Correlations in double parton distributions at small *x*

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Introduction - Motivation

Multiple hard parton (q,g) collisions are common in high energy *pp* collisions

For example:

- 4 jets in 63 AGeV events @ CERN ISR (AFS)
- 4 jets and 3 jets + γ in 1.8 TeV events @ Tevatron (CDF, D0)

Larger probability found than expected for uncorrelated hard subcollisions

→ ? @ LHC

Literature

J. Kuti and V. F. Weisskopf, *Phys. Rev.* **D4** (1971) 3418–3439.

V. P. Shelest, A. M. Snigirev, and G. M. Zinovev, *Phys. Lett.* **B113** (1982) 325.

T. Sjöstrand and M. van Zijl, *Phys. Rev.* **D36** (1987) 2019.

T. T. Chou and C. N. Yang, *Phys. Rev.* **D32** (1985) 1692.

A. M. Snigirev, *Phys. Rev.* **D68** (2003) 114012, `arXiv:hep-ph/0304172`.

J. R. Gaunt and W. J. Stirling, *JHEP* **03** (2010) 005, `arXiv:0910.4347 [hep-ph]`.

M. Diehl and A. Schafer, *Phys.Lett.* **B698** (2011) 389–402, `arXiv:1102.3081 [hep-ph]`.

J. R. Gaunt and W. Stirling, `arXiv:1103.1888 [hep-ph]`.

Connection between correlations in momentum and impact parameter (b) space have not yet been studied

Correlation studies

Earlier ***Sjöstrand and van Zilj*** assumed that the dependence of double-parton density on kinematic variables (x, Q^2) and on the separation in impact parameter space (b) factorizes.

Implemented in PYTHYA and HERWIG event generators

Problem: how to extrapolate to higher energies (LHC)

Our solution: detailed dynamical model for parton evolution (Lund Dipole Cascade Model)

Correlation studies

Lund Dipole Cascade Model

Based on BFKL and Müller's dipole cascade model

E. A. Kuraev, L. N. Lipatov, and V. S. Fadin, *Sov. Phys. JETP* **45** (1977) 199–204.

I. I. Balitsky and L. N. Lipatov, *Sov. J. Nucl. Phys.* **28** (1978) 822–829.

A. H. Mueller, *Nucl. Phys.* **B415** (1994) 373–385.

A. H. Mueller and B. Patel, *Nucl. Phys.* **B425** (1994) 471–488, `arXiv:hep-ph/9403256`.

A. H. Mueller, *Nucl. Phys.* **B437** (1995) 107–126, `arXiv:hep-ph/9408245`.

Correlation sources in the model:

1) from fluctuations (event by event)
2) "hot spots" makes the profile narrower

Double Parton Scattering & Double Parton Distributions - Experimental results

Measure of correlation is defined by σ_{eff} according to

$$\sigma^{D}_{(A,B)} = \frac{1}{(1+\delta_{AB})} \frac{\sigma^{S}_{A}\sigma^{S}_{B}}{\sigma_{\text{eff}}}$$

$\sigma^{D}_{(A,B)}$ is the cross-section of the two hard processes

σ^{S}_{A} and σ^{S}_{B} are the single inclusive cross-sections

If hard interactions were uncorrelated, σ_{eff} would be equal to the total non-diffractive corss-section

Experimental results

Tevatron (CDF, D0) results:

$$\sigma_{\text{eff}} \approx 15 \text{ mb} \qquad \text{with } \sum p_{\perp \text{jet}} > 140 \text{ GeV}$$

CERN ISR (AFS) results:

$$\sigma_{\text{eff}} \approx 5 \text{ mb} \qquad E_{\perp} \text{ for the four jets is about 30 GeV}$$

Essential formulae

The formalism:

$$\sigma^D_{(A,B)} = \frac{1}{1+\delta_{AB}} \sum_{i,j,k,l} \int \Gamma_{ij}(x_1, x_2, b; Q_1^2, Q_2^2) \hat{\sigma}^A_{ik}(x_1, x_1') \hat{\sigma}^B_{jl}(x_2, x_2')$$
$$\times \Gamma_{kl}(x_1', x_2', b; Q_1^2, Q_2^2) dx_1 dx_2 dx_1' dx_2' d^2b.$$

Stirling and Gaunt:

$$\Gamma_{ij}(x_1, x_2, b; Q_1^2, Q_2^2) = D^{ij}(x_1, x_2; Q_1^2, Q_2^2) F^i_j(b).$$

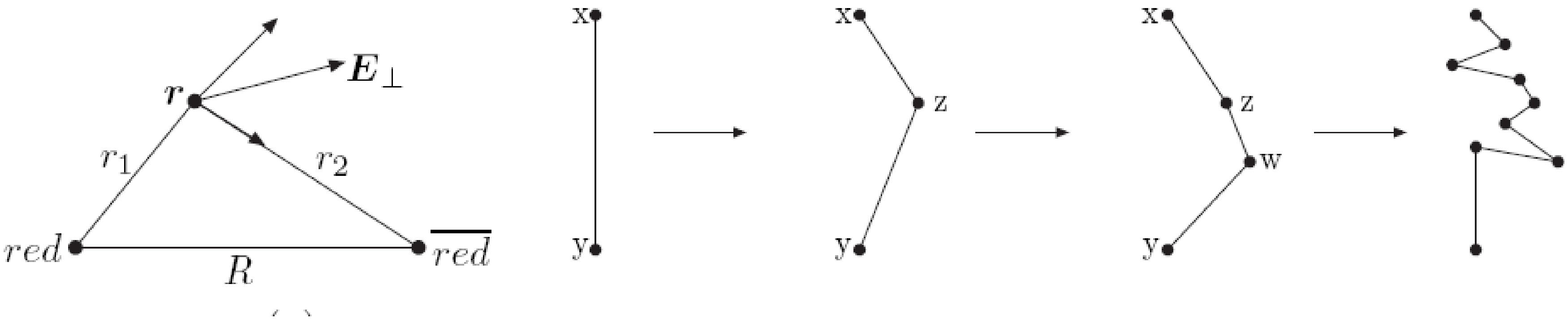
$$\sigma_{\text{eff}} = \left[\int d^2b (F(b))^2 \right]^{-1}.$$

The Lund Dipole Cascade Model

- LL BFKL is not good enough. NLL corrections are very large.
- Non-linear effects in the evolution are not included.
- Massless gluon exchange implies a violation of Froissart's bound.
- It is difficult to include fluctuations and correlations; the BK equation represents a mean field approximation.
- They can only describe inclusive features, and not the production of exclusive final states.
- Analytic calculations are mainly applicable at extreme energies, well beyond what can be reached experimentally.

The Lund Dipole Cascade Model

Dipole cascades:



The Lund Dipole Cascade Model

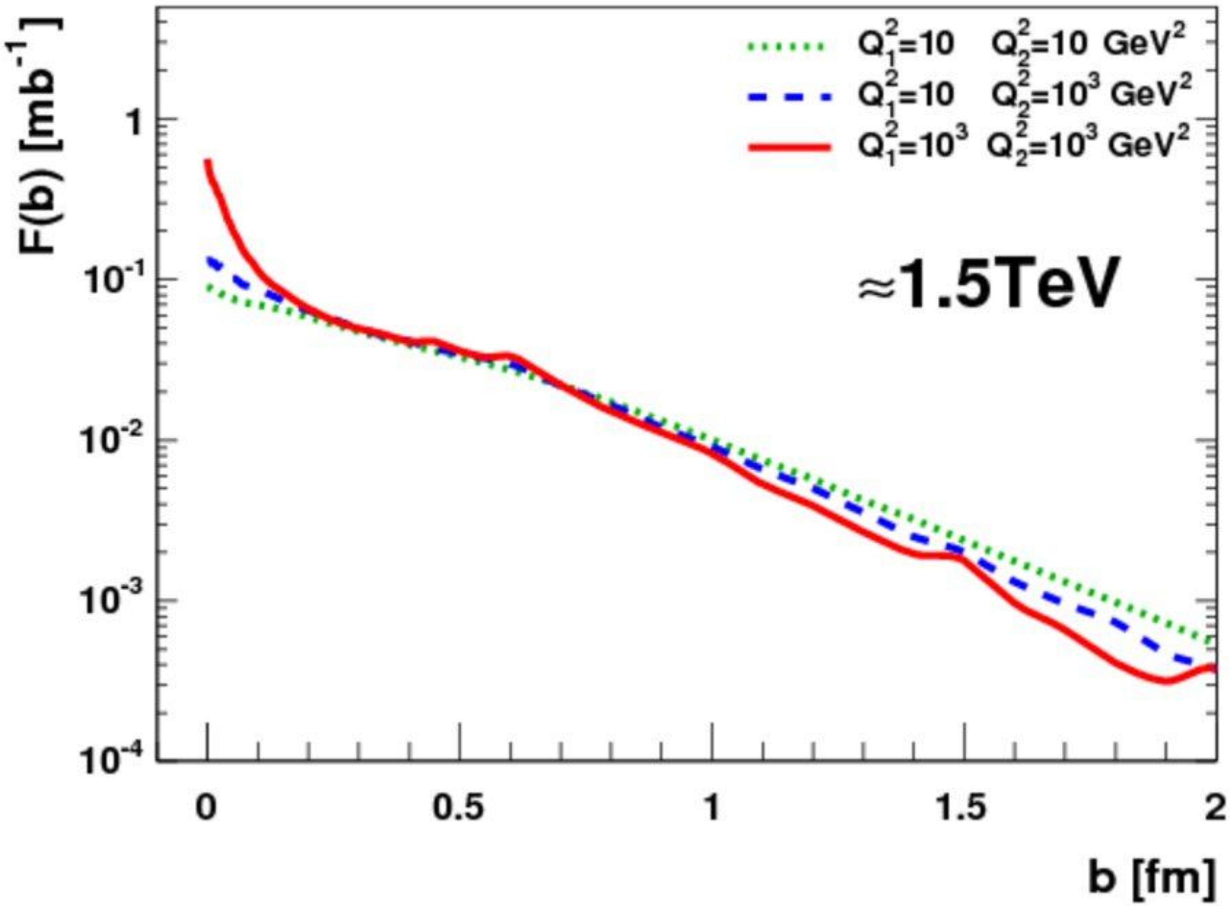
We define:

$$\Gamma(x_1, x_2, b; Q_1^2, Q_2^2) = D(x_1, Q_1^2)D(x_2, Q_2^2)F(b; x_1, x_2, Q_1^2, Q_2^2).$$

With the constraint:

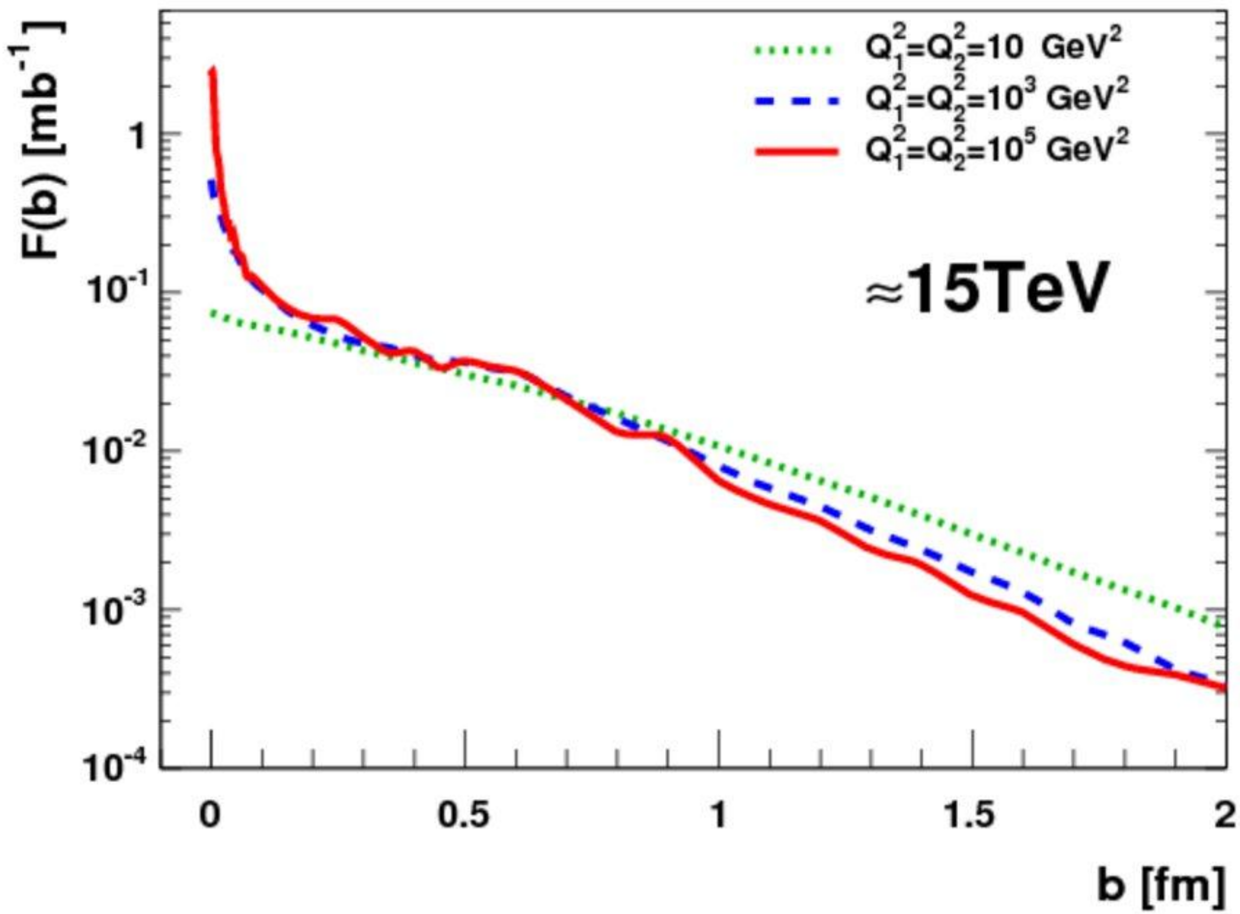
$$s = \frac{Q_1^2}{x_1 x_1'} = \frac{Q_2^2}{x_2 x_2'}.$$

Results



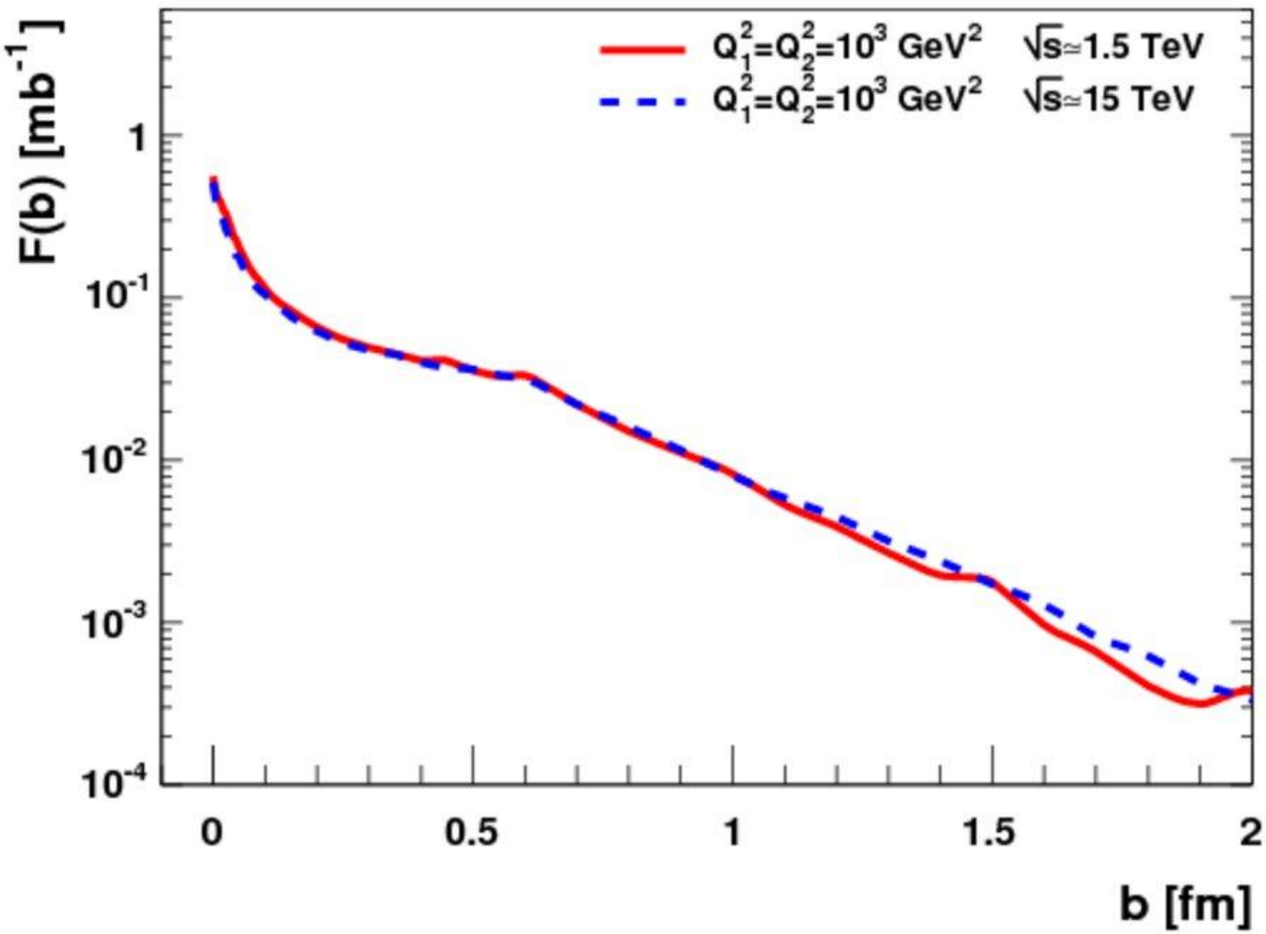
F(b) [mb^{-1}]
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
0.5
1
1.5
2
b [fm]
Q_1^2=10 Q_2^2=10 GeV^2
Q_1^2=10 Q_2^2=10^3 GeV^2
Q_1^2=10^3 Q_2^2=10^3 GeV^2
≈1.5TeV

Results



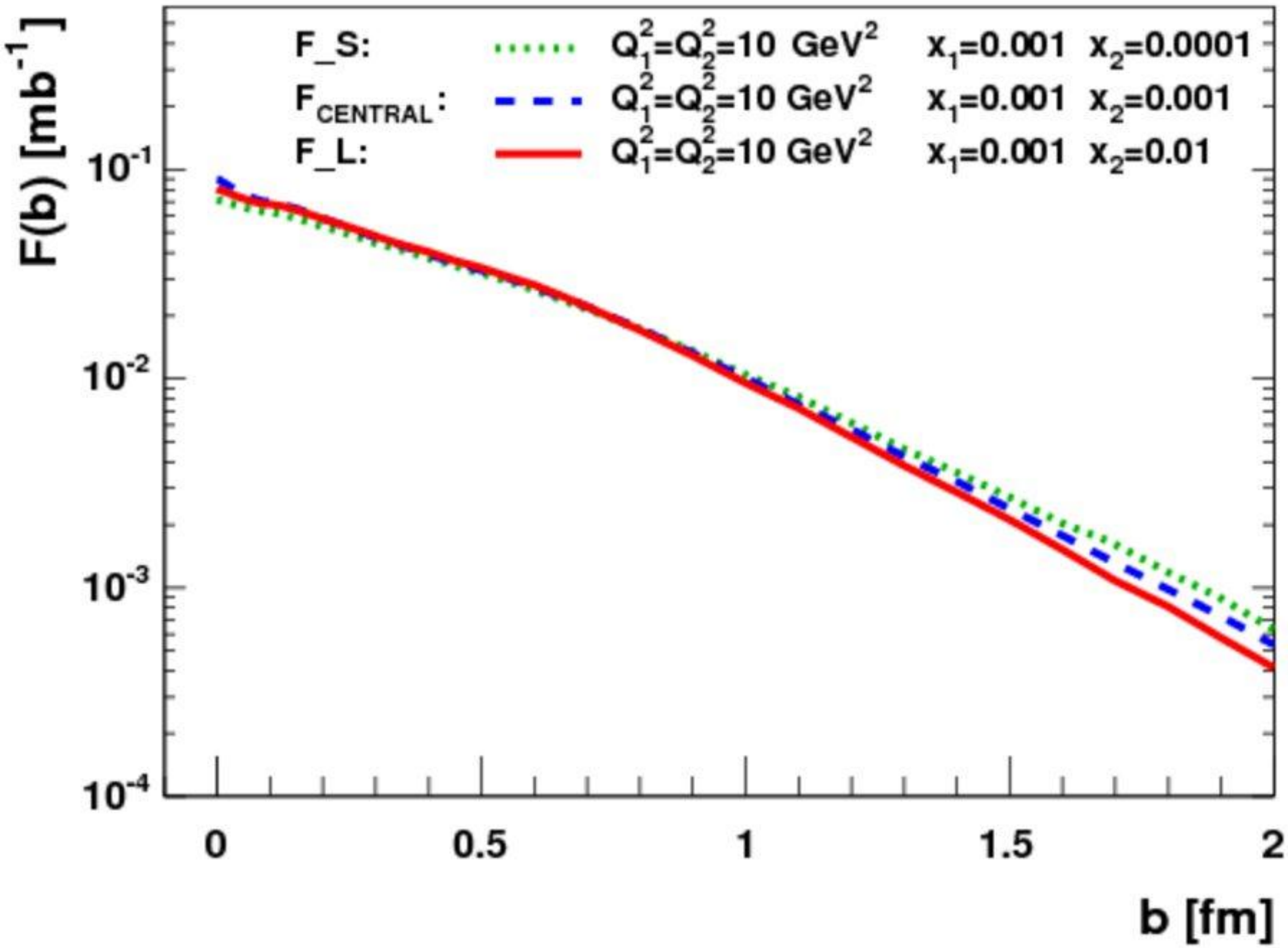
F(b) [mb^{-1}]
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
0.5
1
1.5
2
b [fm]
$Q_1^2=Q_2^2=10$ GeV^2
$Q_1^2=Q_2^2=10^3$ GeV^2
$Q_1^2=Q_2^2=10^5$ GeV^2
≈15TeV

Results



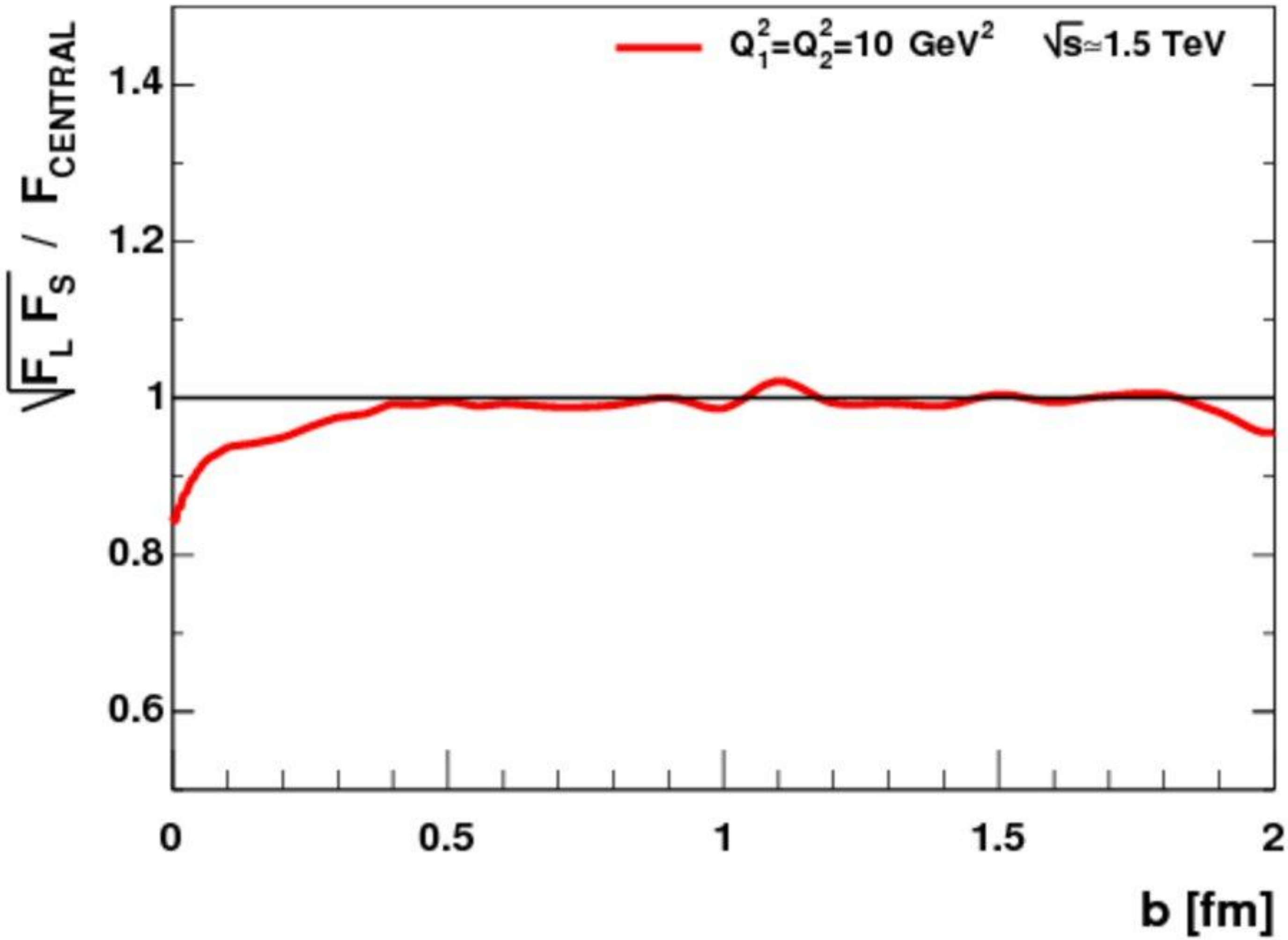
F(b) [mb^{-1}]
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
0.5
1
1.5
2
b [fm]
$Q_1^2=Q_2^2=10^3$ GeV^2 $\sqrt{s}\simeq 1.5$ TeV
$Q_1^2=Q_2^2=10^3$ GeV^2 $\sqrt{s}\simeq 15$ TeV

Results



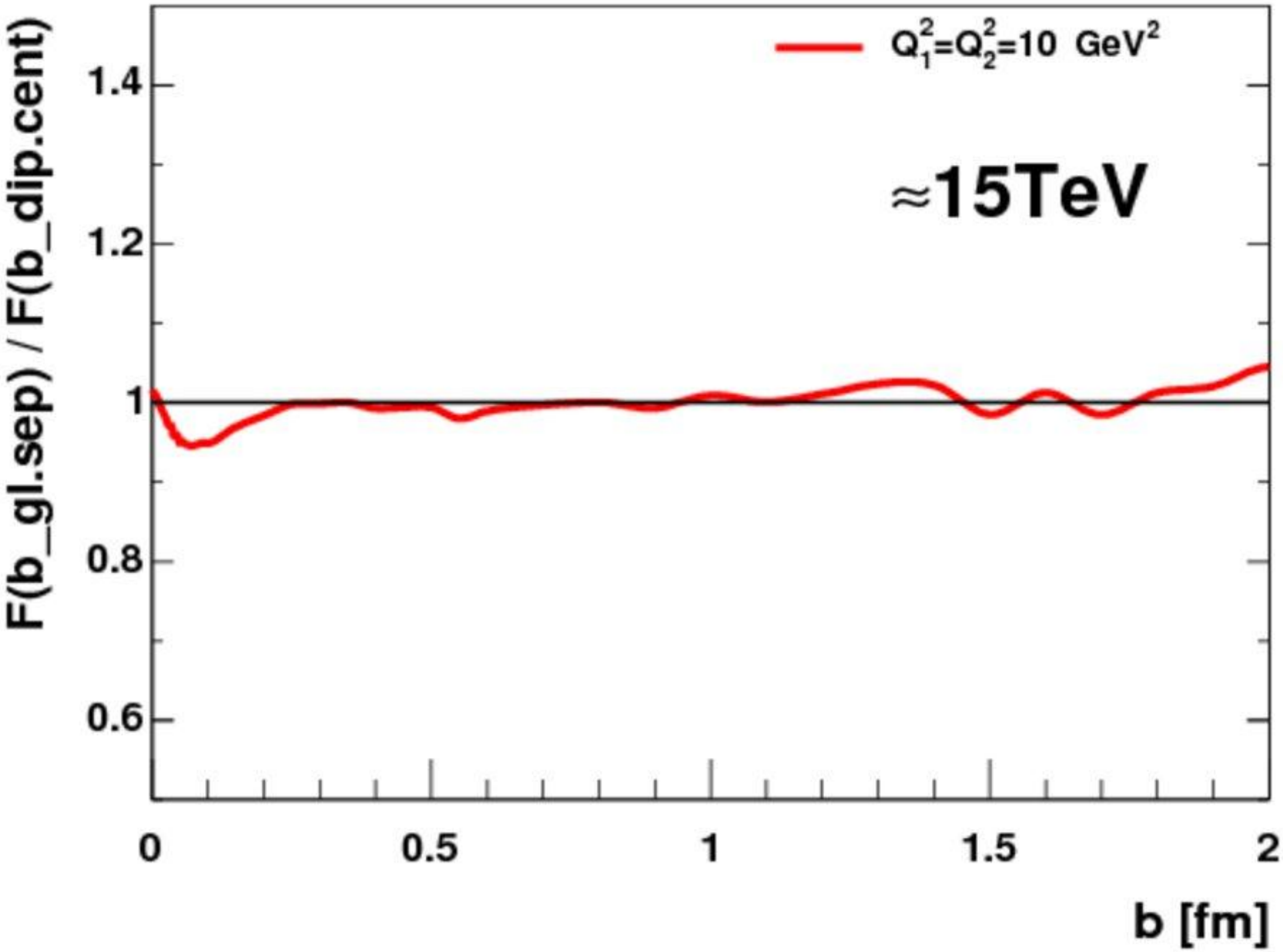
F_S: $Q_1^2=Q_2^2=10$ GeV^2 $x_1=0.001$ $x_2=0.0001$
$F_{CENTRAL}$: $Q_1^2=Q_2^2=10$ GeV^2 $x_1=0.001$ $x_2=0.001$
F_L: $Q_1^2=Q_2^2=10$ GeV^2 $x_1=0.001$ $x_2=0.01$
F(b) [mb^{-1}]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
0.5
1
1.5
2
b [fm]

Results



$Q_1^2=Q_2^2=10\ \mathrm{GeV}^2$ $\sqrt{s}\simeq 1.5$ TeV
$\sqrt{F_L F_S}\ /\ F_{CENTRAL}$
1.4
1.2
1
0.8
0.6
0
0.5
1
1.5
2
b [fm]

Results



$Q_1^2=Q_2^2=10\ GeV^2$
≈15TeV
F(b_gl.sep) / F(b_dip.cent)
1.4
1.2
1
0.8
0.6
0
0.5
1
1.5
2
b [fm]

Results

Q_1^2, Q_2^2 [GeV^2], x_1, x_2				σ_{eff} [mb]	$\int F$
1.5 TeV, midrapidity					
10	10	0.001	0.001	35.3	1.09
10	10^3	0.001	0.01	31.0	1.07
10^3	10^3	0.01	0.01	23.1	1.06
15 TeV, midrapidity					
10	10	0.0001	0.0001	40.4	1.11
10^3	10^3	0.001	0.001	26.3	1.07
10^3	10^5	0.001	0.01	24.2	1.05
10^5	10^5	0.01	0.01	19.6	1.03
1.5 TeV, $y_{\text{pair}\,2} = 2.3$					
10	10	0.001	0.0001	} 37.1	1.08
10	10	0.001	0.01		

Summary

Lund Dipole Cascade Model offers unique possibility to study gluon evolution inside hadrons at small x

In our analysis we have found that the two-parton correlation function $F(b)$ in a non-trivial way on all kinematic variables $x_1, x_2, Q^2{}_1, Q^2{}_2$

Our results show a non-flat energy dependence within errors compatible with experiments in their energy range.