IDEA FOR TYPE-B LABORATORY-DIRECTED RESEARCH AND DEVELOPMENT

PRINCIPAL INVESTIGATOR:
- Co-PI: Xin Xiang (ATRO/IO)
- Co-PI: Xin Qian (NPP/PO)
- Other PI: TBD

TITLE: Calorimetry R&D for PIONEER: a Next-generation Rare Pion Decay

BNL should take a leading role in developing low-cost calorimeter materials with excellent radiation tolerance and time response for the next-generation High Energy Physics (HEP) experiments. BNL has world-leading expertise in pioneering water-based liquid scintillators (WbLS), a low-energy threshold scintillation water that is capable of loading a variety of target elements while still remaining homogeneity and appreciable scintillation emissions. **We propose R&D activities to investigate the production and the key properties of WbLS with heavy metal loading as the calorimetry materials.** This proposal is well aligned with the priority research of the DOE Basic Research Needs Study on High Energy Physics Detector Research and Development. The proposed R&D on the calorimetry technology, if successful, will expand the existing capabilities towards future experiments in particle and nuclear physics at LHC and EIC.

As an example, PIONEER is a next-generation rare pion decay experiment approved by Paul Scherrer Institut (PSI) to test lepton flavor universality (LFU) and of Cabibbo-Kobayashi-Maskawa (CKM) unitarity. BNL is in a unique position to become the leader in developing large uniform calorimetry (CALO). The current concept of CALO requires 10-tonne liquid xenon, which is very expensive in today's market (~$13 M/ton). The alternative design of CALO relies on the crystals, which have limitations in the ultimate energy resolutions. The baseline requirements for CALO are:

- Dense. A compact CALO that is 25x the radiation length of the electrons from the decay.
- Bright. Enough light yield that can produce at least 10^5 photons at ~70 MeV energy.
- Prompt. Scintillation lifetime is short, so PIONEER can accumulate statistics quickly

The initial calculation shows that the required radiation length (<8 cm) for WbLS with heavy metal loading is within the reach.

A variety of metals in the form of salt are highly soluble in water, and the technique to dope WbLS with metal has been demonstrated in several neutrino experiments (e.g. SNO+, PROSPECT, T2K). The CO already has the facility to produce WbLS at the O(10) ton scale in a cost-effective manner. We plan to produce a variety of WbLS samples loaded with different metals at high concentrations. For each sample, we will construct a small (~10 L) high-resolution detector using SiPM as the photosensor to measure the liquid properties with calibration sources. The deliverable measurements are light yield, radiation length, optical transparency, and scintillation time profile. The fund will be mostly allocated to construct a small testing detector and expand human power. A reasonable delivery window for this project is 2 years.

If funded, this project will:

- Establish WbLS with heavy metal loading as an attractive calorimetry material.
- Open a new realm of affordable low-radiation length calorimetry for other HEP experiments.
- Create an opportunity for BNL to be the lead lab for future experiments, such as PIONEER.