

GRAiNITA prototyping

On behalf of the GRAiNITA collaboration

Université Paris-Saclay, CNRS-IN2P3, IJCLab, Orsay, France

Institute for Scintillation Materials of NASU, Kharkiv, Ukraine

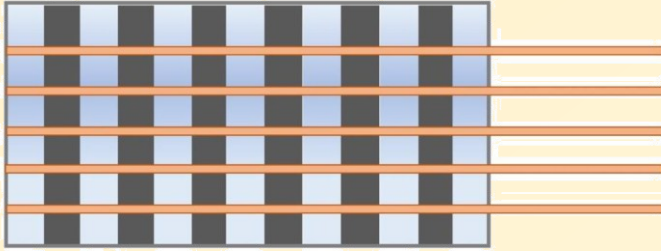
Université Blaise Pascal, CNRS-IN2P3, LP-Clermont, Aubiere, France

Kyiv National Taras Shevchenko University, Kyiv, Ukraine

CERN, Geneva, Switzerland

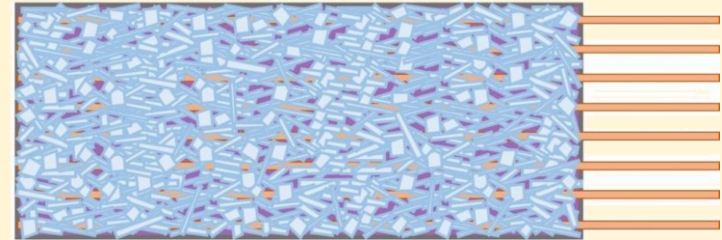
GRAiNITA concept

Shashlyk-type calorimeter

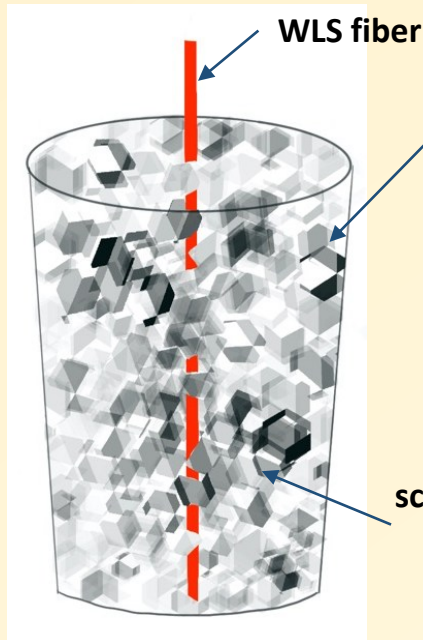


$$\frac{\sigma_E}{E} \sim \frac{10\%}{\sqrt{E}}$$

GRAiNITA



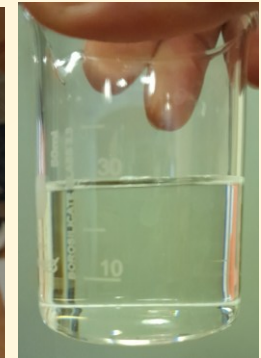
$$\frac{\sigma_E}{E} \sim \frac{1\% \div 2\%}{\sqrt{E}} \text{ is expected}$$



high-density transparent liquid

- ✓ to optimize the overall density and compactness of the calorimeter
- ✓ to provide a better optical matching with the scintillation grains

scintillation grains with high density and Z_{eff}



LST Fastfloat

aqueous solution of hydrated sodium heteropolytungstates, $3\text{Na}_2\text{WO}_4 \cdot 9\text{WO}_3 \cdot \text{H}_2\text{O}$
 $\rho = 2,8 \text{ g/cm}^3$, $n = 1.548$

Scintillation grains

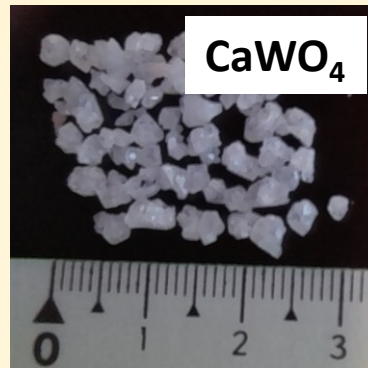
	N_{phe}' phe/MeV $\gamma, {}^{137}\text{Cs}$	Z_{eff}	$\rho, \text{g/cm}^3$	refractive index	decay time, μs	$\lambda_{\text{max}}^{\text{em}}$	Possibility of the grains obtaining by the flux method
ZnWO_4 SC	$\approx 1\,720$	61	7.87	2.2	20*	490	Yes 😊
CaWO_4 SC	$\approx 4\,400$	62	6.06	1.94	10*	430	Yes 😊
$\text{Bi}_4\text{Ge}_3\text{O}_{12}$ (BGO) SC	$\approx 1\,370$	74	7.13	2.1	0.3	480	No 😞

*The rather long decay time constant of ZnWO_4 (20 μs) is not an issue in the context of FCC e^+e^- due to the Z_0 production rate (50 kHz) and the low occupancy of the detector

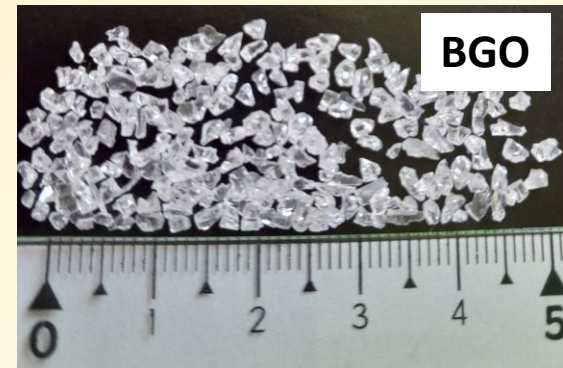
Scintillation grains provided by Institute for scintillation materials (ISMA, Kharkiv, Ukraine)



1380 g (October 2022)



≈ 250 g (May 2023)

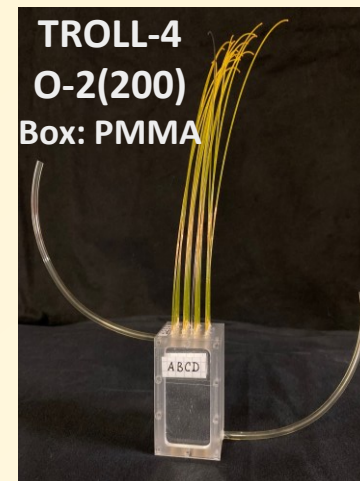
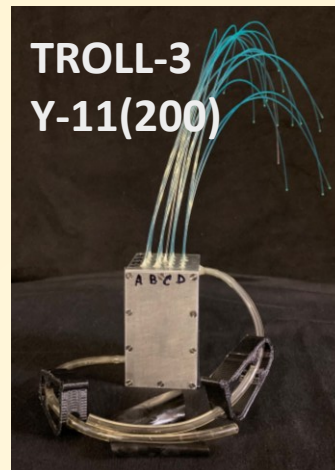
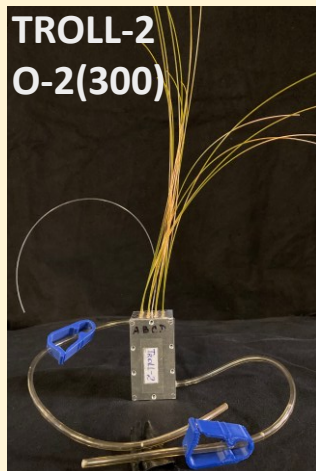
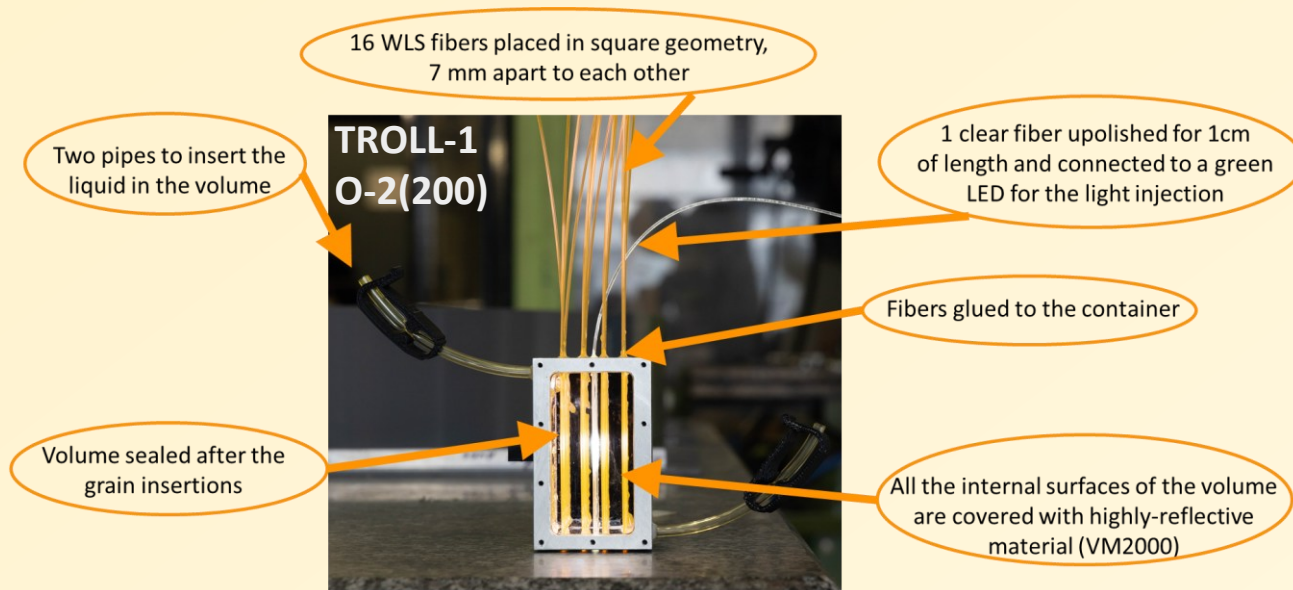


≈ 350 g (May 2023)

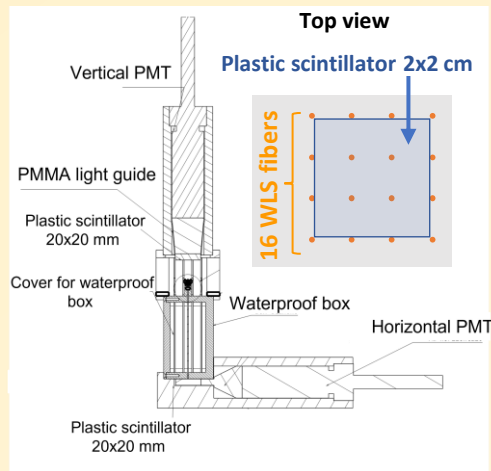
mechanical crushing of the single crystal (SC)

grown by the flux method

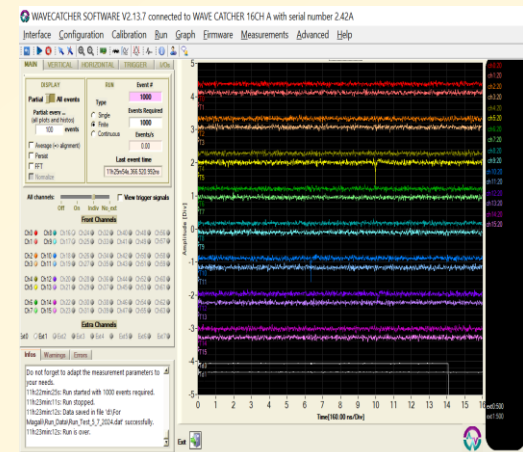
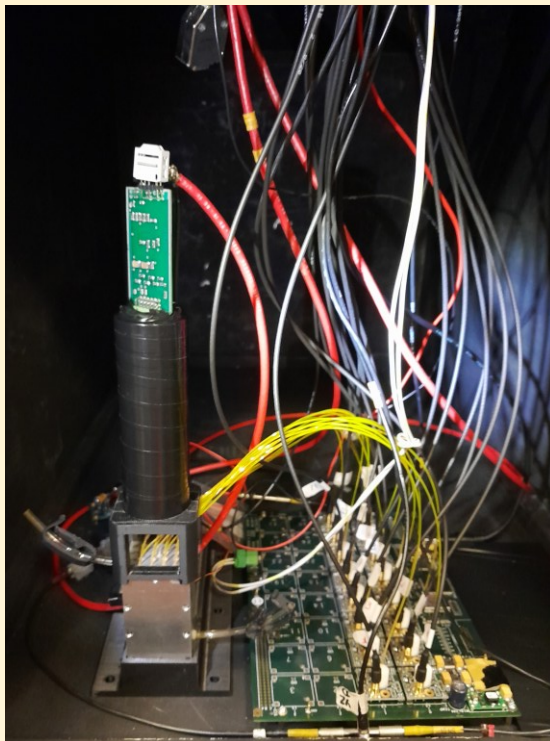
Small-size-prototype for cosmic ray and beam tests: TROLL



Cosmic ray and beam test setup

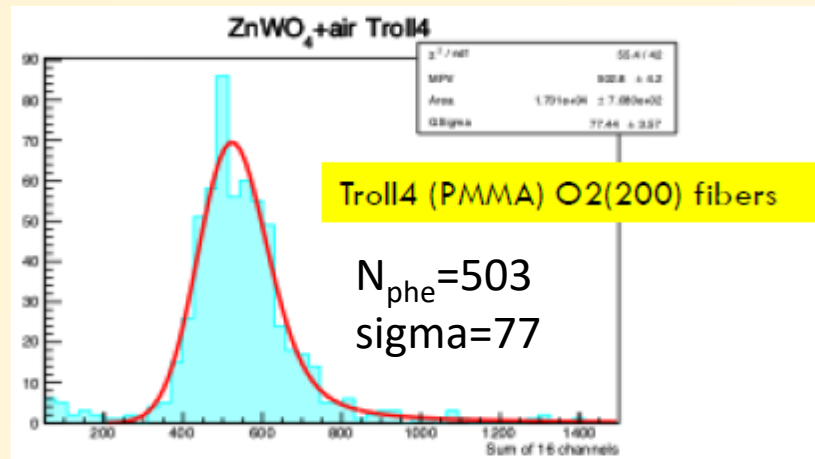
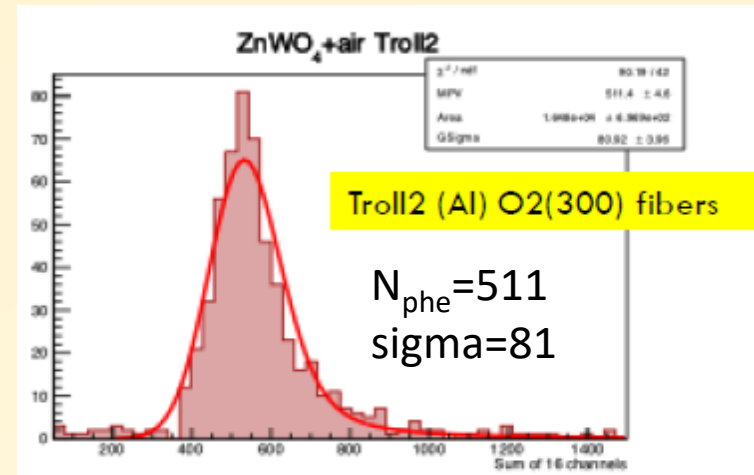
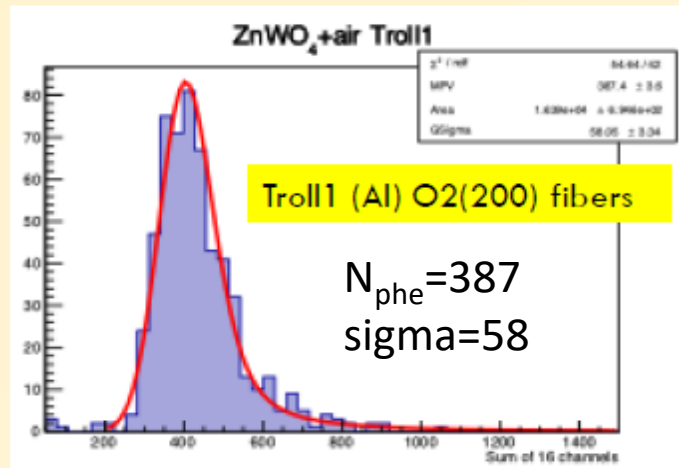


- Two 2 cmx2 cm plastic scintillators connected to PMT's
→ double coincidence for cosmic rays triggering
- 16 WLS fibers read by 16 SiPMs coupled to 16 amplifiers on a PCB. The amplified pulse shape depends on the output inductance, for small values, only the fast part of the pulse is kept;
- 16 acquisition channels are connected to 16 channel Wavecatcher (with an external trigger: the signal from the two PMTs R7899 => NIM discriminator => coincidence circuit);
- counting the number of the single photoelectron pulse (N_{phe}) on a longer time scale 25 μs ($ZnWO_4$) using fast pulse shaping and counting the number of pulses in an interval of time;



Tests with cosmic muons : ZnWO_4 grains in different Trolls

- To check the feasibility of GRAiNITA detector concept
- To estimate the number of photo-electrons by MeV



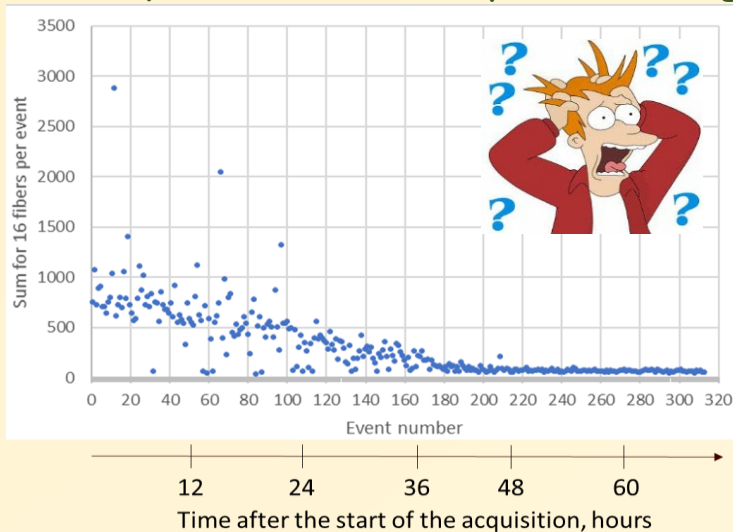
Estimated light yield is ≥ 400 phe per 40 MeV deposited by the muons in the test device,
i.e. $\geq 10000/\text{GeV} \Rightarrow$ statistical constant $\approx 1\%$ for 1 GeV high energy photon 6

Tests with cosmic muons : ZnWO_4 grains with heavy liquid

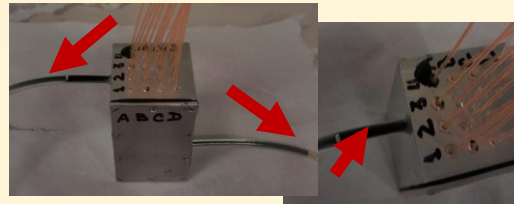
Heavy Liquid (LST FastFloat) serves to:

- ✓ provide a better optical matching with the scintillator grains
- ✓ optimize the overall density and compactness of the calorimeter

After about 3 days from the start of the acquisition we totally lost the signal



Red-Ox reaction between W^{+6} (heavy liquid) and Al(TROLL's body)
precipitation of blue tungsten oxide $\text{WO}_{2.72-2.9}$

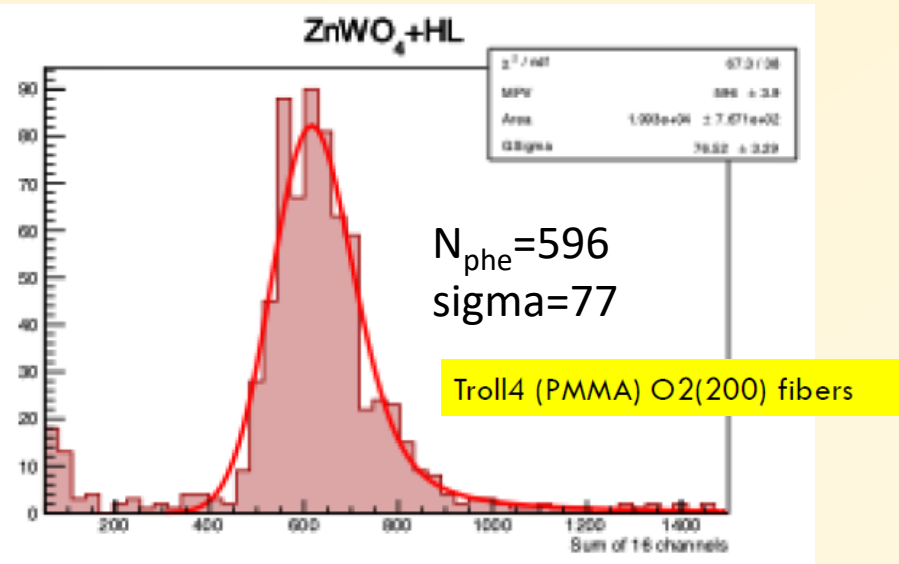
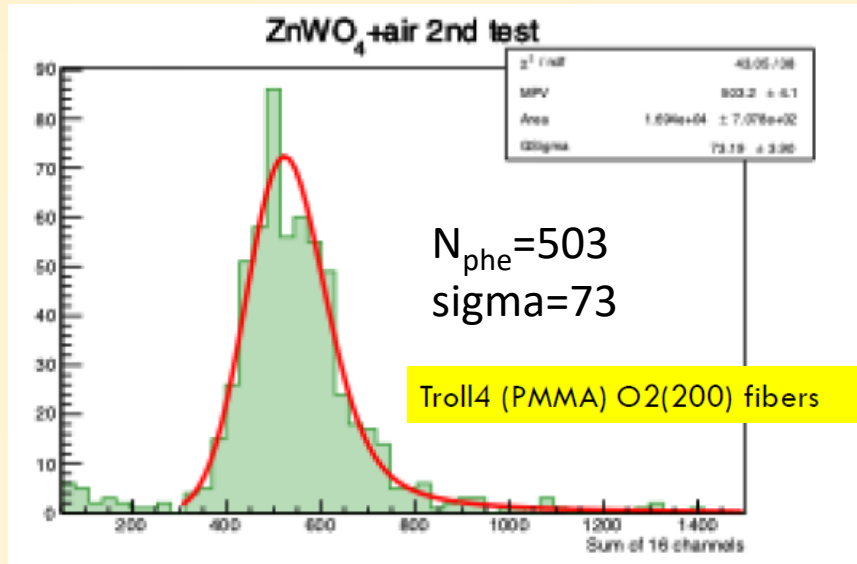


Solution: TROLL made of

- ✓ stainless steel (hard to mechanically process) ☹
- ✓ **PMMA** ☺



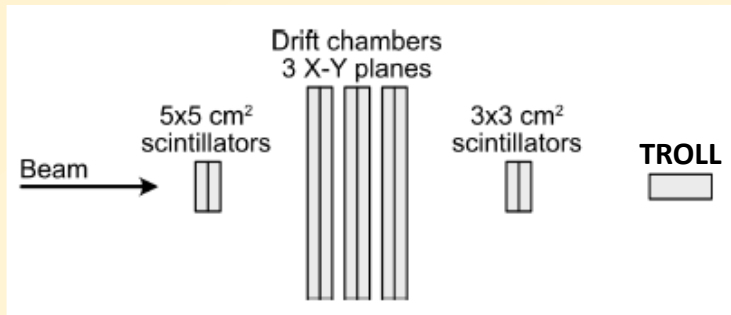
Tests with cosmic muons : ZnWO_4 grains with heavy liquid



✓ Adding of Heavy Liquid increases the light amount by about of 16% with respect to air

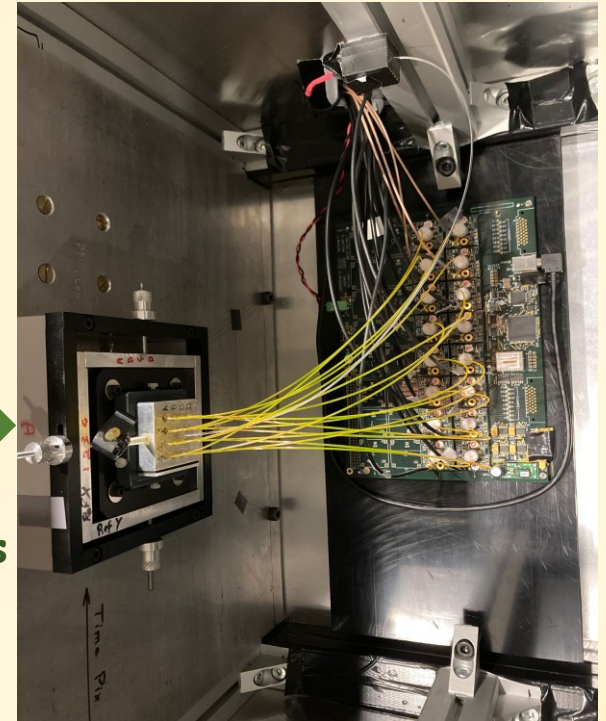
TROLL: muon beam tests

H1 area of the SPS, CERN, June 2024



Beam

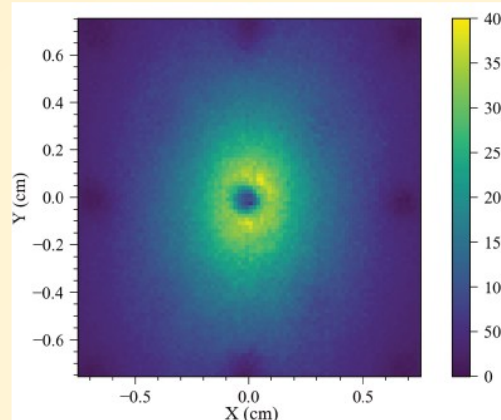
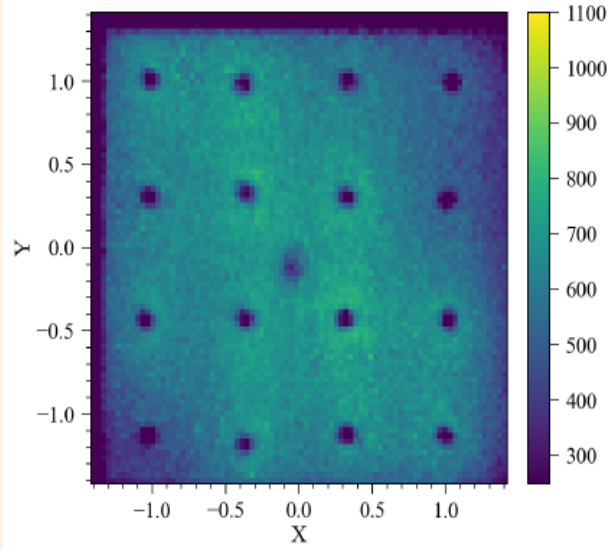
~ 0.2 million
of high-quality muons
are passing through
TROLL



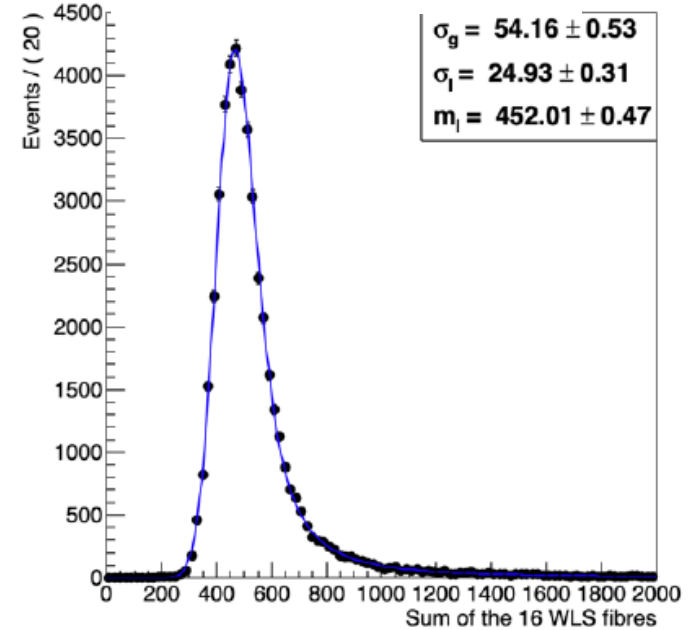
We would like to thank Loris Martinazzoli (CERN) and his team for having welcome us during the PicoCal test beam. We are grateful to Yuri Guz who patiently accompanied our test campaign!

TROLL: muon beam tests

Mean N_{phe} detected by the TROLL as a function of the incoming muonparticle position



ZnWO₄+Heavy Liquid TROLL-1



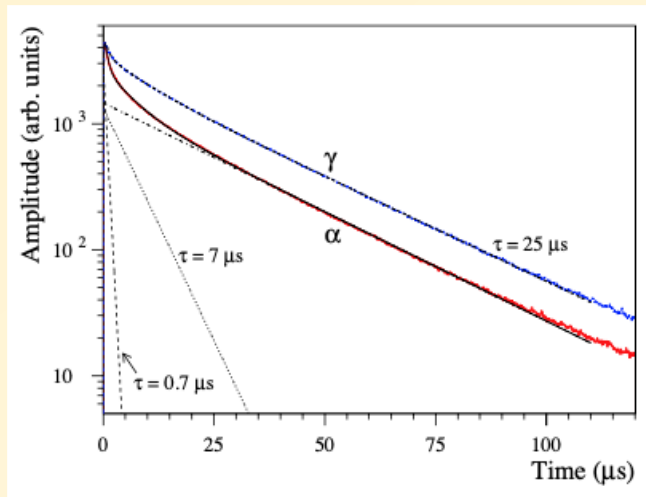
- ✓ The light confinement is confirmed
- ✓ The obtained light yield is $\approx 10\,000$ phe/GeV in a good agreement with previous studies
- ✓ The measurements confirm that the contribution to the energy resolution due to the number of photo-electrons is of the order of $1\%/\sqrt{E}$
- ✓ Obtained non-uniformity maps were inputted into a GEANT-4 simulations of the calorimeter concept. The constant term from non-uniformity is expected to be $< 1\%$ (limitations due to the prototype size). The full-size prototype tests are needed for precise values.

GRAiNITA as an dual redout calorimeter

Idea: using of the Pulse Shape Discrimination (PSD) technique to separate the electromagnetic part from the hadronic part of the shower

- ZnWO_4 crystals (and grains) have several scintillation decay time components;
- The values of the time constants and their contributions depend on the type of the particle, i.e. dE/dx . Higher ionising particles (low-energy protons, α , etc.) have a larger fraction of the fast component

Clear discrimination between α -particles and γ -rays

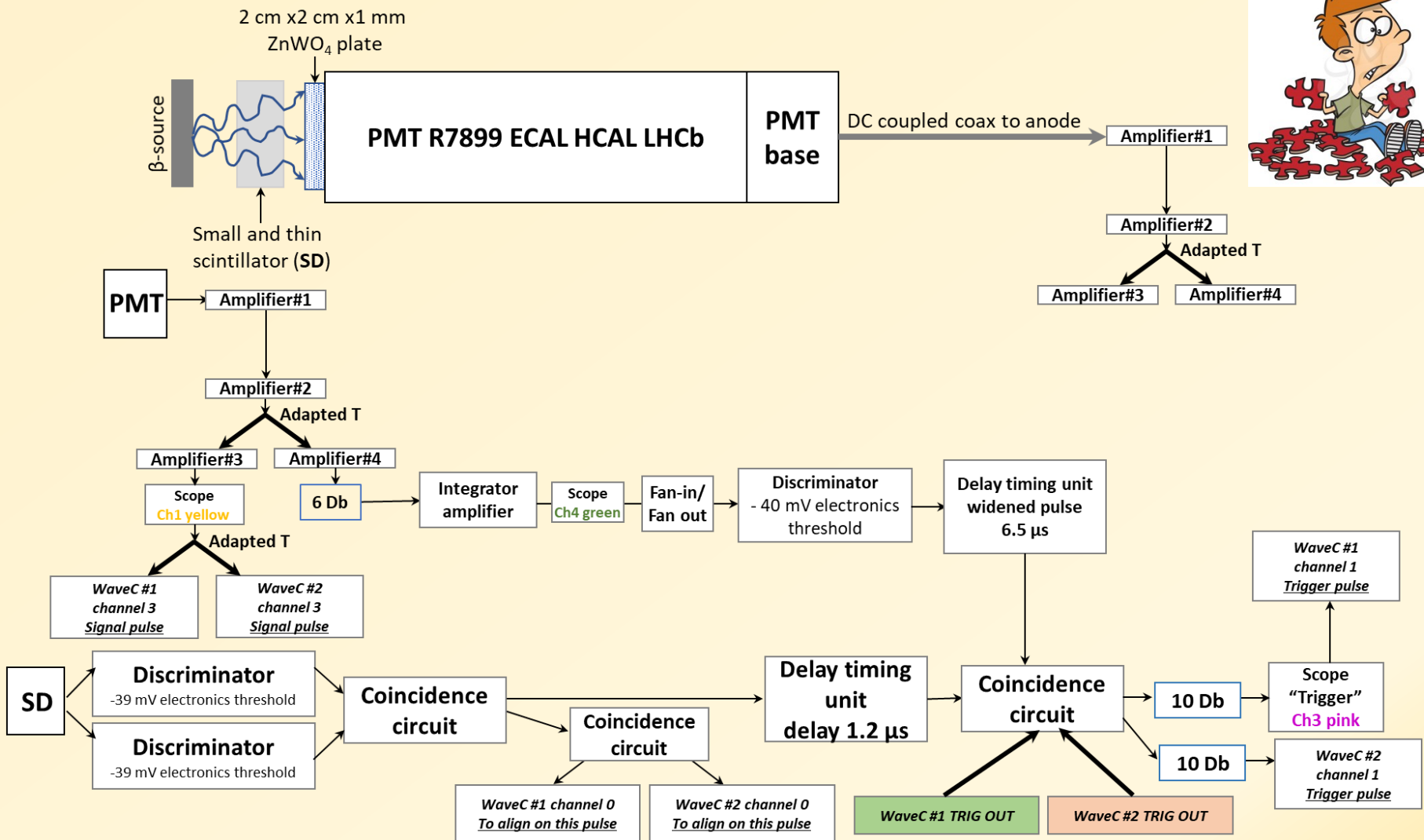


Type of irradiation	Decay constants, μs		
	$\tau_1 (A_1)$	$\tau_2 (A_2)$	$\tau_3 (A_3)$
γ ray	0.7 (2%)	7.5 (9%)	25.9 (89%)
α particles	0.7 (4%)	5.6 (16%)	24.8 (80%)

F.A. Danevich et al., NIM A 544 (2005) 553–564

MISSING: actual scintillation times for the particles with different dE/dx

GRAiNITA test bench for decay time constants measurements



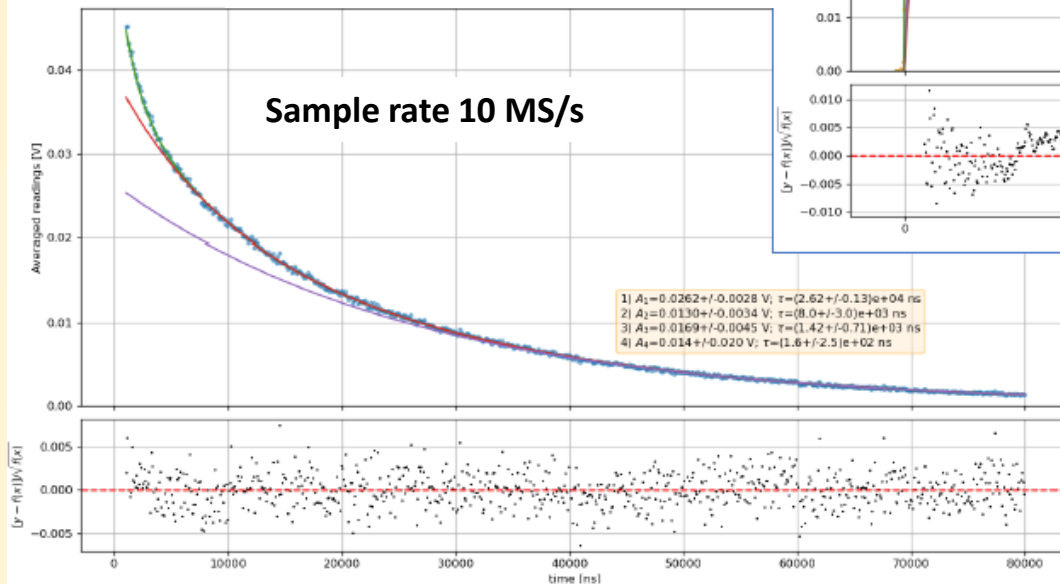
Experimental proofs for PSD: electrons

10 000 waveforms were registered and processed for 2.5 and 100 μs range

ZnWO_4 1 mm single crystal plate

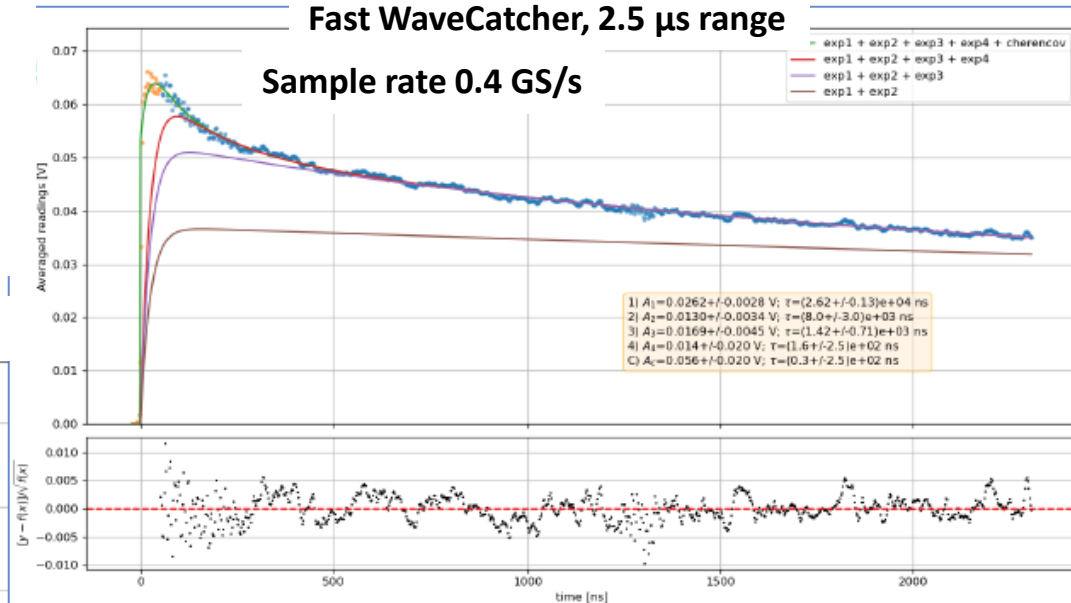
$\text{Sr}^{90}\text{-Y}^{90}$ source

Slow WaveCatcher, 100 μs range



Fast WaveCatcher, 2.5 μs range

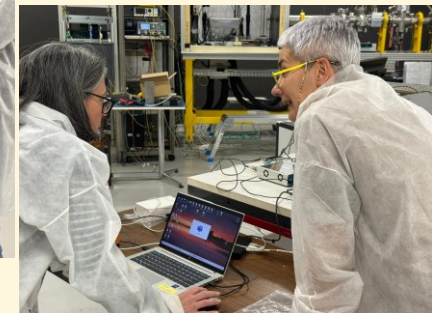
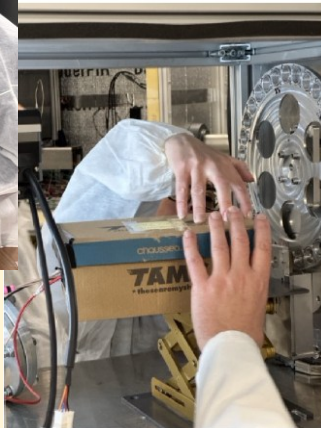
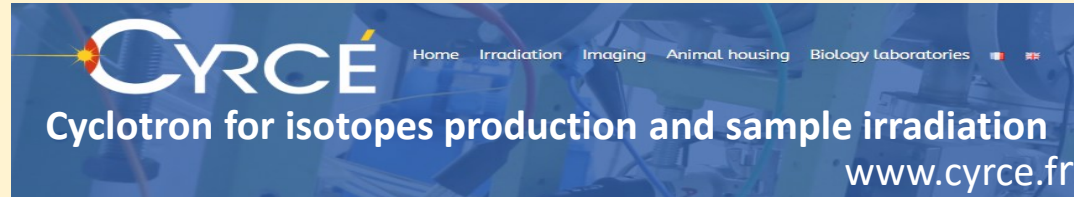
Sample rate 0.4 GS/s



✓ Fitting gives 4 decay components

Experimental proofs for PSD: proton beam

April 2026, Strasbourg



We are deeply grateful to the members of the CYRCÉ team for their kind attitude and assistance at each step of our tests!

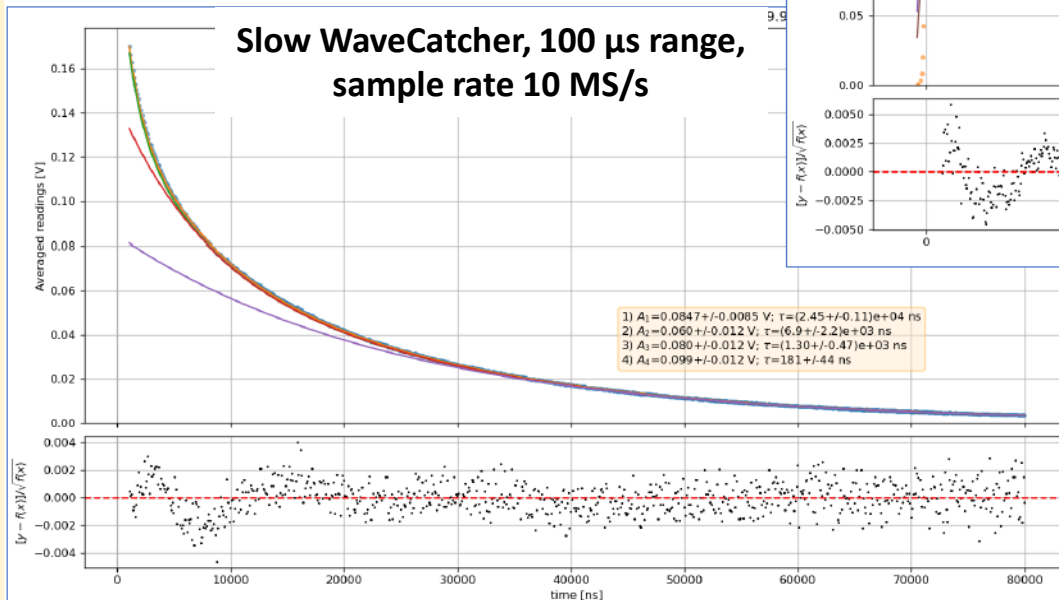
Experimental proofs for PSD: proton beam

Run	4, 5	6, 7	8, 9	11	12	12	14	15	17	18, 19	20, 21
Beam energy, MeV	24.78	24.27	23.77	23.26	22.76	22.26	21.26	20.24	19.23	16.23	9.98

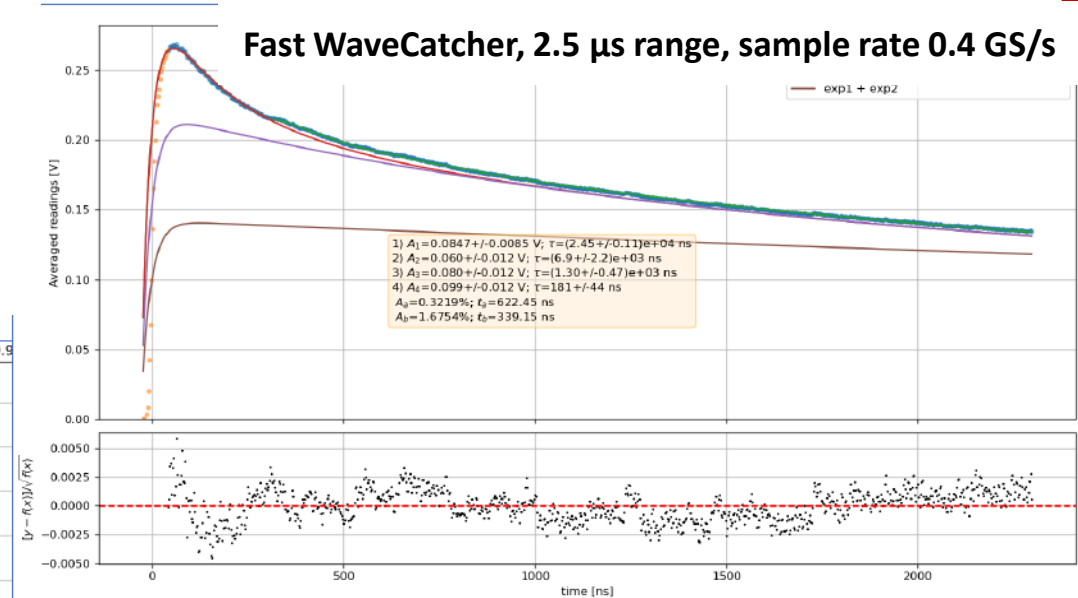
10 000 waveforms were registered for 2.5 and 100 μ s range for each energy of protons

ZnWO₄ 1 mm single crystal plate
9.98 GeV protons

Slow WaveCatcher, 100 μ s range,
sample rate 10 MS/s



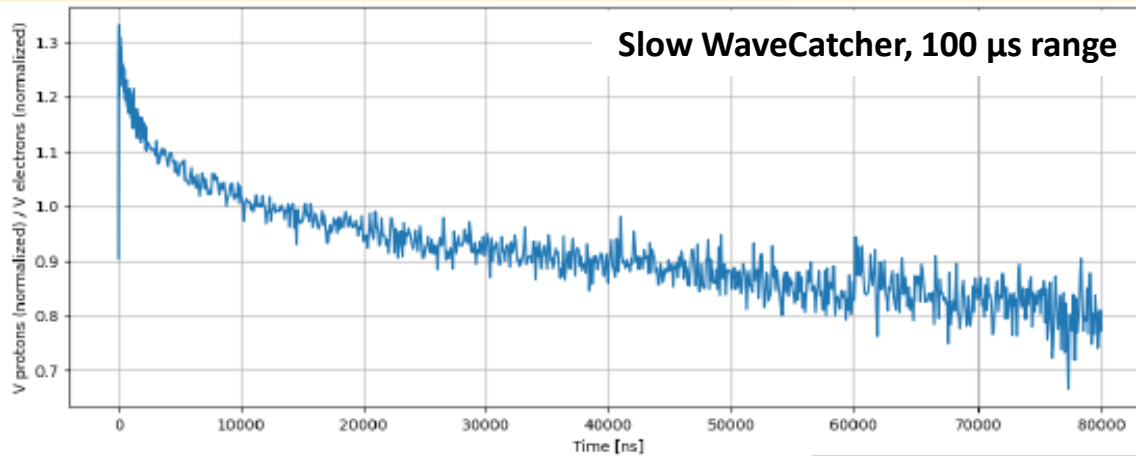
Fast WaveCatcher, 2.5 μ s range, sample rate 0.4 GS/s



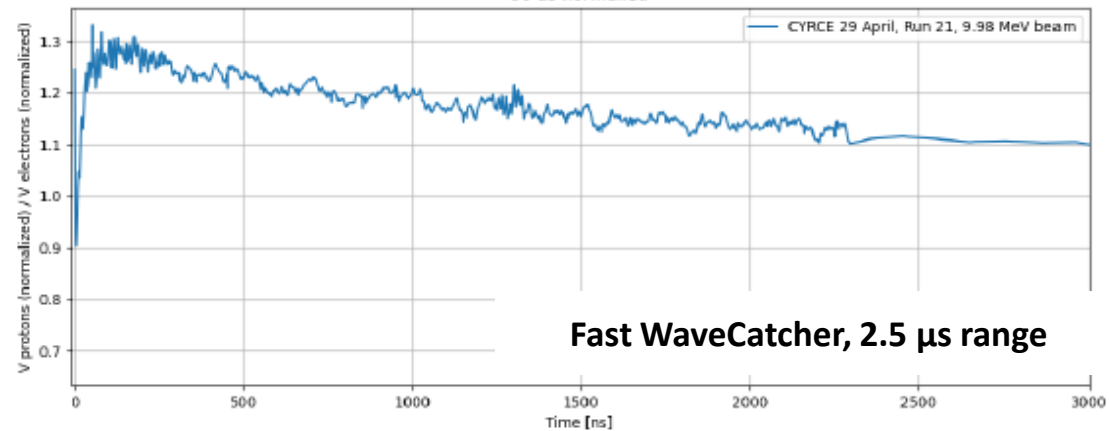
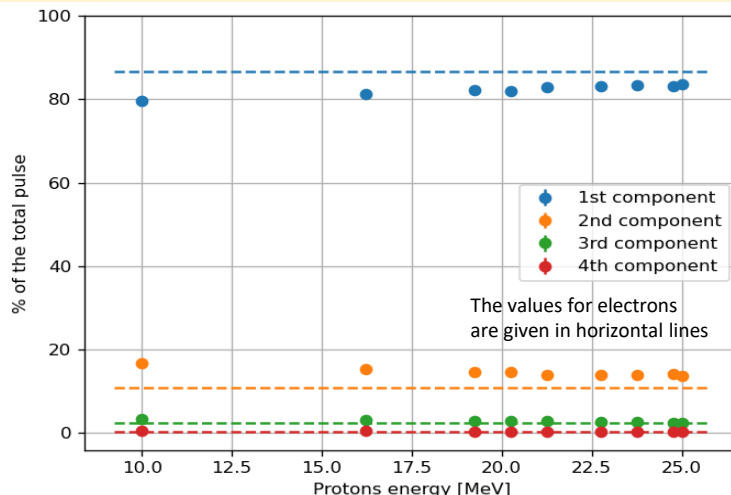
✓ Fitting gives 4 decay components

Experimental proofs for PSD: protons vs. electrons

9.98 MeV protons vs. electrons ratio



The ratio of the pulses can be used to estimate the PSD power and can be built using raw data, fit is not required



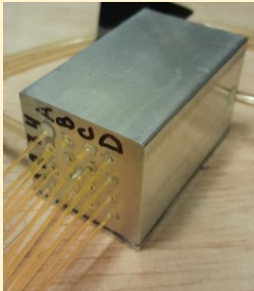
The contributions of the decay components depends on the type of the particle/energy -> the possibility of PSD between low-energy protons and electrons

From TROLL to full-size GRAiNITA demonstrator

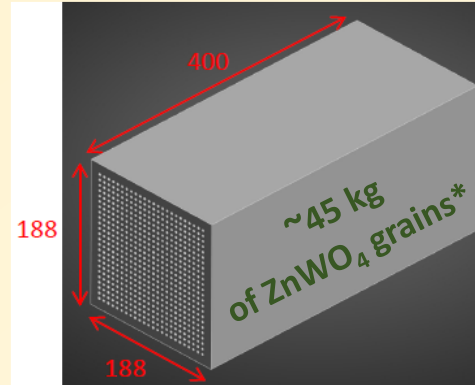
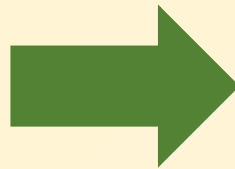
Since October 2025: funding from French National Research Agency

Full-size demonstrator "MEGATROLL"

TROLL



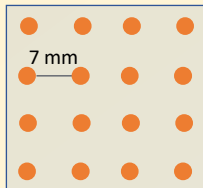
40 mm x 40 mm x 60 mm



* The first 10 kg of ZnWO_4 high quality grains have been recently received from ISMA (September 2026)

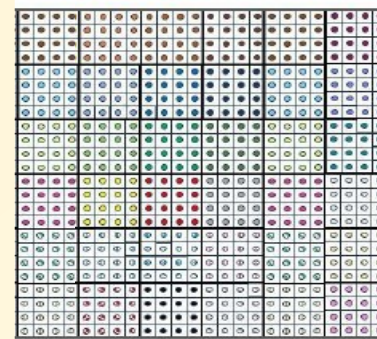
188 mm x 188 mm x 400 mm

These dimensions correspond to $25 X_0$, i.e. the detector should entirely contain a photon shower of at least 25 GeV



16 WLS fibers
coupled to 16 SiPMs

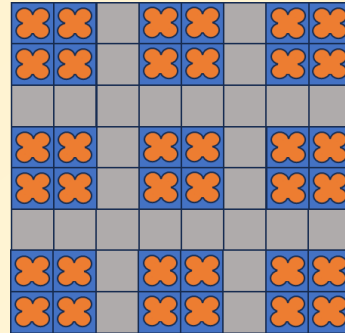
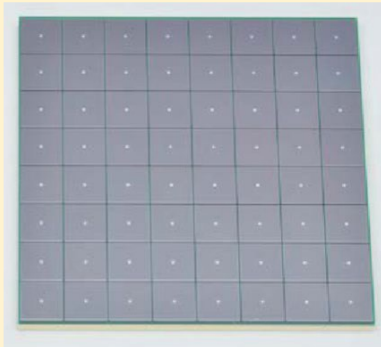
X 36



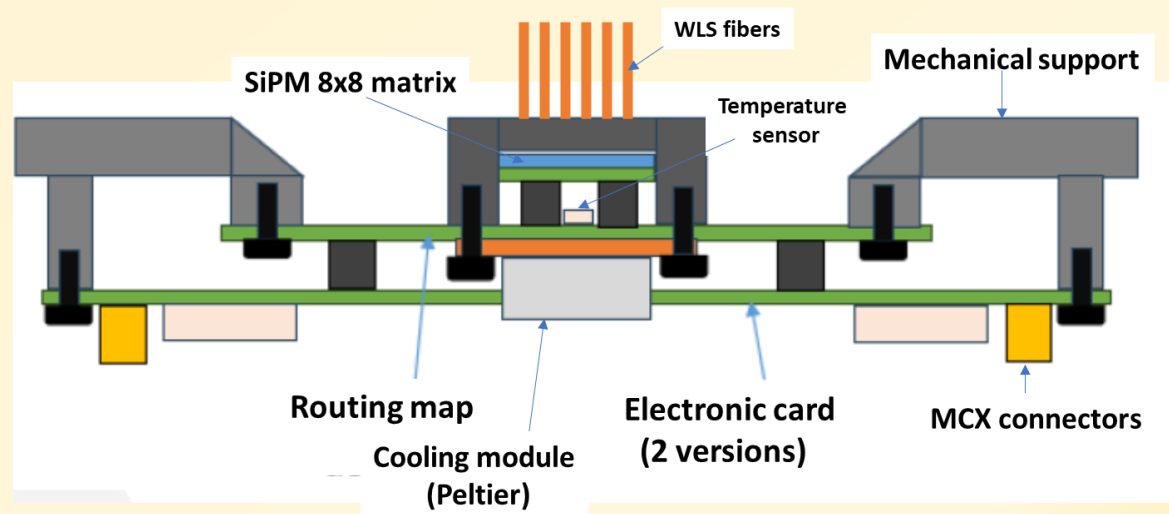
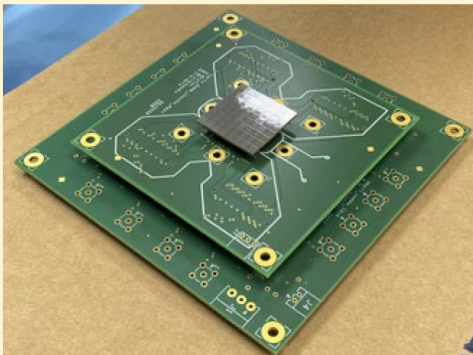
576 WLS fibers coupled to **144** large-area SiPMs
(4 fibers per SiPM)

Developments for MEGATROLL

8x8 SiPM matrix



36 SiPM to read WLS fibers (4 fibers/SiPM)
28 (grey) to read the dark counts.

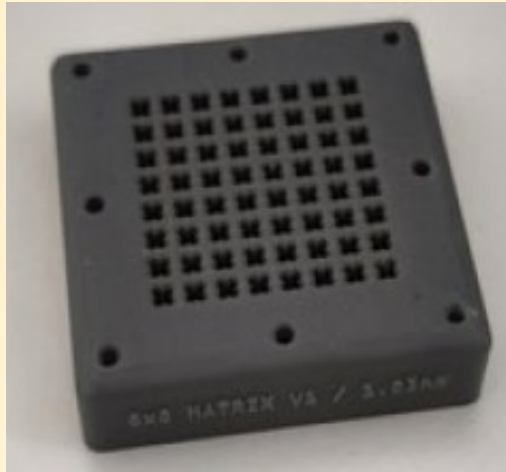


Two versions of the electronic card has been developed:

- to have the sum of 4 SiPM (i.e. the signal from 16 fibers)
- to read the individual signal of the selected SiPM (i.e. the signal from 4 fibers)

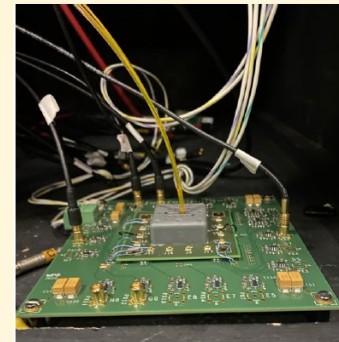
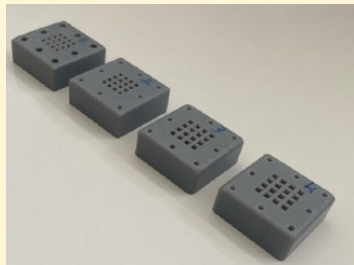
Developments for MEGATROLL

3D-printed support for WLS fibers 8x8 SiPM Matrix



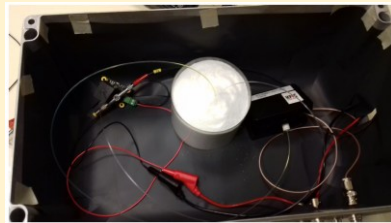
For ongoing potentially "destructive" tests

4x4 SiPM matrix



Summary

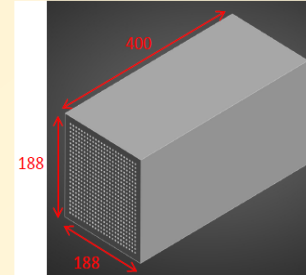
GRAiNITA time scale



First studies
of the light propagation
for the grains
of the kitchen salt
2021



Building the TROLL;
first cosmic ray test
2023

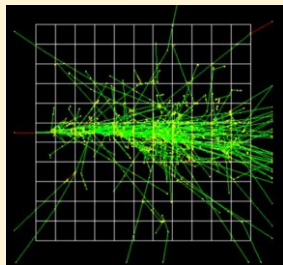


ANR support to develop,
build and test
the demonstrator
2025



end of 2019

Birthday of
GRAiNITA concept;
first G4 simulations



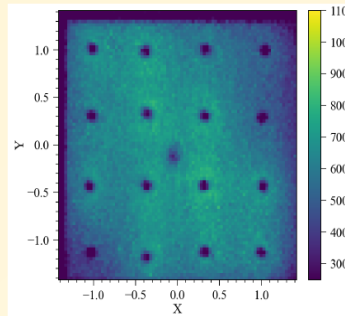
2022

Scintillation characterization
and light propagation tests
with ZnWO_4 grains;
start a collaboration
with LPC-Clermont



2024

Test the TROLL
with muon beam at CERN



2026

start of the collaboration
with CERN

To be continued ☺...

Дякую за увагу!
Merci pour votre attention!
Thank you for attention!

