Development of Fine Grained Opaque Scintillator Detectors

1. Details

Summary

In this project we will deliver scintillator detectors that are simultaneously finer grained and lower cost than currently possible. We propose to build two prototypes in a staged approach, each growing in complexity while re-using many existing engineering solutions. The first prototype will be optimised for muon tomography and the second for fundamental neutrino physics.

Traditionally, scintillators have been transparent to allow efficient light detection. The novelty here is the combination of a short scattering length opaque scintillator and a lattice of optical fibres. The light bounces around close to the point of production and the fibres extract the light. By analysing which fibres are hit and how much light each collects, precise position and tracking information is obtained.

Transparent scintillators can provide position and tracking information by manually dividing the scintillator into many segments. With our approach the fibres are placed in position and the opaque scintillator poured around them, removing the need for manual segmentation. This new approach greatly simplifies construction, lowering cost and becoming highly scalable. Furthermore, substantially better spatial resolution per readout channel is achieved by utilising the profile of the light detected across multiple fibres. The use of a liquid medium allows the

scintillator to be exchanged, e.g. oil-based for water-based.

Recent muon tomography research has demonstrated its capability in assessing the condition of ageing infrastructure from concrete walls/bridges to nuclear waste storage, providing a potentially huge market worldwide. Discussions with industry have confirmed the need for more practical detectors, e.g. physically smaller, with higher performance for lower cost. We will prototype a robust, compact, portable, low hazard, fine grained detector that provides two times better spatial resolution per readout channel than a traditional segmented scintillator.

GeV-scale neutrino interactions with matter are complex and involve many-body nuclear effects. Limited knowledge leads to significant systematic uncertainties on searches for leptonic CP violation, an area of huge worldwide investment. These searches require massive detectors capable of precision measurements. We will demonstrate that our approach offers a compelling way to scale to larger detectors while also improving the granularity per readout channel compared to current approaches.

The team formed for this project brings together crucial areas of expertise and builds on substantial existing investment in equipment, software and people. Our new approach utilises many well-established technologies such as optical fibres, liquid scintillators and SiPMs while combining them in a novel way.

Justification of resources

This proposal builds significantly on existing resources and people. The resources requested on this grant are largely postdoc effort. Sussex requests 0.4 FTE in the first year (5 months full time) and 0.3 FTE in the second year (3.5 months full time), which will part-fund one of our existing postdocs in the neutrino group for constructing the detector prototypes and carrying out initial testing and validation of the detector performance using radioactive sources at Sussex. Bristol requests 12 months of postdoc effort spread across the first two years of the grant to fund a postdoc to work with us on integrating our prototype into their muon tomography system and analysing the data to confirm the angular resolution performance. RAL requests 0.5 FTE PDRA for over 28 months for simulation effort supporting both detector prototypes (Full-time months: 3.5 Y1; 6 Y2; 4.5 Y3). The 12 months of postdoc effort requested for Warwick are in the third year where the focus will be on data analysis and publication of results.

Besides postdoc effort, we are requesting 0.4 FTE of Sussex electronics technician Earle for the first two years, who will implement the readout and trigger systems for the two prototypes. In addition, Antony Gibson-Foster is a core technician funded on the STFC Consolidated Grant at Sussex. He has designed and constructed all our LiquidO prototypes to-date and will work 30% on this project for the first two years. We request only 0.05 FTE of funding for the PI throughout the grant, supplemented by strong institutional support from Bristol, RAL, Sussex, and Warwick for the additional time of academic personnel.

Several PhD students will work on this project. Jessica Lock started at Sussex in 2022 and will work 50% on this project. Wonjong Chang will start a joint PhD studentship between RAL and Warwick this year and will work on this project to develop our concept for use in NuStorm. In 2024 a joint RAL-Sussex student will work on this project. While it can't be guaranteed at this stage, further STFC quota PhD students are also expected to join the project.

In terms of equipment, we will use the Sussex PETsys TOFPET2 ASIC system purchased using STFC Capital Equipment grant funding in March 2022. This system can digitise up to 2048 readout channels. We have ten 8x8 SiPM arrays in hand plus 16 front-end modules (FEMs, one is required per SiPM array). RAL has committed to purchase a further 14 SiPM arrays (£22.4k) plus Sussex requests £6k to purchase 8 additional FEMs to bring our readout channel count to 1536. In order to construct the two detector prototypes RAL will provide the wavelength-shifting fibre (£20k) and we request £11.3k for additional consumables for the mechanical structures and opaque scintillator.

For initial commissioning of the detectors, we will use a range of radioactive sources that we have at Sussex (e.g. ^{60}Co, ^{137}Cs, ^{90}Sr, ^{22}Na) and have already used extensively in our opaque scintillator detector development work.

Bristol's extensive expertise and existing equipment for muon tomography are a crucial part of this project. £2k in consumables is requested for adapting their equipment to allow the new prototypes to be integrated, both mechanically and to incorporate the passing of trigger signals. Their existing equipment provides high precision position and direction information for each cosmic ray muon entering our prototypes. By comparing the precise measurements from the Bristol instrumentation with that reconstructed directly from the prototypes, the position and angular resolution capabilities will be quantified.

Travel funds of £11.5k are requested for the project. £4k of this is needed for travel of personnel to Bristol for integrating the 16x16x5 cm^3 tile detector into their muon tomography system in the first year, and then again for the larger 40x40x20 cm^3 prototype in the second year. The remaining travel funds will allow for additional travel between the institutes for project meetings and collaboration.

7. Core team

Name	Role	Organisation
Jeffrey Hartnell	Project lead	University of Sussex
Antony Earle	Technician	University of Sussex
Lily Asquith	Project co-lead (UK)	University of Sussex
William Griffith	Project co-lead (UK)	University of Sussex
Anna Holin	Project co-lead (UK)	Rutherford Appleton Laboratory
Claire Shepherd-Themistocleous	Project co-lead (UK)	Rutherford Appleton Laboratory
David Petyt	Project co-lead (UK)	Rutherford Appleton Laboratory
Sajan Easo	Project co-lead (UK)	Rutherford Appleton Laboratory
Jaap Velthuis	Project co-lead (UK)	University of Bristol
Xianguo Lu	Project co-lead (UK)	University of Warwick