

Dynamical pair production at sub-barrier energies for light nuclei

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In the collision of two heavy ions, the strong repulsion coming from the Coulomb field is enough to produce e^+e^- pair(s) from vacuum fluctuations [1]. The energy is provided by the kinetic energy of the ions and the Coulomb interaction at the production point. If, for instance, the electron is located at the center of mass (C.M.) of the two ions moving along the z-axis, and the positron is at a distance x from the electron, the ions can be accelerated towards each other since the Coulomb barrier is lowered by the presence of the electron. This screening results in an increase in the kinetic energy of the colliding ions and may result in an increase in the fusion probability of light ions above the adiabatic limit.

In Fig. 1, we plot the effective potential (bottom panel) and the potential ($\pm m_T$ —top panel) vs. the relative distance between the pair. The only acceptable solution is the lowest one given by the red line. A simple inspection of the top panel shows that the positron for this case is initially in the negative energy region and tunnels to the positive one. The other solution gives the positron already in the positive energy region (green line); thus, is not allowed by our proposed mechanism. Other possible solutions can be found

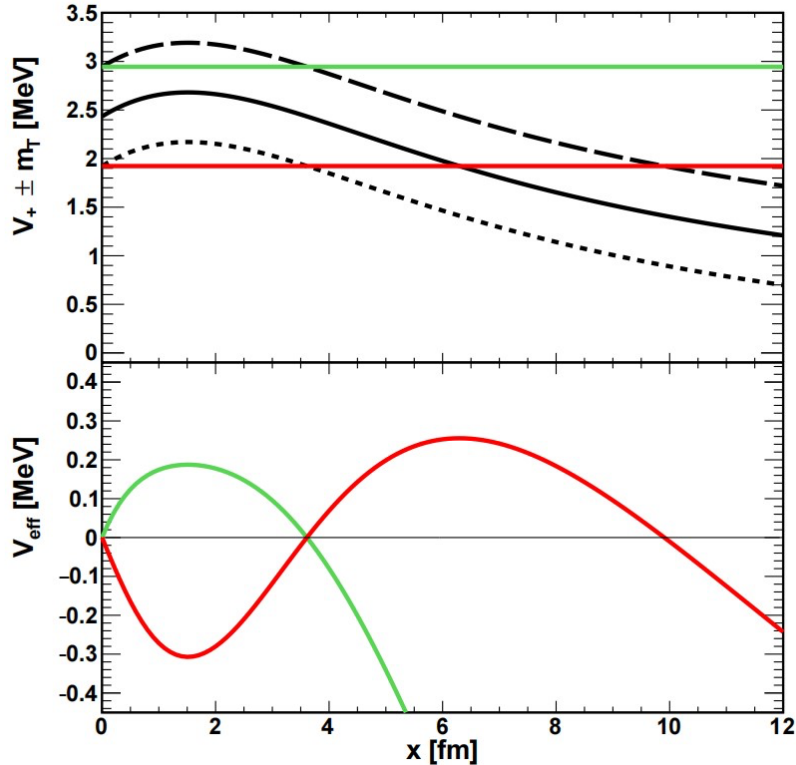


Fig. 1. (Color online) An illustrative example when $V_{\text{eff}}(R, 0) = 0$. In the bottom panel we plot V_{eff} vs. x and the corresponding potential with full line ($\pm m_T = m_e$ —top panel, dashed and dotted lines) seen by the positron. The calculations are performed for $^{12}\text{C}+^{12}\text{C}$ collisions.

if $V_{\text{eff}}(R, x = 0) < 0$. From this discussion, we learned that the two ions can gain kinetic energy because of the location of the electron (in the middle) and the positron (away from the ions) (Fig. 1), and may enhance the sub-barrier fusion probability

For $^{12}\text{C}+^{12}\text{C}$, we find the maximum number of pairs produced in the collisions by summing over the trajectory without taking into account the energy loss after a pair is produced. The maximum is attained near $E_{\text{c.m.}} = 4 \text{ MeV}$ ($\Delta E_k = 2m_e$) in Fig. 2. Clearly, the maximum number of pairs produced in the collisions, and the relative cross-section of Fig. 2, critically depends on the ultraviolet cutoff x_s and it must be confirmed or modified by future experimental data. Furthermore, microscopic calculations following the heavy ion trajectory and the dynamics of one or more pairs created during the time evolution must be implemented in order to make predictions for heavier colliding nuclei and collisions of different mass number nuclei.

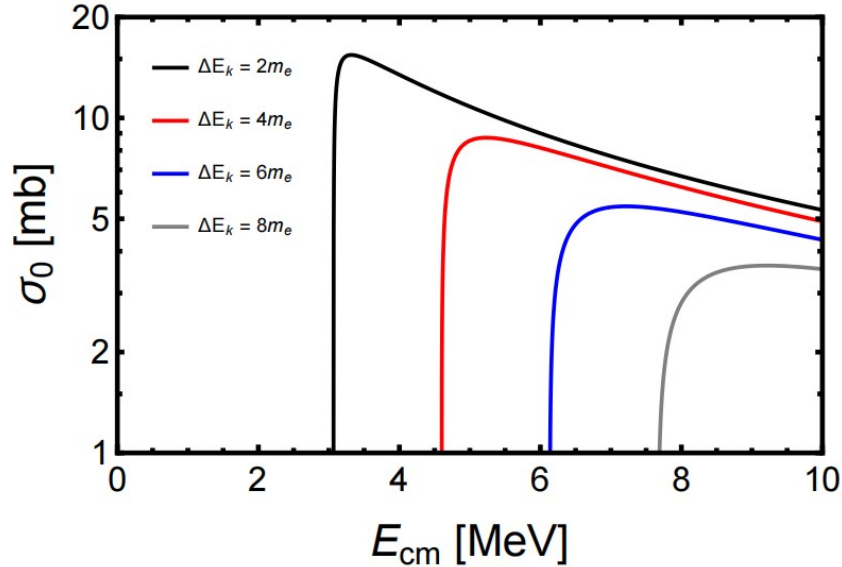


Fig. 2. (Color online) Upper limit for the integrated cross-section for e^+e^- production in $^{12}\text{C}+^{12}\text{C}$ scattering below the Coulomb barrier for different values of ΔE_k . We stress that $\Delta E_k \geq 0$.

We have discussed pair production from a vacuum within the Schwinger formalism. We have shown the conditions for tunneling and the possibility that, if the electron is situated at the c.m. of the colliding nuclei, extra screening may occur. This screening may enhance sub-barrier fusion of light nuclei above the adiabatic limit. For $^{12}\text{C}+^{12}\text{C}$ collisions, we predict $E_{\text{c.m.}} \geq 1 \text{ MeV}$ for this effect to occur. The cross-sections are of the order of mb or less. These predictions call for detailed experimental investigation of pair production for this system, and also their energies, in coincidence with fusion fragments to be able to extract correlation functions. An enhancement may be shown by performing a correlation between fusion events with and without pair production.

[1] T. Settlemyre, H. Zheng and A. Bonasera, *Particles* **5**, 580 (2022).