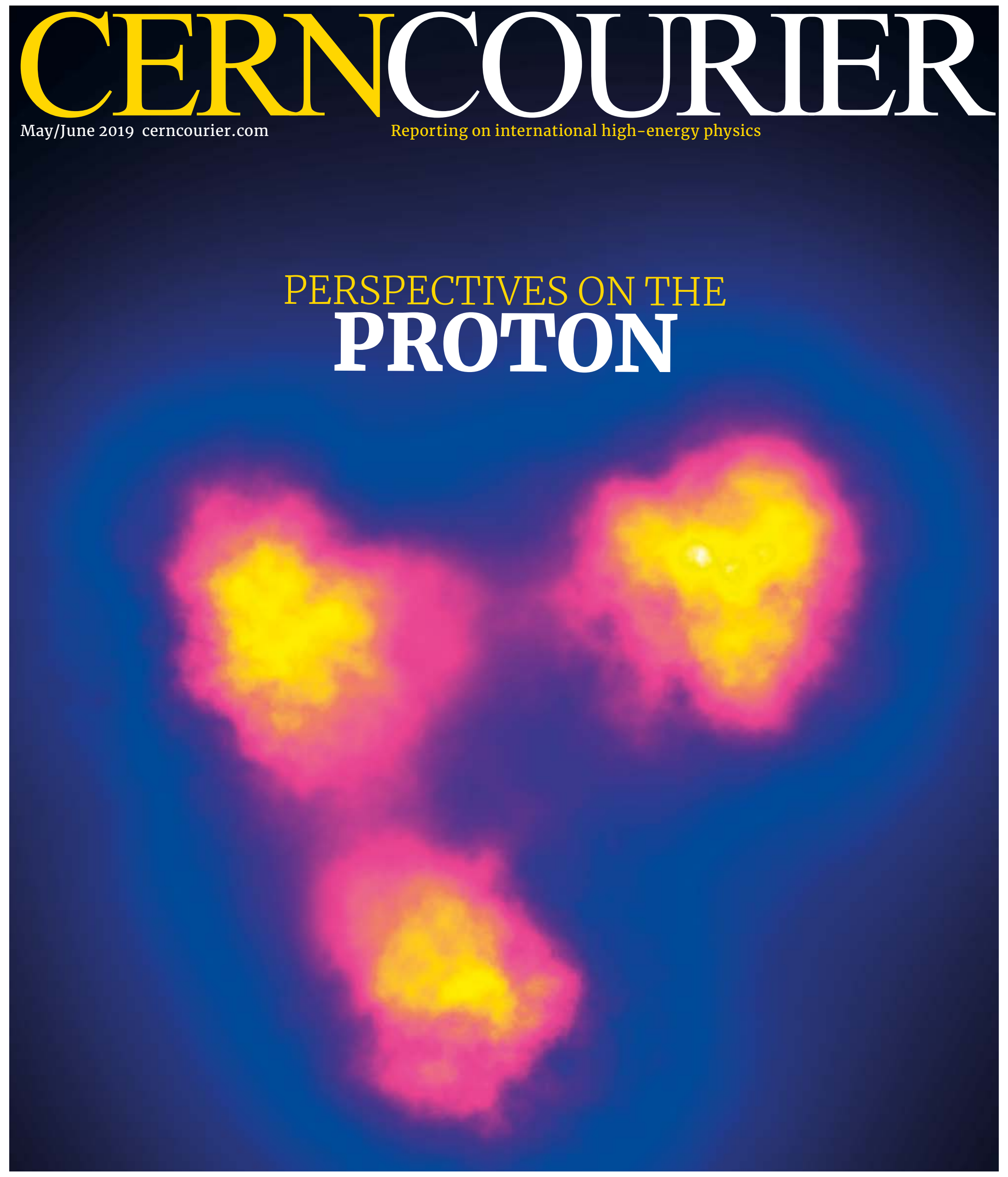
INFLUENCE OF INITIAL CONDITIONS WITH SUBSTRUCTURE IN SMALL SYSTEMS



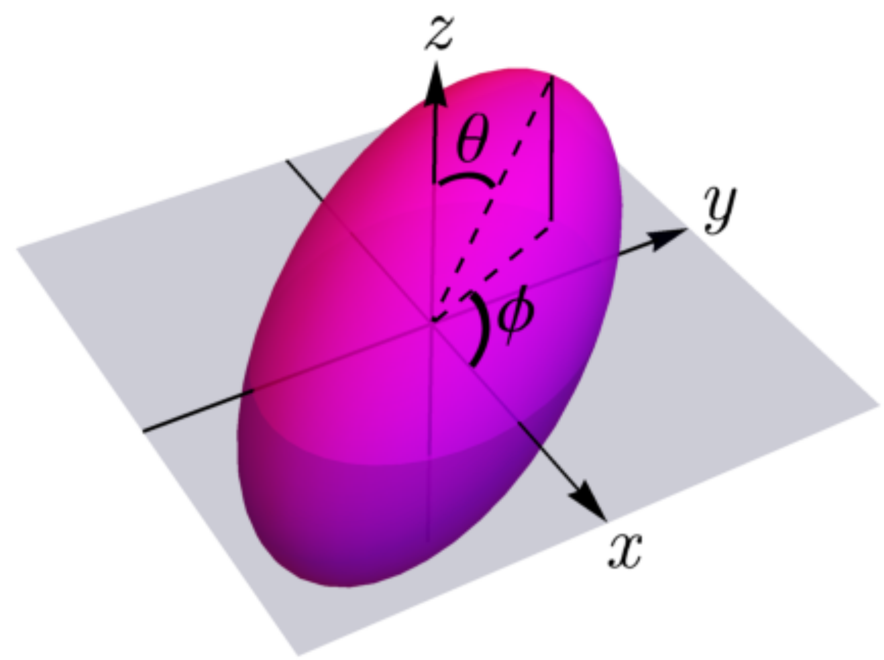
[Credit: Heikki Mantysaari]

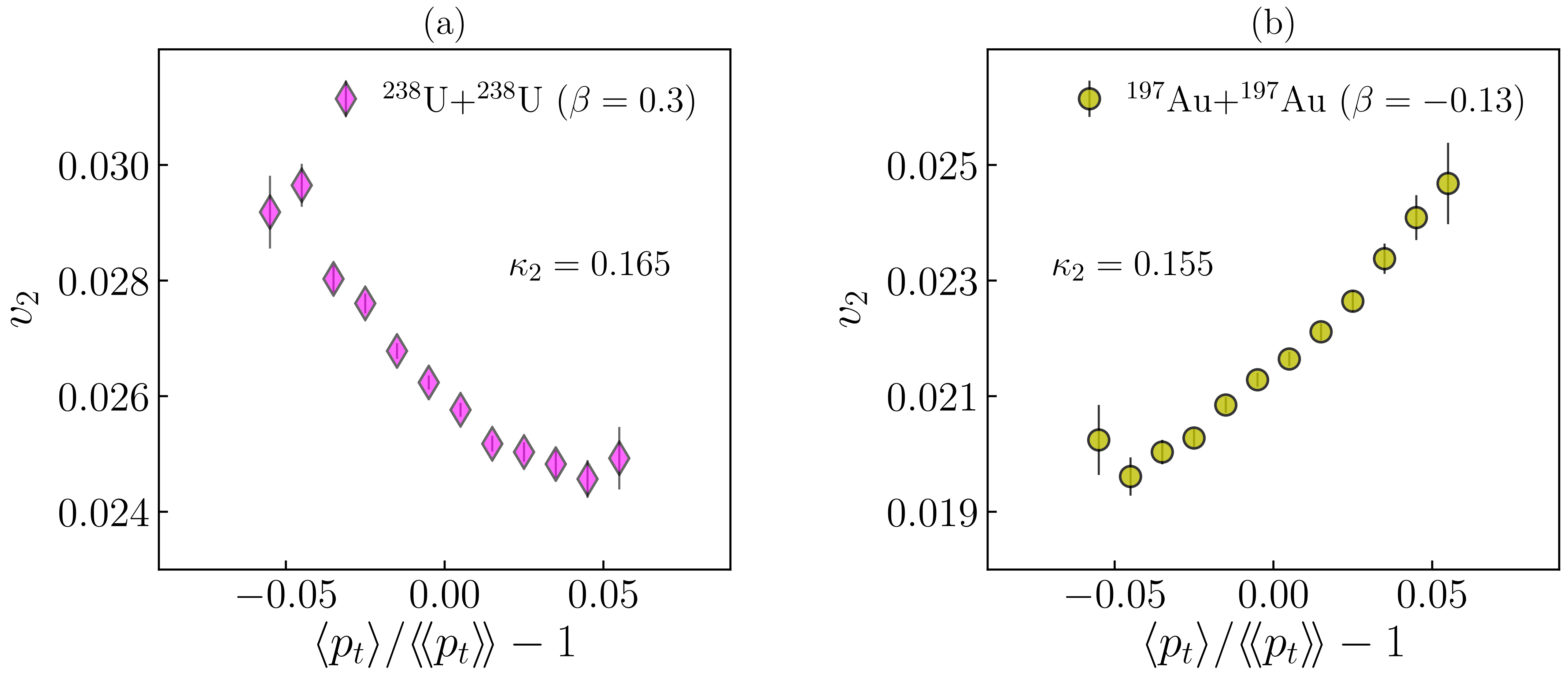
Alba Soto-Ontoso

Initial Stages 2021

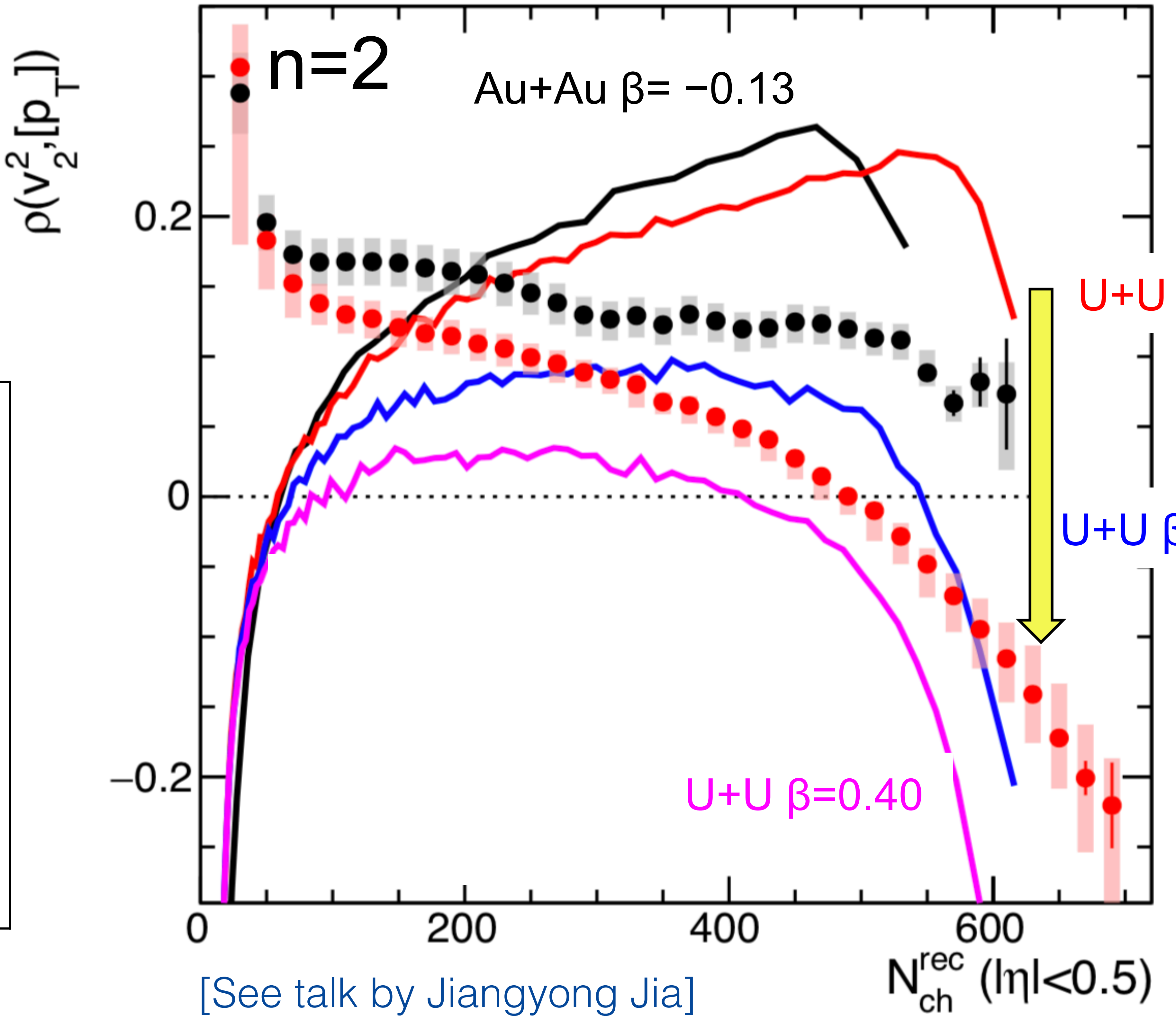
Remote, 15th January, 2021

Brief detour to the nuclear case





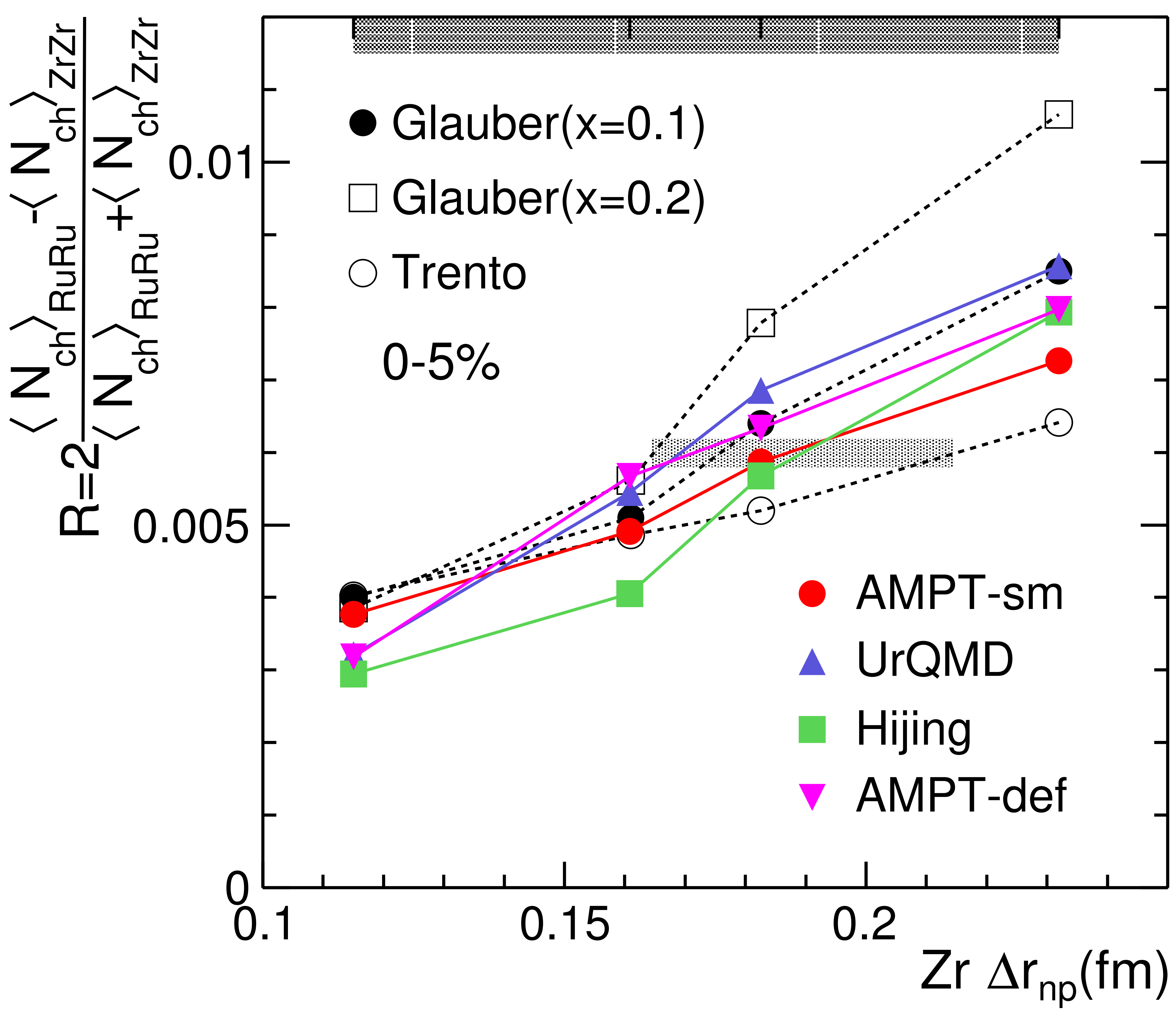
[G.Giacalone PRL'20, PRC'20]



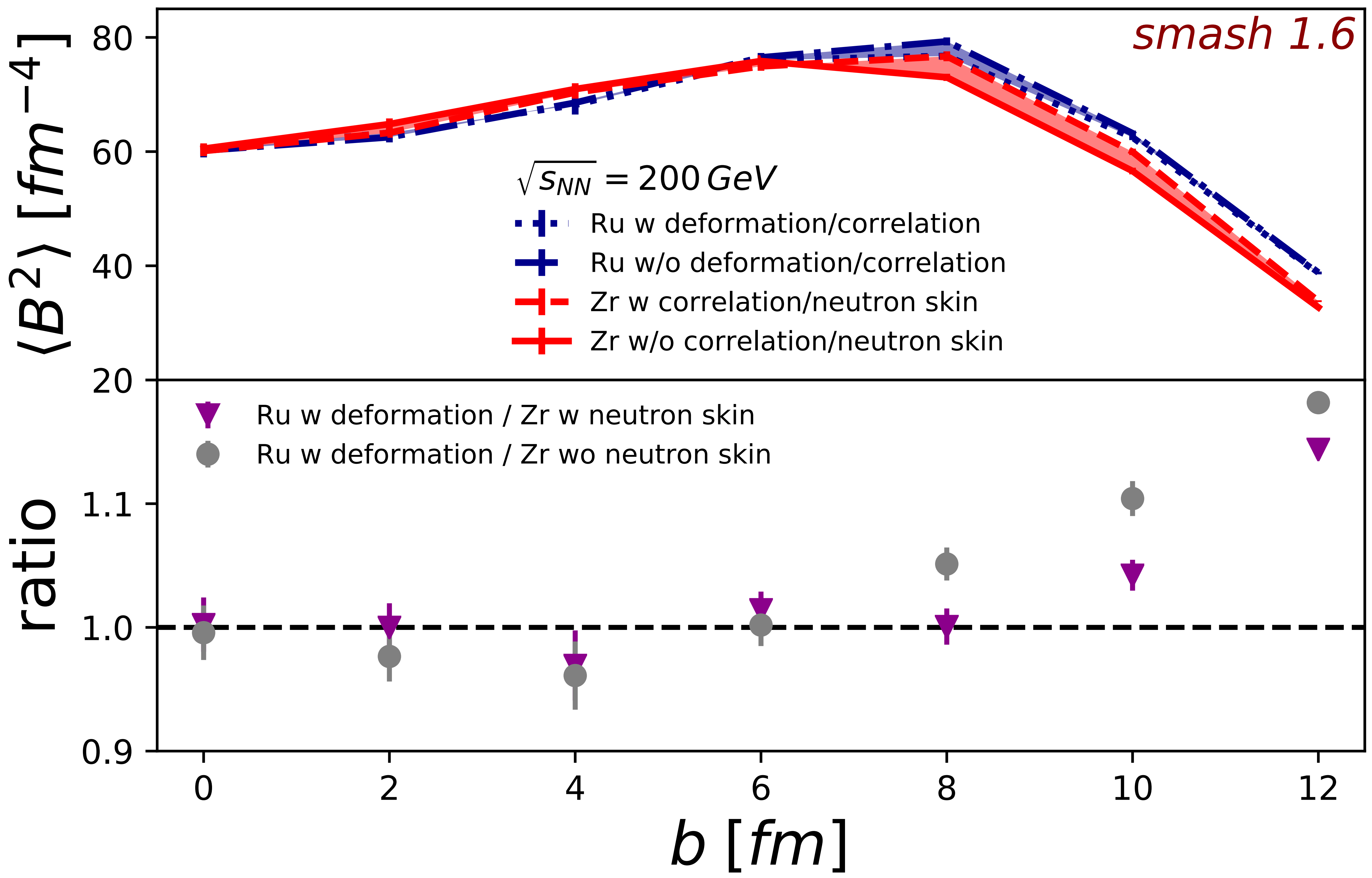
[See talk by Jiangyong Jia]

New ideas to constraint the quadrupole deformation of nuclei with HICs

Brief detour to the nuclear case



[H.Li, H.Xu et Al. PRL'20]

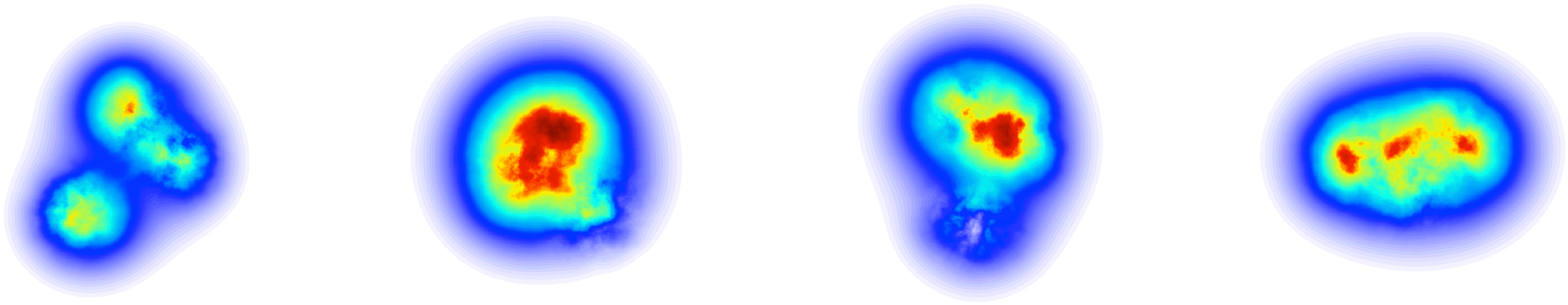


[J.Hammelman, M.Alvioli, H.Elfner, ASO, M.Strikmann PRC'19]

New ideas to constraint the neutron skin of nuclei with isobaric HICs

Main question of this talk (and in IS2016)

What can we learn about the transverse geometry of the proton $T_p(\vec{r}_1, \vec{r}_2 \ldots \vec{r}_n)$



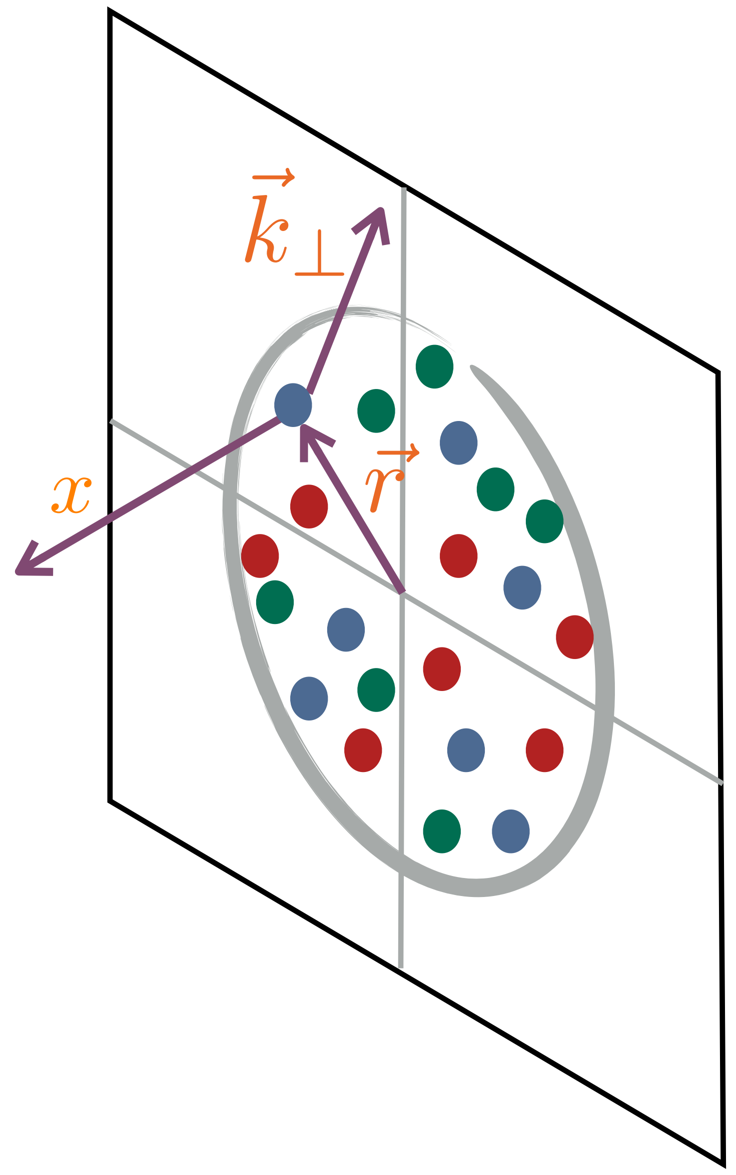
through e+p, p+p and p+A collisions?

[Images: H.Mäntysaari, B.Schenke PRL'16]

e+p: Generalized parton distributions and the EIC

GPDs are well defined objects in QCD [M.Diehl PhD Thesis'03]

$$G^q(x,\xi,\mathbf{\Delta}_\perp) = \int \frac{\mathrm{d}\eta^-}{2\pi} e^{-\mathrm{i}x\overline{P}^+\eta^-} \langle P'|\overline{\Psi}(0,\eta^-,\mathbf{0}_\perp)\gamma^+ G_{[\eta^-,0]}\Psi(0,0,\mathbf{0}_\perp)|P\rangle\Big|_{\eta^+=\eta_\perp=0}$$

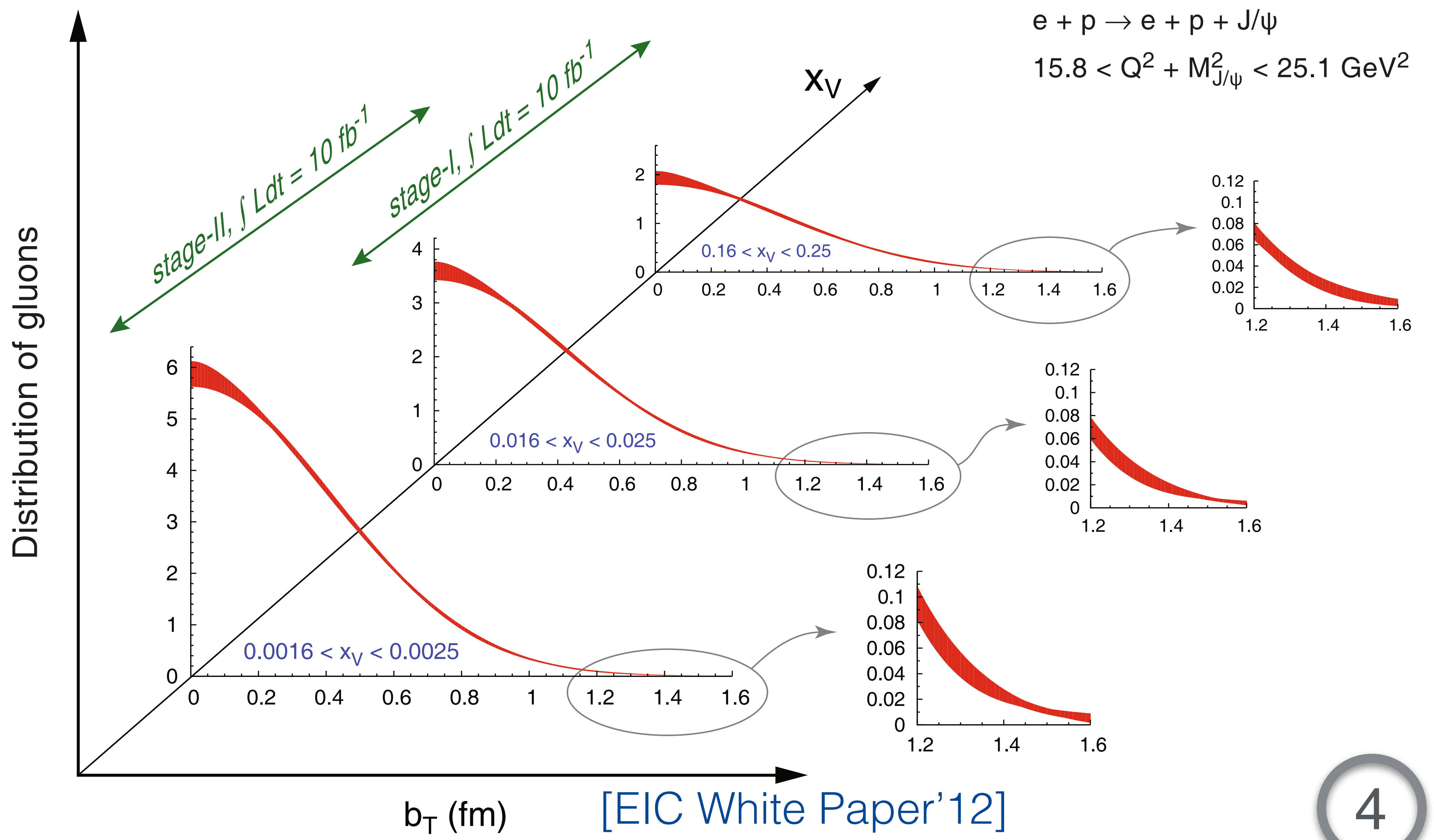


From them, we can derive our object of interest

$$I(x,\mathbf{b}_\perp) = \int \frac{\mathrm{d}^2\Delta_\perp}{(2\pi)^2} e^{-\mathrm{i}\mathbf{b}_\perp\cdot\mathbf{\Delta}_\perp} G(x,0,\mathbf{\Delta}_\perp)$$

Not computable in pQCD. A certain degree of modelling is required.

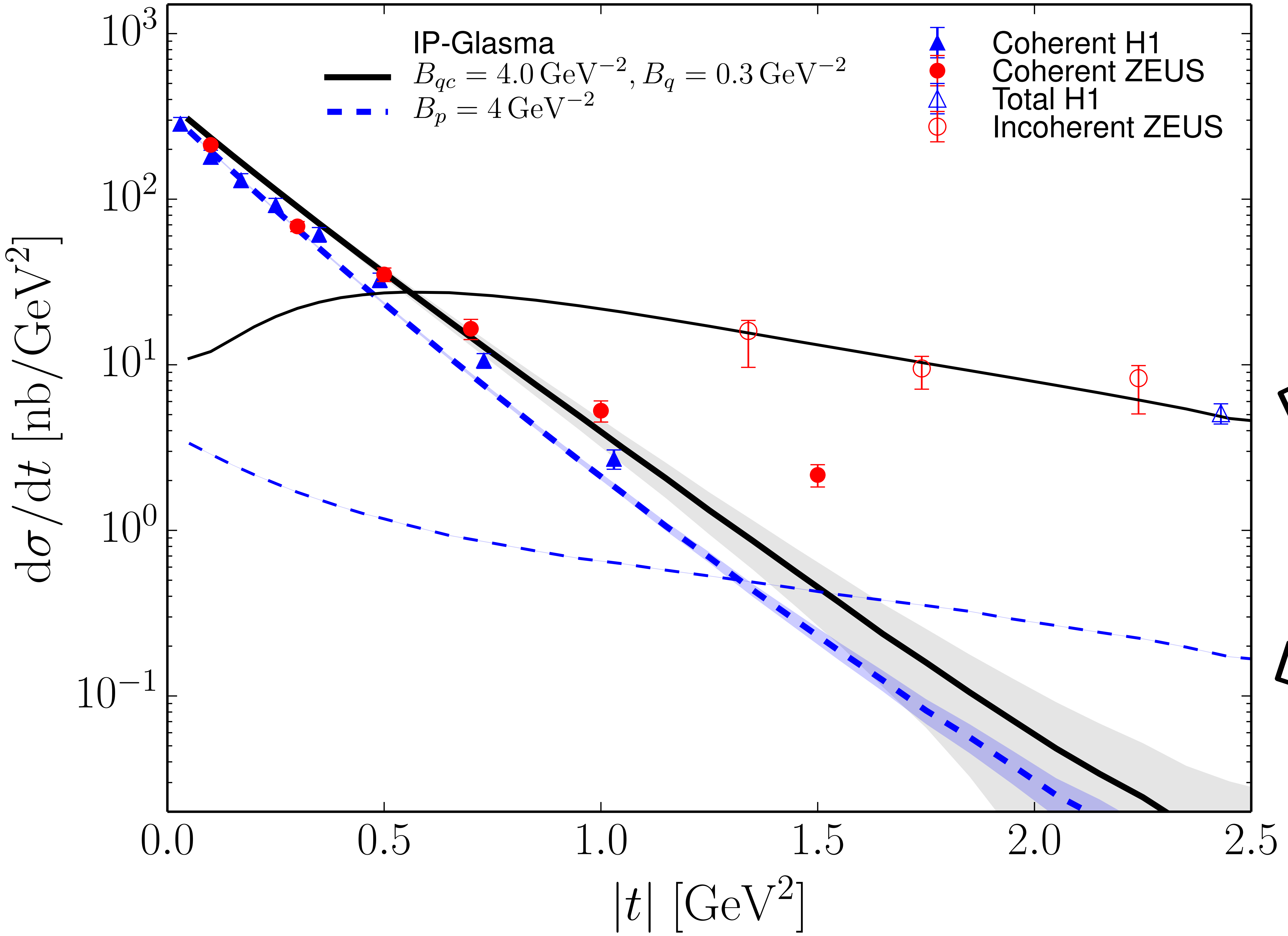
But…accessible experimentally through e.g. DVCS



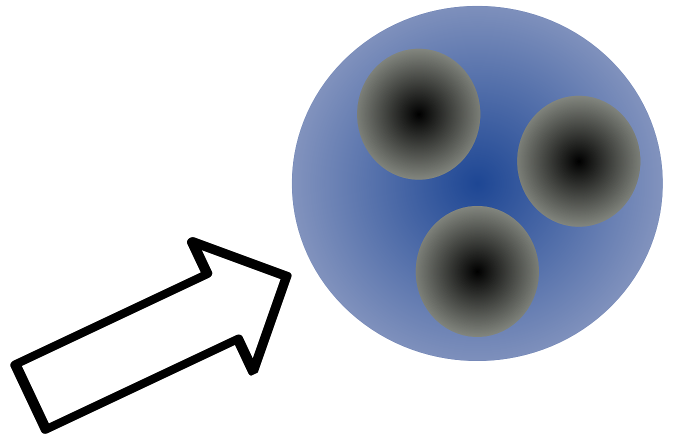
[EIC White Paper'12]

e+p: exclusive vector meson production at HERA $e + p \rightarrow e + p + J/\psi$

[H.Mäntysaari, B.Schenke PRL'16]

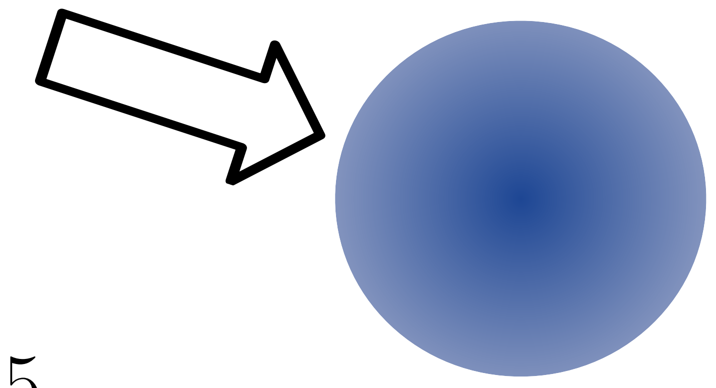


[Also used by Weller, Romatschke PLB'17
BozeK, Broniowski, Rybzynski PRC'16,
Welsh, Singer, Heinz PRC'16]



$$T_p(\mathbf{b}) = \frac{1}{N_q} \sum_{i=1}^{N_q} T_q(\mathbf{b} - \mathbf{b}_i)$$

with $$T_q(\mathbf{b}) = \frac{1}{2\pi B_q} e^{-b^2/(2B_q)}$$

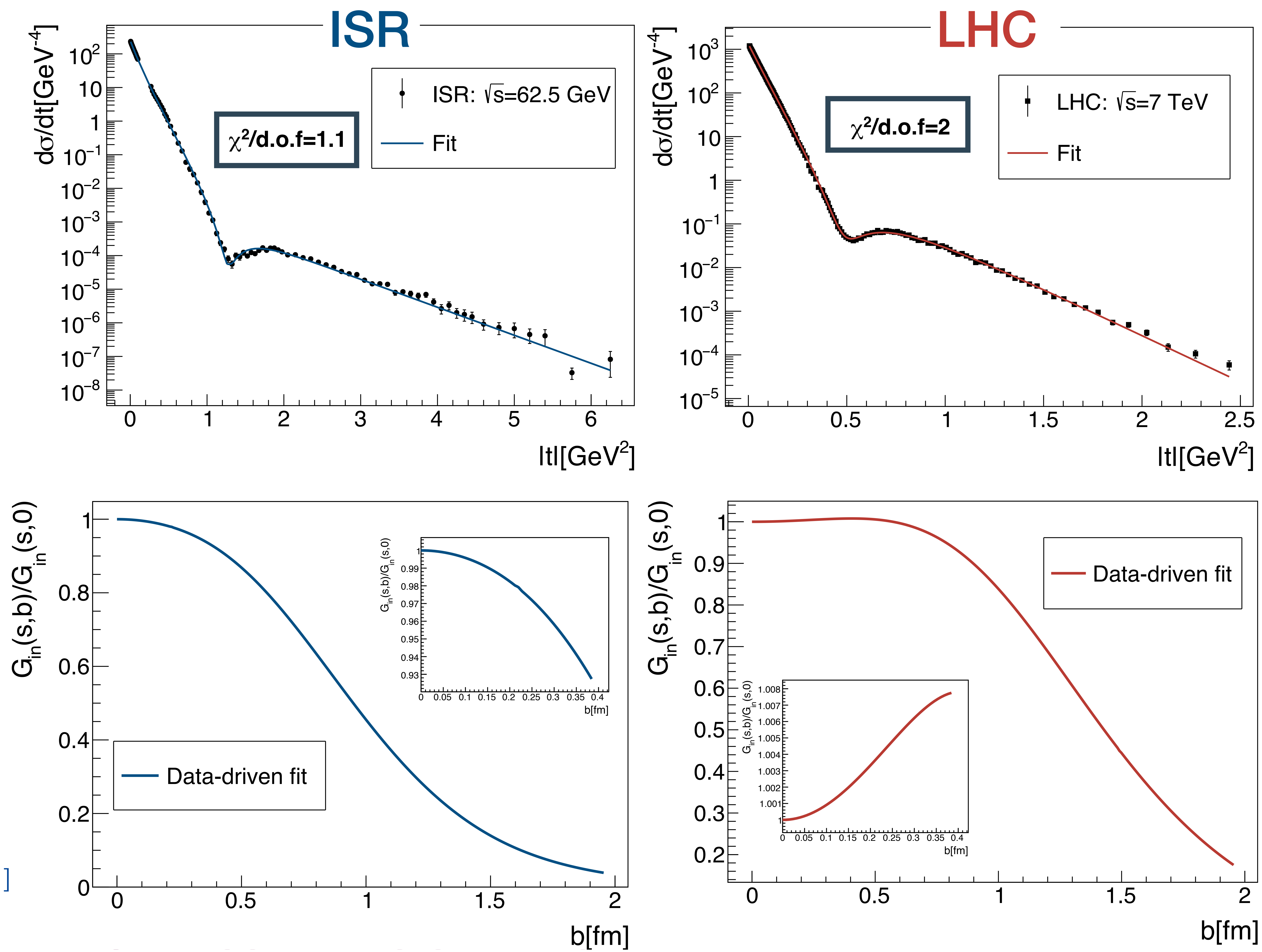


$$T_p(\mathbf{b}) = \frac{1}{2\pi B_p} e^{-b^2/(2B_p)}$$

Proton with 3 constituents Gaussianly distributed clearly favored by data

p+p: elastic scattering and the hollowness effect $p + p \to p + p$

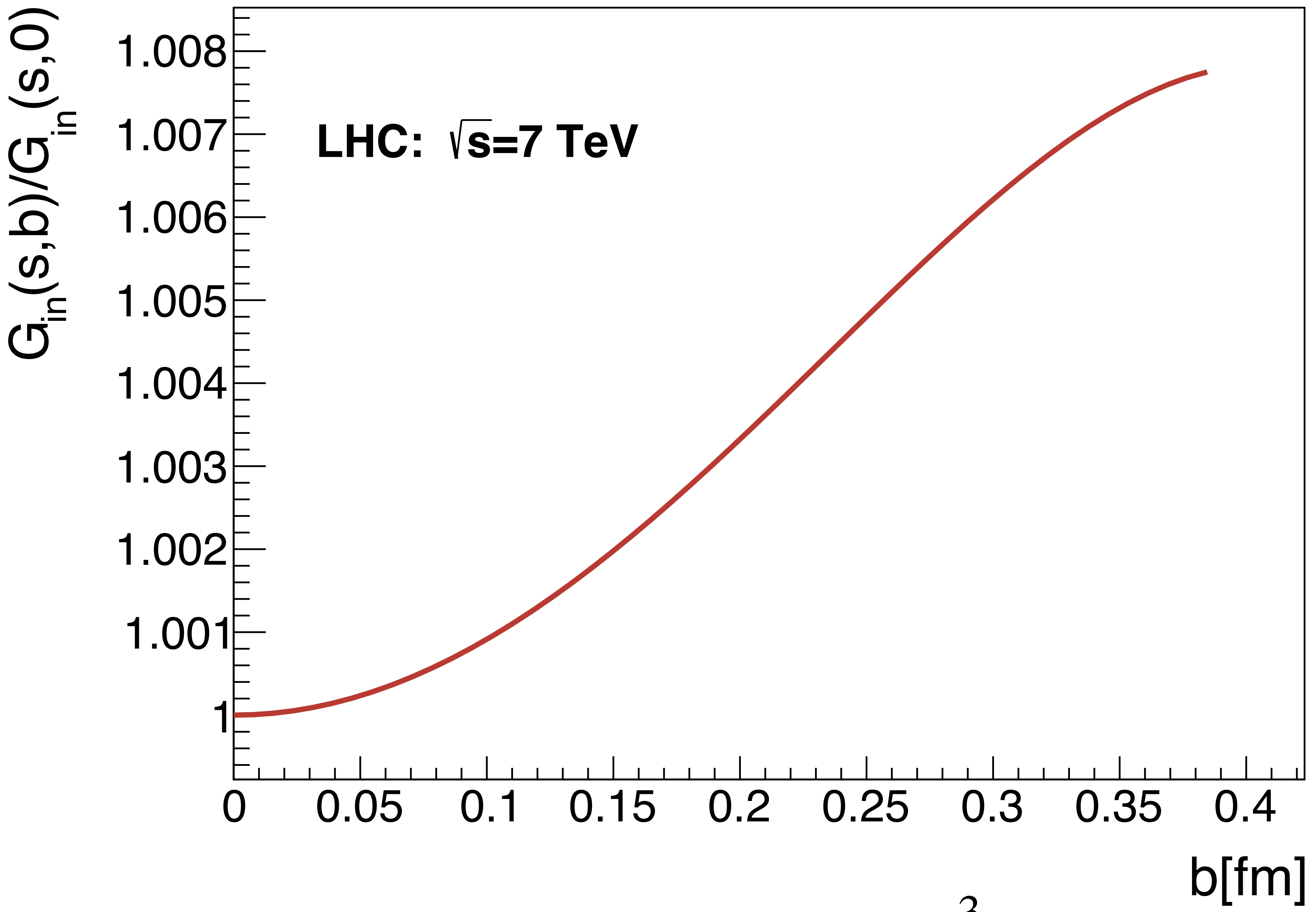
$$G_{\mathrm{in}}(s, b) = 2\mathrm{Im}T_{el}(s, b) - |T_{el}(s, b)|^2$$

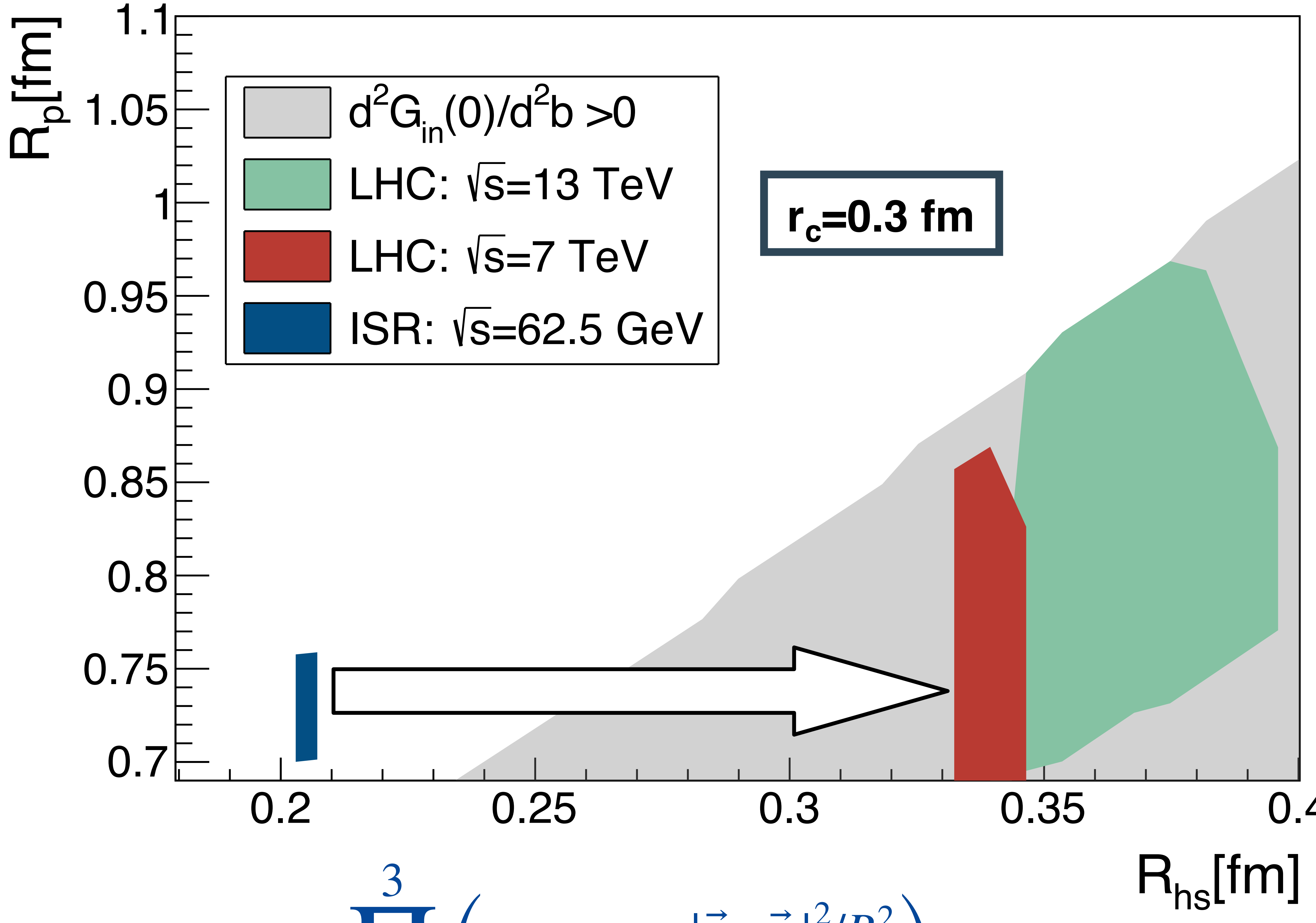


[JL Albacete, ASO PLB'16]

[E. Ruiz-Arriola,W. Broniowski'16
A.Alkin et al'14, I.Dremin, S.Troshin…]

p+p: elastic scattering and the hollowness effect $p+p \to p+p$





[JL Albacete, ASO PLB'16]

$$T_p(\vec{r}_1, \vec{r}_2, \vec{r}_3) = \mathcal{N} \prod_{i=1}^{3} e^{-r_i^2/R^2} \delta^2(\vec{r}_1 + \vec{r}_2 + \vec{r}_3) \times \prod_{i<j}^{3} \left(1 - e^{-\mu|\vec{r}_i - \vec{r}_j|^2/R^2}\right)$$

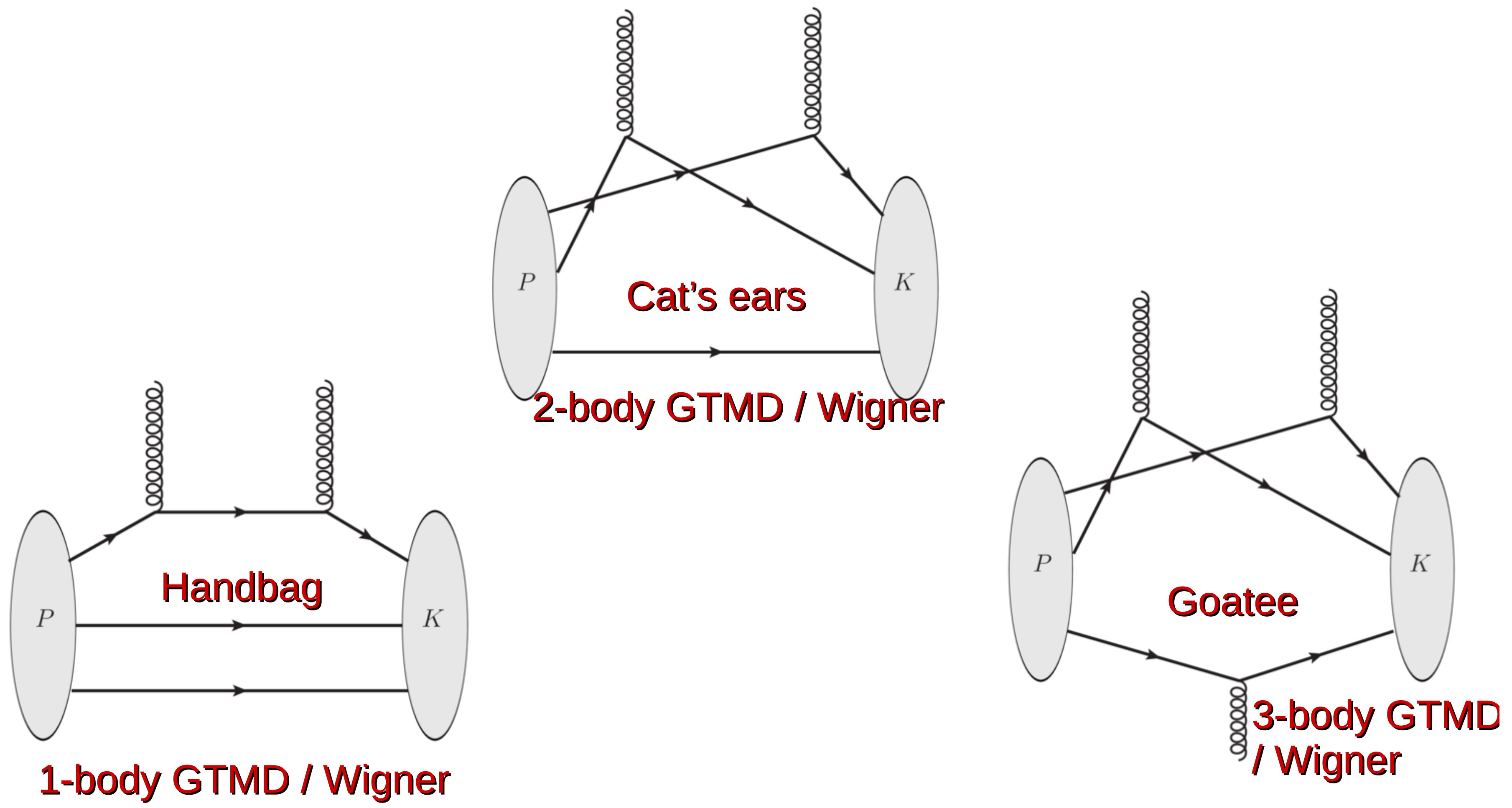
Proton with >2 constituents Gaussianly distributed including short-range repulsive correlations clearly favored by data

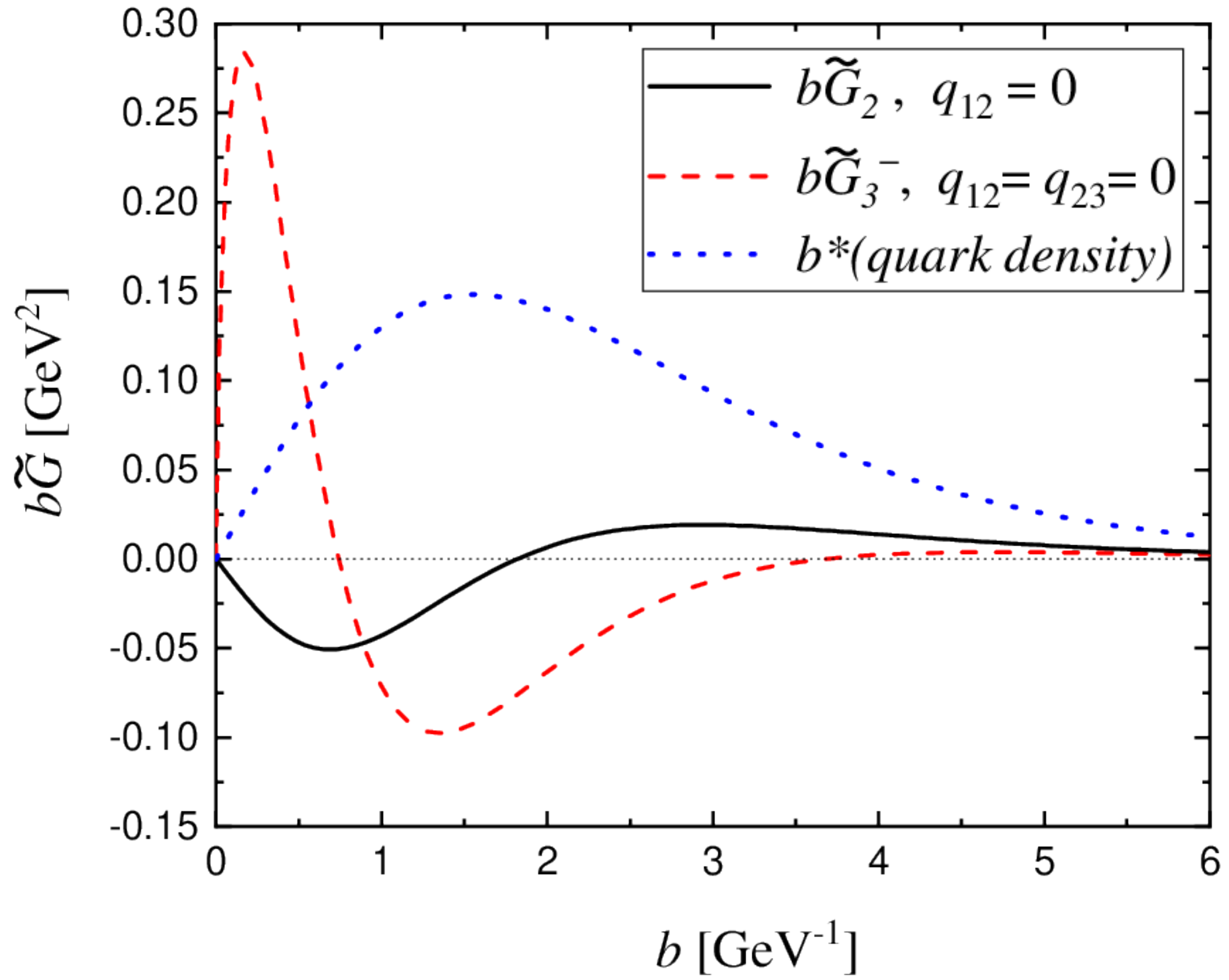
p+p: color charge correlations in the proton [See talk by A.Dumitru]

The proton shape function, $T_p(\mathbf{b})$,enters the 2-point correlator of color charges in the CGC

$$\langle \rho(\mathbf{x})\rho(\mathbf{y})\rangle \sim g^2\mu^2(x,\mathbf{b})\delta^{(2)}(\mathbf{x}-\mathbf{y}) \quad \text{with} \quad \mu^2(x,\mathbf{b}) \sim T_p(\mathbf{b})$$

One can compute it from field theory using the light-front approach

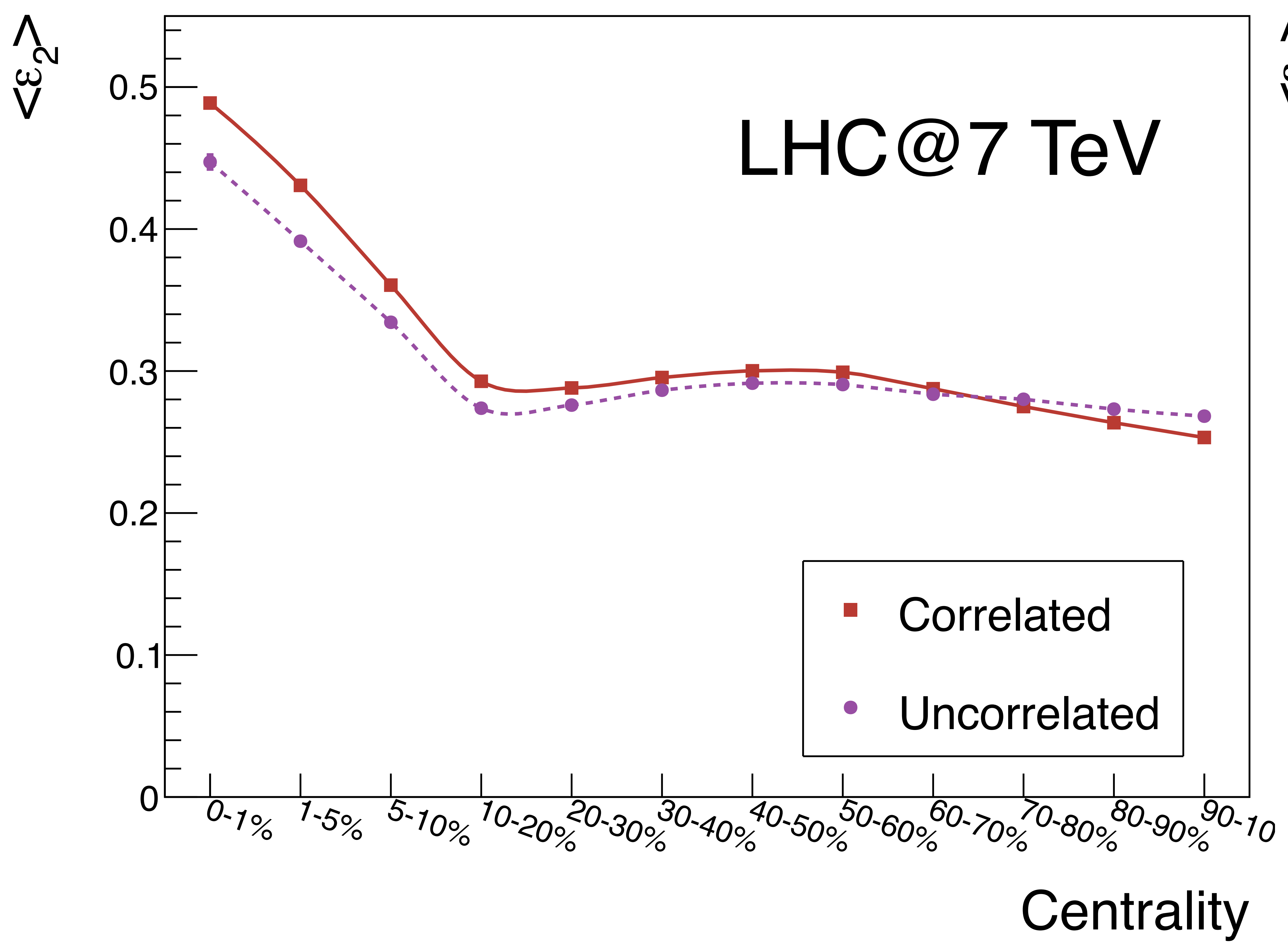


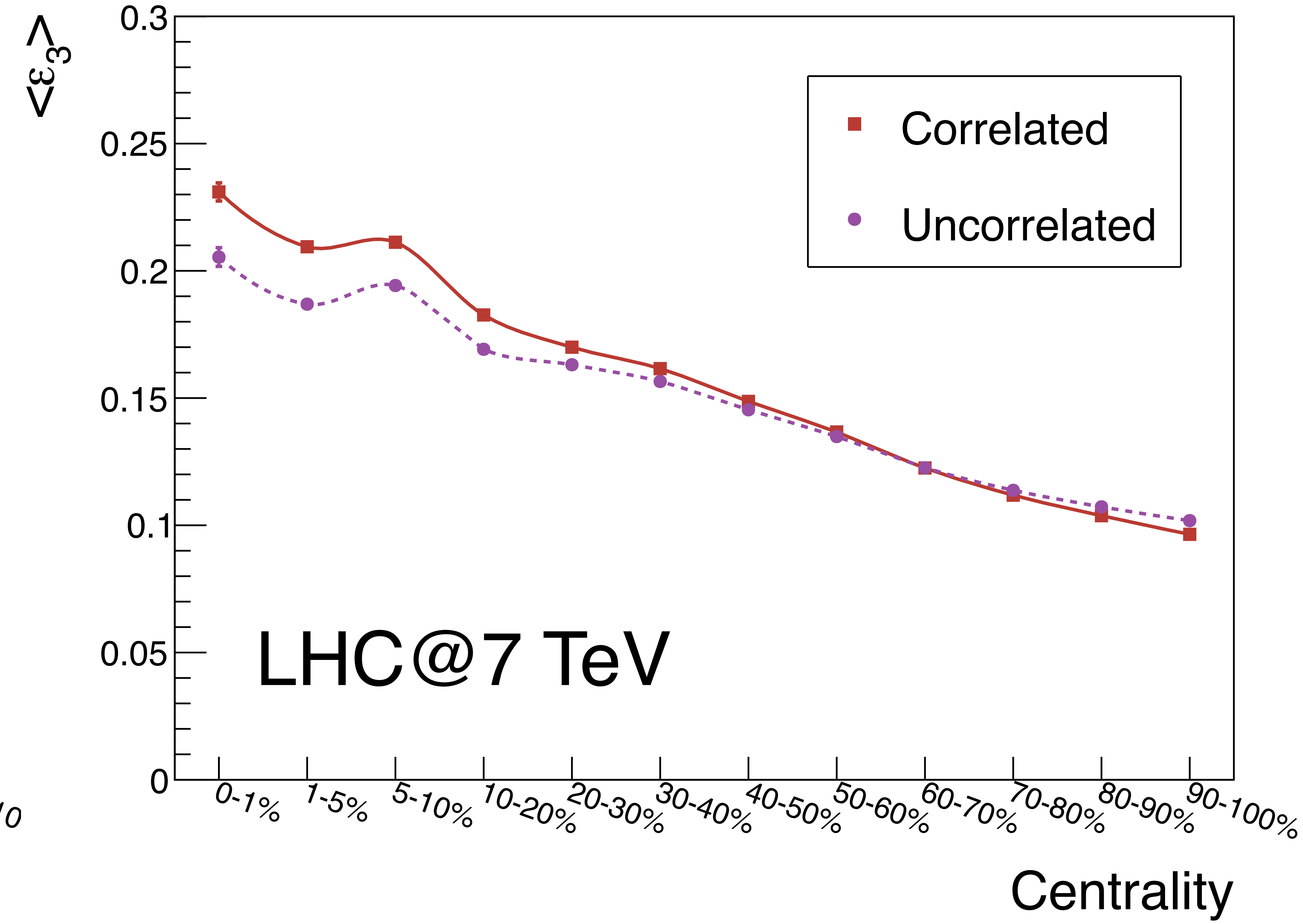


[A.Dumitru, H.Mäntysaari, G.Miller, R. Paatelainen, T. Stebel, R.Venugopalan]

Uncorrelated picture of the proton disfavoured from theory $\langle \rho(\vec{x})\rho(\vec{y})\rangle \neq T_p(\vec{b})$

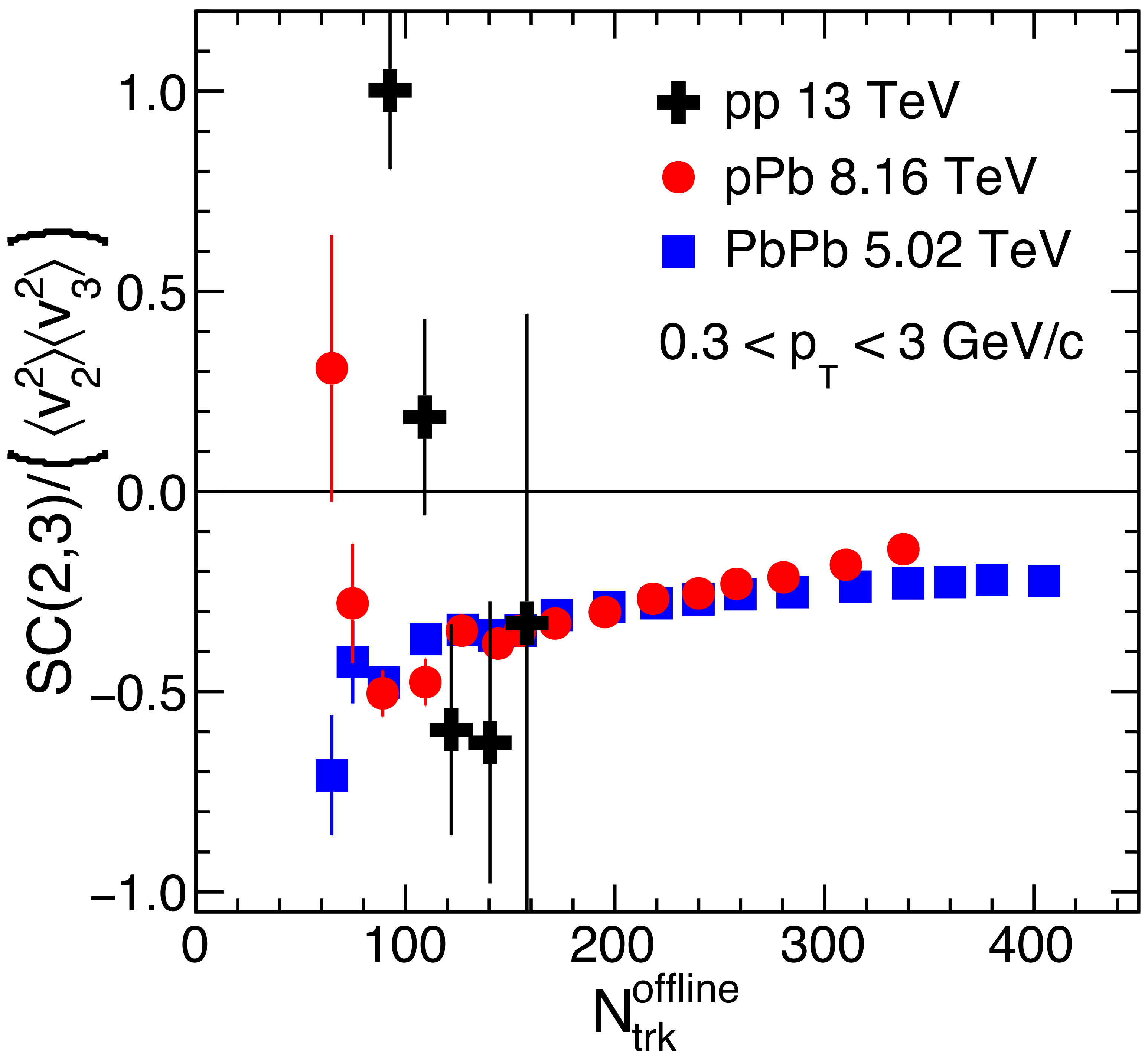
p+p: eccentricity and triangularity [JL Albacete, H.Elfner, ASO PRC'17]



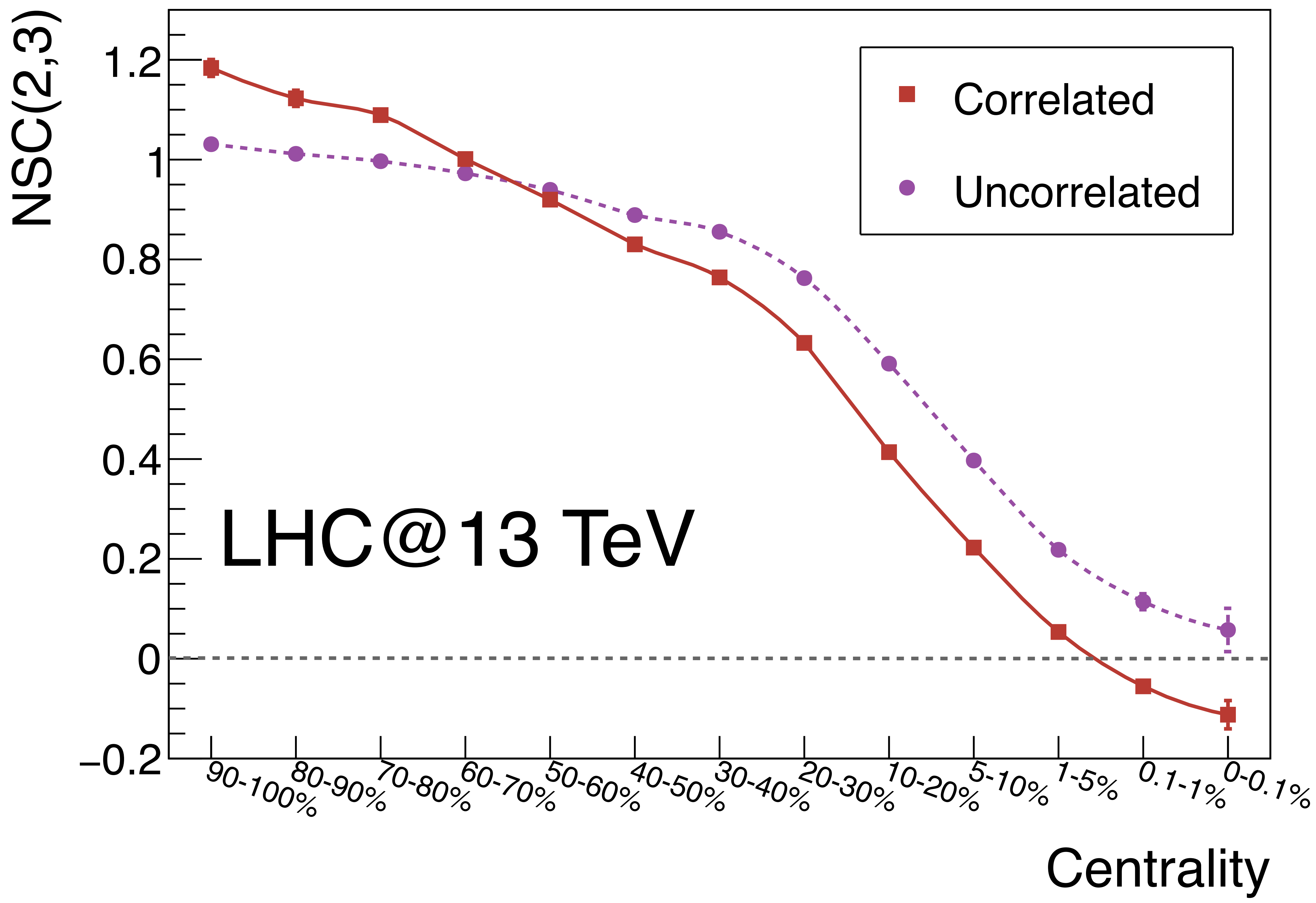


MC-Glauber implementation of the correlated initial state suggests enhancement of spatial anisotropies in ultra-central collisions

p+p: normalised symmetric cumulants [JL Albacete, H.Elfner, ASO PLB'17]

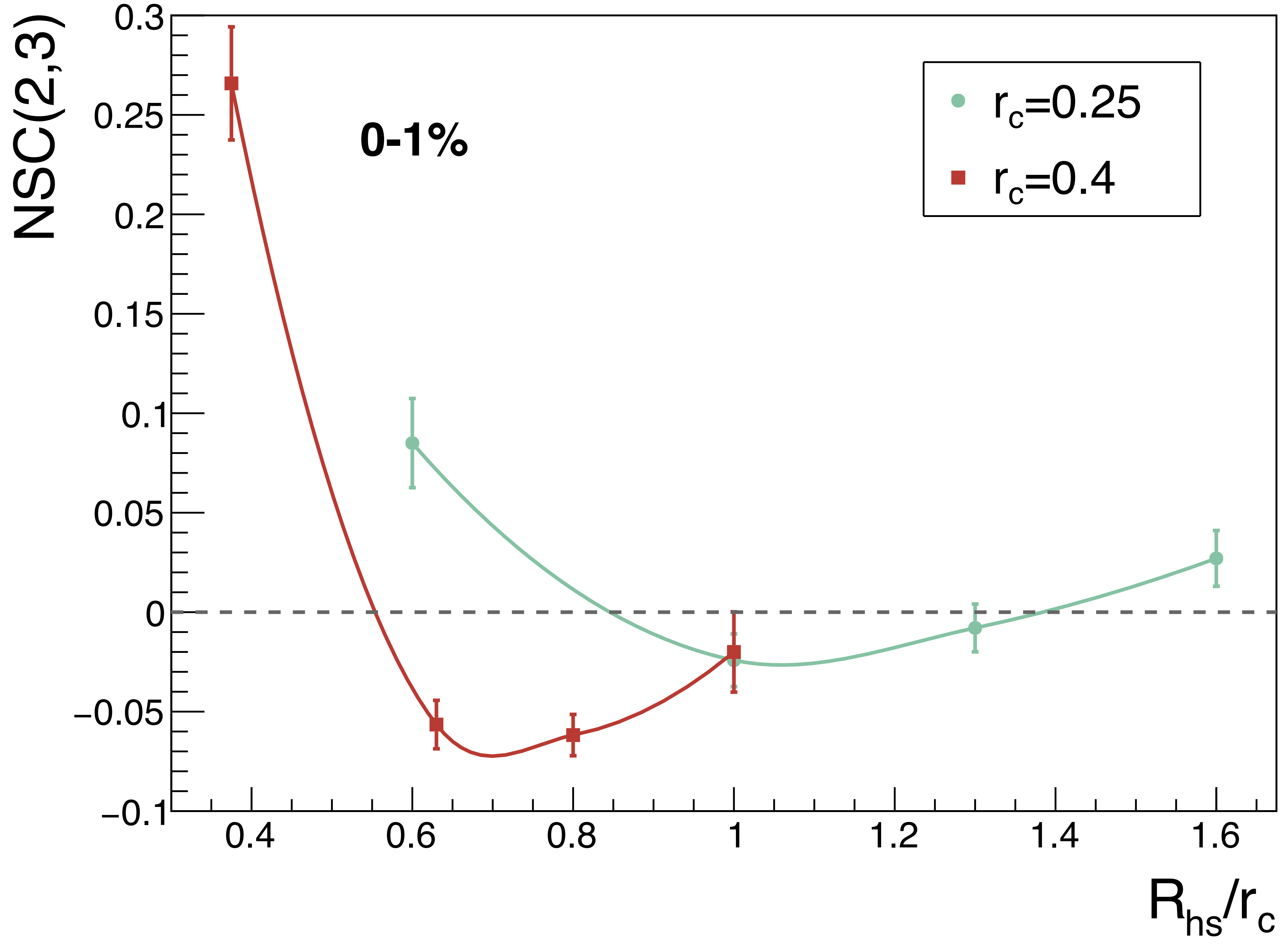


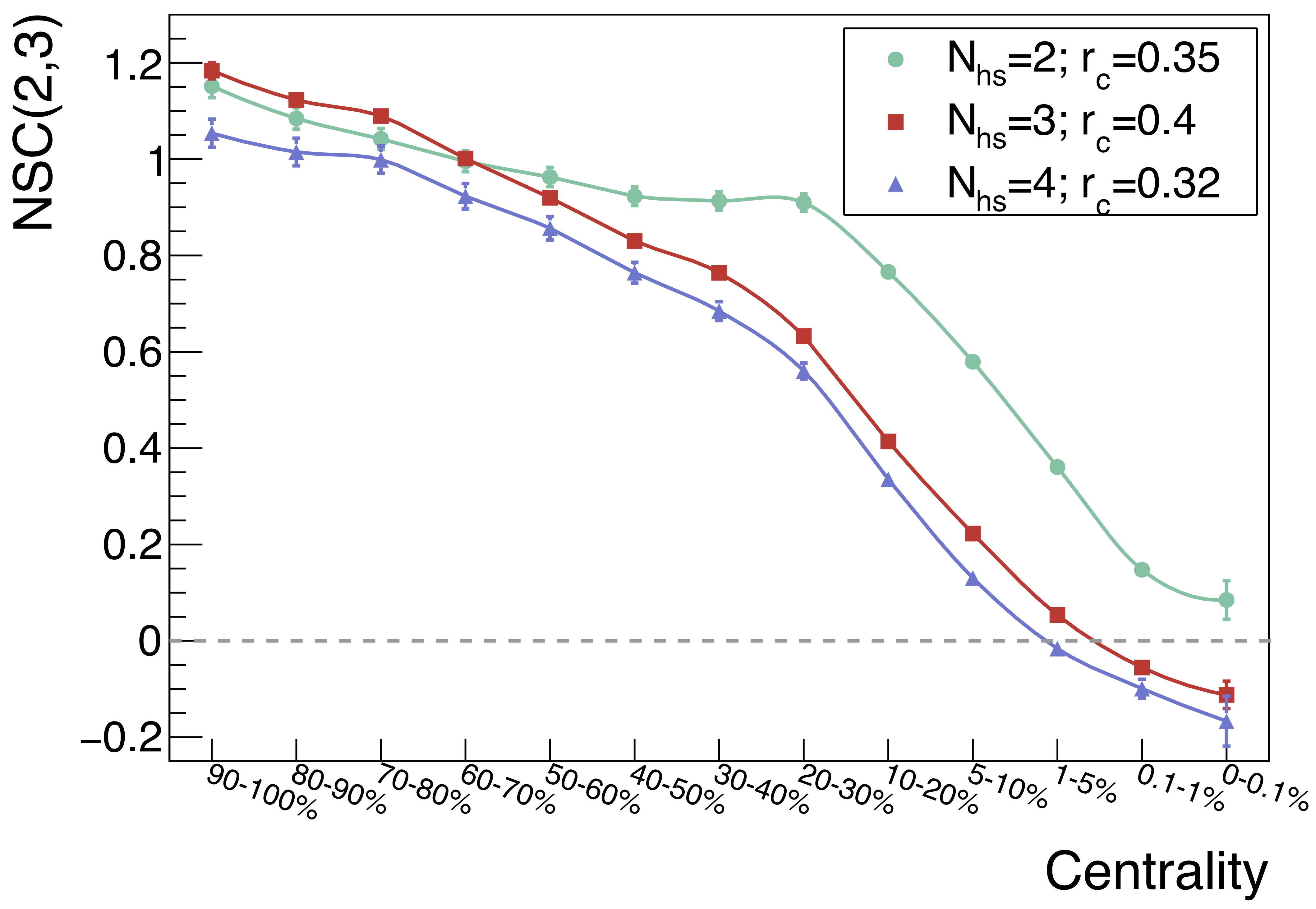
[CMS PLB'17]



The presence of spatial repulsive correlations inside the proton builds up a **negative NSC(2,3) in the highest centrality bin** at the geometric level

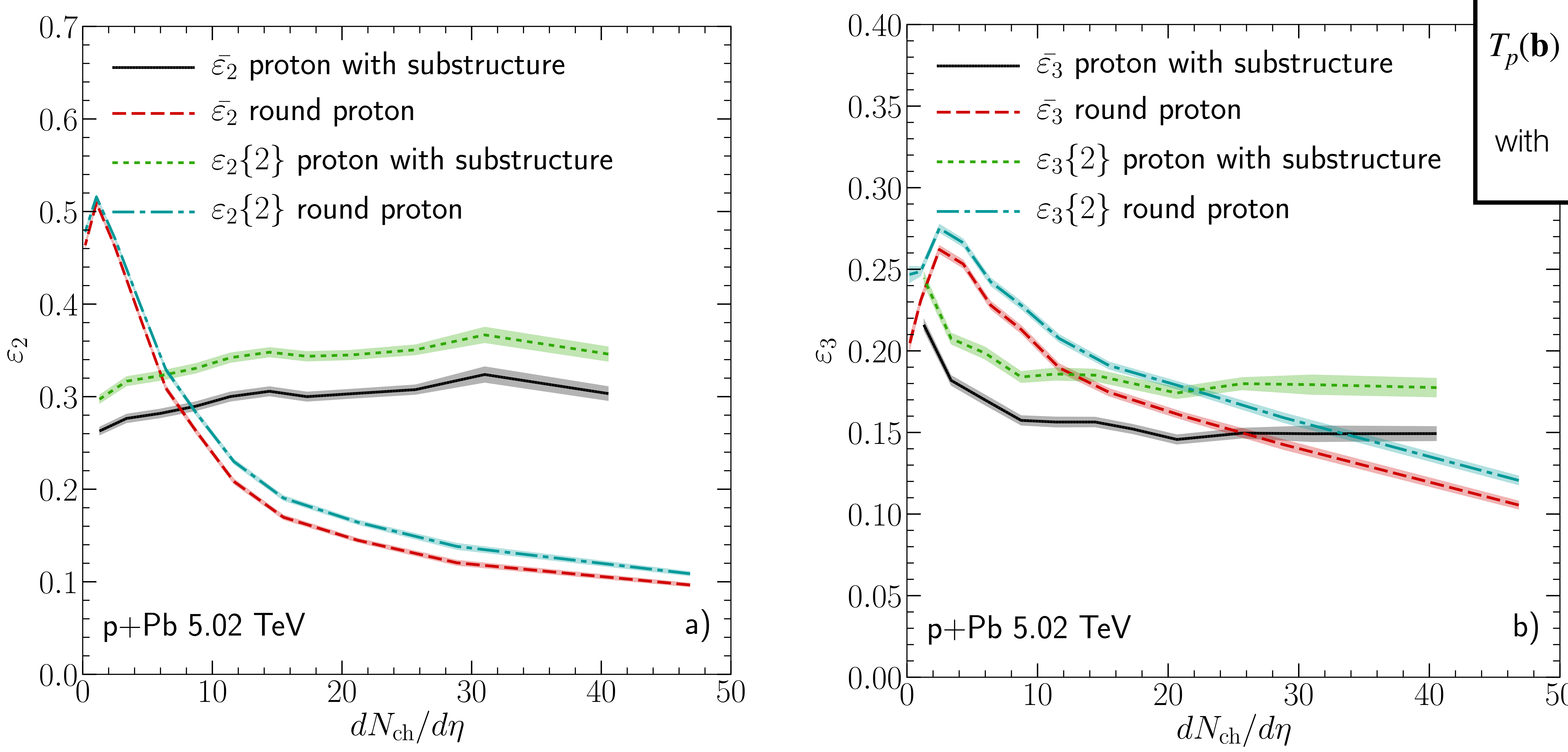
p+p: normalised symmetric cumulants





NSC(2,3) supports N_{hs}>2 too + constraint on the repulsive distance

p+Pb: eccentricity and triangularity [Private communication with B.Schenke]



$$T_p(\mathbf{b}) = \frac{1}{N_q}\sum_{i=1}^{N_q} T_q(\mathbf{b}-\mathbf{b}_i)$$

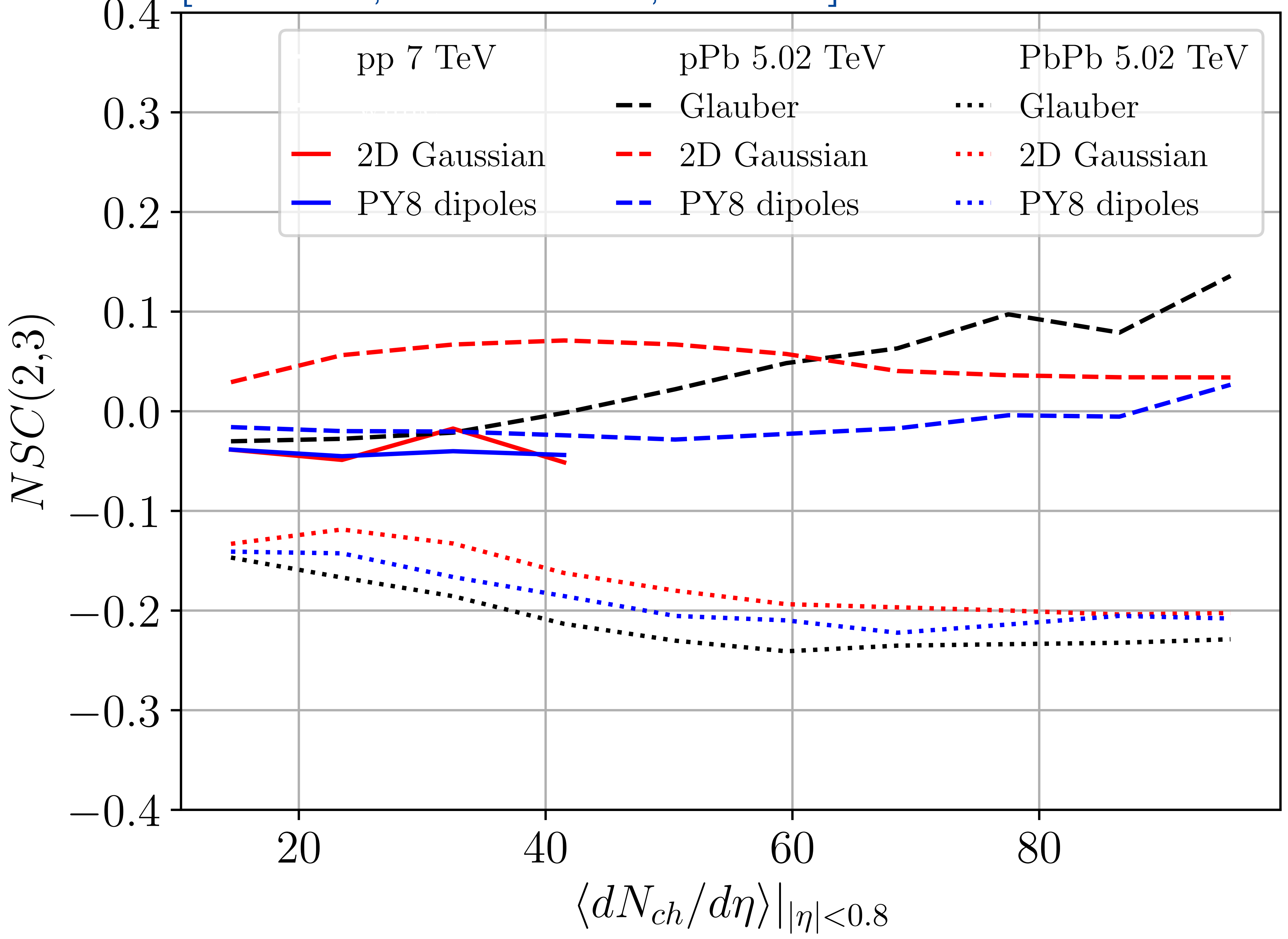
with $T_q(\mathbf{b}) = \frac{1}{2\pi B_q} e^{-b^2/(2B_q)}$

Like in p+p: subnucleonic d.o.f enhance spatial anisotropies

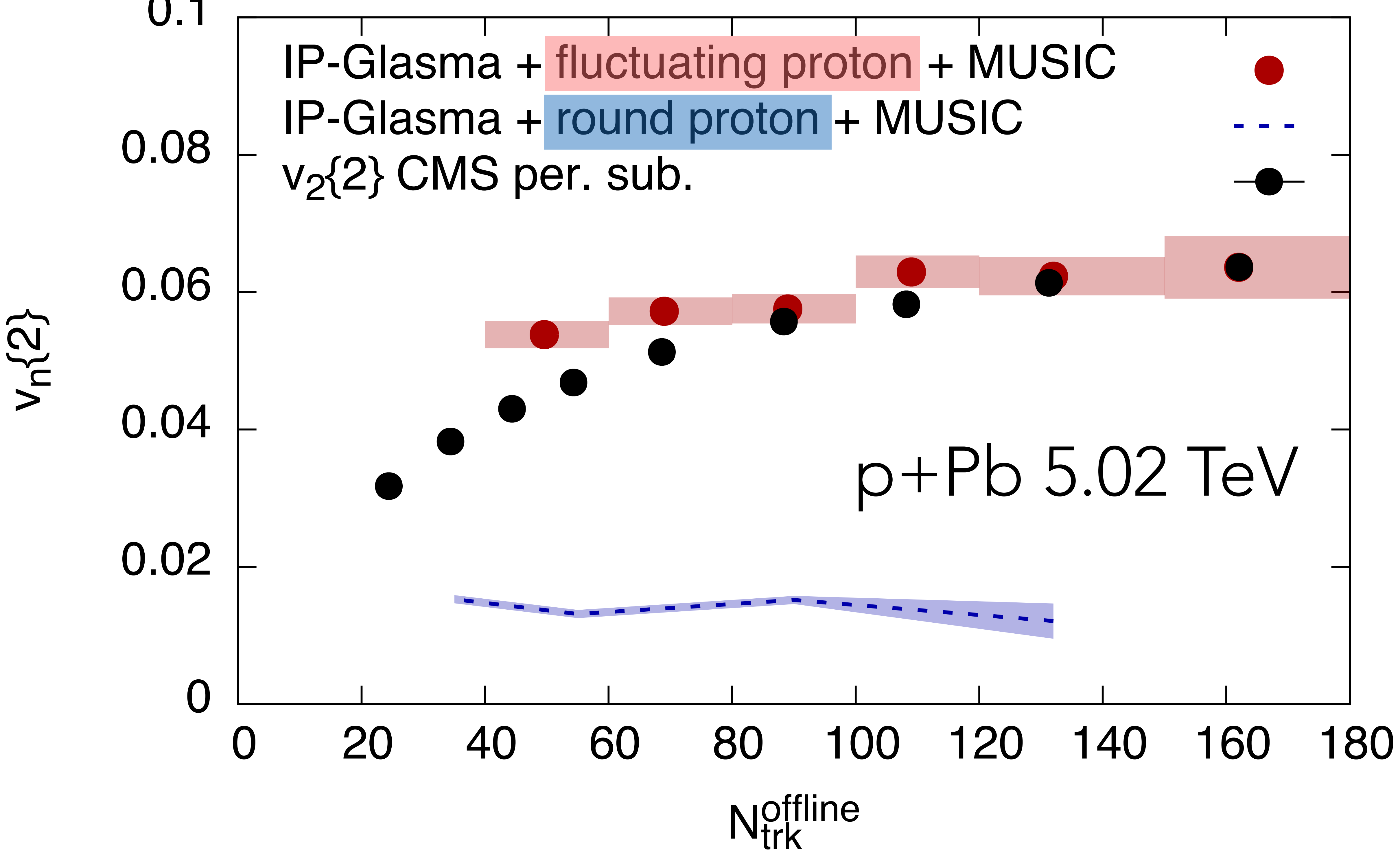
p+Pb: symmetric cumulants and elliptic flow

[For RHIC results see: Noronha-Hostler et al. NPA'19]

[C.Bierlich, C.Rasmussen, JHEP'19]



[H.Mäntysaari, B.Schenke, C.Shen, P. Tribedy PLB'17]



Downside of p+Pb: transport coefficients of QGP might lead to same theory-to-data agreement without substructure

p+Pb: dilute-dense CGC calculation insight

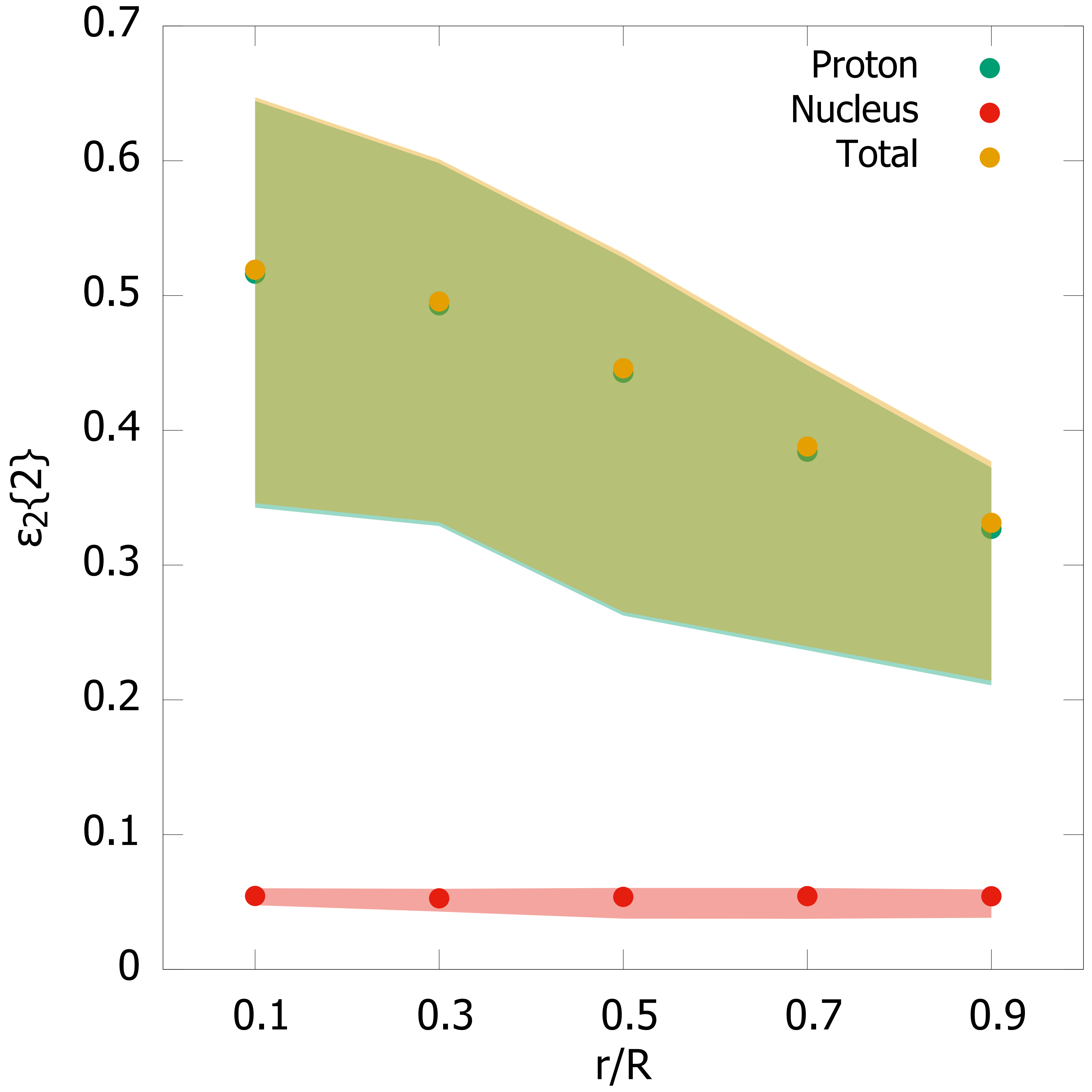
[For dense-dense results see: JL Albacete, P.Guerrero-Rodriguez, Cyrille Marquet. JHEP'18]

Energy density two-point function, $\langle \varepsilon(\mathbf{x})\varepsilon(\mathbf{y})\rangle$, at $\tau = 0^+$ in a dilute-dense limit i.e.

Dilute proton: $\langle \rho(\mathbf{x})\rho(\mathbf{y})\rangle \sim \sum_{i=1}^{N_q} \mu^2(\frac{\mathbf{x}+\mathbf{y}}{2} - \mathbf{b}_i)$ with $\mu, T_p(b)$ Gaussians

Dense nucleus: only color charges fluctuations

Geometric fluctuations of hot spots inside the proton are the dominant source of eccentricity

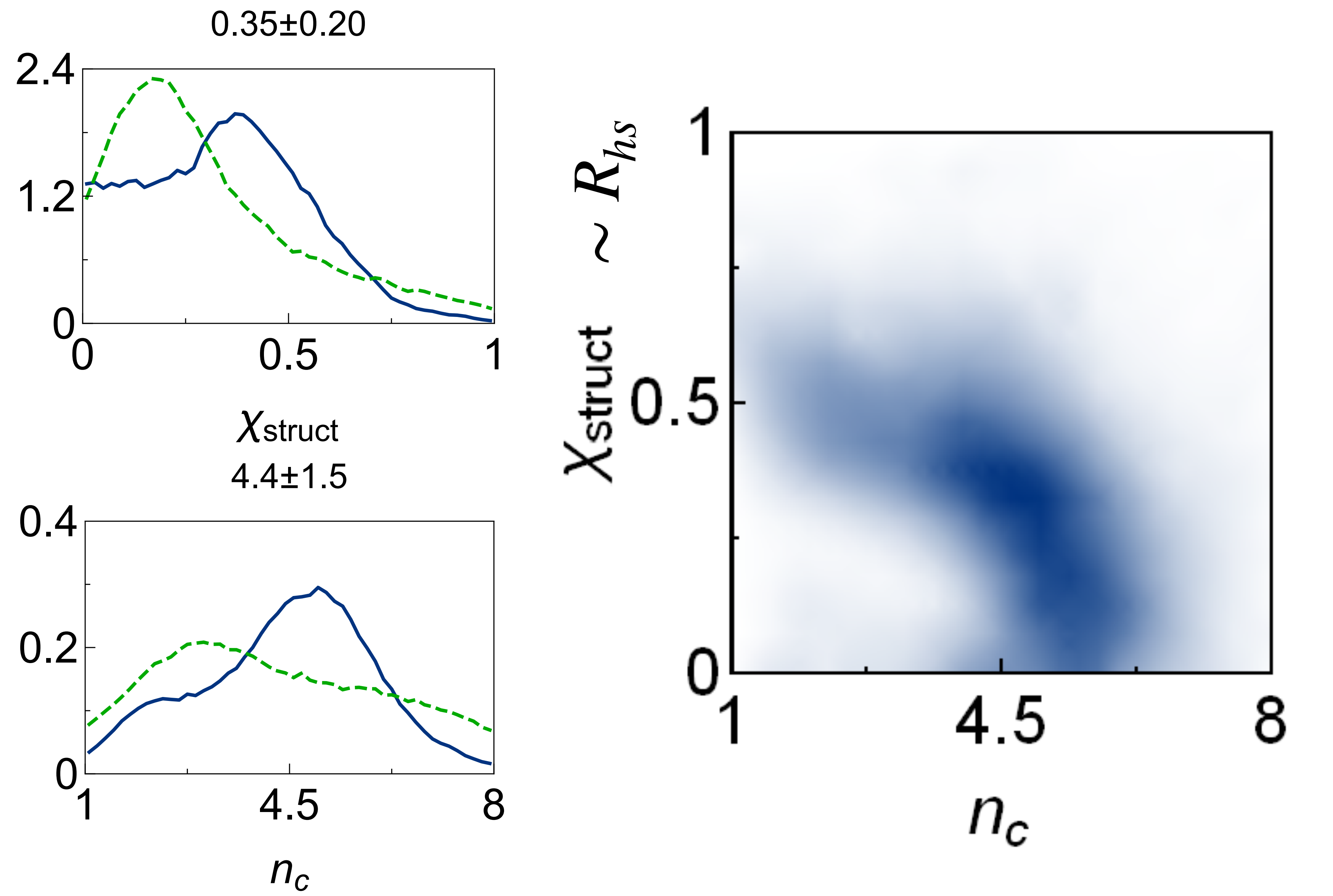


[See poster by S.Demirci]

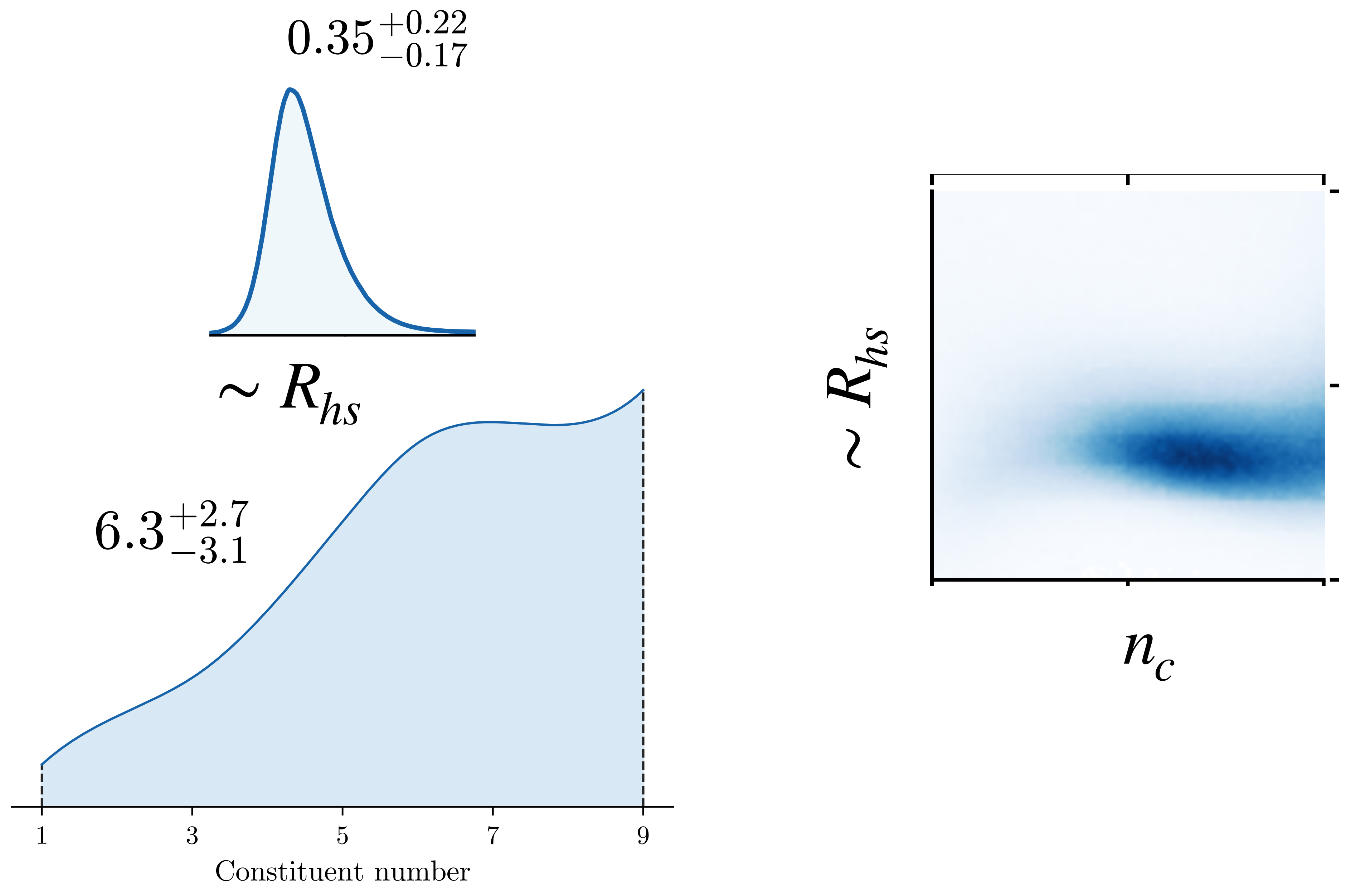
[S.Demirci, T.Lappi, S.Schlichting arXiv: 2101.03791]

p+Pb (and Pb+Pb): Bayesian analyses

[G.Nijs, W.van der Schee, U. Gürsoy, R. Snellings arXiv: 2010.15130]



[JS.Moreland, J.Bernhard, S.Bass PRC'20]

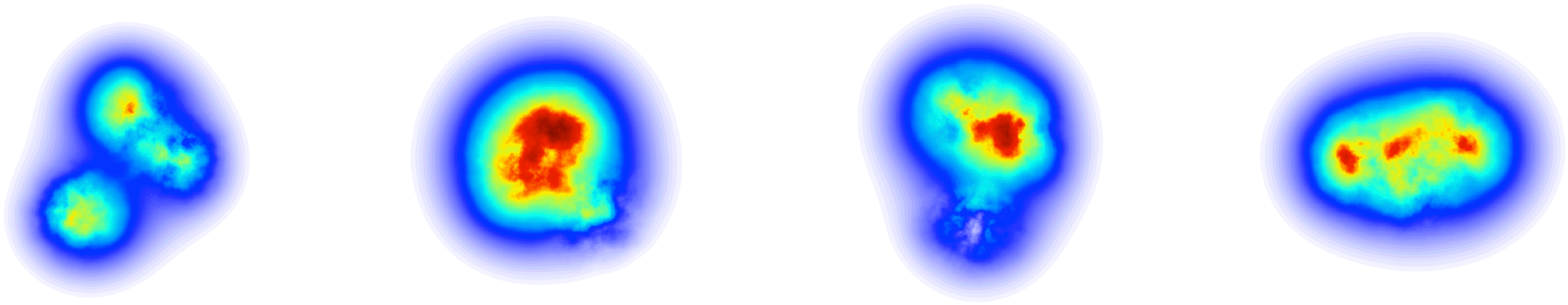


Bayesian analyses prefer 4 or more hotspots with R_{hs} ~0.35 fm

while Mäntysaari, Schenke: 3 hotspots with R_{hs} ~0.23 fm
Albacete, Elfner, ASO: 3 or more hotspots with R_{hs} ~0.3 fm

Emerging picture of the proton's transverse structure

What can we learn about the transverse geometry of the proton $T_p(\vec{r}_1, \vec{r}_2 \ldots \vec{r}_n)$



through e+p, p+p and p+A collisions?

✓ Sub-nucleonic d.o.f, a.k.a hotspots, are paramount for phenomenological success at HERA, RHIC and LHC

✓ Theoretical insight is very much needed to reduce modelling, e.g. origin of spatial correlations, energy dependence of the relevant scales

✓ What about a global fit with current data before landing into the EIC era?