DPS and its relevance for LHC phenomenology

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Introduction

A particular case of *multiple parton interactions* so-called *Double Parton Scattering* (DPS), a process when two partons from each proton participate in two hard collisions. These processes:

- constitute an important background to *Single Parton Scattering* (SPS),
- acquire enhancement in specific regions of phase space (like *back-to-back* di-jets),
- probe correlations between partons.

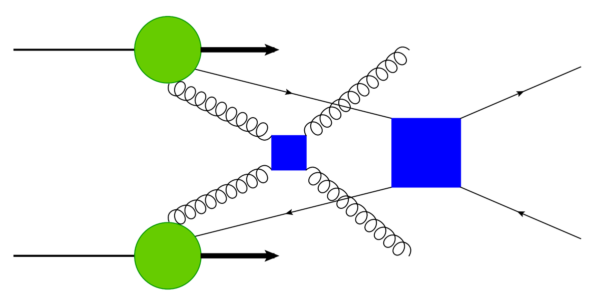


Figure 1 : Schematic sketch of proton (green) collision that leads to two hard (blue) interactions.

DPS sensitive variables: the case of 4-jet production

In the *back-to-back* dijet kinematics (when transversal momenta of dijets compensate each other) the contribution of SPS is suppressed with respect to contribution of DPS [3].

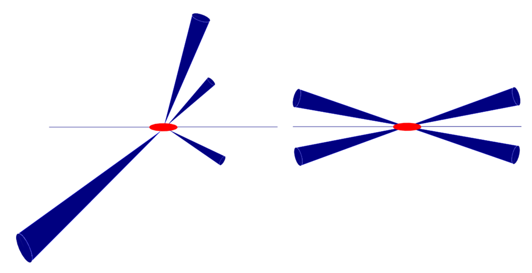
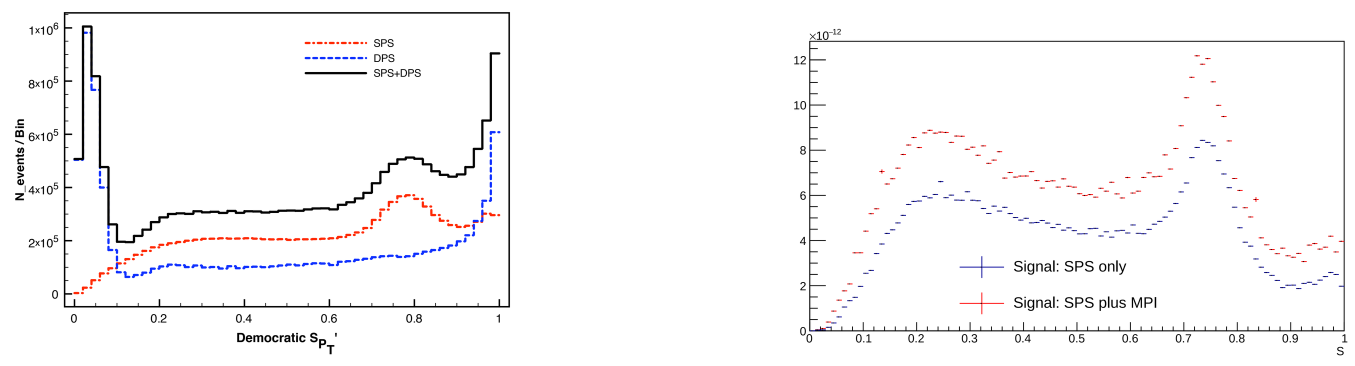


Figure 2 : Four jet production in SPS (left side) and DPS (right side).

Using this fact one can search for DPS events by defining transverse momenta imbalance variables, *e.g.*

$$S'_{pT} = \frac{1}{\sqrt{2}}\sqrt{\left(\frac{|p_T(j_a, j_b)|}{|p_T(j_a, j_b)| + |p_T(j_a, j_b)|}\right)^2 + \left(\frac{|p_T(j_c, j_d)|}{|p_T(j_c, j_d)| + |p_T(j_c, j_d)|}\right)^2},$$



a) b)

Figure 3 : a) MadGraph simulations [2]. b) Pythia simulations. Comparison between DPS and SPS four-jet events (both histograms in this canvas are normalized according to a number of their entries).

Some outstanding problems

- Mismatch between theory and experiment: choosing a certain profile of transverse distribution of partons $F(\mathbf{b})$ one can evaluate the value of σ_{eff} (see the frame on dPDF); however, there is a significant mismatch between such estimates, obtained assuming no correlations between partons, and a value extracted from experimental data [5], [6].
- Double counting problem: DPS processes receive contributions from diagrams where two partons in each proton originate from a perturbative splitting of a single parton. However, it was pointed out that such processes give rise to divergent UV contributions to the cross section (which goes to infinity as transverse distance between partons becomes smaller) [14]. Different solutions to this problem were proposed in [9], [10], [11], [12], [13]. Recently, a consistent regularization scheme based on the usage of special cutoff functions $\Phi(y\nu)$ in transverse position space (which allows to treat both and DPS and SPS without divergent contributions) has been proposed [15].
- Lack of information about dPDF: the input values of dPDF (obtained by solving numerically generalized DGLAP equations) are unknown and thus have to be constructed out of standard PDF. The ambiguity in choice of initial conditions turns dPDF into model dependent functions.

My current project

Currently I am working on:

- a code to solve a system of generalized DGLAP equations and produce grids of dPDF. It will allow me to study different forms of the evolution equations and produce my own dPDF sets,
- a DPS Monte-Carlo event generator to study phenomenology of 4-jet and 3-jet $+\gamma$ production in pA collisions, in particular effect of longitudinal parton correlations and various regularization schemes.

Double parton distribution functions (dPDF)

Assuming that hard processes factorize one can write

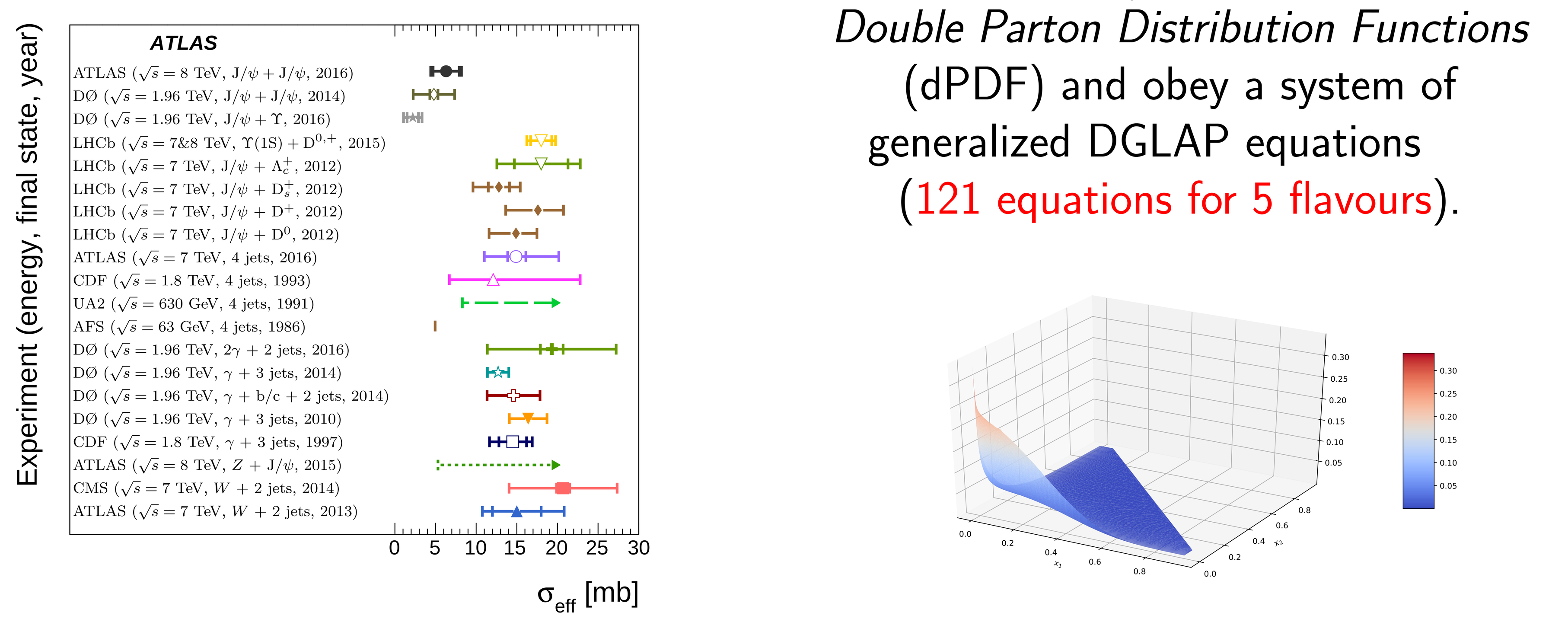
$$\sigma_{AB}(s) = \sum_{i,j,k,l}\int\prod_{a=1}^{4} dx_a\, d^2\mathbf{b}\, \hat\sigma_{ik\to A}\hat\sigma_{jl\to B}\,\Gamma_{ij}(x_1, x_2, \mathbf{b}, Q_A^2, Q_B^2)\,\Gamma_{ij}(x_1, x_2, \mathbf{b}, Q_A^2, Q_B^2),$$

where a function $\Gamma_{ij}(x_1, x_2, \mathbf{b}, Q_A^2, Q_B^2)$ gives a probability to find two partons, separated by transversal distance $\mathbf{b}$, in a hadron.

Factorizing out $\mathbf{b}$-dependence $\Gamma_{ij}(x_1, x_2, \mathbf{b}, Q_A^2, Q_B^2) \simeq D_p^{ij}(x_1, x_2, Q_A^2, Q_B^2)\,F(\mathbf{b})$ one can write

$$\sigma_{AB}(s) = \frac{1}{\sigma_{eff}}\sum_{i,j,k,l}\int\prod_{a=1}^{4} dx_a\, D_p^{ij}(x_1, x_2, Q_A^2, Q_B^2)\, D_p^{kl}(x_3, x_4, Q_A^2, Q_B^2)\,\hat\sigma_{ik\to A}\hat\sigma_{jl\to B},$$

where a quantity $1/\sigma_{eff} = \int d^2\mathbf{b}\,[F(\mathbf{b})]^2$ can be used to estimate contribution of DPS processes and functions $D_p^{ij}(x_1, x_2, Q^2)$ are called *Double Parton Distribution Functions* (dPDF) and obey a system of generalized DGLAP equations (121 equations for 5 flavours).



a) b)

Figure 4 : a) Different measurements of σ_{eff} [16]. b) Solution of *decoupled* DGLAP equations. *Quark-quark* dPDF ($u\bar d$) in x_1, x_2 plane. In order to decouple a system of DGLAP equations a *gluon-gluon* dPDF was taken from Gaunt&Stirling dPDF set (see https://gsdpdf.hepforge.org/ and [1], [8]).

Correlations in DPS

- Longitudinal correlations break the ansatz $D_p^{ij}(x_1, x_2, Q_A^2, Q_B^2) \simeq D_p^i(x_1, Q_A^2)\,D_p^j(x_2, Q_B^2)$. Such violation was predicted by several quark models in valence quark region [17].
- Correlations between x_1, x_2 and the relative transversal distance $\mathbf{b}$ were predicted for some quark models when proton wave function has higher than $\mathcal{S}$-wave terms [17]. Some lattice computations of Mellin moments of a single parton distribution $\int dx\, x^n f(x, \mathbf{b})$ show correlation between x and average value of $\mathbf{b}$ [7], [18].
- Correlations between partons in color and spin spaces [7].

DPS in Proton-Nucleus collisions

- Study of four-jet production in both pp and pA collisions allows to determine the longitudinal two-parton correlations inside the proton [4].
- The ratio between DPS and SPS cross sections can be written in terms of a nucleon number A, an effective transverse area S, a geometrical overlap function $W(A)$ and a parton correlation function $K(x_1', x_2')$ [4]:

$$R_{pA}^{4jet}(x_1, x_2, x_1', x_2') \equiv \frac{d\sigma_{4jet}^{pA}(x_1, x_2, x_1', x_2')}{d\hat t_1 d\hat t_2}\Bigg/\frac{A}{S}\frac{d\sigma_{2jet}(x_1', x_1)}{d\hat t_1}\frac{d\sigma_{2jet}(x_2', x_2)}{d\hat t_2} = 1 + S\,W(A)\,K(x_1', x_2'),$$

where $K(x_1', x_2') = D_p^{ij}(x_1, x_2, Q_A^2, Q_B^2)/D_p^i(x_1, Q_A^2)\,D_p^j(x_2, Q_B^2)$.

The correlation function $K(x_1', x_2')$ thus can be written as $K(x_1', x_2') = \left(R_{pA}^{4jet} - 1\right)\big/SW(A)$ and any deviation of it from unity would be a clear signal of longitudinal correlations inside the proton [4].

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