GLUONIC HOT SPOTS AND SPATIAL CORRELATIONS INSIDE THE PROTON

Javier L. Albacete, Hannah Petersen, **Alba Soto-Ontoso**

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Universidad de Granada · MARIE CURIE ACTIONS · FIAS Frankfurt Institute for Advanced Studies · GOETHE UNIVERSITÄT FRANKFURT AM MAIN · HGS-HIRe for FAIR Helmholtz Graduate School for Hadron and Ion Research

What?

➡A novel **initial state geometry for proton-proton interactions** based on:

★Proton formed by 3 gluonic hot spots with R_{hs}

★Spatial distribution of the hot spots in transverse space

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

Repulsive correlations ← $\times \prod_{i<j}$; fixes C.o.M → $\delta^{(2)}(\vec{s}_1+\vec{s}_2+\vec{s}_3)$

★Transverse diffusion of R_{hs} with increasing $\sqrt{s}$

➡Motivated by its successful realization of the **hollowness effect @LHC7**.

➡Analysis of the effect of non-trivial correlations among subnucleonic d.o.f on **initial state properties**:

★# wounded hot spots

Wounded hot spot == suffered at least one collision

★Spatial distributions

★Energy dependence

$\sqrt{s}=52.6, 7000, 13000$ GeV (ISR, LHC)

★Eccentricities

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

within a Monte-Carlo Glauber approach. [1,2]

Why?

➡Suggestive signals of **collective behavior in high-multiplicity *pp* collisions** @LHC7 and @LHC13:

★ Non-zero elliptic/triangular flow

★Long range azimuthal correlations=the ridge

➡Intense theoretical interest on the **initial geometry of pp.** [3,4,5]

➡Models @market assume totally independent subnucleonic components.

HOWEVER

➡New and intriguing feature of hadronic interaction: **hollowness effect** [6]

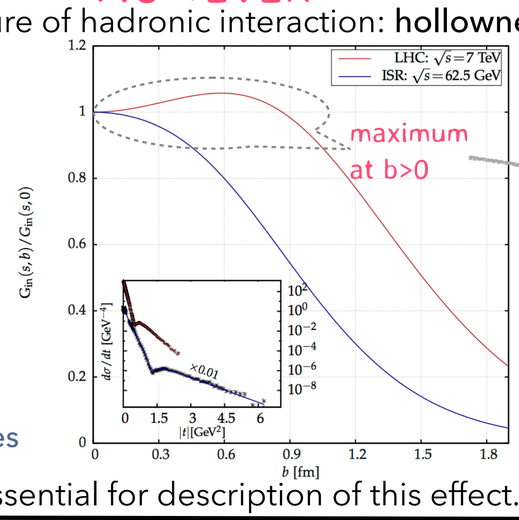
Procedure:

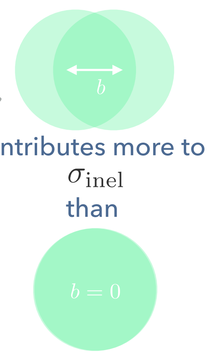
1) Fit data on [7,8] $d\sigma_{\rm el}/dt \propto |T_{\rm el}|^2$

2) Fourier Transform $T_{\rm el}(s,t) \to \widetilde{T}_{\rm el}(s,b)$

3) Extract $G_{\rm in}(s,b) \propto \widetilde{T}_{\rm el}(s,b)$

@ISR and LHC energies



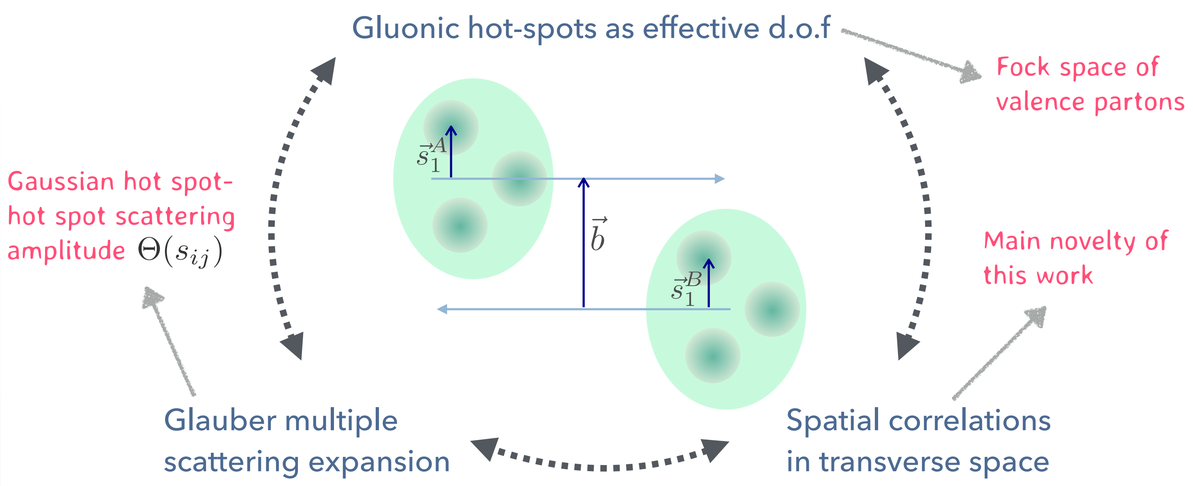


contributes more to $\sigma_{\rm inel}$ than

➡Correlations are essential for description of this effect. [9]

How?

➡To construct the **elastic scattering amplitude** in *pp* collisions



➡Model completely determined by **4 parameters** related to dynamics

★R_{hs}: radius of the gluonic hot spot. ★μ: repulsive correlations.

★R_p: radius of the proton. ★ρ_{hs}: relative contribution of Re and Im parts to $\Theta(s_{ij})$

➡Monte-Carlo implementation needed to access **event-by-event fluctuations**

★Transverse positions of the hot spots ★Entropy deposition ∝ particle production

➡ Regarding the correlations 3 different cases considered:

★r_c=0: uncorrelated + $\{R_{hs}, R_p, \rho_{hs}\}$ to reproduce $\sigma_{\rm tot}$ and ρ

★r_c=0.4: correlated + $\{R_{hs}, R_p, \rho_{hs}\}$ to reproduce $\sigma_{\rm tot}$ and ρ

★r_c=0,nc: correlated + $\{R_{hs}, R_p, \rho_{hs}\}$ do not reproduce $\sigma_{\rm tot}$ and ρ

Net effect of correlations

Results

SPATIAL CORRELATIONS AMONG SUBNUCLEONIC D.O.F REDUCE ECCENTRICITY IN PP INTERACTIONS

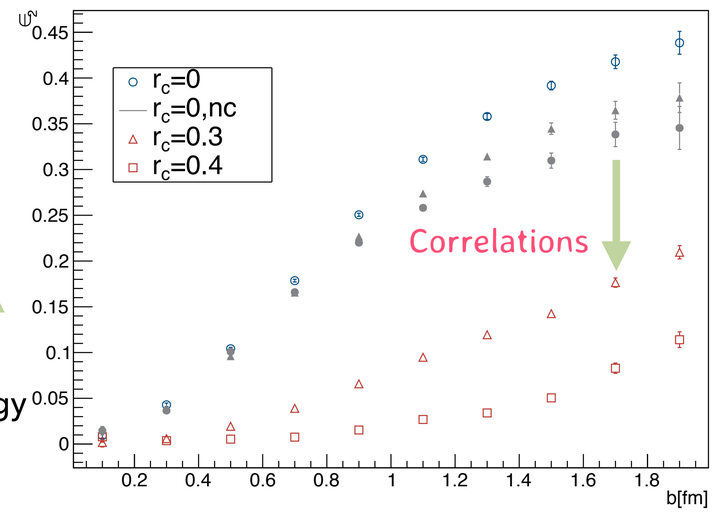
➡In agreement with *AA* studies. [10]

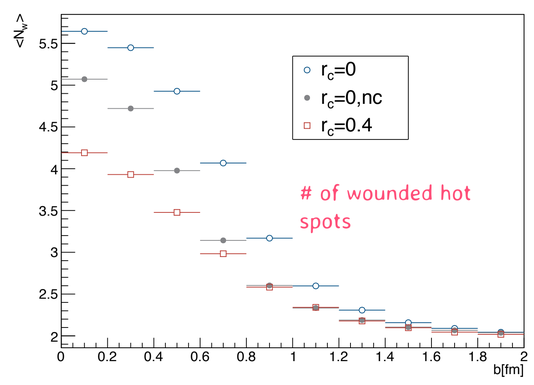
➡Very sensitive to the value of r_c

r_c, 20% ↓↓

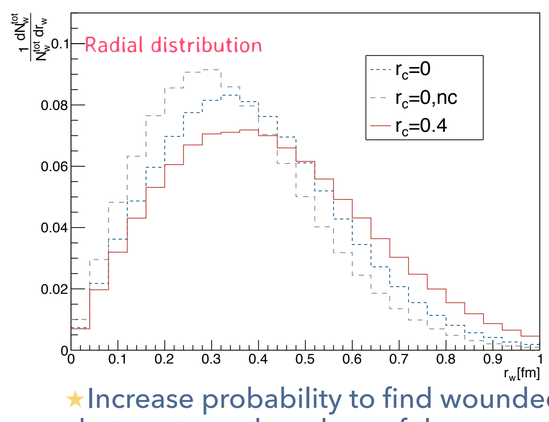
eccentricity, 40% ↑↑

➡In contrast, **mild energy dependence.** [11]





★No qualitative change but quantitative reduction in central collisions with r_c=0.4

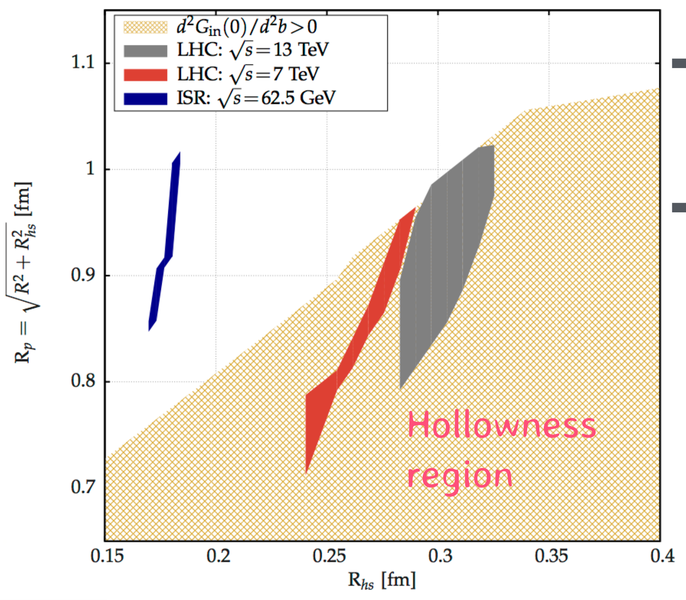


★Increase probability to find wounded hot spots on the edges of the interaction region with r_c=0.4

➡Values of $\{R_{hs}, R, \mu, \rho_{hs}\}$? Scan the parameter space imposing:

★$d^2G_{\rm in}(0)/d^2b > 0\big|_{\rm LHC}$ Definition of hollowness

★Reproduce $\sigma_{\rm tot}$ and ρ Phenomenological constraints

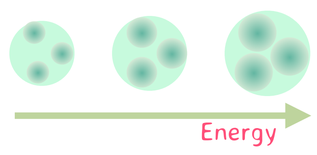


➡In the absence of non-trivial correlations, no hollowness effect.

➡**Transverse diffusion** of as the main dynamical mechanism for:

★Onset hollowness effect

★Growth of $\sigma_{\rm tot}$ with $\sqrt{s}$



References

[1] C. Loizides, **Phys. Rev. C94, 024914** (2016).
[2] P. Bozek et Al., **Phys. Rev. C94, 014902** (2016).
[3] H. Mantysaari and B. Schenke, **Phys. Rev. Lett. 117, 052301** (2016).
[4] K. Welsh et Al., **Phys. Rev. C94, 024919** (2016).
[5] S. Schlichting and B. Schenke, **Phys. Lett. B739, 313** (2014).
[6] I. M. Dremin, (2016), **arXiv:1610.07937 [hep-ph]** .
[7] U. Amaldi and K. R. Schubert, **Nucl. Phys. B166, 301** (1980).
[8] G. Antchev et al. (TOTEM), **Europhys. Lett. 95, 41001** (2011).
[9] E. Ruiz Arriola and W. Broniowski, **Few Body Syst. 57, 485** (2016).
[10] G. S. Denicol et Al. (2014), **arXiv:1406.7792 [nucl-th]** .
[11] H. Petersen, **Phys. Rev. C84, 034912** (2011)

Acknowledgments

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