2 - 27 Experimental Measurement of ^{7}Be, ^{8}B and ^{9}C on ^{nat}Pb Elastic Scattering Above the Coulomb Barriers

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The experiment was performed at the National Laboratory of Heavy Ion Research of the Institute of Modern Physics, Lanzhou, China. The secondary beams of radioactive isotopes were produced by the fragmentation of the $^{12}C^{6+}$ primary on a ^{9}Be target with a thickness of 2 652 μm[1,2]. The secondary beams, ^{7}Be, ^{8}B and ^{9}C beams were delivered by the Radioactive Ion Beam Line in Lanzhou (RIBLL)[3, 4] and impinged on a ^{nat}Pb target at RIBLL Terminal. The energies of the secondary beams, at the physical target, were about three times the Coulomb barriers, 130 MeV for ^{7}Be, 178 MeV for ^{8}B and 227 MeV for ^{9}C, respectively. A 301 μm thick Al plate located on the second focal plane (F2) of RIBLL was utilized to degrade energy and improve the purity of the secondary beams. The average intensities of ^{7}Be, ^{8}B and ^{9}C were 1.5×10^{4} pps, 1×10^{3}, and 5×10^{2} particles per second, respectively. Before hitting the physical target, the secondary beams were identified using a time of flight and energy loss (TOF-ΔE) technique. TOF was measured by two 50 μm thick plastic scintillators located on the second (F2) and fourth focal planes (F4) of the RIBLL. ΔE was measured by a 280 μm thick silicon detector at F4. During the beams, the silicon detector was set to be "off-beam" to reduce the disturbance of the beams. The time resolution of TOF originated from the time resolution of plastic scintillator and the energy dispersive of the beams.

Two position-sensitive Parallel Plate Avalanche Counters (PPACs), with a position resolution of 1 mm, were fixed in front of the ^{nat}Pb target with distances of 100 mm and 500 mm, respectively. Each PPAC had 80 gold-plated tungsten wires as the anodes in both X and Y directions, respectively. The tungsten wires, 20 μm in diameter, were spaced 1 mm apart, providing a sensitive area of 80 cm×80 cm. The signals from the strip electrodes were connected to a delay line with 4 ns delay between neighboring wires. The actual position and direction of the beam on the target were provided by counting the two hit points on the PPACs and extending to the target plane event by event.

The ^{nat}Pb target was a self supporting foil with a thickness of 4.2 mg/cm^2. The elastic scattering events were detected using two sets of ΔE−E silicon telescopes, which consisted of one 150 μm double-sided silicon strip detector (DSSD, 48 strips in 1 mm width each with 0.1mm interval) and one 1 500 μm large surface silicon detector (SSD). Each telescope covered a polar angle of $7^\circ \sim 30^\circ$ in the laboratory frame. The distances from the ^{nat}Pb target to the center of the telescopes were 247 and 201 mm, respectively. Applying the energy window to each spectrum in the off-line data analysis, the elastic scattering events were experimentally identified.

The elastic scattering angle was calculated using the incident position and direction of the beam on the target provided by PPACs and the hitting point on the Si telescopes. In order to consider the broad and nonuniform beam profiles on the target, a Monte Carlo simulation was performed to evaluate the the absolute differential cross sections. More detailed descriptions about this Monte Carlo technique (data normalization and correct for the detectors misalignments) are found in Ref.[5, 6]. The systematic error arising from the target thickness, total number of incoming beam particles and the calculation of the solid angles was eliminated in the simulation.

The experimentally measured elastic scattering angular distributions for ^{9}C, ^{8}B and ^{7}Be+^{nat}Pb, which have been reduced as a ratio of the experimentally measured scattering angular distribution and the Rutherford elastic scattering angular distributionare shown in Fig. 1. The error bars in the figure originate from the statistical errors only.

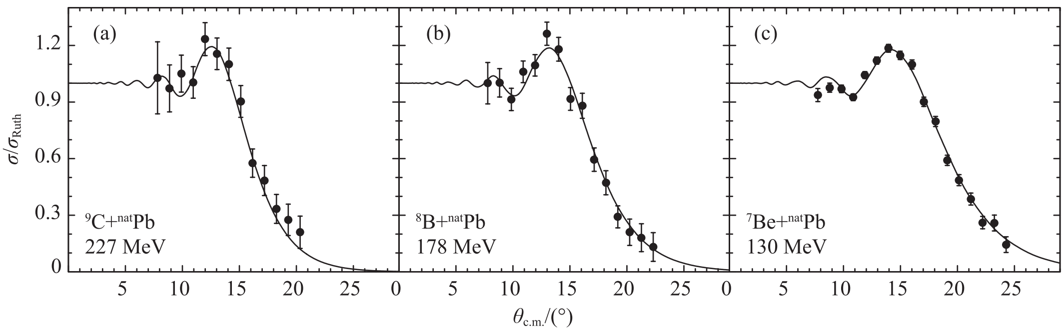

Fig. 1 (color online) Experimentally measured elastic scattering angular distributions for ^{9}C (a), ^{8}B (b) and ^{7}Be (c) on the ^{nat}Pb target and the corresponding results from the optical model calculations with the systematic nucleus-nucleus potential of Xu and Pang[7].

The experimental data in this work are actually from quasi-elastic scattering including both elastic and inelastic contributions, since it is difficult to separate elastic scattering events from inelastic ones, due to the energy dispersion of secondary beams and energy resolution of silicon detectors. However, the contributions from the inelastic scattering channels are negligible in the present data within the angular range covered by our measurements[5, 6].

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References

[1] J. W. Xia, W. L. Zhan, B. W. Wei, et al., Nucl. Instr. and Meth. A, 488(2002)11.

[2] W. L. Zhan, J. W. Xia, H. W. Zhao, et al., Nucl. Phys. A, 805(2008)533c.

[3] Z. Sun, W. L. Zhan, Z. Y. Guo, et al., Nucl. Instr. and Meth. A, 503(2003)496.

[4] Z. Sun, W. L. Zhan, Z. Y. Guo, et al., Chin. Phys. Lett., 15(1998)790.

[5] Y. Y. Yang, J. S. Wang, Q. Wang, et al., Nucl. Instr. and Meth. A, 701(2013)1.

[6] Y. Y. Yang, J. S. Wang, Q. Wang, et al., Phys. Rev. C, 90(2014)014606.

[7] Y. P. Xu, D. Y. Pang, Phys. Rev. C, 87(2013)044605.

2 - 28 Charmonium Production from Two-photon Processes in Relativistic Heavy Ion Collisions*

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The two-photon interactions[1] for charmonium at unprecedentedly high energies can be studied in ultra-peripheral heavy ion collisions at Relativistic Heavy Ion Collider (RHIC), Large Hadron Collider (LHC), and Future Circular Collider (FCC) energies. We investigate the semi-coherent two-photon processes for large-p_T charmonium (J/ψ) production in proton-proton and nucleus-nucleus collisions at RHIC, LHC, and FCC energies. If the transverse momenta of both photons are the same large (non-coherent) or small (coherent), the total transverse momentum would have a very small value, then the charmonium could not obtain large-p_{T} in the $\gamma\gamma \to \mathrm{H}$ interaction, where H is the charmonium. Indeed, the single track condition[2,3] leads to the weak contribution of non-coherent and coherent photon-photon processes for large-p_T charmonium production compared with the semi-coherent processes. Therefore we work in the semi-coherent two-photon approach that one photon is relatively hard and is incoherently emitted by participating projectile, while another can be soft enough to be in a coherent domain.

The cross-section for the charmonium produced by the semi-coherent two-photon interaction in ultra-peripheral collisions can be written as

$$\mathrm{d}\sigma = \widehat{\sigma}_{\gamma\gamma\to\mathrm{H}}(W)\mathrm{d}N_1\mathrm{d}N_2, \tag{1}$$

where the total cross section is given by $\hat{\sigma}_{\gamma\gamma\to\mathrm{H}}(W) = 8\pi^2(2J+1)\dfrac{\Gamma_{H\to\gamma\gamma}}{M_{\mathrm{H}}}\delta(W^2 - M_{\mathrm{H}}^2)$, and the decay width $\Gamma_{\mathrm{H}\to\gamma\gamma}$ for the charmonium can be taken from the experiment[4,5]. Furthermore, J and M_{H} are the spin and mass of the produced state, respectively.

The equivalent photon fluxes for the relativistic proton and nucleus can be obtained as

$$\mathrm{d}N_{1,2} = \frac{\alpha Z^2}{\pi^2}\frac{1-\omega/E+\omega^2/2E^2}{\omega/E}\frac{q_{\mathrm{T}}^2\left[F_{\mathrm{N}}\left(q_{\mathrm{T}}^2+\dfrac{\omega^2}{\gamma^2}\right)\right]^2}{\left(q_{\mathrm{T}}^2+\dfrac{\omega^2}{\gamma^2}\right)^2}, \tag{2}$$

where ω is the energy of the photon, γ is the relativistic factor, E is the energy for the projectiles, and $F(\mathrm{q}^2)$ is the proton and nuclear form factor of the equivalent photon source[6,7].

In Figs.1 and 2, we plot the differential cross section for large-p_{T}charmonium (J/ψ) in ultra-peripheral heavy ion collisions at RHIC, LHC, and FCC energies. Our calculations show that the large values of the differential cross sections for nucleus–nucleus and non-negligible values in proton–proton collisions can be obtained with the semi-coherent approach in ultra-peripheral heavy ion collisions at the RHIC, LHC, and FCC energies.