Small-x Physics and an Improved Dipole Model

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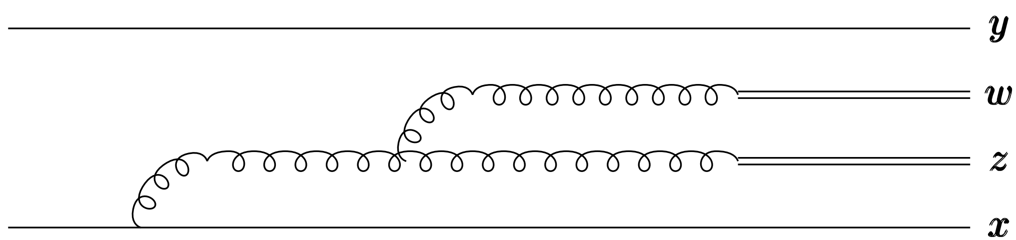
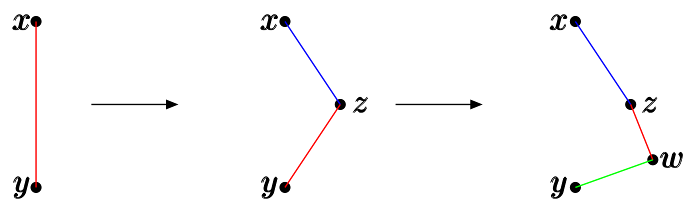
Outline

- Mueller's Dipole Model.
- Improving the Dipole Model.
- HERA Phenomenology.
- Some predicitons.
- Summary and Conclusions.

Mueller's Dipole Model





- Decay probability given by

$$\frac{d\mathcal{P}}{dY} = \frac{\bar{\alpha}}{2\pi}\frac{(\boldsymbol{x}-\boldsymbol{y})^2}{(\boldsymbol{x}-\boldsymbol{z})^2(\boldsymbol{z}-\boldsymbol{y})^2}d^2\boldsymbol{z}$$

$$\bar{\alpha} = \frac{\alpha_s N_c}{\pi}, \quad Y = \ln 1/x$$

Energy-Momentum Conservation

- $d\mathcal{P}/dY \to \infty$ as $(\boldsymbol{x}-\boldsymbol{z})^2$ or $(\boldsymbol{z}-\boldsymbol{y})^2 \to 0$. Must be screened by a cutoff.
- Small dipoles interact weakly $\Rightarrow$ cascade contains many noninteracting virtual dipoles.
- Dipole size $r \sim 1/k_\perp \Rightarrow$ Constraint from energy conservation. Evolution similar to LDC model.
- Large effects on the evolution, JHEP 0507:062, hep-ph/0503181.

Multiple Interactions

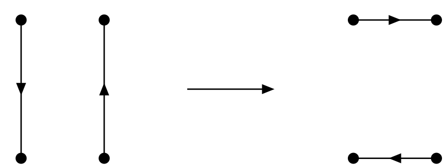
- In Mueller's model all dipoles interact independently via two gluon exchange.

$$f_{ij} = f(\boldsymbol{x}_i, \boldsymbol{y}_i | \boldsymbol{x}_j, \boldsymbol{y}_j) = \frac{\alpha_s^2}{8}\left[\log\left(\frac{(\boldsymbol{x}_i - \boldsymbol{y}_j)^2(\boldsymbol{y}_i - \boldsymbol{x}_j)^2}{(\boldsymbol{x}_i - \boldsymbol{x}_j)^2(\boldsymbol{y}_i - \boldsymbol{y}_j)^2}\right)\right]^2.$$

- Multiple scattering series can be summed in eikonal approximation.
- $\Rightarrow$ Unitarised formula for amplitude, $T = 1 - \text{exp}(-\sum_{ij} f_{ij})$.
- Multiple scatterings $\Rightarrow$ pomeron loops.

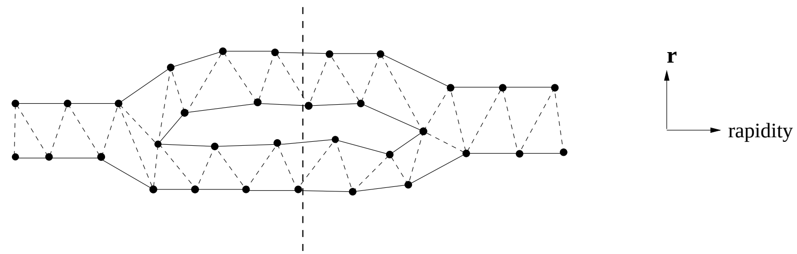
Saturation and Frame Independence

- Mueller's cascade include saturation effects only from multiple collisions. No loops in cascade evolution.
- $\Rightarrow$ formalism not frame independent.
- Need colour suppressed effects also during evolution.
- Dipole swing: $2 \to 2$ transition.

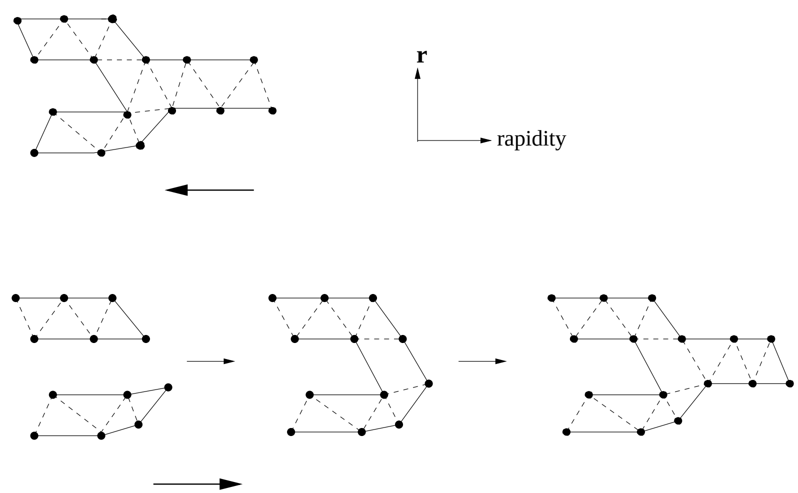


- Gives almost frame independent formalism. hep-ph/0610157, JHEP 01(2007)012.

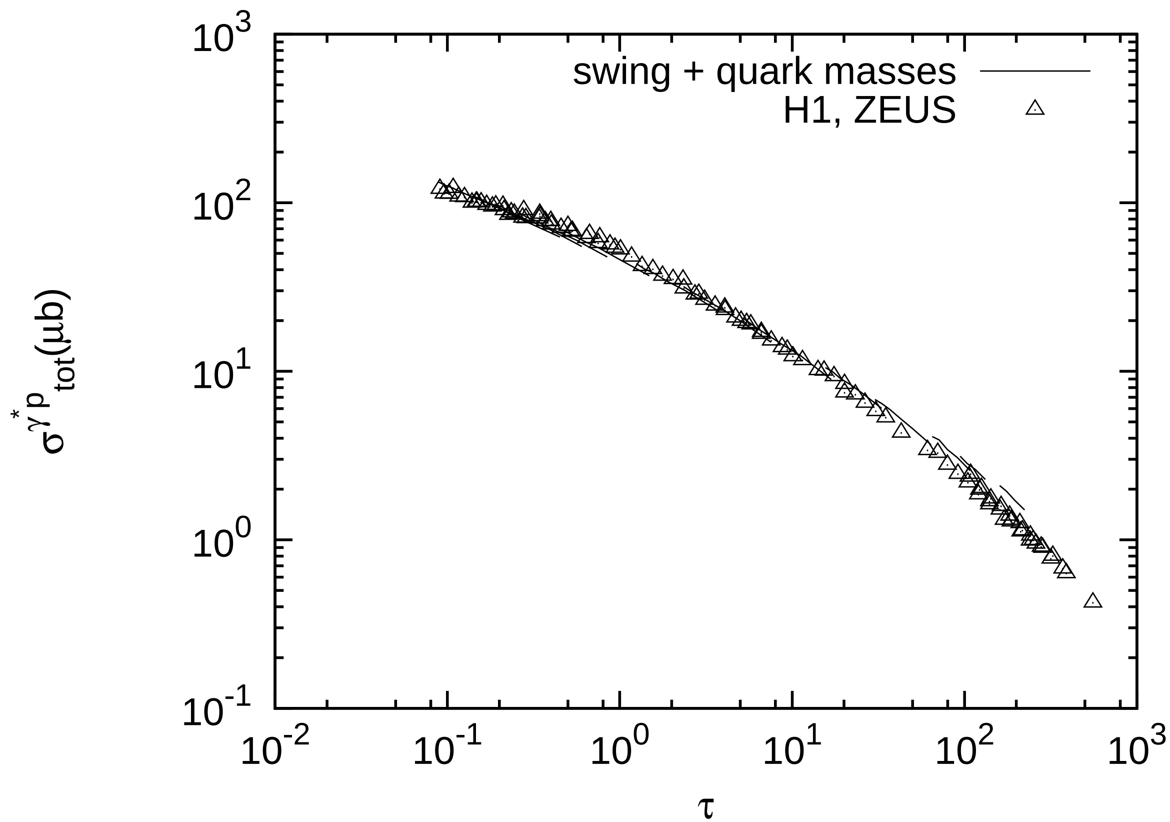
Generating the Loops



- Loops can be generated by $1 \to 2$ splitting $+2 \to 2$ “swing”.

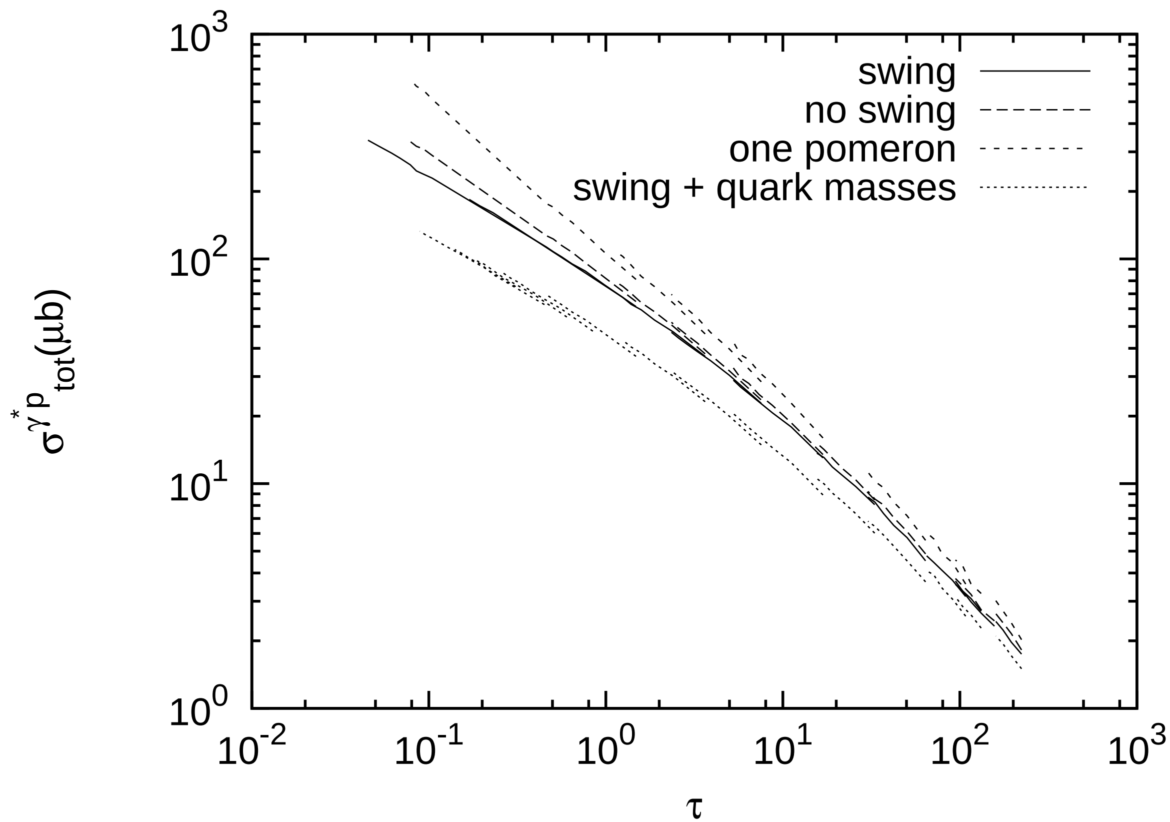


Full Results



- $\tau \equiv Q^2/Q_s^2(x)$, $Q_s^2(x) = (x_0/x)^{0.3}$, $x_0 = 3 \cdot 10^{-4}$. Effective light quark mass $=$ 60MeV and $m_c =$1.4GeV.

Effects of Saturation and Charm Mass

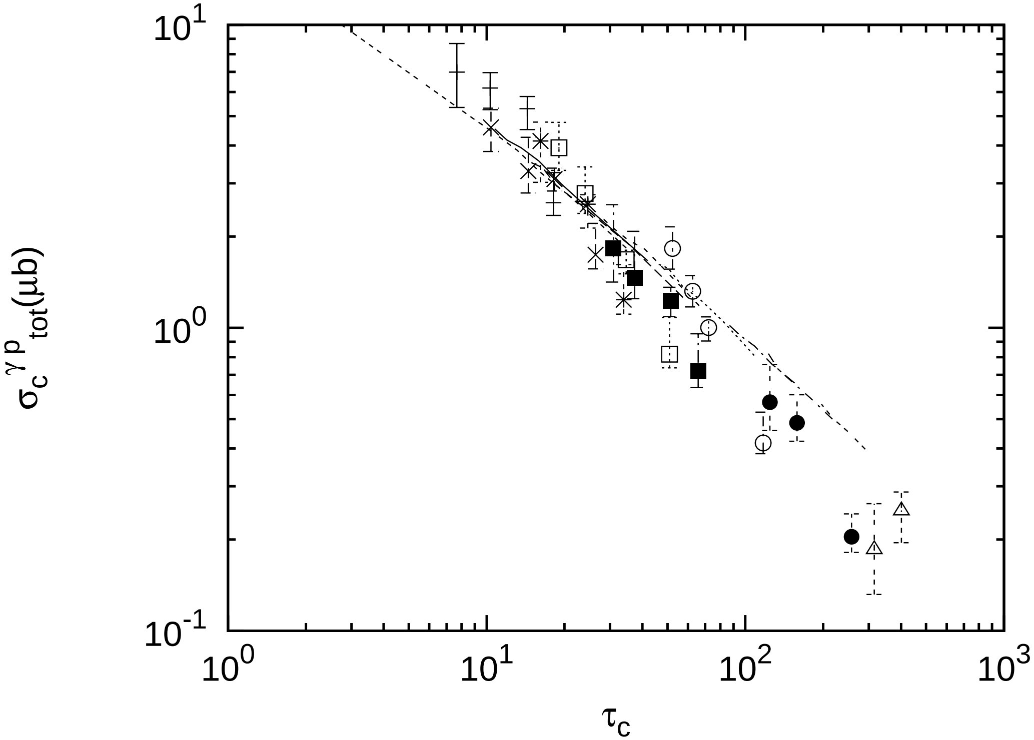


- Large effect from $c-$quark mass. Scaling also in linear approximation. hep-ph/0702087.

Scaling in the Charm Contribution

- HERA charm data does not scale with $\tau = Q^2/Q_s^2$. Large c-mass modifies the scaling properties.
- γ^* splitting to $q\bar{q}$ given by $\psi_L(z, r, Q^2)$ and $\psi_T(z, r, Q^2)$.
- $\psi \sim \psi(\epsilon r)$ where $\epsilon^2 = z(1-z)Q^2 + m_f^2$.
- Scaling restored if $Q^2/Q_s^2 \rightarrow (Q^2 + n \cdot m_c^2)/Q_s^2$ with $n \sim 4$.
- Finite $m_f \Rightarrow$ cutoff for large dipoles, confinement.

Charm results

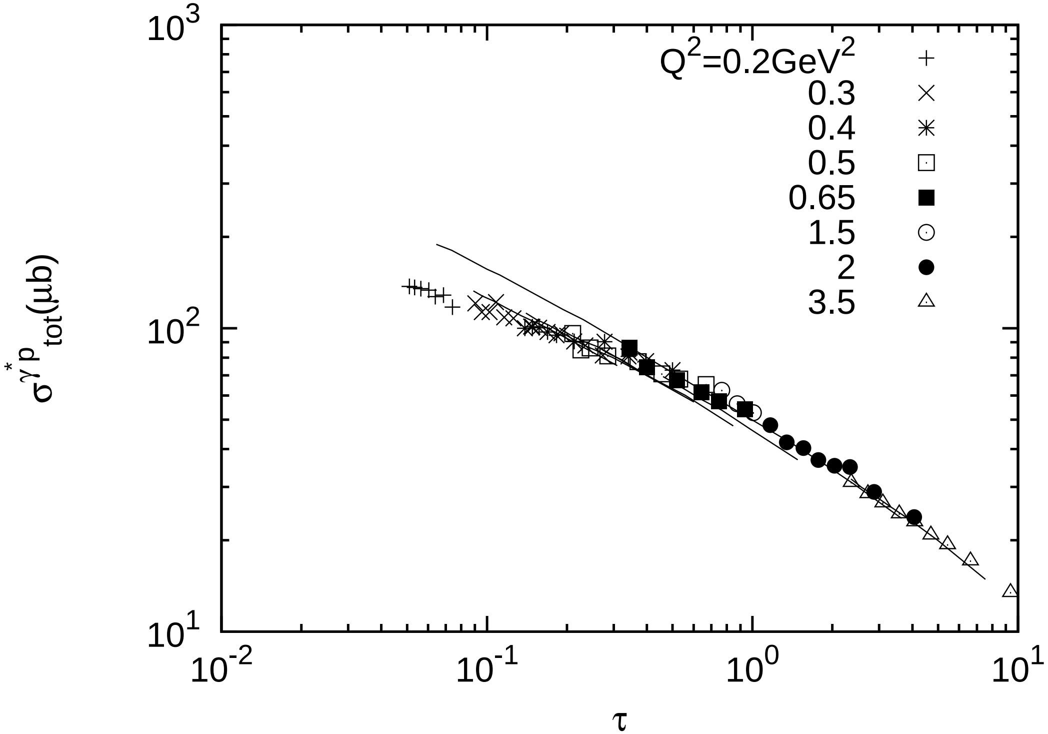


- $\tau_c \equiv (Q^2 + 6m_c^2)/Q_s^2$, $m_c = 1.4$GeV.

Scaling below Q_s^2 ?

- Effect of finite mass approximately multiplicative factor which suppresses σ for smaller Q^2.
- For higher energy one can reach $\tau < 1$ while keeping $Q^2 > 1$GeV^2 $\Rightarrow$ small suppression from light quark mass.
- Real scaling curve will lie above present HERA results.

Results below Q_s^2



- Difference about a factor 1.4 for $\tau \approx 0.07$. Q^2 =2GeV^2 $\Rightarrow$ $x \approx 3 \cdot 10^{-9}$. For $x \approx 1.4 \cdot 10^{-7}$, $\tau \approx 0.2 \Rightarrow$ factor 1.2.

Summary and Conclusions

- We have constructed a dipole model based on a set of fairly simple ingredients.
- Using these in a MC we reproduce σ_{tot} for $\gamma^* p$, and also for pp collisions.
- For DIS, charm has large effect. Scaling not dependent on saturation.
- Charm contribution scales fairly well with $(Q^2 + n \cdot m_c^2)/Q_s^2(x)$, $n \sim 4$. (Goncalves et al hep-ph/0607125.)
- Scalebreaking effects at low Q^2 due to large c-quark mass and also due to confinement related effects for u, d and s.