EXPLORING THE EFFECT OF CORRELATED CONSTITUENTS IN P+P INTERACTIONS @LHC

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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
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

[Schenke, Venugopalan’14]

P+PB

[See talk by Schenke]

IP-Glasma + round proton + MUSIC
CMS peripheral subtr.

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

[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

Flow harmonics

**CGC**

\[ Q_s^2 = 1 \text{ GeV}^2 \]
\[ Q_s^2 = 2 \text{ GeV}^2 \]

\[ \text{P+PB} \]

**MC-GLAUBER+HYDRO**

[See talks by Rezaeian, Mace]

**Puzzle:** good description of flow harmonics in p+Pb in both paradigms.
SYMMETRIC CUMULANTS
**NEW INSIGHTS OF PARTICLE AZIMUTHAL CORRELATION WITH SC IN PP, PbPb, AND Pb1Pb**

SC(n, m) = \langle v_n^2 v_m^2 \rangle - \langle v_n^2 \rangle \langle v_m^2 \rangle

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}

**P+P**

13 TeV pp

10^-6

SC(n,m)

0.3 < p_T < 3 GeV/c

N_{trk}^{offline}

0 50 100 150

**P+PB**

5.02 TeV 8.16 TeV pPb

10^-6

SC(n,m)

0.3 < p_T < 3 GeV/c

N_{trk}^{offline}

0 100 200 300 400

**PB+PB**

5.02 TeV PbPb

10^-6

SC(n,m)

0.3 < p_T < 3 GeV/c

N_{trk}^{offline}

0 100 200 300 400

**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.**
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.
Models @market assume **UNCORRELATED** subnucleonic components.
Set up
THE MODEL

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

   \[ D(\vec{s}_1, \vec{s}_2, \vec{s}_3) \propto \prod_{i=1}^{3} e^{-s_i^2/R^2} \cdot \delta^{(2)}(\vec{s}_1 + \vec{s}_2 + \vec{s}_3) \times \prod_{i<j}^{3} \left(1 - e^{-\mu|\vec{s}_i - \vec{s}_j|^2/R^2}\right) \]

   \[ \text{E.g: } N_{hs} = 3 \]
   \[ \text{uncorrelated} \]
   \[ \text{fixes C.o.M} \]
   \[ \text{Repulsive correlations} \]

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

   \[ \mathcal{P}(s_0) \propto \mathcal{P}(N_{ch}) \]

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

[GLISSANDO], [TGlauberMC]

Set Up
The Model: Parameters

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

<table>
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<tr>
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<td>(R_{hs})</td>
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<td>(R)</td>
<td>0.69</td>
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In order to avoid swelling effects we consider 2 additional scenarios

- \(r_c=0, nc\): same as \(r_c=0.4 \text{ fm}\) but setting \(r_c = 0\).

- \(\langle s_1 \rangle\) fixed: same as \(r_c=0.4 \text{ fm}\) but choosing \(R\) such as

\[
\langle s_1 \rangle \equiv \int s_1 \, ds_1 \, ds_2 \, ds_3 \, D(s_1, s_2, s_3) = \langle s_1 \rangle \bigg|_{r_c=0.4 \text{ fm}}
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<td>0.41</td>
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SPATIAL ECCENTRICITIES
**Definition**

Quantitative measurement of the **spatial anisotropy of the geometry**

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

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

**Entropy** as an estimator of centrality. Division of events in centrality classes.
Spatial eccentricities

Centrality

[Albacete, Petersen, ASO’17]
Correlations reduce $\langle \varepsilon_2 \rangle$ in minimum bias and enlarge it in ultra-central collisions.

Spatial eccentricities

[Albacete, Petersen, ASO’17]
Spatial eccentricities

**Triangularity**

Correlations reduce $\langle \epsilon_3 \rangle$ in minimum bias and enlarge it in ultra-central collisions

$\langle \epsilon_3 \rangle$ vs Centrality

- $r_c=0$
- $r_c=0, nc$
- $r_c=0.4$
- $<s_1>$ fixed

[Albacete, Petersen, ASO’17]
SYMMETRIC CUMULANTS
**NSC(2,3)**

![Graph showing NSC(2,3) vs Centrality]

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

New insights of particle azimuthal correlation with SC in pp, Pb, and PbPb collisions as a function of multiplicity.

[Albacete, Petersen, ASO’17]
**NSC(2,3)**

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

\[ r_c=0 \]
\[ <s_T> \text{ fixed} \]
\[ r_c=0.4 \]

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

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**Symmetric cumulants**
Same qualitative behavior as NSC(2,3) but **NSC(2,4) always positive.**

**NSC(2,4)**

[Albacete, Petersen, ASO’17]
**Interpretation**

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

![Diagram](image)

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.

![Diagram](image)

Symmetric cumulants
Symmetric cumulants

**INTERPRETATION**

**CONFIGURATIONS WITH LARGE $N_w$ AND SMALL $N_{\text{coll}}$ 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]

**NSC(2,3)**

$R_{hs} = \{0.15, 0.25, 0.32, 0.4 \}$ fm

$r_c = 0.25$

$r_c = 0.4$

$0-1\%$
**SENSITIVITY TO NUMBER OF HOT SPOTS**

- Constraints to the parameters when varying $N_{hs}$:
  - Reproduce $\sigma_{tot}$ while keeping the radius of the proton fixed

![Graph showing sensitivity to number of hot spots](image)

- $N_{hs} > 2$ to have $\text{NSC}(2,3) < 0$.
- $N_{hs} = 4$: $\text{NSC}(2,3)$ 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\}

Symmetric cumulants
Wrapping up
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?