

QM2018 results from Beam Energy Scan

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post QM meeting

Jun. 30, 2018 @ Nagoya University



筑波大学
University of Tsukuba

• BES II

- BES II program and detector upgrade, STAR, Q.Yang (talk)
- FXT test run results STAR, Y.Wu (talk)

• BES I, flow, small system and HBT

- Directed flow of quarks, STAR, Gang.Wang (talk)
- Longitudinal flow decorrelation in 200GeV STAR, Maowu Nie (talk)
- Collectively in Small Systems, STAR, Shingle Huang (talk)
- Geometry and Dynamics seen by the Femtoscopy, STAR, Sebastian Siejka (talk)

• BES I, fluctuation

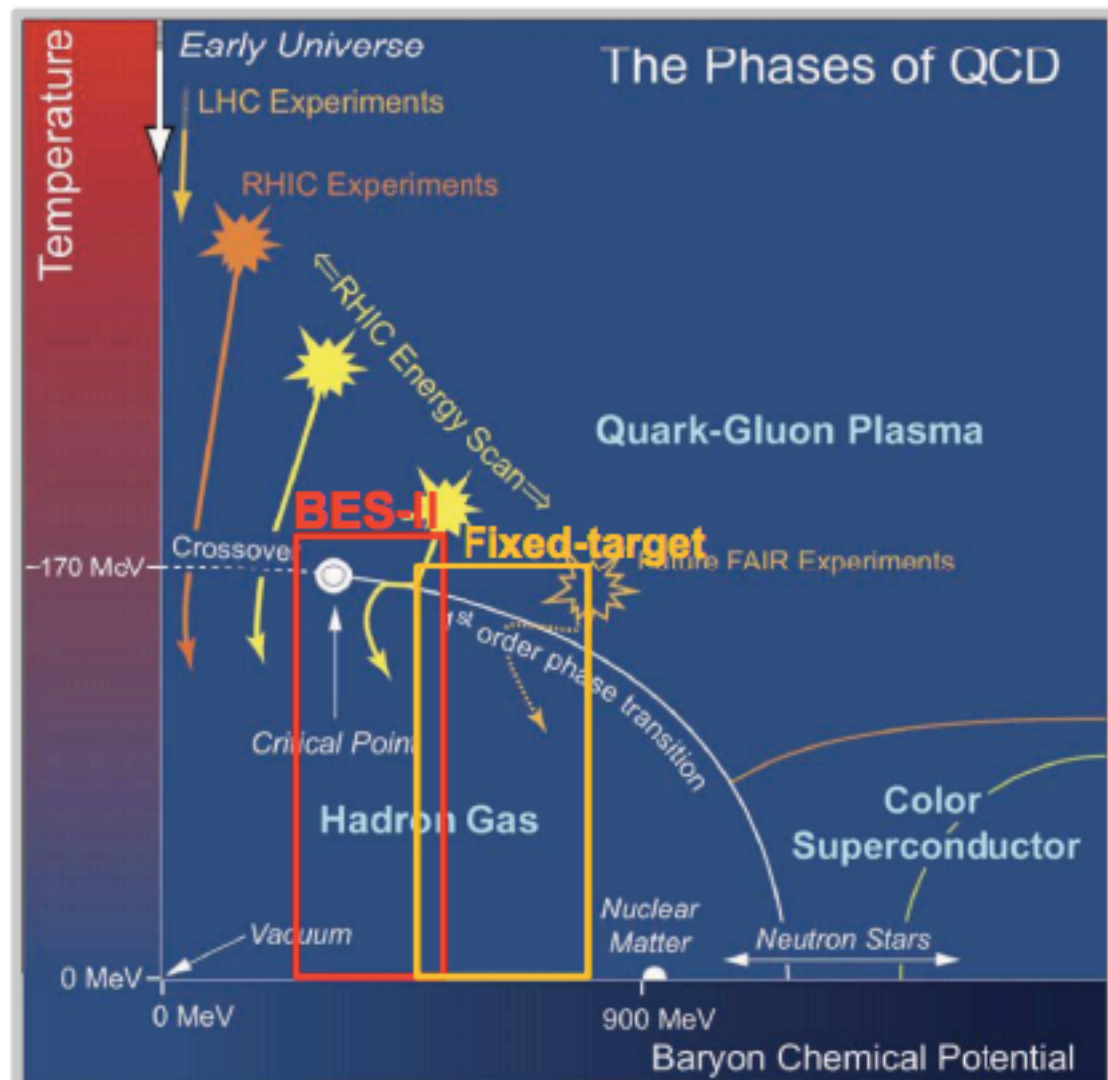
- Net-lambda cumulants, STAR, N.Kulathunga (poster) T.Nonaka (talk)
- Off-diagonal cumulants STAR, A.Chetterjee (poster) T.Nonaka (talk)
- 6th order cumulant of net-charge, STAR, T.Sugiura (poster) T.Nonaka (talk)
- Net-proton cumulants by unfolding at 19.6 GeV , STAR, T.Nonaka (talk)

• BES I, Vorticity, CME, and Thermodynamics

- Global Hyperon Polarization in 200 GeV Au+Au, STAR, Takafumi Niida (talk)
- Chiral Magnetic Effect at RHIC Top Energy, STAR, Jie Zhao
- Triton Production in Beam Energy Scan, STAR, Pens Liu (talk)

Beam Energy Scan Phase II (BES-II)

STAR, Q.Yang (talk)



$\sqrt{s_{NN}}$ (GeV)	Proposed Event Goals (M)	BES-I Event (M)
7.7	100	4
9.1	160	N/A
11.5	230	12
14.5	300	20
19.6	400	36
3.0 - 7.7	~100 per energy	N/A

■ Collider mode
■ Fixed-target mode

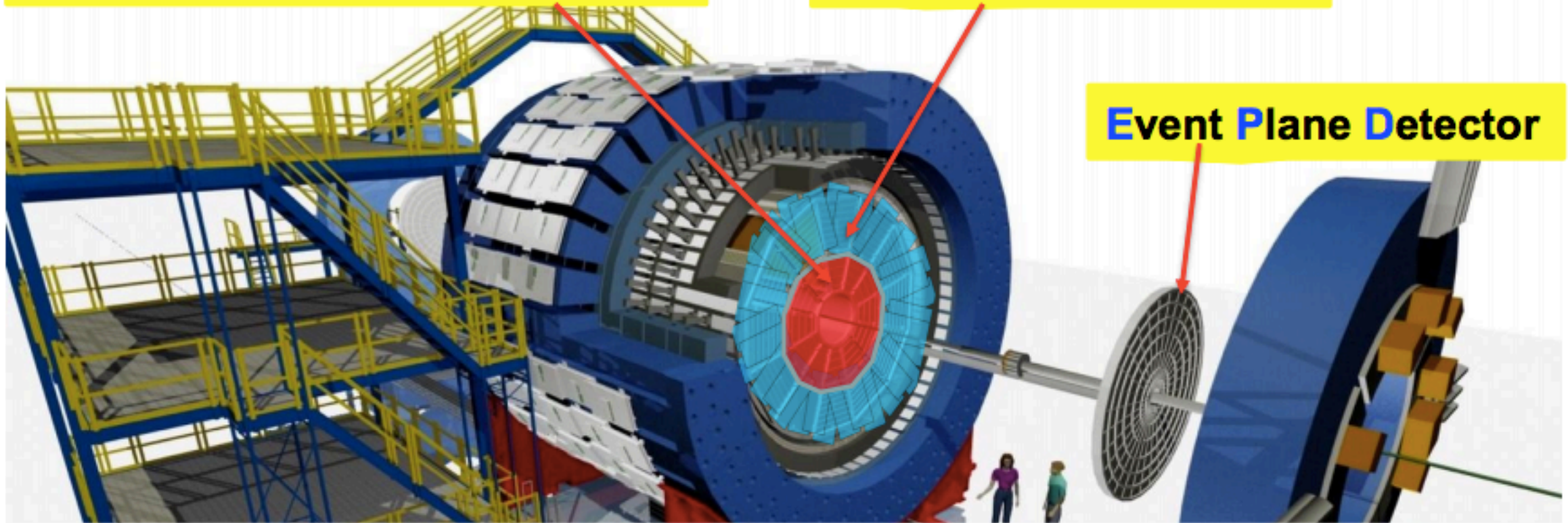
- RHIC BES II : 10-25 times more statistics and detector upgrade
→ **Dramatically reduce the uncertainties.**
- Precise map the QCD phase diagram $200 < \mu_B < 720$ MeV

Detector upgrades

inner Time Projection Chamber

endcap Time-Of-Flight

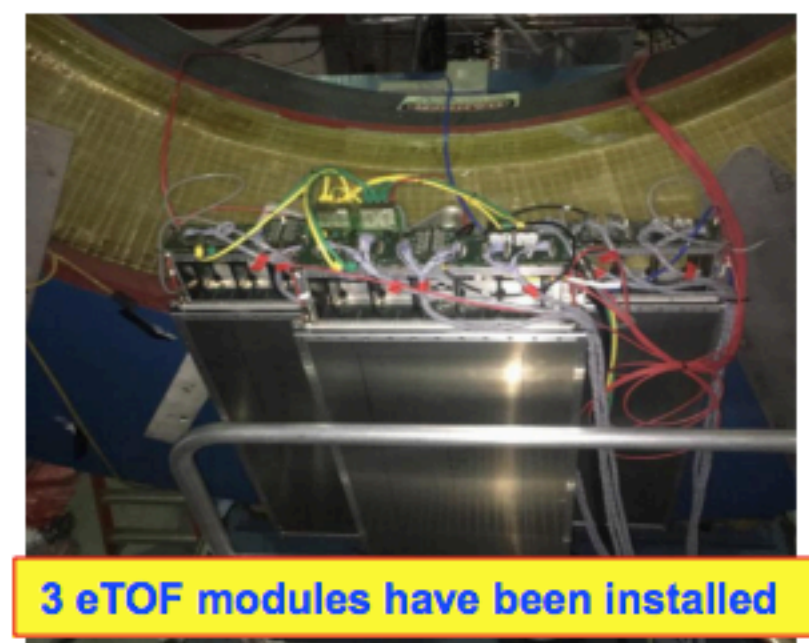
Event Plane Detector



One iTPC sector has been installed



Full EPD has been installed



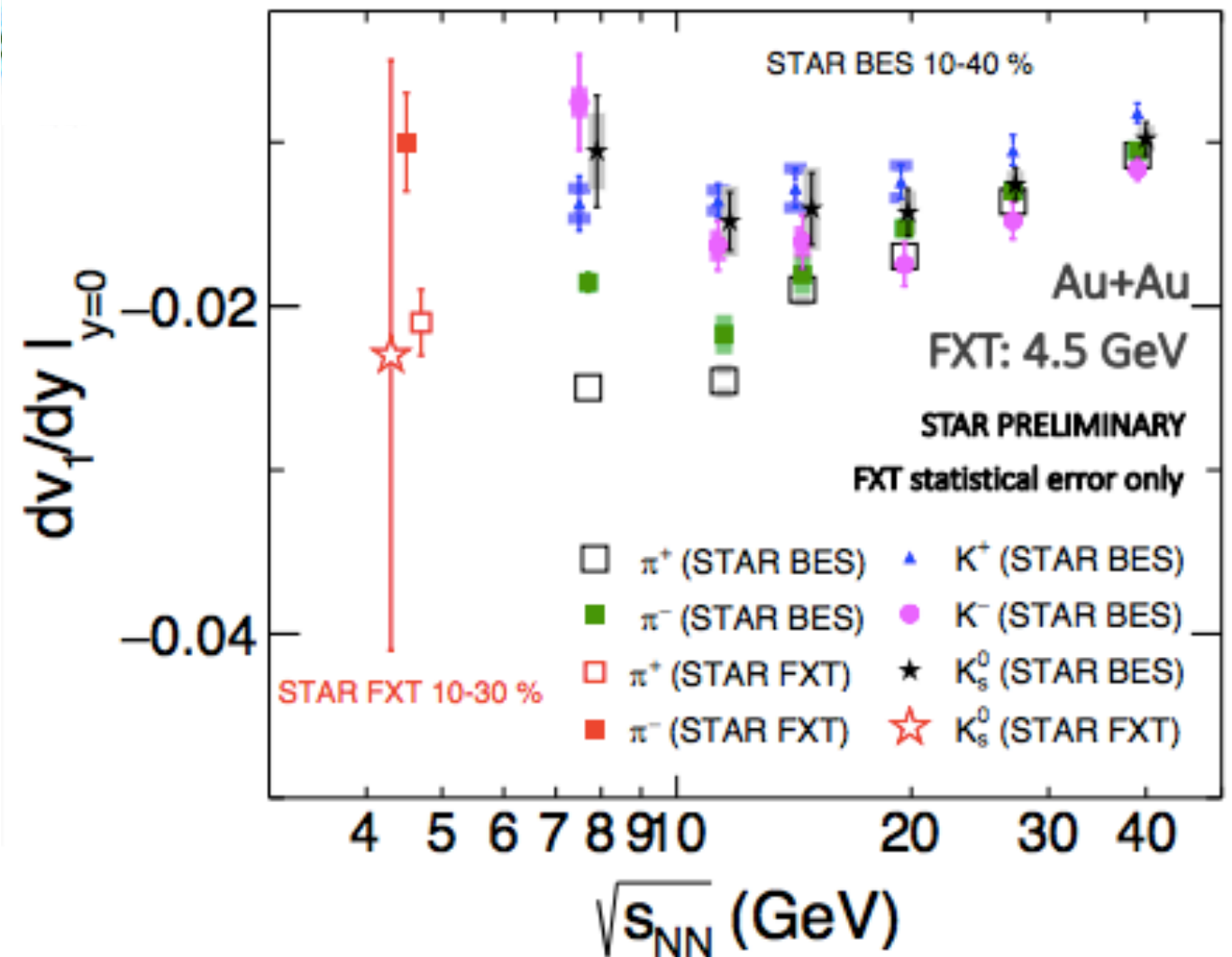
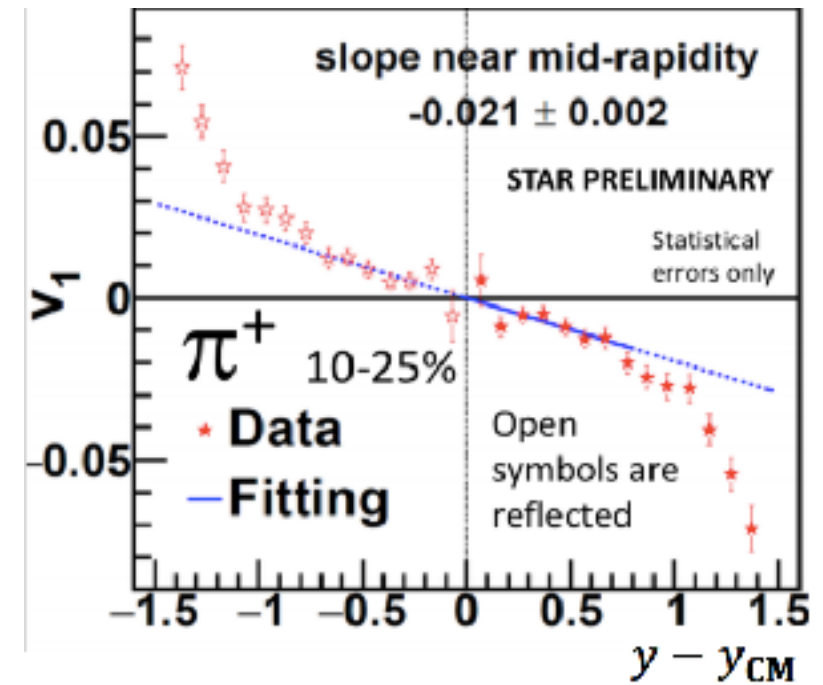
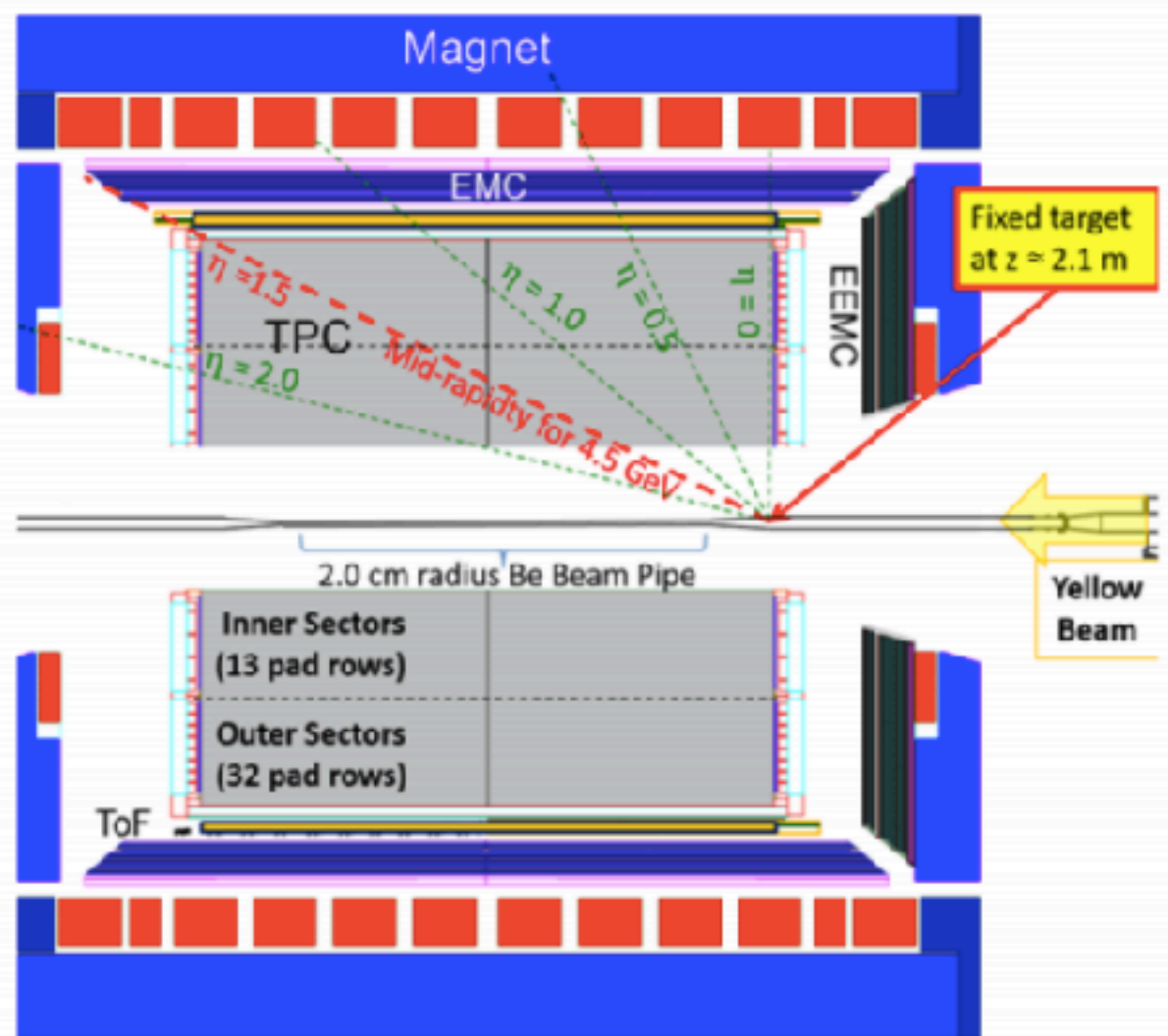
3 eTOF modules have been installed

STAR, Q.Yang (talk)

Fixed target test run for Au+Au at $\sqrt{s_{NN}}=4.9$ GeV⁵

- First π direct flow at this energy range, turning up towards lower energy. Dedicated FXT runs (3.0-7.7 GeV) in 2019-2020 to explore high baryon density regime.

STAR, Y.Wu (talk)



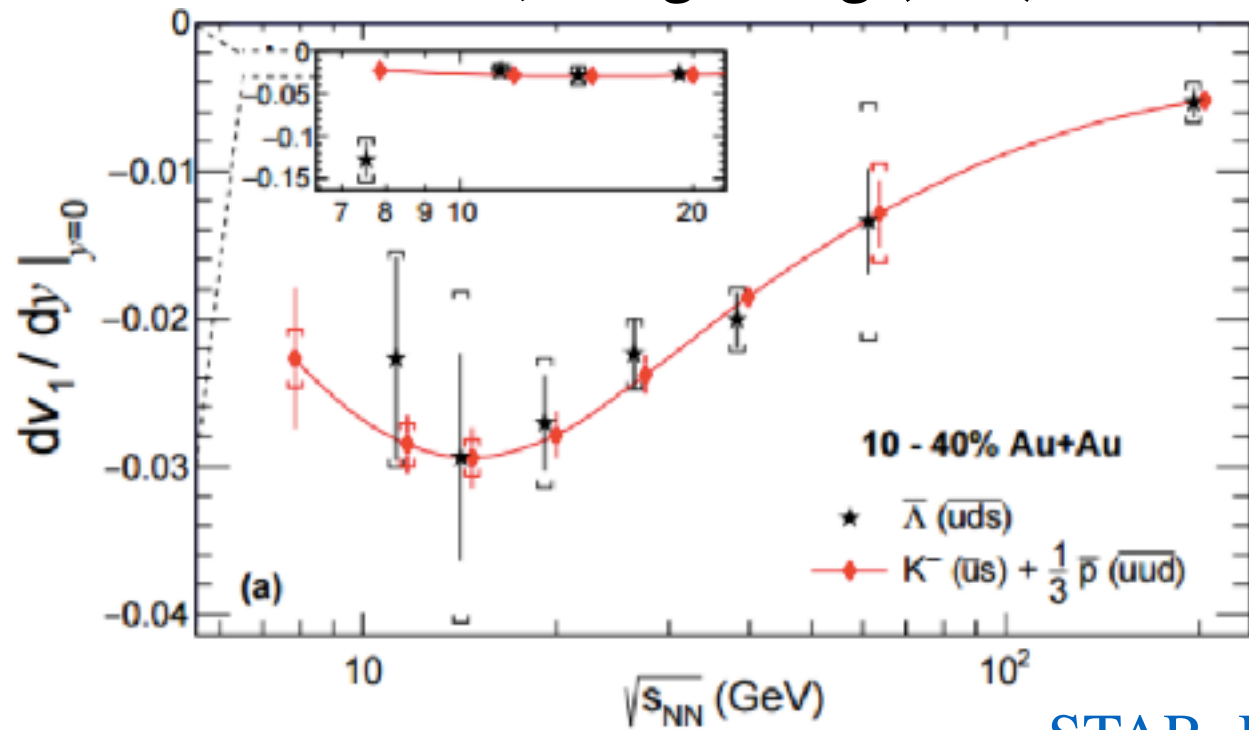
Directed flow of quarks

STAR, Gang.Wang (talk)

Assumption

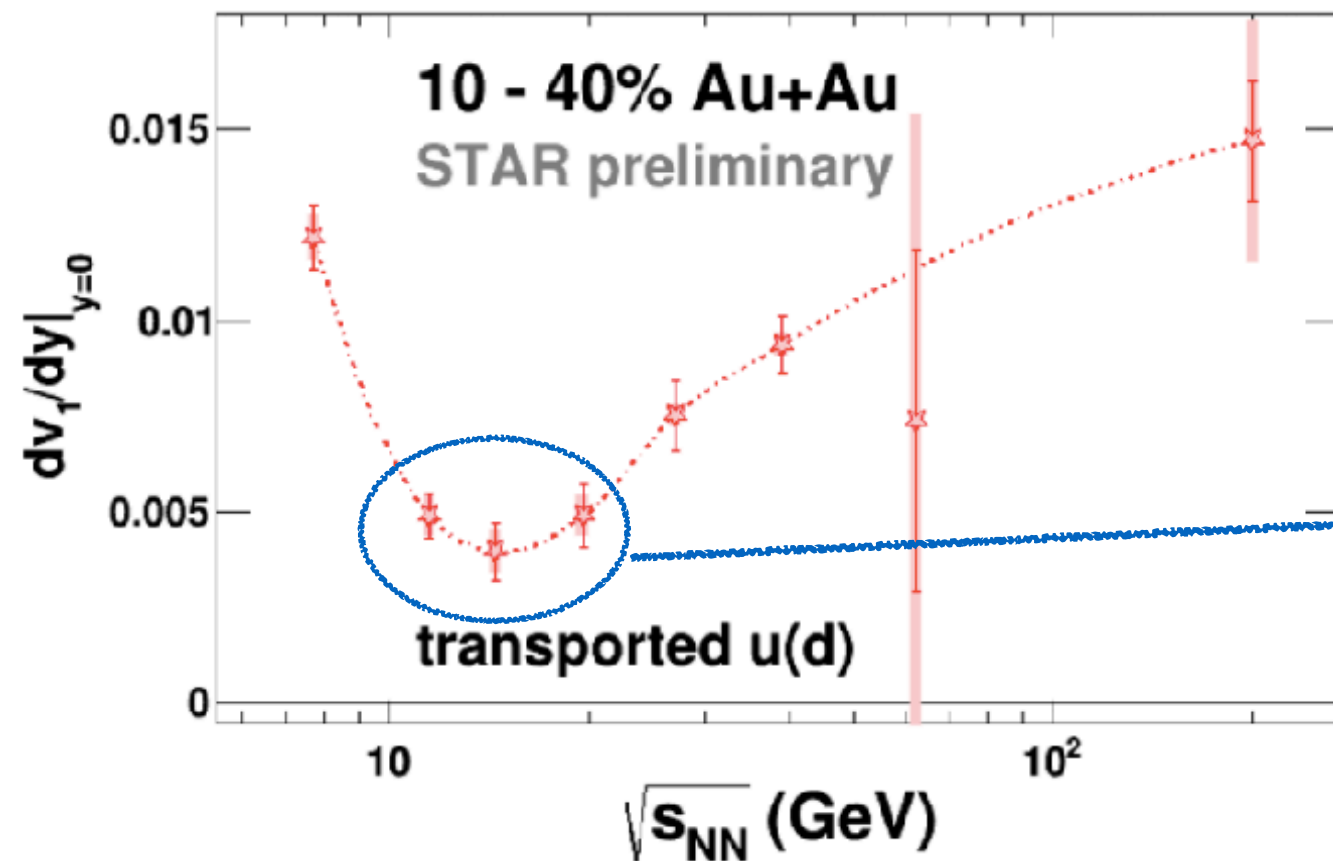
$$(v_n)_{\text{hadron}} = \sum (v_n)_{\text{constituent quarks}}$$

$$(v_1)_{\bar{u}} = (v_1)_d \text{ and } (v_1)_s = (v_1)_{\bar{s}}$$



- anti-p, anti- Λ and K are all produced in collision.
- For anti- Λ s, prediction using coalescence sum rule agrees with measured v_1 above 11.5 GeV but disagree at 7.7 GeV.

STAR, Phys. Rev. Lett. 120 (2018) 62301



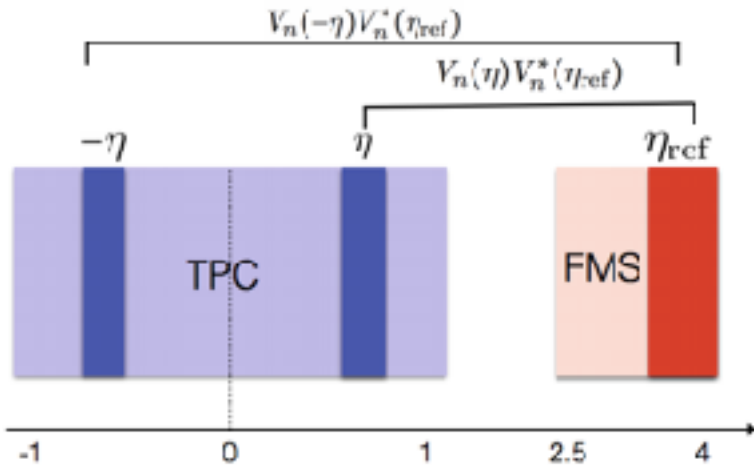
$$(V_1)_{\text{trans. u(d)}} = [(V_1)_{\text{net p}} - (3 - N_{\text{trans. u+d}}) * (v_1)_{\bar{u}(d)}] / N_{\text{trans. u+d}}$$

- v_1 of transported u(d) is positive for all beam energies.
- A minimum at 14.5 GeV.



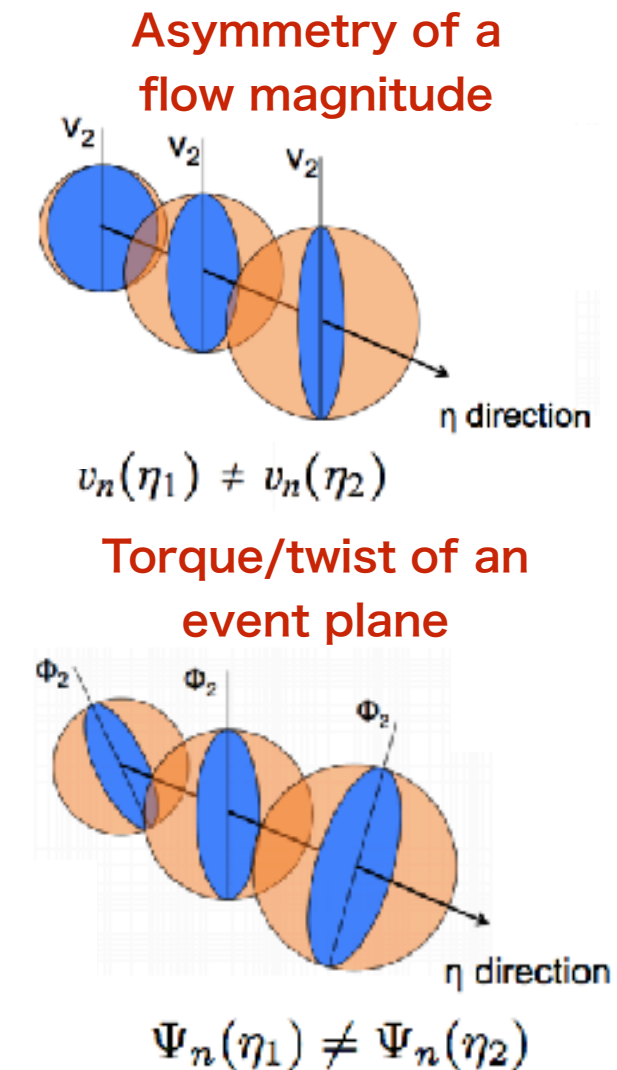
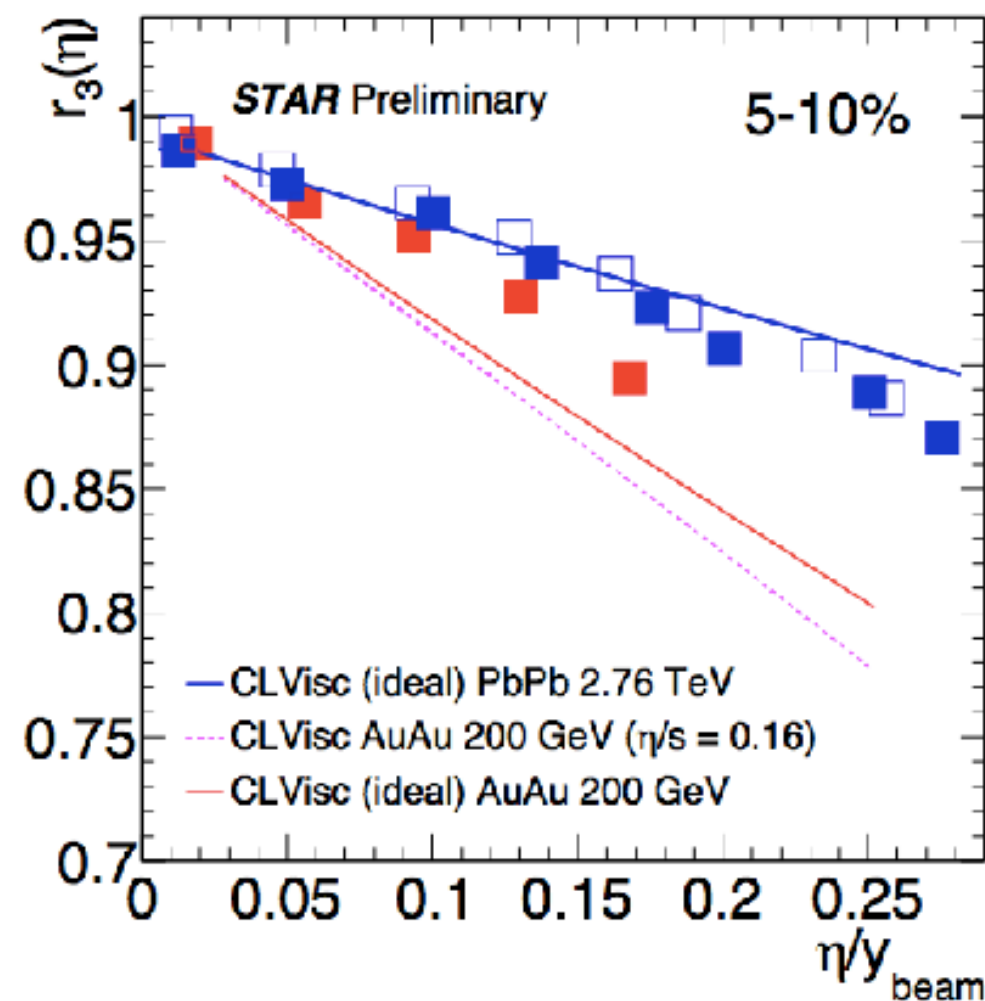
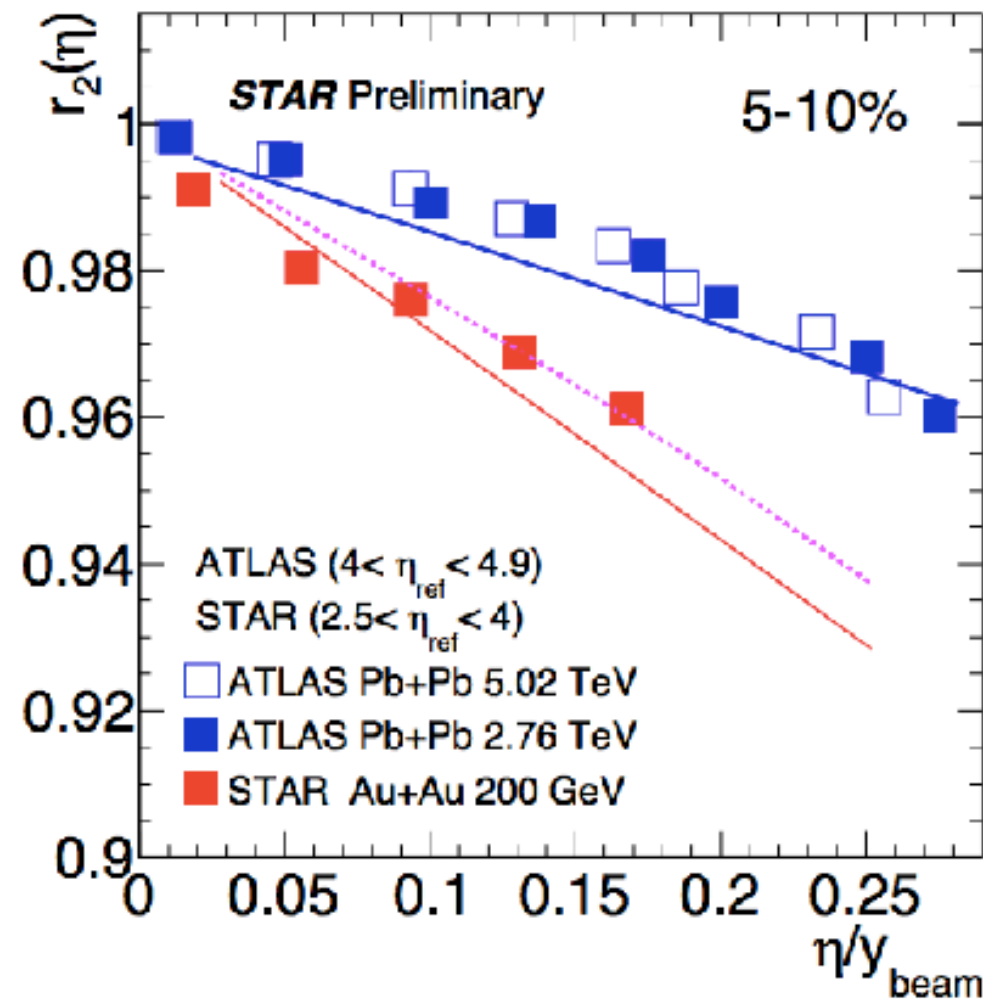
Evidence of softest point?

Longitudinal Flow Decorrelation in 200GeV



$$r_n(\eta) = \frac{\langle v_n(-\eta)v_n(\eta_{ref}) \cos n(\Psi_n(-\eta) - \Psi_n(\eta_{ref})) \rangle}{\langle v_n(\eta)v_n(\eta_{ref}) \cos n(\Psi_n(\eta) - \Psi_n(\eta_{ref})) \rangle}$$

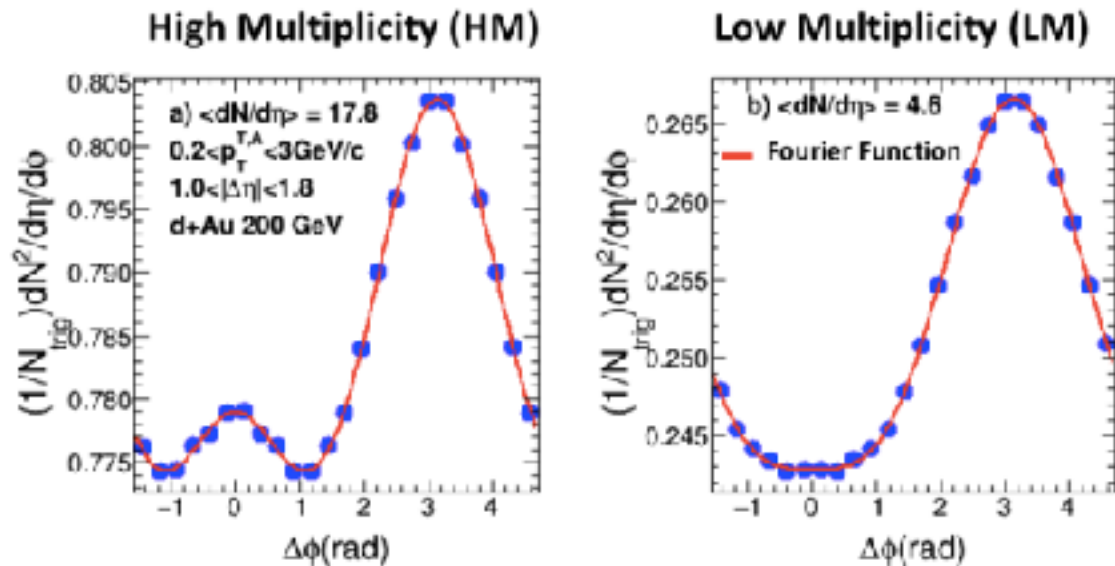
STAR, Maowu Nie (talk)



- Stronger longitudinal flow decorrelation at RHIC than at LHC
- Hydro calculations can not simultaneously describe LHC and RHIC data.

Collectivity in Small Systems

d+Au 200GeV

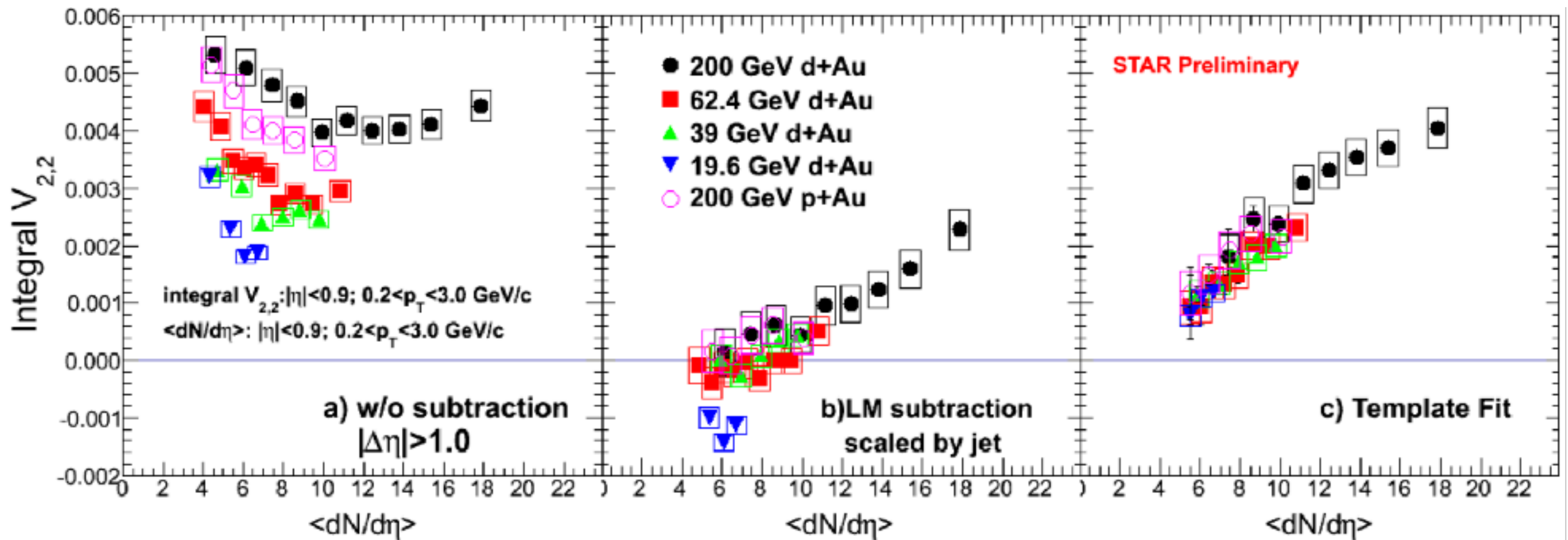


- A near-side ridge is observed in the HM d+Au
- A Fourier function is employed to extract the $V_{n,n}$

$$dN/d\Delta\phi \sim 1 + \sum_{n=1}^4 2V_{n,n} \times \cos(n\Delta\phi)$$

$$\text{Integral } v_n = \text{sqrt}(V_{n,n}); v_n(p_T) = V_{n,n}(p_T)/v_n$$

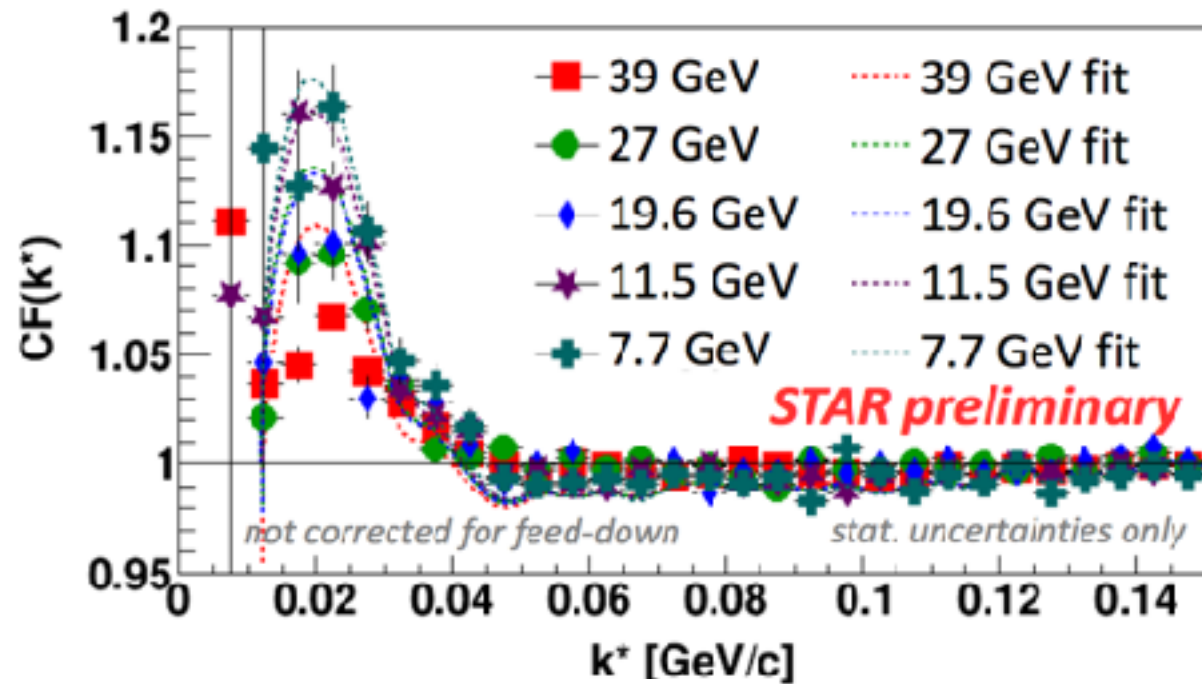
STAR, Shengli Huang (talk)



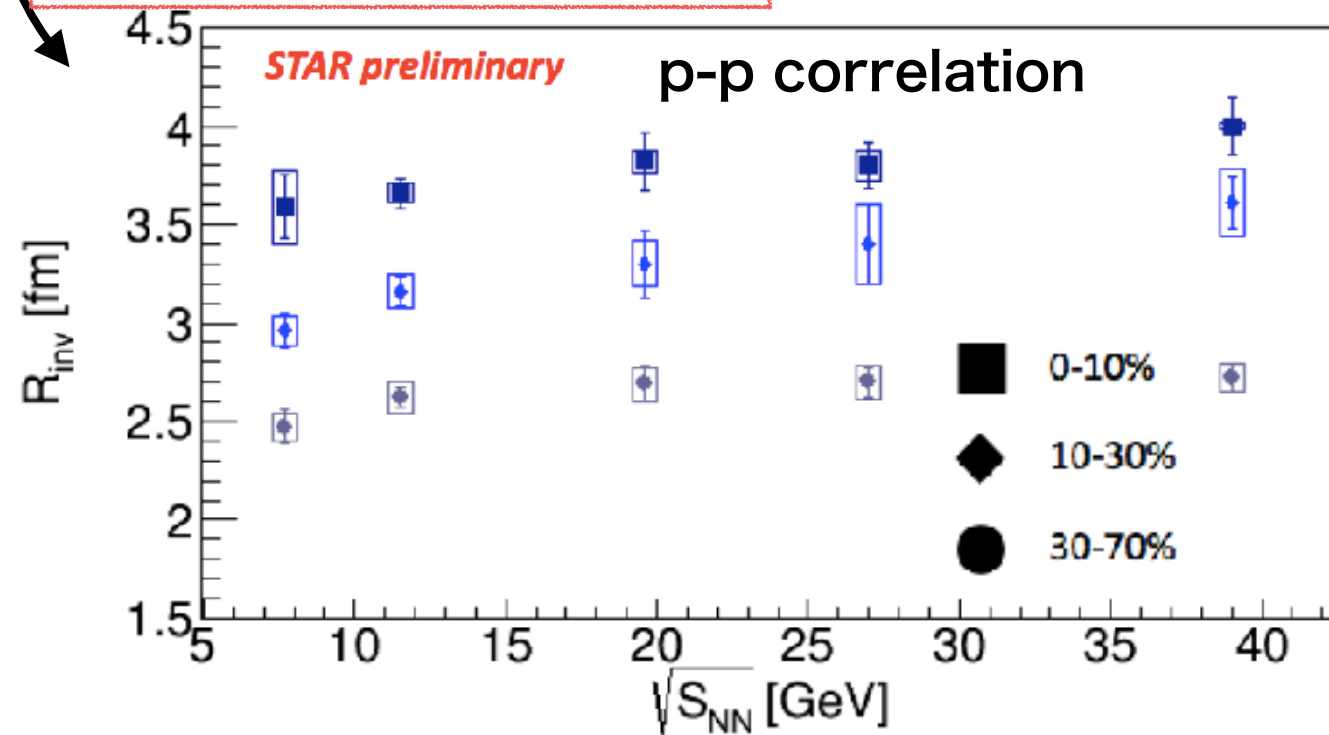
- Different $V_{2,2}$ from different methods to correct for non-flow background in p/d+Au collisions. Be careful about the assumption ions of the methods.

Geometry and Dynamics seen by the Femtoscopy ⁹

$p - p$: Au+Au 0-10%

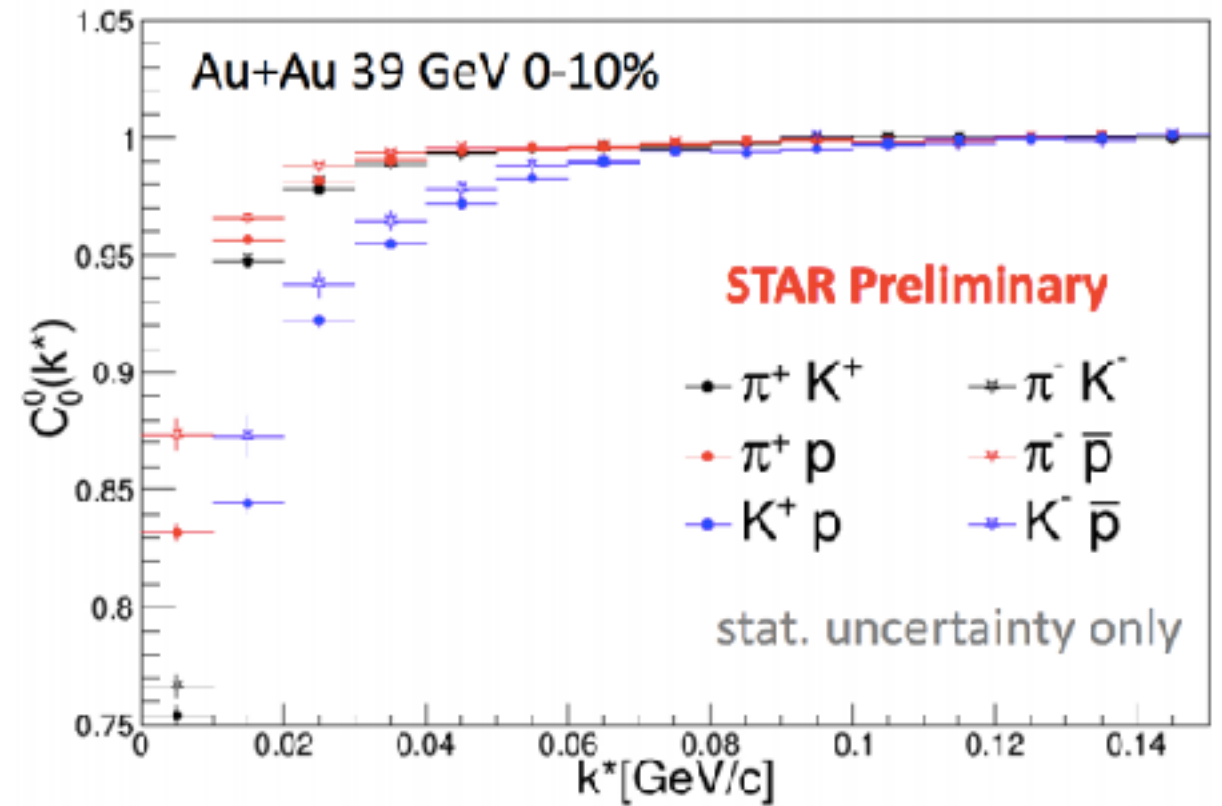


$$C_2(q_{inv}) = 1 \pm \lambda_{inv} \exp(-R_{inv}^2 q_{inv}^2)$$



- Energy and centrality dependence of HBT with BES data.

STAR, Sebastian Siejka (talk)



$$C(\mathbf{q}) = \sum_{l,m} C_l^m(q) Y_l^m(\theta, \phi)$$

Ω – full solid angle

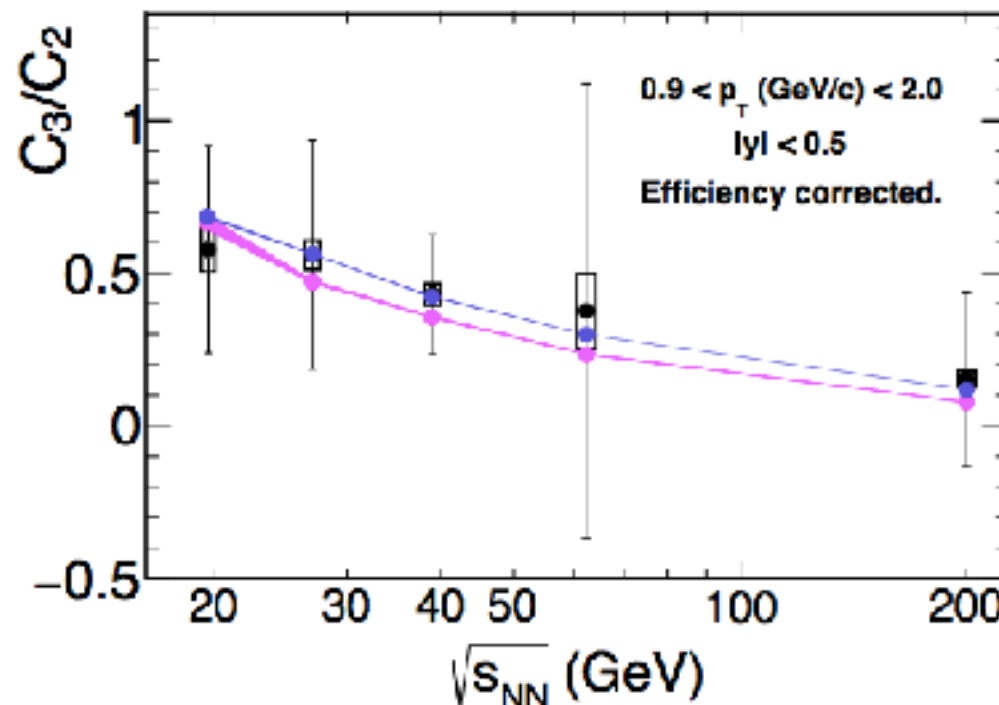
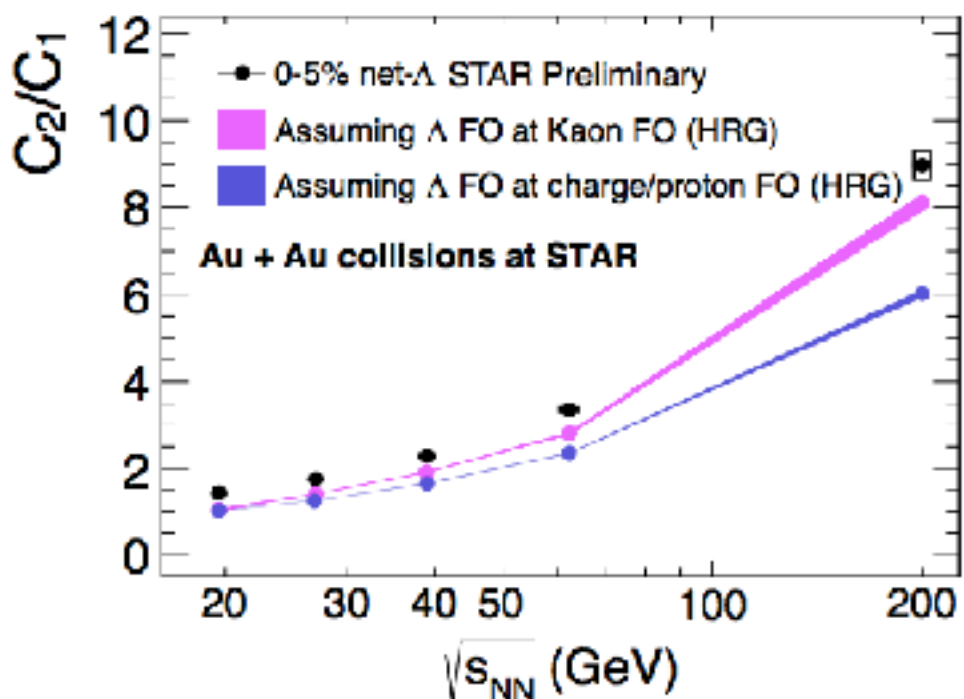
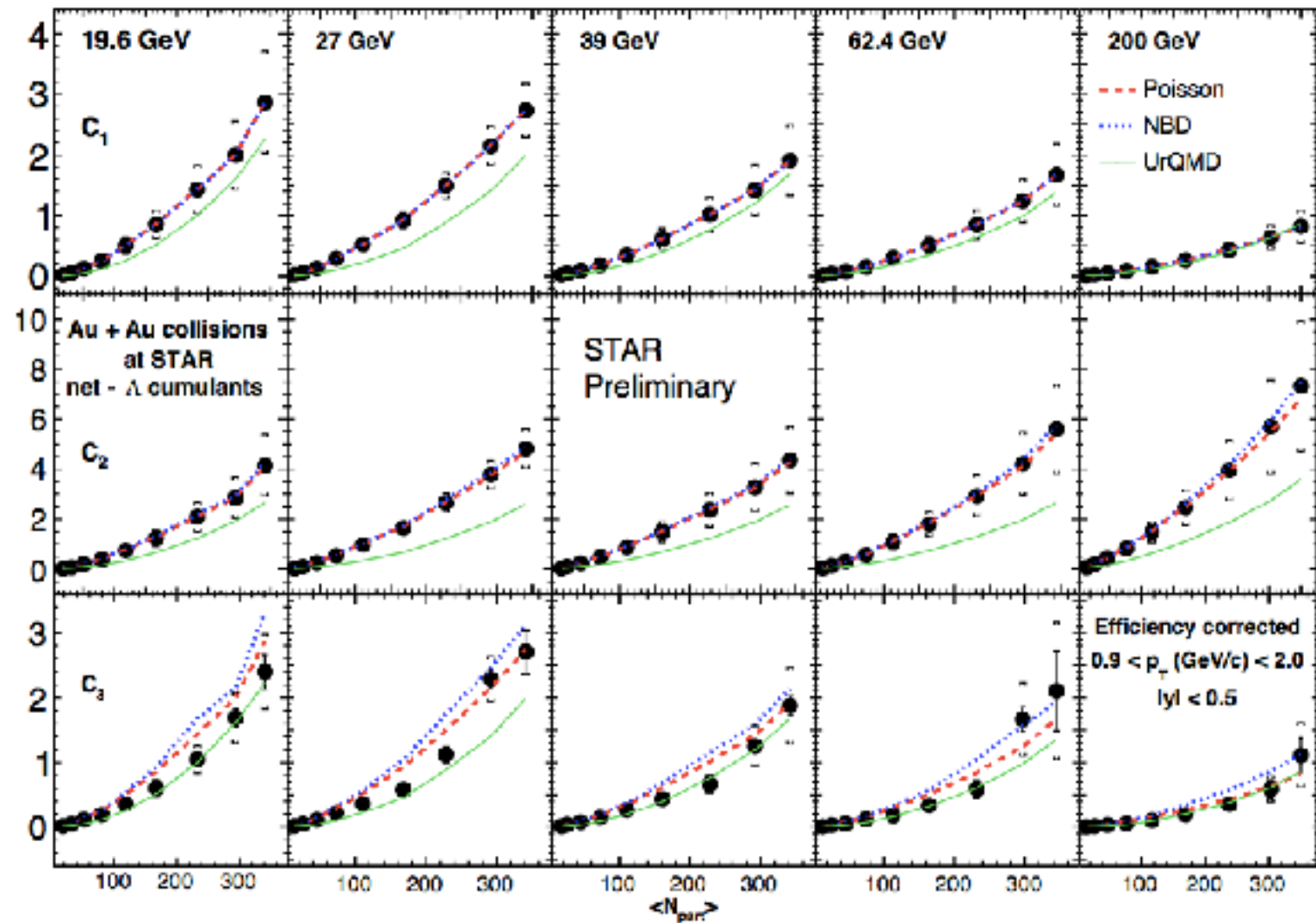
$Y_l^m(\theta, \phi)$ – spherical harmonic function

$q = |\mathbf{q}|, \theta, \phi$ – spherical coordinates

- Lighter particles emitted closer to the center of the source than heavy particles.

Net-lambda cumulants

- Strange quarks freeze-out is earlier than that of light quarks?
- Net-lambda cumulants were measured for the first time.
- C_2/C_1 is close to HRG model results with Kaon FO condition, and far away from those of charge and proton.



STAR,
N.Kulathunga (poster)
T.Nonaka (talk)

Off-diagonal cumulants

$$\begin{pmatrix} \sigma_Q^2 & \sigma_{Q,p}^{1,1} & \sigma_{Q,k}^{1,1} \\ \sigma_{p,Q}^{1,1} & \sigma_p^2 & \sigma_{p,k}^{1,1} \\ \sigma_{k,Q}^{1,1} & \sigma_{k,p}^{1,1} & \sigma_k^2 \end{pmatrix}$$

- Off-diagonal cumulants of conserved charges will provide additional constraints on the freeze-out conditions.

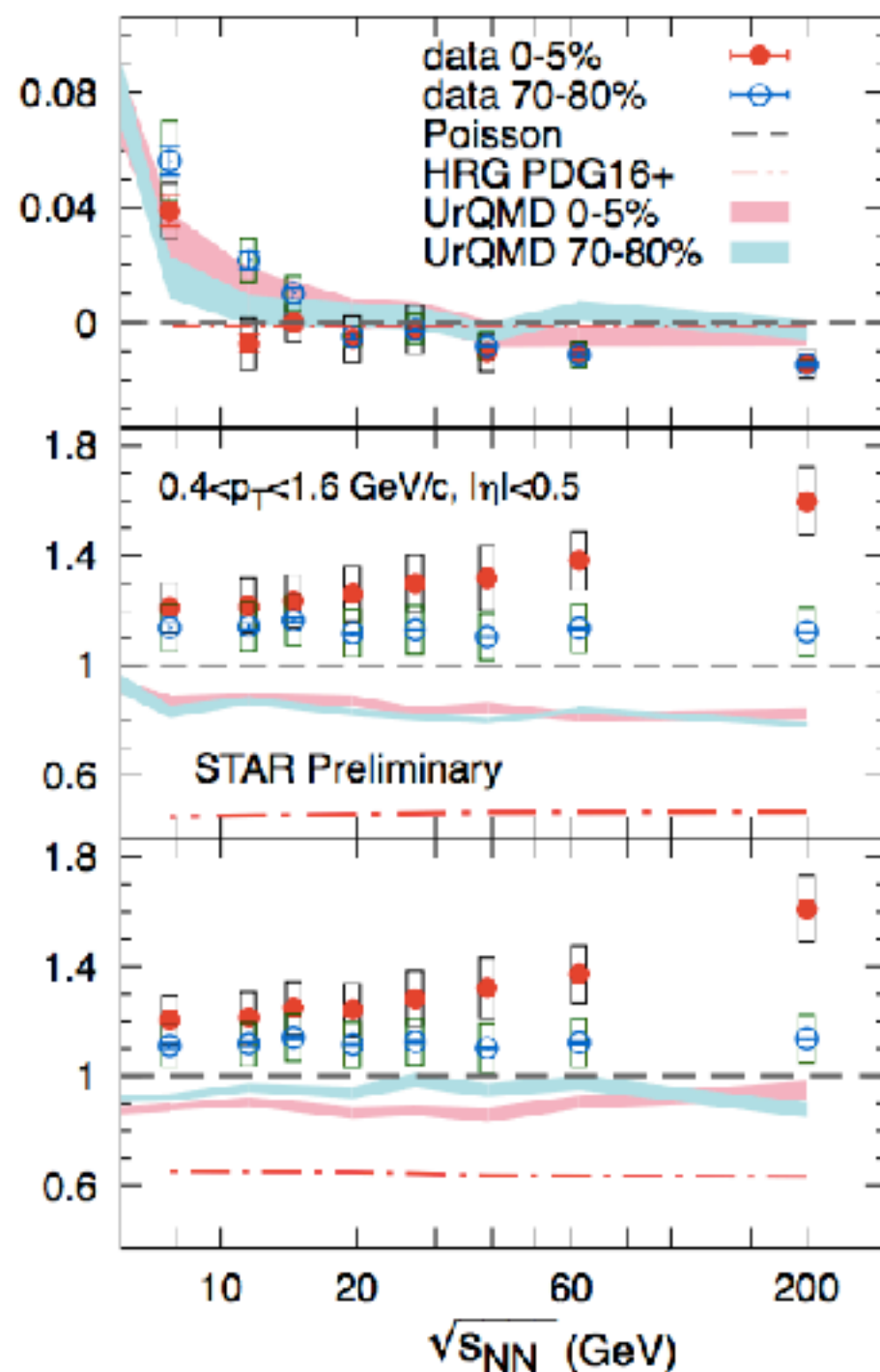
$$\sigma_{x,y}^2 = \langle xy \rangle - \langle x \rangle \langle y \rangle$$

- First measurement of off-diagonal cumulants.

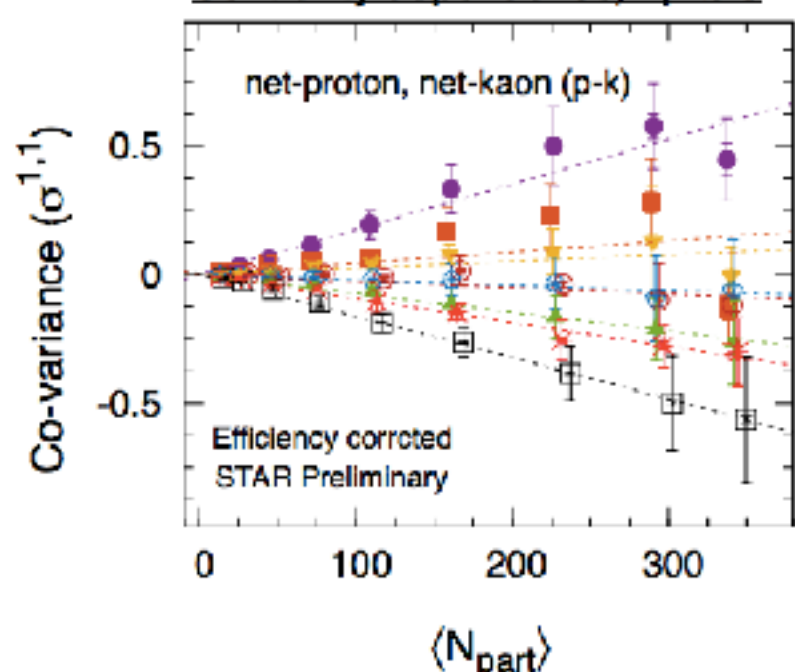
$$C_{x,y} = \frac{\sigma_{x,y}^{1,1}}{\sigma_y^2}$$

- Normalized p-k correlation is positive at lower energies negative at higher energies.
- Significant excess is observed in Q-k and Q-p w.r.t the Poisson baseline and UrQMD.

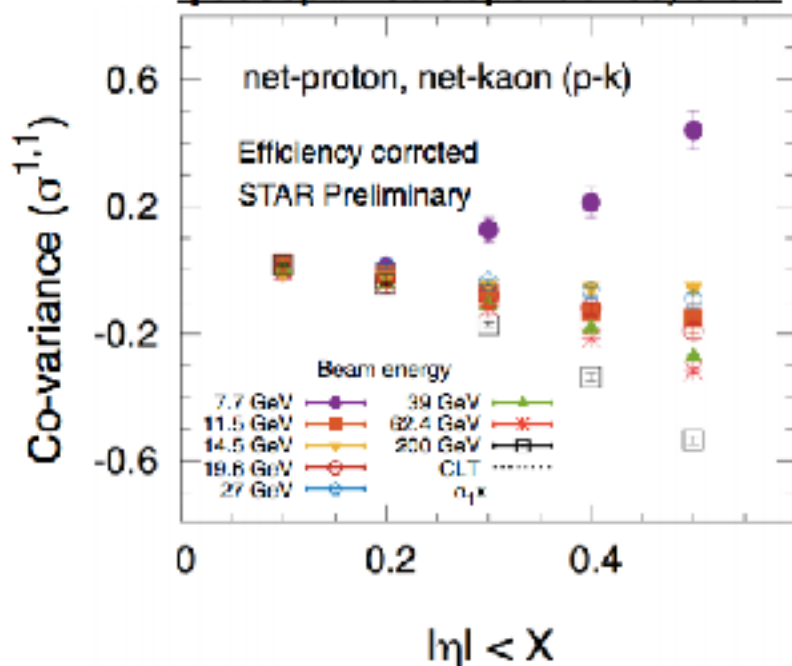
STAR,
A.Chetterjee (poster)
T.Nonaka (talk)



Centrality dependence, $|\eta| < 0.5$



η acceptance dependence, 0-5%

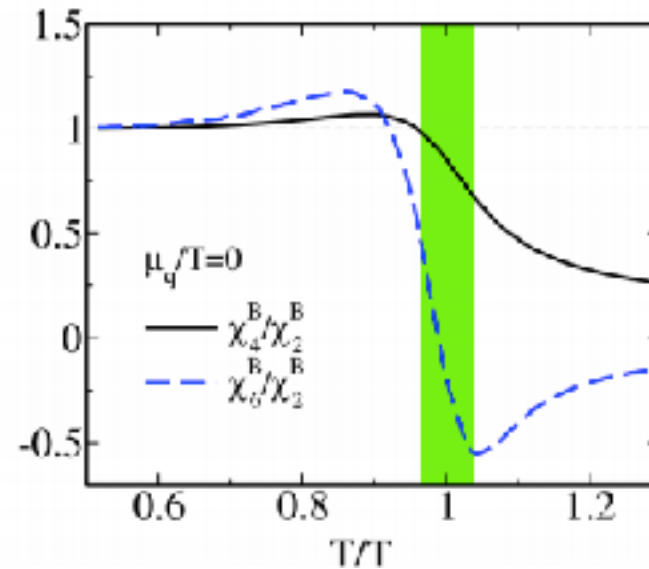


6-th order cumulant of net-charge fluctuation

- According to theoretical predictions, the **6th-order cumulants of net-variable may be the signal of cross-over transition.**

($\chi_6/\chi_2 < 0$ near the T_{pc})

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



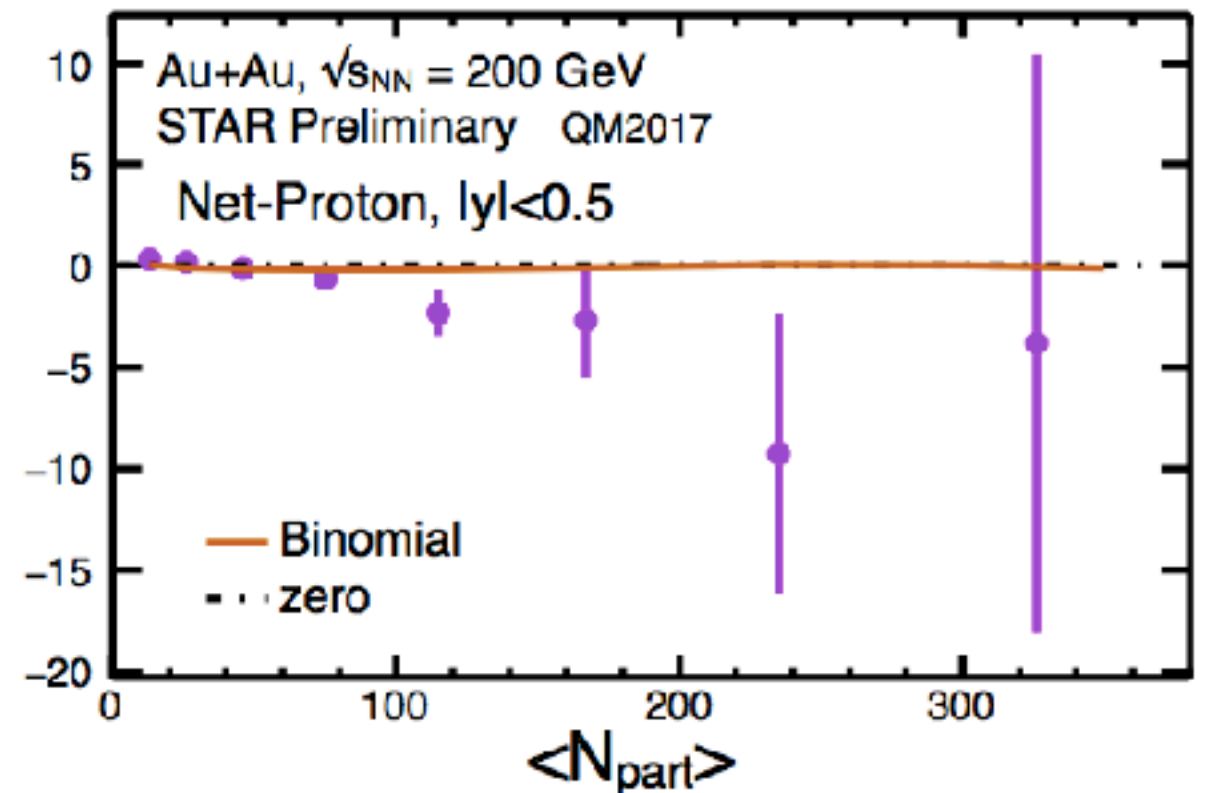
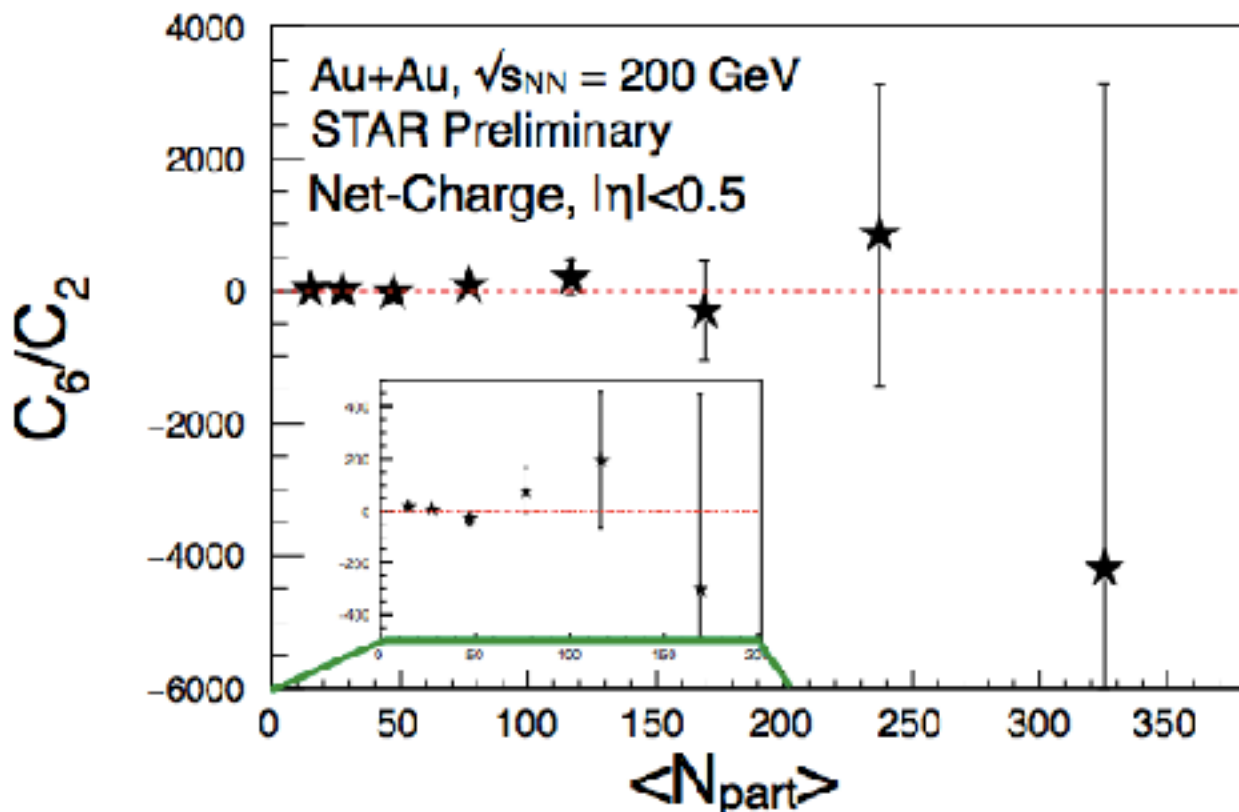
C.Schmidt, Prog. Theor. Phys. Suppl. 186, 563–566 (2010)
 Cheng et al, Phys. Rev. D 79, 074505 (2009)
 Friman et al, Eur. Phys. J. C (2011) 71:1694

Freeze-out conditions	χ_4^B/χ_2^B	χ_6^B/χ_2^B	χ_4^Q/χ_2^Q	χ_6^Q/χ_2^Q
HRG	1	1	~ 2	~ 10
QCD: $T^{freeze}/T_{pc} \lesssim 0.9$	$\gtrsim 1$	$\gtrsim 1$	~ 2	~ 10
QCD: $T^{freeze}/T_{pc} \simeq 1$	~ 0.5	< 0	~ 1	< 0

Predicted scenario for this measurement

- C_6/C_2 is consistent with zero** within statistical uncertainty for all centralities

STAR, T.Sugiura (poster) T.Nonaka (talk)



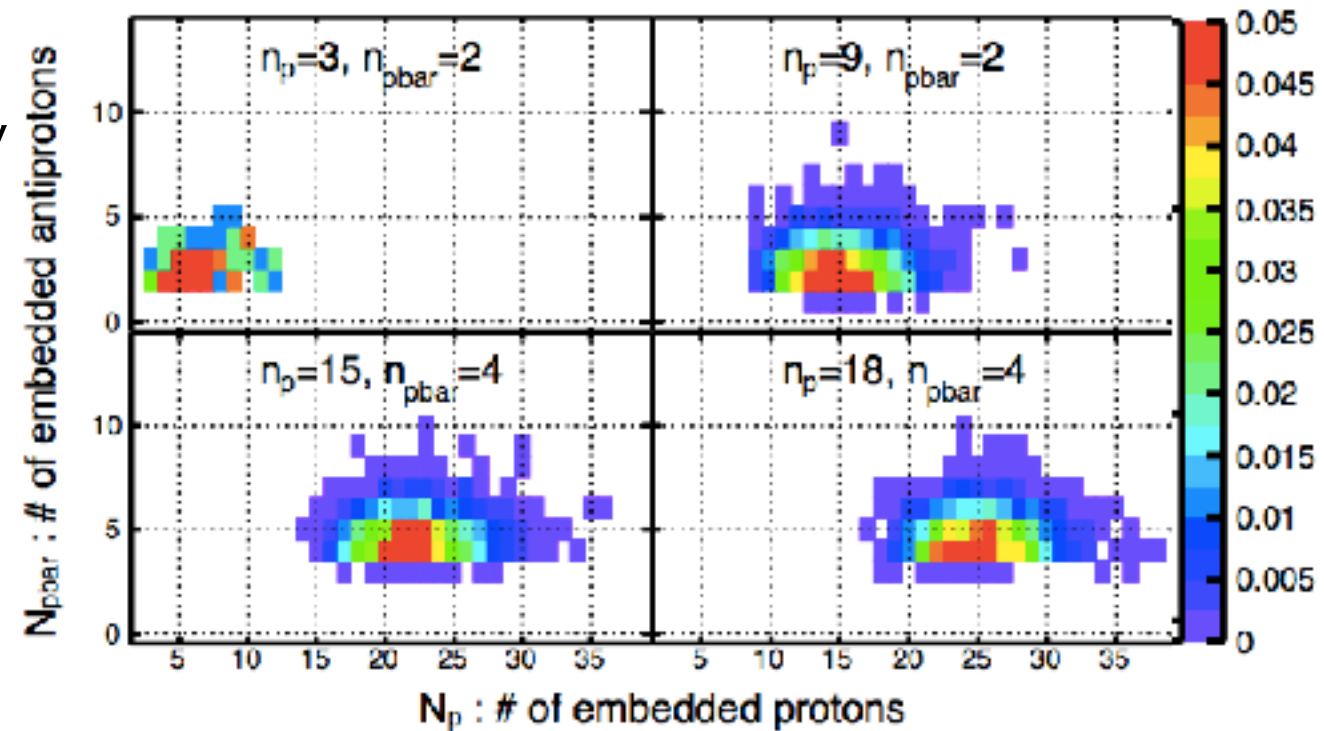
Net-proton cumulants by unfolding at 19.6 GeV

STAR, T.Nonaka (talk)

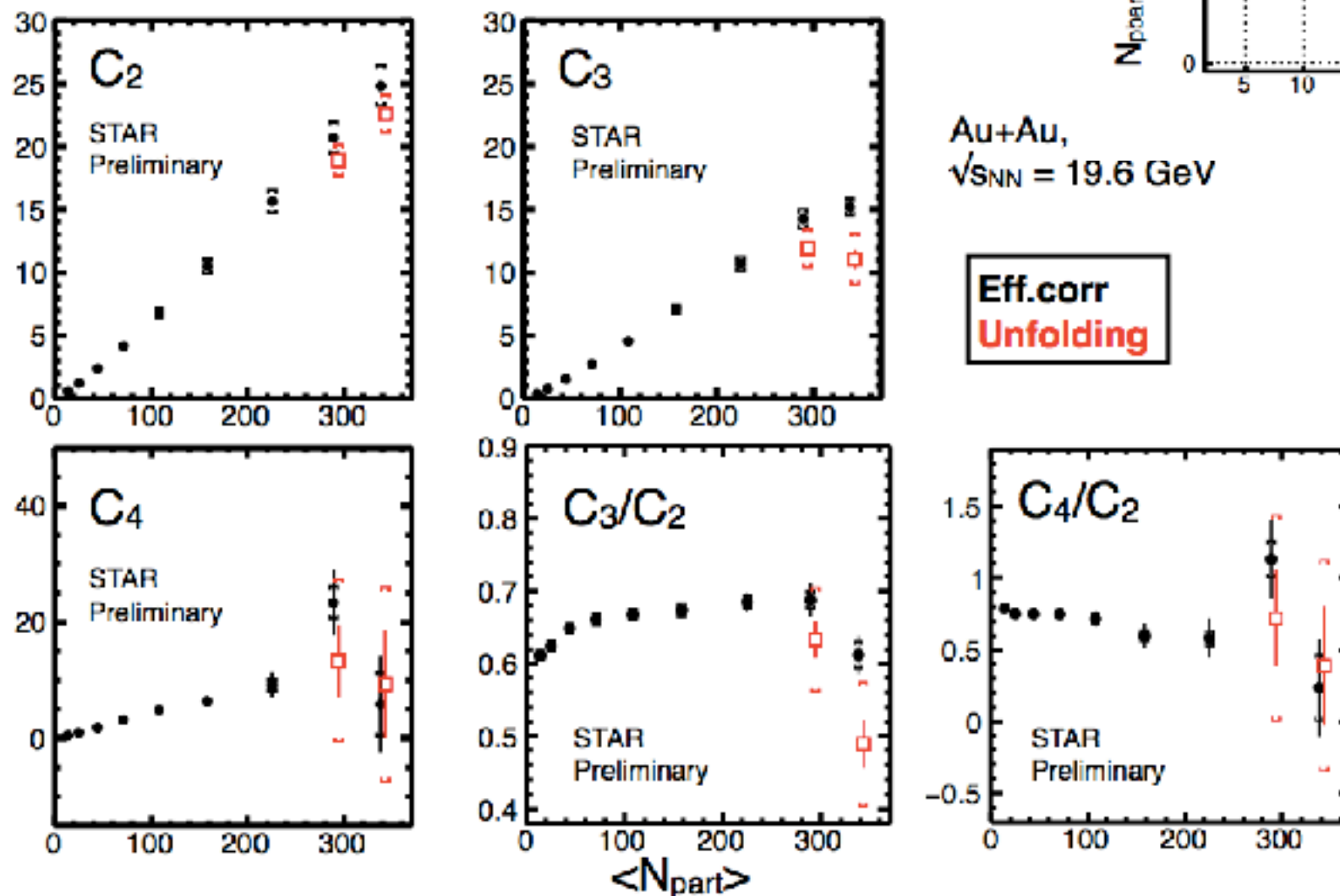
- In current fluctuation analysis, efficiency corrections are based on Binomial distribution.
- However, actually the detector efficiency may not be binomial.
- Unfolding was done using response matrix based on embedding at 19.6 GeV.

$$\mathcal{R}(N_p, N_{pbar}; n_p, n_{pbar})$$

Reversed response matrix



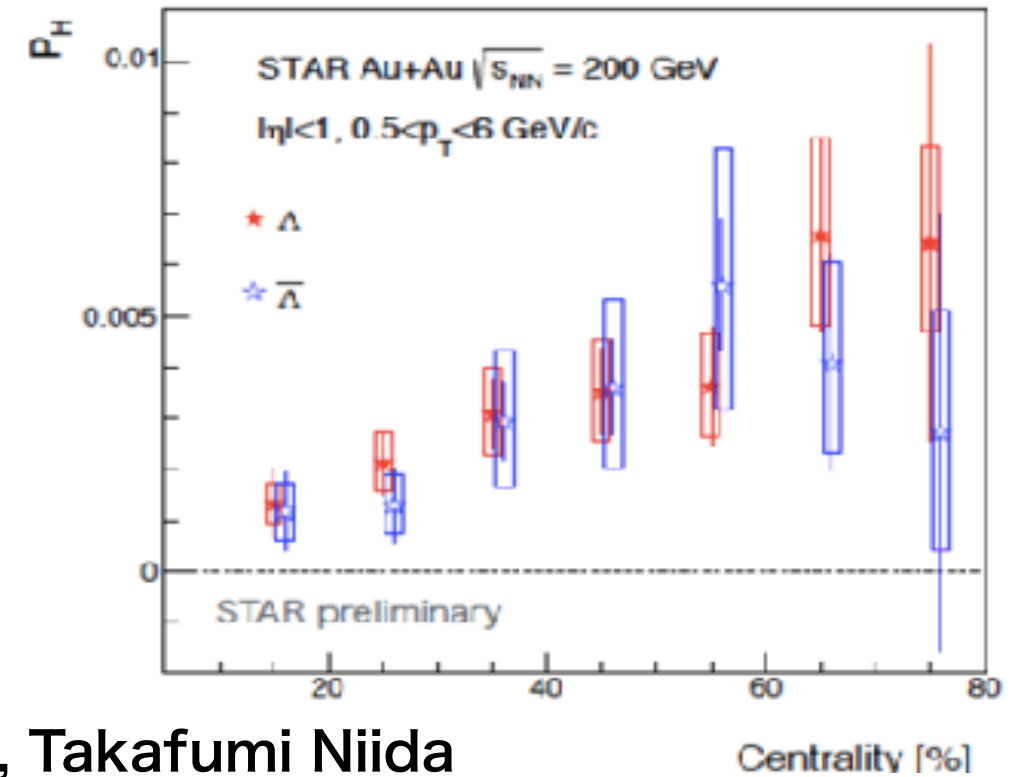
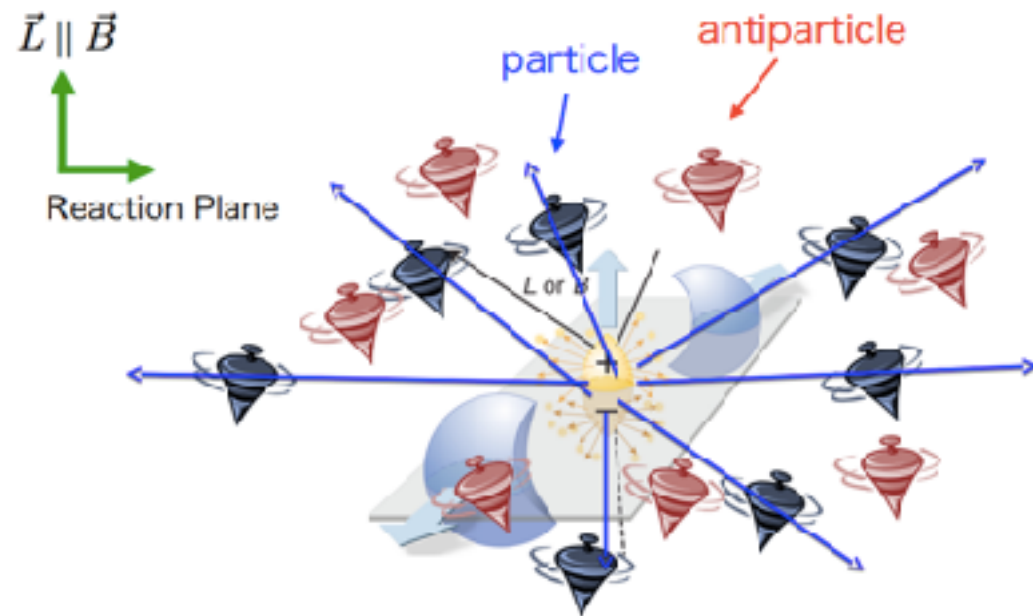
STAR, T.Nonaka (talk and poster)



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

Eff. corr
Unfolding

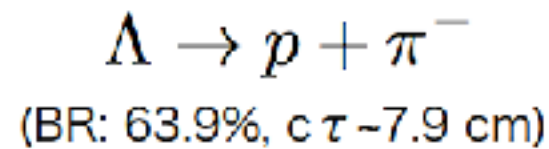
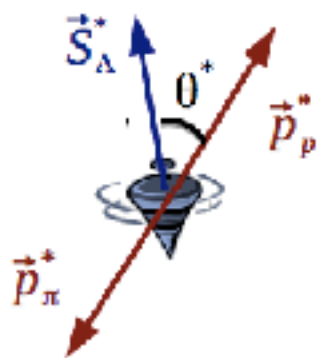
- Systematic suppression is observed for C2 and C3 with respect to the results of efficiency correction assuming binomial efficiencies.
- C4, C3/C2 and C4/C2 are consistent within large systematic uncertainties limited by embedding samples.



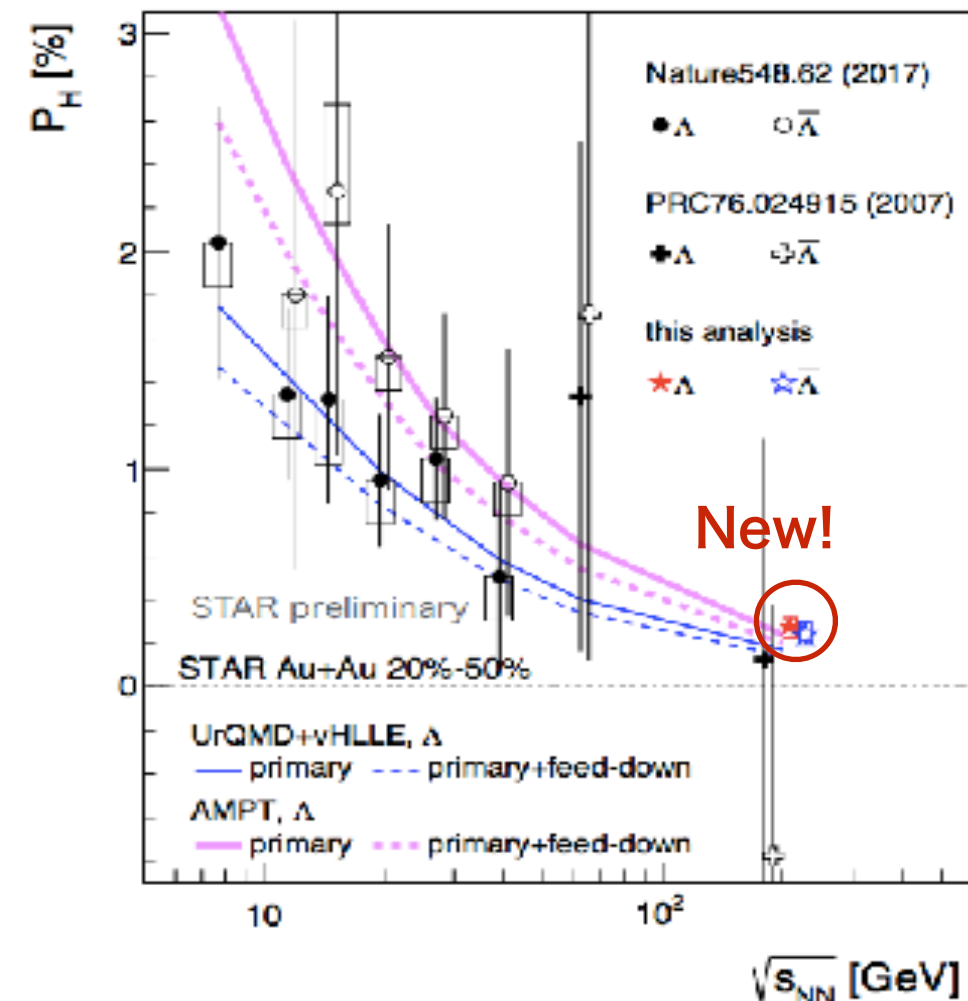
STAR, Takafumi Niida

$$\frac{dN}{d\Omega^*} = \frac{1}{4\pi} (1 + \alpha_H \mathbf{P}_H \cdot \mathbf{p}_p^*)$$

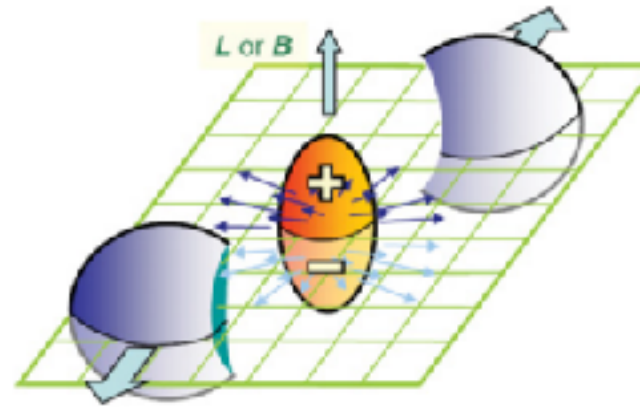
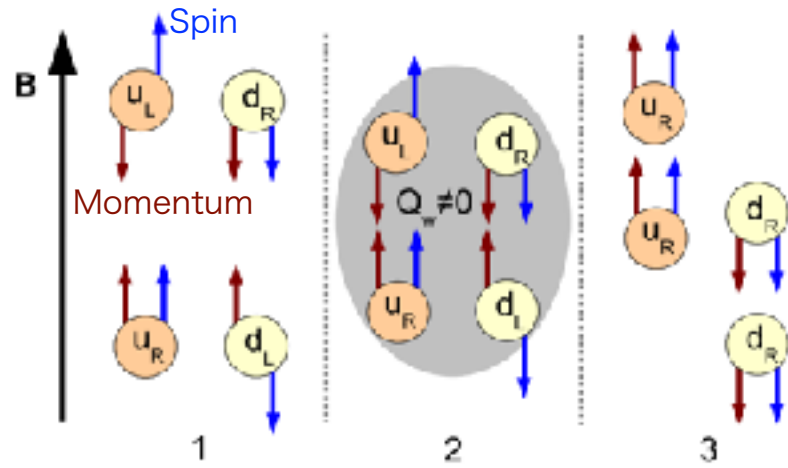
P_H : Λ polarization
 \mathbf{p}_p^* : proton momentum in Λ rest frame
 α_H : Λ decay parameter
 $(\alpha_\Lambda = -\alpha_{\bar{\Lambda}} = 0.642 \pm 0.013)$



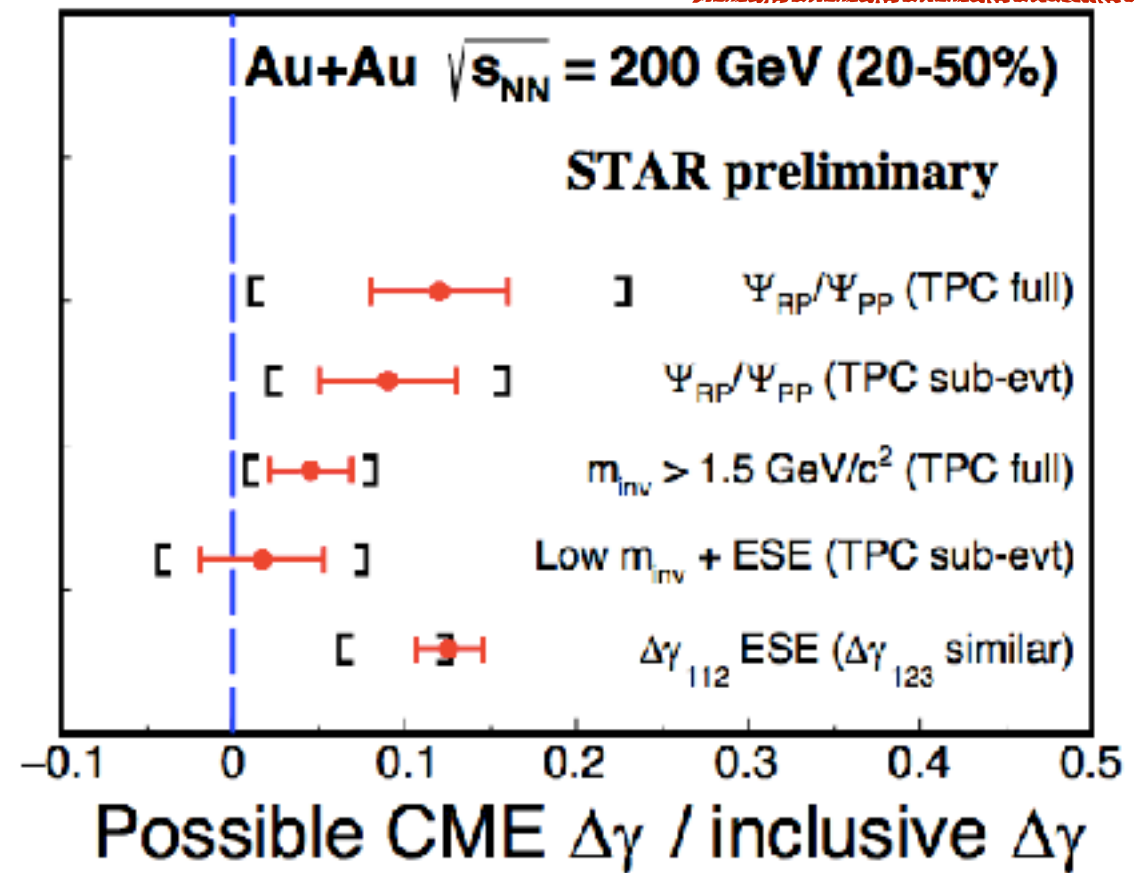
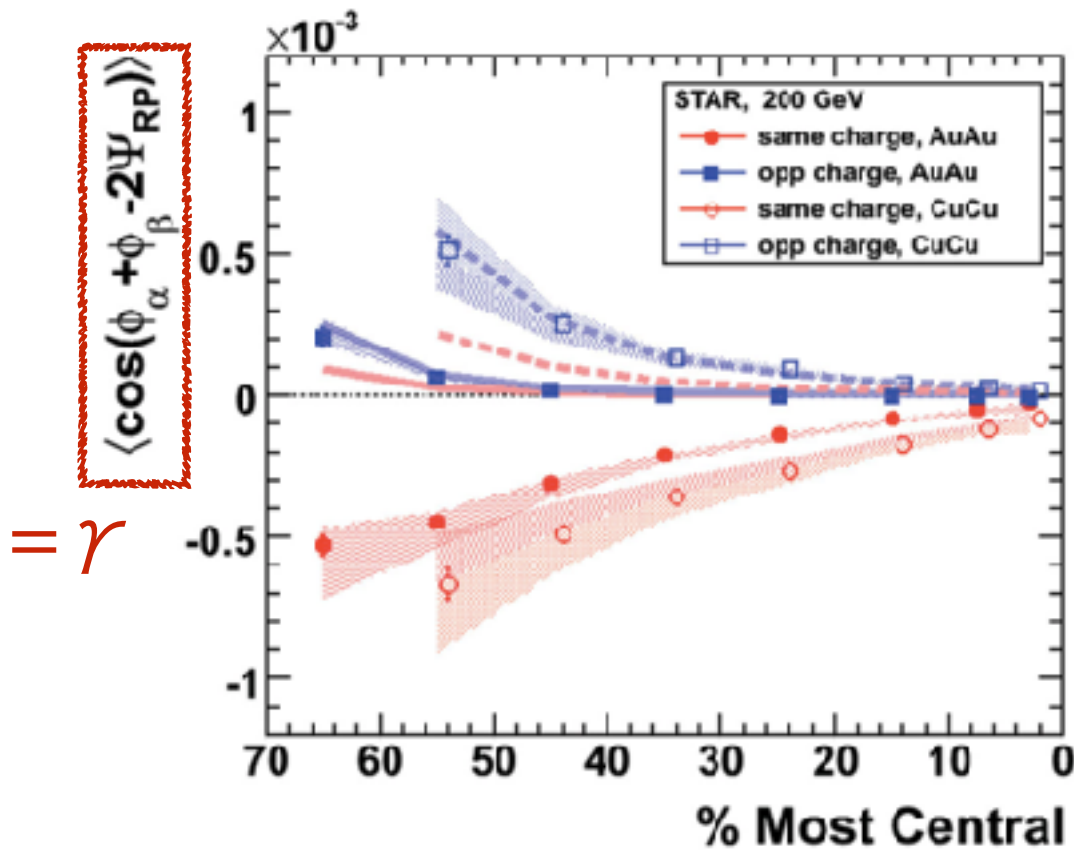
- First observation of Λ global polarization at 200 GeV



Chiral Magnetic Effect at RHIC Top Energy



$$\Delta\gamma \equiv \gamma_{os} - \gamma_{ss}$$



H.-J. Xu et al. arXiv:1710.07265

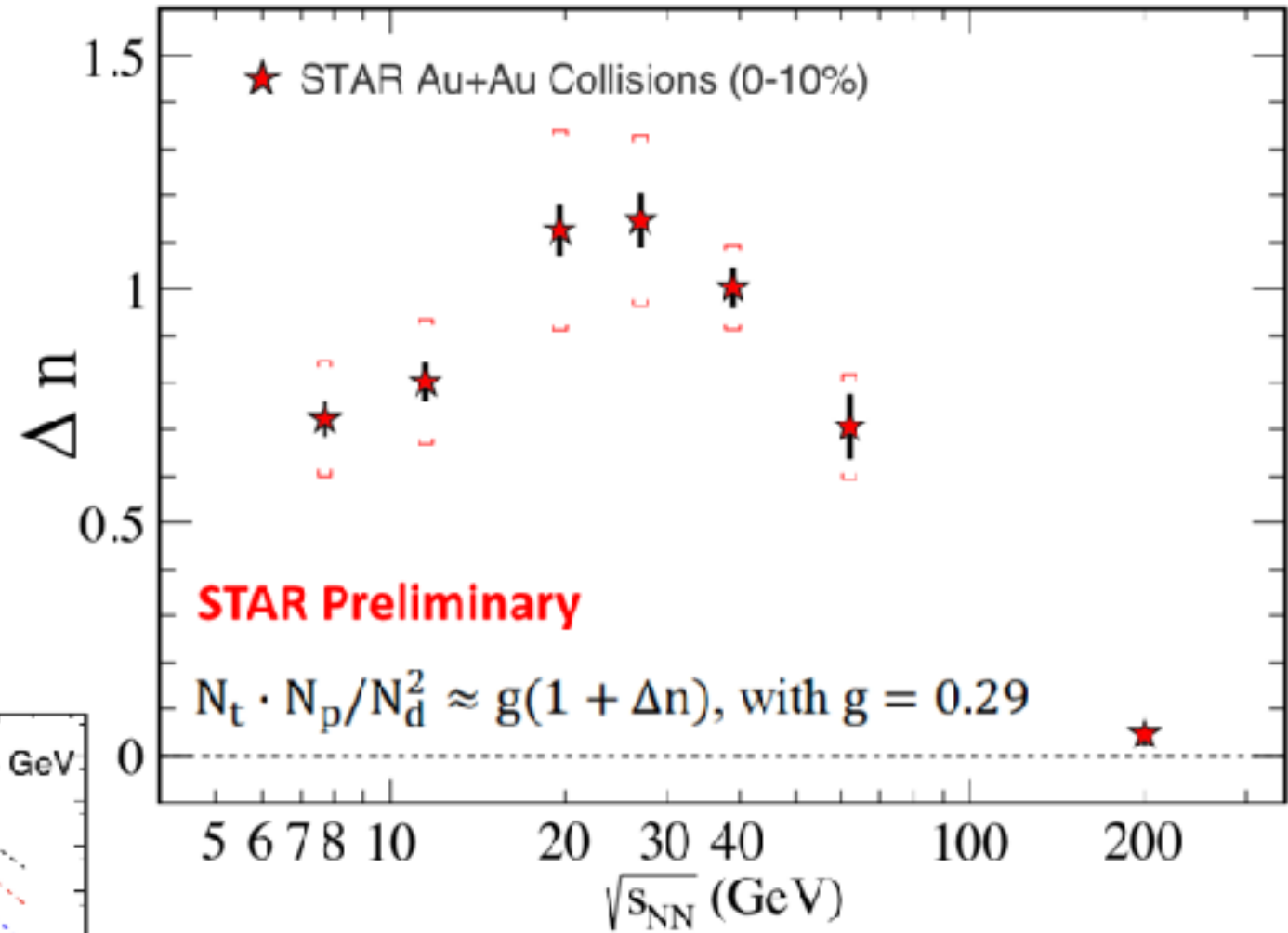
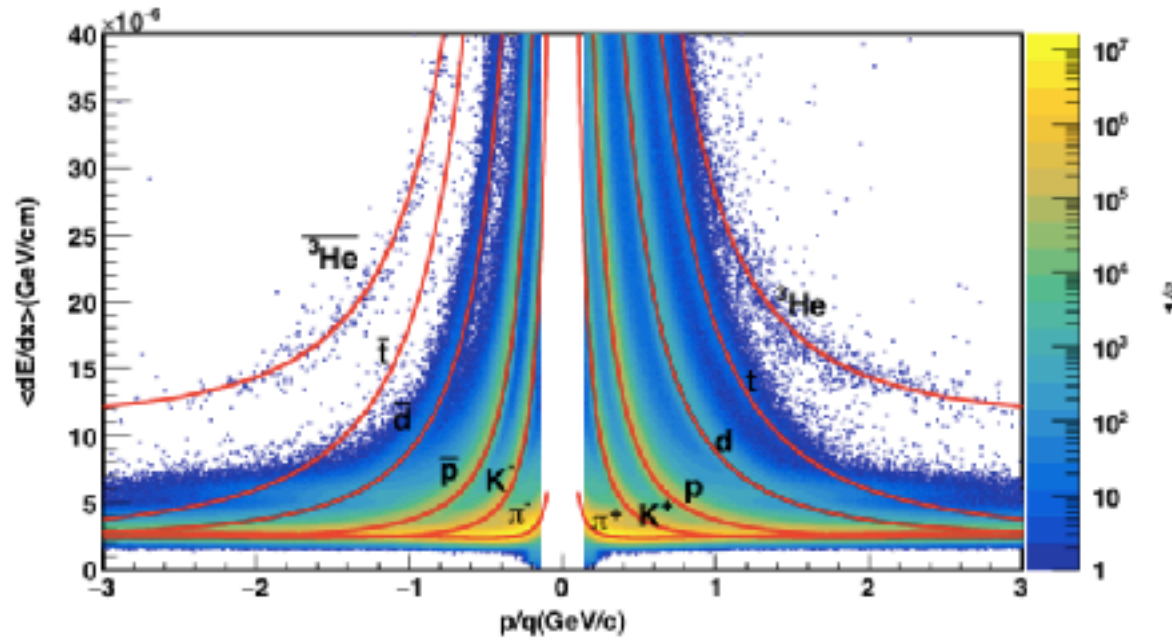
J. Zhao et al. arXiv:1705.05410

STAR, Jie Zhao

STAR, PRL 103,251601 (2009)

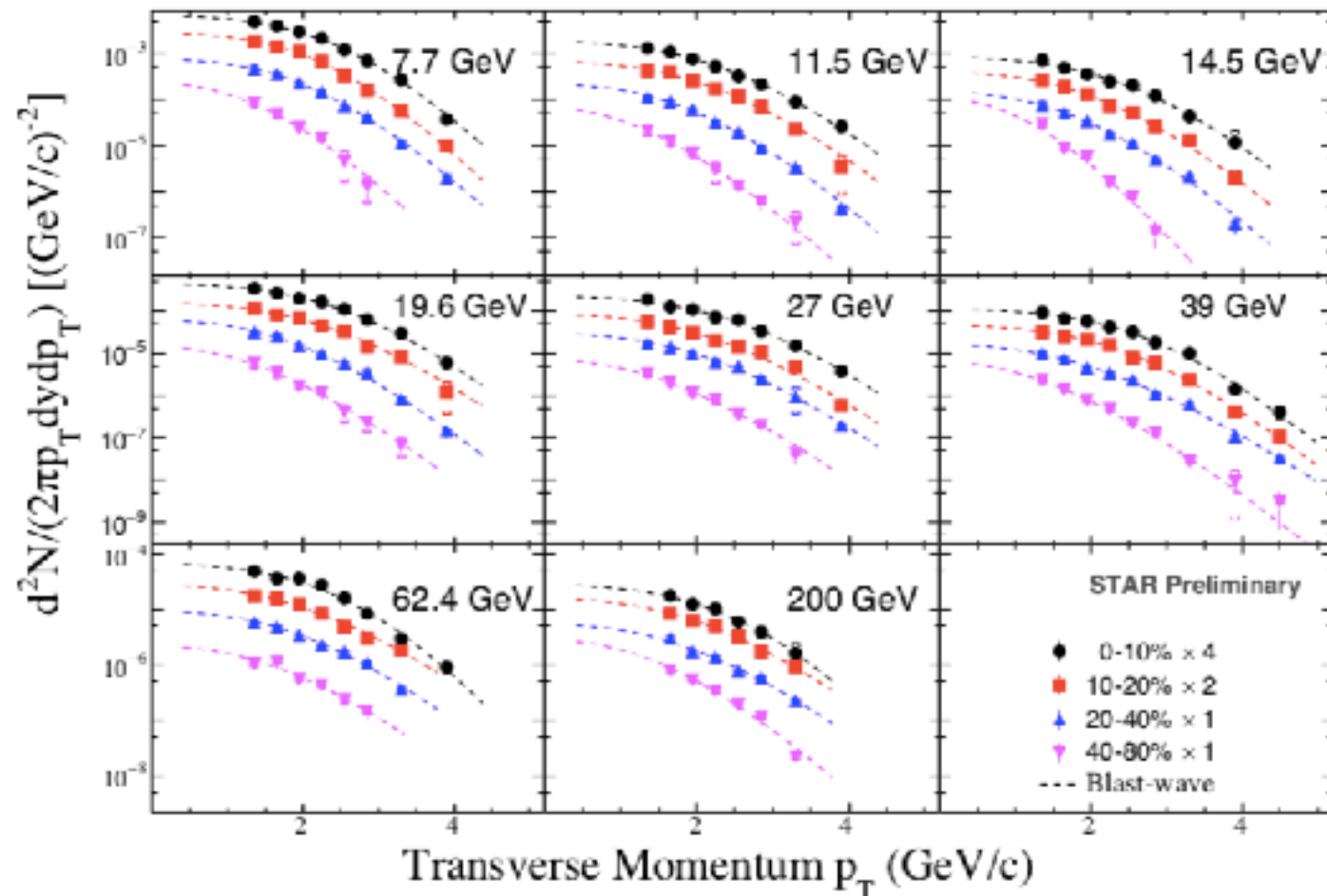
- Isolate possible CME signal in inclusive $\Delta\gamma$ by different methods.
- Dedicated isobar run this year completed, blind analysis for CME studies being conducted.

Triton Production in Beam Energy Scan



STAR, Pens Liu (talk)

Triton from Au+Au Collision



- First results of triton production in Au+Au collisions at BES energy.
- Non-monotonic energy dependence of neutron density fluctuation

$$\Delta n = \langle \delta_n^2 \rangle / \langle n \rangle^2$$

BES2 Plan

	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 1 st order P.T. CME, CVE

<http://www2.yukawa.kyoto-u.ac.jp/~nfqcd2018/Slide/Esumi.pdf>

Summary

- A lot of interesting results from BES1.
 - flow, small system, femtoscopy, fluctuation, vorticity and so on.
- Detector upgrade and test run of BES2 are finished.
 - Probably a lot of new BES2 results will be reported from next QM.

Back up