Two-Photon Interactions in Meson Production at Energies at the CERN Large Hadron Collider (LHC)

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With the development of experiments in particle accelerators, there have been many new particles discovered. Some of these new particles are called *exotic particles* and are predicted by Quantum Chromodynamics (QCD). There are various models for the study of these particles, and a possible way to study the exotic particle production is through the study of meson production in two-photon interactions at high-energy collisions due his clean experimental signal. In this contribution, we calculate the meson production in two-photon interactions at LHC energies considering proton-proton collisions to estimate the total cross section for the production of exotic states.

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1. Introduction

The production of exotic states such as glueballs, hadronic molecules, hybrid mesons, tetraquarks and others have been subject of intense discussion in the context of hadron spectroscopy. In particular it is possible to study the possible existence of anomalous couplings, constrain the partial widths $\Gamma_{\gamma\gamma}$, quark content and spin structure of meson resonances considering hadron - hadron collisions at LHC energies.

In this work we want to estimate the total cross section for the production of exotic mesons through of two-photon interactions at LHC energies considering proton-proton collisions. For this we consider a large parameter of impact

$$b > R_{h_1} + R_{h_2}, \quad (1)$$

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and in ultra-relativistic interactions. The present results are complementary to those of Ref. ¹.

When considering ultra relativistic protons in $pp(\bar{p})$ collisions that give rise to strong electromagnetic fields, the photon originated from these fields of one of the two colliding hadrons can interact with one photon of the other hadron (photon-photon process) or with the other hadron (photon-hadron process). Our interest on these processes comes from the possibility of the production of a neutral X state which has the total cross section given by (See, e.g., Ref. ²)

$$\sigma(h_1 h_2 \rightarrow h_1 \otimes X \otimes h_2) = \int_0^1 \int_0^1 dx_1 dx_2 f_{h_1}^\gamma(x_1) f_{h_2}^\gamma(x_2) \sigma_{\gamma\gamma}^X(x_1 x_2 s), \quad (2)$$

where $\otimes$ characterizes the presence of a rapidity gap in the final state, s is the squared center of mass energy, $f_{h_i}^\gamma$ is the distribution function which is associated to the flux of photons generated by the hadron h_i , $x = \omega/E$, with ω and E the photon and hadron energies, respectively. Moreover, $\sigma_{\gamma\gamma}^X$ is the photon-photon cross section given by

$$\sigma_{\gamma\gamma}^X(x_1 x_2 s) = 8\pi^2 (2J + 1) \frac{\Gamma_{X \rightarrow \gamma\gamma}}{m_X} \delta(x_1 x_2 s - m_X^2), \quad (3)$$

where J , m_x and $\Gamma_{X \rightarrow \gamma\gamma}$ are the spin, mass and the photon-photon partial decay width of the final state X , respectively.

2. The Equivalent Photon Flux

Currently there are different models for the equivalent photon flux available in the literature. In particular, we in our study of meson production we consider the following models (See, e.g., Ref. ³)

$$f_h^\gamma(x) = \frac{\alpha}{\pi} \left(\frac{1 - x + 0.5x^2}{x} \right) \left[\frac{A + 3}{A - 1} \ln(A) - \frac{17}{6} - \frac{4}{3A} + \frac{1}{6A^2} \right], \quad (4)$$

and

$$f_h^\gamma(x) = \frac{\alpha}{\pi} \left(\frac{1 - x + 0.5x^2}{x} \right) \left[\ln(A) - \frac{11}{6} + \frac{3}{A} - \frac{3}{2A^2} + \frac{1}{3A^3} \right], \quad (5)$$

where

$$A = 1 + (0.71 \text{ GeV}^2)/Q_{min}^2, \quad (6)$$

$$Q_{min}^2 = (xM_A)^2/(1 - x), \quad (7)$$

and M_A is the mass of the projectile. These two models are denoted, respectively, by Nystrand (N) and Dress-Zeppenfeld (DZ) in Fig. 1. Moreover, we present also the photon flux proposed by Kniehl (Ref. ⁴) and the well-known Weizsacker-Williams one using a minimal impact factor $b_{min} = 0.7$ fm in the proton photon flux. We have that the N and DZ models can be considered an upper and lower bound for the photon flux, respectively.

Fig. 1. Equivalent photon flux as a function of the fractional photon energy x .

3. Results

Following is the presentation of our predictions for the total cross section considering proton - proton collisions at LHC and center-of-mass energies of 7 TeV and 14 TeV. We used the Nystrand model for the equivalent photon flux in our calculations,

Table 1. Theoretical values for the total cross section for glueballs candidates at LHC energies.

State	$\Gamma_{\gamma\gamma}^{th.}(\text{eV})$ $G \rightarrow \gamma\gamma$	σ (pb)	
		7 TeV	14 TeV
$f_0(1500)$	0.77	0.080	0.088
$f_0(1710)$	7.03	0.38	0.51
$X(1835)$	0.021	0.0009	0.0012

Table 2. Theoretical values for the total cross section for hadronic molecules candidates at LHC energies.

State	Mass (MeV)	$\Gamma_{\gamma\gamma}^{th.}(\text{keV})$ $H \rightarrow \gamma\gamma$	σ (pb)	
			7 TeV	14 TeV
$f_2(1270)$	1276	2.25	1703.9	2254.3
$f_0(1370)$	1523	1.31	108.16	144.08
$f'_2(1525)$	1525	0.05	20.55	27.37
$f_0(1710)$	1721	0.05	2.71	3.63
$X(3940), 0^{++}$	3943	0.33 ± 0.01	1.01	1.40
$X(3940), 2^{++}$	3943	0.27 ± 0.01	4.12	5.73
$X(4140), 0^{++}$	4143	0.63 ± 0.01	1.62	2.25
$X(4140), 2^{++}$	4143	0.50 ± 0.01	6.41	8.94

which implies our predictions should be considered a lower bound, where our results are for glueballs and hadronic molecules candidates.

In the Table 1 below we present our predictions for glueballs candidate using theoretical decay ratios as given in Ref. ⁵.

Finally, in Table 2 below we present our predictions for the hadronic molecule candidates with theoretical decay ratio and masses as given in Refs. ^{6–7}.

4. Conclusions

We have obtained non-negligible values for the total cross section to the candidates the glueballs and hadronic molecules, showing that the experimental study for these states is feasible through the meson production in two-photon at LHC, characterized by two rapidity gaps in the final state.

The next step will be the application for others candidates to exotics particles.

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