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Centrality selection through fluctuation measures

17 OCTOBER 2023

Main topic of the grant

- Prepare for the forthcoming studies of the diagram of strongly interacting matter by analysis of sensitivity of known fluctuation observables to the event selection techniques
- Check feasibility of the proposed centrality determination (based on multiplicity, energy deposition in FHCals, combined) procedures for the fluctuations analysis

- NB: sensitivity of the considered observables to the track reconstruction efficiencies and corrections methods have been studied by the SPbU group previously (RFBR project 18-02-40097) for the centrality classes determined by the impact parameter

Event selection

Centrality estimation

- impact parameter (ideal case)
- multiplicity in two forward sub-events $-1.2 < \eta < -0.8$ and $0.8 < \eta < 1.2$ (for simplicity we call it 'V0' method)
- FHCal method (by INR group)
- 3d method: combines multiplicity and FHCal (by INR group)

- detailed description of the methods were given by A. Seryakov (10.10.23 https://indico.jinr.ru/event/4066/)

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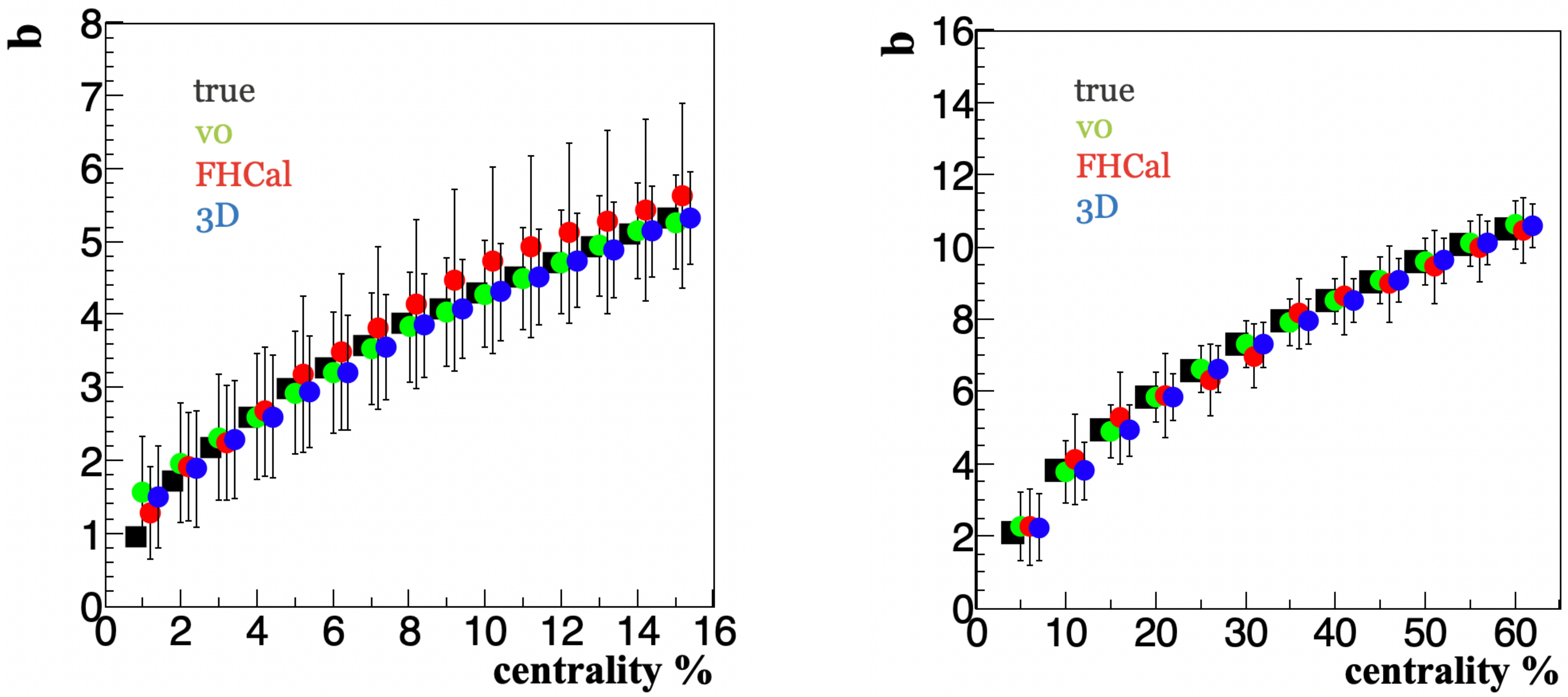

Findings:

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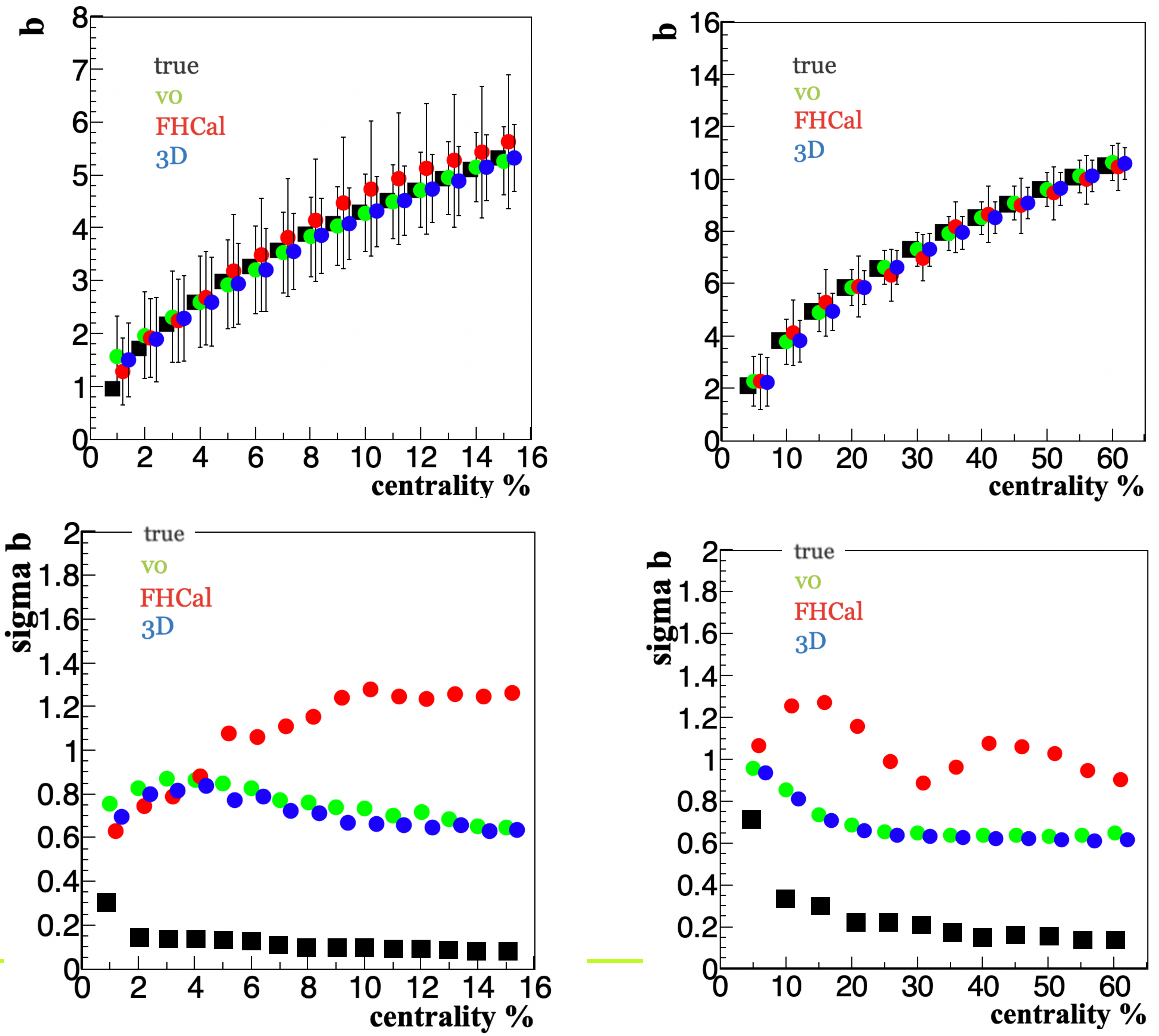

Findings:

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- But the shape and the width of the impact parameter distributions for selected by proxy classes are not so nicely reproduced

DCM-SMM min.bias Au+Au 11A GeV

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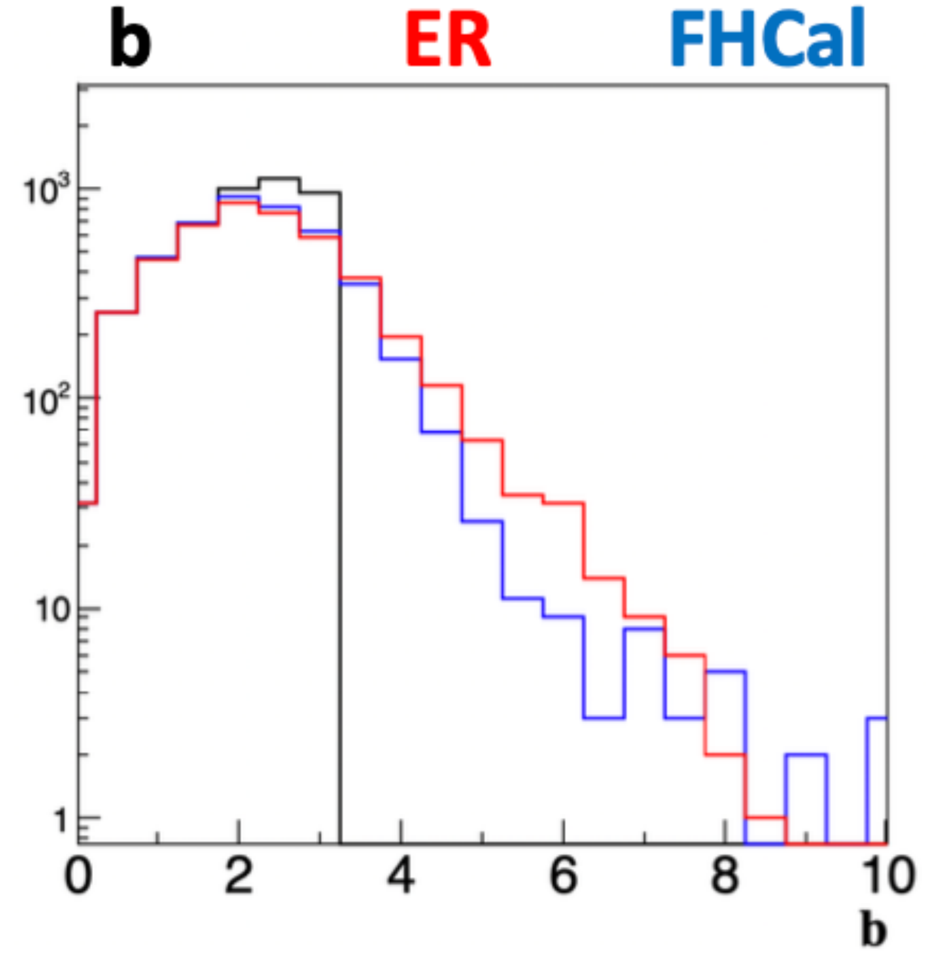

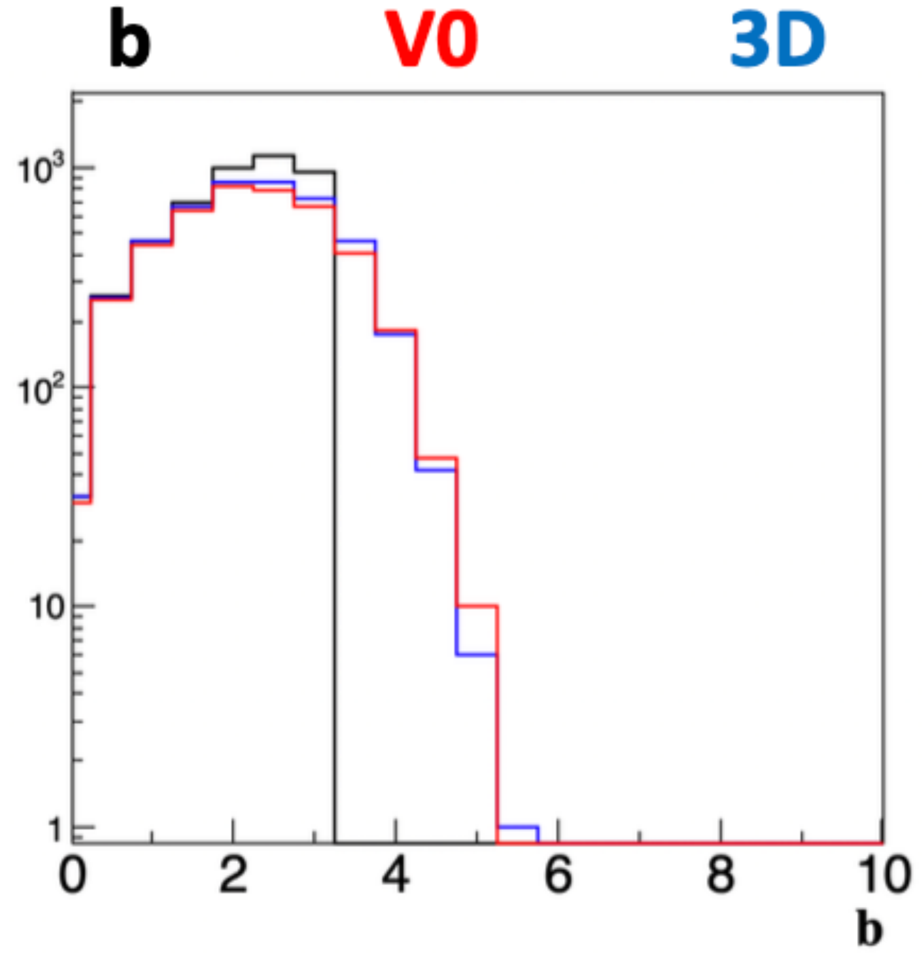

0-5% centrality

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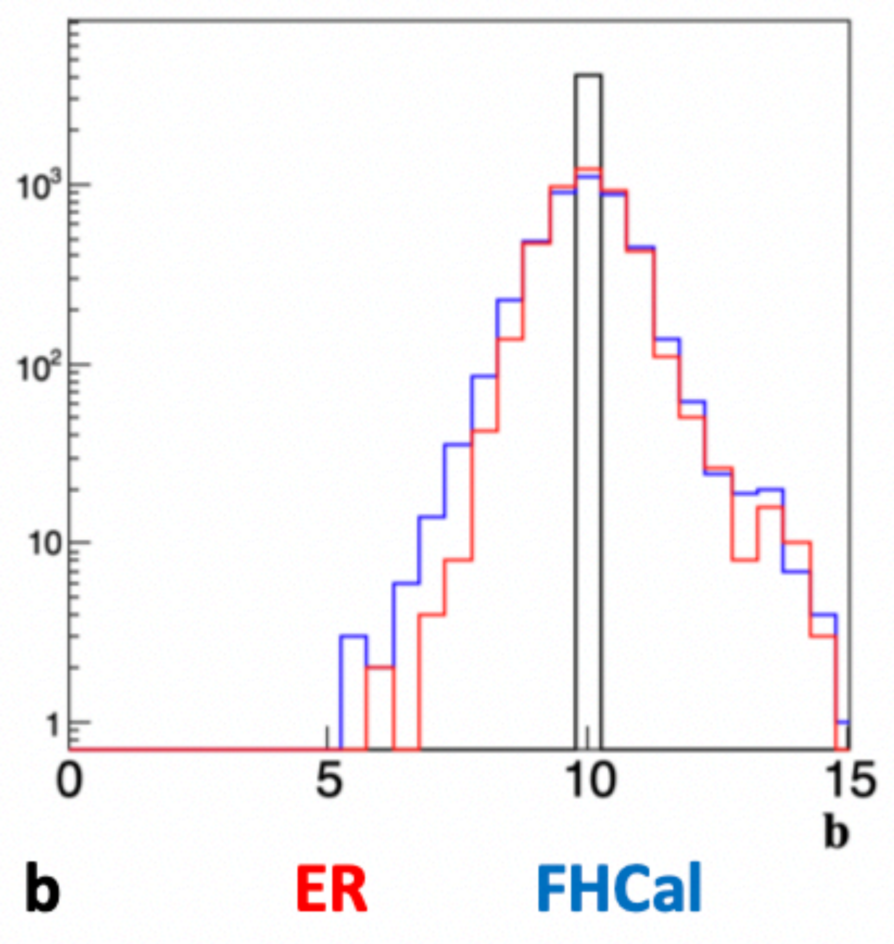
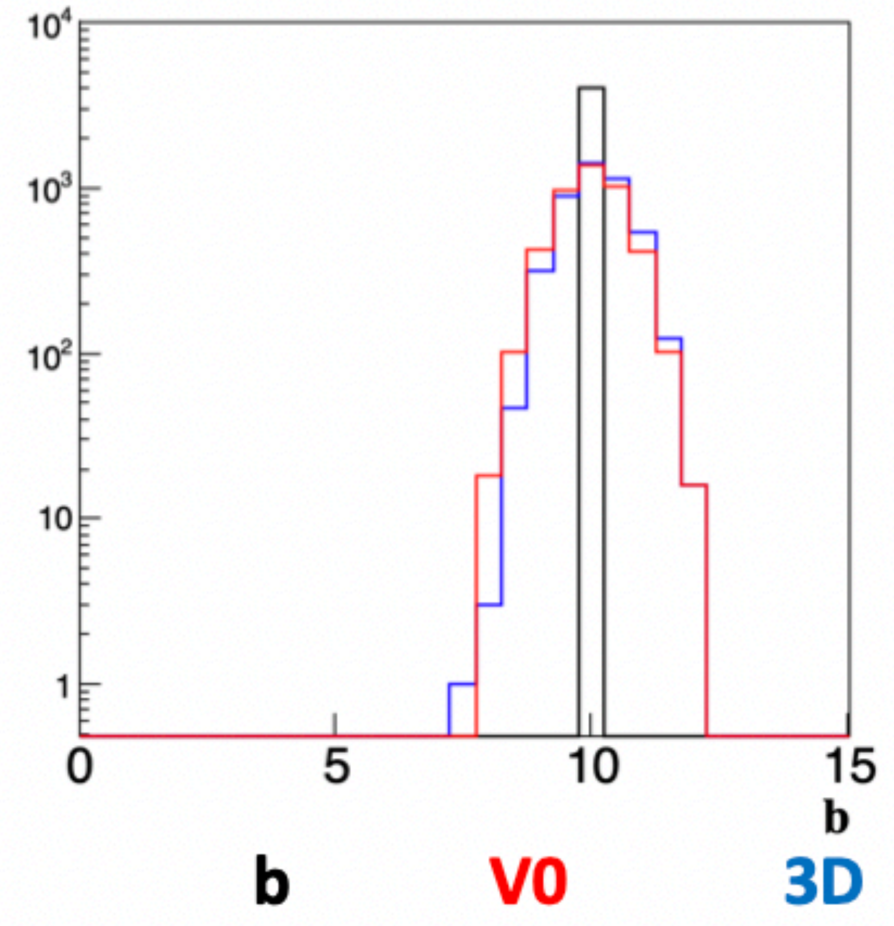
- All methods are able to reproduce mean values of impact parameters (except for 0-1%)
- But the shape and the width of the impact parameter distributions for selected by proxy classes are not so nicely reproduced





50-55% centrality

Observables for fluctuations studies

Fluctuations

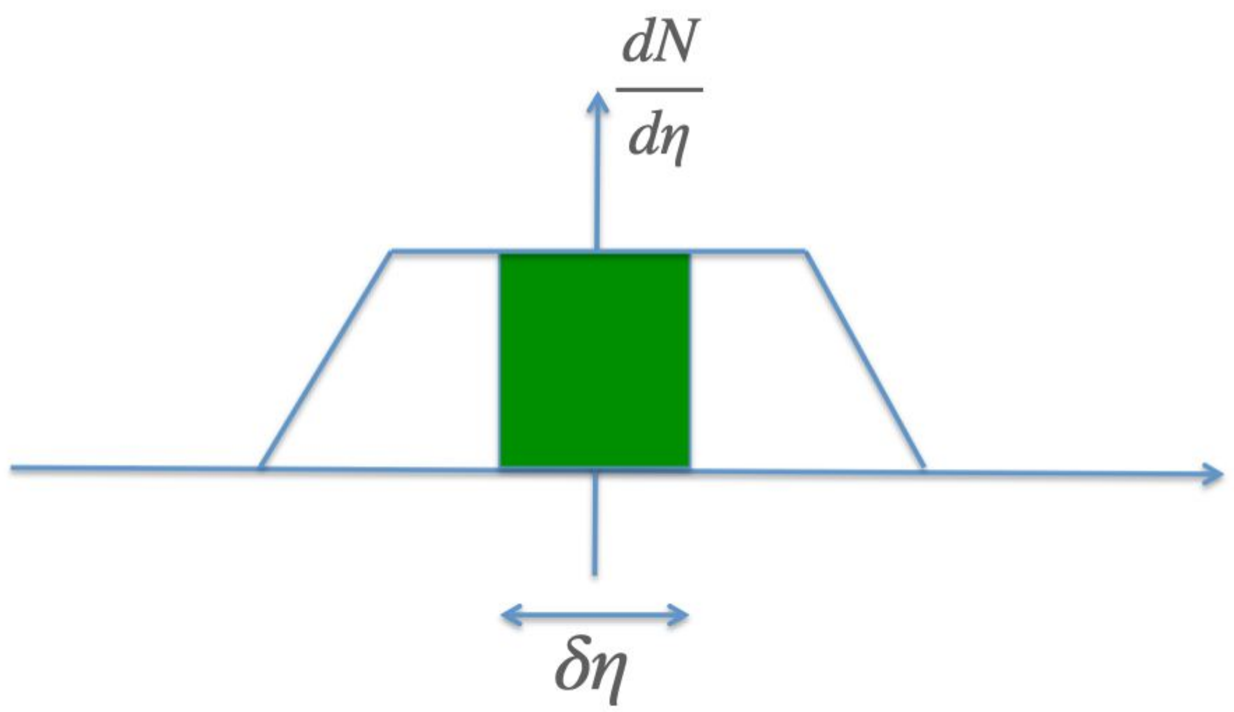
To study fluctuations = to study a distribution of a given observable

Any distribution is fully parametrized by (full, infinite) set of moments or factorial moments or cumulants or factorial cumulants

Experimentally

1) one typically looks at a few of them with the lowest order (i.e. mean, variance, skewness, kurtosis etc.)
2) one tries to combine them in a way to suppress ‘trivial’ effects (e.g. ratio of cumulants)
3) one can have a joint distribution of x observables, i.e. under the term ‘fluctuations’ one can also study ‘correlations’ (in this project we limit x to 2)
4) ‘correlations’ can be studied between observables in the same kinematic acceptance (1 subevent of the full event) or between observables in the separated kinematic acceptances (x subevents)
5) the size of subevents can be varied

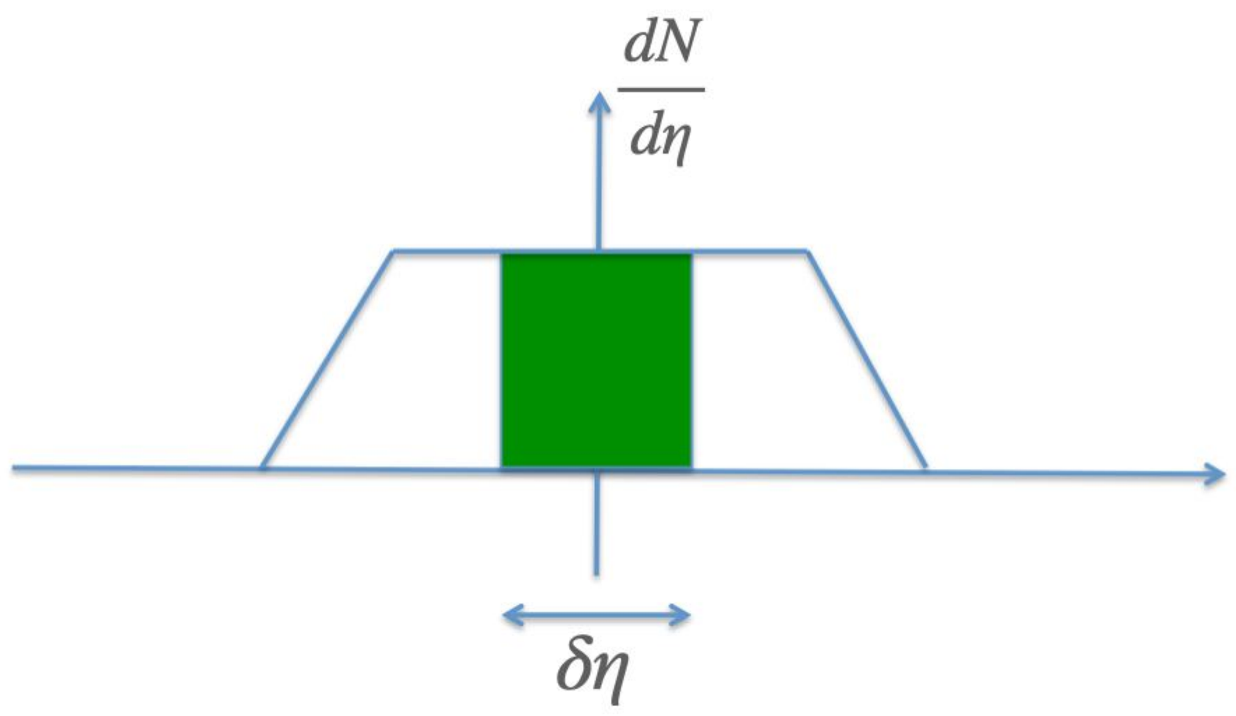
Observables



For 1 subevent:

- multiplicity of charged hadrons (N)
- net electric charge ($N_+ - N_-$)
- sum of transverse momenta of charged hadrons ($P_T = \sum_{i=1}^{N} p_{T,(i)}$)
- mean transverse momentum in an event ($M(p_T) = \frac{P_T}{N}$)

Fluct. measures



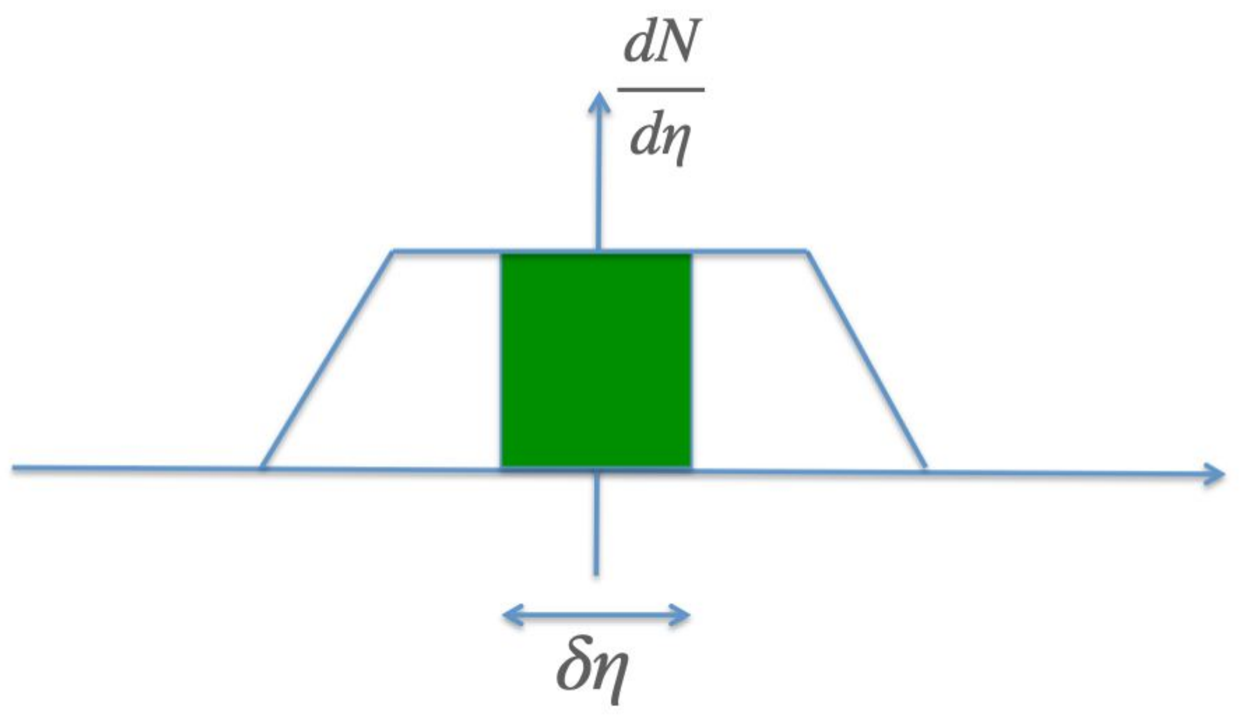
For 1 subevent:

- mean multiplicity (event-average) $\langle N \rangle = \frac{\sum_{j=1}^{n_{events}} N_j}{n_{events}}$
- scaled variance (event-average) $\omega[N] = \frac{\langle N^2 \rangle - \langle N \rangle^2}{\langle N \rangle}$
- net charge cumulants $\kappa_i = \frac{d^i}{dz^i} ln \left(\sum_{N_+ - N_-} P(N_+ - N_-) z^n \right)_{z=1}$
- scaled variance (event+track-average) $\omega[[p_T]] = \frac{\langle\langle pT^2 \rangle\rangle - \langle\langle p_T \rangle\rangle^2}{\langle\langle p_T \rangle\rangle}$
- strongly intensive quantities:
  - $\Delta[P_T, N] = \frac{\langle N \rangle \omega[P_T] - \langle P_T \rangle \omega[N]}{\langle N \rangle \omega[[p_T]]}$
  - $\Sigma[P_T, N] = \frac{\langle N \rangle \omega[P_T] + \langle P_T \rangle \omega[N] - 2(\langle N \cdot P_T \rangle - \langle N \rangle \langle P_T \rangle)}{\langle N \rangle \omega[[p_T]]}$

M. Gorenstein, M. Gazdzicki, Phys. Rev. C84, 014904 (2011)

covered by A. Seryakov (10.10.23 https://indico.jinr.ru/event/4066/)

Fluct. measures



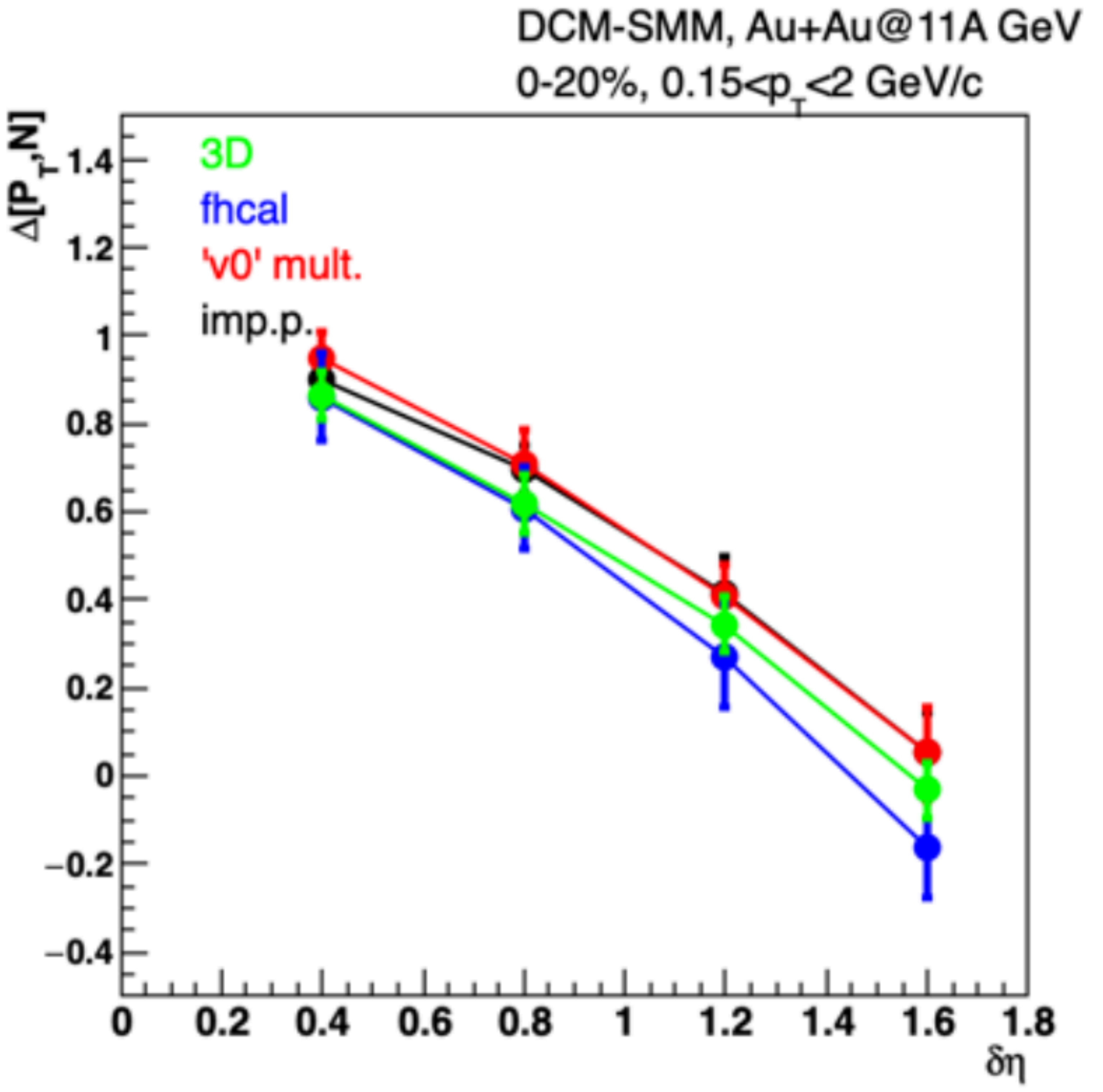
Findings:

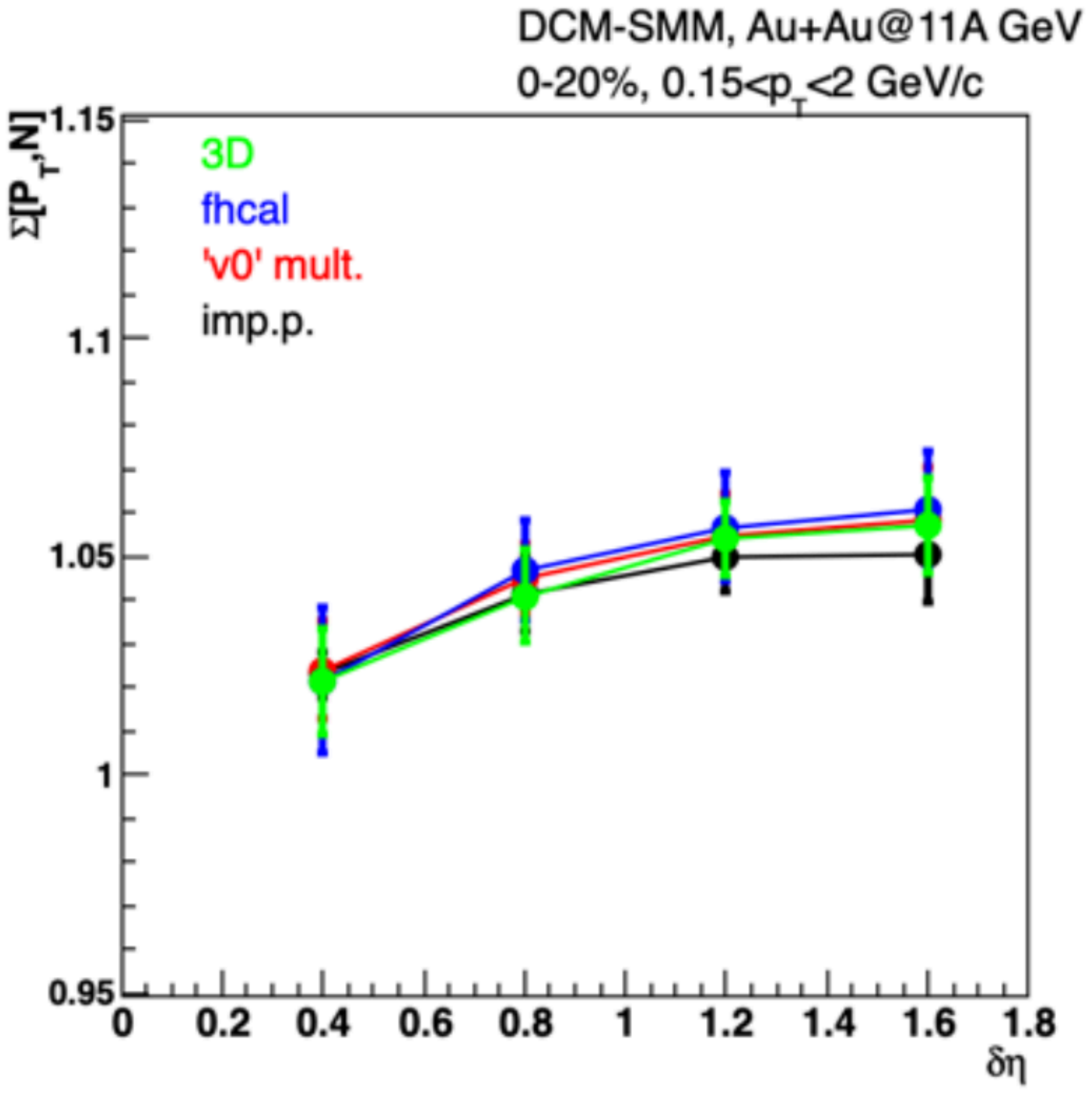
- Current version of 3D method have to be modified to exclude auto-correlations. The multiplicity for it has to be measured in separate rapidity windows ([-1.2,-0.8]U[0.8,1.2])
- Standard FHCal method (energy vs max.E) produces better or equal results to ER method (energy vs radius of the fit).
- For very central events FHCal* is recommended to use as a centrality proxy.
- For periphery – V0*, however there will be an effect which has to be taken into account.
- Hight moment fluctuations can't be measured for peripheral events
- Adding a multiplicity V0 cut on periphery makes solely FHCal selection better, but there is a room for improvement and careful studies.

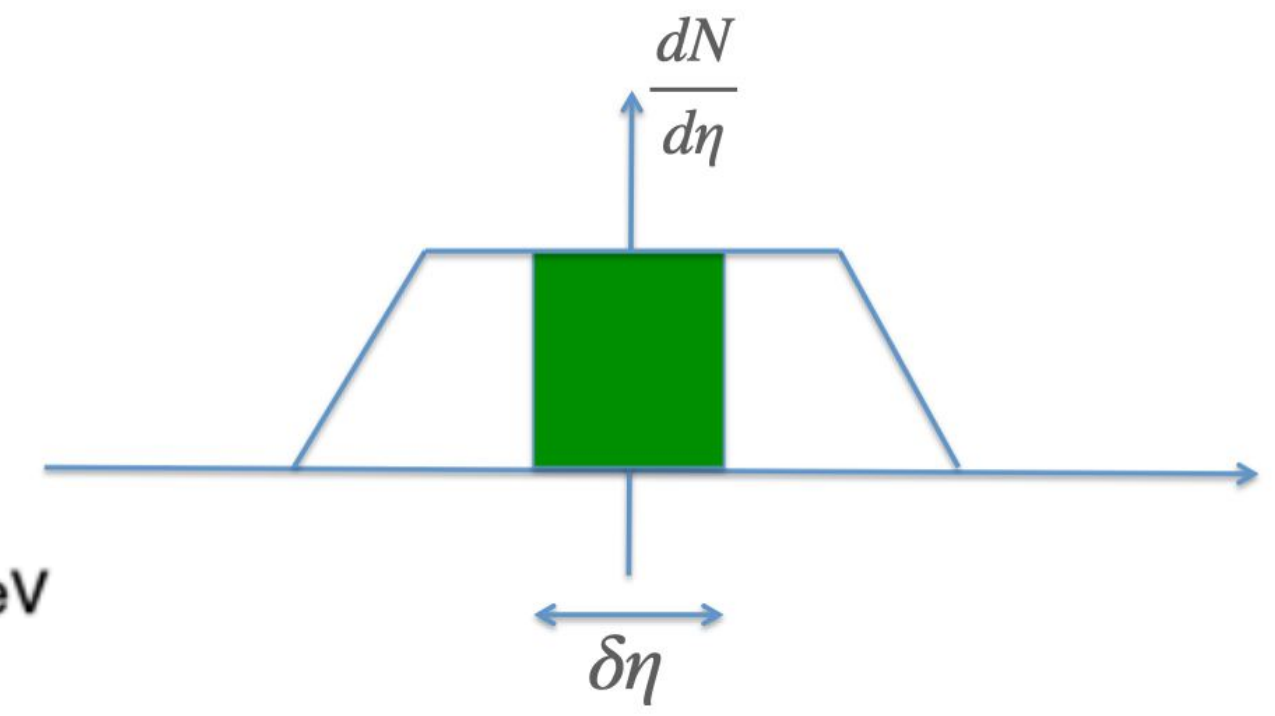
covered by A. Seryakov (10.10.23 https://indico.jinr.ru/event/4066/)

Fluct. measures

Dependence on width of the subevent:



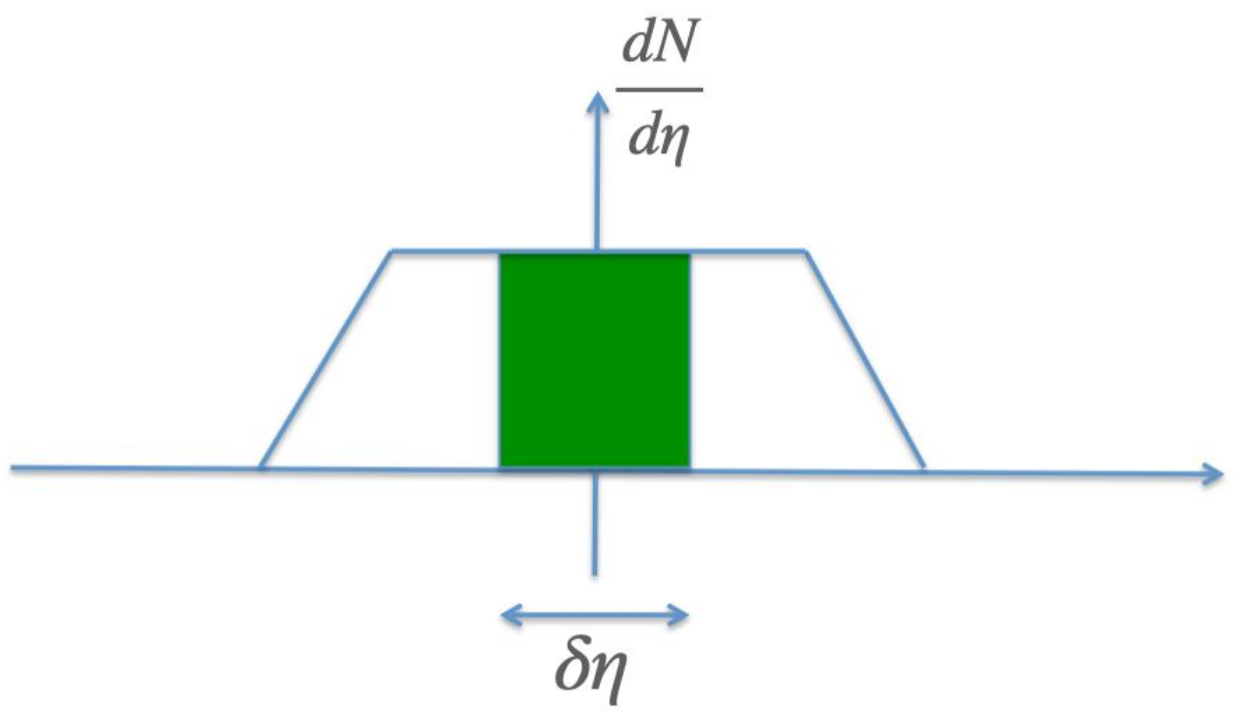




Findings:

- Both $\Delta[P_T, N]$ and $\Sigma[P_T, N]$ tend to 1 with a decrease of acceptance
- ‘True’ results for $\Delta[P_T, N]$ are best reproduced by the’v0’ method
- ‘True’ results for $\Sigma[P_T, N]$ are consistent with all methods

Fluct. measures



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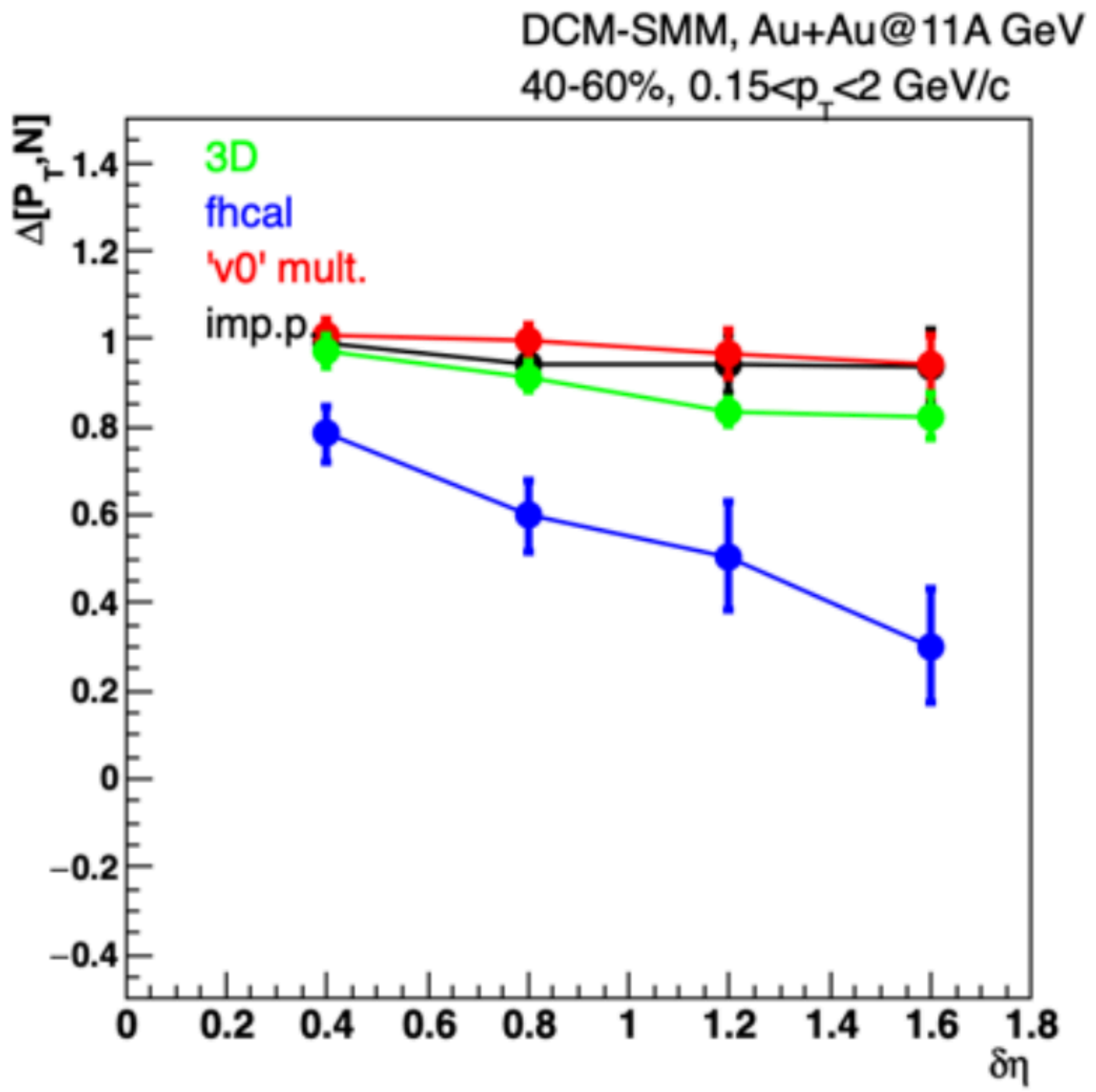
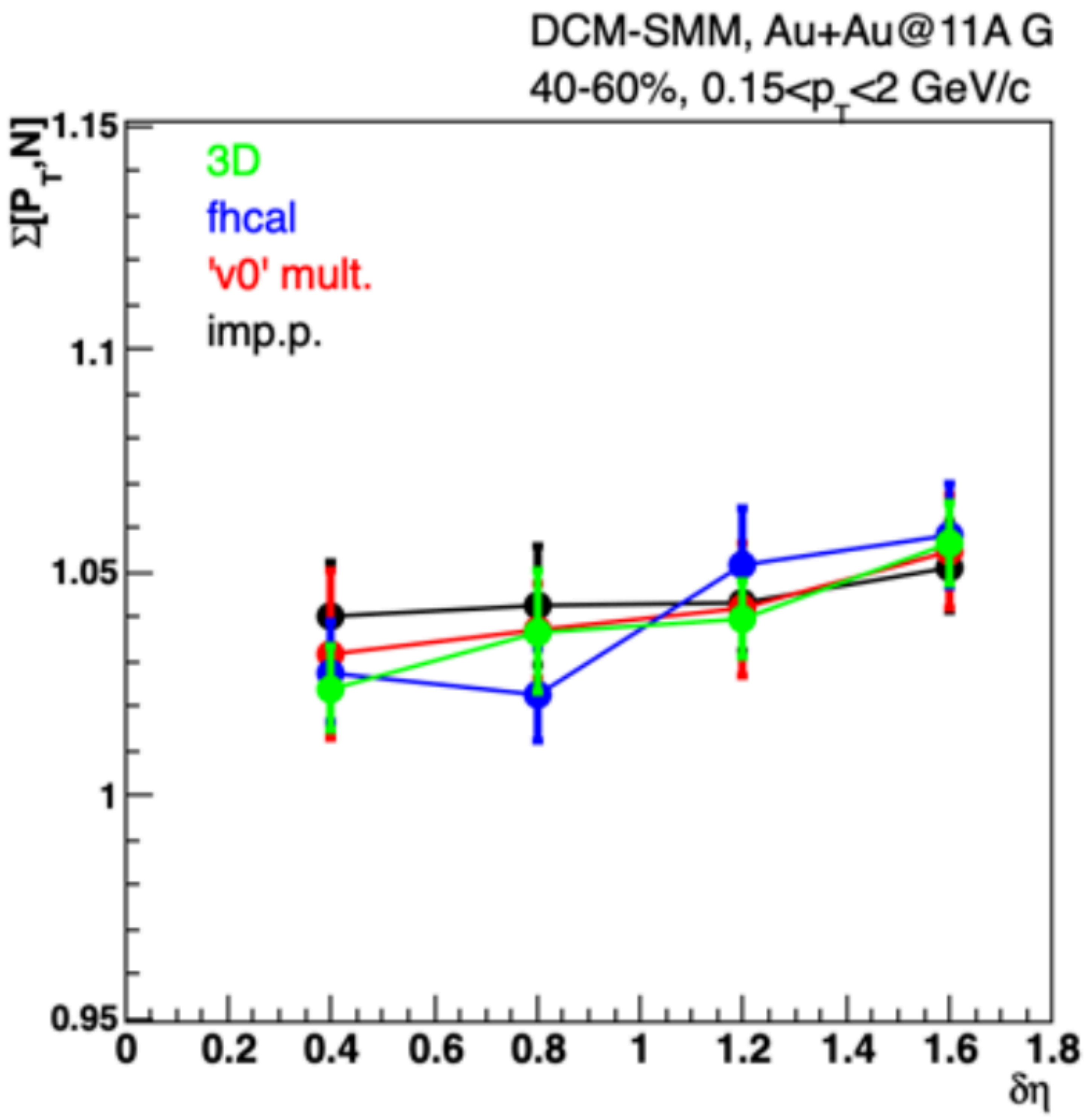




Findings:

- Both $\Delta[P_T, N]$ and $\Sigma[P_T, N]$ tend to 1 with a decrease of acceptance
- For more peripheral events FHCal method is not applicable for $\Delta[P_T, N]$

Observables

For 1 subevent:

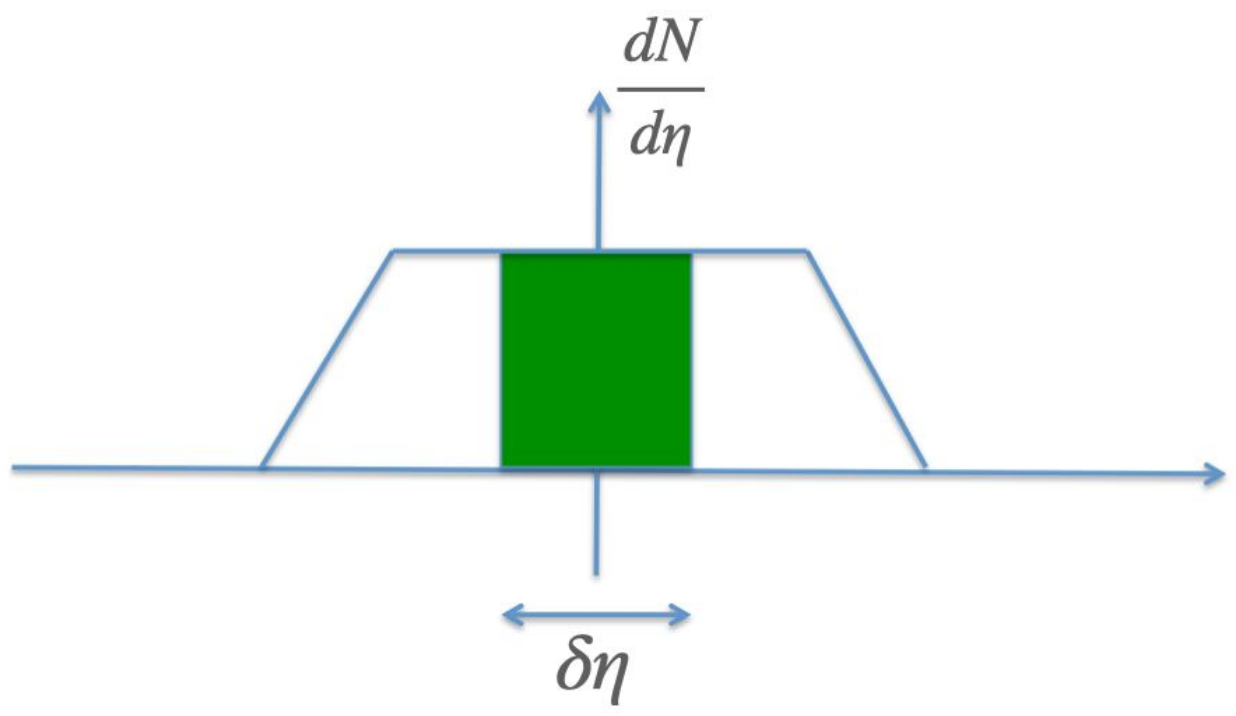
- p_T 'correlator' ($C_n = \frac{\sum_{i1=1}^{N} \ldots \sum_{in=1, i1 \neq i2 \neq \ldots \neq in}^{N} (p_{T,(i1)} - M(p_T)) \ldots (p_{T,(in)} - M(p_T))}{N(N-1)\ldots(N-n)}$)

This measure can be considered as complementary to anisotropic flow studies (it is sensitive to the initial stage of the collision) (—>recent interest to v_n-p_T correlations) G. Giacalone et al., Phys. Rev. C 103, 024910 (2021)

Higher order cumulants are sensitive to EoS that are inserted into hydro simulations

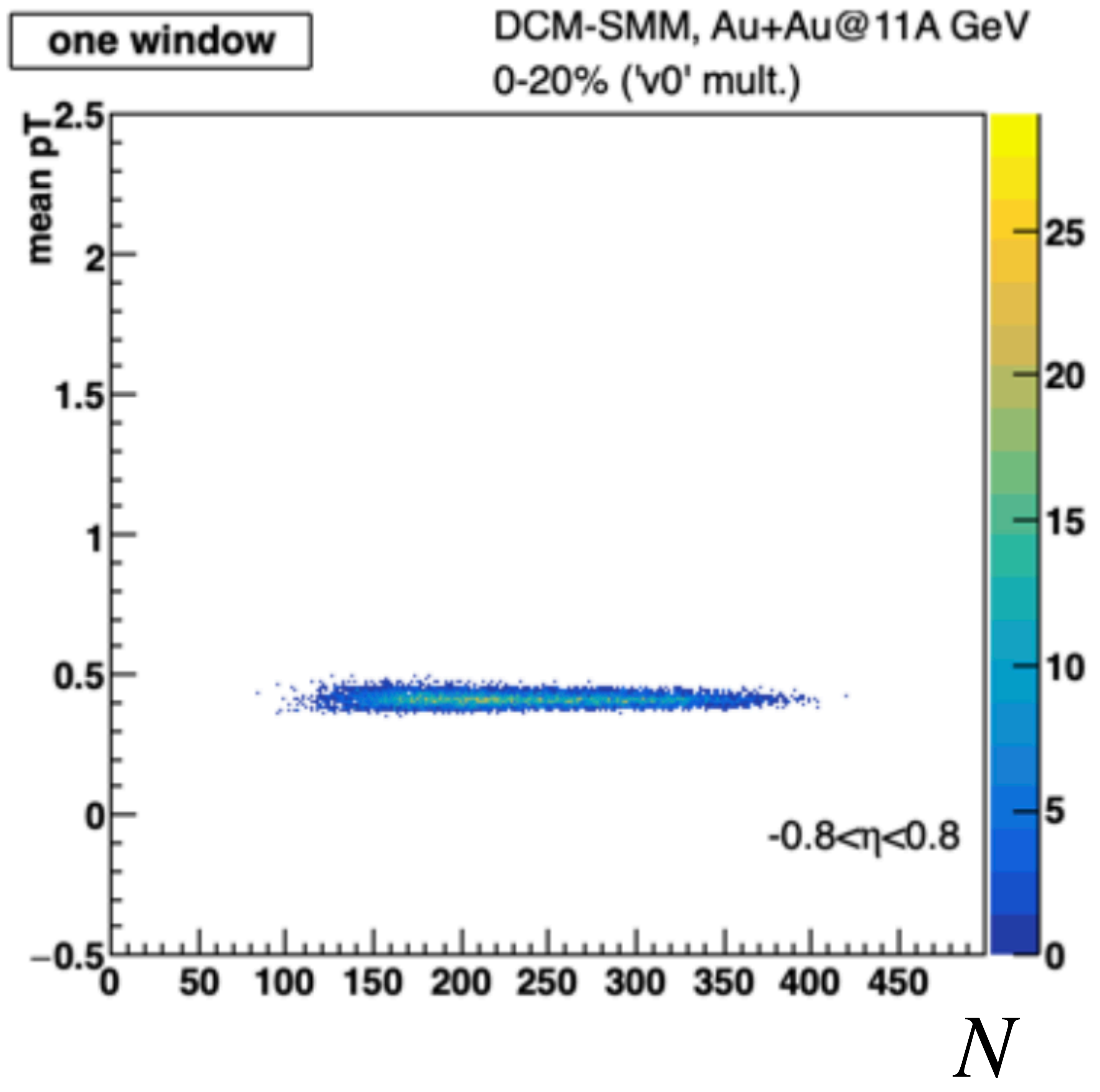
- C_2 by ALICE, STAR, ATLAS etc. ALICE, Eur. Phys. J. C 74, 3077 (2014) STAR, Phys. Rev. C 99, 044918 (2019)
- recent C_3 and C_4 by ALICE ALICE, e-Print: 2308.16217 [nucl-ex] ATLAS, ATLAS-CONF-2023-061

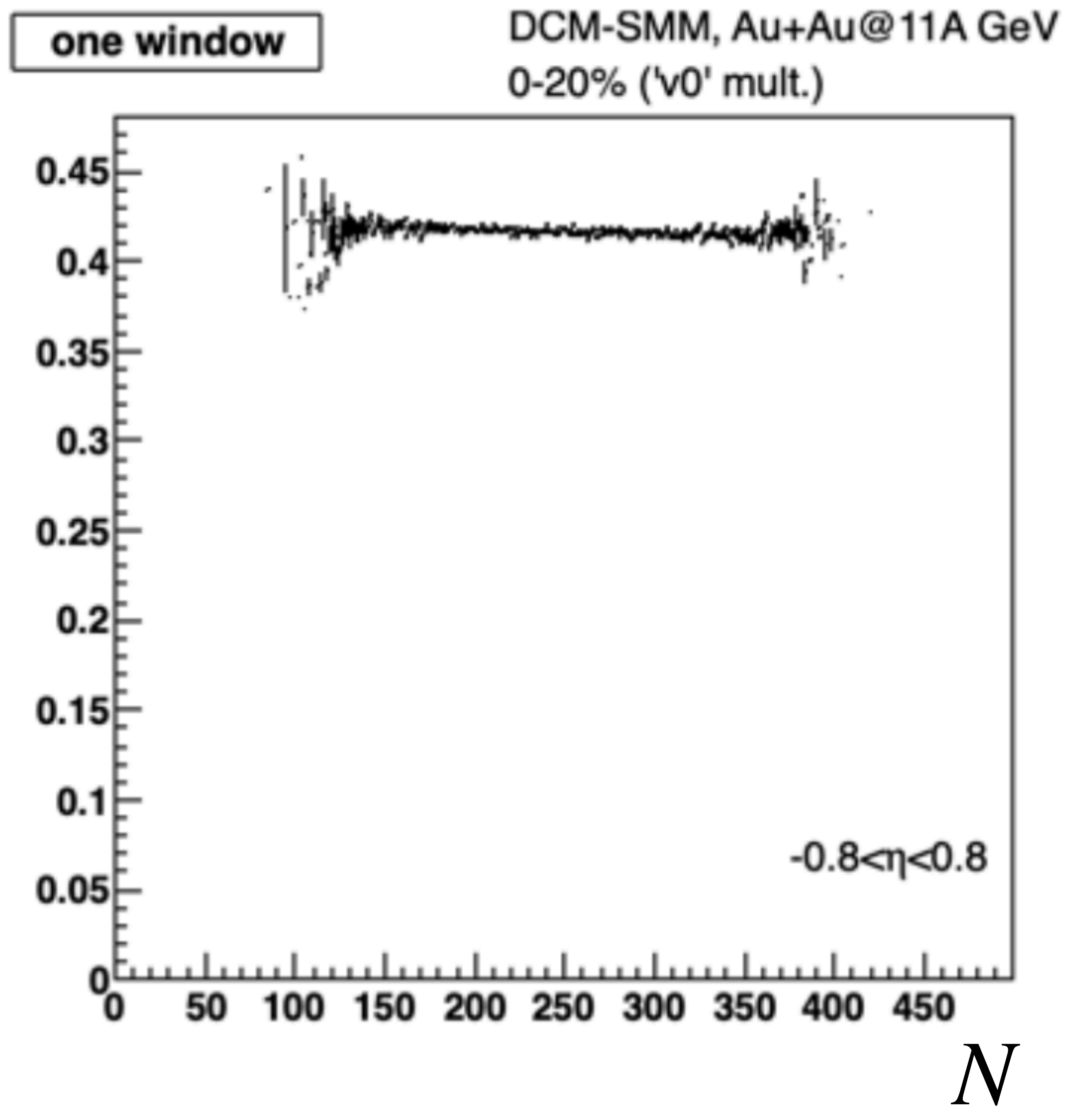
Fluct. measures



For 1 subevent:

- p_T 'correlator' of the order 1 is $M(p_T) = \frac{P_T}{N}$
- typically studied as a function of multiplicity

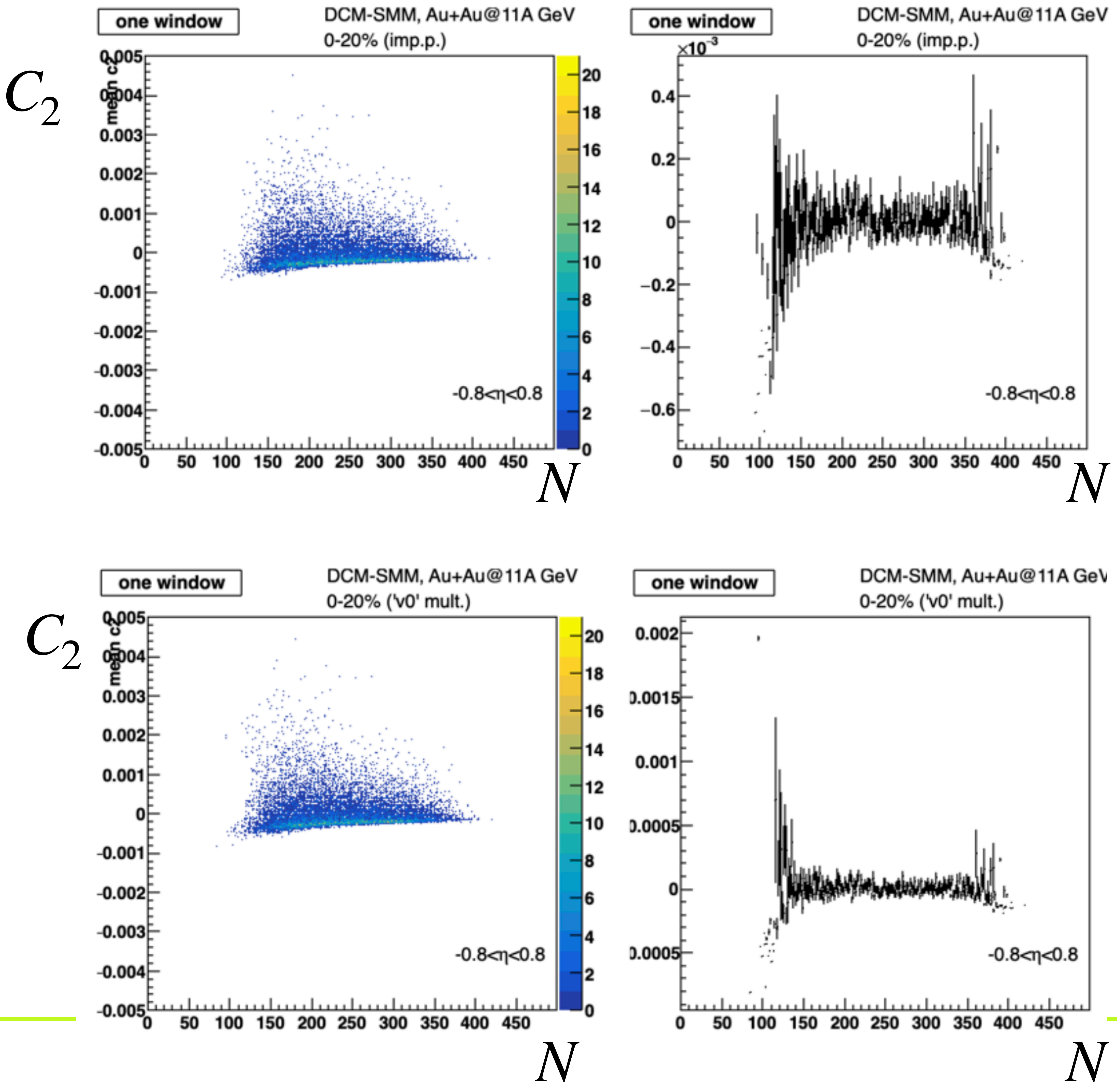


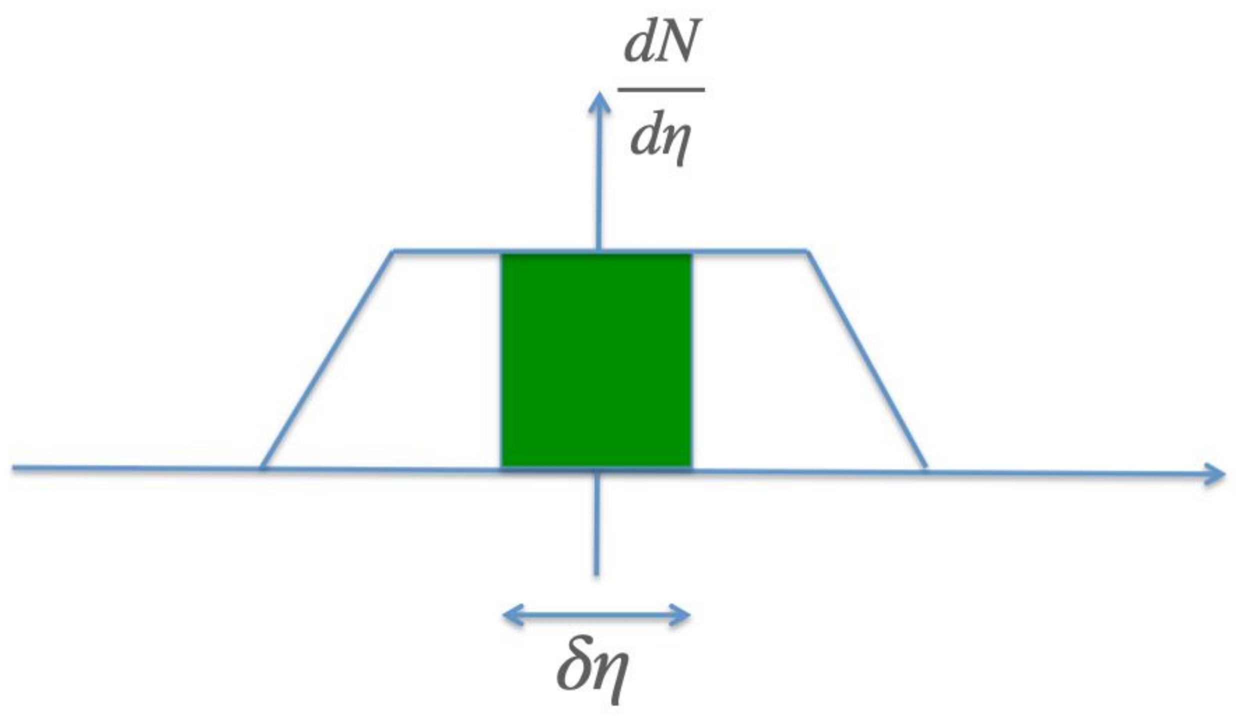


Findings:

- Slightly negative correlations for 'true' central events
- Well reproduced by all centrality selection methods

Fluct. measures

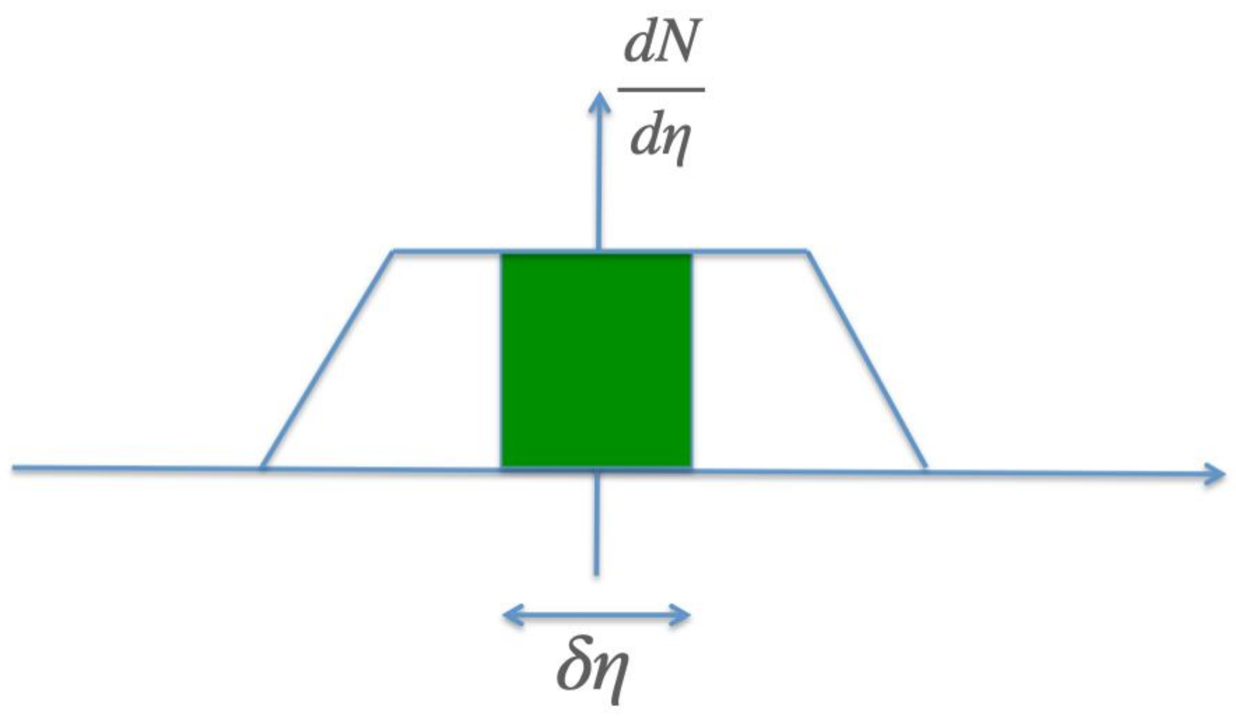




Findings:

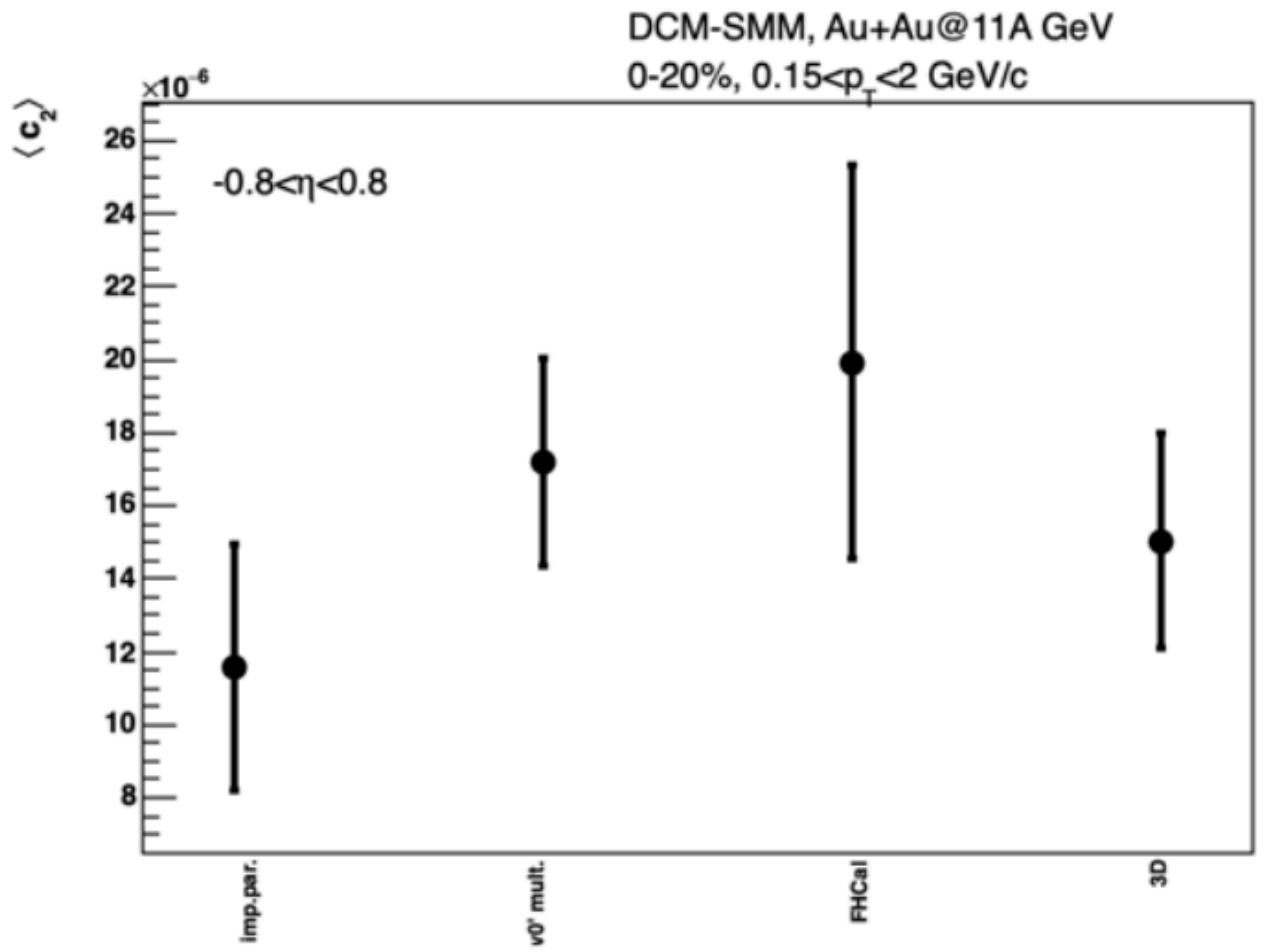
- C_2 is well reproduced for central events
- Clearly larger statistics is needed for more precise conclusions

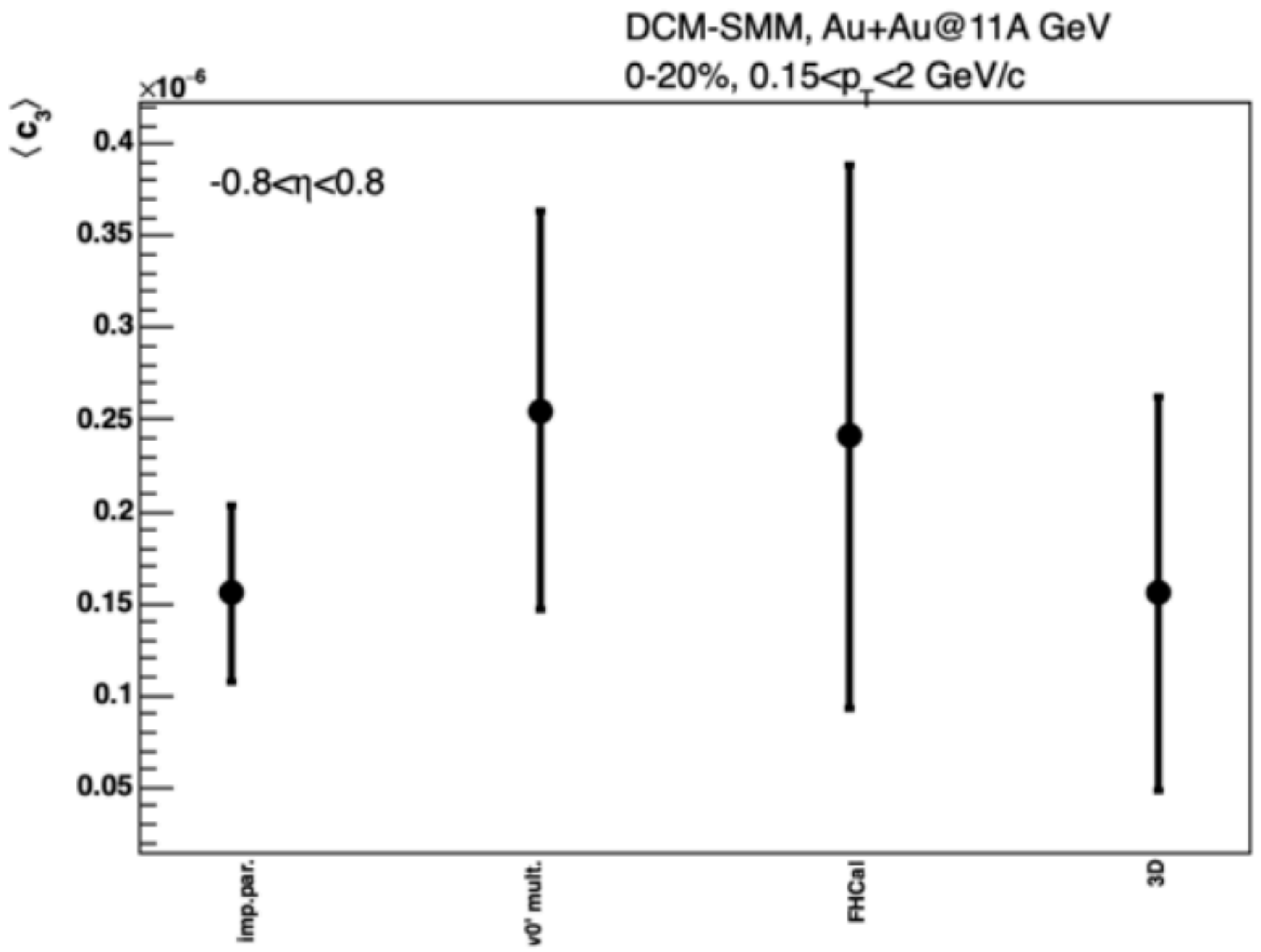
Fluct. measures



For 1 subevent:

- p_T 'correlators' C_2 and C_3 with an integrated multiplicity

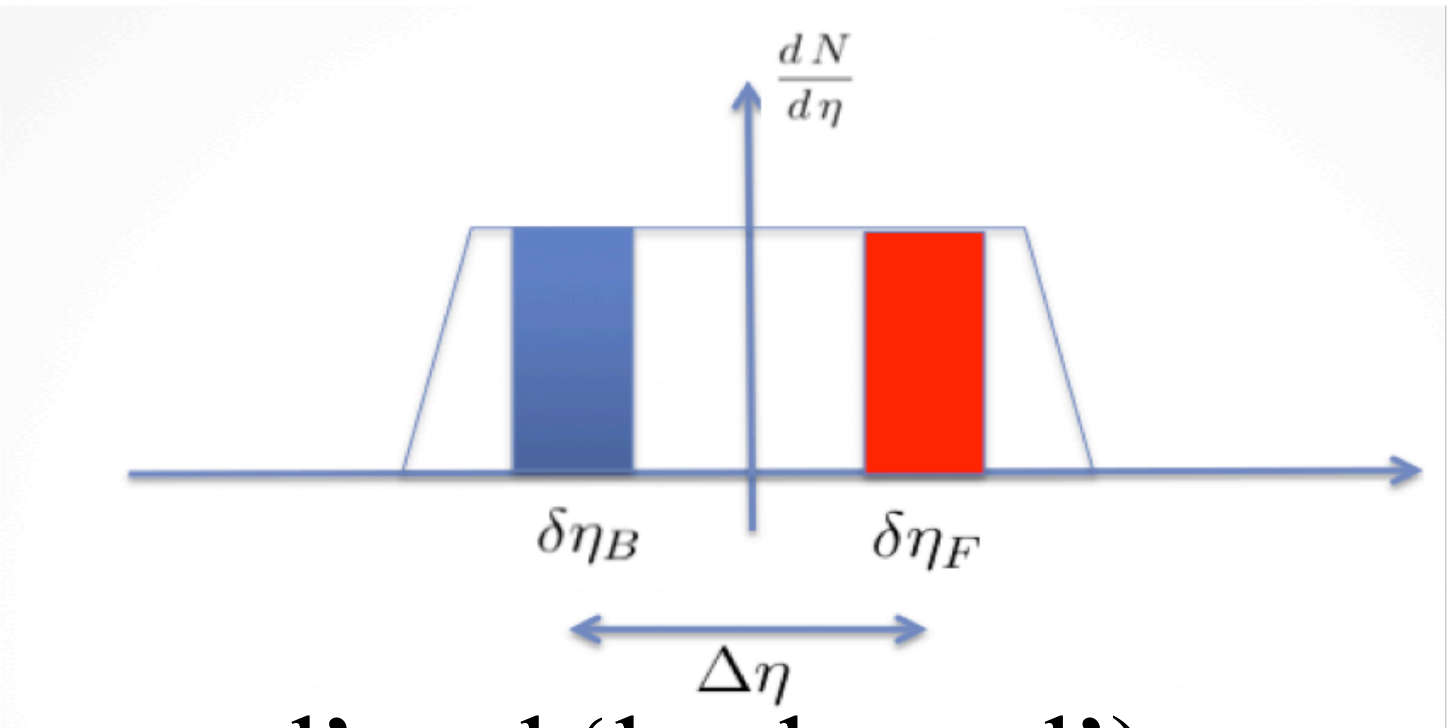




Findings:

- C_2 and C_3 are well reproduced for central events (within stat. uncert.)
- For more peripheral events FHCal method deviates significantly

Observables

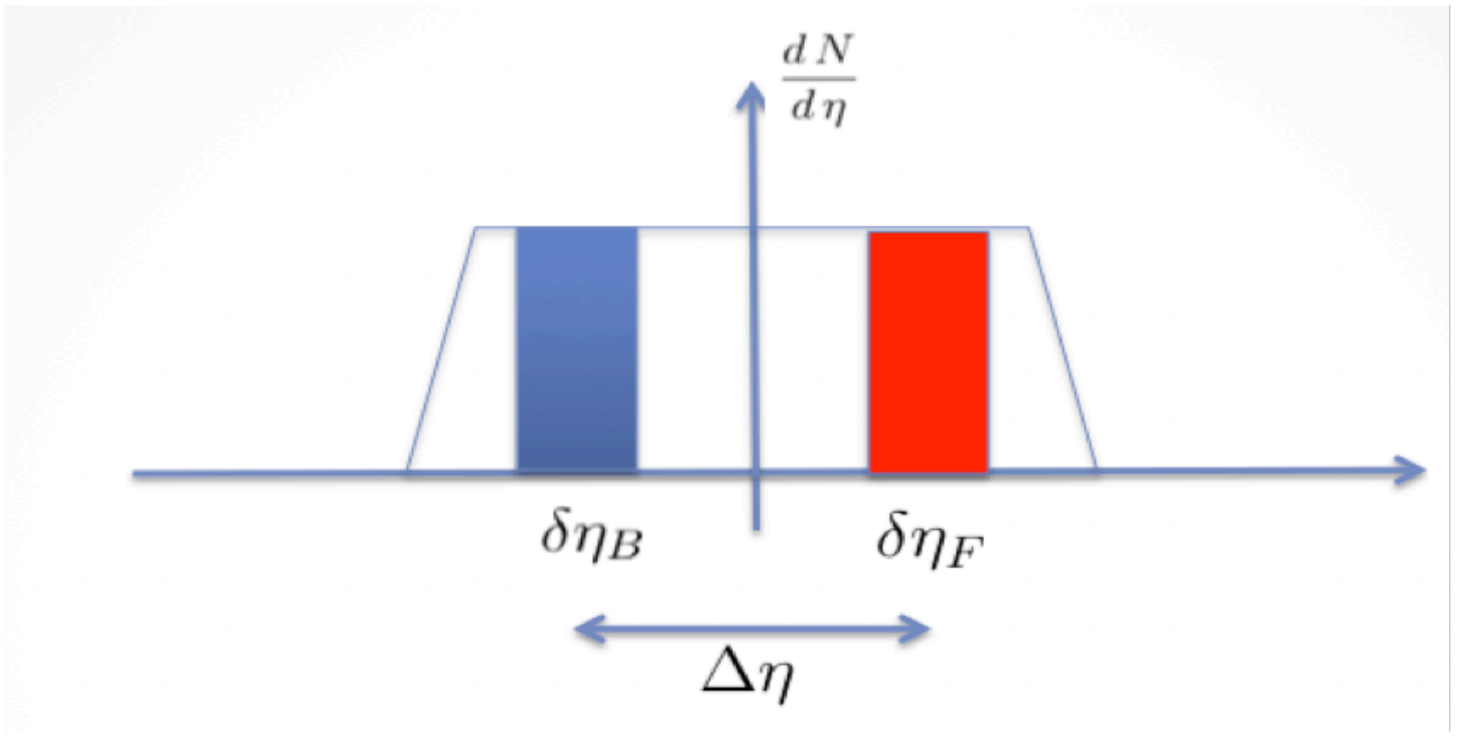


For 2 subevents (typically, two pseudorapidity intervals called ‘forward’ and ‘backward’):

- multiplicity of charged hadrons $(N)_{\mathrm{F,B}}$
- net electric charge $(N_+ - N_-)_{\mathrm{F,B}}$
- sum of transverse momenta of charged hadrons $(P_T = \sum_{i=1}^{N} p_{T,(i)})_{\mathrm{F,B}}$
- mean transverse momentum in an event $(M(p_T) = \frac{P_T}{N})_{\mathrm{F,B}}$

In this project we limit ourselves to F-B multiplicities correlations and F-B p_T ‘correlators’

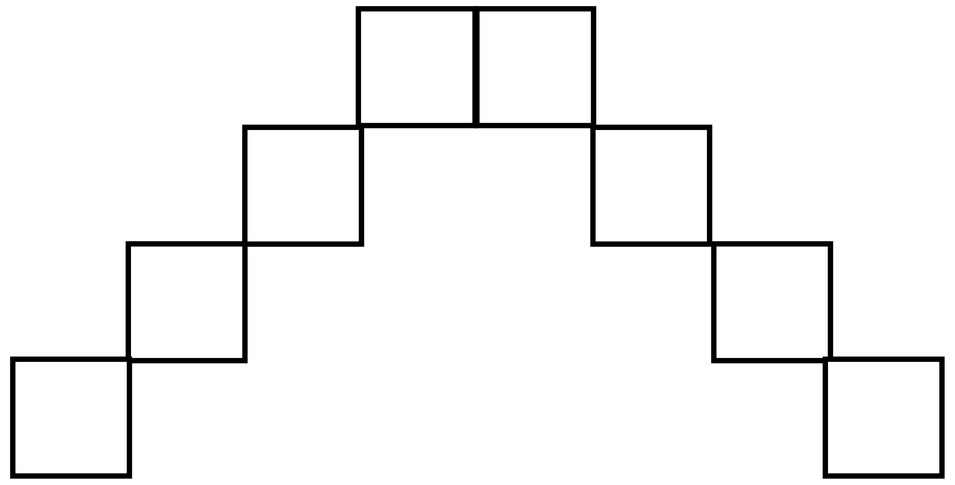
Fluct. measures



For 2 subevents:

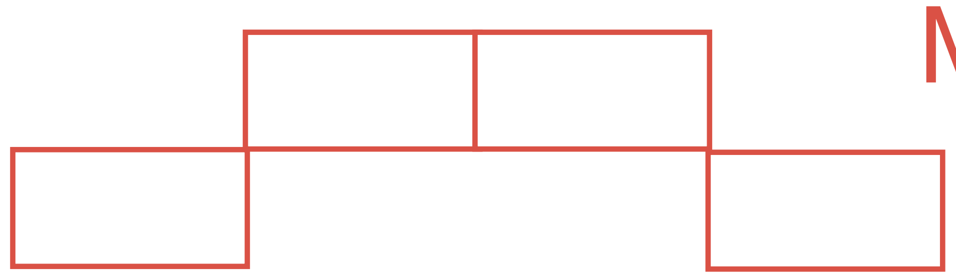
- correlation coefficient $b_{corr} = \dfrac{\langle N_F \cdot N_B \rangle - \langle N_F \rangle \cdot \langle N_B \rangle}{\langle N_F^2 \rangle - \langle N_F \rangle^2}$ (not strongly intensive) ALICE, JHEP 05, 097 (2015)
- strongly intensive $\Sigma[N_F, N_B] = \dfrac{\langle N_B \rangle \omega[N_F] + \langle N_F \rangle \omega[N_B] - 2\left(\langle N_F \cdot N_B \rangle - \langle N_F \rangle \cdot \langle N_B \rangle\right)}{\langle N_F + N_B \rangle}$ M. Gorenstein, M. Gazdzicki, Phys. Rev. C84, 014904 (2011) E. Andronov, Theor.Math.Phys. 185, 1383 (2015)
- asymmetry $C = \dfrac{N_F - N_B}{\sqrt{N_F + N_B}}$ PHOBOS, Phys.Rev. C 74, 011901(R) (2006)
- almost strongly intensive $\sigma^2(C) = \langle C^2 \rangle - \langle C \rangle^2 \approx \Sigma[N_F, N_B]$ (under certain assumptions valid for high multiplicities)

Subevents configurations



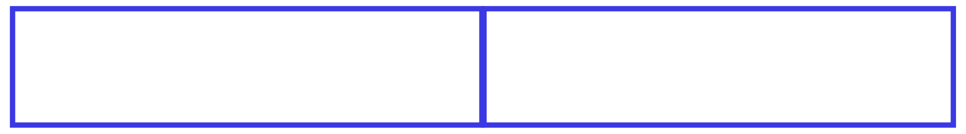
Small windows

$\delta\eta = 0.2$



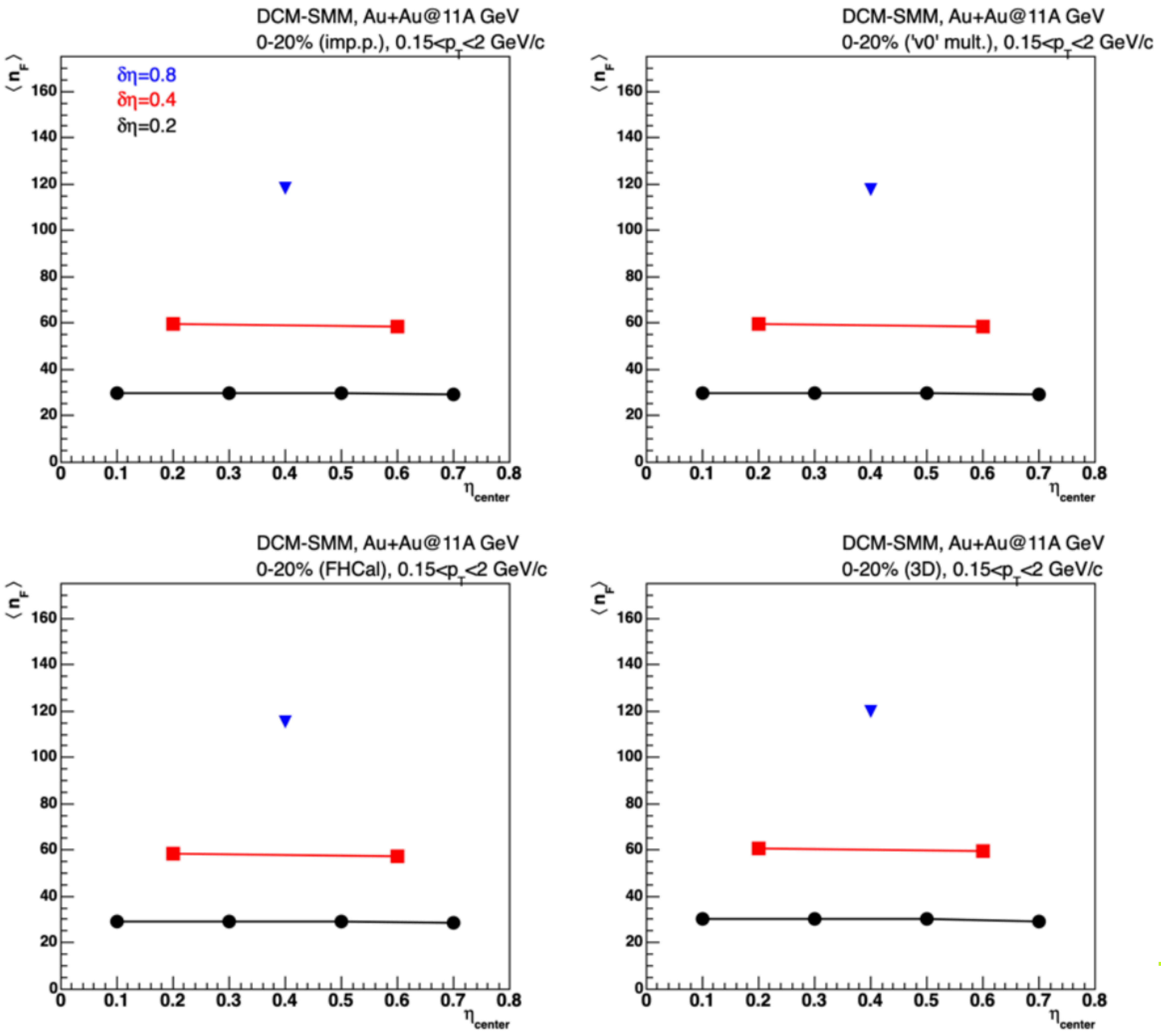
Medium windows

$\delta\eta = 0.4$



Large windows

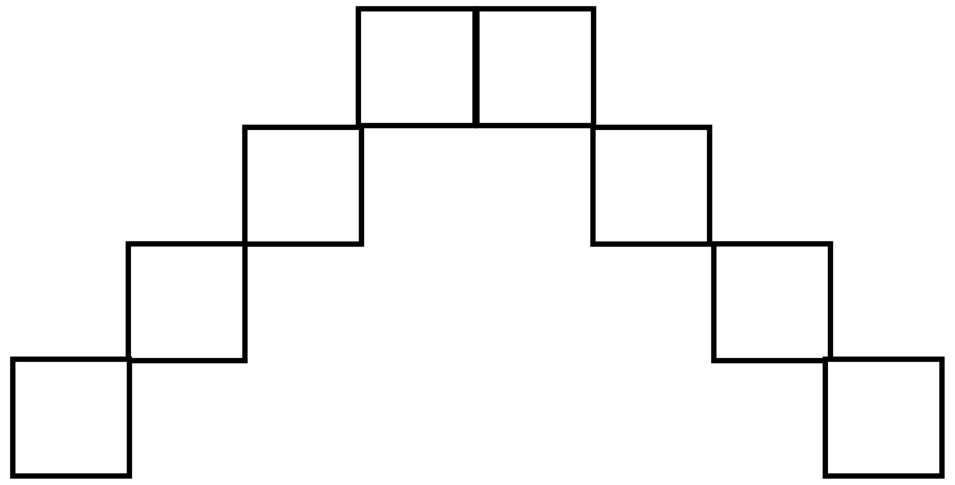
$\delta\eta = 0.8$



Findings:

- mean multiplicities in forward windows are well reproduced

Subevents configurations and $\langle N_F \rangle$



Small windows

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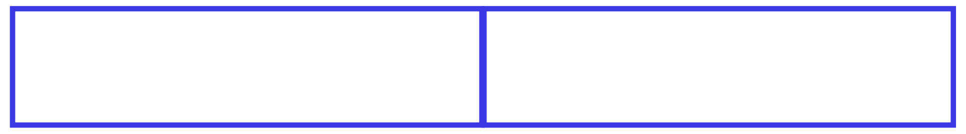
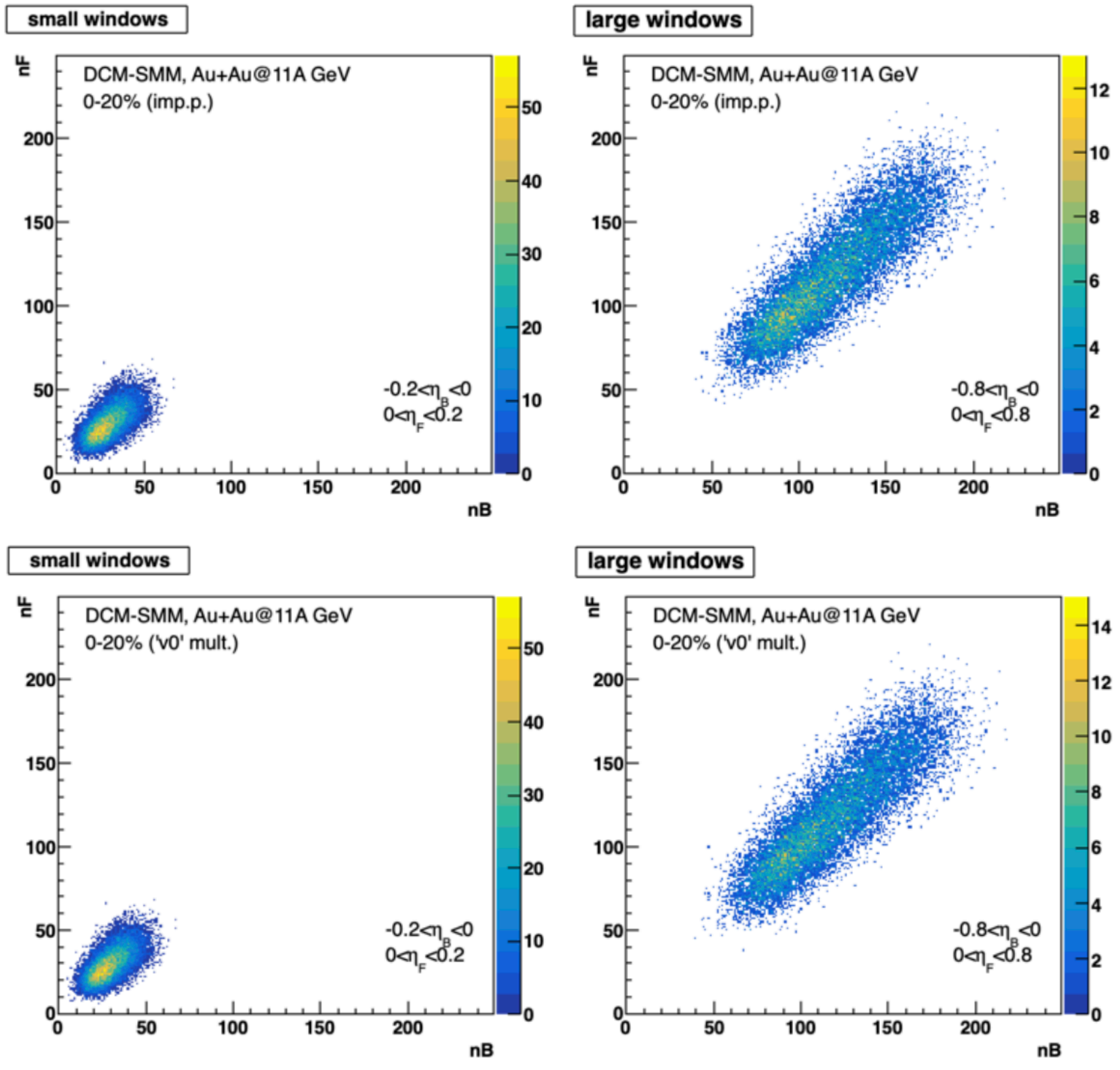


Large windows

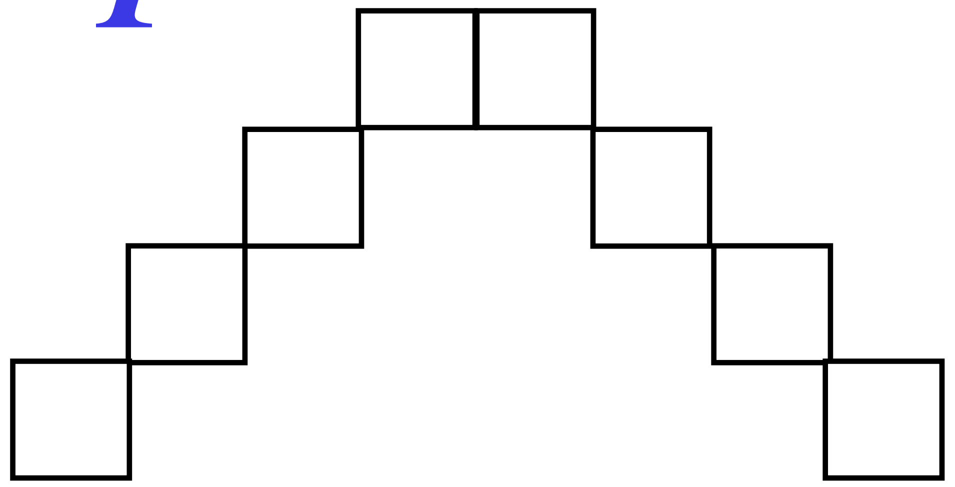
$\delta\eta = 0.8$



Findings:

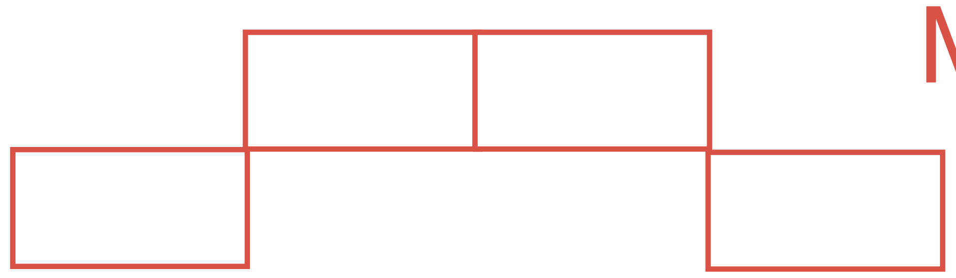
- the shape of the correlation 'cloud' looks similar to the true distribution

$\omega[N_F]$



Small windows

$\delta\eta = 0.2$



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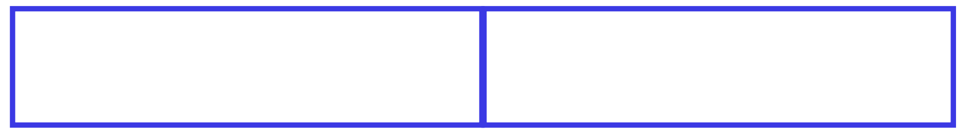
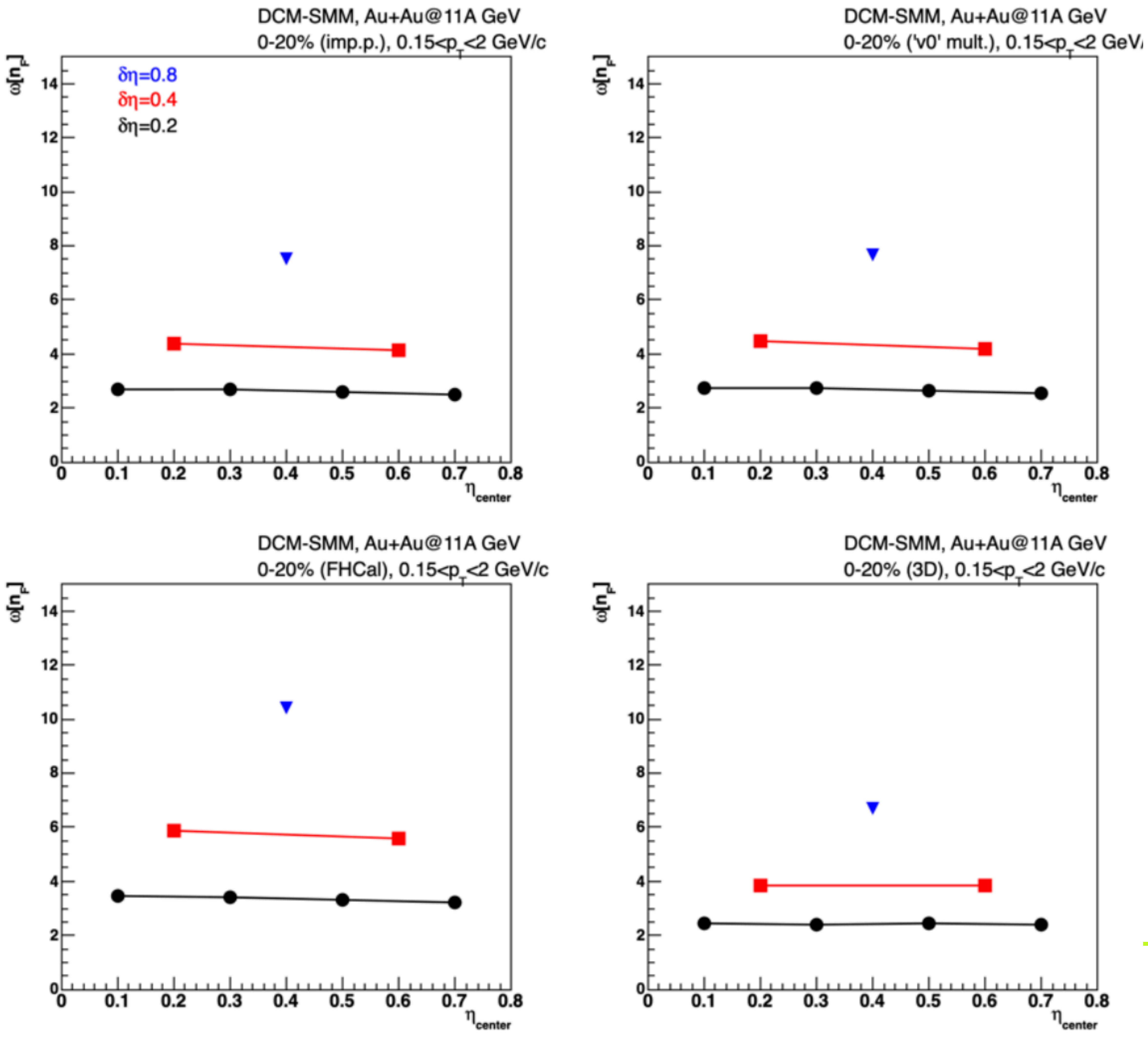


Large windows

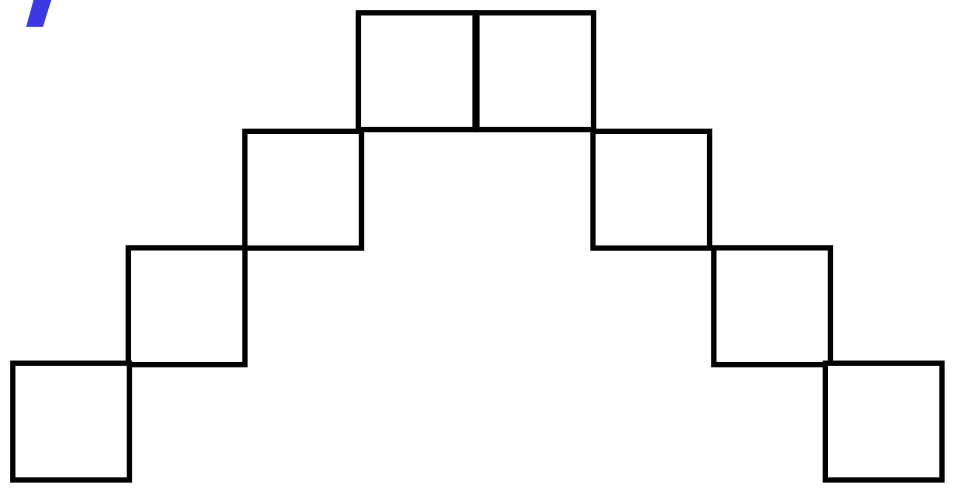
$\delta\eta = 0.8$



Findings:

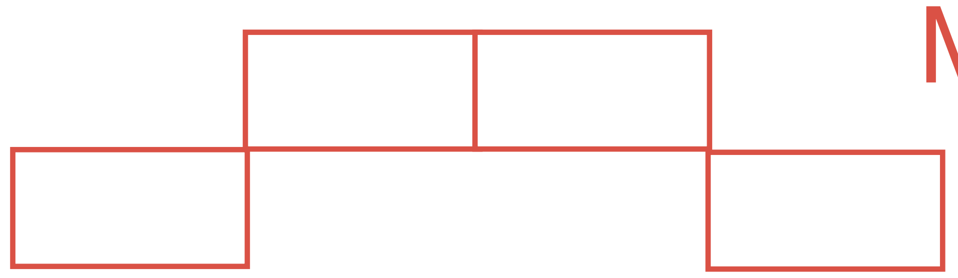
- scaled variances for forward windows are deviated for 3D method

b_{corr}



Small windows

$\delta\eta = 0.2$



Medium windows

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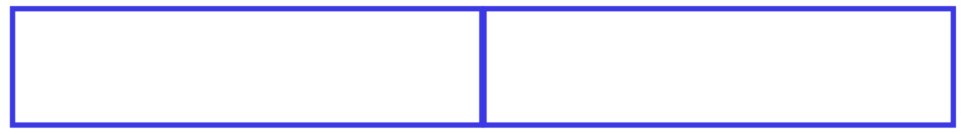

Large windows

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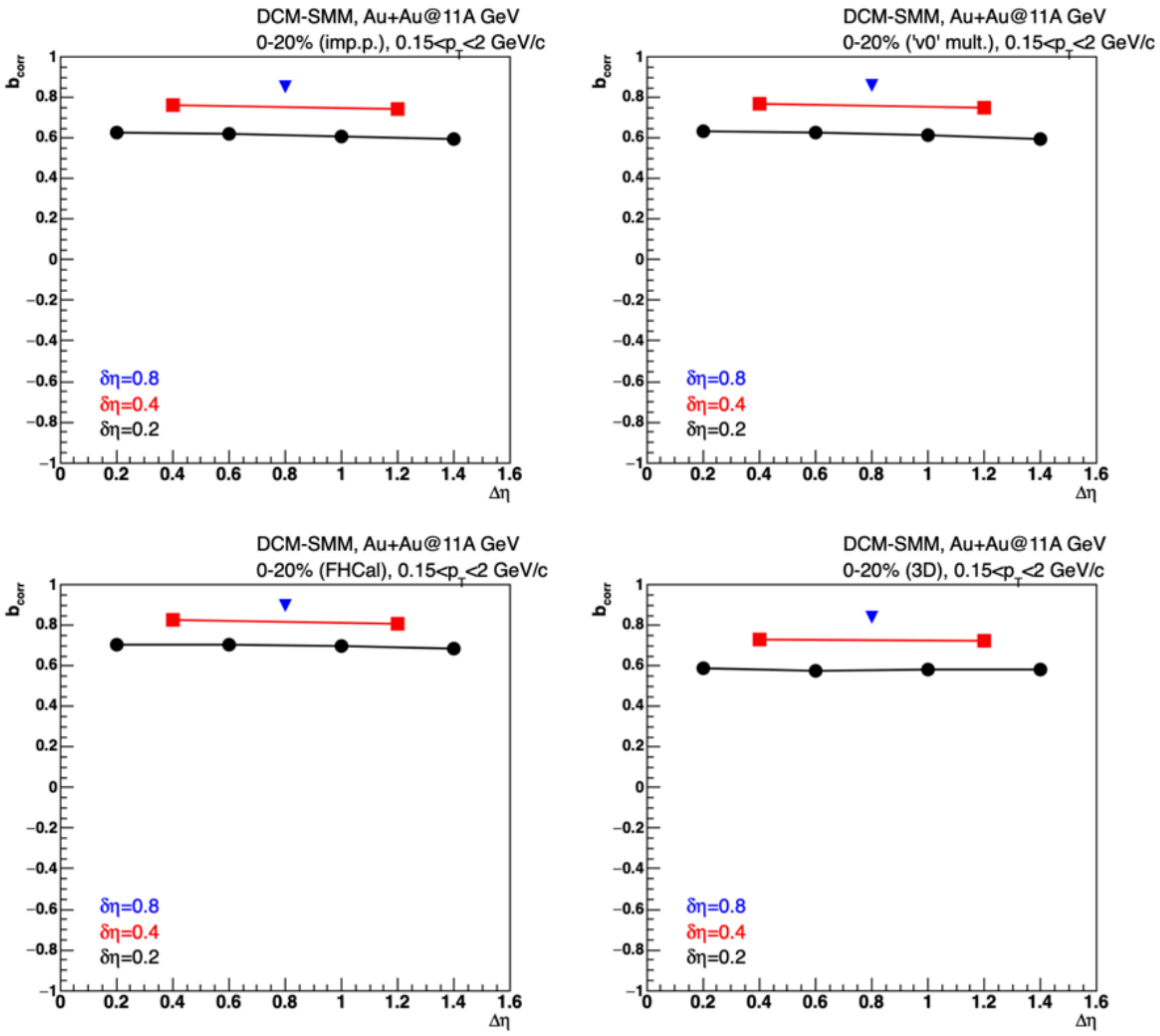
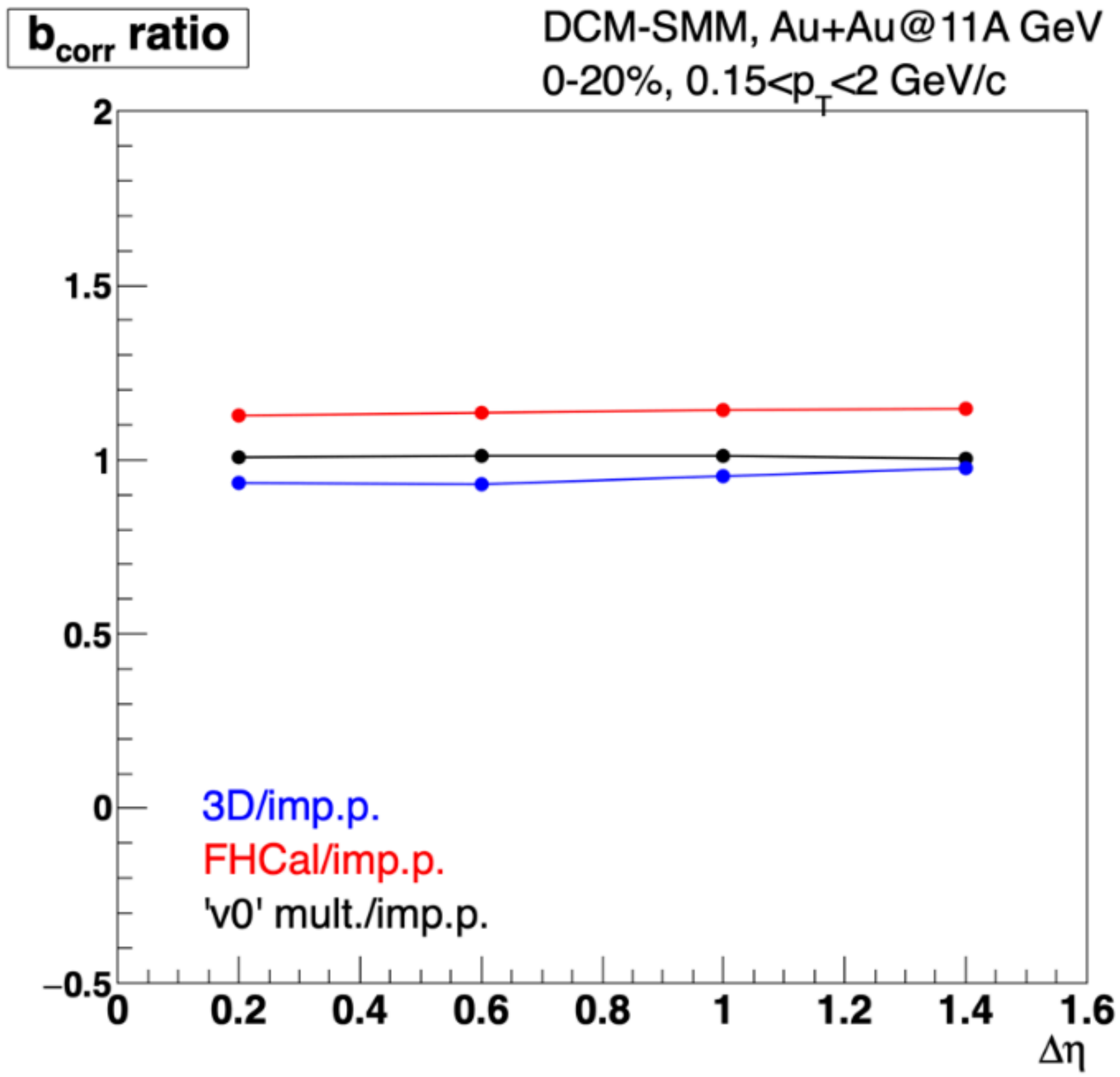


Findings:

- deviations for FHCal and 3d method are present

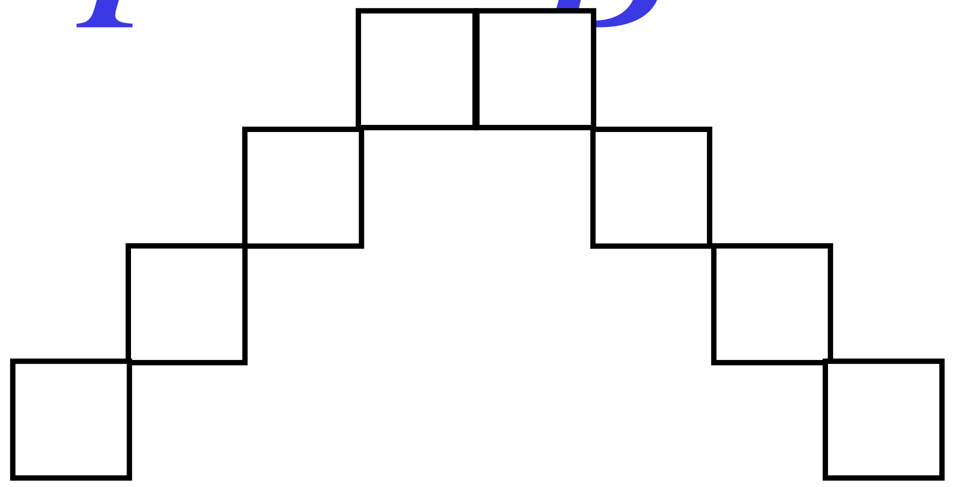
b_{corr}



Findings:

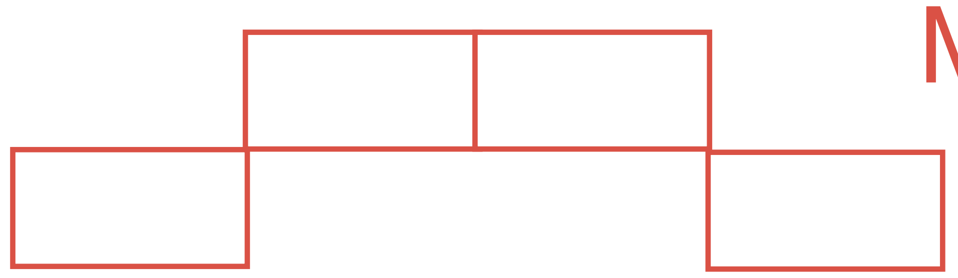
- for central events all methods produce results that are close to the 'true' one
- for peripheral events FHCal and 3d deviate even stronger (backup)

$\Sigma[N_F, N_B]$



Small windows

$\delta\eta = 0.2$



Medium windows

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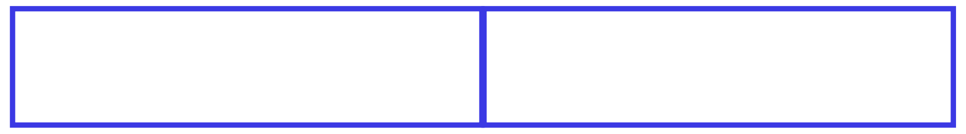
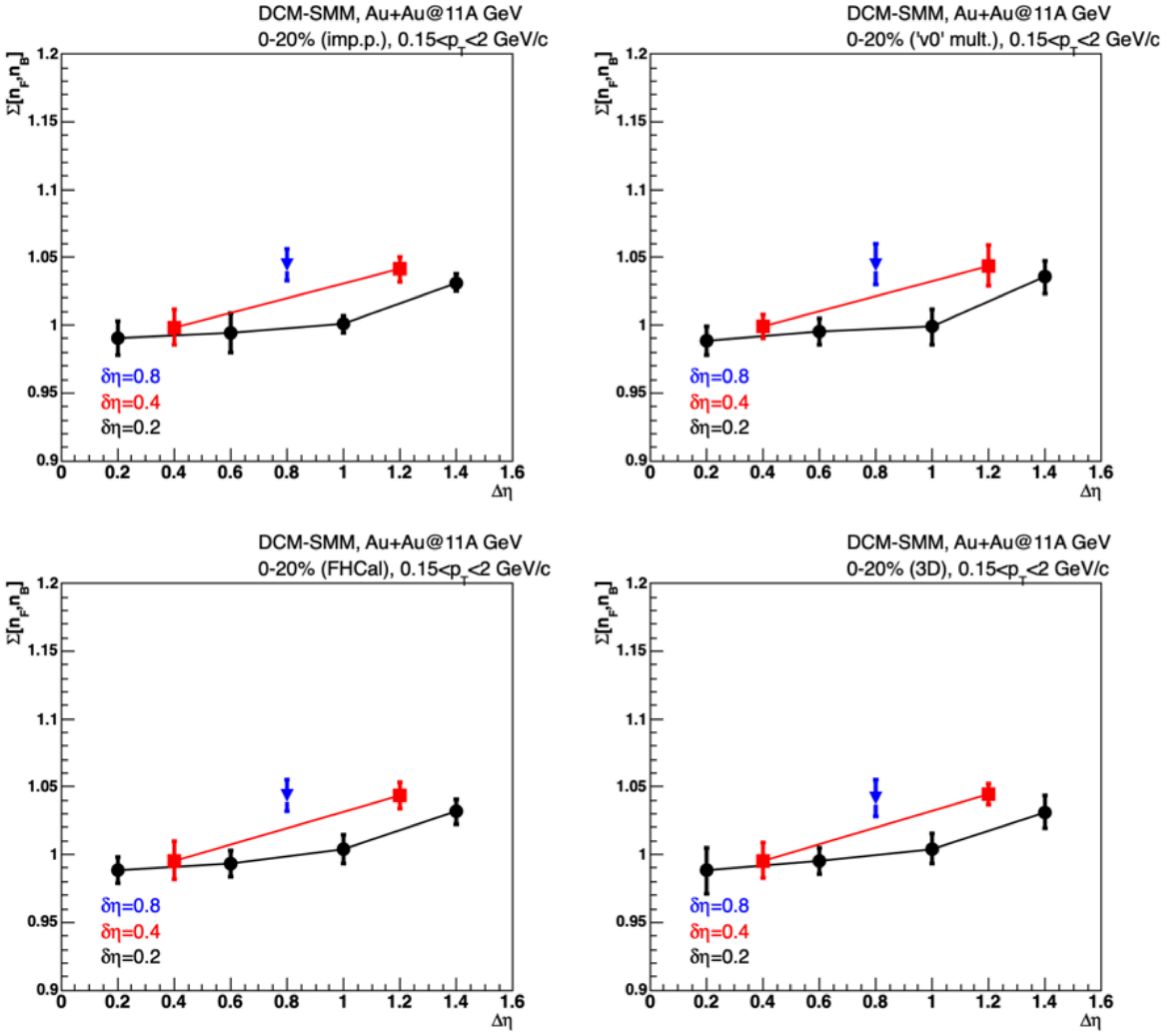


Large windows

$\delta\eta = 0.8$



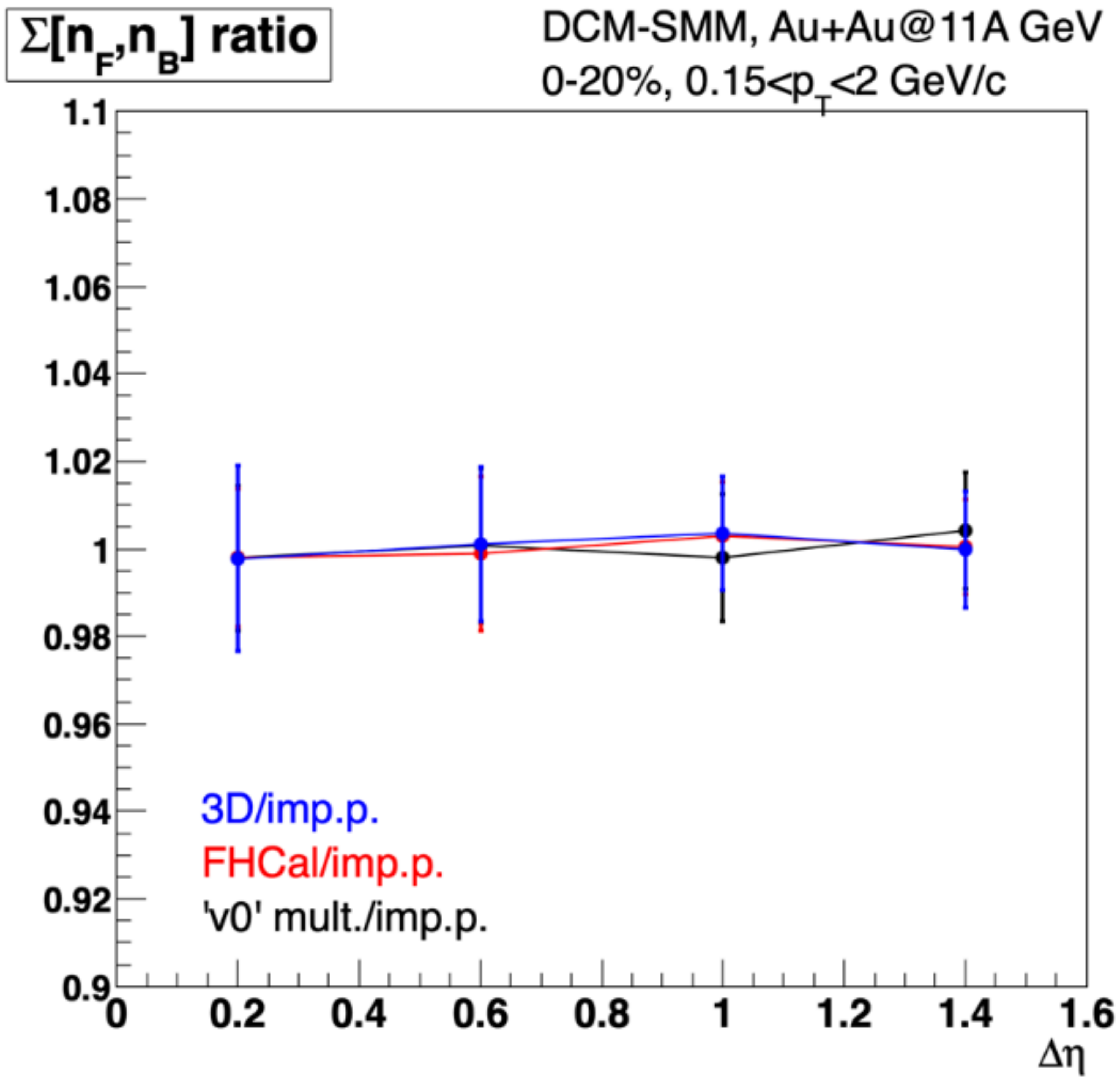
Findings:

- very stable results for central and peripheral (backup)

$\Sigma[N_F, N_B]$

Findings:

- for all events all methods produce results that are close to the 'true' one
- the same is true for $\sigma^2(C)$ (backup)



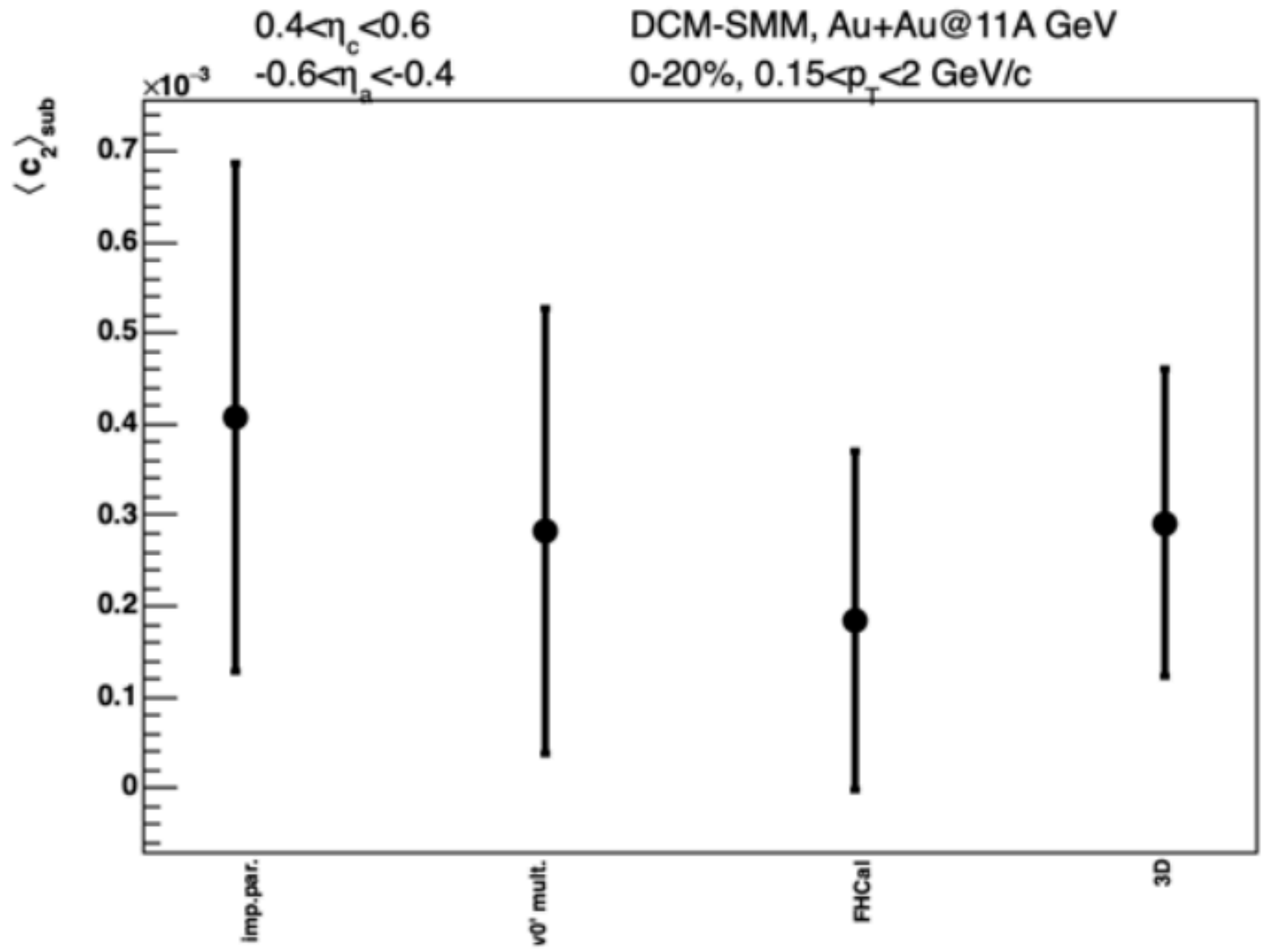
$C_{2,sub}$ and $C_{3,sub}$

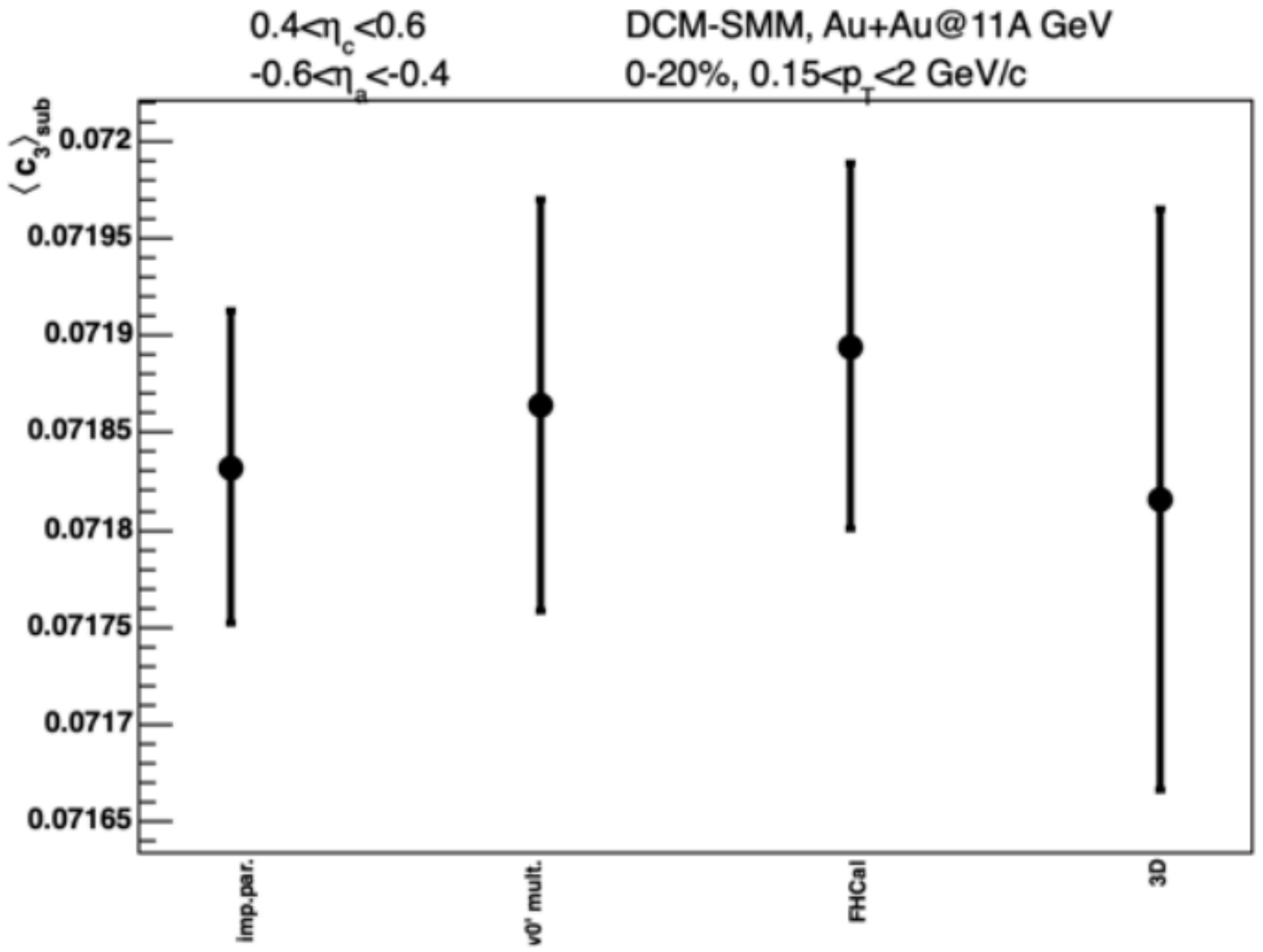
S. Bhatta, C. Zhang, J. Jia, Phys. Rev. C 105, 024904 (2022)

For 2 subevents:

You may construct the same p_T 'correlators' using particles from separated subevents in order to suppress short-range correlations effects (similar to introduction of pseudorapidity gap in flow studies)

We selected $-0.6 < \eta < -0.4$ and $0.4 < \eta < 0.6$ so that both subevents are separated from each other and from centrality estimation acceptance





Findings:

- $C_{2,sub}$ and $C_{3,sub}$ are larger than C_2 and C_3
- $C_{2,sub}$ and $C_{3,sub}$ are well reproduced for central events (within stat. uncert.)
- For more peripheral events FHCal method deviates significantly

Short summary

- Presented results indicate a different sensitivity of fluctuation measures to the centrality estimation procedure
- Strongly intensive observables tend to suppress this influence (not $\Delta[P_T, N]$, too sensitive)
- Pure FHCal method has to be enhanced with additional info on multiplicity (otherwise only for central events)
- The current implementation of the 3D method will be reevaluated using multiplicity from forward subevents
- New 3d and higher order moments would be studied using official MC productions

Thank you for your attention!

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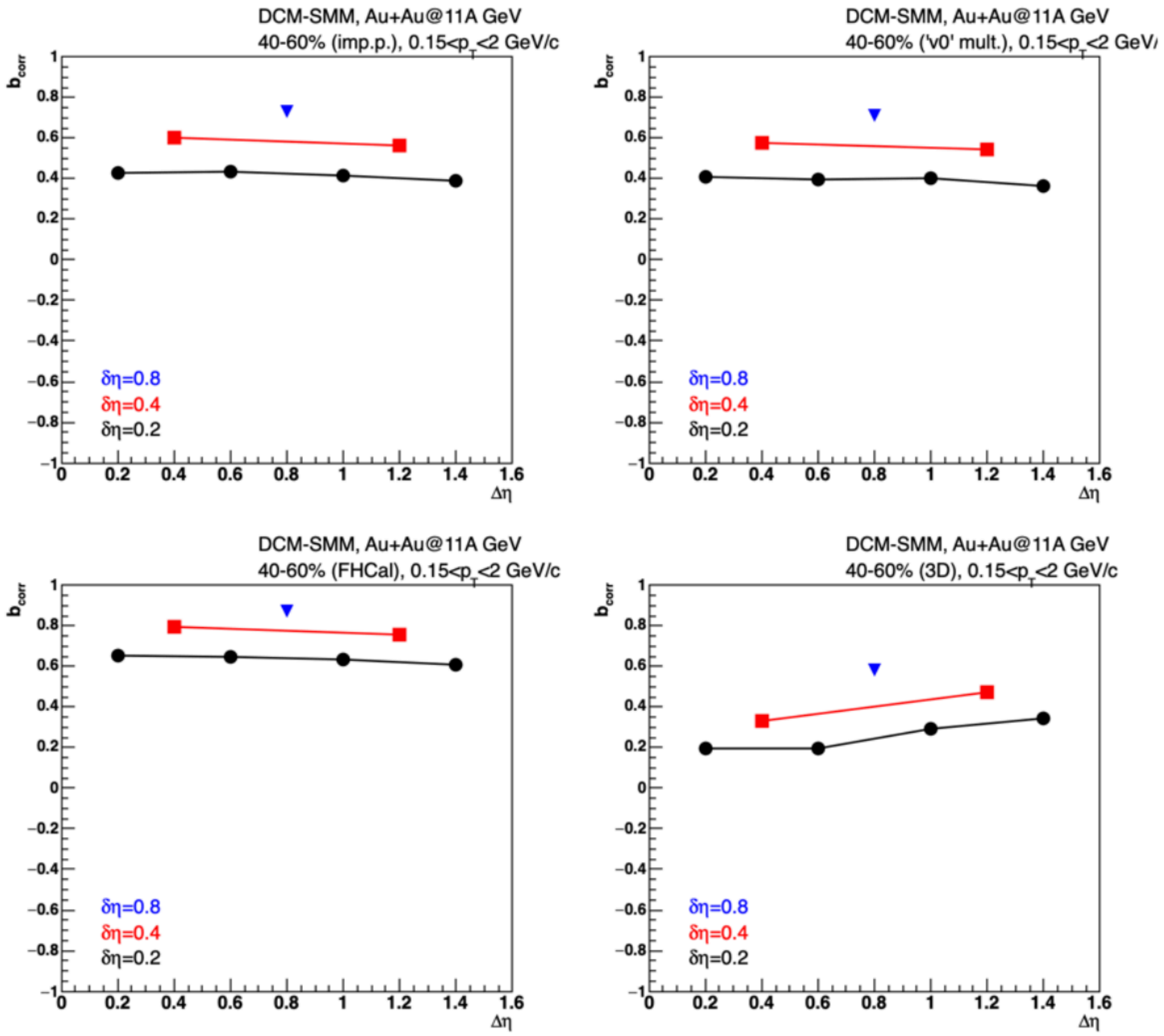
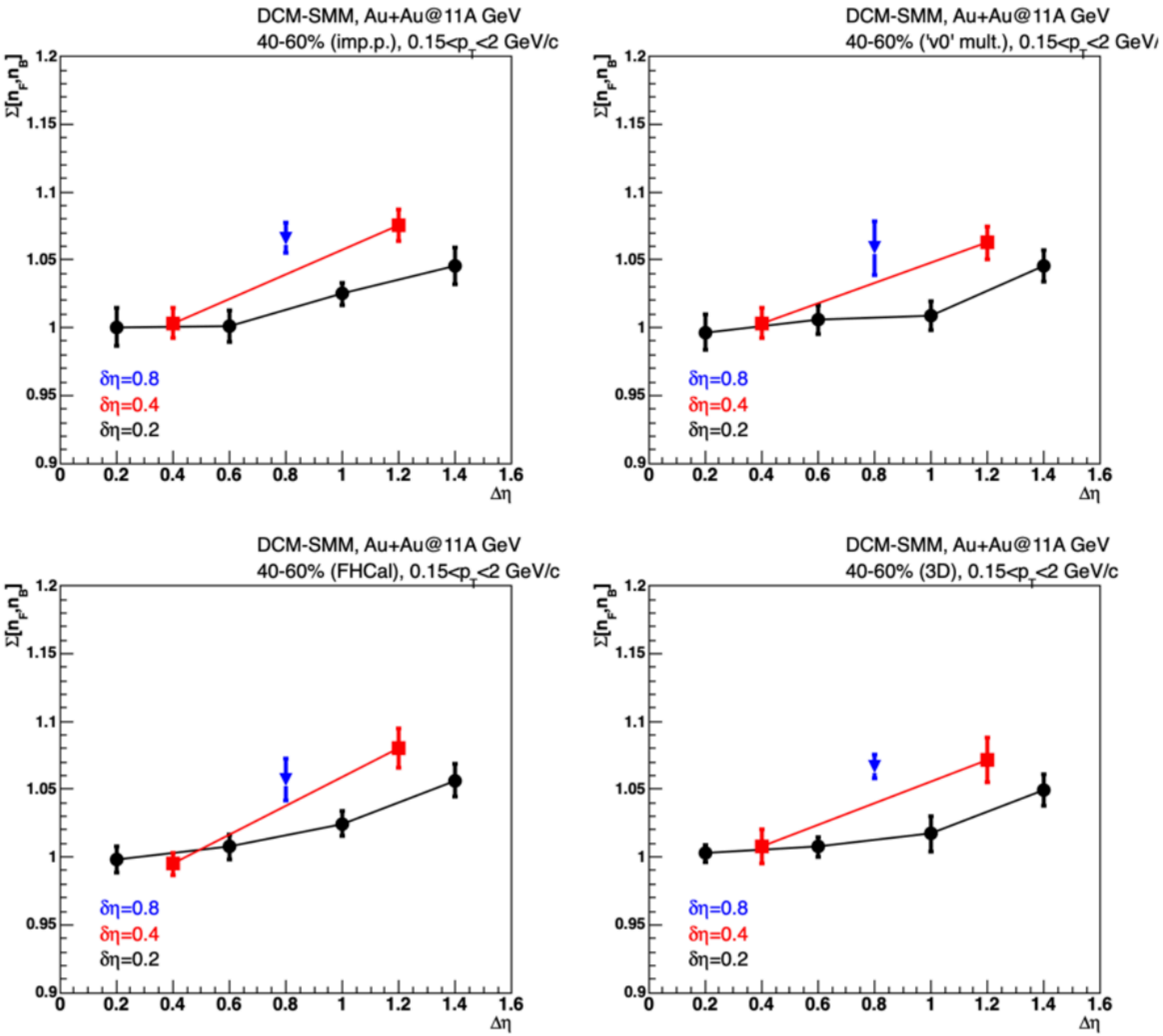
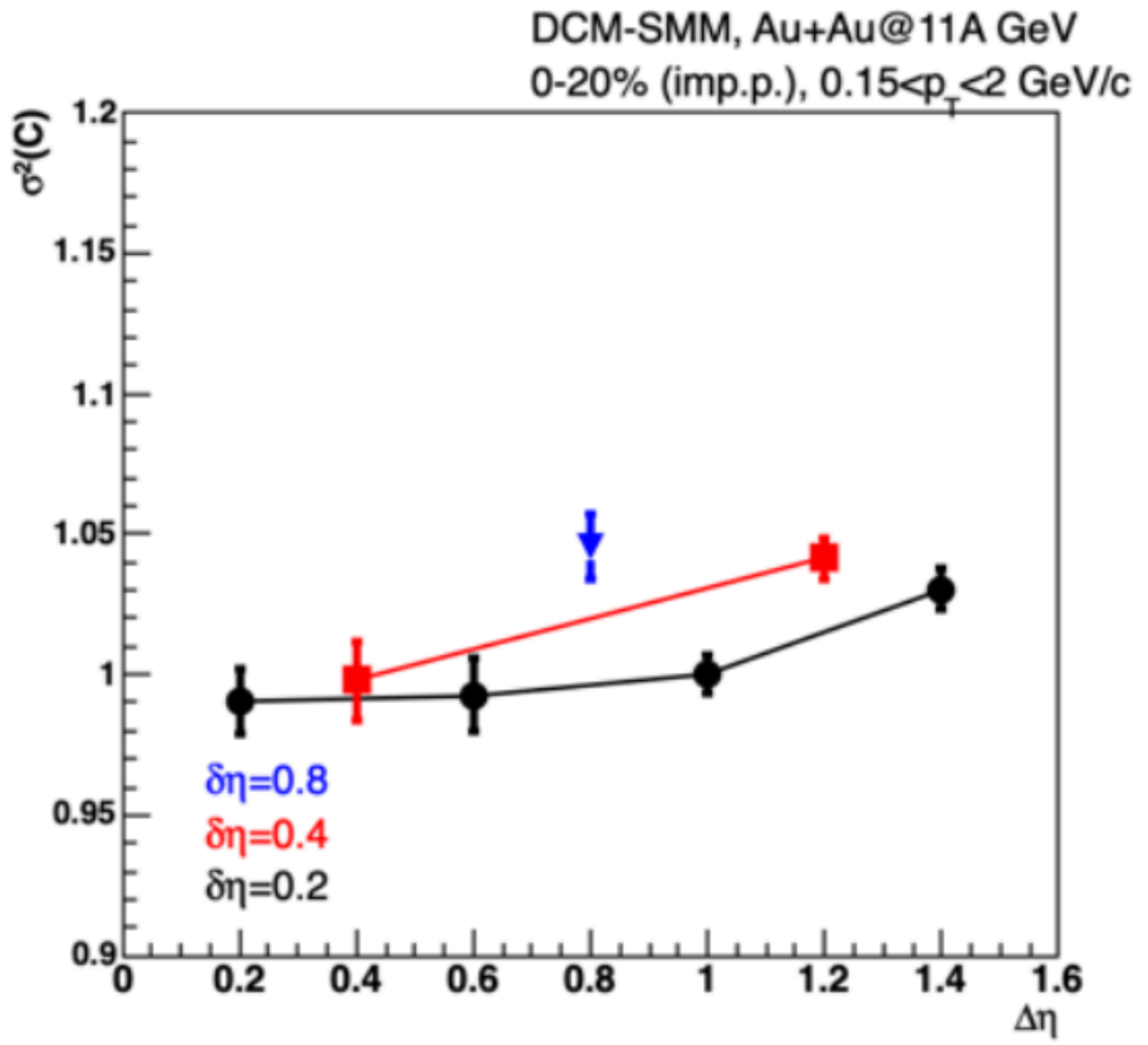
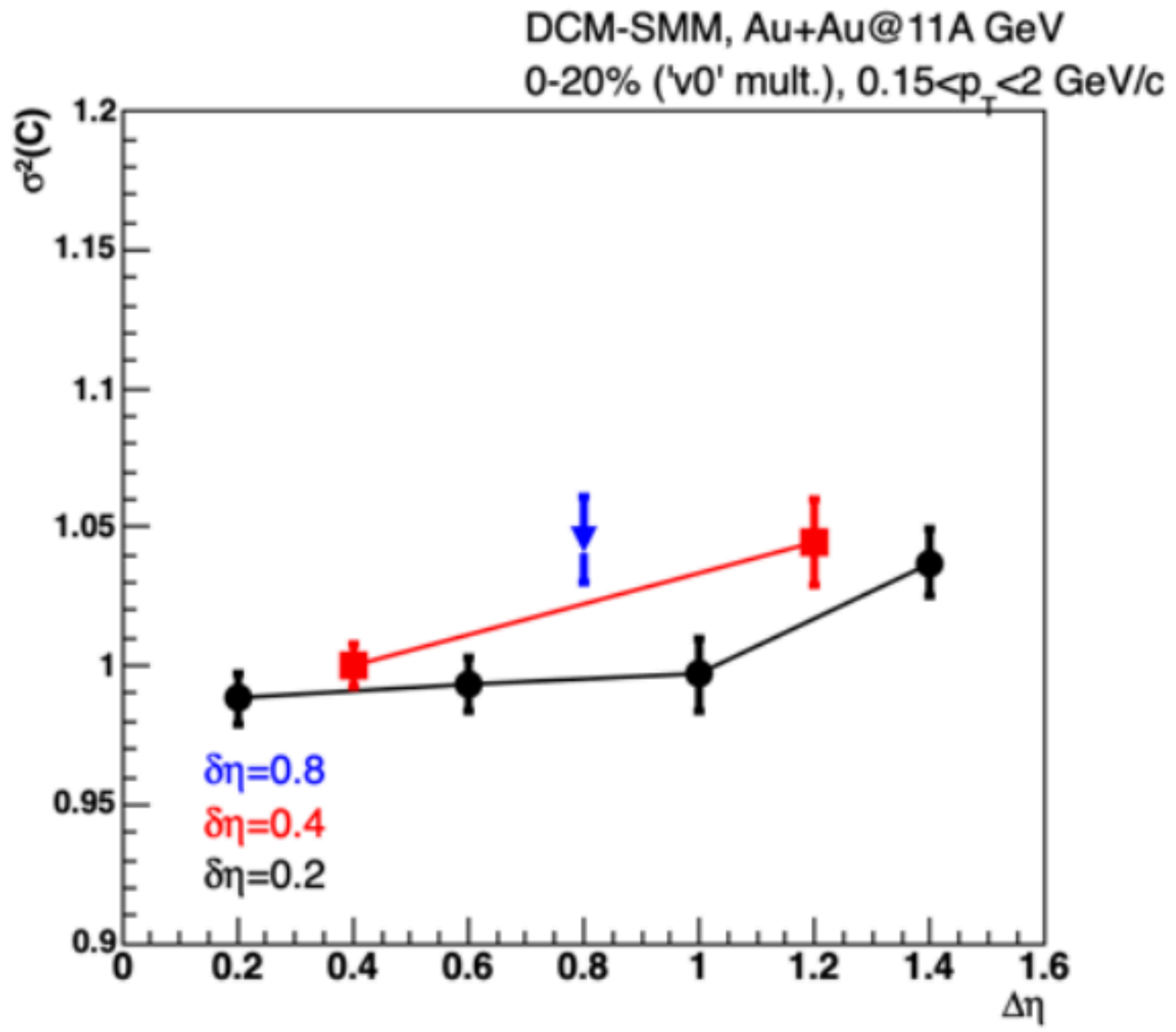
backup

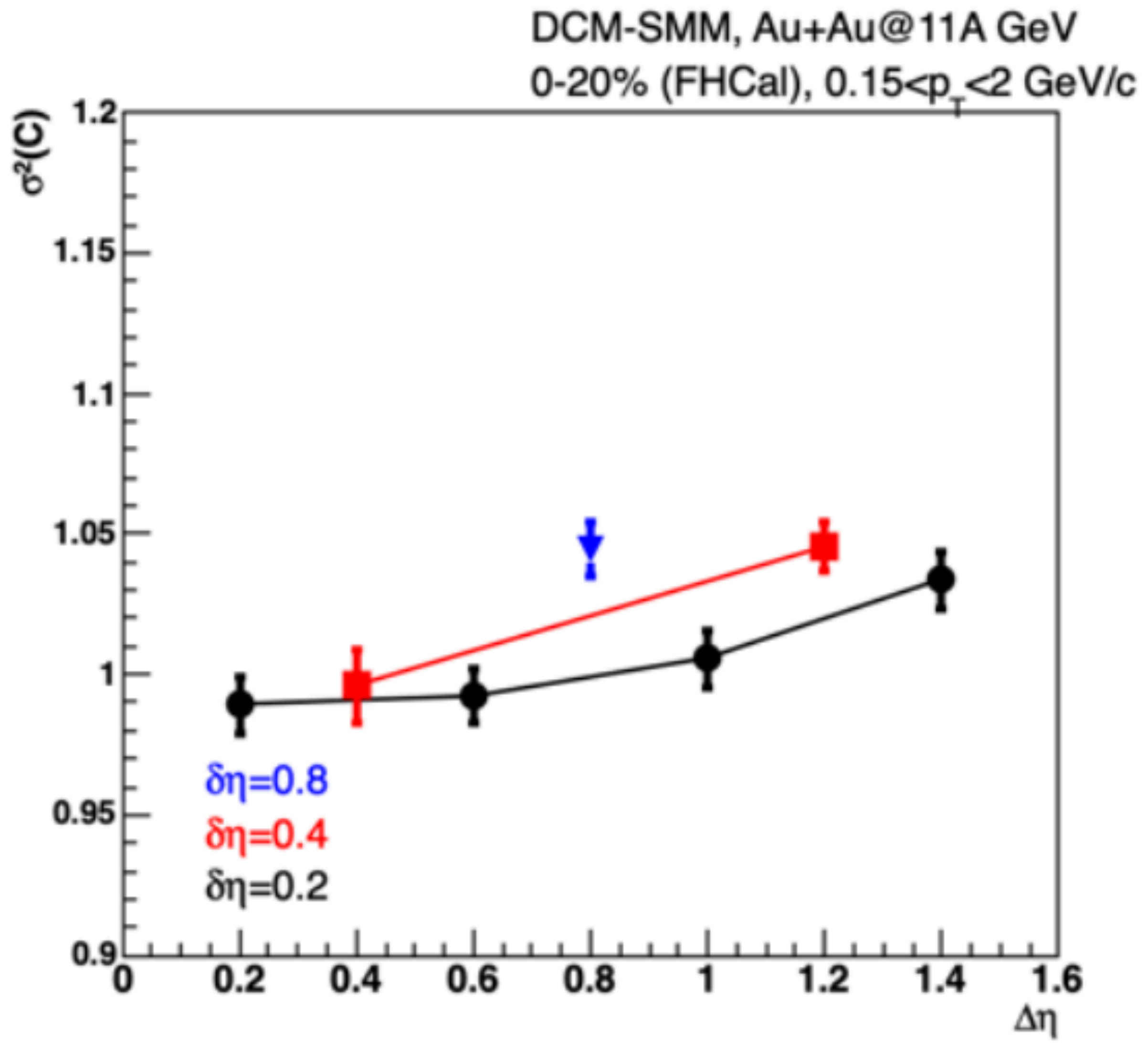


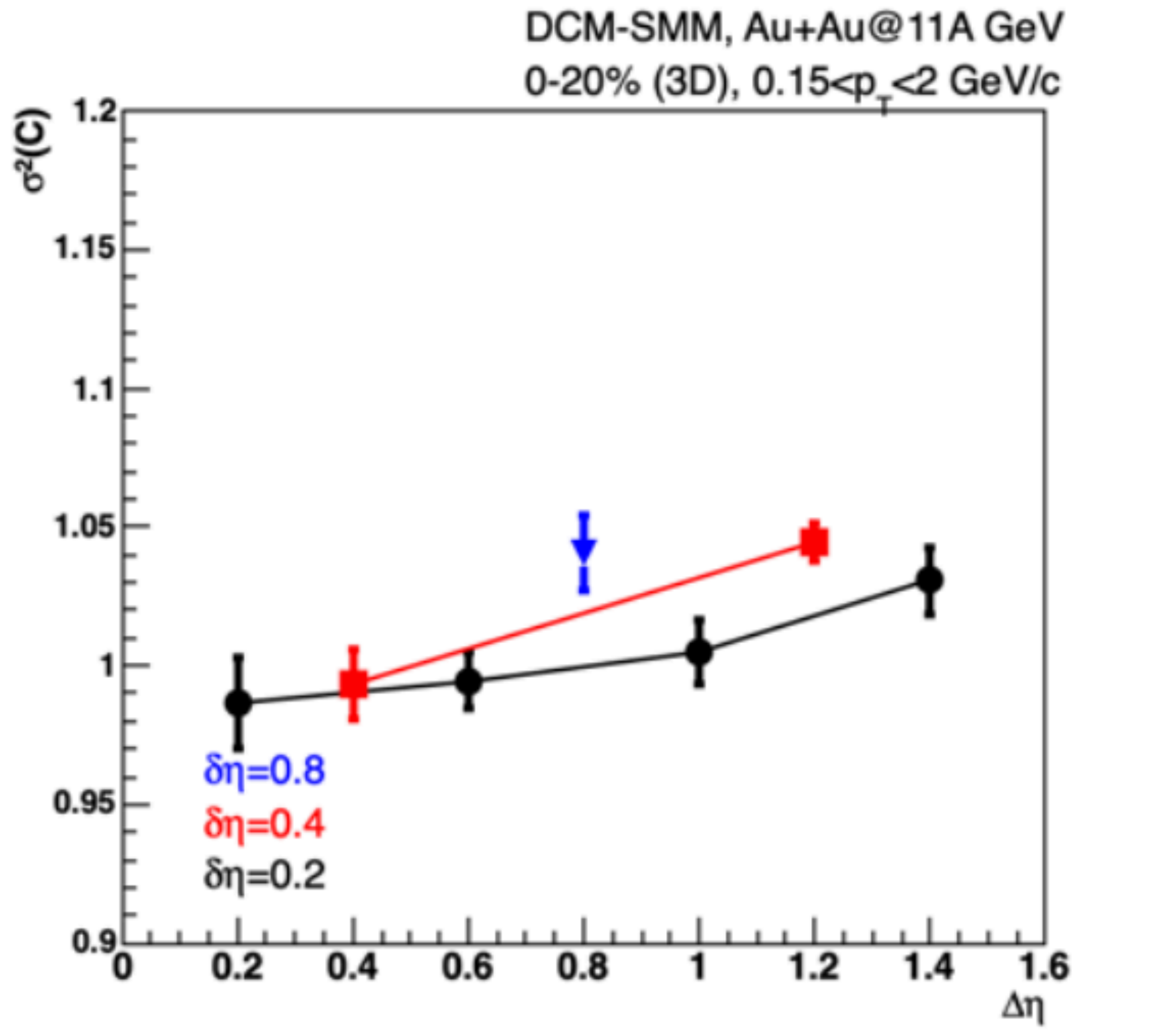
DCM-SMM, Au+Au@11A GeV
40-60% (imp.p.), 0.15<p_T<2 GeV/c
DCM-SMM, Au+Au@11A GeV
40-60% ('v0' mult.), 0.15<p_T<2 GeV/
DCM-SMM, Au+Au@11A GeV
40-60% (FHCal), 0.15<p_T<2 GeV/c
DCM-SMM, Au+Au@11A GeV
40-60% (3D), 0.15<p_T<2 GeV/c
b_corr
Δη
δη=0.8
δη=0.4
δη=0.2

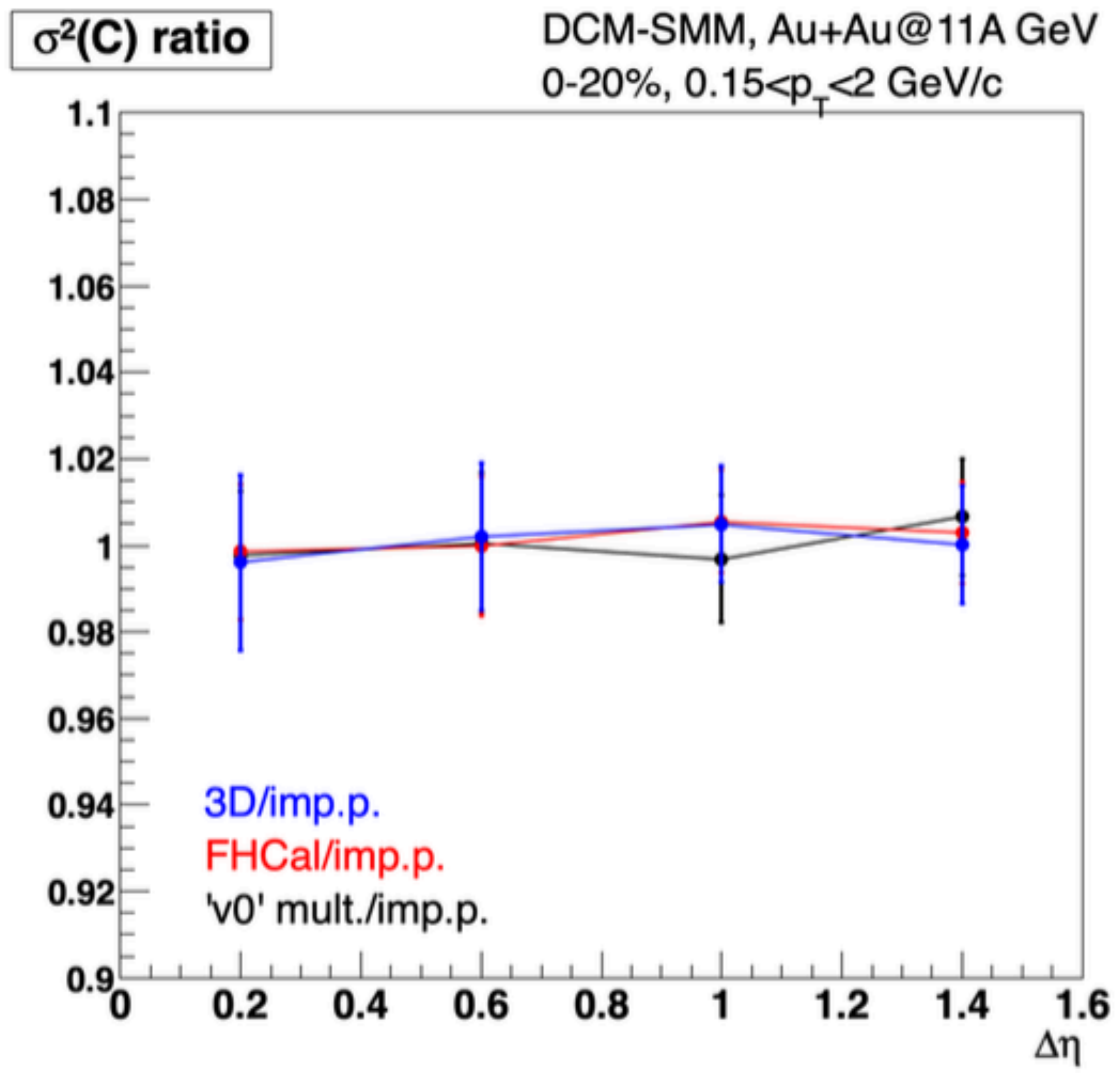

DCM-SMM, Au+Au@11A GeV
40-60% (imp.p.), 0.15<p_T<2 GeV/c
Σ[n_F,n_B]
Δη
δη=0.8
δη=0.4
δη=0.2
DCM-SMM, Au+Au@11A GeV
40-60% ('v0' mult.), 0.15<p_T<2 GeV/
Σ[n_F,n_B]
Δη
δη=0.8
δη=0.4
δη=0.2
DCM-SMM, Au+Au@11A GeV
40-60% (FHCal), 0.15<p_T<2 GeV/c
Σ[n_F,n_B]
Δη
δη=0.8
δη=0.4
δη=0.2
DCM-SMM, Au+Au@11A GeV
40-60% (3D), 0.15<p_T<2 GeV/c
Σ[n_F,n_B]
Δη
δη=0.8
δη=0.4
δη=0.2

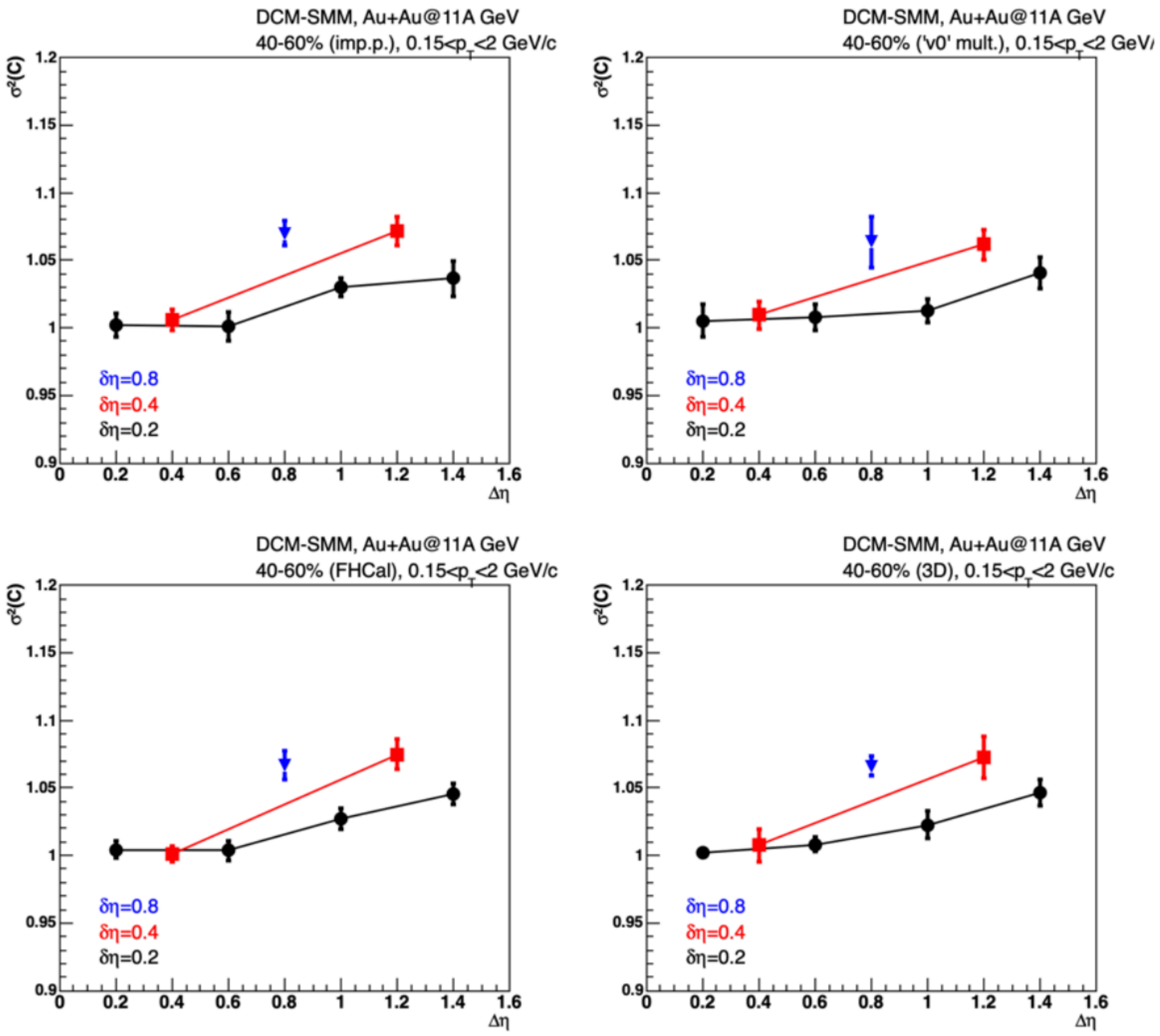

DCM-SMM, Au+Au@11A GeV
0-20% (imp.p.), 0.15<p_T<2 GeV/c
σ²(C)
Δη
δη=0.8
δη=0.4
δη=0.2


DCM-SMM, Au+Au@11A GeV
0-20% ('v0' mult.), 0.15<p_T<2 GeV/c
σ²(C)
Δη
δη=0.8
δη=0.4
δη=0.2


DCM-SMM, Au+Au@11A GeV
0-20% (FHCal), 0.15<p_T<2 GeV/c
σ²(C)
Δη
δη=0.8
δη=0.4
δη=0.2


DCM-SMM, Au+Au@11A GeV
0-20% (3D), 0.15<p_T<2 GeV/c
σ²(C)
Δη
δη=0.8
δη=0.4
δη=0.2


σ²(C) ratio
DCM-SMM, Au+Au@11A GeV
0-20%, 0.15<p_T<2 GeV/c
Δη
3D/imp.p.
FHCal/imp.p.
'v0' mult./imp.p.


DCM-SMM, Au+Au@11A GeV
40-60% (imp.p.), 0.15<p_T<2 GeV/c
DCM-SMM, Au+Au@11A GeV
40-60% ('v0' mult.), 0.15<p_T<2 GeV/c
DCM-SMM, Au+Au@11A GeV
40-60% (FHCal), 0.15<p_T<2 GeV/c
DCM-SMM, Au+Au@11A GeV
40-60% (3D), 0.15<p_T<2 GeV/c
σ²(C)
Δη
δη=0.8
δη=0.4
δη=0.2