

# Double Parton Scattering at the LHC

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**Abstract.** In this short presentation, we will briefly discuss the status of Double Parton Scattering (DPS) at the Large Hadron Collider (LHC). Often DPS, which can be described as perturbative process, can occur when two pairs of partons interact in a same and single p-p (proton-proton) collision. Until the advent of LHC, this kind of process was not very well understood, because collisions at very high energies are necessary for a more visible double scattering contribution. We start our presentation speaking about what is the DPS phenomena. Next, we discuss the cross section calculation for the DPS process with its details. Naively, the DPS process can be calculated by the multiplication of two independent parton cross sections and dividing the result by an effective cross section. We review this possibility. And finally, we explain the concept of effective cross section and show some experimental results measured by different experiments.

## 1. Introduction

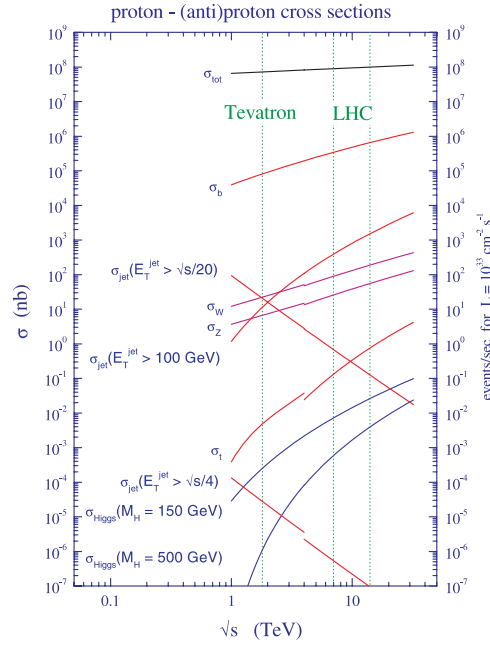
Because of asymptotic freedom, the collisions between hadrons can be calculated perturbatively in the high energy limit as a parton collision. In high energies, the partons can be studied through the perturbative QCD, while the hadrons are studied by non-perturbative QCD. This separation is due the factorization, which define parton distributions inside each hadron. It should be remembered that a perturbative process is a process where the hard scale is well defined. A example of hard process is the production of heavy objects.

Fig. 1 shows the values for the cross section for various processes. As we can see, the cross section for a p-p scattering is dominated by soft-QCD [1], which gives interactions with low momentum transfer. In comparision, the total cross section does not change very much with the increase in energy. However, the Higgs mechanism and the production of  $W$  and  $Z$  bosons are highly dependent on energy.

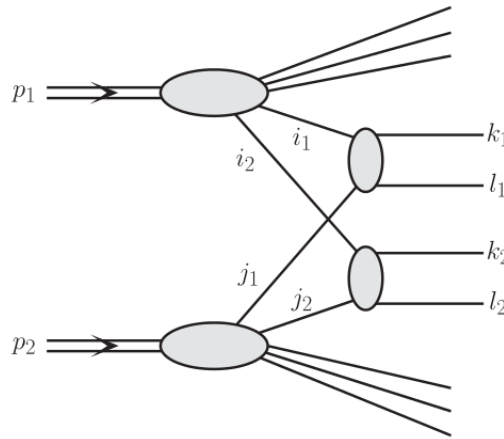
Multi Parton Interactions (MPI) occurs when more than one parton takes part in the same hadron - hadron collision. With the advent of the LHC in the last decade, this kind of physical process can be more detailed studied. A typical MPI interaction at lower scales is the double parton scattering (DPS), that occurs when two partons from two different protons interact, producing particles with large mass or transverse momentum. Fig. 2 illustrates this phenomenon, which is the simplest MPI process.

The occurrence of a DPS process in proton collisions depends strongly on the density of partons inside the colliding hadrons. With the LHC (which operates at 13 TeV) smaller momentum fractions are probed, instead other colliders. Consequently, more smaller momentum fractions leads to a increase in parton density. Therefore, a increase in parton density means that there a more probability to occur DPS.





**Figure 1.** Cross Section values for many processes. The discontinuity in some lines shows the change from  $p\bar{p}$  collisions at the Tevatron to  $pp$  collisions at the LHC. Processes driven by strong interactions have cross sections larger than processes governed by electroweak interactions. This Figure was obtained from [2].



**Figure 2.** Mechanism of Double Parton Scattering in which the partons of the first proton are labelled  $i_1$  and  $i_2$  and of the second proton  $j_1$  and  $j_2$ . The two hard scattering subprocess are  $A(i_1 j_1 \rightarrow k_1 l_1)$  and  $B(i_2 j_2 \rightarrow k_2 l_2)$ . This Figure was adapted from [3].

The aim of this study is to review the DPS process. The simplest calculation of the cross section for this process is given by the multiplication of the two SPS (Single Parton Scattering) cross sections from the two resulting hard scattering subprocess. However, is required a normalization of the result through a factor called the *effective cross section*.

## 2. Cross Section for the DPS process

To calculate the cross section for the DPS process illustrated above, it is required calculate the SPS cross section for the independent processes. The differential cross section for the SPS process are:

$$d\sigma_1^{\text{SPS}} = \sum_{i_1, j_1} \int f_{p_1}^{i_1}(x_1, \mu_1) f_{p_2}^{j_1}(x'_1, \mu_1) d\hat{\sigma}_{(i_1 j_1 \rightarrow k_1 l_1)}(x_1, x'_1, \mu_1) dx_1 dx'_1 \quad (1)$$

$$d\sigma_2^{\text{SPS}} = \sum_{i_2, j_2} \int f_{p_1}^{i_2}(x_2, \mu_2) f_{p_2}^{j_2}(x'_2, \mu_2) d\hat{\sigma}_{(i_2 j_2 \rightarrow k_2 l_2)}(x_2, x'_2, \mu_2) dx_2 dx'_2 \quad (2)$$

In the above equations,  $f(x_i, \mu_i)$  are the parton distribution functions (PDF's) and  $d\sigma$  are the perturbatively-calculable partonic cross section. The differential DPS cross section is then calculated by the equation (3):

$$d\sigma^{\text{DPS}} = \frac{m}{2} \frac{d\sigma_1^{\text{SPS}} d\sigma_2^{\text{SPS}}}{\sigma_{\text{eff}}} \quad (3)$$

The factor  $m$  that appears in (3) determine the distinctness from the final states created after the collisions. If  $m = 1$ , the final states are indistinguishable and if  $m = 2$ , the final states are distinguishable [4]. The effective cross section  $\sigma_{\text{eff}}$  makes a quantitative prediction of the transverse distribution of partons in a hadron collision [5].

### 2.1. Factorization

As a first approximation, the DPS process basically depends of the longitudinal momentum fractions and their corresponding factorization scales. However, recent studies [6] and [7], show that these are not enough to describe the p-p scattering; we need the transverse distance  $\mathbf{b}$  between the two partons, besides two longitudinal momentum fractions from the two partons  $x_1$  e  $x_2$ . Thus, we need a double parton distribution designated  $F(x_1, x_2, \mathbf{b})$ .

It can be assumed that the density of the two partons factorizes as [8]:

$$F(x_1, x_2, \mathbf{b}) = f(x_1) f(x_2) G(\mathbf{b}) \quad (4)$$

The double PDF can be decomposed into longitudinal and transverse components, which brings us two assumptions [9]:

i) the transverse component is expressed in terms of the overlap function

$$G(\mathbf{b}) = \int F_{\perp}(\mathbf{b}_1) F_{\perp}(\mathbf{b}_1 - \mathbf{b}) d^2 \mathbf{b}_1 \quad (5)$$

which represents the effective transverse overlap area of partonic interactions that produce the characteristic phenomena of the DPS process. The parton function  $F_{\perp}(\mathbf{b})$  gives us the partons density inside the colliding protons

ii) the longitudinal component can be calculated as the "diagonal" product of the two independent single-PDF.

In some cases (4) obviously is not valid, for example, when  $x_1 = 0.8$  and  $x_2 = 0.7$ , by momentum conservation. However, when  $x_i \rightarrow 0$ , this is a reasonable approximation.

### 2.2. Effective Cross Section

The effective cross section  $\sigma_{\text{eff}}$  can be written as:

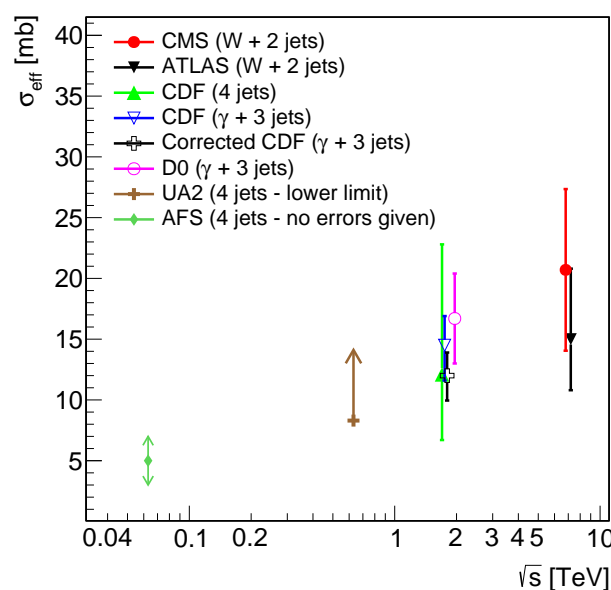
$$\frac{1}{\sigma_{\text{eff}}} = \int d^2 \mathbf{b} G^2(\mathbf{b}) = \int \frac{d^2 \mathbf{r}}{(2\pi)^2} [F(\mathbf{r})]^4 \quad (6)$$

The expression after the second equality in (6) was recently found by [10] and uses the Fourier transform  $F(\mathbf{r})$  of  $G(\mathbf{b})$ , which is dependent only on  $\mathbf{r}^2$ .

### 3. Effective Cross Sections Measurements

Fig. 3 shows the effective cross sections measured by different experiments and energies. At first sight, it looks like it is growing with the energy, but this one has to take into account the large error bars. The average effective cross section, according to the more recent experiments, is approximately 15 mb.

The effective cross section will be measured again this year 2015, when the LHC will resume its activities with an energy around 13 TeV.



**Figure 3.**  $\sigma_{\text{eff}}$  measured by different experiments using different processes [11]. The "Corrected CDF" data point indicates a  $\sigma_{\text{eff}}$  value corrected [12]. This correction was performed, taking into account a normalized overlap function  $G(\mathbf{b})$ , which leads us a  $\sigma_{\text{eff}}$  independent of the individuals SPS cross sections. This Figure was obtained from [5].

### 4. Conclusion

We have reviewed the nature of the DPS process, showing the correct form of the simplest cross section calculation. Also was shown that this calculation, requires a normalization factor, the effective cross section, which makes a quantitative prediction of the transverse distribution of partons in a hadron collision. We also conclude, according to the more recent experiments, that the average effective cross section is approximately 15 mb. So, we can affirm that the Double Parton Scattering is a promising line of research in physics with very good work perspectives for the future, that is seen in the quality and quantity of published articles in last years. Indeed, this area offers opportunities to develop and test new phenomenological models.

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