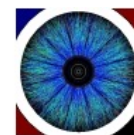
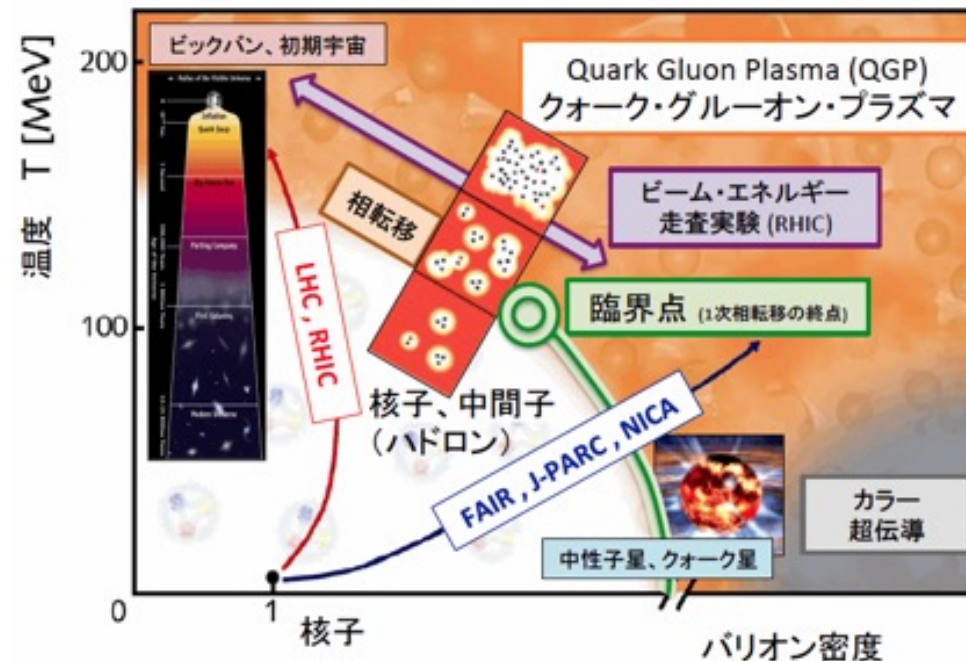


ビームエネルギー走査実験から 相転移・臨界点の探索へ

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

- ビームエネルギー走査実験
- フロー測定
- ゆらぎ測定
- まとめと将来計画



The STAR experiment

at the Relativistic Heavy Ion Collider, Brookhaven National Laboratory

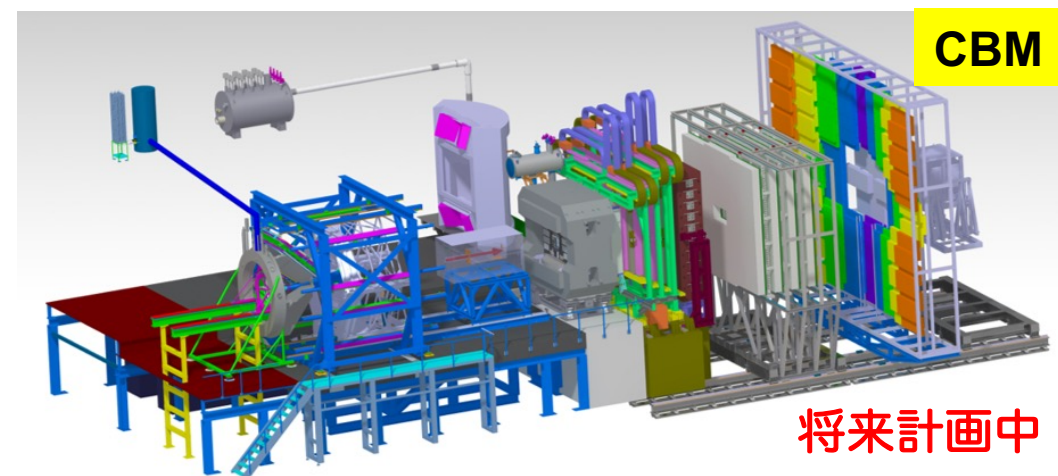
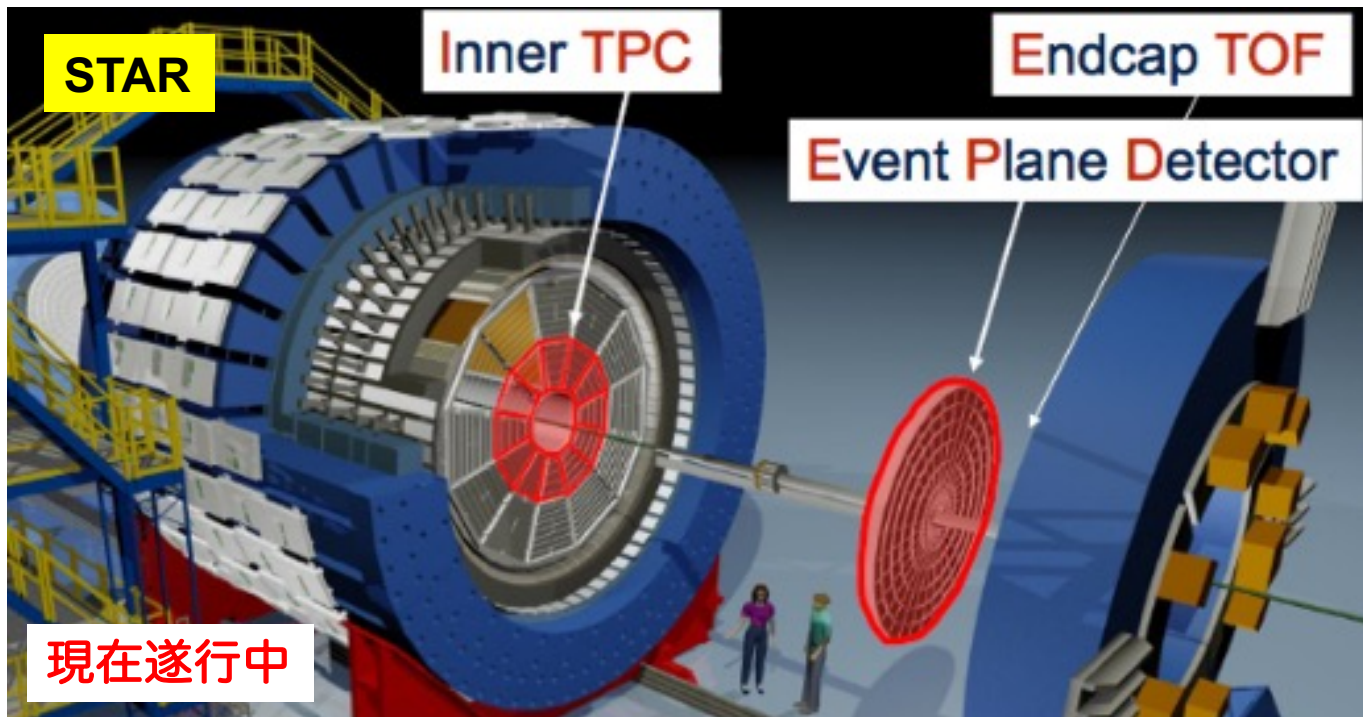
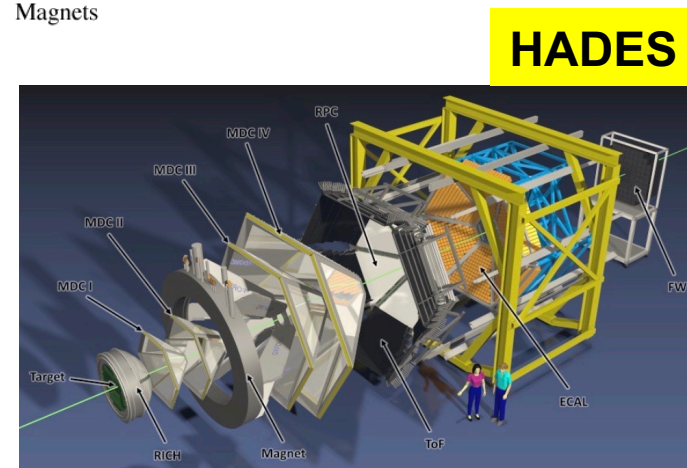
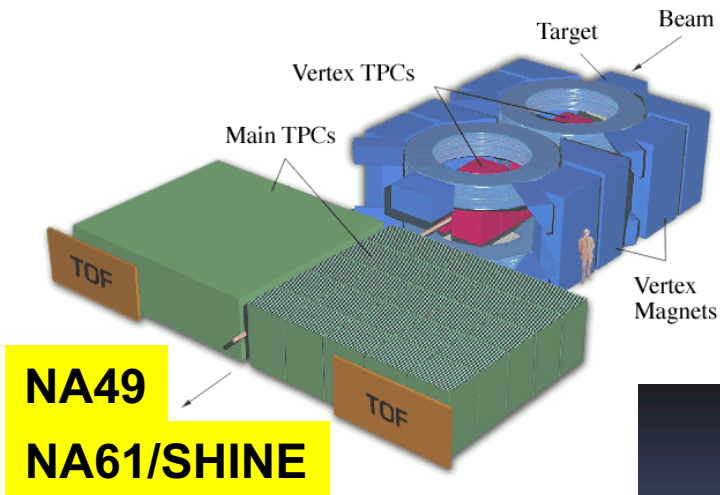
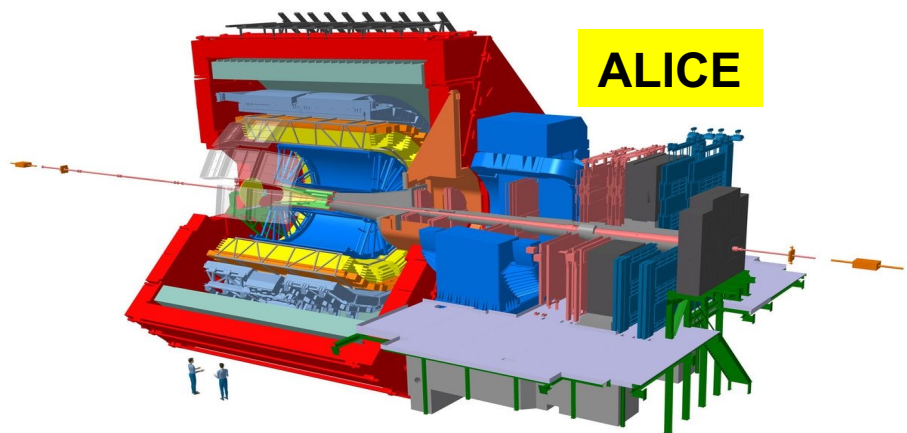


筑波大学
University of Tsukuba



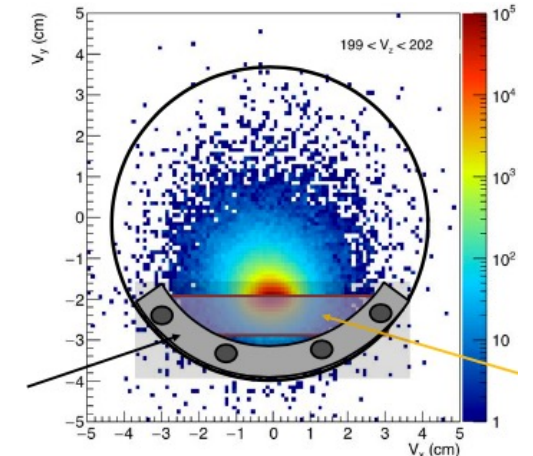
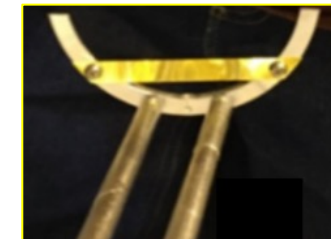
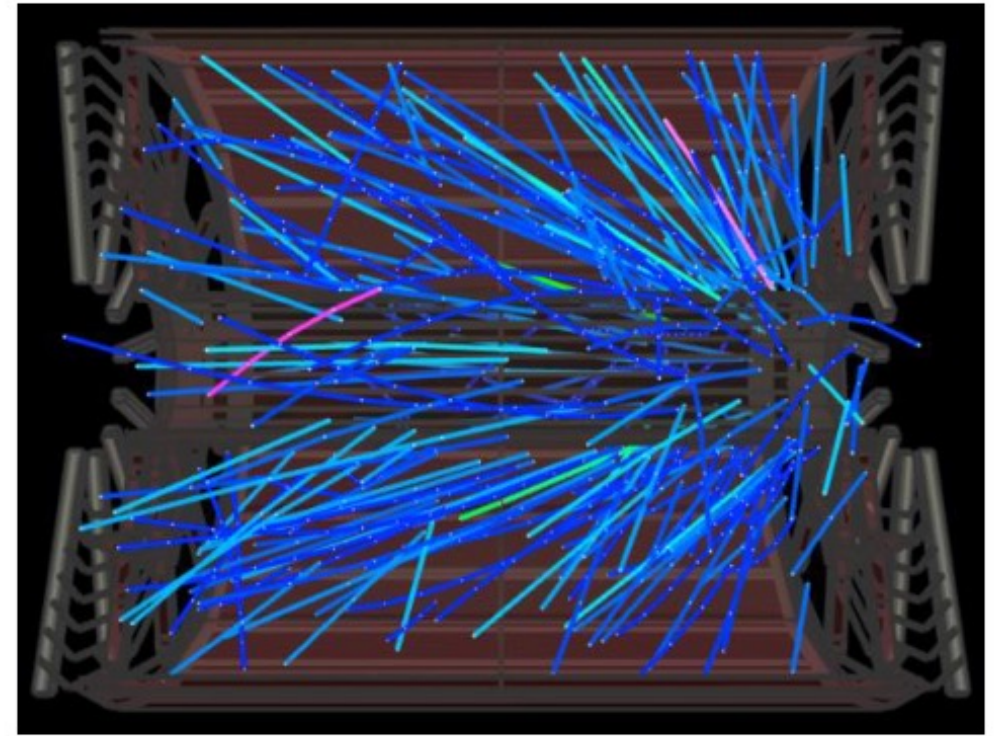
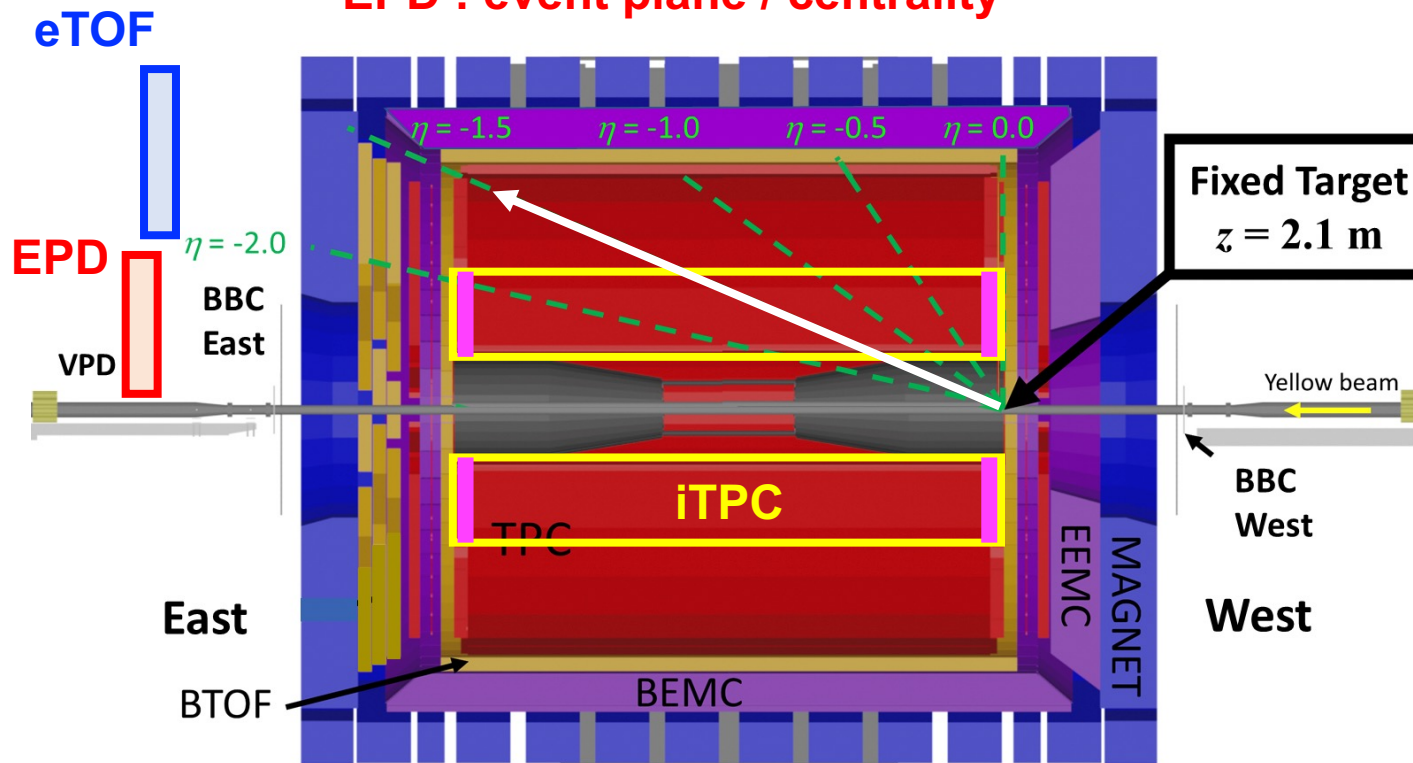
筑波大学
宇宙史研究センター
Tomonaga Center for the History of the Universe

Experiments at CERN, GSI, BNL

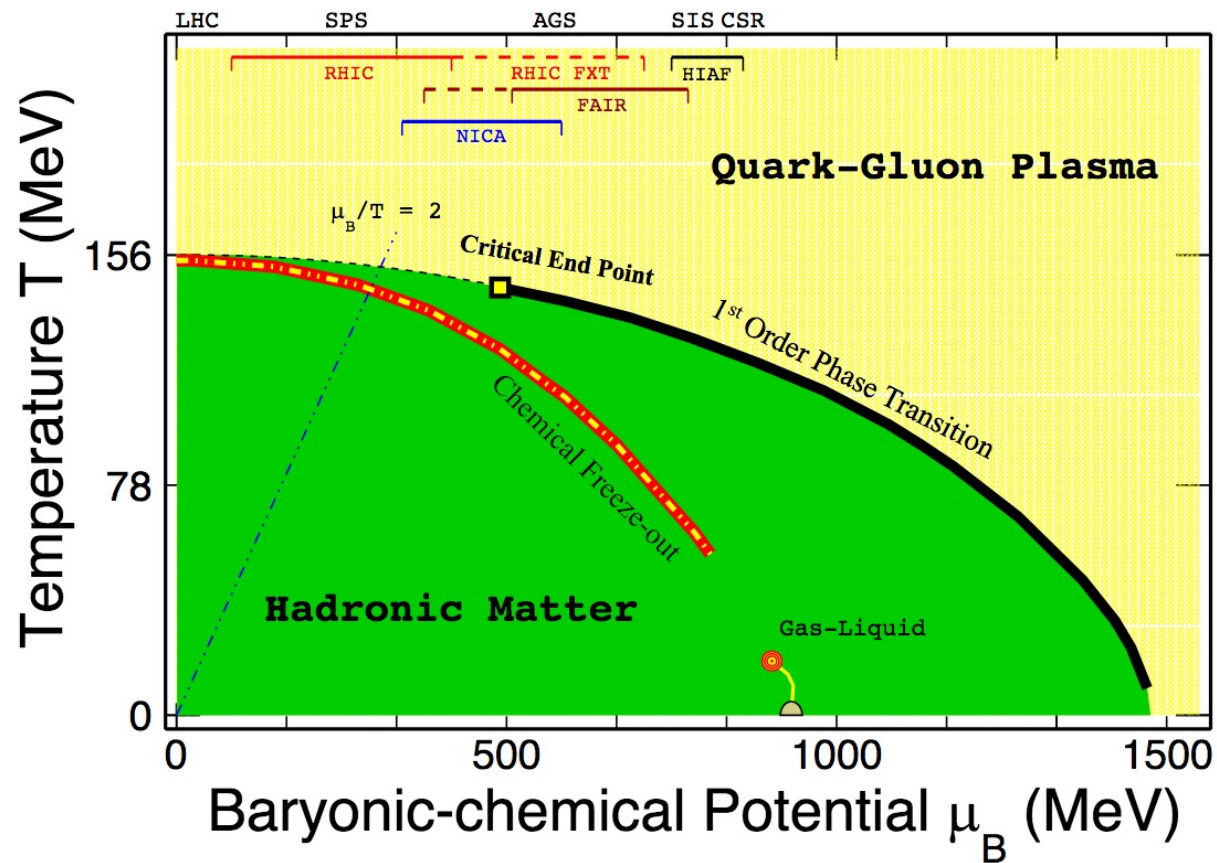


Fixed Target Set-up (FXT) at STAR Experiment

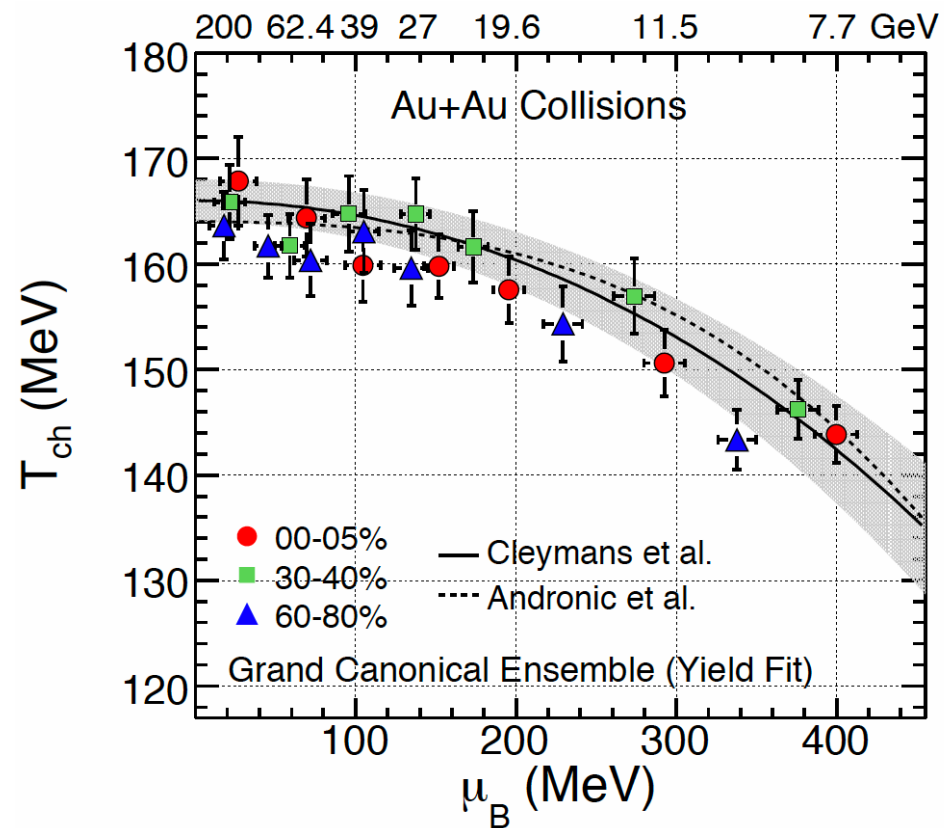
iTPC : inner TPC, forward tracking
eTOF : end-cap TOF, forward PID
EPD : event plane / centrality



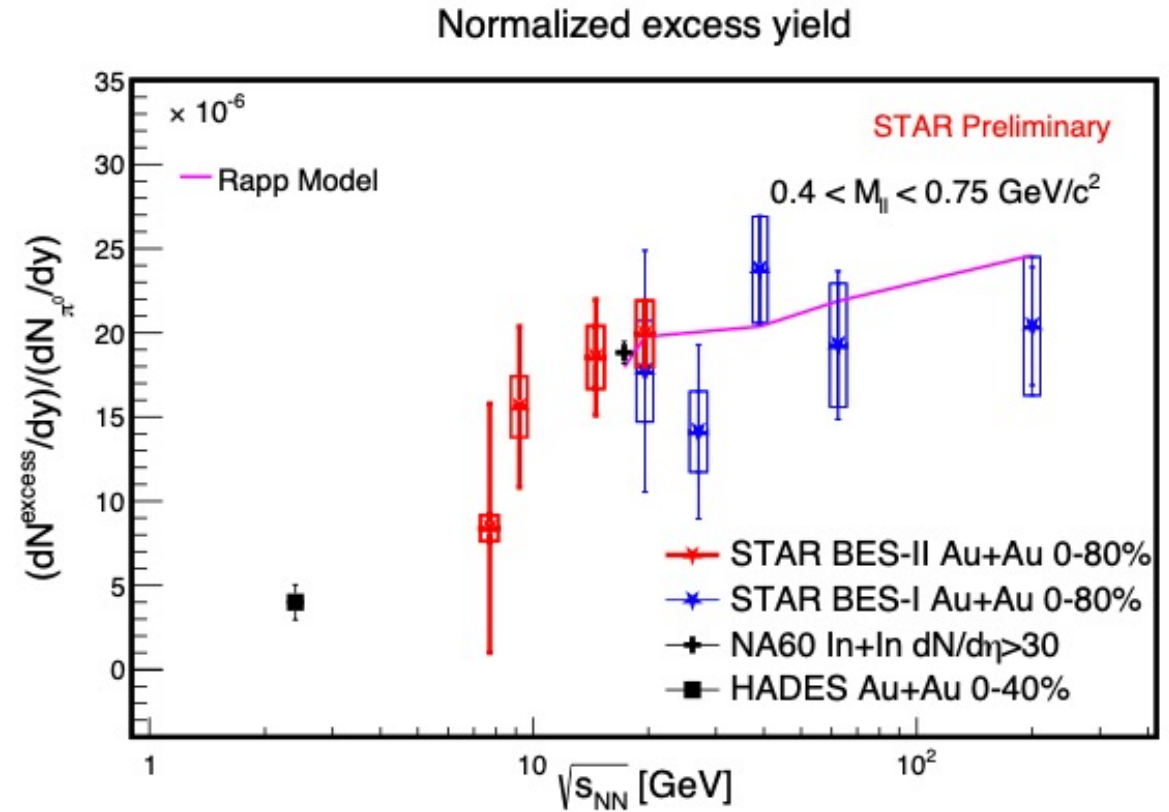
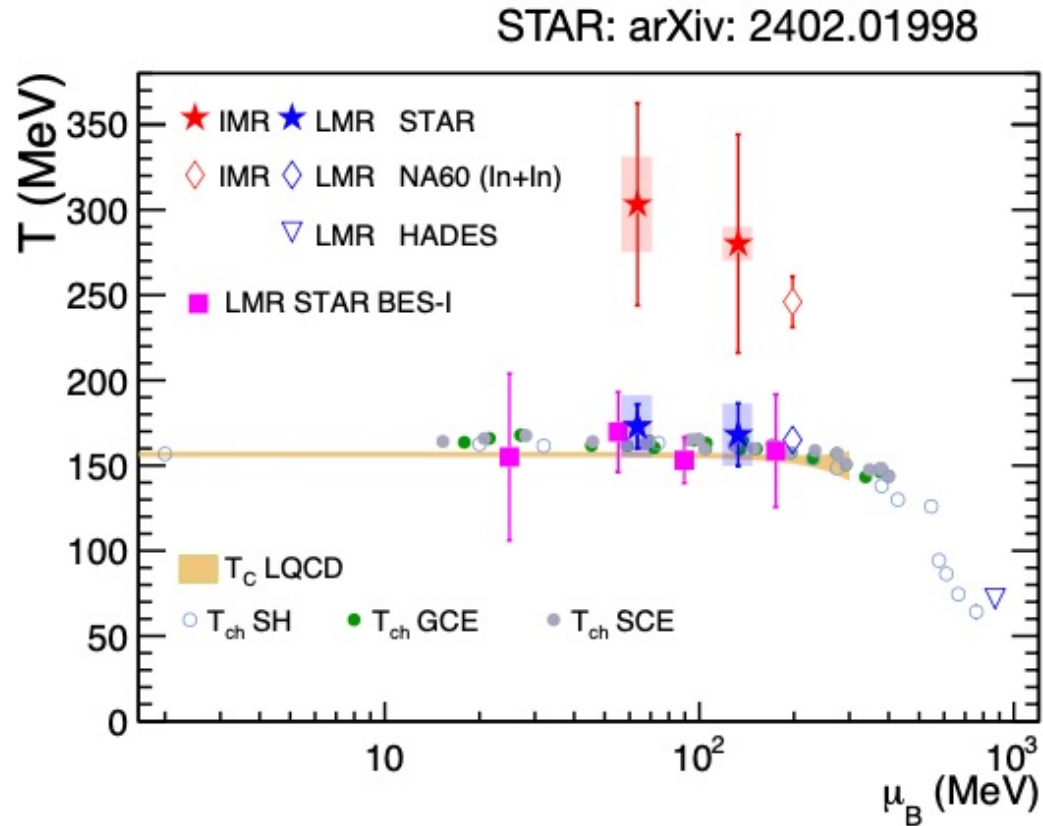
QCD Phase diagram and Beam Energy Scan



PRC 96 (2017) 4, 044904

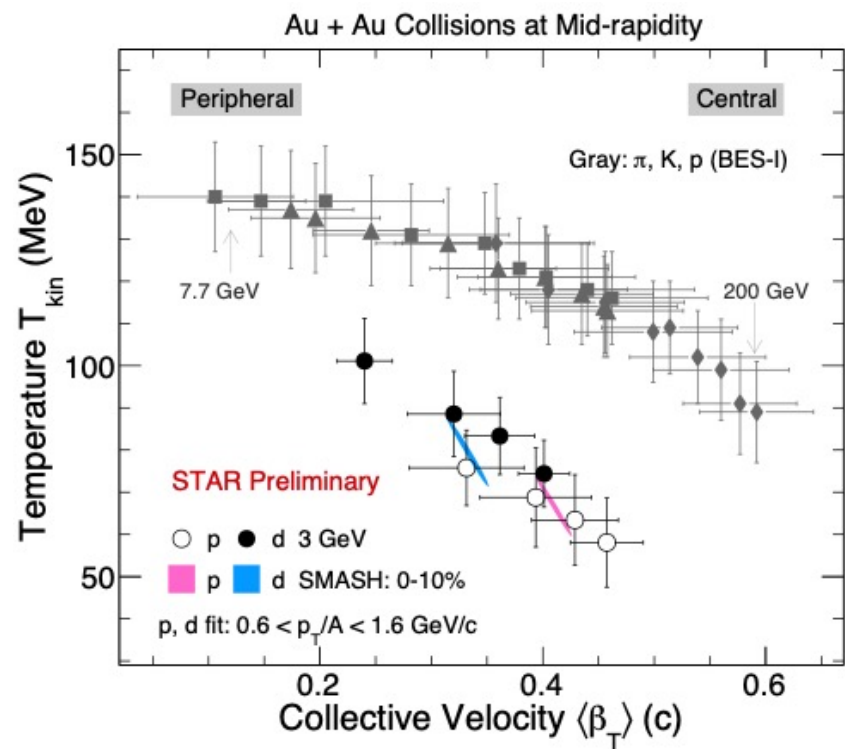


Thermal Di-Lepton Measurements

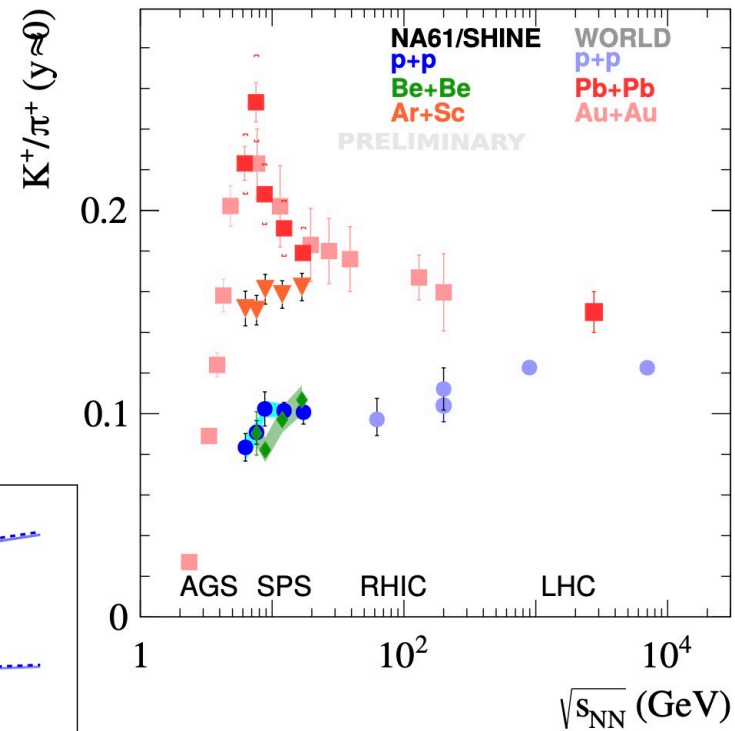
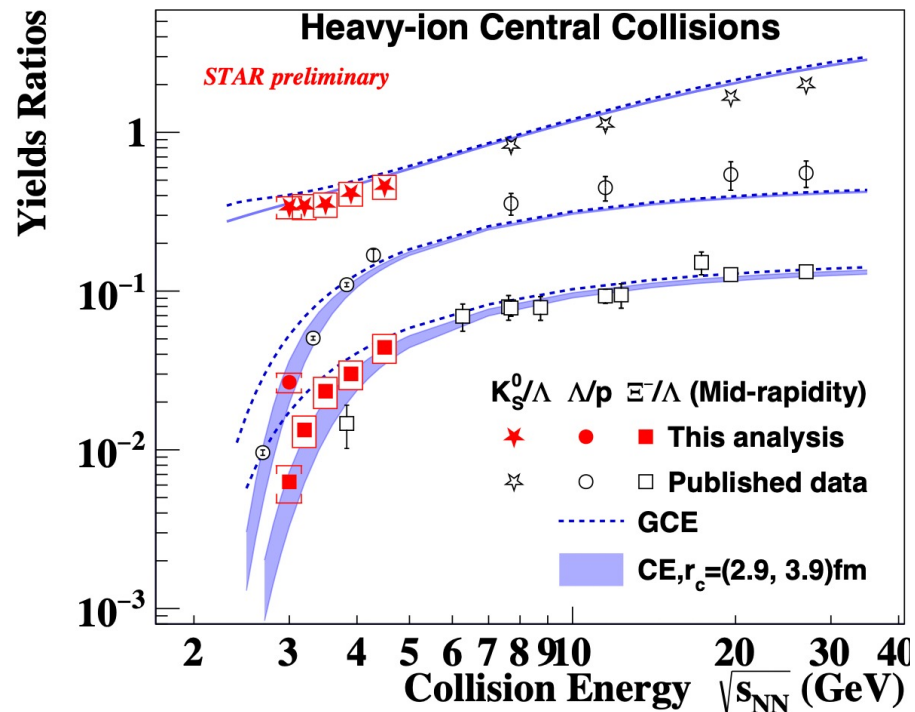


Transition from Quark Matter back to Hadronic Matter

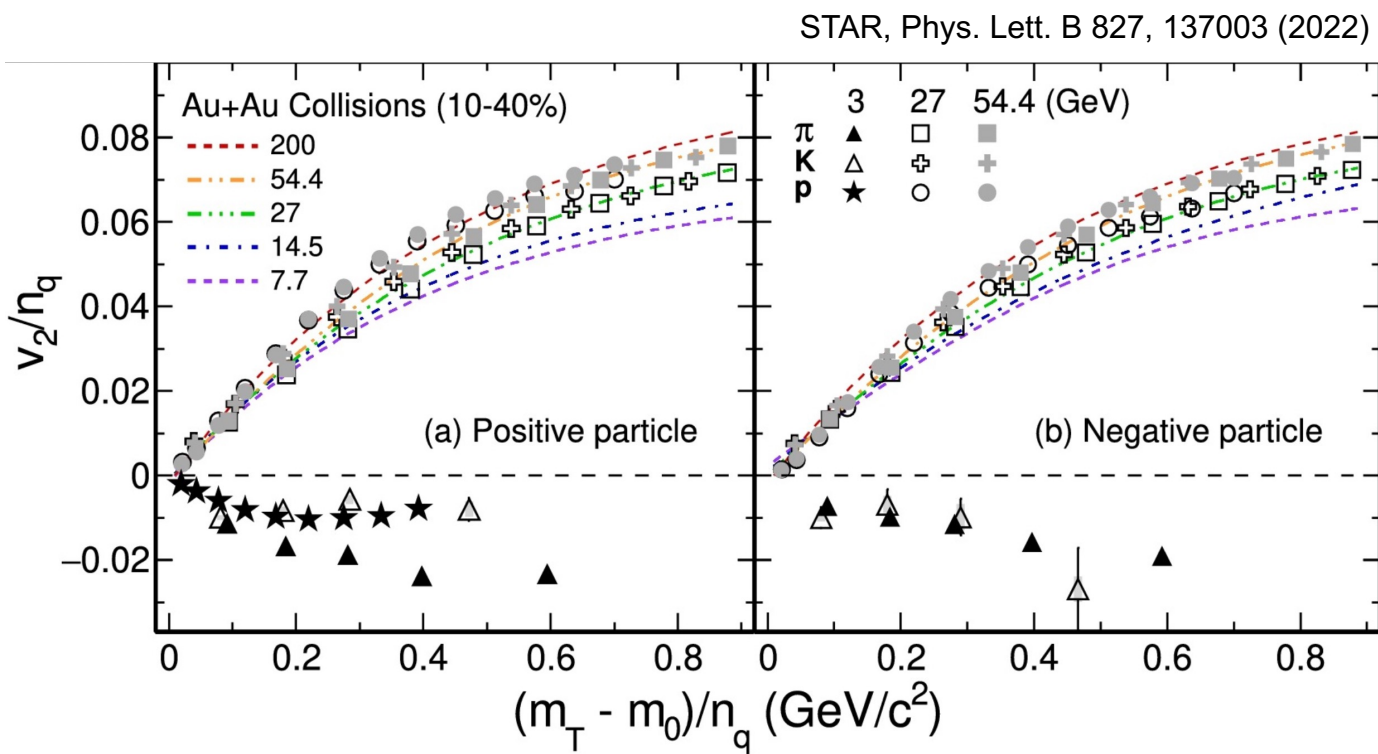
Thermal freeze-out



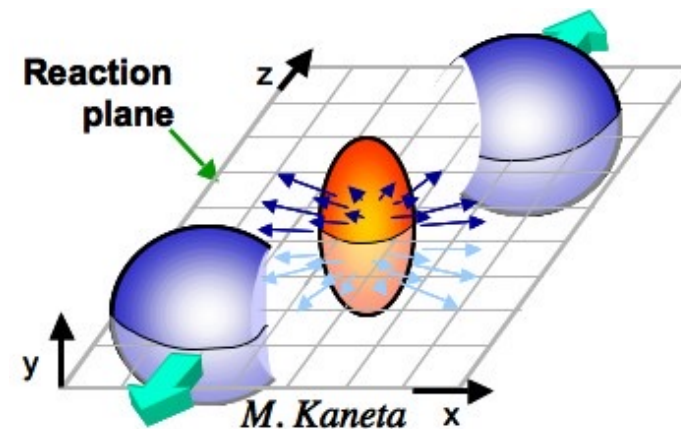
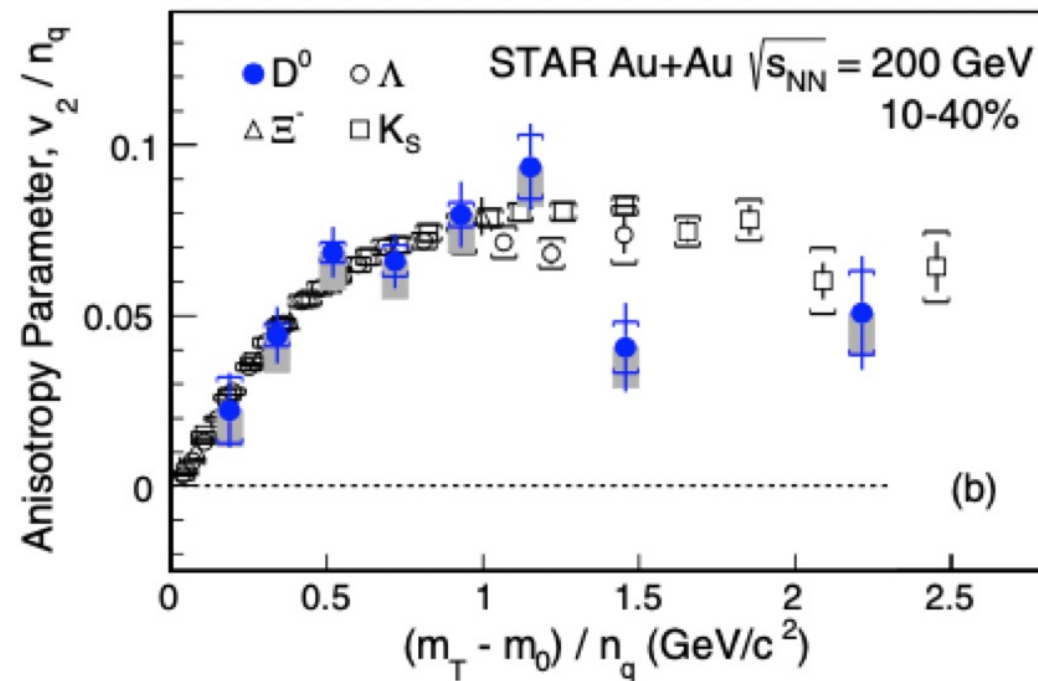
Strangeness



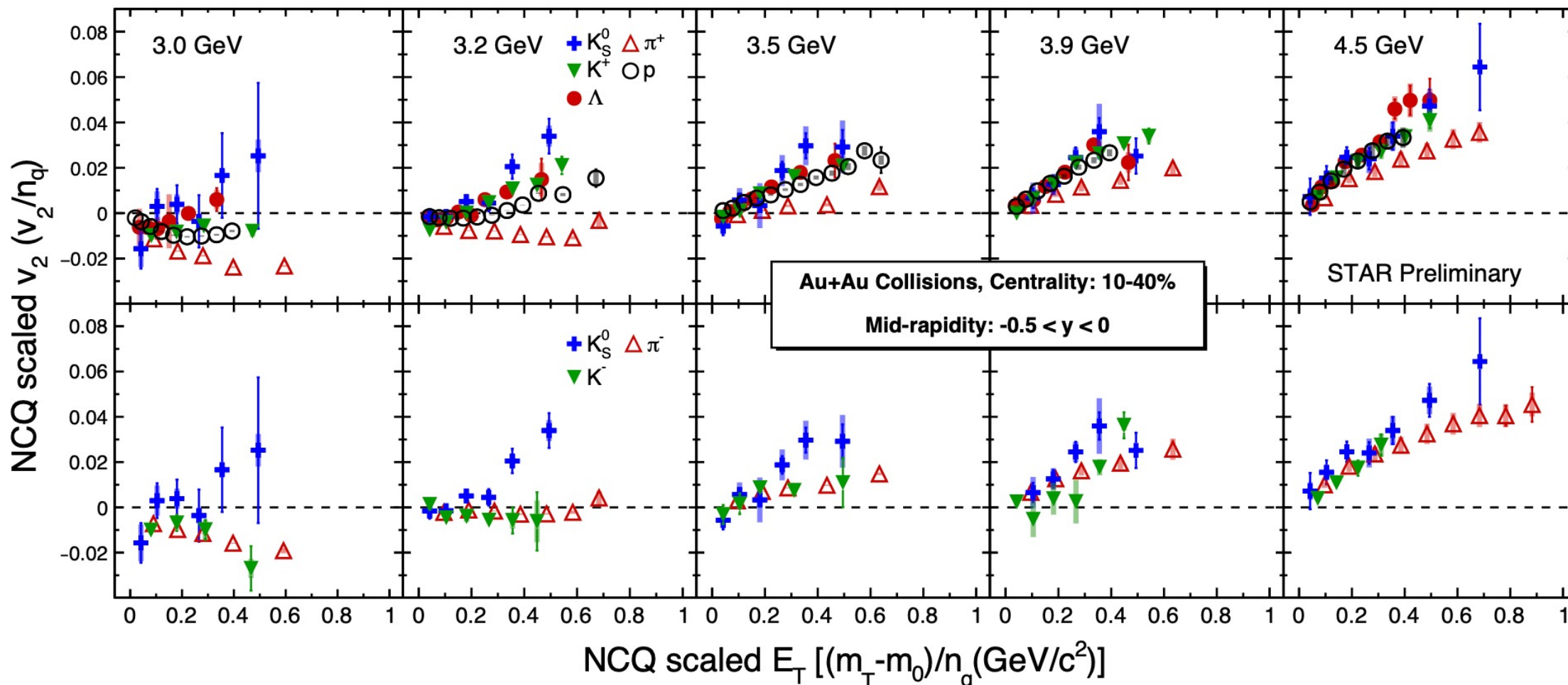
Departure from the Quark Number Scaling of v_2



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



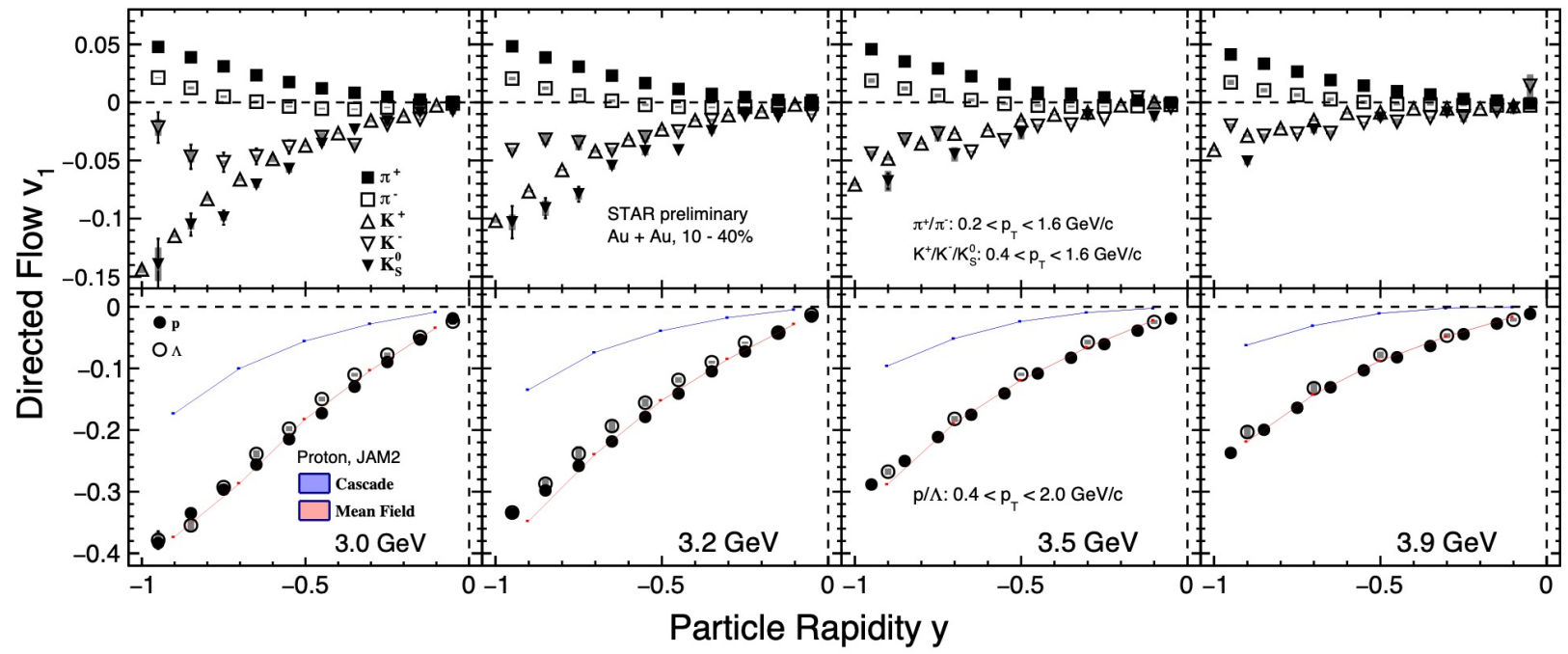
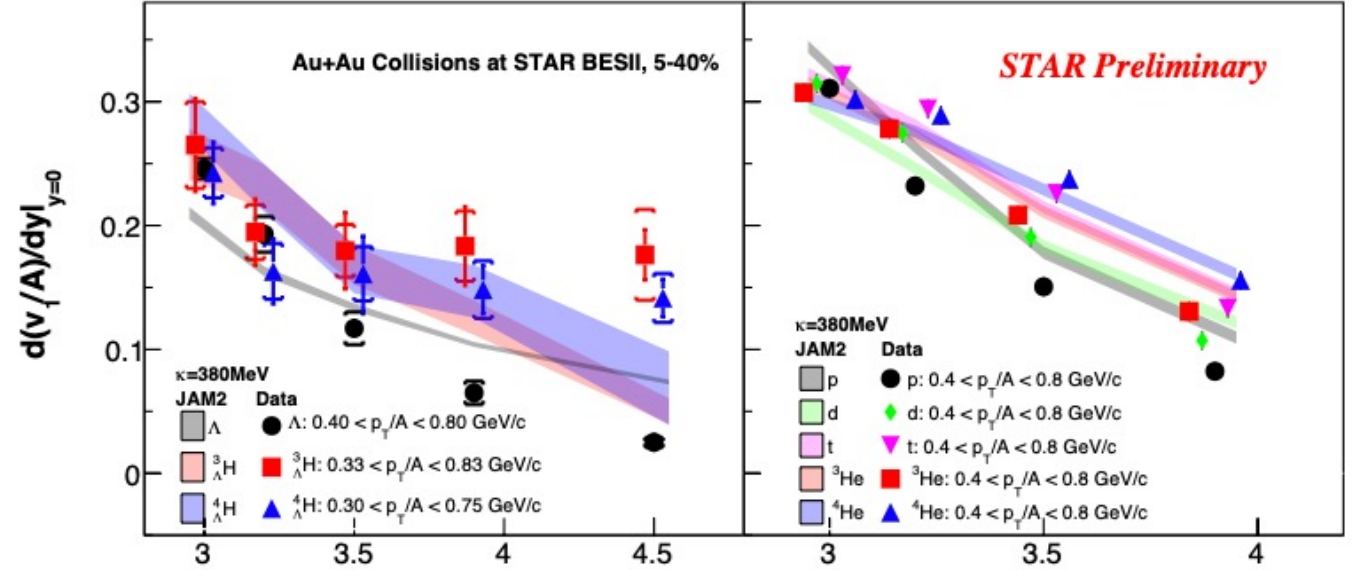
Quark Number Scaled v_2 at FXT beam energies (3.0 ~ 4.5 GeV)



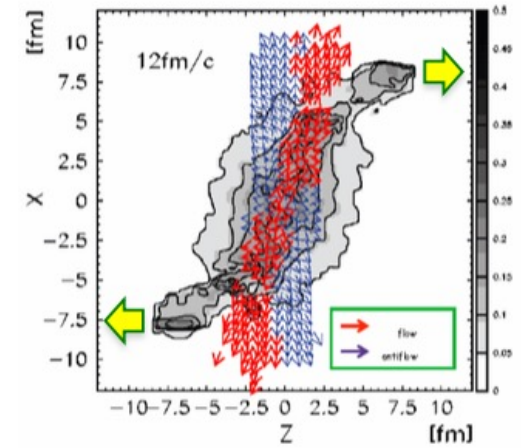
v_1 vs rapidity and v_1 slope of hyper-Nuclei at FXT beam energies

$\Lambda, {}^3_\Lambda\text{H}$ and ${}^4_\Lambda\text{H}$

$p, d, t, {}^3\text{He}$ and ${}^4\text{He}$



Collision Energy $\sqrt{s_{NN}}$ (GeV)

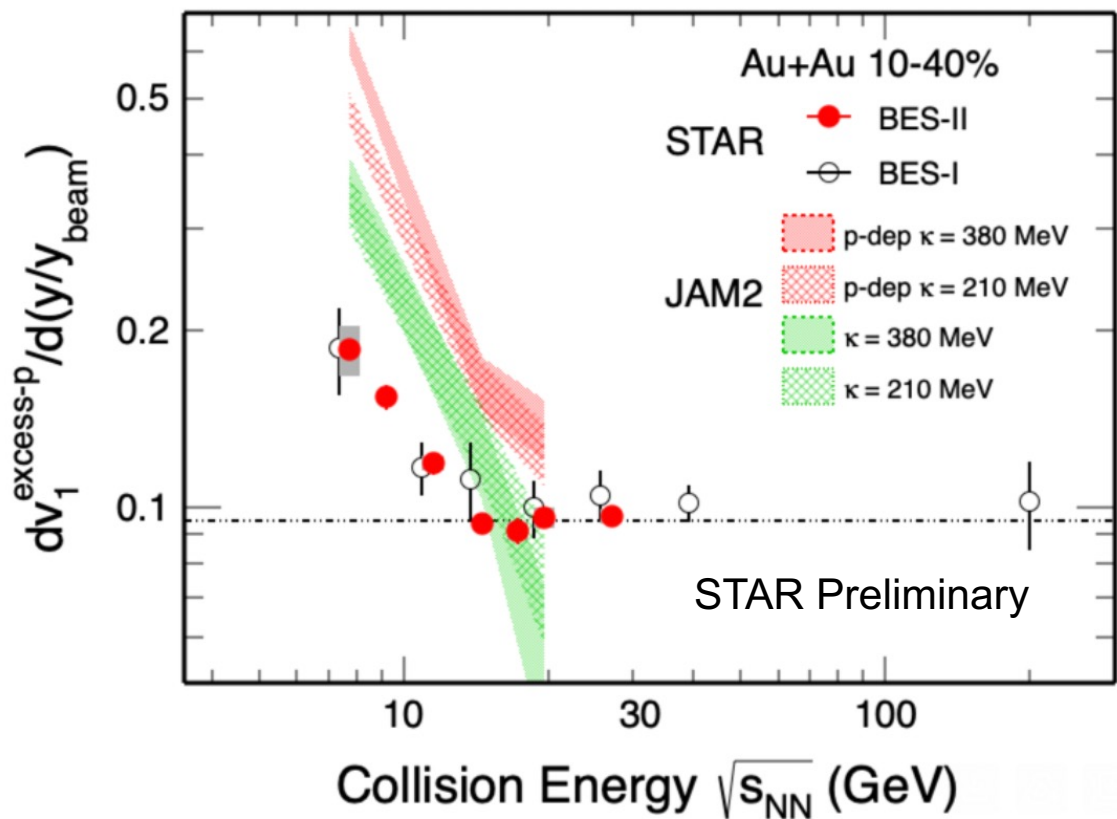


Excess-proton v_1 or Net-proton v_1

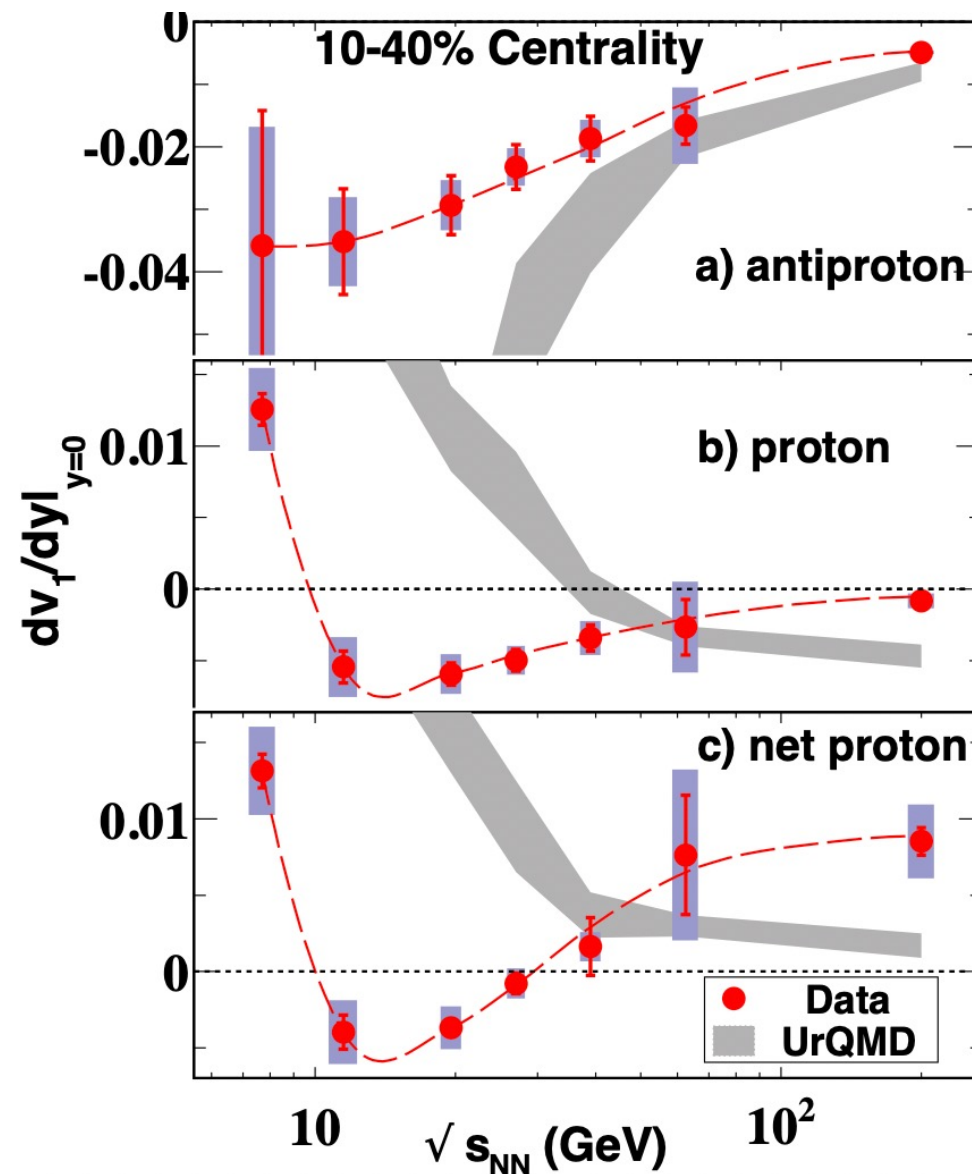
$$v_1^{\text{excess-p}} = \frac{v_1(p) - v_1(pbar)}{1 - r}$$

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

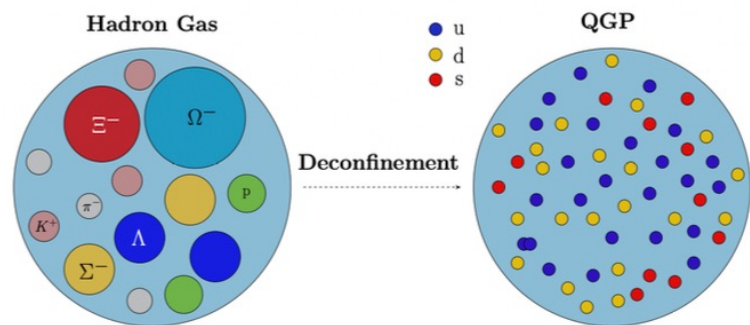
$$r = \frac{N_{pbar}}{N_p}$$



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

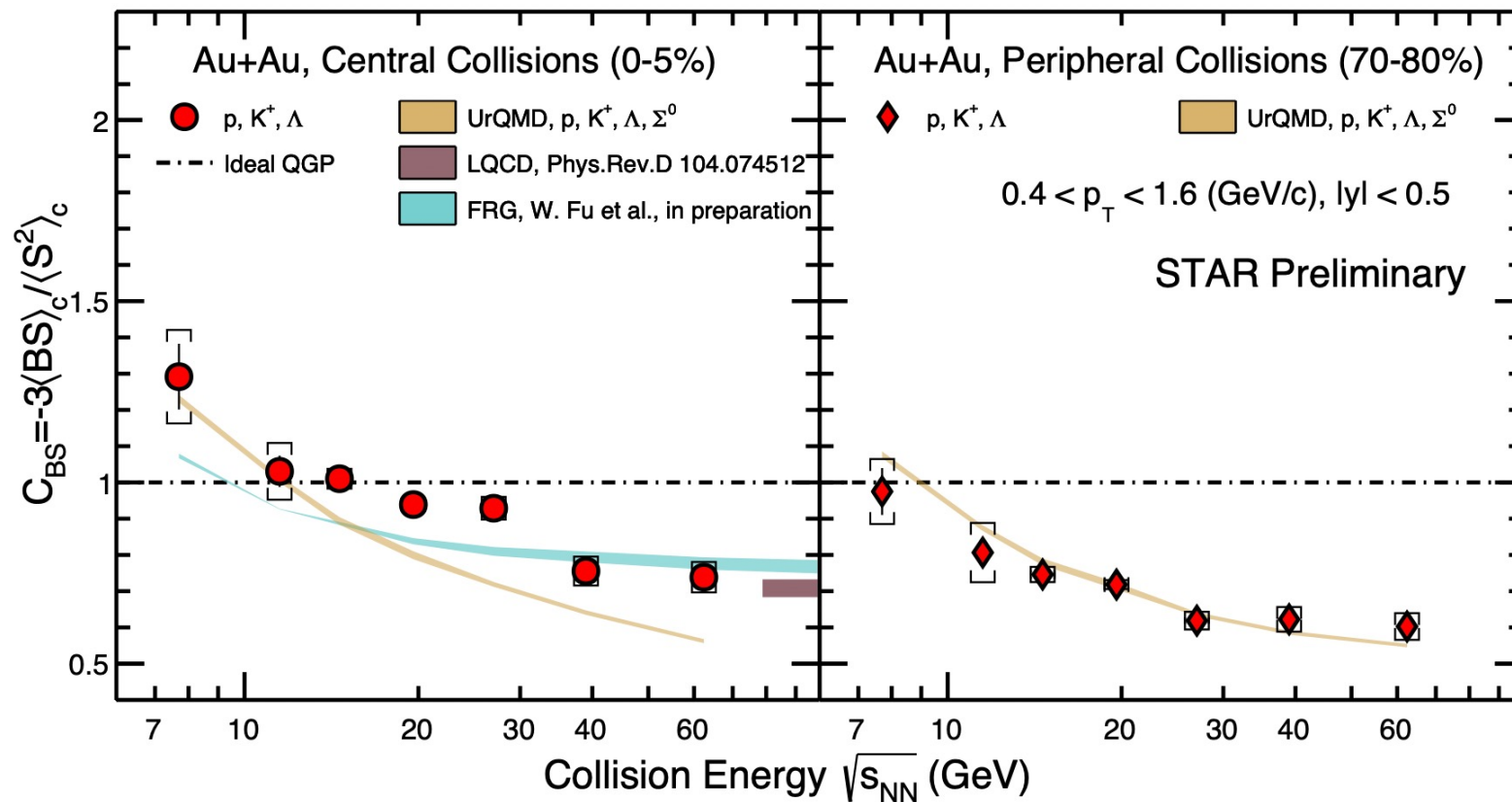


Baryon – Strangeness correlation



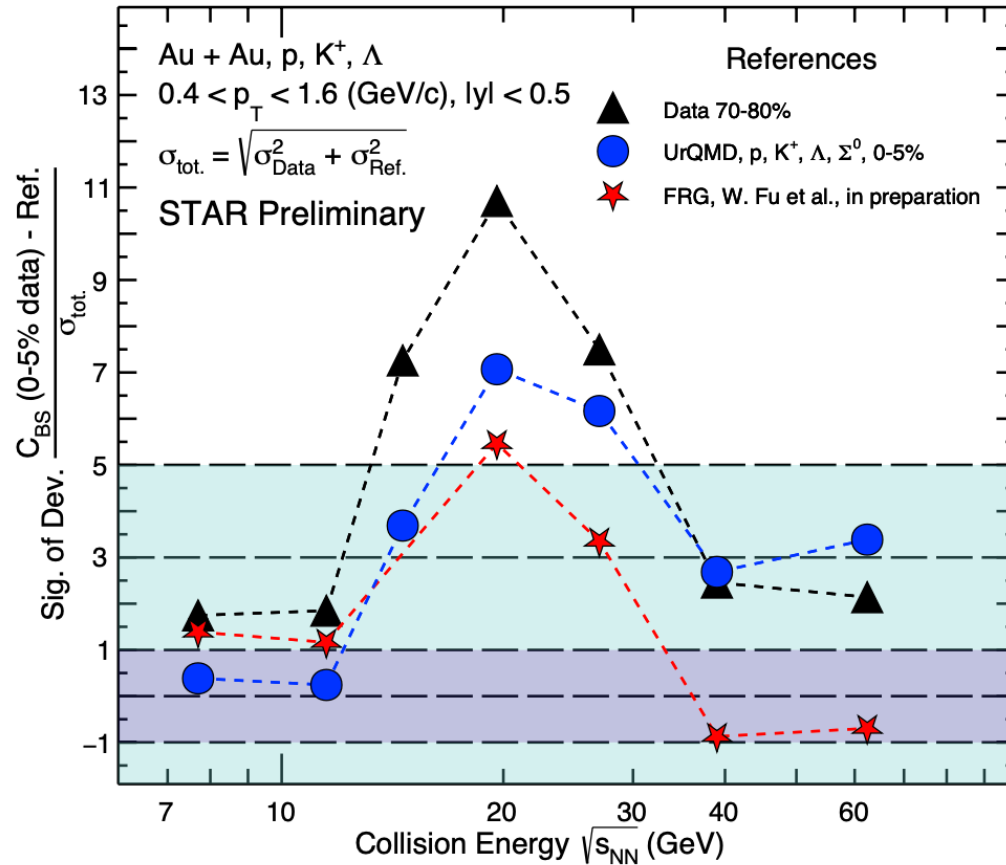
$$C_{BS} = -3 \frac{\langle BS \rangle_c}{\langle S^2 \rangle_c} = -3 \frac{\langle BS \rangle - \langle B \rangle \langle S \rangle}{\langle S^2 \rangle - \langle S \rangle^2}$$

B-S correlations

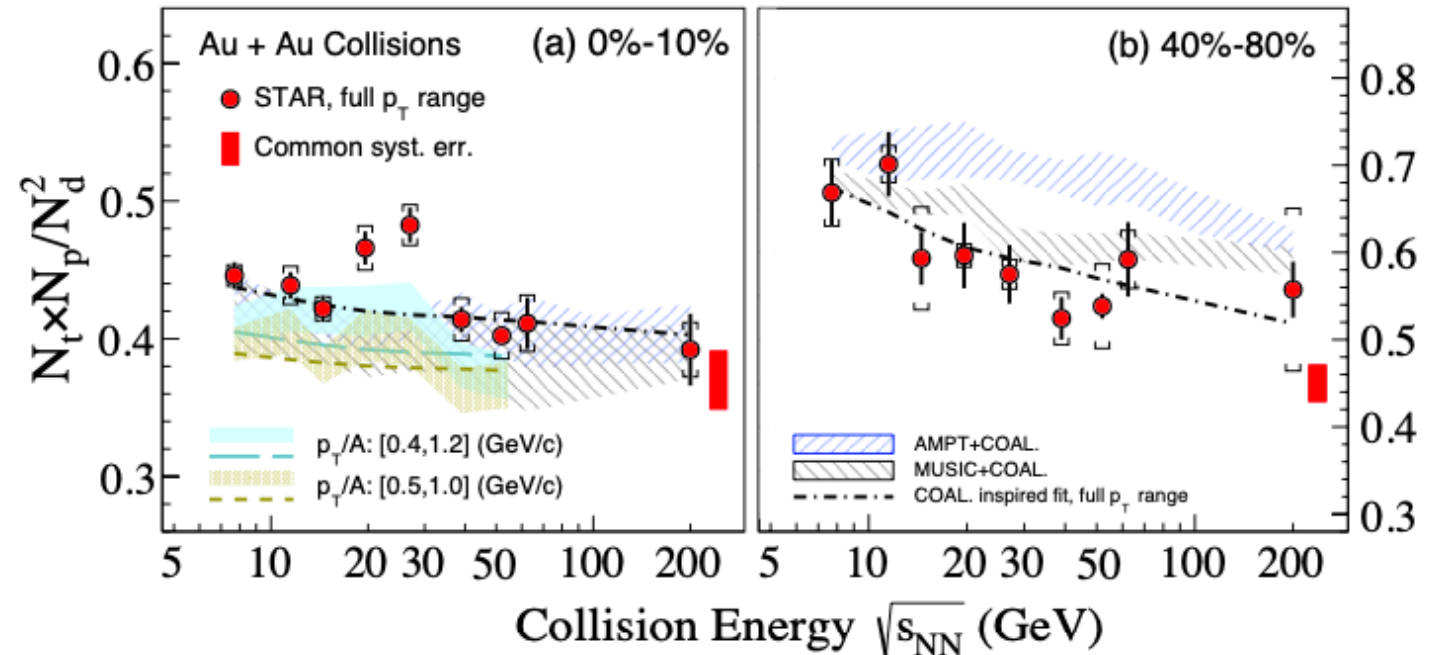


Baryon – Strangeness correlation and Neutron Density Fluctuation

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

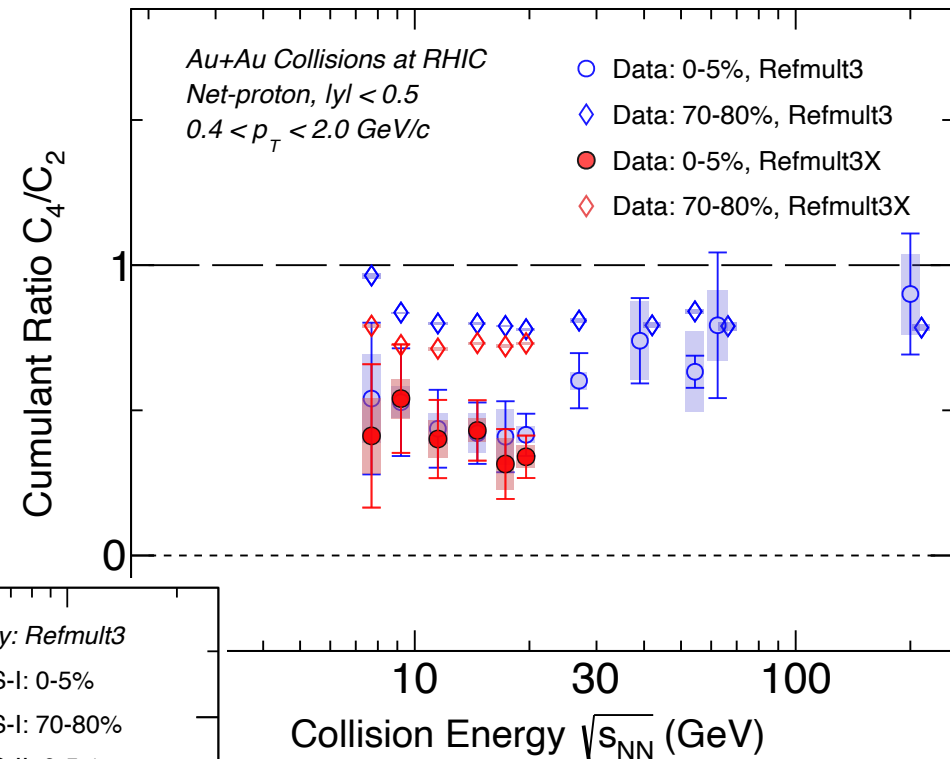
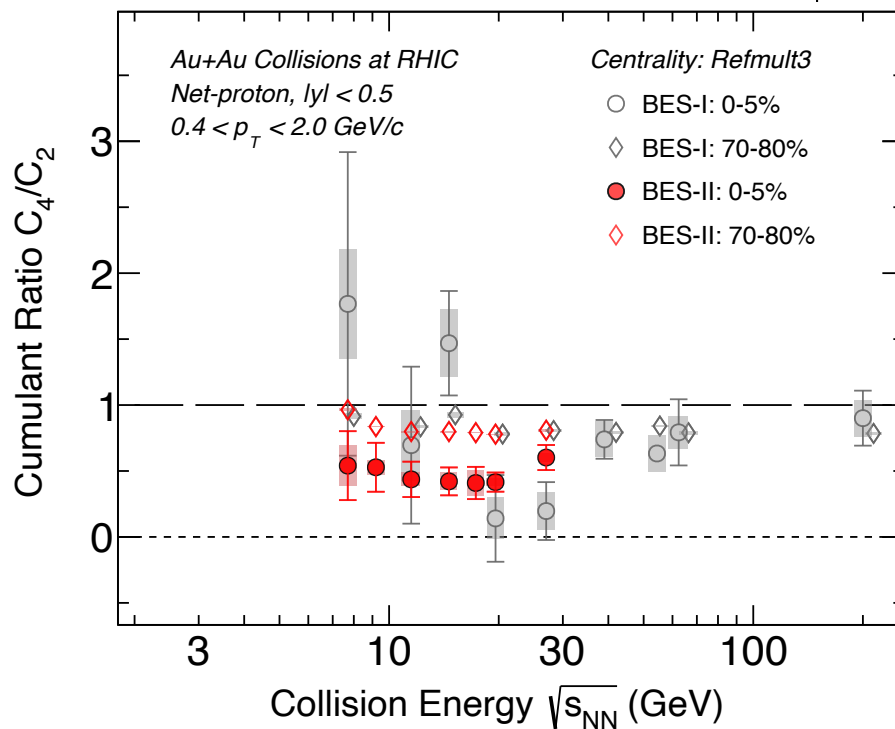
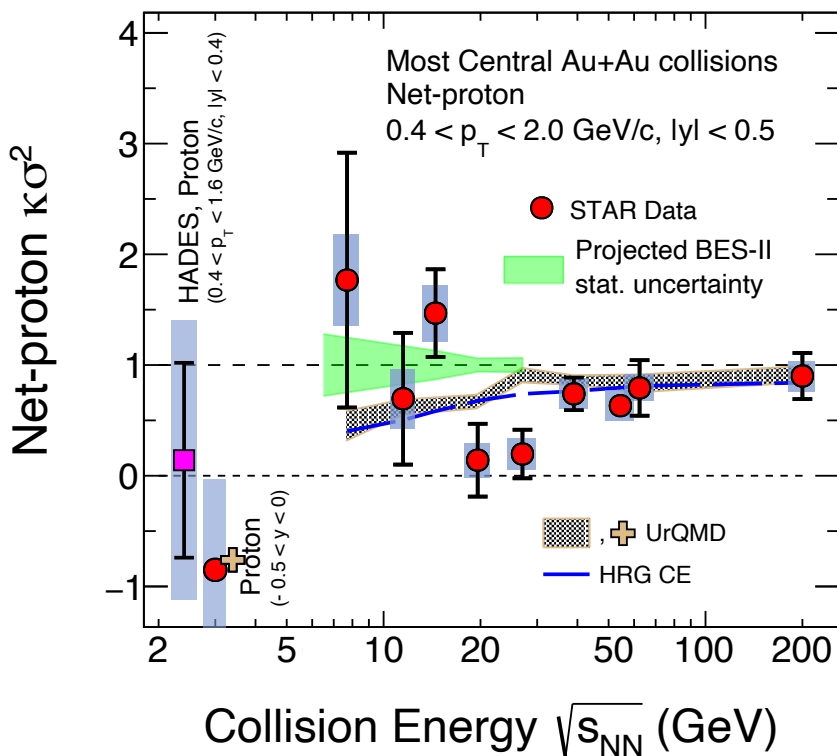


STAR, Phys. Rev. Lett. 130, 202301 (2023)



New Result on Net-proton Cumulant Ratio C_4/C_2

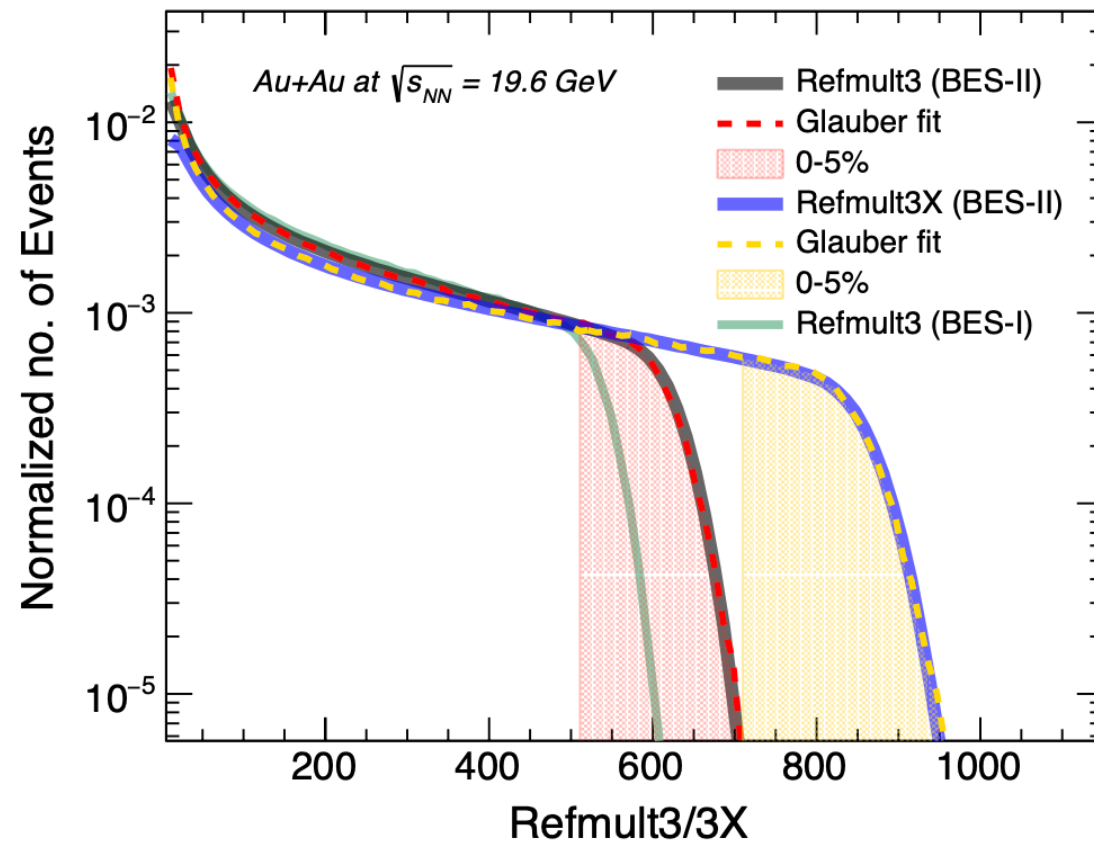
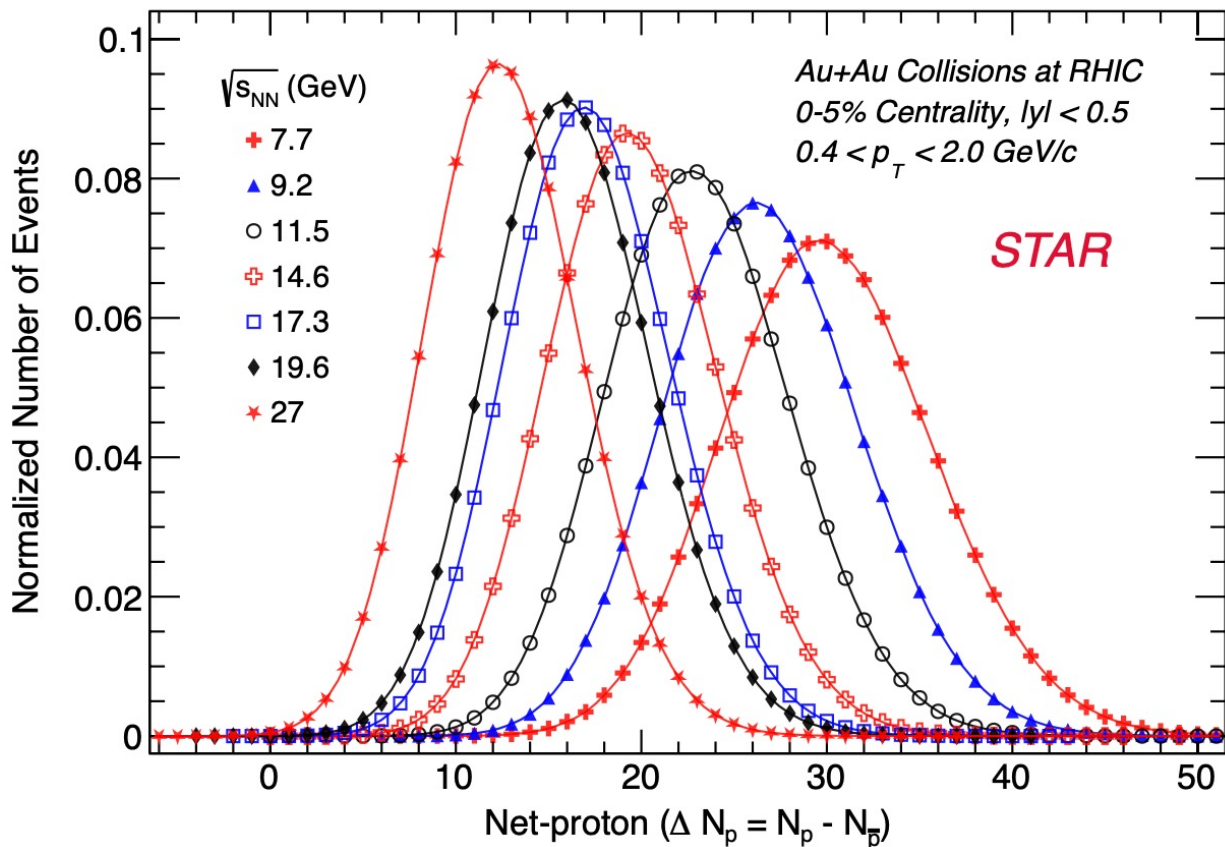
STAR, Phys. Rev. Lett. 127, 262301 (2021)
 STAR, Phys. Rev. Lett. 128, 202302 (2022)



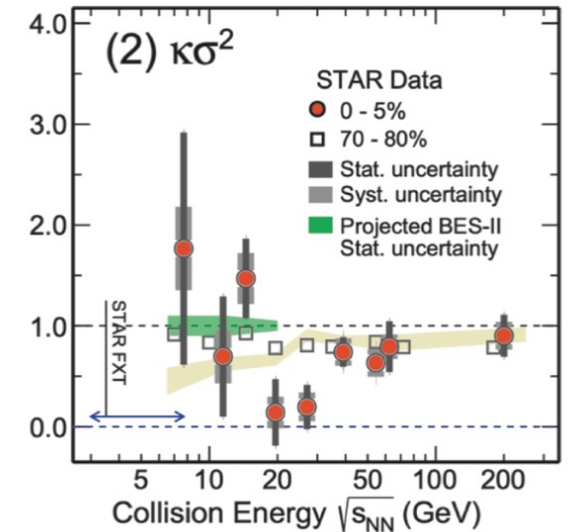
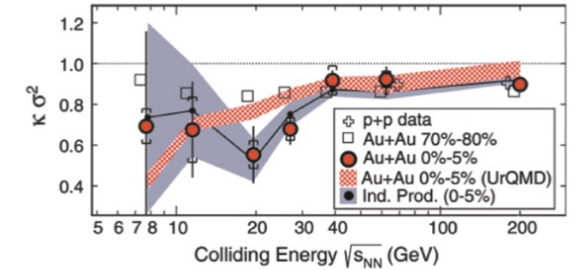
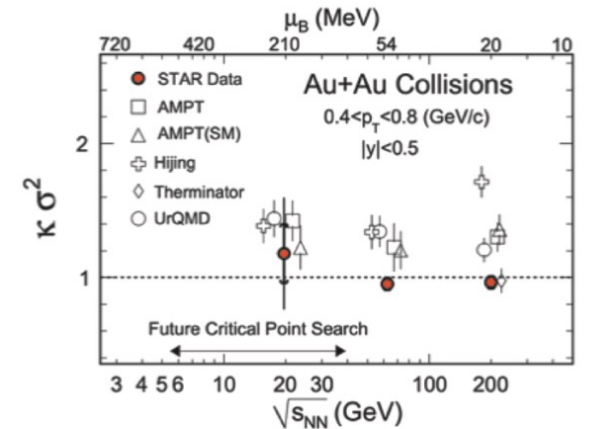
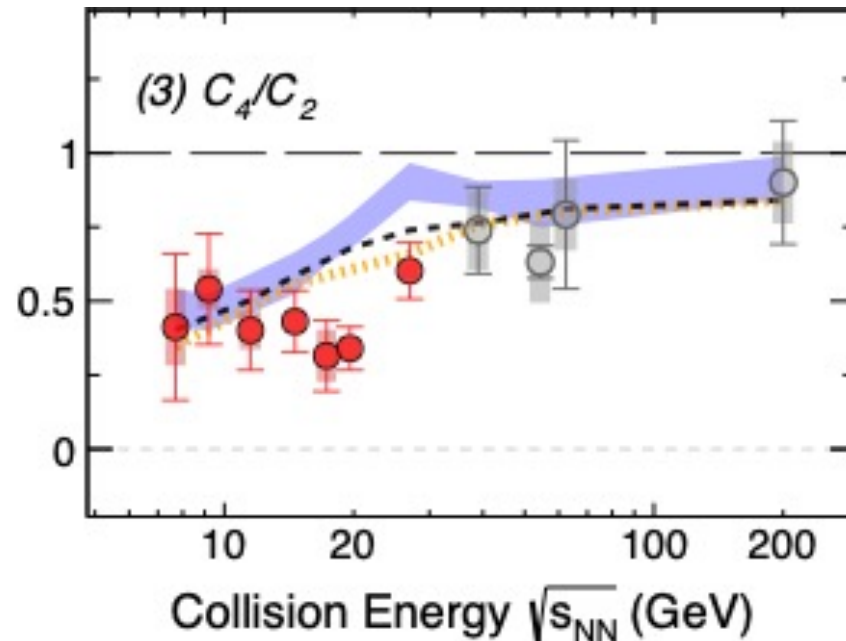
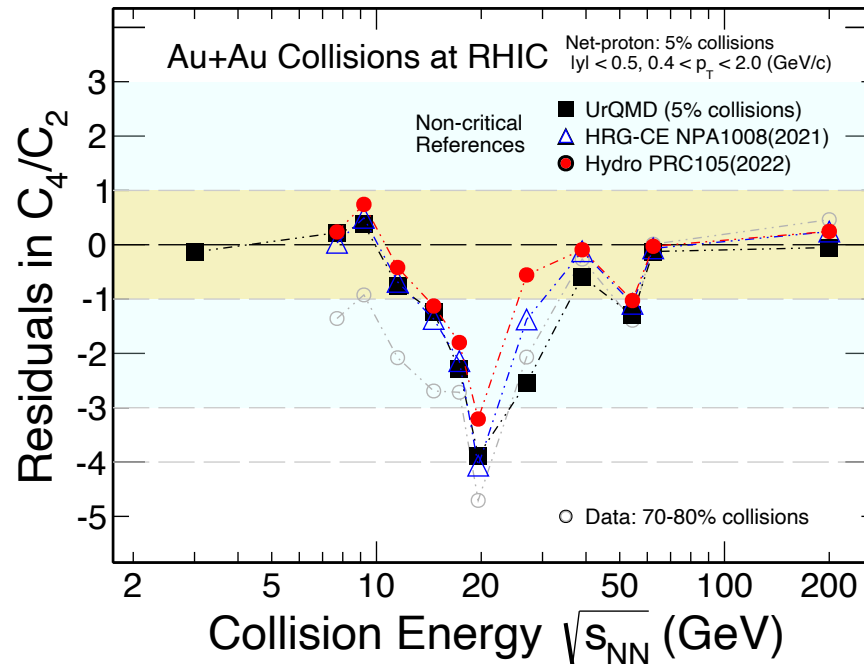
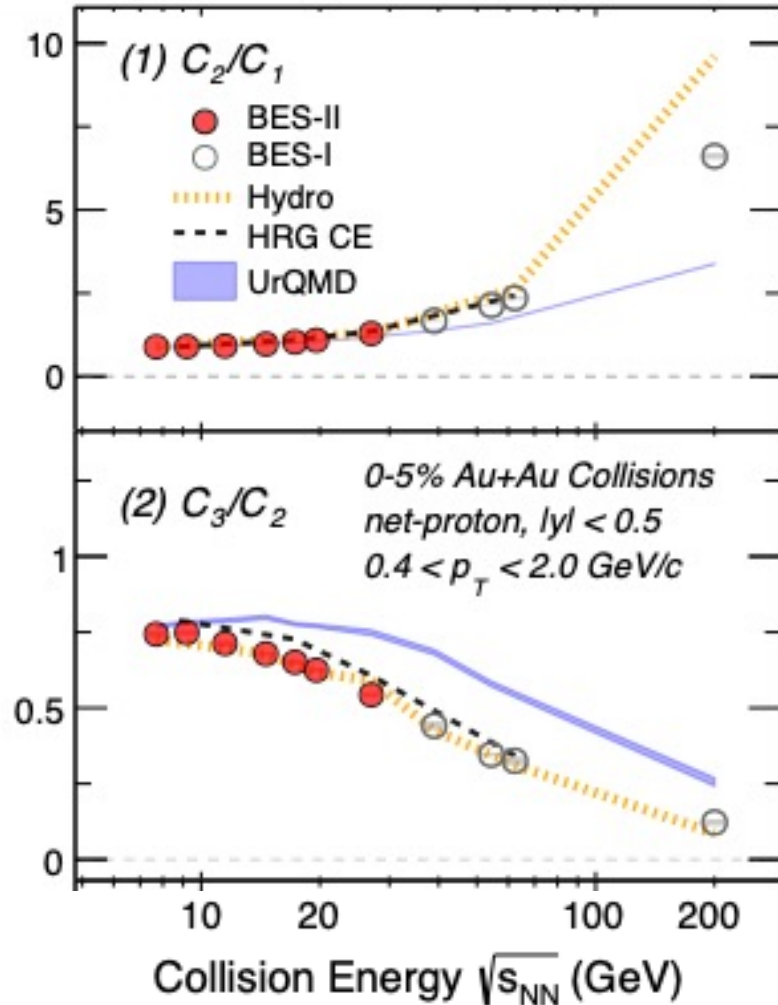
BES-I RefMult3
BES-II RefMult3
BES-II RefMult3X

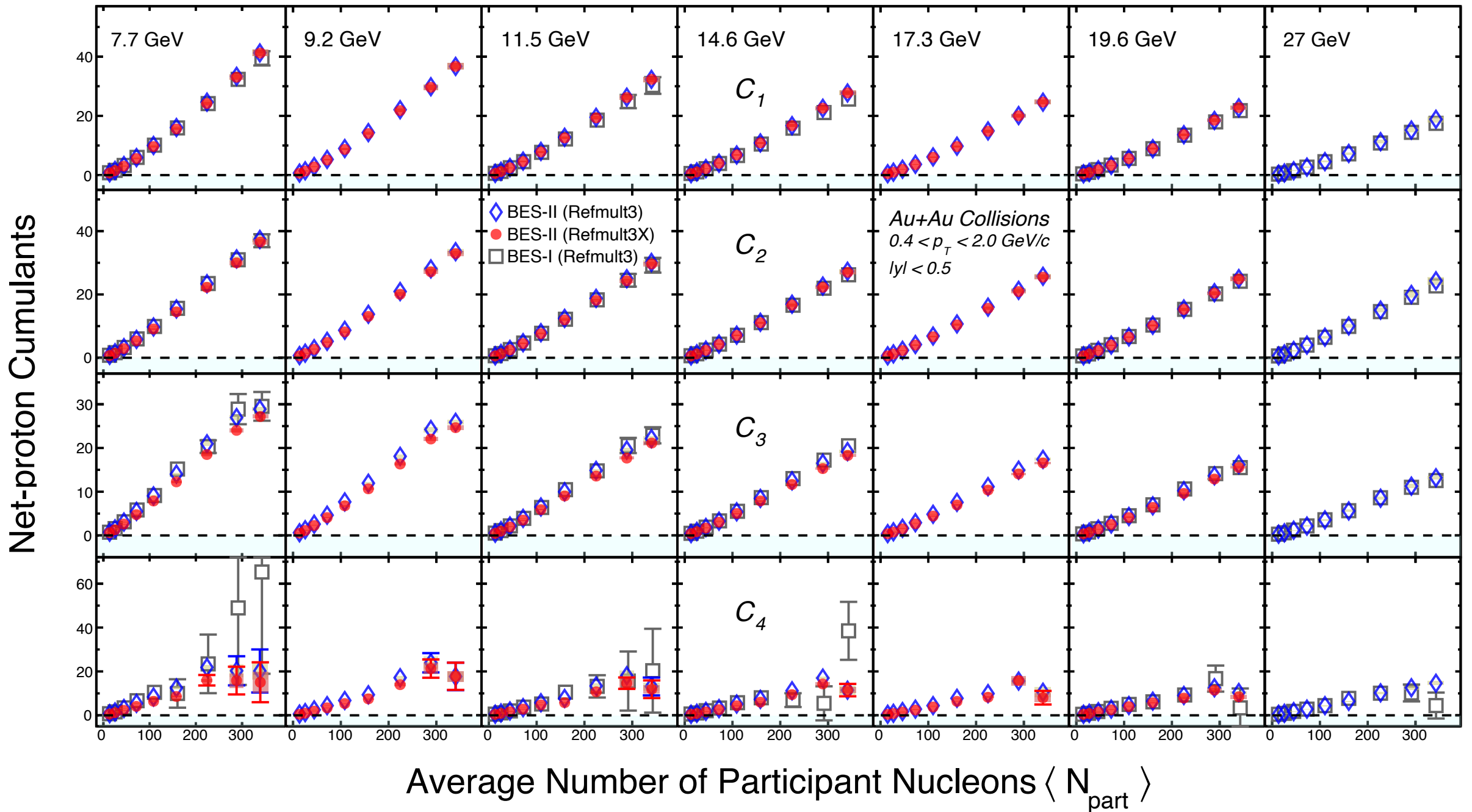
Net-proton distribution and Centrality determination

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

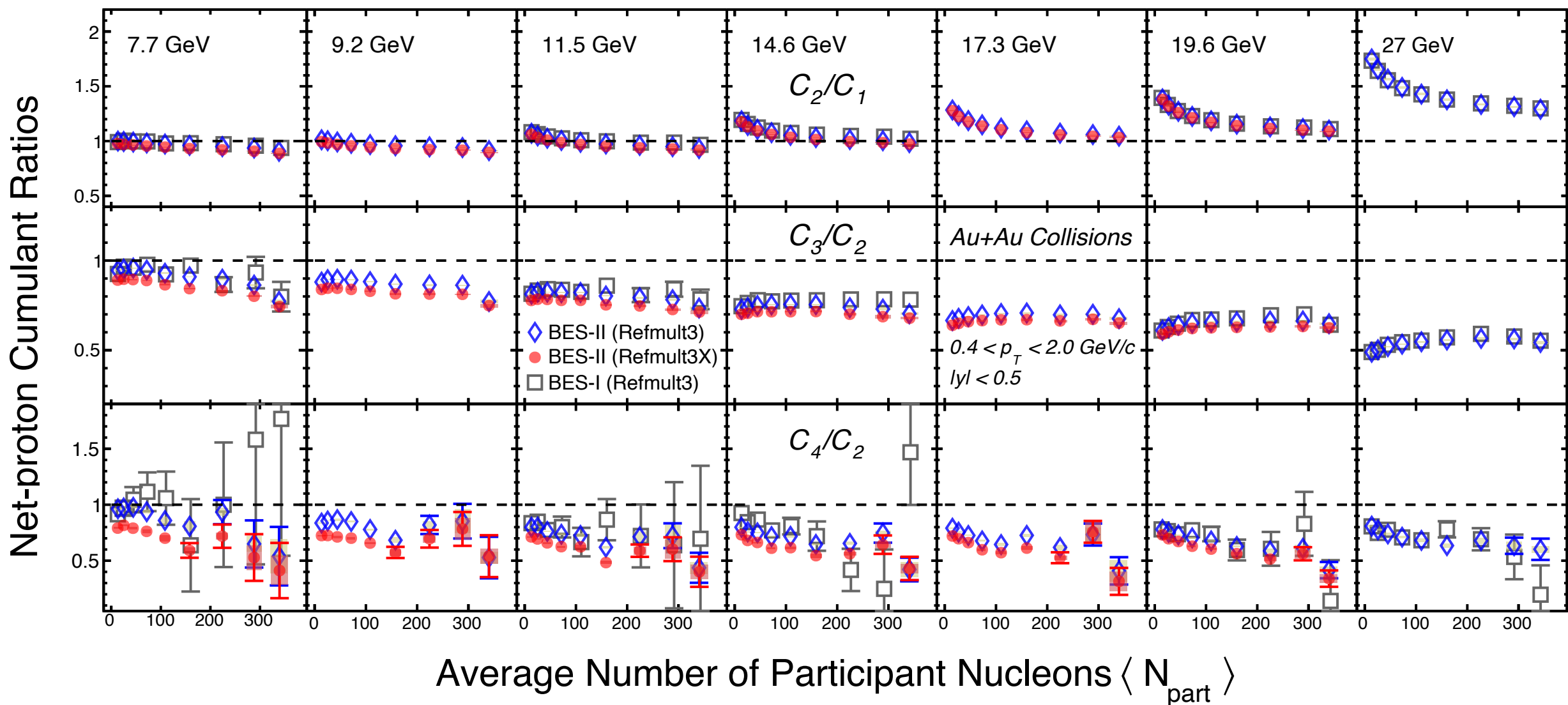


Dip remains ?



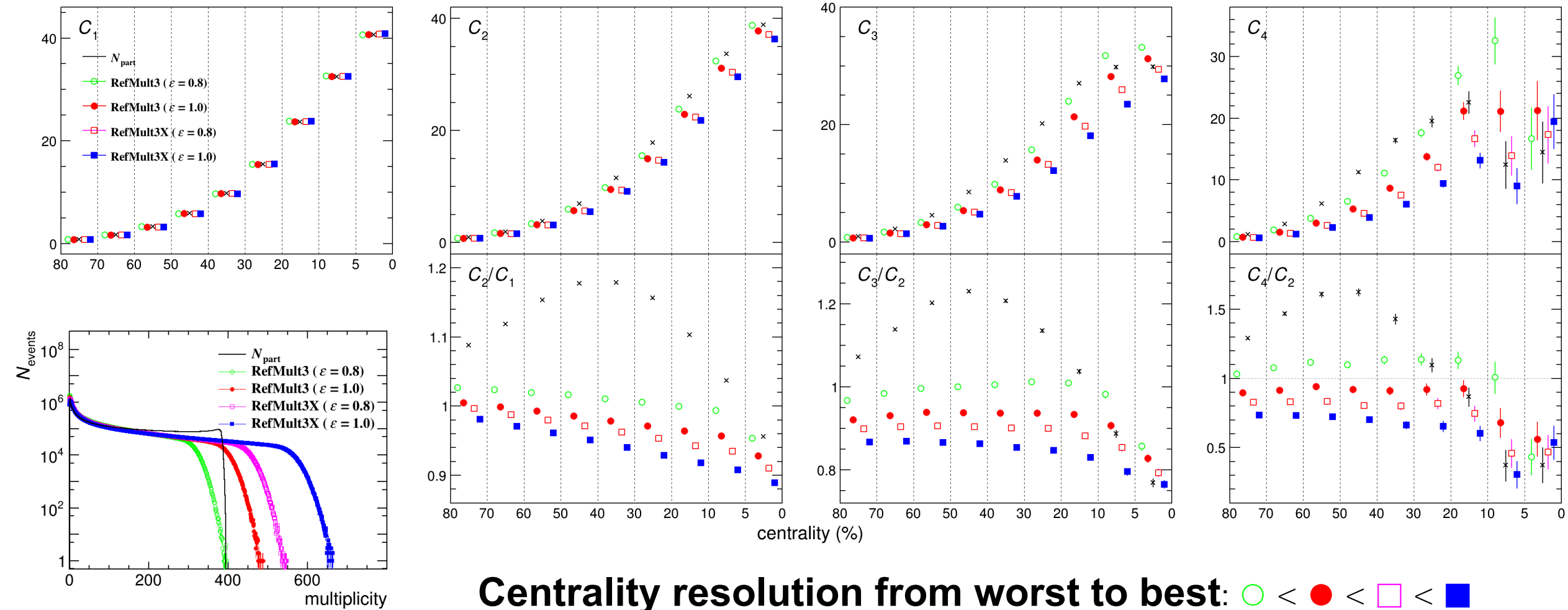


Net-proton Cumulant Ratios as a function of Centrality



UrQMD simulation study : Au+Au at 7.7 GeV

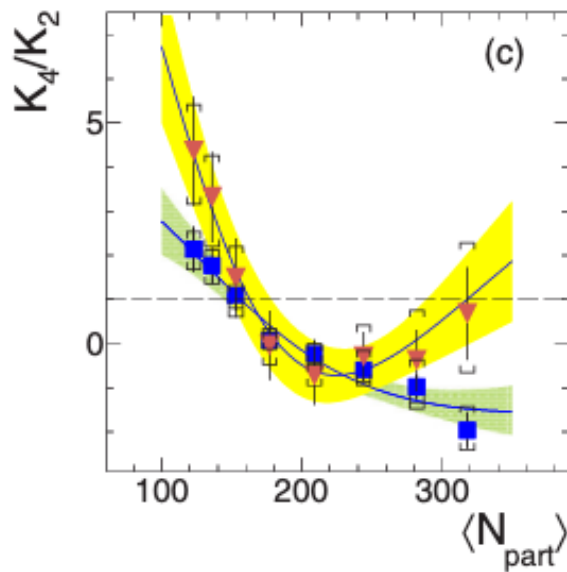
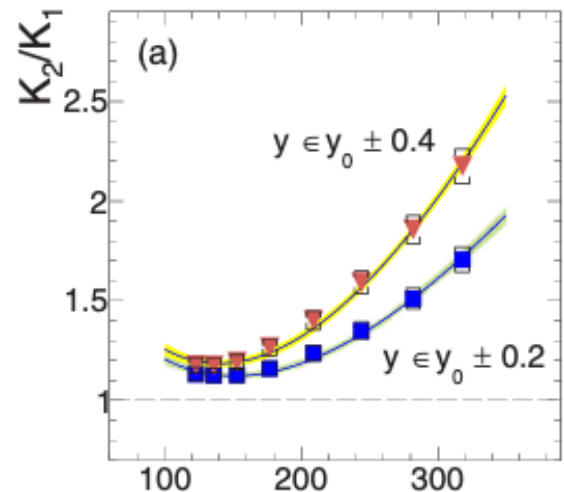
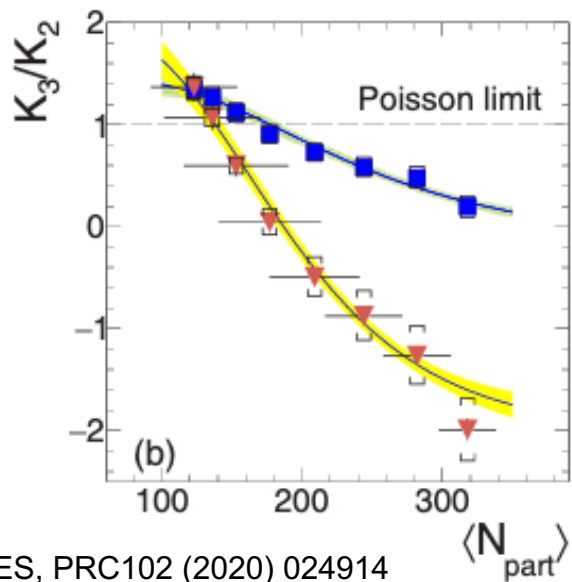
Fan Si, grad. stu.
USTC/Tsukuba



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

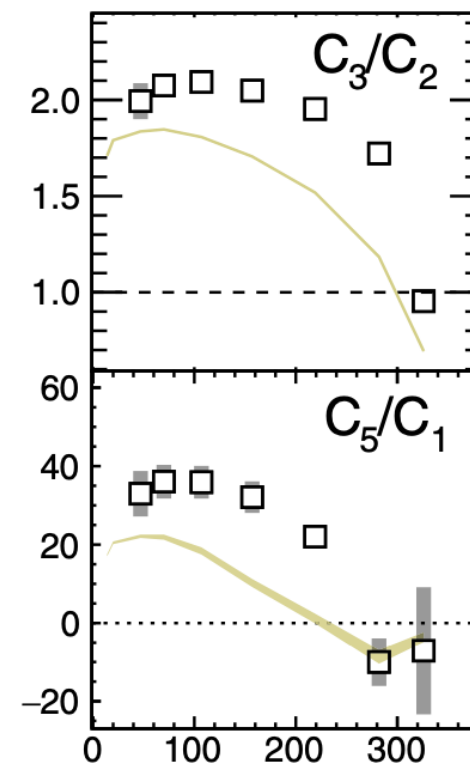
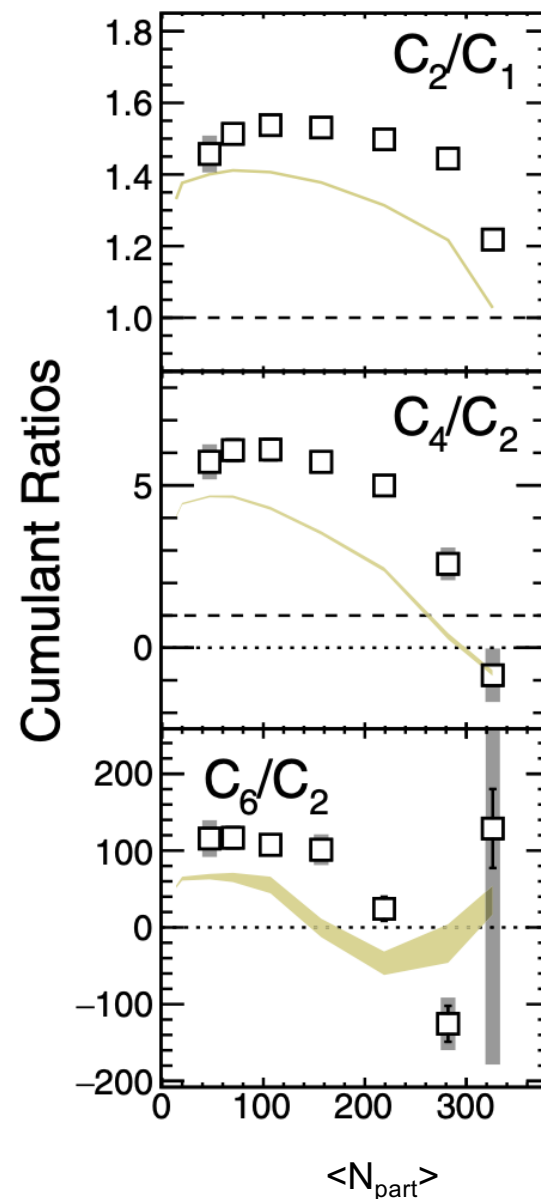
Au+Au 2.4 GeV HADES

with spectator based centrality
with volume correction



Au+Au 3 GeV STAR CBWC only

with participant based centrality
without volume correction



Au + Au, $\sqrt{s_{NN}} = 3.0$ GeV
Proton, $-0.5 < y < 0$
 $0.4 < p_T < 2.0$ GeV/c

□ Data
■ UrQMD

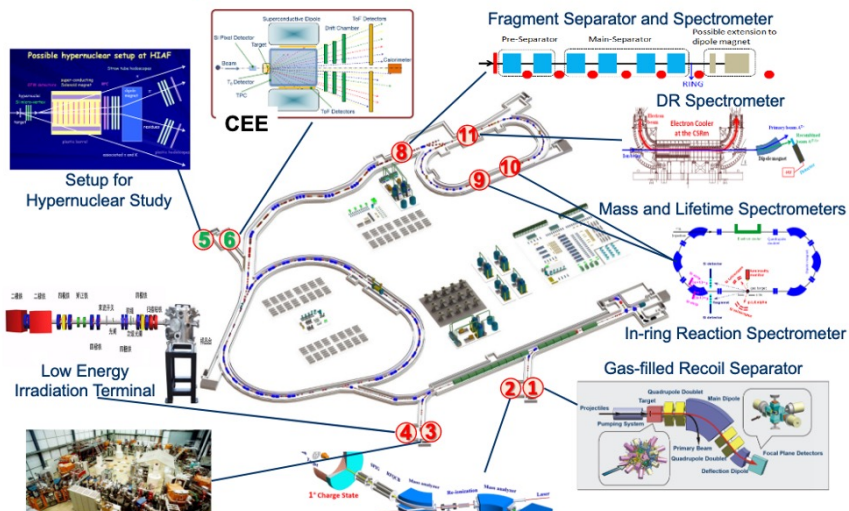
STAR, PRC107 (2023) 024908

HADES, PRC102 (2020) 024914

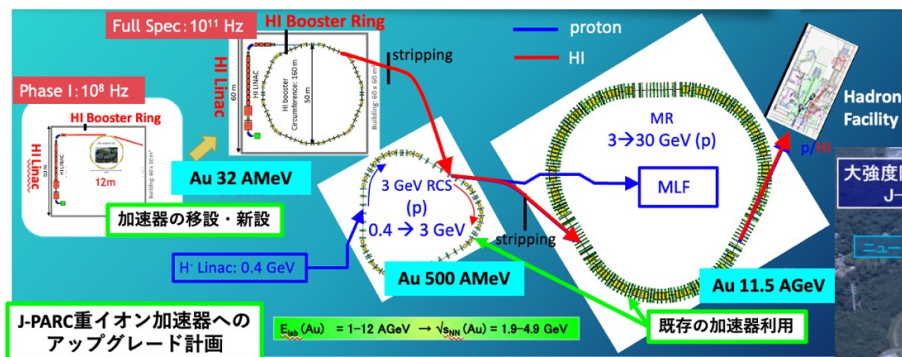
中国における実験

- HIRFL-CSR計画
- HIAF計画 2025年～

High Intensity heavy ion Accelerator Facility (HIAF)



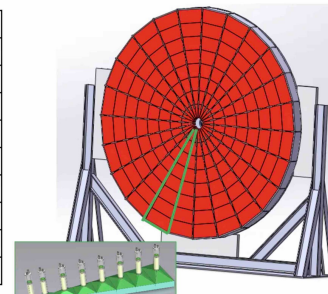
茨城県東海村 J-PARC (原研・KEK)



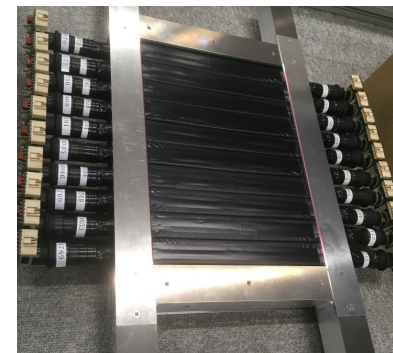
概述 - ZDC探测器介绍

- 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	> 1m ²

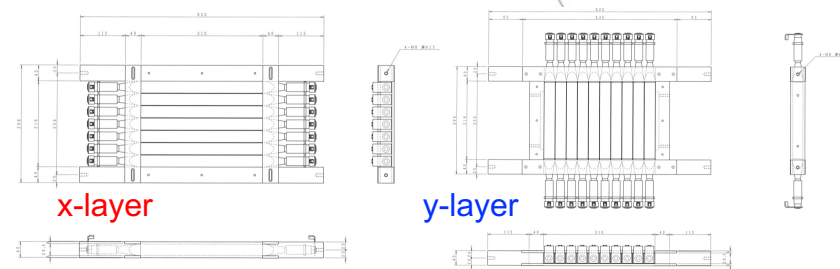
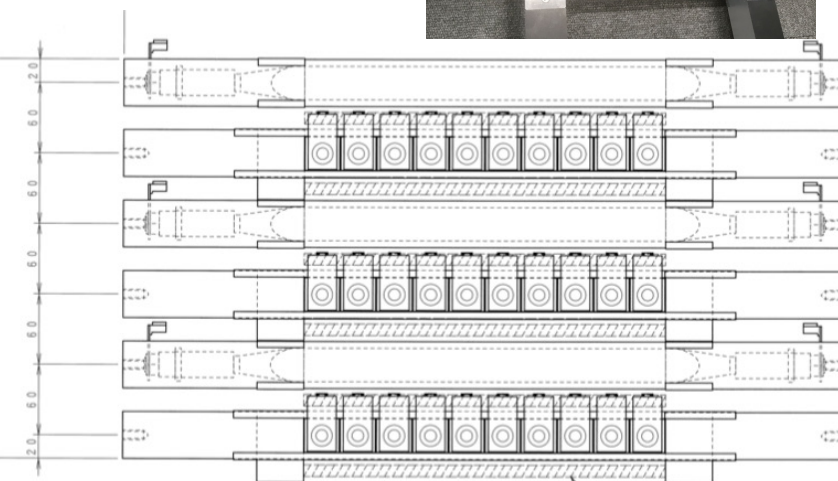


ZDC・RP検出器 HIAF-CEE実験

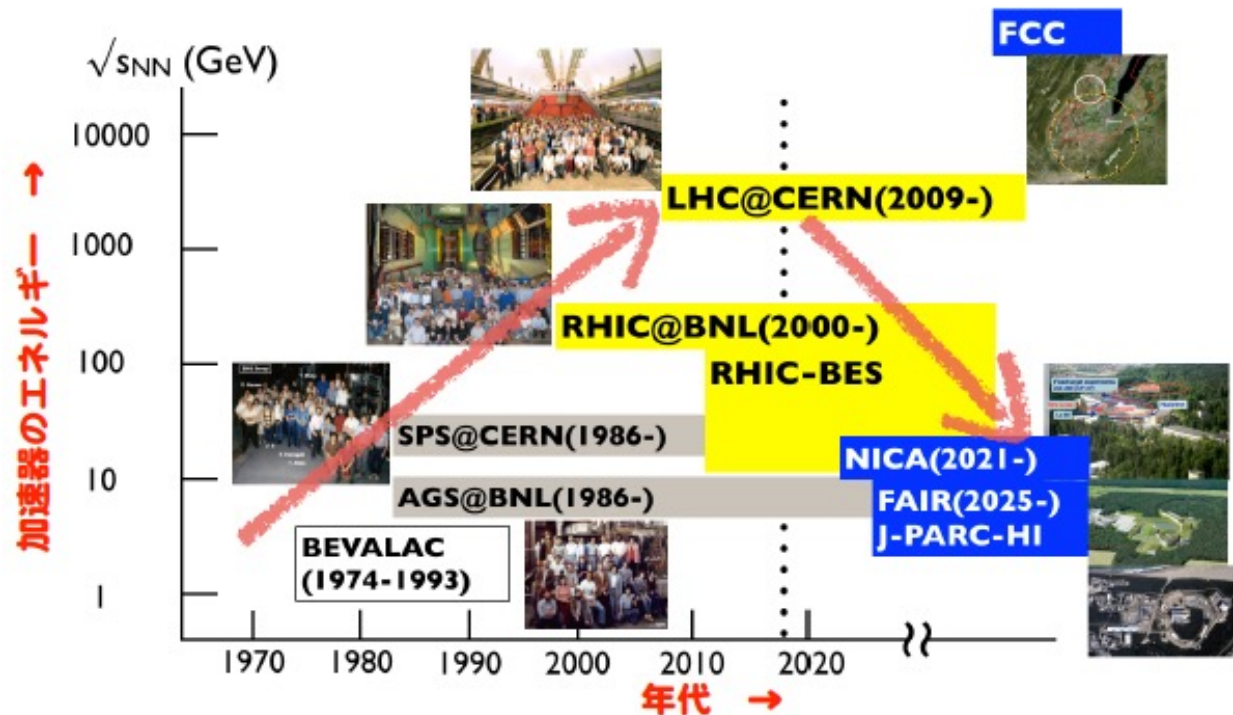
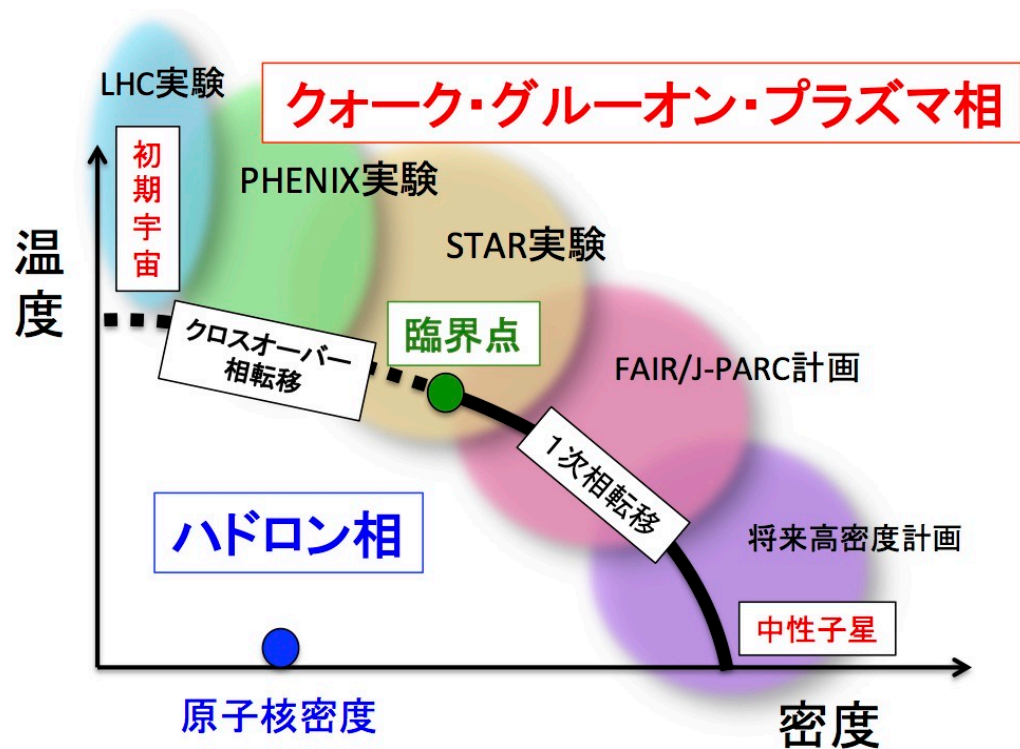


中性子検出器 FAIR-CBM実験 J-PARC重イオン

x-layer
y-layer
x-layer
y-layer
x-layer
y-layer



History of Heavy-Ion Facilities and My Interests ...



おわりに

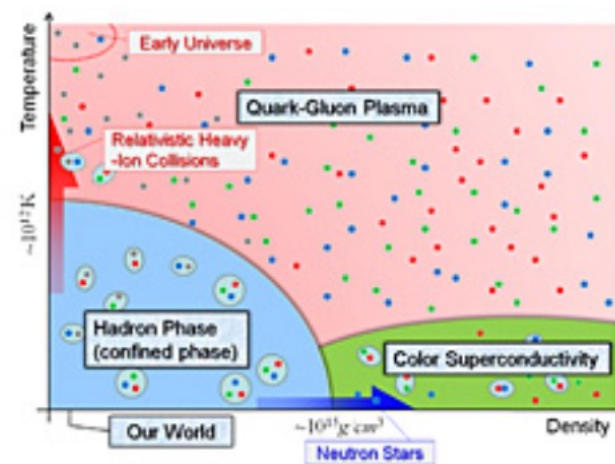
- ビームエネルギー走査実験
- 温度・フロー・ゆらぎ測定
- まとめと将来計画

浅川さん、還暦おめでとうございます。
これからもご活躍され、そしてご指導下さい。
大学院生の頃に、既に海外で活躍されていた浅川さんに励まされた事をよく思い出します。
浅川さんたちが予言されてきた臨界点の発見や、QCD相図の理解を目指して、今後も頑張ります。
今後とも、どうぞよろしくお願ひします。
筑波大物理、江角

浅川さんの
紹介ページより

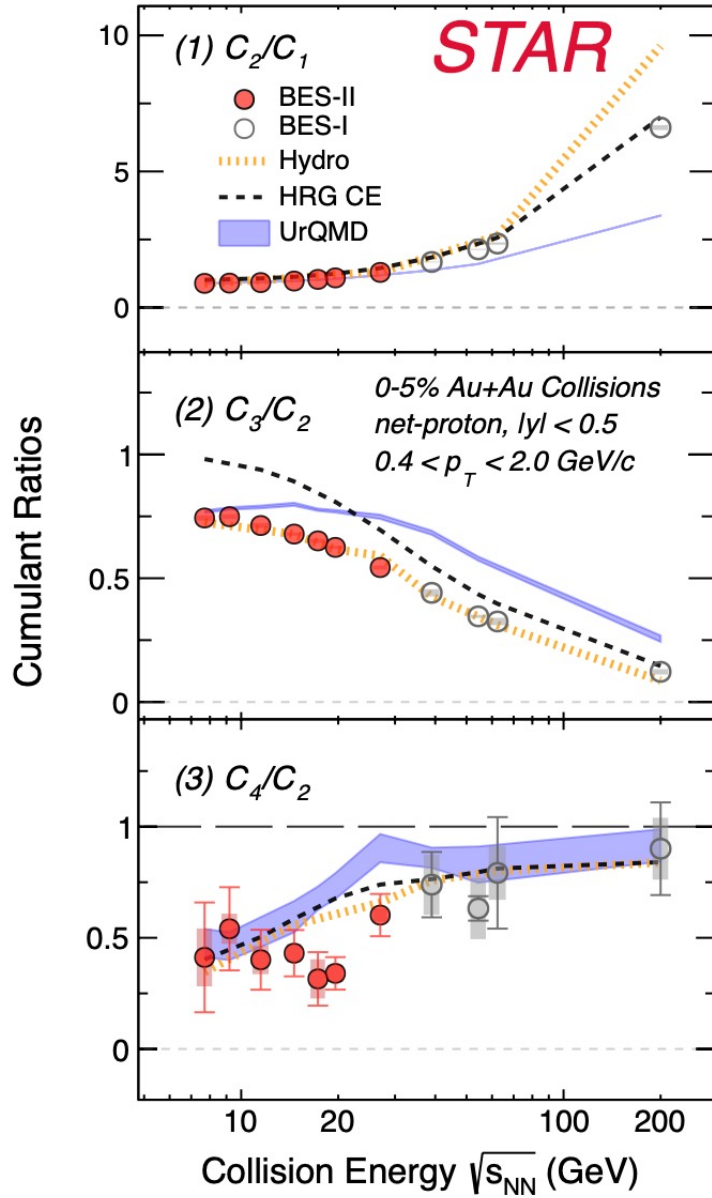


臨界点はどこ？



Expected phase diagram of QCD matter

Net-proton cumulant ratios



Proton/antiproton factorial cumulant ratios

