Simulation of Star configurations in BINA detector

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1. Introduction

Star Anomaly is one of the most intriguing and still unsolved problem in the domain of few-nucleon systems. Significant discrepancies between theoretical predictions and the available experimental data are observed for Space Star configurations [1,2]. Unfortunately, all recent research has focused on low energies [3,4], so it is important to increase the amount of experimental data and verify that the anomaly is only characteristic for low energies, which could bring us closer to understanding the Star Anomaly.

One of the equipment that allows the study of 3-nucleon systems is the BINA detector located in Cyclotron Center Bronowice (CCB) in Krakow. The dedicated simulation was created in order to check the ability of this detector to register events in the Star configuration.

2. Space Star Anomaly

In proton-deuteron breakup reactions the Star condition is defined as a configuration in center of mass system, where the momentum of the three outgoing particles has the same magnitude and plane containing these particles can be inclined by α from the beam direction. Depending on this angle we can distinguish coplanar Star (α=0 or α=180), Space Star (α=90) and intermediate Star (angle between those two extremes) configurations (Fig.1). Each α condition can be additionally rotated by an angle β, which is a new approach in the studies of the Star Anomaly.

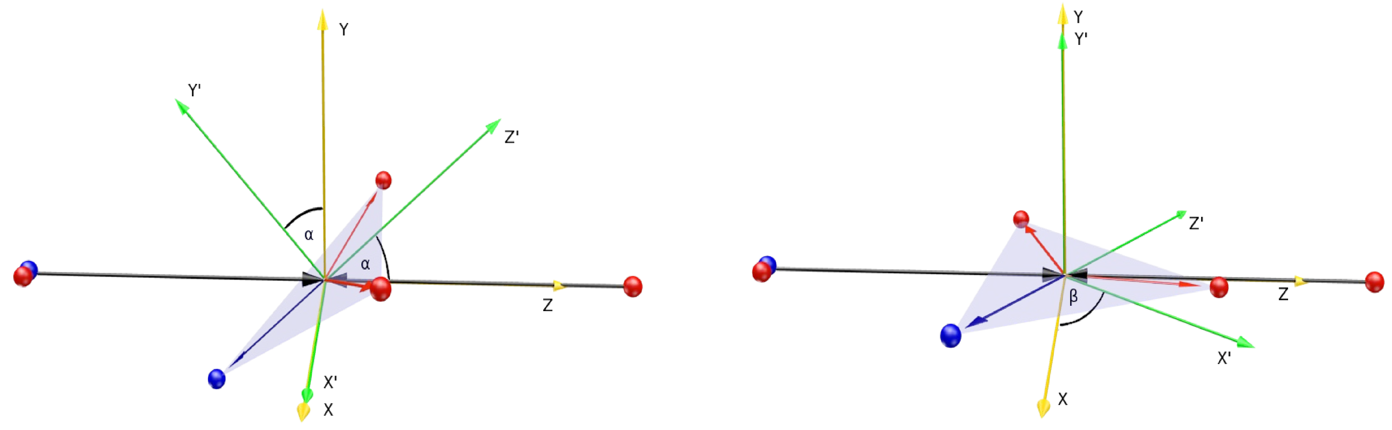


Figure 1. Definitions of α and β in star conditions.

The main feature of the Star Anomaly are significant discrepancies in cross setions between the experimental data and theoretical predictions. For n(13 MeV) + d breakup, differences are about 25% above theory [1]. Interestingly, for proton-deuteron breakup at 13 MeV the differences are about 15% below theoretical predictions [5]. An interesting observation is also the reduction of anomalies for the configuration closer to coplanar Stars (Fig.2) [2]. At this moment the star anomaly has been observed at low energies, so it is also important to perform experiments at higher energies.

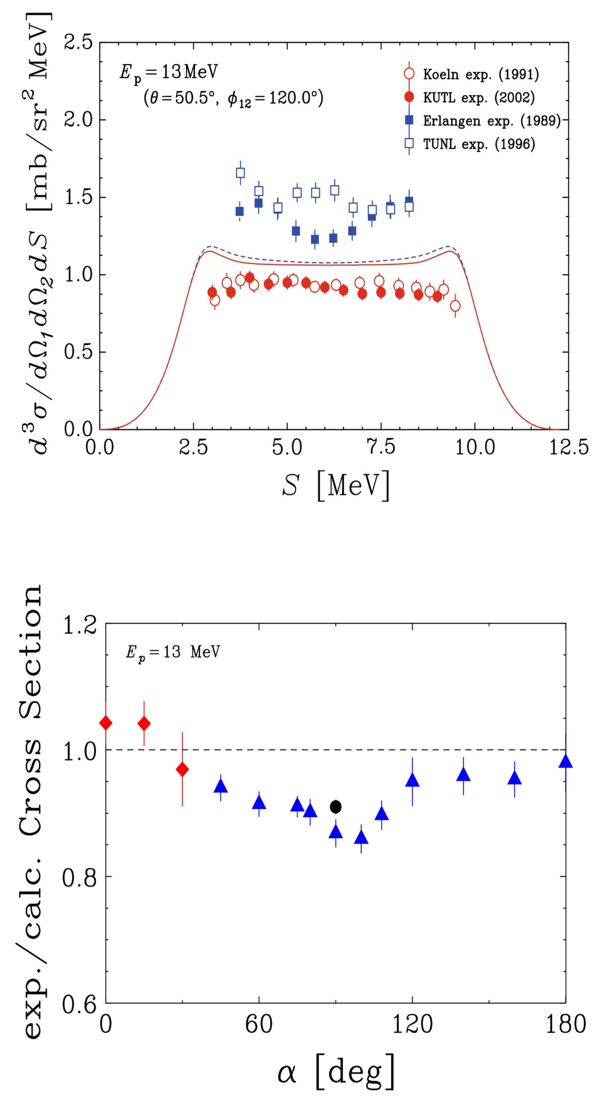
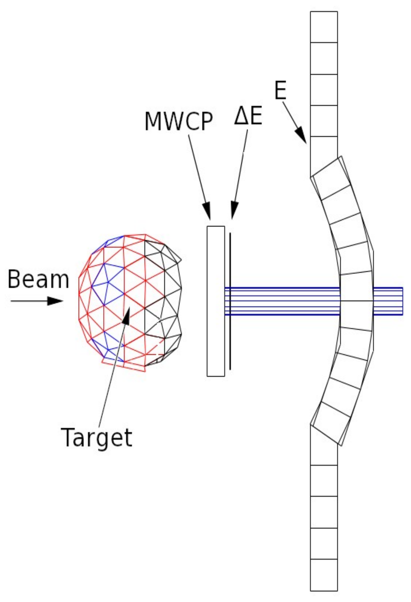


Figure 2. Space Star Anomaly

3. BINA@CCB

Upcoming experiment in CCB (Cyclotron Center Bronowice) using BINA (Big Instrument for Nuclear-polarization Analysis) detector will be a great opportunity to provide more data containing Star configurations at intermediate proton beam energies (108 MeV, 135 MeV and 160 MeV) [6]. BINA consists of two detector systems, "Wall" and "Ball", which together cover the angular range 10° -165°.

The Ball segment consists of 149 "phoswich" scintillators covering the anguar range above 40°. The target holder is located in the center of the Ball. The entire chamber is separated from the air by kapton-kevlar window.



The Wall is composed of a 3-plane Multi-Wire Proportional Chamber (MWPC) to determine positions of the reaction products and two layers of scintillators ΔE – E for particle identification and energy measurement, which cover angular range below 40°.

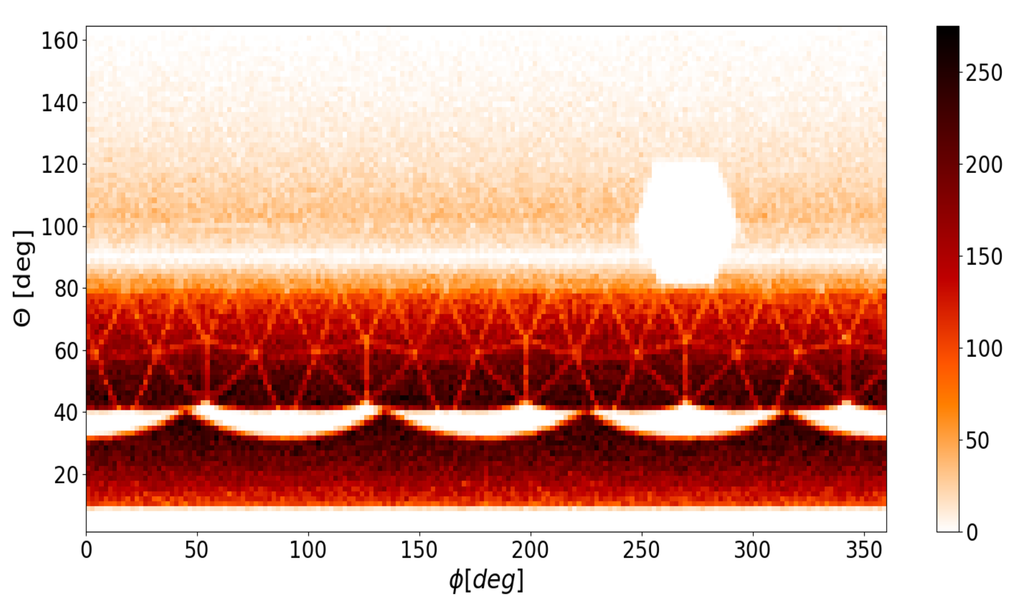


Figure 3. Angular distribution of events detected in scintillator detectors obtained from simulation for $^{2}H(p,pp)n$ at 160MeV ($2\cdot10^{6}$ events)

Since "Wall" is characterized with higher angular resolution (about 5°) than "Ball" (depends of scintillator number), the acceptance for Star configurations registered as coincidences of two protons in "Wall" or with one proton registered in "Wall" and one proton in "Ball" should be studied separately.

4. Results

The simulation was based on older branch of the detector simulation program written using Geant4 framework. The Pluto (HADES@GSI) framework was used to generate proton-deuteron breakup events and new function with star kinematics allows to generate or select particles in star condition from all breakup events.

In order to check detector's ability to register star configurations, a relationship between β and α was generated. Extracting information about coincidence for each part of the detector allows to obtain distributions of detections (Fig.4). For $^{2}H(p,pp)n$ reaction at 160MeV, 38% protons was detected as Ball-Ball coincidence, 54% as Ball-Wall and 8% as Wall-Wall.

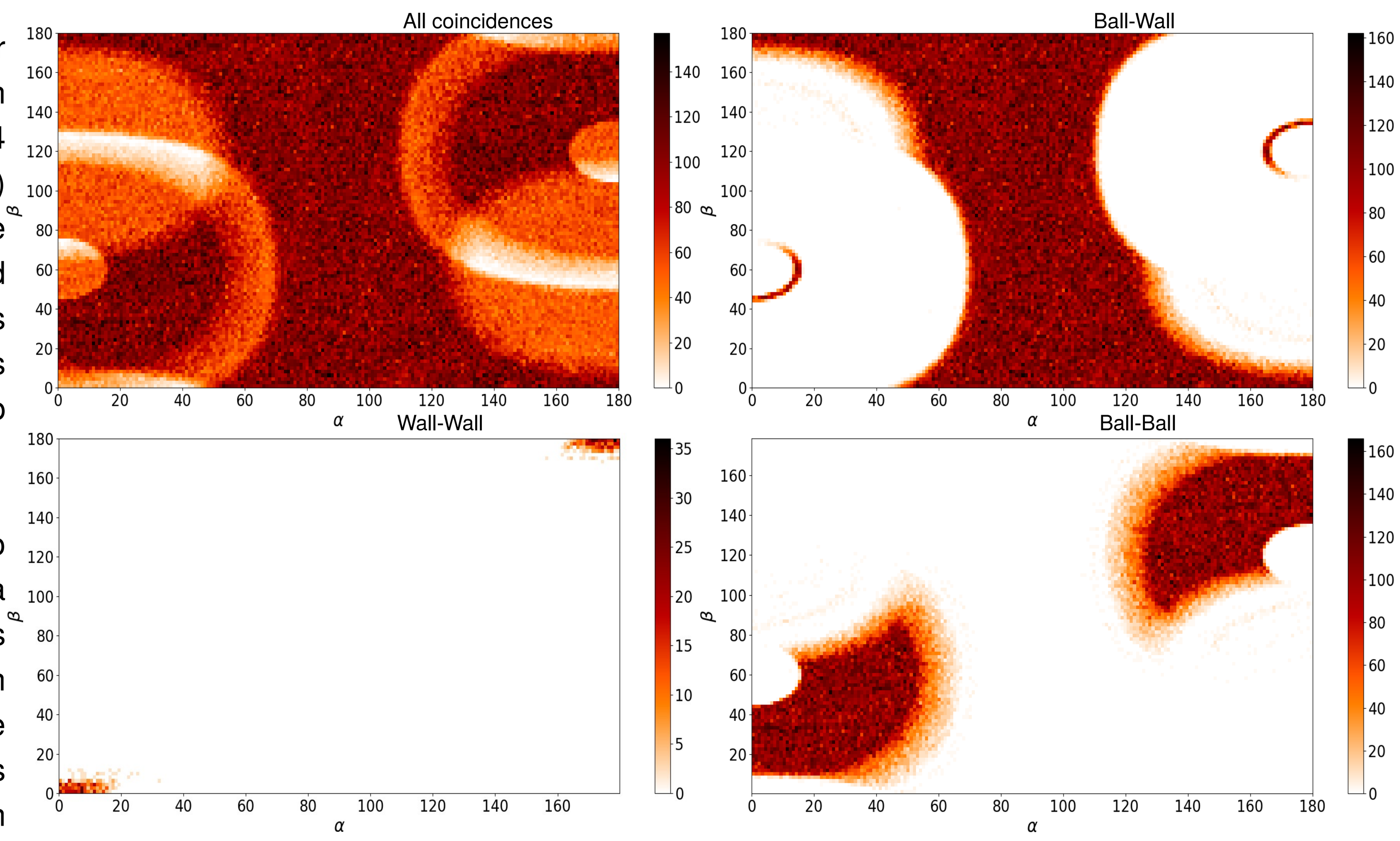


Figure 4. Protons coincidences in β(α) for Wall-Ball, Wall-Wall and Ball-Ball

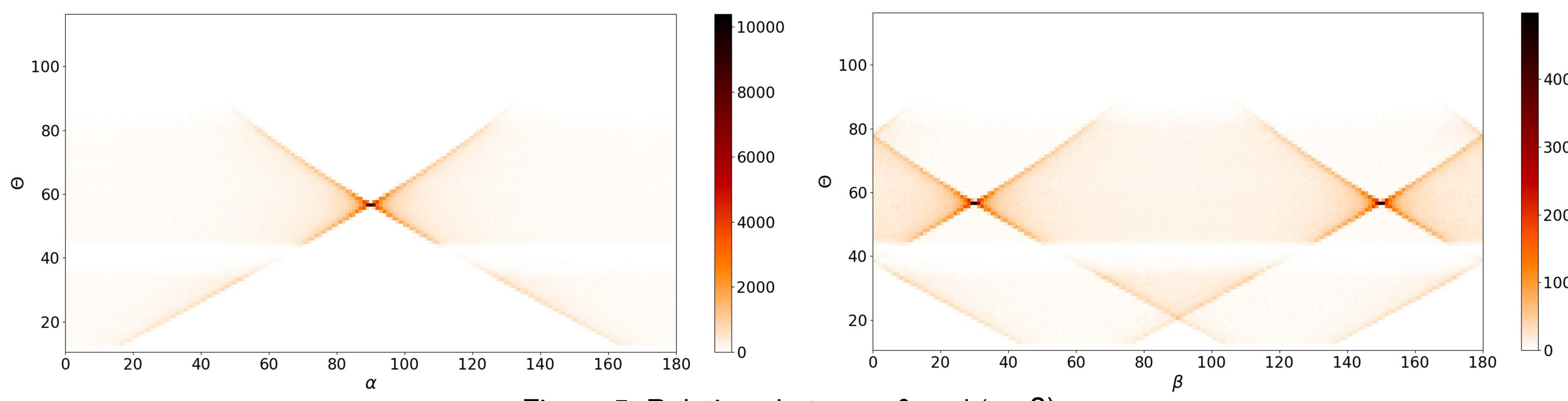


Figure 5. Relations between θ and (α, β).

Studying the relationship between protons scaterring angle θ and α and β several symmetry points can be seen. For θ(α), point (90,57) corresponds to Space Star configuration (it's invariant for rotation β). However, the relationship θ(β) allows to notice two symmetry points (three if a neutron would be detectable) related to invariant for α rotation.

The consequence of this observation is that there is a detector that registers protons from the Space Star and all other star configurations. Therefore, it is possible to study the entire space for star conditions by considering only one detector in the Ball segment.

References

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[2] K. Ohnaka et al., Few-Body Syst. 55 (2014) 725
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5. Conclusions

According to the simulation, there are no significant differences in the angular distribution between reactions at 108, 135 and 160 MeV. For the proton beam, all Space Star events are registered in the Ball segment (θ≈57°). In addition, owing to consideration of β angle, the scintillator that registered the proton in this configuration can also be chosen to study coincidence for other star conditions.

Studying all configurations in a classic way, i.e. without defining β (β=0), contains impoverished field between α=0° and α=40° associated with small amount of coincidences in Wall. Therefore, it is important to use the concept of β significantly increasing the possibilities of analyzing data in domain of Space Star Anomaly.

Abstract [link]