Beam-energy scan in relativistic heavy-ion collisions

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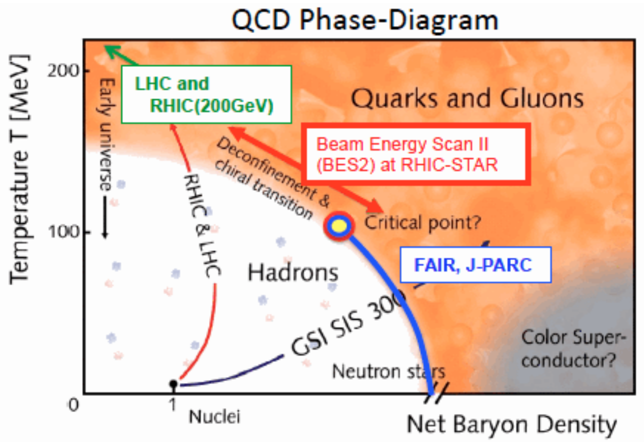
Contents

- Critical fluctuation
- Collective expansion
- Vortical, Chiral magnetic fluid
- Future plan



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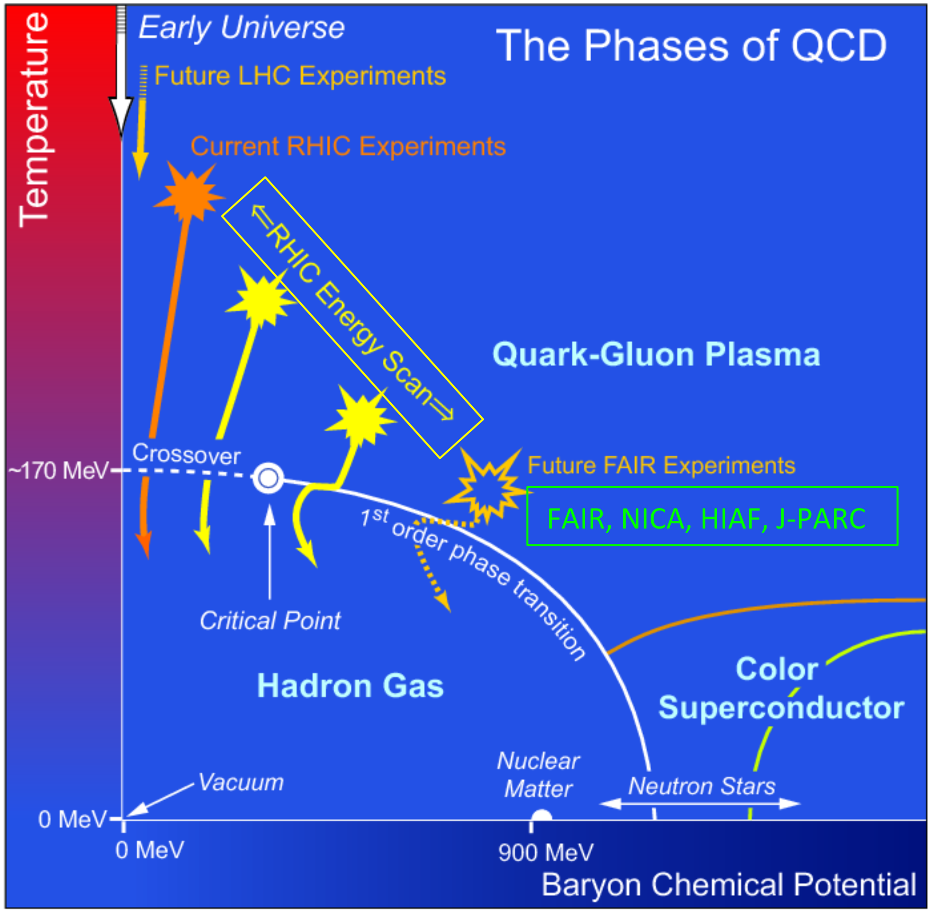
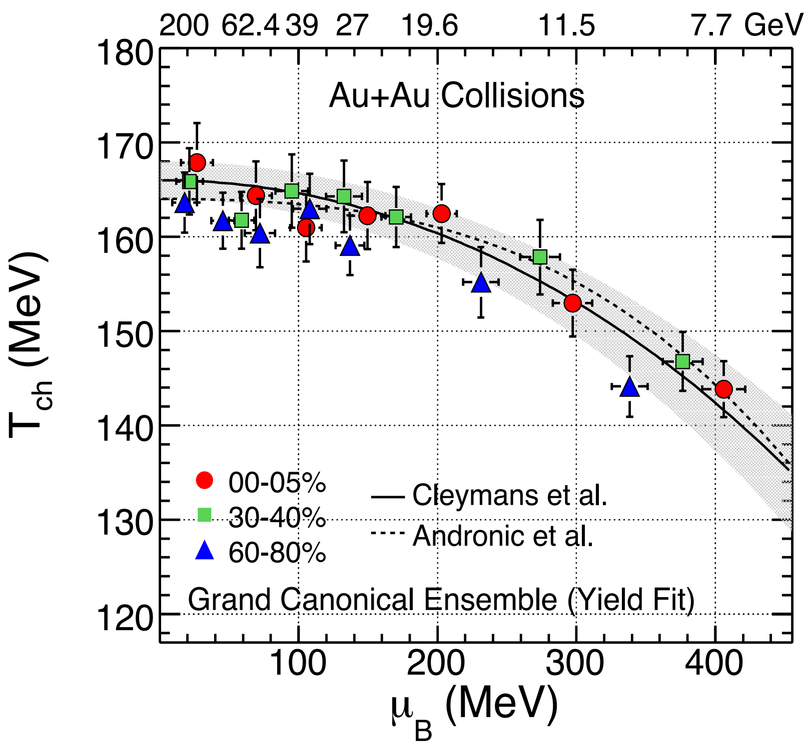
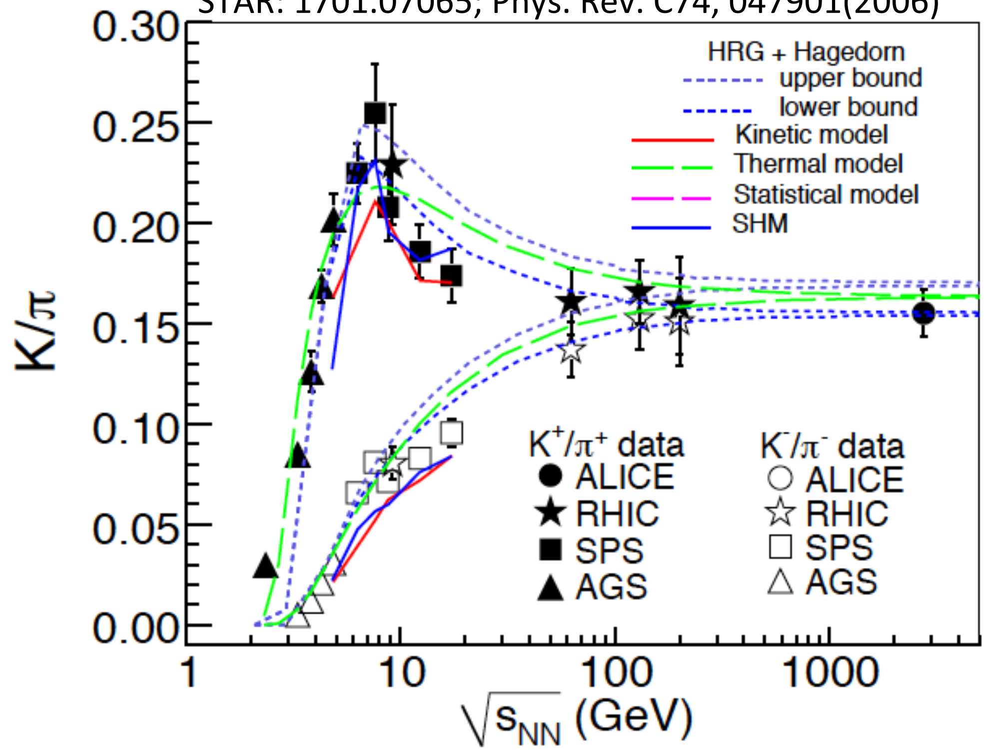
QCD phase diagram and Critical Point



- Cross over phase transition at high T and small μ_B
- 1st order phase transition at high μ_B
- Critical end point search via RHIC beam energy scan program
- New direction towards high-density matter in future fasilities

Baryon density and chemical freeze-out

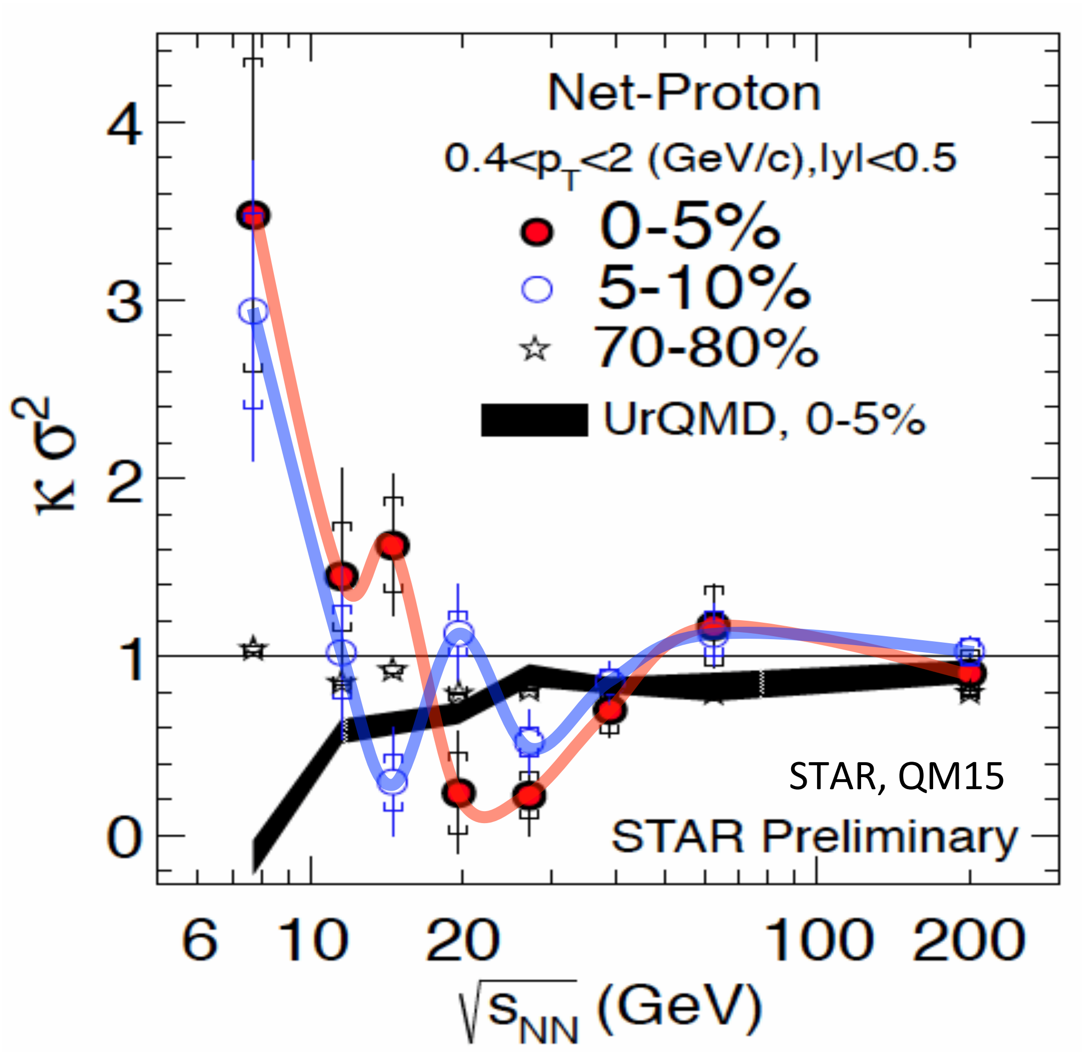


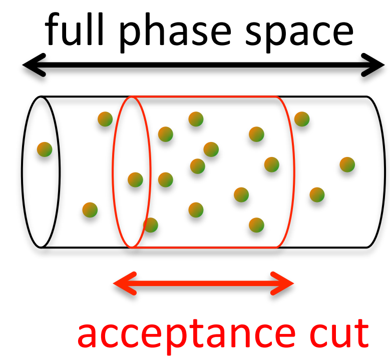


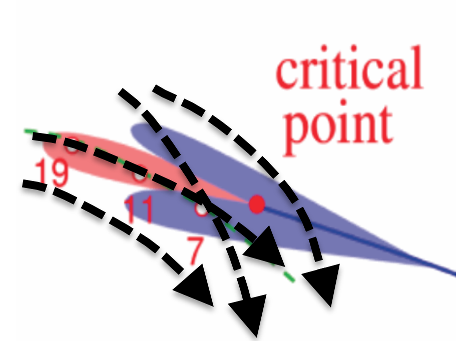
Baryon density increases with reducing beam energy.

Baryon density peaks at about 8GeV based on model.

Net-proton as a proxy for conserved net-Baryon fluctuation



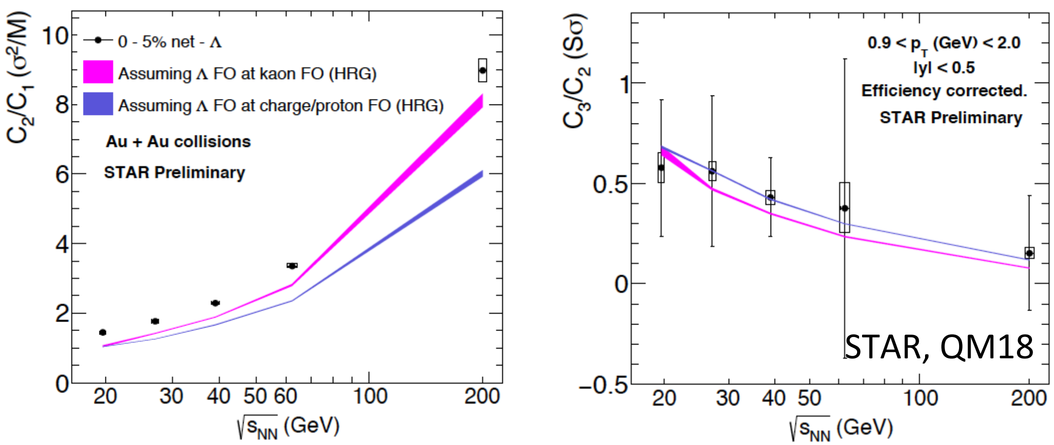




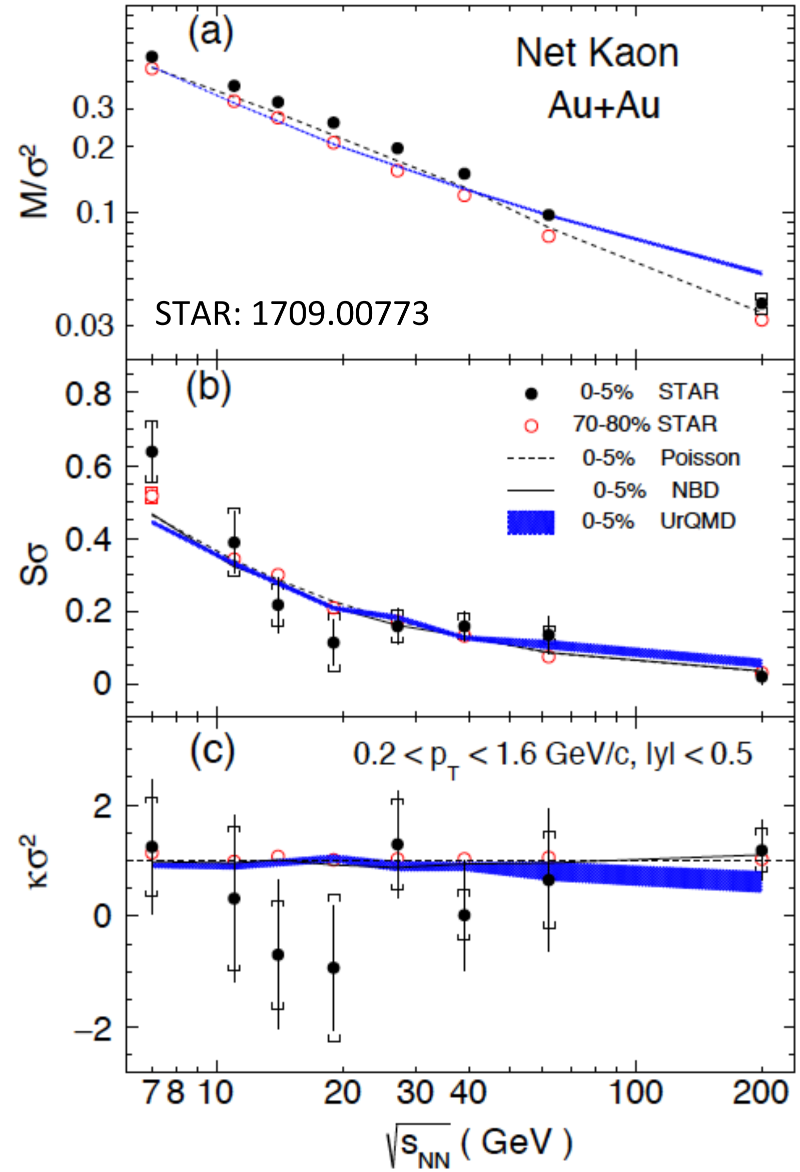
possible signal from critical point which could be taken as a change of correlation length with 4th order cumulant .

from Net-Baryon towards net-Strangeness

Net Lambda cumulant ratio



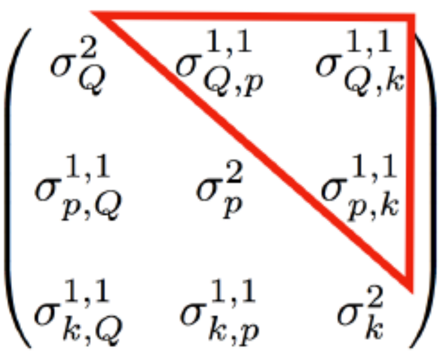
Net Kaon cumulant ratio



Trying to get signal from net-strangeness to be compared with net-proton and net-charge results

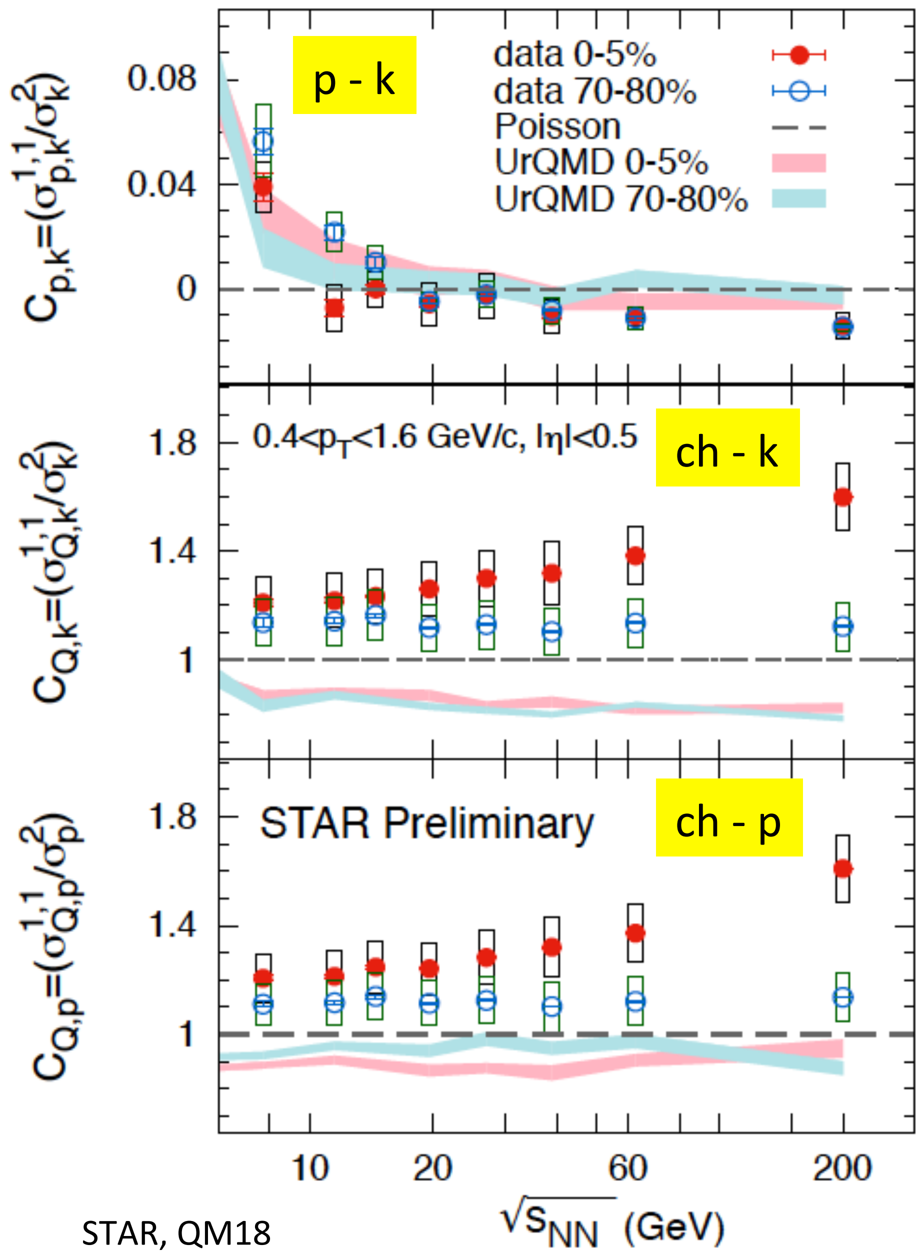
Off-diagonal cumulants among net-proton, net-kaon and net-charge

p : net-proton
k : net-kaon
Q : net-charge



$$\sigma^2_{x,y} = \langle xy \rangle - \langle x \rangle \langle y \rangle$$

$$C_{x,y} = \frac{\sigma^{1,1}_{x,y}}{\sigma^2_y}$$

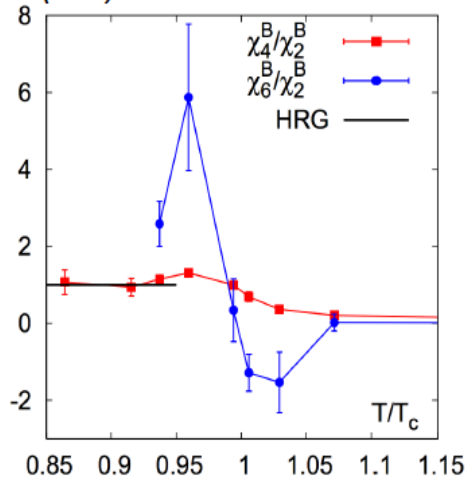


STAR, QM18

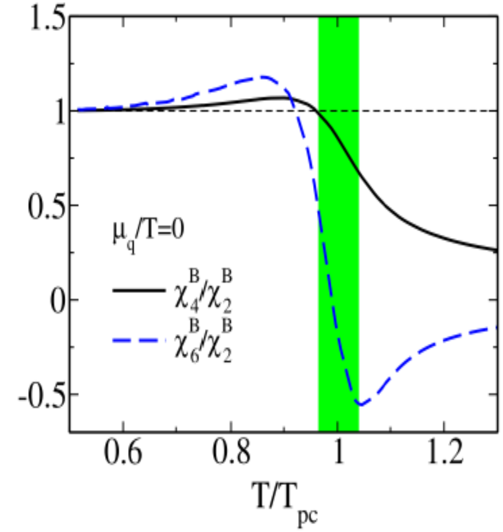
6^{th} order cumulants of net-proton and net-charge

Higher order cumulants are expected to be more sensitive to the critical fluctuation than lower orders.

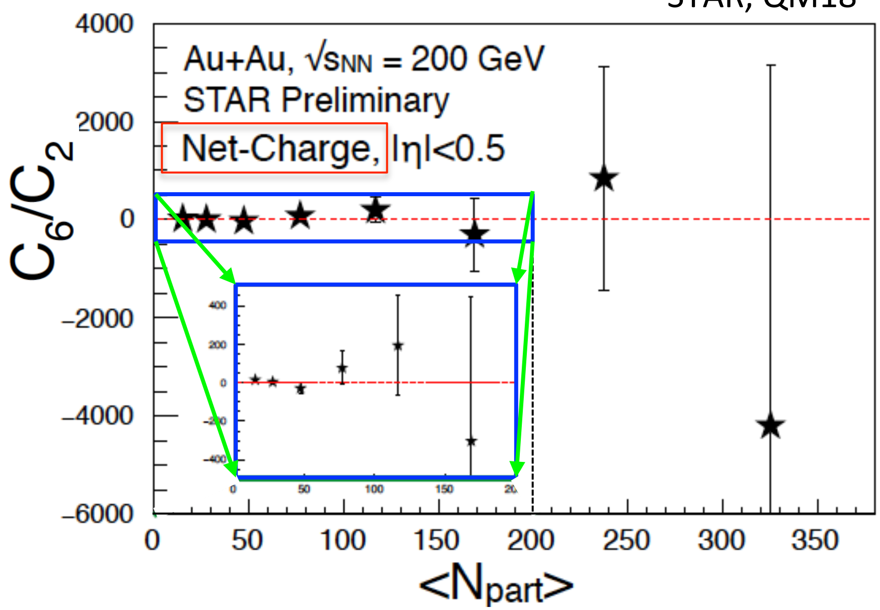
Cheng et al, Phys. Rev. D 79, 074505 (2009) : Lattice QCD



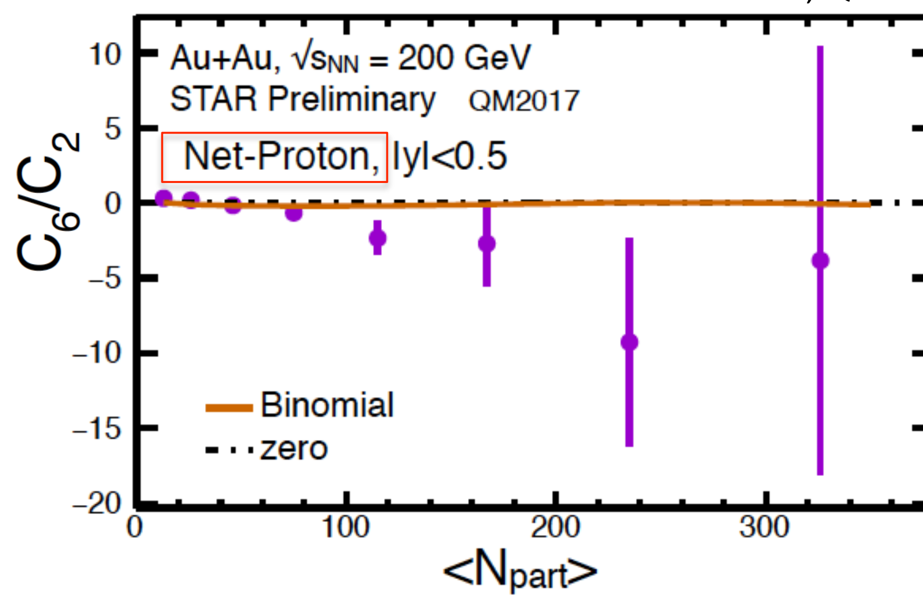
Friman et al, Eur. Phys. J. C (2011) 71:1694 : O(4) scaling functions



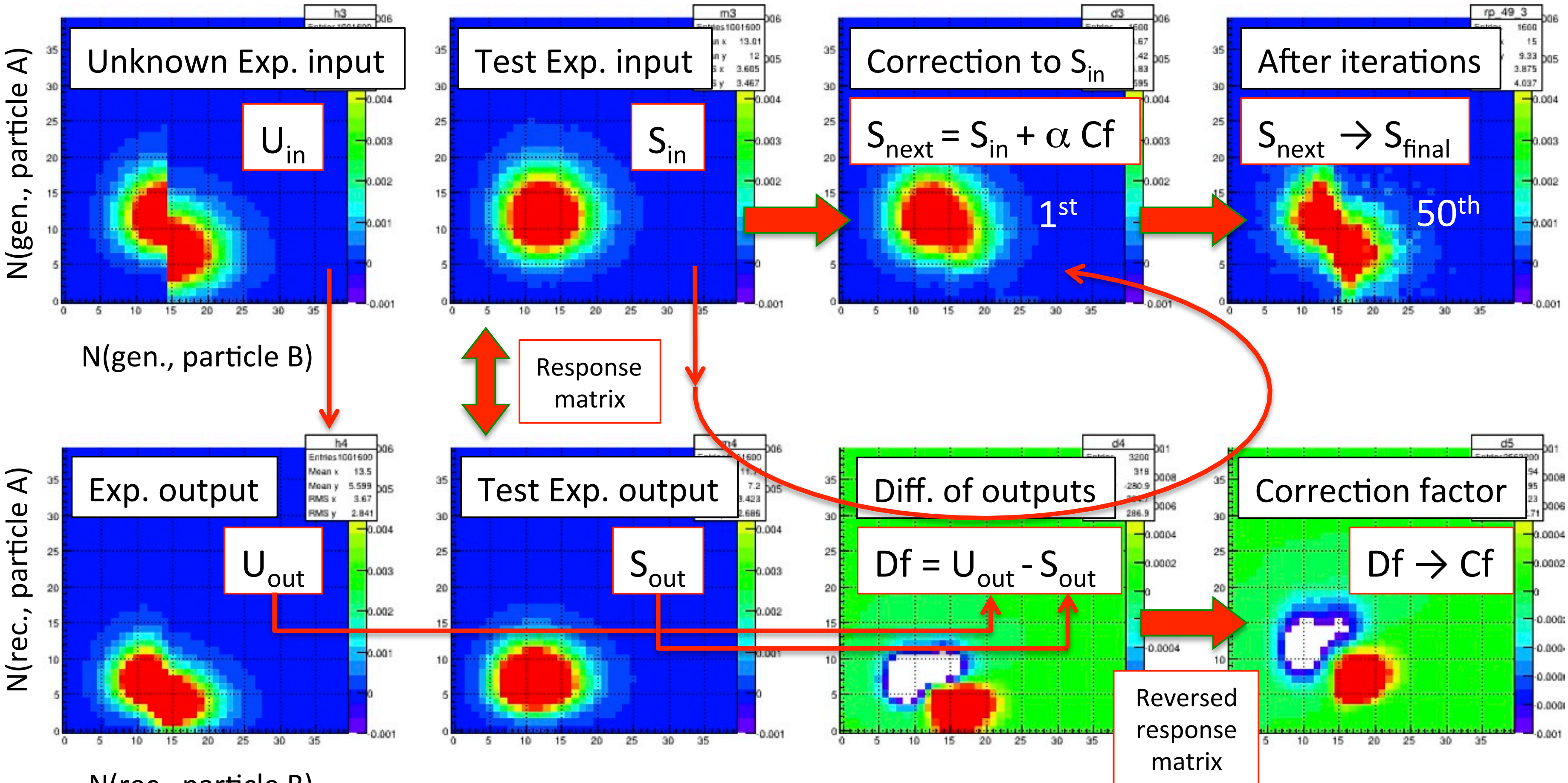
STAR, QM18



STAR, QM17



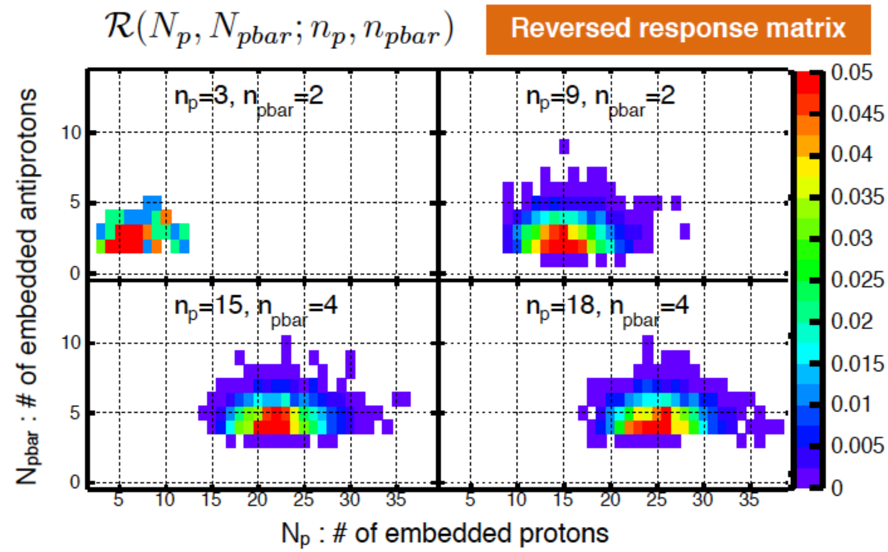
Unfolding of “unkown and critical” net-distribution

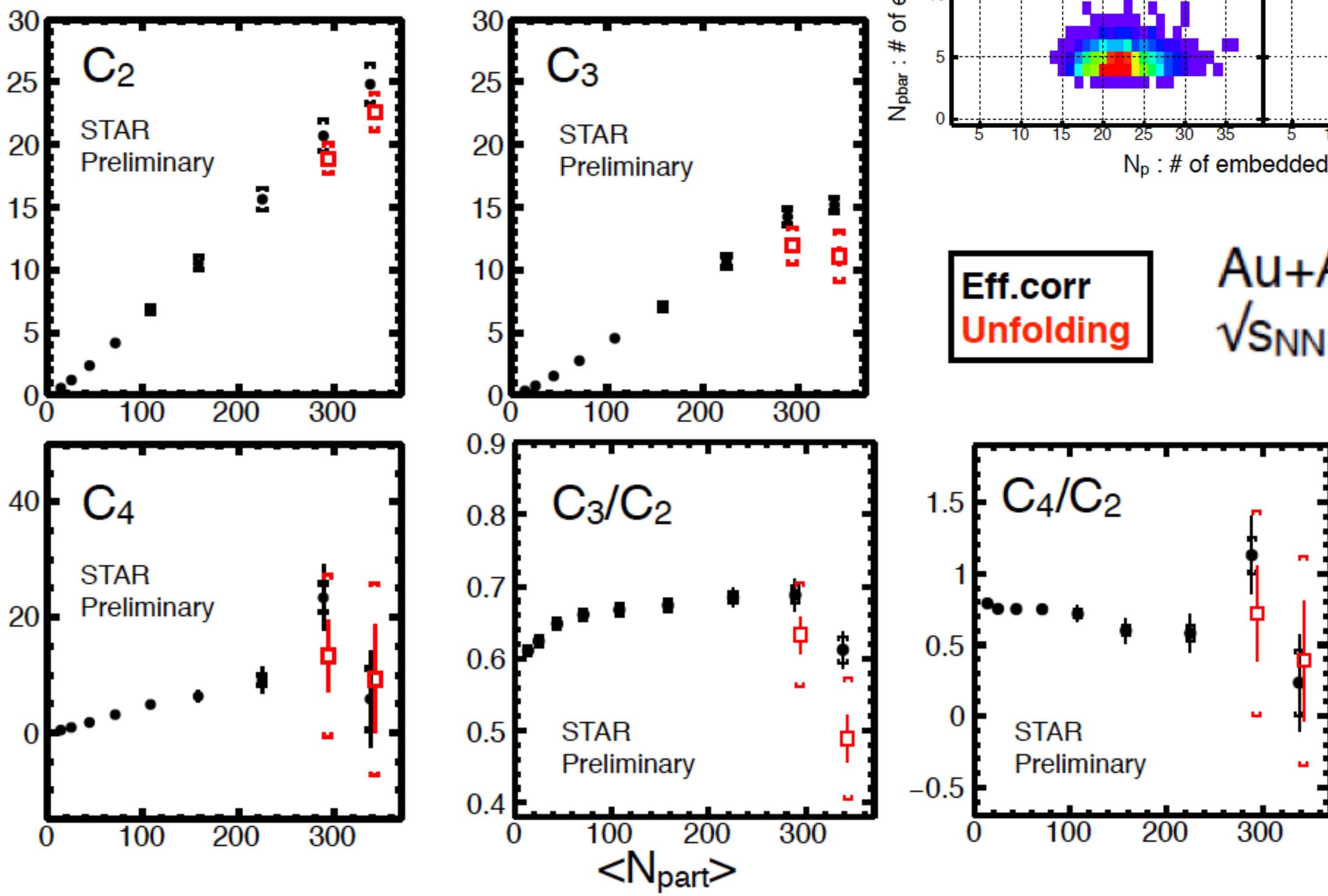


volume fluctuation can be included as a part of response matrix

EMMI workshop
in Wuhan 2017

Unfolding of net-proton distribution based on GEANT detector response matrix



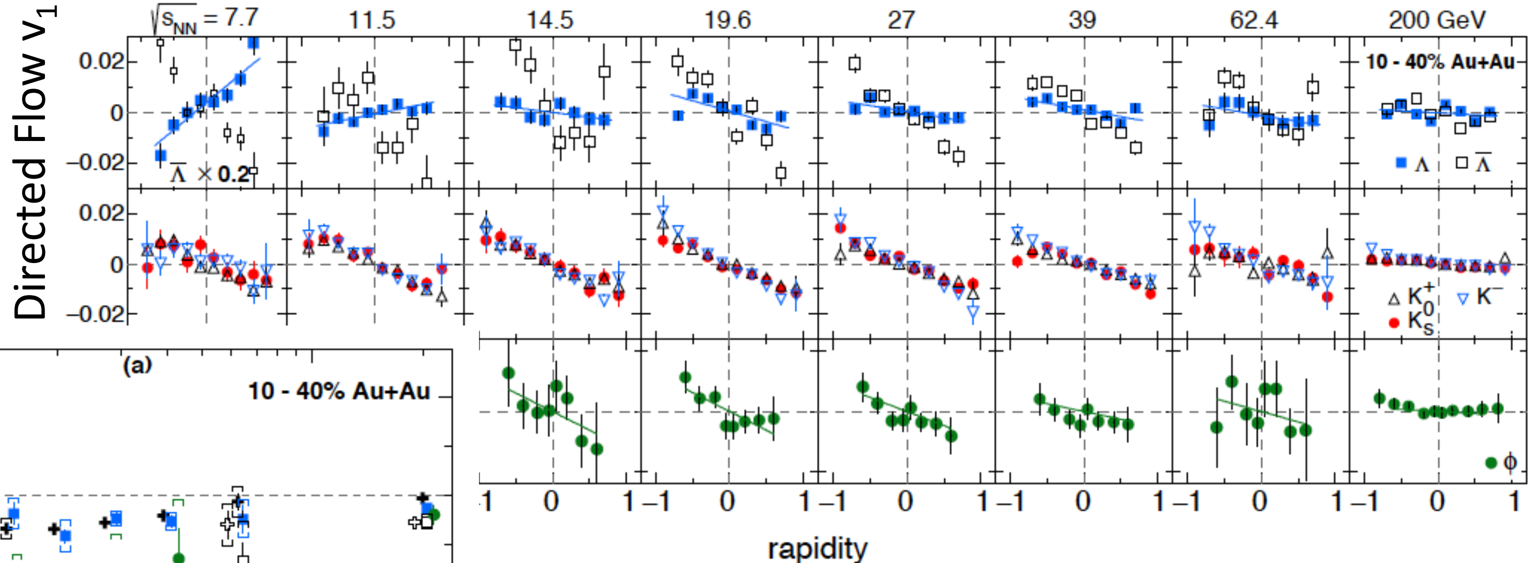


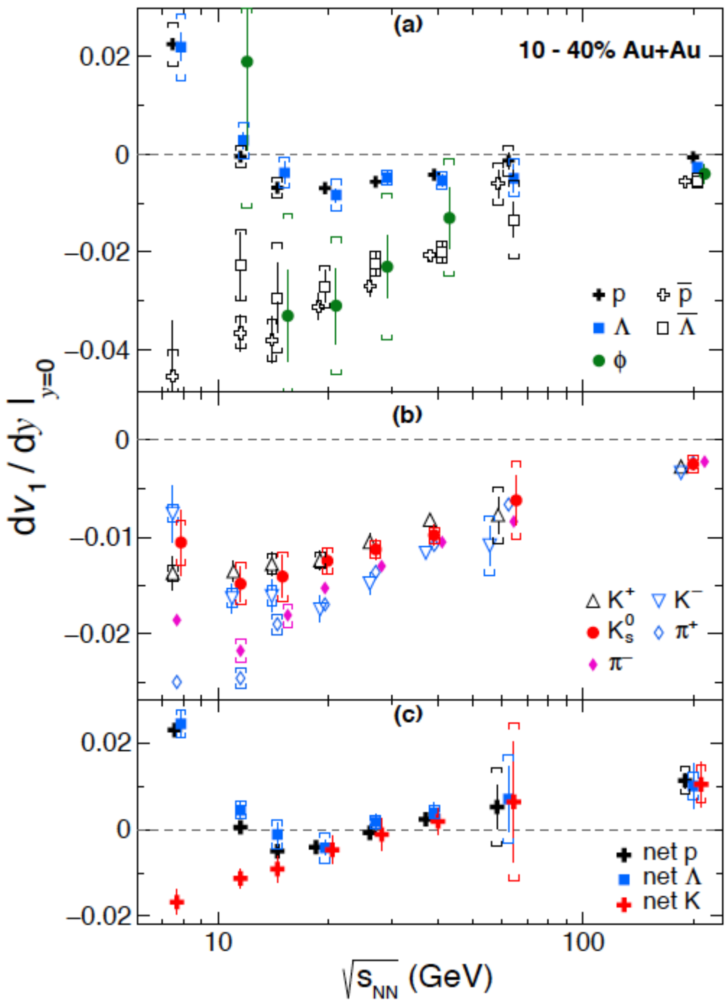
Eff.corr
Unfolding

Au+Au, $\sqrt{s_{NN}}$ = 19.6 GeV

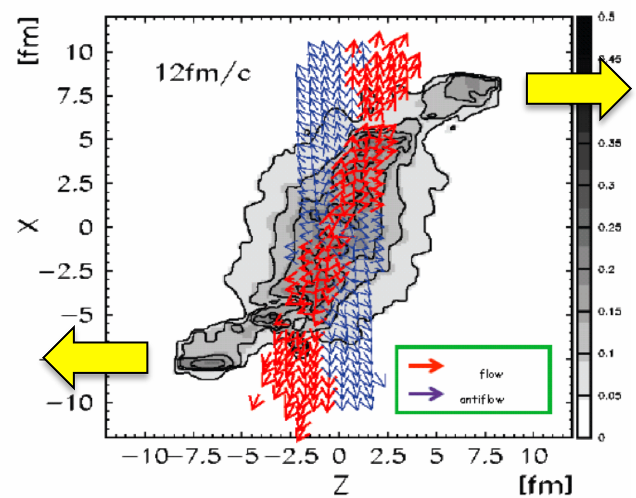
STAR, QM18

STAR:
1708.07132





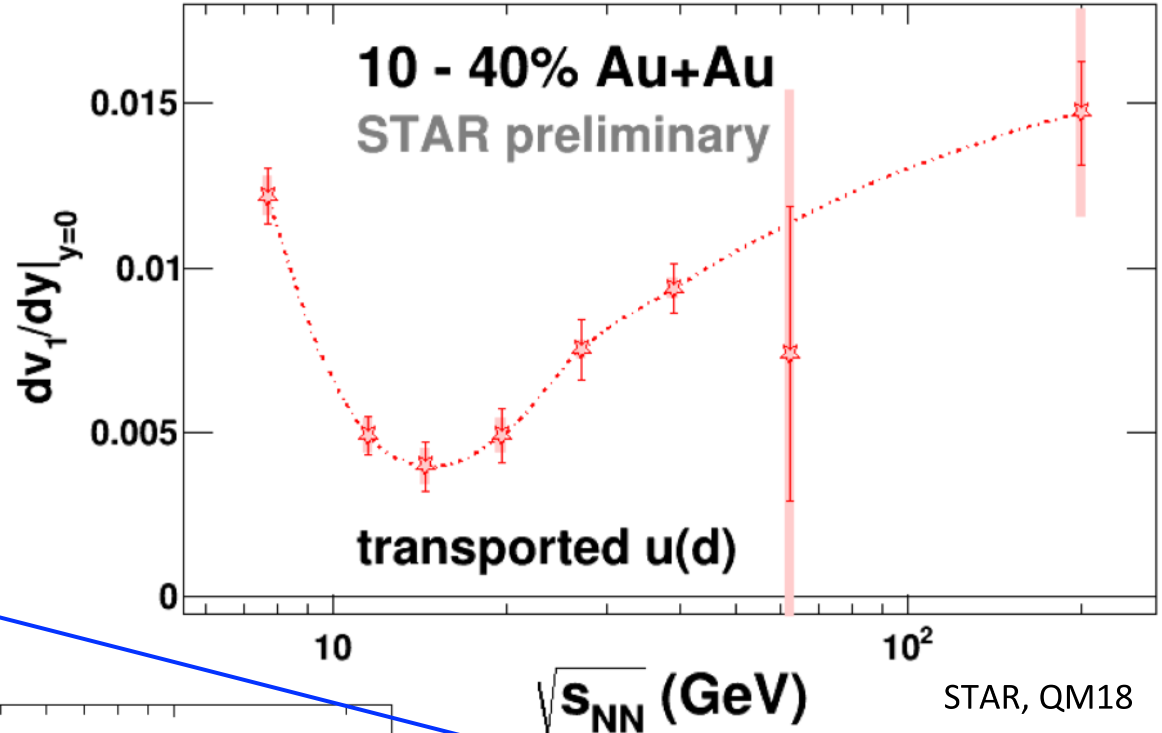
Directed flow v_1 and its slope with respect to rapidity



J. Brachmann et al., PRC 61, 24909 (2000).

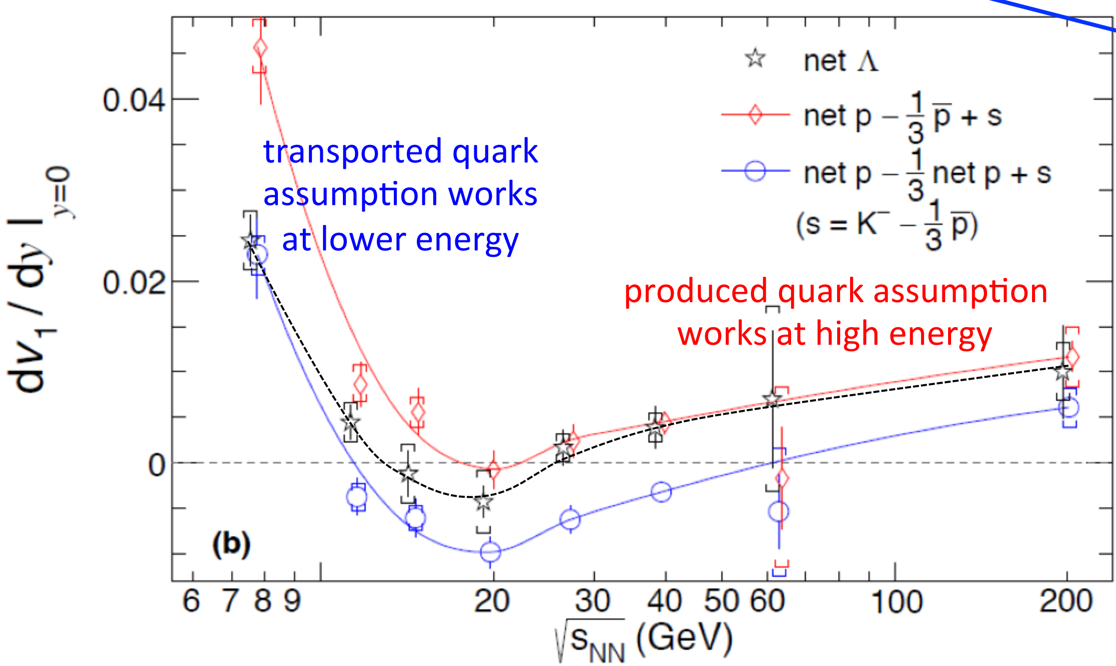
v_1 slope (dv_1/dy) of quark based on the quark coalescence

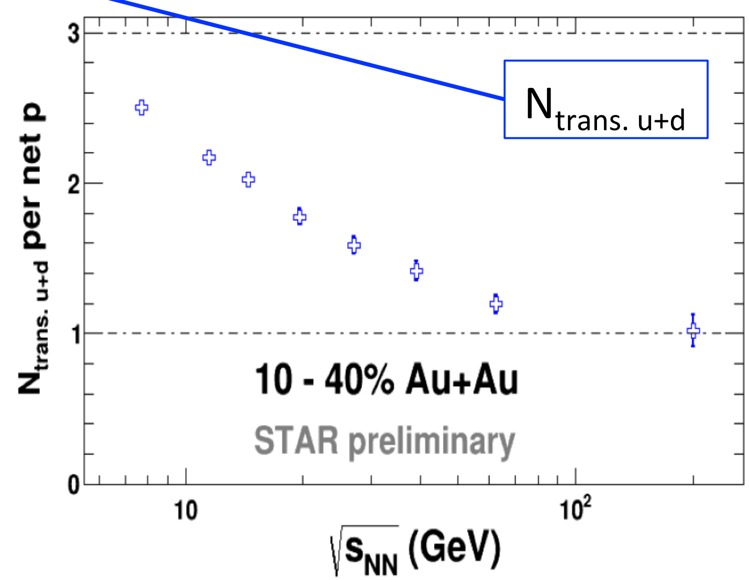
$$v1_{trans.\ u(d)} = \frac{v1_{net\ p} - v1_{pbar}(3 - N_{trans.\ u+d})/3}{N_{trans.\ u+d}}$$



STAR, QM18

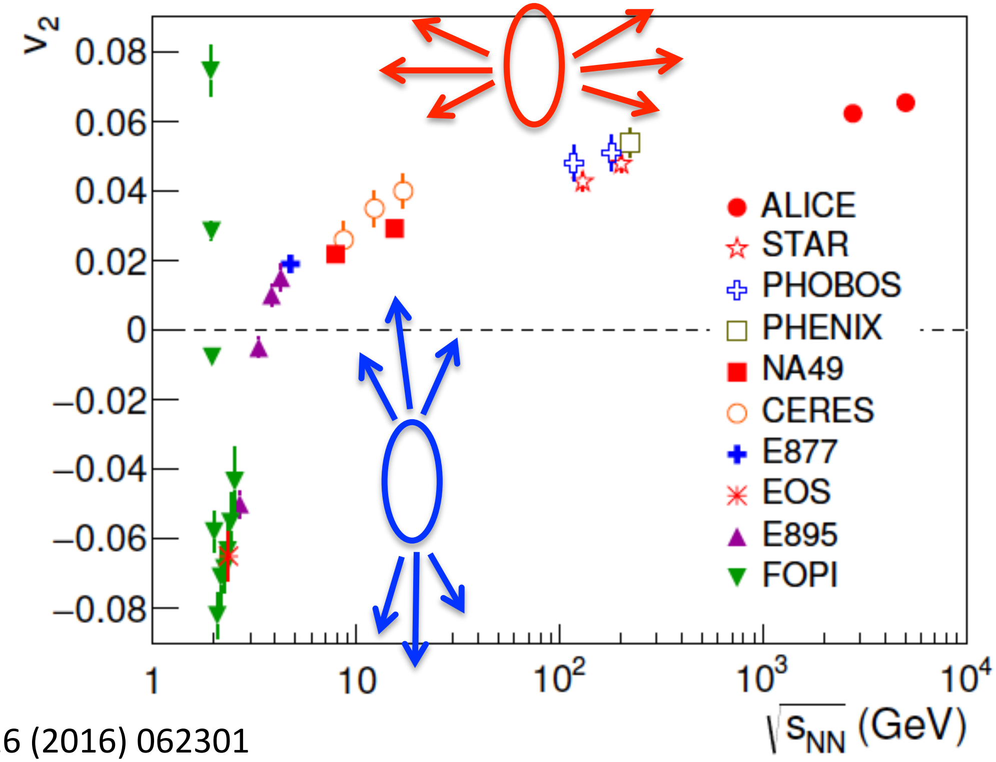
STAR: 1708.07132



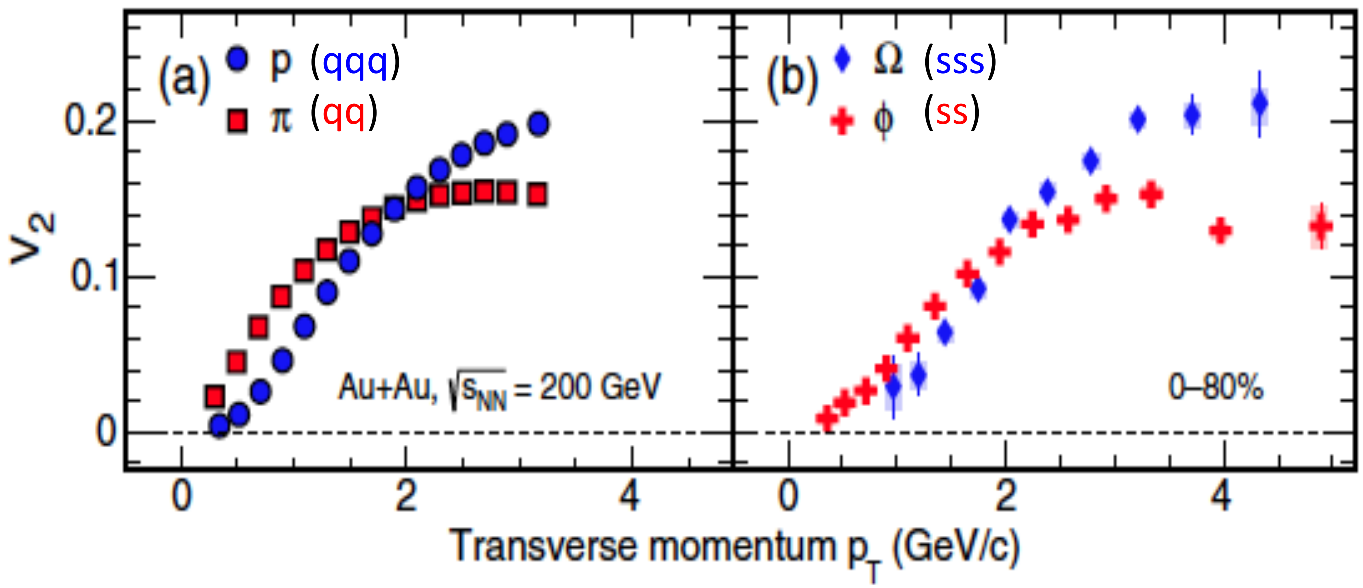


v_2 evolution with beam energy and quark coalescence

- Squeeze out and sign change
- Mass splitting
- Number of quark scaling

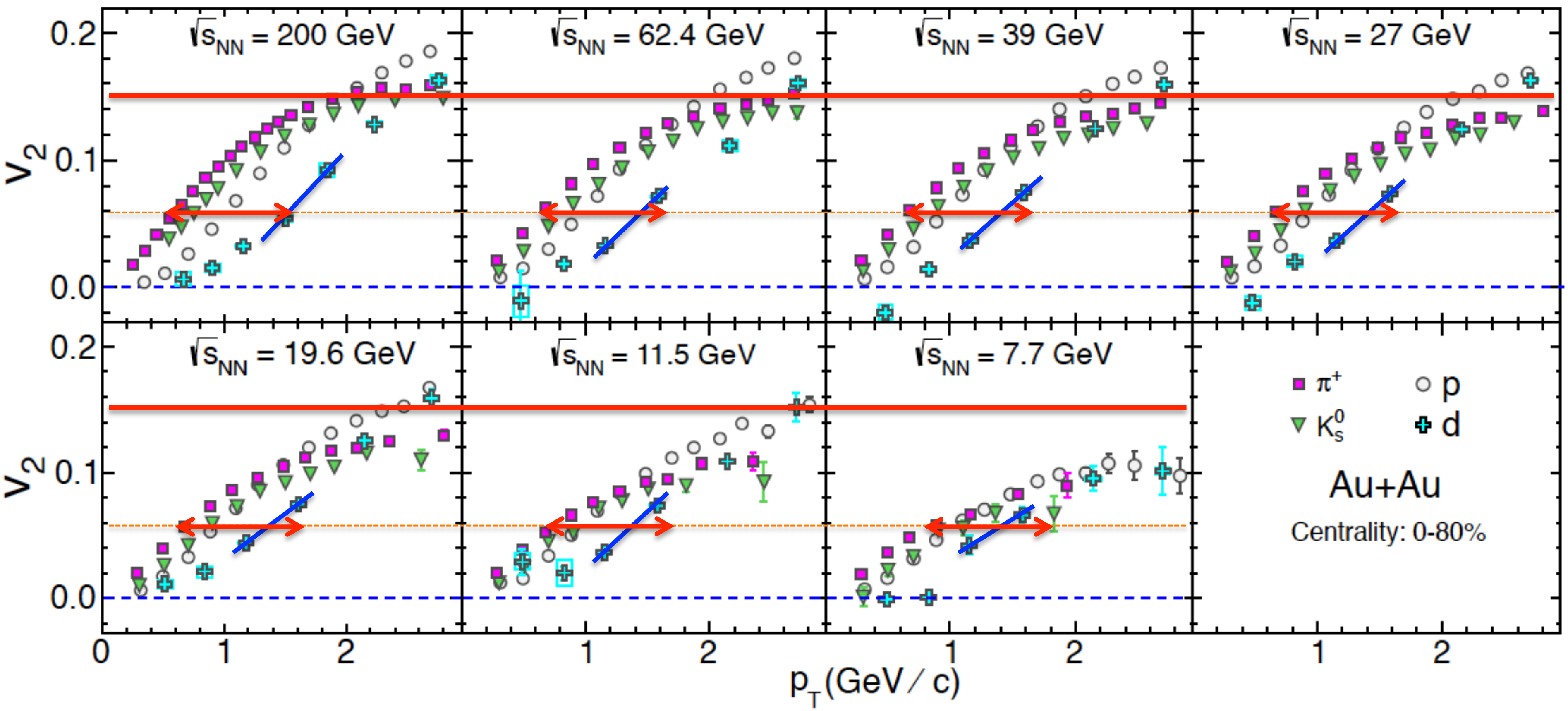


STAR: 1507.05247, Phys. Rev. Lett. 116 (2016) 062301



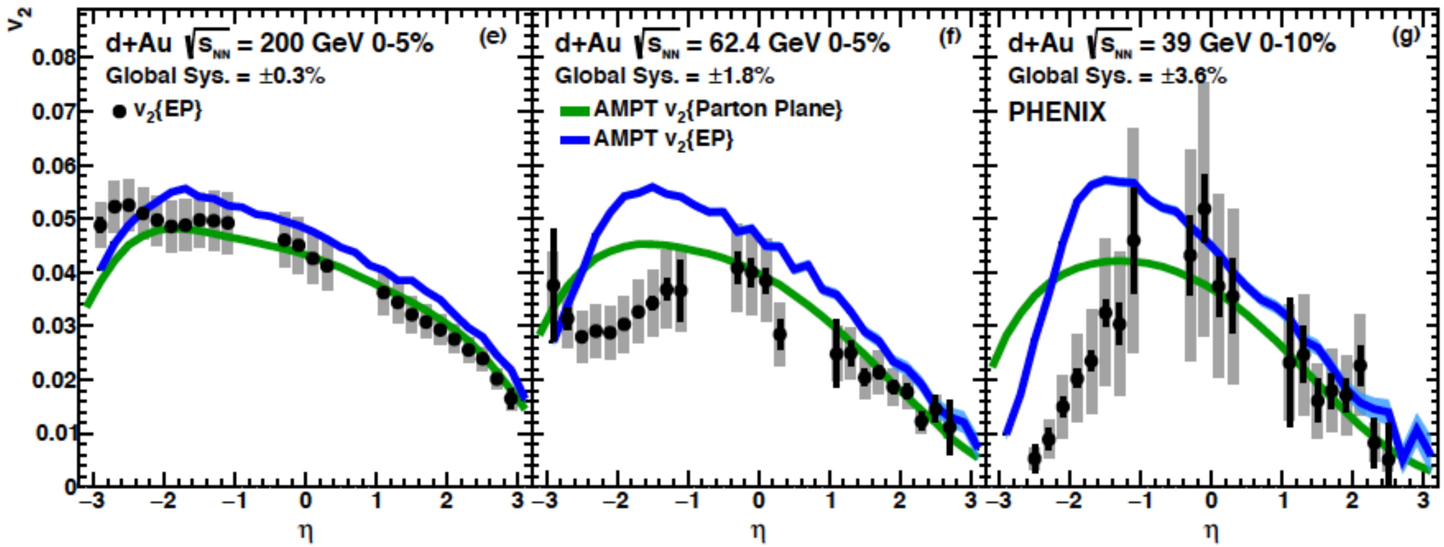
mass dependence of v_2 and evolution with beam energy

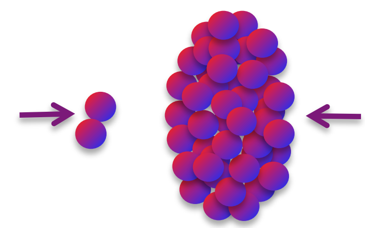
STAR: 1601.07052



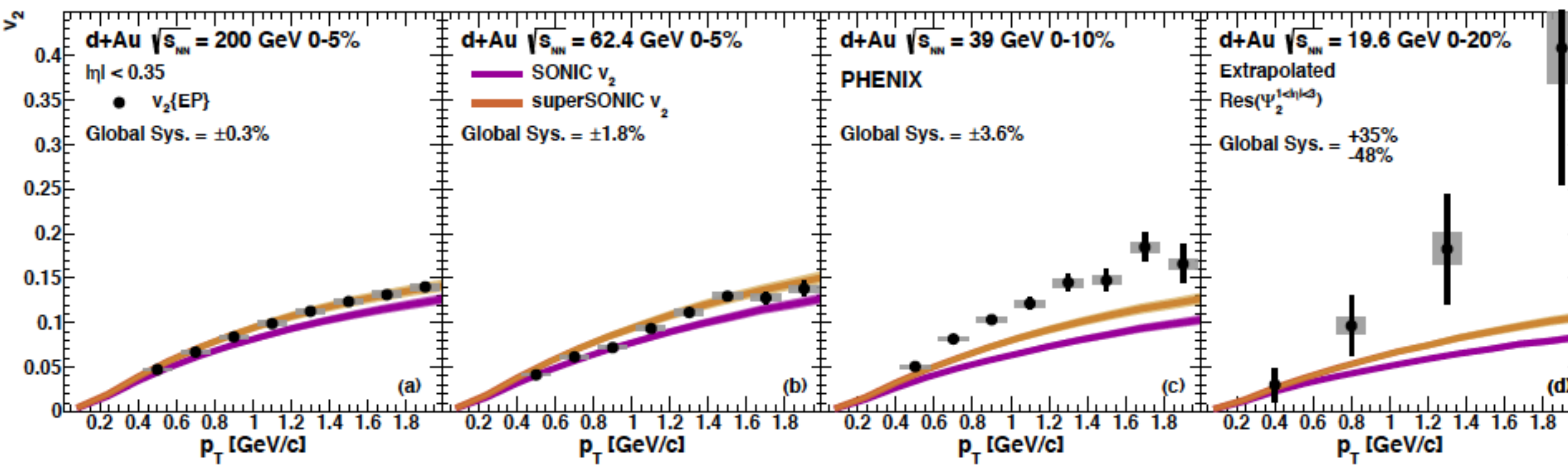
increasing radial and elliptic flow with beam energy

beam energy dependence of v_2 in small system at d+Au collisions





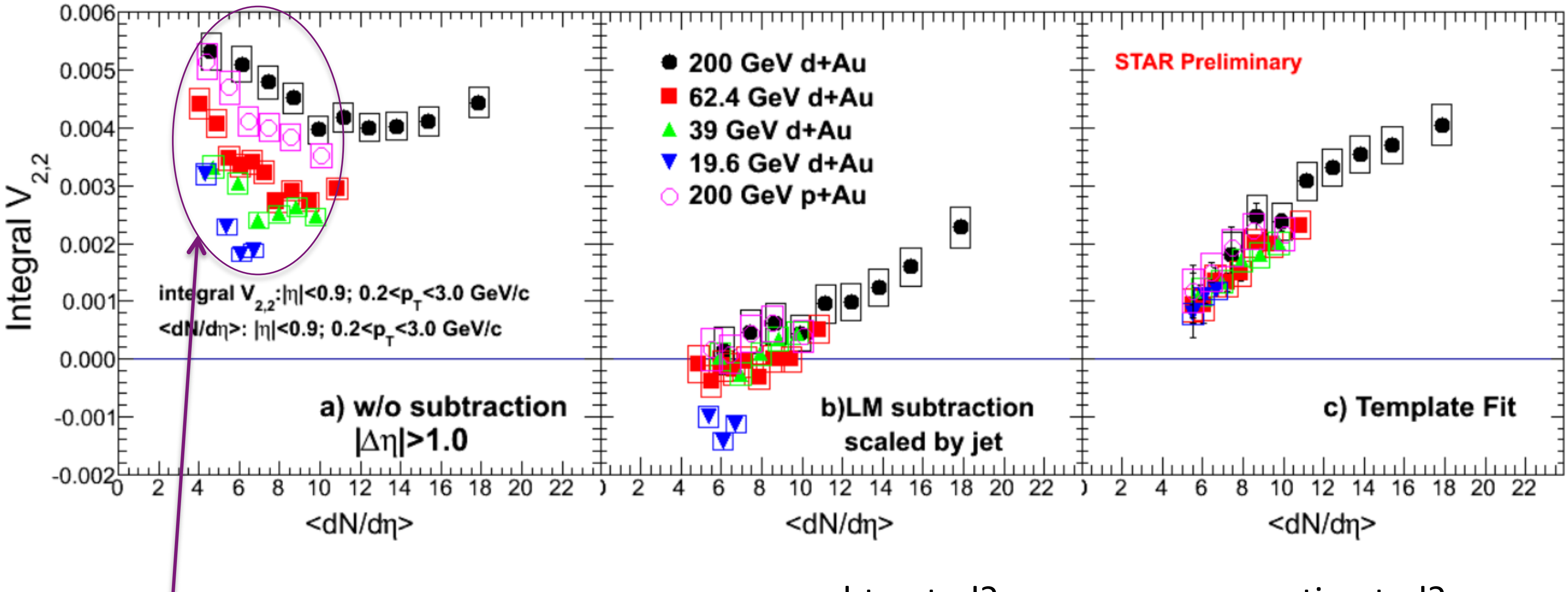
PHENIX: 1708.06983,
Phys. Rev. C96 (2017) 064905



beam energy and multiplicity dependence of v_2 in small system

--- 3 different methods (<u>no-subtr.</u>, <u>near-side scaled subtr.</u>, <u>templ. fit</u>) ---

STAR, QM18



non-flow dominated

over-subtracted?

over-estimated?

reference fitting to be in the middle

Longitudinal de-correlation of event plane of Φ_2 (top) and Φ_3 (bot.)

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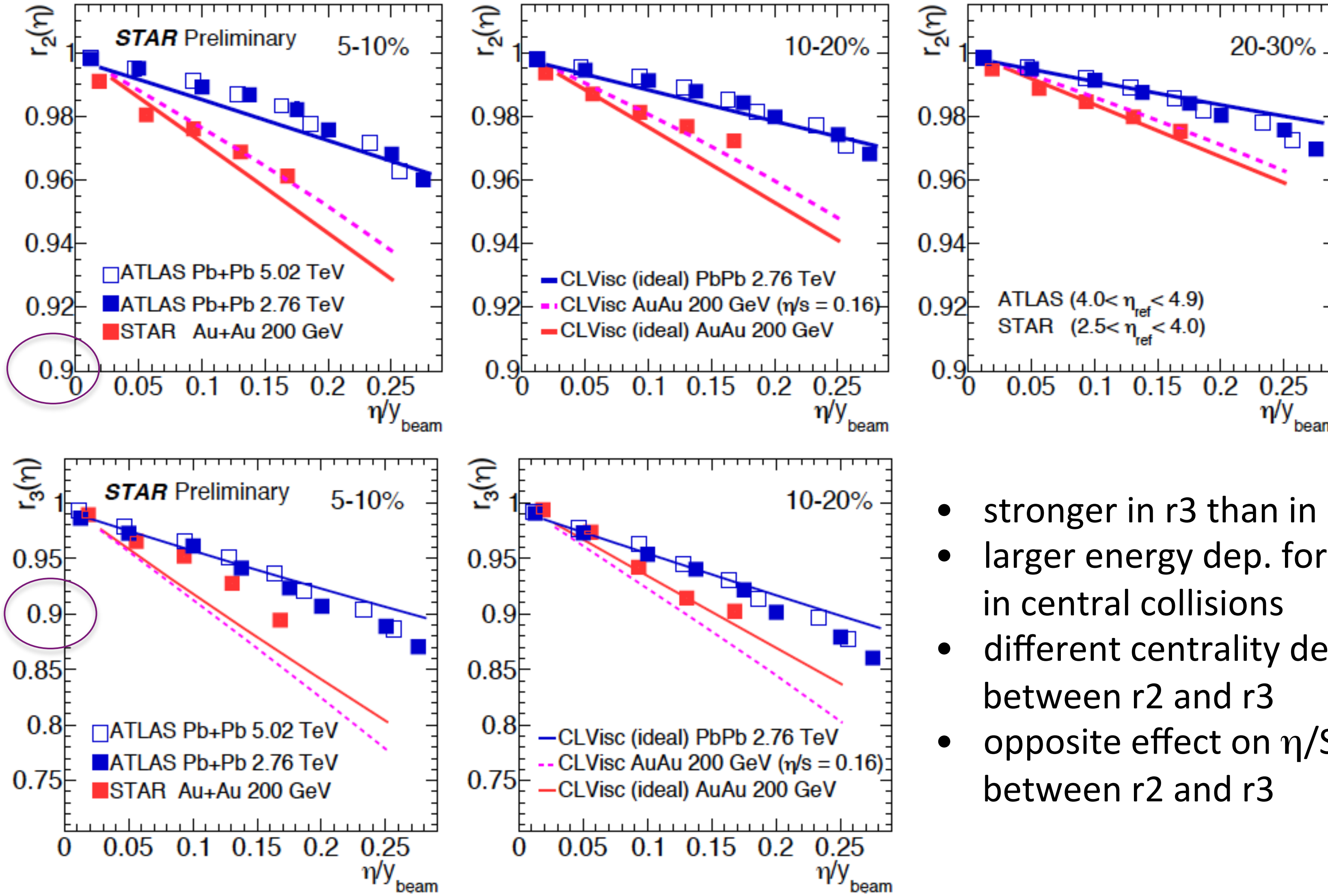
$r_2(\eta)$ for Φ_2

$r_3(\eta)$ for Φ_3

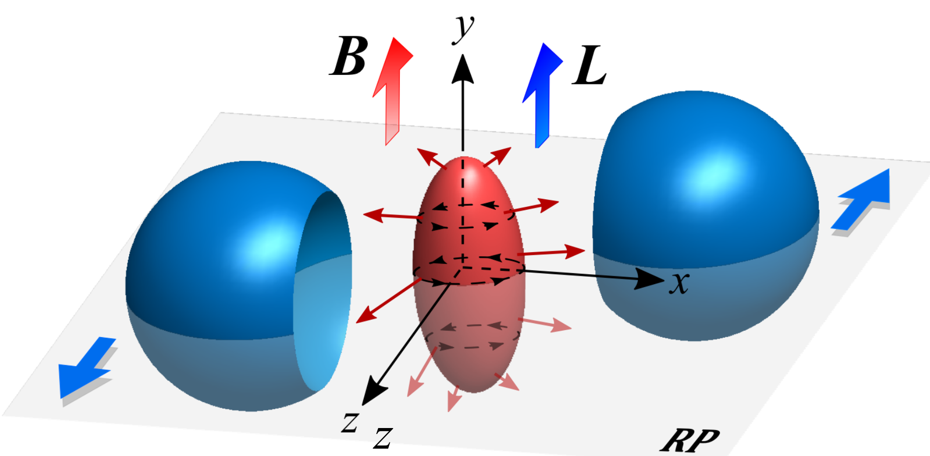


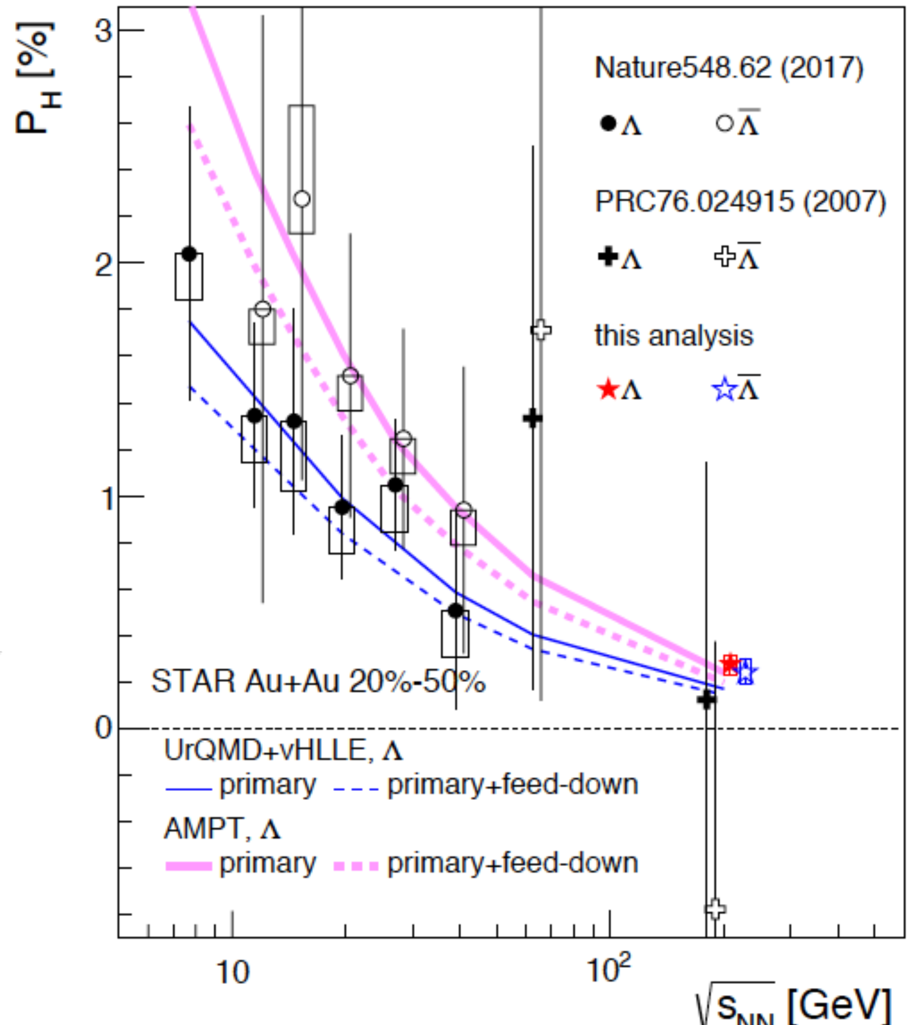
- stronger in r3 than in r2
- larger energy dep. for r2 in central collisions
- different centrality dep. between r2 and r3
- opposite effect on η/S between r2 and r3

Global polarization via Lambda decay

#38

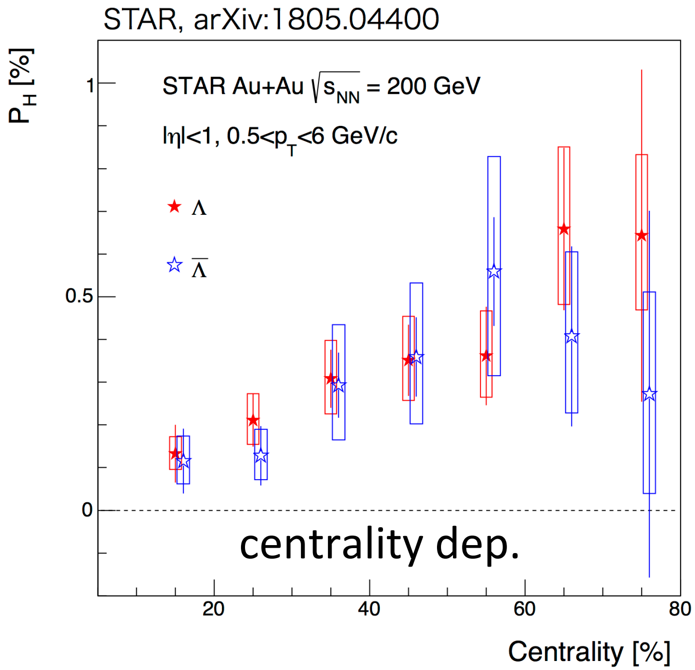
The Fastest Fluid
by Sylvia Morrow
Superhot material spins at an incredible rate.



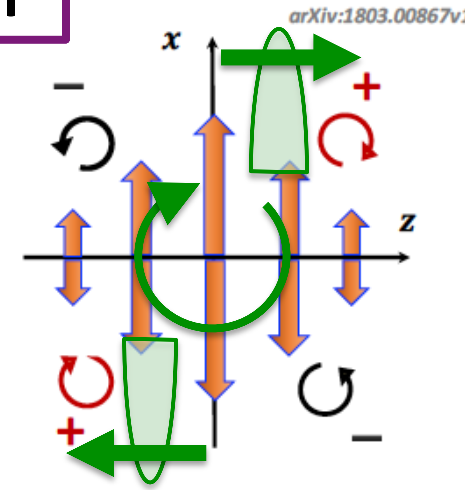


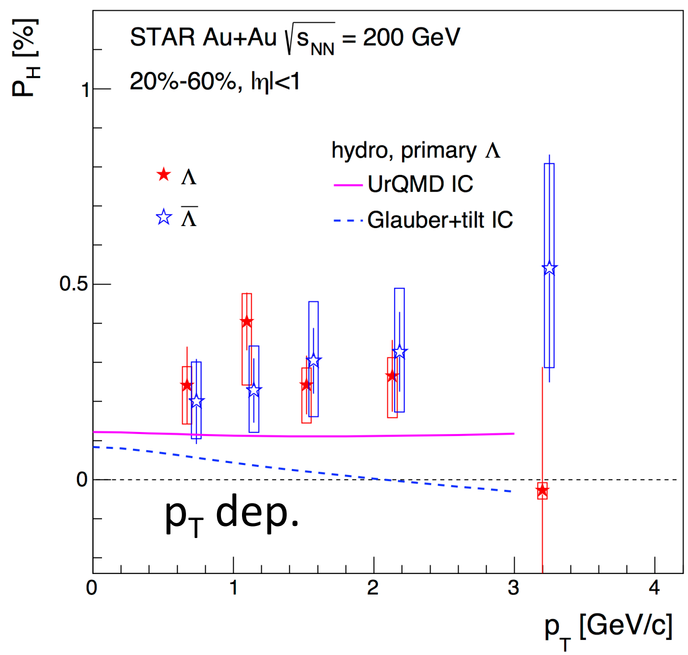
STAR, arXiv:1805.04400

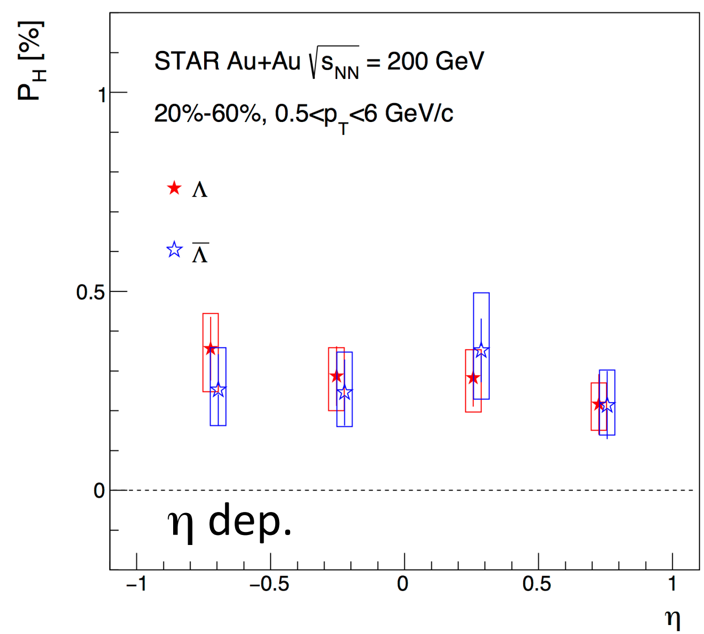
Lambda polarization



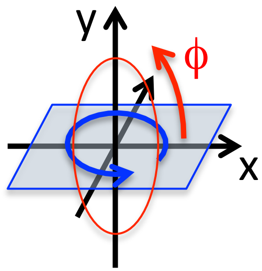
- Strong centrality dependence
- No significant p_T and η dependences

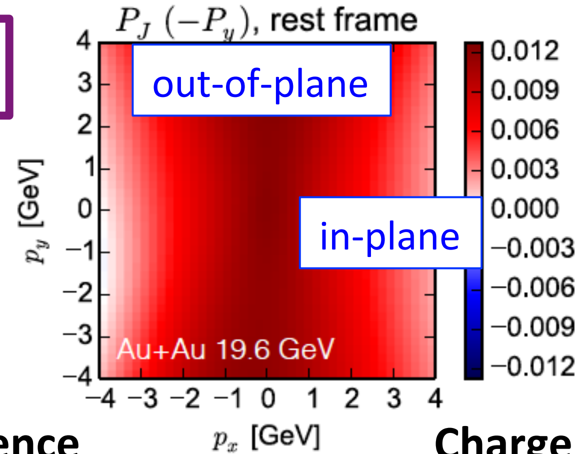






Lambda polarization

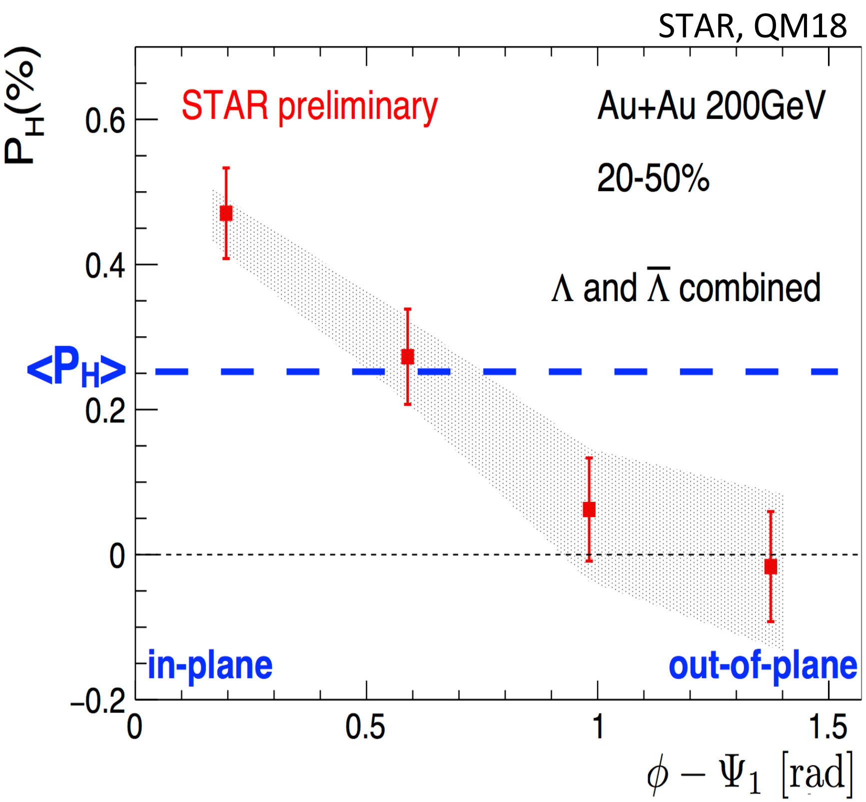


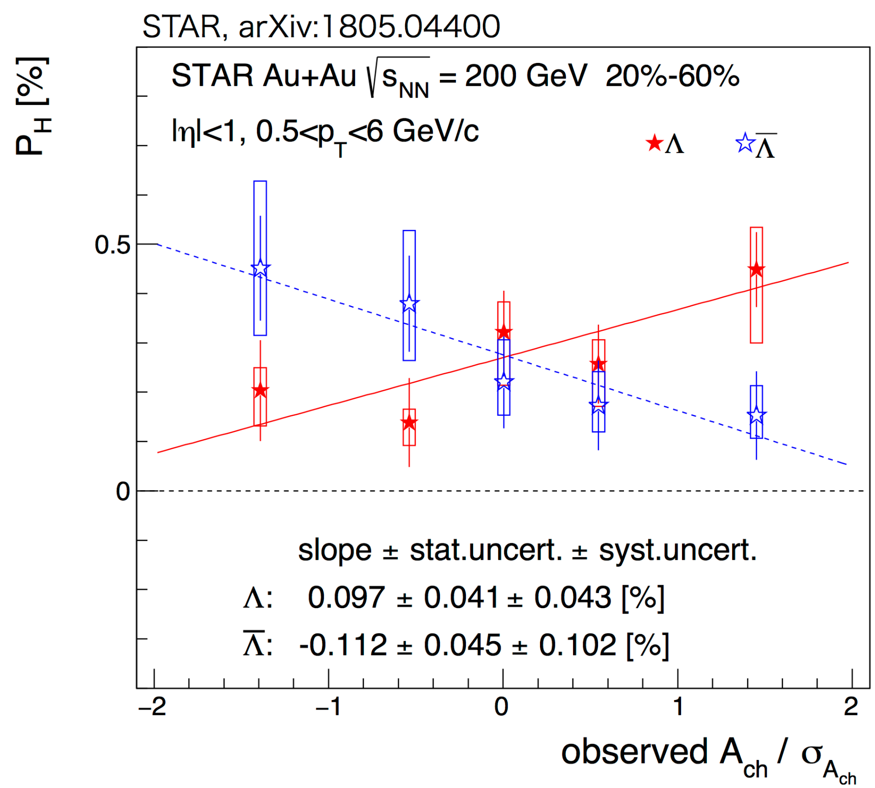


$$A_{ch} = \frac{N_+ - N_-}{N_+ + N_-}$$

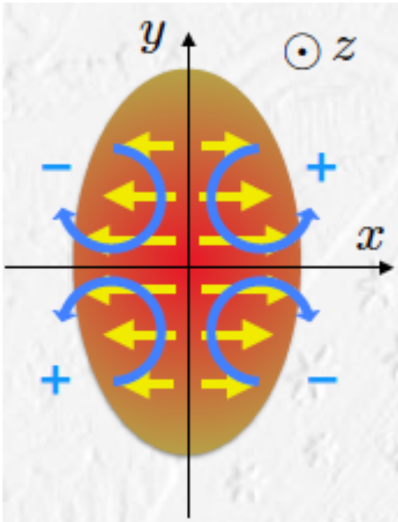
Azimuthal angle dependence

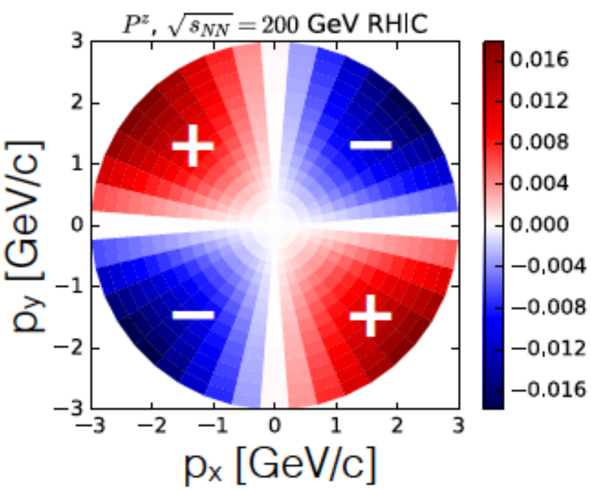
Charge asymmetry dependence

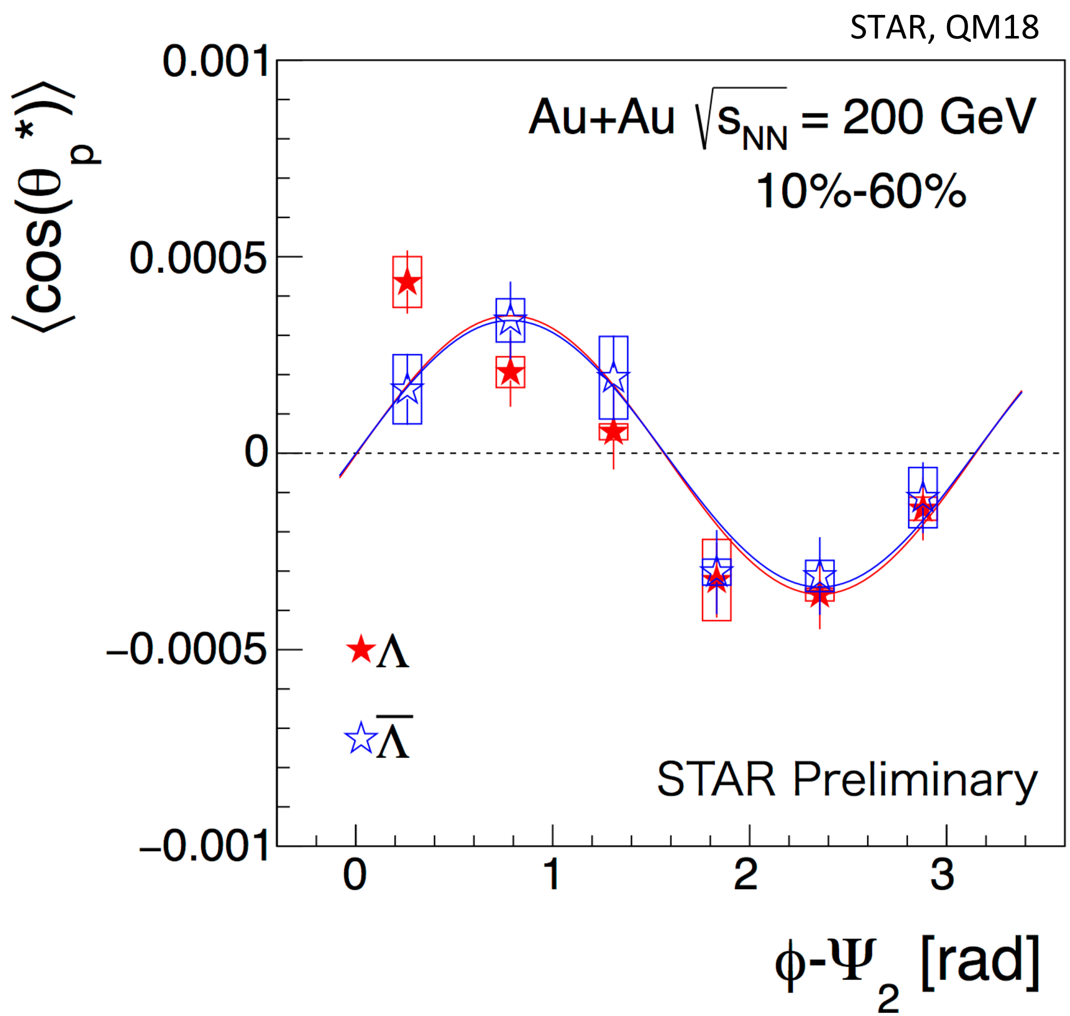




Lambda longitudinal-local polarization

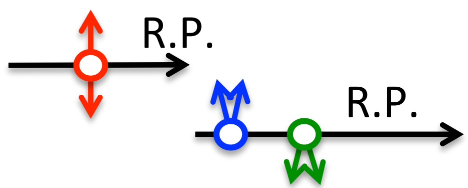




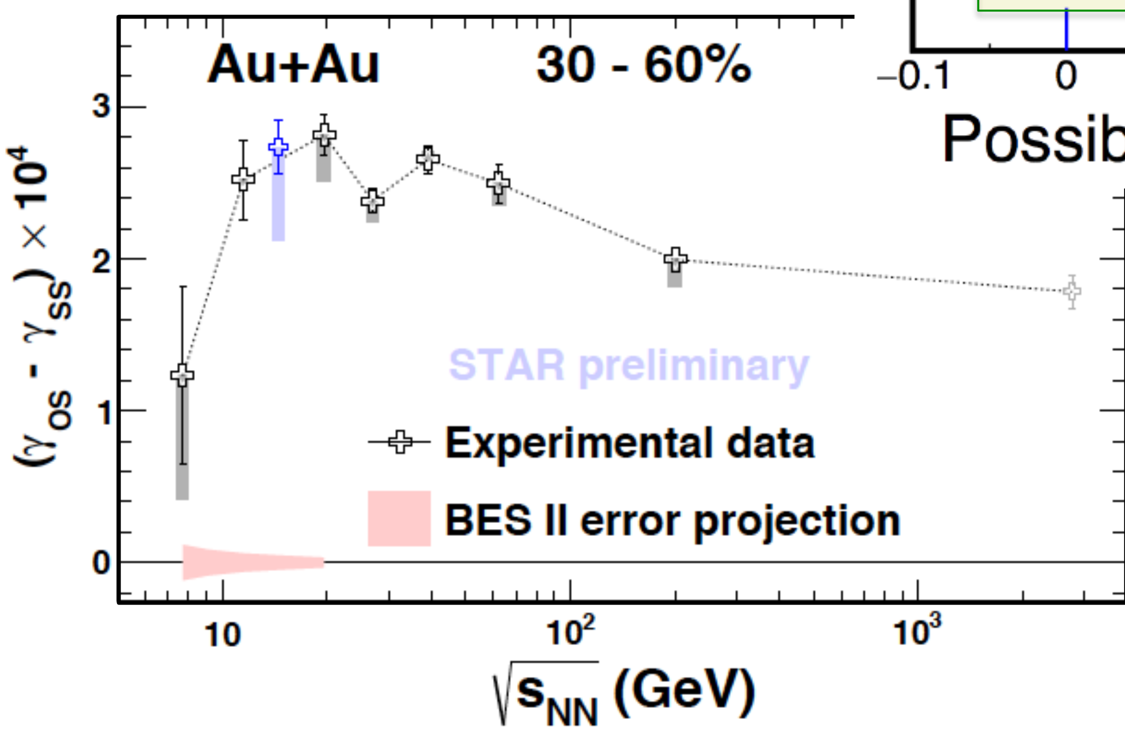


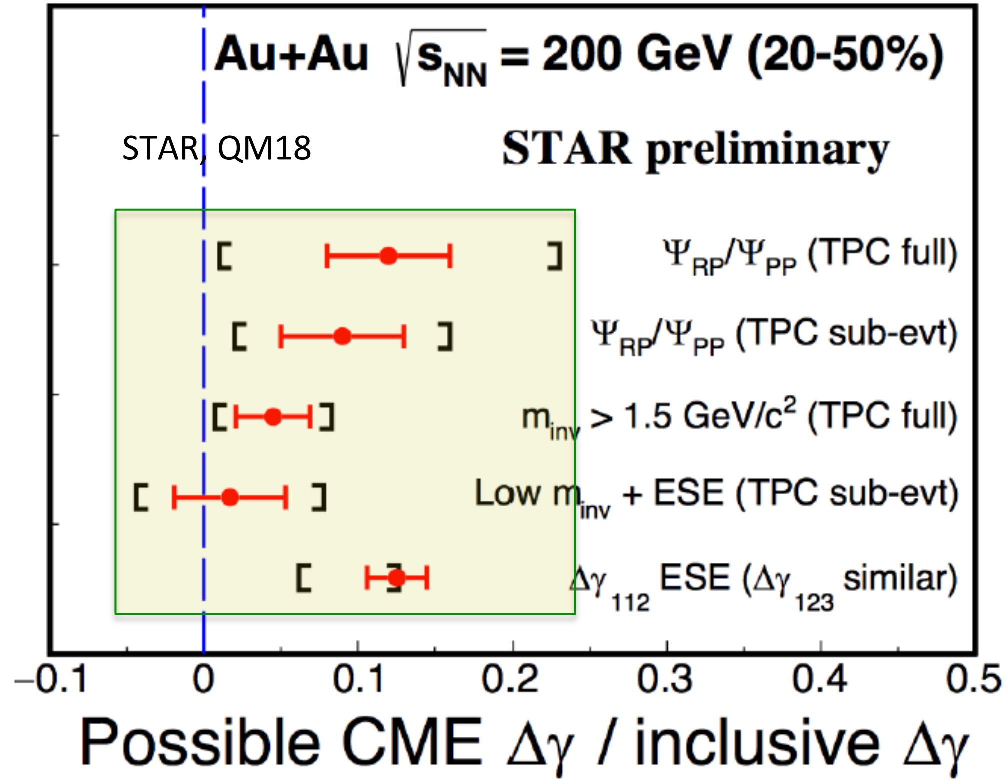
Chiral Magnetic Effect via $\gamma_{os,ss}$ correlator

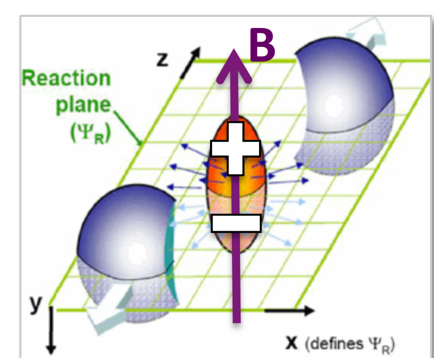
$$\gamma = \langle \cos(\phi_A + \phi_B - 2\Phi_{RP}) \rangle$$



Phys. Rev. Lett. 113 (2014) 052302







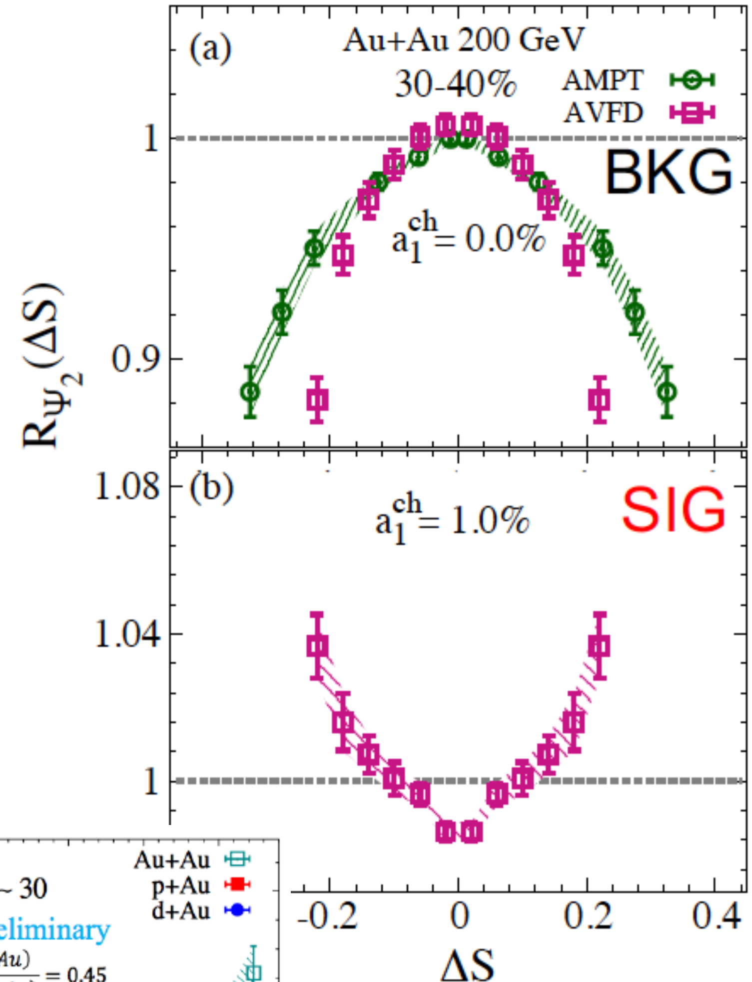
Chiral Magnetic Effect

via R.P. projected event-by-event charge asymmetry distribution

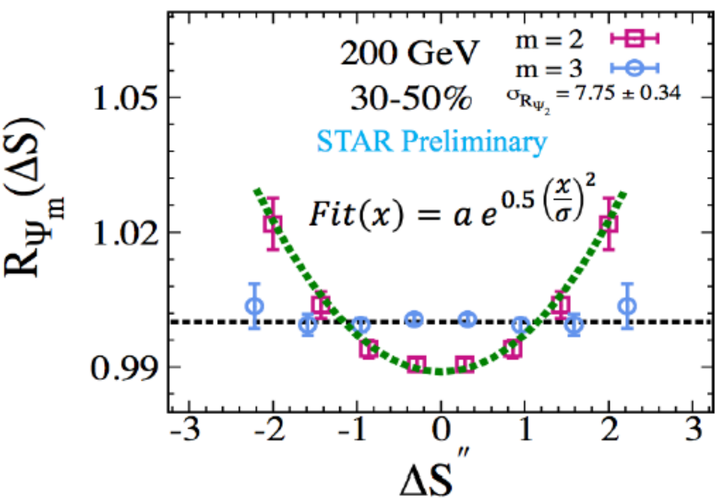
$\langle \sin\phi_+ \rangle - \langle \sin\phi_- \rangle$

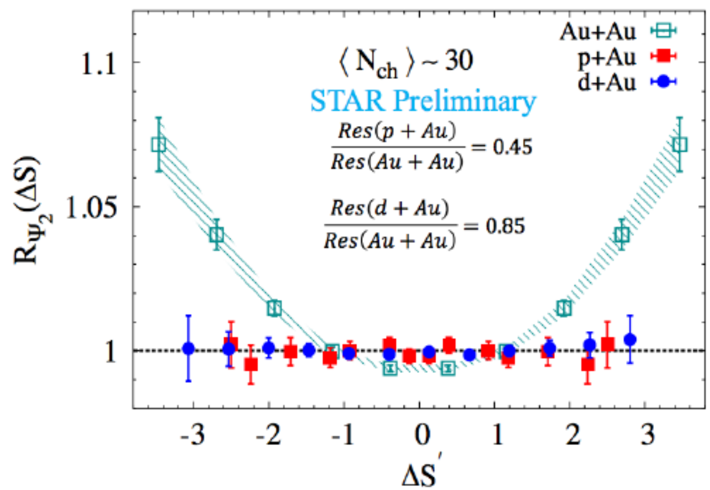
with "charge shuffling + cos term" normalization

--- Ajit correlator ---



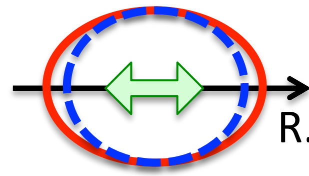
STAR, QM18, Chirality workshop 2018



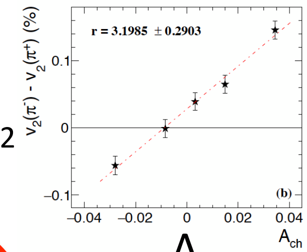


Chiral Magnetic Wave via charge asymmetry of v_2

charge dependent v_2 (Δv_2) vs
charge asymmetry of event (A_{ch})

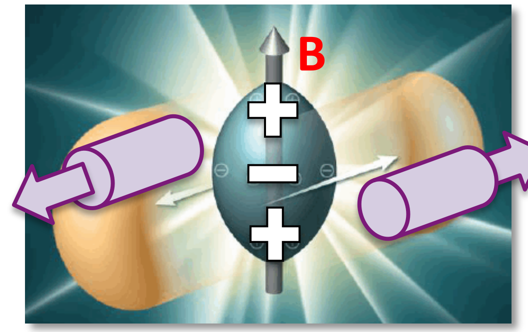


Δv_2

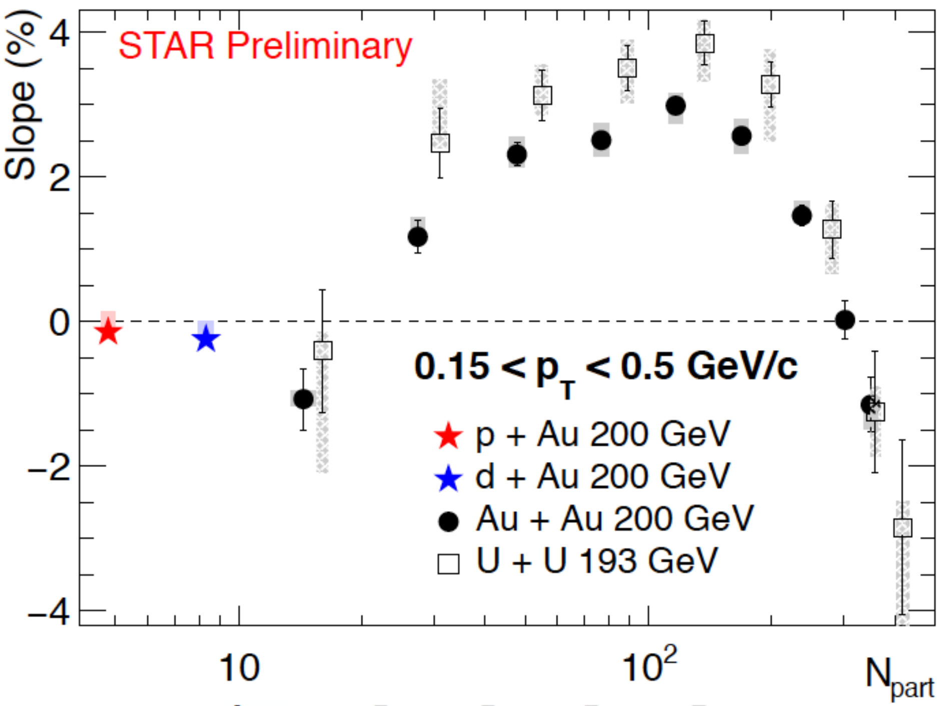


A_{ch}

Phys. Rev. Lett. 114 (2015) 252302



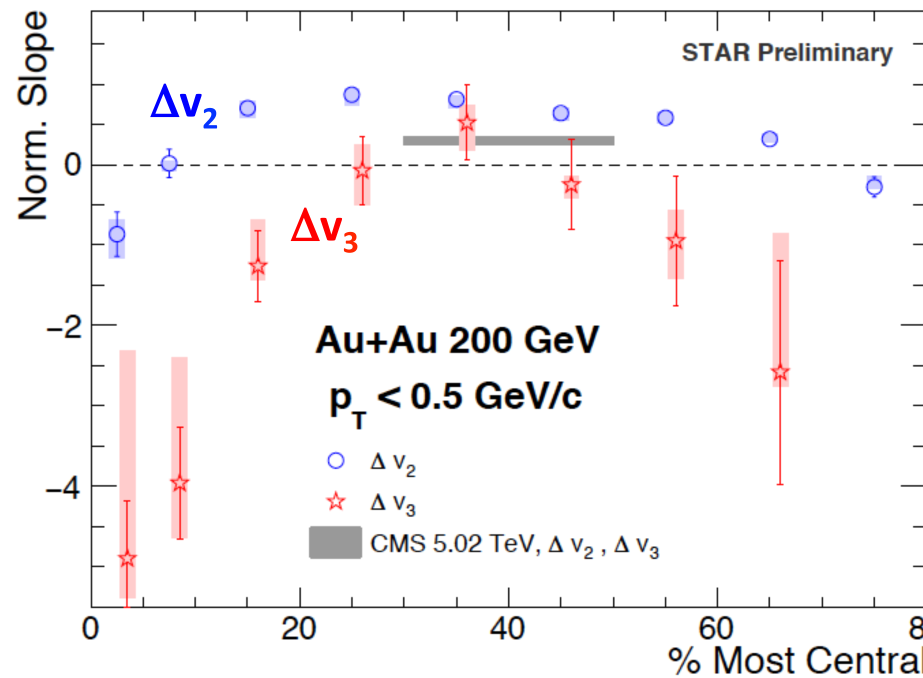
STAR, QM18



$$A_{ch} \equiv (\bar{N}_+ - \bar{N}_-)/(\bar{N}_+ + \bar{N}_-)$$

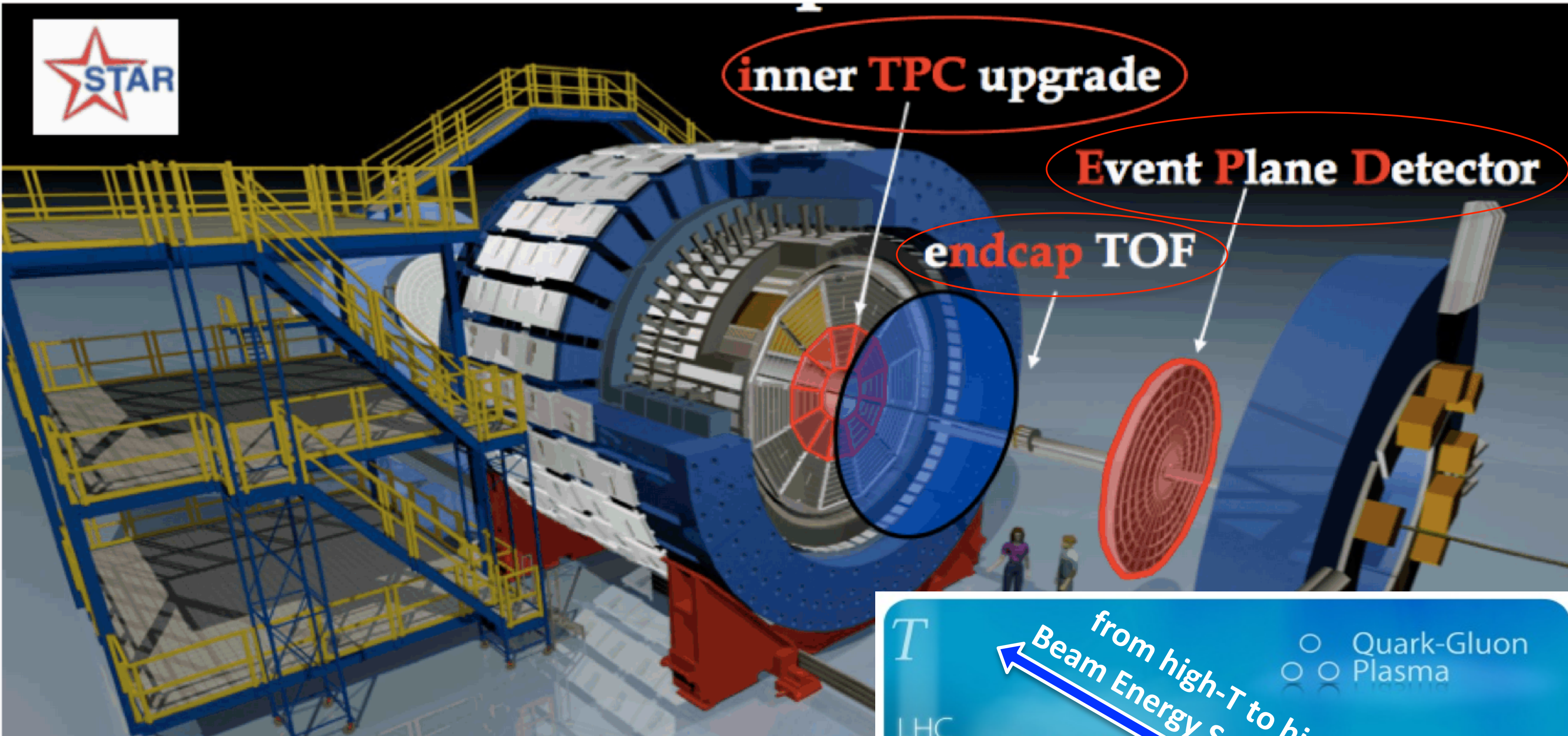
$$\Delta v_2 = v_2^- - v_2^+ \approx r\, A_{ch}$$

STAR, QM18

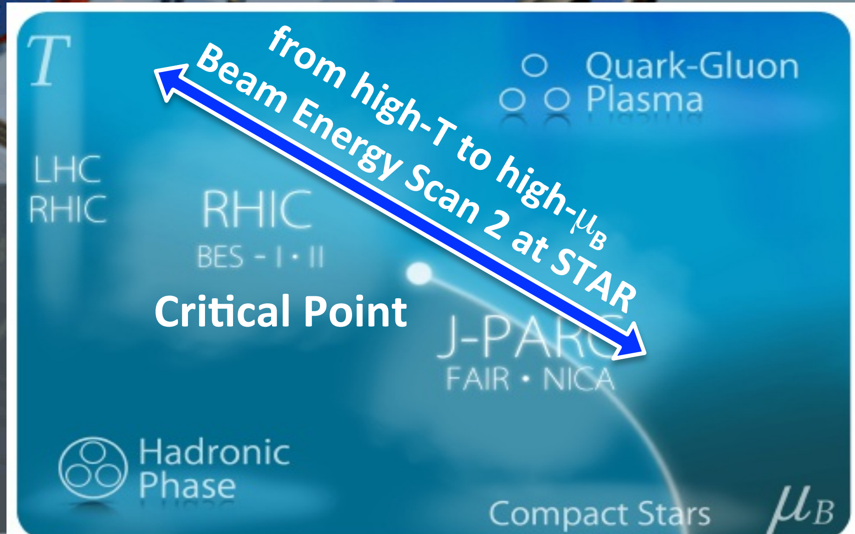


$$\mathrm{Norm.}\Delta v_n = 2\frac{v_n^- - v_n^+}{v_n^- + v_n^+}$$

STAR experimental detector upgrade for BES2



- New forward trigger + Event Plane Detector
- Very important for flow and fluctuation analyses
  → independent from main detector
  → reduces systematics (non-flow, centrality)!
- iTPC upgrade
  → increases TPC acceptance to ~1.5 in η
  → improves dE/dx resolution

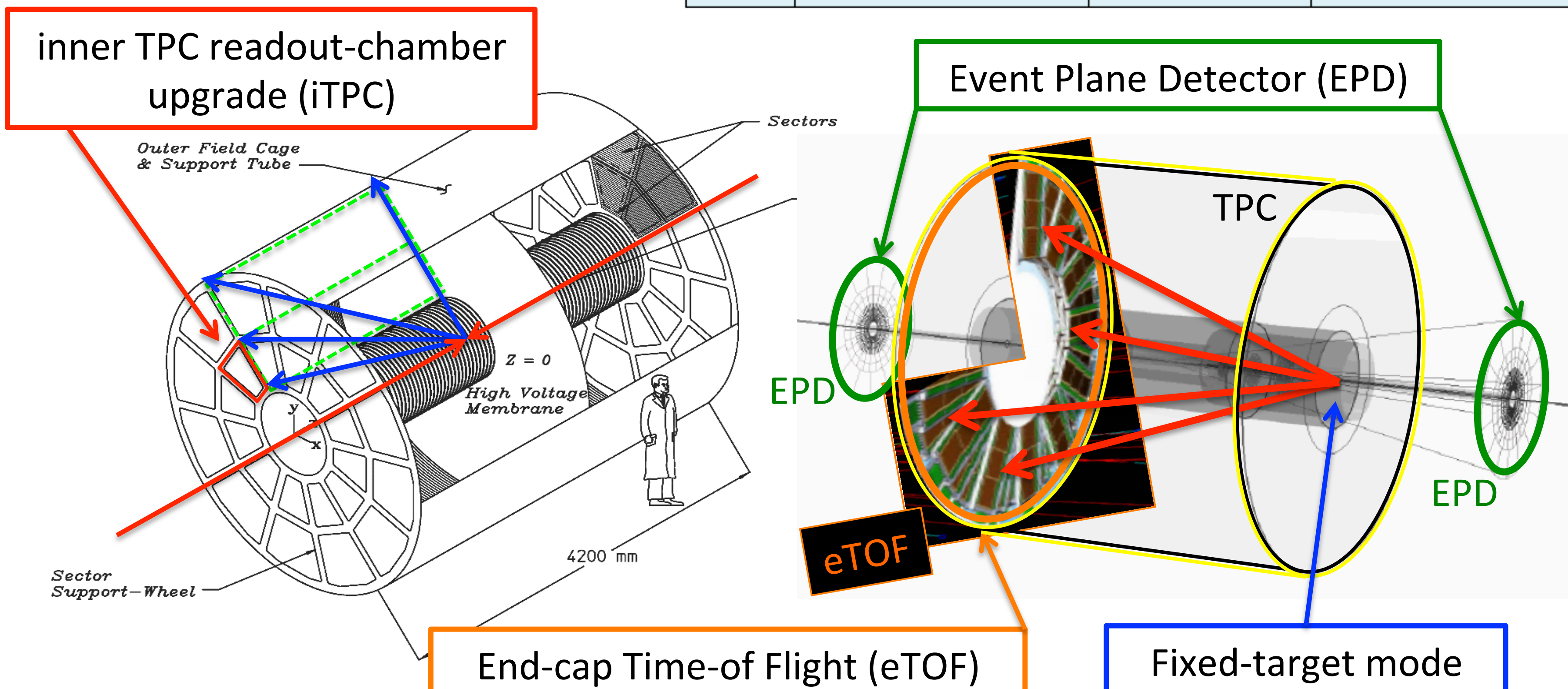


STAR Experiment at RHIC

Beam Energy Scan

--- Program Phase 2 ---

	Beam energy, species	Detec. upgrade	Primary goal
Run17	500GeV pp 54GeV Au+Au	1/8 EPD eTOF prototype	Spin, High mult. pp >10^9 events Au+Au
Run18	200GeV Zr+Zr, Ru+Ru 27GeV Au+Au Fixed Target 3GeV	Full EPD eTOF prototype iTPC prototype	Isobar, CME, CVE di-Lepton comp. HADES/GSI
Run19 Run20	14.5-20GeV Au+Au Fixed Target 7-11GeV Au+Au Fixed Target	Full EPD Full eTOF Full iTPC	Critical Point 1st order P.T. CME, CVE



Summary

- Critical fluctuation
- Collective expansion
- Vortical, Chiral magnetic fluid
- Future plan (including FAIR,NICA,HIAF, J-PARC)