Alternative Design for Large Scale Liquid Scintillator Detectors: Stratified LIquid Plane Scintillator (SLIPS)

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(paper in progress)

The construction of large-scale liquid scintillator detectors is complicated by the need to separate the scintillation region from photomultiplier tubes (PMTs) due to their intrinsic radioactivity. This is generally done using acrylic and/or nylon barriers, whose own intrinsic activity can also lead to substantial cuts to the fiducial detection volume for a number of low energy (~MeV) studies. Such barrier constructions also become increasingly difficult and expensive for larger detector volumes, with JUNO already pushing the boundaries of what might be achievable. The SLIPS concept is to do away with such physical barriers entirely by instead mounting PMTs on the bottom of a wide cavity and covering them with a distillable, lipophobic liquid, above which a less dense scintillator is layered. Liquids such as various ethylene glycols are good candidates for the bottom layer as they provide a good refractive index match to a number of liquid scintillator solvents. Thin, opaque and highly reflective (>90%) surfaces are used near the top and side areas of the detector to provide a buffer region against radioactivity from the walls and to reflect scintillation light back to the bottom PMT array, where the time-separated reflected signals are used to reconstruct the 3D vertex position as well as the event energy. Initial simulation studies indicate that good position and energy reconstruction can be achieved with this approach. The notion is to use a shallow layer of scintillator relative to the cavity width, where the vertical depth of scintillator is chosen to be much less than the optical absorption length and can be optimised to balance fiducial volume, light level and reconstruction accuracy.

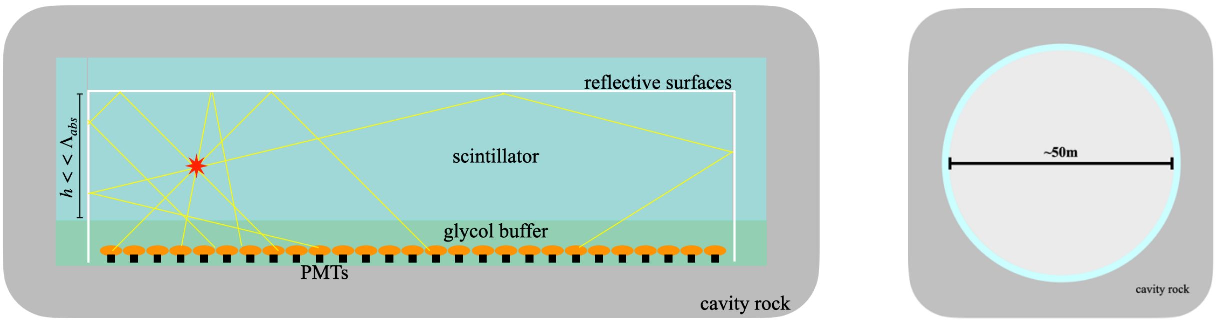

Fig 1: SLIPS design. Left - cross-sectional side view; right - top view.

The dense packing of PMTs on just one surface of the cavity can potentially be made highly economical and efficient for light collection. For example, preliminary studies suggest that a similar fiducial volume and energy resolution as JUNO might be achievable with half the number of PMTs. On the other hand, the design could also be optimised to make the best use of a smaller number of PMTs, potentially using further segmentation with internal reflective partitions, which might be more useful for long baseline reactor monitoring. In principle, one could also mount PMTs on the top surface by adding a lower density buffer liquid and using a relatively high-density scintillator solvent, such as PXE, though the relative benefits of such a configuration would need further exploration. This design may allow for a much more simple and economical construction of large-scale scintillation detectors, which could have impact in a number of areas, including $0\nu\beta\beta$ and solar, supernova and geo neutrinos as well as long baseline monitoring of reactors, which could require detector masses of the order of ~50kT.

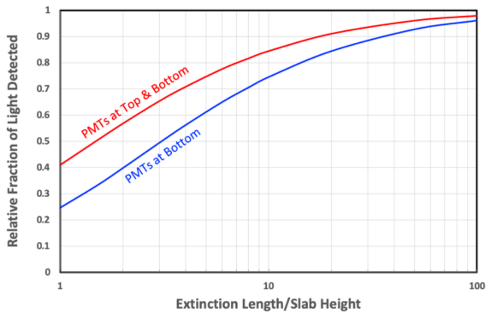

Fig 2: Simplified analytical model of the relative fraction of produced light detected vs extinction length/scintillator depth ratio.

Initial simulations have been carried out assuming a densely packed array of R5912-100 HQE PMTs in a pillbox-shaped detector with a diameter of 50m, an ethylene glycol layer extending 2m above the PMTs, a scintillator layer composed of LAB + 2g/L PPO, and 90% specular reflective surfaces. Figure 3 shows the resulting number of detected photons from a 1 MeV electron as a function of event position for vertical scintillator heights of both 5m and 10m. These correspond to fiducial volumes of ~8kT and 16kT, respectively. Figure 4 shows timing and spatial distributions of PMT hits for an individual 3 MeV electron at different locations in the scintillator volume of 10m height. Distinctive reflection peaks and correlations with the spatial position can be clearly seen, indicating the capability for event position reconstruction.

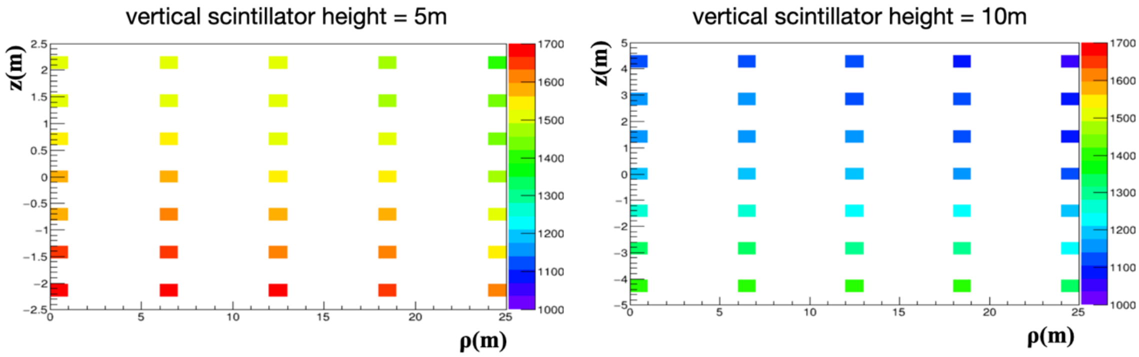

Fig 3: Detected number of photoelectrons for a 1 MeV electron for the simulated configuration as a function of ρ (cylindrical radius from the centre of the detector) and z (vertical height relative to the centre of the scintillator layer). The left plot is for a scintillator layer height of 5m and the right is for a height of 10m.

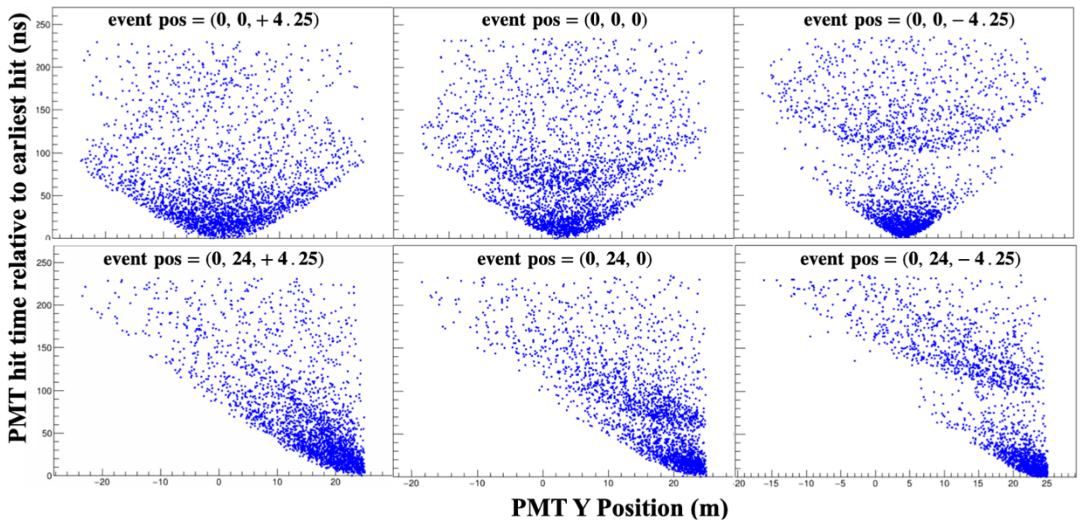

Fig 4: Relative times of PMT hits vs PMT y coordinate for a 3 MeV electron generated at different positions within a scintillator volume of height 10m.