Final state electromagnetic interaction of electrons and positrons with heavy nuclei in ultra-peripheral ultra-relativistic heavy-ion collisions

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Pb + Pb Collision - electron and positron - spectator interaction

(a) \((b_x=0, b_y=0)\)  
(b) \((b_x=0, b_y=15 \text{ fm})\)  
(c) \((b_x=15 \text{ fm}, b_y=0)\)

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Pb + Pb Collision - electron and positron - spectator interaction

Reduced rapidity distributions for final electrons (blue) and positrons (red) for fixed $b$ and ($b_x=0, b_y=0$) plane of emission points at three collision energies: $\sqrt{s_{NN}}=17.3$, 50 and 200 GeV.

(a) $\sqrt{s_{NN}} = 17.3$ GeV

(b) $\sqrt{s_{NN}} = 17.3$ GeV

(c) $\sqrt{s_{NN}} = 50$ GeV

(d) $\sqrt{s_{NN}} = 200$ GeV
Electron and positron production - EPA model

The equivalent photon approximation (EPA) is standard semiclassical alternative to the Feynman rules for calculating the cross section of EM interaction. Due to coherent action of all the protons in the nucleus, the EM field surrounding the ions is very strong. Produce the 'equivalent' or 'quassireal' photons.

\[
\sigma_{A_1A_2 \rightarrow A_1A_2 e^+e^-} (\sqrt{s_{A_1A_2}}) = \int \frac{d\sigma_{\gamma\gamma \rightarrow e^+e^-}}{d \cos \theta} (W_{\gamma\gamma}) N(\omega_1, b_1) N(\omega_2, b_2) S_{abs}^2 (b) \cdot 2\pi b db db_x db_y W_{\gamma\gamma} \frac{dW_{\gamma\gamma}}{2} dY_{e^+e^-} \ d \cos \theta,
\]

where \( N(\omega_i, b_i) \) are photon fluxes, \( W_{\gamma\gamma} = M_{e^+e^-} \) is invariant mass and \( Y_{e^+e^-} = (y_{e^+} + y_{e^-})/2 \) is rapidity of the outgoing system and \( \theta \) is the scattering angle in the \( \gamma\gamma \rightarrow e^+e^- \) center-of-mass system.

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EM lepton interaction with spectator

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Distribution of electrons ((a), (c)) and positrons ((b), (d)) for $\sqrt{s_{NN}} = 17.3$ GeV at $b=50$ fm integrated over $(b_x, b_y)=(-100 \text{ fm}, 100 \text{ fm})$, $p_T^{ini}=(0, 0.1 \text{ GeV})$. 
Rapidity distribution of electrons for $\sqrt{s_{NN}} = 17.3$ GeV (b=14 fm, 50 fm) and 50 GeV and 200 GeV with b=14±0.05 fm (only) integrated over $(b_x, b_y)=(-50$ fm, 50 fm), $p_T^{ini}=(0, 0.1$ GeV).

Summary

- Spectator-induced EM effects in charged pion production give insight to space-time properties of the system of hot and dense matter created in HIC.
- They suggest a picture of the longitudinal evolution of the system at the initial stage at CERN SPS energies largely governed by the energy-momentum conservation.
- The cross section of electrons/positrons produced via photon-photon fusion in HI UPC can be rather reliably calculated and seems to be large, especially for low transverse momentum electrons/positrons.
- The impact parameter equivalent photon approximation is well suitable for investigating the EM effects.
- On the experimental side only rather large transverse momentum electrons/positrons could be measured so far at RHIC and the LHC, typically larger than 0.5 GeV.
- The integration over full $(b_x, b_y)$ plane washes out this effect to large extent.
- We have found that only at small transverse momenta of electrons/positrons one can observe sizeable EM effects.