GlueX-Doc-2595

GlueX/Hall-D Solenoid Studies
Interim Report

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Introduction

Studies have been carried out on the impact of reducing the Hall-D solenoid current from its nominal $1500\,A$ to around $1300\,A$. This reduction in current could affect several aspects of the experimental program.

- For a fixed photon rate on target, the electromagnetic background rates in the detector will rise as the magnetic field strength is reduced. This can affect the ability of some detector elements to take data as well as impact the lifetime of detectors.
- The momentum resolution of charged particles will be reduced as the magnetic field is reduced.
- The ability to reconstruct final states at a particular purity may be affected by the change in magnetic field.

In order to study these effects, the GlueX Collaboration has undertaken a series of studies using the GEANT based simulation of the detector as well as the full reconstruction and physics analysis tools. The results from those studies are presented in this report.

As a reference, the GlueX detector was designed to handle rates corresponding to $10^8\,\gamma/s$ in the coherent photon peak. This beam will be generated with a $12\,GeV$ electron beam impinging on a a $20\,\mu m$ thick diamond radiator on the Hall-D Tagger Hall. These rates nominally corresponds to an electron beam current in the tagger hall of $1\,\mu A$.

Electromagnetic Backgrounds

The electromagnetic rates in various detectors in GlueX have been examined [1] for magnetic field currents of $1500\,A$ (nominal), $1200\,A$ (80% of nominal) and $1050\,A$ (70% of nominal). This study also looked at the affect of the size of the dead region around the beam line in the Forward Drift Chambers (FDC). Since the time of the report, both the start counter and the hole size in the FDC have been changed based on information in the report. As such, we avoid using the absolute normalization numbers from this report, but use how fast the electromagnetic background rates in several of the detectors close to the beam line increase as the magnetic field is decreased. From this study, the detectors most affected by the electromagnetic backgrounds are those closest to the beam. In particular, the forward drift chambers and the start counter.

Taking the data from this study [1], we can normalize the rates in the FDC and the start counter to those observed at full solenoid current. The normalized values are given in Table 1. We plot these for the two detectors as a scale factor by which the rate increases against the solenoid current, as shown in Figure 1. In the FDC, the rates electromagnetic

Solenoid Current (A)	FDC Rates	Start Counter Rates
1050	2.40	1.89
1200	1.67	1.44
1500	1.00	1.00

Table 1: The rates in the Forward Drift Chamber and the Start Counter as a function of the solenoid current, normalized to the rate at nominal current ($1500\,A$).

background rates appear to increase by about 30% for a drop in the solenoid current of $100\,A$. In the start counter, the increase is about 20% for the same drop in current. Thus, for a solenoid current of $1300\,A$, we would expect that the electromagnetic background rates in the most sensitive detector elements will be 40% to 60% higher than they would be a $1500\,A$ solenoid current. We have fit these data to a linear expression as

$$\begin{aligned} R_{FDC} &= -(2.98 \times 10^{-3}\,A^{-1})\,I + 5.42 \\ R_{ST} &= -(1.91 \times 10^{-3}\,A^{-1})\,I + 3.83\,, \end{aligned}$$

where the 2.98 and 1.91 coefficients correspond to the 30% and 20% numbers as quoted above.

From Figure 1, it is clear that a simple linear model may not be the most accurate description of the data. As such, we have also used a quadratic expression in the current, where the results to these fits are given as

$$\begin{aligned} R_{FDC} &= (5.93 \times 10^{-6}\,A^{-2})\,I^2 - (1.82 \times 10^{-2}\,A^{-1})\,I + 15.0 \\ R_{ST} &= (3.29 \times 10^{-6}\,A^{-2})\,I^2 - (1.04 \times 10^{-2}\,A^{-1})\,I + 9.15\,. \end{aligned}$$

This model would predict somewhat lower electromagnetic rates for $1300\,A$ than the linear model. However, as the solenoid current continues to be lowered, the linear model would under predict the quadratic model. An another study, see reference [2] used the quadratic model to estimate the electromagnetic rates, and then assumed that the beam current would need to be decreased to maintain constant electromagnetic rates. The study also looked at the degradation of the width of narrow states. The overall conclusion of that study was that there was a degradation effect that went with B^2 for the electromagnetic backgrounds and B for the resolution of the detector, leading to an increase in run time that scaled like B^{-3}.

We need to caveat this with the fact that while the experiment is designed for $1 \times 10^8\,\gamma/s$ running, we do not know how close we will be able to come to this with full field running. Thus, we do not know the starting point, and probably will not until we have started taking data. We also not that the high-intensity running that has been approved assumed an average flux of 5×10^7—a factor of two below the design value. Thus, if we are at the limits of the rate that the detector can handle, we may need to increase the running time at lower rates, this may have already been accounted for in the beam time estimates.

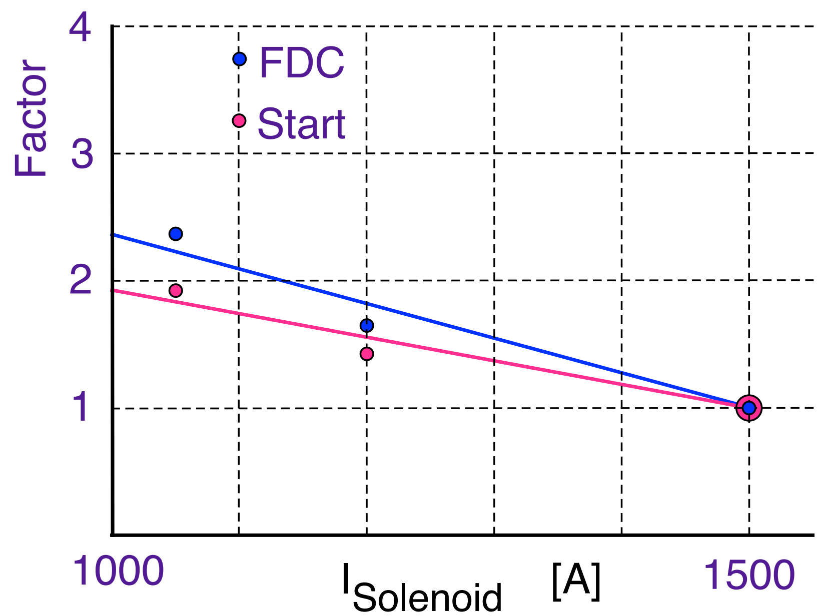

Figure 1: The scale factor by which the electromagnetic rate increases as a function of the solenoid current. The data suggest that for each drop of $100\,A$ in the current, the electromagnetic background rates increase by about 30% in the FDC and by about 20% in the start counter.

Momentum and Angular Resolution

It is expected that the momentum resolution should scale directly with the strength of the magnetic field, and hence the solenoid current. This is indeed verified for for the π^+ and π^- momenta, but is not exactly true for the proton's momentum. In the latter case, other effects such as energy loss and multiple scattering tend to limit the effect, and the degradation in the proton is less than what would be expected. [3]

To the level that we have been able to check, the angular resolutions (in the lab frame) are not affected by the magnetic field strength. We have also examined the angular resolution in the Gottfreid-Jackson frame for the decay of the ω. These angular resolutions also do not appear to depend on the magnetic field strength.

Finally, for the ω channel as studied above, we have examined the post-kinematic fit invariant mass resolution for the ω. For a 20% decrease in the magnetic field strength, we see a 10% increase in the width of the ω meson.

Reconstruction Efficiency

Several physics channels that share features with many of the channels to be analyzed in GlueX have been studied. All of these likely contain more specific final states, but in order to carry out an analysis, it is necessary to be able to exclusively reconstruct these.

$$\gamma p \rightarrow p\pi^+\pi^-\pi^+\pi^-\gamma\gamma \quad (1)$$
$$\gamma p \rightarrow p\pi^+\pi^-\pi^+\pi^- \quad (2)$$
$$\gamma p \rightarrow p\pi^+\pi^-\gamma\gamma \quad (3)$$

In studying these reactions, a sample containing 10×10^6 PYTHIA events were thrown and simulated for each solenoid current, and for each of two photon rates. These represent the full hadronic cross section for $7\,GeV$ photon energy up to the endpoint ($\sim 12\,GeV$). The two photon rates correspond to electromagnetic backgrounds rates expected for the initial GlueX running and for the longer running at higher intensity. The latter was approved by the PAC in 2013 and 2014. Neither of these represent the design rate (10^8) of the experiment. The design rate is twice as large as the assumed rate used in the proposals and to the maximum simulated rate in these studies.

The reactions were extracted using simple analyses that employed reconstruction cuts and kinematic fitting of the exclusive final states. No effort was made to optimize the cuts to a given setting, rather a common cut was used in all cases. The most selective element of the cuts was the convergence of the kinematic fitting to some small but non-zero confidence level.

Because the events were simulated, knowledge of the actual reaction in each event was retained. Thus, the actual number of events for each of the reaction types is known. We also know the number of these events selected in the final sample (signal), and the number of events that were not the correct reaction that were accepted in the final sample (background). From these, we form three measures of our reconstruction:

- *Reconstruction Efficiency* given as the number of signal events divided by the number of thrown events of the correct type.
- *Signal Purity* given as the fraction of all selected events that are the correct topology.
- *Signal/Background* given as the number of signal events divided by the number of background events in the resulting sample.

In Table 2, we present these quantities for the events in reaction 1. Interestingly, the efficiency steadily increases as the solenoid current is decreased from the nominal $1500\,A$ value, but the signal purity is decreasing at the same time. The most useful measure is probably the *Signal/Background* which is approximately constant at the highest currents, but falls rapidly when the current goes below about $1300\,A$. The same behavior is repeated for both photon rates, when somewhat lower efficiences in the higher rates. These three quantities are plotted agains the solenoid current for the lower photon rate in Figure 2 .

I_S (A)	γ/s	Reconstruction Efficiency	Signal Purity	Signal/Background	$S/\sqrt{B}$
750	1×10^7	5.82%	75.9%	3.15	354
1200	1×10^7	5.45%	84.1%	5.31	445
1350	1×10^7	4.64%	87.0%	6.71	461
1500	1×10^7	4.38%	86.8%	6.55	442
1200	5×10^7	4.60%	83.7%	5.12	403
1350	5×10^7	4.20%	86.9%	6.66	407
1500	5×10^7	4.00%	87.3%	6.90	432

Table 2: The reconstruction information for the $\gamma p \to \pi^+\pi^-\pi^+\pi^-\pi^0$ reaction.

I_S (A)	γ/s	Reconstruction Efficiency	Signal Purity	Signal/Background	$S/\sqrt{B}$
750	1×10^7	12.5%	83.6%	5.086	674
1200	1×10^7	10.5%	90.8%	9.893	859
1350	1×10^7	9.6%	91.8%	11.231	1048
1500	1×10^7	8.5%	93.0%	13.288	928
1200	5×10^7	9.7%	90.4%	9.430	891
1350	5×10^7	8.9%	91.2%	10.407	914
1500	5×10^7	8.0%	92.9%	13.052	808

Table 3: The reconstruction information for the $\gamma p \to \pi^+\pi^-\pi^+\pi^-$ reaction.

I_S (A)	γ/s	Reconstruction Efficiency	Signal Purity	Signal/Background	$S/\sqrt{B}$
750	1×10^7	19.71%	83.0%	4.89	388
1200	1×10^7	19.42%	89.0%	8.07	498
1350	1×10^7	17.86%	92.9%	13.07	505
1500	1×10^7	17.86%	91.1%	10.26	517
1200	5×10^7	17.3%	88.9%	8.037	465
1350	5×10^7	16.1%	92.6%	12.593	438
1500	5×10^7	16.6%	91.1%	10.175	498

Table 4: The reconstruction information for the $\gamma p \to \pi^+\pi^-\pi^0$ reaction.

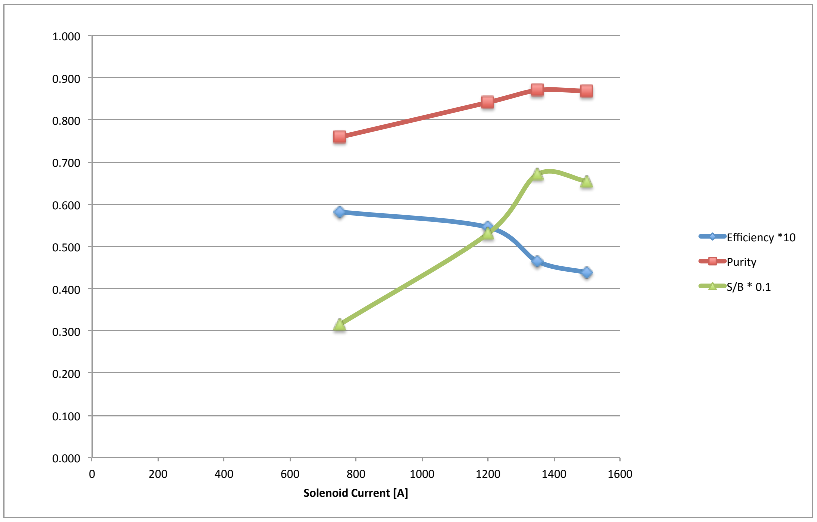

Figure 2: Plots for the reaction $\gamma p \to p\pi^+\pi^-\pi^+\pi^-\pi^0$. The *Reconstruction Efficiency* (blue), the *Signal Purity* (red) and the *Signal/Background* (green) as a function of the solenoid current. The three quantities have been scaled as indicated in the figure caption so that they are all visible on the same vertical scale. The *Signal/Background* shows little change in the $1300\,A$ to $1500\,A$ region, but then starts to deteriorate rapidly as the solenoid current decreases.

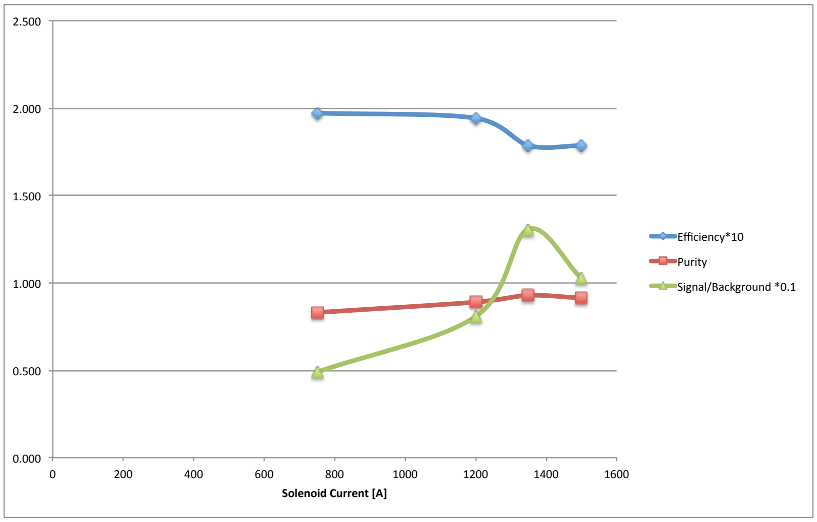

Figure 3: Plots for the reaction $\gamma p \to p\pi^+\pi^-\pi^0$. The *Reconstruction Efficiency* (blue), the *Signal Purity* (red) and the *Signal/Background* (green) as a function of the solenoid current. The three quantities have been scaled as indicated in the figure caption so that they are all visible on the same vertical scale. The *Signal/Background* shows little change in the $1300\,A$ to $1500\,A$ region, but then starts to deteriorate rapidly as the solenoid current decreases.

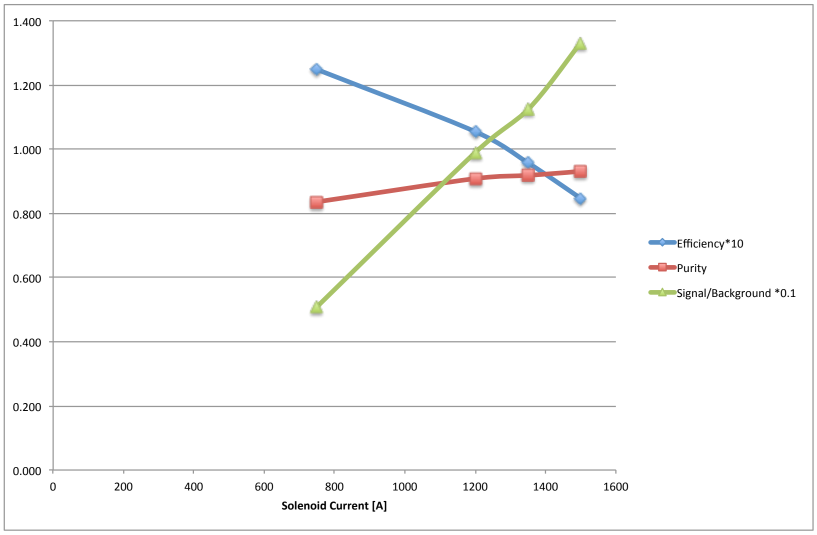

Figure 4: Plots for the reaction $\gamma p \to p\pi^+\pi^-\pi^+\pi^-$. The *Reconstruction Efficiency* (blue), the *Signal Purity* (red) and the *Signal/Background* (green) as a function of the solenoid current. The three quantities have been scaled as indicated in the figure caption so that they are all visible on the same vertical scale. The *Signal/Background* falls steadily from the highest solenoid current to the lowest. This is different from the reactions where there is a π^0 in the final state.

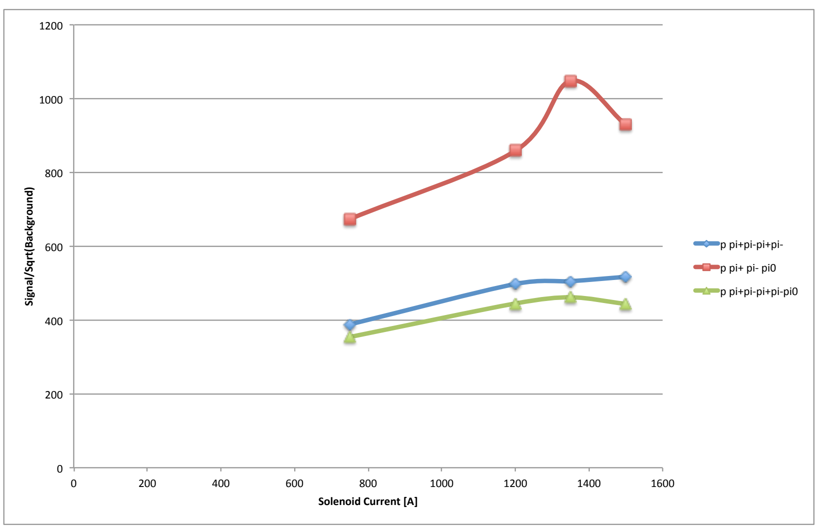

Figure 5: The signal divided by the square root of the background, $S/\sqrt{B}$, as a function of the solenoid current for the three reactions. The green curve is reaction 1, the blue curve is for reaction 2 and the red curve is for reaction 3.

Summary

These studies indicate as long as the electromagnetic background rates do not impact the performance or lifetimes of the detector elements closes to the beam line, that the ability to extract pure samples of events in GlueX will not be adversely affected by running at solenoid currents down to about 1300 A. We show this in Figure 6 the signal to background: S/B and $S/\sqrt{B}$ as a function of the solenoid current for the three reactions. The values have been normalized to that obtained at 1350 A. While there is clearly a dependence of the ratios to the exact reaction for currents above 1300 A, what seems apparent is that the physics will not be adversely affected by running in the range of 1300 A to 1500 A. However, as the solenoid current is continued to be lowered, there is a clear degradation of performance for all reactions studied.

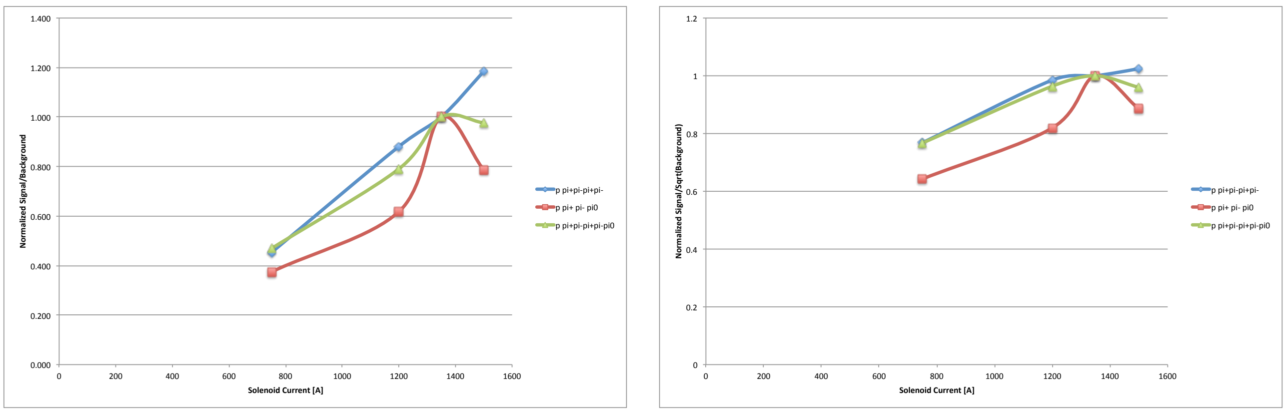

Figure 6: The left-hand plot shows the signal divided by the background (S/B) normalized to the value at 1300 A solenoid current for each of the three reactions. The right-hand plots shows the signal divided by the square root of the background ($S/\sqrt{B}$) under the same conditions.

References

[1] A. Somov, **Electromagnetic Background Rate Studies (for different solenoid magnetic fields and FDC hole sizes)**, GlueX-doc-1471, (2010).

[2] E. Smith, **omega reconstruction / Justification for Bfield settings**, GlueX-doc-1489, (2010).

[3] M. Staib, **Investigating the Resolution of Reconstruction for the Reaction** $\gamma p \to p\omega\pi^+\pi^-$, GlueX-doc-2538, (2014).

[4] R. Mitchell, **A Simple Analysis of a Few Reactions using Pythia MC**, GlueX-doc-2552, (2014).