Multi parton interactions MPI@LHC

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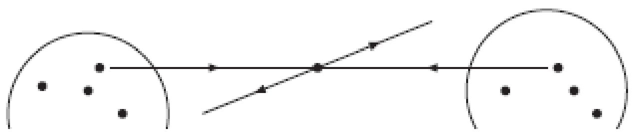
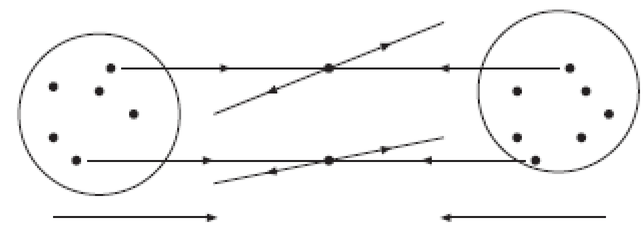
Introduction

The conventional dijet production in high energy process:

$$\frac{d\sigma^{(2\to 2)}}{d\hat{t}} \propto \frac{\alpha_s^2}{Q^4}.$$





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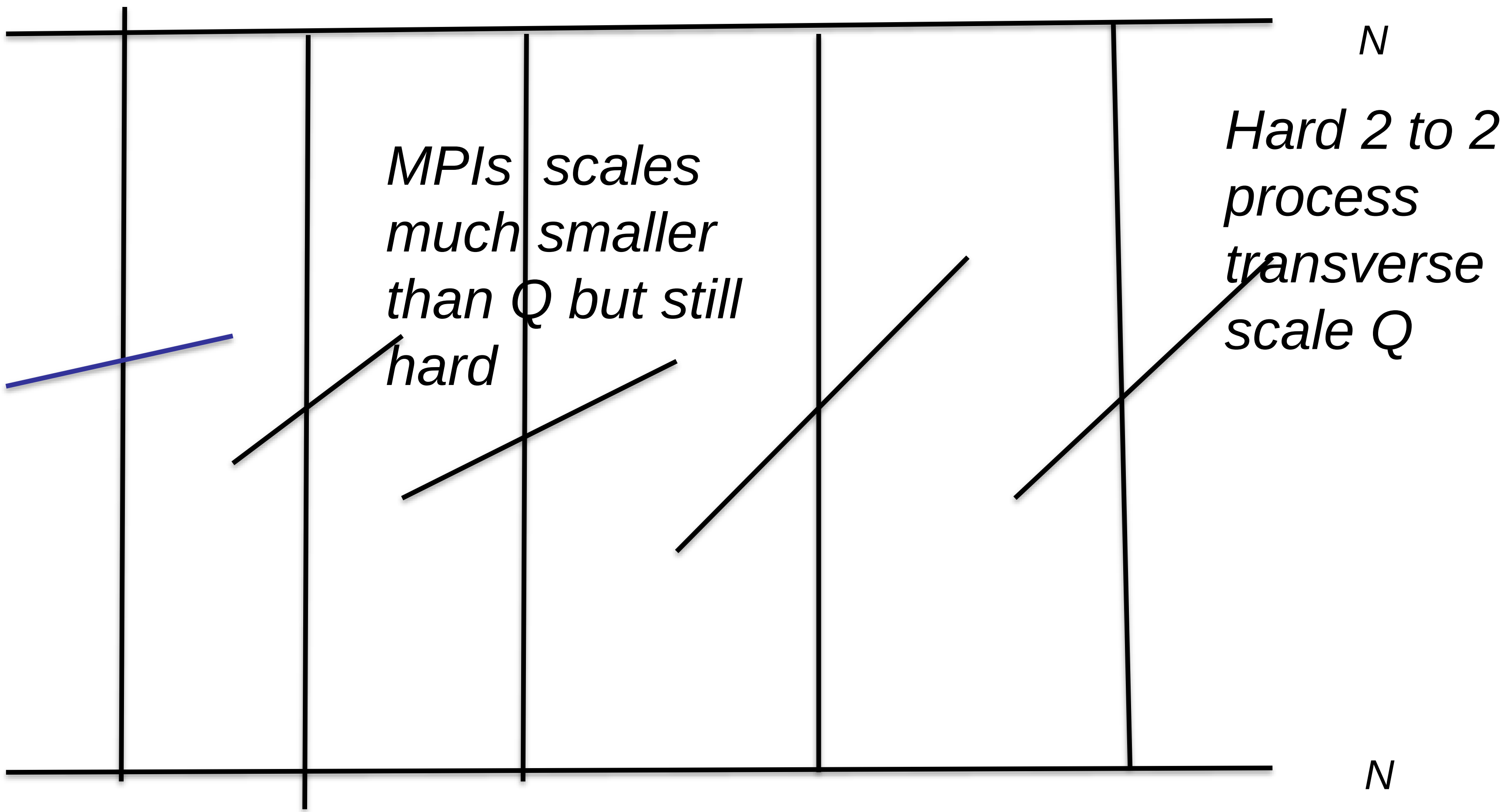
2

Realistic process however-more than I hard interactions-MPI. Can occur either accompanying hard process –form 1-2 (Minimal Bias) to 2-3 (Underlying way (UE)-to large number-high multiplicity events.-or on its own-Double Parton Scattering (DPS)-two hard processes both scales are hard-currently 40-20 GeV.

MPI picture of UE in hard processes at high energies



DPS-Double parton scattering-4 jet production

Basic evidence for MPI: a) UE b)DPS c) close on direct observation W+W+

The description of MPI demands new theoretical concepts beyond 2 to 2 processes: General ised parton distributions-GPD, ladder splitting.
MPI are important for precision meauserements at hadronic colliders ar high energies and can be a source of interesting correlations at high energies.

Let us briefly review MPI in pp collisions.

The most interesting property of MPI-they can be seen in the back-to-back kinematics.

Indeed, they are not the leading twist process.

The 2 to 4 processes give a contribution to cross section

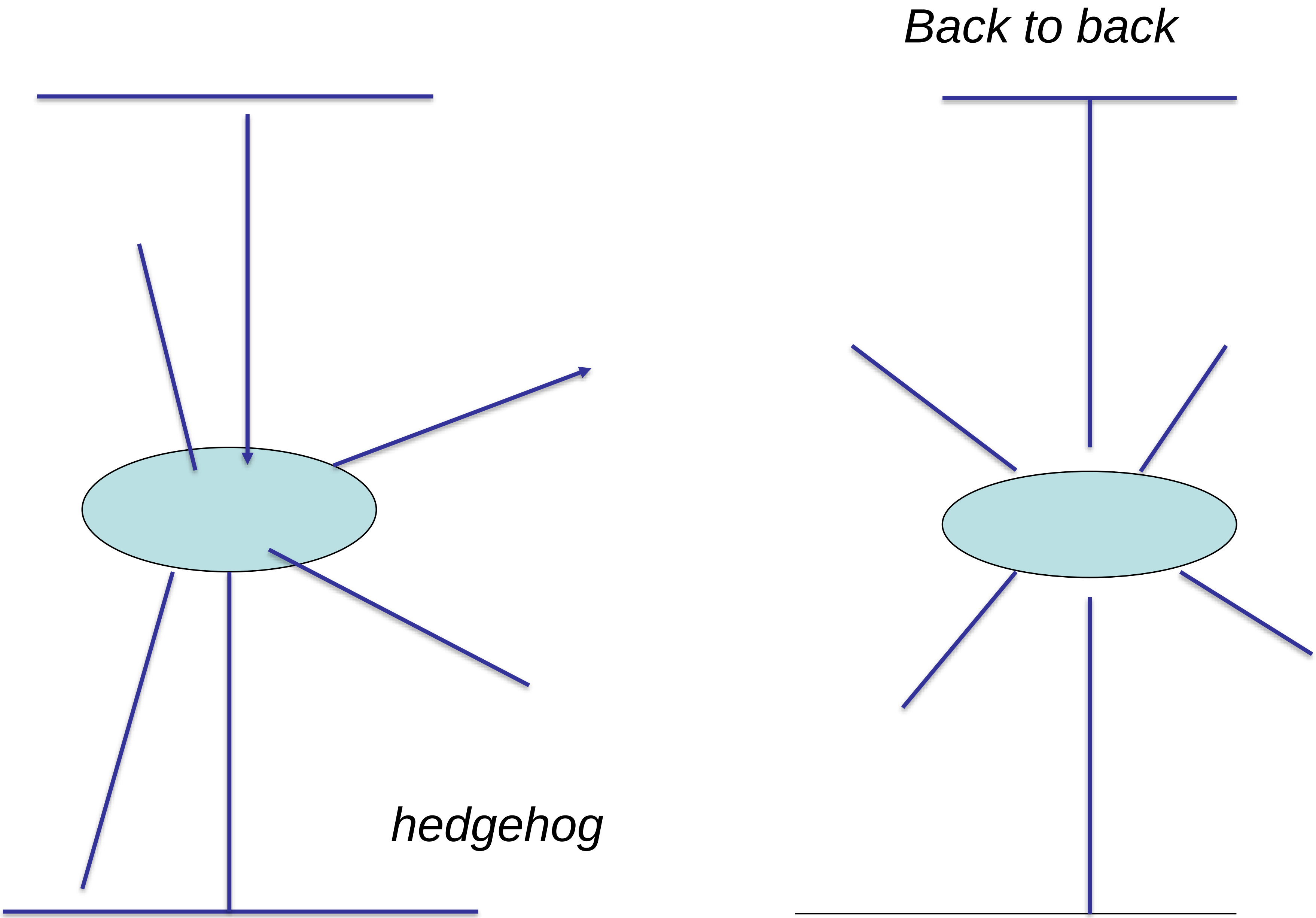
$$\frac{d\sigma^{(2\to 4)}}{d\hat{t}_1 d\hat{t}_2} \propto \frac{\alpha_s^4}{Q^6}$$

On the other hand $$\frac{d\sigma^{(4\to 4)}}{d\hat{t}_1 d\hat{t}_2} \propto R^{-2} \cdot \left(\frac{\alpha_s^2}{Q^4}\right)^2 \propto \frac{\alpha_s^4}{R^2\, Q^8};$$

i.e. they can be seen as a higher twist process.

the scale R is given by

$R^2 = 1/\left\langle \Delta^2 \right\rangle$ the characteristic distance between the two partons in the hadron wave function.


Back to back
hedgehog

Recently new pQCD formalism for MPI was developed:

B.Blok, Yu.Dokshitzer, L. Frankfurt ,M. Strikman, ***Phys.Rev. D83 (2011) 071501***
Eur.Phys.J. C72 (2012) 1963, ***Eur.Phys.J. C74 (2014) 2926***

Numerical implementation:B. Blok, P. Gunnellini **Eur.Phys.J. C75 (2015) no.6, 282Eur.Phys.J. C76 (2016) no.4, 202**

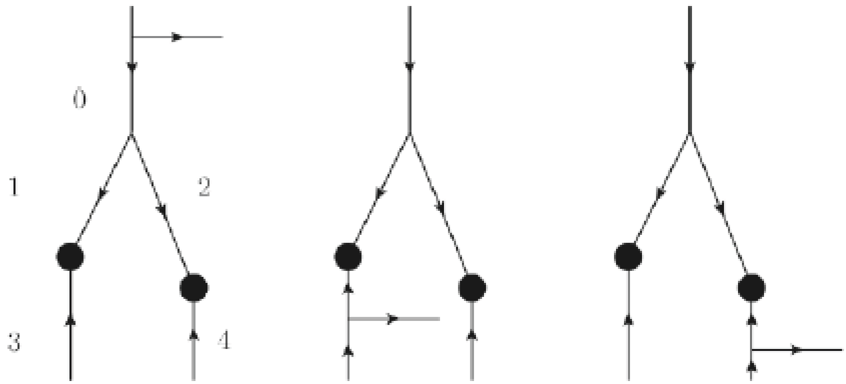
There are now experimental measurements by ATLAS CMS LHCb and D0 at Tevatron .at different regions of the phase space.

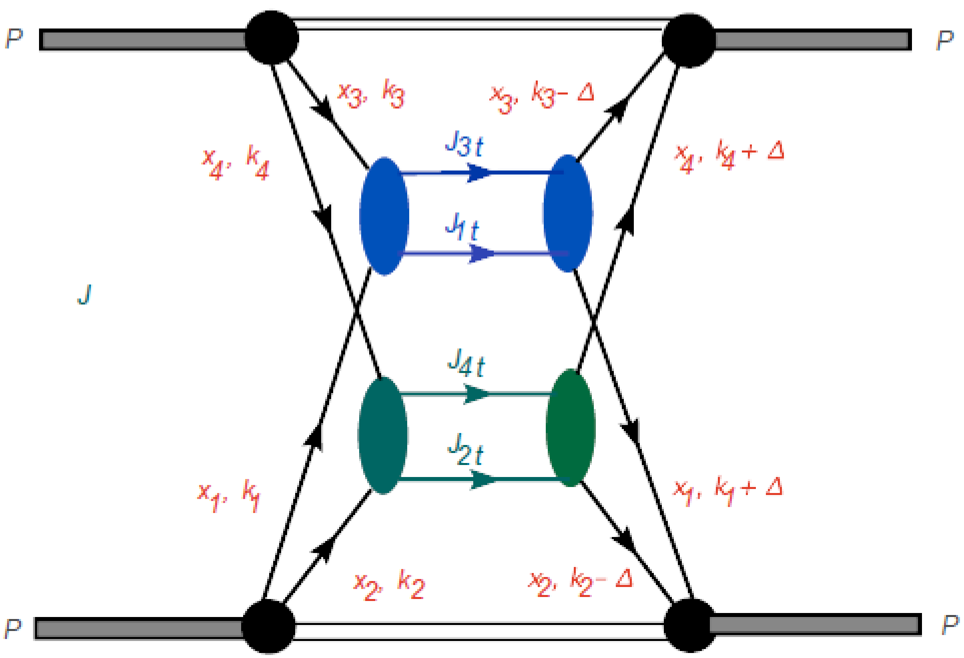
We shall talk here: mean field approach, impact parameter distributions, 3 to 4 versus 4 to 4 mechanism, MPI in pA collisions, MPI in direct photon-nuclei collisions, first steps in numerical implementation.

New basic ideas:1) new universal objects 2 parton GPD $D(x_1, x_2, p_1^2, p_2^2, \vec{\Delta})$

2) DGLAP/parton ladder splitting mechanism-3 to 4, numerically gives the same order contribution as parton model 4 to 4 mechanism.

3) Double collinearly enhanced classification





G. 1: Kinematics of double hard collision - momenta of t

$$d\sigma^{(4\to4)} \;\propto\; \frac{\alpha_s^2}{\delta_{13}^2\,\delta_{24}^2}\, d^2 j_{3\perp} d^2 j_{4\perp} \cdot d\Sigma,$$

$$\delta_{13}^2 \ll Q^2, \quad \delta_{24}^2 \ll Q^2;$$

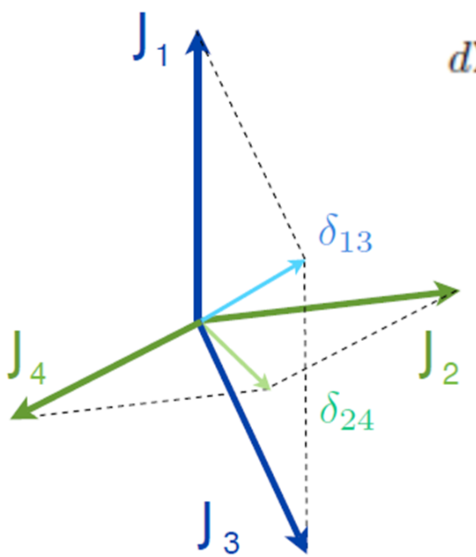
$$d\sigma^{(3\to4)} \;\propto\; \frac{\alpha_s^2}{\delta'^2\,\delta^2}\, d^2 j_{3\perp} d^2 j_{4\perp} \cdot d\Sigma,$$

$$\delta'^2 \ll \delta^2 \ll Q^2,\; \delta^2 = \delta_{13}^2 \simeq \delta_{24}^2.$$

In back-to back kinematics they are double collinear enhanced (and 2 to 4 are not)

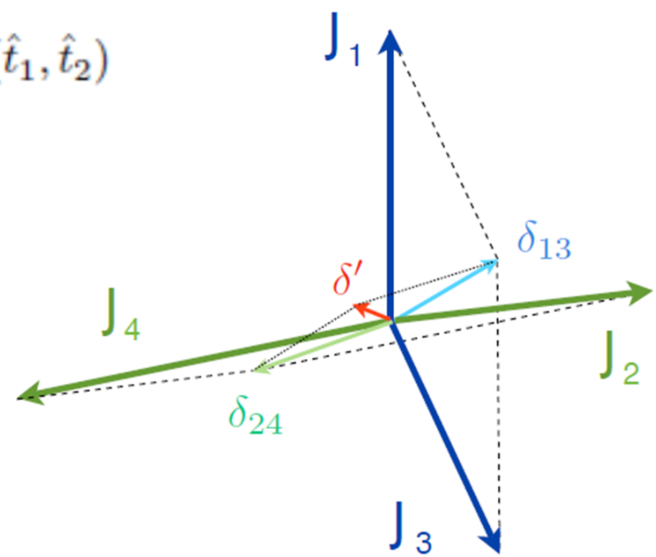
back-to-back kinematics

$$\delta_{13}^2, \delta_{24}^2 \ll J_{i\perp}^2$$



$$d\Sigma(\hat{t}_1, \hat{t}_2)$$

$$\delta'^2 \ll \delta_{13}^2 \simeq \delta_{24}^2 \ll J_{i\perp}^2$$



$$d\sigma^{(4\to4)} \propto \frac{\alpha_s^2}{\delta_{13}^2\,\delta_{24}^2}\, d^2 j_{3\perp} d^2 j_{4\perp} \cdot d\Sigma$$

$$d\sigma^{(3\to4)} \propto \frac{\alpha_s^2}{\delta'^2\,\delta^2}\, d^2 j_{3\perp} d^2 j_{4\perp} \cdot d\Sigma$$

The four jet cross-section in the parton model.

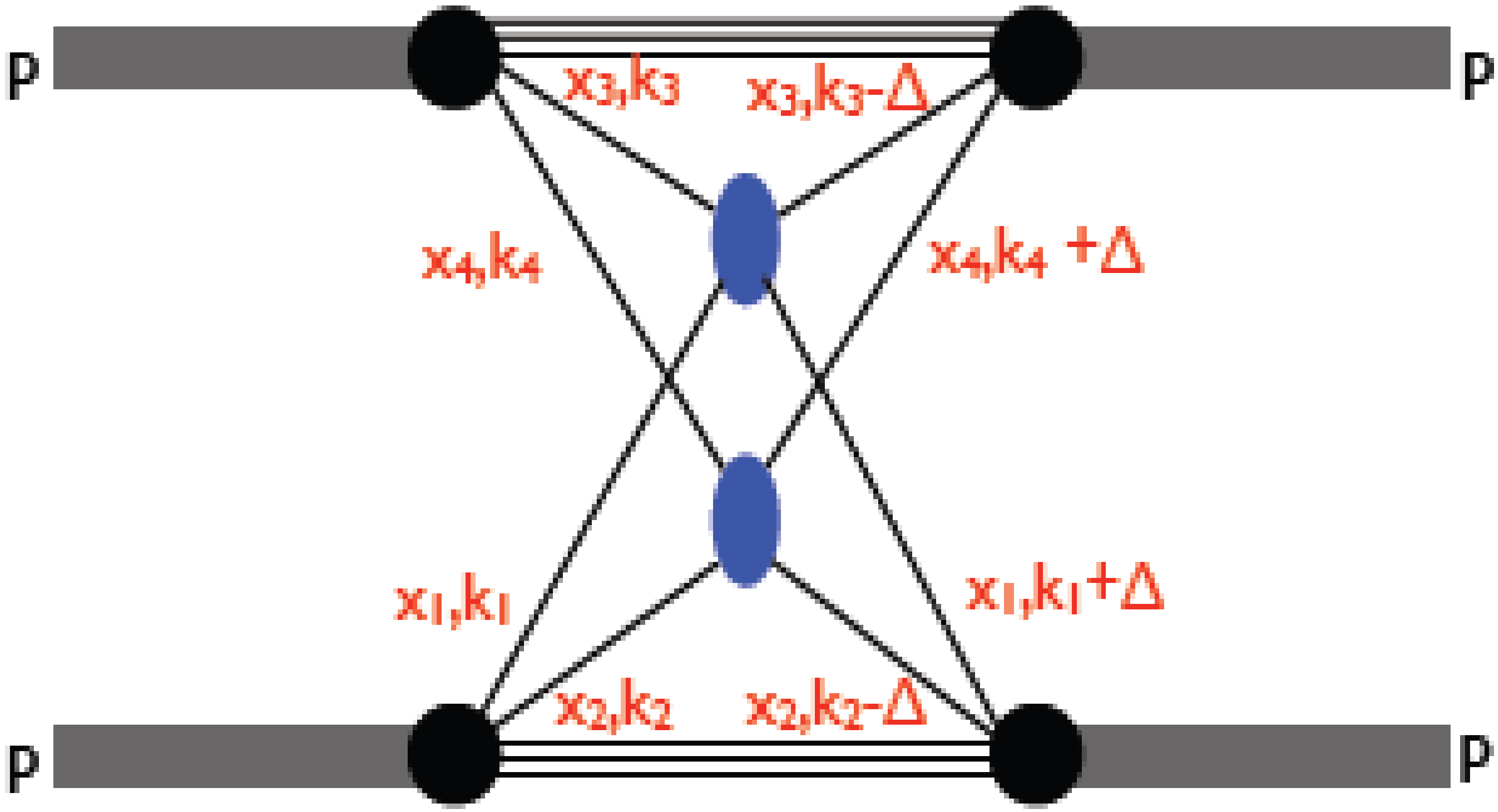
The four jet cross-section can be directly calculated in momentum space and is given by the formula:

$$\sigma_4(x_1,x_2,x_3,x_4) = \int \frac{d^2\vec{\Delta}}{(2\pi)^2} D_a(x_1,x_2,p_1^2,p_2^2,\vec{\Delta}) \times D_b(x_3,x_4,p_1^2,p_2^2,-\vec{\Delta}) \times \frac{d\sigma^{13}}{d\hat{t}_1}\frac{d\sigma^{24}}{d\hat{t}_2} d\hat{t}_1 d\hat{t}_2. \qquad (2)$$

Experimentalists often denote:

$$\sigma_4 = \sigma_1\sigma_2/\pi R_{\rm int}^2,$$

Coordinate representations calculations first-in Treleani Paver (1985), Mekhfi (1985)


p
p
p
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x3,k3
x3,k3-Δ
x4,k4
x4,k4 +Δ
x1,k1
x1,k1+Δ
x2,k2
x2,k2-Δ

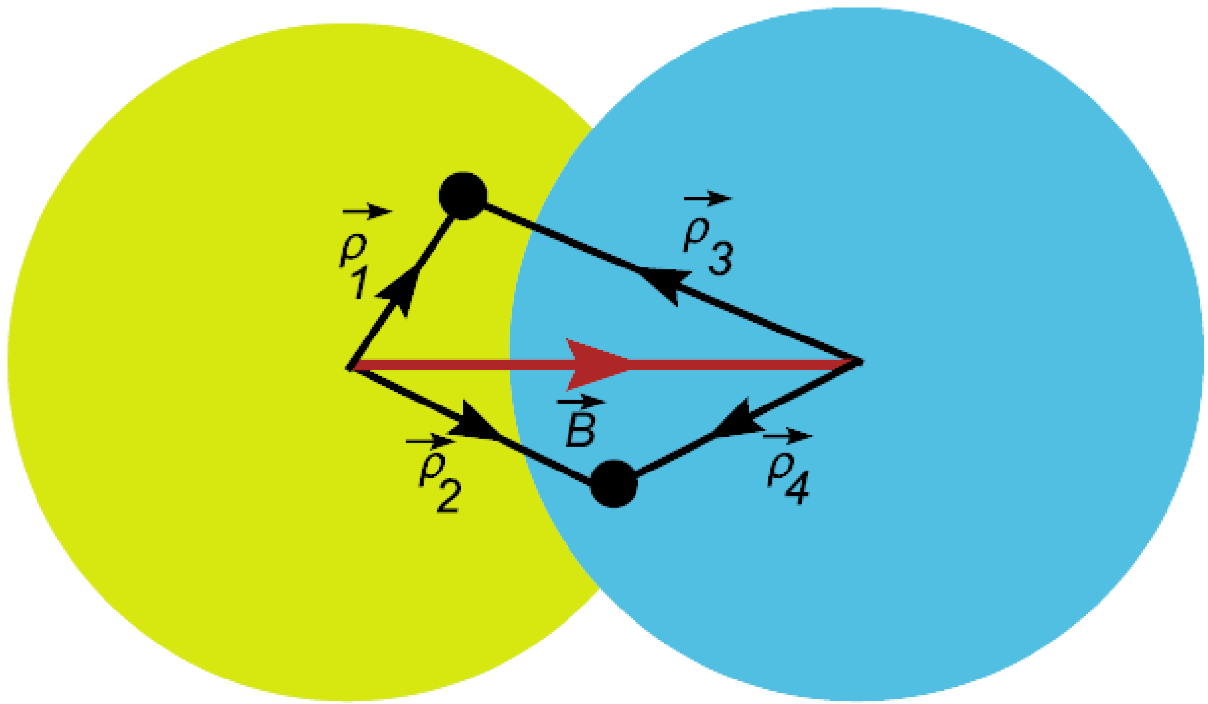


FIG. 2 (color online). Geometry of two hard collisions in impact parameter picture.

It follows from the discussion above that the area can be written explicitly in terms of these new two particle GPDs as

$$\frac{1}{\pi R_{\rm int}^2} = \int \frac{d^2\vec{\Delta}}{(2\pi)^2} \frac{D(x_1, x_2, -\vec{\Delta})D(x_3, x_4, \vec{\Delta})}{D(x_1)D(x_2)D(x_3)D(x_4)},$$

This formula is valid for inclusive dijet production. When the momentum fraction are different, the exclusive production DDT formula can be easily obtained. This

formula expresses the interaction area in the model independent way as the single integral over the transverse momenta.

The new GPDs can be explicitly expressed through the light cone wave functions of the hadron as

$$
\begin{aligned}
D\ (x_1, x_2, p_1^2, p_2^2, \overrightarrow{\Delta}) &= \sum_{n=3}^{\infty} \int \frac{d^2k_1}{(2\pi)^2} \frac{d^2k_2}{(2\pi)^2} \theta(p_1^2 - k_1^2) \\
&\times\ \theta(p_2^2 - k_2^2) \int \prod_{i \neq 1,2} \frac{d^2k_i}{(2\pi)^2} \int_0^1 \prod_{i \neq 1,2} dx_i \\
&\times\ \psi_n(x_1, \vec{k}_1, x_2, \vec{k}_2, .., \vec{k}_i, x_i..) \\
&\times\ \psi_n^+(x_1, \overrightarrow{k_1} + \overrightarrow{\Delta}, x_2, \overrightarrow{k_2} - \overrightarrow{\Delta}, x_3, \vec{k}_3, ...) \\
&\times\ (2\pi)^3 \delta(\sum_{i=1}^{i=n} x_i - 1) \delta(\sum_{i=1}^{i=n} \vec{k}_i). \qquad (5)
\end{aligned}
$$

Here psi are the light cone wave functions of the nucleon in the initial and final states.

The approximation of independent particles.

Suppose the multiparton wave faction factorise, i.e. we neglect possible interparton correlations and recoil effects. Then it's straightforward to see that the two particle GPDs factorise and acquire a form:

$$D(x_1, x_2, p_1^2, p_2^2, \vec{\Delta}) = G(x_1, p_1^2, \vec{\Delta})G(x_2, p_2^2, \vec{\Delta}),$$

The one-particle GPD-s G are conventionally written in the dipole form:

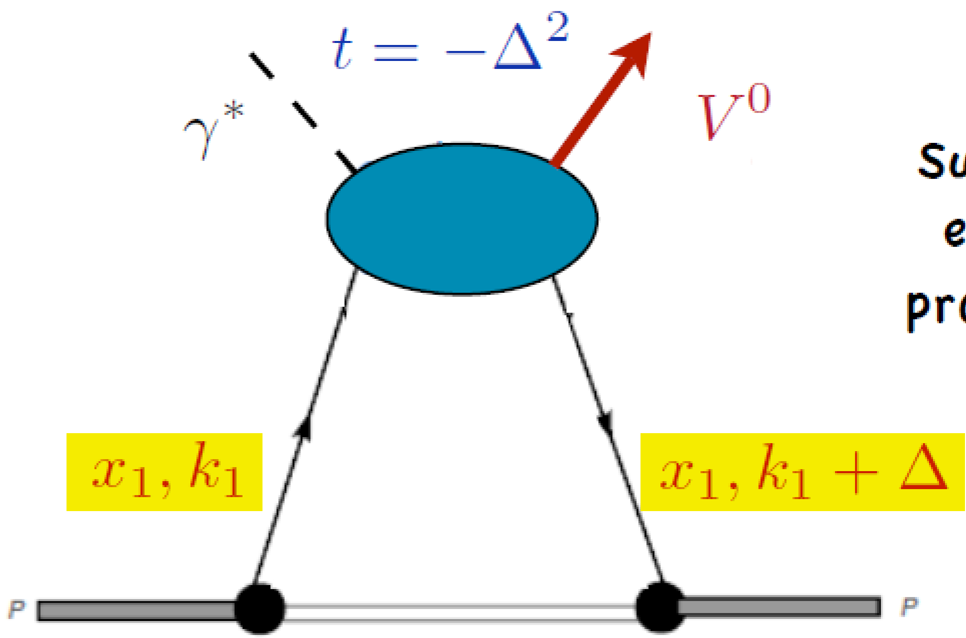
$$G_N(x, Q^2, \vec{\Delta}) = G_N(x, Q^2)F_{2g}(\Delta)$$

G - the usual 1-parton distribution (determining DIS structure functions)

F - the two-gluon form factor of the nucleon

the dipole fit : $$F_{2g}(\Delta) \simeq \frac{1}{\left(1+\Delta^2/m_g^2\right)^2}$$

$$m_g^2(x \sim 0.03, Q^2 \sim 3\text{GeV}^2) \simeq 1.1\text{GeV}^2$$



G P D

Such an amplitude describes exclusive photo-(/electro-) production of vector mesons at HERA !

$$\frac{1}{\pi R_{\rm int}^2} = \int \frac{d^2\Delta}{(2\pi)^2} F_{2g}^4(\Delta) = \frac{m_g^2}{28\pi}.$$

$$R_{\rm int}^2 = 7/2 r_g^2, \qquad r_g^2/4 = dF_{2g}(t)/dt_{t=0}.$$

Let us note that this result coincides with the one obtained in a geometric picture (Frankfurt,Strikman and Weiss 2003) However the latter computation involved a complicated 6 dimensional integral that potentially could lead to large numerical uncertainties

The dependence of r^2_g on Q^2 and x is given by the approximate formula that takes into account the DGLAP evolution:

$$\langle\rho^2\rangle(x,Q^2) = \langle\rho^2\rangle(x,Q_0^2)\left(1 + A\ln\frac{Q^2}{Q_0^2}\right)^{-a},$$

$$\langle\rho^2\rangle = \frac{8}{m_g^2}.$$

where

$$Q_0^2 = 3\,\mathrm{GeV}^2, \quad A = 1.5, \quad a = 0.0090\ln\frac{1}{x}.$$

The similar analysis for quark sea leads to slightly bigger transverse area (Strikman and Weiss 2009). Recoil may be important for large x_i but also leads to smaller total cross section, i.e. to larger R_{int}

Then we see the problem: the approximation of independent particles leads to the cross section two times smaller than the experimental one (Frankfurt,Strikman and Weiss 2004), *The experimental result is 15 mb, while the use of the electromagnetic radius of the nucleon leads to this area being 60 mb while we obtain in independent particle approximation 34 mb*

Even more naïve way-take $\sigma_{eff} = 1/\pi R^2$

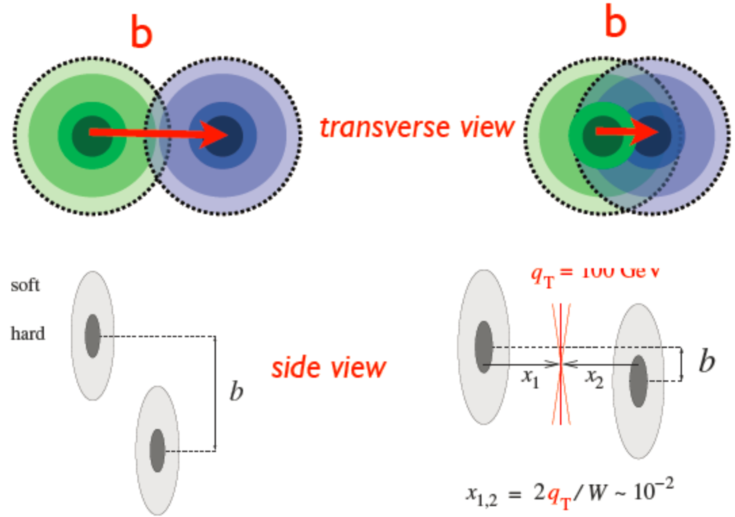
(most MC generators do)

The distribution in impact parameter b

Important characteristic of high energy collisions is the impact parameter of collision.

Well defined since angular momentum is conserved and L = bp

Different intensity of interactions for small and large impact parameters



Peripheral pp collisions

Central pp collisions

Two scale picture

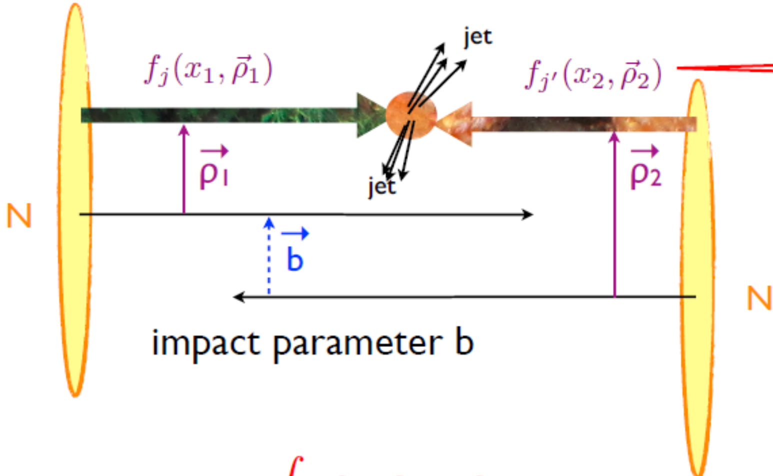
Small b ➠ large overlap of partons

Large probability of multiparton, soft/hard interactions

Using realistic transverse parton distributions is critical for genuine understanding of final states in pp

Frankfurt Strikman Weiss (2008),2011),
Rogers,Stasto, Strikman 2008

Geometry of pp collision with production of dijet in the transverse plane



Diagonal Generalized Parton distribution -

For hard collision

$$\vec{\rho}_1 + \vec{b} - \vec{\rho}_2 \propto 1/p_{tjet} \sim 0$$

$$\sigma_h \propto \int d^2b d^2\rho_1 d^2\rho_2 \delta(\rho_1 + b - \rho_2) f_1(x_1, \rho_1) f_2(x_2, \rho_2) \sigma_{2\to 2}$$

$$= \int d^2\rho_1 d^2\rho_2 f_1(x_1, \rho_1) f_2(x_2, \rho_2) \sigma_{2\to 2} = f_1(x_1) f_2(x_2) \sigma_{2\to 2}$$

$\Downarrow$

For inclusive cross section at high virtuality *transverse structure does not matter* - convolution of parton densities.

$\Downarrow$

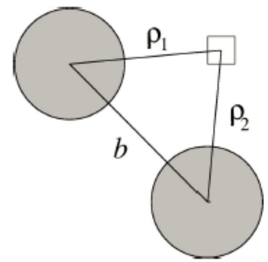
However critical for understanding global structure of inelastic events

Gluon GPDs and difference between transverse s b distributions for four jet, dijet triggers and minimal bias collisions

The distribution of interactions over b for events with *inclusive* dijet trigger (Higgs production,...) is given by

$$P_2(b) = \int d^2\rho_1 \int d^2\rho_2 \delta^{(2)}(\vec{b} - \vec{\rho}_1 + \vec{\rho}_2) F_g(x_1, \rho_1) F_g(x_2, \rho_2),$$

differential probability for dijet production to occur at given b



for $F_g(x,t) = 1/(1 - t/m_g(x)^2)$ $\quad F_g(x,\rho) = \frac{m_g^2}{2\pi}\left(\frac{m_g\rho}{2}\right) K_1(m_g\rho)$

$$P_2(b) = \frac{m_g^2}{12\pi}\left(\frac{m_g b}{2}\right)^3 K_3(m_g b)$$

$$P_N(b) = \frac{P_2(b)^N}{\int d^b P_2(b)^N}$$

Other distributions can be found in the same way.
Problem:

$$\mathcal{N}_{2k}(s,b) = \mathcal{N}_{2k}(b,\bar{x},p_t^c) = (\sigma_{2jet}^{inc} P_2(b,\bar{x},p_t^c))^k \; .$$

$$\Gamma_{jets}^{inel}(s,b) = 1 - \exp\left[-\sigma_{2jet}^{inc} P_2(b,\bar{x},p_t^c)\right]$$

$$\Gamma_{jets}^{inel}(s,b) \leq \Gamma^{inel}(s,b).$$

This unitarity condition is violated at small b unless unreasonably large more than 3.5 GeV transverse cut off is taken. Correlations improve the situation,
But if we add diffraction the problem probably returns.

Perturbative QCD and differential cross sections

Two basic ideas (relative to conventional one dijet processes-2 to2 in our notations):

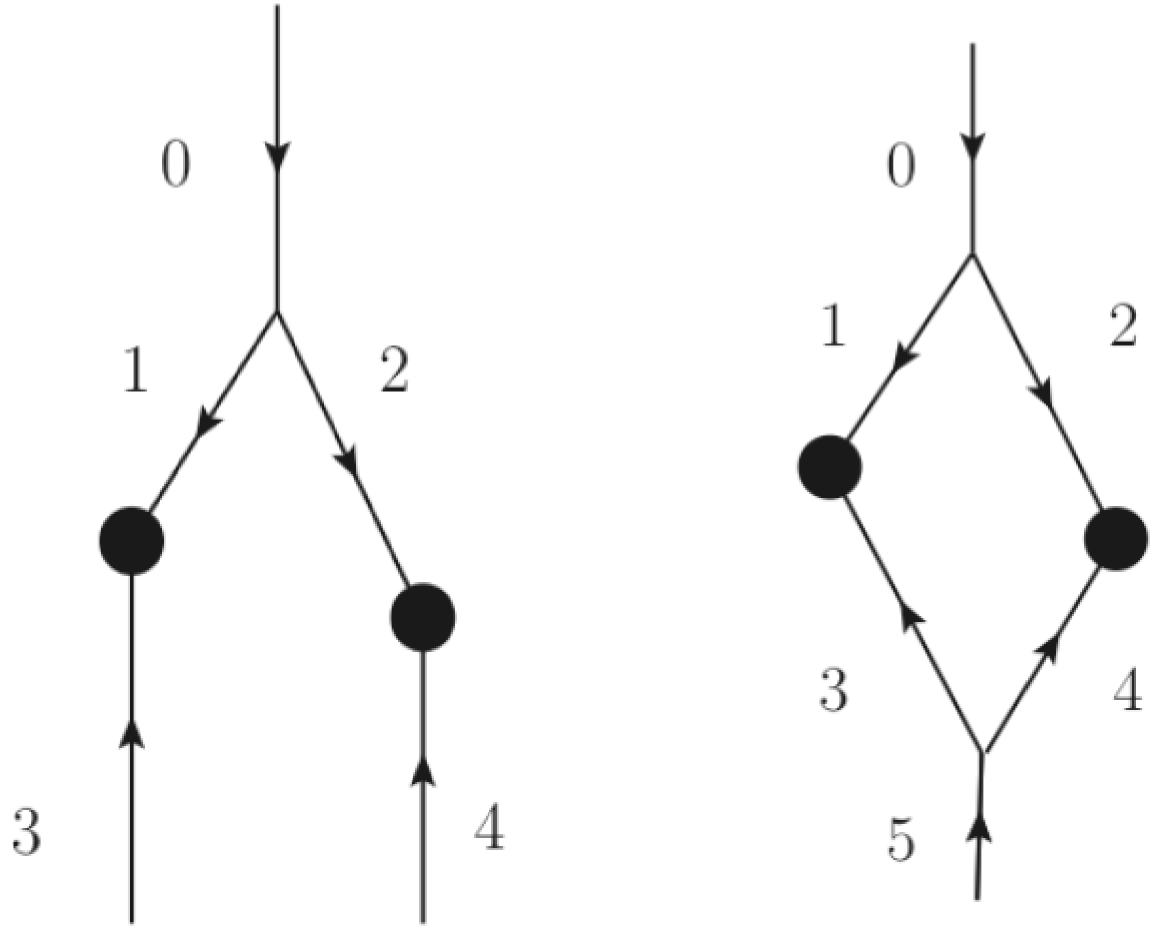
1. Double collinear enhancement in total cross sections-i.e. double pole enhancement in differential two dijet cross sections.

2. new topologies-in addition to conventional pQCD bremsstralung-parton/ladder splitting .

a) 4 to 4

b) 3 to 4

But no 2 to 4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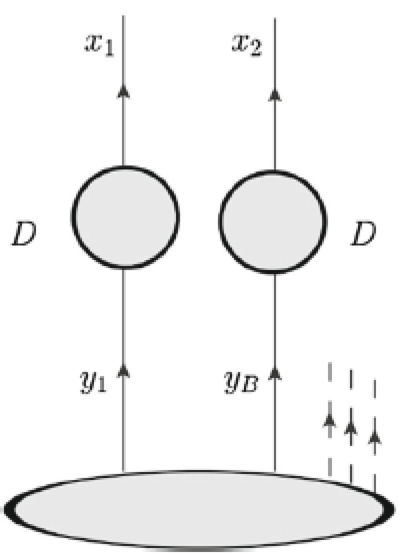
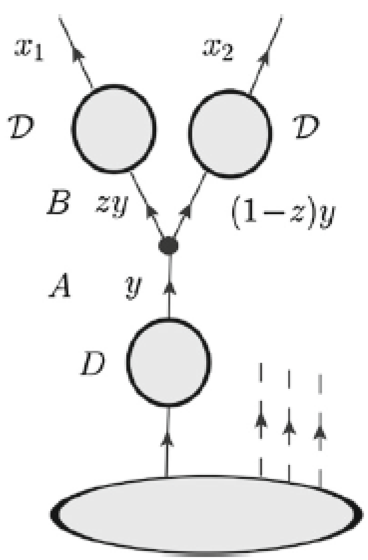
$$
{}_{[1]}D_a^{b,c}(x_1,x_2;q_1^2,q_2^2;\vec{\Delta})
= \sum_{a',b',c'} \int_{Q^2_{\min}}^{\min(q_1^2,q_2^2)} \frac{dk^2}{k^2}\frac{\alpha_s(k^2)}{2\pi}
\times \int \frac{dy}{y^2} G_a^{a'}(y;k^2,Q_0^2)
\times \int \frac{dz}{z(1-z)} P_{a'}^{b'[c']}(z)\, G_{b'}^{b}\left(\frac{x_1}{zy};q_1^2,k^2\right)
\times G_{c'}^{c}\left(\frac{x_2}{(1-z)y};q_2^2,k^2\right).
$$

$$
\begin{aligned}
{}_{[2]}D_a^{b,c}(x_1,x_2;q_1^2,q_2^2;\vec{\Delta})
&= S_b(q_1^2,Q^2_{\min})\,S_c(q_2^2,Q^2_{\min})\,{}_{[2]}D_a^{b,c}(x_1,x_2;Q_0^2,Q_0^2;\vec{\Delta}) \\
&+ \sum_{b'} \int_{Q^2_{\min}}^{q_1^2} \frac{dk^2}{k^2}\frac{\alpha_s(k^2)}{2\pi} S_b(q_1^2,k^2) \\
&\times \int \frac{dz}{z} P_{b'}^{b}(z)\,{}_{[2]}D_a^{b',c}\left(\frac{x_1}{z},x_2;k^2,q_2^2;\vec{\Delta}\right) \\
&+ \sum_{c'} \int_{Q^2_{\min}}^{q_2^2} \frac{dk^2}{k^2}\frac{\alpha_s(k^2)}{2\pi} S_c(q_2^2,k^2) \\
&\times \int \frac{dz}{z} P_{c'}^{c}(z)\,{}_{[2]}D_a^{b,c'}\left(x_1,\frac{x_2}{z};q_1^2,k^2;\vec{\Delta}\right). \qquad (16)
\end{aligned}
$$





$$
D_a^{b,c}(x_1,x_2;q_1^2,q_2^2;\vec{\Delta}) = {}_{[2]}D_a^{b,c}(x_1,x_2;q_1^2,q_2^2;\vec{\Delta}) + {}_{[1]}D_a^{b,c}(x_1,x_2;q_1^2,q_2^2;\vec{\Delta})
$$

$$\frac{1}{\sigma_{eff}} \equiv \int \frac{d^2\vec{\Delta}}{(2\pi)^2}[\ {}_{[2]}G_2(x_1,x_3,Q_1^2,Q_2^2;\vec{\Delta})_{[2]}G_2(x_2,x_4,Q_1^2,Q_2^2;-\vec{\Delta})$$

$$+\ {}_{[1]}G_2(x_1,x_3,Q_1^2,Q_2^2;\vec{\Delta})_{[2]}G(x_2,x_4,Q_1^2,Q_2^2;-\vec{\Delta})$$

$$+\ {}_{[1]}G_2(x_2,x_4,Q_1^2,Q_2^2;\vec{\Delta})_{[2]}G_2(x_1,x_3,Q_1^2,Q_2^2;-\vec{\Delta})].$$

2G2 and 1G2 are two parts of GPD ,calculated in two different ways. 2G2-in mean field approach, using GPD1 from charmonium photoproduction at HERA

$${}_{[2]}GPD_2(x_1,x_3,Q_1^2,Q_2^2,\Delta) = D_q(x_1,Q_1)D_g(x_3,Q_2)F_{2g}(\Delta,x_1)F_{2g}(\Delta,x_3),$$

$$GPD_{q,g}(x,Q^2,\Delta) = D_{q,g}(x,Q)F_{2g,2q}(\Delta,x).$$

We use parametrisation due to Frankfurt,Strikman,Weiss (2011)

1G2 is calculated solving evolution equation for GPD

The final answer for effective cross section is convenient to represent as

$$\sigma_{\rm eff} = \frac{\sigma_{\rm eff}^{(0)}}{1+R},$$

Here $\sigma_{\rm eff}^{(0)}$ *is the 4 to 4 cross section in mean field approximationwhile the function R corresponds to contribution due to 3 to 4 mechanism, and is calculated analytically.*

Note: only one unknown paramter-Q0, separating soft and hard scales, so approach is practically model independent.

- Concequently, in the differential distributions we have 3 terms, corresponding to 4 to 4 and 3 to 4 (long and short):

$$\pi^2 \frac{d\sigma^{(4\to 4)}}{d^2\delta_{13}\, d^2\delta_{24}} = \frac{d\sigma_{\rm part}}{d\hat{t}_1\, d\hat{t}_2} \cdot \frac{\partial}{\partial\delta_{13}^2}\frac{\partial}{\partial\delta_{24}^2}\Big\{ {}_{[2]}D_a^{1,2}(x_1,x_2;\delta_{13}^2,\delta_{24}^2) \times {}_{[2]}D_b^{3,4}(x_3,x_4;\delta_{13}^2,\delta_{24}^2) \times S_1\left(Q^2,\delta_{13}^2\right) S_3\left(Q^2,\delta_{13}^2\right) \times S_2\left(Q^2,\delta_{24}^2\right) S_4\left(Q^2,\delta_{24}^2\right) \Big\}.$$

$$\pi^2 \frac{d\sigma_1^{(3\to 4)}}{d^2\delta_{13}\, d^2\delta_{24}} = \frac{d\sigma_{\rm part}}{d\hat{t}_1\, d\hat{t}_2} \cdot \frac{\partial}{\partial\delta_{13}^2}\frac{\partial}{\partial\delta_{24}^2}\Big\{ {}_{[1]}D_a^{1,2}(x_1,x_2;\delta_{13}^2,\delta_{24}^2) \cdot {}_{[2]}D_b^{3,4}(x_3,x_4;\delta_{13}^2,\delta_{24}^2) \times S_1\left(Q^2,\delta_{13}^2\right) S_3\left(Q^2,\delta_{13}^2\right) \cdot S_2\left(Q^2,\delta_{24}^2\right) S_4\left(Q^2,\delta_{24}^2\right) \Big\}.$$

- here S are the corresponding Sudakov formfactors . We see that 4 to 4 and long split 3 to 4 are expressed through convolution of 2GPD of two colliding hadrons – the expressions look
- quite similar to DDT formula

The total cross sections

$$\frac{d\sigma(x_1,x_2,x_3,x_4)}{d\hat{t}_1\, d\hat{t}_2} = \frac{d\sigma^{13}}{d\hat{t}_1}\,\frac{d\sigma^{24}}{d\hat{t}_2} \times \left\{ \frac{1}{S_4} + \frac{1}{S_3} \right\}.$$

$$\frac{1}{S_4} = \int \frac{d^2\vec{\Delta}}{(2\pi)^2}\, {}_{[2]}D_{h_1}(x_1,x_2;q_1^2,q_2^2;\vec{\Delta})\, {}_{[2]}D_{h_2}(x_3,x_4;q_1^2,q_2^2;-\vec{\Delta}).$$

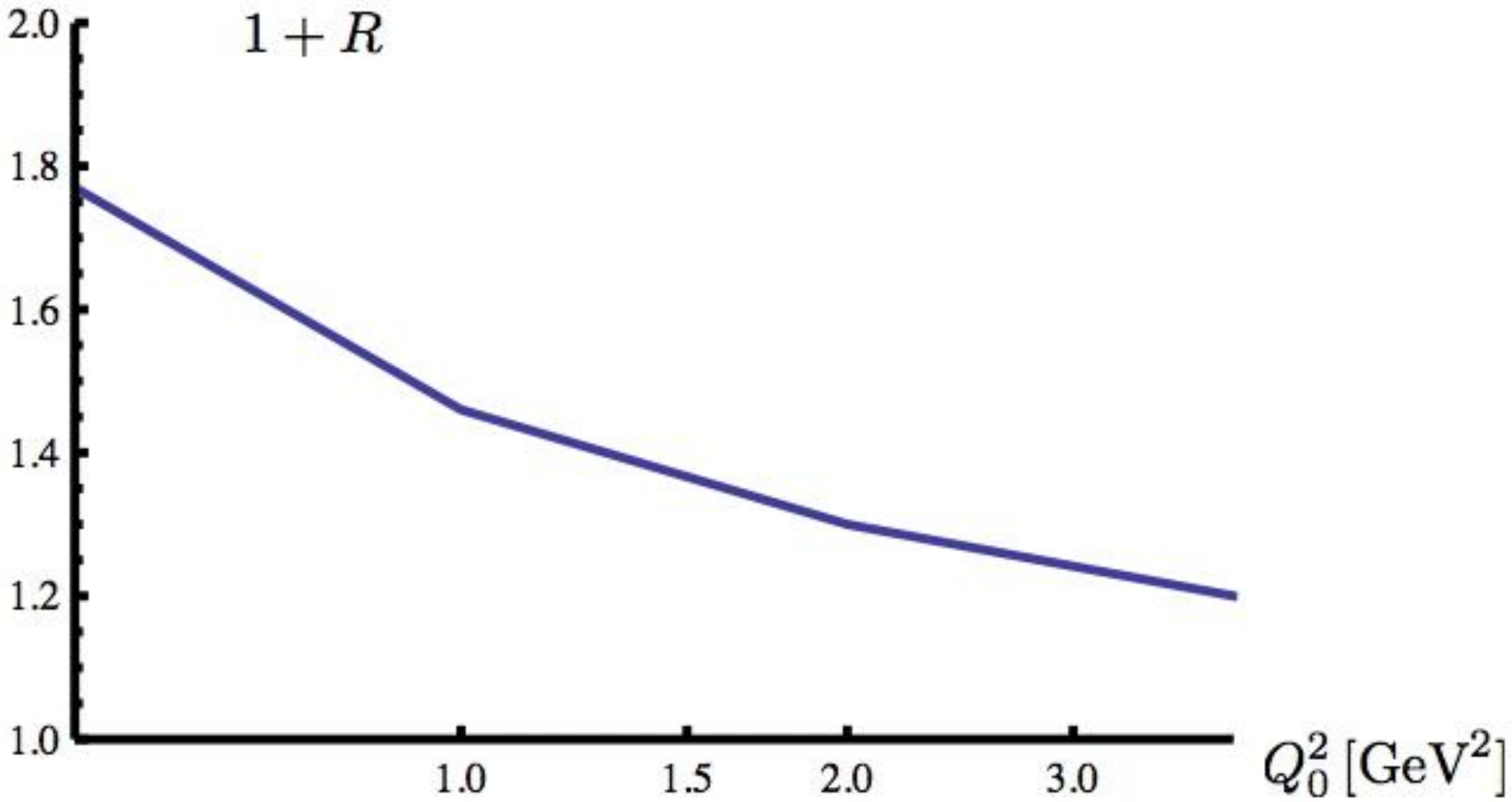
$$\frac{1}{S_3} = \int \frac{d^2\vec{\Delta}}{(2\pi)^2} \left[{}_{[2]}D_{h_1}(x_1,x_2;q_1^2,q_2^2;\vec{\Delta})\, {}_{[1]}D_{h_2}(x_3,x_4;q_1^2,q_2^2) + {}_{[1]}D_{h_1}(x_1,x_2;q_1^2,q_2^2)\, {}_{[2]}D_{h_2}(x_3,x_4;q_1^2,q_2^2;\vec{\Delta}) \right].$$

Analytical estimate

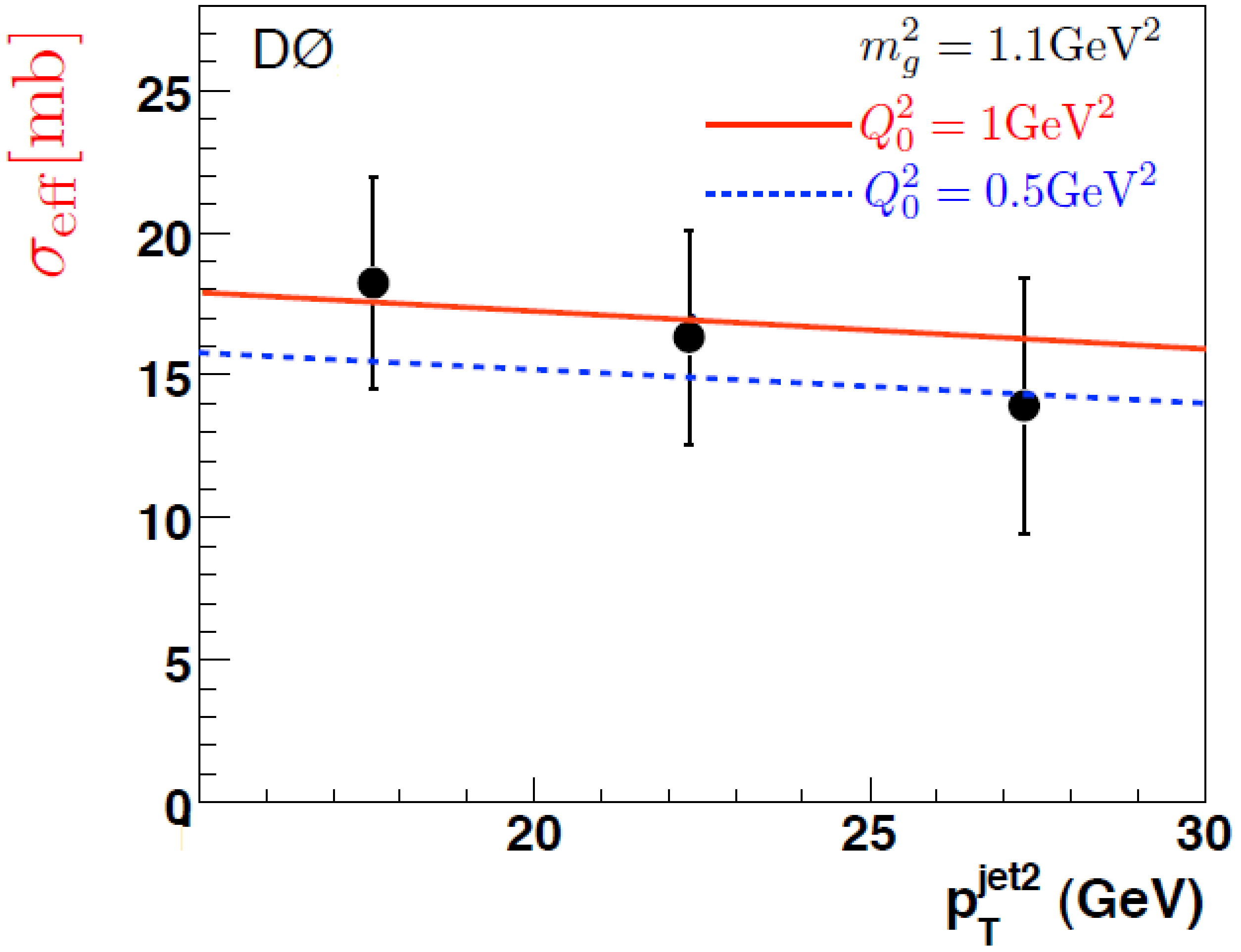
$$\frac{D^{bc}(x_1, x_2; 0)}{G^b(x_1)G^c(x_2)} - 1 \simeq \frac{N_c}{2(n_q C_F + n_g N_c)}.$$

Decreases with x,, of order 2 increase of cross sections

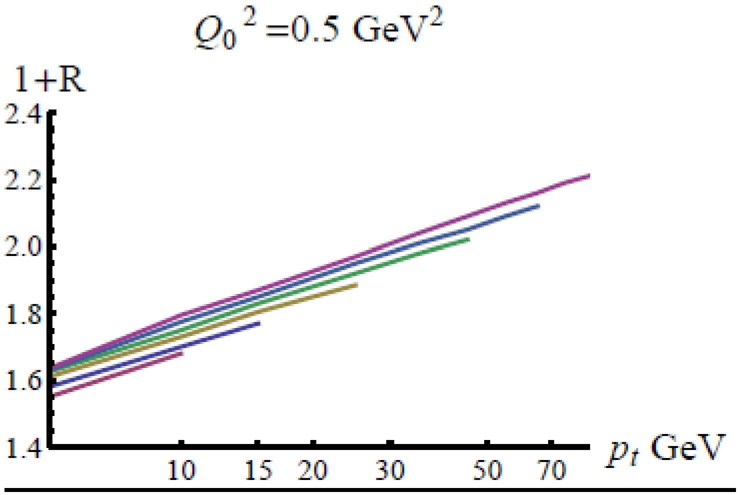
The dependence on Q_0^2 (ladder split scale)

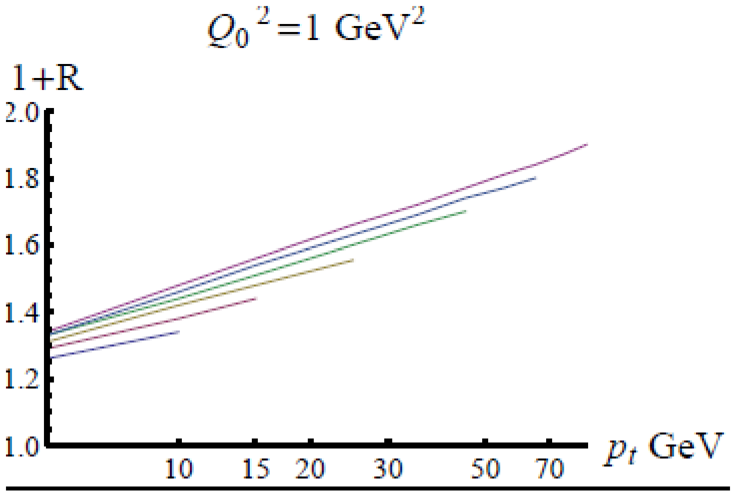


D0 physics (slightly larger energies)



The dependence on transverse momentum of a gluonic dijet for different Photon momenta.





Good agreement with Tevatron, soft and NLO to be included

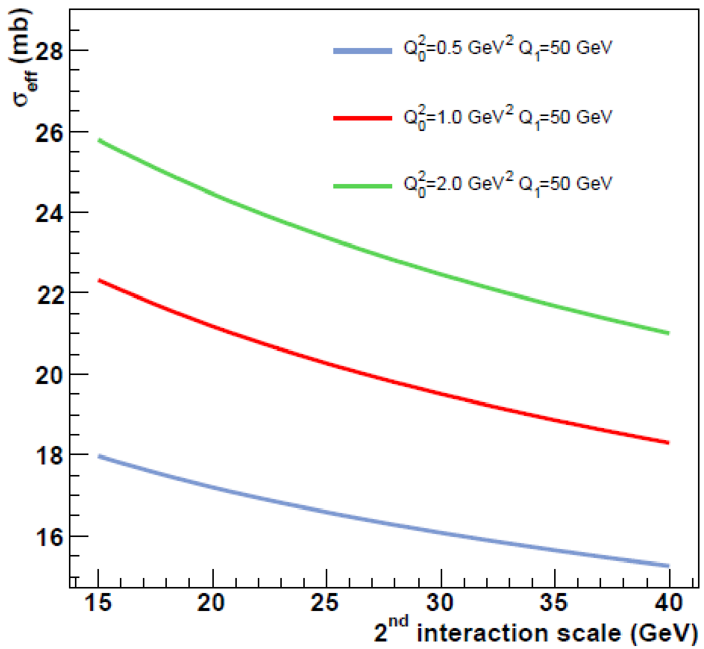


FIG. 10: Values of σ_{eff} as a function of the scale of the 2^{nd} interaction for different scales of the first interaction, Q_1, and different choices of Q_0^2. The values of the longitudinal momentum fractions correspond to the maximal transverse momentum exchange.

Basic Pythia approach: fit the MPI cross section (and other observables) by using only 4 to 4 contribution in mean field approach and fitting the parameters of the corresponding objects-essentially GPD1. For these GPD1-several ansats,
Simplest-gaussian, more complicated-sum of two gaussians (may be x –dependent).The parameters however are fixed and do not depend on transverse scale. Their optimal values-by combining Pythia and Professor. Problem (P. Gunnellini, Ph.D. thesis): can not have reasonable choice of parameters, valid both for DPS and Underlying event.

The way to solve this problem: include 3 to 4 mechanism, i.e. R not equal to zero, while 4 to 4 contribution will be determined in a model independent way from HERA parametrisation, and not from fit of pp experimental data as in Pythia

Algorithm: take pythia tune, then rescale it on event to event basis, so that effective cross section is given by a theoretical number calculated above.

Several comments:
1. for UE the rescaling coefficients are very small and there is no change (less than 4 percent) for all observables
2.We do not renormalise SPS events.
3.If there are 3 and more dijets in an event, we renormalise as if there are 2 dijets, and take hardest scales.
4.We assume that there is no difference if we use differential cross sections and global ones.

More precisely, one will need $\frac{\pi^2 d\sigma^{\rm DPI}}{d^2\delta_{13}\, d^2\delta_{24}}$

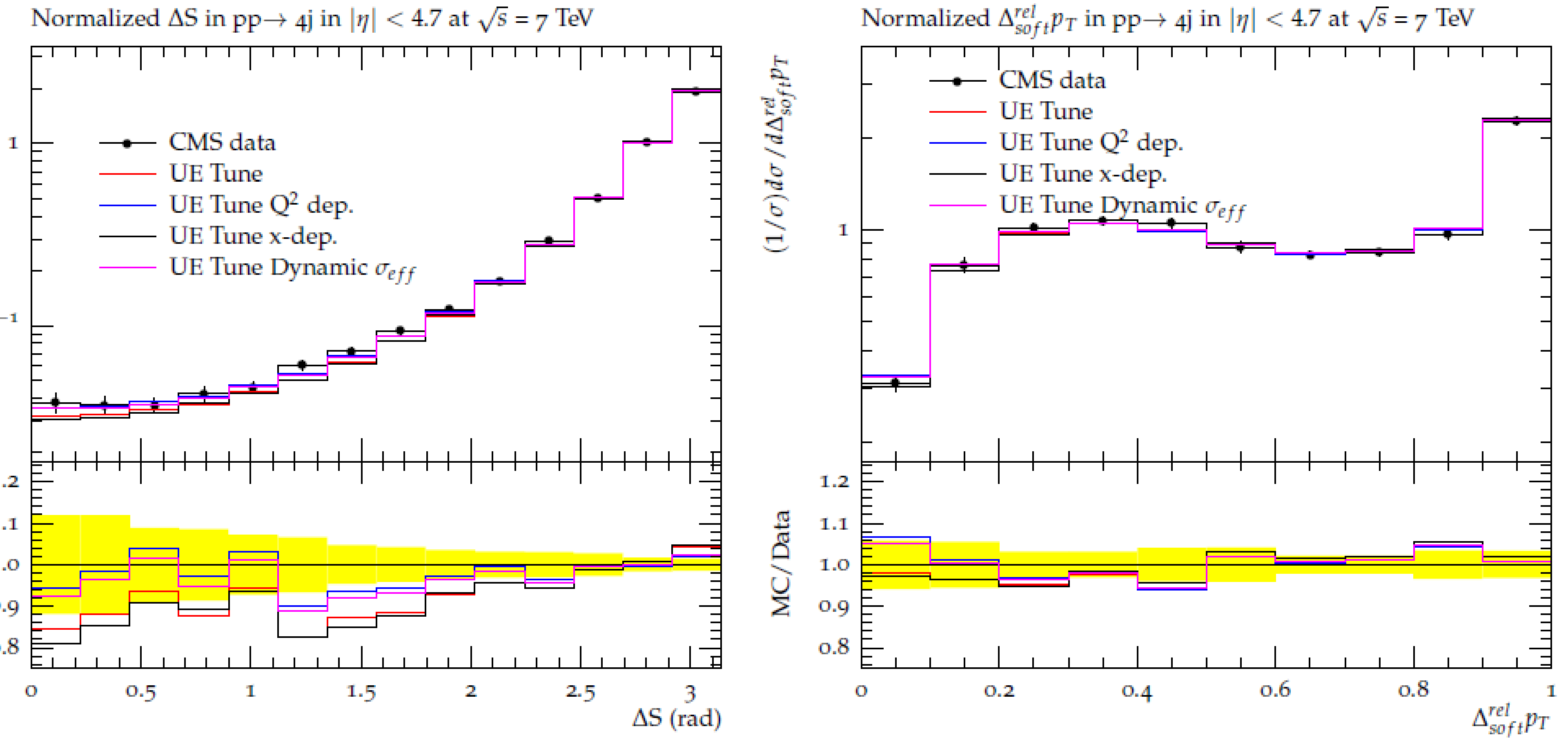


FIG. 4: Normalized cross section distributions as a function of the correlation observables ΔS (left) and $\Delta^{rel}_{soft} p_T$ (right) measured in a four-jet scenario by the CMS experiment at 7 TeV [38]. The data are compared to various predictions: the new UE tune (red curve), the new UE tune with the x dependence applied (blue curve), the new UE tune with only the scale dependence with Q_0^2=1.0 GeV^2 applied (black curve) and the new UE tune with both x and scale dependence with Q_0^2=1.0 GeV^2 applied (pink curve). The lower panel shows the ratio between the various prediction and the experimental points.

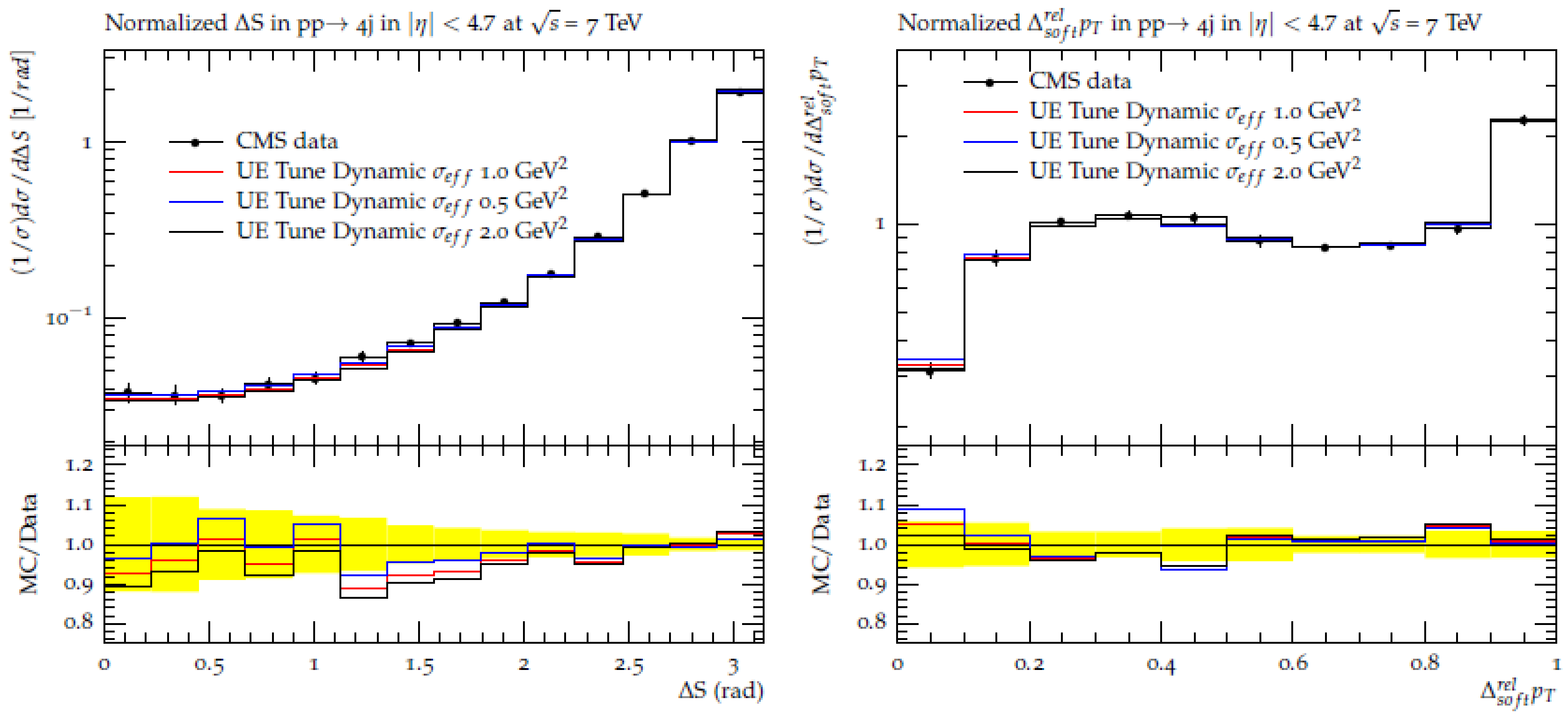


FIG. 5: Normalized cross section distributions as a function of the correlation observables ΔS (left) and $\Delta^{rel}_{soft} p_T$ (right) measured in a four-jet scenario by the CMS experiment at 7 TeV [38]. The data are compared to various predictions obtained with the new UE tune where both x and scale dependence have been applied with Q_0^2 equal to 1.0 (red curve), 0.5 (blue curve) and 2.0 (black curve) GeV^2. The lower panel shows the ratio between the various prediction and the experimental points.

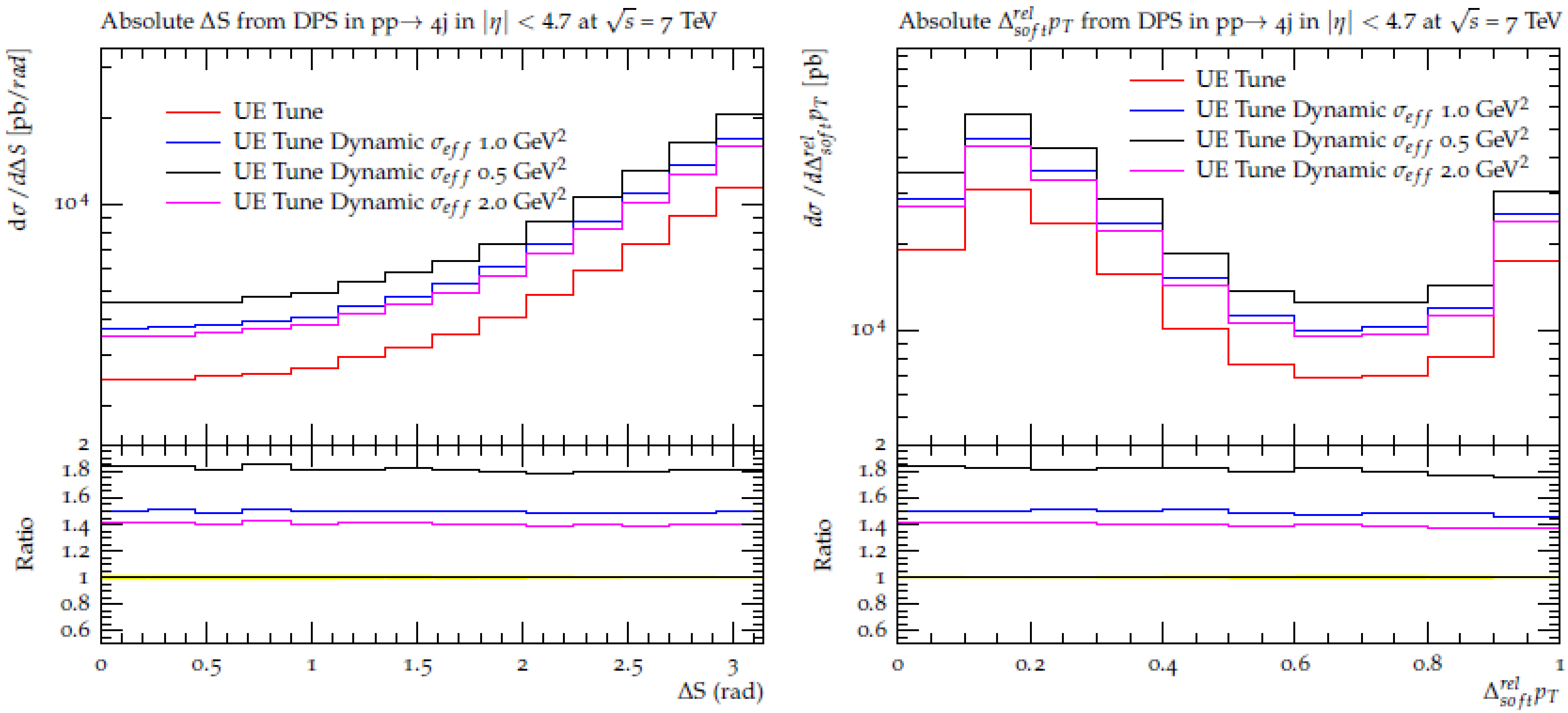


FIG. 6: Absolute cross section distributions as a function of the correlation observables ΔS (left) and $\Delta^{rel}_{soft}p_T$ (right), produced via double parton scattering in a four-jet scenario at 7 TeV. Various predictions are shown in the figures: the new UE tune (red curve), the new UE tune with the x dependence applied (blue curve), the new UE tune with only the scale dependence with Q_0^2=1.0 GeV^2 applied (black curve) and the new UE tune with both x and scale dependence with Q_0^2=1.0 GeV^2 applied (pink curve). The lower panel shows the ratio between the various predictions and the predictions obtained with the new UE tune.

Similar results-for Wjjj/Zjj

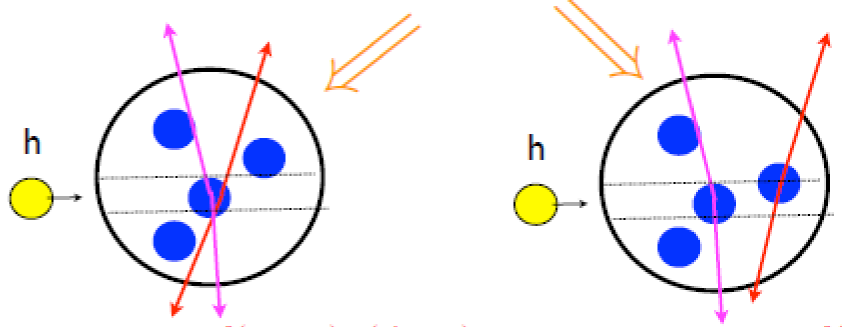
MPI in pA collisions-much bigger number of MPI-s geometrically enhanced, since now all nucleons on given impact parameter interact coherently with a projectile nucleon. The number of MPI-s increases like

$$A^{1/3}$$

Multiparton interactions in proton - nucleus collisions

$$\sigma = \sigma_1 \cdot A + \sigma_2$$

MS & Treleani 95 - PRL 2002



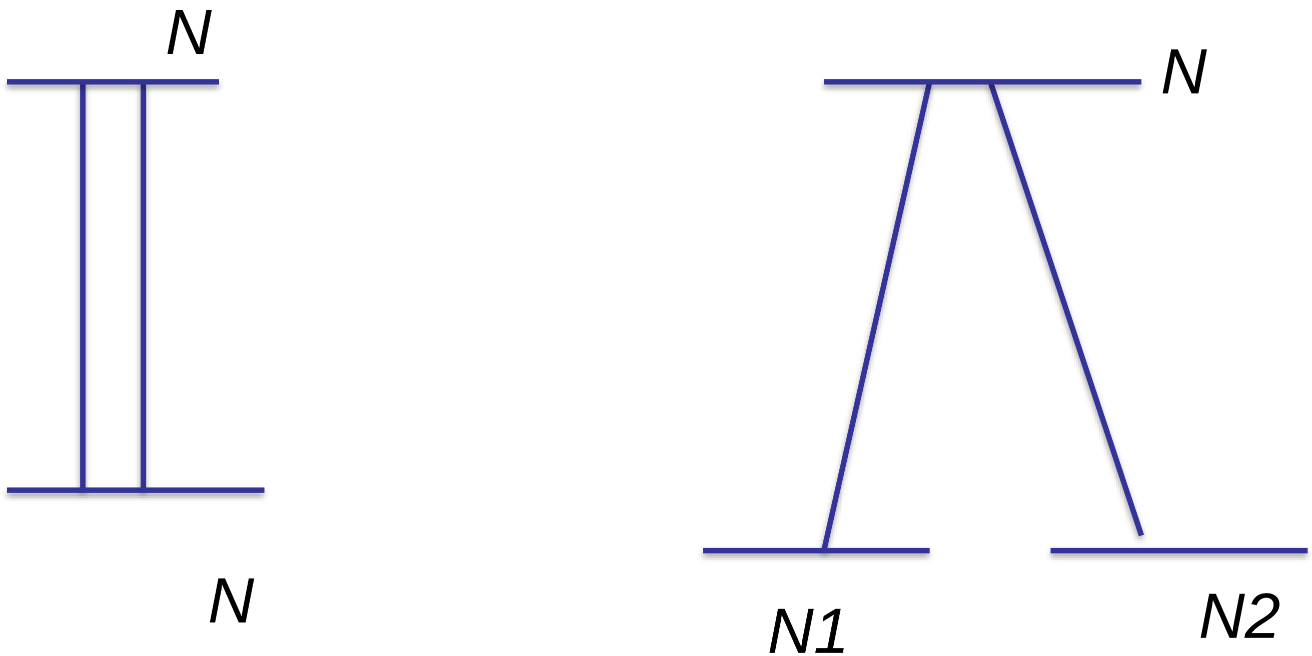
$$\rho \equiv \frac{\sigma_2}{\sigma_1 \cdot A} \approx \frac{f(x_1,x_2)}{f(x_1)f(x_2)} \frac{(A-1)}{A^2} \cdot \sigma_{eff} \int T^2(b)\, d^2b \approx \frac{f(x_1,x_2)}{f(x_1)f(x_2)}\, 0.68 \cdot \left(\frac{A}{12}\right)^{0.39} \Big|_{A\geq 12, S\sim 14mb}$$

$$T(b) = \int_{-\infty}^{\infty} dz \rho_A(z,b), \int T(b) d^2b = A.$$

"Antishadowing effect": For A=200, and S=14 mb $\frac{\sigma_{pA}}{\sigma_{pp}} \approx 3$ if no correlations

Measurement of R allows to separate longitudinal and transverse correlations of partons as it measures $R=f(x_1,x_2)/f(x_1)f(x_2)$ - BDKS R~1.2 from 3 → 4

$$\sigma_{pA}/\sigma_{pp} \approx 3.5$$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MPI in pA scattering B.Blok, M. Strikman, U. Wiedemann)

Eur.Phys.J. C73 (2013) no.6, 2433

$$\frac{d\sigma^{AB}_{4jet}}{d\hat{t}_1 d\hat{t}_2} = \int \frac{d^2\vec{\Delta}}{(2\pi)^2} \frac{d\hat{\sigma}_1(x_1', x_1)}{d\hat{t}_1} \frac{d\hat{\sigma}_2(x_2', x_2)}{d\hat{t}_2} \, {}_2G_A(x_1', x_2', \vec{\Delta}) \, {}_2G_B(x_1, x_2, \vec{\Delta}) \, .$$

$${}_2G_A(x_1, x_2, \vec{\Delta}) = G_A^{\text{single,1N}}(x_1, x_2, \vec{\Delta}) + G_A^{\text{double,1N}}(x_1, x_2, \vec{\Delta}) + G_A^{2N}(x_1, x_2, \vec{\Delta}) \, .$$

First two terms sum to expression increasing as A:

$$\frac{\sigma^{pA,1N}_{4jet}}{d\hat{t_1}\, d\hat{t_2}} \approx A \frac{d\sigma^{pp}_{4jet}}{d\hat{t_1}\, d\hat{t_2}} = \frac{A}{S} \frac{d\sigma^{pp}_{2jet}}{d\hat{t_1}} \frac{d\sigma^{pp}_{2jet}}{d\hat{t_2}} \, .$$

Third term: (3 to 4 from nucleon is suppressed

$$\frac{\sigma_4^{(III)}(x_1', x_2', x_1, x_2)}{d\hat{t}_1 d\hat{t}_2} = \frac{f_p(x_1', x_2')}{f_p(x_1') f_p(x_2')} \frac{d\sigma^{pp}_{\text{2jet}}(x_1', x_1)}{d\hat{t}_1} \frac{d\sigma^{pp}_{\text{2jet}}(x_2', x_2)}{d\hat{t}_2} \frac{(A-1)}{A} \underbrace{\int T^2(b) d^2b}_{\propto A^{4/3}} \, .$$

-leading term A(A-1) (Strikman-Treleani)

$$R_{pA}^{4jet}(x_1,x_2,x_1',x_2') \equiv \frac{d\sigma_{4jet}^{pA}(x_1,x_2,x_1',x_2')}{d\hat{t}_1\, d\hat{t}_2} \Bigg/ \frac{A}{S} \frac{d\sigma_{2\,jet}(x_1',x_1)}{d\hat{t}_1} \frac{d\sigma_{2\,jet}(x_2',x_2)}{d\hat{t}_2}$$

$$= 1 + \frac{S}{A}\frac{A-1}{A}\int T^2(b) d^2b \frac{G_p(x_1',x_2')}{f_p(x_1')\, f_p(x_2')},$$

$$G_p(x_1',x_2') = f_p(x_1',x_2') + G_p^{\mathrm{single}}(x_1',x_2',0)\,.$$

We measure:

$$K(x_1',x_2') = \frac{R_{pA}^{4jet}(x_1,x_2,x_1',x_2')-1}{S\,W(A)} = \frac{G_p(x_1',x_2',0)}{f_p(x_1')f_p(x_2')}\,.$$

$$W(A) = \frac{A-1}{A^2}\int d^2bT^2(b)\,,$$

Distinction of K from 1 will mean longitudinal correlations

$$x \geq 0.005.$$

The corrections due to shadowing will be small in this kinematic region

(see also Treleani, Calucci 2012 for shadowing/interference for pd)

Shadowing-for heavy nuclei factorization, for pD-B. Blok, M. Strikman, Eur. Phys. J. C74(2014) 3038

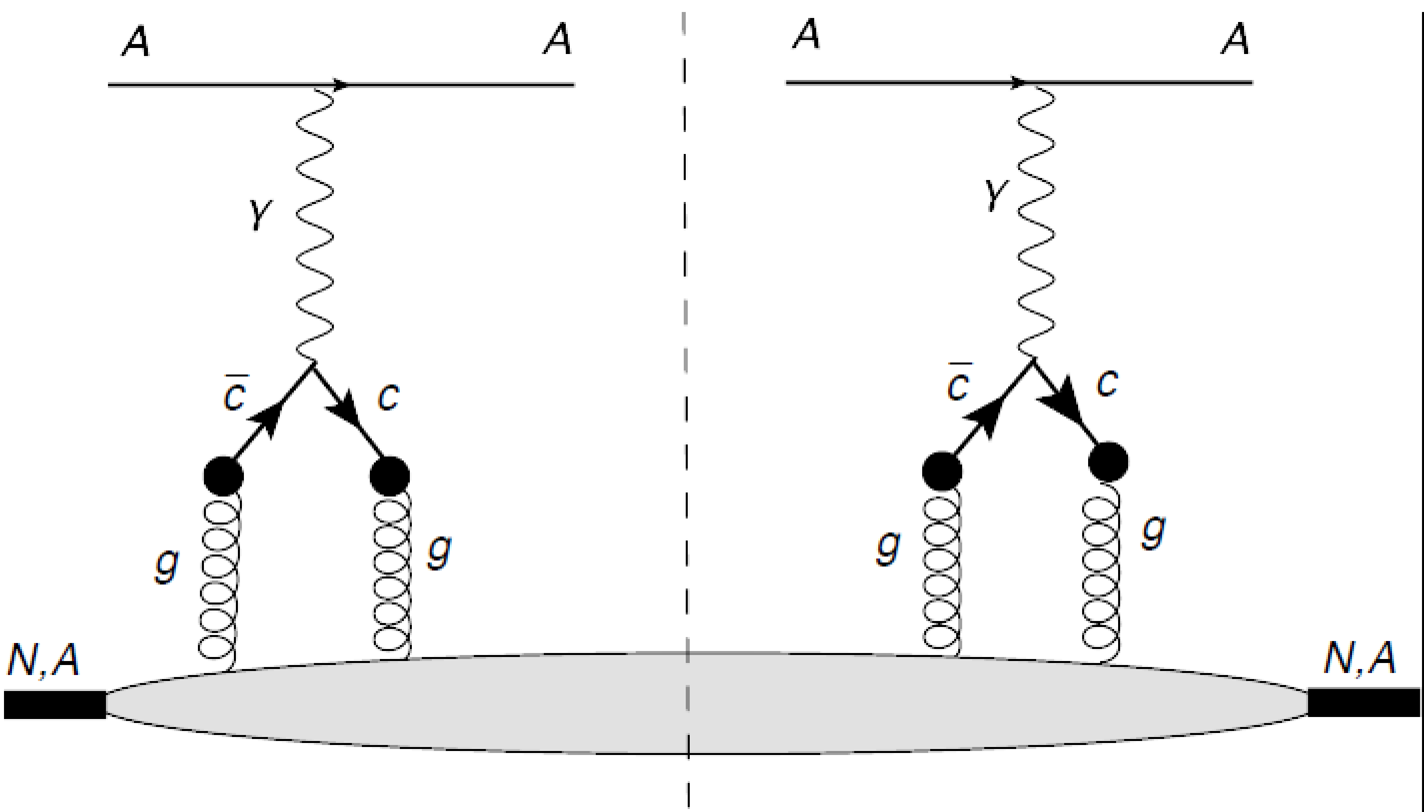
Can one see 3 to 4 directly?direct photons in ultraperipheral collisions

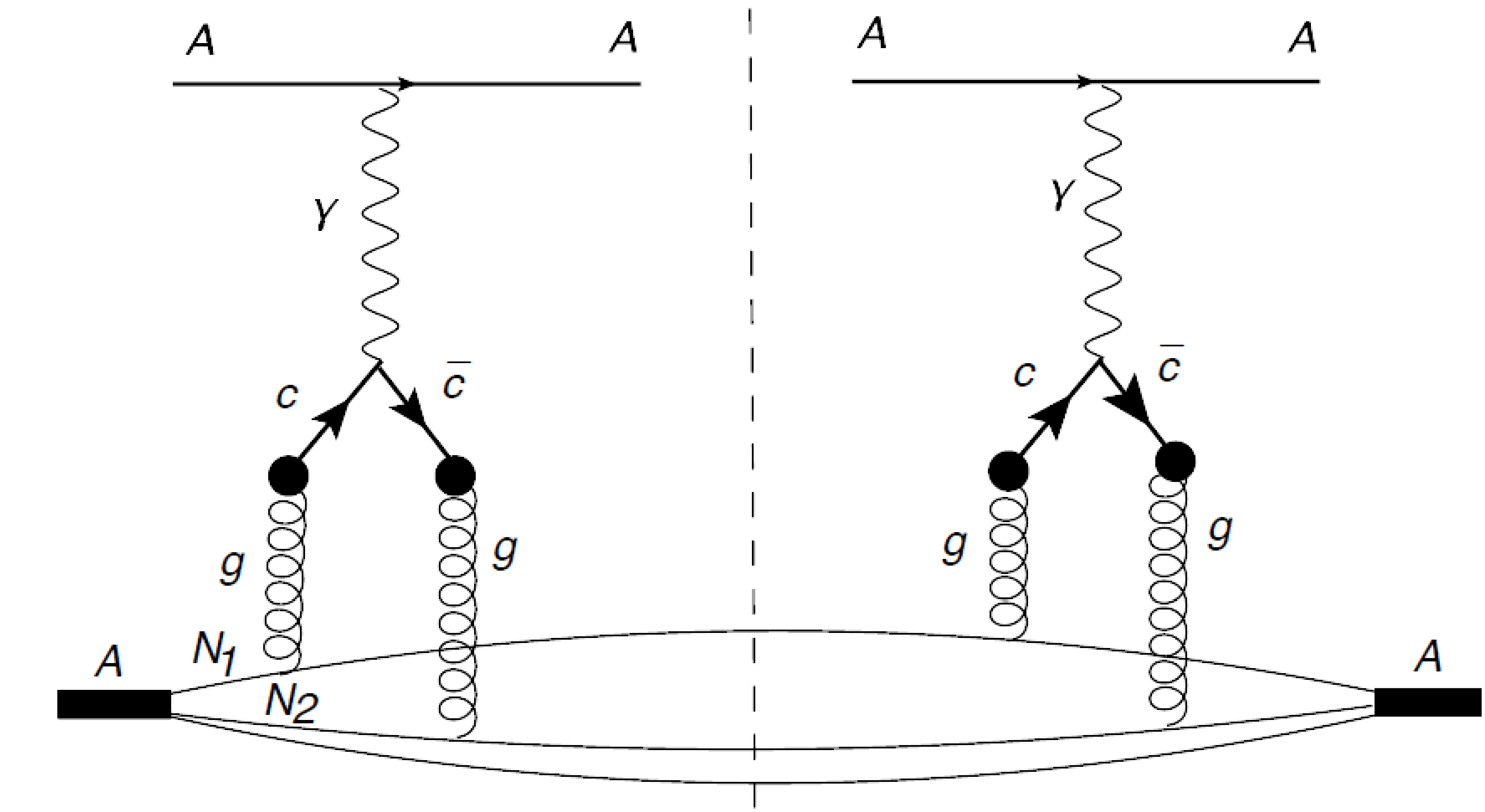
B. Blok , *M. Strikman*

Published in ***Eur.Phys.J. C74 (2014) no.12, 3214***

UPC photon proton-give possibility of clean-free of soft QCD study of MPI. Kinematics: x1,x2 for charmed jets are large, i.e. we consider processes With **direct** *photons, and large pseudorapidity gaps in each pair of dijets, 3—4, with pt 7-15 GeV (can be done due to photons).*

This is very different kinematics from the processes with **resolved** *photons MPI considered at HERA/LHC by Butterworth,Forshaw,Seymour (JIMMY) which are very similar to pp and conatain all the related uncertainties)*

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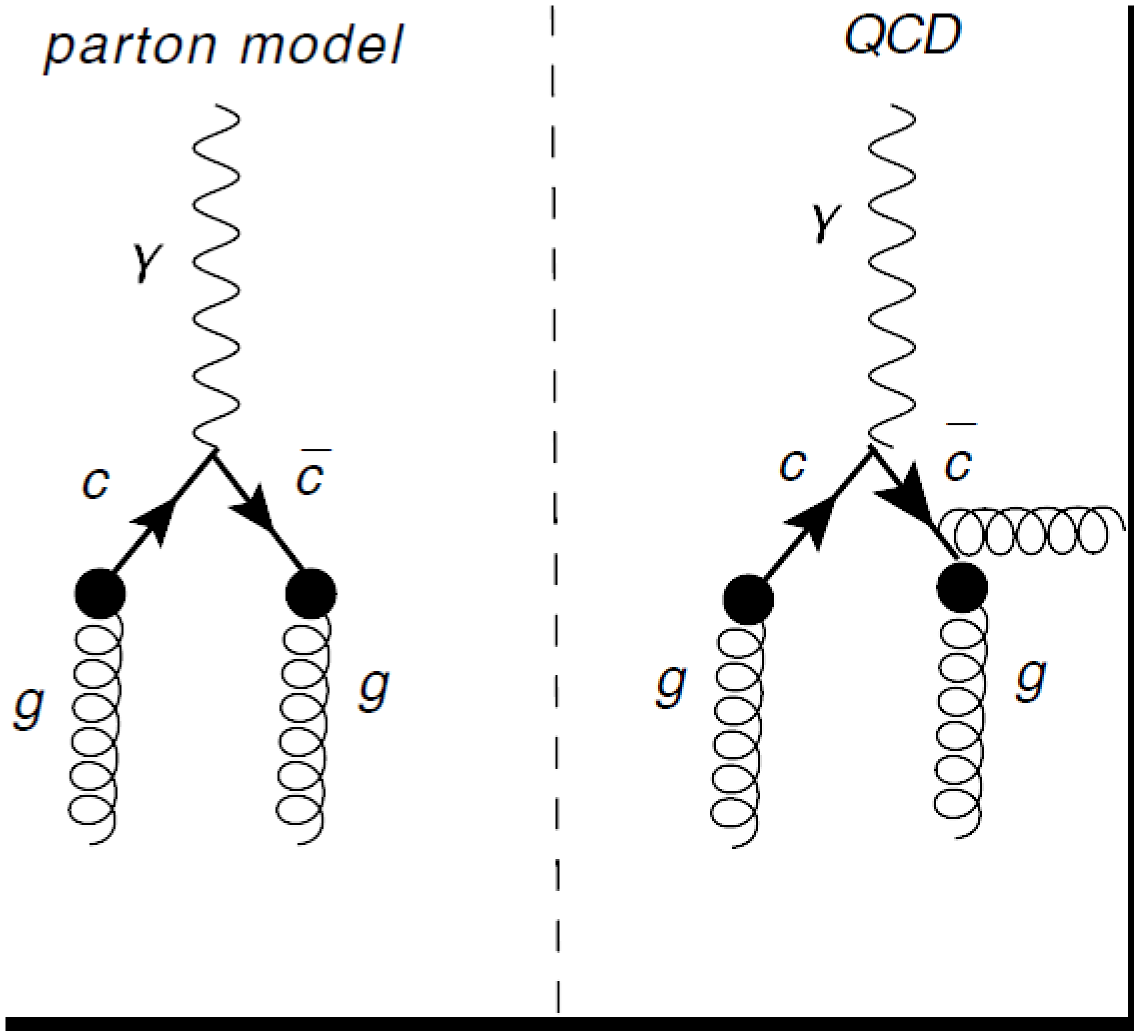

parton model
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$$\pi^2 \frac{d\sigma_1^{(3\to4)}}{d^2\delta_{13}\, d^2\delta_{24}} \;=\; \frac{d\sigma_{\rm part}}{d\hat{t}_1\, d\hat{t}_2} \cdot \frac{\partial}{\partial\delta_{13}^2} \frac{\partial}{\partial\delta_{24}^2} \Big\{ {}_{[1]}D_a^{1,2}(x_1, x_2; \delta_{13}^2, \delta_{24}^2) \cdot {}_{[2]}D_b^{3,4}(x_3, x_4; \delta_{13}^2, \delta_{24}^2)$$

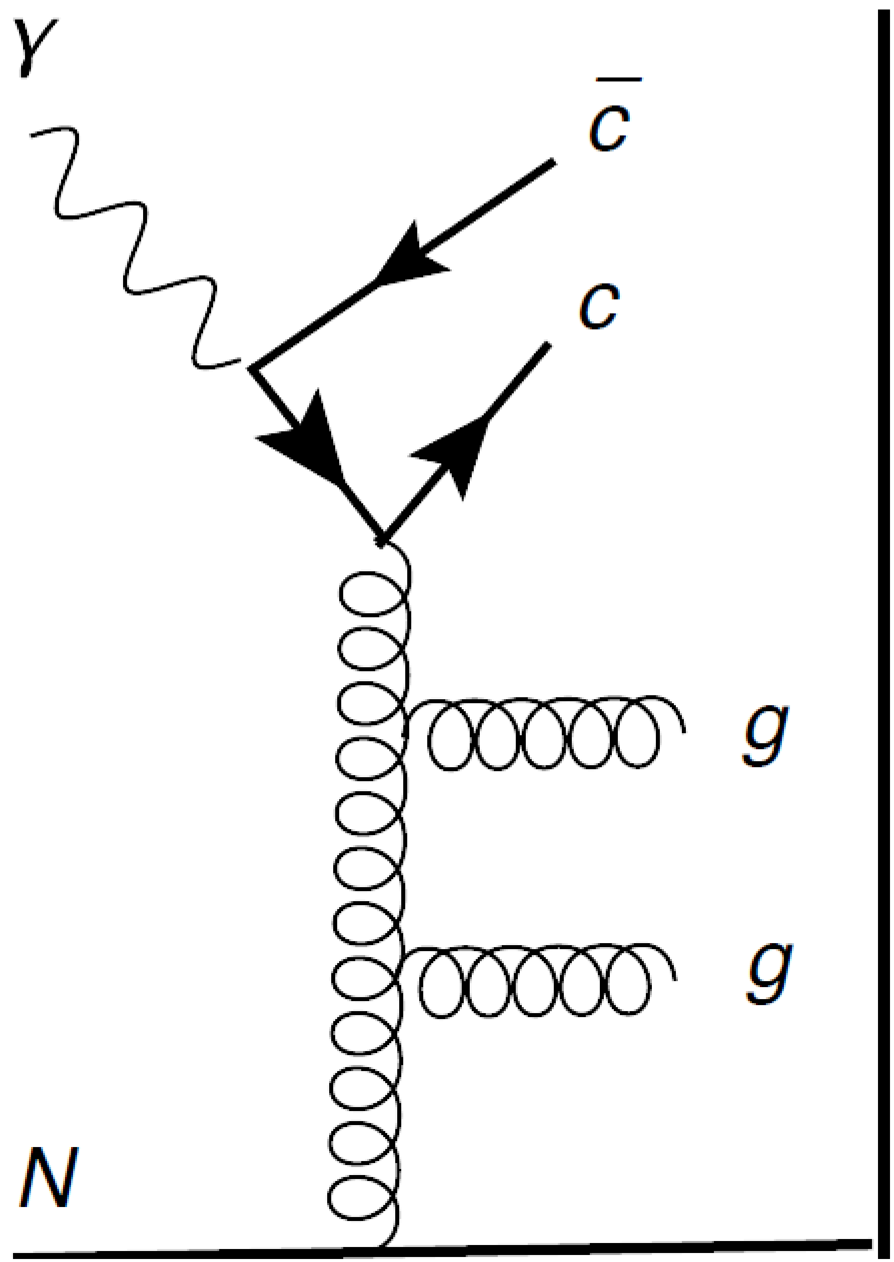
$$\times \; S_1\left(Q^2, \delta_{13}^2\right) S_3\left(Q^2, \delta_{13}^2\right) \cdot S_2\left(Q^2, \delta_{24}^2\right) S_4\left(Q^2, \delta_{24}^2\right) \Big\}.$$

$${}_{[1]}D(x_1, x_2; q_1^2, q_2^2; \vec{\Delta}) = \int_{m_c^2+\Delta^2}^{\min(q_1^2, q_2^2)} \frac{dk^2}{k^2} \frac{\alpha_{em}}{4\pi} \times \int \frac{dz}{z(1-z)} R(z)\; G_{q'}^{q}\left(\frac{x_1}{z}; q_1^2, k^2\right) G_{q'}^{q}\left(\frac{x_2}{(1-z)}; q_2^2, k^2\right).$$

$$R(z) = z^2 + (1-z)^2$$

$$\sigma_{\gamma p\to 4j+X} \;=\; \int dp_{1t}^2 \int dp_{2t}^2 \int dk \int \frac{dx_1 dx_2 dx_3 dx_4}{x_1 x_2 x_3 x_4} \frac{dN}{dk} D(x_1, x_2, p_{1t}, p_{2t})$$

$$\frac{d\sigma_1}{dt_1} \frac{d\sigma_2}{dt_2} \;\times\; \frac{m_g^2}{12\pi^2} G(x_3, p_{1t}^2) G(x_4, p_{2t}^2)$$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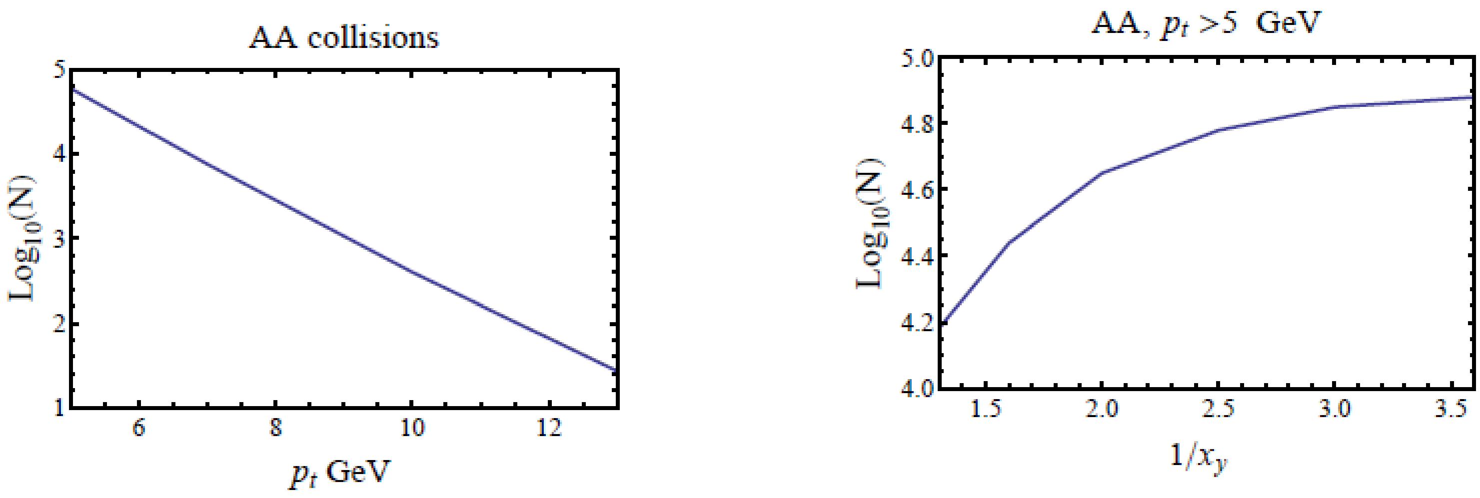

FIG. 5: event rate for MPI in AA collisions

For AA collisions we use: (i) luminosity $10^{27} cm^{-2} s^{-1}$, (ii) running time 10^6 s, and $\sqrt{s} = 5.6$ TeV. The radius of the nuclei Pb is 6.5 Fermi. The factor gamma is nucleon energy divided by $2m_p$ equal to $1.4 \cdot 10^3$. The exponentially decreasing Macdonald function cuts off the contribution of high photon energy. The total number of events for the p_t cut 5 GeV is $5 \cdot 10^4$, while the ratio of MPI events to the total number of dijet events is rather high–0.037%.

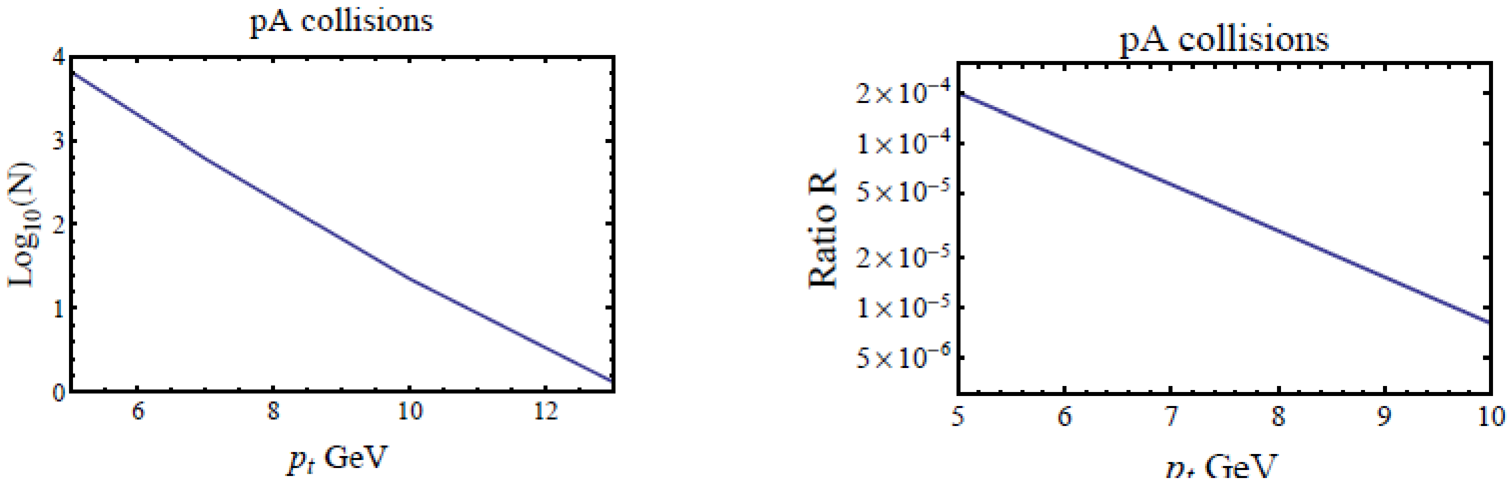

FIG. 8: The event rate for MPI in pA collisions

For pA collisions we use luminosity $10^{29} cm^{-2} s^{-1}$, running time 10^6 s, and the energies $\sqrt{s} = 10$ TeV. The number of events for cut $5GeV$ is of the order $6.6 \cdot 10^3$, and ratio is of order 0.02%, rapidly decreasing as in AA case with increase of p_t. We have seen above that there ie geometric enhancement of a ratio of AA events to dijets, relative to pA case by a factor of the order 2.5, for the same c.m.s. energy per nucleon. The remaining factor 2 difference is connected with difference in energies.

To estimate MPI event rate at LeHC at $\sqrt{s} = 1300$ GeV we used luminosity $10^{34}\ sm^{-2}s^{-1}$.

For cut off $p_t > 5$ GeV we get $2 \cdot 10^8$ events for realistic time 10^6 s. The ratio to a number of dijet events with the same cut offs on x and p_t is 0.045%.

We also considered MPI event rate in similar kinematics at HERA. To estimate MPI event rate at HERA we use the total luminosity accumulated at HERA 1 fb^{-1}, at the energy 300 GeV. For cut off $p_t > 5$ GeV we get $1.2 \cdot 10^5$ events for total luminosity. The ratio to a number of dijet events with the same cut offs on x and p_t is 0.0125%.]

Conclusion: we have now a theoretical formalism for description of MPI and first steps have been done to implement it numerically in MC generators.