UNINTEGRATED GLUON DISTRIBUTION AND GLUON SATURATION IN P-P AT LHC

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in collaboration with

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Low-x 2012

OUTLINE

1. **Quark –Gluon-String Model (QGSM) and gluons in proton.**

2. **Gluon distribution in proton**

3. **Inclusive spectra of charge hadrons in p-p within QGSM including gluons**

4. **Modified un-integrated gluon distribution**

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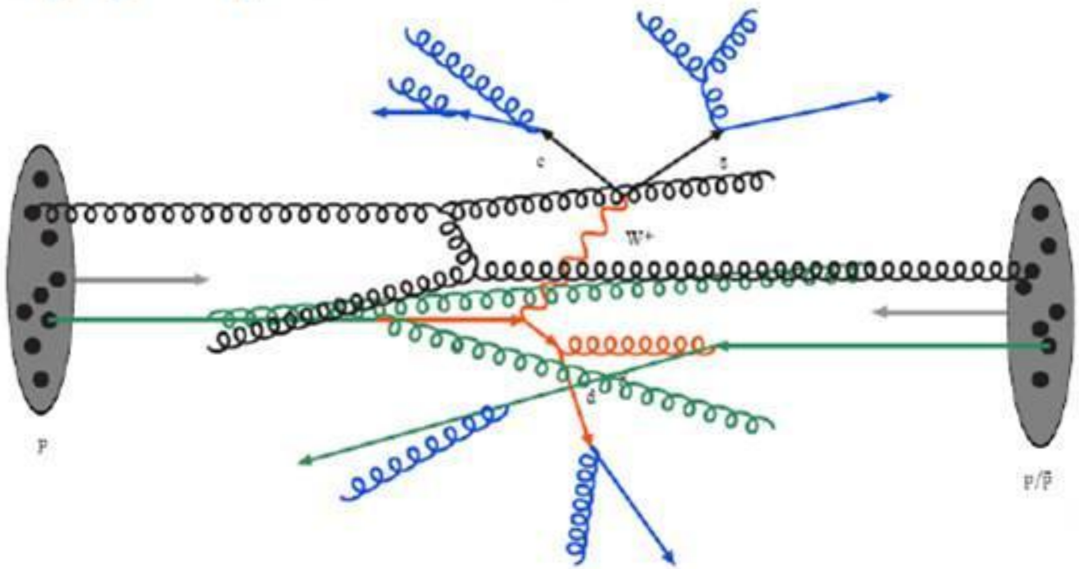
5. **Structure functions and H1 data**

6. **Summary**

Structure of an event

- Multiple parton-parton interactions



DIAGRAMS in *pp* collisions within QGSM

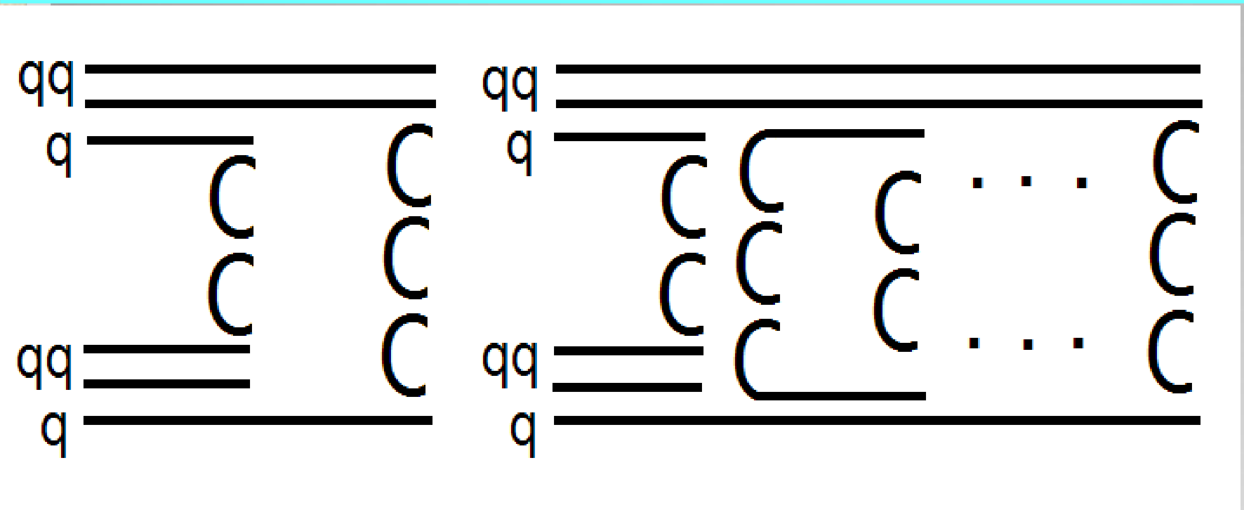


Fig. 1. The one-cylinder graph (at the left) and the multi-cylinder graph (at the right) for the inclusive *pp* → hX process.

QGSM

A.B.Kaidalov, Phys.Lett., B116, 459 (1982)
A.B.Kaidalov, K.A.Ter-Martirosyan, Phys.Lett., B117, 247 (1982)

DPM

A.Capella, J.Tran Thanh Van, Phys.Lett., B114, 450 (1982)

So, the inclusive spectrum is presented in the following form:

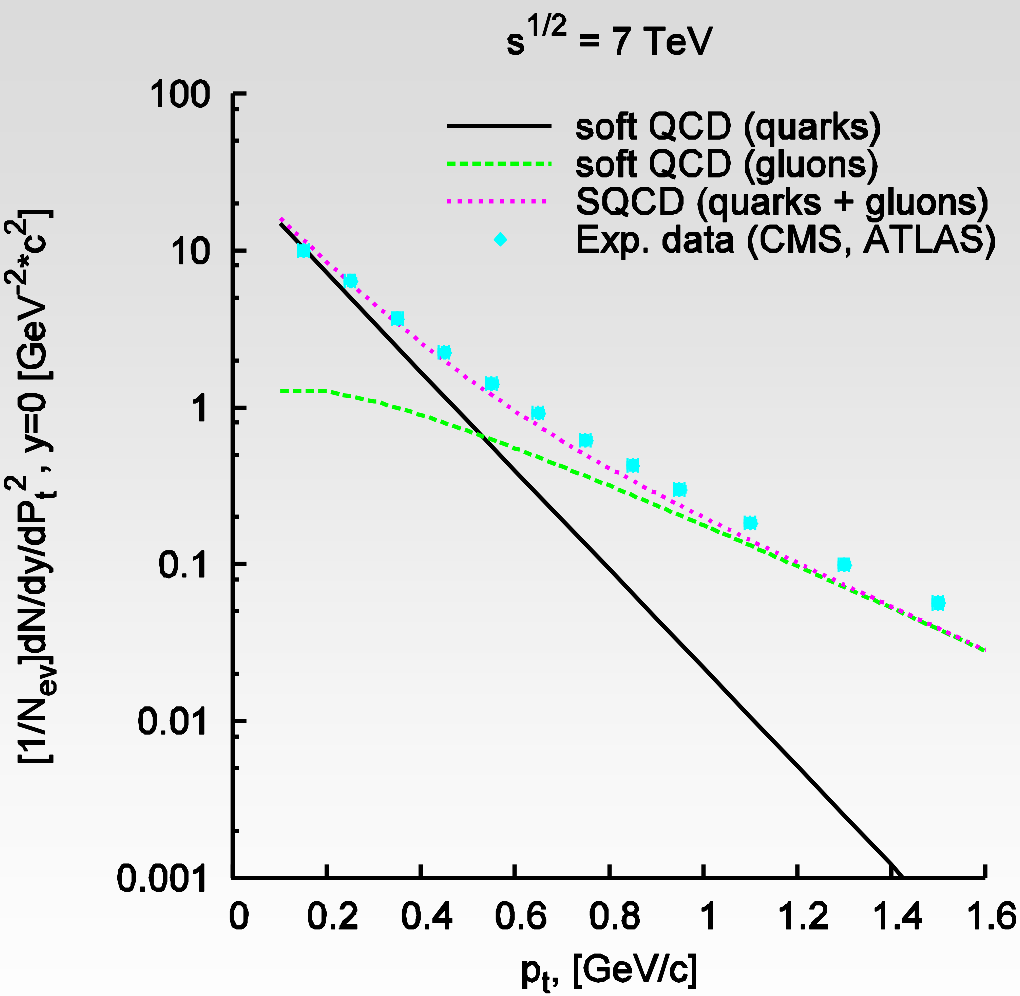
$$\rho\left(x=0,p_t\right)=\rho_q\left(x=0,p_t\right)+\rho_g\left(x=0,p_t\right)$$

Here $$\rho_q=\left(\frac{s}{s_0}\right)^{\Delta}\varphi_q;\varphi_q(0,p_t)=A_q\exp(-b_q p_t)$$

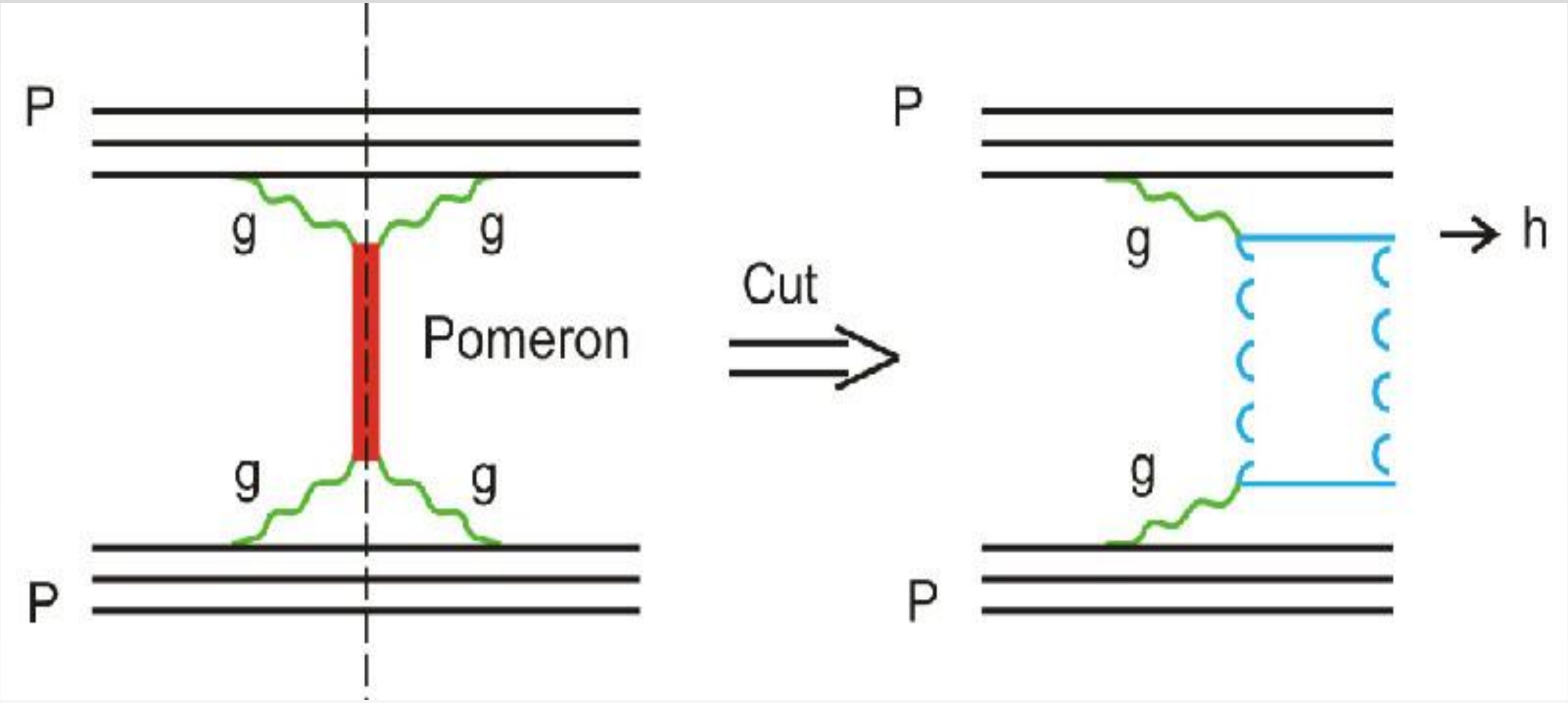
$$\rho_g=\left[\left(\frac{s}{s_0}\right)^{\Delta}-\sigma_{nd}\right]\varphi_g;\varphi_g(0,p_t)=\sqrt{p_t}A_g\exp(-b_g p_t)$$

$$A_q = 11.91 \pm 0.39,\ b_q = 7.29 \pm 0.11$$
$$A_g = 3.76 \pm 0.13\quad b_g = 3.51 \pm 0.02$$

V.A. Bednyakov, A.V. Grinyuk, G.L., M. Poghosyan, Int. J.Mod.Phys. A 27 (2012) 1250012. hep-ph/11040532 (2011); hep-ph/1109.1469 (2011); Nucl.Phys. B 219 (2011) 225.



$s^{1/2}$ = 7 TeV
soft QCD (quarks)
soft QCD (gluons)
SQCD (quarks + gluons)
Exp. data (CMS, ATLAS)
[1/N$_{ev}$]dN/dy/dP$_t^2$, y=0 [GeV^{-2}*c^2]
100
10
1
0.1
0.01
0.001
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
p$_t$, [GeV/c]



One-Pomeron exchange (left) and the cut one-Pomeron exchange (right); P-proton, g-gluon, h-hadron produced in PP

In the light cone dynamics the proton has a general decomposition:

$|uud\rangle, |uudg\rangle, |uudq\bar{q}\rangle, \ldots$ S.J.Brodsky, C.Peterson, N.Sakai, Phys.Rev. D 23 (1981) 2745.

The cut one-pomeron exchange

$$\rho(x, p_{ht}) = F(x_+, p_{ht}) F(x_-, p_{ht})$$

Here

$$F(x_+, p_{ht}) = \int dx_1 \int d^2 k_{1t} \, f_{\mathbb{P}q}(x_1, k_{1t}) G_q^h\left(\frac{x_+}{x_1}, p_{ht} - k_{1t}\right)$$

where

$$G_q^h(z, k_t) = z D_q^h(z, k_t) \qquad f_q = g \otimes P_{g-q\bar{q}}$$

where $P_{g-q\bar{q}}$ is the splitting function of a gluon to the quark-antiquark pair

UN-INTEGRATED GLUON DISTRIBUTION IN PROTON

$$xA\left(x,k_t^2,Q_0^2\right)=\frac{3\sigma_0}{4\pi^2\alpha_s}R_0^2(x)k_t^2\exp\left(-R_0^2(x)k_t^2\right) ,$$

where $R_0=C_1(x/x_0)^{\lambda/2}$, $C_1=1/\mathrm{GeV}$

K.Golec-Biernat & M.Wuesthoff, Phys.Rev. D60, 114023 (1999); Phys.Rev. D59, 014017 (1998)

H.Jung, hep-ph/0411287, Proc. DIS'2004 Strbske Pleco, Slovakia

$$xg(x,k_t,Q_0) = C_0 C_3 (1-x)^{b_g} \left(R_0^2(x) k_t^2 + C_2 (R_0(x) k_t)^a\right)$$
$$\exp\left(-R_0(x) k_t - d\,(R_0(x) k_t)^3\right) ,$$

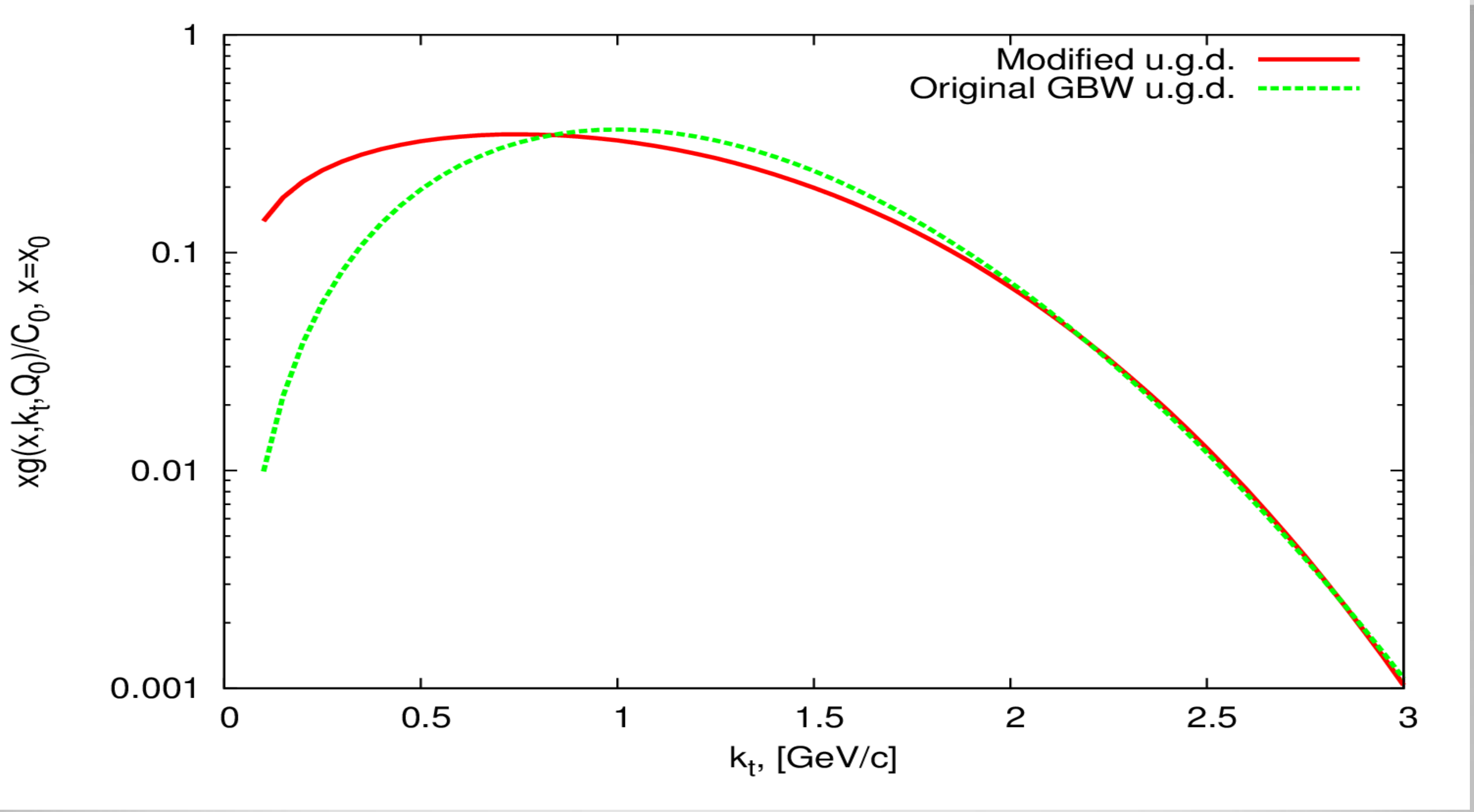
where

$$C_0 = 3\sigma_0 / \left(4\pi^2 \alpha_s(Q_0^2)\right)$$

The coefficient C_3 is found from the relation

$$xg(x,Q_0^2) = \int_0^{Q_0^2} xg(x,k_t^2,Q_0^2)\, dk_t^2$$

A.Grinyuk, H.Jung, G.L., A.Lipatov, N.Zotov, hep-ph/1203.0939; Proc.MPI-11, DESY, Hamburg, 2012.

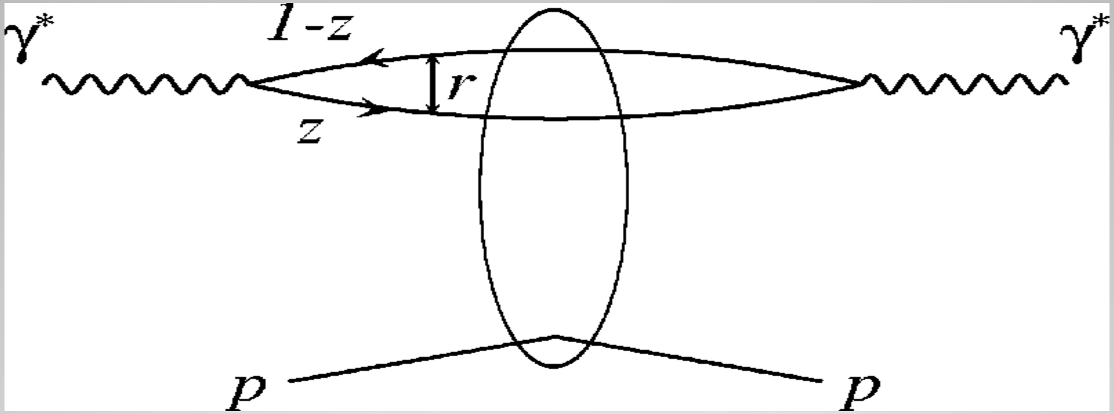


Green line is the GBW u.g.d. K.Golec-Biernat & M.Wuesthoff, Phys.Rev. D60, 114023 (1999).

Red line is the modified u.g.d. A.Grinyuk, H.Jung, G.L., A.Lipatov, N.Zotov, hep-ph/1203.0939; Proc.MPI-11, DESY, Hamburg, (2012.)

K. Golec-Biernat, M Wuesthoff , Phys.Rev. D60, 114023 (1999); D59, 014017 (1998)

Saturation dynamics



$$\sigma^{GBW}_{dipole}(x,r) = \sigma_0 \left\{1 - \exp\left(-\frac{r^2}{4R_0^2}\right)\right\}$$

$R_0 = GeV^{-1}(x/x_0)^{\lambda/2}$ at $x < x_0$ we have $\sigma_{dipole} \approx \sigma_0$

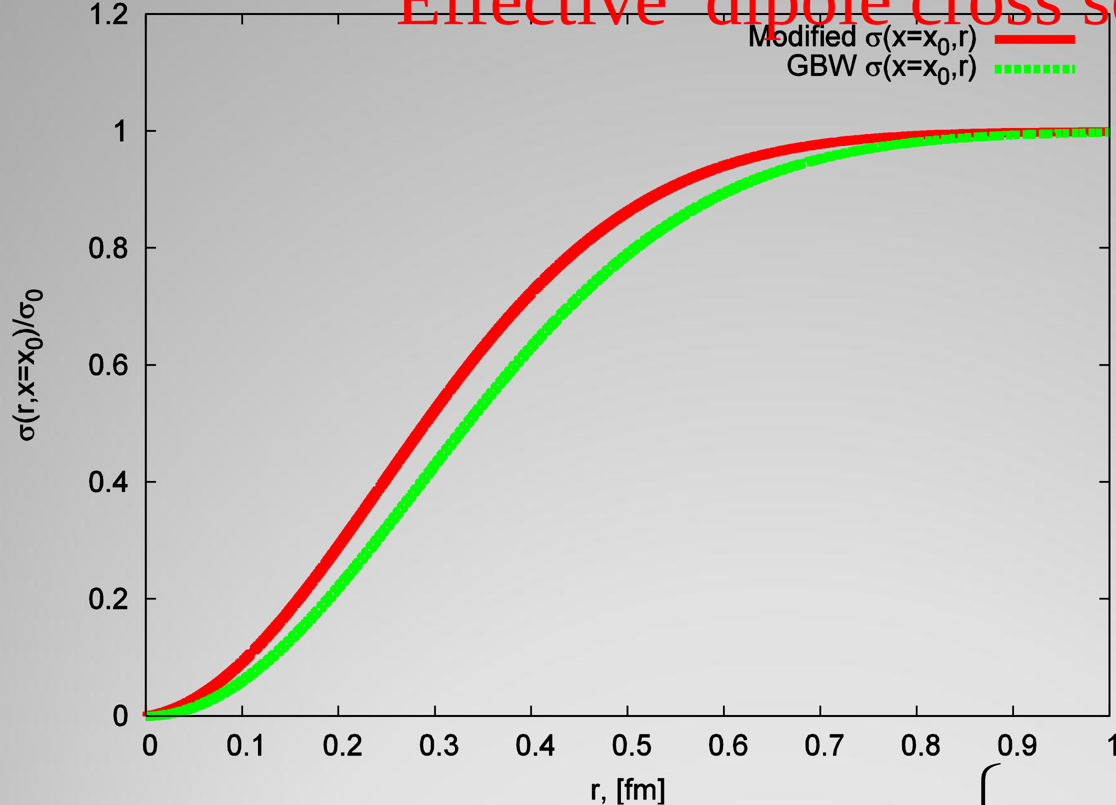
Saturation becomes when $r \sim 2R_0$. It leads to $\sigma_T \sim \sigma_0$ when $QR_0 < 1$ or $Q < 1/R_0$

Effective dipole cross section and unintegrated gluon distribution

$$\sigma_{dipole}(x,r) = \frac{4\pi}{3}\int \frac{dk_t^2}{k_t^2}\left[1 - J_0(k_t, r)\right]\alpha_s xg(x, k_t)$$

Here α_s is the QCD running constant, J_0 is the Bessel function of the zero order.

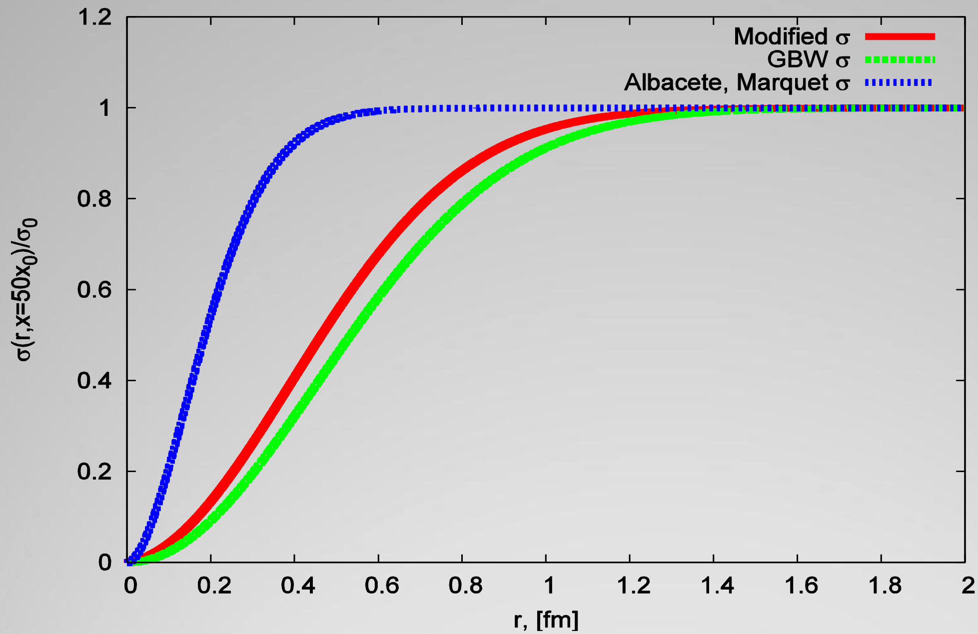
Effective dipole cross section



$$R_0 = 1 GeV^{-1} = 0.2\, fm$$

Green line: $$\sigma_{dipole}^{GBW}(x,r) = \sigma_0 \left\{ 1 - \exp\left(-\frac{r^2}{4R_0^2(x)} \right) \right\}$$

Red line: $$\sigma_{dipole}^{GBW}(x,r) = \sigma_0 \left\{ 1 - \exp\left(-\frac{a_1 r}{R_0(x)} - \frac{a_2 r^2}{R_0^2(x)} \right) \right\}$$



Javier L. Albacete, Cyrille Marquet, arXiv:1001.137 [hep-ph]

Blue line corresponds to

$$\sigma_{dipole}^{AM} = \sigma_0 \left\{ 1 - \exp\left[-\frac{r^2}{4R_0^2} \ln\left(\frac{1}{\Lambda r} + e \right) \right] \right\}; \Lambda = 0.24 GeV = 1.2\, fm^{-1}; R_0 = 1.6 GeV^{-1} = 0.32\, fm$$

Kt-factorization

Photo-production cross section

$$\sigma = \int \frac{dz}{z} d^2 k_t \, \sigma_{part}\left(\frac{x}{z}, k_t^2\right) F\left(z, k_t^2\right)$$

Here $F\left(z, k_t^2\right)$ is the un-integrated parton density function, $\sigma_{part}\left(x/z, k_t^2\right)$ is the partonic cross section.

Classification scheme:

$xF\left(x, k_t^2\right)$ is used by BFKL

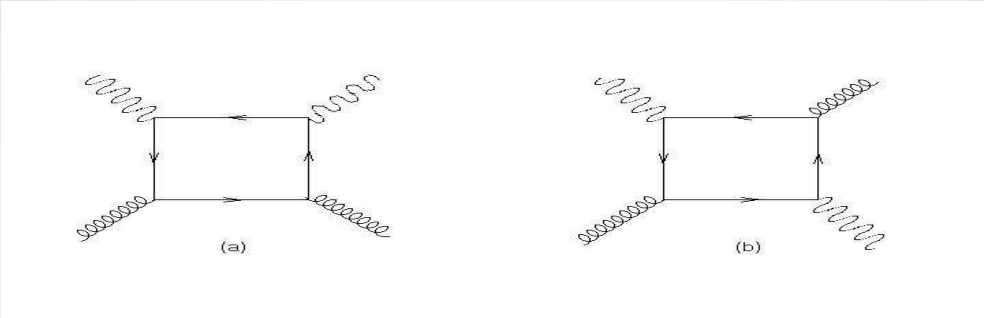
$xA\left(x, k_t^2, \bar{Q}^2\right)$ describes the CCFM type UGD with an additional factorization scale $\bar{Q}$ (such as $\alpha_s\left(\bar{Q}^2\right) \leq 1$)

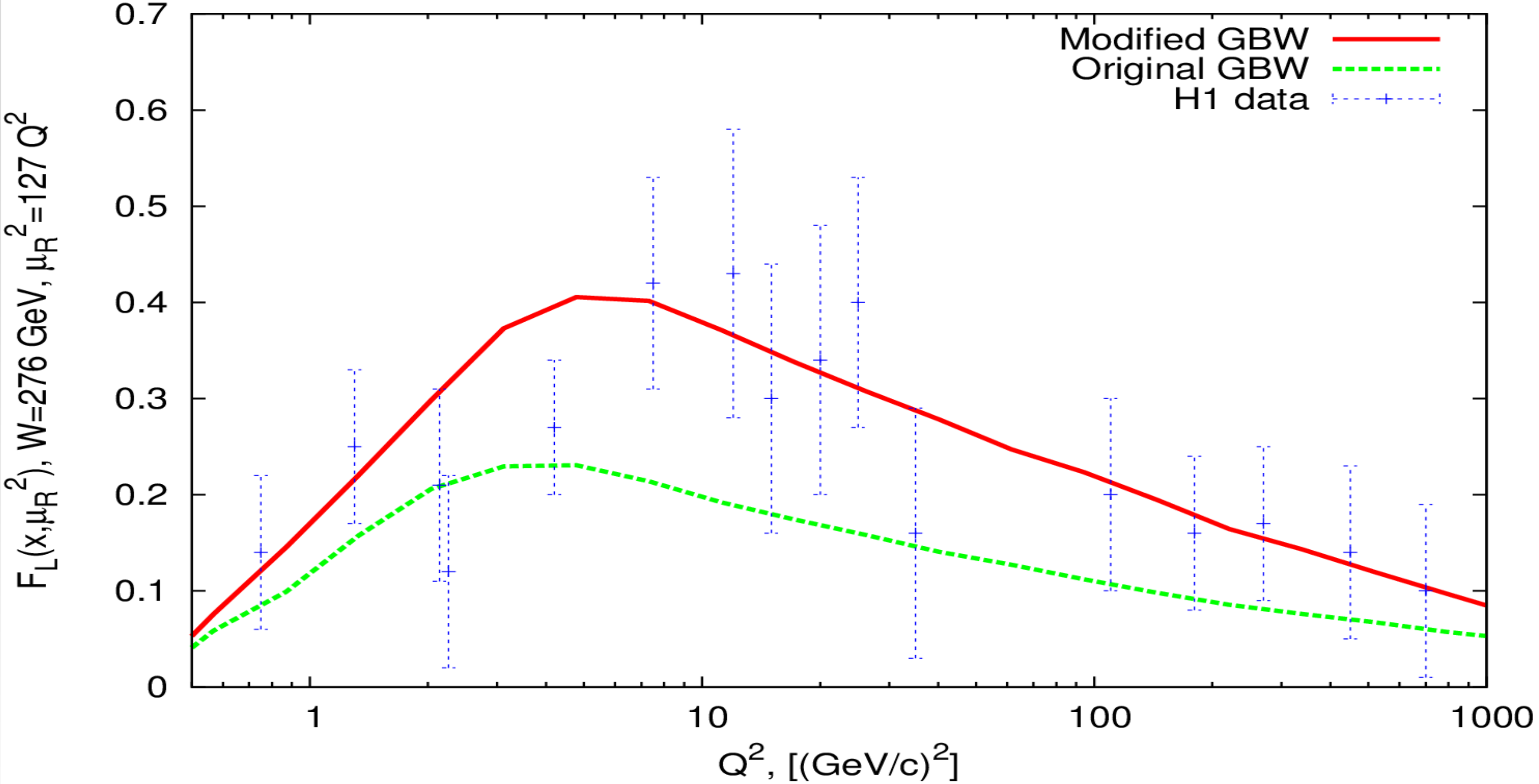
$xG\left(x, k_t^2\right)$ describes the DGLAP type UGD

Longitudinal structure function within the kt-factorization

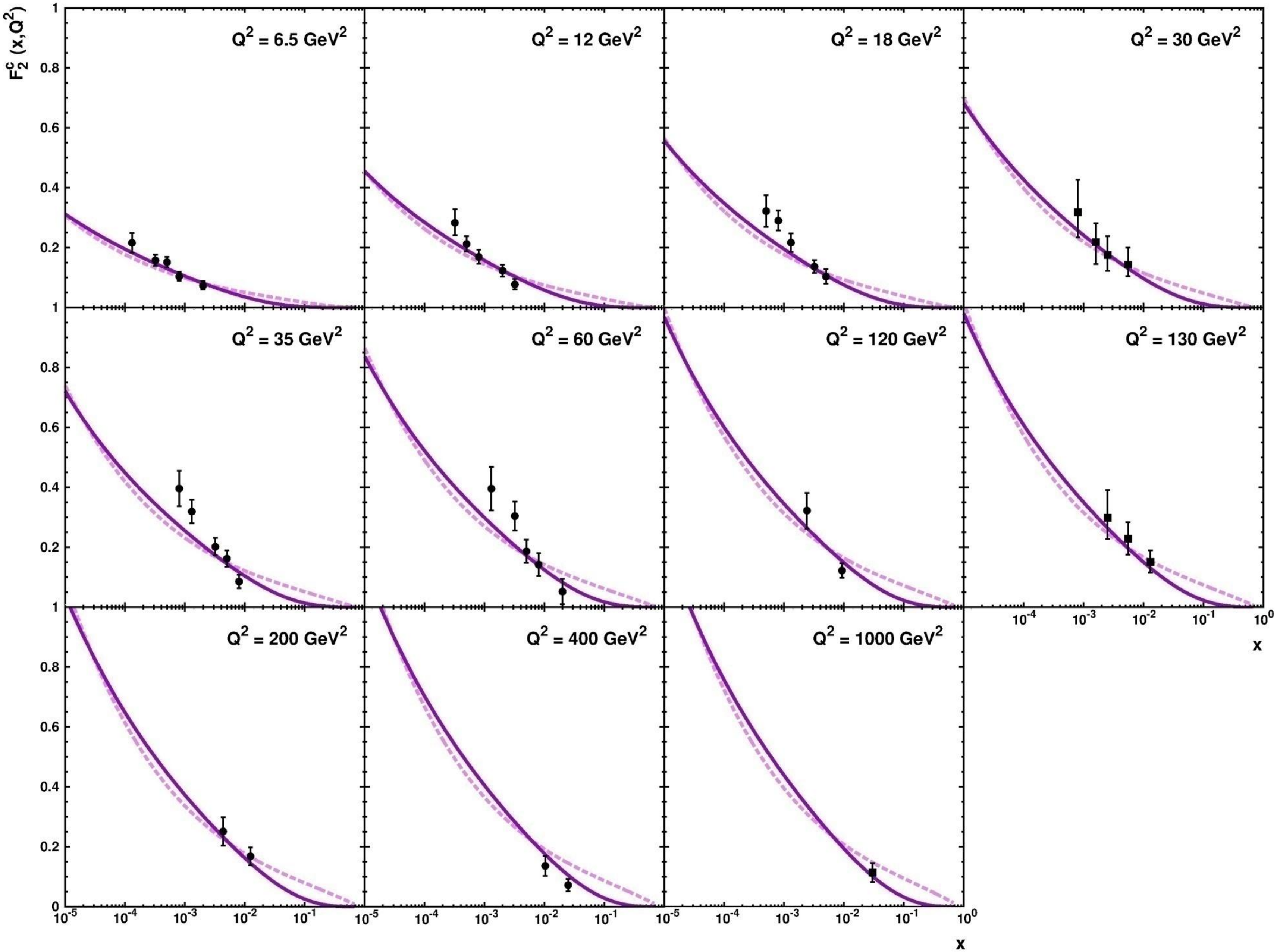
$$F_L(x,Q^2)=\int_x^1 \frac{dz}{z}\int_0^{Q^2} dk_t^2 \sum_{i=u,d,s} e_i^2 C_L^g\left(\frac{x}{z},Q^2,m_i^2,k_t^2\right)\phi_g(z,k_t^2),$$

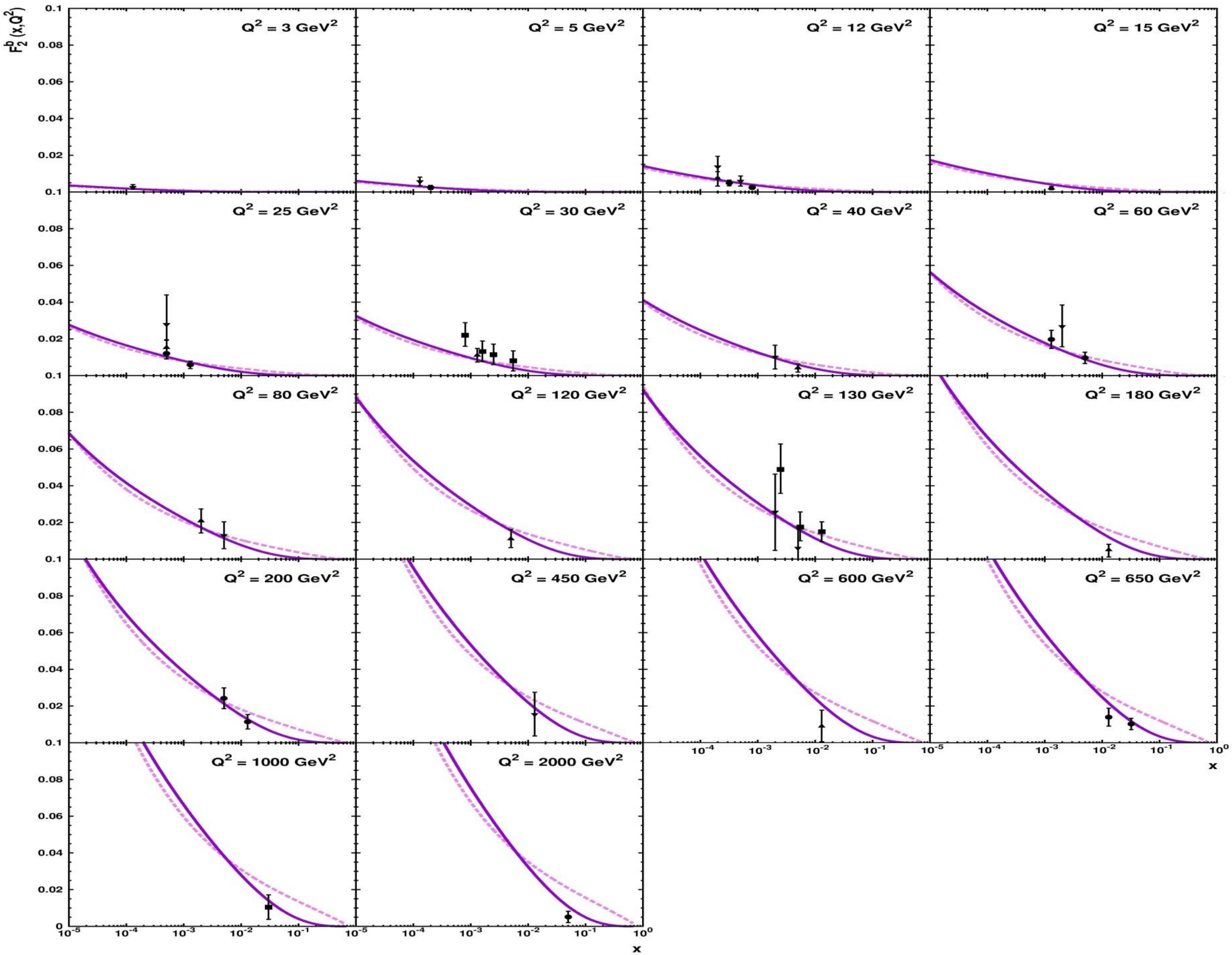
$$\phi_g(x,k_t^2)=xg(x,k_t^2),\quad xg(x,Q^2)=xg(x,Q_0^2)+\int_{Q_0^2}^{Q^2} dk_t^2\phi_g(x,k_t^2)$$





F_L as a function of Q^2 at W=276 GeV and $\mu_R^2 = 127\,Q^2$


$F_2^c(x,Q^2)$
Q^2 = 6.5 GeV^2
Q^2 = 12 GeV^2
Q^2 = 18 GeV^2
Q^2 = 30 GeV^2
Q^2 = 35 GeV^2
Q^2 = 60 GeV^2
Q^2 = 120 GeV^2
Q^2 = 130 GeV^2
Q^2 = 200 GeV^2
Q^2 = 400 GeV^2
Q^2 = 1000 GeV^2
0
0.2
0.4
0.6
0.8
1
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
x



$F_2^b(x,Q^2)$
$Q^2 = 3$ GeV^2
$Q^2 = 5$ GeV^2
$Q^2 = 12$ GeV^2
$Q^2 = 15$ GeV^2
$Q^2 = 25$ GeV^2
$Q^2 = 30$ GeV^2
$Q^2 = 40$ GeV^2
$Q^2 = 60$ GeV^2
$Q^2 = 80$ GeV^2
$Q^2 = 120$ GeV^2
$Q^2 = 130$ GeV^2
$Q^2 = 180$ GeV^2
$Q^2 = 200$ GeV^2
$Q^2 = 450$ GeV^2
$Q^2 = 600$ GeV^2
$Q^2 = 650$ GeV^2
$Q^2 = 1000$ GeV^2
$Q^2 = 2000$ GeV^2
x

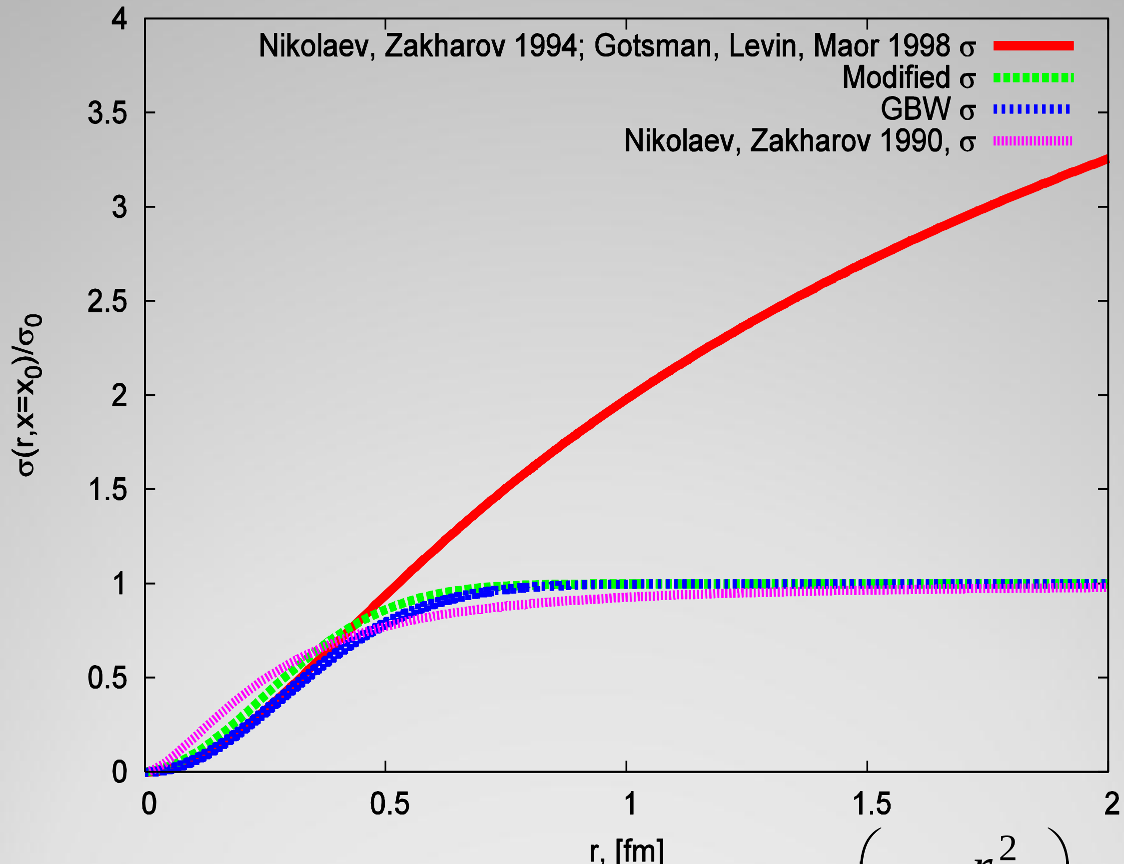
SUMMARY

1. The inclusion of the gluon distributions in proton allows us to apply the QGSM to analyze the hadron production in *p*-*p* at transverse momenta less than 2 – 3 GeV/c.
2. The unintegrated gluon distributions in proton at low intrinsic transverse momenta were calculated and their parameters were found fitting the LHC data.
3. At large intrinsic transverse momenta they coincide to the distributions found by GBW, J.Hannes and others.

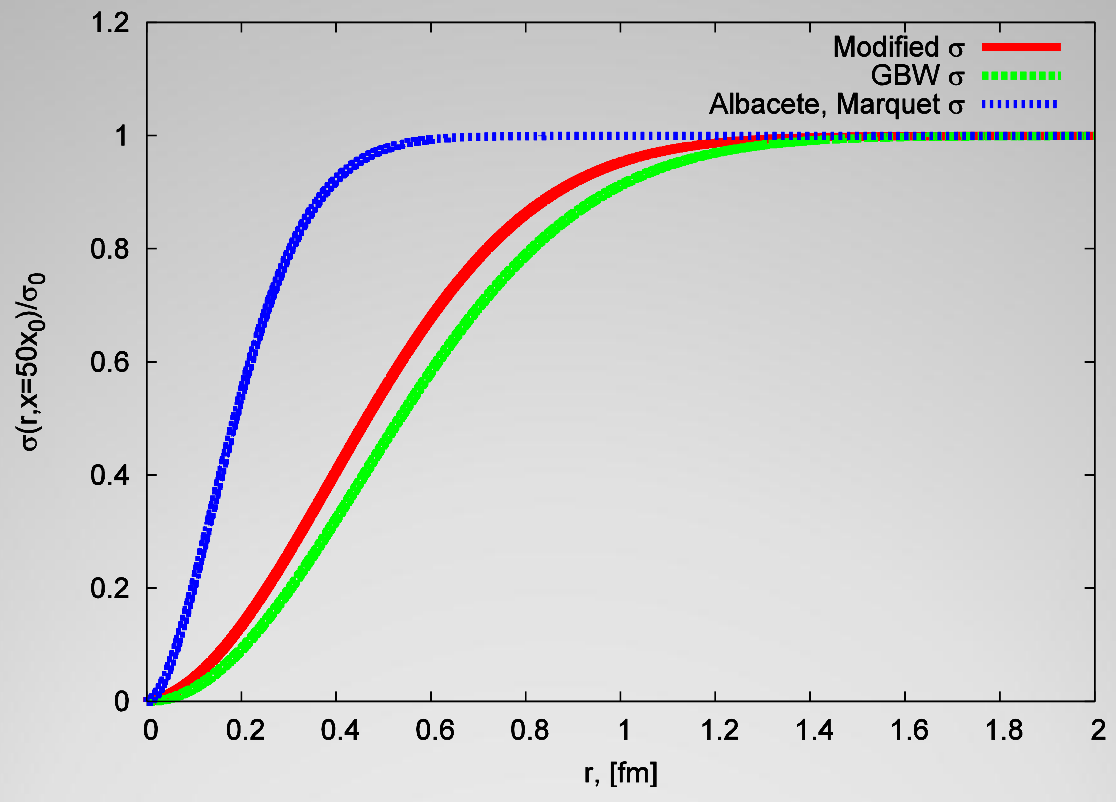
5. The modified UGDF allows us to describe the H1 data on $F_L\left(x,Q^2\right)$ at low x and Q^2 rather satisfactorily.
6. The H1 data on the longitudinal structure function F_L in dependence on Q^2 at $W=276\,GeV$ are described also satisfactorily using the modified UGDF.

THANK YOU VERY MUCH FOR YOUR ATTENTION !

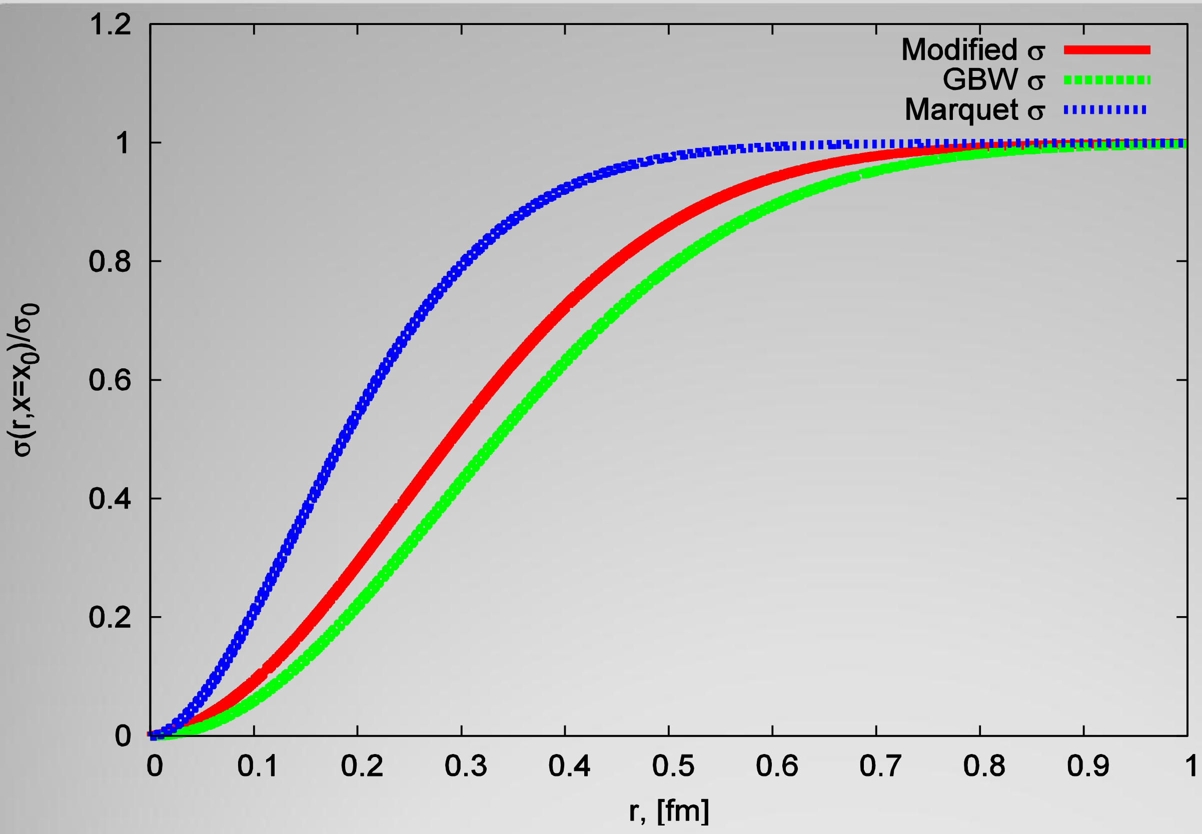
Effective dipole cross section



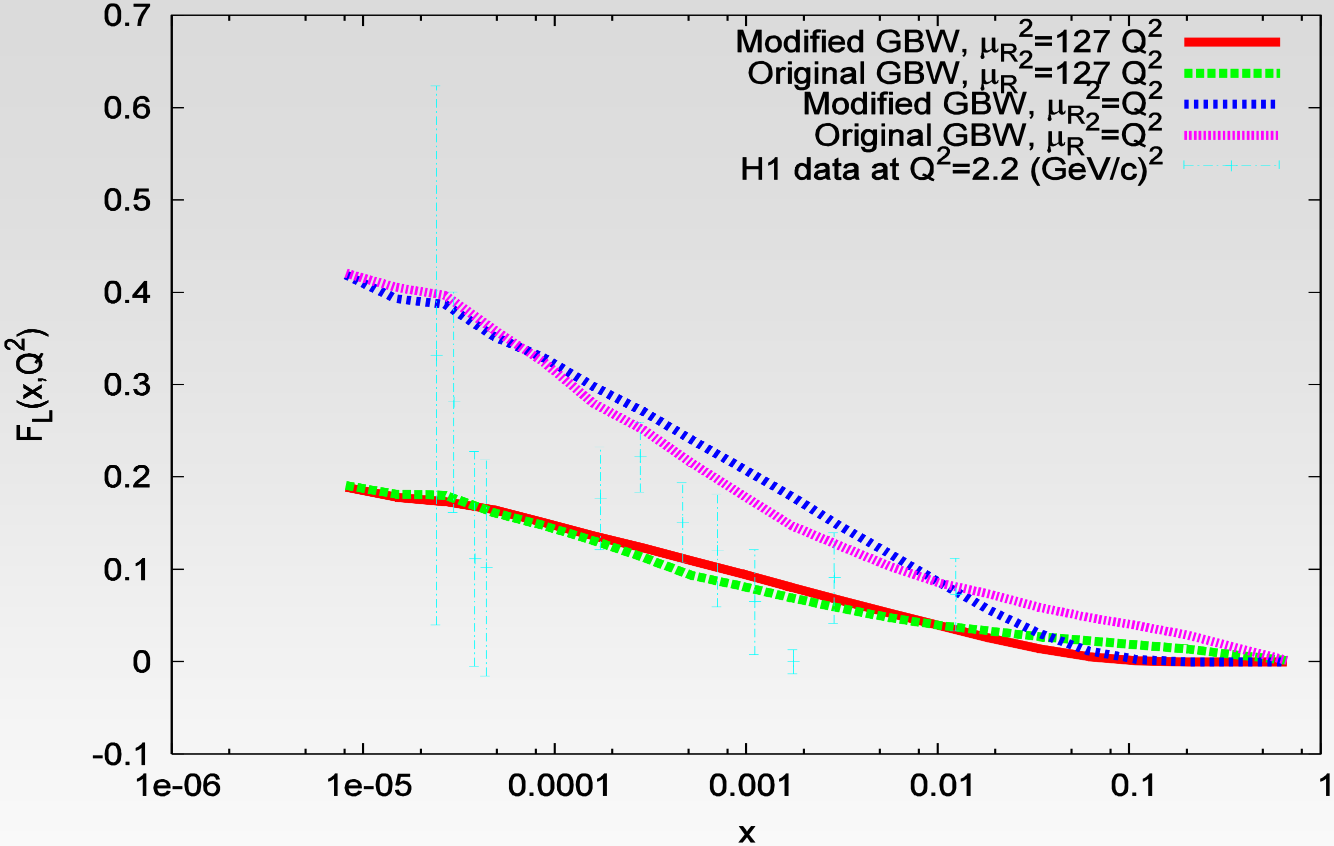
Red line corresponds to $\sigma_{dipole} = \sigma_0 \ln\left(1 + \frac{r^2}{4R_0^2}\right)$



1.2
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
$\sigma(r,x=50x_0)/\sigma_0$
r, [fm]
Modified σ
GBW σ
Albacete, Marquet σ

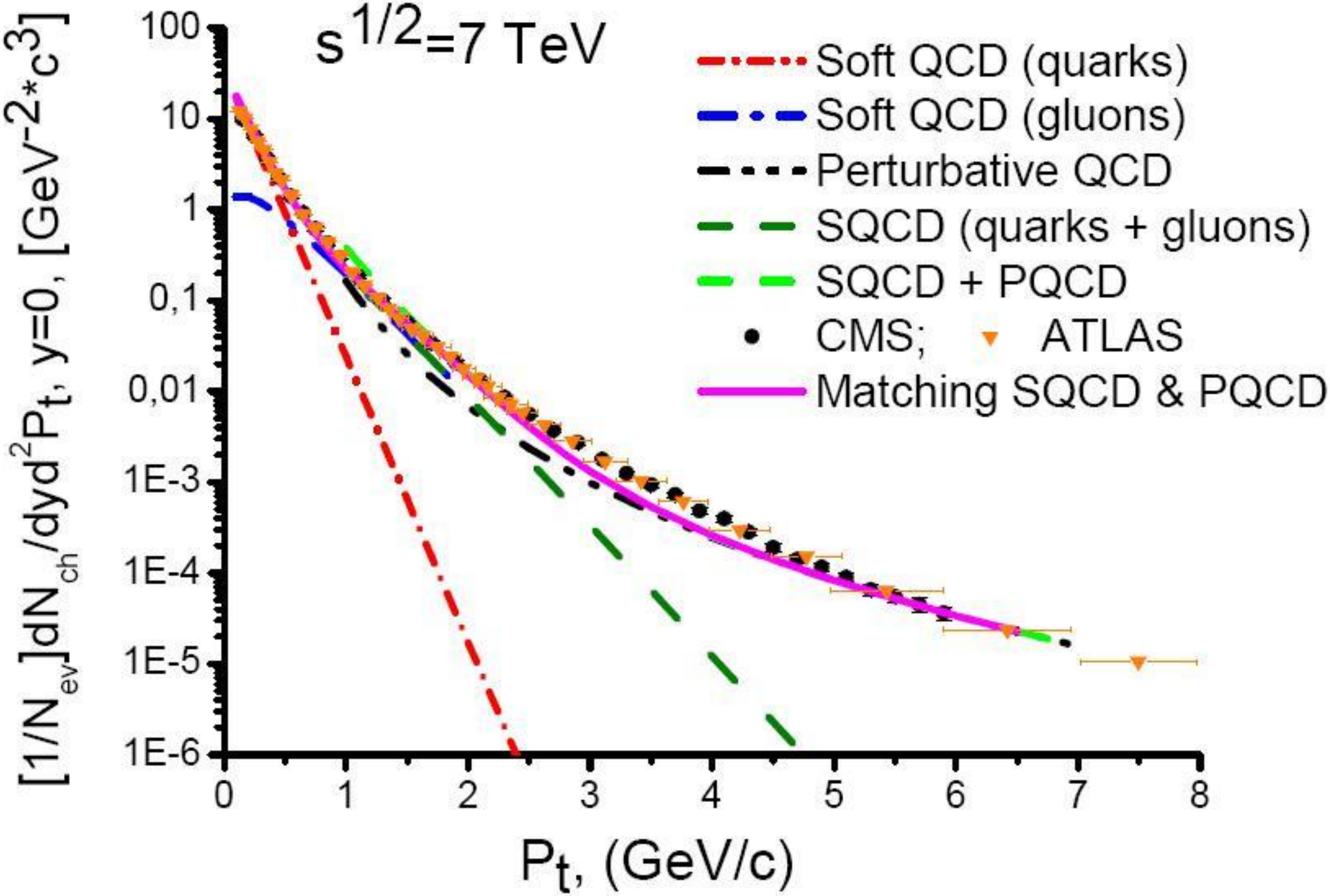


Modified σ
GBW σ
Marquet σ
1.2
1
0.8
0.6
0.4
0.2
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
σ(r,x=x0)/σ0
r, [fm]



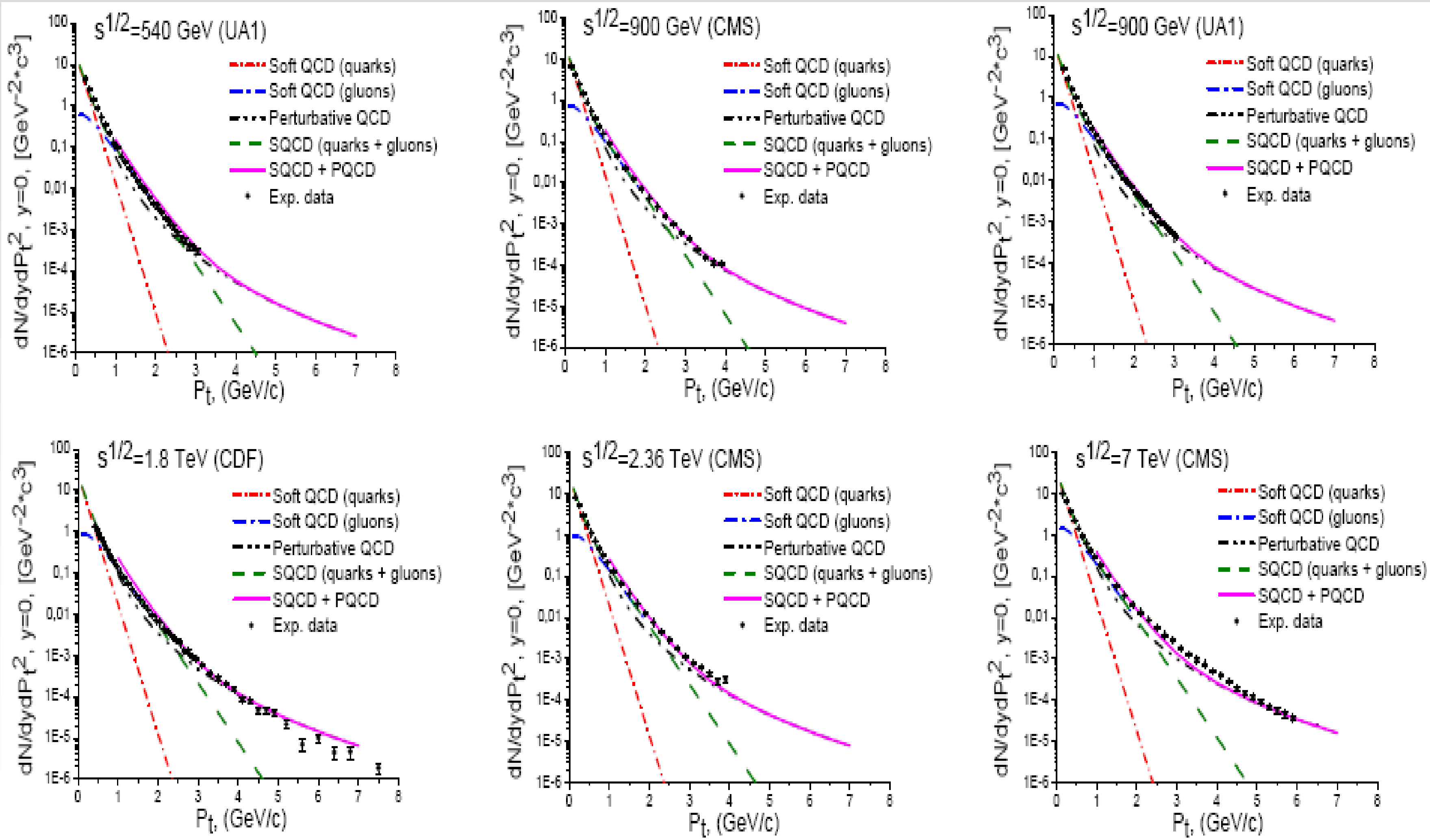
The x-dependence of F_L at $Q^2=2.2(GeV/c)^2$ assuming

$\mu_R^2=KQ^2$ and $\mu_R^2=Q^2$, where $K=127$



$s^{1/2}$=7 TeV
Soft QCD (quarks)
Soft QCD (gluons)
Perturbative QCD
SQCD (quarks + gluons)
SQCD + PQCD
CMS; ATLAS
Matching SQCD & PQCD
[1/N$_{ev}$]dN$_{ch}$/dyd^{2}P$_t$, y=0, [GeV^{-2}*c^3]
100
10
1
0,1
0,01
1E-3
1E-4
1E-5
1E-6
0
1
2
3
4
5
6
7
8
P$_t$, (GeV/c)

2012


s1/2=540 GeV (UA1)
s1/2=900 GeV (CMS)
s1/2=900 GeV (UA1)
s1/2=1.8 TeV (CDF)
s1/2=2.36 TeV (CMS)
s1/2=7 TeV (CMS)
Soft QCD (quarks)
Soft QCD (gluons)
Perturbative QCD
SQCD (quarks + gluons)
SQCD + PQCD
Exp. data
dN/dydPt2, y=0, [GeV-2*c3]
Pt, (GeV/c)

2012

Inclusive hadron production in central region and the AGK cancellation

According to the AGK, the n-Pomeron contributions to the inclusive hadron spectrum at y=0 are cancelled and only the one-Pomeron contributes. This was proved asymptotically, i.e., at very high energies.

Using this AGK we estimate the inclusive spectrum of the charged hadrons produced in p-p at y=0 as a function of the transverse momentum including the quark and gluon components in the proton.

$$\rho_q(x=0,p_t)=\phi_q(0,p_t)\sum_{n=1}^{\infty} n\sigma_n(s)=gs^{\Delta}\phi_q(0,p_t)$$

$$\rho_g(x=0,p_t)=\varphi_g(0,p_t)\sum_{n=2}(n-1)\sigma_n(s)=$$

$$\varphi_g(0,p_t)\left(gs^{\Delta}-\sigma_{nd}\right)$$

2012

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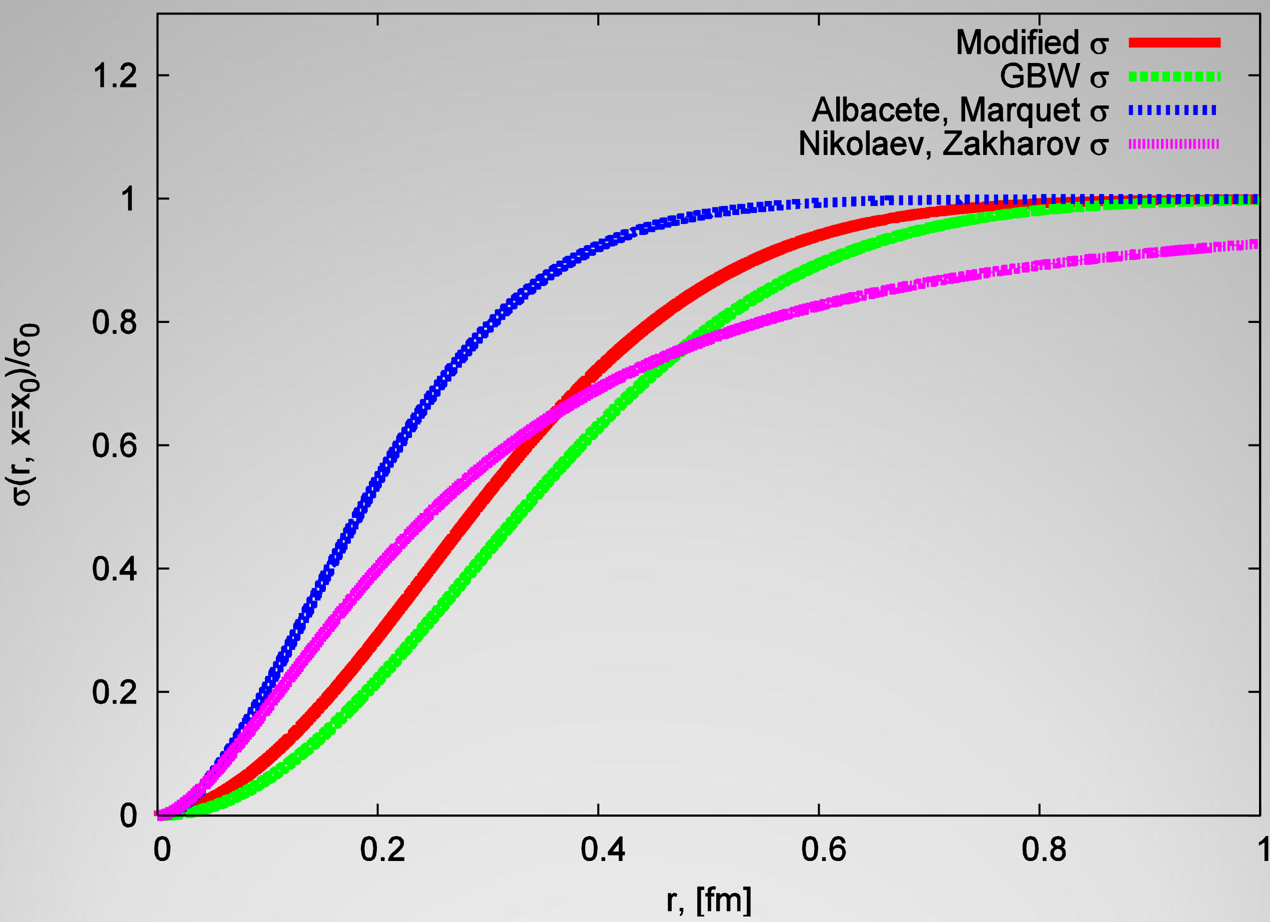
$$\rho_q(x=0,p_t)=\phi_q(0,p_t)\sum_{n=1}^{\infty} n\sigma_n(s)=gs^{\Delta}\phi_q(0,p_t)$$

$$\rho_g(x=0,p_t)=\varphi_g(0,p_t)\sum_{n=2}(n-1)\sigma_n(s)=$$

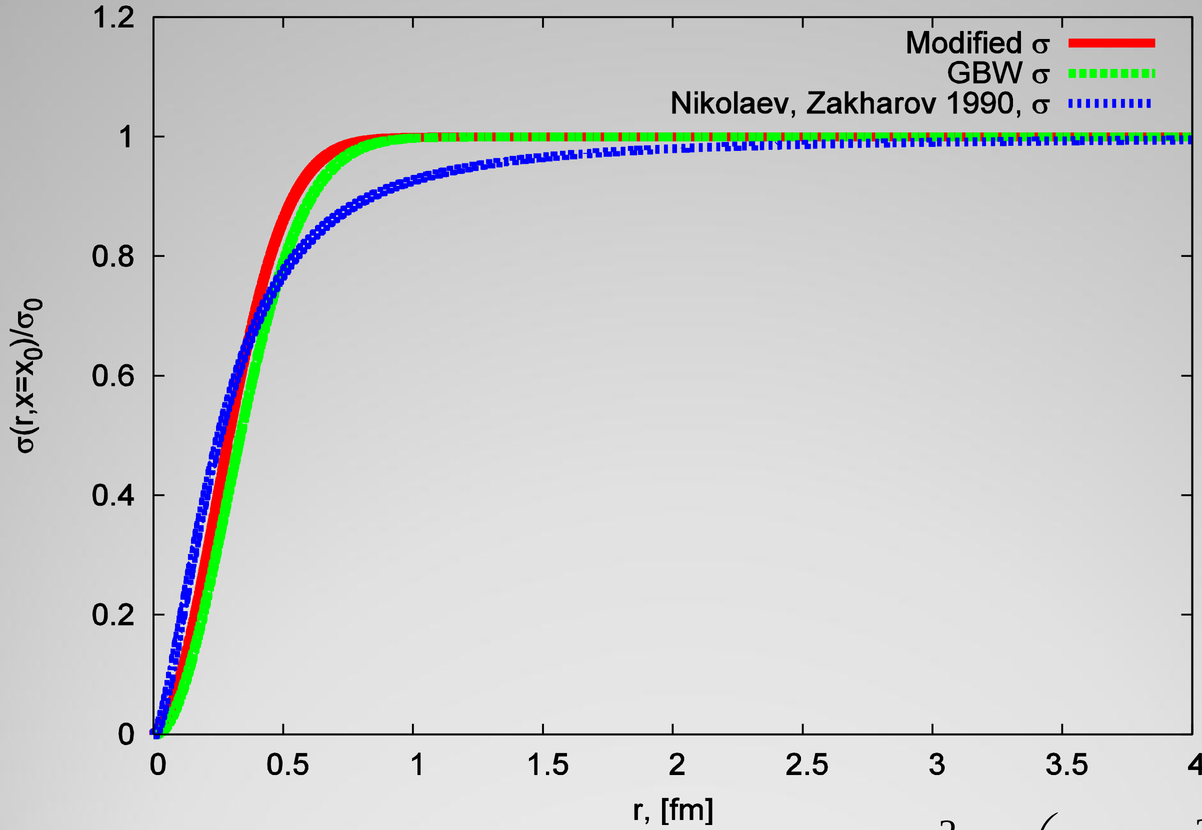
$$\varphi_g(0,p_t)\left(gs^{\Delta}-\sigma_{nd}\right)$$

2012



Modified σ
GBW σ
Albacete, Marquet σ
Nikolaev, Zakharov σ
σ(r, x=x0)/σ0
r, [fm]
0
0.2
0.4
0.6
0.8
1
1.2

Effective dipole cross section



N.Nikolaev, B.Zakharov, Z.Phys.C49, 607 (1990)

Blue line corresponds to $\sigma_{dipole} = \sigma_0 \frac{r^2}{4R_0^2} \ln\left(1 + \frac{4R_0^2}{r^2}\right)$