PWG1 Report on Hadron measurements in J-PARC heavy-ion program

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* Discussion with 新井田、野中(俊宏)、小沢、佐甲、佐藤、山口、
  北沢、奈良、平野、野中(千穂)
* Neutron measurement for net-baryon fluctuation
* Key issues on the fluctuation measurement
  pileup events, non-binomial detector responses,
  centrality resolution and volume fluctuation
* Detectors for the centrality determination
* Multi-dimensional femto-scopic correlation

新井田　：Polarization, Femtoscopy（ハドロン相関）, 中性子運動量

野中（俊）　：バリオン数ゆらぎ、中性子検出効率、UrQMD計算

江角　：中性子検出器を含めたbaryon

小沢　：高密度側の相図、CSC、ϕ→KK、a0/f0

佐甲　：primary neutron, Geant計算、charmed meson <-> CSC、light nuclei

佐藤　：PID hadron production, energy scan

山口　：Chiral Mixing（ee）, Femtoscopy (HBT, バリオン密度の非一様性, Hadron相関）

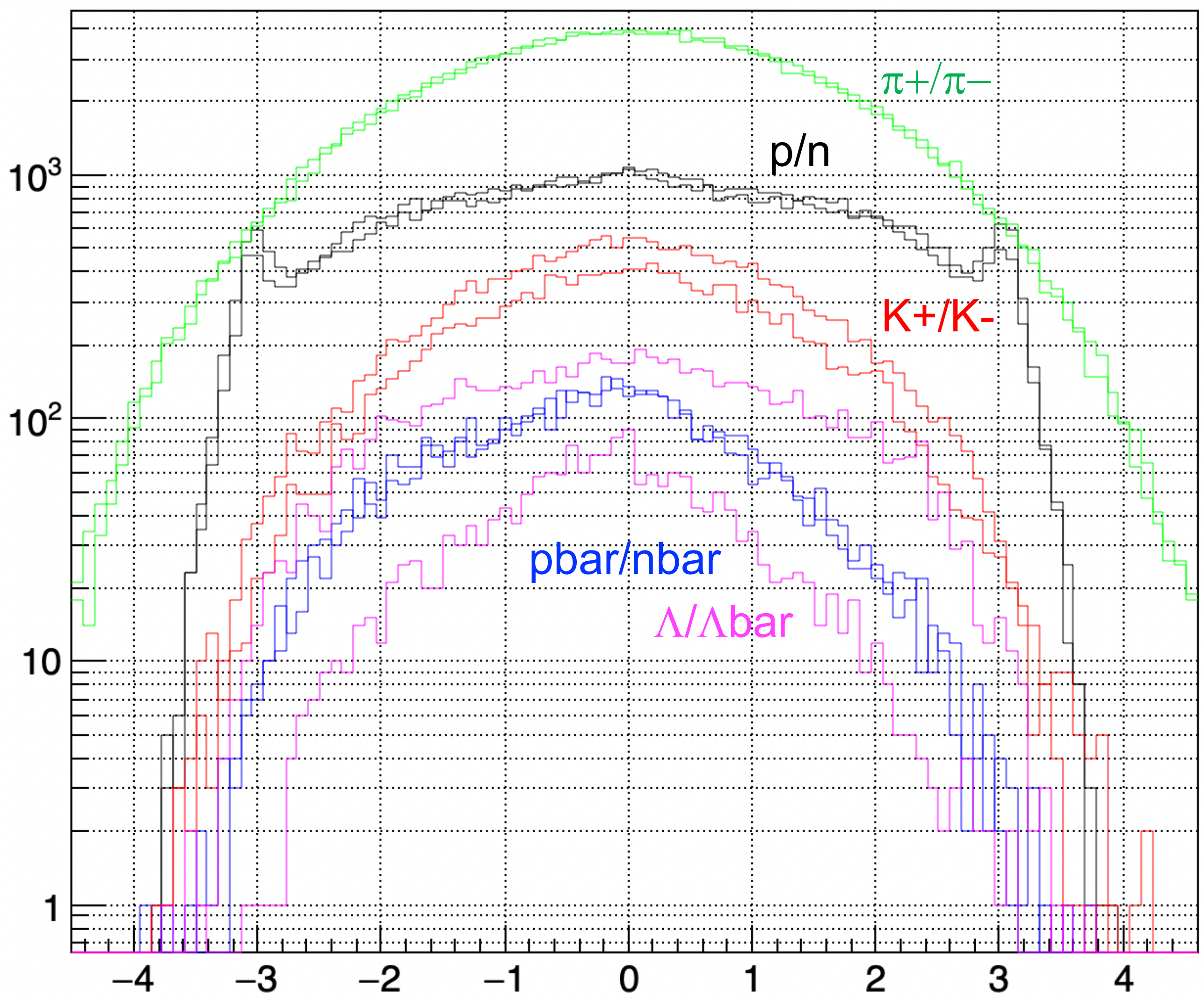
北沢　：中性子のEfficiency、陽子のAcceptance、Event選択、高密度事象、精密化

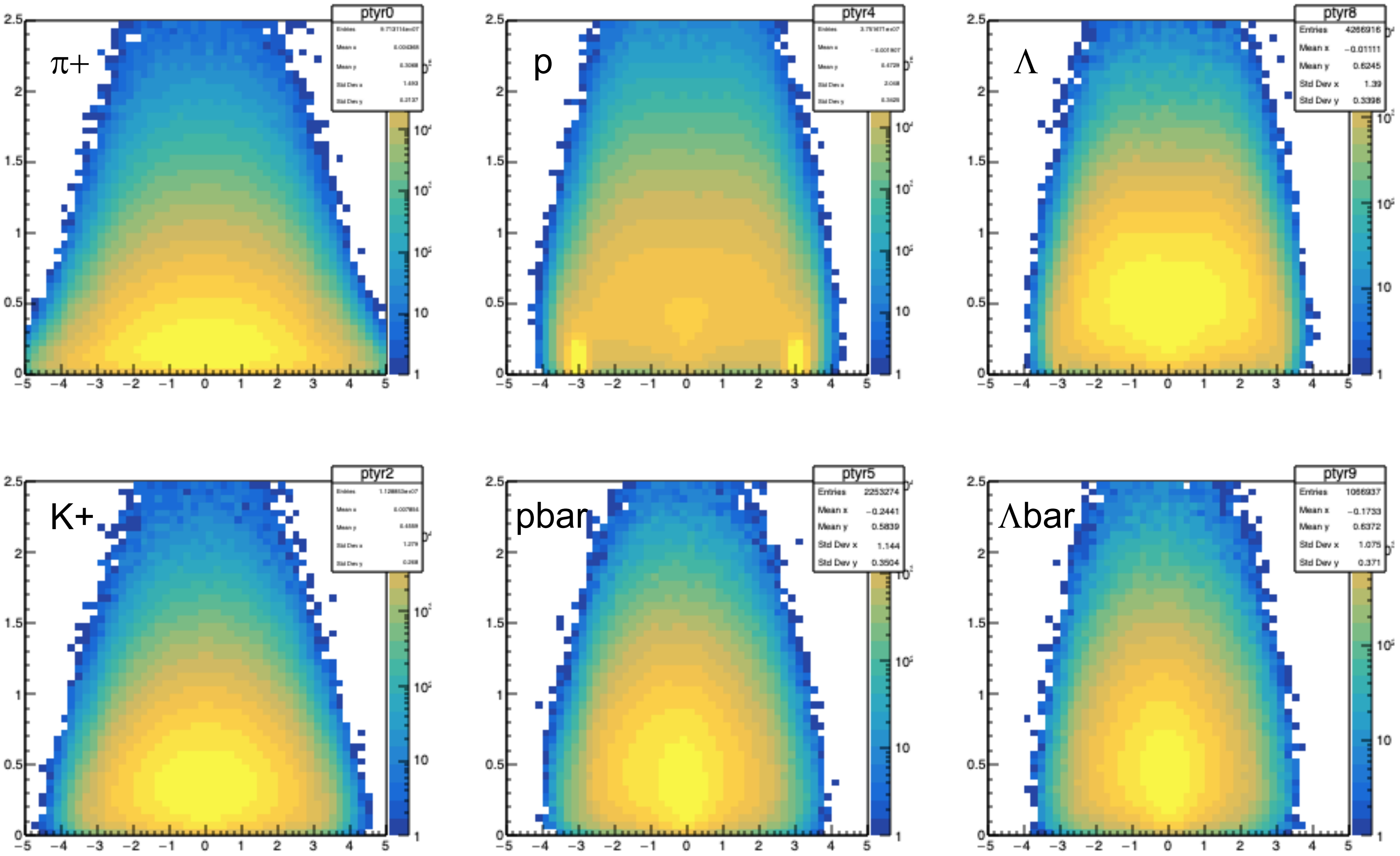
奈良　：Fragment, Nuclear cluster, coalescenceで十分か？v1/v2のpT/rapidity dep.
JAM 様々なEOSのテスト、pT, y分布、v1, v2, バリオン数ゆらぎ、EOS＋CEP

平野　：流体・コア＋コロナでDynamics、平衡・非平衡の割合、バリオン拡散
JAMの中の流体計算（粘性、ゆらぎ）を使って、粒子比、PID、臨界点モデル
e-by-e ストッピング

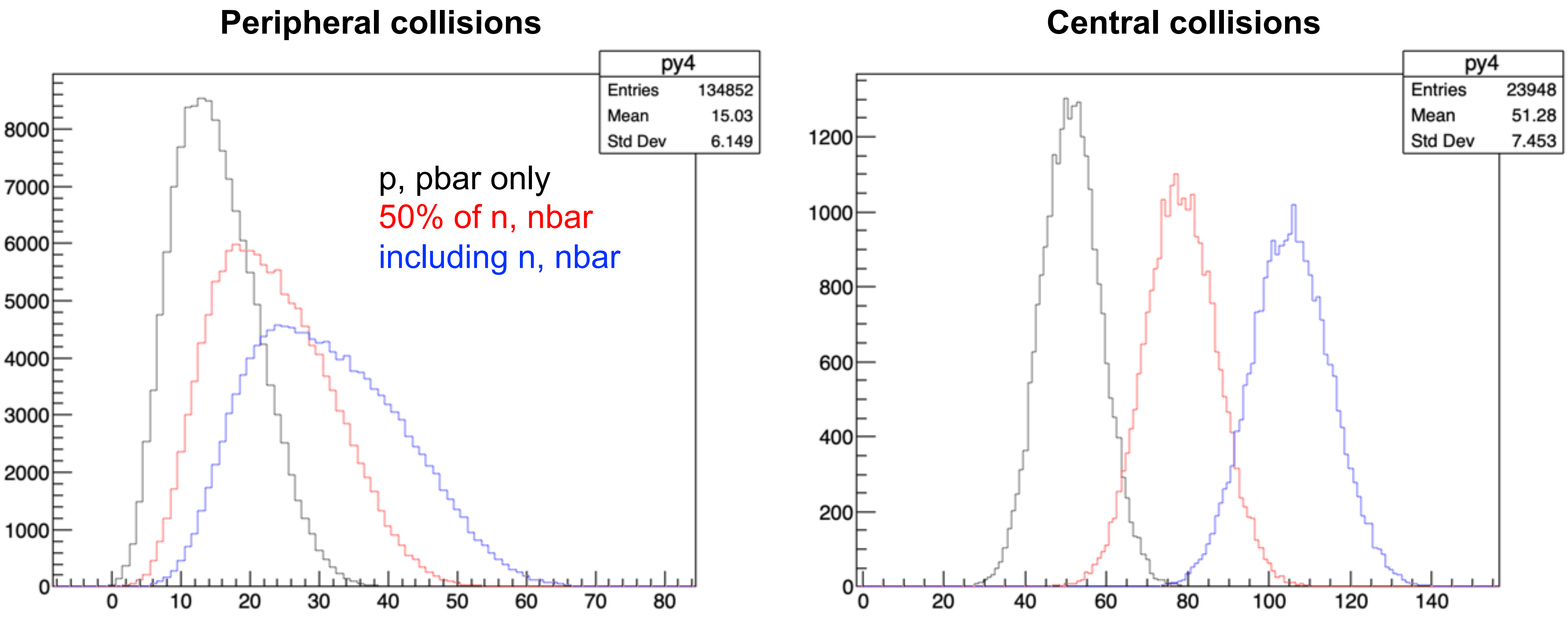
野中（千）　：平衡化、流体化、RattiによるCEPモデルを使ってみる、（電）磁場を入れた流体
JAM（+流体）に電磁場を入れることが可能か？Potentialならすぐ
recombination/coalescence

AMPT 20GeV Au+Au collisions





ptyr0
π+
ptyr4
p
ptyr8
Λ
Entries 4266916
Mean x −0.01111
Mean y 0.6245
Std Dev x 1.39
Std Dev y 0.3396
ptyr2
K+
ptyr5
pbar
Entries 2253274
Mean x −0.2441
Mean y 0.5839
Std Dev x 1.144
Std Dev y 0.3504
ptyr9
Λbar
Entries 1066937
Mean x −0.1733
Mean y 0.6372
Std Dev x 1.075
Std Dev y 0.371

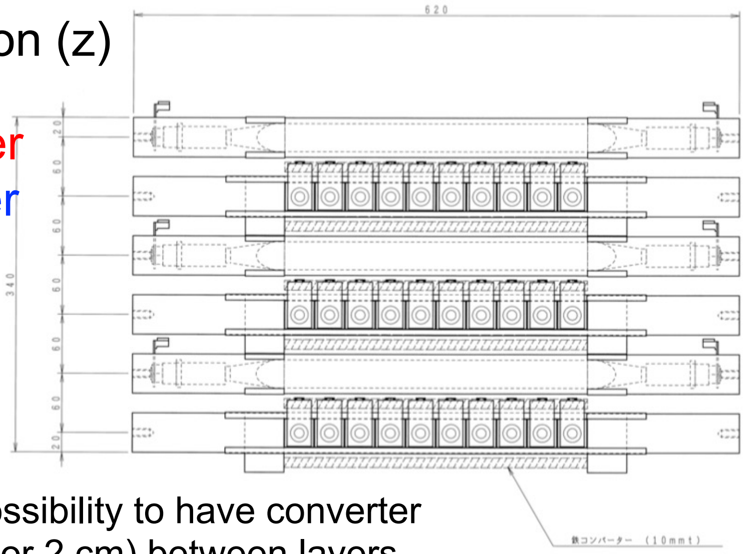


Net-baryon number distribution

~100 PMTs (half TOF panel) have been used for this neutron detector.

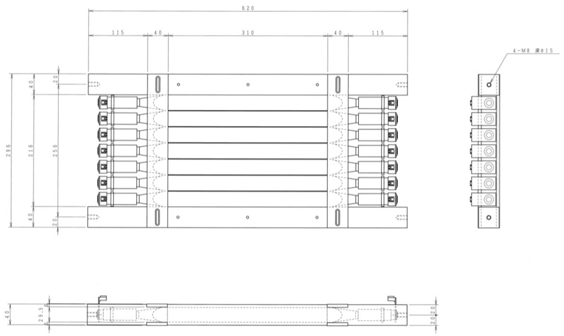
beam direction (z)

X-layer
Y-layer
X-
Y-
X-
Y-

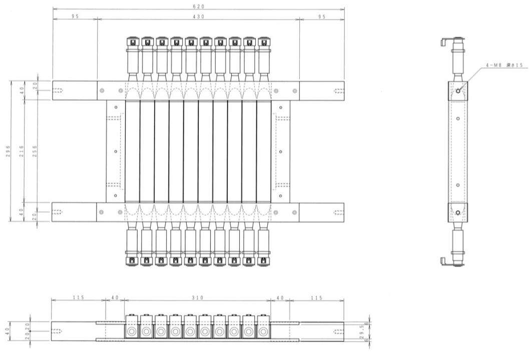


Possibility to have converter (1 or 2 cm) between layers

x-layer

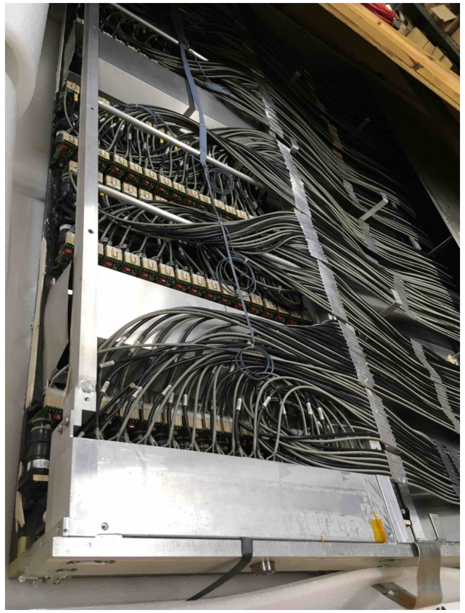


Y-layer

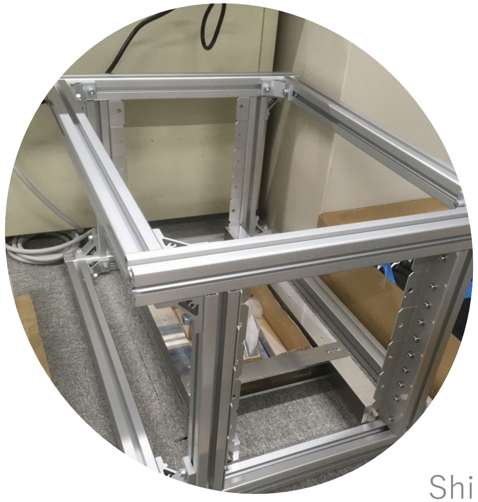


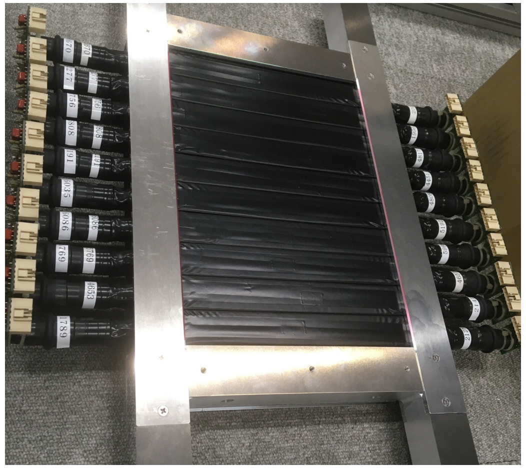
RHIC-PHENIX TOF ~0.5 panel

15 x 15 x 640 (or 430) mm^3
BC-404 (only PMTs re-used)



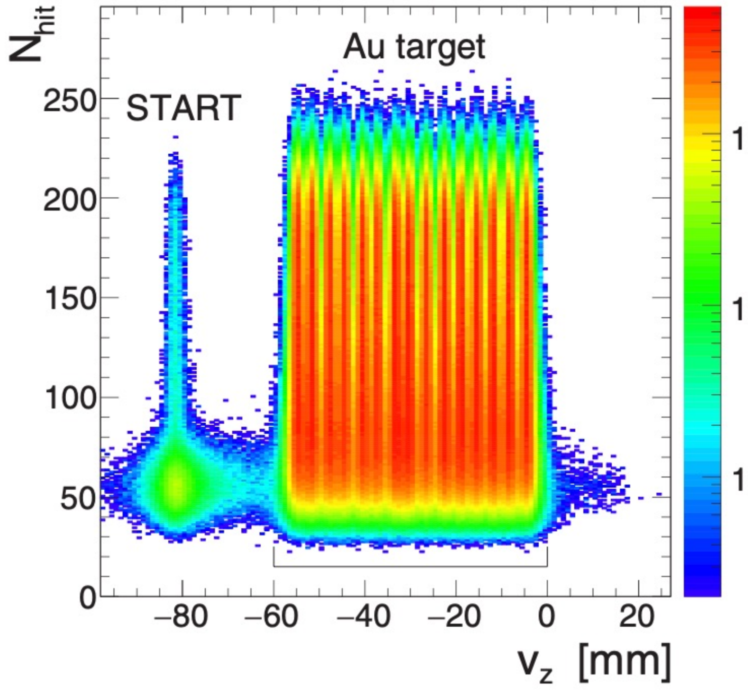
Neutron detector R&D for the future High-Density Quark-Nuclear Matter experiment in FAIR-CBM and J-PARC-HI



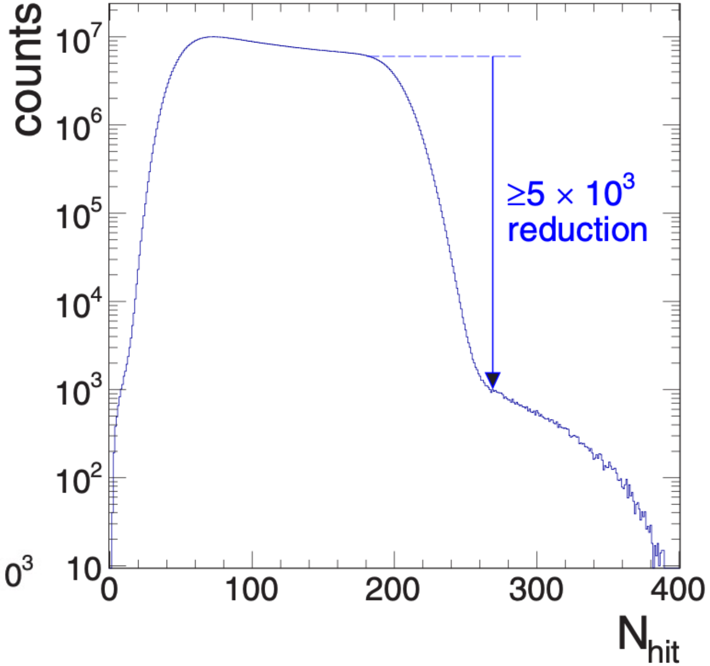


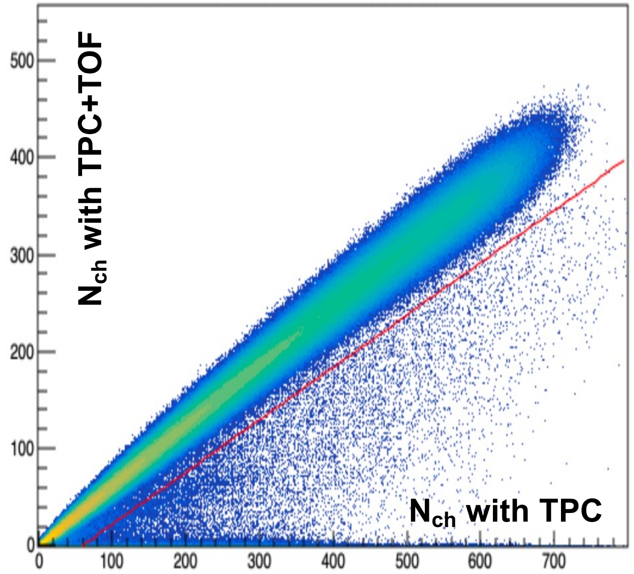
Pile-up events from high rate measurements

Au+Au 2.4 GeV HADES



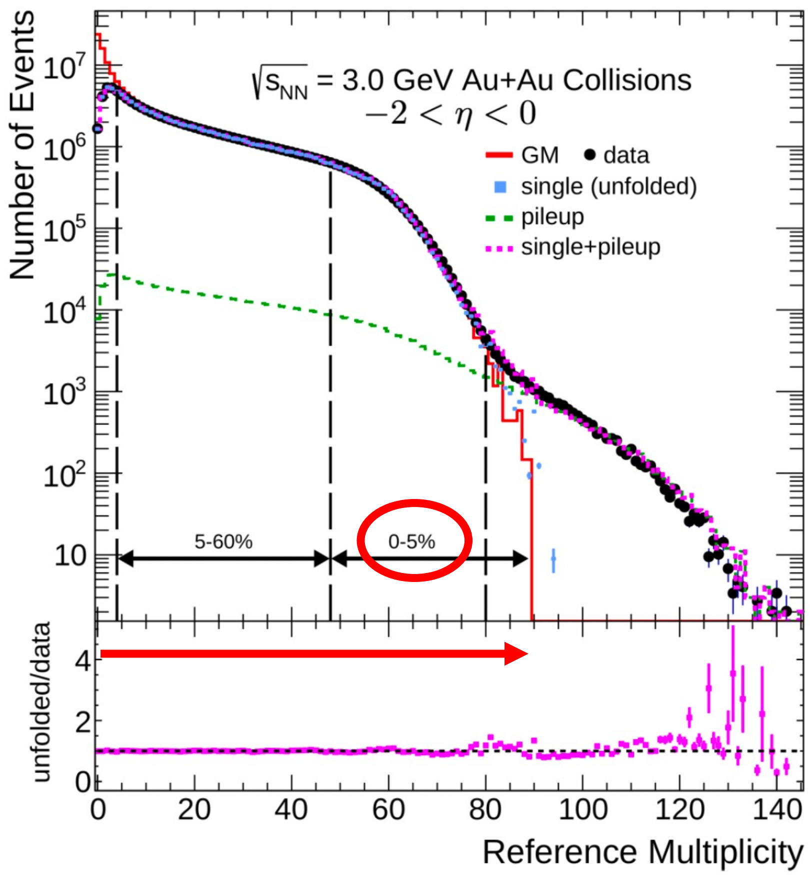
segmented vertex





Au+Au 27 GeV STAR

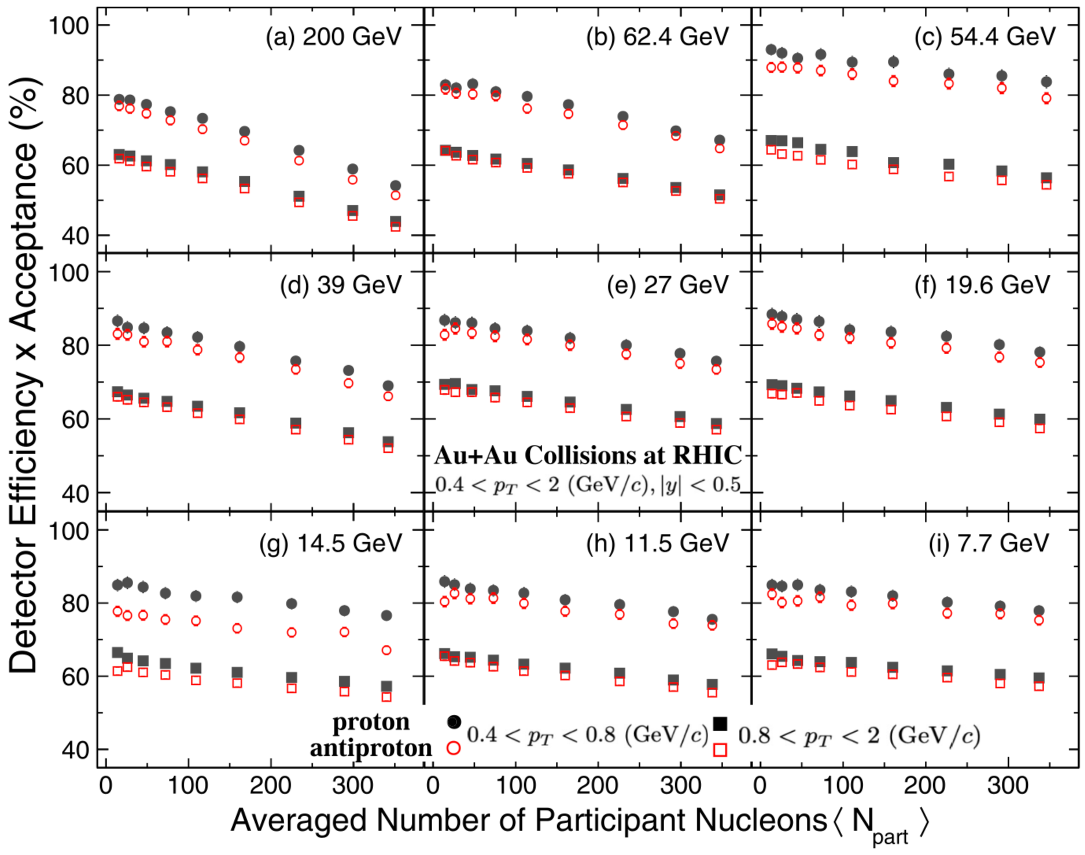
Au+Au 3 GeV STAR



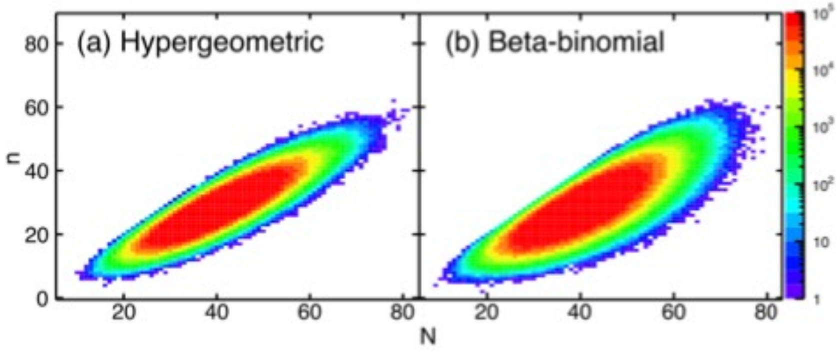
- with/without TOF hit requirement
- Pile-up correction (next slide)

Tracking efficiency and response matrix for unfolding correction

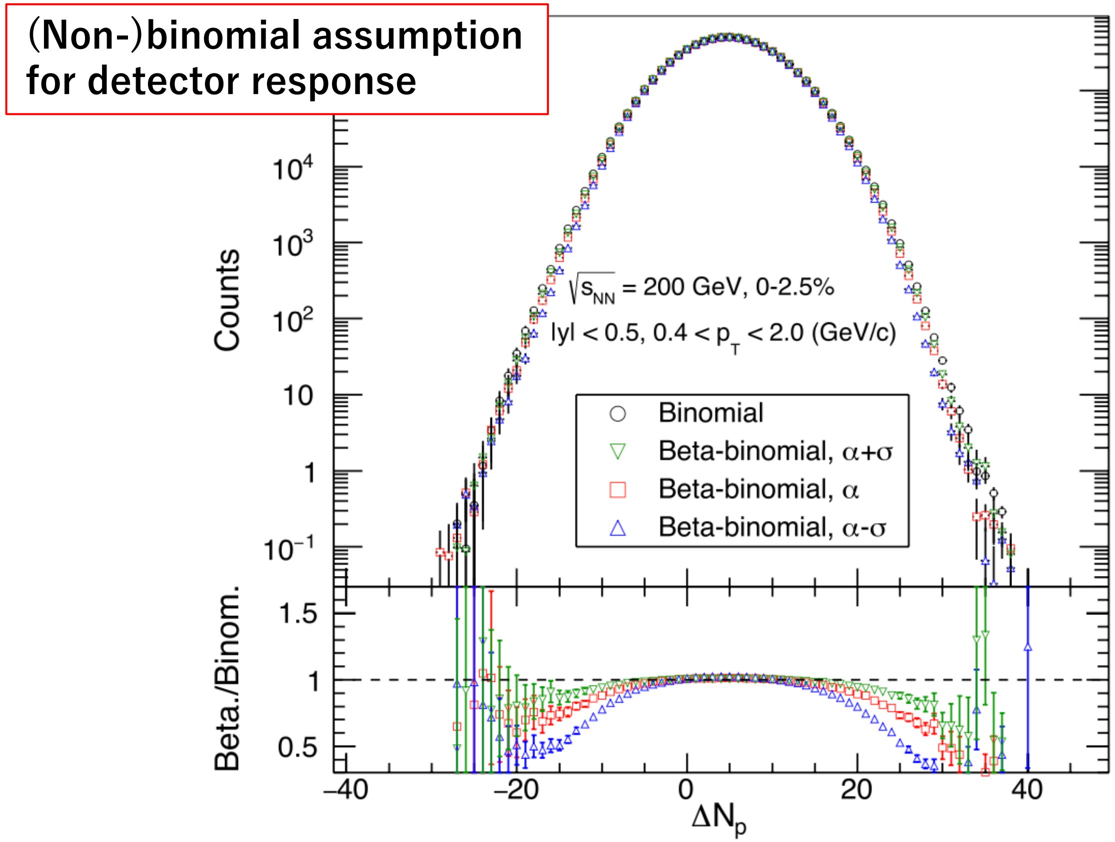
BES-I **PRC104 (2021) 024902**



based on embedding simulation

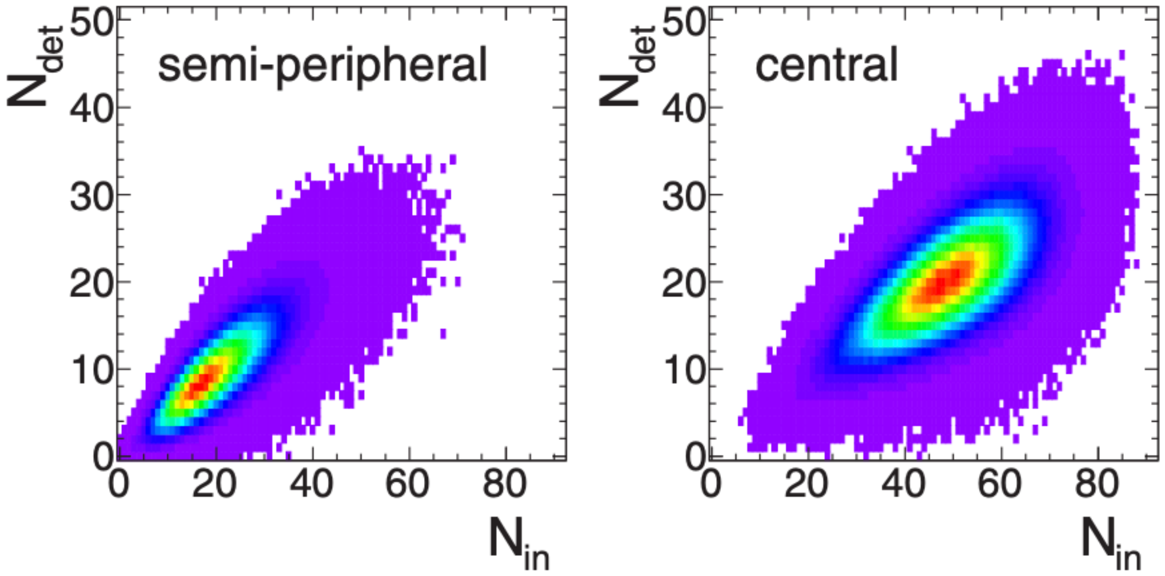


unfolded

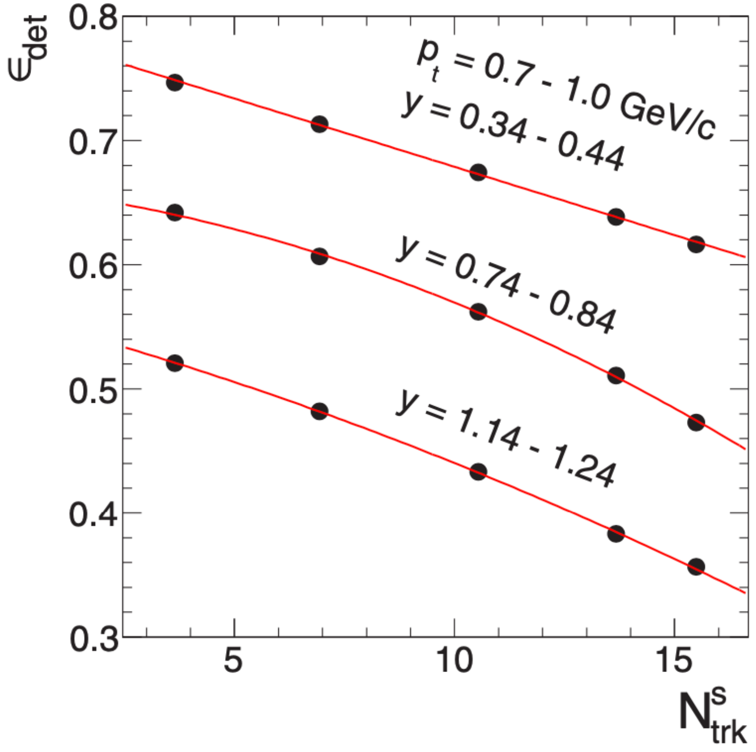


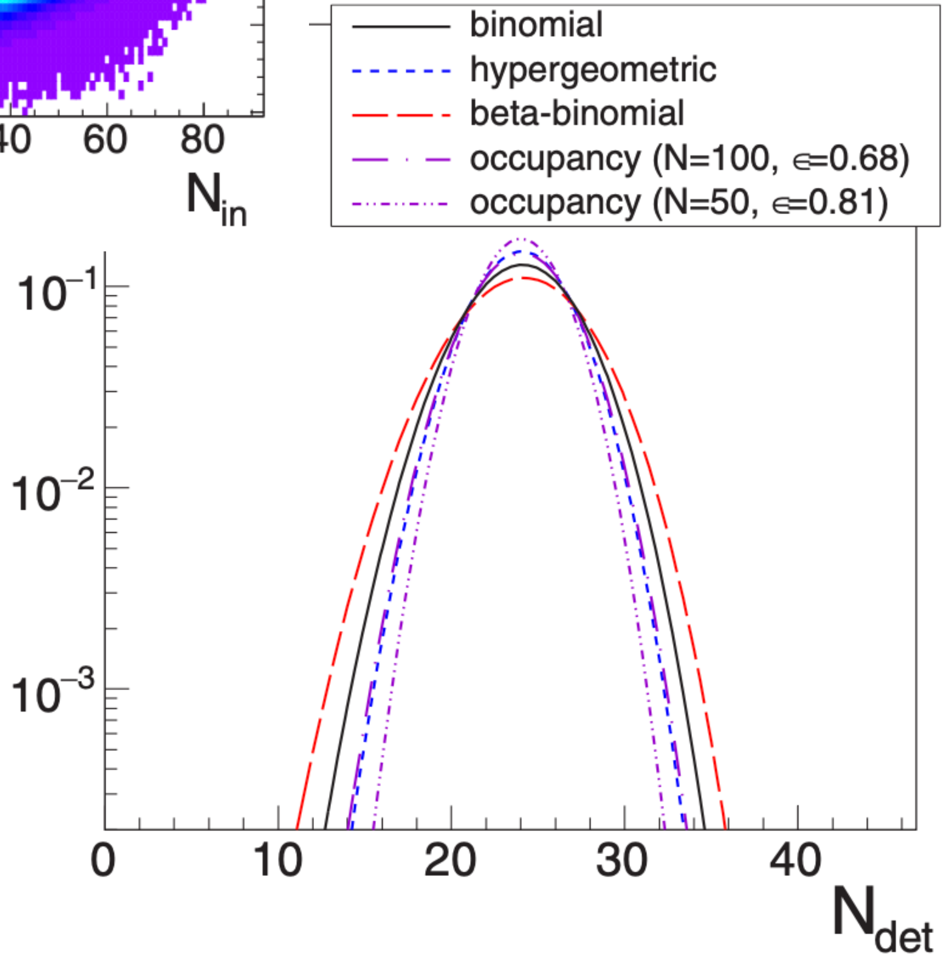
detector efficiency for
multi-particles detection with full Geant simulation

Au+Au 2.4 GeV HADES



detector response





Non-binomial efficiency correction
(Unfolding method)

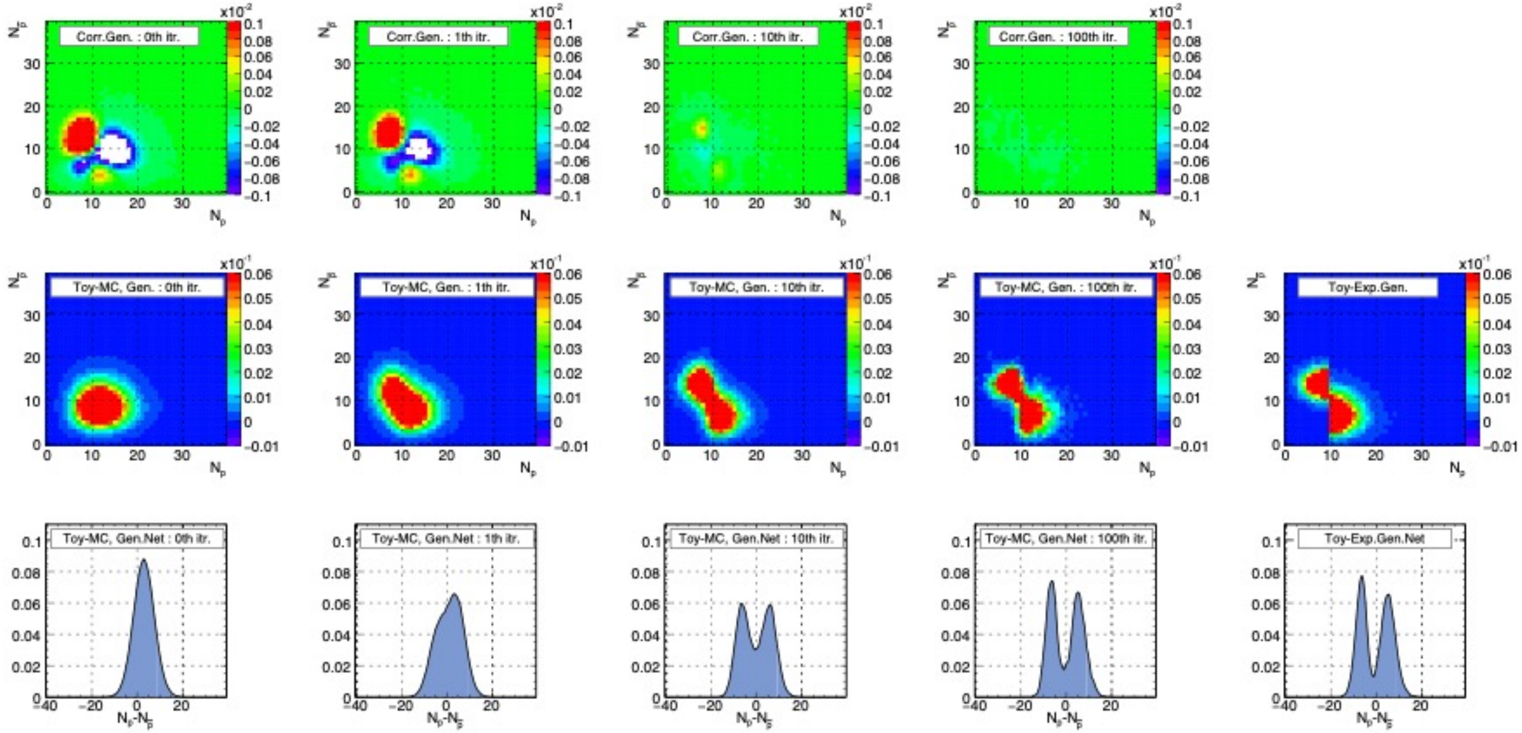


FIG. 4. (Top) Correction functions in the generated coordinates. White-colored bins represent the large negative value outside the z-axis range. (Middle) Toy-MC distributions in the generated coordinates. (Bottom) Toy-MC net-particle distributions in the generated coordinates. The 1st to 4th row from left to right show distributions at the 0th (initial condition), 1st, 10th and 100th iteration. The most right panels show distributions for the toy-experiment sample.

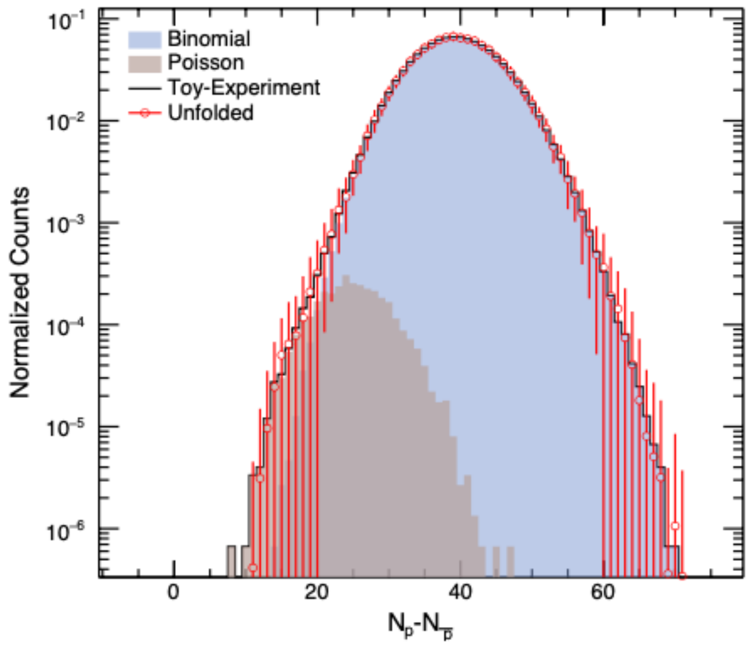
Reconstructing particle number distributions with convoluting volume fluctuations

ShinIchi Esumi,[1,*] Kana Nakagawa,[1] and Toshihiro Nonaka[1,2,†]

[1] *Tomonaga Center for the History of the Universe, University of Tsukuba, Tsukuba, Ibaraki 305, Japan*
[2] *Key Laboratory of Quark & Lepton Physics (MOE) and Institute of Particle Physics, Central China Normal University, Wuhan 430079, China*

We propose methods to reconstruct particle distributions with and without considering initial volume fluctuations. This approach enables us to correct for detector efficiencies and initial volume fluctuations simultaneously. Our study suggests such a tool could investigate the possible bimodal structure of net-proton distribution in Au+Au collisions at $\sqrt{s_{NN}}$ = 7.7 GeV as a signature of first-order phase transition and critical point of hadronic matter [1, 2].

NIM A987, 164802 (2021)



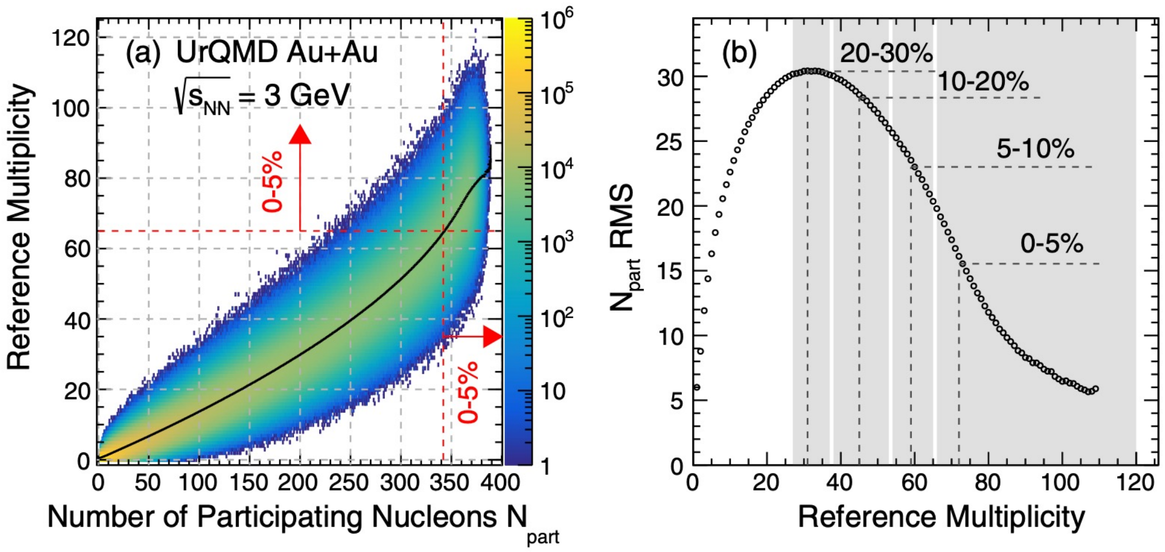
A general procedure for detector-response correction of higher order cumulants

Toshihiro Nonaka,[1,2,*] Masakiyo Kitazawa,[3,4,†] and ShinIchi Esumi[2,‡]

alternative method with moment expansion
NIM A906, 10 (2018)

Centrality determination

trying to improve the centrality resolution by increasing the number of charged particle (as much as in the TPC even in the case of Fixed target mode) excluding protons with Centrality Bin Width Correction (CBWC)



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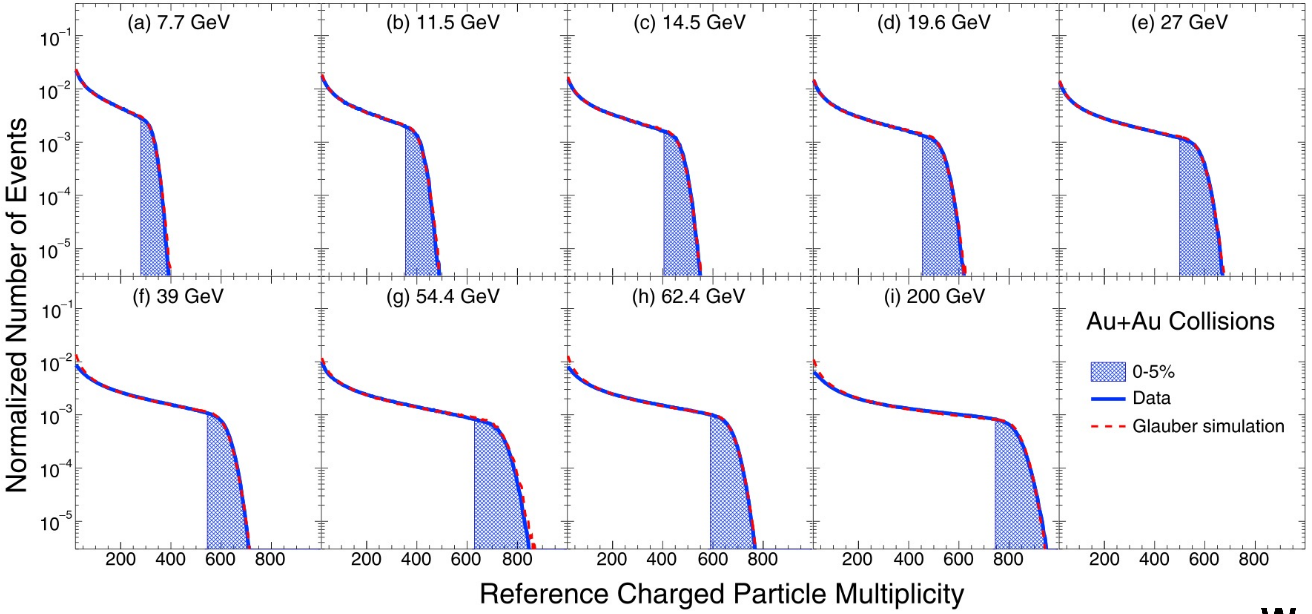
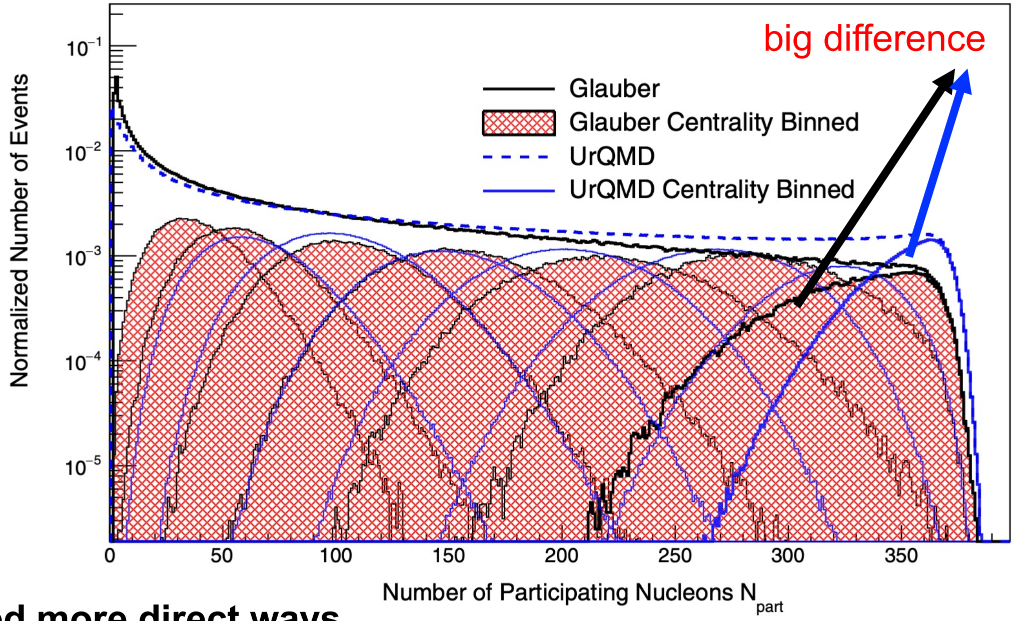


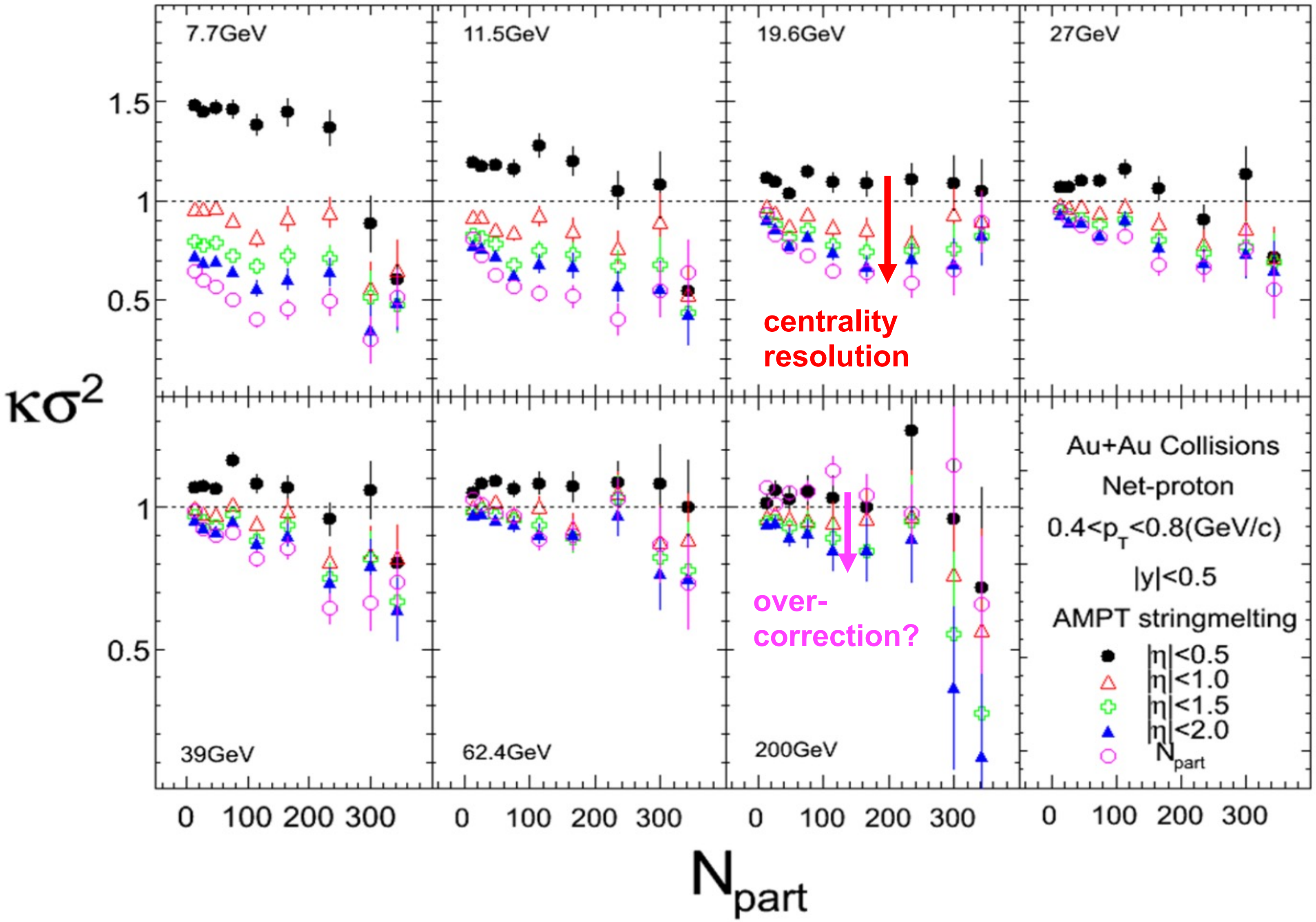


PRC104 (2021) 024902

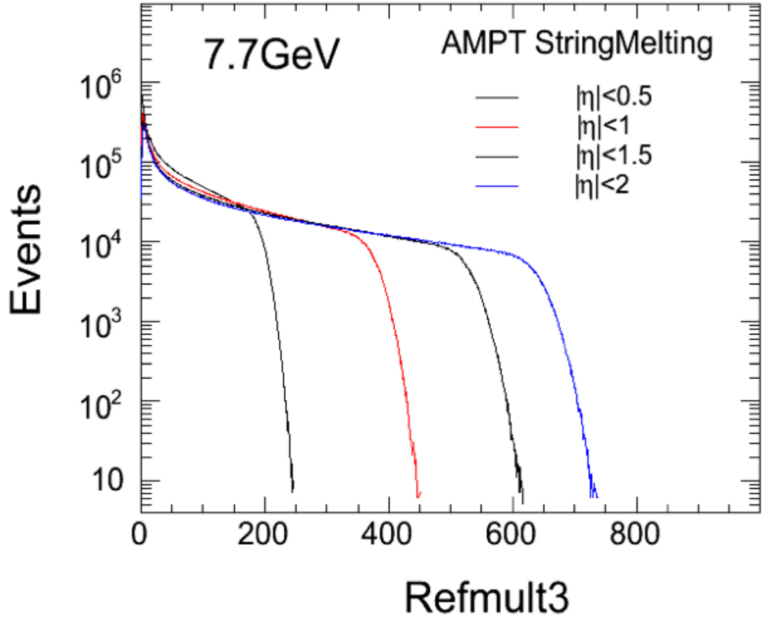
We need more direct ways to determine N_{part} experimentally.

PRC107 (2023) 024908

AMPT model simulation



Xiaofeng Luo (CCNU)



different "CBWC" corrections with various reference multiplicity including N_{part}-CBWC

Centrality selection with the Forward Wall

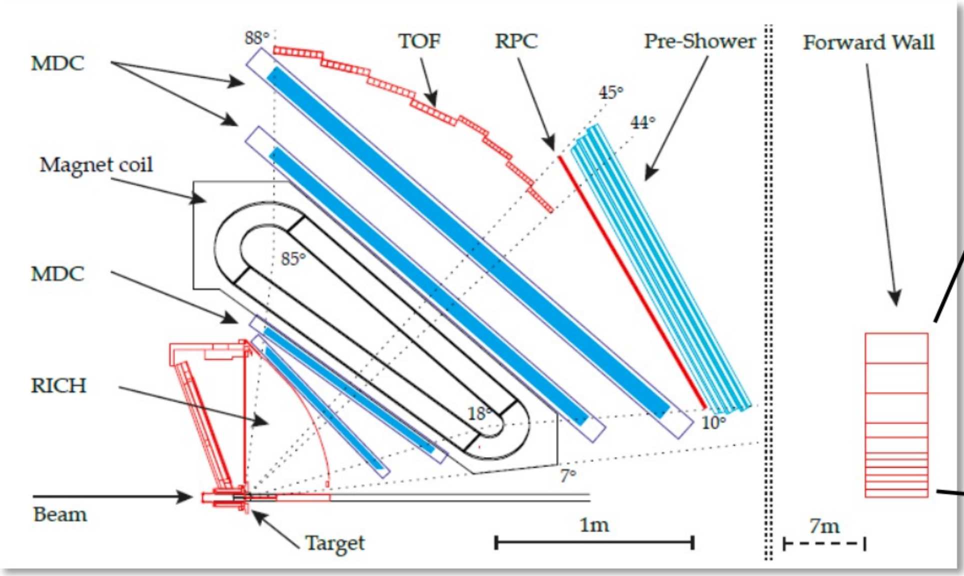
In 1.23 GeV/u Au+Au collisions:

- protons & clusters dominate
- centrality selection based on
  - hit mult in TOF & RPC
  - or track mult
  - or **FW sum of charges**

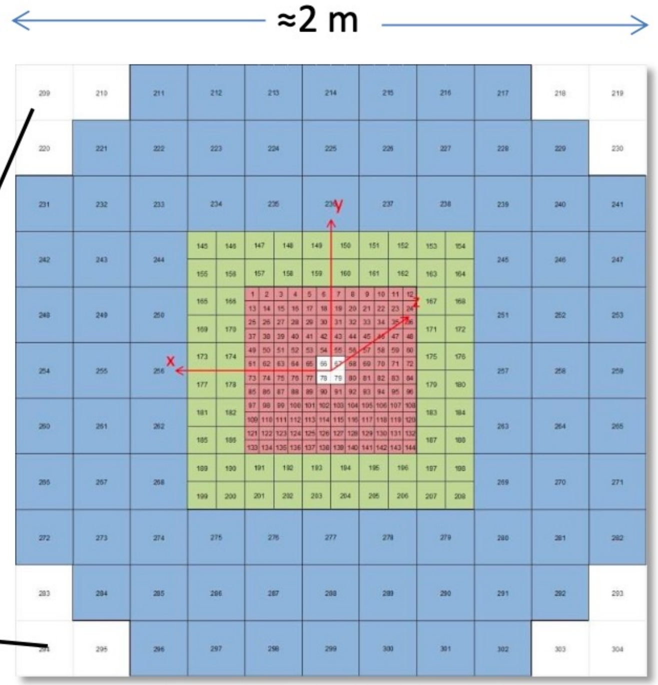
    ➔ reduce auto-correlations!

FW made of plastic scintillator tiles covering polar angles $\theta = 0.5^o - 7.5^o$ i.e. a pseudorapidity of $\eta = 2.7 - 5.4$ (HADES itself covers $y \approx 0 - 1.8$)

➔ Used for event-plane reconstruction



cross section of 1 of 6 HADES sectors



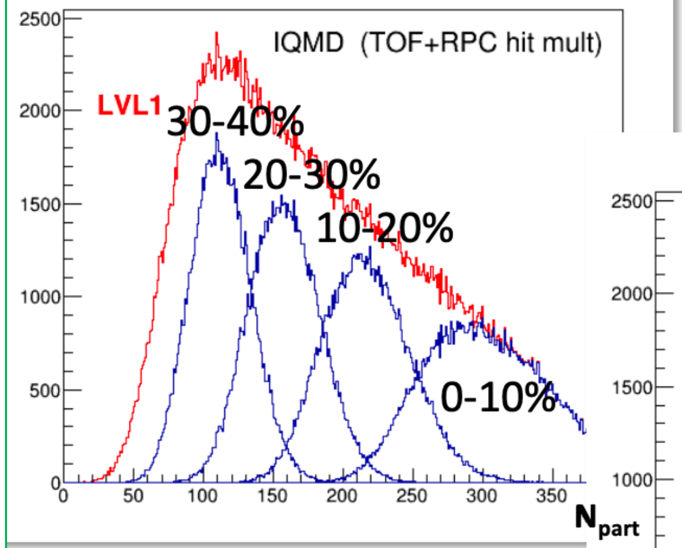
4x4, 8x8, 16x16 cm^2 tiles

07/11/2023 EMMI RRTF | R. Holzmann (GSI) 18

Centrality estimators in the HADES experiment

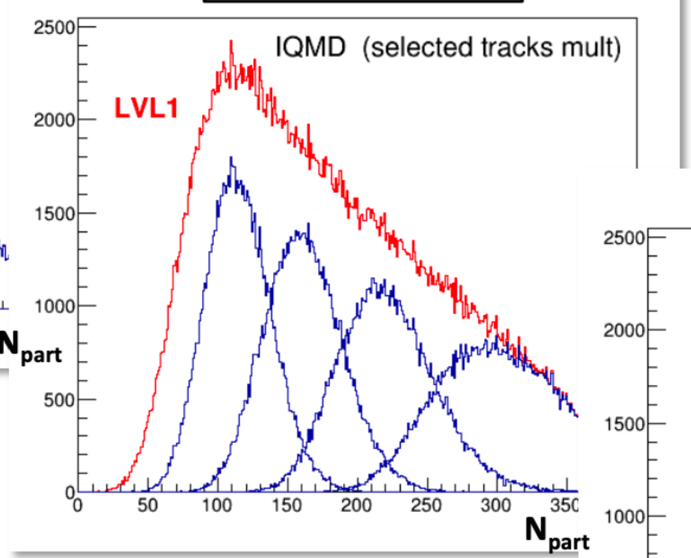
Based on full simulation with events from **IQMD + MST** clusterizer

N_{hit} centrality

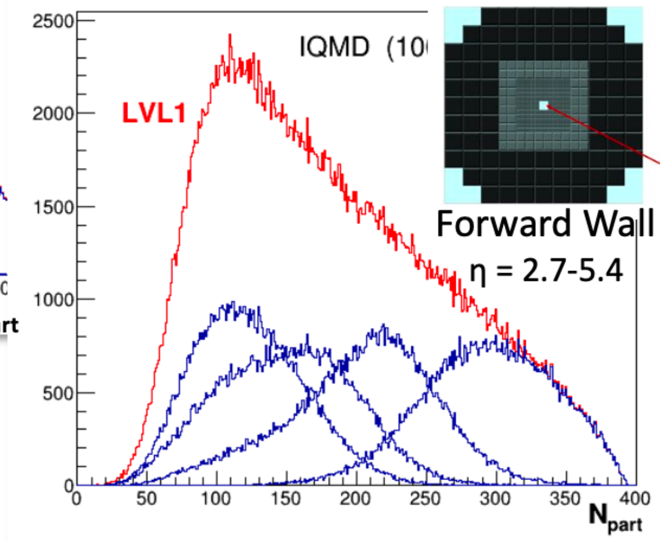


see also EPJA 54 (2018) 85

N_{trk} centrality



Σ_{FW} centrality

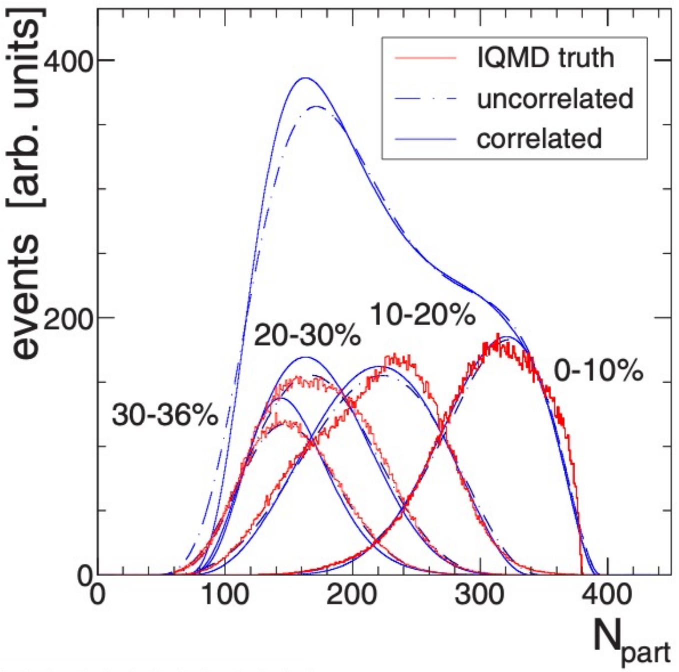


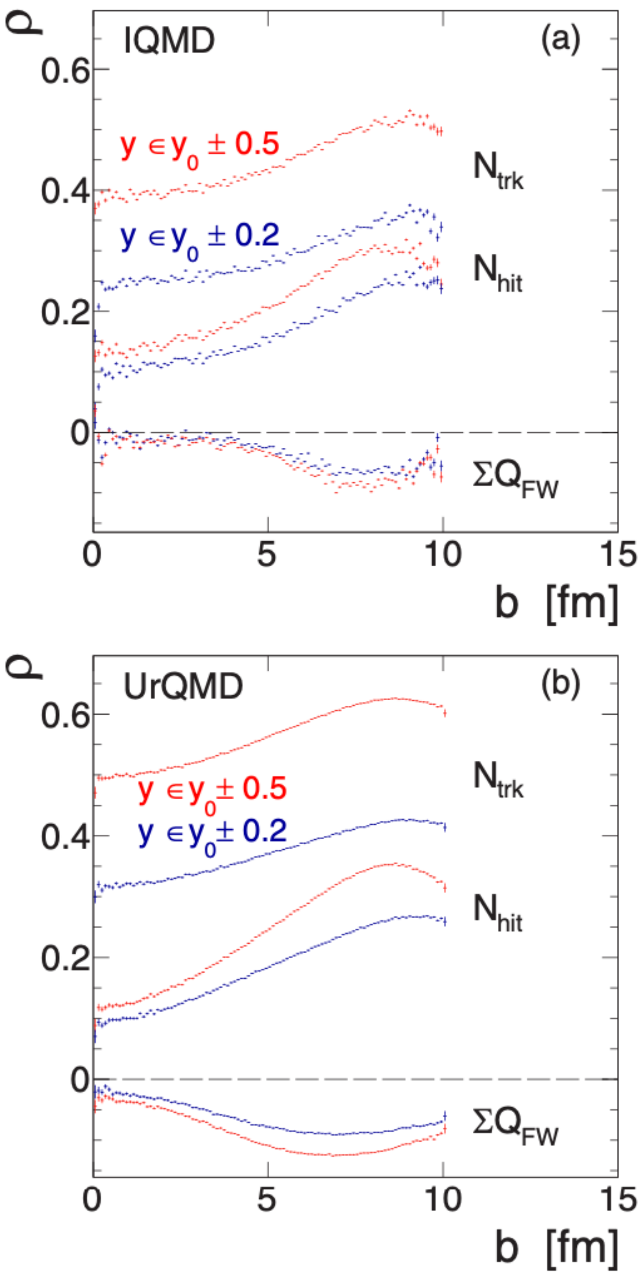
➔ Centrality selections lead to large volume fluctuations $\delta V \equiv \delta N_{part}$, characterized by volume cumulants V_j

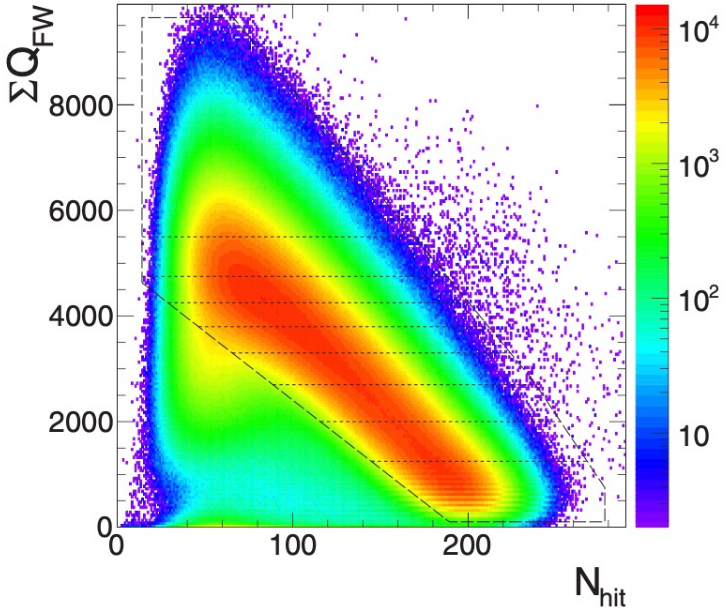
➔ We use FW for fluct. analysis

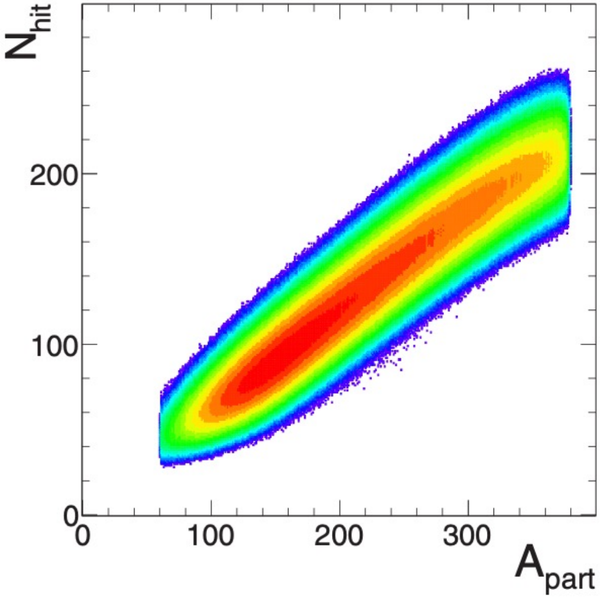
Centrality determination in HADES experiment

$\rho(N_{\rm prot}, \Sigma Q_{\rm FW})$. Unfortunately, such a complete model is not yet at hand, and we have hence taken the pragmatic approach to (1) use the centrality selector with lowest correlations and (2) modify the volume cumulants based on the resulting $N_{\rm hit}$ distributions such as to express the correlation-affected $N_{\rm part}$ distributions.

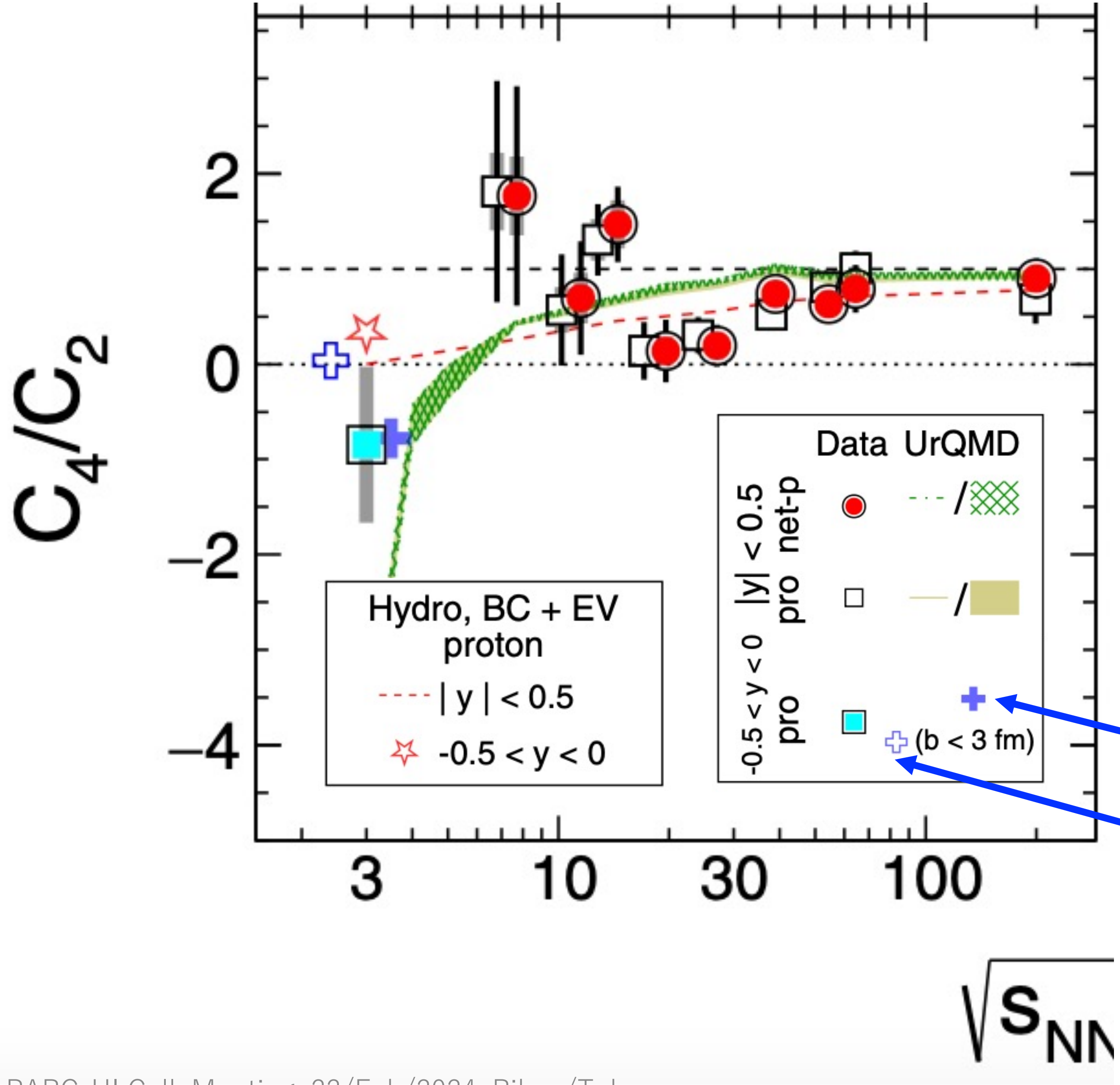




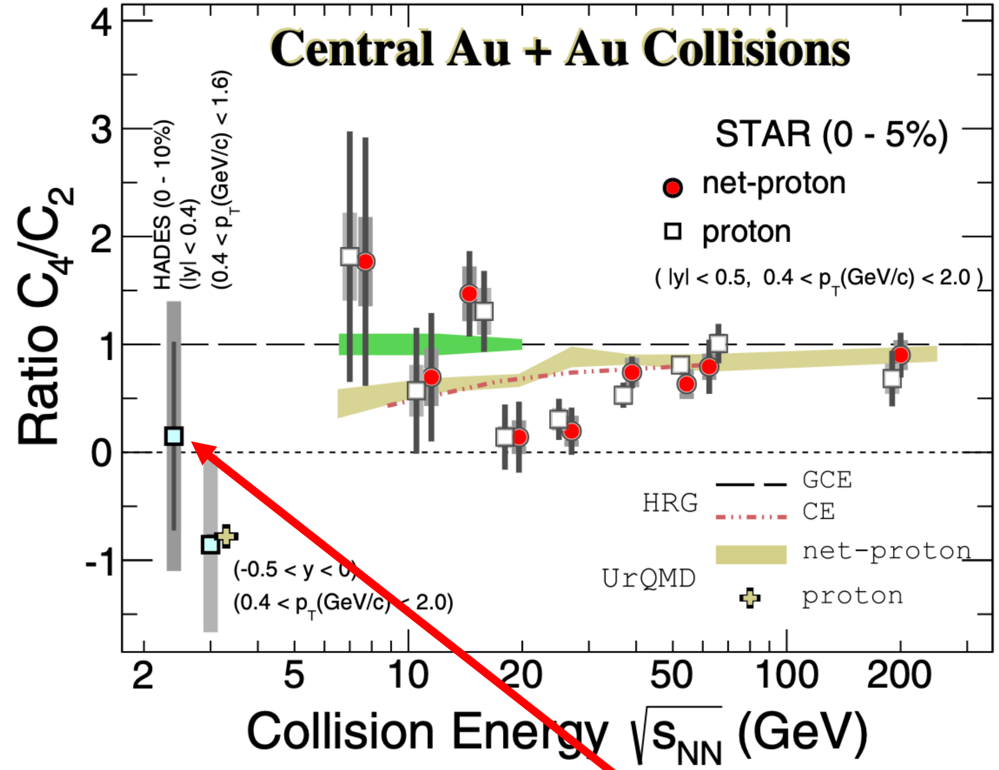




STAR 3GeV net-proton PRC



PRL



with CBWC

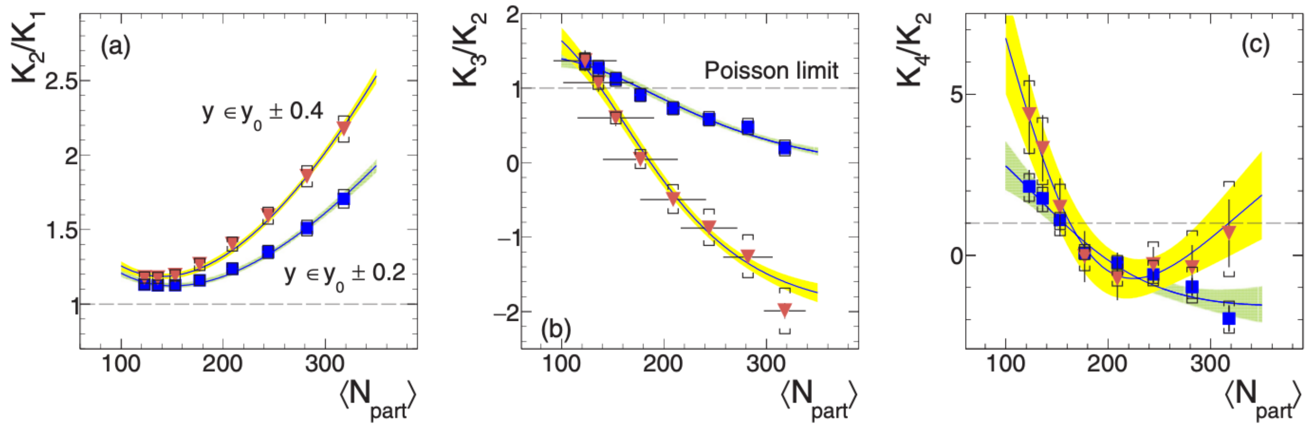
without CBWC

HADES
with VFC
no CBWC

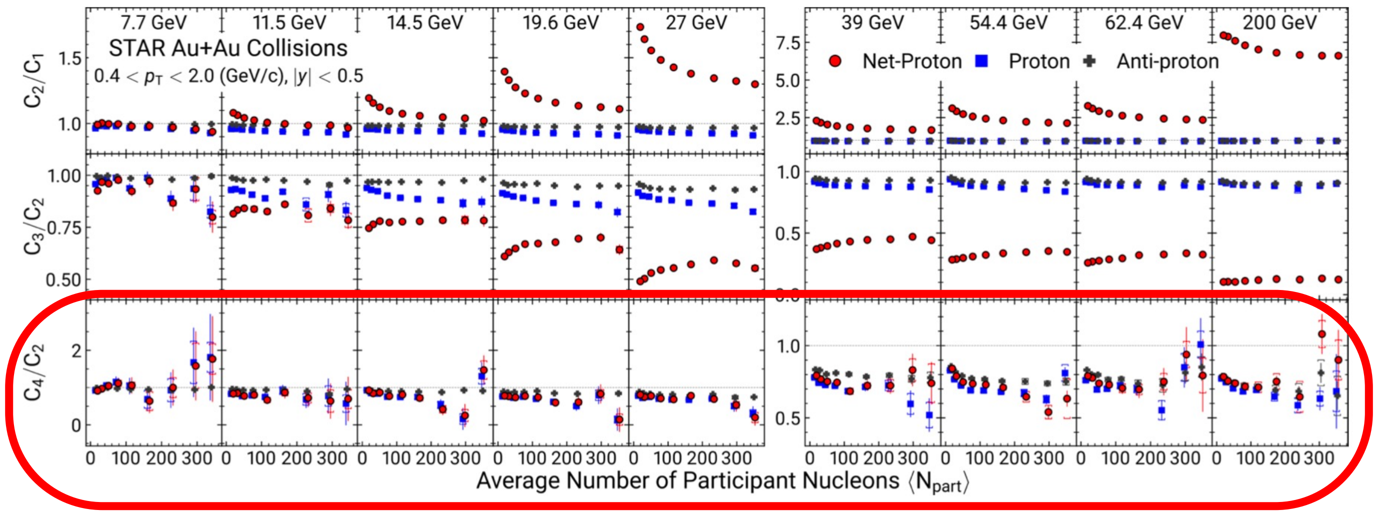
Centrality dependence of cumulant ratio

Au+Au 2.4 GeV HADES

with spectator based centrality
with volume correction

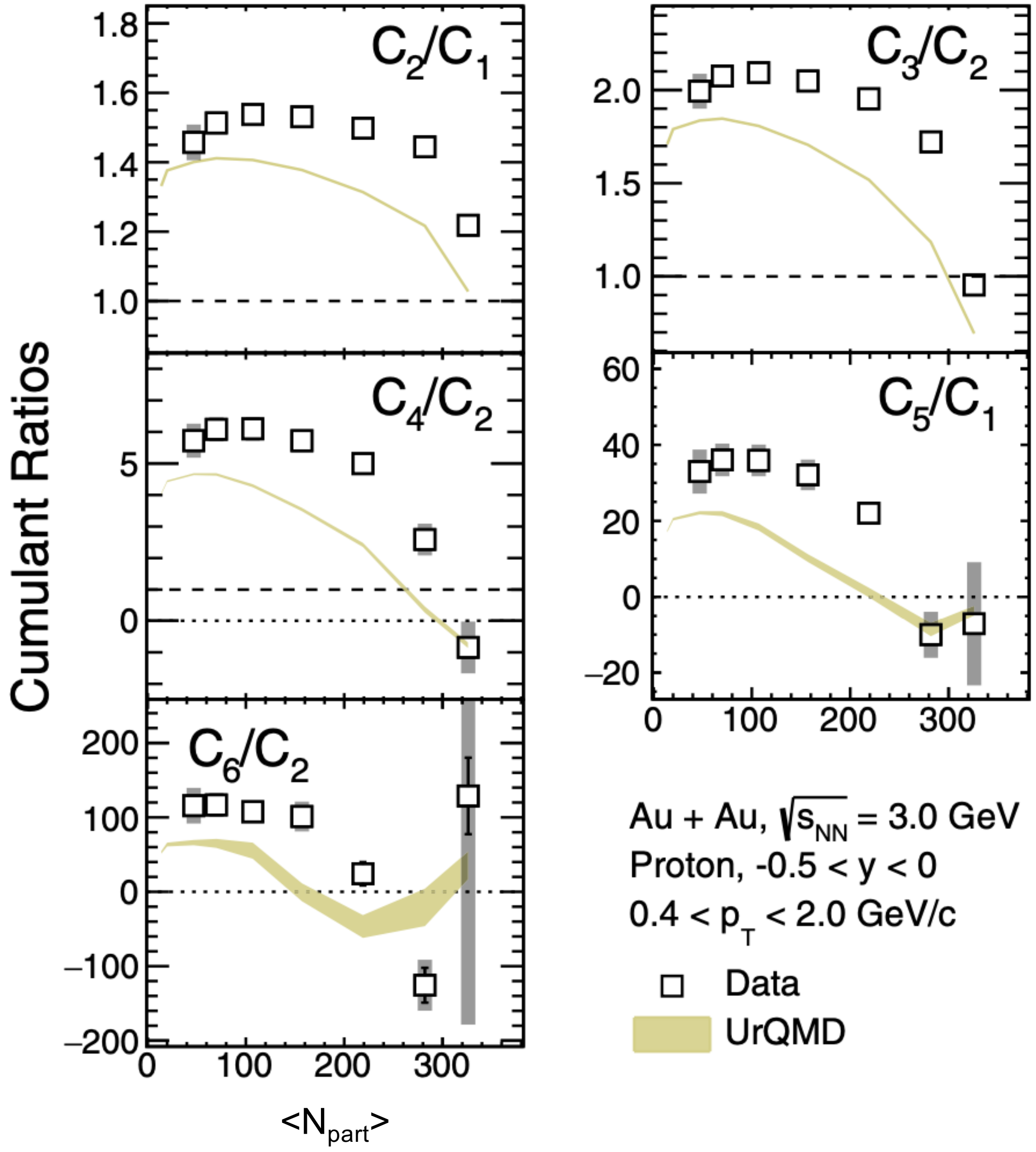


STAR BES1: CBWC only



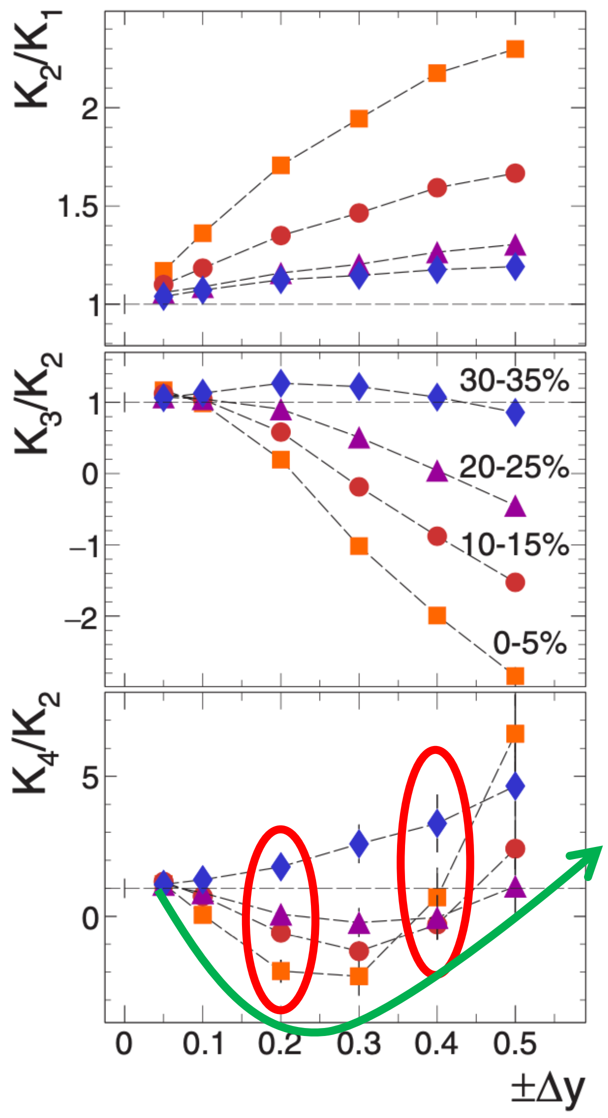
Au+Au 3 GeV STAR: CBWC only

with participant based centrality
without volume correction

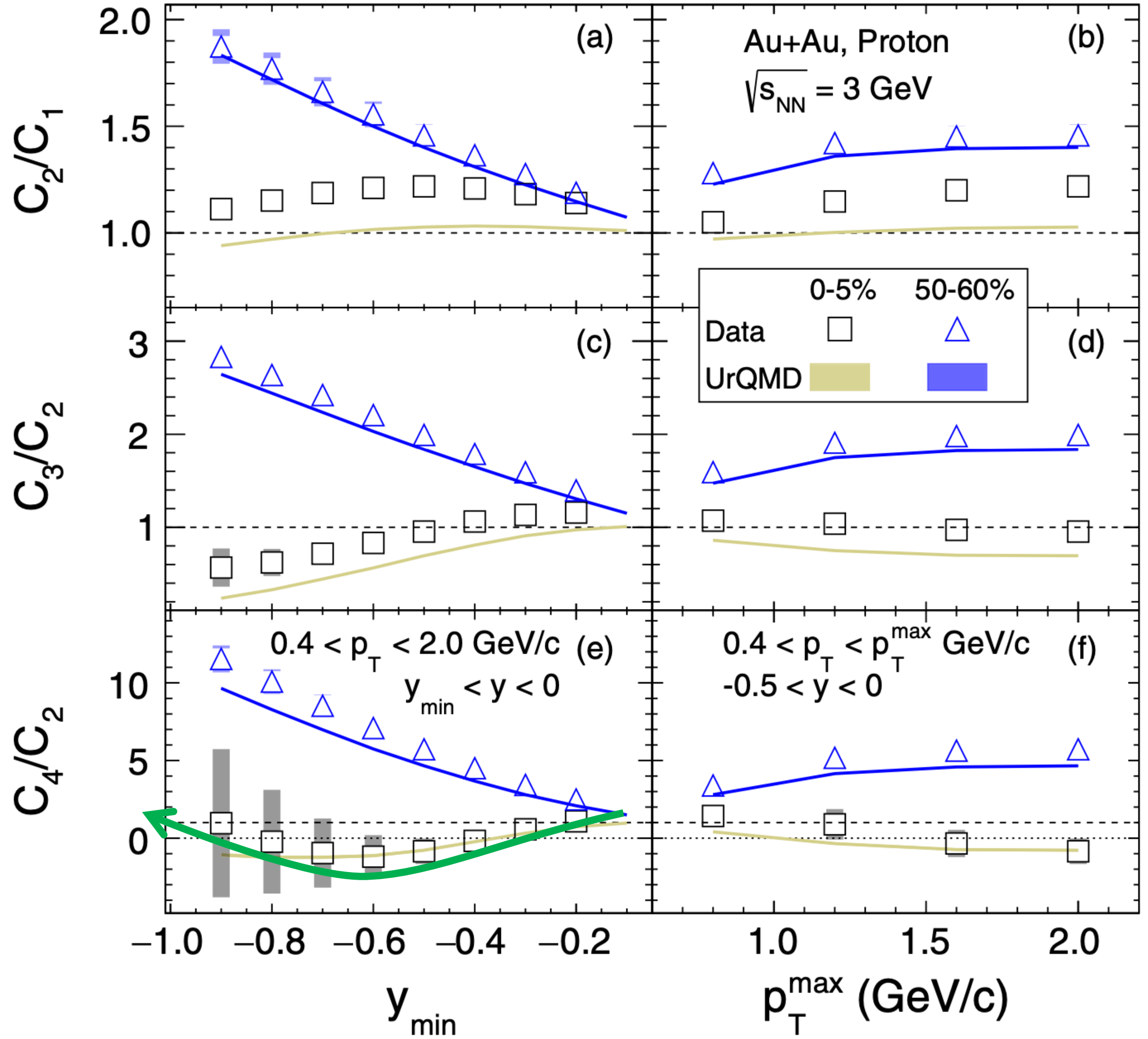


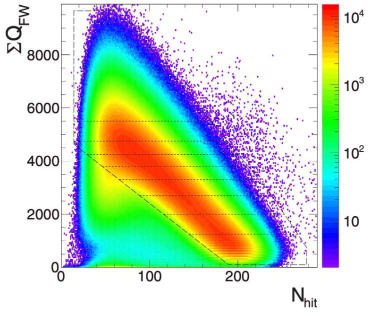
Acceptance dependence of cumulant ratio

Au+Au 2.4 GeV HADES



Au+Au 3 GeV STAR: CBWC only





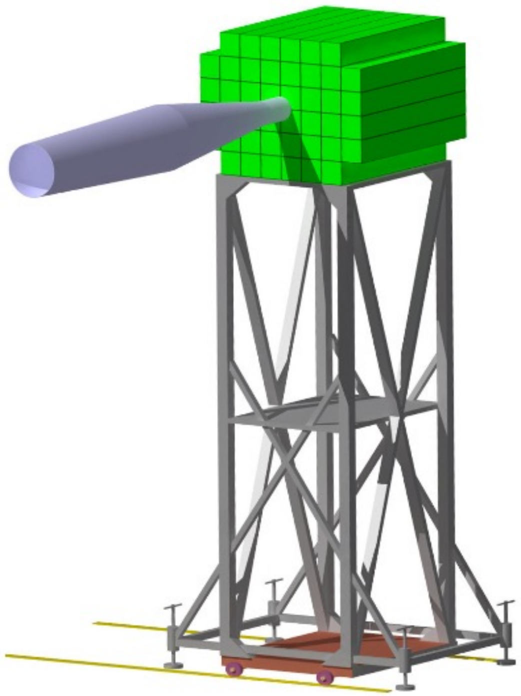
HADES
Forward-Central
correlation

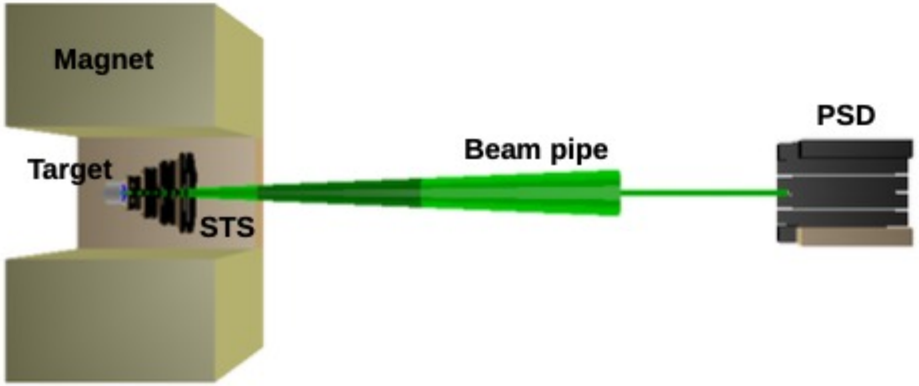
STAR fixed target mode :
EPD (eta = 2.5 ~ 6)
TPC (eta = 0 ~ 2.3)

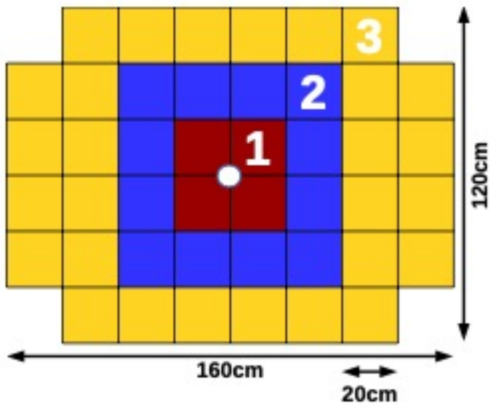
	HADES 2.4 GeV Au+Au	STAR 3 GeV Au+Au
Centrality	Q_{FW} (spectators) N_{hit} or N_{trk} (participants)	TPC (participants) EPD (spectators)
CBWC	Q_{FW} (spectators) N_{hit} or N_{trk} (participants)	TPC (participants) EPD (spectators)
VFC	Q_{FW} (spectators) N_{hit} or N_{trk} (participants)	TPC (participants) EPD (spectators)

CBWC is to take into account the variation of the mean within a centrality bin, which is effectively correcting for the volume fluctuation.

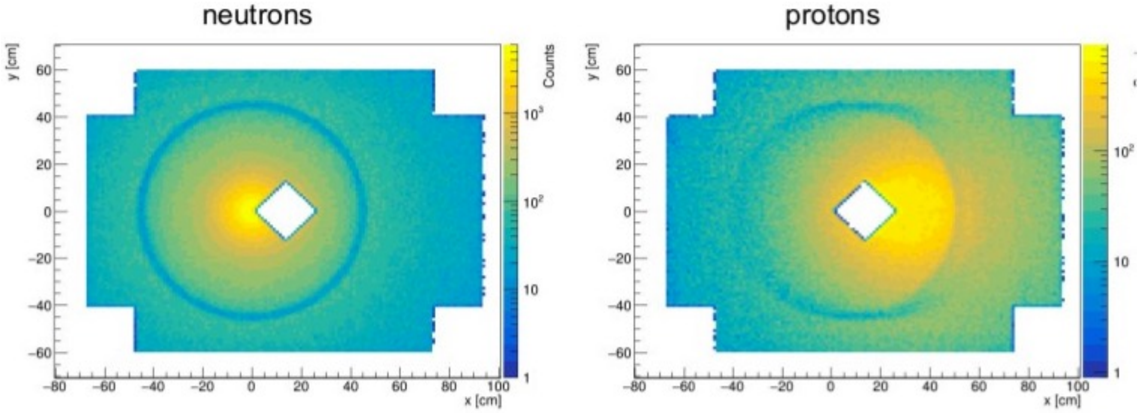
Participant Spectator Detector (PSD)



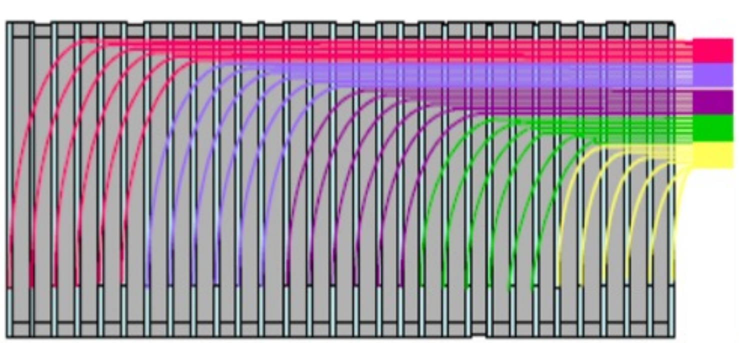


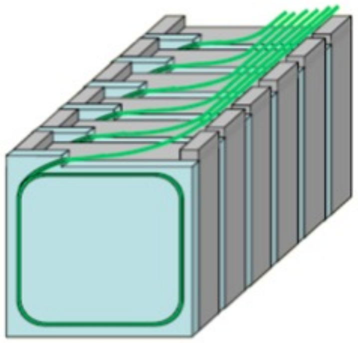


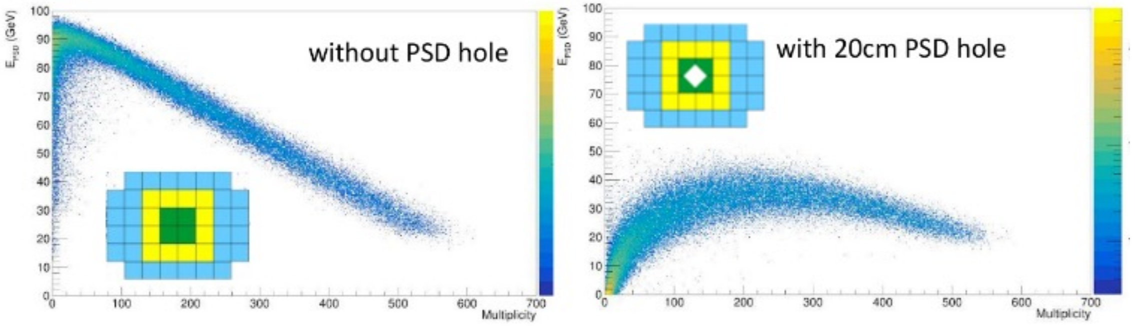
Centrality and Reaction plane determination



DCM-QGSM-SMM, Au-Au @ 12A GeV/c



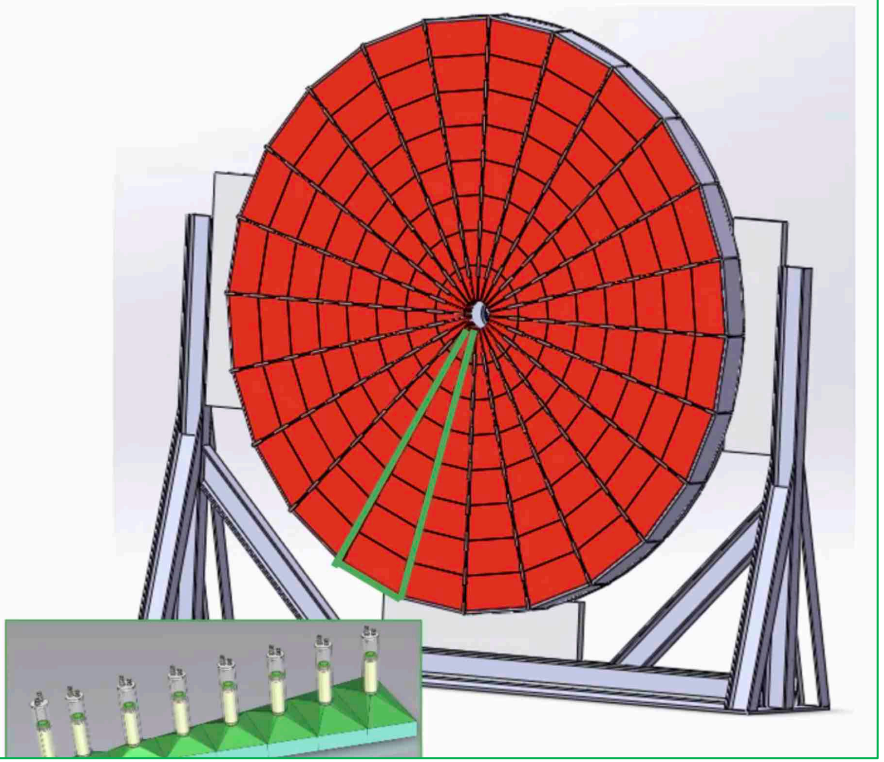


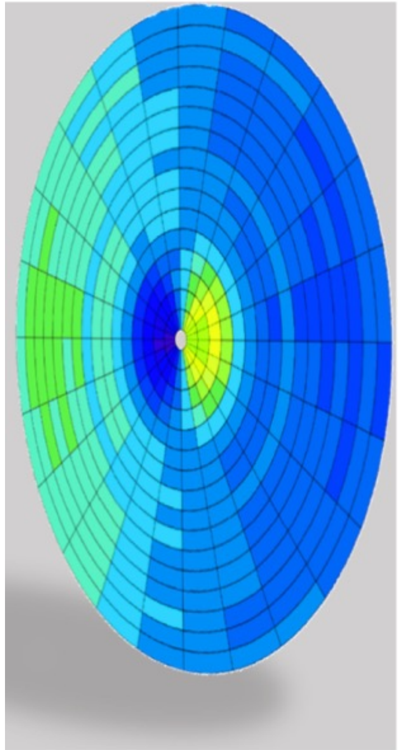


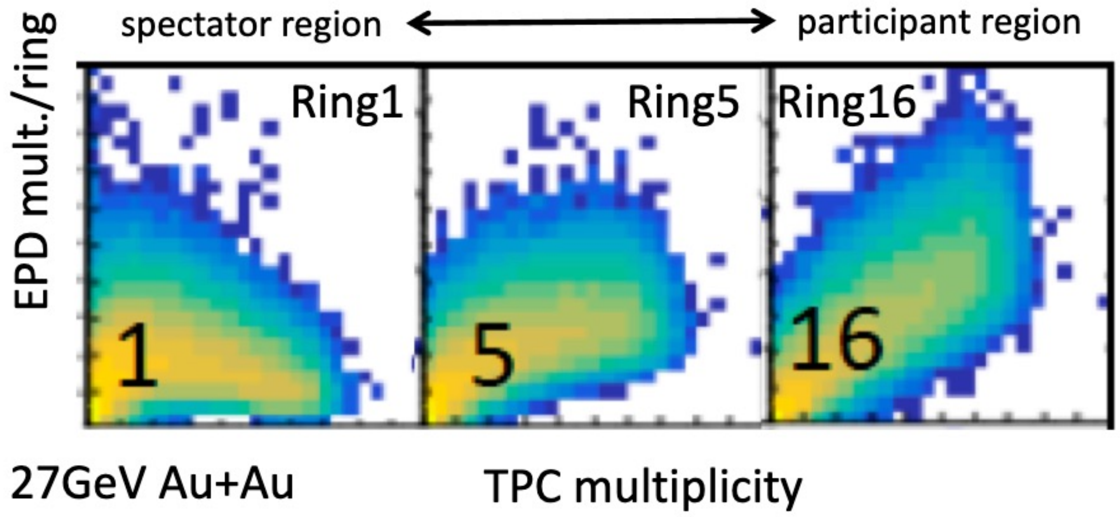
概述 – ZDC探测器介绍

- 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

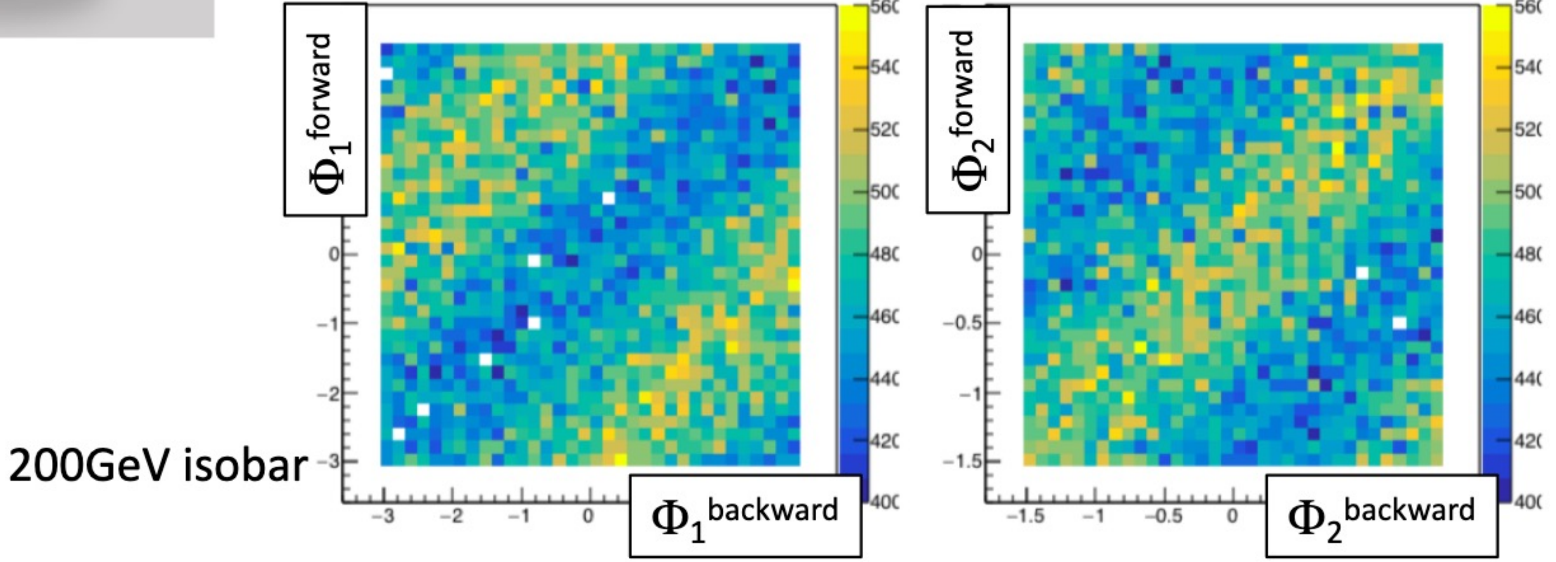
ZDC探测器的几何参数	
距磁铁中心距离	2.95 m
ZDC轮盘内径	5 cm
ZDC轮盘外径	100 cm
探测模块数	192 (24扇区 × 8模块/扇区)
电子学道数(双打拿极输出)	384
ZDC主要技术指标	
探测效率	> 95%
通道占有度	< 15%
有效面积	> $1m^2$



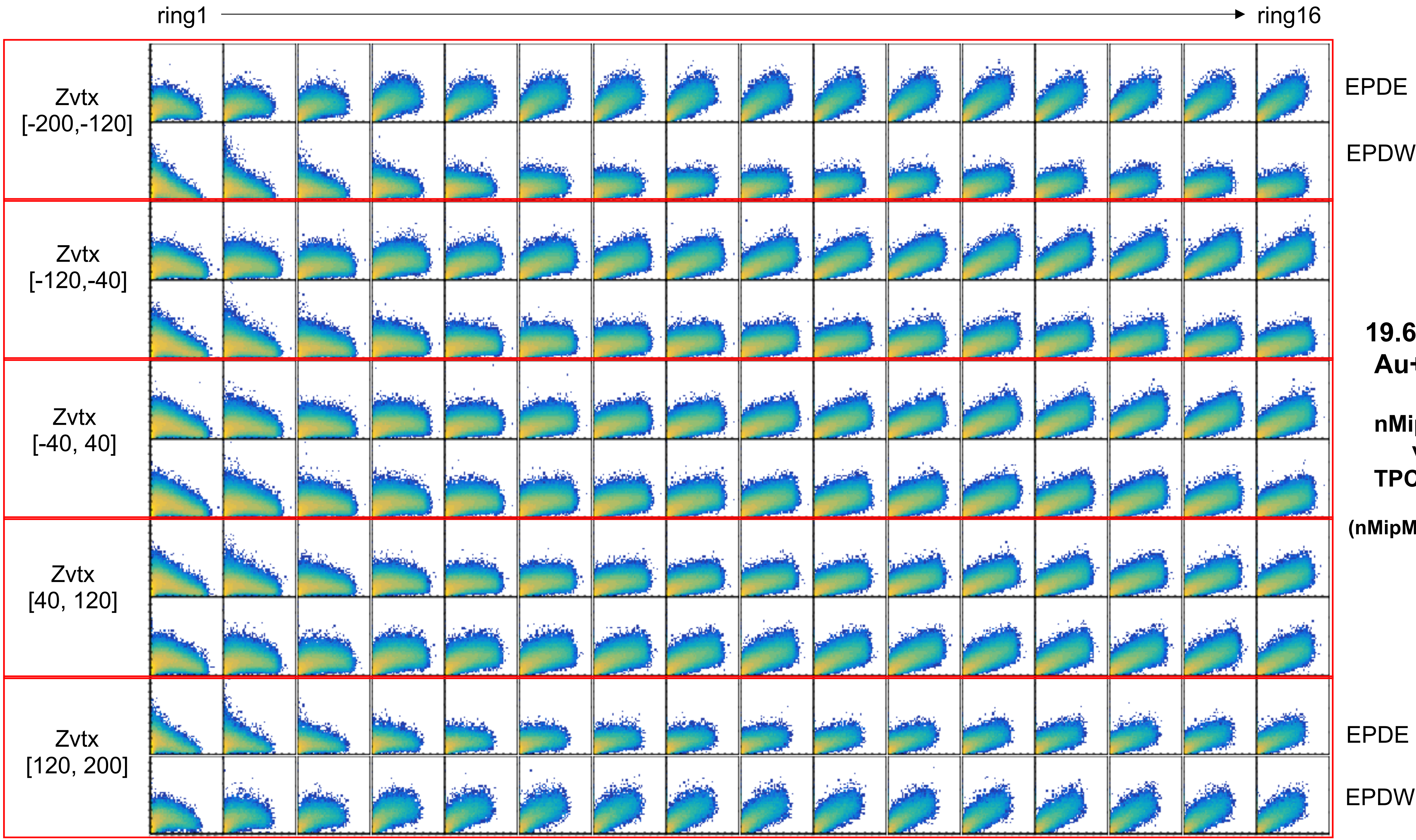




Forward-backward event-plane correlation



STAR collider mode :
EPD (|eta| = 2 ~ 5)
TPC (|eta| = 0 ~ 1.5)
(for zvtx ~ 0 cm)



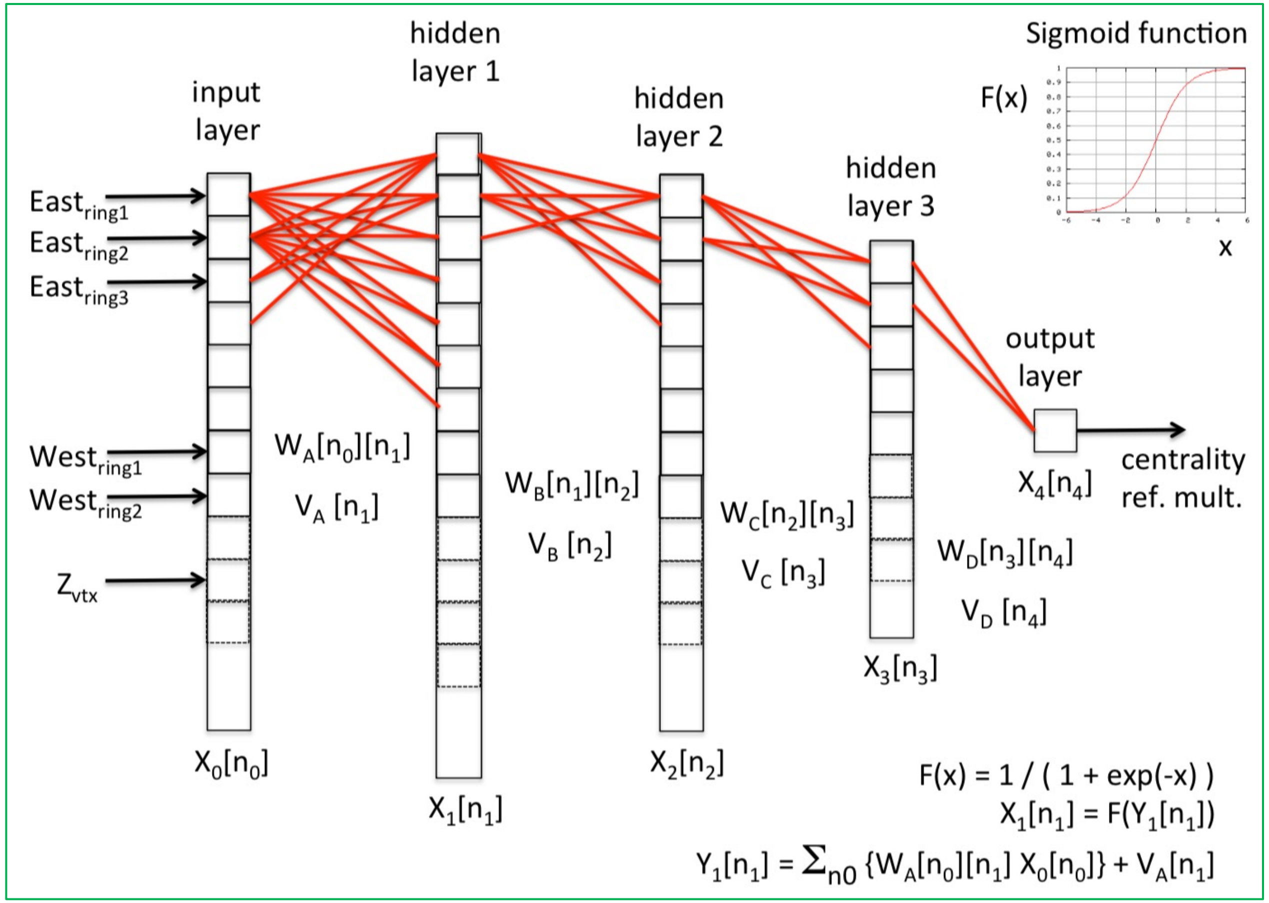
19.6GeV Au+Au

nMip sum vs TPC mult.

(nMipMaxCut=6)

refMult + refMult2 (= refMult3+protons)

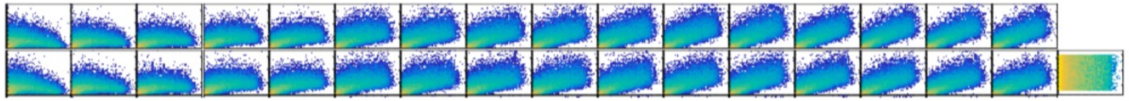
Machine learning of centrality with neural network



"old-standard" back-propagation :
with EPD ring inputs plus z-vertex
educated to the measured TPC multiplicity

27GeV Au+Au 50k education events and 50k test events (EPD+TPC)

16 ADC sum values from 2 arms + zvertex = 33 input neurons



3 hidden layers (n1=66, n2=30, n3=10 neurons)

back-propagation to modify weight W and bias V

Error (target-output) : $E = 0.5\ (X_T[n_4] - X_4[n_4])^2$

$dE/dX_4 = X_T-X_4$, $dX_4/dY_4 = F'(X_4)$, $dY_4/dW_D = X_3$

$dE/dW_D = (dE/dX_4)\ (dX_4/dY_4)\ (dY_4/dW_D)$

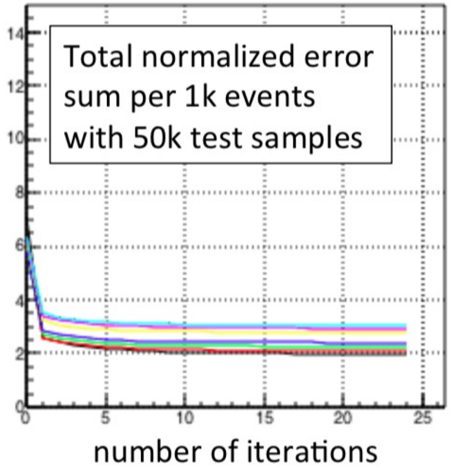
$W_D = W_D + \alpha\ (X_T-X_4)\ F'(X_4)\ X_3$

$V_D = V_D + \alpha\ (X_T-X_4)\ F'(X_4)$

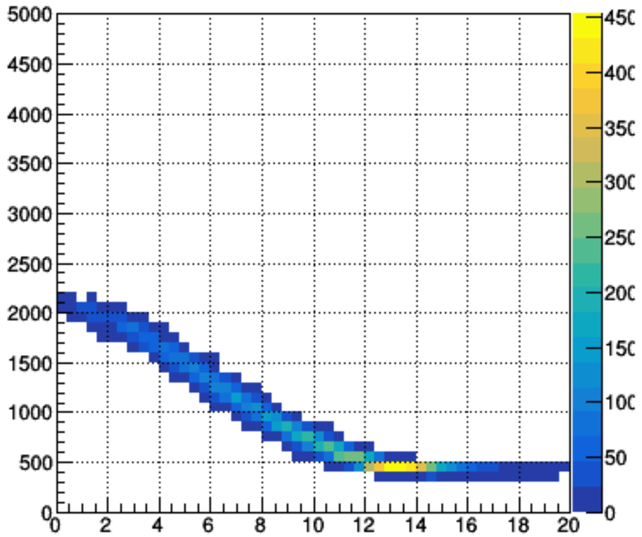
$dE/dX_3 = (X_T-X_4)\ F'(X_4)\ W_D$

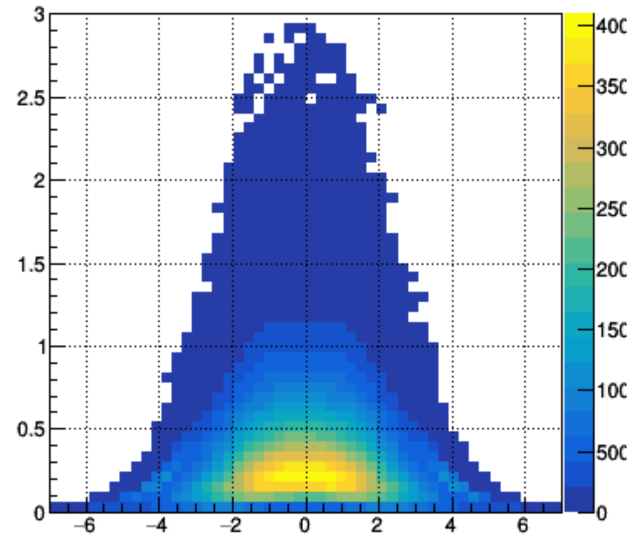
.....

1 output layer with 1 neuron (as refmult)



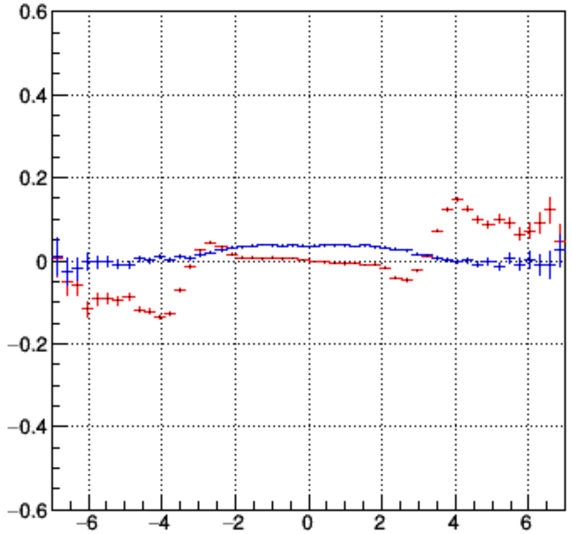
AMPT 10GeV Au+Au

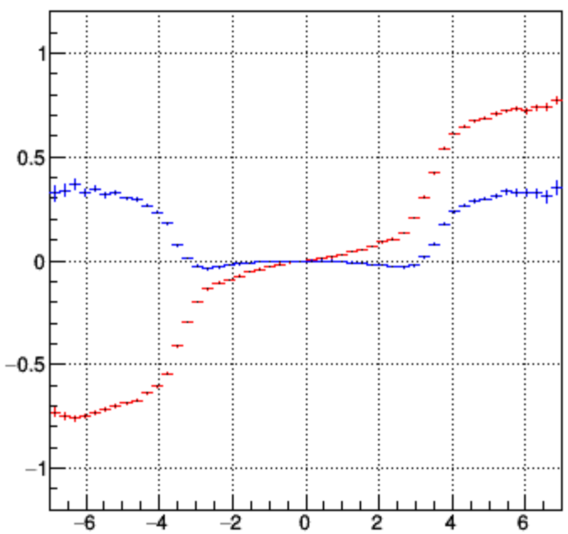




$v1 = <\cos(\phi\text{-R.P.})>$
$v2 = <\cos2(\phi\text{-R.P.})>$

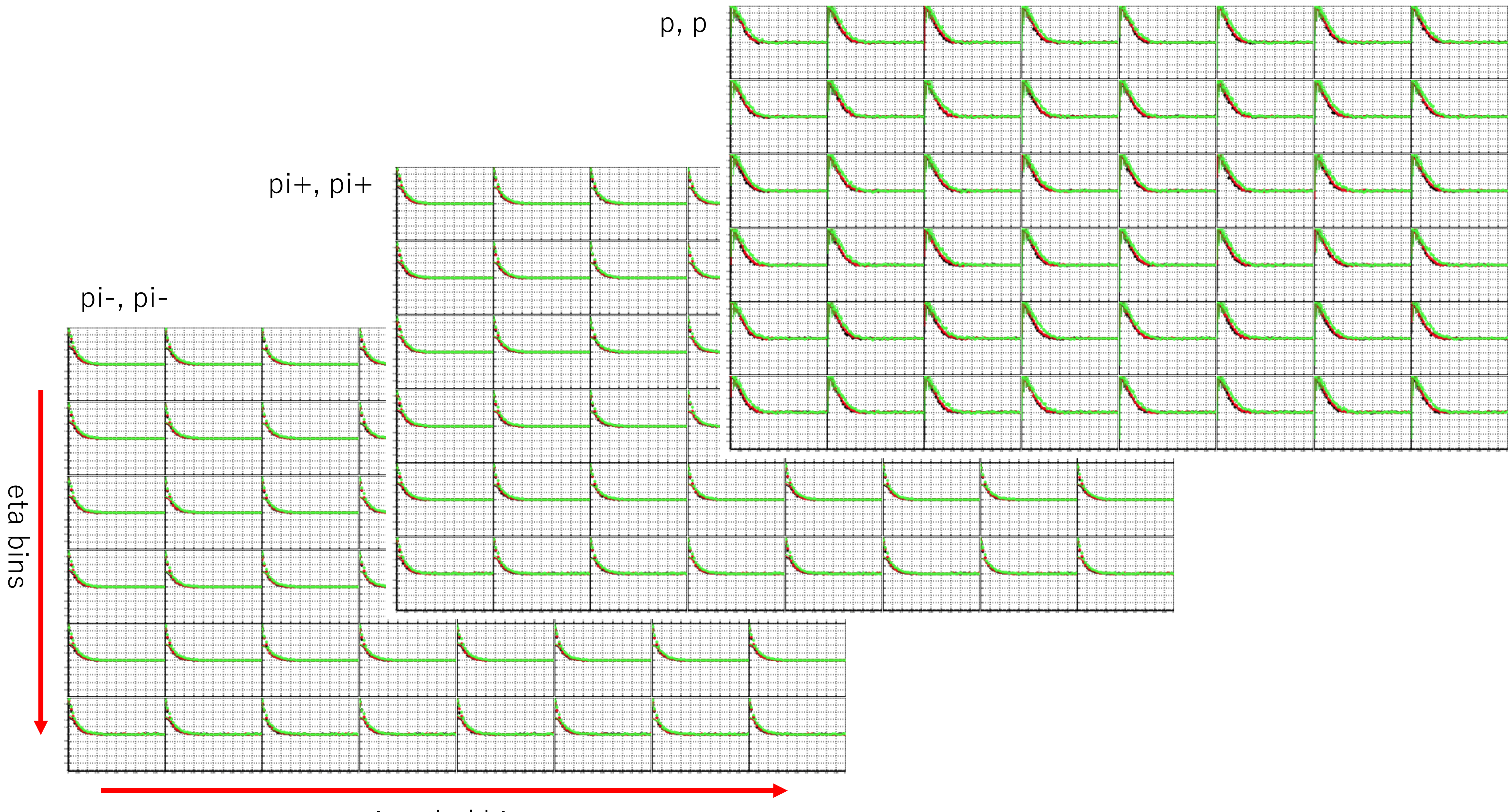
$\phi = \mathrm{atan2}(py, px)$





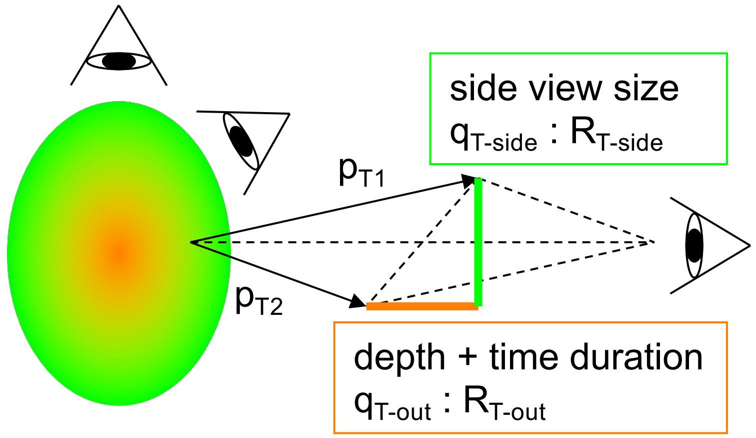
$v1_{geo} = <\cos(\phi_{sp}\text{-R.P.})>$
$v2_{geo} = <\cos2(\phi_{sp}\text{-R.P.})>$

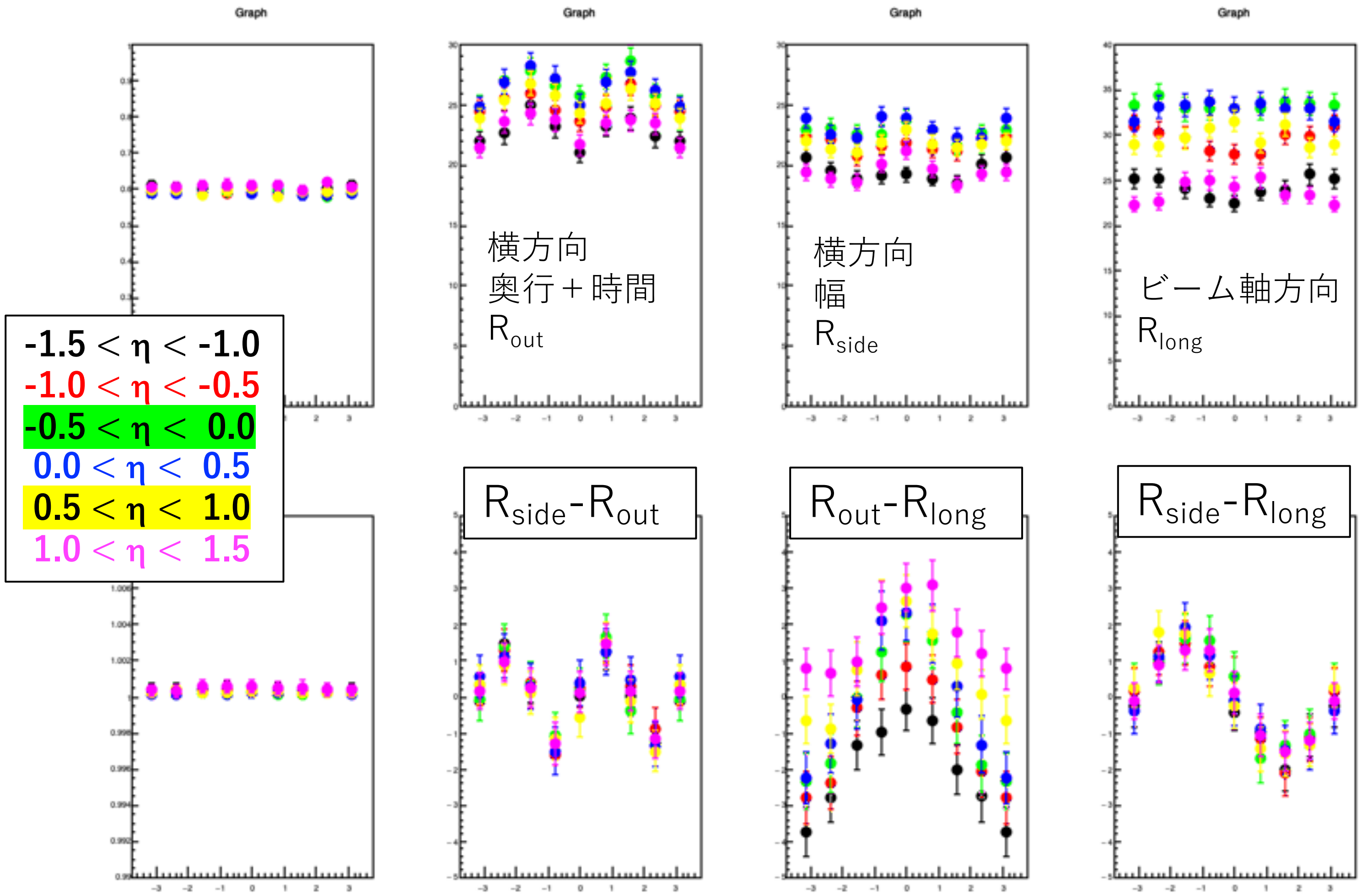
$\phi_{sp} = \mathrm{atan2}(y, x)$

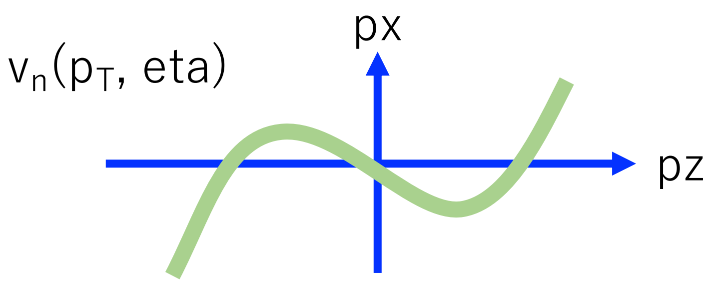

p, p
pi+, pi+
pi-, pi-
eta bins
azimuthal bins

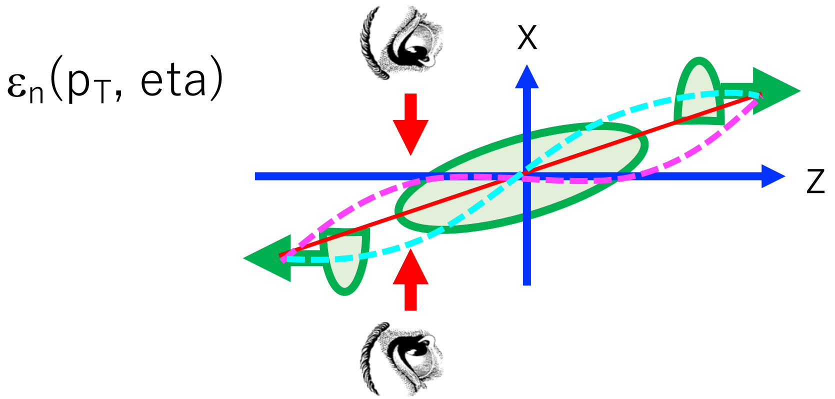
AMPT 10GeV Au+Au
full acceptance (η = [-1.5, 1.5])
100% efficiency (pT > 50MeV/c)
no R.P. resolution ($\sigma_{R.P.}$ = 1)
600M events

→ ~10^8 events used here
realistically ~10^{10} needed





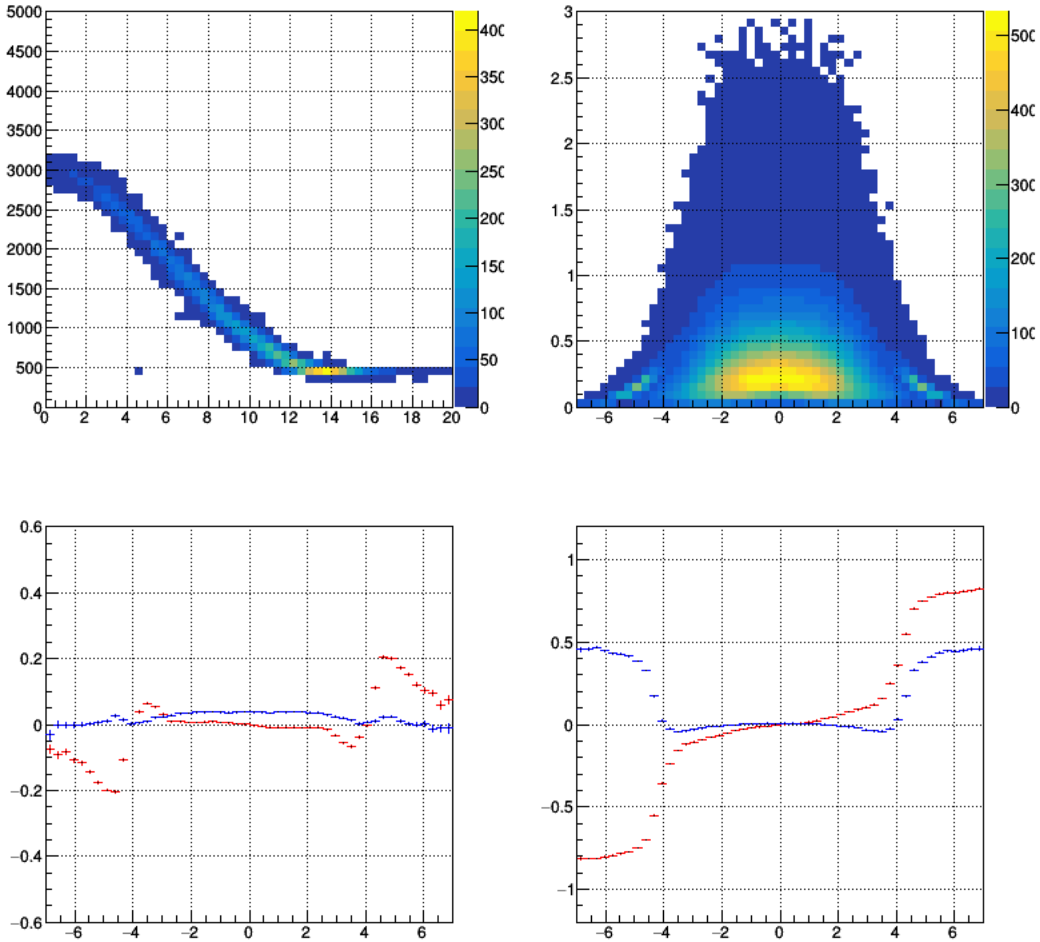




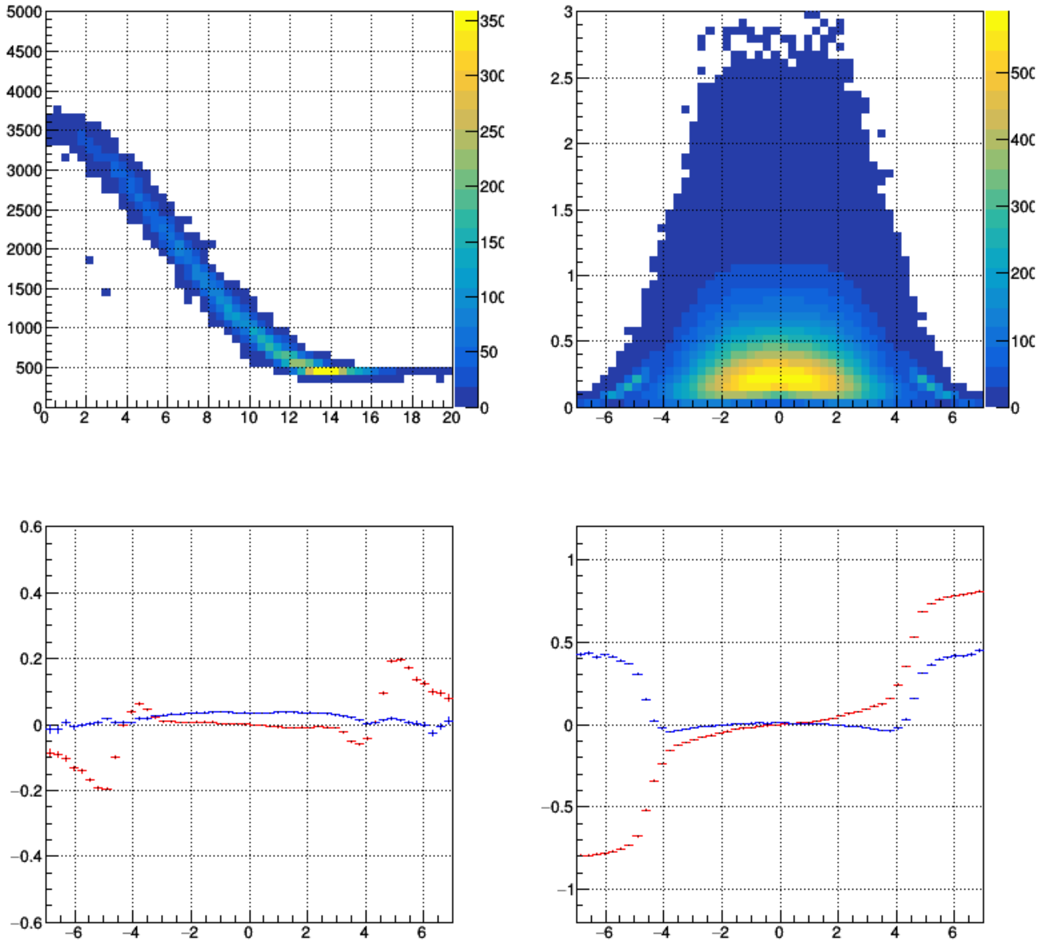
Summary

* Discussion with other colleagues
* Neutron measurement for net-baryon fluctuation
* Key issues on the fluctuation measurement
* Detectors for the centrality determination
* Multi-dimensional femto-scopic correlation

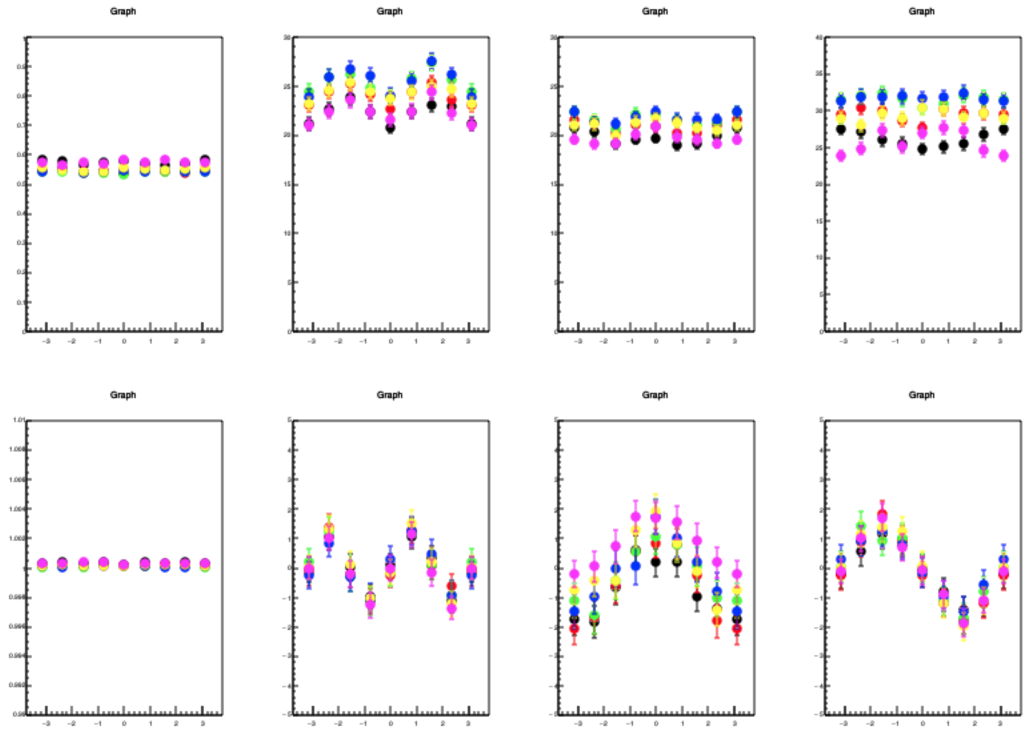
AMPT 19GeV Au+Au



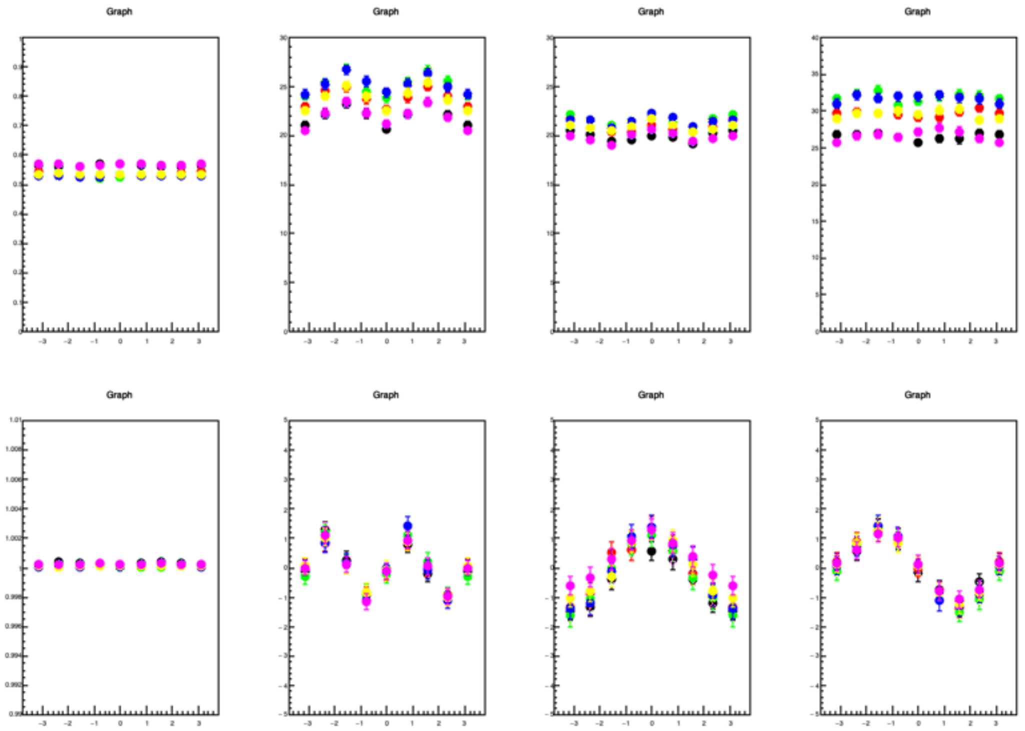
AMPT 27GeV Au+Au



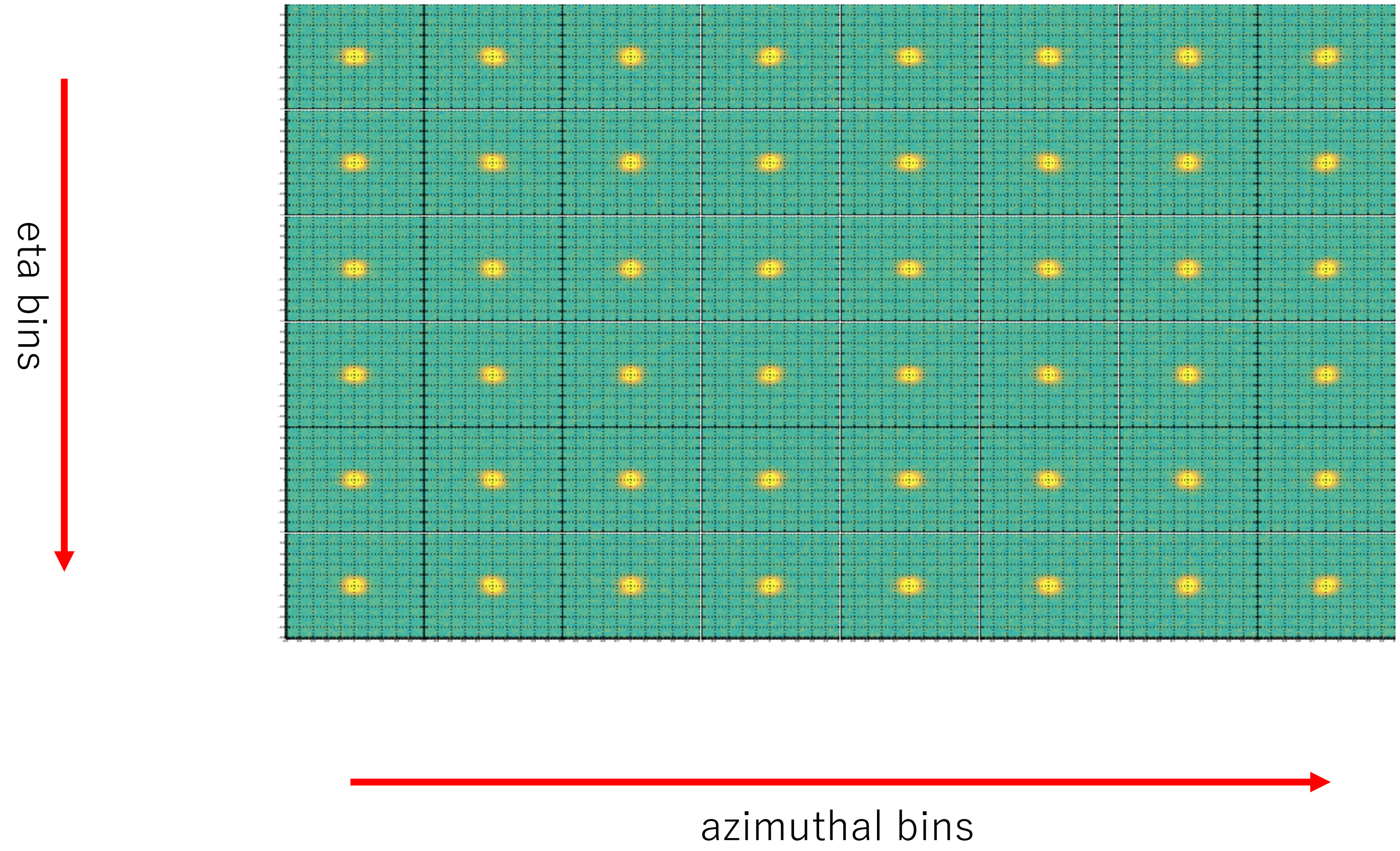
AMPT 19GeV Au+Au



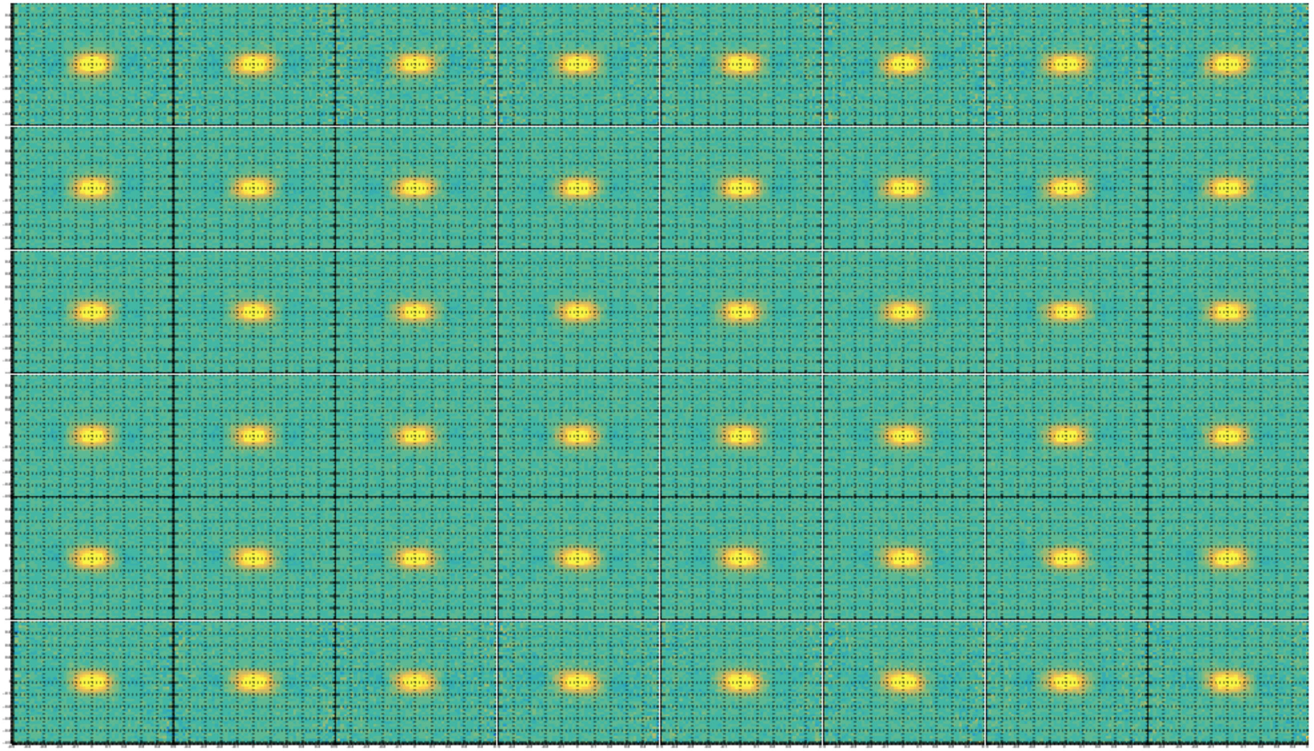
AMPT 27GeV Au+Au



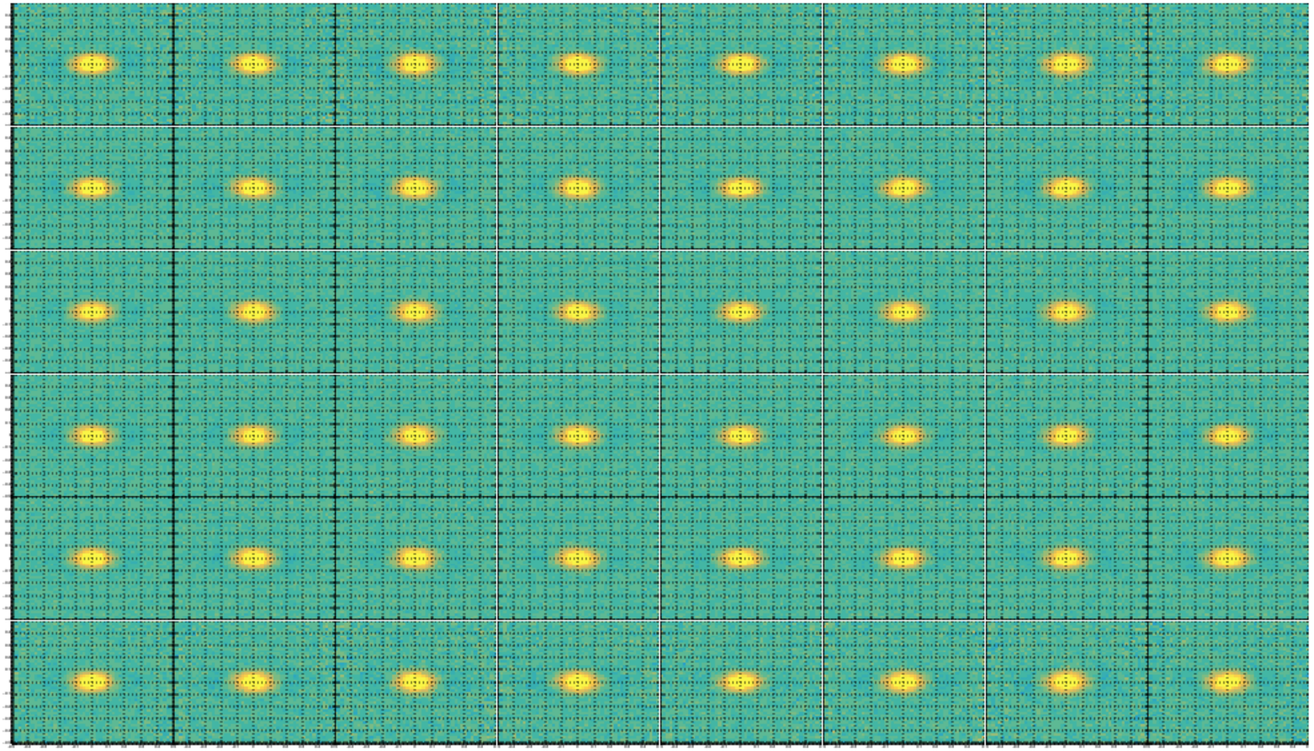
qOut-qSide correlations



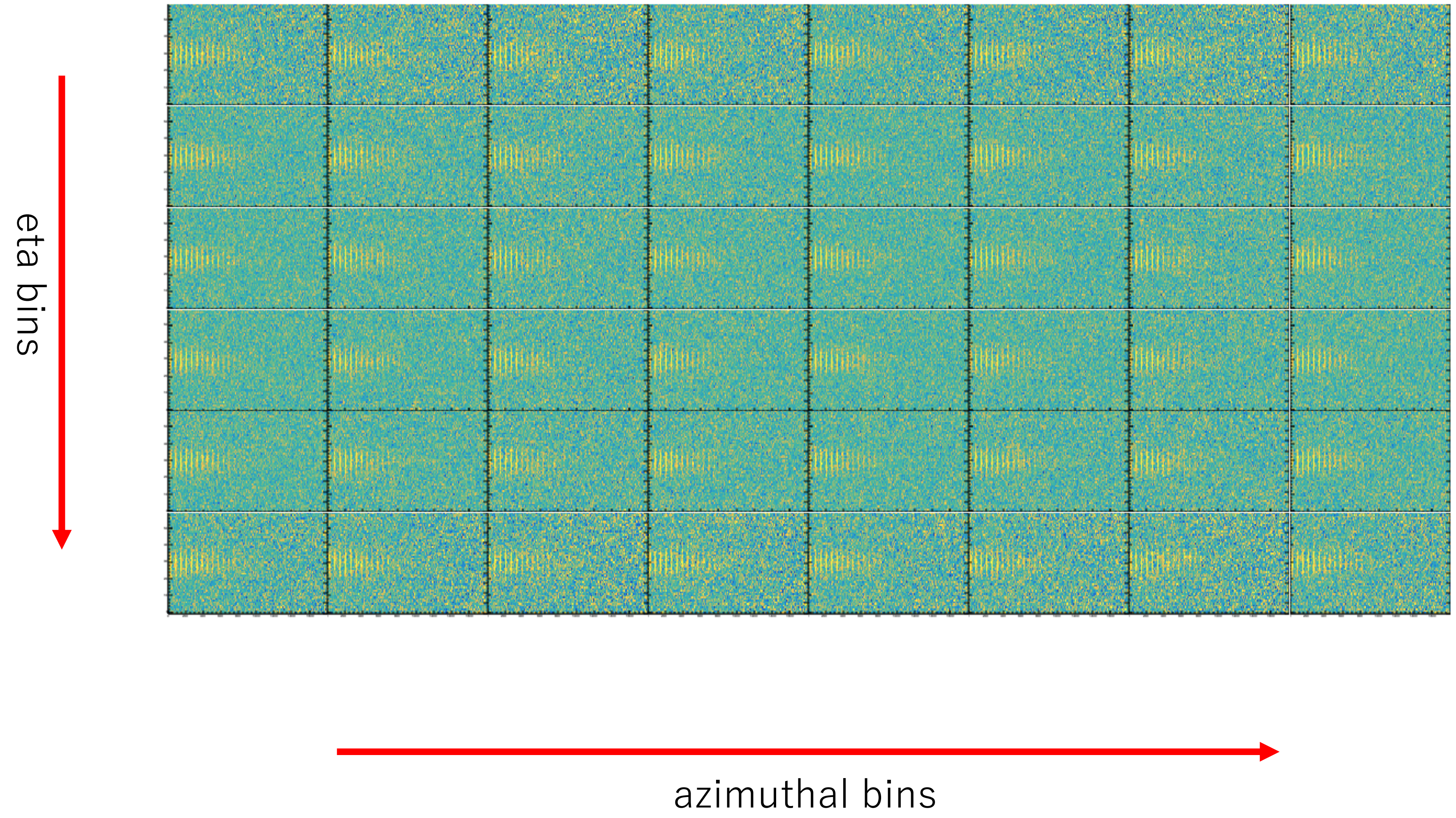
qLong-qOut correlations



qLong-qSide correlations



qLong-qOut-qSide correlation



3D fitting function