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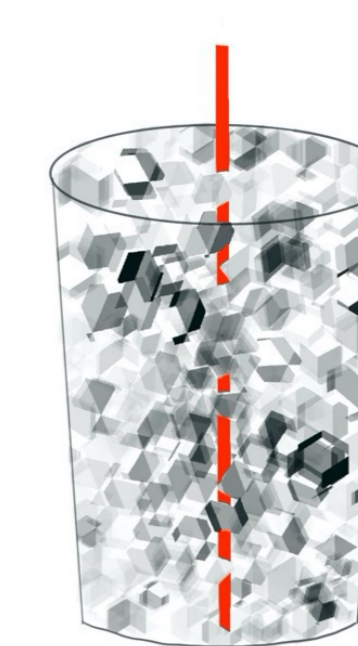
# ZnWO<sub>4</sub> grains characterisation for GRAiNITA – a new-generation calorimeter

G. Hull<sup>1</sup>, I. Boiaryntseva<sup>1,2</sup>, J. Lefrancois<sup>1</sup>, I. Tupitsyna<sup>2</sup>, A.-M. Dubovik<sup>2</sup>, S. Barsuk<sup>1</sup>,  
M.-H. Schune<sup>1</sup>, S. Monteil<sup>3</sup>, D. Breton<sup>1</sup>, A. Boyarintsev<sup>2</sup>

<sup>1</sup> Université Paris-Saclay, CNRS-IN2P3, IJCLab, Orsay, France

<sup>2</sup> Institute of Scintillation Materials of the National Academy of Science of Ukraine, Kharkiv, Ukraine

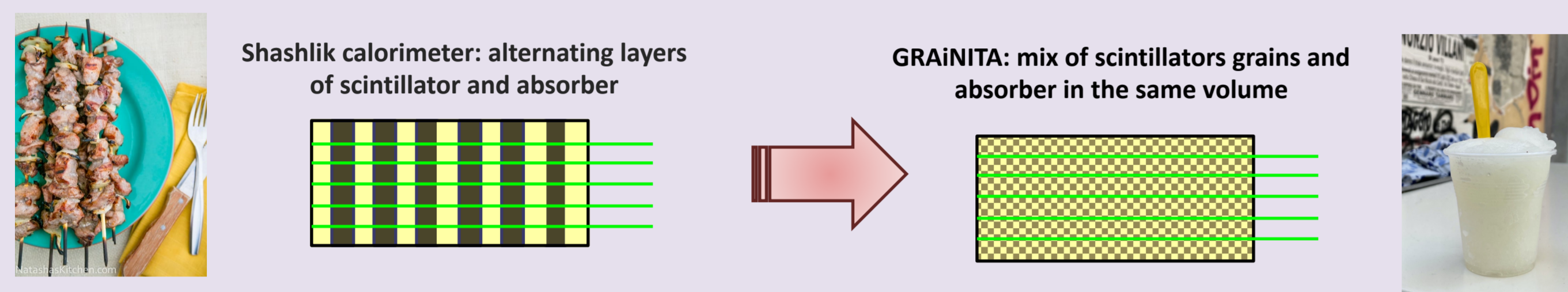
<sup>3</sup> Université Blaise Pascal, CNRS-IN2P3, LP-Clermont, Aubiere, France



**Introduction:** The electromagnetic calorimeters for high-energy physics experiments are often based on the use of scintillator materials and, in order to contain the cost of the detectors, the sampling technique is privileged with respect to the use of uniform inorganic crystals. With **GRAiNITA**, we propose a new version of the Shashlik detector, for possible application in FCC e+e- experiments. The idea is to use, in the same volume, a mixture of high-Z scintillator grains and a high-density transparent liquid as absorber. Due to the stochastic confinement of the light, as in the LiquidO detection technique [1], the scintillation light remains localized in the zone of production and it can be collected on SiPMs, by means of wavelength shifting fibres, uniformly distributed in the detection volume. This new detector will provide extremely fine sampling of the electromagnetic shower and for this reason a very good photon energy resolution ( $R \sim 2\%/\sqrt{E}$ ) is expected with respect to conventional Shashlik detectors (typically  $R \sim 10\%/\sqrt{E}$ , [2]).

## The GRAiNITA detector

**Opaque scintillator technique for the development of a new Shashlik calorimeter with extremely fine sampling**



- For improved high energy and very good sampling
- For costs reduction costs: grains production is less expensive than volumetric crystals production
- For good energy measurements of the jets: study of the possibility of measuring the fraction of energy in the shower via Pulse Shape Discrimination.

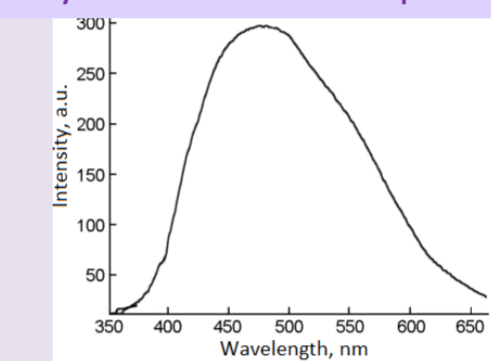
## Candidates scintillators: ZnWO<sub>4</sub> and BGO

Candidate absorber: CH<sub>2</sub>I<sub>2</sub>

ZnWO<sub>4</sub> can be produced directly in grain-shape via spontaneous crystallization

- LY= 10 kph/MeV
- $\tau = 20 \mu\text{s}$
- $Z_{\text{eff}} = 61$
- $\lambda_{\text{max}} = 490 \text{ nm}$
- Crystal price/grains price = 2.5

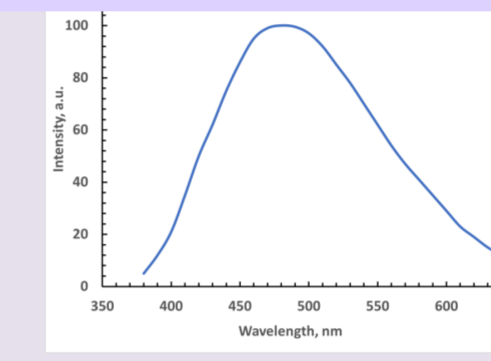
X-ray excited emission spectrum



BGO can be reduced in the form of grains with the « Planetary Ball Milling » technique:

- LY= 8-10 kph/MeV
- $\tau = 300 \text{ ns}$
- $Z_{\text{eff}} = 73$
- $\lambda_{\text{max}} = 480 \text{ nm}$
- Crystal price/grains price > 1.1

X-ray excited emission spectrum



	ZnWO <sub>4</sub>	CH <sub>2</sub> I <sub>2</sub>	Mix
Density [g/cm <sup>3</sup> ]	7.62	3.32	5.47
Refractive index	2.1	1.74	
X <sub>0</sub> [cm]	1.2	2.67	1.65
Molière radius [cm]	1.98	4.58	2.77

	BGO	CH <sub>2</sub> I <sub>2</sub>	Mix
Density [g/cm <sup>3</sup> ]	7.13	3.32	5.47
Refractive index	2.15	1.74	
X <sub>0</sub> [cm]	1.12	2.67	1.50
Molière radius [cm]	2.26	4.58	2.84

## Crystal grains production

ISMA developed the technique to grow ZnWO<sub>4</sub> single crystal granules using the flux method. Several methods have been investigated:

- **NaCl as a solvent + ZnWO<sub>4</sub> salt:** ZnWO<sub>4</sub> grains yield  $\approx 10 \text{ wt } \%$ ; 44% of grains with size > 1mm, 33% of grains with size between 0.5 and 1 mm.
- **Na<sub>2</sub>WO<sub>4</sub> as a solvent + ZnO and WO<sub>3</sub>:** ZnWO<sub>4</sub> grains yield  $\approx 25 \text{ wt } \%$  but brownish color
- **Na<sub>2</sub>WO<sub>4</sub> as a solvent + ZnWO<sub>4</sub> salt:** ZnWO<sub>4</sub> grains yield  $\approx 85 \text{ wt } \%$ , colorless and transparent, average size of grains  $\approx 1 \text{ mm}$  lateral size.



**1<sup>st</sup> batch: 40 g**      **2<sup>nd</sup> batch: 170 g**      **3<sup>rd</sup> batch: 1380 g**  
Size  $\sim 1 \div 3 \text{ mm}$       Size  $\sim 1 \div 2 \text{ mm}$       Size  $\sim 1 \text{ mm}$

For **GRAiNITA**, ZnWO<sub>4</sub> crystalline grains were grown with the flux method from thoroughly mixed ZnWO<sub>4</sub> (5N) and Na<sub>2</sub>WO<sub>4</sub> (4N) starting materials, as this resulted to be the best effective solution to obtain sub-millimetric grains. Starting materials were charged into Pt crucible, placed into the resistive heating furnace, heated up to T=1250°C and then kept for 10 hours at this temperature to assure complete homogenization of the melt. According to the required size of the grains, the melt was cooled down to 750°C and then it was allowed to spontaneous cooling down to room temperature. Obtained ZnWO<sub>4</sub> crystalline grains were rinsed in distilled water at 100°C and dried at T= 400°C.

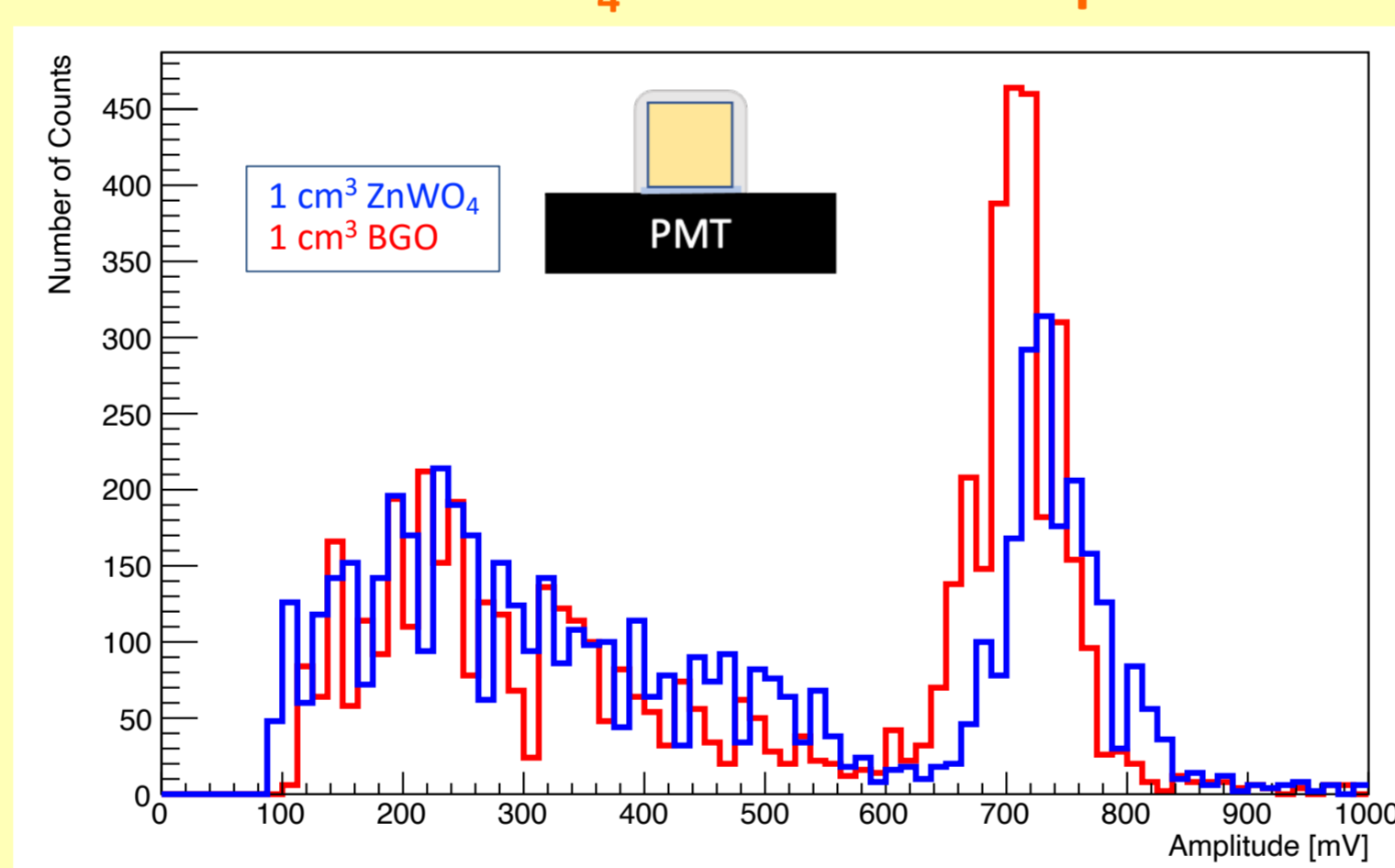
## ZnWO<sub>4</sub> scintillation properties: grains vs crystals

**The experimental set-up:**

- ZnWO<sub>4</sub> crystals: 2 x 2 x 4 cm<sup>3</sup> and 1 x 1 x 1 cm<sup>3</sup>
- ZnWO<sub>4</sub> plates (cut from the same single crystal) : 2 cm x 2 cm, different thickness: 0.85 mm, 1.03 mm, 2.14 mm, 3.14 mm, 4.25 mm
- ZnWO<sub>4</sub> grains, approximate later size: 0.5÷1.5 mm
- High gain PMT Hamamastu R2083, silicon grease, teflon tape
- Integrator circuit:  $\tau_{RC} = 100 \mu\text{s}$
- Digital oscilloscope: LeCroy WavePro 715Zi (acquisition at 100MS/s)
- <sup>241</sup>Am (60keV, completely absorbed in one grain), <sup>137</sup>Cs, <sup>22</sup>Na, <sup>133</sup>Ba sources
- Spectrophotometer: PerkinElmer Lambda 850 UV/Vis

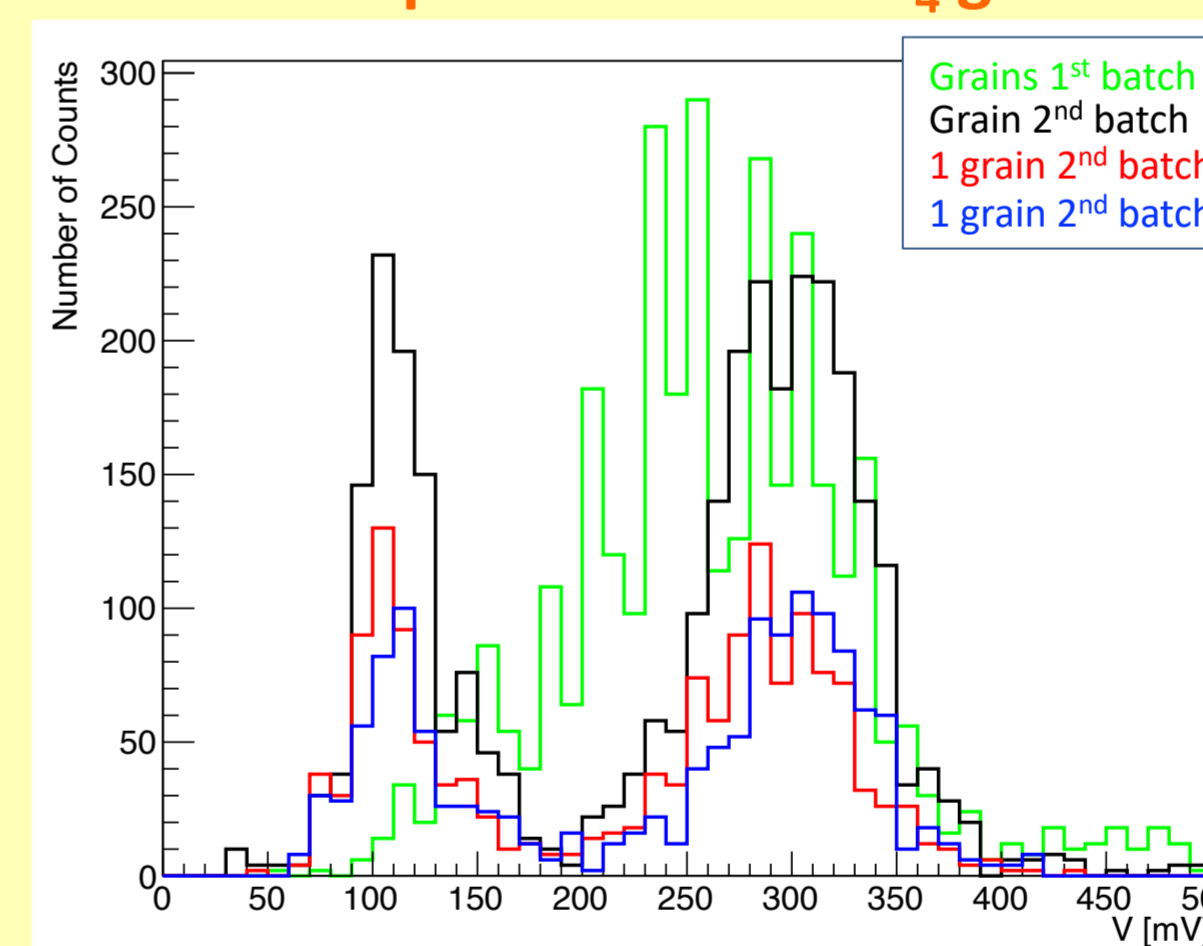


### 1-cm<sup>3</sup> ZnWO<sub>4</sub> and BGO <sup>137</sup>Cs spectra



The light yield and energy resolution of a 1cm<sup>3</sup> ZnWO<sub>4</sub> crystal are comparable with that of a same-sized BGO. At 662 keV we measured an energy resolution of 12.9% for ZnWO<sub>4</sub> and 13% for BGO.

### <sup>241</sup>Am spectra for ZnWO<sub>4</sub> grains

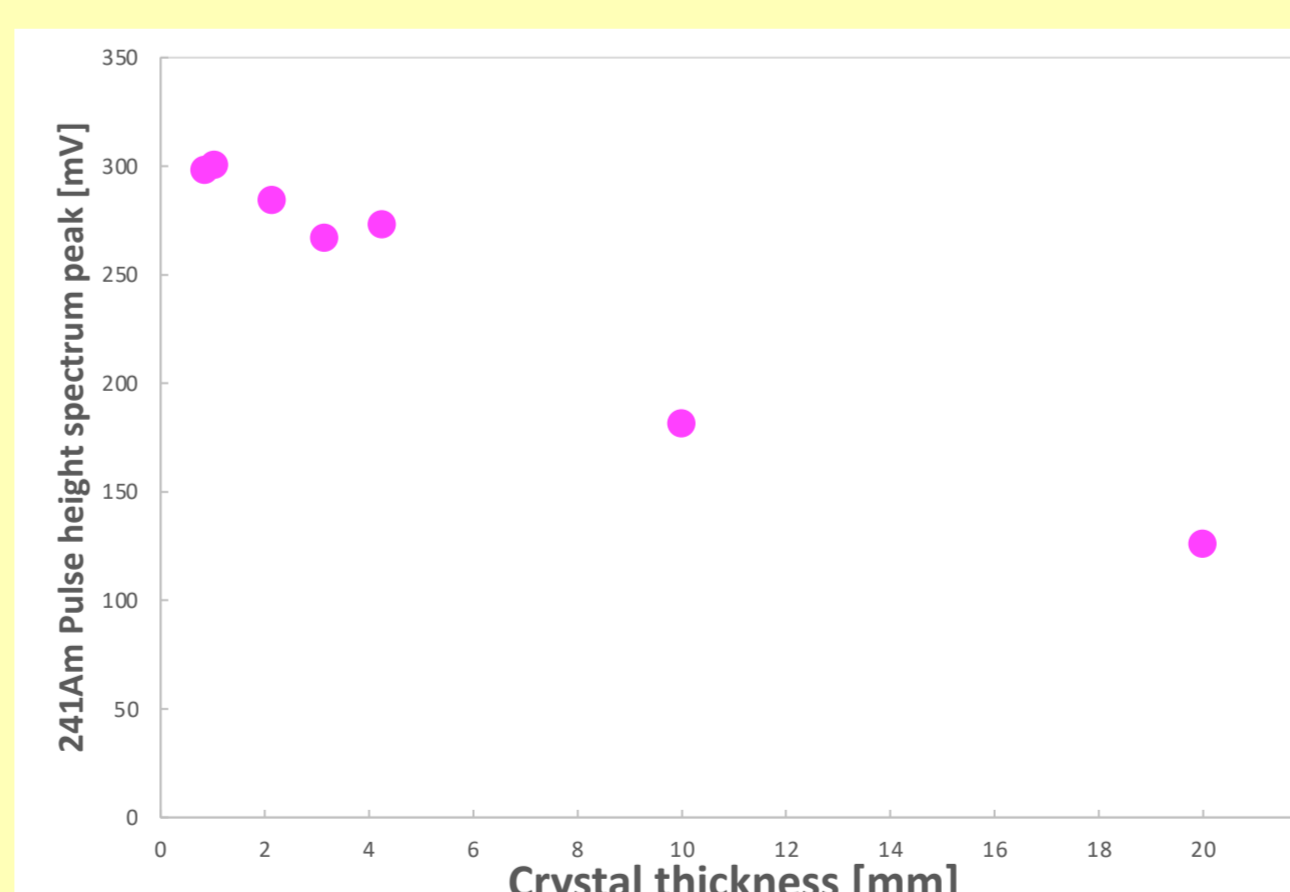


The second production of grains shows a much smaller variance in the amplitude of the <sup>241</sup>Am peak at 60keV, thus indicating a better homogeneity in the grains light yield.

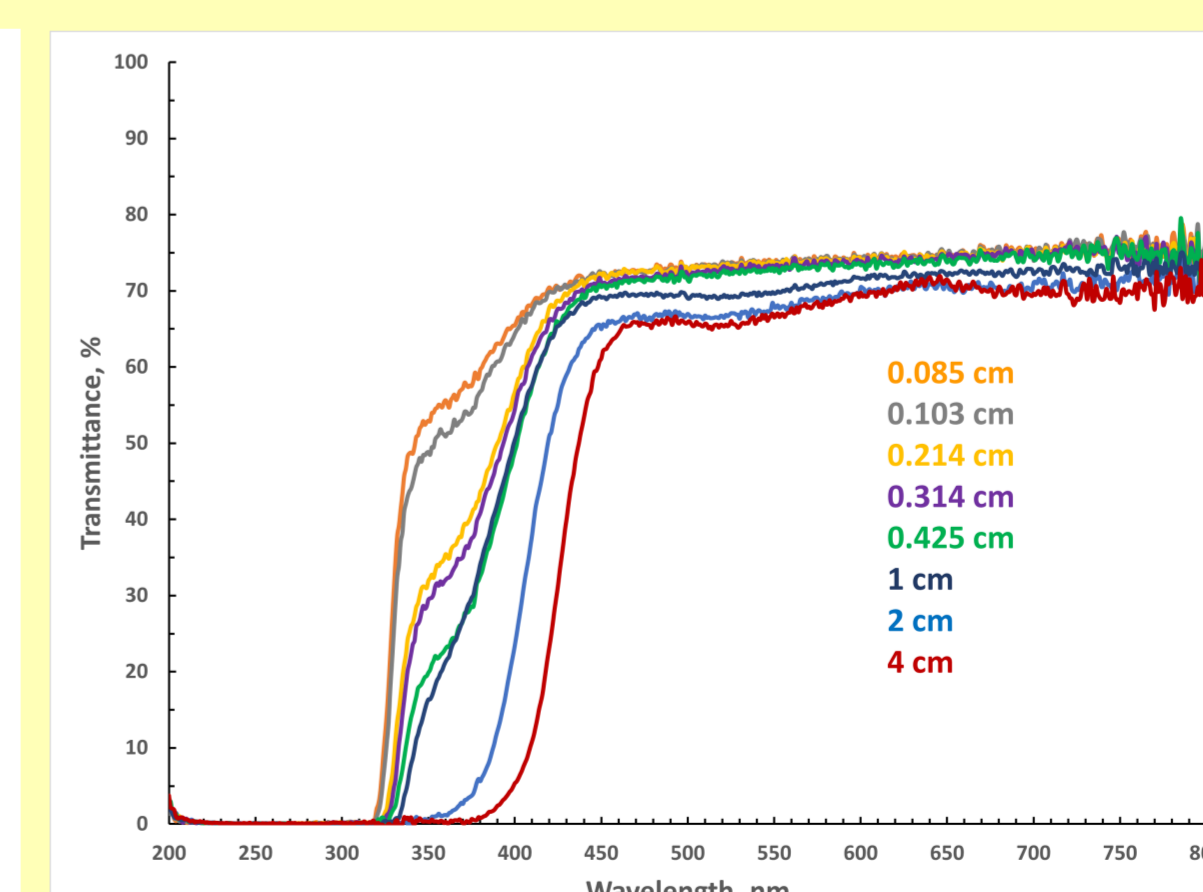
Crystals	Max Amp [mV]	Sigma [mV]
1 grain 1st batch	257.1	36.1
1 grain 1st batch	307.7	34.9
1 grain 2nd batch	302.5	32.9
1 grain 2nd batch	290.2	36.6
Grains 1st batch	260.7	59.2
Grains 2nd batch	292.7	43.1
0.85 mm plate	298.2	36.9
1.03 mm plate	300.3	34.0
2.14 mm plate	284.2	36.6
3.14 mm plate	266.9	35.1
4.25 mm plate	272.8	34.5
1 cm <sup>3</sup> crystal	181.4	26.7
2x2x4 cm <sup>3</sup> crystal	125.9	23.2

### Peak of the <sup>241</sup>Am spectrum vs ZnWO<sub>4</sub> sample thickness

The amplitude of the <sup>241</sup>Am peak at 60 keV decreases as a function of the ZnWO<sub>4</sub> thickness. This effect is mostly due to light losses caused by the absorption of the light that is reflected multiples times in the diffusive material used to tightly wrap the scintillator.



### Transmittance spectra for ZnWO<sub>4</sub> samples of different thickness



The transmittance of ZnWO<sub>4</sub> samples in the maximum emission range (490 nm) slightly decreases from 73% to 66% with increasing of sample thickness from 0.085 to 4 cm. The transmittance is limited mainly by the reflection losses due to the high refractive index of ZnWO<sub>4</sub>.

The observed absorption bands around 370, 530 and 760 nm are due to the transitions in Cr<sup>3+</sup> ions that are present in trace amount as uncontrolled impurity in ZnWO<sub>4</sub> single crystals [3].

## Conclusions and future work

Crystalline grains of ZnWO<sub>4</sub>, grown with the flux method, proved to have scintillation properties comparable with that of volumetric optics. The latest batch of grains produced by ISMA (delivered at the end of October) is enough to assemble a medium-size prototype with approximate size of 5 cm x 5 cm x 10 cm and equipped with 16 WLS fibers, and SiPMs for the signal read-out. At present, we are working on the selection of the best suited optical fiber to be coupled to ZnWO<sub>4</sub> and BGO grains, respectively, as well as on the selection of the best suited liquid to be used as absorber. In the next future, we intent to develop two medium-size GRAiNITA prototypes, employing BGO and ZnWO<sub>4</sub> grains respectively, and to characterize the detectors response with cosmic rays and during an in-beam campaign.

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[3] Reynolds M.L., Hagston W.E., Garlick G.F.J., Experimental Observations of the Absorption, Infra-Red Emission, and Excitation Spectra of Cr<sup>3+</sup> Ions in ZnWO<sub>4</sub>, Physica Status Solidi (b), vol. 30, issue 1 (1968) pp. 113-117, [10.1002/pssb.19680300114](https://doi.org/10.1002/pssb.19680300114)