Photoproduction of J/ψ with dissociation of protons

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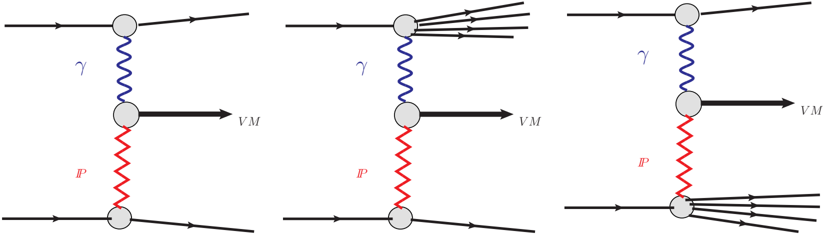
17th conference on Elastic and Diffractive scattering, EDS Blois 2017 Prague, Czech Republic
June 26-30, 2017

Outline

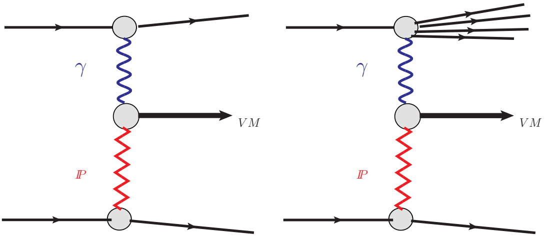
1. **Introduction**
2. **Diffractive photoproduction with electromagnetic dissociation**
3. **Diffractive photoproduction with strong dissociation**

Anna Cisek, W. S. and Antoni Szczurek, "Semiexclusive production of J/ψ mesons in proton-proton collisions with electromagnetic and diffractive dissociation of one of the protons," Phys.Lett. B769 (2017) 176-186.



- large rapidity gaps: no exchange of charge or color. t-channel exchanges with the Regge intercept $\alpha(0)$ or spin $J \geq 1$.
- C-parity constraint: $C_X = C_1 \times C_2$. even: Pomeron, odd: Odderon, photon.
- exclusive amplitude for $V = J/\psi, \psi', \Upsilon$ is a probe of the low-x gluon distribution.
- we often have to deal with diffractive reactions which include excitation of incoming protons. Instead of fully inclusive final states: gap cross sections, or even only vetos on additional tracks(!) from a production vertex.
- Inelastic state of mass M_X populates a rapidity interval $\Delta y \sim \log(M_X^2/m_p^2)$.
- a background for exclusive production – or a possible signal when looking for large p_T vector mesons with a gap.

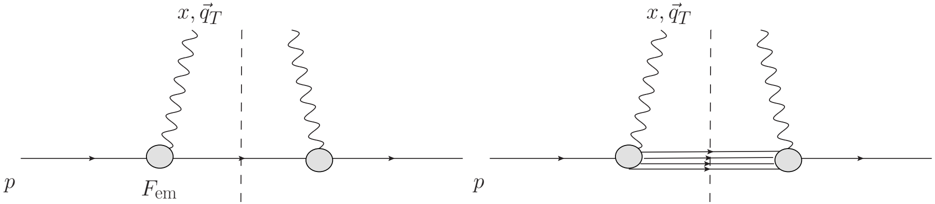
Diffractive production with electromagnetic dissociation



$$\frac{d\sigma(pp\to XVp;s)}{dy\,d^2\boldsymbol{p}} = \int \frac{d^2\boldsymbol{q}}{\pi \boldsymbol{q}^2}\mathcal{F}^{(\mathrm{in})}_{\gamma/p}(z_+,\boldsymbol{q}^2)\frac{1}{\pi}\frac{d\sigma^{\gamma^* p\to Vp}}{dt}(z_+ s, t=-(\boldsymbol{q}-\boldsymbol{p})^2) + (z_+\leftrightarrow z_-)$$

- $z_\pm = e^{\pm y}\sqrt{\boldsymbol{p}^2 + m_V^2}/\sqrt{s}$
- generalization of the Weizsäcker-Williams flux to dissociative processes.
- must in principle add contributions of longitudinal photons. Negligible for heavy mesons as long as $Q^2 \ll m_V^2$.

Unintegrated photon fluxes in the high energy limit



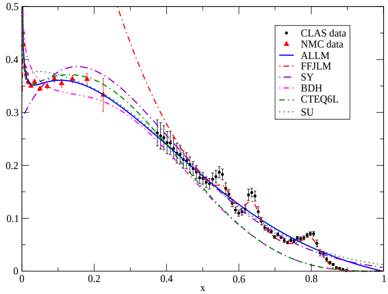
$$\mathcal{F}^{(\rm el)}_{\gamma/p}(z,\boldsymbol{q}^2) = \frac{\alpha_{\rm em}}{\pi}(1-z)\left[\frac{\boldsymbol{q}^2}{\boldsymbol{q}^2+z^2m_p^2}\right]^2 \frac{4m_p^2G_E^2(Q^2)+Q^2G_M^2(Q^2)}{4m_p^2+Q^2} \,.$$

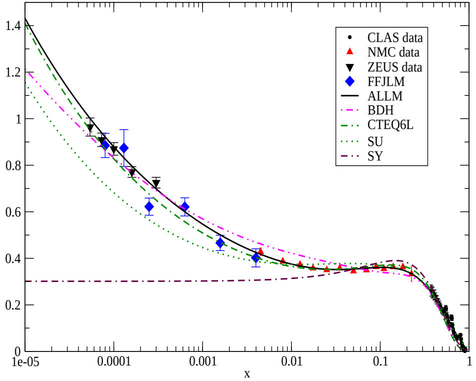
$$\mathcal{F}^{(\rm inel)}_{\gamma/p}(z,\boldsymbol{q}^2) = \frac{\alpha_{\rm em}}{\pi}(1-z)\int_{M^2_{\rm thr}}^{\infty} \frac{dM_X^2 F_2(x_{Bj},Q^2)}{M_X^2+Q^2-m_p^2}\left[\frac{\boldsymbol{q}^2}{\boldsymbol{q}^2+z(M_X^2-m_p^2)+z^2m_p^2}\right]^2 .$$

$$Q^2 = \frac{1}{1-z}\left[\boldsymbol{q}^2+z(M_X^2-m_p^2)+z^2m_p^2\right], x_{Bj} = \frac{Q^2}{Q^2+M_X^2-m_p^2}$$

- a data driven approach to q_T-dependent (!) photon-“partons” in a proton. L. Forthomme, K. Piotrzkowski, G. da Silveira, W. S. and A. Szczurek (2014), M. Łuszczak, W.S. and A. Szczurek (2015)

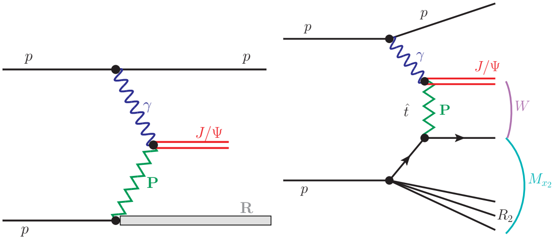
Fits to the $F_2(x, Q^2)$ structure function, $Q^2 = 2.5\,\mathrm{GeV}^2$





- useful fits to F_2 by H. Abramowicz, E. M. Levin, A. Levy and U. Maor ('97) and by R. Fiore, A. Flachi, L. L. Jenkovszky, A. I. Lengyel and V. K. Magas (2011).

Diffractive dissociation of one of the protons



- low p_T; Dissociation into nucleon resonances/low mass continuum states. Dominated by $N^*(1680)$, $J^P = \frac{5}{2}^+$, $N^*(2220)$, $J^P = \frac{9}{2}^+$, $N^*(2700)$, $J^P = \frac{13}{2}^+$. A model by L.L. Jenkovszky, O.E. Kuprash, J.W. Lämsa, V.K. Magas and R. Orava (2011).
- Negative parity resonances like $N^*(1520)$, $J^P = \frac{3}{2}^-$ can also be excited, but are not included in the model.
- larger p_T: incoherent diffractive photoproduction of J/ψ off partons. Large diffractive masses are possible here.

$$\frac{d\sigma(\gamma p \to VX)}{dt dM_X^2} = \left(\frac{s_{\gamma p}}{M_X^2}\right)^{2\alpha_{\mathbf{P}}^{\rm eff}(t)-2} \cdot A_0 f^2_{\gamma\to V}(t) \cdot F(M_X^2, t).$$

The function $f_{\gamma\to V}(t) = \exp[B_{\gamma\to V} t/2]$ is a formfactor of the $\gamma \to V$ transition, while $F(M_X^2, t)$ contains the information on the dynamics of the diffractive dissociation. Following Jenkovszky et al.(2011)

$$F(M_X^2, t) = \frac{x(1-x)^2}{(M_X^2 - m_p^2)(1+\tau)^{3/2}} \Big(\Im m A(M_X^2, t) + A_{\rm Roper}(M_X^2, t) \Big), \tag{1}$$

with

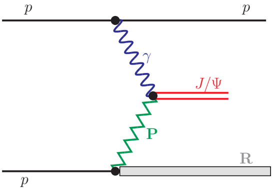
$$x = \frac{|t|}{M_X^2 + |t|}, \; \tau = \frac{4 m_p^2 x^2}{|t|}. \tag{2}$$

The contributions of three positive-parity baryon resonances on the nucleon trajectory are taken into account:

1. $N^*(1680)$, $J^P = \frac{5}{2}^+$,
2. $N^*(2220)$, $J^P = \frac{9}{2}^+$,
3. $N^*(2700)$, $J^P = \frac{13}{2}^+$.

Explicitly, they contribute to the $p\mathbb{P} \to X$ amplitude as:

$$\Im m A(M_X^2, t) = \sum_{n=1,3} [f(t)]^{2(n+1)} \cdot \frac{\Im m\, \alpha(M_X^2)}{(J_n - \Re e\, \alpha(M_X^2))^2 + (\Im m\, \alpha(M_X^2))^2}.$$

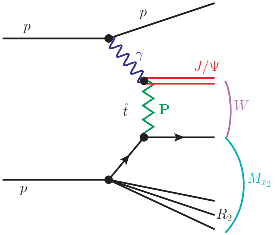


We can now compute the contribution from diffractive excitation of small masses from the formula

$$\frac{d\sigma(pp \to XVp; s)}{dy d^2\boldsymbol{p} dM_X^2} = \int \frac{d^2\boldsymbol{q}}{\pi \boldsymbol{q}^2} \mathcal{F}^{(\mathrm{el})}_{\gamma/p}(z_+, \boldsymbol{q}^2) \frac{1}{\pi} \frac{d\sigma(\gamma p \to VX)}{dt dM_X^2}(z_+ s) + (z_+ \leftrightarrow z_-),$$

with the photon coupling to the elastic leg now given by the well-known electric and magnetic formfactors.

$$\mathcal{F}^{(\mathrm{el})}_{\gamma/p}(z, \boldsymbol{q}^2) = \frac{\alpha_{\mathrm{em}}}{\pi}(1-z)\left[\frac{\boldsymbol{q}^2}{\boldsymbol{q}^2 + z^2 m_p^2}\right]^2 \frac{4m_p^2 G_E^2(Q^2) + Q^2 G_M^2(Q^2)}{4m_p^2 + Q^2}, \; Q^2 = \frac{\boldsymbol{q}^2 + z^2 m_p^2}{1-z}.$$



- dissociative production of vector mesons at large p_T probes the perturbative QCD Pomeron. (Ryskin, Forshaw et al.). An alternative to the "jet - gap - jet" type of processes.

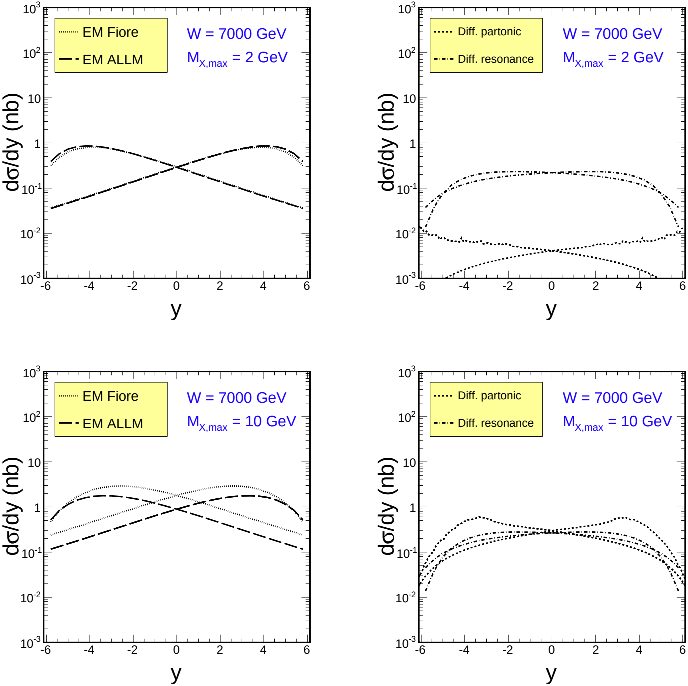
$$\frac{d\sigma^{diff,partonic}_{pp\to Vj}}{dy_V\, dy_j\, d^2p_t} = \frac{1}{\pi} x_1 q_{\rm eff}(x_1,\mu_F^2) x_2 \gamma_{el}(x_2) \frac{d\sigma(\gamma q \to Vq)}{d\hat{t}} + (x_1 \leftrightarrow x_2).$$

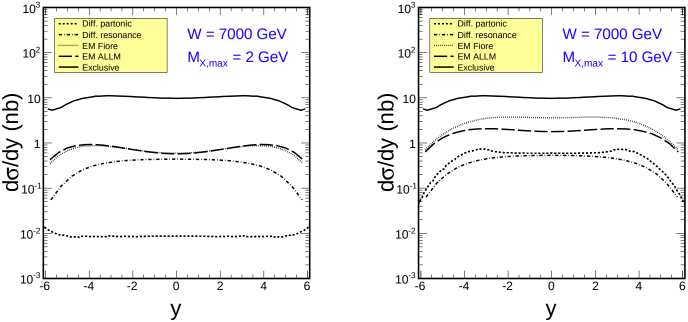
with

$$q_{\rm eff}(x,\mu_F^2) = \frac{81}{16} g(x,\mu_F^2) + \sum_f \Big[q_f(x,\mu_F^2) + \bar{q}_f(x,\mu_F^2) \Big] \ .$$

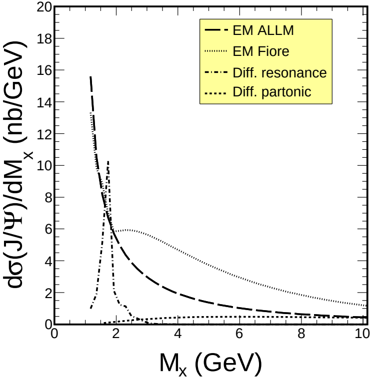
Factorization scale: $\mu_F^2 = m_V^2 + |\hat{t}|$. Simple phenomenological form of the Pomeron-exchange cross section:

$$\frac{d\sigma_{\gamma q \to Vq}}{d\hat{t}} \propto \alpha_s^2(\bar{Q}_t^2)\alpha_s^2(|\hat{t}|) \frac{m_V^3 \Gamma(V \to l^+ l^-)}{(\bar{Q}_t^2)^4} \ , \bar{Q}_t^2 = m_V^2 + |\hat{t}|$$


EM Fiore
EM ALLM
W = 7000 GeV
$M_{X,max}$ = 2 GeV
Diff. partonic
Diff. resonance
W = 7000 GeV
$M_{X,max}$ = 2 GeV
EM Fiore
EM ALLM
W = 7000 GeV
$M_{X,max}$ = 10 GeV
Diff. partonic
Diff. resonance
W = 7000 GeV
$M_{X,max}$ = 10 GeV
dσ/dy (nb)
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
y
-6
-4
-2
0
2
4
6

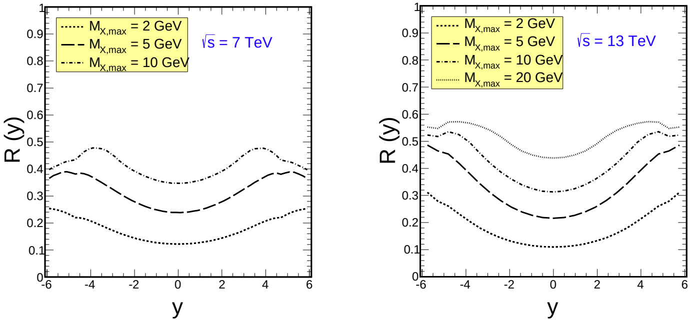


- Rapidity distribution of J/ψ mesons produced when one of the protons is excited due to photon or Pomeron exchange. Both contributions (one or second proton excitation) are added together. We also show a reference distribution for the $pp \to ppJ/\psi$ exclusive process with parameters taken from Cisek, WS & A. Szczurek (2015).



- Distribution in the mass of final state electromagnetic excitation in semiexclusive process of J/ψ mesons production when one of the protons is excited due to photon exchange.

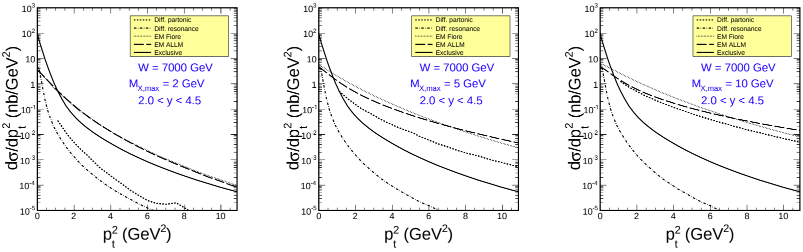
Ratio of dissociative to exclusive cross section



- $$R(y) \quad = \quad \frac{d\sigma_{pp\to pJ/\psi X}(M_X < M_{X,\max})/dy}{d\sigma_{pp\to pJ/\psi p}/dy} \, .$$

$R(y)$ as a function of J/ψ rapidity for different ranges of M_X. Both electromagnetic and diffractive excitations are included here.

Results for LHCb cuts



- Clear emergence of two different slopes. Electromagnetic dissociation dominates!

Summary

- In γ-Pomeron fusion reactions in proton-proton scattering, electromagnetic dissociation is of the same size as strong, diffractive dissociation. It even dominates in some regions of the phase space.
- Electromagnetic dissociation is calculable from F_2 data. Resonance excitation is important at low excited masses.
- Diffractive dissociation requires modelling, there is only little data to constrain it. The resonance contribution is concentrated at very small t, similar to the coherent elastic contribution.
- Continuum dissociation (electromagnetic and strong) is much flatter in t than elastic & resonances and clearly gives rise to a p_T spectrum of vector mesons with two slopes.
- Vector meson photoproduction at large p_T is an interesting probe of the perturbative Pomeron. It can be accessed in pA collisions.