A Summary of The Linear Polarization Discussion

GlueX-doc-385

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Abstract

This document is a summary of the arguments that have been posted for the degree of linear polarization. It addresses both the physical hardware limitations and the physics needs for linear polarization.

1 Introduction

This document attempts to summarize the arguments that have been made to support the degree of linear polarization needed by the GlueX experiment. The operating assumption in this document is that the GlueX experiment will need to run with $9\,GeV$ photons. The question being addressed is what is the impact on the physics reach of GlueX when the electron beam energy that produces these photons is reduced.

The physics quantities of interest depend linearly on the degree of linear polarization, P. In such a situation, if one wants to measure a quantity to given accuracy, then it can be shown that the integrated luminosity on target is proportional to $\frac{1}{P^2}$. For a fixed intensity, the running time increases like P^2.

Table 1: Operating parameters for the GlueX photon source under conditions of varying electron beam energy. The collimator distance and diameter are kept constant at 80 m and 3.4 mm, respectively, and the radiator thickness is 10^{-4} radiation lengths. be 3 μA. The rates in the detector (last two rows) are calculated for a 30 cm liquid hydrogen target and an open hadronic trigger.

electron beam energy	10 GeV	11 GeV	12 GeV	13 GeV
electron beam current	4.3 μA	3.5 μA	3.0 μA	2.5 μA
N_γ in peak	32 M/s	67 M/s	100 M/s	130 M/s
peak polarization	0.14	0.28	0.41	0.48
average polarization	0.08	0.24	0.37	0.47
peak tagging efficiency	0.25	0.43	0.50	0.57
average tagging efficiency	0.15	0.29	0.41	0.51
power on collimator	4.4 W	4.4 W	4.5 W	4.5 W
power on target	510 mW	610 mW	730 mW	850 mW
total hadronic rate	370 K/s	370 K/s	370 K/s	370 K/s
tagged hadronic rate	5 K/s	10 K/s	16 K/s	21 K/s

2 Physical Implications

Richard Jones [2] has looked at the what the impact of changing the electron beam energy is on the GlueX experiment. Not only does the polarization change, but for a fixed hadronic rate (background in the detector), both the rate of good triggers and the ability tag photons varies. The crucial results are summarized in Table 1 which has been reproduced from his work. From the quantities in this note, he defines an overall *figure of merit* that captures the polarization information, P and the flux factors, F:

$$fom = FP^2. \tag{1}$$

This is shown in Figure 1 for both a collimated and uncollimated beam as a function of the electron beam energy. The crucial point is that the *figure of merit* decrease from about 7.5 with a $12\,GeV$ electron beam to about 2 with an $11\,GeV$ electron beam.

In addition to this, Jim Kelly [4] has pointed out that diamond wafers have a finite lifetime which is probably measured in months. An increase in running time by a factor of 3.75 translates to a factor of 4 in the number of diamond wafers that are needed. It also introduces additional down time

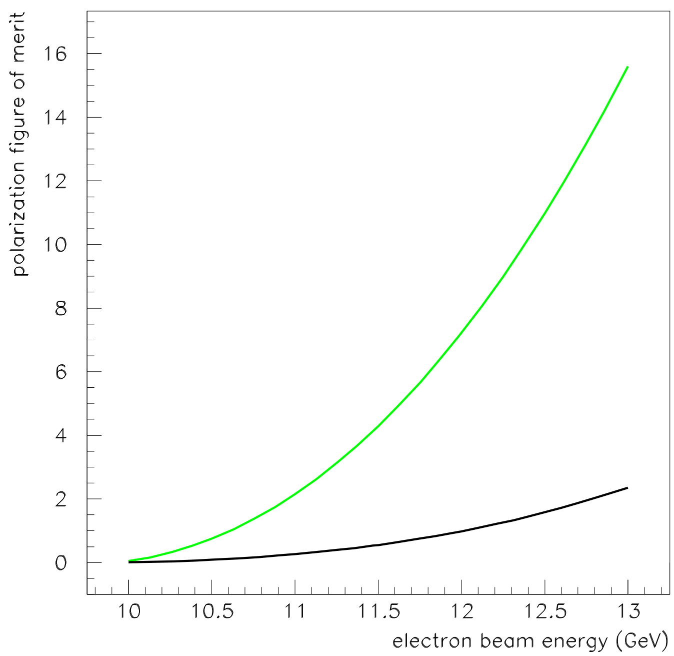

Figure 1: The *figure of merit* as a function of electron energy as taken from Jones [2].

to both change the diamonds, and to then re-align the crystal. All of which introduce non-negligible down time and systematics into the experiment.

Two numbers that are useful to retain are the average linear polarization for $12\,GeV$ and for $11\,GeV$ electrons. These are 0.37 and 0.24 respectively.

3 The Role of Linear Polarization in PWA

Both Szczepaniak [1] and Meyer [3] have looked at the role linear polarization plays in both the discovery and mapping of exotic hybrid mesons in GlueX. While an exact, quantitative *figure of merit* is not possible here, a number of examples are discussed where the linear polarization is essential to the unambiguous extraction of physics.

These discussions build on the idea that linear polarization can be used as a filter on the exchange mechanism in the meson production. This takes advantage of the fact that linearly polarized photons can be thought of a eigenstates of parity. This can be combined with the naturality of both the exchanged object, η_e, and the produced resonance, η_r. As a reminder, the naturality is defined as:

$$\eta = \text{Parity} \times (-1)^J. \tag{2}$$

The naturality is $+1$ for $J^P = 0^+, 1^-, 2^+, \cdots$ and -1 for $J^P = 0^-, 1^+, 2^-, \cdots$ and the *Parity* of a linearly polarized photon is $+1$ for the $y - direction$ and -1 for the $x - direction$. An allowed amplitude satisfies the following relationship between parity and naturality:

$$\text{Parity}_\gamma \times \eta_e = \eta_r. \tag{3}$$

Introducing the notation N_e and U_e for natural and unnatural exchange amplitudes and N_r and U_r for natural and unnatural produced resonances, we can write down the total amplitude as the sum of four possible terms:

$$A = N_e \cdot N_r + U_e \cdot N_r + N_e \cdot U_r + U_e \cdot U_r. \tag{4}$$

While with linear polarization, these can be decomposed into two amplitudes

$$A_x = U_e \cdot N_r + N_e \cdot U_r \tag{5}$$

$$A_y = N_e \cdot N_r + U_e \cdot U_r, \tag{6}$$

which allows us to think of this as two independent experiments that are sensitive to different parts of the meson spectrum.

The separation is carried out by using formula 9 from reference [1],

$$W(\cos\theta, \phi) = |N_e|^2 \sin^2\theta \left[1 + P\cos(2\alpha - 2\phi)\right] + |U_e|^2 \sin^2\theta \left[1 - P\cos(2\alpha - 2\phi)\right]. \tag{7}$$

The angle α is the direction of the linear polarization in rest-frame of the produced resonance and P is the degree of linear polarization of the photon. This can also be written in the perhaps more familiar form:

$$W(\cos\theta,\phi) = |N_e|^2 \sin^2\theta \left[(1-P) + P\cos^2(\alpha-\phi)\right] + |U_e|^2 \sin^2\theta \left[(1-P) + P\sin^2(\alpha-\phi)\right]. \tag{8}$$

For unpolarized photons, ($P=0$), there is no separation, while for polarized we can use the $\sin^2$ and $\cos^2$ to filter the data. The physics implications for polarization now follow a several different tracks. Szczepaniak argues that the difficult to understand background processes tend to be dominated by diffractive production, or N_e, while many exotic signal processes are dominated by U_e. Independent of any other tools that one has for separation, linear polarization allows one to separate these. Meyer looks at the case where both exotic hybrids and normal mesons with the same J^P are produced. Most often, these also correspond to one being N_e and the other being U_e which again allows for a separation using linearly polarized photons. Similar to the difficulties of backgrounds, there are issues if both of these states overlap, and couple to several of the same final states. One of the primary goals of GlueX is to be able to map out the decay patterns of exotic mesons. In the case of an overlap that cannot be easily separated, there will be large uncertainties in the decay rates to the different final states. In some cases, it may not be possible to fully disentangle these without linear polarization.

4 The Degree of Linear Polarization

From earlier in this report, we noted that for a $12\,GeV$ electron beam, the average linear polarization on GlueX will be 0.37 while for an $11\,GeV$ beam, it would be 0.24. We now try to semi-quantitatively address how this affects the physics reach of GlueX. If we have some particular J^P that can be produced via both N_e and U_e, then photons with polarization P can be used to disentangle these as shown in Figure 2. The important thing to note is the even with the separation, both resulting spectra still have a contribution from the unpolarized piece which is proportional to $(1-P)$.

Sufficient polarization implies that the statistical errors on the unpolarized piece are smaller than the size of the contribution from the polarized piece. While it is an extreme upper limit, we can set the two equal and

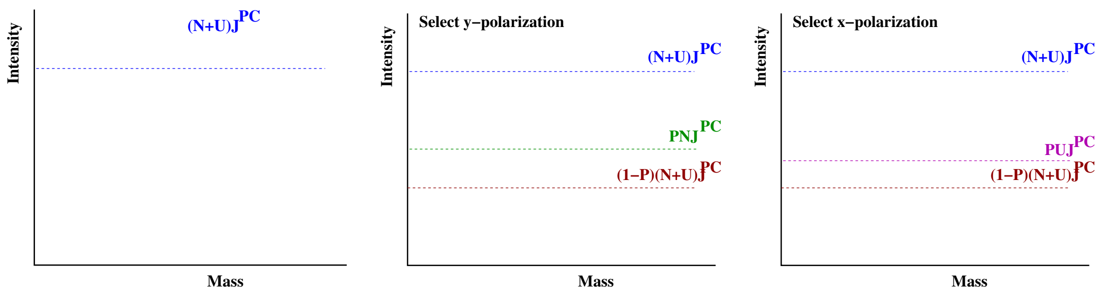

Figure 2: The separation in a particular J^P into natural and unnatural exchange using photons with linear polarization P. The right-hand figure indicates the total that would be accessible without linear polarization. The center figure shows the the extraction of the natural exchange piece while the left-hand figure shows the extraction of the unnatural piece.

evaluate what the consequences are:

$$(1-P)\cdot\sqrt{N_e+U_e} \;=\; P\cdot U_e \tag{9}$$

$$\frac{U_e}{N_e+U_e} \;=\; \frac{1-P}{P}\cdot\frac{\sqrt{N_e+U_e}}{N_e+U_e} \tag{10}$$

This basically says that to be able to separate a signal U_e that is some fixed fraction of the total signal, that the error on the statistical uncertainty is diluted by the function $(1-P)/P$. For $P=0.37$, this factor is 1.7, while for $P=0.24$, this factor is 3.2, or the statistics needs to increase by the ratio squared, which is about a factor of 3.5 to maintain the same ability to separate. If for some reason we were limited to $10\,GeV$ electrons, the increase in statistics needed would be about a factor of 46. As many of the signals that GlueX hopes to uncover are in this *small* realm, where two - three years of running with high luminosity are required to extract sufficient events, the loss of polarization would turn this into 7-10 year exercise.

Beyond the basics statistics limitations, there is also a systematic limitation in a particular channel. In the above example, if the quantity $P\cdot U_e$ falls below this limit, then no amount of statistics will allow you to recover. If the basic limit with $P=0.37$ is about 5%, then with $P=0.24$, this becomes about 8% and for $P=0.08$ this becomes 23%. This is a very slippery slope down which we clearly do not want to slide very far.

5 Summary

Linear polarization has several important consequences on the analysis of GlueX data. Given sufficient linear polarization, it can simplify the analysis by cutting in half the degrees of freedom. It is also important in background rejection when the background and physics have different production exchanges. Lastly, it is crucial when trying to disentangle the decays of overlapping resonances of the same J^P. The ultimate ability of polarization to be used to carry out these tasks depends directly on the degree of linear polarization and the level of systematic errors in the analysis.

Assuming that these limits are not reached, then the effect of going from $12\,GeV$ electron beam energy to an $11\,GeV$ corresponds to a nominal increase in running time of a factor of 3.5 to 4. A direct consequence of this is a corresponding increase in the number of times the diamond radiator needs to be changed , and may well require additional wafers to sustain this.

While the precise run plans of GlueX have not been fully laid out, it has always been anticipated that extracting the smallest signals, and particularly the strangeness physics program is likely to require several *years* of running at the highest intensities possible. While the measure of *year* is a bit soft, it has been assumed that the detector would be taking good data at a rate of about 40-50%. The loss of linear polarization could well turn this into a program of over a decade of keeping GlueX running 8-9 months per year. The effects of such a program on the hardware itself are difficult to judge at this point.

References

[1] Adam Szczepaniak, **Note on Linear Polarization**, GlueX-doc-3xx, November 2004.

[2] Richard Jones, **GlueX Photon Source Characteristics as a Function of Electron Beam Energy**, GlueX-doc-383, November 2004.

[3] Curtis A. Meyer, Online Notebook, `http://www.curtismeyer.com`, November 2004.

[4] Jim Kelly, Private Communication.