Absorptive effects at LHC: the triple-Pomeron vertex scenarios

Emerson Luna

Instituto de Física - UFRGS

High energy diffraction

- The triple-Pomeron vertex $g_{3I\!P}(t)$ is a central ingredient for understanding diffraction:

  $\Rightarrow$ its coupling and t-dependence determine the asymptotic high energy behaviour of total cross sections and the cross section of diffractive dissociation

  $\Rightarrow$ the calculation of the rapidity gap survival factors S^2 depends on the properties of $g_{3I\!P}(t)$

- The t-dependence of $g_{3I\!P}(t)$ is crucial in the solution of the *Finkelstein-Kajantie problem*: if we neglect the t-dependence and S^2 the cross section for multigap events violates the Froissart limit

  $\Rightarrow$ each additional gap brings a $\ln s$ factor arising from the integral over the gap size

  $\Rightarrow$ the sum of these $\ln s$ factors leads to the power behaviour

Triple-Pomeron vertex scenarios

- Two solutions proposed many years ago:

■ In the *weak coupling* solution the vertex *vanishes* as $t \to 0$

$\Rightarrow$ the $\ln s$ factor is compensated by a $1/\ln s$ due to the shrinkage of the t distribution as s increases

$\Rightarrow$ at ultra high energies the total cross sections tend to a universal constant

■ In the *strong coupling* solution the *bare* triple-Pomeron vertex is *non-vanishing* as $t \to 0$

$\Rightarrow$ a large multigap cross section, calculated via the *bare* vertex, is multiplied by a gap survival factor which decreases faster with the energy than the bare cross section

$\Rightarrow$ this scenario leads to the Froissart-like black disc limit

Triple-Pomeron vertex scenarios

- Thus the energy behaviour of the scattering amplitude may be consistently described by two scenarios for asymptotic regime:

■ The *weak coupling* model of the Pomerons

$\Rightarrow$ σ_{tot} tends to the universal constant value: $\sigma_{tot} \to$ constant as $s \to \infty$

$\Rightarrow$ in order not to violate unitarity $g_{3I\!P}(t)$ must vanish with vanishing transverse momentum transferred through the Pomeron: $g_{3I\!P} \propto q_t^2$ as $q_t^2 \to 0$

■ The *strong coupling* scenario

$\Rightarrow$ the cross section grows as $\sigma_{tot} \propto (\ln s)^{\eta}$ with $0 < \eta \leq 2$

$\Rightarrow$ the bare vertex $g_{3I\!P}|_{q_t \to 0} \to$ constant

Triple-Pomeron vertex scenarios

- The present data are usually described within the Froissart-like limit of the strong-coupling scenario

$\Rightarrow$ however we need a *very* high energy to reach asymptotics

$\Rightarrow$ it is the energy at which the slope $B = B_0 + \alpha' \ln(s)$ is dominated by the second term

$\Rightarrow$ that is, when $\alpha' \ln(s) \gg B_0$

$\Rightarrow$ *this is far beyond the energies available at present*

- Another possibility to distinguish between the *weak* and *strong* scenarios is to study the q_t dependence of the *bare* triple-Pomeron vertex

$\Rightarrow$ *it is important to extract the bare vertex before its behaviour is affected by absorptive corrections*

An eikonal model for a triple-Regge analysis

- We have investigated the *weak* and *strong* scenarios via a triple-Regge analysis of the available $pp \to p + X$ and $\bar{p}p \to \bar{p} + X$ data [Luna, Khoze, Martin and Ryskin, Eur. Phys. J. C. **59** (2009) 1]

$\Rightarrow$ we analysed the data in the triple-Pomeron region accounting explicitly for absorptive effects in the framework of a two-channel eikonal

$\Rightarrow$ in our model the Born level amplitude is written as

$$\mathcal{A}_{Born}(s,t) = \mathcal{A}_{I\!P}(s,t) + \mathcal{A}_{a/f}(s,t) + \tau\mathcal{A}_{\omega/\rho}(s,t)$$

and the opacity $\Omega(s,b)$ is given by

$$\Omega(s,b) = \frac{2}{s}\int_0^\infty q\,dq\,J_0(bq)\,\mathcal{A}_{Born}(s,t).$$

- The Pomeron contribution is given by

$$\mathcal{A}_{I\!P}(s,t) = i\beta_{I\!P}^2(t)\left(\frac{s}{s_0}\right)^{\alpha_{I\!P}(t)}$$

$\Rightarrow$ we include pion-loop insertions in the Pomeron exchange which results in a non-linear form for $\alpha_{I\!P}(t)$:

$$\alpha_{I\!P}(t) = \alpha(0) + \alpha' t - \frac{\beta_\pi^2 m_\pi^2}{32\pi^3} h\left(\frac{4m_\pi^2}{|t|}\right), \quad \text{where}$$

$$h(\tau) = \frac{4}{\tau} F_\pi^2(t)\left[2\tau - (1+\tau)^{3/2}\ln\left(\frac{\sqrt{1+\tau}+1}{\sqrt{1+\tau}-1}\right) + \ln\frac{m^2}{m_\pi^2}\right],$$

with $\tau = 4m_\pi^2/|t|$ and $m = 1$ GeV

$\Rightarrow$ $F_\pi(t)$ is the form factor of the pion-Pomeron vertex

- Our eikonalized amplitude is given by

$$\mathcal{A}(s,t) = is\int_0^{\infty} b\, db\, J_0(bq)\left[1 - \frac{e^{-\frac{\Omega}{2}(1+\gamma)^2}}{4} - \frac{e^{-\frac{\Omega}{2}(1-\gamma^2)}}{2} - \frac{e^{-\frac{\Omega}{2}(1-\gamma)^2}}{4}\right],$$

where $\gamma = 0.55$

$\Rightarrow$ the parameter γ defines the two diffractive eigenstates k of the eikonal model, such that their couplings to the Pomeron are $\beta_{I\!P,k}(t) = (1 \pm \gamma)\beta_{I\!P}(t)$

$\Rightarrow$ s-channel unitarity with elastic and a low mass M^2 intermediate state via a 2-ch eikonal approach

- The elastic and total cross section are given respectively by

$$\frac{d\sigma_{el}}{dt}(s,t) = \frac{\pi}{s^2}\,|\mathcal{A}(s,t)|^2 \quad \text{and} \quad \sigma_{tot}(s) = \frac{4\pi}{s}\,\mathrm{Im}\,\mathcal{A}(s,t=0)$$

High-mass diffraction

- The multi-channel eikonal is unable to account for diffraction into high-mass states

$\Rightarrow$ the processes with large M_X are usually described in terms of a triple-Regge formalism:

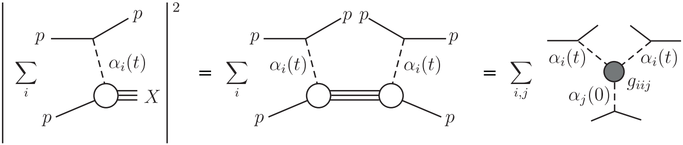

Figure I: *The triple-Regge description of high-mass diffractive dissociation* $pp \to pX$, where $M_X^2 \simeq (1 - x_L)s$

- If we first neglect the absorptive correction, the diagram of Figure I gives the contribution

$$M^2 \frac{d\sigma}{dtdM^2} = \beta_j(0)\beta_i^2(t)g_{iij}(t)\left(\frac{s}{M^2}\right)^{2\alpha_i(t)-2}\left(\frac{M^2}{s_0}\right)^{2\alpha_j(0)-1}$$

Absorptive effects

- Absorptive effects are best included by working in impact parameter space and using suppression factors of the form $\exp(-\Omega(b))$

$\Rightarrow$ to determine the t dependence we take the Fourier transforms with respect to the impact parameter:

$$M^2 \frac{d\sigma}{dtdM^2} = A \int \frac{d^2b_2}{2\pi} e^{i\vec{q}_t\cdot\vec{b}_2} F_i(b_2) \int \frac{d^2b_3}{2\pi} e^{i\vec{q}_t\cdot\vec{b}_3} F_i(b_3) \int \frac{d^2b_1}{2\pi} F_j(b_1) \quad (1)$$

where $$F_i(b_2) = \frac{1}{2\pi\beta_i} \int d^2q_t \beta_i(q_t) \left(\frac{s}{M^2}\right)^{-\alpha_i' q_t^2} e^{-b_{iij}' q_t^2} e^{i\vec{q}_t\cdot\vec{b}_2},$$

$$F_j(b_1) = \frac{1}{2\pi\beta_j} \int d^2k_t \beta_j(k_t) \left(\frac{M^2}{s_0}\right)^{-\alpha_j' k_t^2} e^{-b_{iij}' k_t^2},$$

and $$A = \beta_j(0)\beta_i^2(0) g_{iij}(0) \left(\frac{s}{M^2}\right)^{2\alpha_i(0)-2} \left(\frac{M^2}{s_0}\right)^{\alpha_j(0)-1}.$$

Absorptive effects

- To calculate absorptive corrections we must include in the integrands on the right-hand side of (1) the factors

$$\exp(-\frac{\Omega(\vec{b}_2+\vec{b}_1)}{2})\exp(-\frac{\Omega(\vec{b}_3+\vec{b}_1)}{2}) \equiv S(\vec{b}_2+\vec{b}_1)S(\vec{b}_3+\vec{b}_1)$$

$\Rightarrow$ that is, we need to compute

$$M^2 \left.\frac{d\sigma}{dtdM^2}\right|_{iij} = A \int \frac{d^2b_1}{2\pi} F_j(b_1)|I_d(b_1)|^2$$

where $\quad I_d(b_1) \equiv \int \frac{d^2b_2}{2\pi} e^{i\vec{q}_t\cdot\vec{b}_2} F_i(b_2)\, S_i(\vec{b}_2+\vec{b}_1).$

- The generalization to a two-channel eikonal takes into account the Pomeron couplings to each diffractive eigen component k to be $\beta_{I\!P,k}(t) = (1\pm\gamma)\beta_{I\!P}(t)$

Determination of the triple-Pomeron vertex

- First step: global fit to total and differential cross sections

$\Rightarrow$ model including low mass diffraction, pion loop insertions in the Pomeron trajectory, and rescattering effects via a two-channel eikonal

- Second step: generalization of screening calculations to a two-channel eikonal

$\Rightarrow$ large expressions

$\Rightarrow$ hard computational task

- Third step: triple-Regge analysis of $pp \to pX$ data

$\Rightarrow$ all the screened effects included

$\Rightarrow$ determination of the triple-Pomeron coupling $g_{3I\!P}(0)$

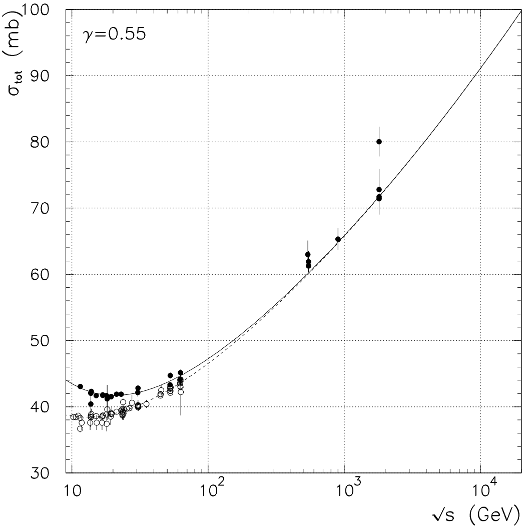

Figure II: *Two-channel model description of total cross section data*

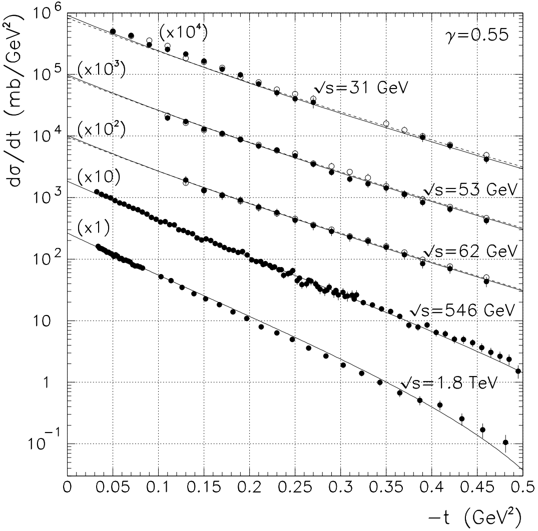

Figure III: *Two-channel model description of differential cross section data*

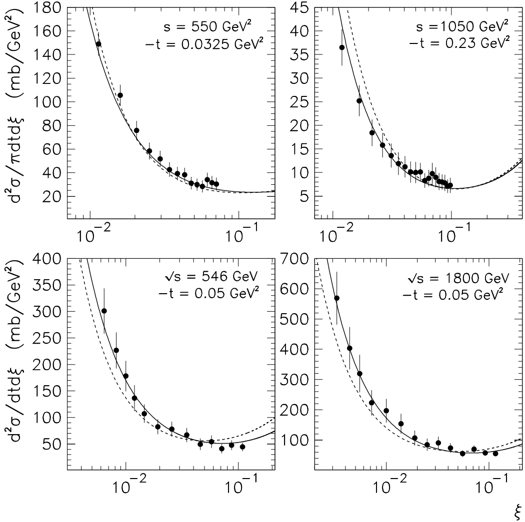

Figure IV: *The description of a sample of the $d^2\sigma/dtd\xi$ cross section data that are fitted using the strong (continuous curves) and weak (dashed curves) triple-Pomeron coupling ansatzes ($\xi \simeq M^2/s$).*

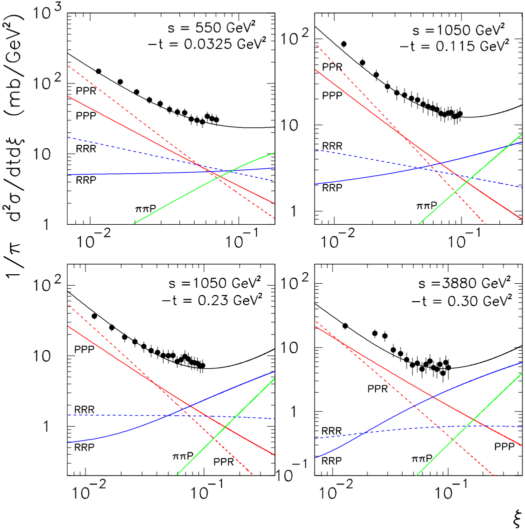

Figure V: *The description of the CERN-ISR* $pp \rightarrow pX$ *cross section data obtained in the strong triple-Pomeron coupling scenario*.

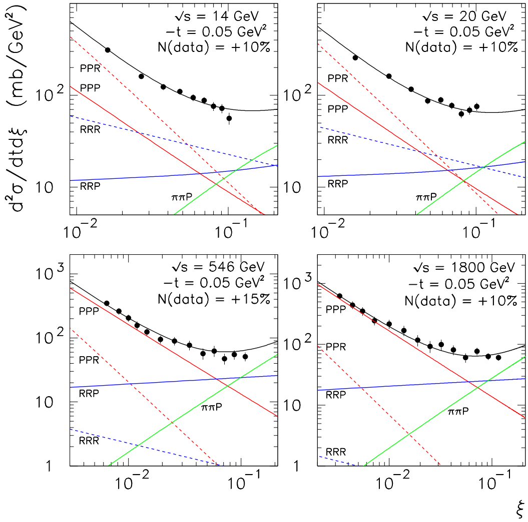

Figure VI: *The description of the* $d^2\sigma/dtd\xi$*, measured in fixed-target and collider experiments at FNAL (strong triple-Pomeron coupling scenario).*

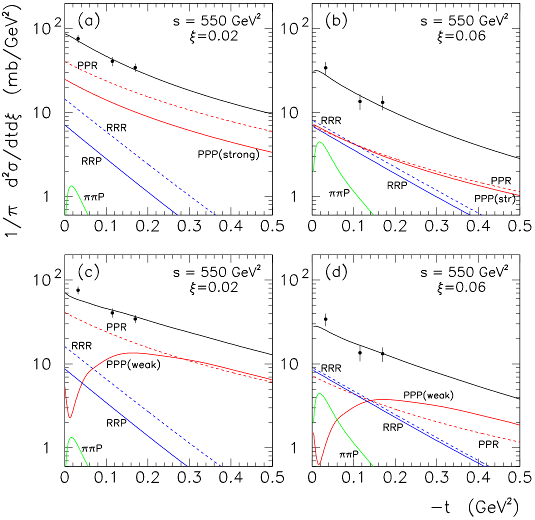

Figure VII: *The t-dependence of the* $d^2\sigma/dtd\xi$ *at* $\xi = 0.02, 0.06$ *and* $s = 550$ *GeV*^{2} *obtained in the strong and weak triple-Pomeron fits.*

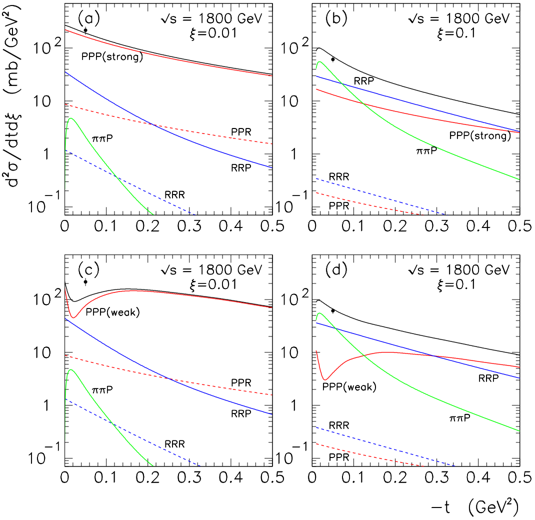

Figure VIII: *The t-dependence of the* $d^2\sigma/dtd\xi$ *at* $\xi = 0.01, 0.1$ *and* $\sqrt{s} = 1800$ *GeV obtained in the strong and weak triple-Pomeron fits.*

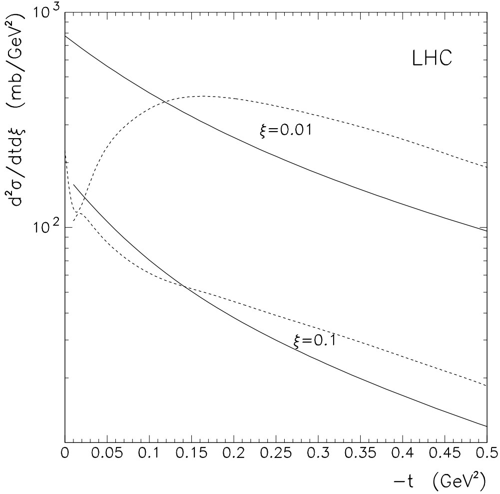

Figure IX: *The continuous curves are the predictions for the t-dependence of the $d^2\sigma/dtd\xi$ at $\xi = 0.01$, 0.1 and $\sqrt{s} = 14$ TeV in the strong triple-Pomeron fit. The disfavoured weak coupling predictions are shown by dashed curves.*

- The process $\gamma p \to J/\psi + Y$ at large values of M_Y offers, in principle, an opportunity to determine the triple-Pomeron coupling where the screening corrections are smaller than in the pure hadronic reactions:

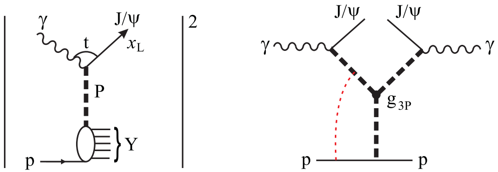

Figure X: *The process of proton dissociation in diffractive J/ψ photoproduction, $\gamma p \to J/\psi + Y$, which is described by a diagram with a triple-Pomeron vertex in which the rescattering effects are small. The dotted line would mean the diagram became an enhanced diagram.*

$\Rightarrow$ unfortunately the M_Y^2 distribution has not measured yet...

- However there exists a comparison of the HERA data for the “elastic” photoproduction process, $\gamma p \to J/\psi + p$ with the proton dissociation data

$\Rightarrow$ the ratio, at the photon-proton centre-of-mass energy $W = 200$ GeV and $t = 0$ is (ZEUS, H1):

$$r \equiv \frac{d\sigma(\gamma p \to J/\psi + Y)/dt}{d\sigma(\gamma p \to J/\psi + p)/dt} \simeq 0.2, \qquad (2)$$

where the “inelastic” cross section has been integrated over the mass region $M_Y < 30$ GeV.

- Our analysis gives $r = r_{3I\!P} + r_{I\!PI\!PI\!R} = 0.12 + 0.06$

$\Rightarrow$ this result is consistent with HERA data, within the uncertainties

- In our formalism

$$r_{3I\!P} = \frac{g_{3I\!P}}{\pi \beta_{I\!P}} \int \frac{dM^2}{M^2} \left(\frac{W^2}{M^2} \right)^{2\hat{\alpha}_{I\!P}-2} \left(\frac{M^2}{s_0} \right)^{2\alpha_{I\!P}(0)-1}$$

and $$r_{I\!PI\!PI\!R} = \frac{g_{I\!PI\!PI\!R}}{\pi \beta_{I\!P}} \int \frac{dM^2}{M^2} \left(\frac{W^2}{M^2} \right)^{2\hat{\alpha}_{I\!P}-2} \left(\frac{M^2}{s_0} \right)^{2\alpha_{I\!R}(0)-1}$$

$\Rightarrow$ here $\alpha_P(0)$ is the usual "soft" Pomeron

$\Rightarrow$ $\hat{\alpha}_P$ include DGLAP evolution from a low initial scale $\mu = \mu_0$ up to a rather large scale $\mu = M_{J/\psi}$ at the J/ψ production vertex

$\Rightarrow$ we adopt $\hat{\alpha}_P = 1.18$, which corresponds to the W dependence observed in the HERA data

Conclusions

- we have described a global analysis of available pp and $p\bar{p}$ in CERN-ISR to Tevatron energy range
- first triple-Pomeron analysis including screening corrections $\Rightarrow$ screening corrections vital $\Rightarrow$ we can use this analysis to predict the diffractive effects at the LHC
- we have obtained $g_{3I\!P}(0) = 0.44 \pm 0.06$ GeV^{-1} $\Rightarrow$ this coupling is supported by an analysis of J/ψ photoproduction data measured at HERA $\Rightarrow$ $g_{3I\!P}(0)$ value consistent with the reasonable extrapolation of the perturbative BFKL Pomeron vertex to the low scale region
- model predict $\sigma_{tot} \sim 94.8$ mb at LHC, due to screening
- soft-hard transition emerges:
  $\Rightarrow$ "soft" compt. $\rightarrow$ heavily screened $\rightarrow$ little growth with s
  $\Rightarrow$ "intermediate" compt. $\rightarrow$ some screening
  $\Rightarrow$ "hard" compt. $\rightarrow$ little screening $\rightarrow$ large growth with s ($\sim$ pQCD)