KamLAND Detector Simulation

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The KamLAND GEANT4 Simulation (KLG4sim) is the detector Monte Carlo simulation for the KamLAND experiment. This software package was designed and written by various members of KamLAND, and currently, the simulation development is being led by collaborators from LBNL and Kansas State University. KLG4sim is built from geometry and material descriptions specific to KamLAND. The underlying structure and physics processes are taken from the GEANT4 toolkit [1]. However, KLG4sim also contains a number of custom-written physics processes, which are intended to optimize its accuracy and efficiency. These include:

- Optical Propagation: Scintillation, elastic scattering, and reemission are modeled by individually tracking each optical photon and applying these processes as the photon propagates through the detector.
- PMT Model: Reflection, refraction and transmission at the photocathode boundary.
- Neutron Diffusion and Capture: Simplified tracking and capture of thermal neutrons

An additional special feature is a torus-stack geometry class, which allows the user to construct non-standard shapes such as a PMT glass envelope.

Work at LBNL has focused on testing and improving the performance of the simulation. Owing to much progress in this area over the past two years, the simulation is now reaching a level of maturity where it can be used to help identify and reduce sources of systematic uncertainty in future KamLAND measurements. Additionally, KamLAND is preparing to measure the Be^7 neutrino flux from the Sun. This measurement will require good understanding of backgrounds. KLG4sim is an ideal tool for this.

Systematic verification of the simulation output against the real detector response is continually ongoing. Specific progress in the past year includes the improvement of KLG4sim's ability to reproduce the energy scale. KLG4sim produces output in a format that allows for application of the same energy and vertex reconstruction algorithms used on the real dataset. Comparison with simulation output and data show good agreement. Examples can be seen in Fig. 1 and Fig. 2, where the energy and reconstructed vertex positions agree at the few percent level and better. This past year has also seen the use of KLG4sim for detailed cross-checks of the energy reconstruction, ^{11}C efficiency studies, 4π reconstruction-bias studies, and fiducial volume estimates.

As stated above, improvements in KLG4sim are ongoing. Particular areas that still need work include:

- Completion of the signal readout simulation (Esim), which is currently under construction.

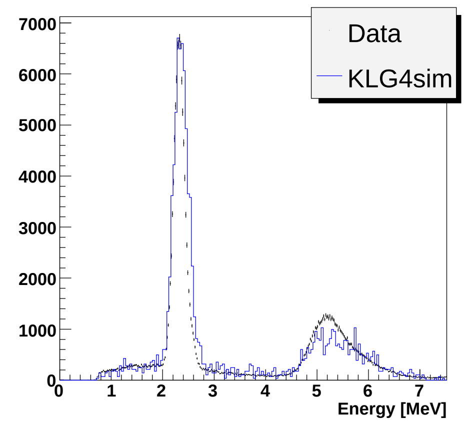

FIG. 1: Data/KLG4sim comparison of reconstructed AmBe calibration-source energy. The high energy peak is produced by 4.4 MeV gammas, and the low, sharp peak is from 2.2 MeV gammas. The broad shoulder stretching from ~ 5 MeV to ~ 4 MeV is quenched proton recoil. Though there appears to be a deficit of 4.4 MeV gammas, the reconstructed energy of these various particles is reproduced very well by KLG4sim.

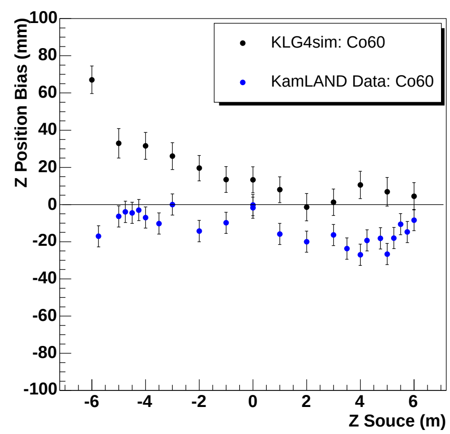

FIG. 2: Data/KLG4sim comparison for vertex reconstruction along the z axis using Co60 calibration data. Bias is defined as reconstructed minus true.

- Improve simulated response to high-energy (GeV) muons.
- Resolution of existing %-level disagreements between data and simulation energy reconstruction.

[1] S. Agostinelli and et al, NIM A **506**, 250 (2003).