Exclusive and semiexclusive production of vector mesons in proton-proton collisions with electromagnetic proton dissociation

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Outline

1. Exclusive production of vector meson
2. Semiexclusive production with electromagnetic dissociation
3. Ratio: electromagnetic dissociation to exclusive production
4. Conclusions

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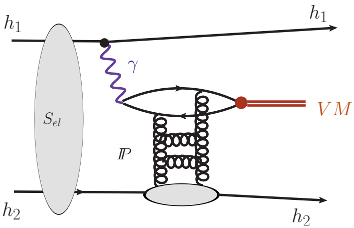
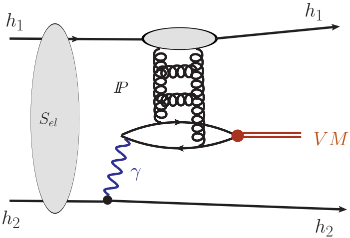
Diagram for exclusive production of vector mesons in proton-proton collisions



photon-Pomeron



Pomeron-photon

The production amplitude for $\gamma p \to Vp$

The full amplitude:

$$\mathcal{M}_T(W,\Delta^2) = (i + \rho_T)\,\Im m\mathcal{M}_T(W,\Delta^2=0,Q^2=0)\,\exp\left(-\frac{B(W)\Delta^2}{2}\right)$$

The imaginary part of the amplitude can be written as:

$$\Im m\,\mathcal{M}_T(W,\Delta^2=0,Q^2=0) = W^2\frac{c_v\sqrt{4\pi\alpha_{em}}}{4\pi^2}\int_0^1\frac{dz}{z(1-z)}\int_0^\infty \pi dk^2\psi_V(z,k^2)$$
$$\int_0^\infty\frac{\pi d\kappa^2}{\kappa^4}\alpha_S(q^2)\mathcal{F}(x_{eff},\kappa^2)\Big(A_0(z,k^2)\;W_0(k^2,\kappa^2)+A_1(z,k^2)\;W_1(k^2,\kappa^2)\Big)$$

Real part

$$\rho_T = \frac{\Re e\mathcal{M}_T}{\Im m\mathcal{M}_T} = \frac{\pi}{2}\,\Delta_{\mathbf{P}}$$

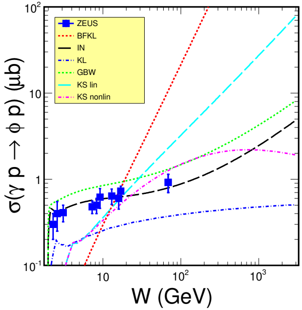
Slope parameter

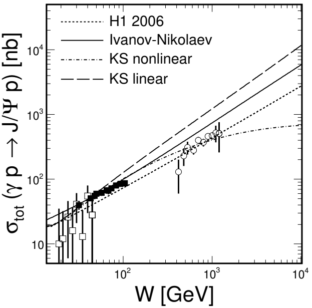
$$B(W) = B_0 + 2\alpha'_{eff}\log\left(\frac{W^2}{W_0^2}\right)$$

Total cross section for $\gamma p \to Vp$

Total cross section can be written as:

$$\sigma_T(\gamma p \to J/\Psi p) = \frac{1+\rho_T^2}{16\pi B(W)} \left| \frac{\Im m \mathcal{M}_T(W, \Delta^2 = 0, Q^2 = 0)}{W^2} \right|^2$$





Amplitude for process $pp \to pV\,p$

Full apmlitude for $pp \longrightarrow pVp$

$$\begin{aligned} \boldsymbol{M}(\boldsymbol{p}_1,\boldsymbol{p}_2) &= \int \frac{d^2\boldsymbol{k}}{(2\pi)^2}\, S_{el}(\boldsymbol{k})\, \boldsymbol{M}^{(0)}(\boldsymbol{p}_1-\boldsymbol{k},\boldsymbol{p}_2+\boldsymbol{k}) \\ &= \boldsymbol{M}^{(0)}(\boldsymbol{p}_1,\boldsymbol{p}_2) - \delta\boldsymbol{M}(\boldsymbol{p}_1,\boldsymbol{p}_2) \end{aligned}$$

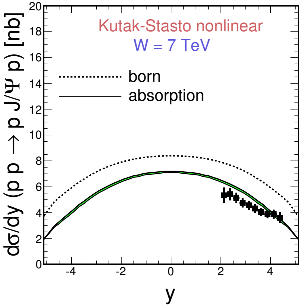
Amplitude without absorption

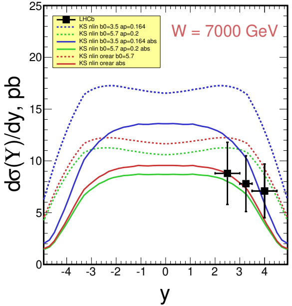
$$\begin{aligned} \boldsymbol{M}^{(0)}(\boldsymbol{p}_1,\boldsymbol{p}_2) &= e_1 \frac{2}{z_1}\frac{\boldsymbol{p}_1}{t_1}\mathcal{F}_{\lambda_1'\lambda_1}(\boldsymbol{p}_1,t_1)\mathcal{M}_{\gamma h_2\to V h_2}(s_2,t_2,Q_1^2) \\ &+ e_2 \frac{2}{z_2}\frac{\boldsymbol{p}_2}{t_2}\mathcal{F}_{\lambda_2'\lambda_2}(\boldsymbol{p}_2,t_2)\mathcal{M}_{\gamma h_1\to V h_1}(s_1,t_1,Q_2^2) \end{aligned}$$

Absorptive corrections for the amplitude

$$\delta\boldsymbol{M}(\boldsymbol{p}_1,\boldsymbol{p}_2) = \int \frac{d^2\boldsymbol{k}}{2(2\pi)^2}\, T(\boldsymbol{k})\, \boldsymbol{M}^{(0)}(\boldsymbol{p}_1-\boldsymbol{k},\boldsymbol{p}_2+\boldsymbol{k})$$

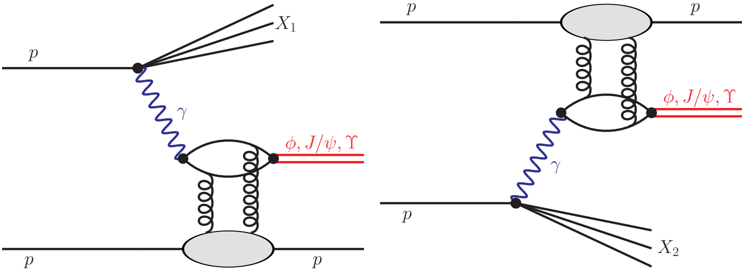
Rapidity distribution





- R. Aaij et al. (LHCb collaboration), J. Phys. **G40** (2013) 045001
- Anna Cisek, Wolfgang Schäfer, Antoni Szczurek
  JHEP **1504** (2015) 159

Diagrams representation of the electromagnetic excitation



- The schematic diagrams representation of the electromagnetic excitation of one (left panel) or second (right panel) photon
- Anna Cisek, Wolfgang Schäfer, Antoni Szczurek Phys. Let. **B769** (2017) 176

Diffractive production with electromagnetic dissociation

- The importent property of these processes is that the $p\gamma^{\star} \to X$ transition is given by the electromagnetic structure function of protons

The cross section for such proces can be written as:

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

$$z_\pm = e^{\pm y} \sqrt{\boldsymbol{p}^2 + m_V^2} / \sqrt{s}$$

- Generalization of the Weizsäcker-Williams flux to dissociative processes.
- Must in principle add contributions of longitudinal photons. Negligible for heavy mesons as long as $Q^2 \ll m_V^2$

Diffractive production with electromagnetic dissociation

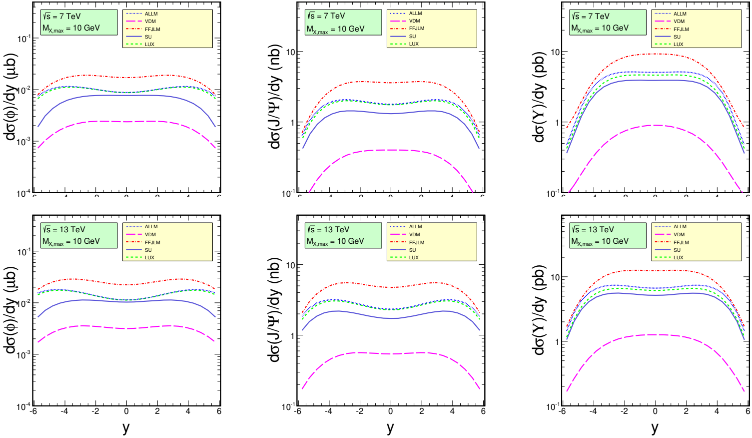
The flux of photons associated with the breakup of protons is calculable in terms of the structure function of protons

$$\mathcal{F}^{(\mathrm{inel})}_{\gamma/p}(z,\boldsymbol{q}^2,M_X^2) = \frac{\alpha_{\mathrm{em}}}{\pi}(1-z)\theta(M_X^2-M_{\mathrm{thr}}^2)\frac{F_2(x_{Bj},Q^2)}{M_X^2+Q^2-m_p^2} \cdot \left[\frac{\boldsymbol{q}^2}{\boldsymbol{q}^2+z(M_X^2-m_p^2)+z^2m_p^2}\right]^2$$

Structure function of proton $F_2(x_{Bj},Q^2)$ - useful fits

- H. Abramowicz, E. M. Levin, A. Levy and U. Maor Phys. Lett. **B269**, (1991) 465; (ALLM)
- R. Fiore, A. Flachi, L. L. Jenkovszky, A. I. Lengyel and V. K. Magas - Phys. Rev. **D70**, 054003 (2004); (FFJLM)
- A. Szczurek, V. Uleshchenko, Eur. Phys. J. **C12** (200) 663-671; (SU)

Rapidity distribution - different structure function of proton



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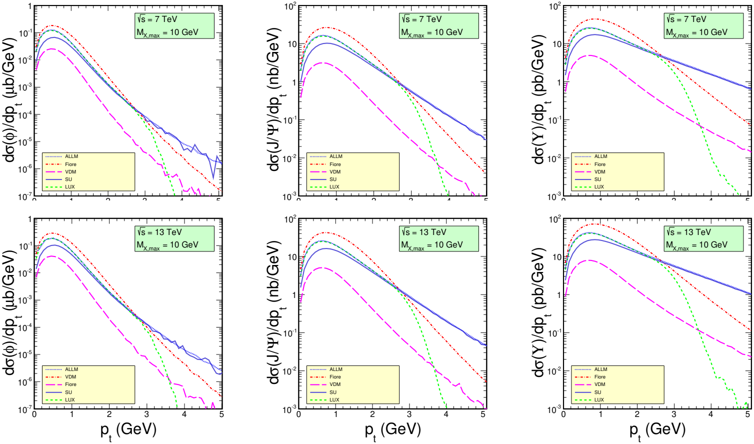
  Phys. Rev. **D100** (2019) 114022

Transverse momentum distribution - different structure function of proton



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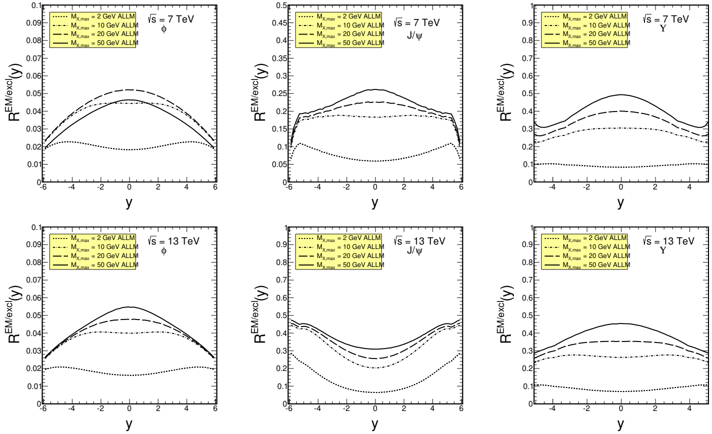
  Phys. Rev. **D100** (2019) 114022

Ratio: electromagnetic dissociation to exclusive production



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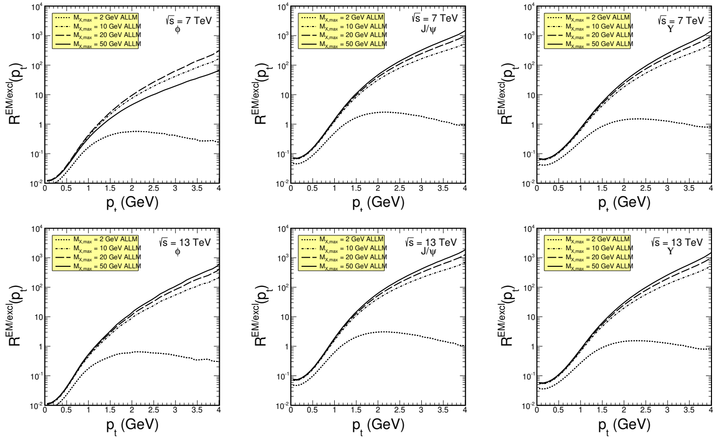
Ratio electromagnetic dissociation to exclusive production



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Conclusions

- For exclusive production we have compared our results with HERA ($\gamma p \longrightarrow Vp$) and LHCb ($pp \longrightarrow p\ Vp$) data.
- The results for exclusive production strongly depends on the model of the wave function and UGDFs.
- Electromagnetic dissociation of protons is calculated using an inelastic unintegrated photon flux which was calculated based on modern parametrizations of deep-inelastic proton structure functions.The results strongly depend on the parametrization of the structure function used.
- 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.
- The ratio of the semiexclusive to the purely exclusive contributions strongly depends on the vector meson transverse momentum and only mildly on rapidity.