Diffractive vector meson photoproduction at large momentum transfer

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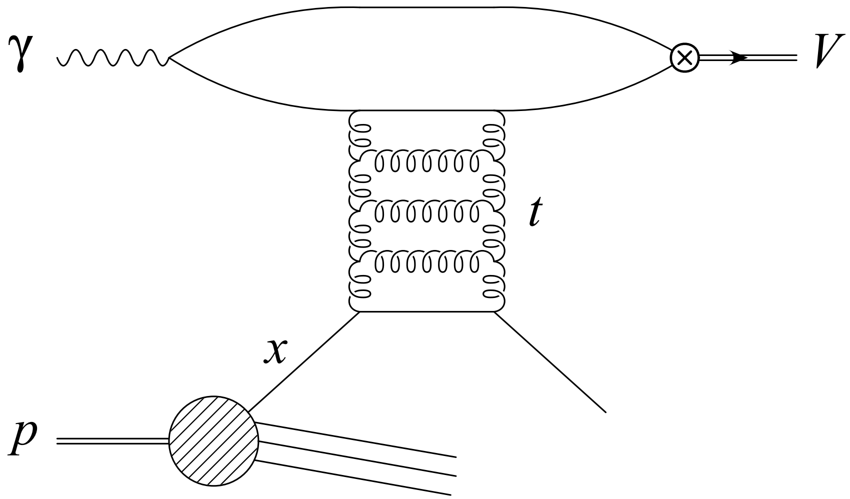
Introduction

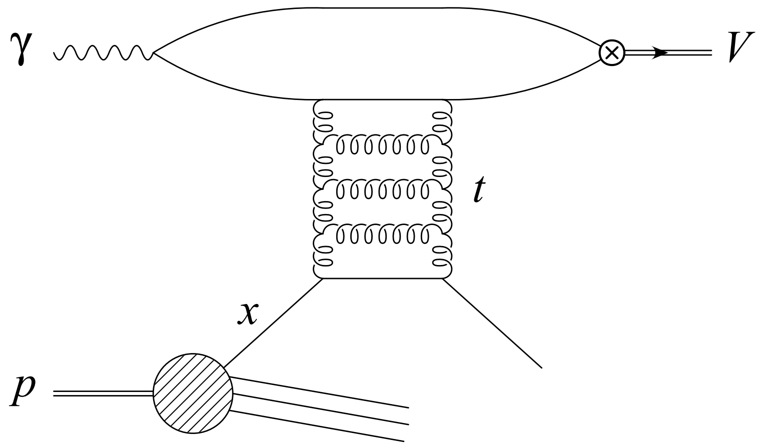
- VM production at large t is a clean observable experimentally



- The large t may serve as a perturbative scale $\rightarrow$ possible to test BFKL dynamics ($xW^2 \gg |t| \gg \Lambda_{QCD}$)

- Wave function of vector meson important!

How to calculate $\gamma p \to VX$



Assume normal factorization:

(i.e. pomeron couples to only one parton)

$$\frac{d\sigma}{dt}(\gamma p \to VX) =$$

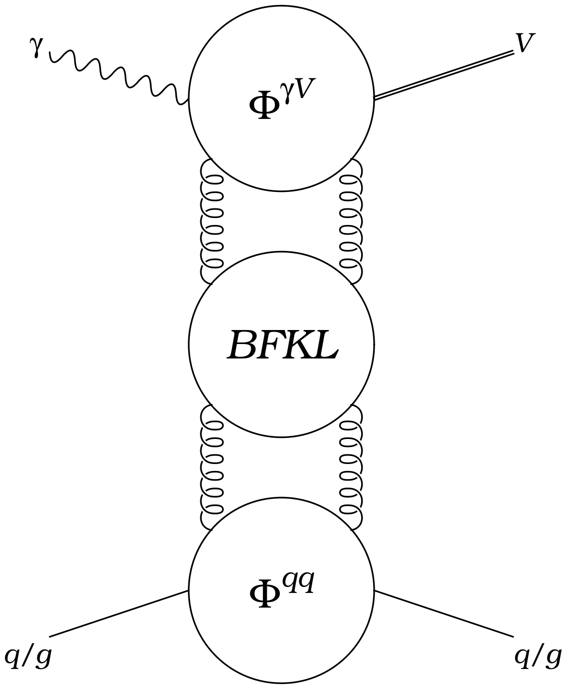
$$\int dx \sum_i f_i(x, |t|) \frac{d\sigma}{dt}(\gamma q_i \to V q_i)$$

$\longrightarrow$ need to calculate $\dfrac{d\sigma}{dt}(\gamma q \to Vq)$ (γg gives only a colour factor)

Do this using BFKL resummation!

The setup – BFKL calculation

For the scattering amplitude, we need 3 pieces:



$$\mathcal{A} \propto \int d^2\boldsymbol{k}\, d^2\boldsymbol{k}' \, [\Phi^{q\to q} \otimes K_{\mathrm{BFKL}} \otimes \Phi^{\gamma\to V}]$$

K_{BFKL}: evolution of ladder
from BFKL equation

$\Phi^{\gamma\to V}$: impact factor for transition $\gamma \to V$ coupled to pomeron
from Feynman diagrams
and VM wave function

Impact factors & conformal eigenfunctions

Lipatov solved the BFKL eqn for $|t| > 0$ using conformal symmetry of the kernel

$\longrightarrow$ expansion in a basis of conformal eigenfunctions $E_{n,\nu}$

$$\mathcal{A} \propto \sum_{n=-\infty}^{\infty} \int d\nu \frac{\nu^2 + \frac{n^2}{4}}{[\nu^2 + (\frac{n-1}{2})^2][\nu^2 + (\frac{n+1}{2})^2]} e^{\omega_n(\nu) y} I^1_{n,\nu}(\boldsymbol{k}, \boldsymbol{q})\, I^{2\,\star}_{n,\nu}(\boldsymbol{k}', \boldsymbol{q})$$

n	conformal spin
ν	scaling dimension
$\omega_n(\nu)$	eigenvalues of the BFKL kernel
$I^{1,2}_{n,\nu}$	projections of the impact factors $\Phi^{1,2}(\boldsymbol{k}, \boldsymbol{q})$ on the BFKL conformal eigenfunctions $E_{n,v}$

Conformal spin

The conformal spin n is an integer labelling the eigenfunctions.

- For $|n| > 0$, $e^{\omega_n(\nu)y} \ll e^{\omega_0(\nu)y}$

  $\Rightarrow$ expect strong suppression of $n \neq 0$ terms with increasing rapidity y
  $\Rightarrow$ amplitude usually approximated by $n = 0$ component

- However. . .
  - y is usually not large enough in present day experiments!
  - Gaps between jets: higher n needed to reproduce data
    Enberg,Ingelman,Motyka [PLB 524,273] & Motyka,Martin,Ryskin [PLB 524,107]

$\Rightarrow$ Gives different behaviour in y and q for moderate rapidities

The $\gamma \to J/\psi$ impact factor

Non-relativistic approximation

- no longitudinal d.o.f., meson wave function $\sim \delta(u - 1/2)$
  $u =$ longitudinal momentum fraction of quark
- $M_V \approx 2m_q$
- The impact factor is

$$\Phi^{\gamma \to V}(\boldsymbol{k}, \boldsymbol{q}) = 2\mathcal{C}\alpha_s \left(\frac{1}{Q^2 + M_V^2 + q^2} - \frac{1}{Q^2 + M_V^2 + 4k^2} \right)$$

- Used previously in BFKL calculations in conformal spin $n = 0$ approximation
  (Forshaw-Ryskin, Bartels-Forshaw-Lotter-Wüsthoff, Forshaw-Poludniowski)

The $\gamma \to \rho$ impact factor

Ivanov, Kirschner, Schäfer & Szymanowski [PLB 478 (2000)] give the 2-gluon exchange helicity amplitudes $M_{(++)}$, $M_{(+-)}$ and $M_{(+0)}$ for vector mesons.

- relativistic calculation, assumes massless quarks
- longitudinal (u) and transverse $(\boldsymbol{r})$ d.o.f. factorized
- include chiral-odd photon wave function

$\Rightarrow$ more complicated impact factors!

For instance:

$$M_{+0} = \; C\,\alpha_s^2 \int \frac{d^2\boldsymbol{k}}{\boldsymbol{k}^2(\boldsymbol{k}-\boldsymbol{q})^2} \qquad \underbrace{\frac{d^2\boldsymbol{r}\,du}{4\pi}\, f^{\mathrm{dipole}}\, \frac{\boldsymbol{r}\cdot\boldsymbol{e}^+}{r^2}\, \frac{f_\rho}{2}\,(1-2u)\phi_\parallel(u)}_{\sim\, \Phi^{q\to q}(\boldsymbol{k}',\boldsymbol{q})\;\times\,\Phi^{\gamma\to V}_{(+-)}(\boldsymbol{k},\boldsymbol{q})\;\times\,\delta(\boldsymbol{k}-\boldsymbol{k}')}$$

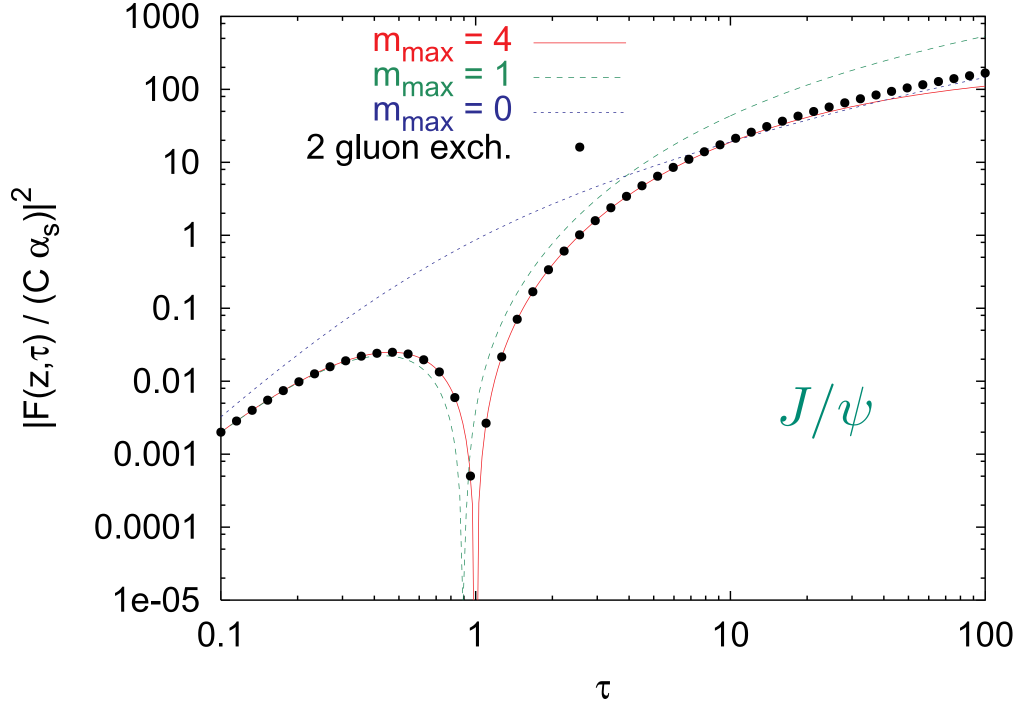
- $f^{\mathrm{dipole}} = e^{i\,\mathbf{q}\cdot\mathbf{r}\,u}(1-e^{-i\,\mathbf{k}\cdot\mathbf{r}})(1-e^{-i\,(\mathbf{q}-\mathbf{k})\cdot\mathbf{r}})$
- $\phi_\parallel(u)$ is the twist-2 vector meson wave function

$\Rightarrow$ We pick the $\Phi^{\gamma\to V}_{(hel.)}$ from IKSS!

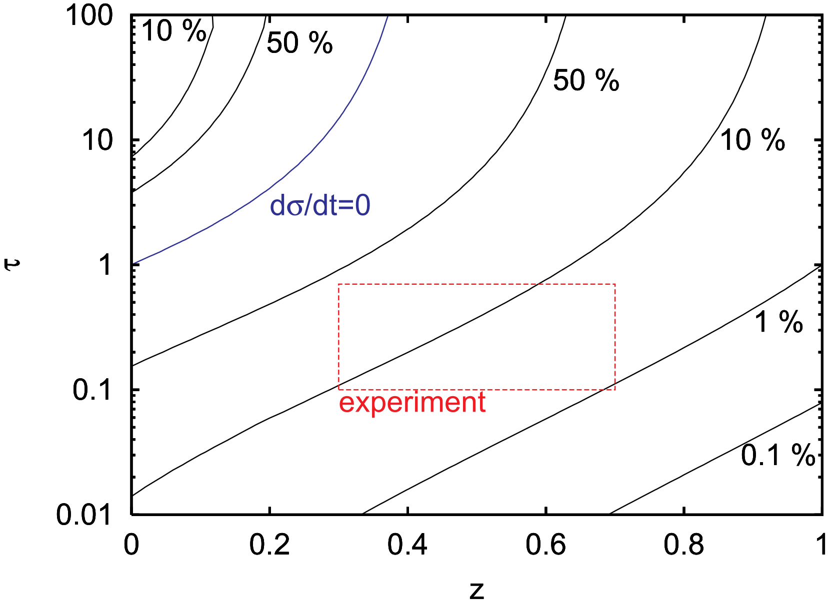
(not including the chiral-odd part)

Important crosscheck:

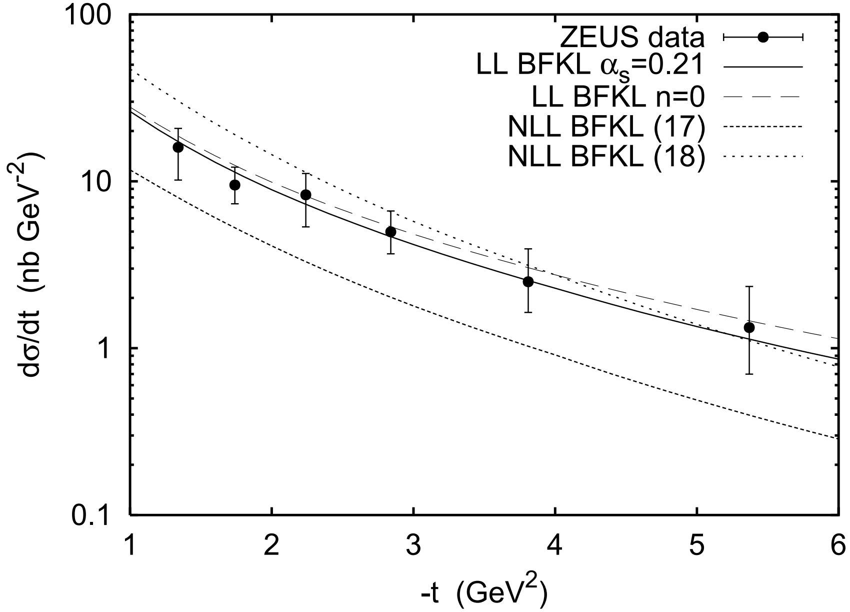
The BFKL amplitude at $y = 0$ has no evolution
$\Rightarrow$ it must reproduce the Born-level (2-gluon) calculation



J/ψ results (hep-ph/0207027)



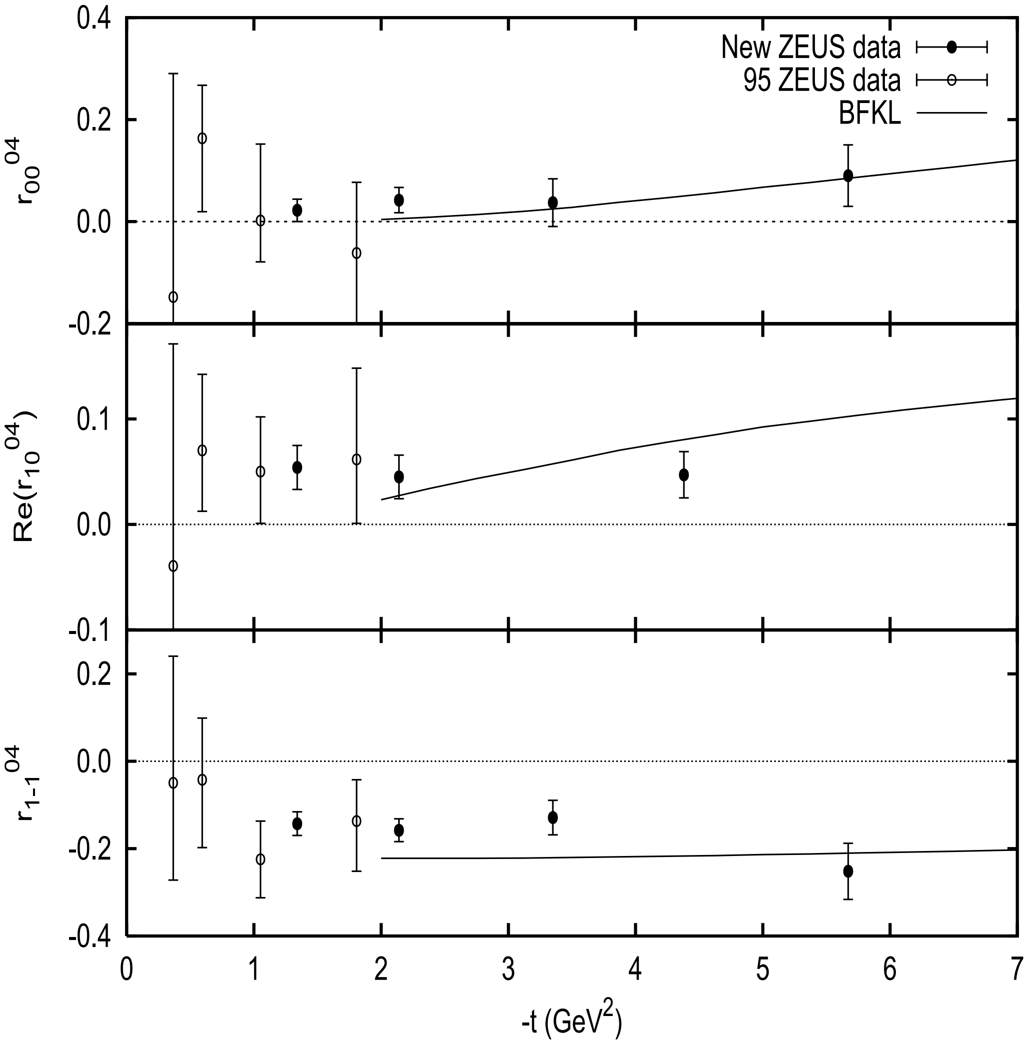
$$\mathcal{E} = \frac{|A_{exact}|^2 - |A_0|^2}{|A_0|^2}$$



$$\frac{d\sigma}{dt}$$

(Here $\tau = \frac{|t|}{M_V^2}$, $\quad z = \frac{3\alpha_s}{2\pi} y$, $\quad y =$ rapidity)

For J/ψ: influence of higher conformal spins not so large at present experiments!



ρ results – a first look:

ZEUS spin density matrix elements

$\alpha_s = 0.24 \Rightarrow \omega_0 = 0.64$ in kernel
$\alpha_s = 0.38$ in prefactor

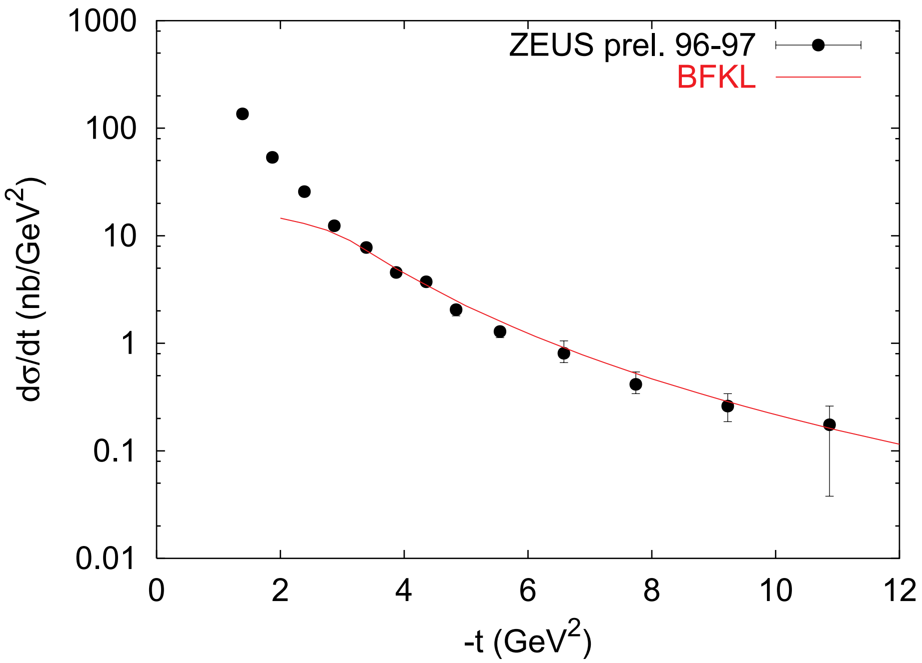
Rapidity defined as $y = \ln \frac{\hat{s}}{m_\rho^2}$

$\rightarrow$ Many conformal spins needed

$\rightarrow$ Spin double-flip amplitude dominates$\rightarrow$ depends on model for wave function!

$\rightarrow$ Agreement real?

ρ **results** (hep-ph/0207034)



Reproduces $d\sigma/dt$ with chosen parameters

$\longrightarrow$ Not reliable for small $|t|$ (pQCD not valid)

$\longrightarrow$ also because of cut-off in u integration: $u_{\rm min} = -m_\rho^2/t$ which is too restrictive

Further analysis is on the way!

The wave function is sensitive to large quark separation
$\longrightarrow$ include Sudakov factor

Discussion

- Different interpretation of helicity amplitudes than the Born-level calculation (IKSS) using chiral-odd photon wave functions

- Intermediate t region:
  - For IKSS, $(++)$ dominates and $(+-)$ has different sign
  - In our simple case, $(+-)$ dominates and $(++)$ changes sign
  - including Sudakov form factor, this is reversed!

- Assumptions:
  - massless quarks
  - wave function factorization at large $\boldsymbol{r}$
    $\rightarrow$ Further investigation being done

Conclusions

- We have obtained exact LL BFKL formulae for the $\gamma q \to V q$ amplitude

  $\longrightarrow$ helicity amplitudes for light vector mesons

- Numerical evaluation $\to$ experimental $\dfrac{d\sigma}{dt}$ is reproduced

- Helicity structure is being studied

  $\longrightarrow$ sensitive to treatment of wave function
  $\longrightarrow$ Sudakov form factor restores expected hierarchy

- Different picture than Born-level with chiral-odd components

Backup transparencies follow. . .

The $q \to q$ impact factor

$$\Phi^{q\to q} = \alpha_s \sim \text{constant} \Rightarrow I^{q\to q}_{n,\nu} \propto \delta\text{-functions}$$

$\Rightarrow$ we use Mueller-Tang prescription generalized to arbitrary n

(Motyka,Martin,Ryskin PLB 524,107)

The $\gamma \to J/\psi$ result

The result for even n is (odd n gives 0)

$$I_{n,\nu}^{\gamma\to V}(q) = \mathcal{C}\,\alpha_s \frac{8\pi^2}{|q|^3}\left(\frac{|q|^2}{4}\right)^{i\nu}\left(\frac{\bar{q}}{q}\right)^{n/2}\left(\frac{1}{4}\right)^{|n|/2}\frac{\Gamma(1/2-i\nu+|n|/2)}{\Gamma(1/2+i\nu+|n|/2)}$$
$$\times\int_{-i\infty}^{i\infty}\frac{ds}{2\pi i}\,\tau^{1/2+s+|n|/2}\,\frac{\Gamma(1-s-i\nu)\,\Gamma(1-s+i\nu)}{\Gamma(1-s/2-i\nu/2)\,\Gamma(1-s/2+i\nu/2)}$$
$$\times\frac{\Gamma^2(1/2+s+|n|/2)}{\Gamma(1/2+s/2-i\nu/2+|n|/2)\,\Gamma(1/2+s/2+i\nu/2+|n|/2)}$$

which represents a generalization of an earlier result for $n=0$ by

Bartels, Forshaw, Lotter and Wüsthoff [PLB 375, 201]

The $\gamma \to \rho$ result

The impact factor $I_{n,\nu}^{\gamma\to V}$ is proportional to the integral $(\mu = \frac{n}{2} - i\nu)$

$$
\begin{aligned}
\mathcal{I} \quad \propto \quad & \left[\sin\pi\left(\frac{1}{2}+\beta+\widetilde{\mu}\right) \; B_{+}(\alpha,\bar{k},\bar{q}) \; \widetilde{B}_{+}(\beta,k,q) \right. \\
- \quad & \left. (-1)^n \sin\pi\left(\frac{1}{2}+\beta-\widetilde{\mu}\right) \; B_{-}(\alpha,\bar{k},\bar{q}) \; \widetilde{B}_{-}(\beta,k,q) \right]
\end{aligned}
$$

where we introduce conformal blocks B:

$$
\begin{aligned}
B_{\pm}(\alpha,k,q) \quad = \quad & \left(\frac{2i}{k}\right)^{\frac{3}{2}+\alpha} \left(\frac{iq}{4k}\right)^{\pm\mu} \frac{\Gamma(\frac{3}{2}+\alpha\pm\mu)}{\Gamma(1\pm\mu)} \\
\times \quad & {}_2F_1\left(\frac{3}{2}+\alpha\pm\mu\,,\; \frac{1}{2}\pm\mu\,;\; 1\pm 2\mu\,;\; \frac{\bar{q}}{\bar{k}}\right)
\end{aligned}
$$

which is similar to an earlier result by Navelet & Peschanski [NPB 507 353] concerning dipole-dipole amplitudes