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Review

Production of electron–positron pairs by nuclear dissociation in peripheral heavy ion collisions

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Abstract

The STAR Collaboration at the Relativistic Heavy Ion Collider present data on electron–positron pair production accompanied by nuclear breakup at small impact parameters where the simultaneous excitation of the two ions, mainly the giant dipole resonance GDR, can occur. We calculate the electron–positron pair production cross section relevant for the STAR experimental setup, and compare our results with the other calculations.

In peripheral relativistic heavy-ion collisions electromagnetic fields are very strong and interact each other for a very short time. Measurement of cross sections and other relevant distributions are very important for understanding the strong field effect [1–3].

We have obtained cross section expressions for electron–positron pair production from relativistic heavy ion collisions based on a lowest order QED calculation. At RHIC and LHC energies, for small impact parameters pair production probabilities violate unitarity. Therefore lowest order diagrams do not describe the pair production process and higher order terms must be included. Including the high order terms, we can obtain the probability of multi-pair production as a Poisson distribution whose mean value is the probability for producing a single pair in lowest order perturbation theory.

Because of some technical difficulties, we have not fully tested the theoretical calculations and experimental results of electron–positron pair production. Vane et al. [4] has obtained

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experimental data at SPS for lepton pair production. In comparison with data, we find that the two-photon external-field model does quite well for the region where a majority of the pairs are being produced. However, for the high-energy (or high-momentum) tail, the theory underpredicts the data.

Recently, the STAR Collaboration has measured electron–positron pairs [5] together with the electromagnetic excitation of both ions, predominantly to the giant dipole resonance. In such measurements, it is assumed that no hadronic interactions occur and the minimum impact parameter is twice the nuclear radius. The STAR Collaboration used Gold atoms at $\sqrt{s_{NN}} = 200$ GeV per nucleon energies. The decay of the excited nucleus generally emits one or two neutrons and these neutrons are detected in the forward Zero Degree Calorimeter (ZDC).

The STAR detector measures the produced electron–positron pairs for the limited kinematic range of pair mass 140 MeV $< M_{ee} <$ 265 MeV, pair rapidity $|Y| < 1.15$ and transverse momentum $p_\perp > 65$ MeV. If the pair production is independent of the nuclear excitation, the total cross section of electron–positron pair production with Giant Dipole Resonance can be written as

$$\sigma_{e^-e^+}^{\rm GDR} = 2\pi \int_{\rho_{\min}}^{\infty} {\rm d}\rho\rho P_{e^-e^+}(\rho) P_{\rm GDR}(\rho) \tag{1}$$

where $P_{e^-e^+}$ is the probability of electron–positron pair production and $P_{\rm GDR}(\rho)$ is the probability of a simultaneous nuclear excitation as a function of impact parameter.

In this work, we calculate the probability of electron–positron pair production in lowest order QED. We use semi-classical approximation in the calculation and use Monte Carlo methods to obtain exact results. We then compare our results with the STAR Collaboration and other theoretical calculations. In order to compare with the STAR experiment, we also restrict the pair rapidity $|Y| < 1.15$ and the transverse momentum $p_\perp > 65$ MeV.

For the probability of GDR excitation in one ion, we use the approximation

$$P_{\rm GDR}(\rho) = S/\rho^2 \tag{2}$$

with

$$S = \frac{2\alpha^2 Z^3 N}{A m_N \omega} = 5.45 \times 10^{-5} Z^3 N A^{-2/3}\ {\rm fm}^2 \tag{3}$$

where m_N is the nucleon mass, N is the neutron number, Z is the proton number and A is the mass number of the ions, respectively. Also, ω is the energy of the GDR state and is approximately equal to 80 MeV $A^{-1/3}$.

Finally, we have calculated the integrated cross section for Au–Au collisions at RHIC energies for the STAR experimental kinematical range. For $\rho_{\min} = 13$, 14, and 15 fm, our results are 1.68, 1.50, and 1.33 mb respectively. These results are consistently smaller than the Kai Hencken et al. calculations in Ref. [6]. On the other hand, we have found the total untagged cross section to be 0.32 b, which is in excellent agreement with Ref. [6]. In our future work, we are going to show our calculations with greater detail and also calculate other distributions.

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