GRAiNITA – a new generation calorimeter

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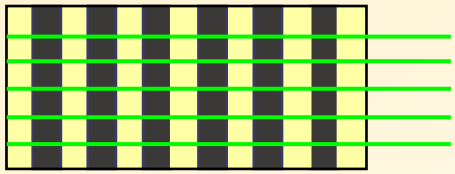
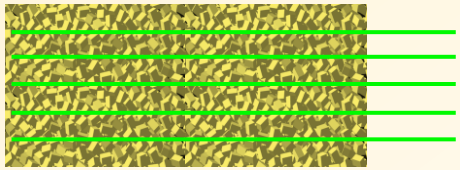
GRAiNITA concept

"Shashlyk"-type calorimeter

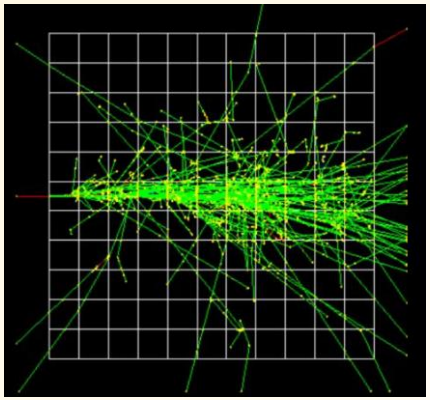


$$\frac{\sigma_E}{E} \sim \frac{10\%-15\%}{\sqrt{E}}$$

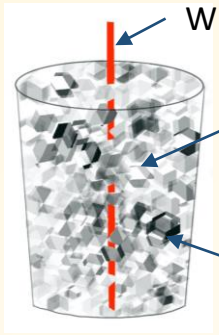
GRAiNITA



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



GEANT4 simulation
$ZnWO_4$ 1mm cubes+
CH_2I_2
(random position)



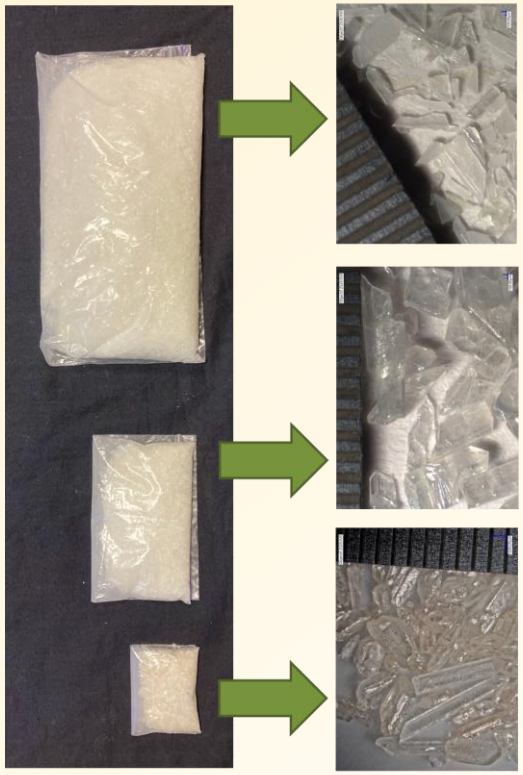
$ZnWO_4$
LY= 10 000 ph/MeV
- Z_{eff}=61
- Density 7.62 g/cm^3
- Index n=2.1-2.3
- τ = 20 μs
- λ_{max}^{em} = 490 nm

$Bi_4Ge_3O_{12}$ (BGO)
LY= 10 000 ph/MeV
- Z_{eff}=74
- Density 7.13 g/cm^3
- Index n=2.1
- τ = 300 ns
- λ_{max}^{em} = 480 nm

Inspired by LiquidO technique for neutrino detector
(A. Cabrera et al. LiquidO Commun Phys 4, 273 (2021))

Scintillators

$ZnWO_4$ crystal grains obtained via the flux method

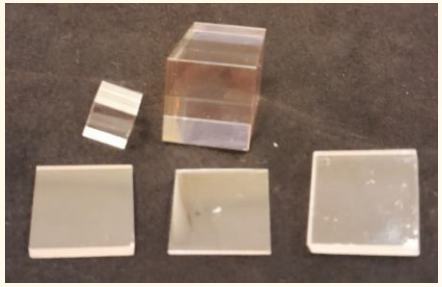


3rd batch: 1380 g
Size ~ 1 mm
October 2022

2nd batch: 170 g
Size ~ 1÷2 mm
May 2022

1st batch: 40 g
Size ~ 1÷3 mm
2021

$ZnWO_4$ single crystals (SC)

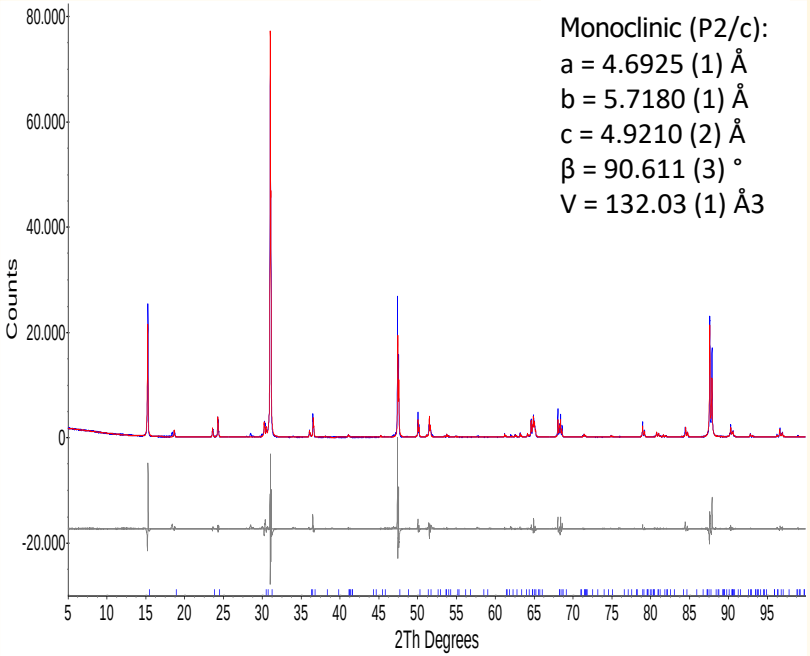


BGO grains and single crystals(SC)

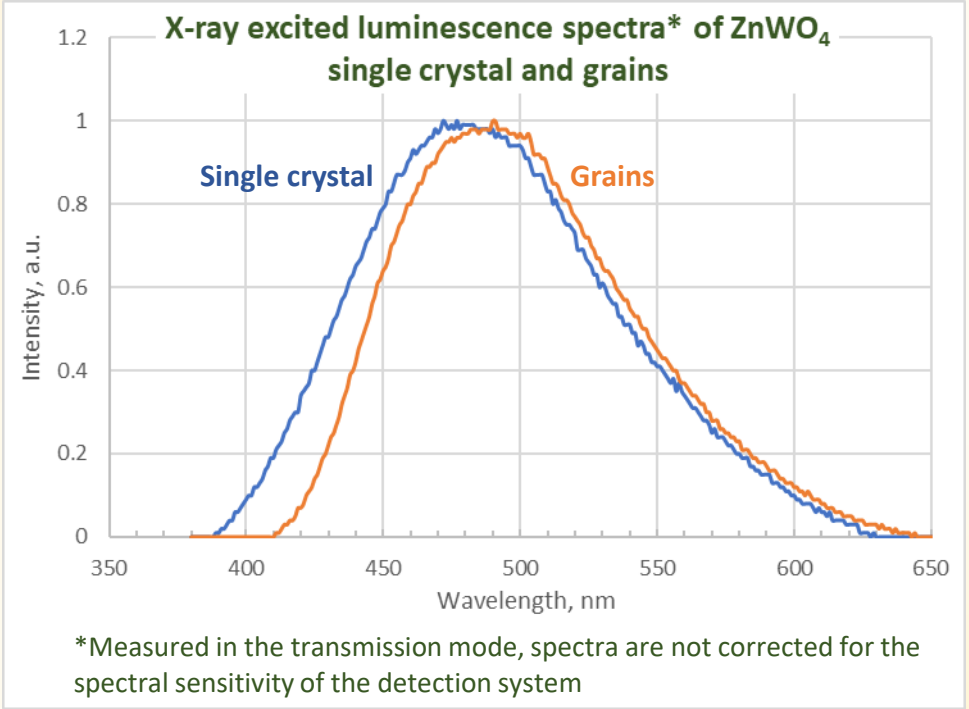
BGO grains are obtained via the mechanical crushing of the SC

Grown in High-melting Scintillation Materials Laboratory, ISMA (Kharkiv, Ukraine)

Structural and luminescence characterization of $ZnWO_4$ grains



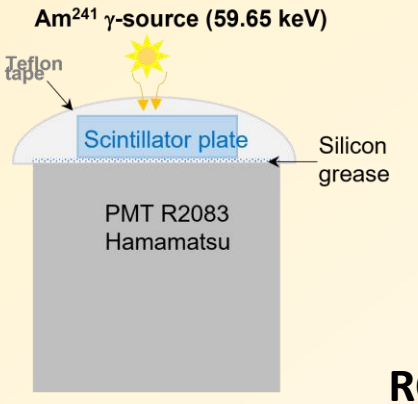
According to the results of X-ray powder diffraction analysis, $ZnWO_4$ grains possess the monoclinic wolframite-phase structure as well as $ZnWO_4$ SC

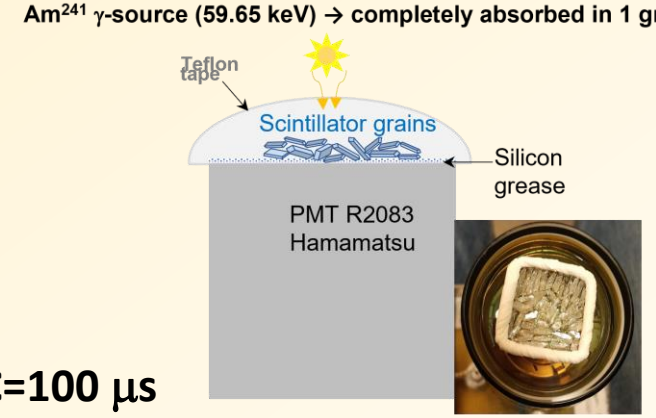


*Measured in the transmission mode, spectra are not corrected for the spectral sensitivity of the detection system

Luminescence spectra of $ZnWO_4$ grains and SC are similar. The small shift of the luminescence maximum towards the long-wavelength region in the case of grains is the result of the of increased absorption/scattering of light by the grains.

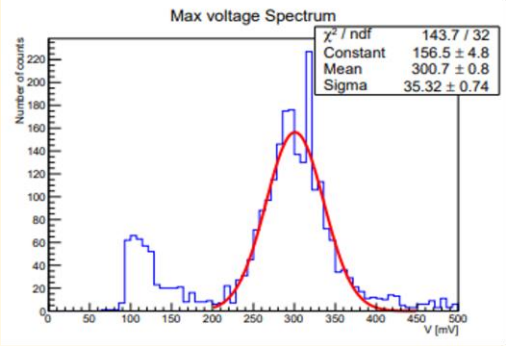
Scintillation performance of $ZnWO_4$ grains



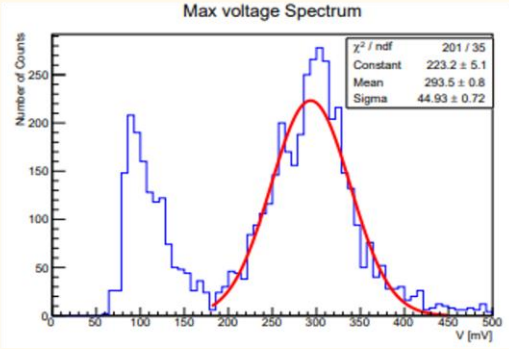


RC=100 μs

$ZnWO_4$ single crystal plate 20x20x1 mm³



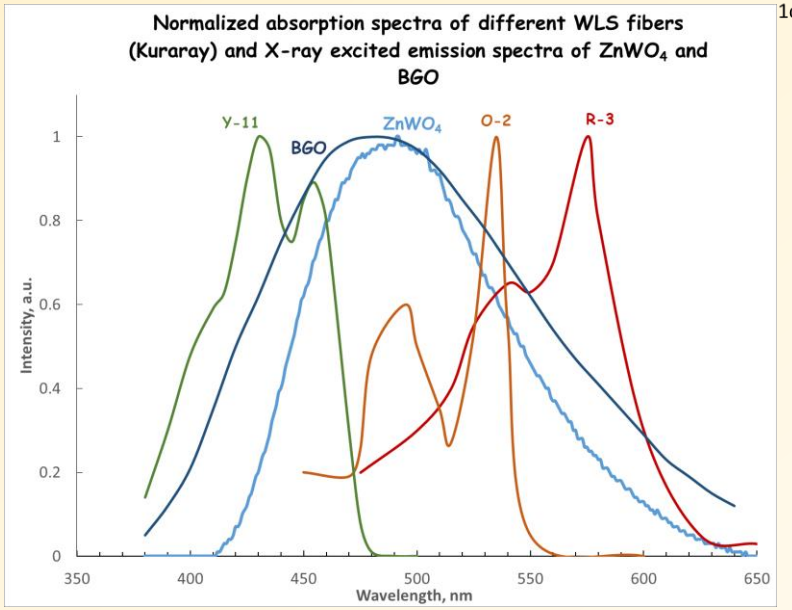
$ZnWO_4$ grains "mosaic" ~20x20x1 mm³

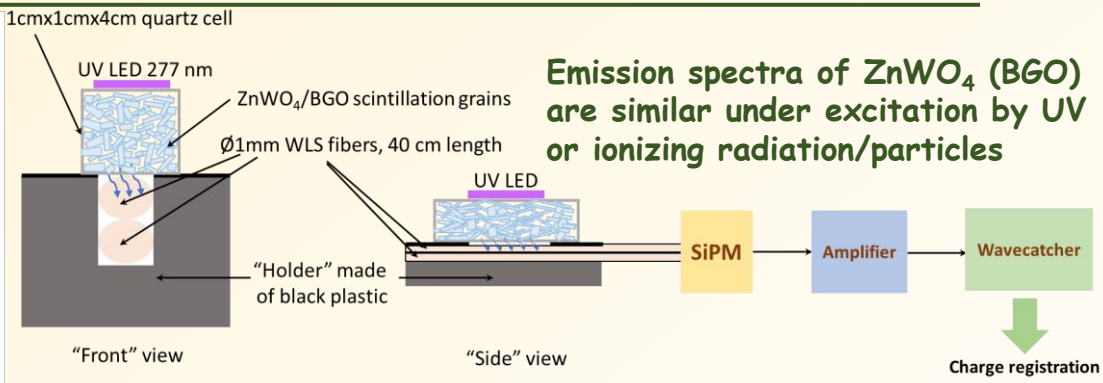


Sample	Mean, mV	Sigma, mV
Grains in the frame 1st batch (40 g)	260.7	59.24
Grains in the frame 2nd batch (170 g)	279.9	43.11
Grains in the frame 3rd batch (1380 g)	293.5	44.93
2x2x0.085 cm^3 plate	296.7 301.9	37.65 36.36
2x2x0.103 cm^3 plate	300.7 298.3	35.32 36.21
2x2x0.214 cm^3 plate	284.7 288.4	35.99 36.91
2x2x0.314 cm^3 plate	265.7 277.2	34.15 30.79
2x2x0.425 cm^3 plate	272.1 268.8	33.39 34.82
1x1x1 cm^3 cube	181.7	26.45

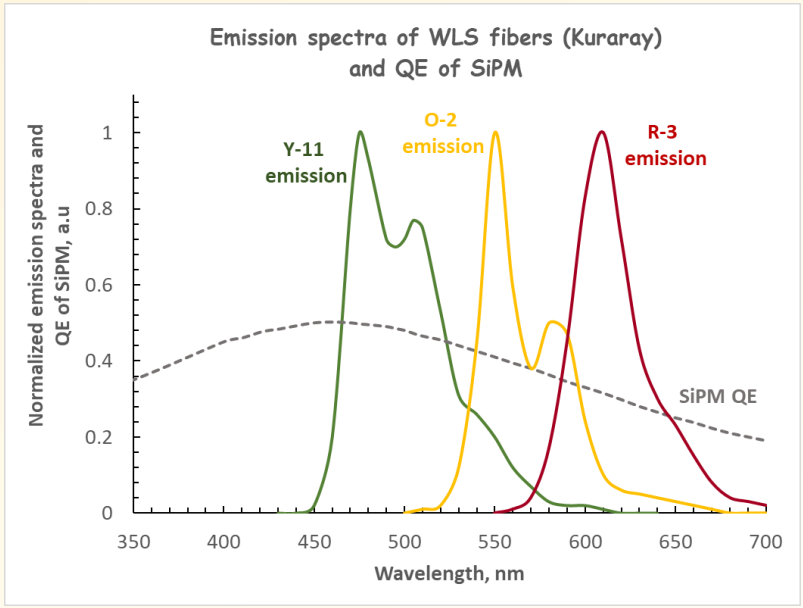
- **Good reproducibility of values measured for grains from the 2nd and 3rd batches → stable technology for grains production**
- **The 2nd and 3rd batches of grains show a much smaller variance in the amplitude of the Am241 peak at 59.65 keV → the better homogeneity in the light yield**

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





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

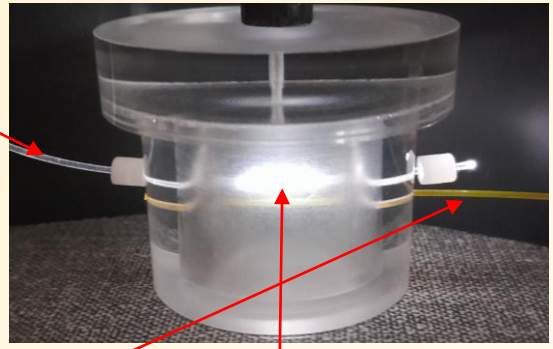


WLS fiber	Estimated N_{phe}	Relative efficiency, %
$ZnWO_4$ grains ~9 mm in the quartz cell		
O-2(300)	302.555064	100
O-2(200)	313.631277	104
Y-11(200)	133.50304	44
R-3(100)	181.404855	60
$ZnWO_4$ grains ~5-6 mm in the quartz cell		
O-2(300)	294.391397	100
O-2(200)	304.384926	103
Y-11(200)	215.041589	73
BGO grains ~9 mm in the quartz cell		
O-2(300)	326.1381617	100
O-2(200)	339.2981441	104
Y-11(200)	318.4178521	98
BGO grains ~5-6 mm in the quartz cell		
O-2(300)	471.9886362	100
O-2(200)	549.6132684	116
Y-11(200)	671.9978981	142

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

Light propagation tests

Clear (light injection) fiber (4 mm away from the WLS fiber)



+ VM2000 specular reflector wrapping

O2(300) WLS fiber

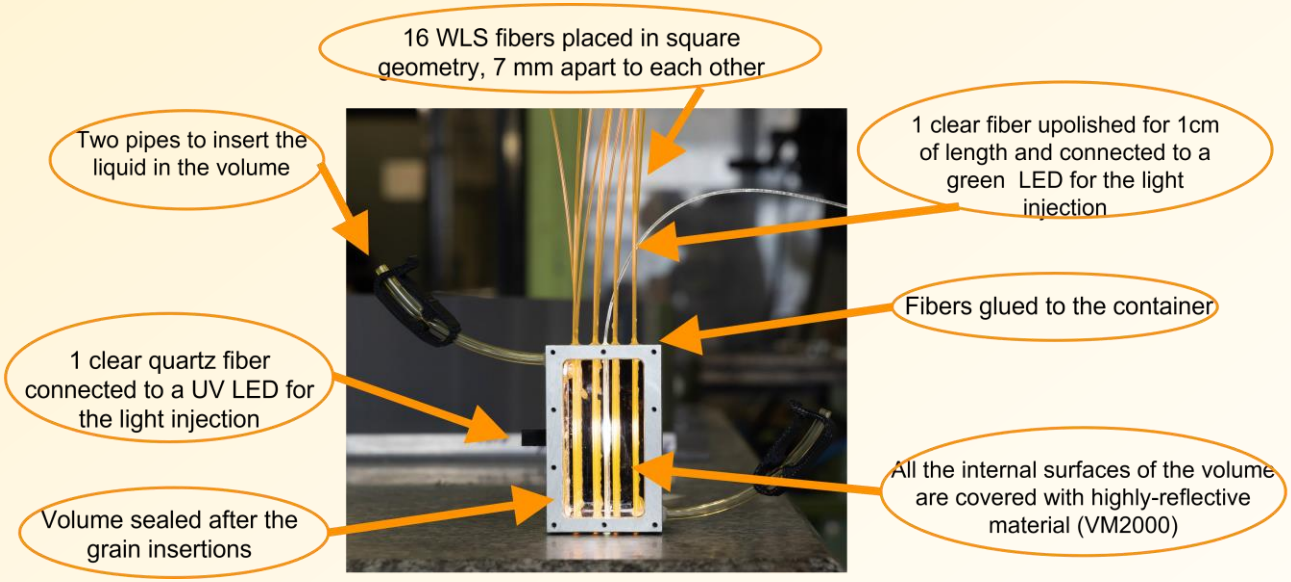
~1 cm de-polished part

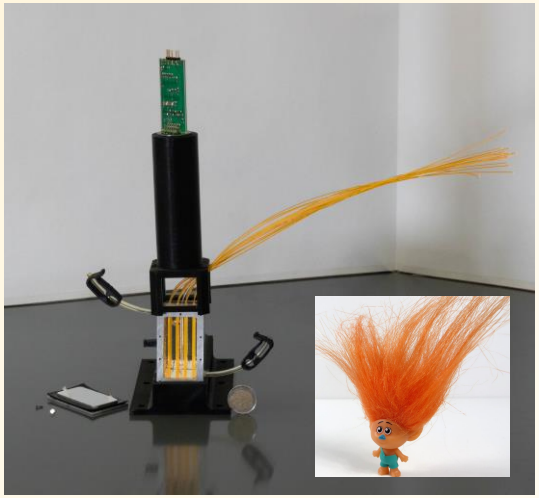
Injection of pulsed (20 ns, 300 Hz) green light from an LED (520 nm)

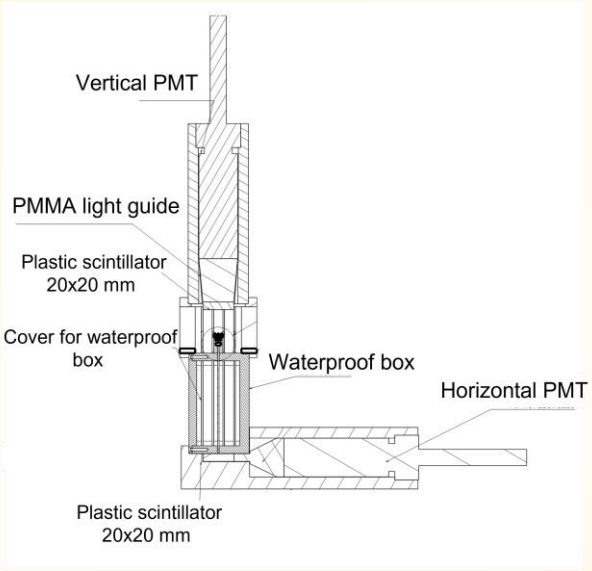
	Charge, pc	RMS, pc	Fraction of the captured light, %
Air	71.938	15.377	100
$ZnWO_4$	60.591	14.263	84
$ZnWO_4$+H_2O	67.455	14.938	94

- ✓ a good fraction of the light is captured in the configuration with grains;
- ✓ adding the liquid ($n(H_2O)=1.33$) decreases the light trapping and increases the amount of the light captured by the WLS fiber (liquids with higher n are possible…)

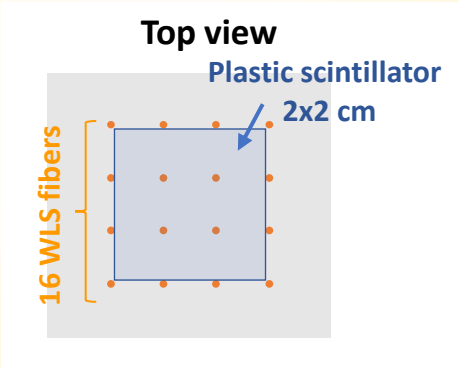
GRAiNITA medium-size-prototype for cosmic rays tests







Two 20x20 mm plastic scintillators connected to PMT's → double coincidence for cosmic rays triggering



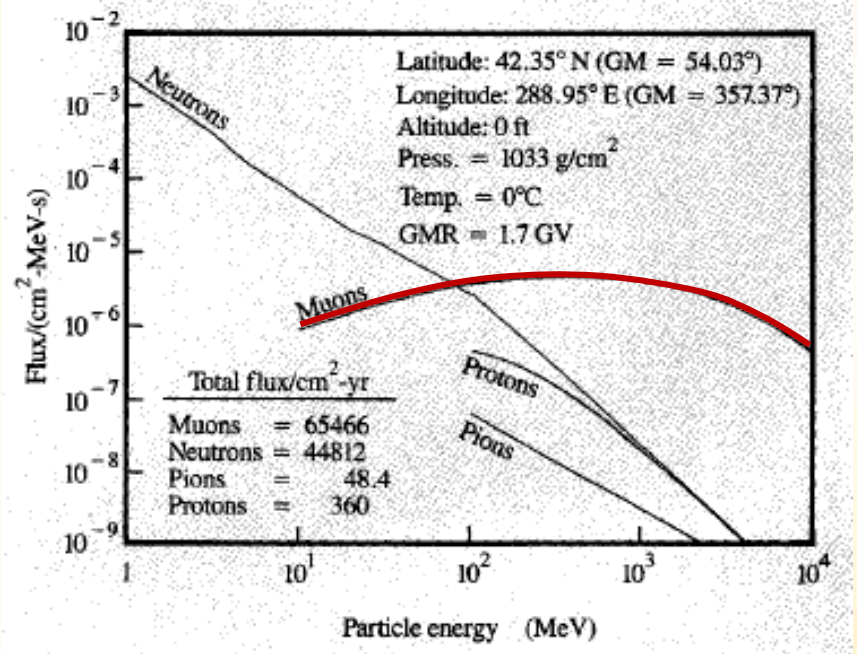
GRAiNITA medium-size-prototype for cosmic rays tests

What would we like to know?

- Number of photo-electrons by MeV
- Study the uniformity of response (muon close to a fiber or half-way)

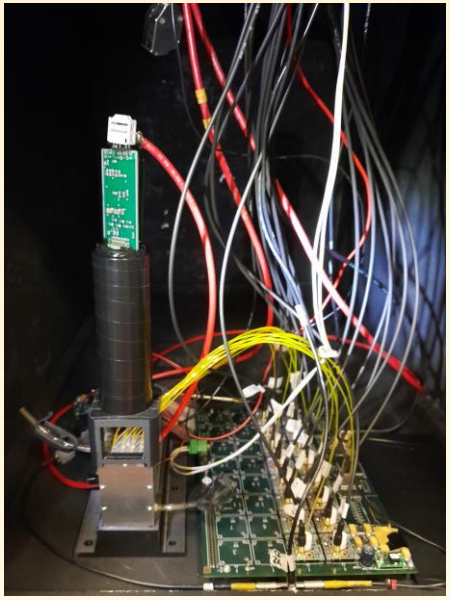
Cosmic rays:

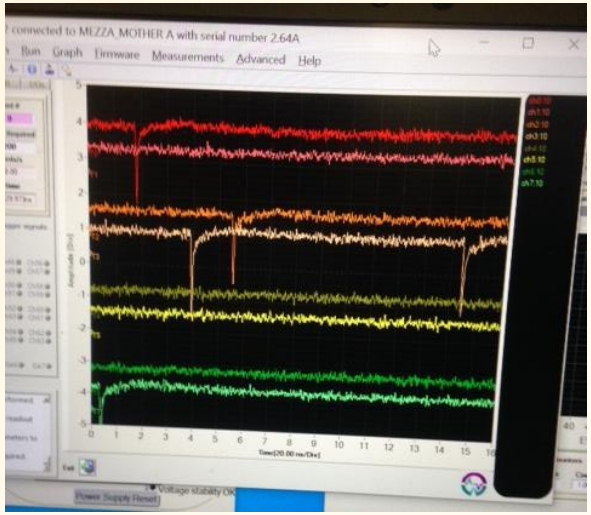
✓ free of charge ☺
✓ available everywhere ☺
✓ 1 event for 10-12 min (in the case of the double coincidence we have) ☹



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

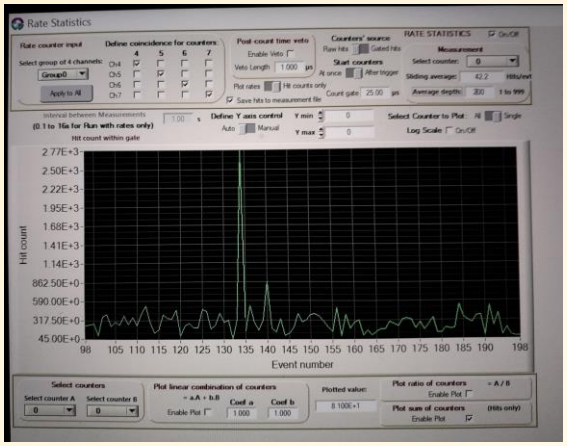
GRAiNITA cosmic rays tests – acquisition system

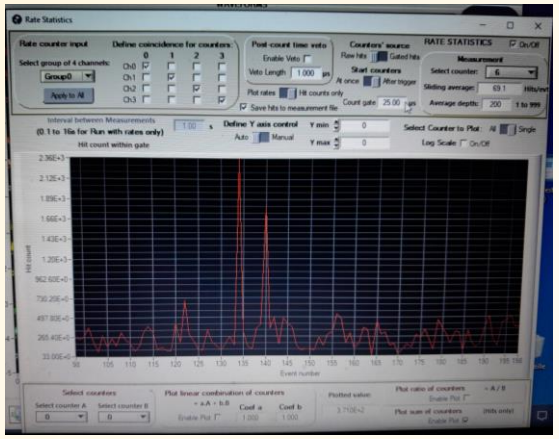




- there are 16 WLS fibers read by 16 SiPMs coupled to 16 amplifiers on a card. The amplified pulse shape depends on the output inductance, for small values, only the fast part of the pulse is kept;
- 16 acquisition channels are connected to two 8 channel wavecatchers (with an external trigger: the signal from the two PMTs R7899 => NIM discriminator => coincidence circuit);
- Since $ZnWO_4$ has a long decay time $\tau \approx 20\ \mu s$, a special program has been implemented allowing to count the number of the single photoelectron pulse on a longer time scale 25 μs.
- using fast pulse shaping and counting the number of pulses in an interval of time.

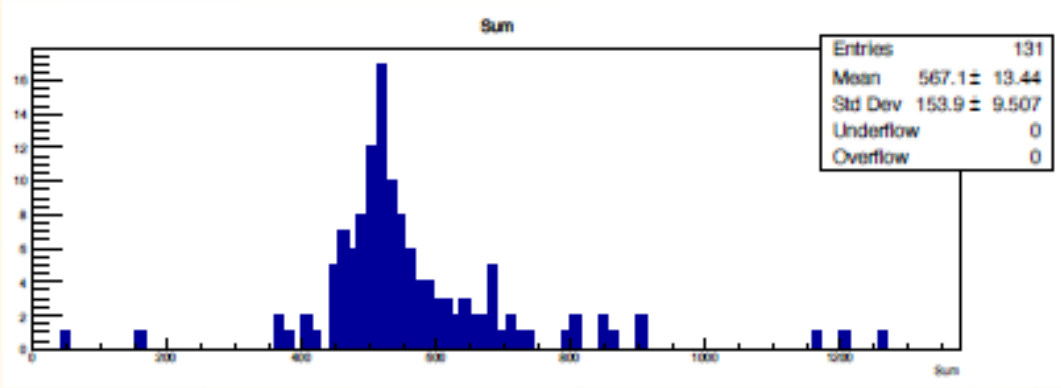
The first results for cosmic rays tests





The output data files from 2 wavecatchers (8+8 channels) are processed by ROOT software

$ZnWO_4$ grains+water

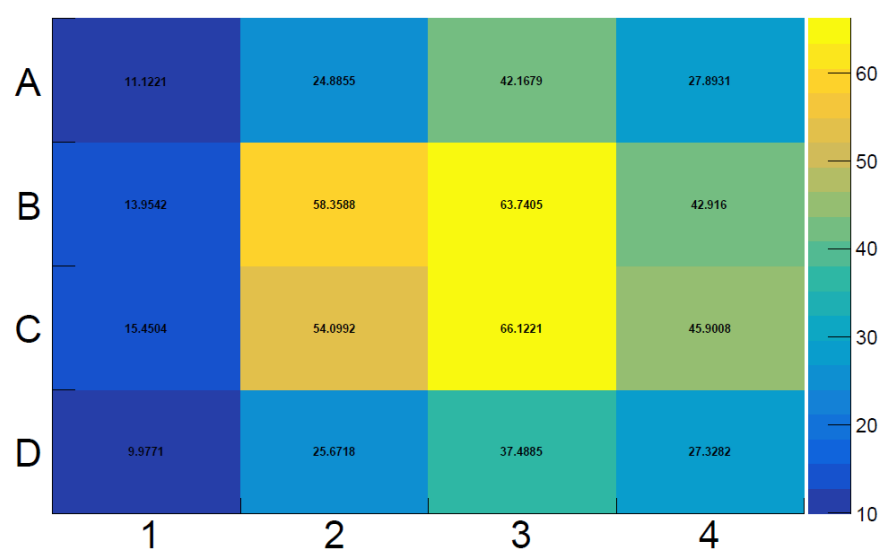


Estimated light yield is about
400 phe per 40 MeV (deposited by the muons in the test device) => 10 phe/MeV
=> 10000/GeV => statistical effect = 1% for 1 GeV high energy photon

The first results for cosmic rays tests

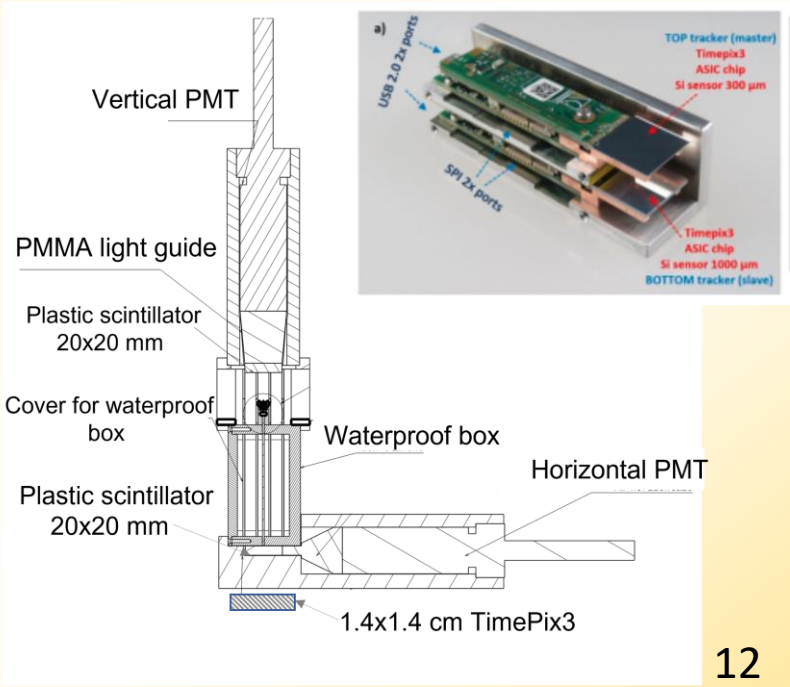
Map for distribution of light registered by 16 WLS fibers

$ZnWO_4$ grains+water



Some asymmetry is observed for the amount of the light "caught" by WLS fibers

Future tests using 2 layers TimePix3 below: we will study the response vs. the position and angle of the muon tracks



What are the next steps?

Cosmic ray tests:

- ✓ $ZnWO_4$ grains + different liquids
- ✓ selection of the most proper size of $ZnWO_4$ grains
- ✓ BGO grains + different liquids
- ✓ tests with TimePix trackers

Beam tests?

Thank you for attention!

Merci pour votre attention!