Reconstruction of the $\eta\pi^0$ System plus PYTHIA background.

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March 14, 2010

Chapter 1

Physics Signal Simulation and Reconstruction

The ultimate goal of the GlueX project is to reconstruct exotic physics signals but before any exotic discoveries can be made it must be made clear that the detector can reconstruct well understood systems. The limitations of the experimental physics analyses will not be statistics, due to the high luminosity of the photon beam, but will instead be systematic uncertainties in the detector and systematic uncertainties in the phenomenology of the exotic hybrid mesons. These are states, after all, that have yet to be unambiguously seen. High statistics will reduce the uncertainties in the phenomenology but the sensitivity to exotics and acceptance of the detector must be well understood. Validation of the detector design and an early attempt at understanding the systematics of the detector are done through Monte Carlo simulation of physics signals in the GlueX detector with reconstruction by the full Hall-D software package.

The key issues in evaluating the performance of the GlueX spectrometer in regards to reconstructing physics signals are signal purity and acceptance. Pure samples of exclusive final states, which requires an understanding of the background, and an ability to distinguish between various amplitudes, which depends on detector acceptance, are preferable for amplitude analysis.

1.0.1 The $a_2(1320)$ Resonance

Little is known about the photoproduction of the neutral $a_2(1320)$ resonant state. A bubble chamber experiment from 1969 placed an upper limit of 0.4 μb on its cross-section at 5.25 GeV [?] but a literature search has turned up nothing new since that time. A high statistics experiment like GlueX will be able to shed more light on the photoproduction of mesons like this. The a_2 will decay primarily to $\rho\pi$ and $\eta\pi$ with branching fractions of $70.1 \pm 2.7\%$ and $14.5 \pm 1.2\%$ respectively [PDG]. Because this thesis focuses on the calorimeters in the GlueX spectrometer, the all-neutral decays are of more interest. The ρ will decay to two pions nearly 100% of the time and the η will decay to $\gamma\gamma$ and $3\pi^0$ 39% and 32% of the time, respectively. For the sake of simplicity, the $\gamma p \to a_2^0(1320)p \to \eta\pi^0 p \to 4\gamma p$ reaction has been chosen which requires only four photons and a recoil proton to be reconstructed. The cross-section for this has an upper limit of 22.5 nb.

1.1 Event Generation

1.1.1 Signal Generators

There are two signal event generators used in GlueX. Genr8 is a *C* based program that generates peripheral phase space Monte Carlo events. The events produced can be as a result of a complex decay chain of intermediary states with both meson and baryon decays allowed. However, the decays must be limited to t-channel production processes and are produced isotropically. The distribution of the four-momentum transfer squared, $|t|$ follows the form

$$\frac{d\sigma}{dt} \propto e^{-b|t|}. \tag{1.1}$$

A value of $b = 5$ is generally used but can be changed by the user.

The second generator, developed by the group at Indiana University in their AmpTools package, produces events with defined amplitudes and proper angular distributions. This was needed as a generator for testing their partial wave analysis (PWA) algorithms, which will be discussed in the following chapter. Since the final goal of this work was to attempt a simple PWA on data passed through the GlueX detector, the AmpTools generator was used to generate sample resonances.

1.1.2 Background Generation and Filtering

The hadronic background was generated using the tuned version of pythia. The relatively large cross section compared to various signal channels of interest requires a large amount of CPU time and disk space if a moderate amount of experimental beam time is to be simulated. In anticipation of studying $\gamma p \to \eta\pi^0 \to 4\gamma$ decays, it was found that by studying a smaller pythia data set, a set of cuts could be determined, from studying which events could possibly be mistaken for the all neutral decay of the $\eta\pi^0$ system, and applied to the pythia data set before any detector simulation occurs. The cuts have the effect of reducing the events that need to be simulated in HDGEANT to 4% of the original data set.

Since the signal event of interest is an all neutral final state with a recoil proton, a simple cut was found from looking at the total number of charged particles for events that passed reconstruction. Fig 1.1 shows multiplicity of charged particles in each generated events and the multiplicity of charged particles that pass the requirements needed for reconstruction. The events that also pass a probability cut are also shown. From the figure it can be seen that there are very few events which have more than one charged particle and still pass recontruction. The can be explained by the fact that the acceptance of charged particles in the GlueX spectrometer is quite good. In the 200,000 PYTHIA events simulated, none with more than one charged particle also pass a cut on the probability from the kinematic fitter of at least 1%. Since a probability cut will be used to examining signal, events with more than one charged particle were filtered out of the PYTHIA data set.

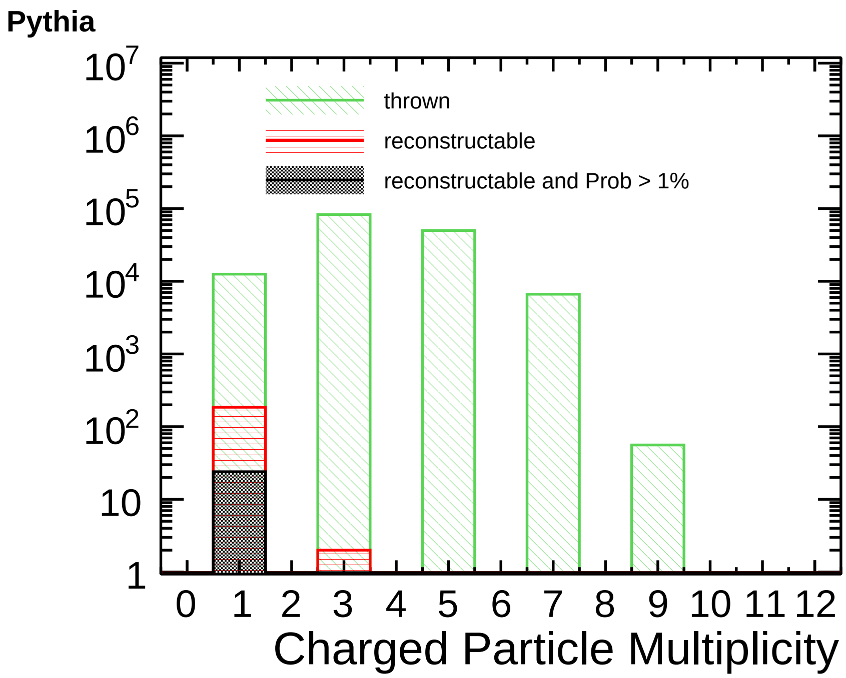

Figure 1.1: The charged particle multiplicity for 2×10^5 PYTHIA events and the events that pass reconstruction.

Also, considering that the final state for the signal is neutral except for the recoil proton, the total energy of the neutral particles will have a narrow spectrum near 9 GeV. The Pythia background, however, will have a very broad total energy spectrum for neutral particles. Fig. 1.2 shows this for all PYTHIA events, $\eta\pi^0 \to 4\gamma$ signal events, and PYTHIA events which are reconstructed; the total neutral energy for the $\eta\pi^0$ is overlayed. From the figure, a cut on the total energy of neutral particles with less than 7.5 GeV and greater than 9 GeV will further reduce the number of background events that should be simulated since those that fail the energy cut will not be possible reconstructed signal events. The effect of these cuts on the PYTHIA data set can be seen in Fig. 1.3.

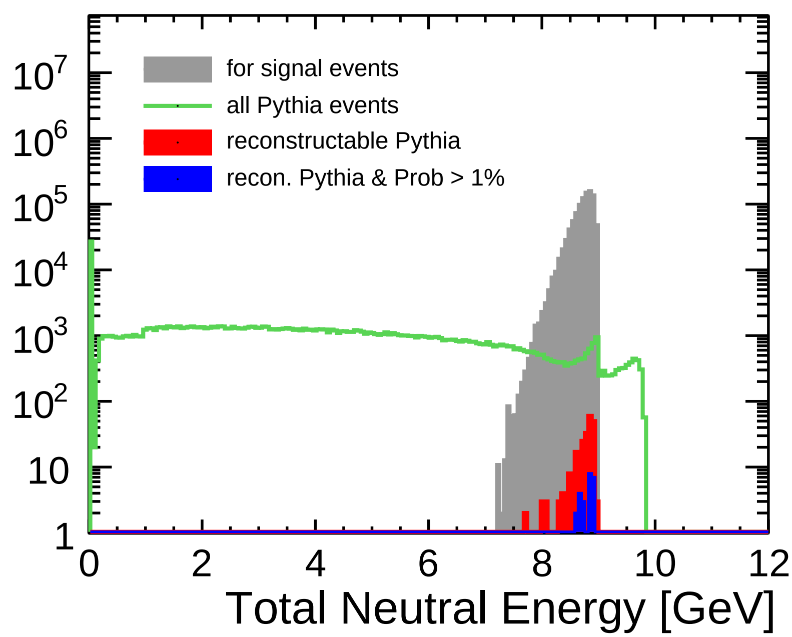

Figure 1.2: The total neutral energy for for all PYTHIA events, signal events, and PYTHIA events which pass reconstruction. The number of events which pass both a cut on charged particle multiplicity and total energy of neutral particles is approximately 4% of the total number of events.

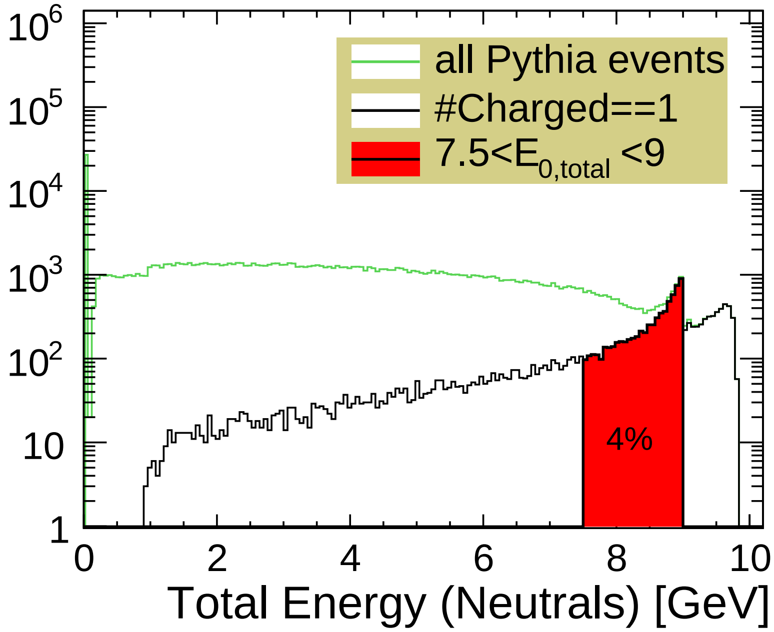

Figure 1.3: The total energy for all neutral particles for all PYTHIA events and PYTHIA events with only 1 charged particle. The red region are those events which fall within 7.5 and 9 GeV.

1.1.3 Event Rates

The total hadronic cross-section, σ_t, for the reaction:

$$\gamma p \rightarrow \text{Anything}$$

is known to be about $124\mu b$ at $9\,GeV$. This number is used to set the rates at which GlueX takes data. To examine this more closely, the $30\,cm$ long liquid hydrogen target in GlueX is examined. This has a number of target centres, N_t given as:

$$N_t = 12.6 \times 10^{23} cm^{-2} = 1.26 b^{-1}.$$

Using, σ_t, N_t, and a tagged photon rate, N_γ of:

$$N_{gamma} = 1 \times 10^7 \gamma / s$$

the event rate can be written as:

$$\begin{aligned} \mathcal{R} &= \sigma_t \times N_t \times N_{gamma} \\ &= (124\mu b) \times (1.26 b^{-1}) \times (10^7 s^{-1}) \\ &= 1.55\,kHz \end{aligned}$$

In agreement with the rates in the GlueX design report [**?**].

Typically, the estimated cross sections for various resonances of interest in searching for hybrid meson are on the order of $0.1 - 3\mu b$. Taking the upper limit for the photoproduction cross-section of $\gamma p \rightarrow a_2^0(1320)p$ to be 0.4 μb the upper limit for $\gamma p \rightarrow a_2(1320)p \rightarrow \eta\pi^0 p \rightarrow 4\gamma p$ is 22.5 nb. The photoproduction cross-section for $\eta\pi^0$ is estimated to be 0.8 μb decaying to 4 photons 40% of the time.

Calculating the event rate for this reaction in a similar way,

$$\begin{aligned} \mathcal{R} &= \sigma \times N_t \times N_{gamma} \\ &= (22.5 \times\ 10^{-9} b) \times (1.26 b^{-1}) \times (10^7 s^{-1}) \\ &= 0.284\,Hz \end{aligned}$$

1.1.4 Data Volume and CPU time

The realities of physics simulations require that enough data storage space and time are available in order to analyze a reasonable set of data. The software packages used in the production and analysis of the data produces data files of sizes:

Since the HDDM file output by HDGEANT contains all the hit information of all the detectors within the simulation, it is possible to prune off the information not required for reconstructing our specific event after wards. A new HDDM can be defined which contains only FCAL, BCAL and the thrown truth information. This

Table 1.1: Estimated file sizes and computer time on the IU cluster. Including log files, the total disc space required is nearly 23 kB per event. Pruning the final HDDM file to remove unneeded hit information reduces this down to 30 to 40% of the original size (7 to 10 kB/event).

Software file	kByte/event	CPU time
bggen.hddm (PYTHIA)	0.81	negligible
hdgeant.hddm	21.7	$\sim$ 1.2 sec/event
analysis.root	0.33	$\sim$ 0.015 sec/event

has an effect of reducing the files size by 60 to 70% and reduces the overall disc space requirements from 23 kB/event to 7 to 10 kB/event depending on the volume of hit information in each detectors.

The expected event rates and associated data volumes for background and a_2^0 signal Monte Carlo are shown in Table 1.2. The volumes for a PYTHIA data set are shown for before and after removing uneccesary events and data records.

Table 1.2: Expected event rates for various production cross sections in photoproduction. The σ column is the cross section. The rate is the equivalent experimental data rate given a beam rate of $10^7\gamma/s$ and the $30cm$ target. A beam rate of $10^8\gamma/s$ will increase the magnitudes of the events and data sets by one order.

$10^7\gamma/s$				
σ	rate	number of events		
		day^{-1}	$week^{-1}$	$year(10^7 s)^{-1}$
$124\,\mu b$	$1.55\,kHz$	1.34×10^8	9.37×10^8	1.55×10^{10}
$0.0225\,\mu b$	$0.284\,Hz$	2.45×10^4	1.72×10^5	2.84×10^6
σ	rate	MC data record size (GB)		
		day^{-1}	$week^{-1}$	$year^{-1}$
$124\,\mu b$	$1.55\,kHz$	4.37×10^3	2.16×10^4	3.57×10^5
$124\,\mu b \times 4\% \times 40\%$		6.99×10^1	3.46×10^2	5.71×10^3
$0.0225\,\mu b$	$0.284.3\,Hz$	0.56	3.95	65.4
$0.0225\,\mu b \times 40\%$	$0.284\,Hz$	0.23	1.58	26.1

1.2 Reconstruction of the $\eta\pi^0$ System

Channels that decay into purely photons are expected to be challenging to identify and may be difficult to cleany separate from the background. In what follows, the focus is on the efficiency for reconstructing an all neutral signal and the anticipated background from other hadronic events. Again, the tuned version of PYTHIA is used to reproduce the know photoproduction cross sections of charged and neutral particles. To ensure that the data set originates from pure background hadronic photoproduction processes, the identies of the particles provided by PYTHIA are examined and events that match our exclusive signal topology are excluded. The AmpTools generator is then used to generate our pure signal events. Of particular interest is the ratio of signal to background efficiency which is key to estimating the sensitivity to a particular physics channel.

The relatively simple two-body channel such as $\gamma p \rightarrow Xp \rightarrow \eta\pi^0 p \rightarrow 4\gamma p$ was examined where X is some resonance. The resonance mass was given a flat distribution from 0.7 to 2.2 GeV/c^2 since it is expected that hybrids will be found in the this mass range.

For signal events, Fig. 1.4 shows the multiplicity of reconstructed photons in both the FCAL and BCAL calorimeters from a sample of 350,000 events.

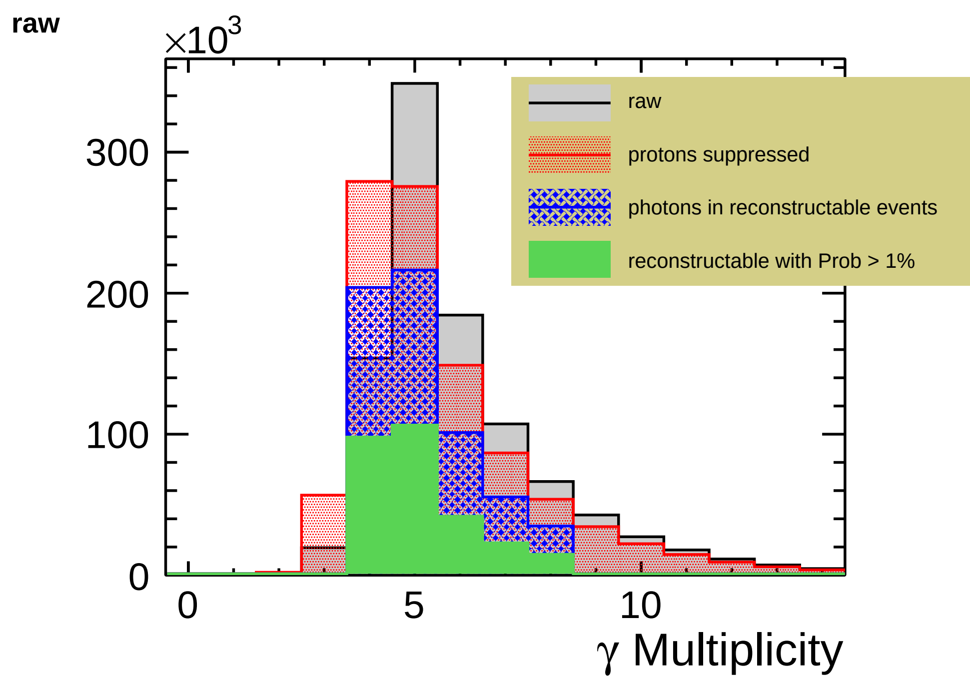

Figure 1.4: Photon multiplicity for $\eta\pi^0$ signal events. The plot shows the raw reconstructed photon multiplicty, the multiplicity after clusters due to charged particles are suppressed. Multiplicity of photons for any reconstructable event and events wich pass a probability cut of greater than 1% are shown in the figure.

Signal $\eta\pi^0$ candidates are selected by requiring that there be at least 4 clusters in the BCAL or FCAL not associated with charged particles and 1 positively charged particle with a mass near that of the proton. The photons in each event are looped over and a kinematic fit is applied to 4 of the photons with constraints on the η

and π^0 masses, and initial and final 4-momenta. The error matrix from the photons are used to form part of the covariant matrix for the kinematic fit with the incident beam, target and final proton not having an associated error currently[1]. The number of possible candidates for the signal reaction are seen in Fig.1.5 where a candidate has at least four photons, one proton and a fit probability greater than 1%. The fit with the highest probability from the kinematic fit is chosen as the primary candidate $\eta\pi^0$.

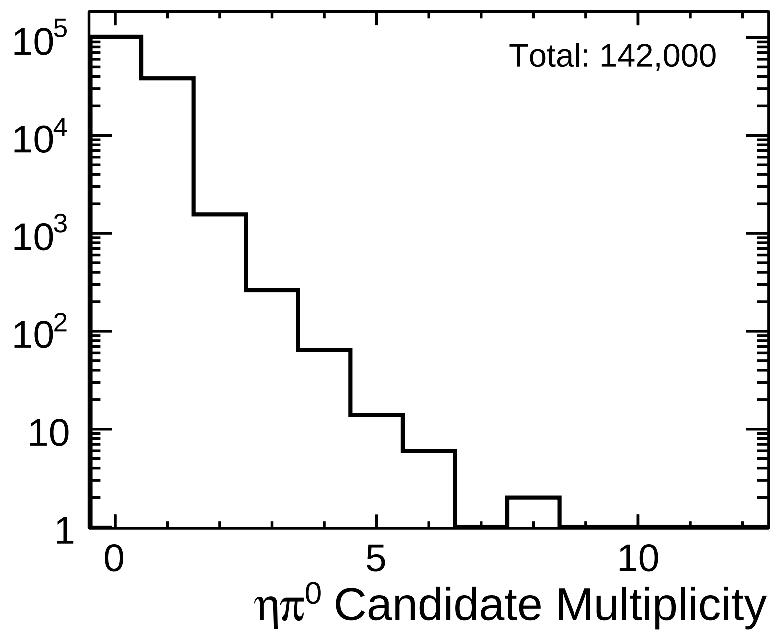

Figure 1.5: The candidate multiplicity for 142,000 generated signal events after reconstruction requirements are applied

The reconstructed 4-photon invariant mass is shown in Fig.1.6 for signal and background. 2.2×10^8 PYTHIA events and 142,000 signal events were simulated for a relative cross section ratio of 124μb:80 nb. The ratio of signal to background at invariant mass greater than 1.25 GeV/c^2 is approximately 20:1. This ratio degrades below 1.25 GeV/c^2 due to issues with reconstruction which are currently being examined. On average, the reconstruction efficiency before any probability cut is 60%. A cut on the kinematic fit probability for events less than 1% reduces the reconstruction efficiency to 30%.

[1]The kinematic fit software was in the process of being modified to include errors for the HDParSim particles at the time this thesis was written.

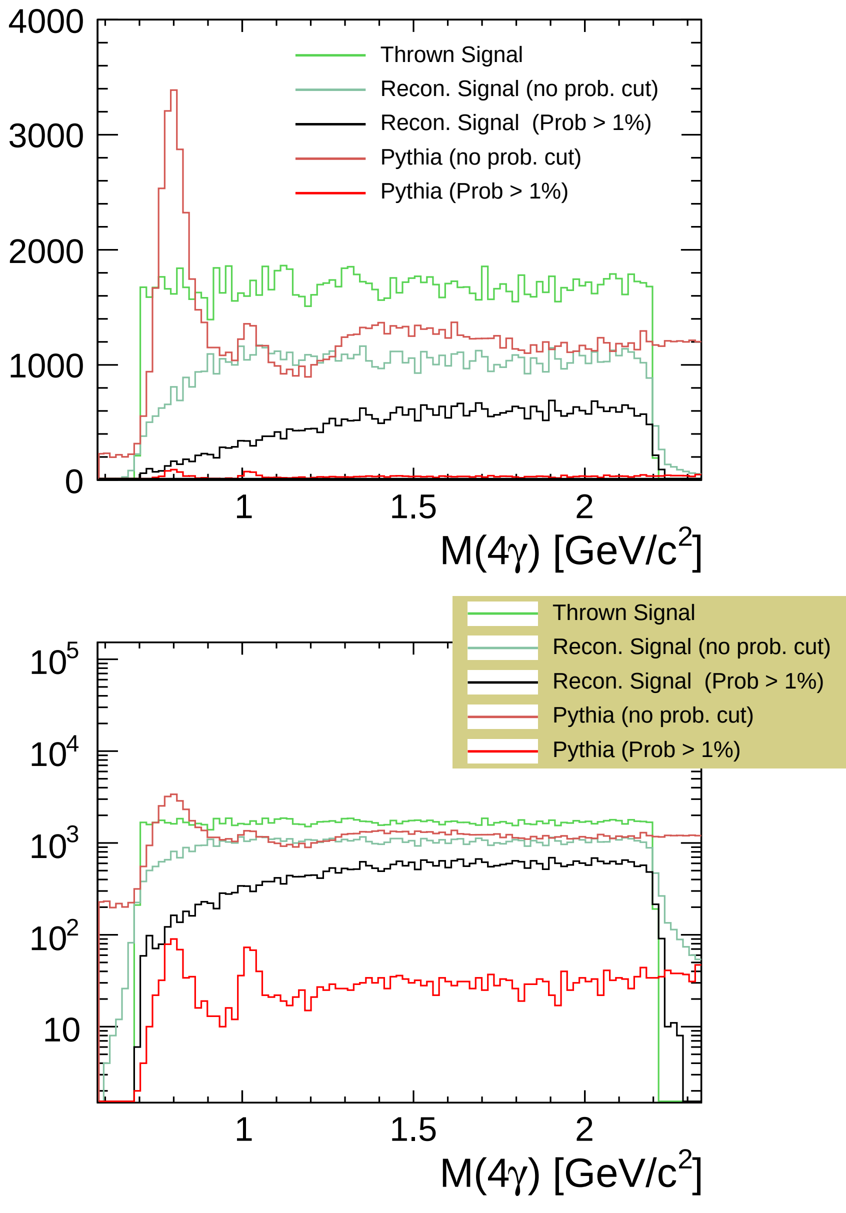

Figure 1.6: The reconstructed 4-photon invariant mass for a flat $\eta\pi^0$ distribution. Signal and background are shown with approximately relative cross-sections. The bottom plot is the same but a logarithmic scale.