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Resonance Production in Peripheral Heavy Ion Collisions

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Abstract

Heavy-ion collisions at ultrarelativistic energies may be used as a powerful source of photons and pomerons. We compute the rates for pseudoscalar meson production through two-photon and two-pomeron scattering, at energies that will be available at RHIC and LHC. Light mesons will mostly be produced by pomeron fusion at large rates, the two processes are comparable for charmed mesons, while electromagnetic production will be dominant for bottom mesons. We discuss the possibility of observing the reaction $\gamma\gamma(PP) \rightarrow R \rightarrow \gamma\gamma$, and comment on the particular case where R could be a scalar resonance at 650 MeV.

Relativistic heavy-ion colliders are planned and considered in Brookhaven (RHIC) [1] and at CERN (LHC) [2], with the main interest in the search of a quark-gluon plasma in central nuclear reactions. In addition to this important feature of heavy-ion colliders, peripheral collisions may give rise to a huge luminosity of photons, and the possibilities of studying electromagnetic physics in such collisions has been considered at length by Baur and Bertulani [3]. In particular, the possibility of the search and discovery of an intermediate-mass standard Higgs boson in $\gamma\gamma$ reactions induced by ion-ion collisions has been discussed by several authors [4, 5], whose production has also been investigated in the case of pomeron-pomeron fusion [6]. The advantage of the enormous photon luminosities in heavy-ion collisions, has also been used to investigate nonstandard $\gamma\gamma$ processes [7].

Despite the intense investigation on peripheral relativistic ion-ion collisions, there are several problems to be circumvented before saying that these colliders are promising tools for the the discovery of new particles or interactions. For instance, Cahn and Jackson [5] have shown that requiring only peripheral collisions reduces the net photon luminosity, and, consequently, the chances to observe a possible intermediate-mass standard Higgs boson. On the other hand it is important to remember that most of the photons will carry only a small fraction of the ion momentum, favouring low mass final states. From the experience with two-photon physics at e^+e^- colliders, we can at least be sure that ion-ion colliders will be extremely useful to study hadronic resonances with $J^{PC} = 0^{-+}, 0^{++}, 2^{-+}, 2^{++}, \dots$. This was already pointed out by Baur and Bertulani [8], and here we will improve their calculation of resonance production through $\gamma\gamma$ fusion, and compute rates for double-pomeron exchange, which will compete with photon fusion. Although pomeron-pomeron scattering is not important for heavy final states, as in the case of the Higgs boson [6], we shall see that it is dominant for light resonances, and will produce such amount of mesons, that will allow the study of decays with very small branching ratios.

The photon distribution in the heavy-ion collision can be determined through the equivalent photon or Weizsäcker-Williams approximation. Denoting by $F(x)dx$ the number of photons carrying a fraction between x and $x+dx$ of the total momentum of a nucleus of charge Ze , we can define the two-photon luminosity through

$$\frac{dL}{d\tau} = \int_{\tau}^1 \frac{dx}{x} F(x) F(\tau/x), \quad (1)$$

where $\tau = \hat{s}/s$, and $s(\hat{s})$ is the square of the c.m.-system (c.m.s) energy of the ion-ion (photon-photon) system. The total cross section $ZZ \rightarrow ZZ\gamma\gamma \rightarrow ZZR$ can be written as

$$\sigma(s) = \int d\tau \frac{dL}{d\tau} \hat{\sigma}(\hat{s}), \quad (2)$$

where $\hat{\sigma}(\hat{s})$ is the cross section of the subprocess $\gamma\gamma \rightarrow R$.

There remains only to determine $F(x)$. In the literature there are several approaches for doing so, and we choose the conservative and more realistic photon distribution of Ref. [5]. Using a prescription proposed by Baur [9], Cahn and Jackson [5] obtained a photon distribution which is not factorizable. However, they were able to give a fit for the differential luminosity which is quite useful in practical calculations:

$$\frac{dL}{d\tau} = \left(\frac{Z^2 \alpha}{\pi} \right)^2 \frac{16}{3\tau} \xi(z), \quad (3)$$

where $z = 2MR\sqrt{\tau}$, $M(R)$ is the nucleus mass(radius), and $\xi(z)$ is given by

$$\xi(z) = \sum_{i=1}^3 A_i e^{-b_i z}, \quad (4)$$

which is a fit resulting from the numerical integration of the photon distribution, accurate to 2% or better for $0.05 < z < 5.0$, and where $A_1 = 1.909$, $A_2 = 12.35$, $A_3 = 46.28$, $b_1 = 2.566$, $b_2 = 4.948$, and $b_3 = 15.21$. For $z < 0.05$ we use the expression [5]

$$\frac{dL}{d\tau} = \left(\frac{Z^2 \alpha}{\pi} \right)^2 \frac{16}{3\tau} \left(\ln \left(\frac{1.234}{z} \right) \right)^3. \quad (5)$$

To estimate the production of single spin zero resonances, we note that these states can be formed by photon-photon fusion with a coupling strength that is measured by their photonic width

$$\hat{\sigma}_{\gamma\gamma \rightarrow R} = \frac{8\pi^2}{M_R s} \Gamma_{R \rightarrow \gamma\gamma} \delta \left(\tau - \frac{M_R^2}{s} \right), \quad (6)$$

where M_R is the resonance mass. The resulting cross sections for a series of resonances are shown in Table 1. We considered collisions of ^{238}U at RHIC, and ^{206}Pb at LHC. The energies involved in these colliders will be $\sqrt{s} = 2.0 \times 10^2$ GeV/nucleon at RHIC, and $\sqrt{s} = 6.3 \times 10^3$ GeV/nucleon at LHC, operating with the luminosities $\mathcal{L}_{RHIC} \simeq 10^{27} \text{ cm}^{-2} \text{ s}^{-1}$ and $\mathcal{L}_{LHC} \simeq 10^{28} \text{ cm}^{-2} \text{ s}^{-1}$. Notice that our results are slightly smaller than the ones of Ref. [8] for the lighter resonances. For the heavier ones the differences with Ref. [8] increase, mainly because the heavy particle production depends strongly on the large τ behavior of the luminosity function, and our approximation at large τ for the photon distribution is more appropriate than the one used by Baur and Bertulani [8].

In the case of double-pomeron scattering the diagram to be computed is the one of Fig.(1), where the pomeron is emitted by the nucleus, and the blob in this figure represents the pomeron effective interaction with the quark forming the resonance. The pomeron distribution in a nucleus can be obtained folding the pomeron distribution function of a pomeron in the nucleon with the elastic nuclear form factor. This has been worked out in detail by Muller and Schramm [6], and is given by

$$F_P(x) = \left(\frac{3A\beta_0 Q_0^2}{2\pi} \right)^2 \frac{1}{x} \left(\frac{s'}{m^2} \right)^{2\epsilon} e^{-(\frac{xM}{Q_0})^2}, \quad (7)$$

where A is the atomic mass, β_0 is the quark-pomeron coupling, and is equal to $\beta_0^2 = 3.93 \text{ GeV}^{-2}$. The factor $s'^{2\epsilon}$ in Eq.(7), where s' denotes the invariant mass of the subprocess with which the pomeron participates, comes from the Regge behavior of the pomeron, whose trajectory is given by $\alpha_P(t) = 1 + \epsilon + \alpha'_{\text{P}} t$, with $\epsilon = 0.085$. In Eq.(7) $Q_0 \approx 60$ MeV determines the width of the nuclear gaussian form factor used to obtain the Pomeron distribution.

To compute the subprocess cross section in the case of double-pomeron scattering, we use the phenomenological fact that the pomeron couples to quarks like a isoscalar photon [10]. This will allow us to obtain the pomeron-pomeron $\rightarrow$ resonance cross section from the photon-photon one. However, it has also been found [11] that it is not always a good approximation to take the pomeron-quark-quark vertex to be pointlike. In fact, when either or both of the two quark legs in this vertex goes far “off-shell”, the coupling must decrease. The simplest assumption that agrees with experiment is to take the pomeron-quark coupling of the form [11]

$$\beta_0(Q^2) = \beta_0 \frac{\mu_0^2}{\mu_0^2 + Q^2}, \quad (8)$$

where we will simply assume $Q = \frac{1}{2}M_R$, and $\mu_0^2 = 1.2 \text{ GeV}^2$ is a mass scale characteristic of the pomeron. According to this, it is easy to verify that we can obtain $\Gamma_{R \rightarrow PP}$ from $\Gamma_{R \rightarrow \gamma\gamma}$ as long as we substitute α^2 by $9\tilde{\beta}_0^4/16\pi^2$, where $\tilde{\beta}_0 = \beta_0(M_R/2)$. The remaining calculation is straightforward, and the resulting cross sections are displayed in Table 1.

It is clear that we do not have a large knowledge of the pomeron distribution within the nucleon, however, even considering the uncertainty involved in the calculation, there is no doubt that light resonances in peripheral heavy ion collisions will be basically produced by double-pomeron scattering. The cross sections we obtained are at least one order of magnitude larger than the electromagnetic ones in the case of the lighter mesons. The rate of meson production decrease with the increase of the meson mass, with the pomeron and photon initiated processes becoming of the same magnitude for charmed mesons. The main reason for this behavior lies in the fast decrease of the pomeron-quark coupling for “off-shell” quarks.

We would like to stress that at RHIC we will obtain approximately 10^9 events/year of π^0, η and η' . Even if we consider a small efficiency in tagging the peripheral collision, we shall still have a large number of events to investigate decays with tiny branching ratios. The possibilities are even better at LHC, due to

the larger cross sections and luminosities. To make this point clear, we will give an example of the detection of a possible σ meson. Although several experiments claim about the presence of a resonance (σ) in the region of $600 - 700 \text{ MeV}$ [12], the existence of such a meson is quite controversial. If this particle does exist, it decays mainly into two pions, and this signal is almost lost in the background. The σ partial widths into electroweak interacting particles are very small when compared with the hadronic one, and the hope to discover this particle may be connected with the possibility of observing the resonance in these other channels. Since a very recent measurement of m_σ finds a clear enhancement in the invariant $\pi^0\pi^0$ mass around 650 MeV [13], we will simply assume this mass for the meson, and will verify if it can be produced in heavy ion collisions, and its decay, for instance, into two-photons can be measured, i.e., the reaction $\gamma\gamma(\text{or } PP) \rightarrow \sigma \rightarrow \gamma\gamma$ could provide a better signal to confirm (or not) the existence of the σ . This will also give us a rough idea of how feasible is the detection of these decays for other mesons.

A model calculation for the partial width of the σ meson into two photons gives [14]

$$\Gamma_{\sigma \rightarrow \gamma\gamma} = \left(\frac{\alpha}{6\pi f_\pi} \right)^2 R_\sigma^2 \frac{m_\sigma^3}{4\pi}, \quad (9)$$

where f_σ is related to the pion decay constant, $f_\sigma = 2f_\pi$, and $R_\sigma = 5/3$, entailing $\Gamma_{\sigma \rightarrow \gamma\gamma} = 0.26 \text{ keV}$. Except from the π^0 , this is the smallest partial width into two photons when compared with the mesons contained in Table (1). With this value we obtain the cross section for photon-photon production of σ mesons at RHIC(LHC) equal to $0.39(5.3) \text{ mb}$, while the double pomeron rate for σ production at RHIC(LHC) is $28(110) \text{ mb}$. These values correspond to 8.7×10^8 and 3.4×10^{10} events/year at RHIC and LHC respectively, assuming 100% efficiency.

The number of σ mesons decaying into two photons will be a very small fraction of all the mesons produced. For a $\bar{q}q$ σ -meson with 650 MeV , the linear σ -model predicts a hadronic width as large as its mass, $\Gamma_\sigma \sim m_\sigma$. Therefore, most of the σ 's will decay into two pions, only 340 and 1.3×10^4 mesons (respectively at RHIC

and LHC) will decay into two photons, and these values assume one year of operation with full efficiency for detecting the photons, and tagging the intact ions in the peripheral collision. The chances are clearly better for LHC. One possible background for this reaction comes from the continuum process of photon-photon scattering (or $PP \rightarrow \gamma\gamma$) through the box diagram. However, this reaction does not pose any problem. If we consider only the photon initiated process, the main contribution for the background near the σ mass, will come from the light quarks, electron and muon. For these particles we may use the asymptotic expression of $\gamma\gamma$ scattering [15] ($\hat{\sigma}(\hat{s}) \approx 20/\hat{s}$), as has been used by Baur and Bertulani [8], but integrate Eq.(2) in a bin centered at 650 MeV, and proportional to $2\Gamma_{\sigma \rightarrow \gamma\gamma}$, which gives a cross section smaller than the resonant one, i.e., the continuum subprocess ($\gamma\gamma \rightarrow \gamma\gamma$) is weaker than the resonant one ($\gamma\gamma \rightarrow R$), with the subsequent decay of the resonance into two photons. The conclusion also holds in the case where the subprocess is initiated by two pomerons, since the difference is only the change of coupling constants, as we discussed above. Notice that the interference between the box and resonant diagrams is not important, because on resonance the two processes are out of phase. Finally, it will be much easier to measure the reaction $PP \rightarrow R \rightarrow \gamma\gamma$ for the other light mesons listed on Table (1), as they have larger branching fractions into two photons. There is also the possibility of an accidental background originating, e.g., from the production and 2γ -decay of two pseudoscalar mesons (π^0, η, η'). However, these events can be easily isolated measuring its invariant mass distribution, and making a cut that discriminates a single photon coming from the σ meson, from a neutral pseudoscalar decaying into 2γ . For example, a pion originated from the σ meson will decay in two photons with a large opening angle ϕ , where $\cos(\phi/2) = \sqrt{1 - 4m_\pi^2/m_\sigma^2}$, and the calorimeters already in use in many experiments are able to distinguish between these two and single photon events with high efficiency (see, for instance, ref.[16]).

In conclusion, we computed the rates for light resonance production in relativis-

tic peripheral heavy ion collisions. The processes considered were double photon or double pomeron fusion. The pomeron-pomeron scattering, in the case of light resonances, give cross sections at least one order of magnitude larger than the electromagnetic one. These rates are of the same order for charmed mesons, and the photon-photon production dominates for bottom mesons. The $J = 0$ mesons with parity and charge-conjugation appropriate to be seen in processes of vector boson fusion, will be produced at rates much larger than in the usual e^+e^- machines, and decays with very small branching fractions can be studied. In particular, these machines operating in the heavy ion mode, will be able to shed light on the existence of a σ meson with a mass near 650 MeV, observing it in the reaction $PP \rightarrow \sigma \rightarrow \gamma\gamma$, as long as the efficiency for separating the peripheral collision is not too low.

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References

- [1] “*Conceptual design of the relativistic heavy ion collider (RHIC)*”, Brookhaven National Laboratory, Report BNL 51932 (May, 1986).
- [2] D. Brandt, LHC/Note No. 87, Physics Today, March 1988, p. 17.
- [3] C. A. Bertulani and G. Baur, Phys. Reports **163**, 299 (1988).
- [4] E. Papageorgiu, Phys. Rev. **D40**, 92 (1989); Nucl. Phys. **A498**, 593c (1989); M. Grabiak *et al.*, J. Phys. **G15**, L25 (1989); M. Drees, J. Ellis and D. Zep-penfeld, Phys. Lett. **B223**, 454 (1989).
- [5] R. N. Cahn and J. D. Jackson, Phys. Rev. **D42**, 3690 (1990).
- [6] B. Muller and A. J. Schramm, Nucl. Phys. **A523**, 677 (1991).
- [7] L. D. Almeida, A. A. Natale, S. F. Novaes and O. J. P. Eboli, Phys. Rev. **D44**, 118 (1991).
- [8] G. Baur and C. A. Bertulani, Nucl. Phys. **A505**, 835 (1989).
- [9] G. Baur, in *Proceedings of the CBPF International Workshop on Relativistic Aspects of Nuclear Physics*, Rio de Janeiro, 1989, edited by T. Kodama *et al.* (World Scientific, Singapore, 1990), p. 127.
- [10] A. Donnachie and P. V. Landshoff, Nucl. Phys. **B244**, 322 (1984); **B267**, 690 (1985).
- [11] A. Donnachie and P. V. Landshoff, Phys. Lett. **B185**, 403 (1987); **207**, 319 (1988); Nucl. Phys. **B311**, 509 (1988/89).
- [12] P. Estabrooks *et al.*, Phys. Rev. **D19**, 2678 (1979); N. Biswas *et al.*, Phys. Rev. Lett. **47**, 1378 (1981); T. Akesson *et al.*, Phys. Lett. **B133**, 241 (1983); N. Cason *et al.*, Phys. Rev. **D28**, 1586 (1983); A. Courau *et al.*, Nucl. Phys. **B271**, 1 (1986); M. Svec *et al.*, Phys. Rev. **D45**, 55 (1992).
- [13] KEK-E179 Collaboration, H. Aoyagi *et al.*, talk presented by H. Shimizu at XIII Int. Conf. Particles and Nuclei, Perugia (Italy) June 1993.
- [14] V. A. Miransky and M. D. Scadron, Sov. J. Nucl. Phys. **49**, 922 (1989); Euro-phys. Lett. **11**, 307 (1990).
- [15] L. D. Landau and E. M. Lifshitz, Physique Theorique, vol. IV (Editions Mir, 1973); R. Karplus and M. Neuman, Phys. Rev. **83**, 776 (1951); B. de Tollis, Nuovo Cimento **32**, 753 (1964); **35**, 1182 (1965); V. Constantini, B. de Tollis and G. Pistoni, Nuovo Cimento **2A**, 733 (1971).
- [16] D. Alde, *et al.*, Z. Phys. **C36**, 603 (1987).

Figure Caption

Fig. 1. Diagram for resonance production through double pomeron scattering. The blob indicates the effective quark-pomeron coupling.

FIG. 1

Meson	$M_R(MeV)$	$\Gamma_{R \rightarrow \gamma\gamma}(KeV)$	$RHIC_{\gamma\gamma}$	$RHIC_{PP}$	$LHC_{\gamma\gamma}$	LHC_{PP}
π^0	135	8×10^{-3}	7.1	124	40	386
η	547	0.463	1.5	92	17	351
η'	958	4.3	1.1	99	22	425
η_c	2979	6.6	0.32×10^{-2}	0.11	0.5	0.8
η'_c	3605	2.7	0.36×10^{-3}	0.83×10^{-2}	0.1	0.06
η_b	9366	0.4	0.13×10^{-7}	0.41×10^{-8}	0.37×10^{-3}	0.8×10^{-6}

Table 1: Cross sections for resonance production. For RHIC ($\sqrt{s} = 0.2$ TeV/nucleon) we assumed collisions of ^{238}U , and for LHC ($\sqrt{s} = 6.3$ TeV/nucleon) the nucleus is ^{206}Pb . The columns with the cross sections for photon and pomeron scattering at RHIC and LHC are identified by the indices $\gamma\gamma$ and PP respectively, and the values are in mb.