Saturation model in diffraction

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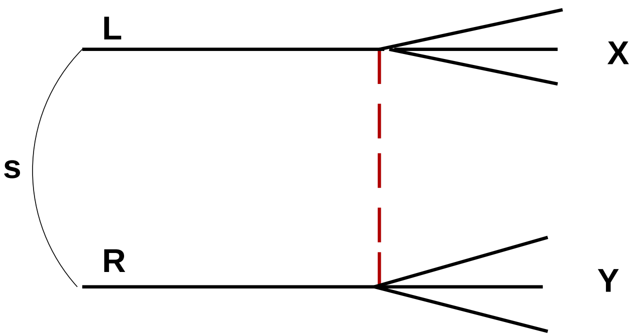
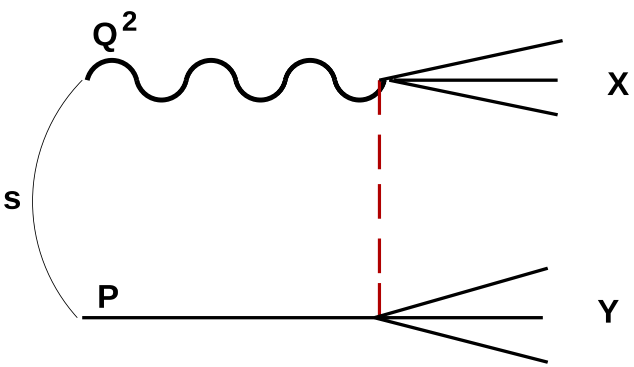
Diffractive processes



- $s \gg -t,\, m_X^2,\, m_Y^2$
- vacuum quantum number exchange
- QCD: two gluons in color singlet state

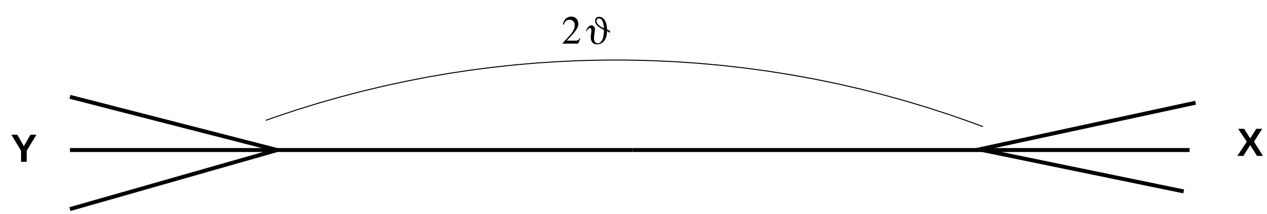


- DIS: $s \gg Q^2 \gg \Lambda_{QCD}^2,\, -t,\, m_p^2$
- semihard processes: $x = Q^2/s \ll 1$
- perturbative QCD applicable

Soft and hard diffraction

Two basic features of diffraction:

- rising cross sections with energy s
- large rapidity gaps: $\eta = -\log\tan(\theta/2)$ (color singlet exchange)



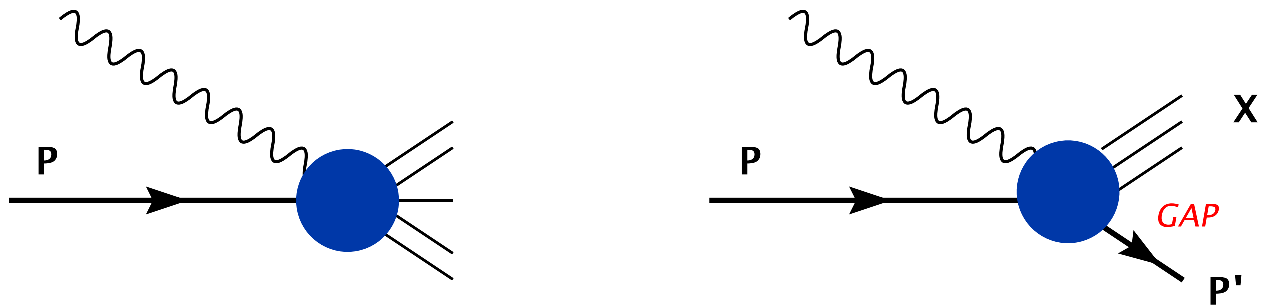
- Soft diffraction (no hard scale): $\sigma \sim s^{\alpha_P(0)}$ $\alpha_P(t) = 1.08 + 0.25 \cdot t$

$$pp \to p + p \qquad \gamma p \to V(\rho, \omega, \phi) + p$$

- Hard diffraction (with hard scale): $1.1 < \alpha_P(0) < 1.4$

$$pp \to jj + pp \qquad \gamma^* p \to X + p \qquad \gamma^* p \to V + p \qquad \gamma p \to J/\psi + p$$

Deep inelastic scattering



- Infinite momentum frame ($P \to \infty$):

  pointlike γ^* resolves partonic constituents of the proton

- Proton rest frame ($P \approx 0$):

  γ^* develops partonic fluctuations long before the proton target

Coherence length: $l_c = \frac{1}{m_p x} \gg \frac{1}{m_p} \approx 0.2 \;\; \mathrm{fm}$

Dipole states

- Hadron wave function in light-cone quantization approach

$$|\Psi\rangle = \sum \Psi_n \, |n\rangle \qquad\qquad |n\rangle = |z_1 \ldots z_n; \, k_{T1} \ldots k_{Tn}\rangle$$

$|n\rangle$ are partonic states – eigenstates of free Hamiltonian

- Eigenstates of diffraction are Fourier transformed partonic states with transverse positions

$$|z_1 \ldots z_n; \, k_{T1} \ldots k_{Tn}\rangle \;\; \rightarrow \;\; |z_1 \ldots z_n; \, \vec{r}_1 \ldots \vec{r}_n\rangle$$

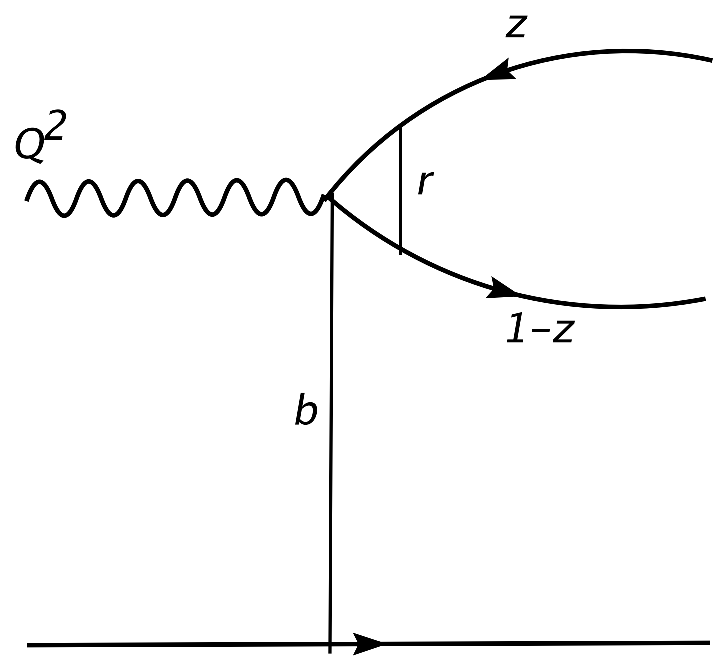
- Virtual photon wave function

$$|\gamma^*\rangle = \sum \, \Psi_{q\bar{q}} \, |q\bar{q}\rangle + \sum \, \Psi_{q\bar{q}g} \, |q\bar{q}g\rangle + \ldots$$

$q\bar{q}$ dipole of size $\vec{r} = \vec{r}_1 - \vec{r}_2$ at impact parameter $\vec{b} = (\vec{r}_1 + \vec{r}_2)/2$.

$q\bar{q}$ dipole

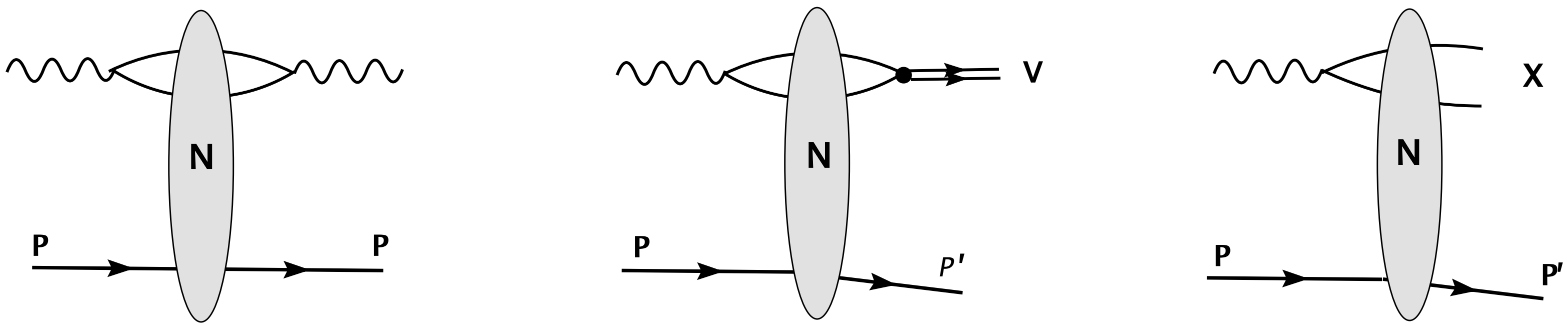
- the lowest component



- light-cone photon wave function: $\Psi^{\lambda}_{h,h'}(r, z, Q^2)$, known from QED
- dipole states are eigenstates of scattering operator
- $\vec{r}$ and z are conserved in the high energy scattering

Color dipole models

Universal description in the leading order in $\log(s)$ *(N. N. Nikolaev, B. G. Zakharov)*



- Scattering amplitude $(A = \gamma^*, \gamma, V)$

$$\mathcal{A}(\gamma^* + p \rightarrow A + p) = \int d^2r dz\, \Psi_A^*\, N_{q\bar{q}}\, \Psi_\gamma$$

- $N_{q\bar{q}}(r, b, Y = \ln(1/x))$ is the dipole scattering amplitude

- Find $N_{q\bar{q}}$ from

$$\sigma_{tot} \sim \mathrm{Im}\, \mathcal{A}(\gamma^* + p \rightarrow \gamma^* + p)$$

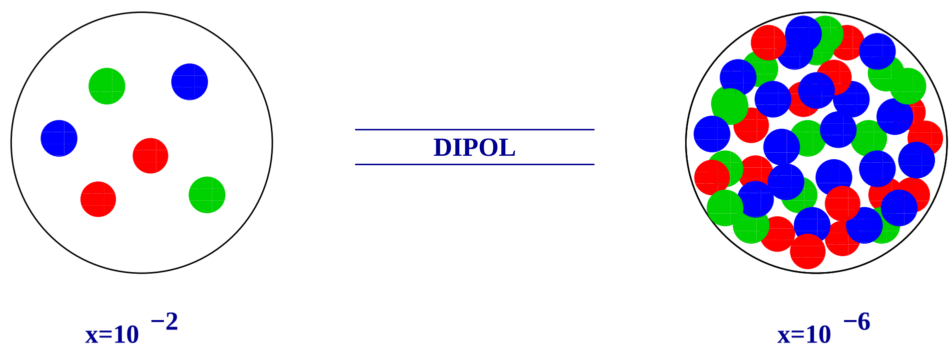
and test in DDIS processes.

Phenomenological parameterizations

- GB–Wüsthoff parameterization with saturation scale $Q_s(x) = Q_0 x^{-\lambda}$

$$N_{q\bar{q}}(r, b, x) \;=\; \theta(b < b_0)\left(1 - \mathrm{e}^{-r^2 Q_s^2(x)}\right)$$

- idea of parton saturation

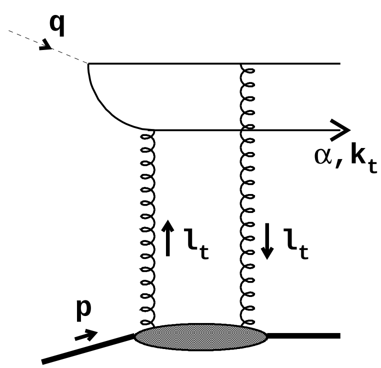


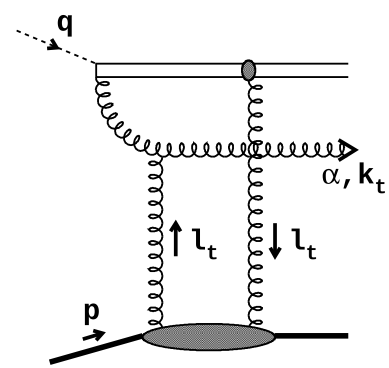
- unitarity fulfilled: $N_{q\bar{q}}(b) \leq 1$

- geometric scaling: $N_{q\bar{q}}(rQ_s(x), b)$

DIS diffraction and saturation

- Parameters b_0, λ, Q_0 from $\sigma_{tot} \sim F_2$
- Successful description of DDIS with two component diffractive state



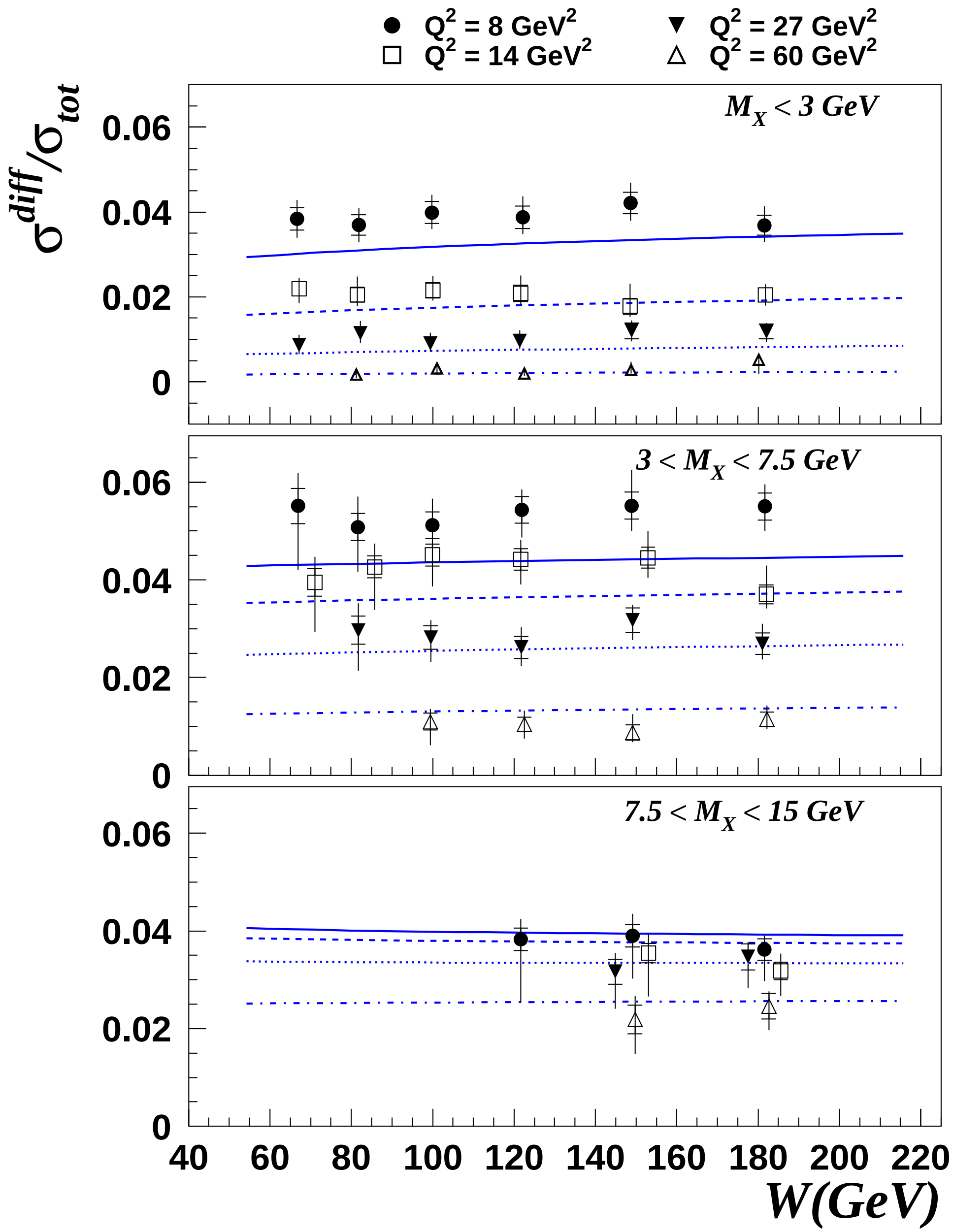


- The only approach which explains constant ratio with energy

$$\frac{\sigma_{diff}}{\sigma_{tot}} \sim \frac{1}{\log(Q^2/Q_s^2(x))}$$

DDIS sensitive to semihard dipoles: $r \sim 1/Q_s$

Constant ratio



Important improvements

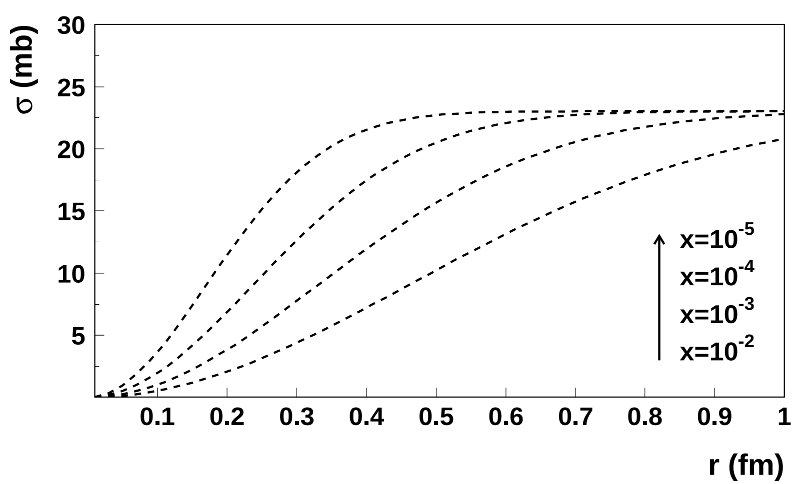
- Small dipole corrections – to match perturbative QCD results
  (Frankfurt, Strikman, McDermott, Bartels, GB, Kowalski, Iancu, Itakura, Munier)

$$N_{q\bar{q}}(r,b,x) \sim r^2\,\alpha_s\,G(x,1/r^2)\,T(b)$$

- Realistic b-profile – t-dependence of exclusive diffractive processes
  (Kowalski, Teaney, Motyka, Watt)

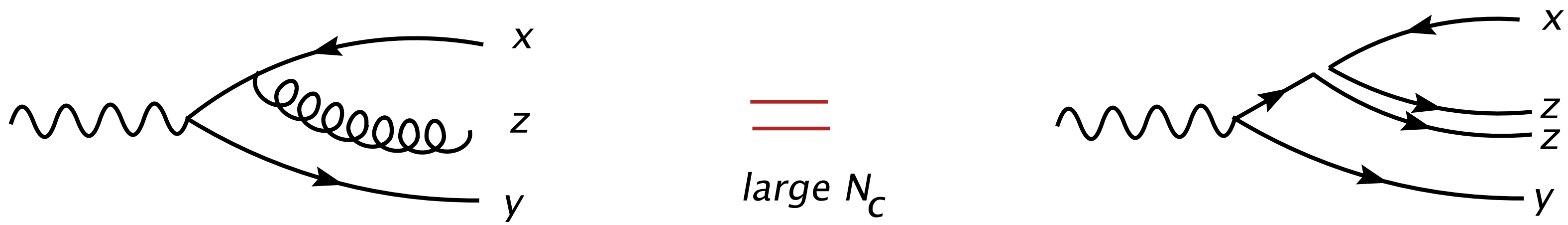
$$T(b) = \exp(-b^2/2B) \qquad\qquad Q_s(x,b) = Q_0\,x^{-\lambda}\,T(b)$$

- Theoretical justification?



Dipole evolution

- Soft gluon emissions with $z_g \ll z_q$



- Splitting probablity $(xy) \to (xz) + (zy)$

$$\frac{dP}{dY} = \frac{N_c \alpha_s}{2\pi^2} \frac{(\vec{x}-\vec{y})^2}{(\vec{x}-\vec{z})^2 (\vec{z}-\vec{y})^2} \, d^2z \equiv K(x,y,z) \, d^2z$$

- Classical branching process *(A. H. Mueller)*

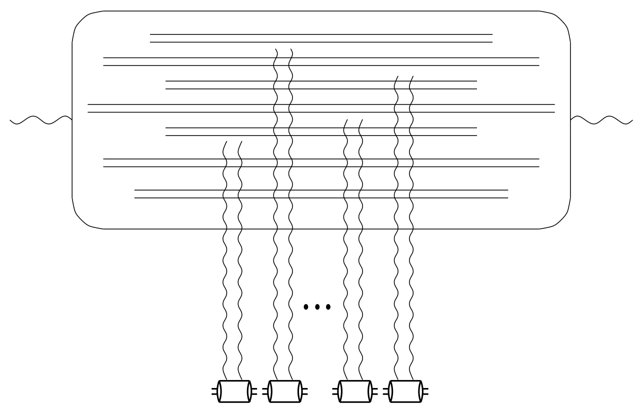
$$\frac{dZ(x,y;u)}{dY} = \int d^2z \, K(x,y,z) \, \{ Z(x,z;u) \, Z(z,y;u) \; - \; Z(x,y;u) \}$$

Multi-dipole distributions: $\quad n_k = \delta^k Z / \delta u^k \big|_{u=0} \qquad k = 1, 2, \ldots$

Balitsky-Kovchegov evolution equation

- BFKL growth of dipole density: $n_1 \sim \mathrm{e}^{4\ln 2\,\bar{\alpha}_s Y}$. Unitarity violated?
- No, if simultaneous, uncorrelated scattering of several dipoles

$$N_{q\bar{q}} = (-\gamma)\,n_1 + (-\gamma)^2\,n_2 + (-\gamma)^3\,n_3 + \ldots$$



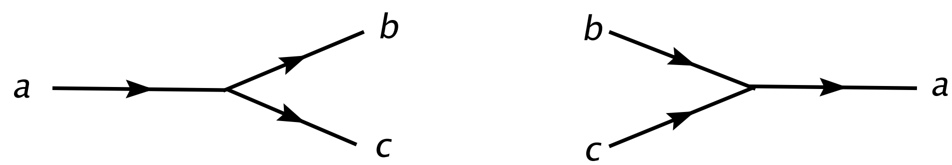
- Nonlinear equation justified in case of $\gamma^* A$ scattering ($S = 1 - N_{q\bar{q}}$)

$$\frac{\partial S(x,y)}{\partial Y} = \int d^2z\, K(x,y,z)\,\{S(x,z)\,S(z,y) - S(x,y)\}$$

- Local unitarity: $S(b) \leq 1$.
- Global unitarity: Froissart bound violated.

Parton saturation

- No saturation in dipole number density in BK equation.
- Missing dipole merging: $2 \rightarrow 1$ (Pomeron loops)



- Necessary for symmetric description in pp scattering.

Summary of studies:

- Lot of efforts in Color Glass Condensate approach.
- Negative transition probabilities prevent probabilistic formulation in terms of color dipoles only.
- Formation of color quadrupols and higher multipoles.
- More intuitive approach ?

Dipole swing

(E. Avsar, G. Gustafson, L. Lönnblad)

- Scattering of two dipoles with the same color – change of color flow

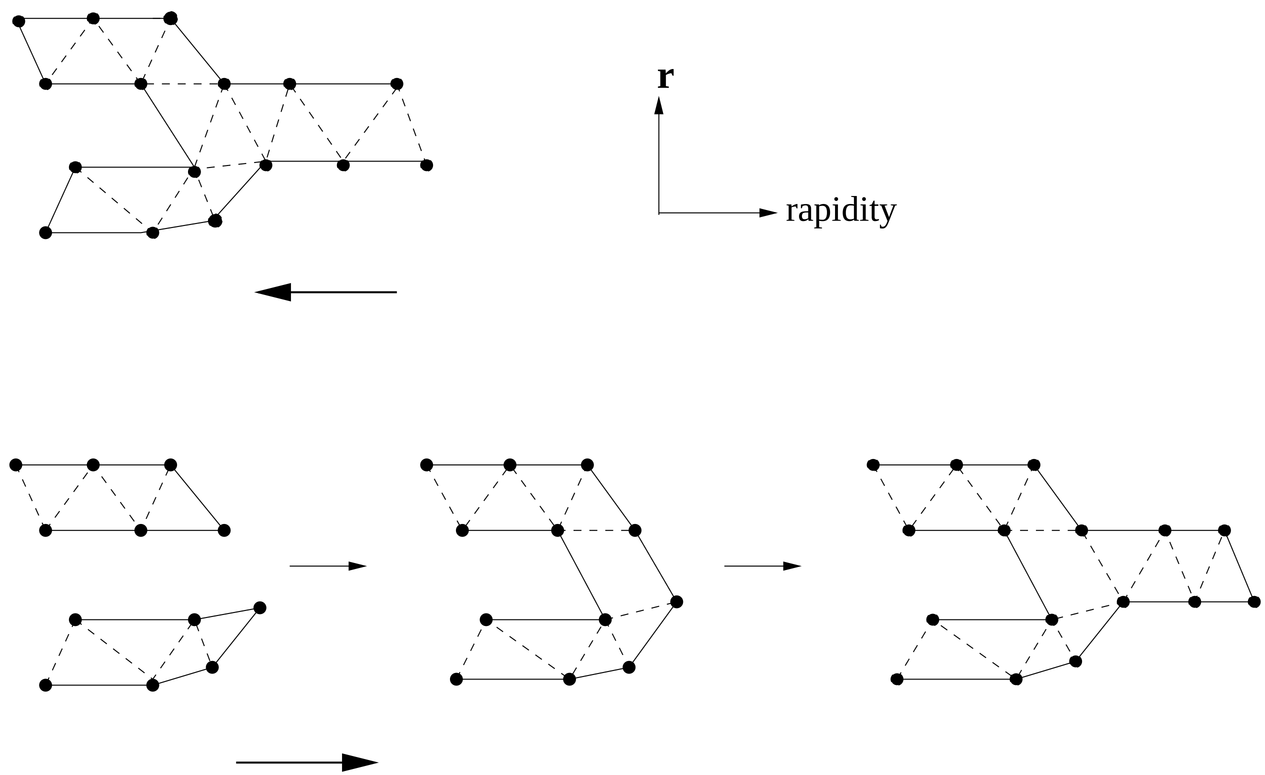
- Weight prefers the formation of smaller dipoles.

$$\frac{(x_1 - y_1)^2 (x_2 - y_2)^2}{(x_1 - y_2)^2 (x_2 - y_1)^2}$$

- Smaller dipoles have smaller cross sections.
- Suppression of the total cross section due to dipole swing.

Dipole chain scattering

- Dipole chain splittings and mergings



- Monte Carlo implementation.

Diffraction in pp scattering

- Good-Walker picture with dipole states as eigenstates of diffraction

$$|\psi_I\rangle = |L,R\rangle = \sum_{n,m} c_n^L\, c_m^R\; |n,m\rangle$$

- The scattered state

$$|\psi_S\rangle = \mathrm{Im}\ \mathrm{T}\ |\psi_I\rangle = \sum_{n,m} c_n^L\, c_m^R\, t_{nm}\ |n,m\rangle$$

- Diffractive cross section (measure of fluctuations)

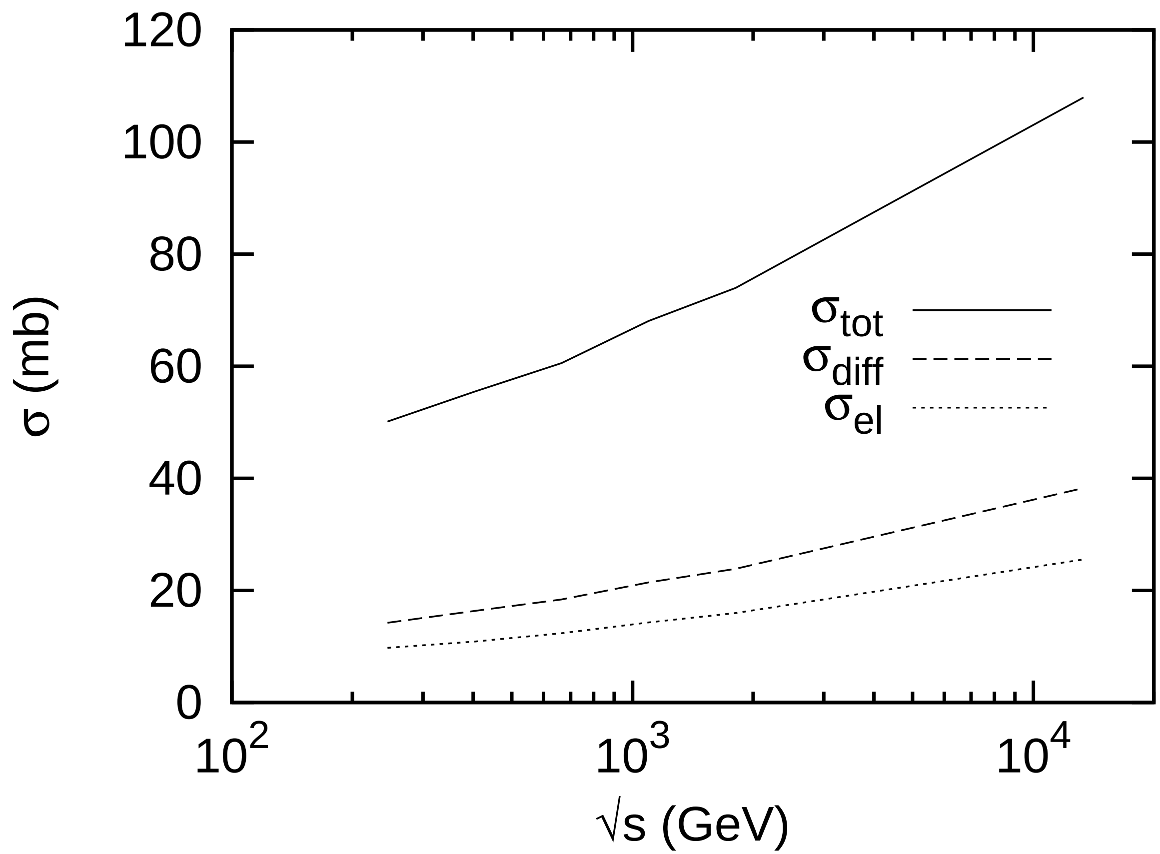
$$\frac{d\sigma_{diff}}{d^2b} = \langle\psi_S|\psi_S\rangle = \sum_{n,m} P_n^L\, P_m^R\, t_{nm}^2$$

- Eikonal form of the scattering ampliudes

$$t_{nm} = 1 - \mathrm{e}^{-F_{nm}} \qquad\qquad F_{nm} = \sum_{i\in n, j\in m} F_{ij}$$

Predictions for the LHC

(E. Avsar, G. Gustafson, L. Lönnblad, 0709.1368 [hep-ph])



- $\sigma_{tot} = 108 \text{ mb} \qquad \sigma_{el} = 26 \text{ mb} \qquad \sigma_{diff} = 12 \text{ mb}$

Conclusions

- Saturation models are very successful in describing diffractive data in ep scattering.
- Dipole approach with saturation can be applied to diffractive pp scattering.
- Let’s listen and discuss.