

# LiquidO: an introduction

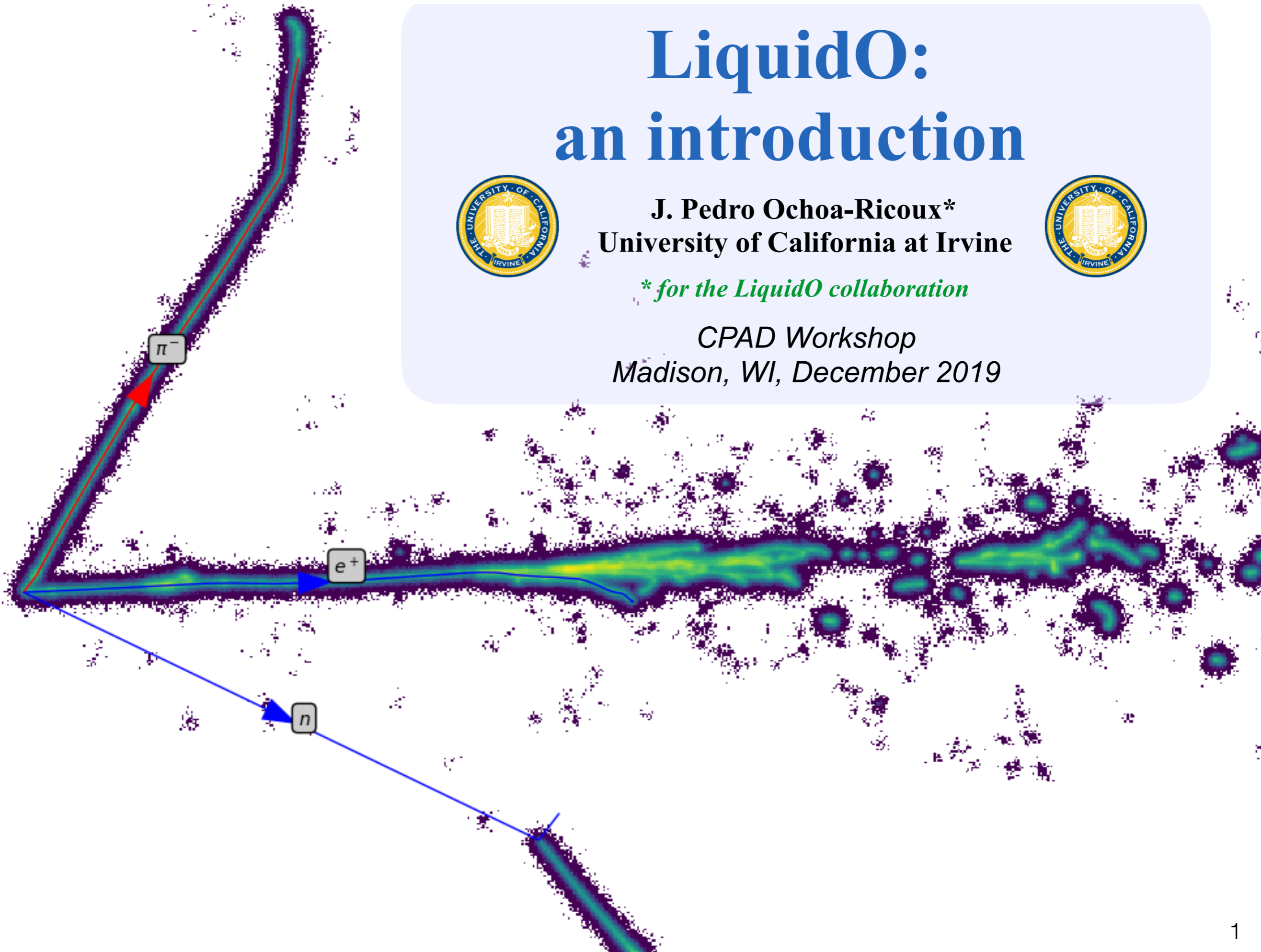


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**University of California at Irvine**



*\* for the LiquidO collaboration*

*CPAD Workshop  
Madison, WI, December 2019*

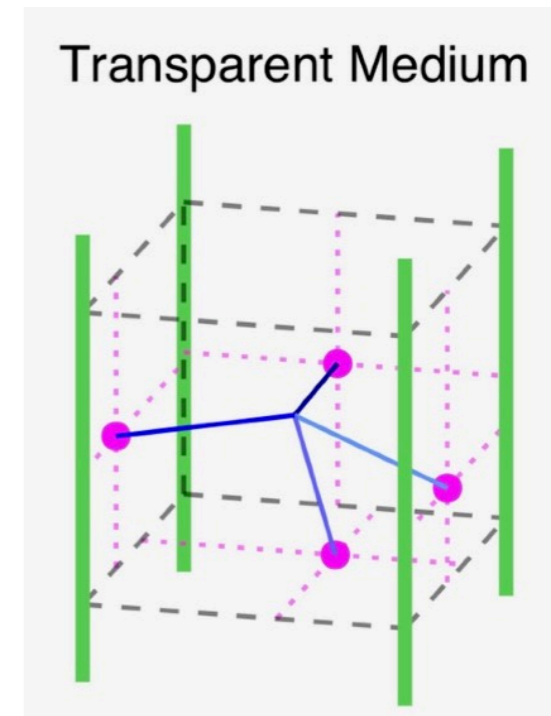
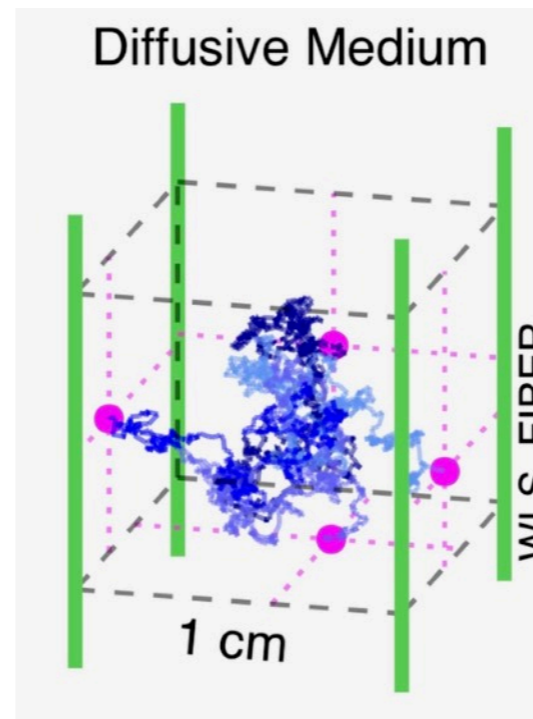


# A new approach!

- Liquid Scintillator (LS) detectors have been a workhorse in neutrino physics
  - Conventional strategy: propagate light through the scintillator to surrounding photosensors
- LiquidO is a departure from the conventional paradigm with **two main features**:

## 1) Use of an opaque scintillator

**Main purpose: stochastically confine light near its creation point**, to preserve the precious topological information of particle interactions



*A new and completely counter-intuitive approach!*

The right opaque scintillator for LiquidO: short scattering length and moderate absorption length



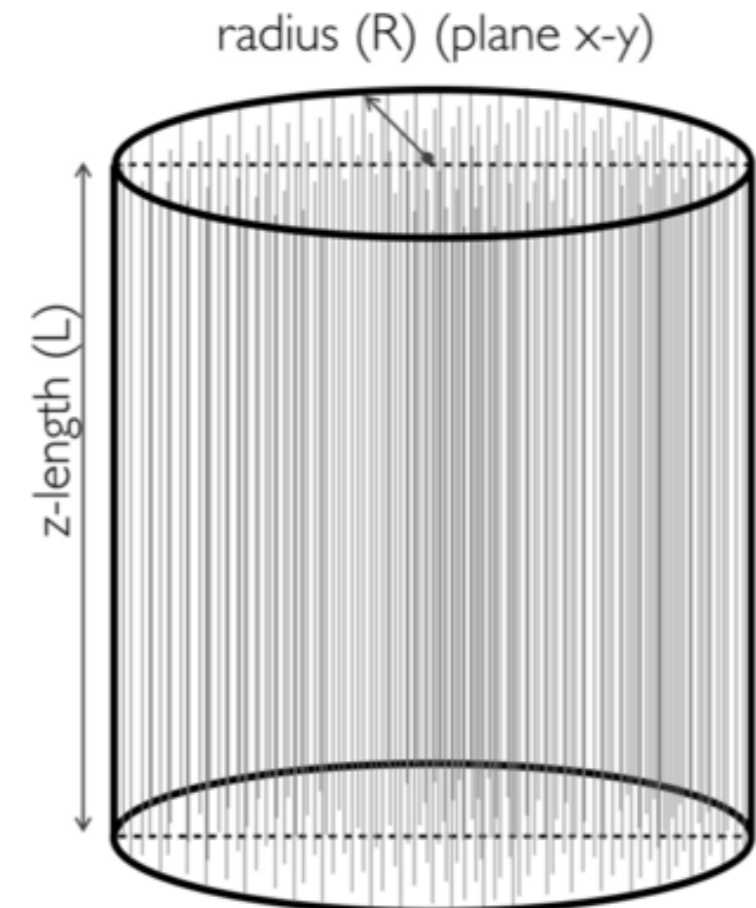
More like milk than like dark beer!

# A new approach!

2) Light collection with a dense fiber array running in at least one direction

**Main purpose:** collect light near its creation point

Archetypical LiquidO detector

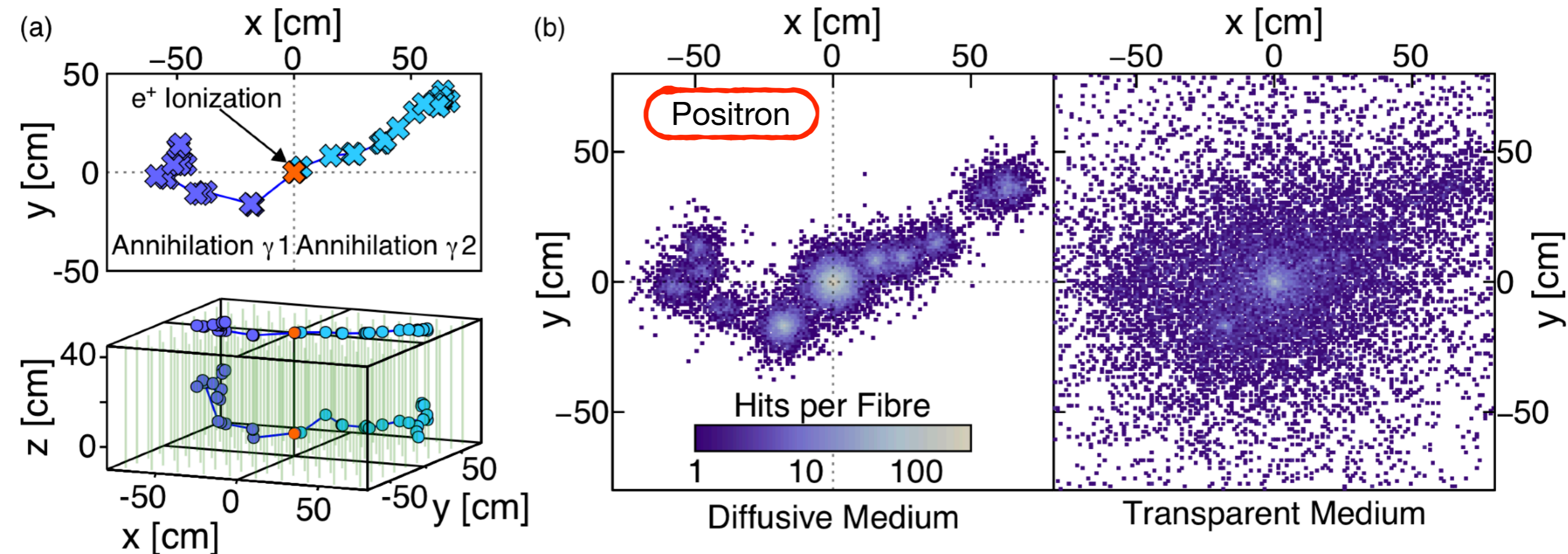


SiPMs are a great choice to readout the fibers  
(low background, high efficiency,  $\sim 0.1$  ns time resolution)

- LiquidO relies on well-understood, commercially available and relatively inexpensive technology!

# Imaging down to the MeV scale!

– Result: **unprecedented imaging capabilities**



Geant4 simulation of 1 MeV positron in a LiquidO detector with fibers running along z direction with a 1 cm pitch. The scintillator has a 5 mm scattering length. Each pixel corresponds to a fiber. The color scale shows all **true hits per fiber**

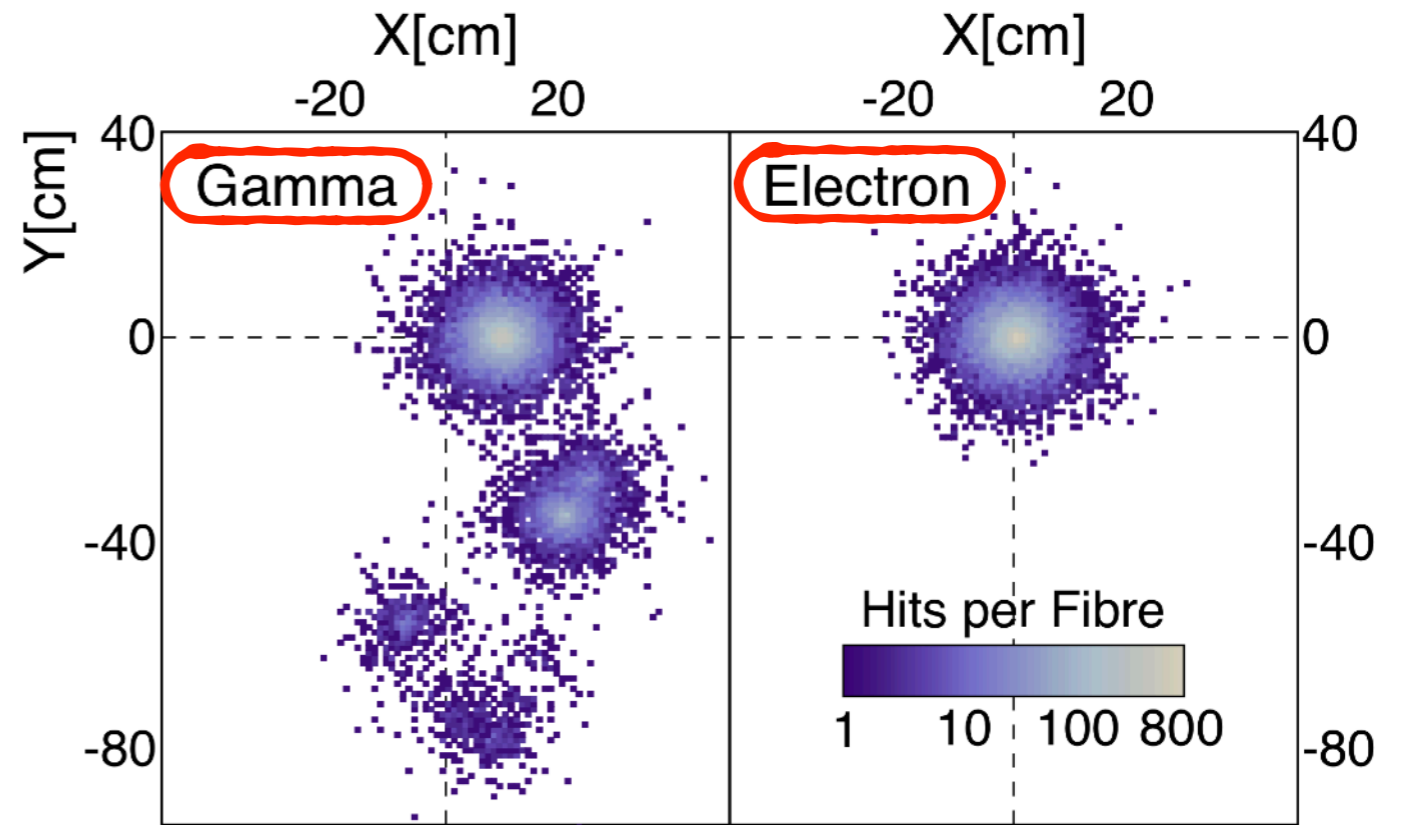
**A self-segmenting detector!** (no need to introduce dead material)

# LiquidO's power

- Can distinguish  $\sim$ MeV gammas, electrons and positrons on an individual basis

**unprecedented!**

Can achieve electron separation from gammas with efficiency  $> 85\%$  and contamination  $\sim 10^{-3}$

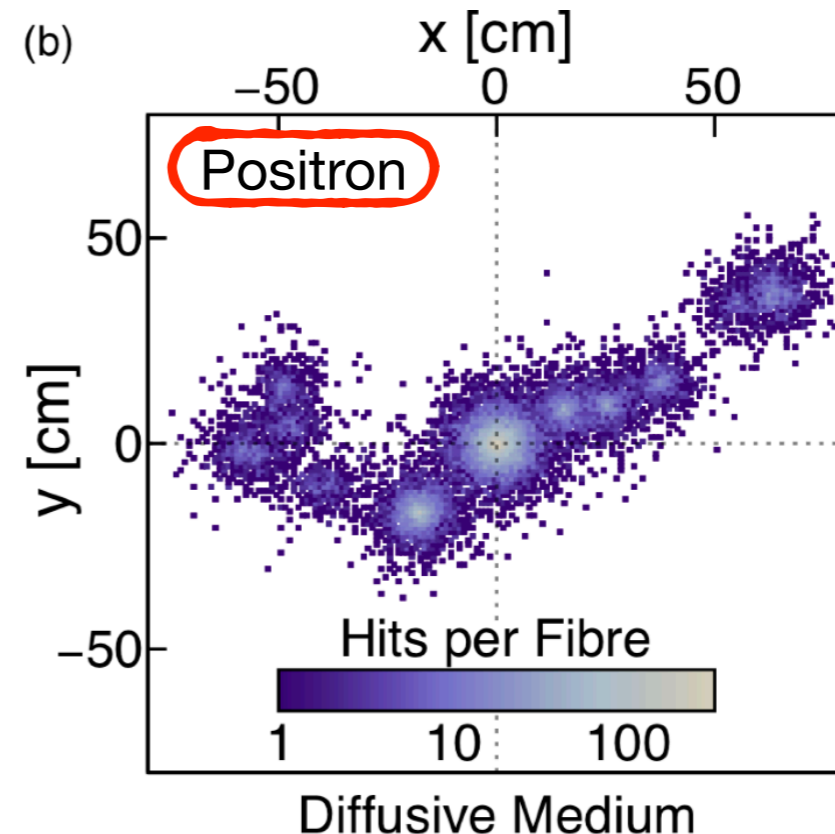


- Additional major advantages:

Unparalleled **affinity for loading**

Plenty of room to **explore unconventional scintillators** (e.g. ultra high light-yield) not deemed transparent enough for conventional detectors

(Both events at the top are 2 MeV; simulation details are the same as in previous page)



Essentially impossible to separate these three on an event-by-event basis in conventional Liquid Scintillator detectors!

# First papers

More information about LiquidO can be found in [arXiv:1908:02859](https://arxiv.org/abs/1908.02859) and [arXiv:1908.03334](https://arxiv.org/abs/1908.03334)

## Neutrino Physics with an Opaque Detector

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August 9, 2019

The discovery of the neutrino by Reines & Cowan in 1956 revolutionised our understanding of the universe at its most fundamental level and provided a new probe with which to explore the cosmos. Furthermore, it laid the groundwork for one of the most successful and widely used neutrino detection technologies to date: the liquid scintillator detector. In these detectors, the light produced by particle interactions propagates across transparent scintillator volumes to surrounding photo-sensors. This article introduces a new approach, called LiquidO, that breaks

with the conventional paradigm of transparency by confining and collecting light near its creation point with an opaque scintillator and a dense array of fibres. The principles behind LiquidO's detection technique and the results of the first experimental validation are presented. The LiquidO technique provides high-resolution imaging that enables highly efficient identification of individual particles event-by-event. Additionally, the exploitation of an opaque medium gives LiquidO natural affinity for using dopants at unprecedented levels. With these and other capabilities, LiquidO has the potential to unlock new opportunities in neutrino physics, some of which are discussed here.

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PUBLISHED BY IOP PUBLISHING FOR SISSA MEDIALAB

RECEIVED: August 12, 2019

REVISED: September 30, 2019

ACCEPTED: October 21, 2019

PUBLISHED: November 5, 2019

### Novel opaque scintillator for neutrino detection

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**ABSTRACT:** There is rising interest in organic scintillators with low scattering length for future neutrino detectors. Therefore, a new scintillator system was developed based on admixtures of paraffin wax in linear alkyl benzene. The transparency and viscosity of this gel-like material can be tuned by temperature adjustment. Whereas it is a colorless transparent liquid at temperatures around 40°C, it has a milky wax structure below 20°C. The production and properties of such a scintillator as well as its advantages compared to transparent liquids are described.

**KEYWORDS:** Detector design and construction technologies and materials; Neutrino detectors; Scintillators, scintillation and light emission processes (solid, gas and liquid scintillators)

ARXIV EPRINT: [1908.03334](https://arxiv.org/abs/1908.03334)

<sup>1</sup>Corresponding author.

~40 scientists  
from Europe,  
Asia and the  
Americas  
currently  
working on  
LiquidO

(see also seminar at CERN: <https://indico.cern.ch/event/823865/>)

# Physics Potential

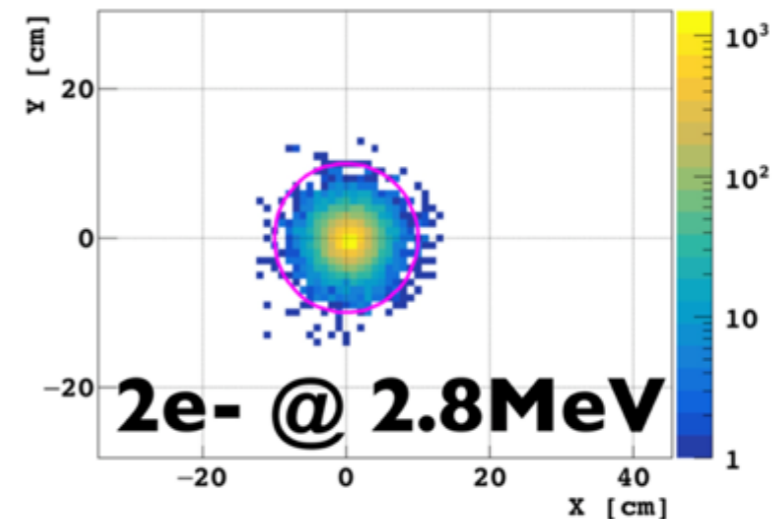
- LiquidO's capabilities open up a realm of possibilities in many areas of neutrino physics. Here I highlight a few:

- **Search for neutrinoless double-beta decay ( $0\nu\beta\beta$ ):**

Key advantages: background control and ability to load well beyond current limits

Looks like a very promising path for reaching deep into the normal ordering region!

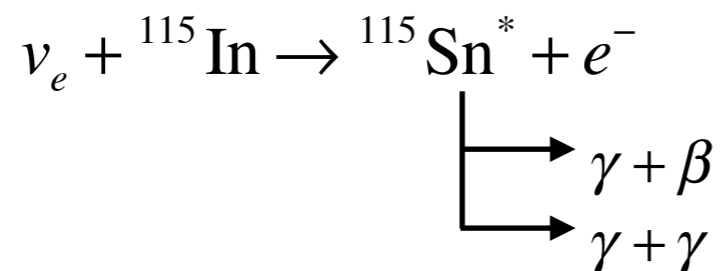
$\beta\beta$  Example Event



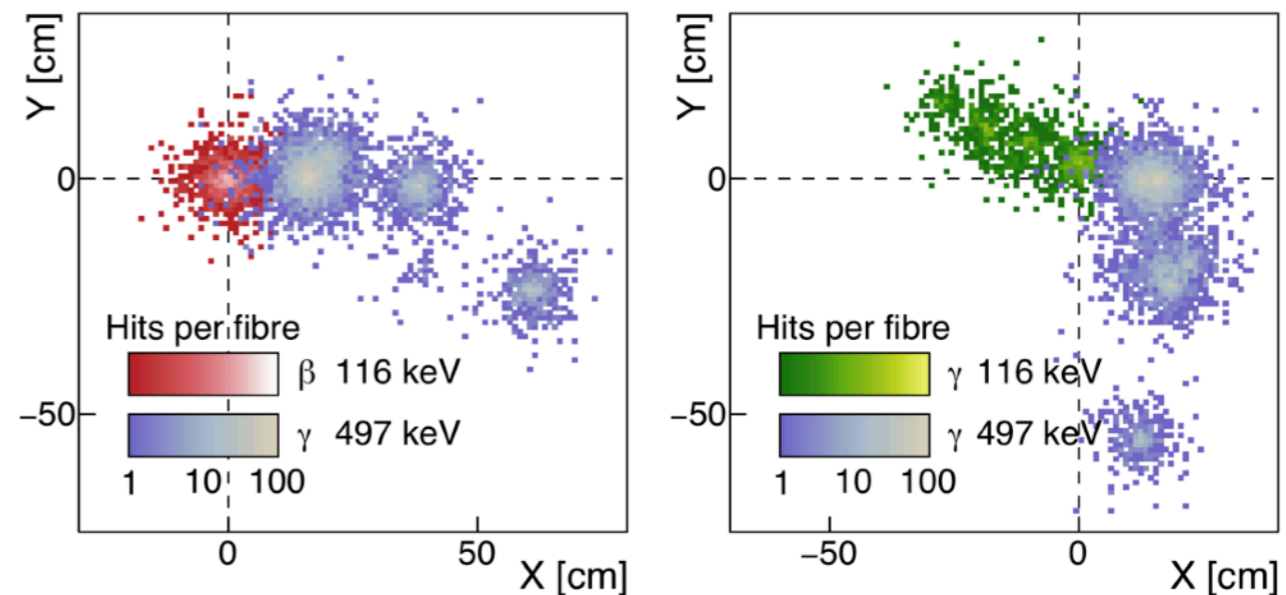
- **Solar neutrinos:**

Expect good performance "as is"

**Exciting possibility:** Indium loading could allow to use the reaction first proposed by Raghavan in 1976 to do  $pp$  solar neutrino physics



Sn\* decay



# Physics Potential

## - Supernova neutrinos:

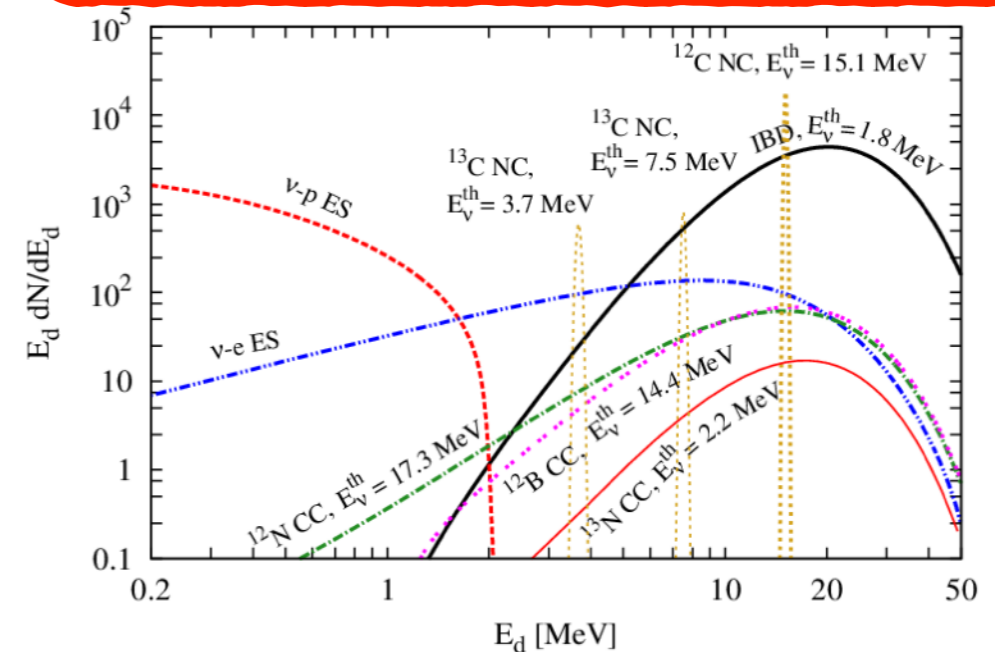
- Low energy threshold ( $\sim 0.1$  MeV)
- Channels not accessible with other detectors
- Charge sign ID ( $e^+/e^-$ )
- Directionality information for events  $\gtrsim 10$  MeV
- Sensitivity to Diffuse Supernova Neutrino Background

## - Search for nucleon decay:

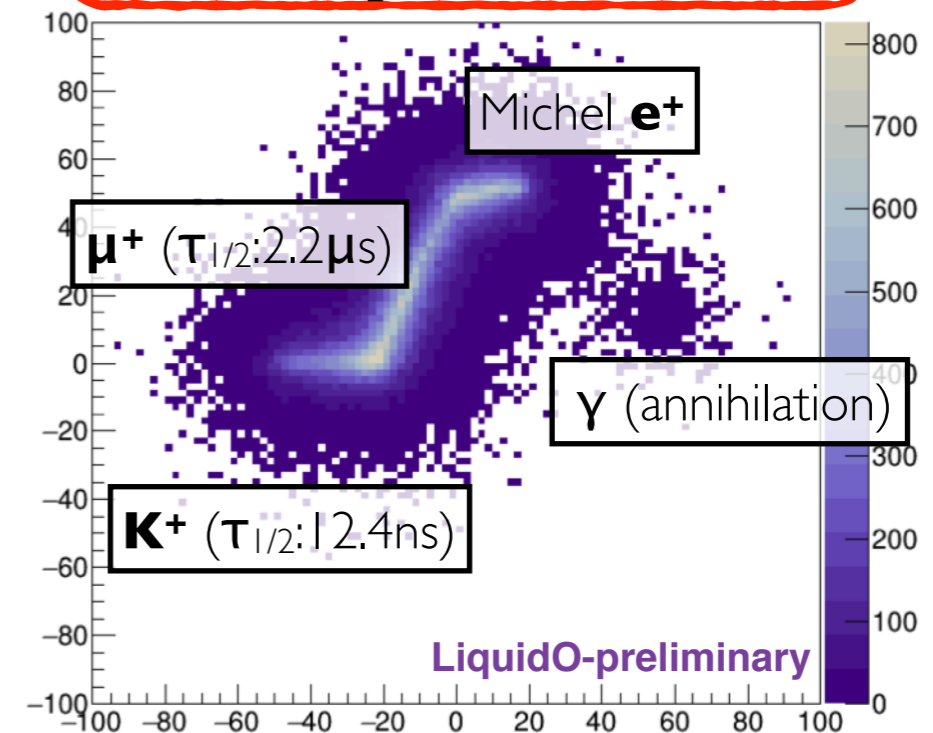
- Can see **\*all\*** channels
- Largest achievable **density of free protons** (thanks to scintillator)
- Very high-efficiency
- Full topological information and sign-ID for some channels through final Michel electron

## - Others (geoneutrinos, reactor antineutrinos... etc)

JUNO spectra for SN @ 10 kpc (for reference)



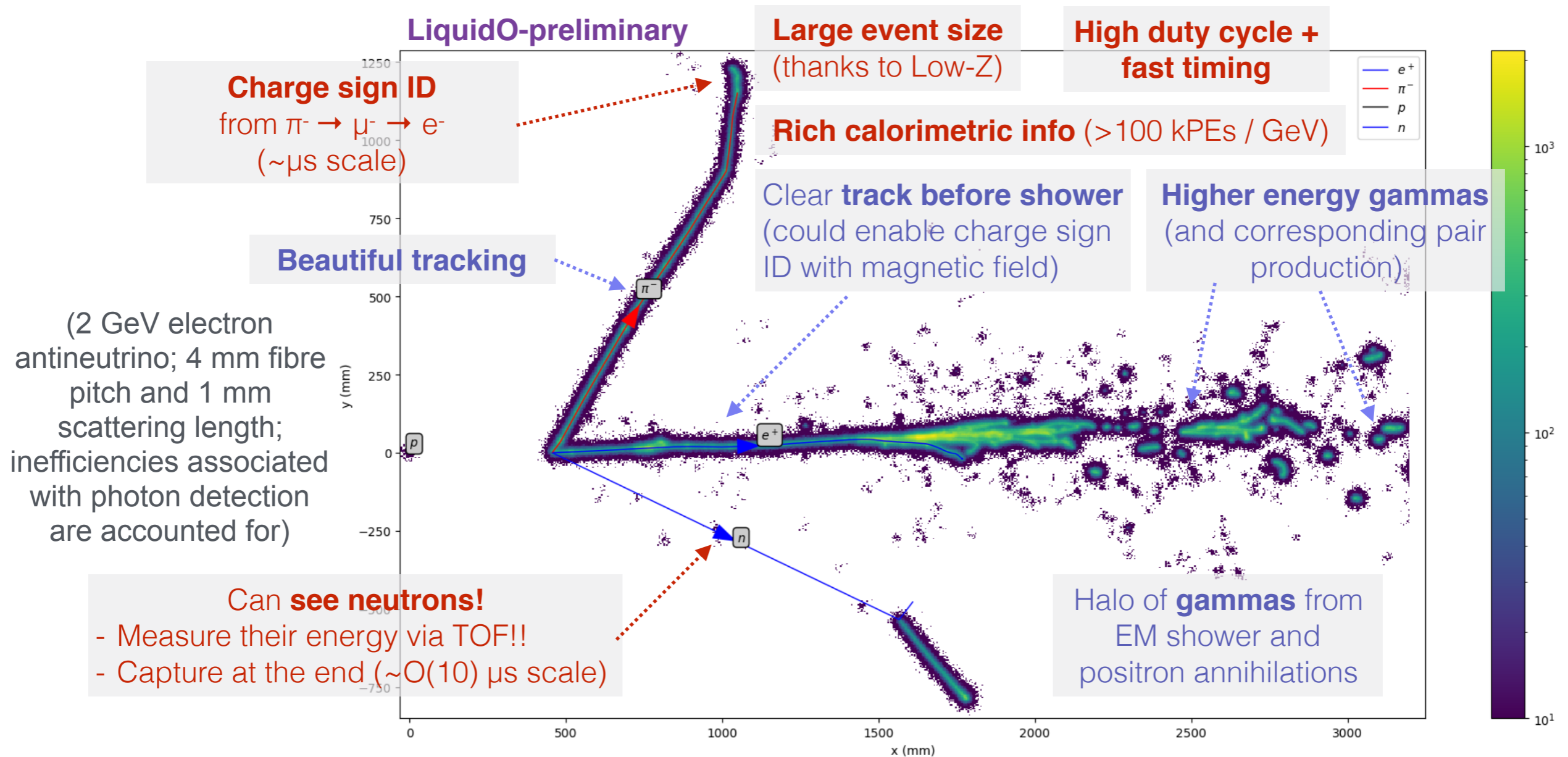
Example  $p \rightarrow \bar{\nu} K^+$  event





# LiquidO can also do beam physics!

– LiquidO would reveal GeV-neutrino interactions in **extremely powerful** way:

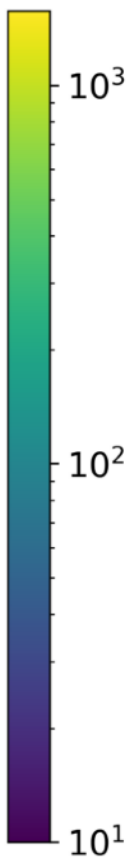
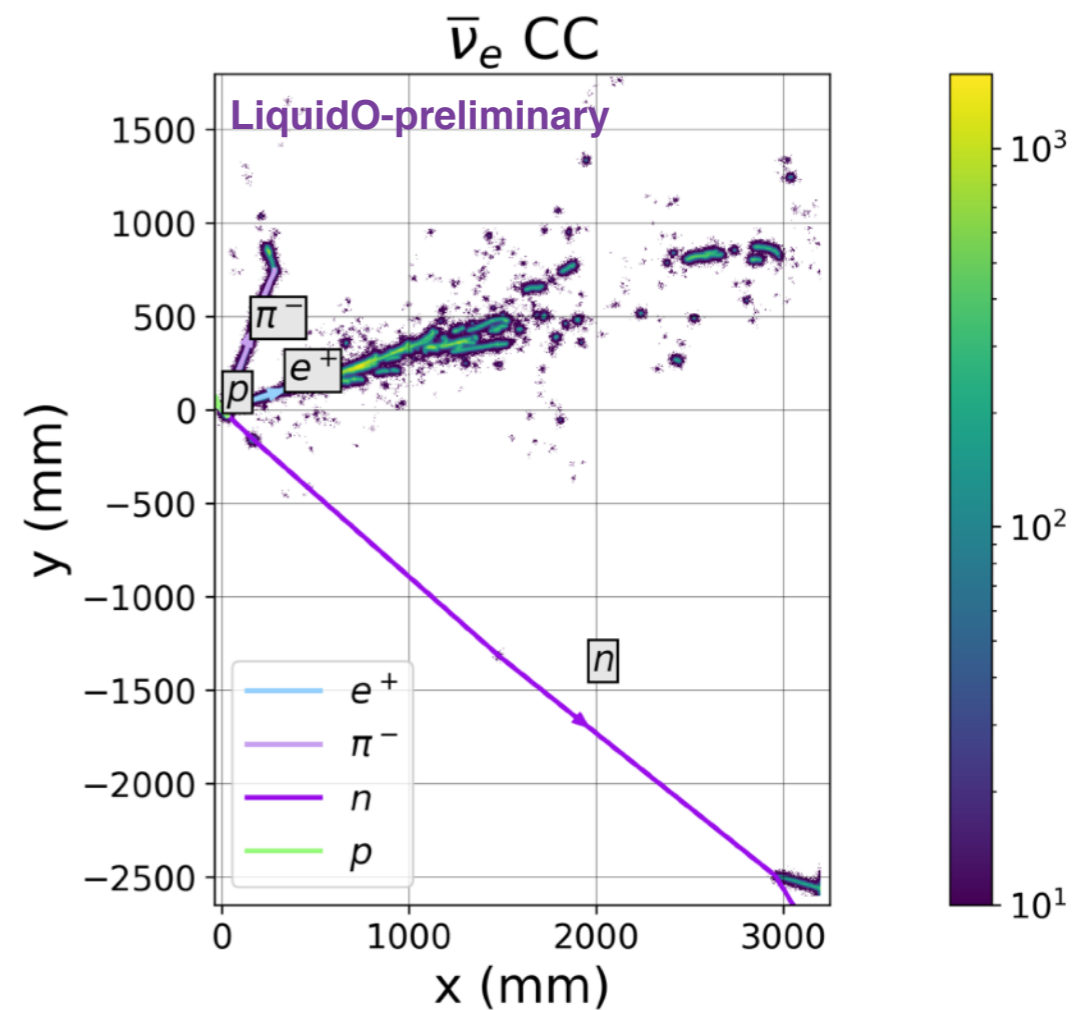
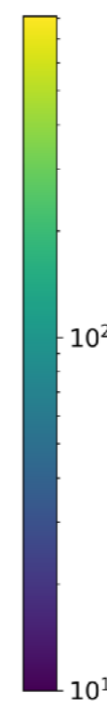
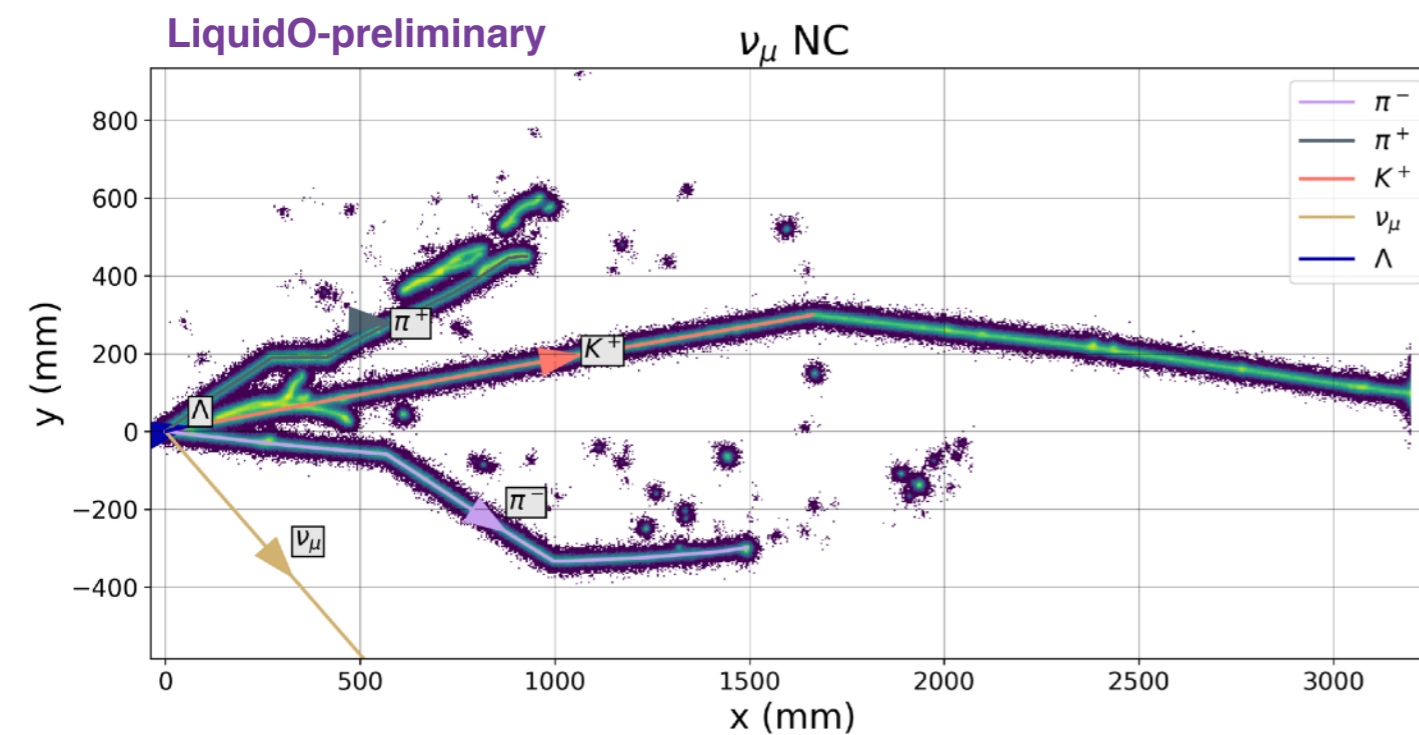
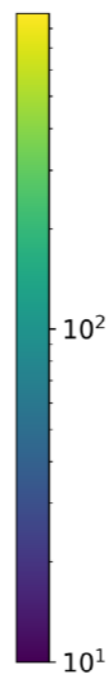
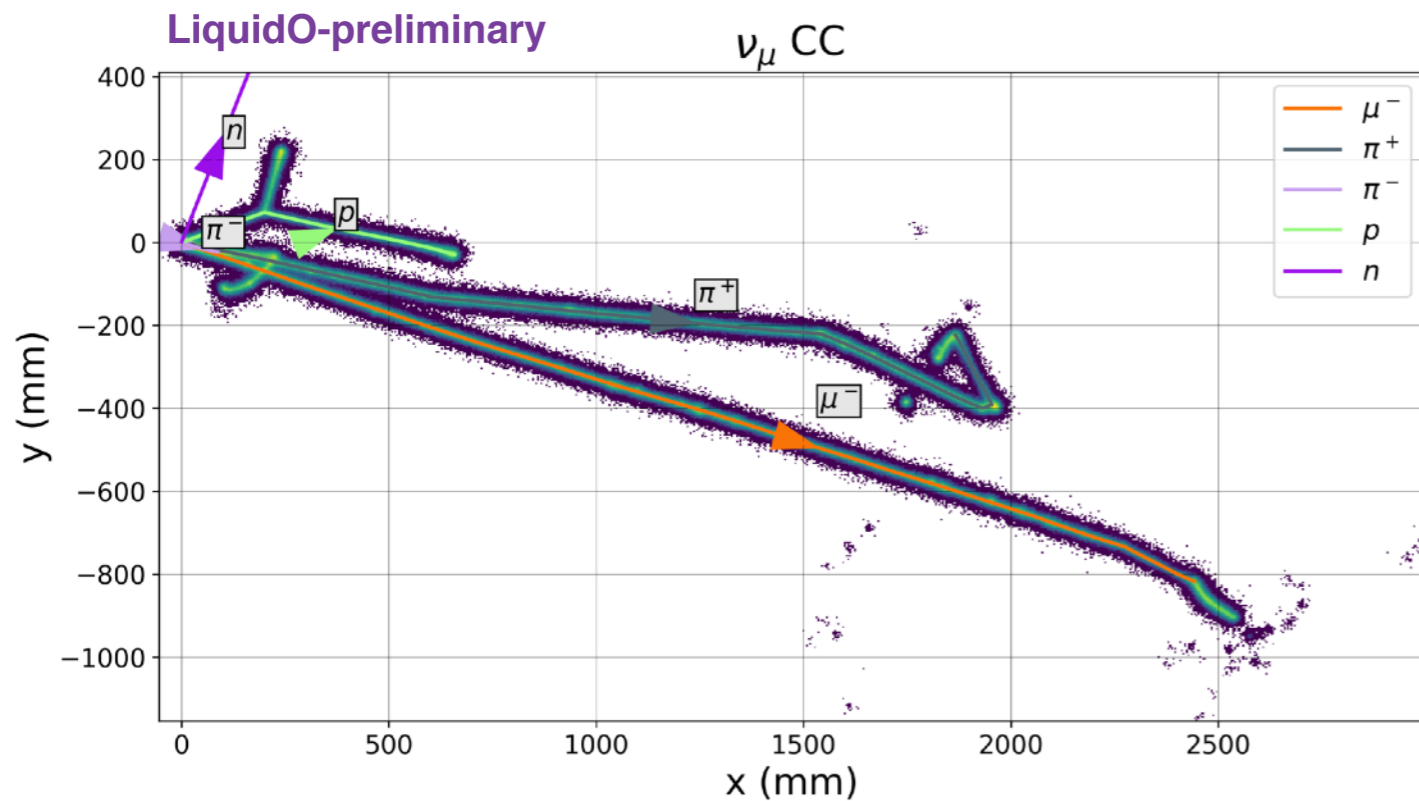


**Imaging capabilities comparable to those of LArTPC**

+

**Complementary features unique to LiquidO**

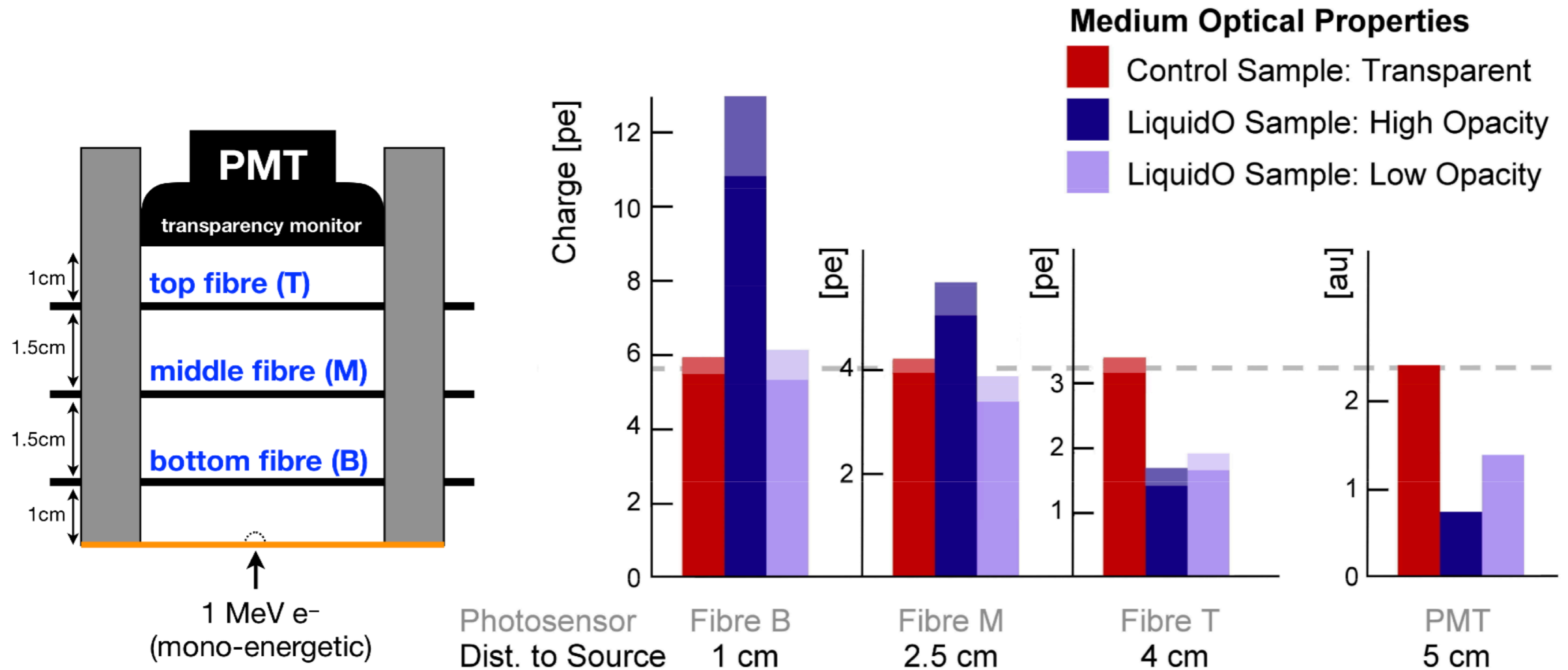
A couple more examples @ 2 GeV



Publications about LiquidO's physics potential are in preparation!

# Does it work?

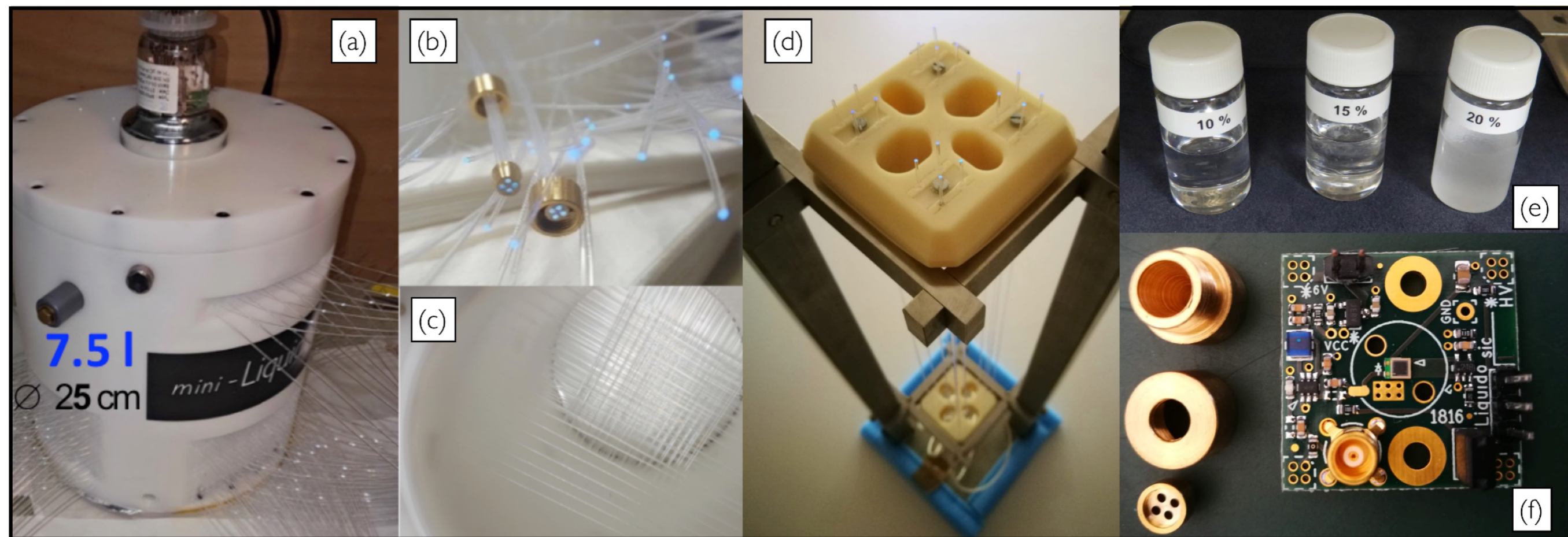
- A first-principles validation of LiquidO has already been accomplished in the laboratory:



Observed stochastic confinement of the light with the opaque sample!  
(see [arXiv:1908.02859](https://arxiv.org/abs/1908.02859) for more details)

# Status of R&D

- R&D well advanced in terms of detector, mechanics, optical readout & scintillator:



- We are about to commission a 7.5 liter prototype called “Mini-LiquidO”
- In parallel, working towards a **multi-ton demonstrator detector**



# Summary & Conclusions



- LiquidO is an innovative neutrino detection technology that exploits the power in opaque scintillators for the first time
- LiquidO builds on successes of mainstream scintillator detectors but brings unprecedented capabilities to the table. For instance:
  - Beautiful imaging from the GeV scale down to the MeV scale
  - Unparalleled doping ability
- LiquidO could have a very strong impact in many areas of neutrino physics:
  - The parameter space is very wide, and LiquidO can be optimized for many different energies and physics goals
  - Plenty of uncharted territory to explore (unprecedented doping levels, unconventional scintillators... etc)
- LiquidO still in early stages, but R&D progressing rapidly and steadily:
  - Proof-of-principle already obtained, and working towards a multi-ton demonstrator

*We have only scratched the surface so far... stay tuned!!*