

*LiquidO*

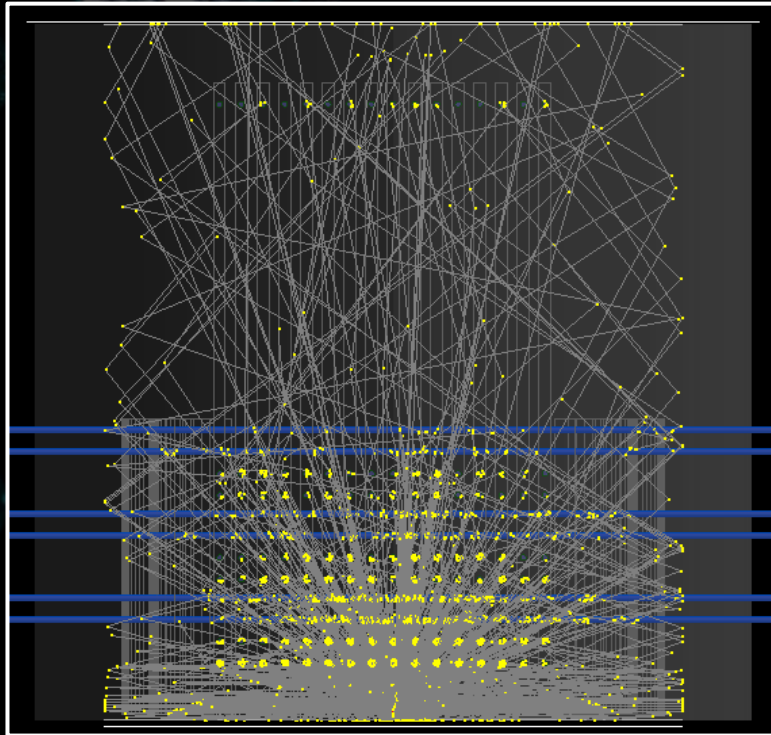
# LiquidO: detecting light in the opacity

Diana Navas Nicolás

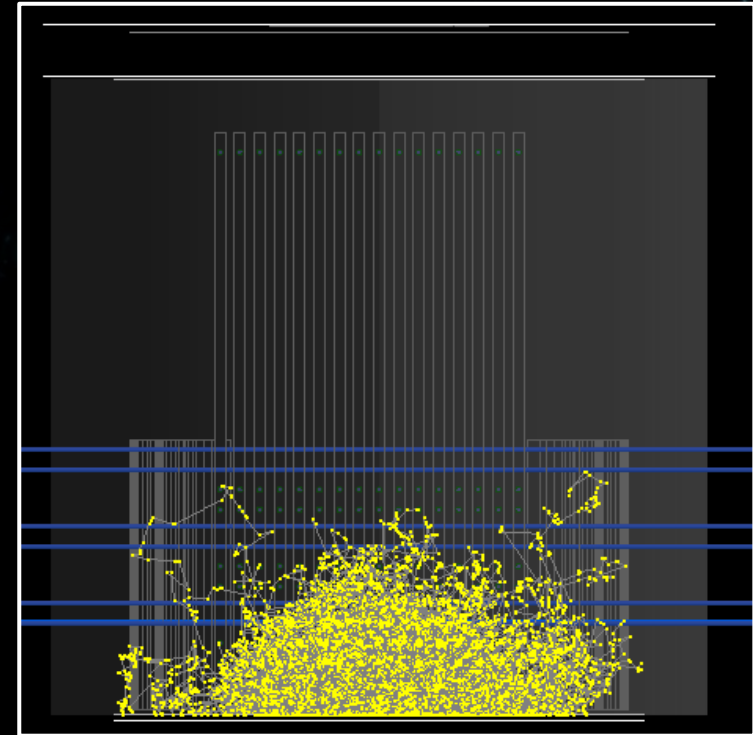
On behalf of the LiquidO consortium

# LiquidO as a new detection approach

Stochastic light confinement near its creation point by using **opaque medium** (short scattering length)



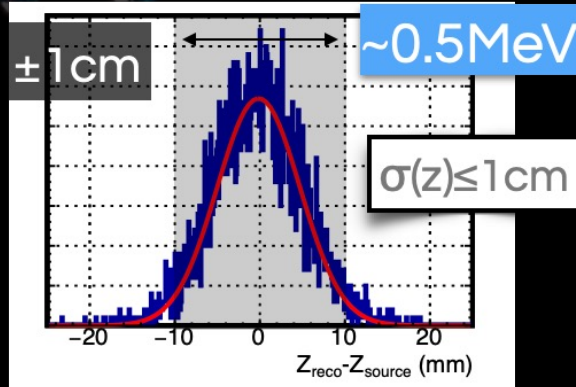
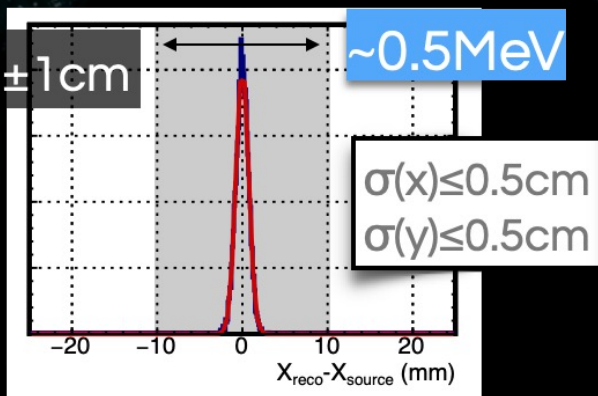
**Transparent:** Today's technology  
Topology information washed out



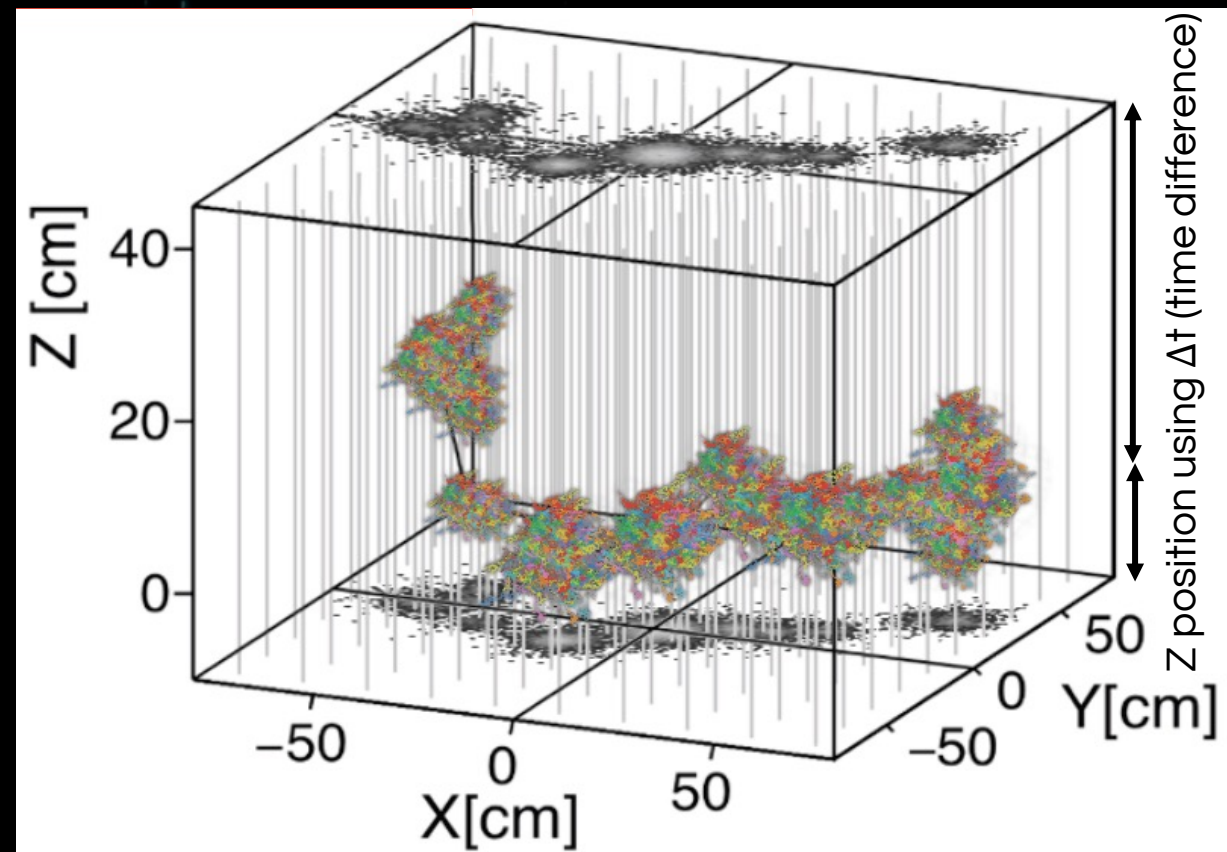
**Opaque:** LiquidO technology  
Light clustering

# Innovative Detection Technique

- ★ Maximal light collection by a **dense array of fibers**
- ★ **Fast time resolution (SiPMs)** ( $< 0.1$  ns)
- ★ **Excellent vertex resolution** (mm scale)

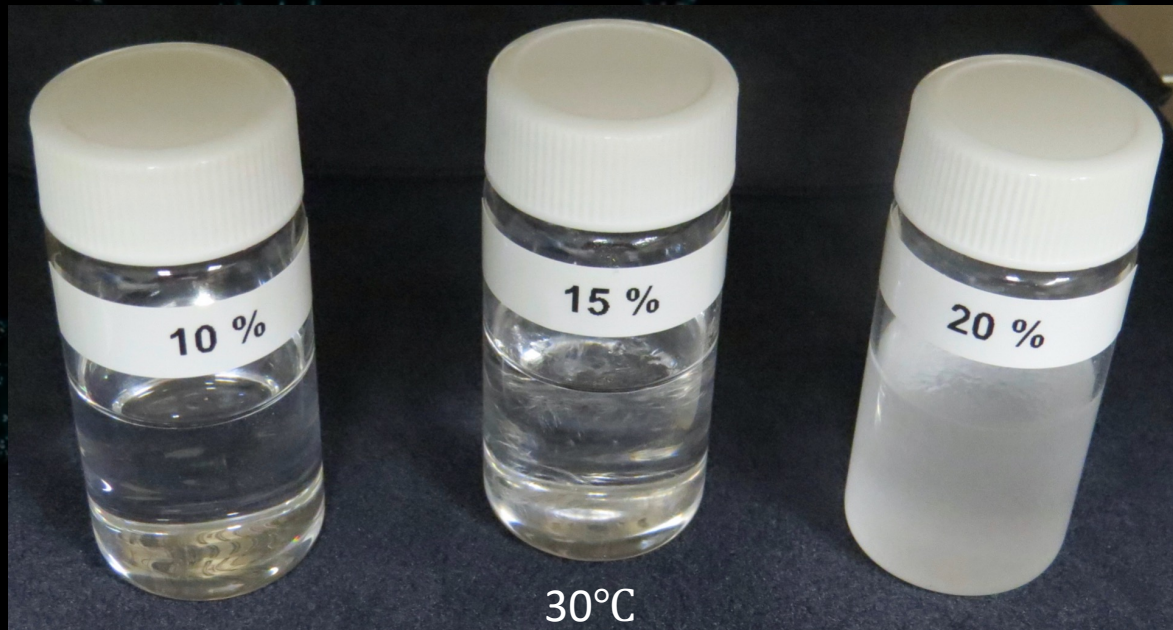


Top view: (x,y) projection



Bottom view: (x,y) projection

# Opaque Scintillator



## NoWaSH (NW)

- ★ Linear Alkyl Benzene (~80 wt.%) + Paraffin Wax (~20 wt.%) + PPO (~0.3 wt.%)
- ★ Opacity depends on paraffin concentration (changes crystallisation temperature)
- ★ **Short scattering length and moderate absorption length**

arXiv:1908.03334

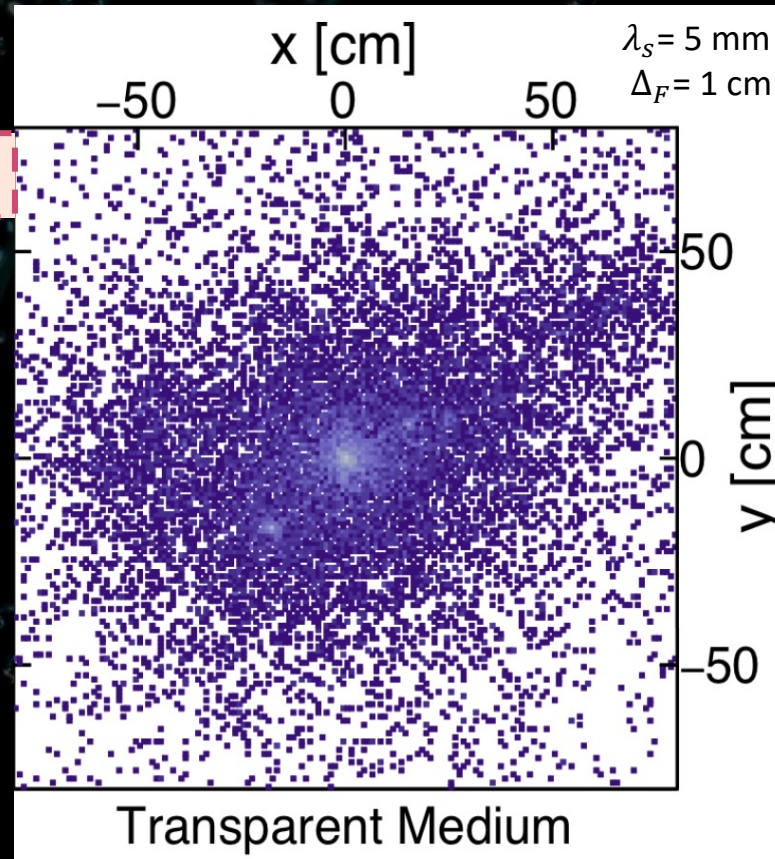
**LiquidO R&D extensive field:** new  $\mu$ Crystal scintillators arXiv:1807.00628, emulsion...(under study)

# Unprecedented Imaging Capabilities

ENERGY DEPOSITION 1 MEV SIMULATED  $e^+$

Reactor  $\bar{\nu}_e \rightarrow e^+$  tagging

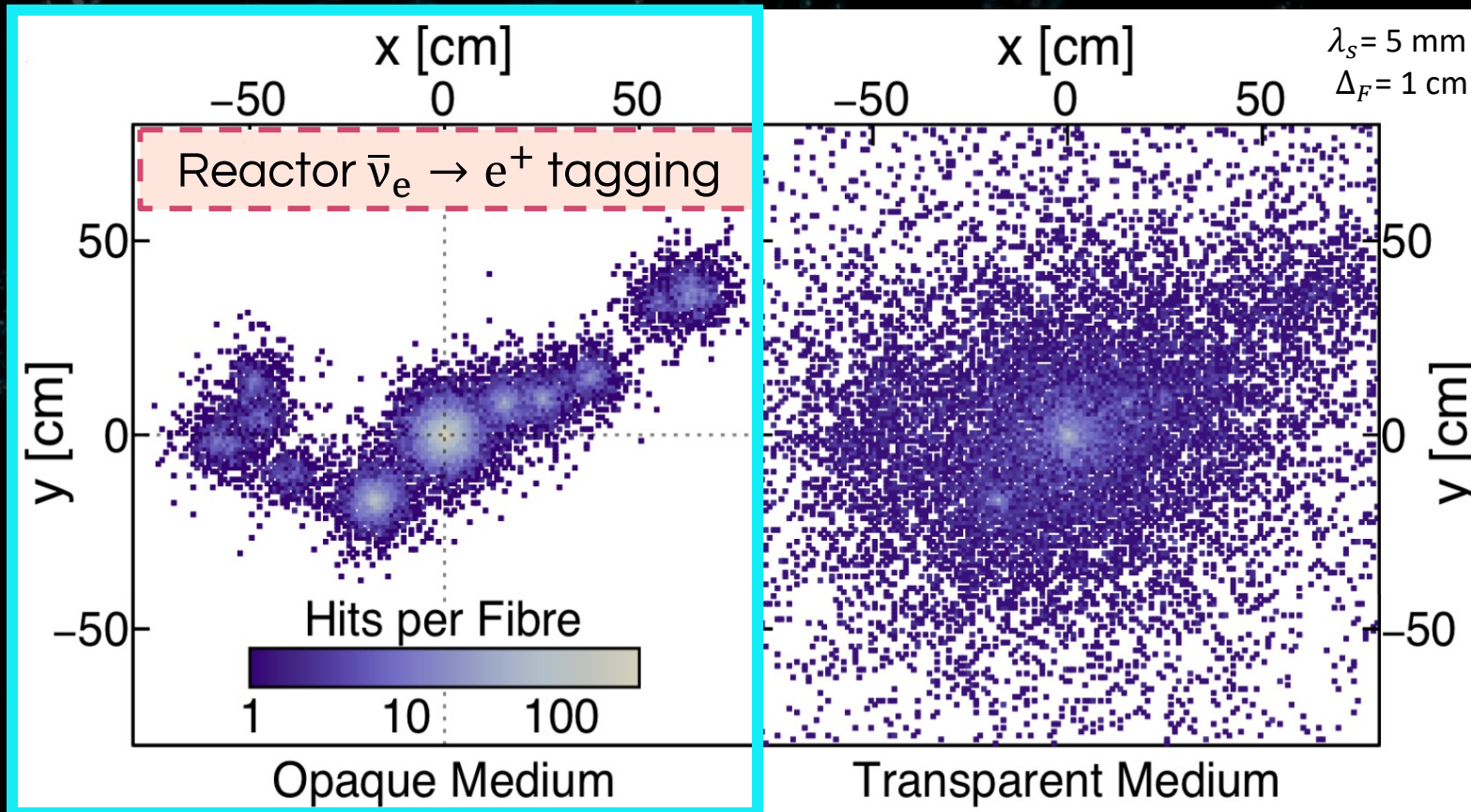
USUAL TRANSPARENT  
LIQUID SCINTILLATOR  
DETECTORS



- ★ Topological Particle Identification (PID) is a challenge in MeV neutrino detection

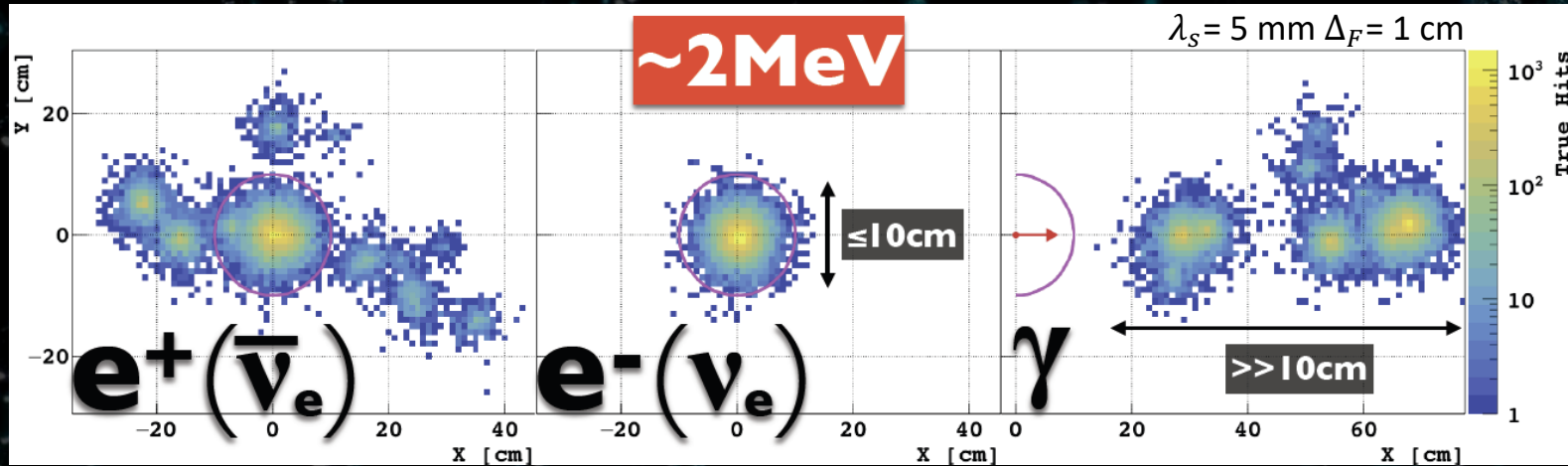
# Unprecedented Imaging Capabilities

ENERGY DEPOSITION 1 MEV SIMULATED  $e^+$



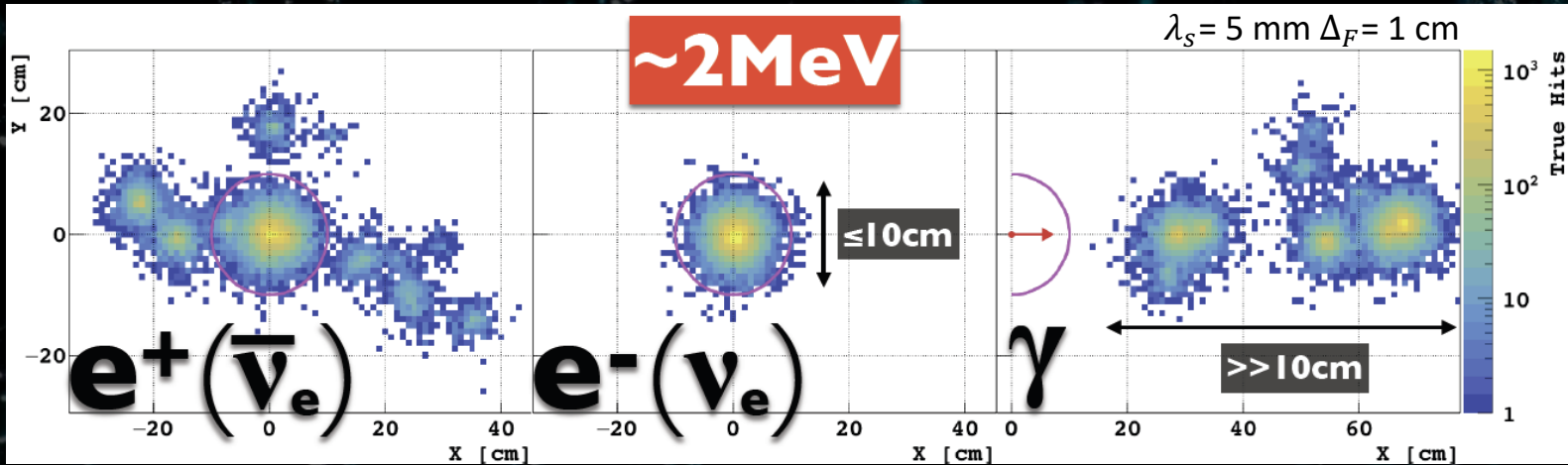
- ★ Topological Particle Identification (PID) is a challenge in MeV neutrino detection
- ★ Confinement of light into **sphere around each ionization point**
- ★ **A self-segmented detector!** (no need to introduce dead material for segmentation)

# Unprecedented Particle Identification

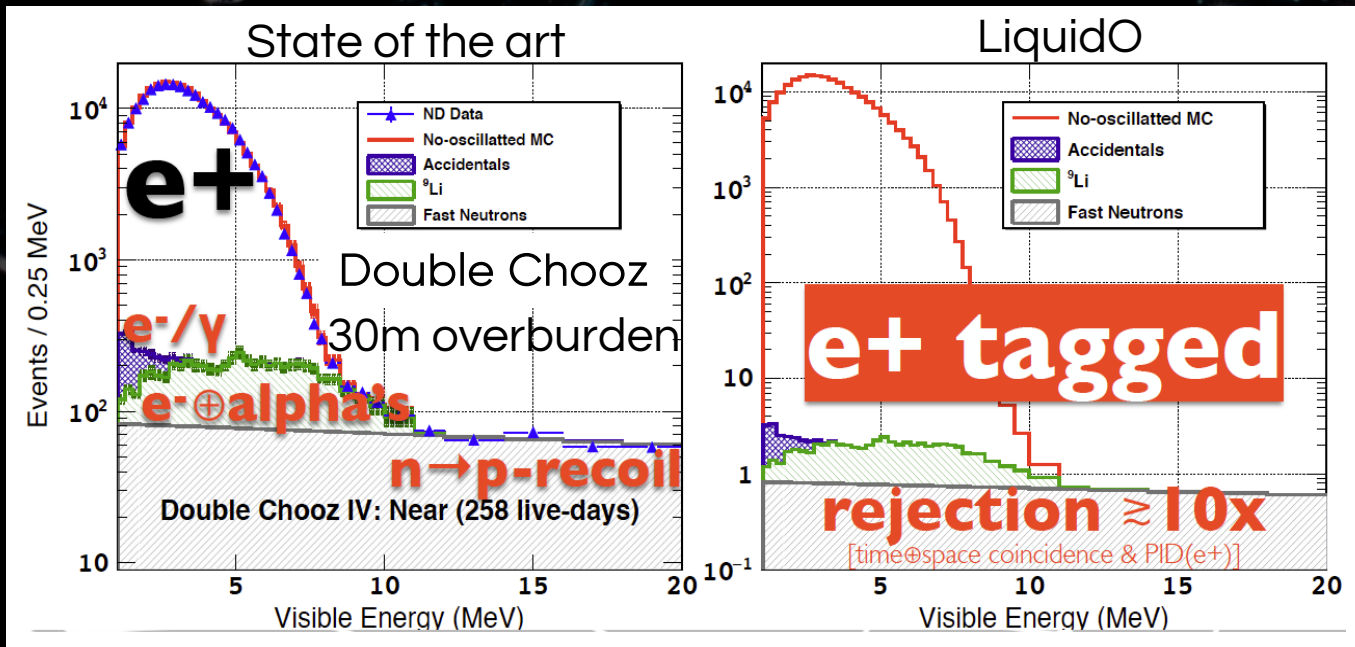


- ★ Discrimination of individual  $e^+$ ,  $e^-$  and  $\gamma$  events @1MeV
- ★ Matter/Antimatter separation  $\rightarrow$  CP violation

# Unprecedented Particle Identification



- ★ Discrimination of individual  $e^+$ ,  $e^-$  and  $\gamma$  events @1MeV
- ★ Matter/Antimatter separation  $\rightarrow$  CP violation



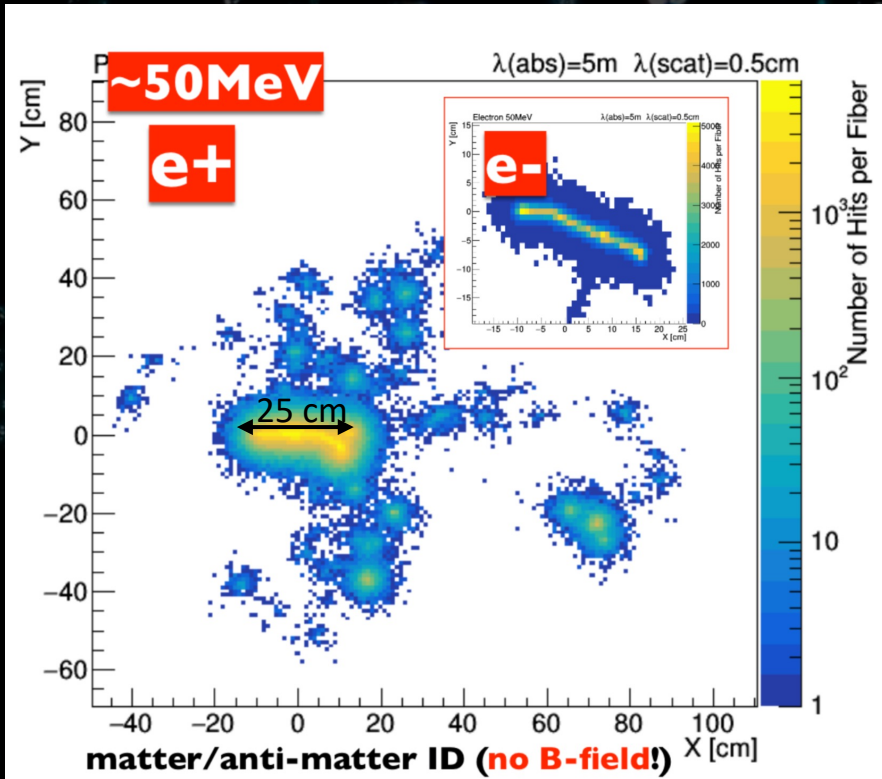
- ★ Powerful Background Rejection
- ★ PID + vertex coincidence

Nat. Phys. 16, 558–564 (2020)



# Wide Physics potential

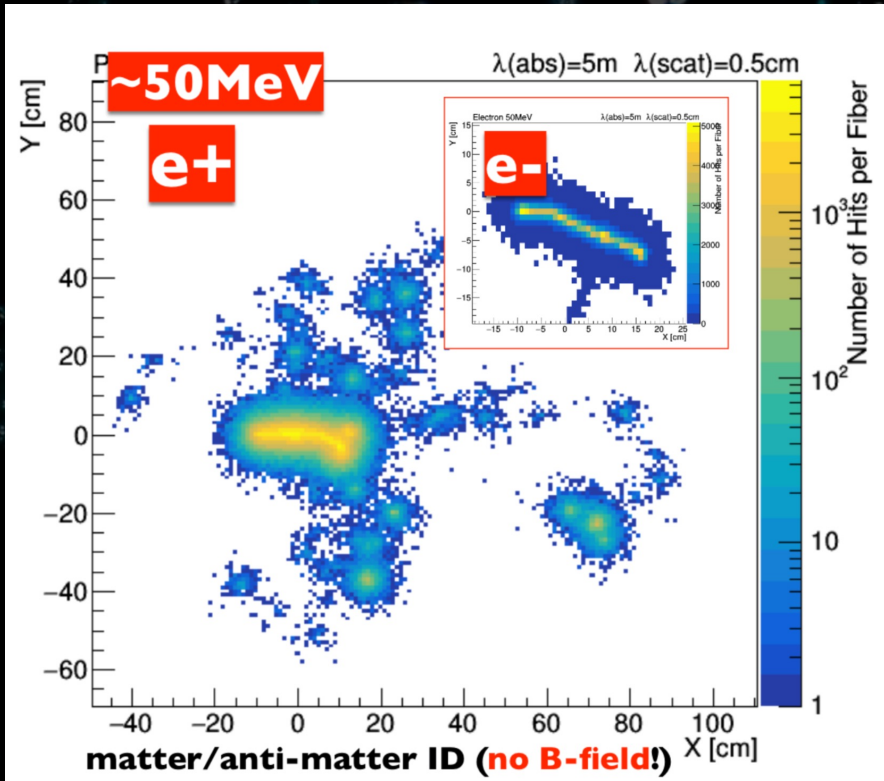
FROM MEV TO MULTIMEV



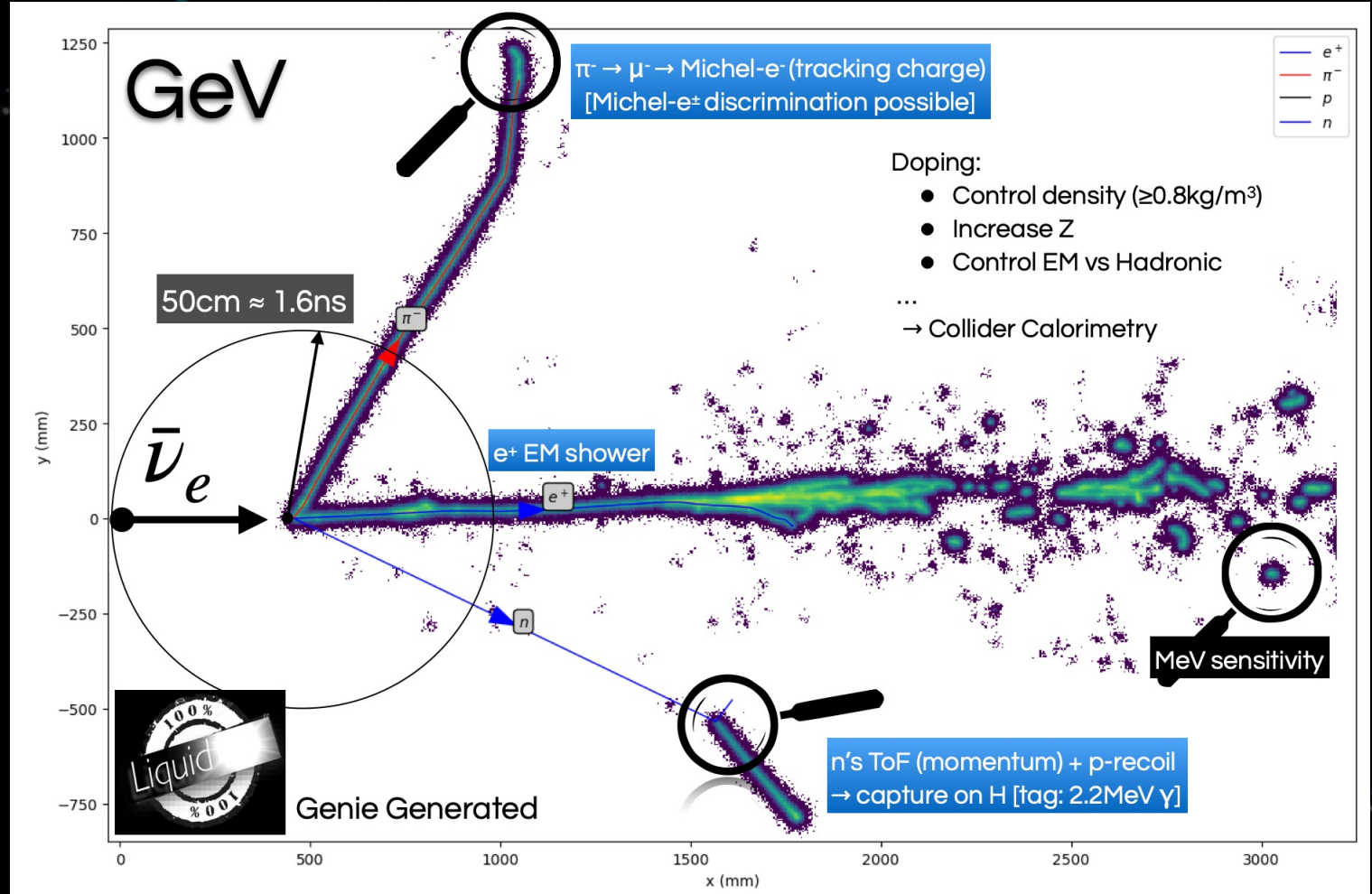
- ★ Powerful PID: **topology** of deposited energy
- ★ Energy Flow: **time pattern** for the light to be collected
- ★ **Tracking** (mm)
- ★ **Directionality**
- ★  $dE/dx$  (range)

# Wide Physics potential

FROM MEV TO MULTIMEV



FROM MULTIMEV TO GEV



# Wide Physics potential

Article | [Open Access](#) | [Published: 21 December 2021](#)

## Neutrino physics with an opaque detector

[LiquidO Consortium](#)

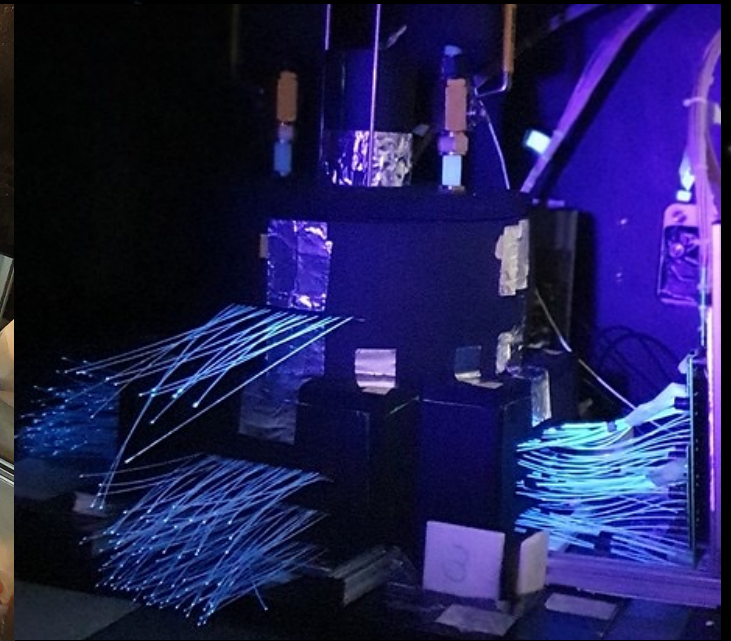
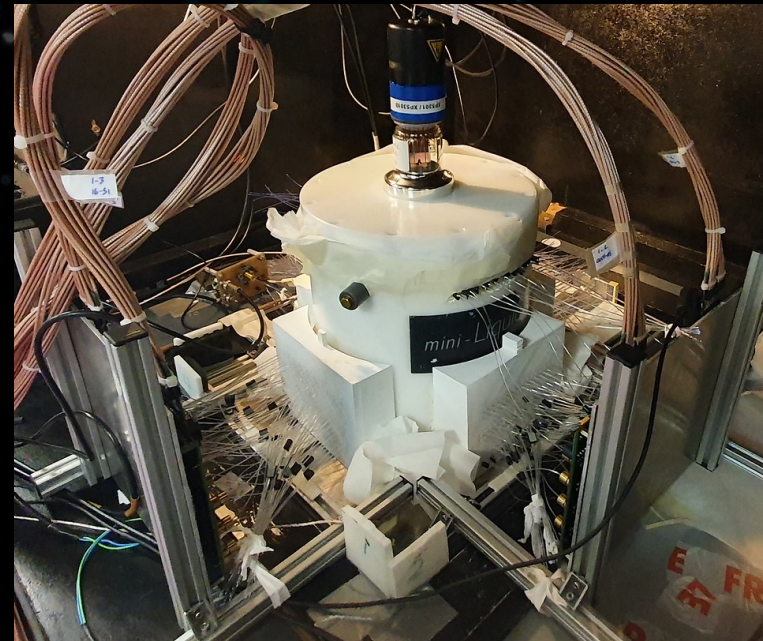
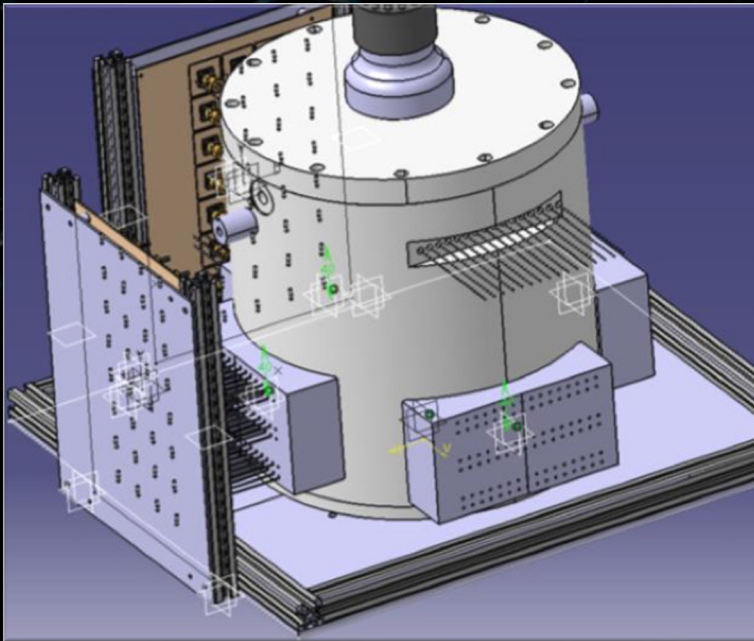
[Communications Physics](#) **4**, Article number: 273 (2021) | [Cite this article](#)

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- ★ Micro-LiquidO: First experimental proof of principle
- ★ Much more physics: reactor and supernova neutrinos, geoneutrinos, solar neutrinos...

# Experimental validation

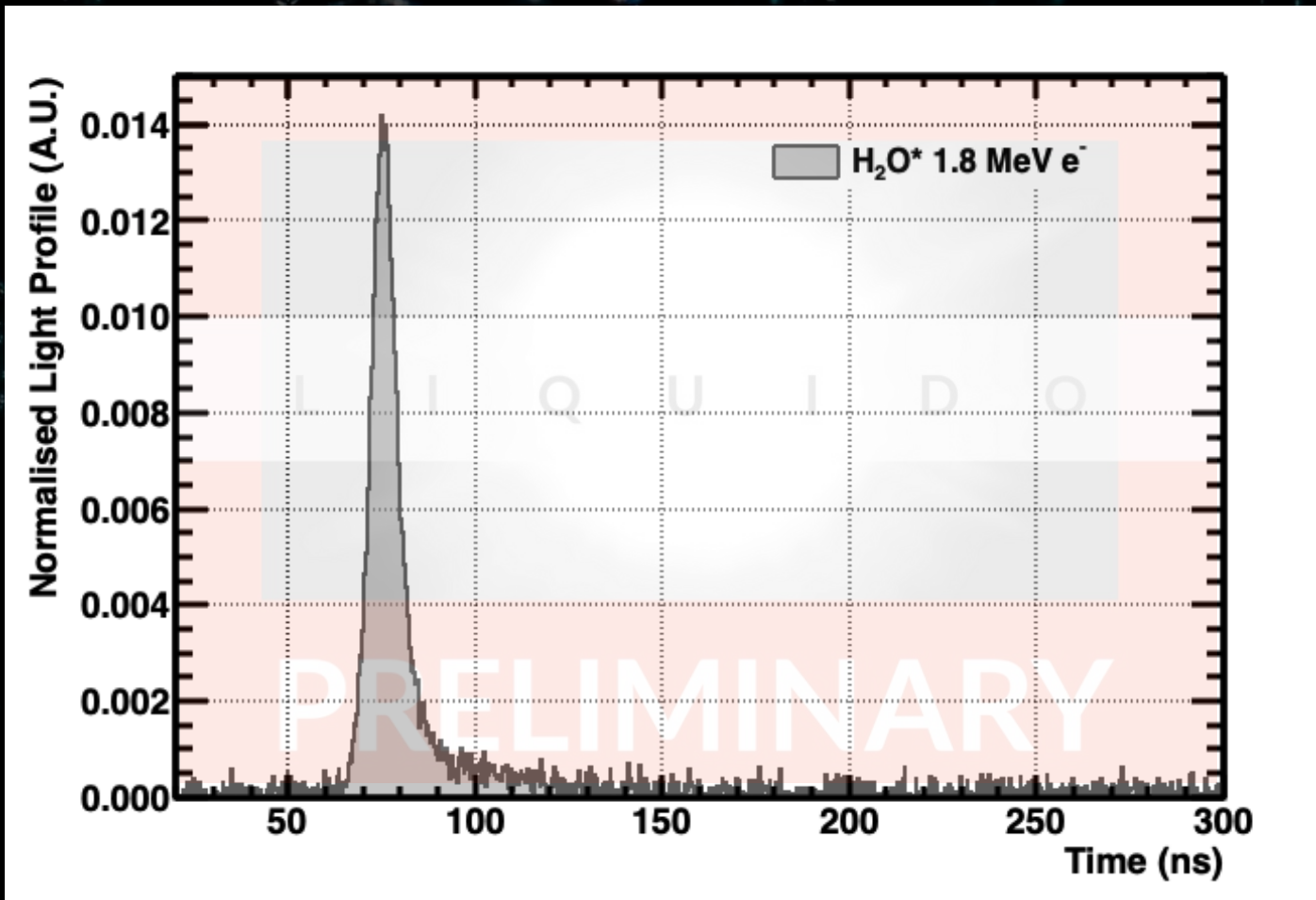
MINI-II (UPGRADE): LIQUIDO'S PROTOTYPE DATA TAKING SINCE 2021



- ★ ~10 L with 64 readout fibres including a 3" PMT
- ★ **e- from monoenergetic beam** ( $^{90}\text{Sr}$ ) [0.4-1.8 MeV]
- ★ **Stochastic light confinement observation**
- ★ **T cycle** [5,40] $^{\circ}\text{C}$  — powerful T control system (Chiller)
- ★ **Very fast electronics:** fast low-power custom preamplifier with sub-ns rise time
- ★ 64-channel WaveCatcher system for waveform digitization (ps time resolution)

# Experimental validation

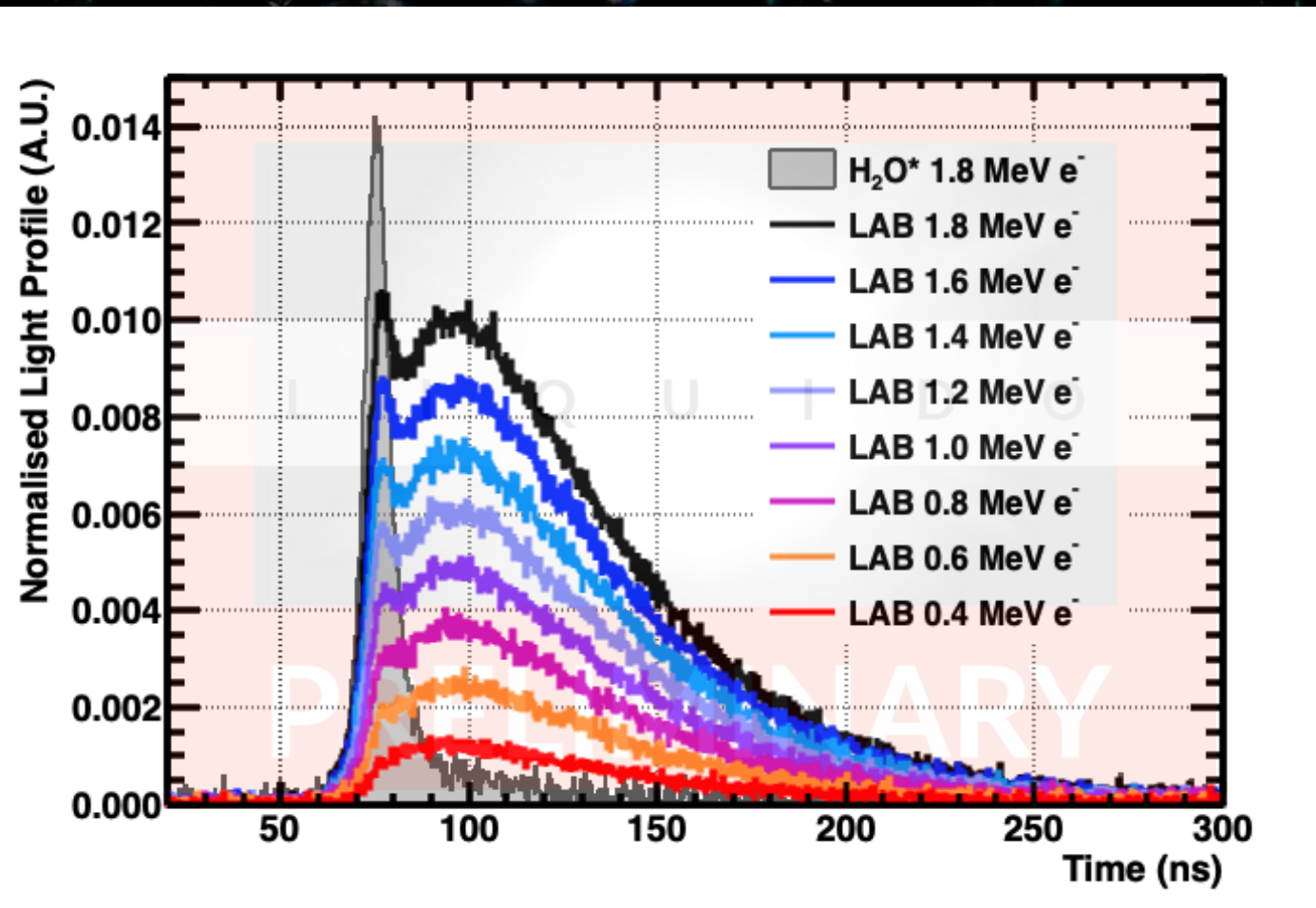
## LIQUIDO'S TIMING POTENTIAL: CHERENKOV VS SCINTILLATION



TRANSPARENT MEDIA REGIME

# Experimental validation

## LIQUIDO'S TIMING POTENTIAL: CHERENKOV VS SCINTILLATION

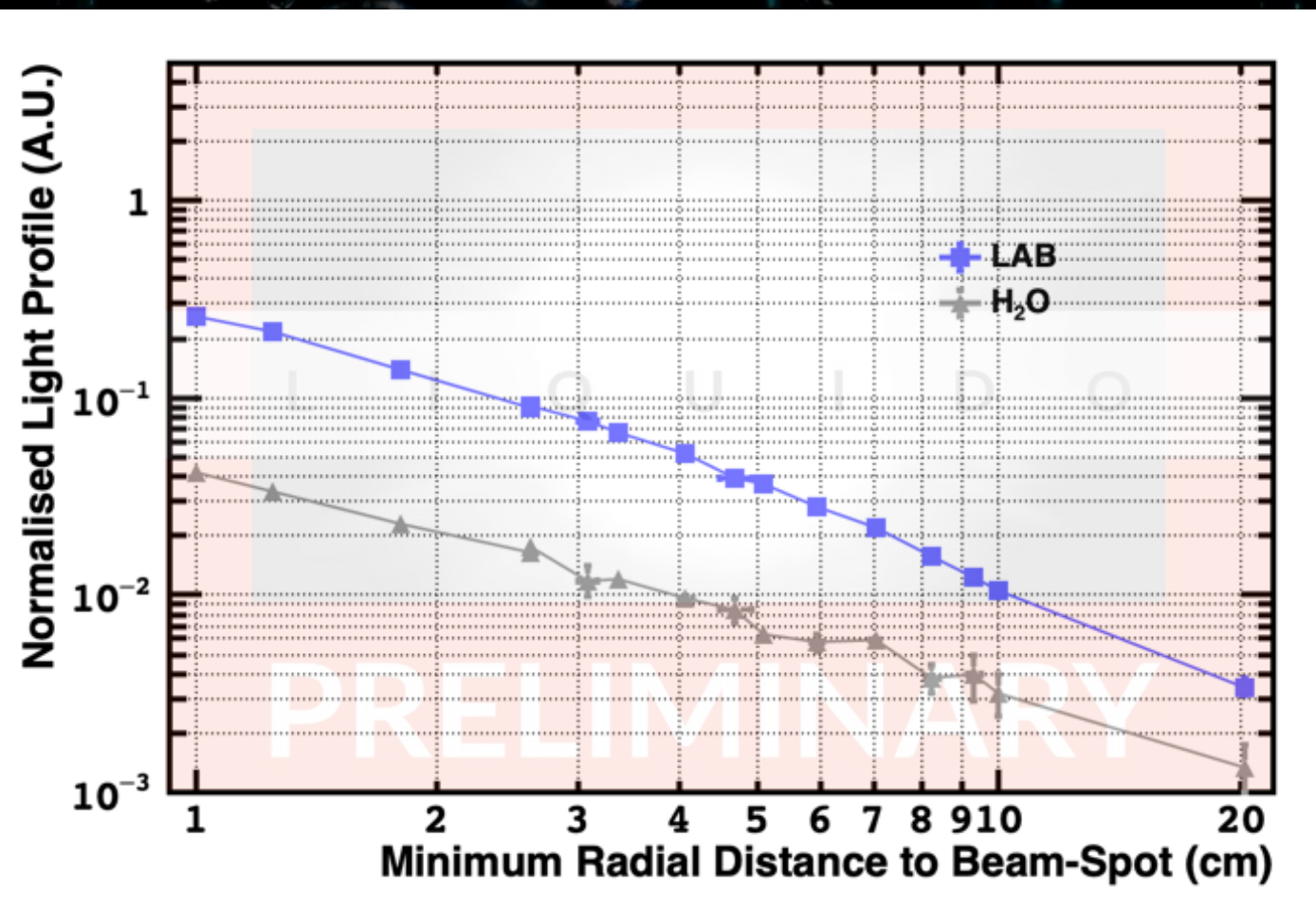


### TRANSPARENT MEDIA REGIME

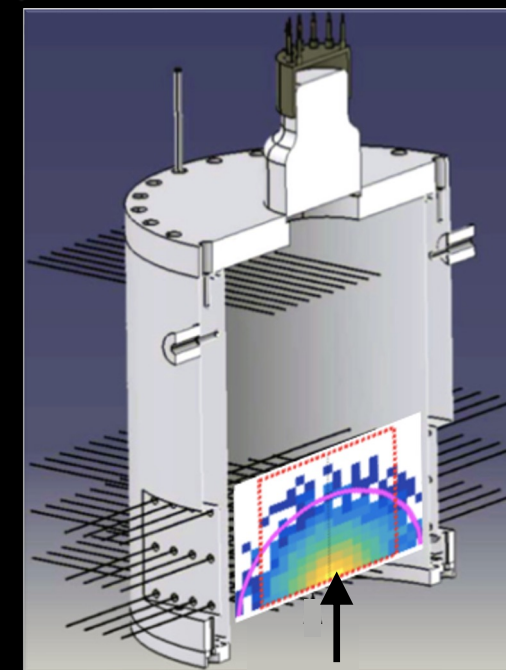
- ★ Liquid scintillator: LAB alone (slow)
- ★ Water data allows confirmation of the Cherenkov peak time position
- ★ Remarkable separation using **only timing**
- ★ **Cherenkov light production threshold**

# Experimental validation

## LIGHT CONFINEMENT DEMONSTRATION: TRANSPARENT VS OPAQUE

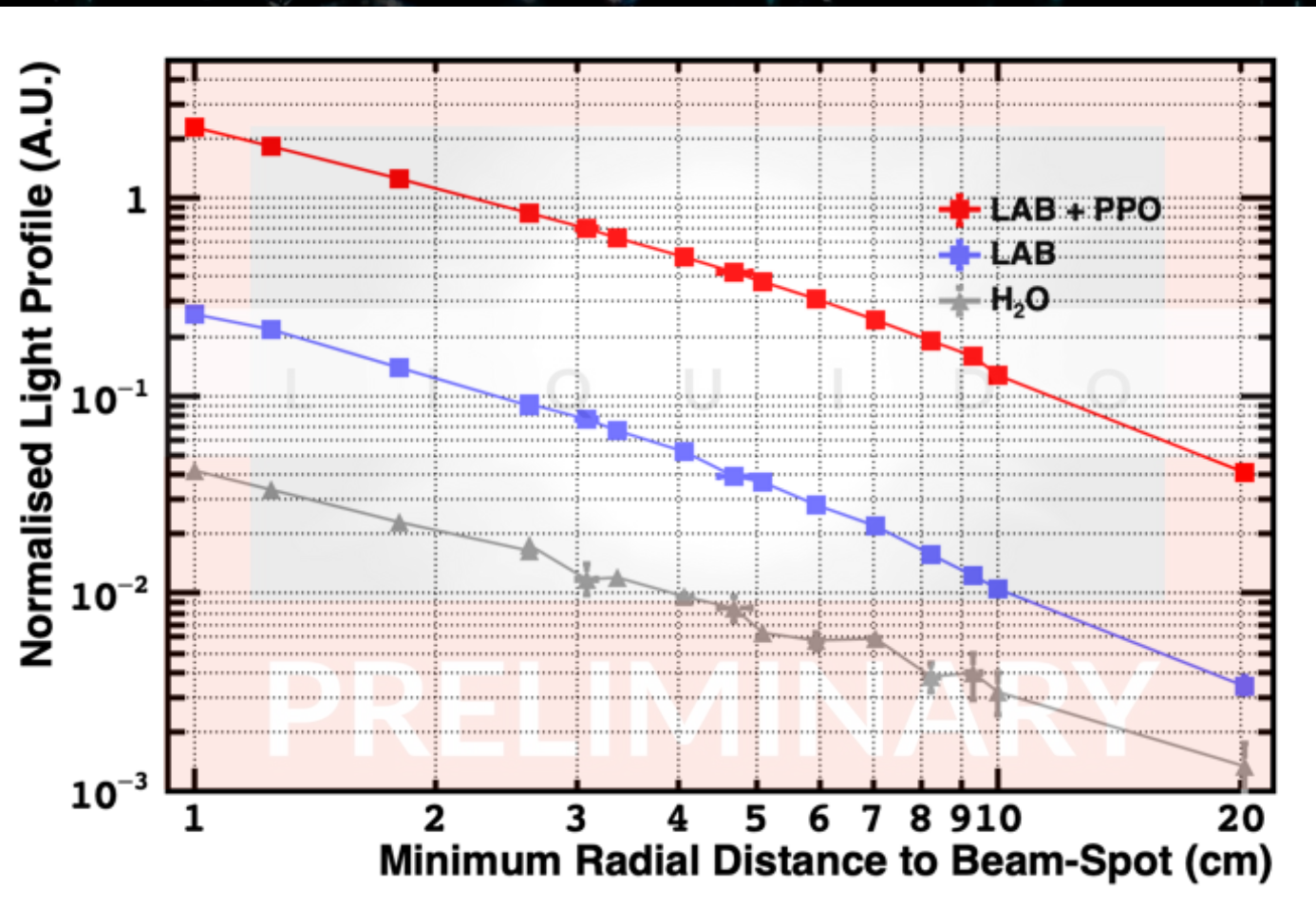


★ Water (LiquidO's lowest acceptance) and LAB (more light due to scintillation)



# Experimental validation

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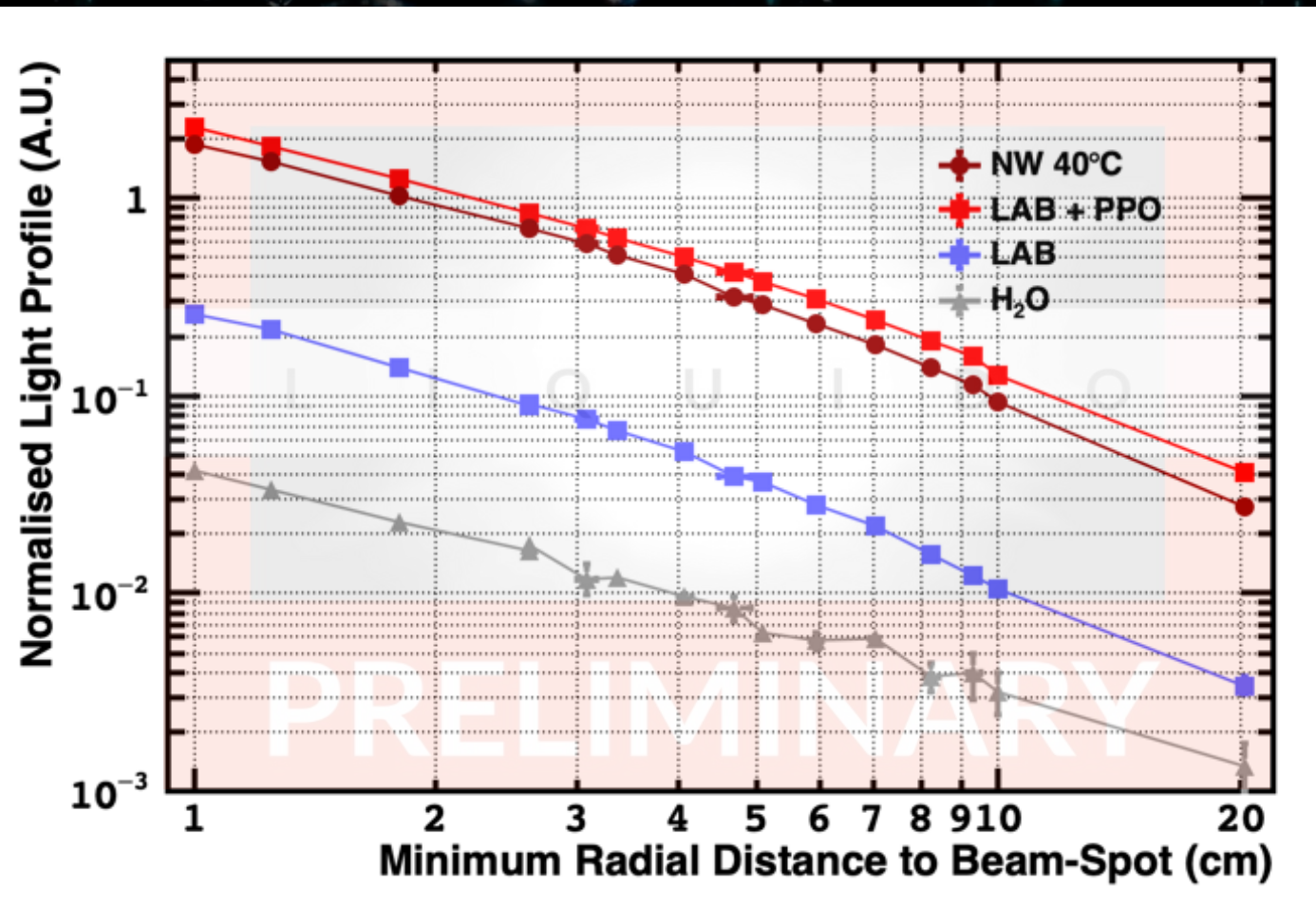


- ★ Water (LiquidO's lowest acceptance) and LAB (more light due to scintillation)
- ★ LAB+PPO ( $\leq 3\text{g/L}$ ): amount of light increased



# Experimental validation

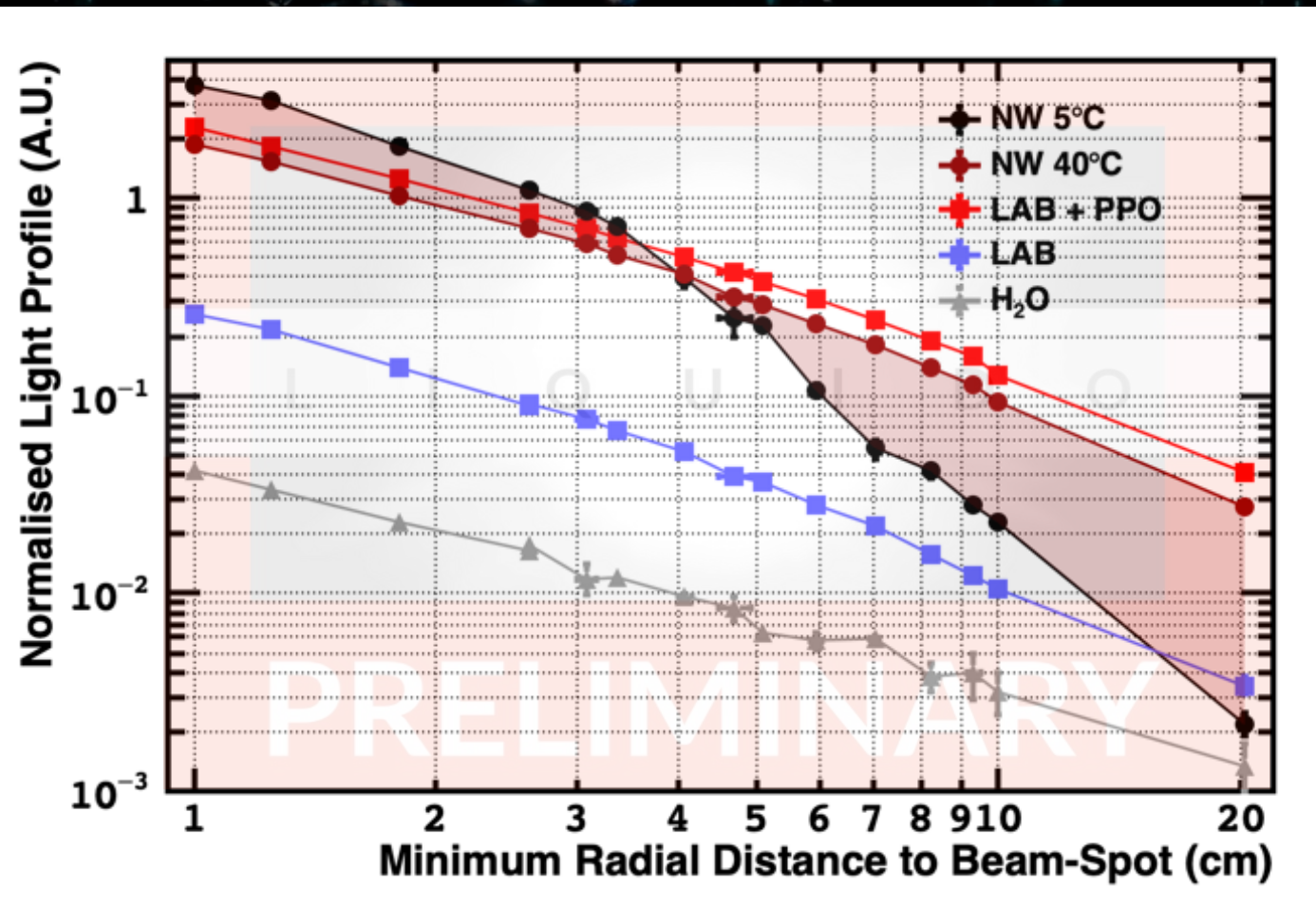
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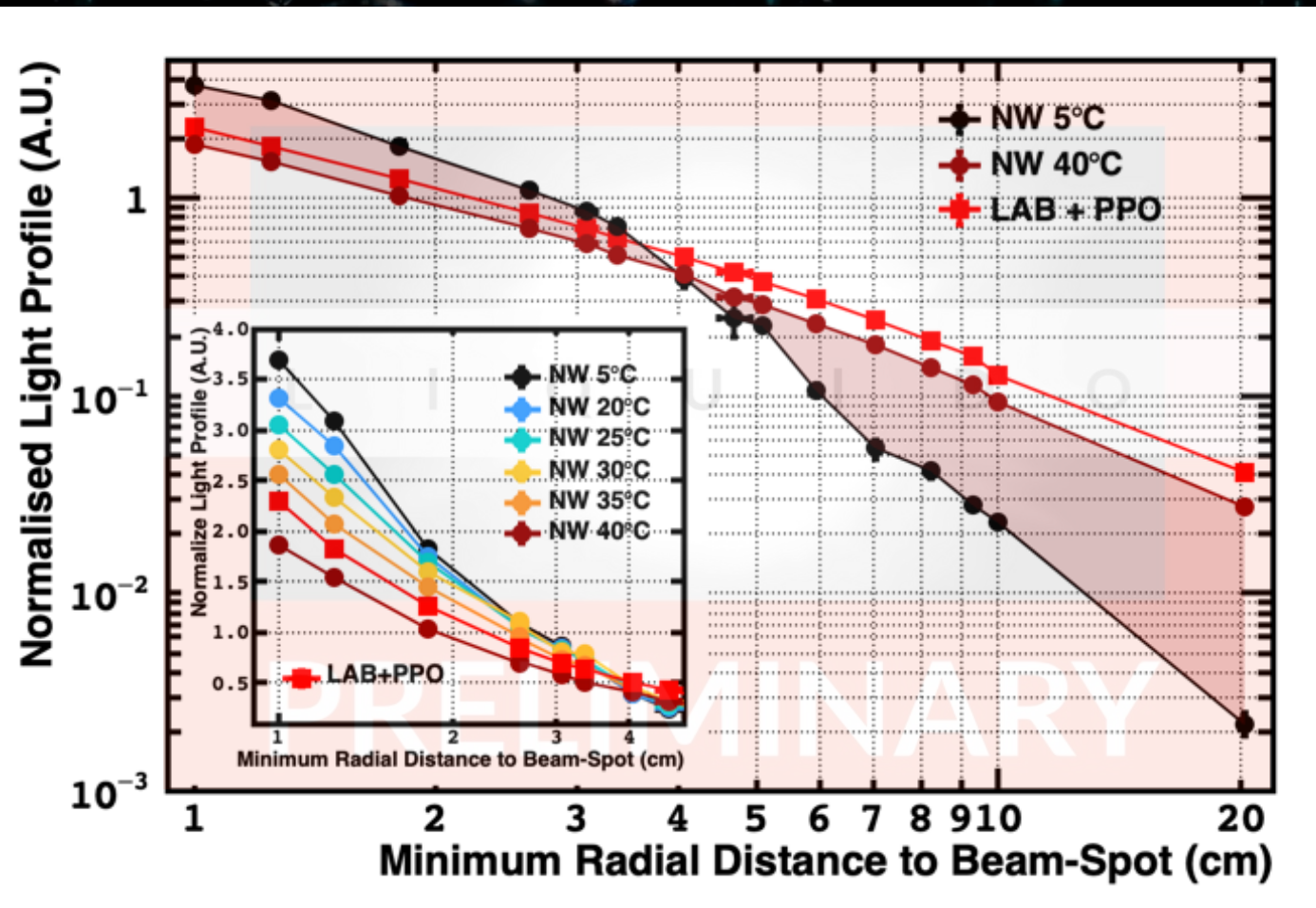
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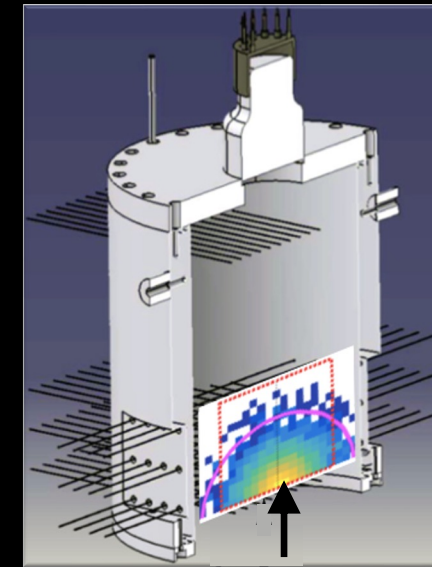
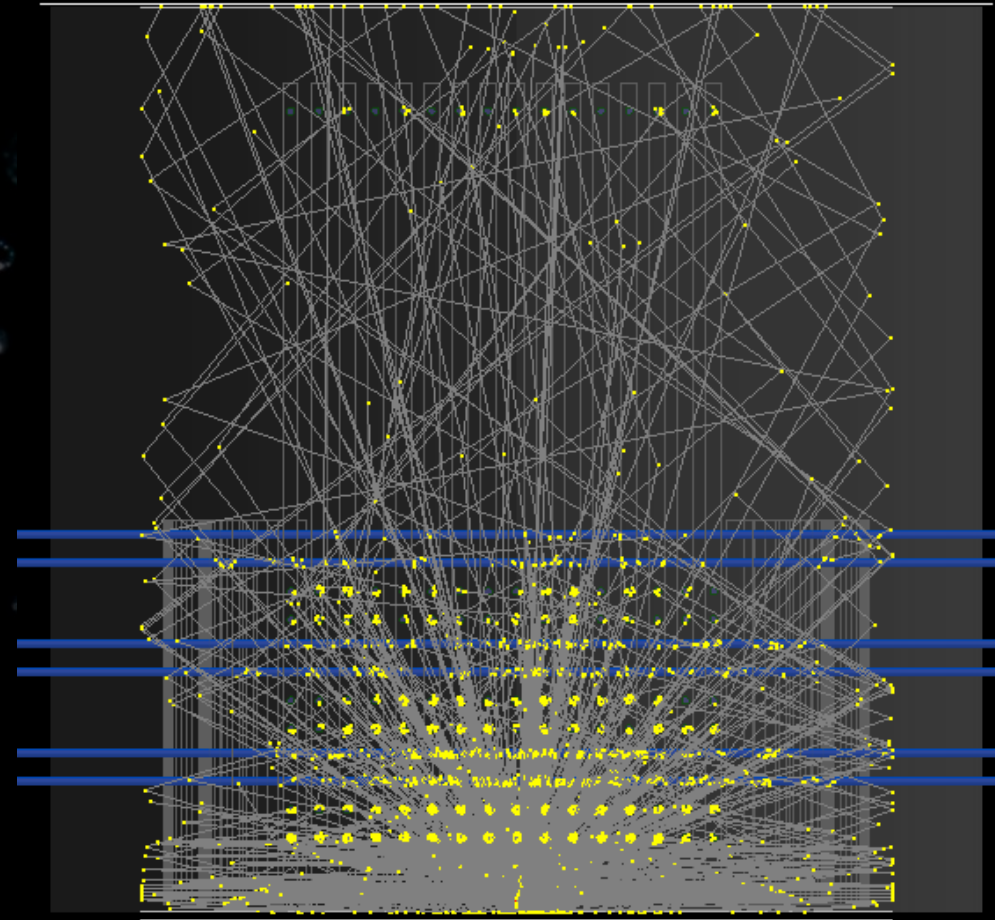
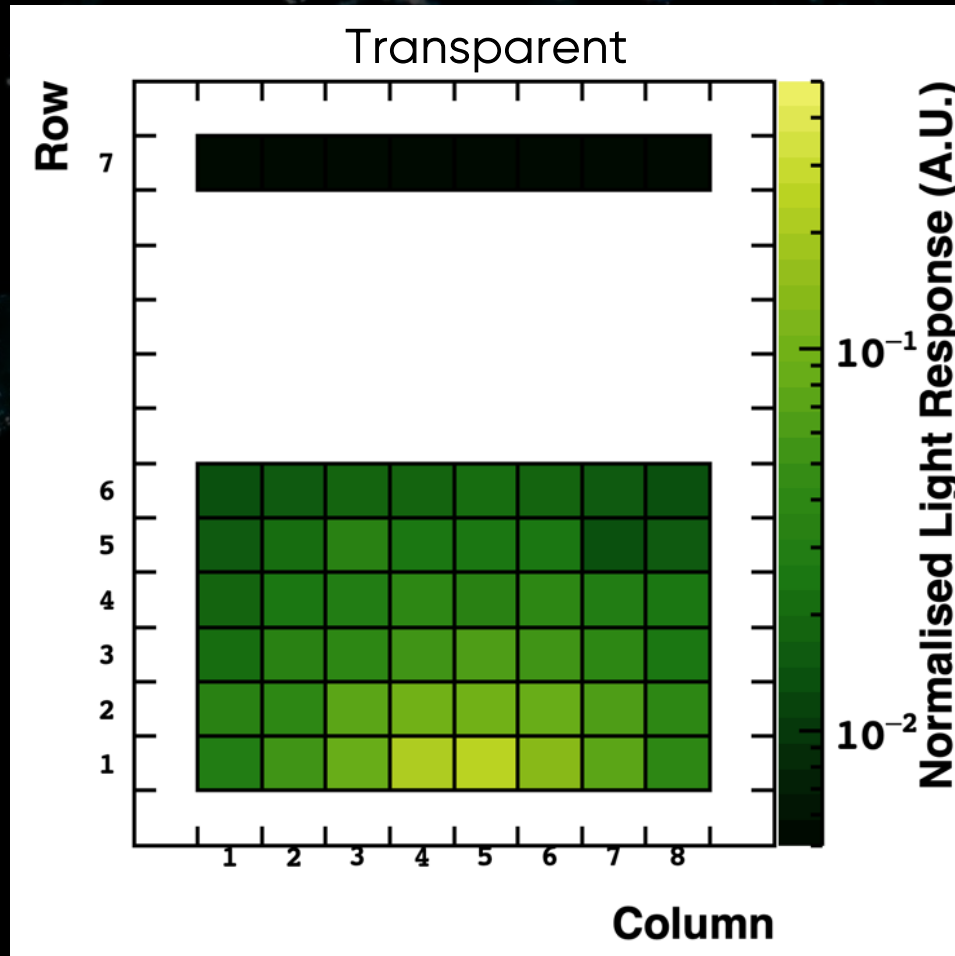
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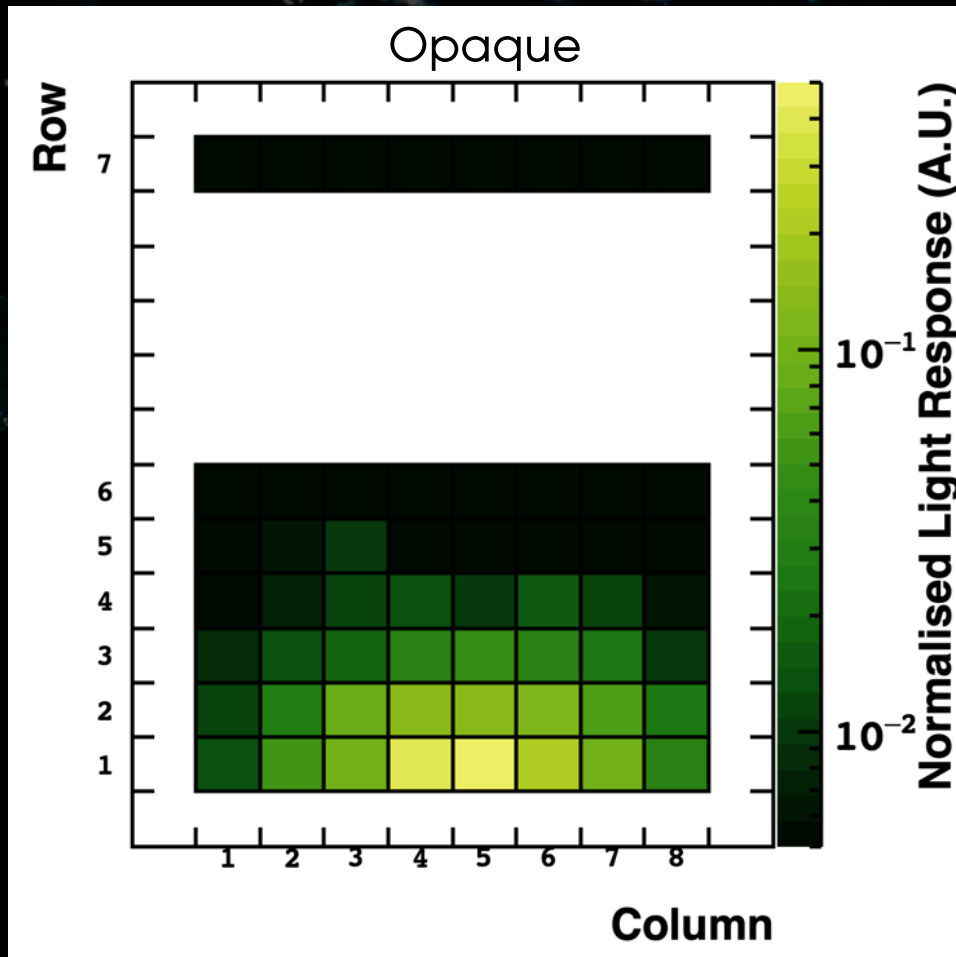
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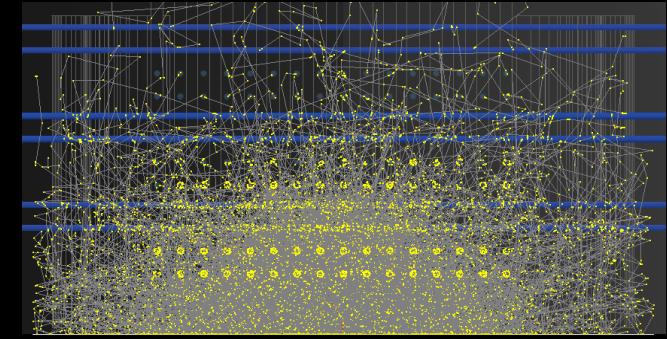
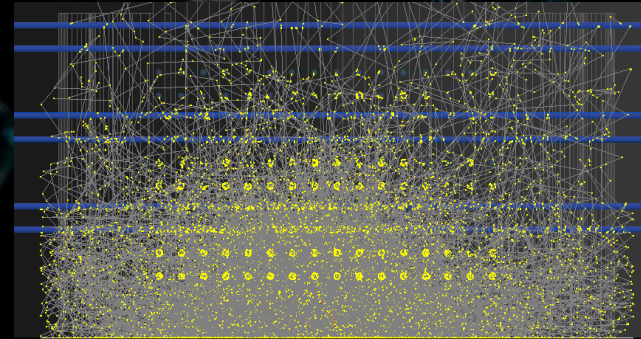
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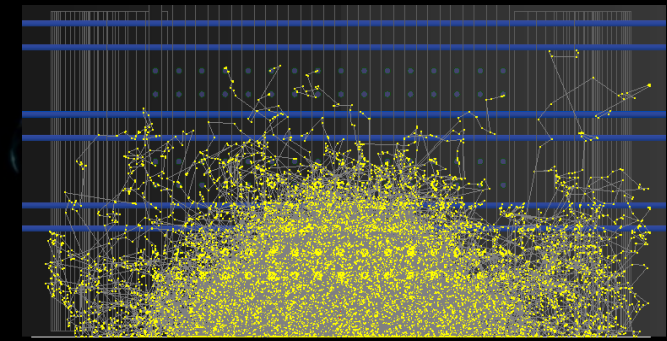
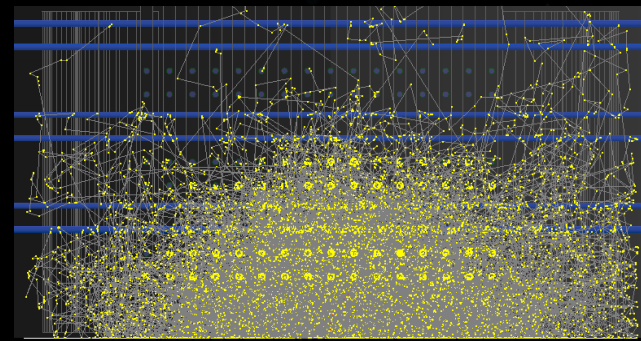
$\lambda_s = 1$  cm

0.75 cm



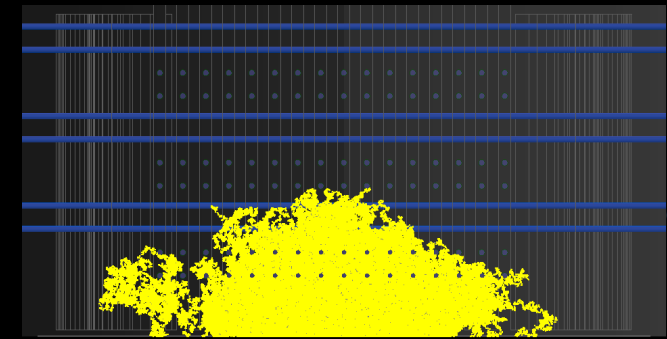
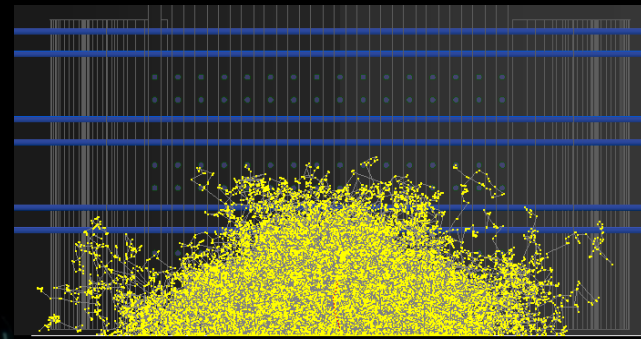
0.5 cm

0.25 cm



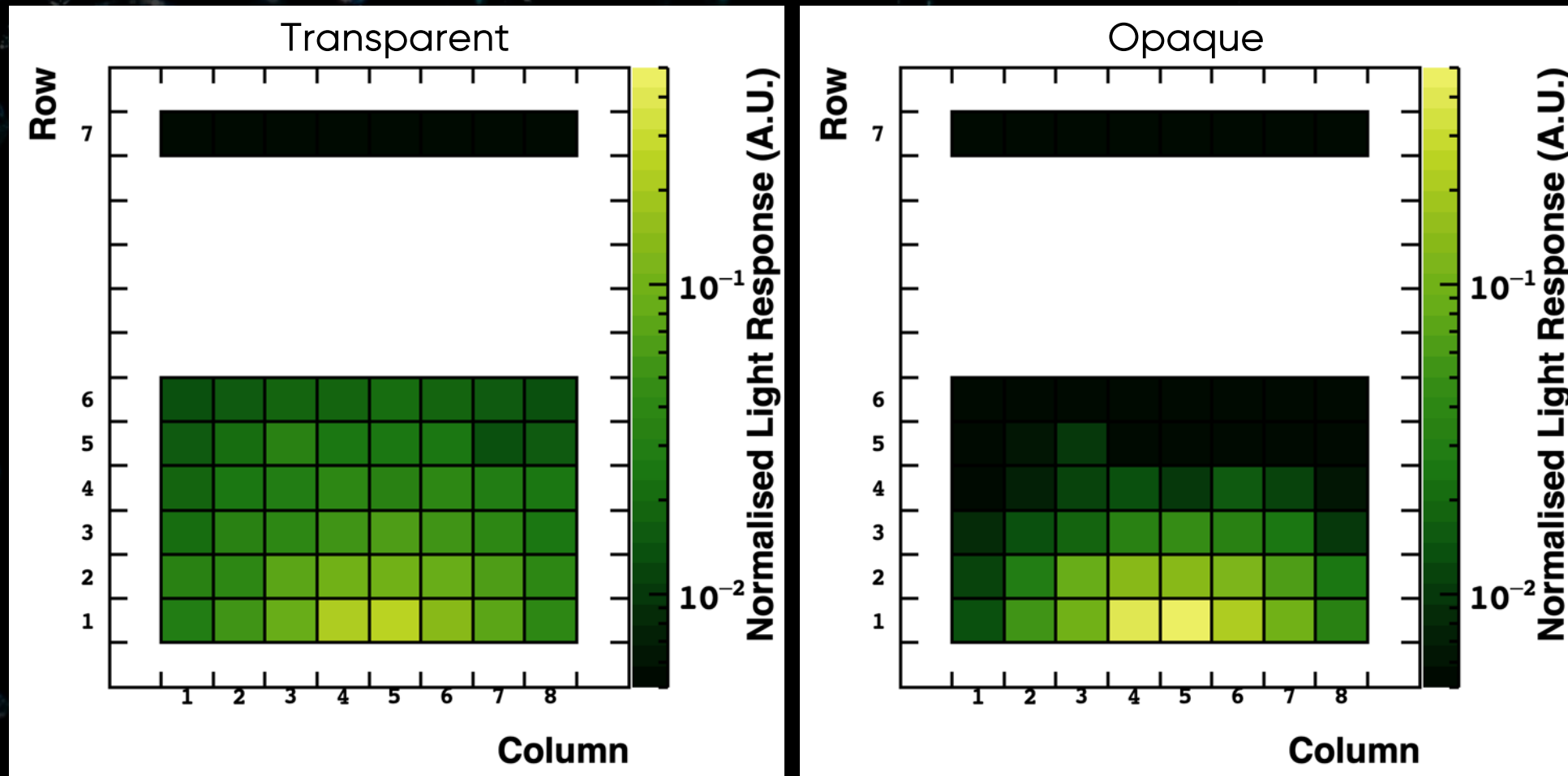
0.1 cm

0.01 cm



# Experimental validation

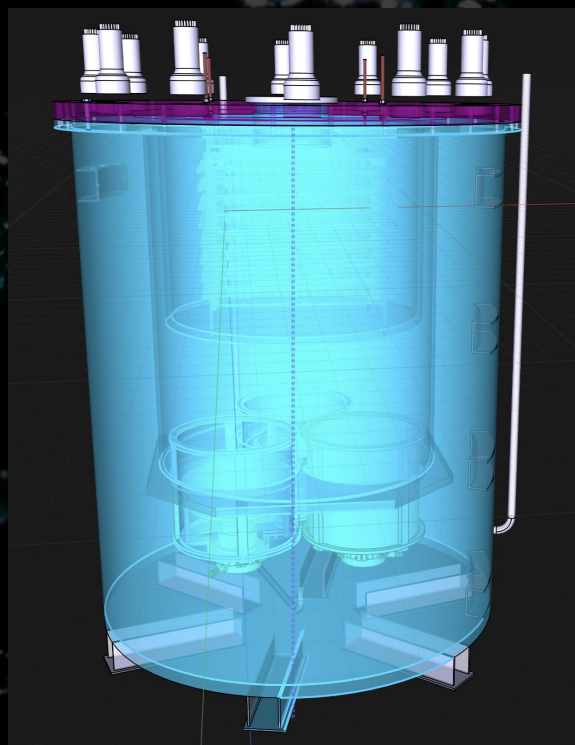
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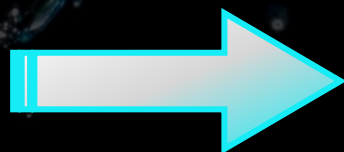
# Future prospects

## PROJECTS SEQUENCE AND TIMELINE

### MINI- $\gamma$ project

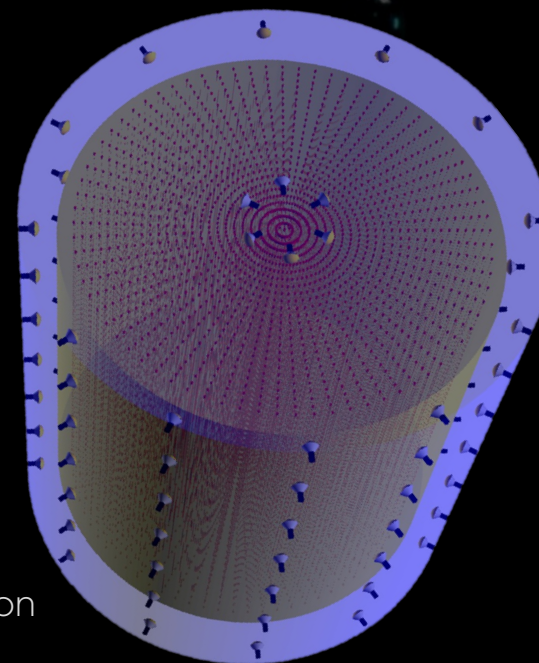


~100 kg  
2022-2023



### AntiMatter-Otech project

Applied & Innovation R&D



Cartoon

~ 5 tons  
2022-2027



<https://antimatter-otech.ijclab.in2p3.fr>

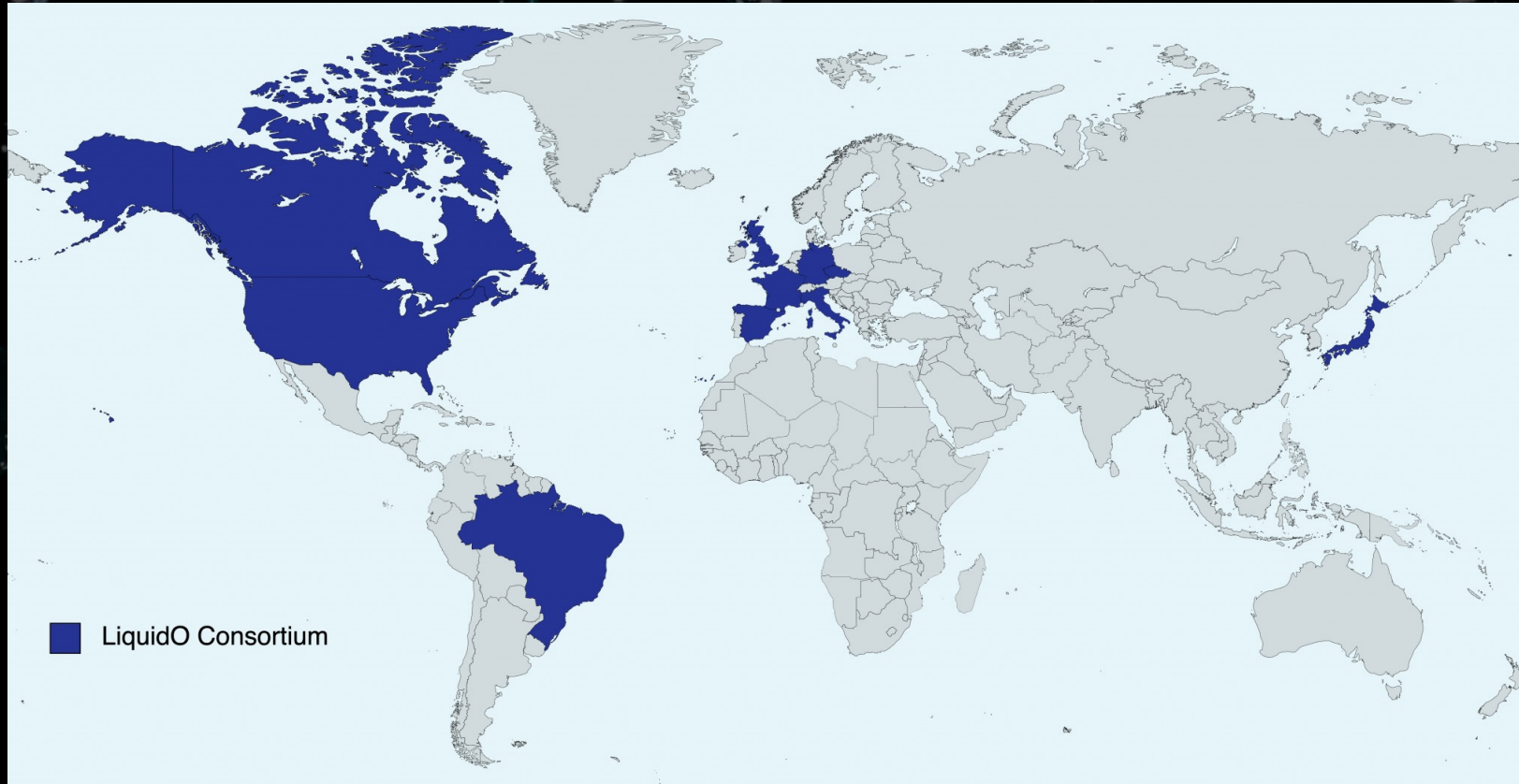
+ LPET-Otech project  
(medical physics)  
2022-2024  
ANR funded

# Future prospects





# LiquidO consortium



LiquidO consortium consists of more than **70 scientists** in 22 academic institutions (universities and/or laboratories) in over **10 countries**

More info

<https://liquido.ijclab.in2p3.fr>

# Conclusions

LiquidO: light/opacity

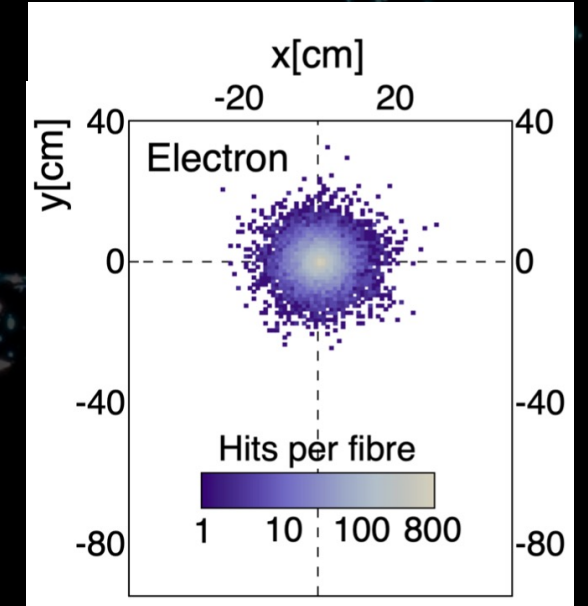
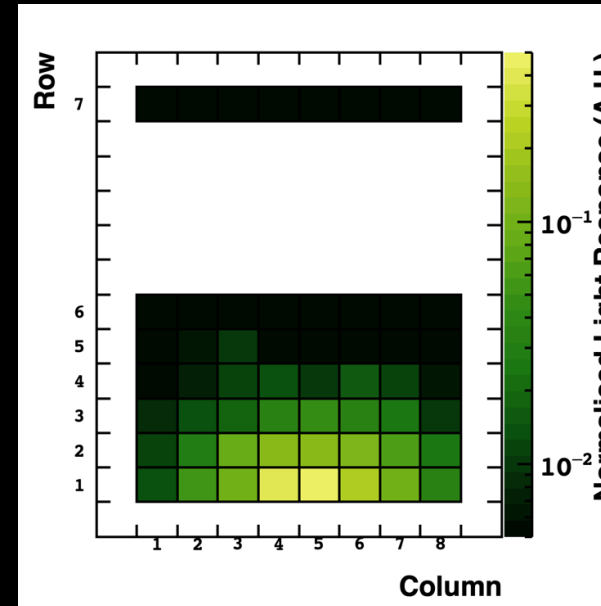


Stochastic light confinement



Light ball formation

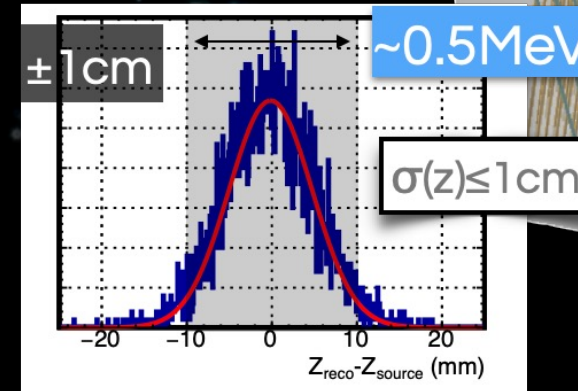
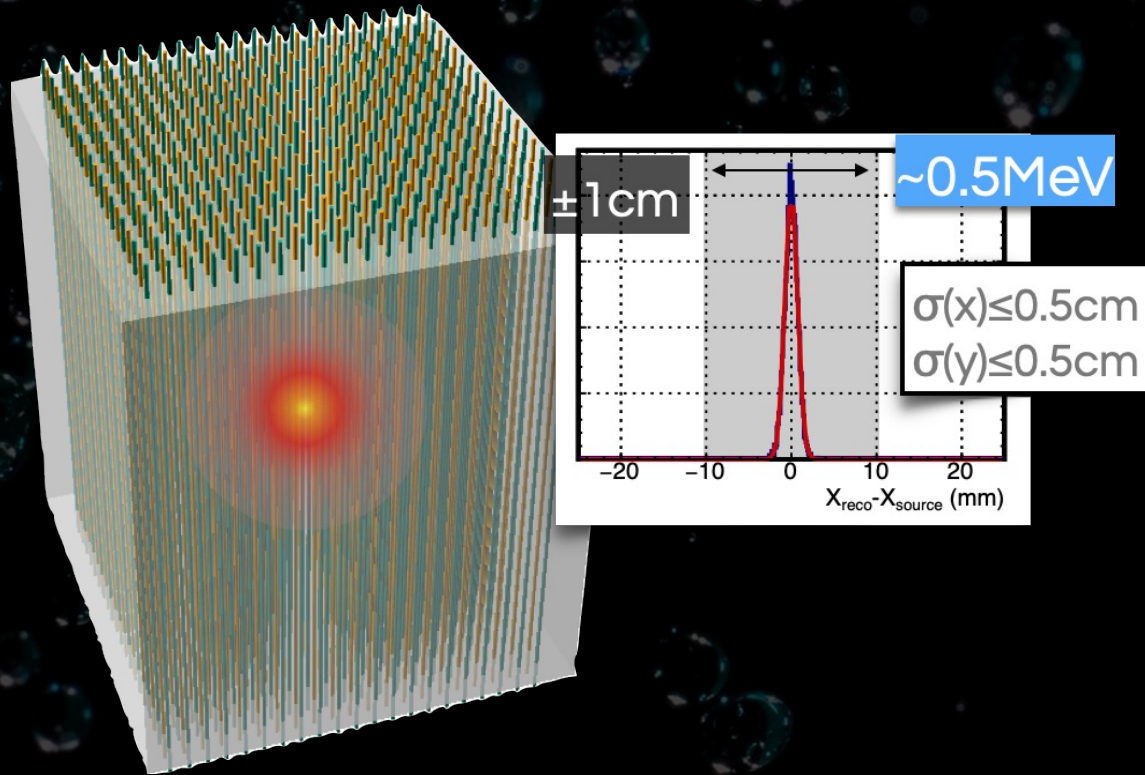
- ★ any source (Cherenkov / scintillation/ opaque scintillator)
- ★ any media (liquid / solid / gas?)



Thank you!

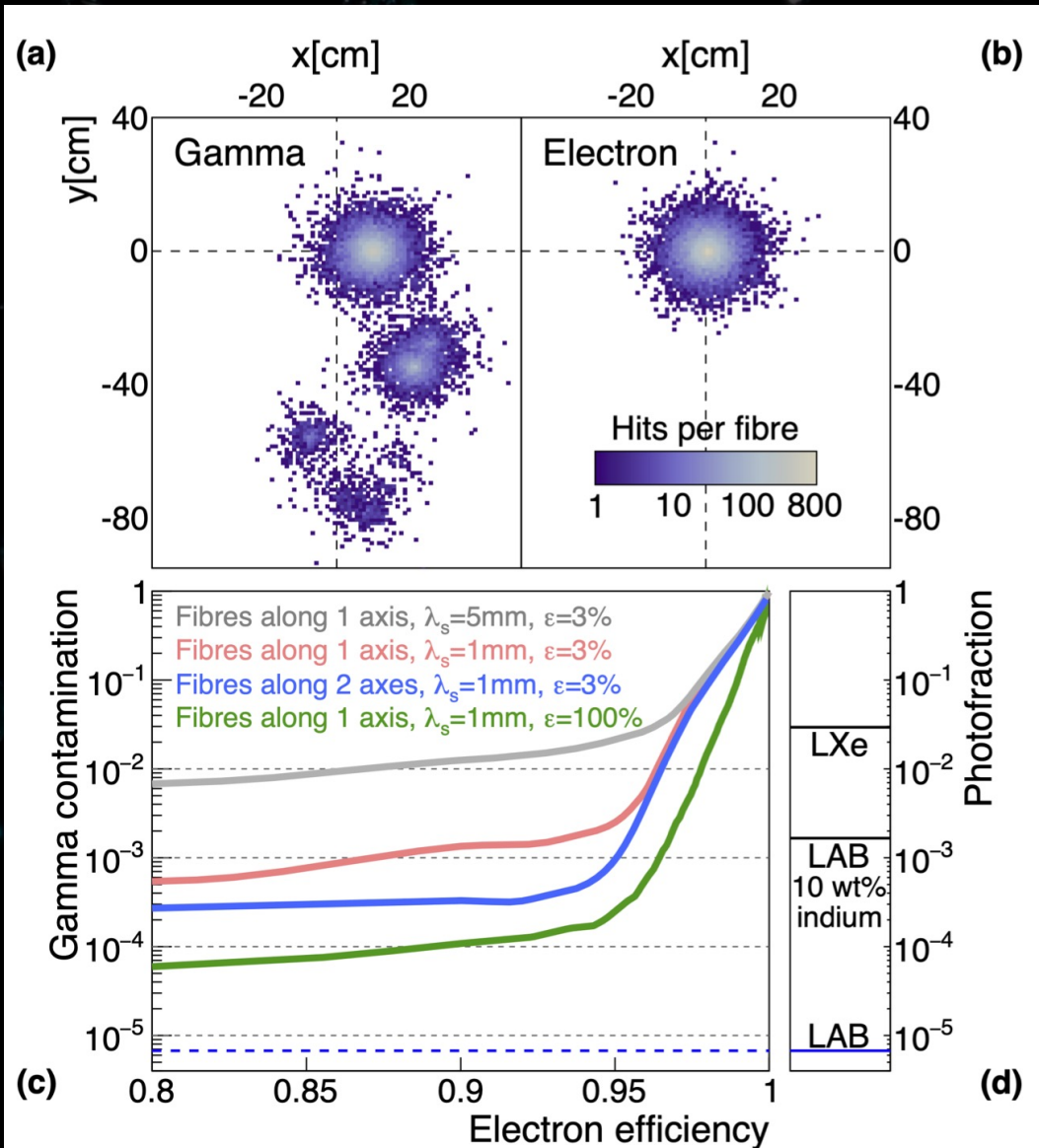
# Back-up

# Novel Engineering Solutions



- ★ 1x Axis(Z) — low cost & simplicity
- ★ (X,Y): topology → mm resolution (robust)
- ★ Z: timing → few cm resolution

- ★ "1x" Axis (twisted-Z @  $\leq 10^\circ$ ) — development
- ★ (X,Y): topology → mm resolution (robust)
- ★ Z: topology →  $\leq 1$  cm resolution (robust)
- ★ (X,Y,Z): timing → over-constrain & energy-flow



- 1-cm-pitch lattice running along the z-axis
- Probability of misidentifying a  $\gamma$  as an  $e^-$  vs. the efficiency of selecting  $e^-$
- mean scattering length  $\lambda_s$  of either 1 mm or 5 mm
- photon detection efficiency  $\epsilon$  of 3% (fibre trapping efficiency ( $\sim 10\%$ ) and SiPM QE ( $\sim 50\%$ ))
- The gray curve shows the probability of misidentifying a 2 MeV  $\gamma$  as an  $e^-$  is estimated to be at the  $10^{-2}$  level with an efficiency of 87% for  $\lambda_s=5$  mm.

# Experimental validation

## MICRO-LIQUIDO: FIRST EXPERIMENTAL PROOF OF PRINCIPLE

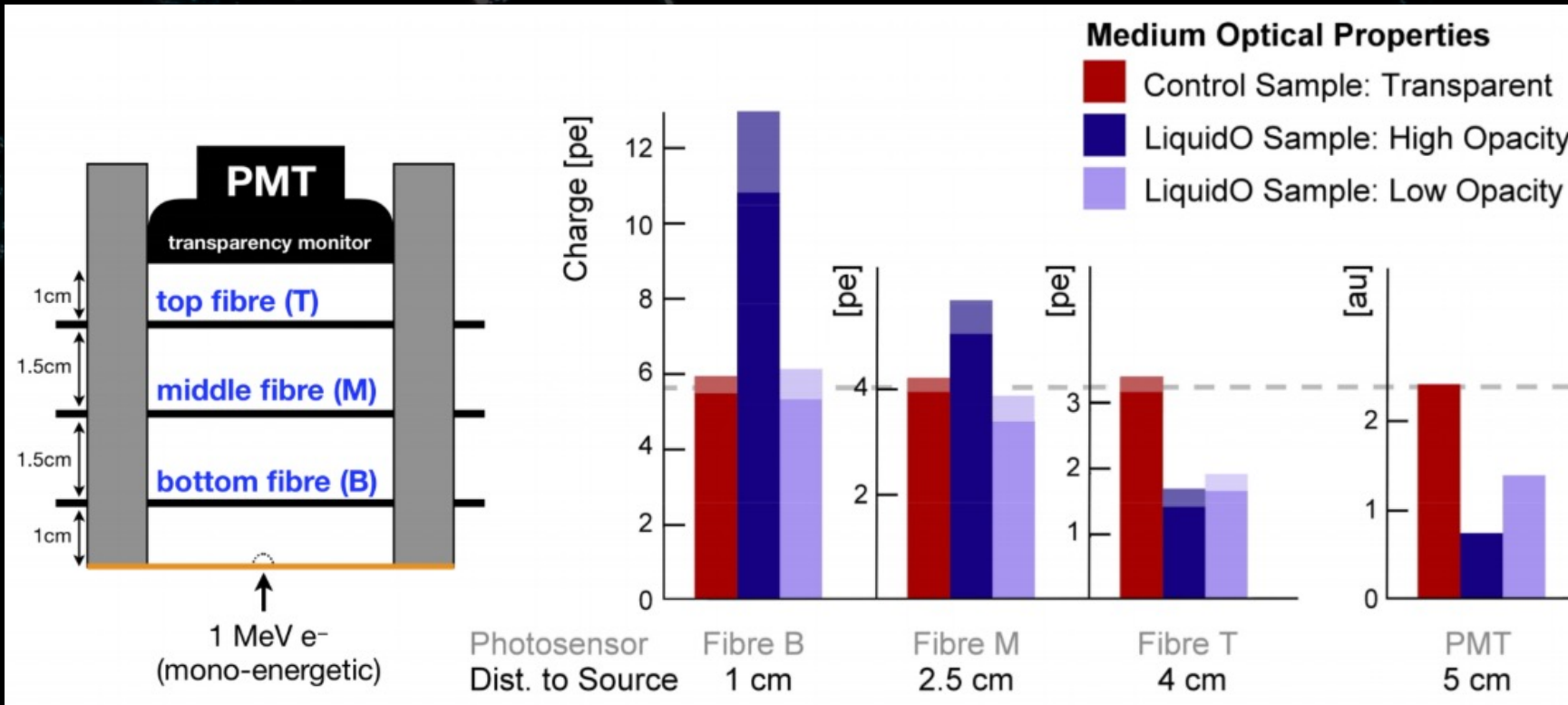
Article | [Open Access](#) | [Published: 21 December 2021](#)

## Neutrino physics with an opaque detector

[LiquidO Consortium](#)

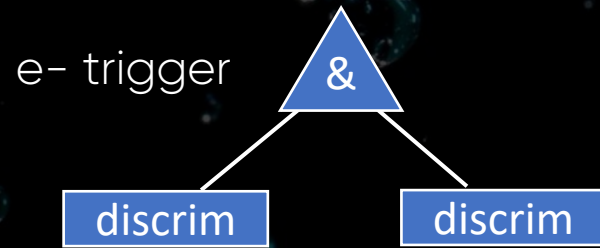
[Communications Physics](#) **4**, Article number: 273 (2021) | [Cite this article](#)

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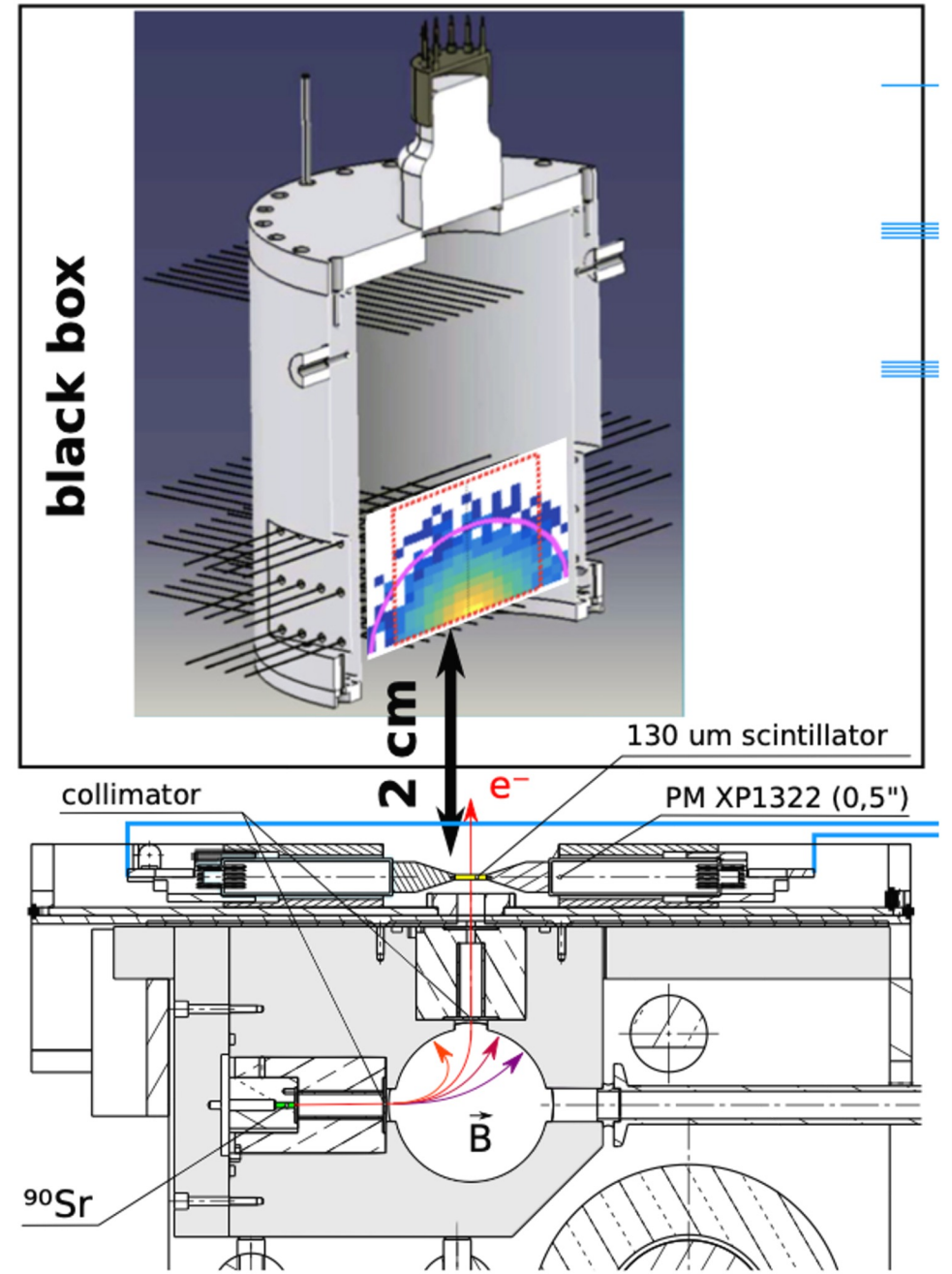


More light collected by the fibres near the light source with the opaque sample!

# Experimental validation



Coincidence between 2 PMT triggers is done directly by wavecatcher

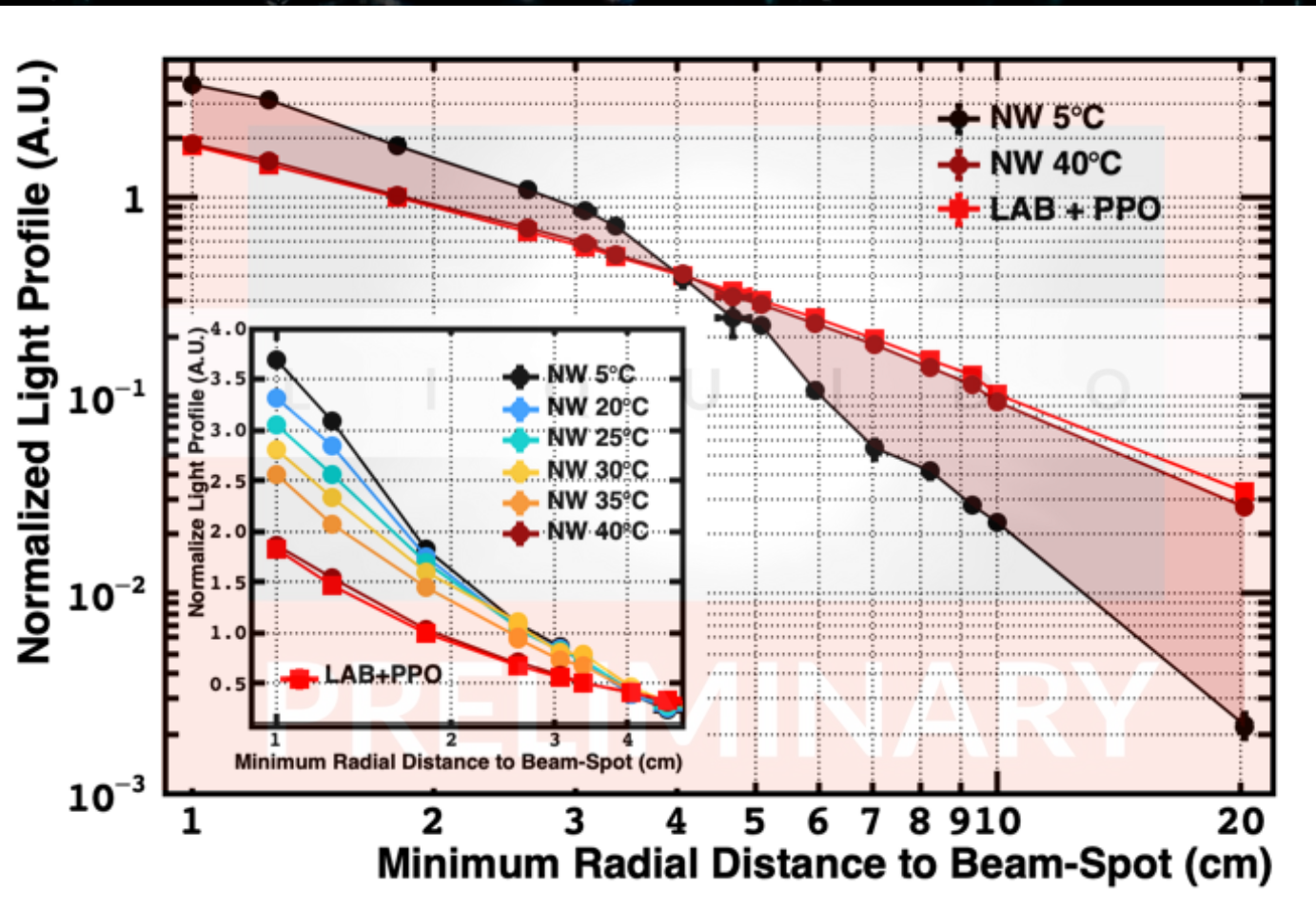




# Experimental validation

LAB+PPO scaled to NW-20 at 40°C:

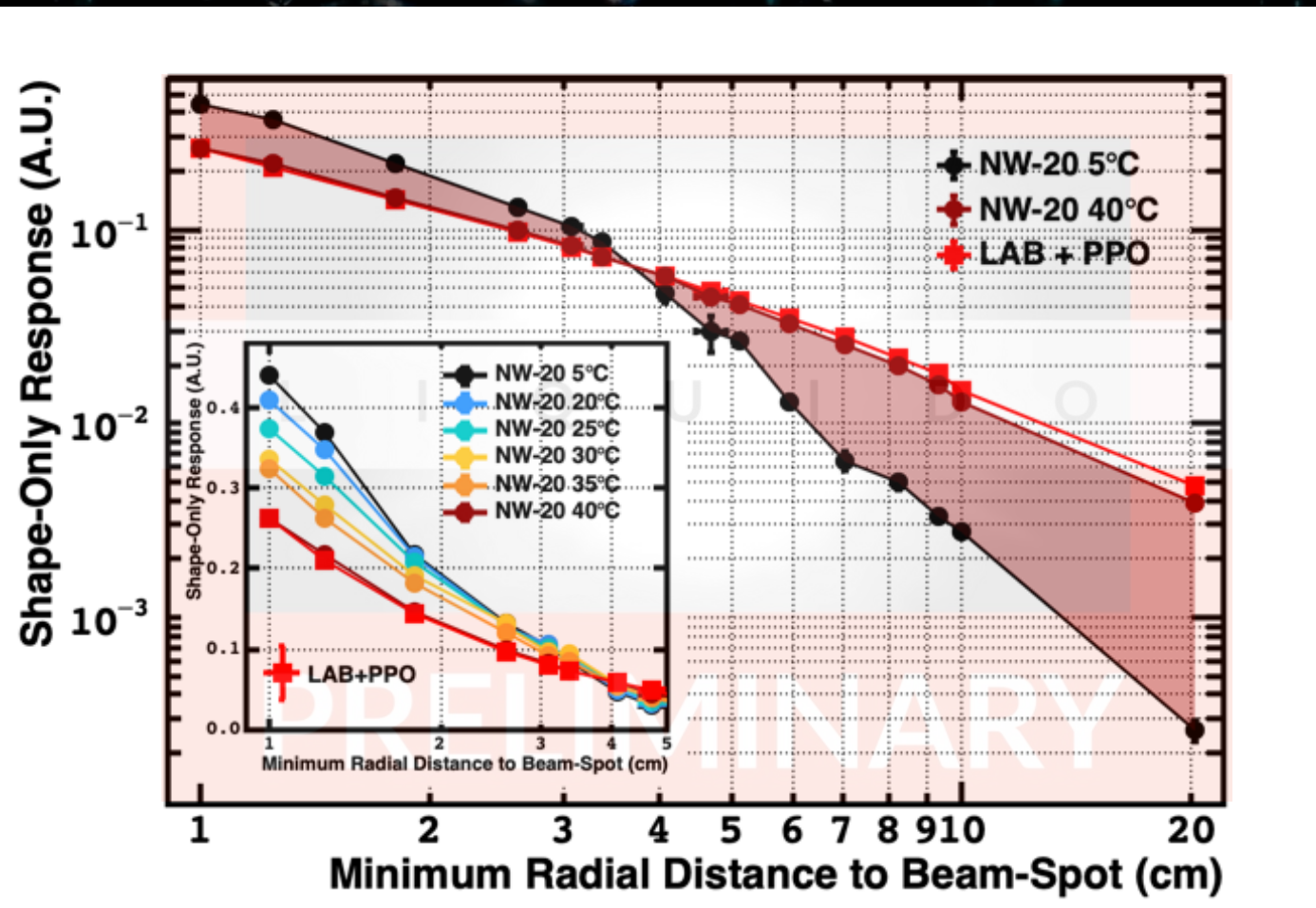
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# Experimental validation

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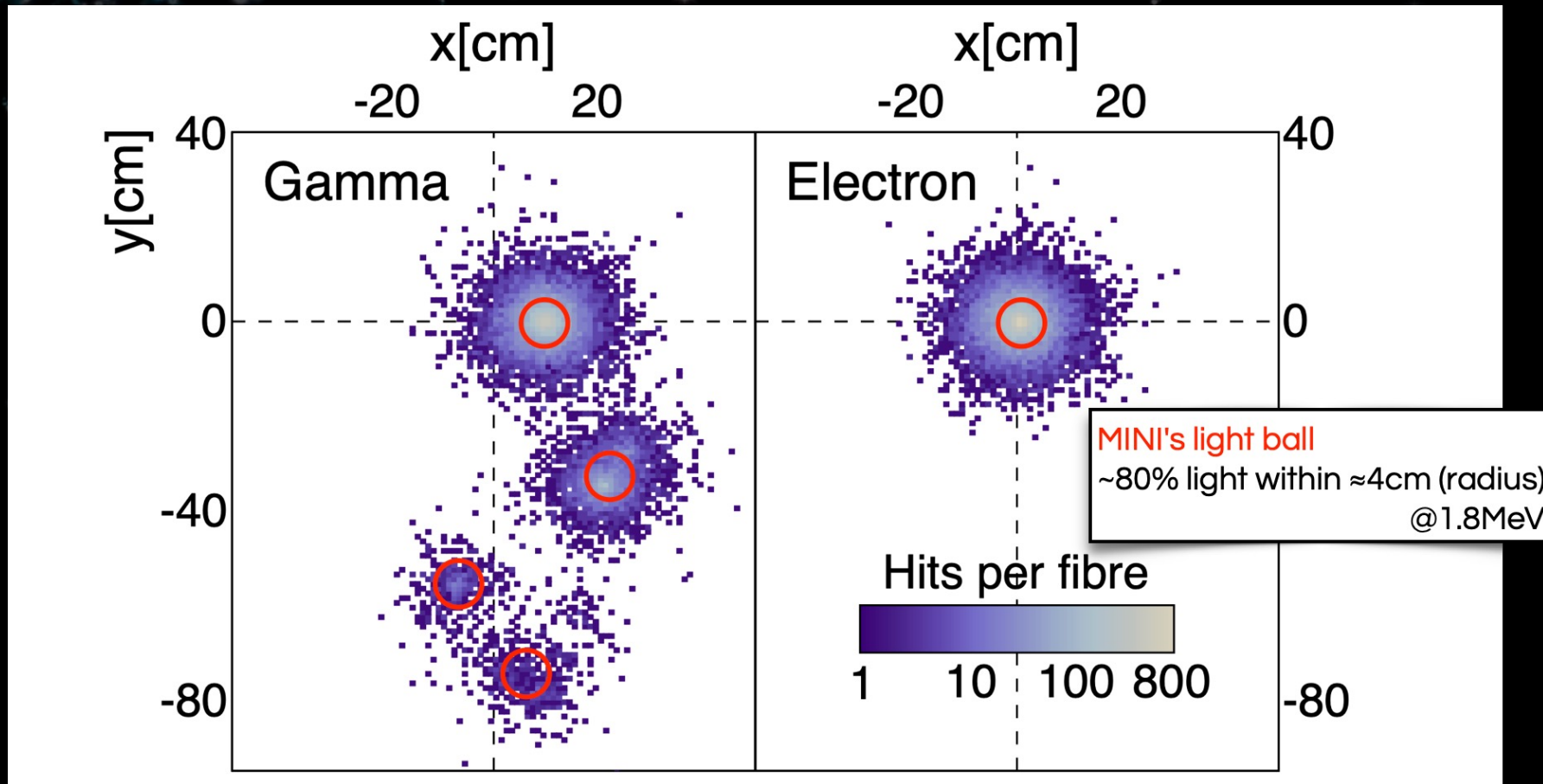


- ★ NW at 5°C: opaque
- ★ NW at 40°C: almost as transparent as usual LAB+PPO LS
- ★ Faster collection and better light containment in the opaque mode
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- ★ Stochastic light confinement → Major demonstration of the LiquidO technology

# Experimental validation

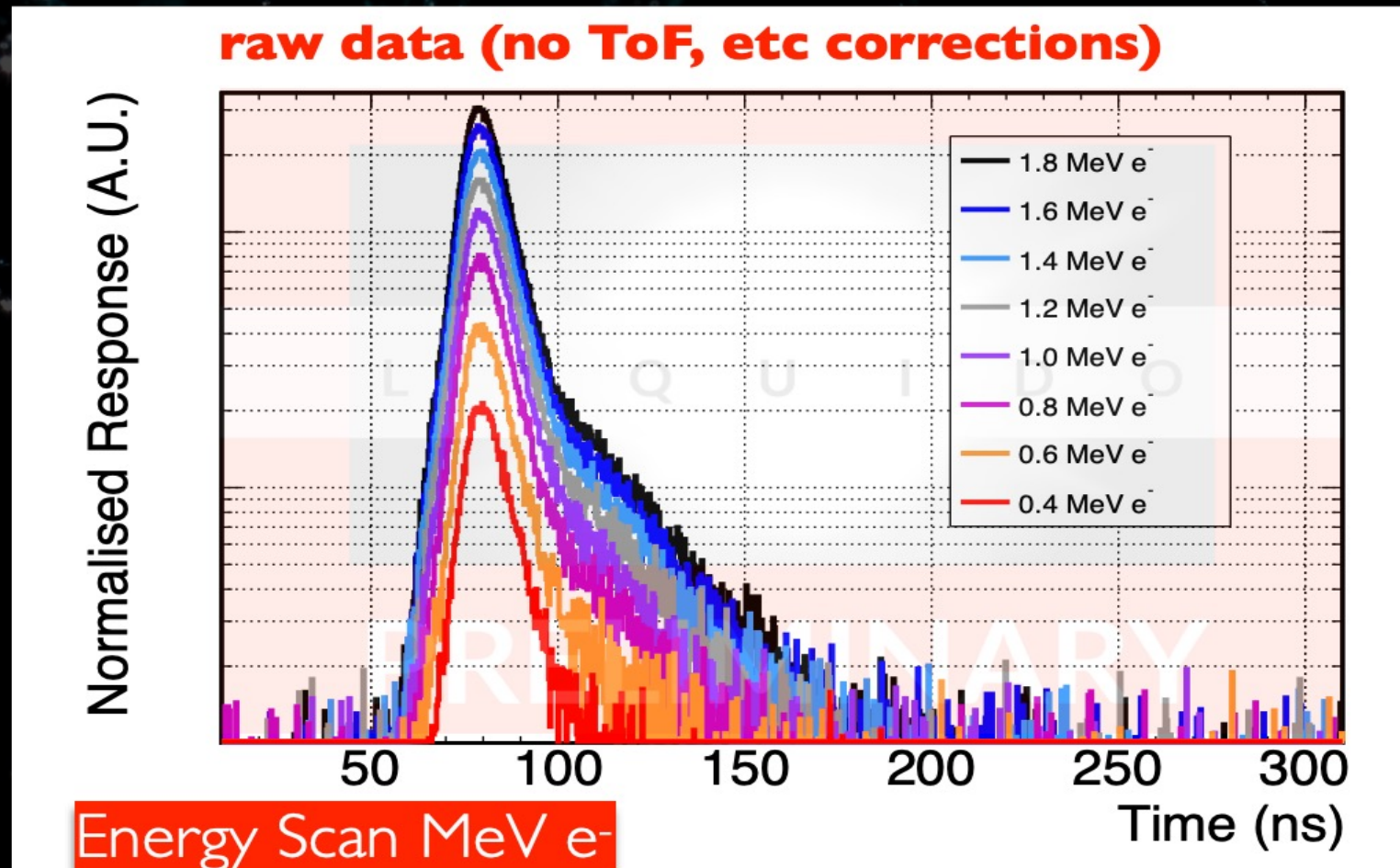
TOPOLOGY PID (NO TIMING)

PID e/ $\gamma$  should be  $\geq 100:1$  rejection @  $\geq 90\%$



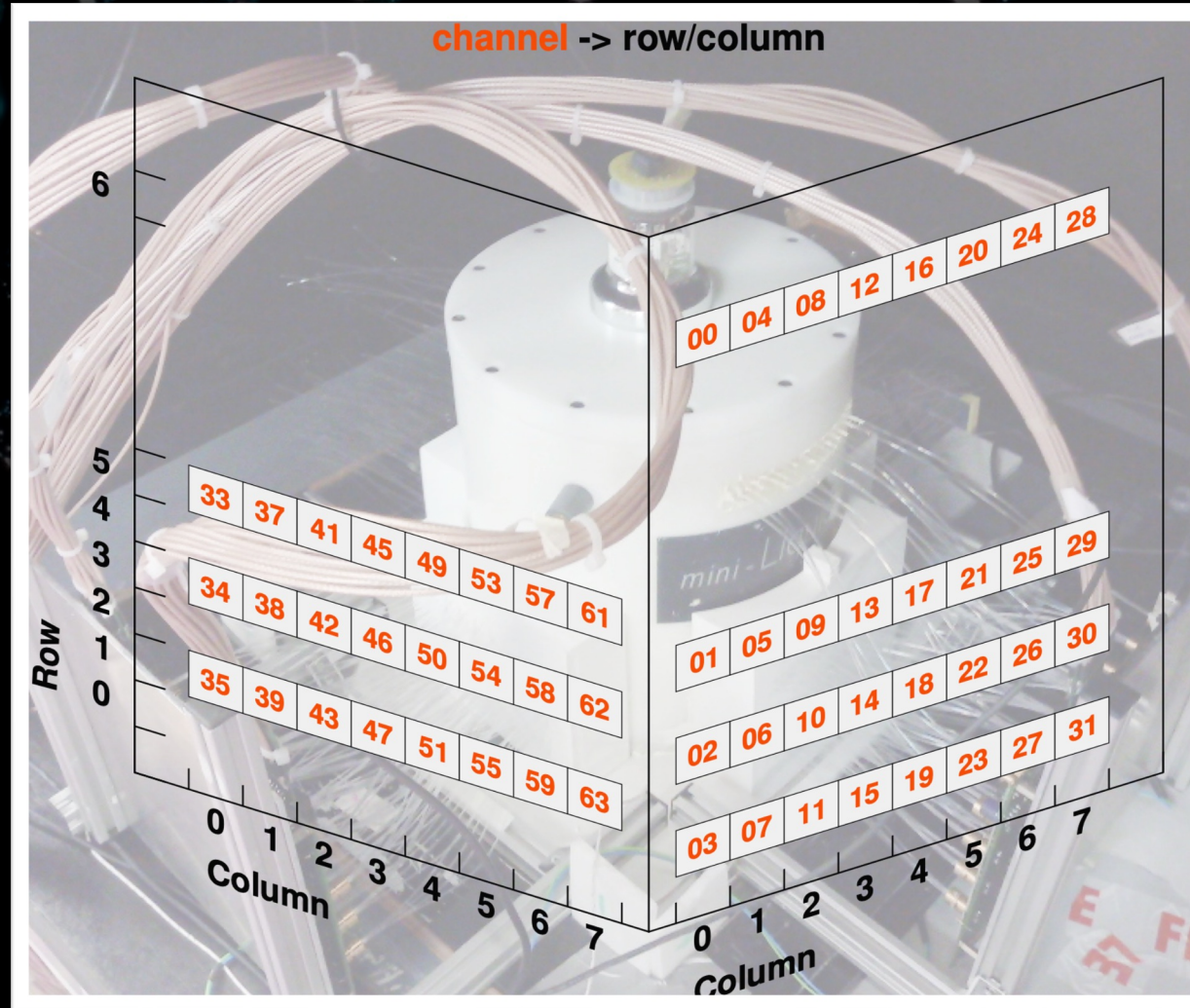
# Experimental validation

## NO-WASH LIGHT PROFILE



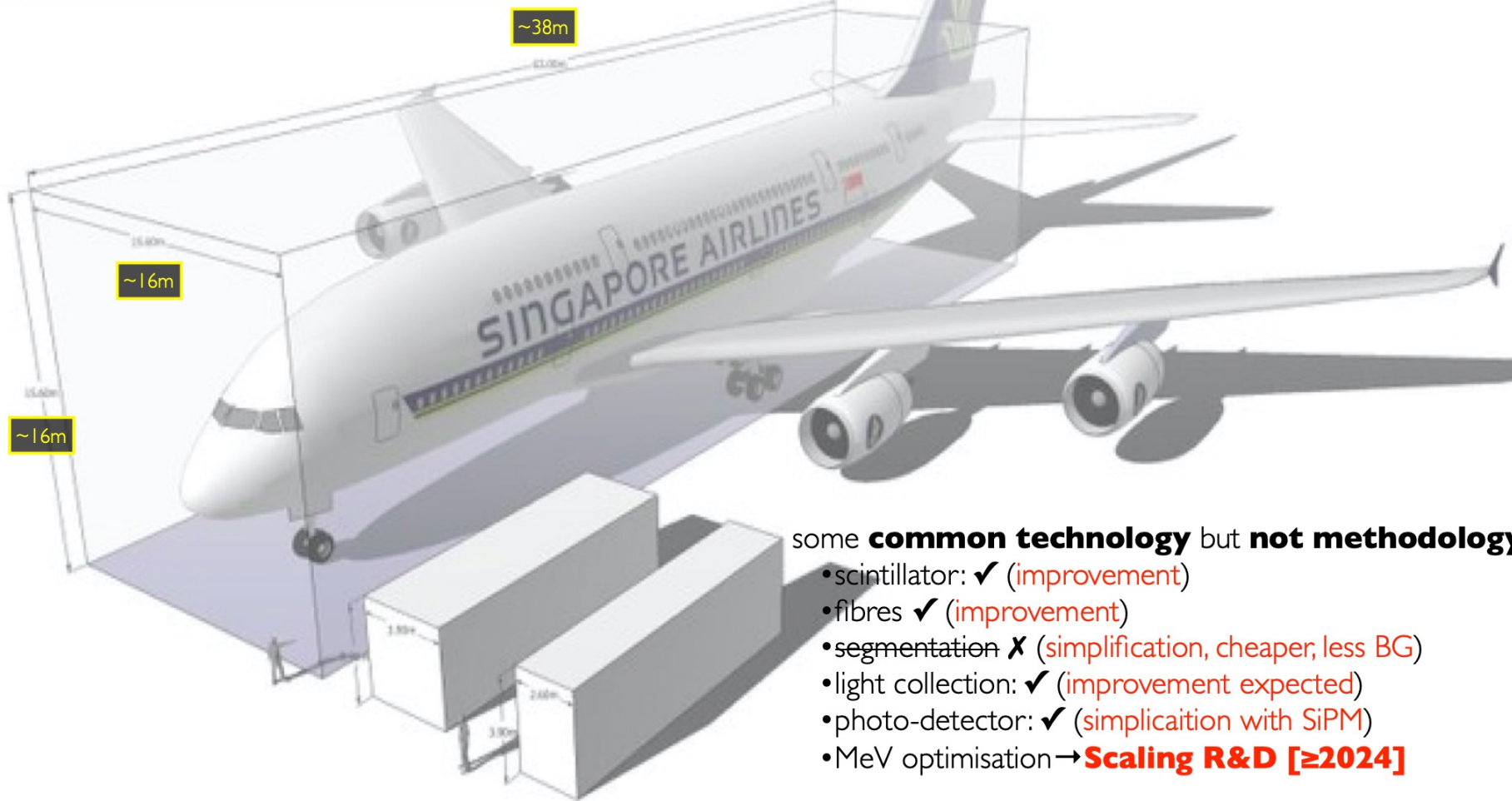
# Experimental validation

## MINI-II SET UP



***a priori no showstopper***

**SuperChooz : ~9 700 m<sup>3</sup>**



some **common technology** but **not methodology**

- scintillator: ✓ (improvement)
- fibres ✓ (improvement)
- segmentation ✗ (simplification, cheaper, less BG)
- light collection: ✓ (improvement expected)
- photo-detector: ✓ (simplification with SiPM)
- MeV optimisation → **Scaling R&D [≥2024]**

**SuperChooz (~10kton)** similar dimensions as **NOVA (~14kton)** & one module of **DUNE (~10kton)**