Snowmass2021 - Letter of Interest

Transparent Thermoplastic Acrylic Scintillator

- ■ (CF1) Dark Matter: Particle Like
- ■ (NF10) Neutrino Detectors
- ■ (IF2) Photon Detectors

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Abstract: Liquid scintillators are widely used in neutrino and dark matter physics. Their high light yield, long term stability and potential for mass production makes them an ideal material for large scale detectors. However, the production of high purity scintillators is not always trivial and the liquid scintillator has to be contained in UV-transparent containers that leads to design constraints. We propose a new type of thermoplastic scintillator in which we dope the LS directly into acrylic. Acrylic is a commonly used material in experimental particle physics with well known properties. Such scintillators have the potential to be mechanically strong, inexpensive and stable. In addition, by doping different rare earths one can built multilayer detectors that enable particle discrimination.

Introduction

For the last few decades liquid scintillators (LS) were used as the main detector target for a variety of experiments such as Borexino[1] , DayaBay[2], SNO+[3] and the outer detector for LUX-Zeplin [4]. Their large light yield, high optical transparency, and low toxicity combined with high flash point ensure safe operations at room temperatures and in challenging experimental environments such as underground experiments. Also handling and infrastructure is fairly straightforward compared to, for example, cryogenic experiments. Doping with suitable rare earths leads to the ability to optimize the scintillator for particular types of radiation. By adding a small amount of the Gadolinium ($\approx 0.1\%$) into liquid scintillator, the thermal neutron capture efficiency can be greatly improved, enabling better detection efficiency on inverse beta decay and neutron background of the direct dark matter detector as well. Plastic scintillator (PS) however exhibits a better mechanical strength, is inexpensive to manufacture and less prone to aging. Traditionally, PS was used in the detection of high energy particles in collider or cosmic ray experiments due to their radiation tolerance. Good endurance to the environmental impacts (temperature, moisture) and mechanical deformation enable the PS to be worked under various environments such as vacuum systems.

The scintillation mechanisms in LS and PS are similar: The incident particles excite the molecule in the solvent, subsequently, the dissolved luminophor absorbs the emitted photons and re-emit light in different wavelengths such that the re-emitted photons are not absorbed. Often a secondary wavelength shifter flour is added to increase efficiency. Also high optical transparency to its own scintillation light is crucial for large-scale PS detectors. By selecting different polymer bases and luminescent dye, the optical transparency of the scintillator can be improved. Polymethyl methacrylate (PMMA), acrylic, has highest transparency to UV and visible light and its application in particle physics was extensively studied.

Scintillator Acrylic Development

To validate the properties of the new acrylic scintillator, various measurements are needed to be carried out:

- **Optical transparency**: Generic acrylic has an attenuation length of about 7 m [5] to the visible light. After doping the attenuation length is typically diminished to about 2m [6] in UV and the visible spectrum due to different luminophor concentrations which reduces the optical transparency. Further, modern silicon photo-multiplier (SiPMs) offer the opportunity to increase the sensor's coverage of acrylic scintillators.

- **Radiopurity** Radiopurity is crucial for rare event searches. DEAP-3600[7] demonstrated that the acrylic can be produced in a radiopure fashion. The assaying of the radio-purity by the LUX-Zeplin collaboration[8] shows that the radiopurity of acrylic[9] is comparable to the PTFE which is widely used as reflector and detector vessel in liquid noble gas detectors. If the acrylic is doped with naphthalene, PPO and POPO, the light yield is about 70-100% of the PST-based PS, depending on the relative concentration[10]. Doping with LS potentially increases the light yield, in addition, the doping feasibility of neutron-enhanced isotopes will also be investigated. Detailed studies of the optimal mixtures and property measurements are under development.

- **Scintillation light timing profile** To enable potential pulse shape discrimination (PSD) a good understanding of the scintillation timing profile is essential. The largest background of the acrylic is coming from the Radon daughter plate out on the surface of the acrylic. While this can be reduced by producing or machining the surface of the acrylic in a radon control environment, the plate out of Rn daughters poses a challenge to the detector. Identifying the alpha decay from the decay process of ^{214}Po to ^{210}Pb might help to understand the amount of the Rn background in the detector. The PSD in LS demonstrates the ability to tag the alpha from other types of particle and the performance of

LS-doped acrylic will be studied under a different mixing ratio of scintillator, flour and wavelength shifter.

Potential applications

Using acrylic as a cryogenic vessel has been demonstrated by DEAP-3600 in dark matter searches. With new AS, it can be a main vessel and also serve as outer/veto detector, which simplifies the detector geometry and subsequent analysis. By the same token, detectors in the neutrino experiment like SNO+, the acrylic is excellent material for housing the LS. With a multilayer structure, it is not only mechanically strong but also can perform as a Veto detector. In addition, the AS doping with different elements (Pb, Li, etc.) could be suitable as an absorber and/or calorimeter for the application in low and high energy collider physics and neutrino physics.

Summary

The mechanically advantageous properties, good thermal resistance and small long-term aging effect makes the acrylic a promising candidate for constructing large PS detectors. Loading acrylic with highly purified LS will increase the light yield, and potentially improve the optical transmission of conventional PS's. In addition, if different heavy elements are doped (Pb, Gd, etc) into the acrylic we might achieve the detection and discriminating of different types of particles, i.e. gamma-rays vs. neutrons. By using modern SiPMs, a multilayer acrylic detector could further provide excellent position and energy reconstruction. This effort provides a path towards developing such a new type of detector.

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