Introduction to Multiple Parton Interactions

Yuri Dokshitzer

CNRS, Paris-VI

& PNPI, St Petersburg

GGI

29 September 2014

KEYWORDS :

- one hadron-hadron collision - two (or more) parton-parton collisions

  partonic “pile-up”

- MPI = additional source of multi-jet production

  source of information about the internal structure of the proton

- DPI = two hard (semi-hard) parton interactions in one event

- Hidden Reefs of the MPI Analysis

- The role of perturbative parton correlations (1 x 2 processes)

- Look for MPI . Where and How? (Homework)

Multi-Parton Interactions

- **prehistory:** Daniele Treleani & Co (1982-)
- **new life:** Tevatron experiments - CDF (1997) & D0 (2009, 2011)
  (dijet together with a photon-jet pair)
- **LHC epoch:** intensive MPI studies in various channels
  (two pairs of jets, W/Z bosons, heavy quark pairs, etc.)

On the theory side, MPI are being pursued by a number of teams.

Will follow the line of reasoning developed in

B. Blok, Yu. Dokshitzer, L. Frankfurt and M. Strikman :

The Four jet production at LHC and Tevatron in QCD
Phys. Rev. D83 : 071501, 2011; e-Print: **arXiv:1009.2714** [hep-ph]

pQCD Physics of Multiparton Interactions
Eur.Phys.J. C72 (2012) 1963; e-Print: **arXiv:1106.5533** [hep-ph]

Perturbative QCD correlations in multi-parton collisions
Eur.Phys.J. C74 (2014) 2926; e-Print: **arXiv:1306.3763** [hep-ph]

Double Parton Interactions

- **Establishing adequate QFT means for describing MPI**

  The origin of *Generalized Double Parton Distributions* (2GPD)

- **Modeling intra-hadron 2-parton correlations (*limited but restrictive*)**

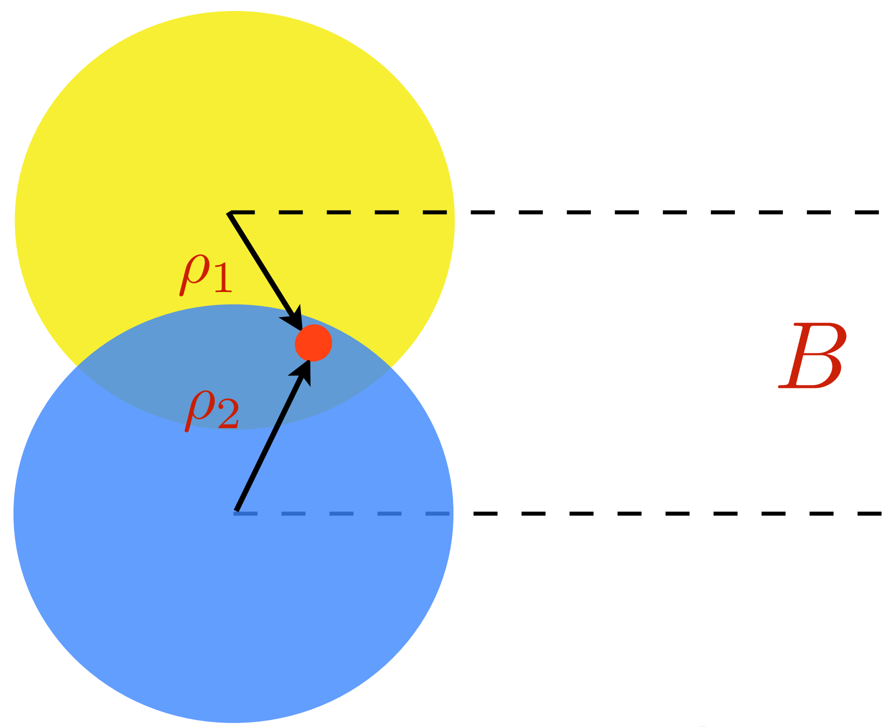
- **Examining the role of pQCD parton-parton correlations in DPI**

- **Giving numerical estimates for Tevatron and LHC experiments**

2-parton collision

The standard approach to the multi-jet production is the QCD improved parton model.

It is based on the assumption that the cross section of a hard hadron–hadron interaction is calculable in terms of the convolution of parton distributions within colliding hadrons with the cross section of a hard ***two-parton collision***.



$$\sigma_2 = \int d^2\rho_1 d^2B \; f(x_1, \vec{\rho}_1, p^2) f(x_2, \vec{B} - \vec{\rho}_1, p^2) \; \frac{d\sigma^h}{d\hat{t}} d\hat{t}$$

parton probability density : $f(x, \vec{\rho}, p^2) = \psi^+(x, \vec{\rho}, p^2)\psi(x, \vec{\rho}, p^2)$

Result of the **impact parameter** integration - squaring of the amplitude in the momentum space:

$$\int \frac{d^2k_\perp}{(2\pi)^2}\psi(x, k_\perp) \int \frac{d^2k'_\perp}{(2\pi)^2}\psi^\dagger(x, k'_\perp) \times \int d^2\rho \, e^{i\vec{\rho}\cdot(\vec{k}_\perp - \vec{k}'_\perp)} \Rightarrow \int \frac{d^2k_\perp}{(2\pi)^2}\psi(x, k_\perp) \times \psi^\dagger(x, k_\perp)$$

Hard collision of two partons produces, typically, ***two*** large transverse momentum ***jets***.

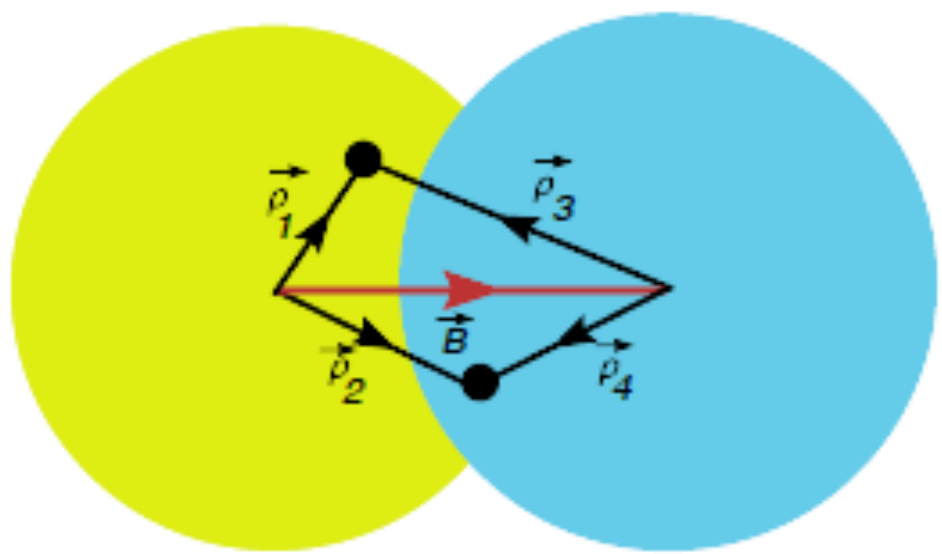
An application of the standard picture to the processes with production of, e.g., ***four jets*** implies that all jets in the event are produced in a hard collision of ***two*** initial state partons.

Recent data of the CDF and D0 Collaborations provide evidence that there exists a kinematical domain where a more complicated mechanism becomes important :

double hard interaction

of two partons in one hadron

with two partons in the second hadron.



Let us see, what difference does it make to our formulae

multi-partons

Multi-parton wave function

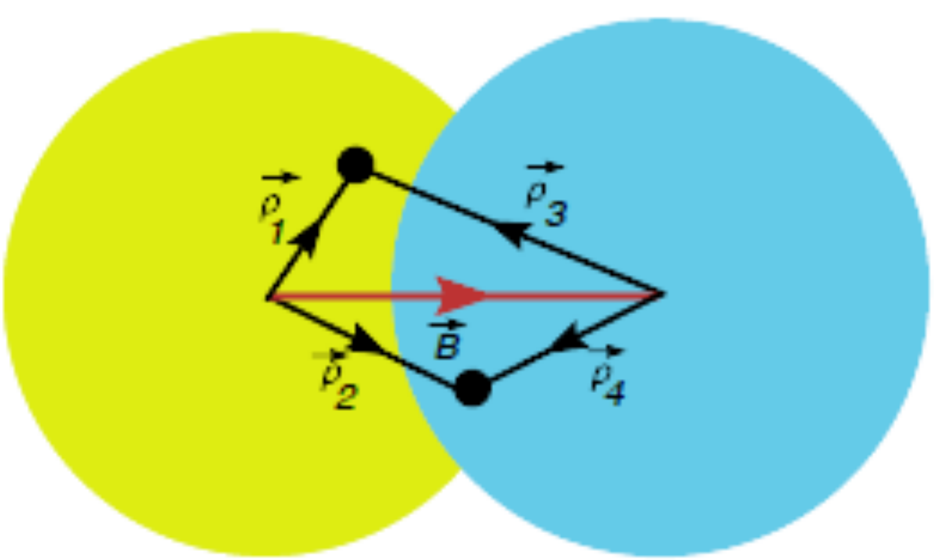
$$\psi_n \ (x_1, \vec{\rho}_1, x_2, \vec{\rho}_2, ...) = \int \prod_{i=1}^{i=n} \frac{d^2 k_i}{(2\pi)^2} \exp(i \sum_{i=1}^{i=n} \vec{k}_i \vec{\rho}_i) \ \psi_n(x_1, \vec{k}_1, x_2, \vec{k}_2, ..)(2\pi)^2 \delta(\sum \vec{k}_i)$$

Inclusive 2-parton probability distribution in the impact parameter space :

$$D \ (x_1, x_2, \vec{\rho}_1, \vec{\rho}_2) = \sum_{n=3}^{n=\infty} \int \prod_{i\geq 3}^{i=n} [dx_i d^2\rho_i] \, \psi_n(x_1, \vec{\rho}_1, x_2, \vec{\rho}_2, ...x_i, \vec{\rho}_i,) \ \psi_n^+(x_1, \vec{\rho}_1, x_2, \vec{\rho}_2, ..., x_i, \vec{\rho}_i, ...) \delta(\sum_{i=1}^{i=n} x_i \vec{\rho}_i)$$

Independent impact parameter integration $\Rightarrow$ equality of parton momenta in ψ and $\psi^\dagger$

$$k_\perp \ = \ k'_\perp$$



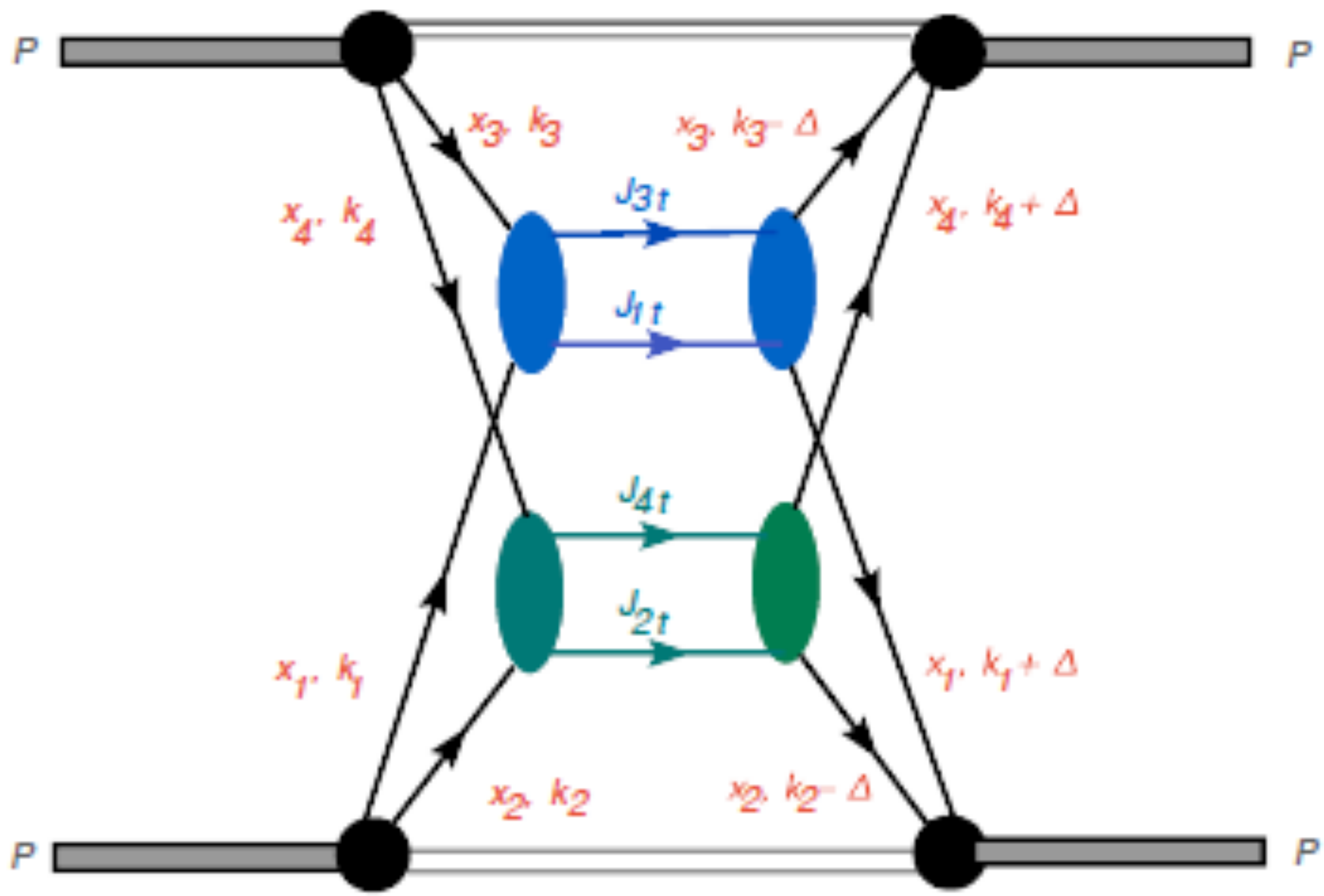
$\rho_1 + \rho_2 \Rightarrow k'_1 - k_1 = -(k'_2 - k_2) \equiv \Delta$

$\rho_3 + \rho_4 \Rightarrow k'_3 - k_3 = -(k'_4 - k_4) \equiv \tilde{\Delta}$

$(\rho_1 - \rho_2) + (\rho_3 - \rho_4) \Rightarrow \Delta = -\tilde{\Delta}$

$\delta\big((\rho_1 - \rho_2) - (\rho_3 - \rho_4)\big) \Rightarrow \vec{\Delta}$ ***arbitrary***

4-parton collision



In order to be able to trace the *relative distance between the partons*, one has to use the mixed *longitudinal momentum – impact parameter* representation which, in the momentum language, reduces to introduction of a **mismatch** between the transverse momentum of the parton in the ***amplitude*** and that of the same parton in the ***amplitude conjugated***.

We have examined the ***transverse momentum*** structure of the interaction amplitude

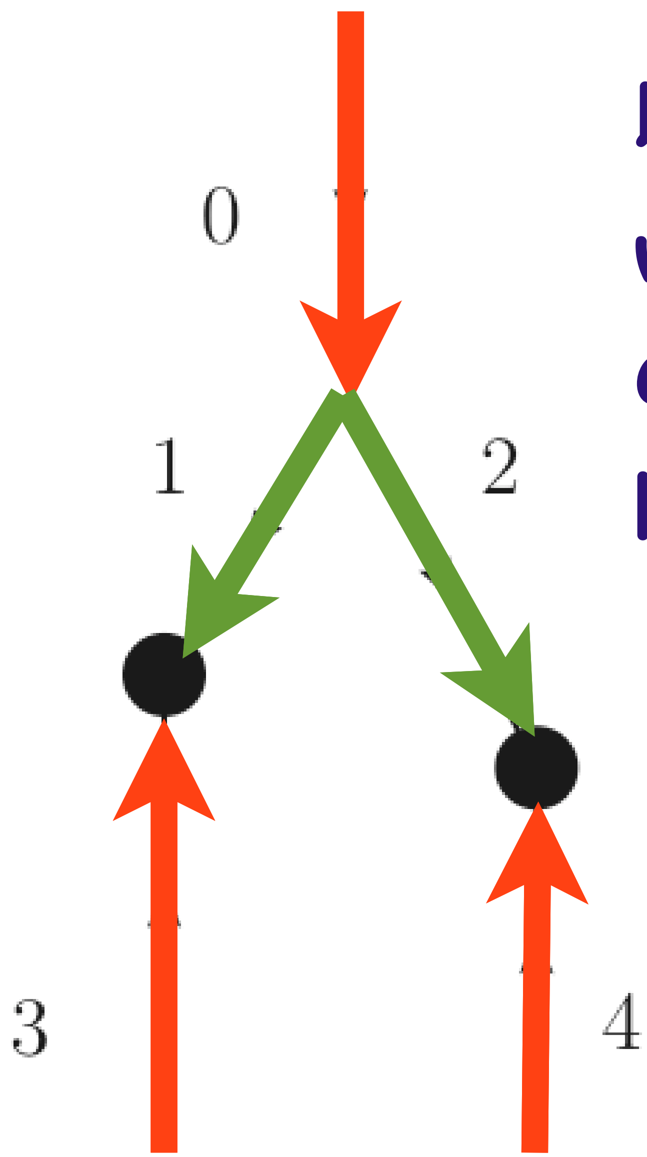
Now, have a look at the ***longitudinal momenta*** of participating partons ...

A hidden reef of the MPI analysis

3-parton collision

Have a look at a peculiar multi-parton process

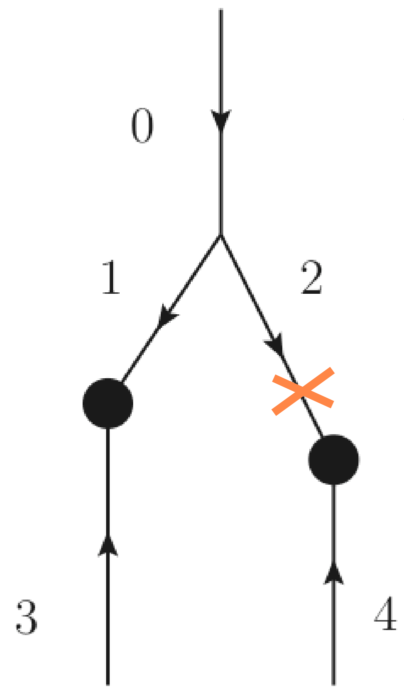
two hard collisions



btw two partons (3,4) from one hadron
with the offspring (1,2)
of a perturbative splitting of a single
parton (0) stemming from another hadron

quasi-on-mass-shell partons

virtual lines

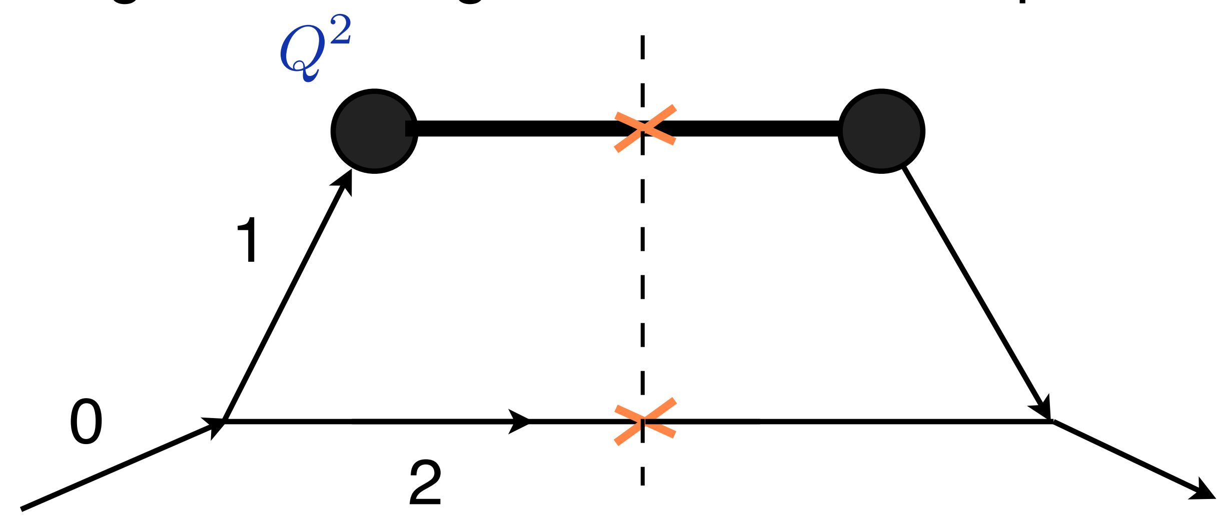


A tree Feynman diagram. Momenta of internal parton lines are fixed ...

not anymore

Singularities in the physical region of parton momenta !

Return to a good old single hard interaction picture :



In DIS we trace the fate of **1** but *integrate* over "histories" of the accompanying parton **2**.

Now we want #**2** to enter 2nd hard interaction.

In the DIS picture this may happen "*in the next room*"...

We, however, want the two hard interactions to occur in the same place !

In fact, partons **3** and **4** ***cannot be*** represented by plainly independent ***plane waves***: they belong to ***one hadron***, and therefore, are ***localized within the hadron pancake***...

Remedy: introduce wave packet smearing (longitudinal momentum fraction integral).
Importantly, this has to be done at the ***amplitude level*** !

$k_{3+} + k_{4+}$ fixed by hard scattering kinematics

$k_{3+} - k_{4+}$ arbitrary

The fake singularity disappears

mind your head

From theory to experiment

▷ General formalism for DPI:

$$\mathrm{d}\sigma^{(\mathrm{DPI})}_{Y+Z}(s) = \frac{m}{2\sigma_{\mathrm{eff}}(s)}\int \mathrm{d}x_1\,\mathrm{d}y_1\,\mathrm{d}x_2\,\mathrm{d}y_2\,[f_{i_1j_1}(x_1,y_1,\mu_F)f_{i_2j_2}(x_2,y_2,\mu_F)\,\mathrm{d}\sigma_{i_1i_2\to Y}(x_1,x_2,s)\,\mathrm{d}\sigma_{j_1j_2\to Z}(y_1,y_2,s)]$$

NO familiar factorization !

The **product** of probability distributions

$$f_{i_1j_1}(x_1,y_1,\mu_F)f_{i_2j_2}(x_2,y_2,\mu_F)$$

gets replaced by a **convolution** :

$$\int d^2\Delta\; f_{i_1j_1}(x_1,y_1,Q_x,Q_y;\vec{\Delta})f_{i_2j_2}(x_2,y_2,Q_x,Q_y;\vec{\Delta})$$

Generalized two-parton distributions

4-parton cross section

$$\frac{1}{S} = \frac{\int \frac{d^2\vec{\Delta}}{(2\pi)^2} D_a(x_1, x_2; \vec{\Delta}) D_b(x_3, x_4; -\vec{\Delta})}{D(x_1)D(x_2)\, D(x_3)D(x_4)}$$

S - effective parton interaction area

$$\boxed{\frac{d\sigma(x_1, x_2, x_3, x_4)}{d\hat{t}_1\, d\hat{t}_2} = \frac{d\sigma^{13}}{d\hat{t}_1} \frac{d\sigma^{24}}{d\hat{t}_2} \times \frac{1}{S}}$$

D - ***the generalized double parton distribution***

- a new object we know very little (hardle anything) about.

Can one model it, for lack of anything better ?

a model

has been developed based on an assumption that the partons are *uncorrelated* at the level of the *non-perturbative* proton wave function.

Such a model cannot be true all over the range of parton momentum fractions.

It has a limited range of applicability : **$0.1 > x > 0.001$**
which, however, covers the Tevatron - as well as the main LHC - kinematics.

Good news: the model has predictive power!

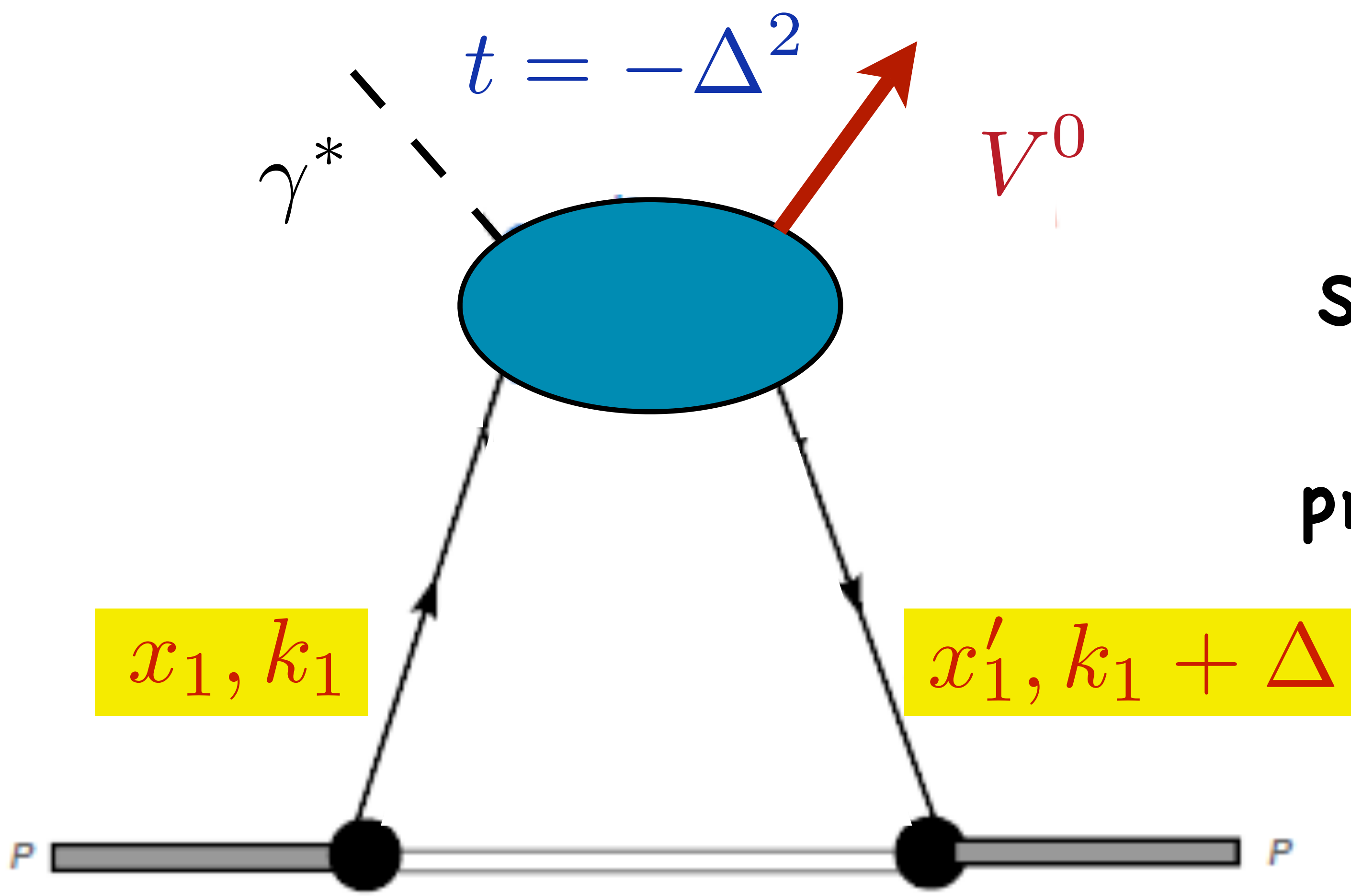
- **Physical input from the HERA physics**

- **Oops: Independent parton approximation** underestimates **the DPI Xsection**

- **In the Tevatron kinematics the PT parton correlations can explain the** missing factor 2 **enhancement**

- ***Non-PT* intra-hadron 2-parton correlations should emerge at $x < 0.001$**
  based on the analysis of ***inelastic diffraction***
  in the framework of the Gribov-Regge Pomeron picture

in: ***Origins of Parton Correlations in Nucleon and Multi-Parton Collisions***
B.Blok et al e-Print: **arXiv:1206.5594** [hep-ph]



2GPD vs 2 GPDs

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

Note : the analogy is ***imperfect***. ***OK*** for ***high enough energies***: $A \simeq i\,\mathrm{Im}A$

Imaginary part of the “skewed” amplitude vs. that of non-diagonal “elastic” transition ...

Generalized parton distribution :

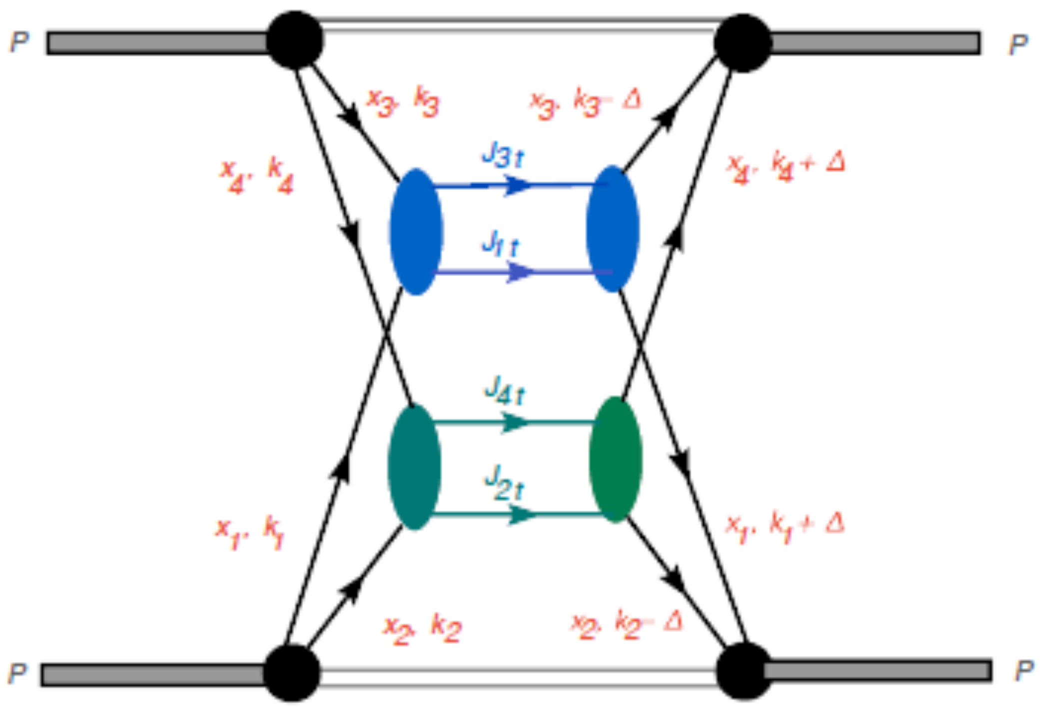
$$\boxed{G_N(x,Q^2,\vec{\Delta}) = G_N(x,Q^2)F_{2g}(\Delta)}$$

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

F - the two-gluon form factor of the nucleon

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

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



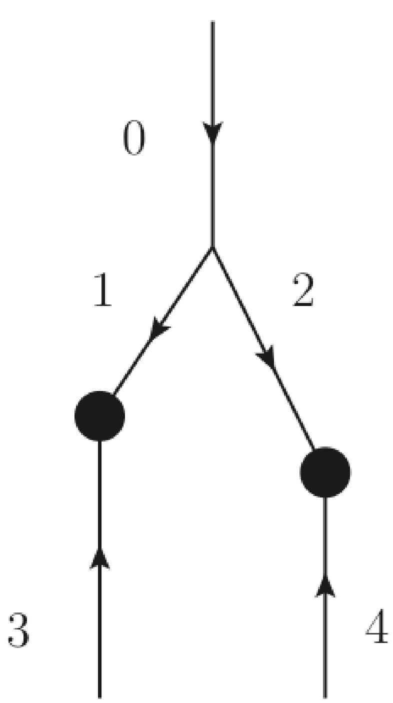
If partons were ***uncorrelated***, we would write

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

and use the dipole fit to get the estimate

$$\frac{D(x_1, x_2, -\vec{\Delta})D(x_3, x_4, \vec{\Delta})}{D(x_1)D(x_2)D(x_3)D(x_4)} \simeq F_{2g}^4(\Delta)$$

The “interaction area” : $\Longrightarrow$ $$\int \frac{d^2\Delta}{(2\pi)^2} F_g^2(\Delta^2) \times F_g^2(\Delta^2) = \frac{m_g^2}{28\pi}$$



Another mechanism : 2 partons from a short-range PT correlation

No Δ —dependence from the upper side ! $\Longrightarrow$ $$\int \frac{d^2\Delta}{(2\pi)^2} F_g^2(\Delta^2) = \frac{m_g^2}{12\pi}$$

1 x 2 contribution vs. **2 x 2** is enhanced by a factor

$$2 \times \frac{7}{3} \simeq 5$$

power counting

4-parton interaction **is a "higher twist effect"**

hard 2-parton scattering :
$$\frac{d\sigma^{(2\to 2)}}{d\hat{t}} \propto \frac{\alpha_s^2}{Q^4}$$

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

4 jets from
4-parton scattering :
$$\frac{d\sigma^{(4\to 4)}}{d\hat{t}_1 d\hat{t}_2} \propto R^{-2} \cdot \left(\frac{\alpha_s^2}{Q^4}\right)^2 \propto \frac{\alpha_s^4}{R^2 Q^8}$$

extra $\frac{m_g^2}{Q^2}$

Always a *small contribution* **to the** *total 4-jet production cross section*

End of story?.. Not at all

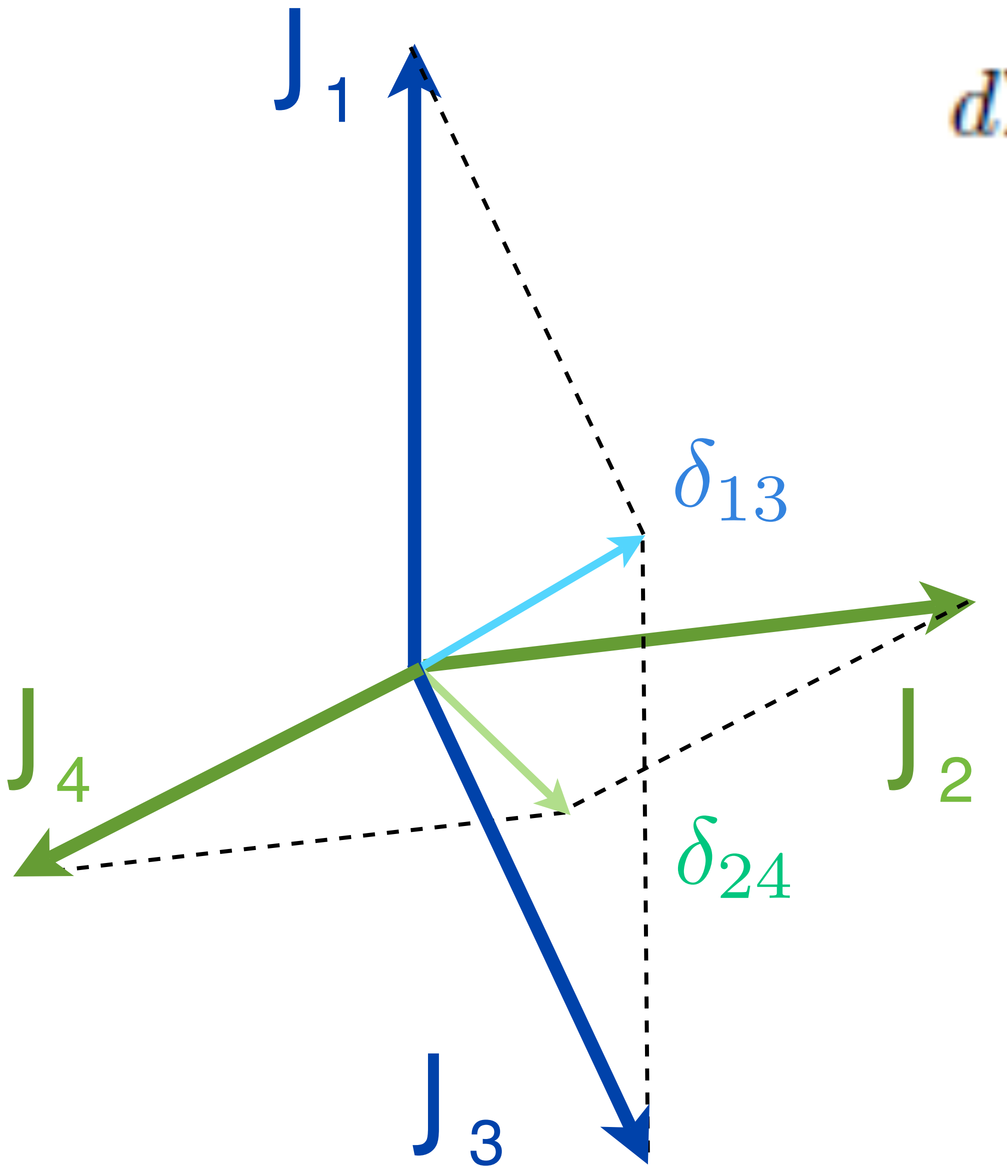
What distinguishes "double hard collisions" is the differential spectrum

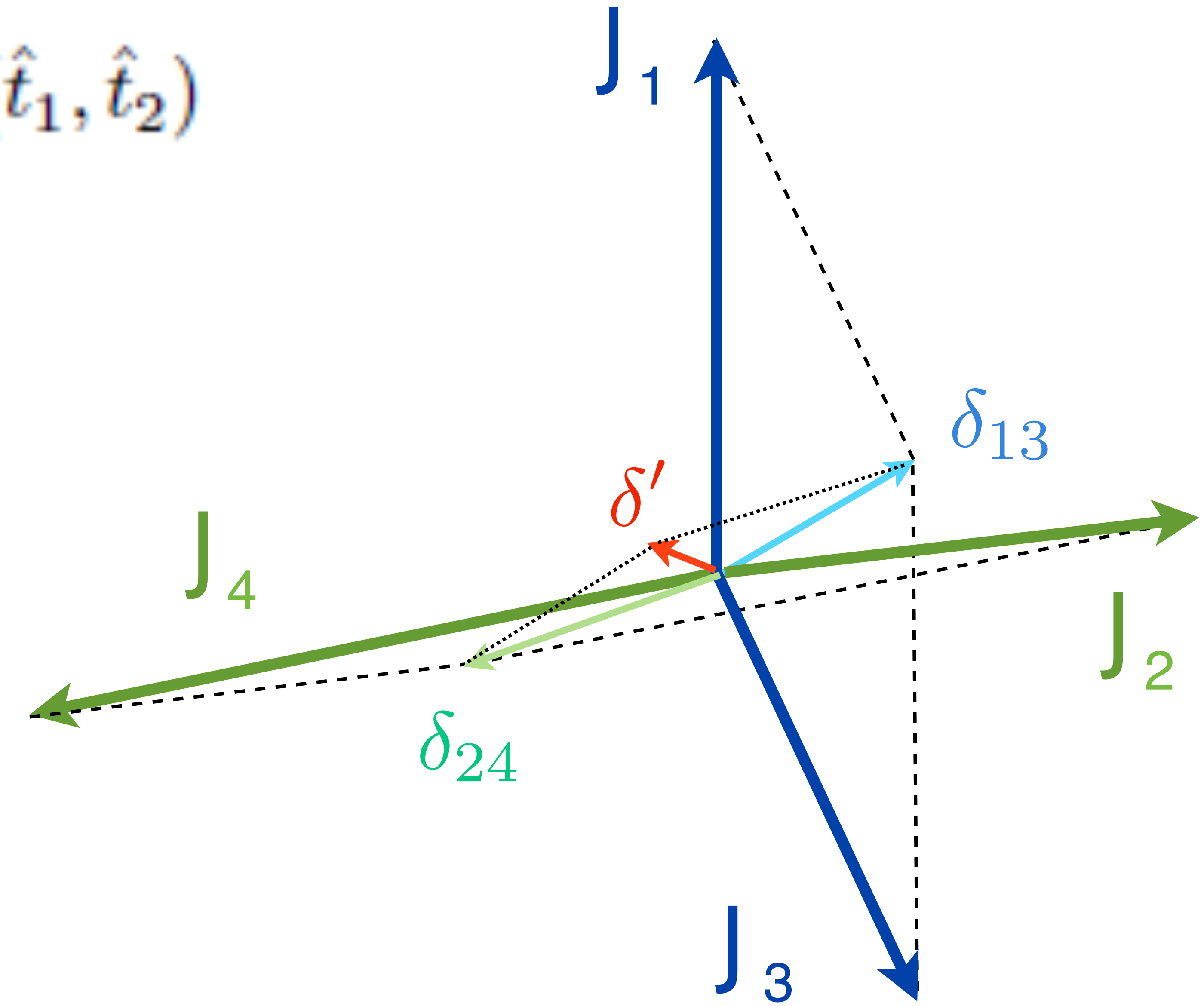
back-to-back kinematics

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

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

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





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

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

2 -> 4 processes

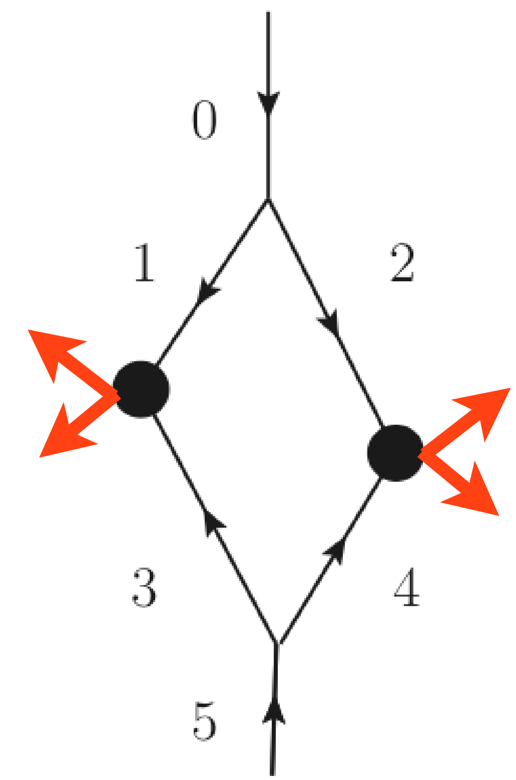
What if *both parton pairs* originate from PT splittings ?

No Δ — dependence whatsoever...

The integral ***diverges*** ?..

This is *not* an amplitude of a *4-parton collision*

but a one-loop correction to the *2-parton collision*



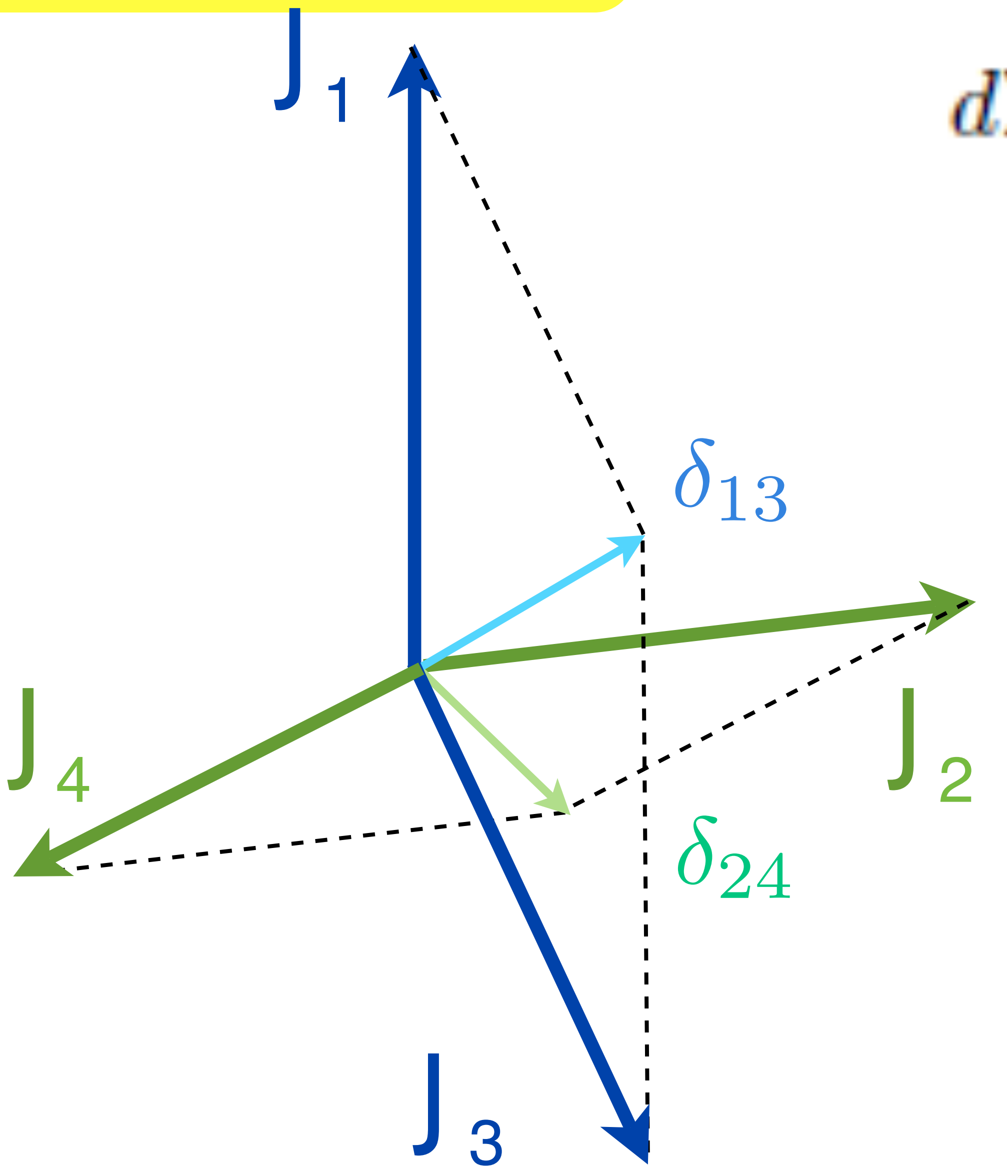
A large (“*leading twist*”) contribution but *not* an MPI (DPI)

No enhancement in the back-to-back kinematical region!

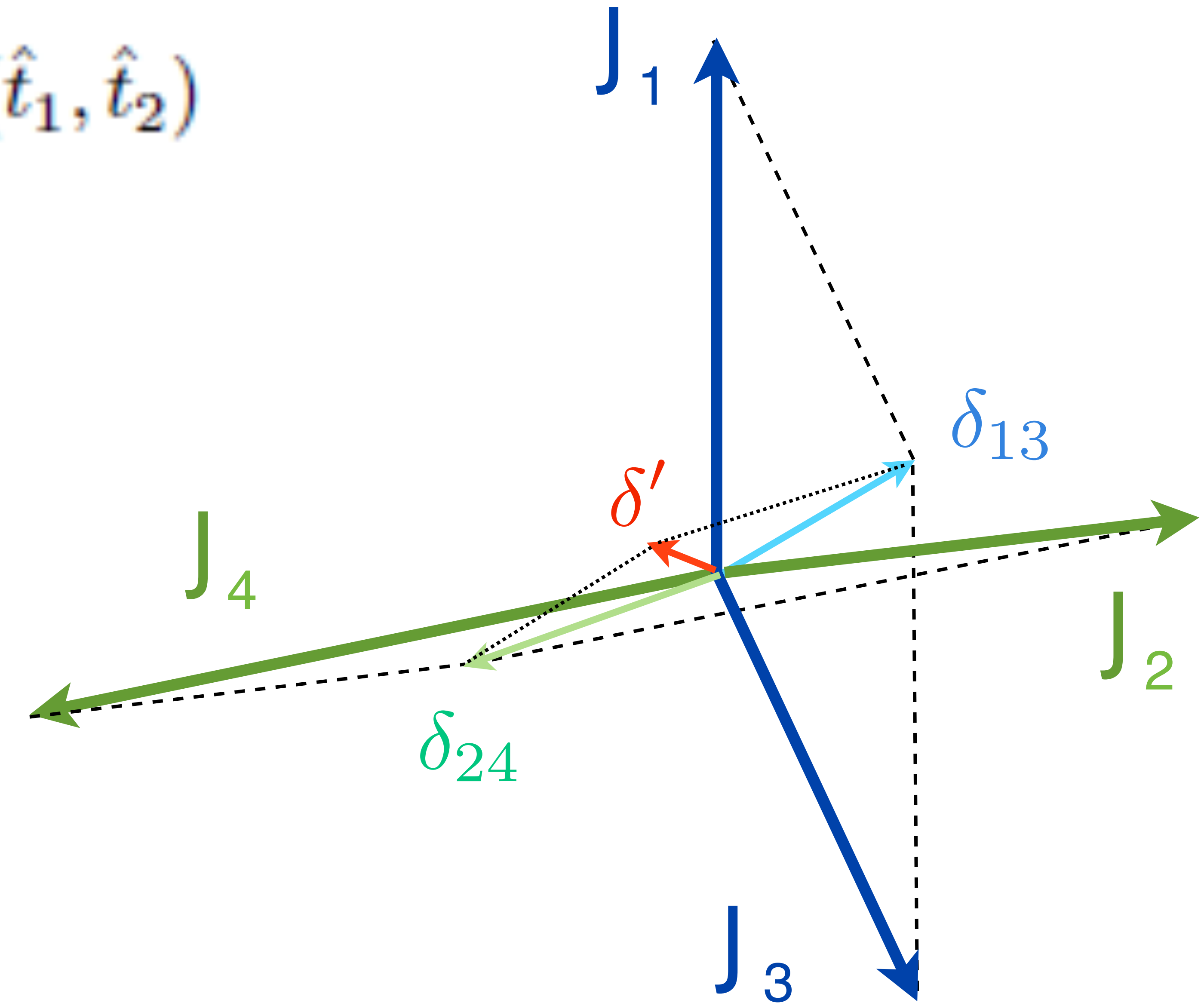
back-to-back kinematics

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

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



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



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

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

Both these regimes are present in differential momentum distributions due to Double-Parton Interactions

reminder :

Drell-Yan process

Massive lepton pair production cross section

$$\frac{d\sigma}{dq^2\,dq_\perp^2} = \frac{d\sigma_{\rm tot}}{dq^2} \times \frac{\partial}{\partial q_\perp^2}\left\{D_a^q\left(x_1, q_\perp^2\right) D_b^q\left(x_2, q_\perp^2\right) S_q^2\left(q^2, q_\perp^2\right)\right\}$$

Quark form factor :

$$S_q(Q^2,\kappa^2) = \exp\left\{-\int_{\kappa^2}^{Q^2}\frac{dk^2}{k^2}\frac{\alpha_s(k^2)}{2\pi}\int_0^{1-k/Q} dz\, P_q^q(z)\right\}$$

Gluon form factor :

$$S_g(Q^2,\kappa^2) = \exp\left\{-\int_{\kappa^2}^{Q^2}\frac{dk^2}{k^2}\frac{\alpha_s(k^2)}{2\pi}\int_0^{1-k/Q} dz\, \left[zP_g^g(z) + n_f P_g^q(z)\right]\right\}$$

Parton splitting probabilities

$$P_q^q(z) = C_F\frac{1+z^2}{1-z}, \qquad P_q^g(z) = P_q^q(1-z),$$

$$P_g^q(z) = T_R\left[z^2+(1-z)^2\right], \qquad P_g^g(z) = C_A\frac{1+z^4+(1-z)^4}{z(1-z)}$$

4-jet diff. spectrum

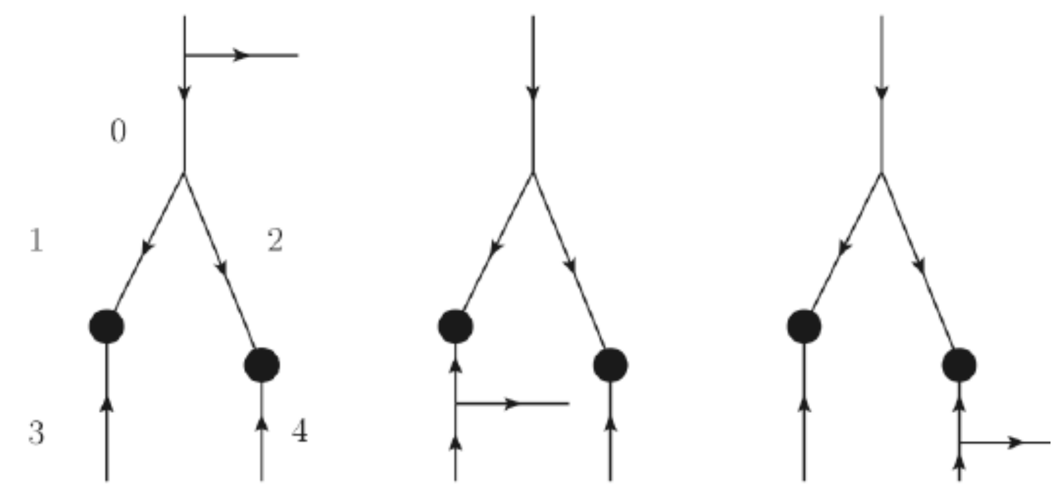
Generalization of the DDT-formula for back-to-back 4-jet production spectrum

$$\pi^2 \frac{d\sigma^{(4\to4)}}{d^2\delta_{13}\, d^2\delta_{24}} = \frac{d\sigma_{\rm part}}{d\hat{t}_1\, d\hat{t}_2} \cdot \frac{\partial}{\partial \delta_{13}^2} \frac{\partial}{\partial \delta_{24}^2} \Big\{ {}_{[2]}D_a^{1,2}(x_1, x_2; \delta_{13}^2, \delta_{24}^2) \times {}_{[2]}D_b^{3,4}(x_3, x_4; \delta_{13}^2, \delta_{24}^2)$$
$$\times\; S_1\left(Q^2, \delta_{13}^2\right) S_3\left(Q^2, \delta_{13}^2\right) \times S_2\left(Q^2, \delta_{24}^2\right) S_4\left(Q^2, \delta_{24}^2\right) \Big\}$$

Not forgetting the Δ —integration and short-range correlations :

$${}_{[2]}D_a \times {}_{[2]}D_b \;+\; {}_{[2]}D_a \times {}_{[1]}D_b \;+\; {}_{[1]}D_a \times {}_{[2]}D_b$$

Additional 1 x 2 contribution :



$$\frac{\pi^2\, d\sigma_2^{(3\to4)}}{d^2\delta_{13}\, d^2\delta_{24}} = \frac{d\sigma_{\rm part}}{d\hat{t}_1\, d\hat{t}_2} \cdot \frac{\alpha_s(\delta^2)}{2\pi\,\delta^2} \sum_c P_c^{1,2}\!\left(\frac{x_1}{x_1+x_2}\right)$$

$$S_1(Q^2,\delta^2)\, S_2(Q^2,\delta^2)\, \frac{\partial}{\partial \delta'^2} \Big\{ S_c(\delta^2,\delta'^2) \frac{G_a^c(x_1+x_2;\delta'^2,Q_0^2)}{x_1+x_2} S_3(Q^2,\delta'^2) S_4(Q^2,\delta'^2) \times {}_{[2]}D_b^{3,4}(x_3,x_4;\delta'^2,\delta'^2) \Big\}$$

effective interaction area

$$\boxed{\frac{d\sigma(x_1,x_2,x_3,x_4)}{d\hat{t}_1\, d\hat{t}_2} = \frac{d\sigma^{13}}{d\hat{t}_1}\frac{d\sigma^{24}}{d\hat{t}_2} \quad \times \frac{1}{S}}$$

two contributions :

$$\sigma_{\text{eff}}^{-1} = \sigma_4^{-1} + \sigma_3^{-1}$$

$2 \otimes 2$

$$\frac{\prod_{i=1}^4 D(x_i)}{\sigma_4} = \int \frac{d^2\vec{\Delta}}{(2\pi)^2}\, {}_{[2]}D_{h_1}(x_1,x_2,Q_1^2,Q_2^2;\vec{\Delta})\, {}_{[2]}D_{h_2}(x_3,x_4,Q_1^2,Q_2^2;-\vec{\Delta})$$

$1 \otimes 2$

$$\frac{\prod_{i=1}^4 D(x_i)}{\sigma_3} = \int \frac{d^2\vec{\Delta}}{(2\pi)^2}\Big[{}_{[2]}D_{h_1}(x_1,x_2,Q_1^2,Q_2^2;\vec{\Delta})\,{}_{[1]}D_{h_2}(x_3,x_4,Q_1^2,Q_2^2)$$
$$+\,{}_{[1]}D_{h_1}(x_1,x_2,Q_1^2,Q_2^2)\,{}_{[2]}D_{h_2}(x_3,x_4,Q_1^2,Q_2^2;\vec{\Delta})\Big]$$

At TEVATRON energies, pQCD **1 x 2** contributions explain, quite naturally, the factor 2 enhancement of the DPI rate

At TEVATRON energies, **1 x 2** contributions explain, quite naturally, the factor 2 enhancement of the DPI rate

Results of Numerical Analysis

Perturbative QCD correlations in multi-parton collisions

Eur.Phys.J. C74 (2014) 2926; e-Print: **arXiv:1306.3763** [hep-ph]

The **1 x 2** contribution in terms of the ratio

$$R \equiv \frac{\sigma_{1\otimes 2}}{\sigma_{2\otimes 2}} = \frac{\sigma_4}{\sigma_3}$$

For the effective interaction area ("cross section")

$$\sigma_{\rm eff} = \frac{28\pi}{m_g^2}\cdot\frac{1}{1+R} \simeq \frac{35\,\mathrm{mb}}{m_g^2\,[\mathrm{GeV}]}\cdot\frac{1}{1+R} \simeq \frac{32\,\mathrm{mb}}{1+R}$$

(using the pheno value (HERA) $m_g^2 = 1.1\,\mathrm{GeV}^2$)

1. $u(\bar{u})$ quark and three gluons which is relevant for "photon plus 3 jets" CDF and D0 experiments,
2. four gluons (two pairs of hadron jets),
3. $u\bar{d}$ plus two gluons, illustrating W^+jj production.
4. $u\bar{d}$ plus $d\bar{u}$, corresponding to the W^+W^- channel.

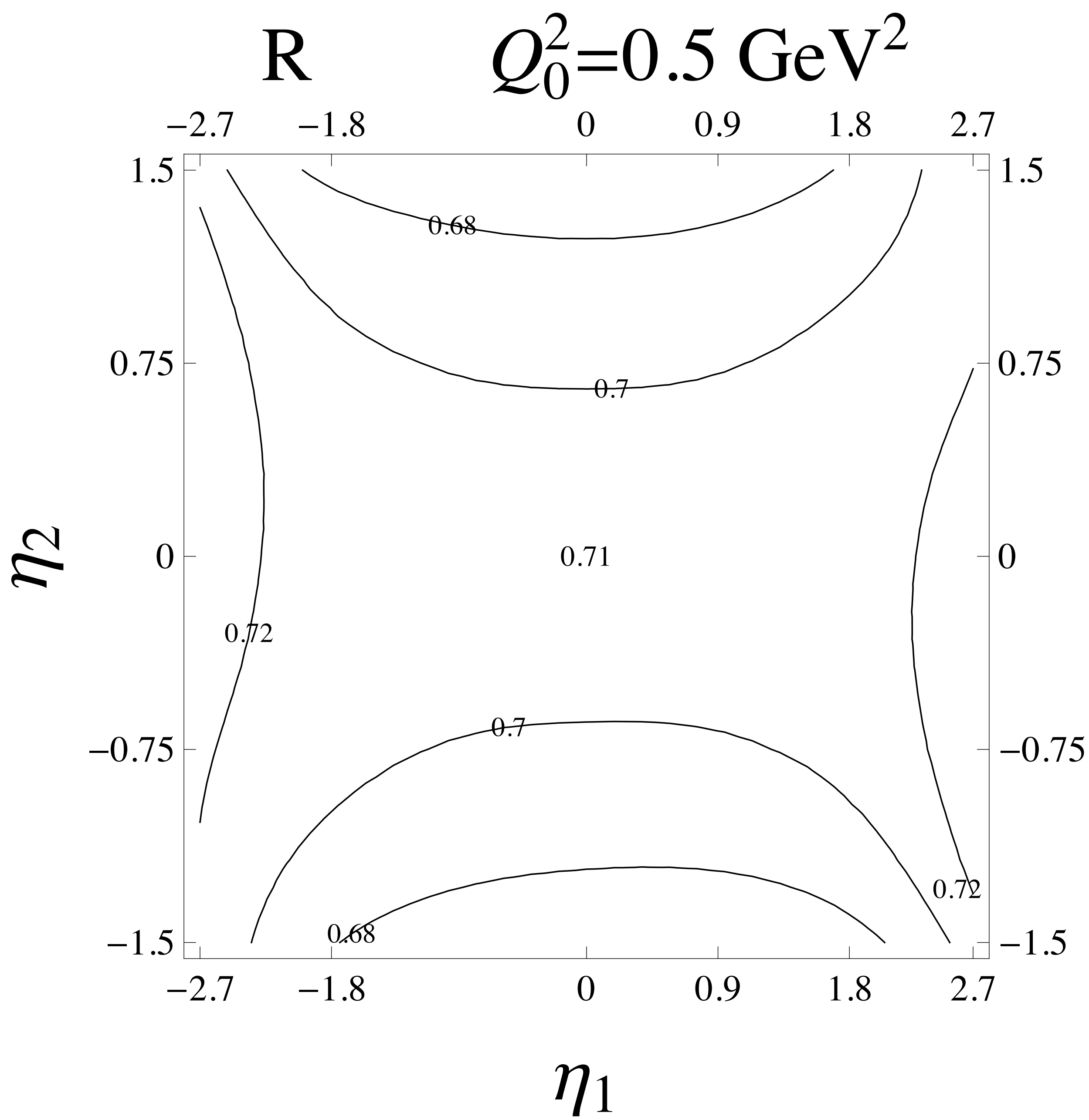
for **Tevatron**

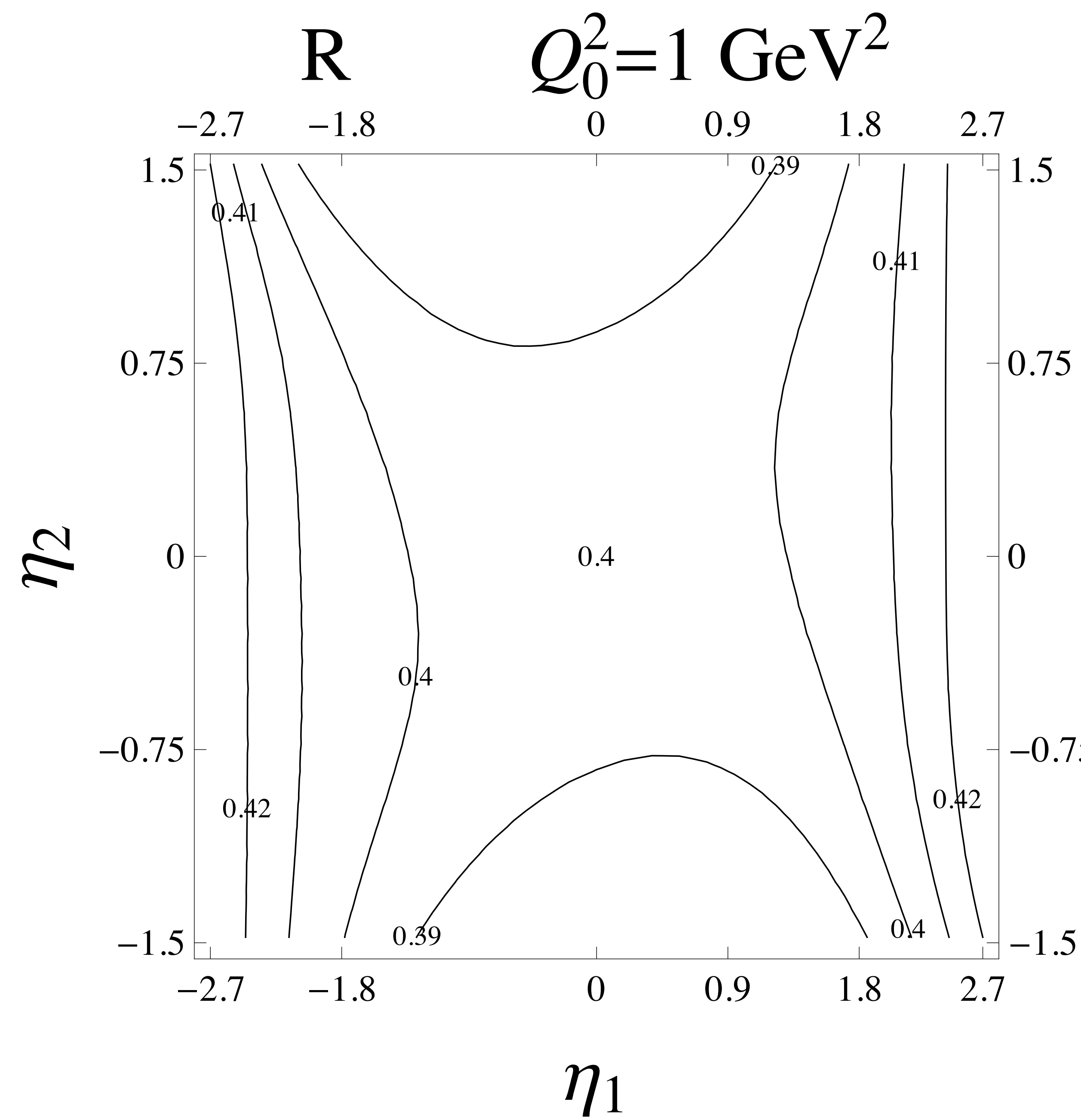
$$\sqrt{s} = 1.8 \div 1.96\,\mathrm{TeV}$$

and **LHC** energies

$$\sqrt{s} = 7\,\mathrm{TeV}$$

CDF: 20 GeV photon &jet plus a pair of 5 GeV jets

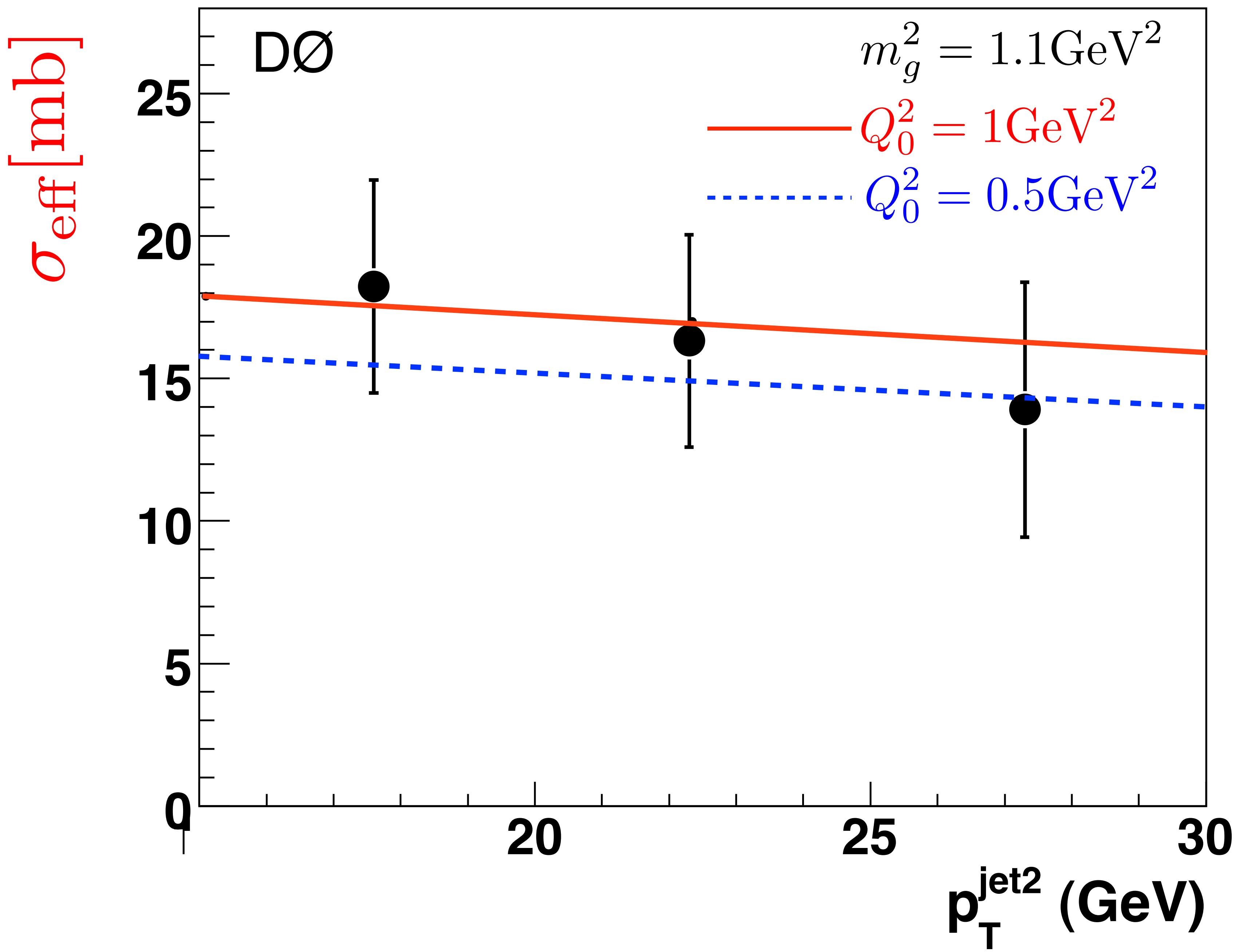




translates into $\sigma_{\rm eff} \simeq 18 \div 21$ mb. cf. CDF: $14.5 \pm 1.7\,^{+1.7}_{-2.3}$ mb.

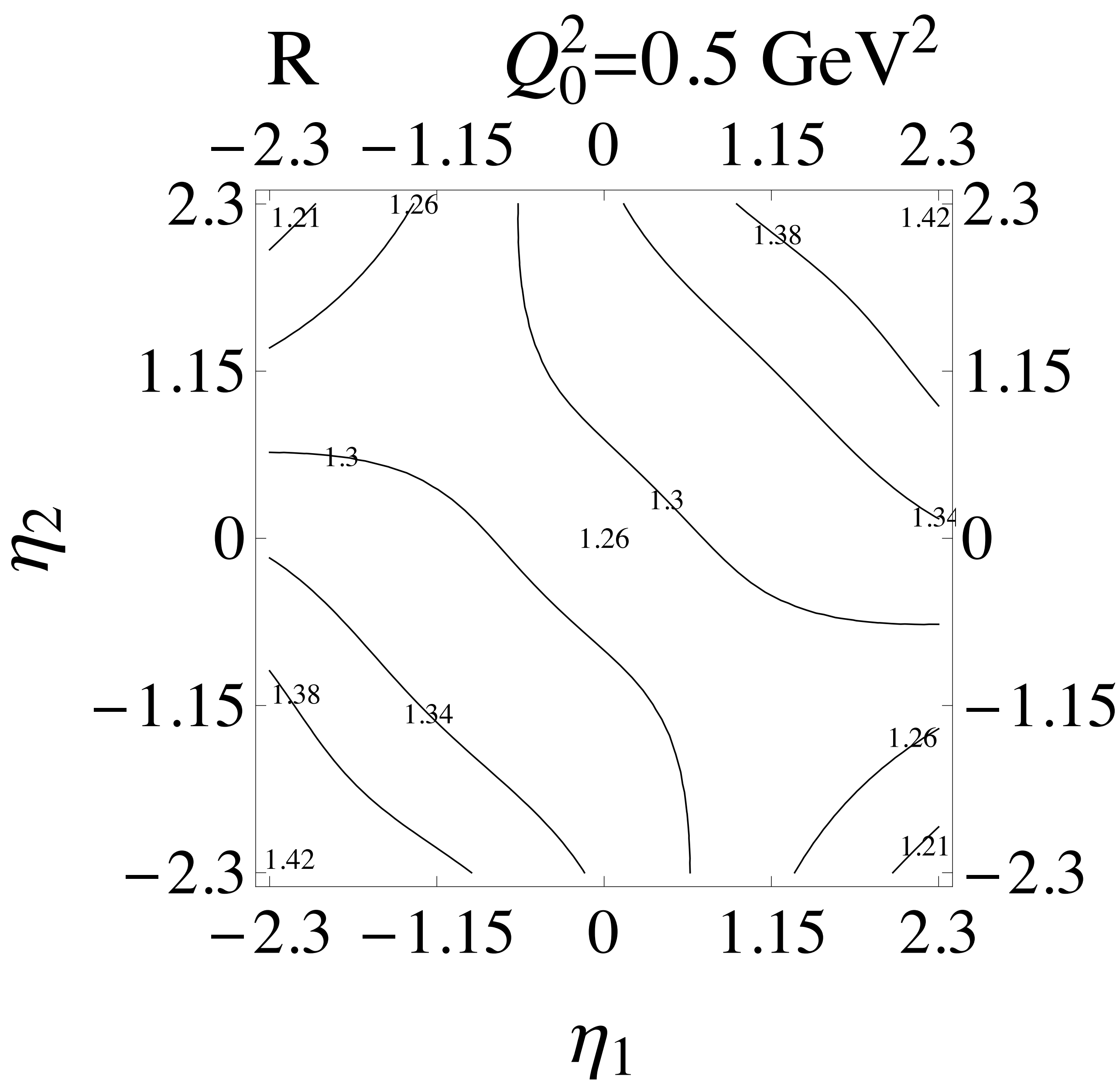
Rather large value. Very mild x-dependence

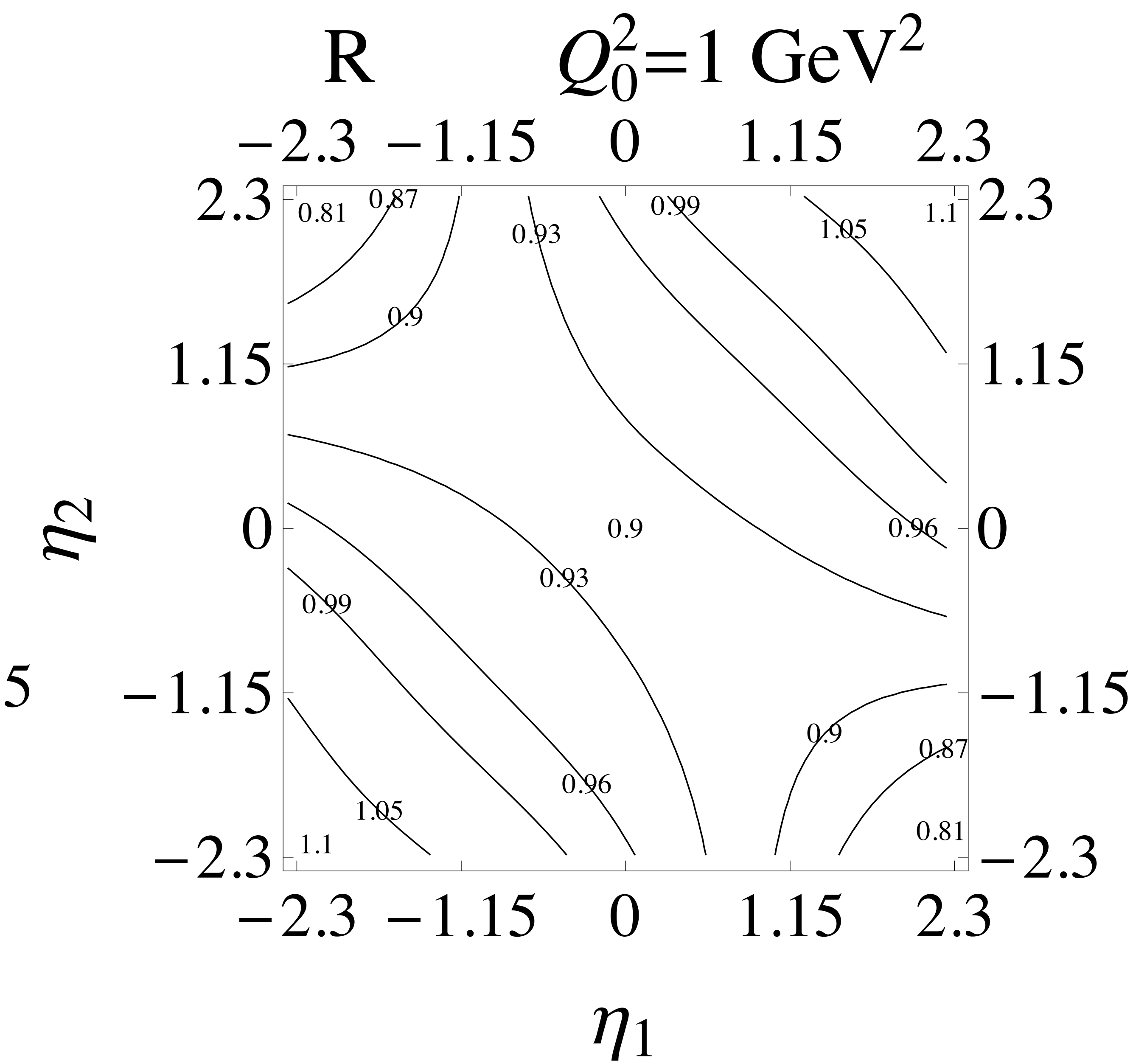
D0: effective interaction area for 70 GeV photon & jet as a function of the transverse momentum of jets in an additional jet pair



mild squeezing with hardness increasing, consistent with data

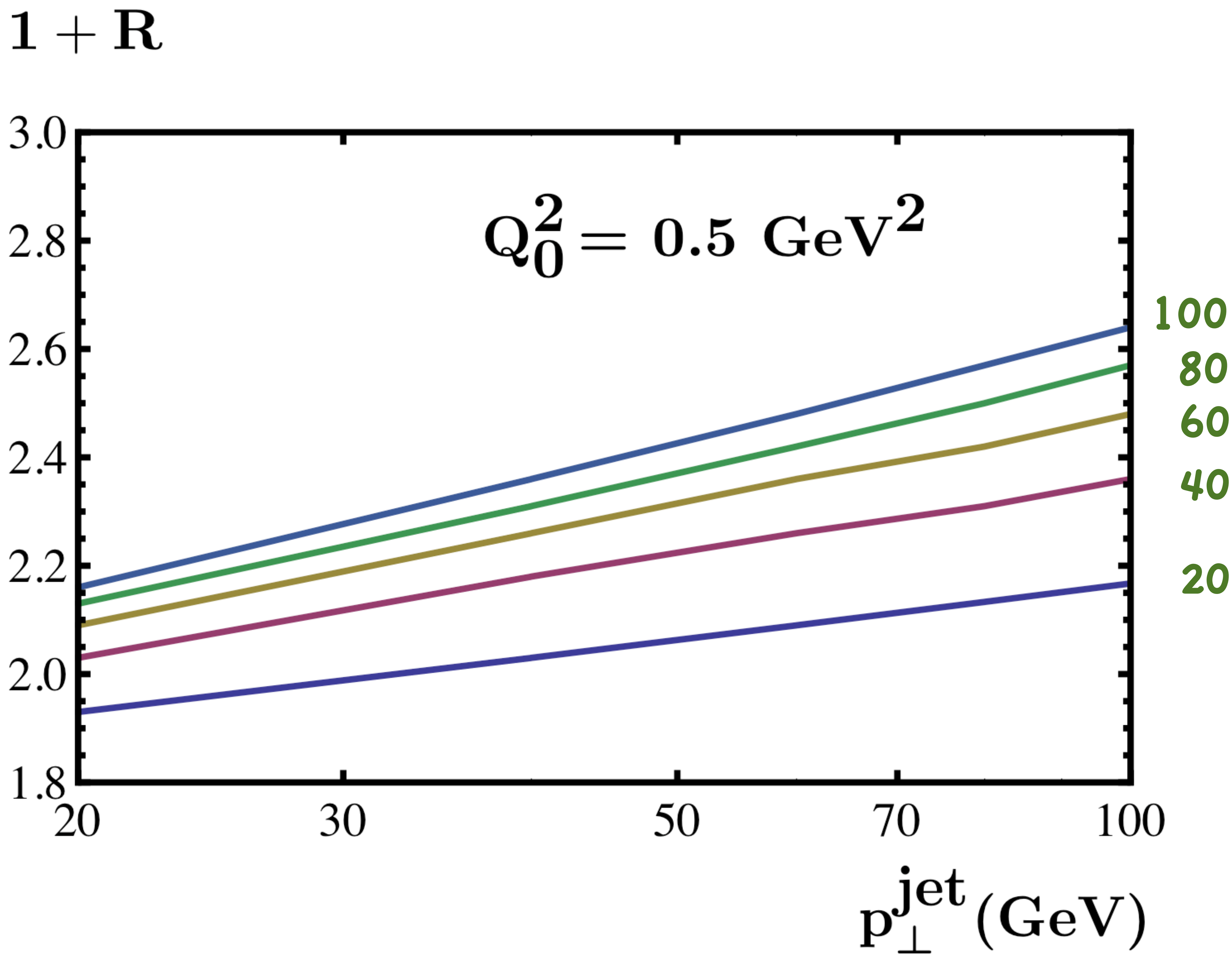
LHC: two pairs of (back-to-back) 50 GeV jets





pQCD correlation: local, increases in fwd regions

LHC: dependence on the hardnesses of 4-gluon collisions



Peculiarities of the 1 x 2 MPI mechanism

- is bound to bring in a visible ***x-dependence*** of $\sigma_{\rm eff}$

  in particular, in "pre-forward" kinemo ($x_1, x_2 \gg x_3, x_4$) where **1 x 2** is ***large***

- should cause ***asymmetry in rapidity*** of accompanying multiplicity density

- introduces ***specific correlation*** between jet-pair ***transverse momentum imbalances***

$$d\sigma^{(3\to 4)} \;\propto\; \frac{\alpha_{\rm s}^2}{\delta'^2\,\delta^2}\, d^2 j_{3\perp} d^2 j_{4\perp}\cdot d\Sigma$$

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

vs.

$$d\sigma^{(4\to 4)} \;\propto\; \frac{\alpha_{\rm s}^2}{\delta_{13}^2\,\delta_{24}^2}\, d^2 j_{3\perp} d^2 j_{4\perp}\cdot d\Sigma$$

punchline

- Multi-parton collisions contribute substantially to 4 jet production in the back-to-back kinematics

- 2 x 2 and 1 x 2 parton subprocesses are both **enhanced** in the back-to-back region, while "double perturbative parton splittings" generate effectively 1 x 1, which is **not**

- To describe multi-parton collisions one has to introduce and explore a new object – Generalized Double-Parton Distributions

$$ {}_{[2]}D_h^{a,b}(x_1, x_2; q_1^2, q_2^2; \vec{\Delta}\,) $$

→ the parameter $\vec{\Delta}$ encodes the information about the impact-parameter-space correlation between the two partons from one hadron

- experimentally observed enhancement of a 4-jet cross section indicates the presence of short range two-parton correlations in the nucleon parton wave function, as determined by the range of integral over $\vec{\Delta}$

- I'd rather experimental studies employed QCD-motivated jet finding algorithms and concentrated on correlations in transverse momenta rather than angles

MPI

A new subject

Theoretically complicated

Experimentally challenging

Conclusions

Theorists : **think harder**

Q: can one get away within the *probabilistic picture*, in some approximation, or interferences ("cross-talk") are unavoidable ?

MC builders : **think twice**

Q: how do you make sure that the two partons originate, space-time-wise, from *one and the same hadron* ?

Experimenters : **do it** (but mind your head, now and then)

A.