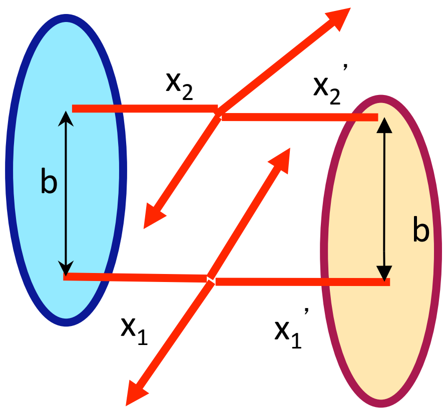
$b\bar{b}$ and $b\bar{b}b\bar{b}$ production in *pp* and *pA* collisions at the LHC

G. Calucci [a)], S. Salvini [a)] and D. Treleani [a,b)]

[a] Physics Department, University of Trieste, Italy
[b] INFN Trieste Section of INFN, Italy

Multiple Parton Interactions originate from the increasingly large flux of partons, active in hard or semi-hard interactions in high energy hadronic collisions. The **simplest case** is **Double Parton Scattering.** The incoming parton flux is maximal when **the hard component of the interaction is disconnected**. In the case of the **DPS** one thus obtains the geometrical picture here below, where the non-perturbative components are factorized into functions, which depend on two fractional momenta and on the relative transverse distance *b* between the two interaction points



When neglecting spin and color, the inclusive double parton-scattering cross-section, for two parton processes A and B in a *pp* collision, is given by

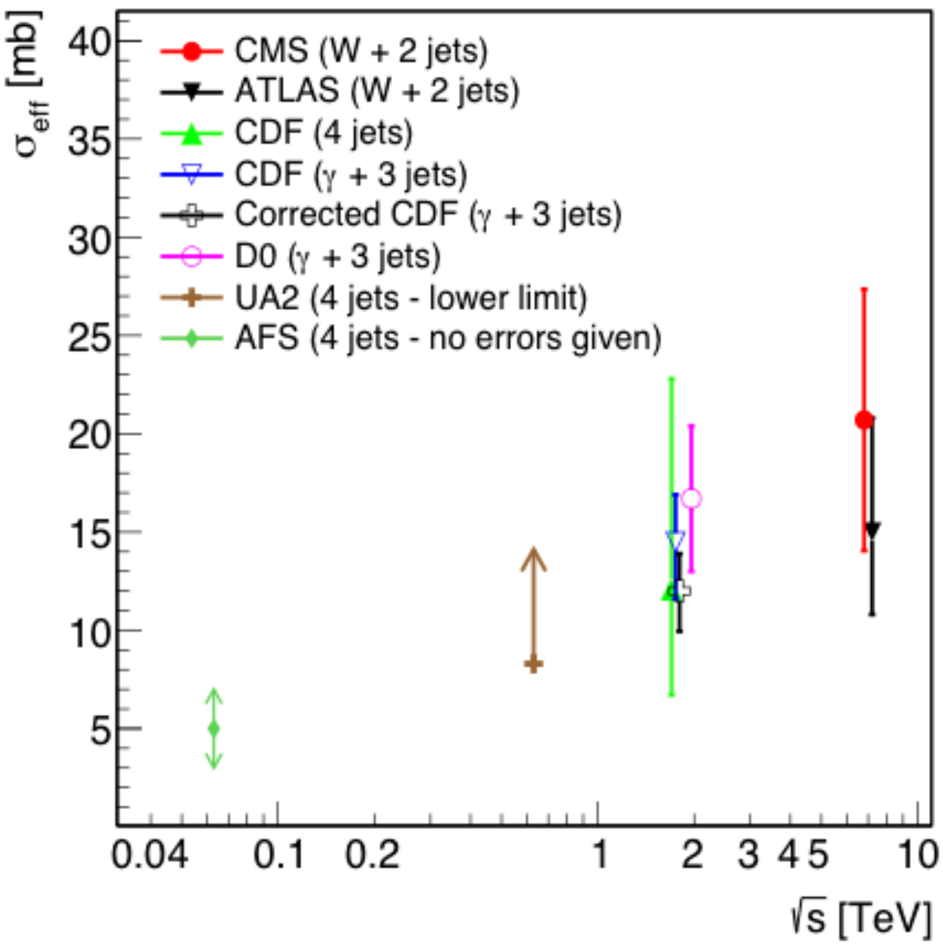
$$\sigma^D_{(A,B)} = \frac{m}{2}\sum_{i,j,k,l}\int D_{ij}(x_1,x_2;b)\hat{\sigma}^A_{ik}(x_1,x_1')\hat{\sigma}^B_{jl}(x_2,x_2')D_{kl}(x_1',x_2';b)dx_1dx_1'dx_2dx_2'd^2b$$

which leads to the "pocket formula" of the cross section utilized in the experimental analysis:

$$\sigma^{(A,B)}_{double} = \frac{m}{2}\frac{\sigma_A\sigma_B}{\sigma_{eff}}$$

DPS in *pp* collisions: comparison with experiment

The experimental analysis of the DPS cross section relies on the "pocket formula", where all unknowns are summarized in the value of a single quantity σ_{eff}, which, for the second interaction, plays "effectively" the role of the inelastic cross section.



Different results of the value of σ_{eff}, where the experimental DPS cross section is given by the "pocket formula":

$$\sigma_{double}^{(A,B)} = \frac{m}{2} \frac{\sigma_A \sigma_B}{\sigma_{eff}}$$

By estimating the DPS cross section with the "pocket formula" one obtains that, at the LHC, the inclusive production of two $b\bar{b}$ pairs is dominated by DPS.

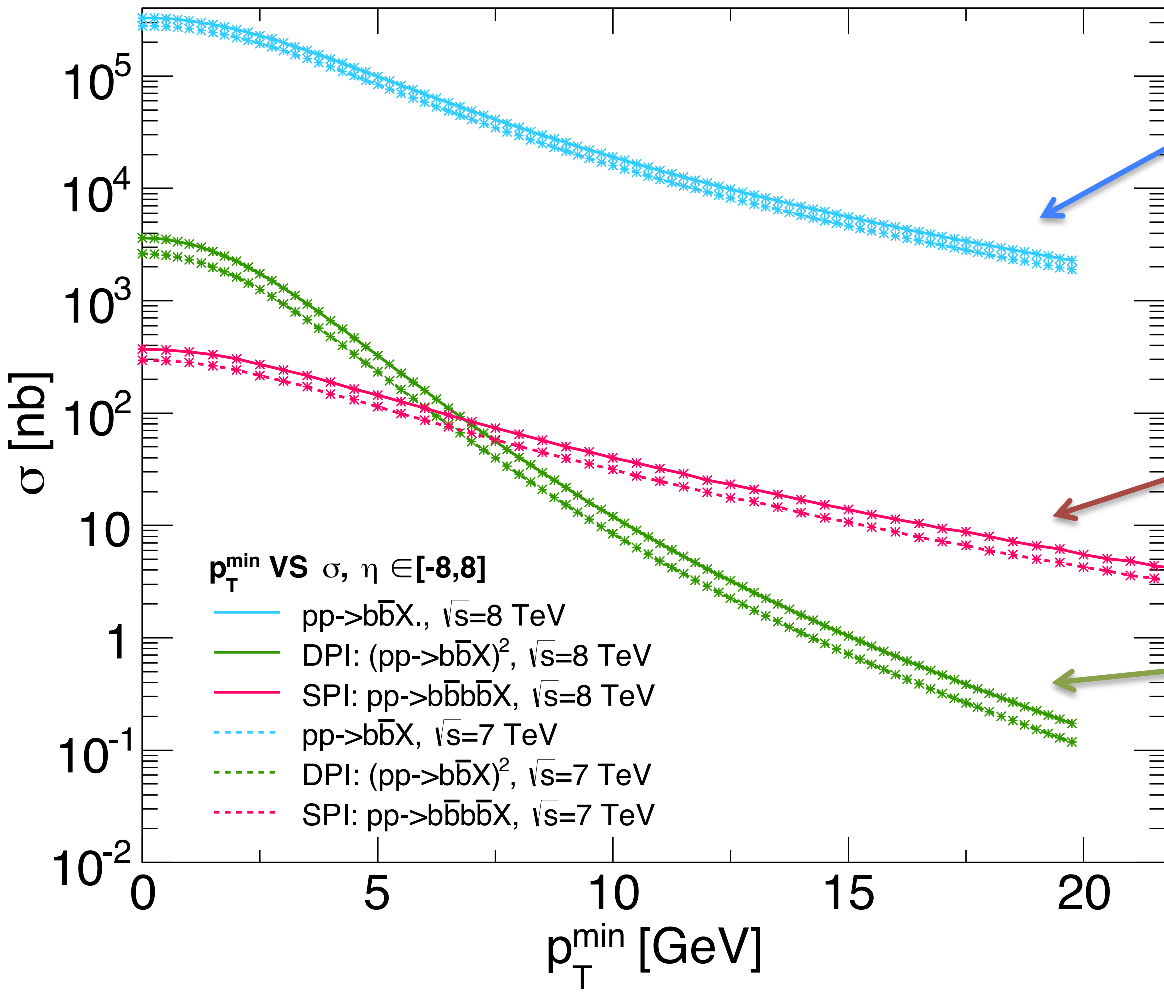
In *pp* collisions at 8 TeV c.m. energy, **the DPS contribution** to the integrated inclusive cross section is in fact expected to be **one order of magnitude larger** as compared to **the SPS contribution**.

The amount of $b\bar{b}b\bar{b}$ pairs produced in a *pp* collisions will thus exceed by a factor 10 the rate expected according with the leading QCD production mechanism.

Notice that ***b*** **quarks are produced strongly and decay weakly**. As a consequence **the integrated amount of heavy quarks**, produced in a hadronic collision, **does not depend on final state interactions**.

The integrated inclusive cross section to produce two $b\bar{b}$ pairs can thus provide a direct measurement of the DPS contribution to the cross section.

$b\bar{b}$ and $b\bar{b}b\bar{b}$ production in pp collisions at the LHC: Integrated cross sections

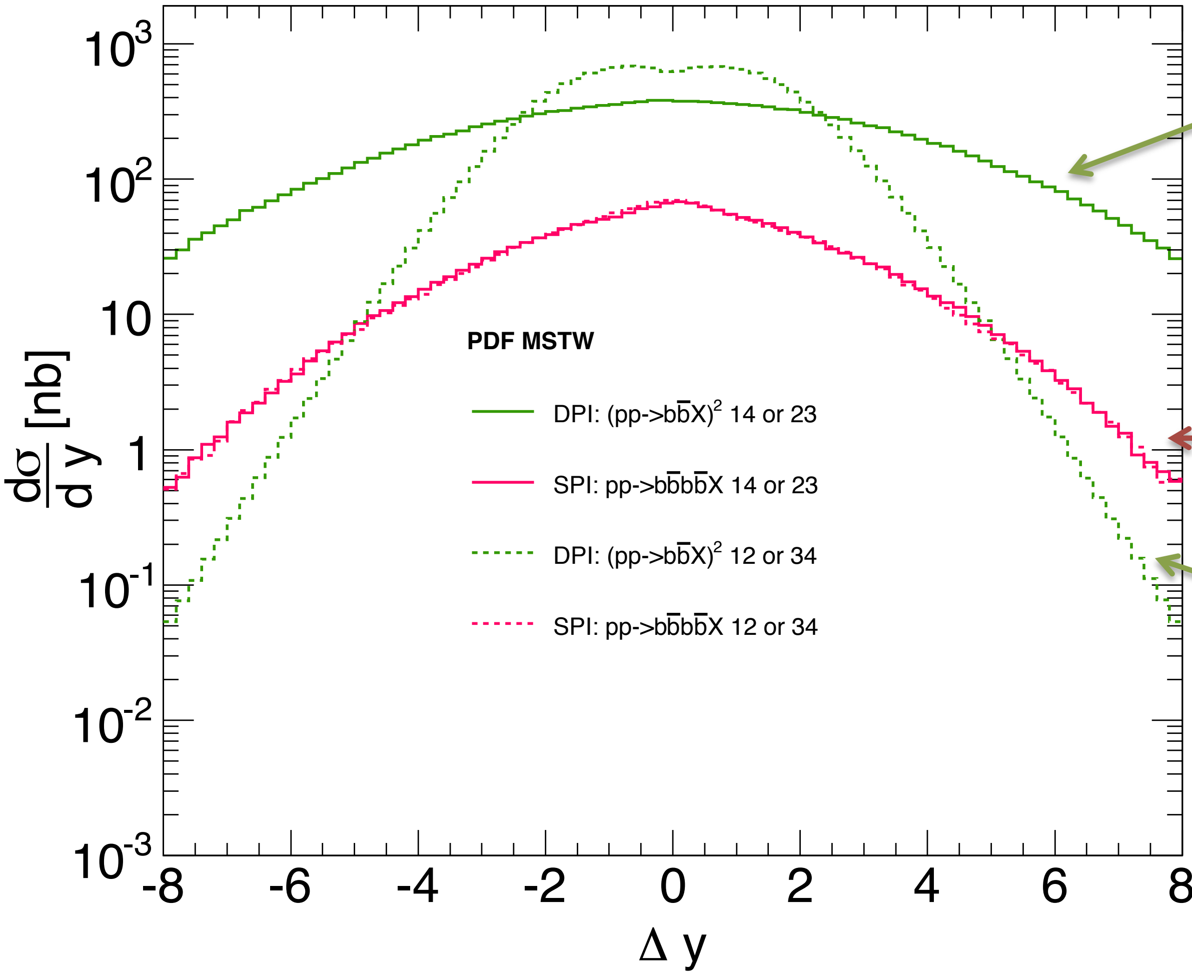


$b\bar{b}$ production: Integrated cross section, with $p_T > p_T^{min}$

$b\bar{b}b\bar{b}$ production by <u>single parton scattering</u>: Integrated cross section, with $p_T > p_T^{min}$

$b\bar{b}b\bar{b}$ production by <u>double parton scattering</u>: Integrated cross section, with $p_T > p_T^{min}$

$b\bar{b}b\bar{b}$ production in pp collisions at the LHC: Correlations in rapidity



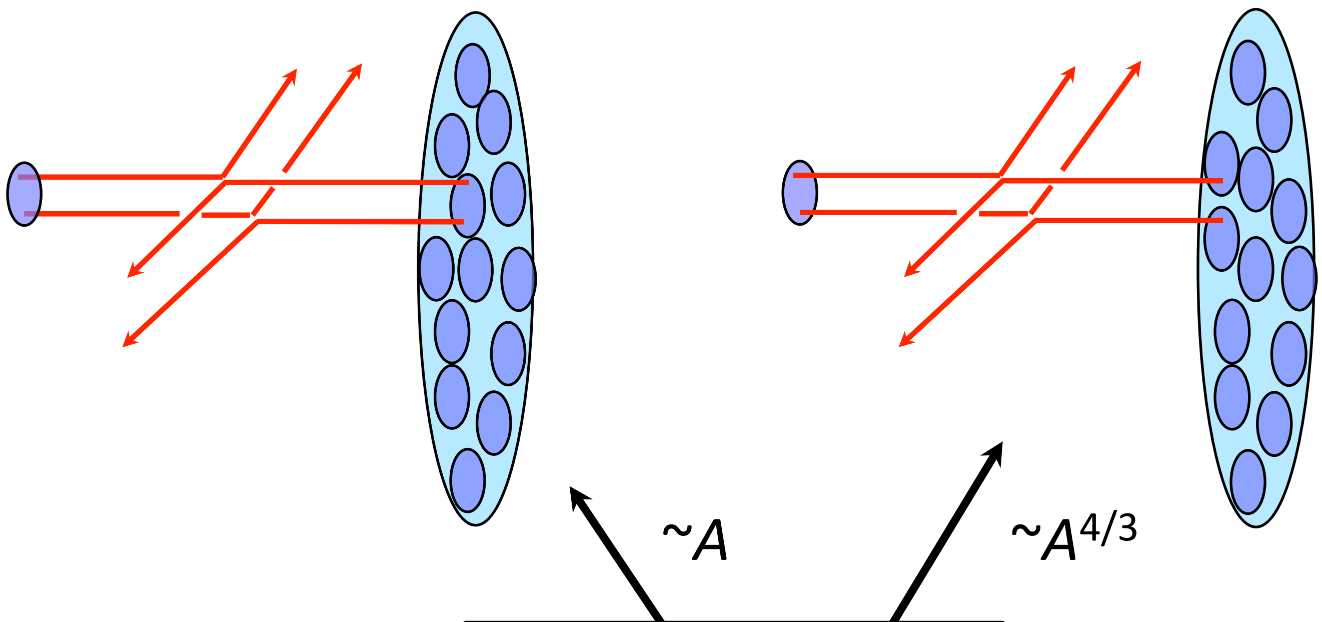
Double parton scattering: correlation between two b-quarks originated in two different elementary interactions

Single parton scattering

Double parton scattering: correlation between two b-quarks originated in the same elementary interaction

DPS in *p-A* collisions

In the case of DPS in *p-A* collisions one may have a double parton scattering against a single or against two different target nucleons:



$$\sigma_D^A = \sigma_D^A\big|_1 + \sigma_D^A\big|_2$$

Simplest estimate of the $b\bar{b}b\bar{b}$ production cross section in *p-Pb* collisions at the LHC:

single - scattering contribution

double - scattering contribution

$$\sigma^{pA}(b\bar{b}b\bar{b}) = \sigma^{pA}_S(b\bar{b}b\bar{b}) + \sigma^{pA}_D(b\bar{b}b\bar{b})$$
$$\sigma^{pA}_D(b\bar{b}b\bar{b}) = \sigma^{pA}_D(b\bar{b}b\bar{b})\big|_1 + \sigma^{pA}_D(b\bar{b}b\bar{b})\big|_2$$

labels 1 and 2 in refer to the number of active target nucleons

$$\sigma^{pA}_D(b\bar{b}b\bar{b})\big|_1 = \frac{A}{2\sigma_{eff}}\left[\sigma^{pp}_S(b\bar{b})\right]^2$$
$$\sigma^{pA}_D(b\bar{b}b\bar{b})\big|_2 = K\frac{1}{2}\left[\sigma^{pp}_S(b\bar{b})\right]^2 \times \int T(B)^2 d^2B$$

anti-shadowing contribution

nuclear thickness function => growth as $A^{4/3}$

linear with A, same as in *pp*

the hadronic transverse size gives the correct dimensionality to $\sigma_D|_1$ through σ_{eff}

$$\sigma_D^{pA}(b\bar{b}b\bar{b})\Big|_1 = \frac{A}{2\sigma_{eff}}\left[\sigma_S^{pp}(b\bar{b})\right]^2$$

$$\sigma_D^{pA}(b\bar{b}b\bar{b})\Big|_2 = K\frac{1}{2}\left[\sigma_S^{pp}(b\bar{b})\right]^2 \times \int T(B)^2 d^2B$$

the correct dimensionality to $\sigma_D|_2$ is provided by the nuclear radius through the nuclear thickness function

related to the multiplicity of pairs of partons in the projectile, for a Poissonian *K*=1

grows as $A^{4/3}$

The two contributions probe different features of the double interaction. In particular, in the case of a heavy nucleus, the anti-shadowing term is proportional to the multiplicity of pairs of partons of the projectile.

$$\sigma_D^{pA}(b\bar{b}b\bar{b})\Big|_1 = \frac{A}{2\sigma_{eff}}\left[\sigma_S^{pp}(b\bar{b})\right]^2$$

Double scattering against a single target nucleon, linear with A

$$\sigma_D^{pA}(b\bar{b}b\bar{b})\Big|_2 = K\frac{1}{2}\left[\sigma_S^{pp}(b\bar{b})\right]^2 \times \int T(B)^2 d^2B$$

Double scattering against two different target nucleons, grows as $A^{4/3}$

By measuring the amount of anti-shadowing one obtains information on *K*, namely on the correlation in multiplicity of the multi-parton distribution.

One may estimate that *K* may vary between 1 and √2

For K=1 (no correlation in multiplicity) one obtains $\frac{\sigma_D^{pA}|_2}{\sigma_D^{pA}|_1} \approx 2$ (200% anti-shadowing correction)

For K= √2 one obtains $\frac{\sigma_D^{pA}|_2}{\sigma_D^{pA}|_1} \approx 3$ (300% anti-shadowing correction)

Summary

At the LHC the inclusive production of two $b\bar{b}$ pairs is dominated by DPS.
In ***pp* collisions** at 8 TeV c.m. energy, **the DPS contribution** to the integrated inclusive cross section is in fact expected to be **one order of magnitude larger as compared to the SPS contribution**.

In ***p-Pb* collisions the dominand contribution** to $b\bar{b}b\bar{b}$ production is **due to** the "**anti-shadowing** contribution" to DPS, where two target nucleons play and active role in the production process.

The value of **the DPS cross section** for $b\bar{b}b\bar{b}$ production, in *p-Pb* collisions at 8 TeV proton-nucleon c.m. energy, **may range between 1 and 2 mb**.
By comparison, the expected $b\bar{b}b\bar{b}$ production cross section due to **the leading QCD mechanism,** in *p-Pb* collisions at 8 TeV proton-nucleon c.m. energy, **may be** about 80 μb, namely **20 – 30 times smaller**.

Of course these estimates are only semi-quantitative and various sources of corrections should be taken into account. As an example, in the anti-shadowing term to DPS, one needs to include also the contribution of an interference term, which may provide a 10% correction.

Thank you