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LBNL-40002
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May 1997
Presented at the
Particle Accelerator Conference,
Vancouver, B.C., Canada
May 12–16, 1997,
and to be published in
the Proceedings

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This work was supported by the Director, Office of Energy Research, Office of Basic Energy Sciences, Chemical Sciences and Materials Sciences Divisions, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

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CAPTURE FROM PAIR PRODUCTION AS A BEAM LOSS MECHANISM FOR HEAVY IONS AT RHIC*

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Abstract

Electron capture from electron-positron pair production is predicted to be a major source of beam loss for the heaviest ions at RHIC. Achieving the highest luminosity thus requires an understanding of the capture process. We report measurements of this process at Brookhaven National Laboratory's AGS using 10.8 GeV/nucleon Au^{79+} projectiles on Au targets. Capture from pair production is a process in which the very high electromagnetic field involved in the collision of two relativistic heavy ions results in the production of an electron-positron pair with the capture of the electron by one of the ions. There are many theoretical papers published on capture from pair production with discrepancies between predicted cross sections. The experimental results are compared to theory and to previous experiments at 1 GeV/nucleon. The implications of extrapolations to RHIC energies are presented.

1 INTRODUCTION

At relativistic energies, the capture of electrons by ions (recombination) occurs by the well-understood collisions processes of Radiative Electron Capture (REC) and Non-Radiative Capture (NRC). These processes, which require an electron in the initial state, have cross sections that decrease rapidly with increasing collision energy. REC is the capture of a target electron by the ion with the simultaneous emission of a photon (to balance momentum and energy). NRC is the capture of an electron that is initially bound to a target atom or ion. Until recently, REC and NRC were thought to be the dominant processes for electron capture at all relativistic energies.

The large transient fields produced in relativistic charged particle atomic collisions (no nuclear contact) have long been known to produce electrons through electron-positron pair production [1]. But, in 1984, Gould pointed out that for bare heavy ions, the probability for pair creation with simultaneous capture of the electron from the pair into the K-shell, was significant [2]. The cross section for this "capture from pair production" mechanism has been shown to increase with energy (as does the cross section for producing free electron-positron pairs), and is predicted to be the dominant electron capture mechanism at highly relativistic energies [3]. Since capture from pair production requires no electron in the initial state, it can take place between two bare ions, possibly limiting the lifetime of stored beams of bare heavy ions in relativistic heavy ion colliders.

A number of theoretical papers aimed at calculating the cross sections for electron capture from pair production have been published since 1984 [4]. Different calculational techniques were used for high and low relativistic factor (γ). Therefore agreement at low energies does not assure agreement at high energies. Until recently, no experimental measurement to check the validity of the theoretical predictions at high γ has existed.

In this article we report measurements of electron capture from electron-positron pair production in relativistic heavy ion collisions at highly relativistic energies, and discuss the possible implications for the lifetime of heavy ions in the Relativistic Heavy Ion Collider (RHIC) now being constructed at Brookhaven National Laboratory [5]. The experiments have been performed at the AGS accelerator at Brookhaven National Laboratory, using 10.8 GeV/nucleon bare gold ions (Au^{79+}) incident on thin, fixed targets of Au, and are compared to experiments at the Bevalac accelerator at Lawrence Berkeley Laboratory, using 0.4 - 1.3 GeV/nucleon bare lanthanum ions (La^{57+}) incident on gold targets.

2 EXPERIMENT DESCRIPTION

Figure 1 shows a diagram of the Advanced Positron Spectrometer (APS) used to detect positrons. The Au^{79+} ion passes through a fixed target located inside the APS, described below. In the case of capture from pair production, the electron is created directly bound to the gold ion, changing its charge by one unit to Au^{78+}. The experimental signature is the detection of the positron emitted during the collision, in coincidence with the charge-changed Au^{78+}. The Au^{78+} is magnetically separated from the main beam of Au^{79+} and each charge state is detected by a scintillator-photomultiplier tube detector.

*Supported by the Director, Office of Energy Research, Office of Basic Energy Sciences, Chemical Sciences Division and (BF) Material Sciences Division, U.S. Department of Energy under contract DE-AC03-76SF00098.

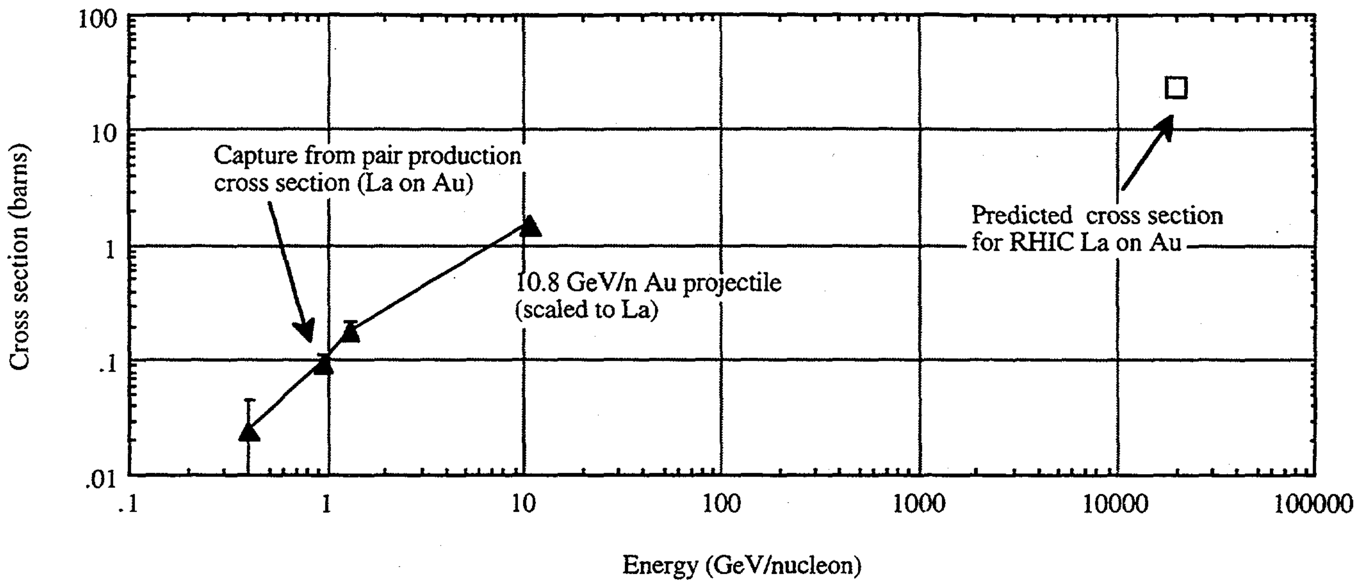

Figure 2 - Graph of capture from pair production as a function of energy. All results are scaled to La on Au, the case for which the most experimental data exists. The triangles represent measured cross sections, while the square point at RHIC energies, scaled to La, is predicted from perturbation theory.

4 DISCUSSION

The preliminary results presented here are in the middle of the range of predictions. These calculations, based on perturbation theory, predict cross sections ranging from 5.7 barns to 12.2 barns [6 - 9].

A convenient way to visualize the cross section for capture from pair production as a function of energy is to scale the collision system to La on Au, where the most experimental results exist [3]. Figure 2 shows the capture from pair production cross section, scaled for a La projectile, as a function of energy. The triangles represent experimental results, scaling the point at 10.8 GeV/nucleon (AGS result) by Z^5 to represent a La projectile rather than a Au projectile. The point for RHIC collider energies is scaled from perturbation theory predictions for Au on Au [10]. A visual analysis of the increase of the experimental cross section with energy indicates that the RHIC predictions are reasonable, but not necessarily assured.

Capture from pair production (resulting in the loss of the charge-changed ion in the collider ring) has been predicted to be the dominant beam loss mechanism for colliding Au + Au beams at RHIC and a significant loss mechanism for lighter ions [5]. If the cross section is an order of magnitude higher than predicted at RHIC energies, then the current after 10 hours will decrease to about 20% of the initial value, instead of 77%, after taking into account intrabeam Coulomb scattering.

Measurements of the cross section for capture from pair production at AGS energies indicate that the high-γ calculations used to predict the loss rate at RHIC are not unreasonable at the low end of their range of validity.

5 ACKNOWLEDGEMENTS

We thank Philip Pile and Joseph W. Glenn III for assistance with the beam optics, David Phillips and David Dayton for timely engineering support, Herman Bartalomy and the entire AGS experimental area support groups for assistance in staging the experiment, and the AGS operators and staff for patience and perseverance in providing the beam tune that made this experiment possible. We thank Harvey Oakley and Robert Aita for providing us with critical equipment and Denise Merkle and Peter Thieberger for assistance in setting up the experiment.

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