GlueX-doc-1241
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Start Counter Simulation

S. Dhamija and A. Somov,

1 Introduction

The main goal of the start counter (SC) is to provide the interaction time of the beam photons with the GlueX target. In coincidence with the tagger microscope counters, it should be able to identify the electron beam bunches that pass through the diamond crystal at a rate of 500 MHz producing Bremsstrahlung beam photons. The start counter is also considered to be integrated into the Level-1 hardware trigger. The current design of the SC comprises 40 scintillators paddles situated around the GlueX target. Each paddle is bent towards the beamline at the downstream end, as shown in Fig. 1. The minimum distance between the photon beam and the scintillator paddle in the bent section (or the hole size in the forward direction) corresponds to 10 mm.

We performed the studies of the start counter rate induced by the electromagnetic and hadronic interactions and the SC acceptance for some typical exotic decays of interest using a Geant detector simulation. The rates and acceptances were evaluated for various radii of the hole at the downstream end of the SC. The SC rates were computed assuming operation of the GlueX detector at high-luminosity, corresponding to a photon beam intensity at the target of 10^8 γ/s in the energy range of 8.4 GeV $\leq E_\gamma \leq$ 9.0 GeV. The results of the simulation are presented in this note.

In Section 2 we will describe the start counter geometry currently implemented in the Geant simulation. The study of the electromagnetic background will be presented in Section 3. The start counter acceptances for the hadronic events and some typical decays of exotic mesons will be given in Section 4 and Section 5.

2 Start Counter Geant Geometry

The recent geometry of the start counter was provided by W.Boeglin and is described in detail in [1]. The 3D view of the start counter is presented in Fig. 1. The SC consists of 40 scintillator paddles, each of which is about 600 mm long, 10 mm wide, and 3 mm thick. The downstream end of the paddle is bent towards the beamline. The lengths of the straight and bent sections are 500 mm and 100 mm, respectively. The upstream end of each paddle is connected to a 140 cm long light guide. The paddles will be glued together forming a self-supported rigid structure. The support structure of the whole SC is currently modeled as the tube segments made of the high and low-density Rohacell materials that are placed below and above the plastic scintillator paddles. The thickness of the inner (high-density Rohacell, $\rho = 0.11\ g/cm^3$) and outer (low-density Rohacell, $\rho = 0.032\ g/cm^3$) support segments are 3.9 mm and 5.3 mm, respectively. The final support structure will be designed in the future. The main specifications of the SC scintillator paddles are listed in Table 1.

The material, in units of the radiation length, seen by a high-momentum track originating from the center of the targer, at X = Y = 0 and Z = 65 cm, as a function of the polar angle with respect to the beamline is presented in Fig. 2. The current thickness of the SC corresponds to about 1% of the radiation length for the particles produced at 90° and increases to about 3% for the particles produced with the polar angles of 20°. For the polar angles below 20°, that corresponds to the bent section of the SC, the track penetrates about two times smaller amount of the SC material; the SC radiation thickness is below 1.5%. The radiation thickness of the SC support structure including the wrapping material constitutes about 29% of the total thickness. The SC layout, in particular the bent section, has to be optimized in the future when the GlueX target design will be finalized. In the current geometry, the bent section is placed rather close to the target support structure, as shown in Fig. 3.

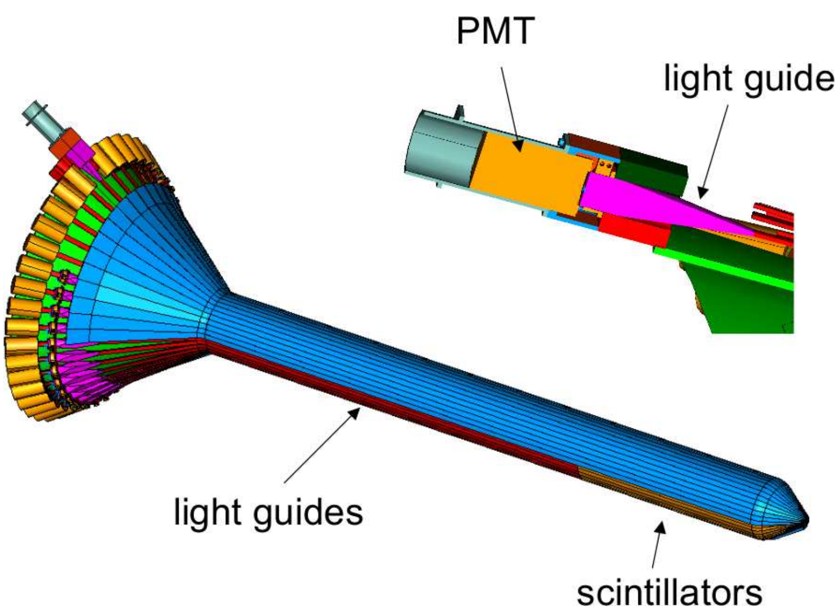

Figure 1: 3D view of the start counter.

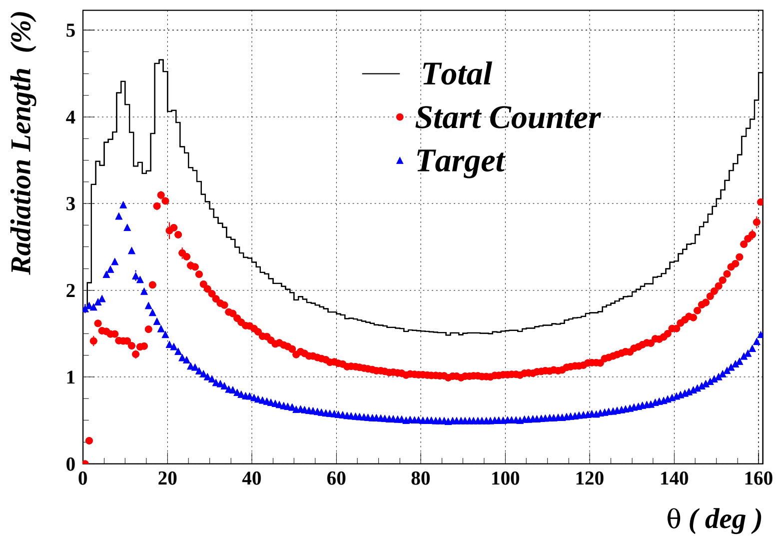

Figure 2: Thickness of the GlueX target and the start counter for tracks originating at the center of the GlueX target, X = Y = 0, Z = 65 cm, as a function of the track polar angle. The solid curve corresponds to the sum of the radiation lengths of the target and the SC.

3 Electromagnetic Background

The hit rate in the start counter is dominated by electromagnetic interactions of the beam photons with the GlueX target. The electromagnetic interactions originate mostly from e^+e^- pair production and Compton scattering processes; the cross section of the later process dominates for $E_\gamma \leq 0.2$ GeV. As most $e^\pm$ produced in the electromagnetic interactions are forward directed, the SC rate depends strongly on the hole size in the downstream end of the counter. We performed a study of the SC rate induced by the electromagnetic interaction for various radii of the hole. The study was based on a MC sample consisting of about $5 \cdot 10^8$ events which were generated and processed through the Geant detector simulation by the *hdgeant* program. The Bremsstrahlung beam photons were modeled in the energy range of 1.1 MeV $\leq E_\gamma \leq$ 12.0 GeV; the photon flux on the target corresponds to about $3 \cdot 10^9$ γ/sec.

The energy deposited by Geant in the SC by particles produced in the electromagnetic interactions is shown in Fig. 4. The energy is computed at the end of a light guide assuming a

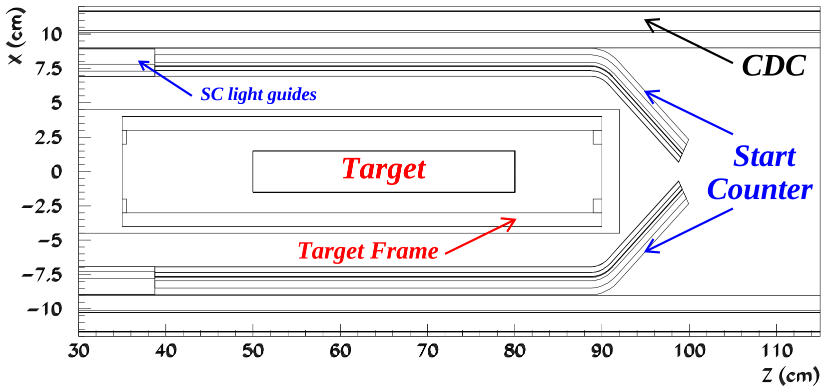

Figure 3: Start Counter geometry (elevation view) implemented to the Geant detector simulation.

light attenuation length of 150 cm. In the analysis we apply an energy threshold of 0.1 MeV. As it will be shown in the next section, the typical energy released in the SC (and measured at the end of the light guide) by a charged track originating from the signal decays constitutes about 0.2 MeV. The SC hit multiplicity of the electromagnetic background events is presented in Fig. 5. The hit occupancy in the SC is shown in Fig. 6. As it can be seen from this plot, the largest occupancy corresponds to the bent section, i.e., the region closest to the beamline. The SC hit rate per paddle for various radii of the SC hole is presented in Fig. 7. The SC paddle rate decreases by more than a factor of 2 from about 350 kHz to 140 kHz when the hole radius is increased from 1 cm to 2 cm. The corresponding rates of having at least one hit in the SC constitute about 10.5 MHz and 3.7 MHz for the 1 cm and 2 cm hole radii, respectively.

4 Hadronic Events

As the main goal of the SC is to provide the interaction time of the beam photons with the target, the SC acceptance should be large enough to detect at least one charged track from the exotic decays of interest. First, we studied the SC acceptance for hadronic events produced by ordinary photoproduction processes (PYTHIA). Events with the hadronic interactions were generated using the *bggen* generator [2] and were passed through the Geant detector simulation. The interactions of the beam photons with the GlueX target were uniformly distributed along the target.

The energy deposited in the SC paddles by particles produced in the hadronic interactions and measured at the end of the light guides is shown in Fig. 8. In the analysis, we required the energy to be larger than 0.1 MeV. The fraction of hadronic events with at least one hit in the

Paddle width	10 mm
Paddle thickness	3 mm
Paddle length:	
- straight section	500 mm
- bent section	97.2 mm
Bend angle	35°
Bend radius	40 mm
Radius from the beamline:	
- straight section	7.3 cm
- bend section (R_{min})	1 cm

Table 1: Start counter scintillator paddle specifications.

start counter as a function of the photon-beam energy is presented in Fig. 9. This fraction was computed for the three radii of the SC hole corresponding to 1 cm, 2 cm, and 3 cm. As can be seen from this plot, about 99% of the hadronic events produced by the beam photons with energy larger than 3 GeV contain at least one hit in the start counter whose forward hole radius is larger than 2 cm. The difference in the fractions of events with no hits in the SC between 1 cm and 2 cm hole radii is less than 1%. The average SC hit multiplicity as a function of the photon-beam energy is shown in Fig. 10. The SC hit multiplicity for hadronic events with the beam energy $E_\gamma > 8$ GeV is presented in Fig. 11.

5 Signal Events

We studied acceptance of the start counter using MC samples of exotic mesons. We considered decay channels with a single charged track in the final state assuming that the probability to have at least one hit in the SC for these decays is the smallest compared with that of any other multi-track exotic states. The SC acceptance for the single track events is defined as the number of charged tracks that produce a hit in the SC divided by the total number of tracks originating inside the target. The acceptance defined in such a way, accounts for the target related effects, i.e., track scattering and stopping inside the target. In the analysis, we do not require the track to be reconstructed or have any hits in the CDC or FDC chambers. Similar to the studies of the electromagnetic background and hadronic events, the energy deposited by a track inside the SC paddle was 'attenuated' to the beginning of the light guide where the energy threshold of 0.1 MeV was applied. The acceptance was studied for two typical channels

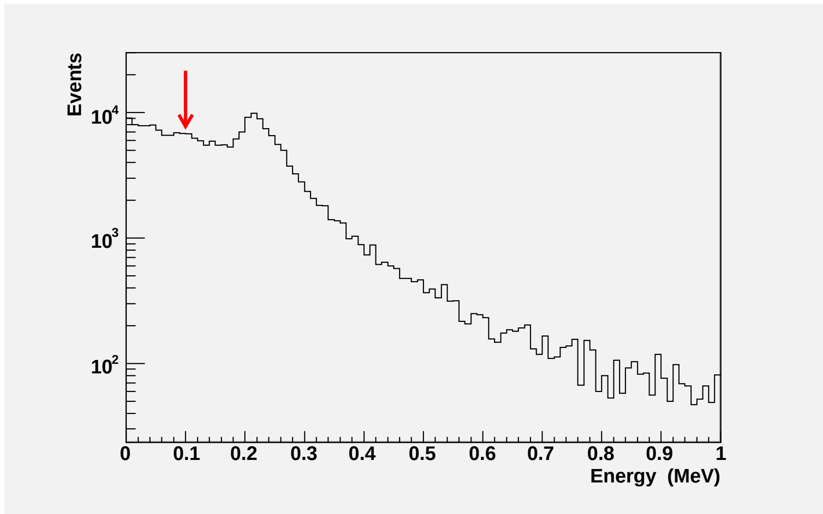

Figure 4: Energy deposited in the paddles of the start counter by particles produced in electromagnetic interactions. The energy is computed at the end of the light guide assuming the light attenuation length of 150 cm. Arrow indicates the energy threshold of 0.1 MeV applied in the analysis.

which contain either relatively soft or energetic charged track in the final state:

- $\gamma p \to pX,\ X \to \eta\pi^0\pi^0$, the final state with the recoil proton.
- $\gamma p \to nX,\ X \to \pi^+\pi^0$, the final state with the charged pion.

These channels were generated using the genr8 program [3] assuming a photon-beam energy of 9 GeV and a typical value of the production t-channel slope of 5 $(GeV/c)^{-2}$. The genr8 program generates events according to the phase space distributions and provides uniform angular distributions of the decayed particles. The SC acceptance for the exotic decays has to be refined in the future using an event generator that will include more realistic decay kinematics.

As the kinematical distributions of the recoil proton depend on the mass of the exotic meson[1], we estimated the SC acceptances for two masses of the exotic meson corresponding to 1.5 GeV and 2 GeV. The kinematical distributions of the recoil proton produced in the $\gamma p \to nX(1500),\ X \to \pi^+\pi^0$ reaction is shown in Fig. 12. The left plot represents the momentum of the recoil proton as a function of the proton production polar angle with respect to the beamline. The protons in this plot are required to be reconstructed in the SC. The right plot in Fig. 12 shows the polar angle distribution for all protons produced in the $\gamma p \to pX$ reaction and those reconstructed in the start counter. The average polar angle of the recoil protons is about 50°; therefore, most of them have hits in the SC. The circles and the hatched histogram

[1] The mass of exotic meson defines the minimum value of t, t_{min}.

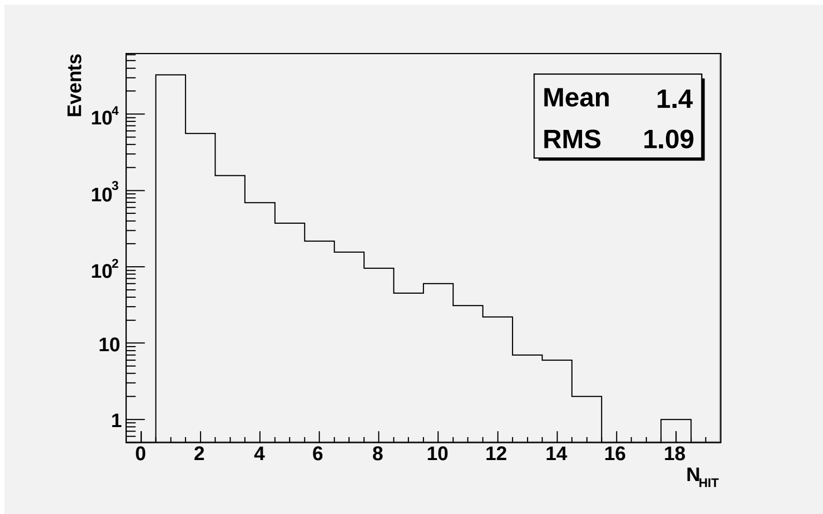

Figure 5: Start counter hit multiplicity for electromagnetic background events. The radius of the hole in the downstream end of the SC corresponds to 2 cm. The threshold to define a hit in the SC is set to 0.1 MeV at the end of the light guide.

on this plot represent the angular distributions for the photon-beam interactions originating at the end and at the beginning of the GlueX target, respectively. Although the geometrical acceptance of the SC is larger for the particles produced at the downstream end of the target, the low-energy protons originating in the beginning of the target are 'absorbed' by the target material (and the target support structure), resulting in a smaller number of protons seen by the SC from the target's upstream end. The acceptance of the SC as a function of the forward hole radius is shown in Fig. 13. The left (right) plot corresponds to the mass of the exotic mesons of 1.5 GeV (2.0 GeV). Polymarkers on these plots represent different Z-coordinates of the beam interactions along the target: at the end of the target, $Z_{\text{Target}} = 80$ cm (triangles), at the beginning of the target, $Z_{\text{Target}} = 50$ cm (circles), and for interactions uniformly distributed along the target (boxes). The SC acceptances for 1.5 GeV and 2.0 GeV exotic mesons are 87% and 96%, respectively. The acceptance is found to be almost independent off the radius of the SC hole for the radius of up to at least 3 cm. The detection inefficiencies mainly arise from losing protons due to the interactions inside the target rather than from geometrical acceptance of the SC.

We subsequently studied the SC acceptance for the decay of a hypothetical 1.6 GeV exotic meson produced in the $\gamma p \to nX$ reaction to the $\pi^+\pi^0$ final state. The SC detection efficiency of the charged pion from this decay is expected to be more sensitive to the hole size in the SC downstream end compared to that for the reactions with the recoil proton, as the charged pions are produced at a relatively small polar angle with larger momentum. The momentum of the charged pion reconstructed in the SC as a function of the π^+ production polar angle is presented in Fig. 14. The three distributions in this plot correspond to the beam interactions

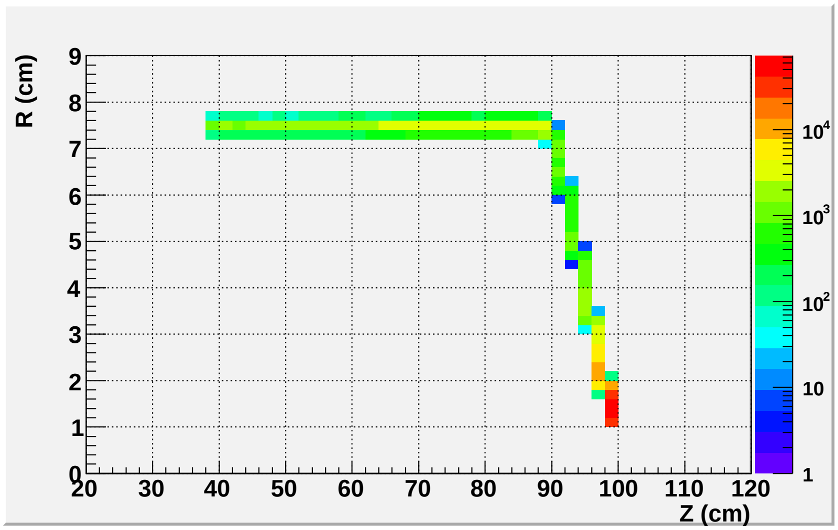

Figure 6: Hit occupancy in the start counter for electromagnetic background events.

at the beginning, end, and uniformly distributed along the target. The polar angle acceptance of the SC varies from 2° to 6° for the z-coordinate of the beam interactions in the target between 50 cm and 80 cm. The SC acceptance for the π^+ meson as a function of the SC hole radius is shown in Fig. 15. The acceptances for the 1 cm and 2 cm radius holes and the beam interactions uniformly distributed along the target are found to be 87% and 95%, respectively. For the hole radius of 2 cm, the SC acceptance varies between 74% and 94% for the beam interactions produced at the upstream and downstream ends of the target.

6 Summary

We performed a Geant simulation of the start counter consisting of 40 scintillator paddles. The SC rate induced by the electromagnetic background and the acceptance for the typical exotic decays of interest were studied for various radii of the hole in the downstream end of the SC. The simulation results are as follows:

- The SC hit rates produced by the electromagnetic background constitute 350 kHz and 140 kHz for the hole radii of 1 cm and 2 cm, respectively. The corresponding rates of having at least on hit in the SC are 10.5 MHz and 3.7 MHz.
- The SC probabilities to detect at least one charged track in the event originating from the hadronic interactions of the beam photons with $E_\gamma \geq 3$ GeV with the GlueX target were found to be about 99% for the hole radius smaller that 2 cm.
- The SC acceptance was studied for the typical exotic meson channels containing a single charged track in the final state. The SC geometrical acceptance for the recoil protons

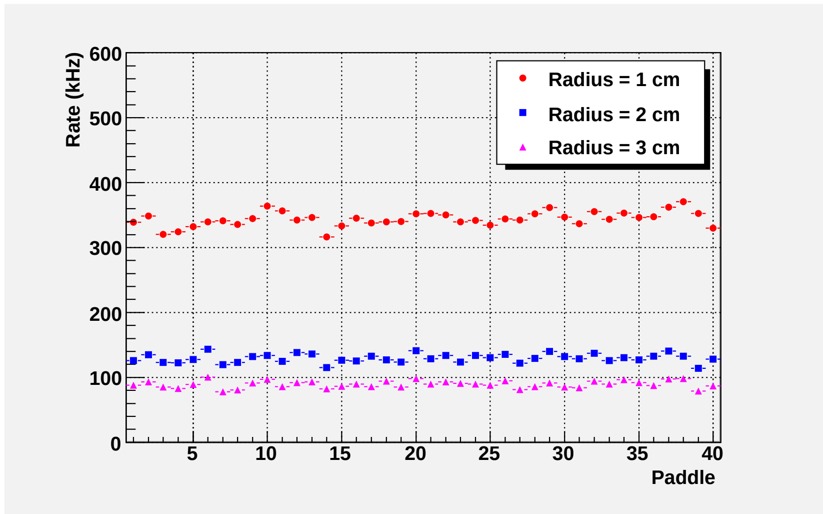

Figure 7: The SC paddle rate induced by the electromagnetic background. Polymarkers correspond to the different SC hole radii: 1 cm (circles), 2 cm (boxes), and 3 cm (triangles).

produced in the $\gamma p \to p(\eta\pi^0\pi^0)$ reaction was estimated for different masses of the exotic meson and was found to be close to 100%. The start counter acceptances for the charged pions produced in the $\gamma p \to nX(1600)$, $X \to \pi^+\pi^0$ reaction constitute 95% and 87% for the hole radii of 1 cm and 2 cm, respectively.

References

[1] W. U. Boeglin, Start Counter Update, GlueX-doc-1212.

[2] *bggen* generator was provided by E. Chudakov, see $HALLD_HOME/src/programs/ Simulation/bggen/README file.

[3] *genr8* generator was provided by P. Eugenio, `http://www-meg.phys.cmu.edu/halld/halld_notes/Note_011/`

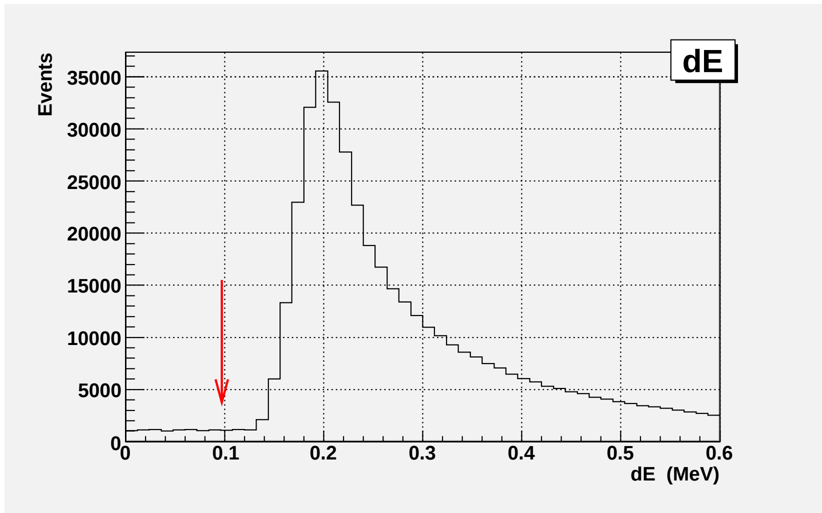

Figure 8: Energy deposited in the start counter by particles produced in hadronic interactions. The energy is computed at the end of the light guide assuming the light attenuation length of 150 cm. Arrow indicates the energy threshold of 0.1 MeV applied in the analysis.

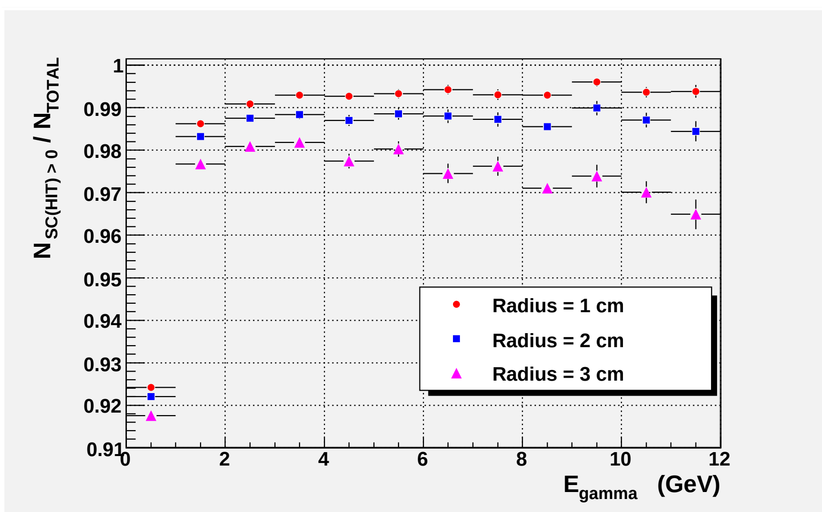

Figure 9: The fraction of hadronic events with at least one hit in the start counter as a function of the photon-beam energy. The fraction is computed for the three radii of the SC hole in the forward direction: 1 cm (circles), 2 cm (boxes), and 3 cm (triangles).

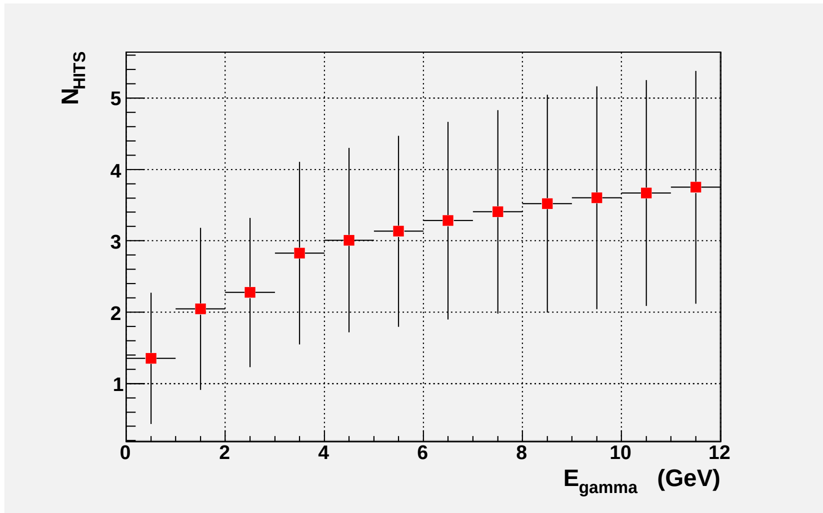

Figure 10: Average hit multiplicity in the start counter for events with hadronic interactions as a function of the photon-beam energy. The distribution corresponds to the SC hole radius of 2 cm.

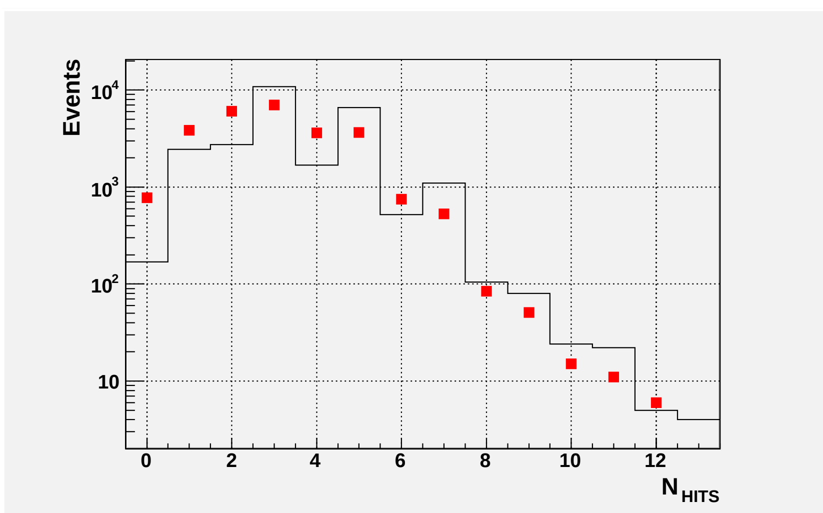

Figure 11: Start counter hit multiplicity for events with hadronic interactions and the energy of the photon beam larger than 8 GeV. The histogram (polymarkers) corresponds to the SC hole radius of 1 cm (2 cm).

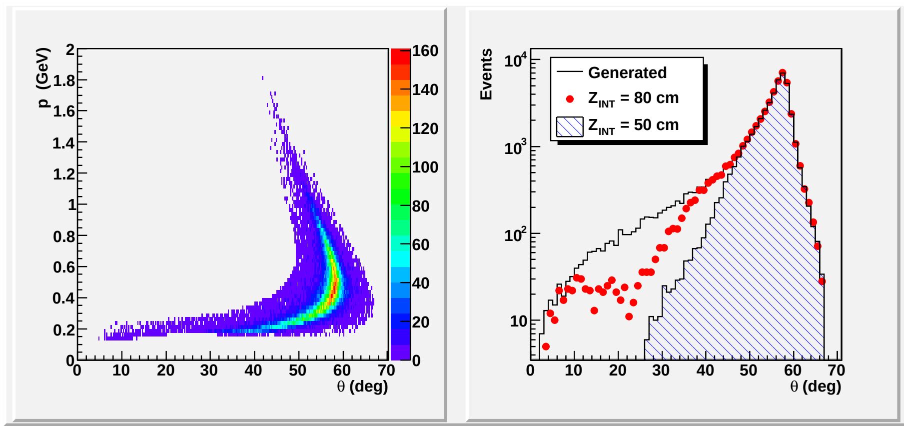

Figure 12: Momentum of the recoil protons originating in a $\gamma p \to pX$, $X \to \eta\pi^0\pi^0$ reaction as a function of the proton production polar angle, θ (left). The proton is required to have a hit in the SC. Distribution of the proton production polar angle, θ (right). The solid curve represents all protons. The circles (hatched histogram) represent protons produced at the end (beginning) of the target and having a hit in the SC.

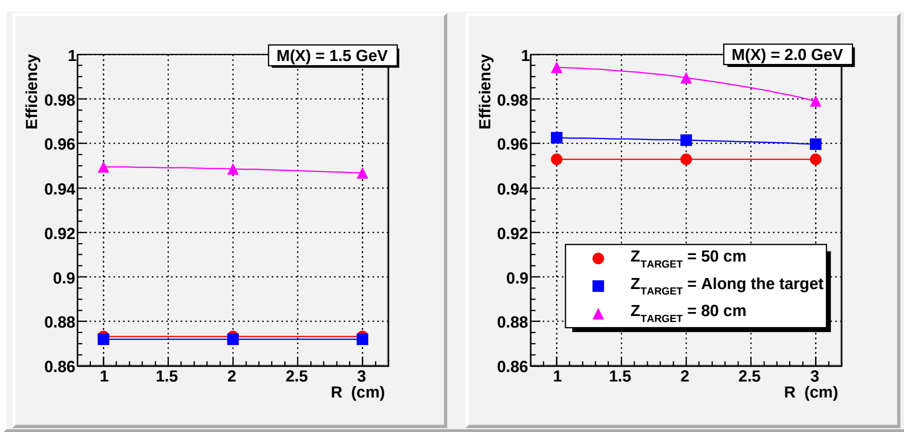

Figure 13: The SC efficiency for the detection of the recoil proton originating in a $\gamma p \to pX$, $X \to \eta\pi^0\pi^0$ reaction as a function of the SC hole radius. The left (right) plot corresponds to the exotic meson mass of 1.5 GeV (2 GeV). Polymarkers represent different Z-coordinates of the $\gamma p \to pX$ interactions in the target: at the end of the target, $Z_{\text{Target}} = 80$ cm (triangles), at the beginning of the target, $Z_{\text{Target}} = 50$ cm (circles), and uniformly distributed along the target (boxes).

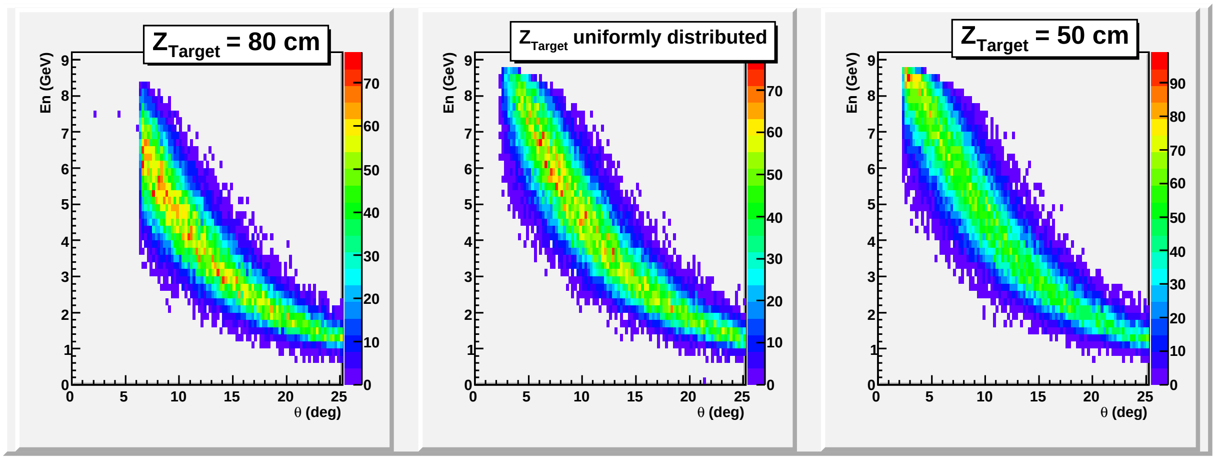

Figure 14: Momentum of the π^+ mesons originating in $\gamma p \to nX$, $X \to \pi^+\pi^0$ decays as a function of the π^+ production polar angle. The $p - \theta$ distributions in the left, right, and middle plots correspond to the Z-coordinate of the $\gamma p \to nX$ reaction at the beginning (z = 50 cm), end (z = 80 cm), and uniformly distributed along the GlueX target.

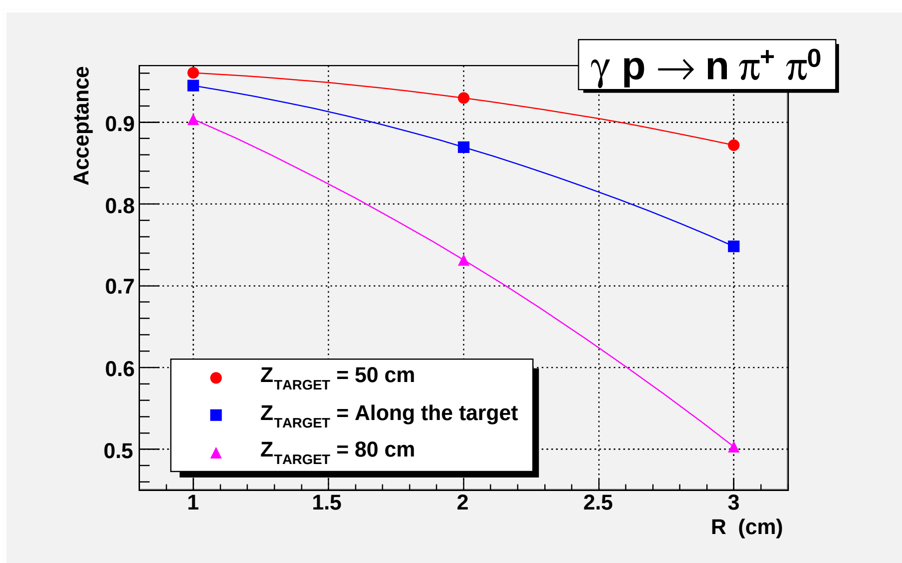

Figure 15: SC efficiency for the detection of the charged pions produced in $\gamma p \to nX$, $X \to \pi^+\pi^0$ decays as a function of the SC hole radius for different Z-coordinates of the nX production along the target: at the beginning of the target, $Z_{\text{Target}} = 50$ cm (circles), at the end of the target, $Z_{\text{Target}} = 80$ cm (triangles), and uniformly distributed along the target (boxes).