Multiple interactions and non-linear screening effects in high energy hadronic collisions

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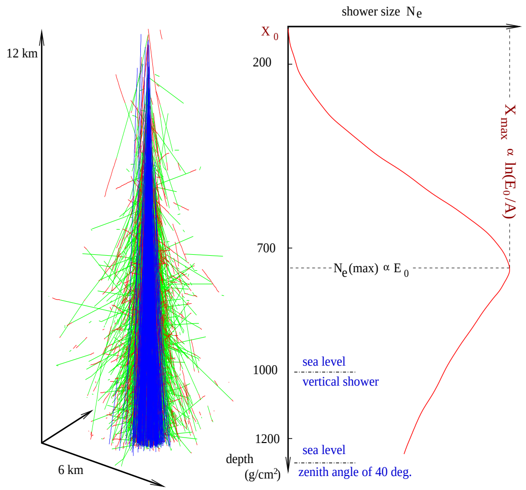
Personal interest - cosmic ray interactions

Cosmic ray measurements ≡ thick target experiment ($\sim$ 30 rad. units):

- hadronic cascade process ⇒ well averaged
- no trigger (minimum bias interactions)
- importance of forward region, diffraction, etc.
- dominance of "soft" physics



Layout:

- Multiple scattering: mini-jet approach
- “Soft” limit - Gribov’s pomeron scheme
- Enhanced pomeron diagrams - re-summations
- Inelastic final states
- Matching with QCD?
- PDFs and cross sections?
- What is missing?
- Outlook

Multiple scattering: mini-jet approach

QCD and hadronic multiple scattering?

- (mini-)jet production ($p_t > p_{t,\min}$) - increases with energy
- small coupling ($\alpha_s(p_t^2)$) - compensated by large logarithms $\ln \frac{x_i}{x_{i+1}}$, $\ln \frac{p^2_{t_{i+1}}}{p^2_{t_i}}$

$\Rightarrow$ "leading-log" re-summations (n-parton "ladders"): $\sum_n \prod_{i=1}^n \left(\int \alpha_s \frac{dx_i}{x_i}\right)$; $\sum_n \prod_{i=1}^n \left(\int \alpha_s \frac{dp^2_{t_i}}{p^2_{t_i}}\right)$

QCD "collinear" factorization $\Rightarrow$ inclusive (leading-log) jet cross section:

$$\sigma^{\rm jet}_{ad}(s, p^2_{t,\min}) = (K) \sum_{I,J=q,\bar{q},g} \int_{p_t^2 > p^2_{t,\min}} dp_t^2 \int dx^+ dx^- \, \frac{d\sigma^{2\to 2}_{IJ}(x^+ x^- s, p_t^2)}{dp_t^2} \, f_{I/a}(x^+, M_F^2) \, f_{J/d}(x^-, M_F^2)$$

$d\sigma^{2\to 2}_{IJ}/dp_t^2$ - differential parton-parton cross section;

$f_{I/a}(x, Q^2)$ - parton I momentum distribution, "probed" at scale Q^2

- PDFs require non-perturbative input
- $\sigma^{\rm jet}_{ad}(s, p^2_{t,\min})$: LL sensitivity to $M^2_{\rm F}$

Nevertheless valuable information

Not sufficient to construct a MC model: pQCD tells nothing about

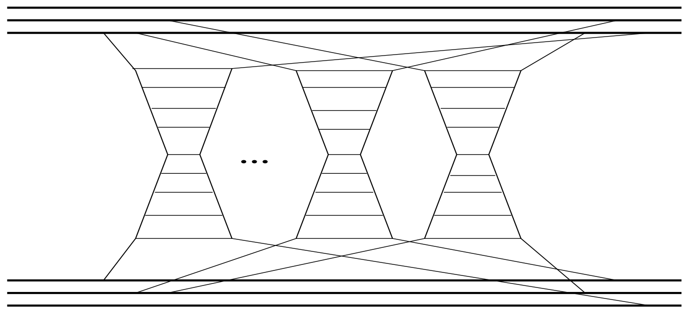
- jet production in an individual event
- interaction cross sections
- "soft" (low p_t) particle production, e.g., about leading particles

$\Rightarrow$ Mini-jet scheme (Gaisser & Halzen, 1985; Durand & Pi, 1987):

- "soft" physics $\equiv$ scaling
- energy increase of $\sigma_{ad}^{\rm tot}(s)$, $N_{ad}^{\rm ch}(s)$ - due to mini-jet production
- $\sigma_{ad}^{\rm jet} > \sigma_{ad}^{\rm tot} \Rightarrow$ multiple scattering $=$ eikonal approach
- number of semi-hard processes per event (for given b) - Poisson:
  $W(n_{\rm jet}) = \frac{1}{n_{\rm jet}!}\left[\langle n_{ad}^{\rm jet}(s,b)\rangle\right]^{n_{\rm jet}} \exp\left(-\langle n_{ad}^{\rm jet}(s,b)\rangle\right)$
- $\langle n_{ad}^{\rm jet}(s,b)\rangle \equiv 2\chi_{ad}^{\rm hard}(s,b) = \sigma_{ad}^{\rm jet}(s,p_{t,\min}^2)\,A_{ad}(b)$
  $A_{ad}(b) = \int d^2s\, T_a^{\rm e/m}(\vec{s})\, T_d^{\rm e/m}(|\vec{b}-\vec{s}|)$ - "overlap" function
- $\Rightarrow$ inelastic cross section: $\sigma_{ad}^{\rm inel}(s) = \int d^2b\left[1 - e^{-2\chi_{ad}^{\rm soft}(s,b)-2\chi_{ad}^{\rm hard}(s,b)}\right]$
  $\chi_{ad}^{\rm soft}(s,b) = \frac{1}{2}\sigma_{\rm soft}\,A_{ad}(b)$, $\sigma_{\rm soft}$ - "soft" parton cross section

Interaction = multiple exchange of DGLAP ladders

(generally coupled both to valence quarks and to gluon clouds)



Open point - where to start the ladder (leg parton virtuality):

$$Q^2_{\rm ini} = p^2_{t,\rm min} \text{ or } Q^2_{\rm ini} = \lambda^2_{\rm QCD}?$$

Anyway general problem - too rapid rise of $\sigma^{\rm inel}_{ad}(s)$, $N^{\rm ch}_{ad}(s)$

Why? Independent interaction picture is inadequate in "dense" limit (large s, small b, large A):

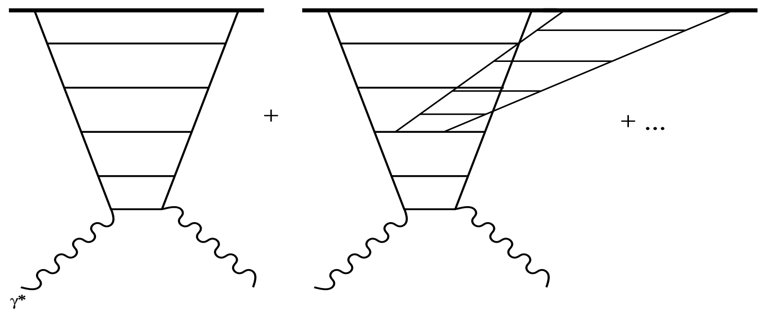
- many partons closely packed
- $\Rightarrow$ expected to interact with each other

Standard approach - energy-dependent p_t-cutoff; ad hoc parameterizations:

- $p_t^{\min}(s) = 3.91 - 3.34\,\ln(\ln\sqrt{s}) + 0.98\,\ln^2(\ln\sqrt{s}) + 0.23\,\ln^3(\ln\sqrt{s})$ (Li & Wang, 1992)
- $p_{t,\min}(s) = 1.9\,(s/10^6)^{0.08}$ (Sjöstrand, 1994)
- $p_{t,\min}(s) = 2.5 + 0.12\left[\log\frac{\sqrt{s}}{50}\right]^3$ (Bopp et al., 1994)

Inspired by the GLR approach (Gribov, Levin & Ryskin, 1983):

- non-linear effects = coupling of QCD ladders
- parton saturation at some scale $Q^2_{\rm sat}(x) \Rightarrow$ “soft” contribution suppressed



$\Rightarrow$ formal justification for the energy-dependence:

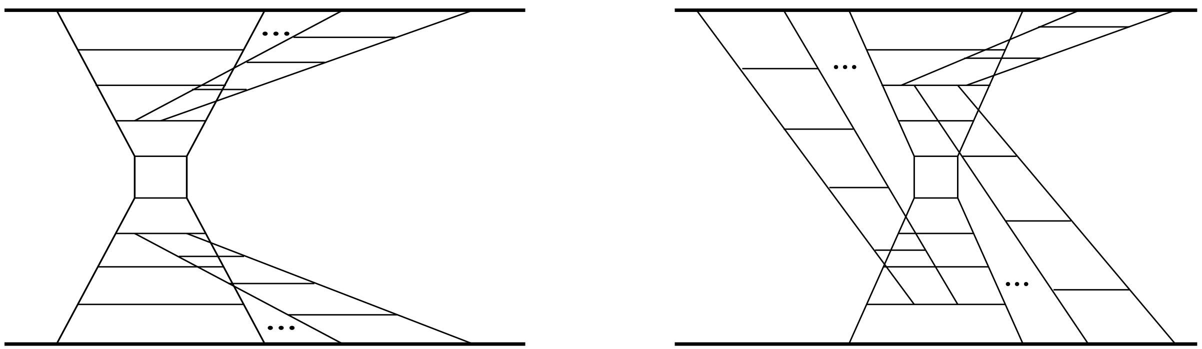
saturation-based picture; $p^2_{t,\min}(s) = Q^2_{\rm sat}(s)$ - effective saturation scale

Drawbacks & open questions:

- not based explicitely on GLR (QCD) $\Rightarrow$ loss of predictive power
- no correlation with parton density (x-, b-, and A-dependence)
- neglects shadowing (pre-saturation corrections)
- no effect on "soft" interactions
- saturation not seen in F_2 measurements?

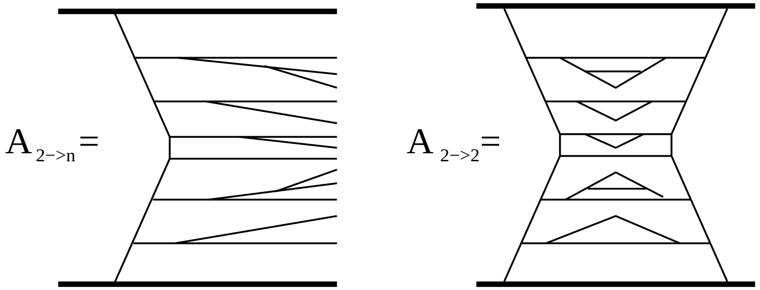
Main questions:

- is it possible to trace saturation with $\sigma_{pp}^{\mathrm{tot(inel)}}(s)$ and/or $N_{pp}^{\mathrm{ch}}(s)$?
- is the factorized ansatz ($\chi_{ad}^{\mathrm{hard}}(s,b) = \frac{1}{2}\sigma_{ad}^{\mathrm{jet}}(s,p_{t,\min}^2)\, A_{ad}(b)$) applicable?



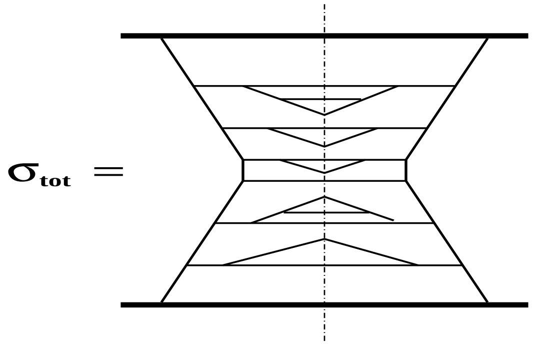
“Soft” limit - Gribov’s pomeron scheme

Elementary interaction - inelastic & elastic amplitudes:



Cross section - optical theorem:

$$\sigma_{\rm tot} = \sum_n \int d\tau_n \; A_{2\to n} \cdot A^*_{2\to n} = \frac{1}{2s} 2{\rm Im}\, A_{2\to 2}\Big|_{t=0}$$



Pomeranchuk: elementary interaction ≡ pomeron exchange

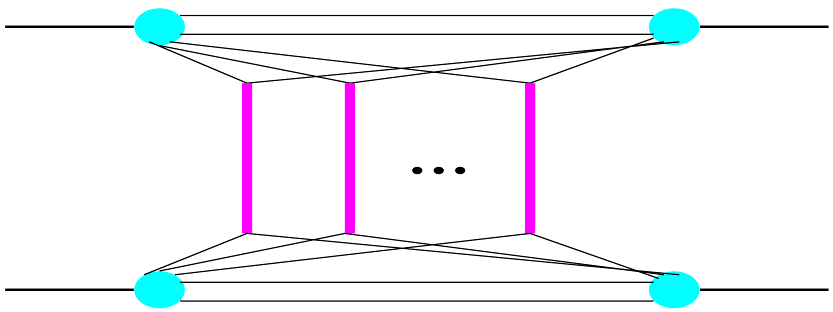
Pomeron amplitude:

$$f^{\mathbb{P}}_{ad}(s,t) = 8\pi i\,\gamma_a\,\gamma_d\,(s/s_0)^{\alpha_{\mathbb{P}}(0)}\,\exp(-\lambda_{ad}(s)t)$$
$$\lambda_{ad}(s) = R_a^2 + R_d^2 + \alpha'_{\mathbb{P}}(0)\,\ln(s/s_0)$$

- pomeron intercept $\alpha_{\mathbb{P}}(0) > 1$ - energy rise
- pomeron slope $\alpha'_{\mathbb{P}}(0)$ - increasing spatial size of the interaction

$\sigma^{\mathbb{P}}_{ad}(s) = \frac{1}{2s} 2\mathrm{Im}\, f^{\mathbb{P}}_{ad}(s,0) \sim s^{\alpha_{\mathbb{P}}(0)-1}$ - violates unitarity bound?

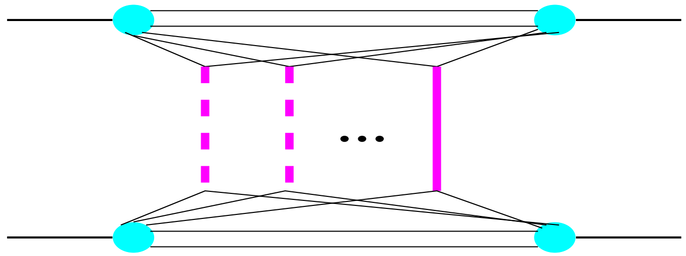
$\Rightarrow$ multiple scattering = multi-pomeron exchange



Assuming eikonal vertices and neglecting inelastic screening (diffraction):

$$\sigma^{\mathrm{tot}}_{ad}(s) = 2\int d^2b\,\left[1 - e^{-\chi^{\mathbb{P}}_{ad}(s,b)}\right] \sim \ln^2 s, \quad s \to \infty$$
$$\chi^{\mathbb{P}}_{ad}(s,b) = \frac{1}{8\pi^2 s}\int d^2q_\perp\, e^{-i\vec{q}_\perp \vec{b}}\,\mathrm{Im} f^{\mathbb{P}}_{ad}(s,q^2_\perp) = \frac{\gamma_a\gamma_d\,(s/s_0)^{\alpha_{\mathbb{P}}(0)-1}}{\lambda_{ad}(s)}\exp\left(\frac{-b^2}{4\lambda_{ad}(s)}\right)$$

Final states - AGK cutting rules (Abramovskii, Gribov & Kancheli, 1973):
no interference between different classes of the interaction:

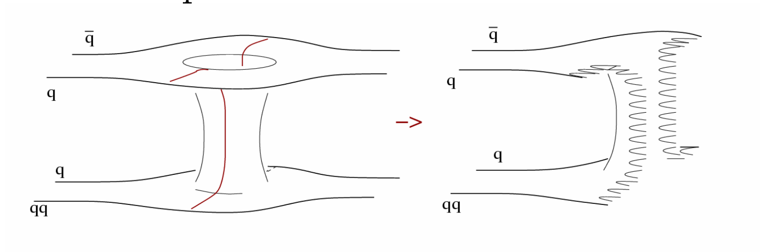


$\Rightarrow$ "topological" cross sections (n "cut" pomerons):

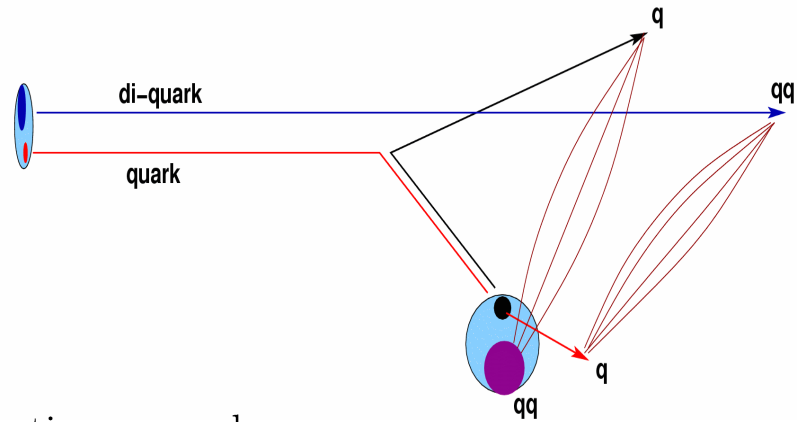
$$\sigma_{ab}^{(n)}(s) = \int d^2b \, \frac{\left[2\chi_{ab}^{\mathbb{P}}(s,b)\right]^n}{n!} e^{-2\chi_{ab}^{\mathbb{P}}(s,b)}$$

$$\sigma_{ab}^{\rm inel}(s) = \sum_{n=1}^{\infty} \sigma_{ab}^{(n)}(s) = \int d^2b \, \left[1 - e^{-2\chi_{ab}^{\mathbb{P}}(s,b)}\right]$$

DTU scheme - $N_c \to \infty$, $N_f \to \infty$ (Veneziano, 1974):
pomeron $\equiv$ cylinder $\Rightarrow$ "cut" pomeron = 2 chains of secondaries:

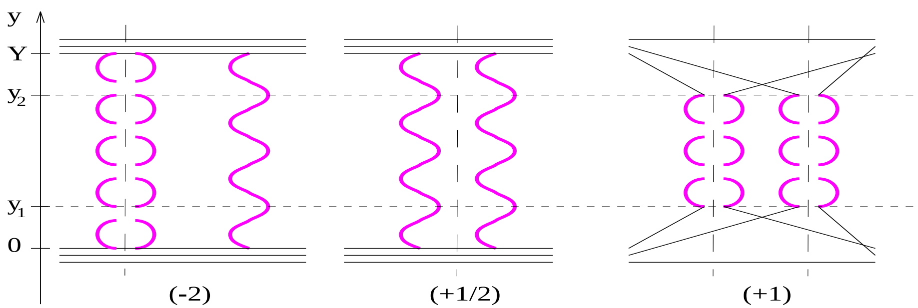


Can be used to establish string picture of hadronization (Capella et al., 1979; Kaidalov & Ter-Martyrosyan, 1982):



⇒ string fragmentation procedures

Important point - AGK cancellations:



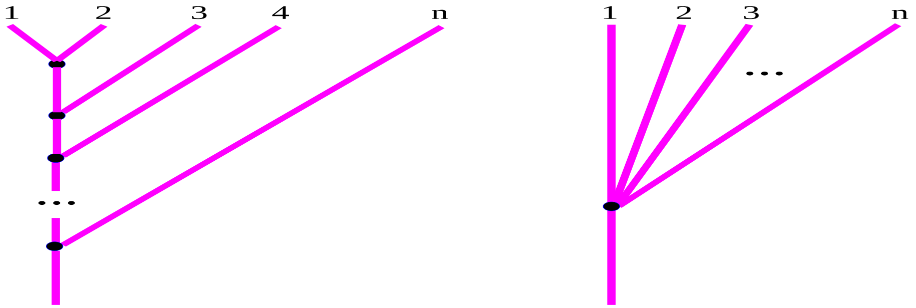
⇒ multi-pomeron graphs contribute to cross sections, not to inclusive spectra

Enhanced pomeron diagrams - re-summations

Non-linear effects: pomeron-pomeron interactions

$\Rightarrow$ all orders - re-summation of the whole pomeron "net"

Why? Example: "fan" contributions with n "legs":



$$\Delta\chi_{ab}^{\rm fan} = \sum_{n=1}^{\infty} \Delta\chi_{ab}^{{\rm fan}(n)} \sim \sum_{n=1}^{\infty} r_{3\mathbb{P}}^{n} \left[-\chi_{\mathbb{P}}(s)\right]^{n+1}, \quad \chi_{\mathbb{P}}(s) \sim s^{\alpha_{\mathbb{P}}(0)-1}$$

Very high energy:

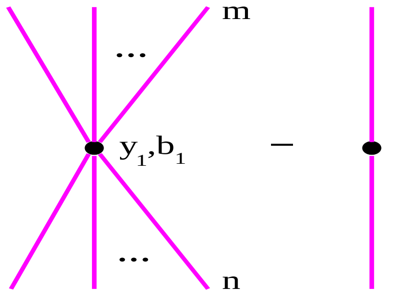
- each next order gives bigger contribution
- with opposite sign

Re-summation can be done assuming eikonal multi-pomeron vertices (Kaidalov, Ponomarev & Ter-Martyrosyan, 1986):

$$g_{mn} = G\,\gamma_{\mathbb{P}}^{m+n}/(m!\,n!),\; G = r_{3\mathbb{P}}/(4\pi\,\gamma_{\mathbb{P}}^3)$$

In particular, pion dominance $\Rightarrow \gamma_{\mathbb{P}} = \gamma_\pi$, $R_{\mathbb{P}}^2 = R_\pi^2$ - vertex slope

Lowest order:



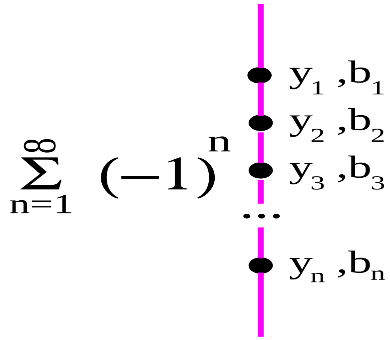
$$\Delta\chi_{ad}^{\mathbb{PPP}(1)}(s,b) = G \sum_{m,n\geq 1; m+n\geq 3} \int_0^{Y=\ln\frac{s}{s_0}} dy_1 \int d^2b_1 \, \frac{\left[-\chi_{a\mathbb{P}}^{\mathbb{P}}(se^{-y_1}, |\vec{b}-\vec{b}_1|)\right]^m}{m!} \frac{\left[-\chi_{d\mathbb{P}}^{\mathbb{P}}(s_0e^{y_1}, b_1)\right]^n}{n!}$$

$$= G\int_0^Y dy_1 \int d^2b_1 \left\{ \left(1 - e^{-\chi_{a\mathbb{P}}^{\mathbb{P}}(se^{-y_1},|\vec{b}-\vec{b}_1|)}\right) \left(1 - e^{-\chi_{d\mathbb{P}}^{\mathbb{P}}(s_0e^{y_1},b_1)}\right) - \chi_{a\mathbb{P}}^{\mathbb{P}}(se^{-y_1}, |\vec{b}-\vec{b}_1|)\,\chi_{d\mathbb{P}}^{\mathbb{P}}(s_0e^{y_1}, b_1)\right\}$$

Dominated by the last term in the “dense” limit ($s \to \infty$, $b \to 0$):

$$\Delta\chi_{ad}^{\mathrm{asympt}(1)}(s,b) \;\sim\; -4\pi\,G\,\gamma_{\mathbb{P}}^2 \ln\frac{s}{s_0}\,\chi_{ad}^{\mathbb{P}}(s,b)$$

Similarly at higher orders:



⇒ Main idea: re-summation of "re-normalized" pomeron graphs:

$$\tilde{\alpha}_{\mathbb{P}}(0) = \alpha_{\mathbb{P}}(0) - 4\pi\, G\, \gamma_{\mathbb{P}}^2$$

- sum of positively defined contributions
- fast convergence
- approaches eikonal scheme in the "dense" limit

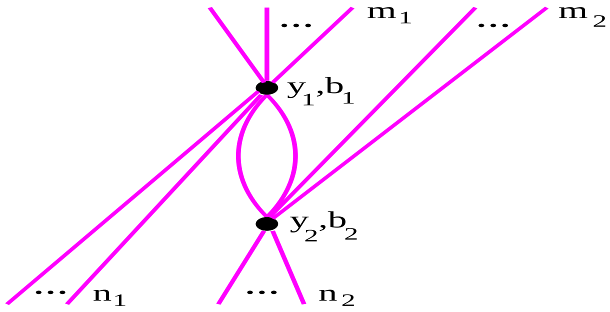
Drawbacks:

- not a closed result
- based on a particular ansatz for the pomeron amplitude
- difficult to generalize for inelastic final states (unitarity cuts)

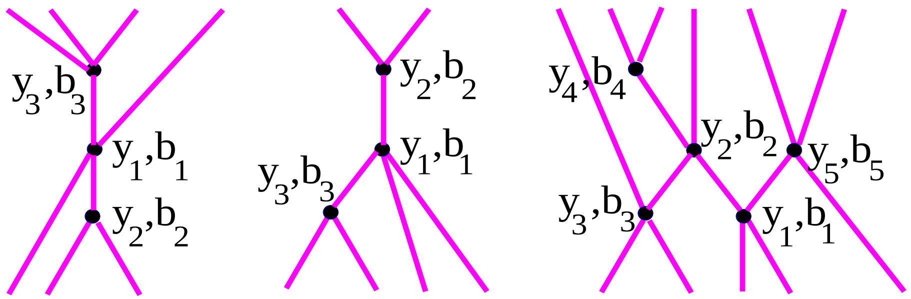
Alternative: "fan"-like re-summation (SO, 2006)

One can neglect "loops" (in fact, not necessary):

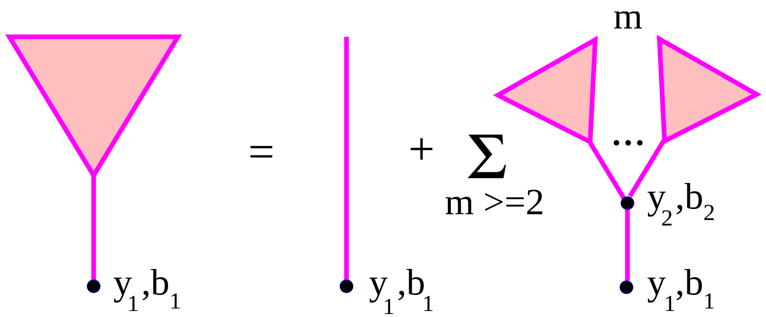
- small at low parton density ($\sim G^2$)
- suppressed at high density: $\sim \sum_{n_1=0}^{\infty} \frac{(-\chi_{d\mathbb{P}}^{\mathbb{P}}(s_0 e^{y_1}, b_1))^{n_1}}{n_1!} = e^{-\chi_{d\mathbb{P}}^{\mathbb{P}}(s_0 e^{y_1}, b_1)}$



One is left with "net" graphs:



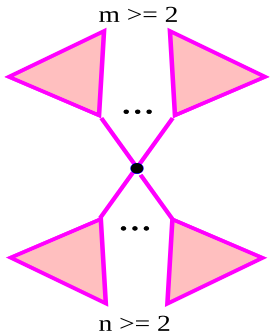
"Tree"-type graphs can be expressed via "fan" contributions
(parton (y,b)-distribution):



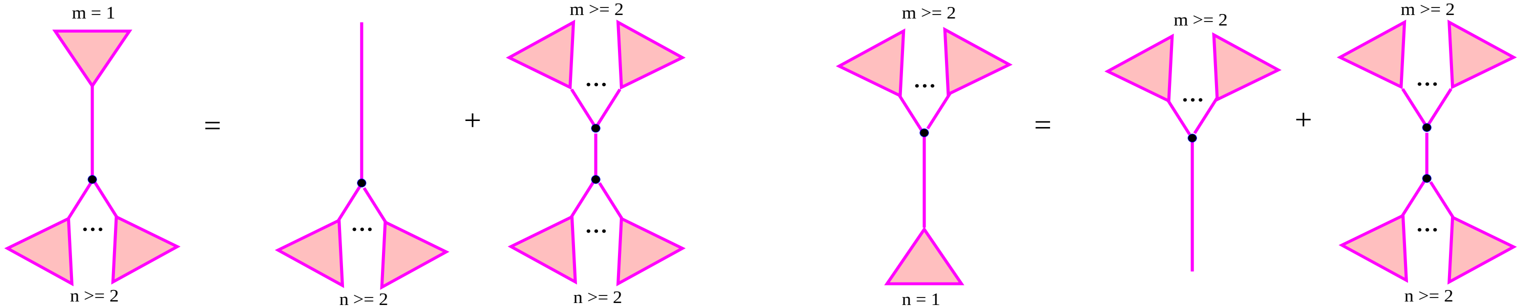
$$\chi_a^{\rm fan}(y_1,b_1) = \chi_{a\mathbb{P}}^{\mathbb{P}}(s_0 e^{y_1},b_1) + G\int_0^{y_1} dy_2 \int d^2b_2\, \chi_{\mathbb{P}\mathbb{P}}^{\mathbb{P}}(s_0 e^{y_1-y_2},|\vec{b}_1-\vec{b}_2|)\ \left[1-e^{-\chi_a^{\rm fan}(y_2,b_2)} - \chi_a^{\rm fan}(y_2,b_2)\right]$$

One vertex with $m,n \geq 2$ "fans" below and above - no double counts:

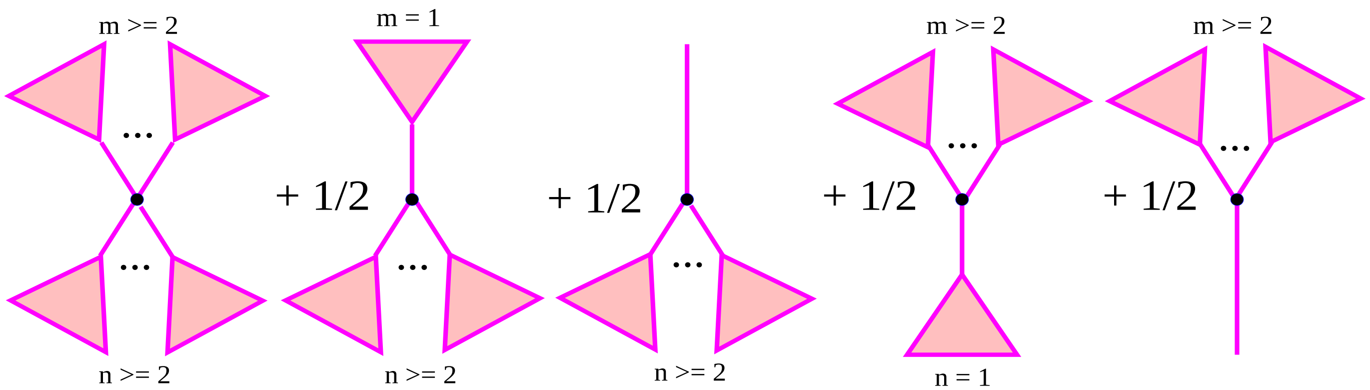
- different $m,n \Rightarrow$ different diagrams
- different structure of "fans" - again different diagrams



Now $m = 1$ or $n = 1$ - some diagrams counted twice:

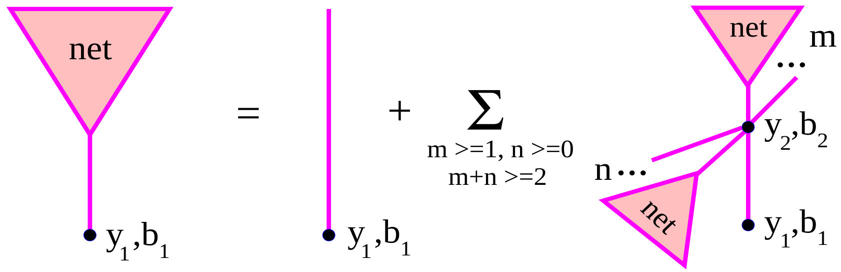


$\Rightarrow$ full set:



Similarly one proceeds in the general case

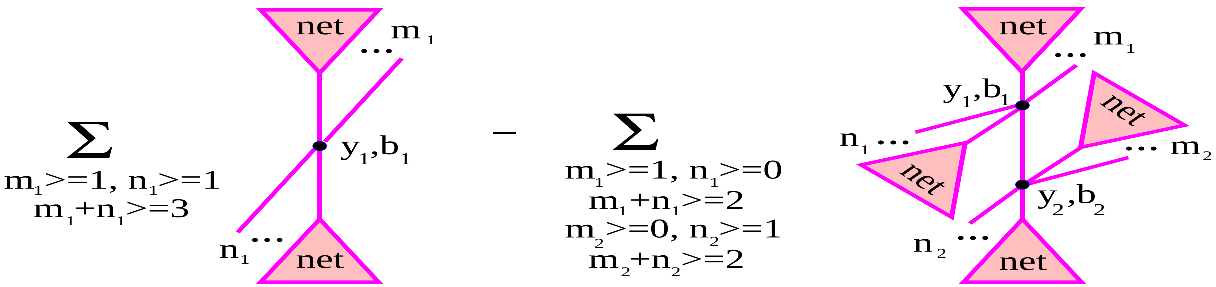
“Net fan” contribution (parton (y,b)-distribution “probed” during interaction):



$$\chi^{\rm net}_{a|d}(y_1,\vec b_1|Y,\vec b)=\chi^{\mathbb P}_{a\mathbb P}(s_0e^{y_1},b_1)+G\int_0^{y_1}dy_2\int d^2b_2\,\chi^{\mathbb P}_{\mathbb{PP}}(s_0e^{y_1-y_2},|\vec b_1-\vec b_2|)$$

$$\times\left\{\left[1-e^{-C_a\chi^{\rm net}_{a|d}(y_2,\vec b_2|Y,\vec b)}\right]\exp\left(-\chi^{\rm net}_{d|a}(Y-y_2,\vec b-\vec b_2|Y,\vec b)\right)\;-\chi^{\rm net}_{a|d}\left(y_2,\vec b_2|Y,\vec b\right)\right\}$$

Summary contribution of all enhanced graphs:



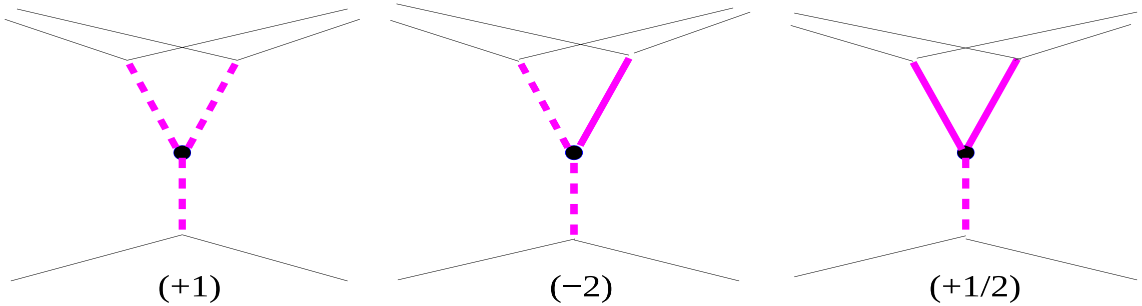
$$\chi^{\rm enh}_{ad}(s,b)=G\int_0^Y dy_1\int d^2b_1\left\{\left[\left(1-e^{-\chi^{\rm net}_{a|d}(1)}\right)\left(1-e^{-\chi^{\rm net}_{d|a}(1)}\right)-\chi^{\rm net}_{a|d}(1)\chi^{\rm net}_{d|a}(2)\right]-G\int_0^{y_1}dy_2\int d^2b_2\right.$$

$$\left.\times\chi^{\mathbb P}_{\mathbb{PP}}(s_0e^{y_1-y_2},|\vec b_1-\vec b_2|)\left[\left(1-e^{-\chi^{\rm net}_{a|d}(1)}\right)e^{-\chi^{\rm net}_{d|a}(1)}-\chi^{\rm net}_{a|d}(1)\right]\left[\left(1-e^{-\chi^{\rm net}_{d|a}(2)}\right)e^{-\chi^{\rm net}_{a|d}(2)}-\chi^{\rm net}_{d|a}(2)\right]\right\}$$

Inelastic final states

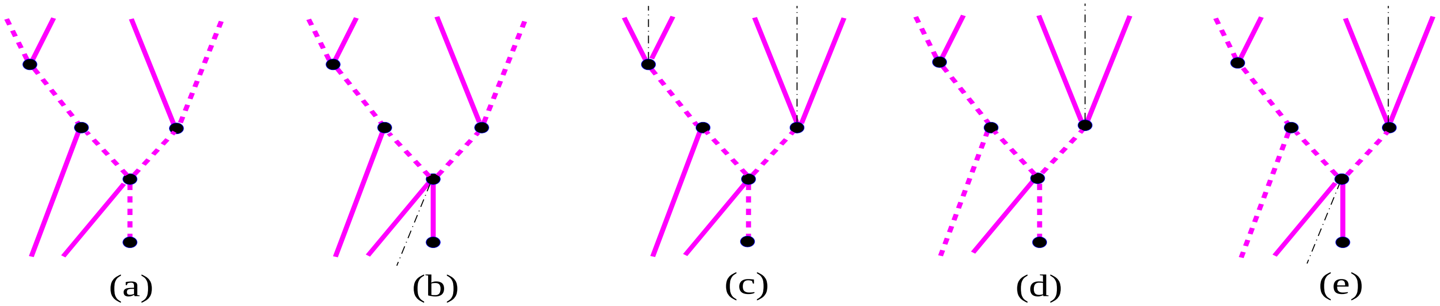
Optical theorem + AGK cutting rules: different inelastic final states can be related to certain unitarity cuts of elastic scattering diagrams

Example: applying AGK cutting rules to the triple-pomeron graph:

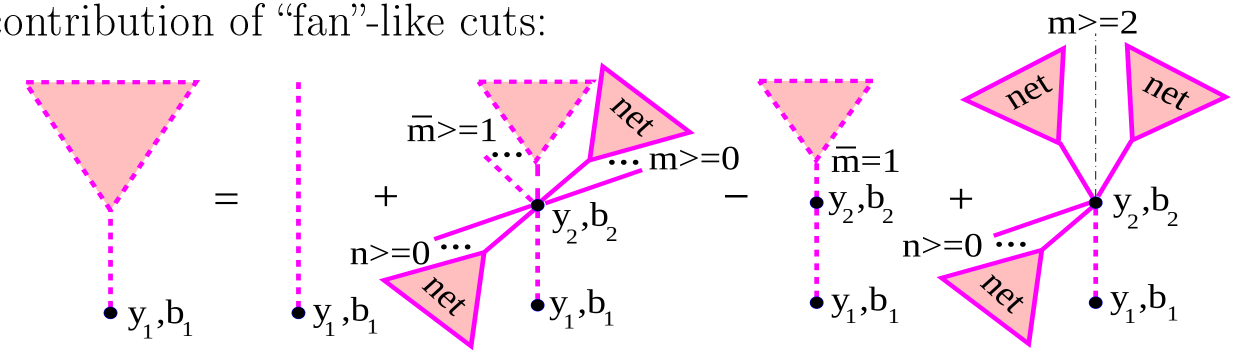


General strategy: "fan"-like re-summation of cut diagrams

Let us consider AGK cuts of "net fans": "fan"-like (a,b,c) and "zig-zag"-like (d,e)



Total contribution of “fan”-like cuts:

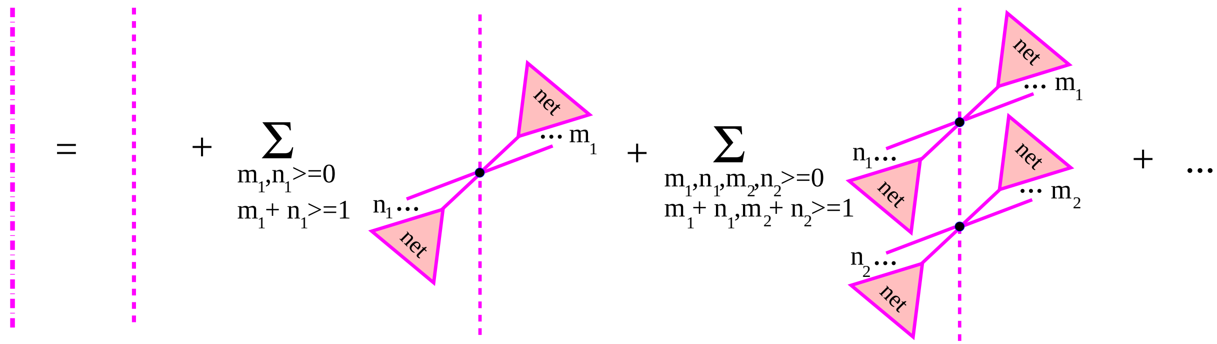


$$\bar{\chi}^{\rm fan}_{a|d}(y_1,\vec{b}_1|Y,\vec{b}) = \chi^{\mathbb{P}}_{a\mathbb{P}}(y_1,b_1) + G\int_0^{y_1} dy_2 \int d^2b_2\; G^{\mathbb{P}}_{\mathbb{PP}}(y_1-y_2,|\vec{b}_1-\vec{b}_2|)\; \Big\{ e^{-\chi^{\rm net}_{d|a}(Y-y_2,\vec{b}-\vec{b}_2|Y,\vec{b})}$$

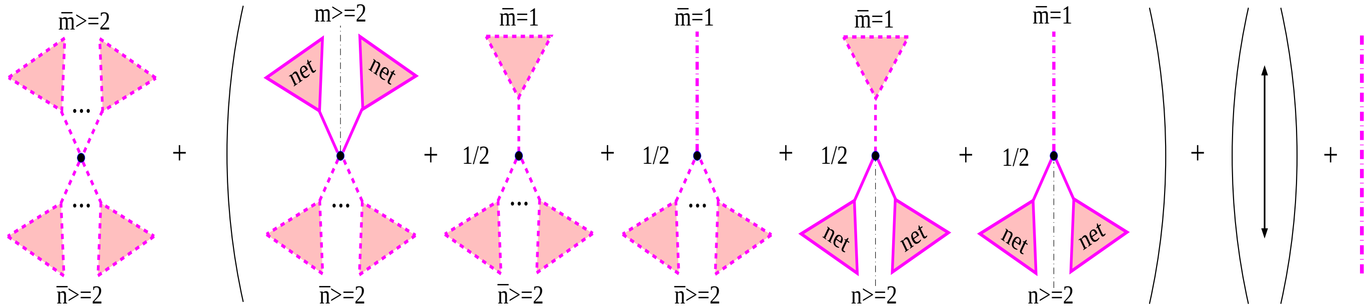
$$\times\,\frac{1}{2}\left[\left(e^{2\,\bar{\chi}^{\rm fan}_{a|d}(y_2,\vec{b}_2|Y,\vec{b})}-1\right)e^{-2\,\chi^{\rm net}_{a|d}(y_2,\vec{b}_2|Y,\vec{b})} + \left(1-e^{-\chi^{\rm net}_{a|d}(y_2,\vec{b}_2|Y,\vec{b})}\right)^2\right] - \bar{\chi}^{\rm fan}_{a|d}(y_2,\vec{b}_2|Y,\vec{b})\Big\}$$

Thus, $\bar{\chi}^{\rm fan}_{a|d}(y_1,\vec{b}_1|Y,\vec{b}) \equiv \chi^{\rm net}_{a|d}(y_1,\vec{b}_1|Y,\vec{b})$ and all “zig-zag” cuts cancel each other

“Screened” cut pomeron:

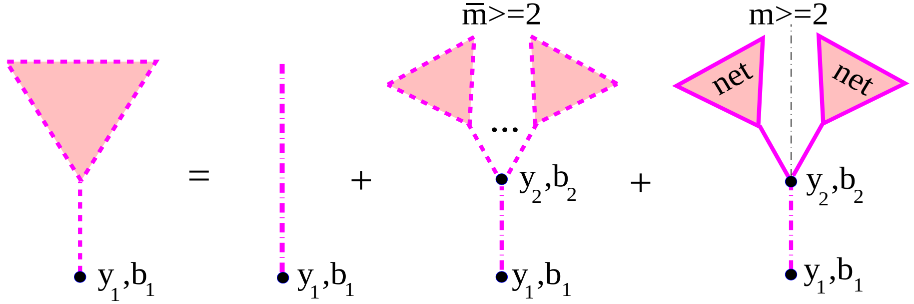


The sum of all unitarity cuts of elastic scattering diagrams
$(\bar{\chi}^{\rm tot}_{ad}(s,b) \equiv \chi^{\mathbb{P}}_{ad}(s,b) + \chi^{\rm enh}_{ad}(s,b))$ can be expressed via "fan"-like cuts:



(only cut structure shown; some sub-dominant contributions omitted here)

The "fan" cut topology can be reconstructed recursively:



(only cut structure shown)

Hadron-nucleus, nucleus-nucleus - similar ⇒ A-enhancement of screening effects

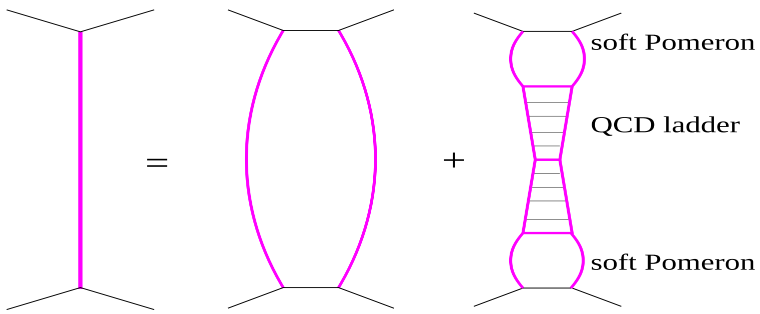
Matching with QCD?

"Semi-hard Pomeron" approach (Levin & Tan, 1994; Donnachie & Landshoff, 1994; Kalmykov, SO & Pavlov, 1994; Drescher et al., 1999):

- introduce a "threshold" scale Q_0^2
- use "soft" Pomeron below Q_0^2
- use DGLAP ladder for $\left|p_t^2\right| > Q_0^2$

$\Rightarrow$ Gribov's scheme based on a "general Pomeron":

$$\chi_{ad}^{\mathbb{P}}(s,b) = \chi_{ad}^{\mathbb{P}_{\mathrm{soft}}}(s,b) + \chi_{ad}^{\mathbb{P}_{\mathrm{sh}}}(s,b)$$



Semi-hard eikonal:

$$\chi_{ab}^{\mathbb{P}_{\rm sh}}(s,b) = \frac{1}{2} \sum_{I,J=g,q_s,\bar{q}_s} \int d^2b' \int \frac{dx^+}{x^+}\frac{dx^-}{x^-}\; \chi_{aI}^{\mathbb{P}_{\rm soft}}\left(\frac{s_0}{x^+}, b'\right)\; \chi_{dJ}^{\mathbb{P}_{\rm soft}}\left(\frac{s_0}{x^-}, |\vec{b}-\vec{b}'|\right)\; \sigma_{IJ}^{\rm lad}(x^+x^-s, Q_0^2)$$

Ladder cross section:

$$\begin{aligned} \sigma_{IJ}^{\rm lad}(\hat{s}, Q_0^2) &= K \sum_{I',J'} \int dp_t^2 \int dz^+ dz^- \, \frac{d\sigma_{I'J'}^{2\to 2}(z^+z^-\hat{s}, p_t^2)}{dp_t^2} \\ &\times\; E_{I\to I'}^{\rm QCD}\big(z^+, Q_0^2, M_{\rm F}^2(p_t^2)\big)\; E_{J\to J'}^{\rm QCD}\big(z^-, Q_0^2, M_{\rm F}^2(p_t^2)\big) \end{aligned}$$

$E_{I\to I'}^{\rm QCD}(z^+, Q_0^2, M_{\rm F}^2(p_t^2))$ - LL parton evolution; $M_{\rm F}^2 = p_t^2/4$ (our choice)

$\chi_{aI}^{\mathbb{P}_{\rm soft}}$ - eikonal for pomeron exchange between hadron a and parton I (using a parameterized pomeron-parton vertex $\gamma_{I/a}(x)$):

$$\chi_{aI}^{\mathbb{P}_{\rm soft}}(\hat{s}, b') = \frac{\gamma_a\; \gamma_{I/a}\big(\frac{s_0}{\hat{s}}\big)\;\; (\hat{s}/s_0)^{\alpha_{\mathbb{P}}(0)-1}}{R_a^2 + \alpha'_{\mathbb{P}}(0)\; \ln(\hat{s}/s_0)} \exp\left(\frac{-b'^2}{4\,(R_a^2 + \alpha'_{\mathbb{P}}(0)\; \ln(\hat{s}/s_0))}\right)$$

$x\, \tilde{f}_{I/a}(x, b', Q_0^2) = \chi_{aI}^{\mathbb{P}_{\rm soft}}\left(\frac{s_0}{x}, b'\right)$ - parton (x, b')-distribution at scale Q_0^2:

- $\tilde{f}_{I/a}(x, b', Q_0^2) \sim x^{-\alpha_{\mathbb{P}}(0)}$
- partons of smaller x cover larger transverse area

"Semi-hard Pomeron" - combines features of "soft" and "hard" ones

- steep energy rise: $\chi_{ad}^{\mathbb{P}_{\rm sh}}(s,b) \sim s^{\Delta_{\rm hard}}$, $\Delta_{\rm hard} \sim 0.3$
- large slope: $\sim \alpha'_{\mathbb{P}}(0)$

One can re-write $\chi_{ab}^{\mathbb{P}_{\rm sh}}(s,b)$ as

$$\chi_{ab}^{\mathbb{P}_{\rm sh}}(s,b) = \frac{1}{2}\int dx^+ dx^- \int dp_t^2 \left\{ K \int d^2b' \sum_{I,J} \tilde{f}_{I/a}(x^+, b', M_F^2)\, \tilde{f}_{J/d}(x^-, |\vec{b}-\vec{b}'|, M_F^2) \frac{d\sigma_{IJ}^{2\to 2}(x^+x^-s, p_t^2)}{dp_t^2} \right\}$$

$$\tilde{f}_{I/a}(x,b,Q^2) = \sum_J \int \frac{dz}{z}\, E_{J\to I}^{\rm QCD}(z, Q_0^2, Q^2)\;\; \tilde{f}_{I/a}(x/z, b, Q_0^2)$$

$$2\int d^2b\, \chi_{ab}^{\mathbb{P}_{\rm sh}}(s,b) = \sigma_{ab}^{\rm jet}(s, Q_0^2)$$

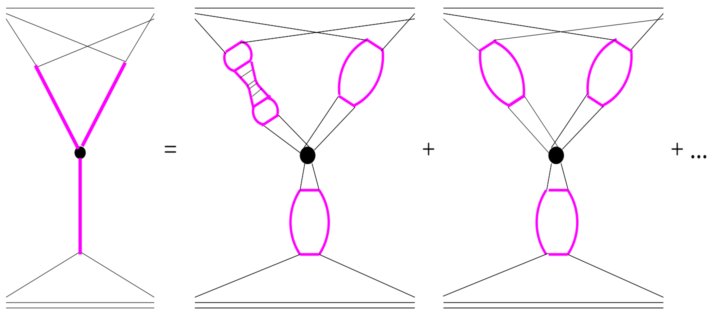
$\Rightarrow$ similar to the mini-jet approach

Important differences from the mini-jet scheme:

- multiple scattering - due to both "soft" and "semi-hard" pomerons
- parton (particle) production extends to "soft" (low p_t) region ("soft pre-evolution")
- low-x partons - distributed over larger transverse area

Non-linear effects:

- assuming no saturation above a fixed Q_0^2 scale
- pomeron-pomeron coupling - only at $|q|^2 < Q_0^2$
- $\Rightarrow$ only "soft" pomeron coupling



$\Rightarrow$ previous (enhanced) scheme based on the "general" ("soft" + "sh") pomeron

PDFs and cross sections?

Cross sections - usual eikonal formulas based on the complete eikonal

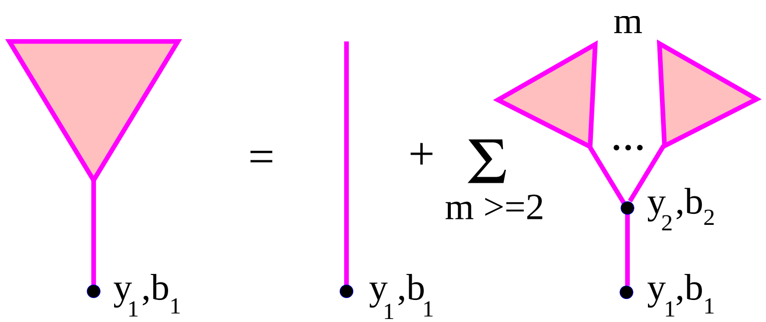
$\chi_{ad}^{\rm tot}(s,b) \equiv \chi_{ad}^{\mathbb{P}}(s,b) + \chi_{ad}^{\rm enh}(s,b)$ $(\chi_{ad}^{\mathbb{P}} = \chi_{ad}^{\mathbb{P}_{\rm soft}} + \chi_{ad}^{\mathbb{P}_{\rm sh}})$:

$$\sigma_{ad}^{\rm tot}(s) \;=\; 2\int d^2b\,\left[1-e^{-\chi_{ad}^{\rm tot}(s,b)}\right]$$

$$\sigma_{ad}^{\rm inel}(s) \;=\; \int d^2b\,\left[1-e^{-2\chi_{ad}^{\rm tot}(s,b)}\right]$$

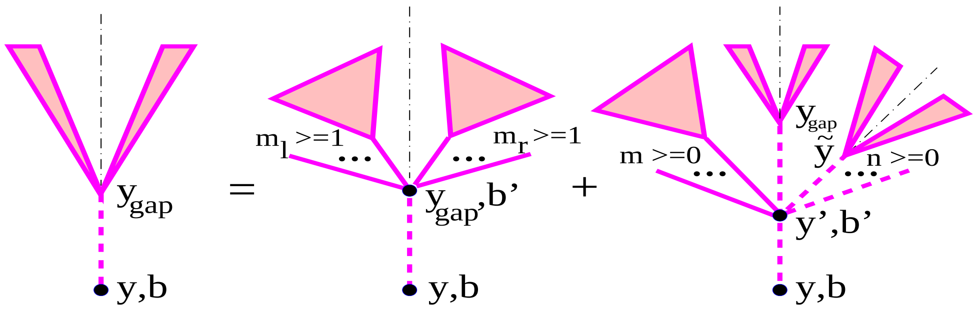
PDFs at Q_0^2 scale are defined by the "fan" contribution

(down-most vertex replaced by pomeron-parton coupling):



$$x\, f_{I/a}^{\rm scr}(x,Q_0^2) = \int d^2b_1 \{x\, \tilde{f}_{I/a}(x,b_1,Q_0^2) + G\int_0^{y_1=-\ln x} dy_2 \int d^2b_2$$
$$\times \chi_{\mathbb{P}I}^{\mathbb{P}_{\rm soft}}(s_0\, e^{y_1-y_2}, |\vec{b}_1-\vec{b}_2|)\, \left[1-e^{-\chi_a^{\rm fan}(y_2,b_2)} - \chi_a^{\rm fan}(y_2,b_2)\right]$$

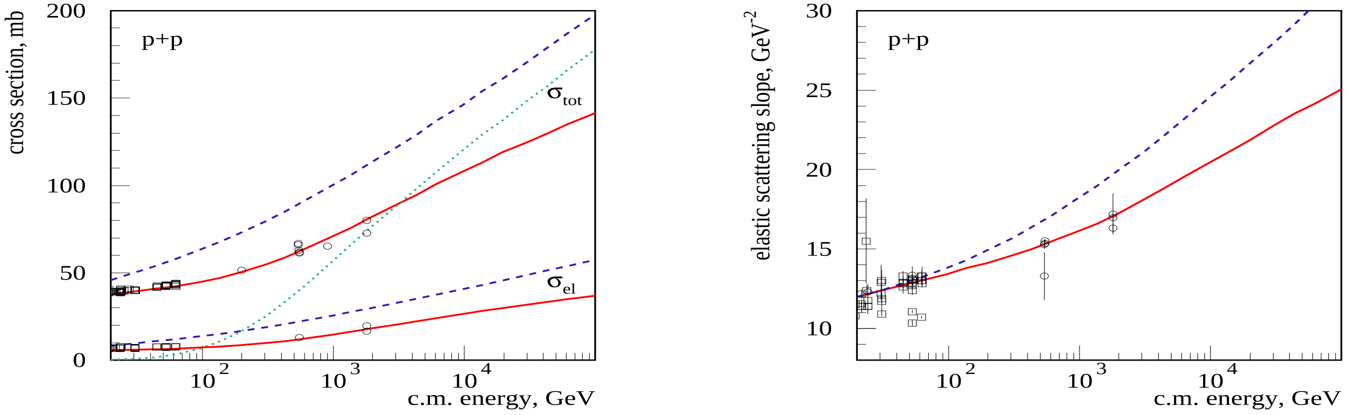
Diffractive PDFs (for $\beta = x/x_{\mathbb{P}} \ll 1$, $x_{\mathbb{P}} = e^{-y_{\rm gap}}$) - diffractive cut of the "fan":

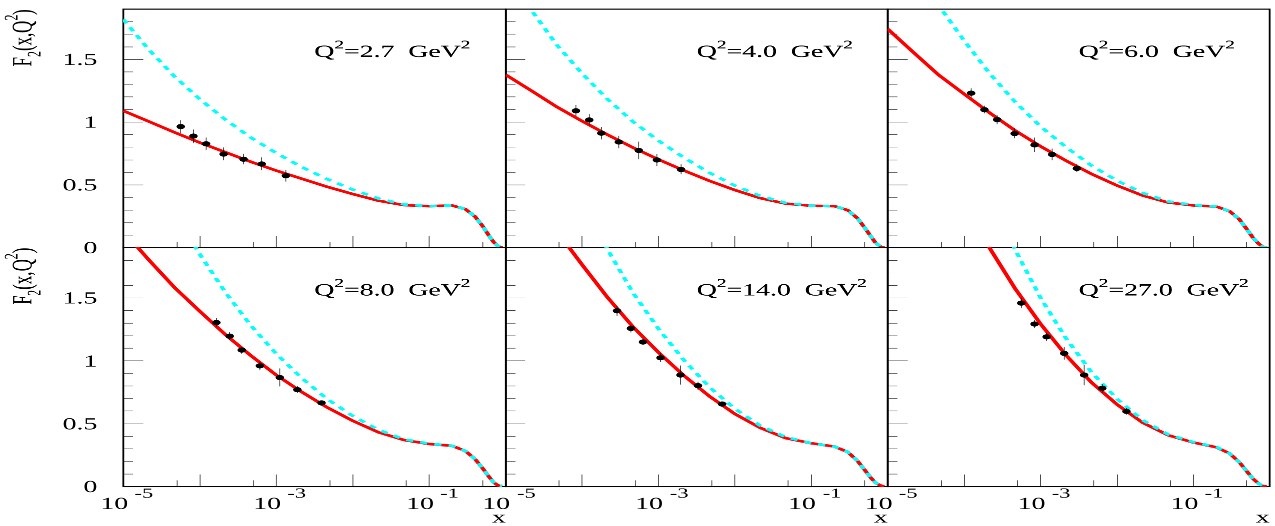


How large are screening corrections?

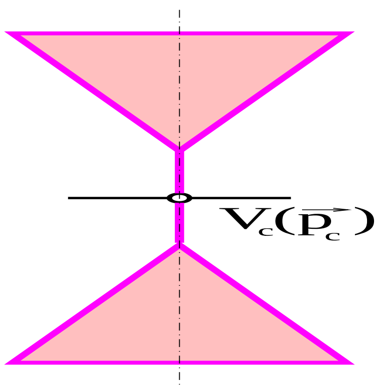
Example: cross sections and SF F_2 with (without) enhanced graphs

(Q_0=1 GeV^2):

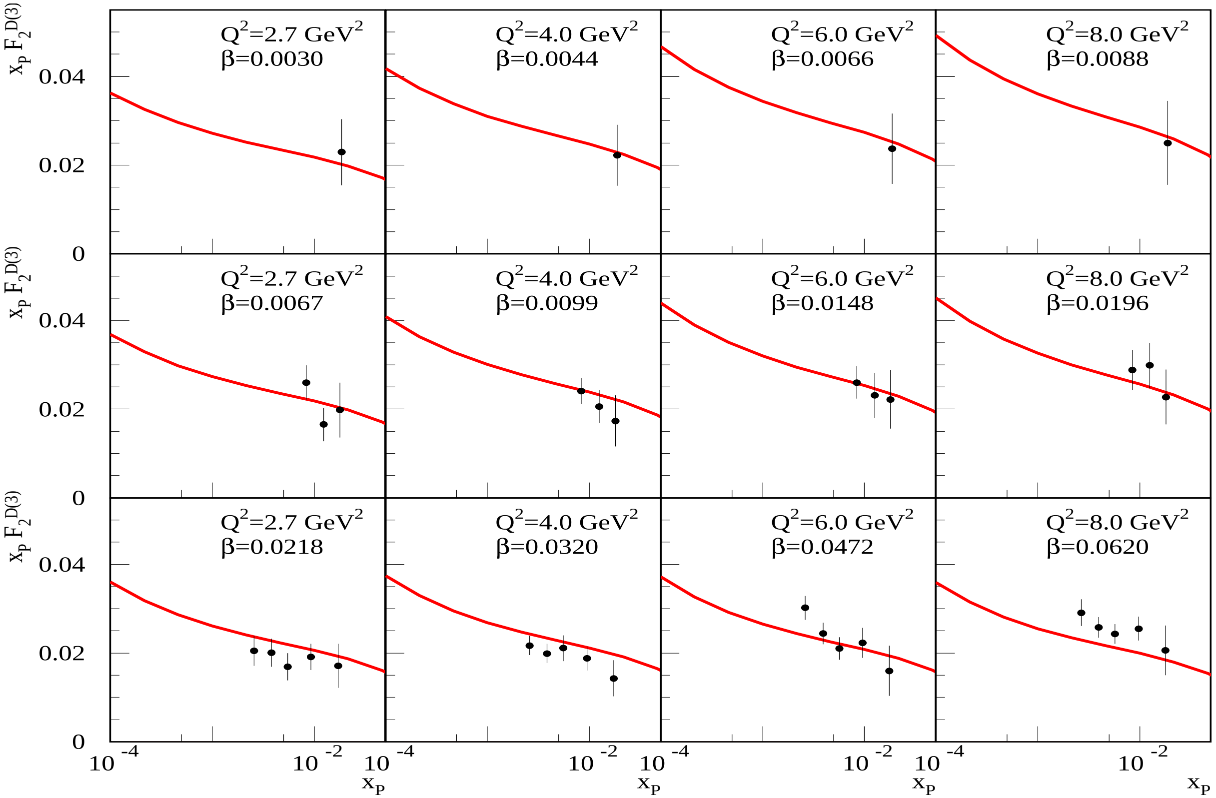




Important remark: inclusive jet spectra - still defined by a factorized ansatz:



Triple-pomeron vertex - can be inferred from "hard" diffraction in DIS (ZEUS forward plug data: Chekanov et al., 2004):



Remark: particle production is more restrictive - $Q_0^2 \geq 2 \div 2.5$ GeV^2 needed

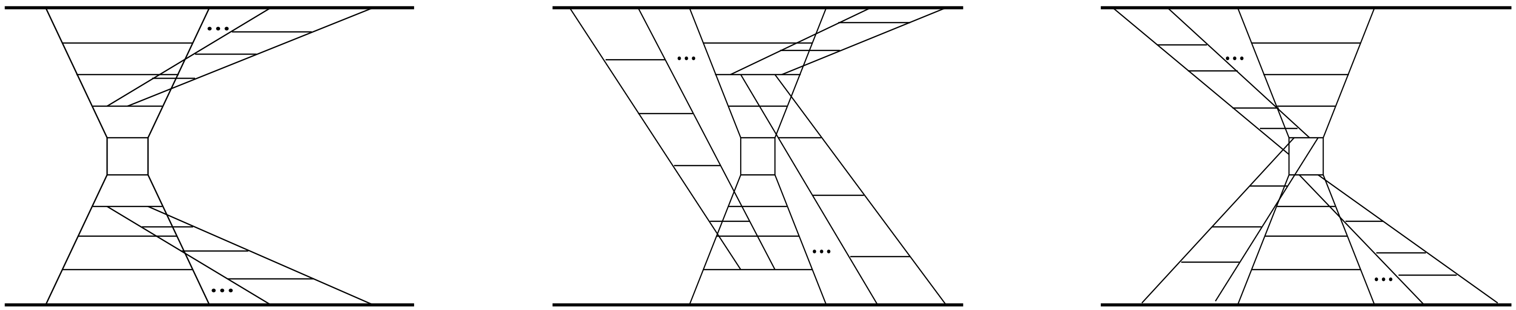
Thus, cross section & SF behavior does not imply a rising saturation scale

What is missing?

Pomeron-pomeron coupling at $|q|^2 > Q_0^2$:

- will not influence $\sigma_{pp}^{\rm tot}$ - requires high parton density $\Rightarrow$ "black" region
- may sizably influence particle production

Contributions of three types:



- factorizable graphs (multi-pomeron vertices hidden in PDFs)
  - seem to be small at HERA?
- non-factorizable ones (not coupled to the hard process):
  - not present in PDFs (SFs)
  - do not influence high p_t production (if AGK cancellations apply?)

- coupling to the hard process - factorization breaking:
  - could significantly influence high p_t production
  - can be (are?) studied at HERA

Key questions (personal view):

- AGK rules validity?
- triple-pomeron coupling or multi-pomeron coupling?

Outlook

Inferring p_t cutoff (saturation scale) from cross sections - misleading:

- significant non-factorizable corrections to semi-hard contribution (not present in SFs)
- $\Rightarrow$ dynamical scheme preferrable

Next step: both "soft" (low $|q|^2$) and "hard" ($|q|^2 > Q_0^2$) pomeron coupling

Coupling to hard process seems to be most important?

Alternative - reggeon calculus based on BFKL pomeron?

Caveat: energy-momentum correlations between multiple re-scatterings?