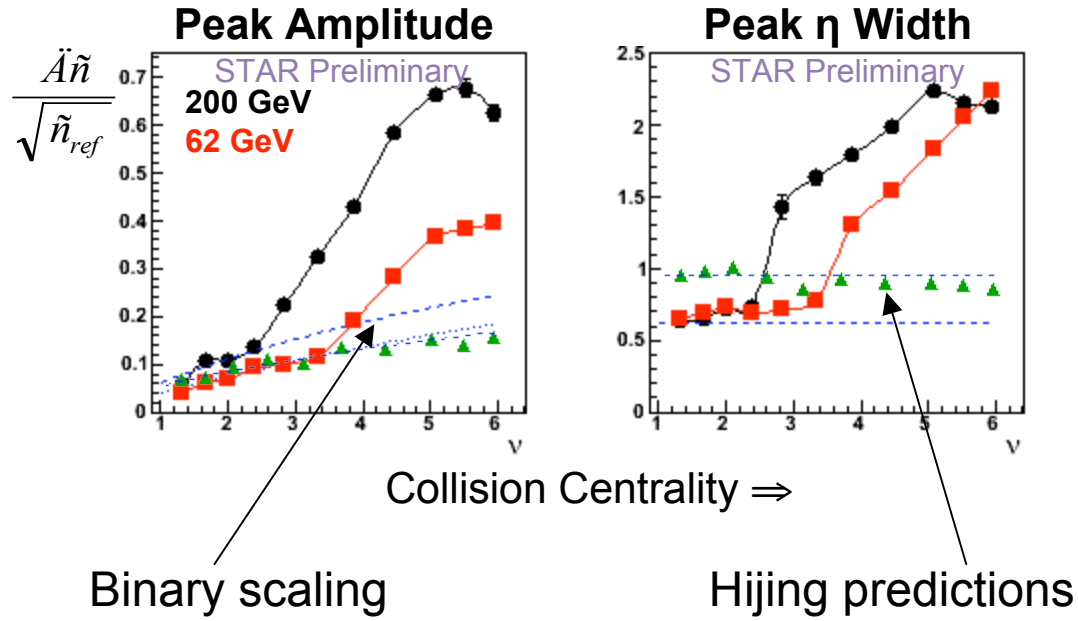
At low p_T region, study the medium response to jets

- Away side (medium side): single ⇒ double peaks
- Near side (jet side): amplitude reduced

Two Particle Correlations



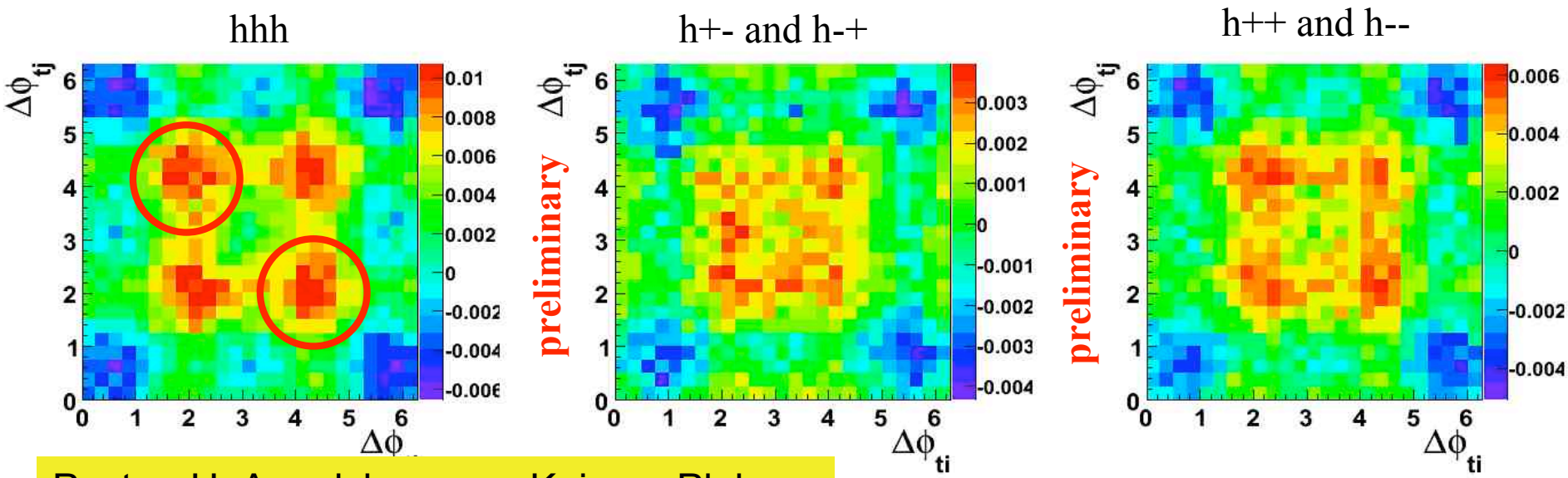
Parallel: M. Daugherity



1) Amplitude and η widths: ***sharp transition***
2) Deviations from binary scaling: ***physics unique to HI collisions***
3) The observed correlation: ***Hijing under predicted*** the correlation
4) Inconsistent with the medium thermalization(?)

Modification of energetic 'jets' in the medium!

March Cone (NA45)



Poster: H. Appelshaeuser; Kniege; Plokson

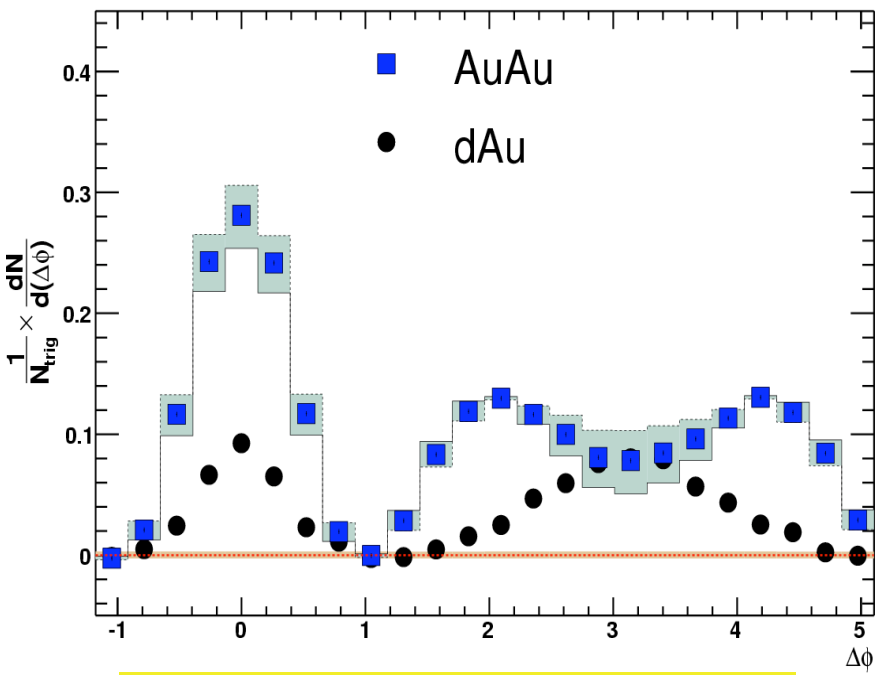
$c_S^2 = p/\varepsilon$ *study EoS of the medium*

1) Conical emission pattern at SPS as strong as at RHIC*.
2) Underlying mechanism?
3) RHIC energy scan will help!

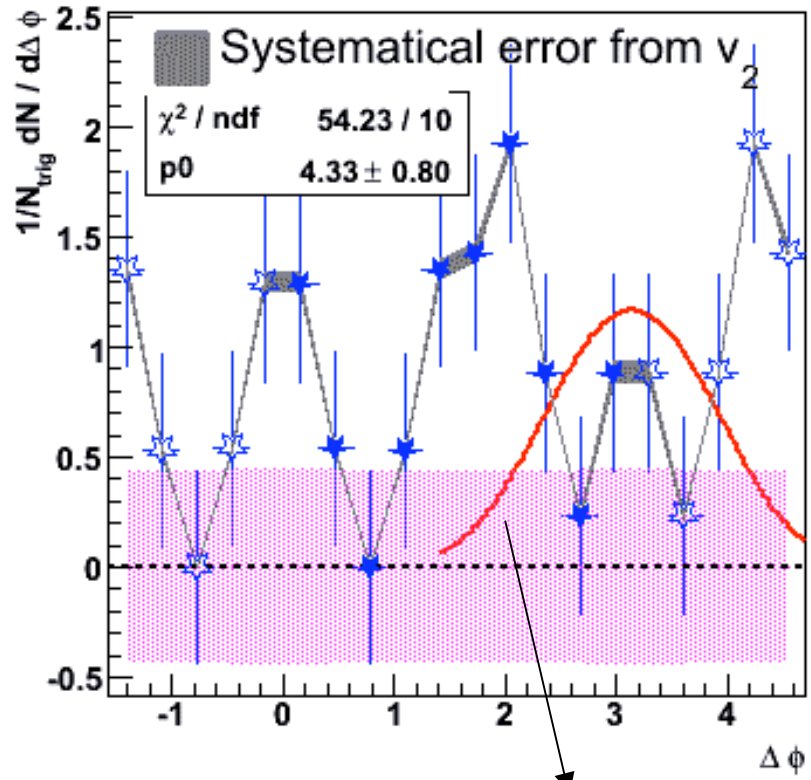
* Important but complicated analysis. More systematic *high p_T triggered data*, more *tests of methods* are needed!

Non-Photonic e-h Correlations

Mark Horner (STAR): J. Phys. G: Nucl. Part. Phys. **34** (2007) S995



200 GeV Cu+Cu



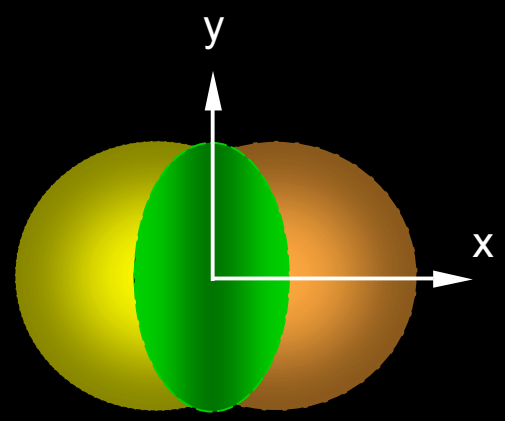
Pythia result

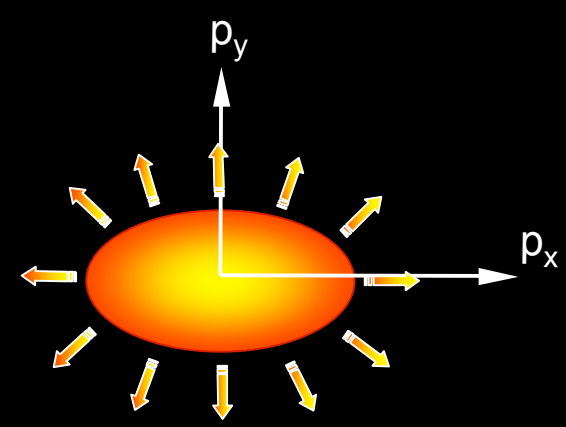
Parallel: G. Wang, A. Mischke
C. Nattrass

Pythia result, without medium modification, is inconsistent with data. High statistics are needed.

Anisotropy Parameter v_2

coordinate-space-anisotropy ➪ momentum-space-anisotropy



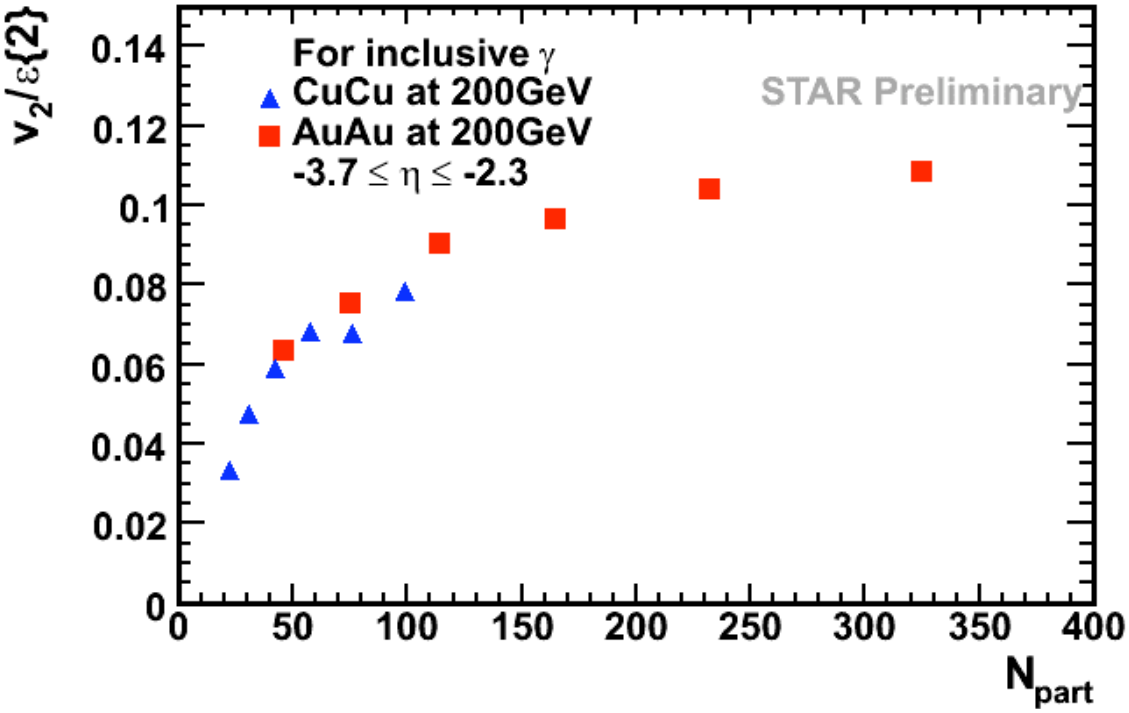


$$\varepsilon = \frac{\langle y^2 - x^2 \rangle}{\langle y^2 + x^2 \rangle} \qquad v_2 = \langle \cos 2\varphi \rangle, \quad \varphi = \tan^{-1}\left(\frac{p_y}{p_x}\right)$$

Initial/final conditions, EoS, degrees of freedom

Forward Inclusive γ v_2

from Cu+Cu and Au+Au collisions at 200 GeV



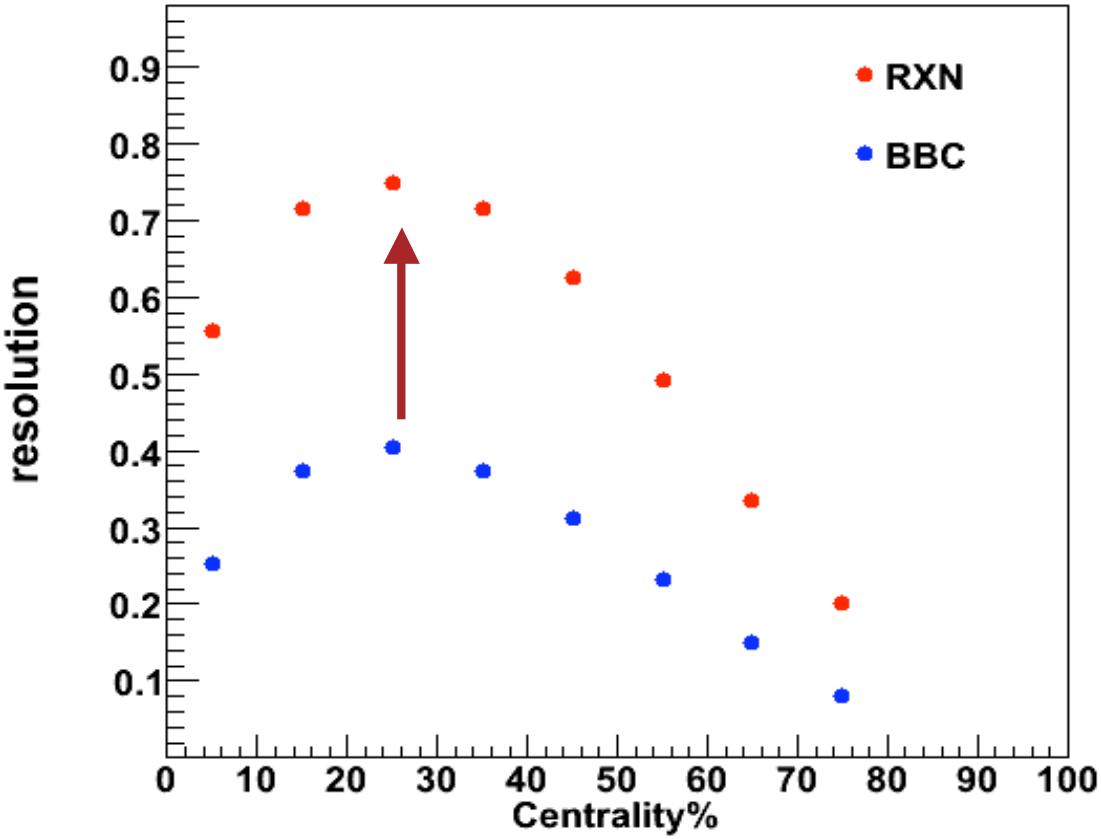
STAR PMD Detector used in the analysis

Parallel: R. Raniwala
S.M. Dogra

1) v_2 scaled with eccentricity increase with centrality: reflects the strength of collective expansion.

2) For large values of N_{part}, scaled v_2 tends to saturate, as expected in an equilibrium scenario.

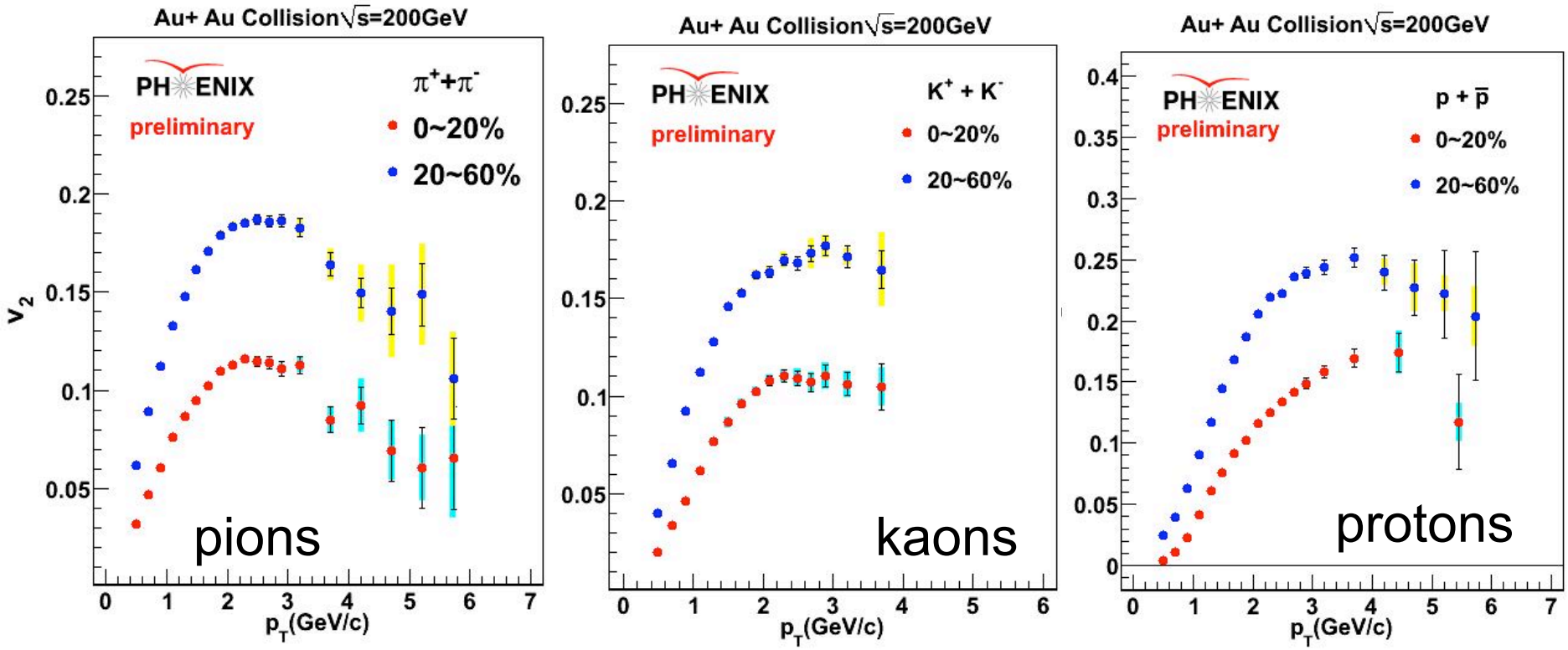
Reaction Plane Determination



Parallel: S. Huang; M. Issah

New reaction plane detector at PHENIX

v_2 - Identified Particles at High p_T



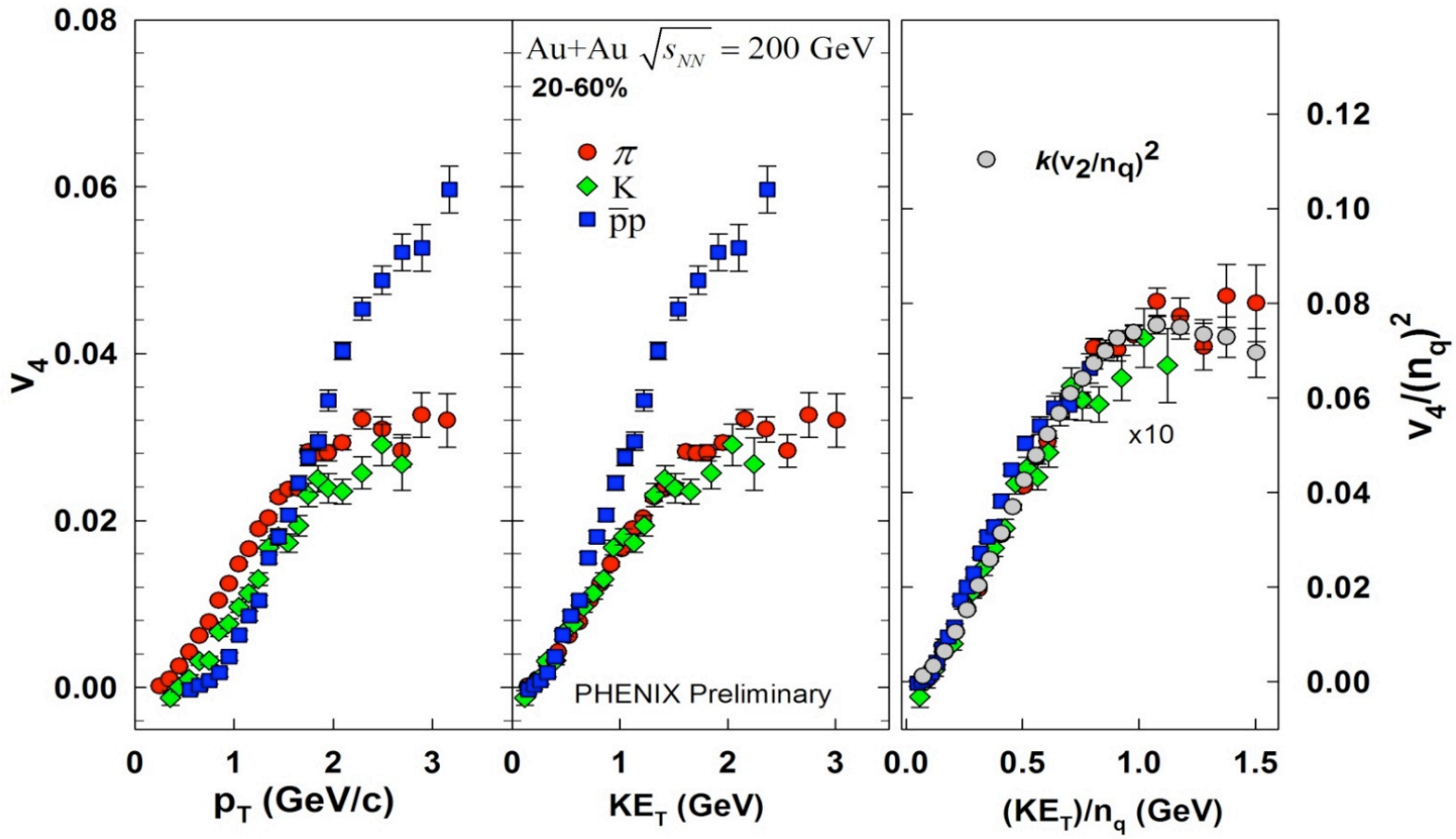
Parallel: S. Huang ; M. Issah

PHENIX results from their new MRPC-TOF and RP detectors!

Extended to higher p_T region!

The more central the collision, the smaller the v_2

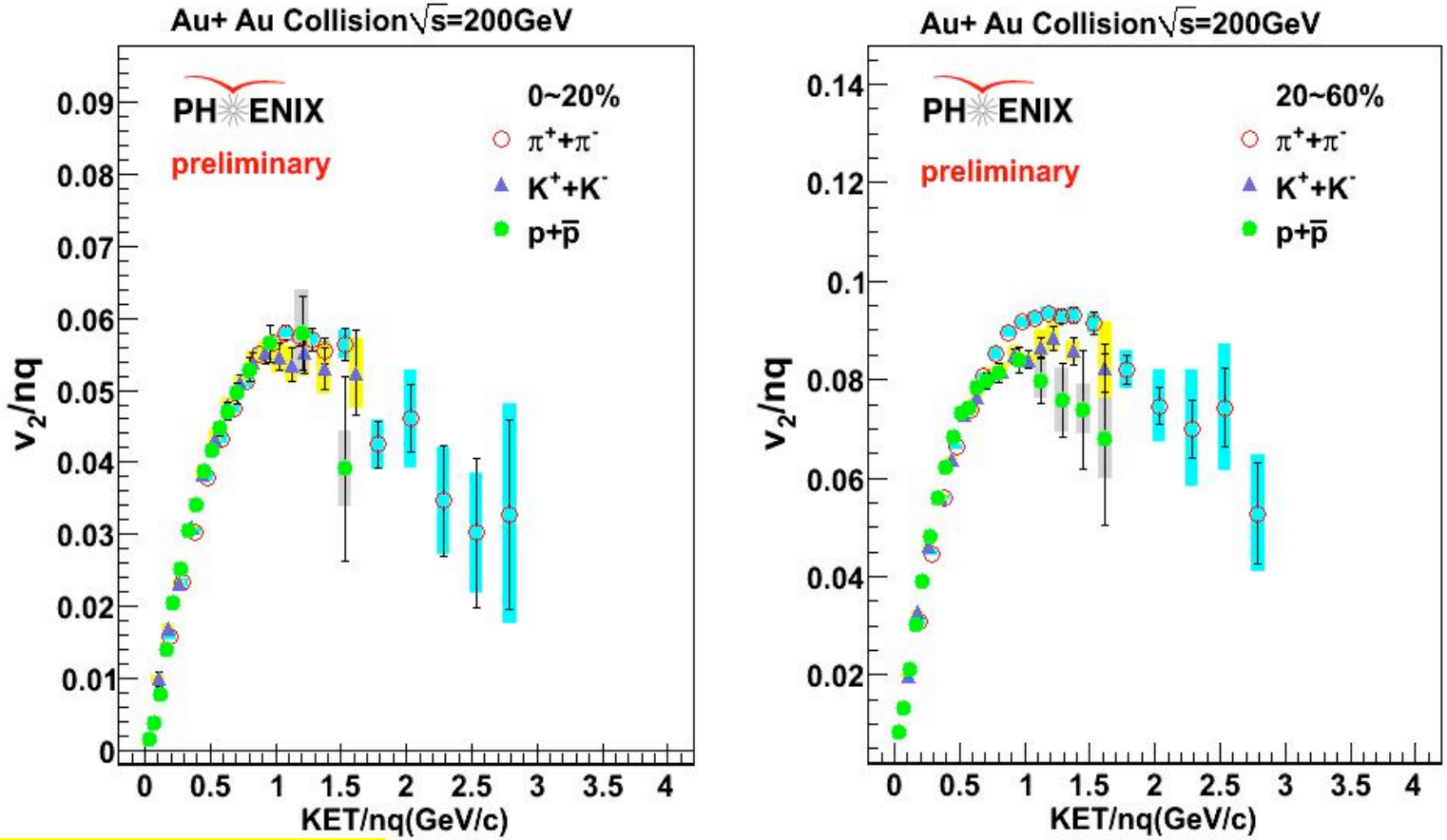
KE_T Scaling of v_4



Parallel: S. Huang; poster: A.Taranenko

v_4 follows the KE_T scaling at KE_T < 1 GeV

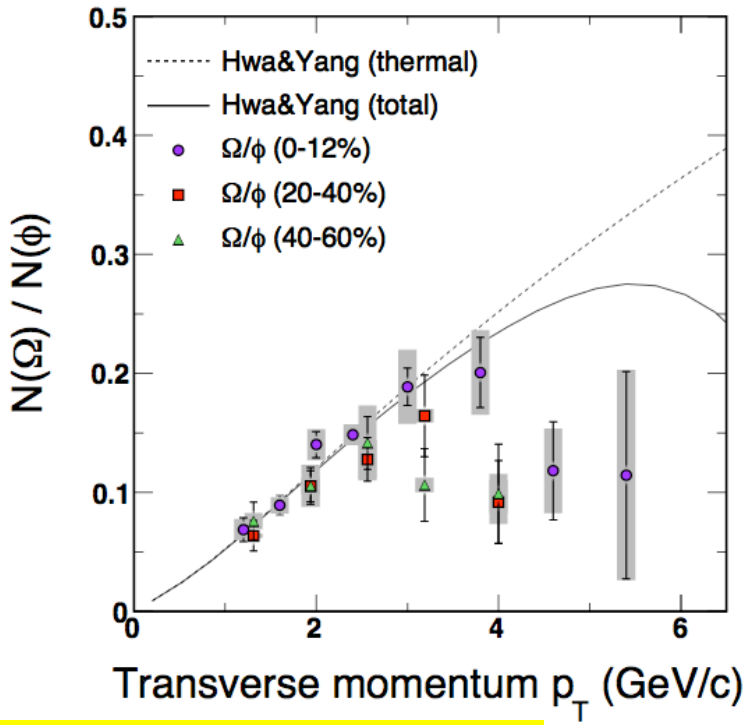
v_2 - High p_T - n_q Scaling

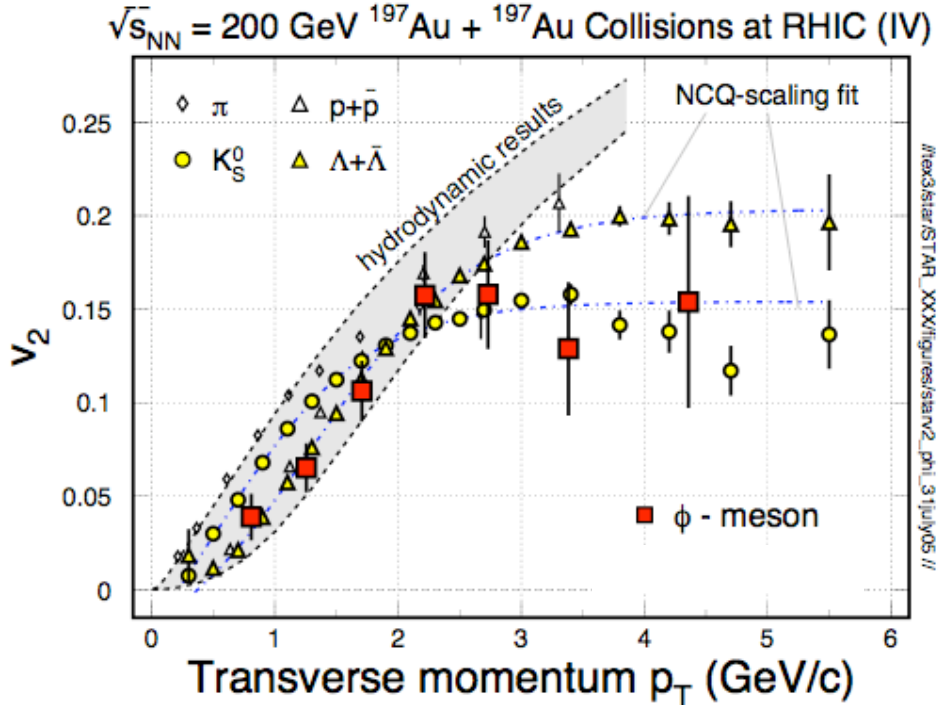


Parallel: S. Huang ; M. Issah

1) Scaling observed at both centralities.
2) KE_T scaling seems break down for $KE_T/n_q > 1$ GeV/c^2 in peripheral collisions - non-flow effects

ϕ -meson Flow: Partonic Flow



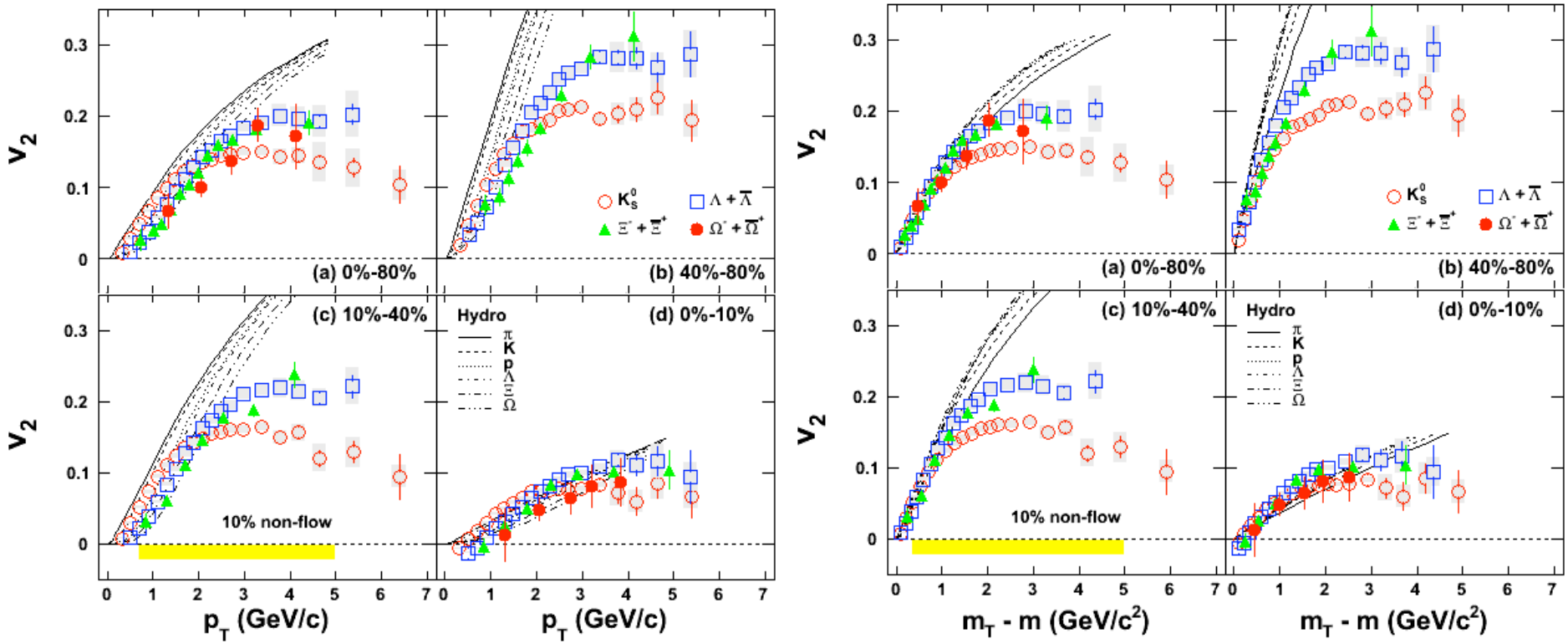


Parallel: J. Chen; X.B. Wang

"ϕ-mesons are produced via coalescence of seemingly thermalized quarks in central Au+Au collisions. This observation implies *hot and dense matter with partonic collectivity* has been formed at RHIC"

Centrality Dependence of PID v_2

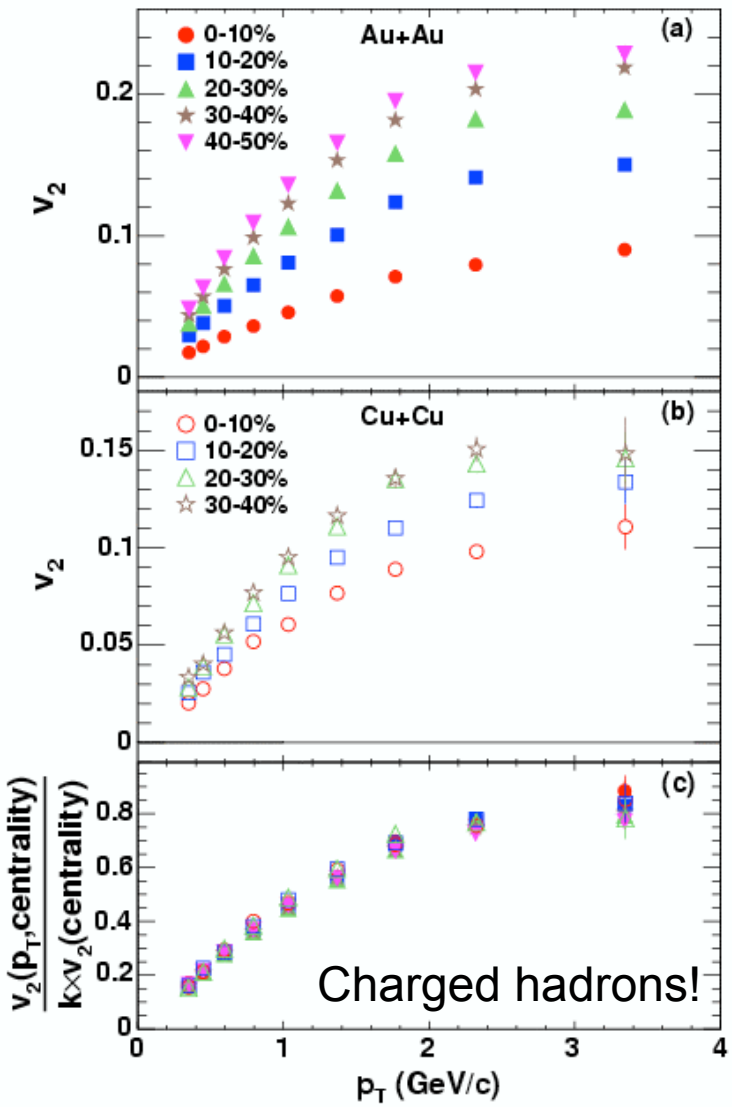
Parallel: Y. Lu; S Dash



- All centralities: mass ordering at low p_T ➔ m_T-m scaling at low m_T-m.
- All centralities: baryon v_2 > meson v_2 at intermediate p_T and m_T-m.
- Hydrodynamic model predictions do not show the scaling behavior.

Non-viscous hydro: P. Huovinen, private communications, 07// STAR data: arXiv:0801.3466v1

Eccentricity Scaling(?)



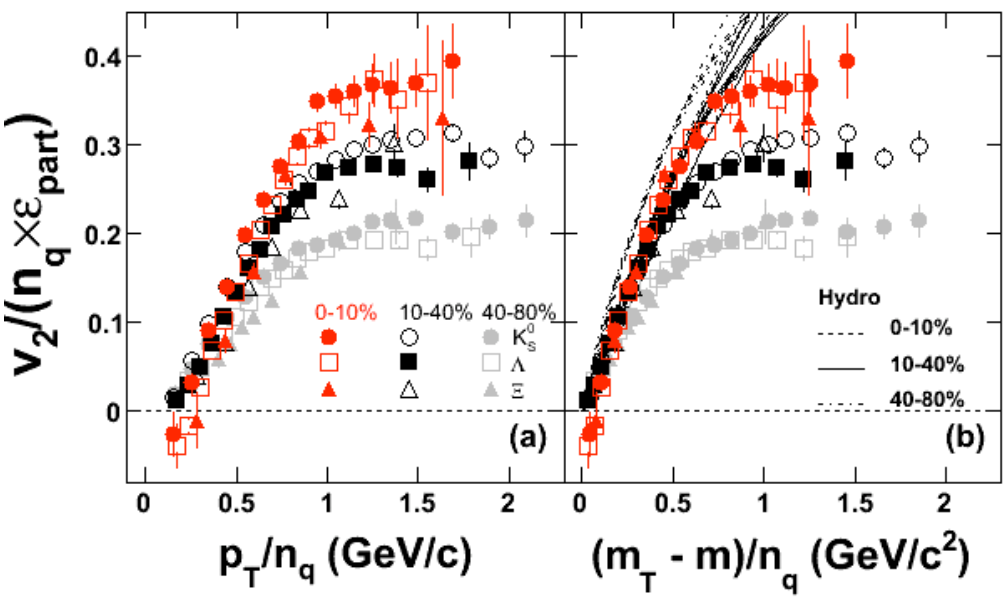
"In summary, we have presented the results from detailed tests of hydrodynamic scaling of azimuthal anisotropy in Au+Au and Cu+Cu collisions at 200GeV. For a broad range of centralities, **eccentricity** scaling is observed for charged hadrons for both the Cu+Cu and Au+Au systems. For a given eccentricity, v_2 is also found to be independent of colliding system size. The observed scaling for identified particles in Au+Au collisions, coupled with ε scaling, gives strong evidence of hydrodynamic scaling of v_2 over a broad selection of the elliptic flow data."

PHENIX: Phys. Rev. Lett, 98, 162301 (2007).

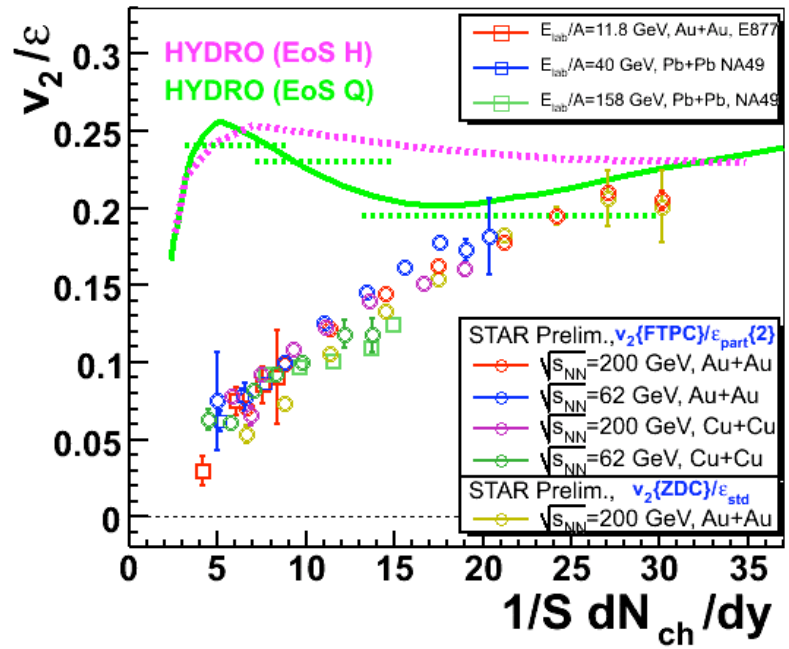
Eccentricity Scaling(?)

STAR: arXiv:0801.3466v1

200 GeV Au+Au



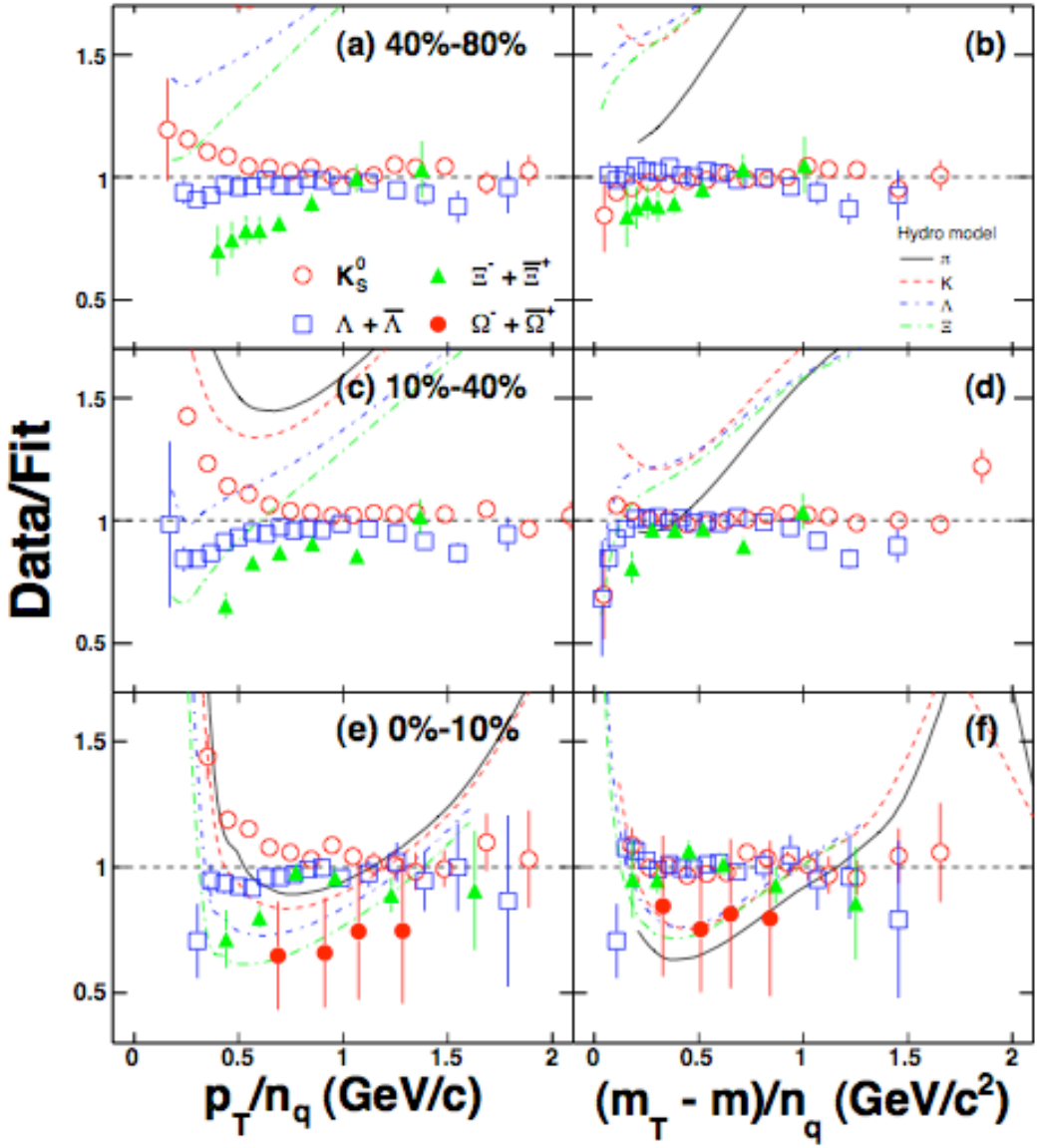
Parallel: Y. Lu ; S Dash



*S. Voloshin, A. Poskanzer, PL **B474**, 27(00).*
D. Teaney, et. al., nucl-th/0110037

- Larger v_2/ε_{part} indicates stronger flow in more central collisions.
- Clearly, no ε_{part} scaling.
- **The observed n_q-scaling does not necessarily mean thermalization.**

(no) Scaling in Hydro Model

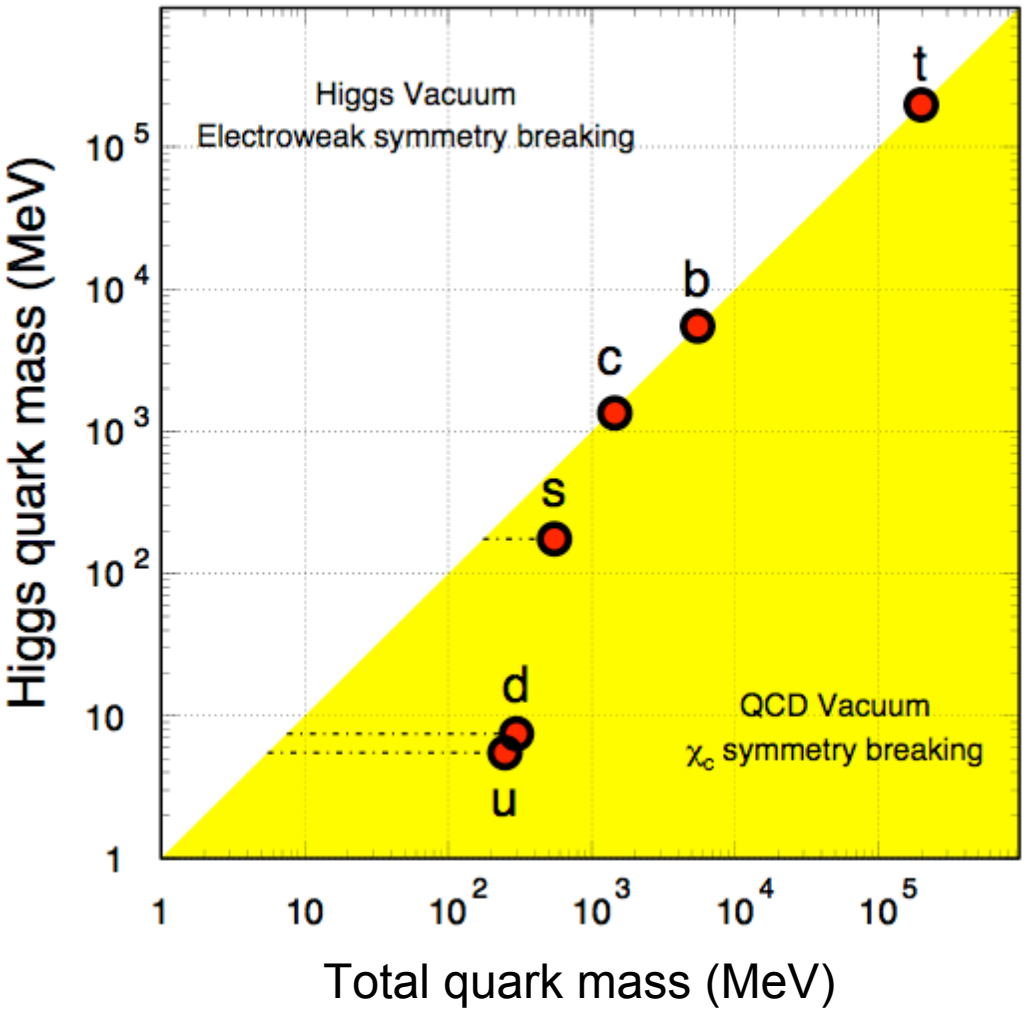


1) No scaling is observed in the non-viscous hydrodynamic model predictions.

2) **Realistic calculations with viscosity are necessary!**

- *STAR data: PRC **72**, 014904, 2005* arXiv:0801.3466v1
- Non-viscous *hydrodynamic results: P. Huovinen, private communications 2007*
- *D. Teaney, J. Lauret, and E.Shuryak, nucl-th/0110037*
- *T. Hirano et al. Phy. Lett. **B636**, 299 (06); J. Phys. **G34** S879(07); arXiv: 0710.5795*

Quark Masses



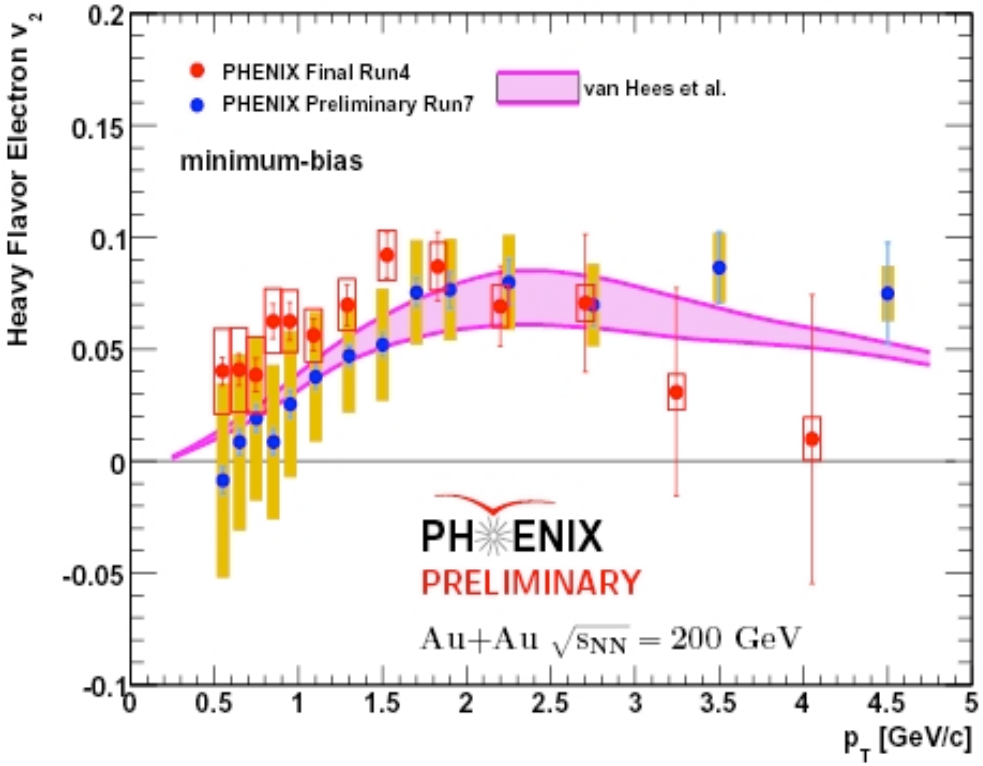
1) Higgs mass: electro-weak symmetry breaking. (current quark mass)
2) QCD mass: Chiral symmetry breaking. (constituent quark mass)

➪ New mass scale compared to the excitation of the system.

➪ Important tool for studying properties of the hot/dense medium at RHIC.

➪ Test pQCD predictions at RHIC.

New Results Non-photonic e v_2



PHENIX run-IV:
*PRL, **98**, 172301 (2007)*

Parallel: R. Averbeck;
Poster: A. Dion

1) Heavy quark collectivity => light quark thermalization! Muller *nucl-th/0404015*
2) Non-photonic electron v_2 indicates non-zero v_2 of Charm-hadrons.
3) Large systematic errors.

Need *directly reconstructed* heavy quark-hadrons!!

Properties of the medium in high-energy nuclear collisions:

- Strong interacting matter
- Partonic collectivity at RHIC
- Qualitative ⇨ Quantitative: T, p, c_s, η/s, …

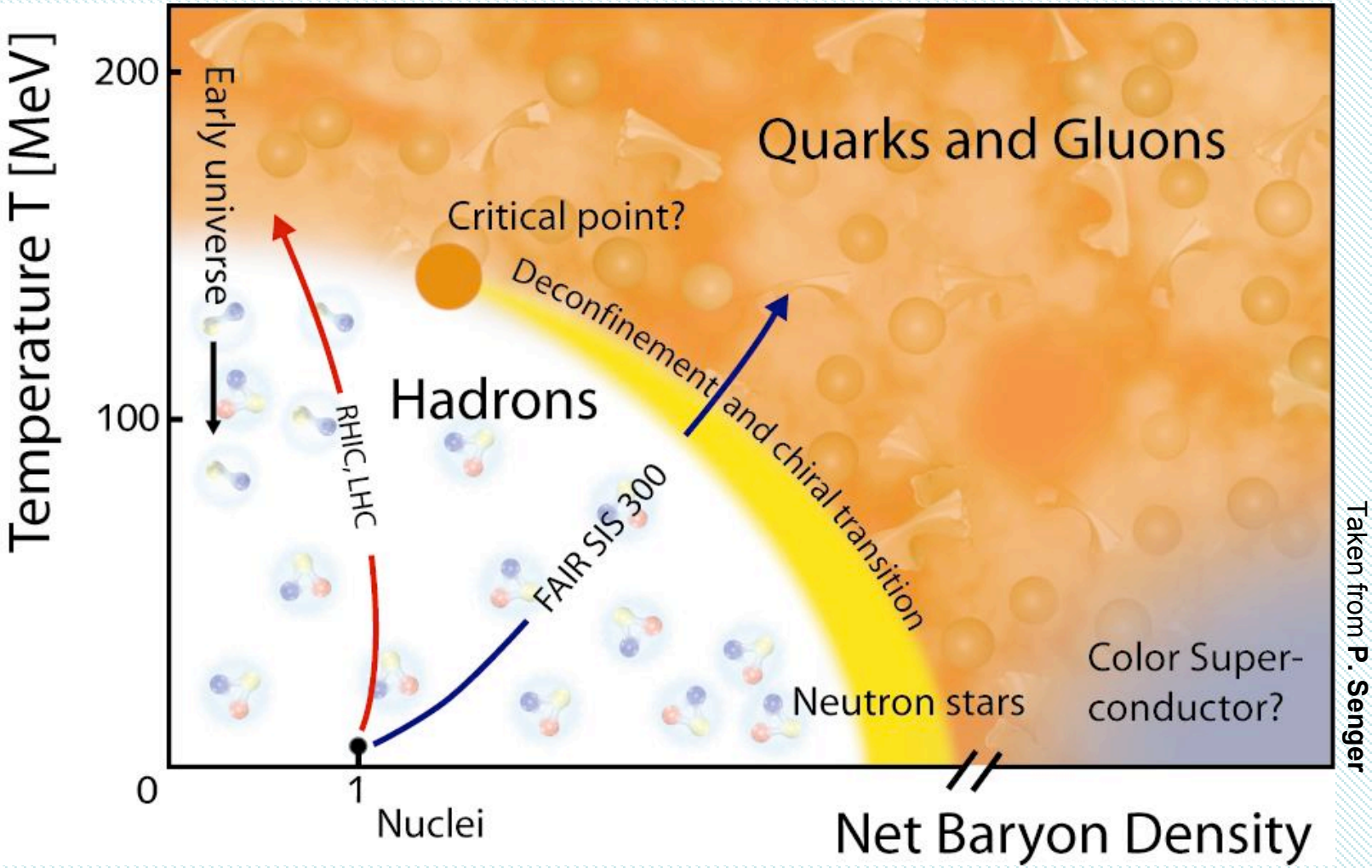
Future:

(i) High quality data, detailed analysis, energy scan

(ii) Leptons and heavy quark data

(iii) **Collaboration between experimentalists and theorists**

Talks: *S. Bass, B. Betz, T. Csorgo, C. Gale, S. Gavin, T. Hirano, T. Kodama D. Molnar, B. Muller, A. Murronga, C. Nonaka, S.S. Padula, H. Song,,, …*



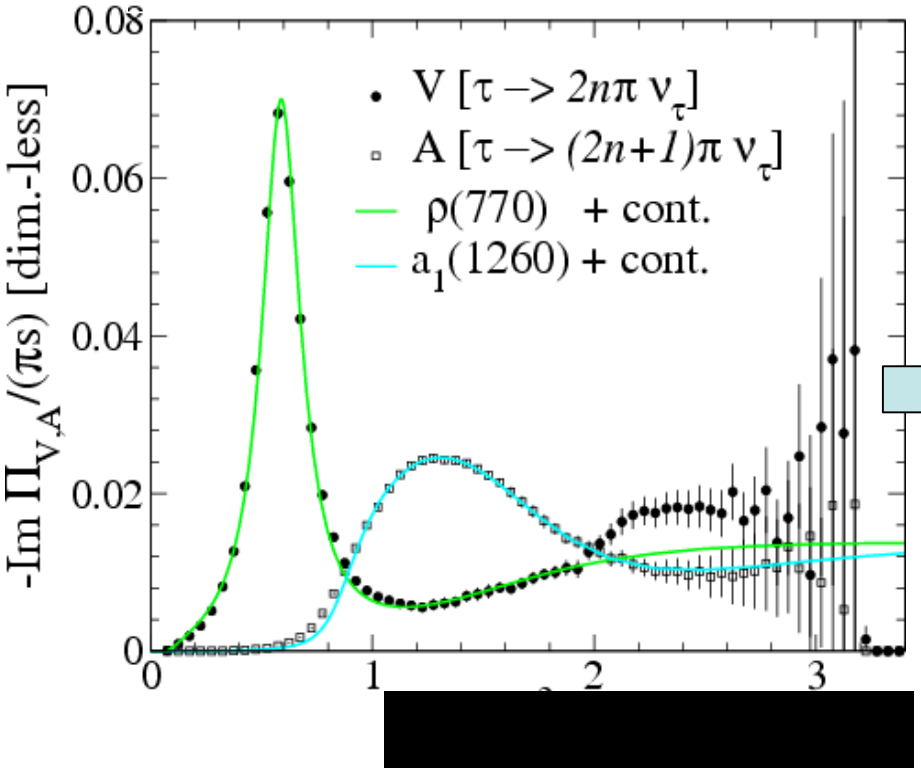
Taken from **P. Senger**

1) RHIC heavy-flavor program / LHC:
- Study ***medium properties***
- pQCD in hot and dense medium

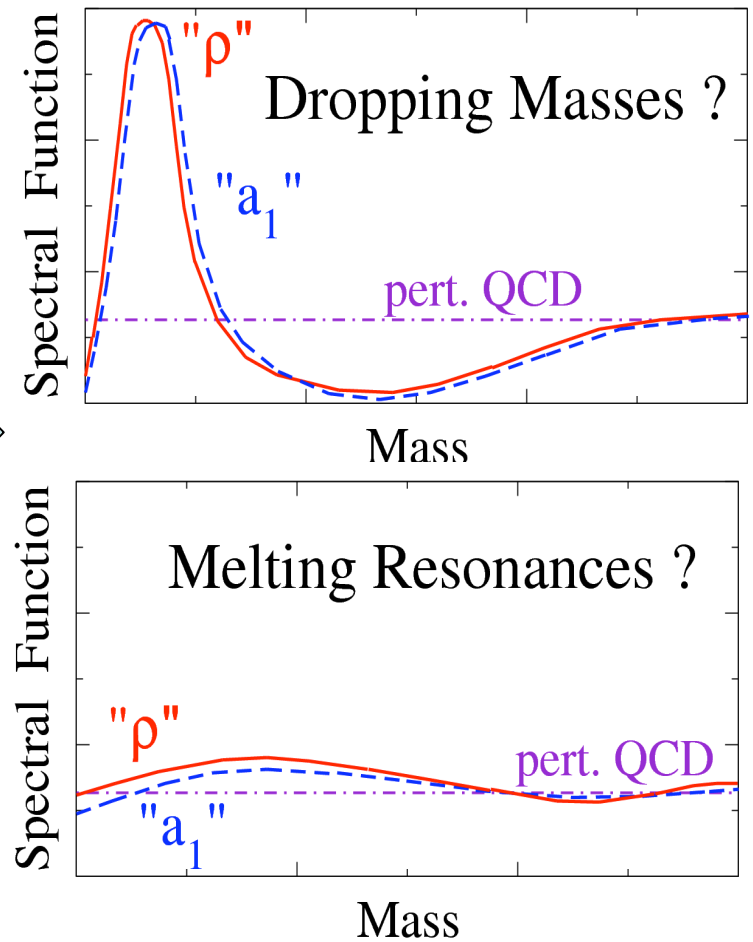
2) RHIC energy scan / GSI program:
- Search for ***phase boundary***.
- Chiral symmetry restoration

Low-mass dileptons + chiral symmetry

ALEPH data: Vacuum



At T_c: Chiral Restoration



- How is the degeneration of chiral partners realized ?
- In nuclear collisions, measure vector→$\mu^+\mu^-$, but axial vector?