PROCEEDINGS OF SCIENCE

# $e^+e^-$ pair production in peripheral collisions of ultrarelativistic heavy ions *

**R. N. Lee† and A.I. Milstein**
*The Budker Institute of Nuclear Physics and Novosibirsk State University,630090, Novosibirsk, Russia*
*E-mail:* r.n.lee@inp.nsk.su

The Coulomb corrections to the cross section of $e^+e^-$ pair production in ultrarelativistic nuclear collisions are calculated in the next-to-leading approximation with respect to the parameter $L = \ln\gamma_A\gamma_B$ ($\gamma_{A,B}$ are the Lorentz factors of colliding nuclei). We found considerable reduction of the Coulomb corrections even for large $\gamma_A\gamma_B$ due to the suppression of the production of $e^+e^-$ pair with the total energy of the order of a few electron masses in the rest frame of one of the nuclei.

*35th International Conference of High Energy Physics - ICHEP2010,*
*July 22-28, 2010*
*Paris France*

*This report is based on Ref.[1]
†Speaker.

 

PoS(ICHEP 2010)357

The process of $e^+e^-$ pair production in ultrarelativistic heavy-ion collisions is important for the beam lifetime and luminocity of hadron colliders. It is also a serious background for many experiments because of its large cross section. The Born cross section of the process has been known for a long time and has the form

$$\sigma^0 = \frac{28}{27\pi}\frac{(Z_A\alpha Z_B\alpha)^2}{m^2}\left[L^3 - 2.198L^2 + 3.821L - 1.632\right], \quad L = \ln(\gamma_A\gamma_B) \tag{1}$$

For heavy nuclei, the effect of higher-order terms (Coulomb corrections) of the perturbation theory with respect to the parameters $Z_A\alpha$ and $Z_B\alpha$ can be very important ($Z_A$ and $Z_B$ are the charge numbers of the nuclei $A$ and $B$, $\alpha \approx 1/137$ is the fine-structure constant). The result for the Coulomb corrections with respect to nucleus $A$ in leading logarithmic approximation has the form

$$\sigma^A_{LA} = \frac{28(Z_A\alpha Z_B\alpha)^2}{9\pi m^2} f(Z_A\alpha)L^2, \quad f(Z_A\alpha) = \mathrm{Re}[\psi(1+iZ_A\alpha) - \psi(1)] \tag{2}$$

The magnitude of the Coulomb corrections $\sigma^A_{LA} + \sigma^B_{LA}$ in the leading approximation is rather large, being, e.g., about 35% for the Au – Au collisions at RHIC. For the conditions of SPS experiments [4, 5], $\gamma \approx 2\gamma_A\gamma_B \approx 200$,$Z_A = 82$, $Z_B = 72$, the Coulomb corrections are expected to halve the exact cross section in comparison with the Born result. However, no evidence of the Coulomb corrections has been found in these experiments. In the present paper, we present a natural explanation of this experimental result calculating the next-to-leading term of the Coulomb corrections. It appears that this term is numerically large and essentially diminishes the magnitude of the Coulomb corrections.

It is convenient to calculate $\sigma^A$ in the rest frame of the nucleus $A$, where the nucleus $B$ has the Lorenz factor $\gamma = 2\gamma_A\gamma_B$ at $\gamma_{A,B} \gg 1$. It can be represented as

$$\sigma^A = \int_{2m}^{\infty} d\omega \int_{(\omega/\gamma)^2}^{\infty} dQ^2 \left[\frac{dn_\perp(\omega,Q^2)}{d\omega dQ^2}\sigma_\perp(\omega,Q^2) + \frac{dn_\parallel(\omega,Q^2)}{d\omega dQ^2}\sigma_\parallel(\omega,Q^2)\right] \tag{3}$$

where $dn_{\perp,\parallel}(\omega,Q^2)$ are the numbers of virtual photons $\gamma^*$ with the energy $\omega$, the virtuality $-Q^2 < 0$, and the transverse and longitudinal polarizations, respectively. The quantities $\sigma_\perp(\omega,Q^2)$ and $\sigma_\parallel(\omega,Q^2)$ are the Coulomb corrections to the cross sections of the processes $\gamma^*A \to e^+e^-A$.

The leading logarithmic contribution $\propto L^2$ comes from the integration of $\sigma_\perp$ over the region

$$\text{I.} \quad m \ll \omega \ll m\gamma, \quad (\omega/\gamma)^2 \ll Q^2 \ll m^2. \tag{4}$$

The leading correction $\propto L$ comes from the following regions:

$$\text{II.} \quad Q^2 \sim m^2, \quad m \ll \omega \ll \gamma m \qquad \text{III.} \quad Q^2 \sim (\omega/\gamma)^2, \quad m \ll \omega \ll \gamma m$$
$$\text{IV.} \quad \omega \sim m, \quad (m/\gamma)^2 \ll Q^2 \ll m^2$$

The contribution of the region IV was not analyzed so far. In Ref. [2] it was conjectured that contribution of the region IV can be neglected and the result for the cross section $\sigma^A$ can be obtained by considering the asymptotics $\omega \gg m$. It gives the following contribution

$$\sigma^A_{\mathrm{as}} = \frac{28(Z_A\alpha Z_B\alpha)^2}{9\pi m^2} f(Z_A\alpha)\left[L^2 + \frac{20}{21}L\right]. \tag{5}$$

Our analysis is based on the simple observation that in region IV one can neglect the photon virtuality $Q^2$ since $Q^2 \ll m^2$. Thus, the contribution of this region can be expressed via the Coulomb corrections $\sigma_\perp(\omega,0) = \sigma_{\gamma A}(\omega)$ to the cross section of the **real** photoproduction of $e^+e^-$ in the field of nucleus $A$. We obtain

$$\sigma^A = \frac{28(Z_A\alpha Z_B\alpha)^2}{9\pi m^2} f(Z_A\alpha)\left[L^2 + \left(G(Z_A\alpha) + \frac{20}{21}\right)L\right], \tag{6}$$

where

$$G(Z_A\alpha) = 2\int_{2m}^{\infty} \frac{d\omega}{\omega}\left[\frac{\sigma_{\gamma A}(\omega)}{\sigma_{\gamma A}(\infty)} - 1\right]. \tag{7}$$

In order to calculate the function $G(Z_A\alpha)$ we use the interpolating formula for $\sigma_{\gamma A}(\omega)$ of Overbo [3]. The consideration shows that the function $G(Z\alpha)$ varies slowly from $-6.6$ for $Z = 1$ to $-6.14$ for $Z = 100$ being large for all interesting values of $Z$. The large value of $G$ leads to a big difference between $\sigma^A$ from Eq. (6) and its leading logarithmic approximation (2) even for very large $\gamma$. In particular, for Au-Au collisions at RHIC one has $\sigma^A/\sigma^A_{\rm LA} \approx 0.42$. The ratio $\sigma^A/\sigma^0$ is shown in Fig. 1. In the next-to-leading approximation for $\sigma^A$ this ratio (solid curve) is small ($\lesssim 5\%$), while the same ratio obtained with $\sigma^A$ approximated by $\sigma^A_{\rm LA}$ reaches 20% at $\gamma \sim 1000$. For the experiments at SPS [4, 5], the Lorentz factor was $\gamma \approx 200$. Naturally, we can not use the result (6) obtained in the logarithmic approximation in the region $\gamma \lesssim 500$ where the logarithmic correction to $\sigma^A$ becomes larger than the leading term $\sigma^A_{\rm LA}$. However, we can claim that, due to the strong compensation between the leading term and the correction, the Coulomb corrections $\sigma^A$ are much smaller than $\sigma^A_{\rm LA}$ at $\gamma \lesssim 500$. Therefore, our consideration naturally explains the results of the experiments [4, 5].

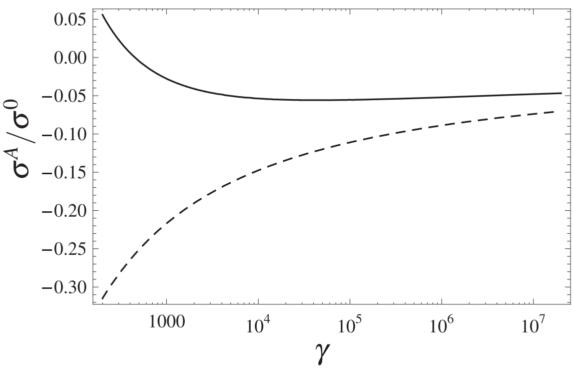


**Figure 1:** The ratio $\sigma^A/\sigma^0$ (solid curve) as a function of $\gamma$ for $Z_A = 82$. Dashed curve shows the ratio $\sigma^A_{\rm LA}/\sigma^0$.

## References


[1] R. N. Lee and A. I. Milstein. *Strong suppression of Coulomb corrections to the cross section of e+e- pair production in ultrarelativistic nuclear collisions Zh. Exp. Teor. Fiz.*, **136** (2009) 1121, [JETP 109 (2009) 968].

[2] S. R. Gevorkyan and E. A. Kuraev. *Lepton pair production in relativistic ion collisions to all orders in $Z\alpha$ with logarithmic accuracy J. Phys. G*, **29** (2003) 1227.

[3] I. Øverbø.*The Coulomb Correction to electron Pair Production by Intermediate-Energy Photons Phys. Lett.*, **B71** (1977) 412.

[4] C. R. Vane *et al. Electron-positron pair production in Coulomb collisions by 6.4-TeV sulfur ions Phys. Rev. A*, **50**(1994) 2313.

[5] C. R. Vane *et al. Measurements of positrons from pair production in Coulomb collisions of 33-TeV lead ions with fixed targets Phys. Rev. A*, **56** (1997)3682.