GRAiNITA calorimeter project

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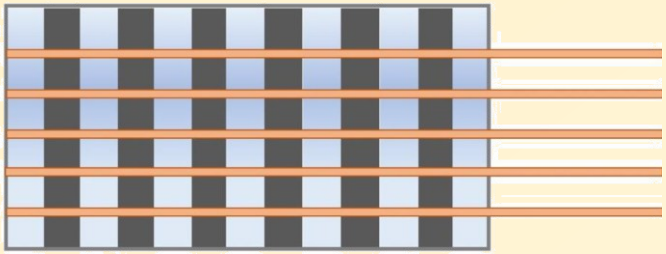
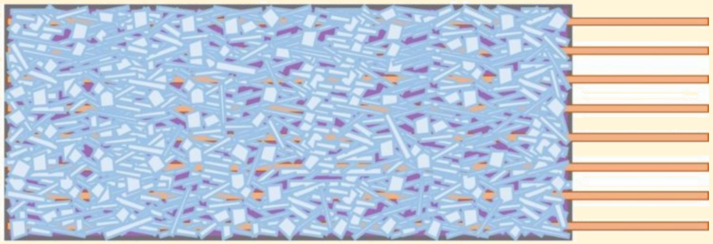
GRAiNITA concept

Shashlyk-type calorimeter

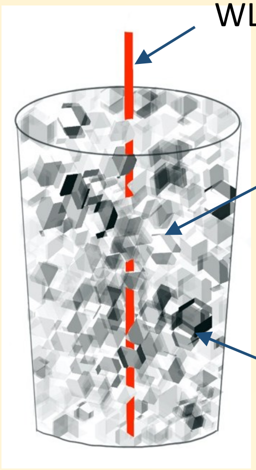


$$\frac{\sigma_E}{E} \sim \frac{10\%}{\sqrt{E}}$$

GRAiNITA



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



WLS fiber

high-density transparent liquid (LST Fastfloat, ρ=2,8 g/cm^3, n=1.548)

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

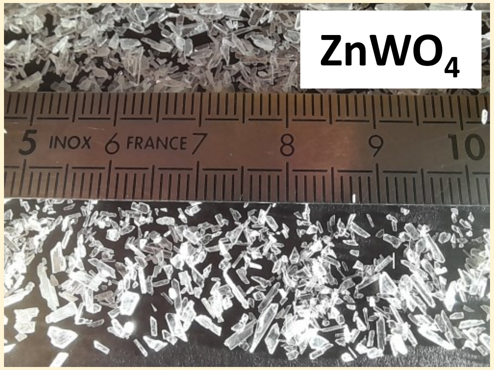
scintillation grains with high density and Z_{eff}

Scintillation grains

	N_{phe}, phe/MeV γ, ^{137}Cs	Z_{eff}	ρ, g/cm^3	refractive index	decay time, μs	λ_{max}^{em}	Possibility of the grains obtaining by the flux method
$ZnWO_4$ SC	≈1 720	61	7.87	2.2-2.3	20*	490	Yes ☺
$CaWO_4$ SC	≈ 4 400	62	6.06	1.94	10*	430	Yes ☺
$Bi_4Ge_3O_{12}$ (BGO) SC	≈1 370	74	7.13	2.1	0.3	480	No ☹

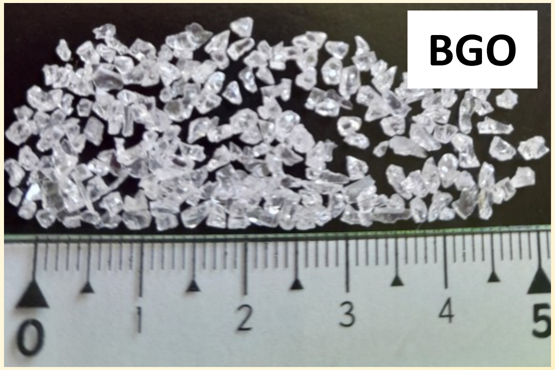
*The rather long decay time constant of ZnWO4 (20μs) is not an issue in the context of FCC e^+e^- due to the Z_0 production rate (50 kHz) and the low occupancy of the detector

Scintillation grains provided by ISMA (Kharkiv, Ukraine)



1380 g (October 2022)

≈250 g (May 2023)

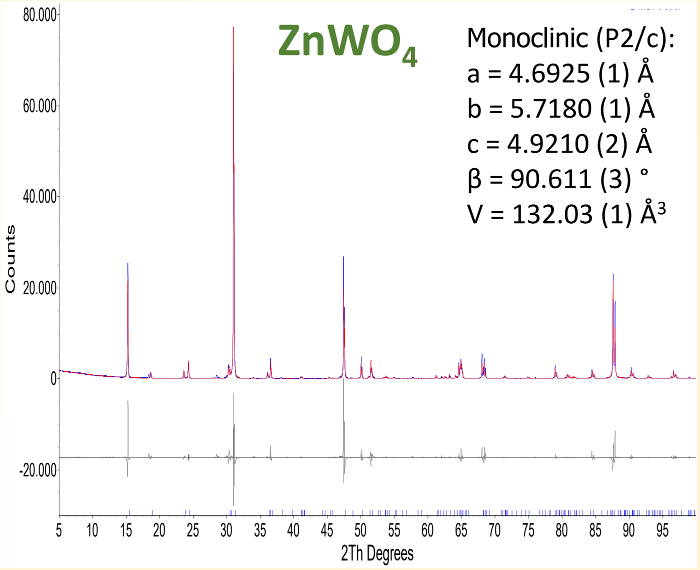


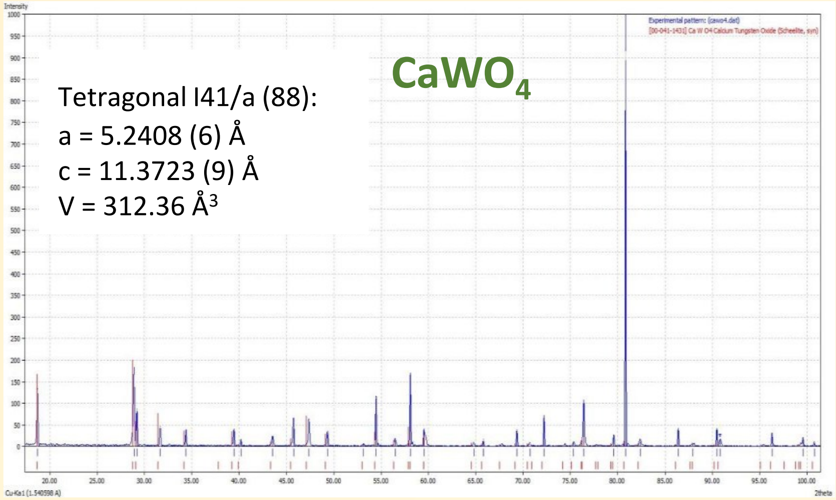
≈350 g (May 2023)

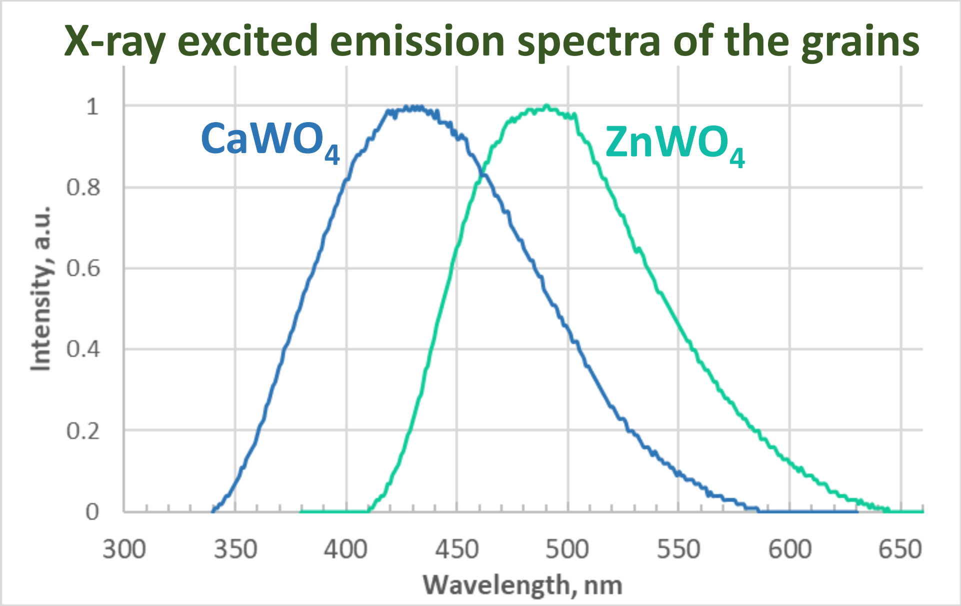
mechanical crushing of the single crystal (SC)

grown by the flux method

Structural and luminescence characterization of $ZnWO_4$ and $CaWO_4$ grains



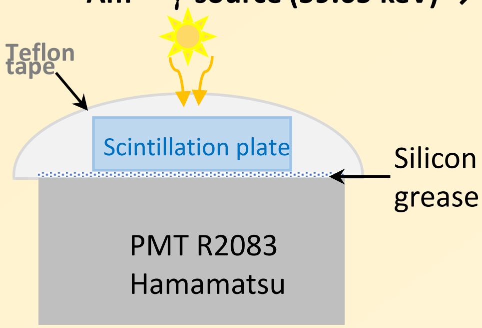


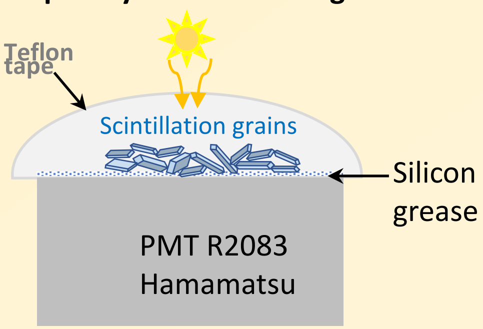


$ZnWO_4$ and $CaWO_4$ grains show the same crystallographic structures and luminescence properties as single crystals

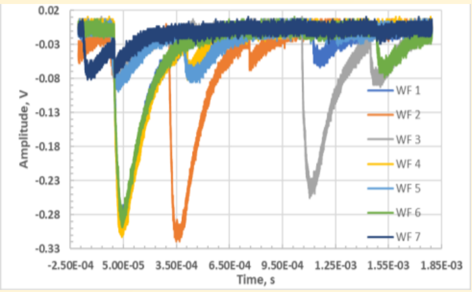
Scintillation performance of the grains

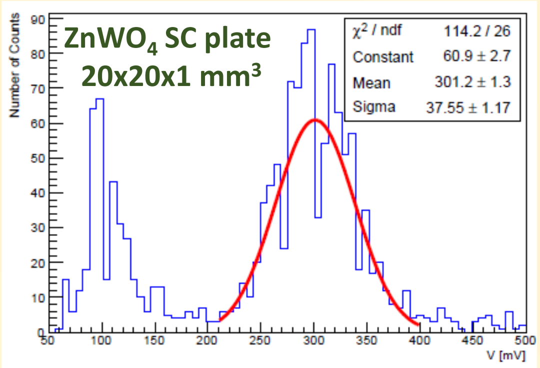
Am^{241} γ-source (59.65 keV) → completely absorbed in 1 grain

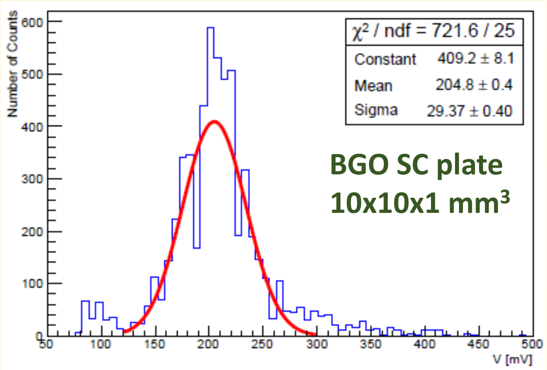


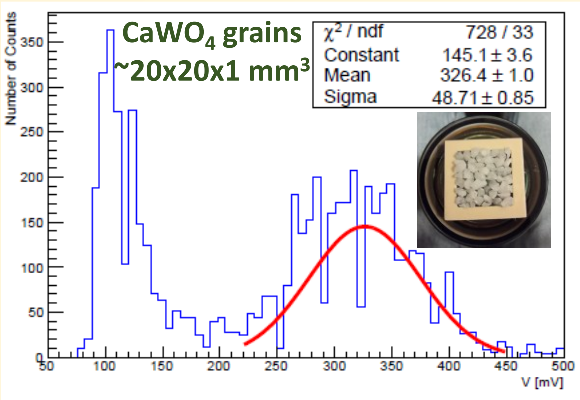


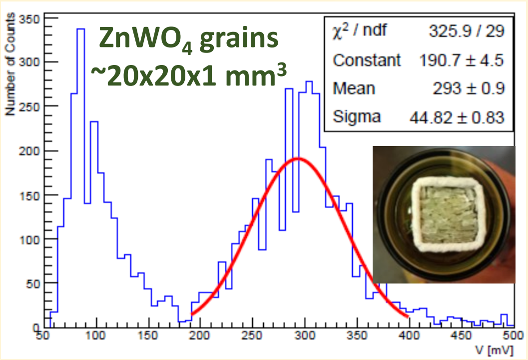
Digital oscilloscope: LeCroy WavePro 715Zi
Integrator circuit: τRC = 100 µs
3000 pulses, 50 000 points per pulse

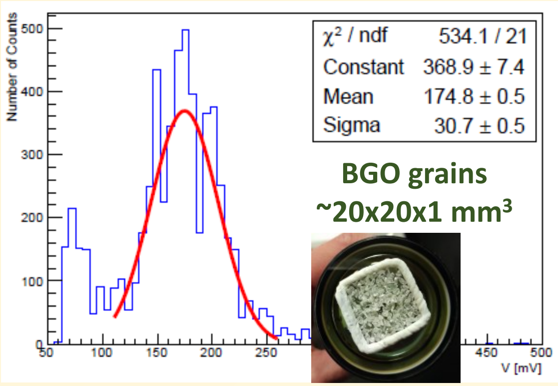








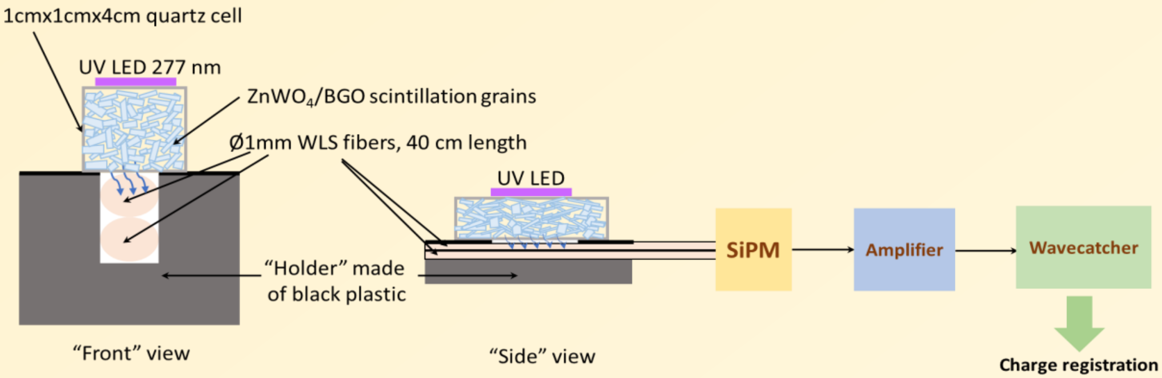


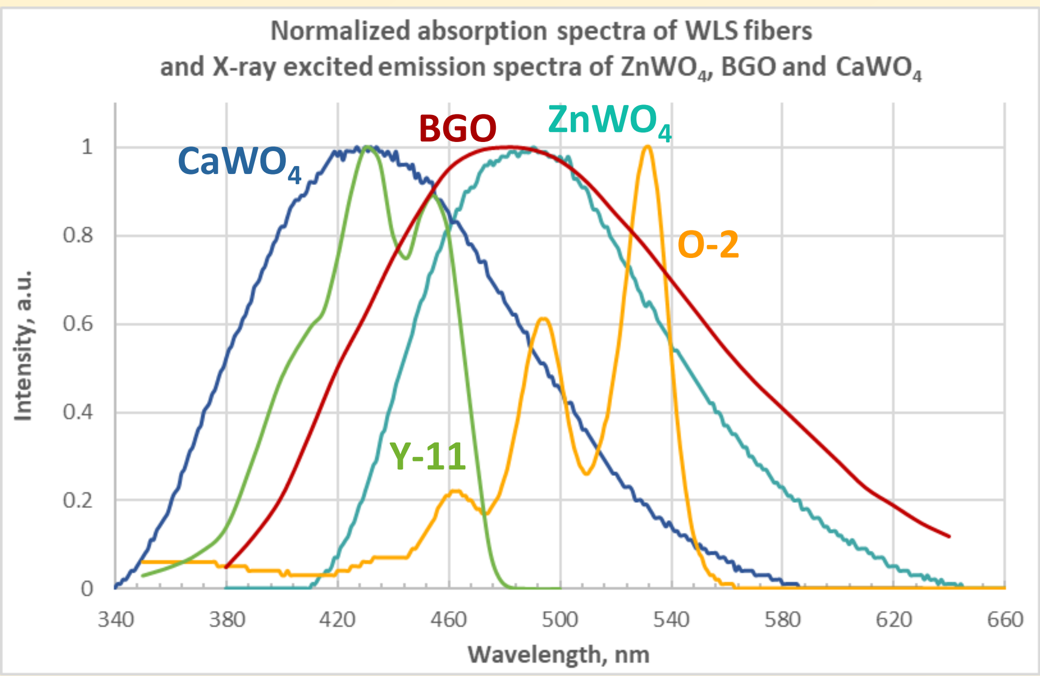


Sample	Mean, mV	Sigma, mV
$ZnWO_4$ grains	293.0	44.8
$ZnWO_4$ SC plate	301.2	37.5
BGO grains	174.8	30.7
BGO SC plate	204.7	29.3
$CaWO_4$ grains	326.4	48.7

Selection of the WLS fiber (Kuraray) for registration of the scintillation light from the grains

(!) Emission spectra of $ZnWO_4$, $CaWO_4$, and BGO are similar under excitation by UV or ionizing radiation/particles





WLS fiber	Relative efficiency, %		
	$ZnWO_4$ grains	BGO grains	$CaWO_4$ grains
Kuraray O-2(300)	**100**	**100**	**100**
Kuraray O-2(200)	103	100	103
Kuraray Y-11(200)	30	83	227

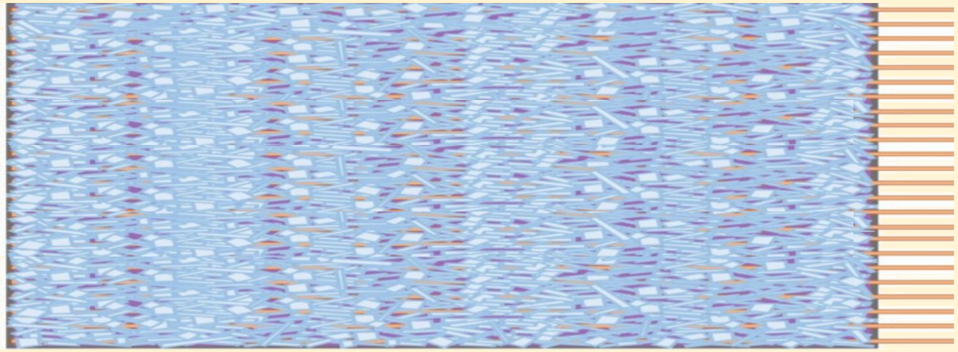
O2(200) is a good candidate for $ZnWO_4$ as well as for BGO

$CaWO_4$ requires using of Y-11

We thank to Kuraray for providing different types of WLS fibers, supporting information and fruitful discussions!

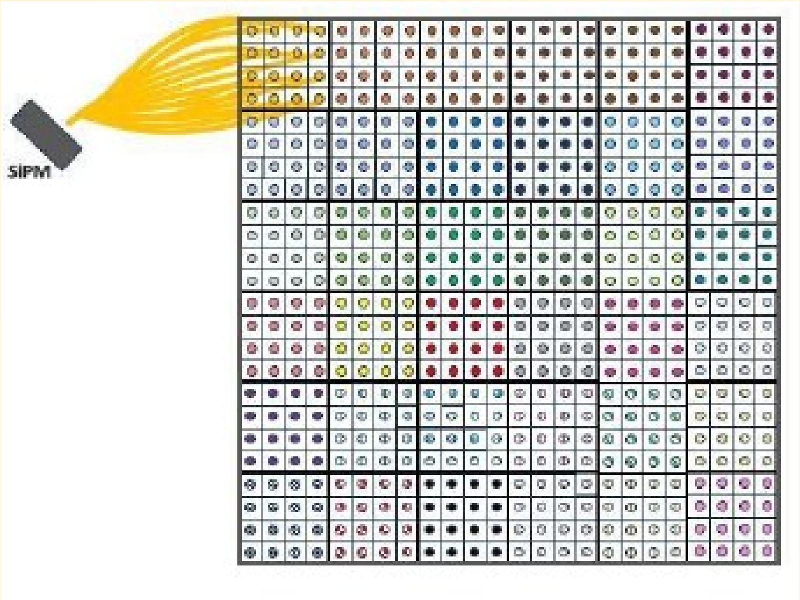
Future full-size GRAiNITA demonstrator and small-size prototype

Full-size demonstrator



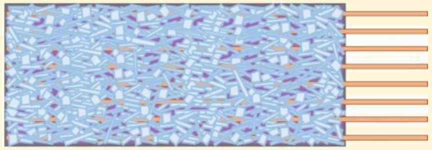
17 cm x 17 cm x 40 cm

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

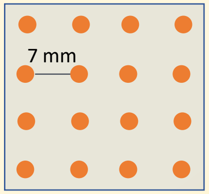


576 WLS fibers, placed 7 mm apart from each other
(36 x 16 fibers bundle) coupled
to 36 large-area SiPMs

Small-size prototype

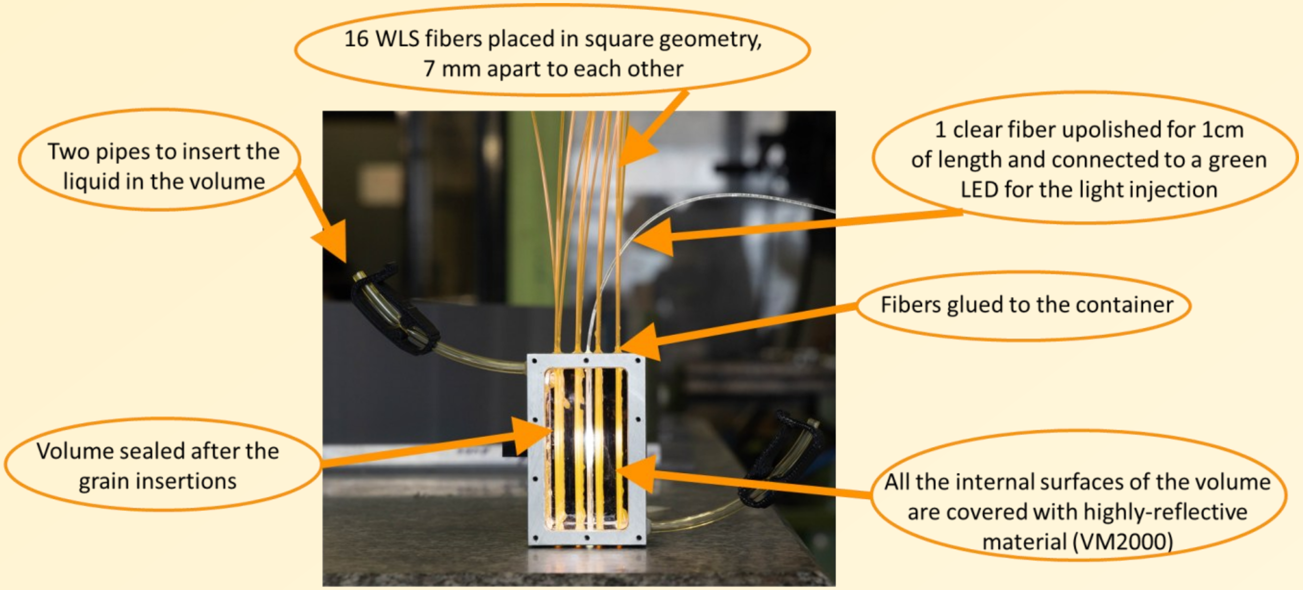


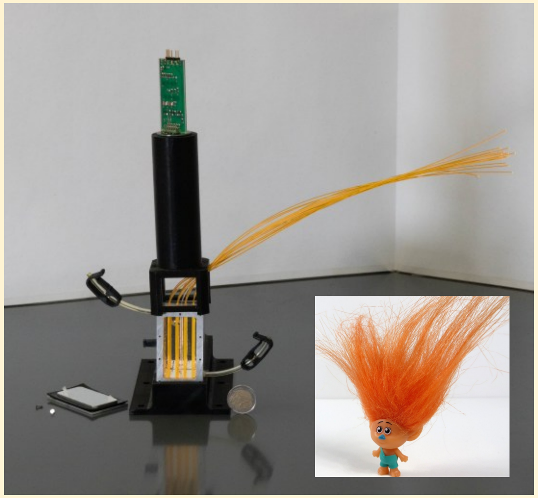
4 cm x 4 cm x 6 cm

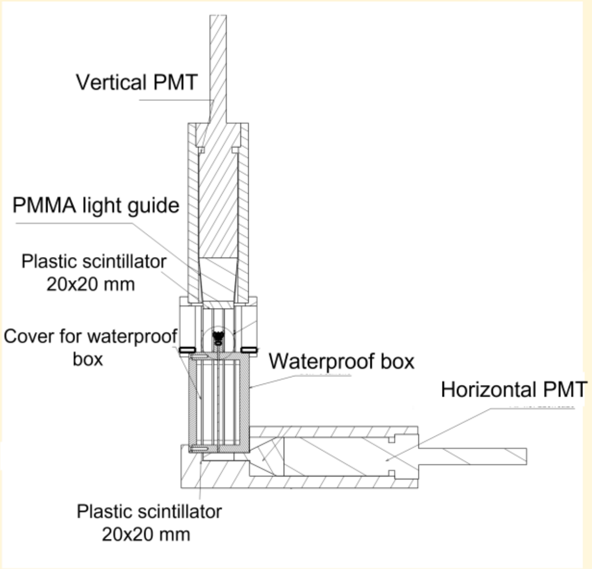


16 WLS fibers, coupled to 16 SiPMs

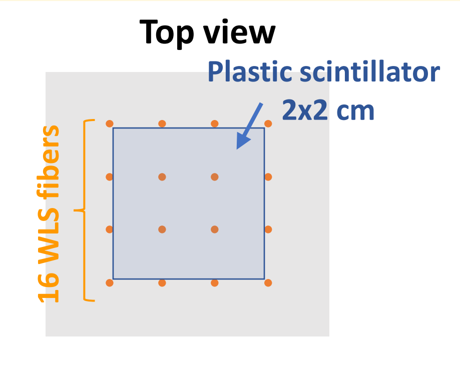
Small-size-prototype for cosmic rays and beam tests: TROLL



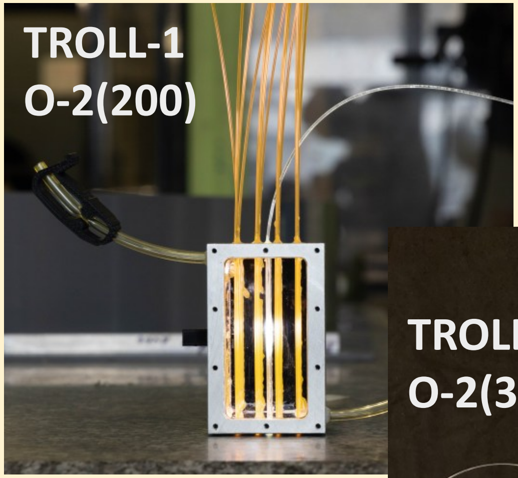


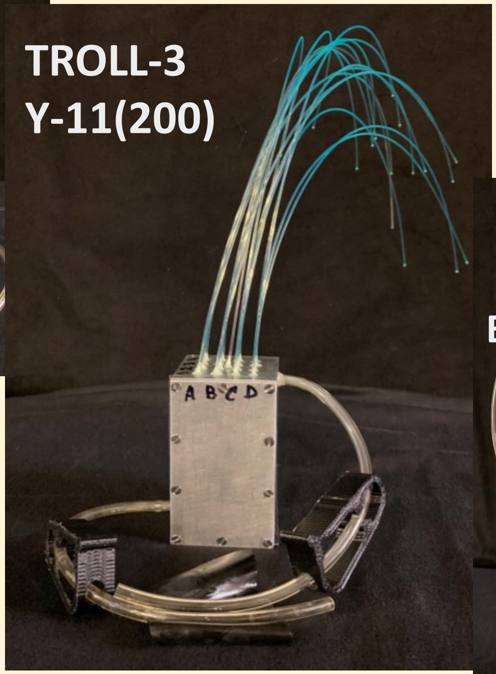


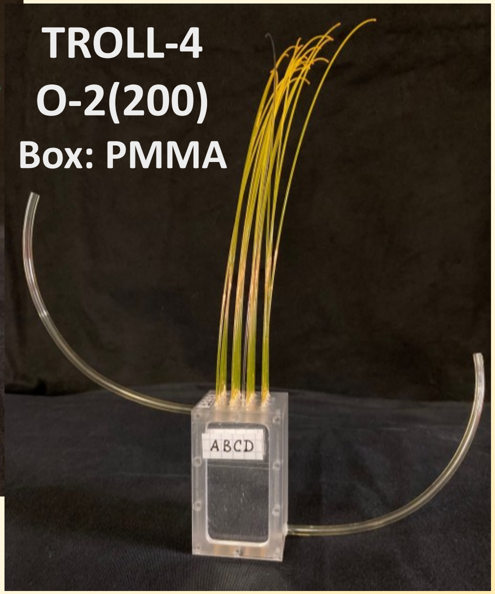
Two 2 cmx2 cm plastic scintillators connected to PMT’s → double coincidence for cosmic rays triggering



TROLLs' dynasty







GRAiNITA small-size-prototype: tests with cosmic ray muons

What would we like to know?

- Check the feasibility of GRAiNITA detector concept
- Number of photo-electrons by MeV

Muons:

<u>accelerator beam</u>

✓ beamtime should be reserved in early advance, not available for routine tests ☹

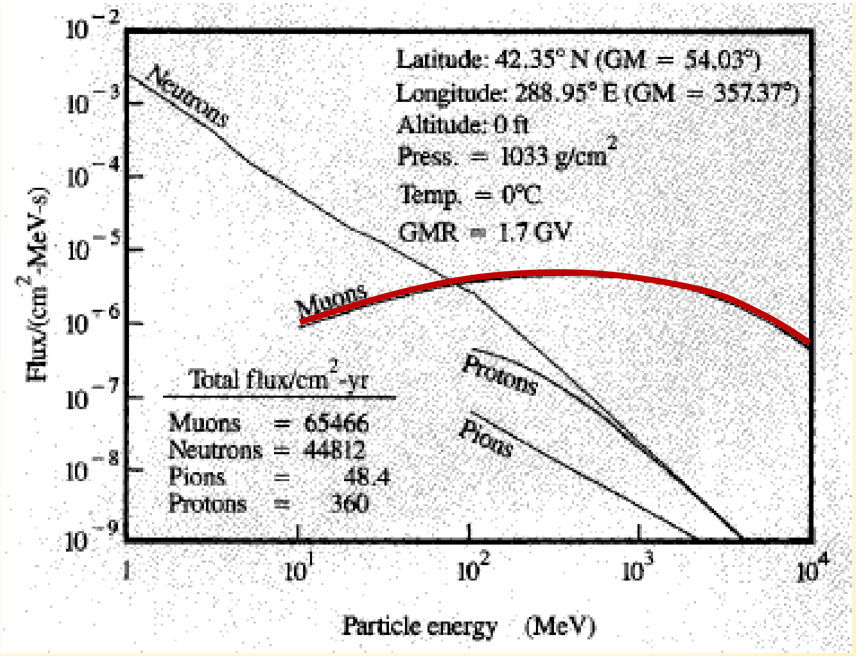
<u>cosmic rays</u>

✓ free of charge ☺

✓ available 24/7 everywhere ☺

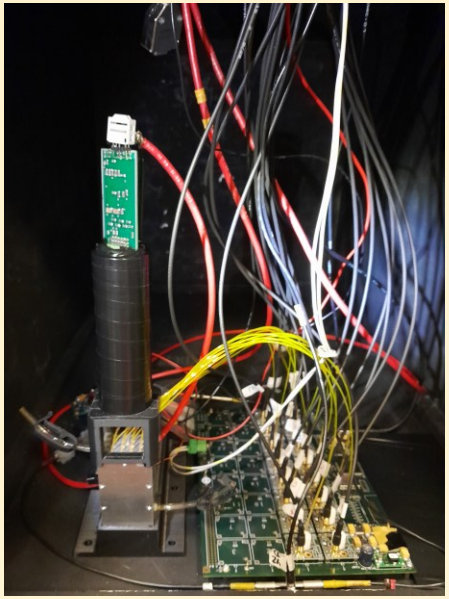
✓ 1 event for 10-12 min (in the case of the double coincidence we have) ☹

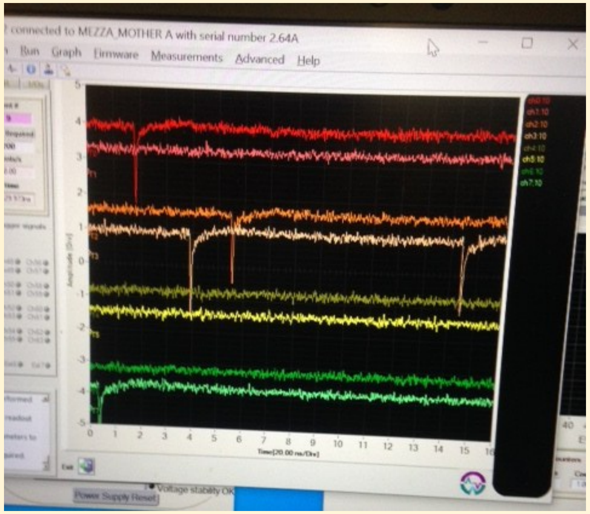
Theoretical calculation of the flux of cosmic ray particles. The most abundant particles are muons



J.F. Ziegler, IBM J. Res. Develop., 40(3) (1996) 19-39

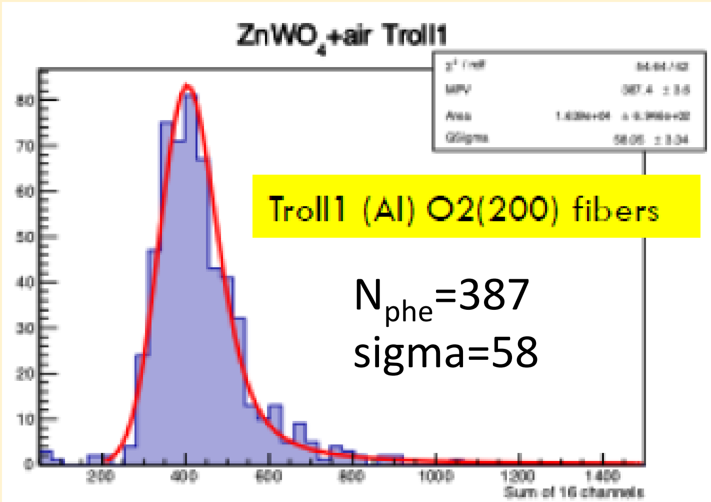
GRAiNITA cosmic rays tests – acquisition system

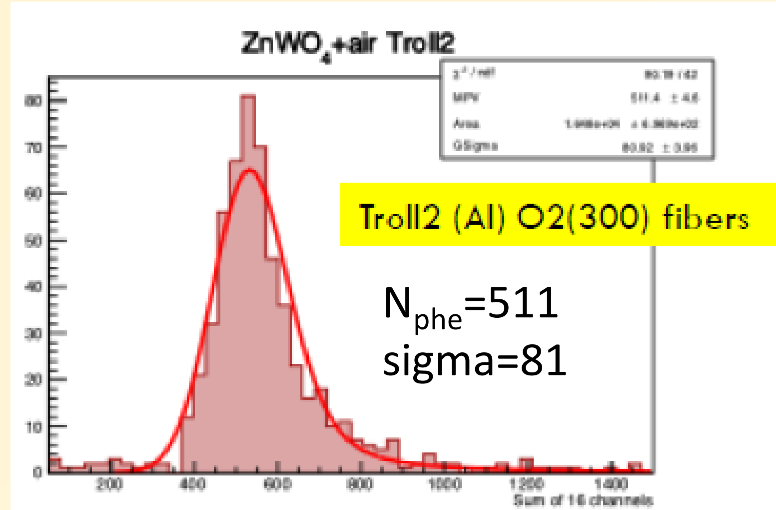


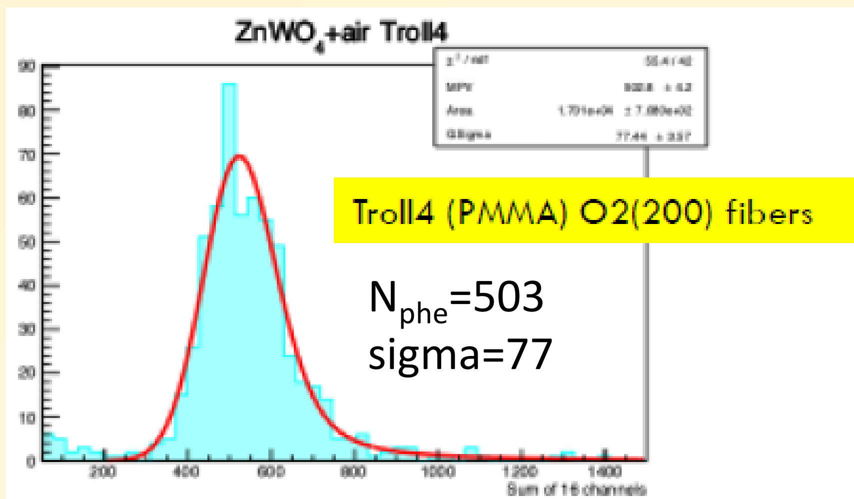


- there are 16 WLS fibers read by 16 SiPMs coupled to 16 amplifiers on a card. The amplified pulse shape depends on the output inductance, for small values, only the fast part of the pulse is kept;
- 16 acquisition channels are connected to 16 channel wavecatcher (with an external trigger: the signal from the two PMTs R7899 => NIM discriminator => coincidence circuit);
- since $ZnWO_4$ and $CaWO_4$ have long decay times (20 μs and 10 μs) , a special program has been implemented allowing to count the number of the single photoelectron pulse (N_{phe}) on a longer time scale 25 μs ($ZnWO_4$) or 12.5 μs ($CaWO_4$);
- using fast pulse shaping and counting the number of pulses in an interval of time;
- for tests of BGO grains with fast (300 ns) decay constant, the inductance on each 16 amplifiers were replaced by 50Ω resistance; the pulses for each SiPM were integrated over 440 ns; the N_{phe} per SiPM was calculated via dividing the registered charge by the experimentally estimated charge of the single photoelectron.

Cosmic rays tests: $ZnWO_4$ grains in different Trolls





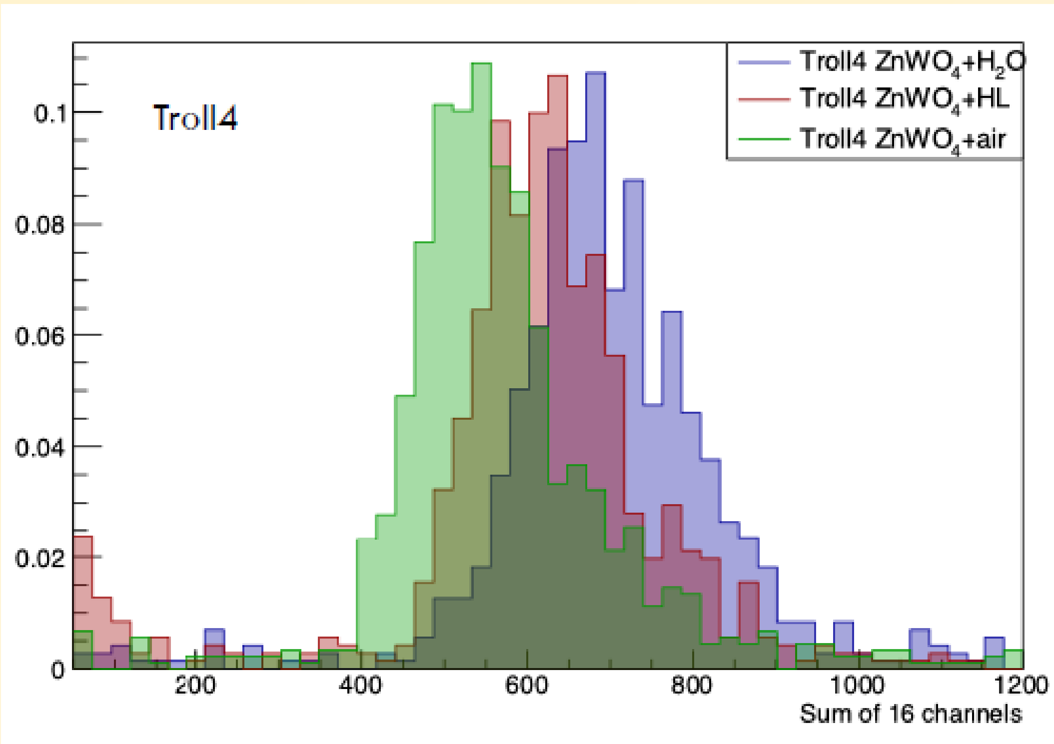


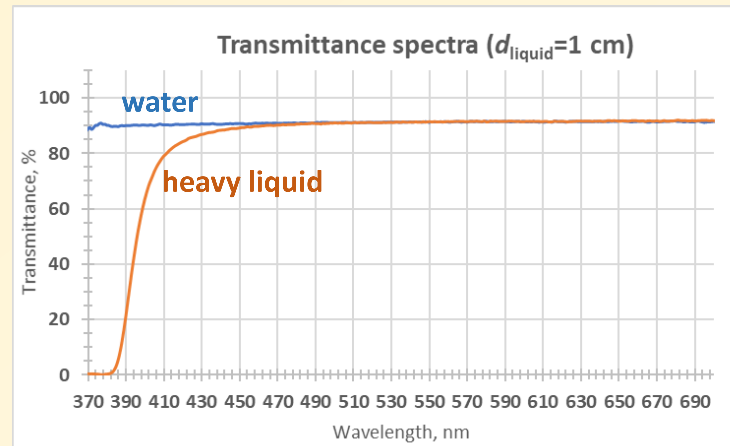
Estimated light yield is ≥400 phe per 40 MeV deposited by the muons in the test device, i.e. ≥10000/GeV => statistical constant ≈ 1% for 1 GeV high energy photon

Cosmic rays tests: $ZnWO_4$ grains with different liquids

Using of liquids (water, Heavy Liquid) serves to:

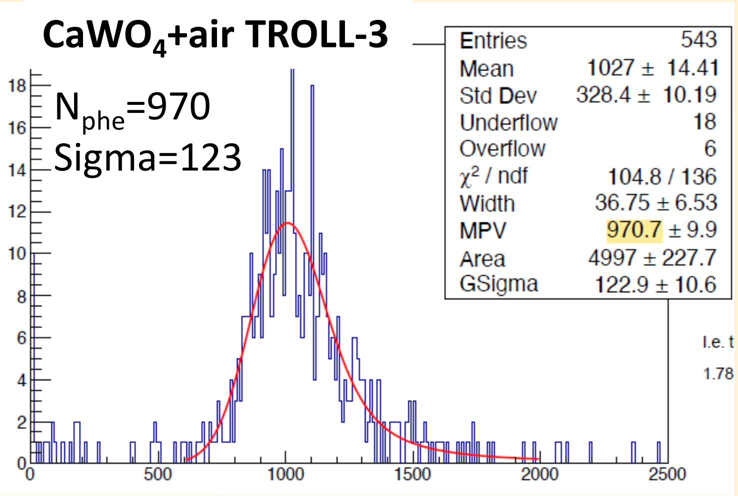
- ✓ provide a better optical matching with the scintillator grains
- ✓ optimize the overall density and compactness of the calorimeter

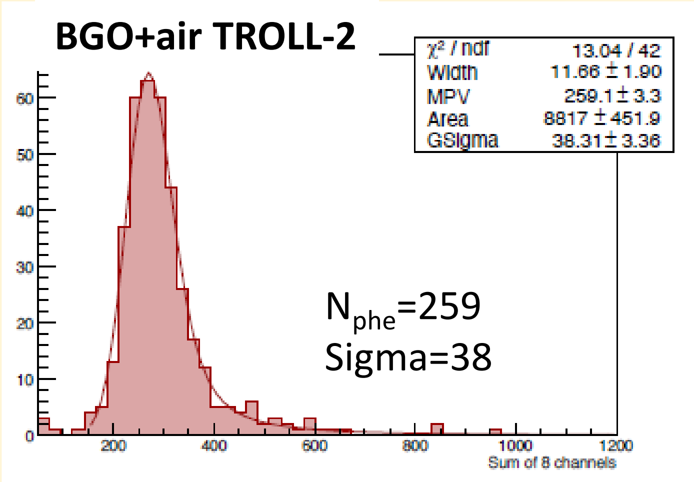


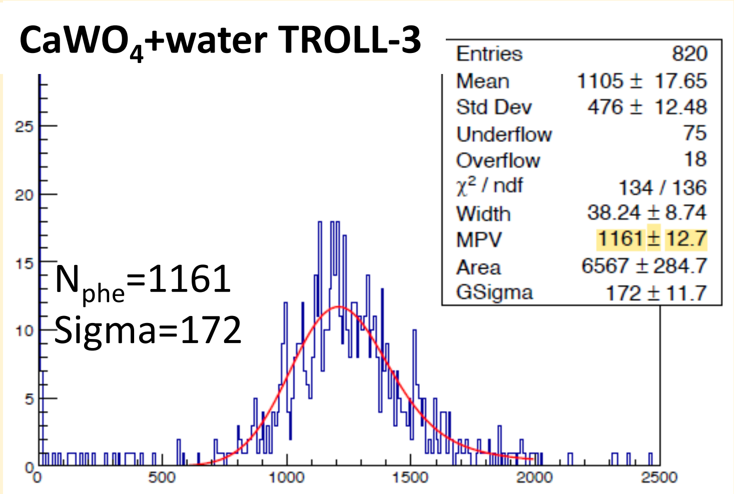


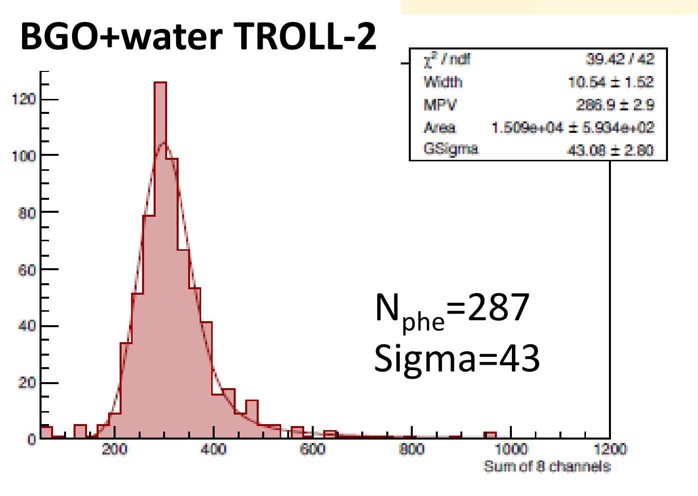
- ✓ Adding of water as an optical medium increases the light amount by about 24% compare to air;
- ✓ With Heavy Liquid the gain in the light amount is slightly lower, about 16% with respect to air (can be explained by the absorption of the heavy liquid in the blue spectral range).

Cosmic rays tests: $CaWO_4$ and BGO grains







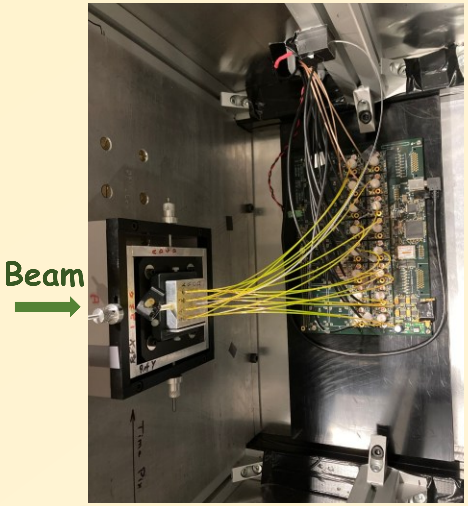


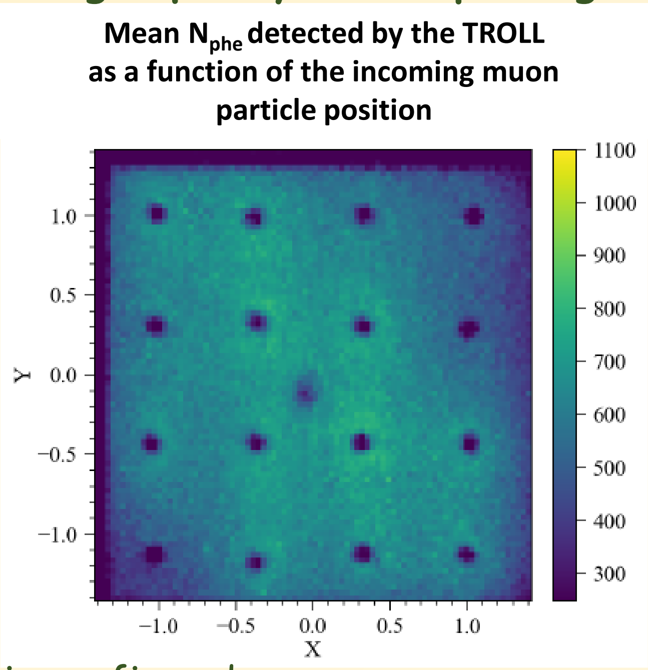
- ✓ The "light yield" for $CaWO_4$ grains is about 1.8 times higher compare to $ZnWO_4$ grains
- ✓ For BGO grains the N_{phe} is about 2 times lower in comparison with $ZnWO_4$ grains
- ✓ Adding of water as an optical medium increases the light amount

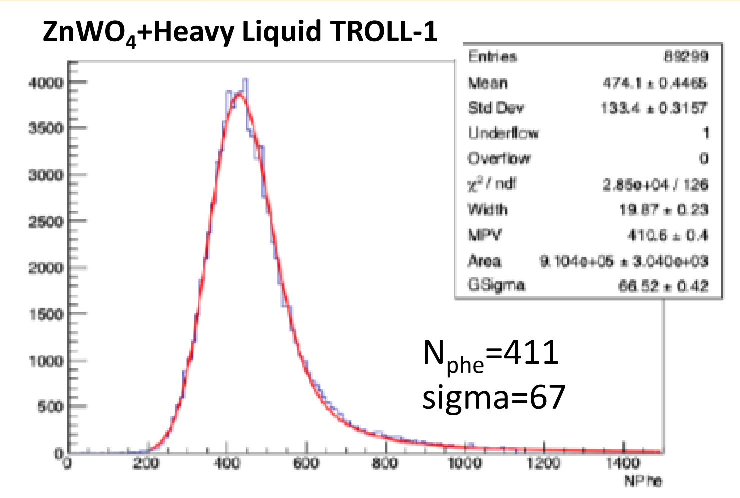
$ZnWO_4$ grains: muon beam tests

H1 area of the SPS, CERN, June 2024

~ 0.2 million of high-quality muons passing through TROLL





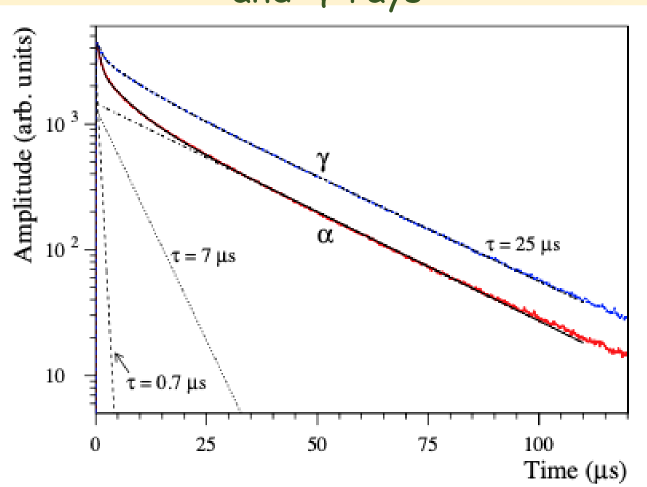


- ✓ The light confinement is confirmed
- ✓ The obtained light yield is ≈ 10 000 phe/GeV in a good agreement with previous studies
- ✓ The preliminary results are quite encouraging and indicate that the statistical contribution to the energy resolution of the order of 1-2%/$\sqrt{E}$ is achievable
- ✓ Obtained non-uniformity maps were inputted into a GEANT-4 simulations of the calorimeter concept. The constant term from non-uniformity < 1% can be expected (limitations due to the prototype size). The full-size prototype tests are needed for precise values

GRAiNITA as an dual redout calorimeter: is it possible?

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

Clear discrimination between α-particles and γ-rays

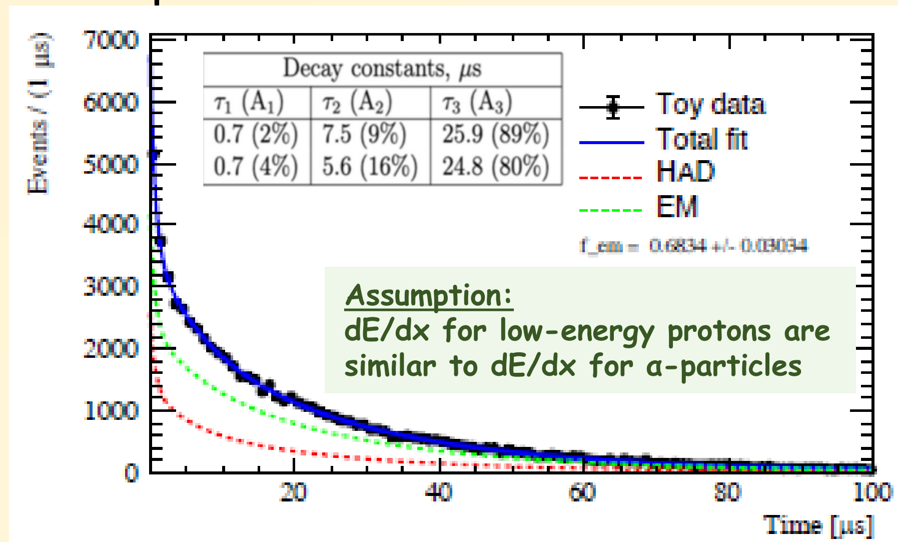


Type of irradiation	Decay constants, μs		
	τ_1 (A_1)	τ_2 (A_2)	τ_3 (A_3)
γ ray	0.7 (2%)	7.5 (9%)	25.9 (89%)
α particles	0.7 (4%)	5.6 (16%)	24.8 (80%)

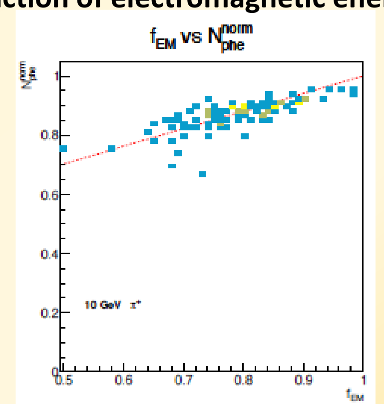
F.A. Danevich et al., NIM A 544 (2005) 553–564

Simulation

N_{phe} induced by an incident 10 GeV charged pion as a function of their detection time



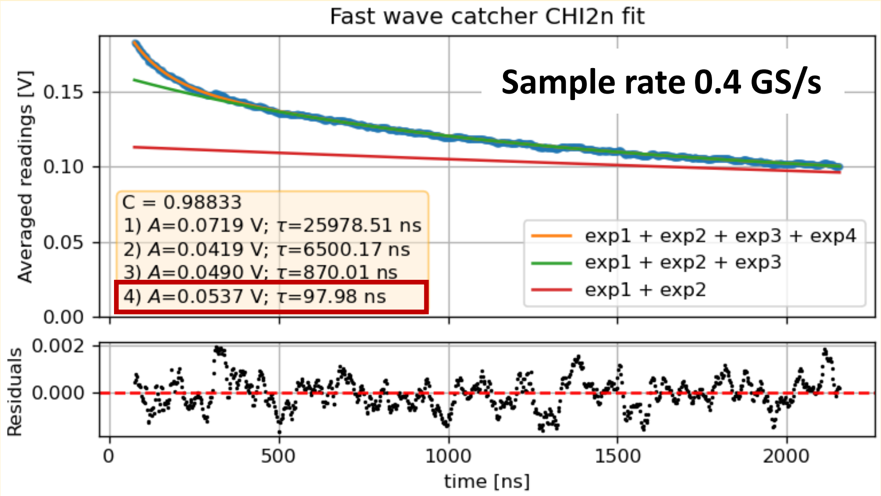
Distribution of the N_{phe} (normalized) as a function of the fitted fraction of electromagnetic energy

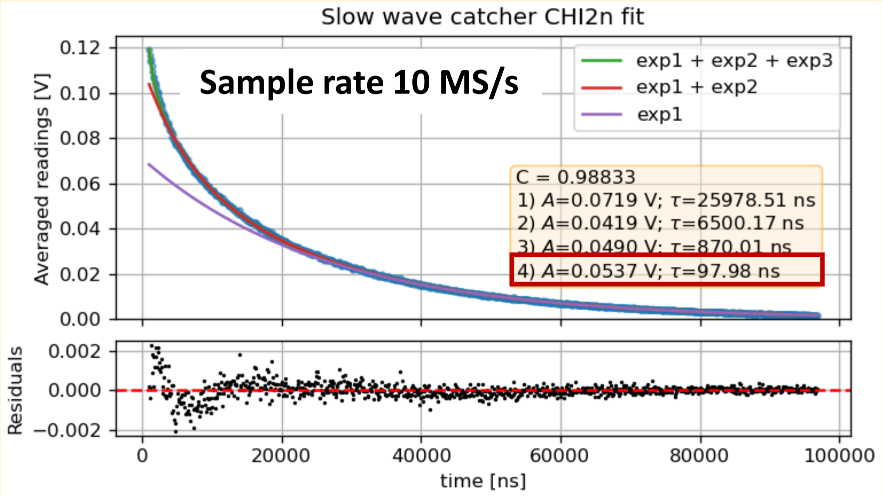


MISSING: actual scintillation times for the particles with different dE/dx

Search for experimental proofs for PSD possibility

β-rays, Sr^{90}-Y^{90} source





Preliminary results:
3 decay constants+additional "fast" one (not reported in the literature) have been found

~20 MeV and ~10 MeV protons, ALTO proton beam

First measurements performed on May 26, 2025 ☺ => data processing is ongoing…

Summary

- ✓ The feasibility of the GRAiNITA detector concept has been proved:

  for $ZnWO_4$ grains N_{phe} ~ 10 000/GeV; statistical fluctuation of 1-2%/$\sqrt{E}$ is at reach; estimated constant term from non-uniformity is < 1%

- ✓ The idea of using the PDS technique for dual redout calorimeter seems to be perspective and should be checked

- ✓ $CaWO_4$ grains can be regarded as the 2nd candidate for the future detector, the studies are ongoing

To be continued ☺…

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