The LiquidO R&D

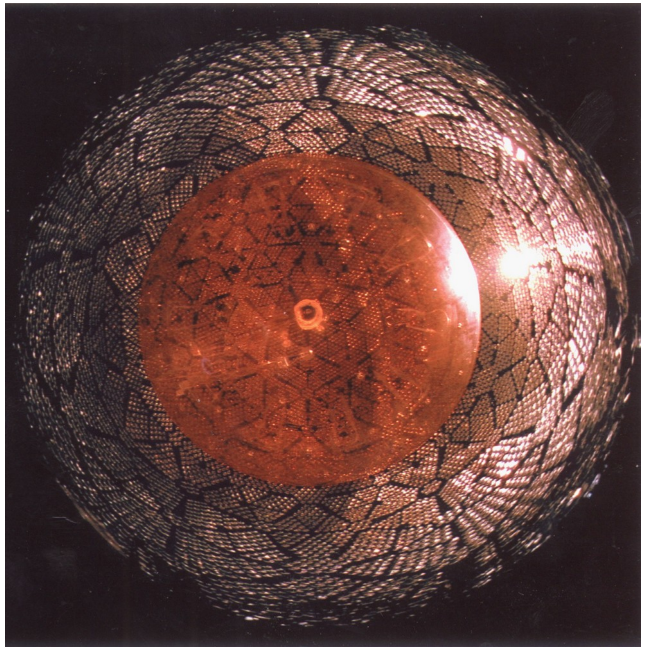
Axel Pin

On behalf of the LiquidO proto-collaboration

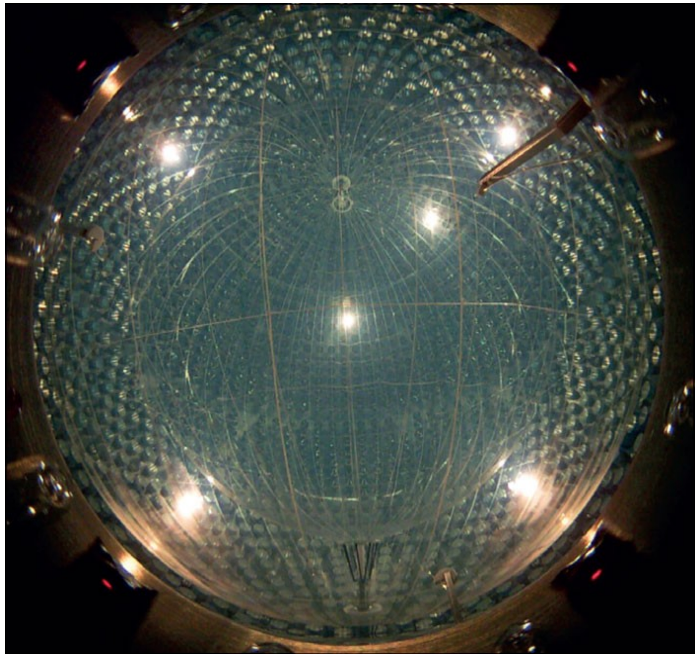
Neutrinos detection techniques

First neutrino detection by Reines & Cowan: use of **transparent liquid scintillator + PMTs + doped target**

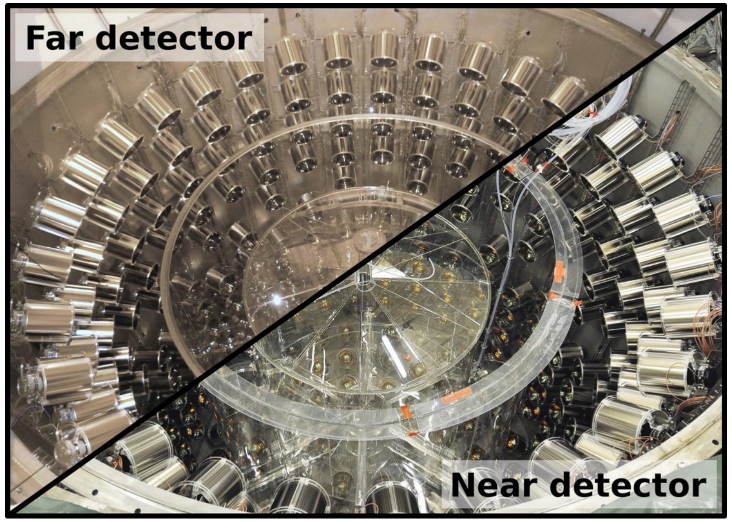
Today … **same technology** as 70 years ago !



SNO



Borexino



Double Chooz

Improvement of the transparency of the liquid scintillator

BUT with transparent medium:

- **Limited doping** (typically 0.1 %)
- Very limited or no event-wise **Particle Identification** (PID)

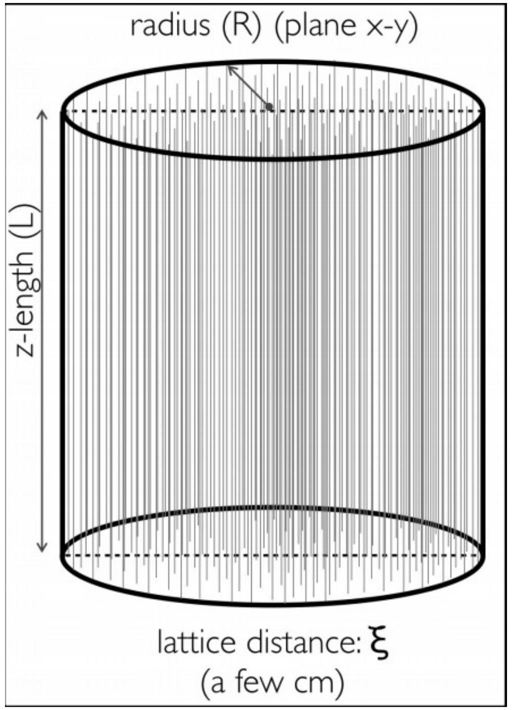
For low background (PMT) → **buffer** volume (typically ≥2x the active volume for ν interactions)

The LiquidO approach

To break this paradigm: use of an **opaque** liquid scintillator !

« Hey ! You want to use opaque stuff and expect to see light ? Good luck ! »

Opaque medium → light **confinement** + **optical fibres** to collect the light where it is created =



LiquidO

See *Neutrino Physics with an Opaque Detector* – Arxiv 1908.02859

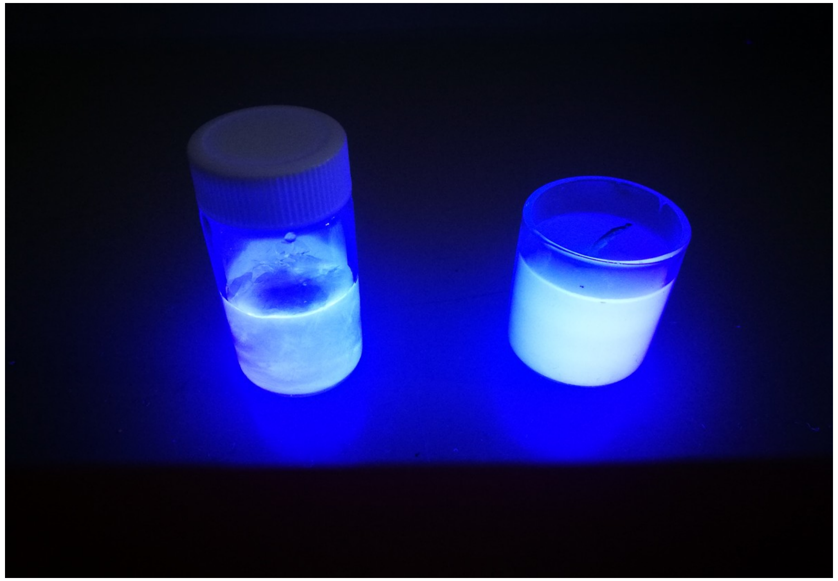
Using opaque scintillator allows:

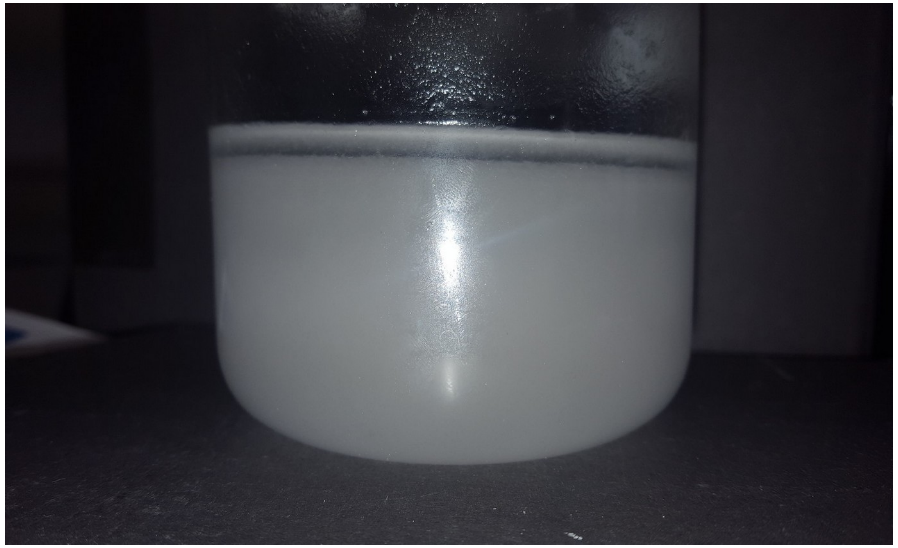
- **Doping** (we do not care anymore about transparency)
- **PID** (to be detailed later) - tracking
- **No buffer** volume
- No need for **segmentation**

What does « opaque » means ?

Like these ?

The opaque liquid scintillator





Opaque scintillator: before LiquidO, it **has never been exploited** !

- Liquid scintillator + something inside ?
- Micro-balls ?
- Solid

Today: opaque scintillator looks like **wax**

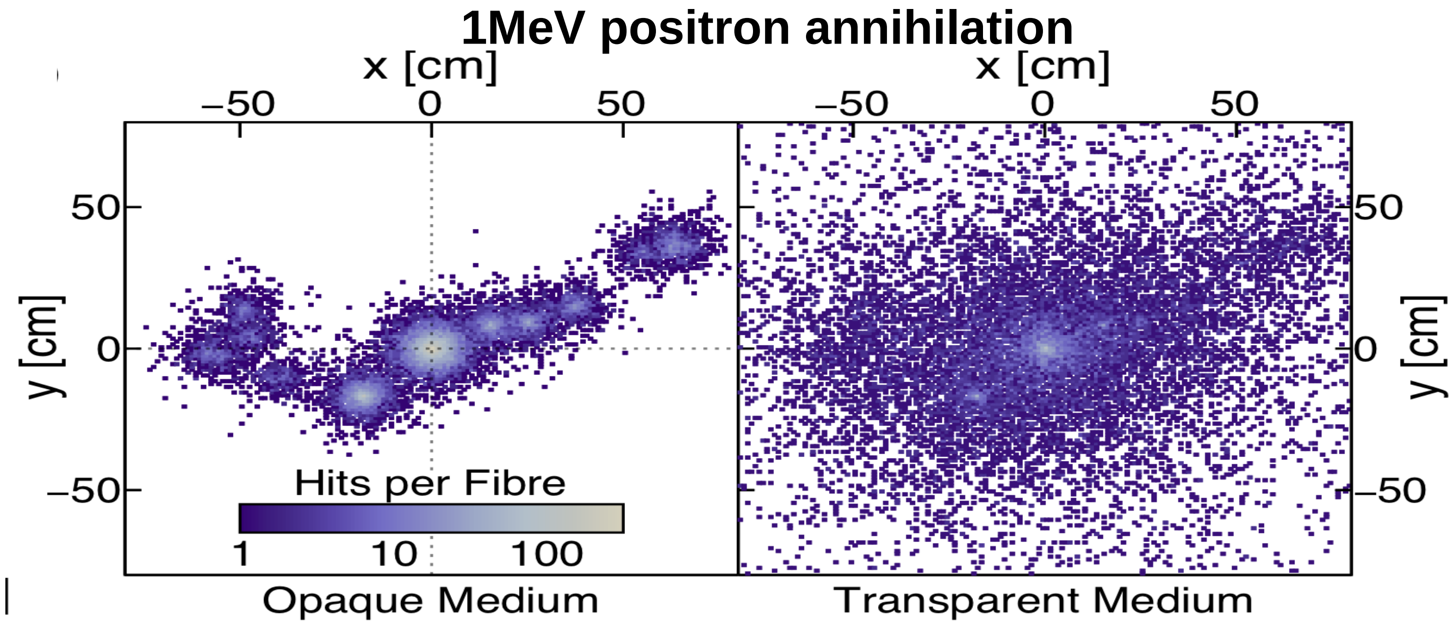
- Linear AlkylBenzene (LAB) based scintillator+ paraffin
- Developped by MPIK (See *Novel opaque Scintillator for neutrino detection - Arxiv 1908.03334*)

Opaque means:

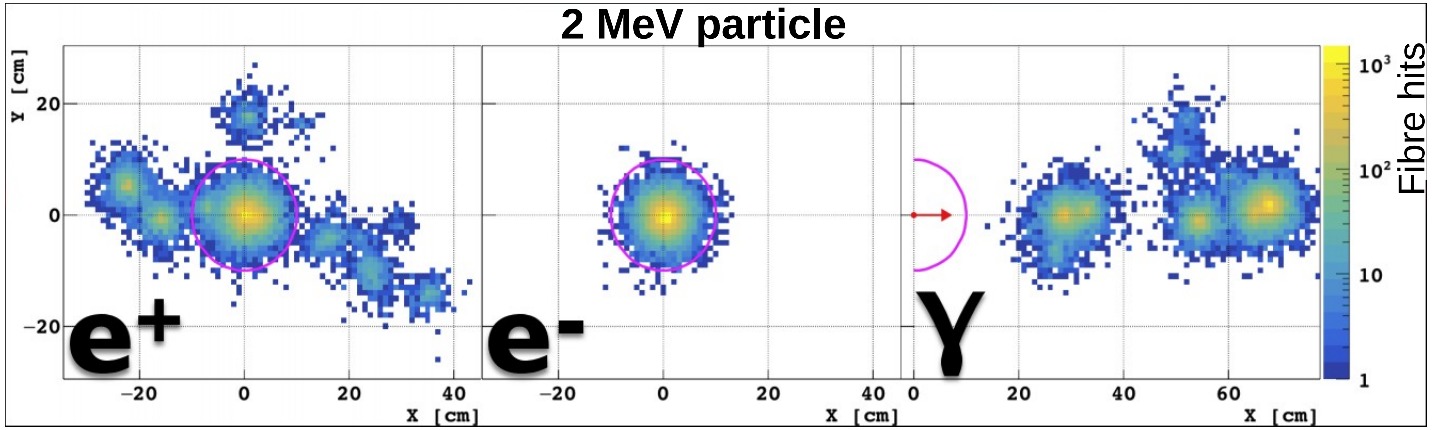
- **Absoption length** of few m
- **Low diffusion length** (~mm)
  - → stochastic confinement of the light
  - → PID possible

The PID power

Capability to distinguish e^+ annihilation and gamma rays' compton

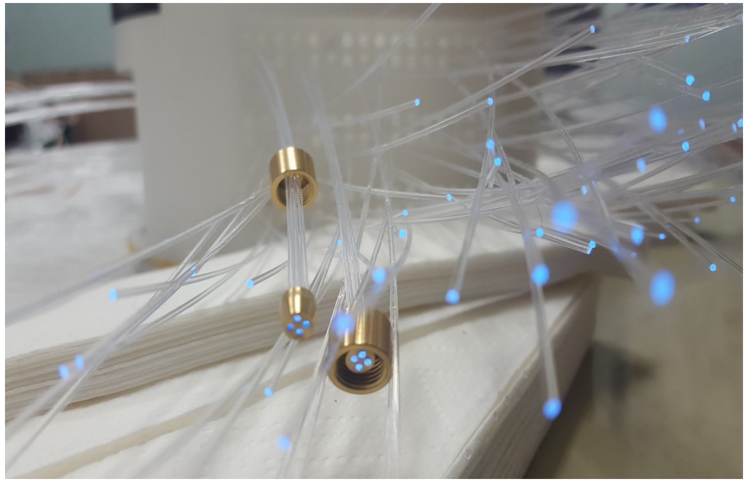


Capability to identify particles (different signal shapes)

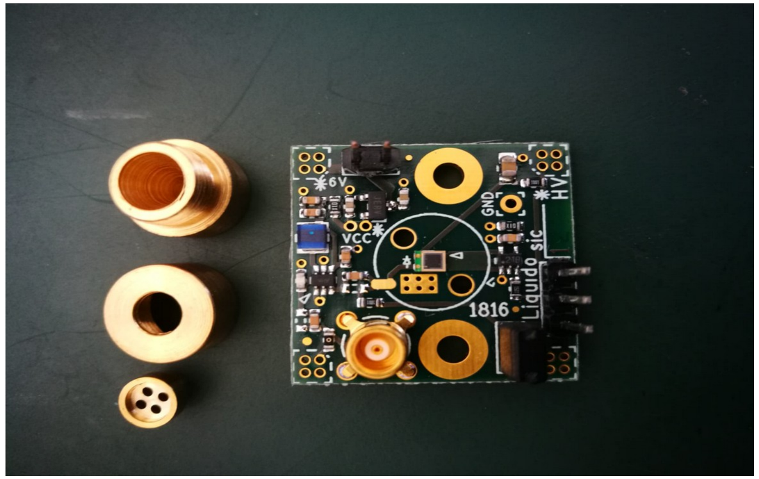


The read-out

With fast electronics, it could be possible access the **event dynamic**
Good vertex reconstruction (<cm scale) = **fast detector** needed
PMTs (few ns TTS) are too slow → **SiPM** technology (~0.1 ns)

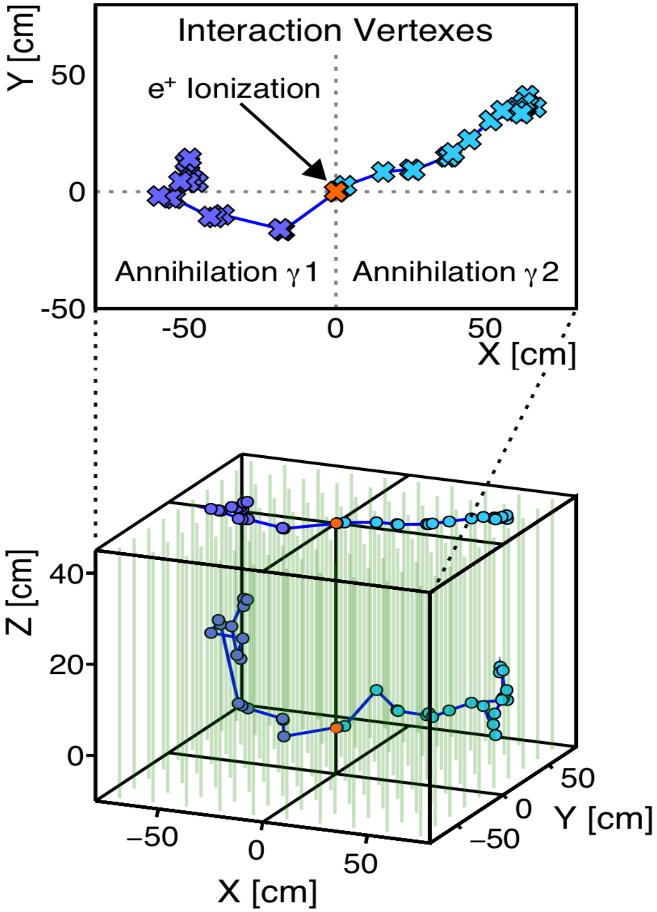


Wavelength shifting fibres to collect the light



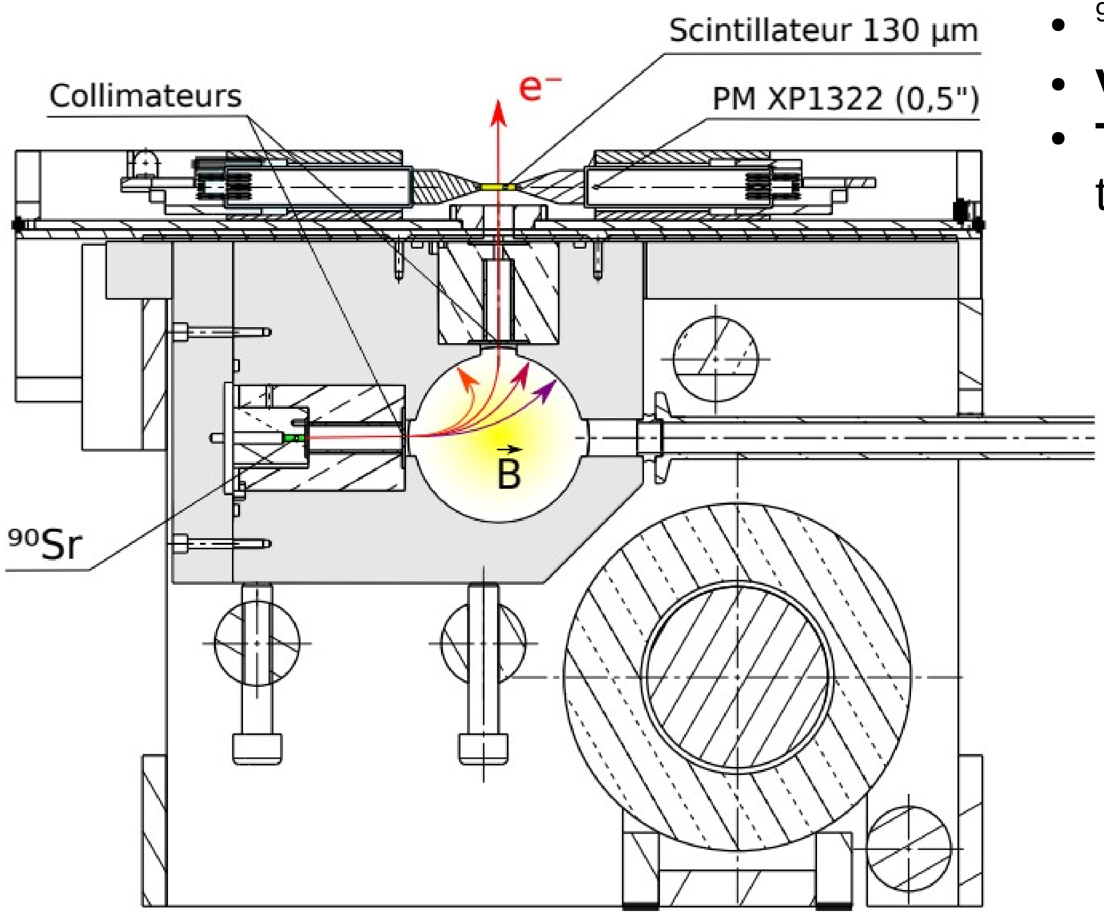
Silicon PhotoMultiplier with fast time response

+



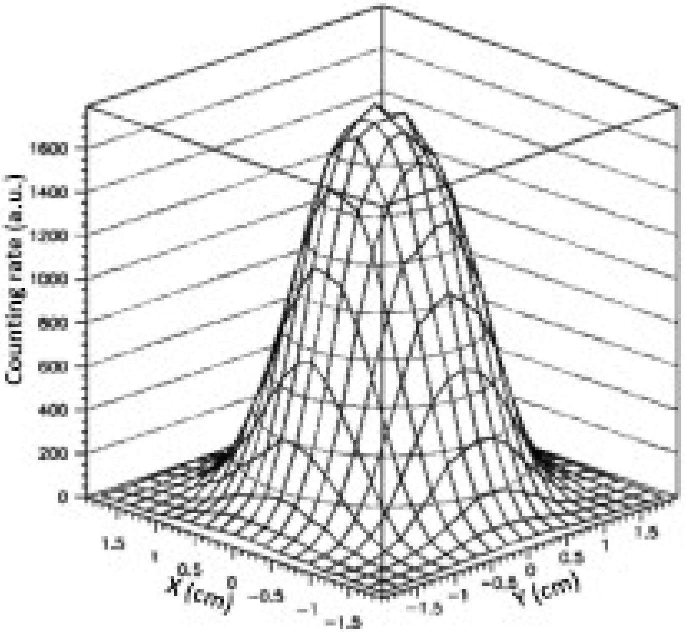
The source

Bordeaux has an electron spectrometer: **mono-energetic electron beam**



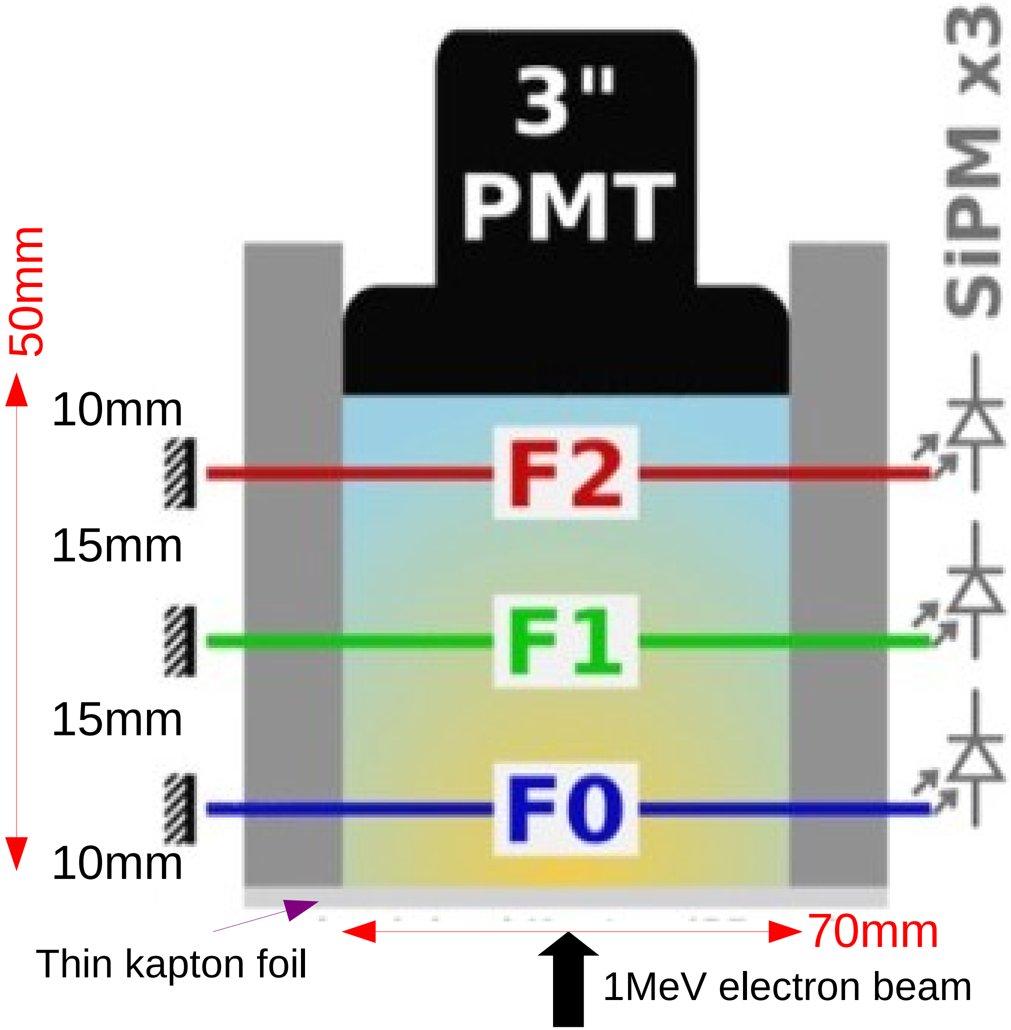
- ^{90}Sr **beta** source with Q_β = 2.3 MeV
- **Variable** magnetic field to select the beam energy
- **Thin scintillator** (called DeltaE) at the exit of the spectrometer to ensure we trigger on these mono-energetic electrons

Beam profile



First results

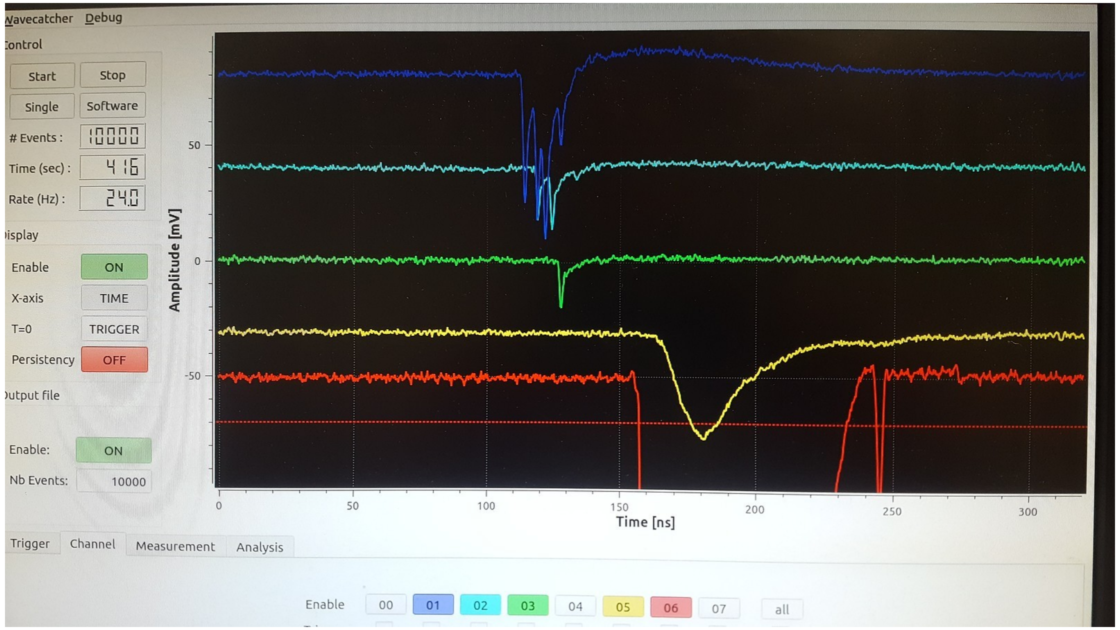
µLiquidO: experimental proof-of-principle



µLiquidO's goals :

- Capability to **confine** the light
- Capability to **collect** the light

The analysis method



F0 (bottom)

F1 (middle)

F2 (top)

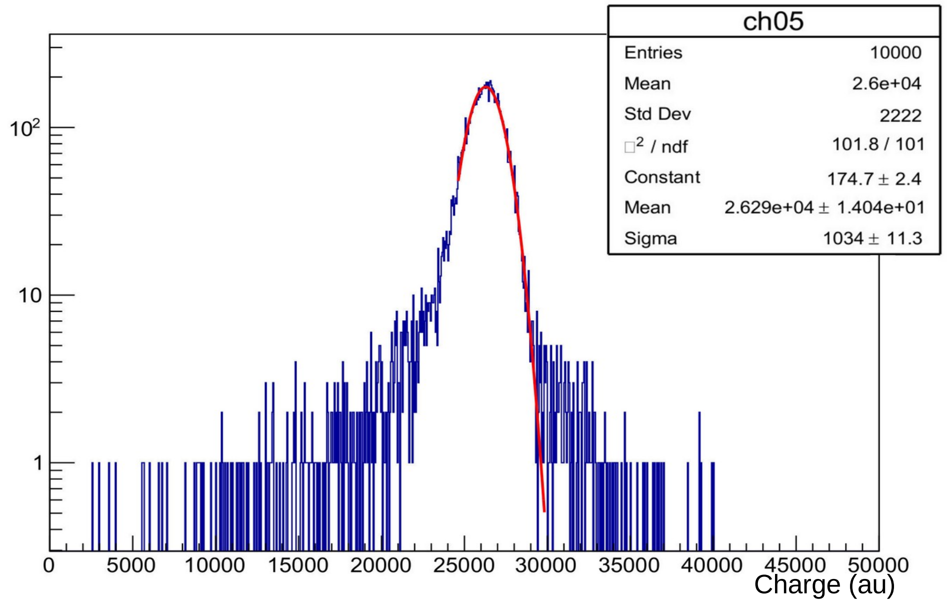
PMT

DeltaE

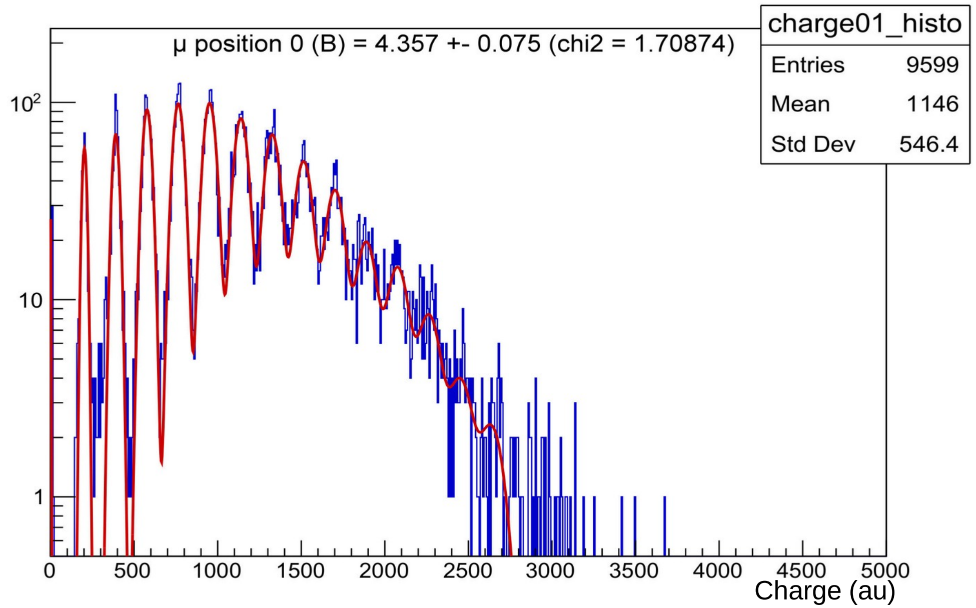
Acquisition

Integral of the pulse = charge

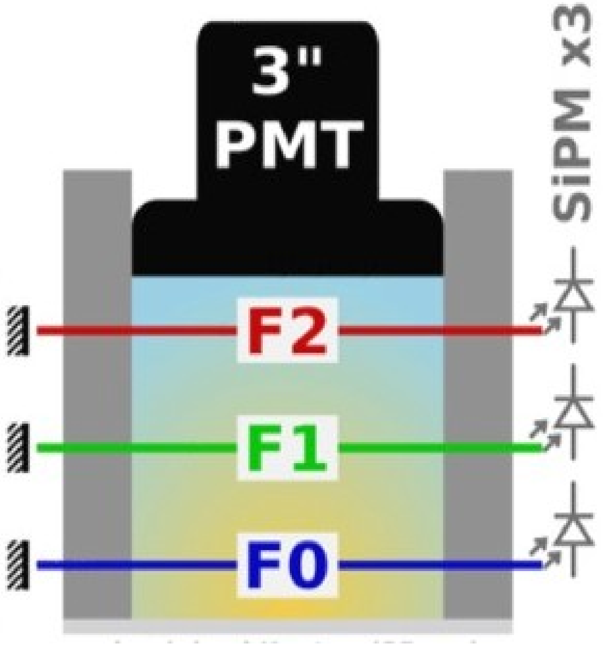
PMT charge spectrum

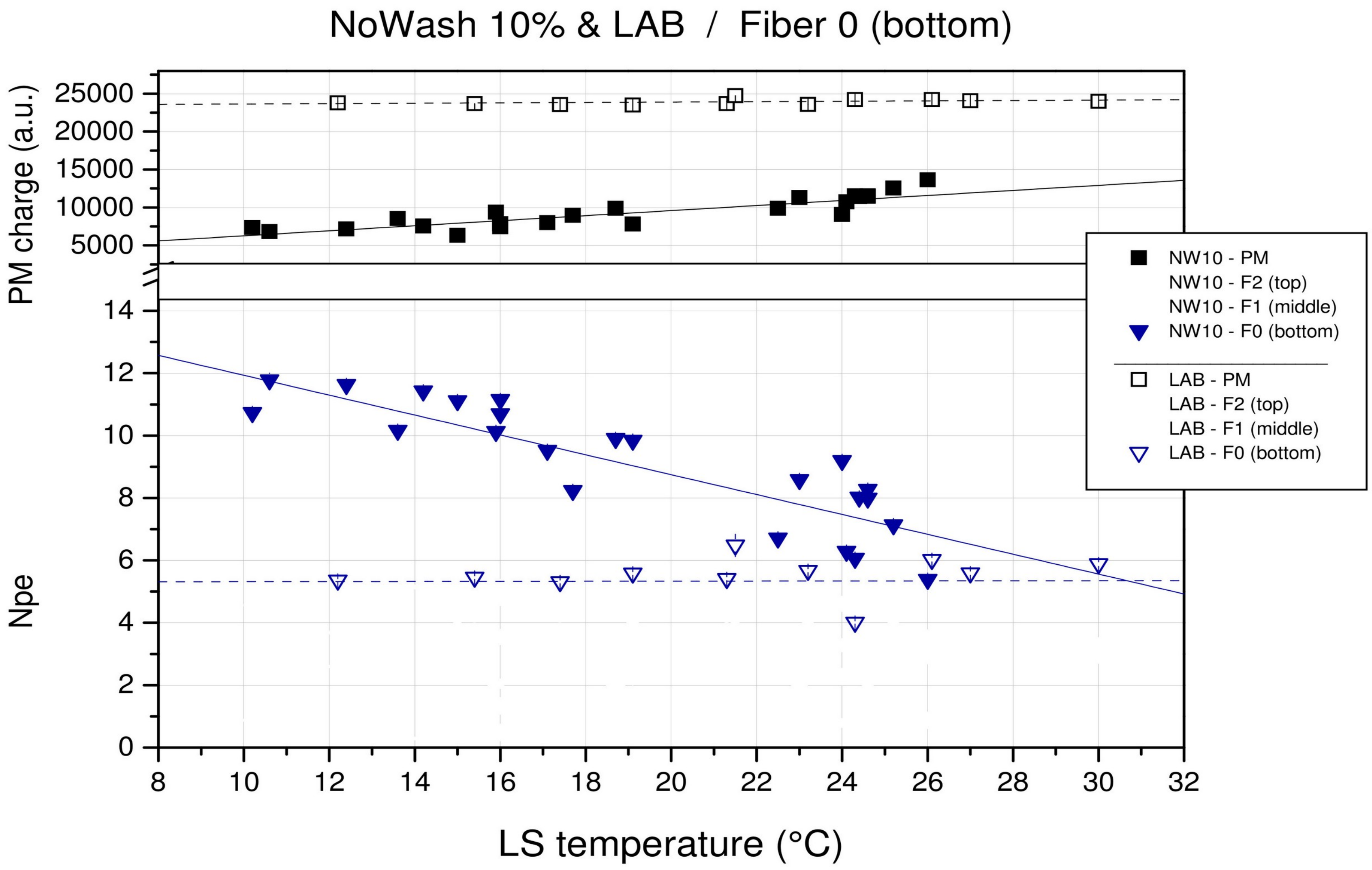


SiPM charge spectrum

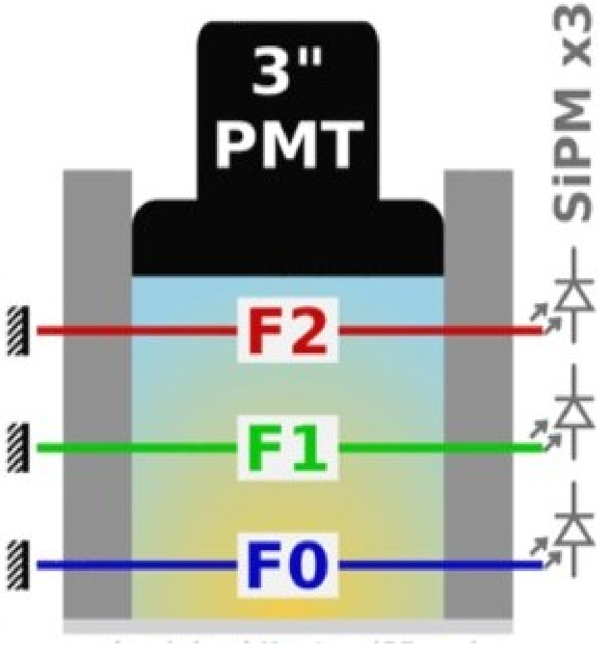


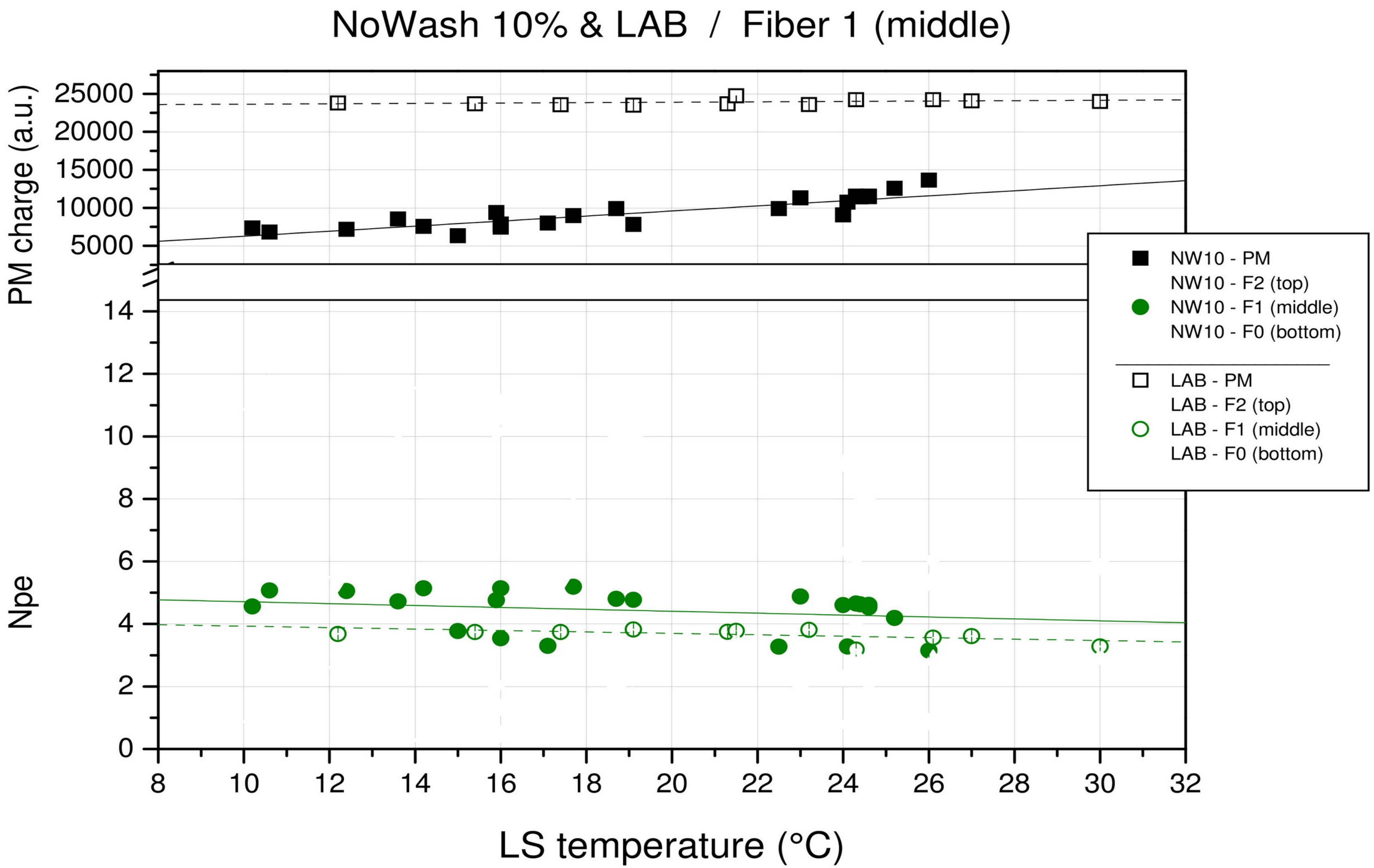
µLiquidO: experimental proof-of-principle



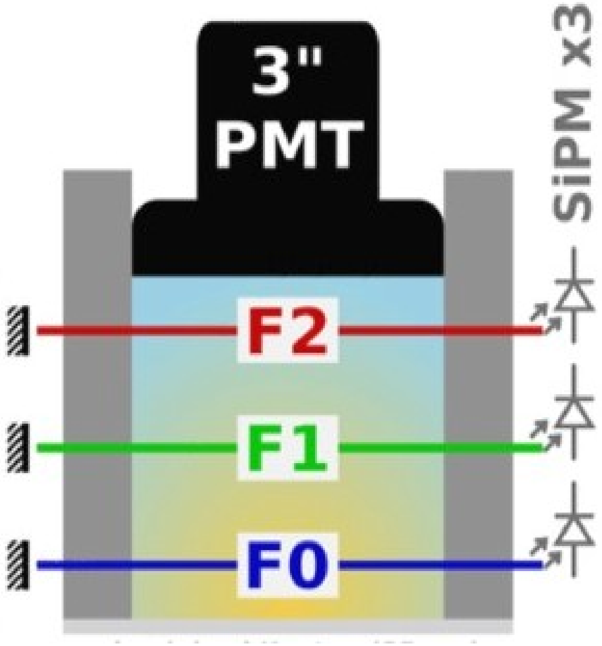


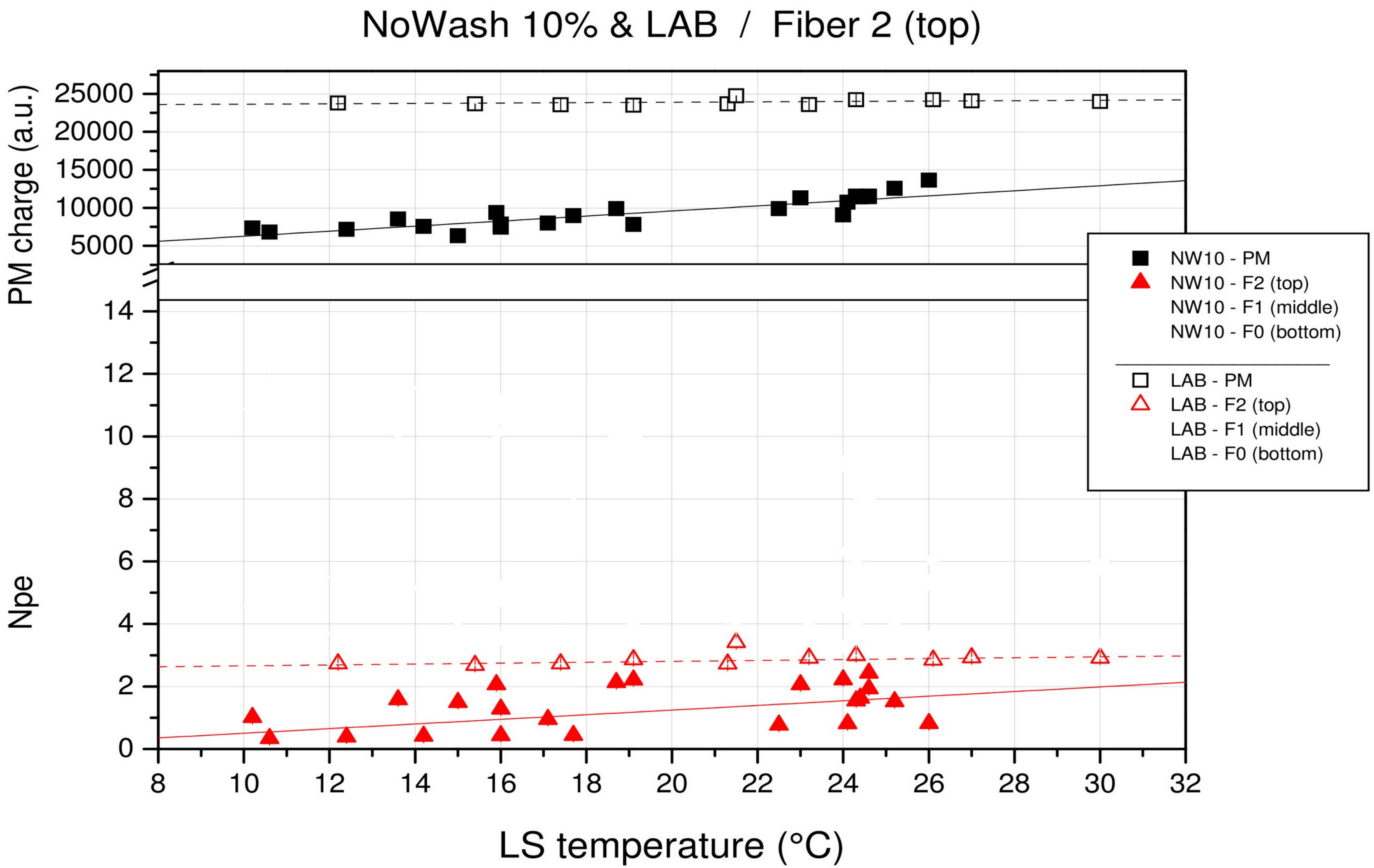
µLiquidO: experimental proof-of-principle





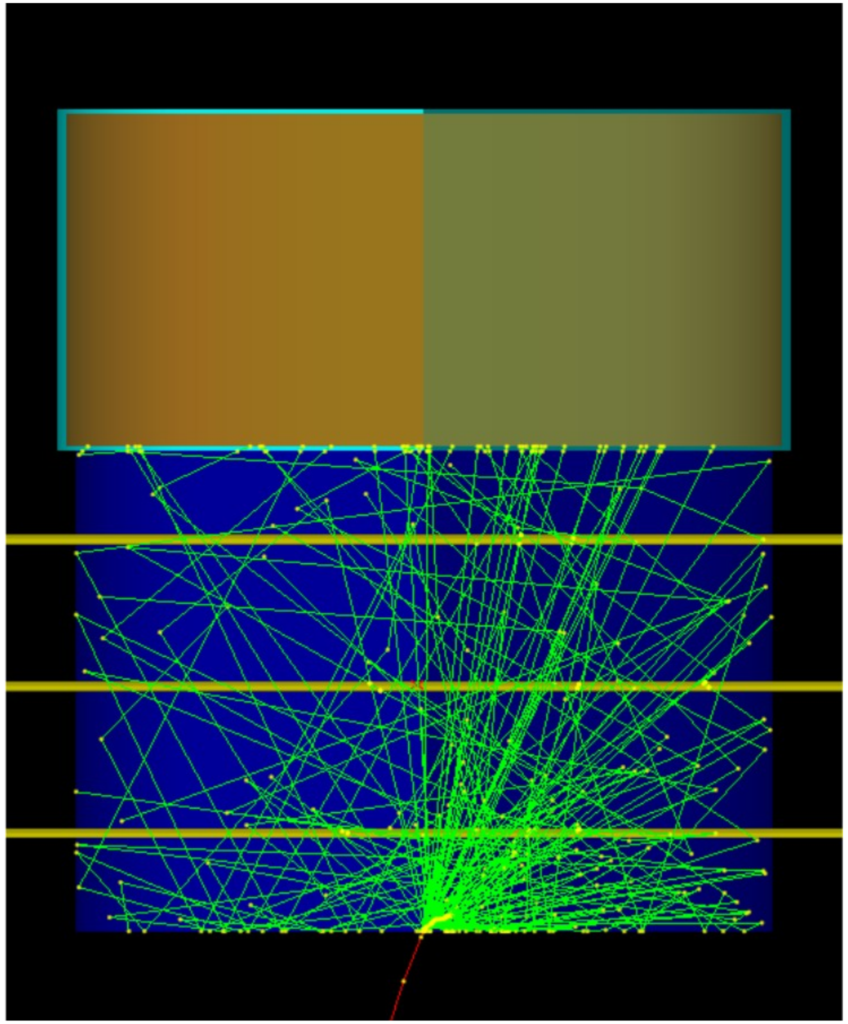
µLiquidO: experimental proof-of-principle



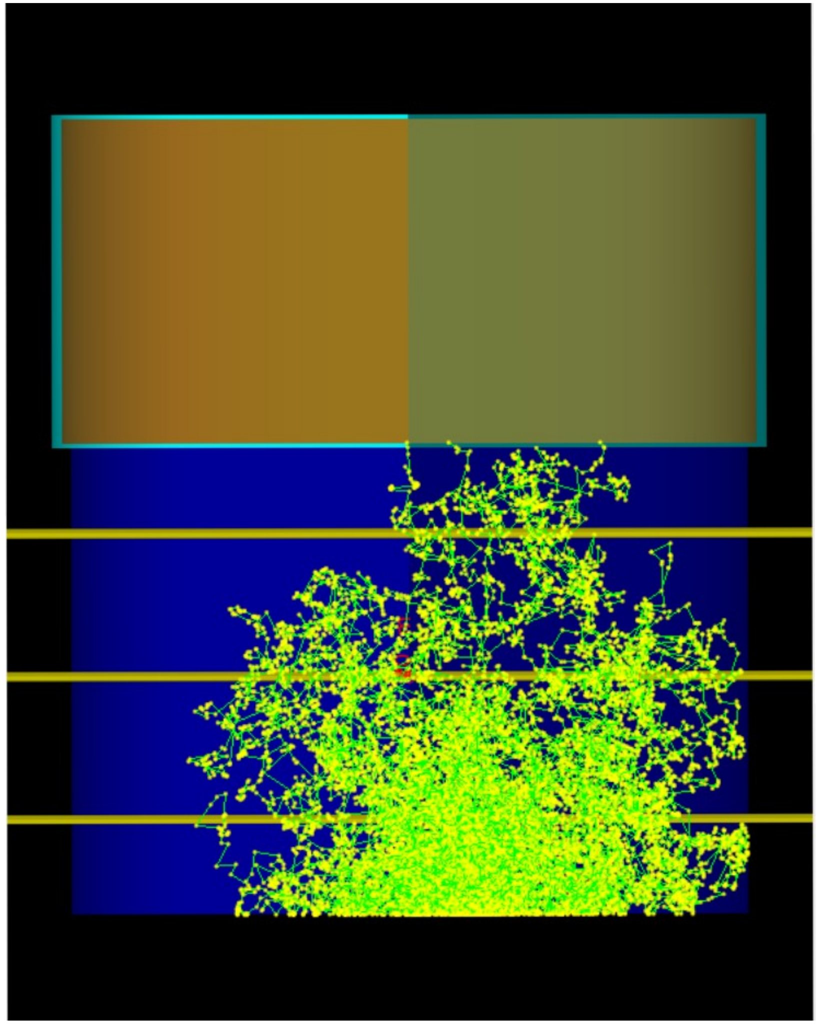


µLiquidO : optical simulation

Optical simulation with GEANT4: **follow each** scintillation **photon** from production to detection.



Transparent liquid scintillator



Opaque liquid scintillator

Liquid scintillator (MPIK):
- Light yield
- Absorption length
- Diffusion length

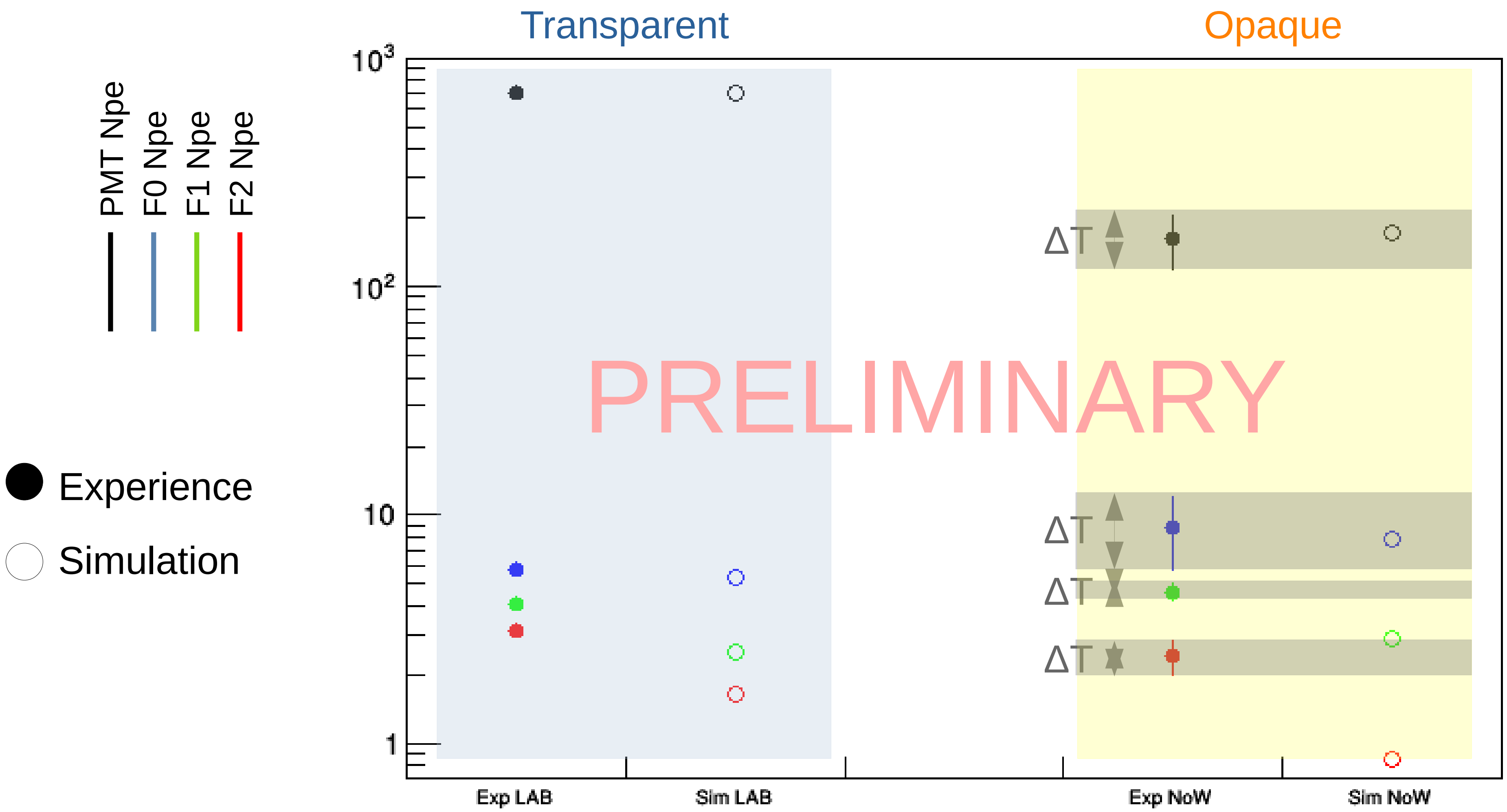
Fibres (Kuraray):
- WLS absoption length
- Attenuation length
- Refractive indexes

SiPM (Hamamatsu):
- PDE

Others (SuperNEMO):
- PMT QE
- Reflection factors

µLiquidO : optical simulation

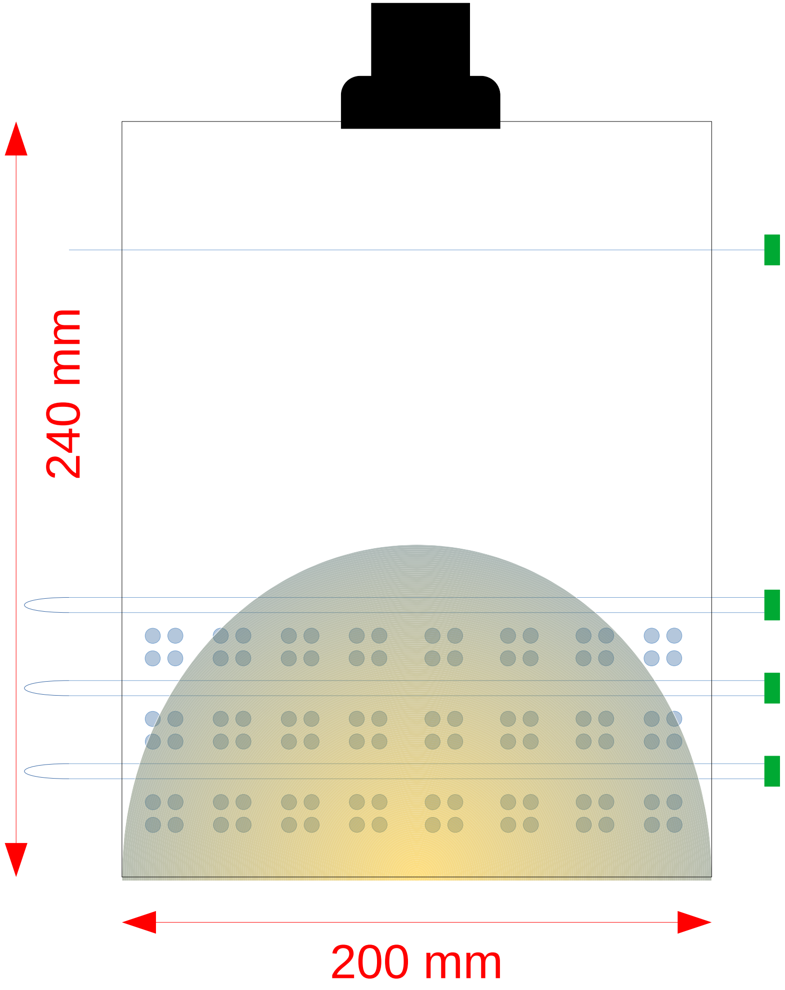
The analysis for simulation is performed exactly as the experimental one



Order of magnitude validated ! **Tunning** of the optical model in progress

Next step

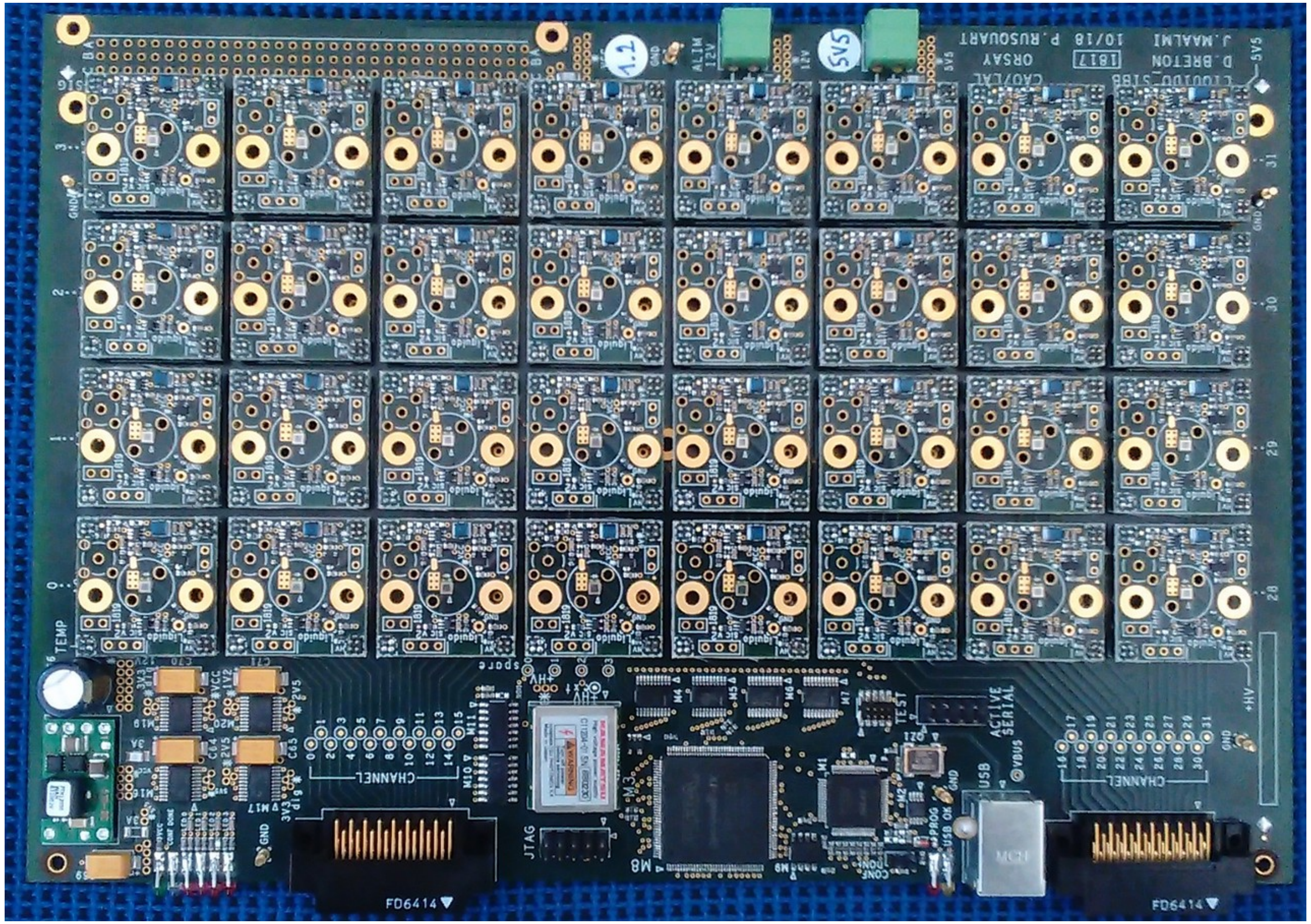
Mini-LiquidO: to see the lightball



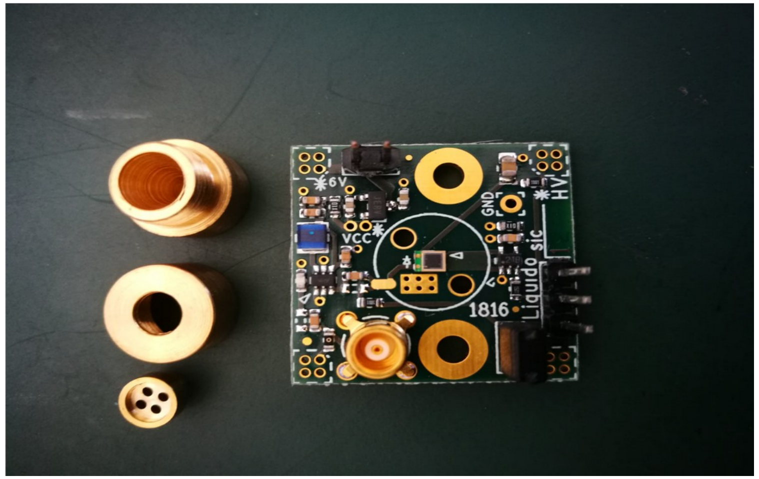
Mini-LiquidO :
- 208 holes
- 104 fibres (fibres are looped)
- 64 SiPMs (4 end-of-fibre per SiPM)
- 1 PMT (for control)

Mini-LiquidO's goals :
- To **see** that the **light** is confined as a **ball**
- To prepare the **reconstruction algorithms**

Mini-LiquidO electronics



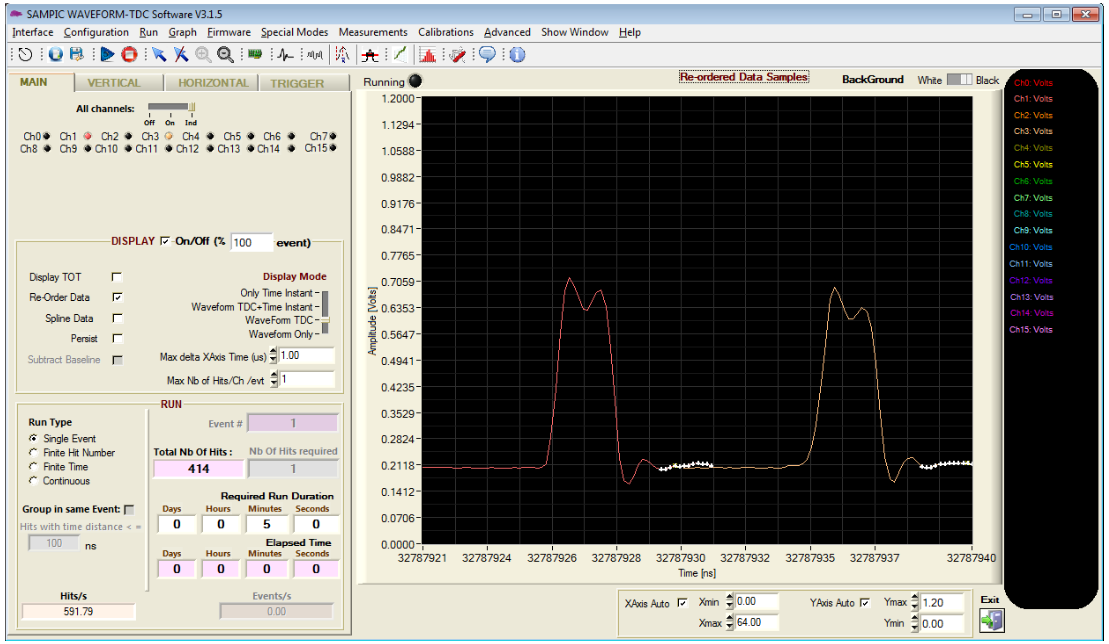
SiPM Base Board (x2) :
- 32 SiPM + 32 connectors for fibres
- Powered with a simple +5.5V
- Temperature monitoring
- HV self-compensation



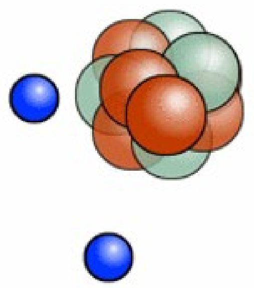
Mini-LiquidO electronics

64-channel Module with sampic technology

- 8.5 GS/s ↔ 117.6 ps sampling
- 3.5 ps rms time resolution
- USB plug and play
- Given with software



LiquidO physics potential



Double beta decay:

- potential for **high loading** = multi ton experiment with **no enrichment**
- powerful single-site / multi-site event ID = **background rejection**

Geo-neutrinos:

- Detection of ^{40}**K** neutrinos
- Dope the target → **lower energy threshold**
- **Single e^{+}** identification

Reactor neutrinos:

- **Zero backgroung** detection

CP-violation:

- **PID** to separate ν_e and $\bar{\nu}_e$
- **Doping** with Pb for ν_e detection

And more ...

Conclusions

LiquidO is a Research and Development project. The LiquidO collaboration counts 45 scientists in 10 countries.

Capability to **identify particle** (PID) using:

- An **opaque scintillator** to confine the photons
- **Optical fibres** to catch light
- **Fast electronics** (SiPM) for event topology reconstruction

High **loading** potential.

New detection approach with scintillator

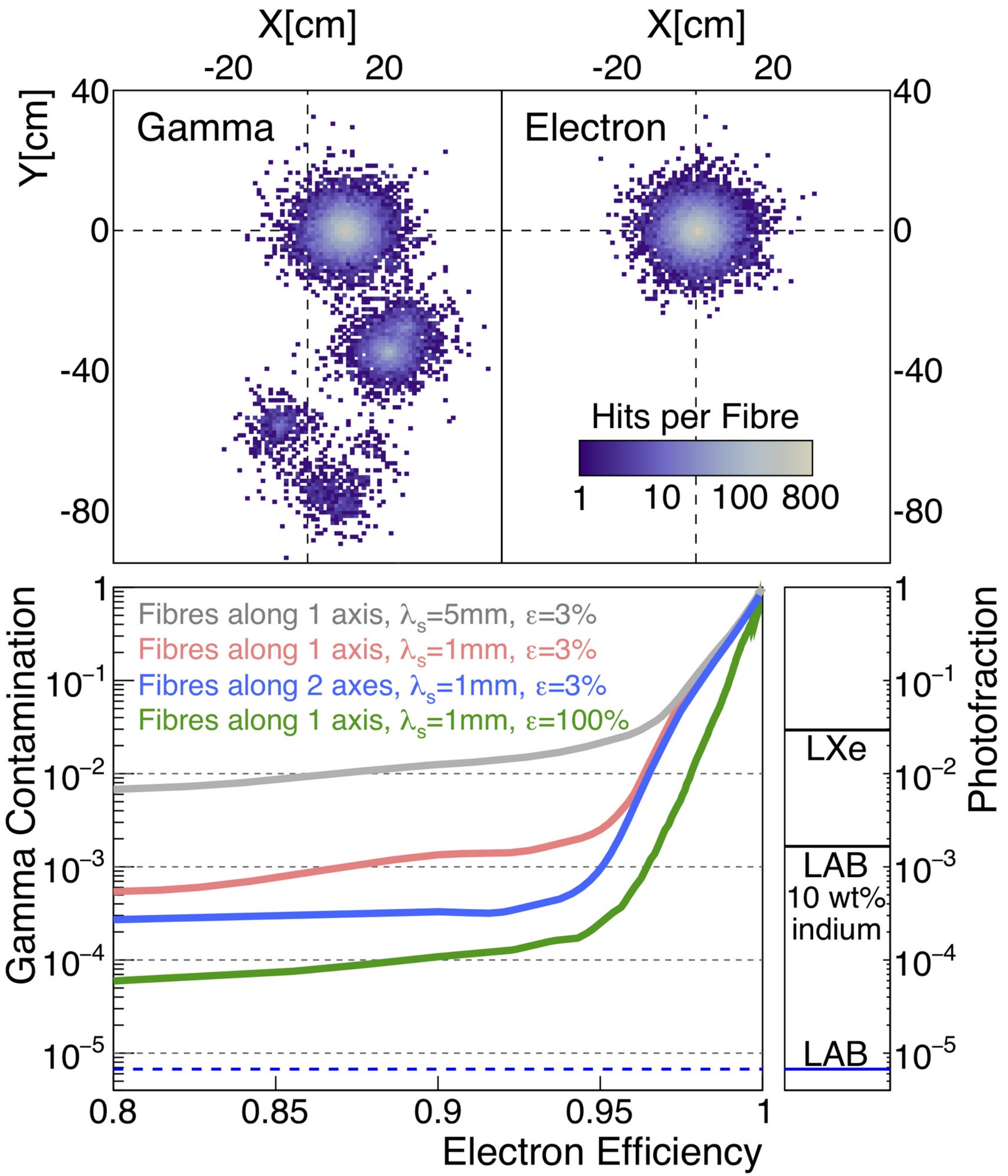
The µLiquidO setup made the **first proof-of-principle** of light confinement.
Optical simulation under development to validate the results.

The mini-LiquidO setup is currently being build @ Bordeaux.

Physics potential under studies.

Thank you !

Backup

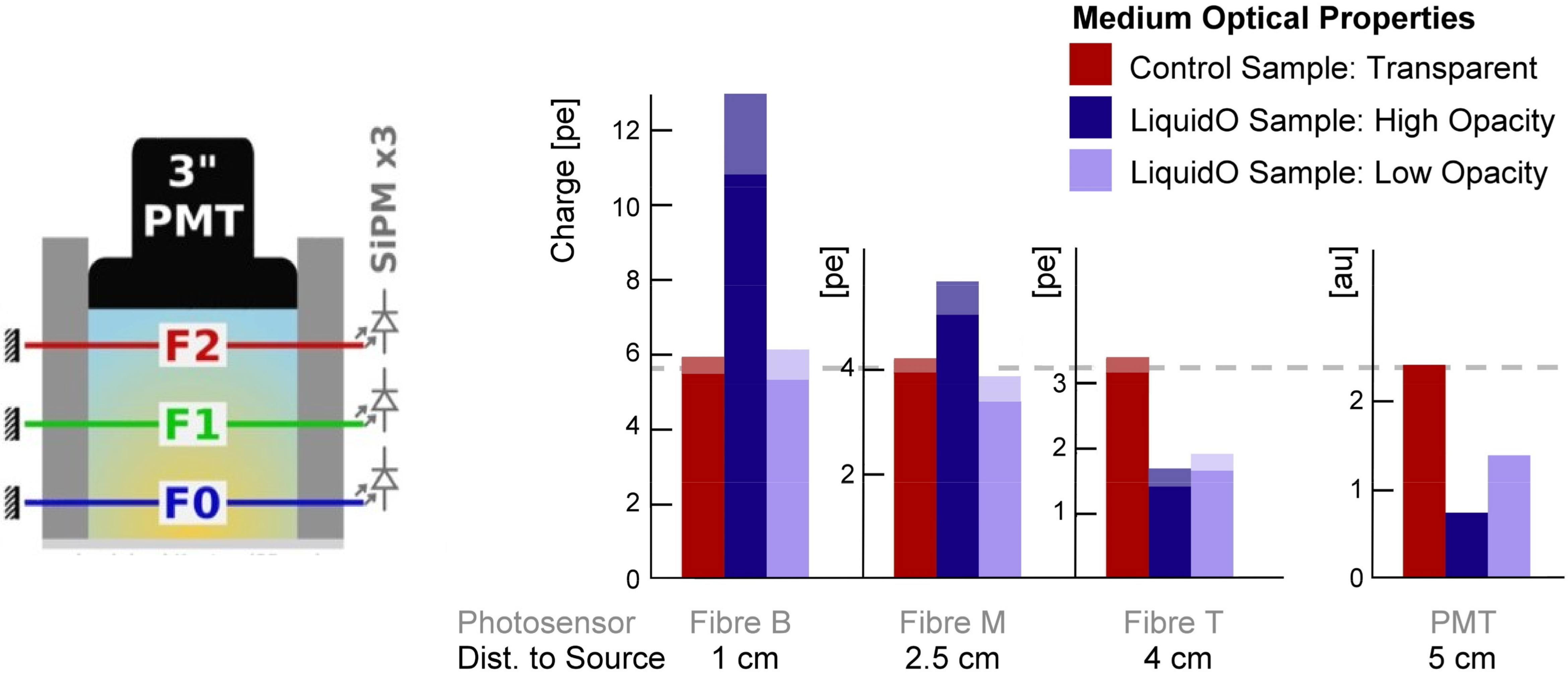


Discrimination gamma vs electron

λ_s : diffusion length of the scintillator

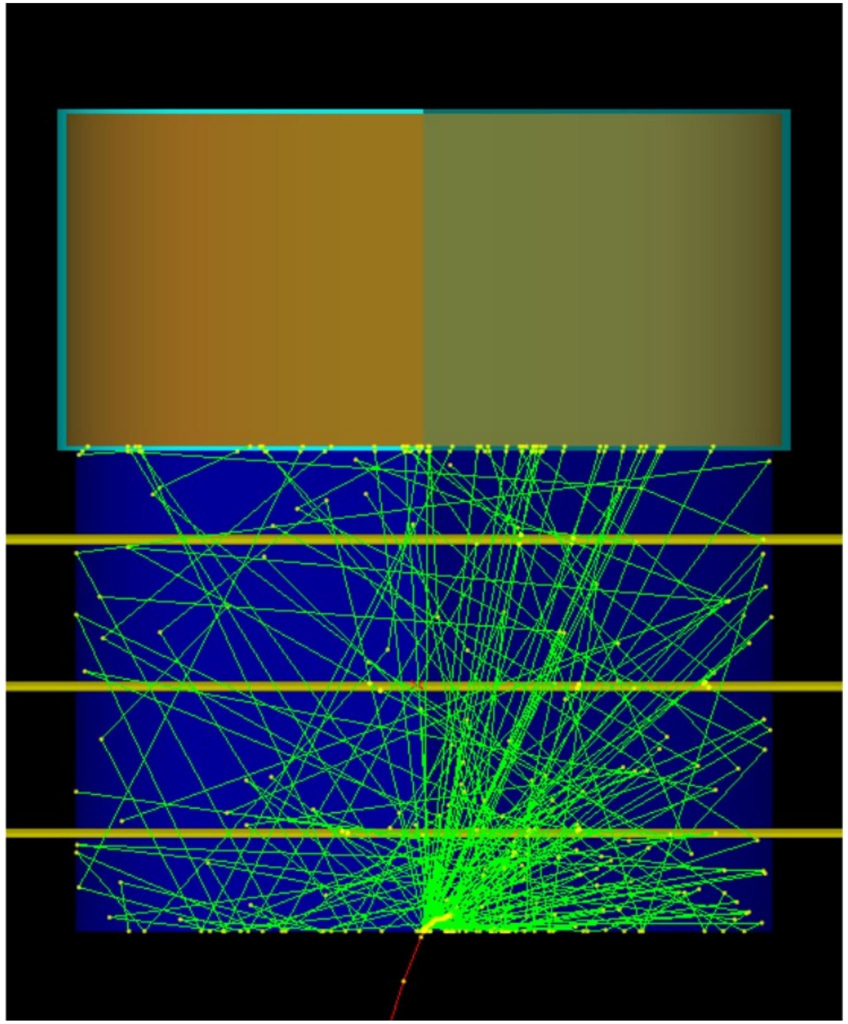
ε : detection efficiency

µLiquidO: experimental proof-of-principle

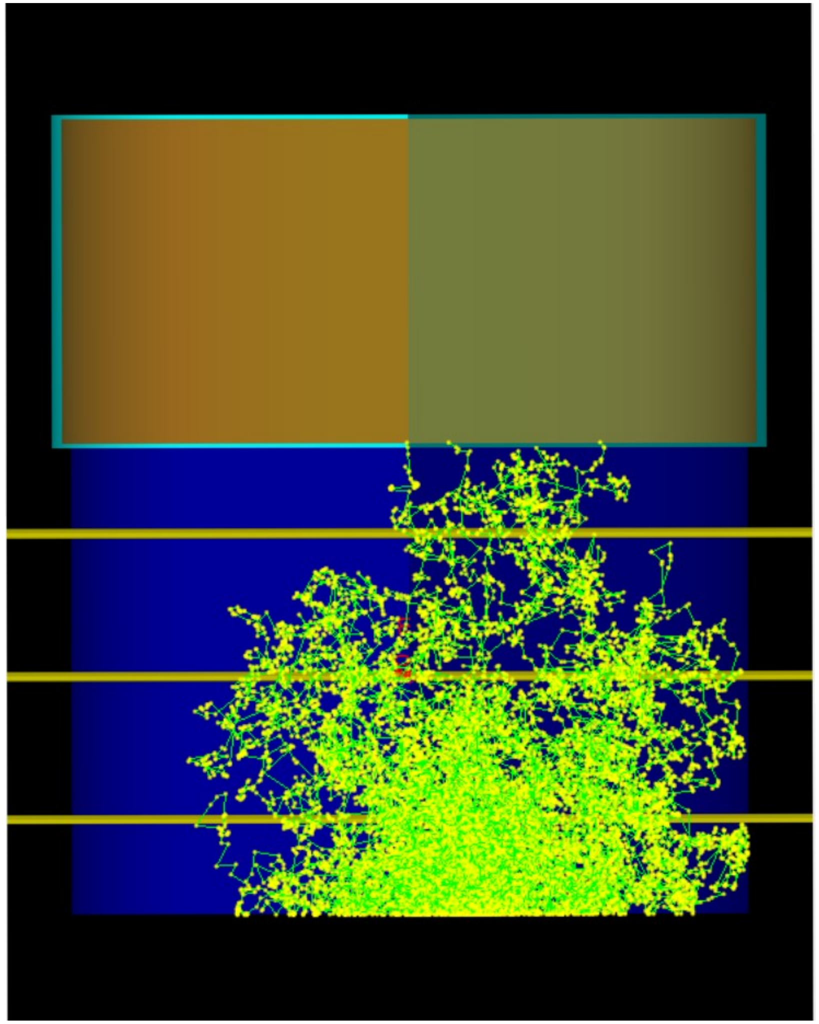


µLiquidO : optical simulation

Optical simulation with GEANT4: **follow each** scintillation **photon** from production to detection.



Transparent liquid scintillator



Opaque liquid scintillator

Light yield: 9000 ph/MeV
Abs. length > 1m (depends on the WL)
Diff. length = 25m for transparent
~ few mm for opaque

PMT: QE_{max} = 36 %
SiPM: PDE_{max} = 37 %

Mirrors: R_{max} = 92 %
Tank: R_{max} = 93 %
Entrance window: R_{max} = 92 %

Fibres abs. length = 4m
Fibres wls. length < 1mm