Nuclear Physics in Astrophysics IX (NPA-IX) IOP Publishing
Journal of Physics: Conference Series **1668** (2020) 012046 doi:10.1088/1742-6596/1668/1/012046

Towards background-free studies of capture reaction in a heavy-ion storage ring

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Abstract. Stored and cooled, highly-charged ions offer unprecedented capabilities for precision studies in the realm of atomic, nuclear structure and astrophysics [1]. After the successful investigation of the ^{96}Ru(p,γ)^{97}Rh reaction cross section in 2009 [2], the first measurement of the ^{124}Xe(p,γ)^{125}Cs reaction cross section has been performed with decelerated, fully-ionized ^{124}Xe ions in 2016 at the Experimental Storage Ring (ESR) of GSI [3]. Using a Double Sided Silicon Strip Detector, introduced directly into the ultra-high vacuum environment of a storage ring, the ^{125}Cs proton-capture products have been successfully detected. The cross section has been measured at 5 different energies between 5.5 AMeV and 8 AMeV, on the high energy tail of the Gamow-window for hot, explosive scenarios such as supernovae and X-ray binaries. The elastic scattering on the H_2 gas jet target is the major source of background to count the (p,γ) events. Monte Carlo simulations show that an additional slit system in the ESR in combination with the energy information of the Si detector will enable background free measurements of the proton-capture products. The corresponding hardware is being prepared and will increase the sensitivity of the method tremendously.

1. Introduction

Highly-charged stable or radioactive ions can be stored and cooled in a heavy-ion storage ring allowing unique precision studies for atomic, nuclear structure, and in the context of astrophysics [1]. Our measurement campaign was realized at the Experimental Storage Ring (ESR) at the GSI facility to investigate astrophysically relevant reactions. In 2009, as a proof-of-concept experiment, the cross section of ^{96}Ru(p,γ) has been successfully measured [2]. Later, in 2016 the study of the ^{124}Xe(p,γ) reaction has been completed using decelerated fully-stripped $^{124}Xe^{54+}$ [3]. Using a Double Sided Silicon Strip Detector (DSSSD), manufactured for the ultra-high vacuum environment of the storage ring, the ^{125}Cs proton-capture products have been successfully detected.

In order to extend our method into the radioactive regime of reactions happening at low, astrophysically important energies, like eg. the ^{91}Nb(p,γ)^{92}Mo reaction at 4 AMeV, the sensitivity of the method has to be increased.

2. Online elimination of the background

Highly charged heavy ions, while orbiting in a storage ring, interact frequently with the target realizing various atomic and nuclear reactions, as well as elastic scattering. The reaction products of interest can be separated from the main beam and from other nuclear or atomic reaction products by using dipole-separation technique right after the target. Based on the magnetic rigidity the ions travel on different trajectories inside the dipole allowing particle identification with spatially segmented detectors. However, the elastic scattered particles, known as Rutherford scattering, are distributed broadly embodying a dominant background for the nuclear reaction events like (p,γ) events.

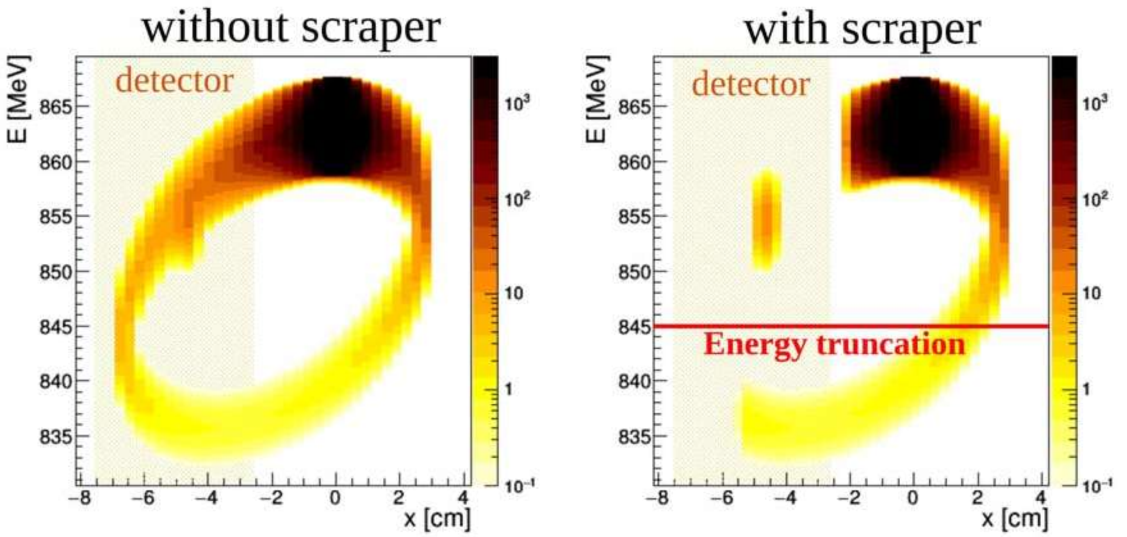

Figure 1. The effect of scraping on the background events underlying to the (p,γ) cluster. Simulation was made with the MOCADI code [4] for a part of the ^{124}Xe(p,γ) dataset.

The ion optical properties of the ESR as well as the reaction kinematics can be modeled by the MOCADI code developed at GSI [4]. Simulation shows, that inserting a scraper device just before the first dipole magnet after the target can tremendously improve the sensitivity for (p,γ) events. Blocking part of the Rutherford scattering on the inner tracks 3 cm away from the beam axis but leaving the beam and the (p,γ) products intact leads to the elimination of the forward scattered component of the elastic scattering underlying to the (p,γ) cluster at the detector position. Without this high rate background events the underlying component of the (p,γ) cluster remains only the backscattered particles as shown in Figure 1 . This improvement will lead to a minimum 95% reduction of the background underlying the (p,γ) peak for the ^{124}Xe experiment at 7 AMeV. A measurement to confirm the online scraping technique is in preparation.

3. Offline elimination of the background

The considerable effect of the online background removal on the signal-to-background ratio can be further improved when in addition to the spatial information of the detector the energy information is used. The remaining part of the Rutherford background still in overlap with the (p,γ) events after scraping can be removed by applying an energy threshold as indicated in Figure 1. However, to distinguish between the two distributions the energy resolution should be better than 2%.

As an input parameter to the Monte Carlo simulations the total energy resolution has to be given, which includes not just the resolution of the used DSSSD particle detector, but also contains the uncertainty of the beam quality and the uncertainty of the geometry of the detector placement. The simulations agree best with the present measurement of ^{124}Xe(p,γ)^{125}Cs when $\delta E/E \approx 0,2\%$, one order of magnitude less than the required energy resolution.

Nevertheless, the downside of the method, that a complete energy reconstruction can be applied only for smallest 85% of the events as a consequence of the properties of the detector. The limit in the dataset implies a maximal 18% uncertainty increase for the number of (p,γ) events which restricts the application of the offline background elimination technique and makes it counterproductive for cases like the ^{124}Xe(p,γ) measurement at 7 AMeV. However, the technique is beneficial when the amount of (p,γ) events is comparable to the number of backscattered Rutherford particles such as measuring with exotic ions at low energies.

Acknowledgements

This project has received funding from the European Research Council (ERC) under the European Unions Horizon 2020 research and innovation programme (grant agreement No 682841 ASTRUm). This work is supported by the Helmholtz International Center for FAIR (HIC and FAIR), by the Bundesministerium für Bildung and Forschung (BMBF) (05P15RFFAA), by the Science and Technology Facilities Council (STFC) UK(ST/L005824/1, ST/M001652/1, ST/M00608), and by the Helmholtz-OCPC Postdoctoral Program 2017 (GSI08). CLW acknowledges support by the European Research Council (grant agreement ERC-2015-StG Nr. 677497 DoRES).

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