Production of vector mesons in $pp \to pVp$ reactions with electromagnetic proton dissociation

Anna Cisek

University of Rzeszow

XXVI Cracow EPIPHANY Conference, LHC Physics:Standard Model end Beyond
Krakow, 7-10 January 2020

Outline

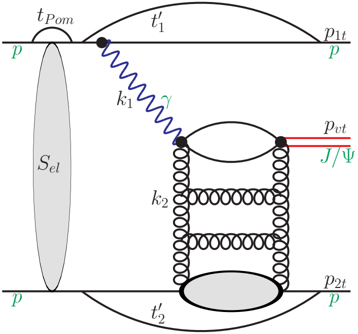
1. Introduction
   - Exclusive production of vector meson
   - Diffractive resonance with strong disociation
   - Diffractive partonic with strong disociation
   - Diffractive production with electromagnetic dissociation
2. Semiexclusive production with electromagnetic dissociation
   - Formalism
   - Results

- **Anna Cisek, Wolfgang Schäfer, Antoni Szczurek**

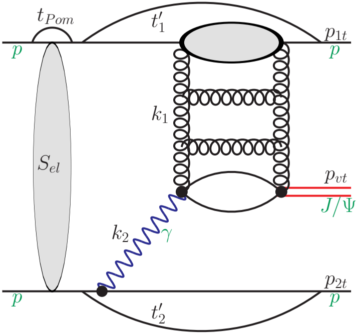
Introduction

- Exclusive production of heavy vector mesons in proton-proton collisions has been studied in rapidyty range $y \sim 2.0 - 4.5$
- Large rapidity gaps: no exchange of charge or color. t-channel exchanges with the Regge intercept $\alpha(0)$ or spin $J \geq 1$.
- 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.

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

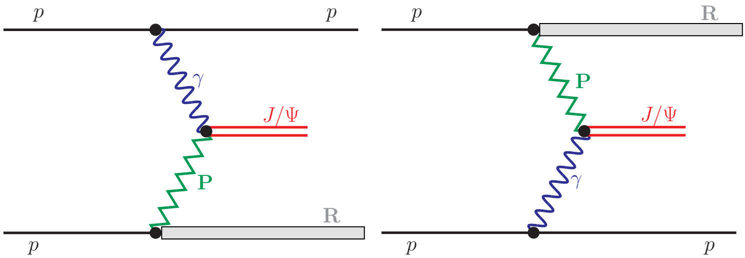


photon-Pomeron



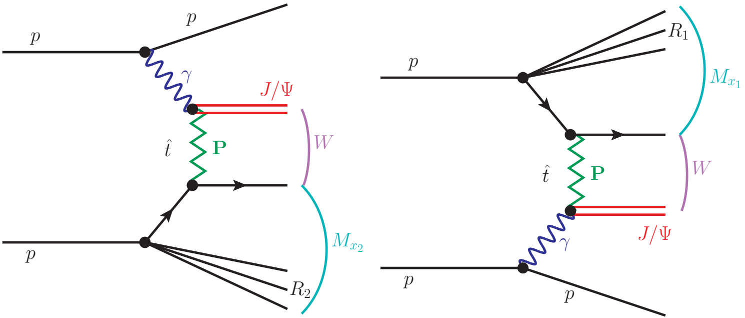
Pomeron-photon

Difractive resonance with strong disociation



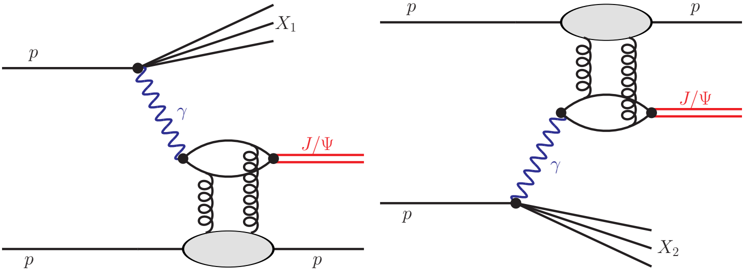
- low $p_T \rightarrow$ Dissociation into nucleon resonances/low mass continuum states. Dominated by $N^*(1680)$, $J^P = \frac{5}{2}^+$, $N^*(2220)$, $J^P = \frac{9}{2}^+$, $N^*(2700)$, $J^P = \frac{13}{2}^+$.
  A model by L.L. Jenkovszky, O.E. Kuprash, J.W. Lämsa, V.K. Magas and R. Orava (2011).
- large $p_T \rightarrow$ Incoherent diffractive photoproduction of J/ψ off partons. Large diffractive masses are possible here.

Difractive partonic with strong disociation



- 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.

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:

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

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

- 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

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

where

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

$$x_{Bj} = \frac{Q^2}{Q^2+M_X^2-m_p^2}$$

Structure function of protons

Useful fits to F2

- H. Abramowicz, E. M. Levin, A. Levy and U. Maor Phys. Lett. **B269**, (1991) 465

$$F_2(x,Q^2) = \frac{Q^2}{Q^2+m_0^2}\left(F_2^{\mathcal{P}}(x,Q^2) + F_2^{\mathcal{R}}(x,Q^2)\right)$$

Useful fits to F2

- R. Fiore, A. Flachi, L. L. Jenkovszky, A. I. Lengyel and V. K. Magas - Phys. Rev. **D70**, 054003 (2004)

$$\mathcal{I}m\alpha(s) = s^{\delta}\sum_n c_n\left(\frac{s-s_n}{s}\right)^{\mathcal{R}e\alpha(s_n)} \cdot \theta(s-s_n)$$

$$\mathcal{R}e\,\alpha(s) = \alpha(0) + \frac{s}{\pi}PV\int_0^{\infty} ds'\,\frac{\mathcal{I}m\alpha(s')}{s'(s'-s)}$$

Structure function of protons

Useful fits to F2

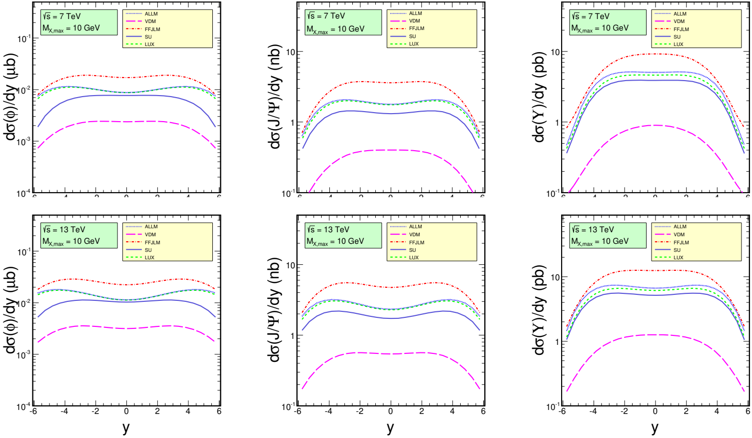
- A. Szczurek, V. Uleshchenko
  Eur. Phys. J. **C12** (200) 663-671

$$F_2^N(x,Q^2) = F_2^{N,VDM}(x,Q^2) + F_2^{N,part}(x,Q^2)$$

$$F_2^{N,VDM}(x,Q^2) = \frac{Q^2}{\pi} \sum_V \frac{M_V^4 \cdot \sigma_{VN}^{tot}(s^{1/2})}{\gamma_V^2 (Q^2 + M_V^2)^2} \cdot \Omega_V(x,Q^2)$$

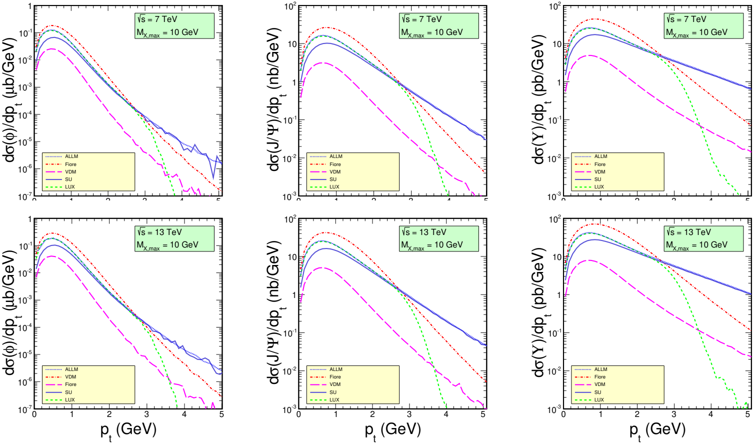
$$F_2^{N,part}(x,Q^2) = \frac{Q^2}{Q^2 + Q_0^2} \cdot F_2^{asymp}(\bar{x},\bar{Q}^2)$$

Rapidity distribution- different structure function of proton



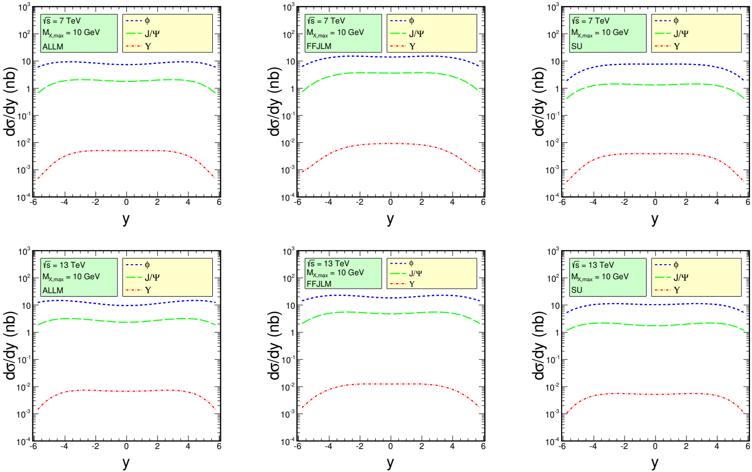
- Anna Cisek, Wolfgang Schäfer, Antoni Szczurek
  Phys. Rev. **D100** (2019) 114022

Transverse momentum distribution- different structure function of proton



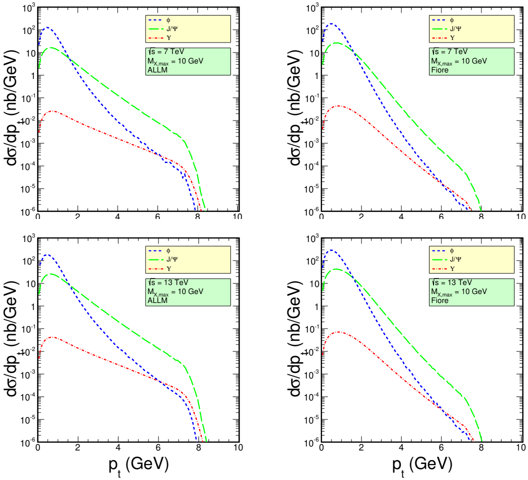
- Anna Cisek, Wolfgang Schäfer, Antoni Szczurek
  Phys. Rev. **D100** (2019) 114022

Rapidity distribution - meson comparison



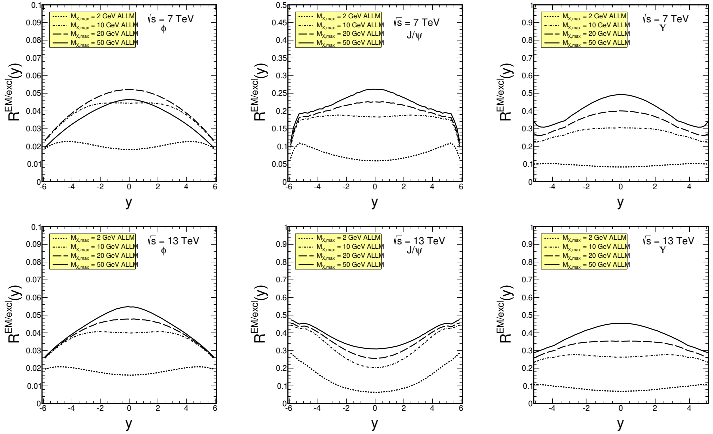
- Anna Cisek, Wolfgang Schäfer, Antoni Szczurek
  Phys. Rev. **D100** (2019) 114022

Transverse momentum distribution



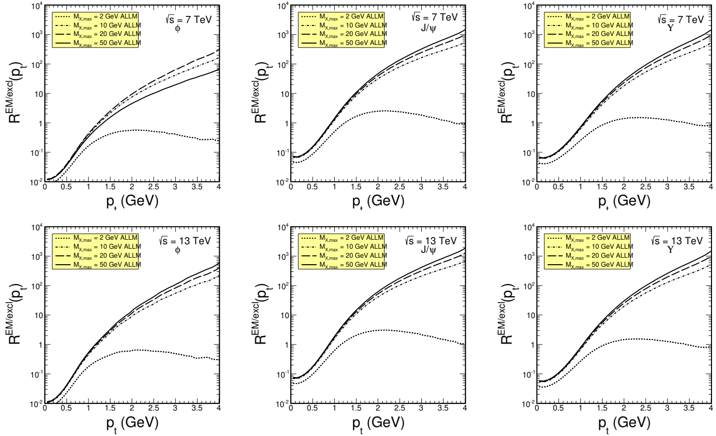
- Anna Cisek, Wolfgang Schäfer, Antoni Szczurek
  Phys. Rev. **D100** (2019) 114022

Ratio electromagnetic dissociation to exclusive production



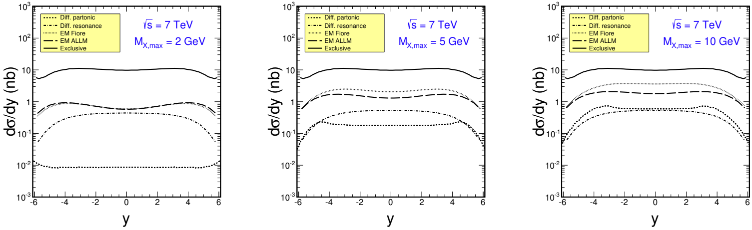
- Anna Cisek, Wolfgang Schäfer, Antoni Szczurek
  Phys. Rev. **D100** (2019) 114022

Ratio electromagnetic dissociation to exclusive production



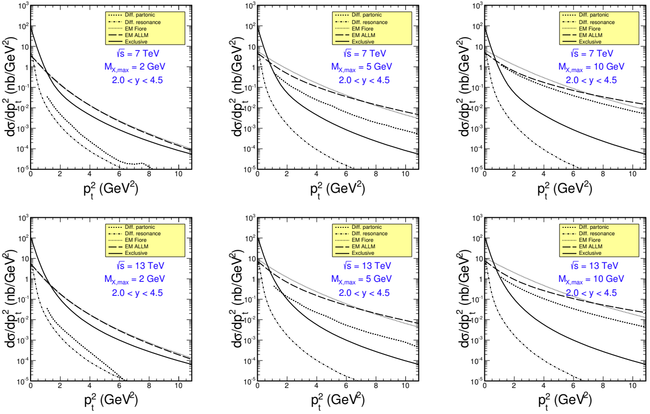
- Anna Cisek, Wolfgang Schäfer, Antoni Szczurek
  Phys. Rev. **D100** (2019) 114022

Rapidity distribution, $\sqrt{s}$ = 7 TeV - different mechanism comparison



- 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 Anna Cisek, Wolfgang Schäfer, Antoni Szczurek: JHEP 1504 (2015) 159.
- Anna Cisek, Wolfgang Schäfer, Antoni Szczurek
  Phys. Let. **B769** (2017) 176, Phys. Rev. **D100** (2019) 114022

Transverse momentum - mechanism comparision



- Anna Cisek, Wolfgang Schäfer, Antoni Szczurek
  Phys. Let. **B769** (2017) 176

Conclusions

- 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.
- The ratio of the semiexclusive to the puerly exclusive contributions strongly depends on the vector meson transverse momentum and only mildly on rapidity.
- 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.