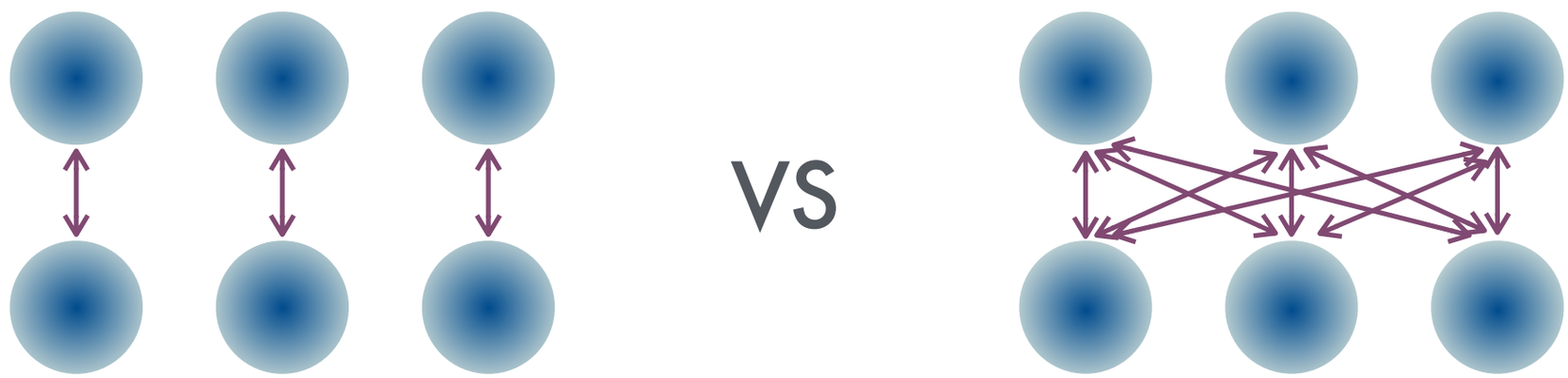
Exploring the effect of correlated constituents in p+p interactions @LHC



Alba Soto-Ontoso[1,2]
+ Hannah Petersen[1], Javier L. Albacete[2]

based on **Phys.Rev. C95 (2017) no.6, 064909, arXiv:1707.05592**

[1]Frankfurt Institute for Advanced Studies, [2]University of Granada

THE CART BEFORE THE HORSE

SIMPLE GEOMETRIC MODEL TO STUDY THE ROLE OF SPATIAL CORRELATIONS INSIDE THE PROTON

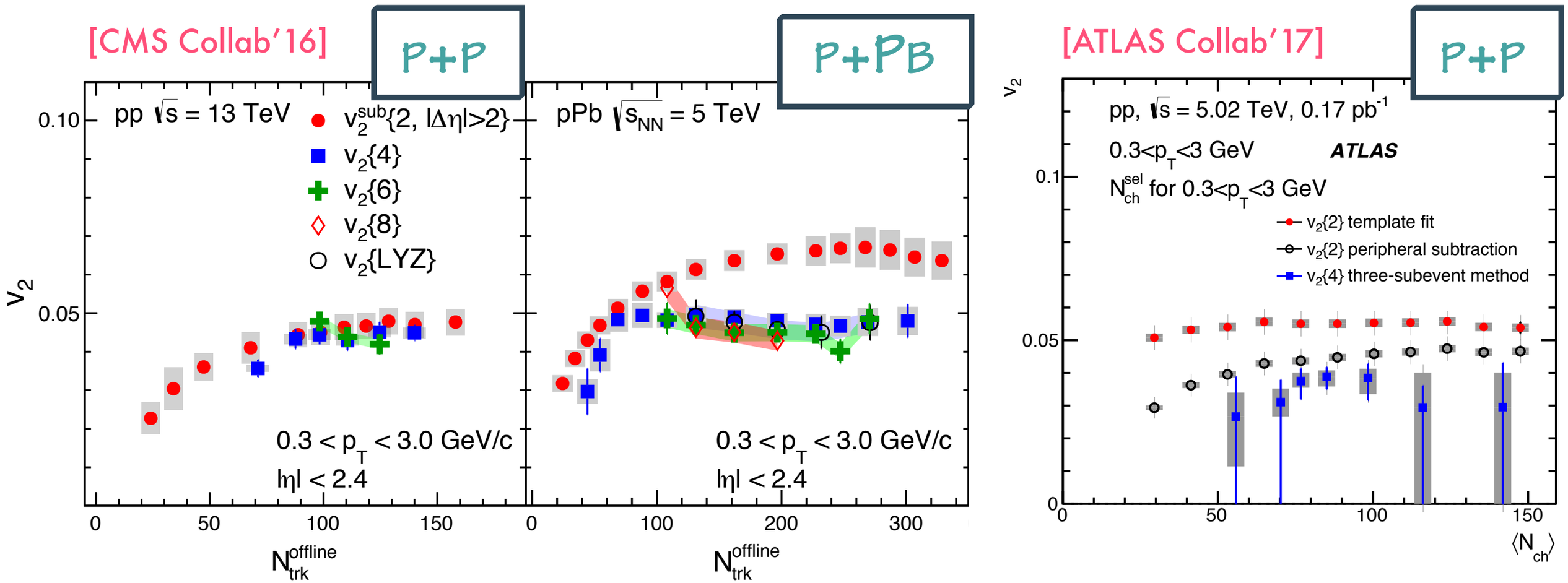
PHENOMENOLOGY (ECCENTRICITIES, SYMMETRIC CUMULANTS) INDICATES THAT THEY DO MATTER

HOWEVER, THE DEVIL IS IN THE DETAILS: SCALES INTERPLAY $\{R_{HS}, R_C, N_{HS}, N_{COLL}, N_W\}$

Flow harmonics

EXPERIMENTAL SIDE

➡ Different methods share a common conclusion: non-zero flow in p+p.



➡ Tension between ATLAS and CMS in the # of tracks dependence.

➡ On-going analyses of LHCb and ALICE show the ridge in p+p @13 TeV.

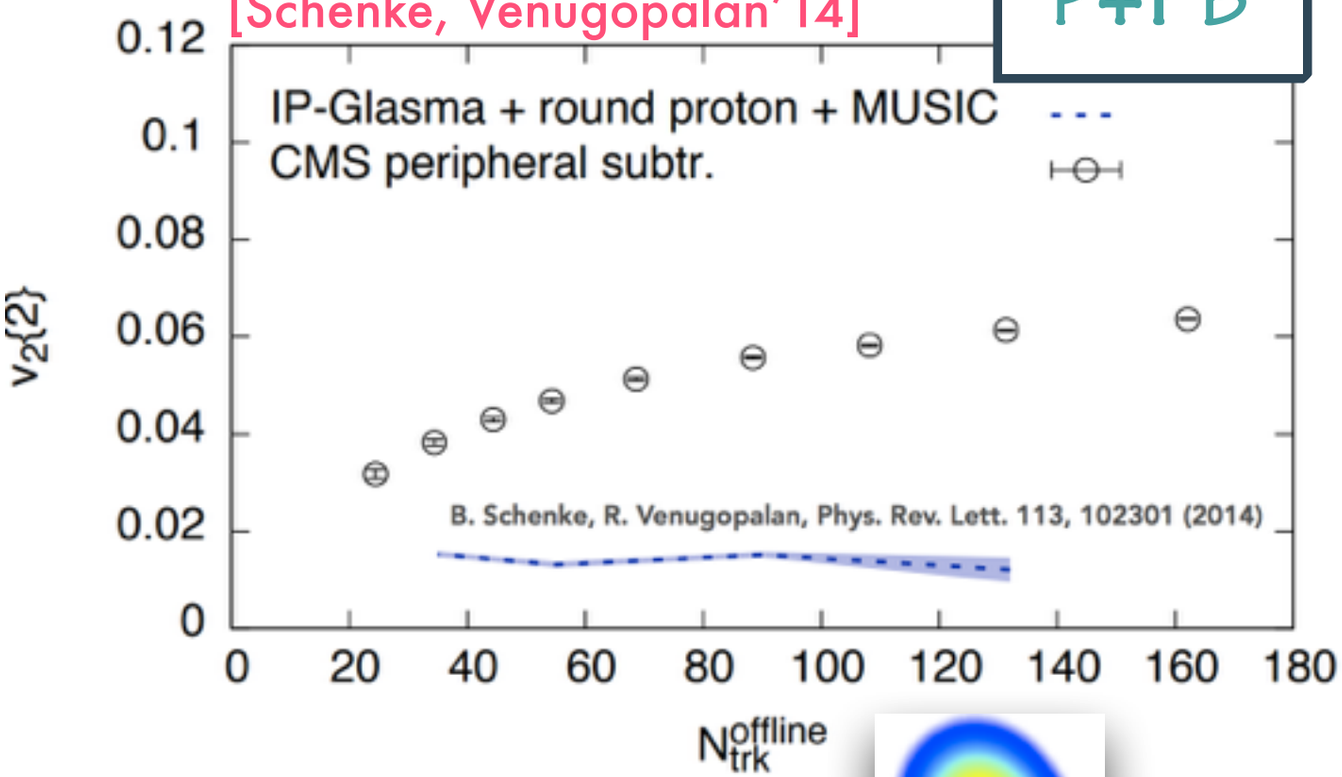
THEORETICAL SIDE

CGC+HYDRO

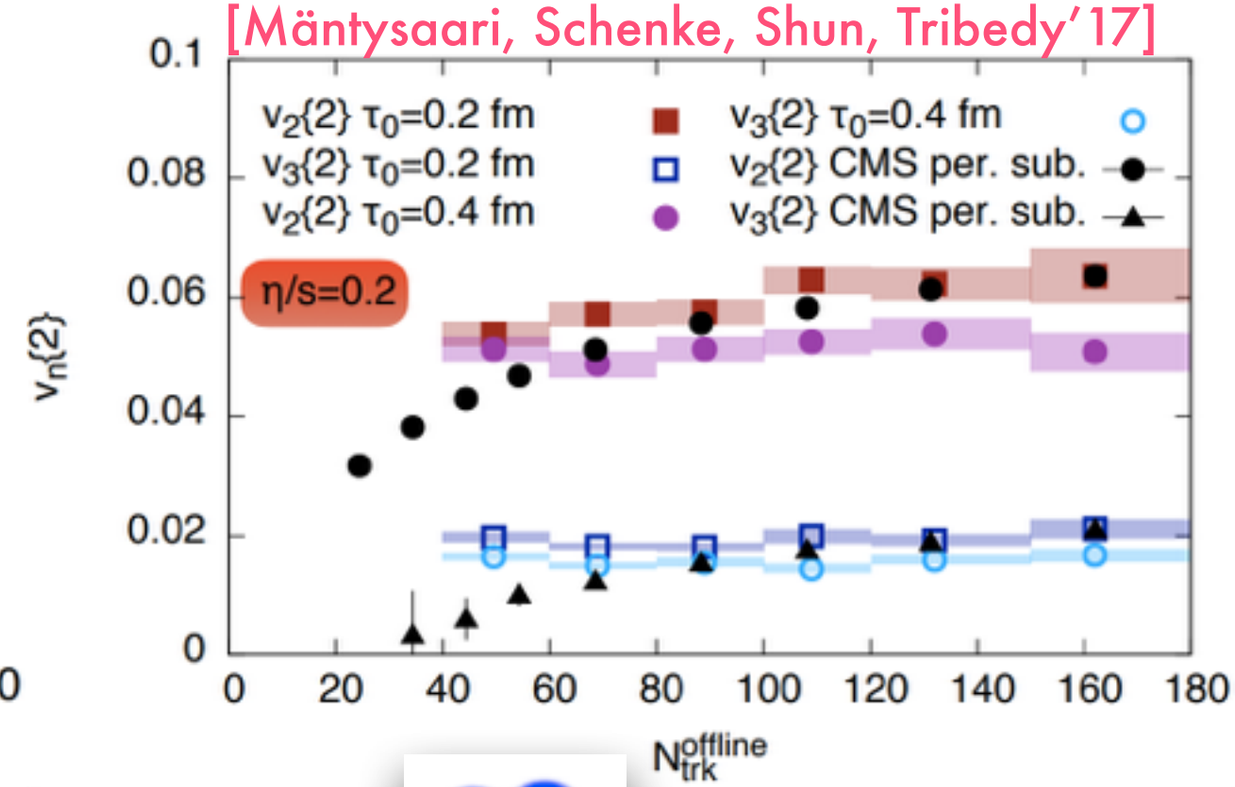
[See talk by Schenke]

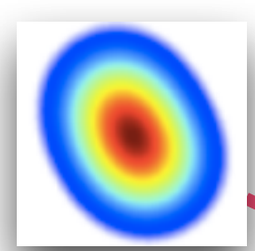
[Schenke, Venugopalan'14]

p+Pb



[Mäntysaari, Schenke, Shun, Tribedy'17]





FLUCTUATING PROTON

WITH INTERNAL D.O.F

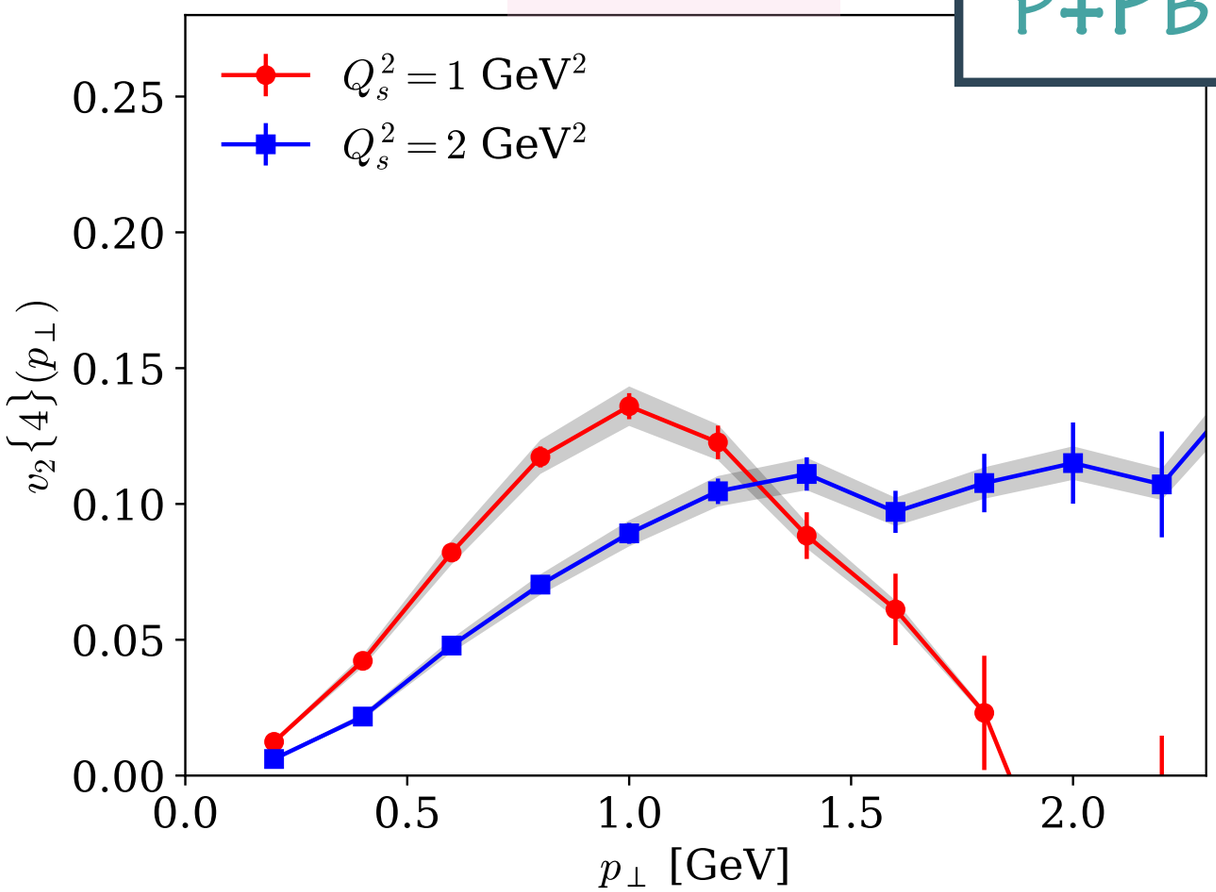
➡Final state interactions also important [Greif, Greiner, Schenke, Schlichting,Xu'17]

THEORETICAL SIDE

[See talks by Rezaeian,Mace]

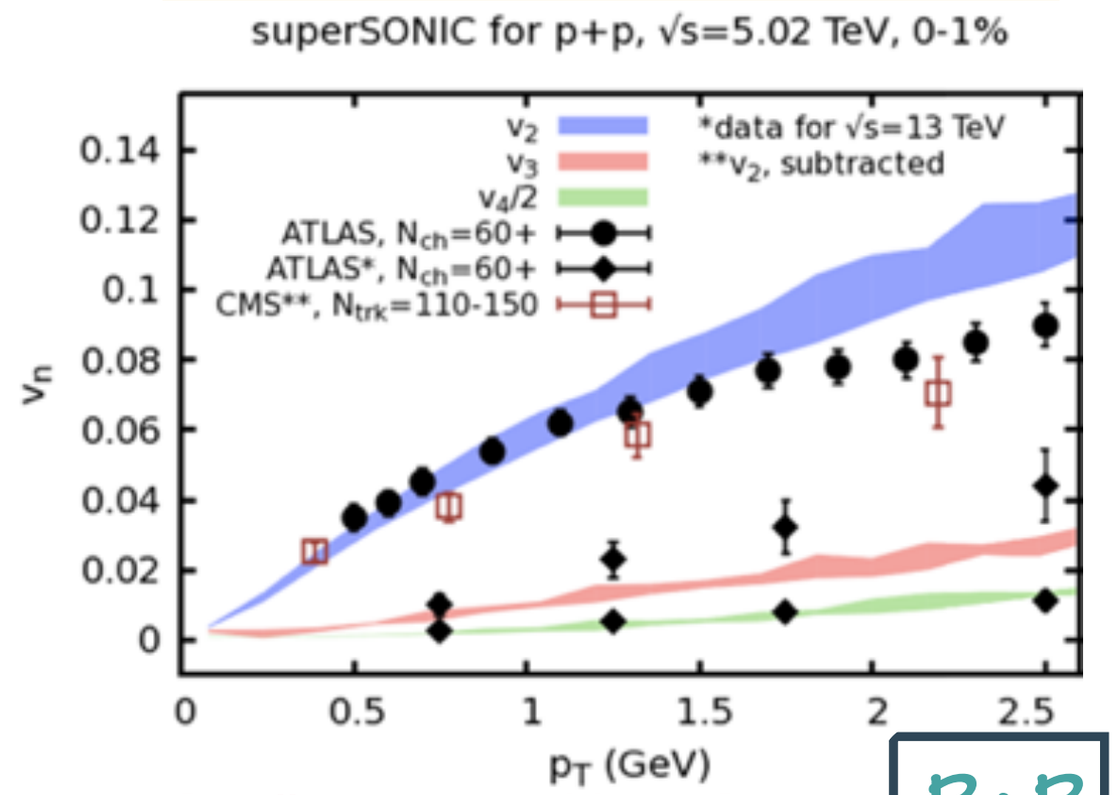
CGC

p+Pb



[Dusling, Mace, Venugopalan'17]

MC-GLAUBER+HYDRO



[Weller, Romatschke'17]

P+P

➡Puzzle: good description of flow harmonics in p+Pb in both paradigms.

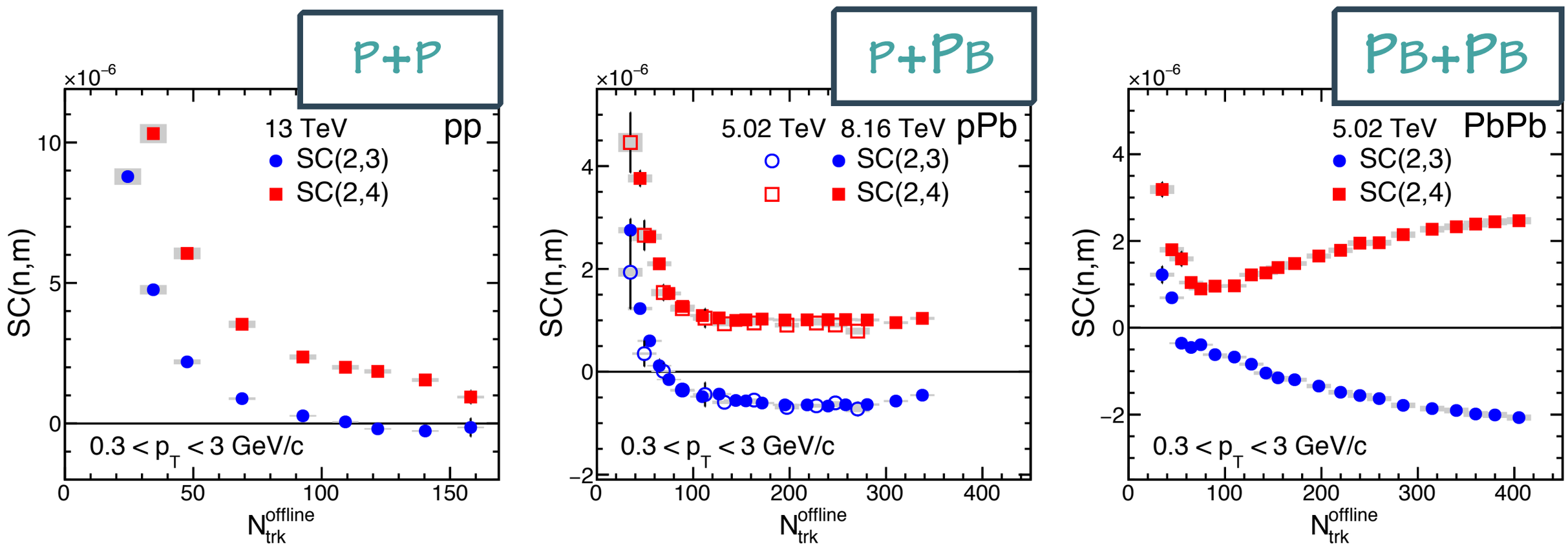
Symmetric cumulants

EXPERIMENTAL SIDE

[CMS Collab'17]

$$\mathrm{SC(n,m)} = \langle v_n^2 v_m^2 \rangle - \langle v_n^2 \rangle \langle v_m^2 \rangle$$

$$\mathrm{NSC(n,m)} = \frac{\langle v_n^2 v_m^2 \rangle - \langle v_n^2 \rangle \langle v_m^2 \rangle}{\langle v_n^2 \rangle \langle v_m^2 \rangle}$$



➡SC(2,3): initial state fluctuations. SC(2,4): medium properties.

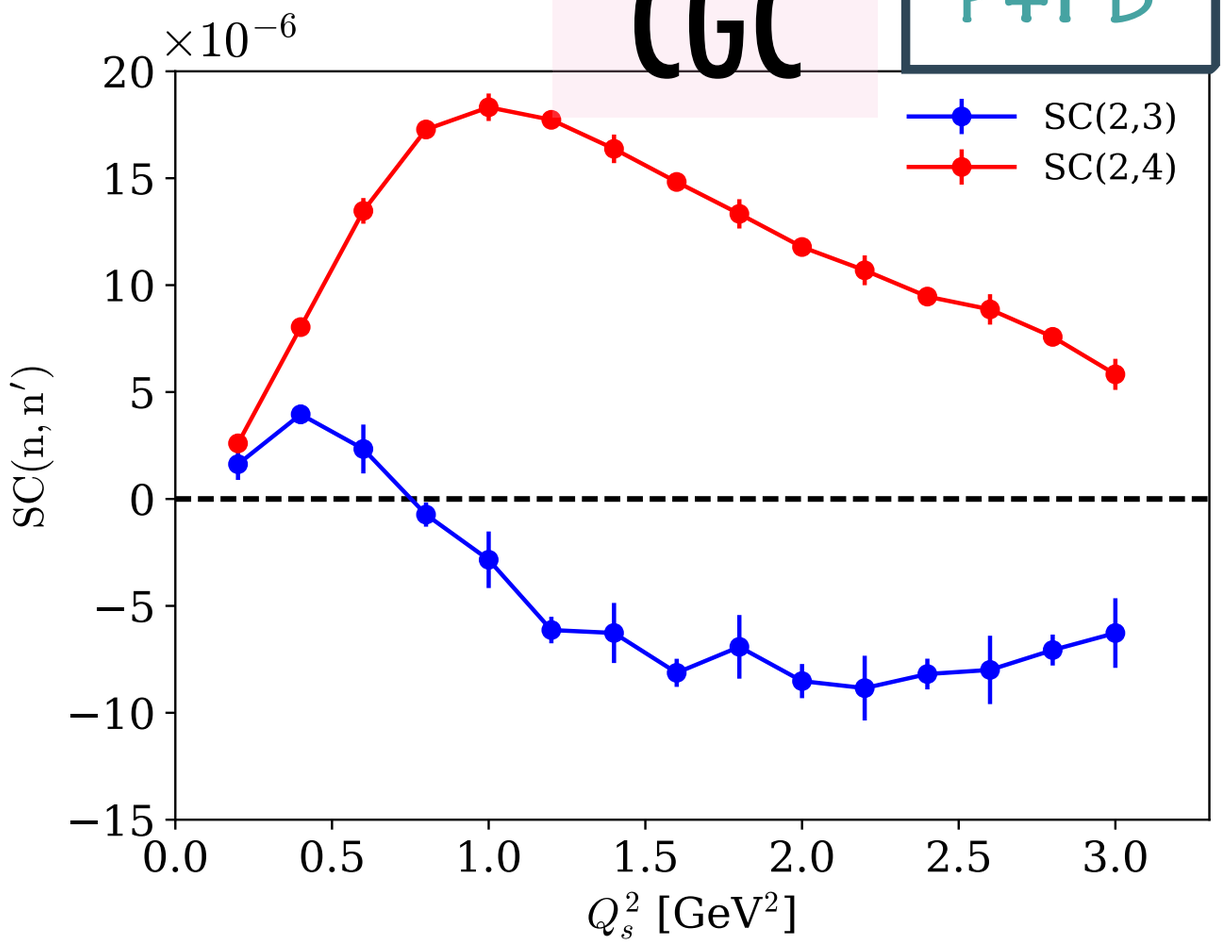
➡Similar pattern observed across systems.

➡Anticorrelation seems to start around the same # tracks ~100.

THEORETICAL SIDE

CGC

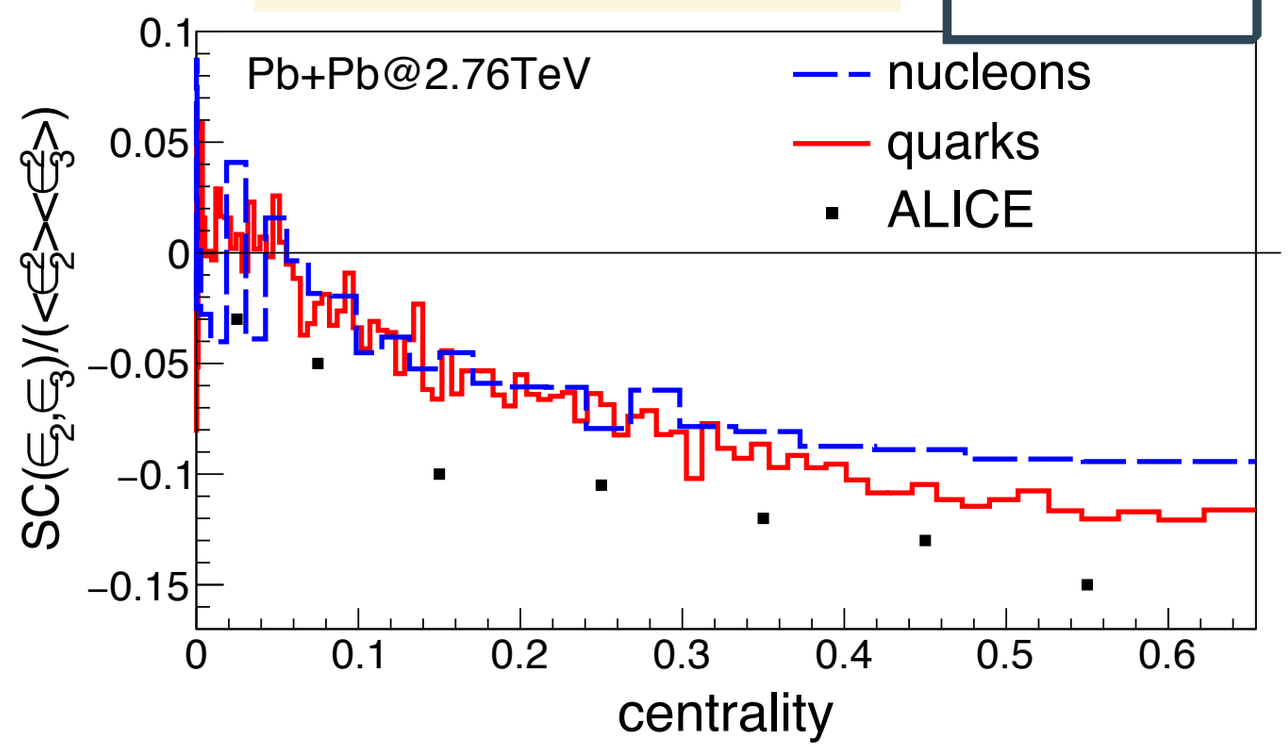
p+Pb



[Dusling, Mace, Venugopalan'17]

MC-GLAUBER

Pb+Pb



[Broniowski, Bozek, Rybczynski'16]

➡ So far no SC(n,m)-results in p+p@LHC energies in the literature.

➡ Common input in all these works: geometric information of the proton.

THE MARKET

MC-Glauber

[Loizides'16]
[Bozek,Broniowski,Rybczynski'16]
[Welsh,Singer,Heinz'16]
[Weller,Romatschke'17]
...

or

IP-Glasma

[Schenke, Tribedy, Venugopalan'12]
[Schilichting,Schenke'14]
[Mäntysaari,Schenke'16]
[Mäntysaari,Schenke,Shen,Tribedy'17]
...

- 3 or more subnucleonic d.o.f:
  - Valence quarks.
  - Constituent quarks.
  - Hot spots.
- Two scales: radii proton & constituents
- Gaussian probability distributions for the constituents transverse positions.

Succesful picture:
✓Flow harmonics
✓DIS
✓Diffractive processes
✓...

➡Models @market assume UNCORRELATED subnucleonic components.

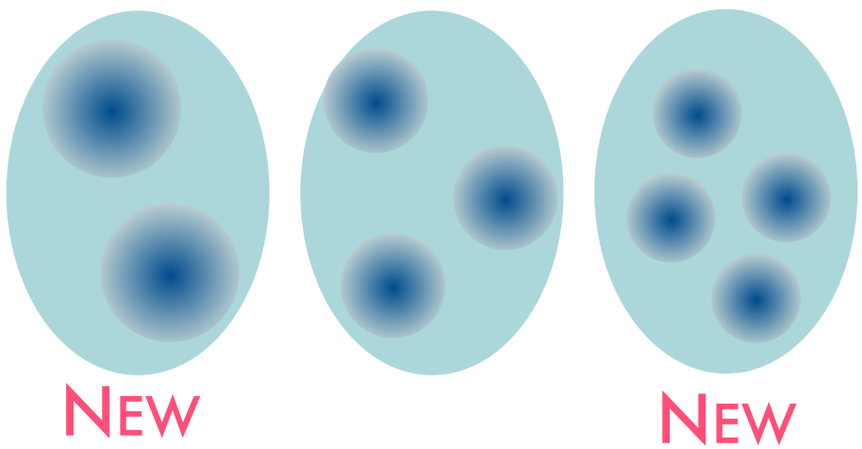
SET UP

The Model

[Similar to A. Bialas et al. '70s]

1) Degrees of freedom: gluonic hot spots.

- Transverse diffusion of R_{hs} with increasing energy



2) Geometry of the proton: spatial correlations in transverse space

E.g: $N_{hs}=3$

$$D(\vec{s}_1,\vec{s}_2,\vec{s}_3) \propto \underbrace{\prod_{i=1}^{3} e^{-s_i^2/R^2}}_{\text{uncorrelated}} \underbrace{\delta^{(2)}(\vec{s}_1+\vec{s}_2+\vec{s}_3)}_{\text{fixes C.o.M}} \times \underbrace{\prod_{\substack{i<j\\ i,j=1}}^{3} \left(1-e^{-\mu|\vec{s}_i-\vec{s}_j|^2/R^2}\right)}_{\text{Repulsive correlations}}$$

3) Monte-Carlo Glauber implementation with e-b-e fluctuations

[GLISSANDO], [TGlauberMC]

→ Wounded hot spots

→ $\mathcal{P}(s_0) \propto \mathcal{P}(N_{\rm ch})$

The Model: Parameters

➡(R_{hs},R,r_c)-chosen to reproduce the value of proton-proton $\sigma_{\rm tot}$

		r_c=0.4 fm		r_c=0 fm	
	C.o.M Energy	R_{hs}	R	R_{hs}	R
Eccentricities →	LHC@7TeV	0.3	0.69	0.39	0.65
Symmetric cumulants →	LHC@13TeV	0.32	0.76	0.41	0.75

➡In order to avoid swelling effects we consider 2 additional scenarios

- r_c=0,nc: same as r_c=0.4 fm but setting r_c = 0.
- <s_1> fixed: same as r_c=0.4 fm but choosing R such as

$$\langle s_1 \rangle \equiv \int s_1 d\vec{s_1} d\vec{s_2} d\vec{s_3} D(\vec{s}_1, \vec{s}_2, \vec{s}_3) = \langle s_1 \rangle \Big|_{r_c = 0.4 \text{ fm}}$$

The Model: Parameters

➡ (R_{hs}, R, r_c)-chosen to reproduce the value of proton-proton σ_{tot}

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Spatial eccentricities

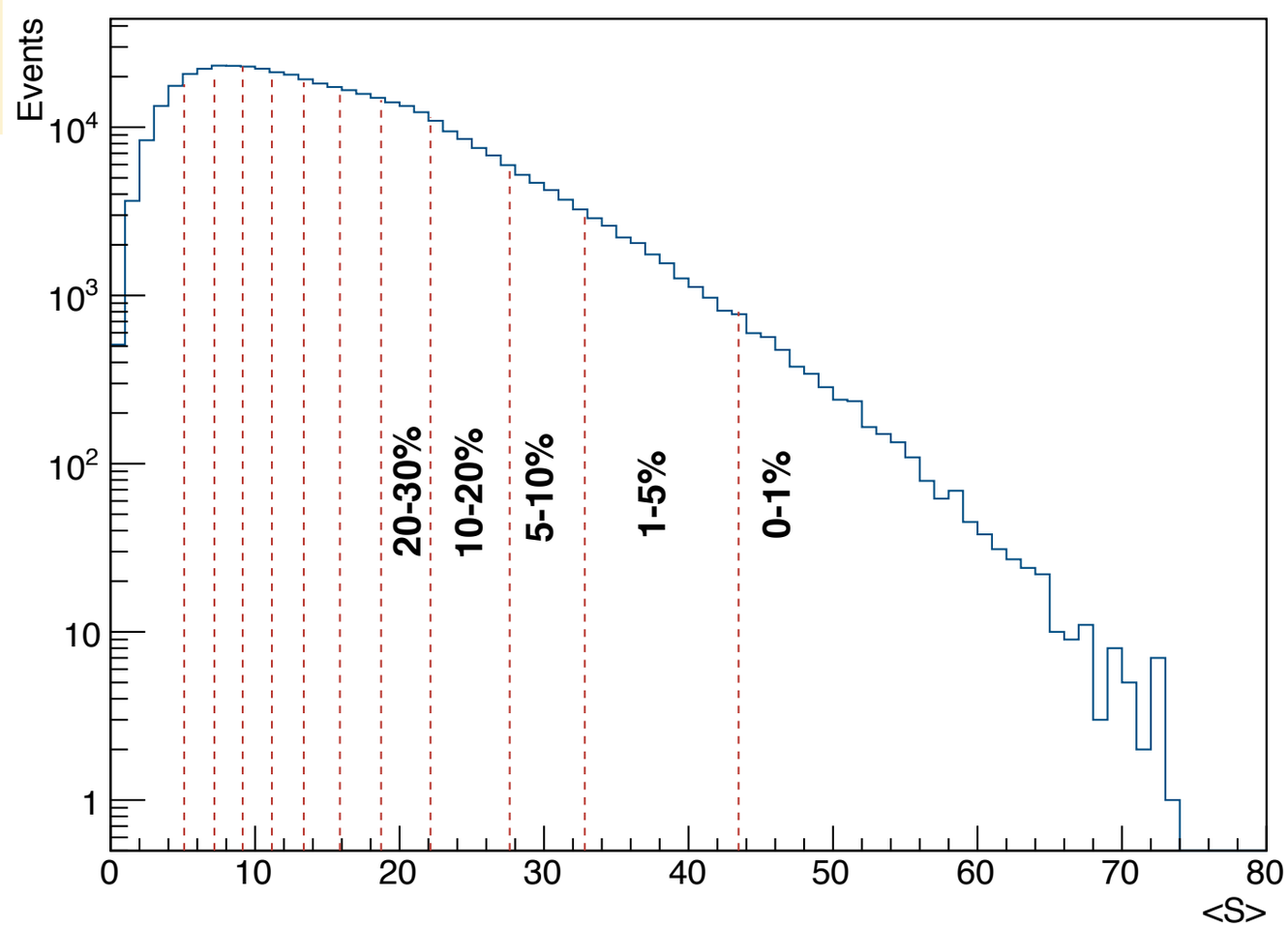
DEFINITION

➡Quantitative measurement of the spatial anisotropy of the geometry

$$\varepsilon_n = \frac{\sqrt{\langle \sum_{i=1}^{N_w} r_i^n \cos(n\phi_i)\rangle^2 + \langle \sum_{i=1}^{N_w} r_i^n \sin(n\phi_i)\rangle^2}}{\langle \sum_{i=1}^{N_w} r_i^n \rangle}$$

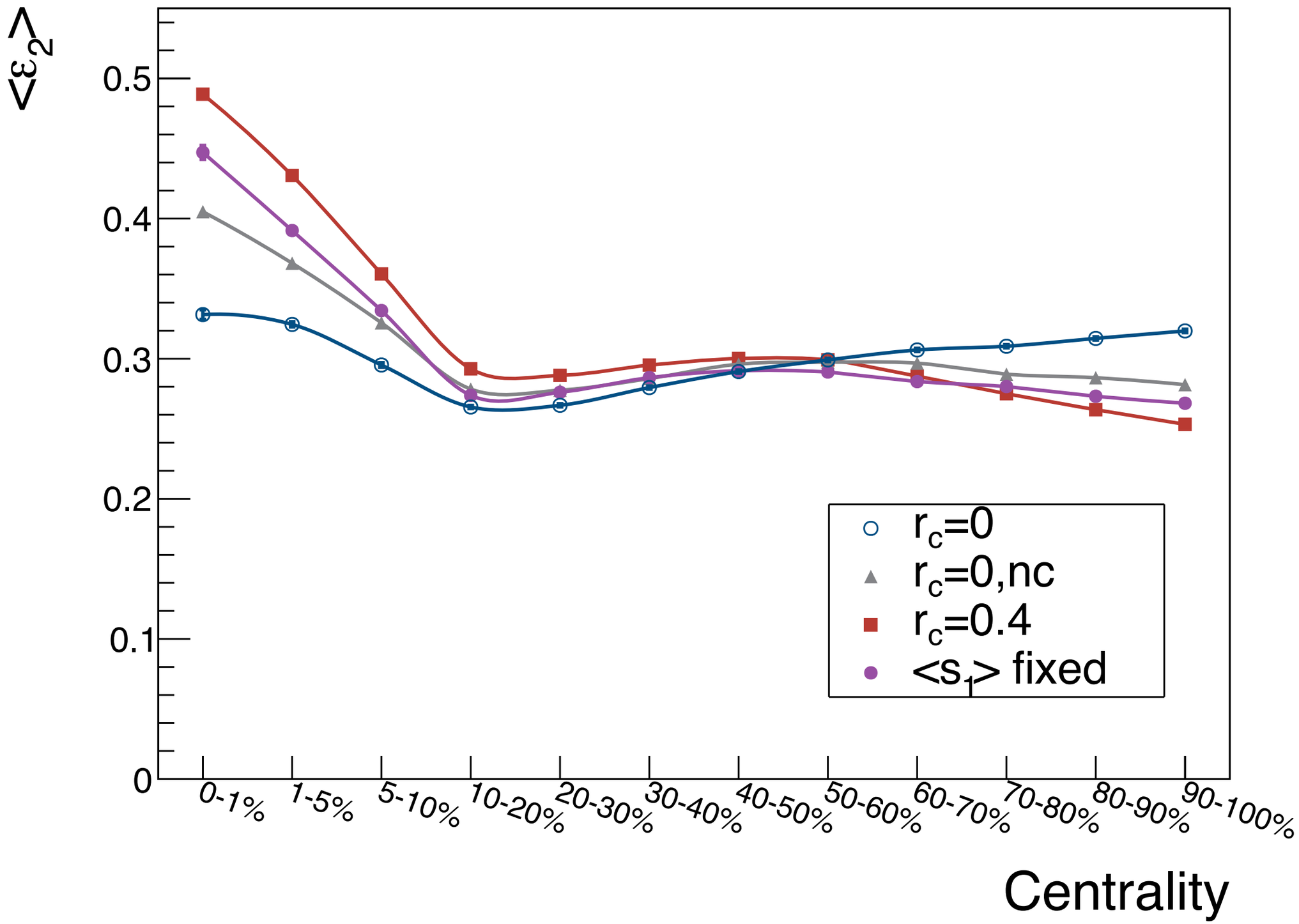
- (r_i,ϕ_i) :wounded hot spots positions after rotation Ψ_{pp}.
- <...>:average weighted by entropy.

➡Entropy as an estimator of centrality. Division of events in centrality classes



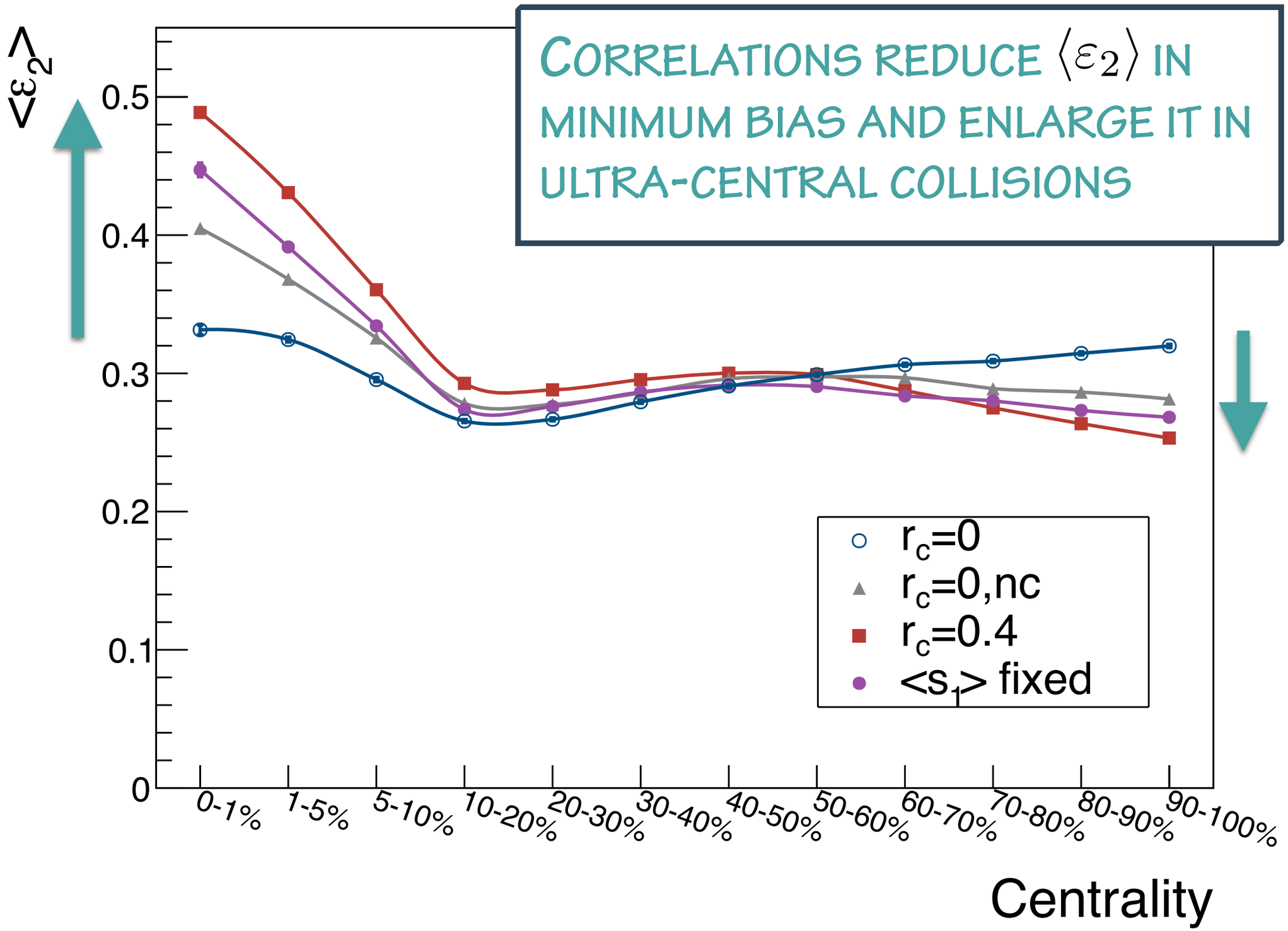
ECCENTRICITY

[Albacete,Petersen, ASO'17]



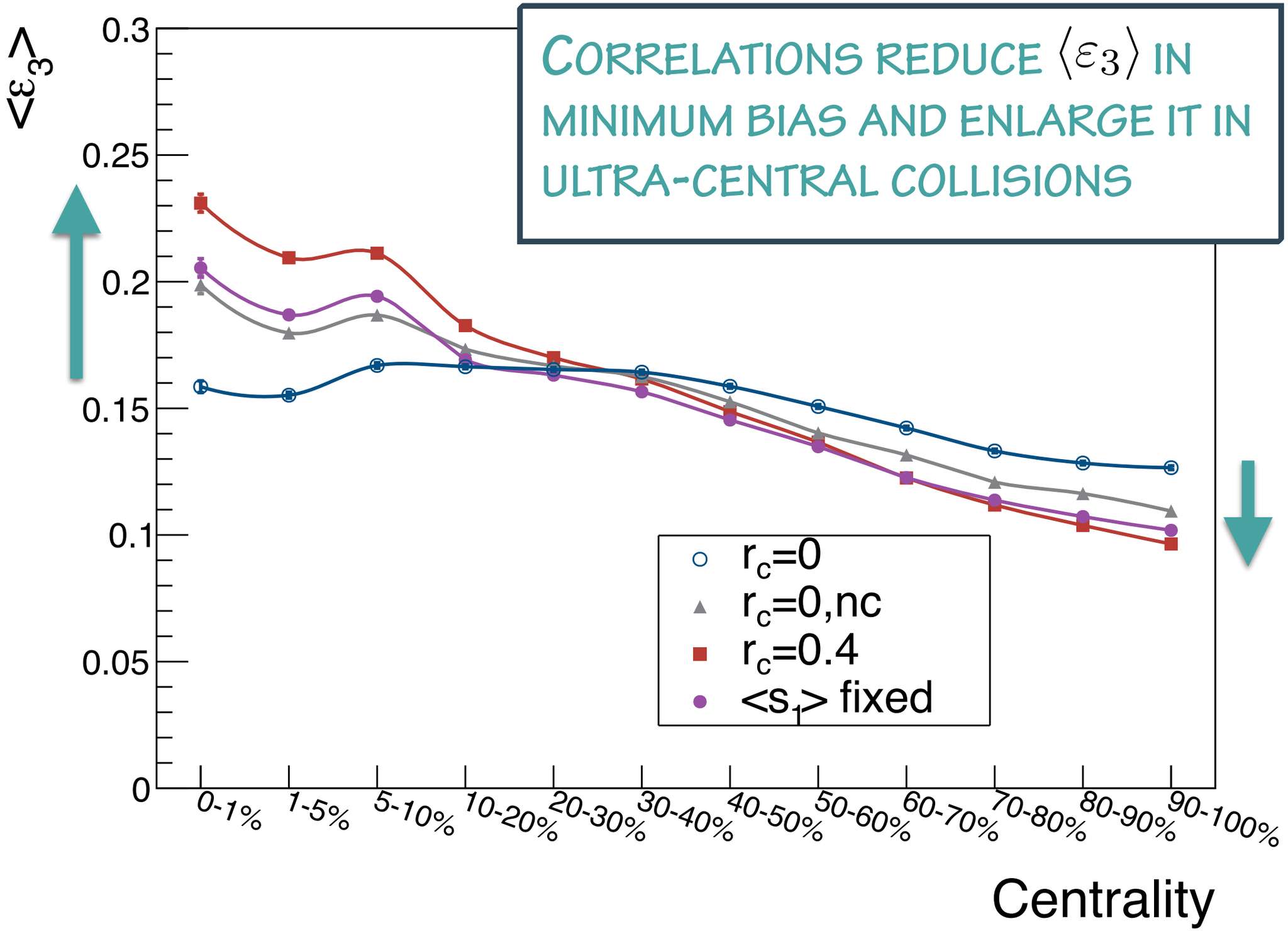
ECCENTRICITY

[Albacete,Petersen, ASO'17]



TRIANGULARITY

[Albacete,Petersen, ASO'17]

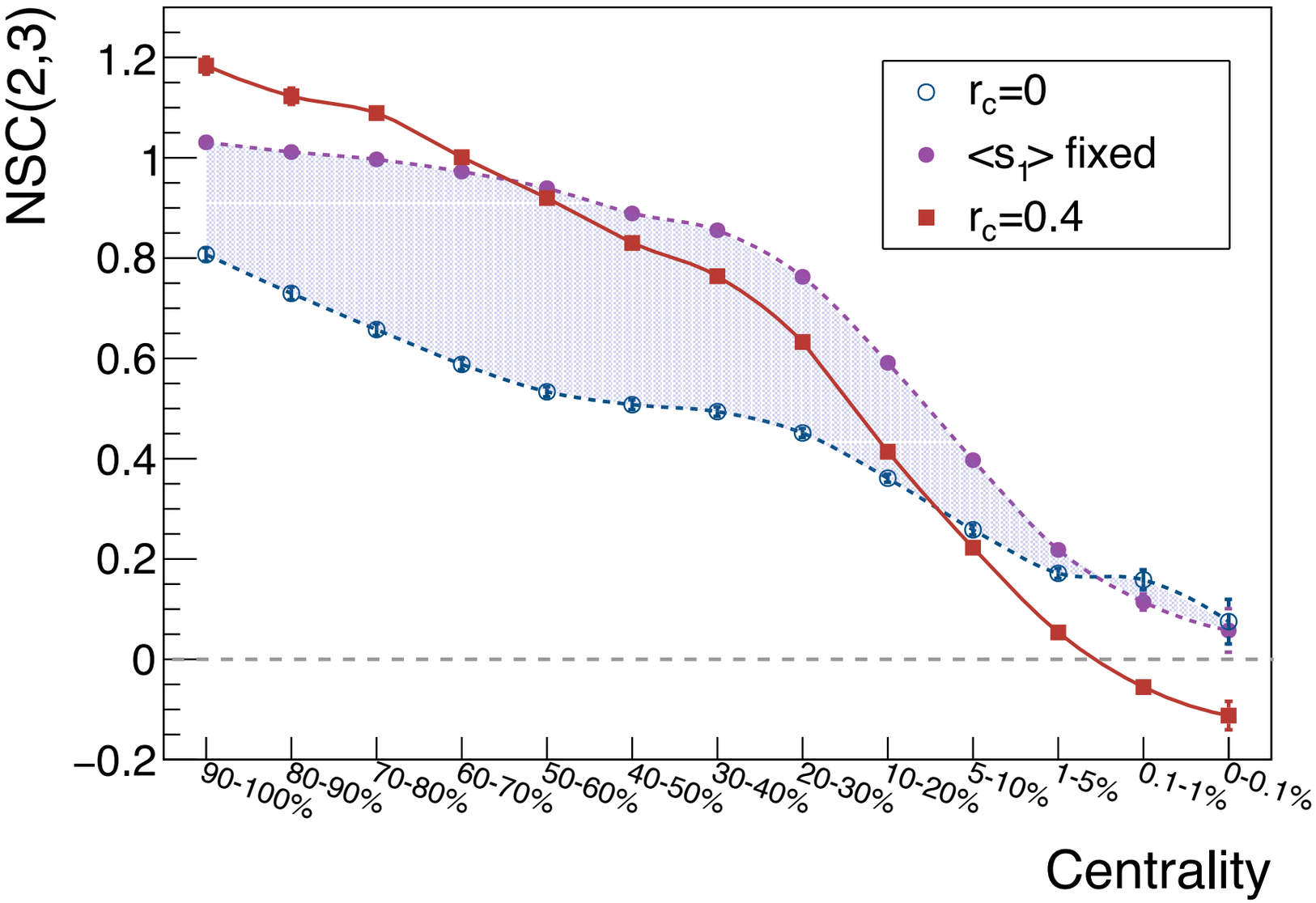


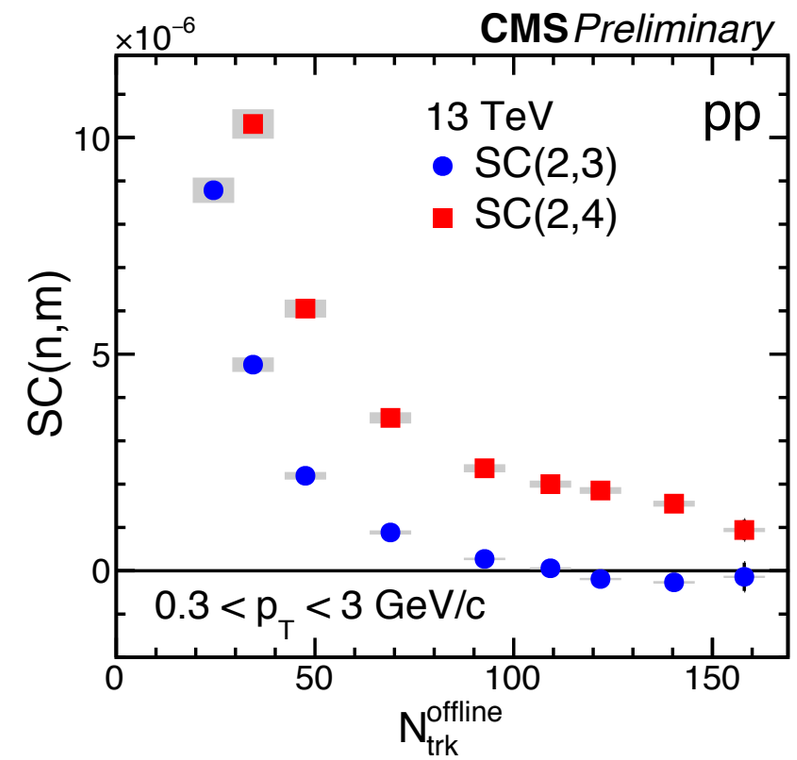
CORRELATIONS REDUCE $\langle\varepsilon_3\rangle$ IN MINIMUM BIAS AND ENLARGE IT IN ULTRA-CENTRAL COLLISIONS

Symmetric cumulants

NSC(2,3)

[Albacete,Petersen, ASO'17]



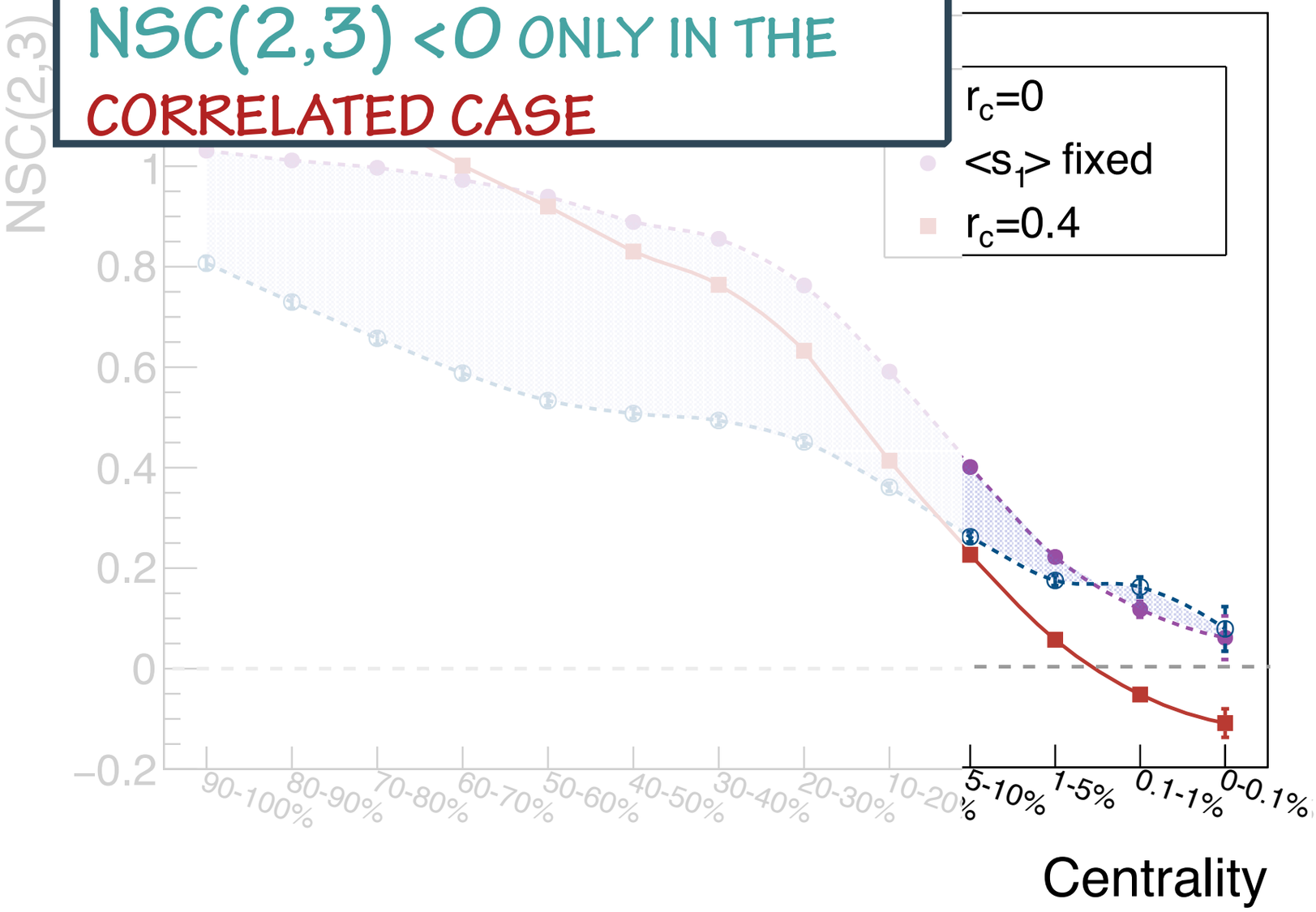


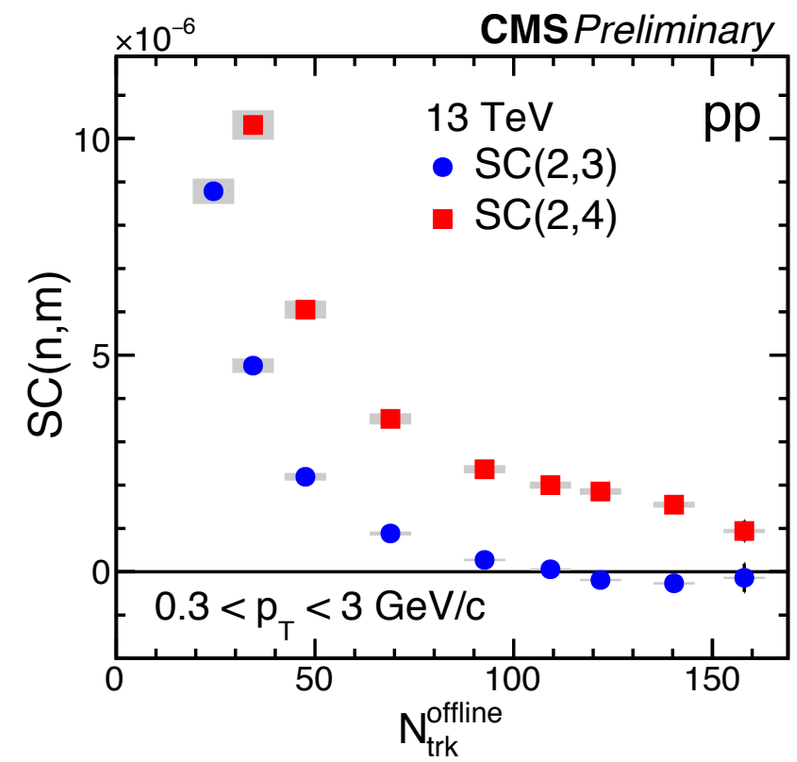
➡DISCLAIMER: data in terms of flow, model just geometry (work in progress).

NSC(2,3)

[Albacete,Petersen, ASO'17]

IN ULTRA CENTRAL COLLISIONS, NSC(2,3) <0 ONLY IN THE CORRELATED CASE

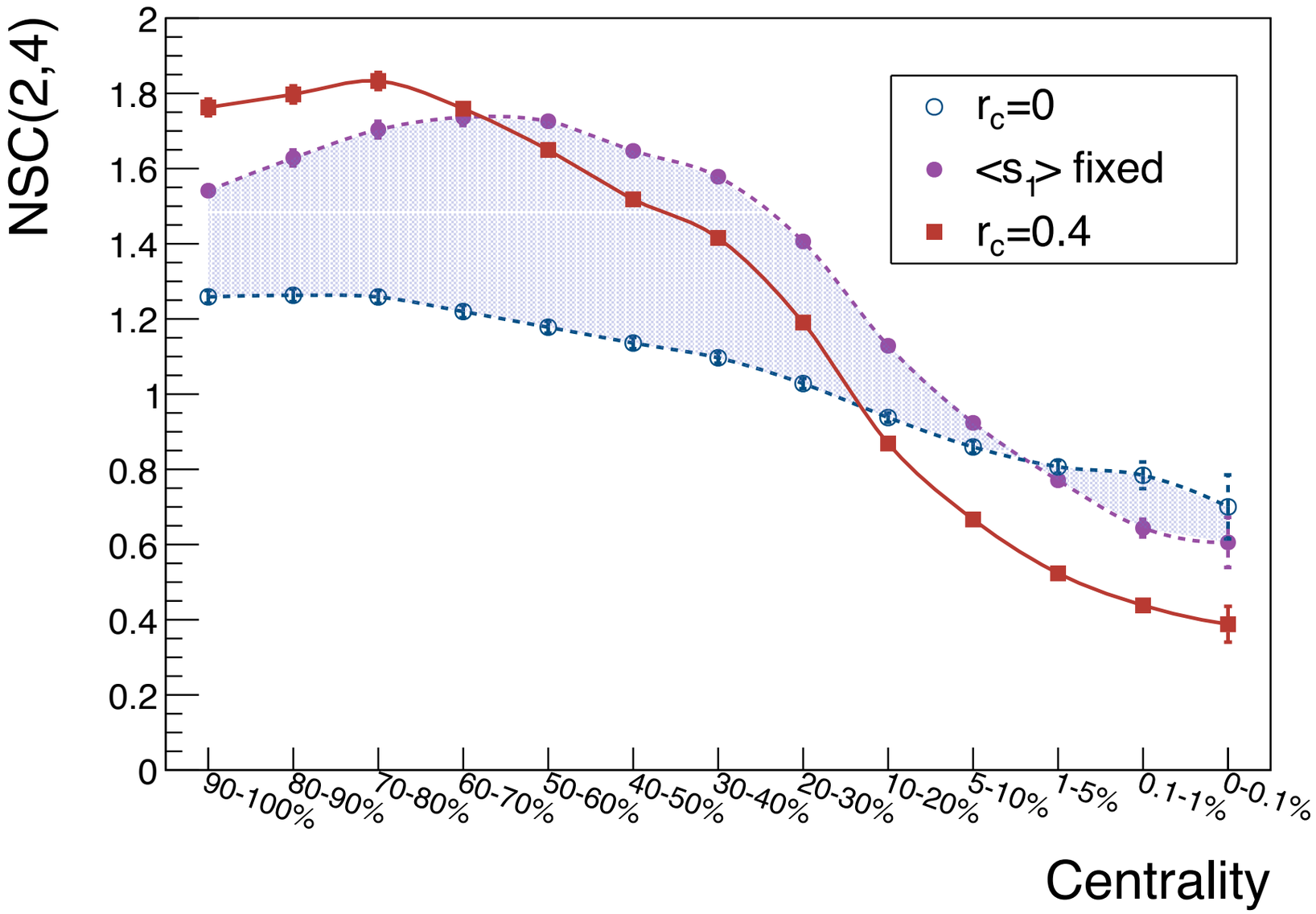


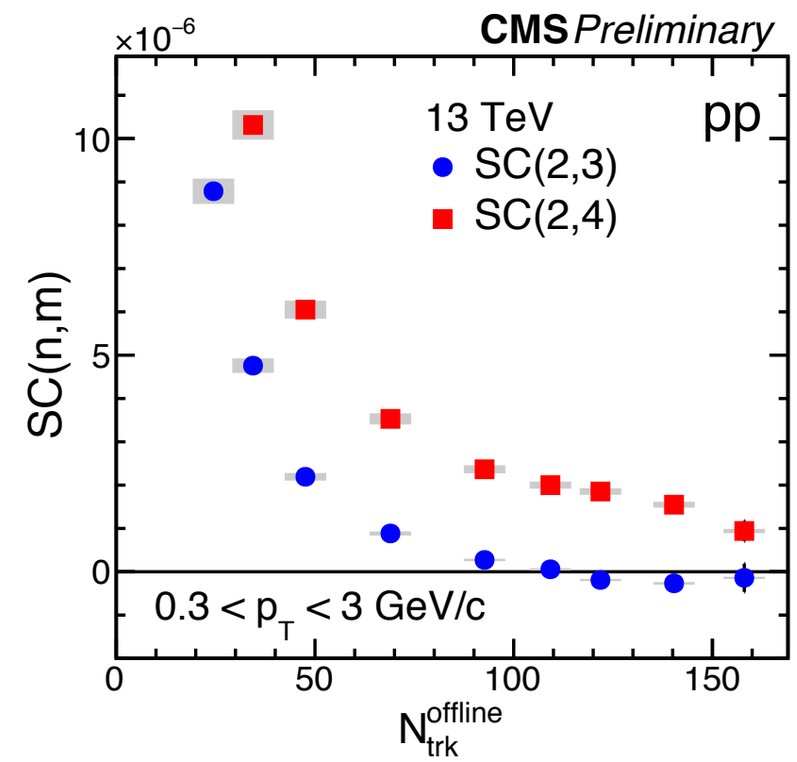


➡DISCLAIMER: data in terms of flow, model just geometry (work in progress).

NSC(2,4)

[Albacete,Petersen, ASO'17]

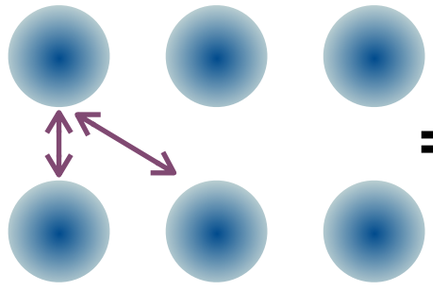




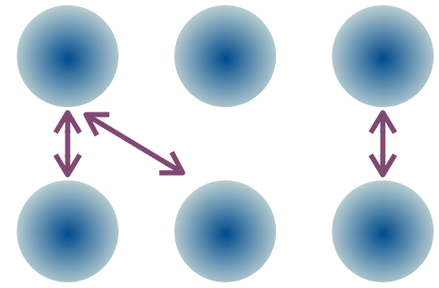
➡Same qualitative behavior as NSC(2,3) but NSC(2,4) always positive.

INTERPRETATION

➡We define interaction topologies characterized by (N_w, N_{coll}) i.e.



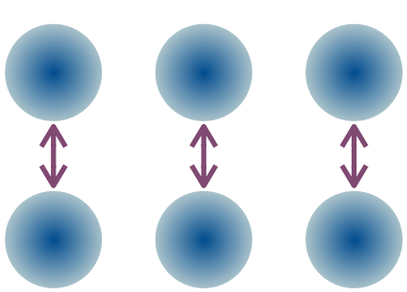
= (3,2)



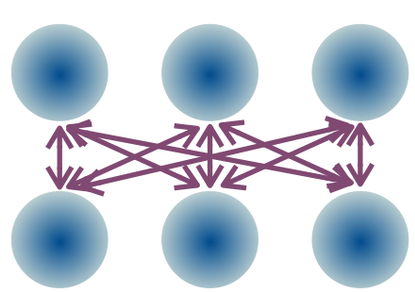
= (5,3)

where $N_w \in [2,6]$ and $N_{coll} \in [1,9]$ and focus on the [0-1%] centrality bin.

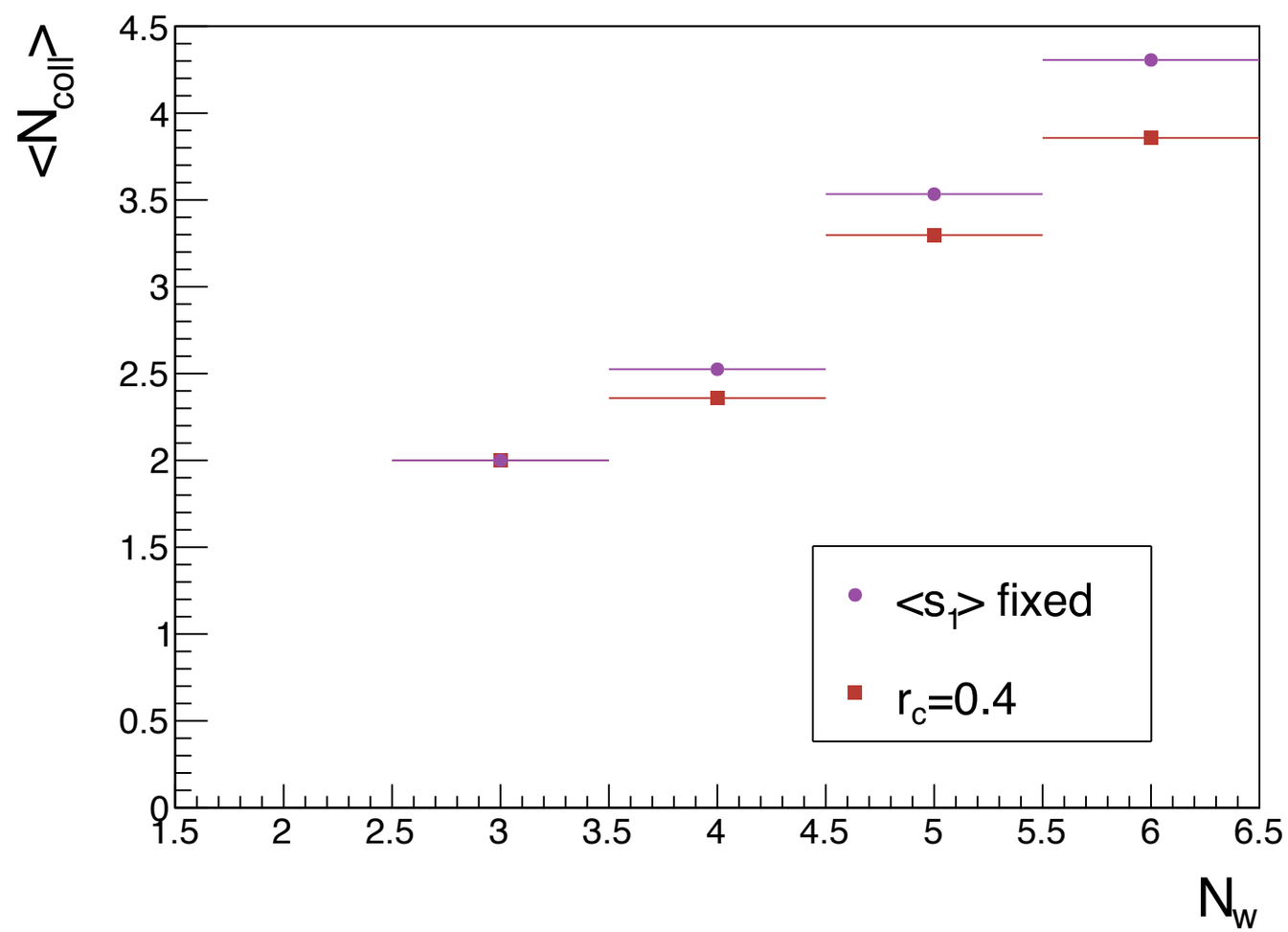
Correlations enhance the probability of having a small N_{coll} i.e.



correlated



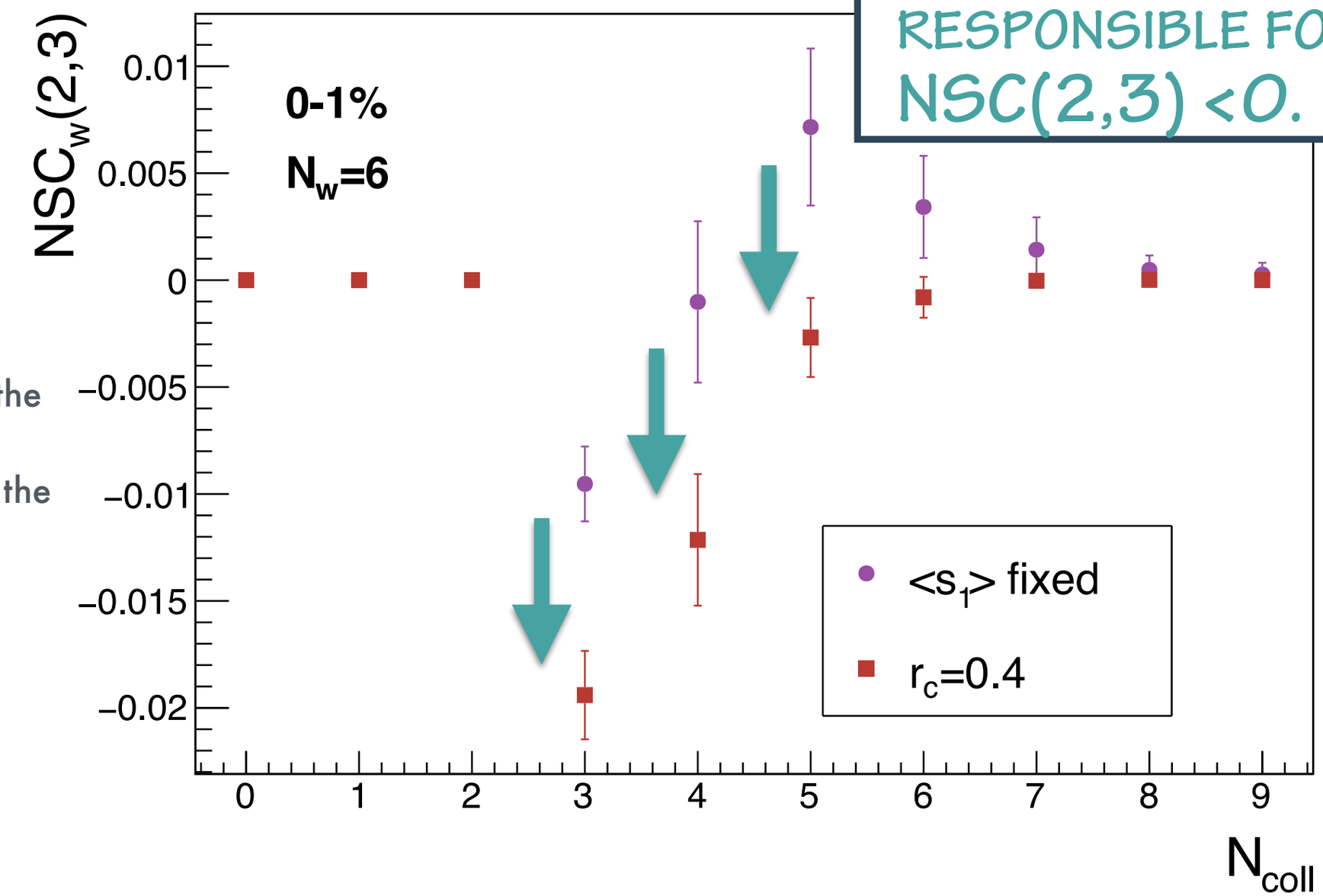
uncorrelated



Interpretation

Configurations with large N_W and small N_{COLL} responsible for making NSC(2,3) <0.

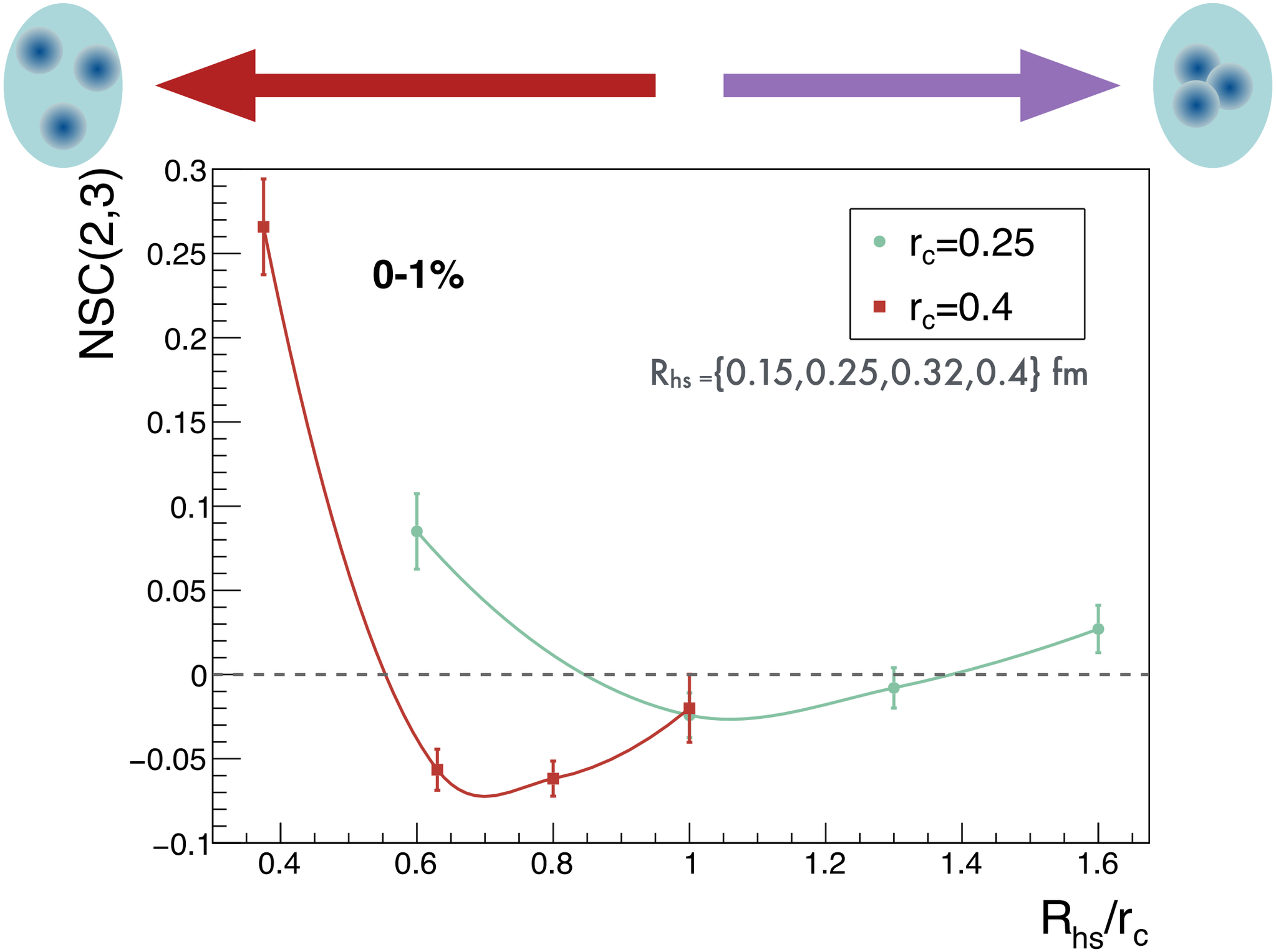
Weighted by the probability of occurrence in the Monte-Carlo.



➡Systematic effect for any N_w. Correlations modify the weight in the MC.

Sensitivity to R_{HS}/R_C

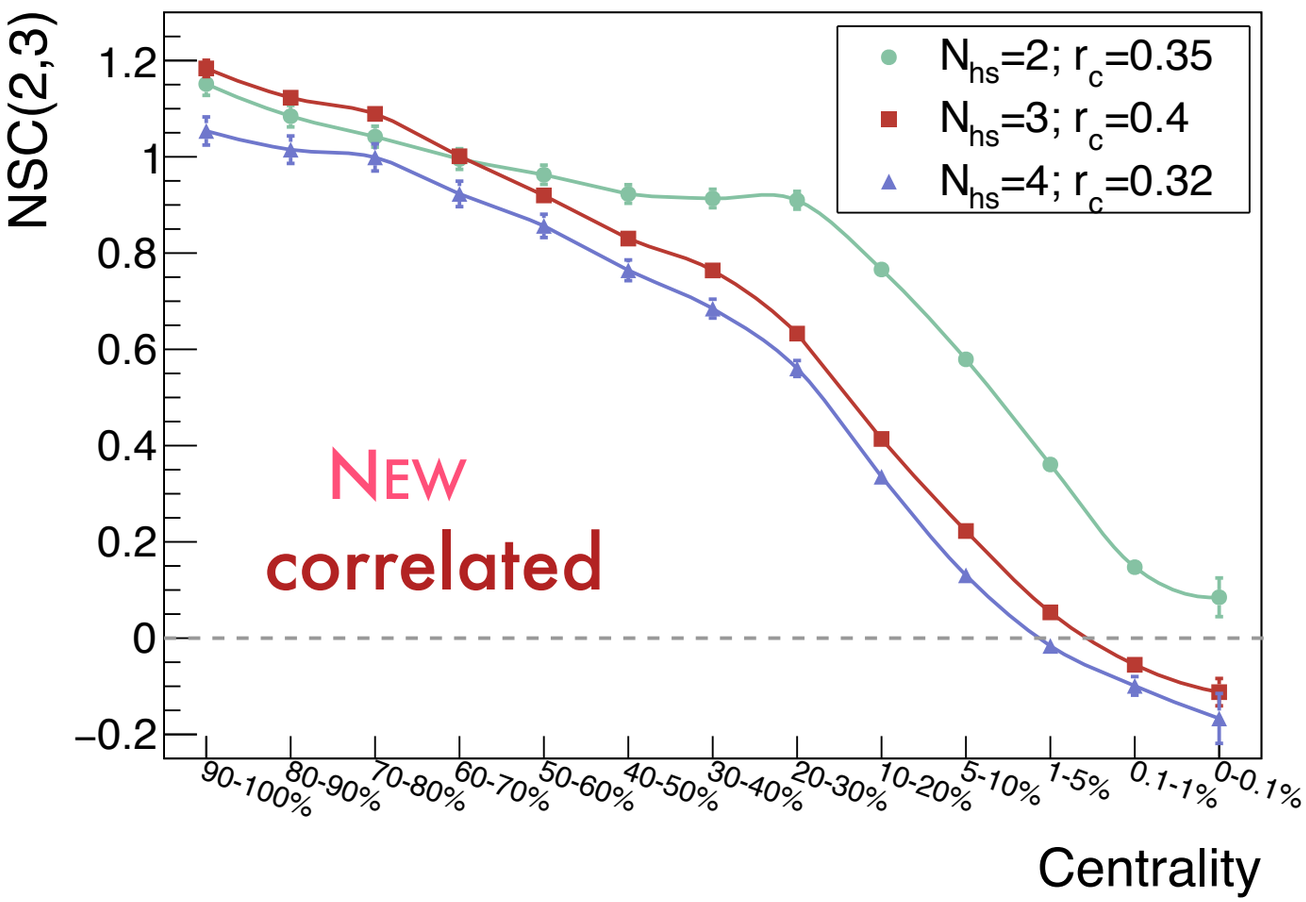
[Albacete,Petersen, ASO'17]

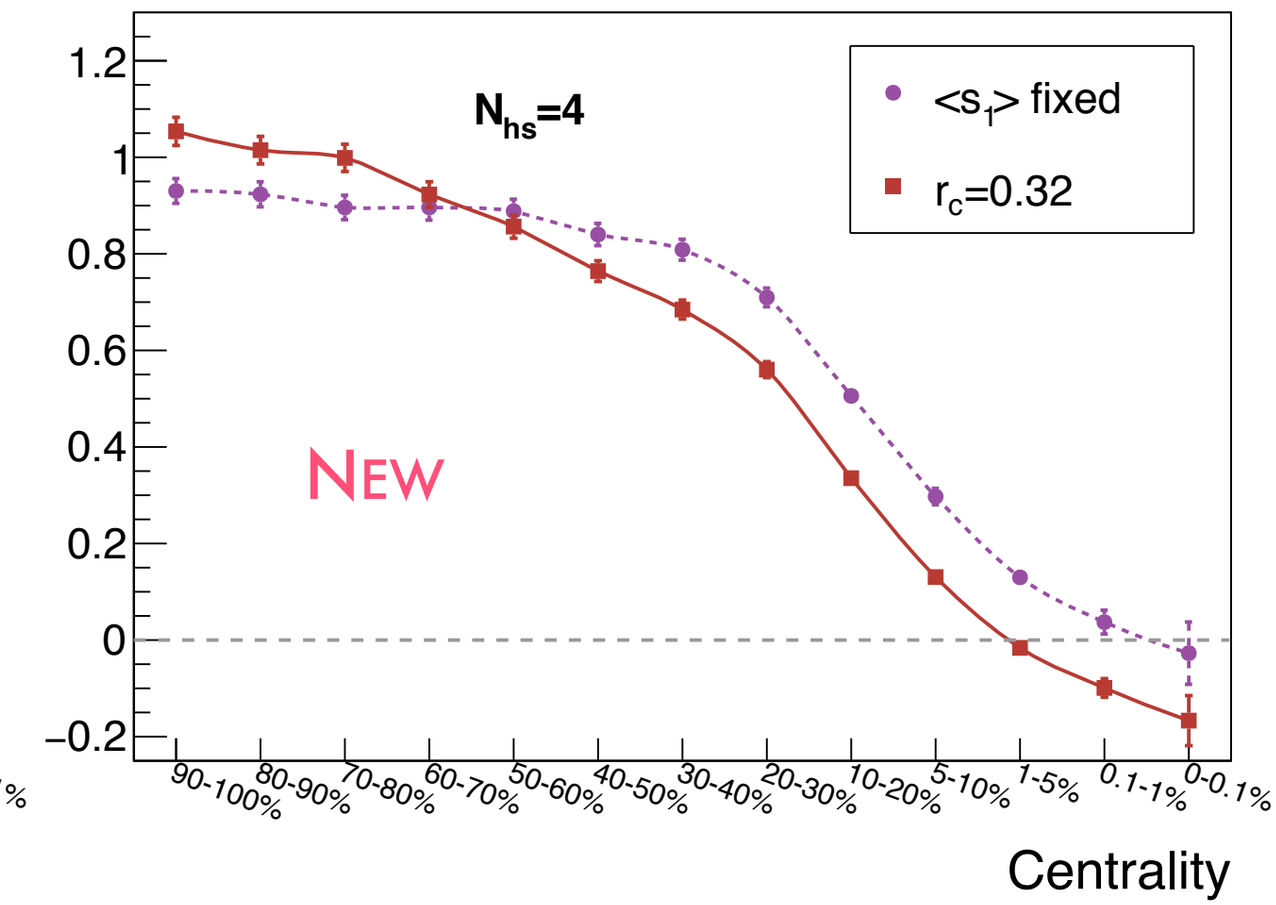


Sensitivity to Number of hot spots

➡Constraints to the parameters when varying N_{hs}:

- Reproduce $\sigma_{\rm tot}$ while keeping the radius of the proton fixed

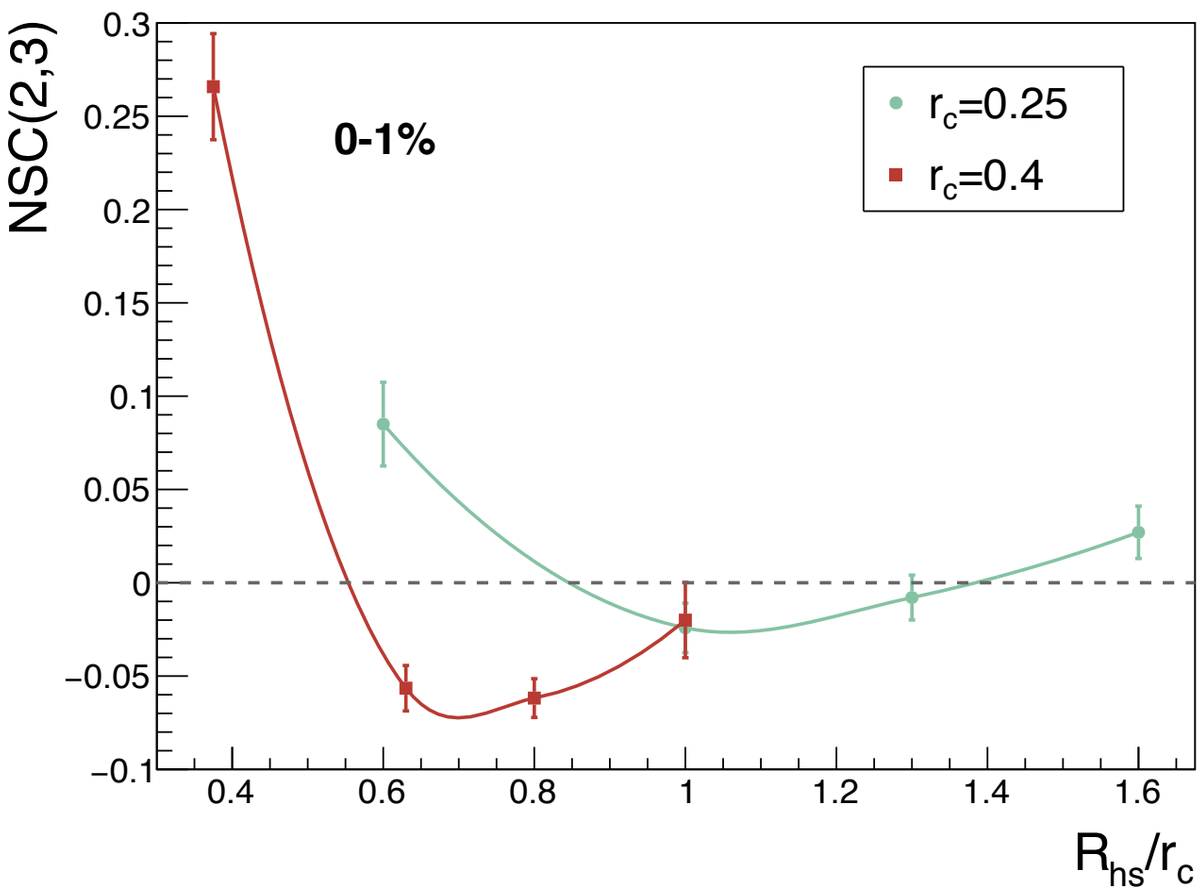


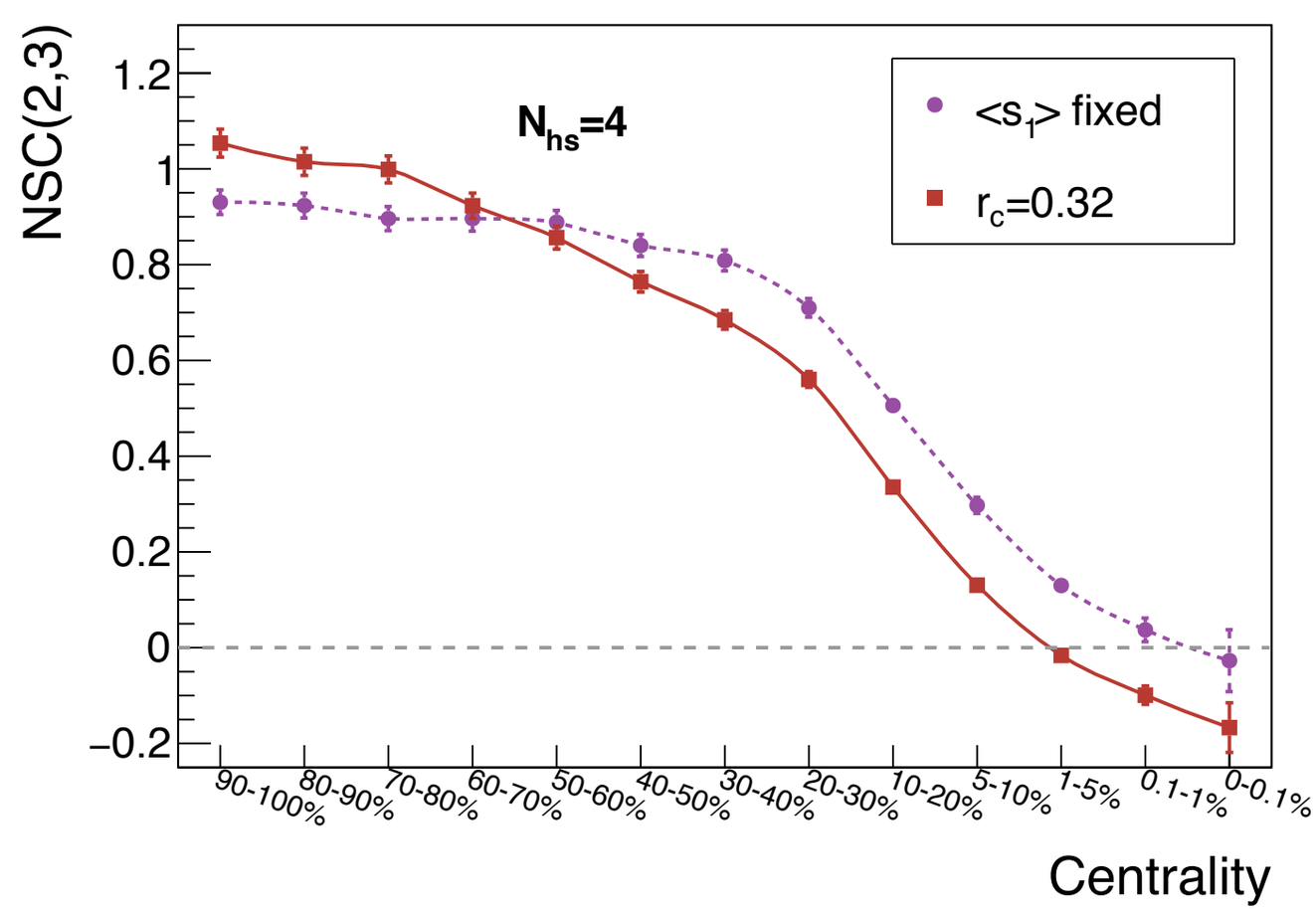


- N_{hs}>2 to have NSC(2,3)<0.
- N_{hs}=4: NSC(2,3) compatible with being <0 in the uncorrelated case.

THE DEVIL & THE DETAILS

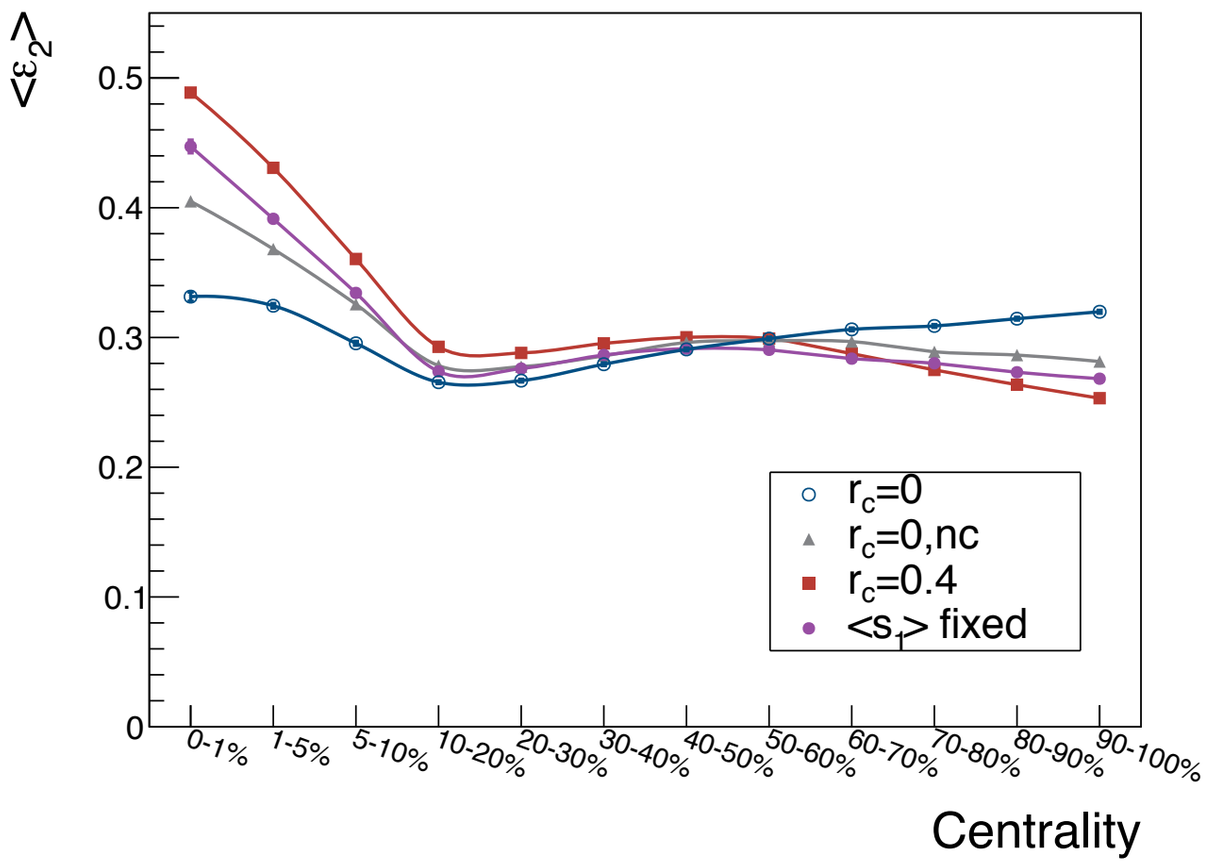
SCALES INTERPLAY IS DECISIVE $\{R_{HS}, R_C, N_{HS}, N_{COLL}, N_W\}$

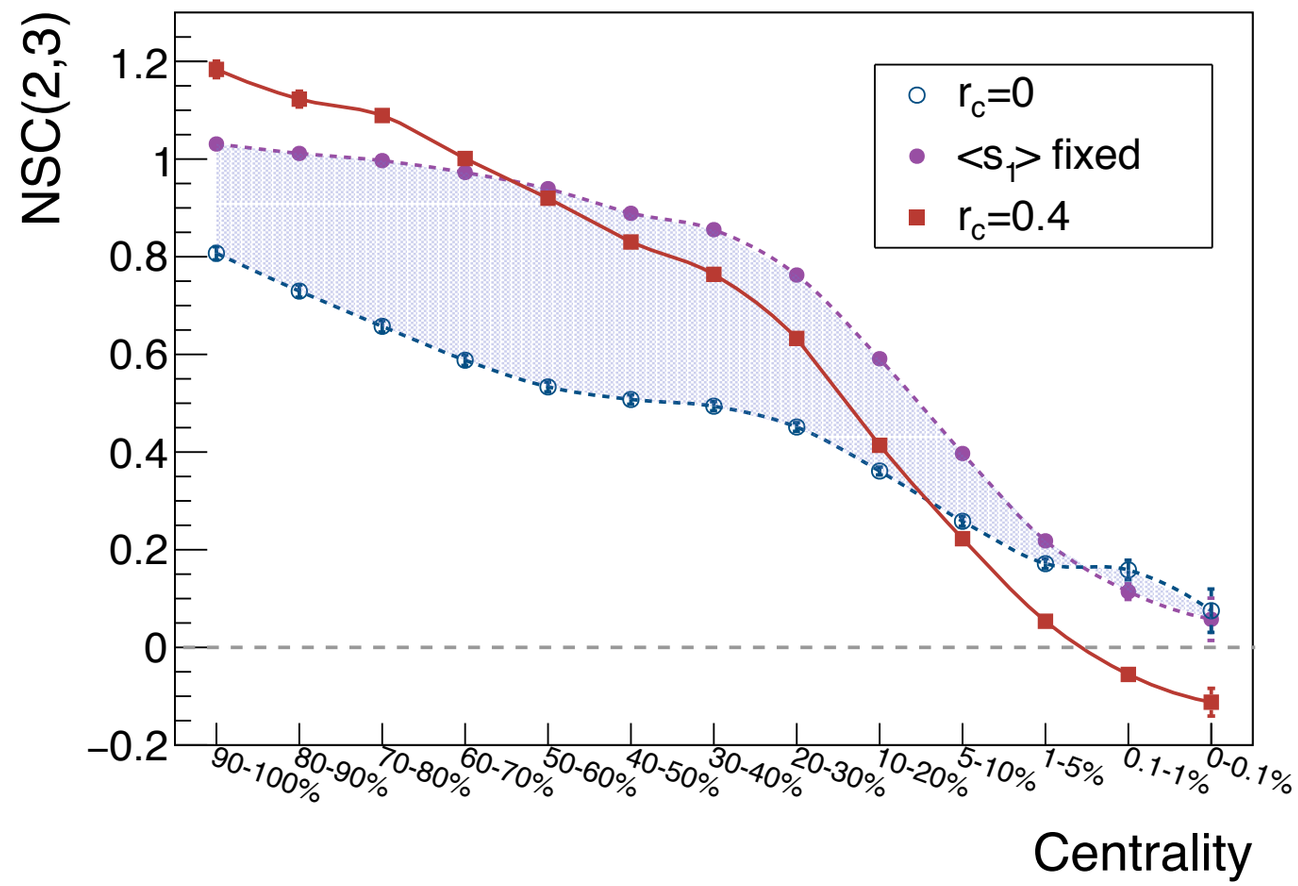




Wrapping up

Up to today





➡To-do list:

- Reinforce the bedrocks of the model via QCD tools
- Study the interplay between the different scales {R_{hs}, r_c, N_{hs}}
- Is the effect of correlations washed out by hydro? in bigger systems?