ELSEVIER

Nuclear Physics B (Proc. Suppl.) 124 (2003) 221–224

NUCLEAR PHYSICS B
PROCEEDINGS
SUPPLEMENTS

www.elsevier.com/locate/npe

Simulation results with ZEPLIN II

Y. Seo[a], H. Wang[a] and D. B. Cline[a]

[a]Dark Matter Laboratory, Department of Physics and Astronomy, University of California, Los Angeles, 405 Hilgard Ave., Los Angeles, CA 90095-1547, USA

Monte Carlo simulation studies of light collection have been performed for the ZEPLIN II central detector. Attenuation, transmission and reflection, and absorption are carefully considered for the simulation. Approximately 3.61 photoelectrons per keV can be obtained with the detector geometry which is currently being built, not including considerations of optical transparencies of fine metallic meshes in the detector. It is also found that the PTFE (Polytetrafluoroethylene) confinement for liquid xenon, coupled with a highly reflective bottom copper plate, improves both the light collection efficiency and the energy resolution.

1. Introduction

The SUSY-neutralino WIMP dark matter scenario has ever been strong, evidenced by plenty of theoretical backgrounds and experimental hunts [1,2]. The ZEPLIN II detector which adopts both scintillation and ionization processes from liquid xenon when a hypothetical WIMP interacts with the xenon nucleus [3]. The detector has over 30-kg fiducial liquid xenon volume, and weighs about 40-kg excluding outside shielding and veto. The double-phase xenon structure of the ZEPLIN II detector works with an excellent background discrimination power by drifting and extracting ionized electrons from liquid to gas phase for amplified electroluminescence signals. The magnitude of these electroluminescence signals differs greatly between gamma backgrounds and nuclear recoils caused by WIMP (or neutron) - Xe scattering [4].

Since the direct search of neutralino dark matter experiments seeks the nuclear recoils mostly in a few tens of keV regions, the energy threshold of the detector must be very low. The germanium detectors are known to have a low energy threshold, but the limit of energy threshold for xenon detectors is not known very clearly. Assuming the neutralino mass in our galactic halo is in the range GeV/c^2 - TeV/c^2, the lowest detectable recoil energy by most of dark matter detectors is required to be below 100-keV.

In addition, recent progresses of theoretical work on SUSY WIMP dark matter cross section calculations suggest that at least one ton target mass be required to cover favored cross section regions of WIMP-nucleon scattering (for example, see [5]). The proposed one ton liquid xenon detector, ZEPLIN IV, is one of the most sensitive dark matter detectors in years to come [6]. In order to increase the sensitivity of liquid xenon detectors, amplification of primary scintillation signal using a CsI internal photocathode was also discussed [7].

2. Simulation

Monte carlo simulation studies of light collection have been performed for the ZEPLIN II central detector volume [8]. Figure 1 shows a flow diagram of how the simulation code tracks a single photon throughout the entire central detector. If an event occurs in the liquid xenon target, depending on its nuclear recoil energy and its corresponding gamma-equivalent energy, a certain number of photons get generated and flashed randomly in 3-D space. If a single photon track is taken, and assuming that the photon hits the wall of the PTFE confinement, the photon diffuse-reflects on the surface. Another random directional photon from the diffuse reflection may arrive at the interface of liquid and gas xenon. At the phase boundary, the reflection and transmission are calculated. The transmitted

doi:10.1016/S0920-5632(03)02110-8

photon, then, can hit the interface of gas xenon and a PMT window. Reflection and transmission are calculated this time again. The transmitted photon can be converted to photoelectrons that will be recorded by PMTs, depending on the PMT's quantum efficiency. The number of recorded photoelectrons is finally calculated after all these processes. Furthermore, when a photon leaves the liquid, the light attenuation value is carefully checked for the loss.

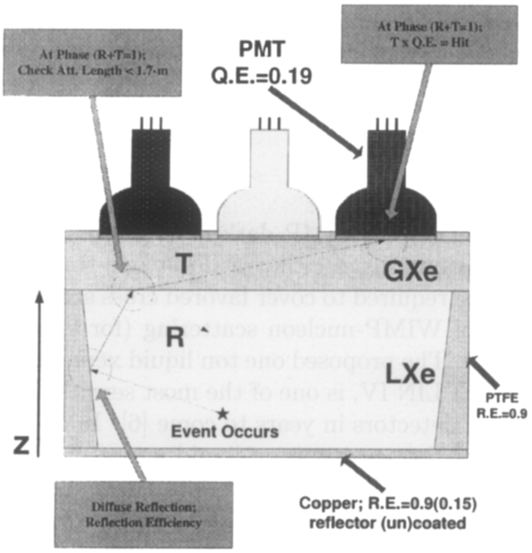

Figure 1. A flow diagram of light collection simulation at every surface and boundary conceivable in the ZEPLIN II detector.

All the following plots use standard parameters: $W_s = 13$, $F = 0.05$, $\lambda = 1.7$-meter [9], PMT QE = 0.19 [10], PTFE reflectivity = 0.9, copper reflectivity = 0.15, and the reflector-coated bottom copper plate reflectivity = 0.9 (similar to PTFE), unless mentioned. The gamma-equivalent energy is always used to designate the energy for any spectrum. The factors due to imperfect (100%) optical transparencies of the metallic meshes are not considered for the simulation. Hence, the total number of photoelectrons recorded by the PMTs must be lower than the predicted simulation values by a small margin.

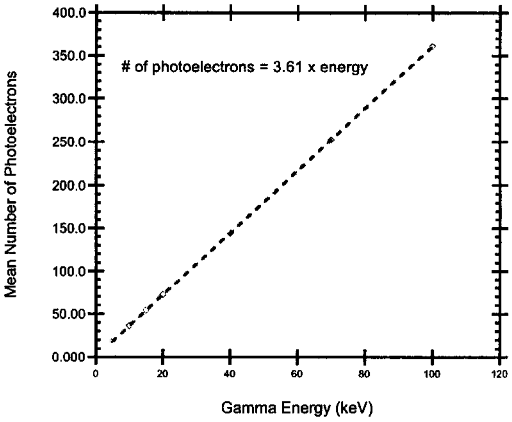

Figure 2. Photopeaks are plotted against their corresponding gamma energies with the linear squares fit.

From 5-keV to 100-keV, the photopeak of the spectra is plotted as a function of the incident gamma energy in Figure 2. One keV incident gamma energy is proportional to about 3.61 photoelectrons recorded by seven PMTs.

For the bottom part of the liquid xenon confinement, a copper plate is placed to apply a very high electric field which might be necessary to detect every ionization signal both from WIMPs and gammas. The bare-copper-like bottom without any reflector coating is assumed to have 15% reflection efficiency, and the PTFE-like bottom with a reflector coating is treated as a 90% reflector. From Figure 3, 49.5% improvement of light collection from 15% (48.5) reflectivity to 90% (72.5) reflectivity and 35.7% improvement of energy resolution R from 15% (45.4%) to 90% (28.0%) are calculated.

Figures 4 and 5 show segmented spectra of 20-keV gamma energy for six difference vertical po-

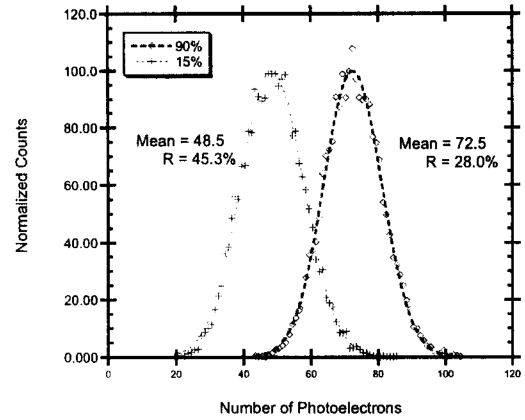

Figure 3. 20-keV spectra with 90% and 15% bottom reflectivities.

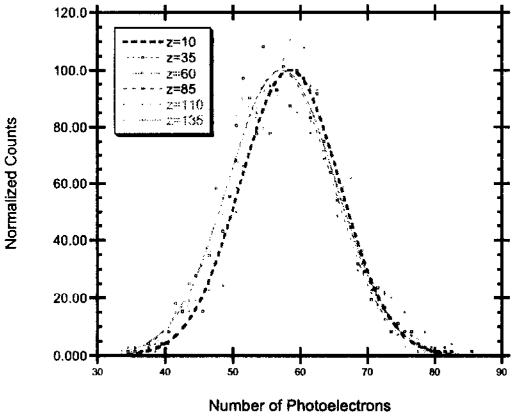

Figure 4. Segmented spectra with 90% bottom reflectivity for 20-keV gamma energy. The vertical position z of event location is mm from the bottom plate.

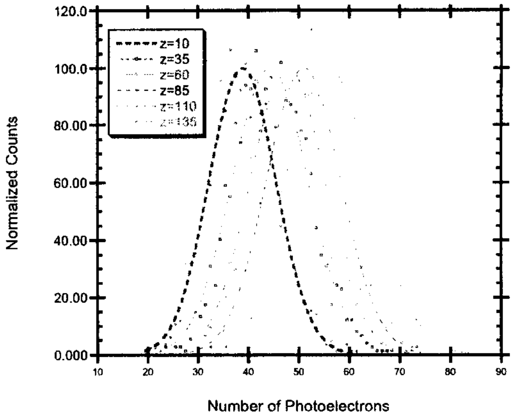

Figure 5. Segmented spectra with 90% bottom reflectivity for 20-keV gamma energy. The vertical position z of event location is mm from the bottom plate.

sitions of event location from 10-mm to 135-mm high from the bottom plate. Each spectrum includes events occurred at each position within 20-mm vertical bins. For example, z =60 is a spectrum for events enclosed in a flat cylindrical frustum between 50-mm and 70-mm from the bottom.

With 90% bottom reflectivity (PTFE-like), there is no visible degradation in both energy resolution and light collection depending on the position of event occurrence (Figure 4). With 15% bottom reflectivity (bare-copper-like), there is a huge discrepancy in both energy resolution and light collection depending on the position of event occurrence (Figure 5). A higher light collection is expected as the location in which the event occurs gets nearer to the top portion of the liquid frustum.

Figure 6 shows more plots for the sensitivity of the detector light collection due to the vertical position from the bottom plate. All solid lines are fitted lines for a detector with 90% bottom reflectivity, and all dashed lines are for a detector with 15% bottom reflectivity. For a higher energy (e.g. 20-keV in the Figure 6), the position dependence of light collection varies more extensively than for a lower energy. It is concluded that the energy resolution is highly affected by the position dependence with a low bottom reflectivity in

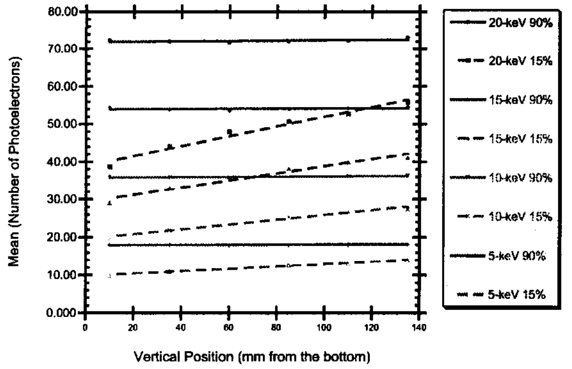

Figure 6. Event location sensitivity is plotted for 5-keV, 10-keV, 15-keV, and 20-keV gamma energies against the vertical position from the bottom.

the detector.

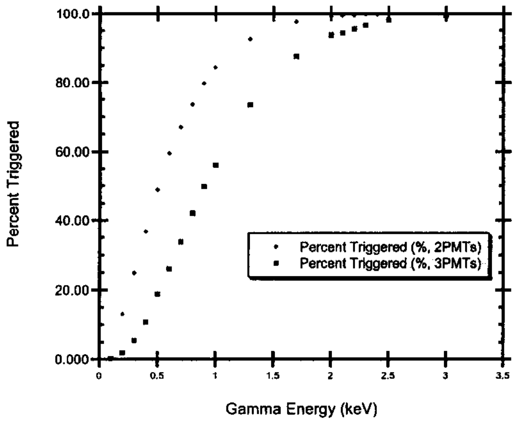

Figure 7. Single photoelectron level trigger with 2- and 3-PMT coincidence.

The energy threshold of the detector can be also adjusted by setting an appropriate trigger. The lowest possible threshold is achieved by a single photoelectron level, requiring a coincidence of any two photomultipliers. The coincidence is a must to avoid the PMT's dark current counting. When a large number of PMTs are used (for example, 76 PMTs for the proposed ZEPLIN IV detector), a coincidence of three or more PMTs might be required to avoid accidental trigger. A better light collection or amplified signal is also necessary to maintain a low energy threshold for such a large detector. Figure 7 indicates that over 99% of events are triggered after 2-keV gamma energy for 2-PMT trigger setting, and after 3-keV energy for 3-PMT setting.

3. Conclusion

The simulation results confirm that the ZEPLIN II detector will achieve a very low energy threshold because of its high light collection sensitivity. Over 3 photoelectrons per keV is possible with desired parameters of liquid xenon scintillation.

REFERENCES

1. Proc. of the 4th Int. Symposium on Sources and Detection of Dark Matter in the Universe, DM2000, Marina del Rey, CA, Feb 2000.
2. These proceedings of the 5th Int. Symposium on Sources and Detection of Dark Matter and Dark Energy in the Universe, DM2002, Marina del Rey, CA, Feb 2002.
3. H. Wang *et al.*, in [1].
4. D. Cline *et al.*, Astropart. Phys. 12 (2000) 373.
5. D. B. Cline *et al.*, astro-ph/0108147.
6. D. B. Cline, astro-ph/0111098.
7. J.-K. Woo *et al.*, in [1].
8. Y. Seo, PhD thesis, UCLA (2002).
9. H. Wang, PhD thesis, UCLA (1998).
10. F. Arneodo *et al.*, Nucl. Instr. Meth. A449 (2000) 147.