LiquidO : Detecting light in an opaque medium

Raphaël Gazzini on behalf of the LiquidO collaboration– 23/06/2023

Contents

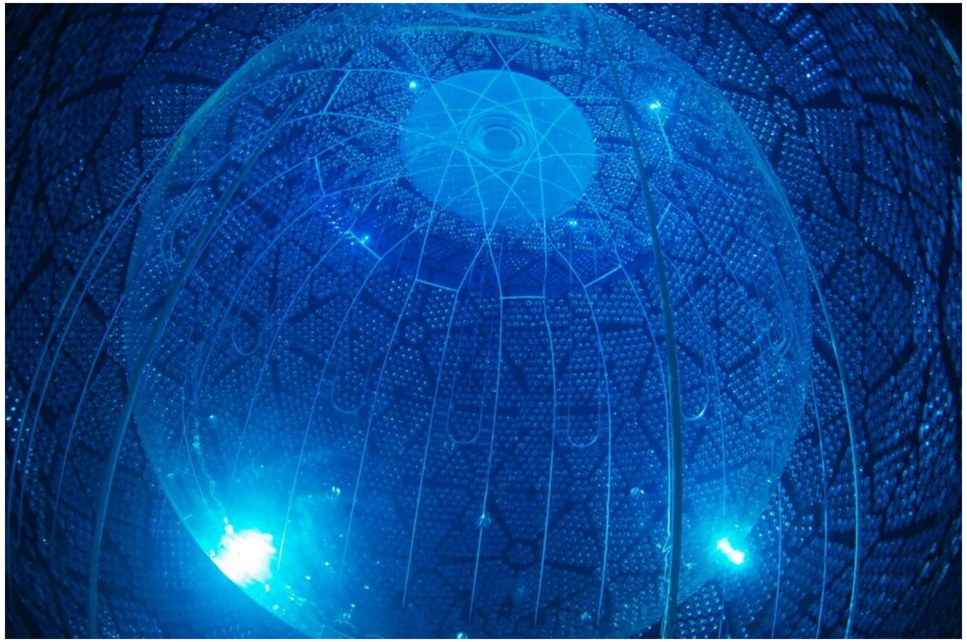
The LiquidO technology

Today's liquid scintillator technology:

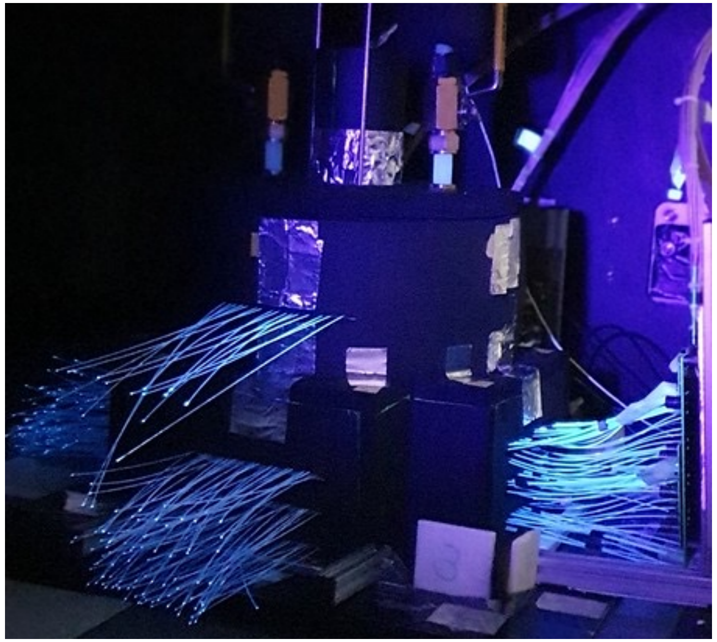
- Collect light on detector walls
- Extreme transparency of medium needed

LiquidO technology:

- Collect light throughout the detector
- Use opacity as part of the detection process, new possibilities for Liquid Scintillator R&D



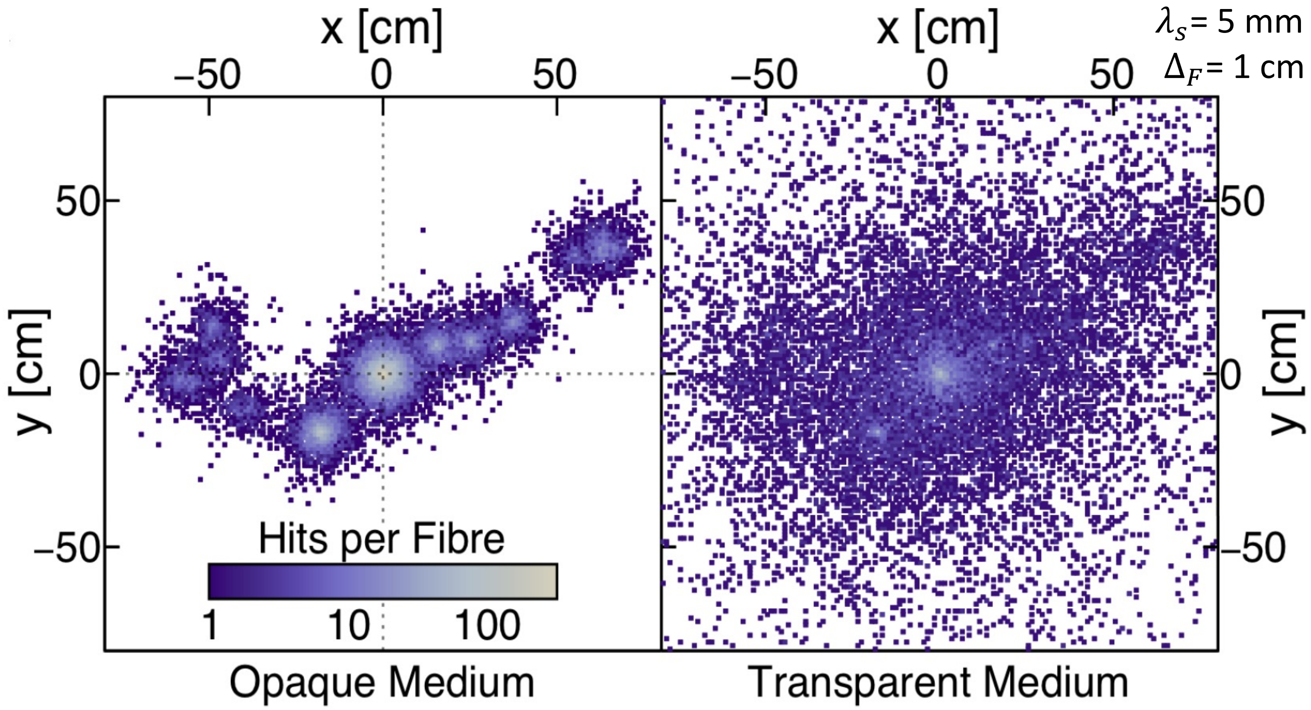
Example: SNO+



Example: Mini-e^-

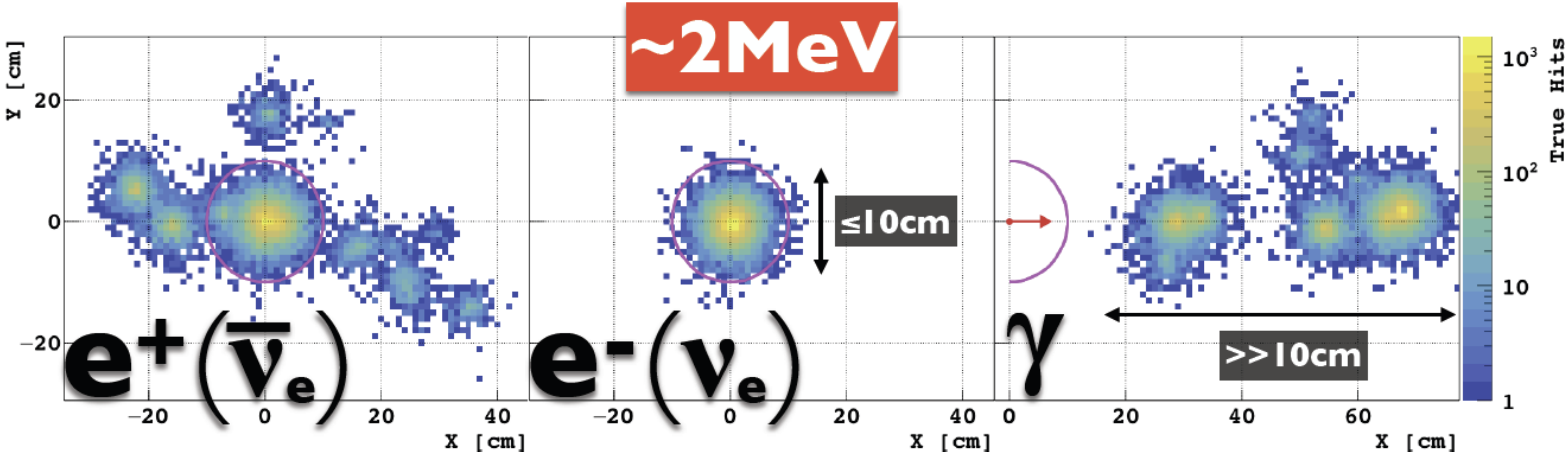
Imaging capabilities

Simulated energy deposition for a 1MeV e^+



- Light is collected by an array of Wave-Shifiting Fibers (WSF)
- The opaque (diffusive) medium confines light stochastically around the interaction point
- Light clusters (or light "balls") give us access to topological information of the interaction

Particle Identification (PID)

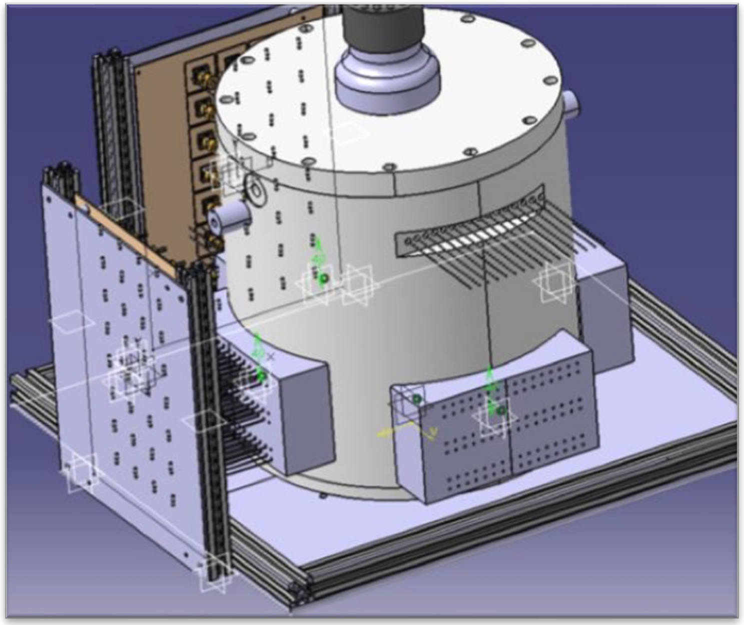


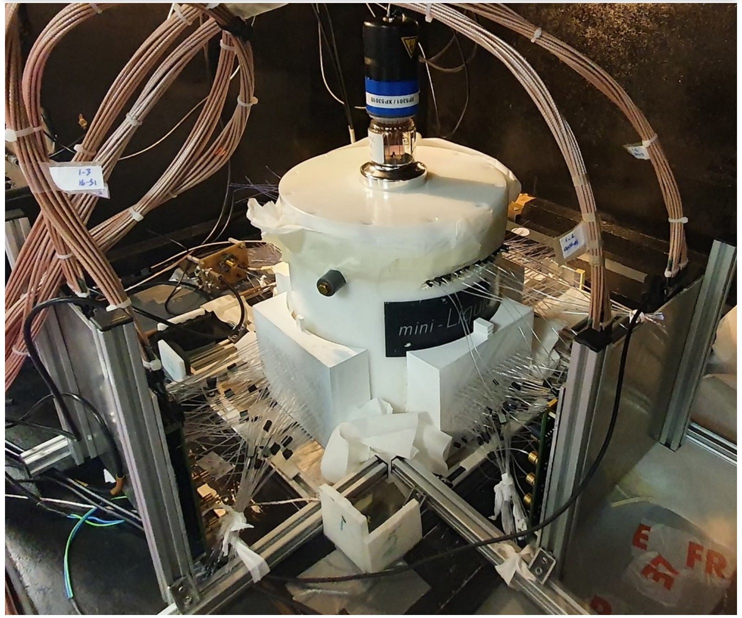
- New solution for topological particle identification
- Matter-antimatter separation capabilities
- Powerful background rejection tool

Contents

- The LiquidO technology
- Mini-e^{-}: experimental validation
  - Design
  - Light confinement validation
- Mini-γ prototype
  - Design
  - Probing the IBD
- Future Prospects

Mini-e^- prototype: Design





- 10 L Detector
- 56 readout fibers
  - 7 rows, 8 columns, ~1.5cm pitch
- 3'' PMT at the top
- 56 SiPMs, custom preamplifier, sub-ns rise time.
- 64 channel WaveCatcher system for digitization (ps time resolution)
- Temp. control system (Chiller), [5-40]°C cycles
- Monoenergetic e^- beam (0.4-1.8 MeV)
- Led by IJCLab, LP2IB, and Subatech

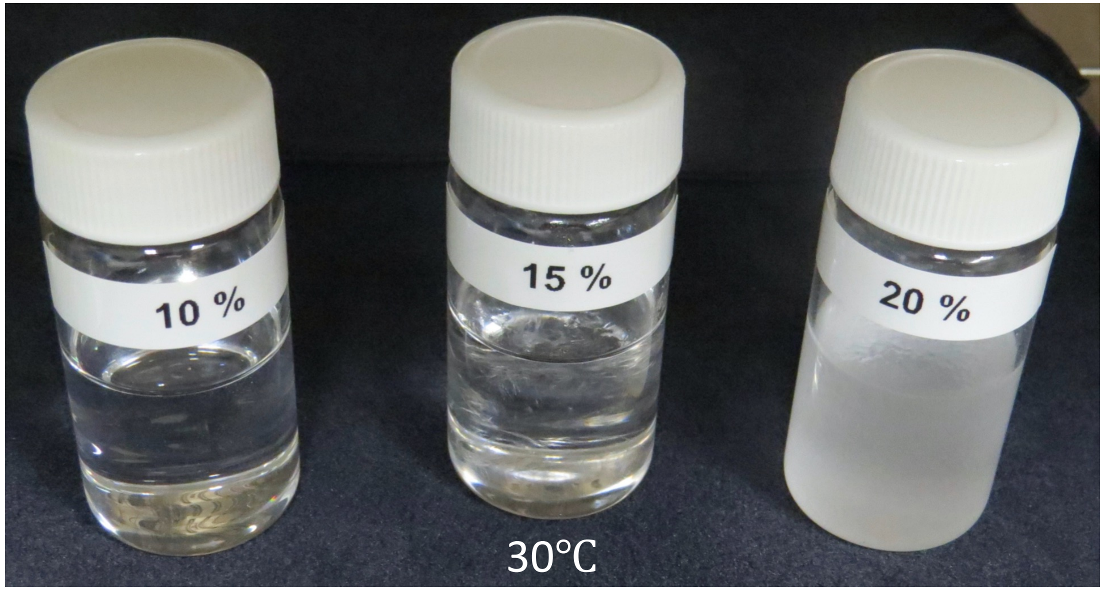
Mini-e^{-}: Mediums used

3 transparent mediums:

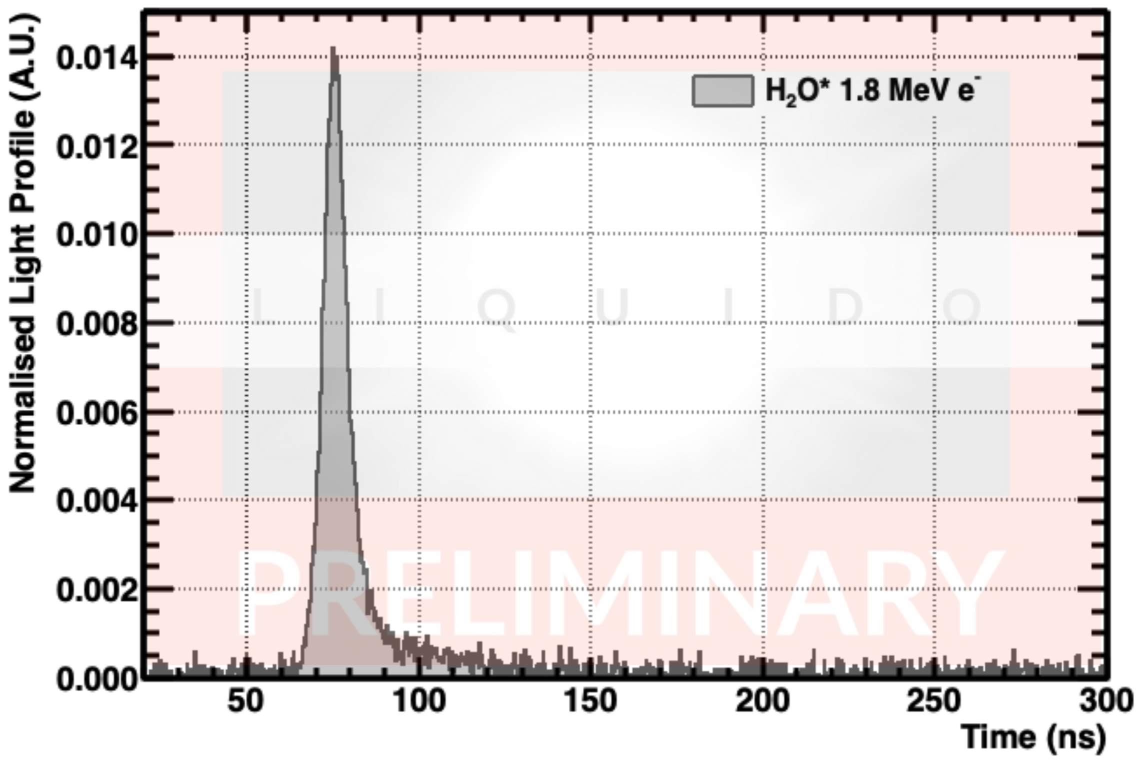
- Water
- Linear Alkyl Benzene (LAB), liquid scintillator with a slow response
- LAB + PPO (~0.3 wt.%), faster response and more light thanks to the PPO doping

1 opaque medium, NoWaSH (NW):

- LAB + PPO + Paraffin Wax (~20 wt.%)
- Opacity depends on paraffin concentration and temperature (Crystallisation processes)
- Short scattering length and moderate absorption length (diffusive medium)



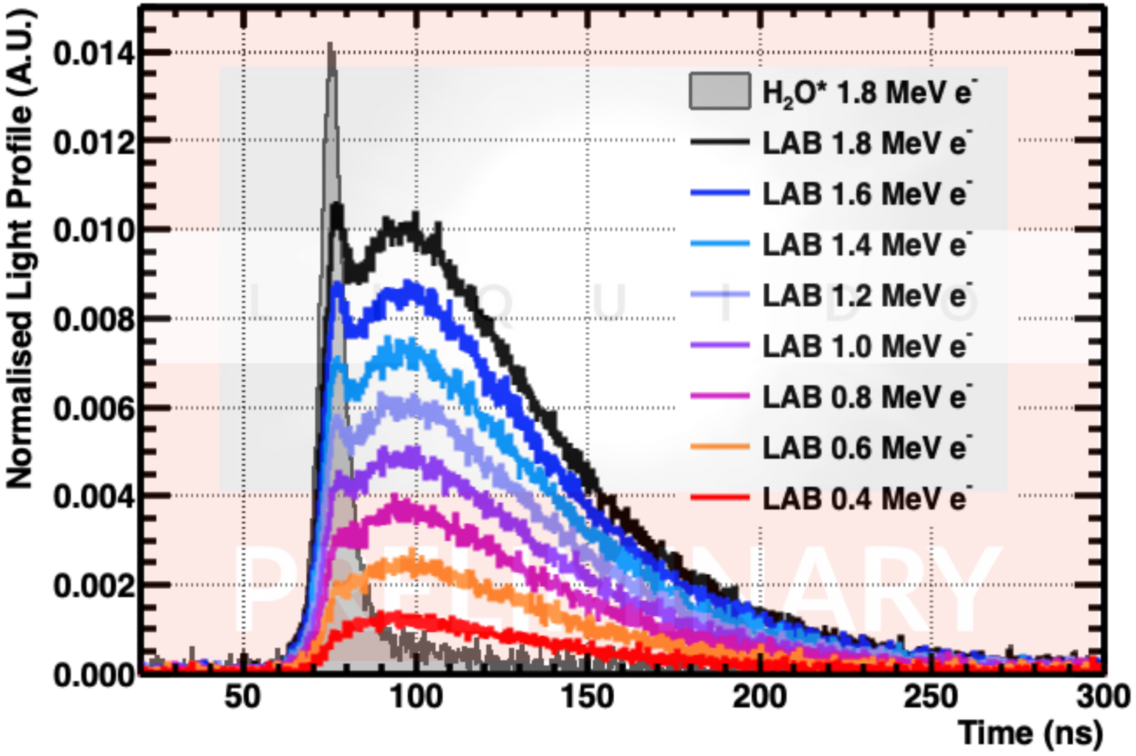
Mini-e^-: Time profile



Transparent media regime:

- Water data: Cerenkov Peak

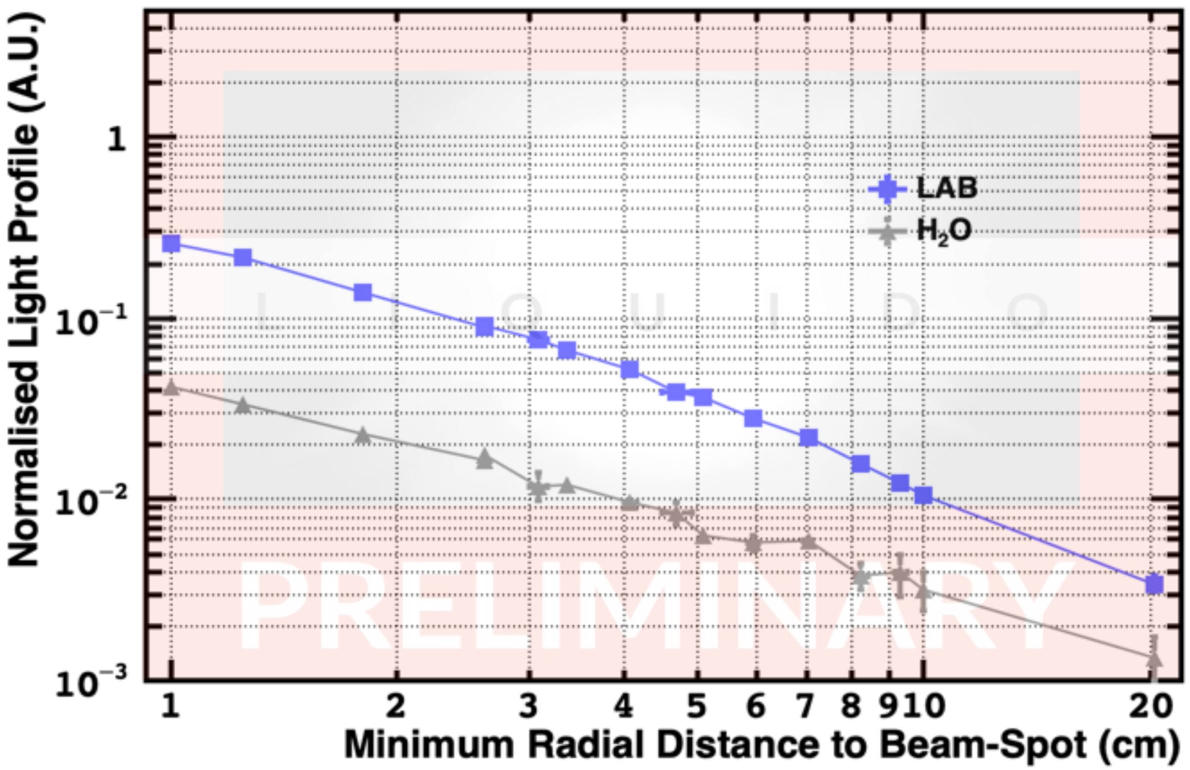
Mini-e^- : Time profile



Transparent media regime:

- Water data: Cerenkov Peak
- LAB data :
  - Slow response + fast electronics
  - Cer./scintillation separation using timing
  - Cerenkov confirmed by water data
  - Energy scan => Cerenkov threshold

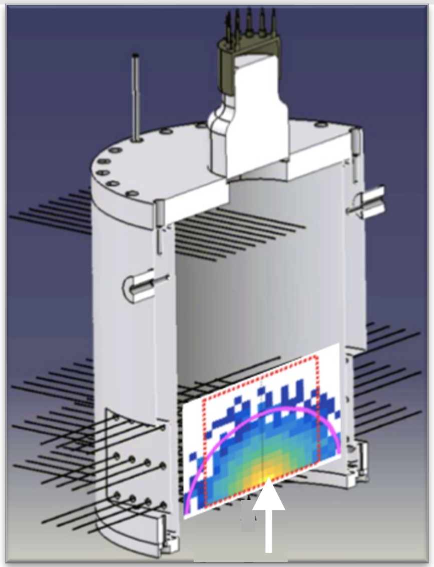
Mini-e^-: Light confinement validation



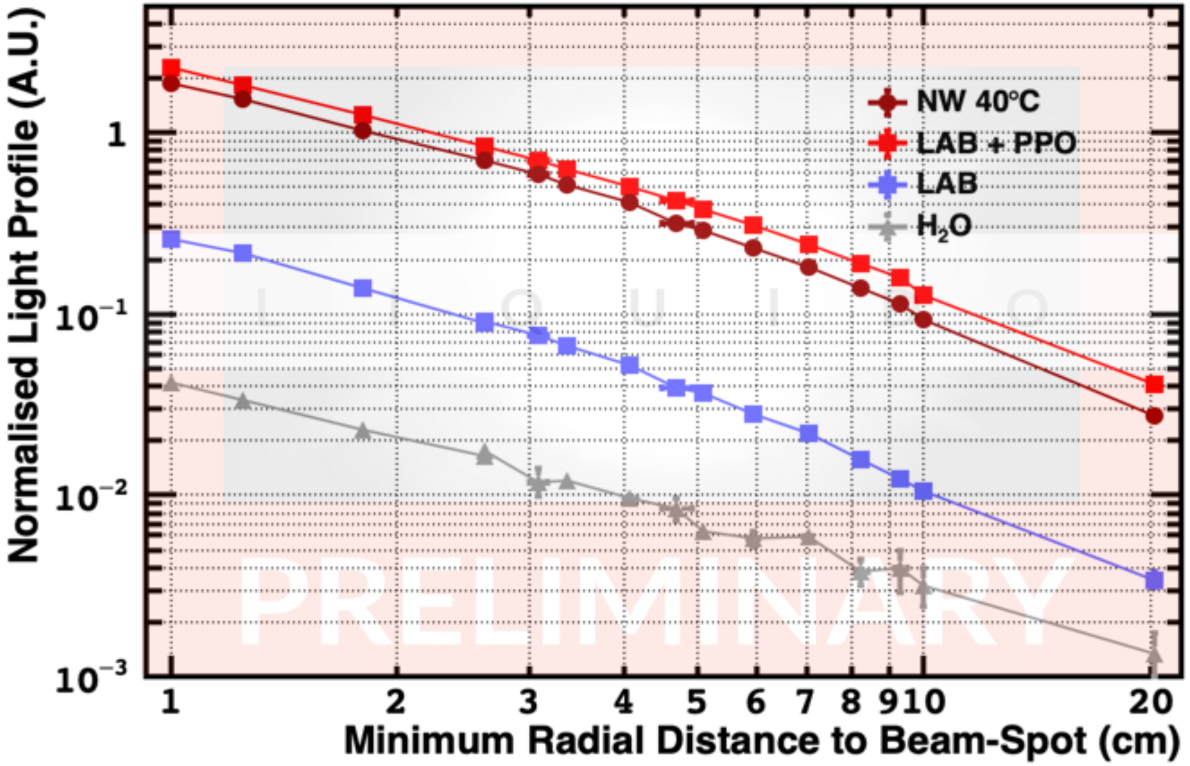
Analysis of light profile as a function of distance to the beam-spot

Transparent regime:

- Water, low acceptance
- LAB, more light thanks to scintillation



Mini-e^-: Light confinement validation

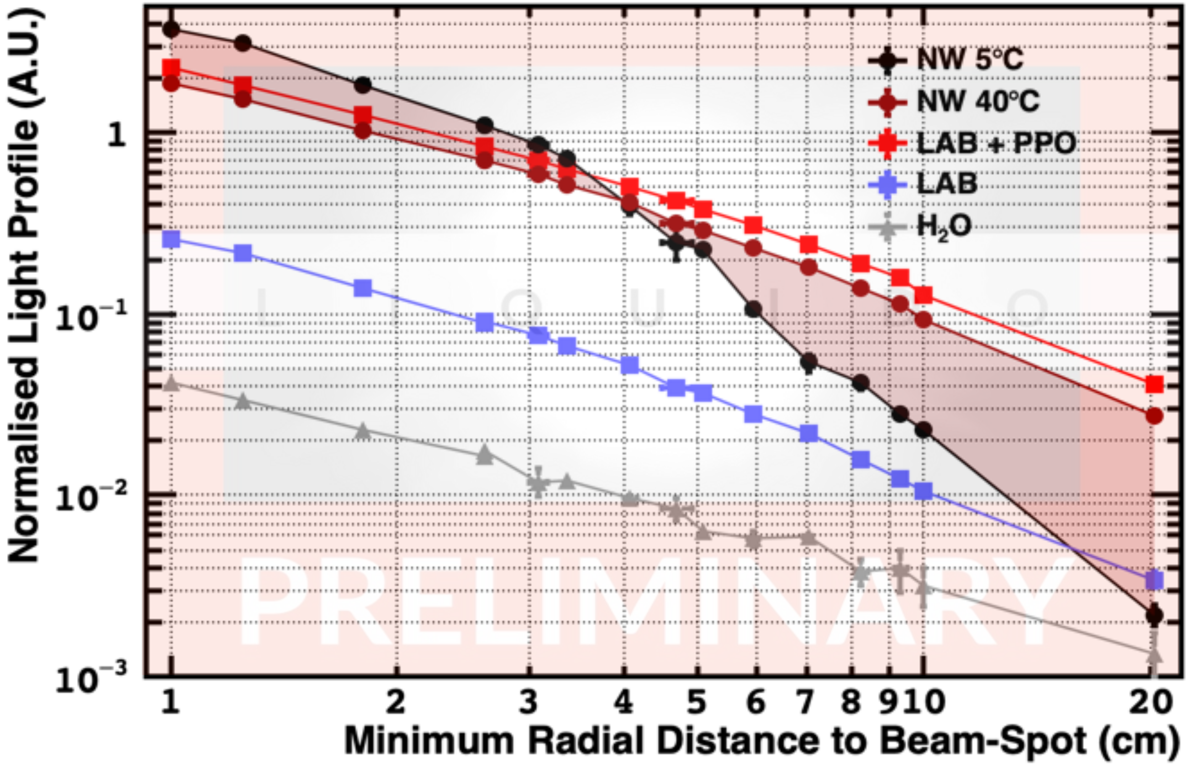


Shape-only analysis of light profile as a function of distance to the beam-spot

Transparent regime:

- Water, low acceptance
- LAB, more light thanks to scintillation
- LAB+PPO, increased amount of light
- NW at 40°C, similar profile with light loss

Mini-e^-: Light confinement validation



Shape-only analysis of light profile as a function of distance to the beam-spot

Transparent regime:

- Water, low acceptance
- LAB, more light thanks to scintillation
- LAB+PPO, increased amount of light
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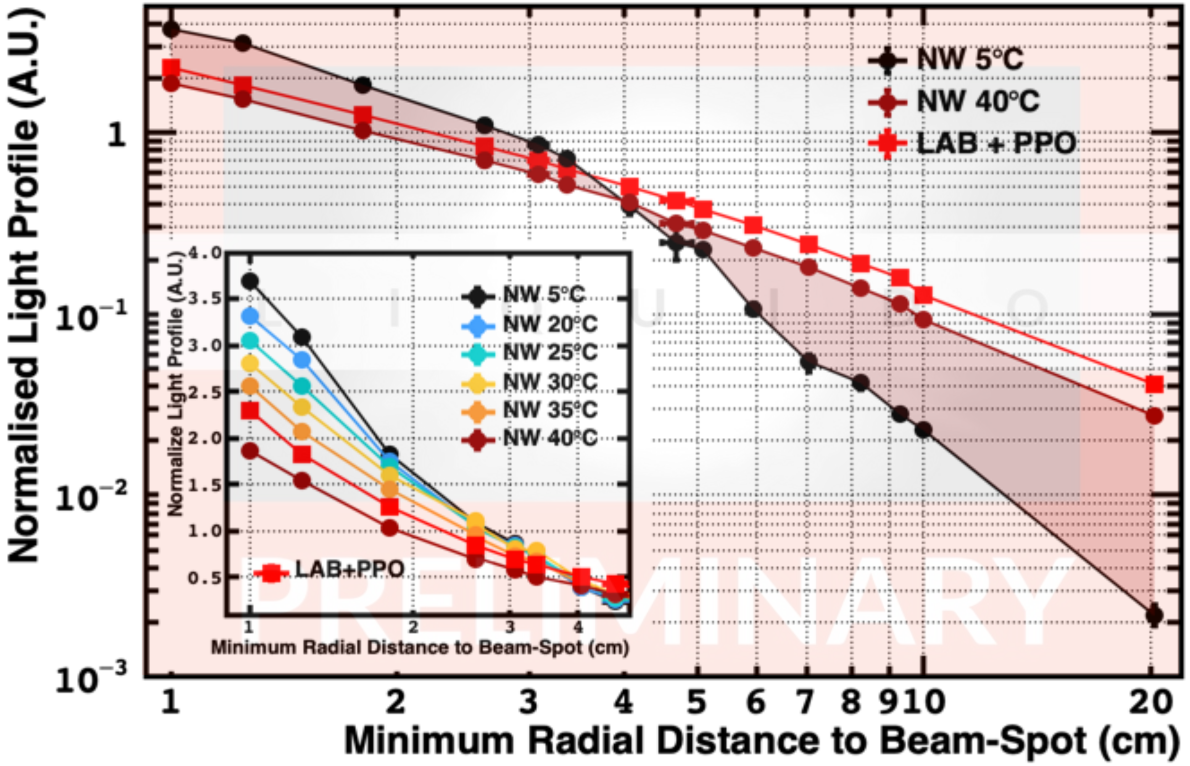
Opaque regime (NW 5°C):

- Increased light before 4 cm
- Decreased light after 4 cm

} Light Ball

Mini-e^-: Light confinement validation



Shape-only analysis of light profile as a function of distance to the beam-spot

Transparent regime:

- Water, low acceptance
- LAB, more light thanks to scintillation
- LAB+PPO, increased amount of light
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Opaque regime:

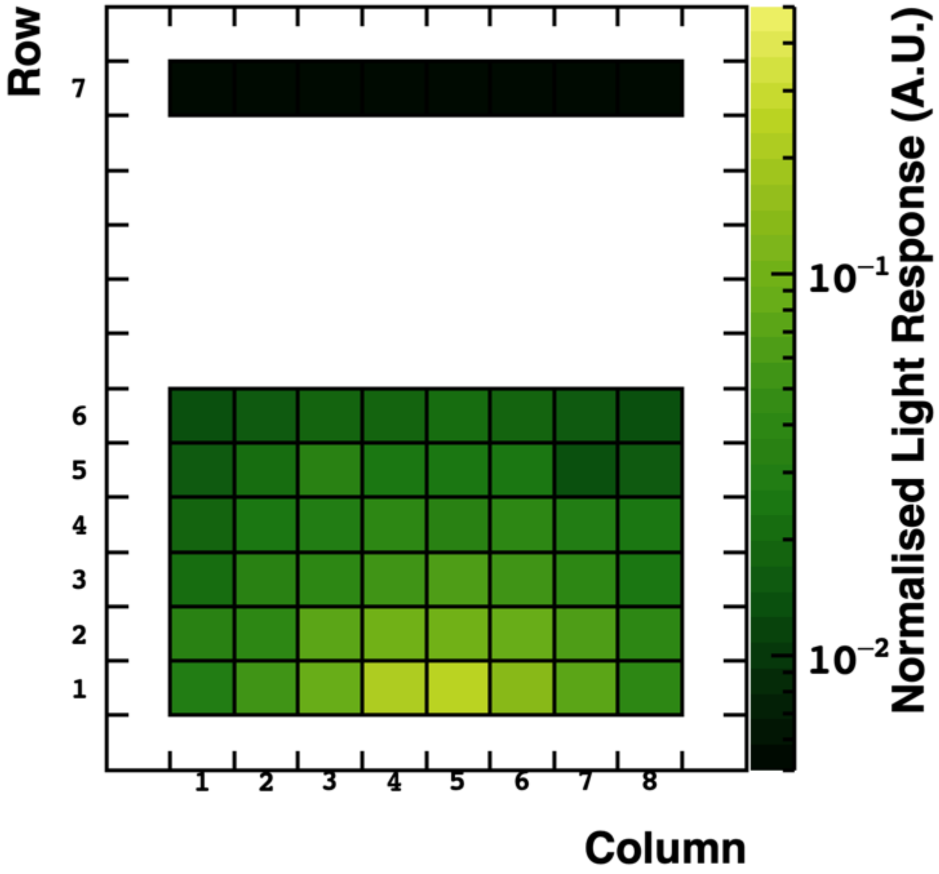
- Increased light before 4 cm
- Decreased light after 4 cm

} Light Ball

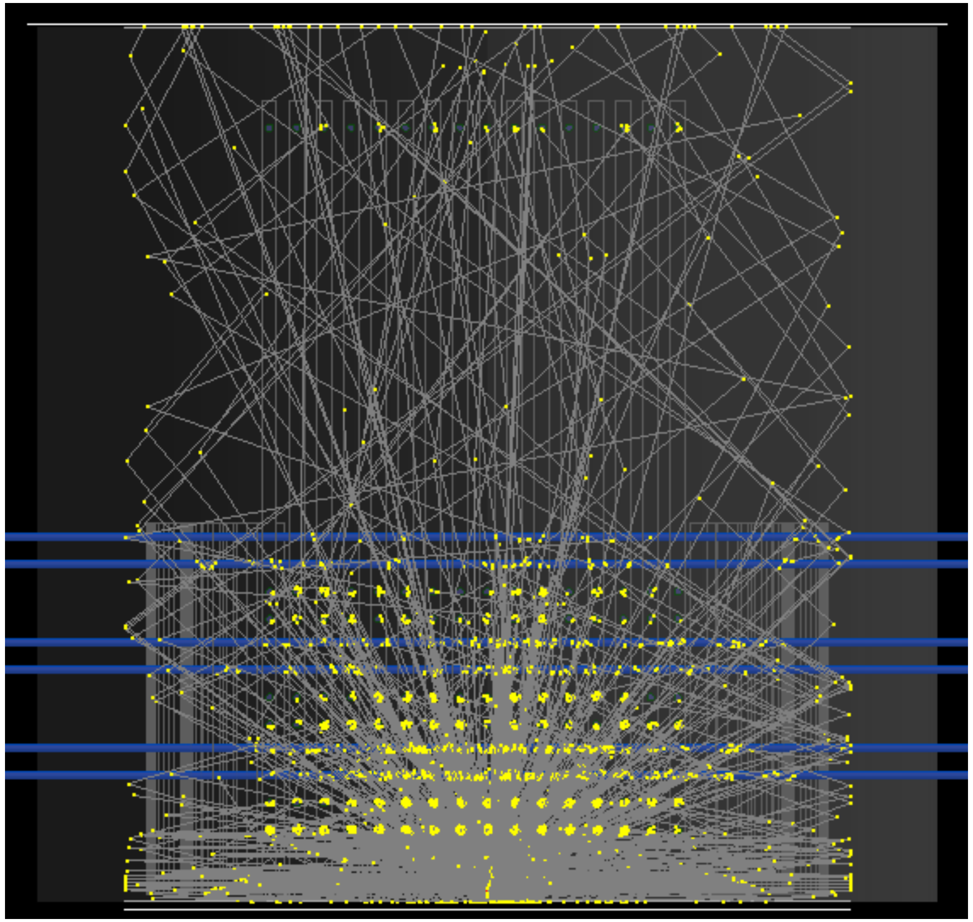
- **Major demonstration of LiquidO**

Mini-e^-: Light confinement channel view

Data (transparent)

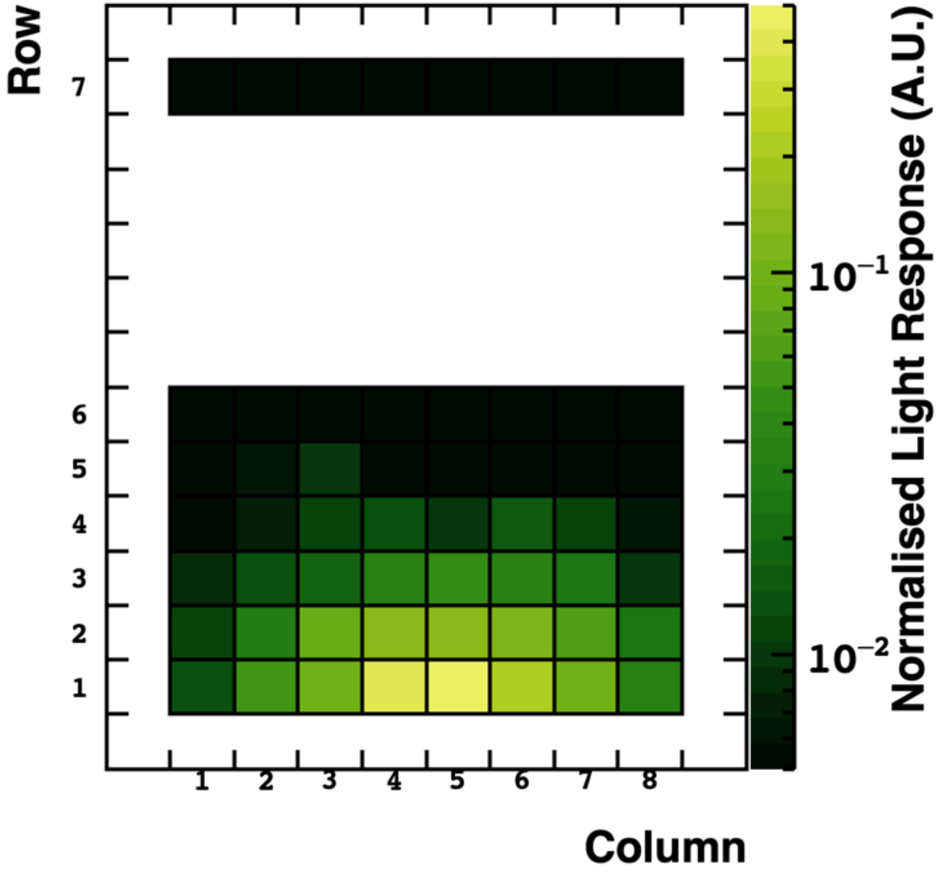


Geant4 Simulation



Mini-e^-: Light confinement channel view

Data (opaque)



Geant4 Simulation (Work in progress)

λ_s=1 cm

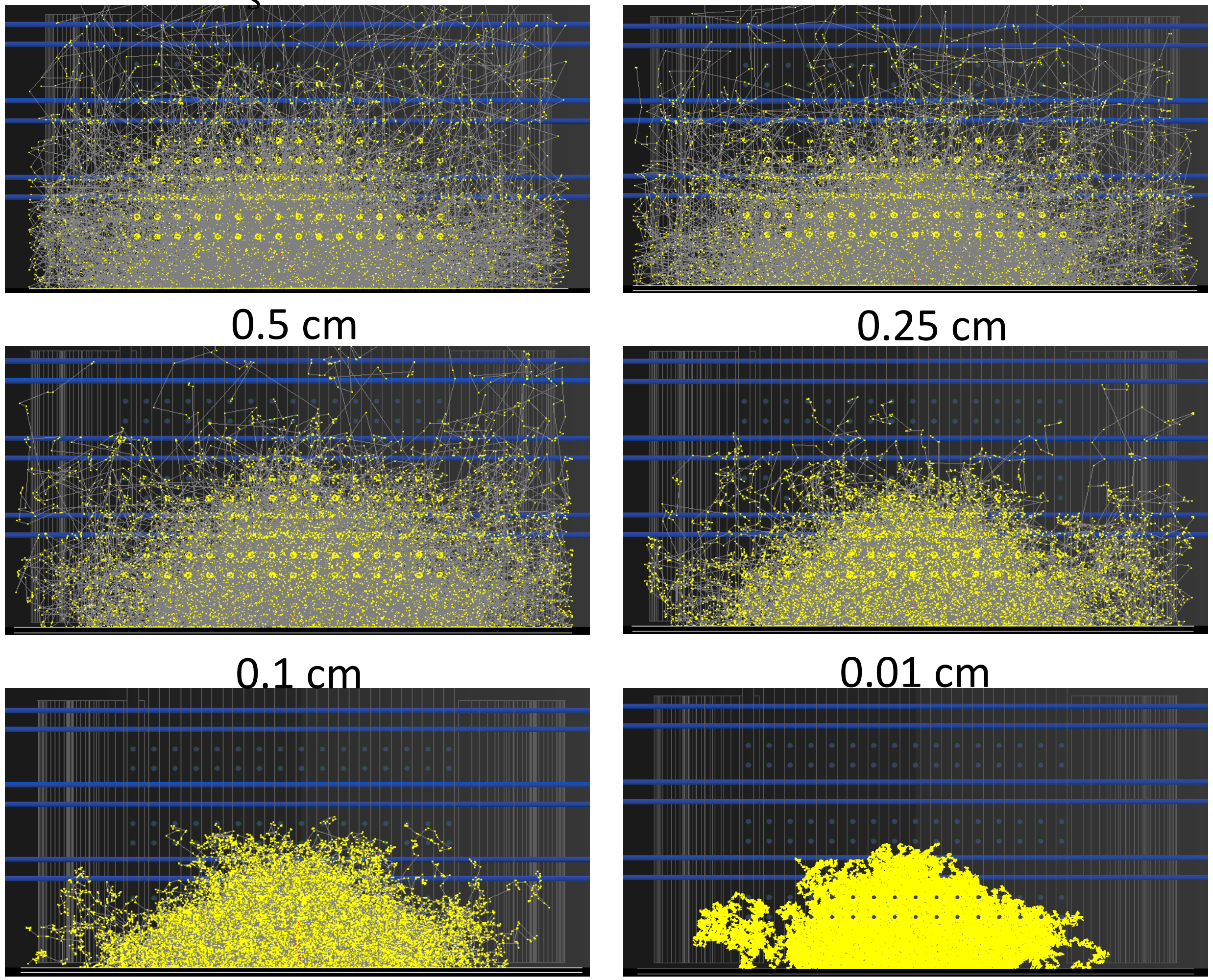
0.75 cm

0.5 cm

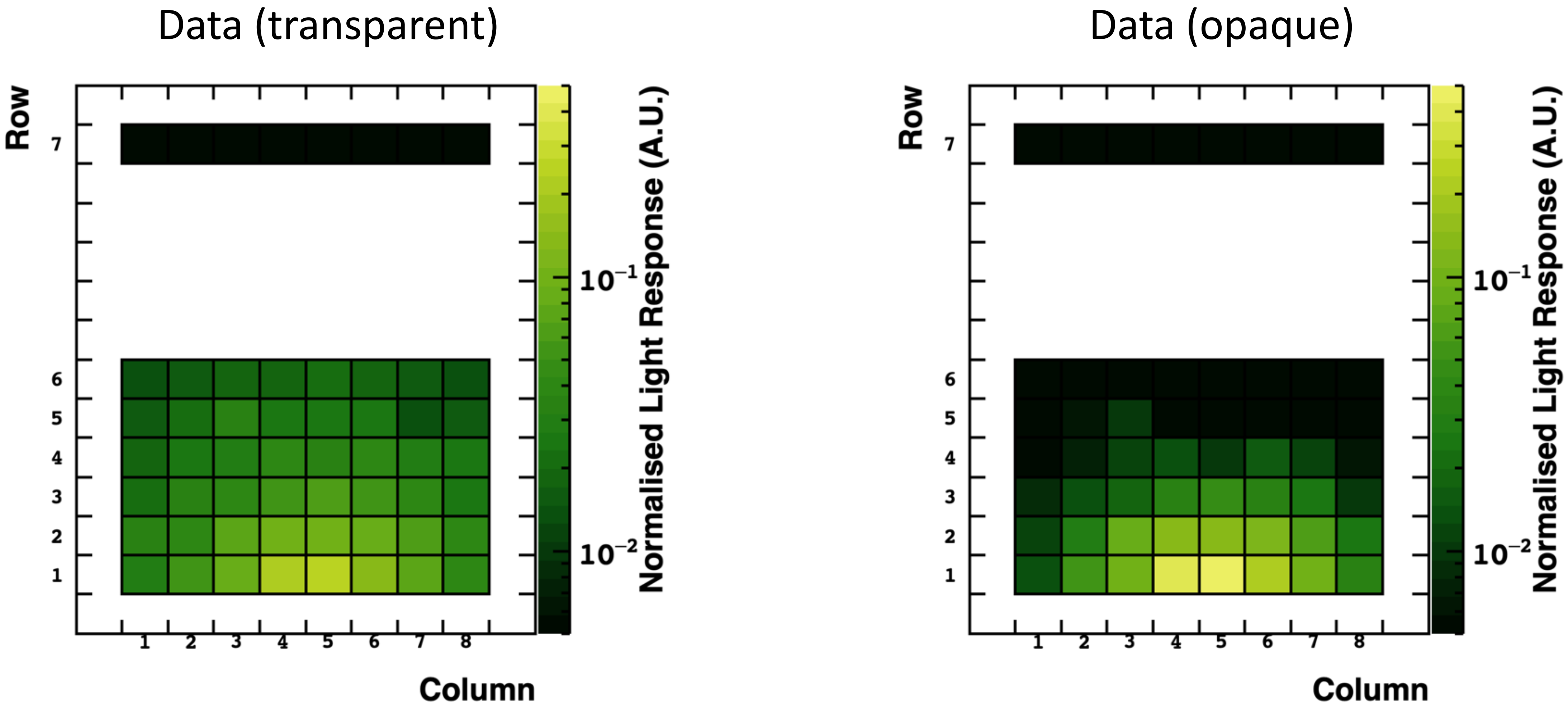
0.25 cm

0.1 cm

0.01 cm



Mini-e^-: Light confinement channel view



- Mini-e^- provided the proof of work of stochastic light confinement (light "ball")
- Next steps: preparing for Mini-γ and characterizing new opaque scintillators

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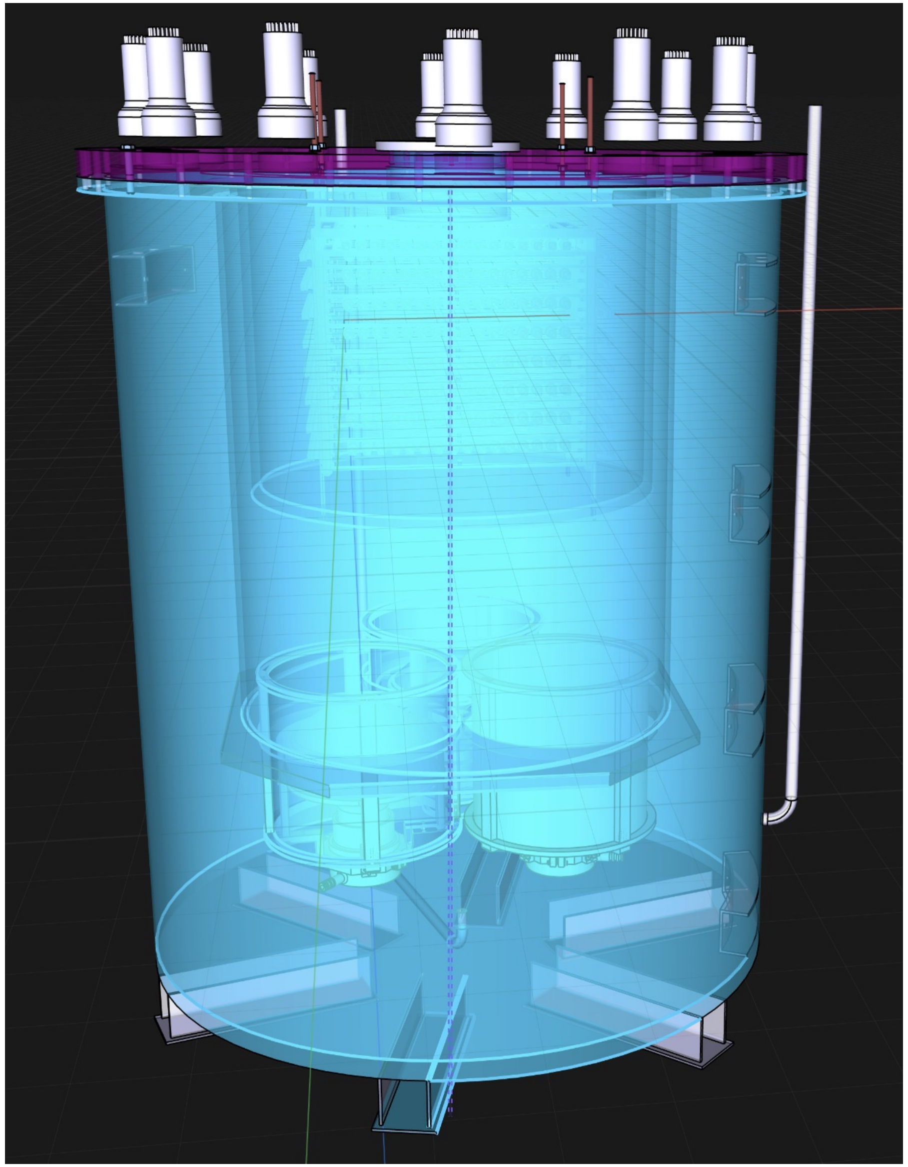
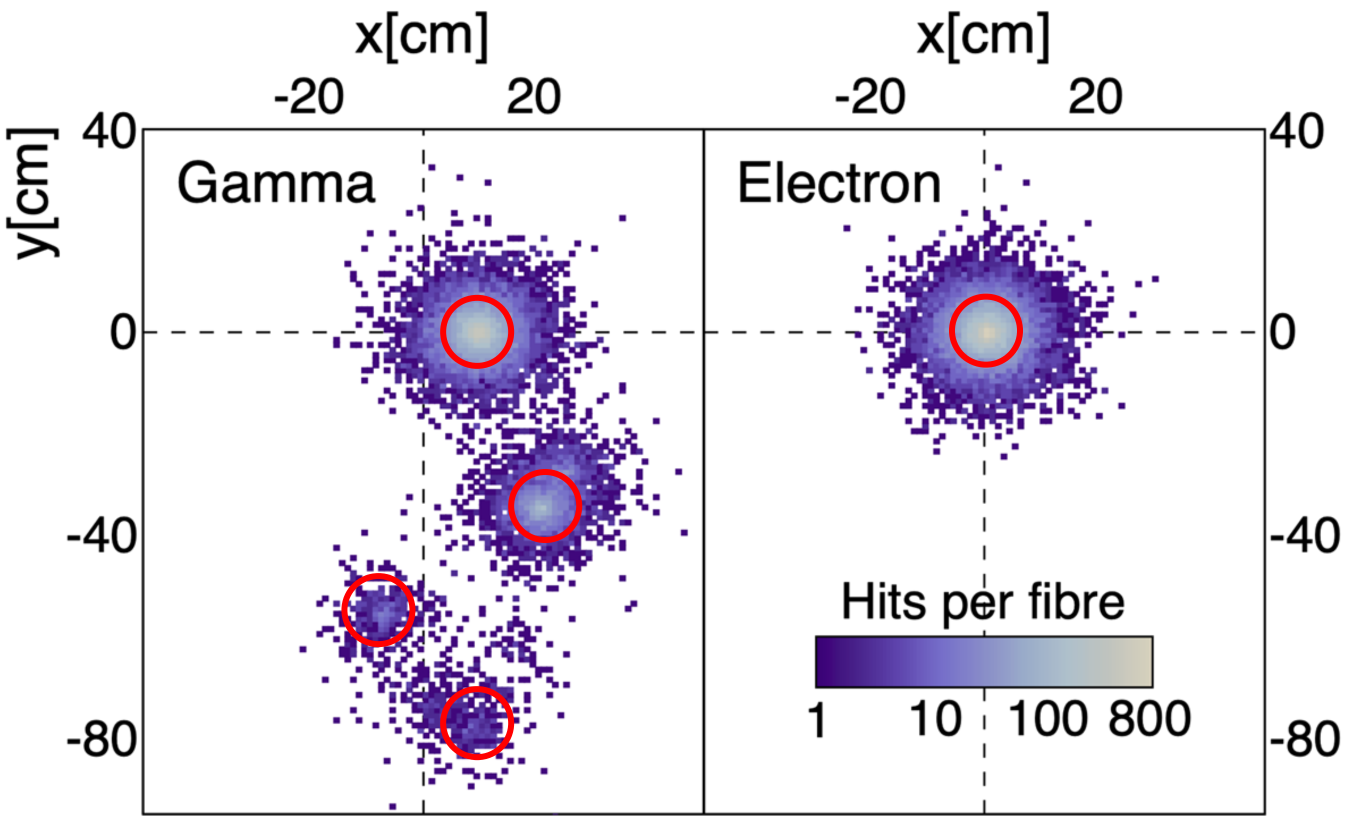
Mini-γ: Future prototype



- Largely optimized ~100 L Detector
  - 256 readout fibers
  - Similar electronics and wavecatcher
  - Temp. control system (Chiller), [5-40]°C cycles
- Calorimeter system
- Muon veto
- Trigger on multiple sources or muons
- Goals:
  - Further proof of work, mainly PID
  - Preparing for future Inverse Beta Decay detectors

Mini-γ: γ/e^- identification

Mini-e^- light ball →
(80% of light in r≈4 cm)

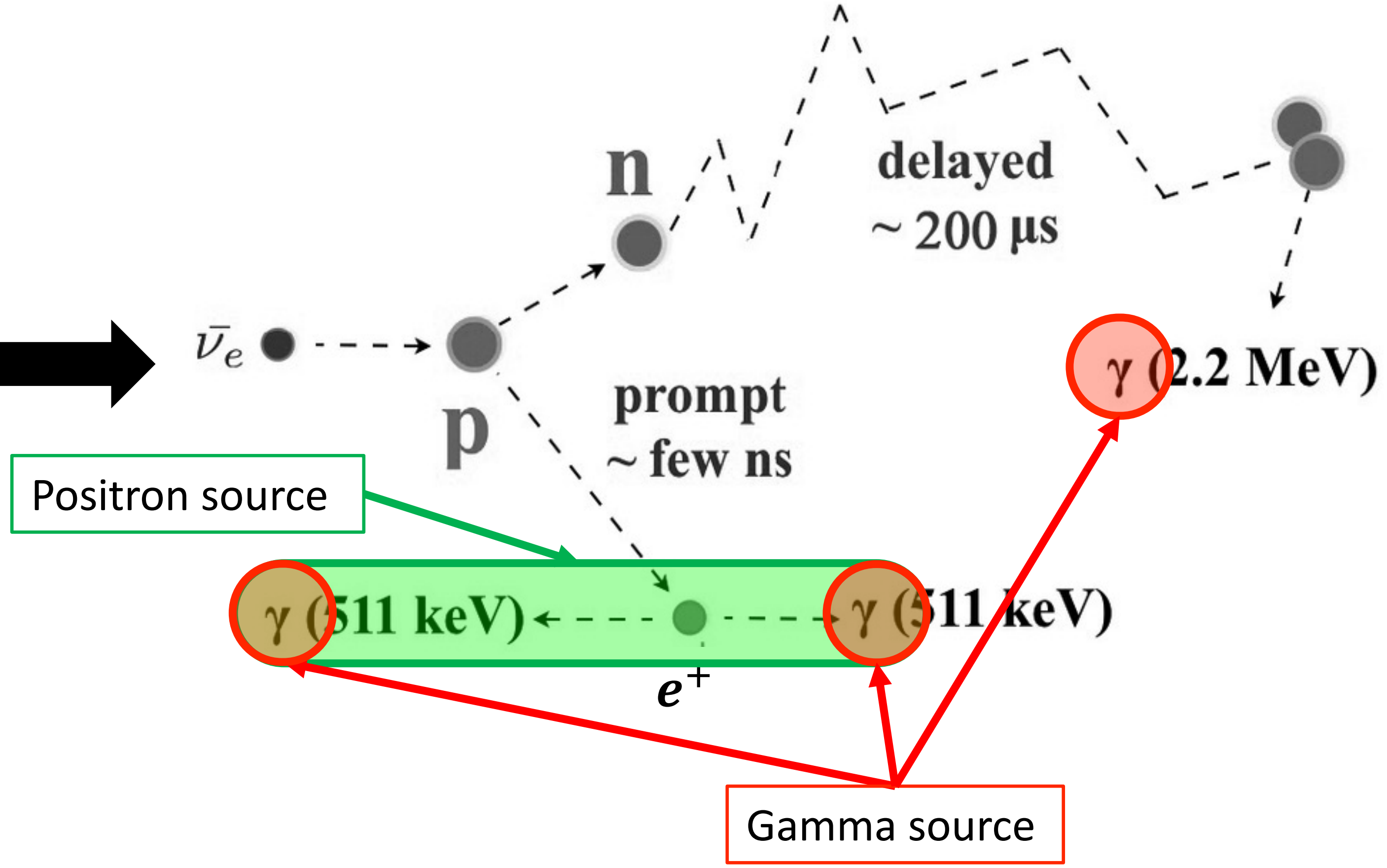


- Spatial dispersion of compton-scattering: series of e^--like light "balls"
- PID highly relies on our knowledge of e^- events

Mini-γ: Probing IBD

- Several sources planned: e^-, e^+ and γ
  - e^-, e^+: First attempt at matter/antimatter separation
  - e^+ and γ: Probing components of the Inverse Beta Decay (IBD) reaction

$$p^+ + \overline{\nu}_e \rightarrow e^+ + n^0$$

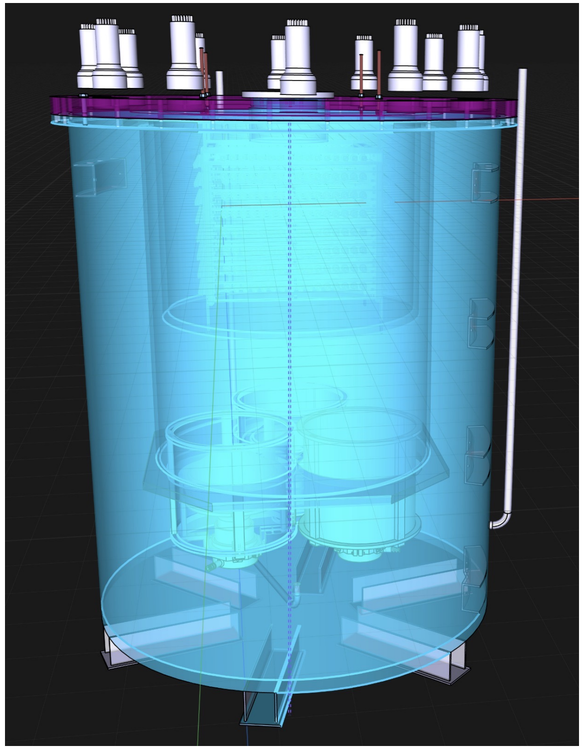


Contents

Future prospects

Mini-e^-

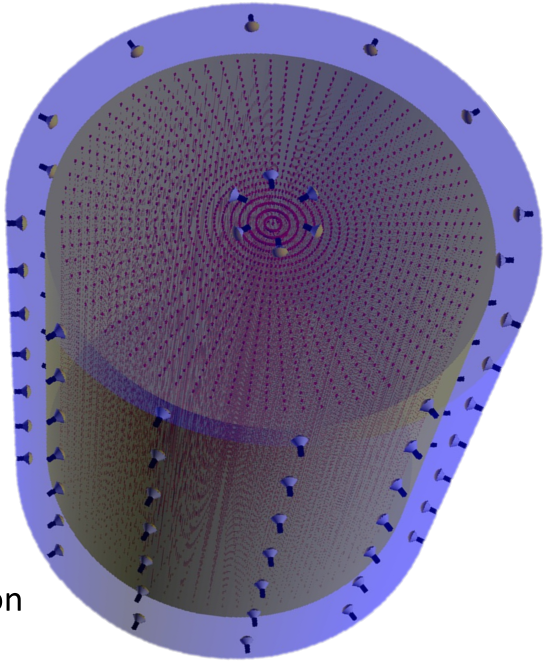
MINI-γ project



~100 L
2022-2023
(Data taking this fall)

AntiMatter-Otech project

Applied & Innovation R&D



Cartoon

~ 10 tons
2022-2027

European Innovation Council

UK Research and Innovation

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

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

anr agence nationale de la recherche AU SERVICE DE LA SCIENCE

Future prospects: SuperChooz

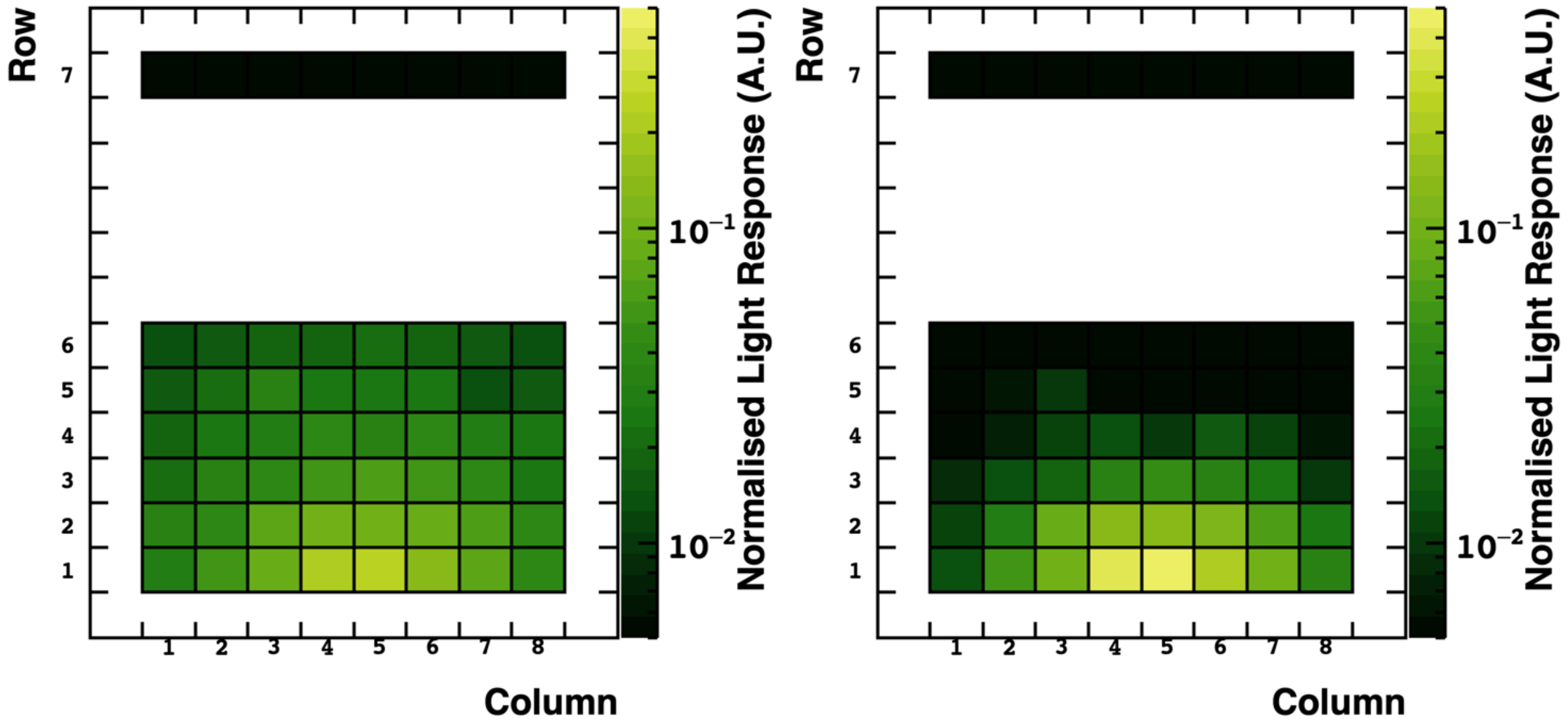
AMOtech/CLOUD

≤10 ktons
≥2030

Conclusion

- Opacity provides new framework/technologies for scintillator detectors
- Stochastic light confinement (light "ball") provides a topological lens for interaction analysis
  - Particle identification
  - Background rejection => reduce need for overburden
  - Intrinsic Matter/antimatter separation capabilities (e^-/e^+ PID)
- Mini-e^- demonstrated the light ball formation
- Mini-γ will allow us to explore this technology's capabilities: PID, tracking etc.

Thank you!

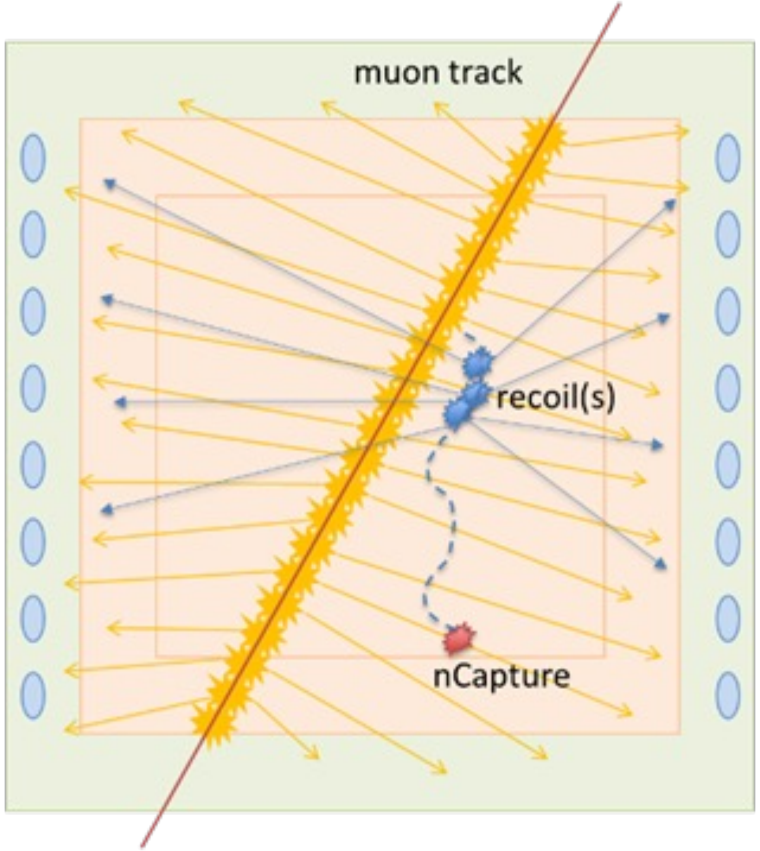


Row
7
6
5
4
3
2
1
1 2 3 4 5 6 7 8
Column
10^{-1}
10^{-2}
Normalised Light Response (A.U.)

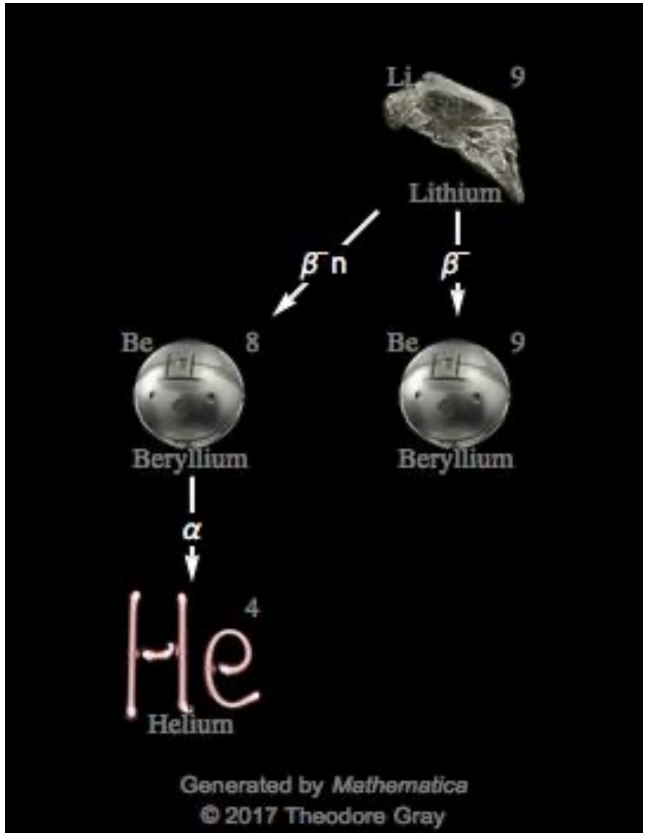
BACK-UP

Mini-γ: Probing IBD, Muon mode

Fast neutron production:



Lithium-9 decay:

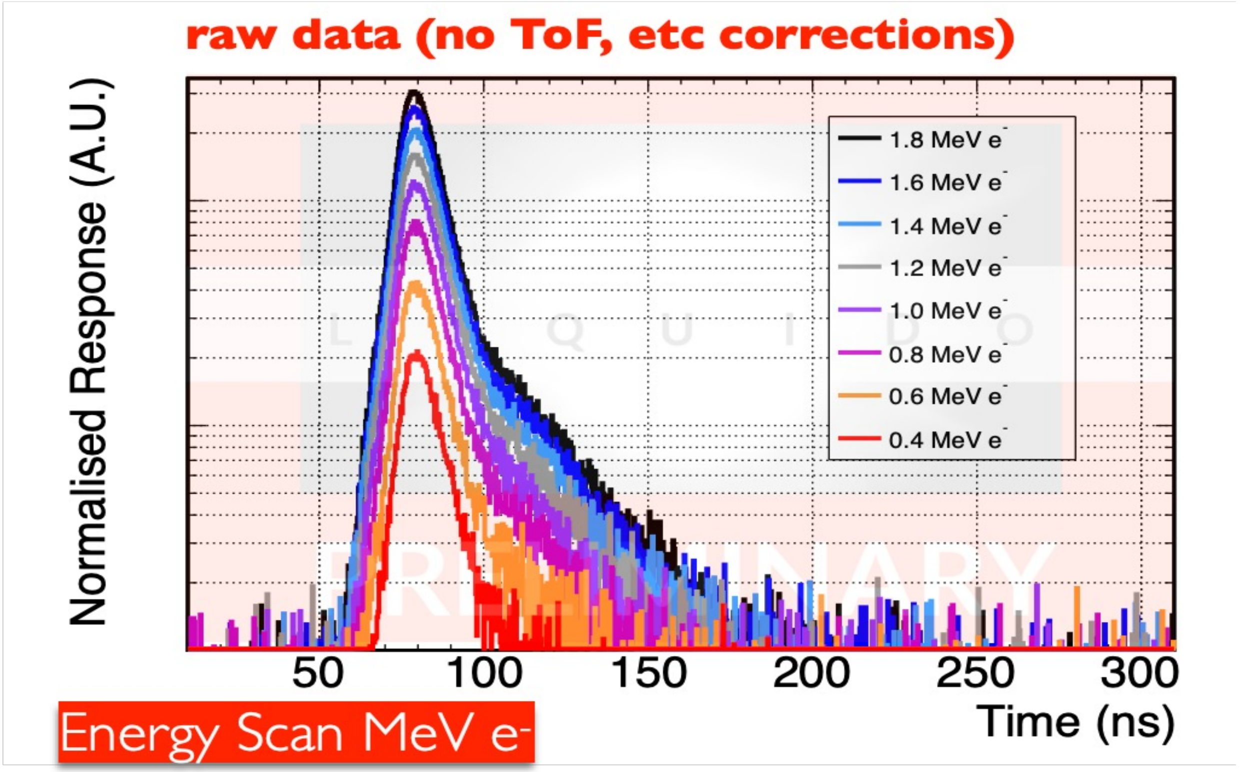


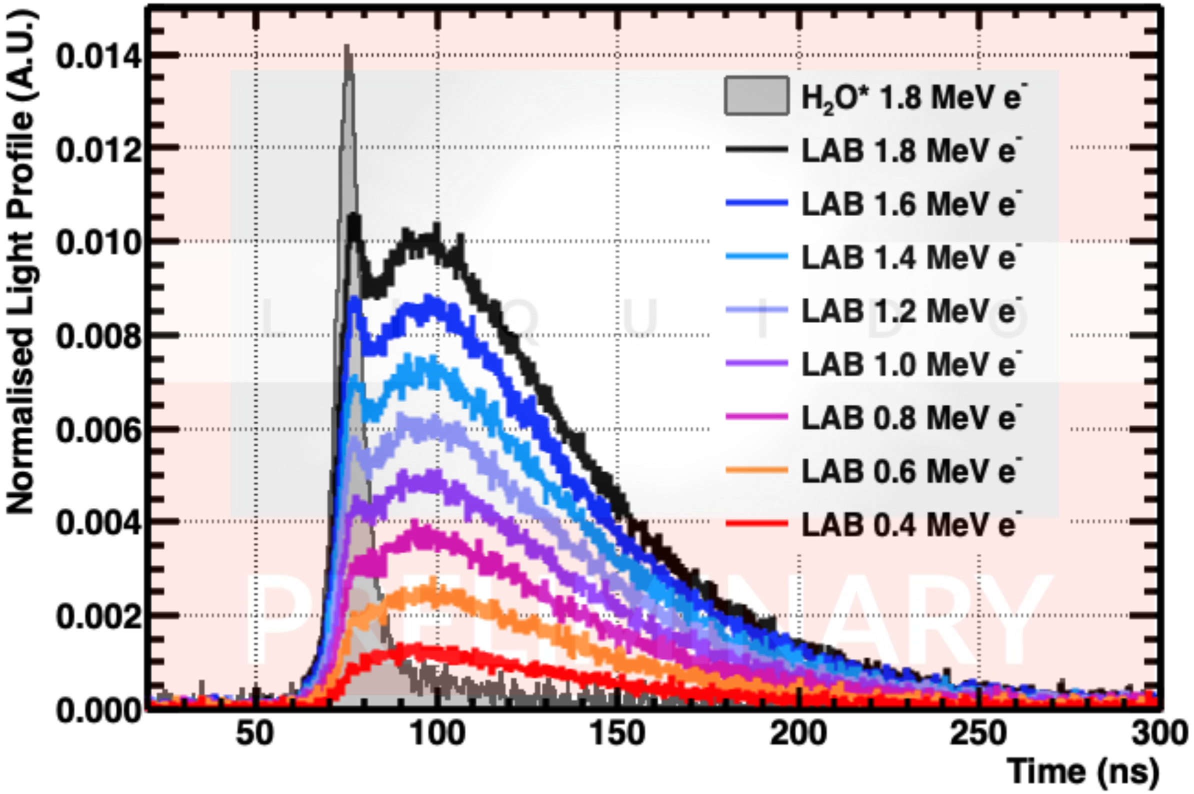
Muon spallation, major source of background for IBD, mimicks delayed signal in two ways:

- Fast neutrons
- Isotope production (mainly ^{9}Li)

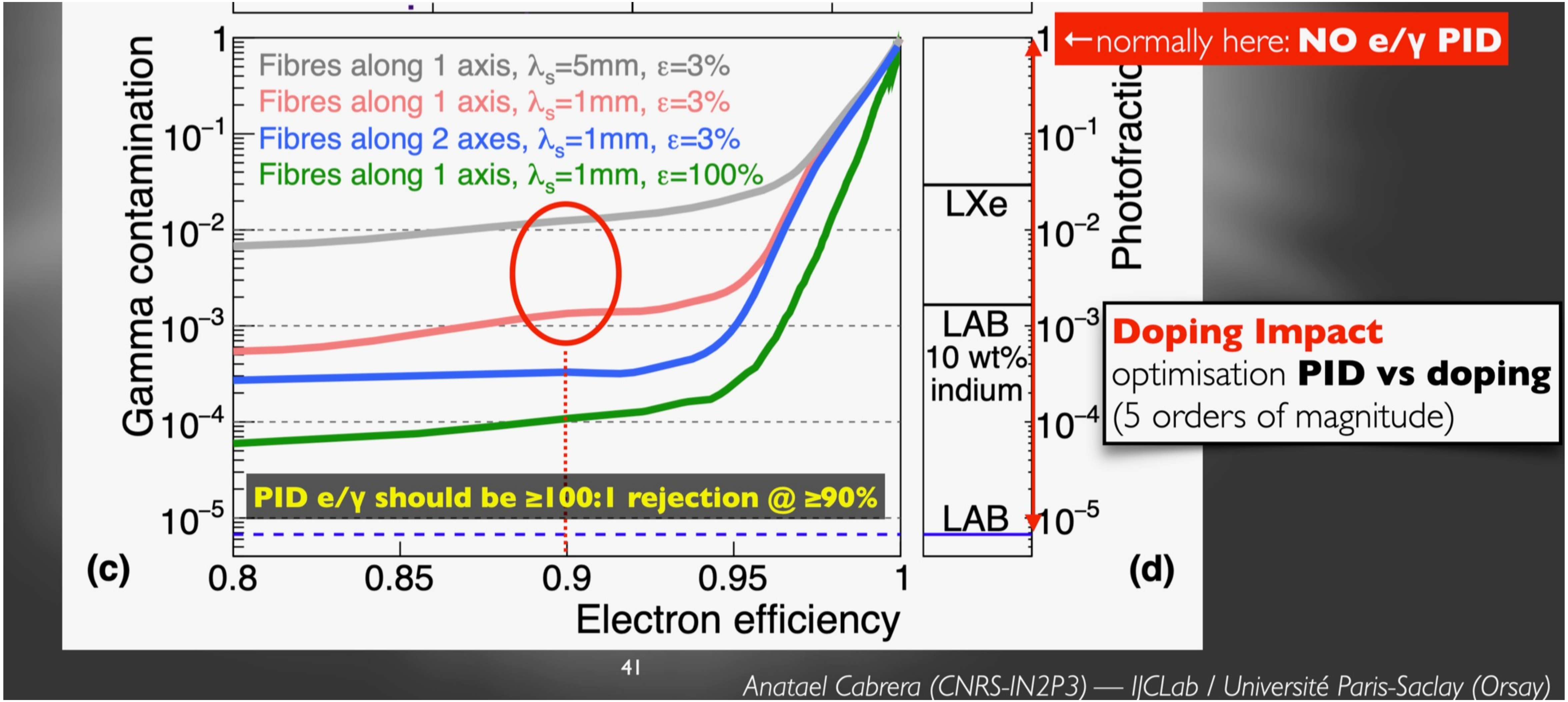
Muon tracking is a way of identifying potential background neutrons => reduce need for big overburden

Mini-e : lab vs lab+ppo time profile



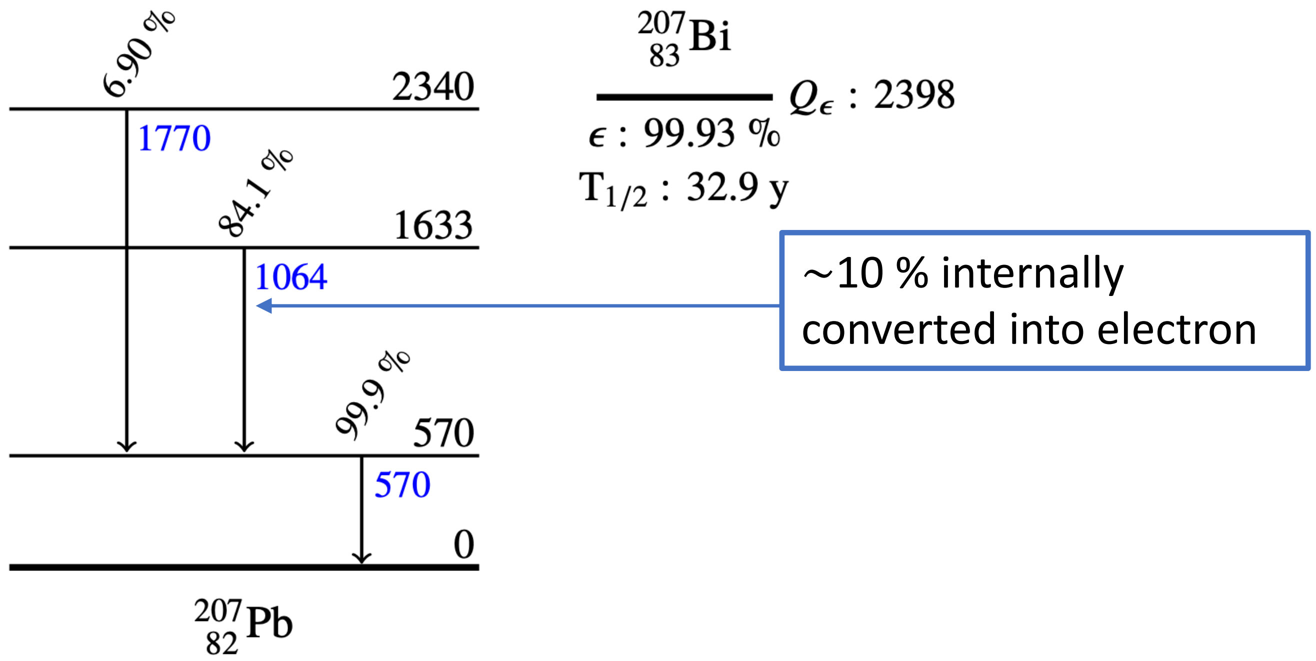


Gamma contamination for electron ID



Source mode : Bismuth

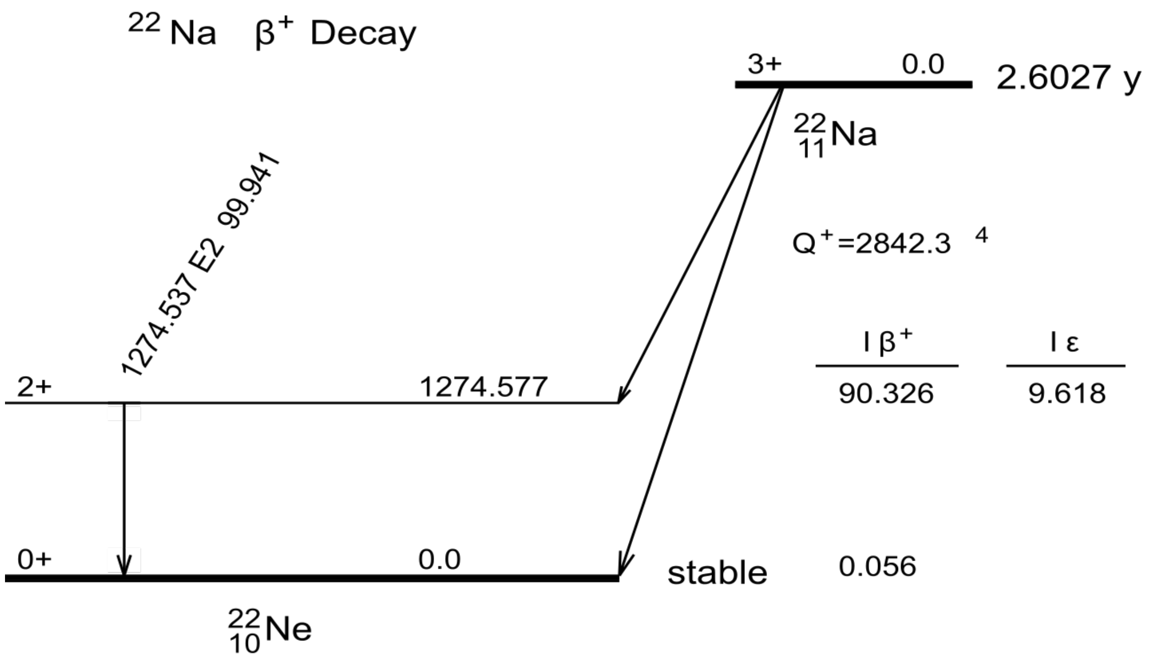
Bismuth 207 is one of the sources that will be used for Mini-γ



- 1 MeV and 570 keV gammas (close to annihilation gamma energy)
- Majority of electrons emitted are 1 MeV, cross-calibration

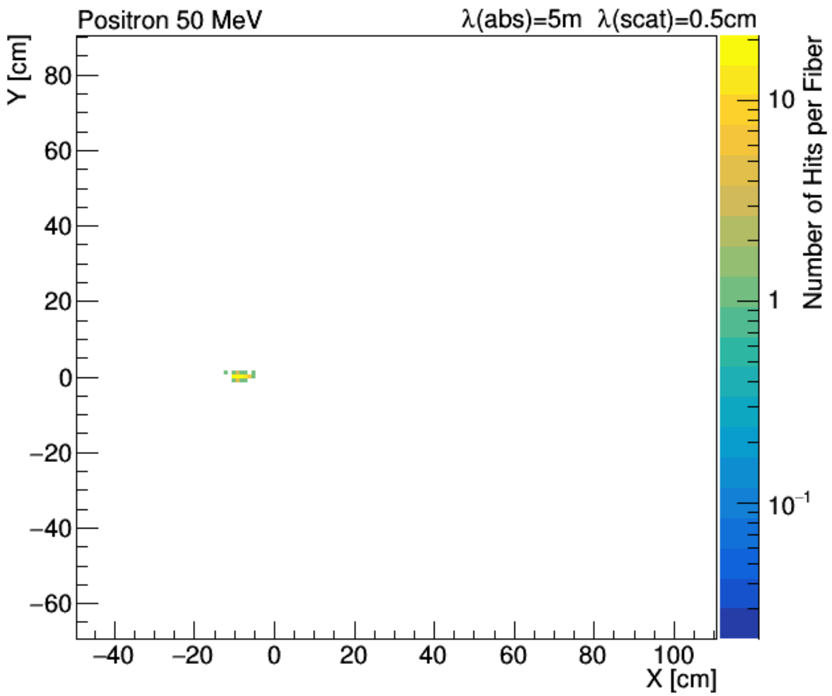
Source mode: Sodium

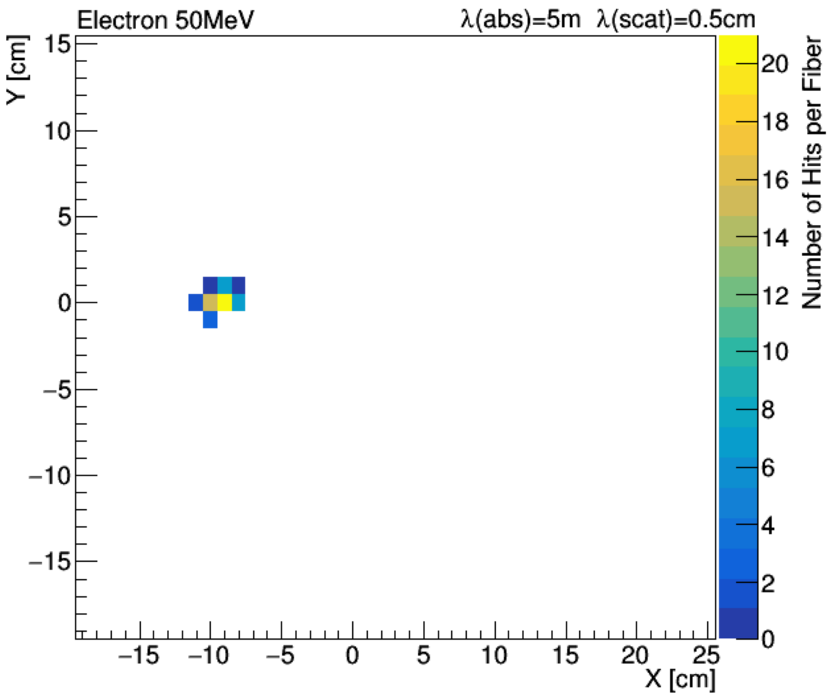
Another source is Sodium-22



- 1274 keV Gammas, for gamma tracking
- Majority of positrons (1.5 MeV), allows for positron+annihilation characterization

Dynamic PID


Positron 50 MeV
λ(abs)=5m λ(scat)=0.5cm
Y [cm]
X [cm]
Number of Hits per Fiber


Electron 50MeV
λ(abs)=5m λ(scat)=0.5cm
Y [cm]
X [cm]
Number of Hits per Fiber

Experimental validation

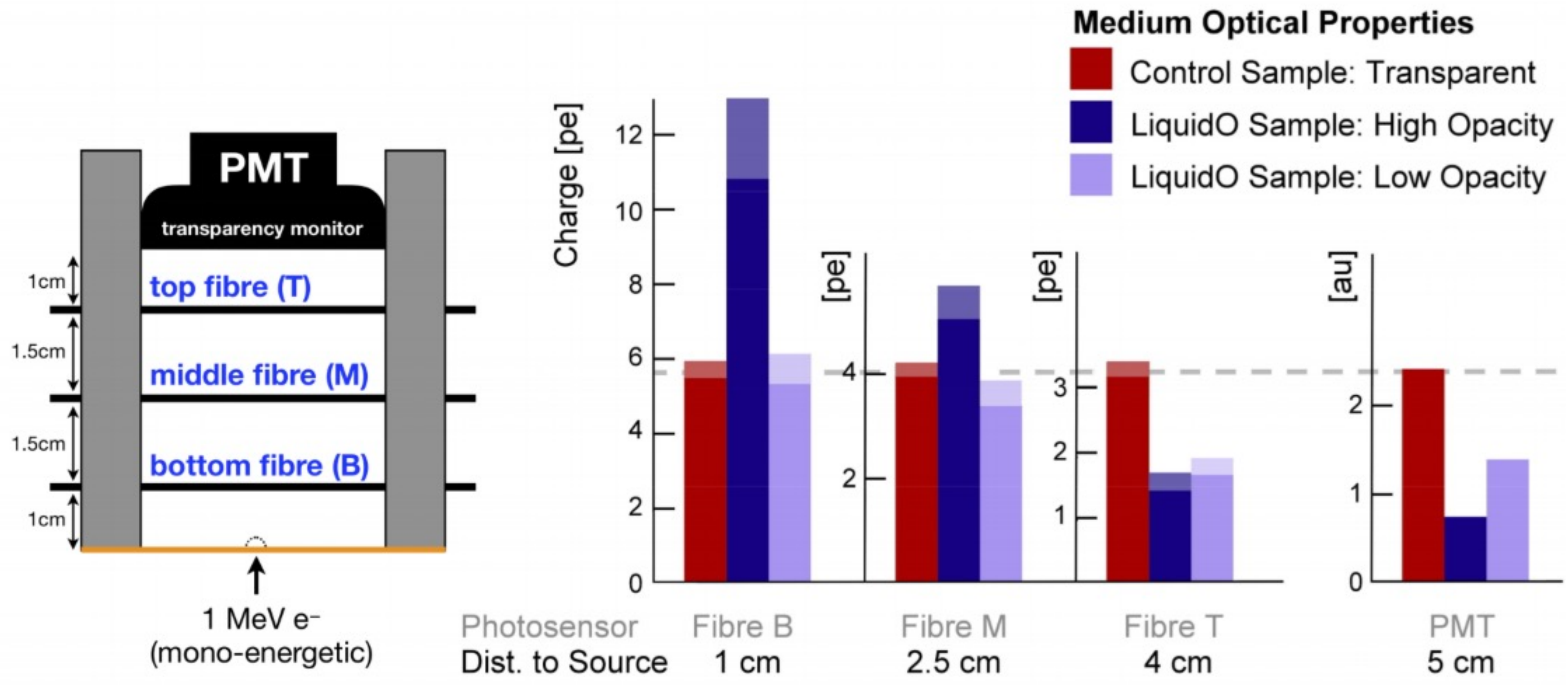
Micro-LiquidO: First experimental proof of principle

Article | Open Access | Published: 21 December 2021

Neutrino physics with an opaque detector

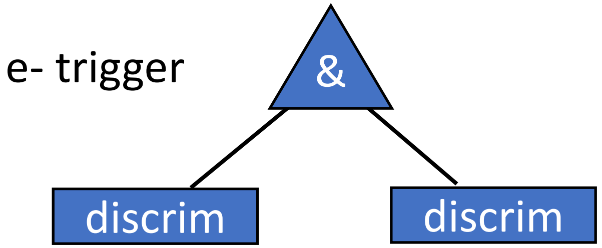
LiquidO Consortium

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

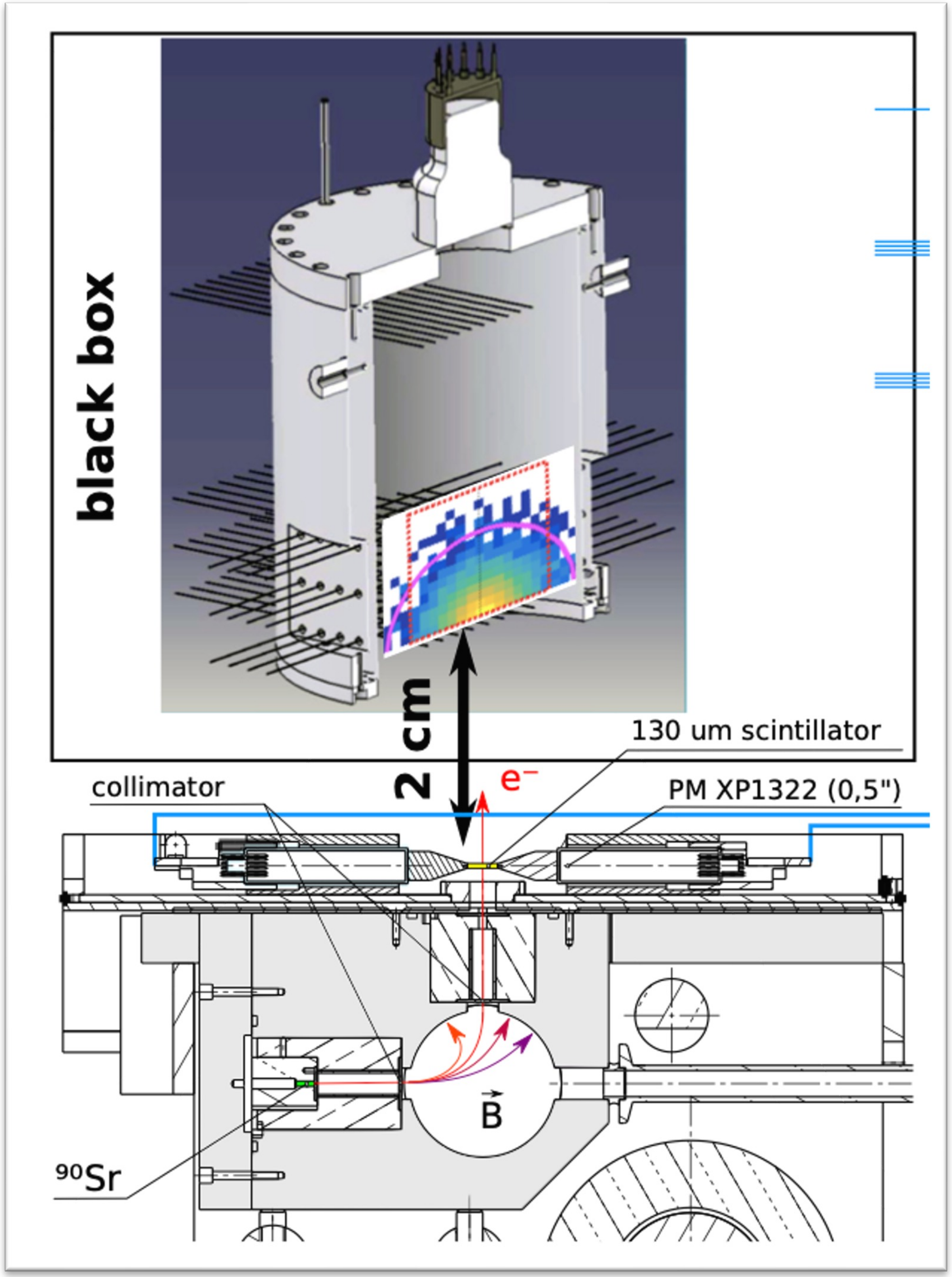


More light collected by the fibres near the light source with the opaque sample!

Experimental validation

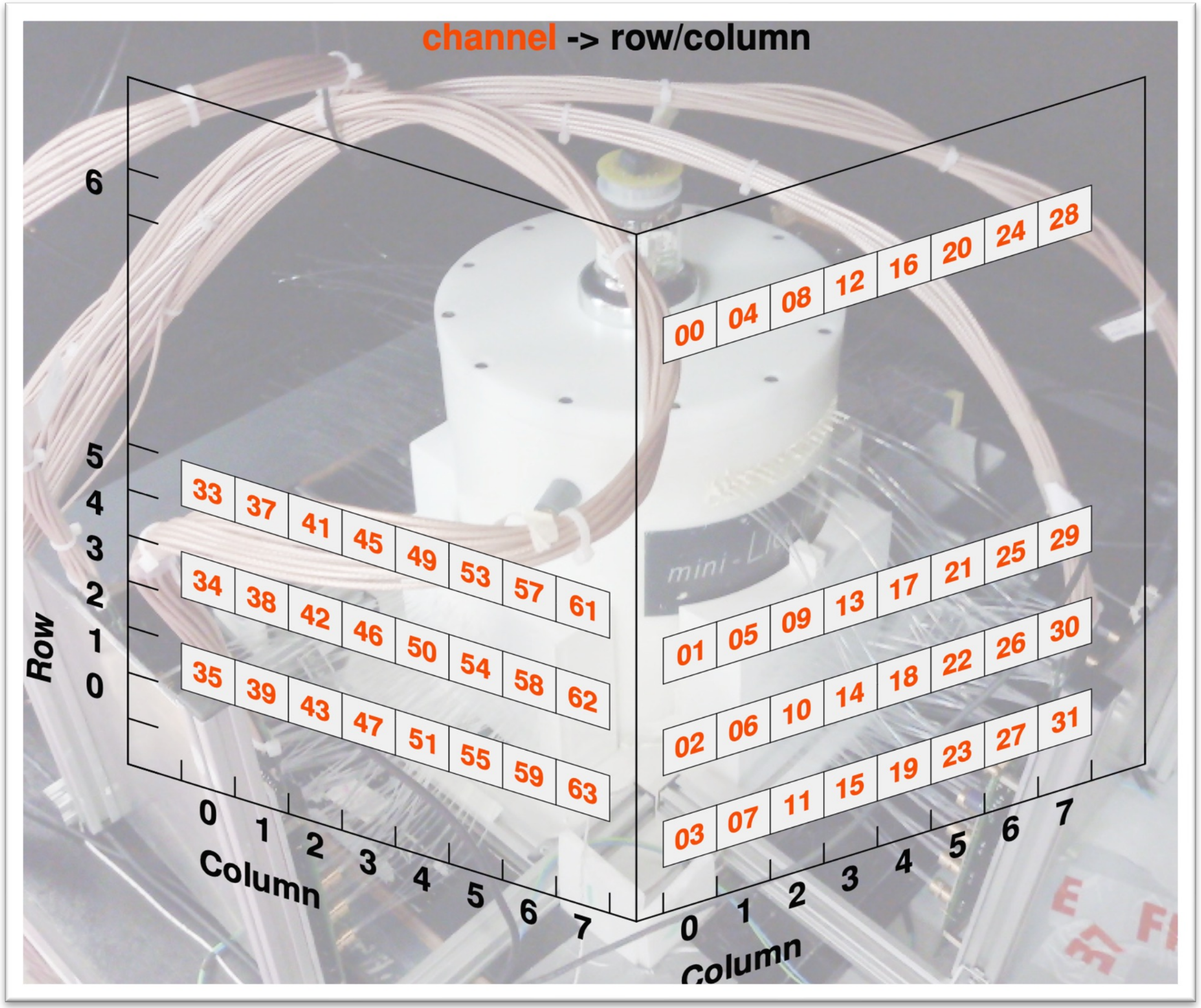


Coincidence between 2 PMT triggers is done directly by wavecatcher



Experimental validation

Mini-II Set Up



experimental demonstration III

a priori no showstopper

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

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

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