Double Parton Scattering with PYTHIA

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10.11.22

MARIE CURIE ACTIONS

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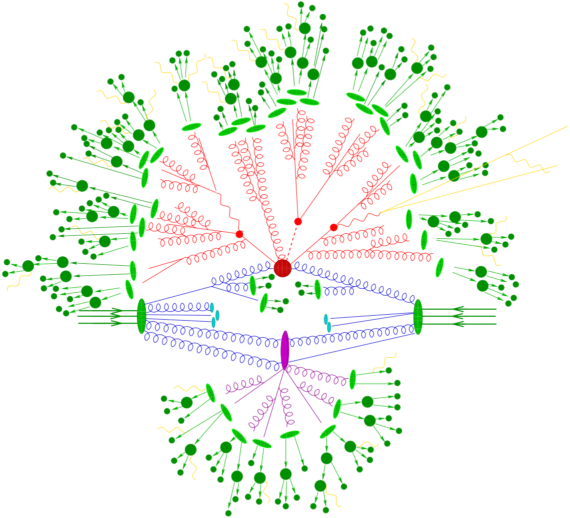
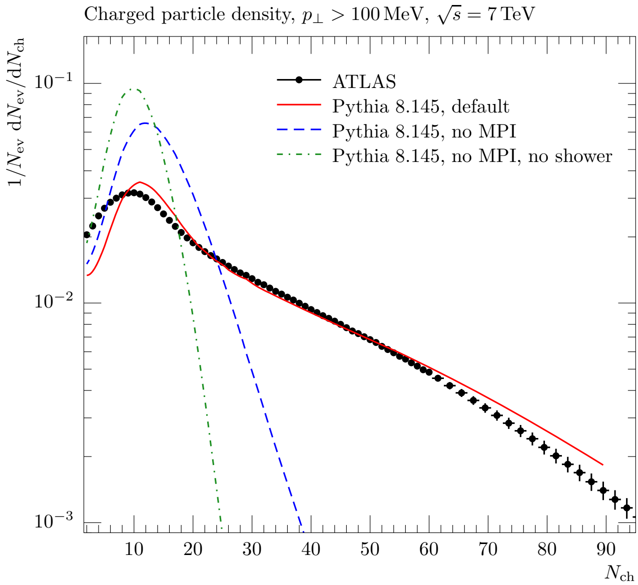
Introduction

MPIs what's that?



Schematic representation of the event shape, 1411.4085

Why MPI exist?



Charged multiplicity distribution, from 1101.2599

Why MPI exist?

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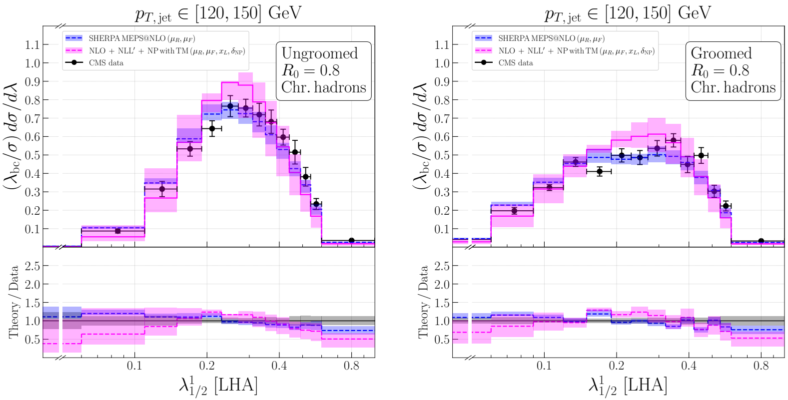
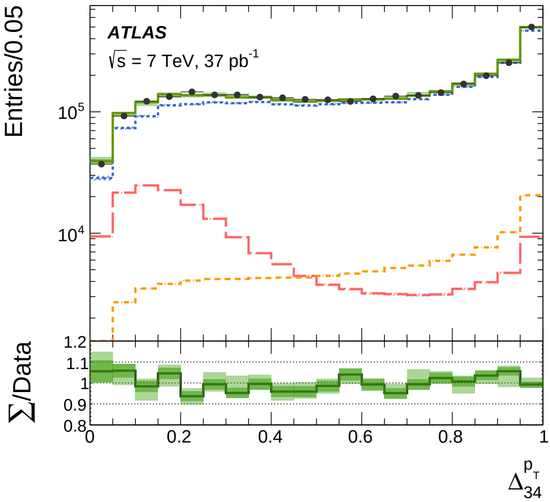


Comparison of theoretic predictions (MC and resummation) against recent CMS data for the Jet Thrust angularity, $p_{T,\text{jet}} \in [120, 150]$ GeV

Data: 2109.03340; Theory: 2104.06920

Why MPI exist?



ATLAS measurements of di-jet momentum imbalance, 1608.01857

Introduction: what is DPS?

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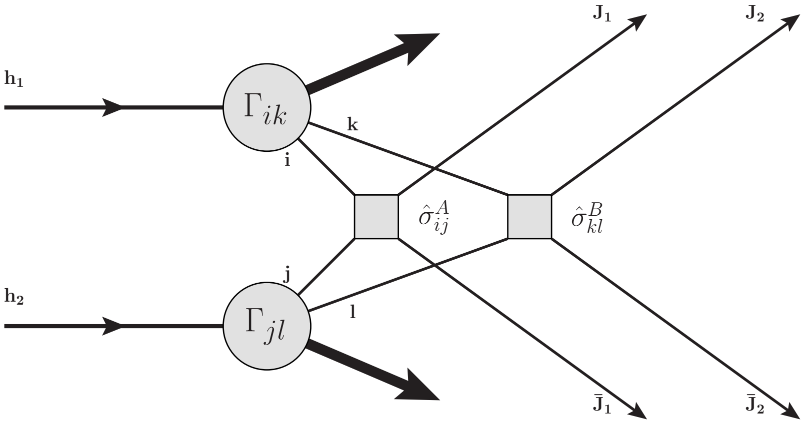
What is double parton scattering?

By *double parton scattering* (DPS) we mean a particular case of the MPI process when two hard interactions occur per one hadron-hadron collision.



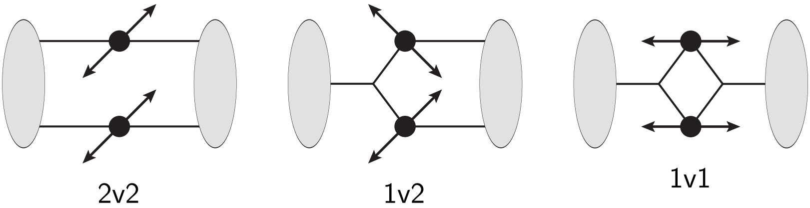
General formalism

Assuming that hard processes factorize one can write

$$\sigma_{AB} = \sum_{i,j,k,l} \int \prod_{a=1}^{4} dx_a \, d^2\mathbf{b} \, \hat{\sigma}_{ij\to A} \, \hat{\sigma}_{kl\to B} \, \Gamma_{ik}(x_1, x_2, \mathbf{b}, Q_A, Q_B) \, \Gamma_{jl}(x_3, x_4, \mathbf{b}, Q_A, Q_B)$$

where functions $\Gamma_{ik}(x_1, x_2, \mathbf{b}, Q_A, Q_B)$ are called *generalized parton distribution functions* (gPDFs) and give a probability to find two partons, separated by transverse distance **b**, in a hadron (in case of *bare* gPDFs).

Several different contributions are possible



Some simplifying assumptions

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Assumption 1

Assuming $\Gamma_{ik}(x_1, x_2, \mathbf{b}, Q_A, Q_B) \simeq D_p^{ik}(x_1, x_2, Q_A, Q_B) F(\mathbf{b})$ one can write

$$\sigma_{AB} = \frac{1}{(1+\delta_{AB})\sigma_{eff}} \sum_{i,j,k,l} \int \prod_{a=1}^{4} dx_a \, D_p^{ik}(x_1, x_2, Q_A, Q_B) \, D_p^{jl}(x_3, x_4, Q_A, Q_B) \, \hat{\sigma}_{ij\to A} \hat{\sigma}_{kl\to B}$$

Assumption 2

Assuming $D_p^{ij}(x_1, x_2, Q_A, Q_B) \approx f_i(x_1, Q_A) f_j(x_2, Q_B)$ one can write

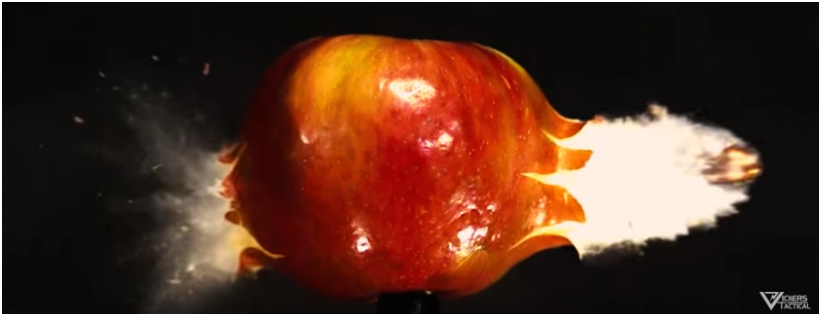
$$\sigma_{AB} = \frac{1}{1+\delta_{AB}} \frac{\sigma_A \sigma_B}{\sigma_{eff}}$$

where we defined

$$\frac{1}{\sigma_{eff}} \equiv \int d^2\mathbf{b} \, [F(\mathbf{b})]^2$$

Note that now we can estimate the value of σ_{eff} (yielding ~ 30 mb).

The difference between pp and pA collisions



YouTube/Vickers Tactical

We expect that number of DPS events in pA collisions will grow!

The difference between pp and pA collisions

Unlike pp case several different DPS contributions are possible

"It is worthwhile to notice that by using targets with multiple nuclear composition, one can unambiguously separate the two production mechanisms [DPS and SPS] experimentally."

Goebel *et. al.* 1980.

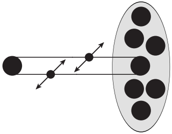
DPS I DPS II

Left panel: DPS occur between a proton and a single nucleon.
Right panel: DPS occur between a proton and two different nucleons.

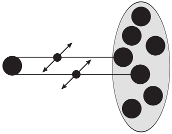
The difference between pp and pA collisions

Unlike pp case several different DPS contributions are possible

- Several authors have predicted the enhancement of the fraction of the DPS events in pA collisions in comparison with pp case (Treleani and Strikman 2001, d'Enterria and Snigirev 2012, Block, Strikman and Wiedemann 2013)



$$\sigma_{AB} \sim A \int \Gamma_p(x_1, x_2, \mathbf{b})\, \Gamma_p(x_3, x_4, \mathbf{b})$$



$$\sigma_{AB} \sim \frac{A-1}{A} \int D_p(x_1, x_2)\, f_p(x_3)\, f_p(x_4)\, \mathrm{T}_A^2(\mathbf{s})$$

Enhancement of the DPS fraction in pA collisions in comparison with pp case

The DPS fraction in pA collisions

$$\sigma_{pA}^{DPS} = \sigma_{pp}^{DPS}\left(A + \sigma_{eff}^{pp} F_{pA}\right) \qquad F_{pA} = \frac{A-1}{A}\int d^2 s\, \mathrm{T}_A^2(\mathbf{s}),$$

$$\mathrm{T}_A(\mathbf{s}) = \int dz\, \rho_A(z, \mathbf{s})$$

It is convenient to study the enhancement factor

$$\sigma_{pA}^{DPS}/A\sigma_{pp}^{DPS} = 1 + C_1(A-1)^{C_2} + C_3(A-1)^{C_4} + \ldots$$

which one can evaluate for certain parametrization of nuclear matter density $\rho_A(z, \mathbf{s})$

Enhancement of the DPS fraction in pA collisions in comparison with pp case

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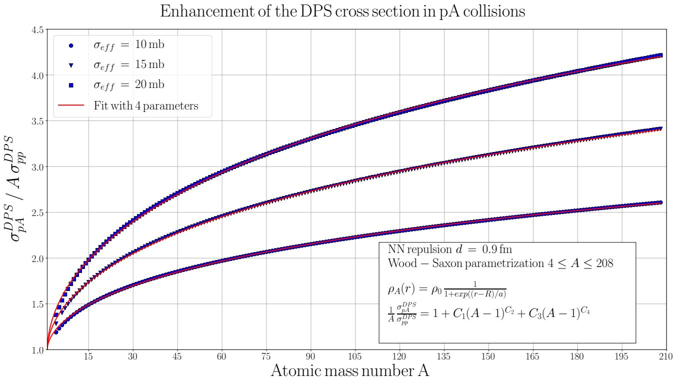


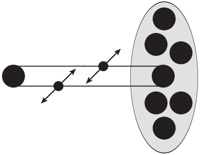
Enhancement of the $\sigma_{\rm pA}^{\rm DPS}$ with respect to $\sigma_{\rm pp}^{\rm DPS}$ normalized according to the atomic mass number A. Wood-Saxon (Fermi) form of the nuclear matter distribution.

Pythia and Angantyr model

“He [Angantyr] was the tallest of the twelve sons of the berserker Arngrim, and he and his eleven brothers spread fear and destruction through the North...”, Wikipedia, picture by Hugo Hamilton.

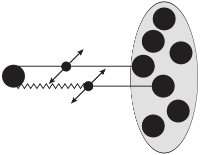
Pythia and Angantyr model

Does Pythia predict enhancement of DPS cross section in pA collisions?



Type I

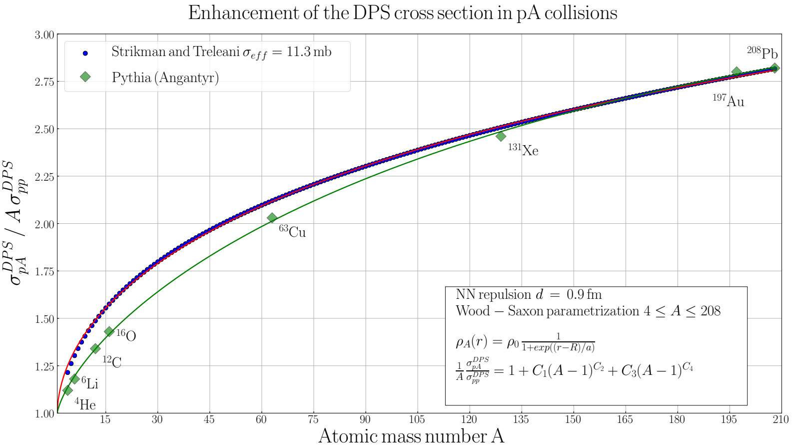
- Second hard interaction is due to the MPI machinery
- No trigger on it (one has to be patient)



Type II

- Second hard interaction is due to a "Pomeron exchange"
- No trigger on it (one has to be patient)

DPS in pA collisions. Pythia (Angantyr)



The DPS enhancement factor $\sigma_{\mathrm{pA}}^{\mathrm{DPS}}/\mathrm{A}\,\sigma_{\mathrm{pp}}^{\mathrm{DPS}}$. Comparison between theoretical predictions of Strikman and Treleani and Pythia (Angantyr) simulations.

OF and L.Lönnblad, 1912.08733

DPS in pA collisions. Impact of radiation

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- Previous results were obtained without PS-effects: partons were used as jet proxies.
- However, PS-effects reduce the value of the enhancement. For example, for pPb collisions we get:

$$\sigma_{\rm pA}^{\rm DPS}/{\rm A}\,\sigma_{\rm pp}^{\rm DPS}\Big|_{parton} \sim 3 \qquad\qquad \sigma_{\rm pA}^{\rm DPS}/{\rm A}\,\sigma_{\rm pp}^{\rm DPS}\Big|_{PS} \sim 1.4$$

- Similar dependence on radiation effects was observed in 2008.08347 (radiation effects spoil the DPS-sensitive jet configurations)
- Some kind of merging is needed ?

First pA measurements by LHCb were done!

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Observation of Enhanced Double Parton Scattering in Proton-Lead Collisions at $\sqrt{s_{NN}} = 8.16$ TeV

"A study of prompt charm-hadron pair production in proton-lead collisions at $\sqrt{s_{NN}} = 8.16$ TeV is performed using data corresponding to an integrated luminosity of about 30 nb-1, collected with the LHCb experiment. Production cross sections for different pairs of charm hadrons are measured and kinematic correlations between the two charm hadrons are investigated. This is the first measurement of associated production of two charm hadrons in proton-lead collisions. The results confirm the predicted enhancement of double parton scattering production in proton-lead collisions compared to the single parton scattering production."

PhysRevLett.125.212001

First pA measurements by LHCb were done!

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Observation of Enhanced Double Parton Scattering in Proton-Lead Collisions at $\sqrt{s_{NN}} = 8.16$ TeV

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DPS in pA collisions. Pythia (Angantyr)

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Some (very!) preliminary results

Final state	$\sigma_{\rm pA}^{\rm DPS}/{\rm A}\,\sigma_{\rm pp}^{\rm DPS}$
$D_0\, D_0,\ p_T \geq 2$ GeV	1.57
$D^+\, D^+,\ p_T \geq 2$ GeV	1.40
$D_0\, D_S,\ p_T \geq 2$ GeV	1.43
$D^+\, D_S,\ p_T \geq 2$ GeV	1.73

PYTHIA: predictions for enhancement factor for DPS in pPb collisions at $\sqrt{S_{NN}} = 5.02$ TeV (10^6 PYTHIA calls).

Note that LHCb measurements for $D_0\, D_0$ are giving 1.3 ± 0.2 (though for somewhat different setup)

Summary

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Angantyr:

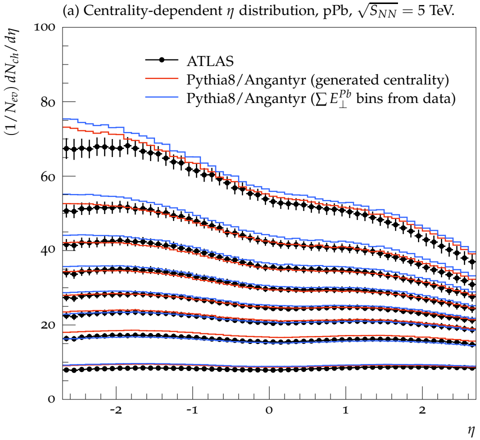
- shows correct behaviour of the DPS enhancement factor $\sigma_{\mathrm{pA}}^{\mathrm{DPS}}/\mathrm{A}\,\sigma_{\mathrm{pp}}^{\mathrm{DPS}}$ for four-jet DPS production.
- for current setup (4-jet with $p_T \geq 20$ GeV) PS-effects reduce the enhancement. For example, for pPb collisions $\sigma_{\mathrm{pA}}^{\mathrm{DPS}}/\mathrm{A}\,\sigma_{\mathrm{pp}}^{\mathrm{DPS}} \sim 1.4$ (instead of ~ 3). Similar dependence on radiation effects was observed in 2008.08347
- What about DPS production of charmed mesons, say double J/ψ production? More detailed study is needed!

Thank you for your attention!

This work has received funding from the Research Training Group "GRK 2149: Strong and Weak Interactions – from Hadrons to Dark Matter", from the European Union's Horizon 2020 research and innovation programme as part of the Marie Skłodowska-Curie Innovative Training Network MCnetITN3 (grant agreement no. 722104) and partially by the curiosity-driven grant "Using jets to challenge the Standard Model of particle physics" from Università di Genova.

Backup slides

DPS in pA collisions. Pythia (Angantyr)



Comparison between the average charged multiplicity as a function of pseudo rapidity in percentile bins of centrality for pPb collisions at $\sqrt{s_{NN}} = 5$ TeV, Bierlich *et. al* 18

DPS in pA collisions. Pythia (Angantyr)

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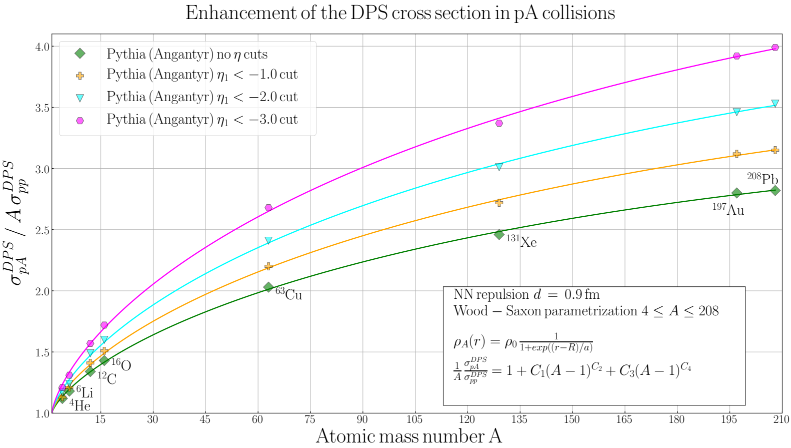

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