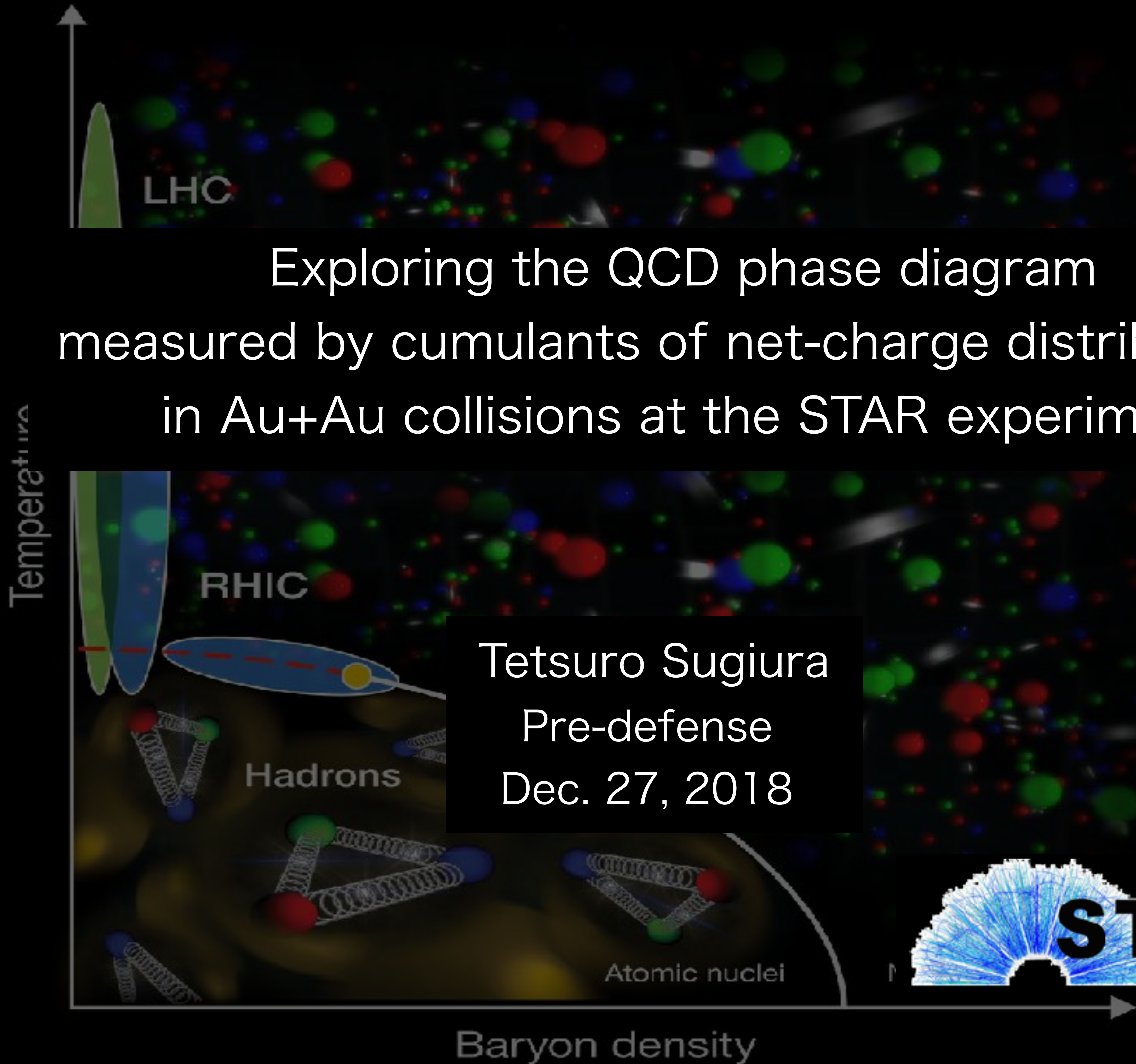
Exploring the QCD phase diagram measured by cumulants of net-charge distributions in Au+Au collisions at the STAR experiment

Tetsuro Sugiura

Pre-defense

Dec. 27, 2018



My activity

✦ **2014 - 2015** Master course ✦ **2016 - 2018** Ph.D course

Conference and workshop : 8 talk and 2 poster presentations

★ **International conference**

- · CiRfSE workshop, Mar. 2015 **talk**
- @University of Tsukuba Jan. 2016 **talk**
- · JPS @University of Miyazaki, Sep. 2016 **talk**
- ★ QM2017 @Chicago, Feb. 2017 **poster**
- · JPS @Osaka University, Mar. 2017 **talk**
- · JPS @Utsunomiya University, Sep. 2017 **talk**
- ★ QM2018 @Venice, May. 2018 **poster**
- · HIP/HIC @ Nagoya University Jun. 2018 **talk**
- ★ APS/JPS joint meeting @Hawaii, Oct. 2018 **talk**
- ★ QNP2018 @Tsukuba, Nov. 2018 **talk**

Blue: $\Delta\eta$ dependence analysis
Red: C_6 net-charge analysis
Green: Correction method

Master thesis:

- "$\Delta\eta$ dependence of net-charge fluctuations in Au+Au collisions at RHIC-STAR experiment"

Teaching experience

Summer challenge TA @KEK
- (M2, D1, D2)

Paper: 1 paper contributed as 2nd author

T. Nonaka, T. Sugiura, S. Esumi, H. Masui, X. Luo
"Importance of separated efficiencies between positively and negatively charged particles for cumulant calculations" PRC. 94. 034909, Sep. 2016

STAR shift taking

: (D1, D2)

Outline

- Introduction
- Motivation
  - Sixth-order cumulants analysis (Experiment)
  - $\Delta\eta$ dependende of net-charge (Experiment)
  -Volume fluctuation study (Simulation)
- Analysis mothod (Experimant)
- Results (Experiment)

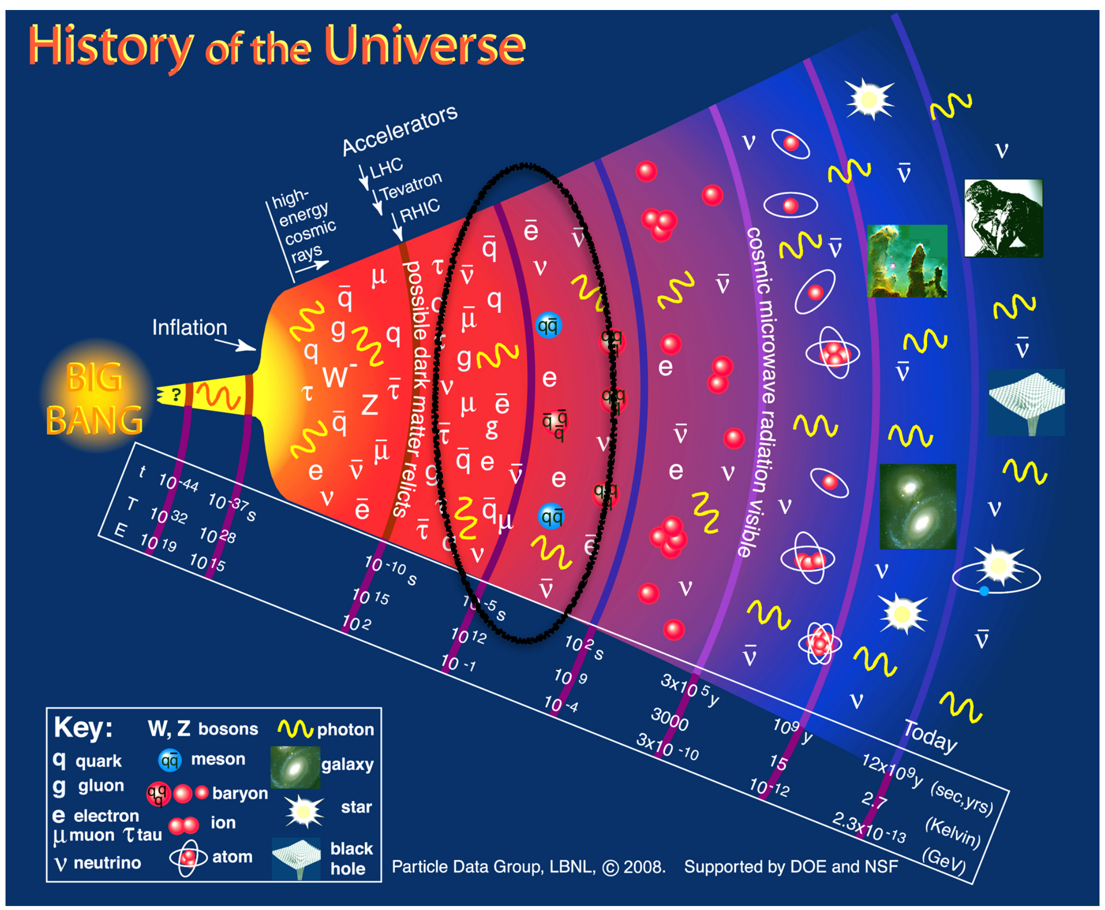
- Analysis mothod (Simulation)
- Results (Simulation)
- Summary and Outlook

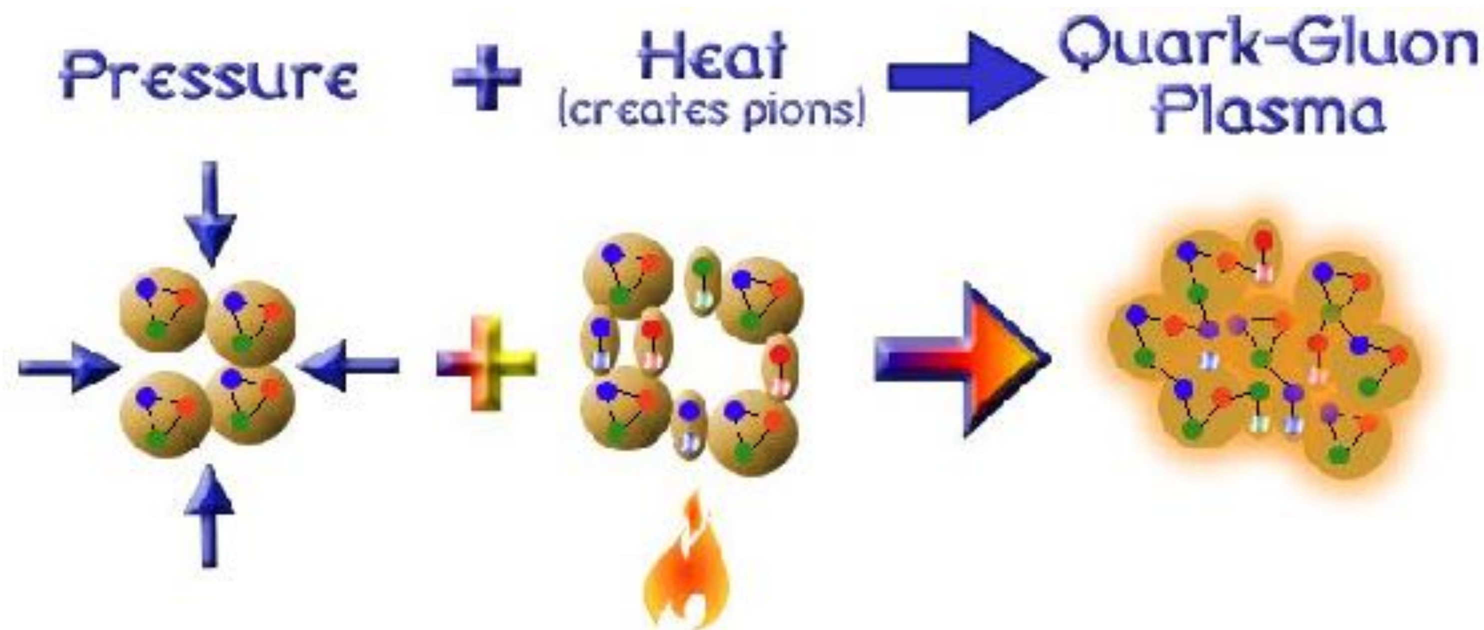
Quark Gluon Plasma (QGP)

- Quarks and gluons are confined inside of nucleons. **(Color confinement)**
- Interactions are very weak inside of nucleons. **(Asymptotic freedom)**

→

- Quarks are de-confined under high density or high temperature.
(Quark Gluon Plasma : QGP)

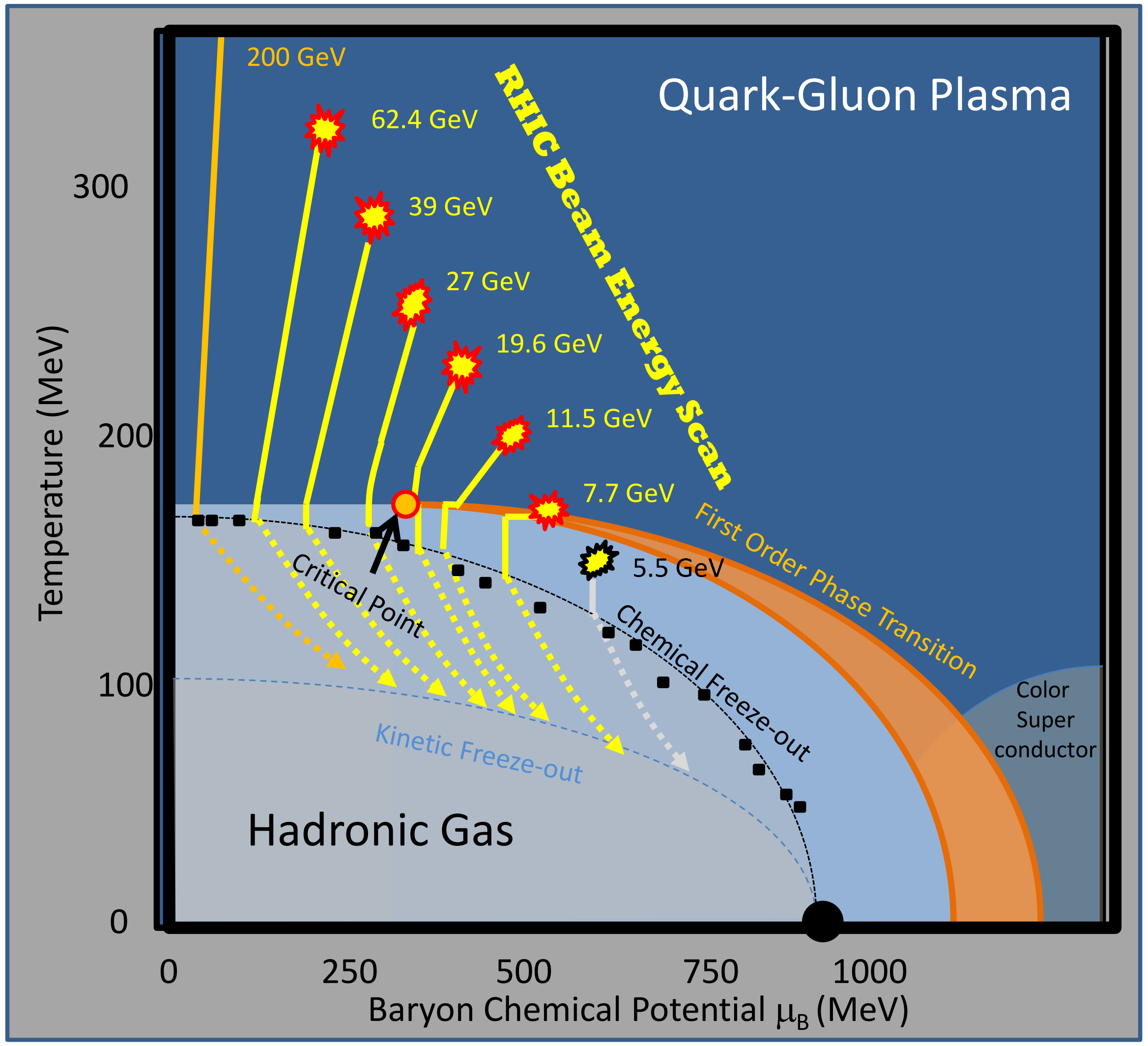




T_C=154 MeV

- QGP is considered to be existed in early universe, μs after big bang.

Phase transition and Beam Energy Scan



- **Cross over transition around μ_B=0** from Lattice QCD but there is no experimental evidence.
- Location of critical point is unknown.

Detail structure of QCD diagram should be discovered experimentally

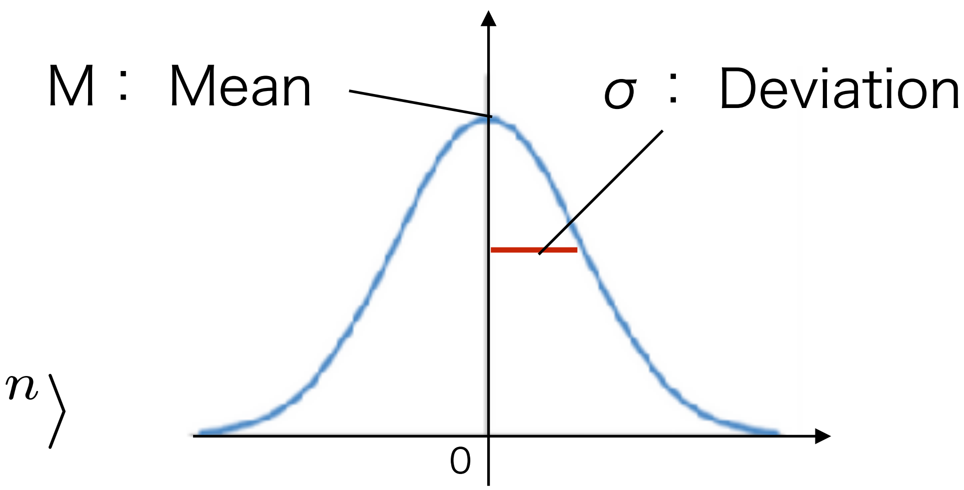
Beam Energy Scan I (BES-I) 2010-2014

- Varying the center of mass energy, $\sqrt{s_{NN}}$ = 7.7, 11.5, 14.5, 19.6, 27, 39, 62.4 and 200 GeV in Au+Au collisions.
- $\sqrt{s_{NN}}$ = 54 GeV in Au+Au collision data was taken in 2017.
- BES-II will start from 2019.

→ Event by event fluctuations are considered as one of the powerful tool to discover the phase diagram.

Event-by-event fluctuations

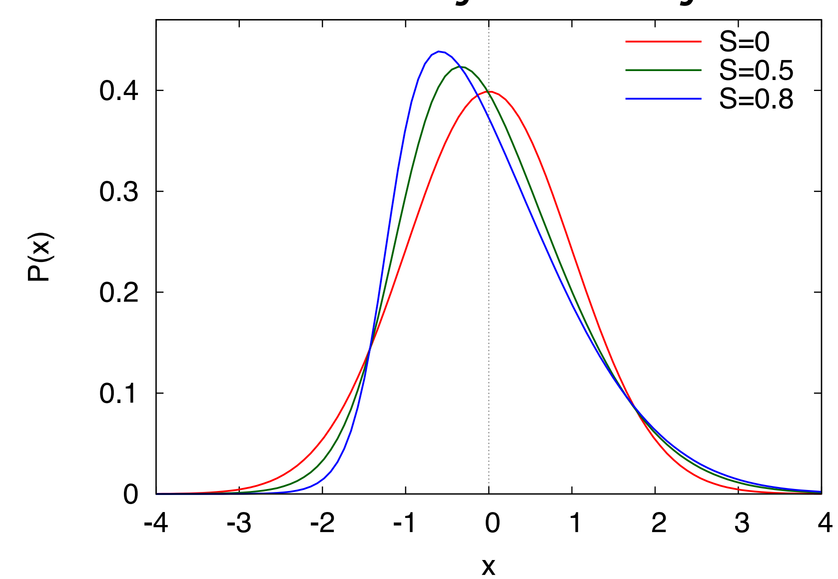
Net-charge : $N_+ - N_-$



- nth-order moment is defined by

$$\langle m^n \rangle = \sum_m m^n P(m)\,, \quad \langle \delta m^n \rangle = \langle (m - \langle m \rangle)^n \rangle$$

S : Asymmetry



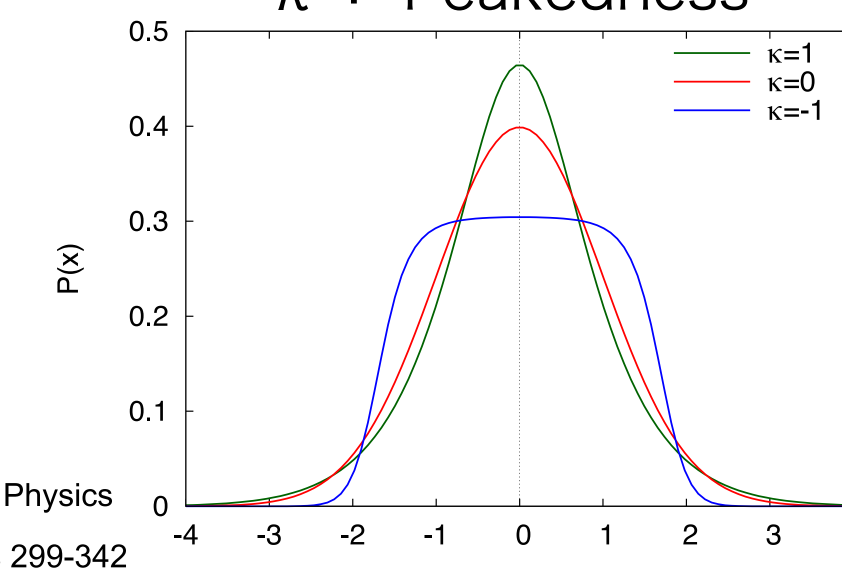
- Cumulants can be written by moments

Cumulants ⟷ Moments

$$C_1 = \langle m \rangle$$
$$C_2 = \langle \delta m^2 \rangle$$
$$C_3 = \langle \delta m^3 \rangle$$
$$C_4 = \langle \delta m^4 \rangle - \langle \delta m^3 \rangle$$

$$M = C_1$$
$$\sigma^2 = C_2$$
$$S = \frac{C_3}{(C_2)^{3/2}}$$
$$\kappa = \frac{C_4}{(C_2)^2}$$

κ : Peakedness



- Cumulants are proportional to the volume (**Additivity**)

Progress in Particle and Nuclear Physics
Volume 90, September 2016, Pages 299-342

Cumulant ratios

- By measuring the **cumulant ratios**, **effect from the volume can be canceled**.
- Cumulant ratios can be directly compared to the ratio of susceptibilities.

Cumulant ratios

$$S\sigma = \frac{C_3}{C_2} = \frac{\chi_3}{\chi_2}$$

$$\kappa\sigma^2 = \frac{C_4}{C_2} = \frac{\chi_4}{\chi_2}$$

- Higher order cumulants are more sensitive to the signal from the critical point.
- These relations are only valid for cumulants of **conserved quantities**.

$$C_2 \approx \xi^2 \qquad C_5 \approx \xi^{9.5}$$

$$C_3 \approx \xi^{4.5} \qquad C_6 \approx \xi^{12}$$

$$C_4 \approx \xi^7$$

ξ : Correlation length

Statistical baseline (Skellam distributions)

- If distribution of N_+ and N_- follow the Poisson distributions, net-charge distribution follow the **Skellam distribution.**

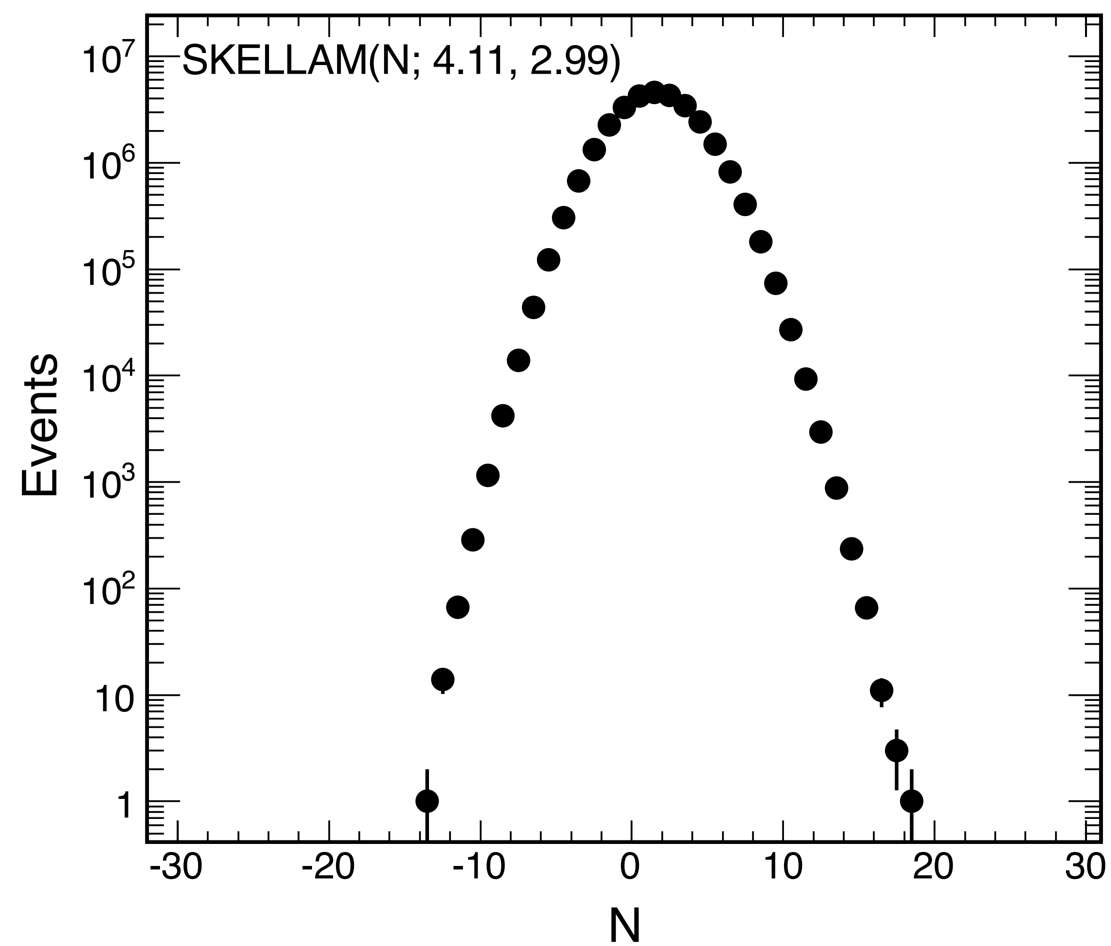
$$C_n = \lambda_1 + (-1)^n \lambda_2$$

$$\frac{C_{2n}}{C_{2m}} = \frac{C_{2n+1}}{C_{2m+1}} = 1$$

$$\frac{C_{2n+1}}{C_{2m}} = \frac{\lambda_1 - \lambda_2}{\lambda_1 + \lambda_2}$$

λ_1 : Poisson parameter of N_+ distribution

λ_2 : Poisson parameter of N_- distribution



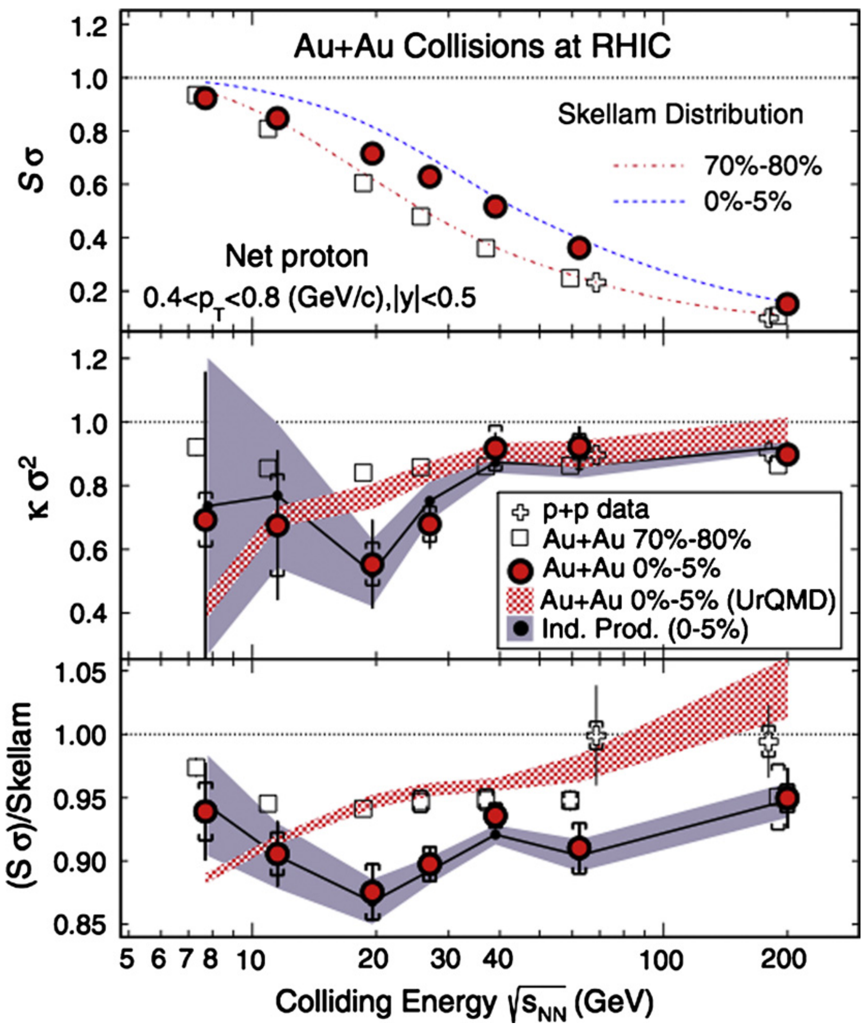
For example

$$\frac{C_6}{C_2} = \frac{C_4}{C_2} = \boxed{1}$$

This values can be used as a statistical baseline.

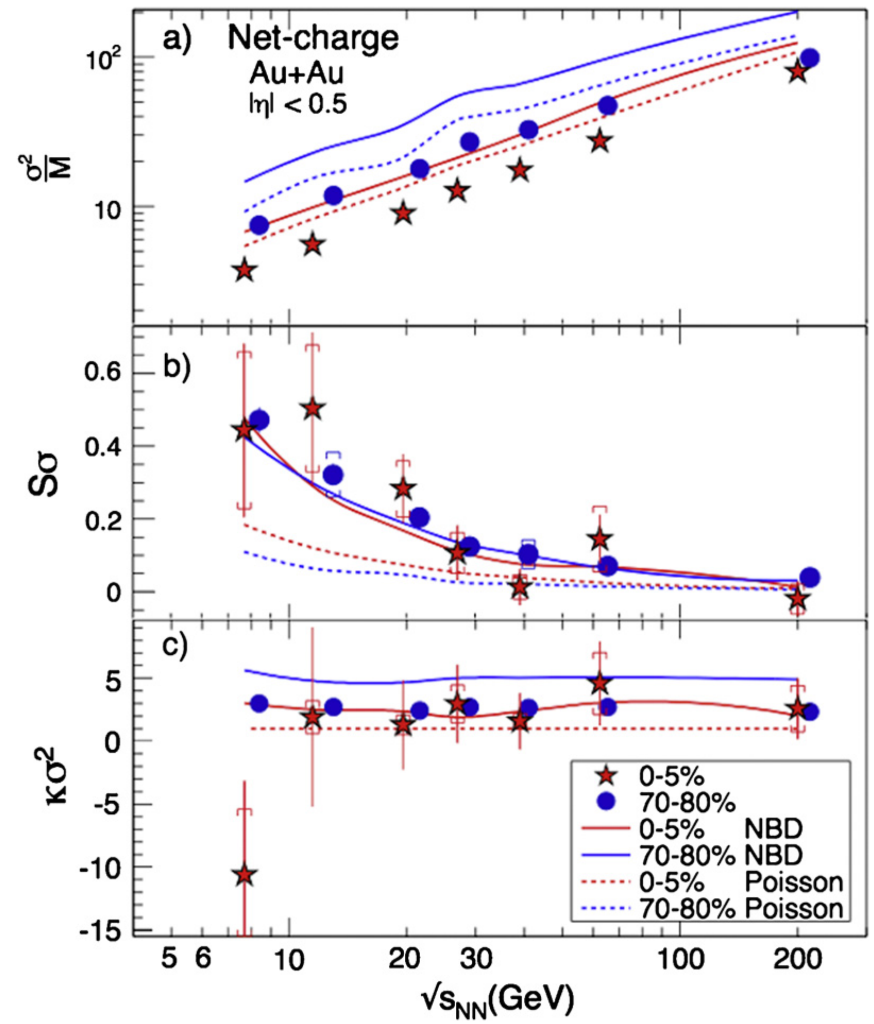
Published results

Net-proton



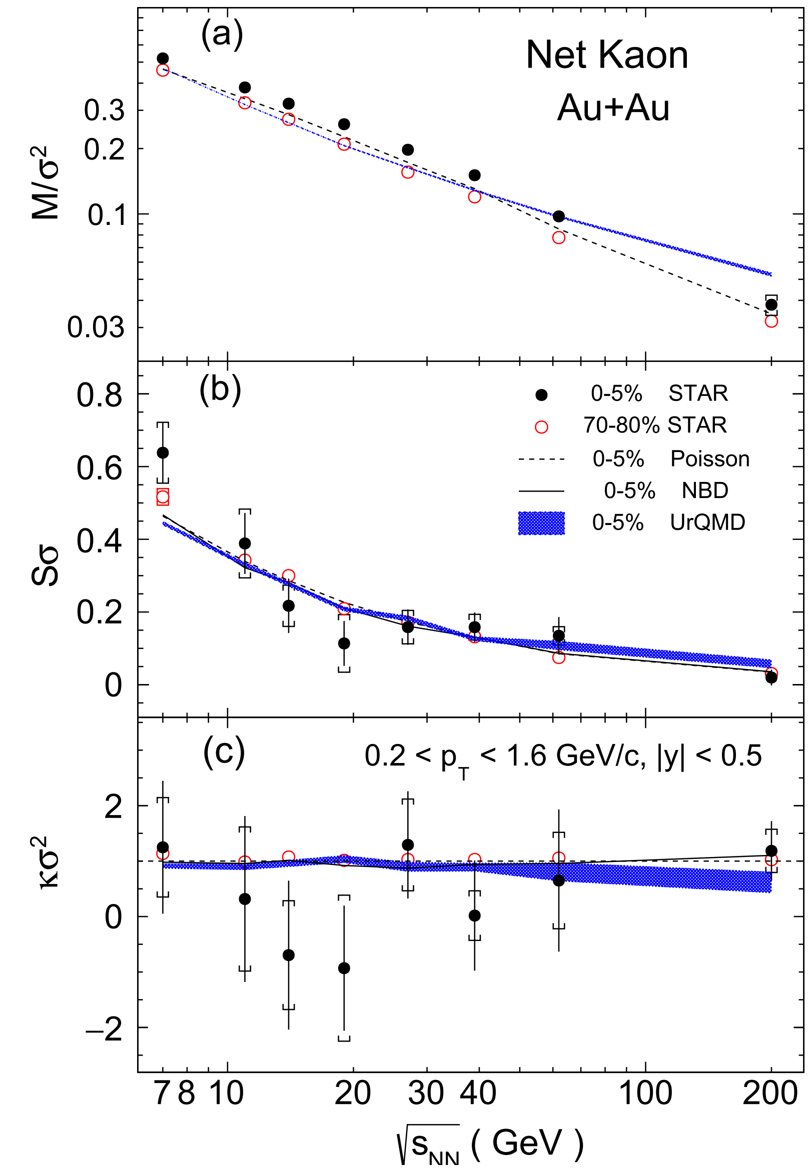
L. Adamczyk *et al.* (STAR Collaboration)
Phys. Rev. Lett. 112, 032302 (2014)

Net-charge



L. Adamczyk *et al.* (STAR Collaboration)
Phys. Rev. Lett. 113, 092301(2014)

Net-Kaon

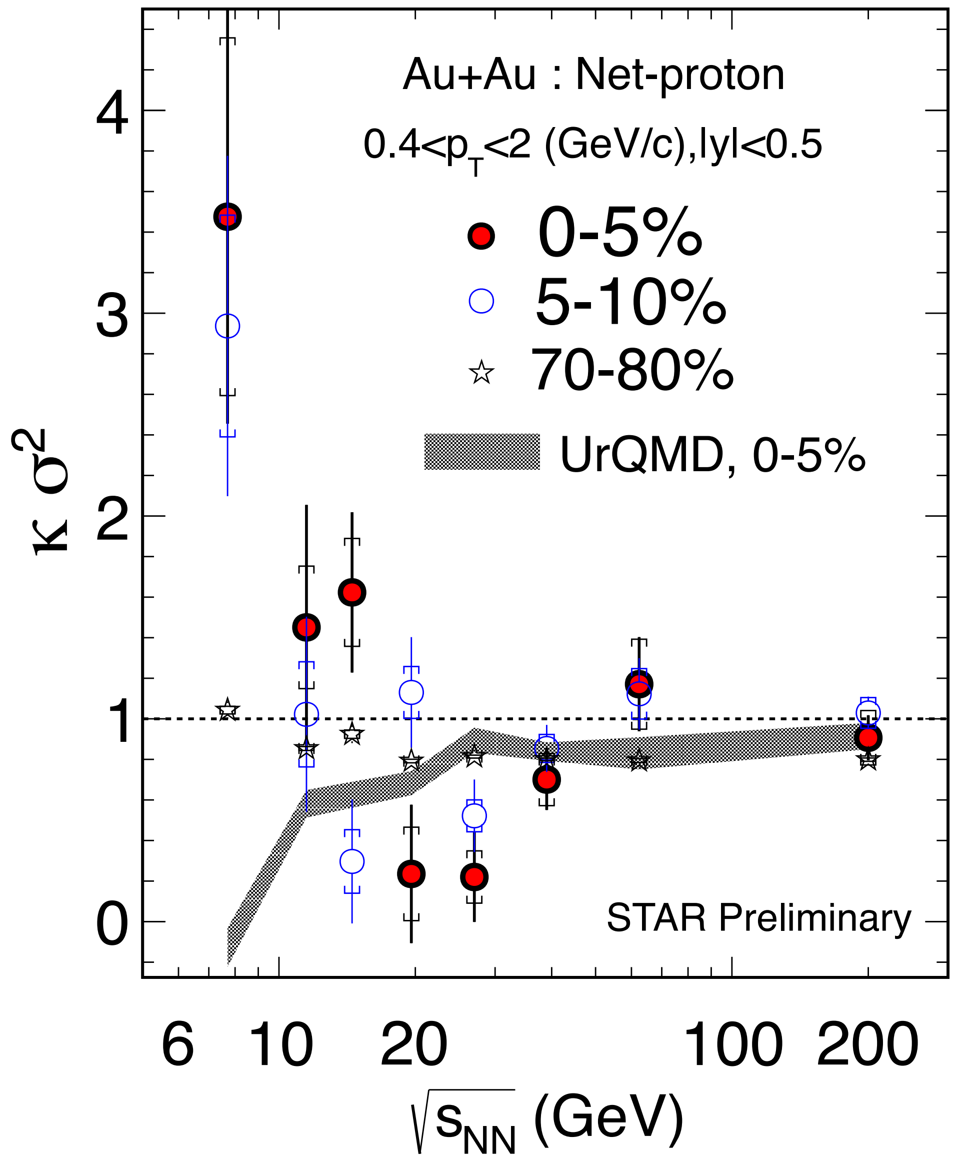


Physics Letters B Volume 785,
10 October 2018, Pages 551-560

- **STAR published up to 4-th order fluctuations** of net-proton, net-charge and net-kaon distributions.
- **Critical phenomena have not been observed yet.**

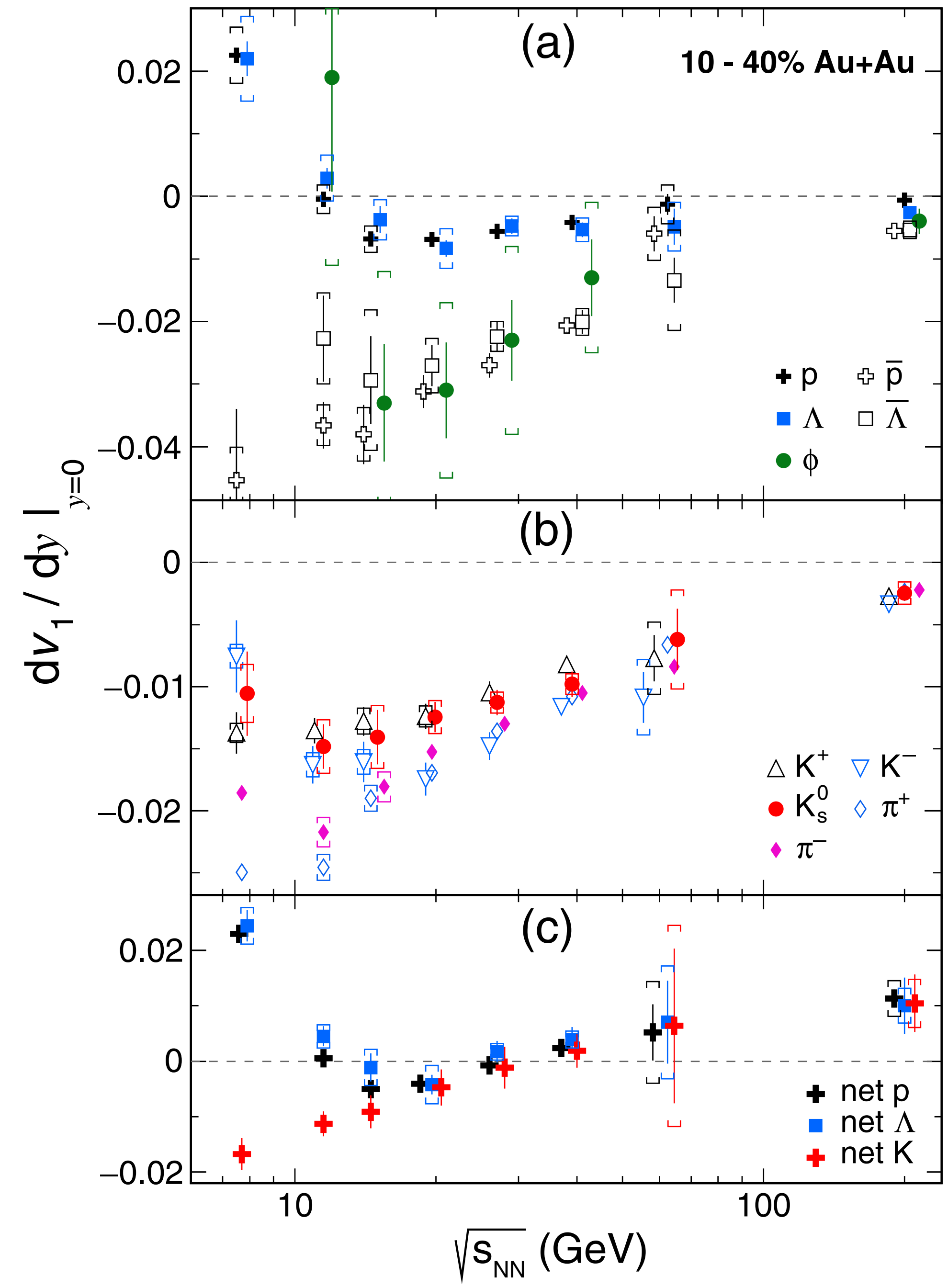
Recent results

Net-proton, 0.4 <pT<2 (GeV/c)



X. Luo, Nucl. Phys. A956 (2016) 75–82, [1512.09215].

Published results of v1 slope

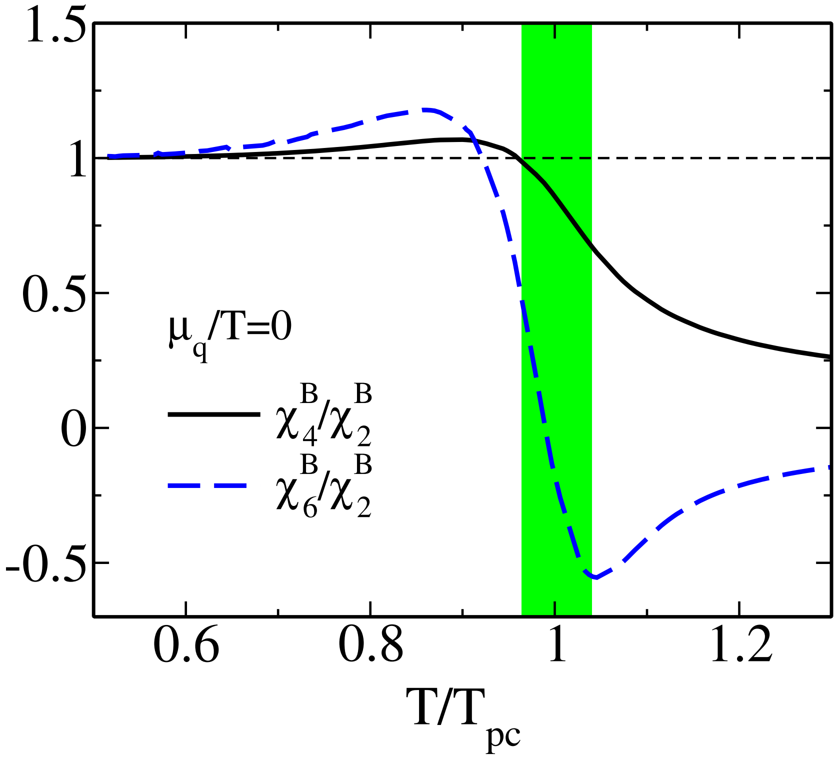


Phys. Rev. Lett. **120**, 062301 – Published 6 February 2018

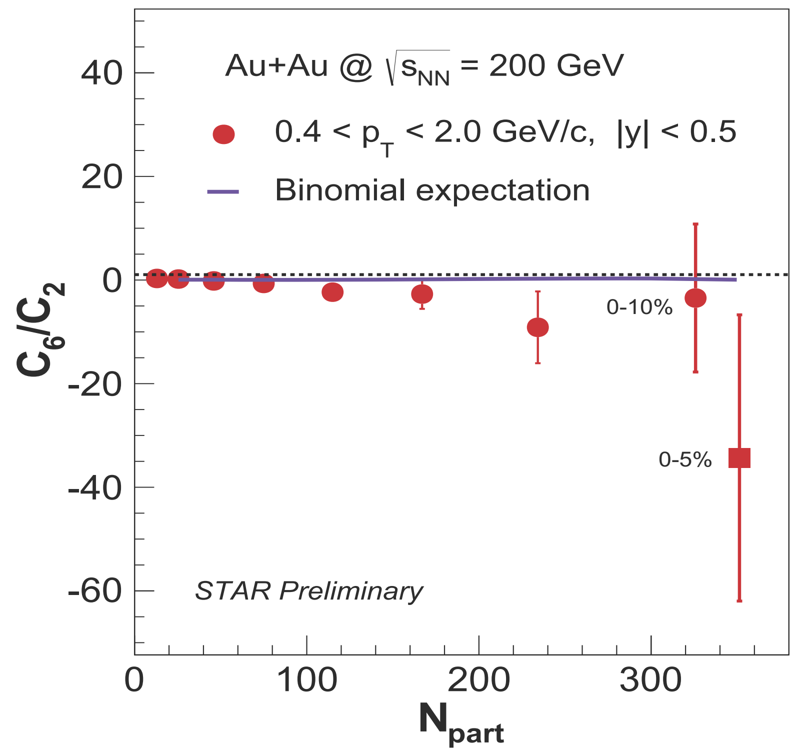
- Interesting energy dependences were observed at lower energy region at various measurement.

Motivation1 -C6 analysis-

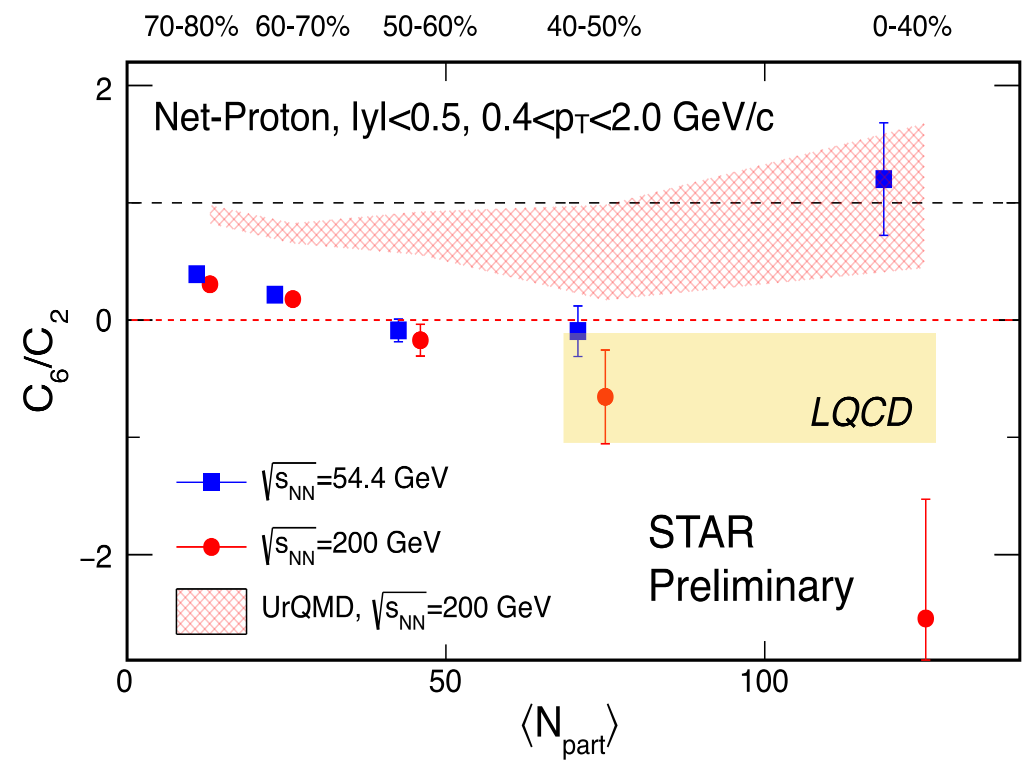
Friman et al, Eur. Phys. J. C(2011) 71:1694



R.Esha (STAR Collaboration),
Nuclear Physics A 967 (2017) 457–460



T.Nonaka (STAR Collaboration),
QNP2018



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

- **Negative C_6** of conserved quantities are predicted to be the signal of **cross-over phase transition**.
- C_6 of net-proton is measured at $\sqrt{s_{NN}}$ = 200 and 54 GeV in Au+Au collisions.
- **C_6 of net-charge** should be measured to compare net-proton results and theoretical predictions.
- 54 GeV net-charge results have not been reported yet.

Motivation2 -Δη dependence-

D-measure (D)

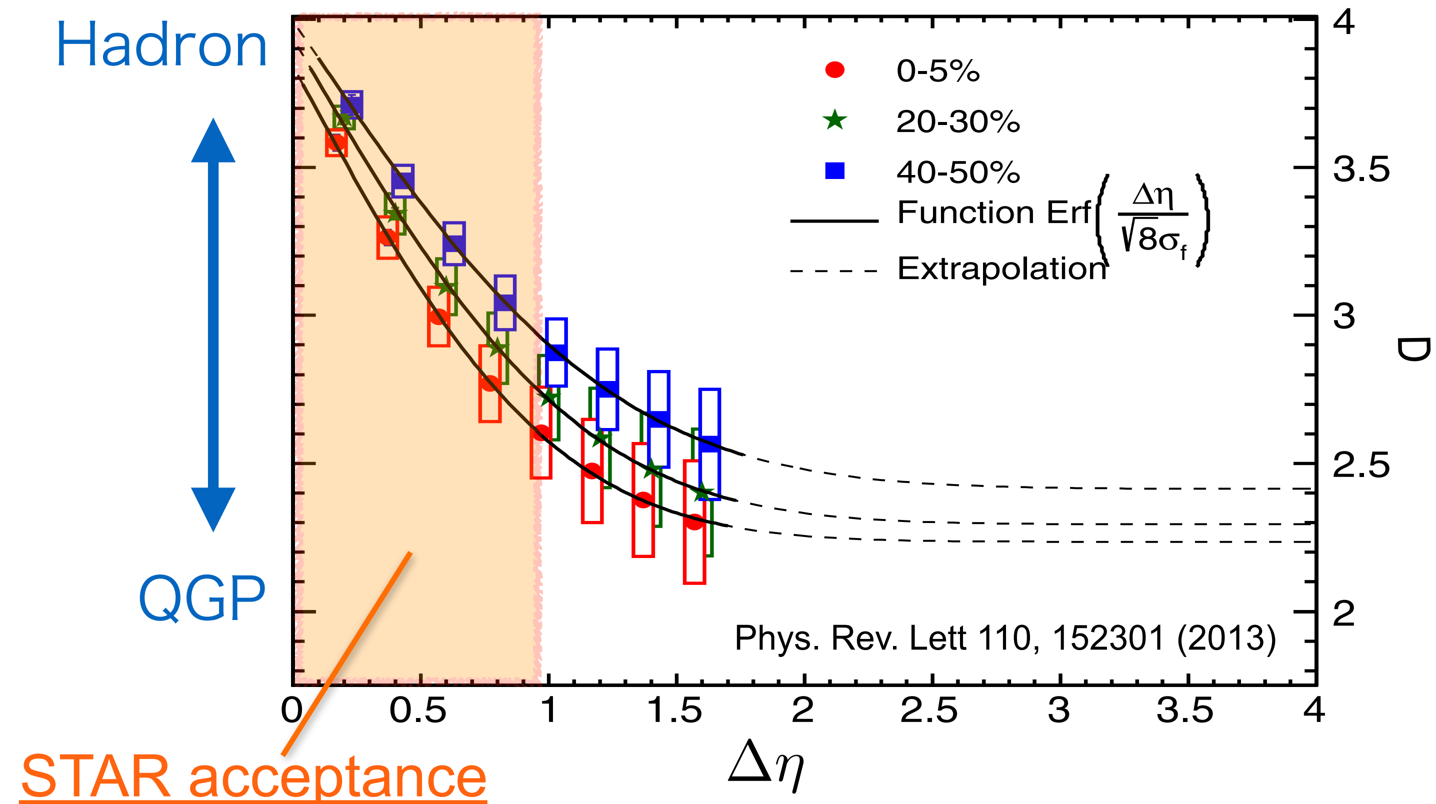
$$D = 4\frac{C_2}{\langle N_{ch}\rangle} \qquad N_{ch} = N^+ + N^-$$

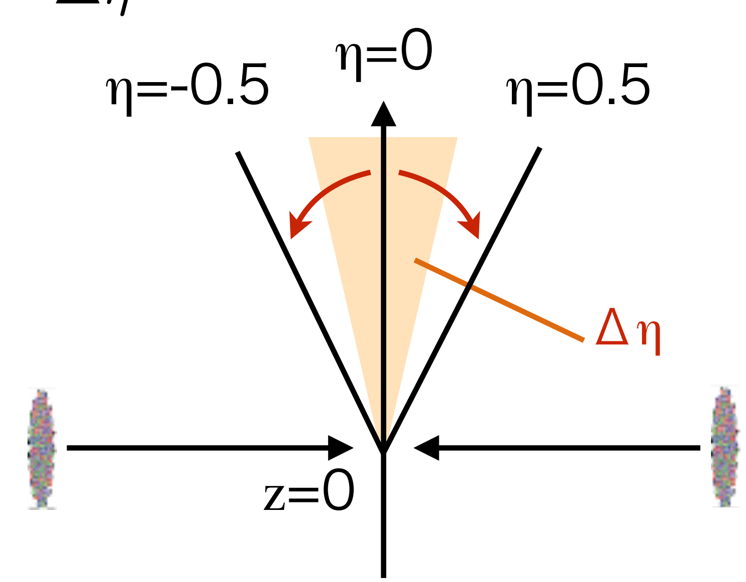
Theoretical predictions

(HRG model, Lattice QCD, etc)

QGP fluctuation :
D =1-1.5
Hadron fluctuation :
D= 3-4

ALICE (2.76TeV Pb+Pb)



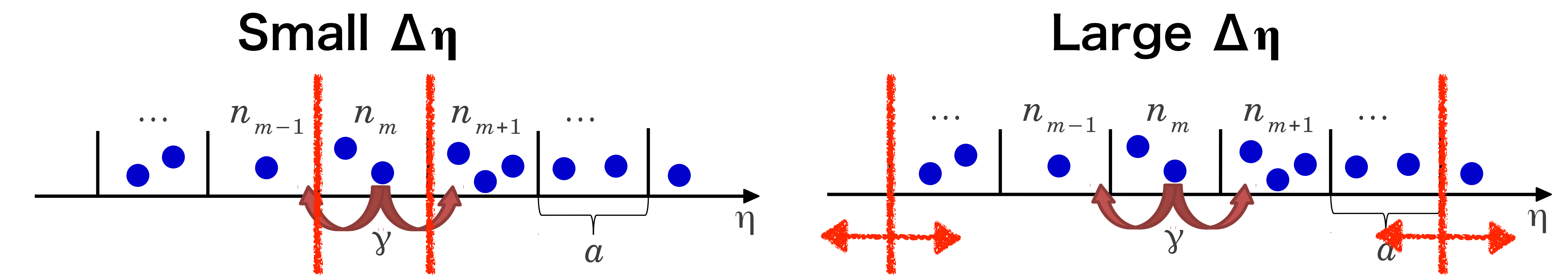


- **D-measure is ovserved to decreace with expanding Δη** in Pb-Pb collisions at 2.76 TeV at ALICE.
- D-measure also decreace from peripheral to central collisions.

Expanding Δη : The signal of QCD transition might been observed

➡ <u>It is important to measure Δη dependence of D-measure in lower energies.</u>

Motivation2 -Δη dependence-

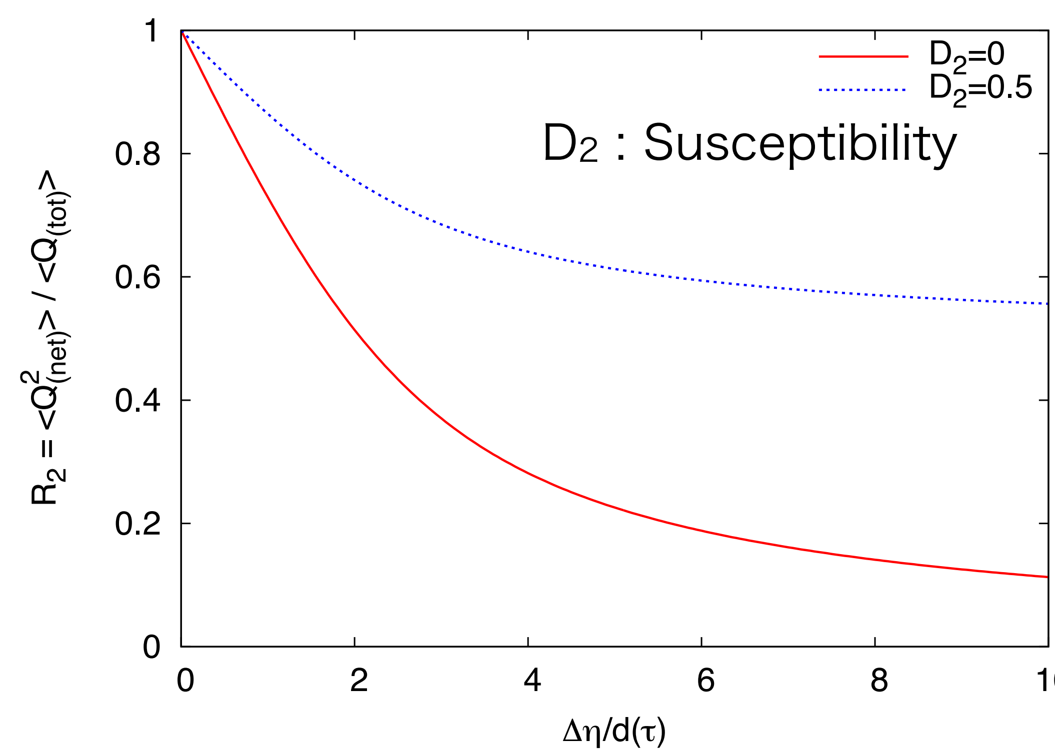


$$\partial_\tau P(\boldsymbol{n},\tau) = \gamma(t)\sum_m \left[(n_m+1)\left\{P\left(\boldsymbol{n}+\boldsymbol{e}_m-\boldsymbol{e}_{m+1},\tau\right)+P\left(\boldsymbol{n}+\boldsymbol{e}_m-\boldsymbol{e}_{m-1},\tau\right)\right\} - 2n_m P(\boldsymbol{n},\tau)\right]$$

$$\boldsymbol{n} = (\cdots, n_{m-1}, n_m, n_{m+1}, \cdots)$$

$$a \to 0$$

M.Asakawa, M.Kitazaw, Progress in Particle and Nuclear Physics Volume 90, September 2016, Pages 299-342

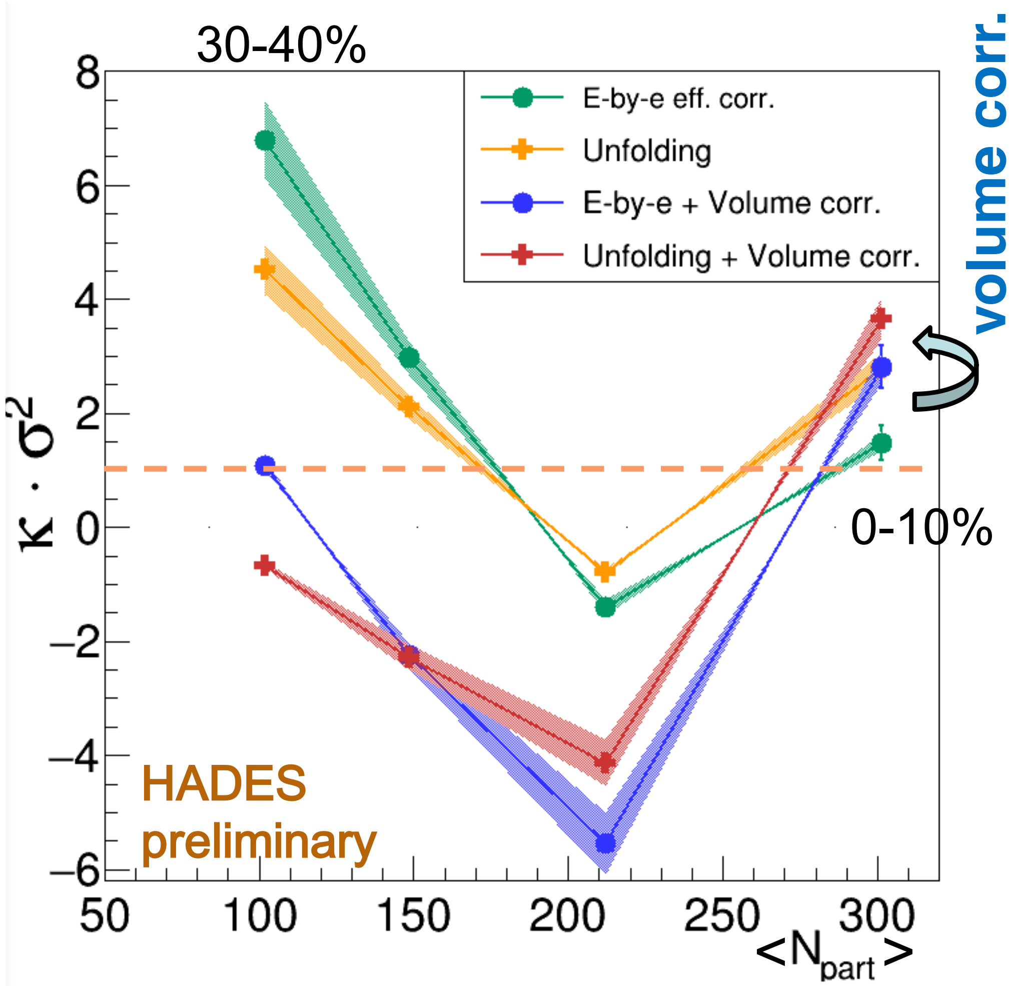


- Decreasing D-measure with Δη **can be descrived by diffusion** model.
- **Third and fourth-order** cumulants by this model are implemented.

→ **Experimental measurement are necessary up to 4th-order**

Motivation3 - Volume Fluctuation study-

R.Holzmann (HADES collaboration) QM 2017



- **Initial volume fluctuation (VF)** which correspond to the e-by-e fluctuation of number participant nucleons (N_{part}=Nw) artificially enhance cumulants and **should be subtracted from measured cumulants**
- STAR applied **Centrality Bin Width Correction (CBWC)** to eliminate VF.
- New correction Volume fluctuation Correction (VFC) was proposed and HADES experiment have already applied VFC to experimental data.

However···

- **VFC is model dependent** correction whereas **CBWC is data driven** correction.

Inportance of subtracting VF and validity of VFC are studied by using toy model and UrQMD.

Why net-charge?

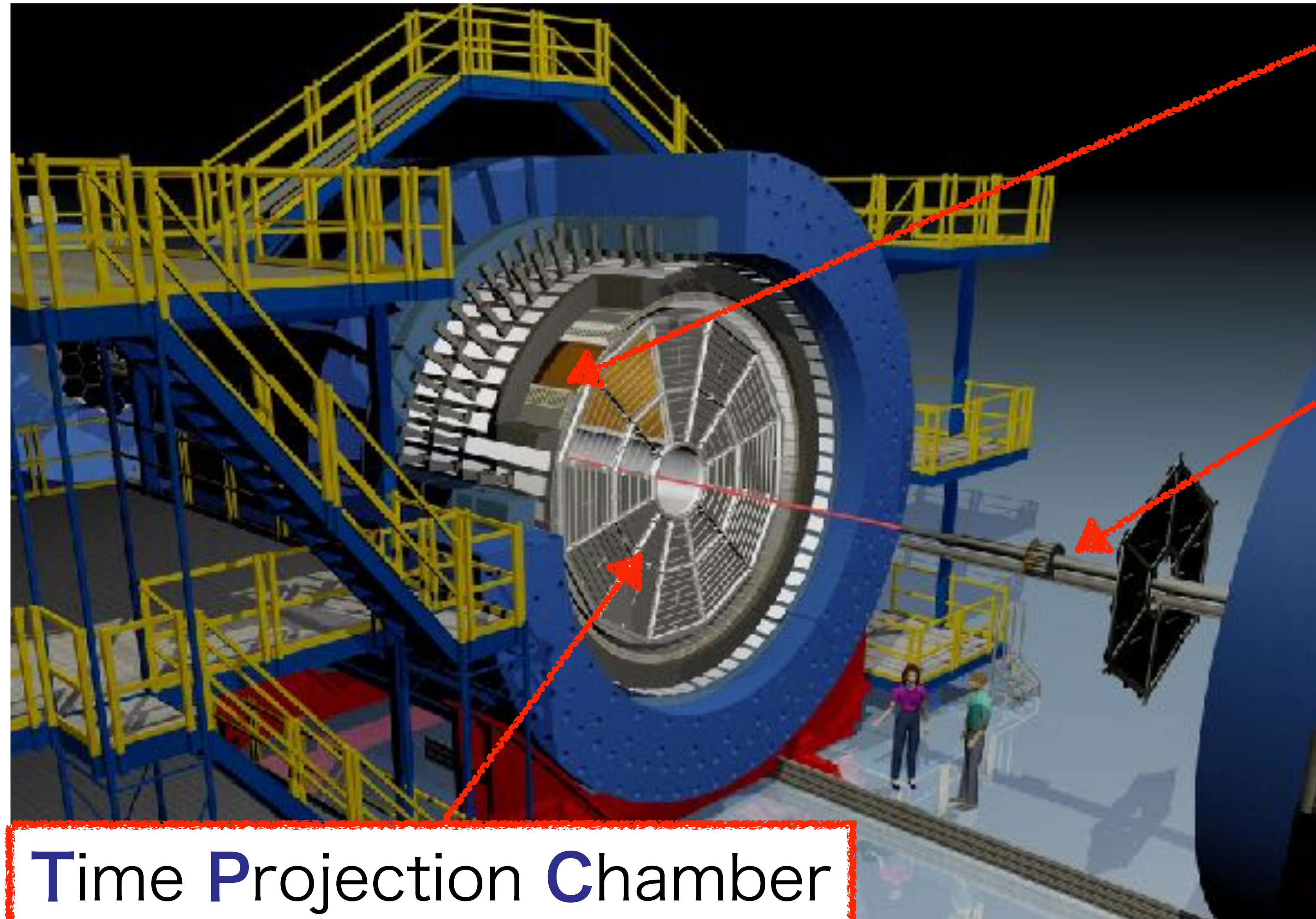
- It is importent to measure **both net-proton and net-charge** cumulants and compare the results in order to understand the phase transition.
- **Net-charge is conserved quantity** whereas net-proton and net-Kaon are measured as a proxy of net-baryon and net-strangeness.
    - My PhD. thesis, University of Tsukuba (2019)
    - T.Nonaka's PhD. thesis, University of Tsukuba (2018)

	net-charge	net-proton	net-Kaon
Conserved quantitiy	**net-charge**	net-baryon	net-strangeness
up to C_4	published (7.7-200 GeV)	published (7.7-200 GeV)	published (7.7-200 GeV)
up to C_6	**200GeV, 54GeV**	**200GeV**, 54GeV	-
$\Delta\eta$ dependence	**7.7-200 GeV (STAR)** 2.76 TeV (ALICE)	-	-

- In **C_6 analysis**, analysis and correction **methods are improved**.
- **$\Delta\eta$ dependence** of D-measure (**2nd order** fluctuation) is reported **by ALICE** whereas **up to 4th-order** cumulants are measured **in this thesis**.
- VFC is studied by T.Nonaka's Doctoral thesis but more studies are necessary.

Analysis mothod (Experiment)

The STAR Detector



Time-Of-Flight

- PID in a broad p_T region.
- Used to remove pile-up events.

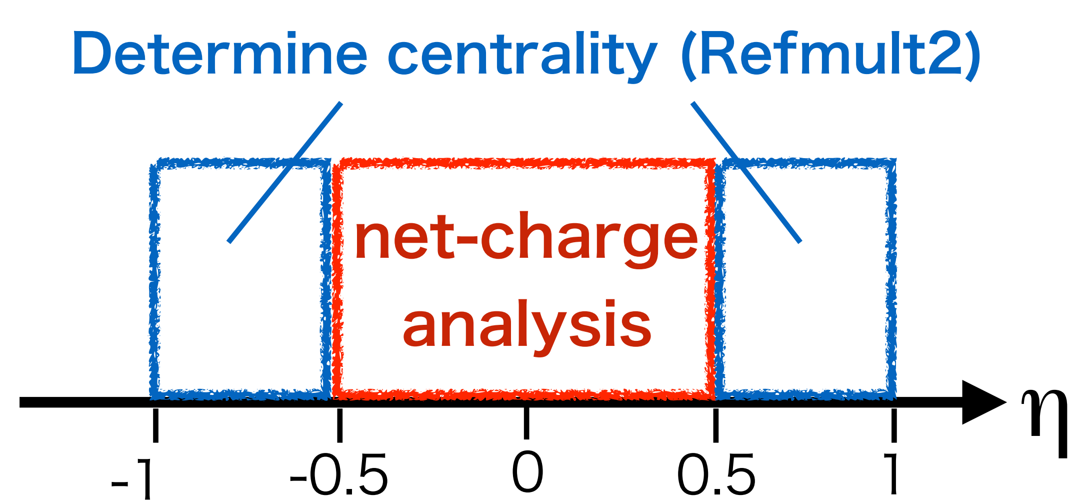
Vertex Position Detector
Zero Degree Calorimeter

- Minimum bias trigger
- Used for start time (VPD)
- Collision vertex (VPD)
- Luminosity monitor (ZDC)

ZDC : 19m from vertex

Time Projection Chamber

- Used for tracking, momentum determination and PID.
- Used to determine centrality and to calculate net-charge cumulants.
  <u>- using different kinematic window to avoid auto-correlation</u>



Data set

√SNN= 200 GeV	Run11(0-80%)	Run10(10-80%)	Run10(0-10%)	UrQMD
NEvent	485M	211M	196M	45M

√SNN= 54 GeV	Run17
NEvent	543M

C_6 analysis

- **C_6 anlysis needs large statistics compared to up to 4th order fluctuation analysis**
  - 200 GeV data was taken from 2010 to 2011 and 54 GeV data was taken in 2017.
  - Statistics of both of them are larger than 100M.
  - Some analysis and correction method are improved compared to published results.

$\Delta\eta$ analysis

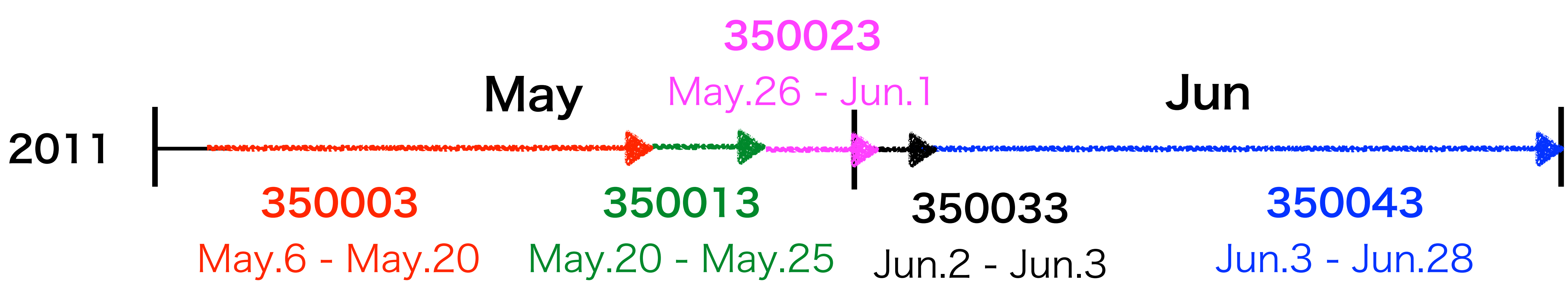
√SNN	NEvent (Million)
7.7	1.55
11.5	2.57
14.5	12
19.6	15.5
27	27.5
39	85.3
62.4	50.4
200	97.8

- **All BES-I data were used for $\Delta\eta$.**
  - analysis method and cuts are almost same as published results (up to 4th order).

Trigger ID

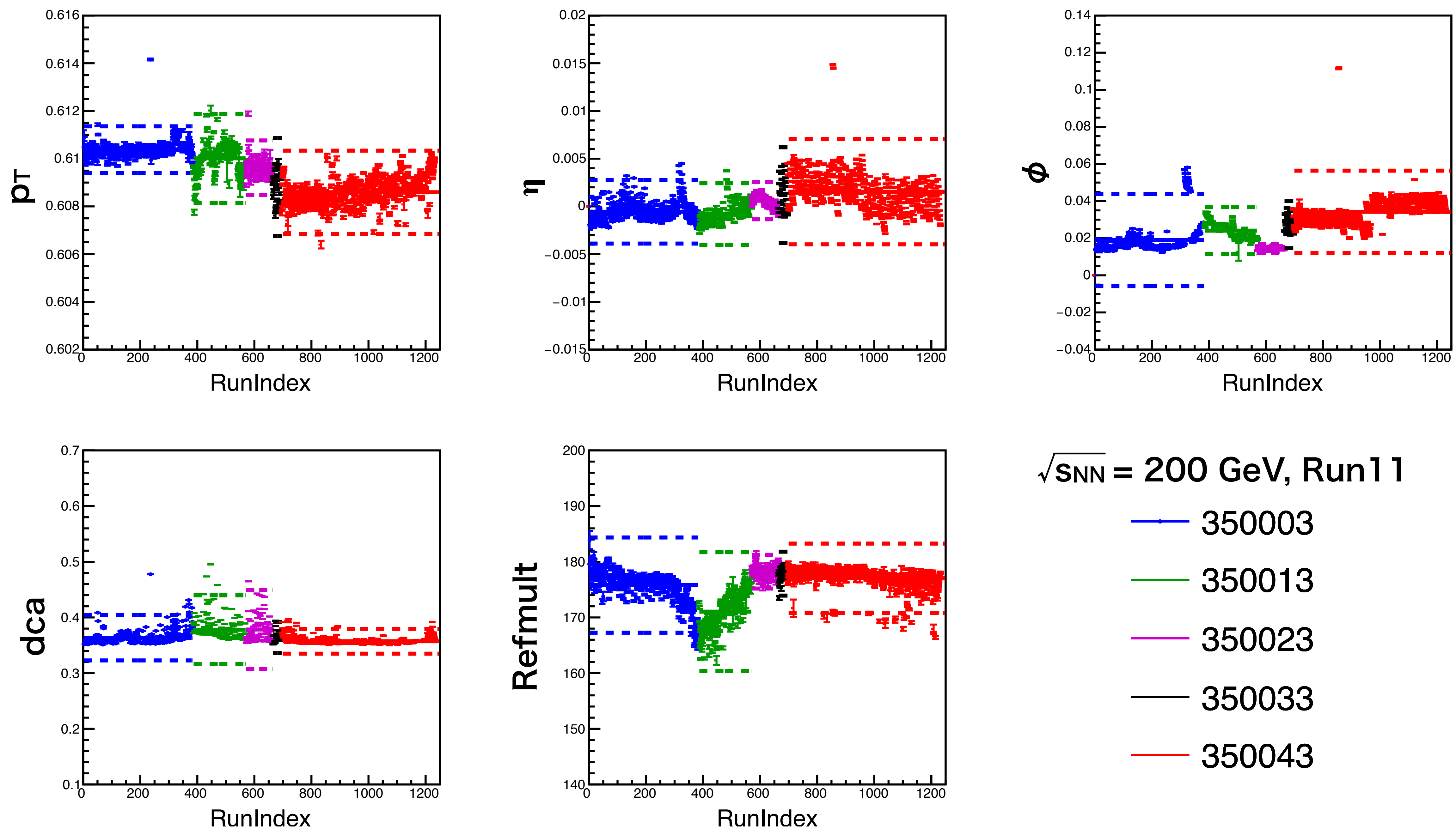
- Run11 data correspond to the data taken in 2011.
- There are several trigger ID. (Minimul bias trigger)
- Trigger ID changed when detector conditions were changed.

$\sqrt{s_{NN}}$= 200 GeV	350003	350013	350023	350033	350043
Run11	200M	74M	15M	12M	187M



- For consistensy check, cumulants are calculated for each trigger ID once and then merged at 200GeV.

Run by run QA

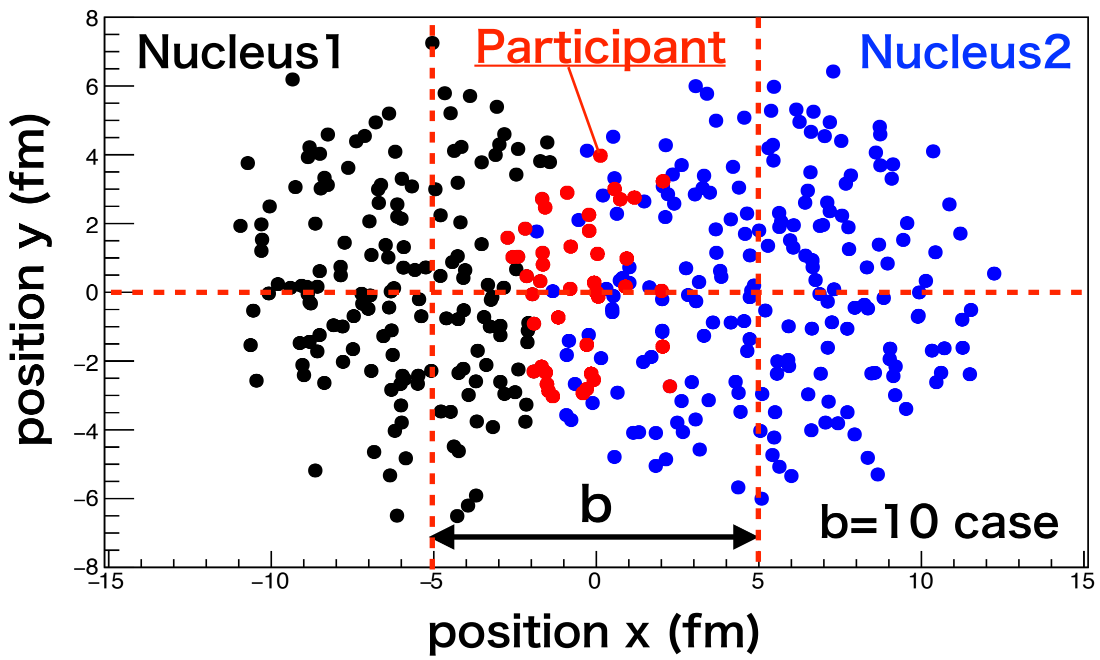


- Run by run <p_T>, <η>, <ϕ>, <dca>, and <Refmult> are measured
- The outlier runs of 3 σ were rejected as bad runs for each trigger ID

Glauber model

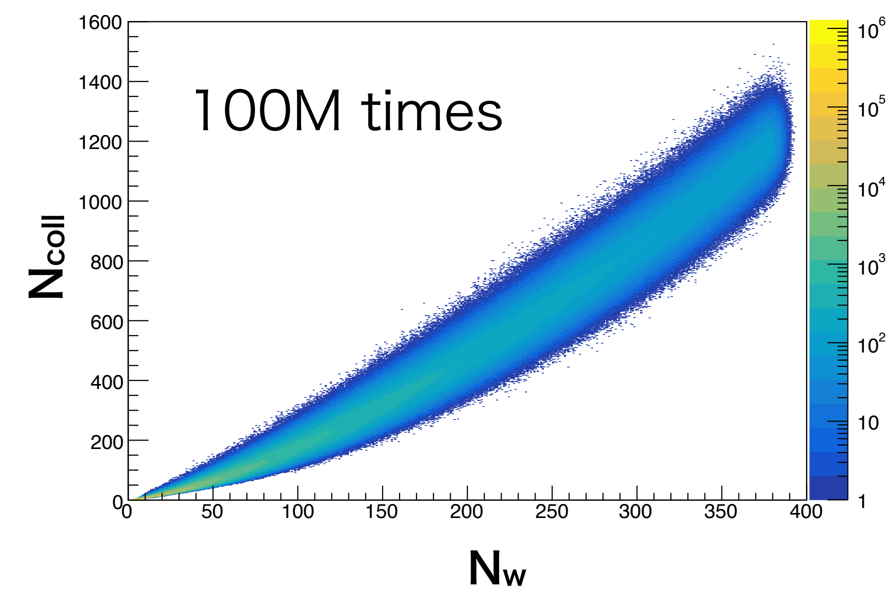
- N_W can't be measured directly by experiment so estimated by Glauber model.

1. Calculate N_W and N_{coll} by Monte Carlo simulation.



- Width : **0.535**
- Radius : **6.4**
- σ : **42** (mb)

Repeat



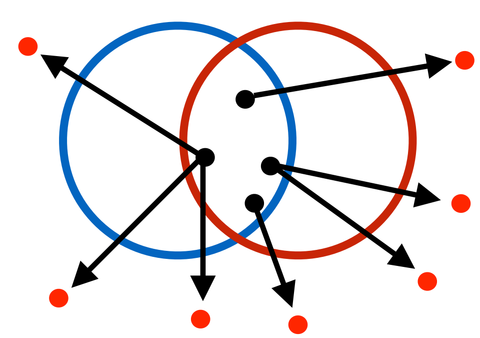
2. Calculate multiplicity by two component model and NBD.

Two component model

Number of source :
$(1-x)*(N_W/2.)+x*N_{coll}$

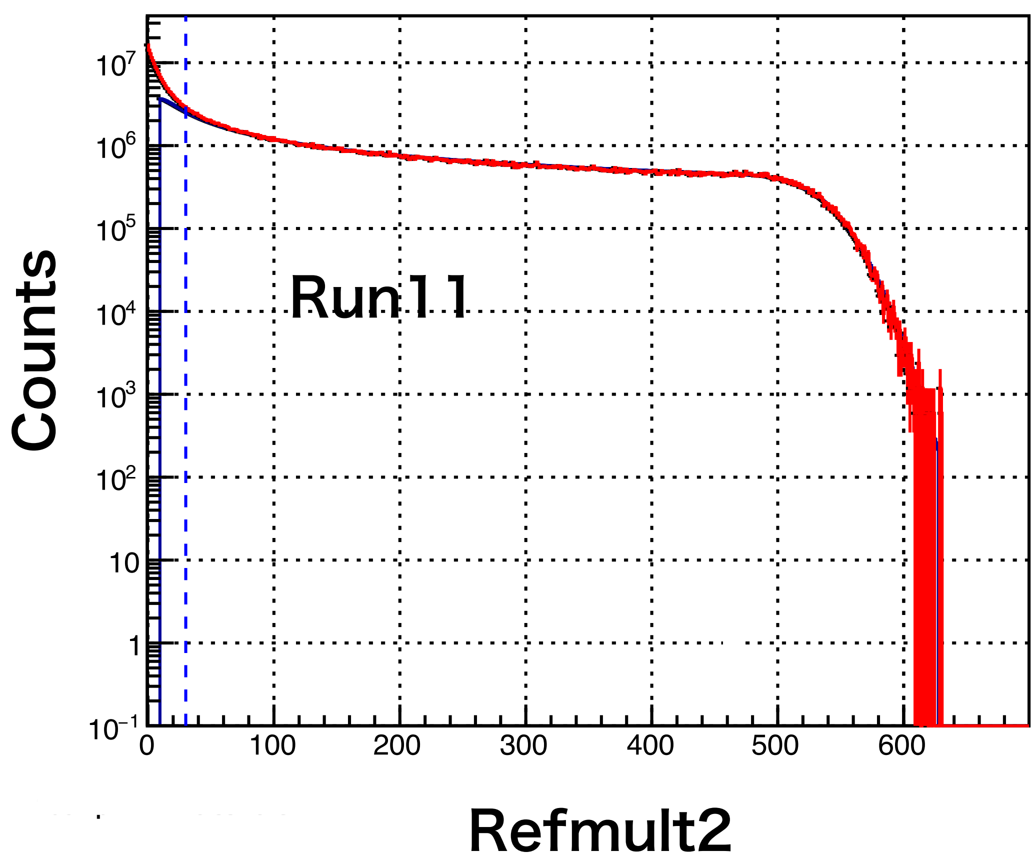
x=0.13

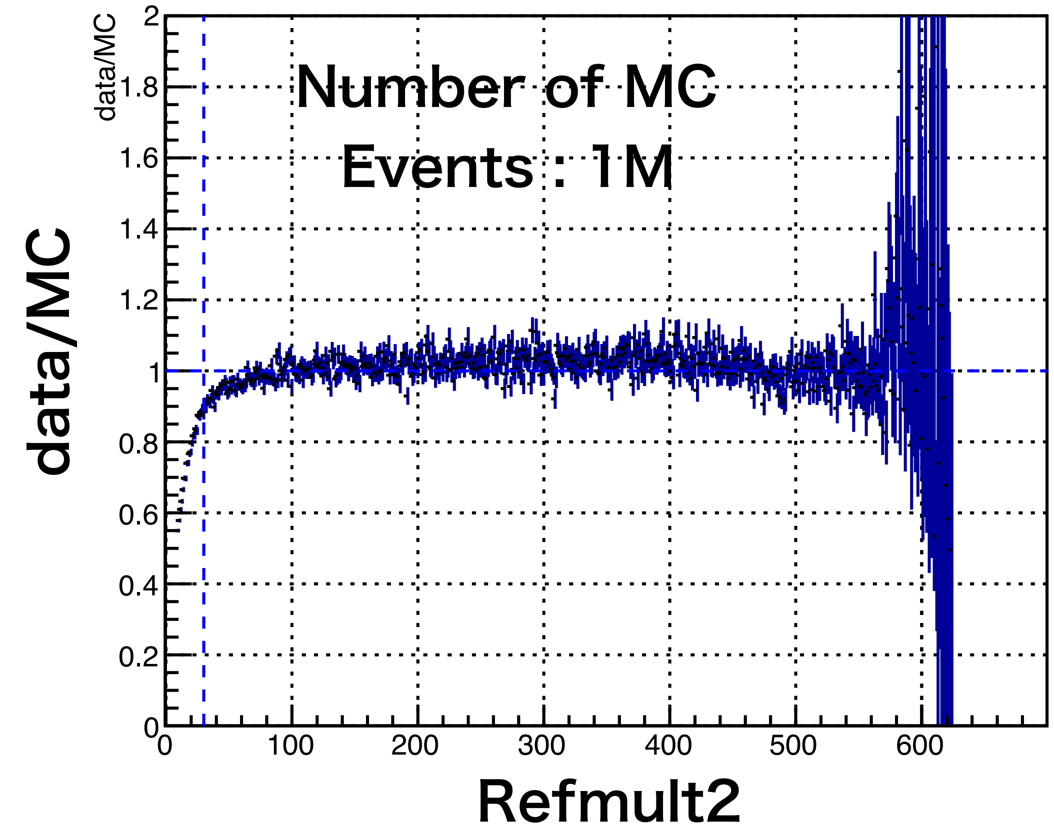
● : initial source
● : final state multiplicity

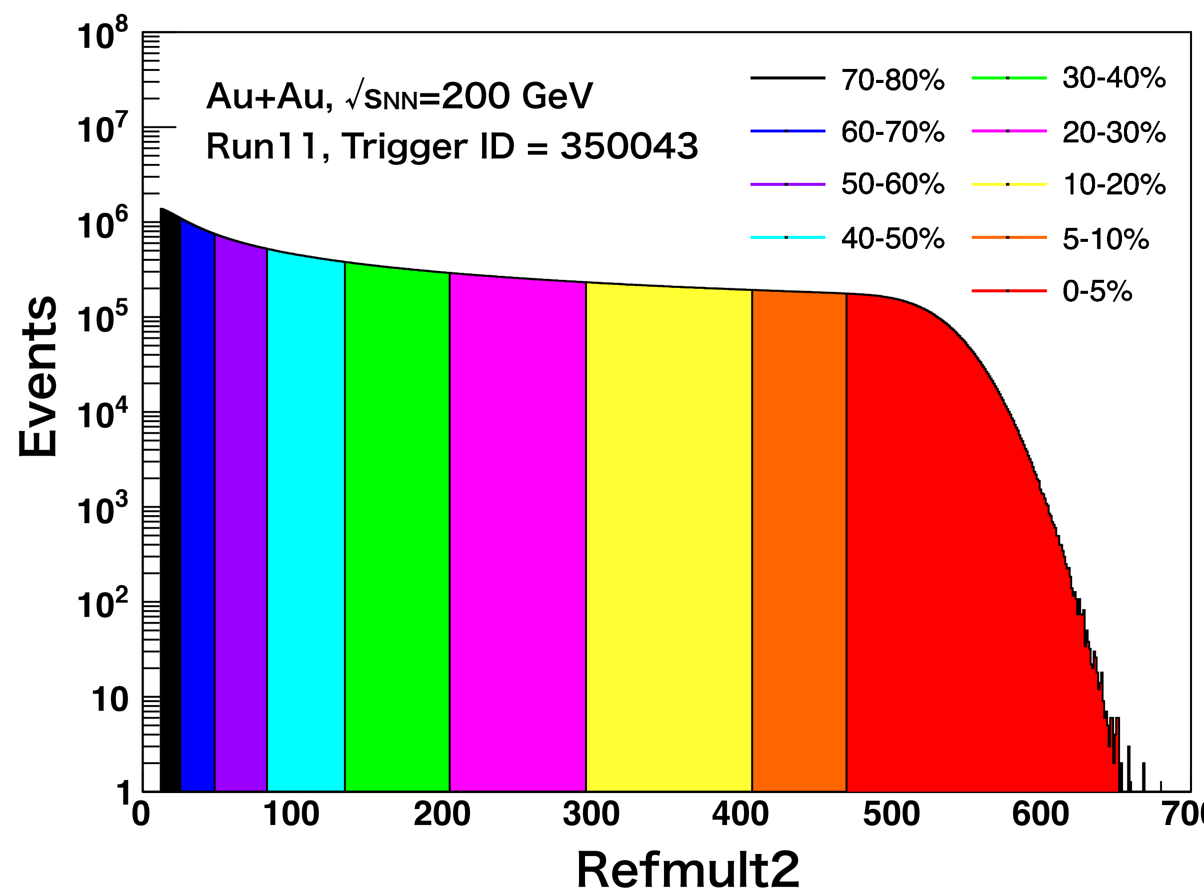


- Final state particles are generated from each source independently. (IPP)
- Number of particles from each source is fluctuating under the NBD.

Glauber fit results







Fitting parameters

n_{pp} : Mean number of generated particles from each source.

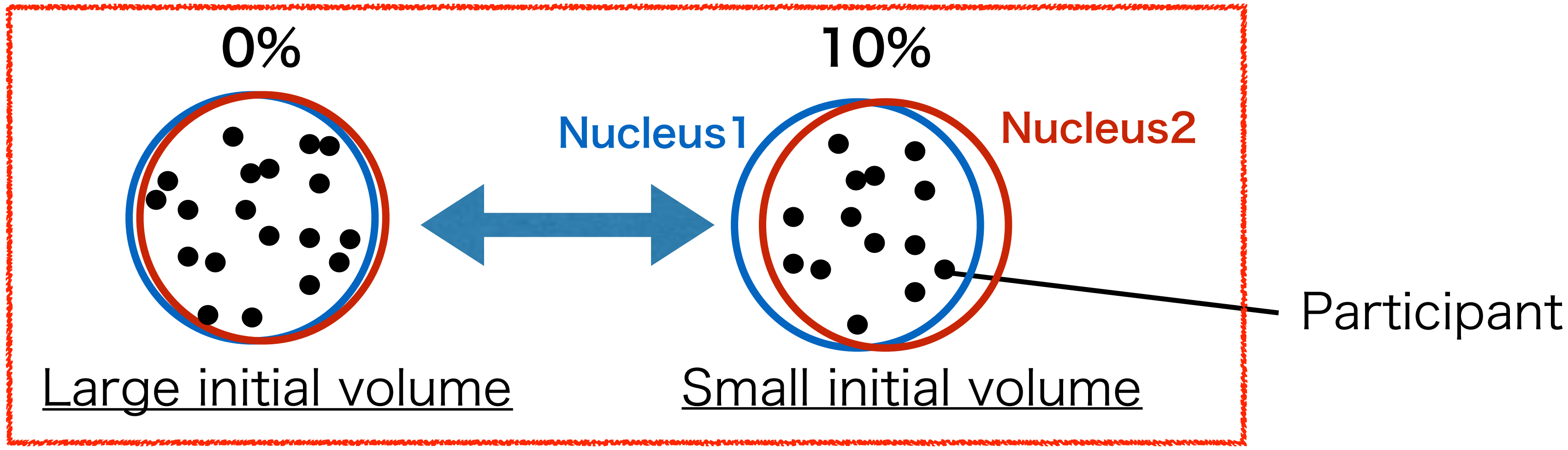
k : Parameters of NBD.

eff : tracking efficiency

Centrality Bin Width Correction

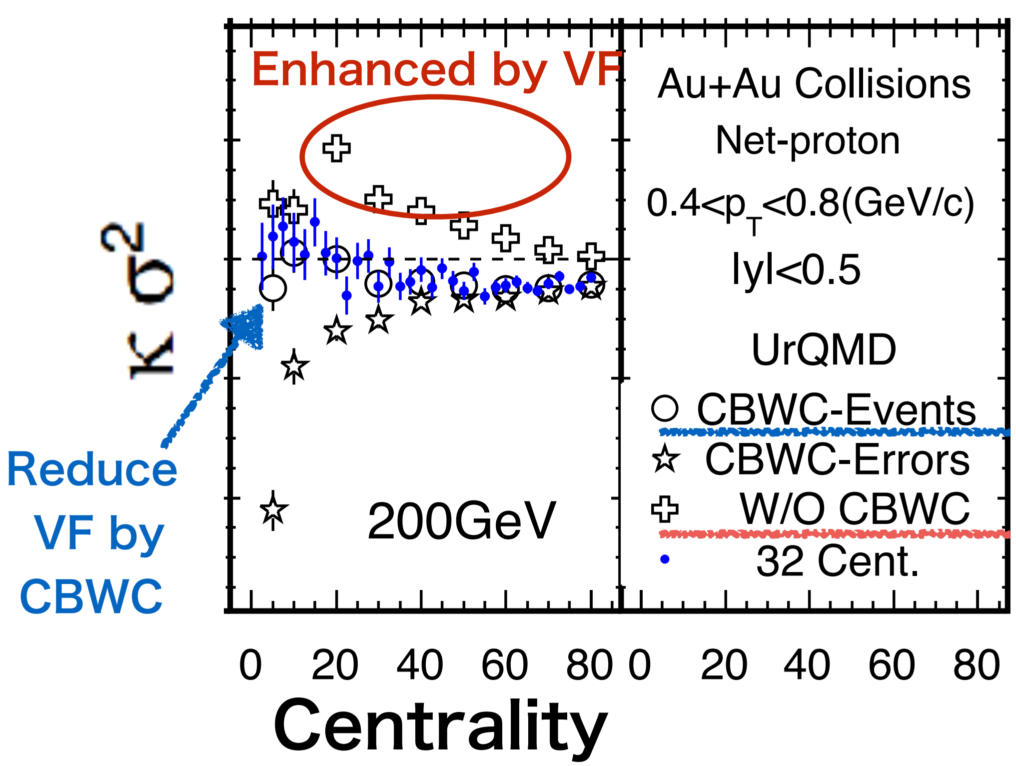
- **Initial volume** which correspond to **number participant nucleons (Nw) are different** even in the same centrality bins.

0-10% centrality bin



- Because of VF, cumulants are **artificially enhanced** which would be the background which should be eliminated.

Xiaofeng Luo, J. Phys. G: Nucl. Part. Phys. 40 105104 (2013)



- STAR applied **Centrality Bin Width Correction (CBWC)**.
- In this correction, cumulants are **calculated for each multiplicity bins**.

$$C_n = \sum_r w_r C_{(n,r)} \qquad w_r = \frac{N_r}{\sum_r N_r}$$

Cumulants for each centrality bins (C_n)

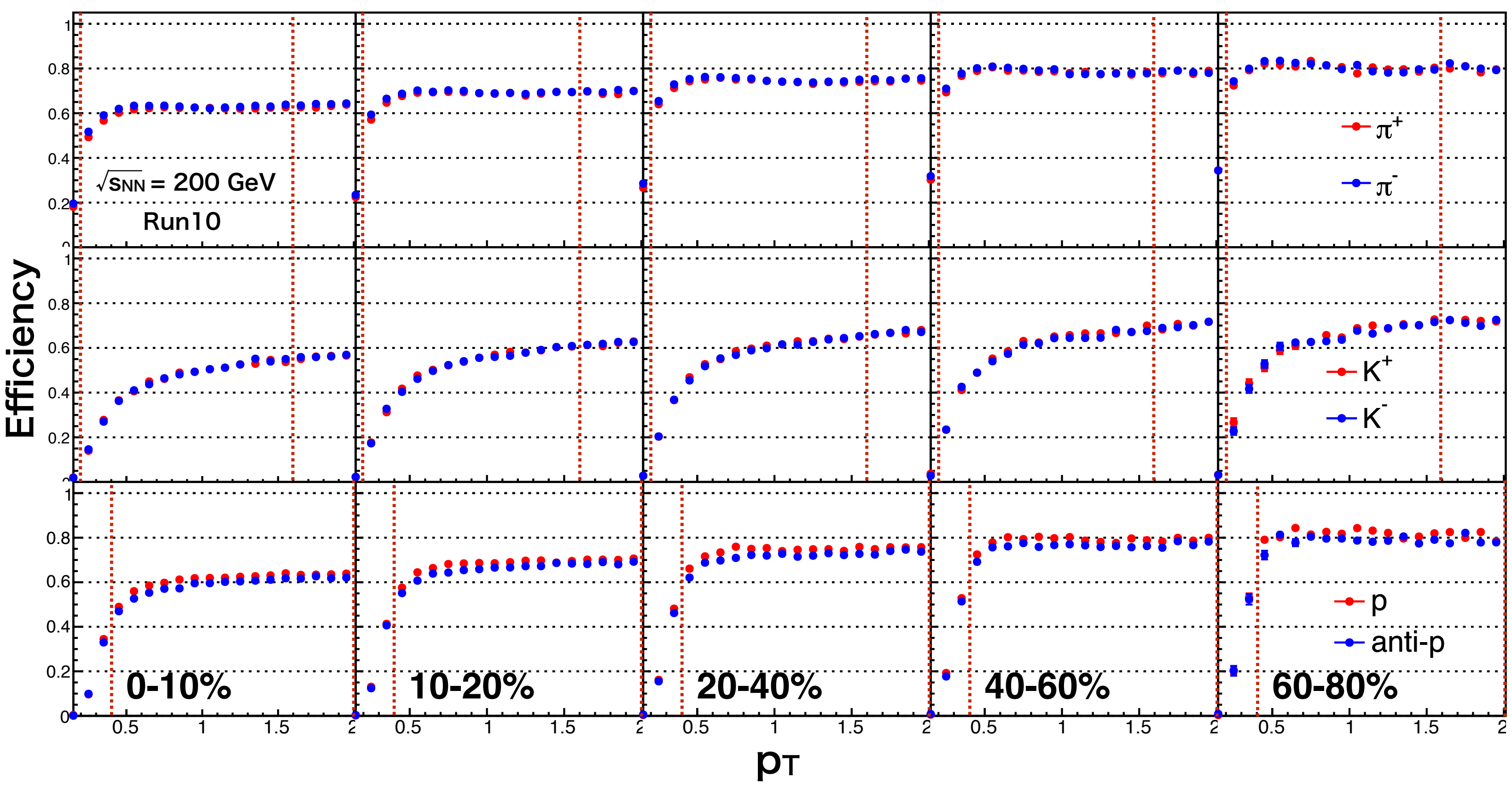
Weight (w_r)

Cumulants in r-th multiplicity bins ($C_{(n,r)}$)

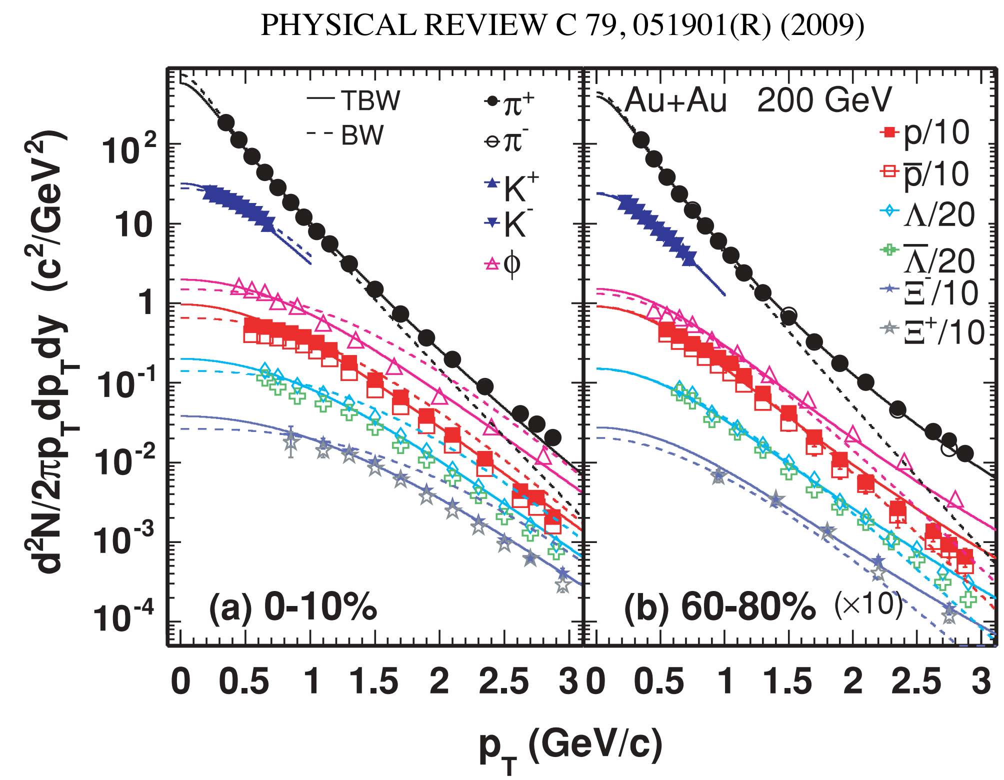
Efficiency estimation

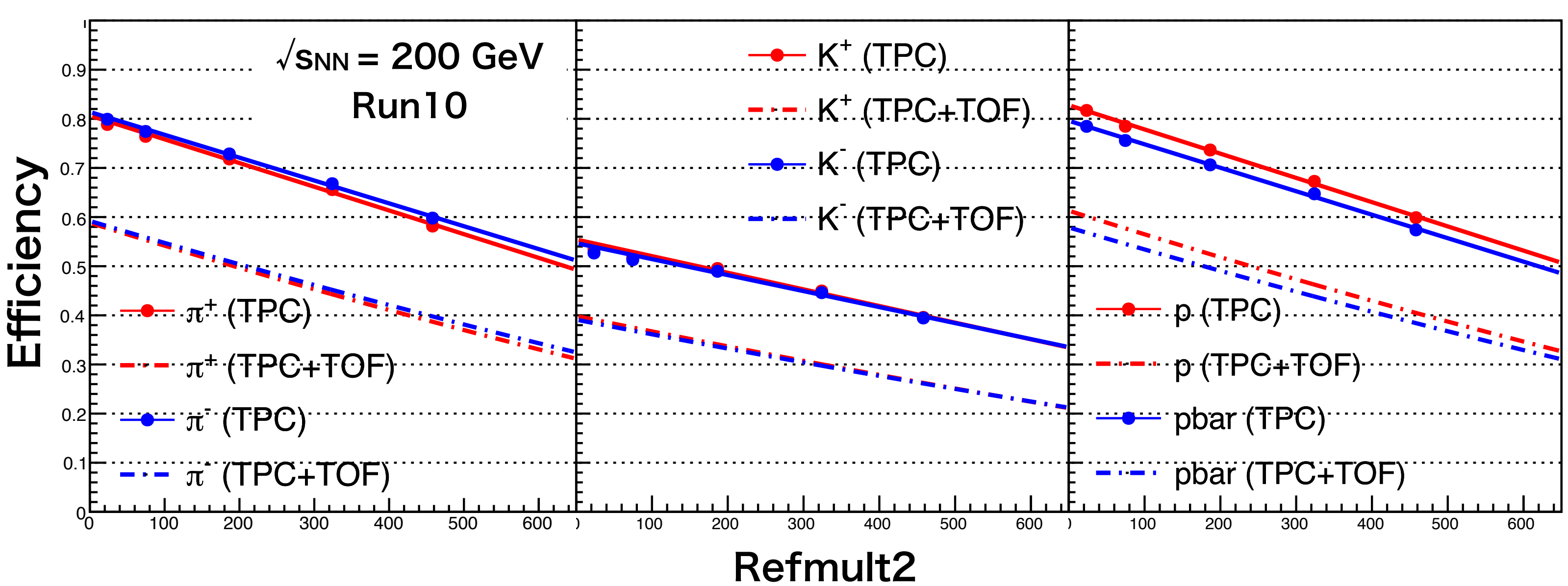
①p_T dependent efficiencies were estimated for each centrality using embedding method.

$|\eta| < 0.5$



② p_T integrated efficiencies were estimated using results of ① and spectra data.

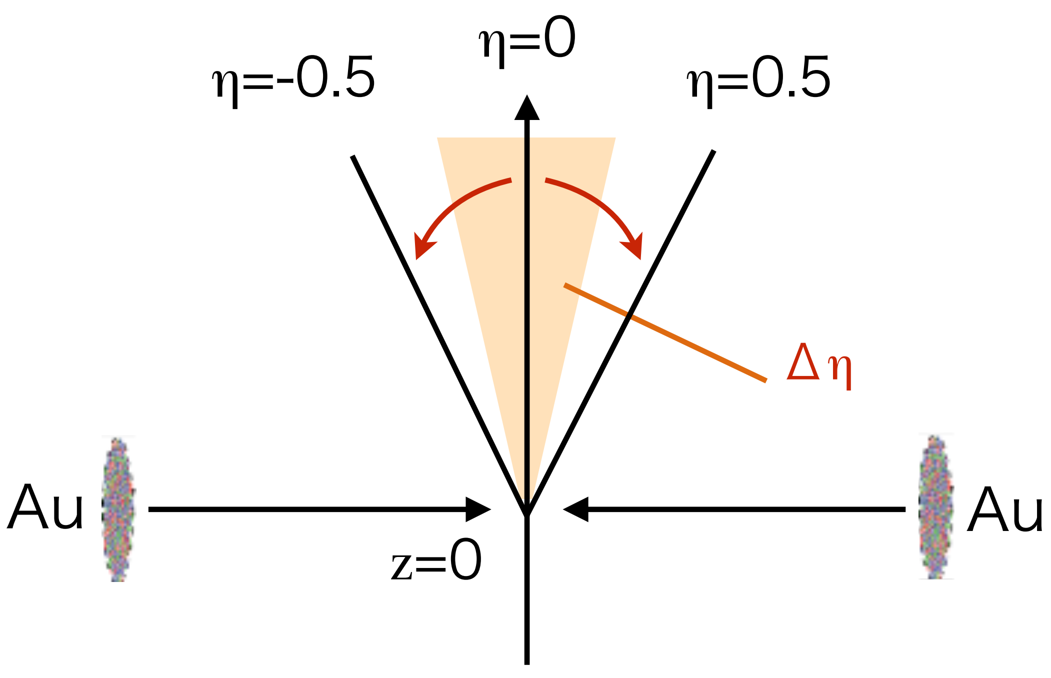


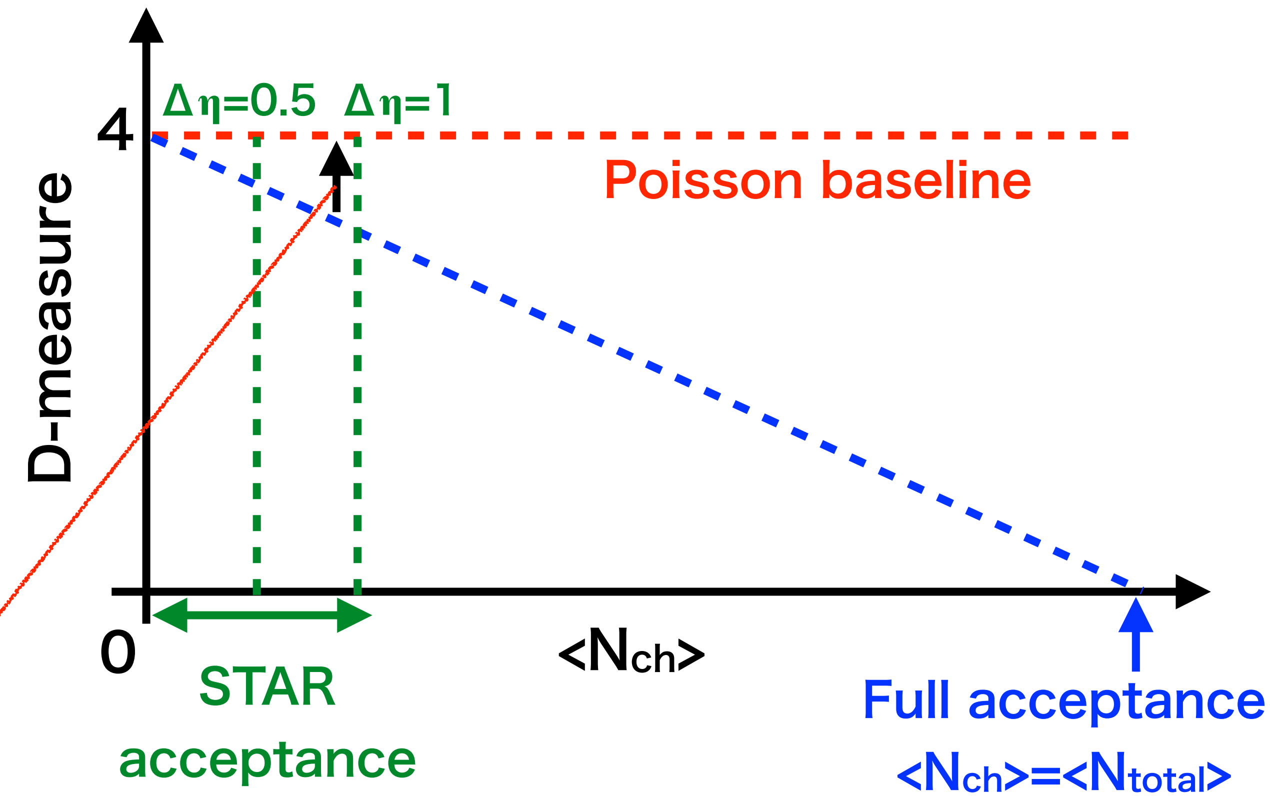


$$\epsilon_i = \frac{\int \epsilon_i(p_T) p_T f(p_T) dp_T}{\int p_T f(p_T) dp_T}$$

③ pol1 fit and estimate tracking efficiencies for each multiplicity bin.

Charge conservation correction on D



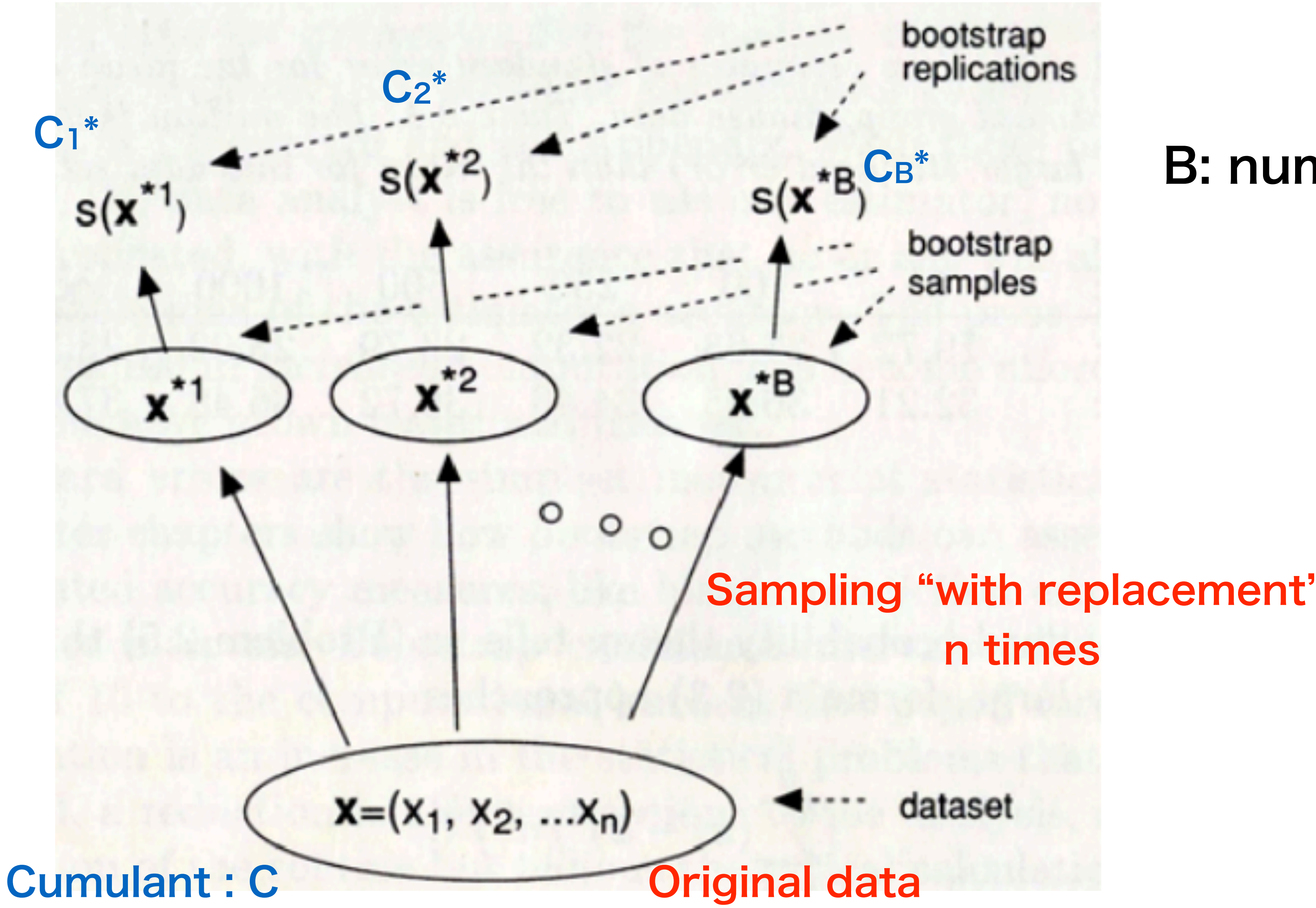


$$D_{corr} = D + 4\frac{\langle N_{ch}\rangle}{\langle N_{total}\rangle}$$

- D-measure decrease with expanding Δη due to charge conservation.
- This effect is critical to measure Δη dependence of D-measure
- Corrected by adding correction term.
- N_{total} is total multiplicity in full acceptance and estimated from PHOBOS experiment results.

Statistical error estimation

- Statistical errors are estimated by **Bootstrap** method.



B: number of bootstrap

- Error of C_n is estimated by calculating **standard error of C_n^*** distribution.
- Number of bootstrap is more than 100 times in this anlaysis.

How to estimate Systematic uncertainty?

$$RMS = \sqrt{\frac{1}{n}\sum_i \left(\frac{Y_i - Y_{st.cut}}{Y_{st.cut}}\right)^2}$$

$$Sys.Err = Y_{st.cut}\sqrt{\sum_j (RMS)^2}$$

Net-charge (published)

dca	0.8, 1.0(default), 1.2
nFitPoints	-18, 20(default), 22
nhitsdedx	8, 10(default), 12
efficiency	±5% $+\alpha$?

- Efficiency of positively charged particle and negatively charged particle are changed ±5% at published results.
  (pos,neg) = (+5%, +5%) and (-5%, -5%)
- In this analysis, efficiencies are changed 0.3% separately in addition to conventional method.
  (pos,neg) =(+5%, +5%), (-5%, -5%), (+0.3%, -0.3%), (+0.3%, -0.3%)

Analysis and correction method improvement (C_6 analysis)

Difference between published and current method

- Earlier method

high p_T ↕ low p_T

All positive charged particles | $|\eta|<0.5$ | All negative charged particles

N_1, ε_1 = $(w_{\pi^+}\epsilon_{\pi^+}) + (w_{K^+}\epsilon_{K^+}) + (w_p\epsilon_p)$

N_2, ε_2 = $(w_{\pi^-}\epsilon_{\pi^-}) + (w_{K^-}\epsilon_{K^-}) + (w_{\bar{p}}\epsilon_{\bar{p}})$

Net-charge : N_1-N_2 **Efficiency : $(\varepsilon_1+\varepsilon_2)/2$**

- Current method

	π^+	K^+	p	π^-	K^-	pbar
high-p_T	n_1, ε_1	n_2, ε_2	n_3, ε_3	n_4, ε_4	n_5, ε_5	n_6, ε_6
low-p_T	n_7, ε_7	n_8, ε_8	n_9, ε_9	n_{10}, ε_{10}	n_{11}, ε_{11}	n_{12}, ε_{12}

Net-charge : $(n_1 + n_2 + n_3 + n_7 + n_8 + n_9) - (n_4 + n_5 + n_6 + n_{10} + n_{11} + n_{12})$

Efficiency : ϵ_1 ϵ_2 ϵ_3 $\cdots$

12 efficiency bins were used

- **Earlier method** : Count all charged particle with averaged efficiency.
- **Current method** : Count π, K, p with separated efficiencies.

Efficiency correction for different phase space

It was suggested that efficiency correction using the average efficiency for different region of the phase space (different p_T bins for different particle species) would give artificial results when distributions do not follow Poisson.

2 distribution model

5% smaller than Poisson | cumulants Poisson

n_A, ε_A | n_B, ε_B

$$\Delta\epsilon = \epsilon_A - \epsilon_B$$

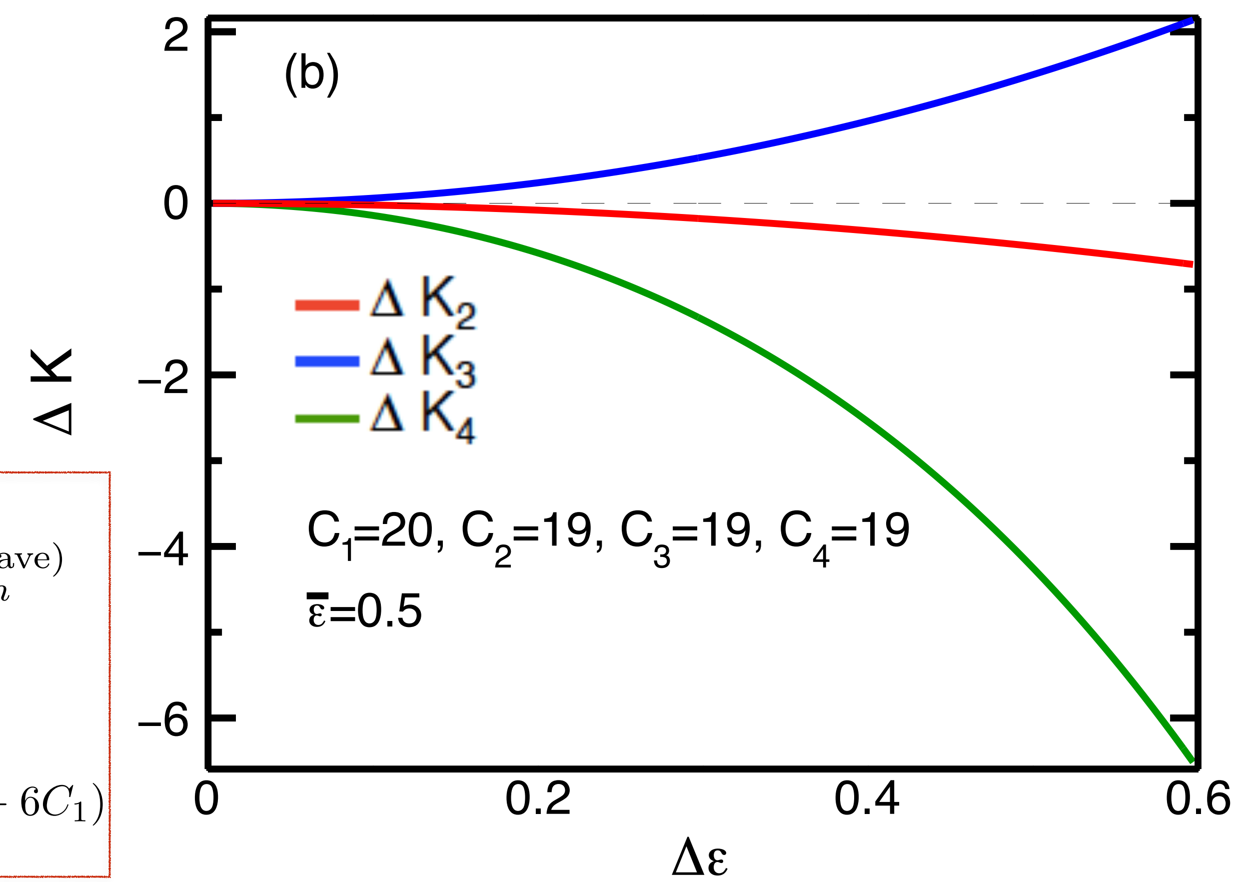
$$\Delta K_2 = \frac{1}{2}\left(\frac{\Delta\varepsilon}{\bar{\varepsilon}}\right)^2 (C_2 - C_1),$$

$$\Delta K_3 = \frac{3}{2}\left(\frac{\Delta\varepsilon}{\bar{\varepsilon}}\right)^2 (C_3 - 2C_2 + C_1),$$

$$\Delta K_4 = \frac{1}{2}\left(\frac{\Delta\varepsilon}{\bar{\varepsilon}}\right)^2 (6C_4 - 18C_3 + 19C_2 - 7C_1) + \frac{1}{8}\left(\frac{\Delta\varepsilon}{\bar{\varepsilon}}\right)^4 (C_4 - 6C_3 + 11C_2 - 6C_1)$$

$$\Delta K_m = K_m - K_m^{(\mathrm{ave})} = 2C_m - K_m^{(\mathrm{ave})}$$

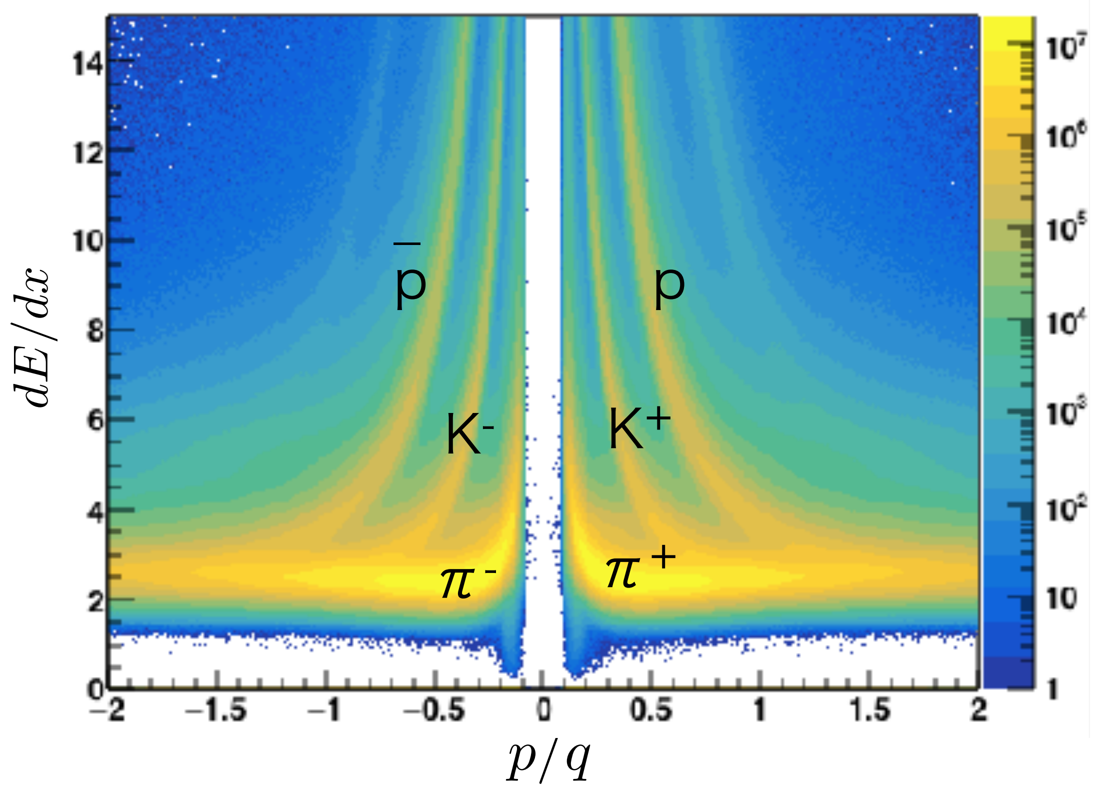
Phys. Rev. C **95**, 064912 T.Nonaka, M.Kitazawa and S.Esumi

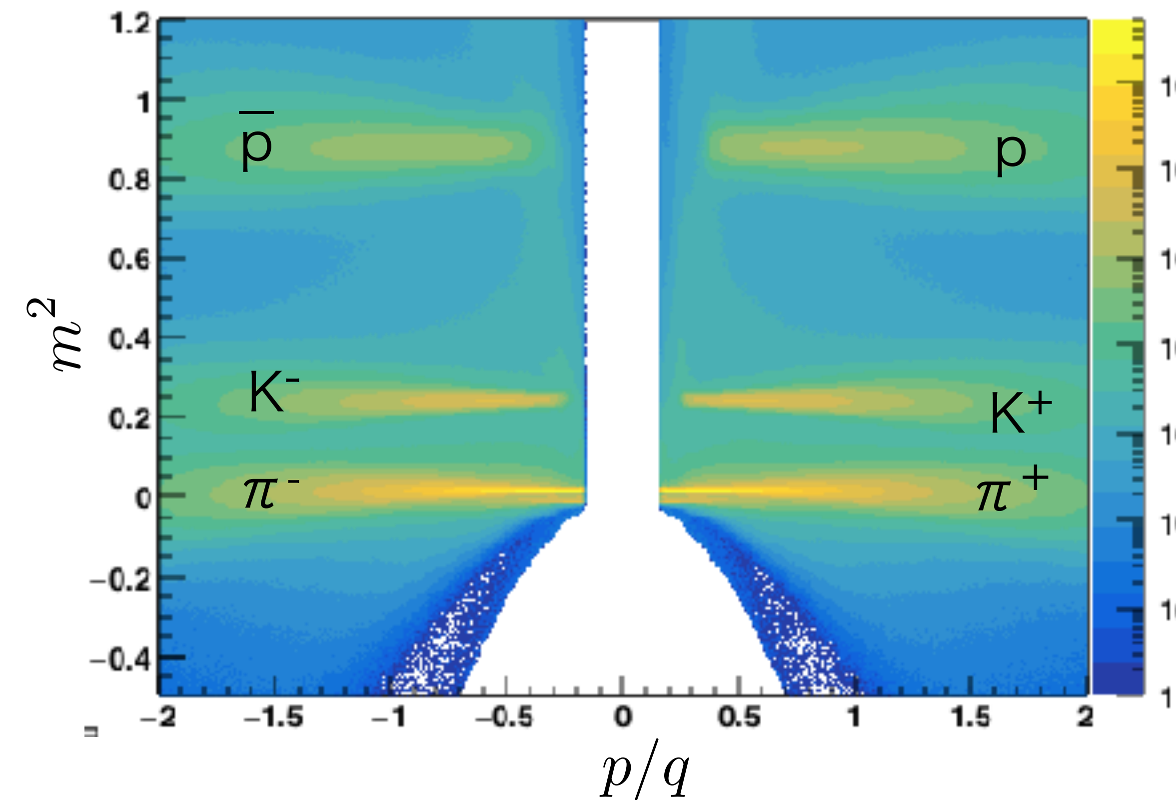


<u>We can't estimate true corrected cumulant when uses average efficiencies if Δ ε is large.</u>

Particle Identification

Au+Au, $\sqrt{s_{NN}}$ = 200GeV
STAR Preliminary





- PID have been done by using dE/dx of TPC
- TOF is also used for PID at high p_T region

Track cut	π	K	p
p_T (TPC only)	0.2 - 0.5 GeV/c	0.2 - 0.4 GeV/c	0.4 - 0.8 GeV/c
p_T (TPC+TOF)	0.5 - 1.6 GeV/c	0.4 - 1.6 GeV/c	0.8 - 2. GeV/c

Factorial cumulant method

Cumulant (measured) → Factorial Cumulant (measured)

↓ Efficiency correction

Cumulant (true) ← Factorial Cumulant (true)

1-4th-order cumulants (factorial cumulant formula)

Phys. Rev. C **95**, 064912

T.Nonaka, M.Kitazawa and S.Esumi

$$\langle Q \rangle_c = \langle q_{(1,1)} \rangle_c,$$

$$\langle Q^2 \rangle_c = \langle q_{(1,1)}^2 \rangle_c + \langle q_{(2,1)} \rangle_c - \langle q_{(2,2)} \rangle_c,$$

$$\langle Q^3 \rangle_c = \langle q_{(1,1)}^3 \rangle_c + 3\langle q_{(1,1)} q_{(2,1)} \rangle_c - 3\langle q_{(1,1)} q_{(2,2)} \rangle_c + \langle q_{(3,1)} \rangle_c - 3\langle q_{(3,2)} \rangle_c + 2\langle q_{(3,3)} \rangle_c,$$

$$\begin{aligned}\langle Q^4 \rangle_c = {} & \langle q_{(1,1)}^4 \rangle_c + 6\langle q_{(1,1)}^2 q_{(2,1)} \rangle_c - 6\langle q_{(1,1)}^2 q_{(2,2)} \rangle_c + 4\langle q_{(1,1)} q_{(3,1)} \rangle_c + 3\langle q_{(2,1)}^2 \rangle_c \\ & + 3\langle q_{(2,2)}^2 \rangle_c - 12\langle q_{(1,1)} q_{(3,2)} \rangle_c + 8\langle q_{(1,1)} q_{(3,3)} \rangle_c - 6\langle q_{(2,1)} q_{(2,2)} \rangle_c \\ & + \langle q_{(4,1)} \rangle_c - 7\langle q_{(4,2)} \rangle_c + 12\langle q_{(4,3)} \rangle_c - 6\langle q_{(4,4)} \rangle_c,\end{aligned}$$

Cumulant (true)

Cumulant (measured)

$$q_{(r,s)} = q_{(a^r/p^s)} = \sum_{i=1}^{M} (a_i^r / p_i^s) n_i.$$

M — Number of phase space

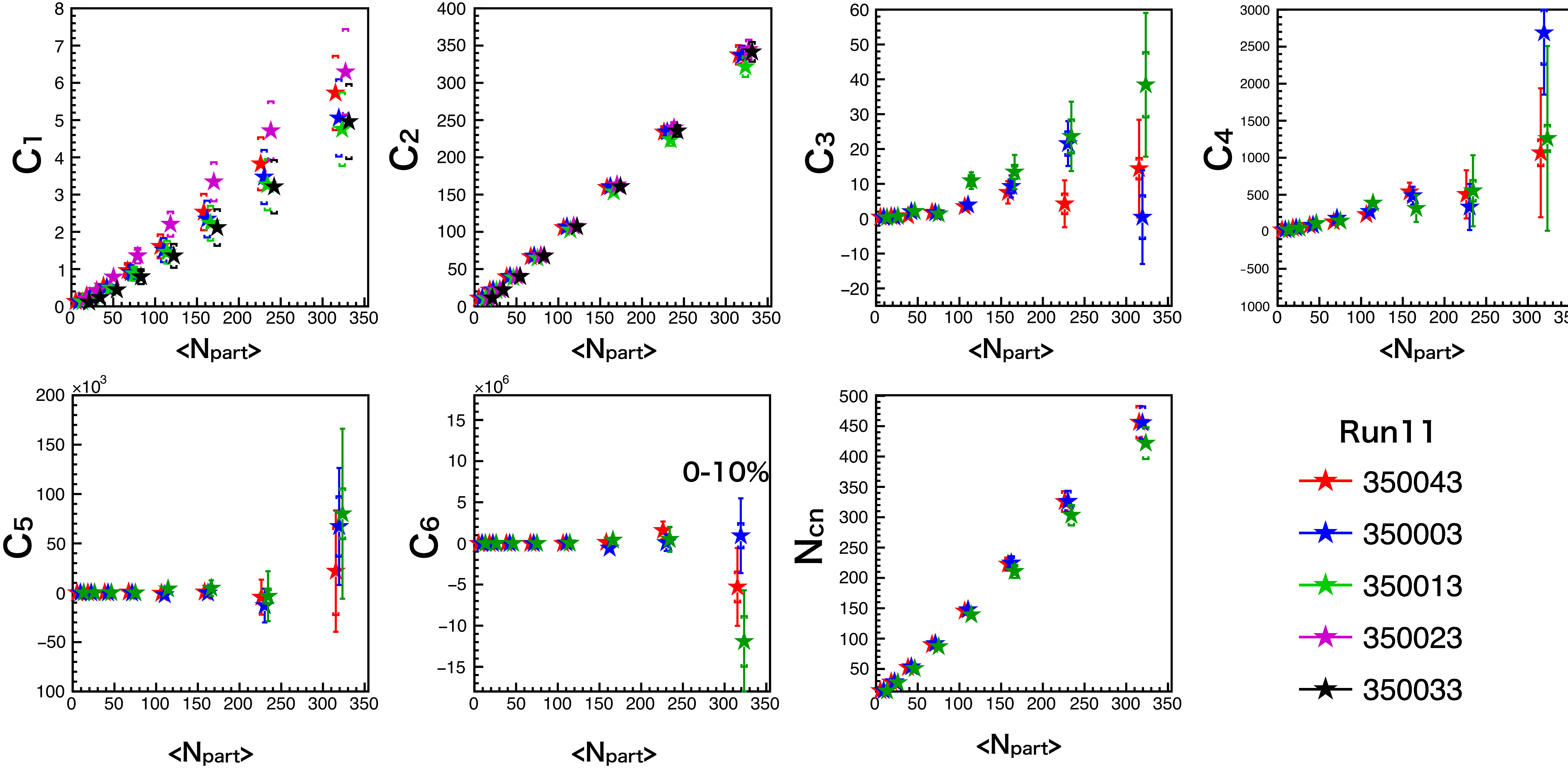
n_i — Number of particle

p_i — Efficiency

a_i — +1 (positive charge) or -1 (negative charge)

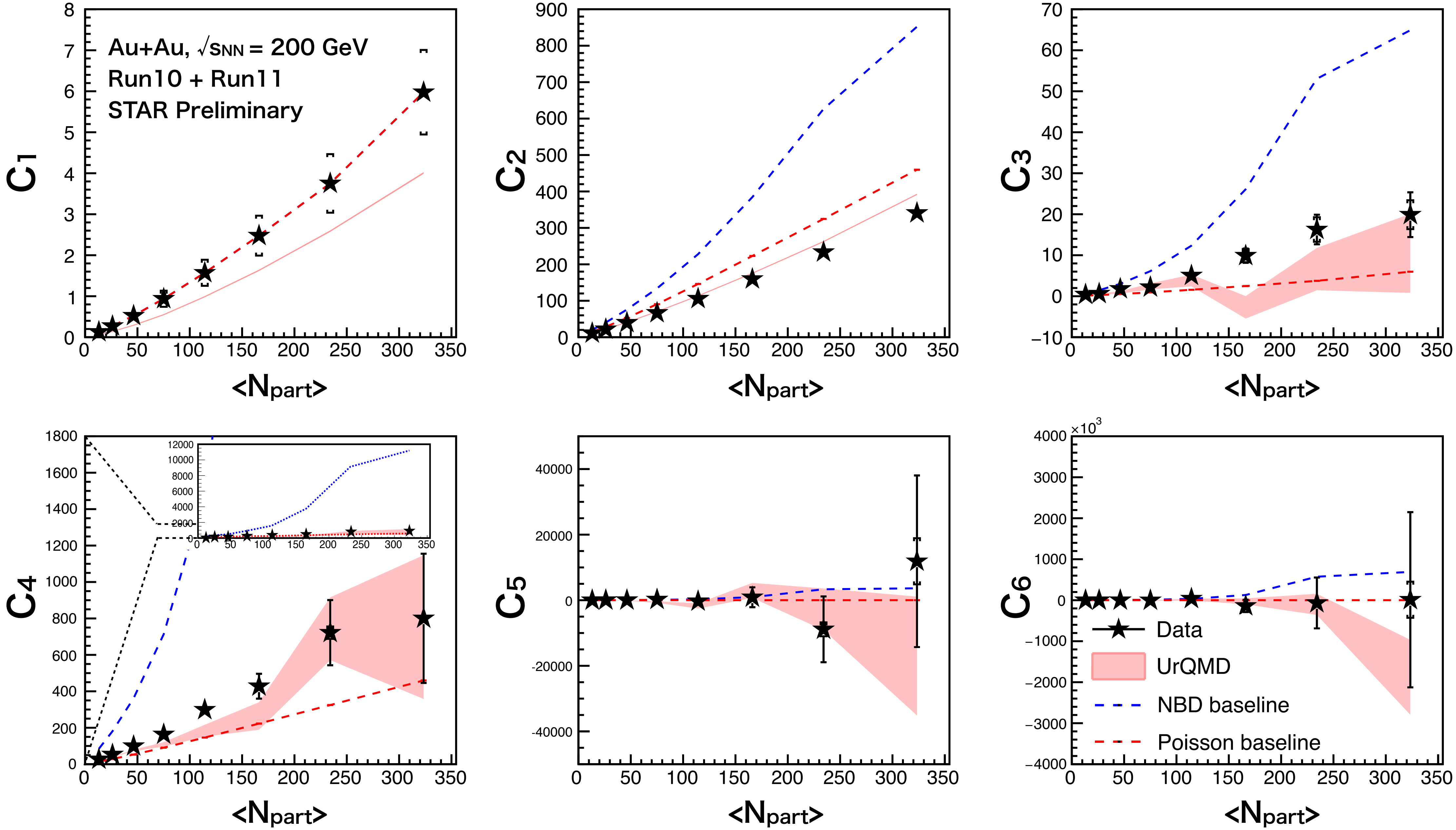
Results (C_6 analysis)

Cumulants (200GeV, Run11)



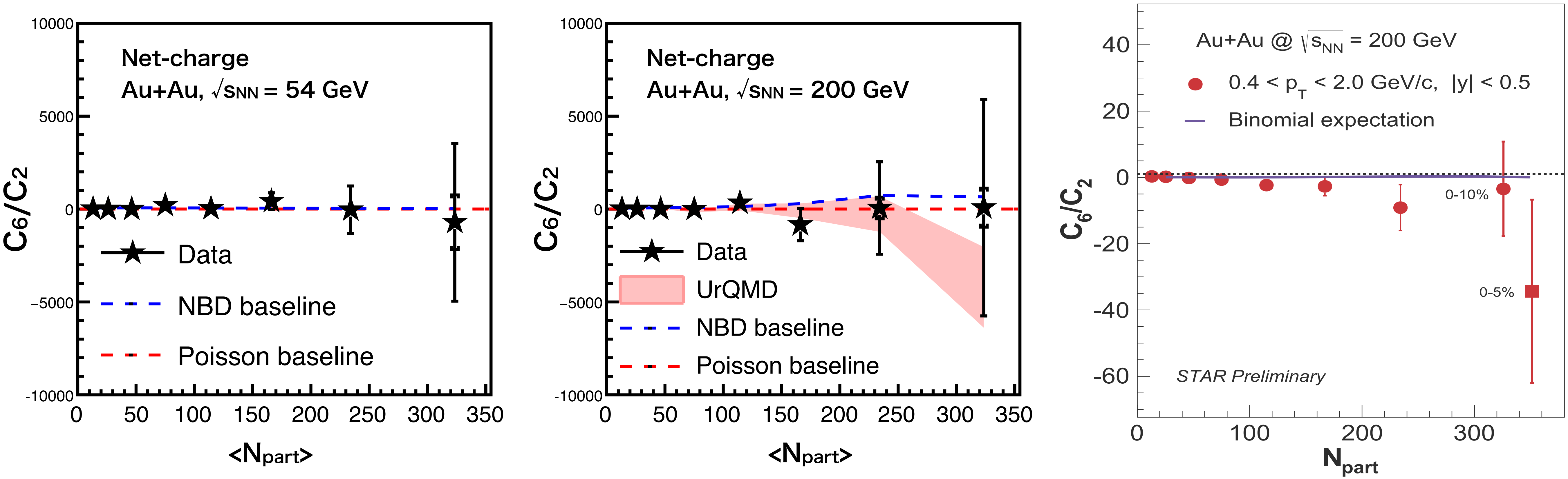
- Cumulants of all trigger ID are consistent within statistical or systematic errors.

Cumulants (200GeV, Run10+Run11)



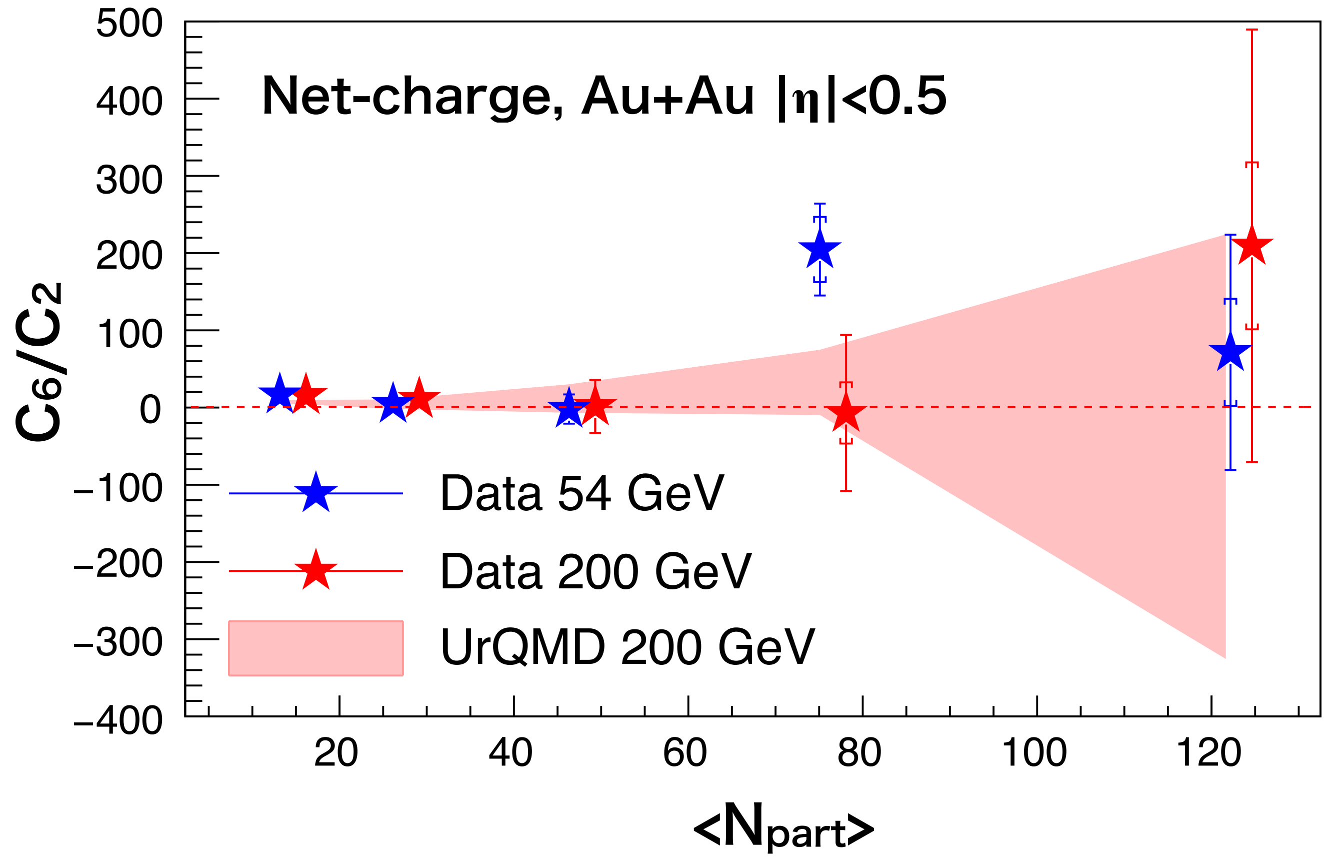
- From 1st- to 6th-order cumulants were measured as a function of <N_{part}>
- Linear trend can be seen.
- For higher-order cumulants, statistical uncertainties are larger than the systematic ones.
- NBD baseline becomes larger than experimental values especially at C_4.

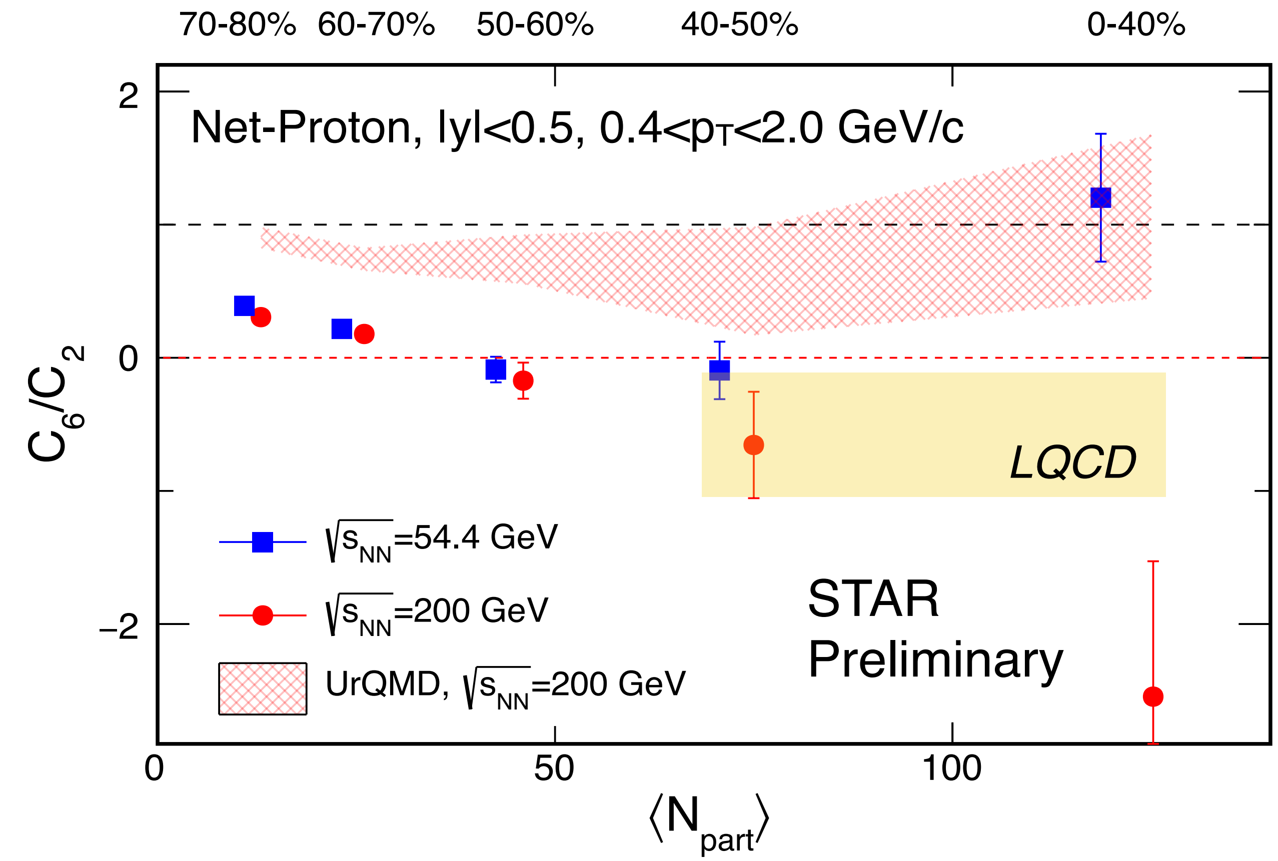
C_6/C_2 at 200 GeV and 54GeV



- Centrality dependecne of C_6/C_2 of net-charge at 200 GeV and 54 GeV are compared to that of net-proton at 200 GeV.
- Compared to Poisson, NBD, and UrQMD.
- All statistical baseline and UrQMD results of C_6/C_2 are consistent within statistical uncertainties and large deviations are not observed.

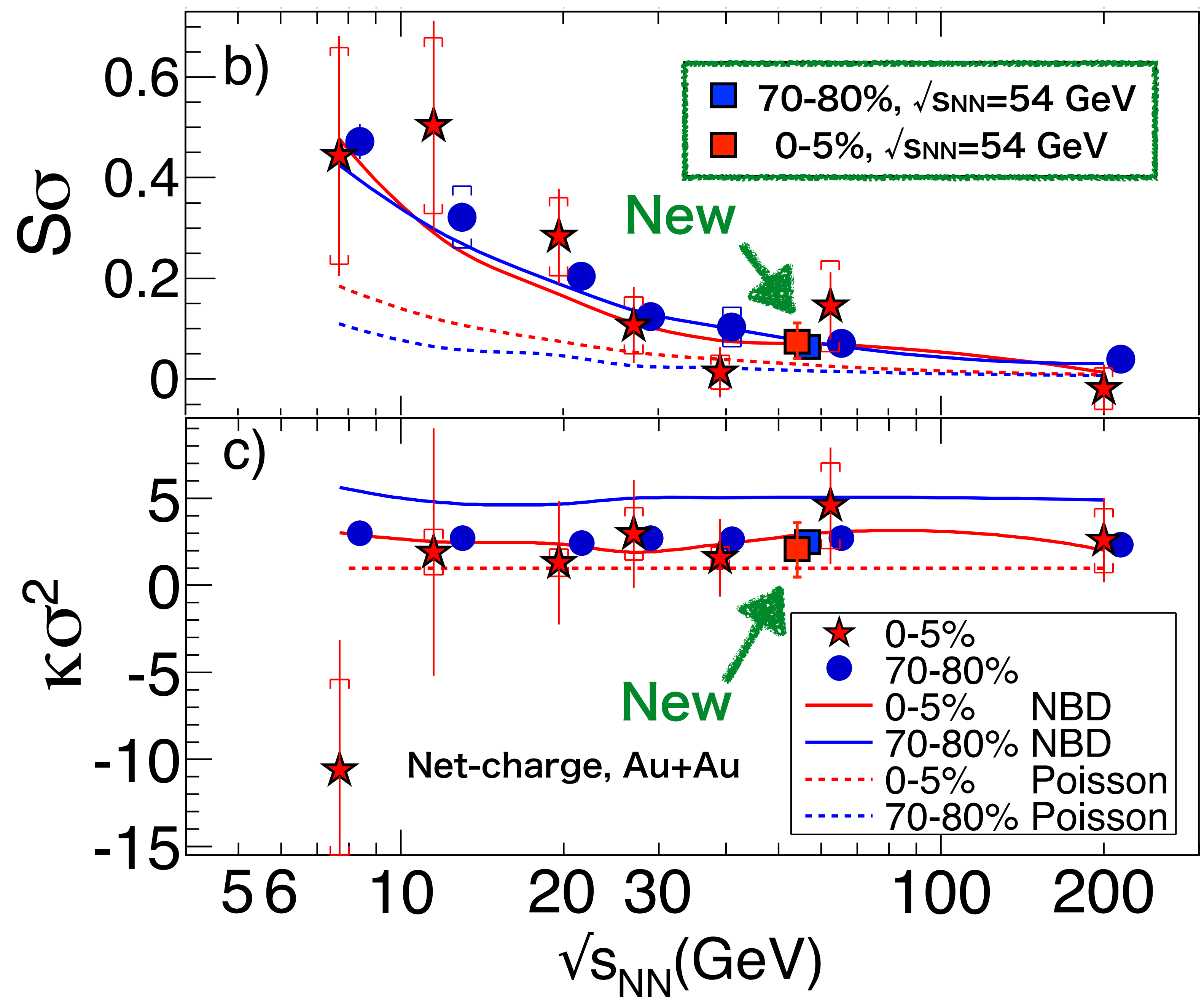
C_6/C_2 (0-40% merged)





- 0-40% centralities are merged.
- Deviation between 200 GeV and 54 GeV is ovserved in 0-40% centrality at net-proton and 40-50% at net-charge.
  → Signal from cross-over??
- Statistical errors are large and which results should be compare to lower energies in future.

C_3/C_2 and C_4/C_2 at 54 GeV



$$S\sigma = \frac{C_3}{C_2} = \frac{\chi_3}{\chi_2}$$

$$\kappa\sigma^2 = \frac{C_4}{C_2} = \frac{\chi_4}{\chi_2}$$

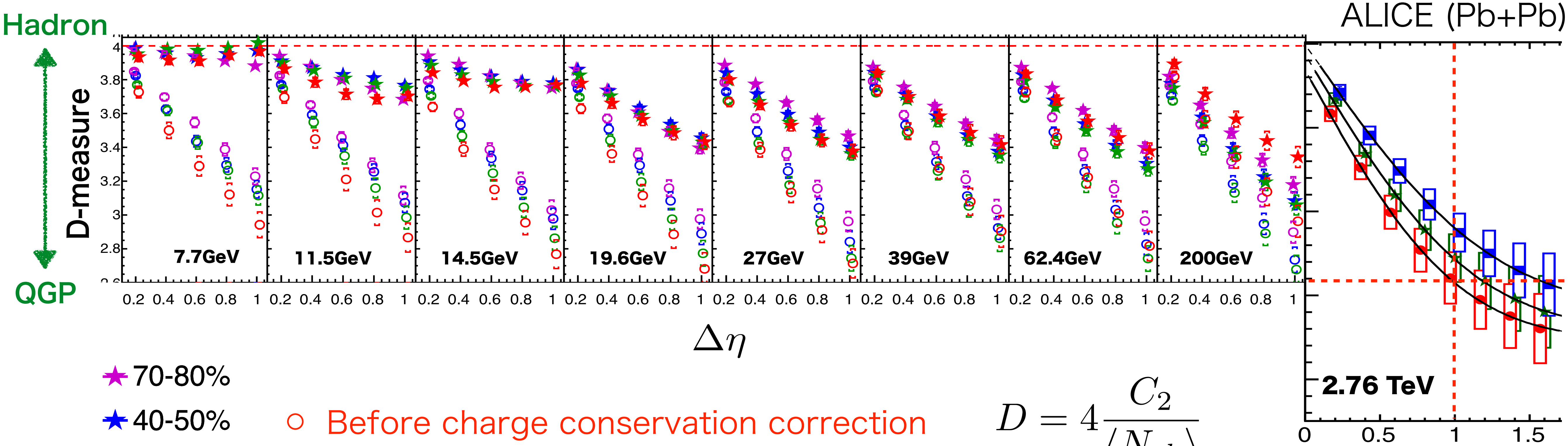
L. Adamczyk *et al.* (STAR Collaboration)
Phys. Rev. Lett. 113, 092301(2014)

- C_3/C_2 and C_4/C_2 of net-charge at 54 GeV are newly measured in addition to BES energies.
- Close to 39 GeV and 62.4 GeV results.

→ Results at 54 GeV are not conflict with publisehd BES-I results.

Results (Δη dependence)

Δη dependence of D-measure



★ 70-80%
★ 40-50%
★ 20-30%
★ 0-5%

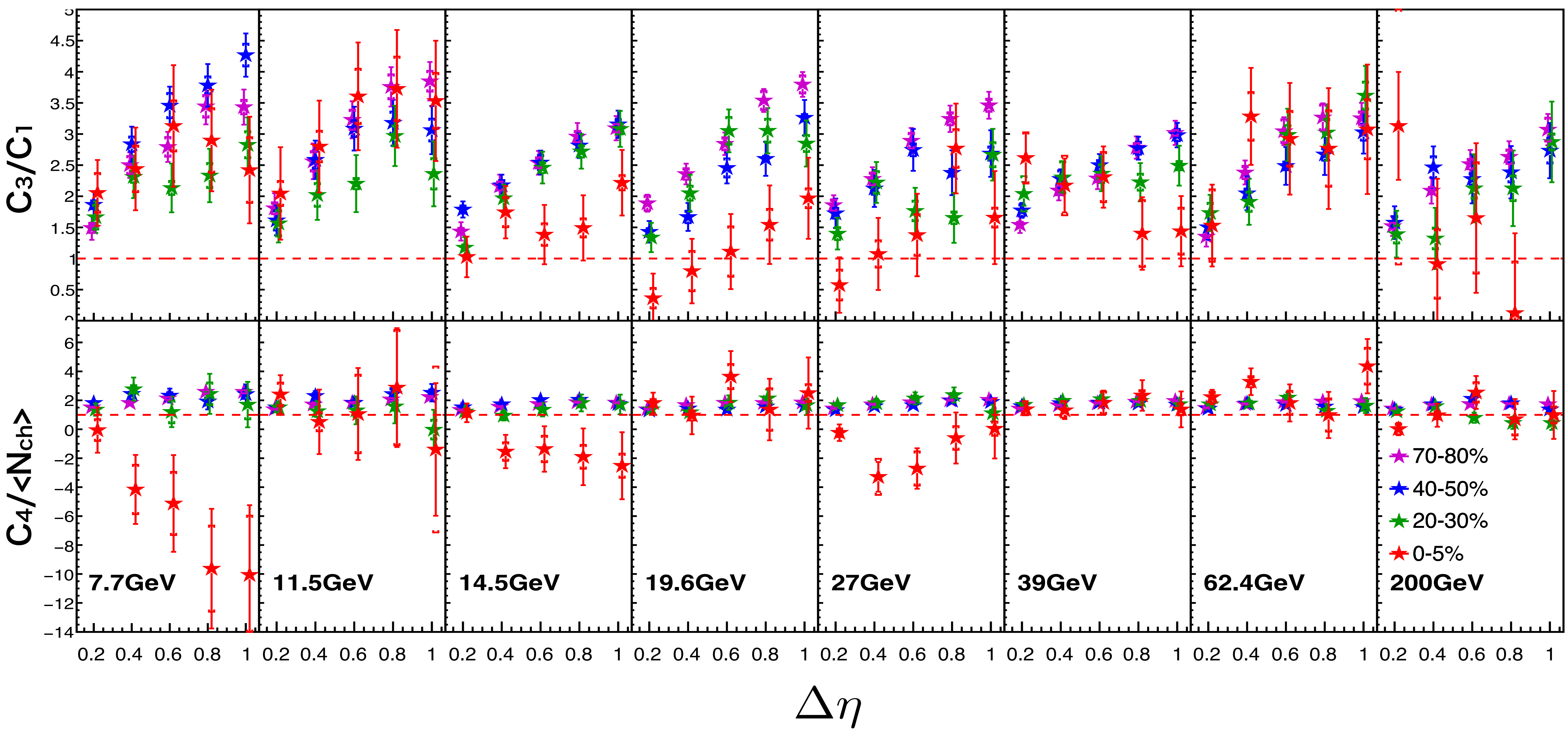
○ Before charge conservation correction
★ After charge conservation correction

$$D = 4\frac{C_2}{\langle N_{ch} \rangle}$$

$$D_{corr} = D + 4\frac{\langle N_{ch} \rangle}{\langle N_{total} \rangle}$$

- D-measure are observed to decreace with Δη.
- Even tough charge conservations are applied, D-measure is decreace with Δη and this trend is stronger with collision energies.
- These results do not conflict with ALICE and the trends of Δη dependence might represent the time evolution of phase transition.

Experimental results of C_3/C_1 and $C_4/\langle N_{ch}\rangle$



- At C_3/C_1 and $C_4/\langle N_{ch}\rangle$, most of the results are observed to increase with $\Delta\eta$ without most central collision at $C_4/\langle N_{ch}\rangle$.
- These treands can not be descrived by diffusion process whereas the treands of D-measure can be explained by this model.

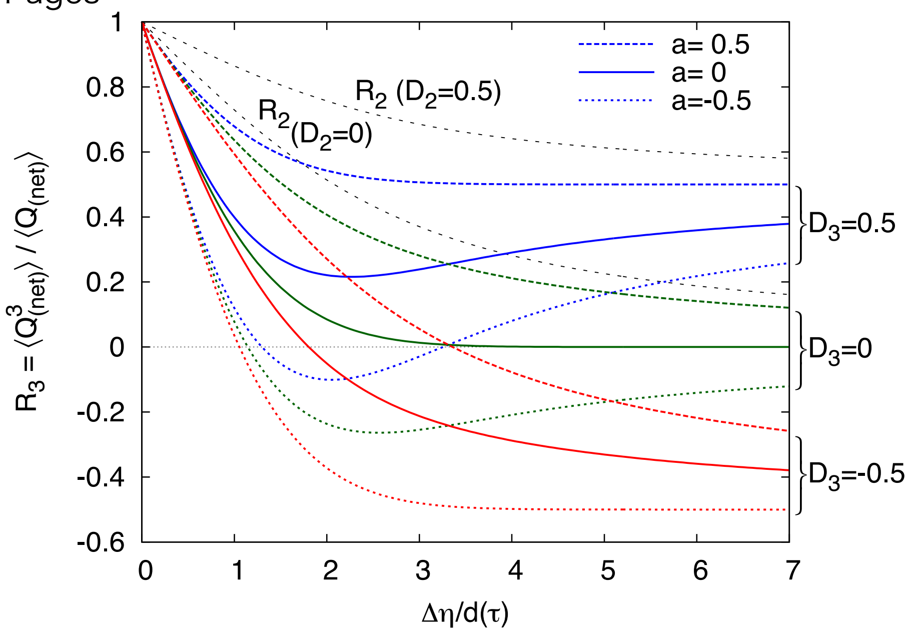
Theoretical predictions of C_3/C_1 and $C_4/\langle N_{ch} \rangle$

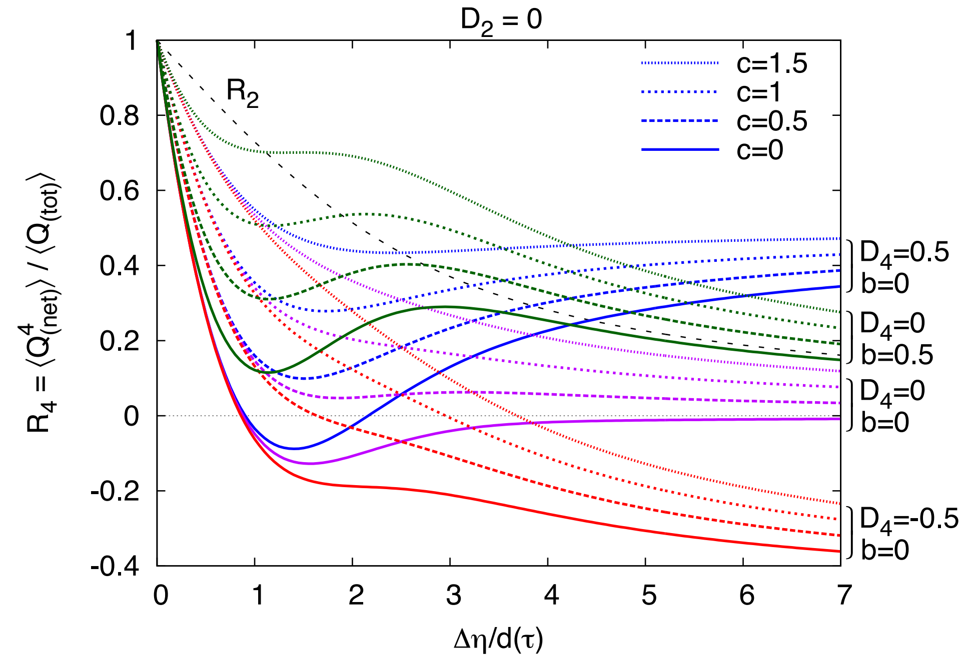
M.Asakawa, M.Kitazaw,
Progress in Particle and Nuclear Physics
Volume 90, September 2016, Pages
299-342

C_3/C_1

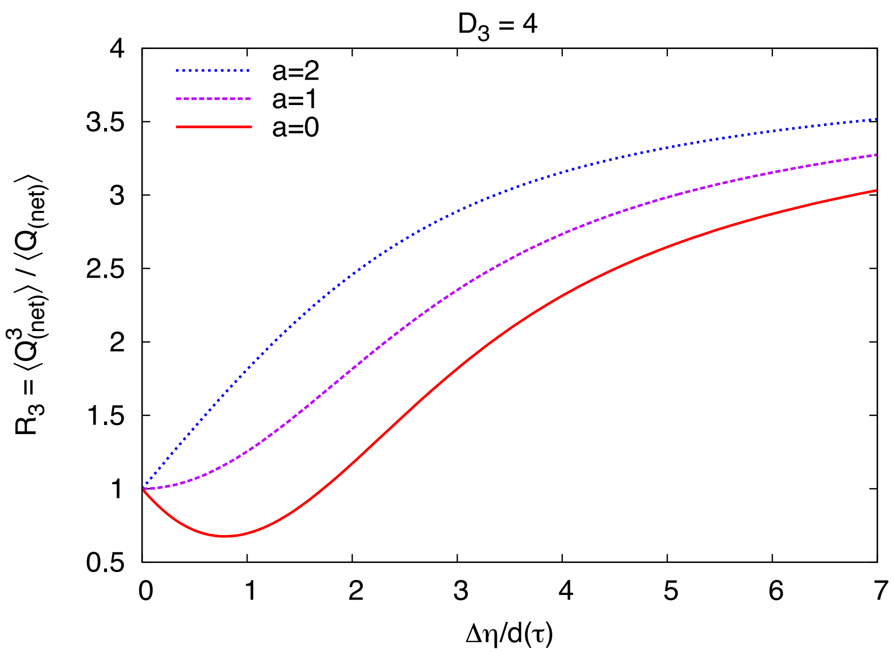
$C_4/\langle N_{cn} \rangle$

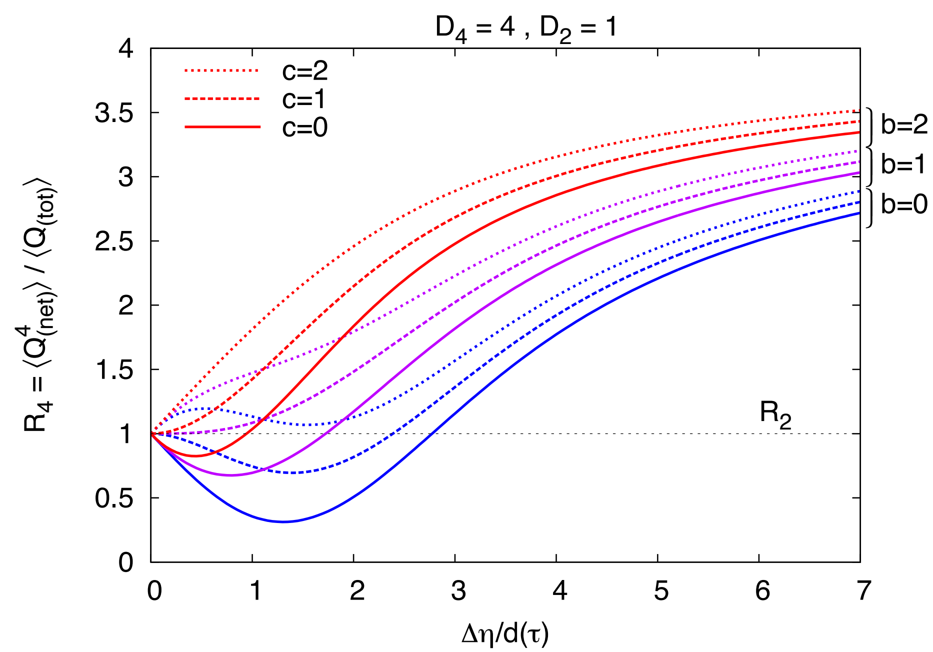
Small susceptibilities





Large susceptibilities



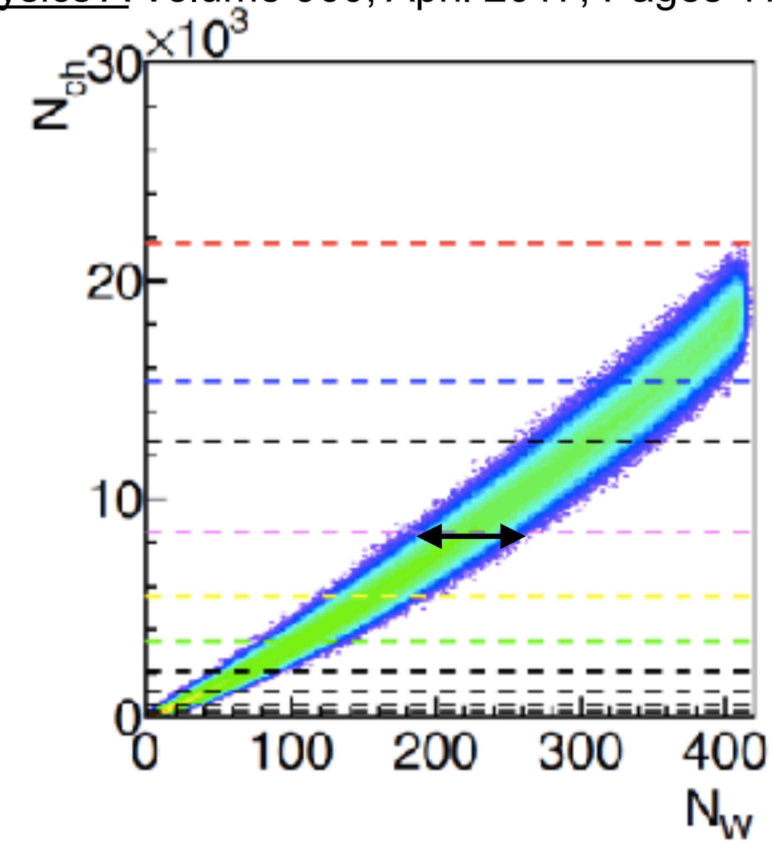


- $\Delta\eta$ dependence of **third and fourth-order cumulant ratios are also predicted** by the model but there are a lot of parameters and depend on initial condition.
- Experimental results are close to theoretical expectation with large susceptibilitiy reults.

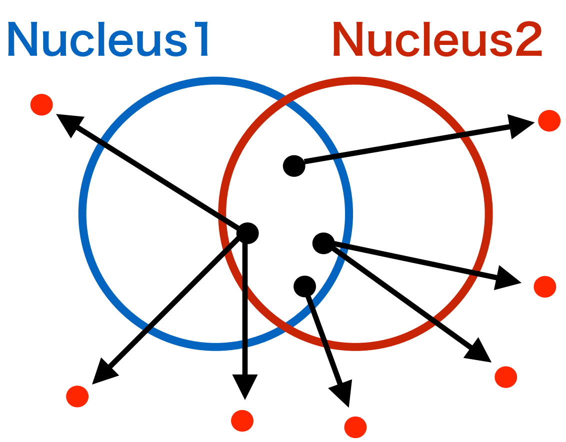
Volume fluctuation correction

Volume fluctuation correction (VFC)

Nuclear Physics A Volume 960, April 2017, Pages 114-130



- Nw is fluctuating even if final state multiplicity is fixed.
  →**CBWC may not be enough to eliminate VF**



Independent particle production (IPP) model

- ● : initial source
- ● : final state multiplicity

- Under the IPP model, measured cumulants include additional term from VF which can be written by Nw cumulants.
- We can know **true cumulants by subtracting additional terms (VFC)**

Measured cumulant   True cumulant

Δn : number of net-particle

Additional term caused from N_W fluctuation

$$\kappa_1(\Delta N) = \langle N_W\rangle \kappa_1(\Delta n)$$

$$\kappa_2(\Delta N) = \langle N_W\rangle \kappa_2(\Delta n) + \langle \Delta n\rangle^2 \kappa_2(N_W)$$

$$\kappa_3(\Delta N) = \langle N_W\rangle \kappa_3(\Delta n) + 3\langle \Delta n\rangle \kappa_2(\Delta n)\kappa_2(N_W) + \langle \Delta n\rangle^3 \kappa_3(N_W)$$

$$\kappa_4(\Delta N) = \langle N_W\rangle \kappa_4(\Delta n) + 4\langle \Delta n\rangle \kappa_3(\Delta n)\kappa_2(N_W)$$
$$+3\kappa_2^2(\Delta n)\kappa_2(N_W) + 6\langle \Delta n\rangle^2 \kappa_2(\Delta n)\kappa_3(N_W) + \langle \Delta n\rangle^4 \kappa_4(N_W)$$

Toy model method

- Generate 2 independent Poisson distribution
- Parameter : λ_+, λ_-

Glauber : 500M events
Poisson : 100M events

$$\lambda_+ * \langle N_W \rangle = N_+$$
$$\lambda_- * \langle N_W \rangle = N_-$$
$$(\lambda_+ - \lambda_-) * \langle N_W \rangle = (N_+ - N_-)$$

Nw Calculated from Glauber

Number of particles

- λ_+ and λ_- are determined to N_+ and N_- describe the real experiment.

Nw fixed : Generate Poisson <Nw> times.
…No Nw fluctuation

Nw fluc : Generate Poisson Nw times.
…Nw fluctuation

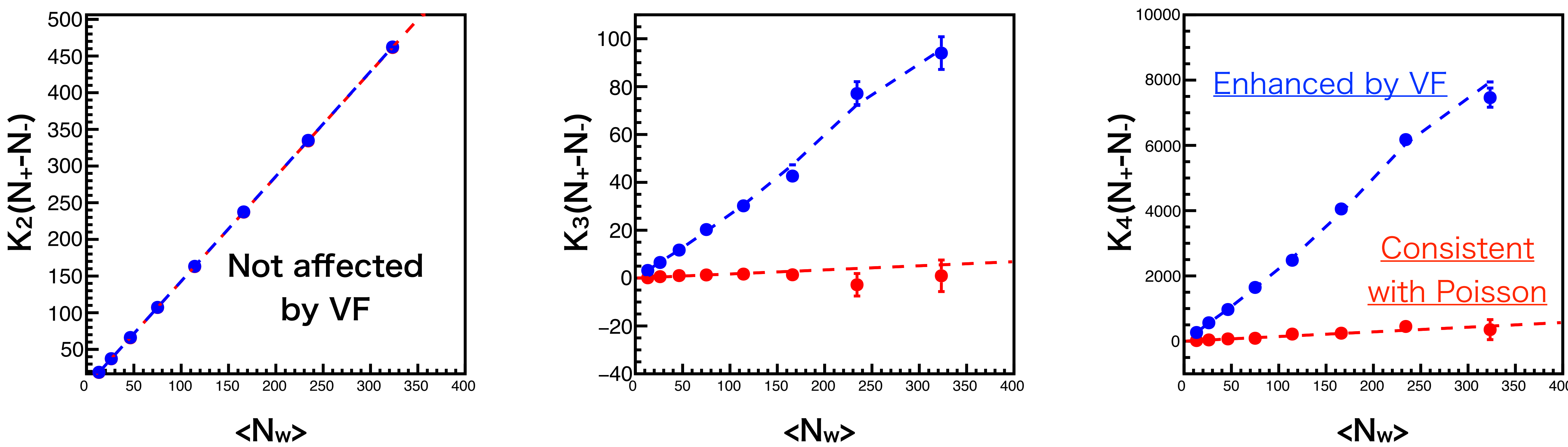
VFC : Subtract Nw fluctuation

- **Nw fixed** and **VFC** results should be same.
- Results from CBWC are also compared.

Should be same

- Nw fixed
- Poisson
- Nw fluc **VF(large)**
- Nw fluc Exp
- VFC
- CBWC+Nw fluc **VF(small)**

Toy model VFC check (10%step)

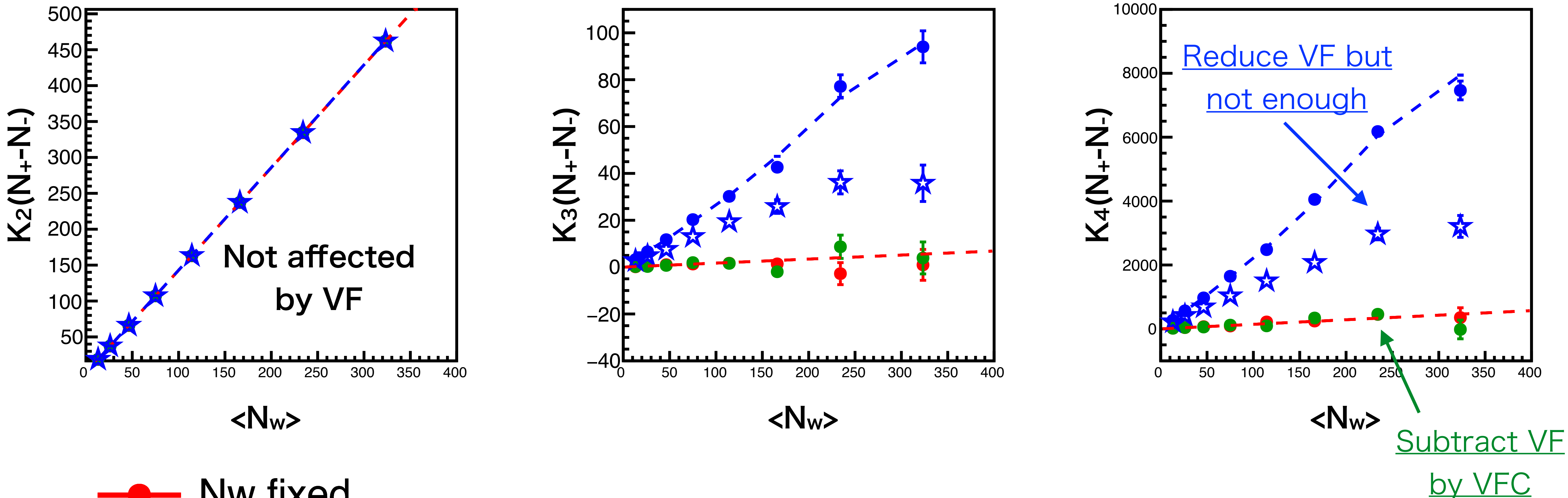


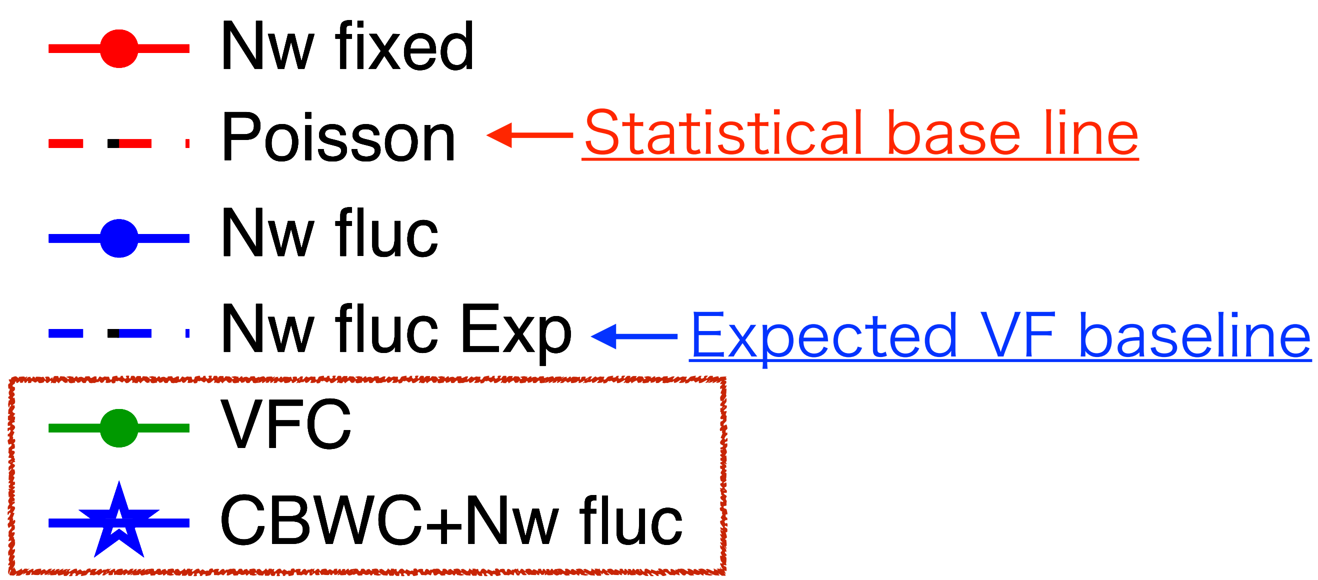
- Nw fixed
- Poisson ← Statistical base line
- Nw fluc
- Nw fluc Exp ← Expected VF baseline

Glauber : 500M
Poisson : 100M
bootstrap=100

- K_2 does not largely affected by participant fluctuation.
- Nw fixed cumulants are consistent with Poisson baseline.
- Nw fluc cumulants are enhanced by VF.

Toy model VFC check (10%step)





Glauber : 500M
Poisson : 100M
bootstrap=100

- VFC works well up to 4-th order cumulants.
- CBWC can reduce VF but not enough.

UrQMD model

- **VFC will be done by using UrQMD** model in which **IPP model might be broken**.
- In this model, **we can directly know N_w without Glauber fit**.

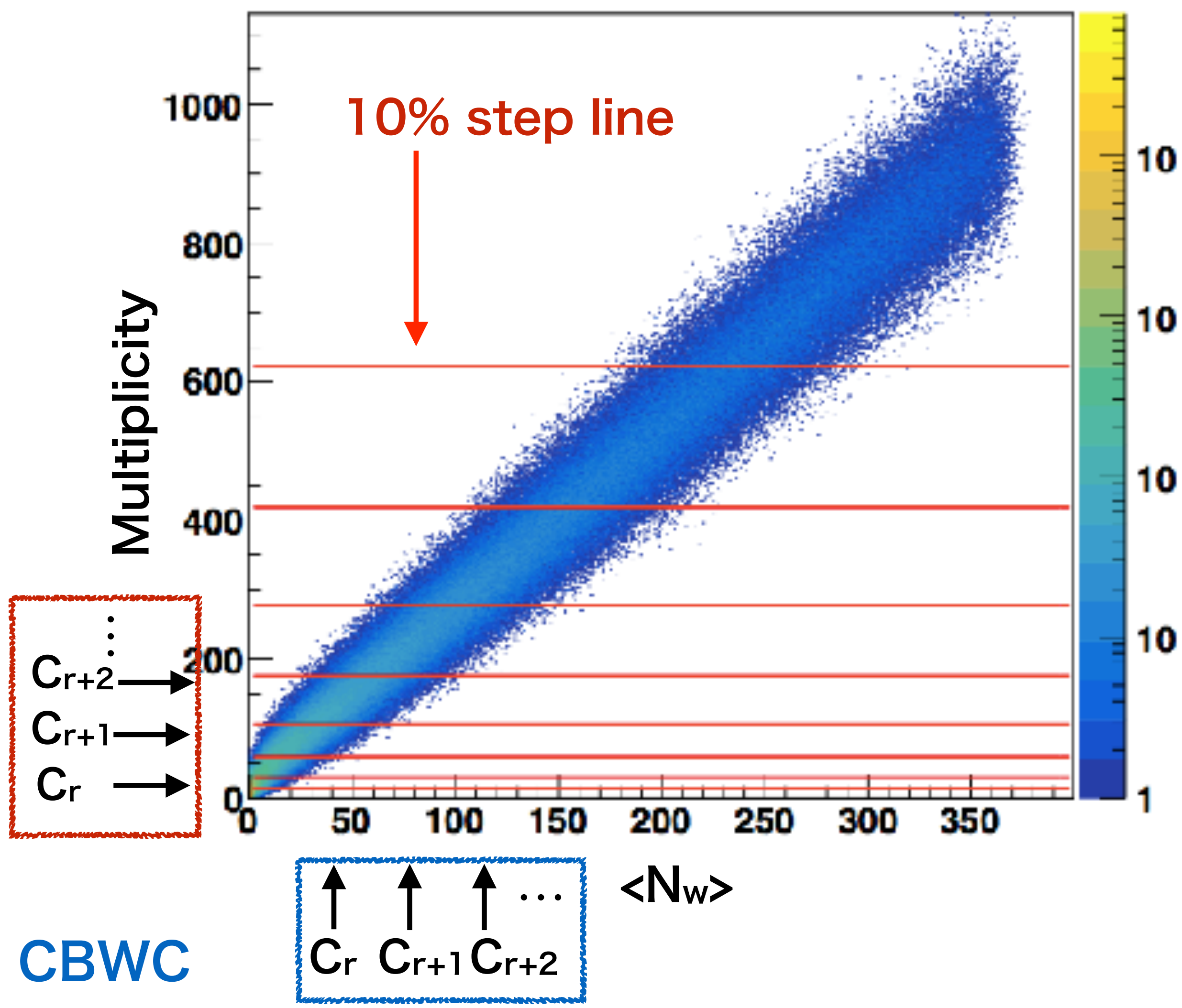
How to know "true" cumulants?

- In order to compare to CBWC and VFC results, we want to know "true" (no VF) cumulants.
- "True" cumulants can be calculated by CBWC using **N_w instead of multiplicities.**

$$C_n = \sum_{r} w_r C_{(n,r)}$$

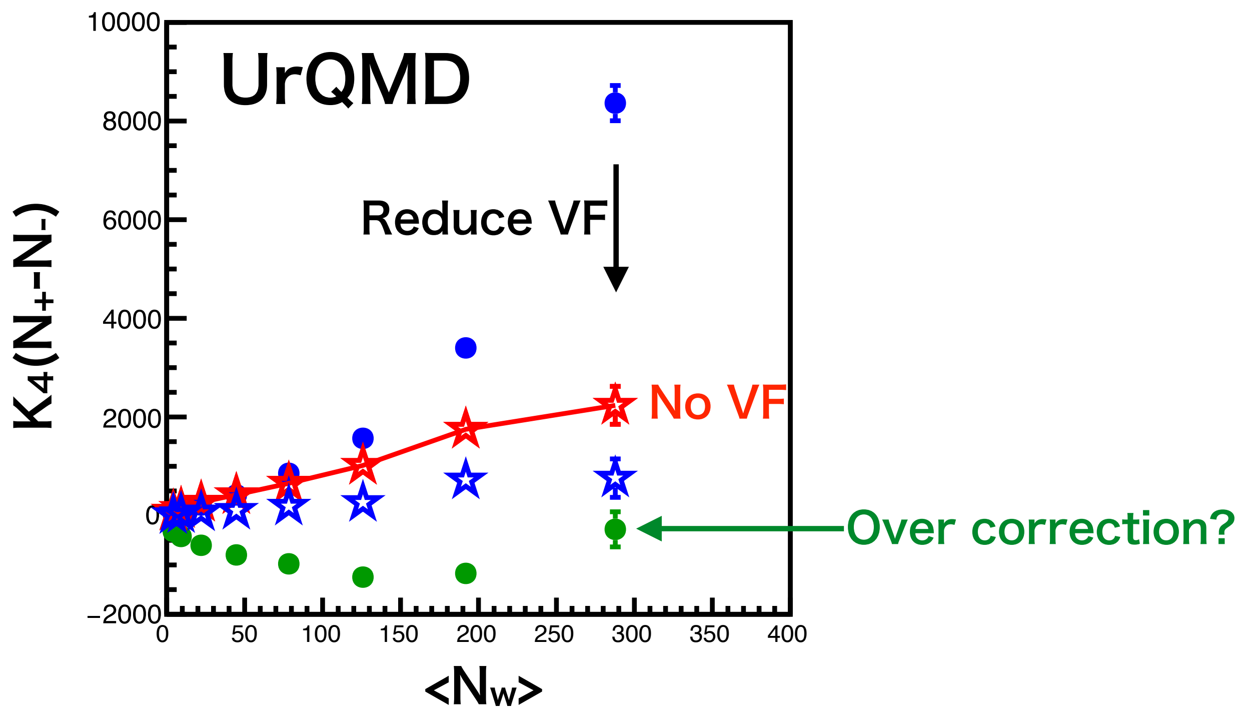
Cumulants in r-th Nw bins

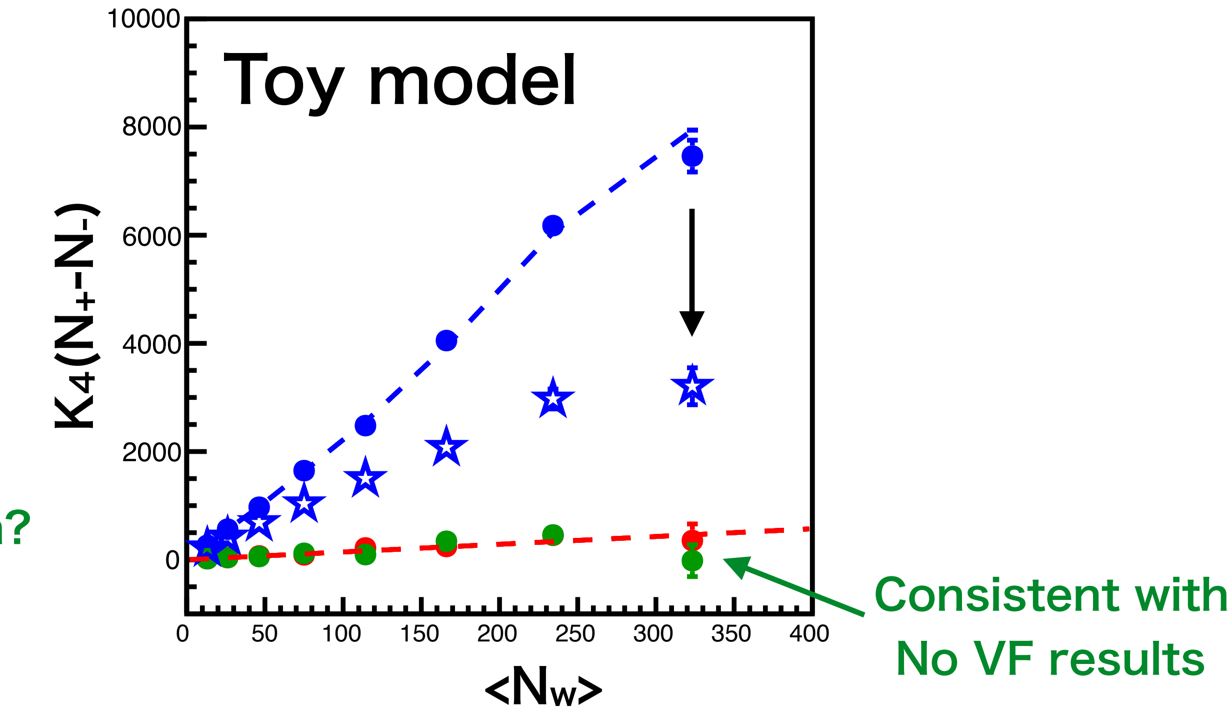
Standatd CBWC



CBWC by Nw (no VF)

UrQMD results

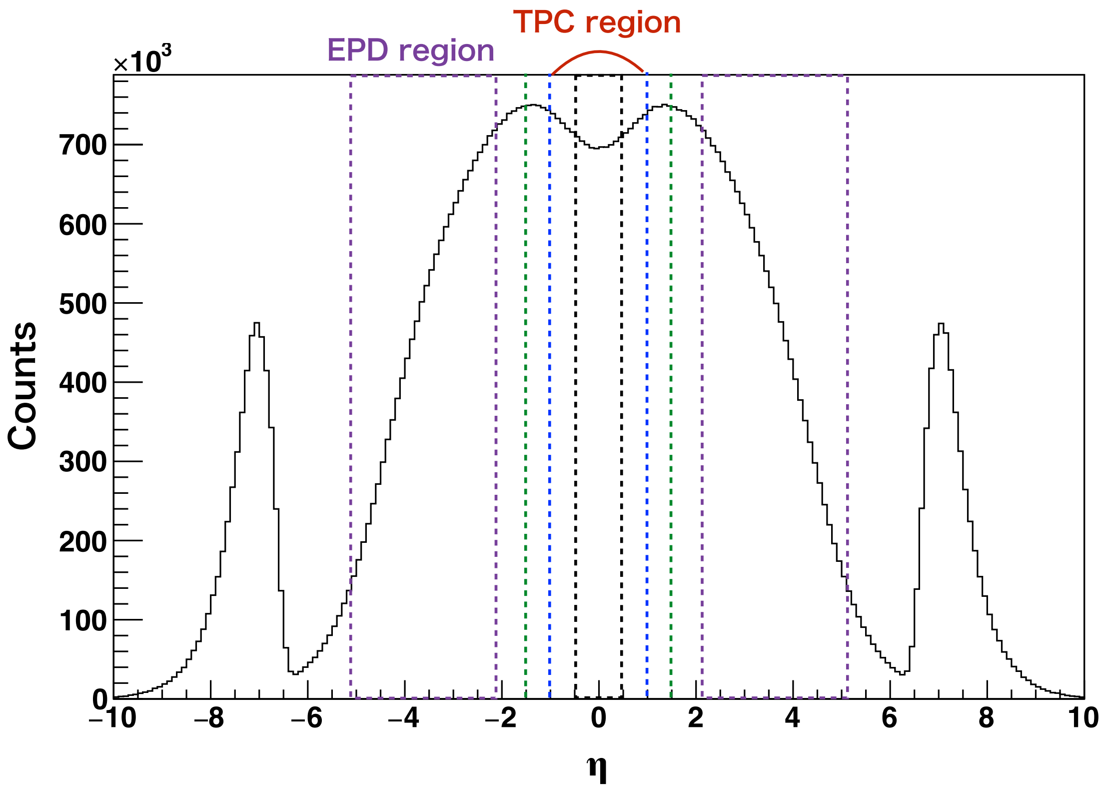




- Raw : No correction
- VFC : VFC was applied
- CBWC-Nw (no VF) : CBWC by Nw (true)
- CBWC : CBWC by multiplicity (experimental CBWC)

- CBWC-Nw (no VF, true) cumulants are larger than CBWC results even though CBWC results include VF.
  - IPP assumption is expected to be broken in UrQMD.
- CBWC results are larger than VFC results and close to CBWC-Nw cumulants.
  - CBWC is better than VFC?

Auto-correlation in UrQMD

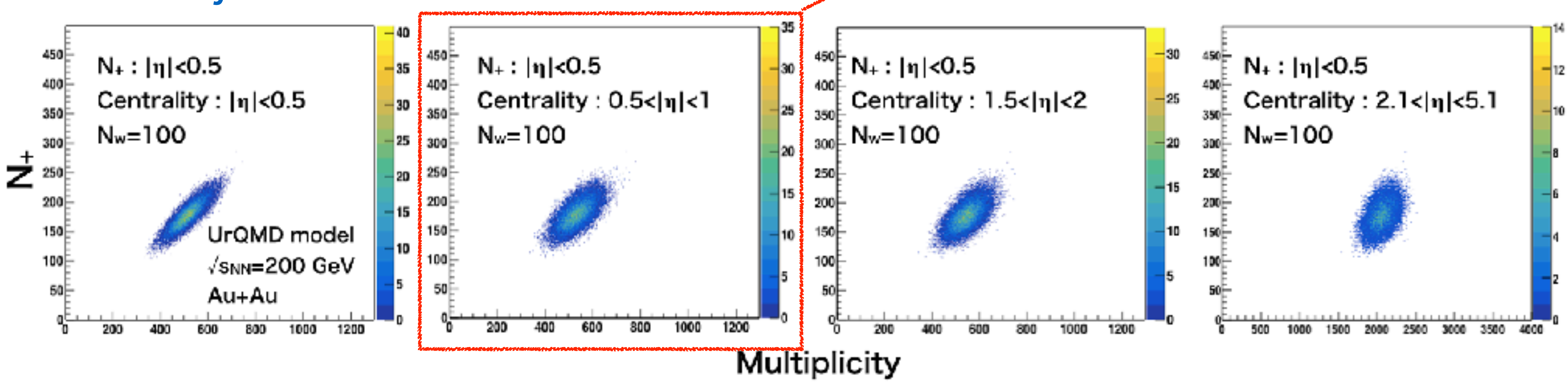


- In Toy model, particles used for centrality determination and particles used for the net-charge calculation are produced independently.
- On the other hand, cumulants in UrQMD may include auto-correlation effect.

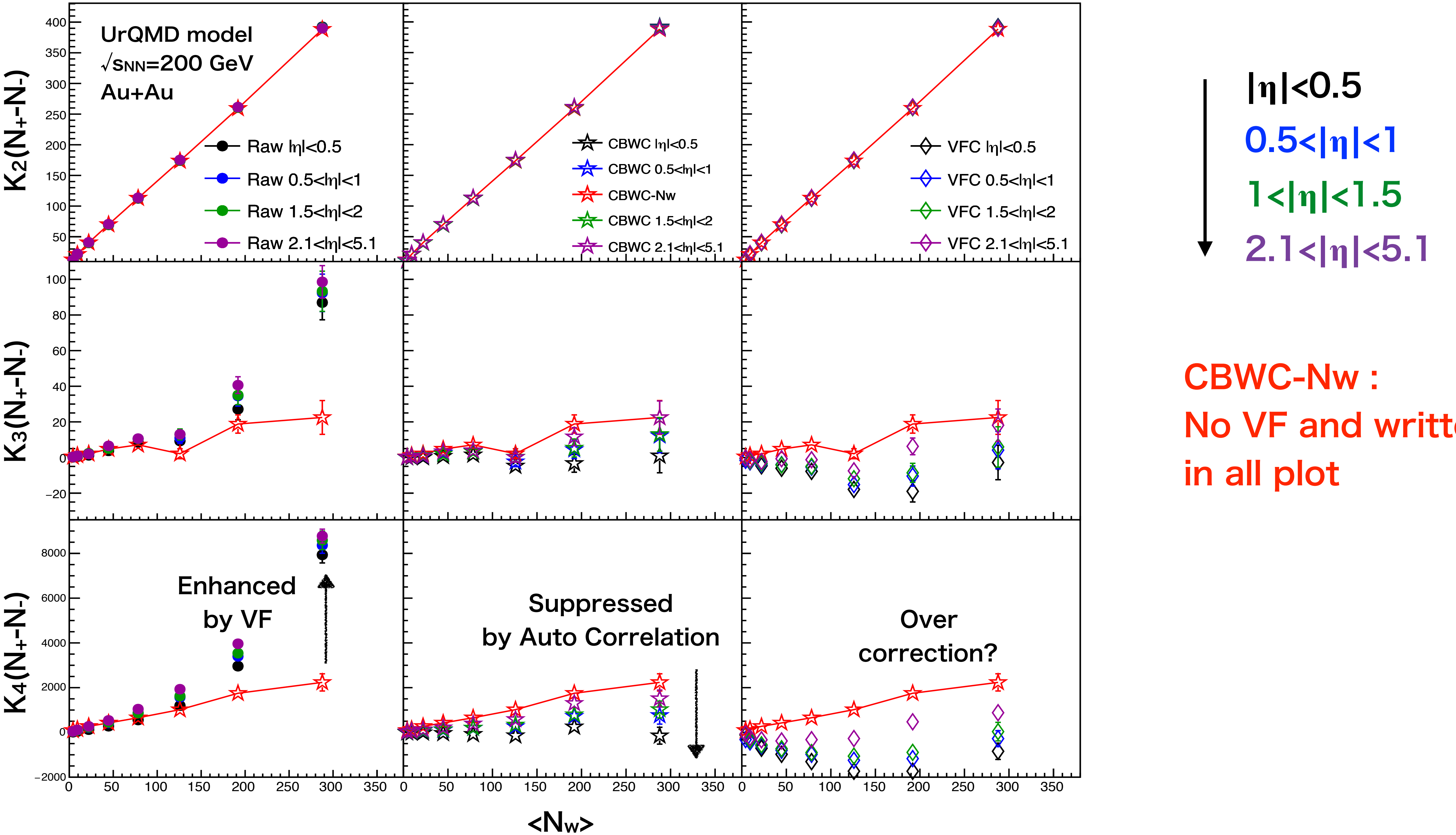
① |η|<0.5 (Refmult)
② 0.5<|η|<1 (Refmult2)
- experimentally used for net-c analysis

③ 1<|η|<1.5
④ 2.1<|η|<5.1 (EPD region)
- centrality determination from BES II

<u>Correlation remain even though different eta regions were used for centrality determination and particles net-charge calculations</u>



UrQMD with different centrality determination



CBWC-Nw : No VF and written in all plot

- Suppressions are observed because of autocorrelation
  - Largest in |η|<0.5 and smallest in EPD region (2.1<|η|<5.1)
- VF are observed in raw results but not observed in CBWC results
  - NOT consistent with Toy model. IPP is broken?
- If CBWC-Nw results are "true", VFC results are over correction

Summary

C_6 net-charge analysis

- Net-charge cumulants **up to 6th-orde**r at $\sqrt{s_{NN}}$**=200 GeV and 54 GeV** in Au+Au collisions were reported.
- C_6/C_2 were compared to Poisson, NBD, UrQMD and net-proton results.
- **Deviation** are ovserved between **200 GeV and 54 GeV** in **0-40%** centrality at **net-proton** and **40-50%** at **net-charge**.
  - These results are **not conflict with the theoretical prediction** of cross-over
  transition but **statistical errors are large**.
  - Results of the other centralities are consistent with statistical baseline within the statistical error.
- **C_3/C_2** and **C_4/C_2** of **net-charge** at $\sqrt{s_{NN}}$**=54 GeV** are newly measured in addition to BES energies and results were **not conflict with publisehd BES-I results**.

Summary

Δη dependence analysis

- **Δη dependence of net-charge cumulants and D-measure** were measured in Au+Au collisions at **$\sqrt{s_{NN}}$=7.7, 11.5, 14.5, 19.6, 27, 39, 62.4 and 200 GeV**.
- D-measure **decreace with Δη** and this trend is **stronger with collision energies**.

  - These results **do not conflict with ALICE** and the trends of Δη dependence **might represent the time evolution of phase transition**.
- $C_4/\langle N_{ch}\rangle$ and $C_3/\langle N_{ch}\rangle$ are observed to increase with Δη in most of centralities which may be the hint of the signal from phase transition.

Summary

VFC

- It is important to eliminate VF in fluctuation analysis.
- **Even though CBWC has applied, we can't completely remove participant fluctuation under the IPP models**.
- However, **VFC does not works well in UrQMD model so IPP model is expected to be broken** in UrQMD.
- Auto-correlation effect is also important and may remain this effect in current centrality determination of net-charge analysis.
- More detail studies for VFC are needed to apply VFC to real experiment.

Ouklook

- BES-II will start from 2019
  - High statistics at lower energy region
  - Access more forward rapidity with new detector (iTPC, eTOF and EPD).
- Sixth-order cumulants can be measured at lower energy region and can be compare to the results at 200 GeV and 54GeV.
- $\Delta\eta$ dependence can be measured from 0 to 1.5 by iTPC and eTOF ($0<\Delta\eta<1$ in currect analysis).
- Auto-correlation effect may become smaller if centrality is determined by EPD and cumulants may become smaller in future analysis.
- It is important to study whether we should apply VFC to experimental results or not for future analysis.

back up

Statistical errors of cumulants

Generally…

✓ Statistical error of **net-charge cumulant** is larger than **net-proton cumulants**

✓ Statistical error of cumulant **in central** is larger than cumualnt in **peripheral**

Why?

Cumulants depend on the width of the distribution ($\boldsymbol{\sigma}$).

For example

Mean value : $\mathbf{C_1 \pm \sigma/\sqrt{N}}$ → Standard Error

- Statistical error of C_1 is proportional to σ.
- Statistical error of nth-order cumulant is written by

$$\mathbf{Err(C_n) \sim \sigma^n/\sqrt{N}}$$

Rough estimation of statistical errors

Efficiency Uncorrected

$$\mathrm{Err}\left(\frac{C_3}{C_2}\right) \propto \frac{\sigma}{\sqrt{n}}$$

$$\mathrm{Err}\left(\frac{C_4}{C_2}\right) \propto \frac{\sigma^2}{\sqrt{n}}$$

$$\mathrm{Err}\left(\frac{C_6}{C_2}\right) \propto \frac{\sigma^4}{\sqrt{n}}$$

Efficiency Corrected

$$\mathrm{Err}\left(\frac{C_3}{C_2}\right) \propto \frac{\sigma}{\epsilon\sqrt{n}}$$

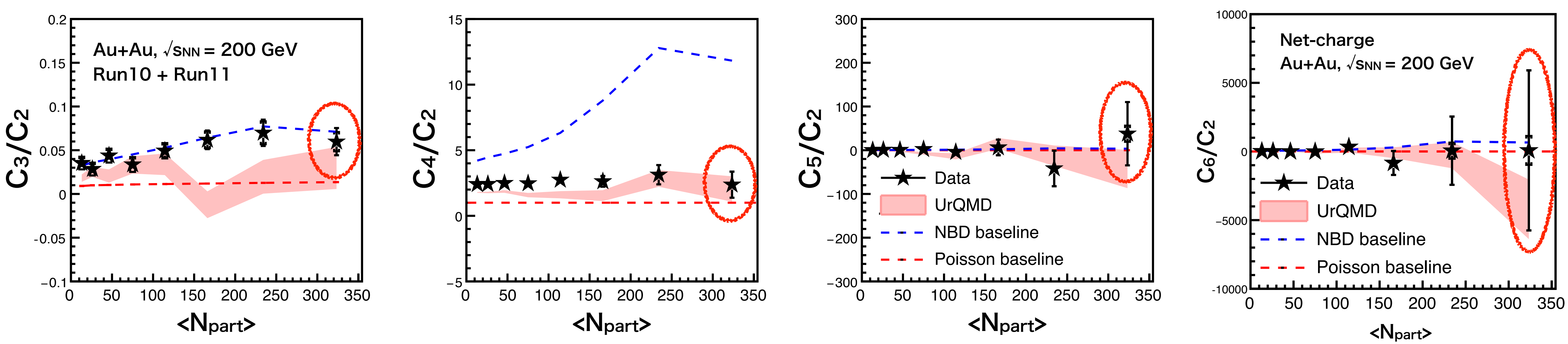
$$\mathrm{Err}\left(\frac{C_4}{C_2}\right) \propto \frac{\sigma^2}{\epsilon^2\sqrt{n}}$$

$$\mathrm{Err}\left(\frac{C_6}{C_2}\right) \propto \frac{\sigma^4}{\epsilon^4\sqrt{n}}$$

For example: σ^2=350, ε =0.4~0.5
(0-10%, 200GeV, Eff corr)

σ / ε =40~100

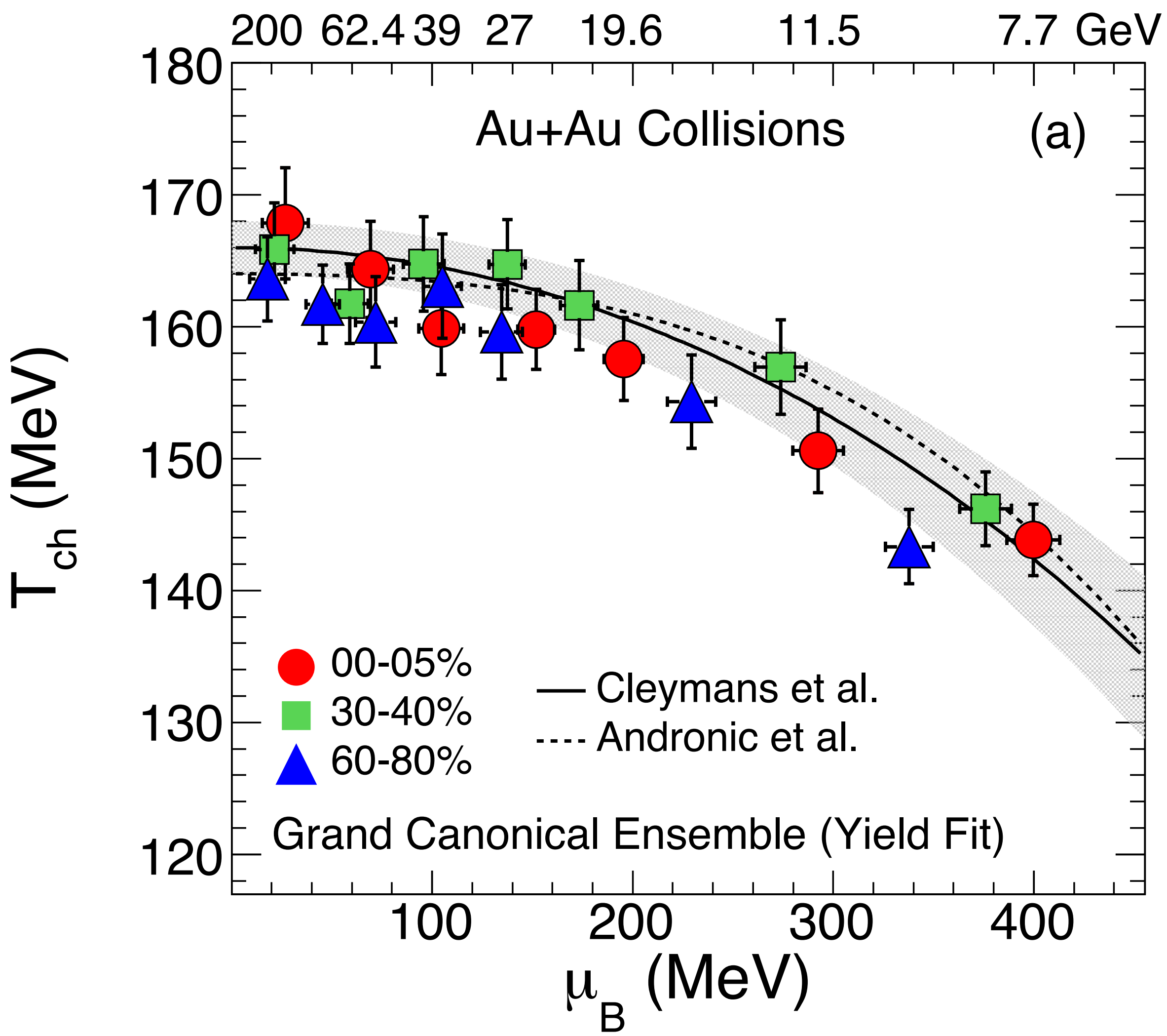
- Error of C_6/C_2 is more than 1000 time large than that of C_4/C_2.

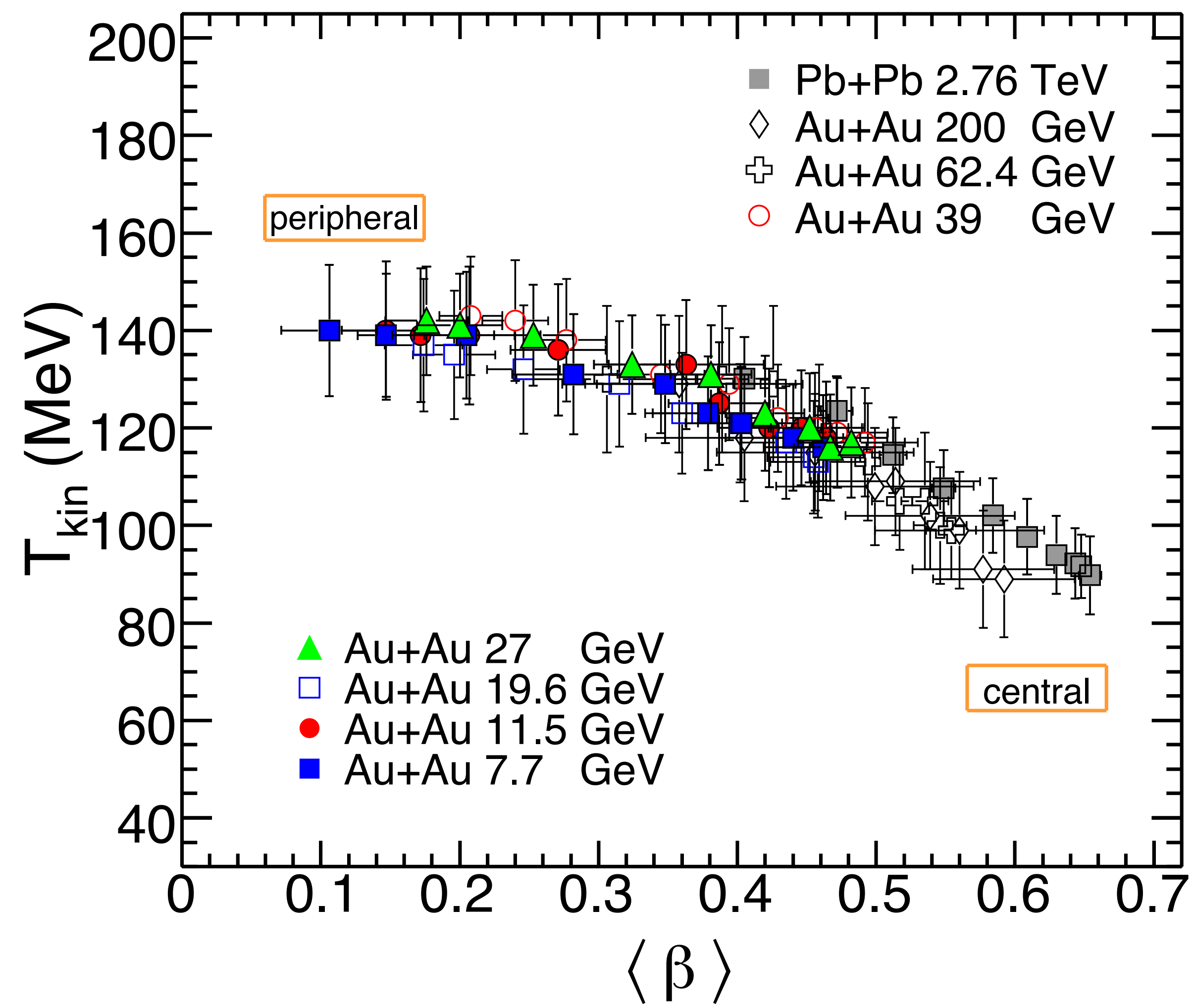


	C3/C2	C4/C2	C5/C2	C6/C2
St.Err	~0.014	~1	~70	~5600

*σ / ε *σ / ε *σ / ε

Freeze-out parameters



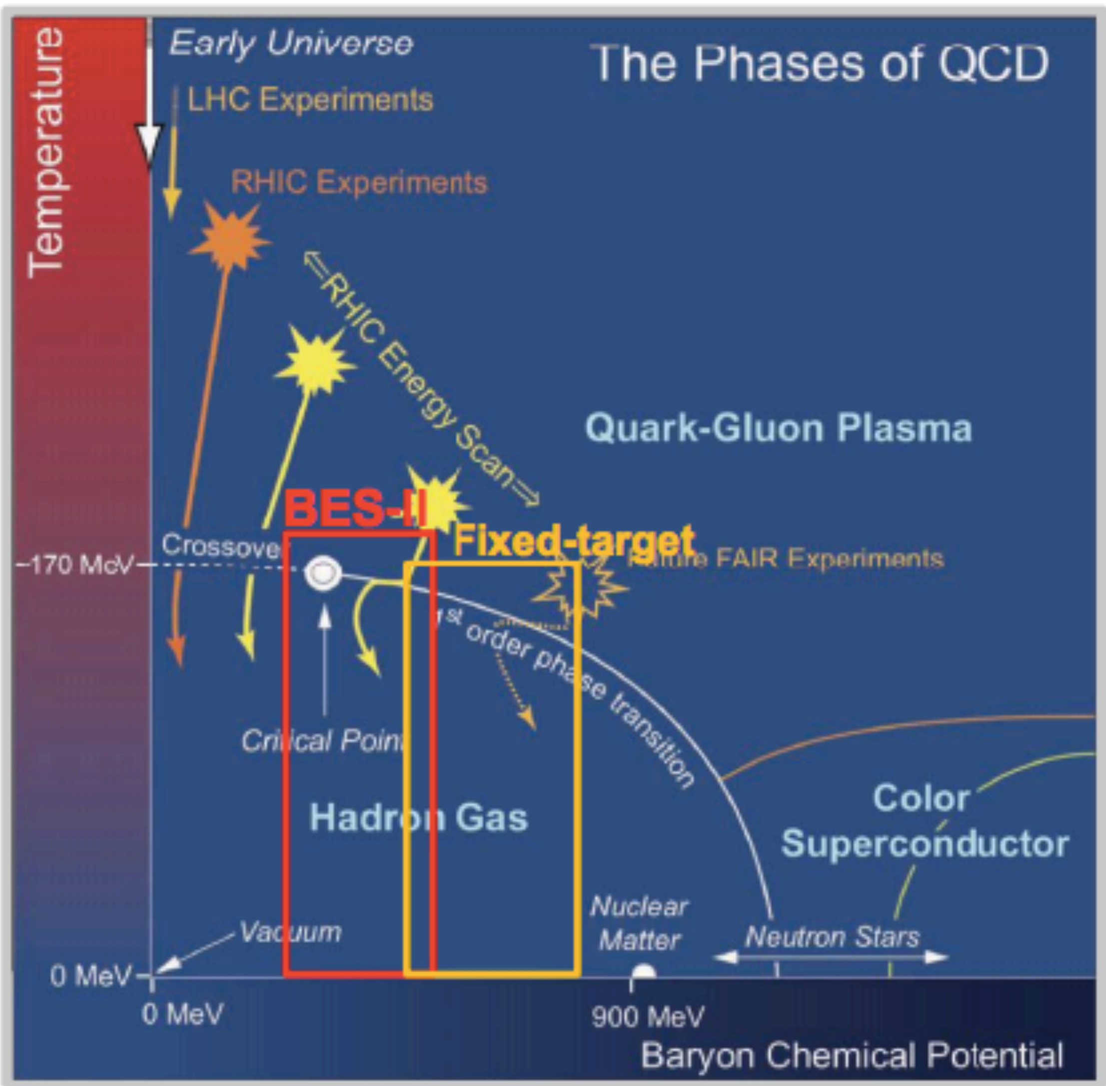


- Chemical and kinetic freeze-out and parameters are obtained from particles yield and spectra.

What is the good observables which is sensitive to the phase transition?

→ Event by event fluctuations are considered as one of the powerful tool to discover the phase diagram.

Beam Energy Scan Phase II (BES- II)



STAR, Q.Yang (talk)

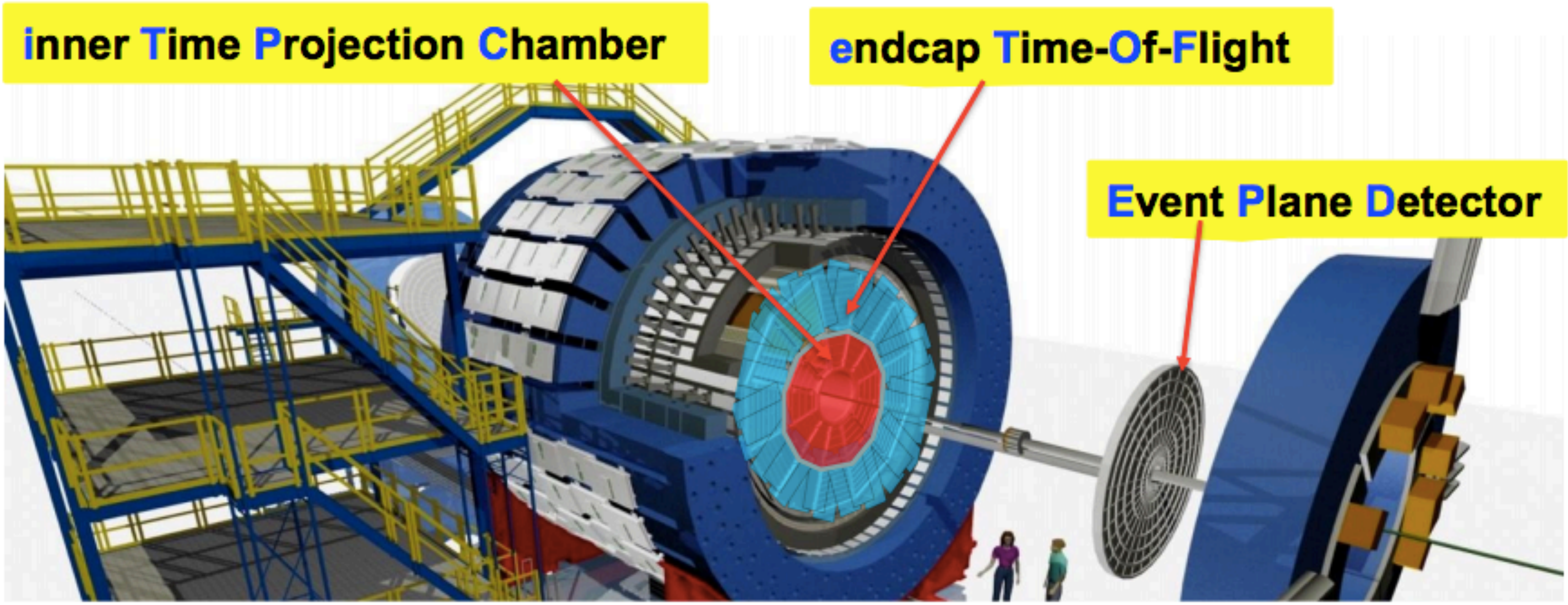
$\sqrt{S_{NN}}$ (GeV)	Proposed Event Goals (M)	BES-I Event (M)
7.7	100	4
9.1	160	N/A
11.5	230	12
14.5	300	20
19.6	400	36
3.0 - 7.7	~100 per energy	N/A

Collider mode

Fixed-target mode

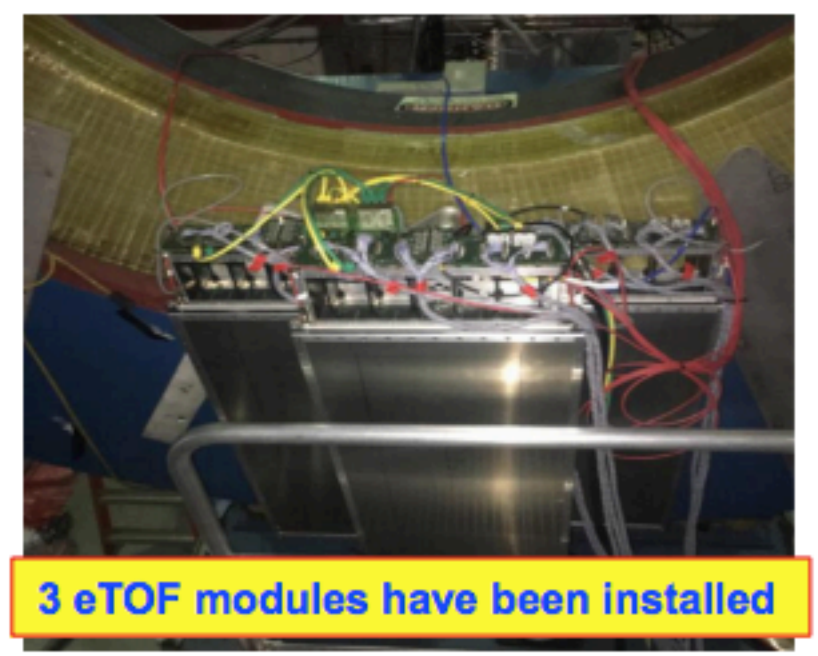
- RHIC BES II :10-25 times more statistics and detector upgrade
  →**Dramatically reduce the uncertainties.**
- Precise map the QCD phase diagram 200<μ_B<720 MeV

Detector upgrades




One iTPC sector has been installed


Full EPD has been installed


3 eTOF modules have been installed

Q.Yang (STAR collaboration) QM2018

Value of D-measure

D-measure (D)

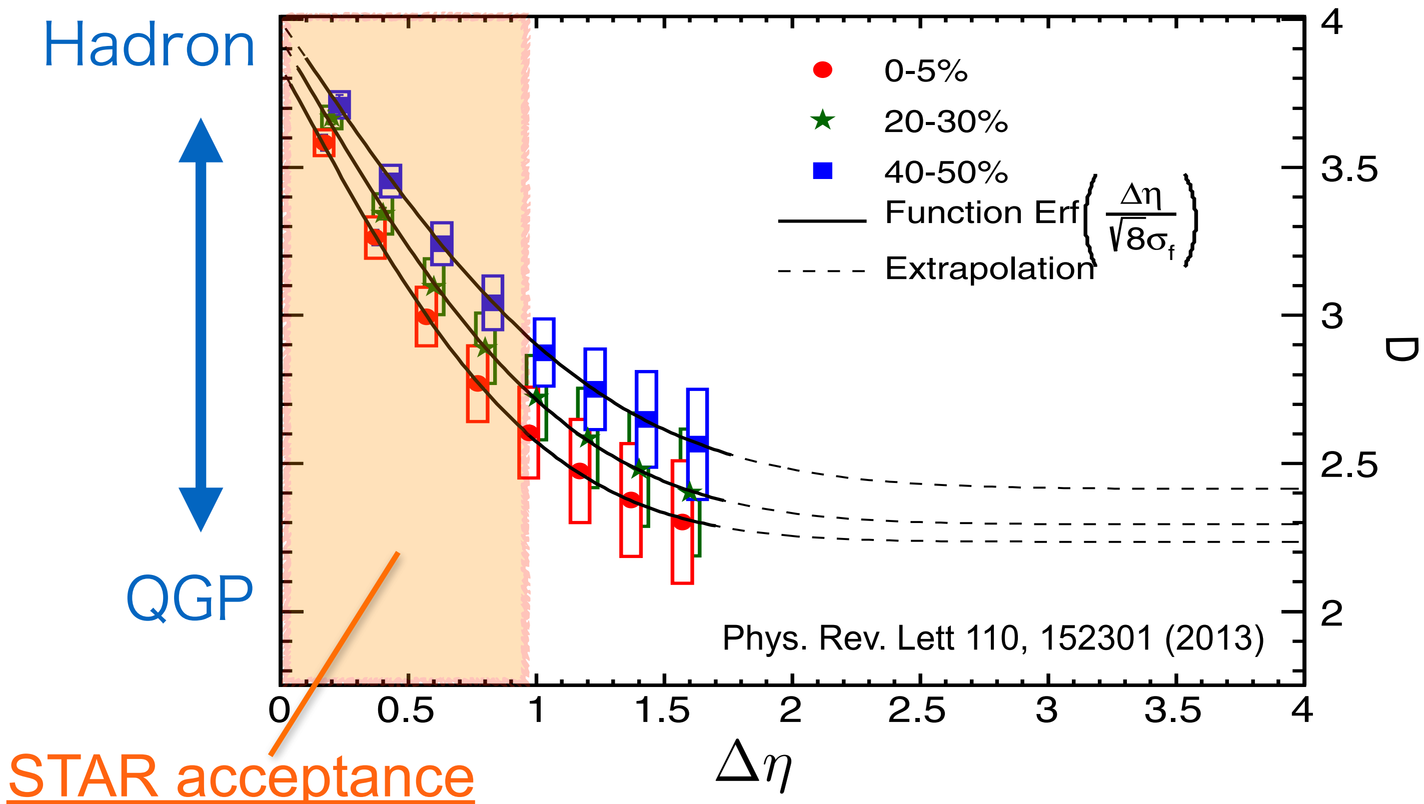
$$D = 4\frac{C_2}{\langle N_{ch} \rangle} \qquad N_{ch} = N^+ + N^-$$

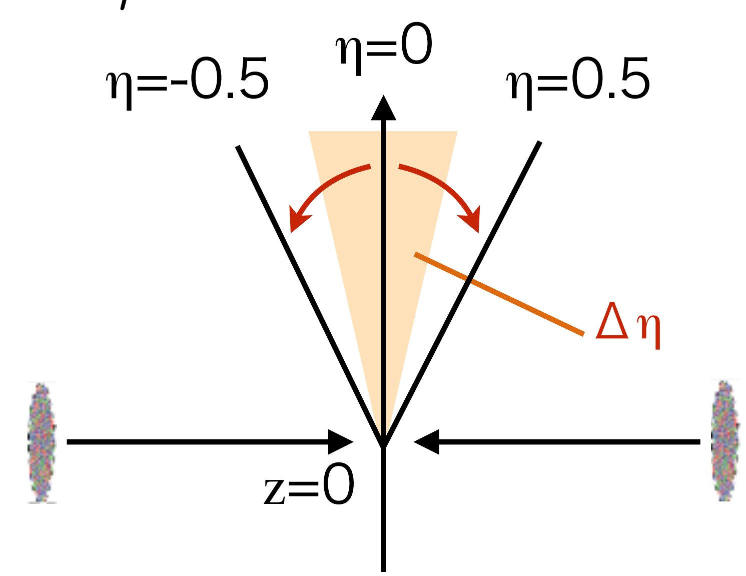
Theoretical predictions

QGP fluctuation : D =1-1.5

Hadron fluctuation : D= 3-4

ALICE (2.76TeV Pb+Pb)

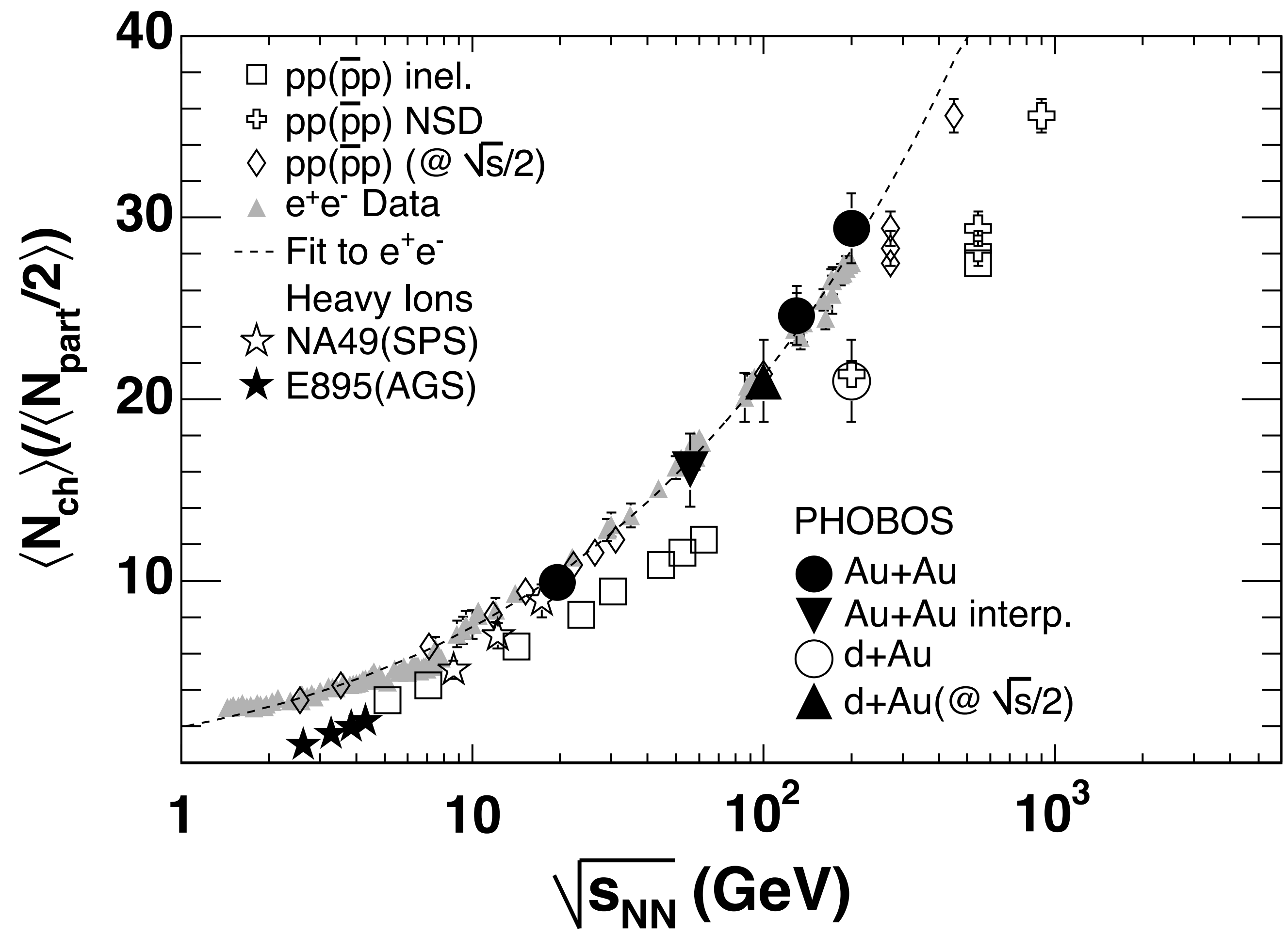




- **D-measure is ovserved to decreace with expanding Δη i**n Pb-Pb collisions at 2.76 TeV at ALICE.
- D-measure also decreace from peripheral to central collisions.

Charge conservation correction on D

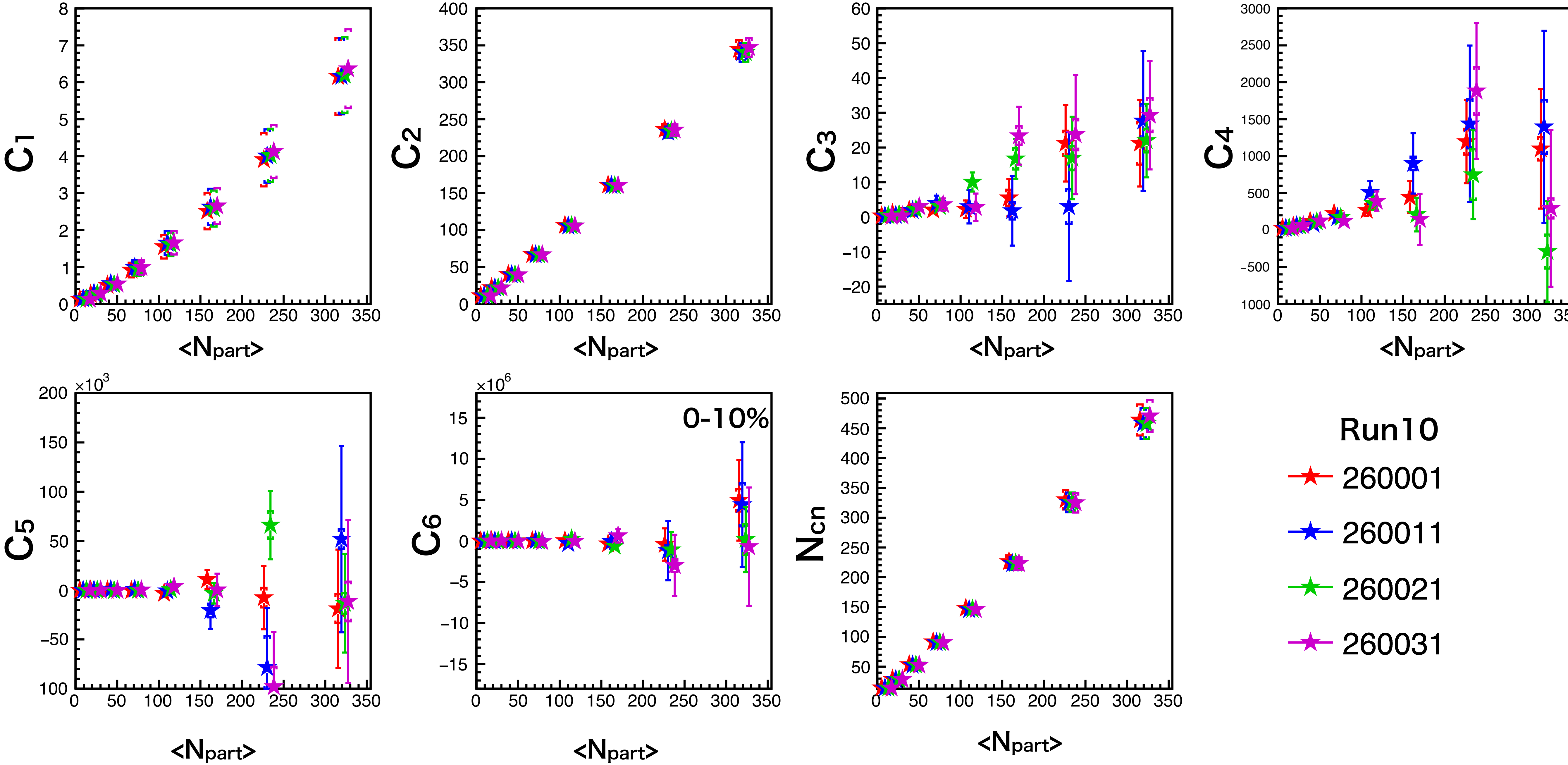
B. B. Back et al. (PHOBOS Collaboration),
Nuclear Physics A Volume 757, Issues 1–2, 8 August 2005, Pages 28-101



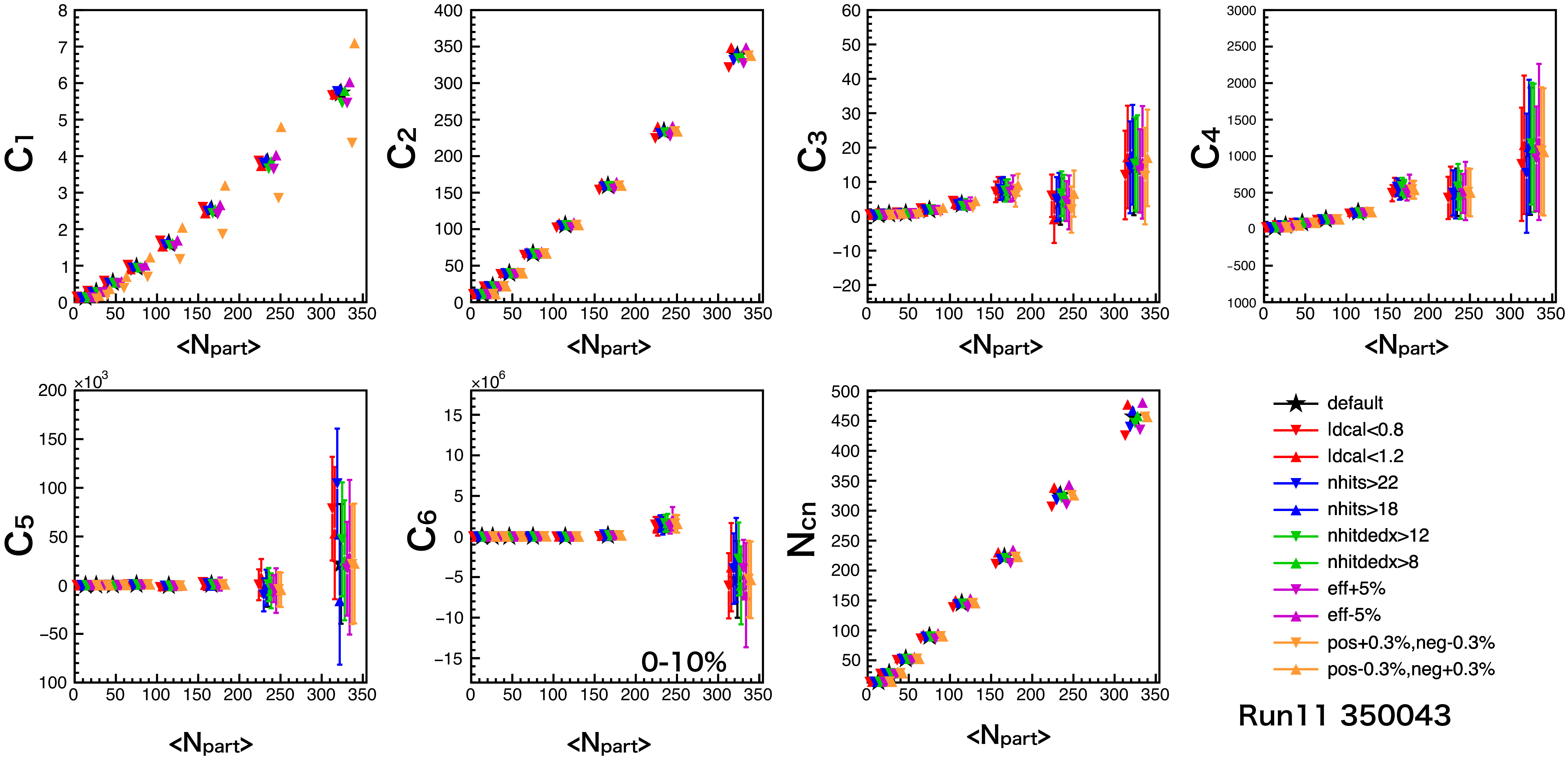
- N_{total} is total multiplicity in full acceptance and estimated from PHOBOS experiment.

back up
(Experimental results)

Cumulants (Run10, trigger by trigger)

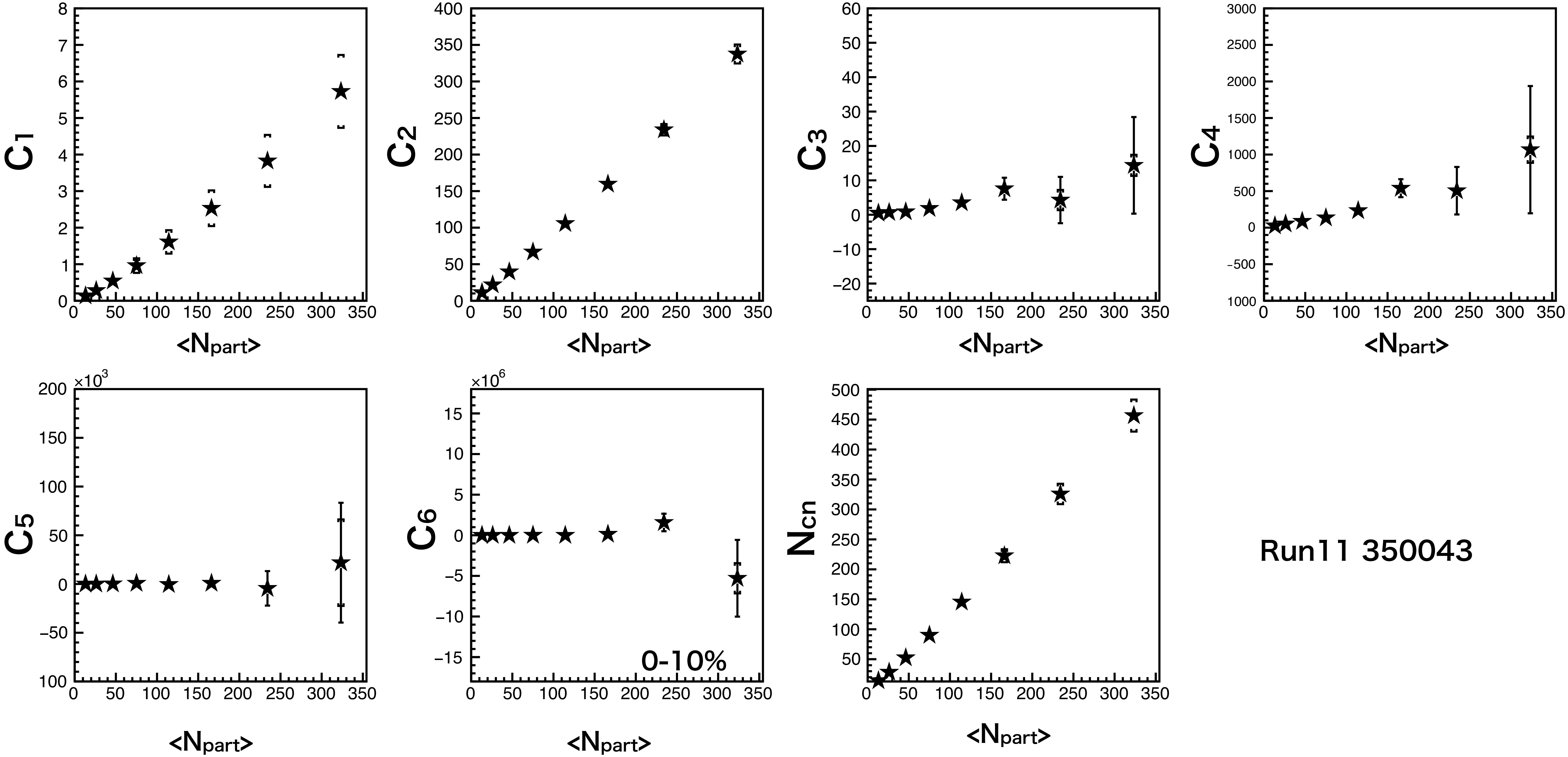


Cumulants (Run11, 350043)

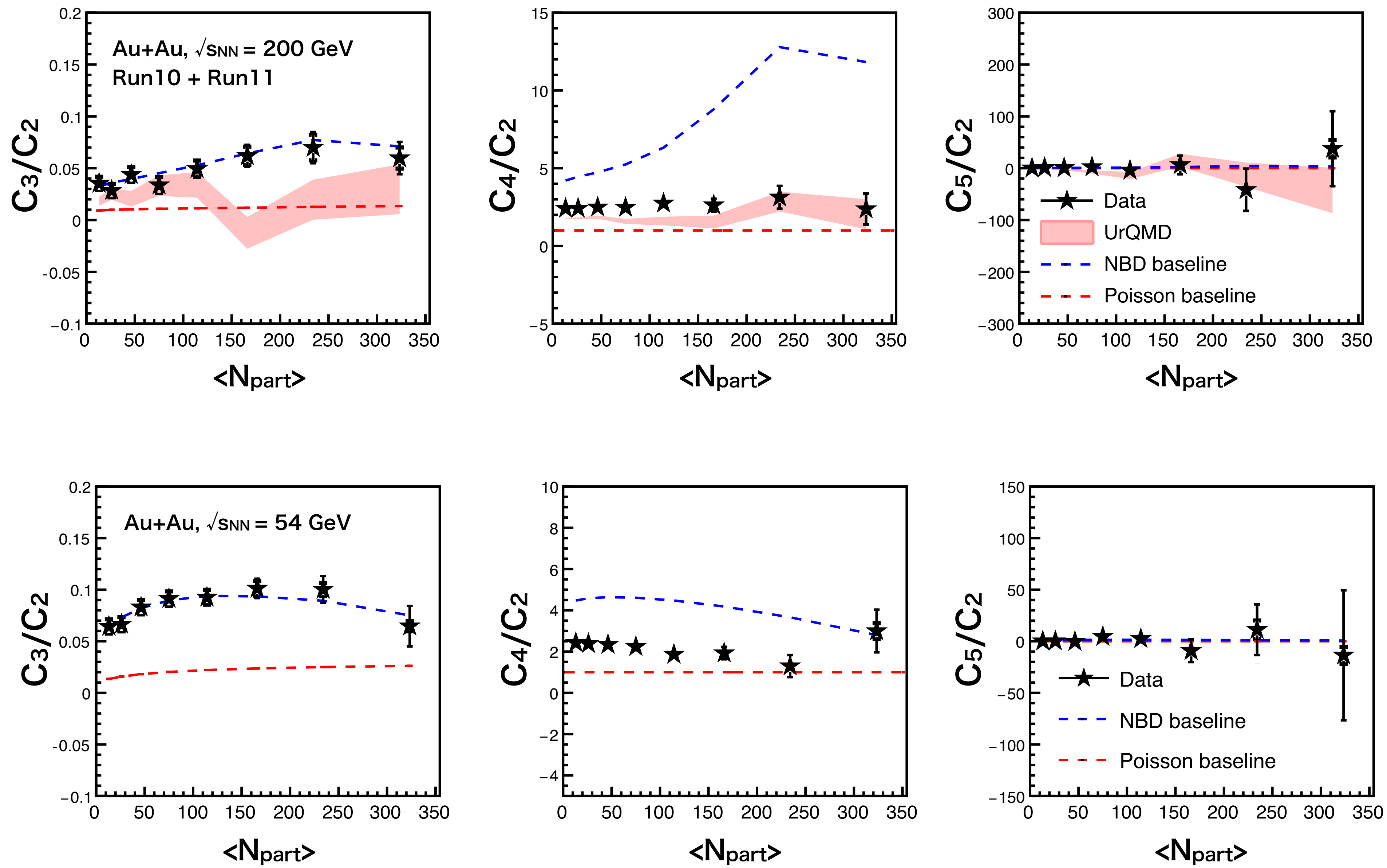


- (Effpos*1.003, Effneg*0.997) and (Effpos*0.997, Effneg*1.003) were calculated to estimate systematic uncertainty of the deviation between positively and negatively charged particle efficiency.

Cumulants (Run11, 350043)

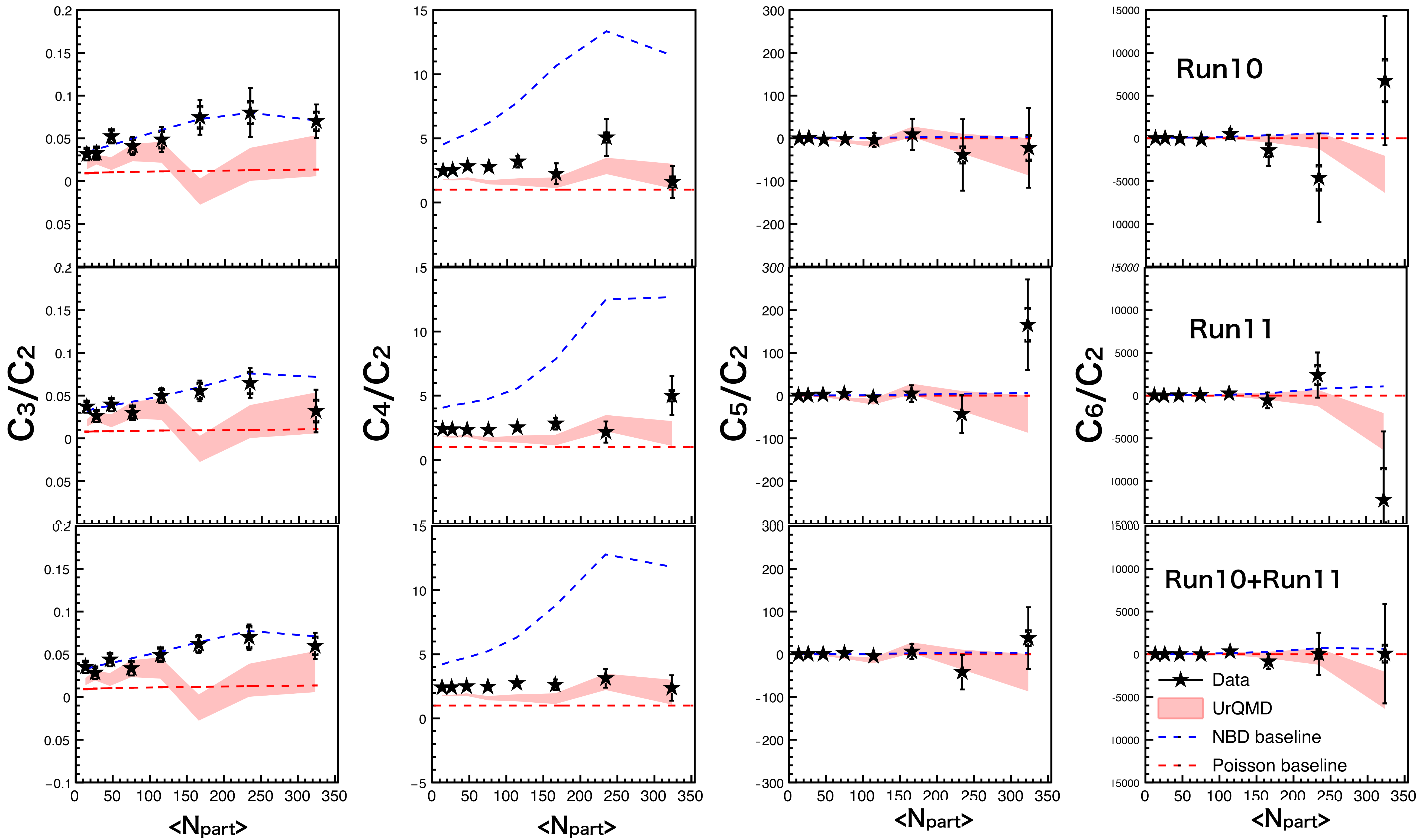


- (Effpos*1.003, Effneg*0.997) and (Effpos*0.997, Effneg*1.003) were calculated to
  estimate systematic uncertainty of the deviation between positively and negatively charged particle efficiency.

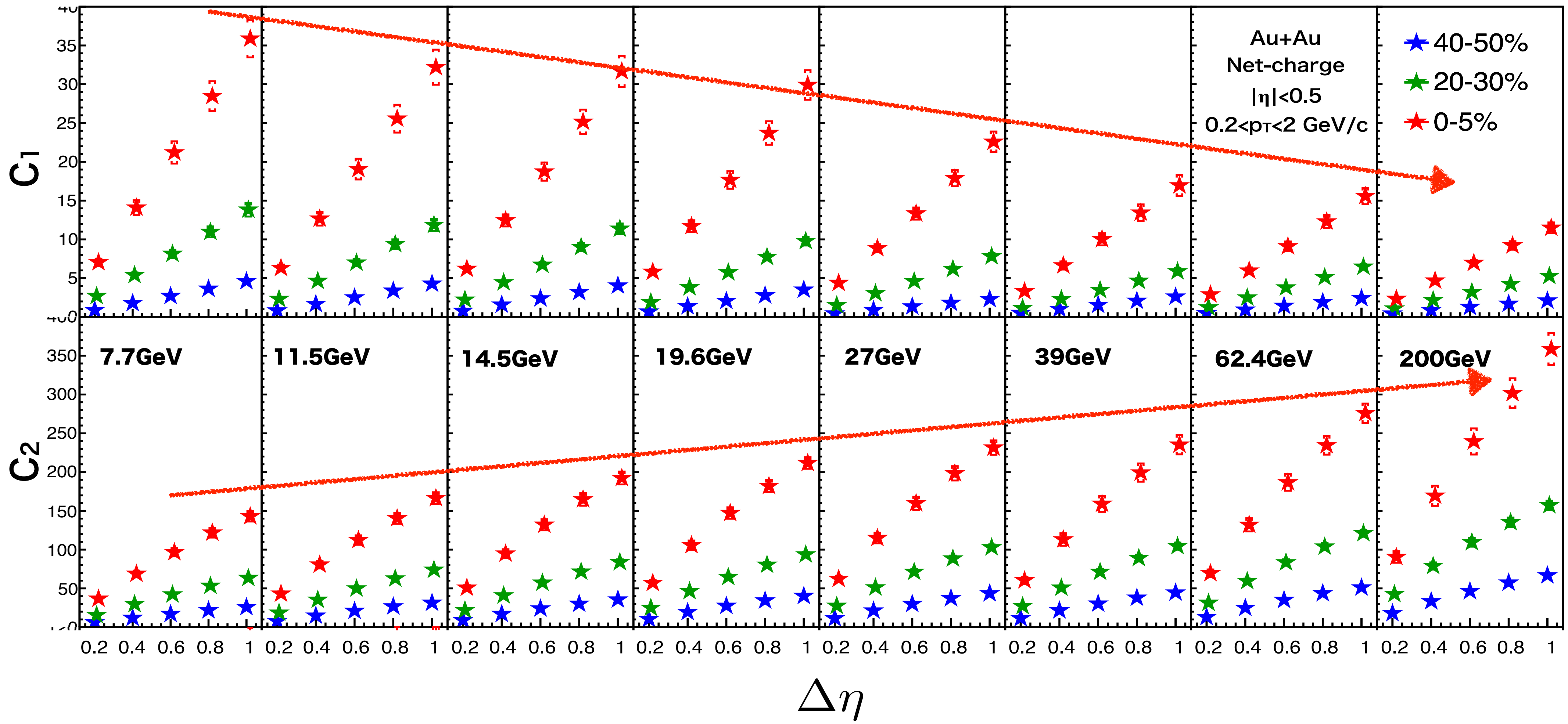


Au+Au, √sNN = 200 GeV
Run10 + Run11
Au+Au, √sNN = 54 GeV
C3/C2
C4/C2
C5/C2
<Npart>
Data
UrQMD
NBD baseline
Poisson baseline

Cumulant ratio (Run10+Run11)

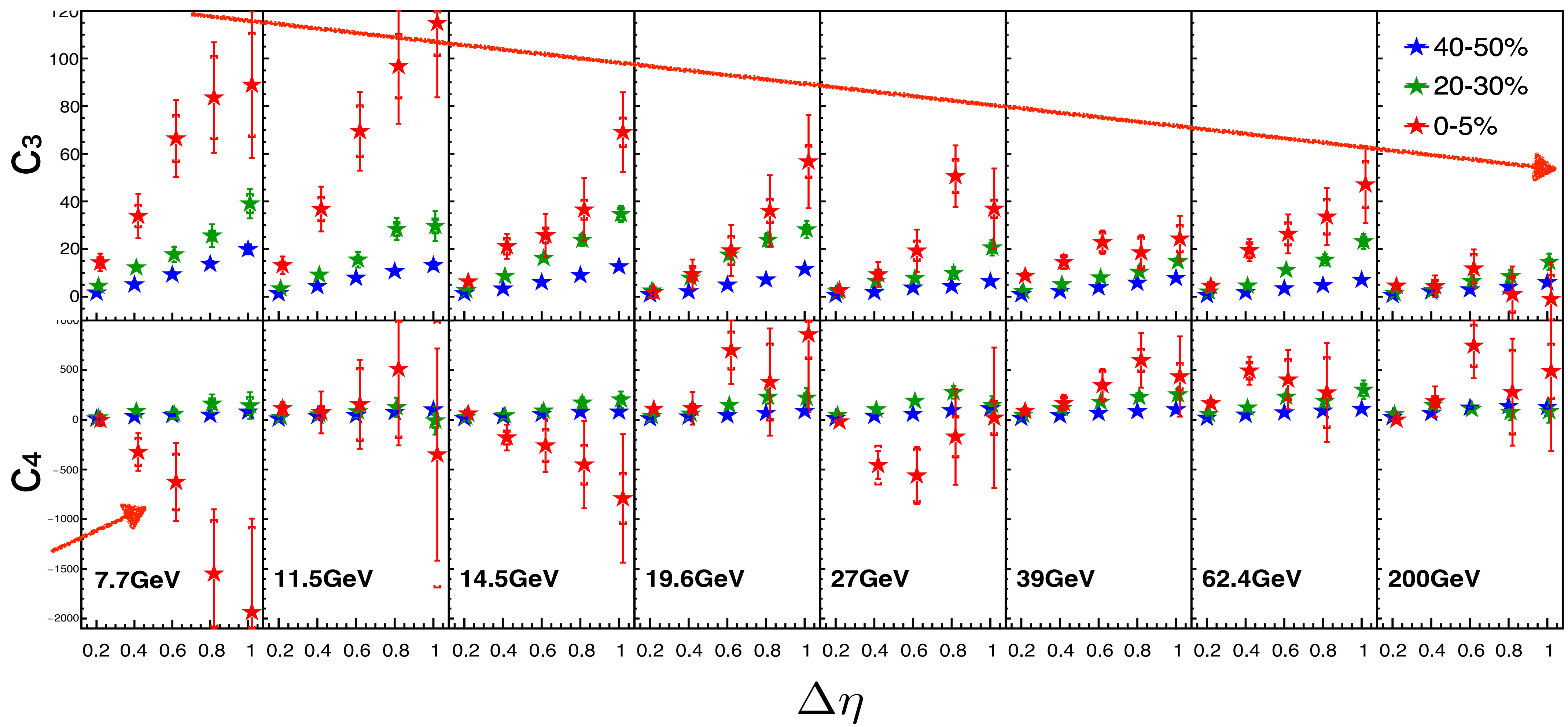


Δη dependence of C_1 and C_2



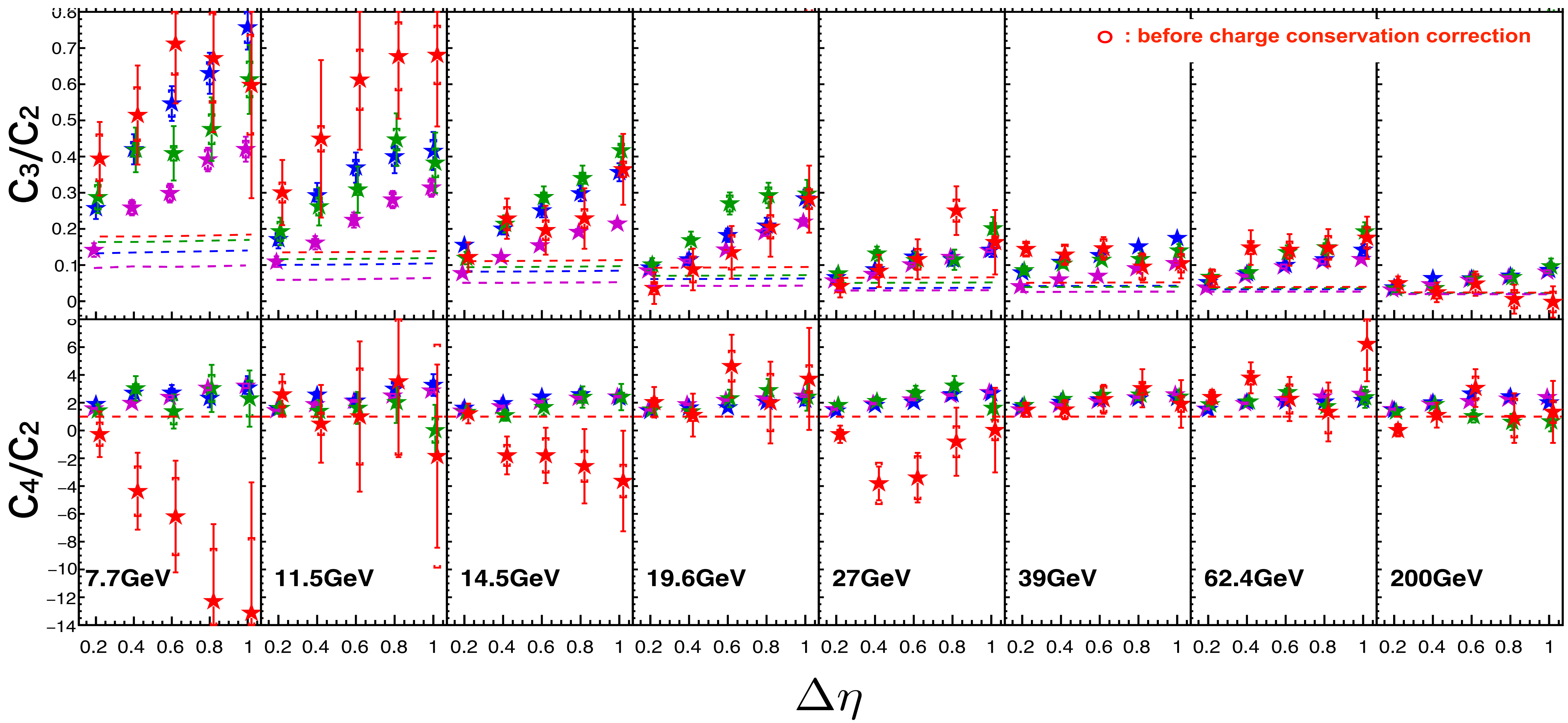
- Cumulants are observed to increace with Δη because of additivity.
- Also cinrease from peripheral to central collisions.
- C_1 is observed to decrease with collision energies because of the baryon stopping.
- C_2 is observed to increase with collision energies because multiplicities are larger with collision energies.

Δη dependence of C_3 and C_4



- Cumulants are observed to increace with $\Delta\eta$ because of additivity.
- Also cinrease from peripheral to central collisions.
- C_3 is observed to decrease with collision energies which trend is similar to C_1.
- Statistical error of C_4 in 0-5% centralities are much larger than that in peripheral collisions.

Δη dependence of cumulant ratios



- At C_3/C_2 and C_4/C_2, most of the results are observed to increase with Δη without most central collision at C_4/C_2 GeV.

back up
(VFC)

Volume fluctuation correction (5,6-th order)

True cumulant

$$\kappa_5(\Delta N) = \langle N_W\rangle\kappa_5(\Delta n) + \{5\kappa_4(\Delta n)\kappa_1(\Delta n) + 10\kappa_3(\Delta n)\kappa_2(\Delta n)\}\,\kappa_2(N_W)$$
$$+\left\{10\kappa_3(\Delta n)\kappa_1^2(\Delta n) + 15\kappa_2^2(\Delta n)\kappa_1(\Delta n)\right\}\kappa_3(N_W) + 10\kappa_2(\Delta n)\kappa_1^3(\Delta n)\kappa_4(N_W)$$
$$+\kappa_1^5(\Delta n)\kappa_5(N_W)$$

Additional term caused from N_W fluctuation

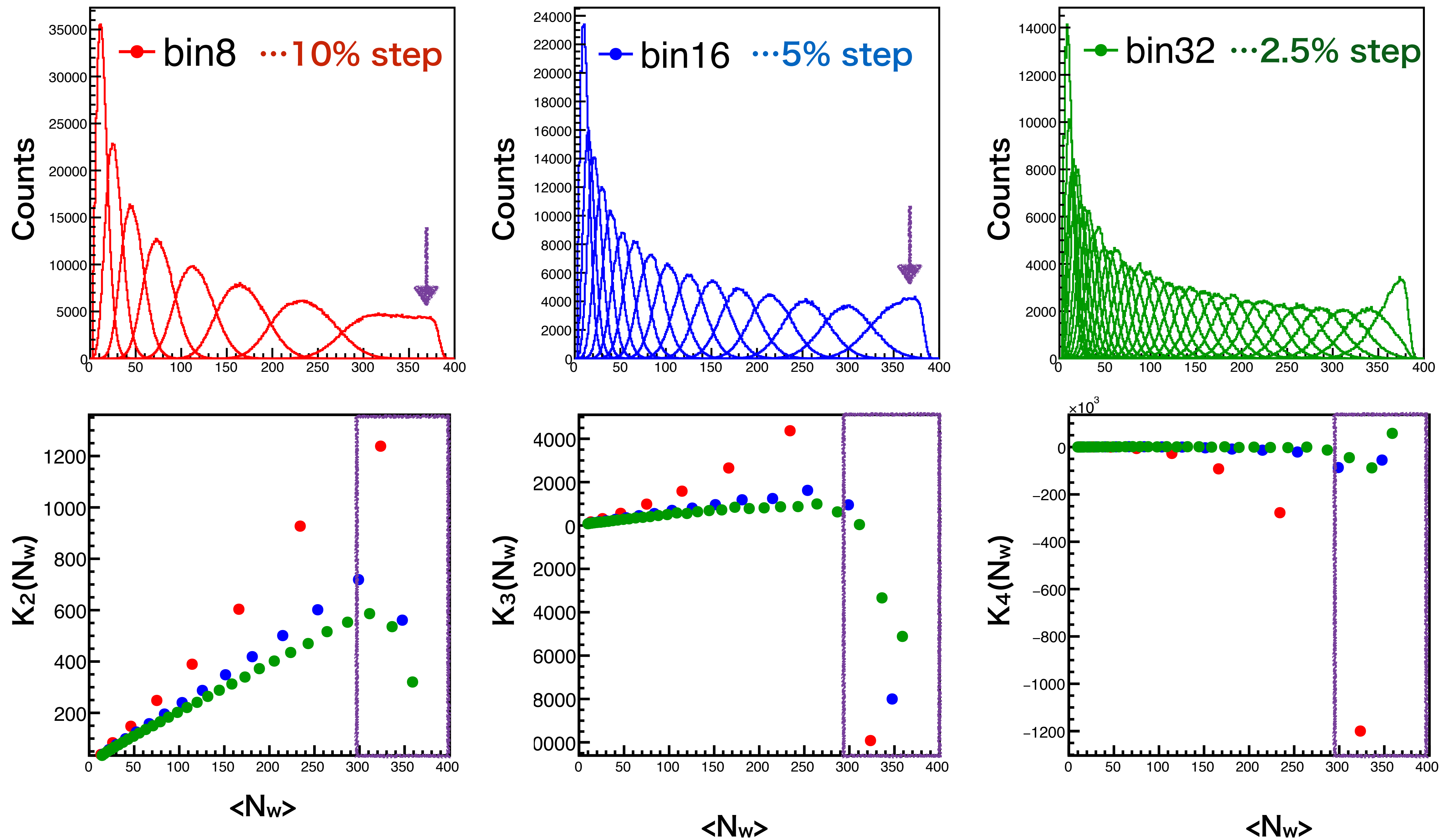
T.Nonaka, Doctoral thesis

$$\kappa_6(\Delta N) = \langle N_W\rangle\kappa_6(\Delta n)$$
$$+\left\{6\kappa_5(\Delta n)\kappa_1(\Delta n) + 15\kappa_4(\Delta n)\kappa_2(\Delta n) + 10\kappa_3^2(\Delta n)\right\}\kappa_2(N_W)$$
$$+\left\{15\kappa_4(\Delta n)\kappa_1^2(\Delta n) + 60\kappa_3(\Delta n)\kappa_2(\Delta n)\kappa_1(\Delta n) + 15\kappa_2^3(\Delta n)\right\}\kappa_3(N_W)$$

Measured cumulant

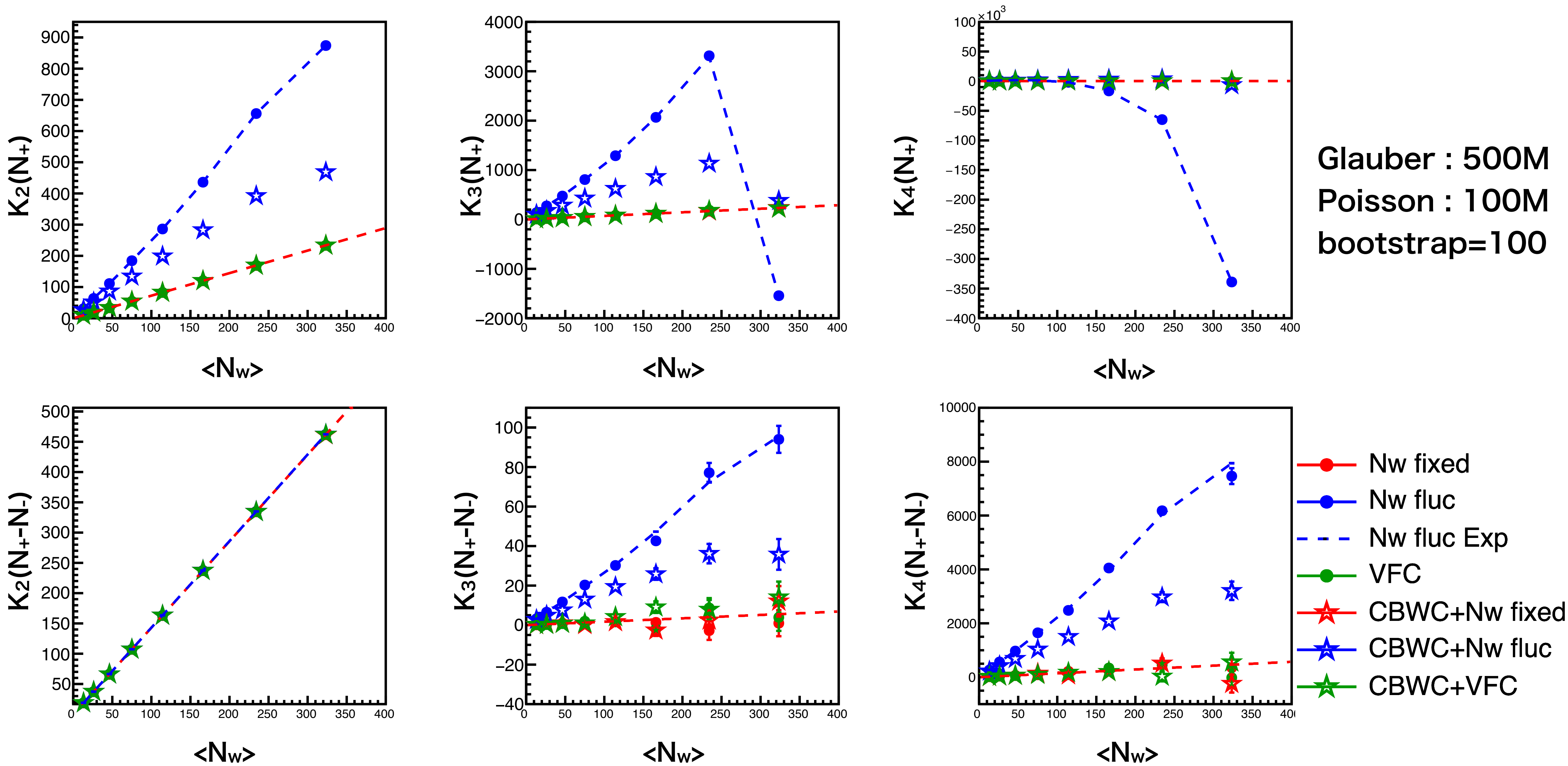
Δn : number of net-particle

Participant fluctuation



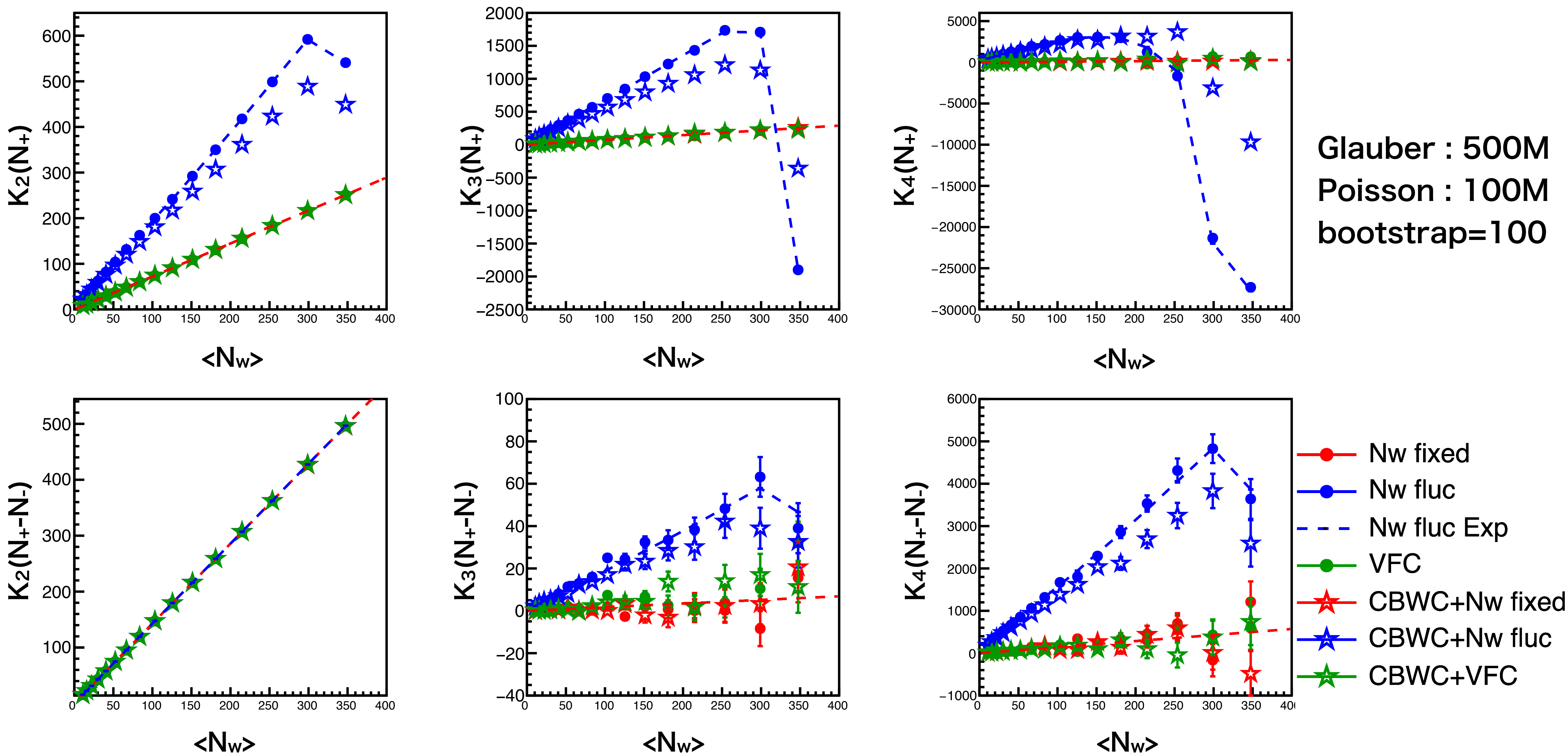
- **Trends are changed around central collision** because maximum value of N_w is fixed.
- Participant fluctuation become larger with number of bin divisions become small.

Toy model VFC check (8bin)



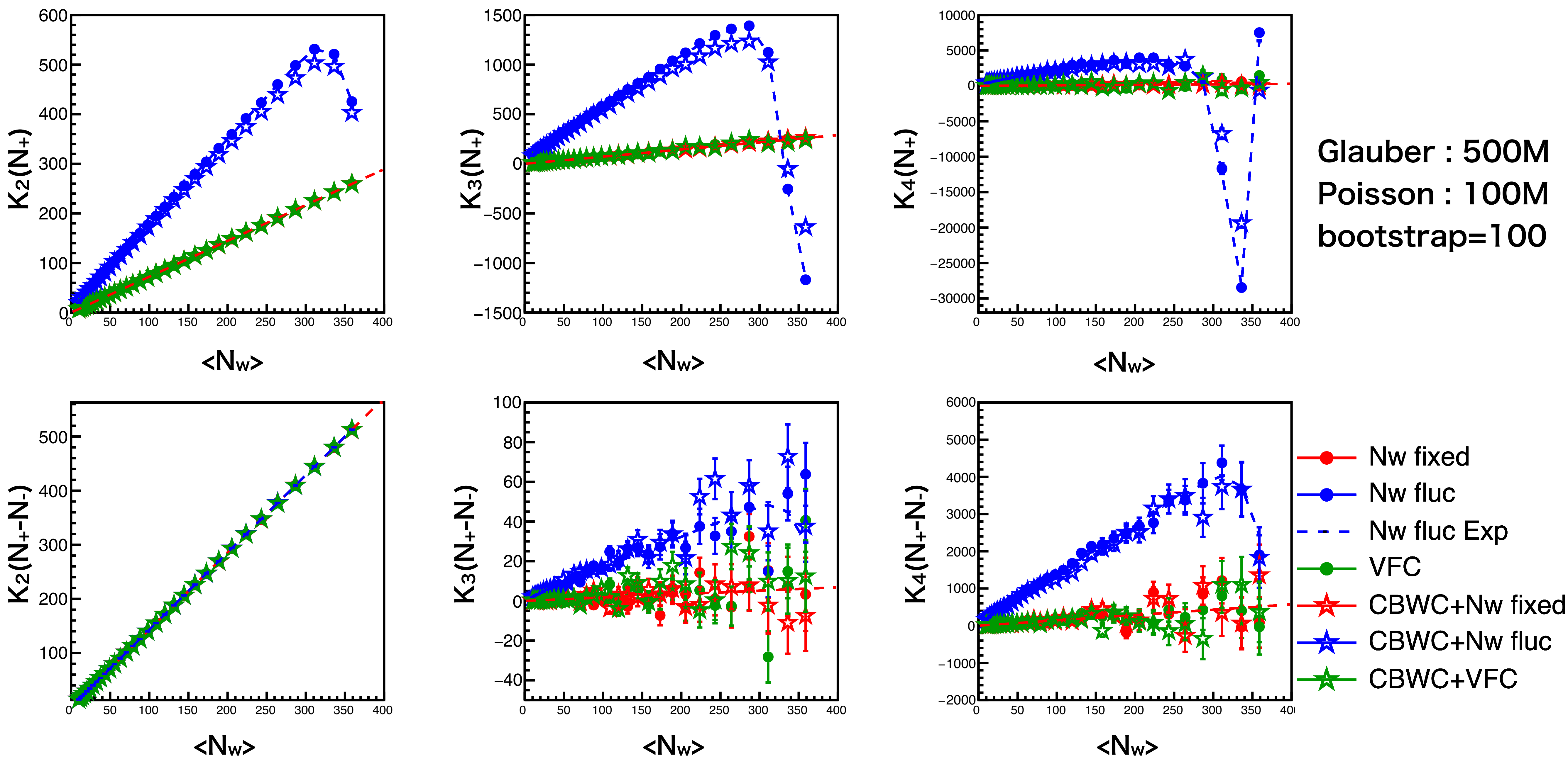
- It seems VFC works well.
- K_1 does not affected by participant fluctuation.
- In net-charge fluctuation, effect from participant fluctuation is smaller than N_+ cumulants because Δn of net-charge is smaller than N_+.

Toy model VFC check (16bin)



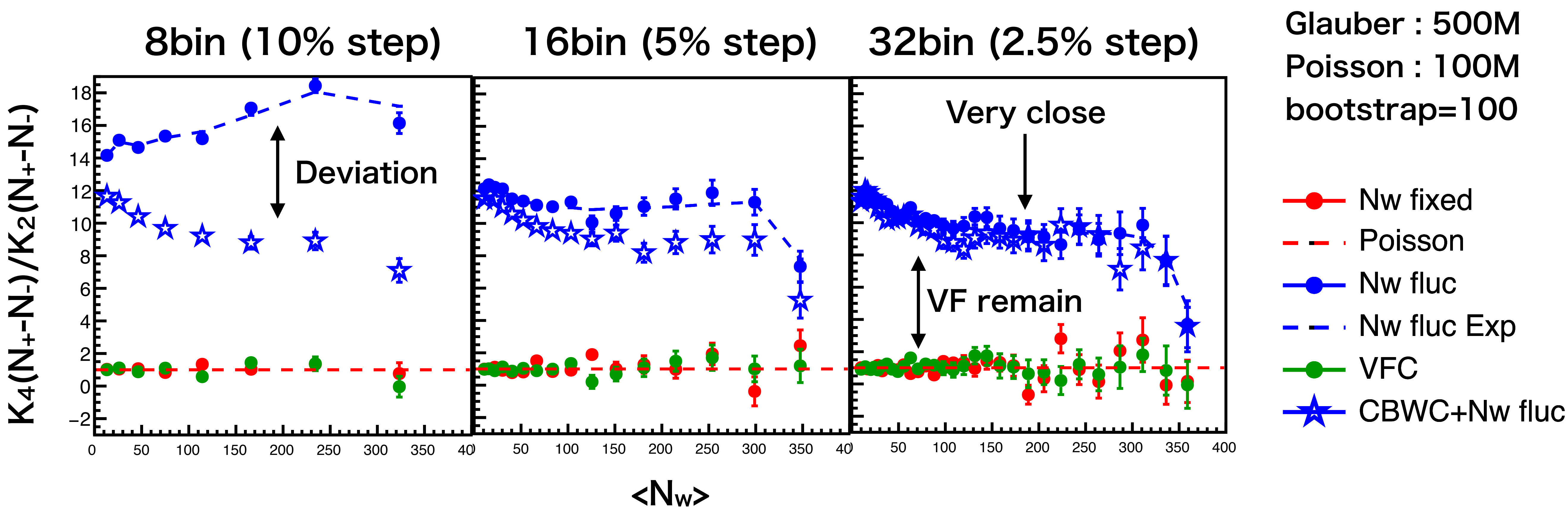
- It seems VFC works well.
- K_1 does not affected by participant fluctuation.
- In net-charge fluctuation, effect from participant fluctuation is smaller than N_+ cumulants because Δn of net-charge is smaller than N_+.

Toy model VFC check (32bin)



- It seems VFC works well.
- K_1 does not affected by participant fluctuation.
- In net-charge fluctuation, effect from participant fluctuation is smaller than N_+ cumulants because Δn of net-charge is smaller than N_+.

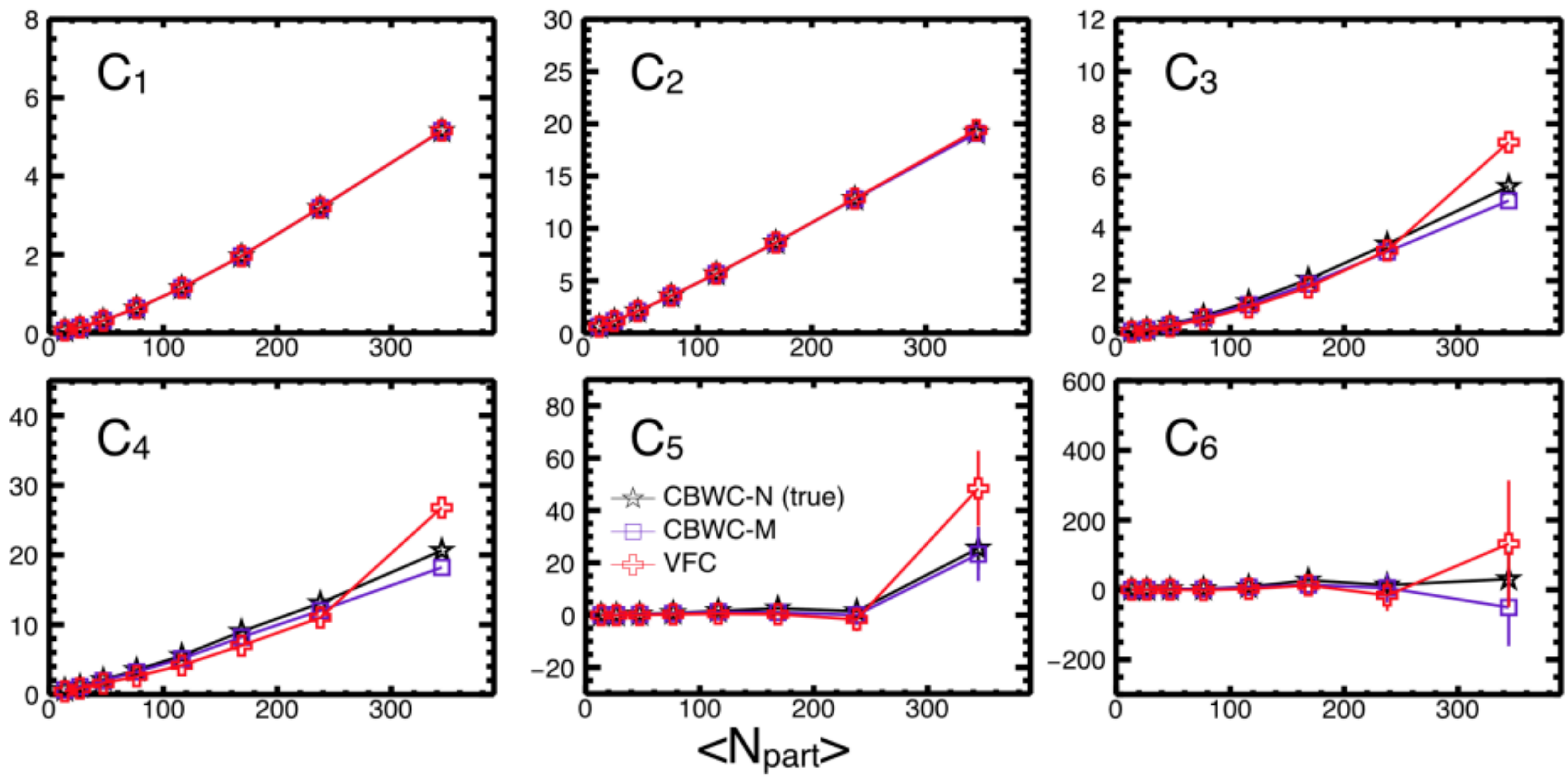
Toy model VFC check (bin dependence)



- CBWC cumulants and Without CBWC cumulants become very close if centrality step become 2.5%.

Net-proton case

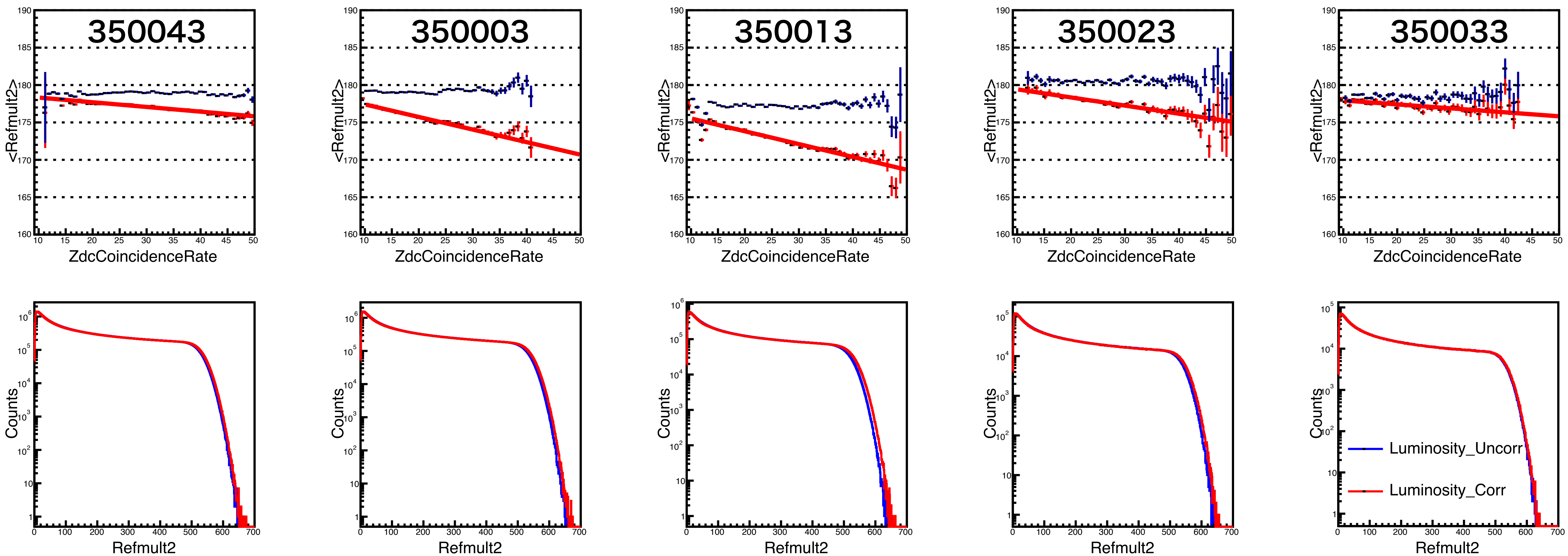
T.Nonaka, Doctoral thesis



back up
(Centrality)

Correction parameter of Refmult2 (Run11)

- Refmult2 was used to determine centrality at net-charge analysis. (multiplicity of $0.5<|\eta|<1$)
- Refmult2 depend on z-vertex and luminosity and trigger ID.
- Calculate z-vertex and luminosity correction parameter for each trigger ID.



- Fit by pol1 ([0]+[1]x)

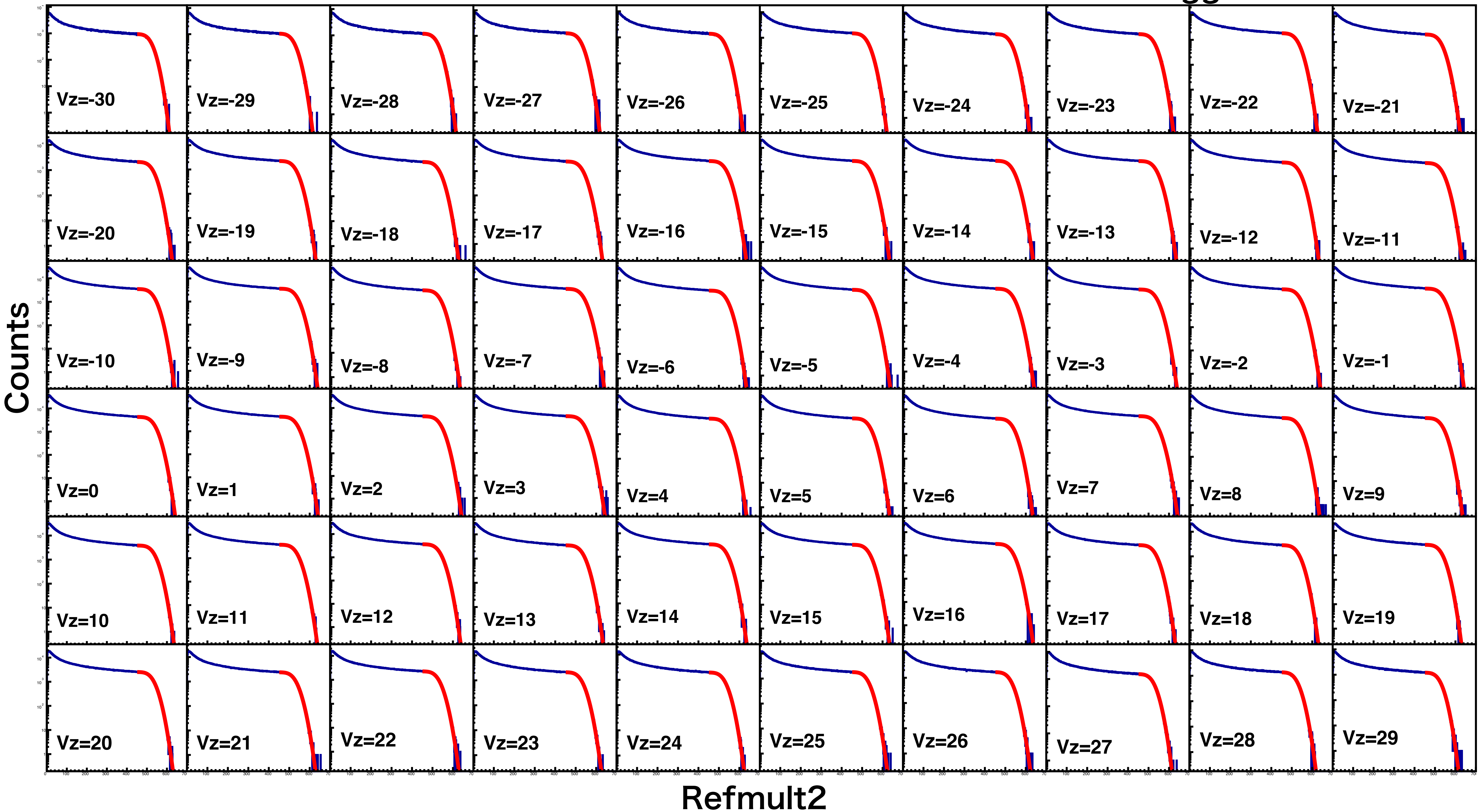
$$\text{correction\_luminosity} = \frac{1}{1 + [1]/[0] * \text{ZdcCoincidenceRate}}$$

luminosity correction factor

Refmult2 distributions of each Vz

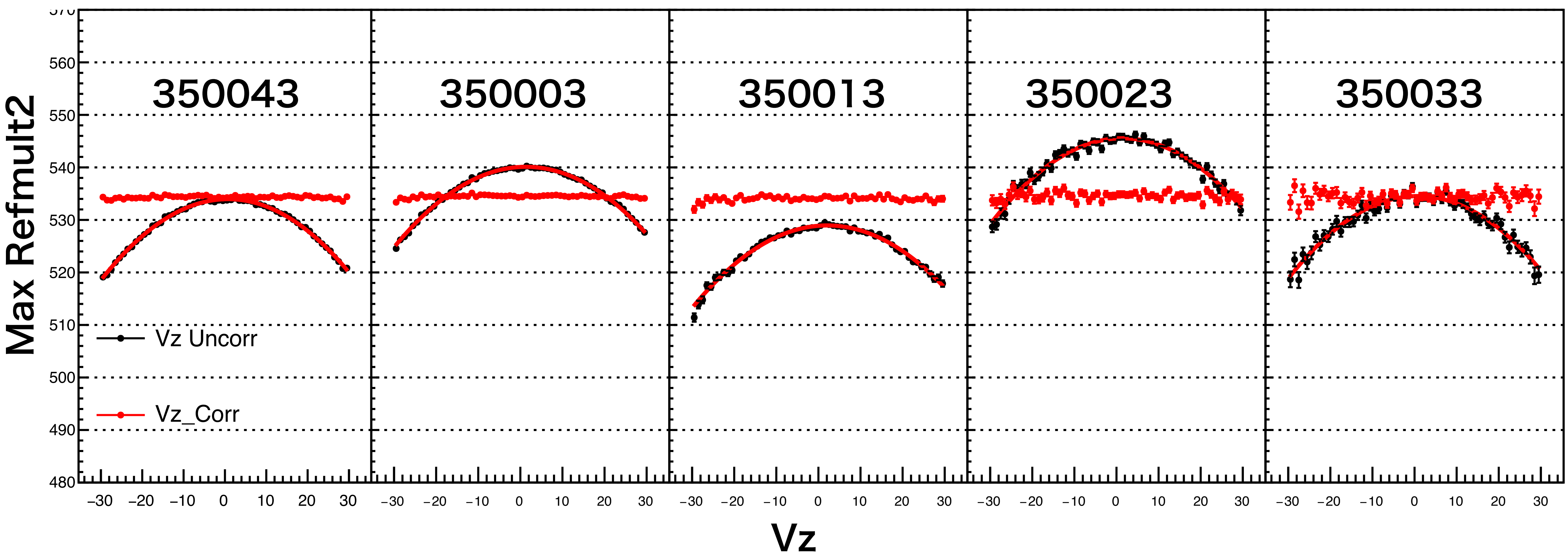
- Maxrefmult2 was measured that is defined by error function for each Vz bins from -30 to 30 after luminosity corrections.

Trigger ID = 350043



- Fit by ([1]*TMath::Erf(-[1]*(x-[2]))+[0]) → **[2] : Maxrefmult2**

Z-vertex correction (Run11)



- Fit by pol2 ([0]+[1]x+[2]x^2)

$$\text{Hovno} = \frac{[0] + \text{par}}{[0] + [1]*x + [2]*x^2}$$

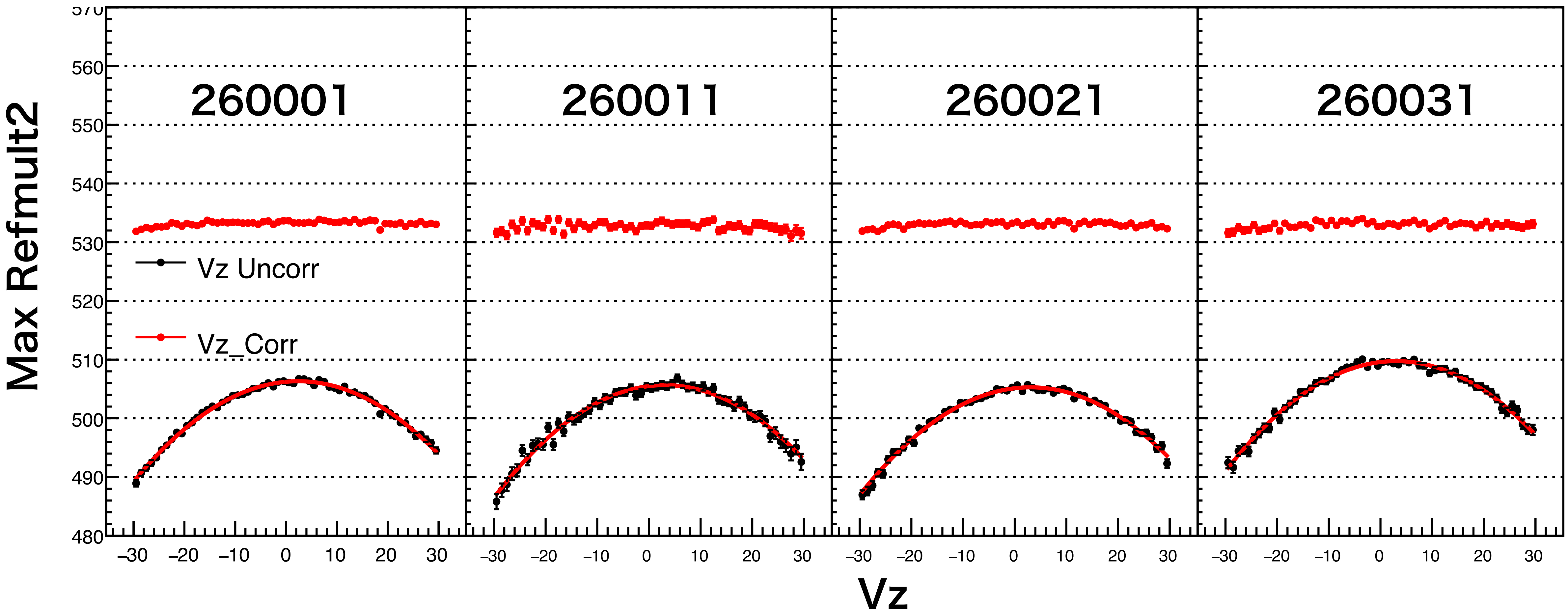
([0] of 350043) - [0] Scaled to 350043

Vz correction factor

Refmult2Corr = (Refmult2+gRandom->Rndm())*correction_lunimosity*Hovno

Corrected Refmult2	**Raw Remult2**	**0 to 1 random number to remove kink structure**	**Luminosity correction factor**

Z-vertex correction (Run10)



- Fit by pol2 ([0]+[1]x+[2]x^2)

$$\mathrm{Hovno} = \frac{[0] + \mathrm{par}}{[0] + [1] * x + [2] * x^2}$$

([0] of 350043) - [0]
Scaled to 350043

Vz correction factor

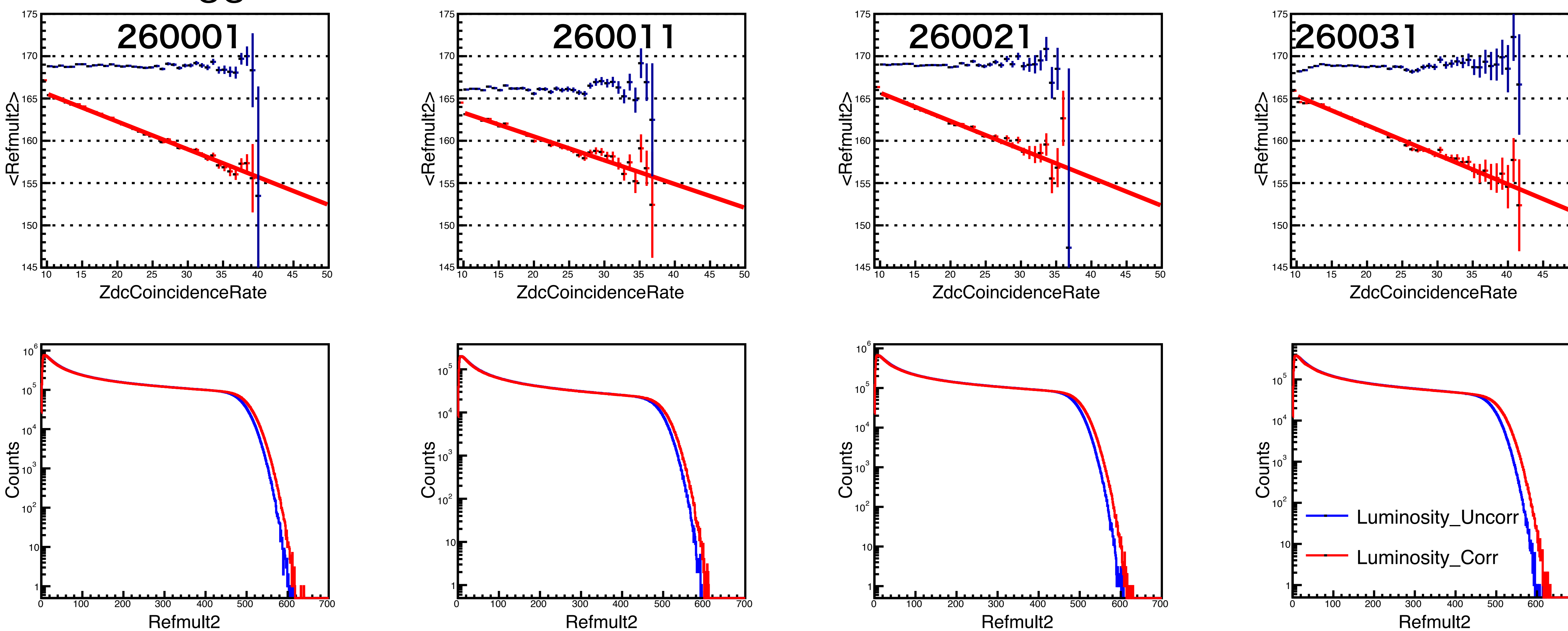
Refmult2Corr = (Refmult2+gRandom->Rndm())*correction_lunimosity*Hovno

Corrected Refmult2	Raw Remult2	0 to 1 random number to remove kink structure	Luminosity correction factor	Vz correction factor

Using StRefmultCorr class

Correction parameter of Refmult2 (Run10)

- Refmult2 was used to determine centrality at net-charge analysis. (multiplicity of $0.5<|\eta|<1$)
- Refmult2 depend on z-vertex and luminosity and trigger ID.
- Calculate z-vertex and luminosity correction parameter for each trigger ID.

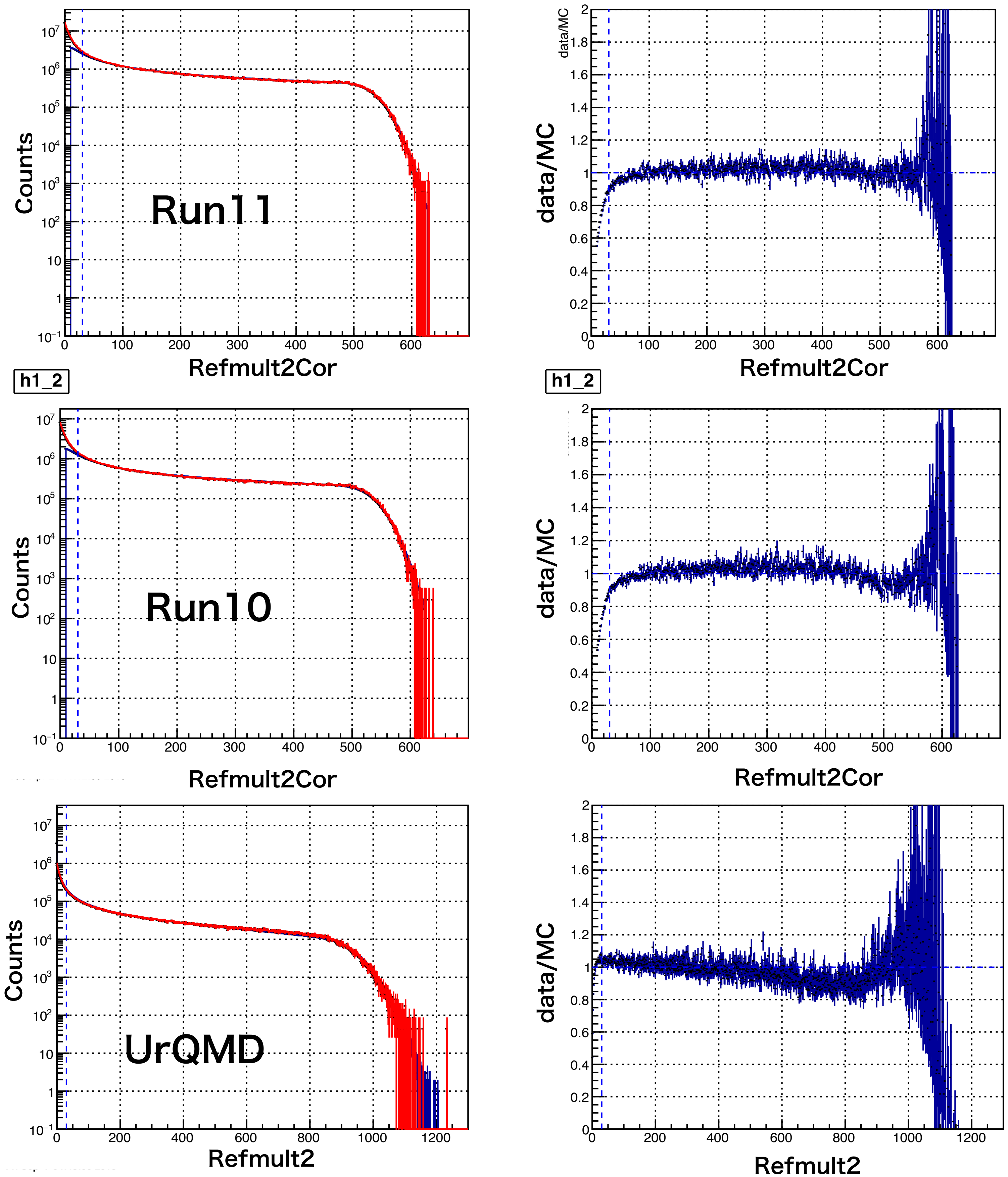


- Fit by pol1 ([0]+[1]x)

$$\mathrm{correction\_luminosity} = \frac{1}{1 + [1]/[0] * \mathrm{ZdcCoincidenceRate}}$$

luminosity correction factor

Glauber fit results



MC : 1M

Experiment

- n_{pp}=2.35
- x=0.13
- k=0.9
- efficiency
  =1-Refmult2Cor*(0.206/560)

n_{pp} : Mean number of generated particles from each source.
k : Parameters of NBD.
x : Parameter of two component model.
Number of source :
$(1-x)*(N_{part}/2.)+x*N_{coll}$

UrQMD

- n_{pp}=**2.90**
- x=0.13
- k=0.9
- efficiency=**1**

Negative binomial distribution

Binomial distribution

r success , given n trials

$$f(r;n,p) = \binom{n}{r} p^r (1-p)^k$$

Negative binomial distribution (NBD)

r success before k failures

$$f(r;k,p) = \binom{r+k-1}{r} p^r (1-p)^k$$

Expand k and r to positive real values.

$$f(r;k,p) = \frac{\Gamma(r+k)}{\Gamma(r+1)\Gamma(k)} \left(\frac{n_{pp}}{k+n_{pp}}\right)^r \left(\frac{k}{k+n_{pp}}\right)^k$$

n_{pp} : Mean number of generated particles from each ancestors.

k : Parameters of NBD.

r : success

k : failures

n : trials

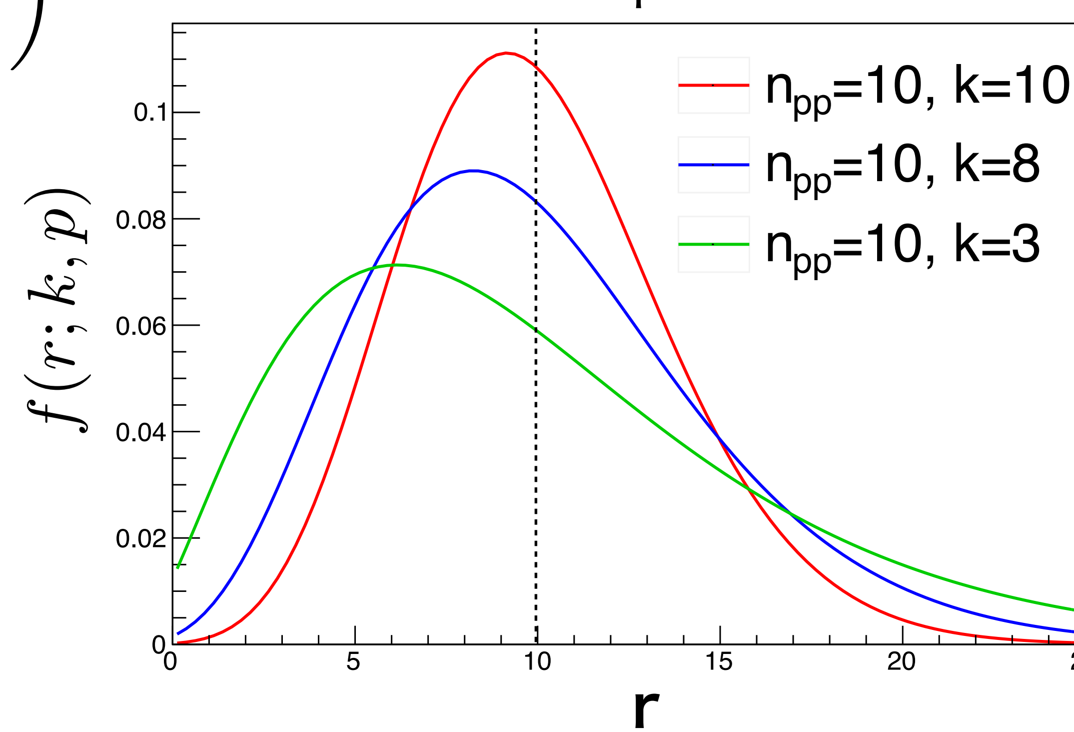
p : probability of success

$$\frac{\langle r \rangle}{p} = \frac{k}{1-p} = (k+r)$$

number of trials

$$\rightarrow \langle r \rangle = \frac{pk}{1-p} \equiv n_{pp}$$

Example



Centrality bins

8 bin

Centrality	bin	<N_{part}>
0-10	406	323.41
10-20	295	234.16
20-30	204	166.14
30-40	134	114.3
40-50	82	75.09
50-60	47	46.32
60-70	24	26.14
70-80	11	13.15

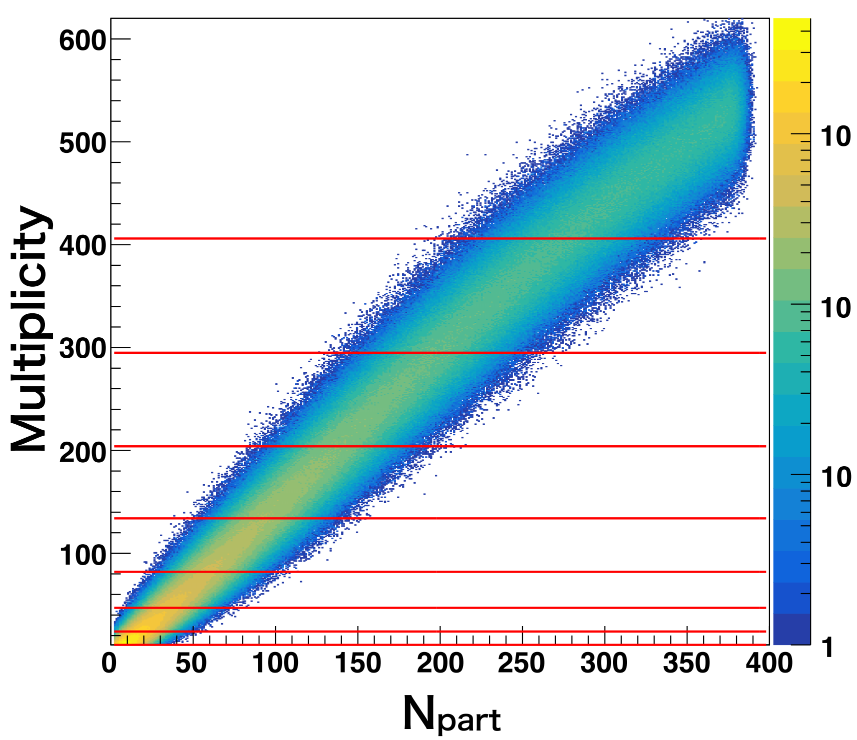
16 bin

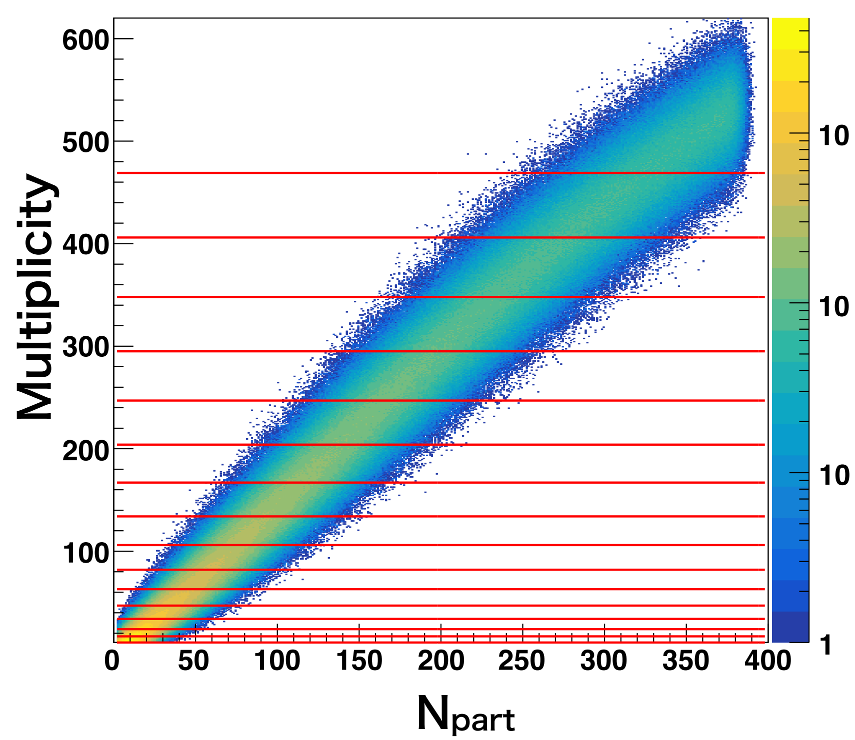
Centrality	bin	<N_{part}>
0-5	469	347.47
5-10	406	298.9
10-15	348	253.64
15-20	295	214.79
20-25	247	180.99
25-30	204	151.34
30-35	167	125.669
35-40	134	103.2
40-45	106	83.61
45-50	82	66.65
50-55	63	52.38
55-60	47	40.46
60-65	34	30.28
65-70	24	22.0
70-75	17	15.73
75-80	11	10.93

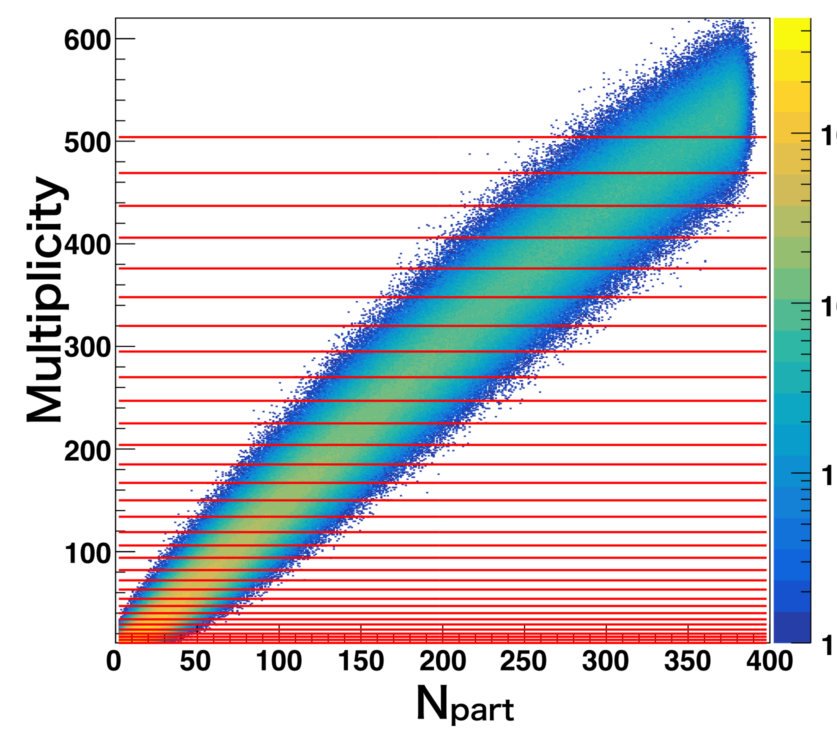
32 bin

Centrality	bin	<N_{part}>
0-2.5	504	358.83
2.5-5	469	336.16
5-7.5	437	311.16
7.5-10	406	286.74
10-12.5	376	263.97
12.5-15	348	243.02
15-17.5	320	223.61
17.5-20	295	205.41
20-22.5	270	188.85
22.5-25	247	172.91
25-27.5	225	158.33
27.5-30	204	144.42
30-32.5	185	131.64
32.5-35	167	119.78
35-37.5	150	108.56
37.5-40	134	97.93
40-42.5	119	88.02

⋮







Tetsuro Sugiura Univ. of Tsukuba

back up
(Data set, QA, Analysis mothod, etc)

Data set (200 GeV)

	Run11(0-80%)	Run10(10-80%)	Run10(0-10%)	UrQMD
NEvent	485M	211M	196M	45M

Event Selection

$\lvert v_z \rvert$	<30
$\lvert v_r \rvert$	<2
Pile up event cut	0.46 * nRefMult - 10 < nTOFMatch

Track cut	π	K	p
p_T (TPC only)	0.2 - 0.5 GeV/c	0.2 - 0.4 GeV/c	0.4 - 0.8 GeV/c
p_T (TPC+TOF)	0.5 - 1.6 GeV/c	0.4 - 1.6 GeV/c	0.8 - 2. GeV/c
$\lvert \eta \rvert$		< 0.5	
dca		<1	
nhitsfits		>20	
track quality		>0.52	
nhitsdedx		>10	
Centrality		Refmult2 ($\lvert \eta \rvert$>0.5)	
PID (TPC)	nSigmaPion < 2	nSigmaKaon < 2	nSigmaProton < 2
PID (TOF)	-0.15< m^2 <0.14	0.14< $\lvert m^2 \rvert$ <0.4	0.6 < $\lvert m^2 \rvert$ <1.2

Same as net-charge published results

Number of Events

NEvent	350003	350013	350023	350033	350043	Total
Run11 (0-80%)	200M	74M	15M	9M	187M	**485M**

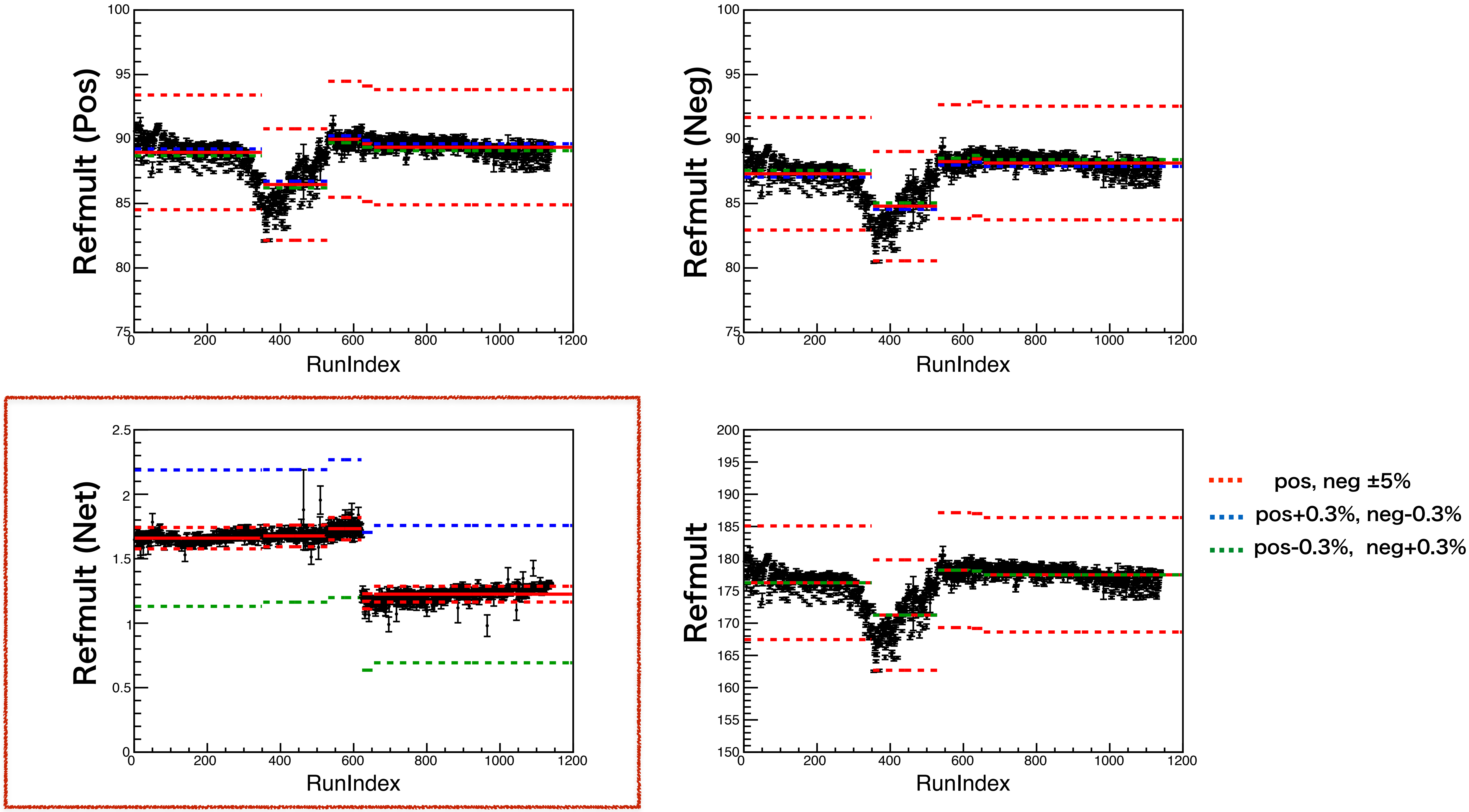
NEvent	260001	260011	260021	260031	Total
Run10 (10-80%)	80M	21M	70M	40M	**211M**
Run10 (0-10%)	53M	20M	76M	47M	**196M**

NEvent	Total
UrQMD	**45M**

Run by run check (Run11, 350043)

Only Good runs are shown

Refmult(Pos)+Refmult(Neg)=Refmult



- When we change (pos,neg)=(+0.3%,-0.3%) and (+0.3%,-0.3%), run by run Refmult (Net) are fluctuate within blue and green line.
- **(pos+0.3%, neg-0.3%) and (pos-0.3%, neg+0.3%) seem enough to estimate systematic uncertainty of net-charge.**

Factorial cumulant method

Example (the 1st-order net-charge fluctuation)

Cumulant (true)

Number of phase space

Number of particle

Efficiency

+1(positive charge) or -1(negative charge)

$$\langle Q\rangle_c = \langle q_{(1,1)}\rangle_c, \qquad q_{(r,s)} = q_{(a^r/p^s)} = \sum_{i=1}^{M} (a_i^r/p_i^s) n_i.$$

$$= \frac{n_{(\pi^+,lowpt)}}{p_{(\pi^+,lowpt)}} + \frac{n_{(\pi^+,highpt)}}{p_{(\pi^+,highpt)}} - \frac{n_{(K^+,lowpt)}}{p_{(K^+,lowpt)}} + \frac{n_{(K^-,highpt)}}{p_{(K^+,highpt)}} + \frac{n_{(pbar,lowpt)}}{p_{(pbar,lowpt)}} + \frac{n_{(p,highpt)}}{p_{(p,highpt)}}$$

$$- \frac{n_{(\pi^-,lowpt)}}{p_{(\pi^-,lowpt)}} - \frac{n_{(\pi^-,highpt)}}{p_{(\pi^-,highpt)}} - \frac{n_{(K^-,lowpt)}}{p_{(K^-,lowpt)}} - \frac{n_{(K^-,highpt)}}{p_{(K^-,highpt)}} - \frac{n_{(pbar,lowpt)}}{p_{(pbar,lowpt)}} - \frac{n_{(pbar,highpt)}}{p_{(pbar,highpt)}}$$

- 2(charge)*3(πKp)*2(highpt,lowpt)=12 efficiency bins are used at net-charge fluctuation analysis.

NBD check

$$C_1 = \mu$$

$$C_2 = \mu\epsilon$$

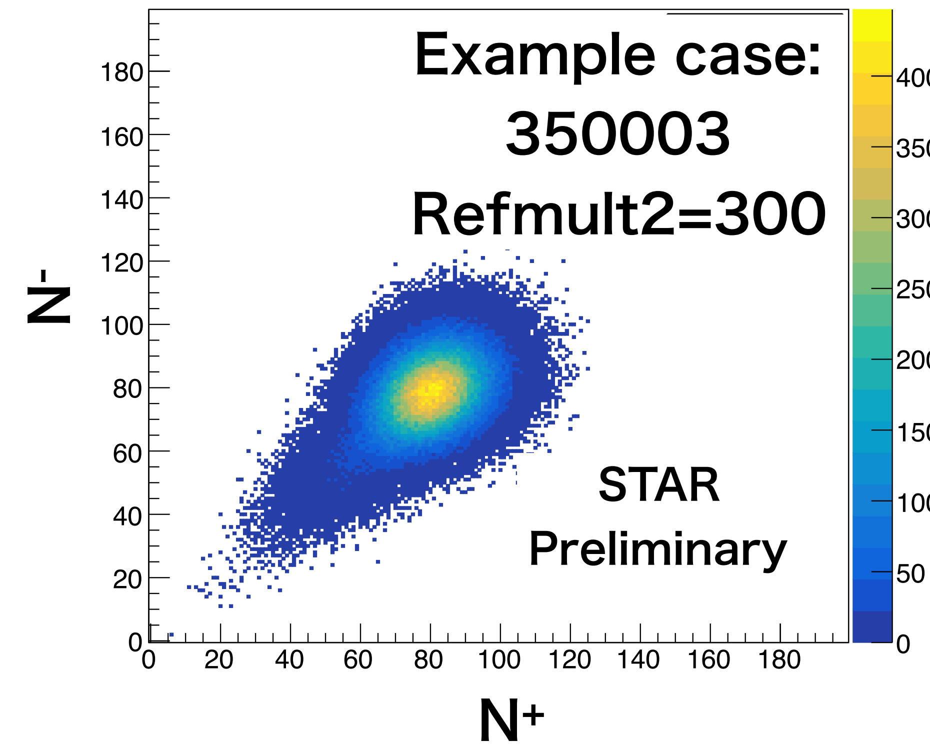
$$C_3 = \mu\epsilon(2\epsilon - 1)$$

$$C_4 = \mu\epsilon(6\epsilon^2 - 6\epsilon + 1)$$

$$C_5 = \mu\epsilon(2\epsilon - 1)(12\epsilon^2 - 12\epsilon + 1)$$

$$C_6 = \mu\epsilon(120\epsilon^4 - 240\epsilon^3 + 150\epsilon^2 - 30\epsilon + 1)$$

$$C_n^{net-c} = C_n^+ + (-1)^n C_n^-$$



For example : 350003, Refmult2=300,

Efficiency Uncorrected case

$C_1^+=79.53$	$C_1^-=77.81$
$C_2^+=122.1$	$C_2^-=117.93$
$\varepsilon^+=C_2/C_1=1.53$	$\varepsilon^-=1.51$

used as NBD parameters.

$C_3^+=253$	$C_3^+=240$
$C_4^+=724$	$C_4^+=671$
$C_5^+=2746$	$C_5^+=2486$
$C_6^+=13027$	$C_6^+=11525$

NBD	Poisson
$C_1^{net}=1.72$	$C_1^{net}=1.72$
$C_2^{net}=240$	$C_2^{net}=157$
$C_3^{net}=13.3$	$C_3^{net}=1.72$
$C_4^{net}=1395$	$C_4^{net}=157$
$C_5^{net}=260$	$C_5^{net}=1.72$
$C_6^{net}=24552$	$C_6^{net}=157$

Odd: $C_1^+ - C_1^-$
Even: $C_1^+ + C_1^-$

- **NBD baseline is larger than Poisson because of large ε at 200GeV.**
- **If ε=1, NBD and Poisson baseline are exactly the same.**

NBD check

For example : 350003, Refmult2=300,
Efficiency Corrected case

$C_1^+=139.44$	$C_1^-=136.54$
$C_2^+=265.5$	$C_2^-=256.26$
$\varepsilon^+=C_2/C_1=1.90$	$\varepsilon^-=1.87$

used as NBD parameters.

$C_3^+=745$	$C_3^+=705$
$C_4^+=3007$	$C_4^+=2786$
$C_5^+=16145$	$C_5^+=14640$
$C_6^+=108378$	$C_6^+=96183$

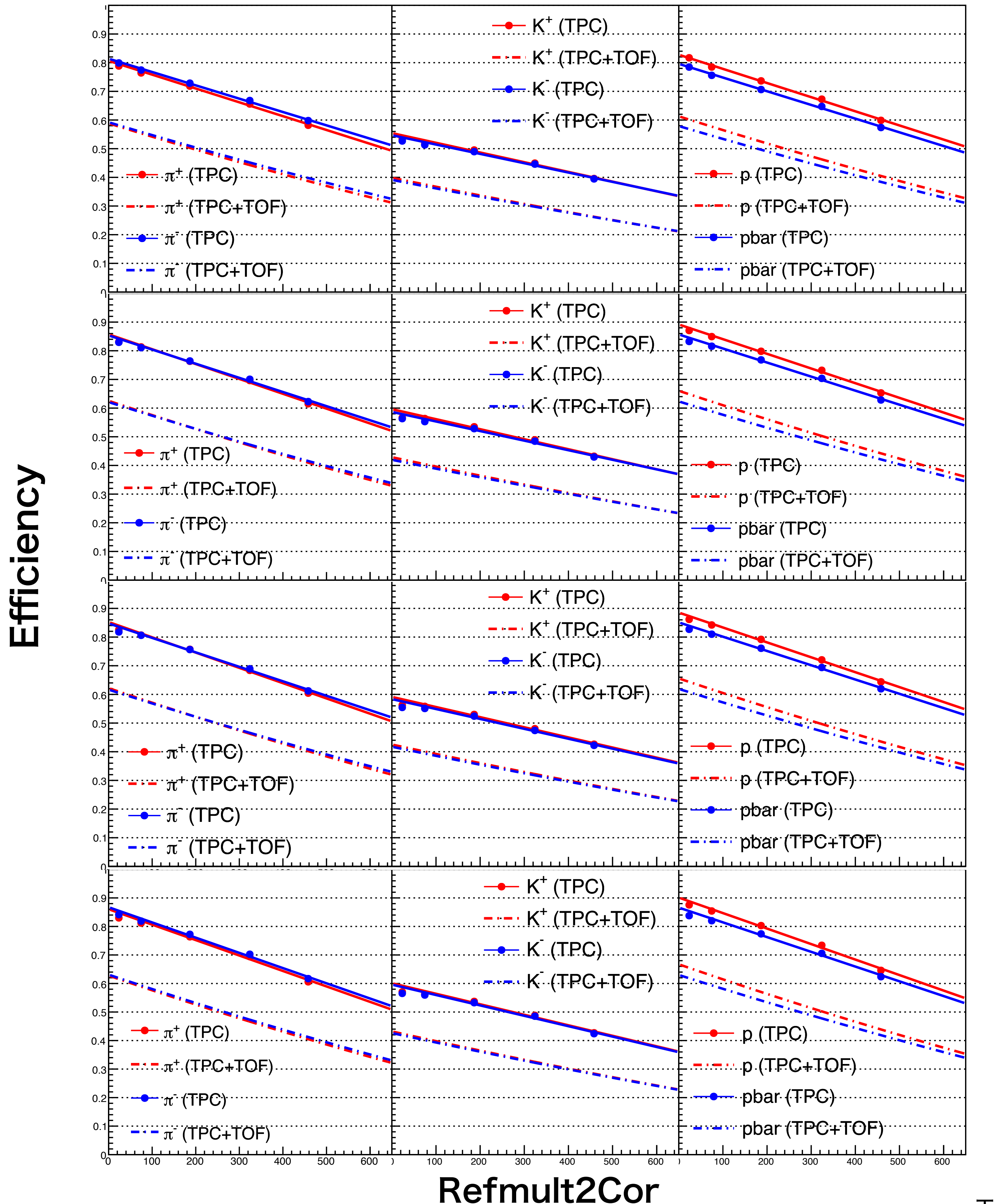
N^+

NBD	Poisson
$C_1^{net}=1.72$	$C_1^{net}=1.72$
$C_2^{net}=521$	$C_2^{net}=157$
$C_3^{net}=40.0$	$C_3^{net}=1.72$
$C_4^{net}=5794$	$C_4^{net}=157$
$C_5^{net}=1505$	$C_5^{net}=1.72$
$C_6^{net}=204561$	$C_6^{net}=157$

Odd: $C_1^+-C_1^-$
Even: $C_1^++C_1^-$

- **NBD baseline is larger than Poisson because of large ε.**
- **If $\varepsilon=1$, NBD and Poisson baseline are exactly the same.**

Tracking efficiency



Run10

350003

350013

350043