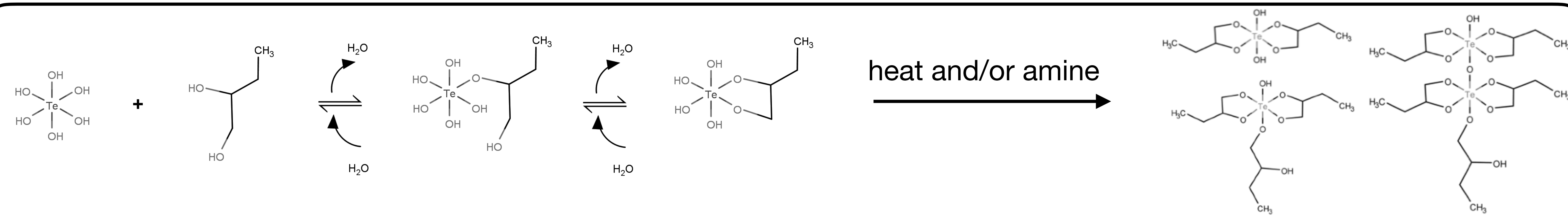
Liquid Scintillators:

New Detector Technology from Old Detector Technology

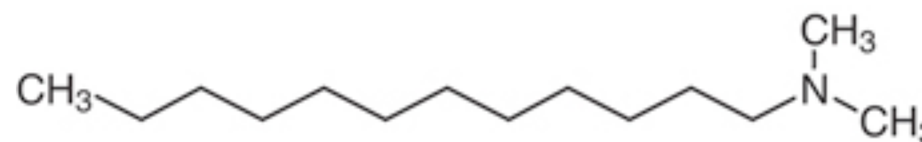
Steve Biller, Oxford University

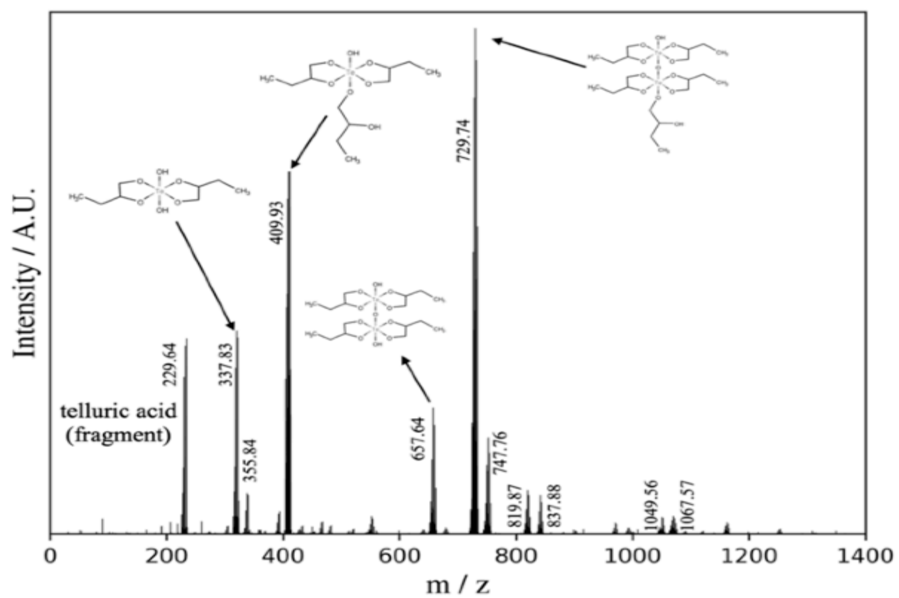
Te Loading in Liquid Scintillator for 0νββ

(paper in progress)

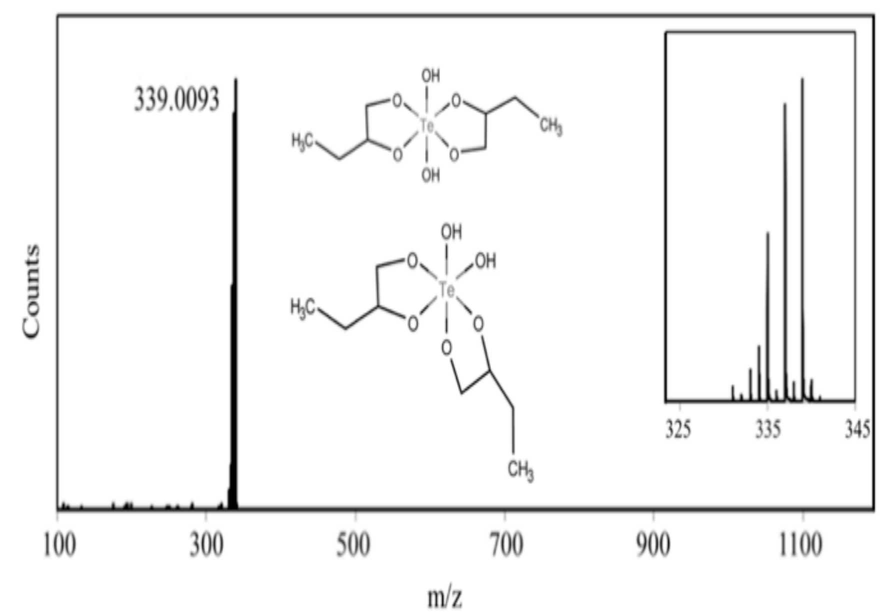


Dimethyldodecylamine (DDA) used as a solubilising/stabilisation agent





pure heated solubilisation



pure DDA solubilisation

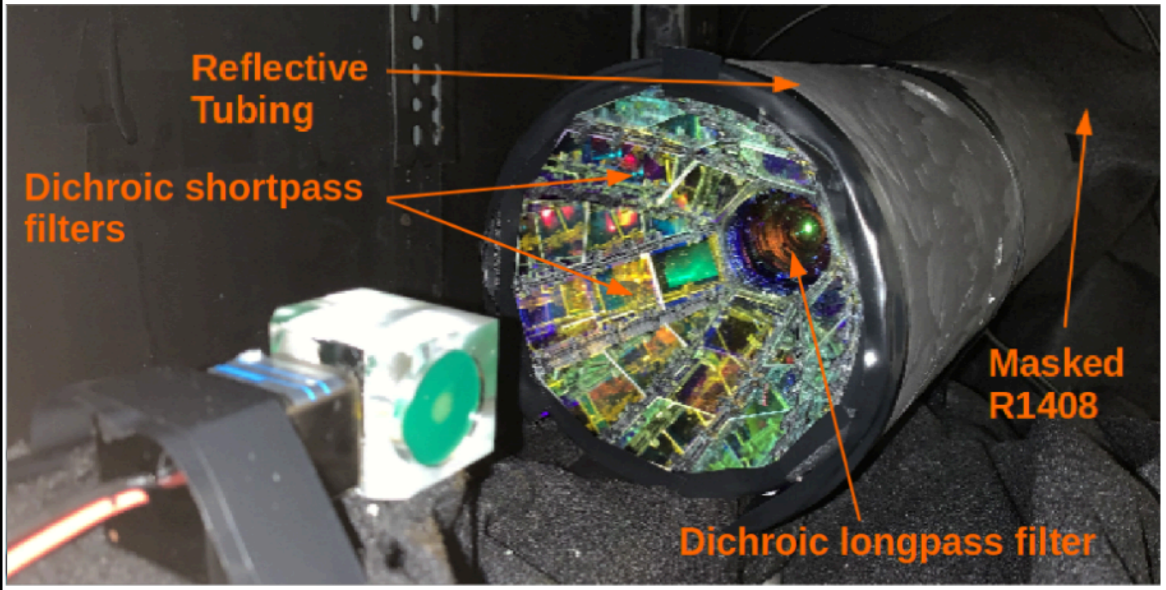
miscible with LAB

Scope for significant impact with improved loading techniques:
Aiming for practical experiment with sensitivity to Normal Mass Ordering

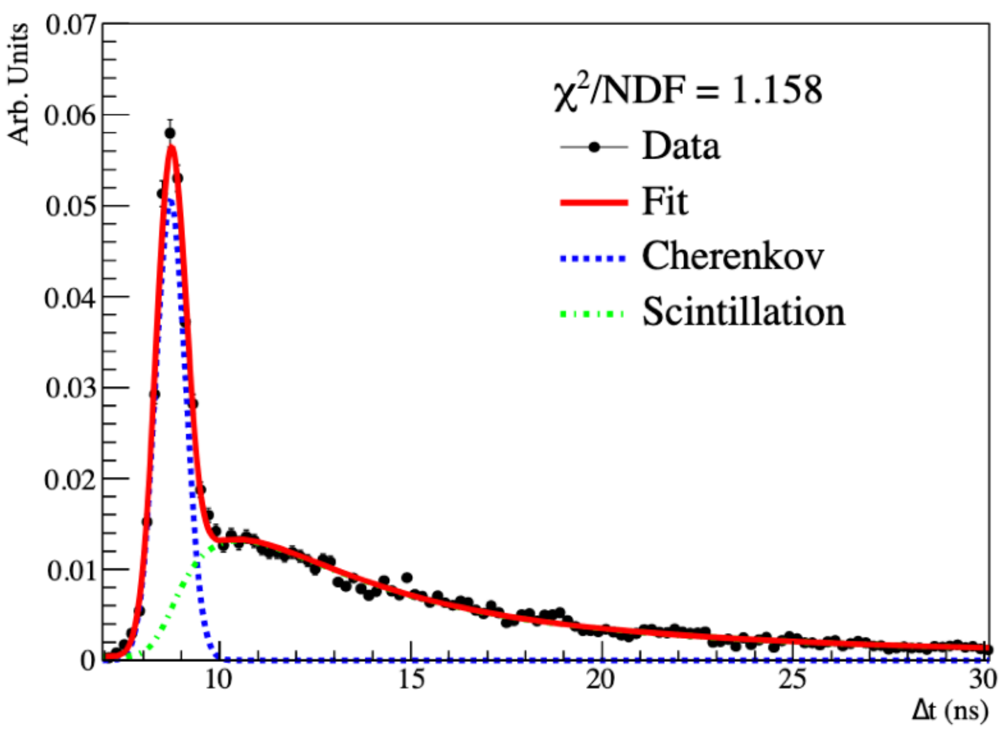
Cherenkov Separation

Topological, directional, and PID information while maintaining very good energy resolution

Dichroic Concentrators

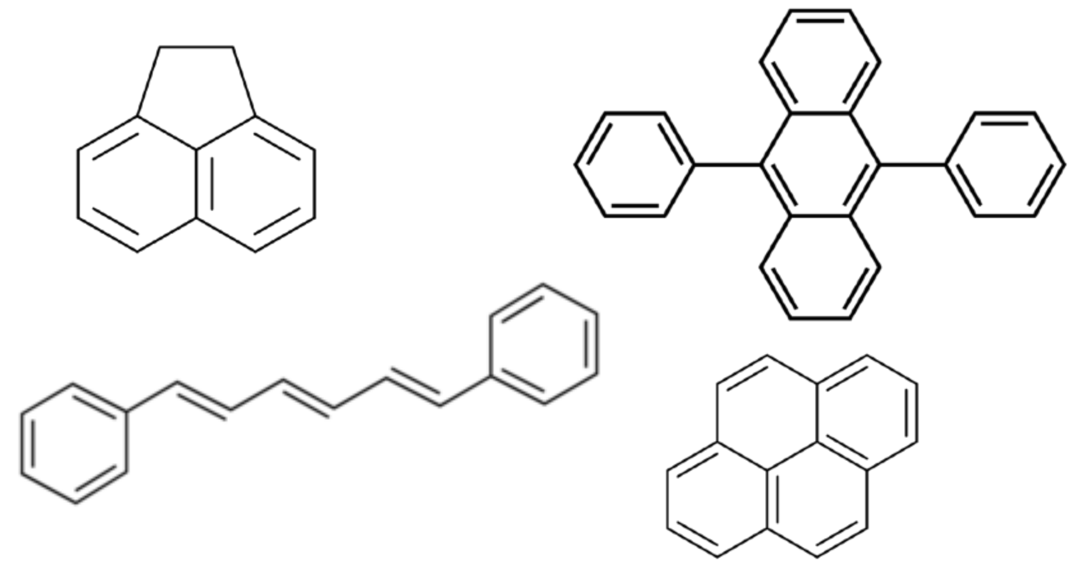


Kaptanoglu, Luo, Land, Bacon & Klein, PRD 101 (2020)

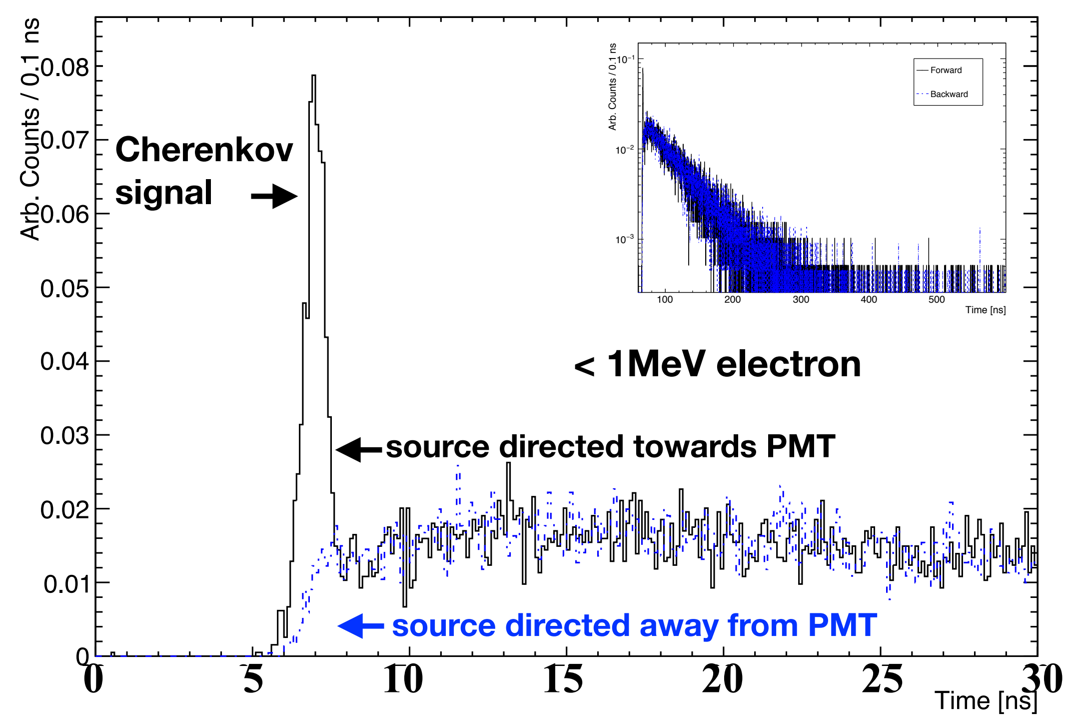


Low efficiency & expensive, but dedicated production lines for dichroic films could open numerous possibilities

Slow Fluors



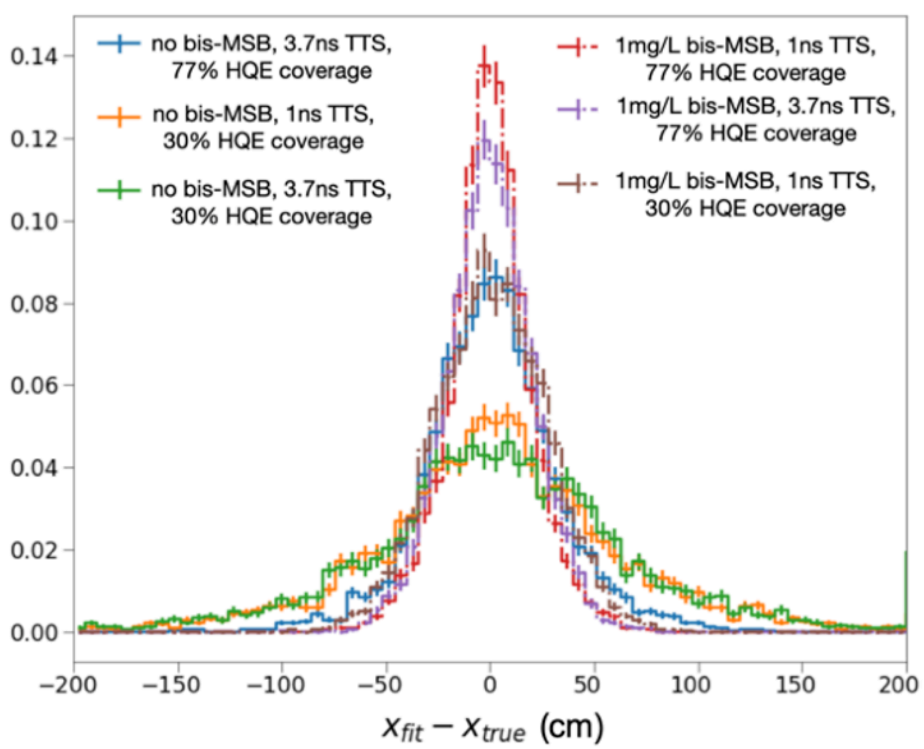
Biller, Leming & Paton, NIM A 972 (2020)

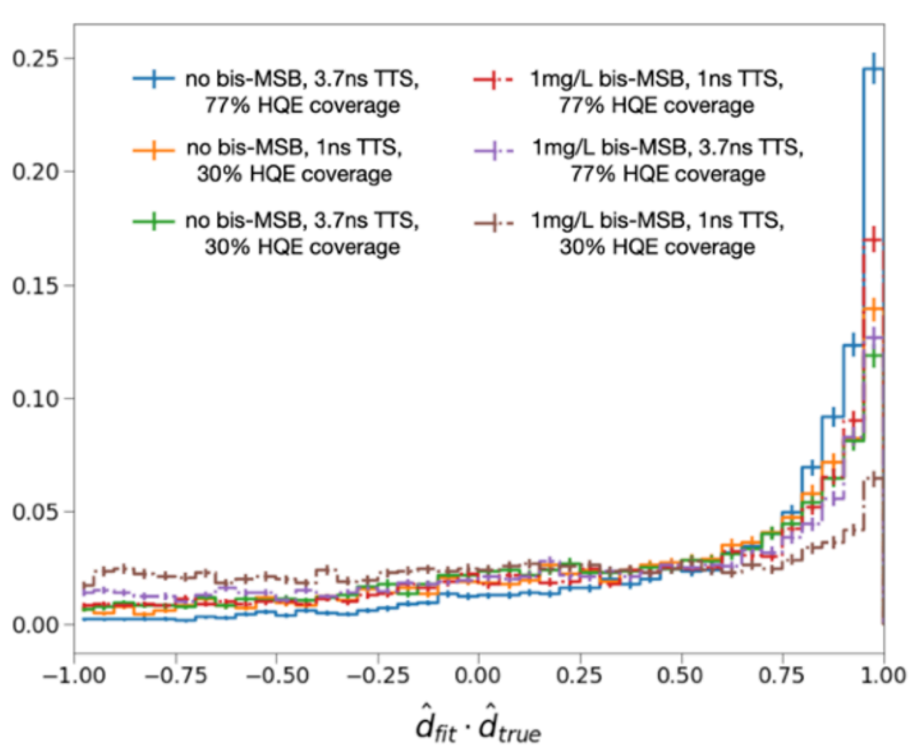


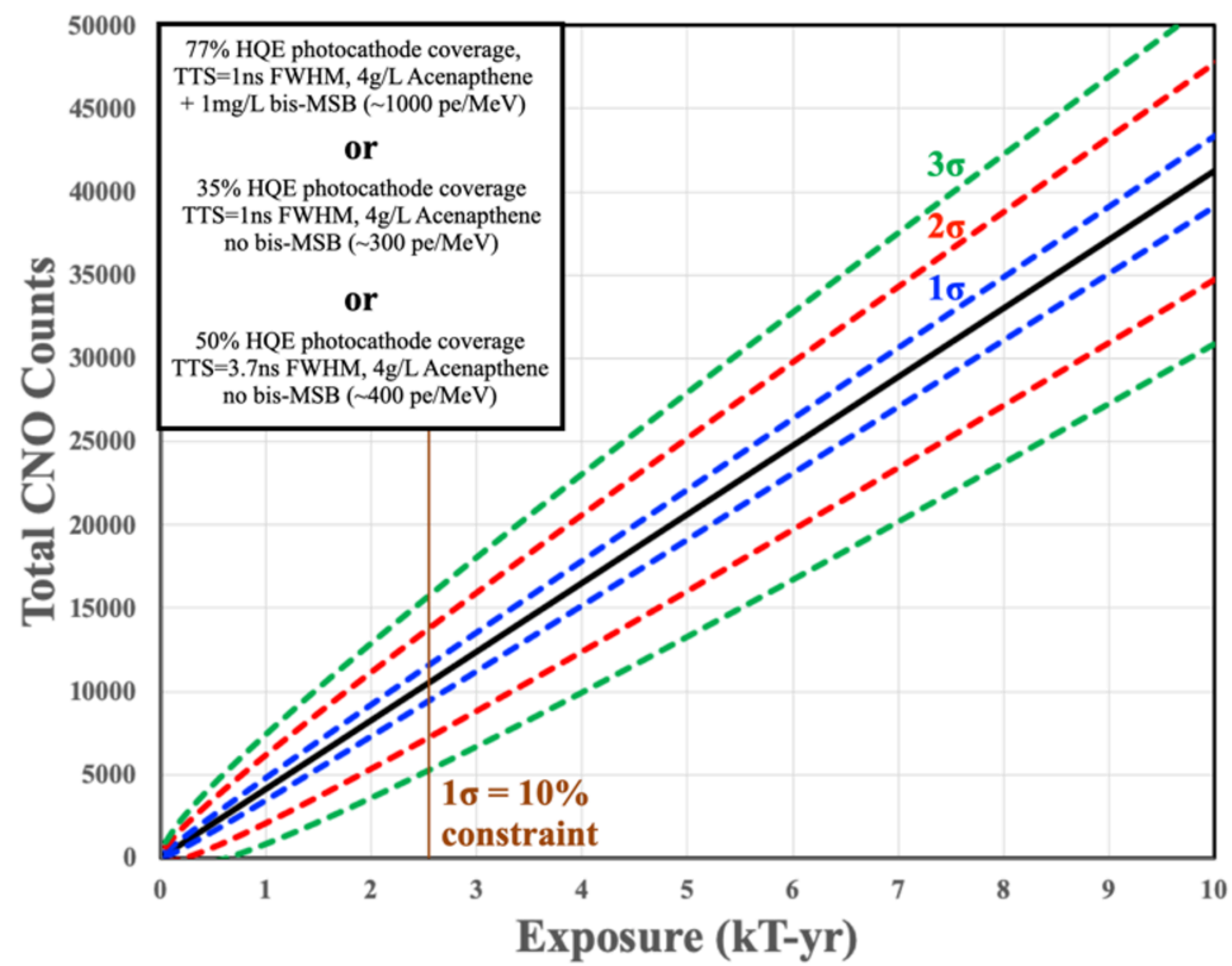
High efficiency and inexpensive, though there is some compromise with vertex resolution

Low Energy Solar Neutrinos Using Slow-Fluor Liquid Scintillators

(Dunger, Leming and Biller - paper in progress)



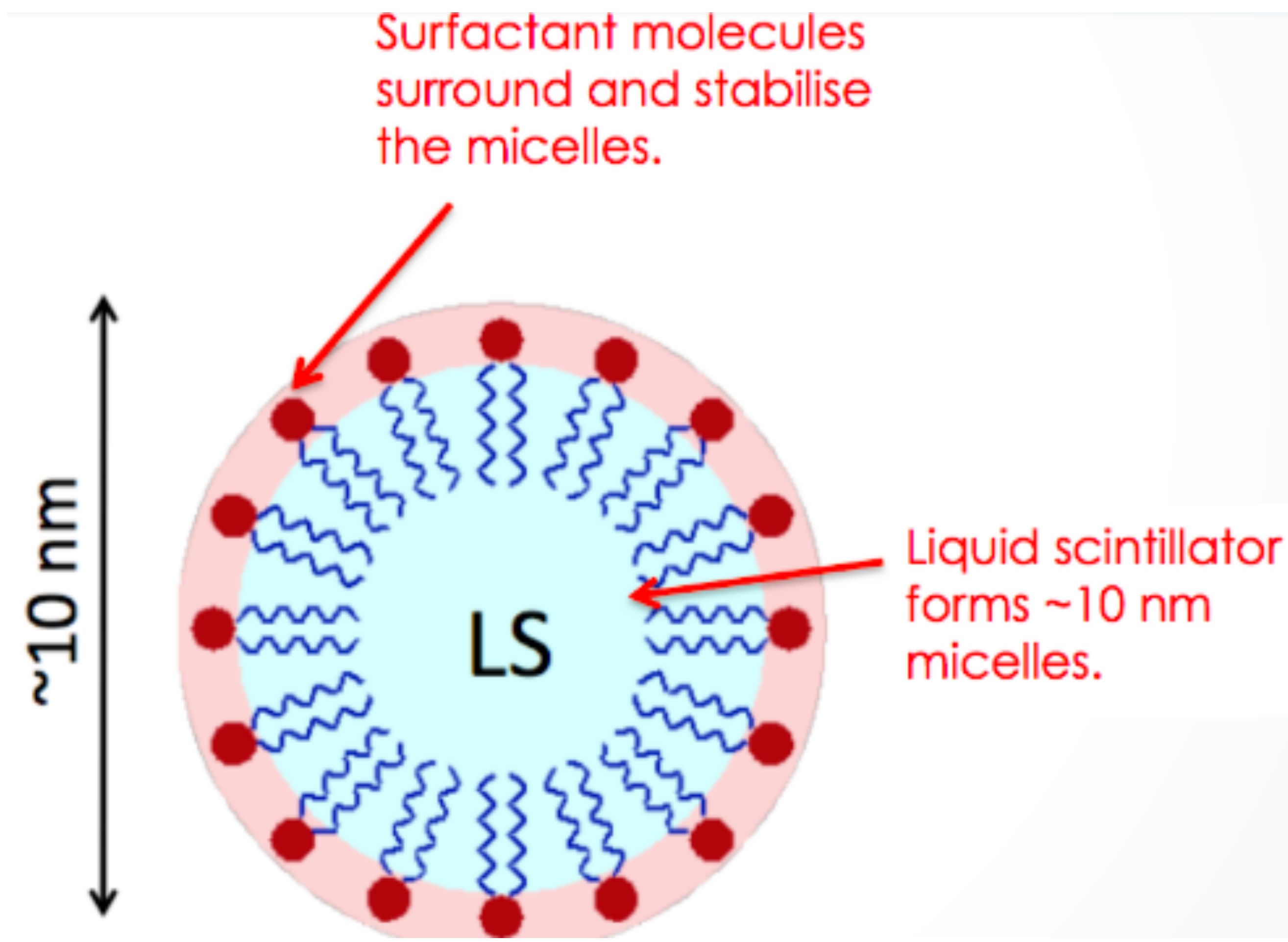




Best way to do high-precision measurement of CNO neutrinos with inexpensive, "off-the-shelf" technology and a modest sized detector

Water-based Liquid Scintillators

Yeh *et al.*, NIM A 660 (2011)

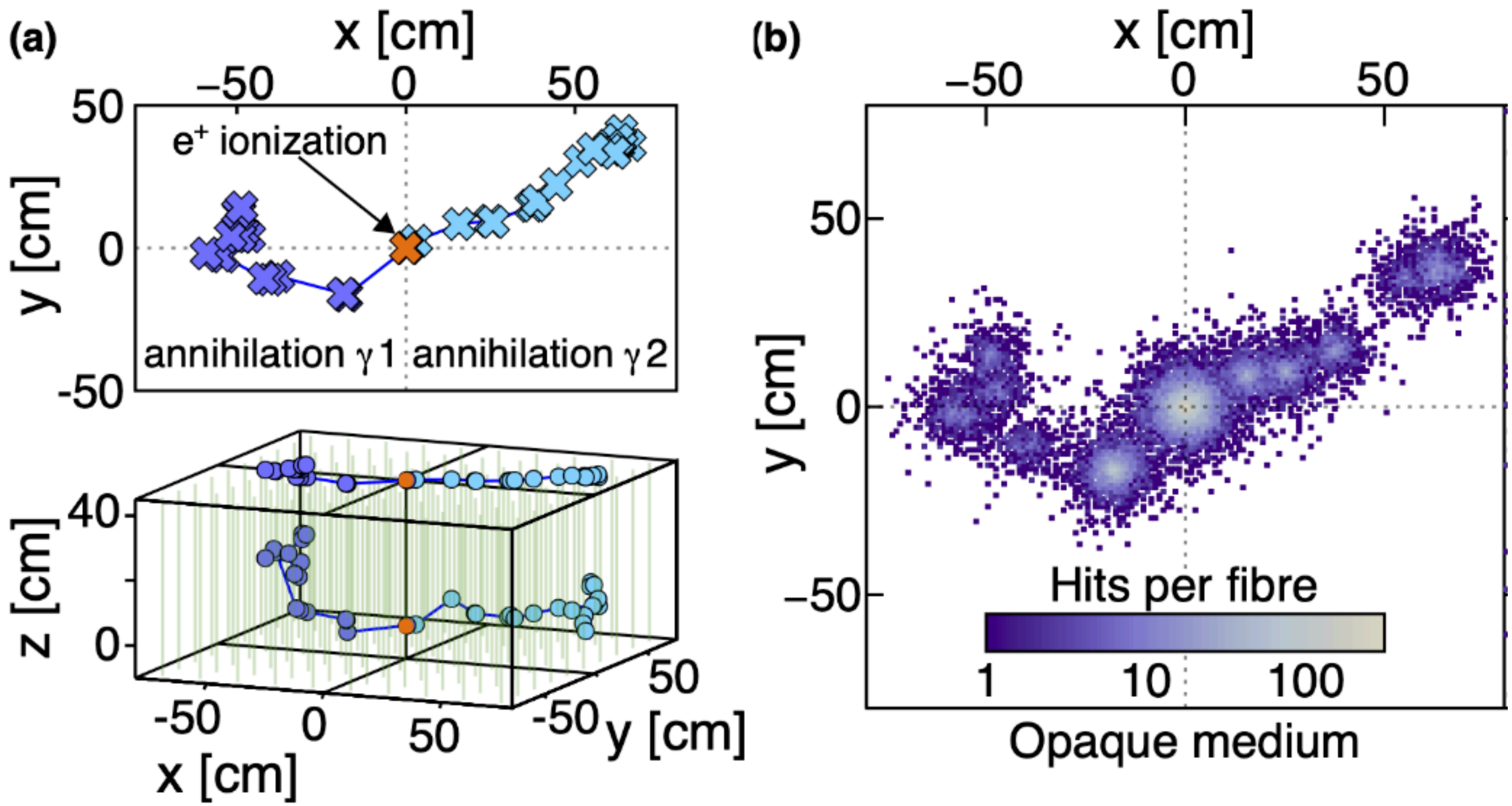


Potential route to inexpensive scintillator on a large scale (THEIA, Watchman, *etc.*)

Though current formulations either have low light output or exhibit significant scattering

“LiquidO”: an Opaque Liquid Scintillator Detector

Cabrera *et al.*, arXiv:1908.02859



Uses scattering to localise light for imaging, read out with fibre optics

Challenges: radioactivity in fibres, reduced light collection efficiency, limited time-localisation in z-direction, practicality on kT scale

But interesting approach with potential niche applications

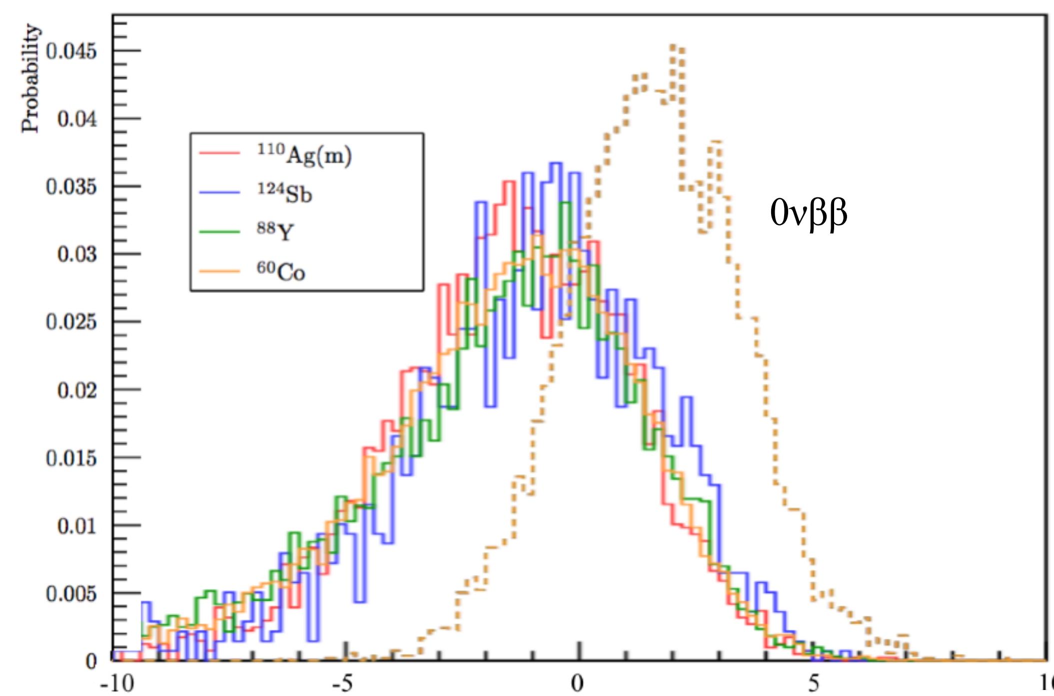
Multi-site event discrimination in large liquid scintillation detectors

(Dunger and Biller, NIM A 943, 162420 (2019))

Compton length for 1 MeV γ in LAB ~20cm, vs vertex resolution of ~10cm →

use time residuals from vertex fit to form PDFs for a likelihood discriminant

↓



$\Delta \log \mathcal{L}$

In situ **calibration of technique**

multi-site events:

- α-tagged ^{214}Bi & ^{208}Tl decays
- external γ's (dominant at higher radius)

single-site events:

- 2νββ events (dominant at lower energy)
- ^{8}B solar ν (dominant at higher energies)

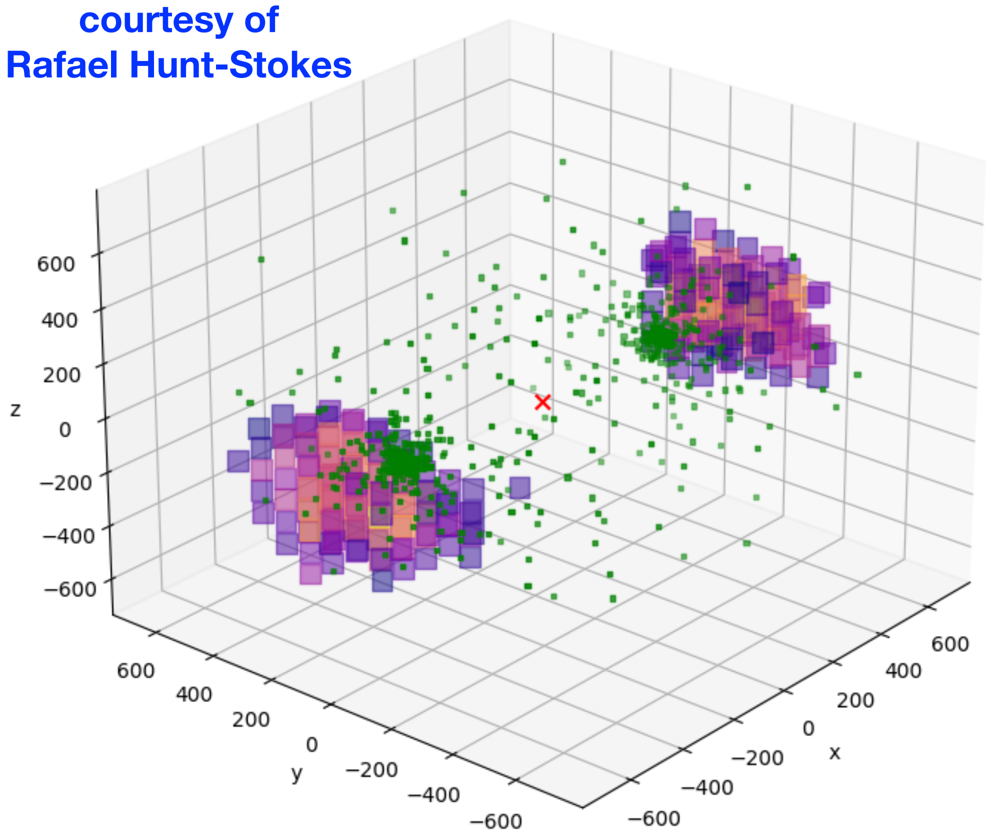
can also use deployed sources

Can identify 0νββ as distinct from cosmogenic background -> discovery experiment!

Fast-Fluor Liquid Scintillators and Imaging

- Typical scintillator formulations for large-scale detectors have characteristic time constants of ~5ns and spatial resolutions for point-like energy depositions of ~10cm
- We are beginning to explore new formulations with characteristic time constants of ~1.5ns, which should then be capable of spatial resolutions of a few cm. At this level, there is the potential to begin to image the energy deposition in the detector!

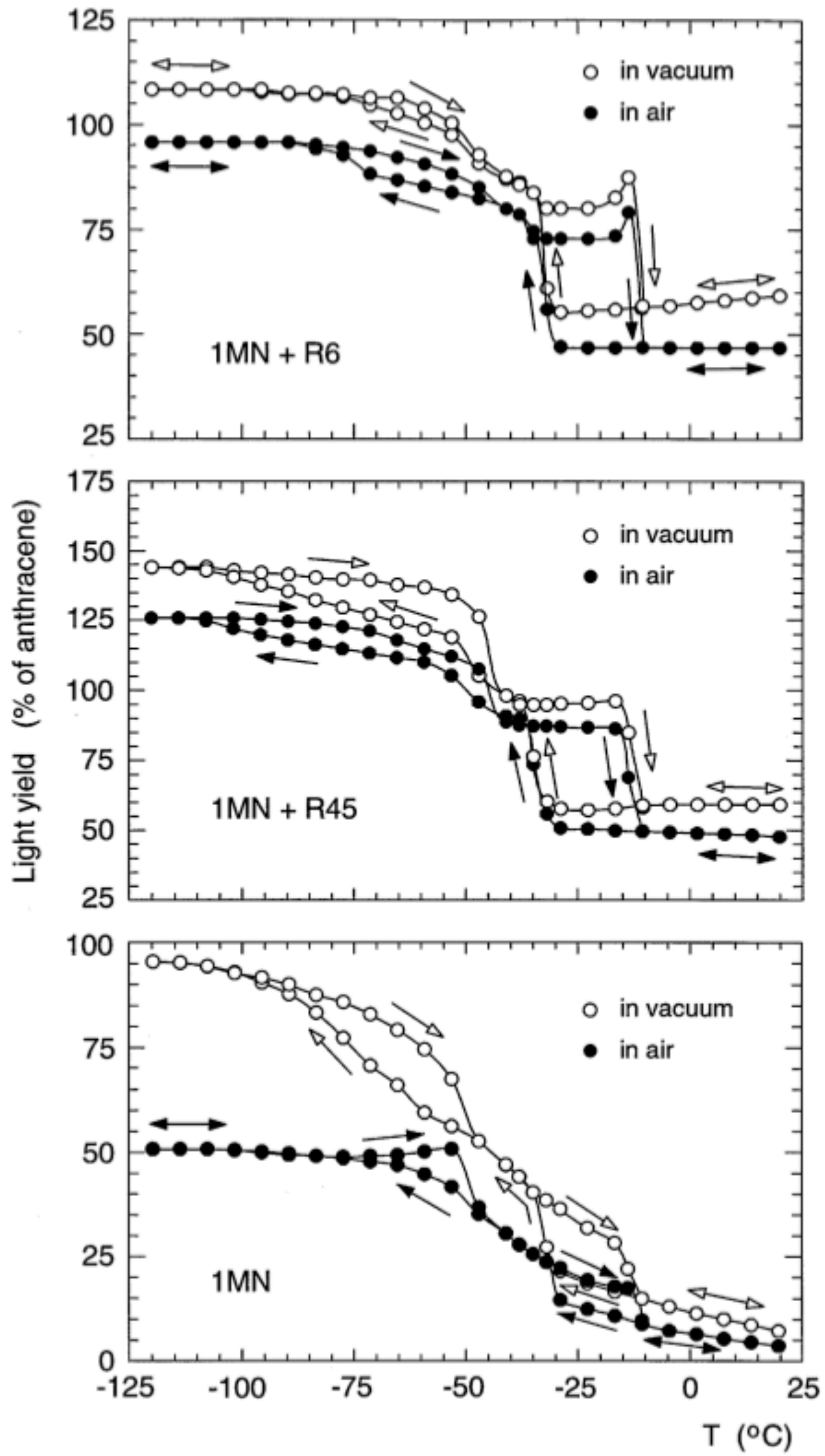
courtesy of
Rafael Hunt-Stokes



Preliminary imaging attempt of two 1MeV electrons separated by 1m in a 1kT detector. Green areas indicate actual scintillation photon production sites and coloured blocks show reconstructed image. This simulation assumes scintillator with a 0.8ns rise time and a 2ns decay time and conventional ‘fast’ HQE PMTs.

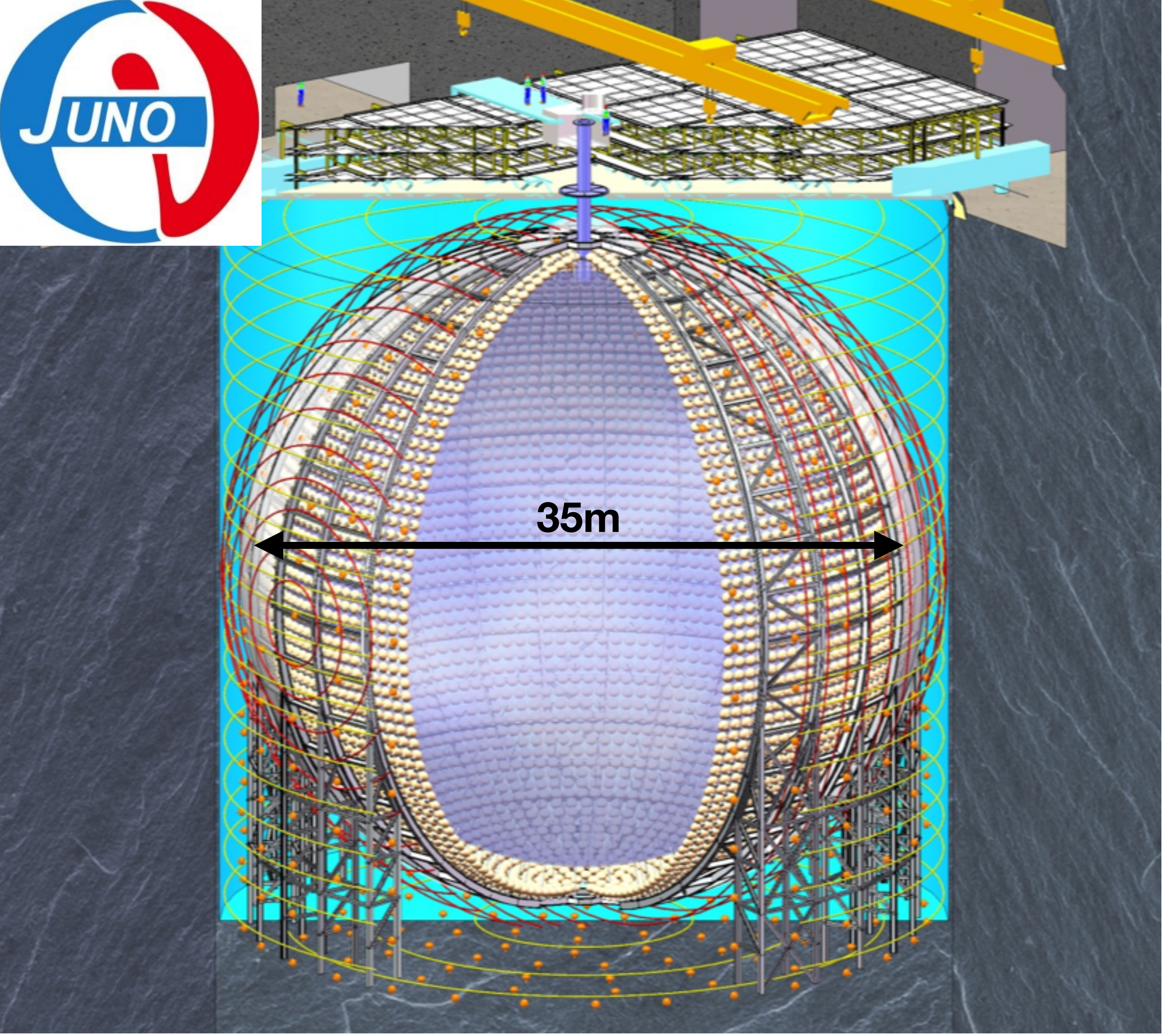
Potential to image Compton and neutron scatters, provide topological and directional information, etc. Many possible applications!

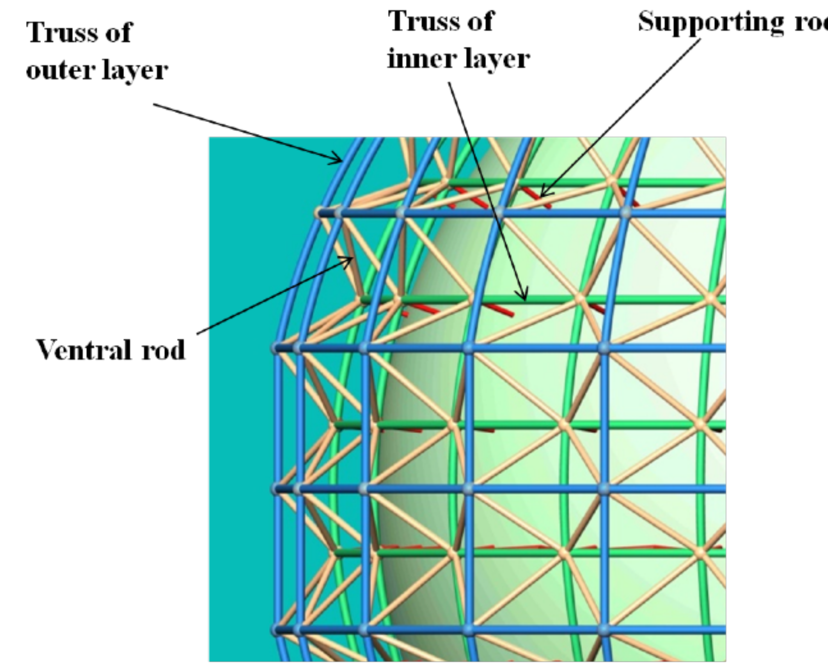
Frozen Liquid Scintillators

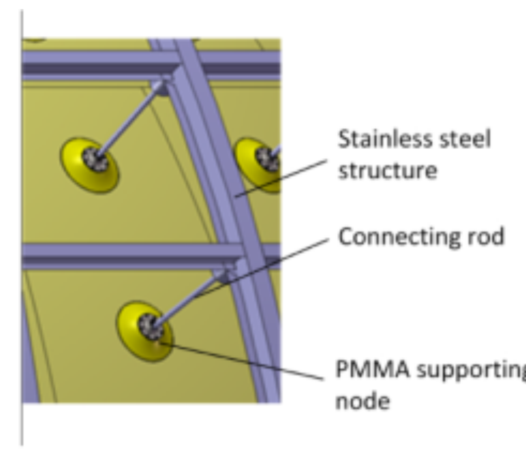


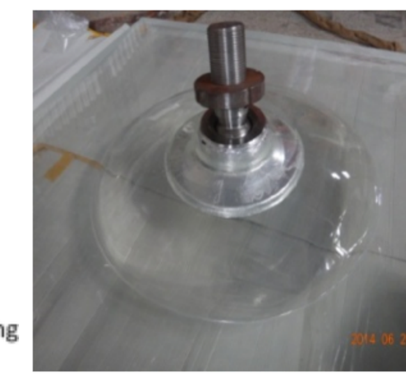
G.I. Britvich et al., NIM A 425 (1999)

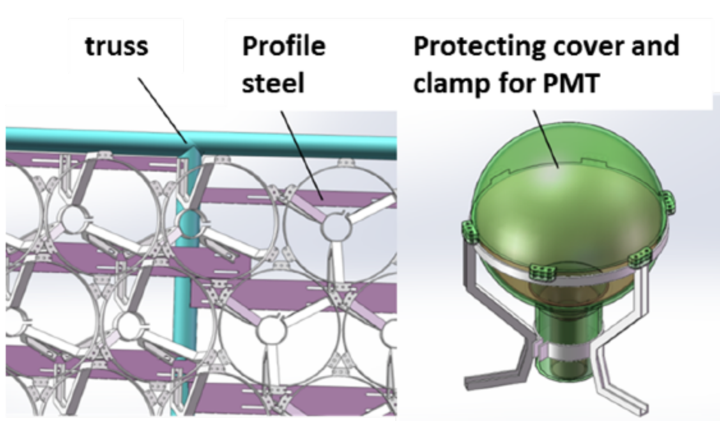
Can significantly increase light output by a factor of ~2 or more, changes quenching and timing characteristics… very little exploration done so far. Could lead to new family of instruments.

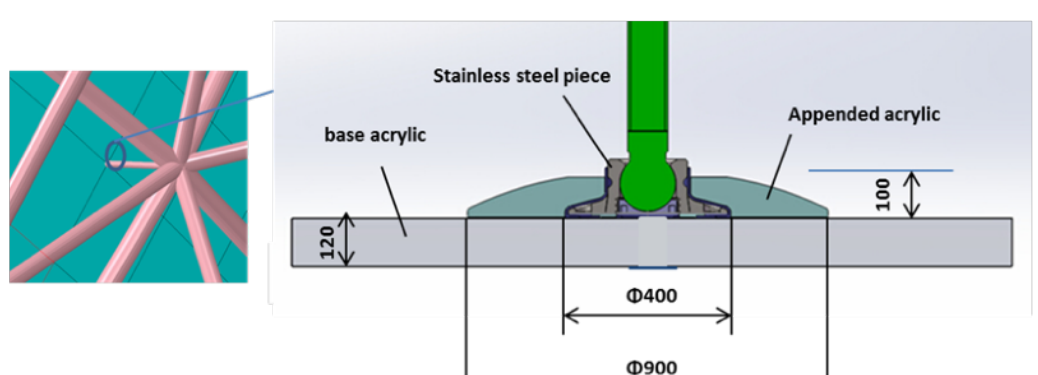

35m

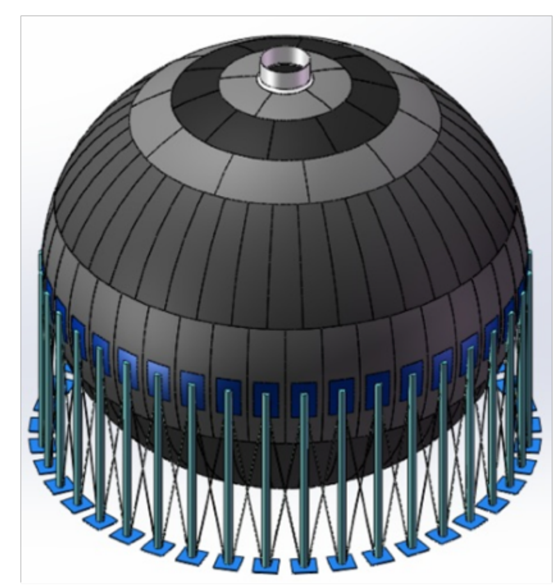

Truss of outer layer
Truss of inner layer
Supporting rod
Ventral rod


Stainless steel structure
Connecting rod
PMMA supporting node



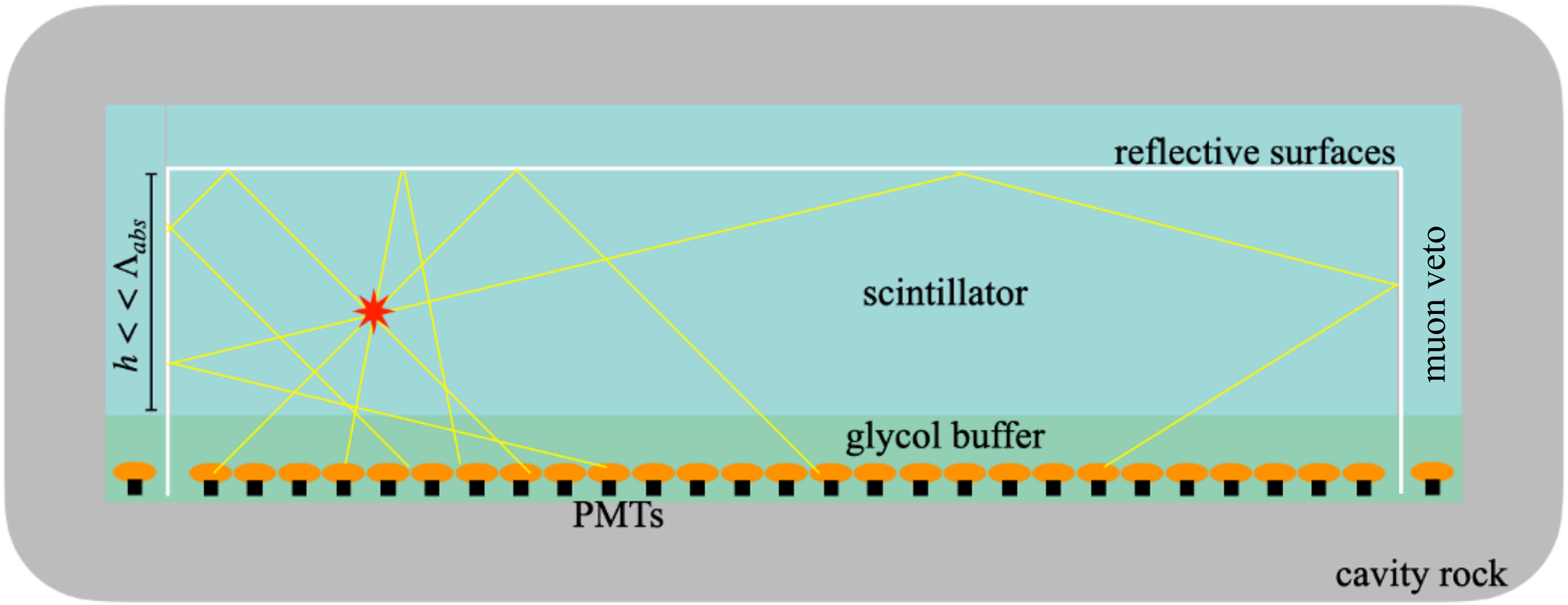

truss
Profile steel
Protecting cover and clamp for PMT


Stainless steel piece
base acrylic
Appended acrylic
120
100
Φ400
Φ900

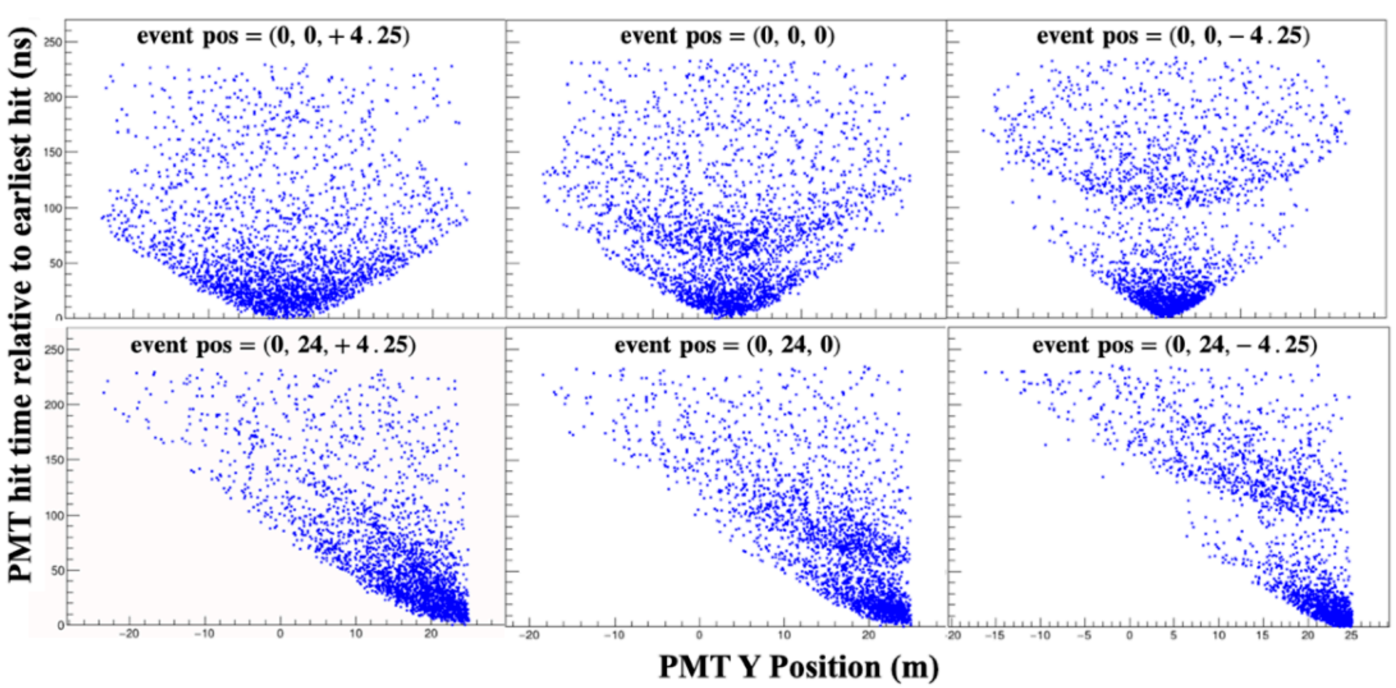


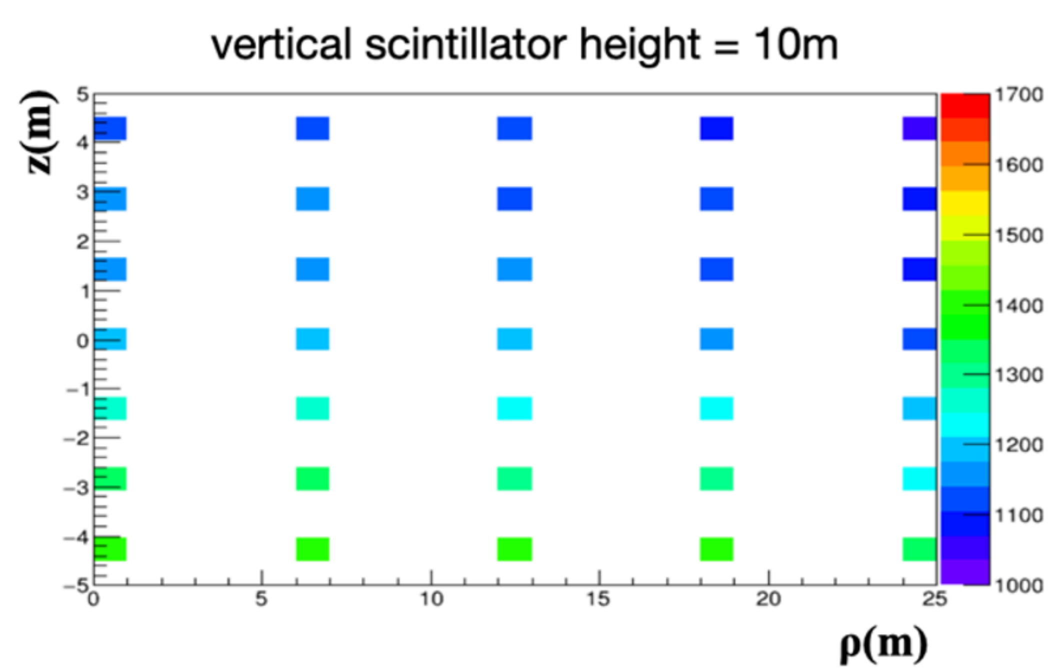
New Design Concept for Large Scale LS Detectors: Stratified LIquid Plane Scintillator (SLIPS)

(Biller and Morton-Blake - paper in progress)



JUNO-scale performance for a fraction of the cost with a much simpler construction





Implications for 0νββ, solar neutrinos, long baseline reactor neutrinos…

Summary:

There is a lot of potential to explore with liquid scintillators, with many new ideas coming to the forefront having wide-ranging applications and significant implications for future experiments

We have been doing world-leading work in liquid scintillator R&D, **NONE** of which has ever received any direct support from STFC

There is a significant opportunity here for the UK, but it requires modest investment to support this work and allow prototyping and testing of a number of these concepts.