VECC

Paper Proposal

Charge particle multiplicity fluctuations in Pb-Pb collisions at \sqrt s_{NN} = 2.76 TeV in ALICE

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VECC, Kolkata

ALICE-India Collaboration Meeting
(SINP, 6-7th Feb, 2016)

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Motivation : Fluctuations in Particle Multiplicity

- QCD phase transition can manifest itself by characteristic behavior of several observables which may vary dramatically from one event to the other.
- Multiplicities, Average transverse momenta, particle ratios and conserved quantities are basic fluctuation measures.
- Fluctuations are usually characterized by scaled variances.
- Dynamical fluctuations (other than the statistical fluctuation and fluctuation in the number of participants) may provide insights on the intrinsic mechanisms of the particle production.

Scaled variance can be defined as:

$$\omega_{N_{ch}} = \frac{\langle N_{ch}^2 \rangle - \langle N_{ch} \rangle^2}{\langle N_{ch} \rangle} = \frac{Var(N_{ch})}{\langle N_{ch} \rangle}$$

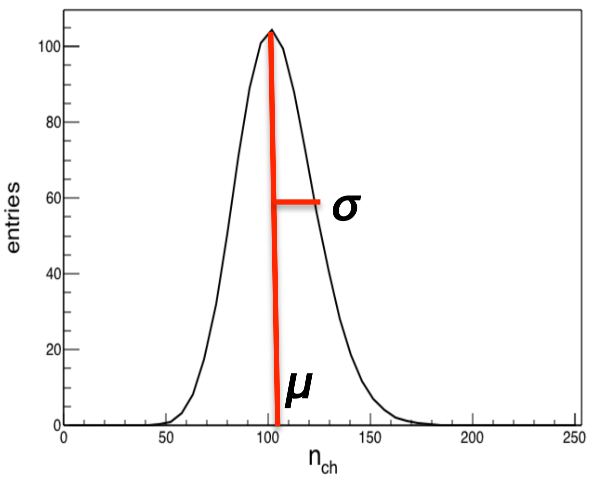
Where, $$< N_{ch} >= \frac{\sum N_{ch}}{n}$$

$$Var(N_{ch}) = \sigma_{ch}^2 =< N_{ch}^2 > - < N_{ch} >^2$$

Multiplicity fluctuations studied in WA98, NA49, CERES, PHENIX,PHOBOS, NA61 experiments ….

This work is the First time study at LHC ….

Definitions



Scaled variance can be defined as:

$$\omega_{ch} = \frac{\sigma^2}{\mu}$$

μ→ Mean,
σ² → Variance
of the charged particle multiplicity distributions.

Charge particle multiplicity distributions can be described by negative binomial :

$$P(n) = \frac{\Gamma(n+k_{NBD})}{\Gamma(n+1)\Gamma(k_{NBD})} \frac{(\mu / k_{NBD})^n}{(1+\mu / k_{NBD})^{n+k_{NBD}}}$$

$$where, \mu = < N_{ch} >$$

$$\sigma^2 = \mu + \mu^2 / k_{NBD}$$

Distribution-parameters are connected to fluctuations :

$$\omega_{ch} = 1 + \frac{\mu}{k_{NBD}}$$

Motivation : Fluctuations in Particle Multiplicity

- Variance is directly related to isothermal compressibility (k_T) of the system formed in heavy ion collisions..

$$\sigma_N^2 = \frac{k_B T < N >^2}{V} k_T$$

<N> : mean multiplicity
k_B : Boltzmann's constant.

Clear signature of the critical behaviour is possible to observe by looking for the expected power law scaling of k_T :

$$k_T \propto \left(\frac{T - T_C}{T_C} \right)^{-\gamma} \propto \varepsilon^{-\gamma}$$

γ : critical exponent for k_T

k_T is expected to increase by at least an order of magnitude close to the QCD critical point.

We can estimate the value of k_T from measurement of scaled variance.

Motivation : Fluctuations in Particle Multiplicity

- **Model calculations with Colour Glass Condensate (CGC) initial energy distributions have shown that ,experimental multiplicity distributions from d+Au collisions at RHIC, are better explained if multiplicity fluctuations are included.**

  (Ref : Adrian Dumitru and Yasushi Nara,Phys. Rev. C 85, 034907 (2012))

- **Various moments of the eccentricity of the collision zone in nucleus-nucleus collisions may be affected by multiplicity fluctuations in NN collisions.**

  (Ref: A. Chaudhuri, Phys. Rev. C **87**, 034908)

- **Entropy, and in turn, multiplicity fluctuate from event by event due to hydrodynamic evolution of the system.**

  (Ref : T.Hirano, QM 2014, Nuclear Physics A 931 (2014) c831).

Thus, measurement of multiplicity fluctuation is very important.

MULTIPLICITY FLUCTUATIONS

Statistical Fluctuations (have direct impact on Other measured quantities.)

Fluctuations having Dynamical Origin (of Physics interest)

MAIN SOURCES

- Choice of Centrality
- Fluctuations in Npart
- Effect of limited acceptance of detector

Prescription : Minimize statistical contributions as much as possible.

ANALYSIS FLOW-CHART

Minimum bias Events

↓

Vertex-Selection

↓

Centrality selection

↓

Track selection

↓

Results from Multiplicity Distributions

↓

Proper efficiency and contamination corrections

↓

Centrality binwidth corrections of the results

↓

Statistical Error Estimation with proper efficiency corrections

↓

Systematic effect Study

↓

Corrected final results for fluctuations

ALICE DATA ANALYSIS : CUTS USED

(LHC 10h pass2 AOD086)(~14M events)

Event cuts used :

Trigger: Minimum bias trigger (kMB)

Vertex cut: (Vx, Vy, Vz) < (0.3, 0.3, 10)cm

Centrality estimator: VOM

AliCentrality class used for centrality information

Track-cuts used :

Hybrid-track cuts (fb 272)

TPC-Only track-cuts (fb 128)

DCA_{xy} < 2.4 cm

DCA_z < 3.2 cm

Number of clusters > 80

X^2/ndf < 4

Acceptance:

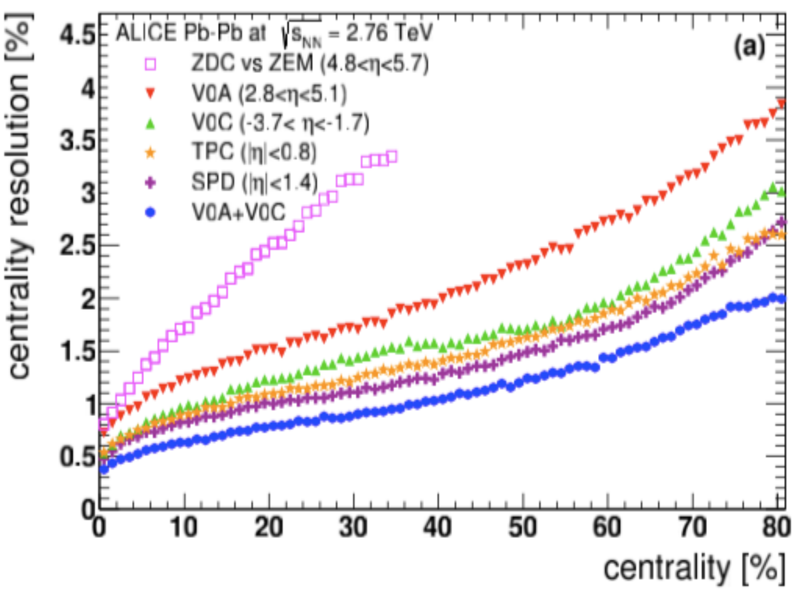
- -0.8 < eta < 0.8
- 0.2 GeV/c < pt < 2 GeV/c

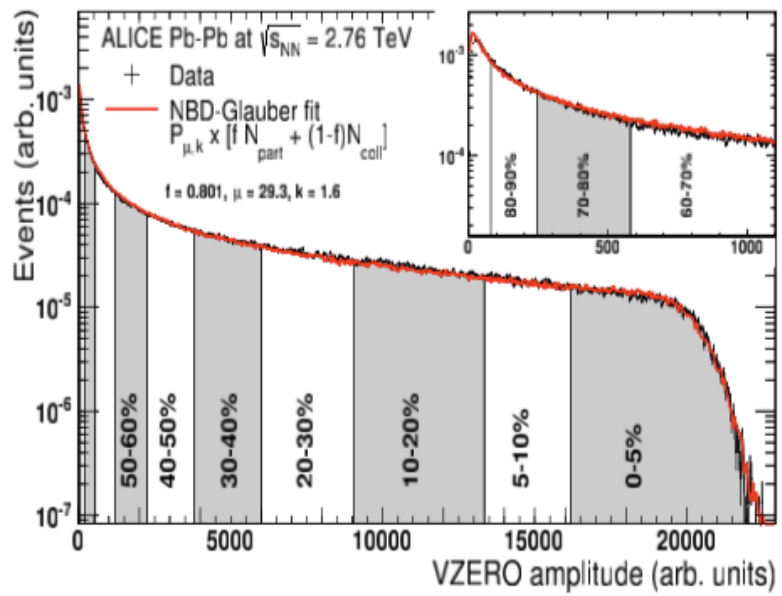
MC Analysis : With
LHC 11a10a bis_AOD090
~1.8M events

Centrality Selection

- Multiplicity distributions are centrality dependent
- Multiplicity fluctuations need to be estimated for narrow bins in centrality to avoid centrality bin width effects.
- Need good centrality resolution for the estimator

ALICE Collaboration: PRC 88 (2013)

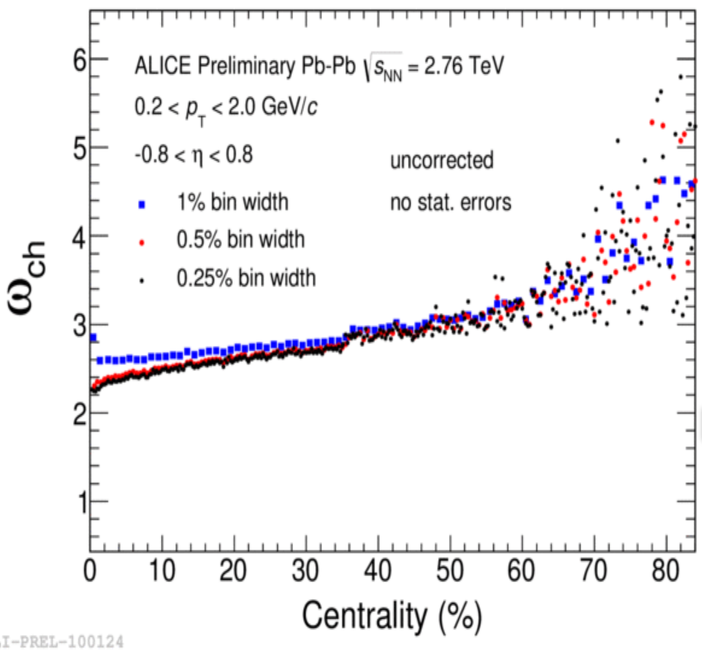


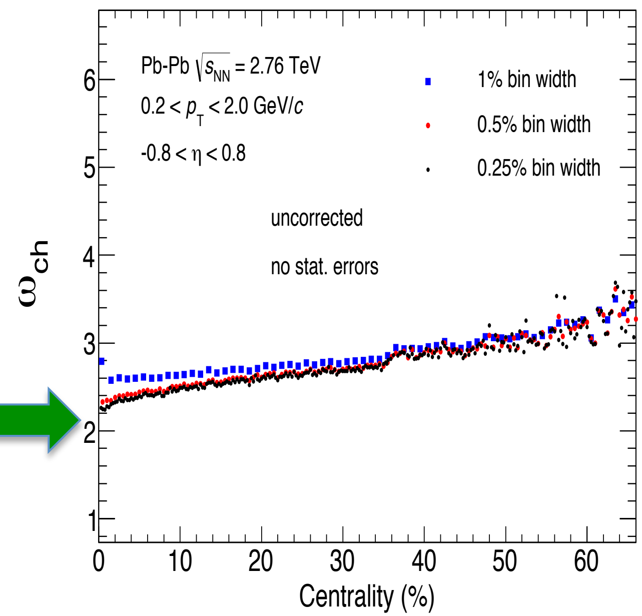


- Vzero amplitude (V0A+V0C) provide the best centrality resolution and has been used for centrality determination in the present work.

Centrality Binwidth Effect

Arises due to non-uniformity in charge-particle distributions.



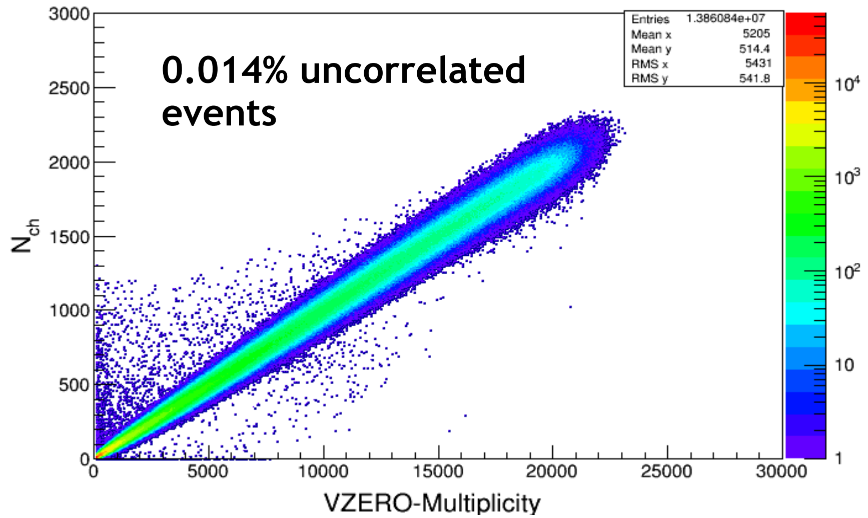


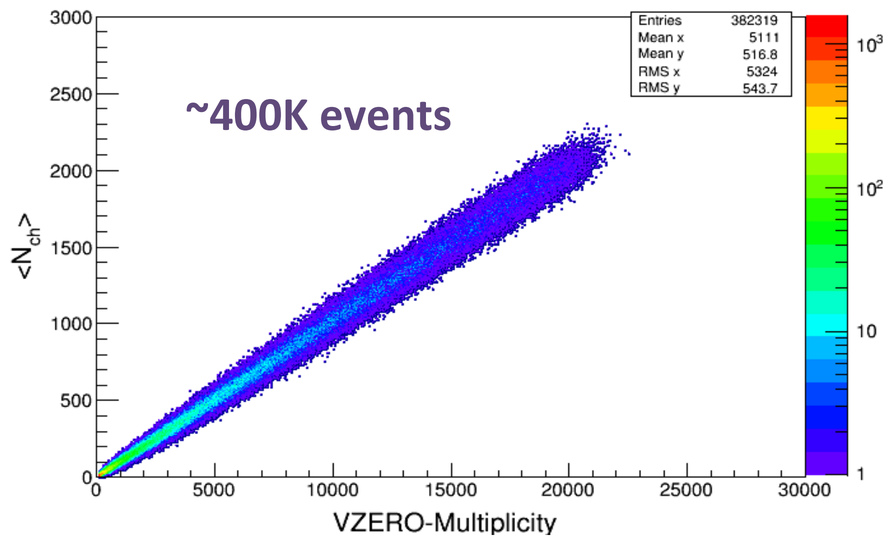
Centrality is selected here from V0-Amp (AliCentrality class)

$$X = \frac{\sum_i^k n_i X_i}{\sum_i^k n_i} = \sum_i^k w_i X_i$$

- **It is evident that for centrality from 0% to 40%, one needs to take 0.5% centrality bin, and from 40% and beyond, 1% centrality bin width is fine.**
- **The final results will be shown for 5% bins throughout – after bin width corrections.**

Data clean-up





Several things tried. Almost all run numbers have a few uncorrelated events. So it is very difficult to cleanup the data.

Run number-by-run number analysis done.
Only 13 runs taken having no outliers.

Investigation done how it affects the final result.

=> Down to Npart~50, cleaned and ALL events give same results
=> Decision: Results are shown down to Npart~50.

Difference ~ 0.5-1%. Added as systematics.

Correction for detector-inefficiency

Detector Efficiency

$$\varepsilon = \frac{Number\ of\ accepted\ tracks\ from\ primary\ particles}{Number\ of\ all\ primary\ particles}$$

For ALL charged particles, efficiency ~ 80%.

But for ALICE, ε is not a constant, rather has a non-flat p_T-dependence.

To correct for local efficiency-effects, equations used are :

$$F_1 = \langle N \rangle = \sum_{i=1}^{m} \langle N(x_i) \rangle = \sum_{i=1}^{m} \frac{\langle n(x_i) \rangle}{\varepsilon(x_i)}$$

$$F_2 = \sum_{i=1}^{m} \sum_{j=i}^{m} \frac{\langle n(x_i)(n(x_j) - \delta_{x_i x_j}) \rangle}{\varepsilon(x_i)\varepsilon(x_j)}$$

$$\sigma_N^2 = F_2 + F_1 - F_1^2$$

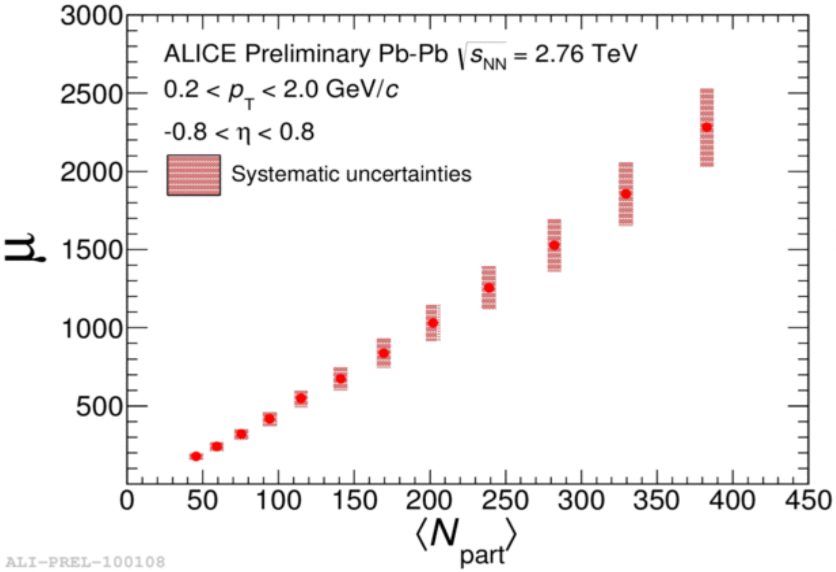
- Efficiency-factors include contamination effect too.
- Transverse-momentum binning used : (0.2,0.3,0.4,0.5,0.6,0.8,1.0,1.2,1.6,2.0) GeV/c

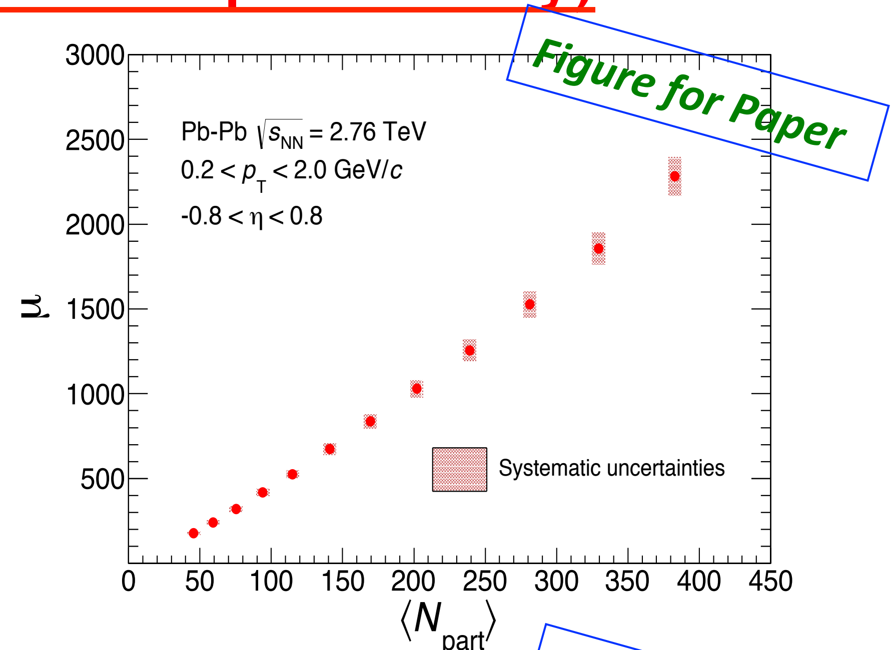
Systematic error : sources

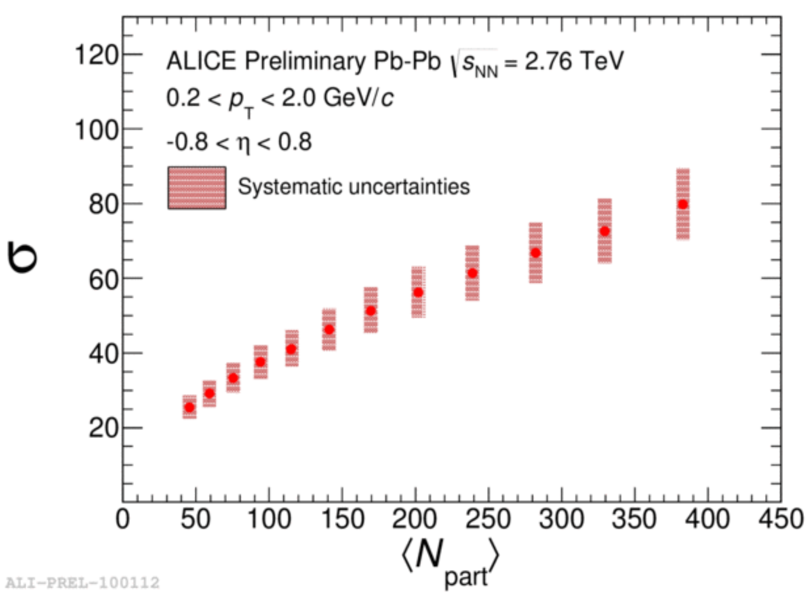
Sources of errors	Mean (μ)	Sigma (σ)	Scaled Variance (ω_{ch})
Diff. Track-cuts	3.5-4.8%	3.8-6%	4-7.5%
MC-closure	~0.01%	~0.7%	~1.4%
Diff vertex-cuts	0.1-0.5%	~0.5%	0.1-0.8%
Removal of Vx,Vy cuts	~0.10%	~0.20%	~0.5%
Mag. Polarity (positive)	0.1-0.5%	0.1-0.7%	0.1-0.8%
Mag polarity (neg)	0.1-0.7%	0.5-1%	0.8-1.5%
Data cleanup	0.1-0.5%	0.3-0.8%	0.9-1.5%
DCAxy	0.5-0.9%	0.8-1.2%	1.3-1.6%
DCAz	0.4-0.9%	0.7-1%	1.2-1.7%
Total	~3.5-5%	~4-6%	~6-8%

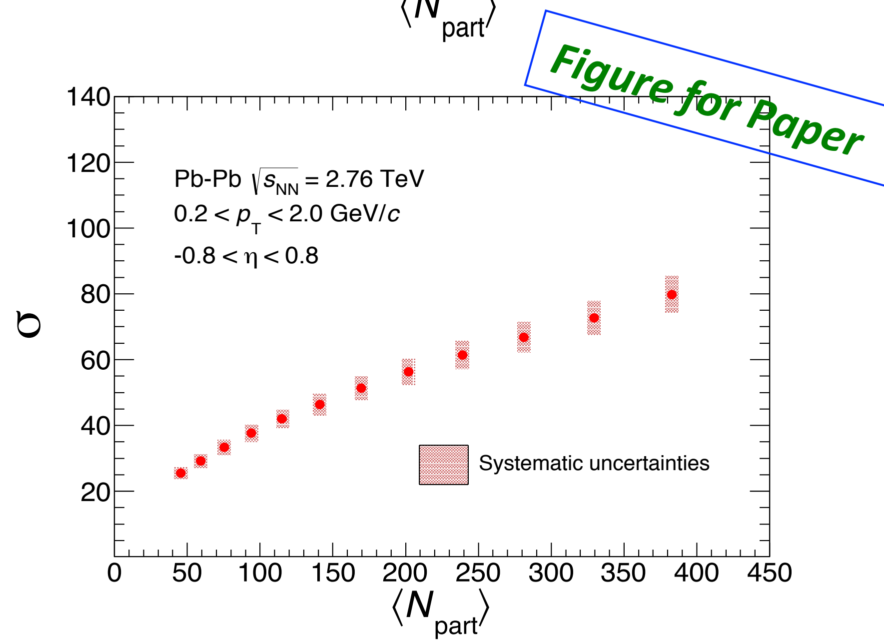
Overall systematic added to mean, sigma and scaled variance : 5%, 6% and 8%.

FINAL RESULTS (changes after preliminary)



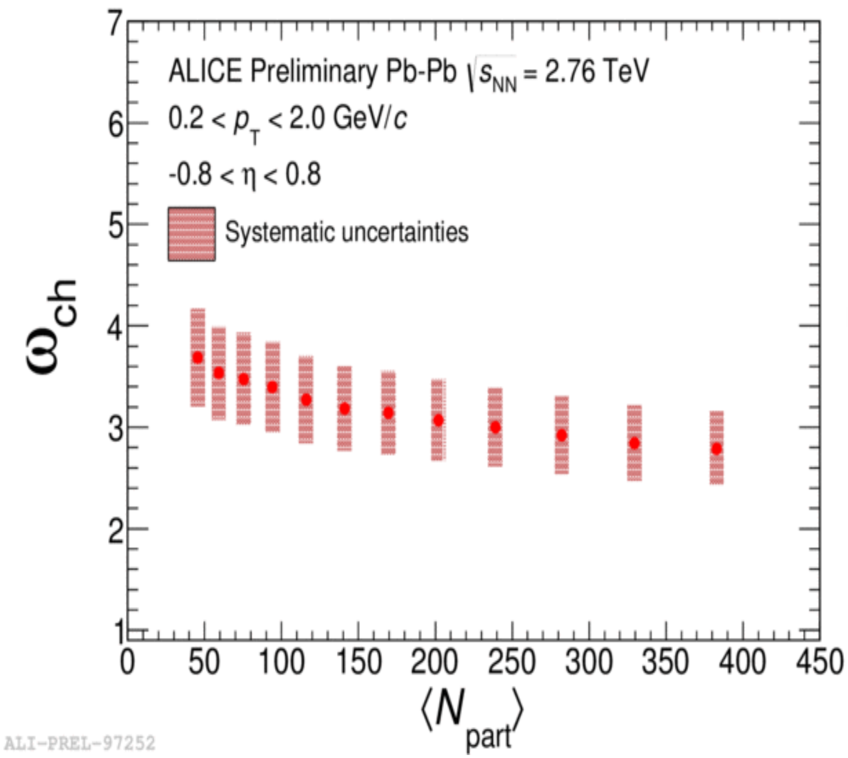


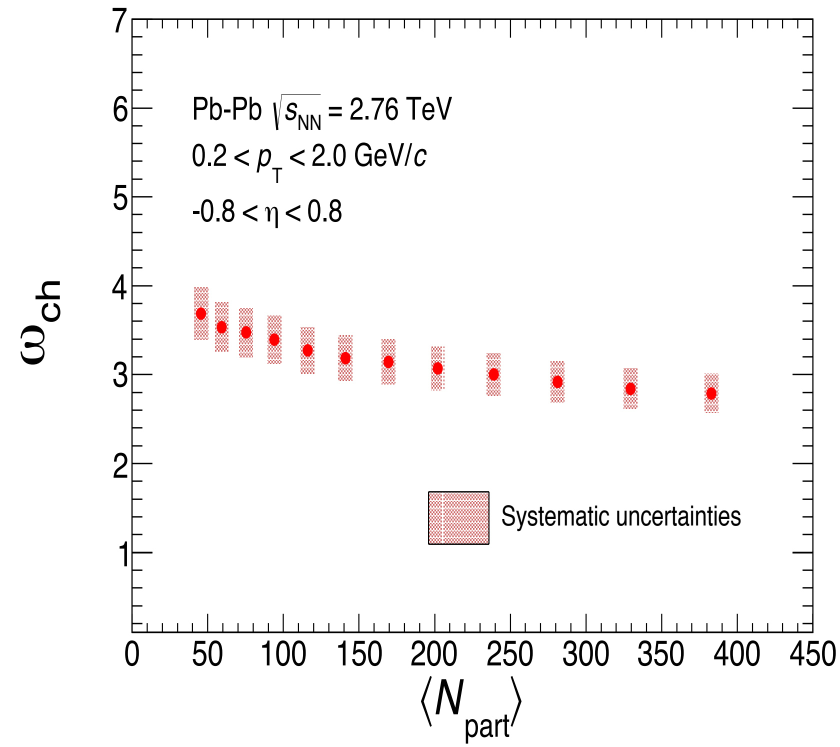




FINAL RESULTS (changes after preliminary)

Figure for Paper

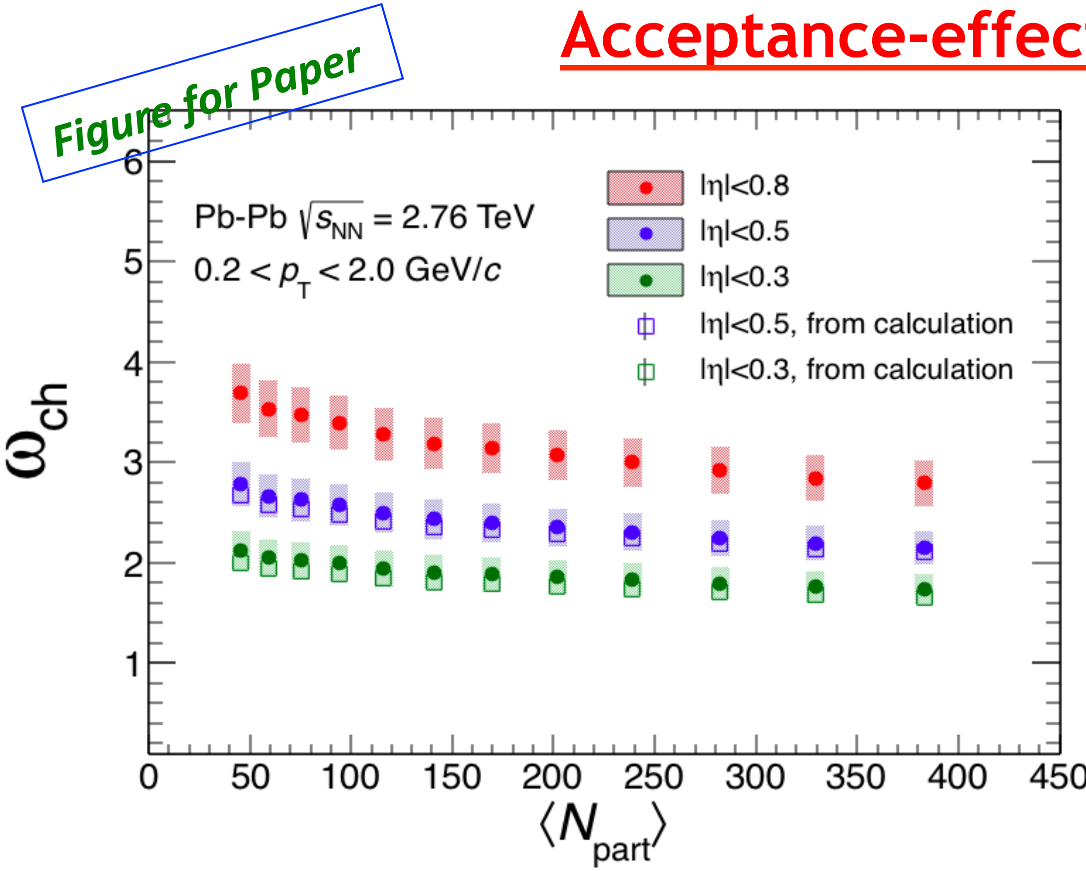




Scaled variance decreases slowly from peripheral to central collisions.

Value of the scaled variance vary within ~2.5 to 4.

Acceptance-effect study



Estimation:

ω_{acc}=1+f_{acc}(ω_{ch}-1), where,
f_{acc} = μ_{acc}/μ_{ch}

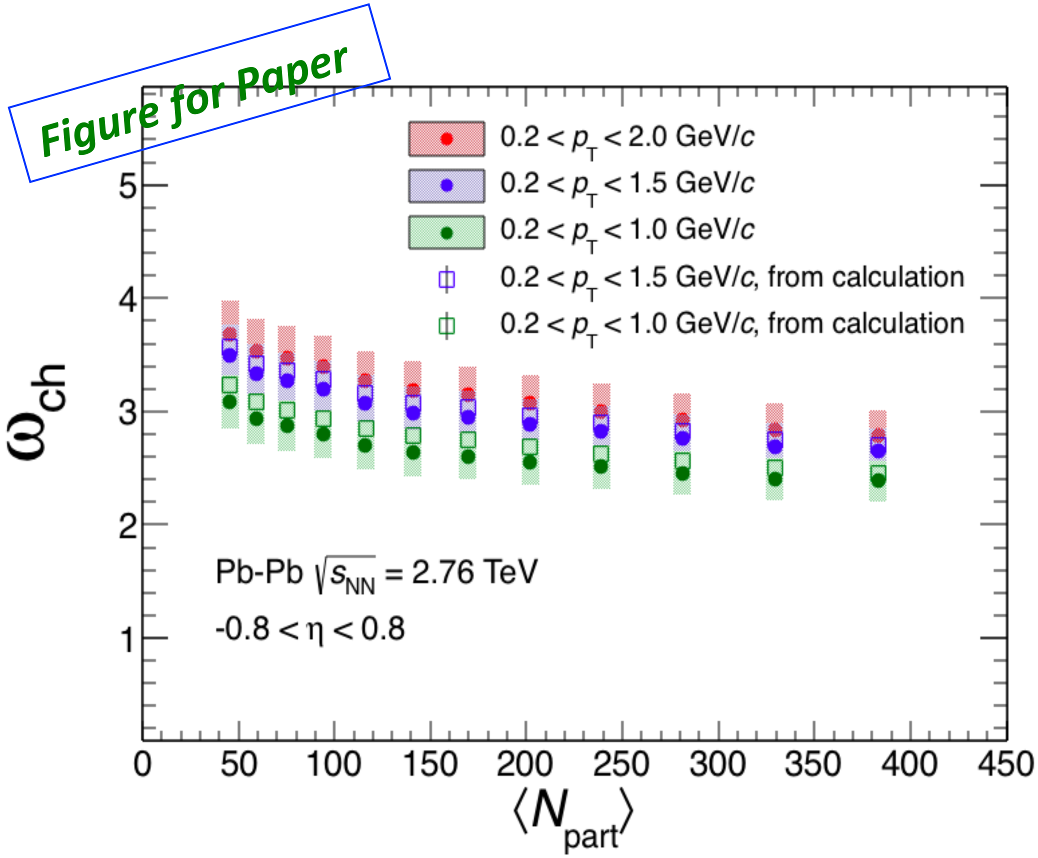
(PHENIX collaboration, arxiv : 0805.1521)

Theoretical estimation assumes: there is no significant correlations present over the acceptance-range.

Advantage of using this formula: We can know value of the observable at any η, by only knowing μ_{acc}.

Estimation using the formula has been superimposed here.
Observation : Calculation matches the results within systematics.

Study with different transverse-momentum ranges



Estimation:

$\omega_{pT}=1+f_{pt}(\omega_{ref}-1)$, where,

$f_{pt} = \mu_{pt}/\mu_{ref}$

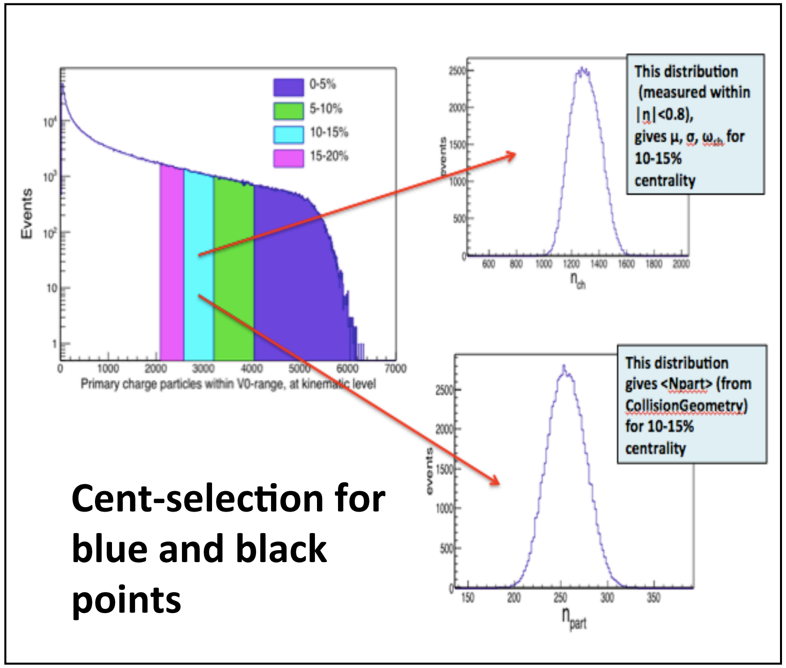
(PHENIX collaboration, arxiv : 0805.1521)

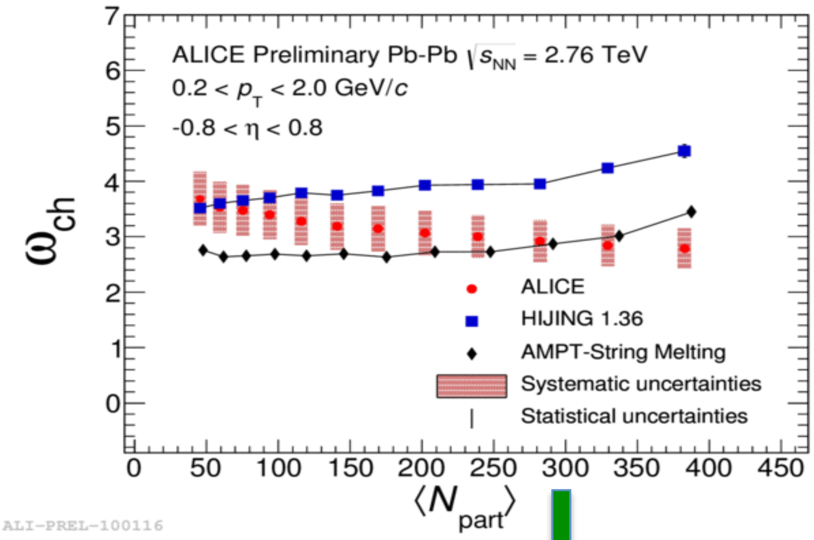
No significant pT-dependent dynamical fluctuations have been observed.

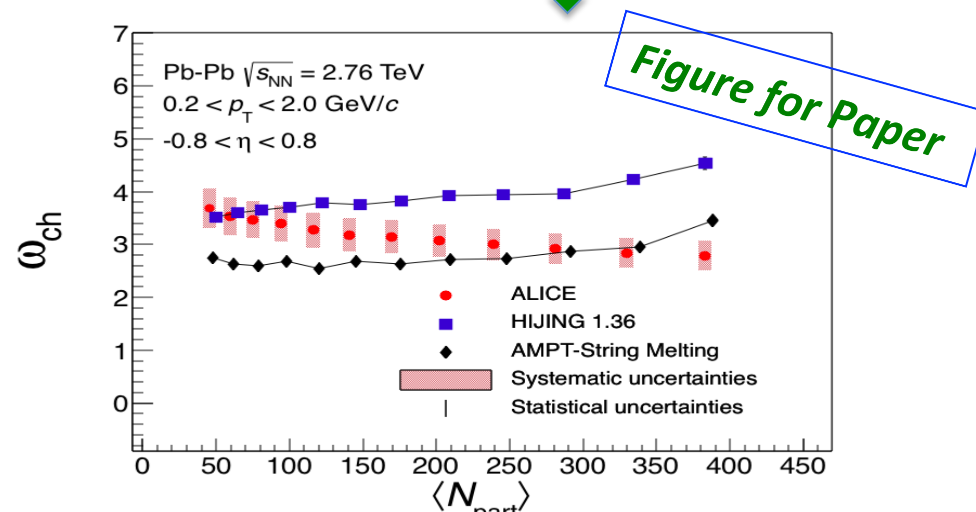
Advantage of using this formula: We can know value of the observable at any pT, by only knowing μ_{pt}.

Estimation using the formula has been superimposed here.
Observation : Calculation matches the results within systematics.

Comparison with Models



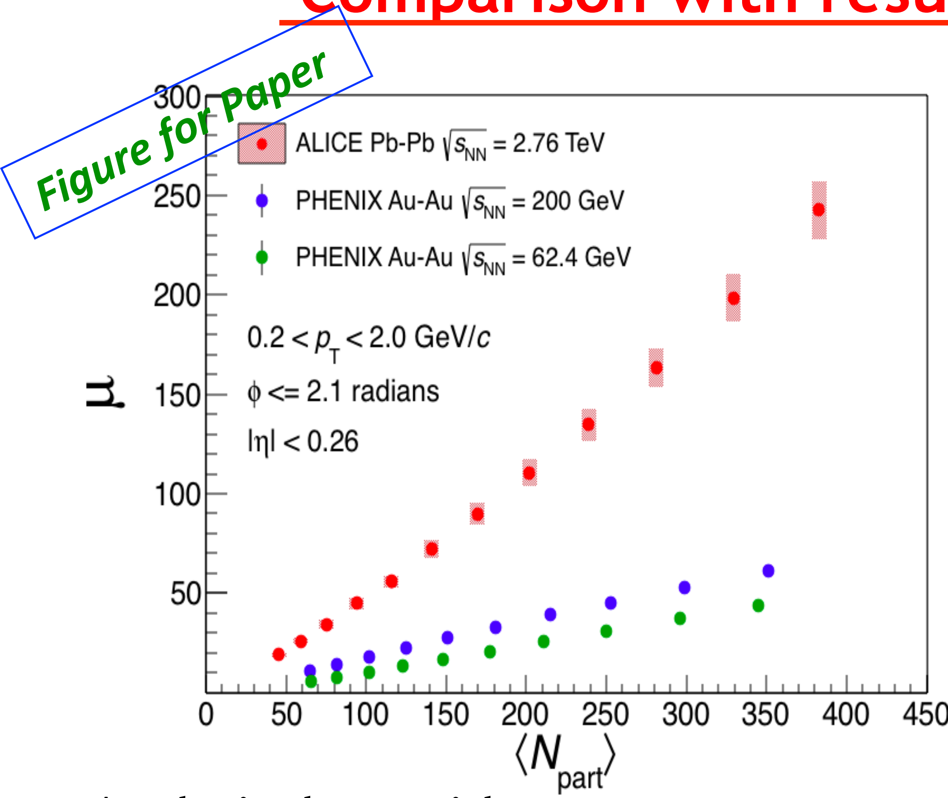


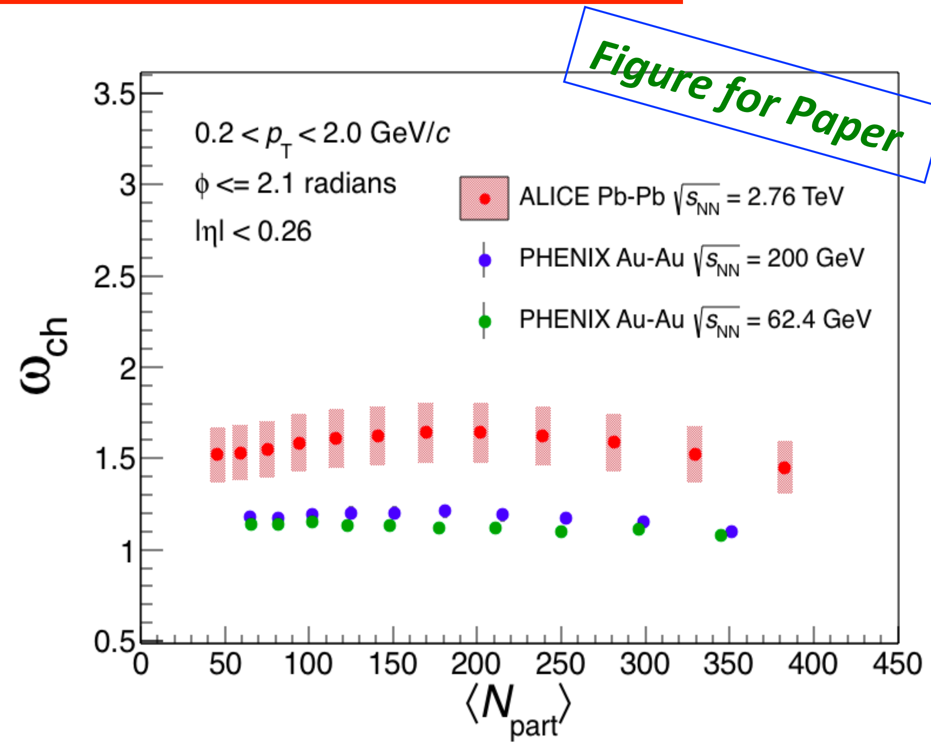


- Blue and black points : Centrality selected from primary charge-particle distribution within 2.8<η<5.1 and -3.7<η<-1.7.
- Red points : Centrality is selected from AliCentrality class.

Neither HIJING, nor AMPT-SM can describe the trend from data, though the results from the models are of comparable values as from data.

Comparison with results from lower energies



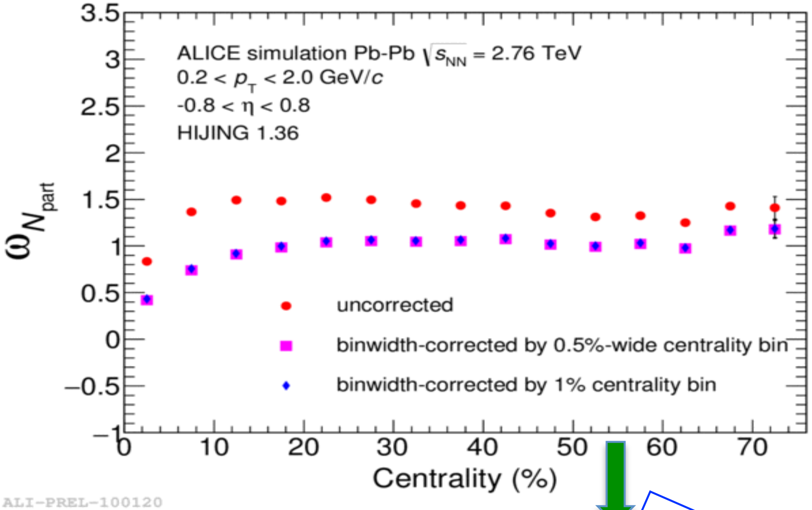


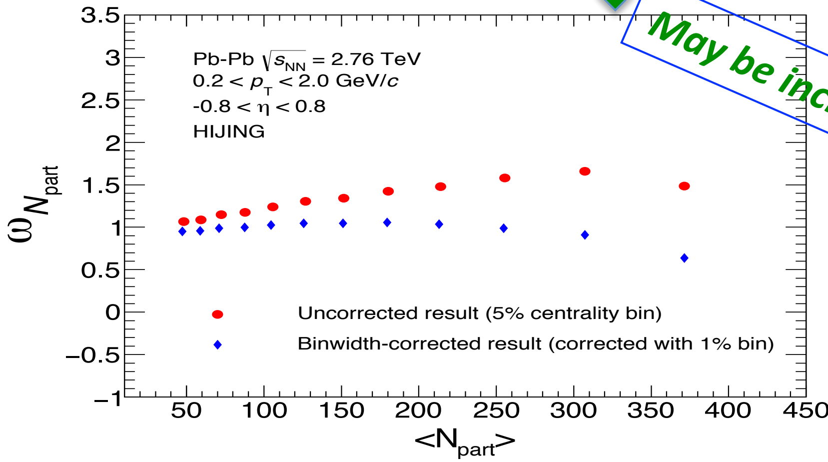
Analysis done with same acceptance-ranges as PHENIX-experiment.

Observation : Mean is much higher in ALICE than PHENIX.
Scaled variance is higher in ALICE, following almost same trend as PHENIX.

Possible explanations : Because of larger multiplicity, initial state fluctuation increases. Also, the correlations coming from resonance decays may affect the result..(Ref : G.V.Danilov and E.V.Shuryak (arxiv : nucl-th/9908027)).

Estimation of Npart-fluctuation:





May be included

Phys. Reports 2001
H. Heiselberg

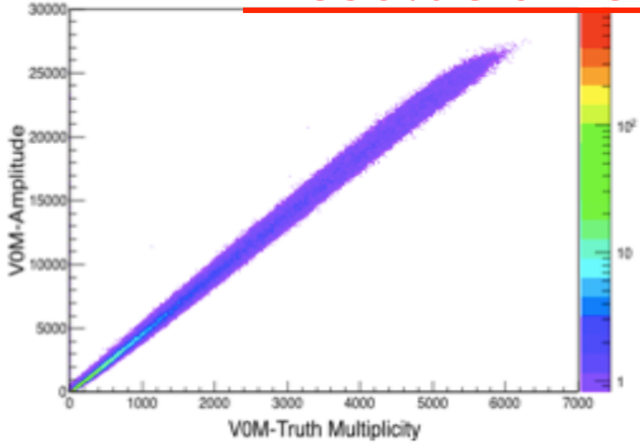
$$\omega_{ch} = \omega_n + \langle n \rangle\, \omega_{Npart}$$

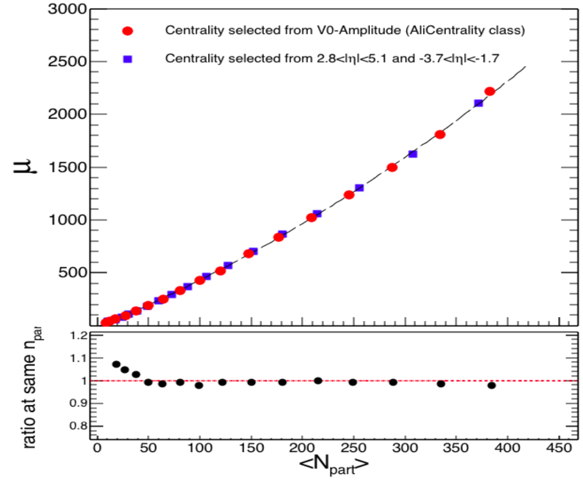
$\langle n \rangle$ is mean multiplicity of hadrons from a nucleon-nucleon source.
ω_{Npart} is fluctuation in Npart.

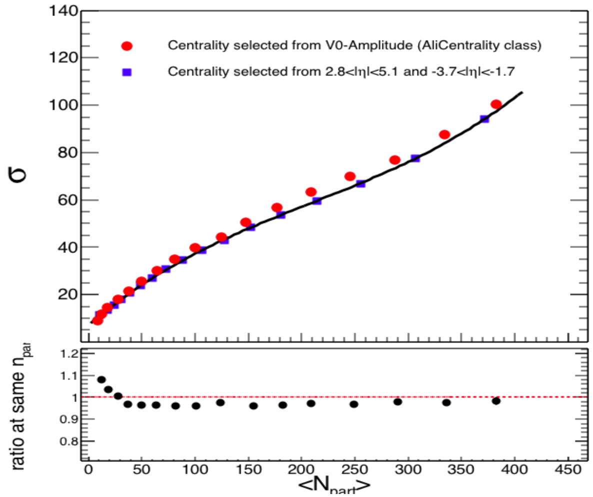
ω_{ch} is strongly dependent on fluctuation in number of participants.

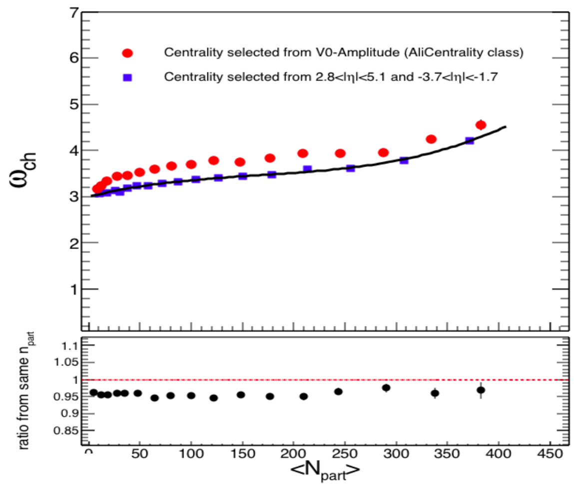
- Volume fluctuation or fluctuation in N_{part} directly affects the measured charged particle fluctuations.
- By choosing narrow bins in centrality, fluctuation in N_{part} has been minimized. In our case, fluctuation in N_{part} is close to unity.

Resolution effect ?





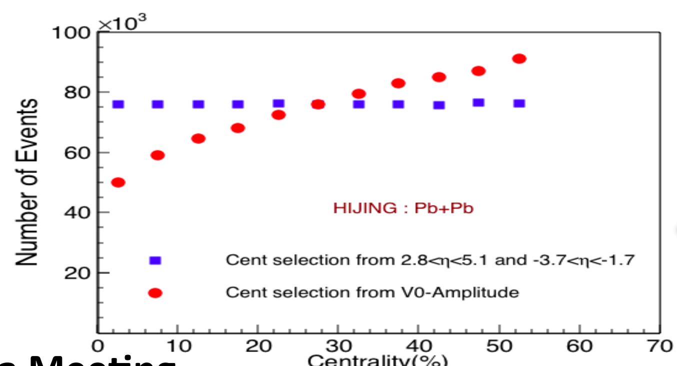




Mean changes within 1% mostly at the edges.

Sigma changes within 1-3%.

Scaled variance varies within 3-6%.



Number of events at same centrality are not same…..
Probably should be tried in some different way, if this effect has to be included.

Paper Proposal:

Title:

Charge particle multiplicity fluctuations in Pb-Pb collisions at \sqrt s_{NN} = 2.76 TeV in ALICE

Target Journal: **Physical Review C**

Paper committee members : Maitreyee Mukherjee, Tapan Kumar Nayak

ARC members : Stefan Thomas Heckel, Alis Rodriguez Manso

Suggested IRC members : will be decided by the conveners

Analysis note link : https://aliceinfo.cern.ch/Notes/node/286

Status : Paper proposal accepted by PF, paper writing ongoing......

BACK-UP SLIDES

Systematic Errors : Mean

Centrality (%)	Track-cuts (%)	Vertex-cuts (%)	Removal of Vx,Vy cuts (%)	Mag pol pos (%)	Mag pol neg (%)	MC-closure (%)	Data Cleanup (%)	DCAxy (%)	DCAz (%)	Total Systematic errors (%)	Stat. errors (%)
0-5	4.73	0.09	0.10	0.23	0.30	0.002	0.20	0.70	0.45	4.83	0.004
5-10	3.85	0.11	0.10	0.25	0.50	0.02	0.25	0.53	0.48	4.53	0.004
10-15	4.76	0.11	0.10	0.33	0.61	0.01	0.10	0.29	0.46	4.85	0.005
15-20	4.58	0.11	0.10	0.38	0.71	0.01	0.10	0.65	0.42	4.72	0.005
20-25	3.38	0.13	0.10	0.38	0.74	0.01	0.45	0.45	0.58	3.59	0.006
25-30	3.57	0.12	0.10	0.20	0.37	0.004	0.50	0.57	0.53	3.72	0.007
30-35	4.31	0.09	0.10	0.15	0.28	0.01	0.50	0.58	0.68	4.44	0.008
35-40	4.39	0.14	0.40	0.08	0.17	0.01	0.35	0.62	0.45	4.49	0.009
40-45	4.39	0.12	0.02	0.15	0.26	0.01	0.45	0.89	0.65	4.56	0.010
45-50	3.75	0.08	0.10	0.31	0.42	0.01	0.45	0.76	0.68	3.95	0.011
50-55	5.30	0.08	0.01	0.47	0.63	0.01	0.25	0.65	0.85	5.47	0.013
55-60	2.72	0.05	0.01	0.42	0.56	0.003	0.50	0.82	0.88	3.10	0.016

Systematic Errors : Sigma

Centrality (%)	Track-cuts (%)	Vertex-cuts (%)	Removal of Vx,Vy cuts (%)	Mag pol pos (%)	Mag pol neg (%)	MC-closure (%)	Data Cleanup (%)	DCAxy (%)	DCAz (%)	Total Systematic errors (%)	Stat. errors (%)
0-5	5.14	0.55	0.10	0.12	0.82	0.001	0.63	1.02	0.98	5.46	0.085
5-10	4.31	0.40	0.10	0.14	0.55	0.02	0.80	0.98	0.93	4.64	0.096
10-15	5.66	0.32	0.10	0.42	0.52	0.06	0.35	1.05	0.95	5.89	0.094
15-20	4.94	0.16	0.10	0.57	0.93	0.69	0.64	1.06	0.92	5.33	0.106
20-25	4.03	0.43	0.10	0.48	0.81	0.56	0.76	1.08	0.89	4.49	0.103
25-30	3.75	0.49	0.10	0.41	0.84	0.17	0.73	1.02	0.76	4.16	0.133
30-35	4.58	0.38	0.04	0.18	0.39	0.70	0.72	1.09	0.85	4.93	0.127
35-40	6.10	0.32	0.40	0.29	0.51	0.29	0.65	0.89	0.82	6.30	0.164
40-45	5.93	0.42	0.30	0.20	0.59	0.65	0.54	0.80	0.98	6.18	0.030
45-50	4.31	0.12	0.10	0.75	0.99	0.58	0.52	1.20	0.92	4.79	0.057
50-55	5.74	0.34	0.10	0.51	0.82	0.42	0.78	1.15	0.93	6.08	0.082
55-60	3.38	0.52	0.20	0.56	0.70	0.12	0.82	1.19	1.09	3.98	0.167

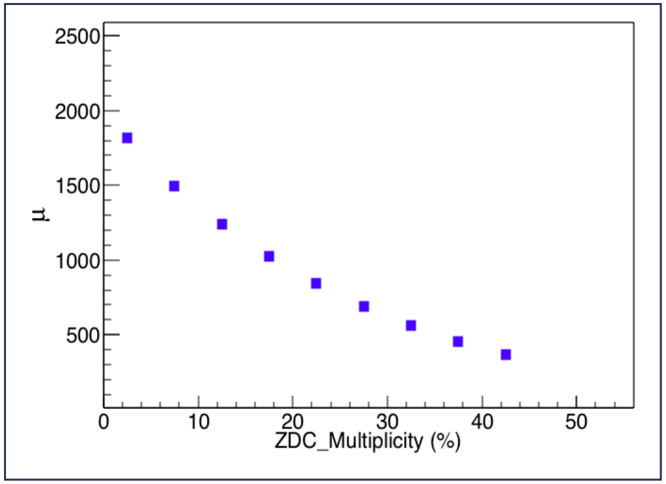
Systematic Errors : Scaled Variance

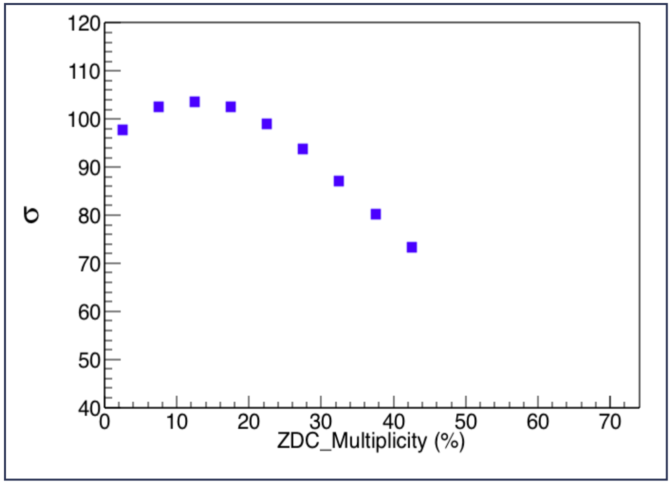
Centrality (%)	Track-cuts (%)	Vertex-cuts (%)	Removal of Vx,Vy cuts (%)	Mag pol pos (%)	Mag pol neg (%)	MC-closure (%)	Data Cleanup (%)	DCAxy (%)	DCAz (%)	Total Systematic errors (%)	Stat. errors (%)
0-5	5.55	1.02	0.10	0.02	1.12	0.001	1.23	1.34	1.29	6.17	0.12
5-10	4.76	0.69	0.10	0.02	0.67	0.02	1.34	1.48	1.47	5.45	0.14
10-15	6.55	0.53	0.02	0.50	0.51	0.13	0.93	1.42	1.76	7.05	0.13
15-20	5.30	0.22	0.01	0.76	1.24	1.37	0.98	1.47	1.78	6.19	0.15
20-25	4.68	0.73	0.10	0.58	0.97	1.11	1.02	1.28	1.56	5.48	0.15
25-30	3.94	0.86	0.10	0.62	1.30	0.34	1.10	1.65	1.53	4.98	0.19
30-35	4.85	0.67	0.04	0.21	0.49	1.39	1.13	1.52	1.50	5.66	0.18
35-40	7.78	0.51	0.50	0.49	0.84	0.58	1.25	1.56	1.27	8.24	0.23
40-45	7.43	0.72	0.35	0.24	0.90	1.29	1.32	1.43	1.58	8.04	0.04
45-50	4.86	0.16	0.20	1.10	1.50	1.15	1.45	1.48	1.68	5.96	0.08
50-55	6.19	0.61	0.20	0.54	0.99	0.84	1.56	1.56	1.62	6.94	0.12
55-60	4.04	1.09	0.40	0.69	0.82	0.24	1.60	1.75	1.71	5.23	0.24

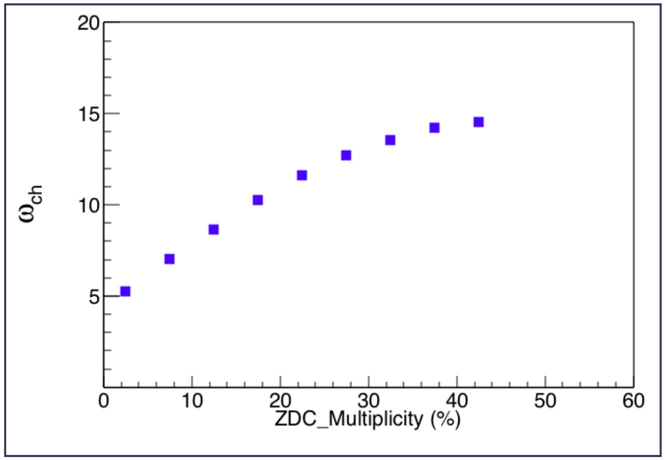
ISSUES WITH THE ANALYSIS : Discussion on possible biases

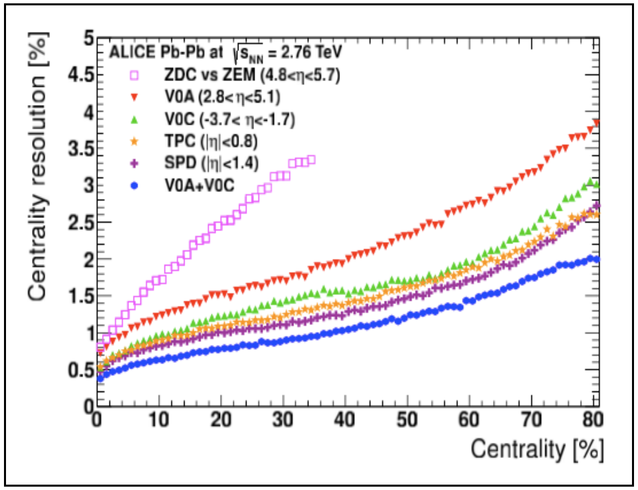
Worry :The centrality selection biases the multiplicity distributions and constrains the possible fluctuations.

Prescription : To select centrality using ZDC, so that we can fix Npart.









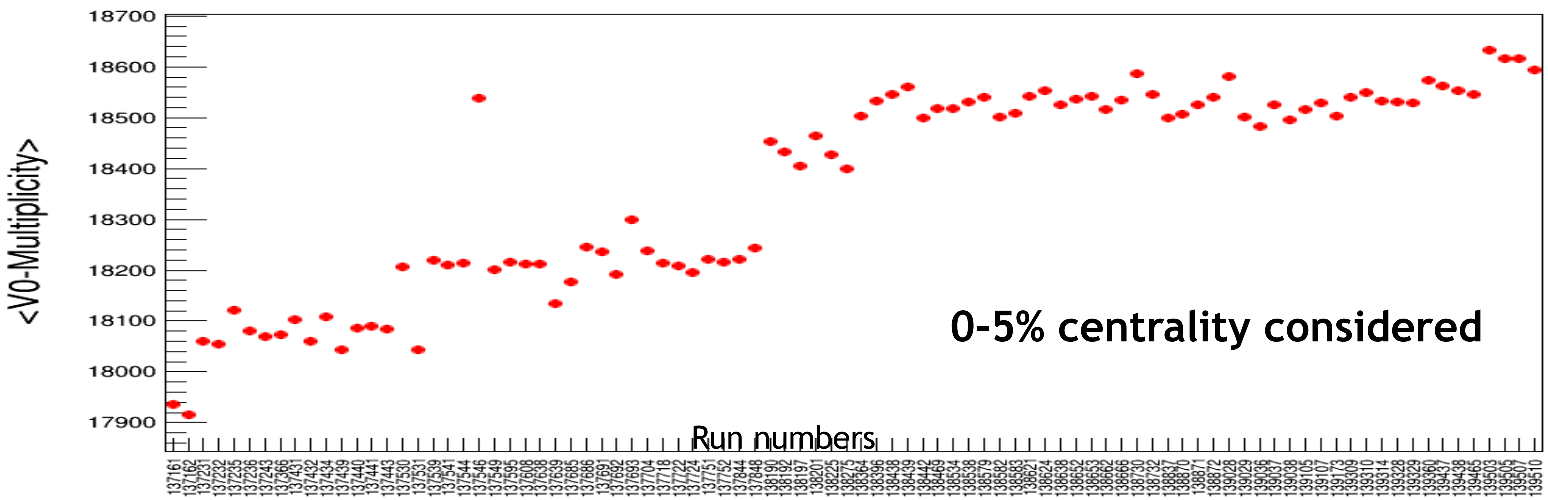
Results are from data and bw-corrected.

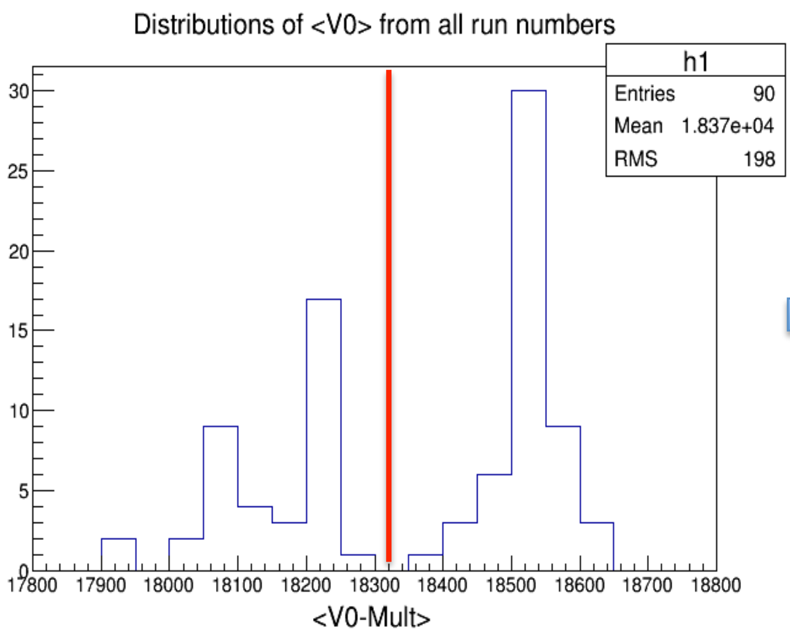
Resolution of ZDC poor. Volume fluctuation is very high in this case.

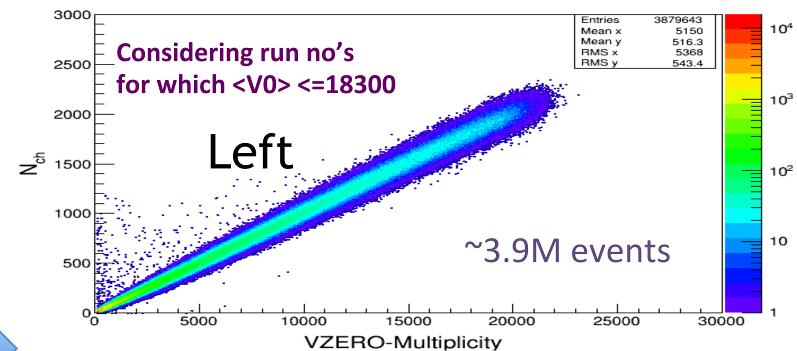
No MC available. Efficiecy-correction not possible.

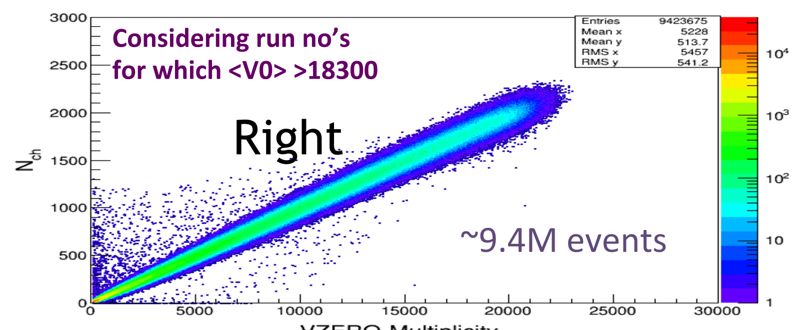
Decided not to use ZDC for this Analysis.

Trial for Data cleanup of uncorrelated events using <V0-Multiplicity>



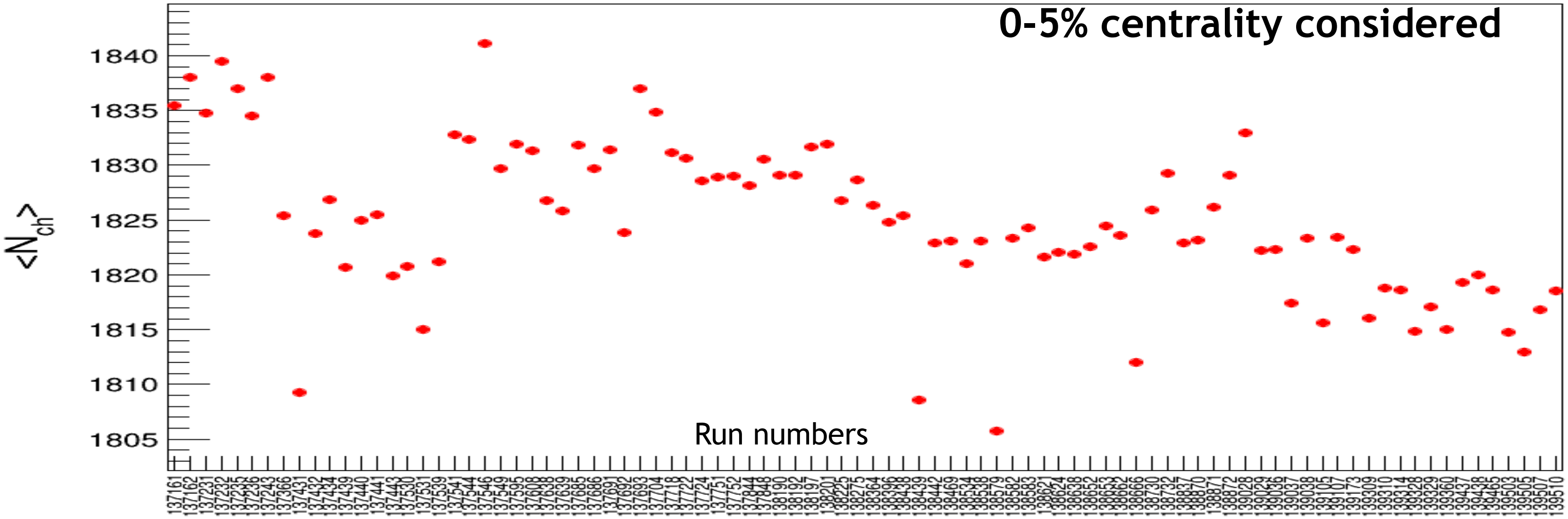


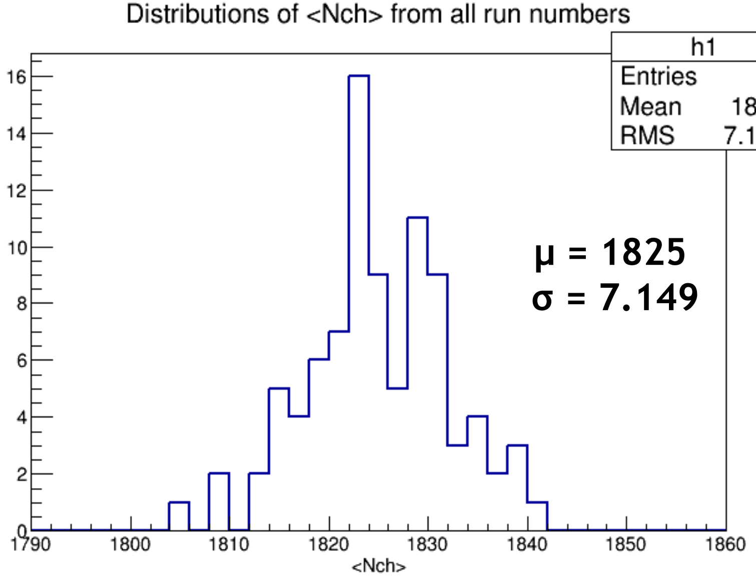


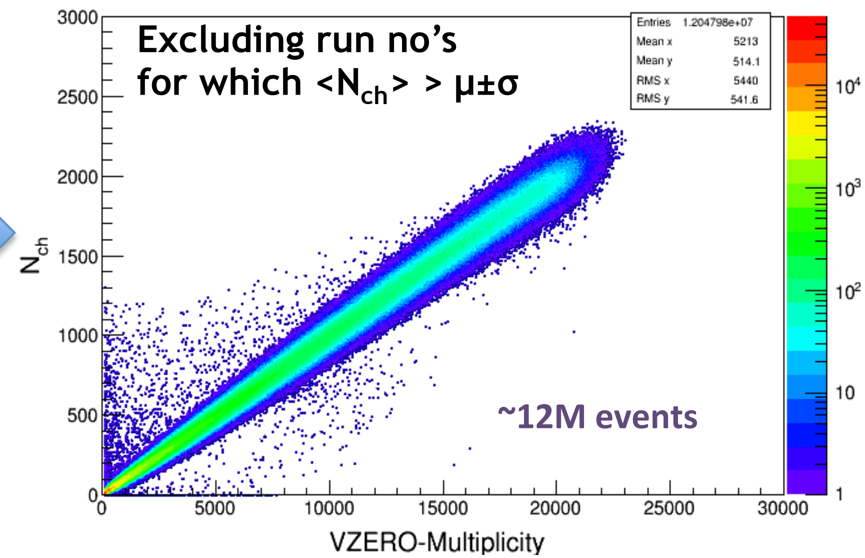


Still not cleaned-up !!!

Trial for cleanup of uncorrelated events using $\langle N_{ch} \rangle$







Still not cleaned-up !!!

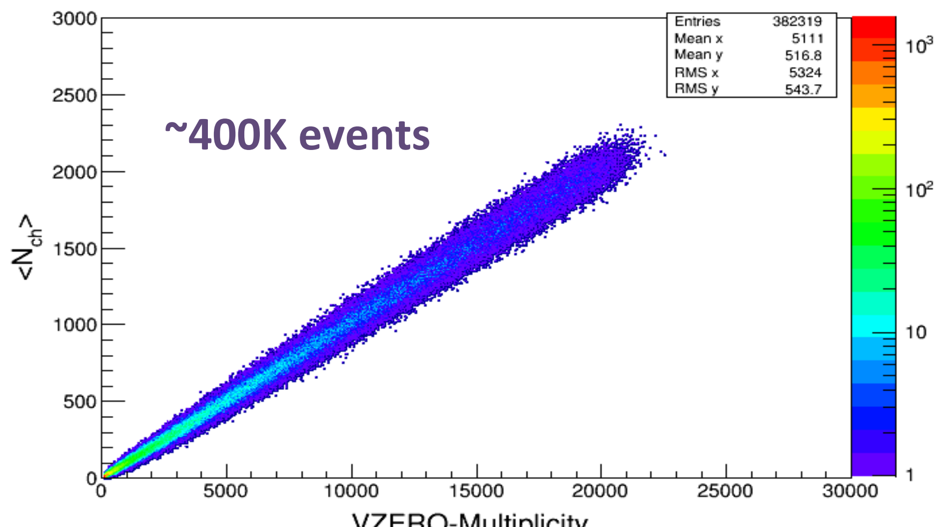
Comments:

Almost all run numbers have a few uncorrelated events. So it is very difficult to cleanup the data.

It is then obviously wise to do run number-by-run number analysis and remove all the run numbers that are responsible for the uncorrelated events.

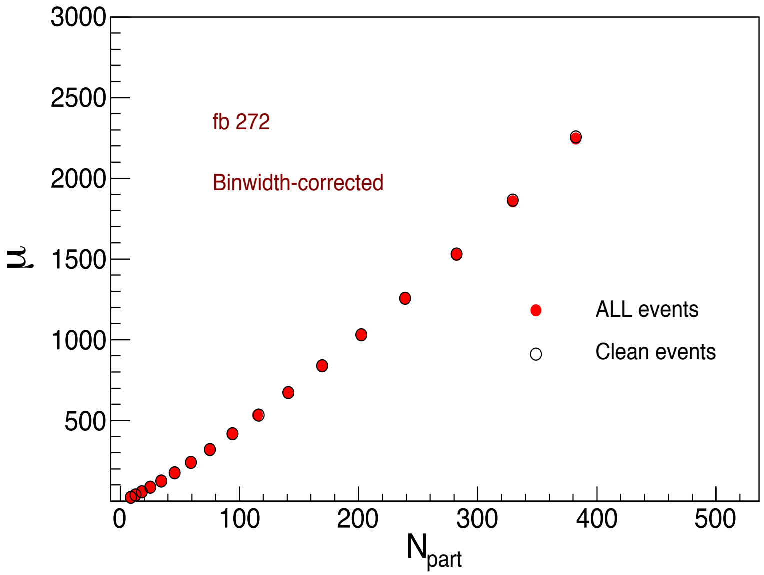
So, we take only 13 runs (~400K events) which have no outliers.

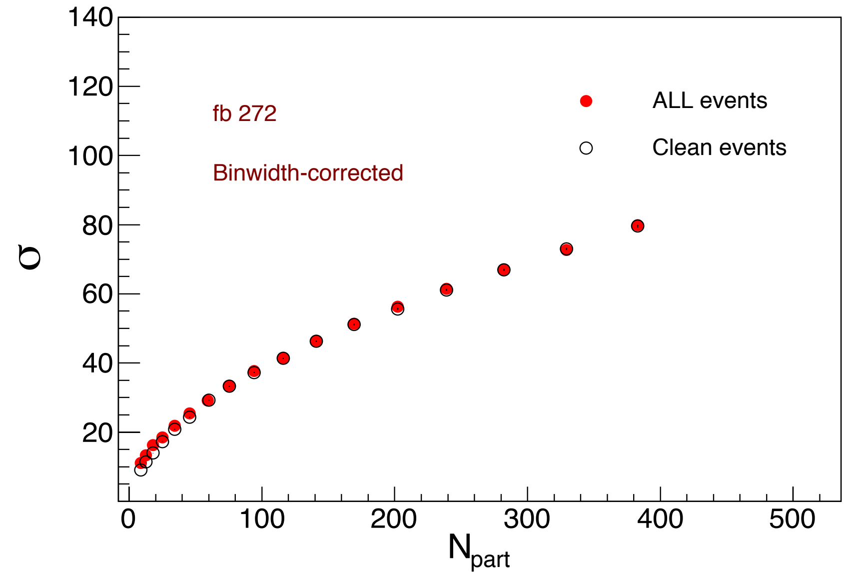
This has been taken only to verify whether there be any effect on The final result if only cleaned-up sample is used..

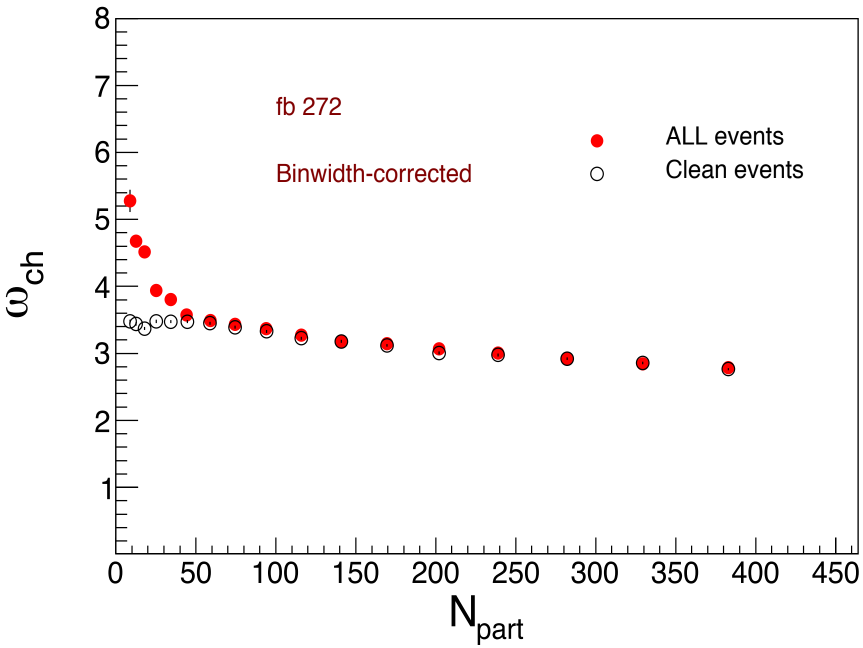


Cleanup done considering only 13 run numbers, i.e, ~400K events.

Comparison between cleaned events (~400K) and ALL events







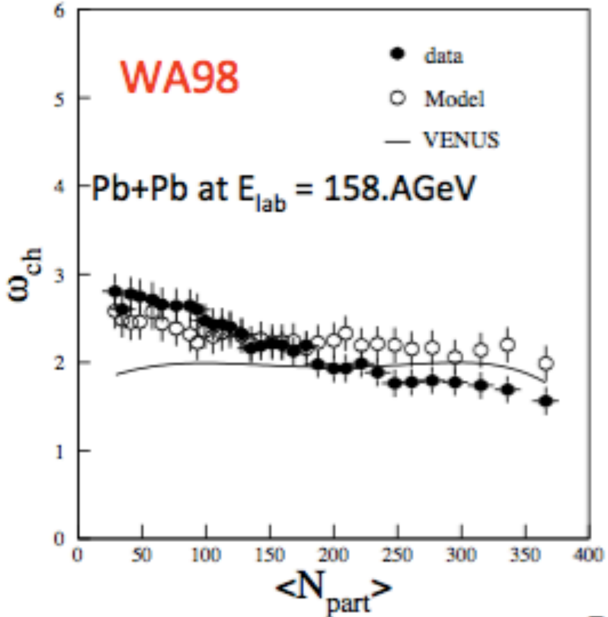
=> Down to Npart~50, cleaned and ALL events give same results

We can show results from cleaned event all throughout or if we take ALL events – then we show from Npart>50.

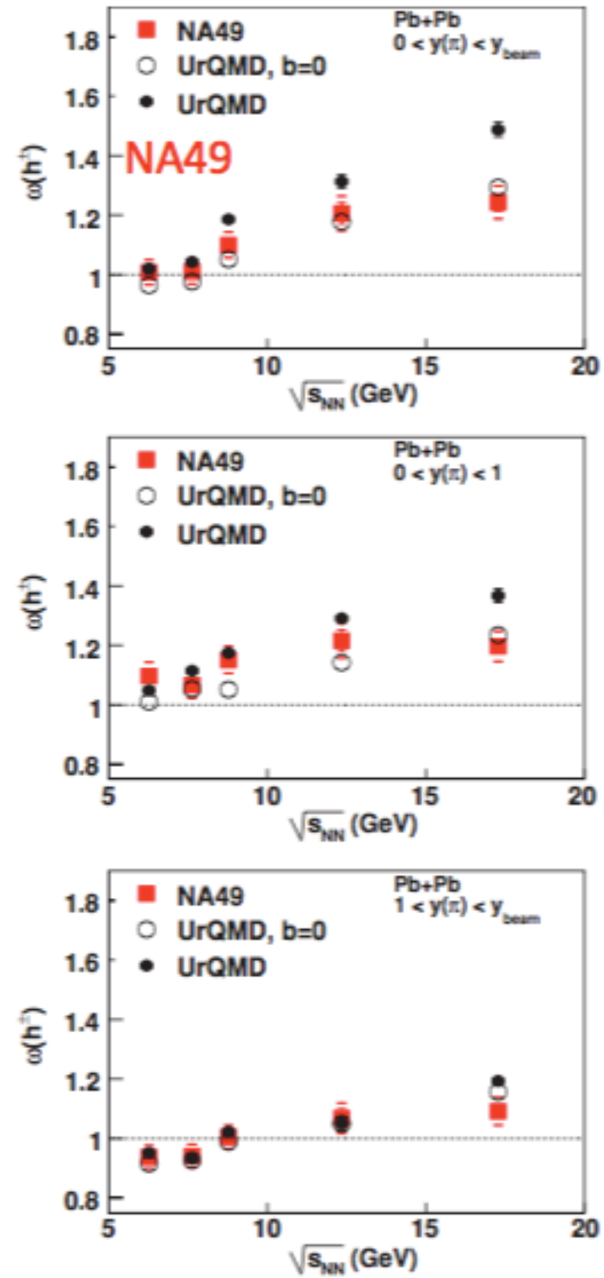
=> For today: Results are shown from central to peripheral, down to Npart~50.

Results from previous Experiments:

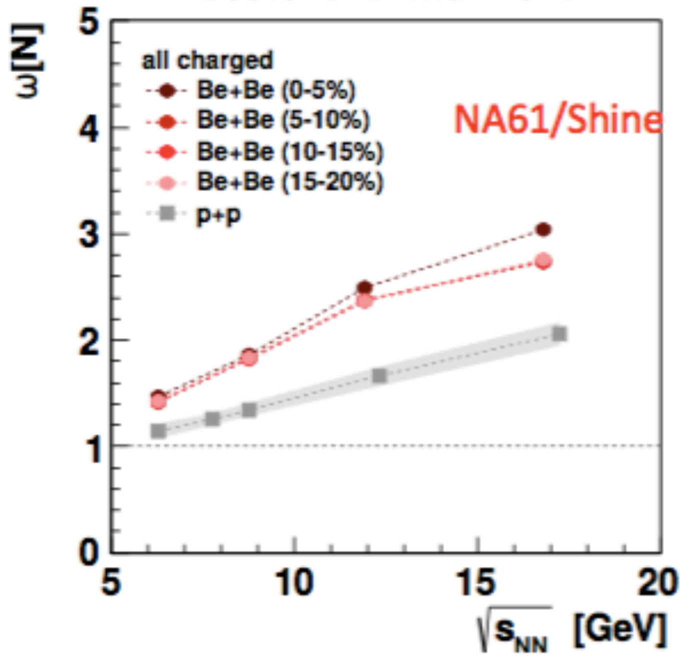
Phys. Rev. C67 (2003) 014906



Phys. Rev. C 78 (2008) 034914



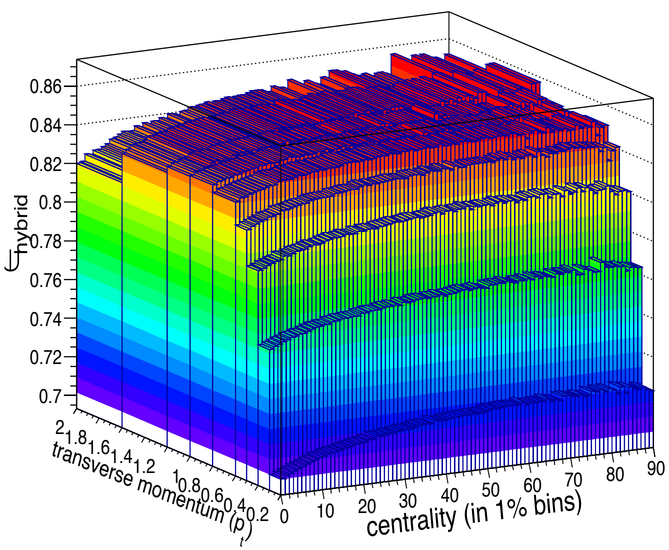
1503.01619 Mar 2015

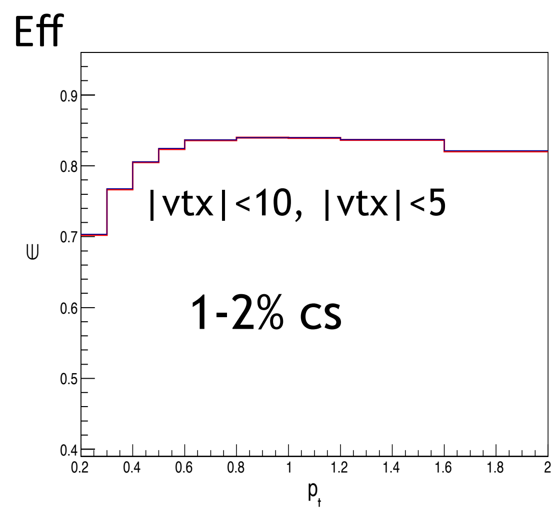


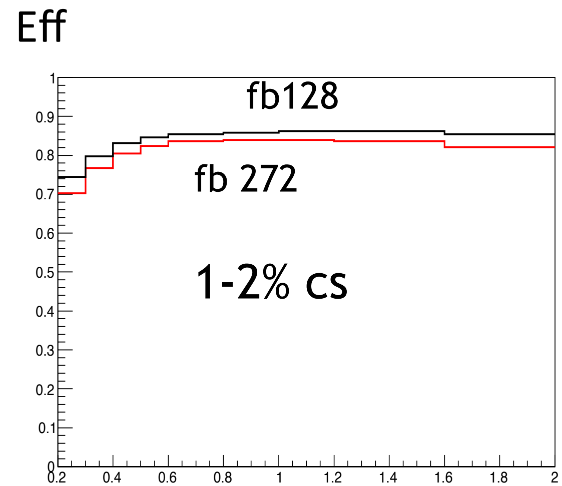
MC-results from Variable transverse momentum-bin study with proper efficiency and contamination correction

Transverse-momentum binning used : (0.2,0.3,0.4,0.5,0.6,0.8,1.0,1.2,1.6,2.0) GeV/c

Efficiency factors :

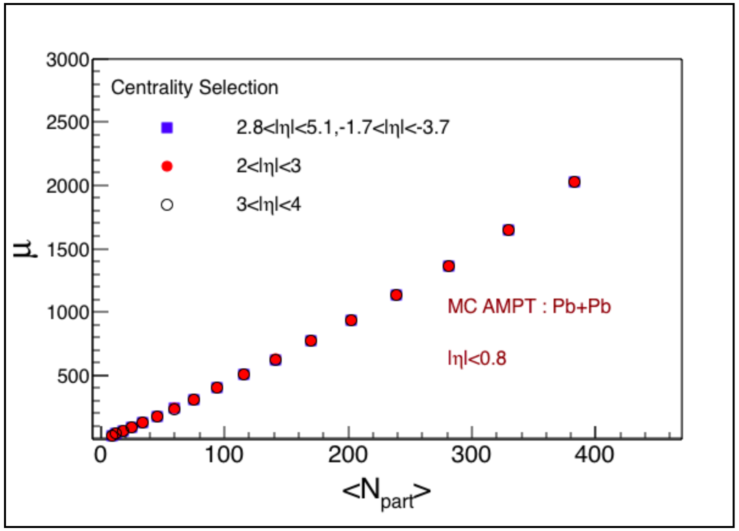


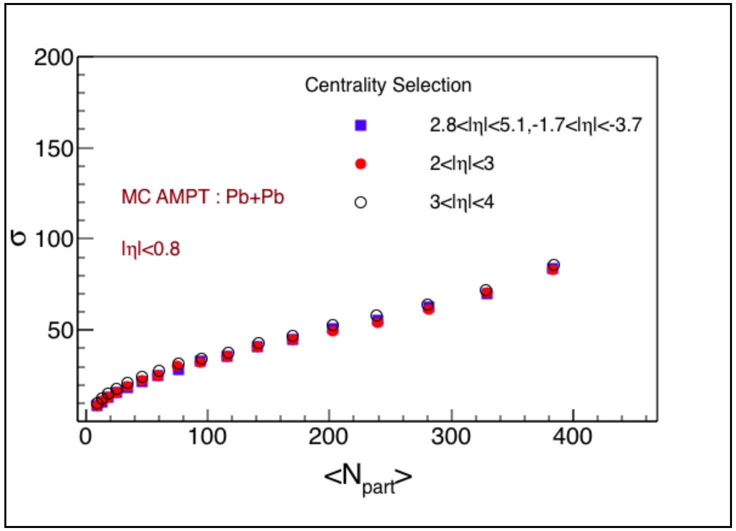


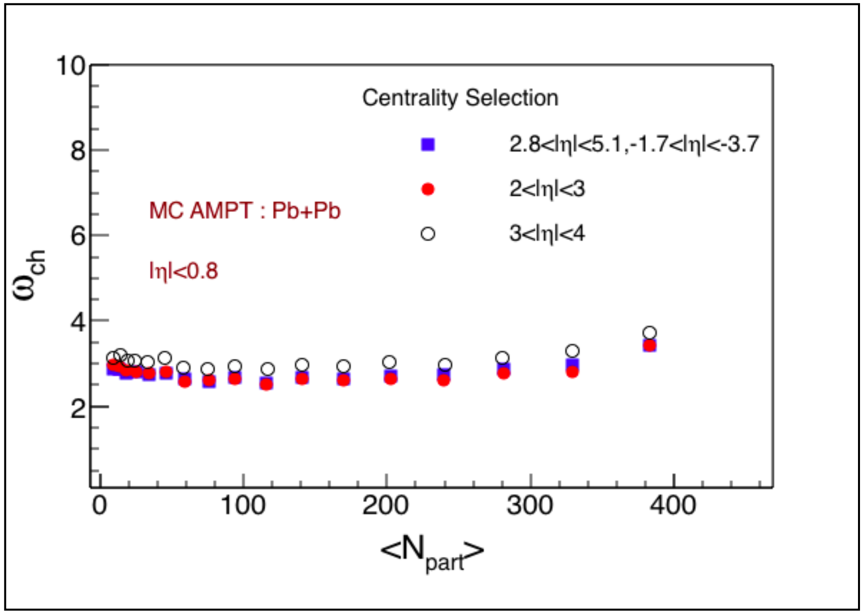


- **Statistical errors have been estimated using delta theorem, with the use of raw moments and factorial moments.**
- **Proper efficiency correction for the factorial moments done.**
- **Covariance-term has been included during statistical error estimation.**

Discussion on possible biases







Mean, sigma and scaled variance matches well even if we use different eta-window.

Centrality selection using multiplicity from a different eta-window does not bias the final result.