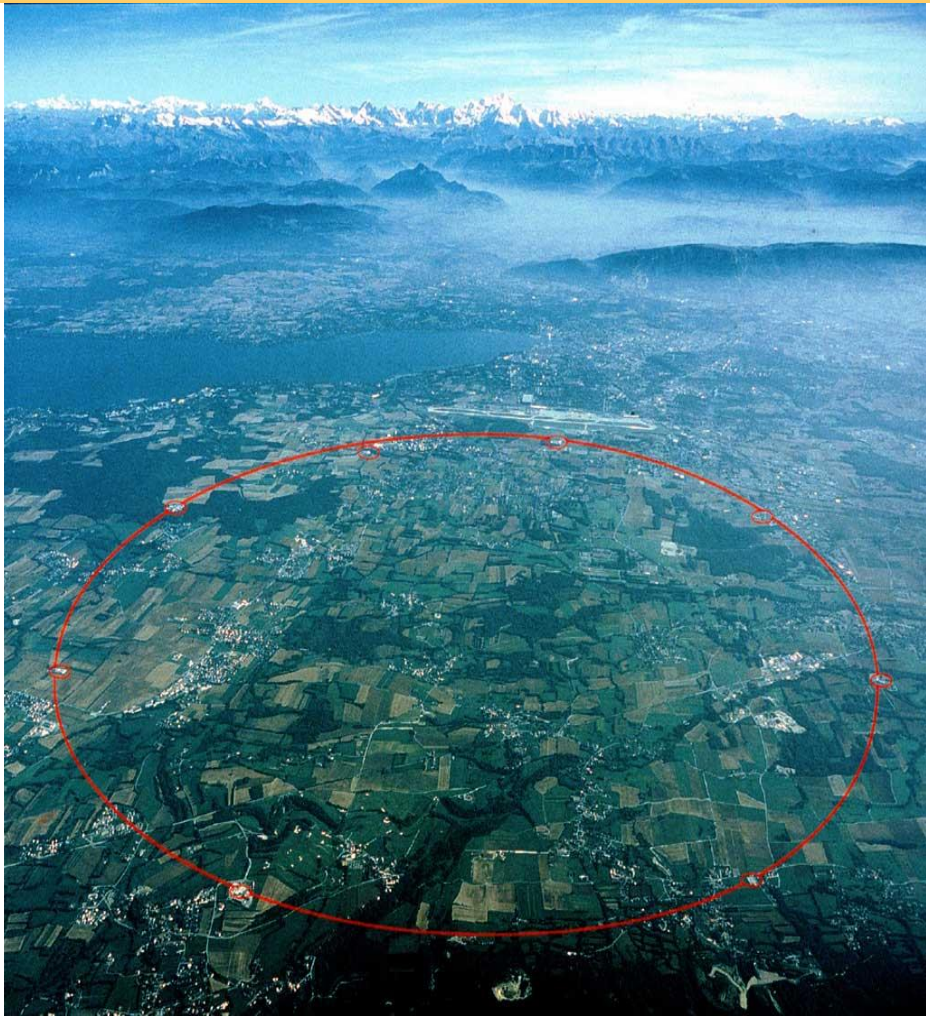
SIGNIFICANCE OF GLUON DENSITY FOR SOFT AND HARD PROCESSES AT LHC



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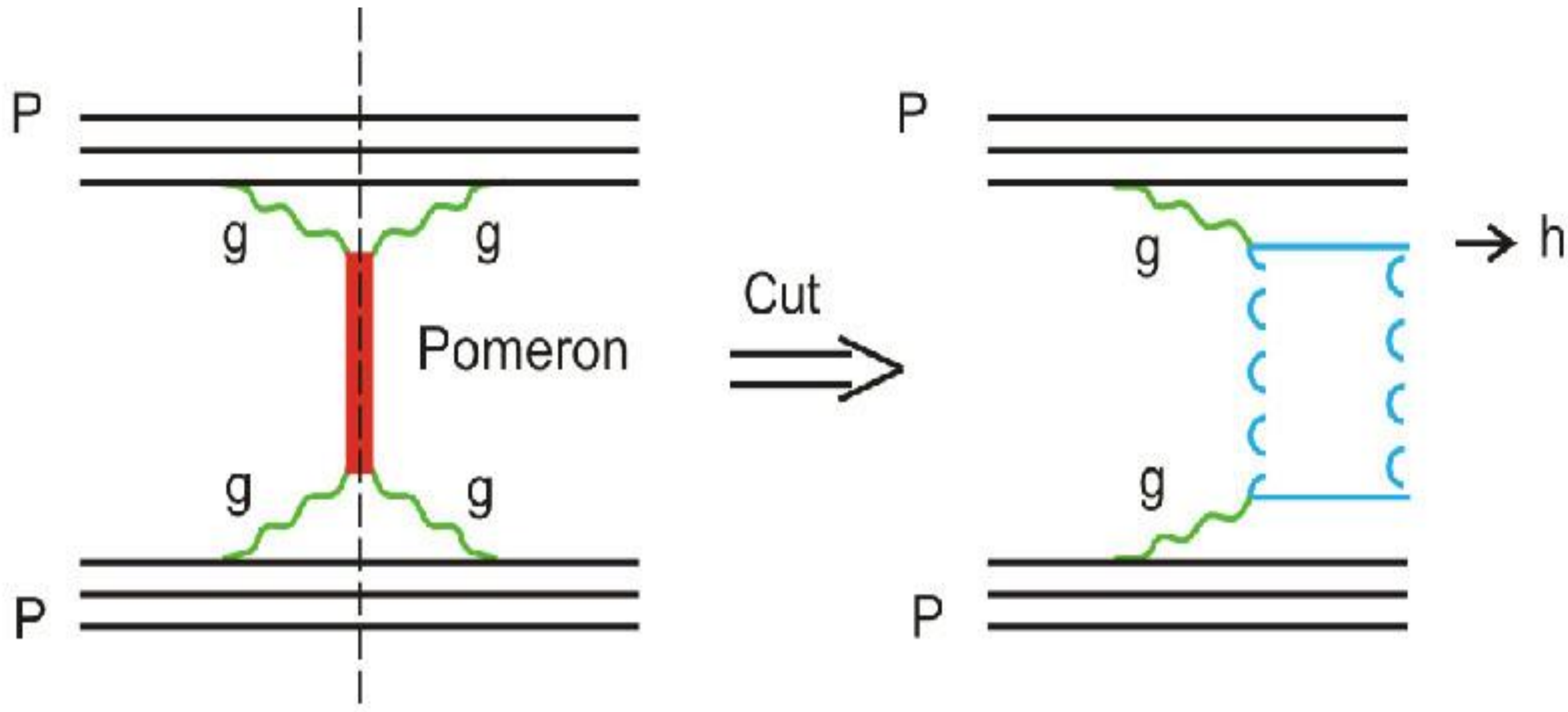
DIS2016, DESY

OUTLINE

1. Non perturbative gluon distribution in proton
2. Inclusive spectra of charge hadrons in p-p within soft QCD model including gluon
3. Modified un-integrated gluon distribution at starting μ_0
4. CCFM-evolution and structure functions
5. Application of the proposed UGD to analyse hard p-p processes at LHC
6. Summary

Non perturbative unintegrated gluon distribution in proton



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:

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

THE CUT ONE-POMERON EXCHANGE

$$\rho(x, p_{ht}) = F^1(x_+, p_{ht})F^1(x_-, p_{ht}) + F^2(x_+, p_{ht})F^2(x_-, p_{ht})$$

Here

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

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

A.A.Grinyuk, A.V.Lipatov, G.L., N.P. Zotov, Phys.Rev. D87, 074017 (2013).

SOFT PP -> h X

The inclusive spectrum is presented in the following form:

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

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

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

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

$g \approx 21$ mb
$\Delta \approx 0.12$

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.

MODIFICATION OF U.G.D. AT LARGE k_T

We construct the new U.G.D. matching their form at low k_T (k_T <2-3 GeV/c) to the one, which is the exact solution of the BFKL outside of the saturation region obtained by Yuri V. Kovchegov (Phys.Rev.D61 (2000) 074018).

$$xg_1(x,k_T,Q_0) = xg_0\left(x,k_T,Q_0\right) + F_M\left(x,k_T,Q_0\right)P_1\left(x,k_T\right)$$

Here xg_1 ***is the new U.G.D.,*** xg_0 ***is our old U.G.D.,*** $\boldsymbol{P_1}$ ***is the Kovchegov's solution at*** $k_T > 1.GeV/c$ ***,*** F_M ***is the matching function of*** xg_0 ***to*** $\boldsymbol{P_1}$

BFKL solution

(Yri V. Kovchegov, Phys.Rev.D61 (2000) 074018.)

$$P_1(k_T, Y) = C_{-1}\frac{\Lambda}{k_T}\frac{\exp[(\alpha_P - 1)Y]}{\sqrt{14\alpha_s N_c \varsigma(3) Y}}\exp\left(-\frac{\pi}{14\alpha_s N_c \varsigma(3) Y}\ln^2\frac{k_T}{\Lambda}\right)$$

α_P ***is the intercept of the subcritical Pomeron,*** $Y = \ln(1/x)$

For the initial conditions, as the two gluon exchange approximation $C_{-1} \sim \alpha_s^2$***. This solution is valid at*** $k_T < \Lambda(1/x)^{\alpha s N c}$

Our matching function

$$F_M(x, k_T, Q_0) = B(x/x_0)^d \exp(-aR_0/k_T)$$

where $R_0 = (x/x_0)^\lambda$ ***,*** B, d, a ***are parameters, which were found from matching of our old U.G.D. to the BFKL solution***

Finally the proposed unintegrated gluon density (MD2015) at initial μ_0^2 has the following form:

$$f_g^{(0)}(x, \mathbf{k}_T^2, \mu_0^2) = c_0 c_1 (1-x)^b \ [R_0^2(x)\mathbf{k}_T^2 + c_2 (R_0^2(x)\mathbf{k}_T^2)^{a/2}] \times \exp(-R_0^2(x)\mathbf{k}_T^2 - d[R_0^2(x)\mathbf{k}_T^2]^{3/2}) + c_0 \left(\frac{x}{x_0}\right)^n \exp\left[-k_0^2 \frac{R_0(x)}{|\mathbf{k}_T|}\right] f_g(x, \mathbf{k}_T^2),$$

where f_g is the BFKL solution

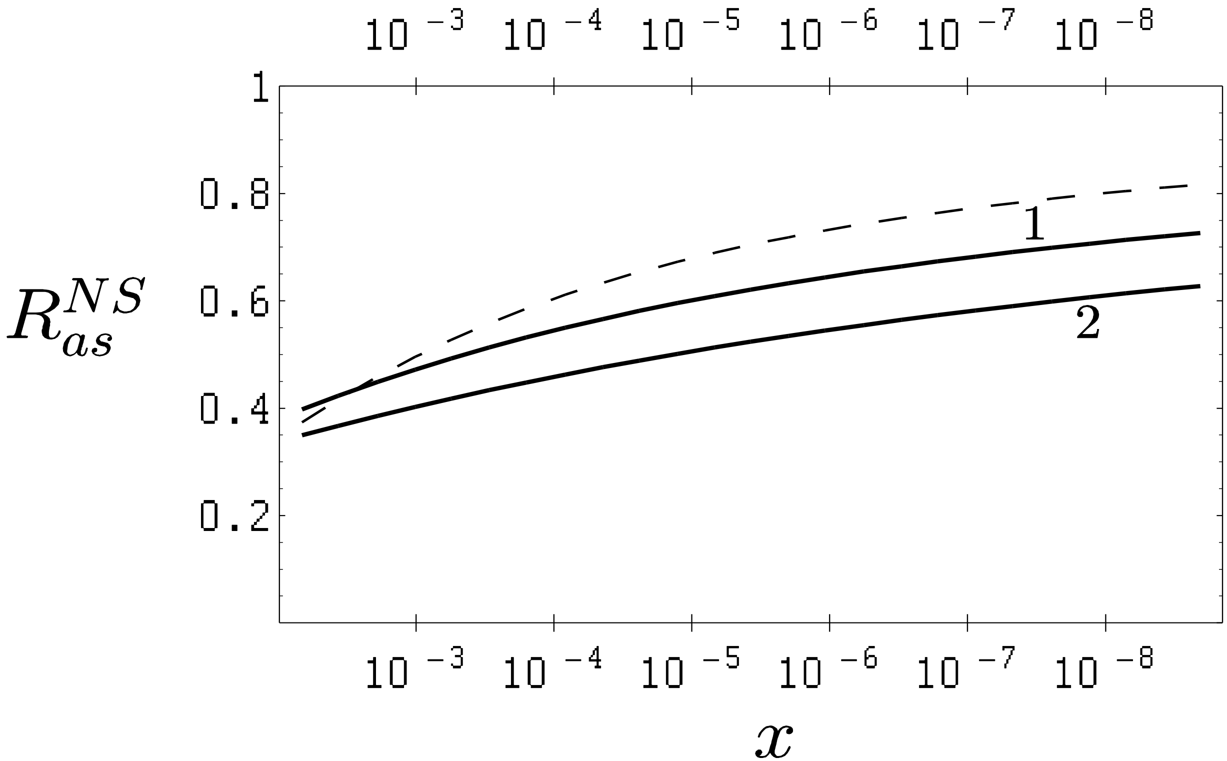
$$f_g(x, \mathbf{k}_T^2) = \alpha_s^2 x^{-\Delta} t^{-1/2} \frac{1}{v} \exp\left[-\frac{\pi \ln^2 v}{t}\right]$$

$k_0 = 1$ GeV, $\mu_0^2 = 1.1$ GeV^2, and $n \simeq 0.81$. $\quad t = 14\alpha_s N_c \zeta(3) \ln(1/x)$, $\quad v = |\mathbf{k}_T|/\Lambda_{QCD}$, $\quad \Delta = 4\alpha_s N_c \ln 2/\pi$.

It is valid at $k_T << \Lambda_{QCD} (1/x)^\sigma$, where $\sigma = \alpha_s N_c$

A.A. Grinyuk, a.v.Lipatov, G.L., N.P.Zotov, Phys.ReV. D93, 014135 (2016)

The ratio of the asymptotic solution for the non singlet structure function to the non asymptotic form including the double logarithms of Q^2/μ^2 and running α_s



Dashed line and lines 1,2 correspond to the cases, when $Q^2 = \mu^2$, $Q^2 = 10\,\mu^2$ and $Q^2 = 100\,\mu^2$, here $\mu^2 = 1\,\mathrm{GeV}^2$.

B.I.Ermolaev, M.Greco, S.I.Troyan, Eur.Phys.J., C71, 1750 (2011); C72, 1953 (2012).

CCFM evolution equation

$$f_g(x, k_T^2, \bar{q}^2) = f_g^0(x, k_T^2, Q_0^2)\Delta_s(\bar{q}^2, Q_0^2) + \int \frac{dz}{z} \int \frac{dq^2}{q^2} \times$$

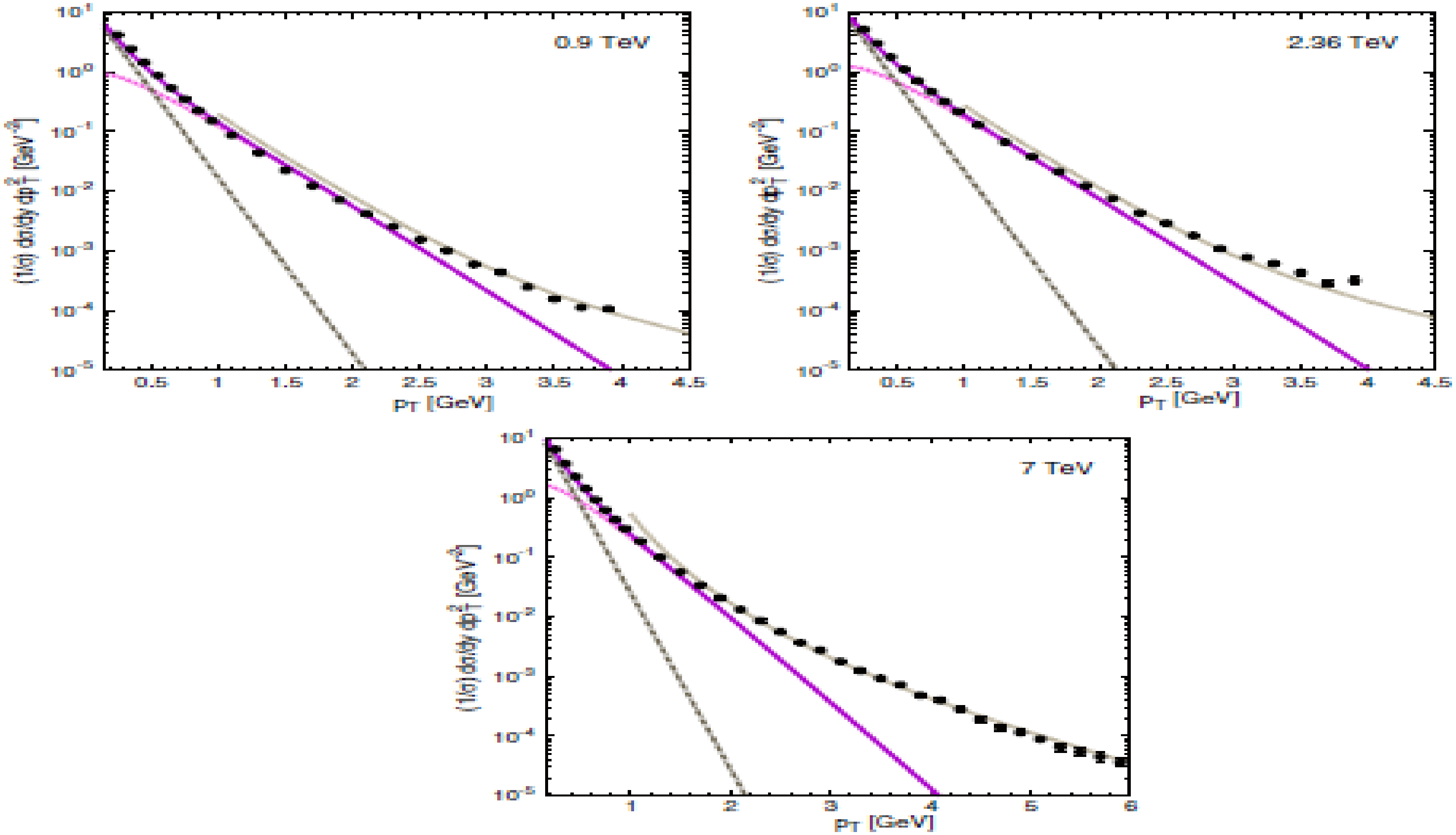
$$\theta(\bar{q} - zq)\Delta_s(\bar{q}^2, q^2) P_{gq\bar{q}}(z, q^2, k_T^2) f_g\left(\frac{x}{z}, k_T'^2, q^2\right)$$

Here $k_T' = q(1-z)/z + k_T$ and the Sudakov form factor $\Delta_s(q_1^2, q_2^2)$ describes the probability of no radiation between q_2 and q_1, $P_{gq\bar{q}}$ is the splitting function, f_g is the gluon density.

The first term means the contribution of non resolvable branchings between the starting scale Q_0 and the factorization scale $\bar{q}$.

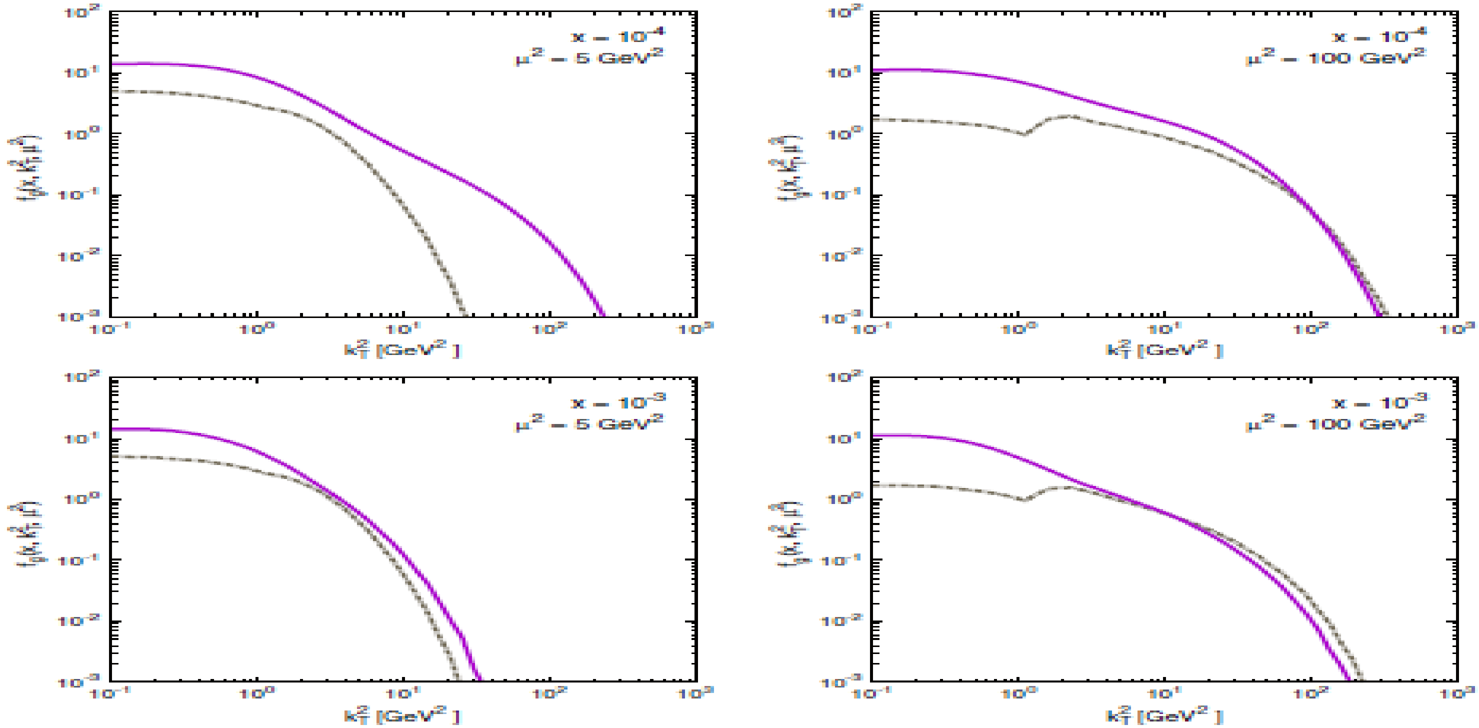
A.V.Lipatov, G.L., N.P.Zotov, Phys.Rev. D89 (2014) 1, 014001

The inclusive spectra of charged hadrons produced in p-p versus their transverse momenta at the mid-rapidity region



The dashed and dash-dotted lines correspond to the gluon and quark contributions, the solid curves are their sum and the dotted lines correspond to the sum of all the contributions of quarks and gluons and the PQCD (NLO).

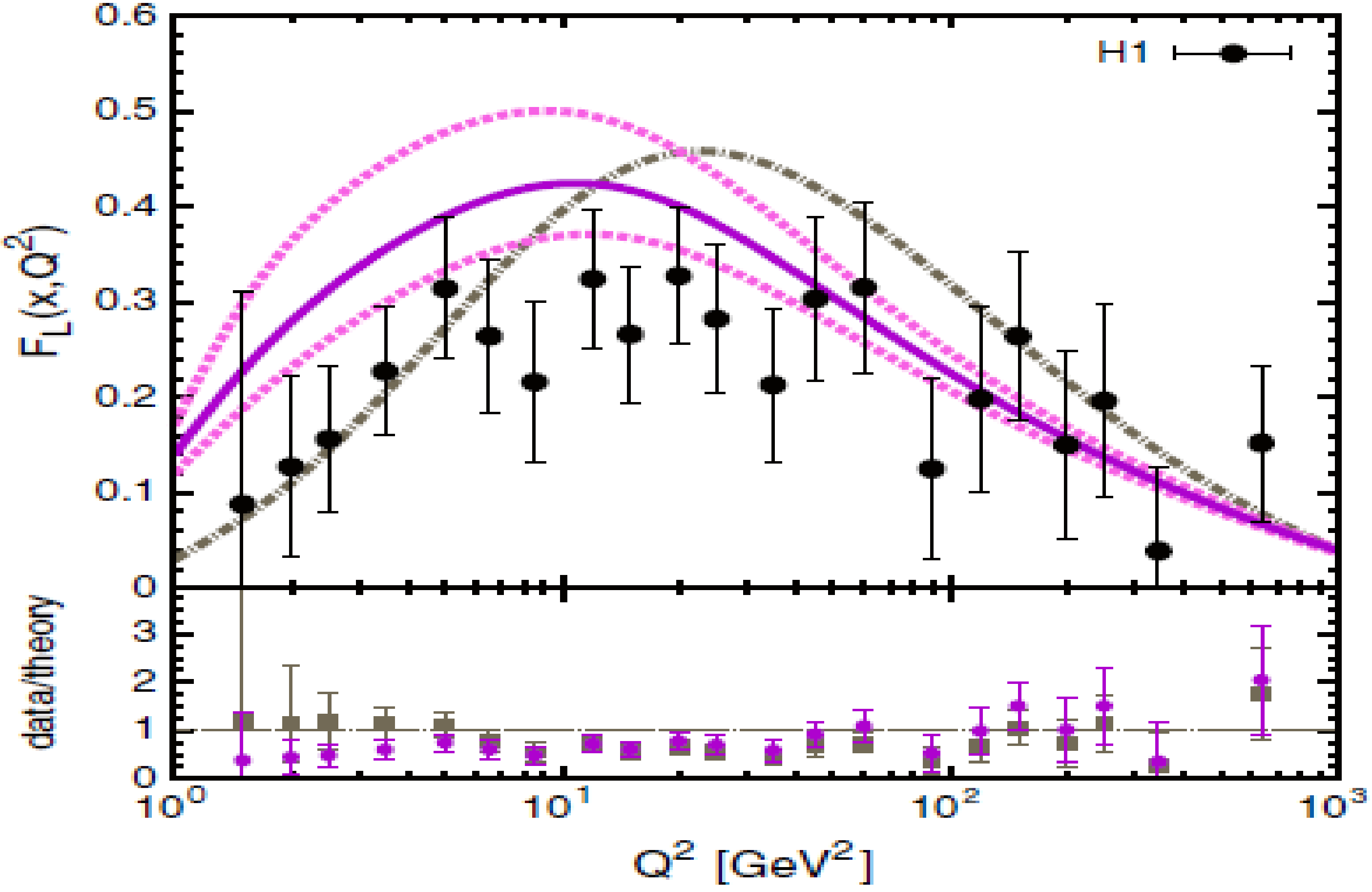
Gluon density as a function of k_T^2



The CCFM evolved TMD gluon density as a function of k_T^2 at different x and μ^2. The solid and dashed lines correspond to the proposed UGD and the A0 set (H.Jung)

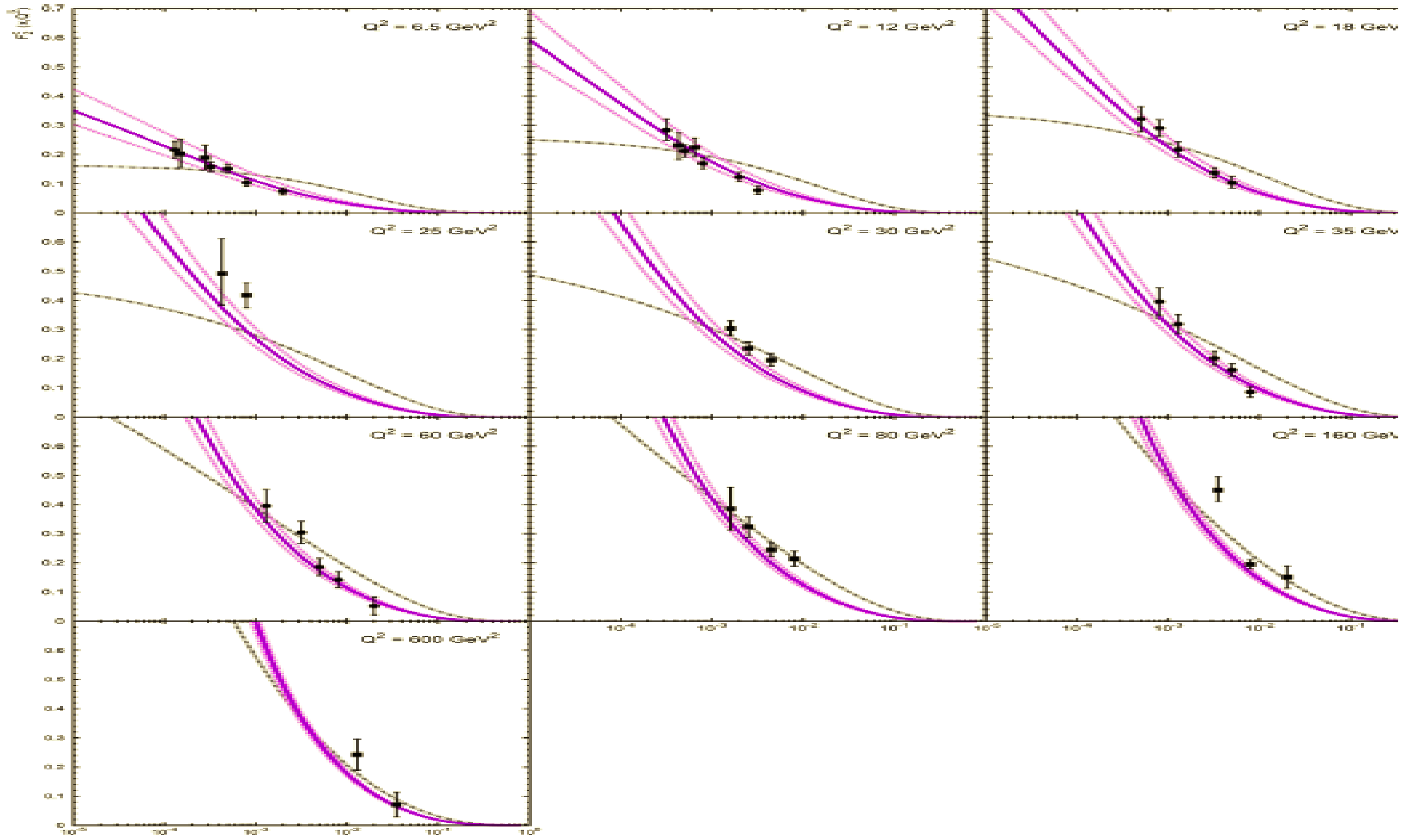
$$f_g^{(0)}(x,k_T^2,Q_0^2) \rightarrow f_g^{(0)}(x,k_T^2,Q_0^2) + f_g^{(k)}(x,k_T^2)$$

$$F_L(x,Q^2) = \sum_f e_f^2 \int \frac{dy}{y} \int d\mathbf{k}_T^2 \mathcal{C}_L(x/y, \mathbf{k}_T^2, Q^2, m_f^2, \mu^2) f_g(y, \mathbf{k}_T^2, \mu^2).$$



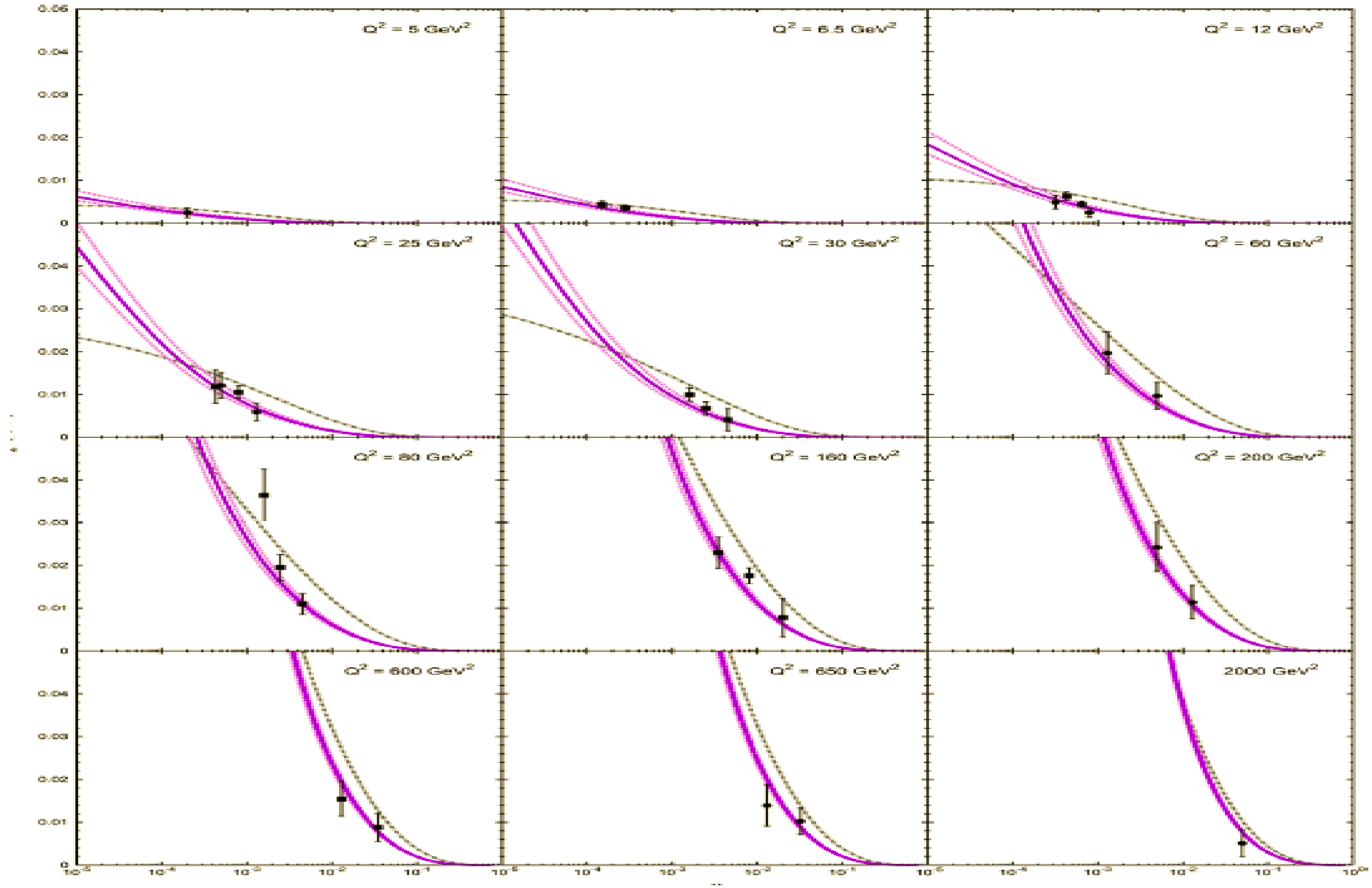
Solid line corresponds to μ_R= Q, the dash top line is for μ_R=Q/2, the bottom line corresponds to μ_R=2Q.

$F_2^c\,(x,Q^2)$



Solid line corresponds to μ_R= Q, the dash top line is for μ_R=Q/2, the bottom line corresponds to μ_R=2Q. Circles are the H1 data, squares are H1 data. Dotted line is the calculations using the set A0, Hannes Jung hep-ph/0411287

F_2^b (x,Q^2)



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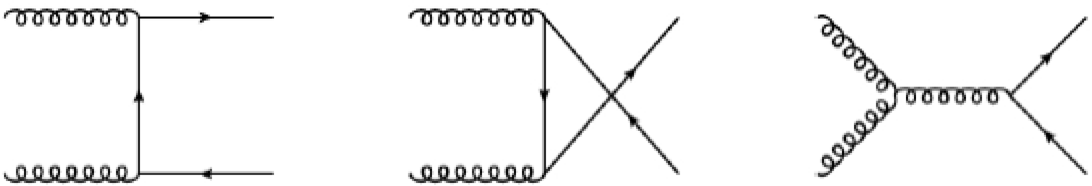
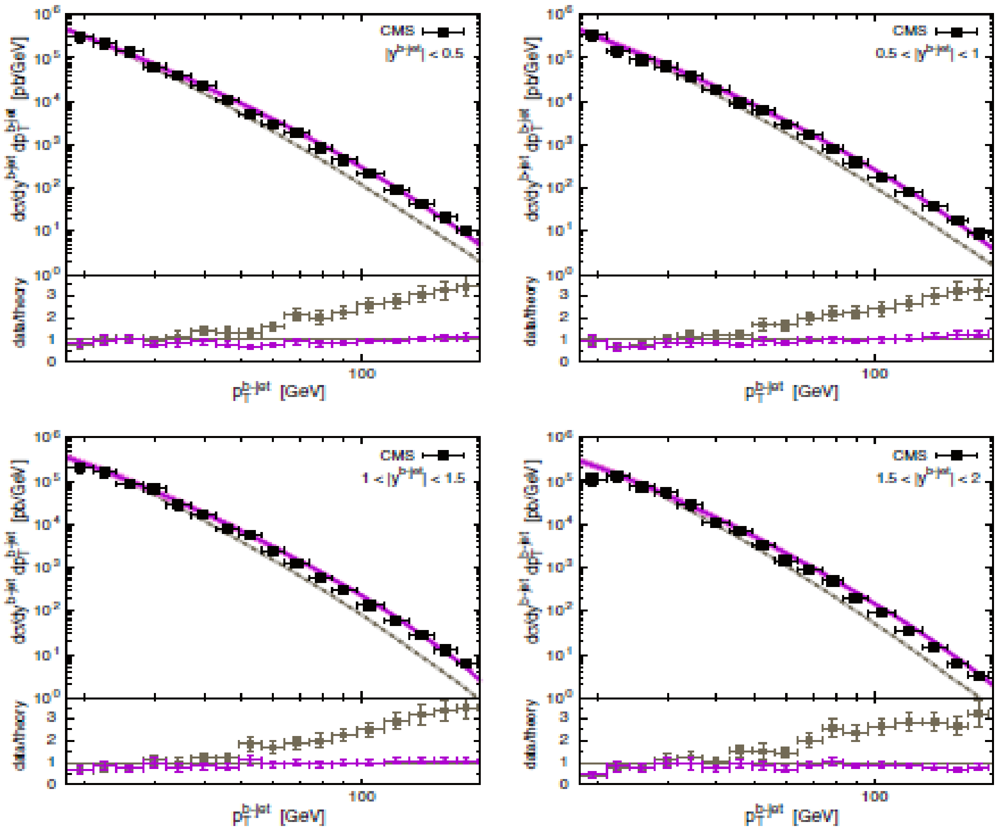
Dotted line is the calculations using the set A0, Hannes Jung hep-ph/0411287

HEAVY FLAVOUR JET PRODUCTION



$$\sigma = \int \frac{|\bar{\mathcal{M}}|^2}{16\pi\,(x_1 x_2 s)^2} f_g(x_1, \mathbf{k}_{1T}^2, \mu^2) f_g(x_2, \mathbf{k}_{2T}^2, \mu^2) d\mathbf{p}_{1T}^2 d\mathbf{k}_{1T}^2 d\mathbf{k}_{2T}^2 dy_1 dy_2 \frac{d\phi_1}{2\pi}\frac{d\phi_2}{2\pi}$$

b-Jet production in p-p collision at $s^{1/2} = 8$ TeV



p_T^b - distribution of b-jet in p-p

Solid red lines are our new calculation, the dashed one is results obtained using set A0 (Hannes Jung)

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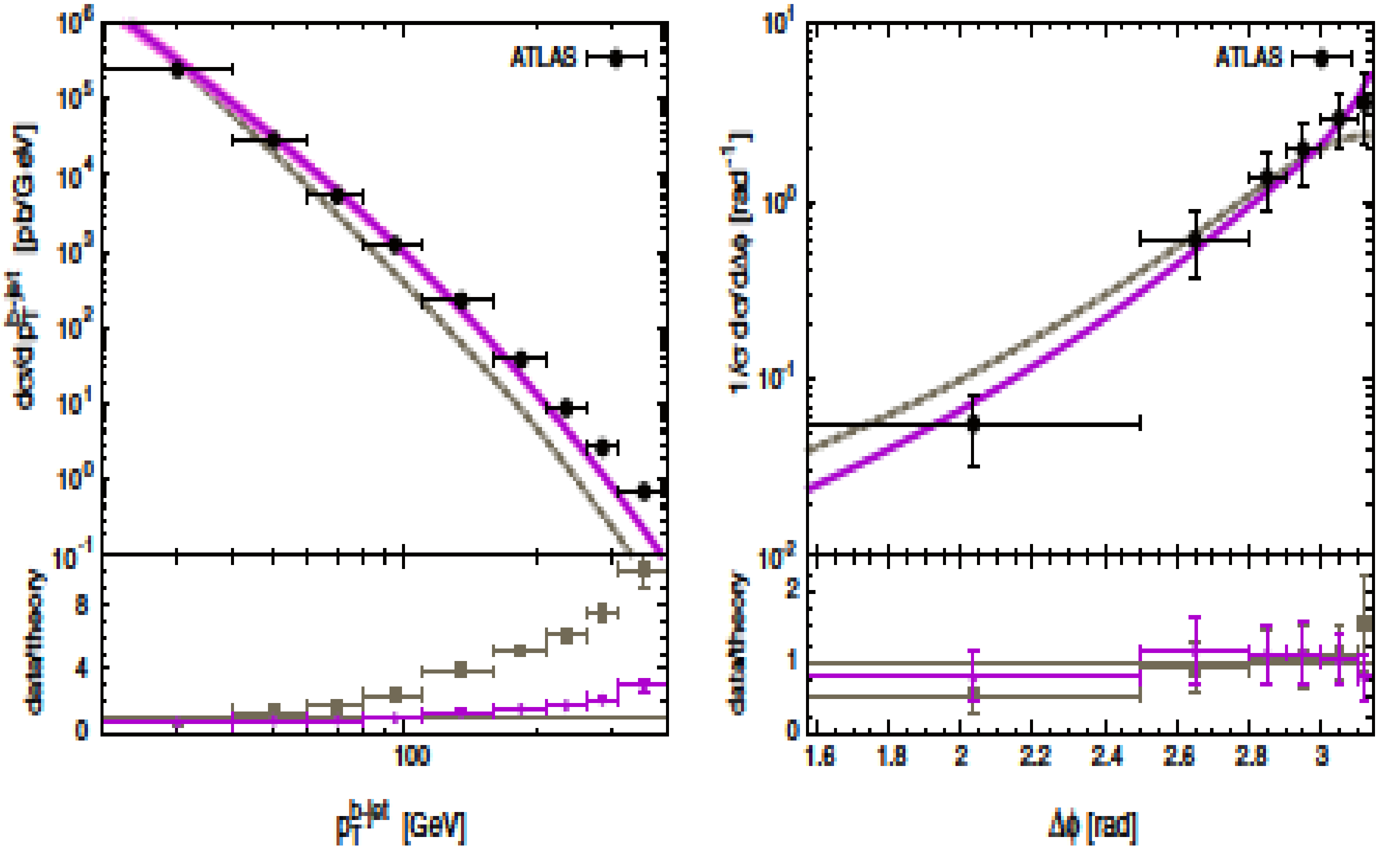
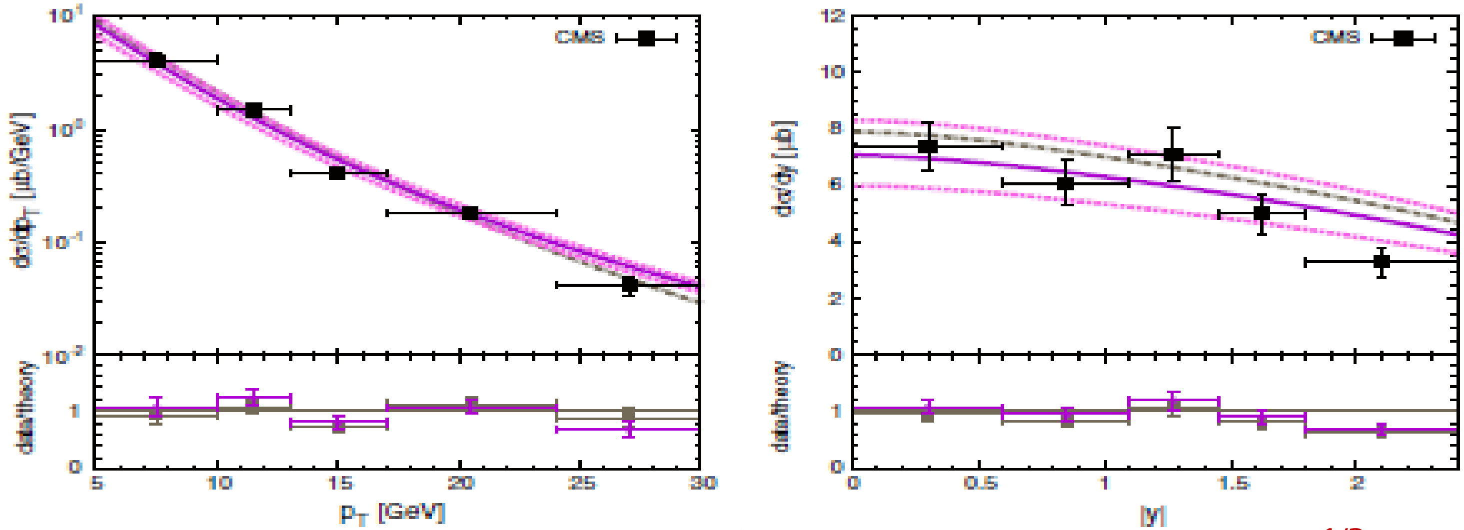
b-Jet production in p-p collision at $s^{1/2}$ = 8 TeV



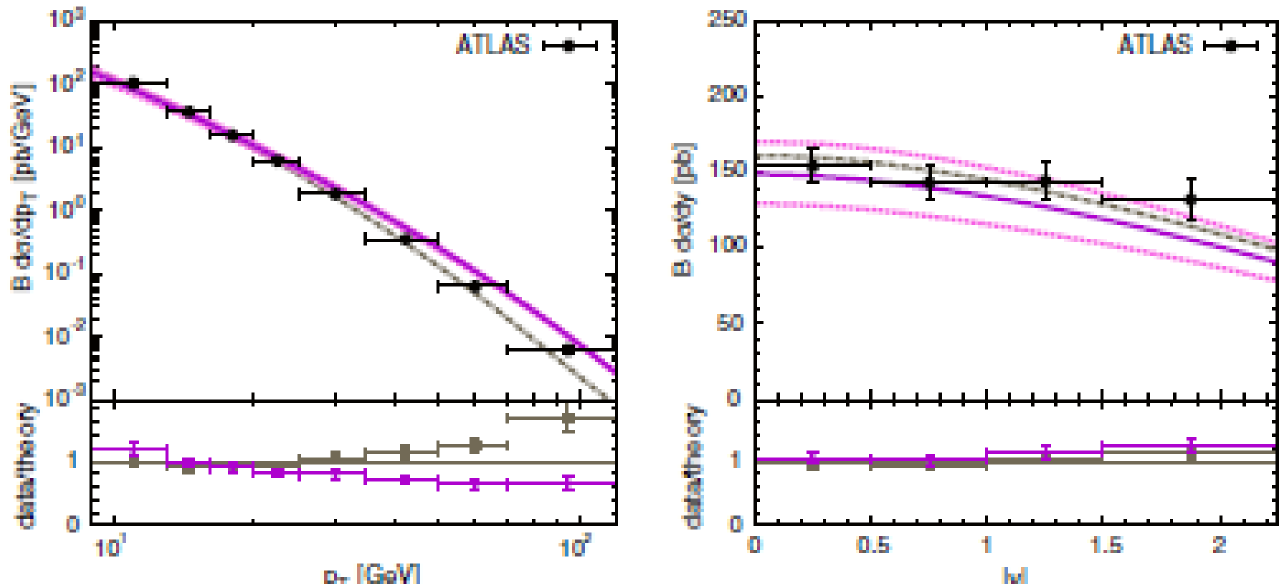
Top: p_T^b - distribution of b-jet in p-p (left) and the azimuthal angle difference between two b-jets (right). Bottom: ratio of the data to theory/

Solid red lines are our new calculation, the dashed ones are results obtained using set A0 (Hannes Jung)

B^+ - meson distribution versus p_T (left) and y (right) in p-p at $s^{1/2}$ = 8 TeV



D^* - meson distribution versus p_T (left) and y (right) in p-p at $s^{1/2}$ = 8 TeV



Solid red lines are our UGD, dash ones are set A_0 (H.Jung)

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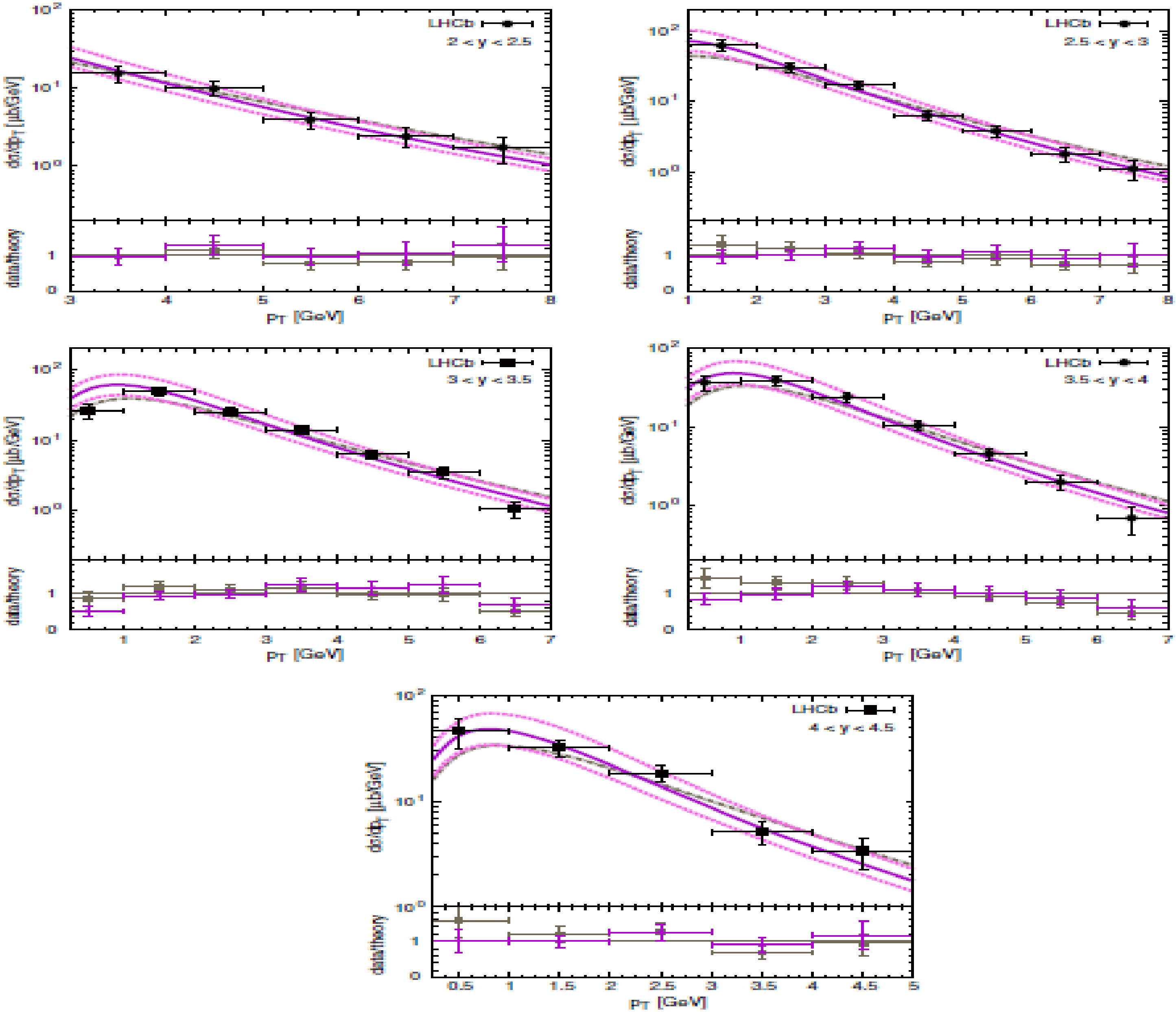
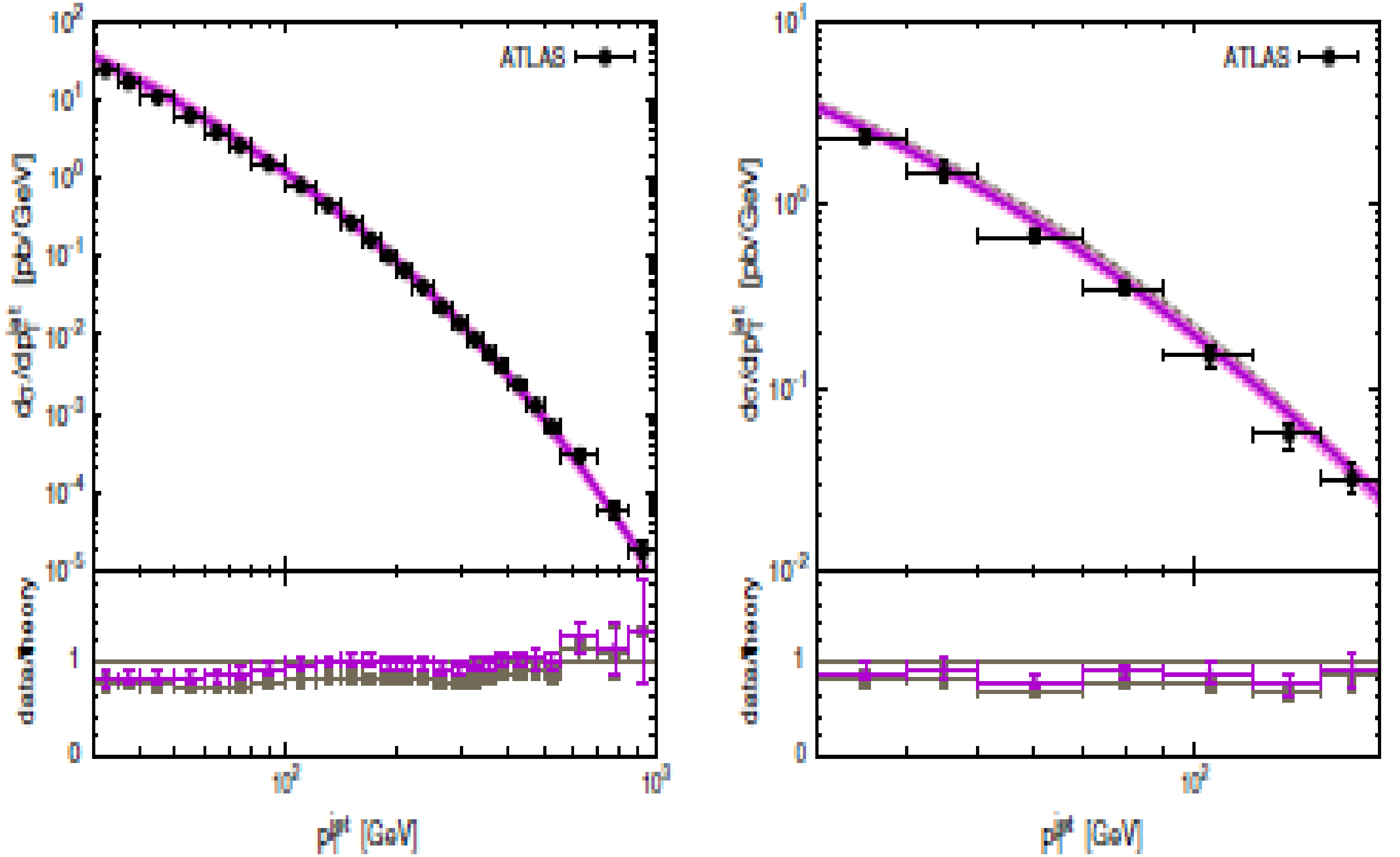
D^* - meson distribution versus p_T compared to the LHCb data in p-p at $s^{1/2}$ = 8 TeV



W+jet (left) and Z/γ^* + jet (right) production in p-p at $s^{1/2} = 8$ TeV



Top: p_T –distribution of the leading jet

Bottom: ratio of the data to theory. Red pointa are our UGD, the dark points are set A_0 (H. Jung)

SUMMARY

1.The new TMD gluon density is proposed at initial Q_0 =1.1 GeV/c. and their parameters are verified by the description of the LHC data on the hadron spectra in the soft kinematical region.

2. The CCFM evolution equation was solved using the proposed TMD g.d. at starting Q_0^2.

3. The CCFM-evolved u.g.d. results in a satisfactory description of the H1 and ZEUS data on $\mathbf{F_L}$, $\mathbf{F_{2b}}$.

4. The modification of the u.g.d. at large k_T is suggested matching the solution of the BFKL obtained by Kovchegov at k_T > 1GeV/c and our u.g.d. at k_T < 1GeV/c.

5.The application of the new u.g.d. to the analysis of these processes allows us to describe rather well many observables on the hard production of heavy flafour mesons and jets at LHC.

7. **The connection between the soft processes at LHC and small x-physics at HERA has been confirmed using the new input for the gluon density**

8. The UGD suggested here can be applied at not large x (<0.01). Probably one can specify the parameters of this UGD at larger x.

THANK YOU VERY MUCH FOR YOUR ATTENTION !

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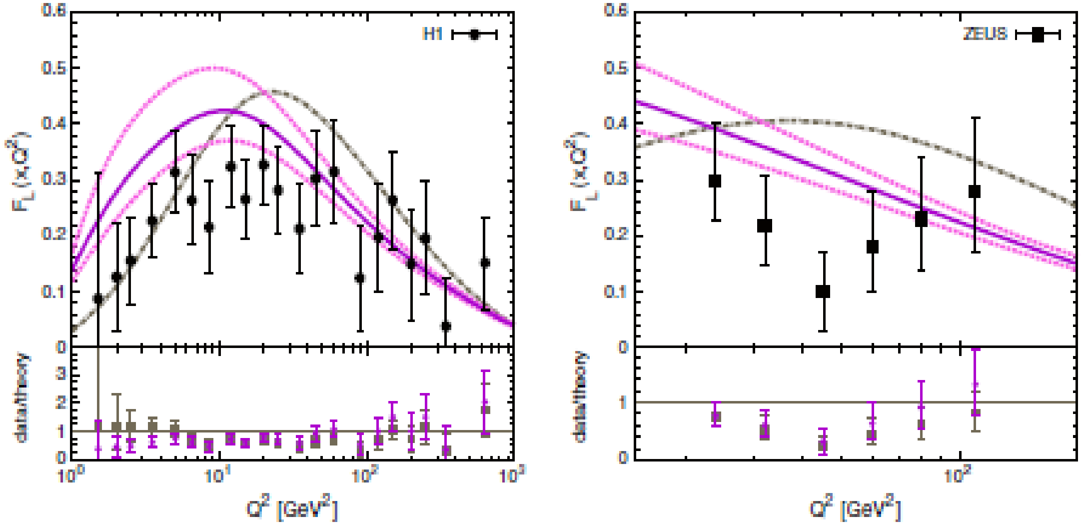
BACKUP

$$F_L(x,Q^2) = \sum_f e_f^2 \int \frac{dy}{y} \int d\mathbf{k}_T^2 \mathcal{C}_L(x/y, \mathbf{k}_T^2, Q^2, m_f^2, \mu^2) f_g(y, \mathbf{k}_T^2, \mu^2)$$



Solid line corresponds to μ_R= Q, the dash top line is for μ_R=Q/2, the bottom line corresponds to μ_R=2Q. Circles are the ZEUS data, squares are H1 data

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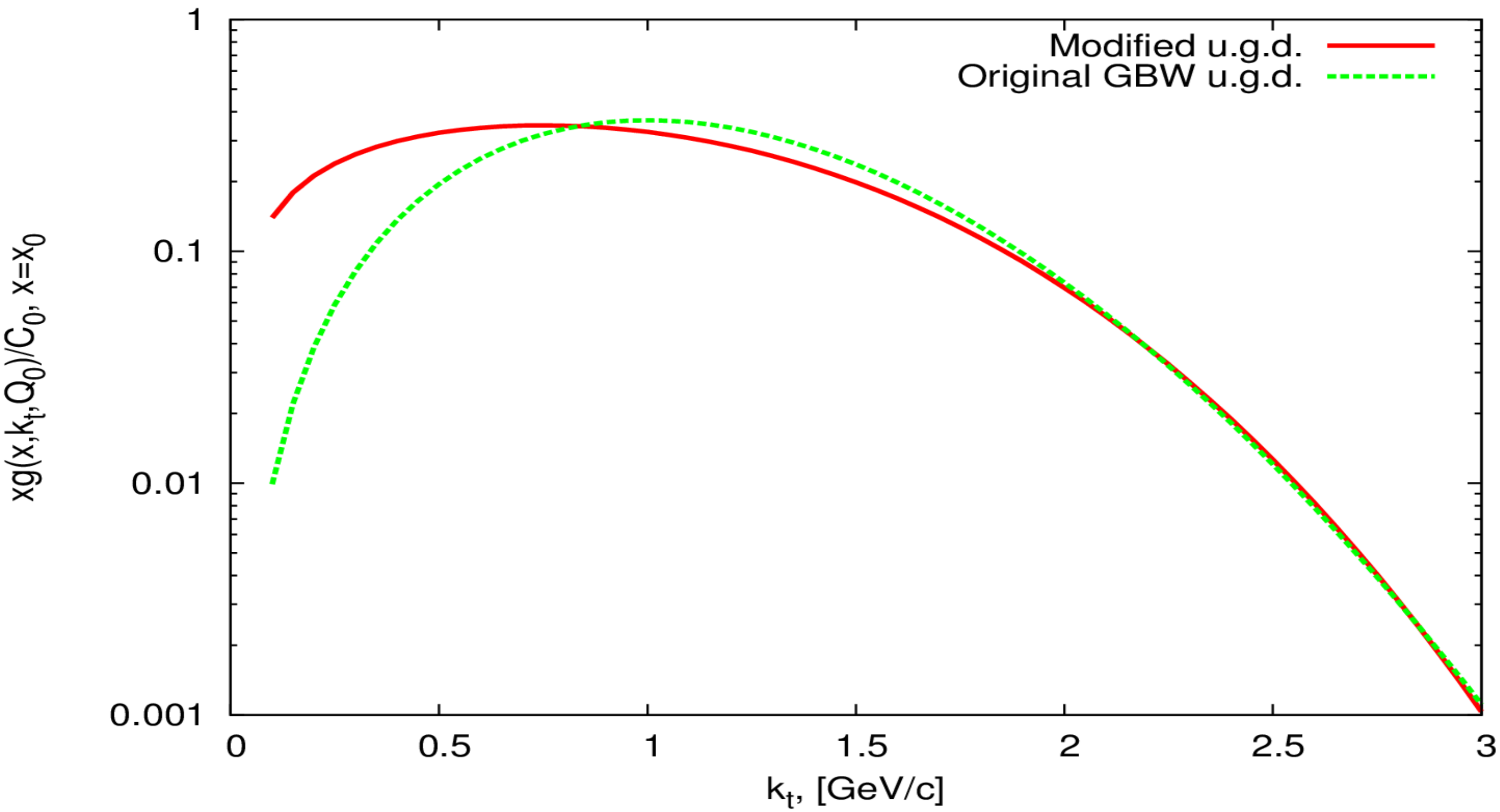


Green line is the GBW u.g.d. K. Golec-Biernat & M. Wuesthoff, Phys.Rev.D60, 114023 (1999).Red line is the modified u.g.d. A.Grinyuk, H.Jung, G.L., A.Lipatov, N.Zotov, hep-ph/1203.0939; Proc.MPI-11, DESY, Hamburg, 2012; A.A.Grinyuk, A.V.Lipatov, G.L., N.P.Zotov, Phys.Rev. D87, 074017 (2013); hep-ph/1301.45

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

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

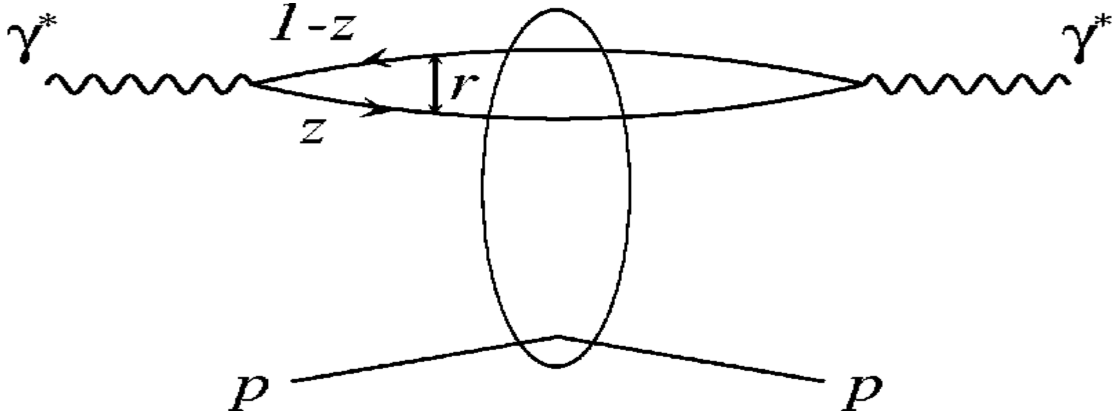
$$F_L(x,Q^2)=\int_x^1 \frac{dz}{z}\int_0^{Q^2} dk_t^2 \sum_{i=u,d,s} e_i^2 C_L^g\left(\frac{x}{z},Q^2,m_i^2,k_t^2\right)\phi_g(z,k_t^2),$$

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

A.V. Kotikov, A.V. Lipatov, N.P. Zotov, Eur.Phys.J., C27 92003)219.
H. Jung, A.V. Kotikov, A.V. Lipatov, N.P. Zotov, DIS 2007, hep-ph/07063793.

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

Saturation dynamics



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

$R_0 = GeV^{-1}(x/x_0)^{\lambda/2}$ 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.