Multiple production of W bosons in pp and pA collisions

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Multiple parton interactions are a manifestation of the unitarity problem caused by the rapid increase of the parton flux at small *x,* which leads to a dramatic growth of all cross sections with large momentum transfer in hadronic collisions at high energies.

A critical regime may be identified by comparing the rate of double collisions with the rate of single collisions. When the two rates become of the same order, multiple collisions are no more a small perturbation, all multiple collision terms become equally important and the production of large p_t partons undergoes a qualitative change.

In its simplest implementation the double parton scattering cross section σ_D is given by

$$\sigma_D = \frac{1}{2}\frac{\sigma_S^2}{\sigma_{eff}}$$

where σ_S is the single scattering cross section.

The kinematical regime where multiple parton interactions are no more a small perturbation hence corresponds to the regime where σ_S and σ_{eff} are of the same order.

The experimental indication is that the value of σ_{eff} is close to 10 mb. One might hence conclude that one should worry about multiple parton collisions only when the single scattering cross section becomes comparable with σ_{eff}

On the contrary multiple parton collisions may produce important effects also in cases where the single scattering cross section is many orders of magnitude smaller that σ_{eff}

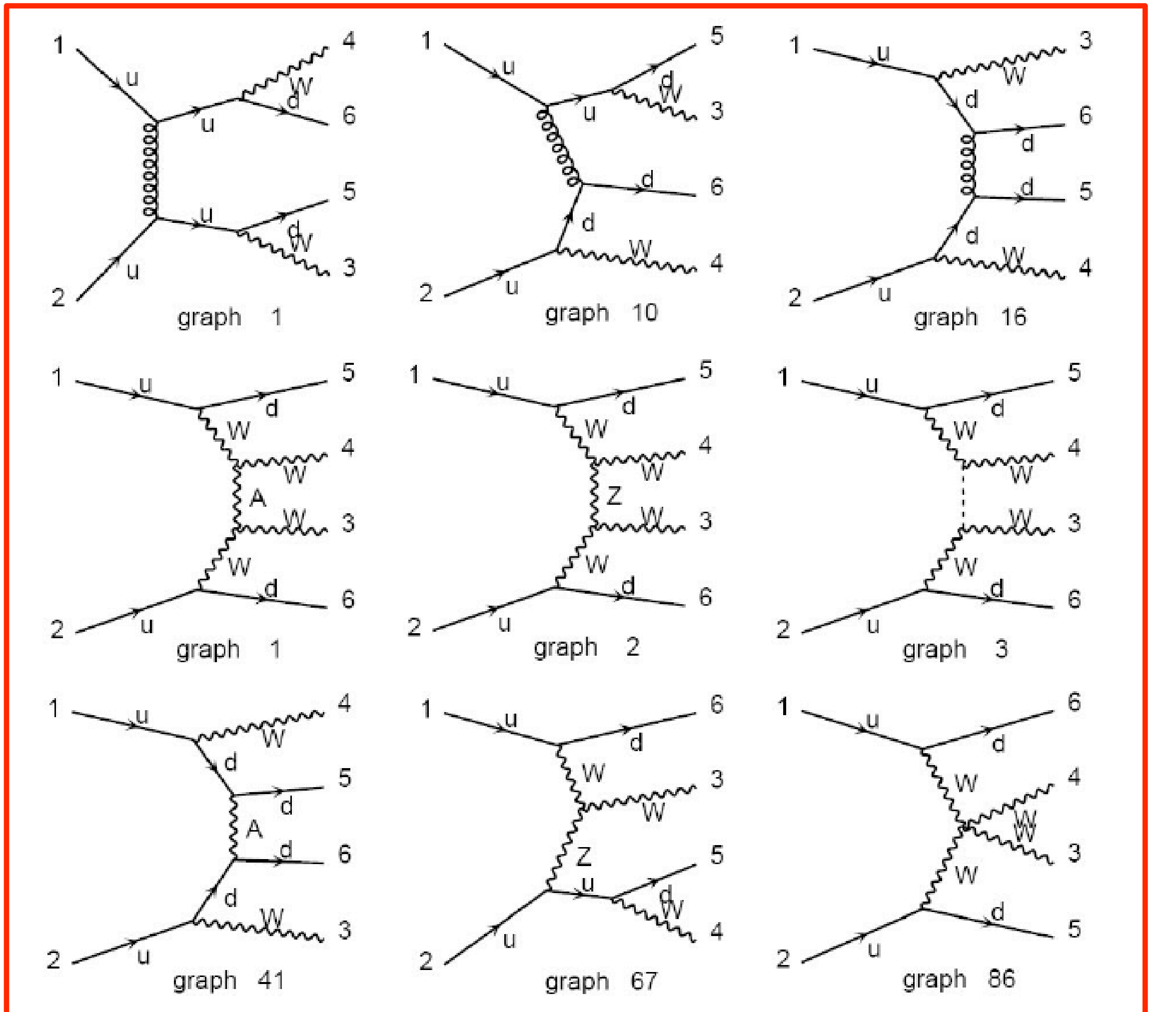
The consideration applies to the interesting case of the production of equal sign W boson pairs

Notice that the leptonic decay channel of equal sign W bosons, which leads to final states with equal sign isolated leptons plus missing energy, is of interest for the search of new physics.

In the SM the production of **two equal sign W bosons is a higher order process.**
Two equal sign W bosons can in fact be produced only in association with two jets

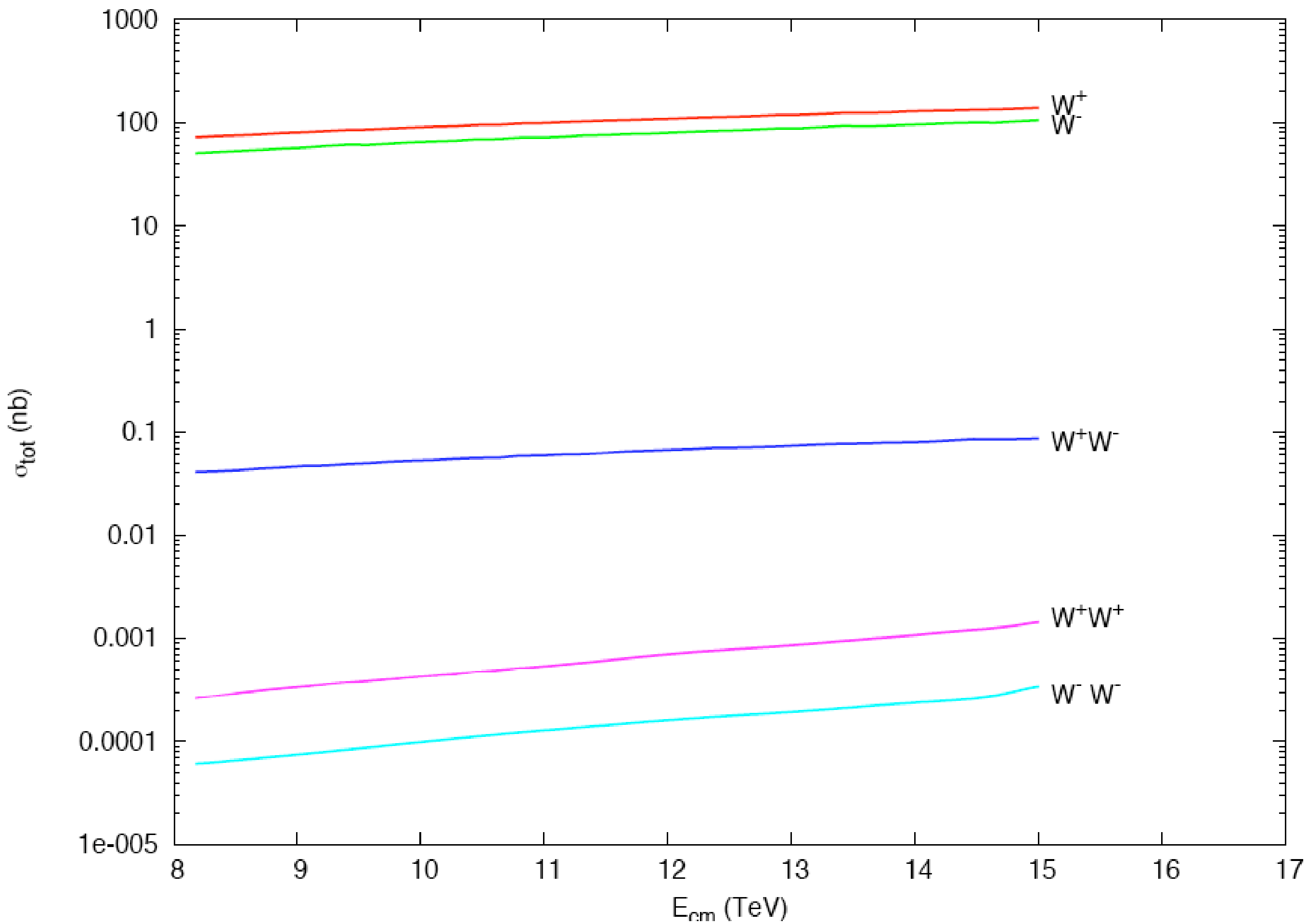
At the lowest order there are 68 diagrams at $\mathcal{O}(\alpha_W^4)$ and 16 diagrams at $\mathcal{O}(\alpha_S^2\alpha_W^2)$ and although $\alpha_S > \alpha_W$ the electroweak contribution is similar to the strong one.

The corresponding **cross section** is **infrared and collinear safe** and can be evaluated without imposing any cutoff in the final state quark jets



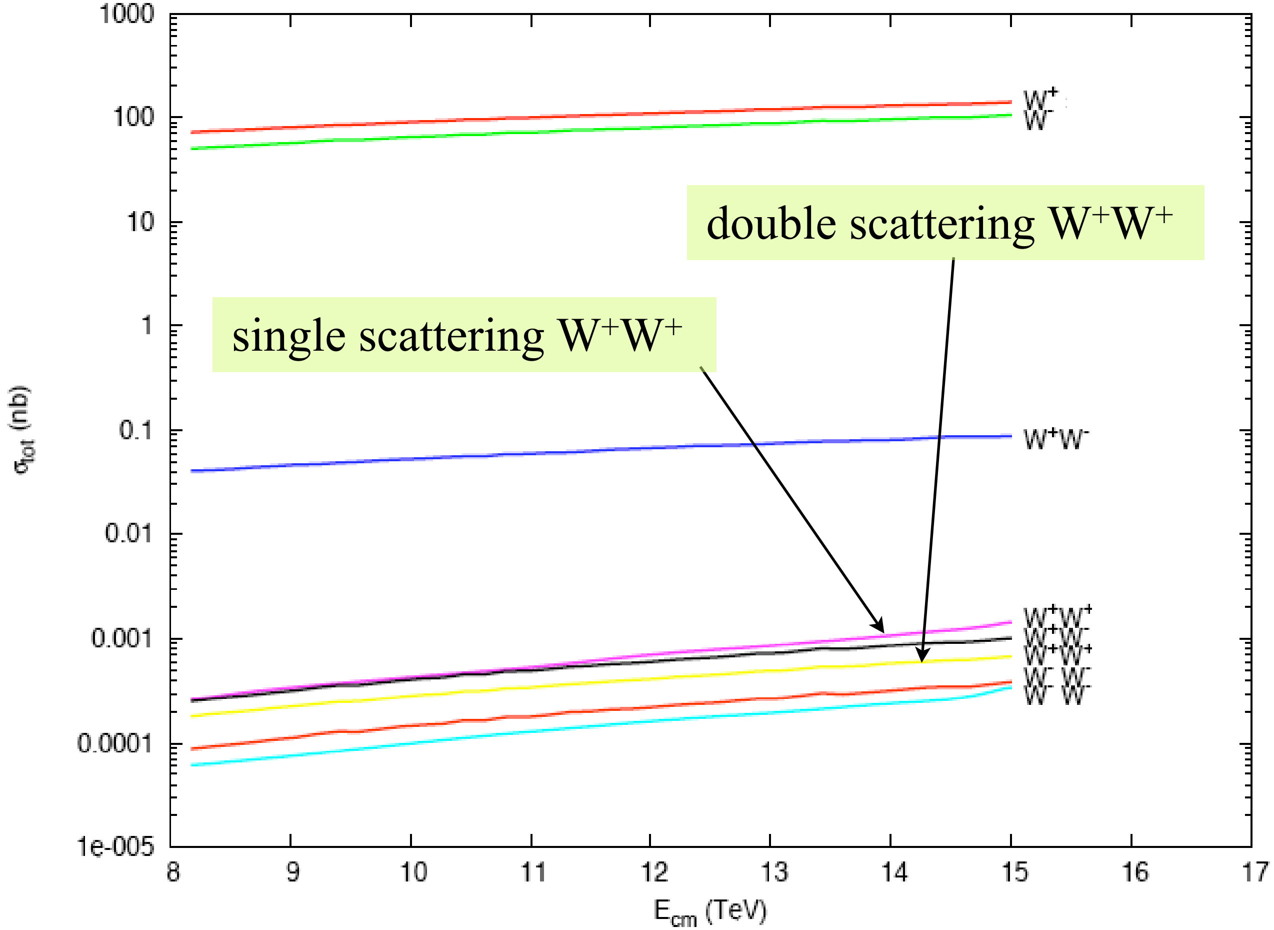
W production cross sections by single parton scattering in pp collisions as a function of the c.m. energy.

Notice that the cross section to produce two equal sign W bosons is **five orders of magnitude** smaller with respect to the cross section of single boson production



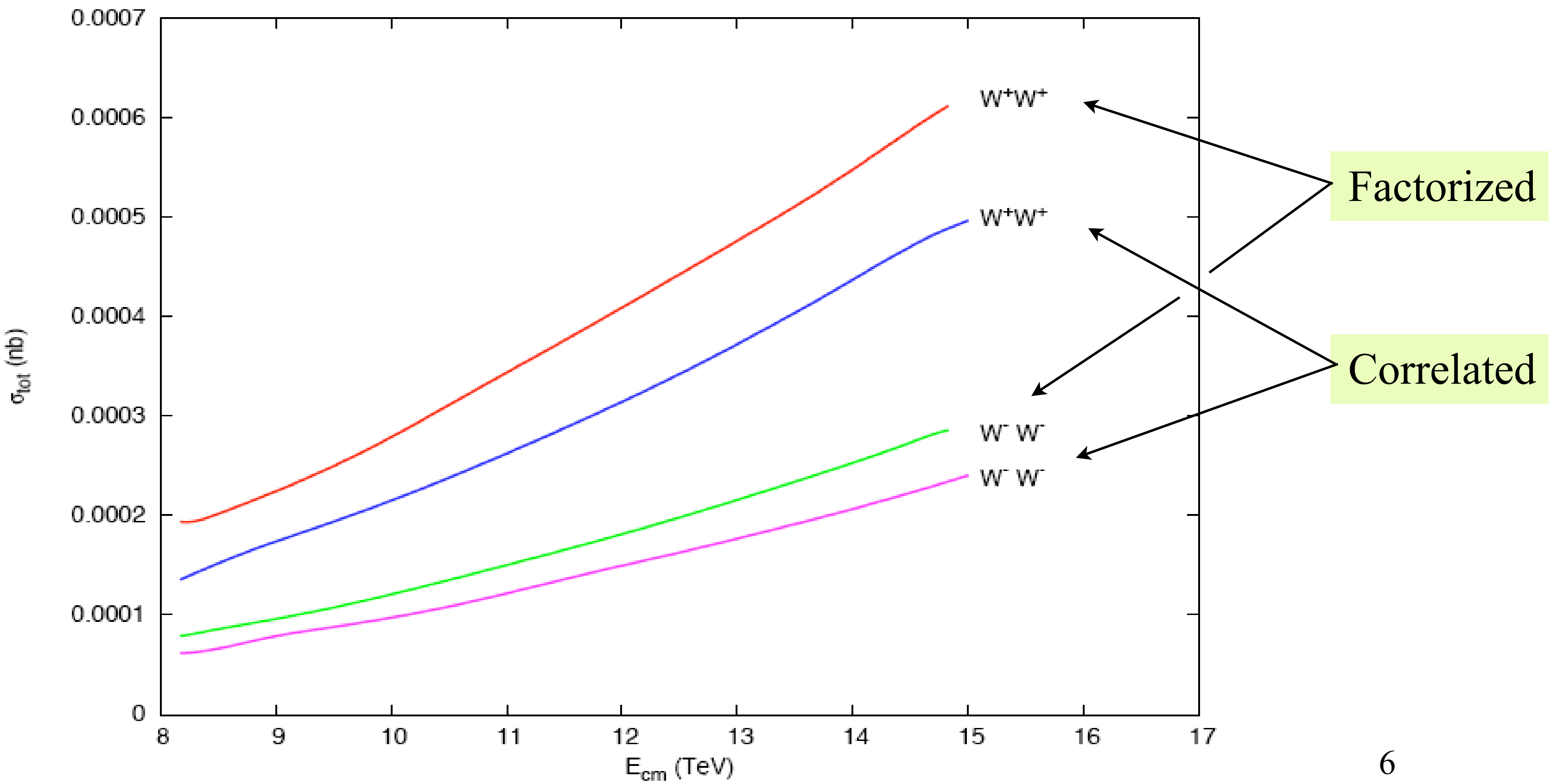
The **same reduction factor** is expected for W production **through multiple collisions** processes:

$$\sigma_{WW} = \frac{1}{2}\sigma_W \frac{\sigma_W}{\sigma_{eff}} \qquad \frac{\sigma_W}{\sigma_{eff}} \simeq \frac{10^2\text{nb}}{10\text{mb}} = 10^{-5}$$

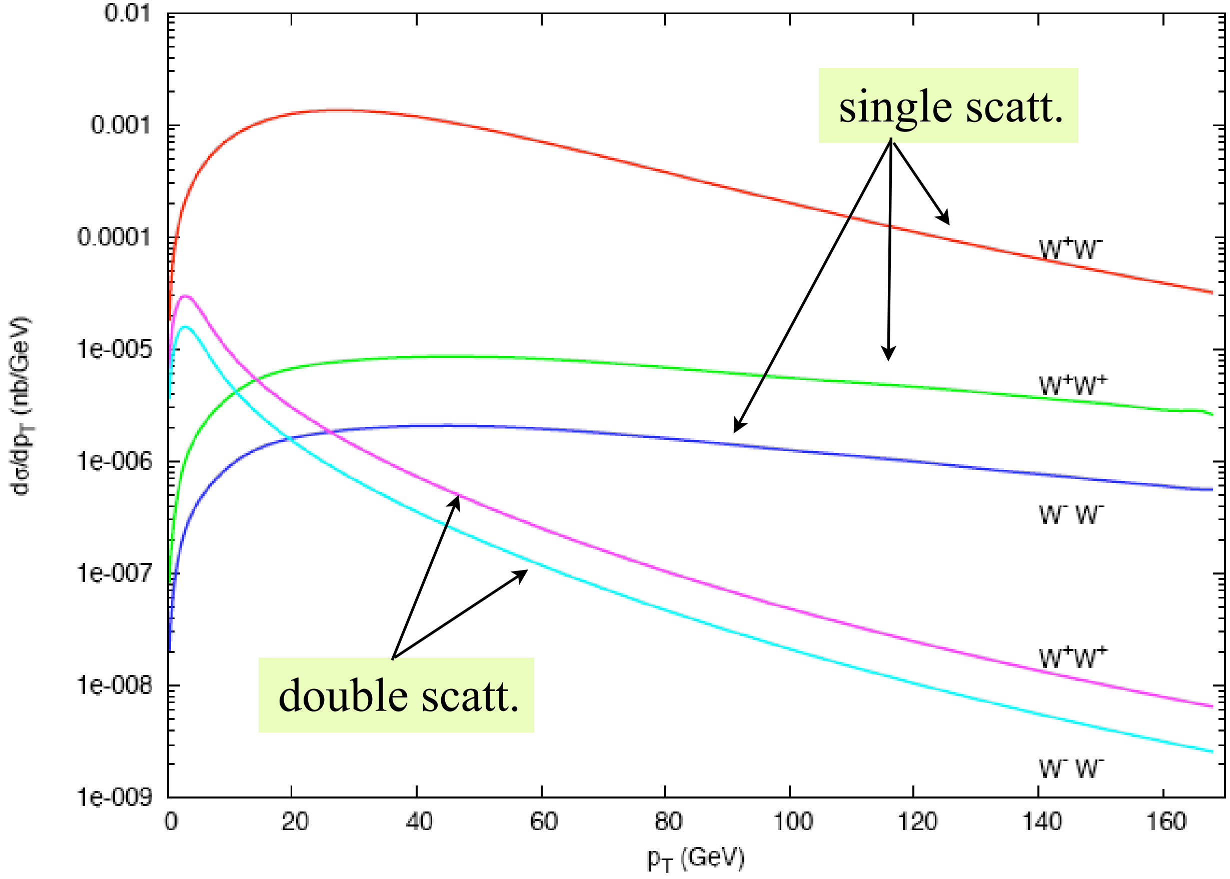


The double scattering expression $\sigma_{WW} = \frac{1}{2}\sigma_W \frac{\sigma_W}{\sigma_{eff}}$ is based on the assumption

of factorization of the double parton distributions. Given the large mass of the W boson one may however expect an important contribution of valence quarks also at the LHC energy. One may hence work out the double scattering cross section by **correlating the valence quarks implementing the flavor sum rules**. In this way, the resulting cross section is reduced by about 20% at the LHC energy.



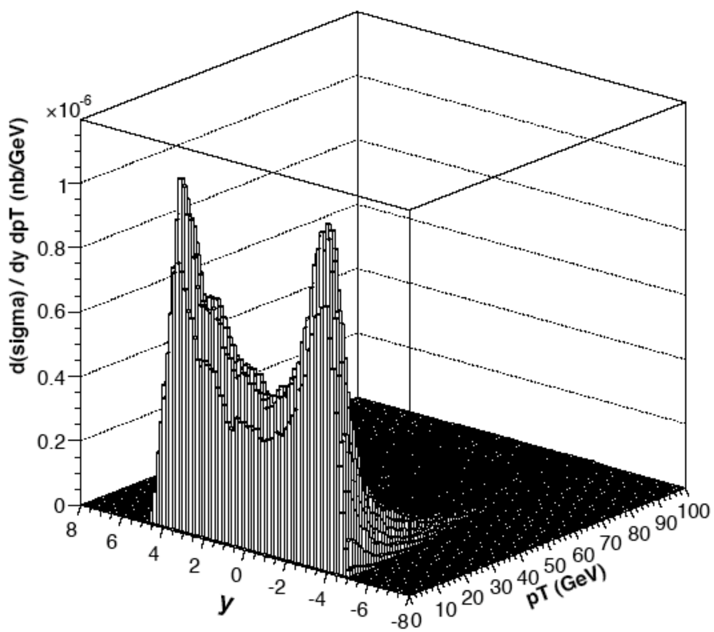
The two equal sign W bosons are distributed differently in phase space by the two production mechanisms, which may be separated with a cut of 15 GeV/c in the transverse momenta of the produced Ws



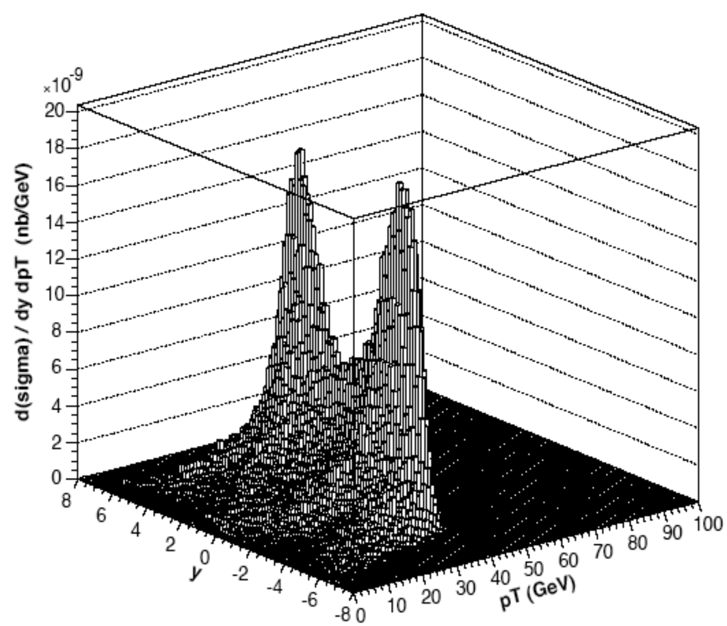
Distribution in phase space in the case of ***double parton collisions***

Distribution in transverse momentum and rapidity of the **W^+ bosons (left figure)** and of the **decay leptons (right figure)** produced by double parton collisions in pp interactions as a function of rapidity and transverse momentum.
The W bosons are produced with with small transverse momentum while the rapidity distribution of the W boson reminds the momentum of the originating up quark. The distributions of the final state charged leptons is peaked at the same rapidity of the parent W boson and at a transverse momentum corresponding to 1/2 of the W boson mass.

W^+W^+



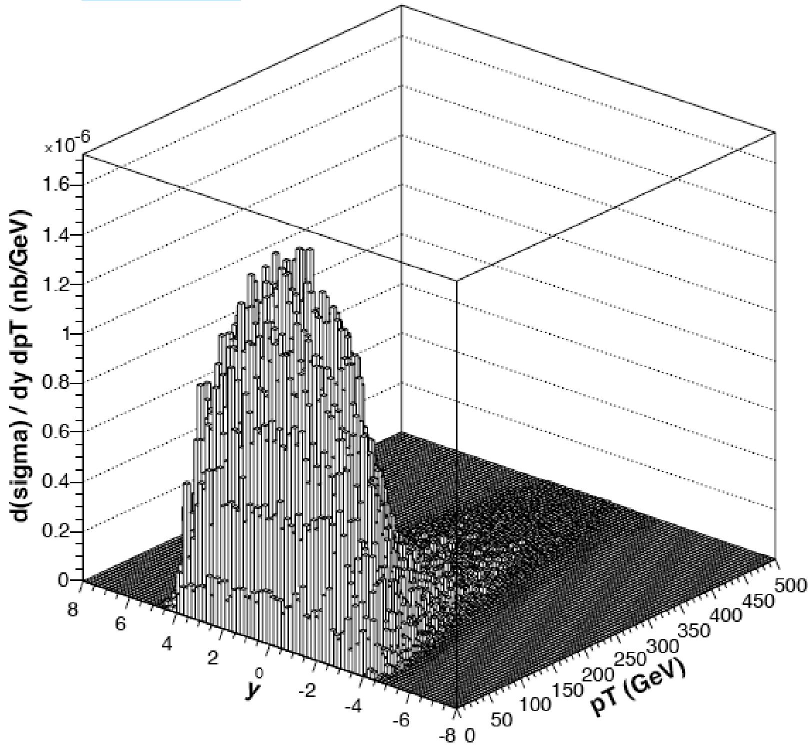
e^+e^+



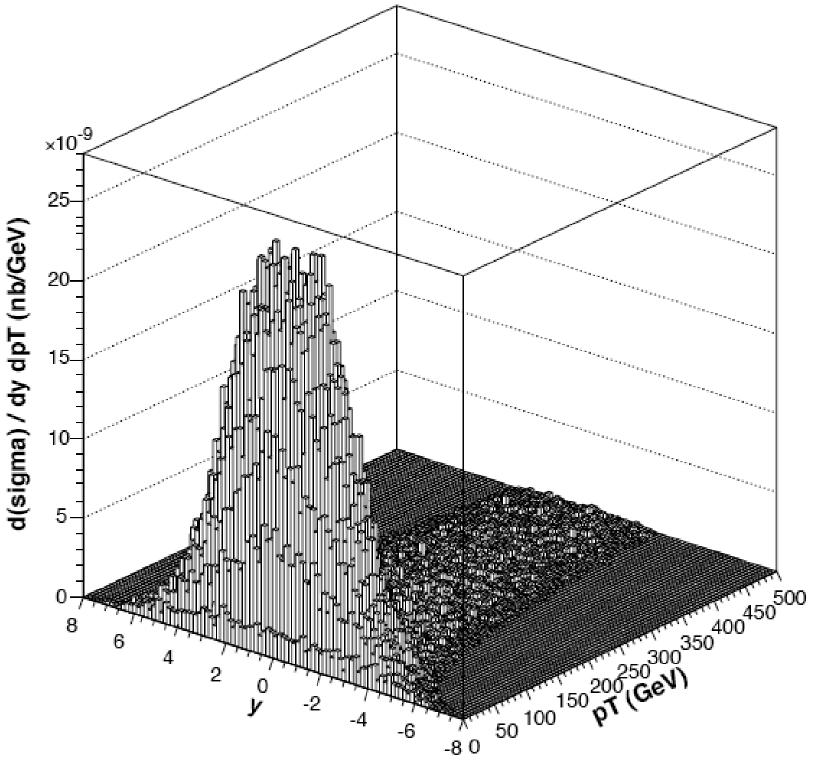
Distribution in phase space in the case of ***single parton collisions***

Distribution of **equal sign W bosons (left figure)** and of the **decay leptons (right figure)** generated by single parton collisions in pp interactions as a function of rapidity and transverse momentum.

W^+W^+

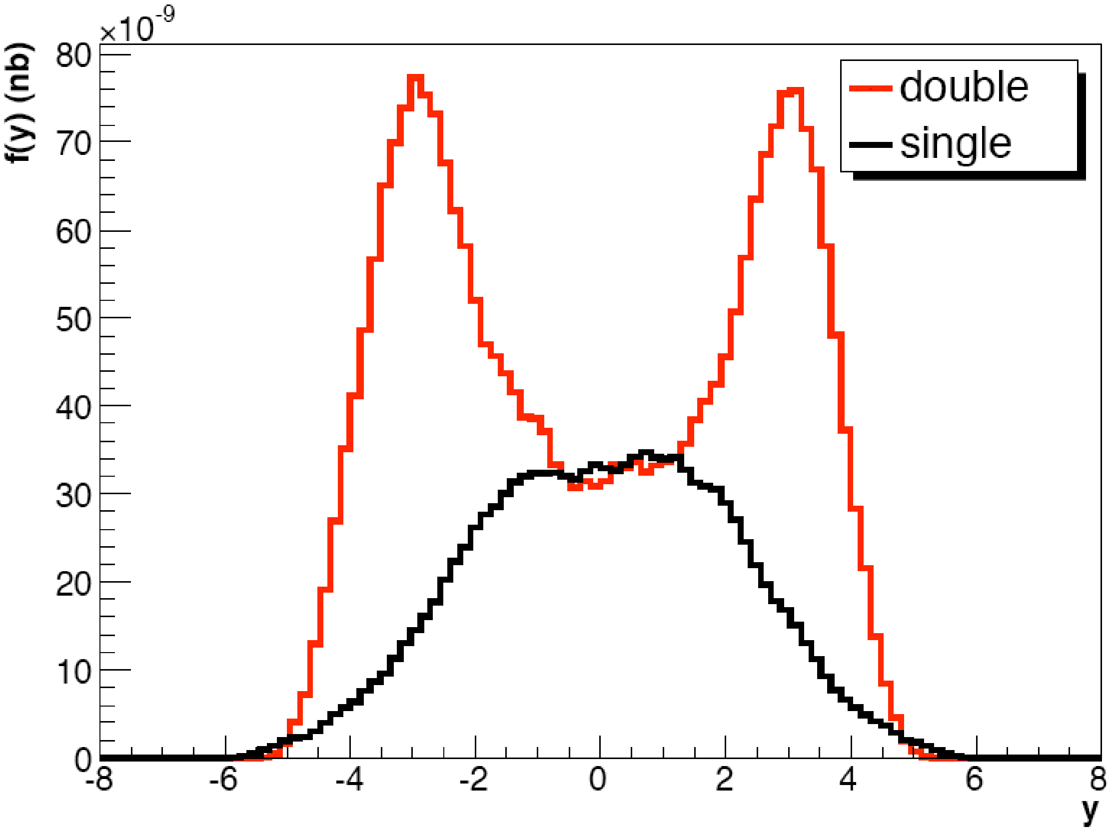


e^+e^+



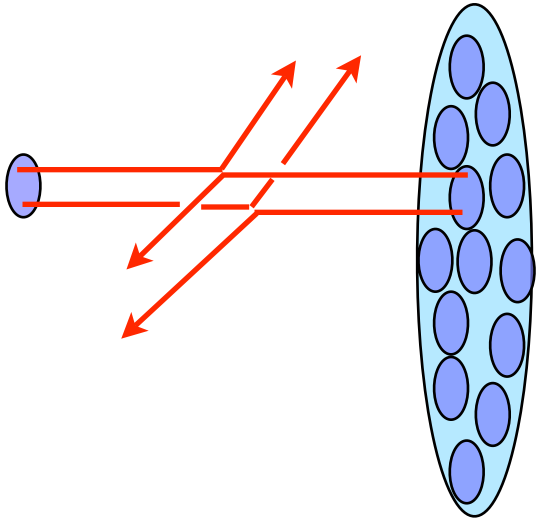
Distribution in rapidity of charged leptons in the interval 37 GeV/c < pt < 42 GeV/c. The **red histogram** refers to the contribution of **double parton interactions**, the **black histogram** refers to the contribution of **single parton interaction**.

The contribution from double scattering may hence be easily disentangled.



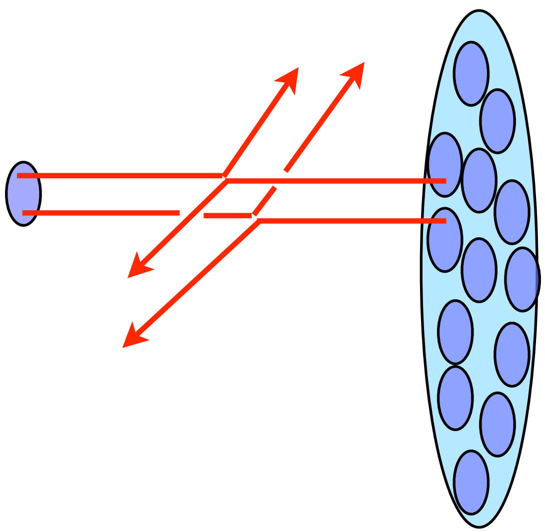
In pA collisions multiple parton interactions are enhanced by the presence of an additional contribution in the cross section, proportional to $A^{4/3}$

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



same A dependence of a single scattering process

$$\sigma_D^A\big|_1 = \frac{1}{2}\frac{\sigma_W^2}{\sigma_{eff}}\int d^2b T(b) \propto A$$

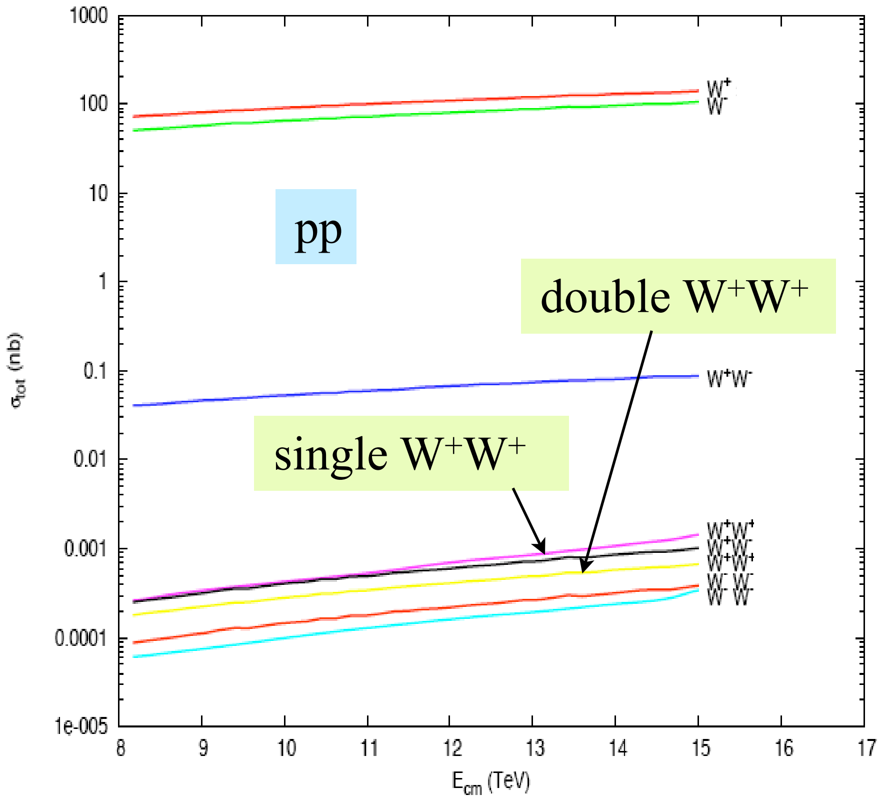


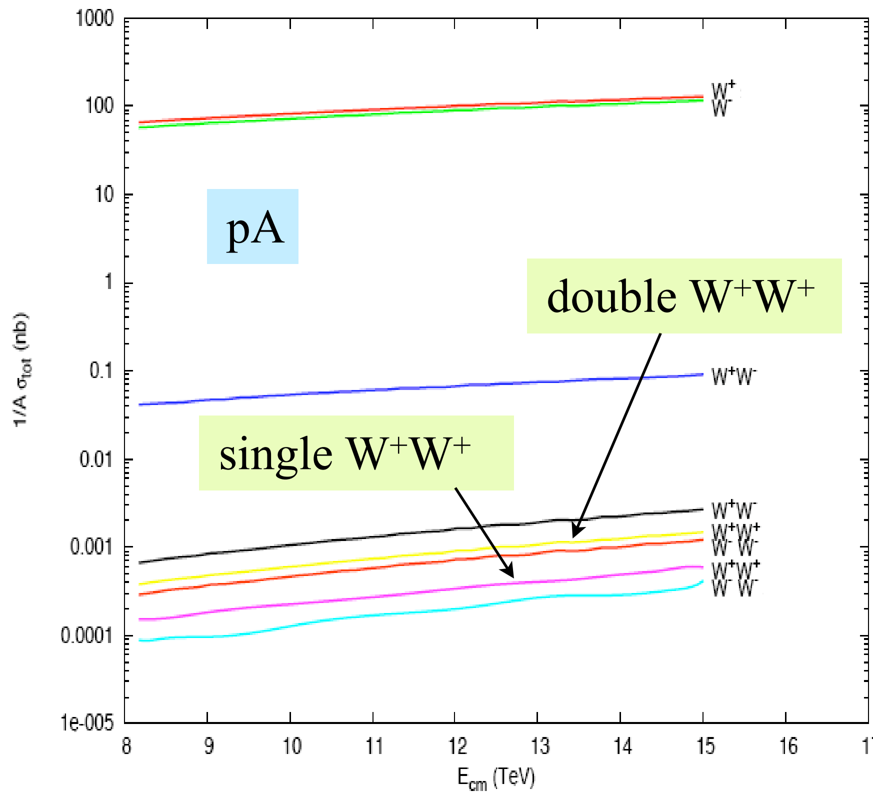
$$\sigma_D^A\big|_2 = \frac{1}{2}\sigma_W^2\int d^2b T^2(b) \propto A^{4/3}$$

notice the stronger A dependence

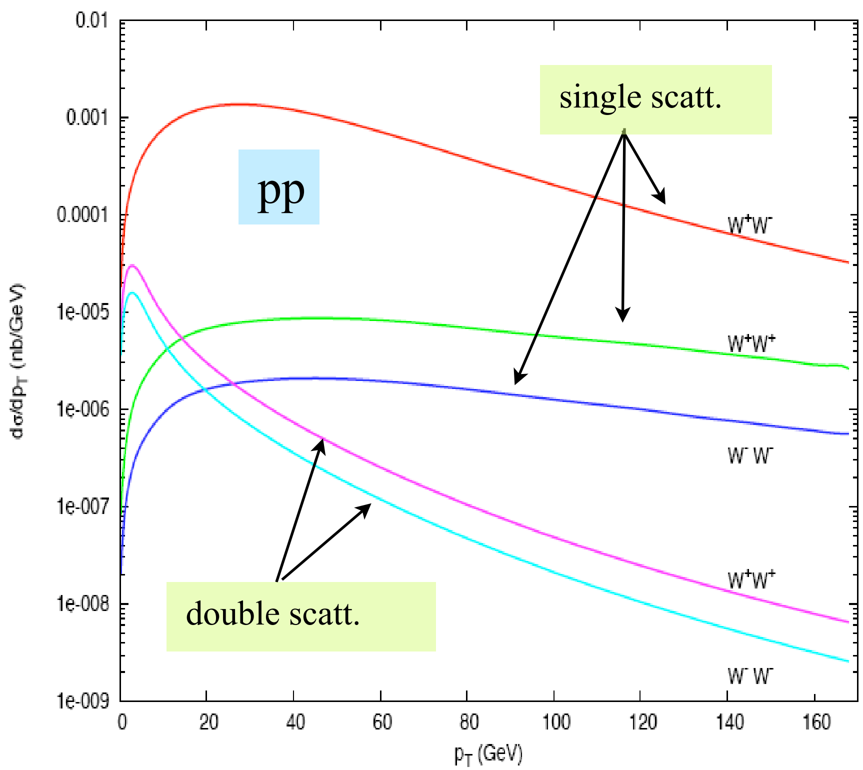
Notice that the presence of the term proportional to $A^{4/3}$ in the double scattering cross section gives rise to a **very strong antishadowing effect**

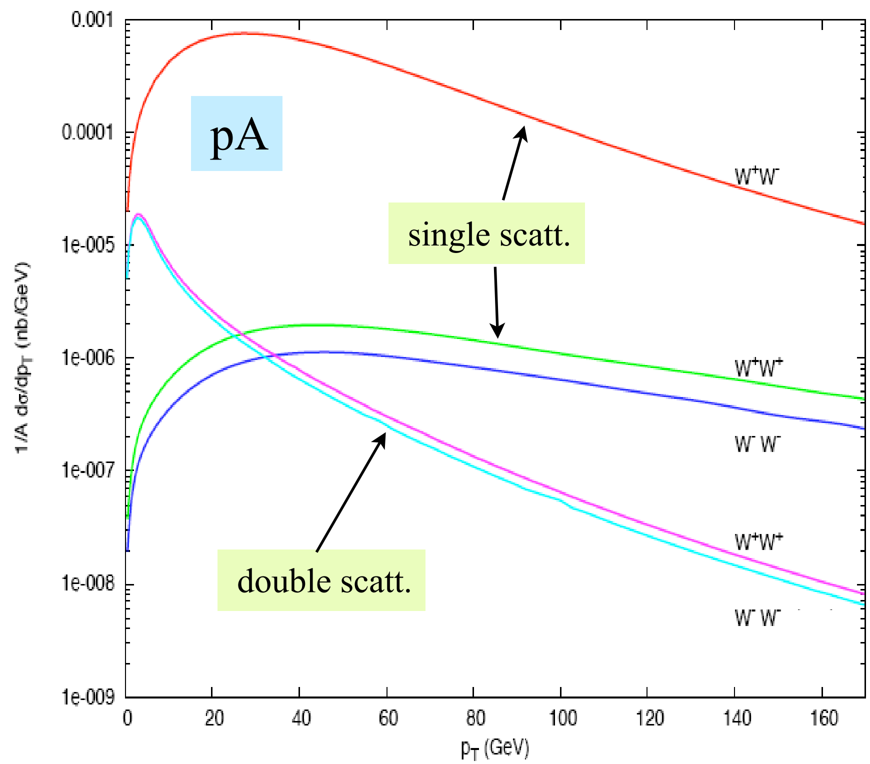
The effect is shown in the figures below, where the W production cross sections are compared in pp and in pA collisions, after dividing by the atomic mass number A





In the case of pA collisions the distribution in transverse momenta of the W^+W^+ bosons is dominated by the contribution of multiple parton interactions, down to transverse momenta of 40 GeV/c

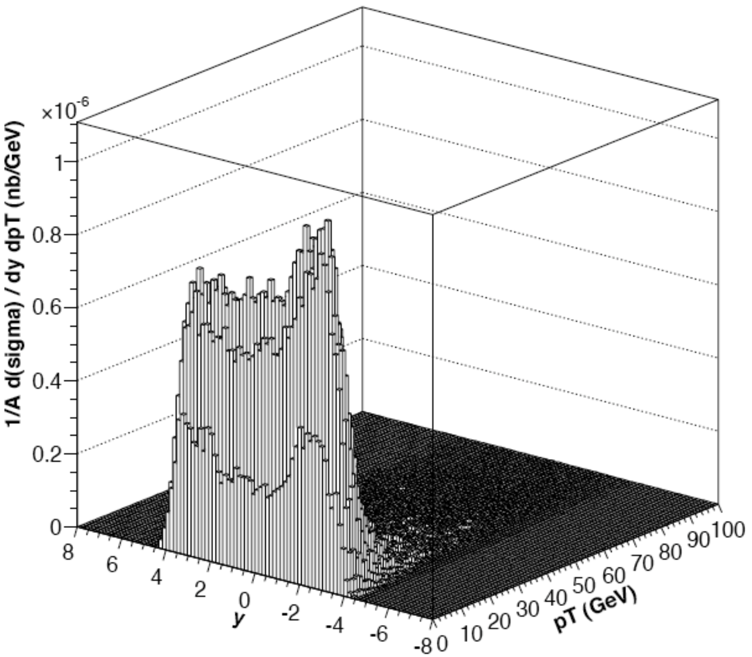




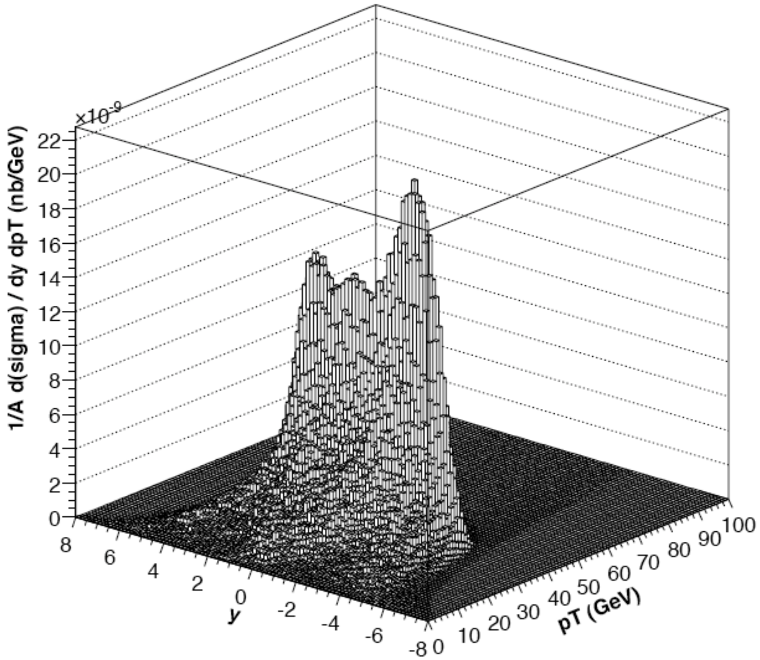
Distribution in phase space in the case of ***double parton collisions***

Distribution in transverse momentum and rapidity of the **W^+ bosons (left figure)** and of the **decay leptons (right figure)** in pA collisions.
The W bosons are produced with with small transverse momentum while the rapidity distribution of the W boson reminds the momentum of the originating up quark. The asymmetry in rapidity is due to the different content of up quarks in the proton and in the pp, pn and nn nuclear pairs, which undergo the double interaction process. The distributions of the final state charged leptons is peaked at the same rapidity of the parent W boson and at a transverse momentum corresponding to 1/2 of the W boson mass.

W^+W^+



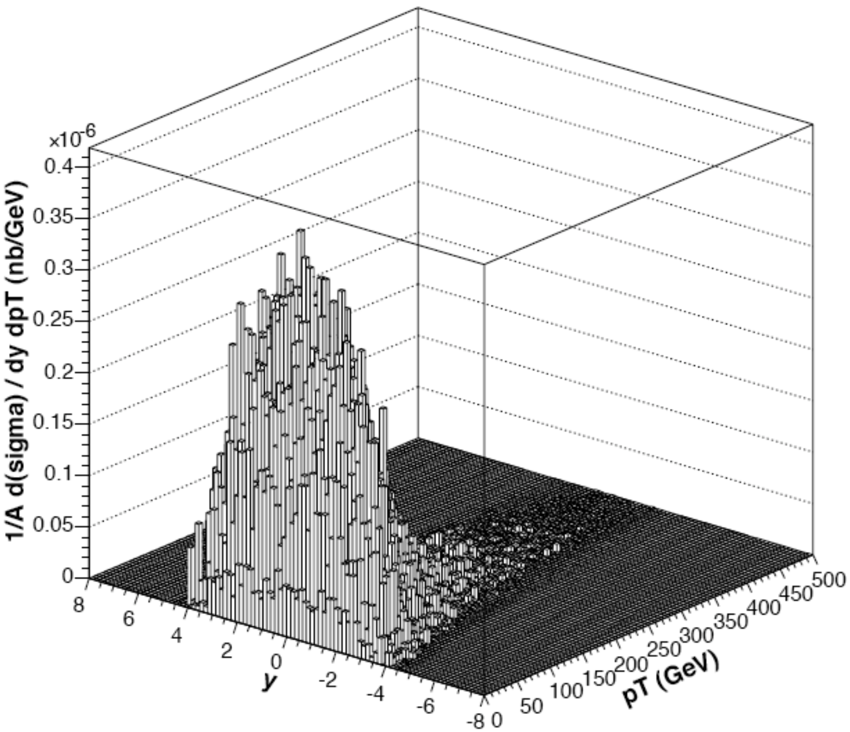
e^+e^+



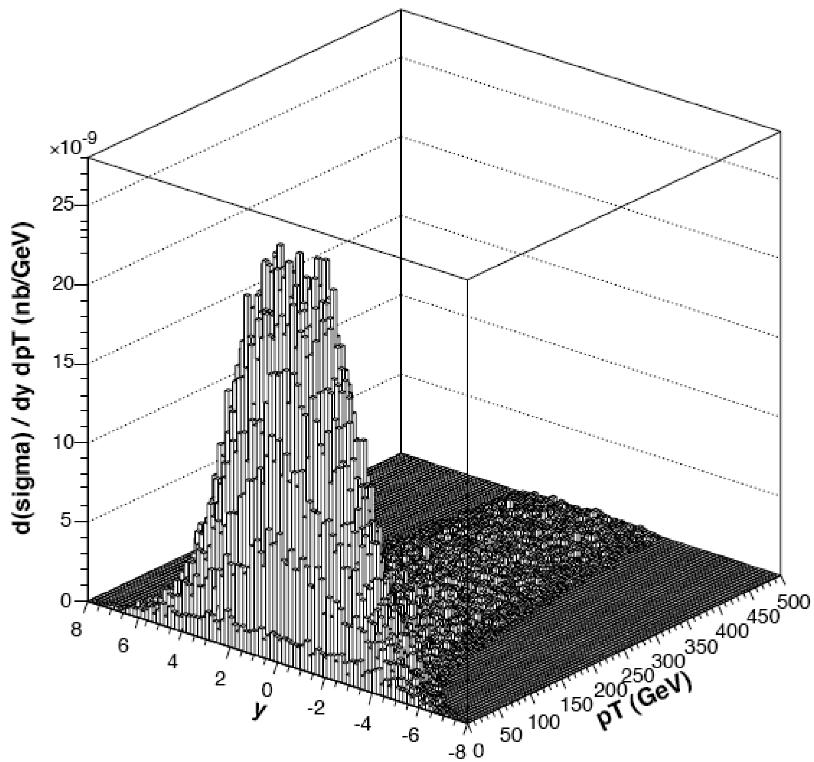
Distribution in phase space in the case of ***<u>single parton collisions</u>***

Distribution of **equal sign W bosons (left figure)** and of the **decay leptons (right figure)** generated by single parton collisions in pA interactions as a function of rapidity and transverse momentum.

W^+W^+



e^+e^+



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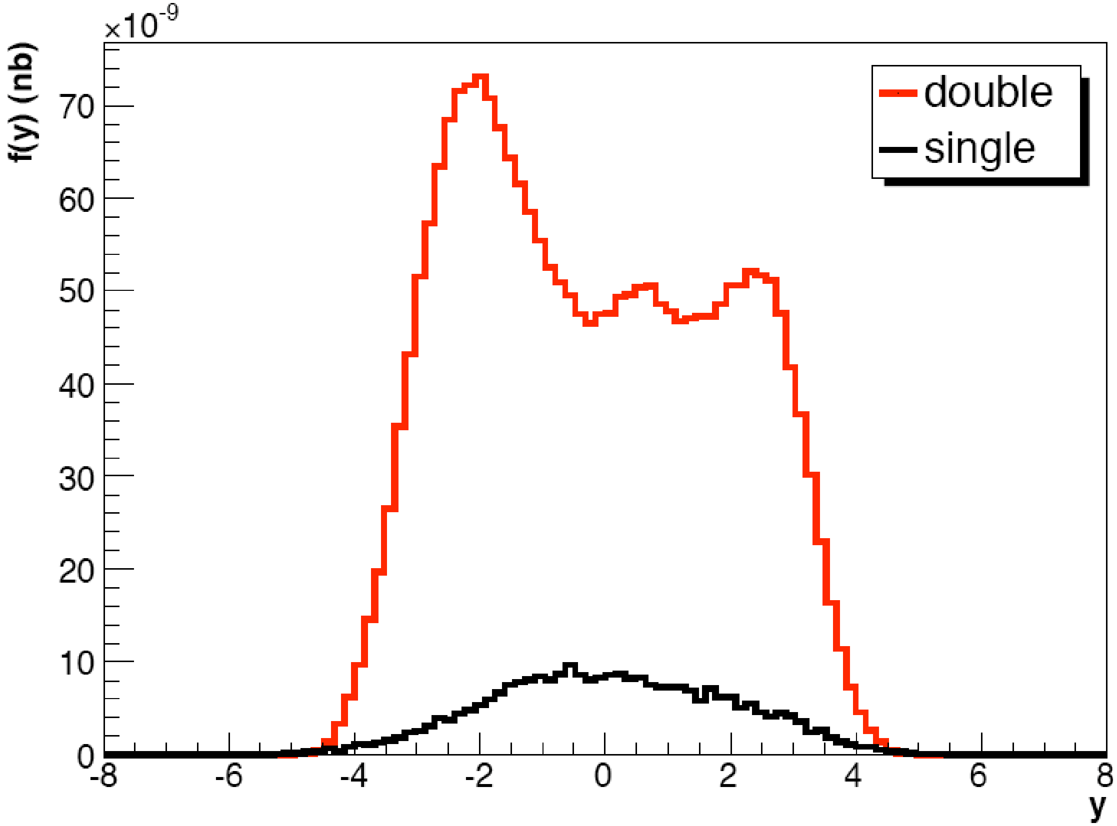
Double scatterings give the dominant contribution.



Concluding summary

Equal sign W boson pairs are produced by a **higher order process** in the SM.

As a consequence, in **pp collisions** at the LHC, the cross section to produce **two equal sign W bosons** is more than **two orders of magnitude smaller,** as compared with the cross section to produce two opposite sign W boson.

In **pp collisions** at the LHC, the cross sections to produce **two equal sign W bosons**, through **single and double parton collisions**, are **similar in magnitude**

The two equal sign W bosons and the corresponding decay leptons are however **distributed very differently in phase space** by the two production mechanisms, in such a way that the two contributions are easily disentangled.

Differently with respect to the more conventional single scattering large p_T processes, the **double parton scattering** processes are **anti-shadowed in collisions with nuclei**. Correspondingly in pA collisions the rate of two equal sign W bosons production is significantly increased.

CMS Analyses on Multiple Parton Interactions Processes

1) Underlying Event in Jet and Drell-Yan Events at the LHC
2) Minimum Bias at the LHC (Multiplicities, P_T spectra)
3) Double Parton Scattering at the LHC
4) Tuning of Monte Carlo Models

on behalf of MB&UE

Florida: Darin Acosta, Rick Field, Khristian Kotov
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NTU: P. Bartalini, Min-zu Wang, Yuan Chao, Chang You Hao
Hamburg: F.Bechtel, P. Schleper, G. Steinbrueck
Cukurova University (Adana): Numan Bakirci
University of Trieste: D. Treleani et al.
CERN: A. De Roeck
Other: E. Izaguirre, L. Garbini

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