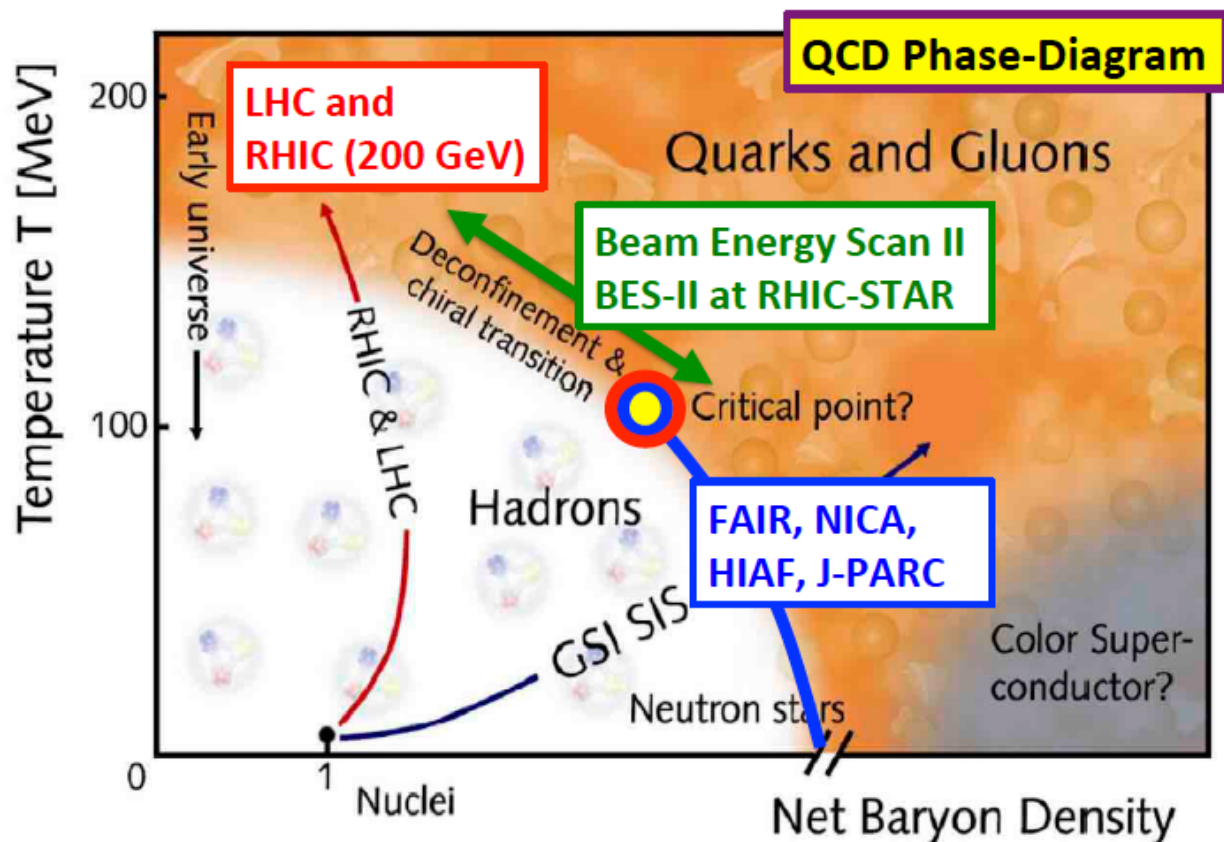


RHIC-STAR実験のBeam Energy Scanによる 1次相転移・臨界点・渦・磁場への挑戦

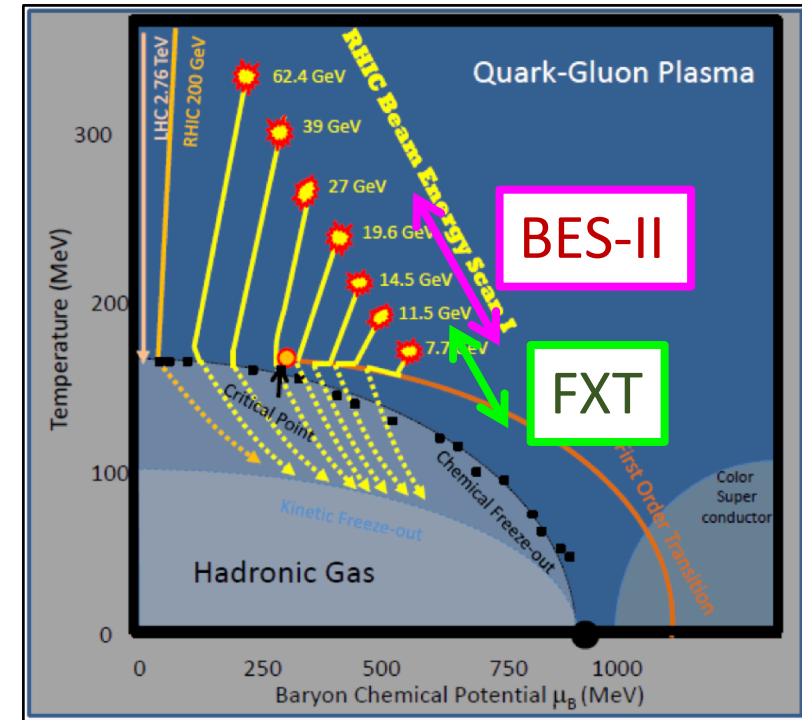
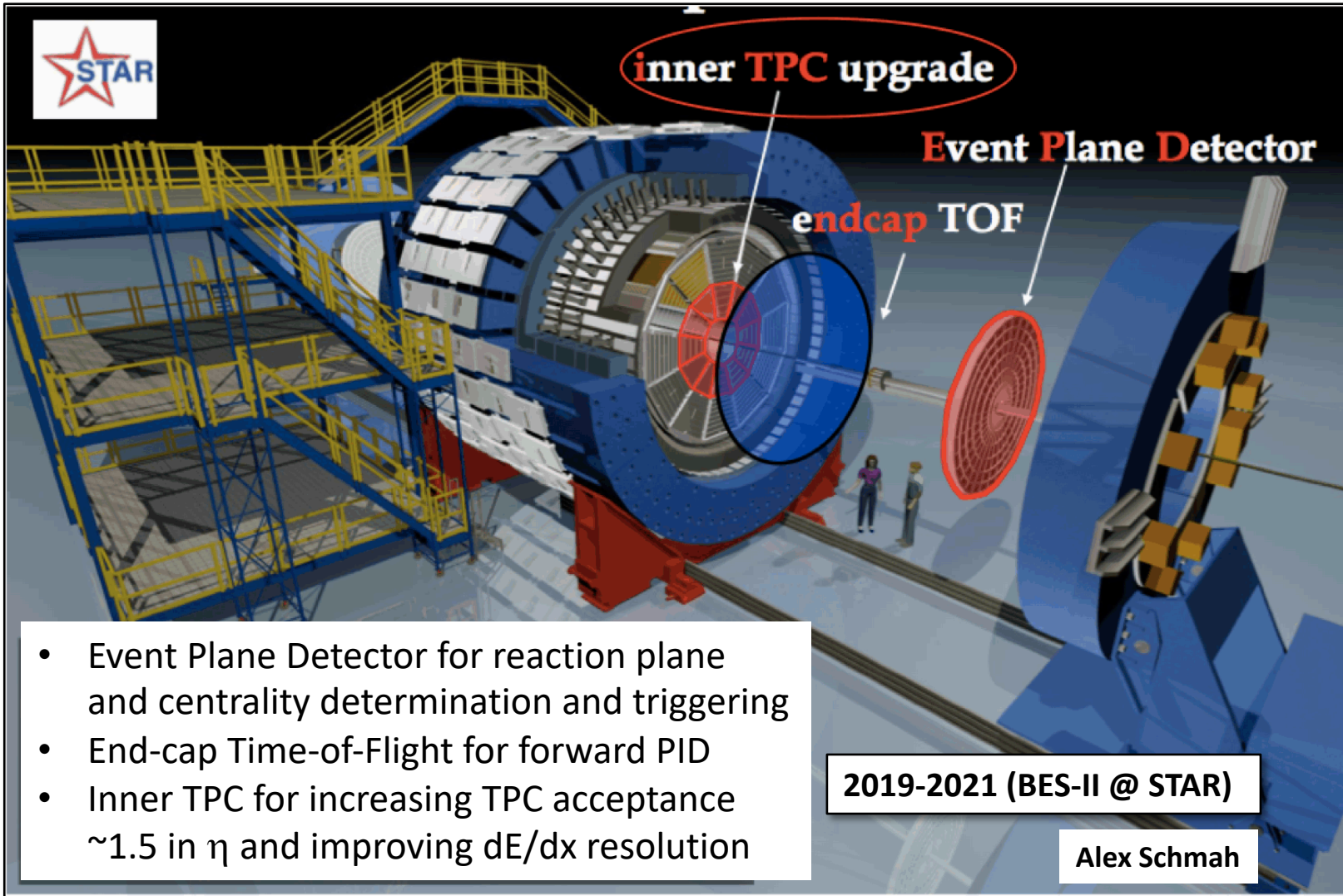


筑波大学 数理物質系 物理学域
宇宙史研究センター 江角晋一

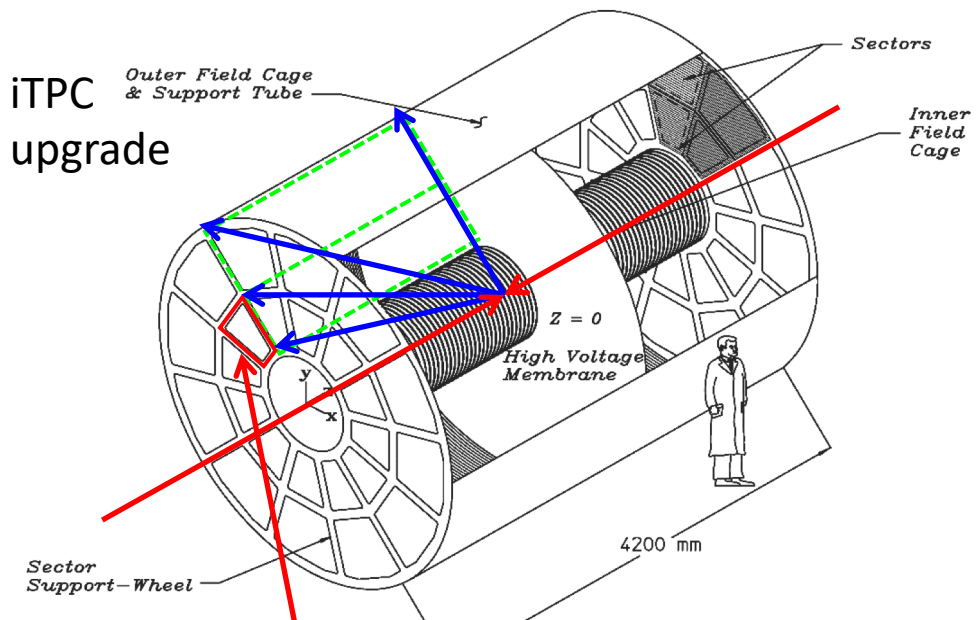
Contents

- Experimental setup
- Freeze-out measurements
- Fluctuation and correlation measurements
- Elliptic and Directed flow measurements
- Vorticity and Chiral magnetic ...

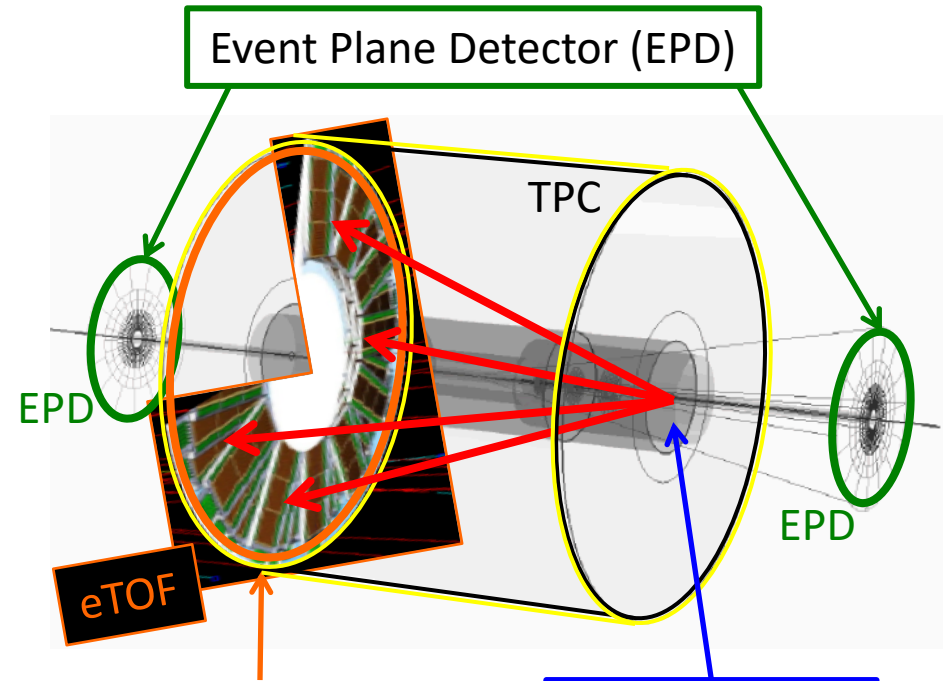
Beam Energy Scan Phase-II @ STAR



STAR detector upgrades for BES-II program



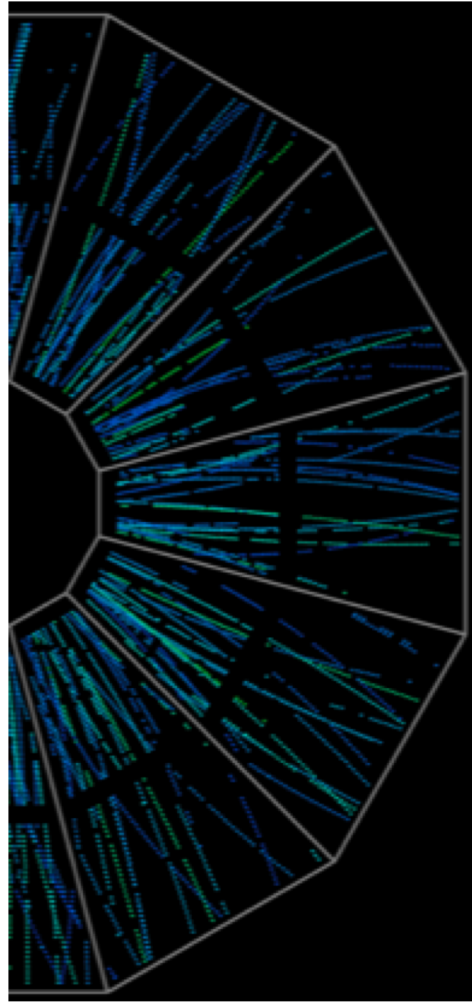
TPC inner sector readout with more segmentation



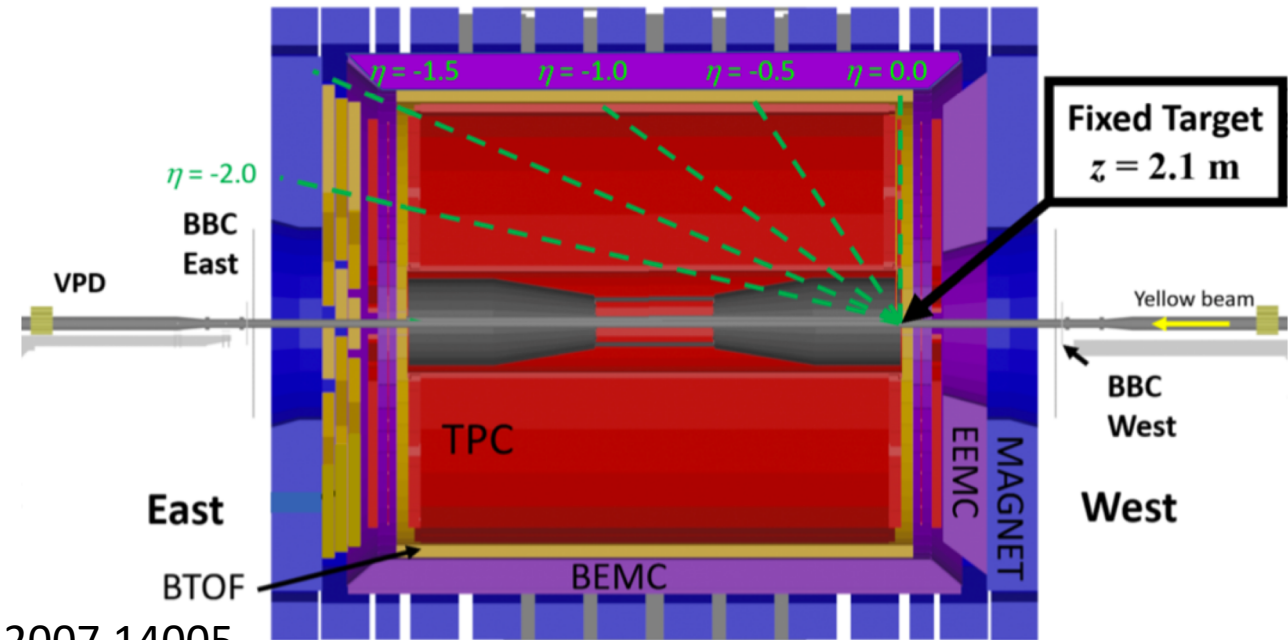
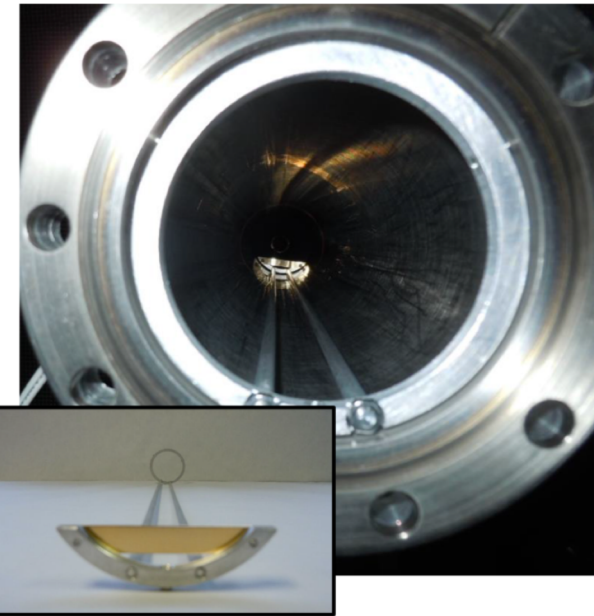
End-cap Time-of-Flight (eTOF) from FAIR-CBM

Fixed target mode

Inner TPC upgrades for wider eta coverage

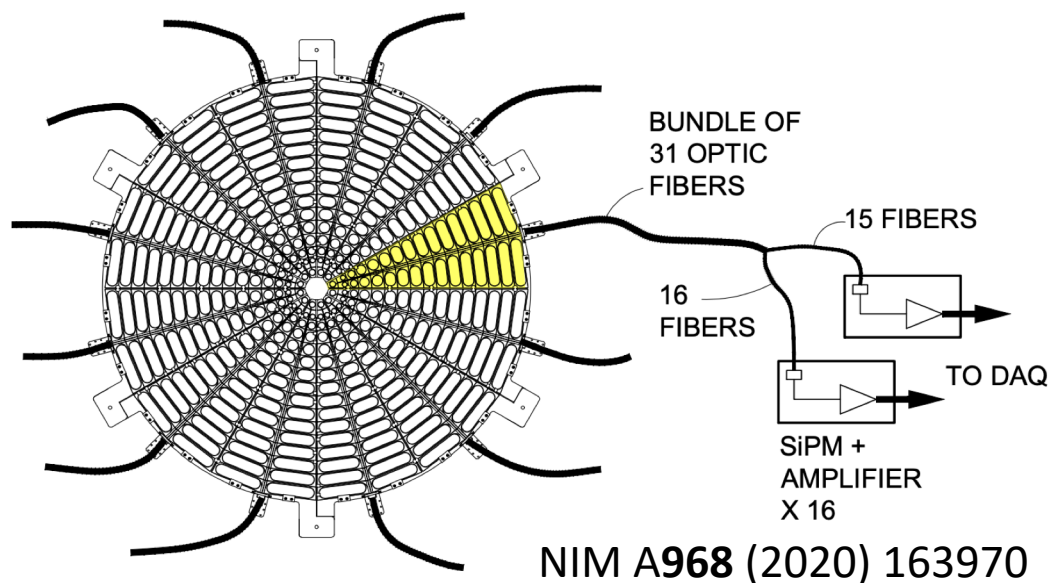
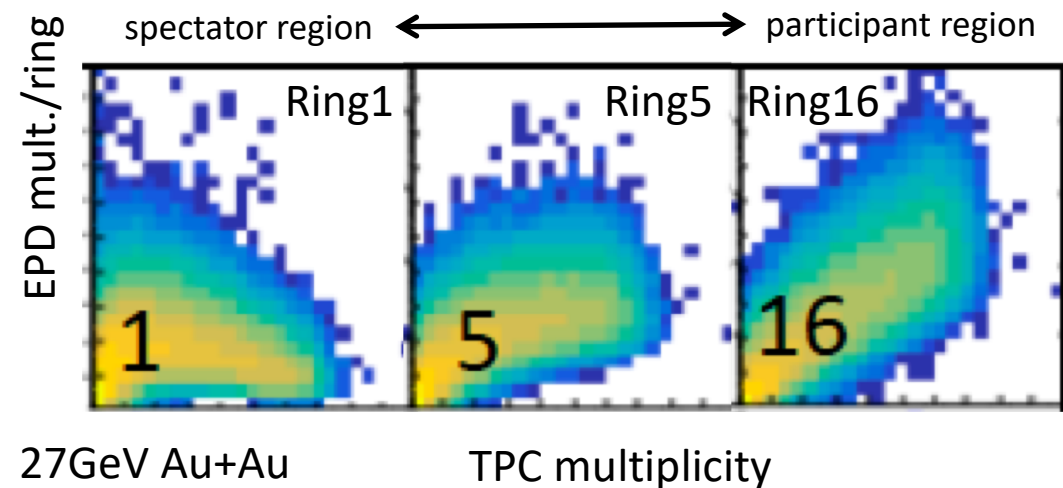


fixed target at $z=210\text{cm}$
inside the beam pipe for
lower CM energy collisions

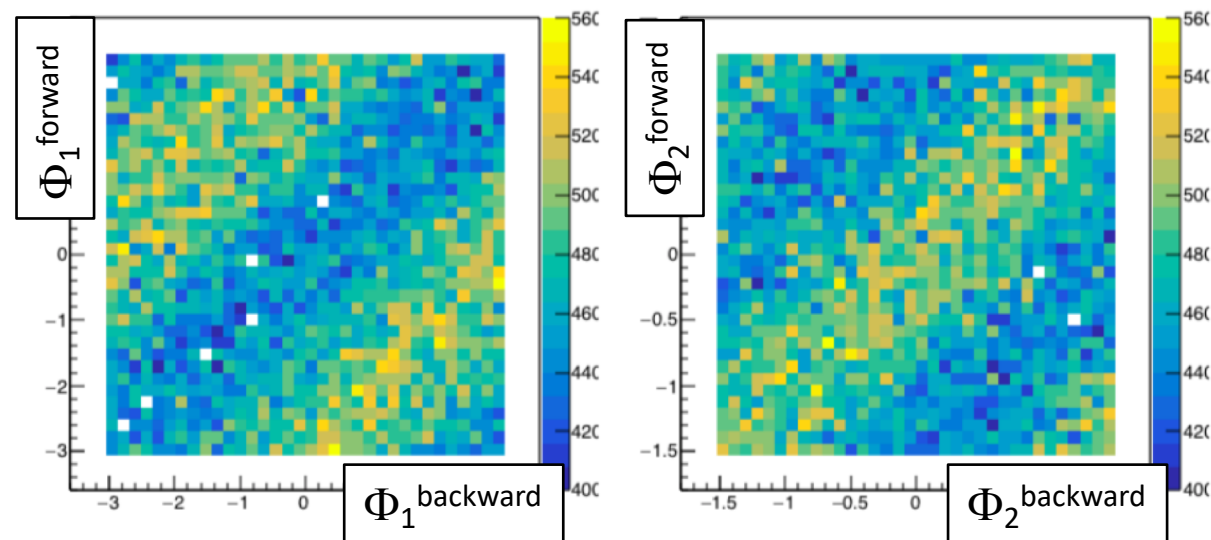


arXiv:2007.14005

Event Plane Detector (EPD) $|\eta|=2\sim 5$ in both forward and backward eta region for reaction plane, centrality and triggering

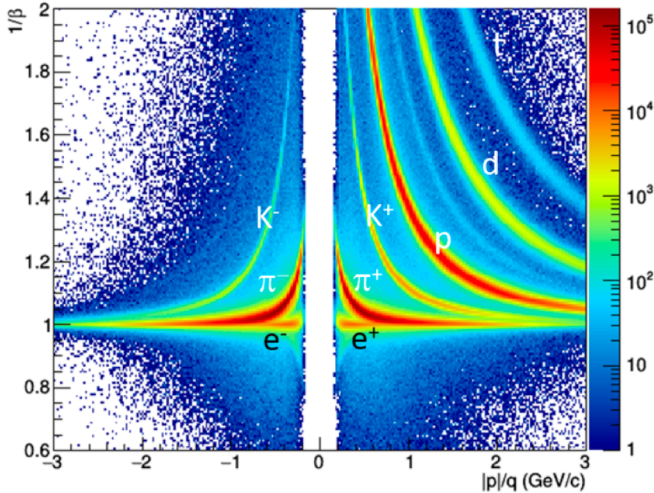
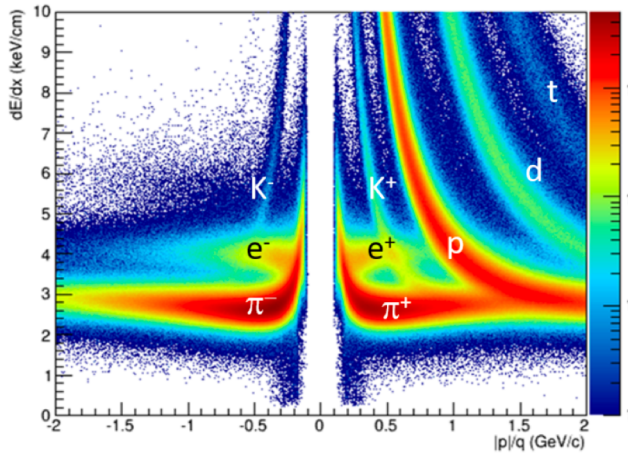


Forward-backward event-plane correlation



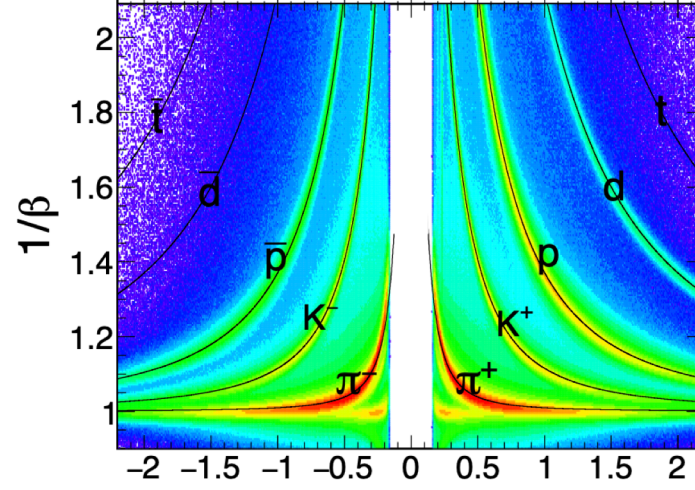
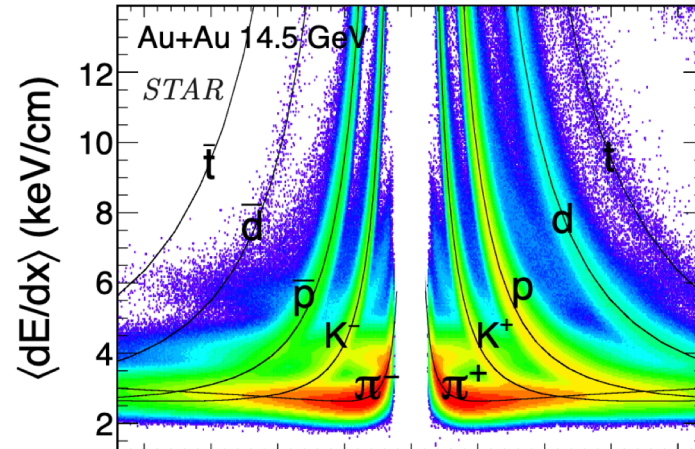
Particle identification via dE/dx (TPC), beta(TOF) and M_{inv} reconstruction

$\sqrt{s}NN=4.5\text{GeV}$ Fixed Target



arXiv:2007.14005

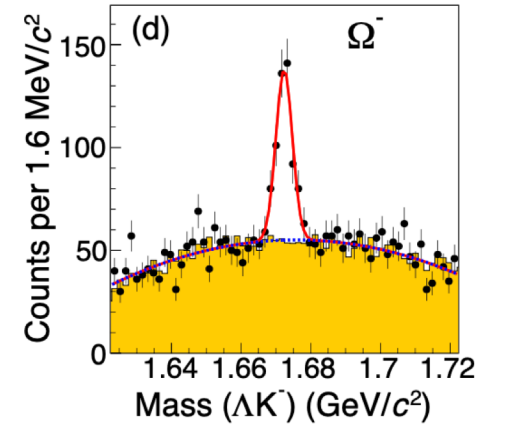
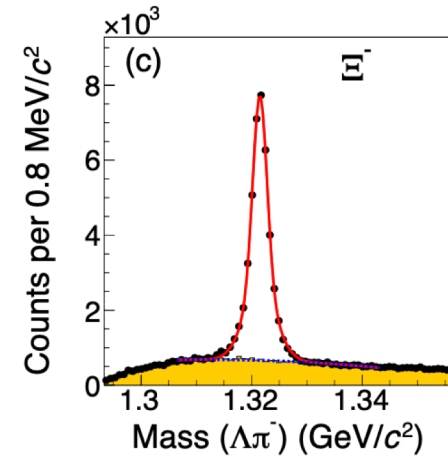
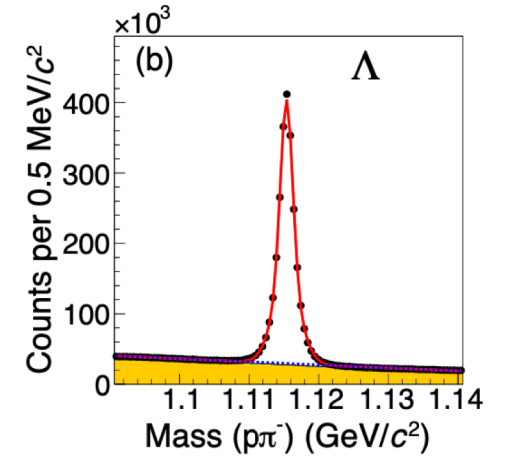
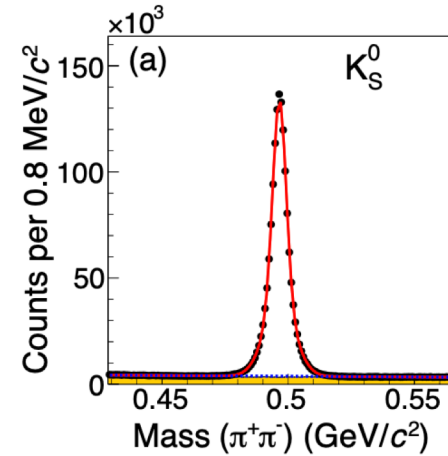
$\sqrt{s}NN=14.5\text{GeV}$ Collider



p/q (GeV/c)

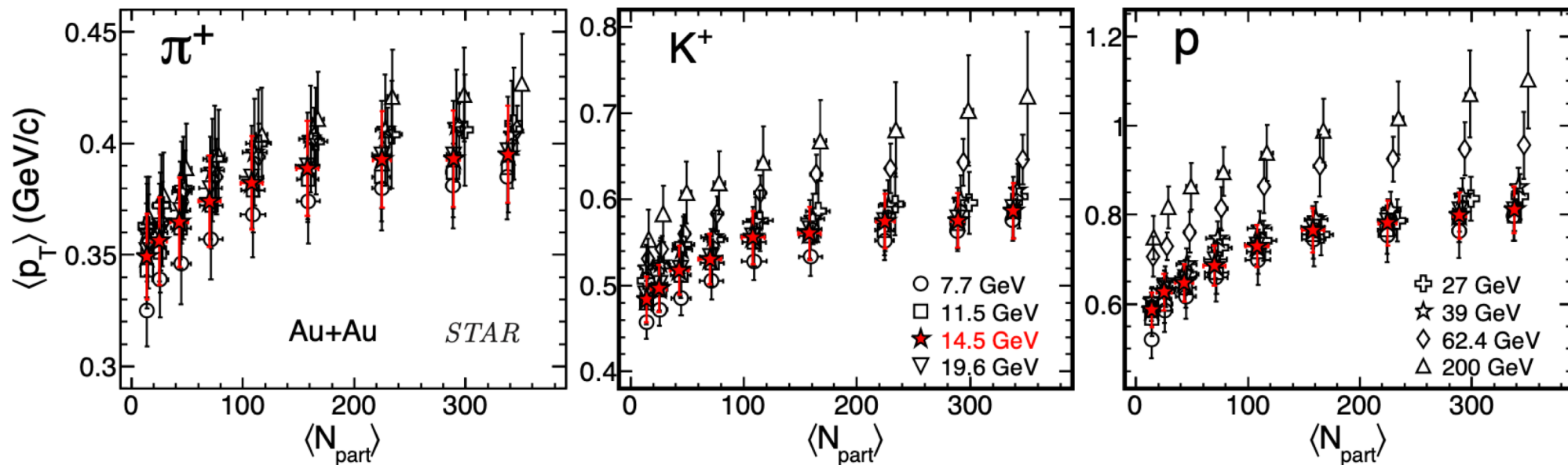
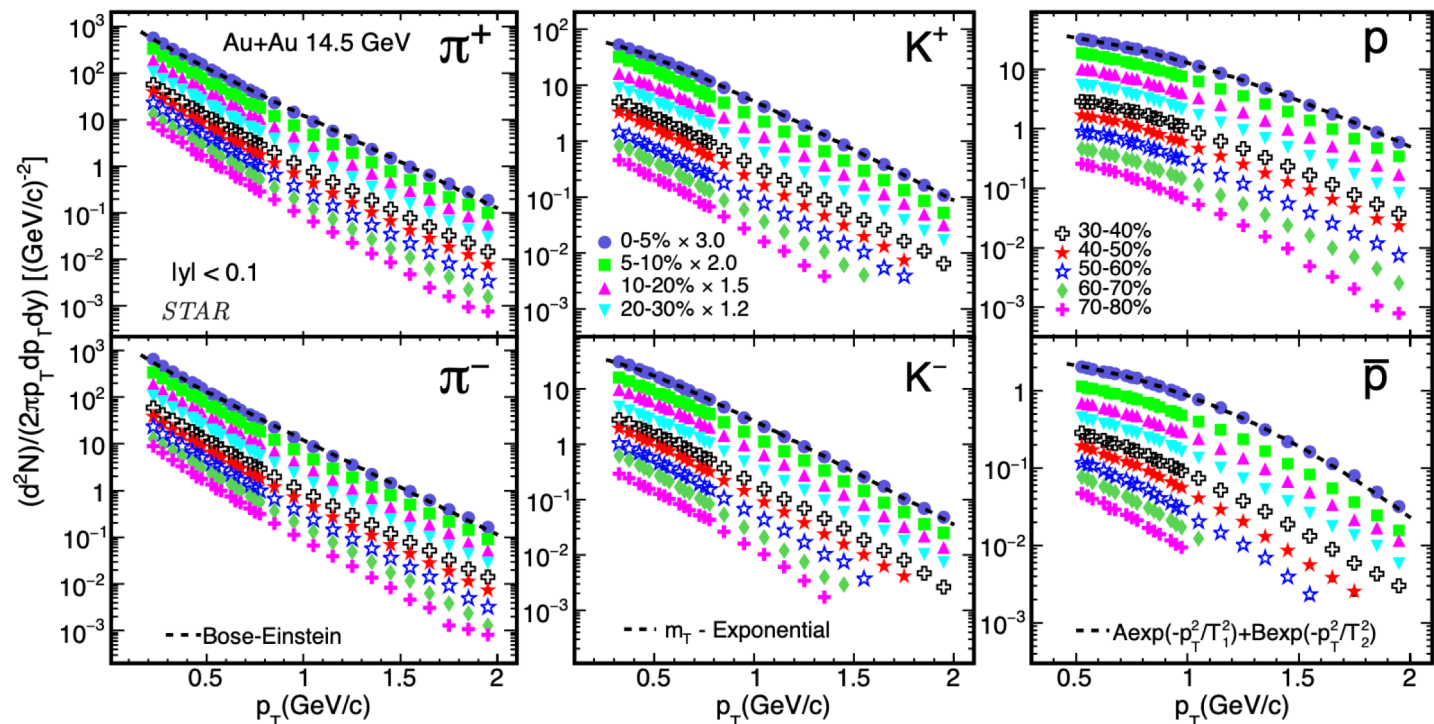
PRC **101** (2020) 24905

$\sqrt{s}NN=7.7\text{GeV}$ Collider



PRC **102** (2020) 34909

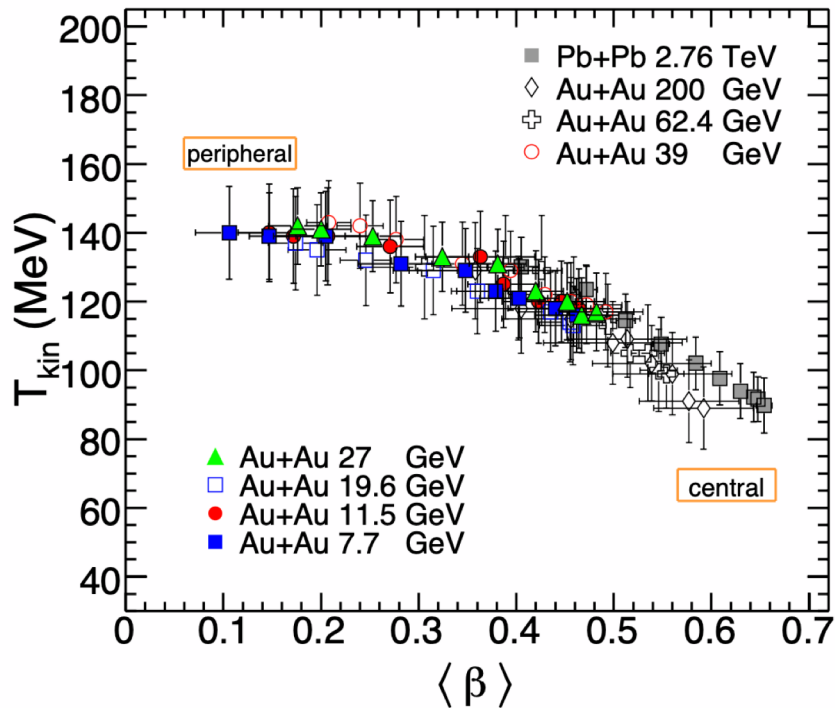
Identified hadron spectra
for pions, kaons, proton
and anti-proton
yields and shapes



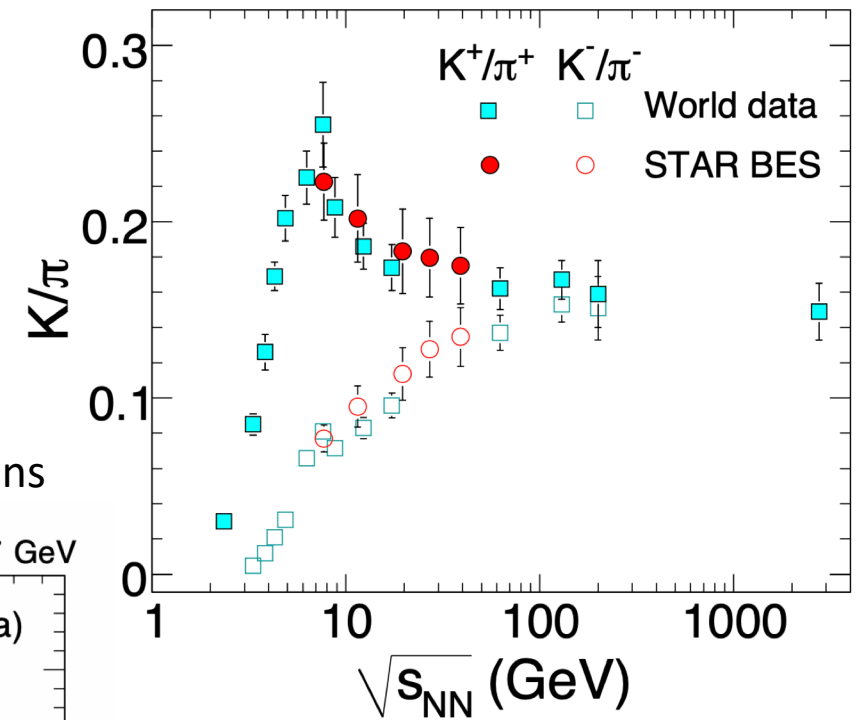
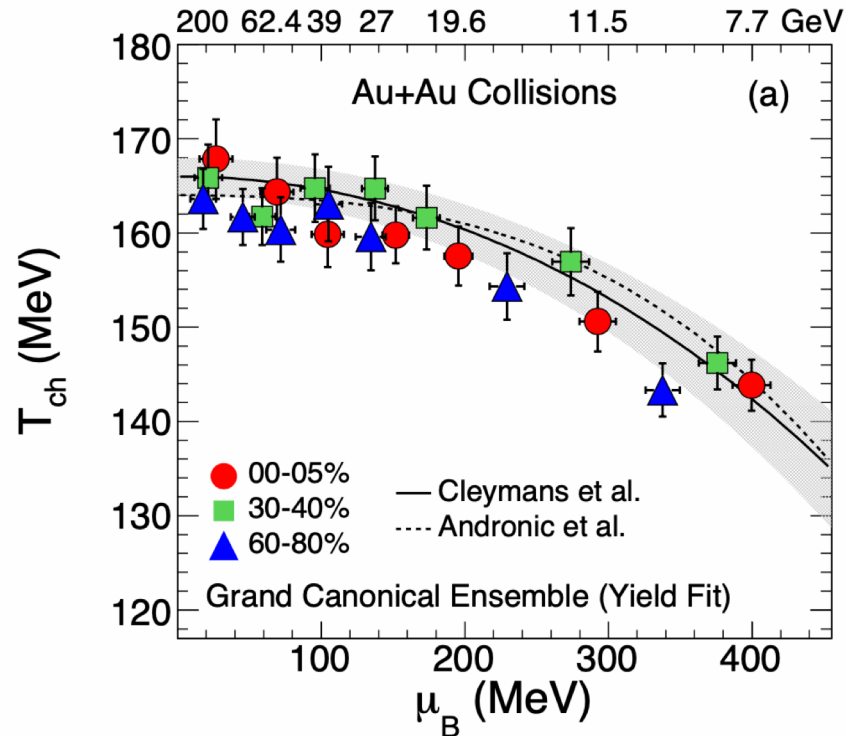
PRC **101** (2020) 24905

Kinetic and chemical freeze-out parameters via fitting based on thermal models

T_{kin} vs β_T at kinetic freeze-out with Blast wave model fitting



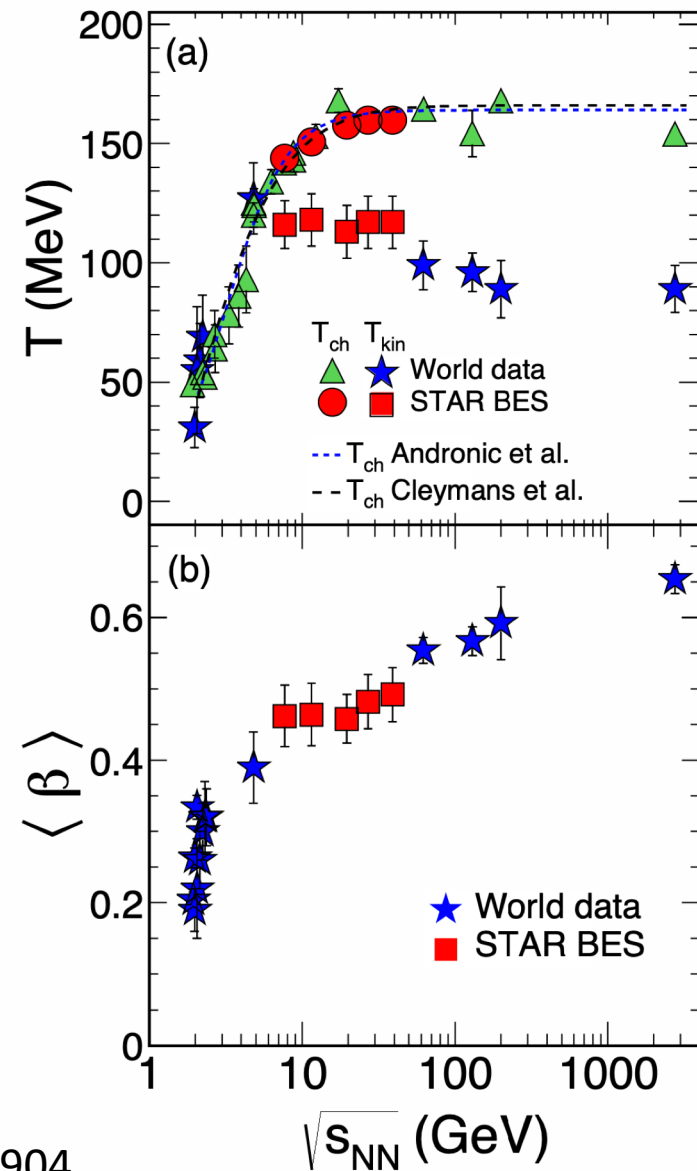
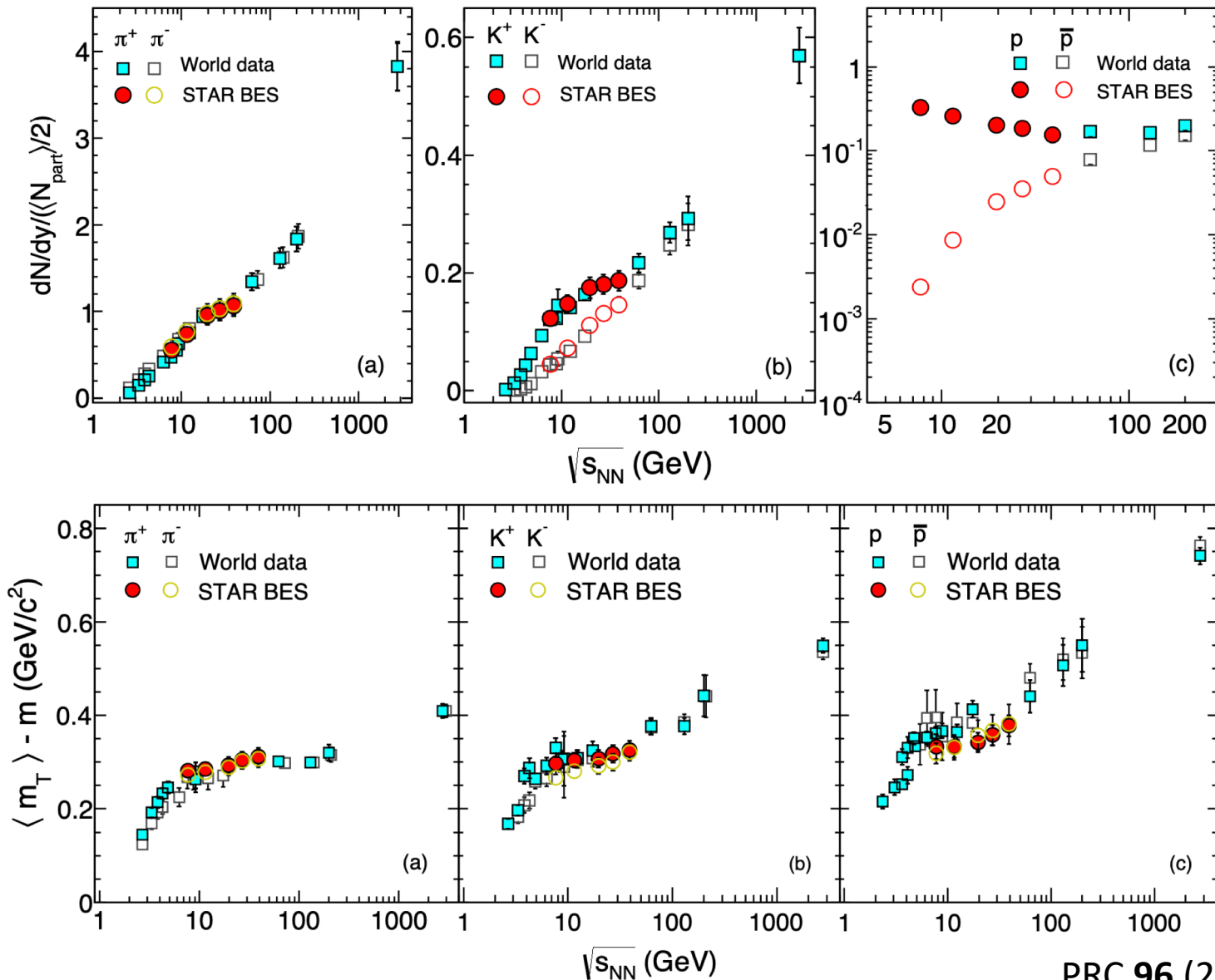
T_{ch} vs μ_B at chemical freeze-out by fitting yields and ratios of hadrons



“K/pi horn (NA49/SPS)”
Associate production with Λ at high baryon density

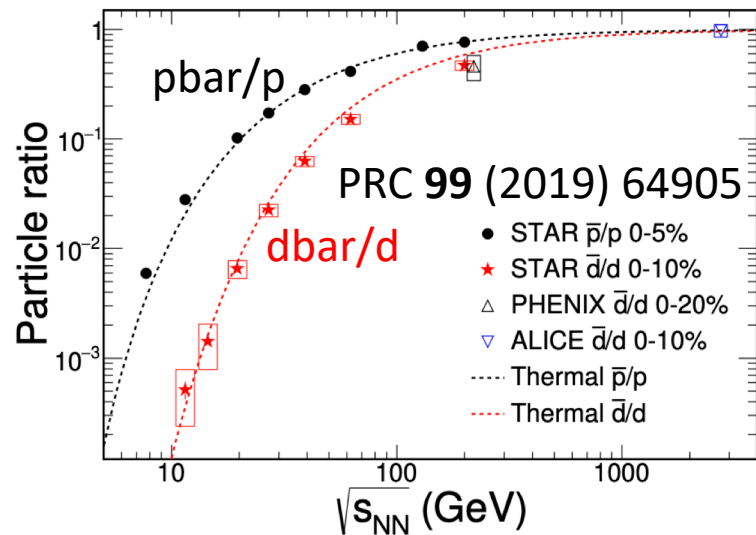
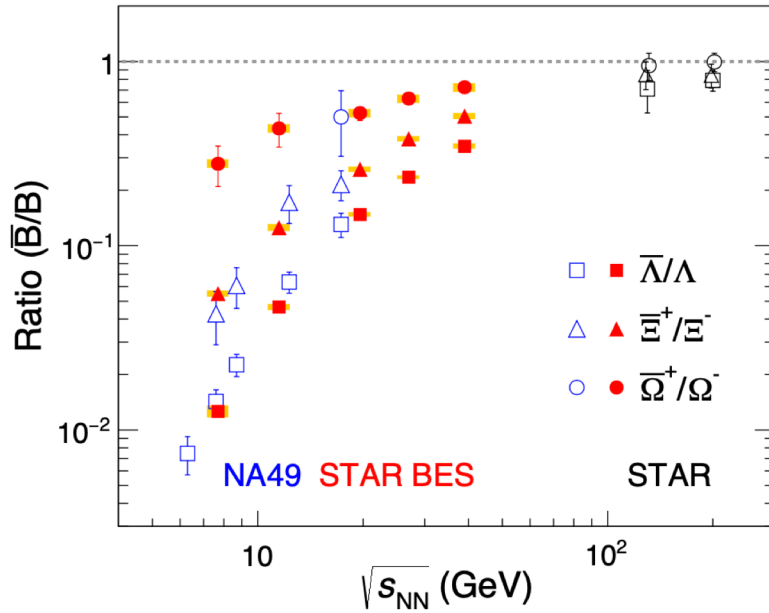
Phys. Rev. C **96** (2017) 44904

Beam energy dependence of yield, shape and freeze-out parameters

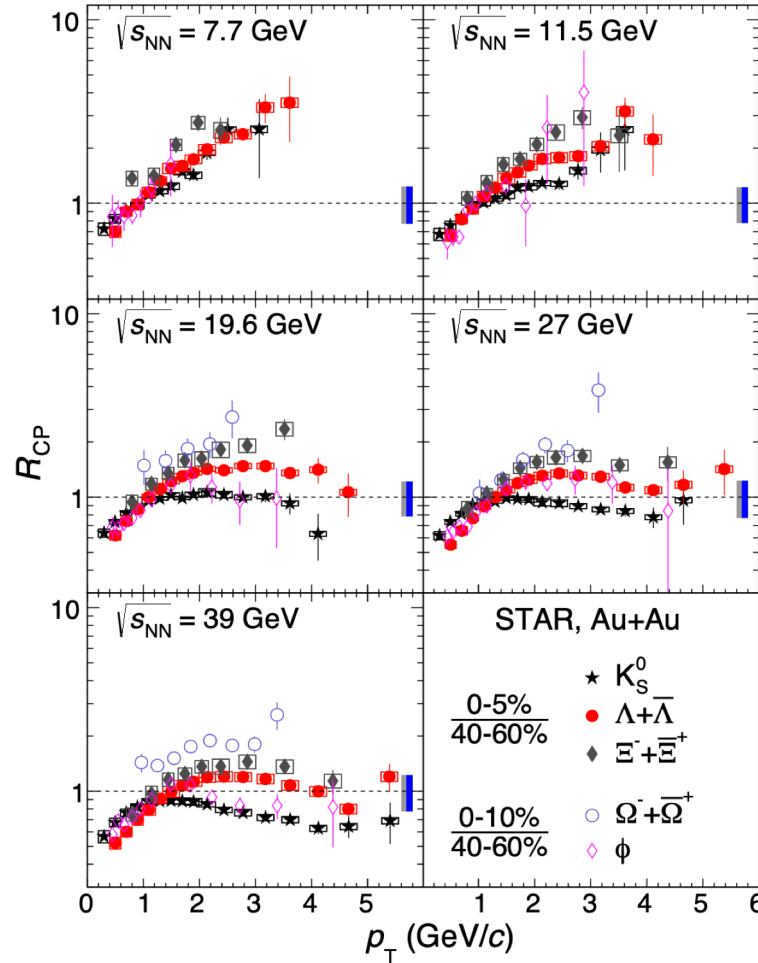


PRC 96 (2017) 44904

Strangeness enhancement and/or jet quenching

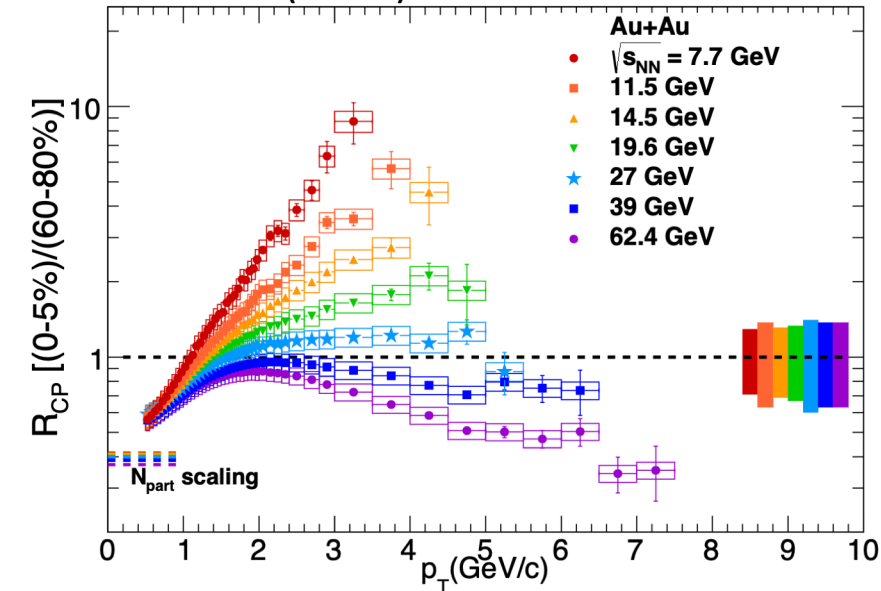


PRC 102 (2020) 34909

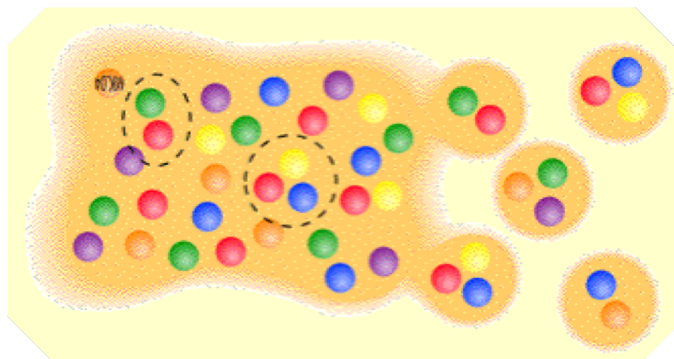
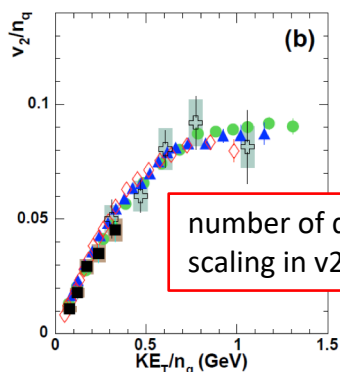


Nuclear modification factor R_{CP} (R_{AA}) of multi-strangeness hadrons and charged particles for different beam energies

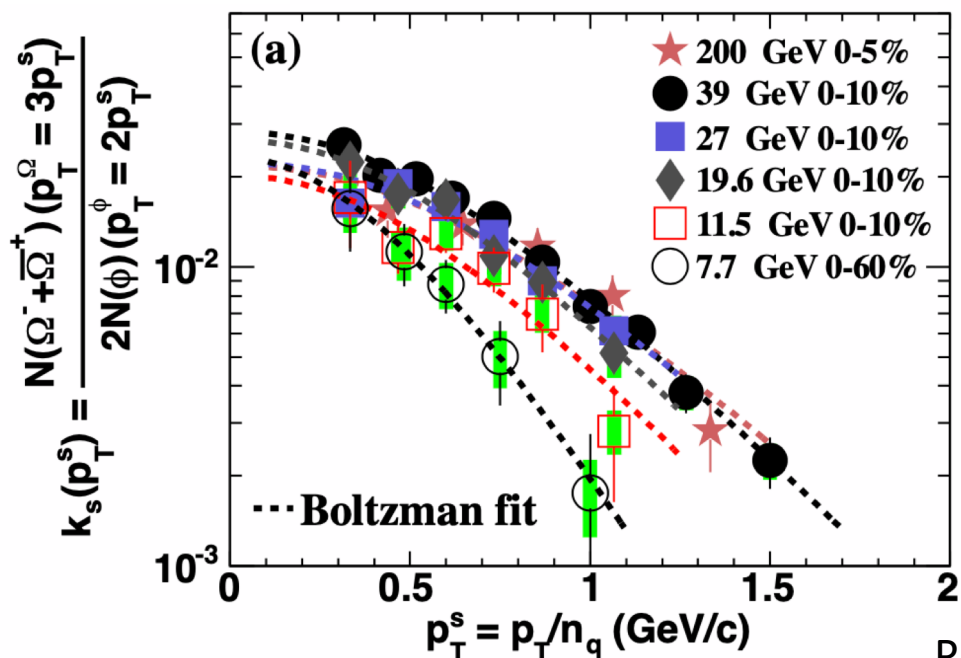
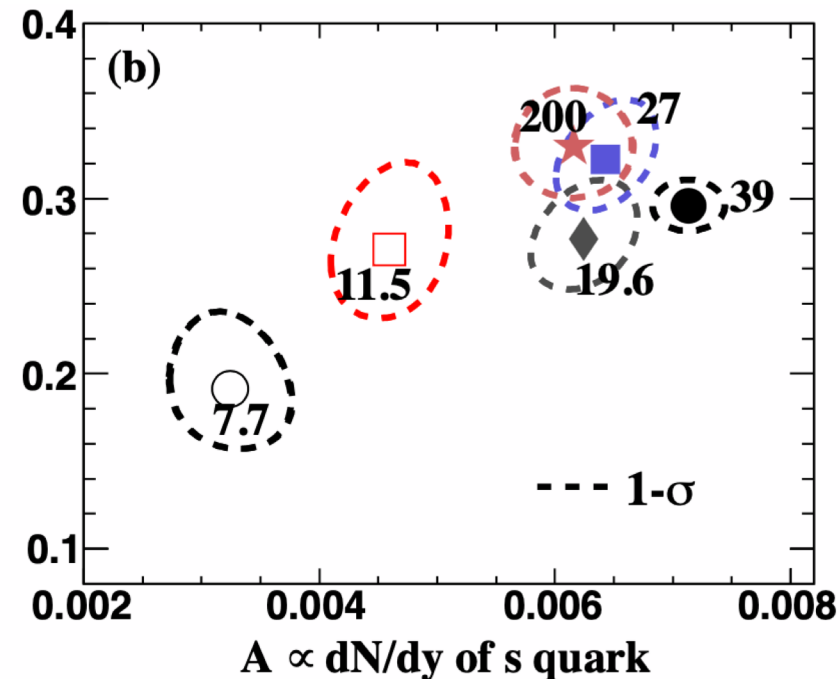
PRL 121 (2018) 32301



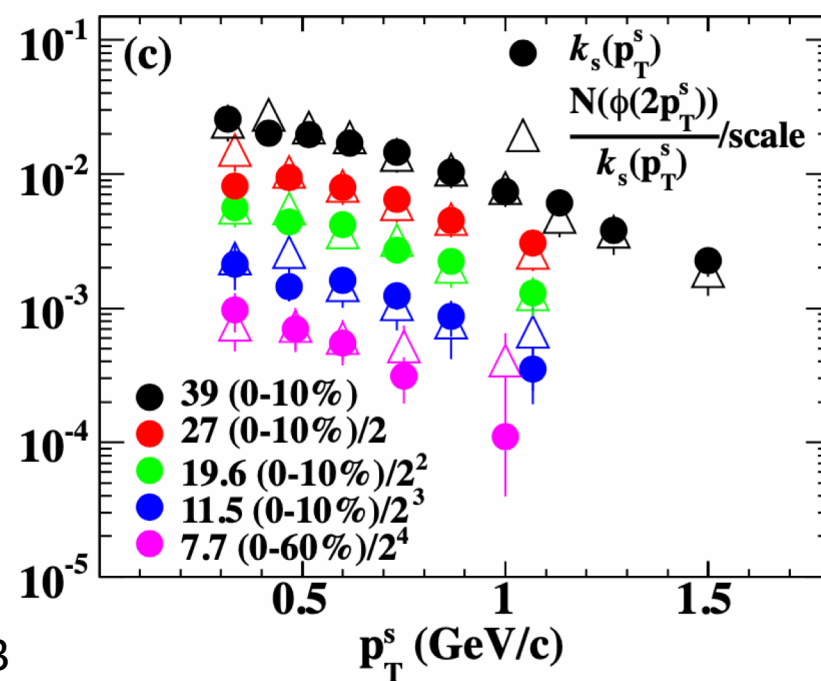
Extraction of strange quark p_T distribution based on quark coalescence picture



Slope T (GeV)

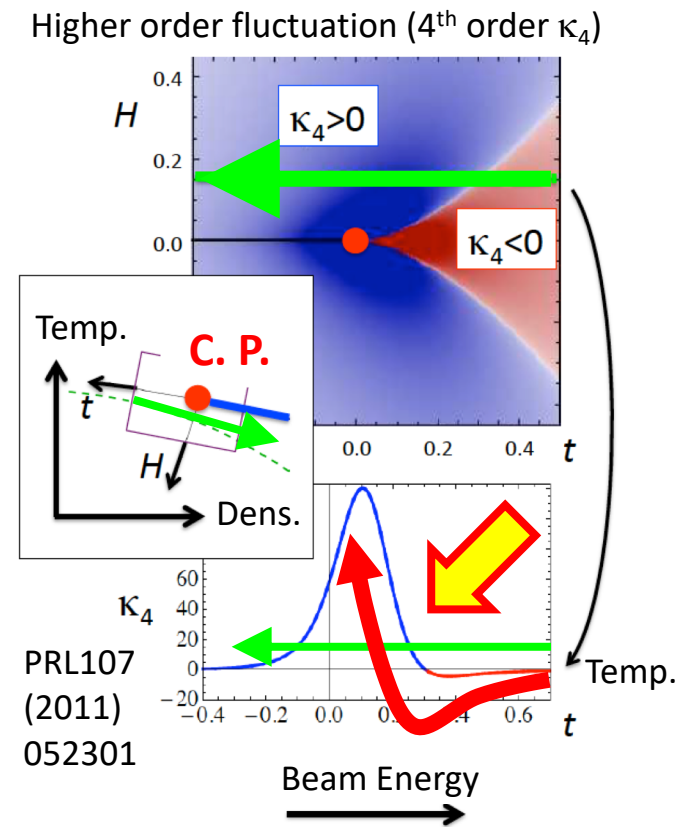
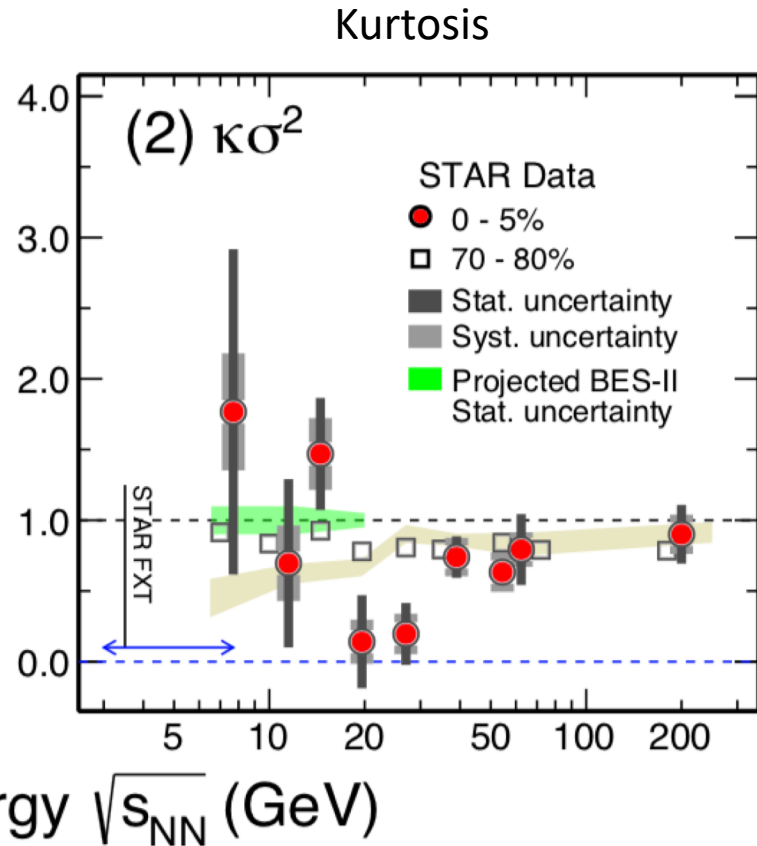
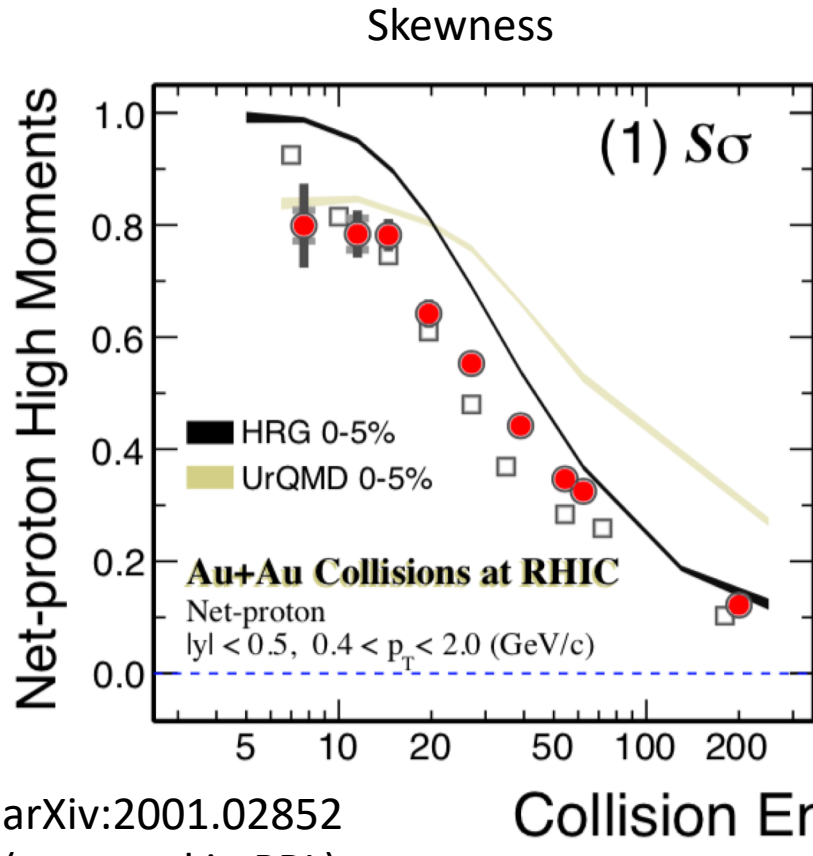


Ratios



PRC 93 (2016) 21903

Higher order fluctuation of net-proton distribution as a proxy for the conserved net-Baryon fluctuation



arXiv:2001.02852
(accepted in PRL)

PRL107
(2011)
052301

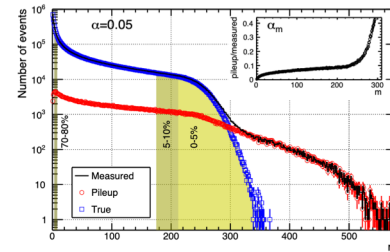
Technical improvements in fluctuation analysis

PRC 95 (2017) 064912

NIN A984 (2020) 164632

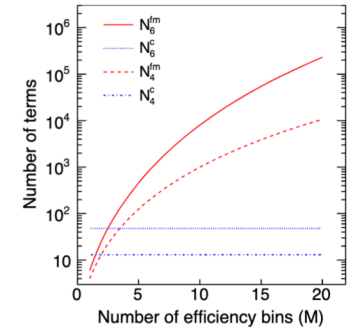
Pileup corrections on higher-order cumulants

Toshihiro Nonaka,^{1,*} Masakiyo Kitazawa,^{2,3,†} and ShinIchi Esumi^{1,‡}



More efficient formulas for efficiency correction of cumulants and effect of using averaged efficiency

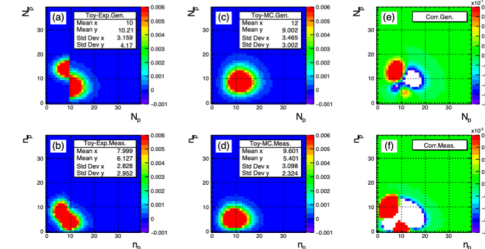
Toshihiro Nonaka,¹ Masakiyo Kitazawa,^{2,3} and ShinIchi Esumi¹



NINA 987 (2020) 164802

Reconstructing particle number distributions with convoluting volume fluctuations

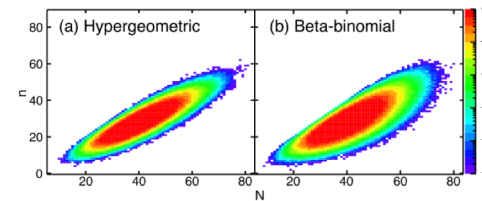
ShinIchi Esumi,^{1,*} Kana Nakagawa,¹ and Toshihiro Nonaka^{1,2,‡}



NIMA 906 (2018) 08.013

A general procedure for detector-response correction of higher order cumulants

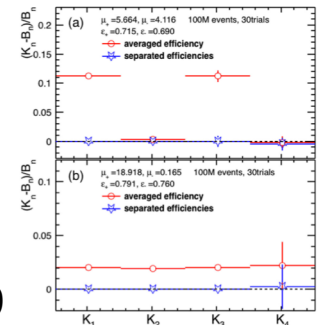
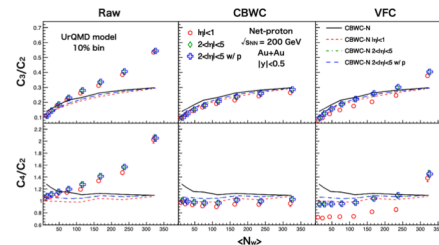
Toshihiro Nonaka,^{1,2,*} Masakiyo Kitazawa,^{3,4,†} and ShinIchi Esumi^{2,‡}



PRC 100 (2019) 044904

Volume fluctuation and multiplicity correlation on higher-order cumulants

Tetsuro Sugiura,^{1,*} Toshihiro Nonaka,^{2,†} and ShinIchi Esumi^{1,‡}



PRC 94 (2016) 034909

Importance of separated efficiencies between positively and negatively charged particles for cumulant calculations

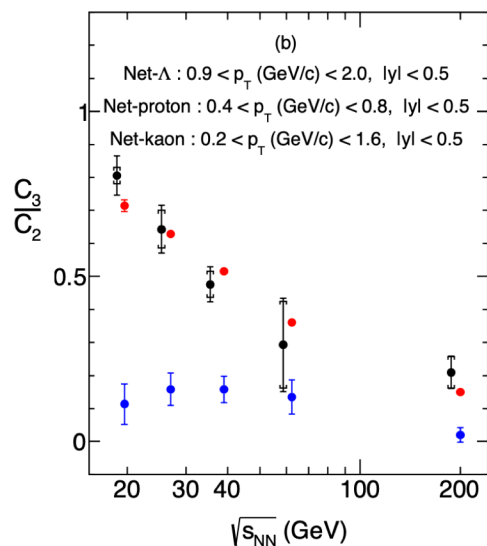
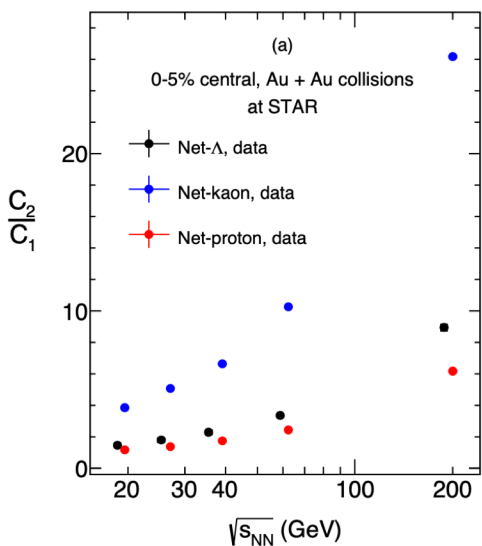
Toshihiro Nonaka,^{1,*} Tetsuro Sugiura,^{1,†} ShinIchi Esumi,¹ Hiroshi Masui,¹ and Xiaofeng Luo²

T. Nonaka (Tsukuba, CCNU), M. Kitazawa (Osaka)

Higher order fluctuation of net-Lambda, net-proton and net-kaon distribution

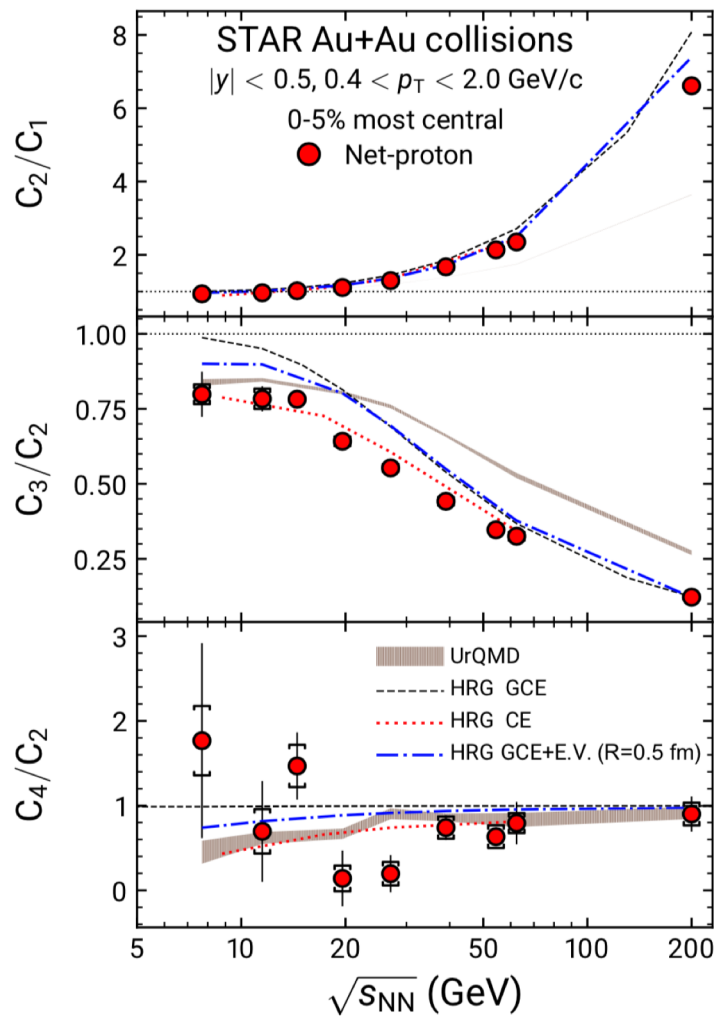
2nd order net-Lambda

3rd order net-Lambda



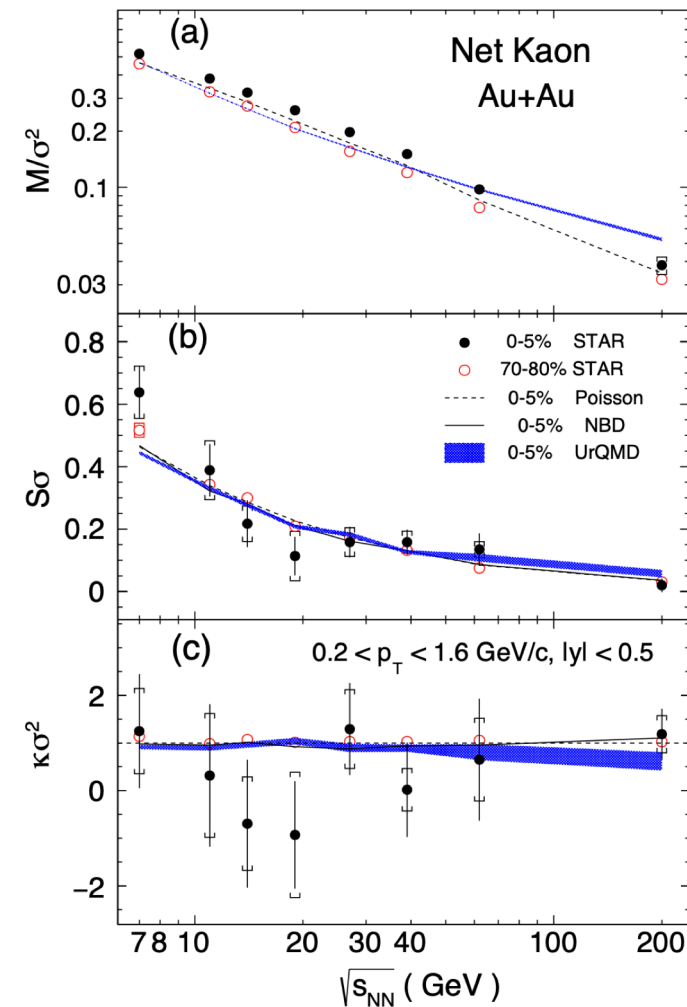
PRC **102** (2020) 24903

2nd – 4th order net-proton



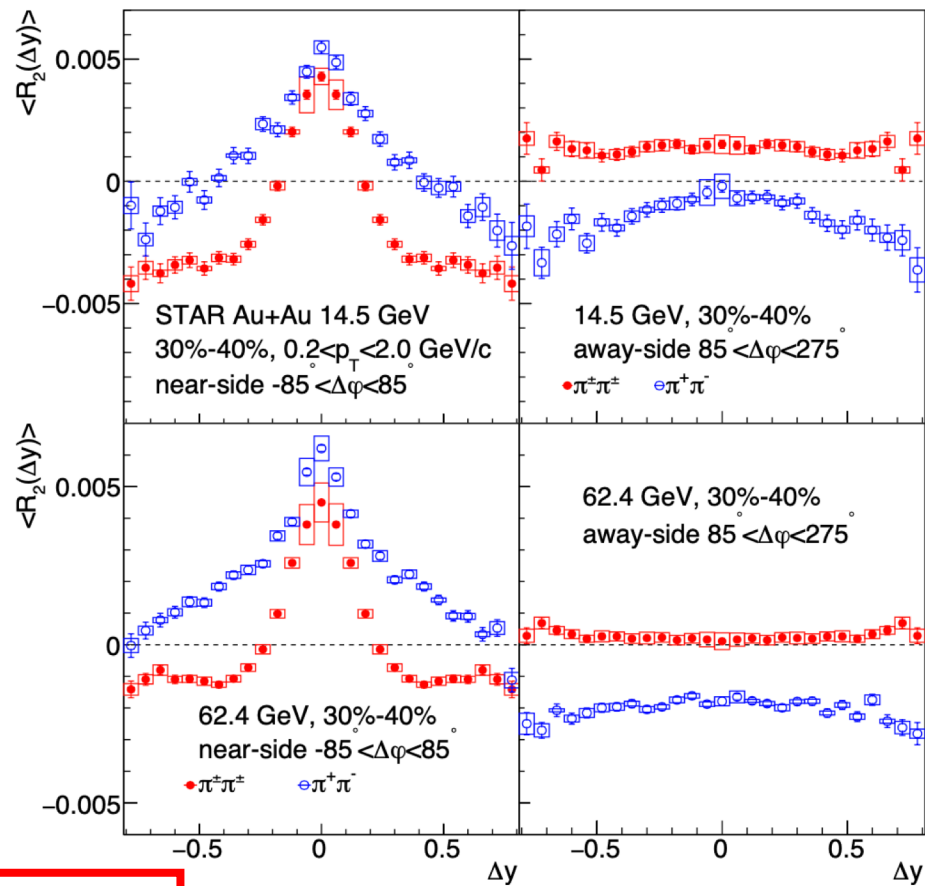
arXiv:2101.12413

2nd – 4th order net-kaon

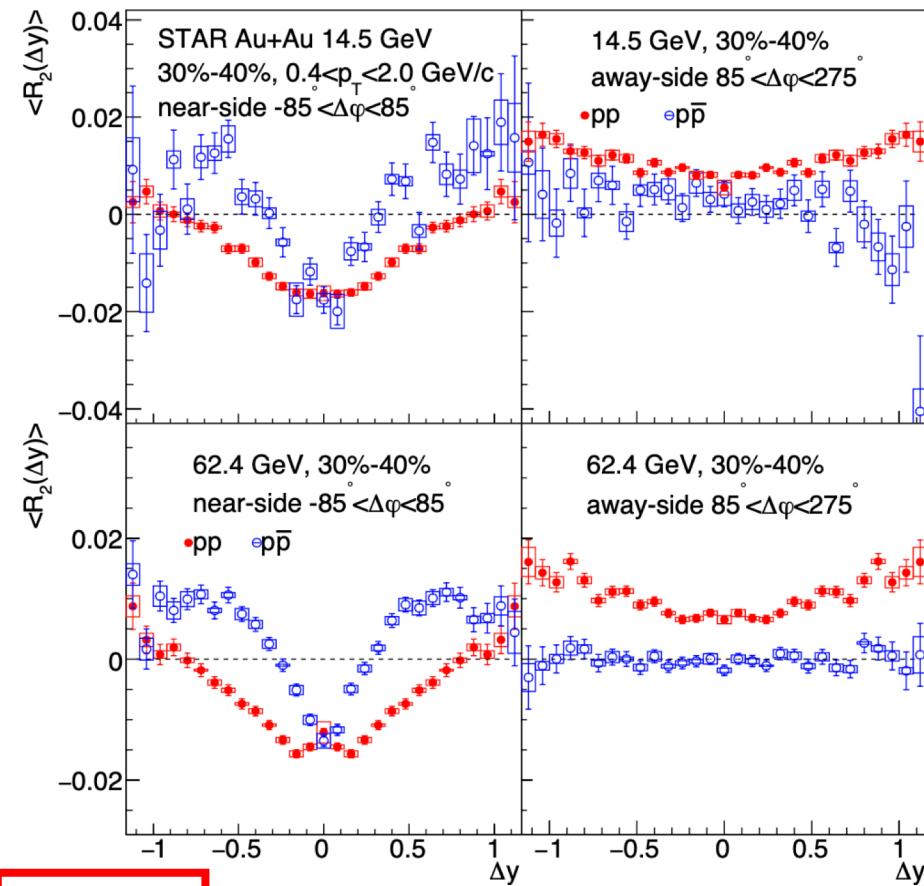


PLB **785** (2018) 551

Two-particle delta-eta correlation between pions or protons



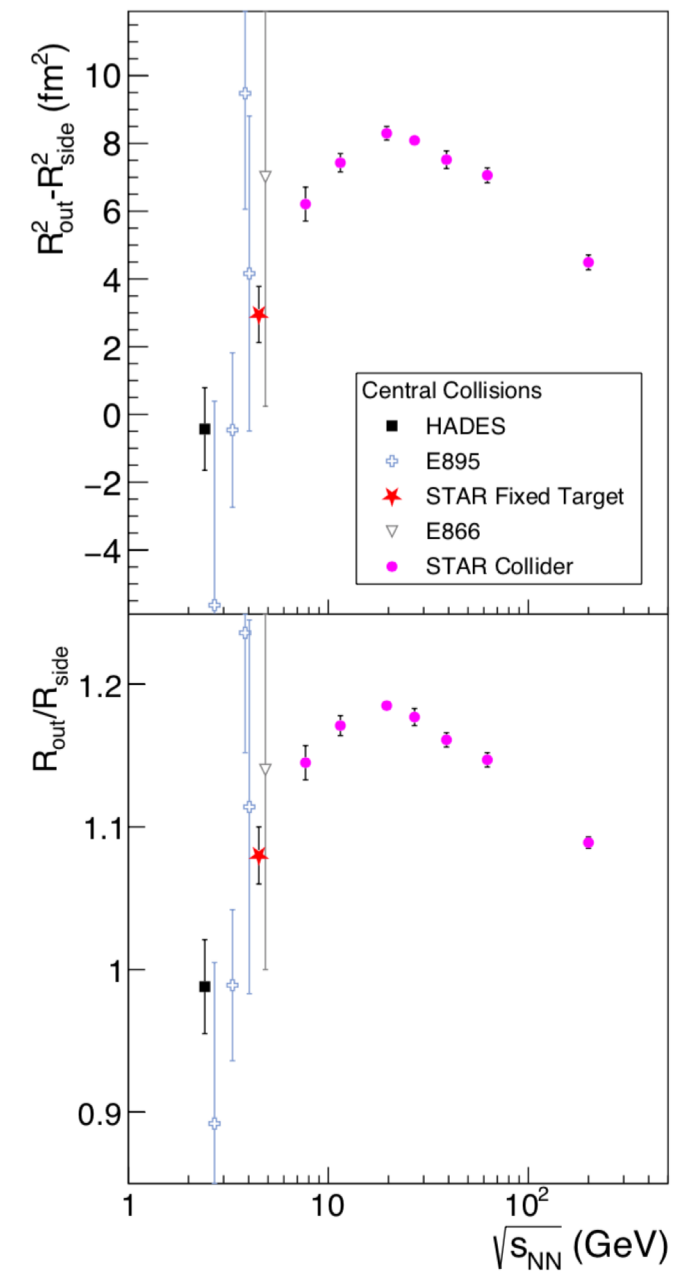
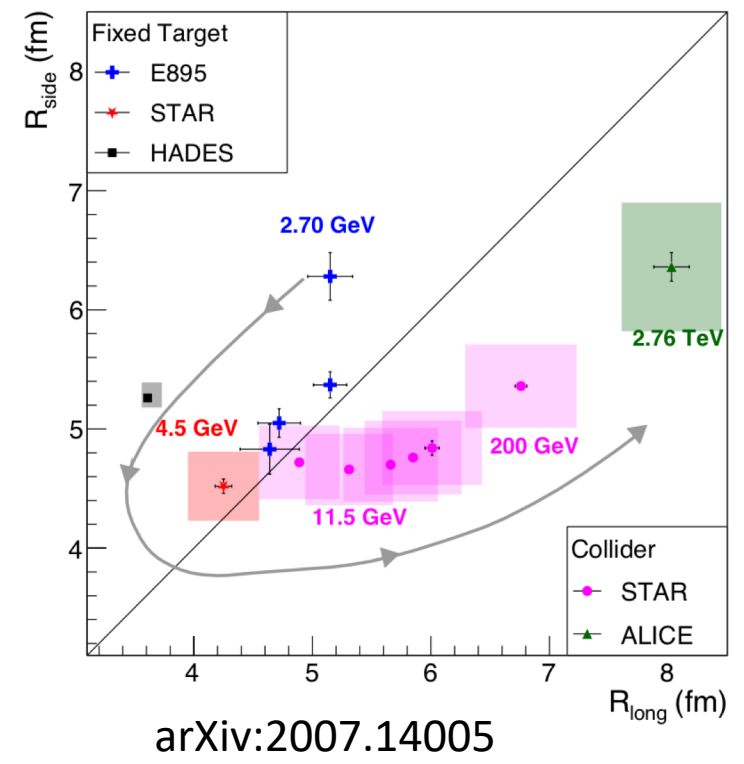
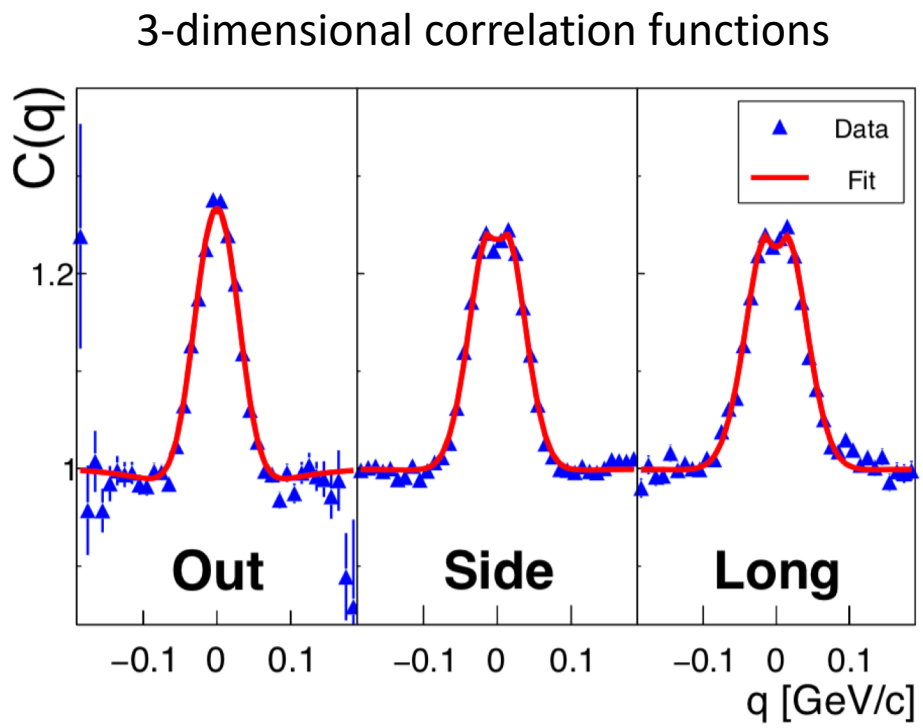
(a) pions



(b) protons

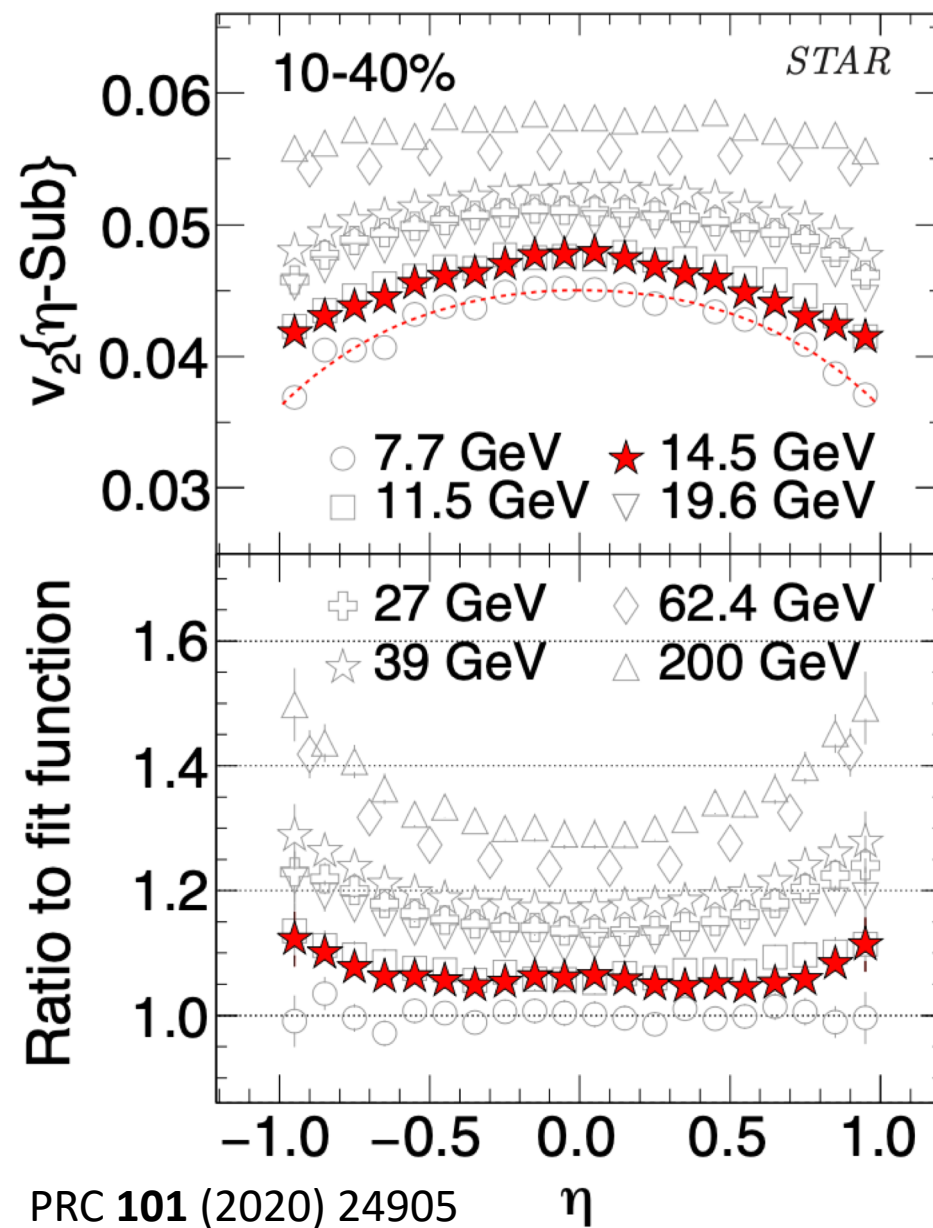
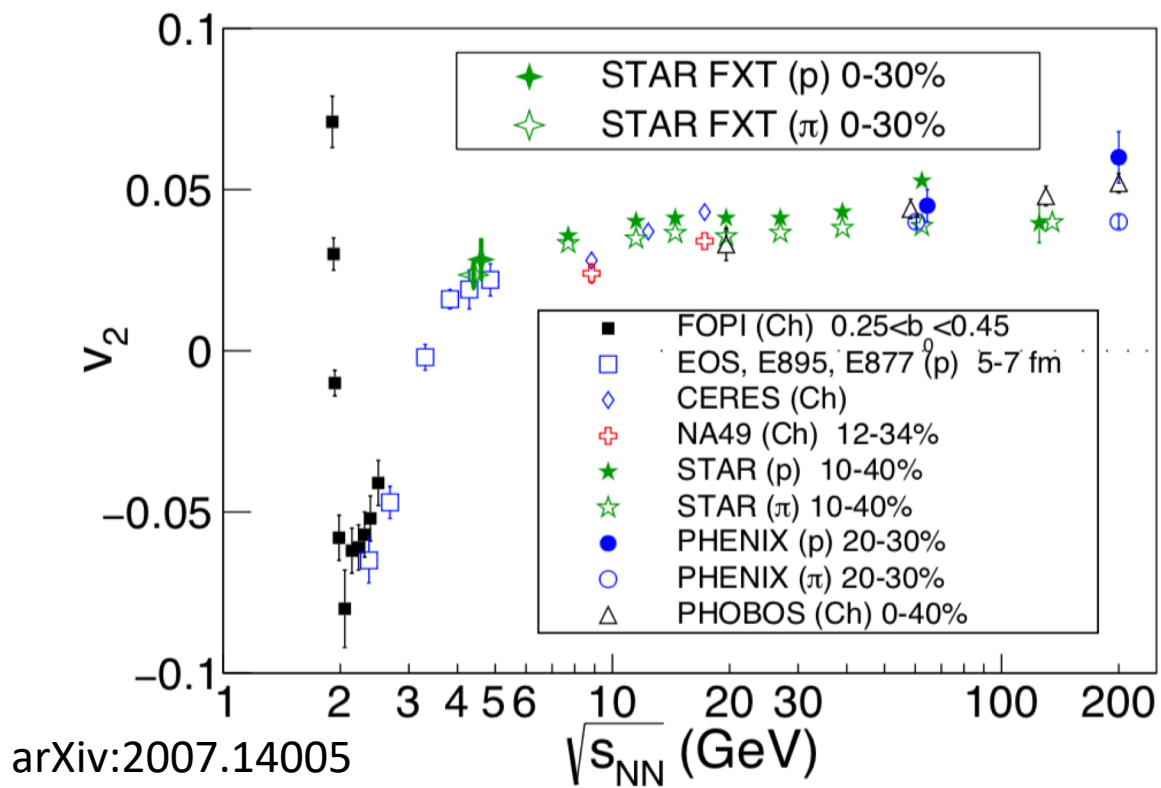
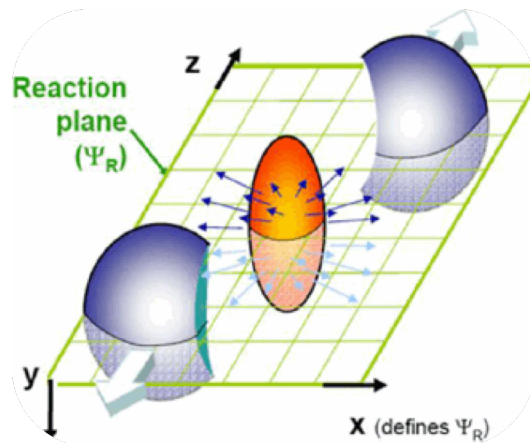
PRC **101** (2020) 14916

Two-particle HBT interferometry to measure the space and temporal extent of freeze-out volume



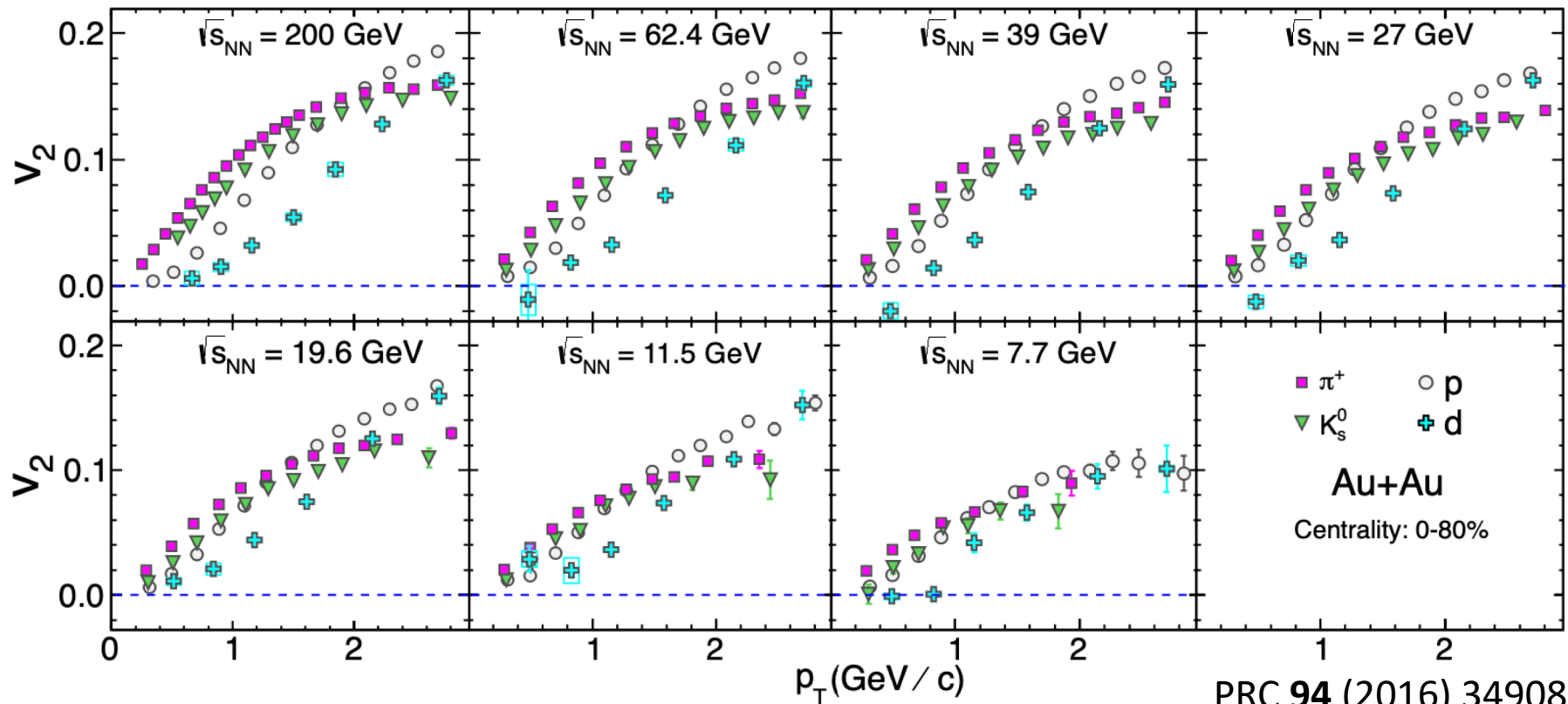
Elliptic emission/flow of charged particles

Energy and eta dependences



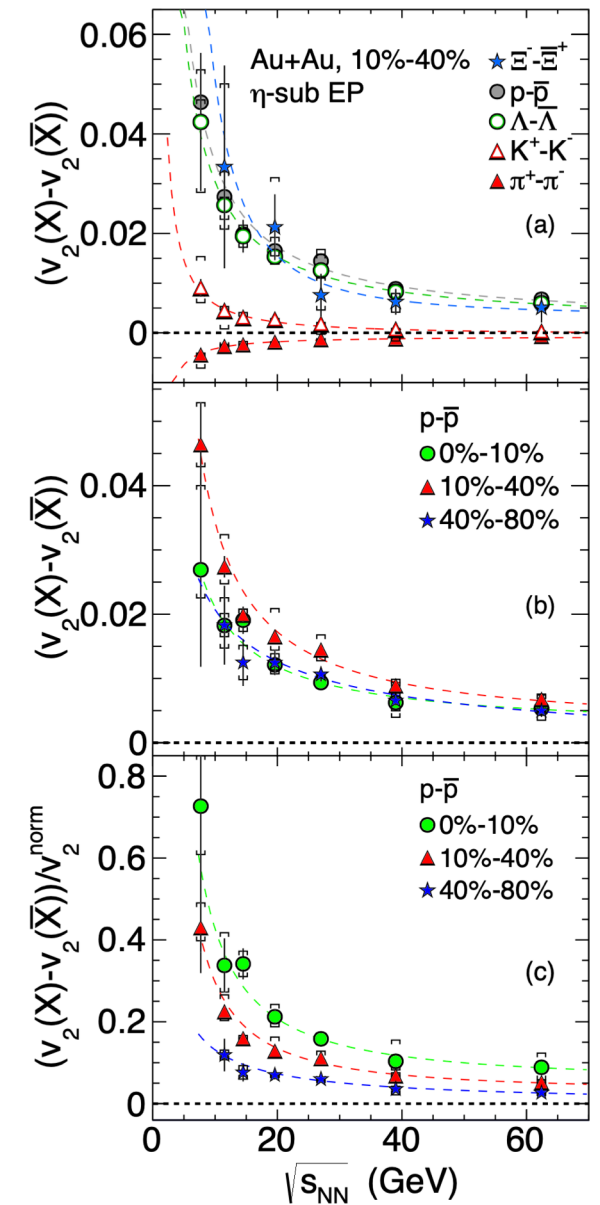
Elliptic flow of identified hadrons

Particle mass dependence and number of quark scaling
beam energy dependence and particle/anti-particle differences



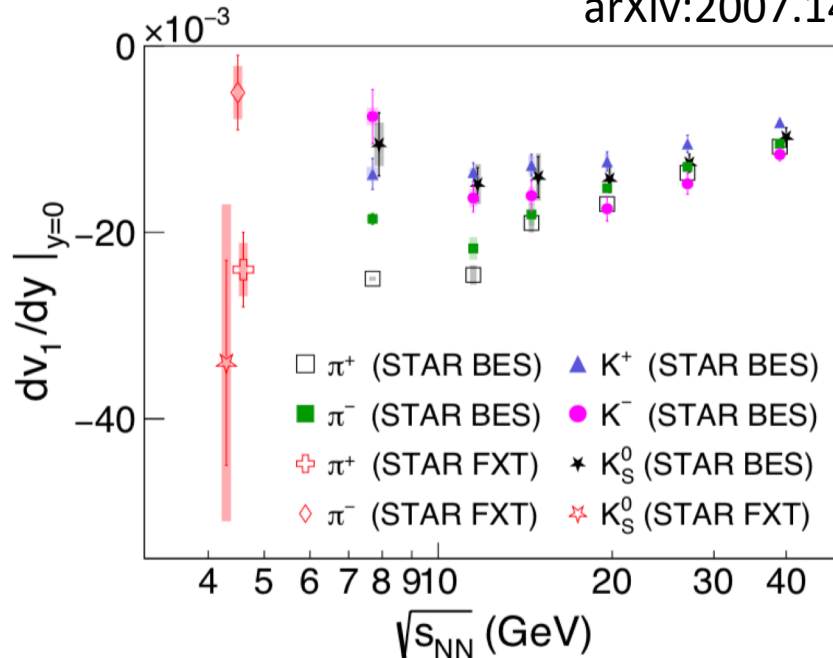
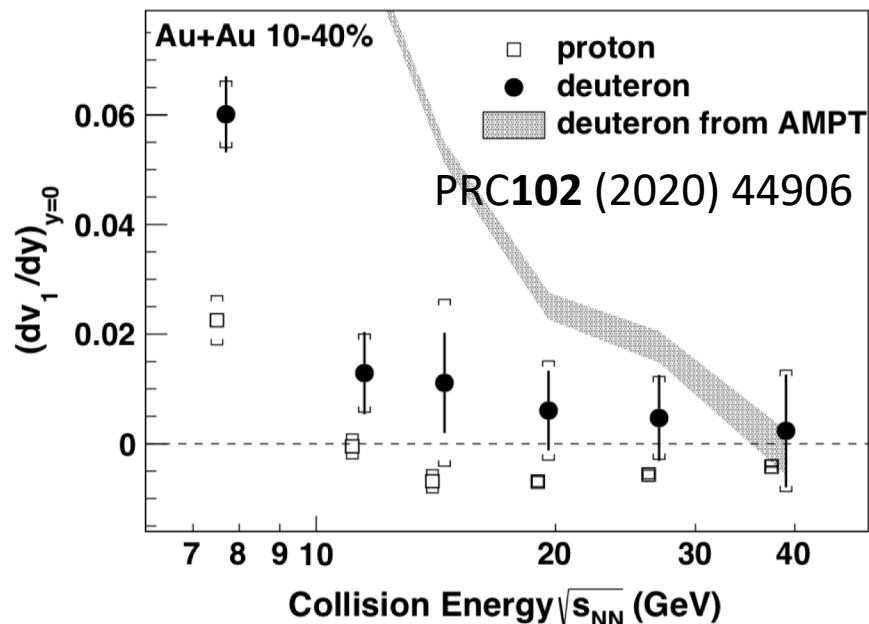
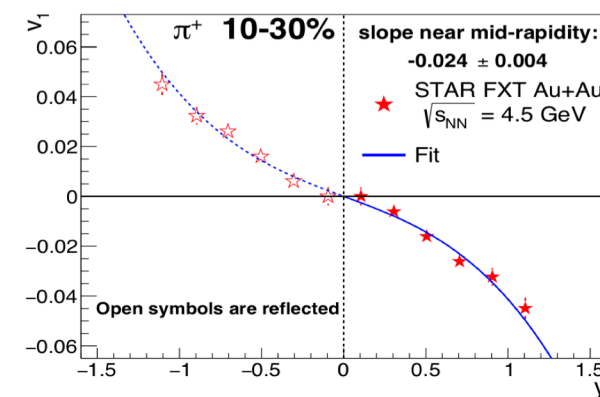
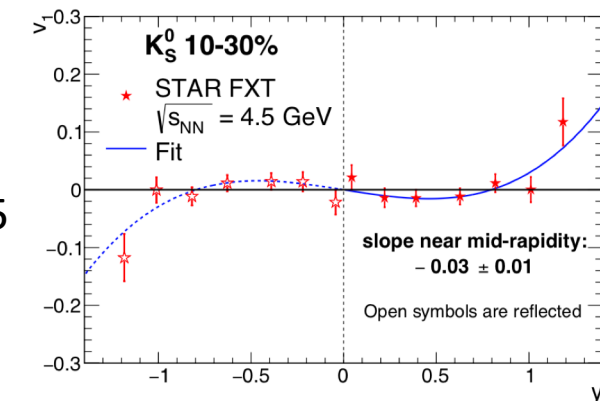
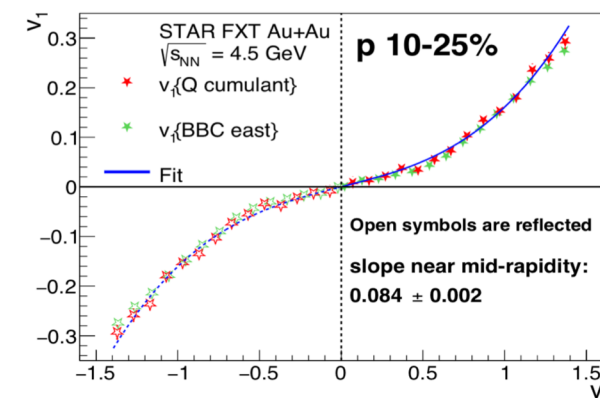
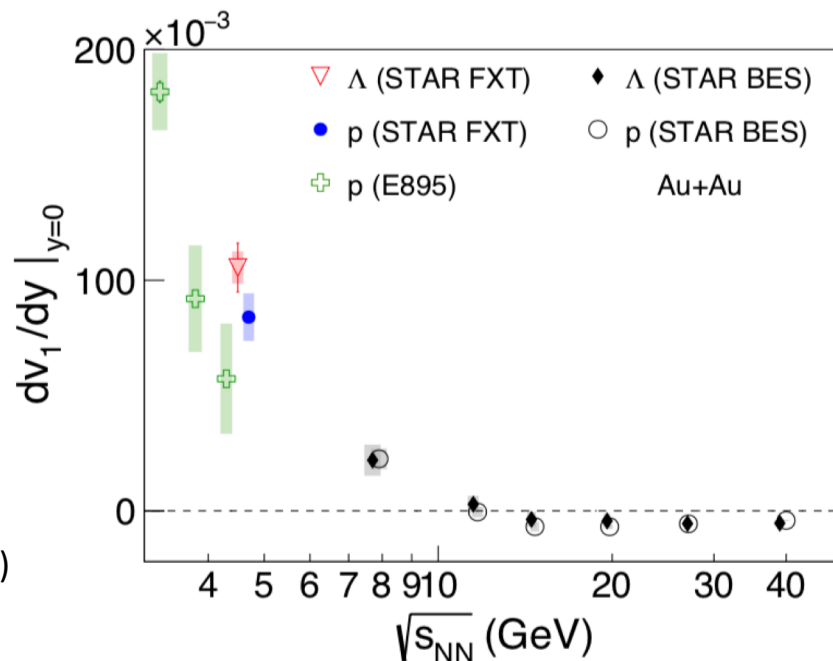
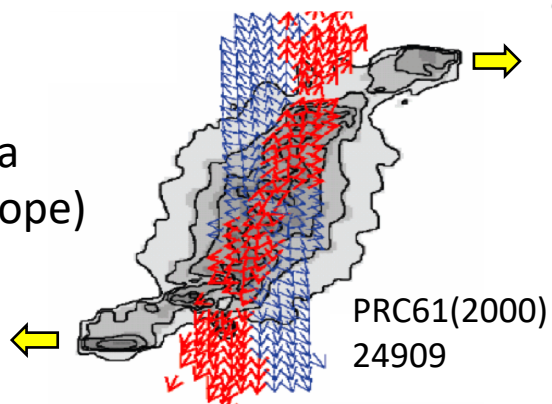
PRC 94 (2016) 34908

PRC 93 (2016) 14907



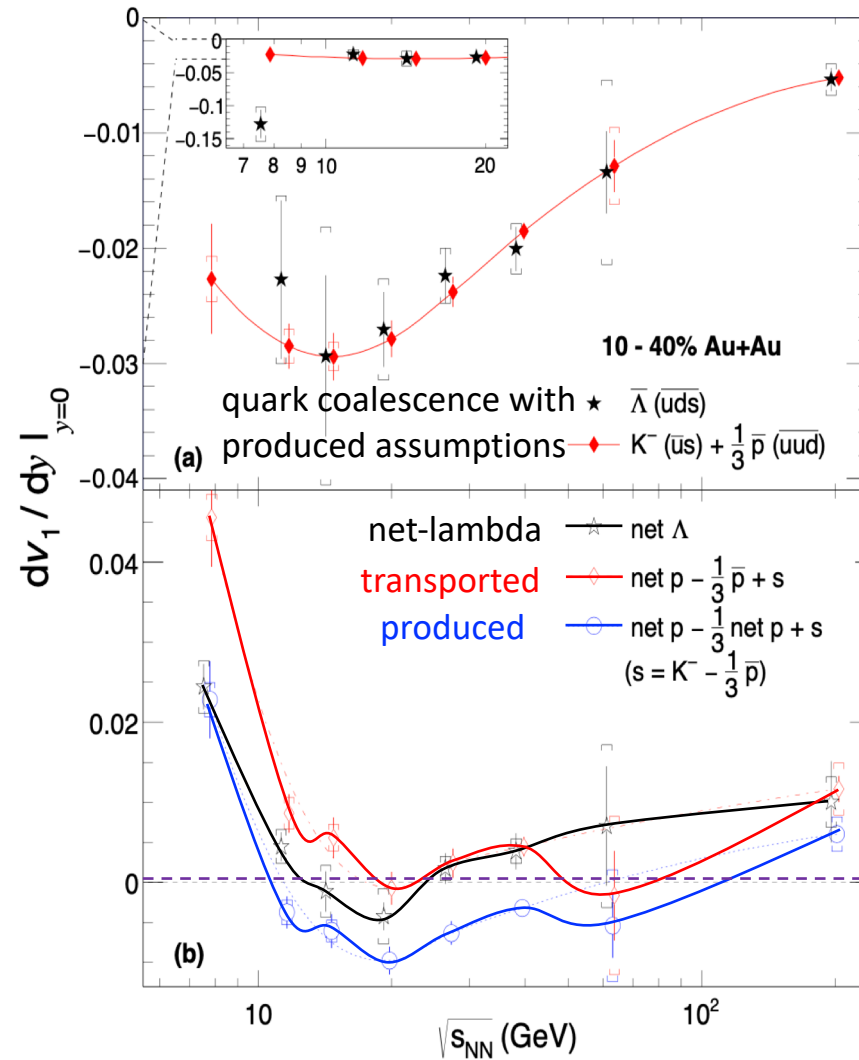
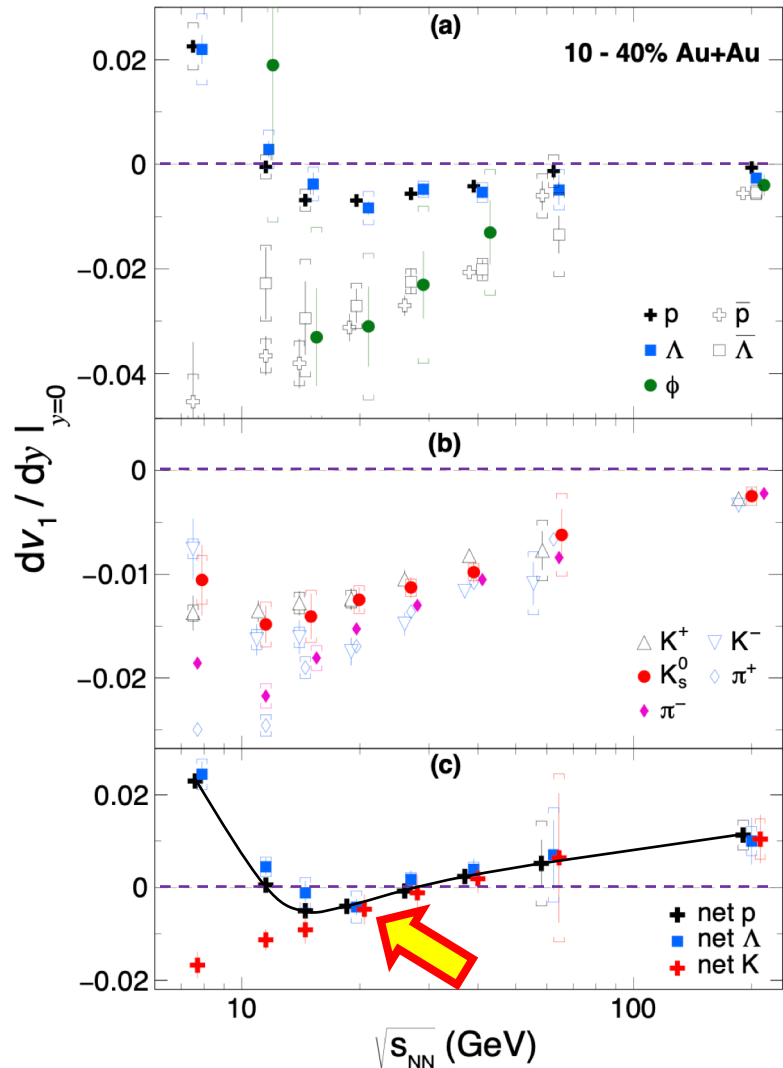
Directed flow of identified hadrons

Energy and eta (and dv_1/dy slope) dependences



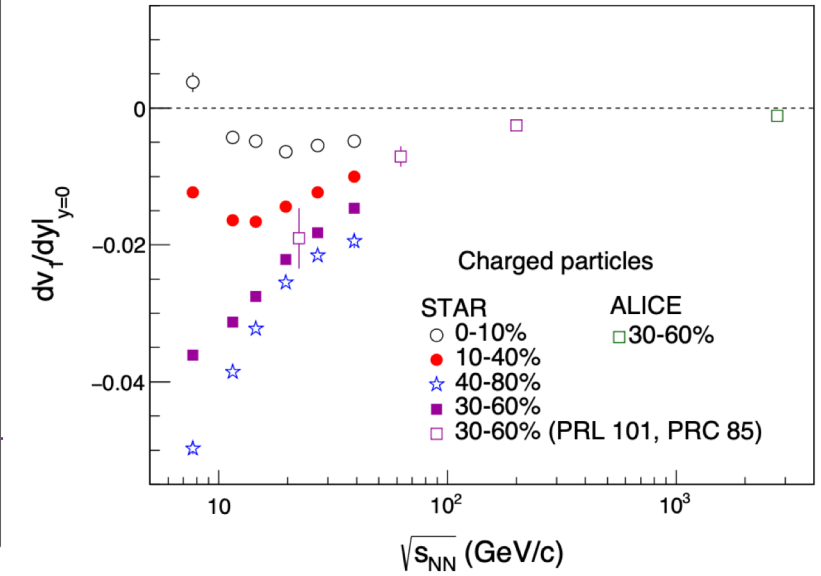
Directed flow of net-baryon and quark coalescence

PRL 120 (2018) 62301



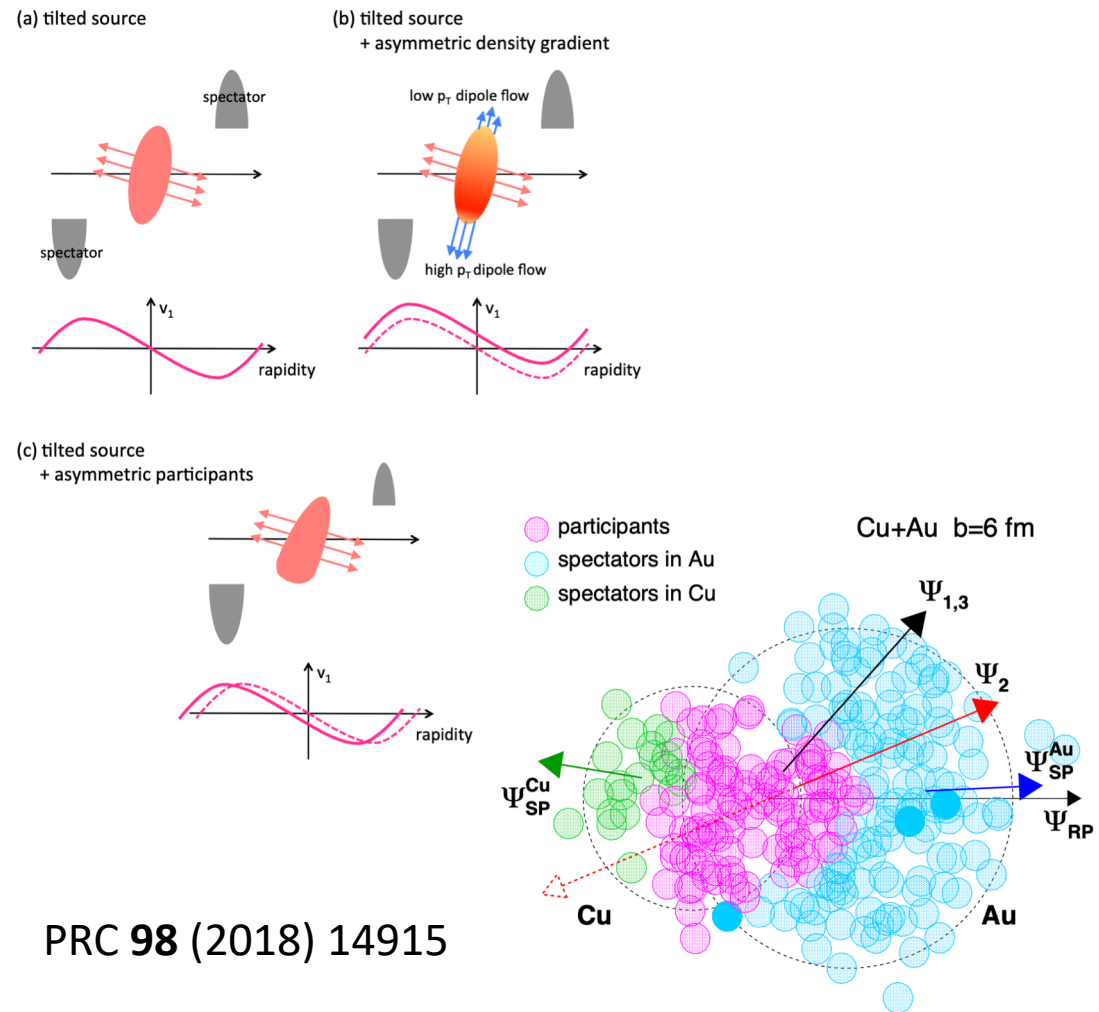
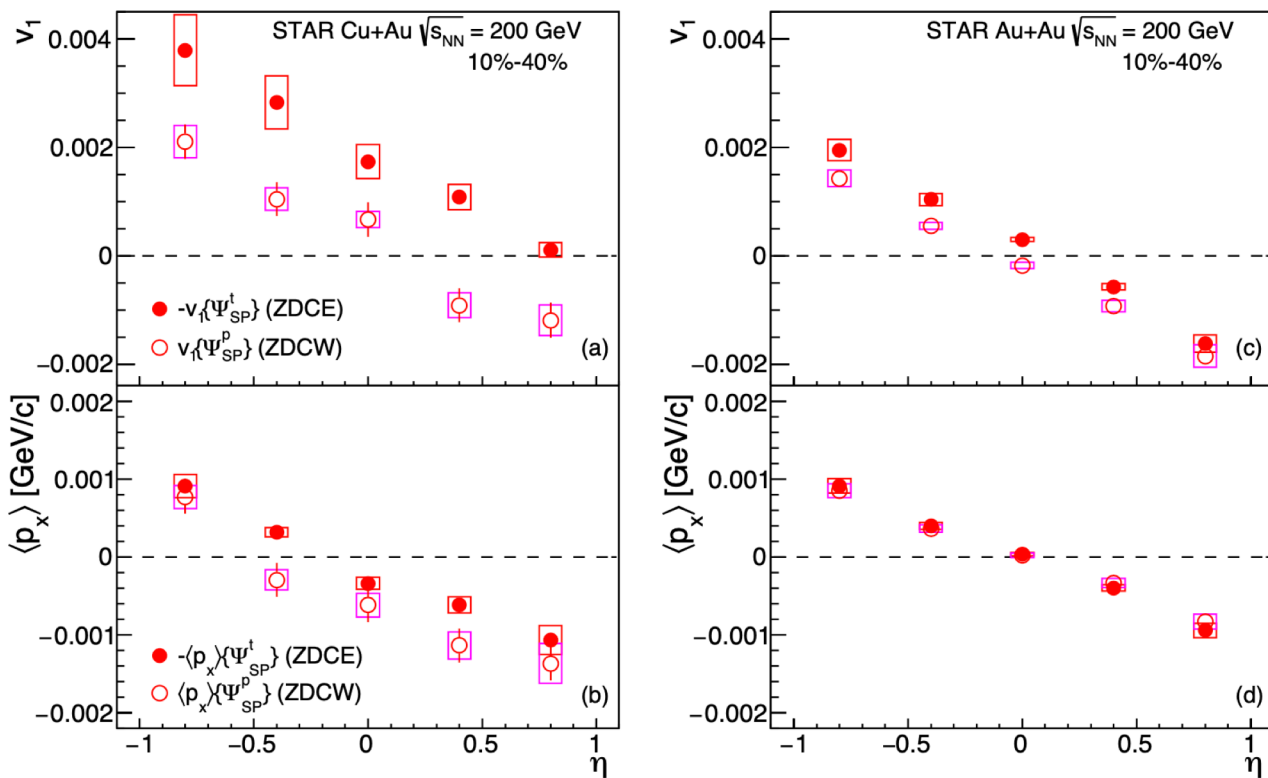
- net-baryon (proton, lambda) v1 negative minimum as a signal of phase transition
- coalescence of transported and/or produced quark flow
- significant centrality dependence

PRC 101 (2020) 24905



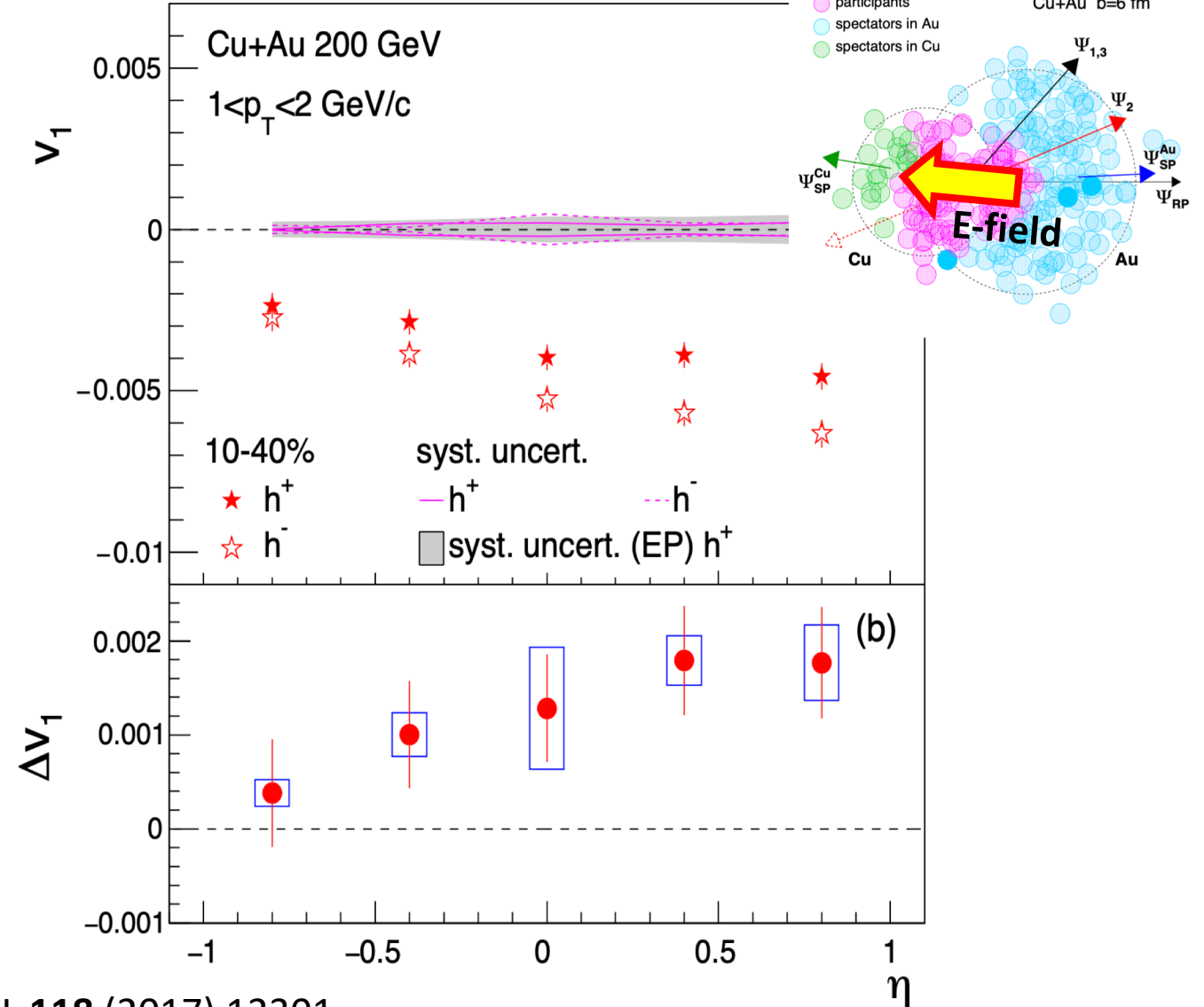
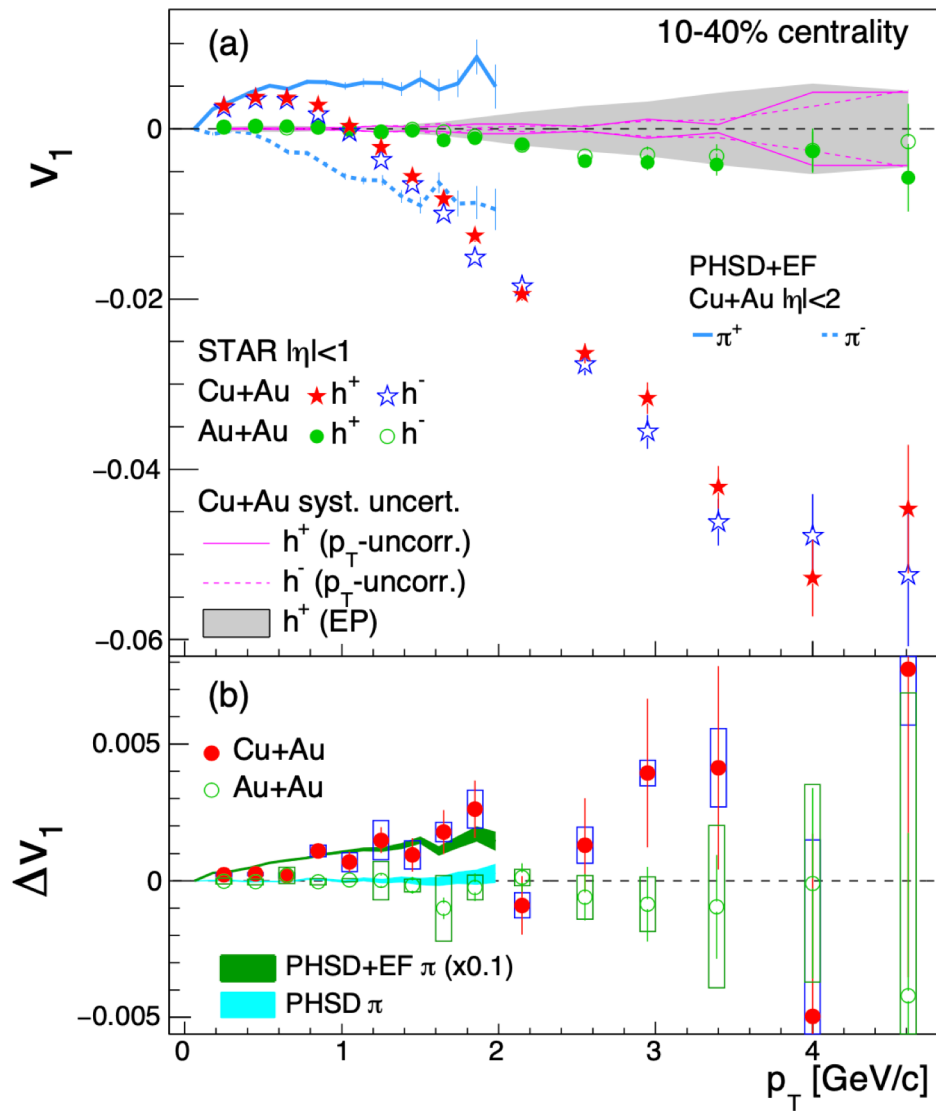
Directed flow in asymmetric system

Directed flow comparison between CuAu and AuAu



T. Niida (Tsukuba, Wayne)

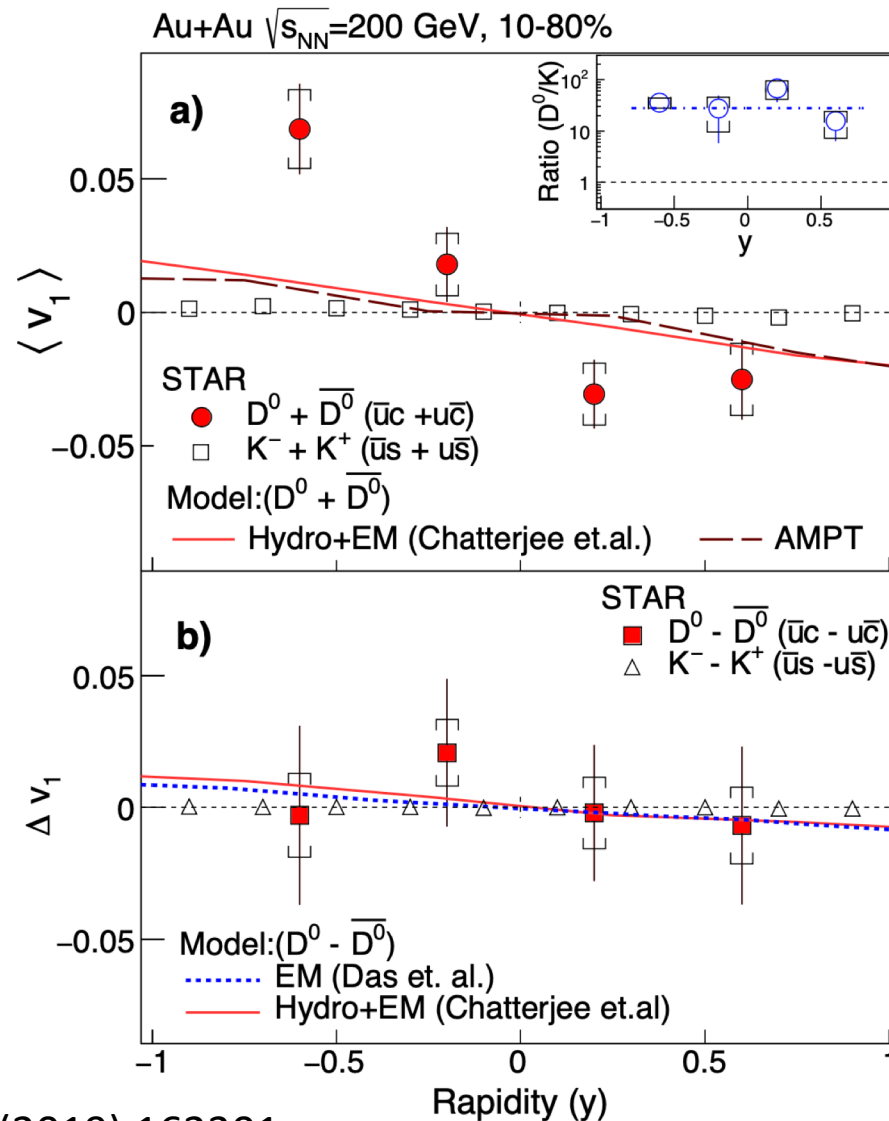
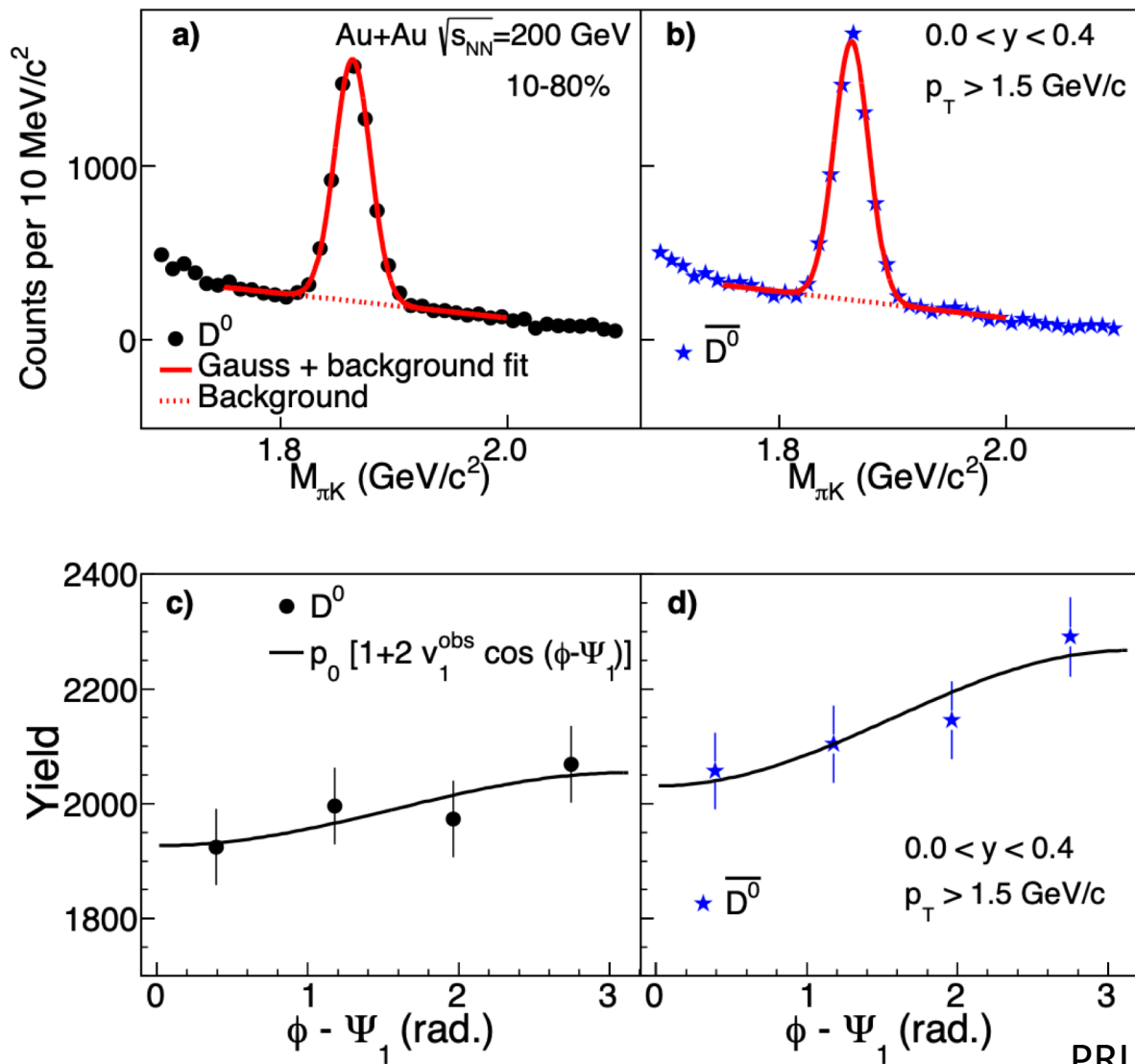
Charge asymmetry in directed flow at Cu+Au to probe E-field in the system



PRL 118 (2017) 12301

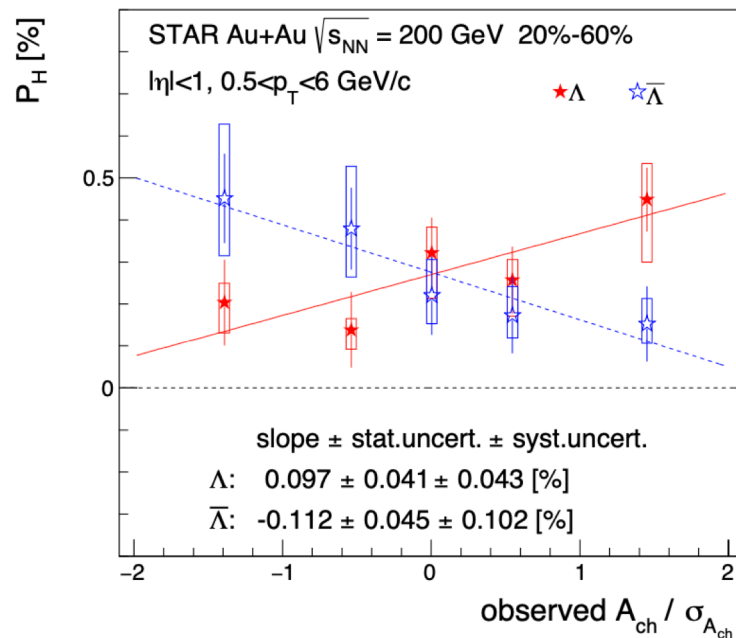
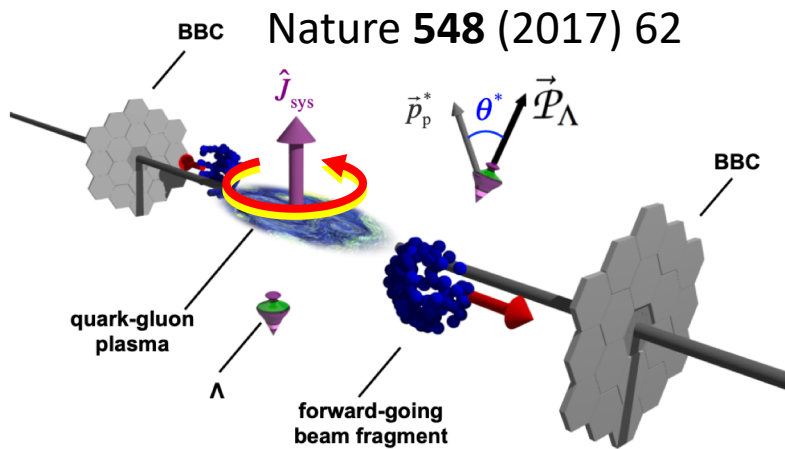
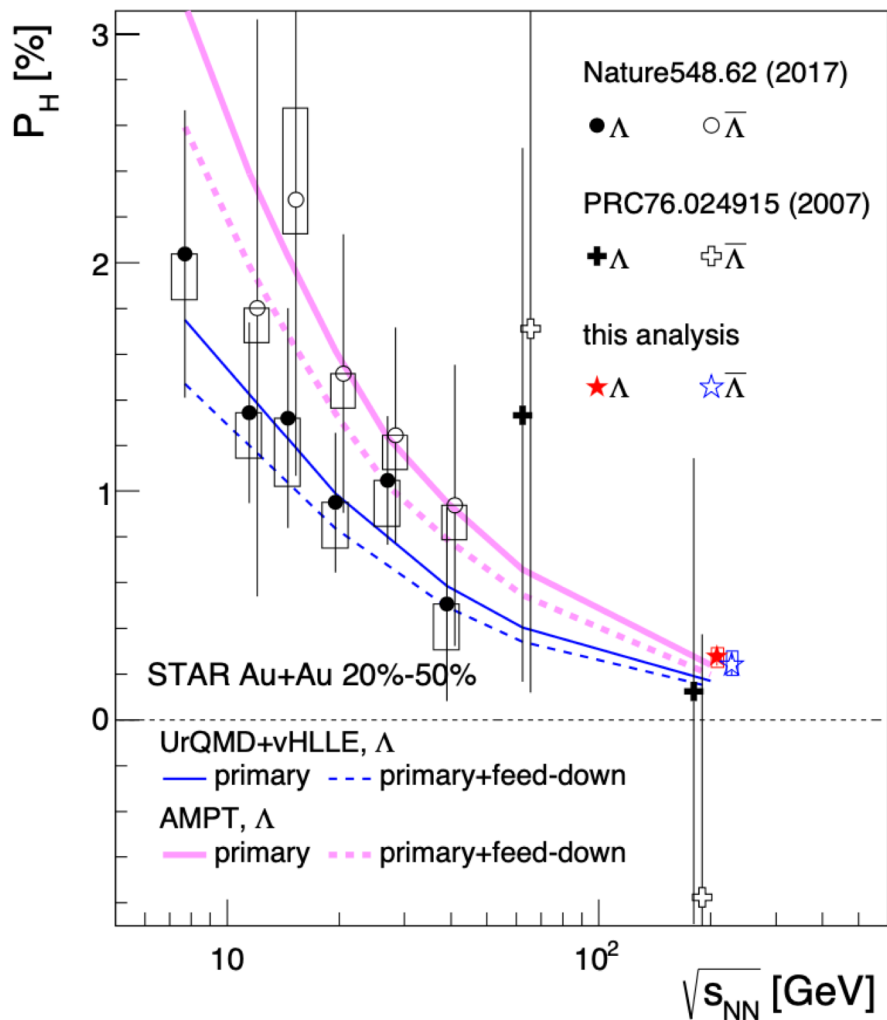
Directed flow of heavy quark

initial E-field or geometrical slope
High p_T v_1 and HBT w.r.t. Ψ_1

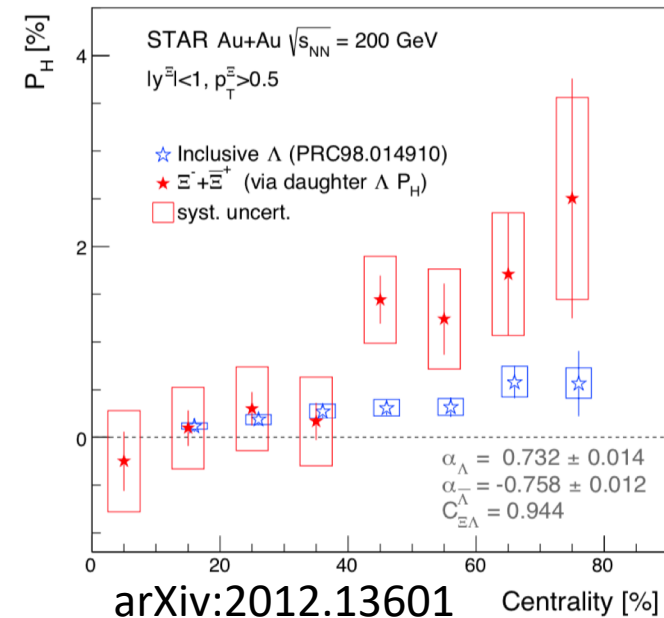
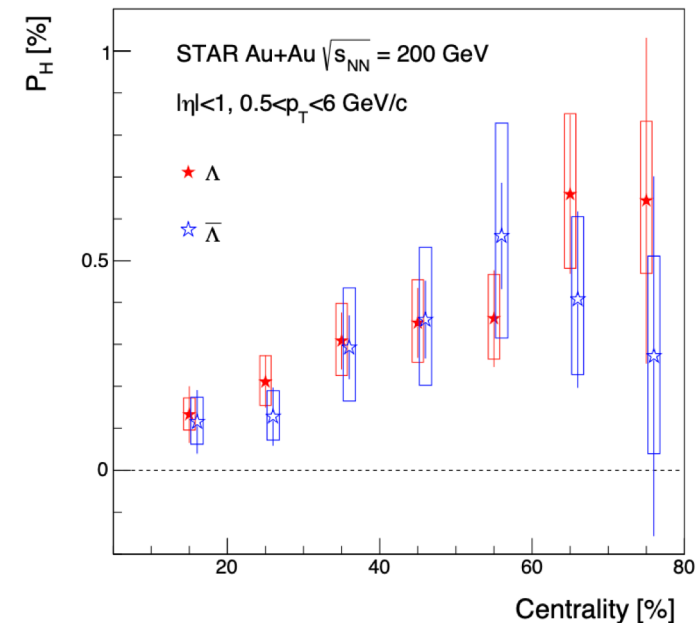


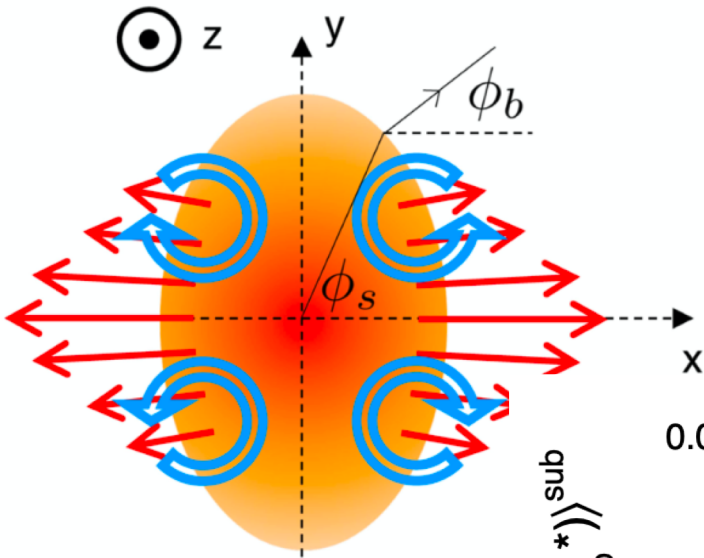
PRL 123 (2019) 162301

Global polarization via Λ , Ξ

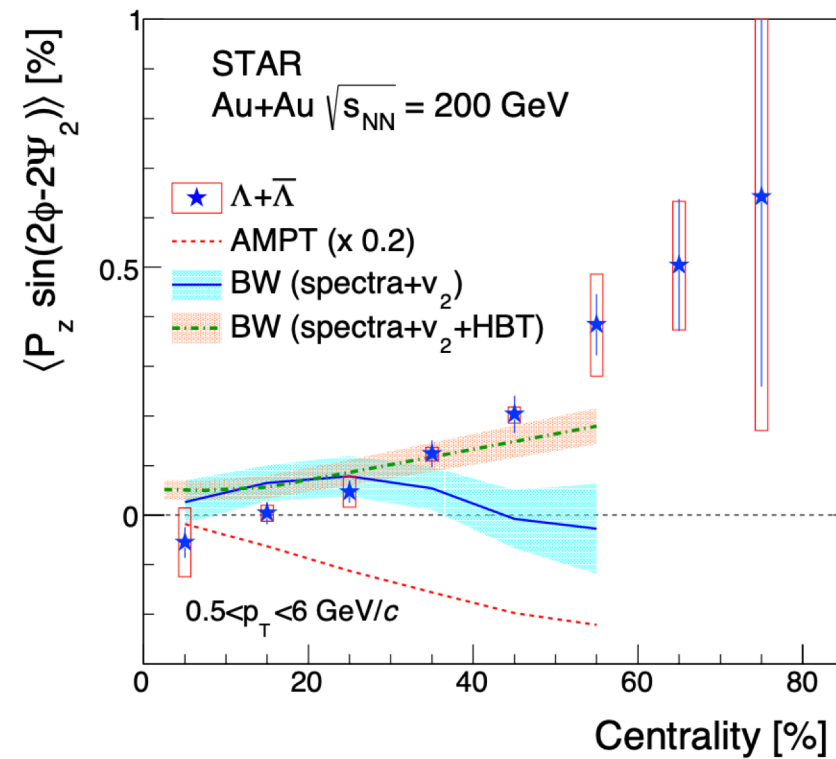
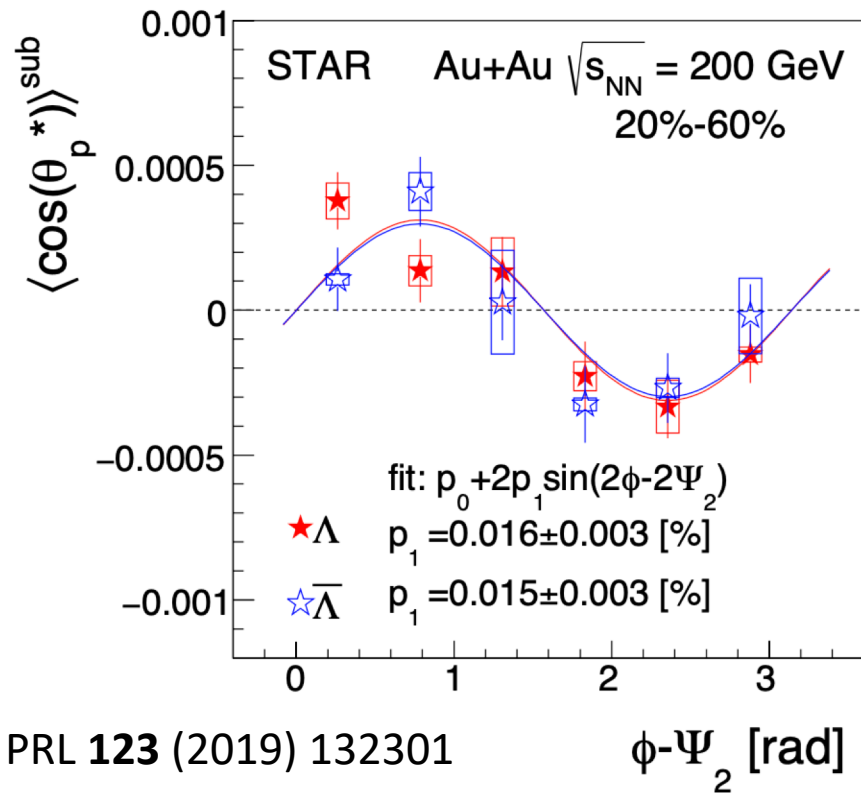


PRC 98 (2018) 14910



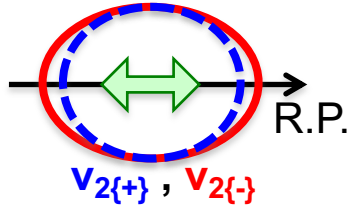


Global (local) polarization via elliptic flow expansion

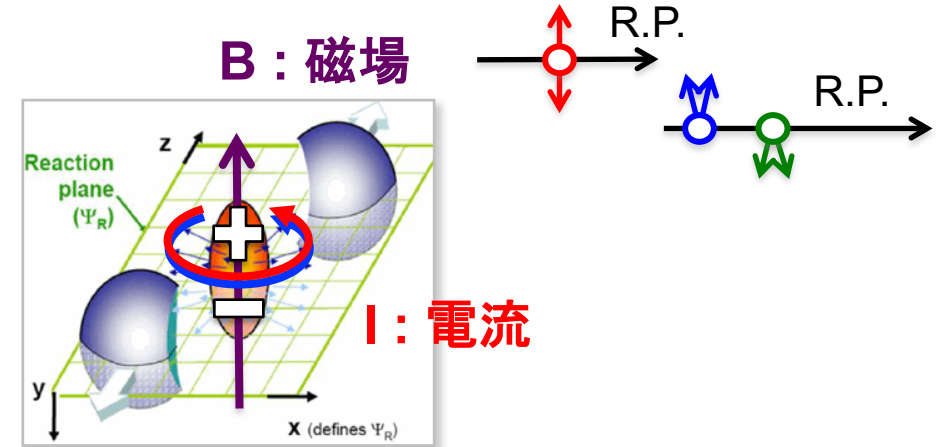
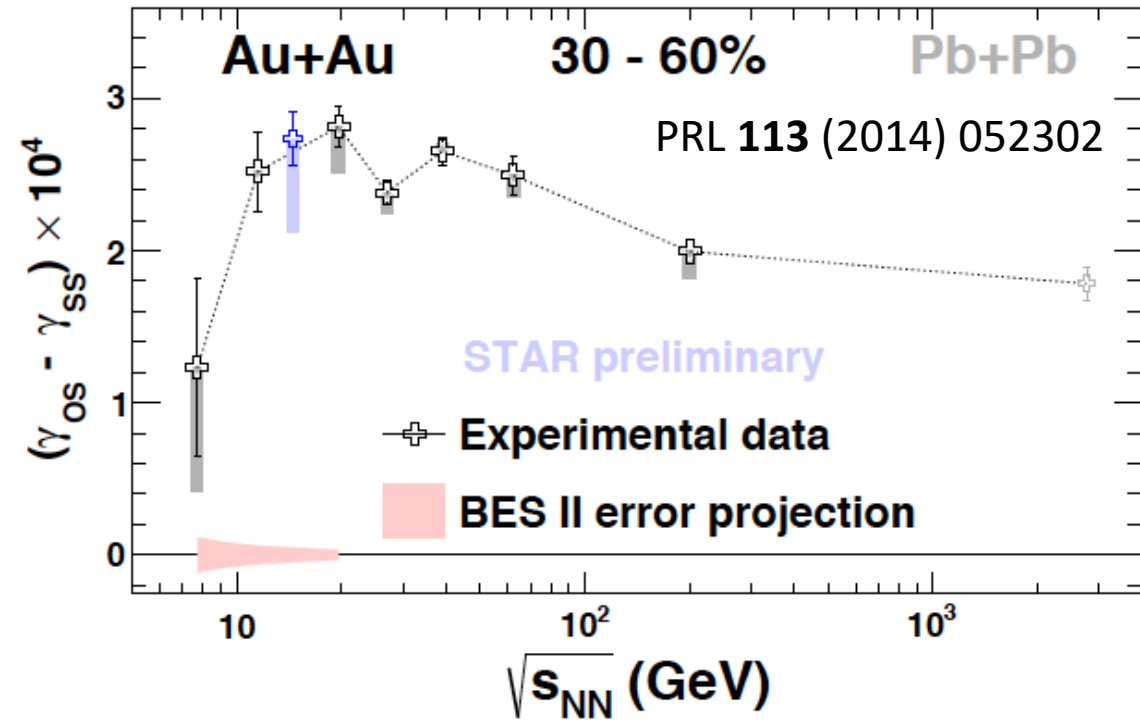
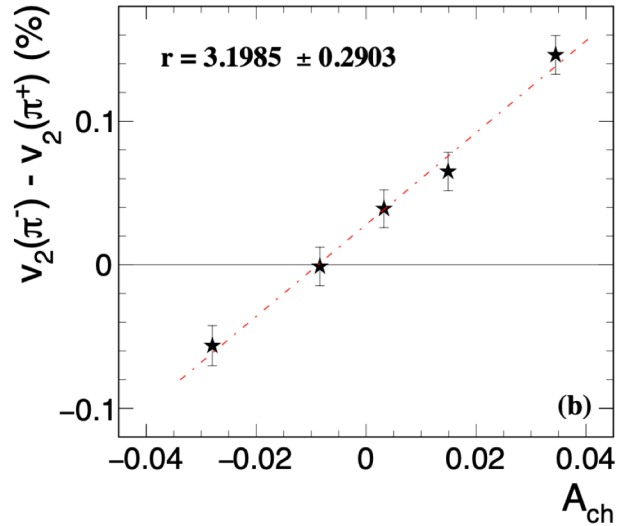
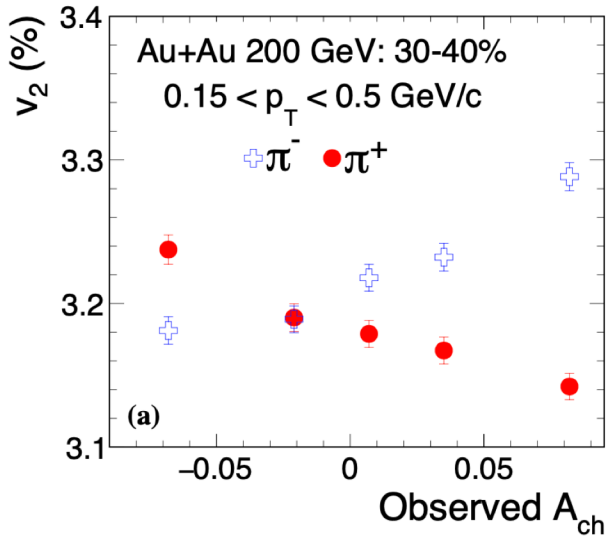


Chiral Magnetic Effect/Wave

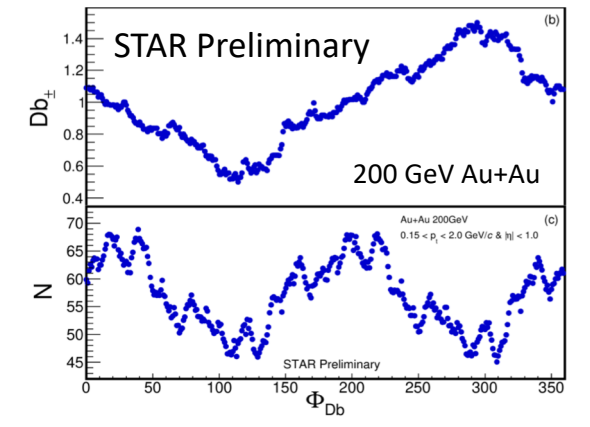
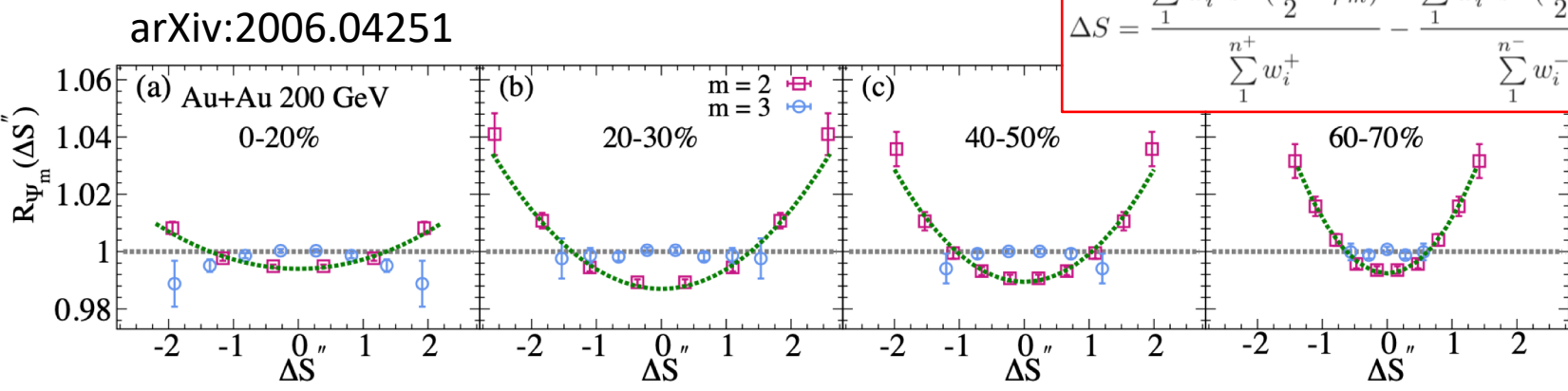
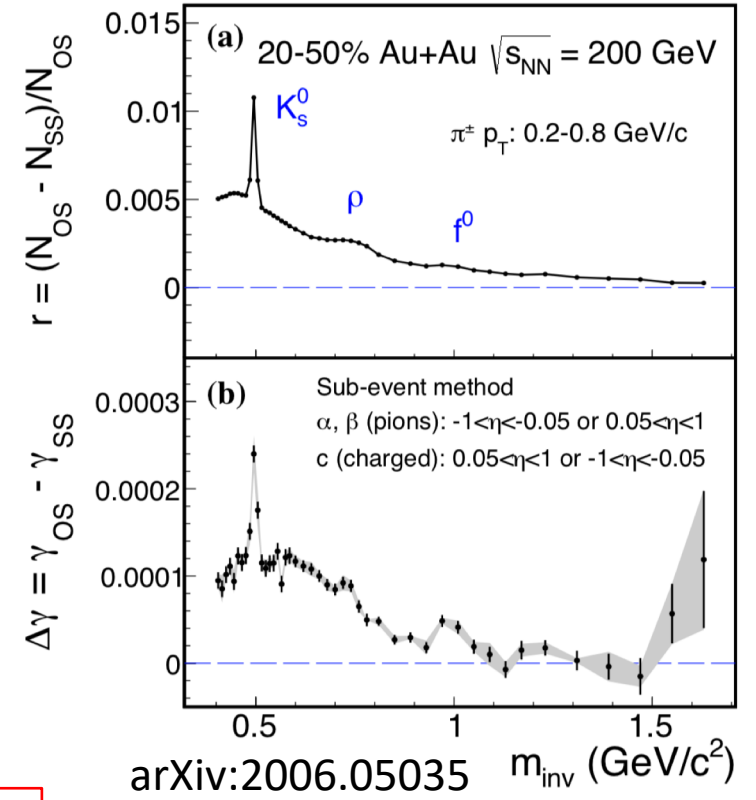
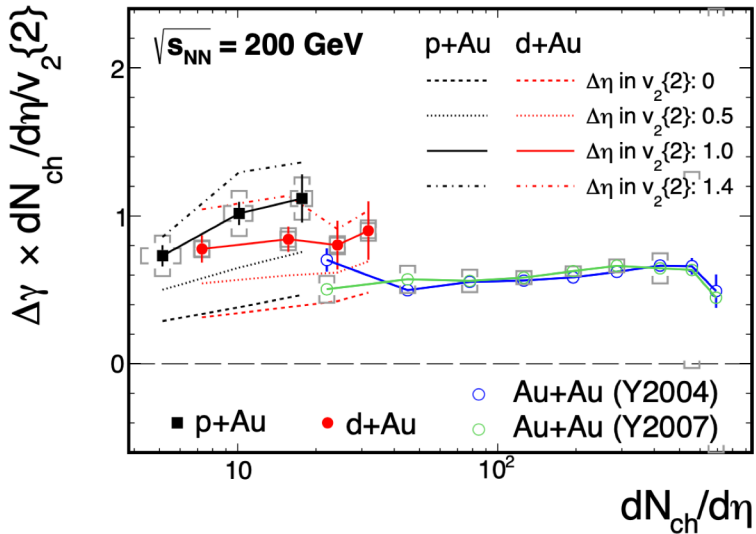
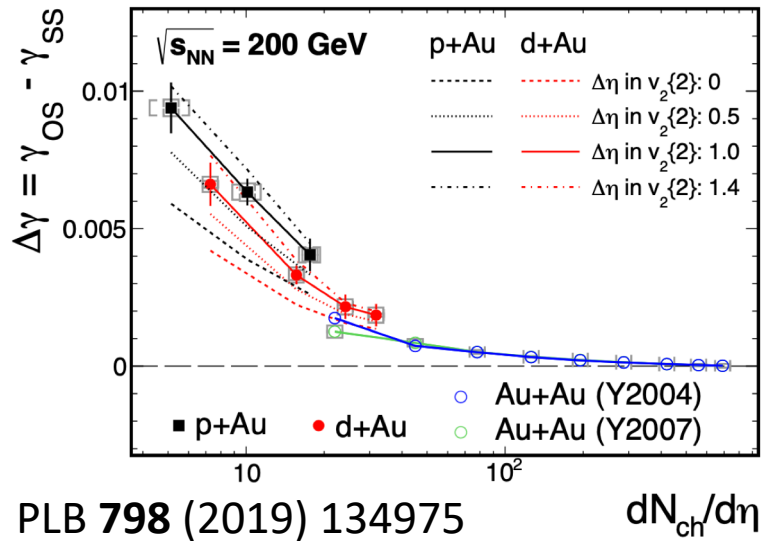
- initial strong B-field perpendicular to reaction plane
- charge dipole asymmetry along B-field (CME)
- charge quadruple asymmetry along B-field (CMW)



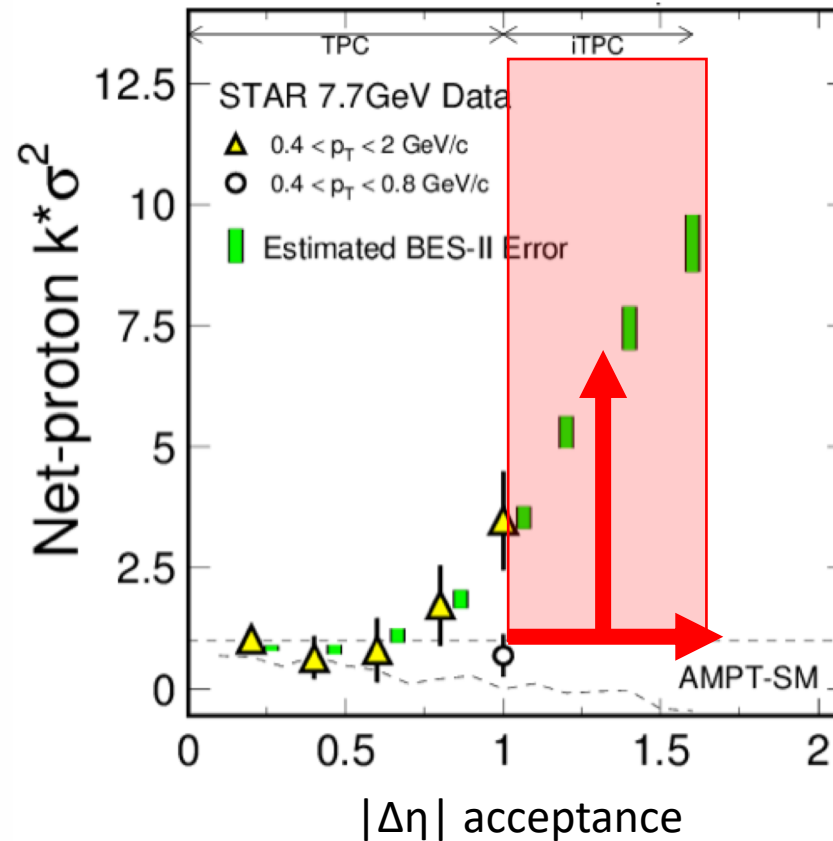
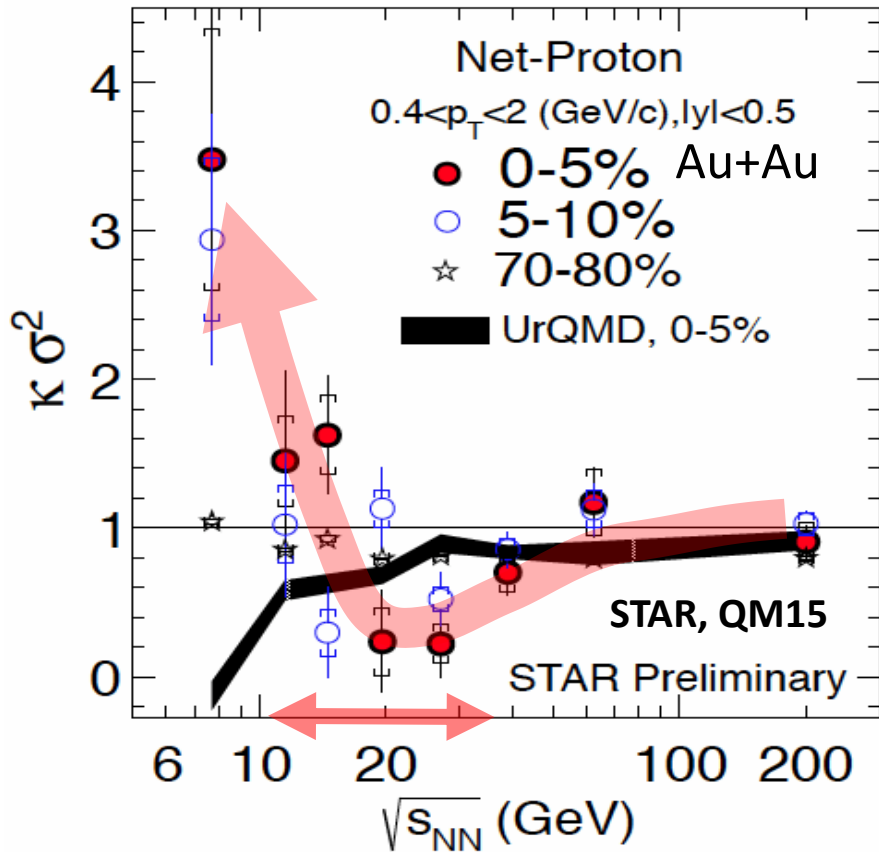
PRL 114 (2015) 252302



Various ways to find and confirm CME



Ongoing BES2 measurements with improved detectors



year	Collider/Fixed target, energy, Au+Au or other
2018	COL : 27 GeV Ru+Ru, Zr+Zr
2019	COL : 15-20 GeV FIX : 4-7 GeV
2020	COL : 9-11 GeV FIX : 3-7 GeV
2021	COL : 7 GeV

Statistics : BES1 x 20 times

Summary

- **Critical point** and **1st order phase transition**
- Freeze-out measurements
- **Fluctuation** and correlation measurements
- Elliptic and **Directed flow** measurements
- **Vorticity** and **Chiral magnetic ...**

our challenge continues...

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and PHENIX+ALICE friends