Rapidity dependence of net-charge distribution

2016 1/19

CiRfSE

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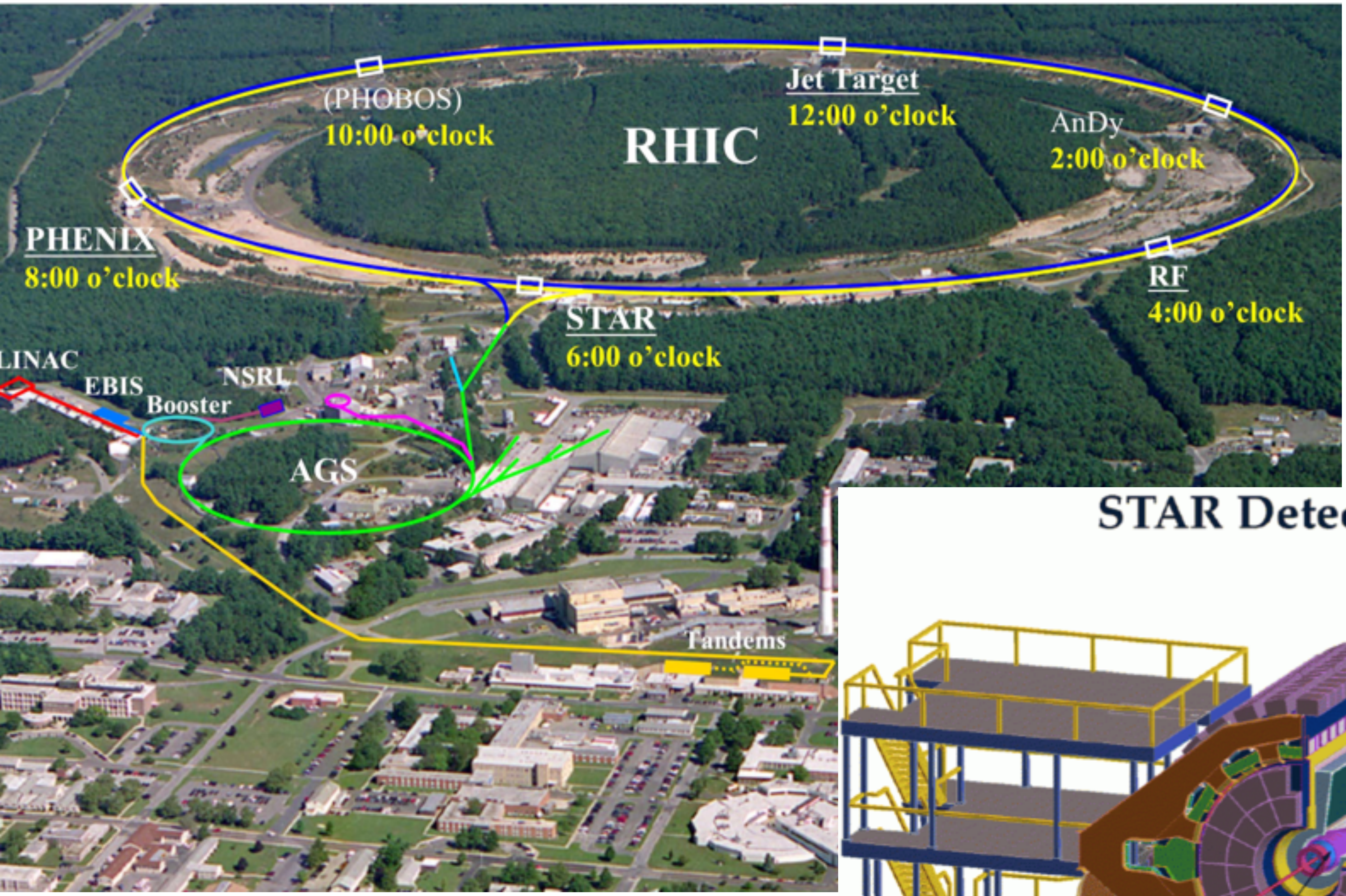
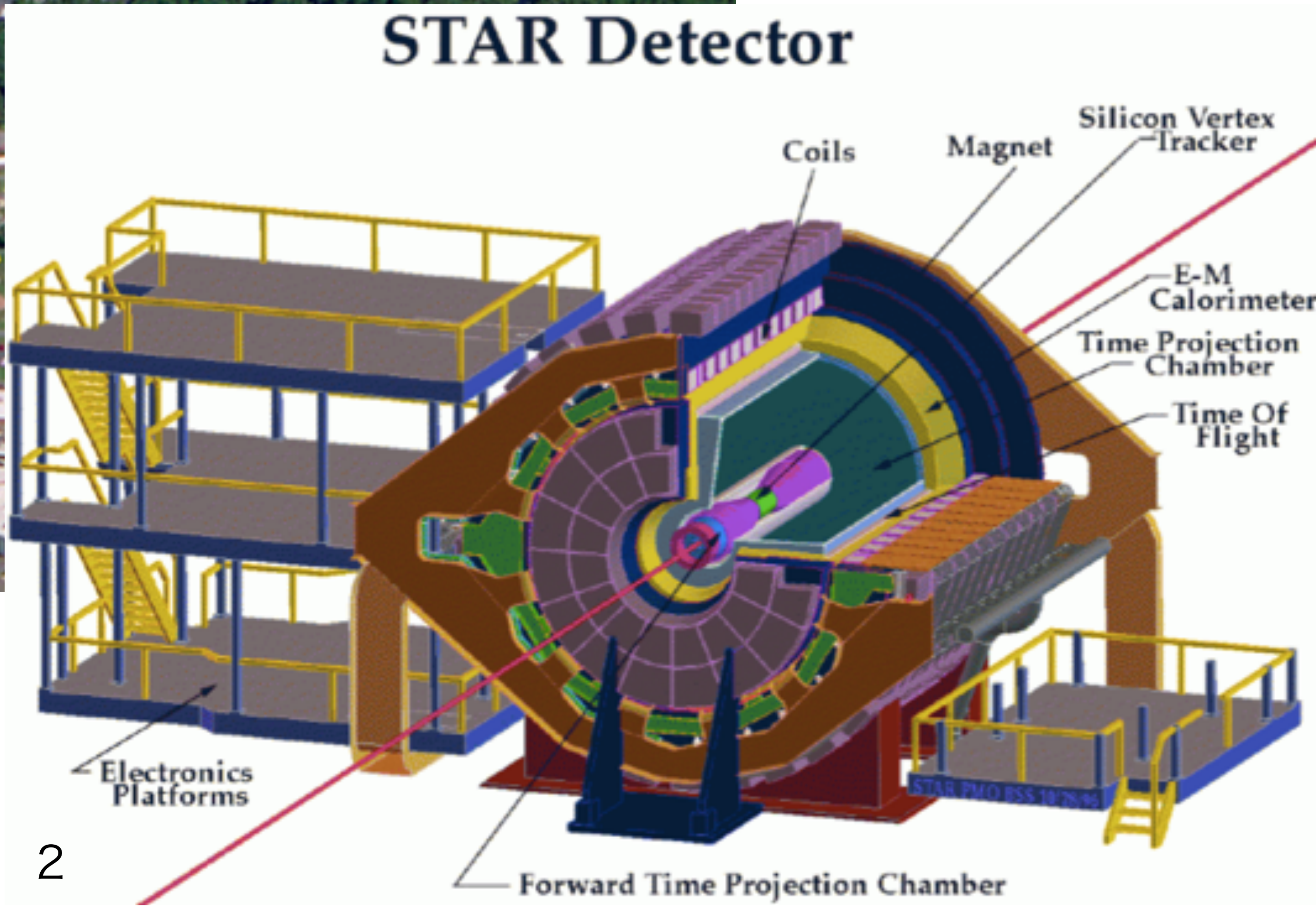
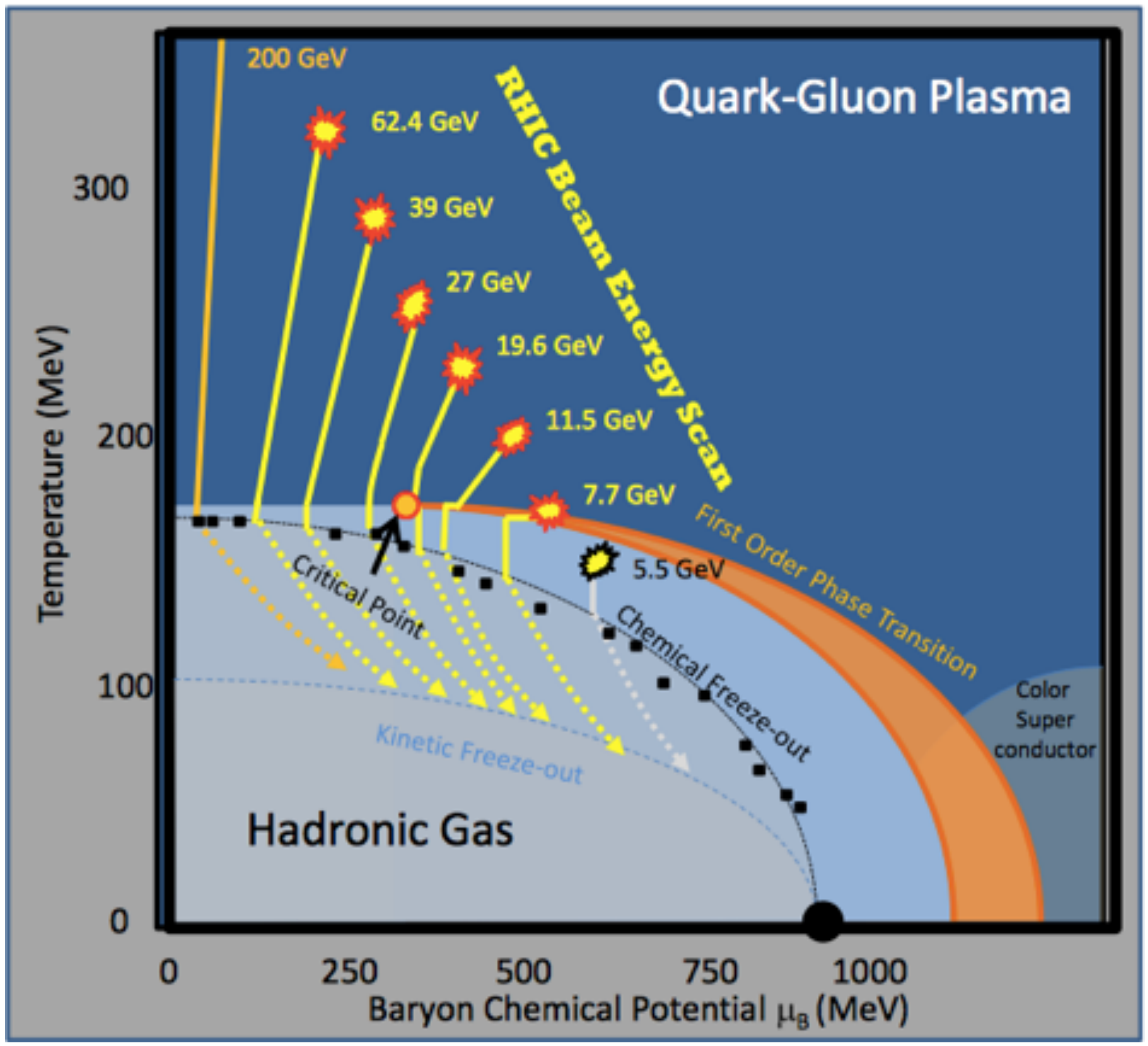
Relativistic Heavy Ion Collider





Beam Energy Scan

Aim : studying in detail the QCD structure, and searching critical point



Varying the center of mass energy $\sqrt{s_{NN}}$ from 7.7GeV to 200GeV

We can "scan" QCD phase diagram

(μ value is observed to increase with decreasing $\sqrt{s_{NN}}$)

→When we scan near the CP we want to see experimental signature

Question

①Where is critical point?
…What is the best experimental signature?

②How catch a QGP's signal?
…We can only observe hadron.

↓

Use Event by Event Fluctuation
①→Fluctuation of Cumulant Ratio
②→Fluctuation of D-measure

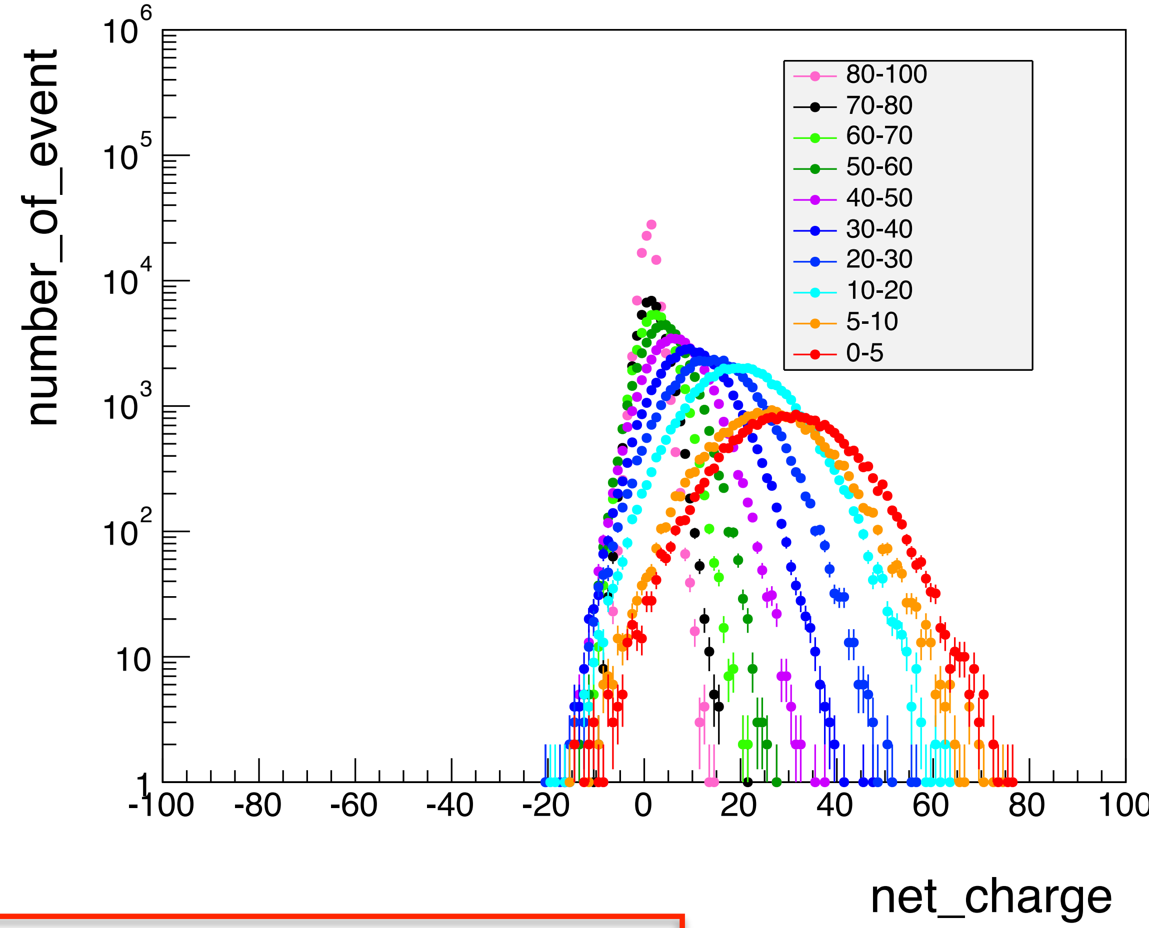
Moment

When studying fluctuation, it is useful to introduce "moment" and "cumulant"

N : net charge number $\cdots N_+ - N_-$

deviation from mean

$$\delta N = N - < N >= N - \bar{\mu}$$



Then r th central moment is defined by

$$\widehat{\mu}_r =< (\delta N)^r > \qquad \widehat{\mu}_1 = 0$$

M, σ ,S, κ is defined as

$$\hat{M} = \hat{C}_{1,N}, \hat{\sigma}^2 = \hat{C}_{2,N}, \hat{S} = \frac{\hat{C}_{3,N}}{(\hat{C}_{2,N})^{3/2}}, \hat{\kappa} = \frac{\hat{C}_{4,N}}{(\hat{C}_{2,N})^2}$$

M : mean

σ : Deviation

S : Asymmetry

κ : Peakedness

Cumulant

Cumulant is related to moment . n_{th} cumulant is

$$\begin{aligned}\hat{C}_1 &= \hat{\mu} \\ \hat{C}_2 &= \hat{\mu}_2 \\ \hat{C}_3 &= \hat{\mu}_3 \\ \hat{C}_n(n>3) &= \hat{\mu}_n - \sum_{m=2}^{n-2} \binom{n-1}{m-1} \hat{C}_m \hat{\mu}_{n-m}\end{aligned}$$

An important property of the cumulants is their "additivity" for independent variables

$$C_{i,X+Y} = C_{i,X} + C_{i,Y}$$

then, moment products can be expressed in term of cumulant ratio.

$$\widehat{S}\widehat{\sigma} = \frac{\widehat{C}_{3,N}}{\widehat{C}_{2,N}} \qquad \widehat{\kappa}\widehat{\sigma}^2 = \frac{\widehat{C}_{4,N}}{\widehat{C}_{2,N}}$$

High order Cumulant

Why should we consider higher order cumulant??

Higher order cumulant(or moment) are proportional to the high power of the correlation length

$$C_3 = S\sigma^3 =< (\delta N)^3 >\sim \xi^{4.5}$$
$$C_4 = \kappa\sigma^4 =< (\delta N)^4 > -3(\delta N)^2 >\sim \xi^7$$

So, higher order cumulant's fluctuation is larger than smaller one.

Skellam distribution

Both N+ and N- are independently distributed as Poisson (parameter μ_1 and μ_2)

Net charge distribution (or net proton)

The difference of two independent Poisson distribution

Skellam distribution

When skellam…

$$\widehat{S}\widehat{\sigma} = \frac{\mu_1 - \mu_2}{\mu_1 + \mu_2}$$

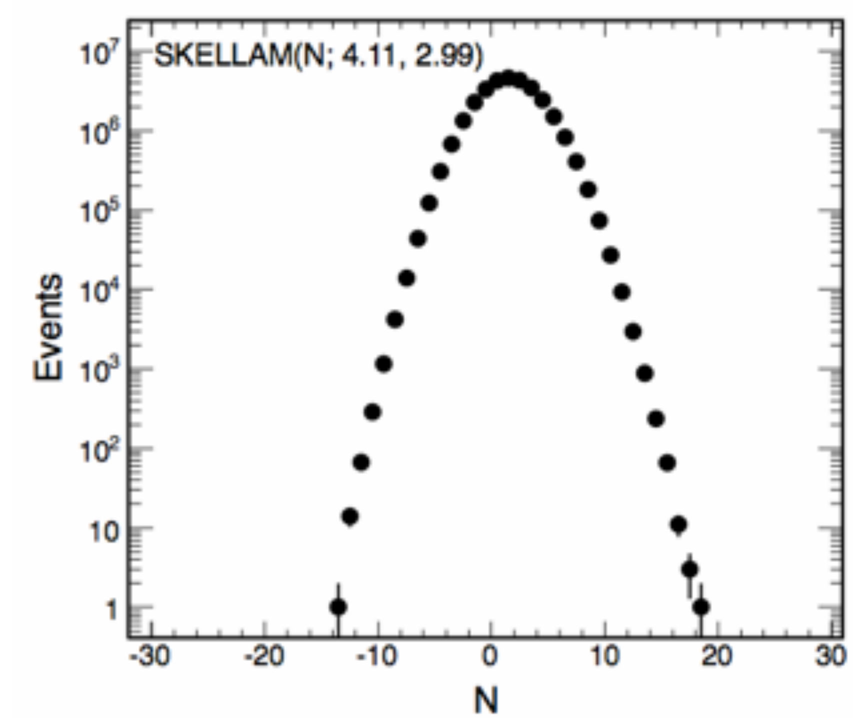
even th order

$$c_{2m} = \mu_1 + \mu_2$$

$$\widehat{\kappa}\widehat{\sigma}^2 = 1$$

odd th order

$$c_{2m+1} = \mu_1 - \mu_2$$

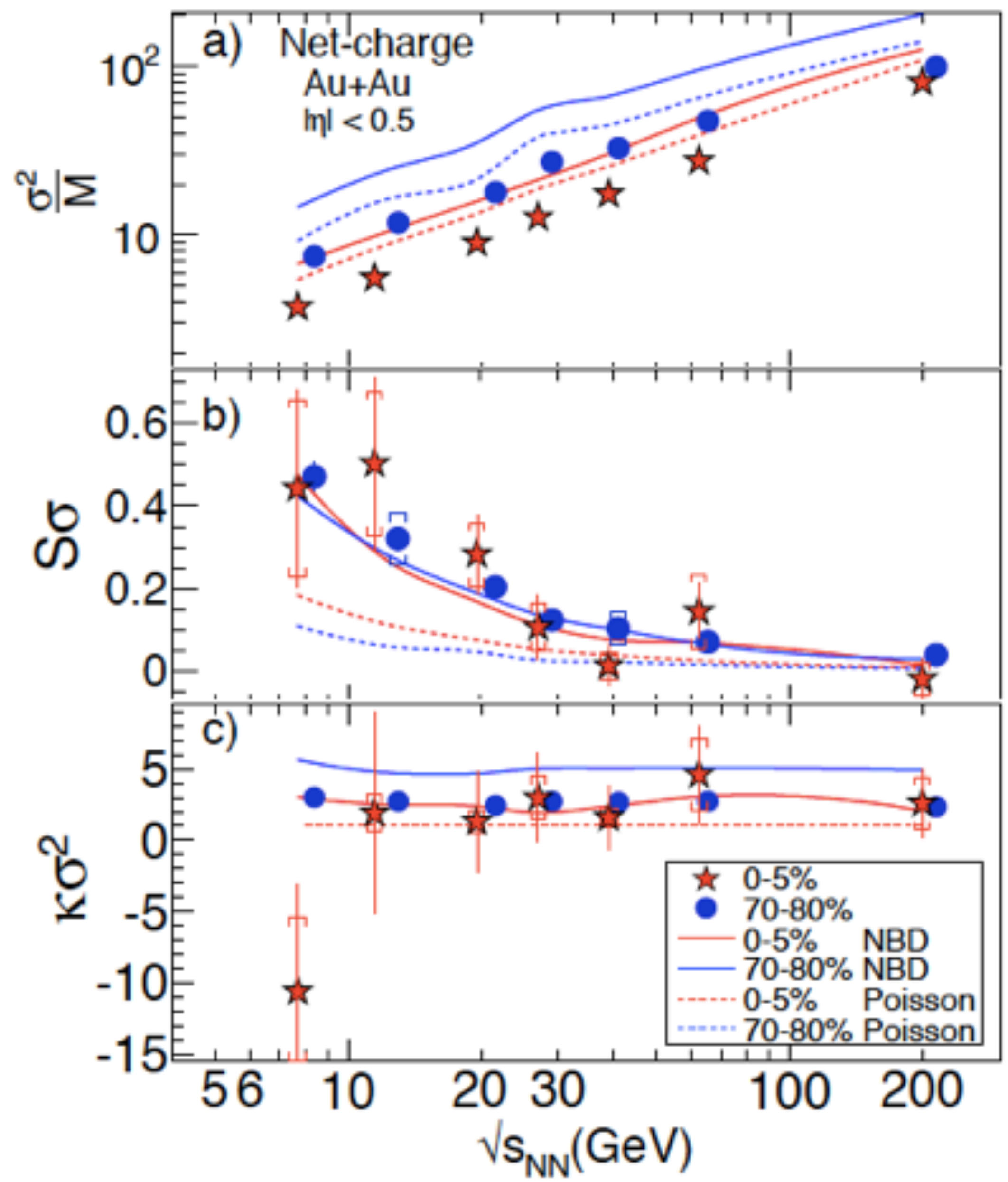


arXiv:1109.0593v1

Result of STAR

In most central collisions,seem to deviate from Poisson, at 7.7GeV

→Statistical error is large ,and fluctuation smaller than theoretical expectation



$$= \frac{c_2}{c_1}$$

$$= \frac{c_3}{c_2}$$

$$= \frac{c_4}{c_2}$$

Phys. Rev. Lett. 113, 092301

→We can't conclude this point is CP, and it is necessary to scan more precisely(BES II)

D-measure

D-measure is defined by 2 formula

D-measure1…

$$D = 4\frac{\langle \delta Q^2 \rangle}{\langle N_{ch} \rangle}$$

$$N_{ch} = N^+ + N^-$$
$$Q = N^+ - N^-$$

D-measure2…

$$D' = \langle N_{ch} \rangle \nu_{(+-,dyn)}$$

$$\begin{aligned} \nu_{+-,\mathrm{dyn}} &= \nu_{+-} - \nu_{+-,stat} \\ &= \frac{\langle N_+(N_+ - 1)\rangle}{\langle N_+\rangle^2} + \frac{\langle N_-(N_- - 1)\rangle}{\langle N_-\rangle^2} \\ &\quad -2\frac{\langle N_+ N_-\rangle}{\langle N_-\rangle \langle N_+\rangle} \end{aligned}$$

$$\langle N_{ch} \rangle \nu_{(+-,dyn)} \sim D - 4$$

Theoretically, it is expected that

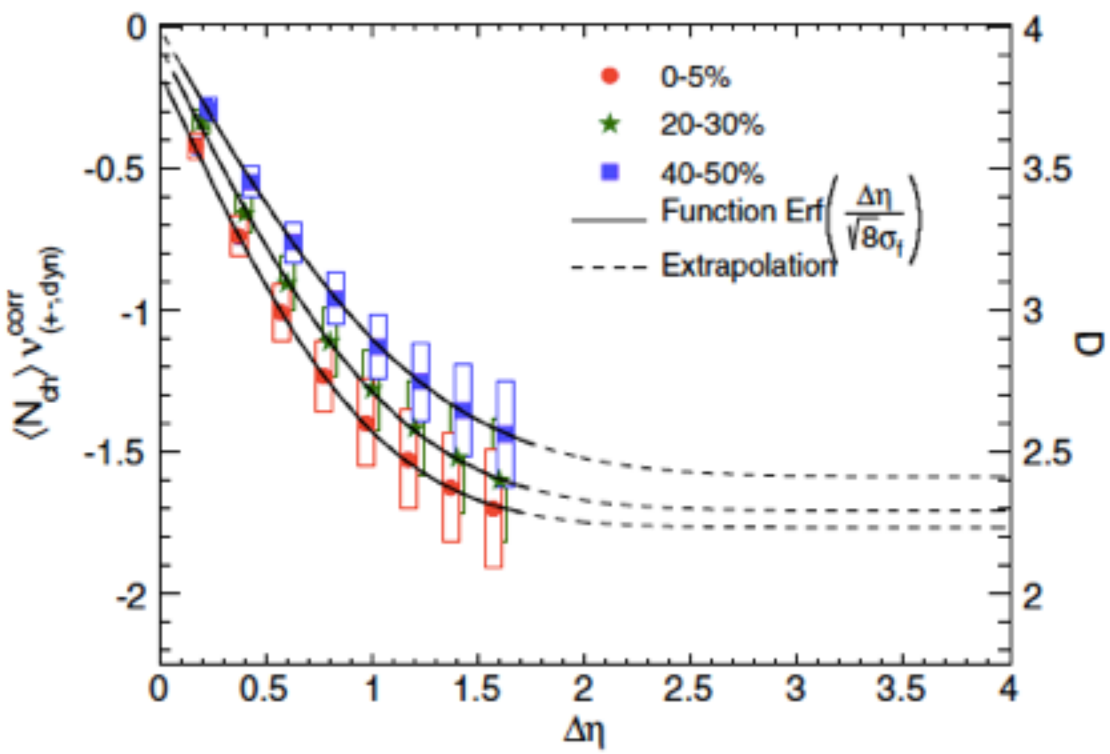
QGP fluctuation : D =1-1.5

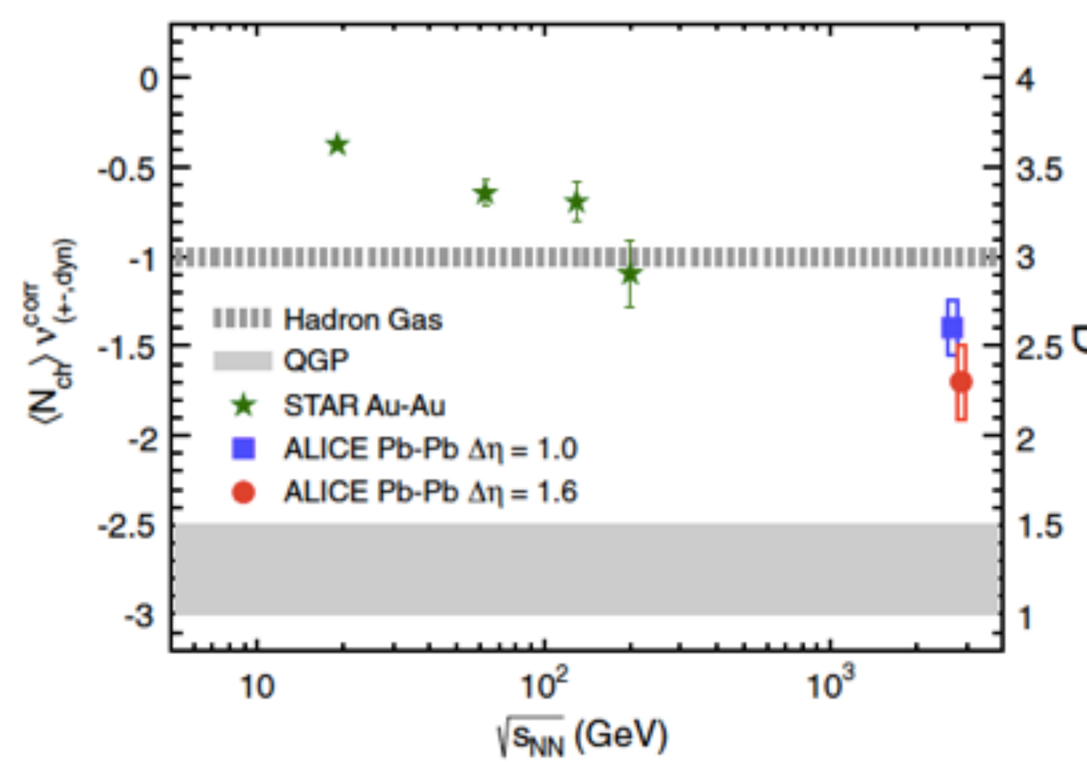
Hadron fluctuation : D= 3-4

D-measure and ALICE result

Pb Pb ALICE(2.76TeV)

PRL 110, 152301 (2013)





- As centrality become central, D-measure become small.
- As energy become large, D-measure become small

Expanding $\Delta\eta$ ··· we can see the signal of QGP fluctuation

My analysis

- At published result of net-charge fluctuation of STAR, it is calculated 1-4th ordered cumulant ratio.

- I calculated Npart and $\Delta\eta$ dependence of 1-6th ordered cumulants and their ratio , because the more higher order the cumulant is, the more high power of the correlation length the cumulant is proportional to.

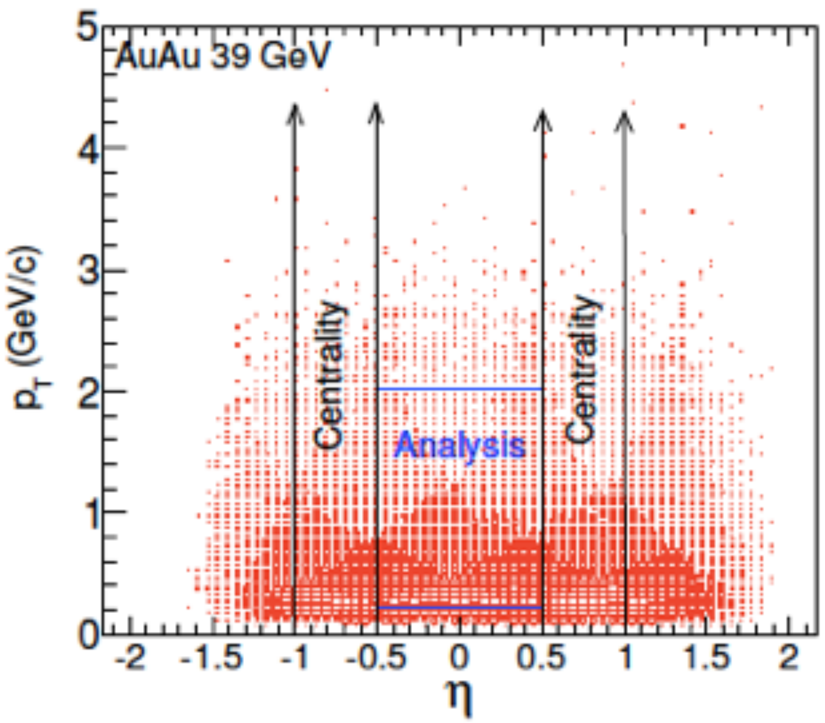
- At published result of D-measure at STAR and ALICE, $\Delta\eta$ and energy dependence of D-measure using nu_dynamics is calculated.

- I calculated 2 definition of D-meausure. D-measure1 is using 2nd order cumulant and D-measure2 is using nu_dynamics.
- I calculated $\Delta\eta$ and energy dependence of D-measure.

Data set

RHIC STAR experiment

Au+Au 7.7GeV, 11.5GeV, 19.6GeV, 27GeV



$0.5 < |\eta| < 1$ …used to define centrality

$\left(\begin{array}{l} |\eta| < 0.5 \\ 0.2 < p_T < 2.0 \end{array} \right.$ …used to net-charge analysis

Event selection

$|V_z| < 30$ $|V_r| < 2$

(Same as Nihar's fluctuation analysis)

Track cut (analysis)

- The list of primary track quality cuts can be found in the following table.

Transverse momentum	0.2 to 2 GeV/c
Pseudorapidity (η)	-0.5 to 0.5
nFitPoints	>20
gDCA	<1 cm
Track quality cut	>0.52
nhitsdedx	>10

- The spallation protons have been removed within p_T range: $200 < p_T < 400$ MeV/c and $|\eta|$ <0.5 [with nFitPoints > 20 and fabs(gDca) < 1 and fabs(nSigmaProton) < 2 and nhitsdedx > 10] . The detail discussion about the background protons due to beam pipe interaction can be found from Ref. [7].

(Same as Nihar's fluctuation analysis)

Track cut (centrality)

$$0.5 < |\eta| < 1$$

$$\text{nhitsdedx} \ > 10$$

- Event by event z-vertex correction has been done for Refmult2 (correction parameter is determined at run by run)

Efficiency Correction

Cumulant is sensitive to tracking efficiency, so we have to correct this effect using factorial moment method.

True cumulant (we want to get and can't know directly at experiment)

Experimental cumulant (we can get directly at experiment)

$$
\begin{aligned}
pK_1 &= c_1 \\
p^2K_2 &= c_2 - n(1-p) \\
p^3K_3 &= c_3 - c_1(1-p^2) - 3(1-p)(f_{20} - f_{02} - nc_1)
\end{aligned}
$$

$$
\begin{aligned}
p^4K_4 &= c_4 - np^2(1-p) - 3n^2(1-p)^2 - 6p(1-p)(f_{20} - f_{02}) + 12c_1(1-p)(f_{20} - f_{02}) \\
&\quad -(1-p^2)(c_2 - 3{c_1}^2) - 6n(1-p)({c_1}^2 - c_2) \\
&\quad -6(1-p)(f_{03} - f_{12} + f_{02} + f_{20} - f_{21} + f_{30})
\end{aligned}
$$

$$f_{ab} = \left\langle \frac{n_1!}{(n_1-a)!} \frac{n_2!}{(n_2-b)!} \right\rangle$$ …factorial moment

Efficiency Correction

published plot ··· using average efficiency

efficiency of N_+ and N_- are both $\frac{\epsilon_+ + \epsilon_-}{2}$

I think we should use separate efficiency

efficiency of N_+ → ϵ_+

efficiency of N_- → ϵ_-

I calculated average and separate efficiency correction and compare the difference of 2 correction.

Other Correction

- Centrality Bin Width Correction has been done

$$\sigma = \frac{\sum_r n_r \sigma_r}{\sum_r n_r} = \sum_r \omega_r \sigma_r \qquad Err\_X = \sqrt{\sum_i w_i^2 \, Err\_X_i^2},$$

Statistical error estimation

- Statistical error is determined by bootstrap method

Number of Bootstrap…100

Systematic Error

For the systematic error estimation, following cuts have been analyzed

- nFitpoints 18, 20(default), 22
- DCA 0.8, 1.0(default), 1.2
- nhitsdedx 8, 10(default), 12
- efficiency ± 5%

i : from 1 to 3

The systematic errors have been estimated as

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

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

Y_i : Moments values from different cut

$Y_{st.cut}$: Moments values from default cut

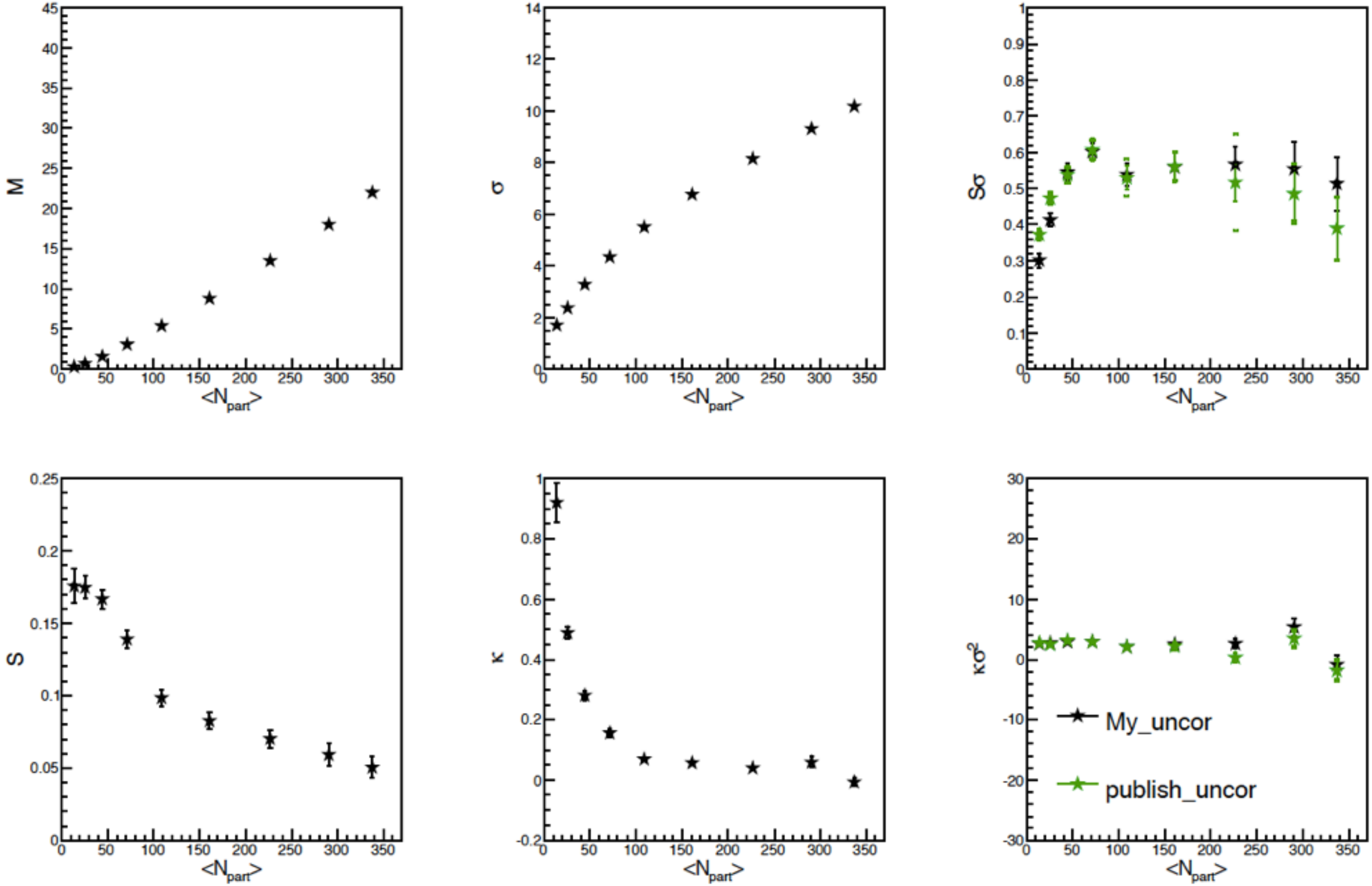
7.7GeV

x-axis… N_{part}

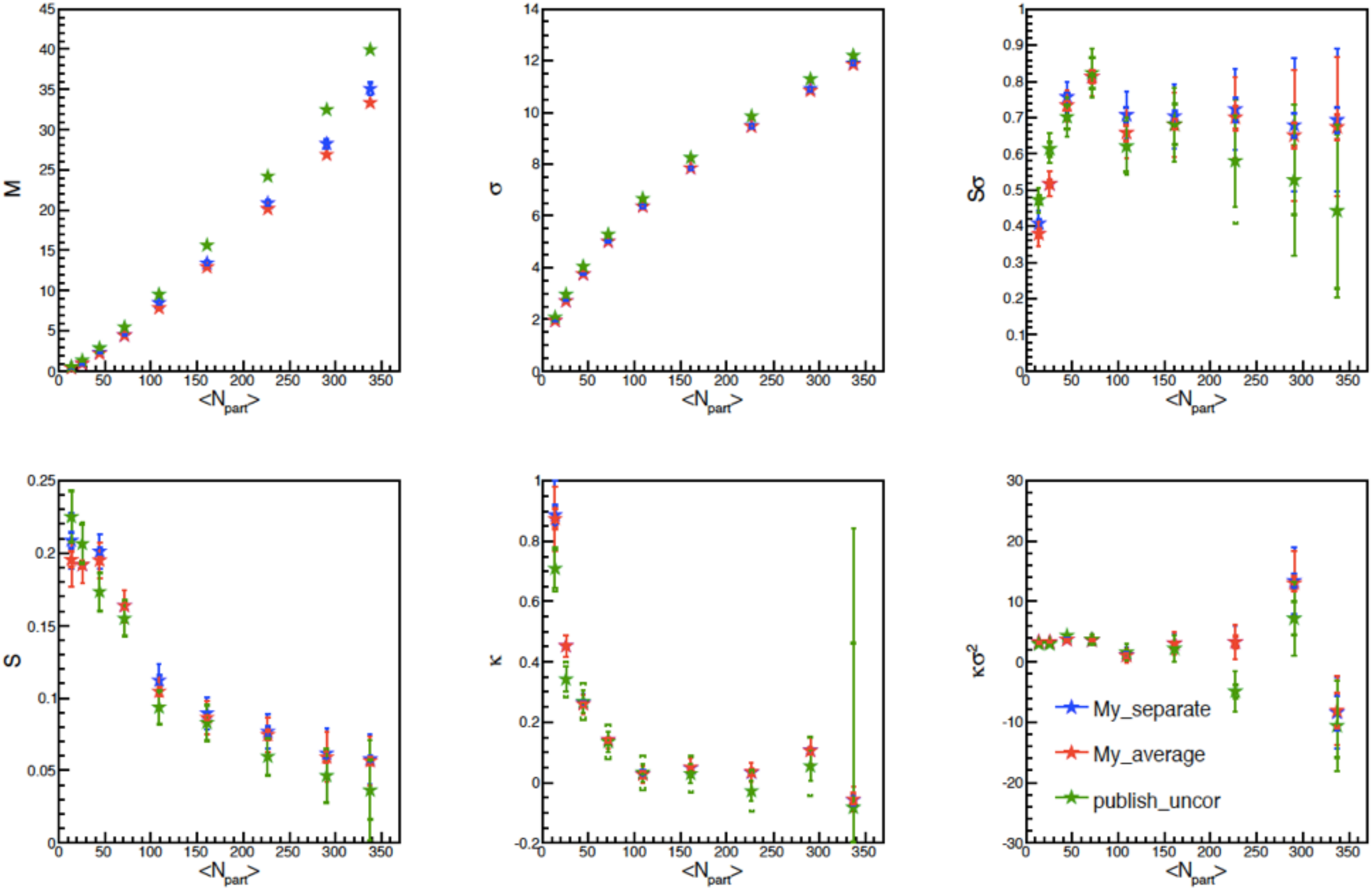
(Efficiency uncorrected,average corrected,

separate corrected will be shown)

Efficiency Un-corrected Moment (7.7GeV)



Efficiency Corrected Moment (7.7GeV)

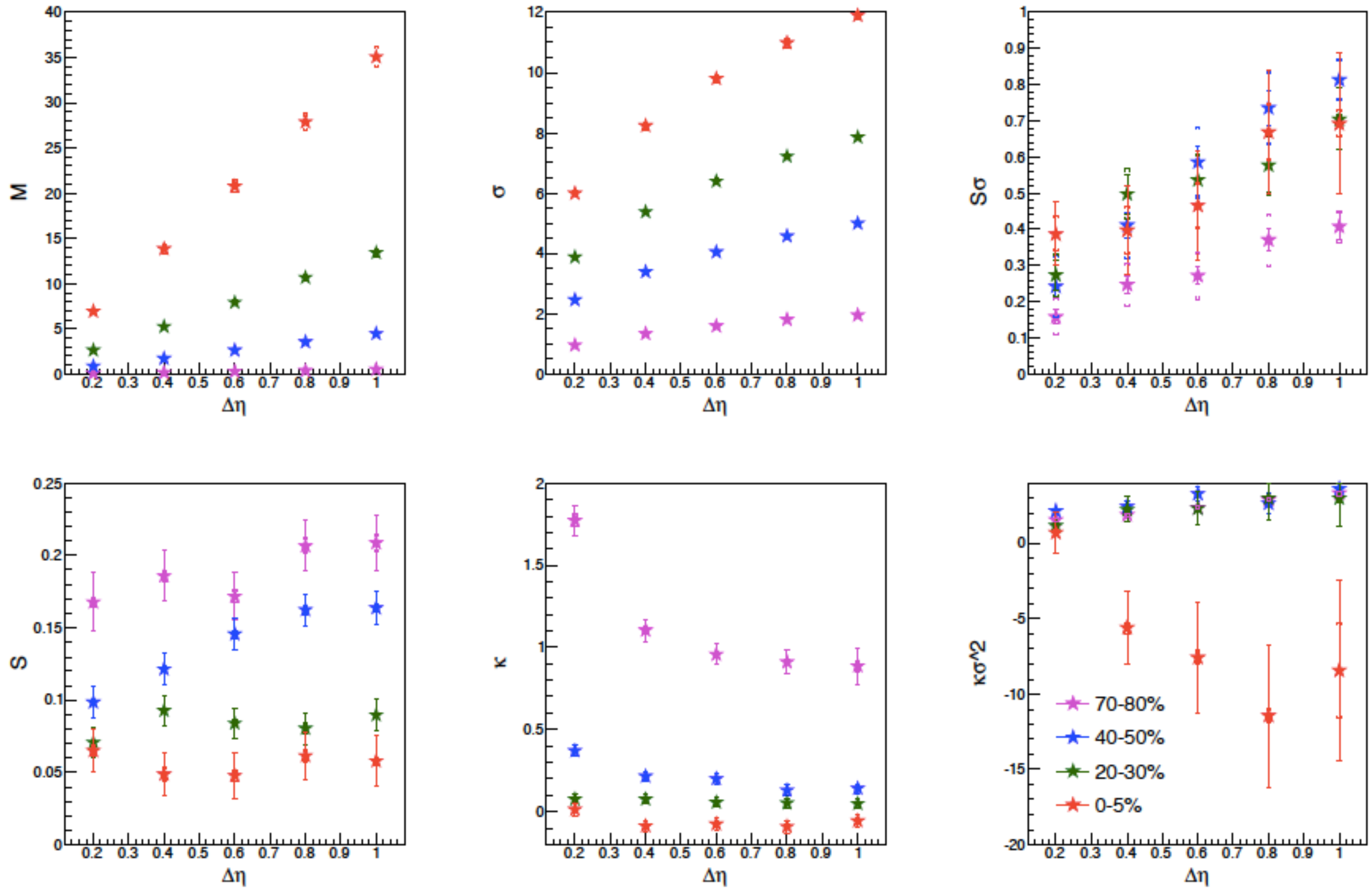


7.7GeV

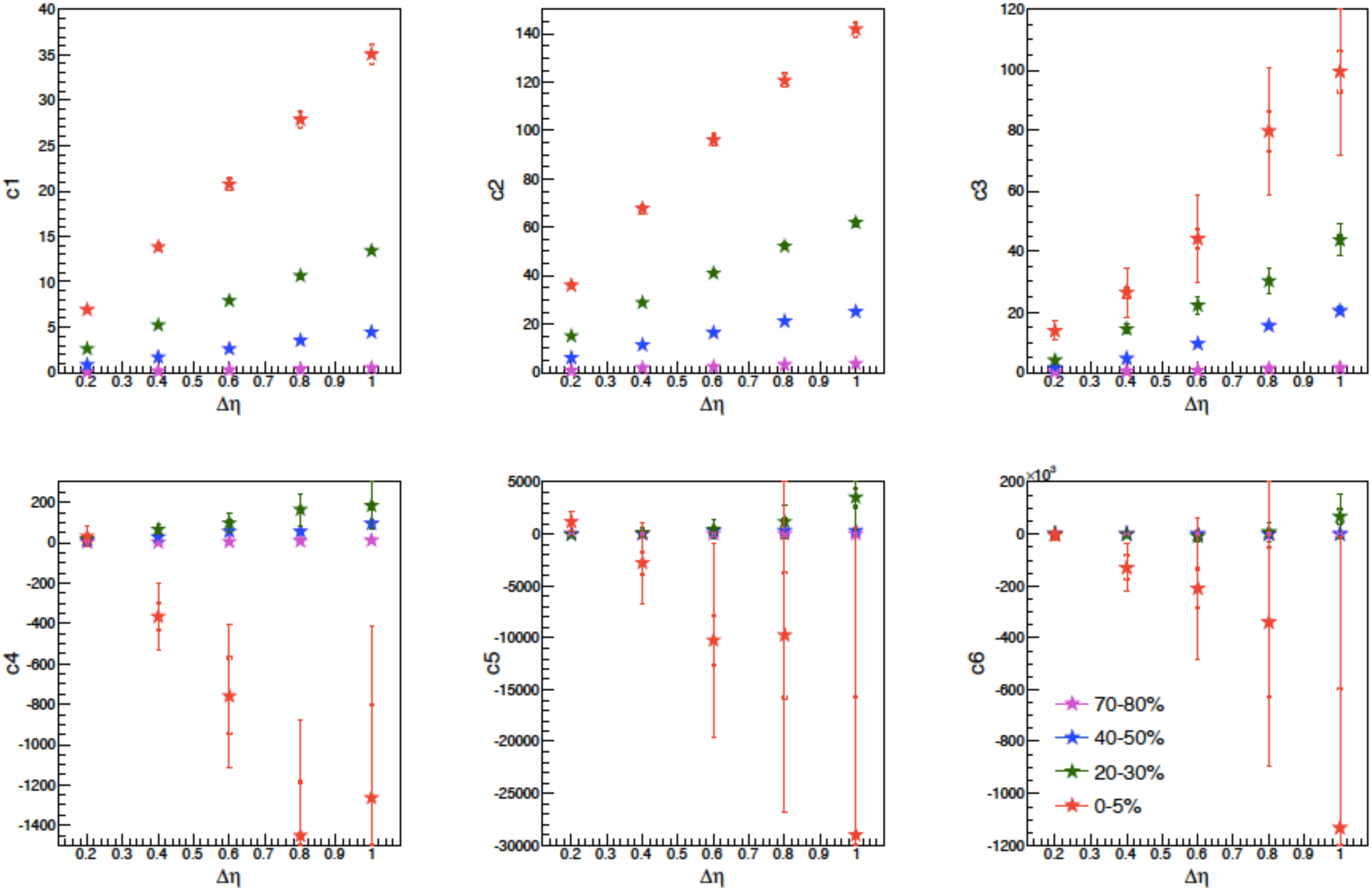
x-axis… $\Delta\eta$

(Centrality 0-5%, 20-30%,40-50%,70-80%)

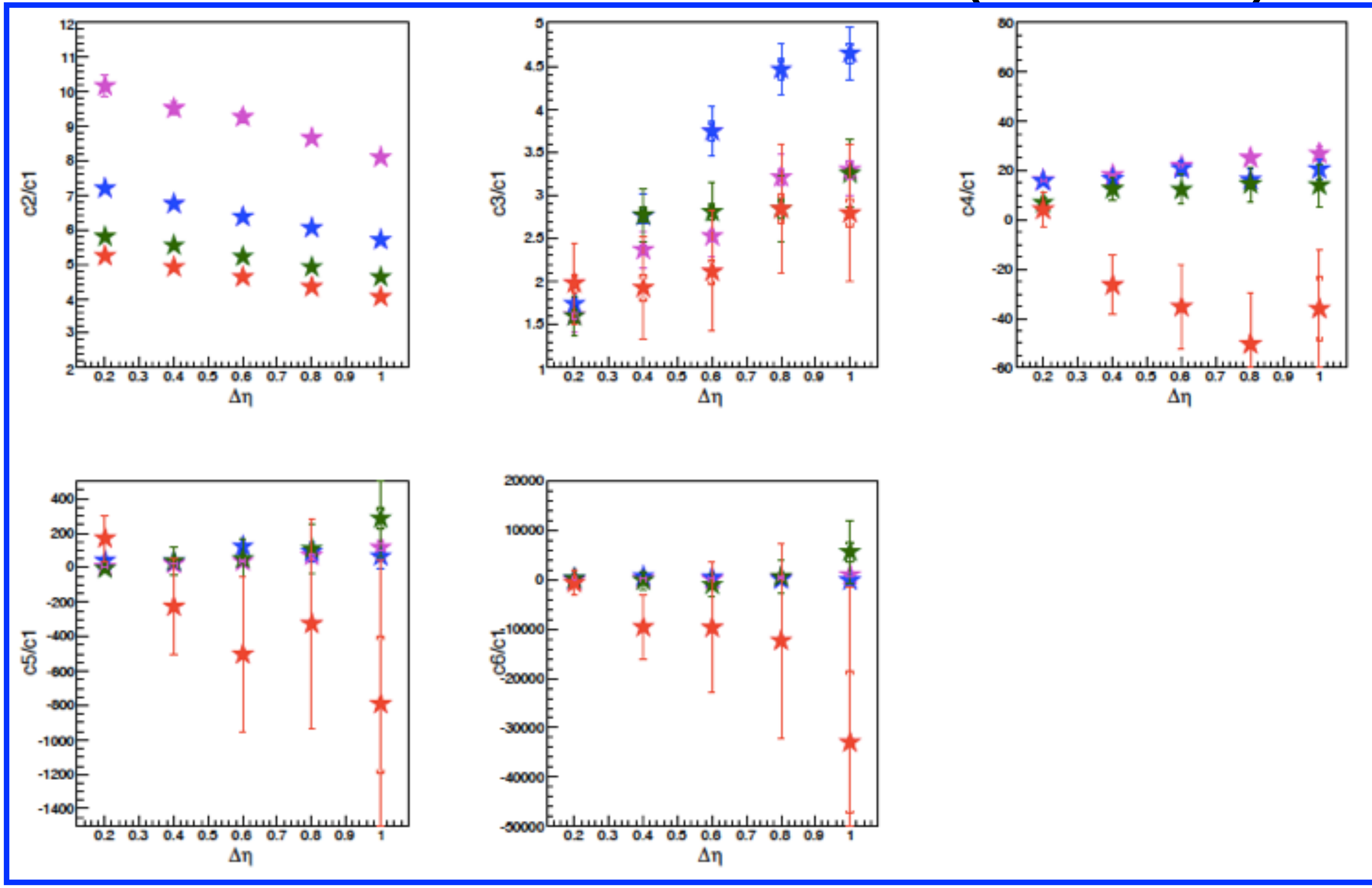
Moment (7.7GeV)



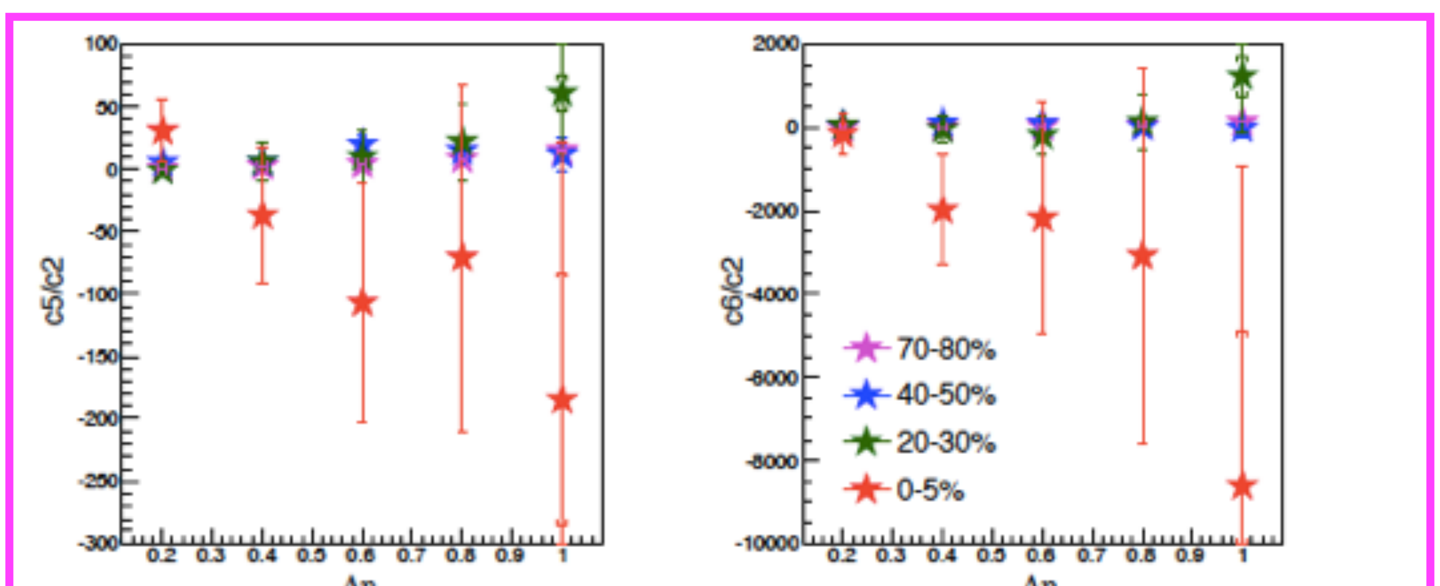
1st to 6th Cumulant (7.7GeV)



Other Cumulant Ratio(7.7GeV)



$$\frac{c_n}{c_1}$$



$$\frac{c_n}{c_2}$$ (without Sσ^2、 κ σ)

D-measure (7.7GeV)

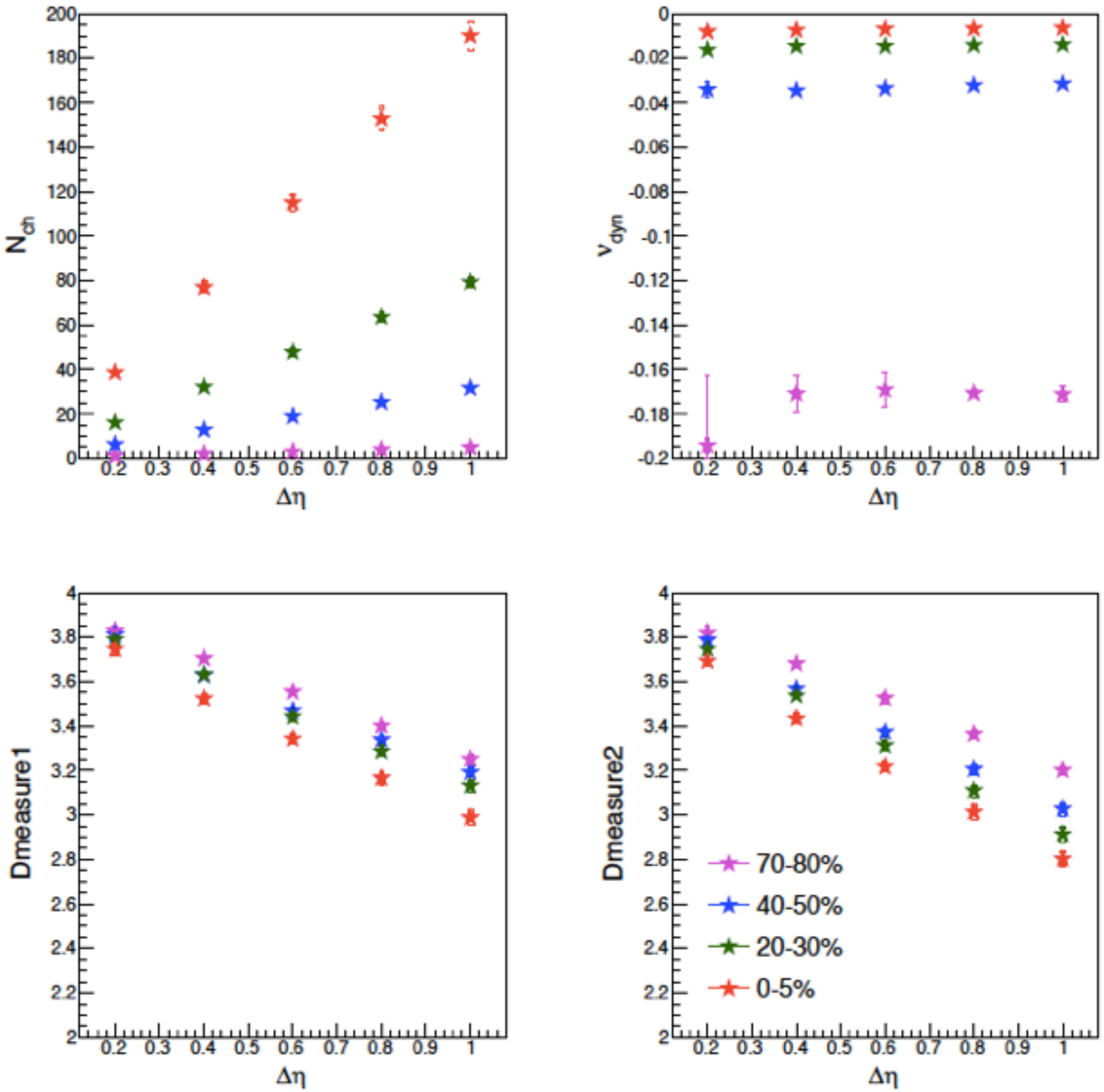
Defined by 2 formula

D-measure1

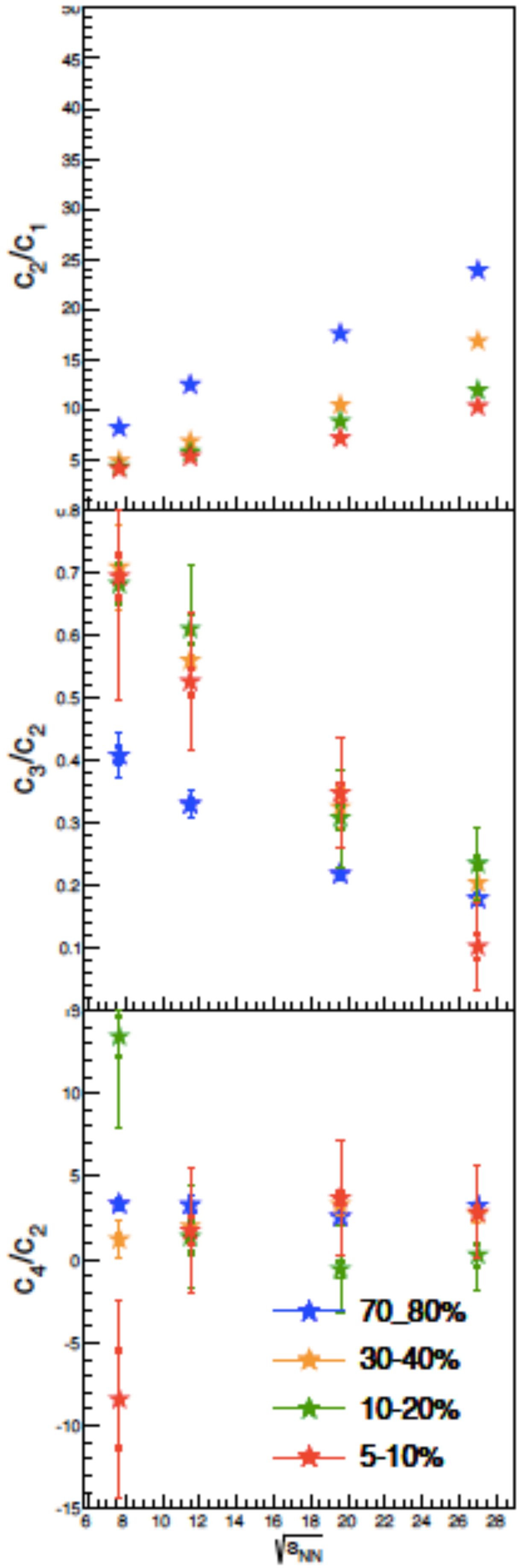
$$D = 4\frac{\langle \delta Q^2 \rangle}{\langle N_{ch} \rangle}$$

D-measure2

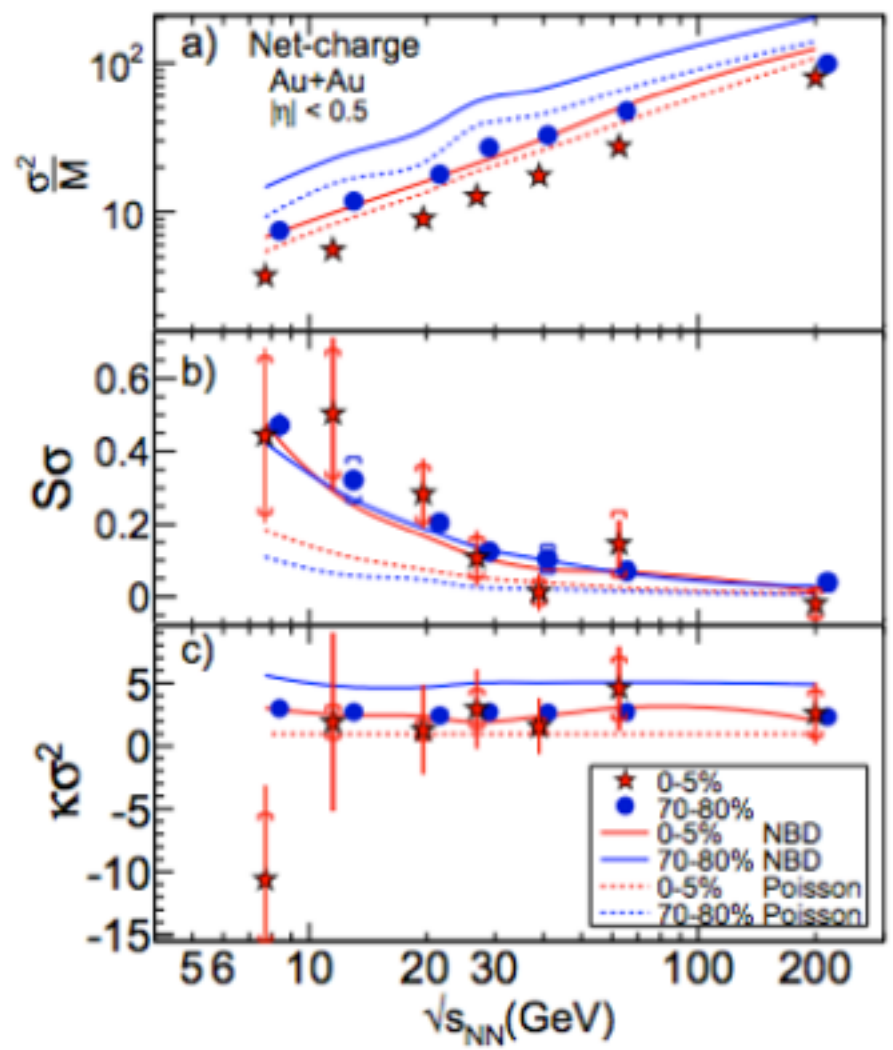
$$D = \langle N_{ch} \rangle \nu_{(+-,dyn)} + 4$$



Energy v.s. Cumulant ratio

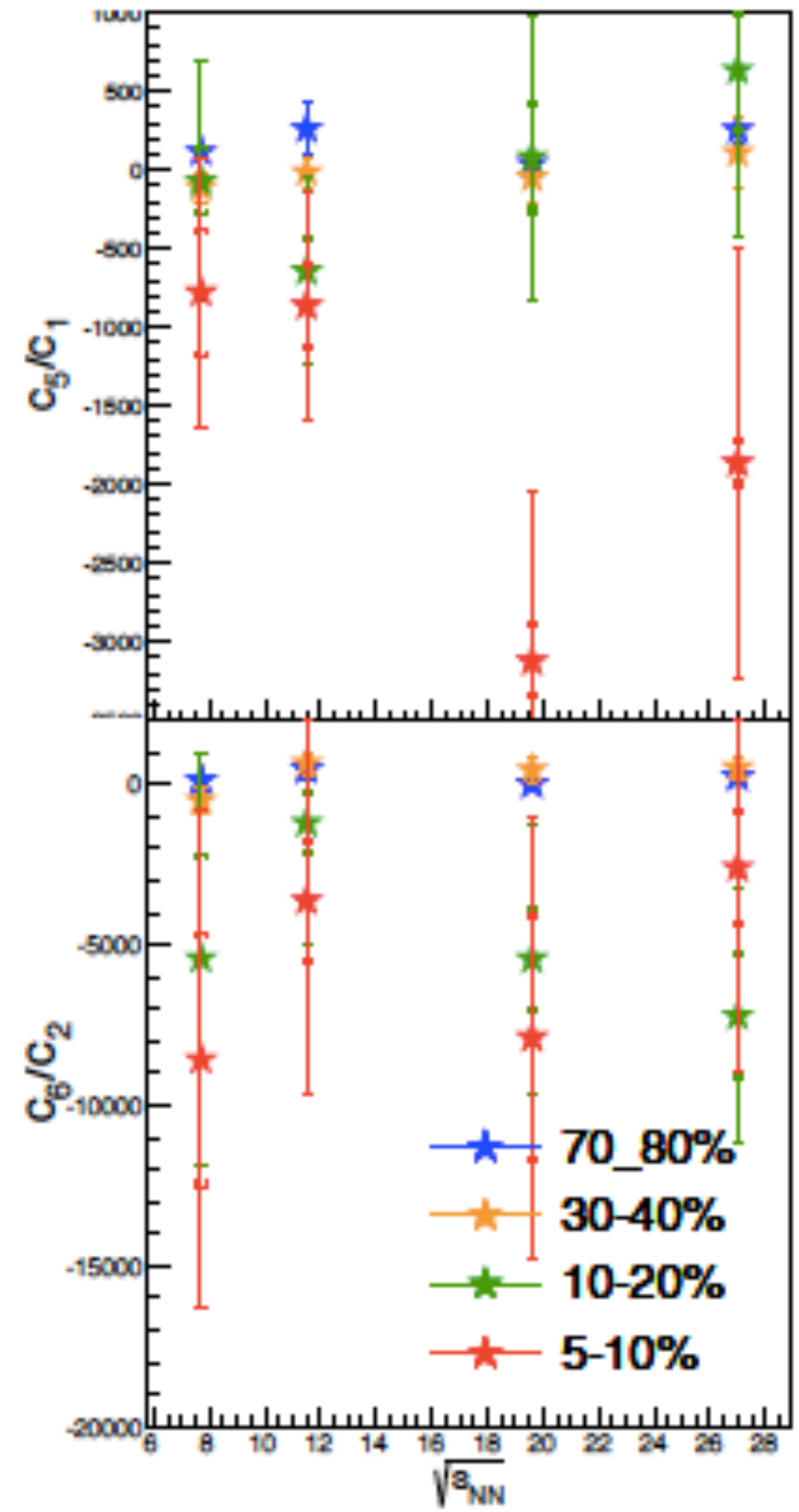


arXiv:1402.1558v3

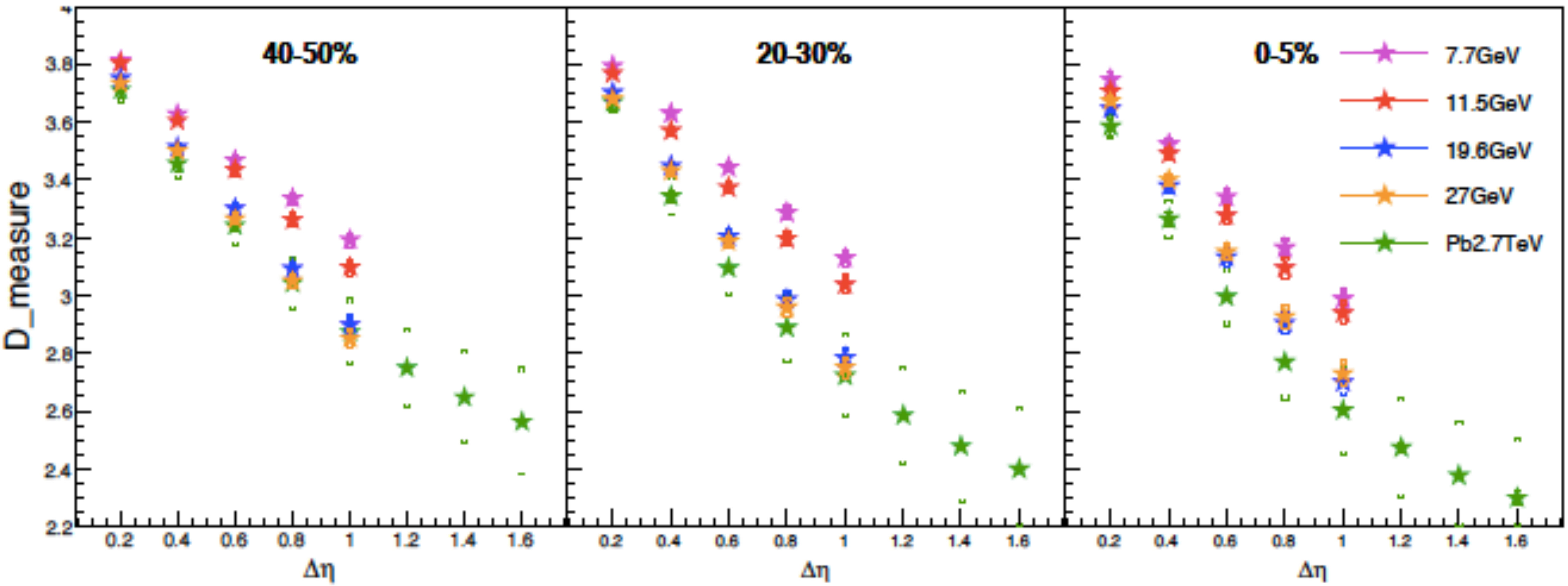


…c_3/c_2

…c_4/c_2

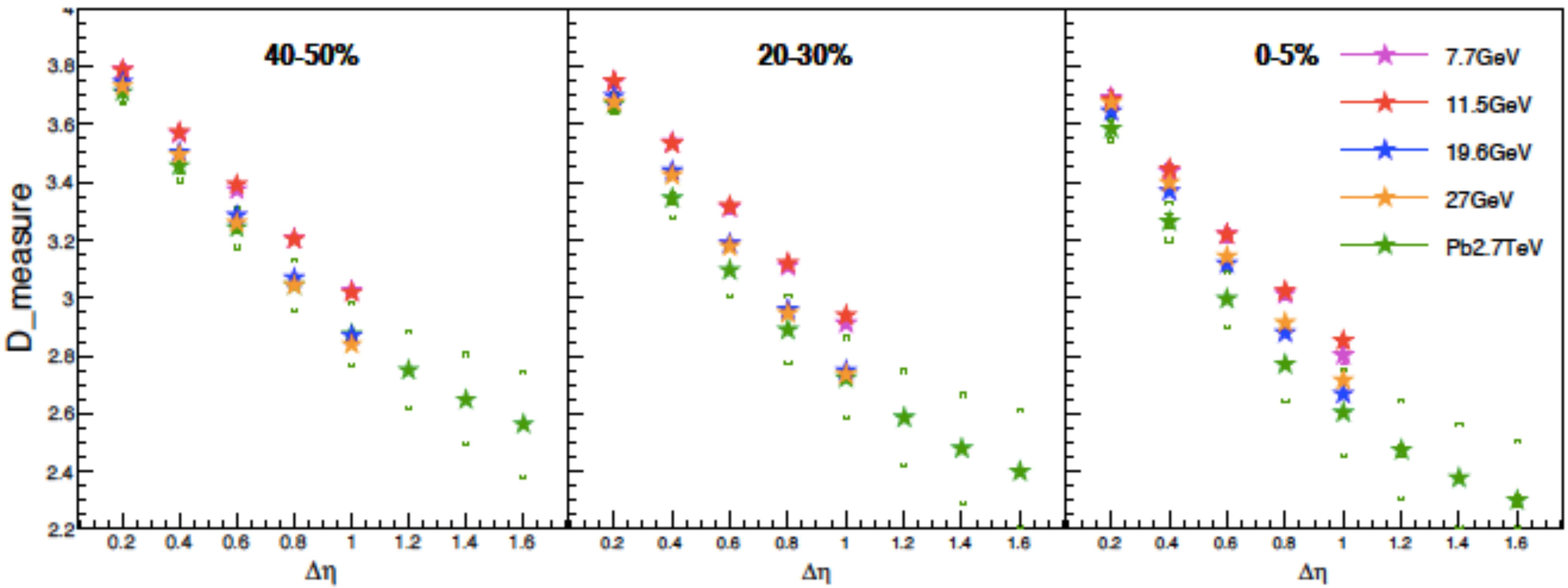


Δ η dependence of D-measure1



- As energy become higher, D-measure become small.
- But centrality 0-5% , we can't see difference of D(27GeV) and D(19GeV) (D(27GeV) > D(19GeV)?)
- Result ALICE(Green) is calculated by D-measure2, so in this figure, result of ALICE is plotted as reference.

Δ η dependence of D-measure2



- As energy become higher, D-measure become small.
- At central, D(11GeV) > D(7GeV) and D(27GeV) > D(19GeV)

Additional correction

But…

I should do additional correction to avoid effect of charge conservation and system size.

Total charged multiplicity in all acceptance

$$\nu_{(+-,dyn)} \rightarrow \nu_{(+-,dyn)} + \frac{1}{\langle N_{total} \rangle}$$

and result of ALICE have already done this correction, so strictly speaking, my result should't compare to result of ALICE yet.

If this correction are applied,
D-measure probably become slightly large.

Summary1

- I calculated 1-6 th Cumulant,cumulant ratio, and D-measure of net-charge at 7.7GeV, 11.5GeV, 19.6GeV, 27GeV.
  I saw N_{part}, $\sqrt{s_{NN}}$, and $\Delta\eta$ dependence.

- D-measure are calculated by 2 definition.

- At N_{part} and $\sqrt{s_{NN}}$ dependence, my data is consistent with published data in statistical and systematic error.
  (1-4 th cumulants and their ratio)

- At Cumulant Ratio, when c4/c2, we can see the deviation from Poisson at central at 7.7GeV (published result).
  But when see higher cumulant ratio
  (c5/c1,c6/c2), I can't see this deviation at central,
  so, I think deviation from Poisson at central at 7.7GeV (c4/c2) is not signal of CP.

Summary2

- Value of cumulant ratio using separate and average efficiency correction are different, but the difference is small.

- At $\Delta\eta$ dependence of D-measure, the same centrality dependence are seen at all energy.

- At analysis of D-measure, D-measure1(using 2nd order cumulant) is larger than D-measure2(using nu-dynamics)

- As energy become higher, D-measure become small.

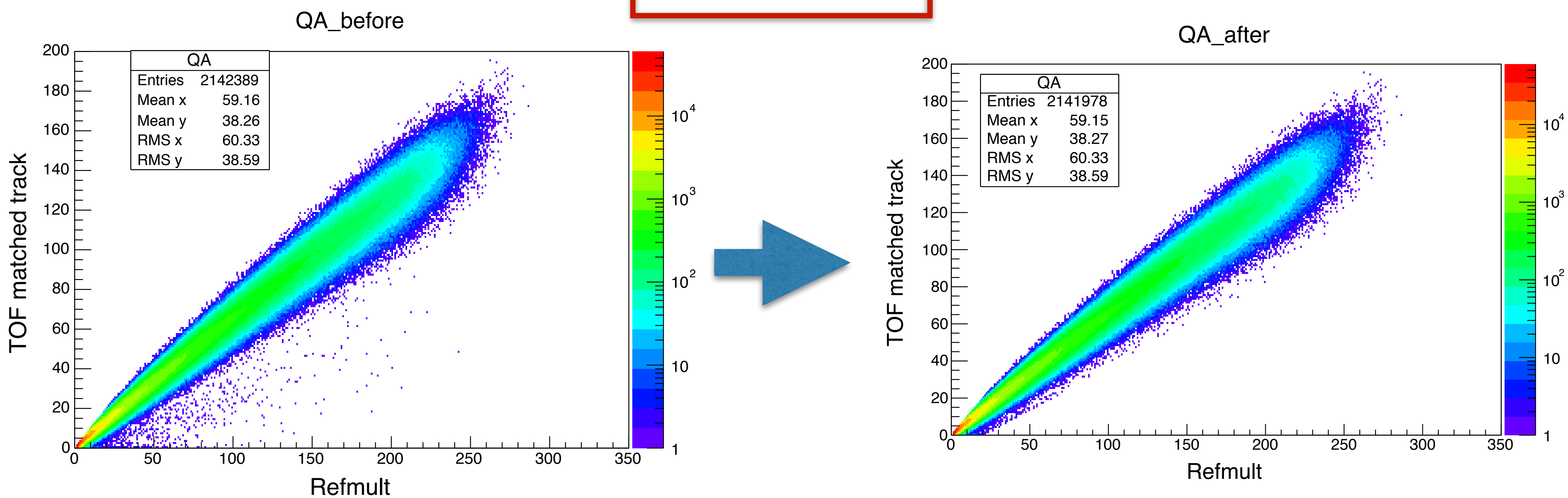
Next

- I should do an additional correction.

back up

Event QA (Remove pile up event)

7.7GeV



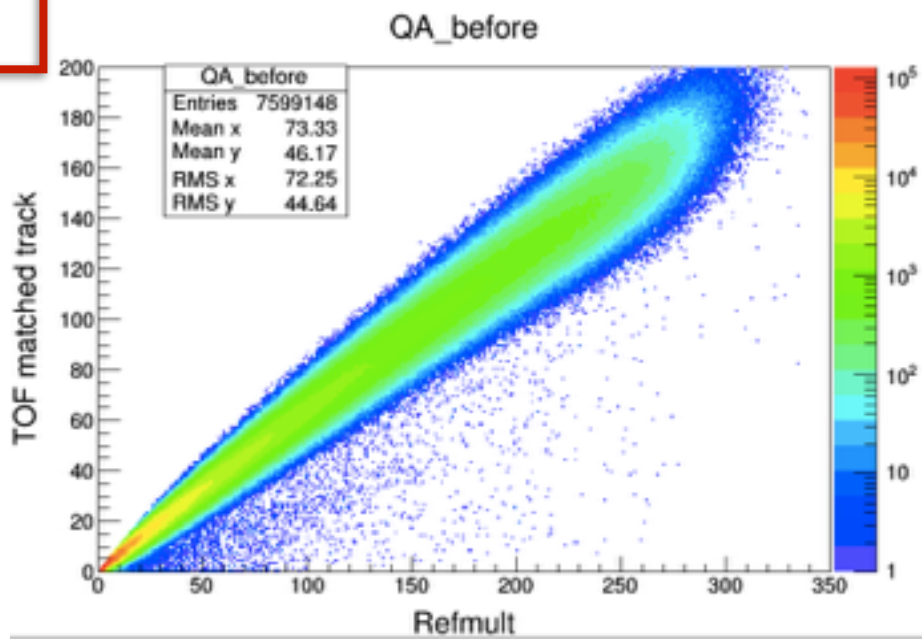
- Cut bewow y=0.46x-20

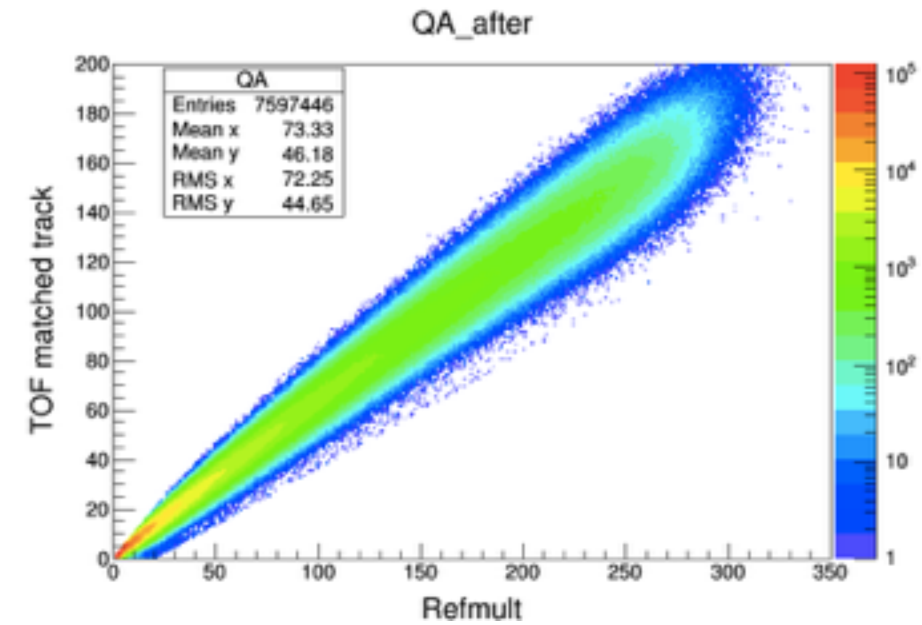
Run-by-run QA

- The run-by-run QA has been performed. The outlier run rejection has also been done (1.6σ). The <dca>, <p_T >, <η>, <Refmult>, <Φ>, <Primary Tracks>, etc. are used for the evaluation of sigma cut on the outlier run rejection. Where < ... > represents the event average for a given run number.

Event QA (Remove pile up event)

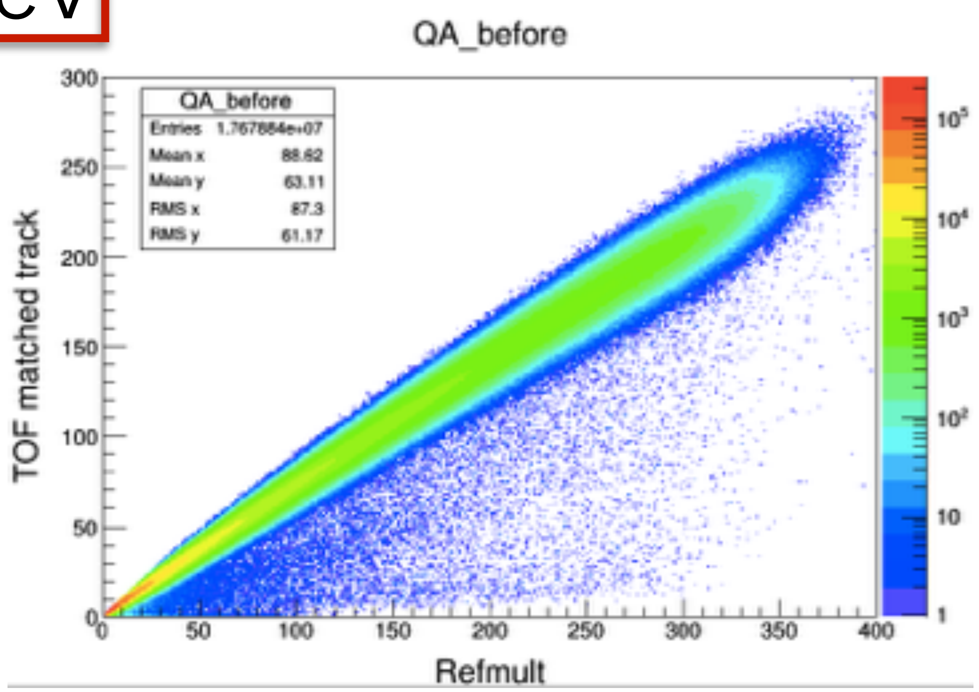
11.5GeV

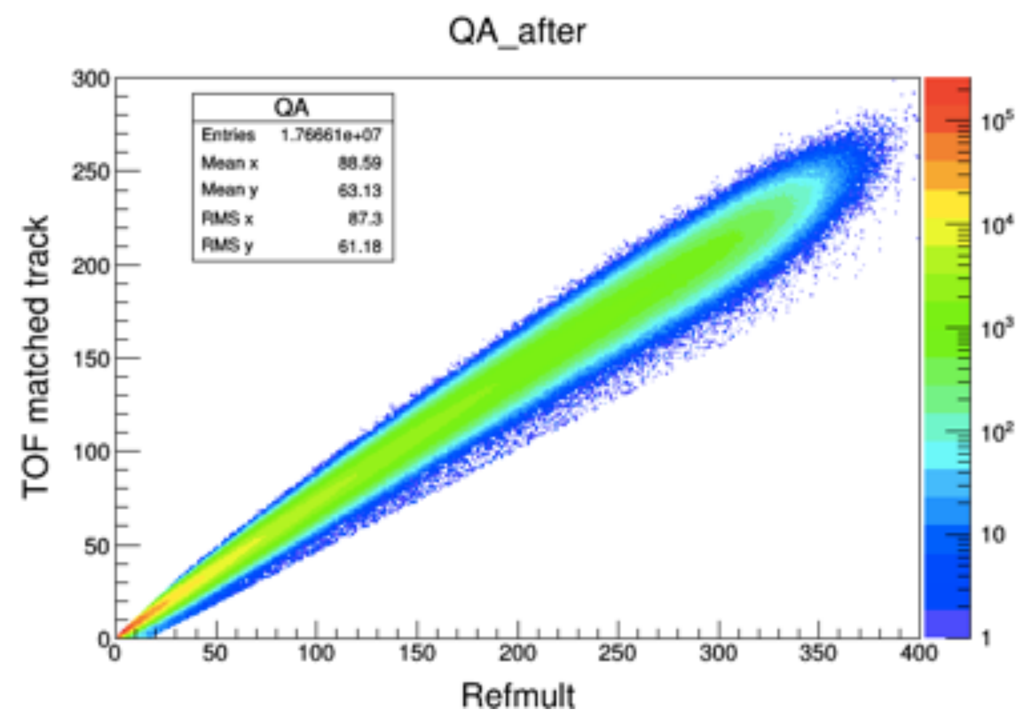




Cut below y=0.46x-20 (same as Nihar's analysis)

19.6GeV

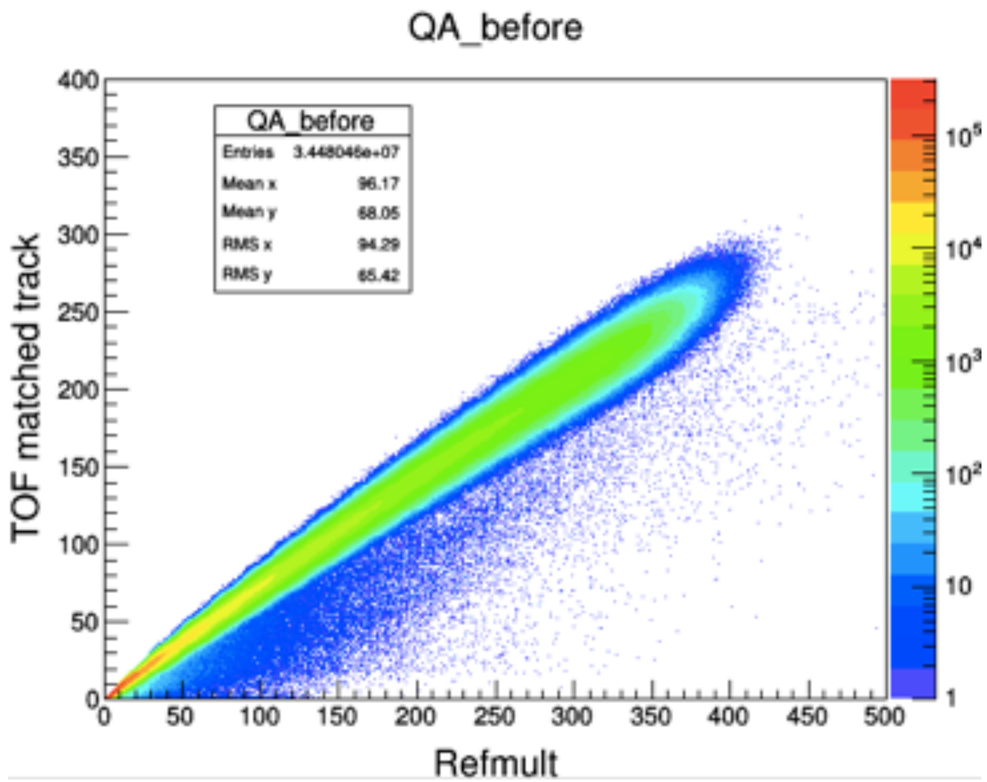


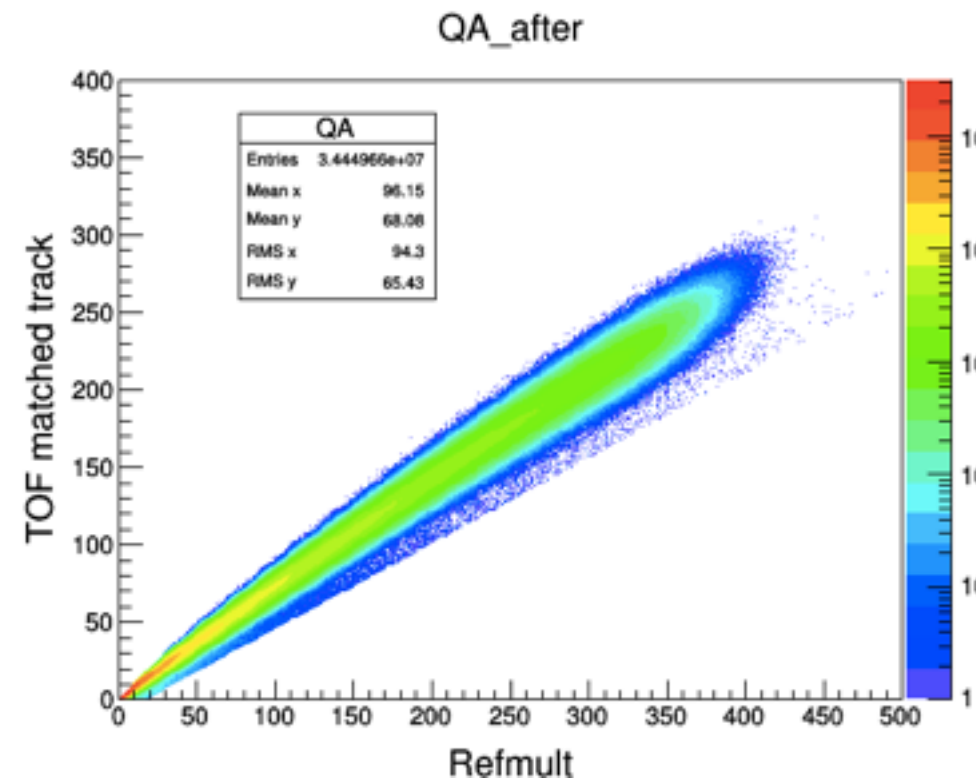


Cut below y=0.55x-20

Event QA (Remove pile up event)

27GeV





Cut below y=0.55x-20

Efficiency Correction

Table 2: Efficiencies for positive and negative particle for different centralities. The average efficiency (ε) is also listed below for different energies and centralities.

$\sqrt{s_{NN}}$(GeV)	0-5%	5-10%	10-20%	20-30%	30-40%	40-50%	50-60%	60-70%	70-80%
Positive charged particles (ε_+)									
62.4	0.62	0.63	0.64	0.65	0.66	0.67	0.69	0.68	0.70
39	0.62	0.64	0.65	0.66	0.67	0.67	0.68	0.70	0.71
27	0.63	0.65	0.65	0.66	0.67	0.68	0.68	0.69	0.70
19.6	0.63	0.66	0.67	0.67	0.68	0.69	0.70	0.71	0.71
11.5	0.64	0.65	0.66	0.67	0.68	0.69	0.70	0.71	0.72
7.7	0.65	0.66	0.67	0.68	0.69	0.70	0.71	0.72	0.72
Negative charged particles (ε_-)									
62.4	0.64	0.65	0.66	0.67	0.68	0.69	0.70	0.71	0.72
39	0.64	0.65	0.66	0.67	0.68	0.69	0.69	0.70	0.72
27	0.65	0.66	0.66	0.67	0.67	0.68	0.69	0.69	0.71
19.6	0.66	0.67	0.67	0.68	0.69	0.70	0.71	0.72	0.72
11.5	0.67	0.67	0.68	0.69	0.70	0.71	0.72	0.72	0.73
7.7	0.66	0.67	0.68	0.69	0.71	0.70	0.72	0.72	0.73
Average ($\varepsilon = (\varepsilon_+ + \varepsilon_-)/2$)									
62.4	0.63	0.64	0.65	0.66	0.67	0.68	0.69	0.69	0.71
39	0.63	0.64	0.65	0.66	0.66	0.68	0.68	0.70	0.71
27	0.64	0.65	0.65	0.67	0.67	0.68	0.68	0.69	0.70
19.6	0.65	0.66	0.67	0.68	0.69	0.70	0.70	0.71	0.72
11.5	0.66	0.66	0.67	0.67	0.68	0.69	0.70	0.71	0.72
7.7	0.66	0.67	0.67	0.68	0.69	0.70	0.71	0.72	0.73

7.7GeV

x-axis… N_{part}

(Efficiency uncorrected,average corrected,

separate corrected will be shown)