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Fractional momentum correlations in multiple production of w bosons and of bb pairs in high energy pp collisions

Enrico CATTARUZZA
Universita' degli Studi di Trieste
Dipartimento di Fisica
Via A. Valerio 2
34127 Trieste
ITALY

Fractional momentum correlations in multiple production of W bosons and of $b\bar{b}$ pairs in high energy pp collisions

E. Cattaruzza,[1] A. Del Fabbro[1] and D. Treleani[2]
[1] Department of Physics of University of Trieste (INFN)
[2] Department of Theoretical Physics of University of Trieste

Fifth International Conference on Perspectives in Hadronic Physics

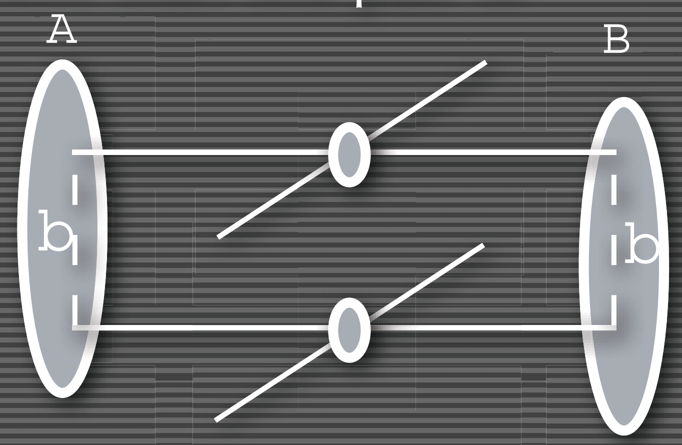
Outline

- Importance of multiparton scattering at new collider energies
- Disconnected collisions: double parton scattering and double parton distribution;
- Double parton distribution in the LLA of pQCD: numerical results for the violation to the factorization ansatz of double parton distributions;
- Multiple production of $b\bar{b}$ pairs and W bosons in pp-collisions: numerical results with and without correlation corrections;
- Conclusions

Introduction

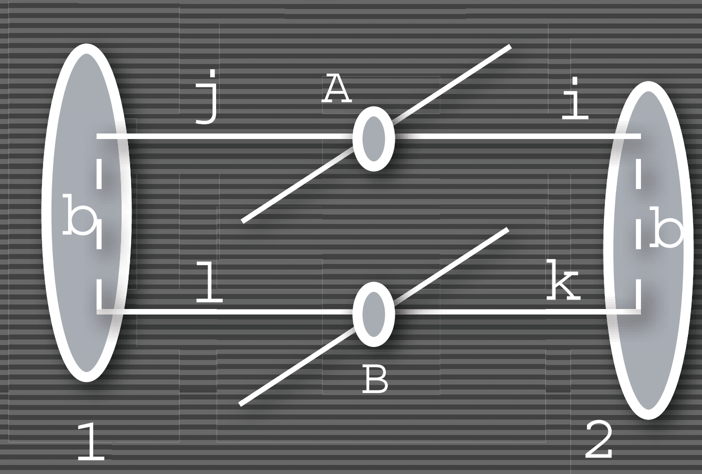
- RHIC and LHC high energy colliders:
  - Regime of very short distances and high momentum transfer:

    asymptotic freedom and validity of perturbative methods
  - small Bjorken x => growing flux of of partons
  - being hadrons extended objects, more than one pair of partons is expected to interact in different points in transverse space, with large transverse momentum exchanged => pQCD



Disconnected collisions: double parton scattering

- Double-parton scattering: simplest case of multiparton interaction



- Presence of two different scales:
  1) hard perturbative scale
  2) inverse of distance in transverse space of the interacting partons
- factorization of perturbative and non-perturbative component of the process

$$D_{(A,B)} = \frac{m}{2} \; {}_{i,j,k,l} \; {}_{jl}(x_1,x_2,b) \; {}_{ik}(x_1,x_2;b) \; \hat{}^{A}_{ij}(x_1,x_1) \; \hat{}^{B}_{kl}(x_2,x_2)$$

- Double parton distribution: non-perturbative ingredient providing correct dimensionality, related to two body correlations

Disconnected collisions: double parton scattering

$$_{ik}(x_1, x_2; b) = G_i(x_1)\, G_k(x_2)\, F_{ik}(b)$$

- correlation in transverse space and fractional momenta are neglected
- the dimensionality of the two body distribution leads to the introduction of a non-perturbative scale factor, effective cross section

$$_{eff} = \quad d^2bF(b)^2 \quad ^{-1}$$

$$D_{(A,B)} = \frac{m}{2} \frac{{}^{A}_{S} \;\; {}^{B}_{S}}{_{eff}}$$

- Inclusive cross-section factorized into the product of inclusive single scattering cross-section of pQCD parton model
- CDF collaboration: $_{eff} = (14.5 \pm 1.7)\,\mathrm{mb}$

Double Parton Distribution in LLA of pQCD

- This symplified hypothesis of factorization in contrast with leading logarithm approximation of pQCD[1]
- If two parton distribution is factorized at reference scale, it becomes dinamically correlated at any different scale of a hard process
- Degree of violation of factorization ansatz can be estimated by solution of the generalized LAPD equation for two parton distribution

$$\frac{d\,{}^{j_1 j_2}_{h}}{dt} = {}^{j_1 j_2}_{h}\quad P_{j_1}\quad {}_{j_1} + {}^{j_1 j_2}_{h}\quad P_{j_2}\quad {}_{j_2} + {}^{j}_{h}\quad P_{j}\quad {}_{j_1 j_2}$$

where: $t = \frac{1}{2\ \ b} \ln\ 1 + \frac{g^2(\mu^2)}{4} b \ln \frac{}{\mu}$ and $b = \frac{33 - 2n_f}{12}$

- ${}^{j}_{h}$ satisfies the evolution equation: $\frac{d\,{}^{j}_{h}}{dt} = D\,{}^{j}_{h}\quad P_{j}\quad {}_{j}$

[1] A. M. Snigirev, Phys. Rev. D 68, 114012 (2003) (hep-ph/0304172);
V.L. Korotkikh, A.M. Snigirev, Phys. Lett. B 594, 171-176 (2004) (hep-ph/0404155).

Double Parton Distribution in LLA of pQCD

- If the following initial condition is taken:

$$ {}^{j_1 j_2}_{h}(x_1, x_2, t = 0) = {}^{j_1}_{h}(x_1, 0)\; {}^{j_2}_{h}(x_2, 0)\; (1 - x_1 - x_2) $$

$$ {}^{j_1 j_2}_{h}(x_1, x_2, t) = {}^{j_1}_{h}(x_1, t)\; {}^{j_2}_{h}(x_2, t)\; (1 - x_1 - x_2) + {}^{j_1 j_2}_{h}(x_1, x_2, t) $$

- the non-factorized contribution is expressed in terms of initial single parton densities and the distribution functions ${}^{j}_{i}(x;t)$:

$$ {}^{j_1 j_2}_{h,corr,1}(x_1, x_2; t) = (1 - x_1 - x_2)\; {}^{j_1}_{h}(t = 0)\; {}^{j_1}_{j_1}(t)\; {}^{j_2}_{h}(t = 0)\; {}^{j_2}_{j_2}(t) $$

$$ {}^{j_1 j_2}_{h,corr,2}(x_1, x_2; t) = \int_0^t dt\; {}^{j}_{h}(t)\; P_{j\; j_1 j_2}\; {}^{j_1}_{j_1}(t - t)\; {}^{j_2}_{j_2}(t - t) $$

Double Parton Distribution in LLA of pQCD

- ${}^{j}_{i}(x;t)$ represents the probability to find a parton j within a parton i; it satisfies the evolution equation:

$$\frac{d\ {}^{j}_{i}}{dt}(x;t) = {}^{j}_{i} \quad P_{j} \quad {}_{j}$$

with the initial condition ${}^{j}_{i}(x;t = 0) = {}_{ij}\ (1 - x)\ .$

- The equation is solved by introducing the Mellin transforms

$${}^{j}_{i}(n\ t) = \int_{0}^{1} dx\, x^{n}\, D^{j}_{i}(x\ t)$$

which lead to a system of ordinary differential equations at first order.

$${}^{j}_{i}(x\ t) = \frac{dn}{2\ {}_{\imath}} x^{-n}\ {}^{j}_{i}(n\ t) = L^{-1}(\ {}^{j}_{i}(n\ t)\ -\ \ln(x))$$

Double Parton Distribution in LLA of pQCD

- Once ${}_{i}^{j}(x;t)$ has been determined, the integral of the LAPD equation has performed using MRS99 as parametrization for parton distribution and Vegas algorithm for numerical integration.

- In the kinematical regime of interest (x never exceeds 0.1) ${}_{h,corr,1}^{j_1 j_2}$ is negligible;

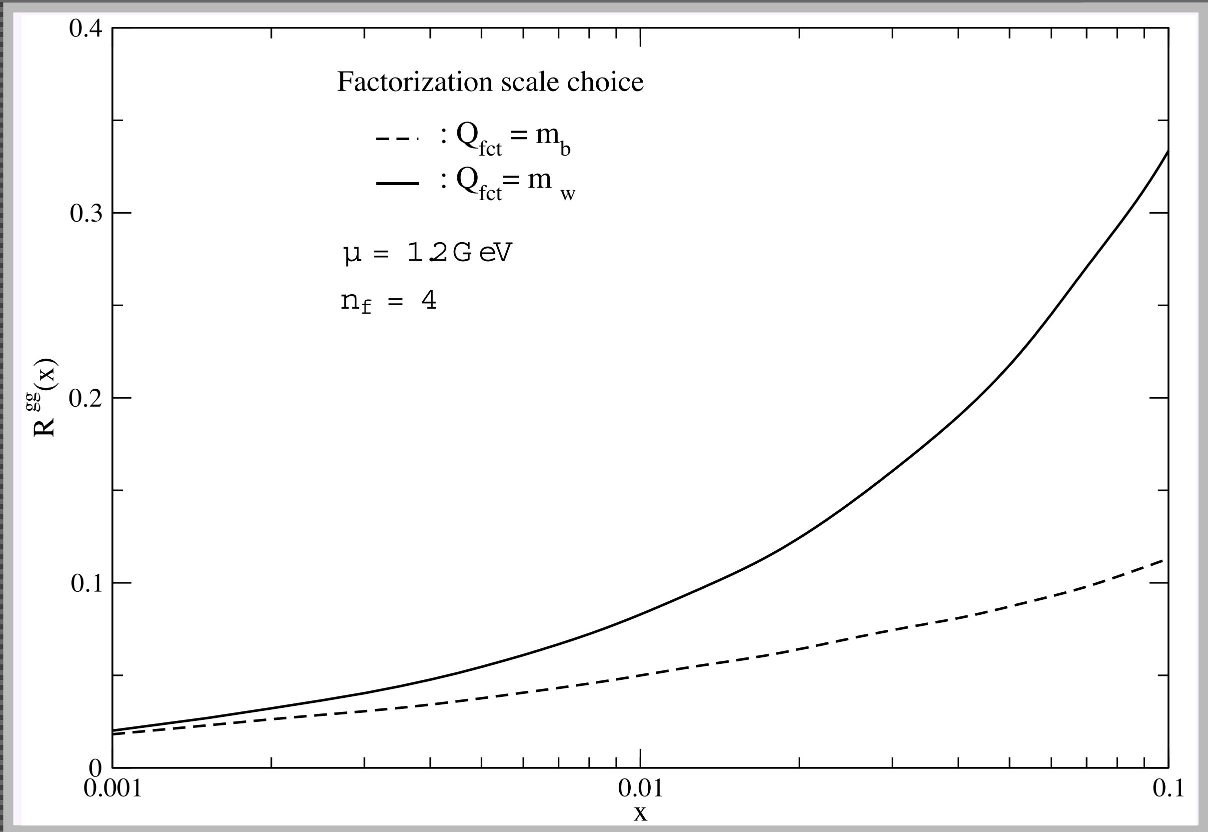
$${}_{h}^{j_1}(x;t) \quad {}_{h}^{j_2}(x;t) \qquad \boxed{\frac{d\,{}_{h}^{j_1 j_2}}{dt} = {}_{h}^{j_1 j_2} \quad P_{j_1} \quad {}_{j_1} + {}_{h}^{j_1 j_2} \quad P_{j_2} \quad {}_{j_2}}$$

- Effect of correlation induced by evolution is estimated by the ratio

$$R^{j_1 j_2}(x_1,x_2;t) = \frac{{}_{h,corr,1}^{j_1 j_2}(x_1,x_2;t) + {}_{h,corr,2}^{j_1 j_2}(x_1,x_2;t)}{{}_{h}^{j_1}(x_1;t) \quad {}_{h}^{j_2}(x_2;t)},$$

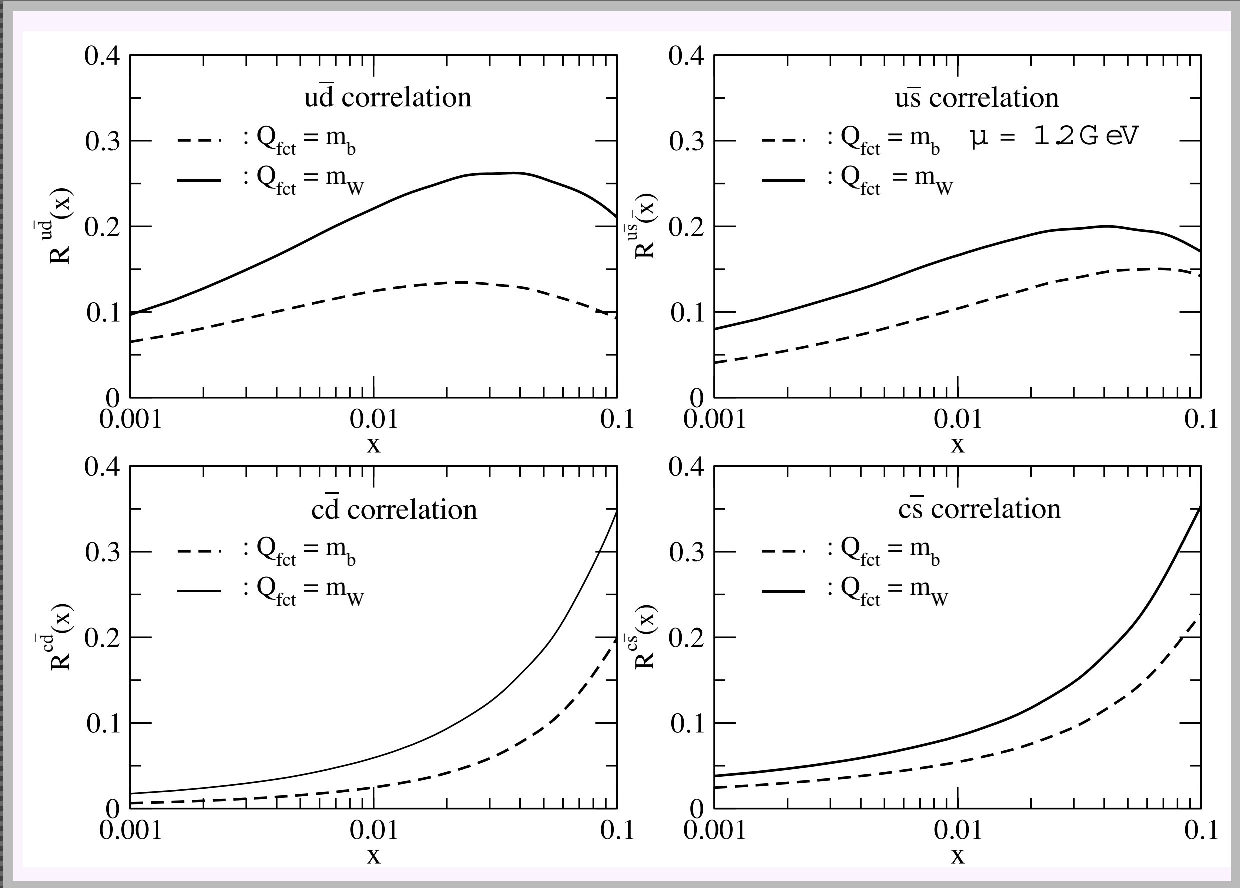
plotted as a function of $x = x_1 = x_2$

Numerical Results for the Correlation Ratio



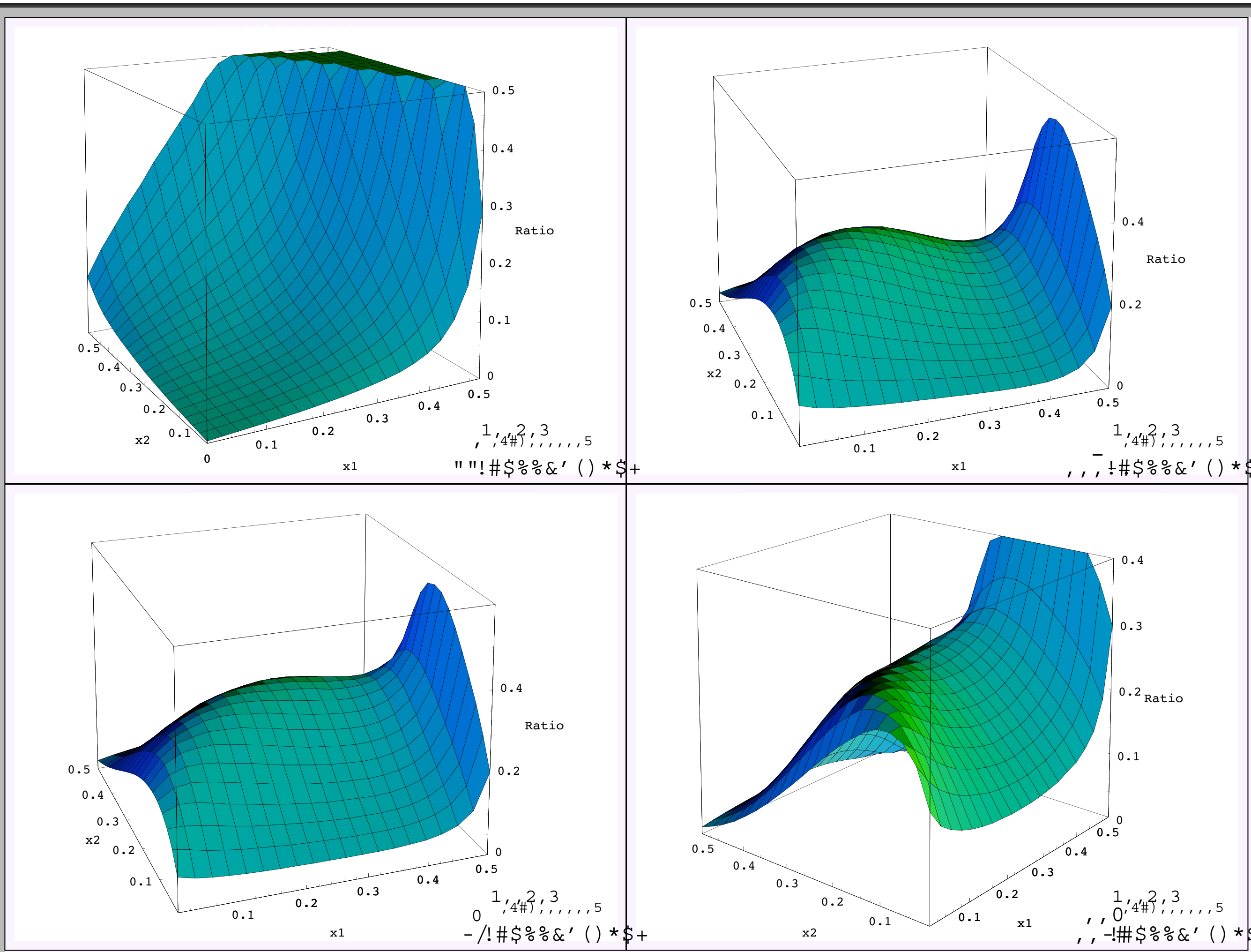
- Ratio $R^{gg}(x;t)$:
  - $Q_{fct} = M_W = 80.4$ GeV:
    R^{gg} 35% for x 0.1
    R^{gg} 8 – 10% for x 0.01
    R^{gg} 2% for x 0.001
  - $Q_{fct} = M_b = 4.6$ GeV:
    R^{gg} 10 – 12% for x 0.1
    R^{gg} 5% for x 0.01
    R^{gg} 2% for x 0.001

Numerical Results for the Correlation Ratio



- Ratio $R^{qq}(x\ t)$
  - $Q_{fct} = M_W = 80.4$ GeV :
    - R^{qq} 35% for x 0.1
    - R^{qq} 20% for x 0.01
    - R^{qq} 10% for x 0.001
  - $Q_{fct} = M_b = 4.6$ GeV :
    - R^{qq} 23% for x 0.1
    - R^{qq} 10% for x 0.01
    - R^{qq} 5% for x 0.001

Numerical Results for the Correlation Ratio



Double Parton Distribution in LLA of pQCD

- Remark:
  - The non-perturbative input of double-parton scattering cross section is not represented by the distribution functions ${}_{h}^{j_1 j_2}(x;t)$, where the transverse variables have been integrated;
  - Double parton scattering cross section depends on relative separation of partons in transverse space => outside control of pQCD;
  - Given the different origin of the terms in ${}_{h}^{j_1 j_2}(x;t)$, it is not unnatural to have different non-perturbative scales for the transverse separation of the factorized and of the correlated terms;
  - Assumption:

    1) in ${}_{h,fact}^{j_1 j_2}$ and ${}_{h,corr,1}^{j_1 j_2}$ => CDF low resolution scale process

    2) in ${}_{h,corr,2}^{j_1 j_2}$ => scale related to size of gluon cloud of a valence quark

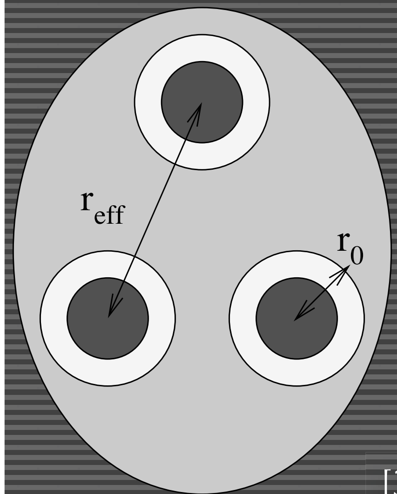
Double Parton Distribution in LLA of pQCD

$$ {}_{j_1 j_2}(x_1, x_2, b; t) \qquad {}^{j_1 j_2}_{h,fact}(x_1, x_2; t) + {}^{j_1 j_2}_{h,corr,1}(x_1, x_2; t) \quad F_{eff}(b) $$

$$ + \; {}^{j_1 j_2}_{h,corr,2}(x_1, x_2; t)\, F_{r}(b) $$

where the parton pair densities satisfy:

$$ d^2 b F_i(b) = 1 \qquad d^2 b F_i(b)^2 = \frac{1}{{}_i} \quad \text{with } i = {}_{eff},\ {}_{r}. $$



- F_{eff}: transverse density of partons at resolution scale leading to scale factor ${}_{eff} = 14.5\, mb$;
- F_r: transverse density for partons correlated in fractional momenta, important at higher resolution scale; ${}_r \quad {}_{r_0} \quad {}_{eff}$, with ${}_{r_0} = 2.8\, mb$ related to the size of the gluon cloud of a valence quark in the hadron.[3]

[3] B. Povh, Nucl. Phys. A 699, 226 (2002)

Multiple Production of $b\bar{b}$ pairs

- Multiple production of $b\bar{b}$ pairs and W bosons in pp-collisions:

  1) $p\bar{p}$ $b\bar{b}b\bar{b}$:

  - higher order corrections in $_{s}$ are very important ; the whole effect of higher order corrections is reduced to a single numerical value, K factor

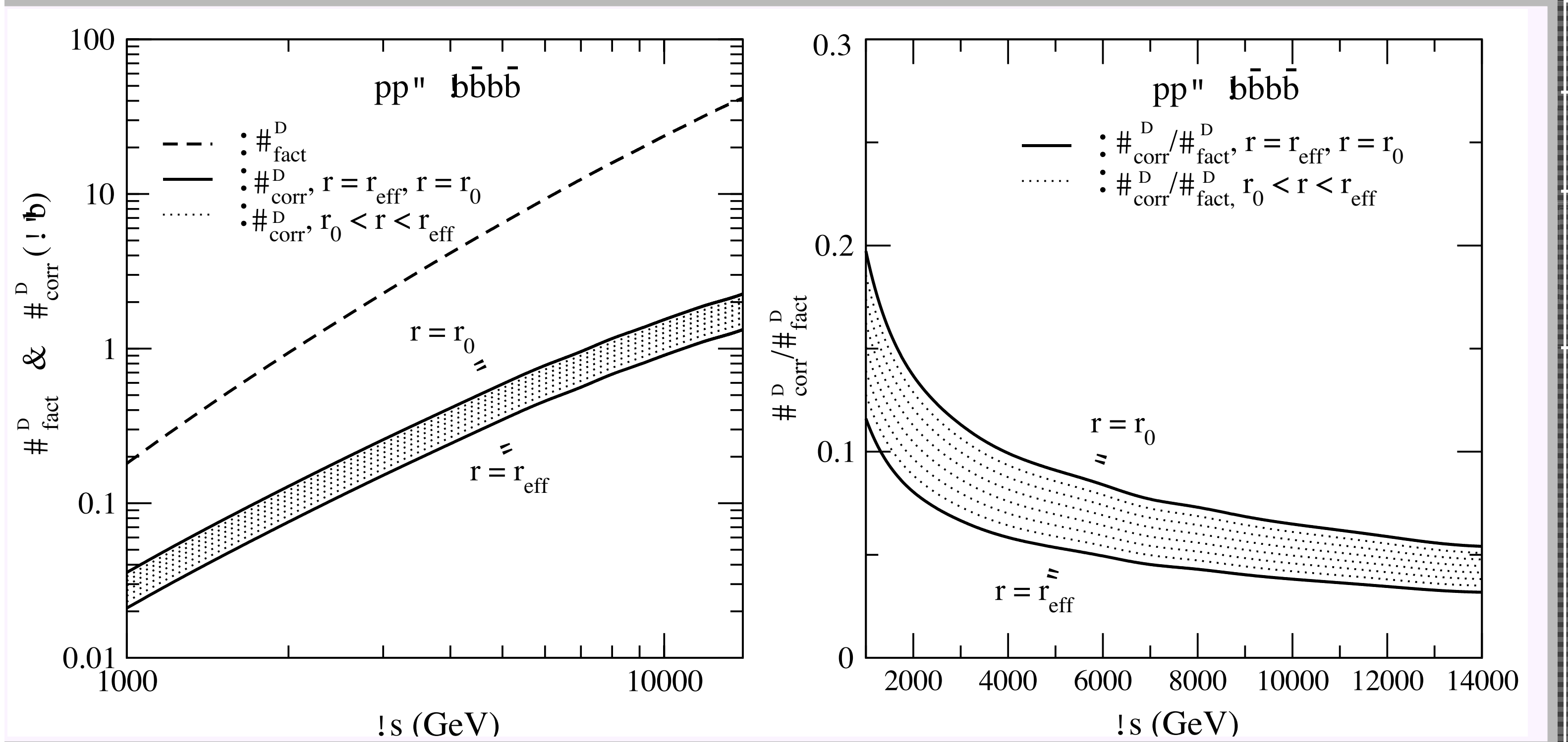
$$K = \frac{(q\bar{q})}{_{LO}\ (q\bar{q})}$$

  - Our assumption is that higher order corrections in double $b\bar{b}b\bar{b}$ production can be taken into account by multiplying the cross section of each connected process by the same K factor

  - In addition to usual factorized contribution, scaling with $_{eff}^{-1}$, double cross section includes not factorized contributions related to the couplings of $^{ik}_{h,corr,2}$ both with $^{jl}_{h,fact}$ and $^{jl}_{h,corr,2}$

Numerical Results at LHC: $b\bar{b}$ production cross-section and correlation effect

[4] E. Cattaruzza, A. Del Fabbro and D. Treleani, Phys. Rev. D 70, 034022 [arXiv:hep-ph/0404177].



1) $K_{factor} = 5.3$ [4]

2) MRS99 for PDF

3) Scale choices: $Q_{fct} = Q_{rn} = m_b$

4) Gaussian distrib. for F_{eff} and F_r

$1/\ eff$

$2/(\ eff + \ r)$

scale factors

for r_{eff}, r_0: ... 12 – 20 % at $\sqrt{s}$ = 1 TeV & & 3.5 – 6 % at $\sqrt{s}$ = 14 TeV

- Effect of correlations decreases increasing c.m; the decrease is faster as $\sqrt{s}$ 5 TeV : for larger c.m x becomes smaller than 0.01 where R^{gg} 0.03

Multiple Production of W pairs

2) $pp \quad W^+W^+, W^-W^-$:

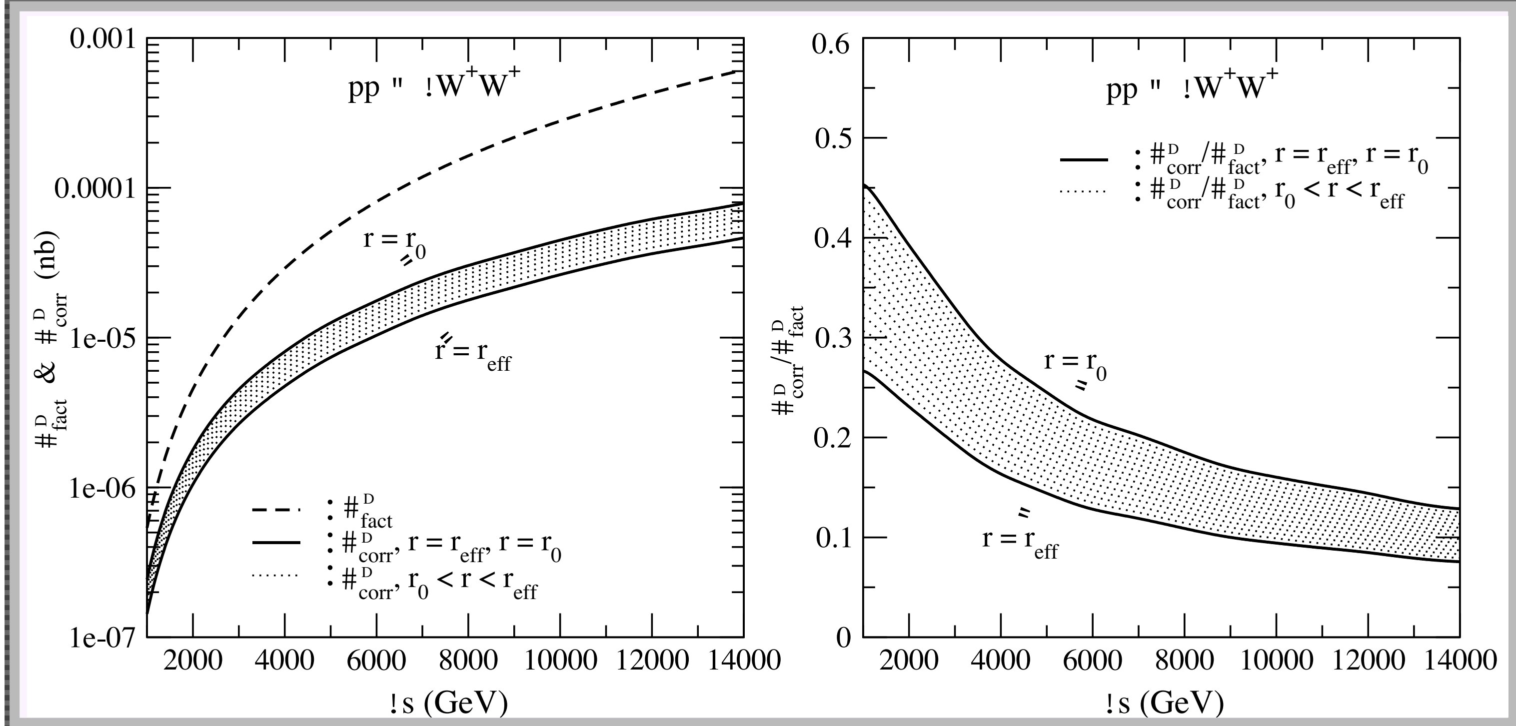
- the cross-sections of like-sign W pair have been evaluated at the leading order, including only quark initiated processes in the elementary interaction ($q\bar{q} \quad W$)

- higher order corrections are taken into account multiplying the lowest order correction by the K factor[5]

$$K \quad 1 + \frac{8}{9} \quad {}_s(M_W^2)$$

[5] V. D. Barger, R. J. N. Phillips, Collider Physics (updated edition), Addison- Wesley Publishing Company, Inc. (1996), p.247.

Numerical Results at LHC: production cross-section and correlation effect



1) MRS99 for PDF

2) Scale choices:
$Q_{fct} = Q_{rn} = M_W$

3) Gaussian distrib. for F_{eff} and F_r

2/ eff

2/ (eff + r)

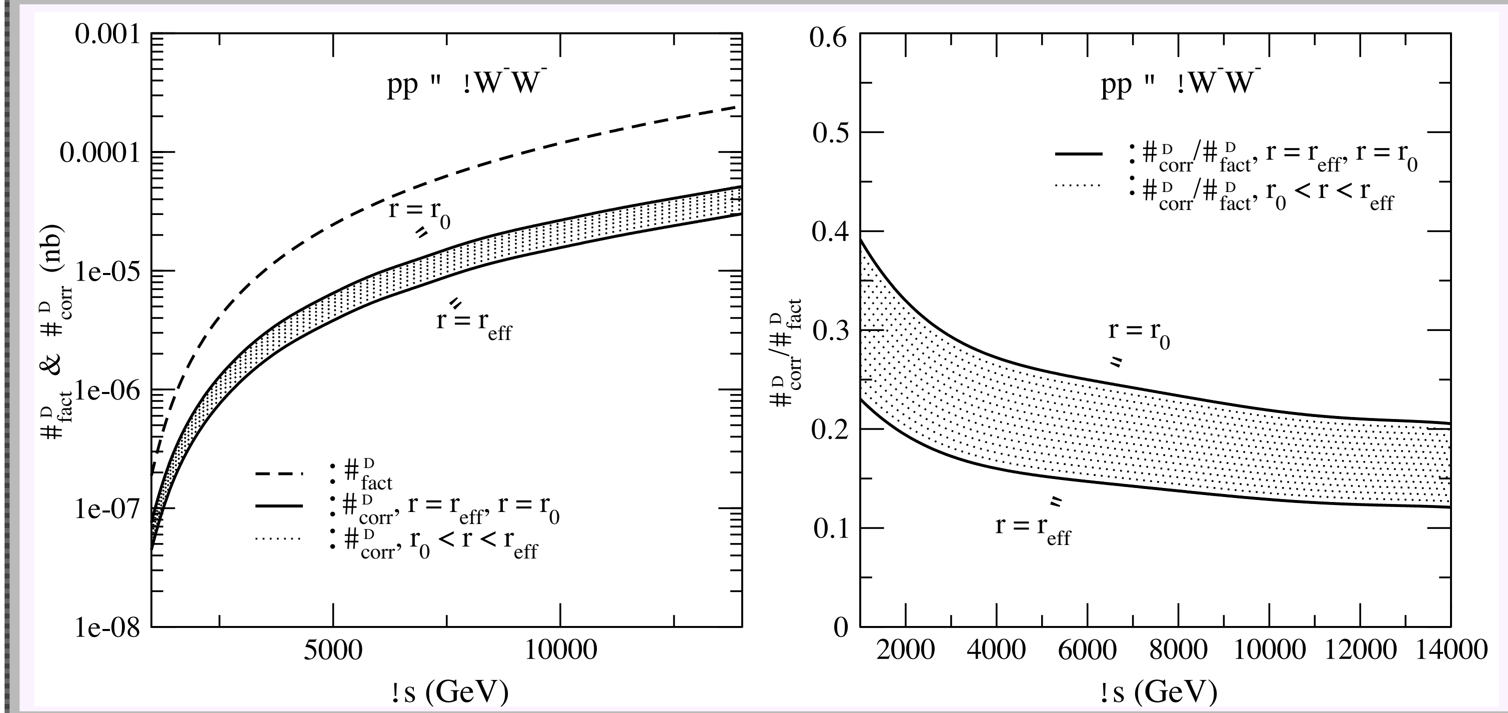
scale factors

$\frac{D_{corr}}{D_{fact}}$ 27 – 45%, 7.5 – 13% for W^+

x 0.2, 6 $\times 10^{-2}$ as $\bar{s}$ 1, 14 TeV

$\frac{D_{corr}}{D_{fact}}$ 23 – 40%, 12 – 20% for W^-

Numerical Results at LHC: production cross-section and correlation effect



1) M RS99 for PDF

2) Scale choices:
Q fct = Q rn = M W

3) Gaussian distrib. for F eff and F r

2/ eff
2/(eff + r)
scale factors

x 0 2, 6. × 10^- 2 as s 1 , 14. TeV

D corr / D fact : 27 – 45% , 7 5 – 13% : fcr W +

D corr / D fact : 23 – 40% , 12 – 20% : fcr W −

Conclusions

- As an effect of evolution, the multiparton distributions are expected to become strongly correlated in momentum fraction at large Q^2 and finite x;
- High resolution scale multiparton process (equal sign W pair production) and a smaller resolution scale process ($b\bar{b}b\bar{b}$ production) in pp collisions in the energy range $\sqrt{s} \in [1,14]\,TeV$ have been considered;
- Disconnected contributions to the cross-section, after evolving multiparton distribution at desired resolution scale, have been evaluated;
- Terms with correlation, in equal sign W pair production, are at most 40% of the cross-section at 1 TeV and a 20% effect at LHC
- The effect is much smaller in $b\bar{b}b\bar{b}$ production, where corrections are of the order of 5%.