A study on central diffractive $f_0(980)$ and $f_2(1270)$ meson production at the LHC*

Magno V. T. Machado

Instituto de Fisica - Universidade Federal do Rio Grande do Sul

High Energy Physics Group - Porto Alegre, RS. Brazil

* M.V.T. Machado, Phys. Rev. D 86, 014029 (2012).

Outline

- Short motivation
- Exclusive light meson production in pp collisions: soft Pomeron phenomenology
- The $f_0(980)$ and $f_2(1270)$ exclusive production
- Numerical results and predictions for the LHC
- Summary

Short Motivation

- The exclusive production of light mesons allows us to investigate soft Pomeron exchange models.
- ALICE collaboration has reported exclusive $f_0(980)$ and $f_2(1240)$ production (double gap events).
- Scalar sector ($J^{PC} = 0^{++}$), seems promising as good candidates for the lightest glueball.
- Exclusive production gives small cross sections but a good balance signal/background.
- In pp collisions, a few channels of production could have similar final state configurations (double gap): the processes $I\!\!P - I\!\!P$ and $\gamma - \gamma$.

The $I\!P I\!P$ process - scalar mesons

- We consider a soft-Pomeron model (NP two gluon exchange) for exclusive production of scalar mesons.

$$\sigma_{I\!P I\!P}(pp \to p + R + p) \propto S^2_{\text{gap}} \int \overline{|M_{fi}|^2} \left[F(t_1)\, F(t_2)\right]^2 dPH$$

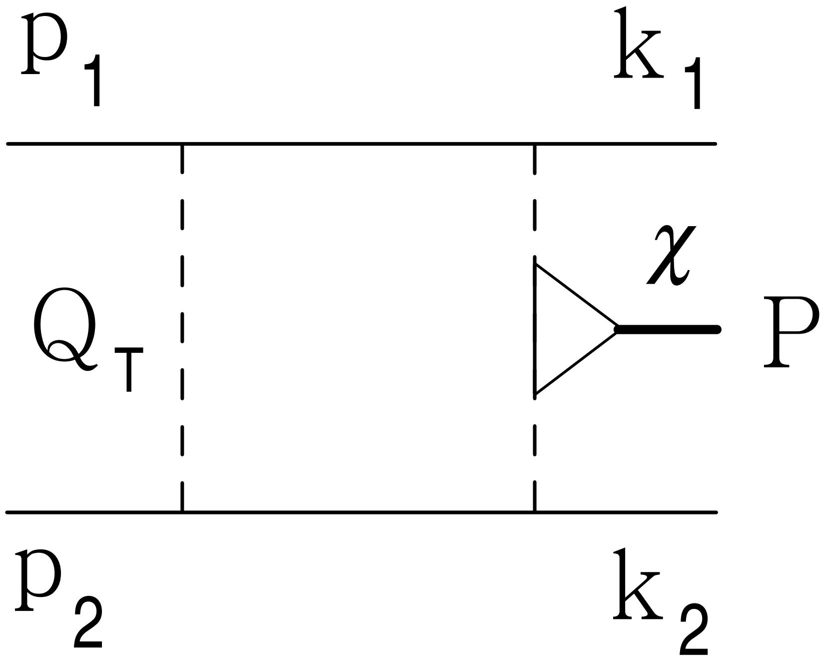
  where $F(t) \approx \exp(b\,t)$, with $b = 2$ GeV^{-2}, is the nucleon form factor and dPH the phase space factor.

- $S^2_{\text{gap}}(\sqrt{s})$ is the gap survival probability factor.
- The scattering matrix is given by,

$$\mathcal{M}_{fi} \quad = \quad \mathcal{M}_0 \left(\frac{s}{s_1}\right)^{\alpha(t_2)-1} \left(\frac{s}{s_2}\right)^{\alpha(t_1)-1} \exp\left(\beta\left(t_1 + t_2\right)\right).$$

- $\mathcal{M}_0$ is the amplitude in forward scattering limit ($t_1 = t_2 = 0$).
- The Pomeron trajectory is given by $\alpha(t) = 1 + \epsilon + \alpha' t$ with $\epsilon \approx 0.08$, $\alpha' = 0.25$ GeV^{-2}.

Diagrams and kinematics



- Notation for variables used in amplitude:

$$
\begin{aligned}
s &= (p_1 + p_2)^2 \\
s_1 &= (k_1 + P)^2, \;\; s_2 = (k_2 + P)^2 \\
t_1 &= (p_1 - k_1)^2, \;\; t_2 = (p_2 - k_2)^2
\end{aligned}
$$

Scalar meson production model

- In what follows, $\mathcal{M}_0$ for colliding hadrons is,

$$\mathcal{M}_0 = 32\,\alpha_0^2\,D_0^3 \int d^2\vec{\kappa}\,p_1^\lambda V_{\lambda\nu}^J p_2^\nu \,\exp(-3\,\vec{\kappa}^2/\tau^2),$$

- $V_{\lambda\nu}^J$ is the $gg \to R^J$ vertex depending on the polarization J of the R^J meson state.
- For the cases considered here, $J = 0$, one obtains:

$$p_1^\lambda V_{\lambda\nu}^0 p_2^\nu = \frac{s\,\vec{\kappa}^2}{2M_R^2} A,$$

- A is expressed by the mass M_R and the width $\Gamma(gg \to R)$ of the scalar meson through the relation,

$$A^2 = 8\pi M_R\,\Gamma(gg \to R)$$

- For decays widths we use $\Gamma(R \to gg) = \mathrm{Br}(R \to gg)\,\Gamma_{tot}(R)$.

Model: parameters and limitations

- For simplicity, we take $\mathrm{Br}\,(R \to gg) = 1$, which will introduce a sizable theoretical uncertainty.
- The factor S_{gap} takes the gap survival effect into account.
- We consider gap factor $S^2_{\mathrm{gap}} = 0.026$ at $\sqrt{s} = 14$ TeV for the nucleon-nucleon collisions (KKMR model).
- The parameter $\alpha_0 = G^2/4\pi$ has been constrained by the experimental result for $\chi_c\,(0^{++})$ production at Tevatron, $d\sigma\,(\chi_{c0})/dy|_{y=0} = 76 \pm 14$ nb.
- Thus, we found the constraint $S^2_{\mathrm{gap}}\,(\sqrt{s} = 2\,\mathrm{TeV})/\alpha_0^2 = 0.45$, which gives $\alpha_0 = 0.316$.
- A limitation of the approach above is that it does not allow to deal with $J = 1, 2$ states.

Results for pp collisions at the LHC

$f_0(980)$	Γ_{tot} [MeV]	$\sqrt{s} = 7$ TeV	$\sqrt{s} = 14$ TeV
$\frac{d\sigma}{dy}(y=0)$	(70 ± 38)	26.9 μb	27.1 μb
σ_{tot}	—	369 μb	407 μb

- Cross sections for exclusive $f_0(980)$ production for LHC energies ($\sqrt{s} = 7$ TeV and $\sqrt{s} = 14$ TeV).
- To be considered only order of magnitude estimate.
- Large compared to the $\gamma\gamma$ channel (EPA approximation):

Meson	$\Gamma_{\gamma\gamma}$ [keV]	$\sqrt{s} = 7$ TeV	$\sqrt{s} = 14$ TeV
$f_0(980)$	(0.29 ± 0.09)	0.12 nb	0.15 nb

Exclusive production of $f_2(1270)$

- The DPE contribution to $J = 1$ and $J = 2$ meson production in the forward scattering limit is vanishing, either perturbative or non-perturbative two-gluon exchange models.
- This limitation can be circumvented considering the soft Pomeron like a isoscalar ($C = +1$) photon when coupling to a quark or anti-quark.
- In this approach, the cross section is written as:

$$\sigma\left(pp \to p + R + p\right) = \frac{1}{2(4\pi)^3 s^2 W_{R_J}^2}$$

$$\times \quad \int dP_R\, dt_1 dt_2 \sum_{j=1}^{2} \omega_j \ell_1^{\mu\alpha} \ell_2^{\nu\beta}\, A_{\mu\nu}^J A_{\alpha\beta}^{J*} \left[D_{I\!P}(t_1) D_{I\!P}(t_2)\right]^2$$

- The effective Pomeron propagator is denoted by $D_{I\!P}(t)$.

Model: technical details

- Explicitly, the Pomeron propagator reads as

$$D_{I\!P}(t) = 3\beta_0^2 \left(\frac{\omega}{E}\right)^{1-\alpha_{I\!P}(t)} F_p(t)$$

- Quantity $F_p(t)$ is the form factor of the nucleon.
- The coupling to the nucleon is described by the tensor $\ell^{\mu\alpha}$ arising from its fermionic current.
- For the Pomeron-energies it is used $\omega_{1,2} = (W_{R_J} \pm P_R)/2$, where W_{R_J} corresponds to the total energy of the meson R_J in the center-of-mass system given by $W_{R_J} = \sqrt{P_R^2 + M_R^2}$.
- For the Pomeron-Pomeron-R vertex, the R particle is treated as a nonrelativistic bound state of a $q\bar{q}$ system.

Model: technical details

- As the $I\!P$ couples approximately like a $C = +1$ photon, the $I\!P$-quark vertex is given by a γ-matrix.

$$
\begin{aligned}
A^{J=0}_{\mu\nu} &= A_0 \left\{ \left[g_{\mu\nu}(q_1 \cdot q_2) - q_{2\mu} q_{1\nu} \right] \left[M_R^2 + (q_1 \cdot q_2) \right] - g_{\mu\nu} q_1^2 q_2^2 \right\} , \\
A^{J=1}_{\mu\nu} &= A_1 \left(q_1^2 \epsilon_{\alpha\mu\nu\beta} \epsilon^{\alpha} q_2^{\beta} - q_2^2 \epsilon_{\alpha\mu\nu\beta} \epsilon^{\alpha} q_1^{\beta} \right) , \\
A^{J=2}_{\mu\nu} &= A_2 \left[(q_1 \cdot q_2) g_{\mu\rho} g_{\nu\rho} + g_{\mu\nu} q_{1\rho} q_{2\sigma} - q_{2\mu} q_{1\rho} g_{\sigma\nu} - q_{1\nu} q_{2\rho} g_{\sigma\mu} \right]
\end{aligned}
$$

- Here, $A_0 = \frac{2}{\sqrt{6}} \frac{a}{M_R}$, $A_1 = ia$ and $A_2 = \sqrt{2} a M_R$.
- In addition, ϵ_μ and $\epsilon_{\mu\nu}$ are the polarization vector and tensor of the $J = 1$ and $J = 2$ states, respectively.
- The factor a is given by:

$$
a = \frac{4}{(q_1 \cdot q_2)} \sqrt{\frac{6}{4\pi M_R}}\, \phi'(0)
$$

Cross section estimate

- $\phi'(0)$ is derivative of the wavefunction at the origin in coordinate space, determined from meson two-photon width $\Gamma(R_{J=2} \to \gamma\gamma)$.
- The nonrelativistic quark model predicts that the two-photon partial width is

$$\Gamma_{\gamma\gamma}(f_2(1270)) = 3\left(\frac{5}{9\sqrt{2}}\right)^2 \frac{12}{5}\frac{2^4\alpha^2}{M^4}|\phi'(0)|^2$$

- Collecting all the ingredients, the cross section estimate can be find.

$f_2(1270)$	$\Gamma_{\gamma\gamma}/\Gamma_{tot}$	$\sqrt{s} = 7$ TeV	$\sqrt{s} = 14$ TeV
σ_{tot}	$(1.64 \pm 0.19) \times 10^{-5}$	1083 nb	1107 nb

- In $\gamma\gamma$ channel we obtain ≈ 3 nb at the same energy.

A note on exclusive f_2 photoproduction

- It was suggested long time ago that high-energy photoproduction of $C = +$ mesons, e.g. π^0, $f_2^0(1270)$ and $a_2^0(1320)$, with nucleon excitation would provide a clean signature for Odderon exchange.
- Theoretical prediction at $\sqrt{s} = 20$ GeV for the $f_2(1270)$ meson gives $\sigma(\gamma p \to f_2^0(1270)X) \approx 21\,\mathrm{nb}$.
- We estimate the photon-Odderon contribution to the $f_2(1270)$ exclusive production using the EPA approximation.

$f_2(1270)$	$\sqrt{s} = 7$ TeV	$\sqrt{s} = 14$ TeV
$\frac{d\sigma}{dy}(y = 0)$	2.4 nb	2.9 nb
σ_{tot}	29 nb	37 nb

Summary and comments

- We have investigated the central diffractive production of mesons $f_0(980)$ and $f_2(1270)$ at the energy of CERN-LHC on proton-proton collisions.
- For the central diffraction processes we have considered two non-perturbative Pomeron models to the meson production.
- In particular, one of them is able to provide the cross section for $J = 1, 2$ meson states like $f_2(1270)$.
- It is the dominant channel compared to $\gamma\gamma$ process.
- Several uncertainties: e.g., two-gluon widths, gap factor, model parameters.
- Order of magnitude calculation.