Theoretical overview on soft diffraction.

A.B.Kaidalov
ITEP, Moscow
EDS09, CERN, 29 June 2009

Contents.

- Introduction. s- and t-channel points of view for diffraction.
- Unitarity effects in Gribov`s approach.
- Interplay of soft and hard diffraction.
- Large mass diffraction and role of pomeron interactions.
- Conclusions.

Introduction.

- Diffractive processes constitute ≈ $\frac{1}{2}\sigma^{(tot)}$. Investigation of these processes gives an important information on dynamics of strong interactions at high energies.

Some important problems of diffraction:

- The nature of the pomeron in QCD.
- Role of s-channel unitarity and multi- pomeron exchanges.
- Small-x problem and "saturation" of partonic densities as $x \to 0$.
- Violation of QCD and Regge factorization in diffractive processes.

s-channel view of diffraction.

Absorption of an initial wave due to existence of many inelastic channels leads by unitarity to diffractive elastic scattering.

Diffractive production. Elastic scattering of costituents. E.Feinberg, I.Pomeranchuk (1952).

Good and Walker interpretation of diffraction.

M.L.Good, W.D.Walker (1960).

It is assumed that diffractive part of S-matrix is

s-channel view of diffraction.

purely imaginary matrix $iD_{ik}(s,b)$, which can be diagonalized by an orthogonal matrix

Eigen states have only elastic scattering.

$$D = QFQ^T, F_{ij} = F_i \delta_{ij}$$

$$\Psi_i = \sum_k C_{ik} \phi_k$$

After diffractive scattering a final state is a new superposition of eigen states and inelastic diffractive transitions take place.

s-channel view of diffraction.

Total, elastic and diffractive cross sections

$$\frac{d\sigma_{\rm tot}}{d^2b} = 2\,{\rm Im}\langle i|T|i\rangle = 2\sum_k |C_{ik}|^2\, F_k = 2\langle F\rangle$$

$$\frac{d\sigma_{\rm el}}{d^2b} = |\langle i|T|i\rangle|^2 = \left(\sum_k |C_{ik}|^2\, F_k\right)^2 = \langle F\rangle^2$$

$$\frac{d\sigma_{\rm el\,+\,SD}}{d^2b} = \sum_k |\langle \phi_k|T|i\rangle|^2 = \sum_k |C_{ik}|^2\, F_k^2 = \langle F^2\rangle.$$

s-channel view of diffraction.

Inelastic diffraction is related to a dispersion of eigen amplitudes

$$\frac{d\sigma_{\mathrm{SD}}}{d^2b} = \langle F^2 \rangle - \langle F \rangle^2,$$

If all F_i are equal (black disc limit) then inelastic diffraction is absent. In general for

$F_i \leq 1$: Pumplin`s bound

$$\sigma^{(el)}(s,b) + \sigma^{(inD)}(s,b) \leq \frac{1}{2}\sigma^{(tot)}$$

s-channel view of diffraction.

Note that GW approach assumes a separation of diffractive and inelastic states, which is not true for large mass diffraction. Pumplin`s bound can be violated at very high energies.

Diffractive production in s-channel approach is peripheral in the impact parameter b. Strong influence of unitarity effects.

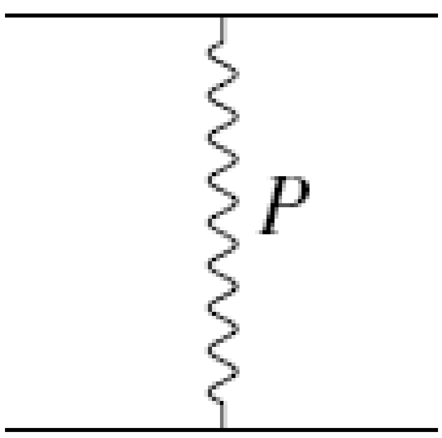
t-channel view of diffraction.

- In the Regge pole model diffractive processes are described by the leading factorizable pole with vacuum quantum numbers – pomeron.

Supercritical pomeron

with $\alpha_P(0)-1 \equiv \Delta > 0$ is

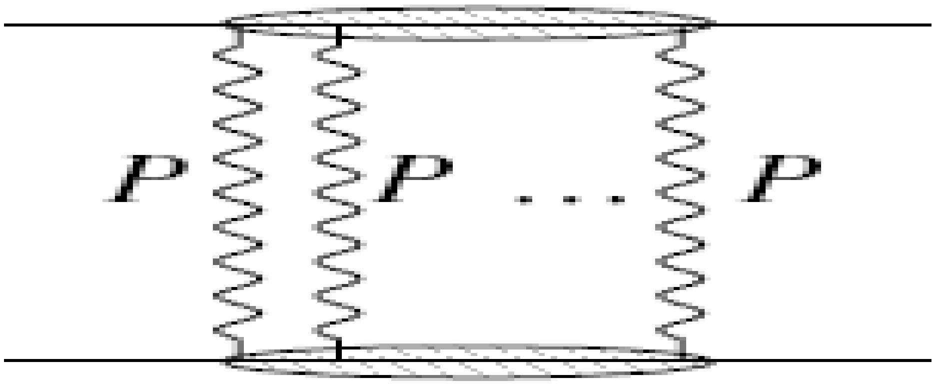
preferred by the data.



t-channel view of diffraction.

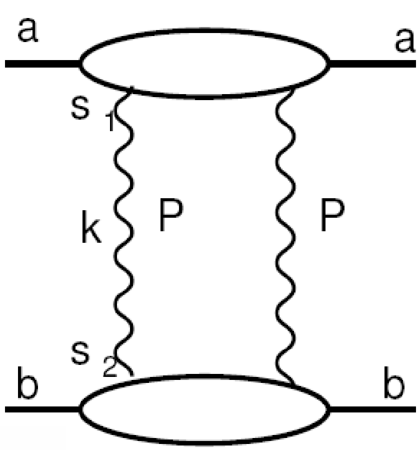
Single P-exchange with Δ > 0 violates unitarity: $f_l^{el} \sim s^{\Delta}, \quad |f_l^{el}| \leq 1.$

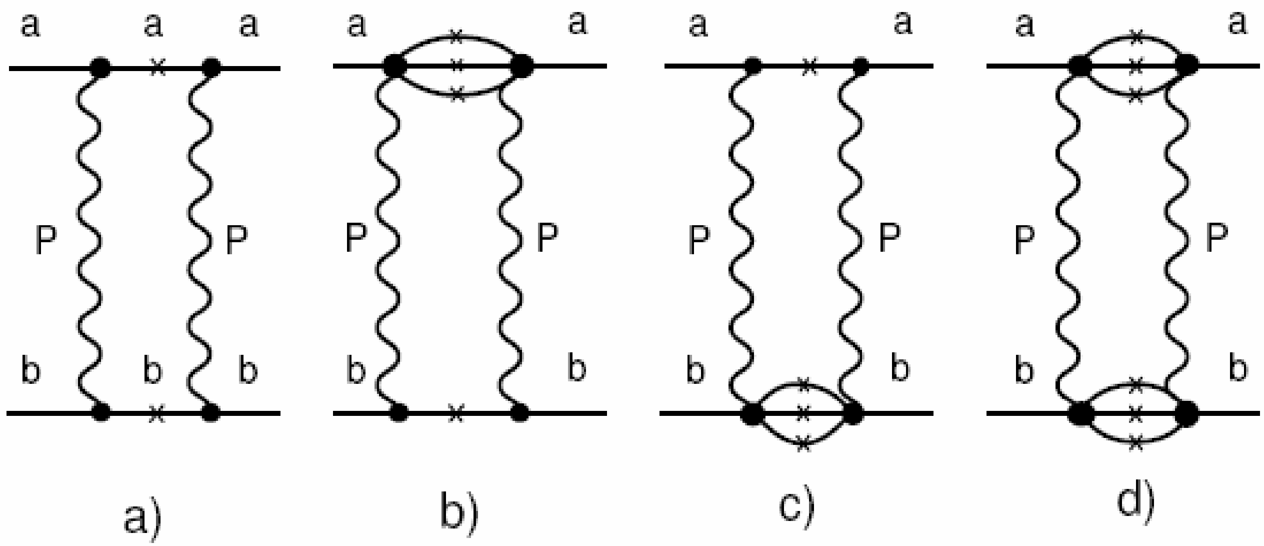
Multi-pomeron exchanges are necessary to restore unitarity.



Unitarity effects in Gribov`s approach.

Consider PP-exchange
Amplitudes can be expressed
In terms of contributions of
diffractive intermediate states.





Gribov`s diagrams technique.

Summation of nP-exchanges with account of poles only leads to the eikonal amplitudes

$$\mathrm{Im}T_{\mathrm{el}}(s,b) \;=\; 1-\mathrm{e}^{-\Omega/2}$$

with i$\Omega \equiv 4\delta_P(s,b)$ -Fourier transform of $T_P(s,t)$.

$$\mathrm{Im}\,\delta_P(s,0) \sim (\frac{s}{s_0})^{\Delta}\exp(-\frac{b^2}{\lambda_P(s)}) = \exp(-\frac{b^2}{\lambda_P(s)} + \Delta\ln\frac{s}{s_0})$$

$$\lambda_P(s) = R^2 + \alpha'_P\ln(\frac{s}{s_0}) \;,\; R^2(s) = \lambda_P(s)\Delta\ln(\frac{s}{s_0}) \simeq \alpha'_P\Delta\ln^2(\frac{s}{s_0})$$

Account of low-mass diffraction.

For resonances in intermediate states Ω_{ik} is a matrix in the space of diffractive states: multi-channel eikonal.

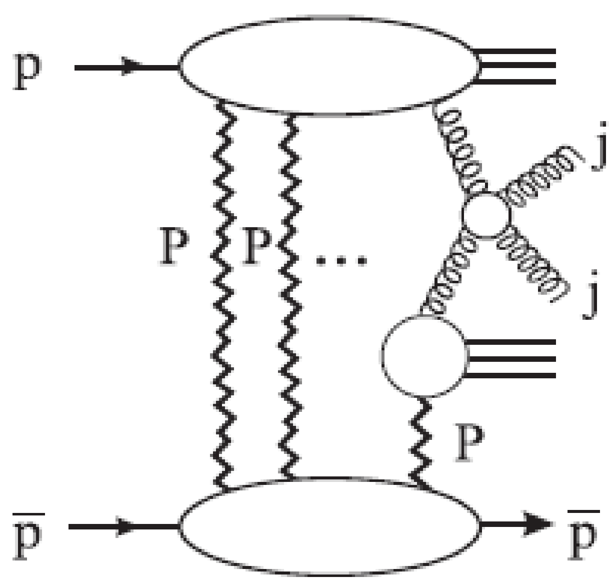
"Quasieikonal" approximation:

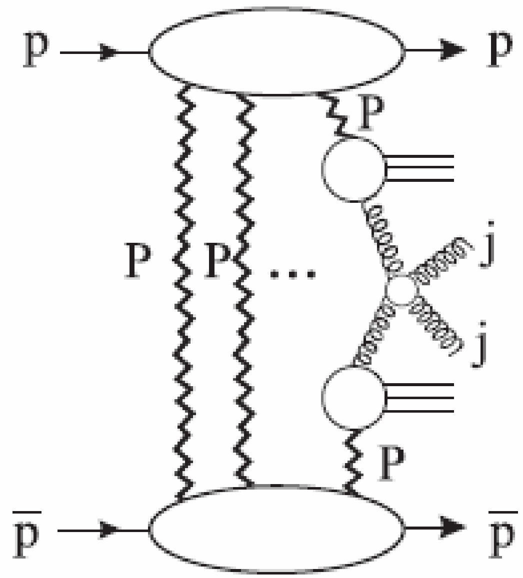
$$f(s,b) = \frac{e^{2i\delta_P(s,b)\cdot C} - 1}{2iC}\ ; \quad C = 1 + \frac{\sigma_{in}^{D}}{\sigma^{(el)}} > 1$$

corresponds to maximum inelastic diffraction consistent with unitarity.

Unitarity effects for hard diffractive processes.

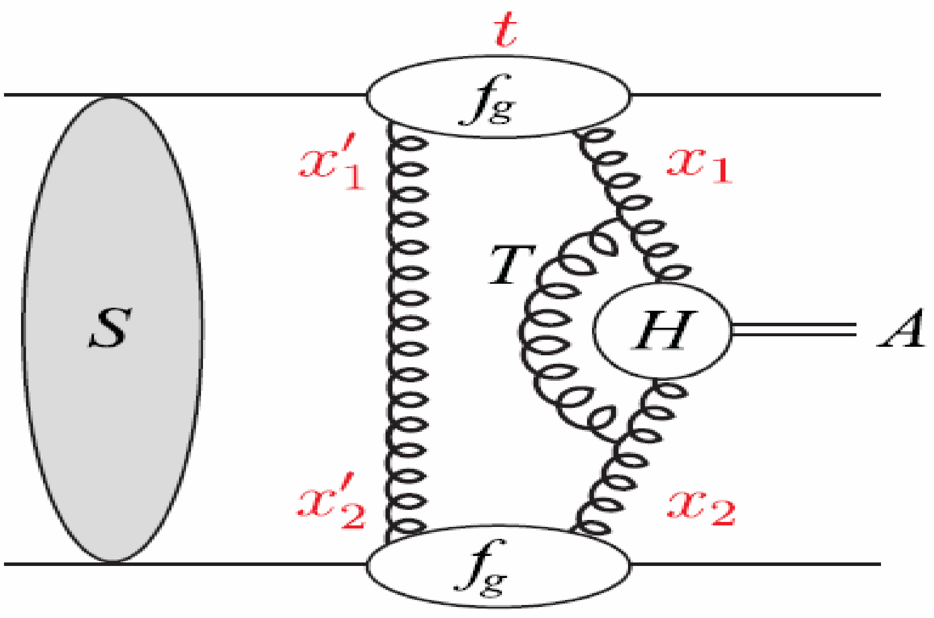
Both Regge and QCD factorizations of the lowest order diagrams are strongly broken due to multipomeron exchanges . Interplay of soft and hard diffraction.





DPE Higgs production.

Central exclusive production of a Higgs boson at very high energies. Cross section depends on gap survival probability.



Survival probability.

A value of suppression of cross section of diffractive production process compared to the “born” (Regge pole exchange) approximation is often called “survival probability” - S^2.

In the eikonal approximation:

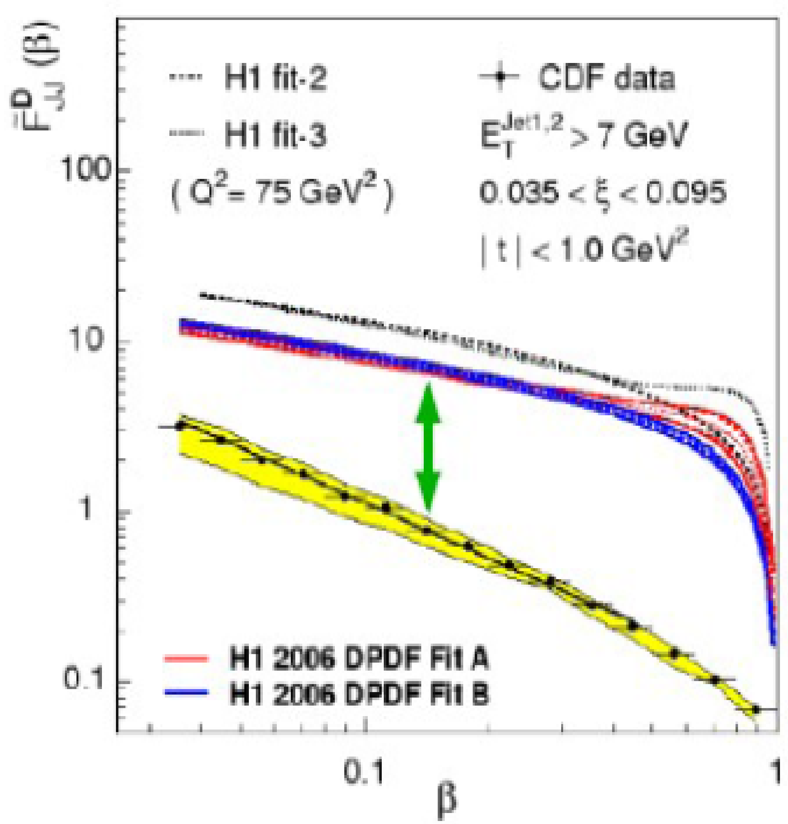
$$S^2 = \frac{\int |\mathcal{M}(s,b)|^2 e^{-\Omega(b)} d^2b}{\int |\mathcal{M}(s,b)|^2 d^2b},$$

$e^{-\Omega(b)}$ -probability not to produce particles (to fill the gap)

$$\Omega(b) \equiv -4i\delta_P(s,b)$$

Suppression of diffractive dijets at Tevatron.

H1 fits vs. Tevatron



Suppression in hadronic interactions is due to multipomeron exchanges.
V.Khoze et al (KKMR)
describe CDF data in multi-channel eikonal model.
Important for Higgs production at LHC.

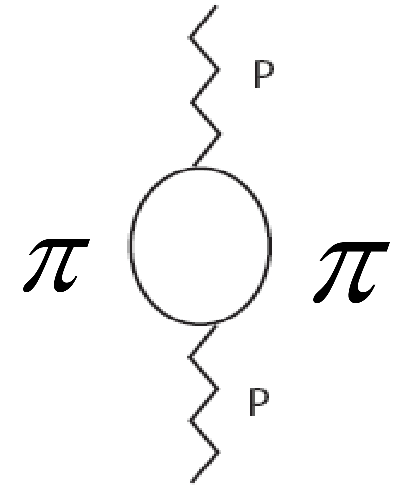
Consequences of unitarity effects.

Strong suppression of inelastic diffraction in the region of small b, where Ω»1. Inelastic diffraction occur at the periphery of interaction region (as in the s-channel approach), where nonperturbative effects are essential.

Account of ππ-cut in the pomeron trajectory and residues is very important (especially for small α'_P). It leads to correct behavior of amplitudes at large impact parameters.

Cut in the pomeron trajectory.

Imagunary part of the pomeron trajectory at ππ-cut follows from t-channel unitarity.



$$\operatorname{Im}\alpha_P(t) = \frac{b_P(t)(t-4\mu^2)^{(\alpha_P(t)+1/2)}}{16\pi C(\alpha_P(t))(4s_0)^{\alpha_P(t)}\sqrt{t}}$$

$$t \to 4\mu^2$$

where $\quad C(j) = \dfrac{\pi\Gamma(2j+2)}{2^{(2j+1)}\Gamma(j+1)^2} \quad , s_0 = 1GeV^2$

$$\sigma^{(tot)}(s) = \frac{b_P(0)}{s_0}\left(\frac{s}{s_0}\right)^{(\alpha_P(0)-1)}$$

Cut in the pomeron trajectory.

- Due to smallness of μ² cut is close to t=0 and influence trajectory at small t. For $\alpha_P(0) = 1$ contribution of ππ-cut has the form A.A.Anselm, V.N.Gribov (1972)

$$\alpha_P^{(\pi\pi)} = -\frac{\sigma_{\pi\pi}^{(tot)}\mu^2}{32\pi^3} h(\frac{4\mu^2}{q^2}), \quad q^2 \equiv -t$$

$$h(\tau) = \frac{4}{\tau}\left(2\tau - (1+\tau)^{3/2} \ln\frac{\sqrt{1+\tau}+1}{\sqrt{1+\tau}-1} + \ln\frac{m^2}{\mu^2}\right)$$

Influence of ππ-cut on α'_P

Large distance dynamics due to pion exchange leads to a lower bound on α'_P

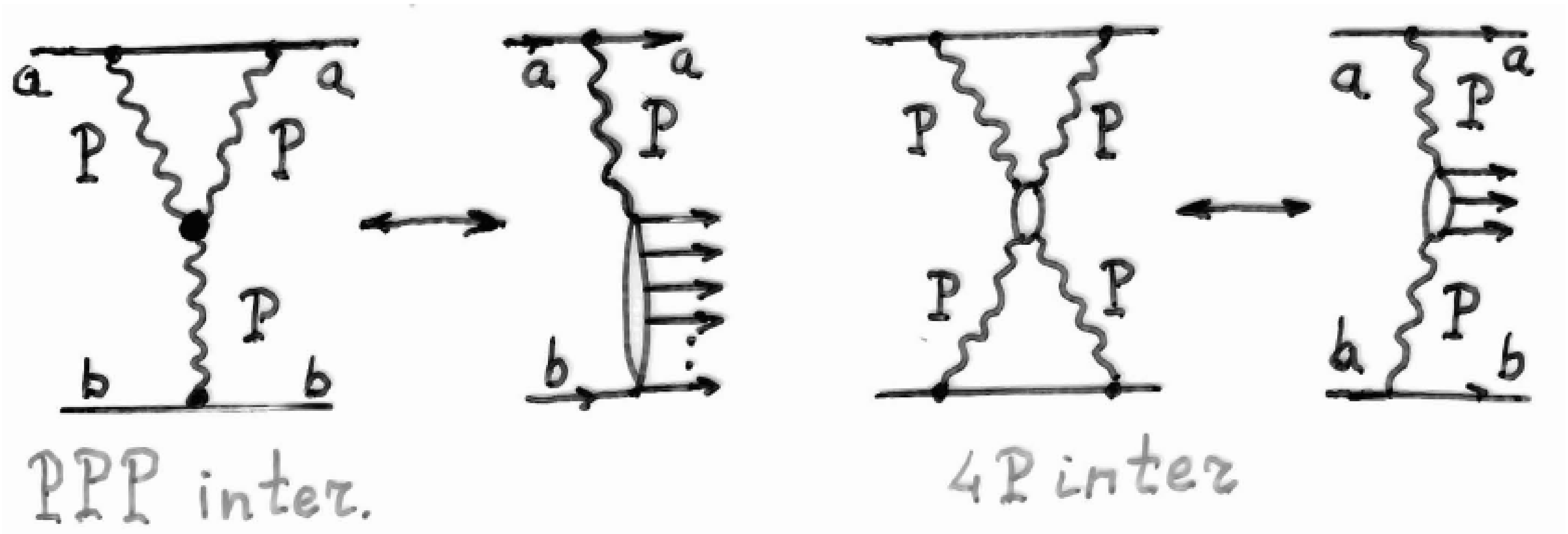
$$\delta\alpha'_P(0) = \frac{\sigma_{\pi\pi}^{(tot)}}{32\pi^3}\left(\ln\frac{m^2}{\mu^2} - 2\right) \approx 0.05 GeV^{-2}$$

Substantial curvature of the pomeron trajectory in the small t-region.

The cut in the pomeron trajectory is important to resolve some problems of inelastic diffraction for supercritical pomeron.

Large mass diffraction.

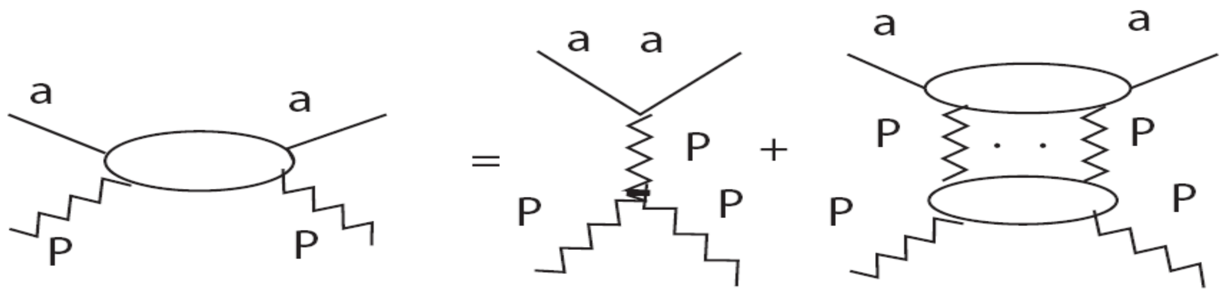
In Regge-model single diffraction dissociation to large masses is described by triple-regge diagrams.



Large rapidity gaps $\delta y > y_0$.

Large mass diffraction and interactions of pomerons.

For large masses $M^2 \gg 1\ GeV^2$



Triple-pomeron and n→2 pomeron vertices. In general there are n→m P vertices g_m^n

In eikonal approximation $$g_m^n = Cg^{n+m}$$

This is natural from point of view of t-channel unitarity.

Different approaches to the theory of interacting pomerons.

Theory of supercritical pomeron with triple-pomeron interactions is studied since 70-ies D.Amati et al (1976)

It is not clear that such theory is consistent with s and t-channel unitarity.

Partonic interpretation indicates that 4P-interaction is necessary for consistency.

K.Boreskov (2001), S.Bondarenko et al (2006)

Different approaches to the theory of interacting pomerons.

Summation of all enhanced diagrams

with $g_m^n = Cg^{n+m}$ has been performed by

A.K., K.Ter-Martirosyan, L.Ponomarev (KT-MP) (1986).

Good description of pp

total cross section, elastic scattering

and σ_{SD} with Δ=0.2. Correct predictions of

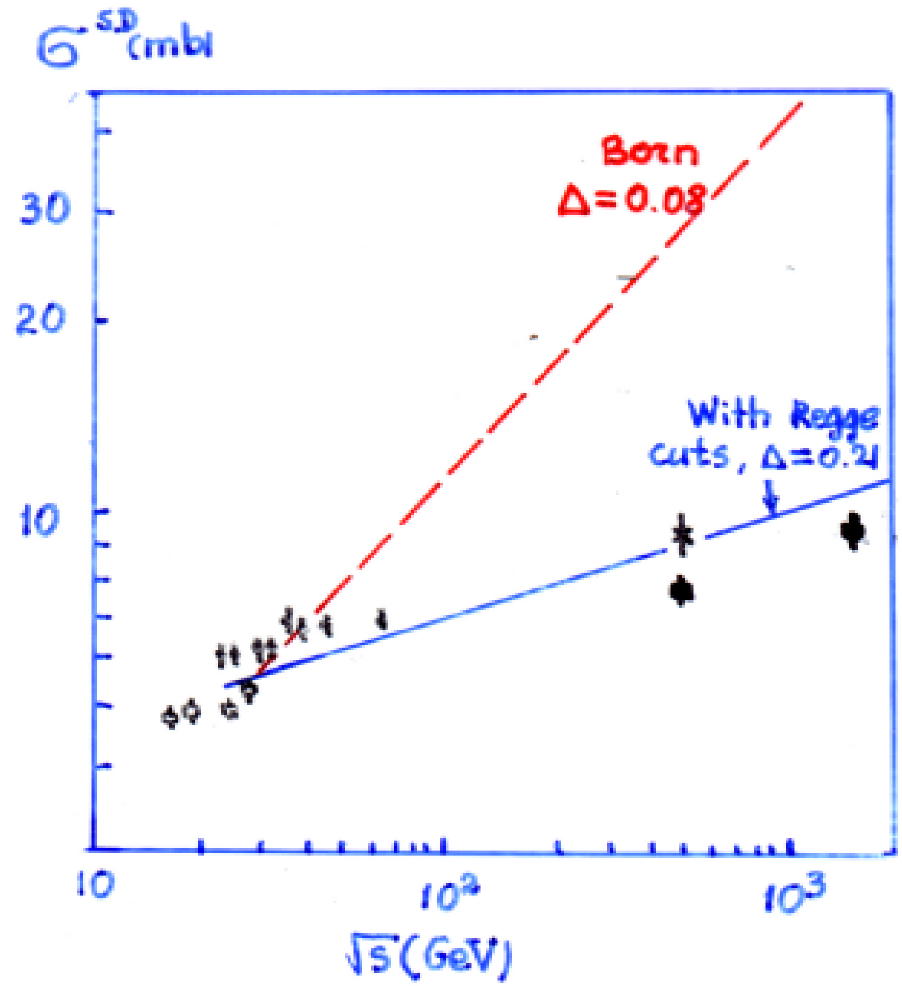
single diffraction dissociation cross section

for Tevatron.

Single diffractive dissociation.

Note a substantial increase of Δ compared to Δ_{eff}. Triple-pomeron coupling is about 3 times larger than the effective one.

Important role of limitations on rapidity gaps $\delta y > y_0$.



Recent models for diffractive processes.

Cutting rules for diagrams, which take into account multi-pomeron interactions and Monte Carlo formulation of the quark-gluon strings model (QGSM) have been developed by S.Ostapchenko (2006-08).

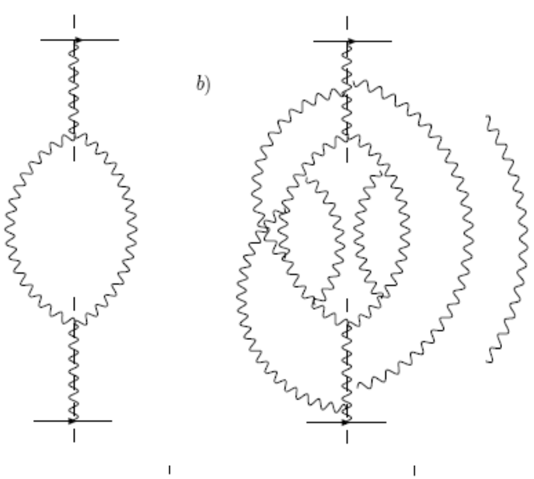
Detailed description of large mass diffractive production with account of multi-pomeron exchanges. M.Poghosyan (2007)

Recent models for diffractive processes.

Durham group KMR (2007,2008) approach
Multi-P vertices based on parton model. Three pomerons: soft, semihard, hard.

$$g_m^n = Cnmg^{n+m}$$

Different approach by Tel-Aviv group
E.Gotsman, E.Levin,U.Maor,J.S.Miller (2008)(GLM)
2-channel eikonal diagrams +
triple-pomeron interaction



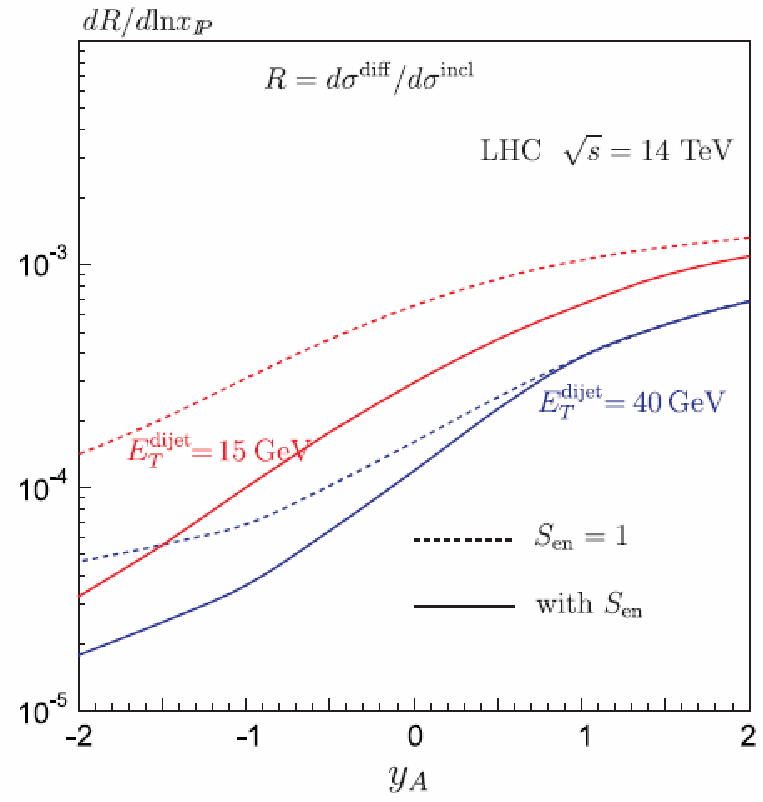
σ_{tot}, $d\sigma_{el}/dt$, σ_{SD}, σ_{DD} in pp collisions are described. $\Delta=0.33$

Role of enhanced diagrams.

Recent calculation of S^2_{enh} by KMR (2008).

Threshold effects play an important role.

S^2_{enh} can be essential for soft processes.



Conclusions.

- Multi-pomeron exchanges are important for understanding of high-energy interactions.

  They lead to a violation of Regge and QCD factorization.
- Nonperturbative effects are essential for inelastic diffraction at large b.
- Investigation of diffractive processes at LHC can give answers to many questions of diffraction theory.