Czech Technical University in Prague
Faculty of Nuclear Sciences and Physical Engineering
Department of Physics

Diffractive deep inelastic scattering

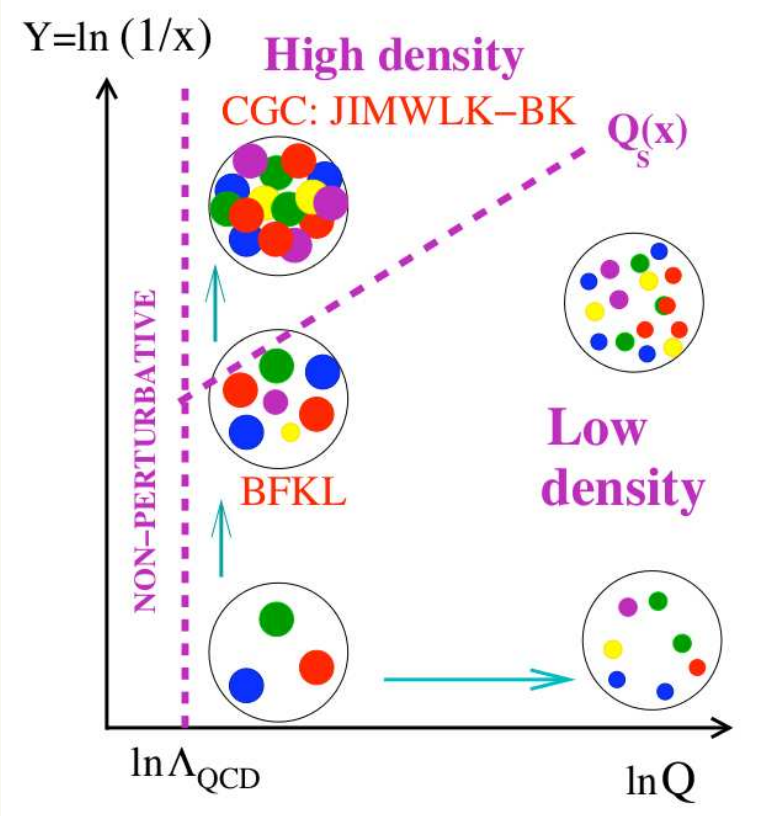
Jan Cepila

based on publication in preparation with
D. Bendová, J.G. Contreras, V. P. Gonçalves, M. Matas

Miniworkshop on Diffraction and Ultraperipheral Collisions, Decin 15.9.2020

What is it good for..

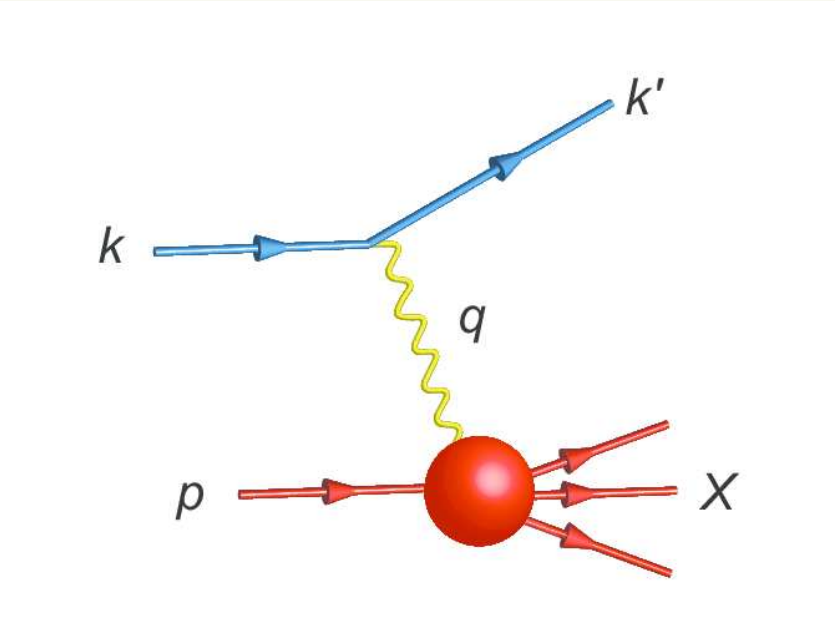
- **We want to study the gluon distribution inside a hadron**
- Towards larger scale Q^2, the number of gluons rises linearly but their size gets smaller
- Towards smaller Bjorken x, the number of gluons rises linearly without changing the size
- When the dilute system gets to dense regime (CGC) by crossing saturation scale Q_s^2, linear evolution no longer holds
- Non-linear regime is described by infinite hierarchy of coupled (JIMWLK) equations for correlators of Wilson lines (don't ask me what it is..)



- In mean field approximation and large N_c limit, the first equation decouples to single non-linear integro-differential equation for 2-point correlator - scattering amplitude of a dipole off the CGC matter.

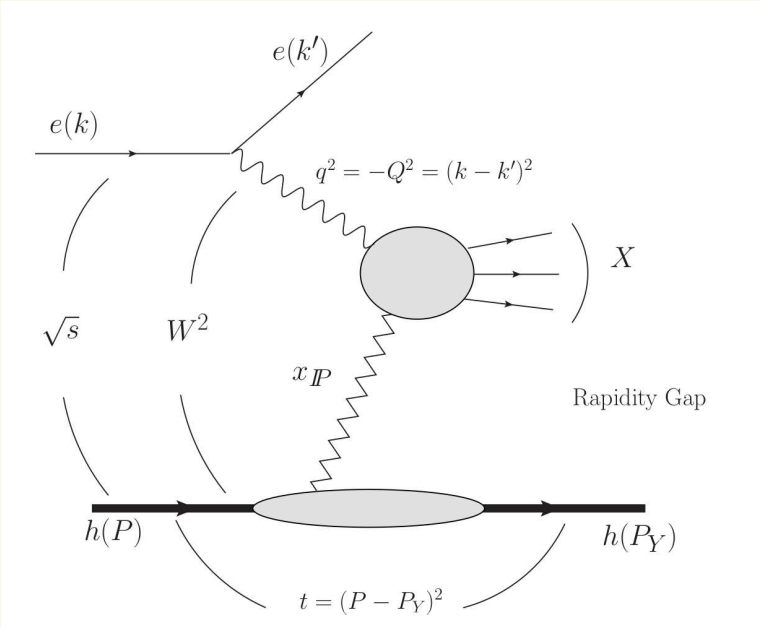
What is diffractive deep inelastic scattering?

- ”Normal” deep inelastic scattering - an electron scatters off the hadron leading to an electron + bunch of hadrons denoted X
- $W_{\gamma p}^2 = M_X^2$ is the center-of-mass energy of the photon-hadron system
- Bjorken-x is
$$x_{Bj} = \frac{Q^2}{W_{\gamma p}^2 + Q^2 - M_N^2}$$
M_N is the mass of the hadron, $Q^2 = -(k - k')^2$ is the scale of the incoming photon
- Low-x limit (saturation regime) manifests at large $W_{\gamma p}$



What is diffractive deep inelastic scattering?

- Diffractive deep inelastic scattering - an electron scatters off the hadron leading to an electron + hadron + bunch of hadrons denoted X
- $W^2_{\gamma p}$ is the center-of-mass energy of the photon-hadron system
- $x_{\mathbb{P}} = \frac{Q^2+M_X^2}{W^2_{\gamma p}+Q^2}$ is a fractional longitudinal momentum loss of a hadron
- One more degree of freedom - $\beta = \frac{Q^2}{M_X^2+Q^2}$
- Bjorken-x is $x_{Bj} = \beta x_{\mathbb{P}} = \frac{Q^2}{W^2_{\gamma p}+Q^2}$, $Q^2 = -(k-k')^2$ is the scale of the incoming photon

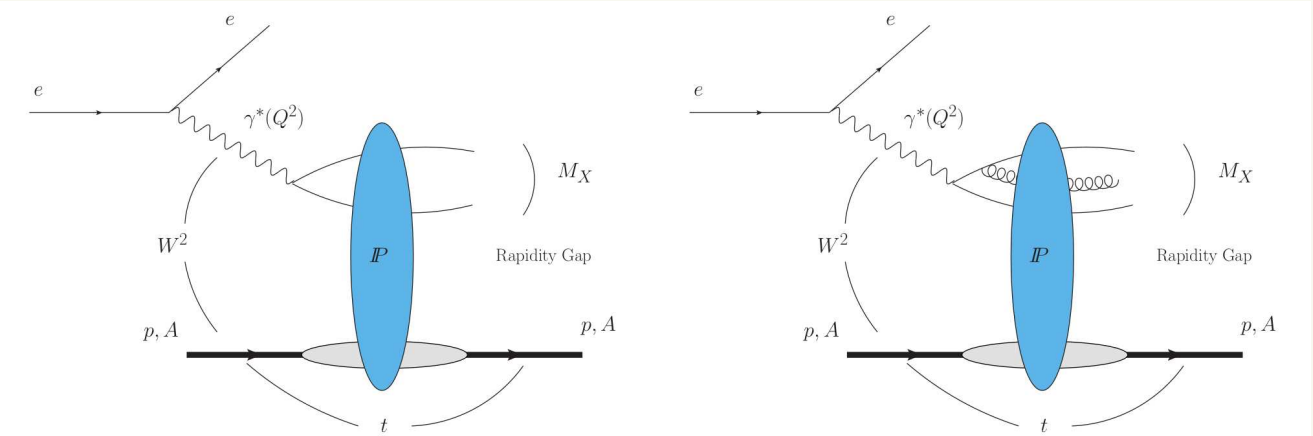


From the cross sections to the structure functions..

- Differential cross section for diffractive DIS

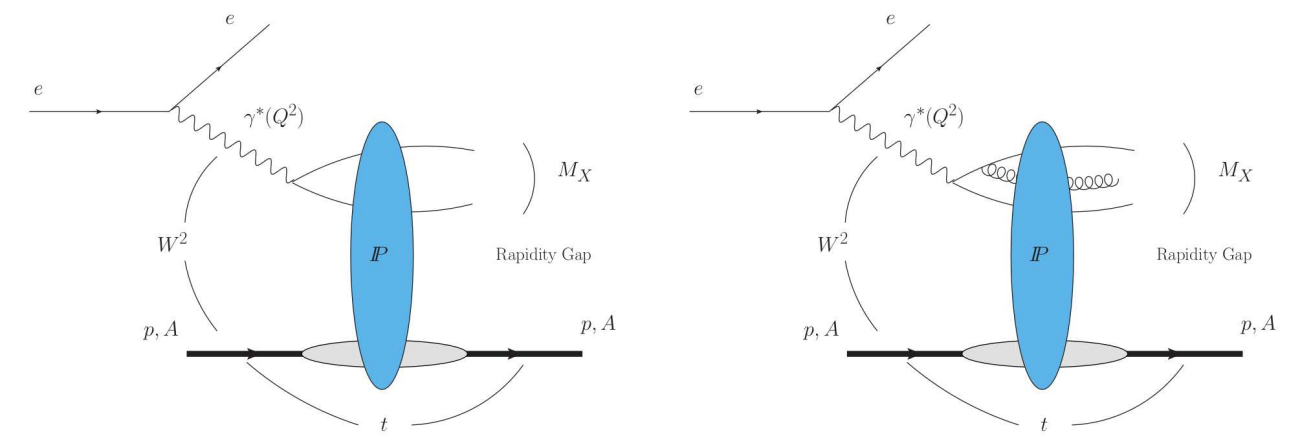
$$\frac{d\sigma^{eh\to eXh}}{d\beta dQ^2 dx_{\mathbb{P}}} = \frac{4\pi\alpha^2}{\beta Q^4}\left[1-y+\frac{y^2}{2}\right]\left(F_2^{D(3)}(x_{\mathbb{P}},\beta,Q^2) - \frac{y^2}{1+(1-y)^2}F_L^{D(3)}(x_{\mathbb{P}},\beta,Q^2)\right)$$

- y is the fractional energy loss of the electron in the hadron rest frame
- $F_2^{D(3)}$ and $F_L^{D(3)}$ are diffractive structure functions
- Experimentally, the process is recognized by the presence of a leading hadron and the rapidity gap of the width $\ln(1/x_{\mathbb{P}})$
- In the color dipole approach, we take a photon and expand it into the series of colorless parton states, that scatter elastically on the hadron



From the cross sections to the structure functions..

- We restrict ourselves to two simplest states $q\bar{q}$ and $q\bar{q}g$



$$F_2^{D(3)} = F_{T,q\bar{q}}^D + F_{L,q\bar{q}}^D + F_{T,q\bar{q}q}^D (+F_{L,q\bar{q}q}^D)$$

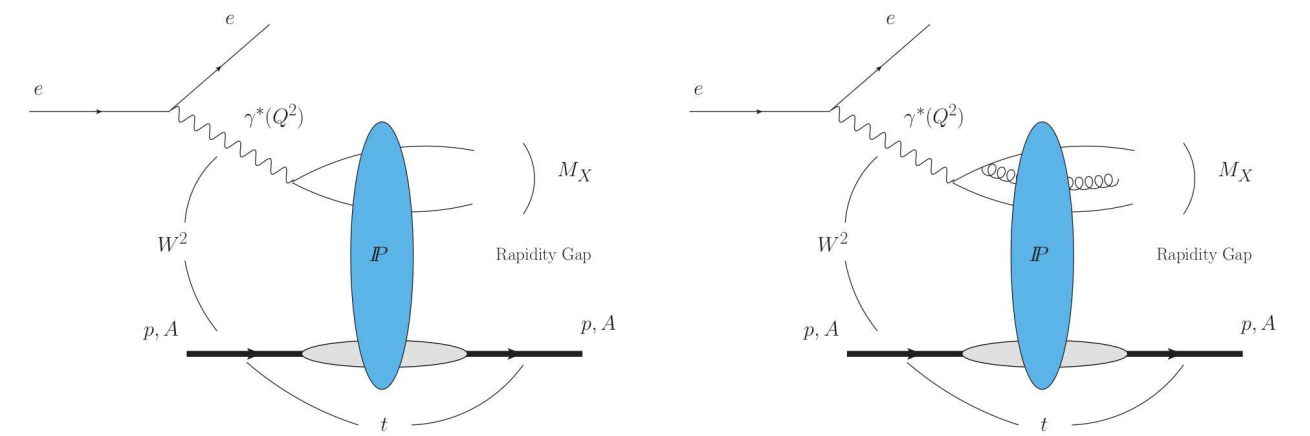
T, L denote the transverse and longitudinal degrees of freedom of the photon, last term has no leading log in Q^2

$$x_{\mathbb{P}} F_{T,q\bar{q}}^D(x_{\mathbb{P}}, \beta, Q^2) = \frac{N_c Q^4}{16\pi^3 \beta} \sum_f e_f^2 \int_{z_0}^{1/2} dz z(1-z) \left\{ \varepsilon^2 [z^2 + (1-z)^2] \Phi_1 + m_f^2 \Phi_0 \right\}$$

$$\varepsilon^2 = z(1-z)Q^2 + m_f^2 \qquad z_0 = \frac{1}{2}\left(1 - \sqrt{1 - \frac{4m_f^2}{M_X^2}}\right)$$

From the cross sections to the structure functions..

- We restrict ourselves to two simplest states $q\bar{q}$ and $q\bar{q}g$



$$F_2^{D(3)} = F_{T,q\bar{q}}^D + F_{L,q\bar{q}}^D + F_{T,q\bar{q}q}^D (+F_{L,q\bar{q}q}^D)$$

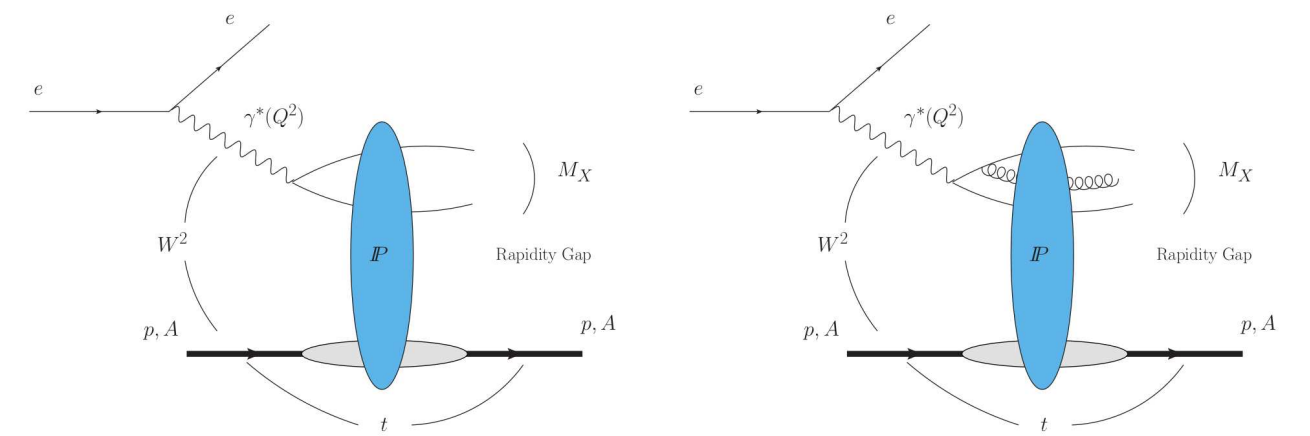
T, L denote the transverse and longitudinal degrees of freedom of the photon, last term has no leading log in Q^2

$$x_{\mathbb{P}} F_{L,q\bar{q}}^D(x_{\mathbb{P}}, \beta, Q^2) = \frac{N_c Q^6}{4\pi^3 \beta} \sum_f e_f^2 \int_{z_0}^{1/2} dz z^3 (1-z)^3 \Phi_0$$

$$\Phi_{0,1} = \int d^2 b_t \left[\int_0^\infty dr r K_{0,1}(\varepsilon r) J_{0,1}(kr) \frac{d\sigma}{d^2 b_t}(b_t, r, x_{\mathbb{P}}) \right]^2 \qquad k^2 = z(1-z) M_X^2 - m_f^2$$

From the cross sections to the structure functions..

- We restrict ourselves to two simplest states $q\bar{q}$ and $q\bar{q}g$



$$F_2^{D(3)} = F_{T,q\bar{q}}^D + F_{L,q\bar{q}}^D + F_{T,q\bar{q}q}^D (+F_{L,q\bar{q}q}^D)$$

T, L denote the transverse and longitudinal degrees of freedom of the photon, last term has no leading log in Q^2

$$x_{\mathbb{P}} F_{T,q\bar{q}g}^D(x_{\mathbb{P}}, \beta, Q^2) = \frac{\alpha_s \beta}{8\pi^4} \sum_f e_f^2 \int d^2 b_t \int_0^{Q^2} d\kappa^2 \int_\beta^1 dz \left\{ \kappa^4 \ln \frac{Q^2}{\kappa^2} \left[(1-\frac{\beta}{z})^2 + (\frac{\beta}{z})^2 \right] \right.$$

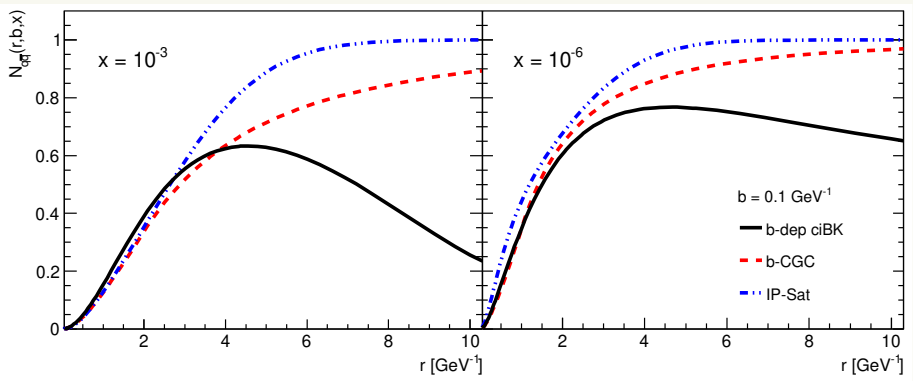
$$\left. \cdot \left[\int_0^\infty dr r \frac{d\sigma_g}{d^2 b_t} K_2(\sqrt{z}\kappa r) J_2(\sqrt{1-z}\kappa r) \right]^2 \right\} \qquad \frac{d\sigma_g}{d^2 b_t} = 2\left[1 - \left(1 - \frac{1}{2} \frac{d\sigma}{d^2 b_t} \right)^2 \right]$$

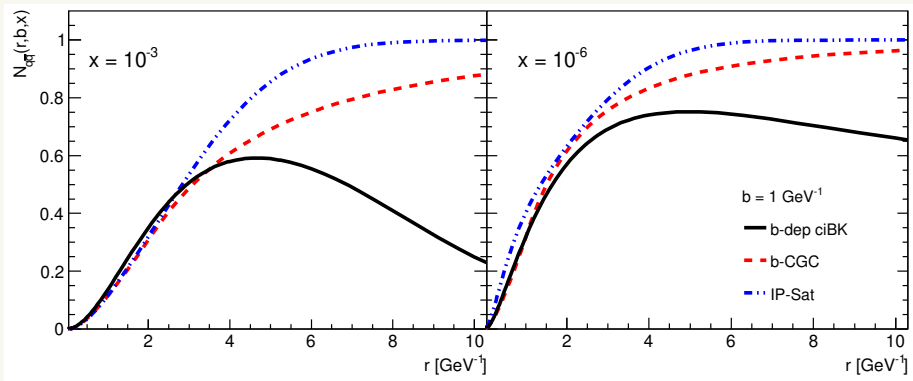
Dipole cross section

- From the optical theorem

$$\frac{\mathrm{d}\sigma_{q\bar{q}}}{\mathrm{d}^2 b_t} = 2N(r, b_t, Y)$$

- IPSat model - CGC inspired phenomenological model, Gaussian profile of a proton
- b-CGC model - continuous connection of two limiting BK solutions, Gaussian profile of a proton
- impact parameter dependent solution of collinearly improved BK equation (talk by Marek)





Nuclear dipole cross section

- IPSat + Glauber-Gribov (GG) approach

$$N^A(r,b_t,Y) = 2\left(1 - e^{-\frac{1}{2}\sigma_{q\bar{q}}(r,Y)T_A(b_t)}\right) \qquad \sigma_{q\bar{q}}(r,Y) = 2\int d^2b_p N^{IPSat}(r,b_p,Y)$$

- b-CGC + Glauber-Gribov (GG) approach

$$N^A(r,b_t,Y) = 2\left(1 - e^{-\frac{1}{2}\sigma_{q\bar{q}}(r,Y)T_A(b_t)}\right) \qquad \sigma_{q\bar{q}}(r,Y) = 2\int d^2b_p N^{b-CGC}(r,b_p,Y)$$

- b-dep ciBK + Glauber-Gribov (GG) approach

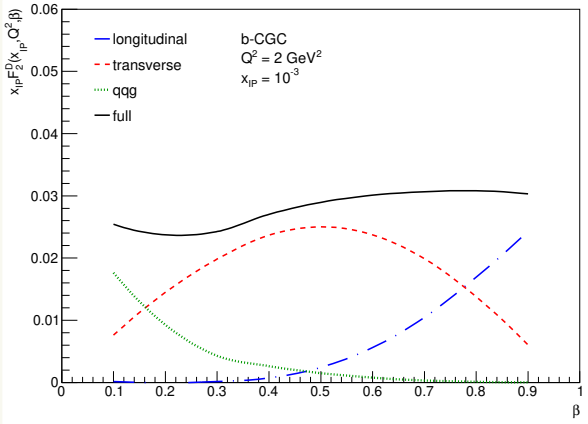
$$N^A(r,b_t,Y) = 2\left(1 - e^{-\frac{1}{2}\sigma_{q\bar{q}}(r,Y)T_A(b_t)}\right) \qquad \sigma_{q\bar{q}}(r,Y) = 2\int d^2b_p N^{bdepBK}(r,b_p,Y)$$

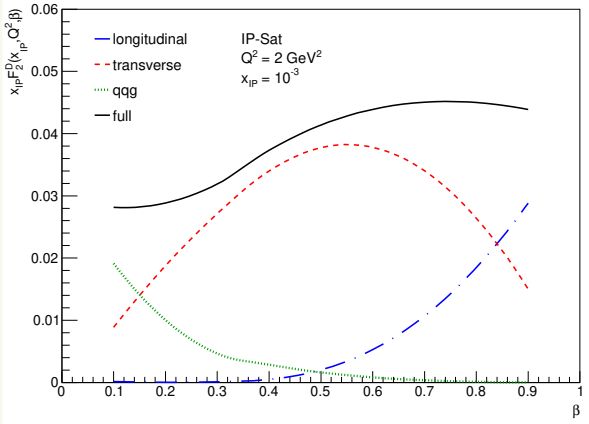
- b-dep ciBK evolved nucleus

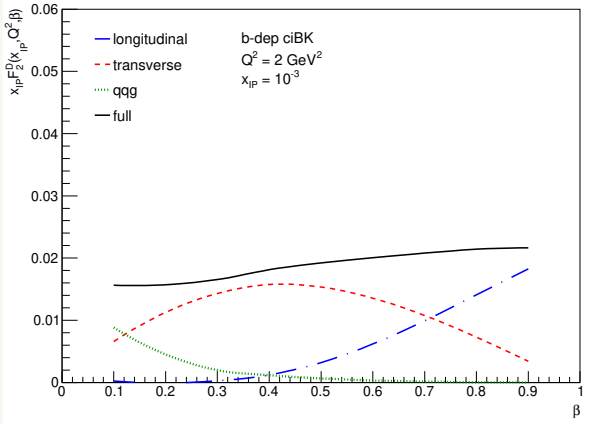
$$N^A(r,b_t,Y=0) = \left(1 - e^{-\frac{1}{2}\sigma_{q\bar{q}}(r,Y)T_A(b_t)}\right) \qquad \sigma_{q\bar{q}}(r,Y) = \frac{r^2Q_{sA}^2(Y)}{4}$$

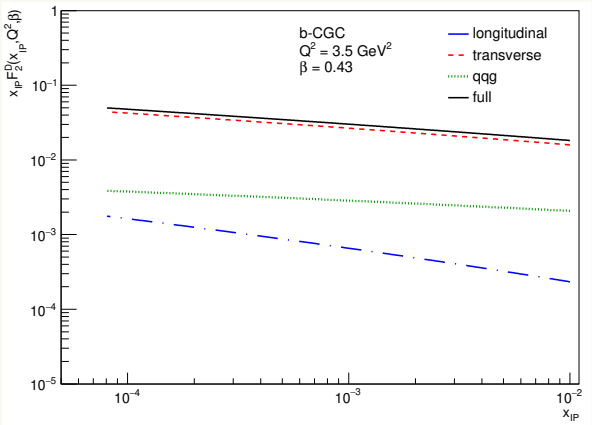
- T_A is the nuclear profile function from Wood-Saxon distribution

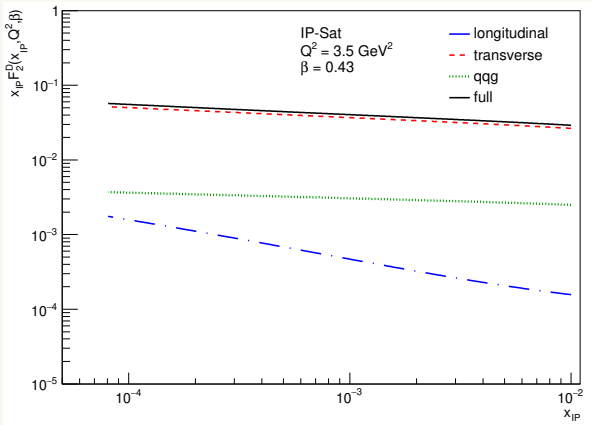
Results for proton target

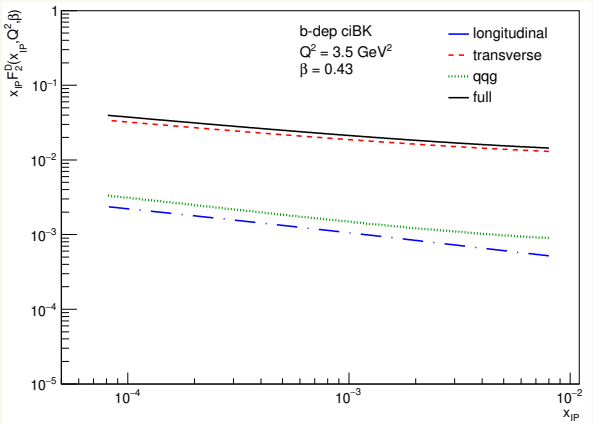
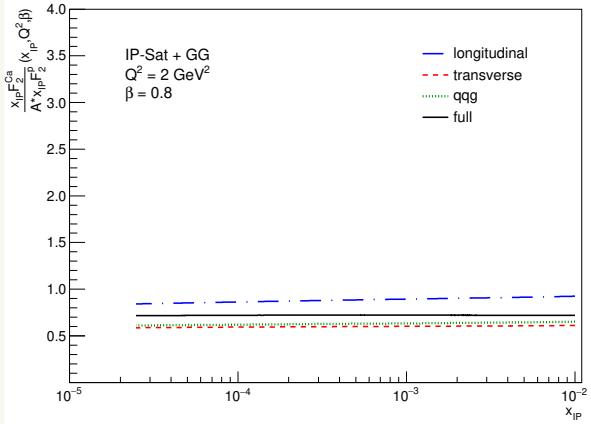
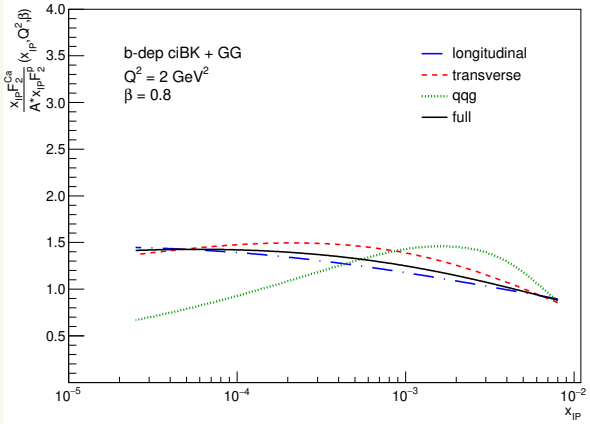
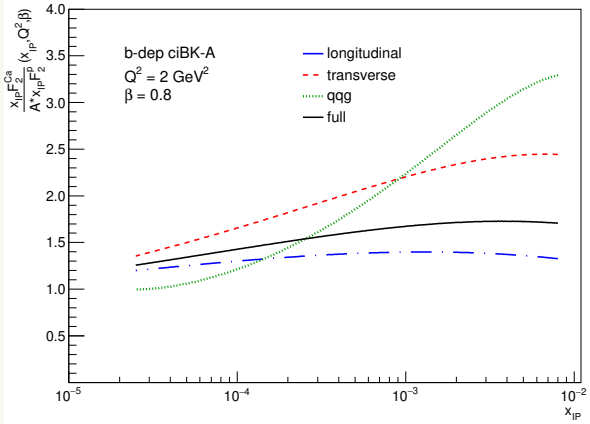
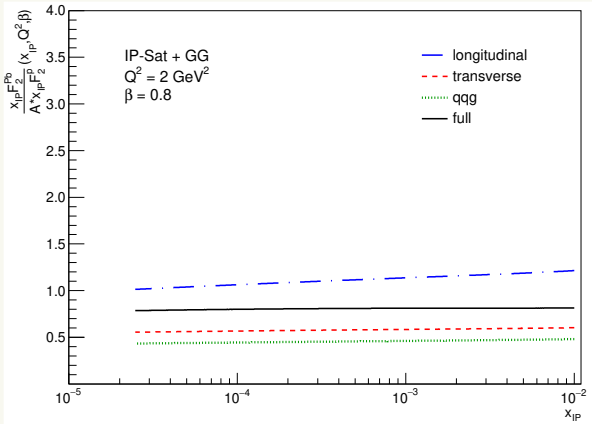
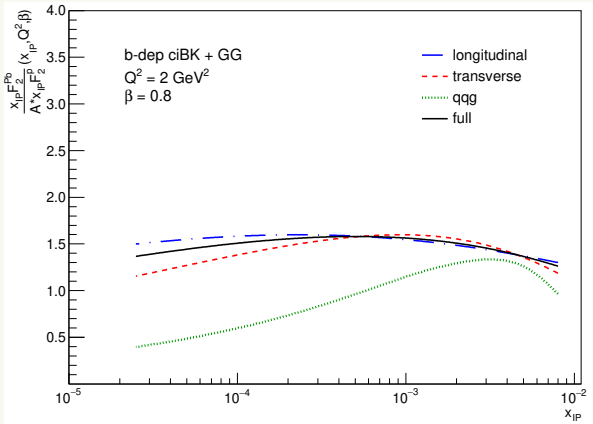
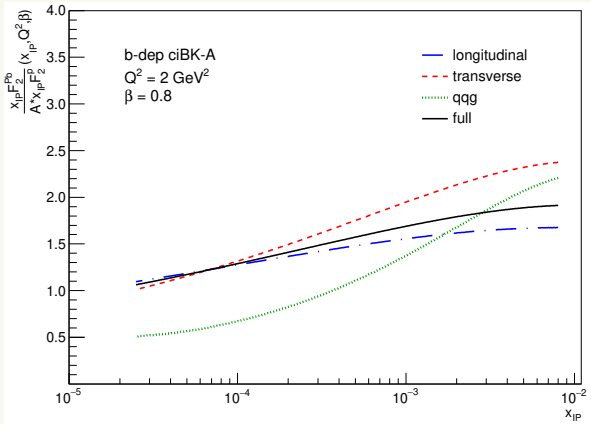












Results for nuclear targets