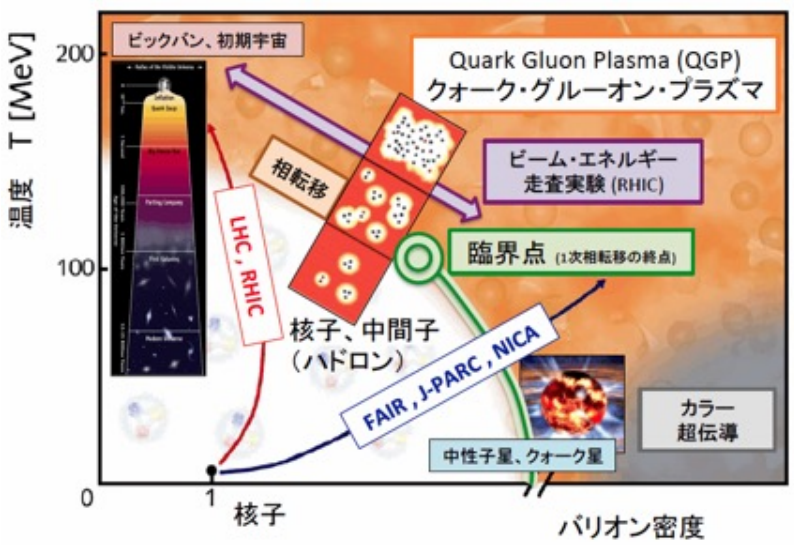
2nd Symposium on Intermediate-energy Heavy Ion Collisions (iHIC24), Tsinghua University, Beijing, China

Flow and Fluctuation Studies in Beam Energy Scan at High Baryon Density



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筑波大学 数理物質系 物理学域
宇宙史研究センター
江角晋一

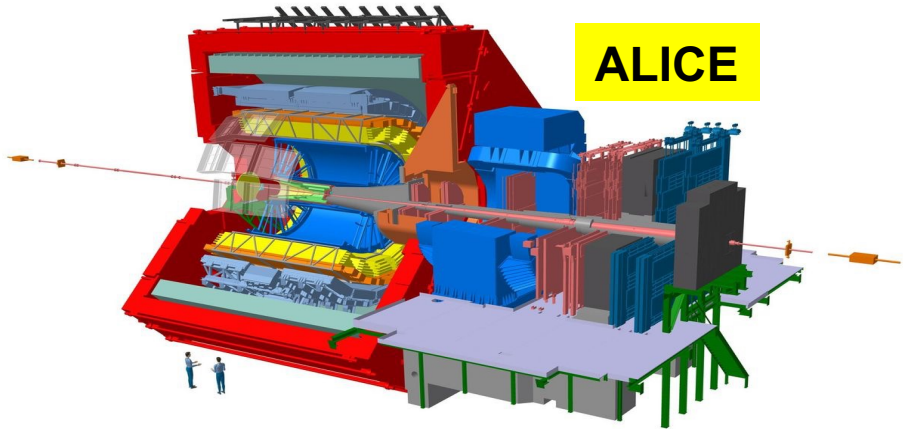
- **Beam Energy Scan at High Baryon Density**
- **Flow and correlation studies**
- **Fluctuation studies**
- **Summary and outlook**

The STAR experiment
at the Relativistic Heavy Ion Collider, Brookhaven National Laboratory

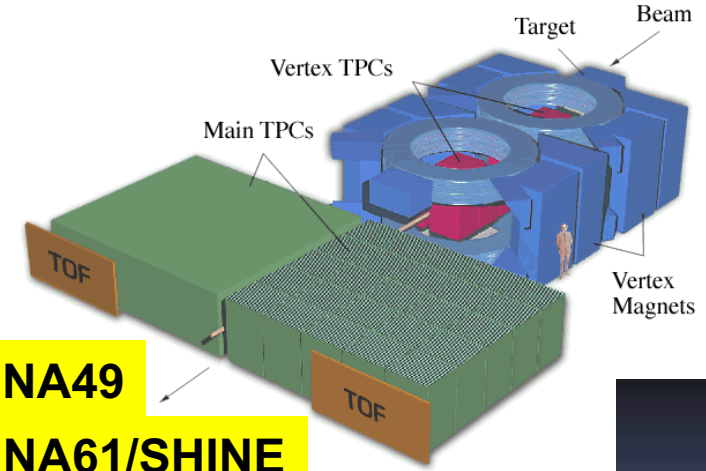
筑波大学
University of Tsukuba

筑波大学
宇宙史研究センター
Tomonaga Center for the History of the Universe

Experiments at CERN, GSI, BNL



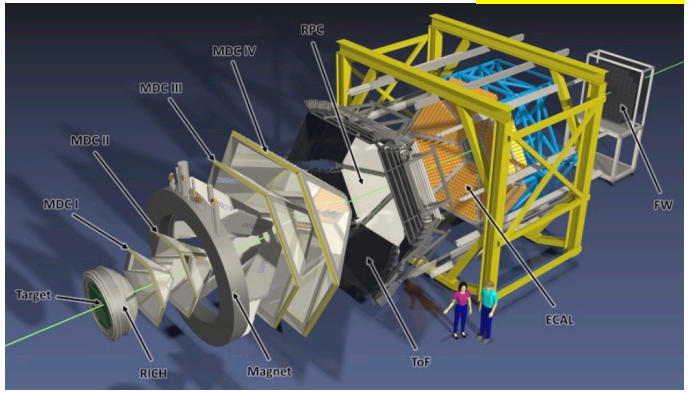
ALICE

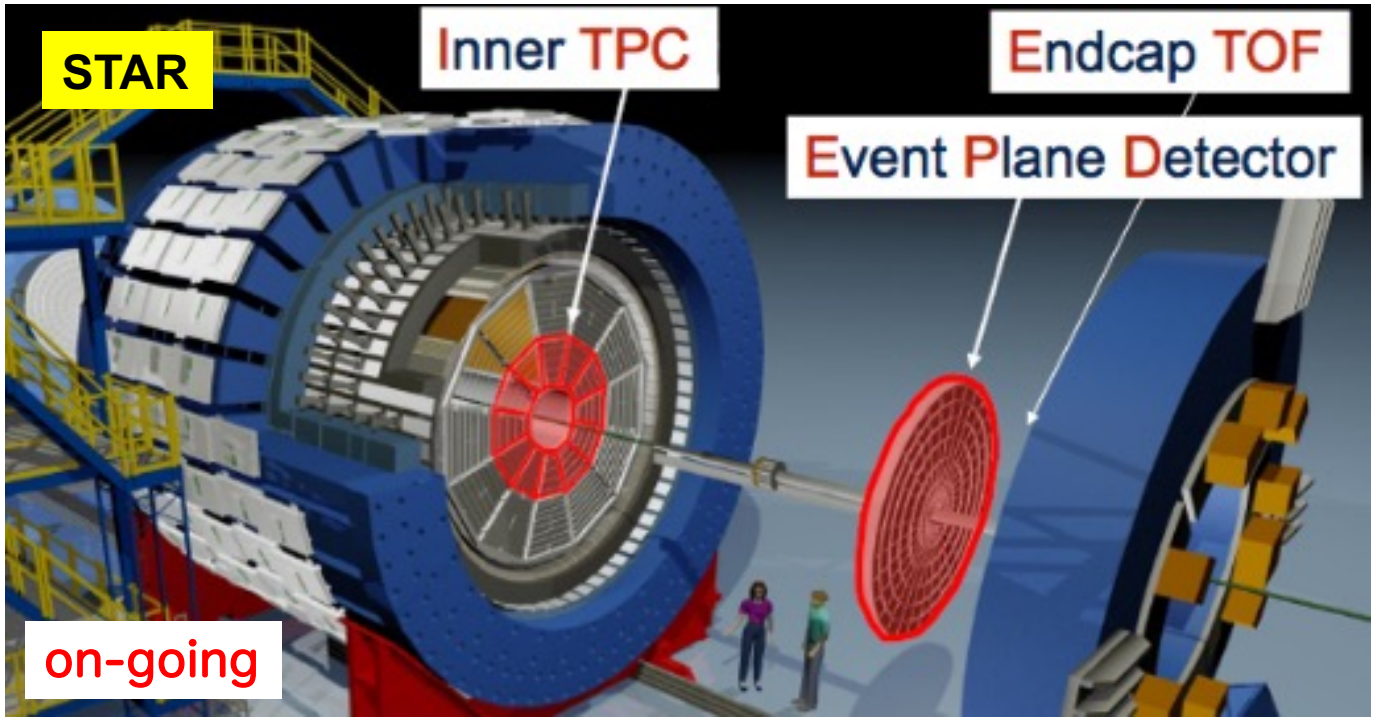


NA49

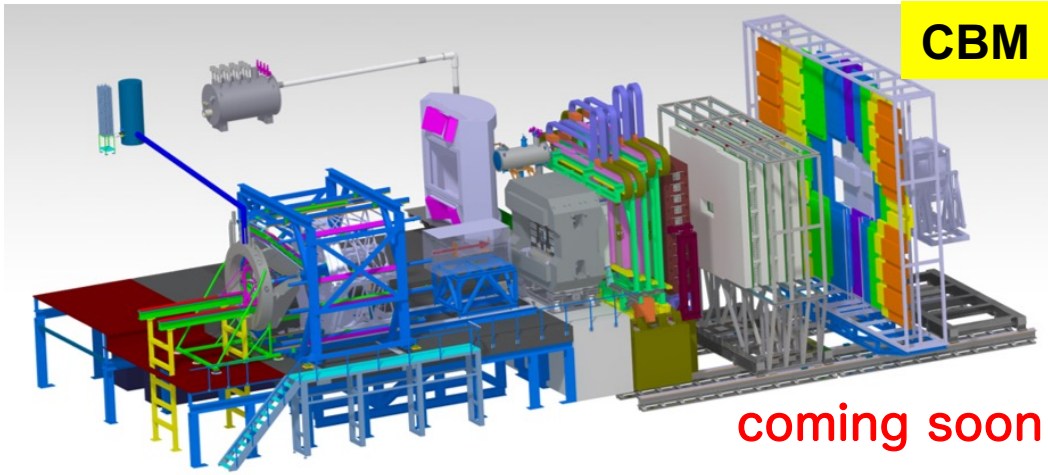
NA61/SHINE

HADES



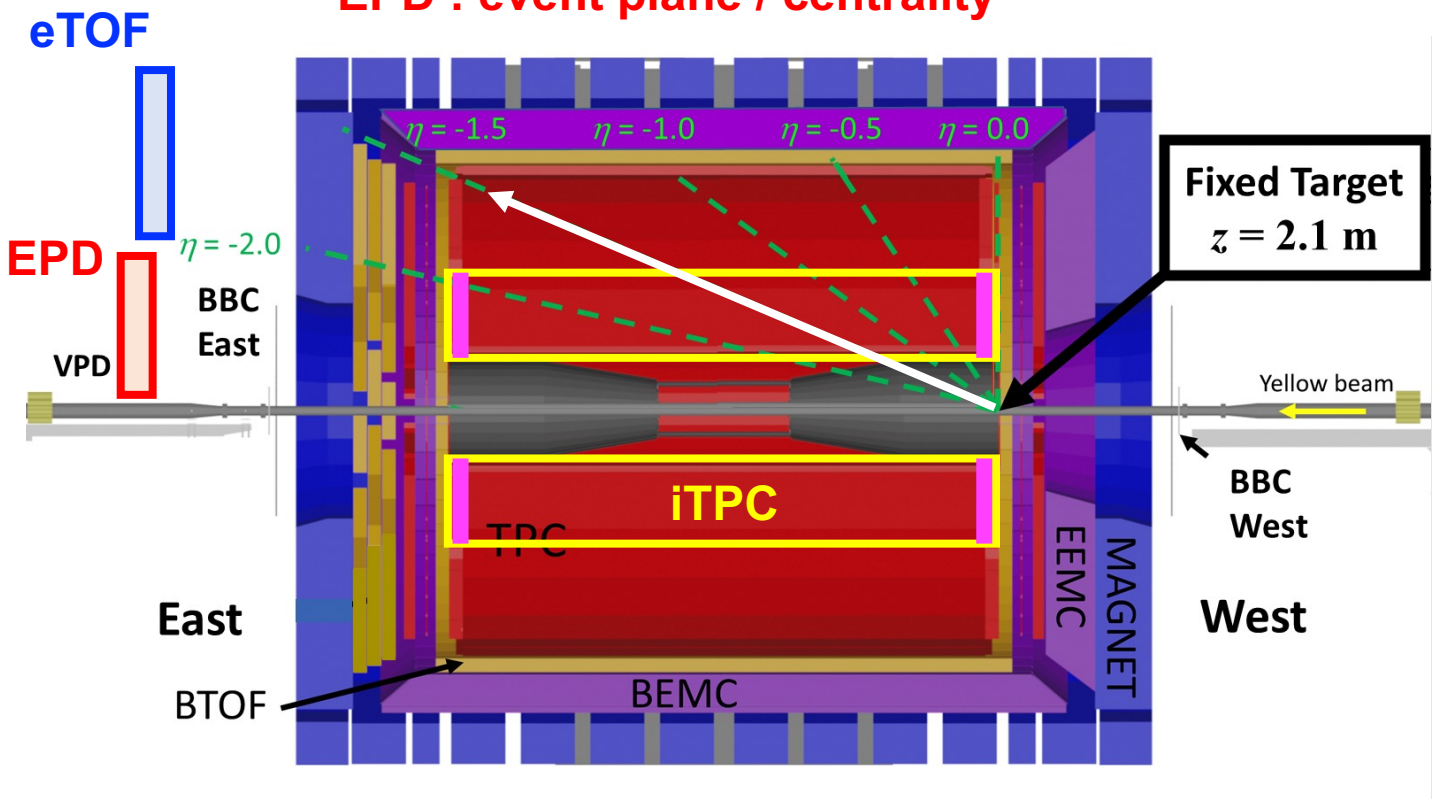


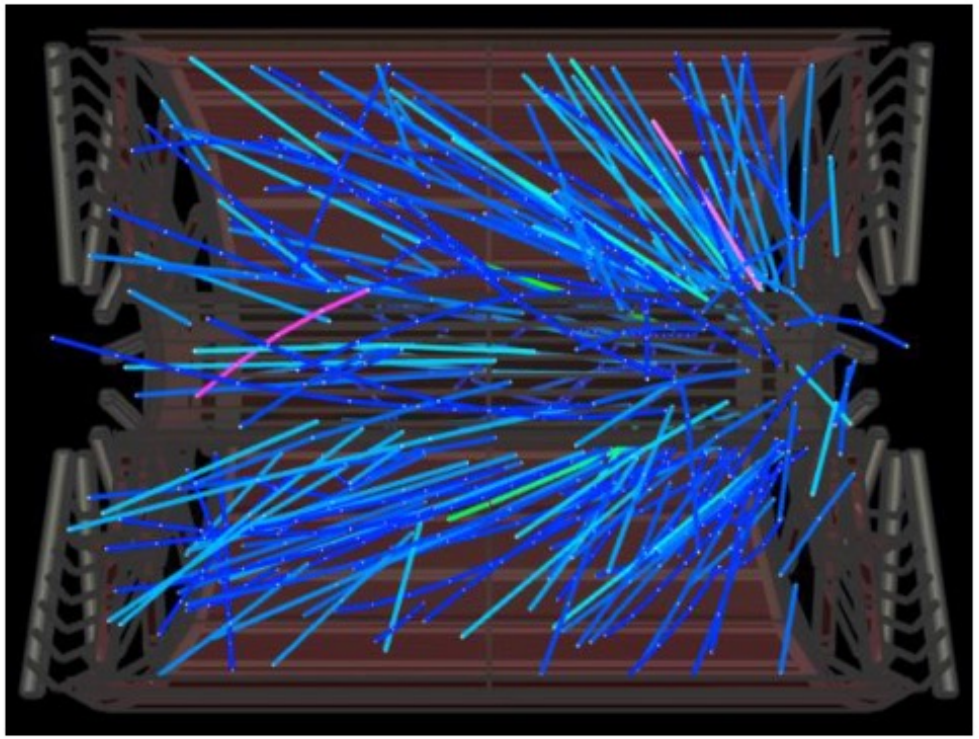
CBM



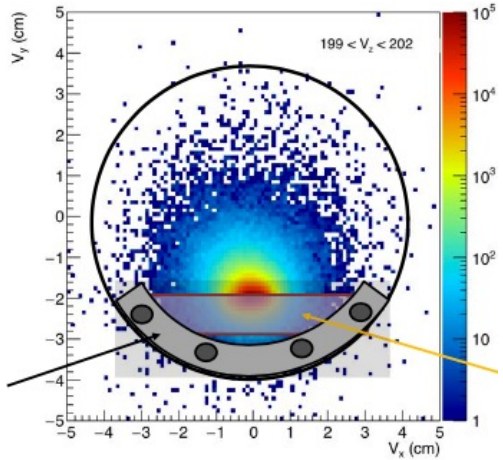
Fixed Target Set-up (FXT) at STAR Experiment

iTPC : inner TPC, forward tracking
eTOF : end-cap TOF, forward PID
EPD : event plane / centrality

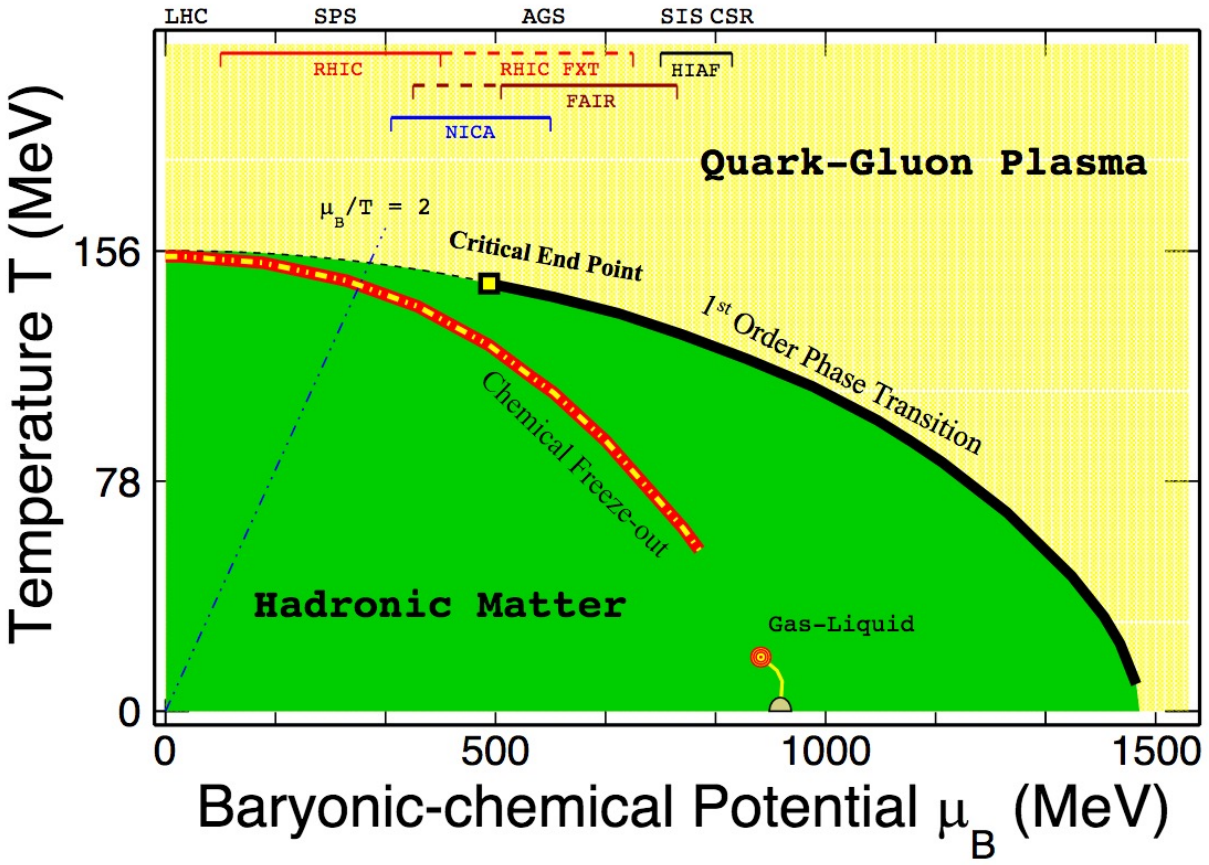




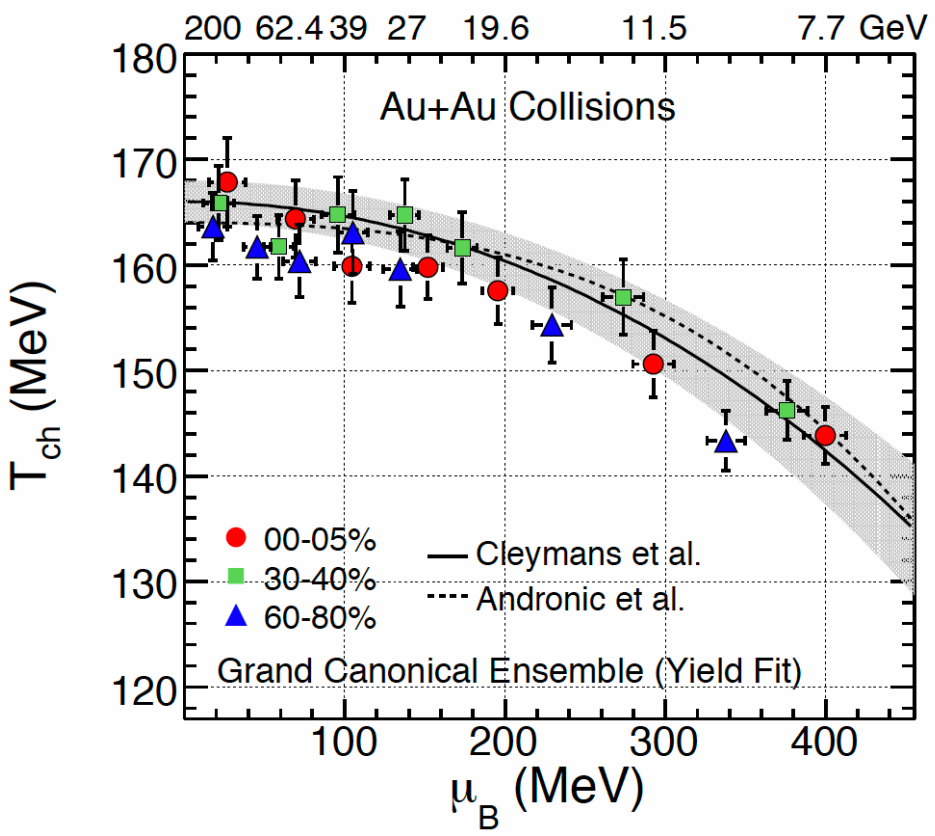




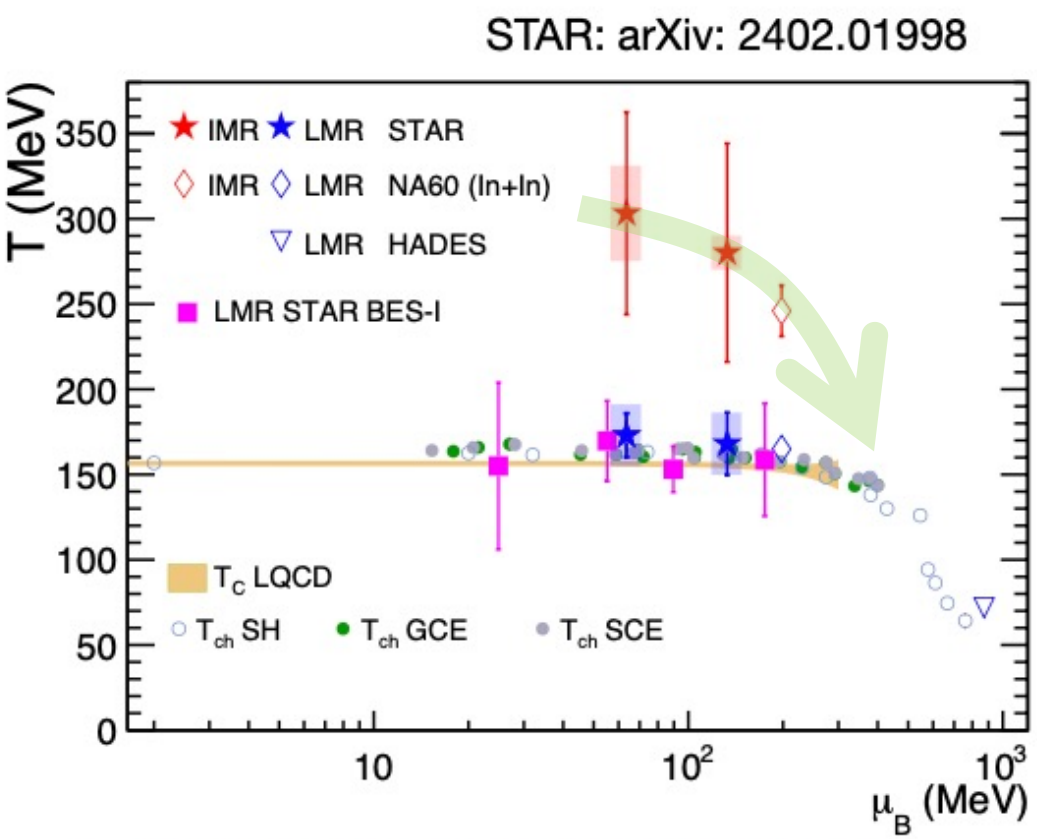
QCD Phase diagram and Beam Energy Scan

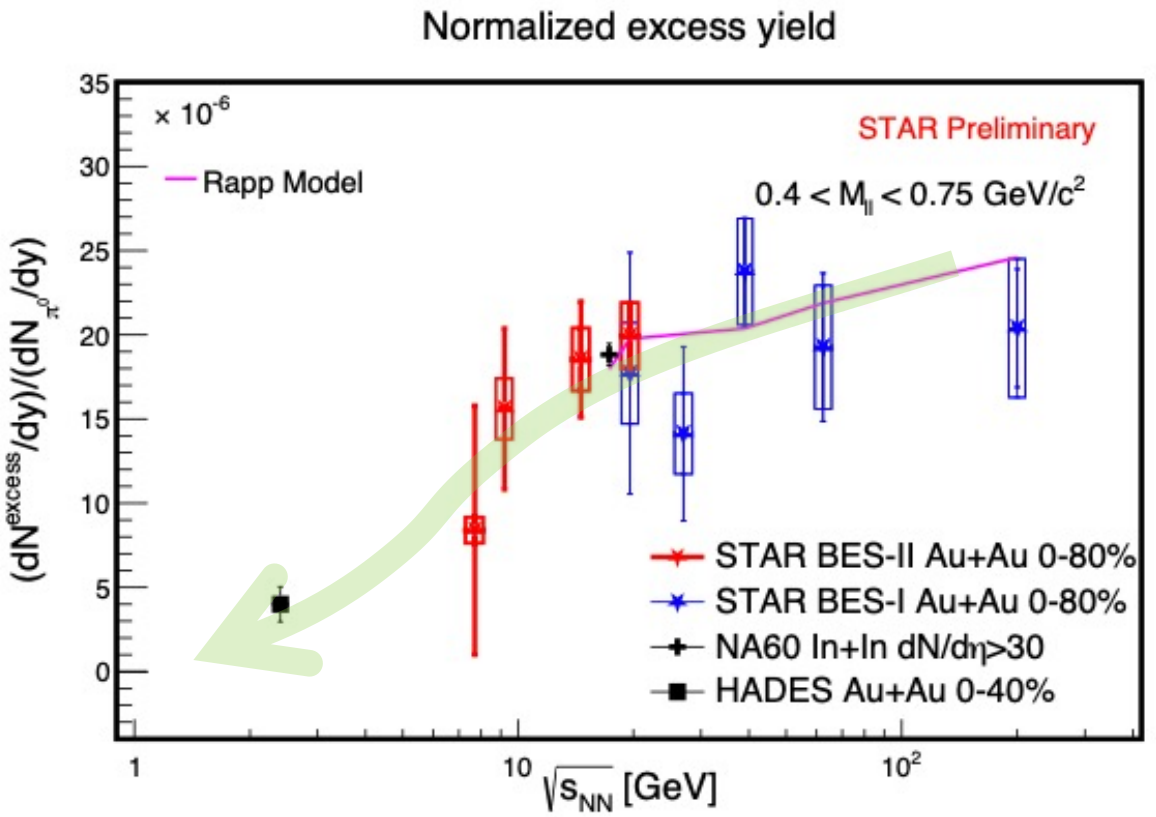


PRC 96 (2017) 4, 044904



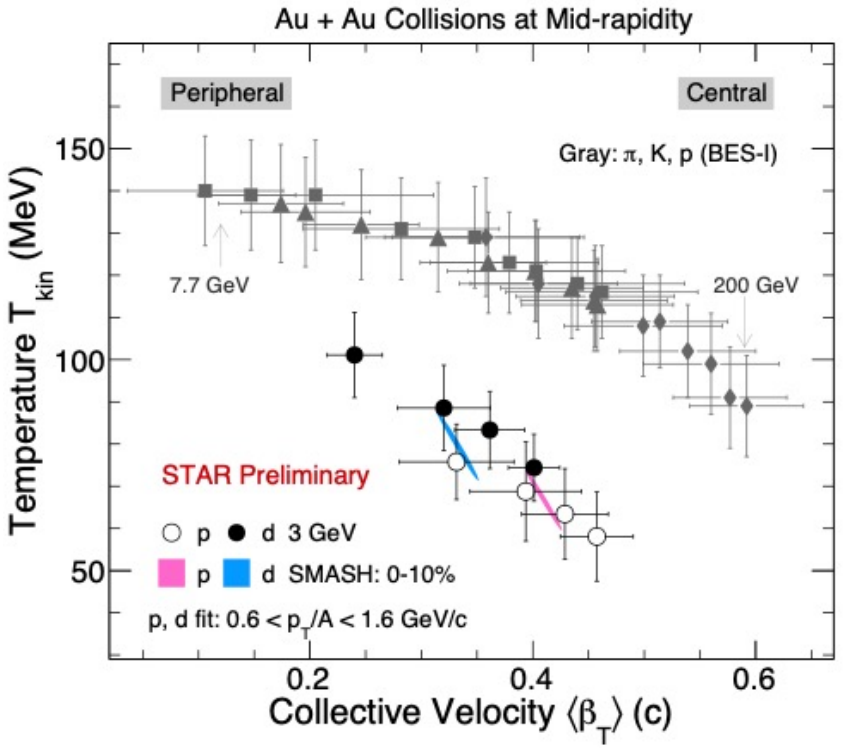
Thermal di-lepton measurements



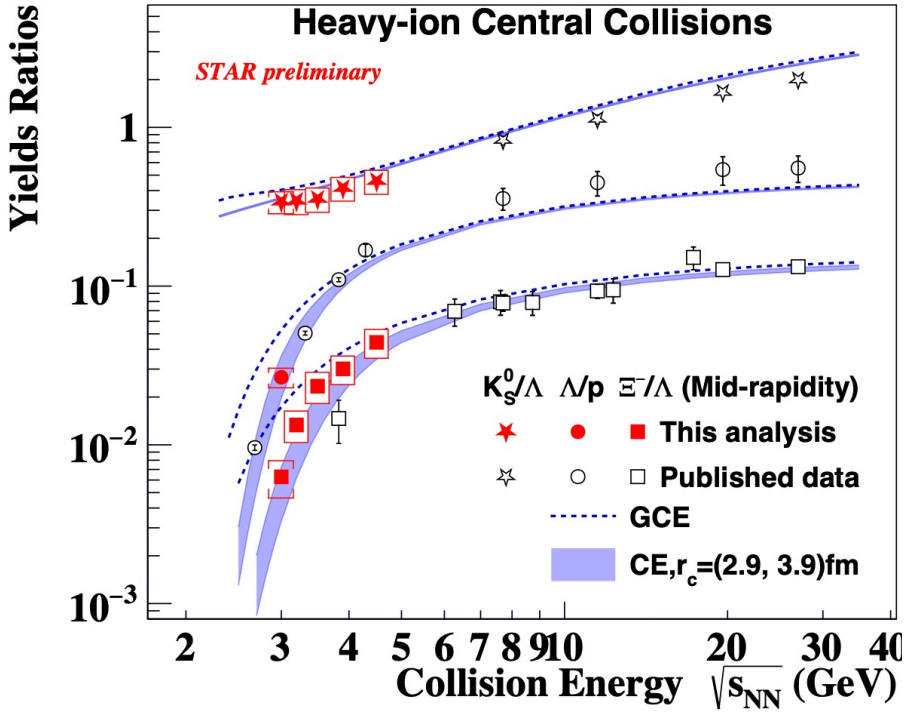


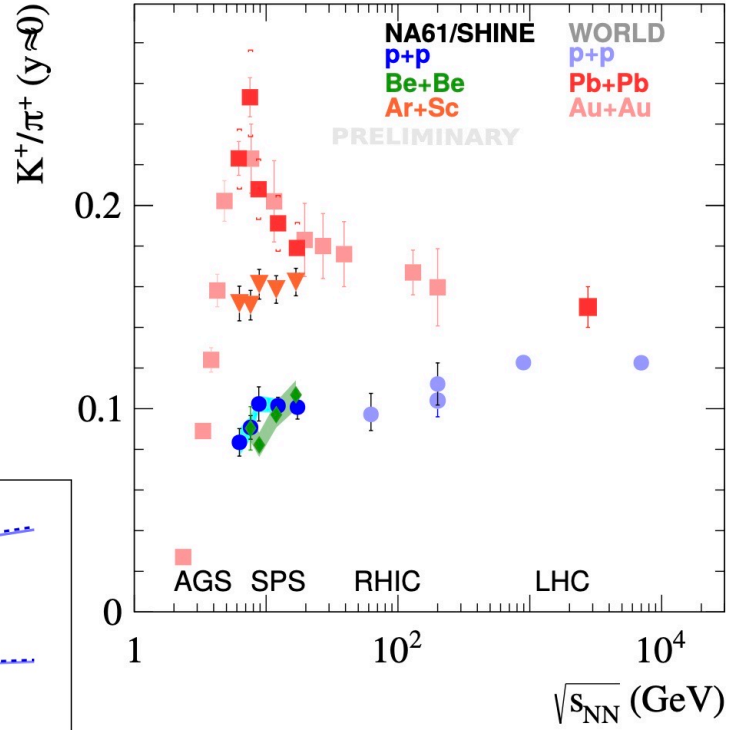
Transition from Quark Matter back to Hadronic Matter

Thermal freeze-out



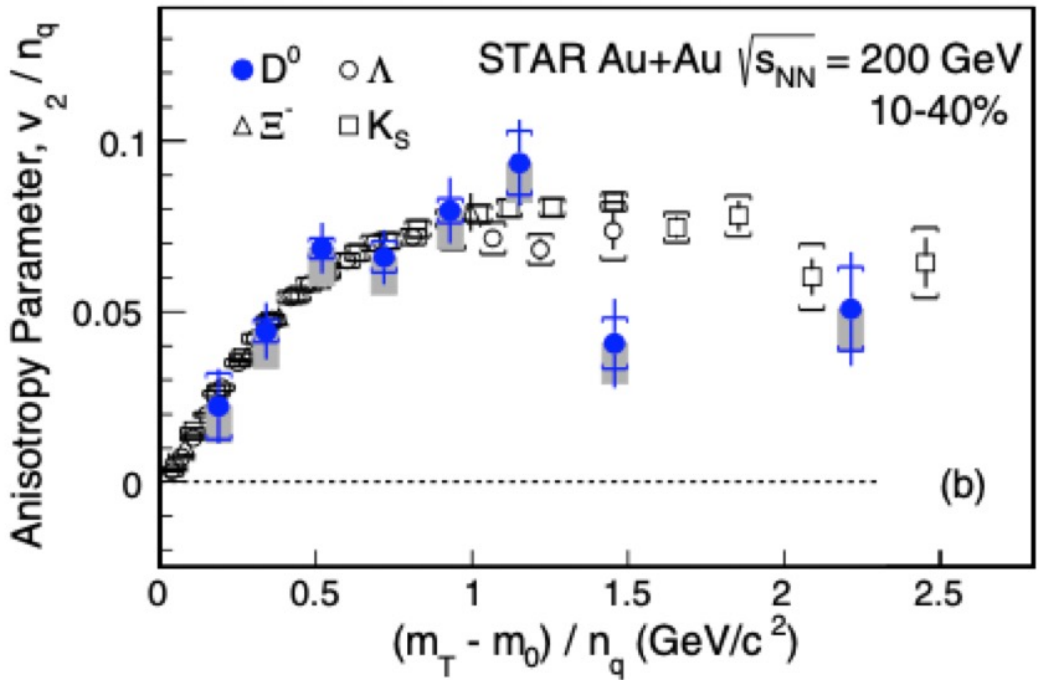
Strangeness



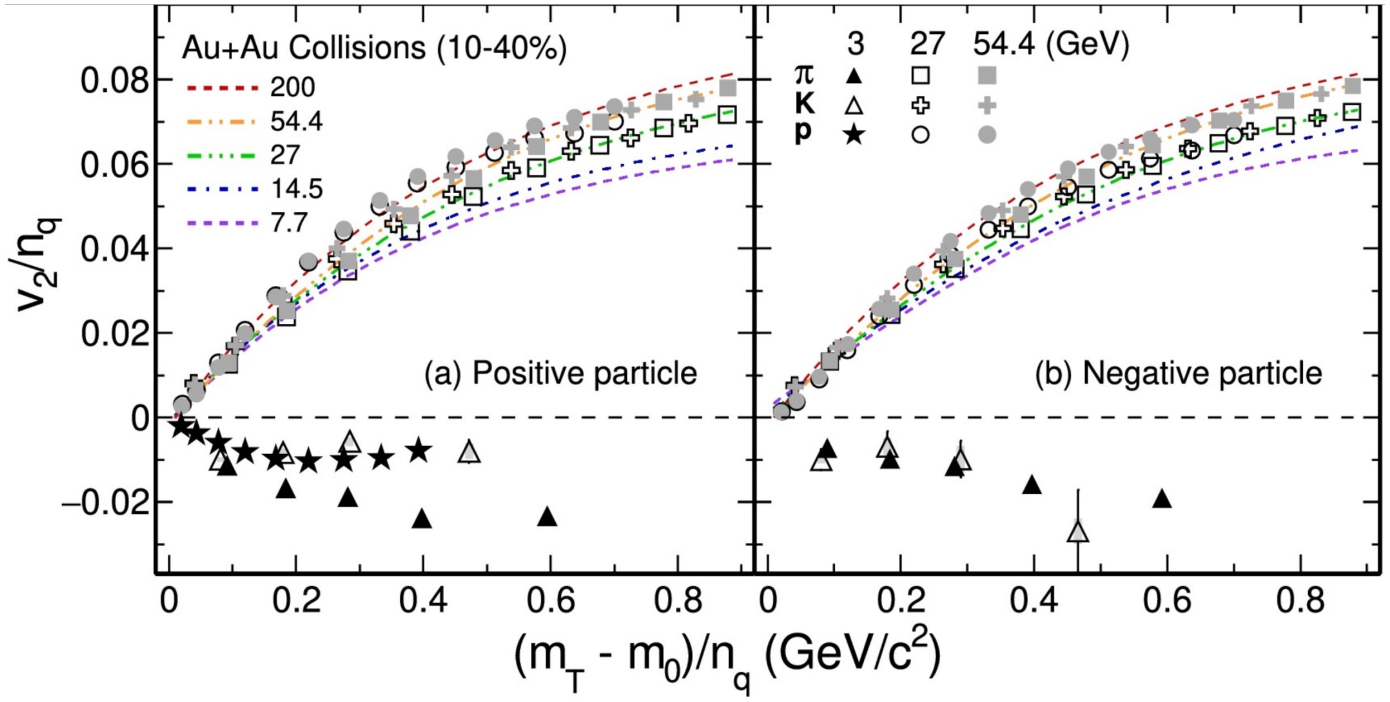


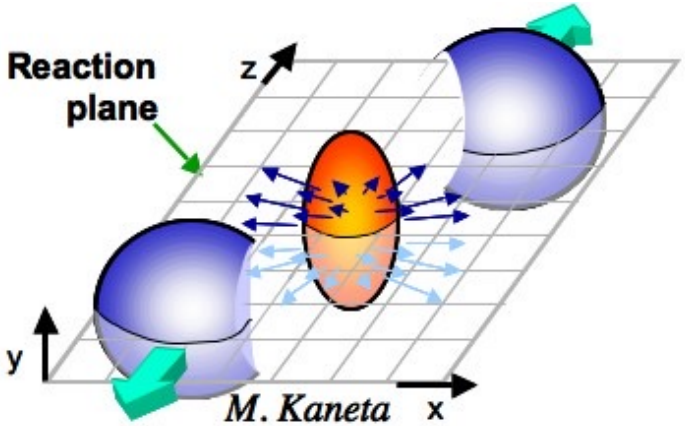
Departure from the Quark Number Scaling of v_2

STAR, Phys. Rev. Lett. 118, 212301 (2017)

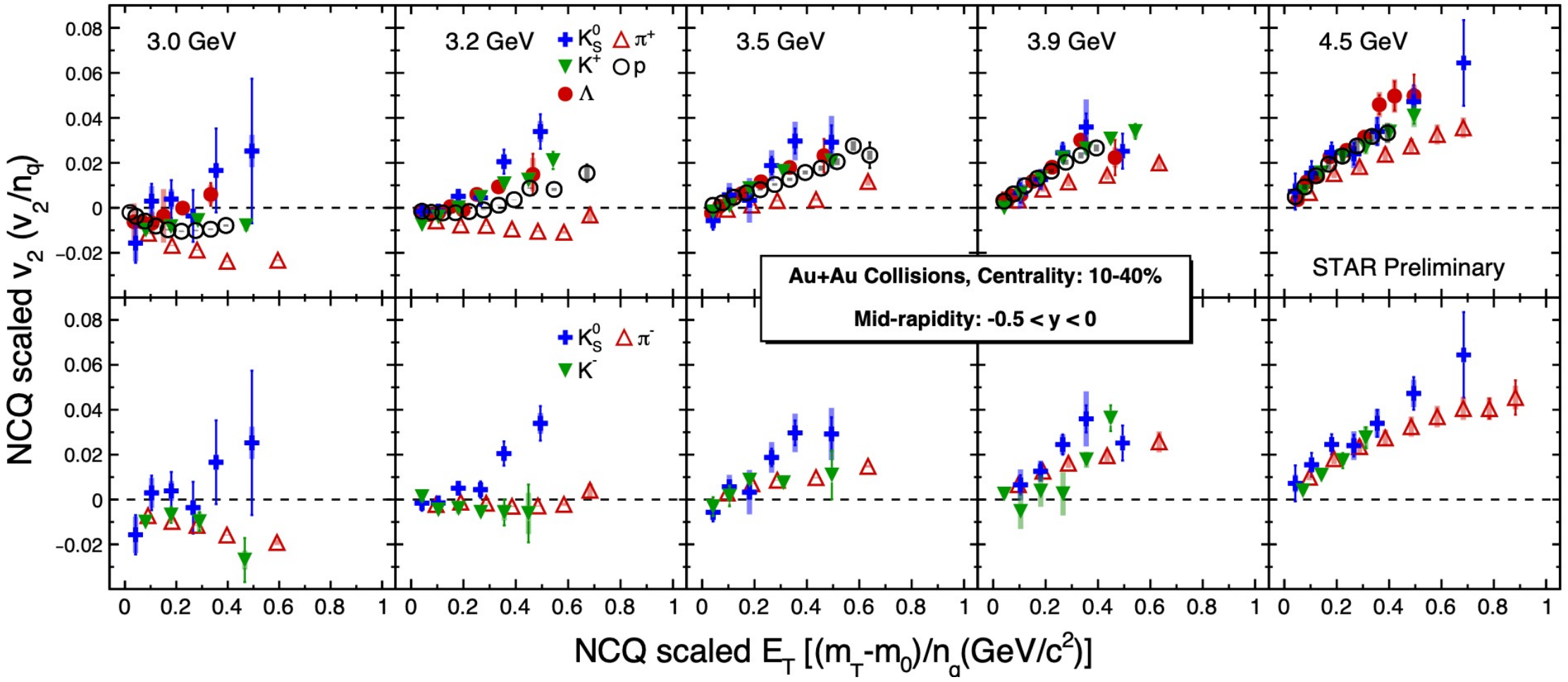


STAR, Phys. Lett. B 827, 137003 (2022)

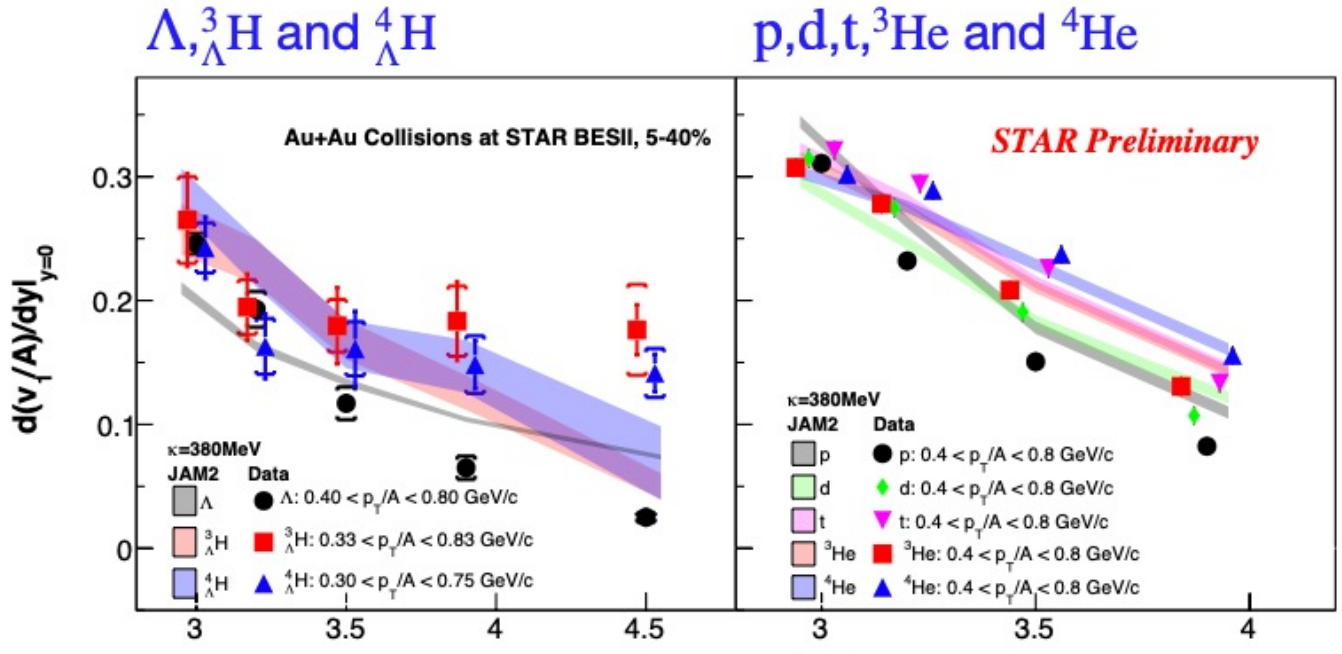


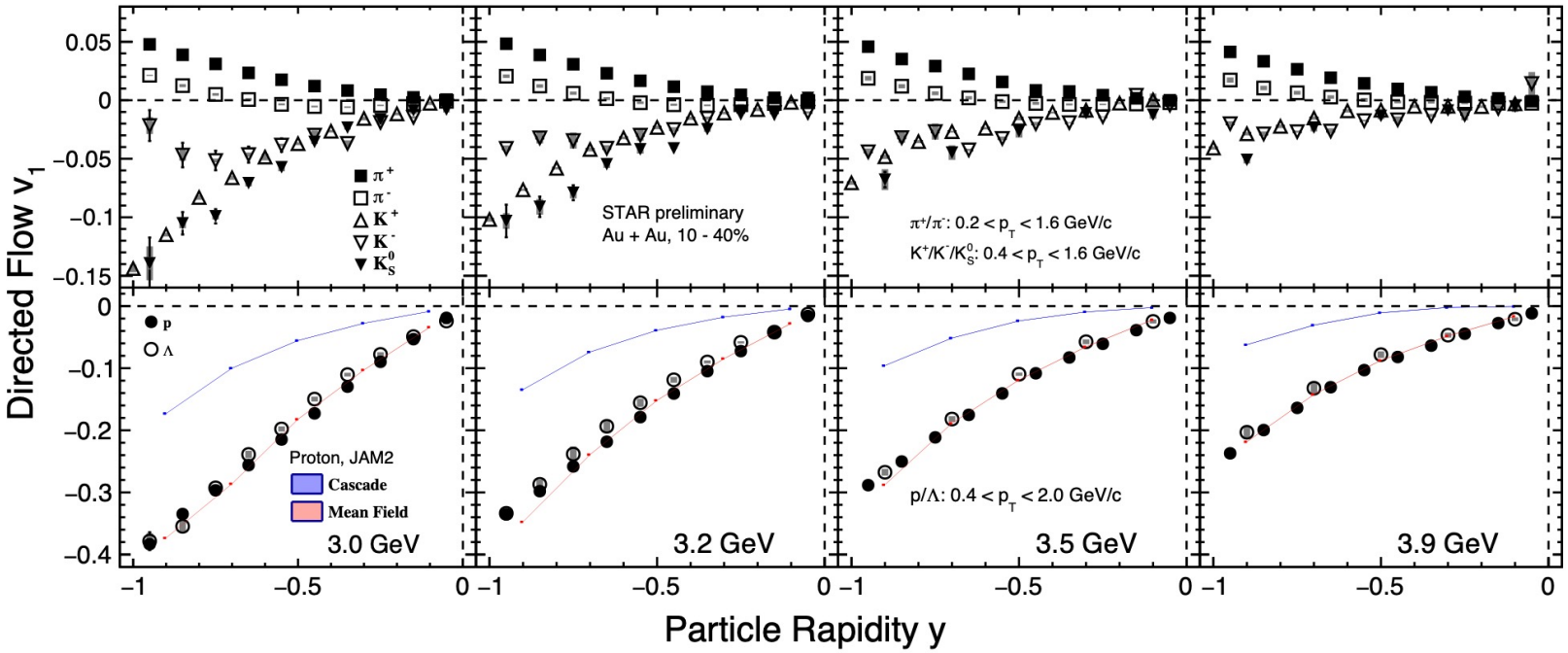


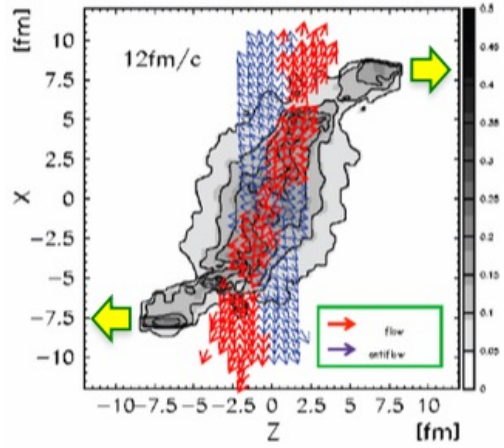
Quark Number Scaled v_2 at FXT beam energies (3.0 ~ 4.5 GeV)



v_1 vs rapidity and v_1 slope of hyper-Nuclei at FXT beam energies



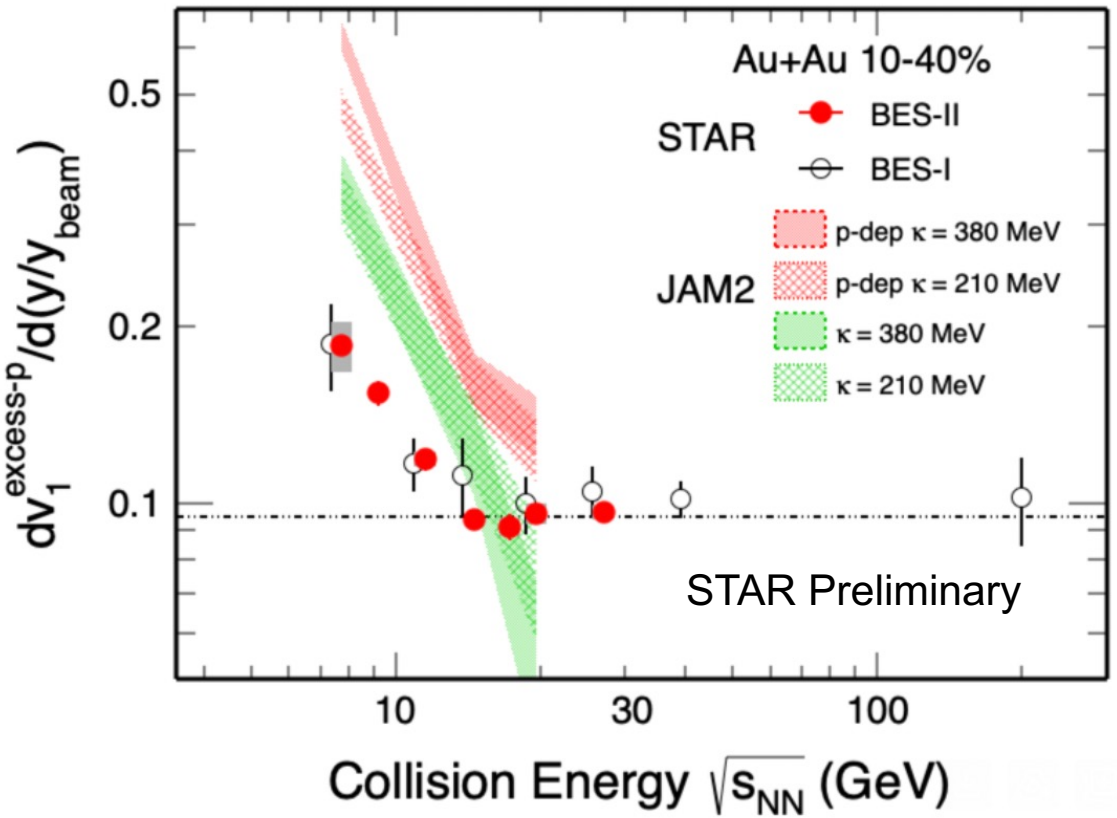




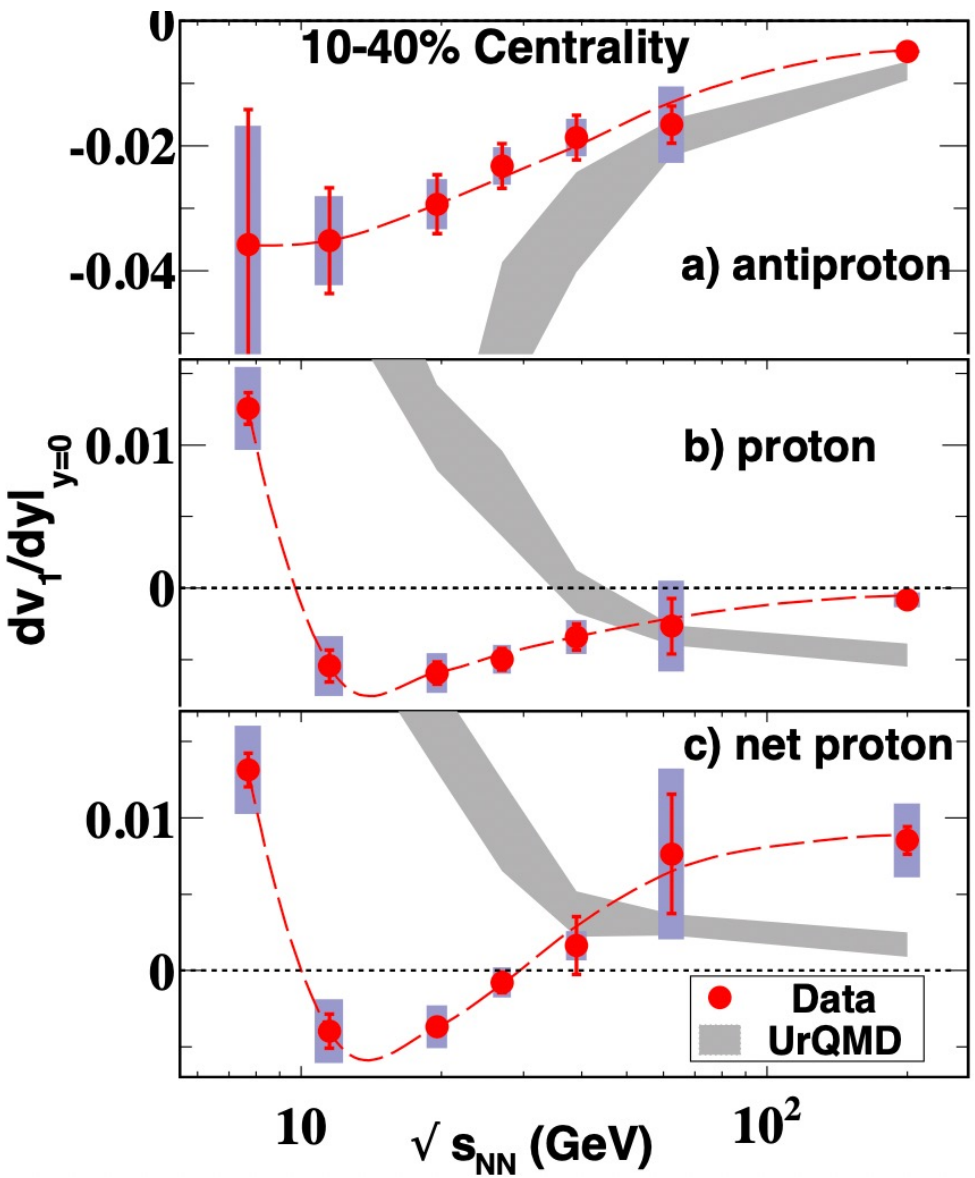
Excess-proton v_1 or Net-proton v_1

$$v_1^{excess-p} = \frac{v_1(p) - v_1(pbar)}{1-r} \qquad v_1^{net-p} = \frac{v_1(p) - r\, v_1(pbar)}{1-r}$$

$$r = \frac{N_{pbar}}{N_p}$$

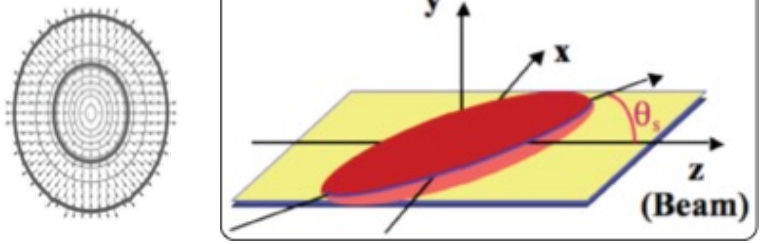


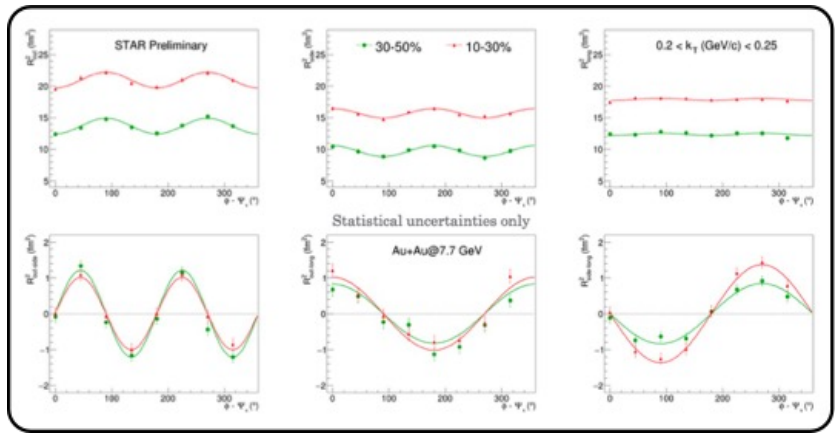
STAR, Phys. Rev. Lett. 112,162301 (2014)



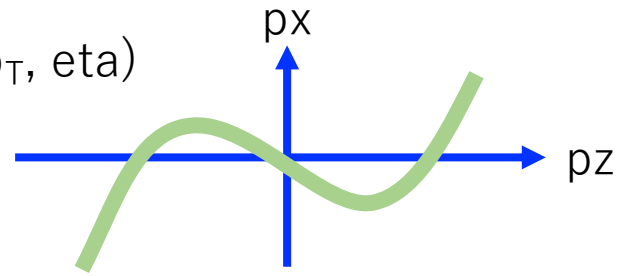
Correlations

- **geometry, expansion, interaction**
- **identical, non-identical correlation**
- **meson-meson, baryon-baryon**
- **global/local polarization**
- **vorticity and EM-field**

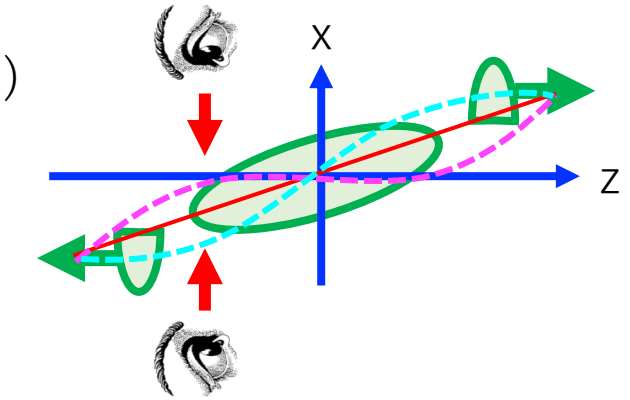


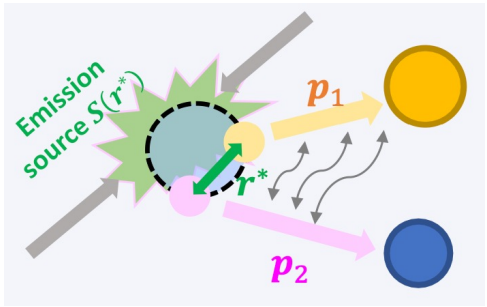


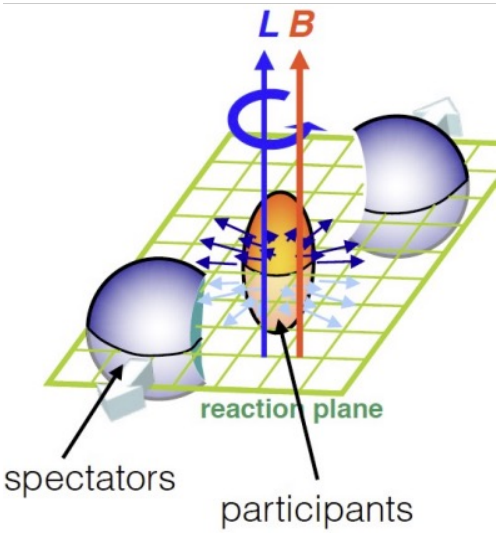
$v_n(p_T, eta)$

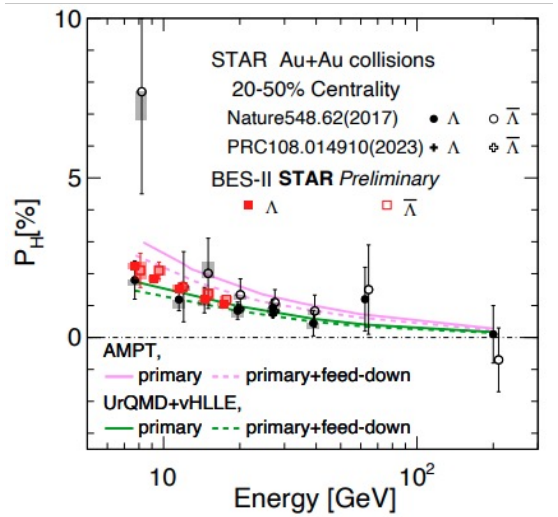


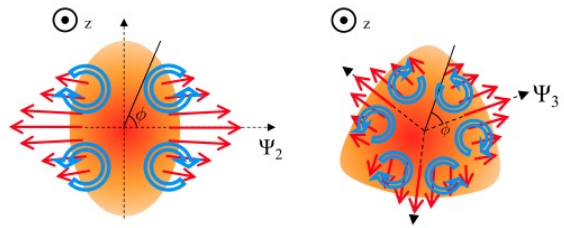
$\varepsilon_n(p_T, eta)$



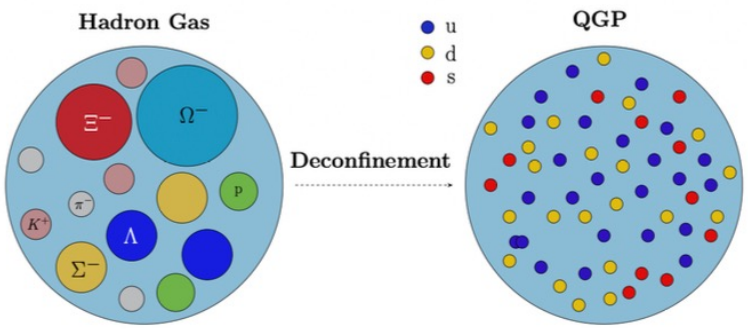






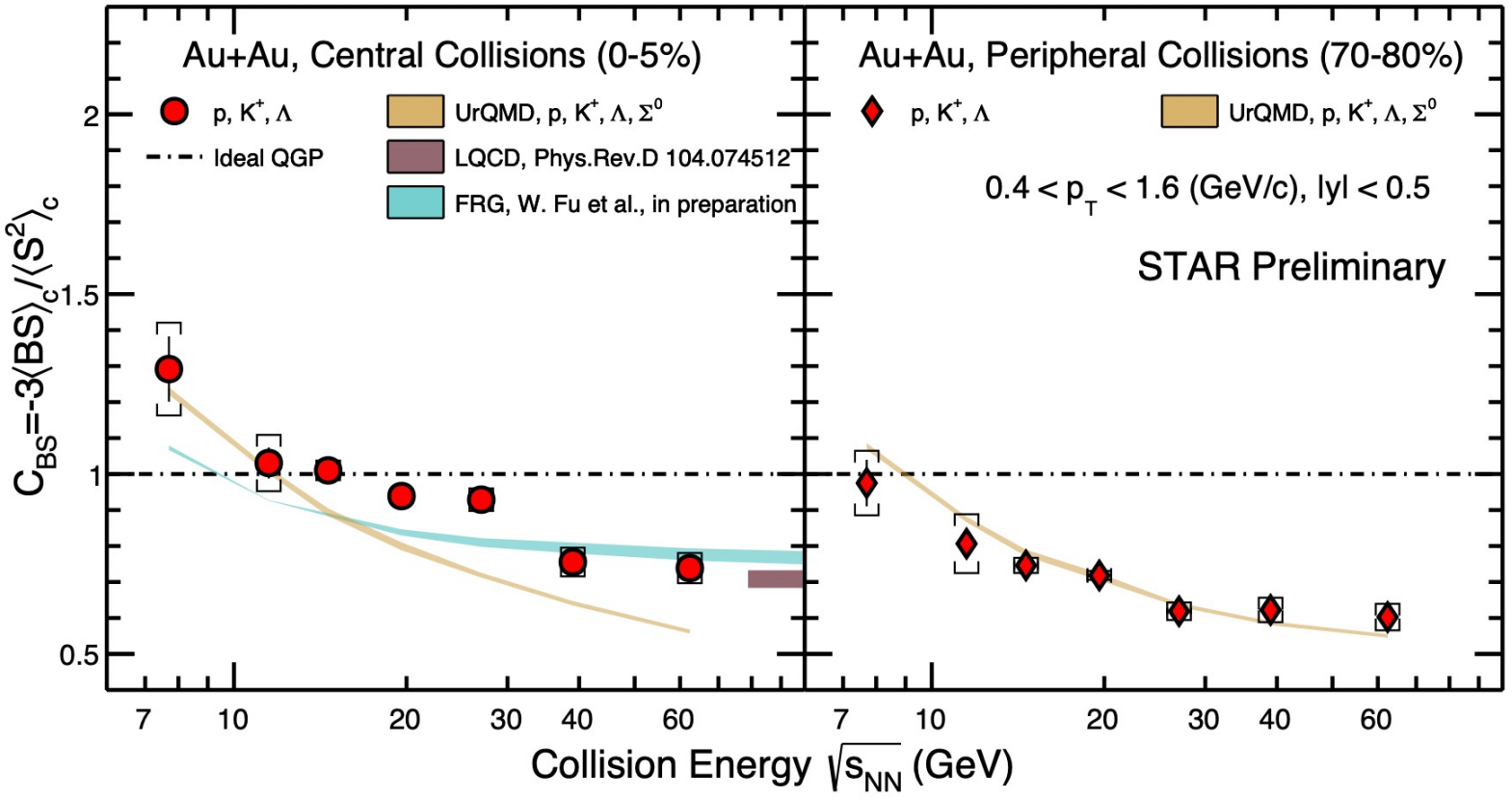


Baryon – Strangeness correlation



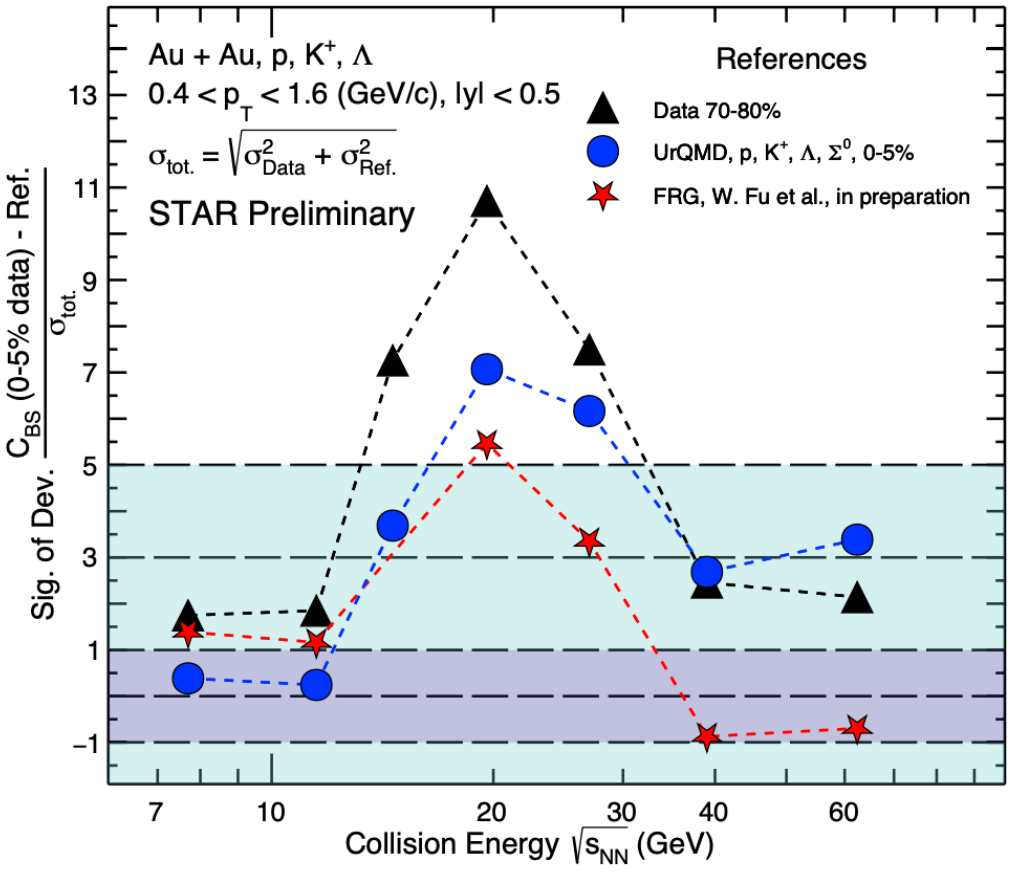
$$C_{BS} = -3\frac{\langle BS\rangle_c}{\langle S^2\rangle_c} = -3\frac{\langle BS\rangle - \langle B\rangle\langle S\rangle}{\langle S^2\rangle - \langle S\rangle^2}$$

B-S correlations

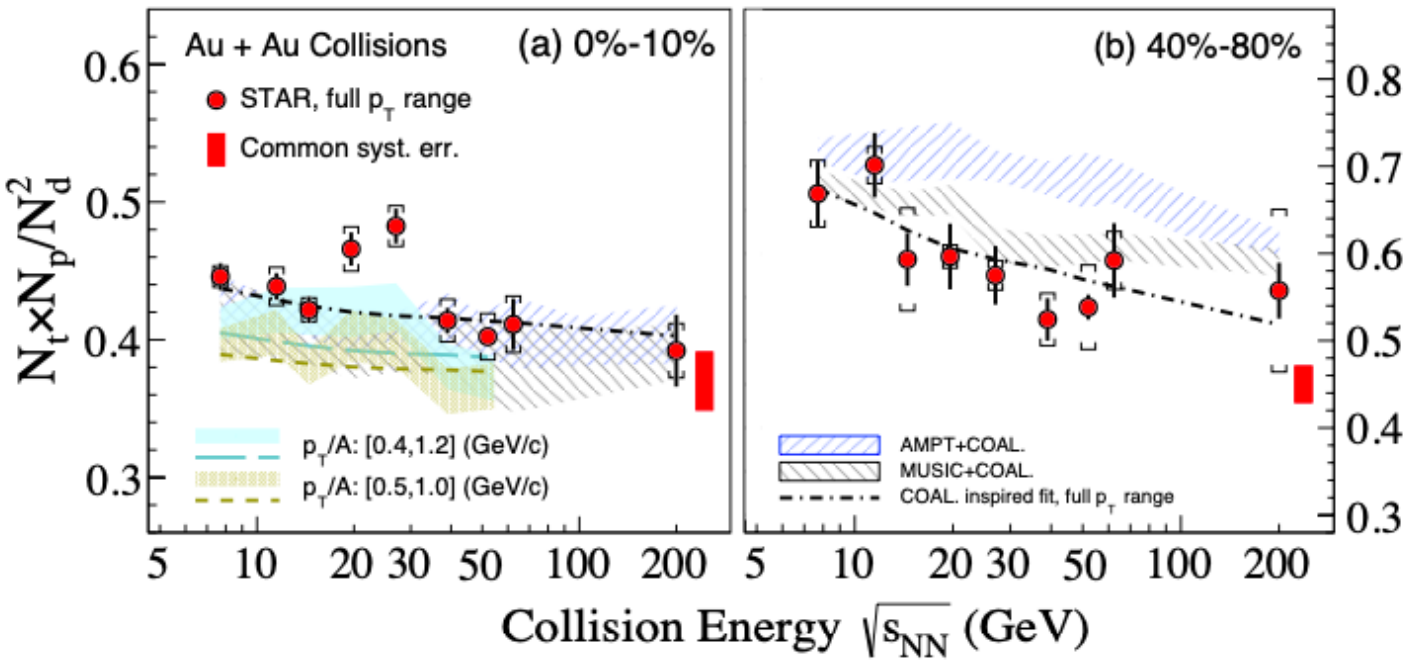


Baryon – Strangeness correlation and Neutron Density Fluctuation

$$\frac{N_t N_p}{(N_d)^2} = \frac{(pnn)(p)}{(pn)(pn)}$$

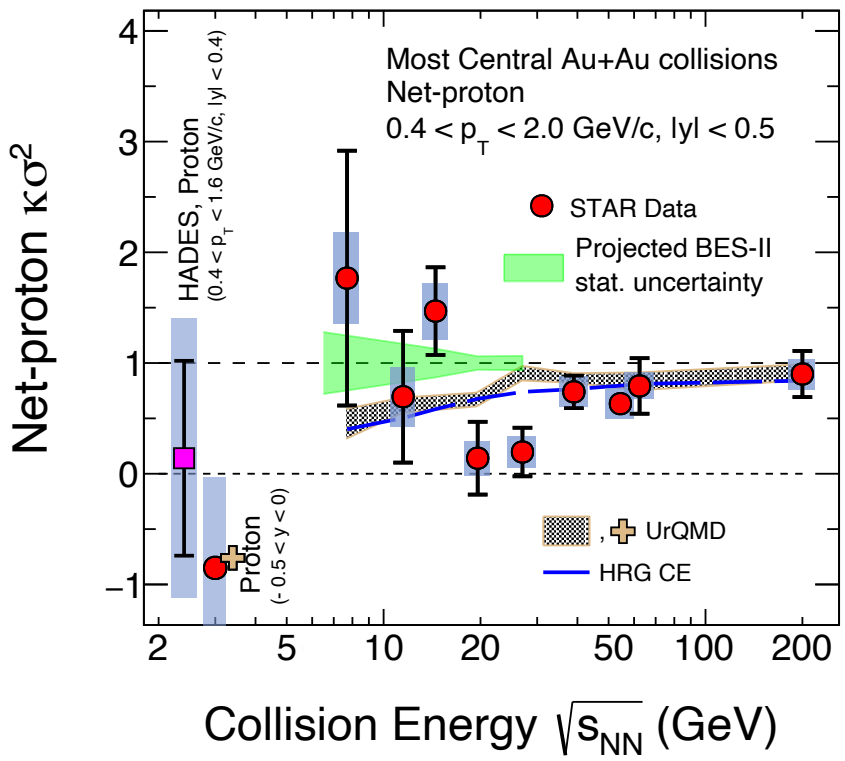


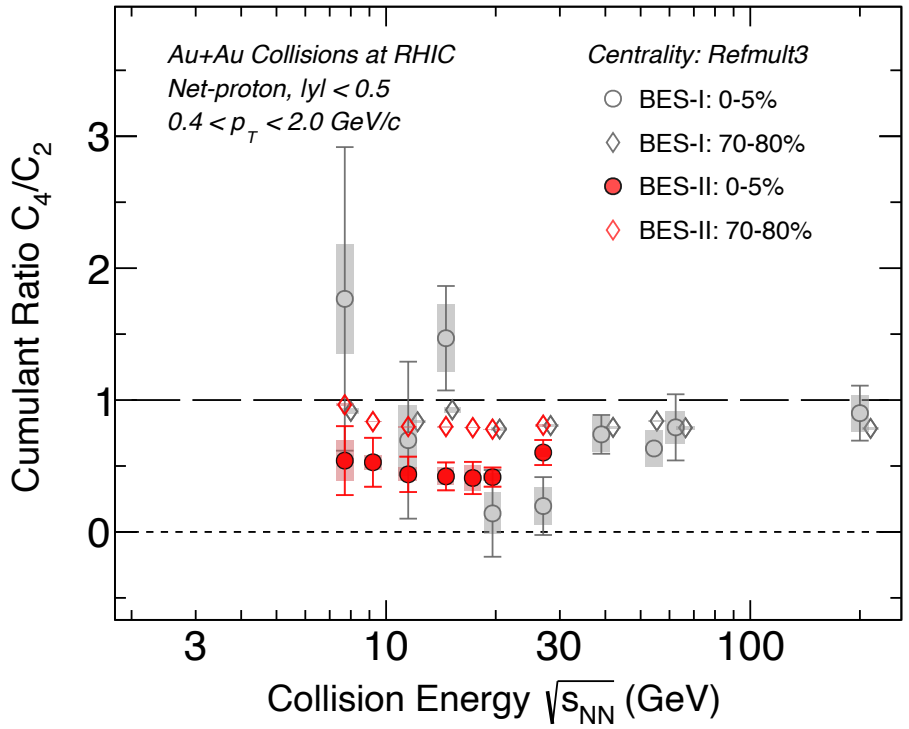
STAR, Phys. Rev. Lett. 130, 202301 (2023)

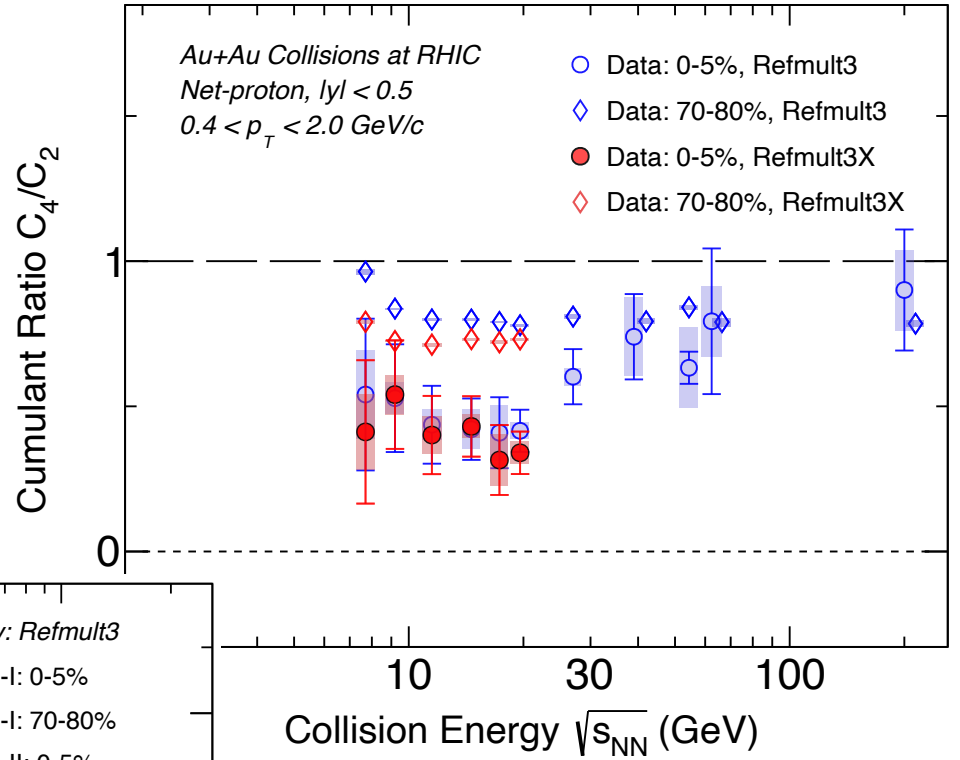


New Result on Net-proton Cumulant Ratio C_4/C_2

STAR, Phys. Rev. Lett. 127, 262301 (2021)
STAR, Phys. Rev. Lett. 128, 202302 (2022)



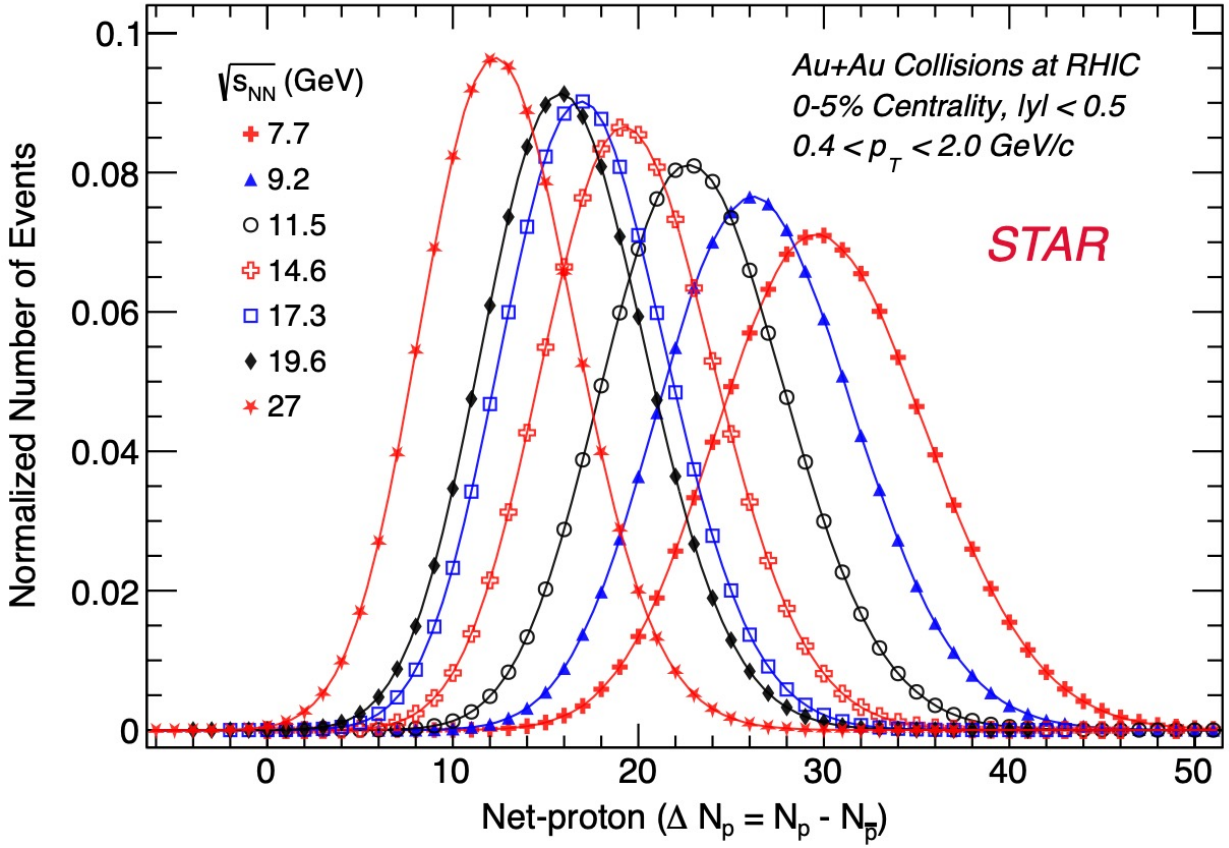


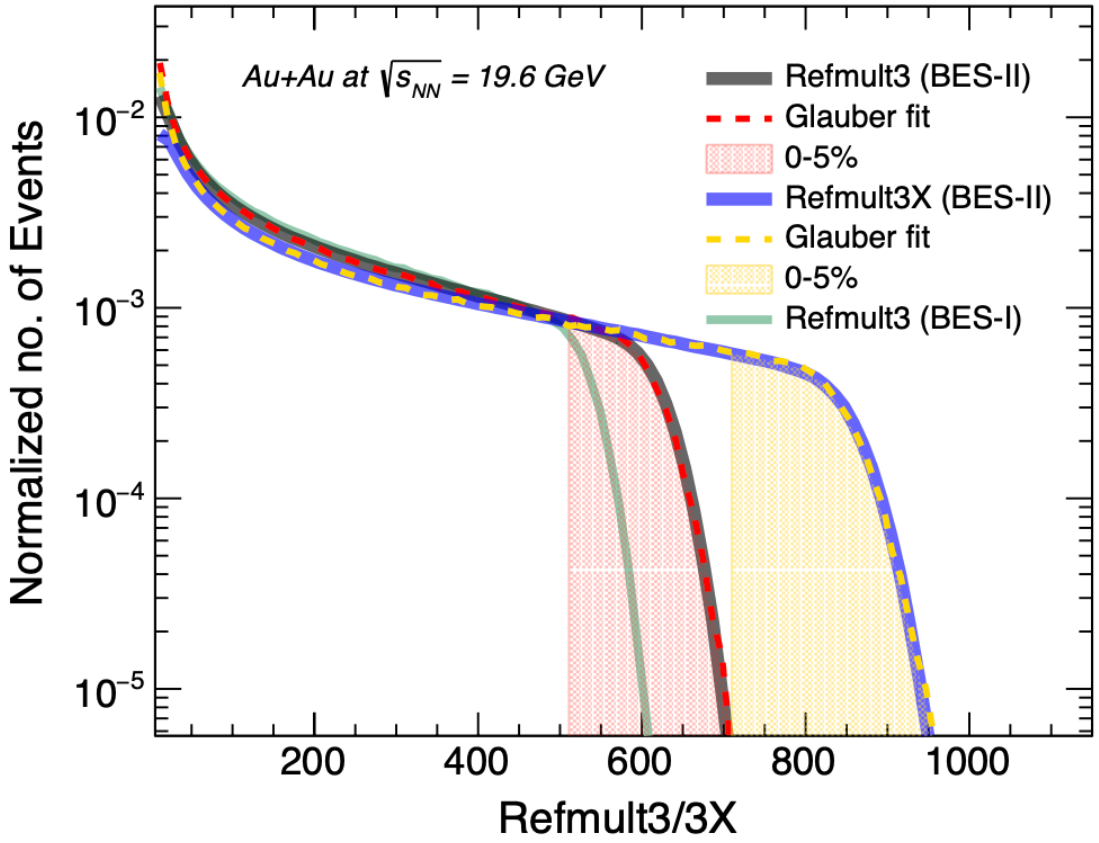


BES-I RefMult3
BES-II RefMult3
BES-II RefMult3X

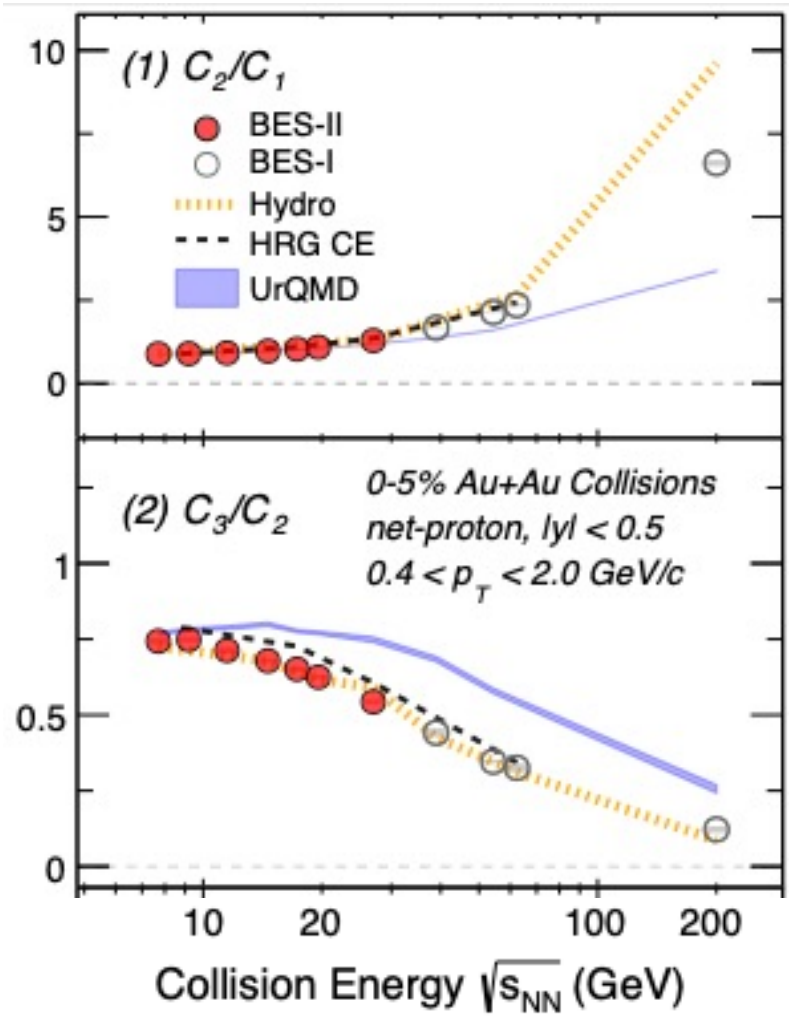
Net-proton distribution and Centrality determination

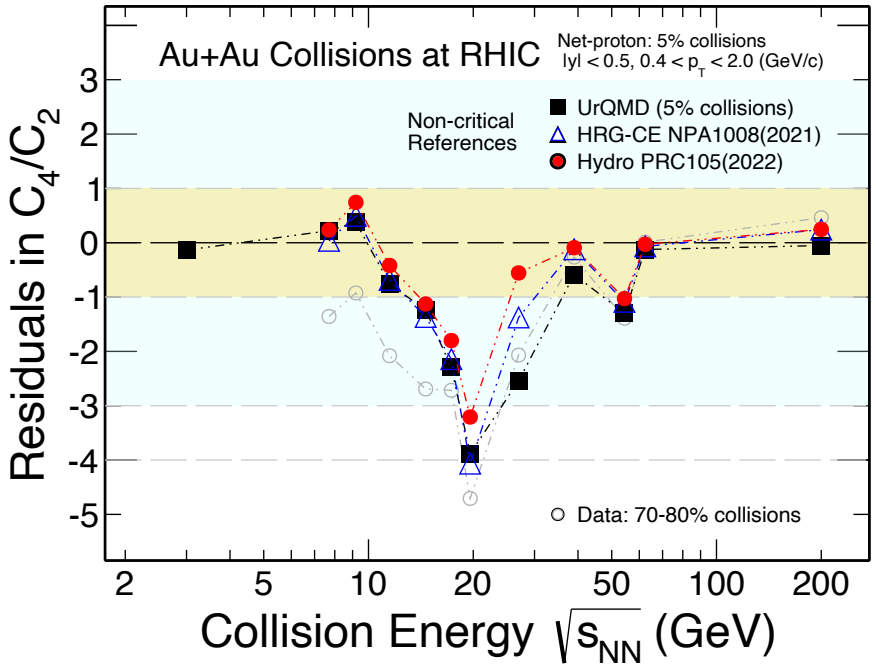
BES-I RefMult3
BES-II RefMult3
BES-II RefMult3X

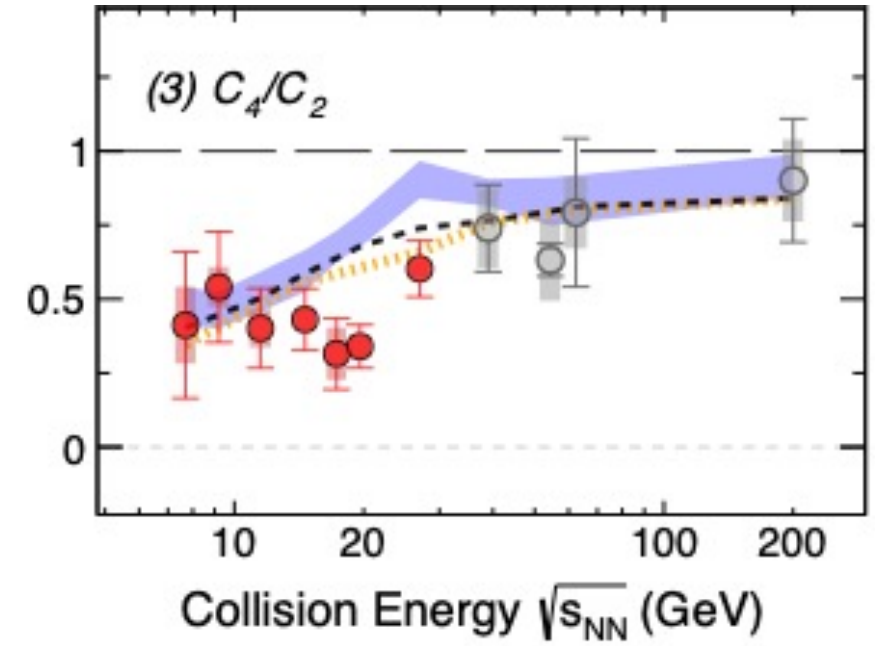


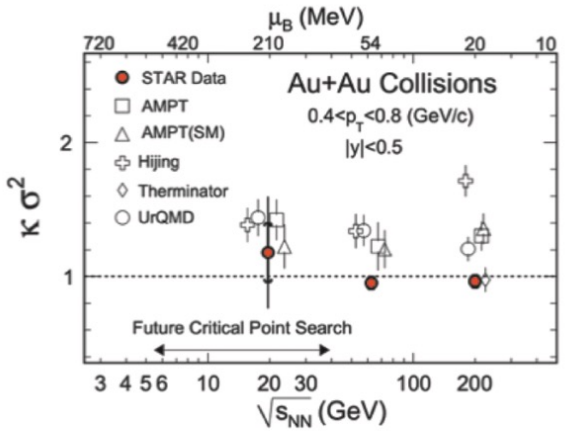


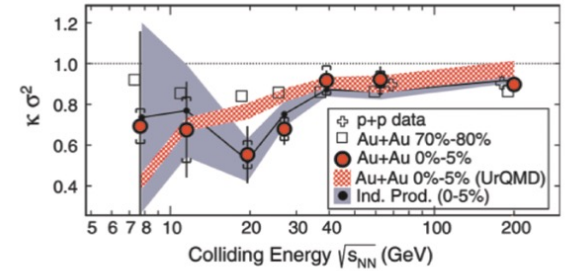
Dip remains ?

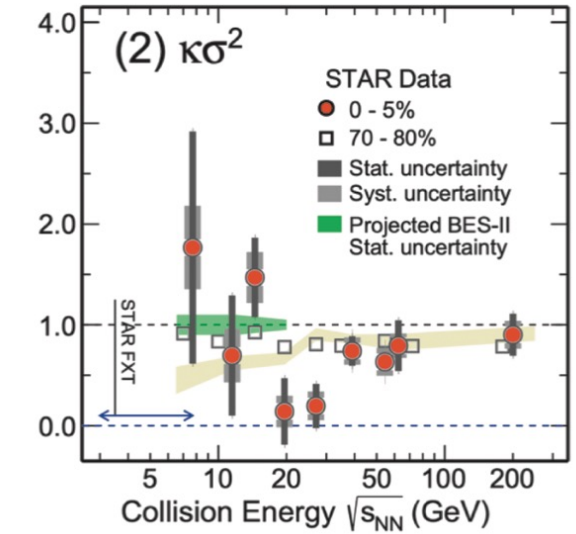

(1) C_2/C_1
BES-II
BES-I
Hydro
HRG CE
UrQMD
(2) C_3/C_2
0-5% Au+Au Collisions
net-proton, |y| < 0.5
0.4 < p_T < 2.0 GeV/c
Collision Energy $\sqrt{s_{NN}}$ (GeV)


Au+Au Collisions at RHIC
Net-proton: 5% collisions
|y| < 0.5, 0.4 < p_T < 2.0 (GeV/c)
Non-critical References
UrQMD (5% collisions)
HRG-CE NPA1008(2021)
Hydro PRC105(2022)
Data: 70-80% collisions
Residuals in C_4/C_2
Collision Energy $\sqrt{s_{NN}}$ (GeV)

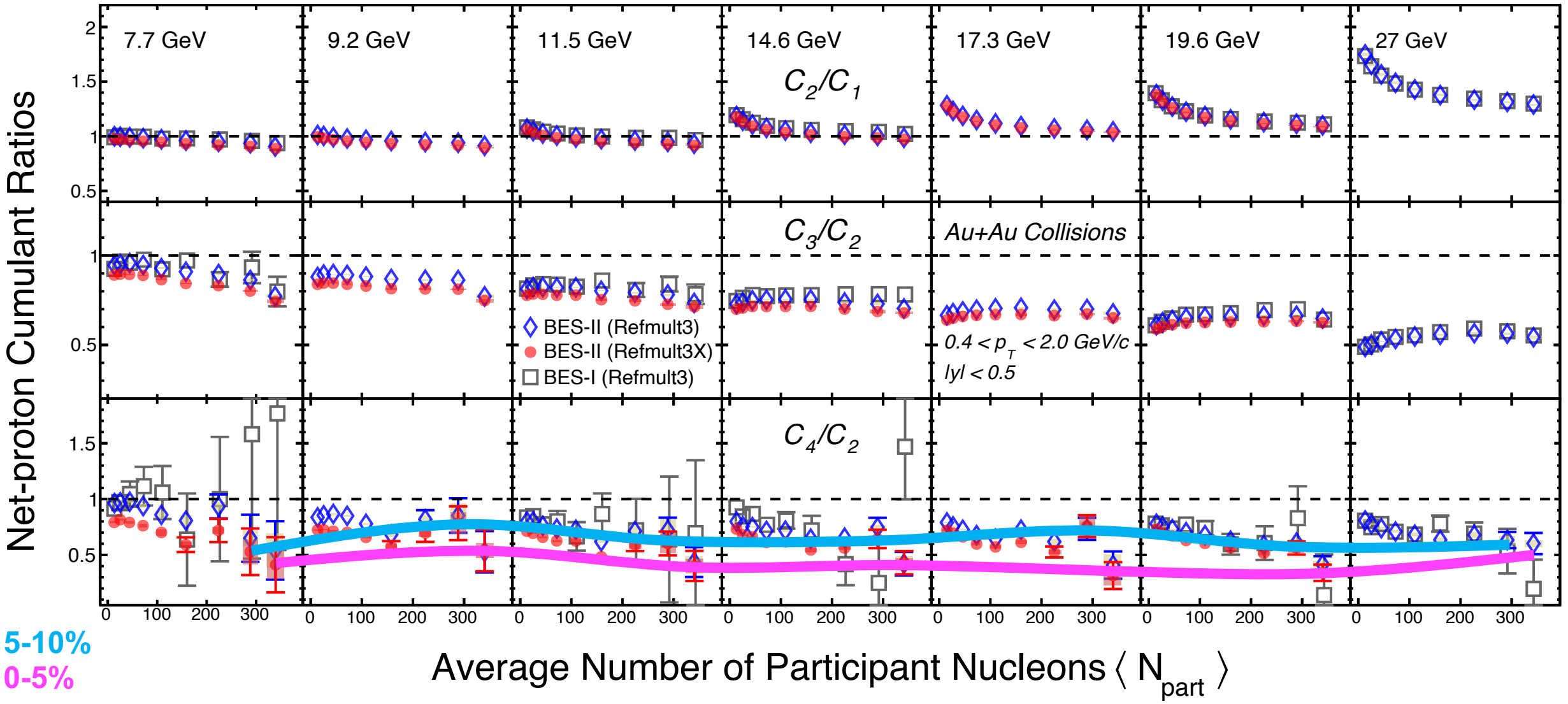

(3) C_4/C_2
Collision Energy $\sqrt{s_{NN}}$ (GeV)


μ_B (MeV)
STAR Data
AMPT
AMPT(SM)
Hijing
Therminator
UrQMD
Au+Au Collisions
0.4<p_T<0.8 (GeV/c)
|y|<0.5
Future Critical Point Search
$\kappa\sigma^2$
$\sqrt{s_{NN}}$ (GeV)


p+p data
Au+Au 70%-80%
Au+Au 0%-5%
Au+Au 0%-5% (UrQMD)
Ind. Prod. (0-5%)
$\kappa\sigma^2$
Colliding Energy $\sqrt{s_{NN}}$ (GeV)

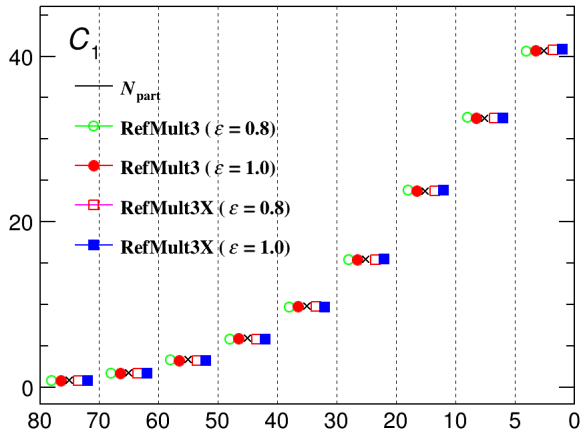

(2) $\kappa\sigma^2$
STAR Data
0 - 5%
70 - 80%
Stat. uncertainty
Syst. uncertainty
Projected BES-II Stat. uncertainty
STAR FXT
Collision Energy $\sqrt{s_{NN}}$ (GeV)

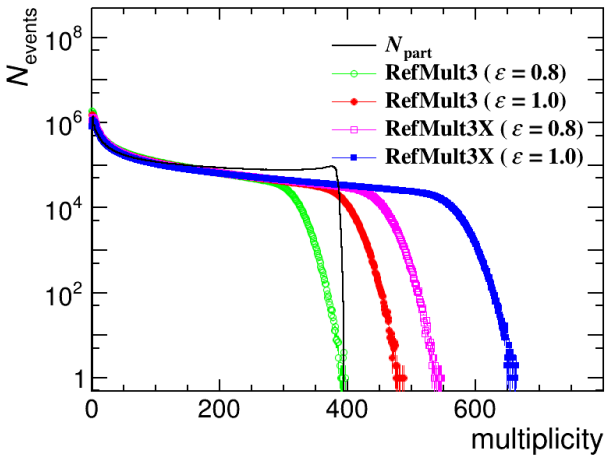
Net-proton Cumulant Ratio as a function of Centrality

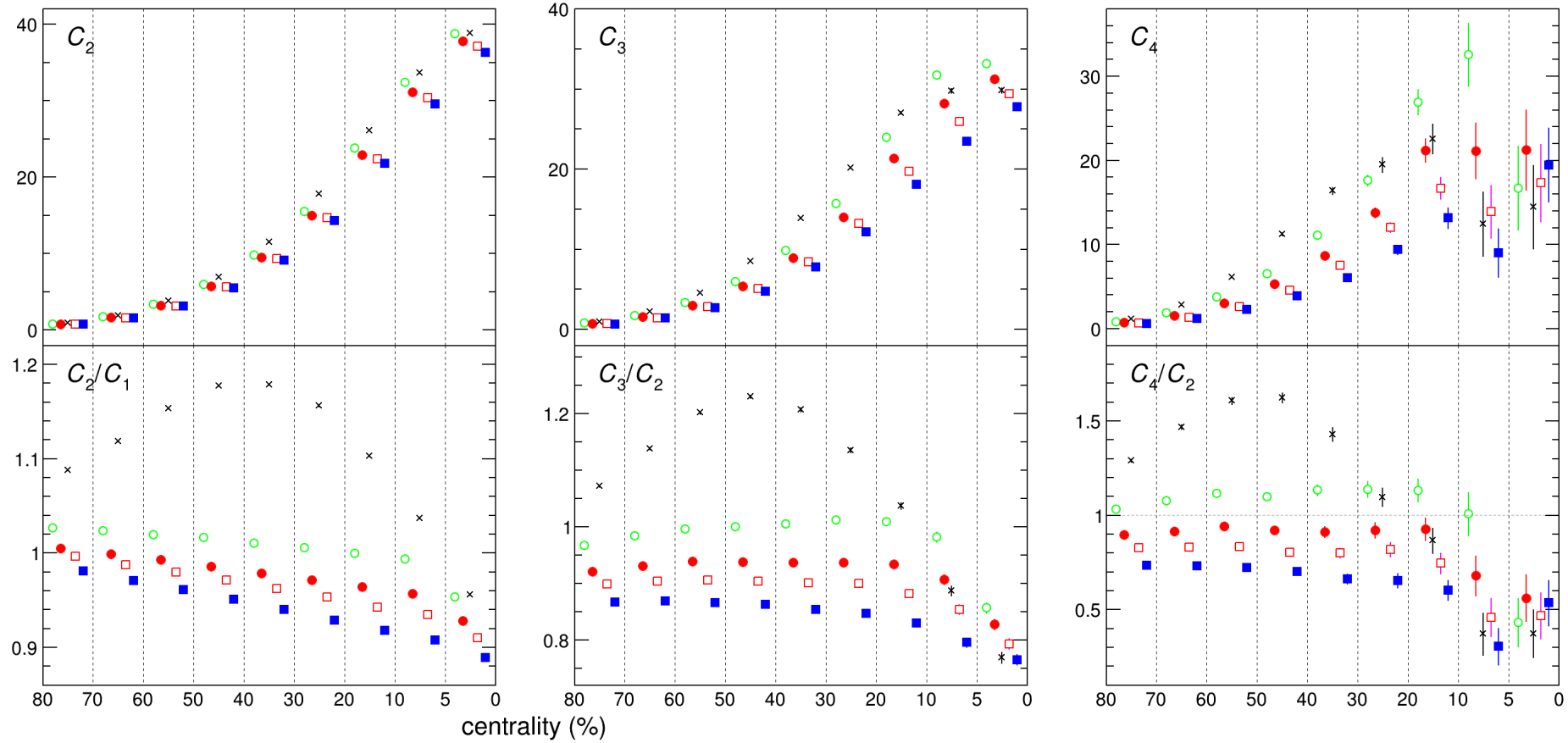


UrQMD simulation study : Au+Au at 7.7 GeV

Fan Si,
grad. student
USTC/Tsukuba







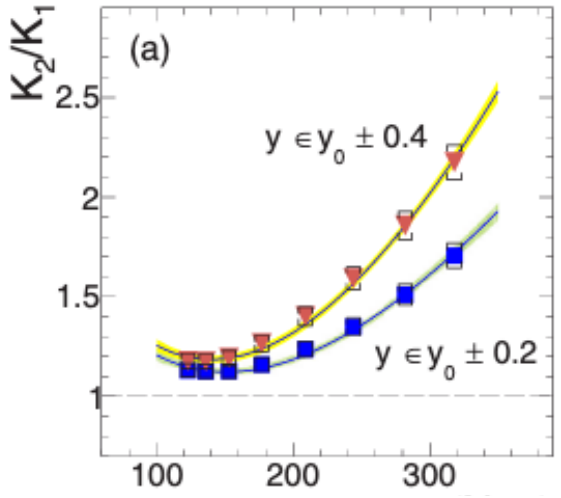
Centrality resolution from worst to best: ○ < ● < □ < ■

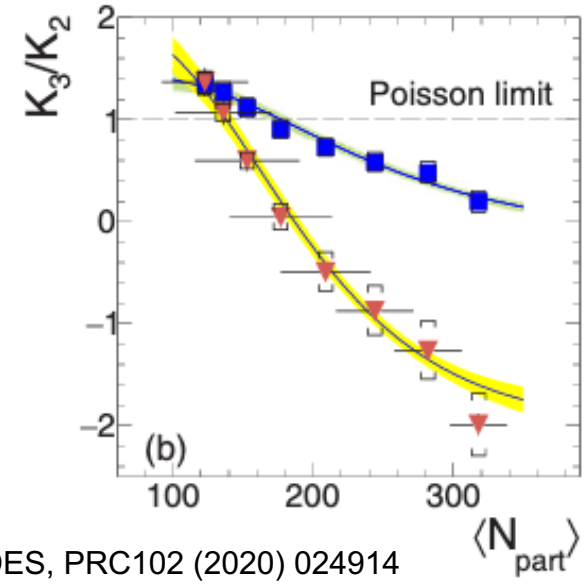
clear centrality resolution ordering: better resolution => lower cumulants/ratios

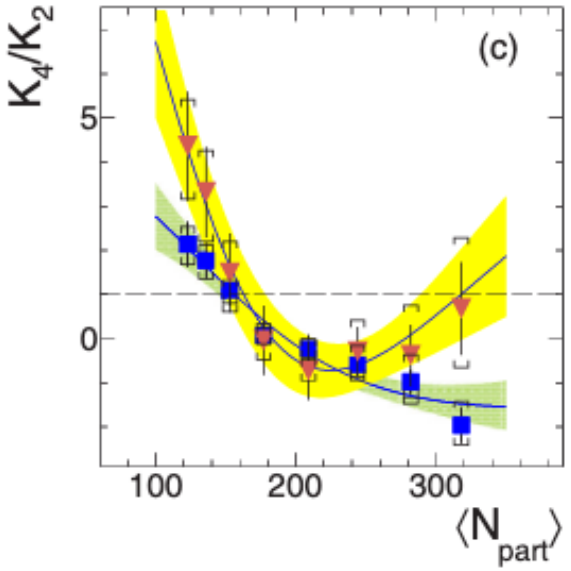
HADES at 2.4 GeV Au+Au collisions & STAR at 3.0 GeV

Au+Au 2.4 GeV HADES

with spectator based centrality
with volume correction



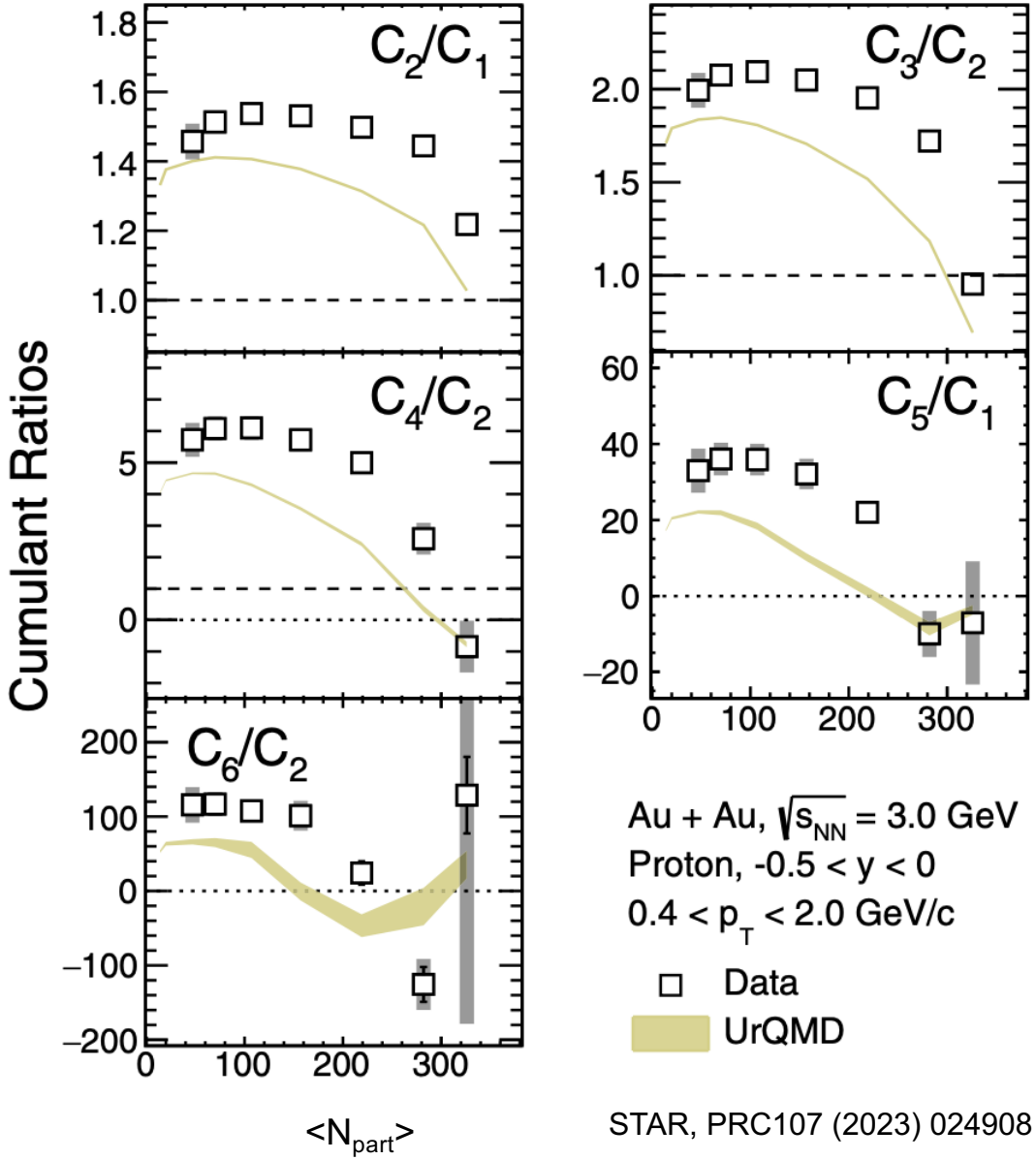




HADES, PRC102 (2020) 024914

Au+Au 3 GeV STAR CBWC only

with participant based centrality
without volume correction

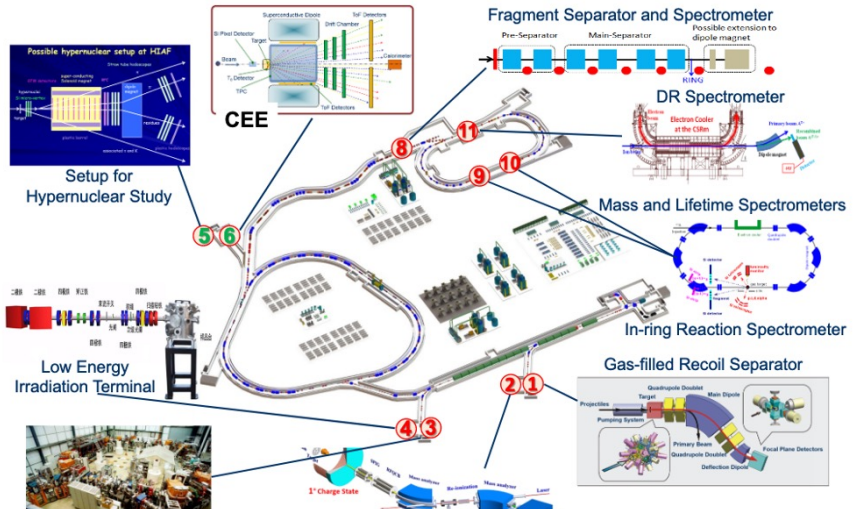


STAR, PRC107 (2023) 024908

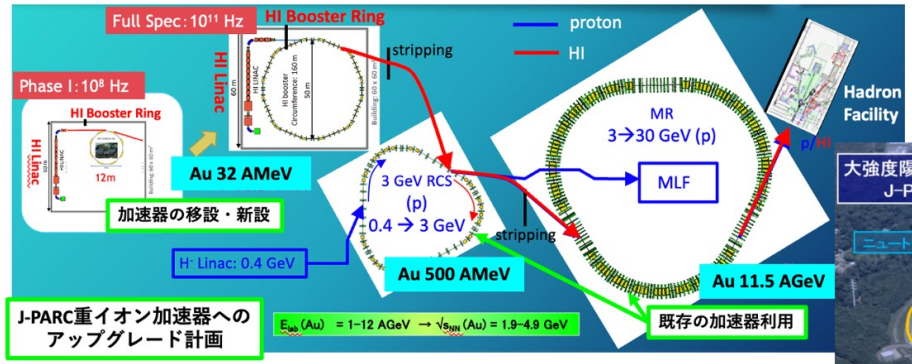
HIAF / HIRFL-CSR in China (2025~)

High Intensity heavy ion Accelerator Facility（HIAF）





J-PARC Heavy-Ion project

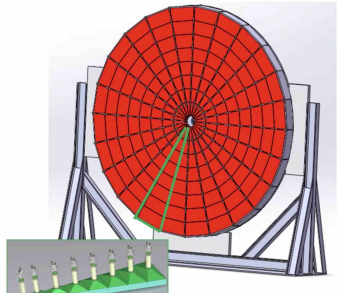




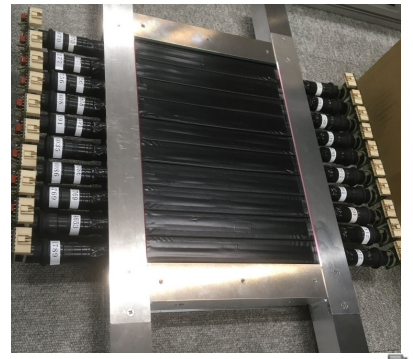
概述 – ZDC探测器介绍

- ZDC探测器安装在CEE的磁铁下游方向，为轮盘结构，前表面距磁铁中心2.95m，束流垂直从轮盘内径里穿过
- ZDC探测器采用“塑闪+光导+真空光电倍增管(PMT)”设计方案
- ZDC探测器测量前向区带电粒子在ZDC里的沉积能量和击中位置信息，确定核核碰撞中事件碰撞中心度和事件平面，为CEE以后的物理分析提供基本测量量

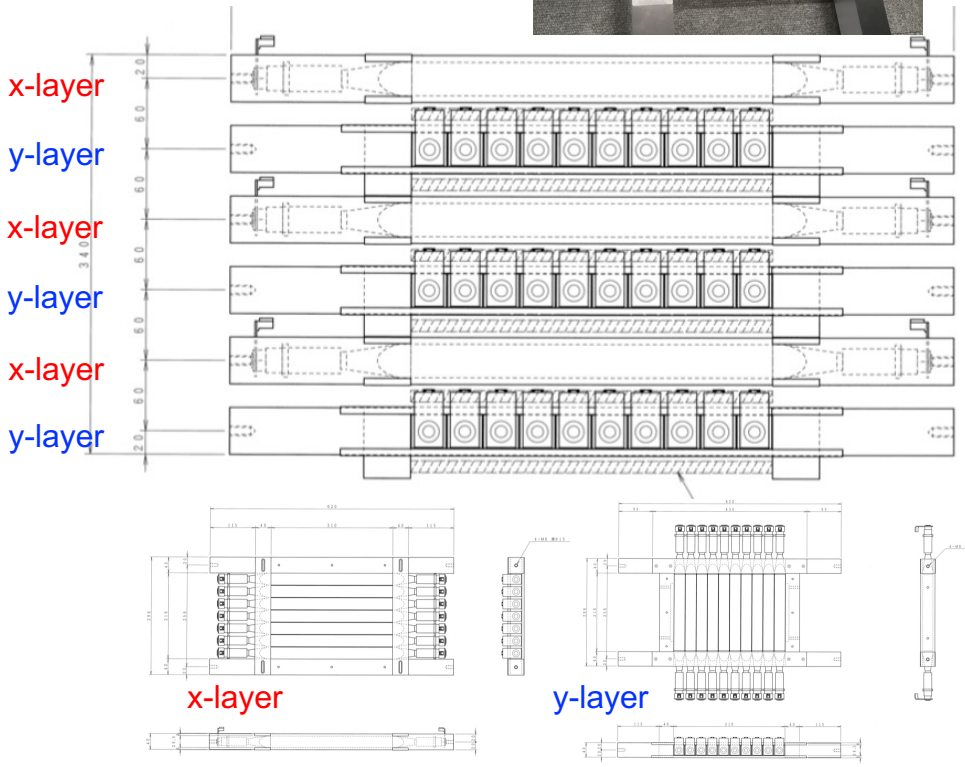
ZDC探测器的几何参数	
距磁铁中心距离	2.95 m
ZDC轮盘内径	5 cm
ZDC轮盘外径	100 cm
探测模块数	192 (24扇区 × 8模块/扇区)
电子学道数(双打拿极输出)	384
ZDC主要技术指标	
探测效率	> 95%
通道占有度	< 15%
有效面积	> 1m²



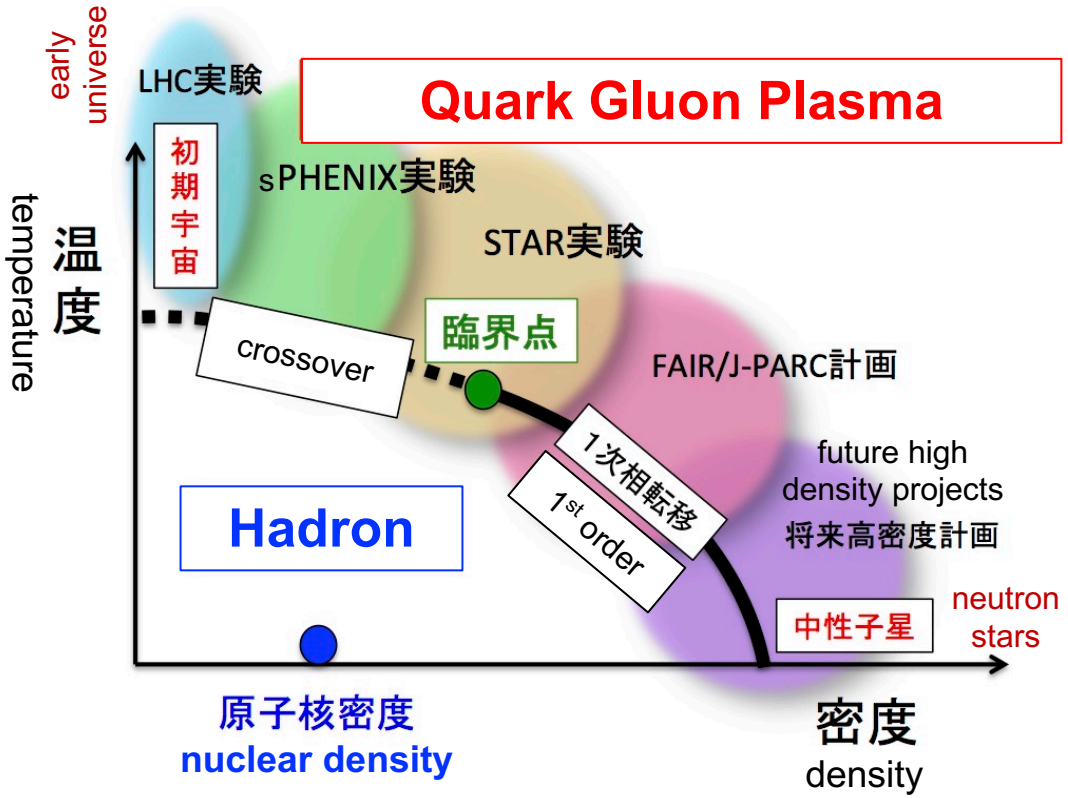
ZDC for centrality and event plane at CEE experiment

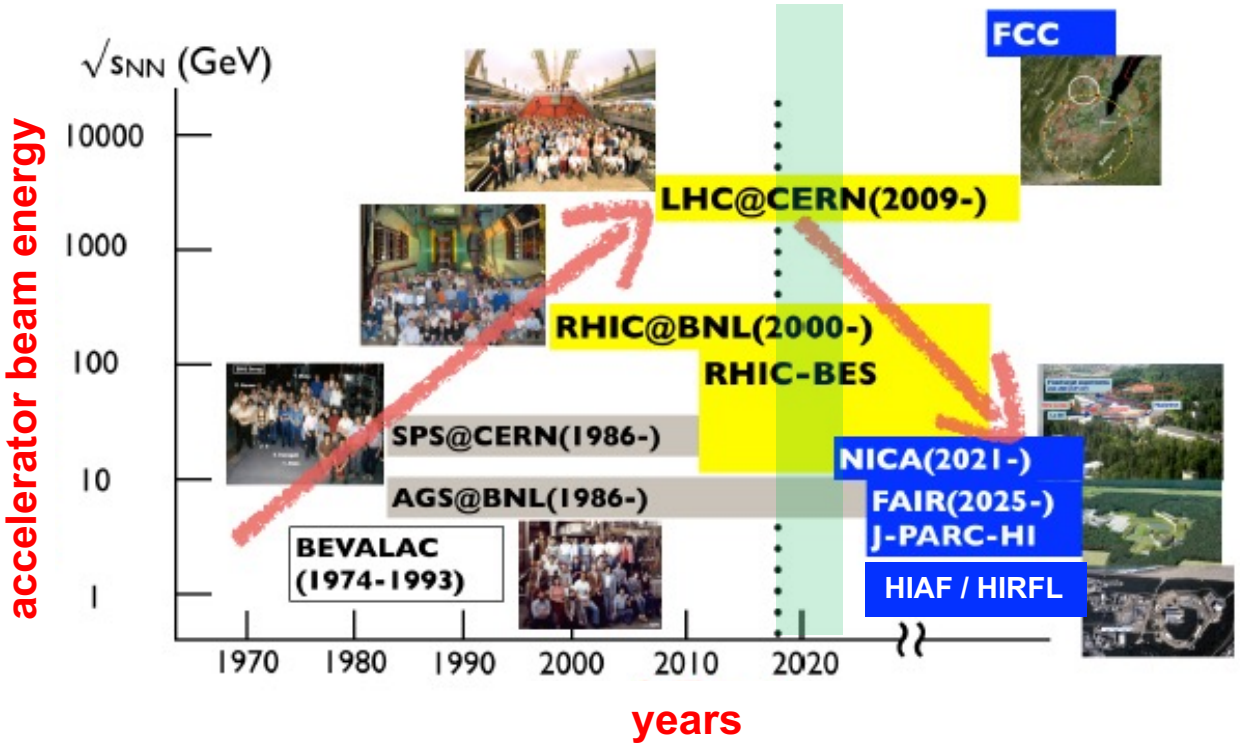


Neutron detector FAIR-CBM and J-PARC Heavy-Ion



History of Heavy-Ion Facilities and My Interests …

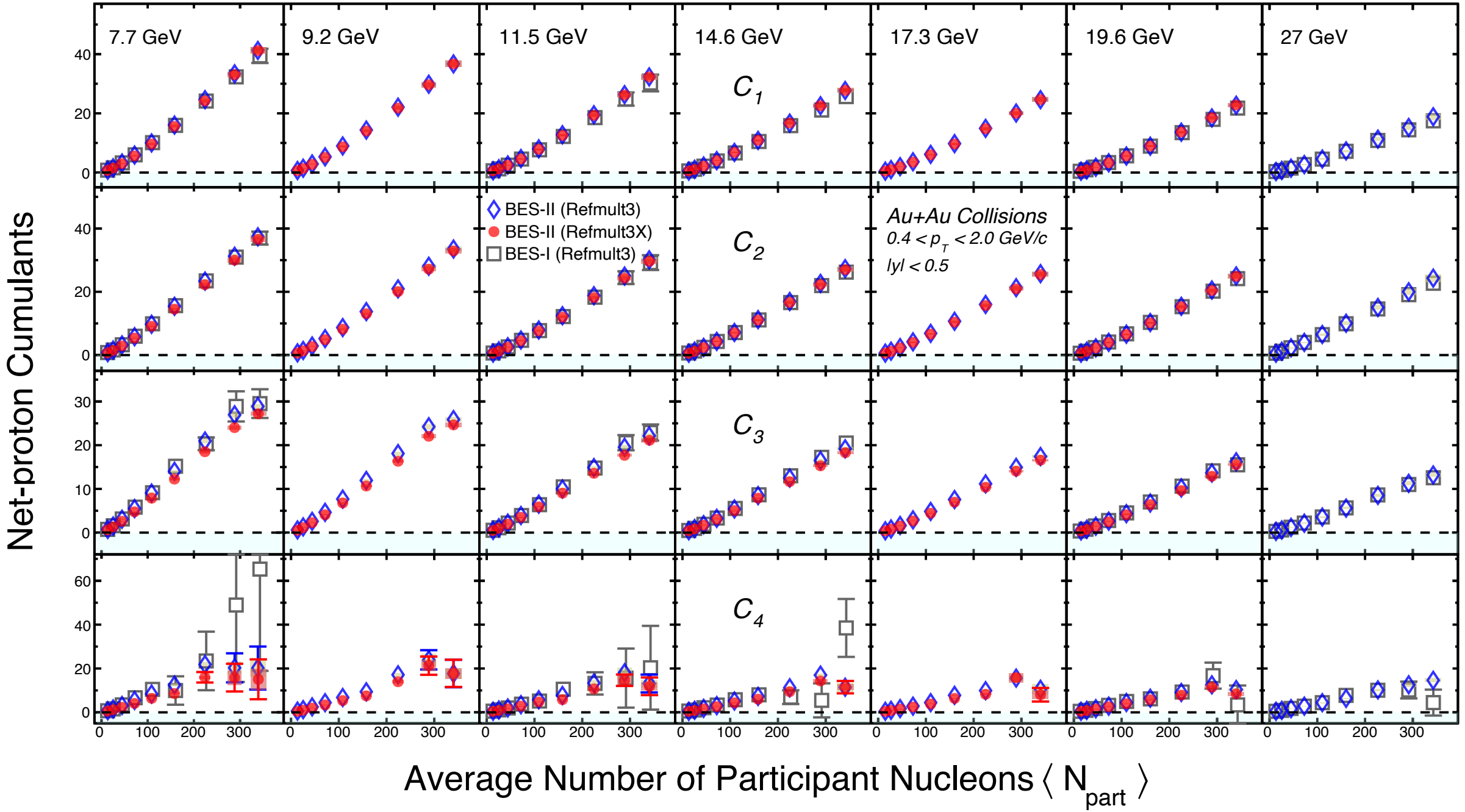




- **Beam Energy Scan at High Baryon Density**
- **Flow, correlation and fluctuation studies**

Thank you. 謝謝

Back-up slides


7.7 GeV
9.2 GeV
11.5 GeV
14.6 GeV
17.3 GeV
19.6 GeV
27 GeV
C_1
C_2
C_3
C_4
BES-II (Refmult3)
BES-II (Refmult3X)
BES-I (Refmult3)
Au+Au Collisions
$0.4 < p_T < 2.0$ GeV/c
$|y| < 0.5$
Net-proton Cumulants
Average Number of Participant Nucleons $\langle N_{part} \rangle$

back-up slide

