The tensor pomeron and low x DIS

by

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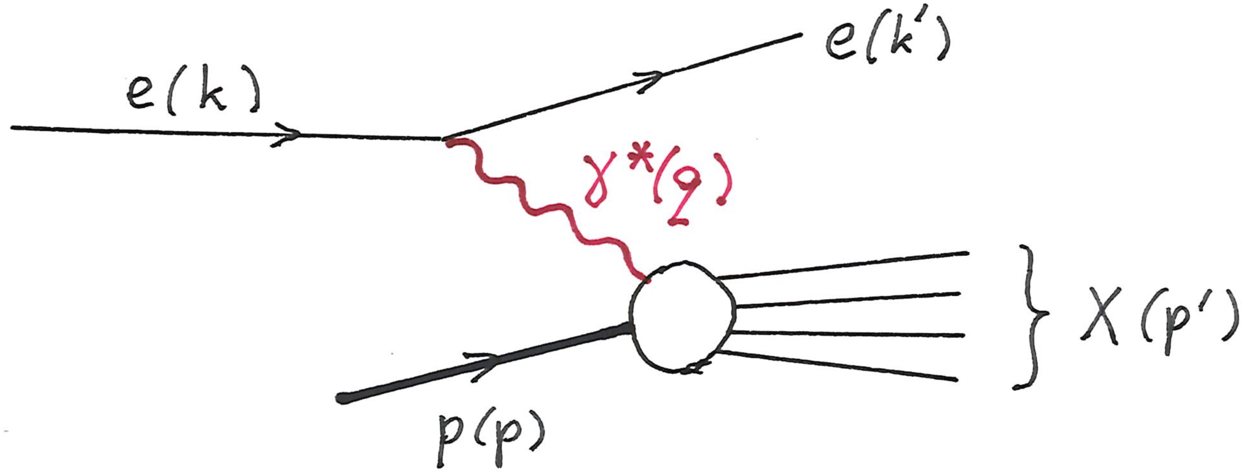
1 Introduction

High-energy hadron-hadron scattering is dominated by pomeron exchange. We think we could clarify the spin structure of the soft pomeron, describing it as effective exchange of a traceless second-rank symmetric tensor in a Regge ansatz. See my talk at this conference: "Helicity in proton-proton elastic scattering and the spin structure of the pomeron".

What can we say in the tensor-pomeron approach when going from soft to hard scattering?

We investigate this for DIS:

$$e(k) + p(p) \longrightarrow e(k') + X(p')$$



kinematic variables:

$$s = (p+k)^2 \,, \quad q = k - k' \,, \quad Q^2 = -q^2 \,,$$

$$W^2 = p'^2 = (p+q)^2 \,, \quad \nu = p\cdot q / m_p = \frac{W^2 + Q^2 - m_p^2}{2 m_p}$$

$$x = \frac{Q^2}{2 m_p \nu} = \frac{Q^2}{W^2 + Q^2 - m_p^2} \,, \quad y = \frac{p\cdot q}{p\cdot k}$$

We follow in our work Donnachie & Landshoff, PL B 437 (1998) 408, and assume that there are two pomerons, but of <u>tensor type</u>:

hard pomeron $\mathbb{P}_0$

soft pomeron $\mathbb{P}_1$

Our aim is to develop a model describing in one framework

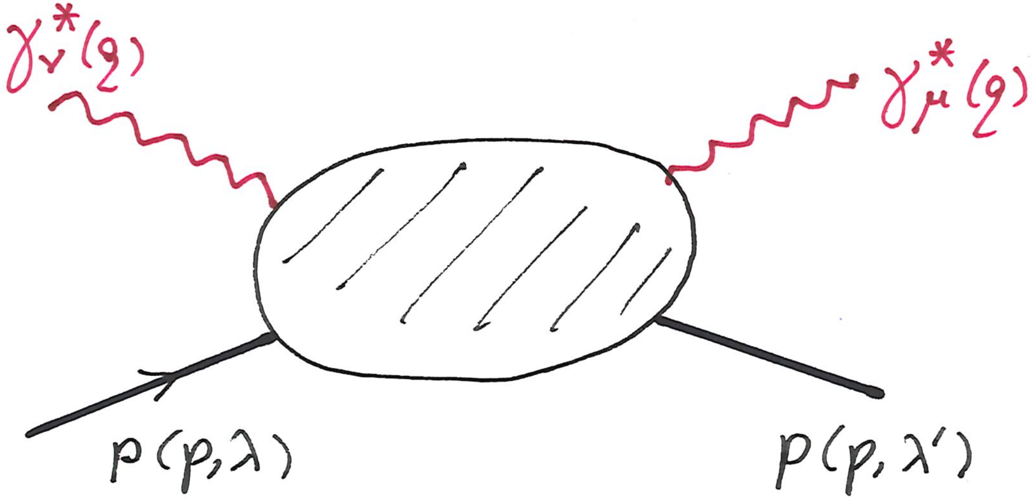
- the hard regime of low x DIS, that is, HERA data for $x \leq 0.01$, $Q^2 \leq 50\ \mathrm{GeV}^2$;
- the soft regime, $Q^2 \lesssim 1\ \mathrm{GeV}^2$, in particular photoproduction, $Q^2 = 0$.

2 The two-tensor-pomeron model

The reaction we study as theorists is forward real and virtual Compton scattering

$$\gamma_\nu^{(*)}(q) + p(p,\lambda) \longrightarrow \gamma_\mu^{(*)}(q) + p(p,\lambda')$$

$$\lambda, \lambda' \in \{ 1/2, -1/2 \}$$



$$\mathcal{M}^{\mu\nu}_{\lambda'\lambda}(p,q)$$

Hadronic tensor of DIS:

$$W^{\mu\nu}(p,q) = \sum_{\lambda',\lambda} \frac{1}{2}\delta_{\lambda\lambda'} \frac{1}{2i}\left[\mathcal{M}^{\mu\nu}_{\lambda'\lambda}(p,q) - \left(\mathcal{M}^{\nu\mu}_{\lambda\lambda'}(p,q)\right)^*\right]$$

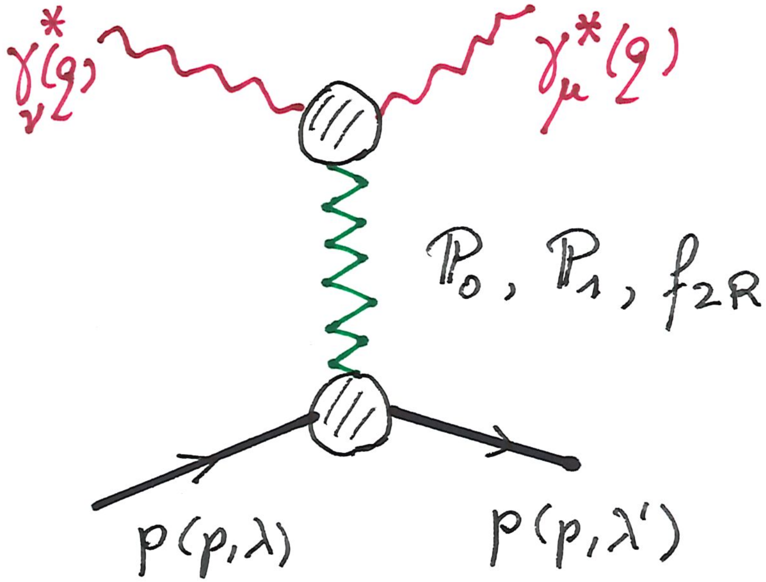
From this we get in the usual way the cross sections for absorption of transverse and longitudinal virtual photons on the proton

$$\sigma_T(W^2, Q^2) \quad , \quad \sigma_L(W^2, Q^2).$$

The photoabsorption cross section for real photons is

$$\sigma_{tot,\gamma p}(W^2) = \sigma_T(W^2, 0).$$

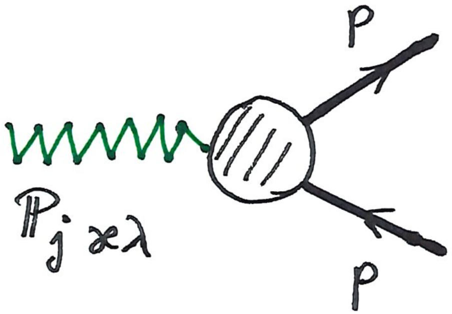
In our model we describe the virtual Compton amplitude at high energies by exchange of hard and soft pomeron. In addition we consider f_{2R} reggeon exchange, relevant for lower W.



Exchange diagrams for

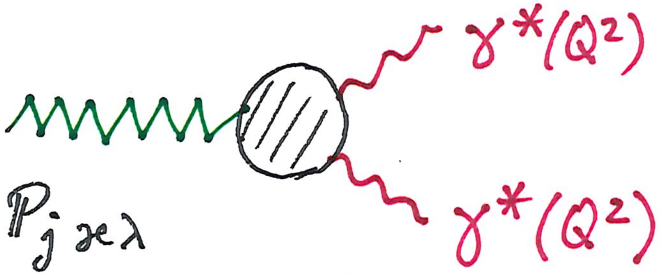
$$\mathcal{M}^{\mu\nu}_{\lambda'\lambda}(p,q)$$

Vertices and propagators



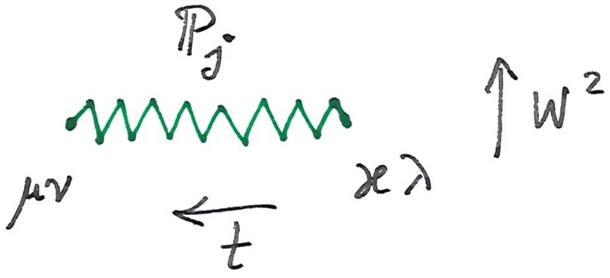
$$\mathcal{L}'_{\mathbb{P}_j pp}(x) = -3\beta_j\, \mathbb{P}_{j\,\varkappa\lambda}(x)\, \frac{i}{2}\, \bar{\psi}_p(x)\left[\gamma^{\varkappa}\overleftrightarrow{\partial}^{\lambda} + \gamma^{\lambda}\overleftrightarrow{\partial}^{\varkappa} - \frac{1}{2} g^{\varkappa\lambda}\gamma^{\rho}\overleftrightarrow{\partial}_{\rho}\right]\psi_p(x),$$

$$j = 0, 1, \qquad \beta_j = 1.87\ \mathrm{GeV}^{-1},$$



$$\mathcal{L}'_{\mathbb{P}_j \gamma^*\gamma^*}(x) = \left(g^{\varkappa\varkappa'} g^{\lambda\lambda'} - \frac{1}{4} g^{\varkappa\lambda} g^{\varkappa'\lambda'}\right)\mathbb{P}_{j\,\varkappa'\lambda'}(x)\, e^2\left[\hat{a}_j(Q^2)\left(\partial_{\varkappa}F_{\mu\nu}(x)\right)\left(\partial_{\lambda}F^{\mu\nu}(x)\right) + \hat{b}_j(Q^2)\, F_{\mu\varkappa}(x)\, F^{\mu}{}_{\lambda}(x)\right],$$

$$j = 0, 1, \qquad F_{\mu\nu}(x) = \partial_\mu A_\nu(x) - \partial_\nu A_\mu(x),$$



$$i\Delta^{(\mathbb{P}_j)}_{\mu\nu,\kappa\lambda}(W^2,t) = \frac{(-iW^2\tilde{\alpha}'_j)^{\alpha_{\mathbb{P}_j}(t)-1}}{4W^2}\left(g_{\mu\kappa}g_{\nu\lambda}+g_{\mu\lambda}g_{\nu\kappa}-\frac{1}{2}g_{\mu\nu}g_{\kappa\lambda}\right),$$

$\alpha_{\mathbb{P}_j}(t)$ $\mathbb{P}_j$ trajectory $(j=0,1)$,

$\alpha_{\mathbb{P}_j}(0) = 1+\varepsilon_j$ intercept,

$\tilde{\alpha}'_j = 0.25\ \mathrm{GeV}^{-2}$ scale parameter

Our ansatz for the f_{2R} reggeon is similar.

Theoretical results, neglecting for this presentation terms of order m_p^2/W^2 and Q^2/W^2:

$$\sigma_{tot,\gamma p}(W^2) = \sigma_T(W^2, 0) = 4\pi\alpha \sum_{j=0,1} 3\beta_j (W^2 \tilde{\alpha}_j')^{\varepsilon_j} \cos\left(\frac{\pi}{2}\varepsilon_j\right) \hat{b}_j(0)$$

$$+ \; f_{2R} \text{ reggeon term},$$

$$\sigma_T(W^2, Q^2) + \sigma_L(W^2, Q^2) = 4\pi\alpha \sum_{j=0,1} 3\beta_j (W^2 \tilde{\alpha}_j')^{\varepsilon_j} \cos\left(\frac{\pi}{2}\varepsilon_j\right) \hat{b}_j(Q^2),$$

$$\sigma_L(W^2, Q^2) = 4\pi\alpha Q^2 \sum_{j=0,1} 3\beta_j (W^2 \tilde{\alpha}_j')^{\varepsilon_j} \cos\left(\frac{\pi}{2}\varepsilon_j\right) 2\hat{a}_j(Q^2).$$

All gauge invariance relations are satisfied, in particular,

$$\sigma_L(W^2, Q^2) \propto Q^2 \quad \text{for} \quad Q^2 \to 0.$$

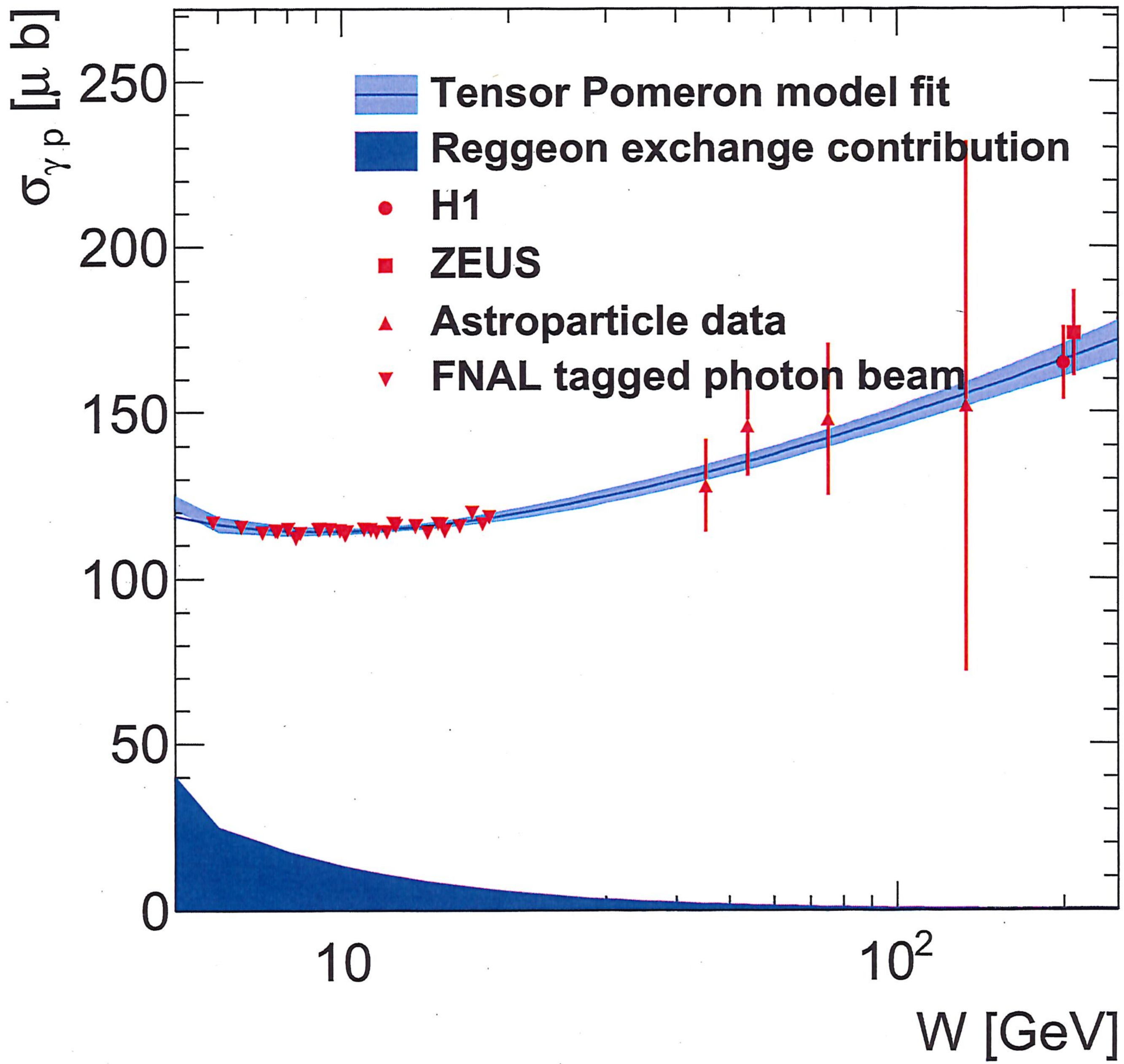
3 Results

Important: all results referring to data shown in the following are preliminary!

We make a global fit to the following data set:

- HERA inclusive data for $x \leq 0.01$ and $Q^2 \leq 50$ GeV^2 (Abramowicz et al., H1 and ZEUS Coll., EPJ C75 (2015) 580)
- Photoproduction data from
  H1 at $W = 200$ GeV (Aid et al. Z. Phys. C69 (1995) 27)
  ZEUS at $W = 209$ GeV (Chekanov et al. NP B 627 (2002), 3)
  astroparticle obs. at $W = 40$ to 250 GeV
  (Vereshkov et al. Phys. Atom. Nucl. 66 (2003) 565)
  FNAL at $W \cong 6$ to 19 GeV
  (Caldwell et al. PRL 40 (1978) 1222)

Fit result for photoproduction



For real photoabsorption, a soft reaction, we find dominance of the soft pomeron $\mathbb{P}_1$. The hard pomeron, $\mathbb{P}_0$, contribution is compatible with zero. At $W = 200$ GeV, for instance, we find the following contributions to $\sigma_{tot,\gamma p}$:

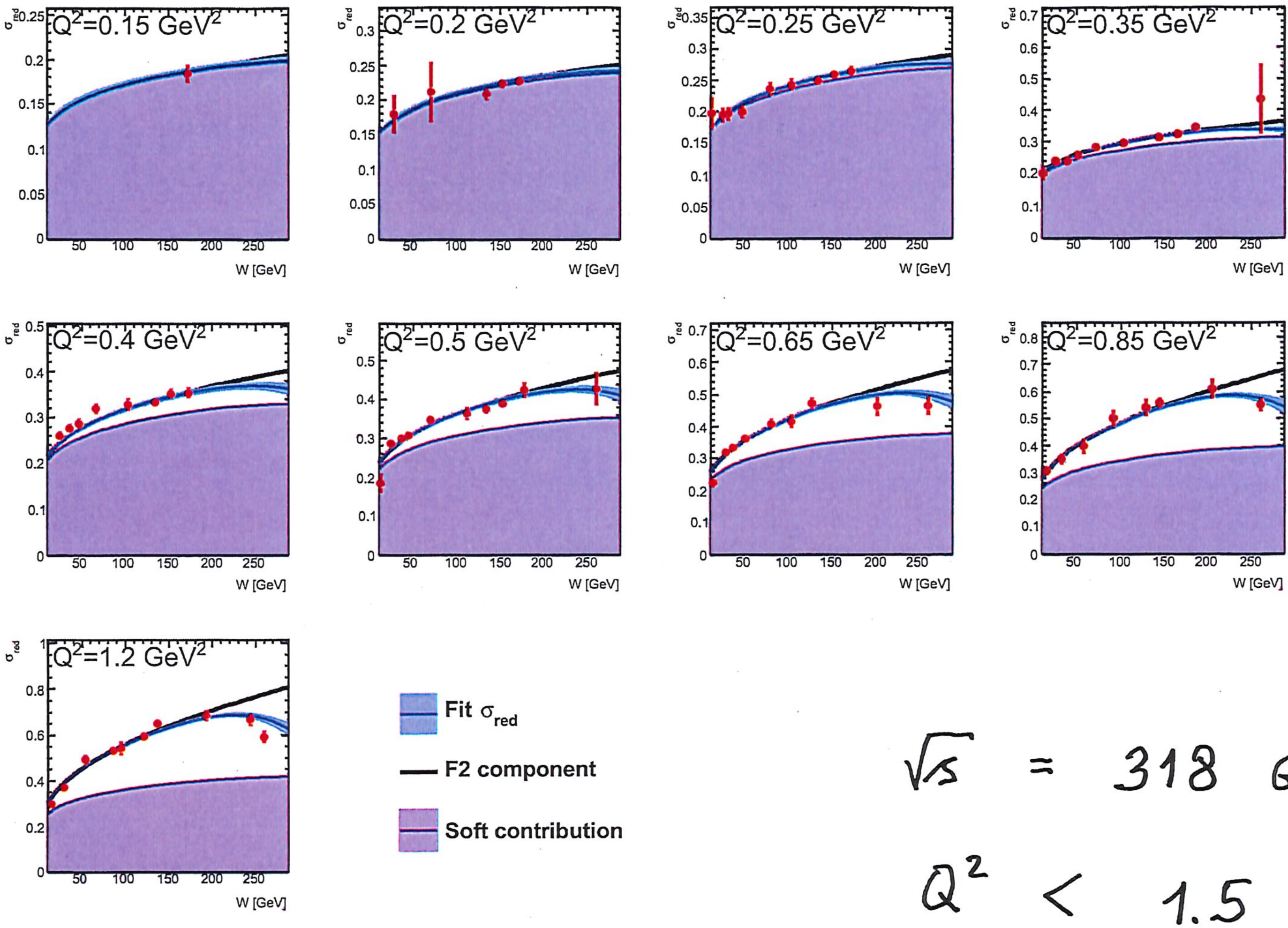
soft pomeron	$\mathbb{P}_1$	$165.9 \pm 5.0\ \mu b$,
hard pomeron	$\mathbb{P}_0$	$0.04 \pm 0.17\ \mu b$,
reggeon	f_{2R}	$0.33 \pm 1.14\ \mu b$.

For DIS the directly measured quantity is the reduced cross section:

$$\sigma_r(W^2, Q^2, y) = \frac{Q^4 x}{2\pi \alpha^2 [1 + (1-y)^2]} \frac{d^2\sigma(ep \to eX)}{dx\, dQ^2}$$

$$= \frac{Q^2}{4\pi^2 \alpha}(1-x)\left[\sigma_T(W^2, Q^2) + \sigma_L(W^2, Q^2) - \frac{y^2}{1+(1-y)^2}\sigma_L(W^2, Q^2)\right]$$

As an example we show our fit to the HERA data at $\sqrt{s} = 318$ GeV. The fits at the other values of $\sqrt{s} = 225$, 251, and 300 GeV are similar.

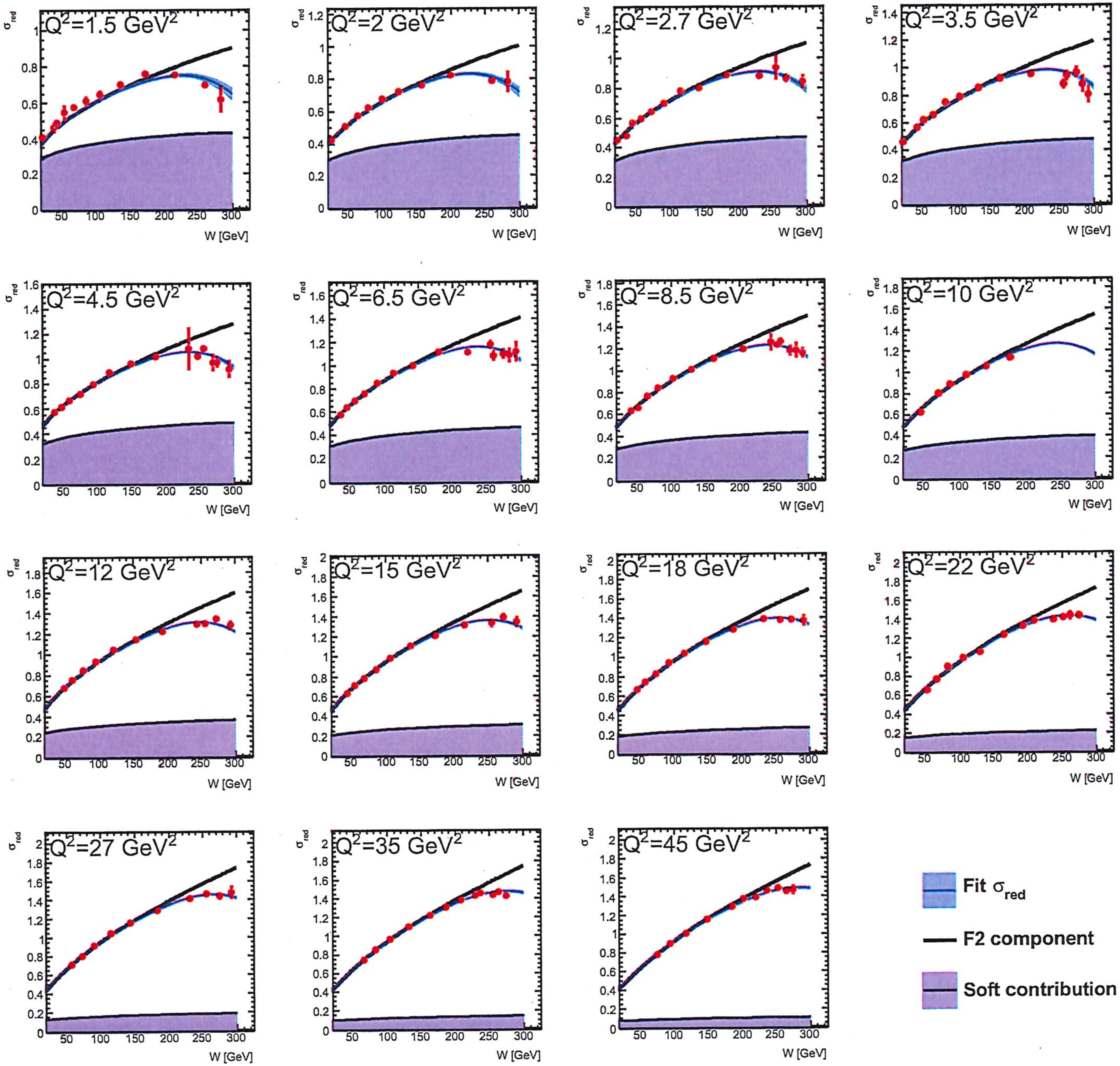


$\sqrt{s} = 318$ GeV

$Q^2 < 1.5$ GeV^2

$\sqrt{s} = 318$ GeV , $1.5 \leq Q^2 \leq 45$ GeV^2

Note the decrease of the soft contribution and the need for $\sigma_L \neq 0$.



Fit results:

- intercepts:

  hard pomeron $\alpha_{\mathbb{P}_0}(0) = 1 + \varepsilon_0$, $\varepsilon_0 = 0.3070\,(83)$

  soft pomeron $\alpha_{\mathbb{P}_1}(0) = 1 + \varepsilon_1$, $\varepsilon_1 = 0.082\,(14)$

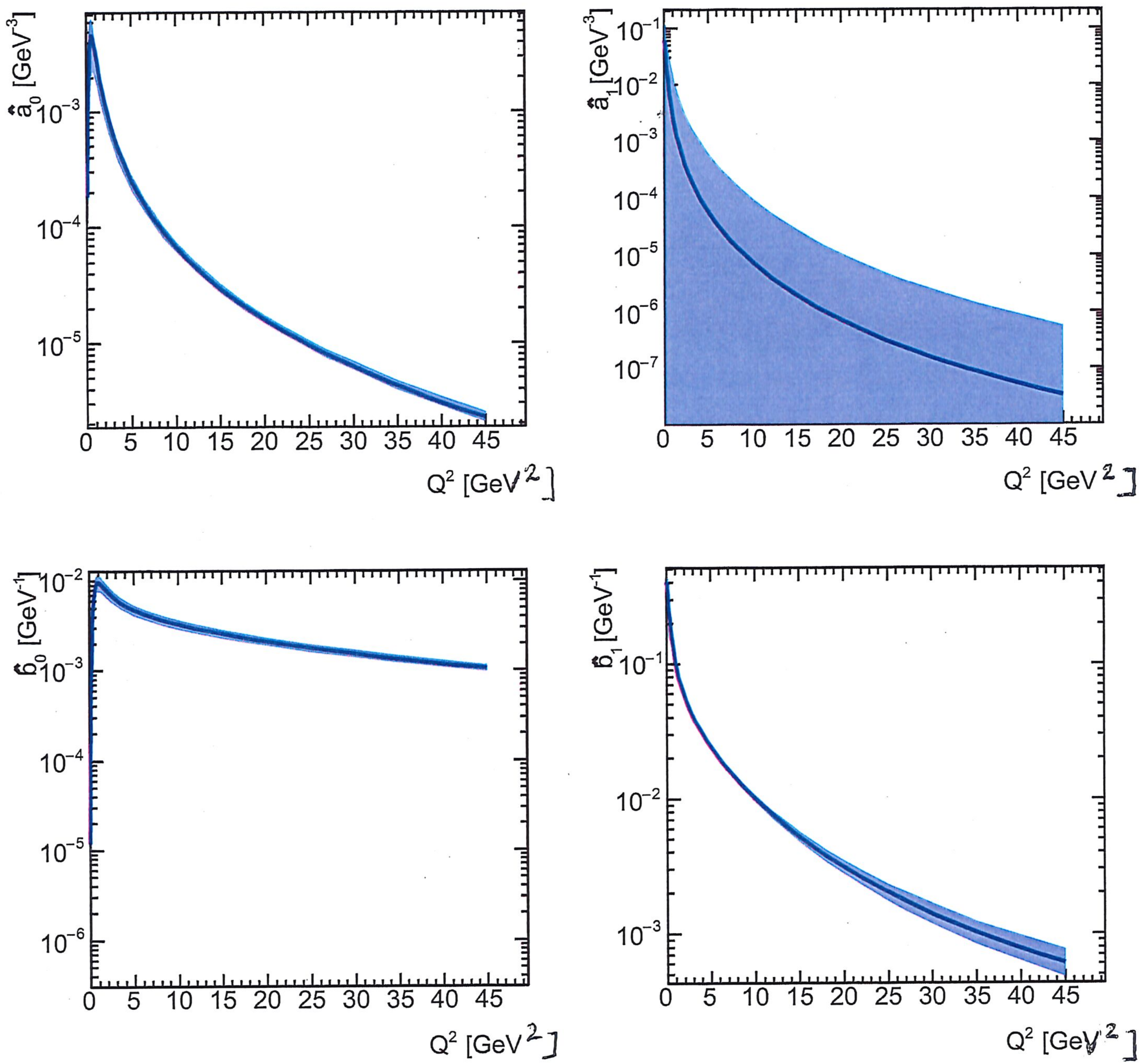
  reggeon $\alpha_{f_{2R}}(0) = 0.38\,(26)$.

- coupling functions $\hat{a}_j(Q^2)$, $\hat{b}_j(Q^2)$.

- the fit seems to prefer rather large values for the ratio

$$R(W^2, Q^2) = \frac{\sigma_L(W^2, Q^2)}{\sigma_T(W^2, Q^2)}.$$

This is currently under further investigations.



The functions $\hat{a}_j(Q^2)$ and $\hat{b}_j(Q^2)$, logarithmic scale for the amplitude.

4 Conclusions

We have developed a two-tensor pomeron model describing low x DIS data from photoproduction, $Q^2 = 0$, up to $Q^2 = 50\ \mathrm{GeV}^2$. We find cross sections rising like powers of W in the region explored ($W \lesssim 300\ \mathrm{GeV}$).

- Photoproduction: $\sigma_{\gamma p}(W^2) \propto (W^2)^{\varepsilon_1}$, $\varepsilon_1 = 0.082(14)$. This rise is as for hadron-hadron scattering.
- DIS, $Q^2 > 0$: $\sigma_{T,L}(W^2, Q^2) \propto (W^2)^{\varepsilon_0}$, $\varepsilon_0 = 0.3070(83)$.

In the energy range explored we find no sign of saturation. There is no unitarity, Froissart-like, bound for $\sigma_{T,L}$. The power-like rise of $\sigma_{T,L}$ could go on, as suggested e.g. by QCD arguments relating low x DIS to a critical phenomenon. (O. N., EPJ C 26 (2003) 579).