Simulation of Tagger Backgrounds Returning from the Electron Beam Dump

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Abstract

The civil engineering design team has proposed a layout of the tagger area for Hall D that has the electron beam dump located at the end of a corridor that is connected to the main tagger hall. A labyrinth composed of concrete shielding walls is proposed to shield the instrumentation in the tagger area from radiation back-streaming from the dump. The purpose of this note is to estimate residual backgrounds in the tagging counters under these conditions. Backgrounds originating within the main tagger hall, in the exit electron beam line, and in the dump itself have been investigated separately using a high-statistics Monte Carlo study. This study shows that the backgrounds coming from the electron beam downstream of the tagger vacuum chamber are negligible compared to sources located in the tagger area proper. At the level of sensitivity of this study, no backgrounds coming from the dump itself were detected in the tagging counters.

1 Simulations

A diagram of the proposed layout for the Hall D tagger area is shown in Fig. 1. The view shown is taken using a horizontal cut plane through the setup at the height of the beam. The track of a single beam electron is represented by the red trajectory superimposed on the figure. The square box at the far left is the vacuum housing containing the radiator crystal. Downstream of the radiator is a quadrupole magnet followed by the two dipoles of the tagging spectrometer. The long wedge-shaped volume surrounding the dipoles is the vacuum box of the spectrometer. The magnetic field bends electrons downward in the figure. At the lower edge of the vacuum box are located the tagging counters, the broad-band array shown in blue and the microscope shown in red. The unscattered electron beam exits the downstream end of the vacuum box and travels inside a vacuum pipe through three shielding walls down the beam dump corridor to the beam dump.

Gamma rays produced by the beam electron showering in the dump are represented by dotted blue lines. This is the dominant form of radiation that comes back from the beam dump from the showers of high energy electrons, but there are also significant numbers of neutrons, electrons and positrons. The aim of this study is to estimate the rate of this back-scattered radiation that is able to escape from the beam dump containment and generate background hits in the tagging counters.

At a nominal operating beam current of 3 μA, there are 1.9×10^{13} 12 GeV electrons per second entering the dump. Of these, only something of order 10^{10} electrons radiate a significant fraction of their energy in the radiator crystal and are detected in the tagging counters. All of them are capable, however, of producing background in the tagger area if their interactions in the electron beam line or dump produce backward-going secondaries. Fortunately most of this radiation is too low in energy to produce a hit in a scintillation detector, but it would only take a very small fraction of beam particles producing significant backward-going energy to create big problems for the tagger. For example, under nominal conditions at 3 μA the aggregate rate in the tagging microscope counters is 2.5×10^{8} s^{-1}. If one out of 10^{6} 12 GeV electrons in the dump produced a background hit in the microscope it would degrade the signal/background ratio by 10%.

There are several sources of background in the tagging counters. A design goal for the Hall D tagger is to limit the background from any single source to less than 1%. Based on guidance from the several sources, the civil designers chose a layout that is expected to be at least this good or better. To show that this is the case using Monte Carlo simulation requires large event samples. For example, if the tagger microscope background rate from the dump is 1% of the signal rate then one would expect to have to generate 10^{7} beam dump events before the first background hit would be registered in one of the microscope counters. A Monte Carlo measurement giving some information on the background spectrum requires 10^{8} events at this upper bound on the background rates.

The sensitivity of the Monte Carlo to low background levels can be greatly enhanced using the so-called *cascading* simulation technique. A cascaded simulation takes advantage of the fact that the back-streaming radiation from the dump behaves like a diffuse source. Consider the green line in Fig. /ref-darea that divides the tagger area between the dump tunnel and the main hall. When cascading is enabled at that surface, any particle that crosses that boundary in the direction of entering the hall from the tunnel is amplified by a factor 1000. It is as if the particle died at the boundary and produced 1000 copies of itself, identical in energy and direction, which are all individually simulated before that event is complete. A single amplification event produces a very non-representative picture of the sources in the tunnel, but over a large number of events fluctuations smooth out and the background distribution settles approaches the true distribution, with 1000 times better statistics as regards what the effects of that radiation are in the hall.

A similar cascade can be performed at the surface represented by the green line in front of the dump in Fig. 1. Cascading from both surfaces yields a net amplification in the tagger hall of anything coming back into the hall from the dump. The goal of these cascaded simulations is to be able to measure a non-zero value for the dump backgrounds, even if they are very small.

2 Results

Three simulation runs were performed, each of 10^8 beam events. The beam particles were launched at the entrance to the radiator with an energy of exactly 12 GeV and a transverse profile consistent with the design of the GlueX photon beam line. In the place of a diamond crystal, a film of amorphous carbon was used because it was easier to set up and is equivalent for the purposes of a background simulation.

The first simulation run employed no cascading amplification. Each event released 12 GeV of energy and eventually dissipated that energy in the form of ionization. Electrons which radiated a photon of sufficient energy in the radiator were bent into the focal plane of the spectrometer and generally deposited energy in one or more of the tagging counters. Fig. 2 shows the spectrum of deposited energy in the tagger microscope (first panel) and broad-band detectors (second panel) for the complete simulation of 10^8 beam particles. The spectrum at energies below 500 keV is dominated by background coming from sources within the tagger hall, electron exit tunnel, and the dump. These sources are not differentiated in this simulation, but already it is clear that in both cases the background is less than 1% above a reasonable threshold choice for the signal amplitude.

The microscope spectrum shows a sharp minimum-ionizing peak at 4 MeV corresponding to the full 2 cm length of the individual scintillating fibers. The small peak at 8 MeV corresponds to primarily events where the electron interacted in the exit window of the vacuum box and produced a second electron or positron passing through the same counter. The broad hump under the peak in the spectrum for the broad-band array comes about because of the large variation in the effective path length inside the scintillator that takes place between the two ends of the array. These counters were modeled in the simulation as a long continuous piece of scintillator along the full length of the focal plane. A more detailed model with individual counters oriented perpendicular to the signal electron trajectories would not show this broad hump.

The second simulation was a repetition of the first, starting from a different Monte Carlo seed, with the cascade factor of 1000 set at the boundary going from the tunnel to the tagger hall. Any component of the shaded areas shown in Fig. 2 that are coming from the beam tunnel and dump should be amplified by a factor 1000 in the results from the second simulation. In the third simulation, the cascade at the tunnel-area boundary was left at a factor 1000 and a second factor 1000 cascade was turned on at the boundary going from the dump into the tunnel. In this simulation any component in the shaded areas shown in Fig. 2 coming from sources in the tunnel will be amplified by a factor 1000, and coming from the dump will be amplified by a factor 10^6. The results of both simulations two and three are shown in Fig. 3 for the tagger microscope and Fig. 4 for the broad-band array. The spectra shown in Fig. 2 have been subtracted to show only the excess coming from the tunnel and dump sources.

3 Conclusions

The simulations showed total backgrounds in the microscope tagging counters from all sources at a level of 1% of the signal rate. The corresponding level in the broad-band array counters was much higher at the 10% level, although this is not a realistic estimate for those counters because their shape and orientation in the simulation was not optimal. The point of the simulations was not to focus on background sources within the tagger hall, but those located in the electron beam exit tunnel and beam dump. The simulations produced statistically significant spectra for the background coming from the tunnel region. One likely origin for this radiation is interactions of slightly degraded electrons in the walls of the beam pipe. The energy deposition spectrum of the background from this source was very soft. For the microscope counters the count rate of these hits above a 2 MeV threshold for signal hits was statistically consistent with zero, leading to an upper bound of approximately 10^{-4} in background/signal at the 90% confidence level for background sources in the tunnel and dump. The corresponding level for background/signal in the broad-band array is $(3.0 \pm 1.3) \times 10^{-4}$.

Comparison between spectra with and without a cascade amplification factor of 1000 at the entrance to the beam dump shows that the two sets are consistent with no back-streaming from the dump. It follows that the tagger background rate coming from the dump is less than a factor 1000 smaller than those coming from sources within the exit tunnel. This leads to an upper limit of 10^-7 in the ratio background/signal in the microscope and 6×10^-7 in the broad-band counters for radiation coming from the dump.

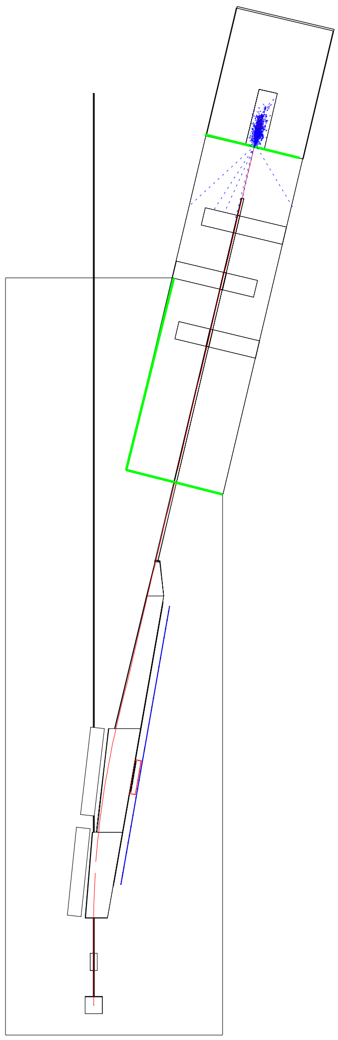

Figure 1: Cut view through the Hall D tagger area at the plane $y = 0$ in the simulation geometry. The electron beam enters the figure at the far left, passes through the radiator housing (square box), the quadrupole magnet and two dipoles of the tagging spectrometer, and continues on to the dump located in the lower right corner of the figure. The tagging counters are shown in red (microscope) and blue (broad-band array).

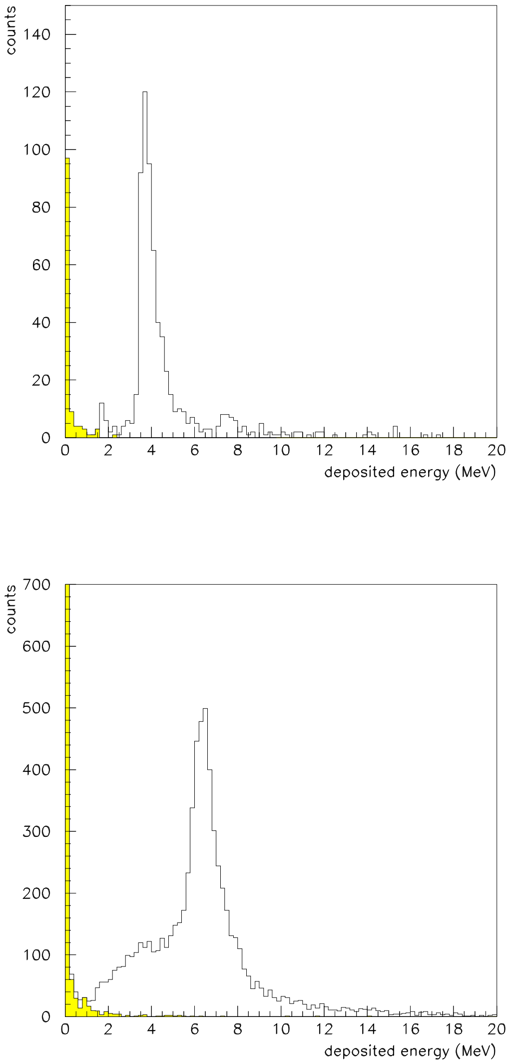

Figure 2: Spectrum of energy deposited in the microscope tagging counters (first panel) and broad-band array (second panel). The open histograms include all hits above 100 keV, both signal and background, while the shaded histograms exclude tracks that come from the direction of the radiator.

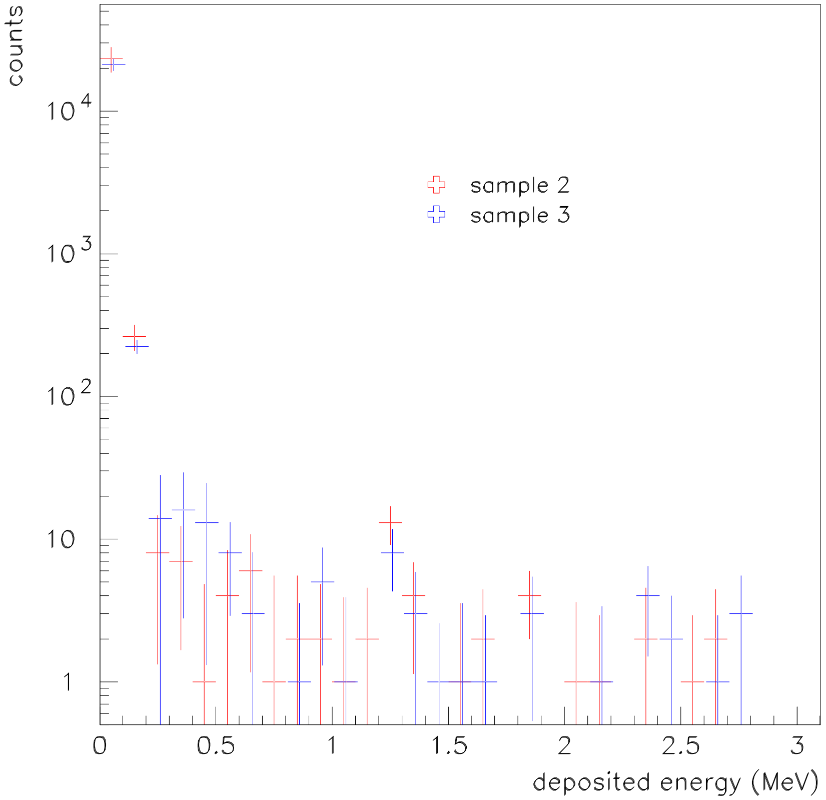

Figure 3: Spectrum of energy deposited in the microscope tagging counters after the contributions from all sources in the main tagger area have been subtracted. The red points reflect the background rates from all sources located in the electron beam dump tunnel area. The blue points are obtained under the same conditions, with any contributions coming from the dump itself amplified by a factor 1000.

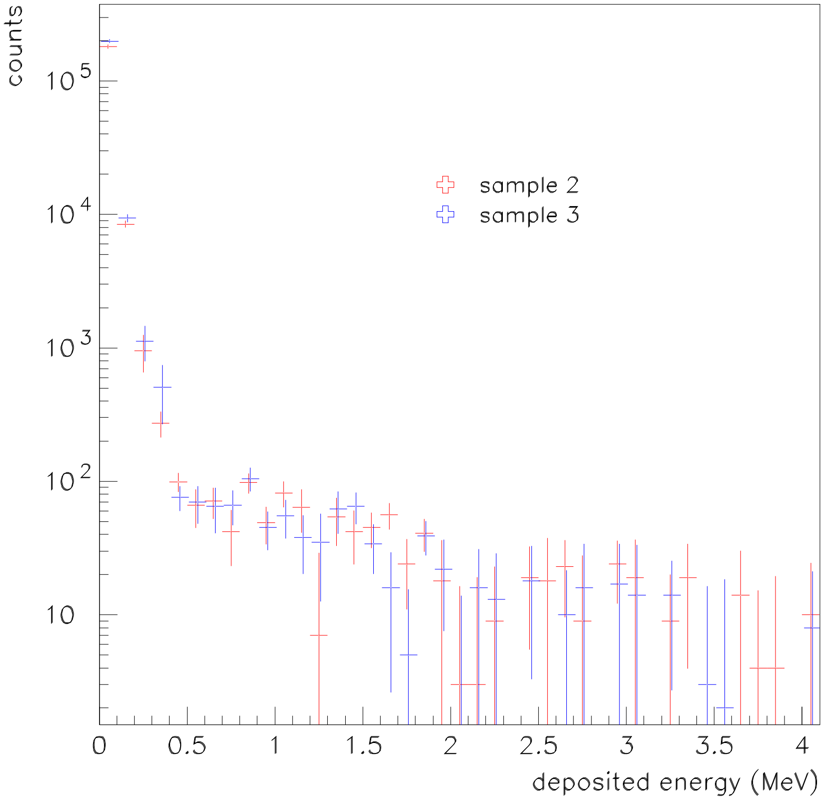

Figure 4: Spectrum of energy deposited in the broad-band tagging counters after the contributions from all sources in the main tagger area have been subtracted. The red points reflect the background rates from all sources located in the electron beam dump tunnel area. The blue points are obtained under the same conditions, with any contributions coming from the dump itself amplified by a factor 1000.