Opportunities using Opaque Liquid Scintillator

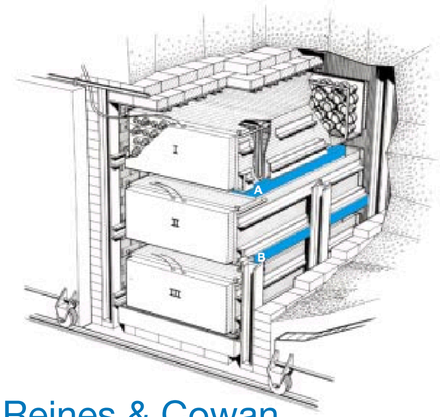
Oct 27 @ K-Neutrino Symposium 2026, CAU

Yoomin Oh

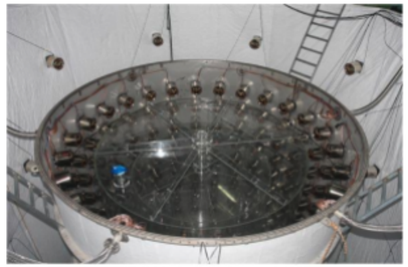
CENTER FOR UNDERGROUND PHYSICS
ibs

Organic LS for ν experiments

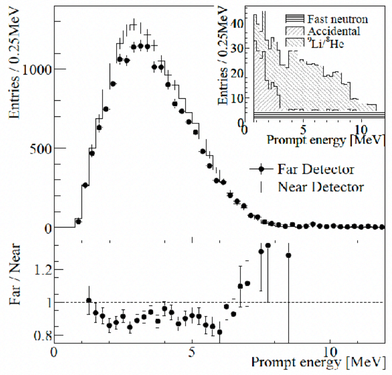
From discovery to precision



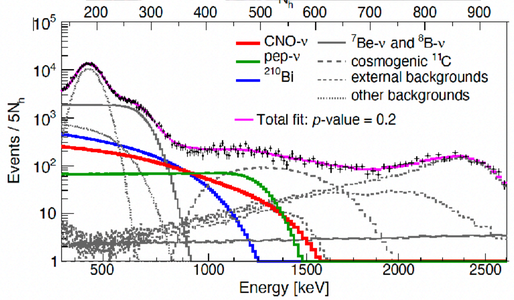
Reines & Cowan
ν discovery

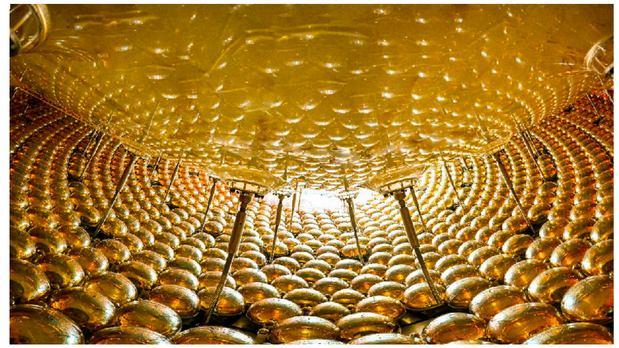


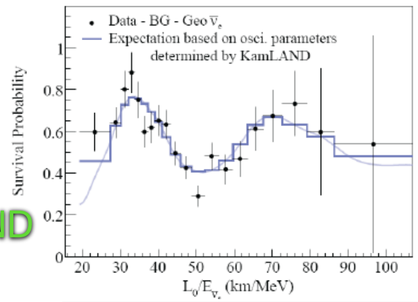
RENO θ_{13}

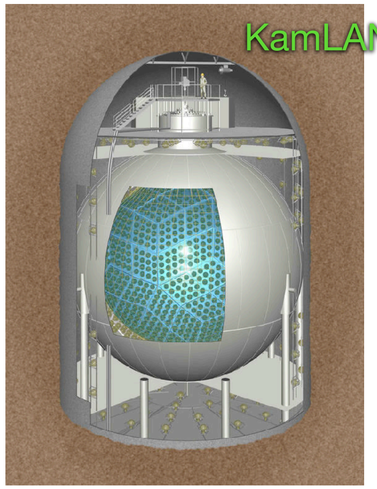


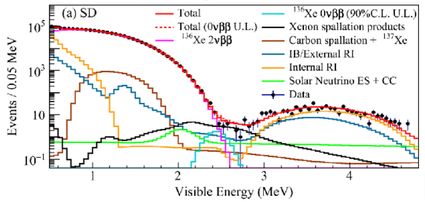


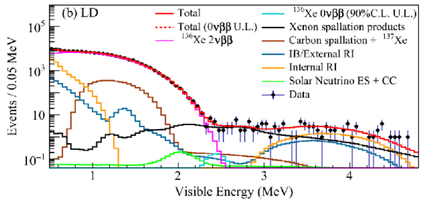


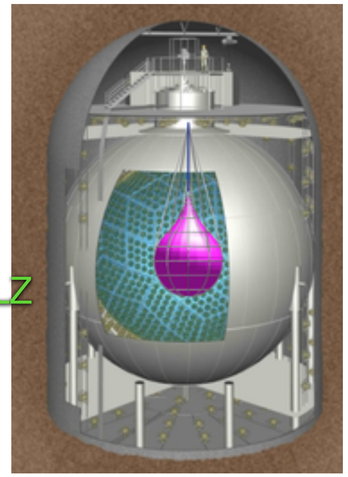


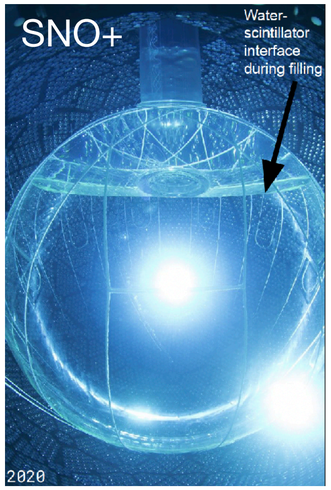


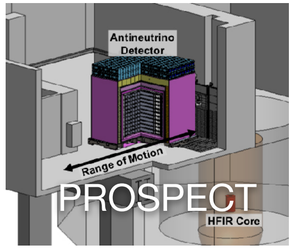




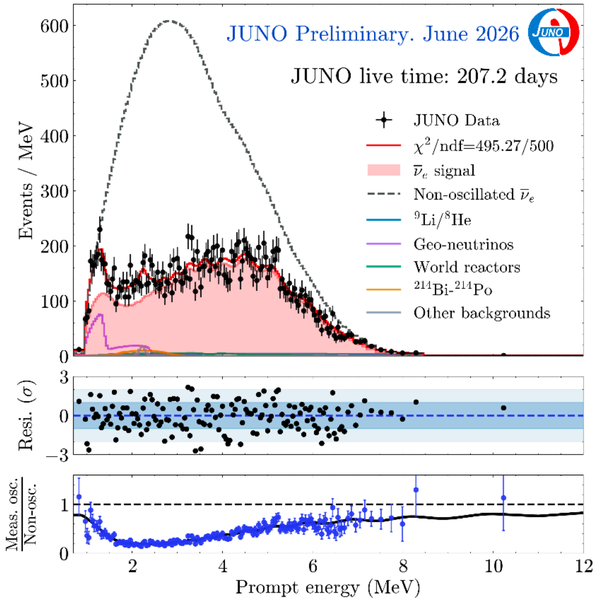










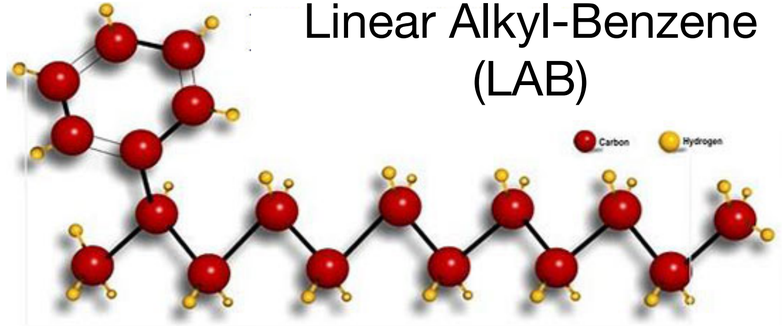


ν Nobel prize history

- 1988, Leon Lederman, Melvin Schwartz, Jack Steinburger —Discovery of ν_μ Phys. Rev. Lett. 9, 36 (1962) Acc beam
- 1995, Frederick Reines—First ν detection Science 124, 103 (1956) O-LS
- 2002, Ray Davis Jr, Masatoshi Koshiba—ν astronomy
  ApJ 495, 505 (1998), Phys. Rev. Lett. 58, 1490 (1987) chem. & water
- 2015, Takaaki Kajita, Arthur B. McDonald—ν oscillation Water
  Phys. Rev. Lett. 81, 1562 (1998), Phys. Rev. Lett. 87, 071301 (2001)
- 2026, Francis Halzen—Astrophysical high E ν ICE
  Nobel Prize in Physics 2026

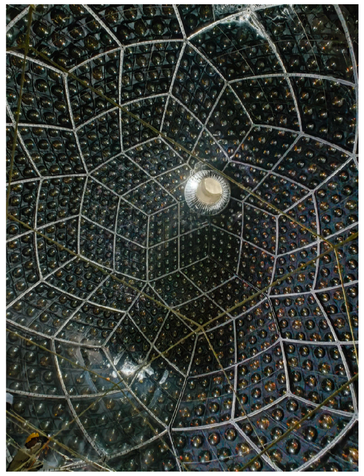
Organic LS for ν experiment

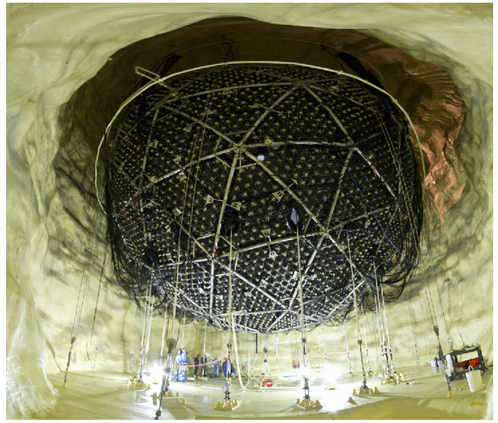
- Inverse beta decay: $\bar{\nu}_e + p \rightarrow e^+ + n$ (free proton; prompt – delayed)
- Free-form—easy for scale-up and shaping.
- Radiopurity—U/Th < 10^{-16}g/g
- Material loading
  - ββ experiments—Xe (KamLAND-Zen), Te (SNO+), …
  - n-capture—Gd, Li, … (reactor exps.)

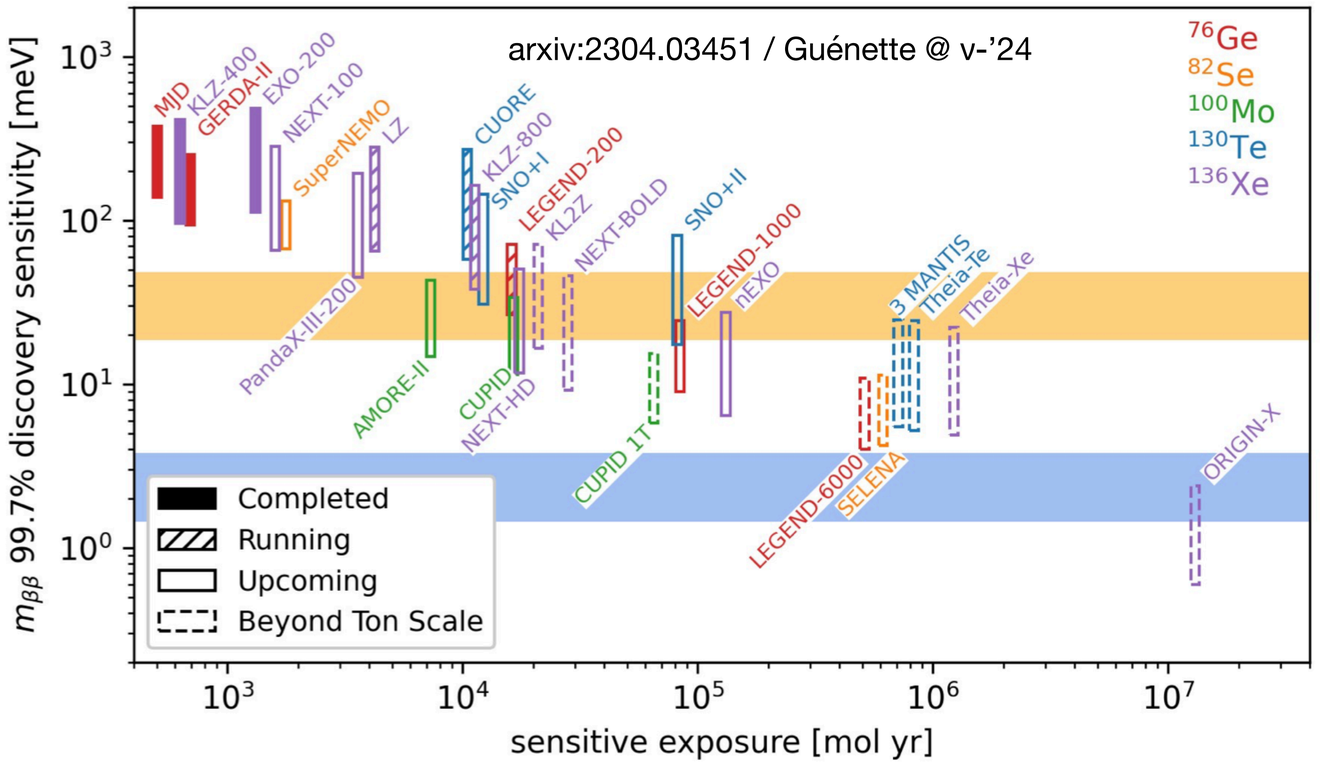


Linear Alkyl-Benzene (LAB)

More with LS for future?



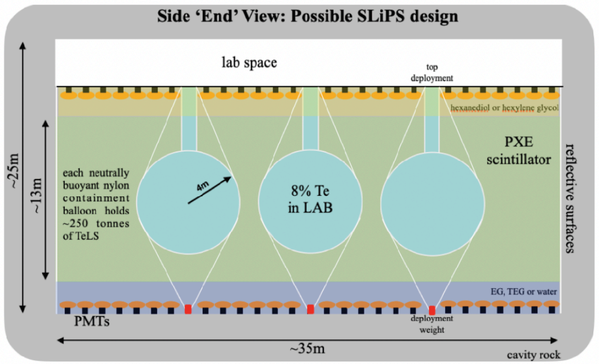




- 0νDBD experimental sensitivity for normal ν mass ordering.
- Larger LS detector with isotope loading?

MANTIS

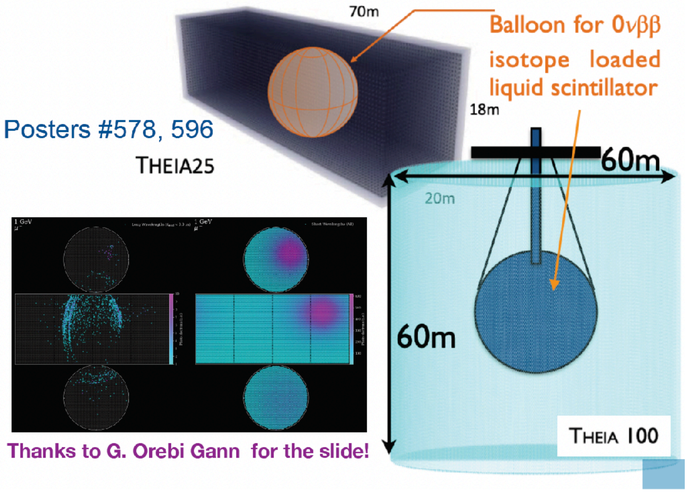
Modular Approach for Nββ with Tellurium In Scintillator



Morton-Blake and Biller, Physical Review D, 105(7) (2022)

Taken from A.McDonalds' talk at 2nd Summit on the Future of Neutrinoless Double-beta Decay (2023)

THEIA



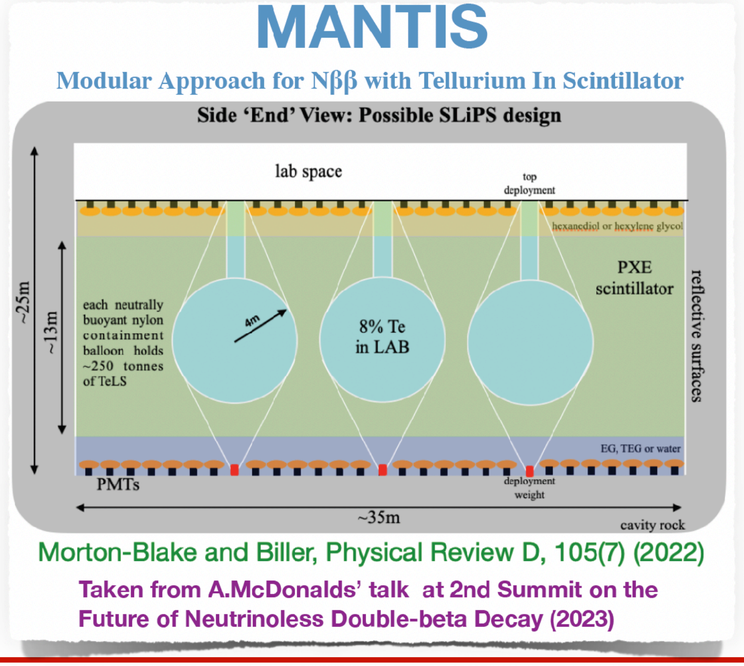
Posters #578, 596

THEIA25

Thanks to G. Orebi Gann for the slide!

LS scale-up and limitation

- Ongoing discussions/proposals for future larger scale LS experiments, especially for 0νββ decay search.
- Topology impractical unless segmented.
  - β decay of ^{14}C—inevitable background and pileup.
- Solar ν (^{8}B) can be a considerable background for 0νDBD search.
- Material loading— concentration limited by:
  - Unwanted background by additional chemicals,
  - Light yield, transparency degradation.



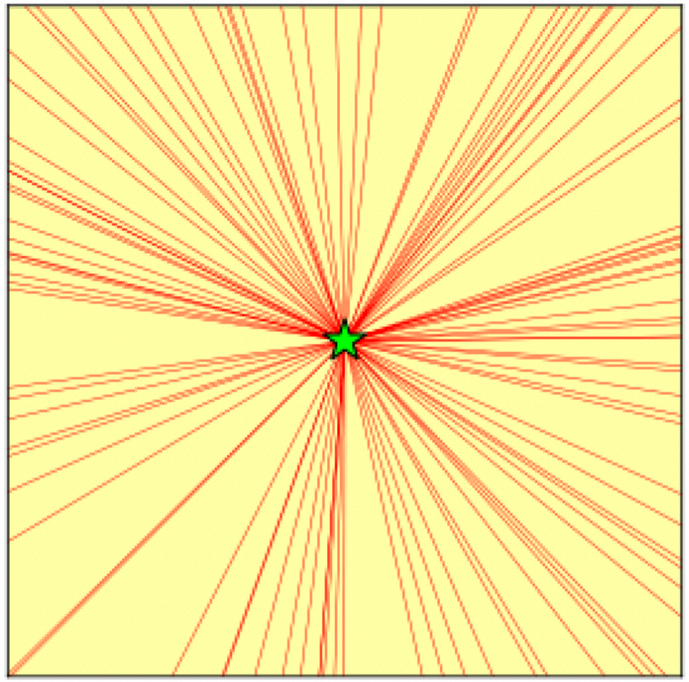
Morton-Blake and Biller, Physical Review D, 105(7) (2022)

Taken from A.McDonalds' talk at 2nd Summit on the Future of Neutrinoless Double-beta Decay (2023)

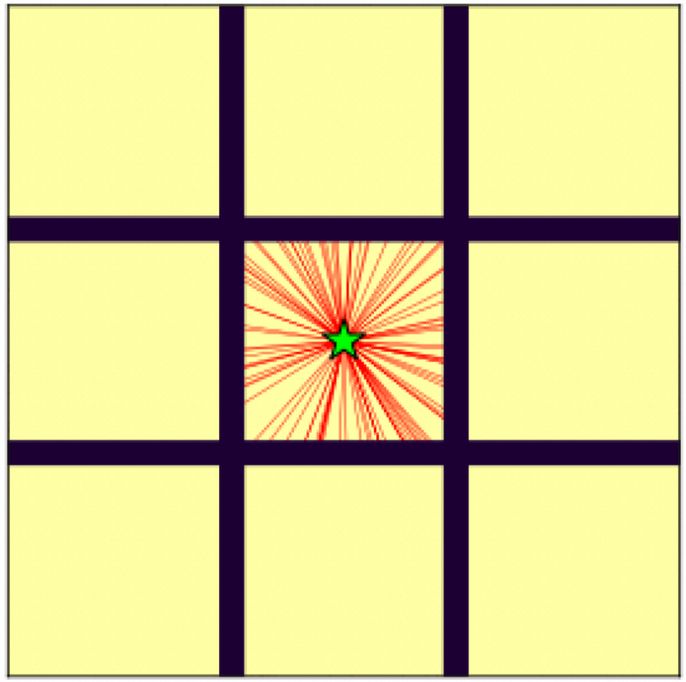
LiquidO = Liquid + Opaque!

Jeff Hartnell at v-2026

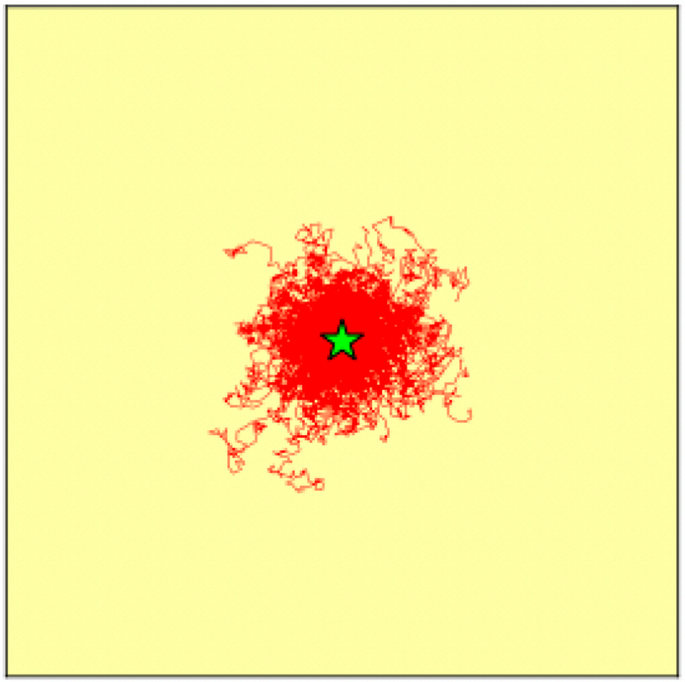
Transparent,
Single volume



Transparent,
Segmented



Opaque,
Self-segmented

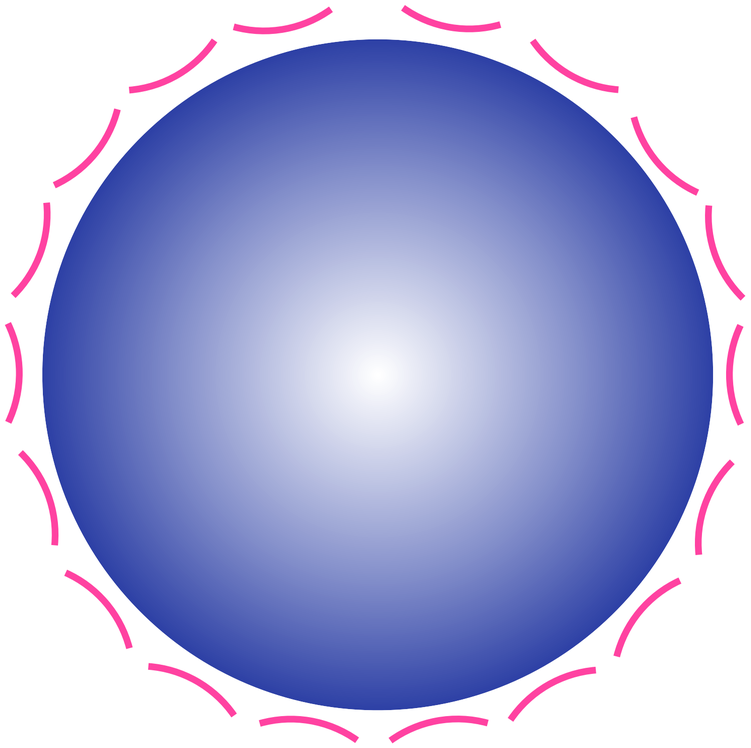


Traditional

New approach:
Stochastic light confinement

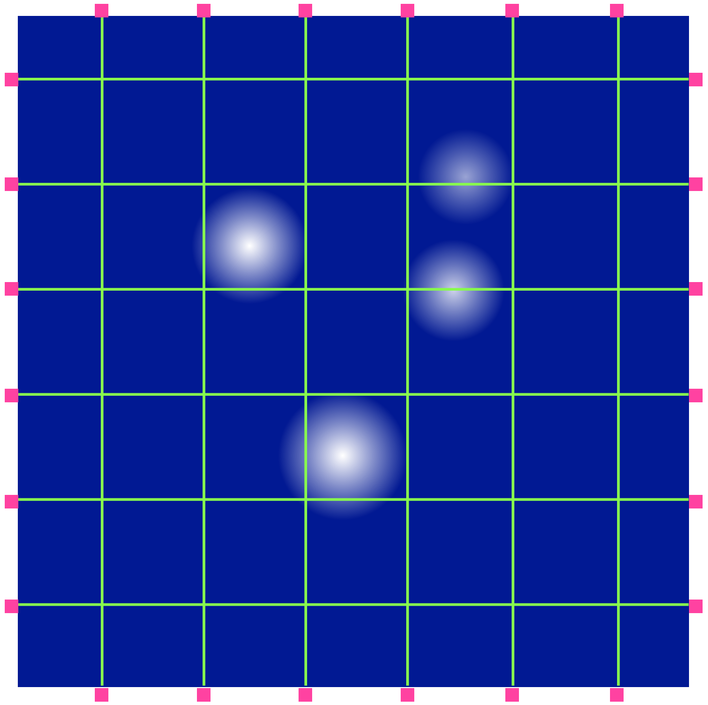
LiquidO = Liquid + Opaque!

Transparent scintillator



Absorption length > m,
Scattering length > m.

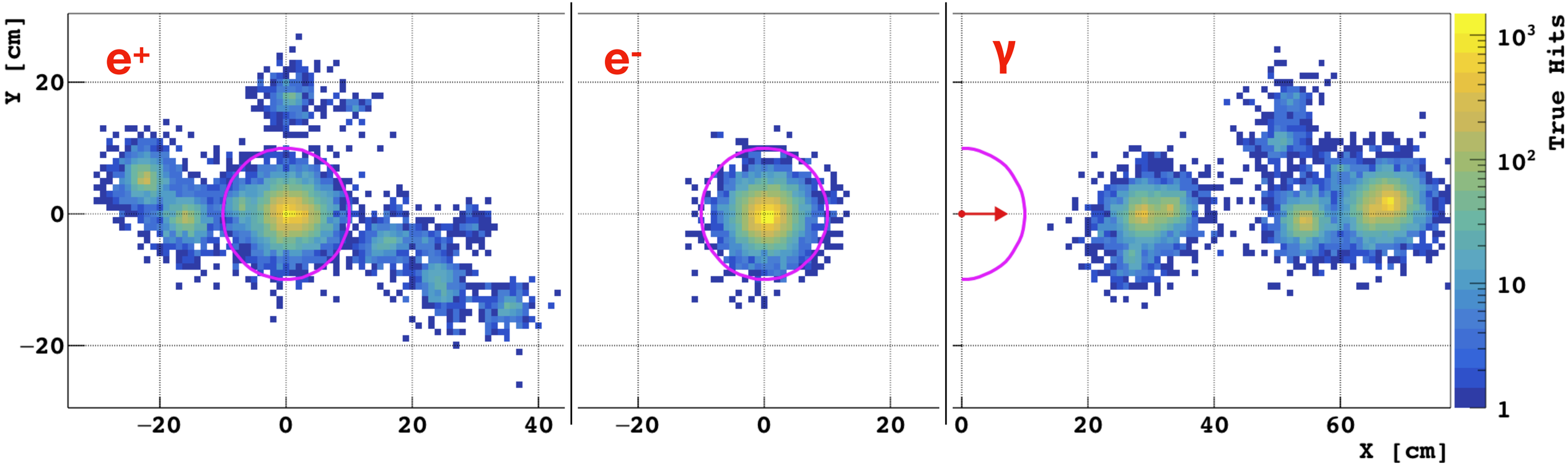
Opaque scintillator



Absorption length > m,
Scattering length ~ mm,
Stochastic light confinement,
Discrimination between
single- and multi-site event.

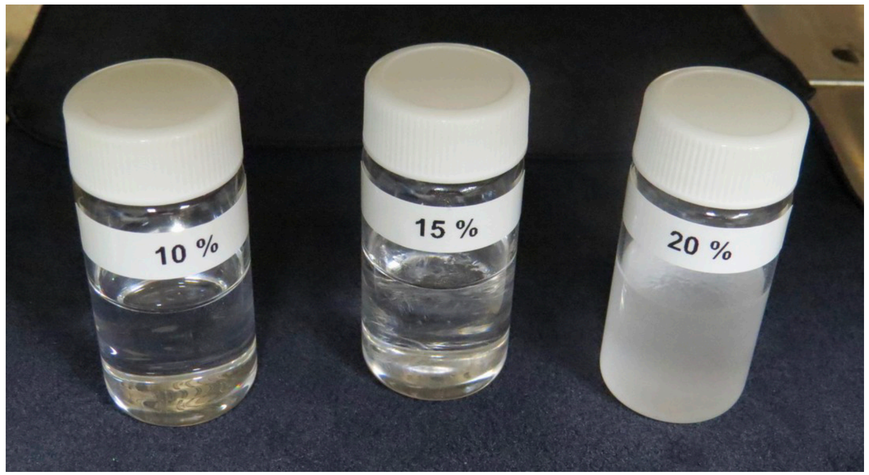
Particle identification

A. Cabrera



Deposit energy ~2 MeV for all.

LiquidO recipes





JINST 14 (2019) P11007
NIM A 1071 (2024) 170075
arxiv:1807.00628

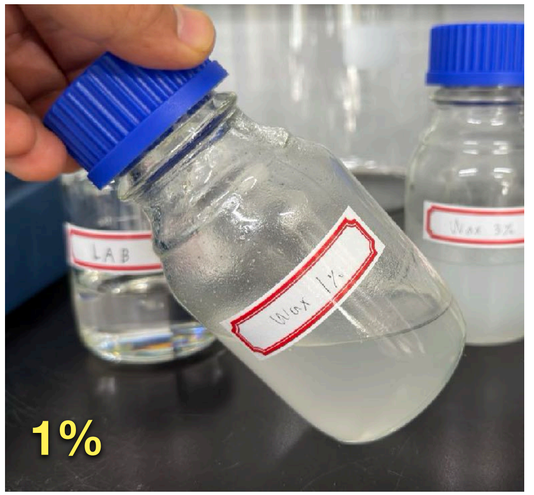
↑ LS (LAB) + Paraffin wax (NoWaSH),

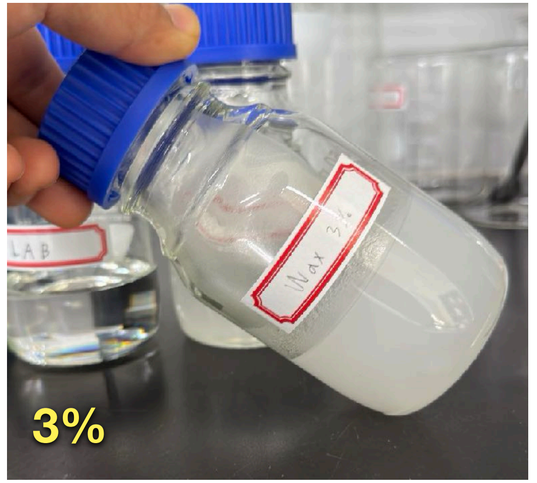
↓ μ-crystal

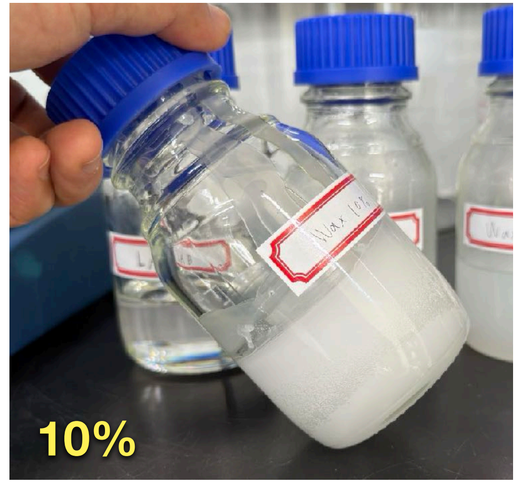




↑ LS (DIN) + water+surfactant







Opacity / fluidity can be controlled by temperature, too.

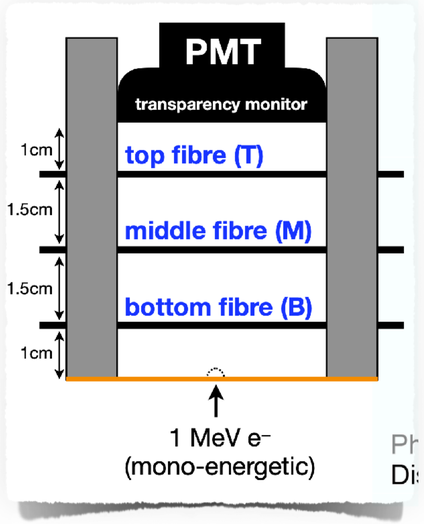
Opacity+Solidification+Loading

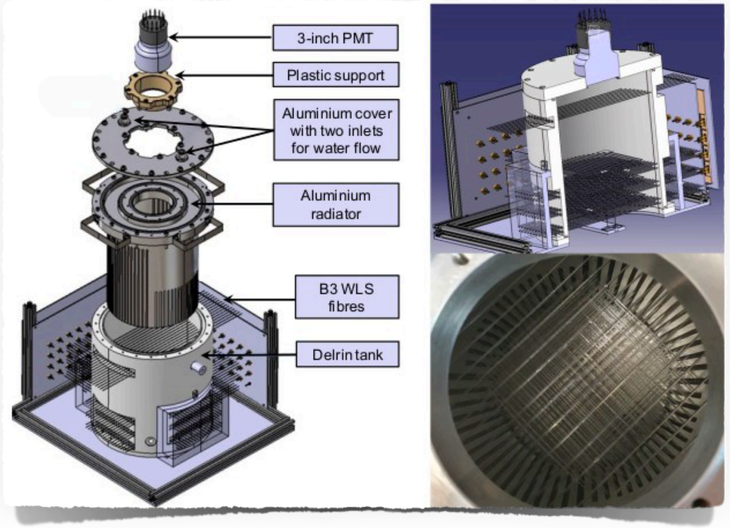
Expectation

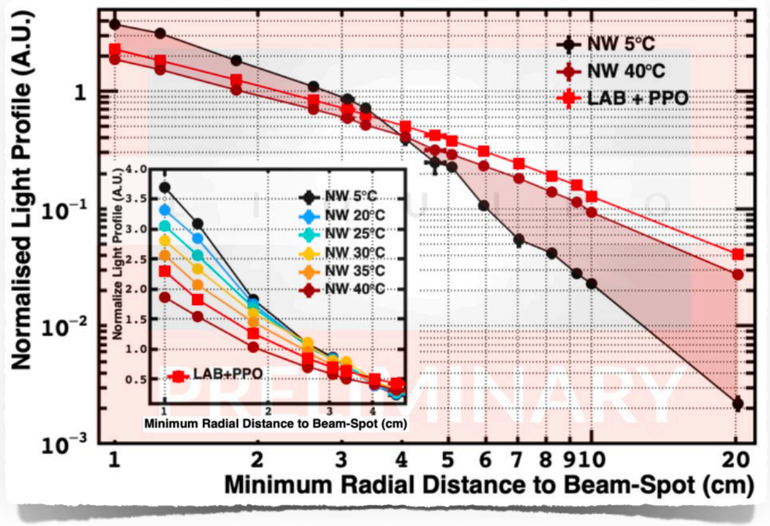
- Mixing physically, not chemically dissolving.
  - No additional chemicals/surfactants.
- May load up to 30%wt, depending upon materials.
  - Limited by light yield degradation; not by solubility.
  - C.f. SNO+II expects up to 3%wt of Te in the transparent LS.

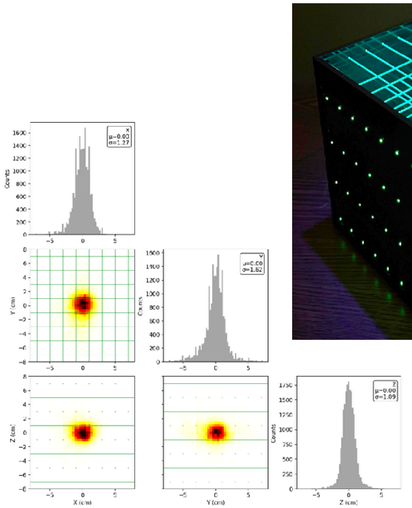
Existing R&Ds

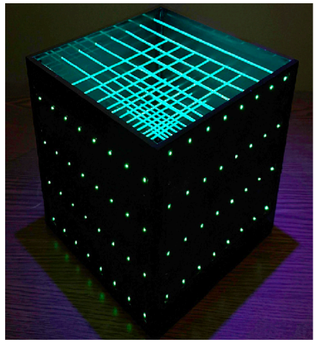
Comm. Phys. 4:273 (2021),
2503.02541, 2505.11201,
talks/posters @ v-2026, …

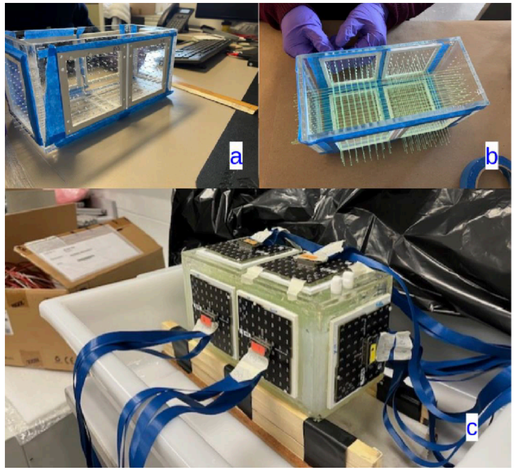


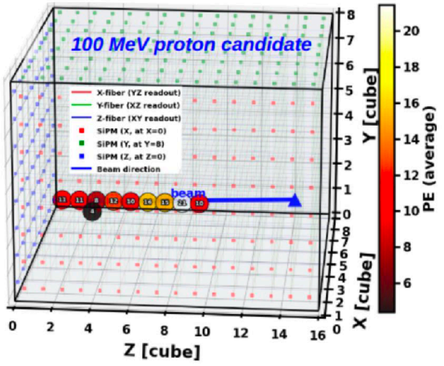




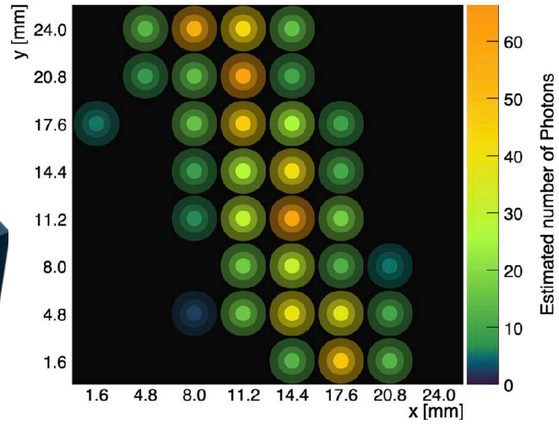






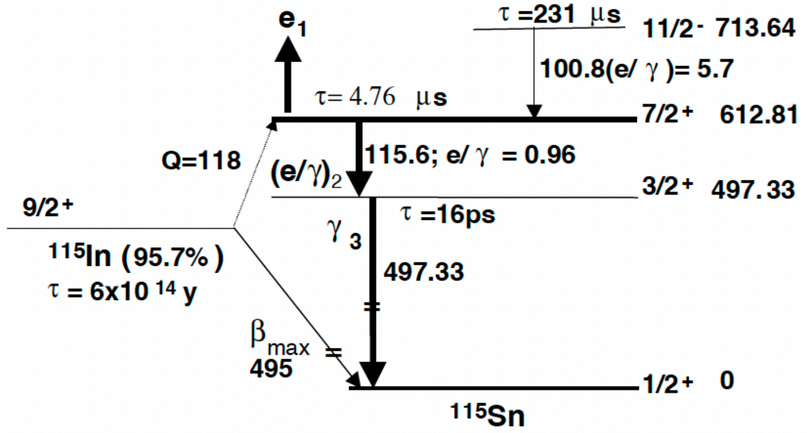


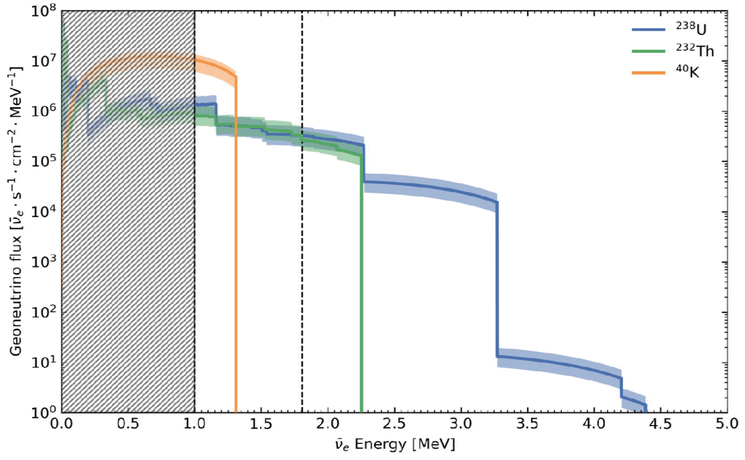


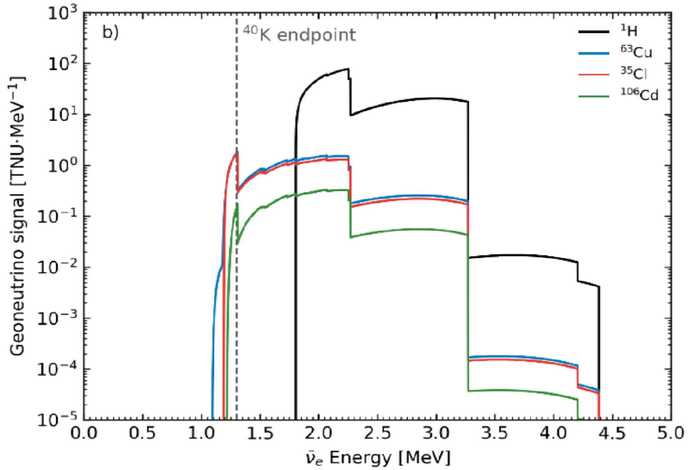


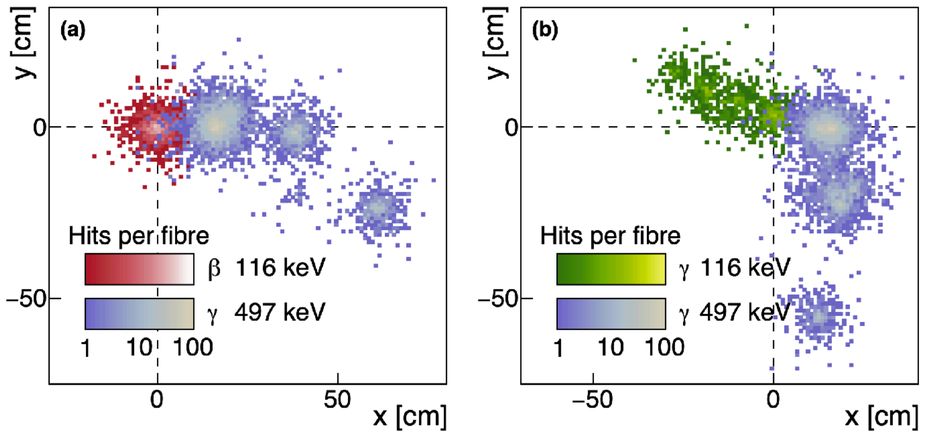
Physics opportunities

- Refining IBD and reactor ν measurements.
- IBD threshold lower than 1.8 MeV:
  - ^{40}K geo-neutrino using ^{63}Cu.
- Solar neutrino (pp) using ^{115}In.
- BSM decay searches: 0νβ$^{\mp}$β$^{\mp}$.

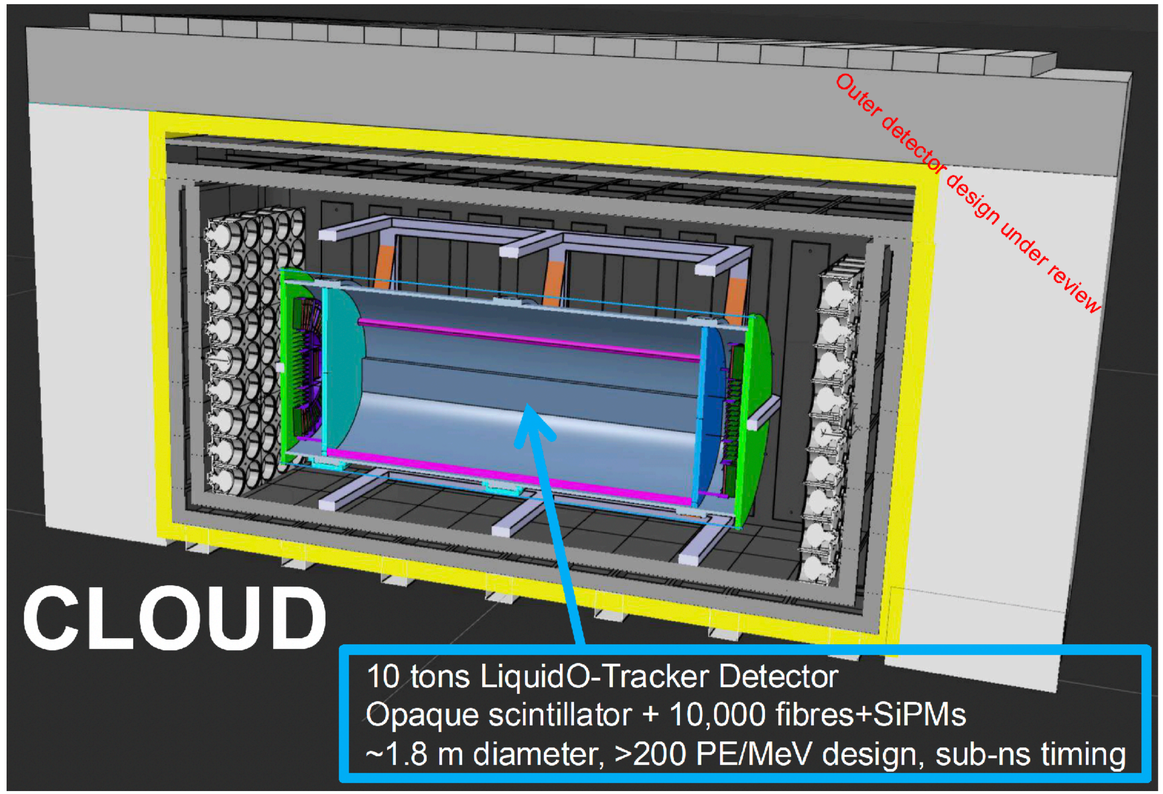




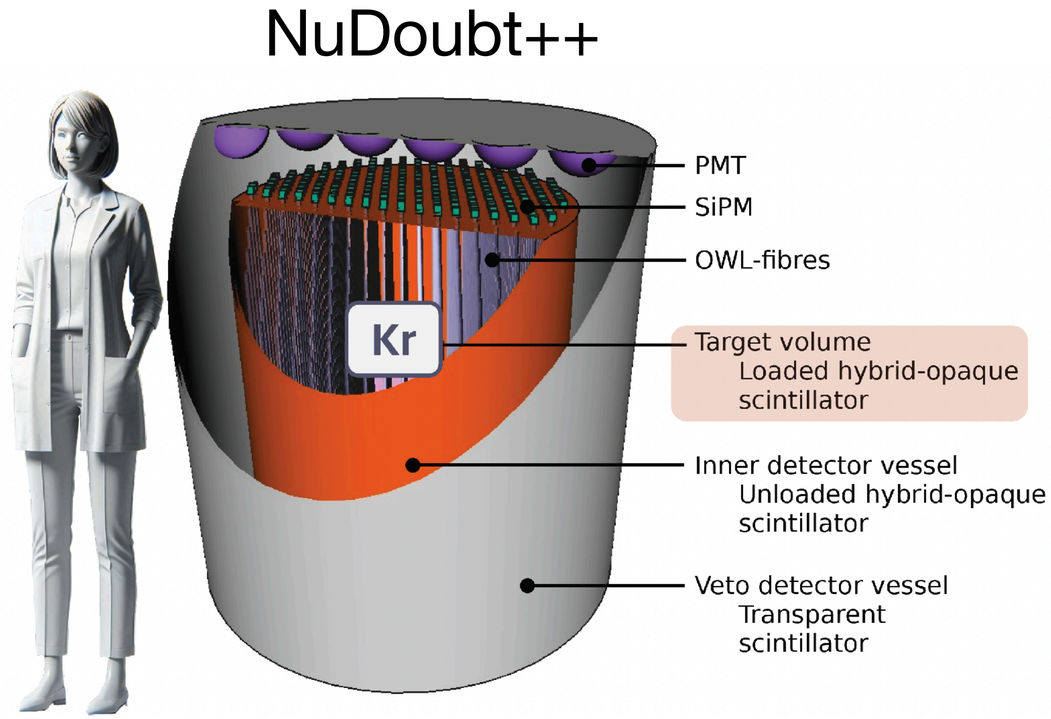




Physics opportunities



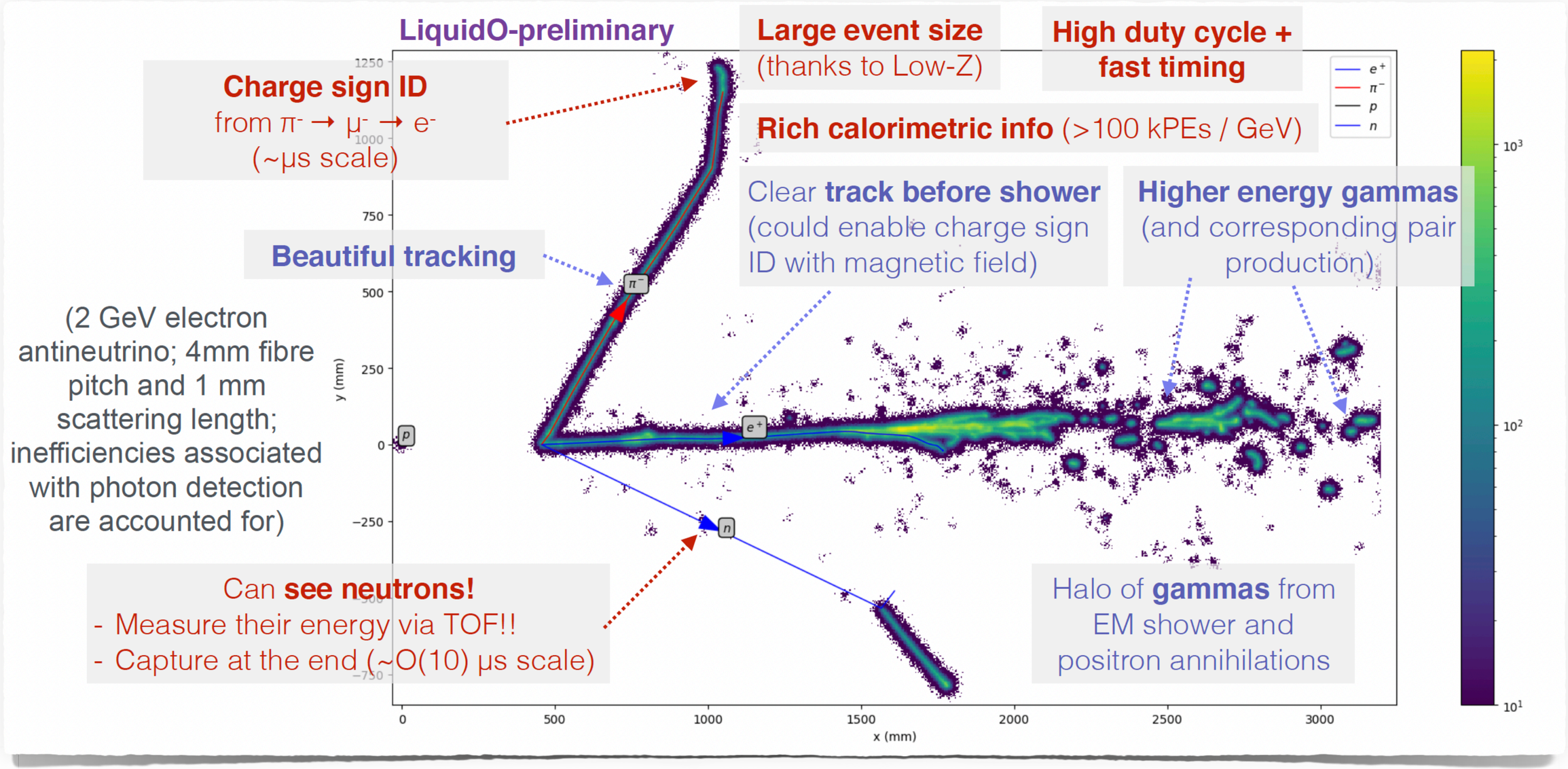
A. Cabrera on Thursday @ NNN



V. Palusova on Wednesday @ NNN

Physics opportunities

Courtesy of J. Pedro Ochoa-Ricoux (2019)



Challenges toward physics test

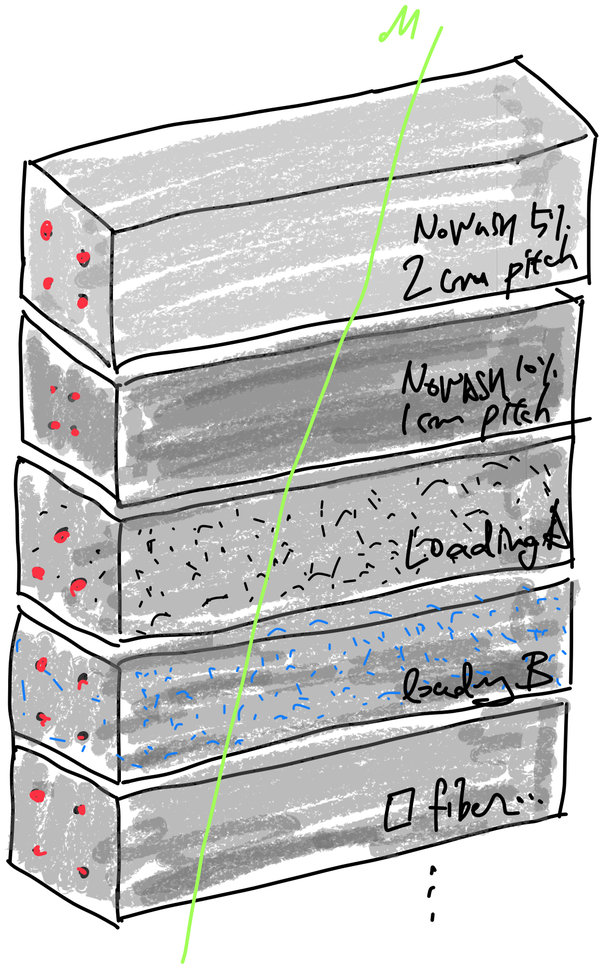
- Light collection $\gtrsim$ 400 photons/MeV ~ 5% energy resolution.
  - LiquidO recipe, fiber, fiber arrangement and pitch, SiPM coupling.
- Material loading capacity $\gtrsim$ 10%wt.
- Particle ID capability.
- # of detector channels.
- Radiopurity—LS and fiber
- Simulation—optical photons!
- Data acquisition/analysis.

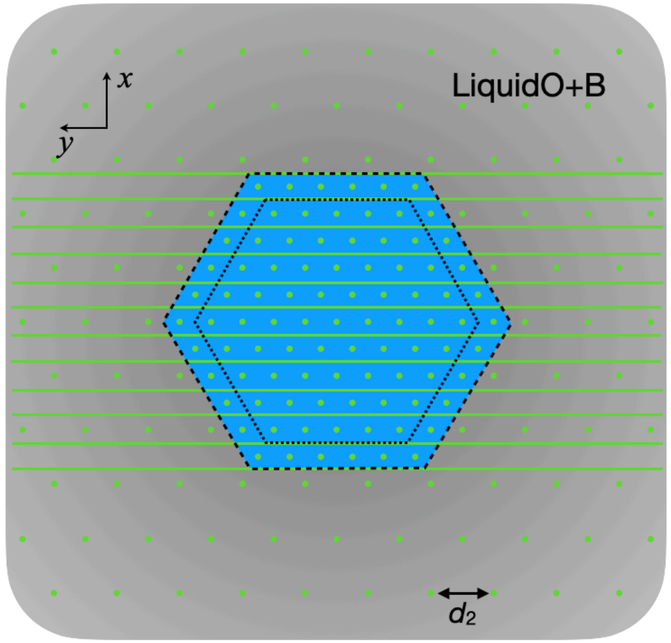
All along with the SCALABILITY ~~wwwwwwwww~~

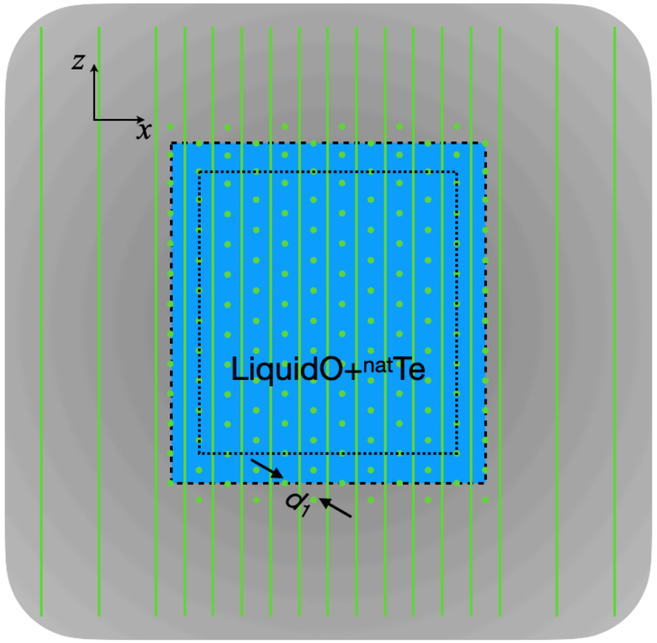
R&D plans

Demonstrator	Babies	Junior	Prototype	
Primary Objectives	LY vs recipes / fibers / doping / temperature / solidification	E resolution, Coincidence event, with loading	Background discrimination, Productions using sources, Scalability, and Physics sensitivities	
Volume, Dimension	Up to ~1 liter, long and thin rod/bar type	~10 liters, 15×15×30 cc	~1 m^3 / Tens of liters' active volume + surrounding passive volume	
Fiber configuration	1 direction: square / triangular / plain	2 directions	2D/dense for active V, 1D/sparse for passive V	
Measurement	Light sources, Through-going muons	Compton edge(s) using γ sources	β/ββ spectra, reactor	
	Simulation, DAQ, analysis			

Conceptual sketch







Closing

- LiquidO technology to overcome limitations for future neutrino experiments!?
- Proof-of-concepts RnDs, components (LiquidO recipes, fibers, …) developments, and detector prototyping's are on-going.
- The 5-year R&D program officially starts in November '26.
  - Feasibilities for various measurements with material loading will be studied for 0νββ, solar-ν, …
- NNN talks by Veronica Palusova and Anateal Cabrera.