Saturation at HERA and LHC

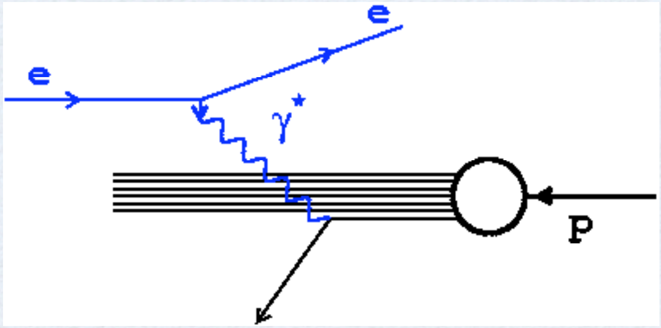
Short review of saturation and multiple scattering at HERA,

CMS correlation as a signal of saturation?

H. Kowalski, Analysis Center, 1 of November 2010

Partons vs Dipoles

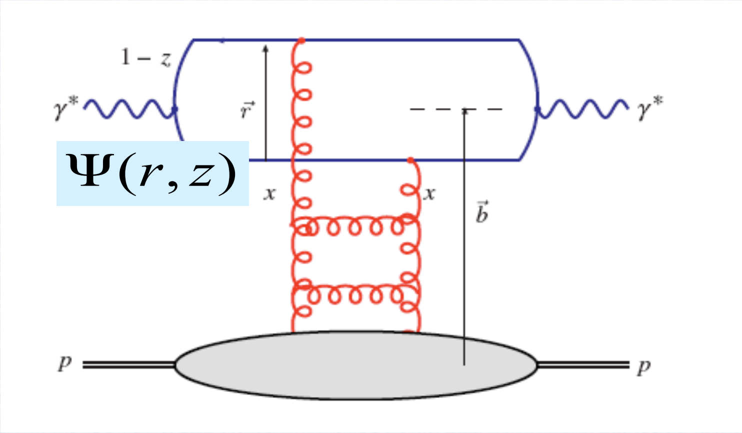
Infinite momentum frame: Partons



F_2 measures parton density at a scale Q^2

$$F_2 = \Sigma_f \, e_f^2 \, xq(x, Q^2)$$

Proton rest frame: Dipoles - long living quark pair interacts with the gluons of the proton *dipole life time ≈ 1/(m_p x) = 10 - 1000 fm at x = 10^{-2} - 10^{-4}*

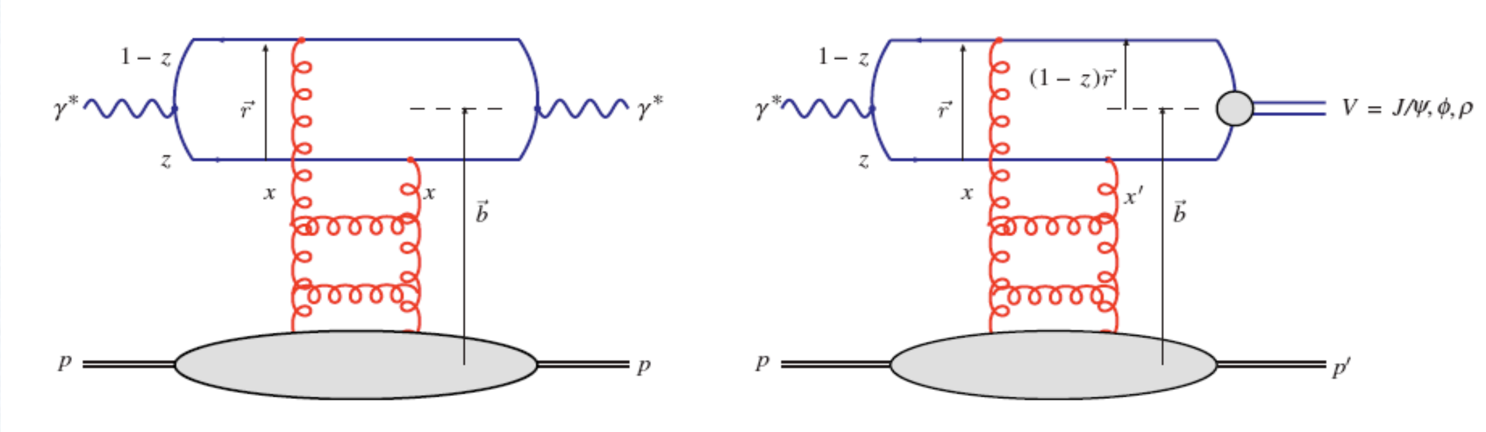


$$\sigma_{tot}^{\gamma^* p} = \int \Psi^* \sigma_{qq} \Psi \; ; \qquad F_2 = \frac{Q^2}{4\pi^2 \alpha_{em}} \sigma_{tot}^{\gamma^* p}$$

for small dipoles, at low-x, dipole picture is equivalent to the QCD parton picture

Diffraction

Observation of inclusive and exclusive diffractive reaction established the dipole picture of DIS



$$\boxed{\sigma_{tot}^{\gamma^* p} = \int \Psi^* \sigma_{qq} \Psi}$$ ← **Optical Theorem** → $$\boxed{\frac{d\sigma^{\gamma^* p \to V p}}{dt} \sim \left| \int d^2 b \, \Psi_V^* \, \Psi e^{-i\vec{b}\cdot\vec{\Delta}} \frac{d\sigma_{q\bar{q}}}{d^2 b} \right|^2}$$

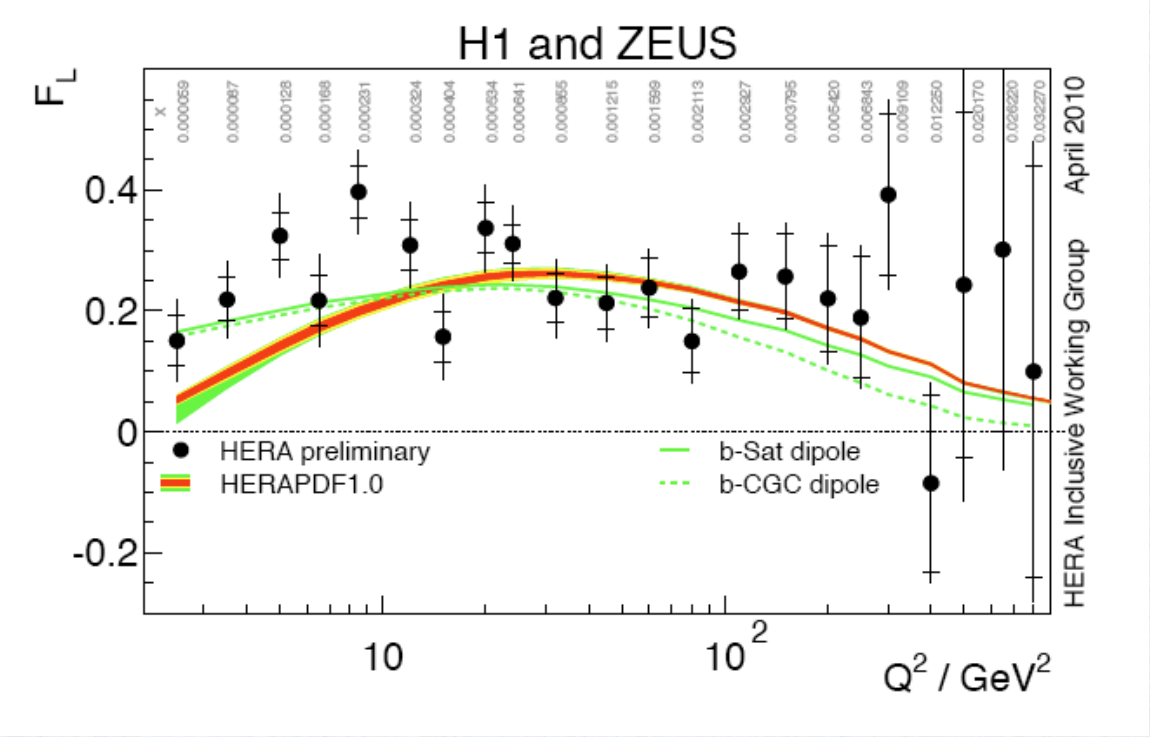
$$\boxed{\frac{d\sigma_{q\bar{q}}}{d^2 b} \sim r^2 \alpha_S x g(x, \mu^2) T(b)}$$ **for small gluon density**

The same, universal, gluon density describes the properties of many reactions: F_2, F_L, inclusive diffraction, exclusive J/Psi, Phi and Rho production, DVCS, diffractive jets

F_L measurements combined H1 and ZEUS data

F_L more directly connected to gluon density than F_2

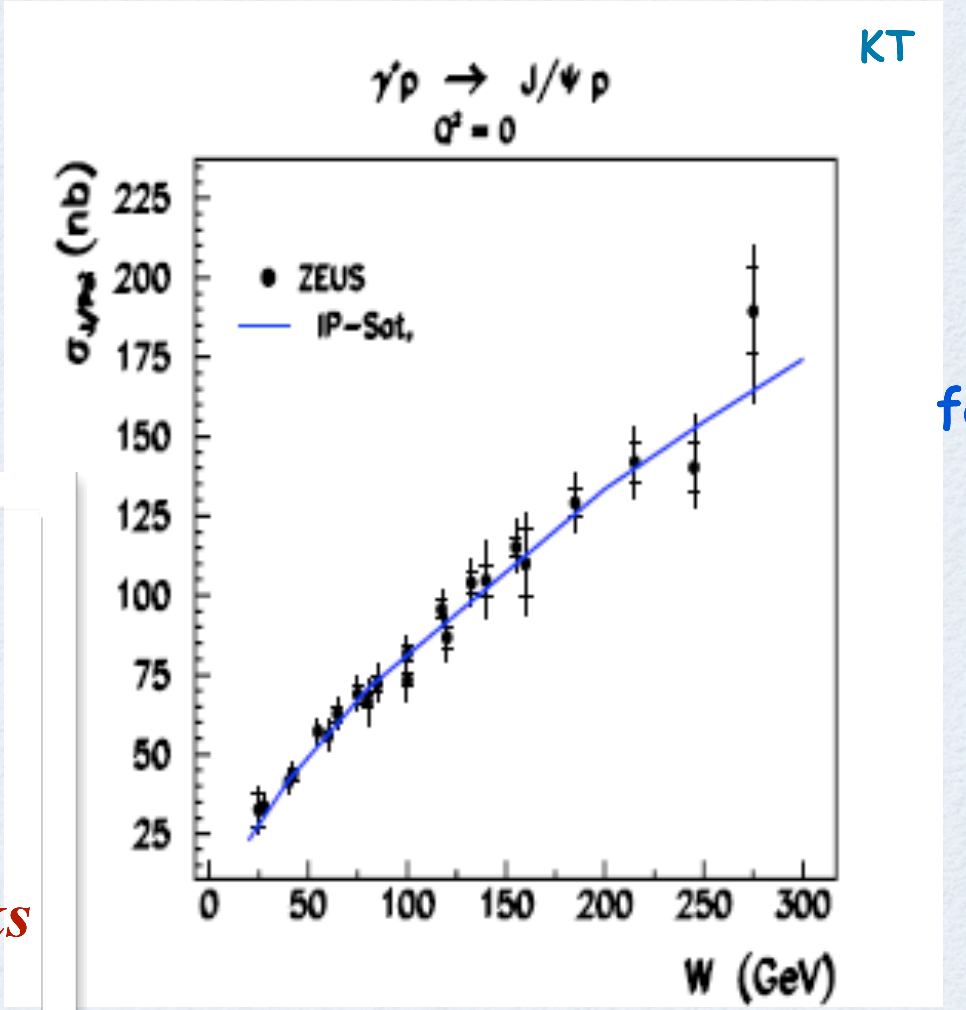
at HERA I+II measurement precision of F_L much worse than of F_2



☛ F_L measurement at HERA suffers from systematic errors of small angle electron measurement

In focus: Exclusive J/psi production

educated guess for VM wf is working very well for J/psi and phi and DVCS

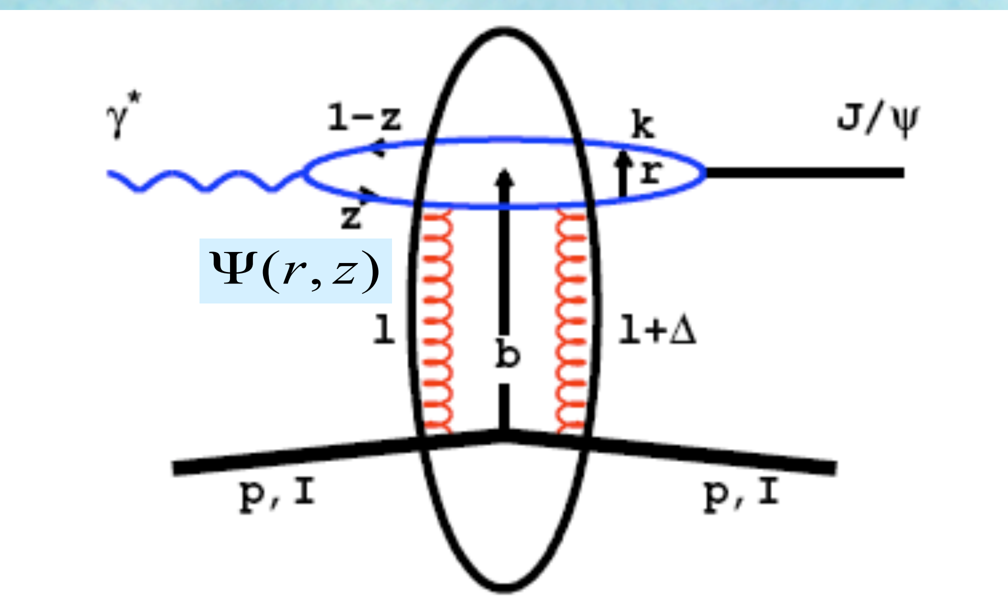


equally good description of Q2 and σ_L/σ_T dependences for J/psi and phi and DVCS

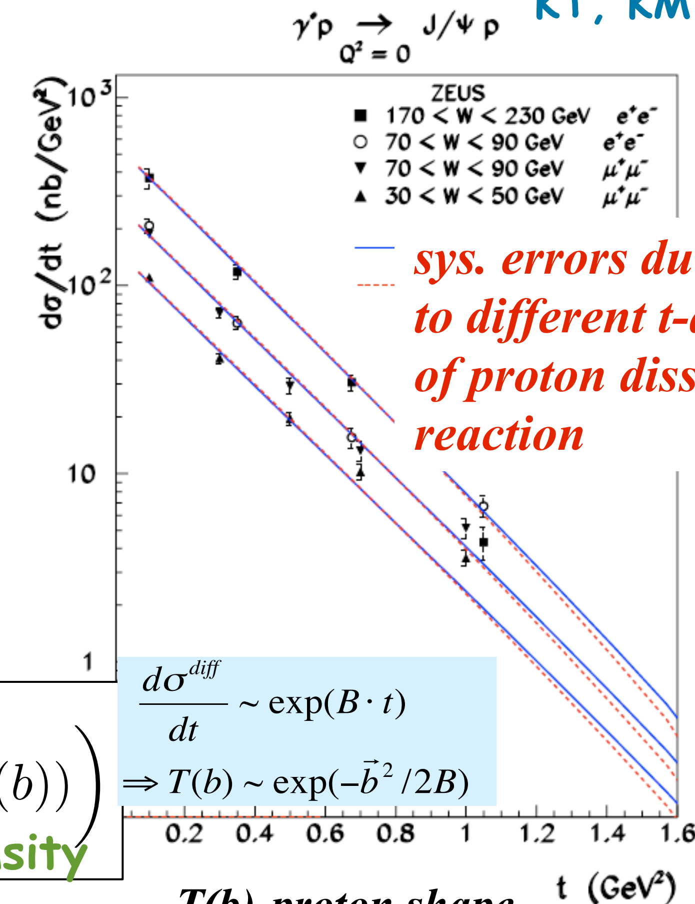
Note:
J/psi x-section grows almost like
$\sigma \propto (x\, g(x,\mu^2))^2$
no valence quarks contribution

➤ **the determination of gluon density with J/psi would be more precise than by F_2 or F_L (MRT) if J/psi would have small systematic errors**

Extracting Proton Shape using dipoles



KT, KMW



sys. errors due to different t-dep. of proton diss. reaction

$$\frac{d\sigma^{diff}}{dt} \sim \exp(B \cdot t)$$

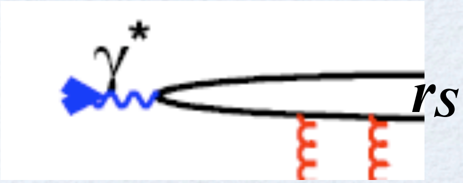
$$\Rightarrow T(b) \sim \exp(-\vec{b}^2/2B)$$

T(b)-proton shape

$$\frac{d\sigma_{qq}}{d^2b} = 2\left(1 - \exp(-\frac{\pi^2}{2N_C} r^2\,\alpha_s(\mu^2)\,xg(x,\mu^2)\,T(b))\right)$$

for larger gluon density

v.g. description of B for all VM and DVCS with the same wf ansatz
➡ determination of the gluonic proton radius, r_{gg} = 0.6 fm is smaller than the quark radius r_p=0.9 fm



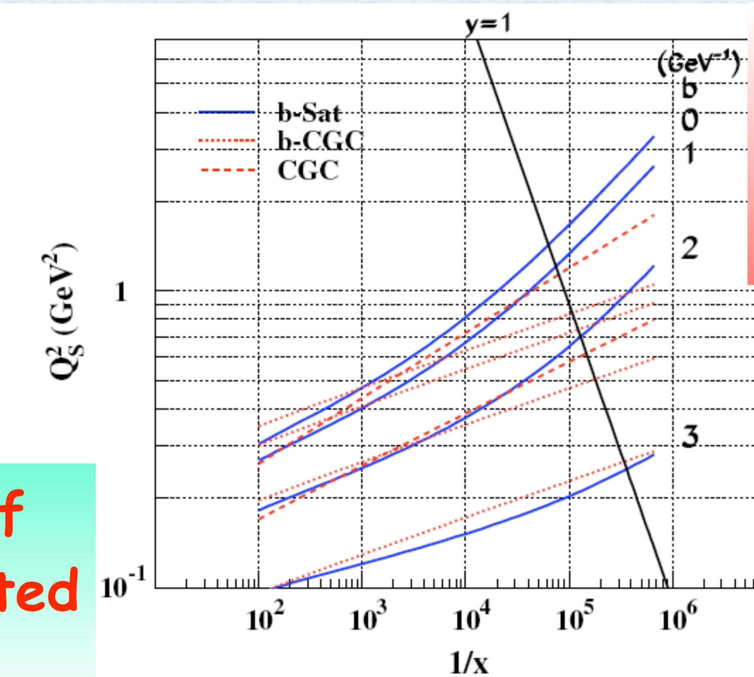
Saturation at HERA

Saturation of gluon density is characterized by the size of the dipole, r_S which, at a given x, starts to interact multiple times

$$\frac{d\sigma_{q\bar{q}}}{d^2b} = 2\left[1 - \exp\left(-\frac{\pi^2}{2N_C} r^2 \alpha_s \, xg(x,\mu^2) T(b)\right)\right] = 2(1 - \exp(-1/2))$$

Saturated gluons form a new state of matter, CGC?

$$Q_S^2 = 2/r_S^2$$



$(Q_S)^2$ =
0.5 GeV^2 at x=10^{-3}
0.8-1.8 GeV^2 at x=10^{-5}
$(Q_{S\text{-}LHC})^2$ = 9/4 $(Q_{S\text{-}HERA})^2$

$A^{1/3}$ increase of saturation expected in nuclei

strong correlations expected between momenta of saturated gluons

CMS correlation?

A Modification of the Saturation Model: DGLAP Evolution

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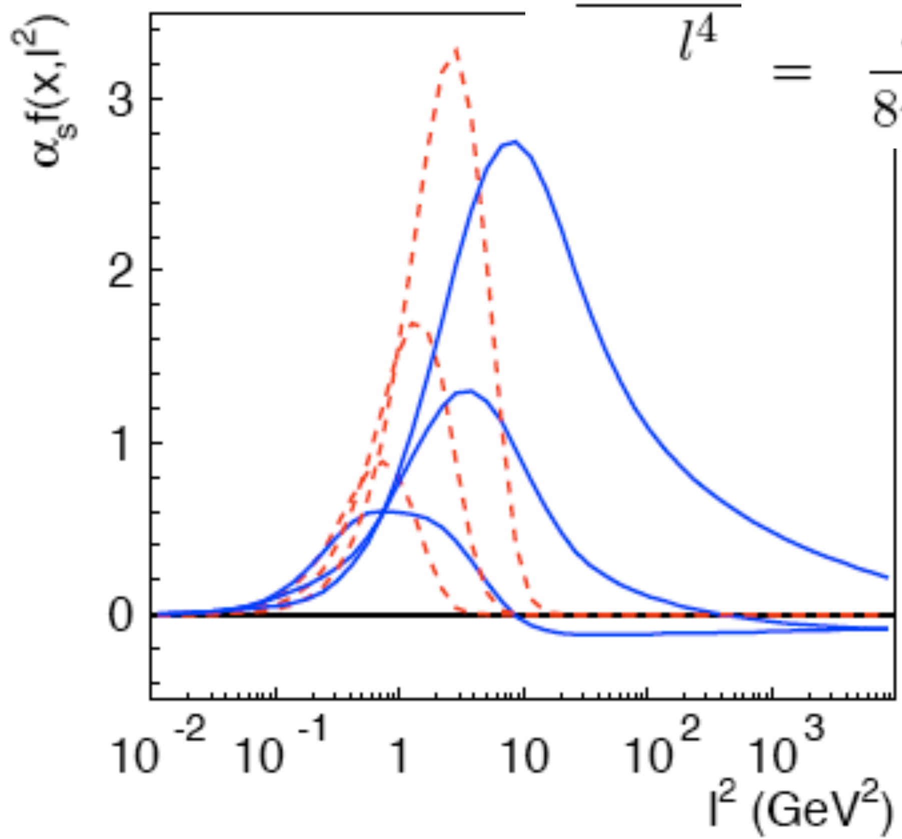
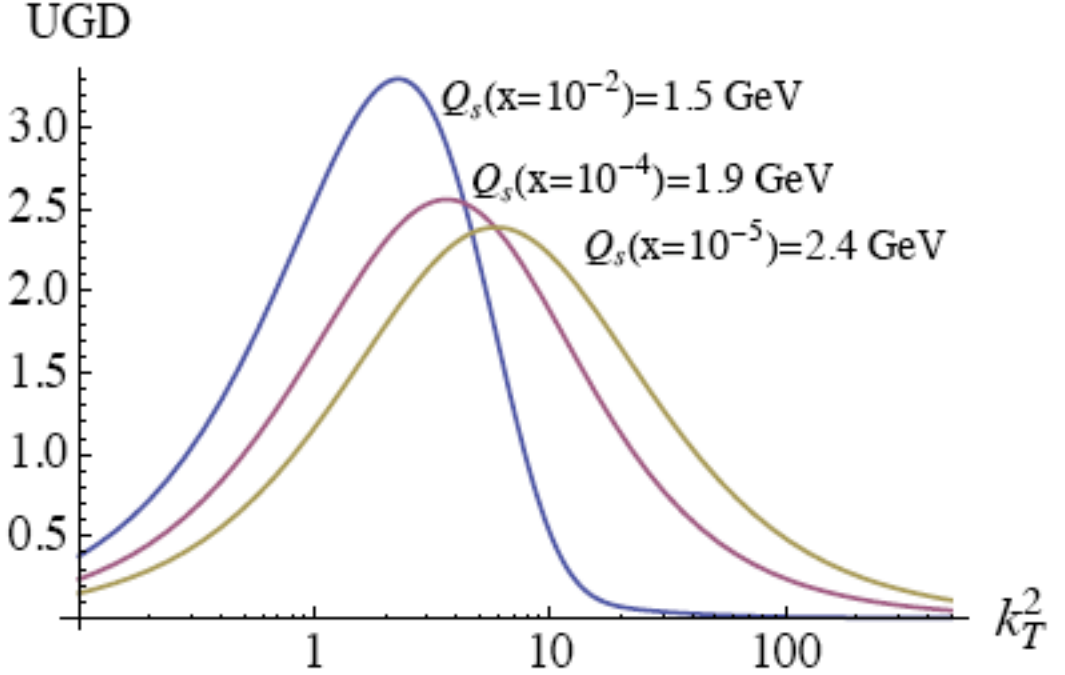
Unintegrated Gluon Distribution

$$\frac{\alpha_s\, f(x,l^2)}{l^4} = \frac{3}{8\pi^2}\int_0^\infty dr\, r\, J_0(lr)\, \{\hat\sigma_\infty(x) - \hat\sigma(x,r)\}\,.$$



The ridge in proton-proton collisions at the LHC

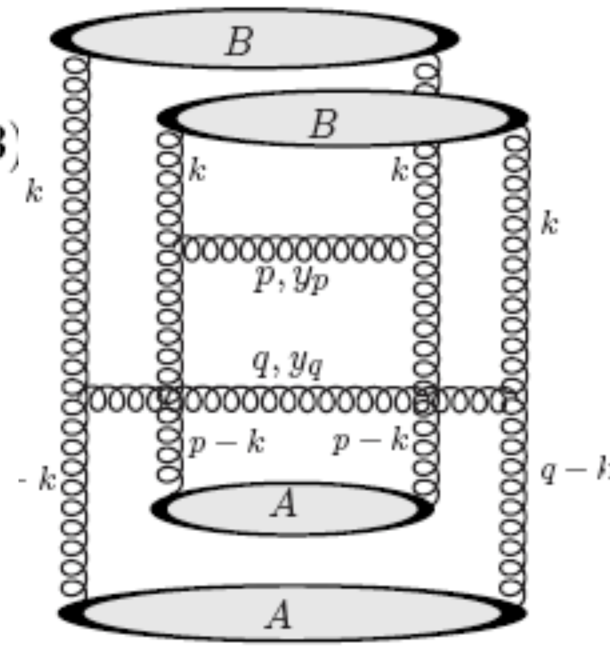
Adrian Dumitru,[1,2] Kevin Dusling,[3] François Gelis,[4]
Jamal Jalilian-Marian,[2] Tuomas Lappi,[5,6] and Raju Venugopalan[3]



Two particle correlation

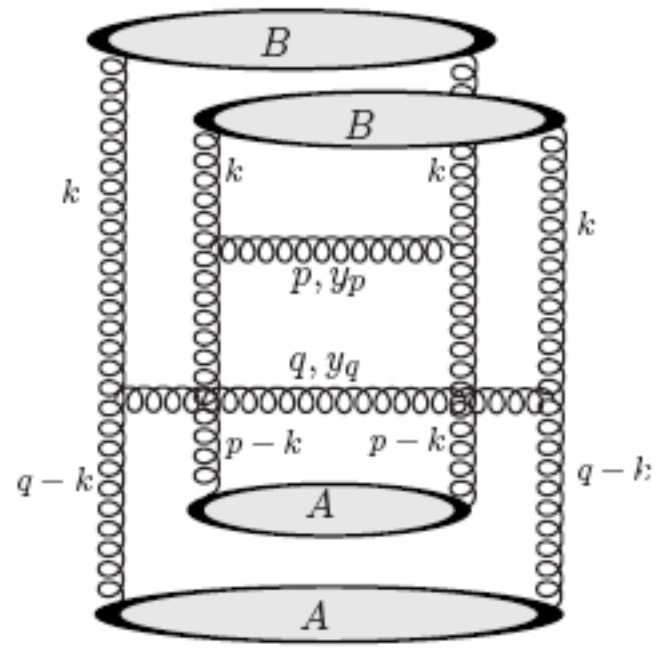
$$C_2(\mathbf{p}_\perp, y_p, \mathbf{q}_\perp, y_q) \equiv \frac{\mathrm{d}N}{\mathrm{d}y}\left[\frac{\frac{\mathrm{d}N_2}{\mathrm{d}^2\mathbf{p}_\perp \mathrm{d}y_p \mathrm{d}^2\mathbf{q}_\perp \mathrm{d}y_q}}{\frac{\mathrm{d}N}{\mathrm{d}^2\mathbf{p}_\perp \mathrm{d}y_p}\frac{\mathrm{d}N}{\mathrm{d}^2\mathbf{q}_\perp \mathrm{d}y_q}} - 1\right], \quad (2)$$

$$\frac{\mathrm{d}N_2}{\mathrm{d}^2\mathbf{p}_\perp \mathrm{d}y_p \mathrm{d}^2\mathbf{q}_\perp \mathrm{d}y_q} = \frac{\alpha_s^2}{16\pi^{10}}\frac{N_c^2 S_\perp}{(N_c^2-1)^3\,\mathbf{p}_\perp^2\mathbf{q}_\perp^2}$$
$$\times \int \mathrm{d}^2\mathbf{k}_\perp \Big\{\Phi_A^2(y_p,\mathbf{k}_\perp)\,\Phi_B(y_p,\mathbf{p}_\perp-\mathbf{k}_\perp)$$
$$\times\left[\Phi_B(y_q,\mathbf{q}_\perp+\mathbf{k}_\perp)+\Phi_B(y_q,\mathbf{q}_\perp-\mathbf{k}_\perp)\right]$$
$$+\Phi_B^2(y_q,\mathbf{k}_\perp)\,\Phi_A(y_p,\mathbf{p}_\perp-\mathbf{k}_\perp)$$
$$\times\left[\Phi_A(y_q,\mathbf{q}_\perp+\mathbf{k}_\perp)+\Phi_A(y_q,\mathbf{q}_\perp-\mathbf{k}_\perp)\right]\Big\}. \quad (3)$$



Inclusive gluon spectrum

$$\frac{\mathrm{d}N}{\mathrm{d}^2\mathbf{p}_\perp \mathrm{d}y_p} = \frac{\alpha_s N_c S_\perp}{\pi^4(N_c^2-1)}\frac{1}{\mathbf{p}_\perp^2}$$
$$\times \int \frac{\mathrm{d}^2\mathbf{k}_\perp}{(2\pi)^2}\Phi_A(y_p,\mathbf{k}_\perp)\,\Phi_B(y_p,\mathbf{p}_\perp-\mathbf{k}_\perp)\,.$$

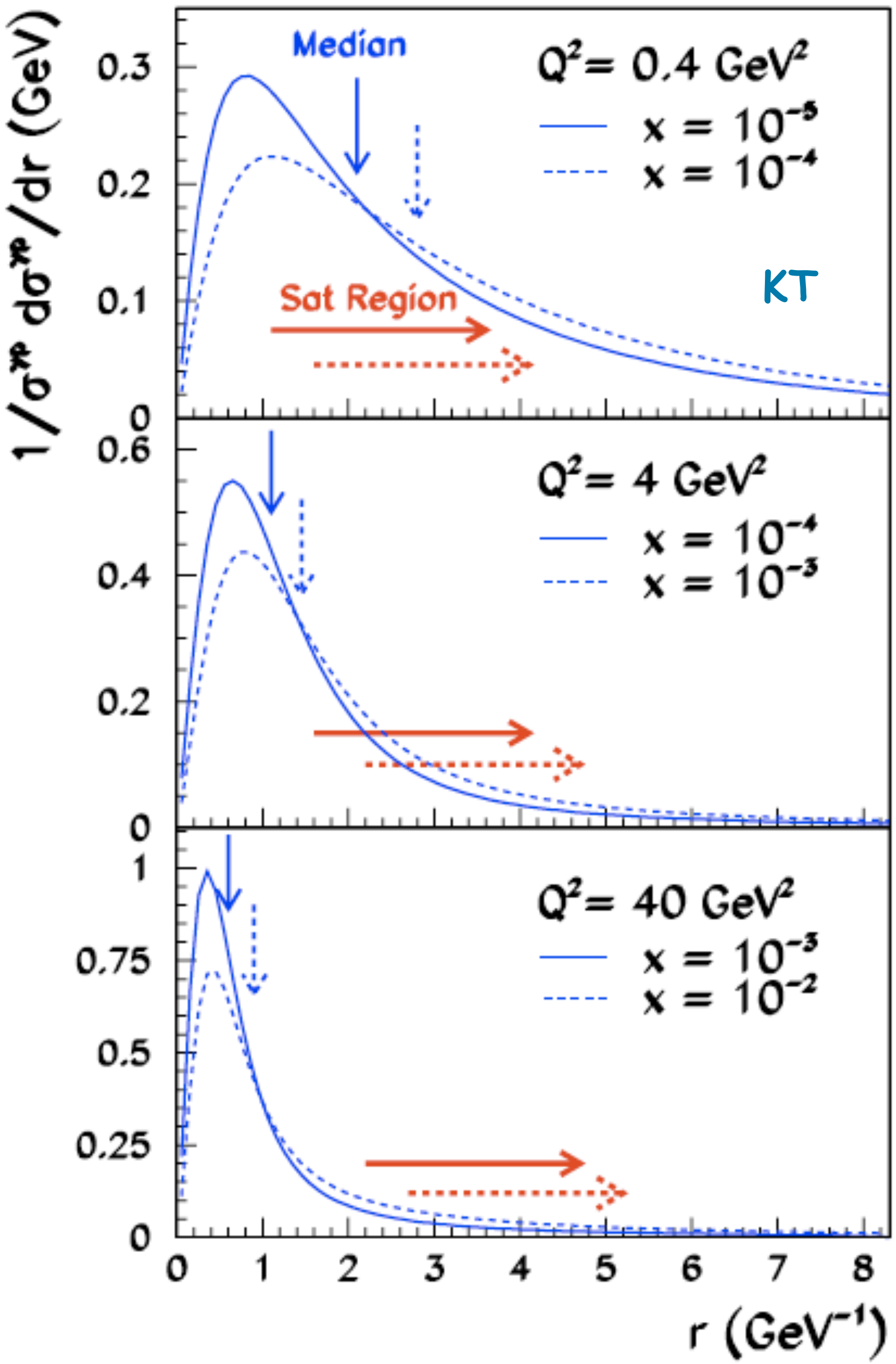


:G. 5: A typical diagram which gives an angular collimation.

$|p_T - k_T| \sim Q_S$ and $|q_T - k_T| \sim Q_S$

➔

$p_T \,||\, k_T$



Median
Q^2= 0.4 GeV^2
x = 10^{-5}
x = 10^{-4}
KT
Sat Region
Q^2= 4 GeV^2
x = 10^{-4}
x = 10^{-3}
Q^2= 40 GeV^2
x = 10^{-3}
x = 10^{-2}
$1/\sigma^{\gamma p}\, d\sigma^{\gamma p}/dr$ (GeV)
r (GeV^{-1})
0.3
0.2
0.1
0
0.6
0.4
0.2
0
1
0.75
0.5
0.25
0
0
1
2
3
4
5
6
7
8

Multiple Interactions in DIS

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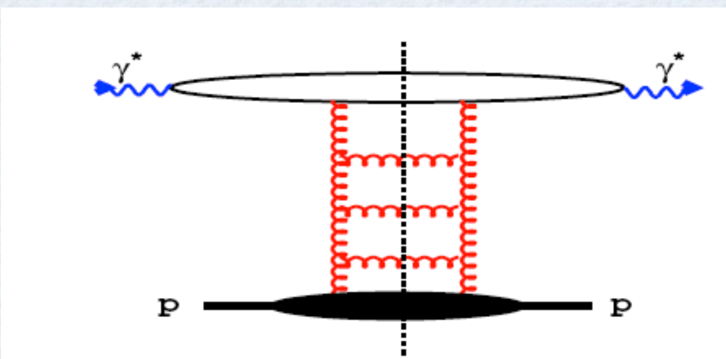
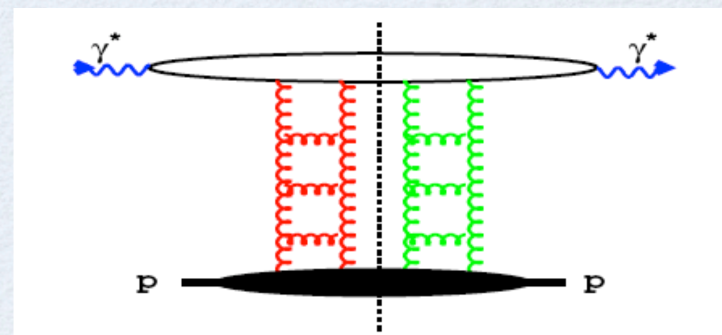
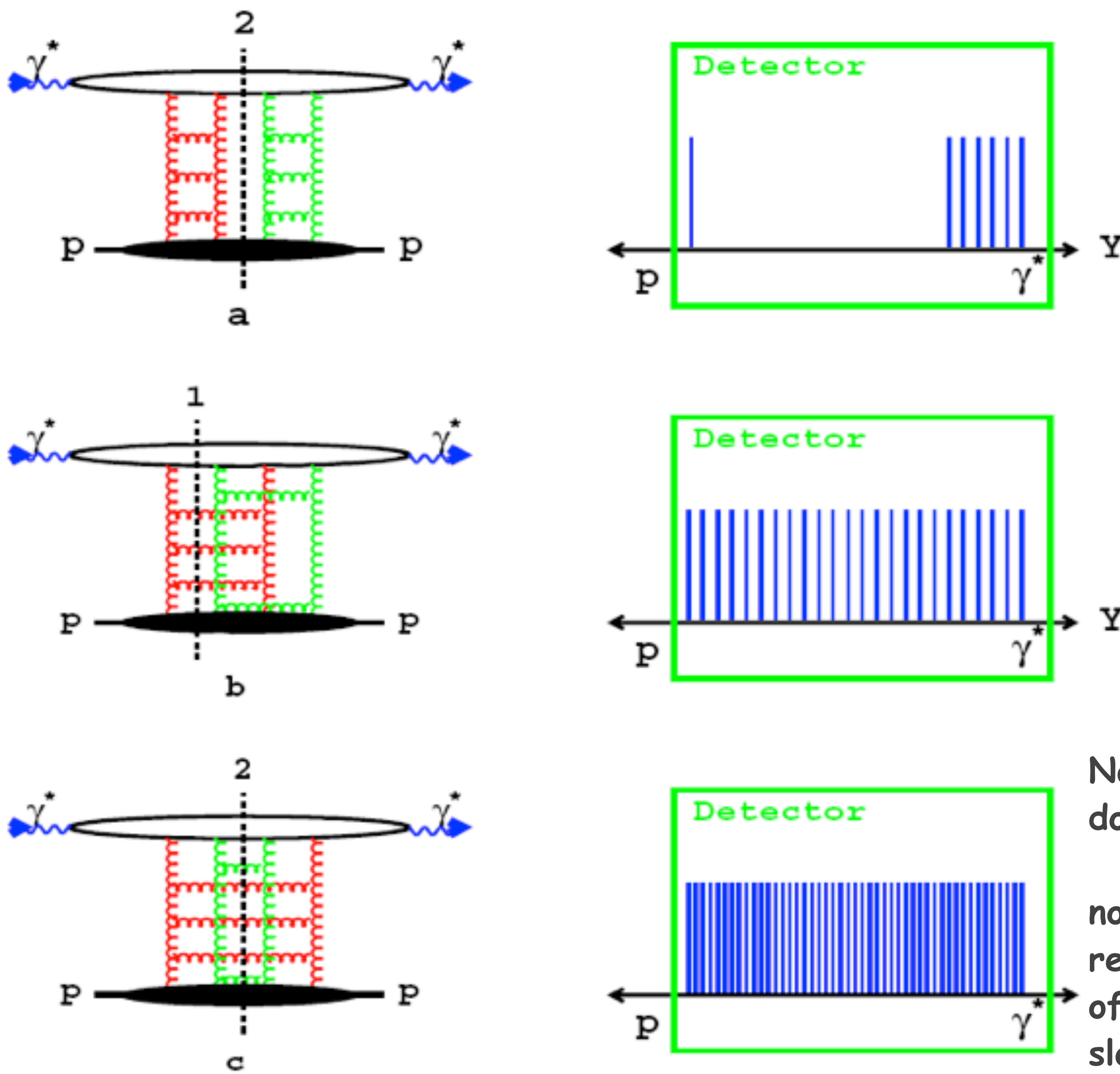
published in proceedings of the HERA-LHC Workshop





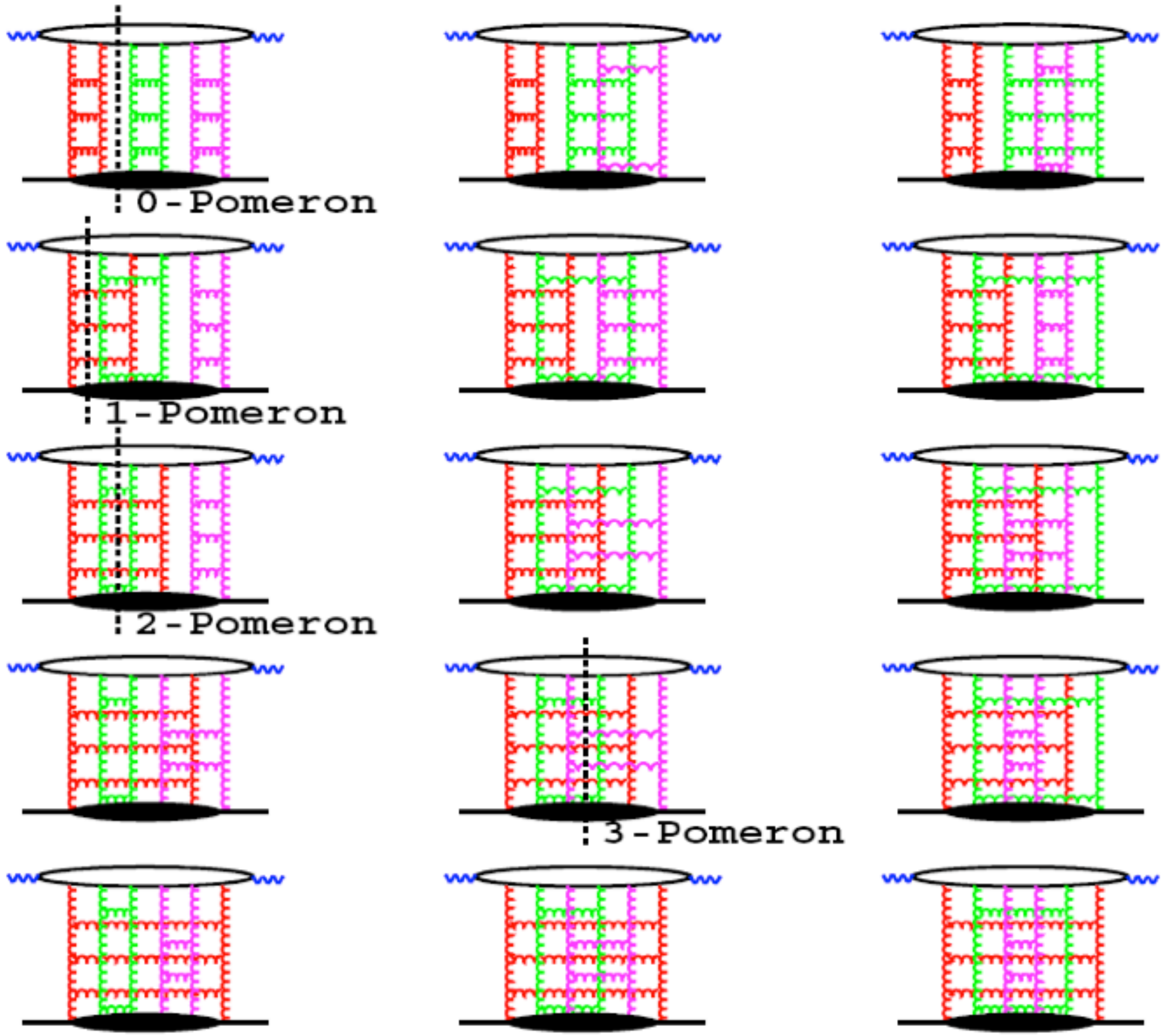
$$\sigma_{\gamma^* p} = \frac{1}{W^2} Im\, A_{\gamma^* p \to \gamma^* p}(W^2, t=0).$$



Naive expectaction: doubling of multiplicity

not happening in reality - the increase of multiplicity is slower than the increase of F2

Fig. 4: *Three examples of 2-ladder contributions (lhs), with the corresponding, schematical, detector signatures (rhs). Top row: the diagram (a) with the cut positions (2) describes diffractive scattering.* Middle row: *the diagram (b) with the cut position (1) describes inclusive final states with single densityof cut partons.* Bottom row: *the diagram (c) with the cut position (2) describes inclusive final states with increased multiplicity.*


0-Pomeron
1-Pomeron
2-Pomeron
3-Pomeron

AGK cutting rules

X-section for observing a final state with k-cut pomerons, σ_k with the amplitude for exchange of m pomerons, $F^{(m)}$

$$\frac{d\sigma_{qq}}{d^2b} = 2\sum_{m=1}^{\infty}(-1)^{m-1}\,F^{(m)}$$

$$\sigma_k = \sum_{m=k}^{\infty}(-1)^{m-k}\,2^m\,\frac{m!}{k!(m-k)!}F^{(m)}.$$

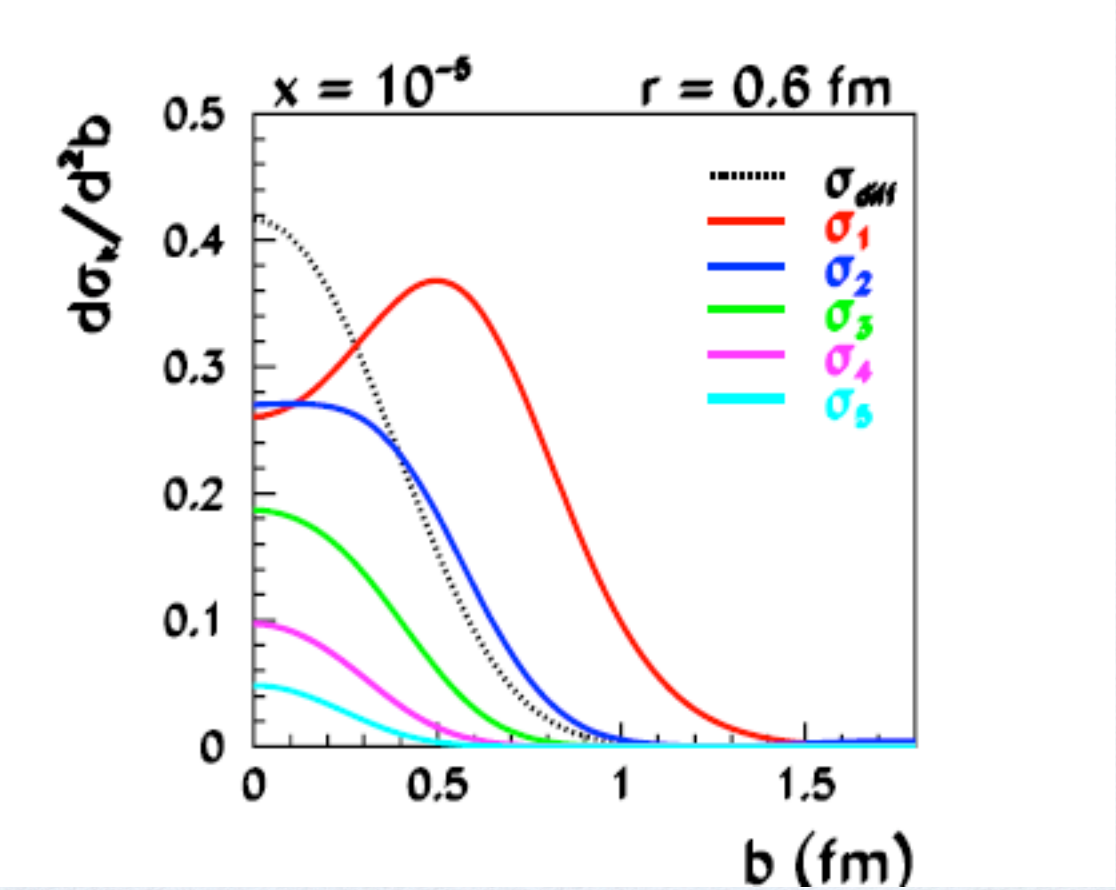
$$\frac{d\sigma_{qq}}{d^2b} = 2\left(1-\exp(-\frac{\Omega}{2})\right).$$

$$\Omega = \frac{\pi^2}{N_C}\,r^2\,\alpha_s(\mu^2)\,xg(x,\mu^2)\,T(b)$$

$$\frac{d\sigma_{qq}}{d^2b} = 2\left(1-\exp(-\frac{\Omega}{2})\right) = 2\sum_{m=1}^{\infty}(-1)^{m-1}\left(\frac{\Omega}{2}\right)^m\frac{1}{m!}$$

$$F^{(m)} = \left(\frac{\Omega}{2}\right)^m\frac{1}{m!},$$

$$\frac{d\sigma_k}{d^2b} = \frac{\Omega^k}{k!} \exp(-\Omega)$$



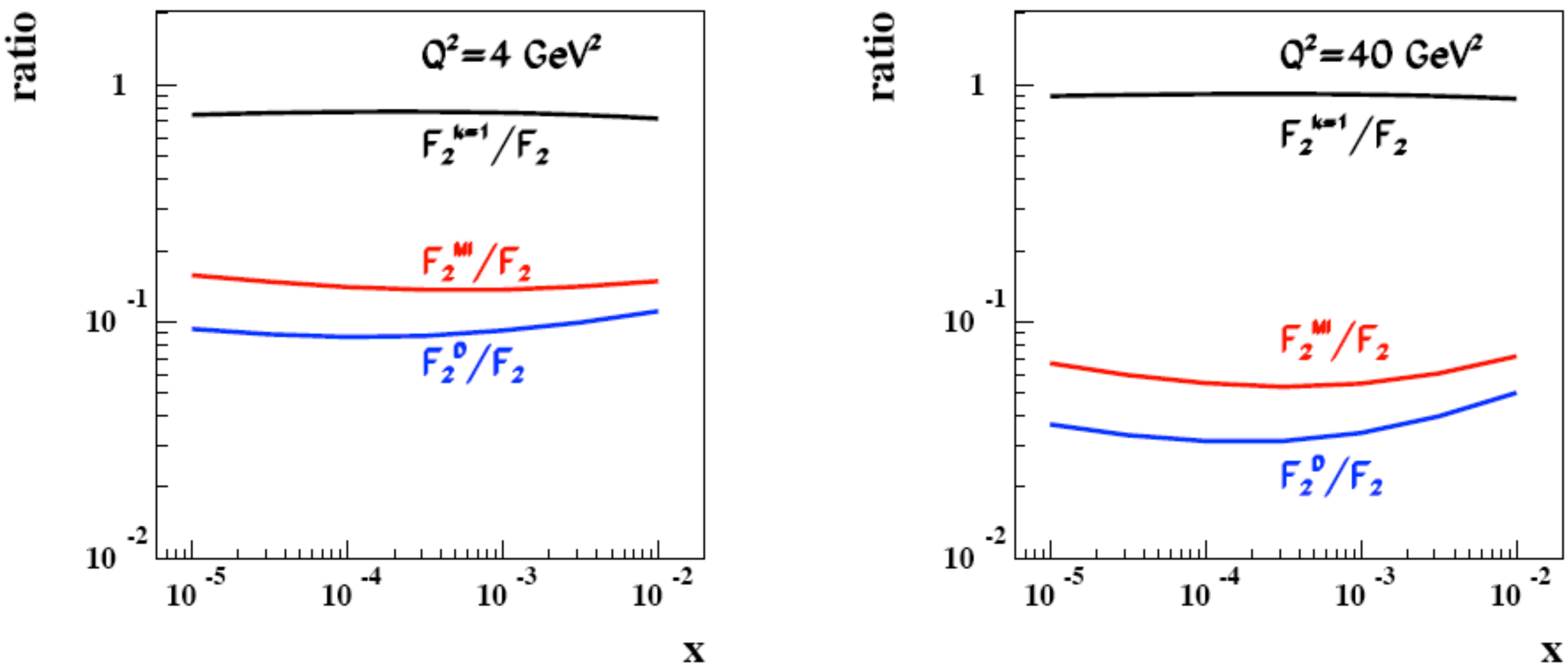
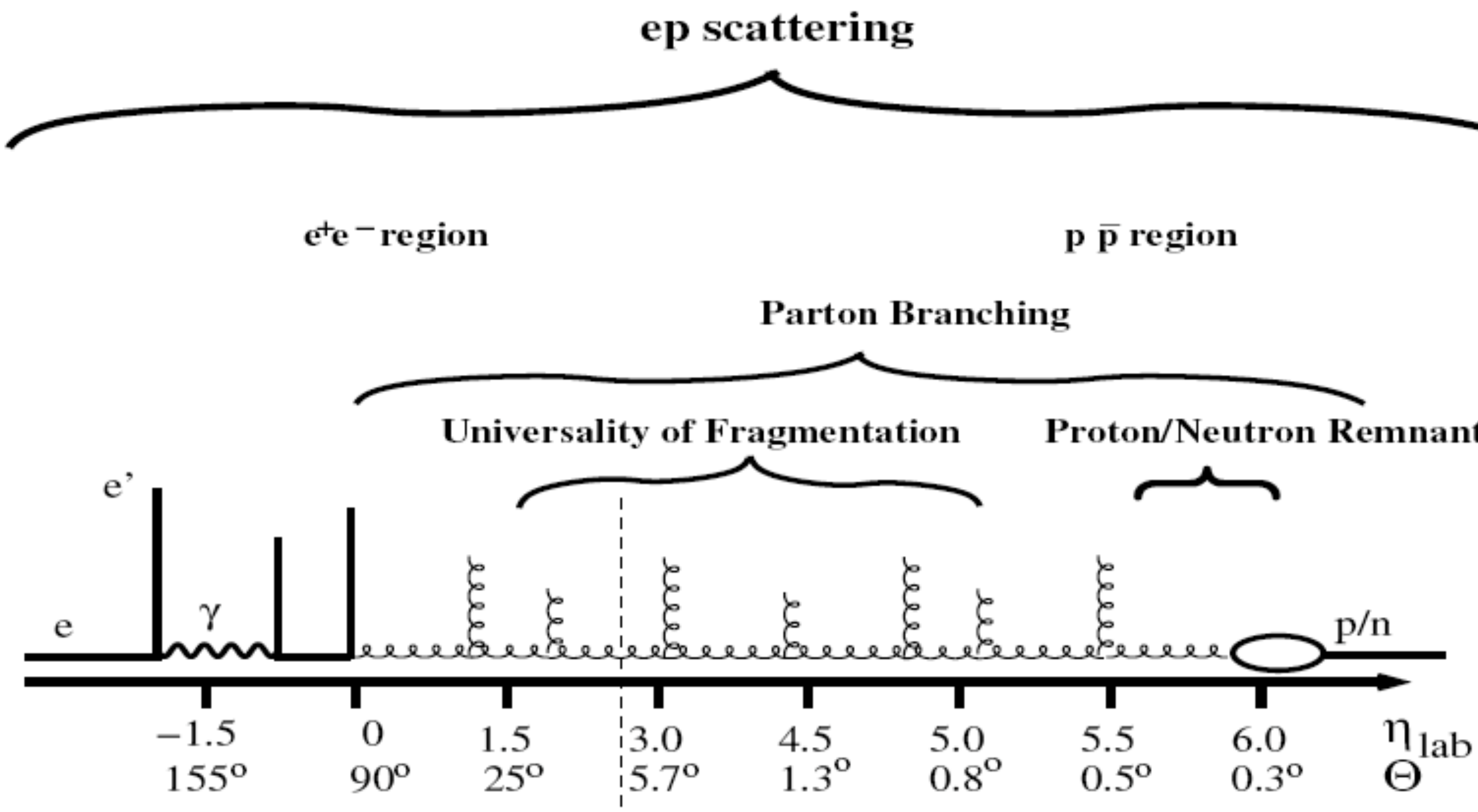


Fig. 10: *Fractions of single (k=1), multiple interaction (MI) and diffraction (D) in DIS*

Forward correlations



ZEUS & H1 ⇐ improved acceptance

CMS correlation ?