A Baryonic Impact Factor

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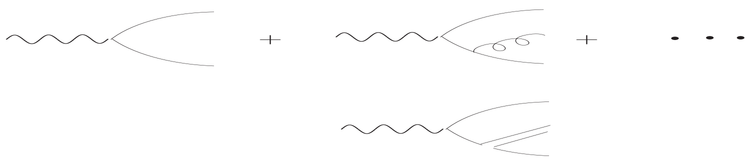
- Introduction
- The baryon wave function
- Decomposition of the Impact Factor
- Evolution
- Conclusions

Collaboration with Leszek Motyka

Introduction

Very popular: color dipole picture (large-N_c), much used in DIS:



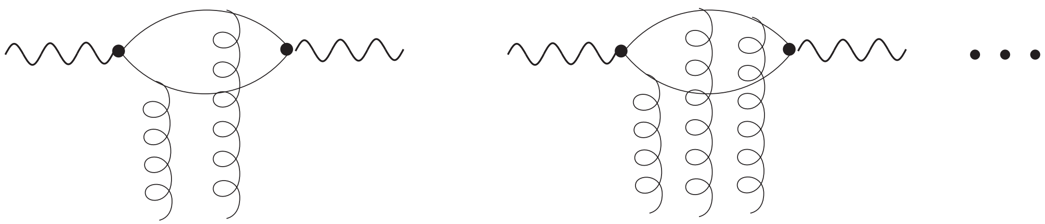
Question: how much of the dipole picture can be used in hadron-hadron (hadron-nucleus) scattering? Obviously:

- proton is 3 quark state - not a dipole
- In large-N_c: proton would be N_c-quark state

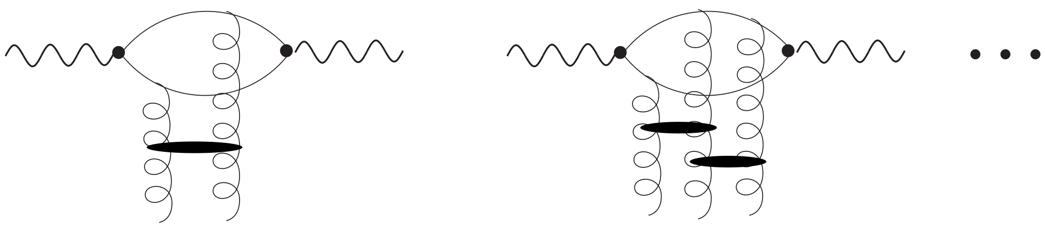
About ten years ago (Praszalowicz,Rostworowski)):
Problem with color dipole picture for the proton,
'Each step in rapidity evolution creates new color configuration'

Two steps: baryon impact factor and evolution.
How to address: t-channel approach, BFKL approximation

Impact factor:

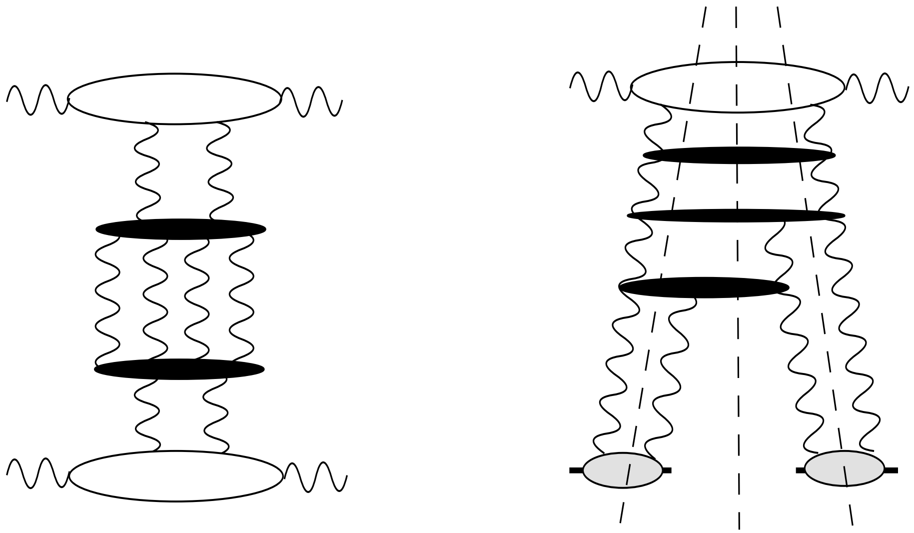


Gluon emission $\longrightarrow$ evolution:



Repeat the analyis of DIS: use virtual photon $\longrightarrow$ heavy baryon.

How to perform systematic study: consider scattering on nucleus, multiple energy discontinutity:

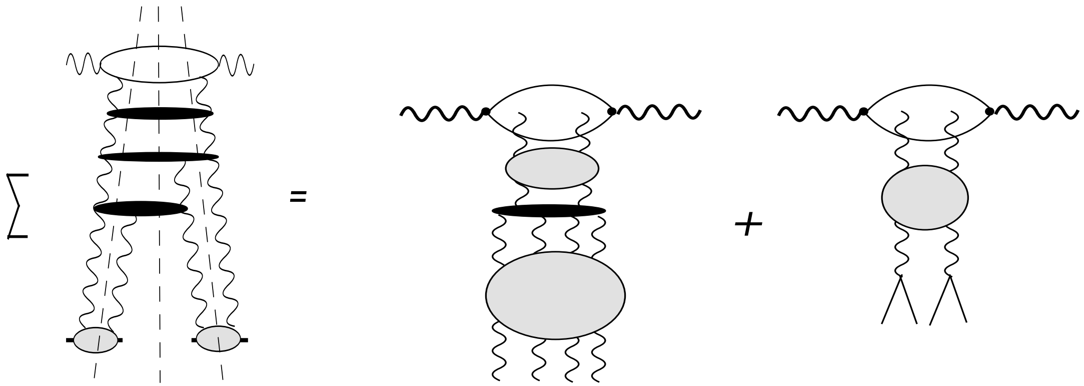


Advantage: independent energy variables, stay in leading log approximation.

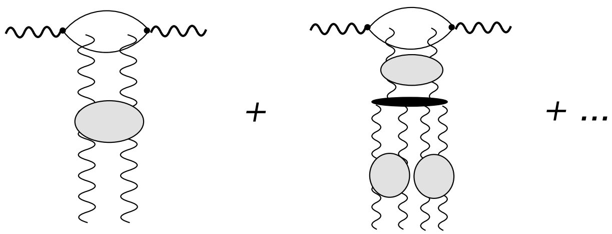
In order to go from multiple discontinuities to amplitudes: use signature factors, e.g.

$$disc\ \ T(s,t) = s \int \frac{d\omega}{2\pi i} s^{\omega} F(\omega,t) \leftrightarrow T(s,t) = s \int \frac{d\omega}{2\pi i} s^{\omega} \frac{e^{-i\pi\omega} - 1}{\sin \pi\omega} F(\omega,t)$$

In the photon case one finds a remarkable simplification: after reordering (bootstrap), a fan-like structure emerges:



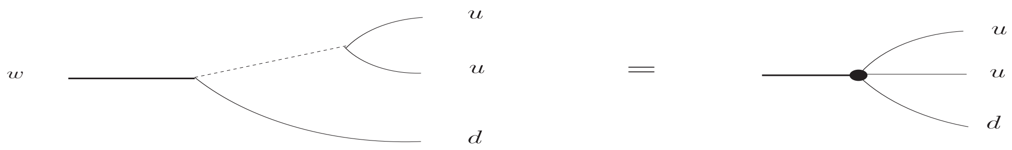
Reggeization, bootstrap.
Contains elastic unitarity. Large N_c: BK equation.



In the following: apply the same analysis to a baryonic impact factor.

The baryon wave function

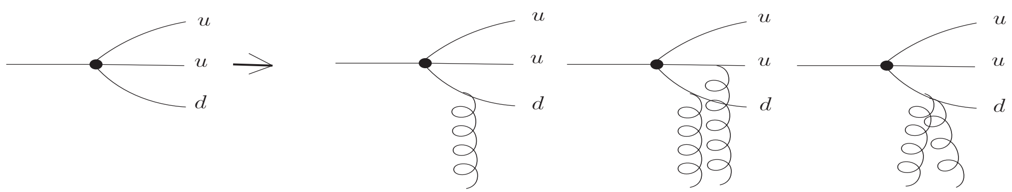
A few technicalities:
start from 4-Fermi operator (Ioffe):



$$\epsilon_{abc} u(x)^{aT} C \gamma^{\mu} u(x)^{b} \; w(x) \gamma_5 \gamma_{\mu} d(x)^{c}$$

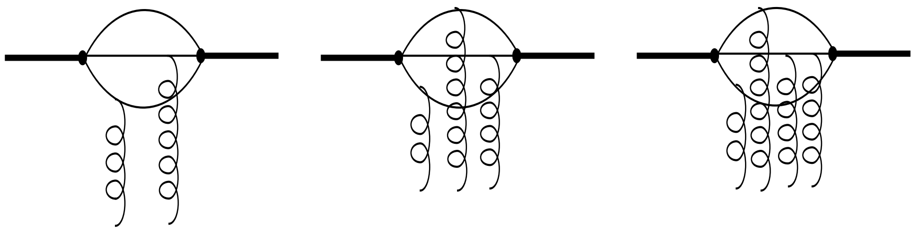
More realistic: include nonperturbative wave function;
Borel transform, from QCD sum rules.

Use helicity basis, infinite momentum frame, eikonal approximation:



$$\Theta_{\lambda}^{(\lambda_1,\lambda_2)\,\lambda}(\{\alpha_i\},\{\boldsymbol{p}_1,\boldsymbol{p}_2,\boldsymbol{p}_3\},\boldsymbol{P}) = \lambda\,\mathcal{N}\,\frac{2\sqrt{\alpha_1\alpha_2\alpha_3}}{M^2+\boldsymbol{P}^2-\frac{\boldsymbol{p}_1^2}{\alpha_1}-\frac{\boldsymbol{p}_2^2}{\alpha_2}-\frac{\boldsymbol{p}_3^2}{\alpha_3}}\;\delta_{-\lambda_1,\,\lambda_2}\;\delta^{(2)}(\boldsymbol{p}_1+\boldsymbol{p}_2+\boldsymbol{p}_3-\boldsymbol{P})$$
$$\cdot\Big\{\,\delta_{\lambda_1,\,\lambda}\,\Big[\Big(\frac{\boldsymbol{p}_1}{\alpha_1}-\boldsymbol{P}\Big)\cdot\Big(\frac{\boldsymbol{p}_2}{\alpha_2}-\frac{\boldsymbol{p}_3}{\alpha_3}\Big)\;-\;i\lambda\,\Big(\frac{\boldsymbol{p}_1}{\alpha_1}-\boldsymbol{P}\Big)\times\Big(\frac{\boldsymbol{p}_2}{\alpha_2}-\frac{\boldsymbol{p}_3}{\alpha_3}\Big)\Big]$$
$$+\,\delta_{\lambda_2,\,\lambda}\,\Big[\Big(\frac{\boldsymbol{p}_2}{\alpha_2}-\boldsymbol{P}\Big)\cdot\Big(\frac{\boldsymbol{p}_1}{\alpha_1}-\frac{\boldsymbol{p}_3}{\alpha_3}\Big)\;-\;i\lambda\,\Big(\frac{\boldsymbol{p}_2}{\alpha_2}-\boldsymbol{P}\Big)\times\Big(\frac{\boldsymbol{p}_1}{\alpha_1}-\frac{\boldsymbol{p}_3}{\alpha_3}\Big)\Big]\Big\}$$

Square, sum over helicities, compute color traces, sum over all possibilities of attaching gluons:



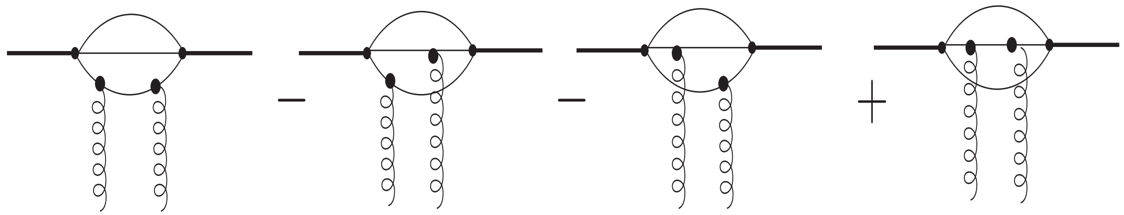
Results: decompose the impact factor into irreducible (under evolution) and gauge invariant pieces:

$$T = T_{dipole} + T_{odderon} + T_{new}$$

Main task: color structere.

Decomposition of the impact factor

A.Two Gluons (C even): 'normal' dipole structure. The pair (23):

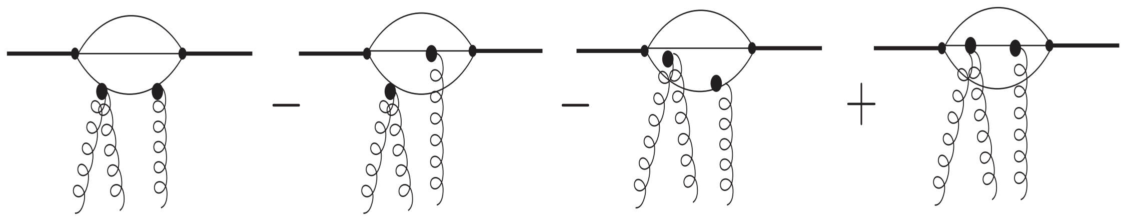


Dipole structure, but lines 2 and 3 are in antitriplet.
'Antitriplet dipole'
Contains diquark configuration, depends upon dynamics of wave function.

$$\left(D_{20}^{23}(k_1, k_2) + D_{20}^{13}(k_1, k_2) + D_{20}^{12}(k_1, k_2) \right) \delta_{ab}$$

Satisfies Ward identities.

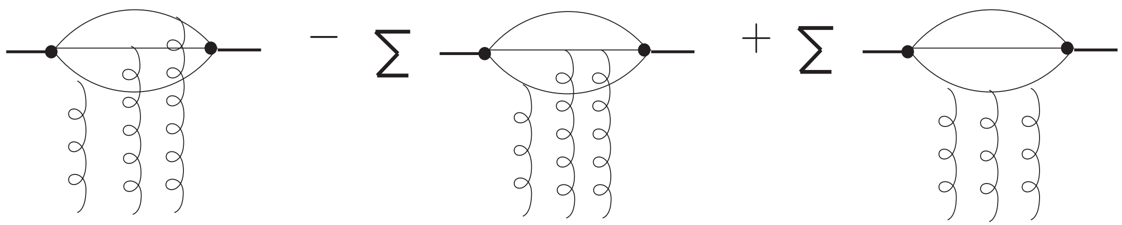
B. Three gluons (C even): reggeization of the 2 gluon system



$$\left(D_{20}^{23}(k_1+k_2,k_3)+D_{20}^{23}(k_1+k_3,k_2)+D_{20}^{23}(k_1,k_2+k_3)\right) f_{abc}+D_{20}^{12}+D_{20}^{13}$$

Reggeization + bootstrap, similar to photon impact factor.

Three gluons (C odd): Odderon (C.Ewerz)

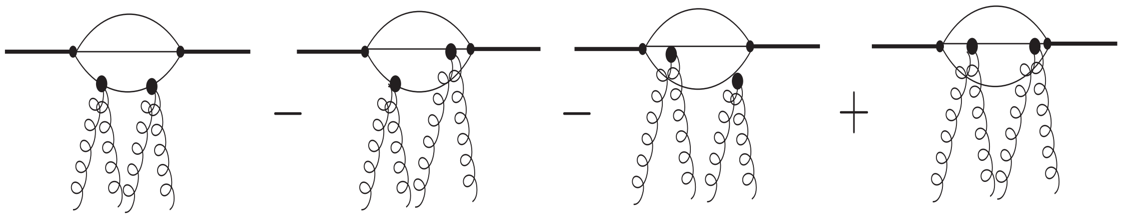


New function: $E_{30}(k_1,k_2,k_3)$. Satisfies Ward identities. Nonabelian charge configuration.

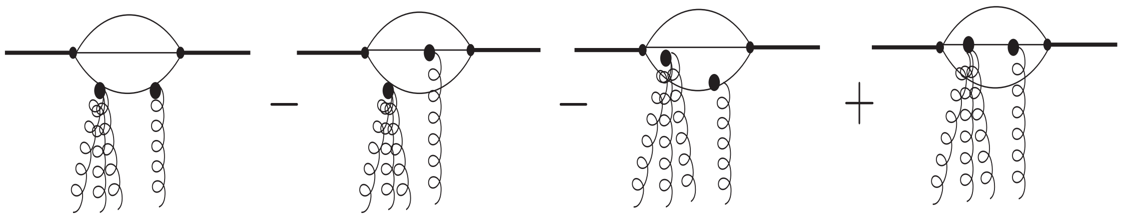
C. Four gluons (C even): different pieces

- reggeization of the 2 gluon system
- new configuration

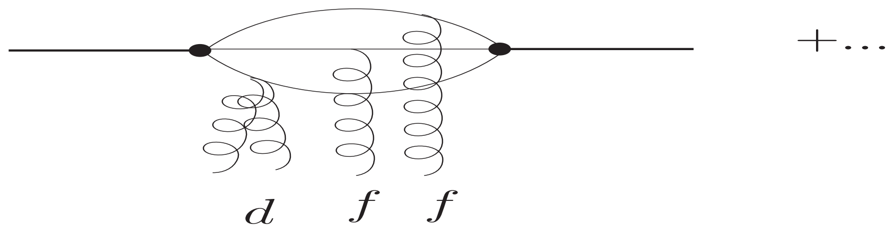
$D_{20}^{23}(k_1 + k_2, k_3 + k_4)$:



$D_{20}^{23}(k_1 + k_2 + k_3, k_4)$:



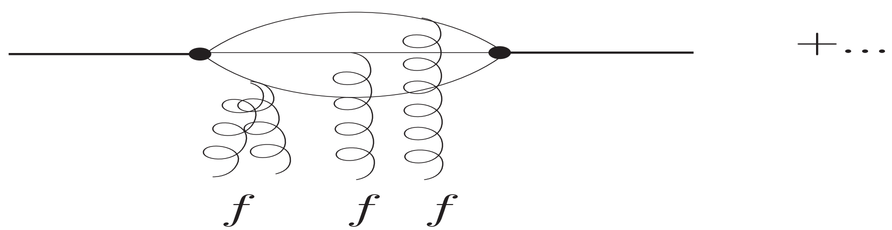
The new configuration: C even, even signature



$$Q_{4,0}(1,2,,3,4) = \left(d_{a_1a_2c}d_{a_1a_2c} - \frac{1}{3}\delta_{a_1a_2}\delta_{a_3a_4}\right)\left[E_{30}(1+2,3,4,) + E_{30}(1,2,3+4)\right]$$

Sum over all permutations satisfies Ward identities. Needs all 3 quarks.

Four gluons (C odd): reggeization of the odderon (C.Ewerz)



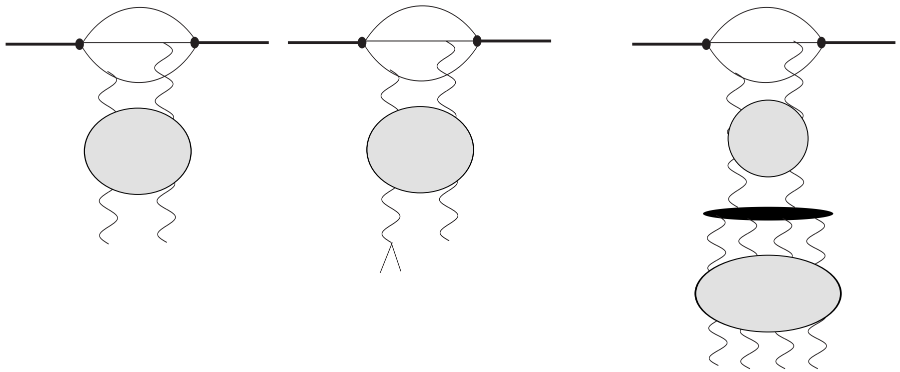
$$E_{30}(k_1+k_2,k_3,k_4)d_{a_1a_2c}f_{a_1a_2c}$$

S-channel picture: Fourier transform to transverse coordinates.

Evolution, gluon radiation

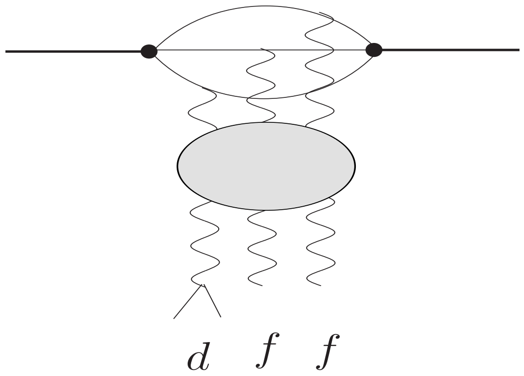
The decomposition of the impact factor is preserved under evolution.

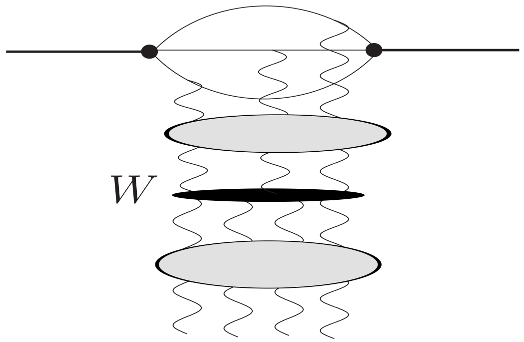
Dipole-like term (color anti-triplet):



Looks like photon impact factor, fan structure... (BK equation?)
Contains the diquark configuration, but it also allows for spacial separation.

The new piece:
a new vertex appears (good properties, e.g. Möbius invariant):



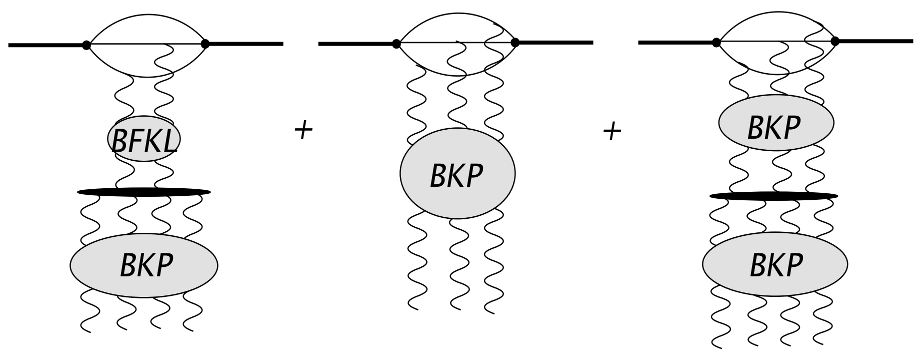


s-channel picture: radiation from all three quarks, new evolution kernel.

In addition:
C-odd, Odderon: both the BLV and the WJ solutions couple.

Summary and Discussion

In comparison wirth photon or meson (=color dipole), baryon has more complex pattern of gluon radiation:



+ reggeizing pieces

- Baryon contains dipole-like configuration (diquark): same pattern as in the photon case, but with relative coupling $1/2$.
- Baryon couples to the Odderon (C-odd), both WJ and BLV solutions

- New vertex: transition from C-even three gluon state $\longrightarrow$ two-Pomerons
- In LO no direct coupling of two Pomerons: 'disappearance of elastic intermediate state' (reggeization and bootstrap).

Can we neglect the 'new' contributions? Most likely not.

Unitarity requires:

$$|T(s,b)| = |\frac{1}{2}\sum T_{dipole} \pm T_{odderon} + T_{new}| \leq 1$$

Assume: each dipole-like configuration saturates at high energies

$$T_{dipole} \longrightarrow 1,$$

sum of three dipole configurations violates bound!

New contribution is needed for unitarity!

Deeper connection between all pieces.

Consequences:

QCD reggeon field theory contains more than BFKL Pomerons $+$ interactions, importance of three gluon state (not necessarily odderon!) and d-reggeons.

Interesting possibility: connection with Casimir Operators.
In SU(2): two Casimirs, baryon couples to states with two gluons (BFKL) and three gluons (Odderon).
Two 'fundamental excitations'.
In $SU(N)$: $N-1$ Casimir operators.
Baryon consists of N quarks, couples to t-channel states with 2, 3, ...N gluons (in fundamental representation):

Baryon excites all the 'fundamental excitations of high energy QCD'.

Applications:

- Model for nucleon (spin and color structure).
- elastic pp scattering at intermediate t (ISR: 3 gluon model)
- Spin physics?

Most important:

Think about finding solutions to QCD reggeon field theory!