# The GRAiNITA project

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# The overall idea (in a nutshell)

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

Typical sampling calorimeters:

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

Crystal calorimeters :

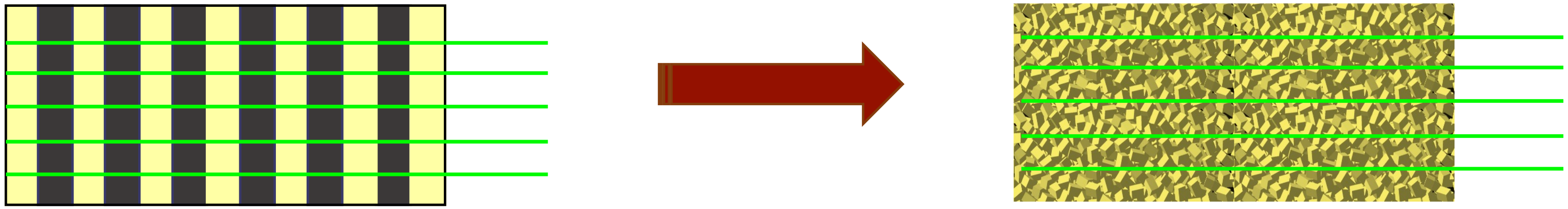
$$\frac{\sigma_E}{E} \sim \frac{1\%-2\%}{\sqrt{E}}$$

Requirements:

- fine sampling
- scintillation light locally contained

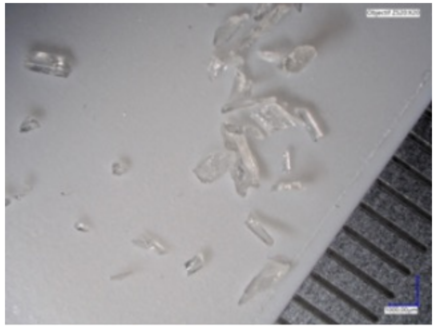
Shashlyk-type calorimeter

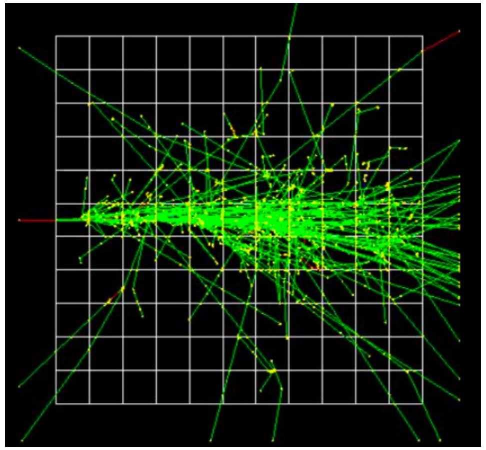
GRAiNITA



# $ZnWO_4$

$ZnWO_4$ possible candidate:
- LY= 10kph/MeV
- Density 7.62
- Index n=2.1
- $\tau$ = 20 $\mu s$
- $\lambda_{max}$ = 480 nm
- grain size : 0.5 mm - 1 mm





GEANT4 simulation
ZnWO4 + CH2I2 cubes
(random position)

1mm cubes $\frac{\sigma_E}{E} \sim \frac{2\%}{\sqrt{E}}$

ISMA has done specific R&D and has produced grains & plates of $ZnWO_4$
- "flux method" production of $ZnWO_4$ is under control

- ~ 1kg of $ZnWO_4$
- grains of BGO (200 g)
- small plates of BGO & of $ZnWO_4$

# Towards a 16 fibers test bench

- Active volume = 2.8 x 2.8 x 6 $cm^3$ (~200 g of $ZnWO_4$)
- Fibers spacing: 7 mm
- 16 fibers read-out by SiPM
- Possibility to repeat the study with the well known BGO

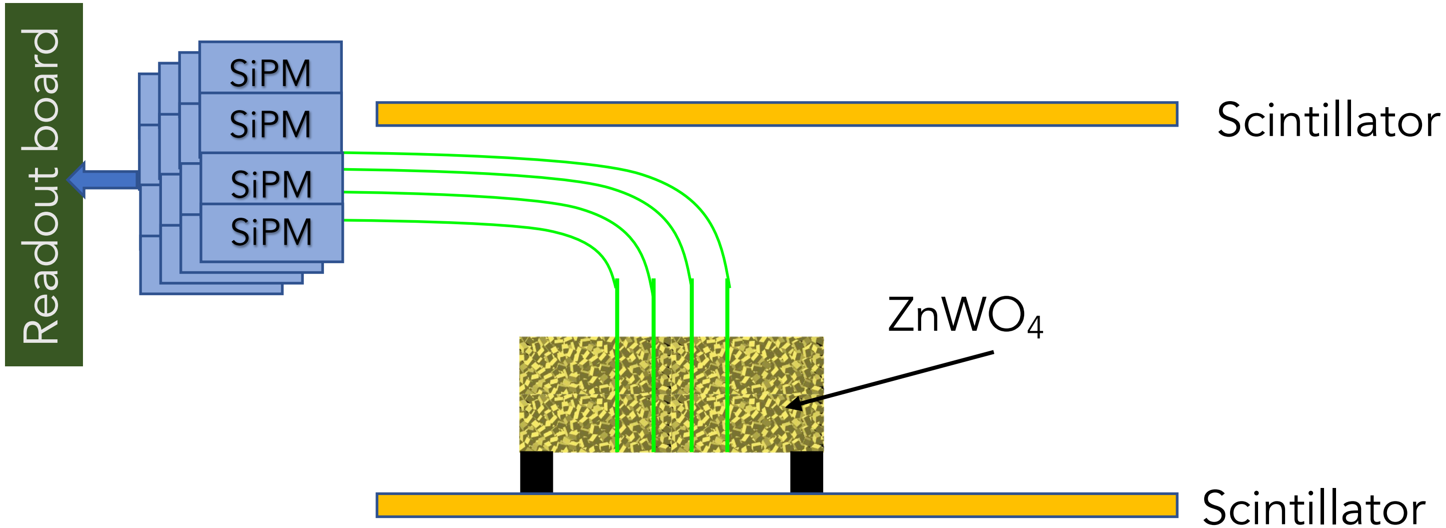
- Blue/Green LED injected in the middle (& UV LED with a quartz fiber ?)
- Cosmic rays triggering

time

What will we learn ?
- Number of photo-electrons by MeV on the SiPM (need 2.5k to 10k per GeV to reach 1 to 2 % energy resolution)
- Study the uniformity of response (μ close to a fiber or half-way)
- Study the angular dependence of response

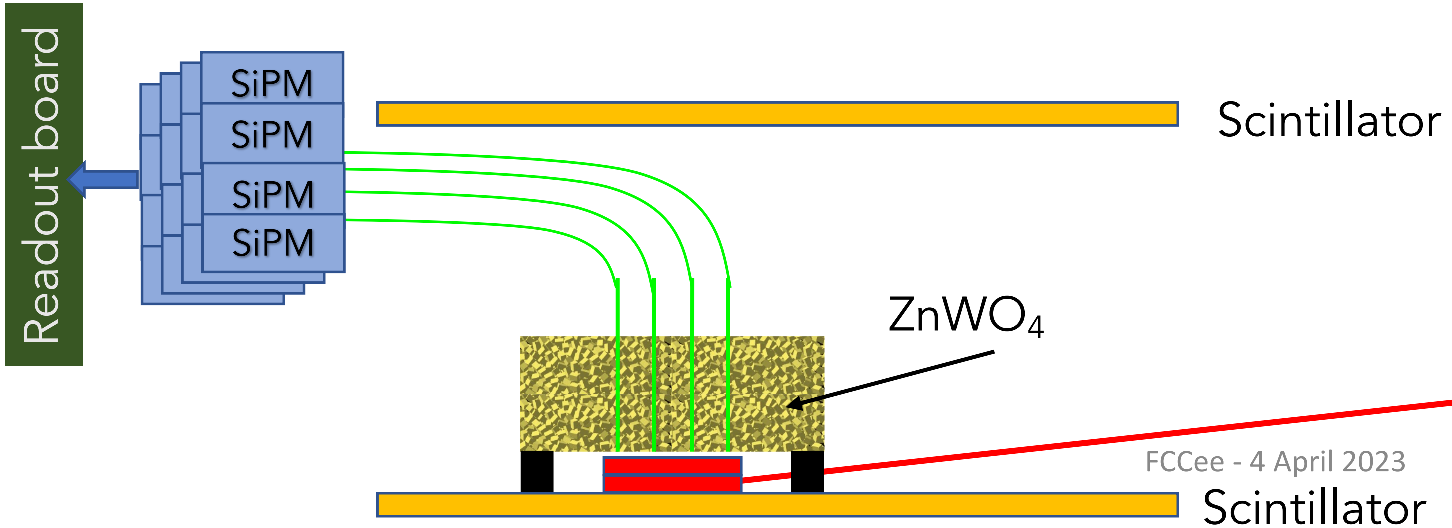
# Cosmic rays test bench design

## 1) Two scintillators (below and above) : determine the number of photo-electrons

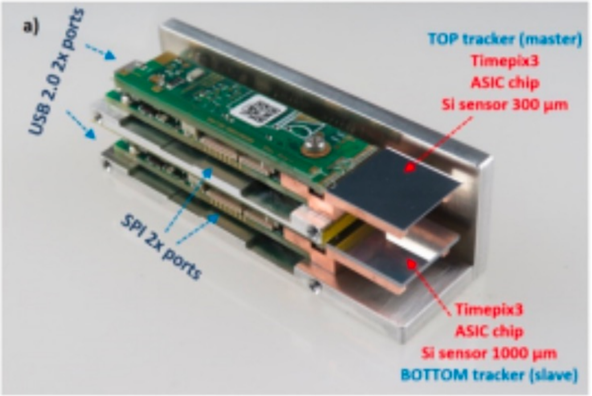



Muon cosmic rate should be fine

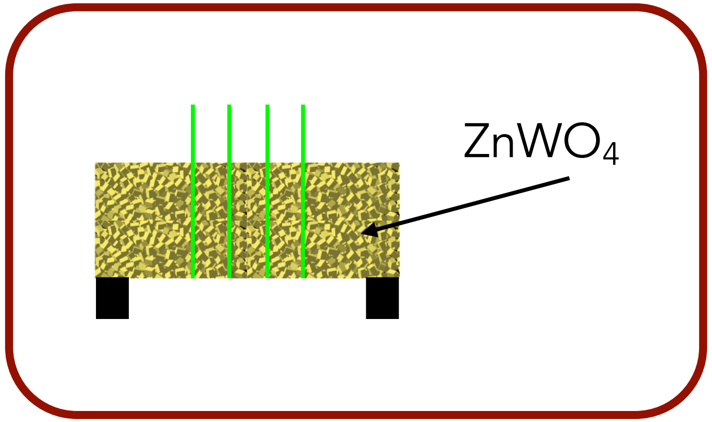
## 2) + TimePix (1.4 x 1.4 cm$^2$) : precise knowledge of the muon position and angle (0.3 deg angular)

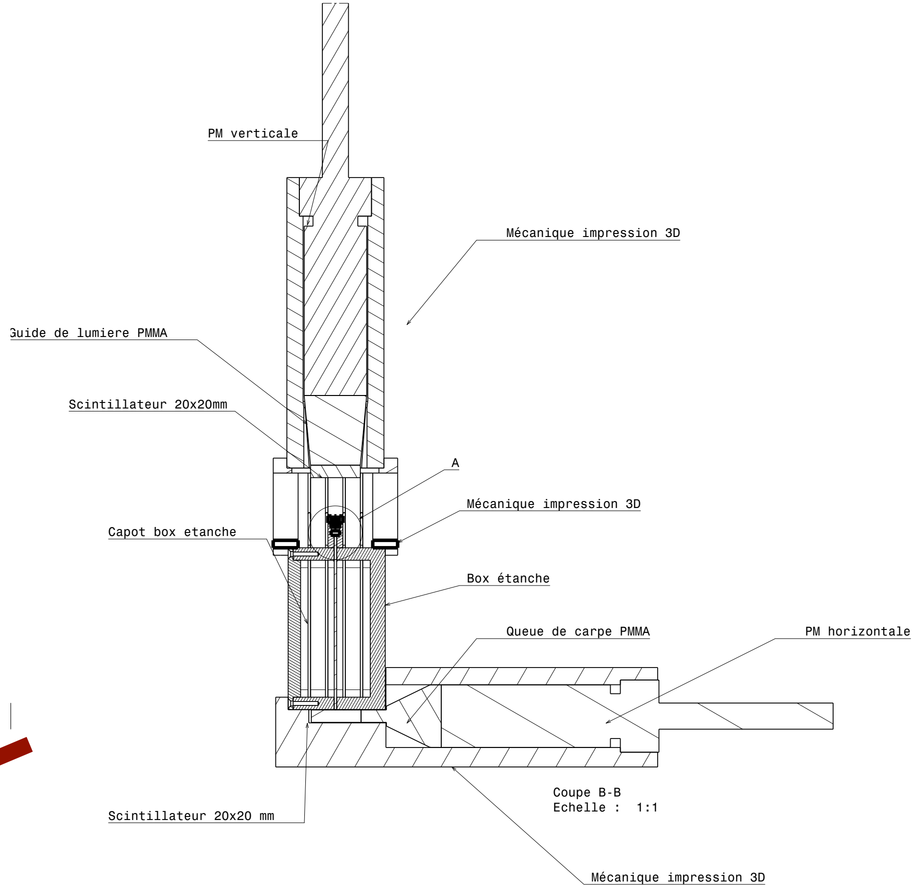



TimePix



# Final mechanical design for the prototype



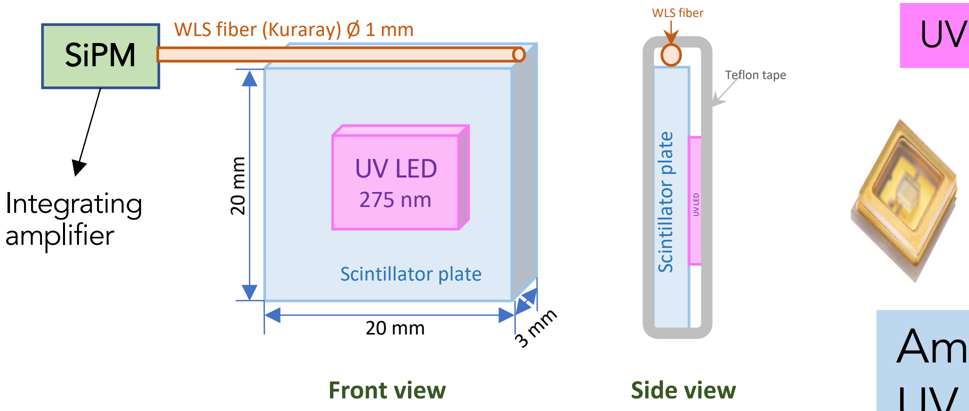




Expected for April 2023

# Understanding before the cosmic test: WLS fiber matching

A set of different fibers provided by Kuraray: Y11(200), O2(100), O2(200), O2(300), R3(300)

Test of the ZnWO4 WLS fiber matching:

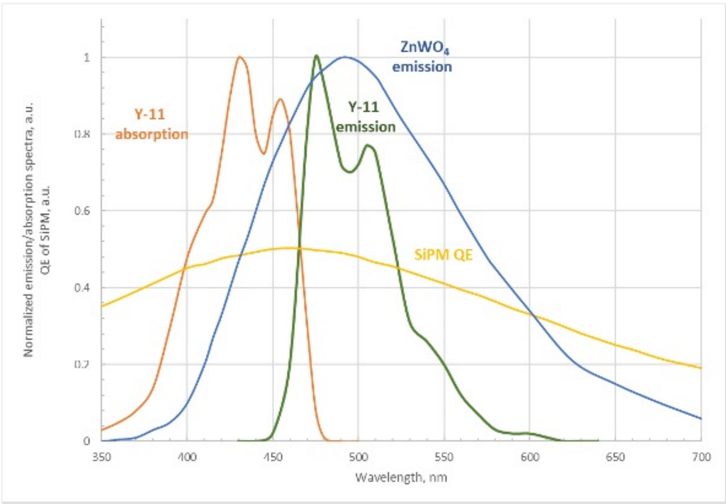



UV LED :

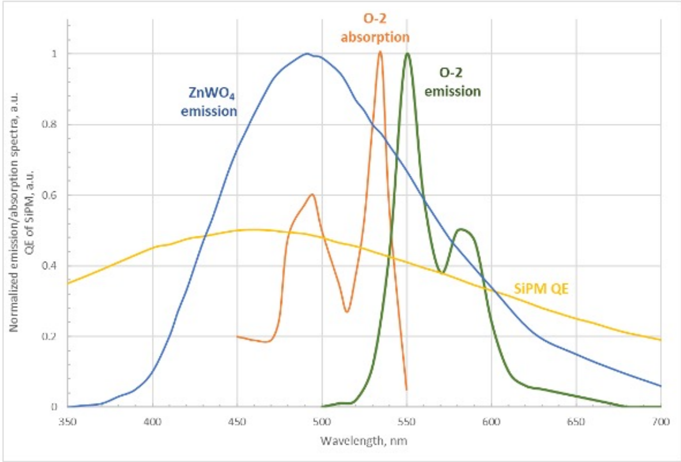
VLMU35CB2.-275-120
λ: 270 – 280 nm

Amount of light created by the UV LED is different from those created by ionizing particles but the wave length is very similar

Y11(200)




O2(100)




**O2(200) is a good candidate**
**Also working well with BGO**

*Optimization in close contact with Kuraray*

# Understanding before the cosmic test: amount of light (1)

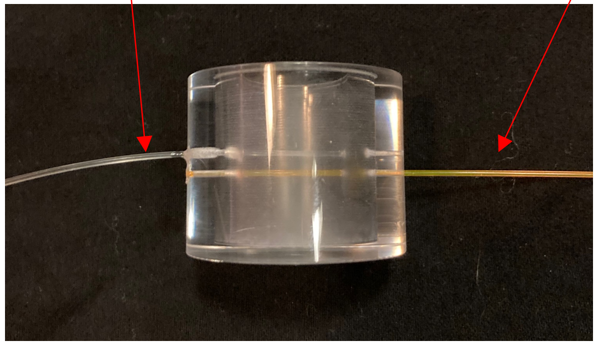
detailed test of the ZnWO4/O2 matching using a small size prototype
-Pulsed green light from an LED injected by a clear fiber depolished in the central 1cm

-Light collected with a O2 fiber placed 4 mm far from the injection point

Box surrounded by black fabric

Green light injection fiber

O2 fiber



3 configurations:

Air

$ZnWO_4$

BGO

'Standard' LED intensity

| | Charge [pC] | RMS [pC] |
|---|---|---|
| Air | 44 | 13 |

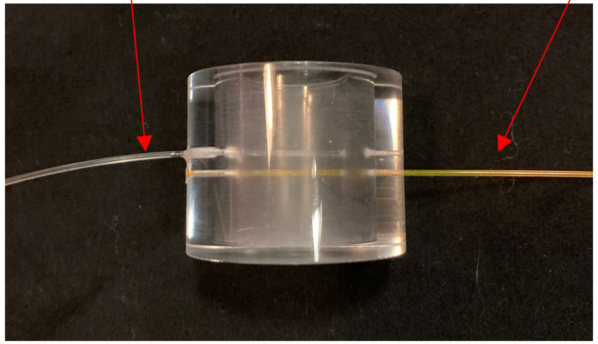
Higher LED intensity

| | Charge [pC] | RMS [pC] |
|---|---|---|
| Air | 70 | 13 |

$$\frac{RMS}{Mean} = \frac{1}{\sqrt{N_{phe}}}$$

Green light injection fiber

O2 fiber



About 3 pC per photo-electron

Light collection not very efficient

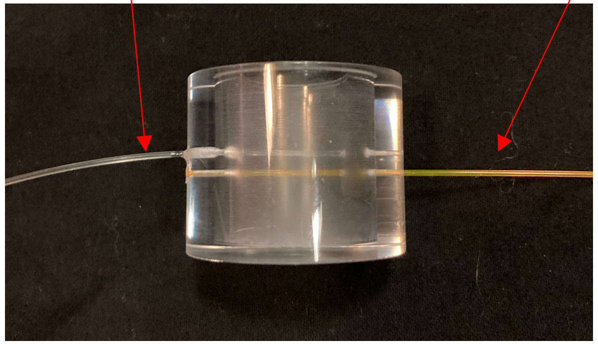
'Standard' LED intensity

| | Charge [pC] | RMS [pC] |
|---|---|---|
| Air | 44 | 13 |
| BGO | 118 | 22 |
| ZnWO4 | 76 | 18 |

$$\frac{RMS}{Mean} = \frac{1}{\sqrt{N_{phe}}}$$

Green light injection fiber

O2 fiber



About 3 pC per photo-electron

Higher LED intensity

| | Charge [pC] | RMS [pC] |
|---|---|---|
| Air | 70 | 13 |
| BGO | 185 | 25 |
| ZnWO4 | 122 | 18 |

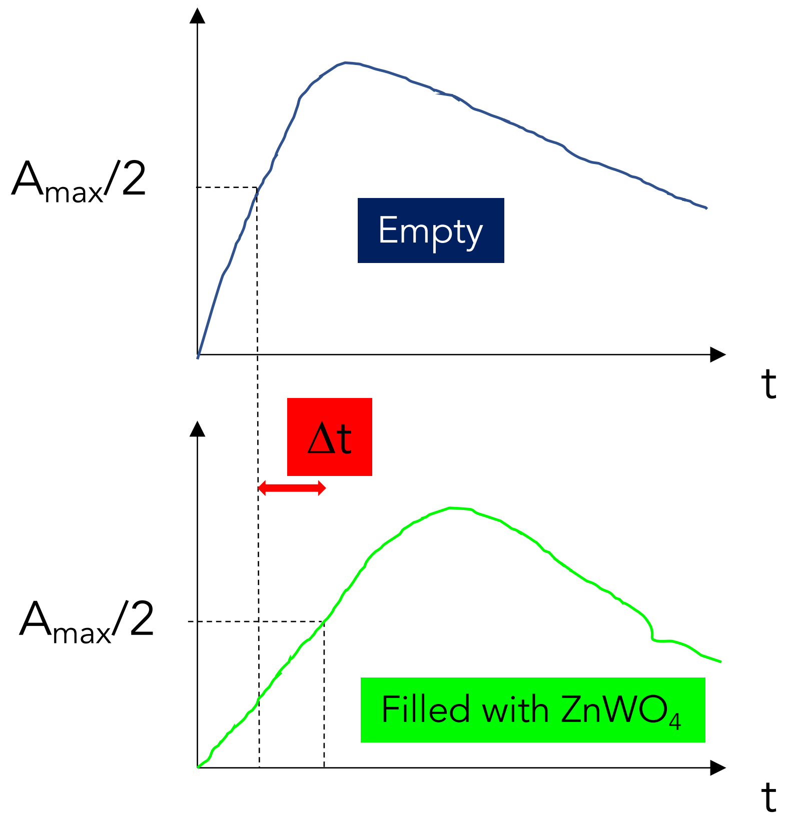
More chance to collect light with the grains

Slightly less light with $ZnWO_4$ (but not too bad)

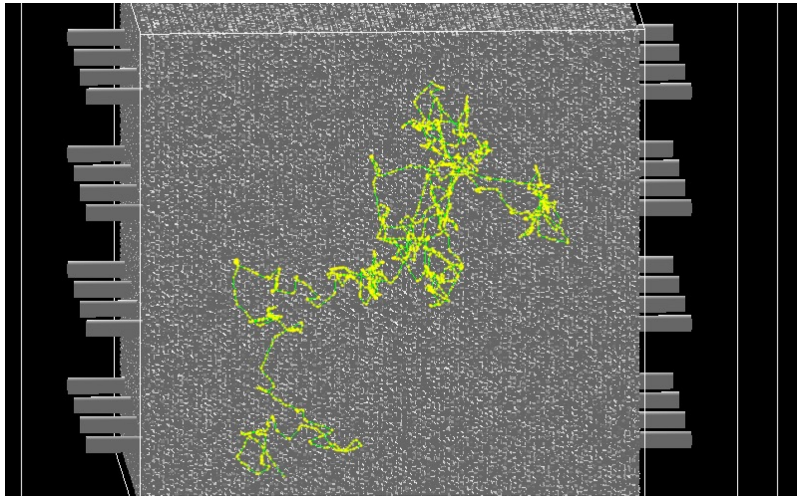
# Understanding before the cosmic test: light propagation

The light is passing through many grains before being caught by the WLS fiber.

To measure it: compare the arrival time of the signal when the jar is empty and when the jar is filled with $ZnWO_4$




| | $\Delta t$ (ns) |
|---|---|
| BGO - Air | 0.4 +/- .2 |
| ZnWO4 – Air | 1.0 +/- .2 |



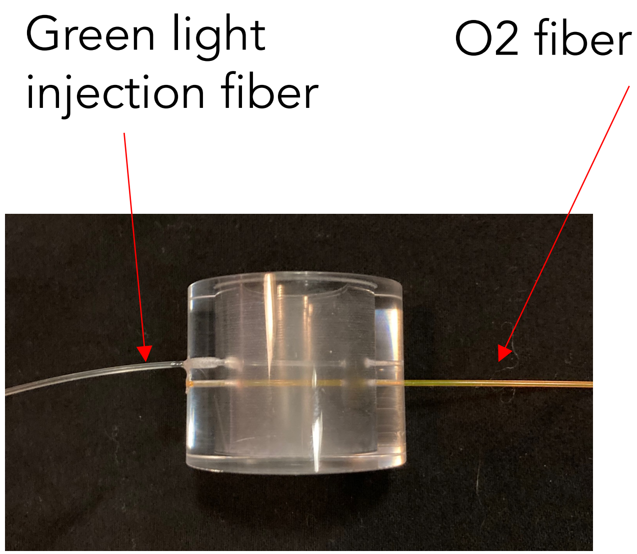
*similar numbers with the 2 LED intensities*

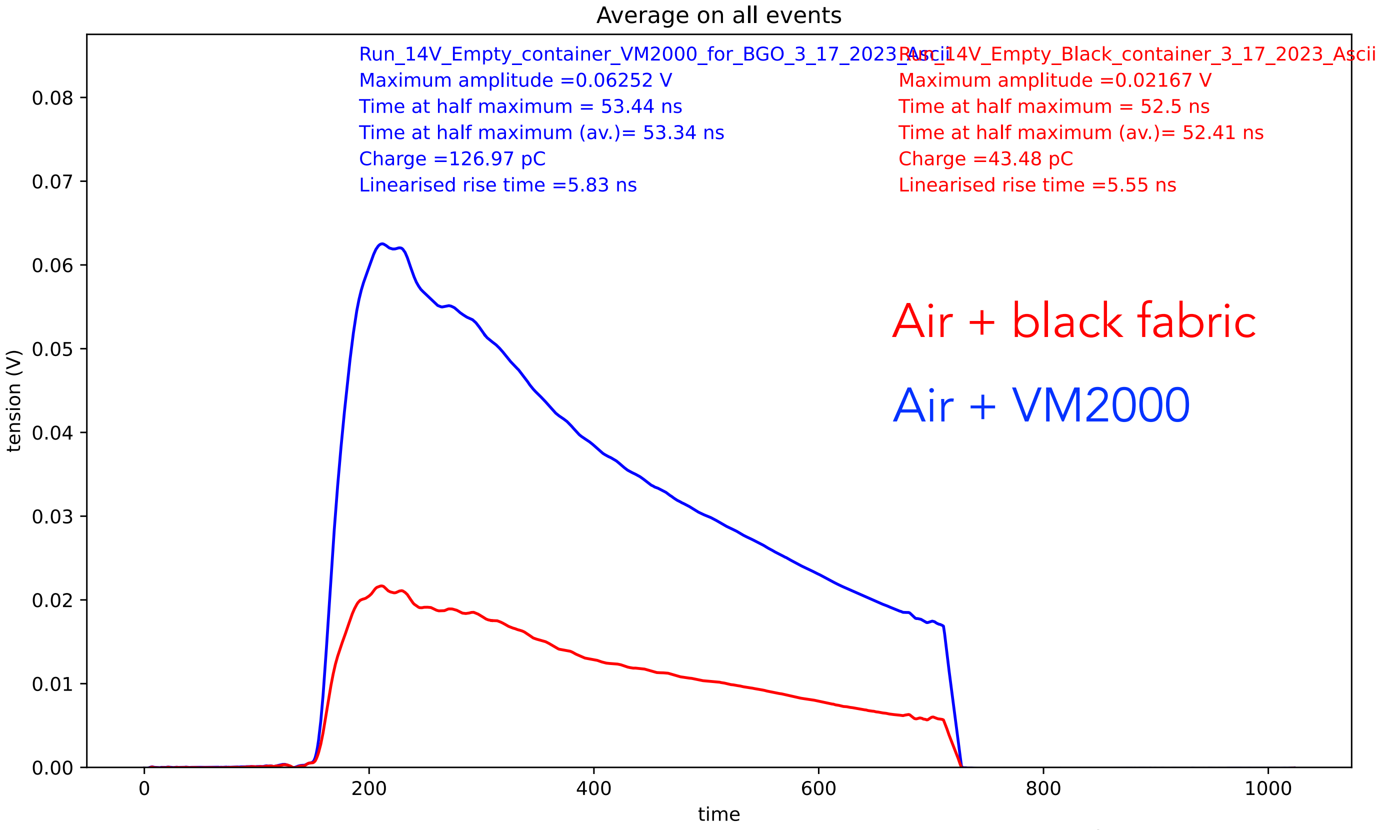
**average light path in $ZnWO_4$ : ~ 20 cm !**

The injecting fiber is 4 mm away from the WLS fiber

# Understanding before the cosmic test: amount of light (2)

The small prototype is wrapped with VM2000 specular reflector to increase the light collection efficiency




'Standard' LED intensity

‘Higher’ LED intensity

**With black fabric**

| | Charge [pC] | RMS [pC] |
|---|---|---|
| Air | 70 | 13 |
| BGO | 185 | 25 |
| ZnWO4 | 122 | 18 |

**With VM2000**

| | Charge [pC] | RMS [pC] |
|---|---|---|
| Air | 197 | 21 |
| BGO | 202 | 23 |
| ZnWO4 | 188 | 24 |

About 3 pC per photo-electron

Empty container vs Container filled with BGO / $ZnWO_4$ : similar charge
A good fraction of the light captured in the configurations with grains

Very positive in view of the cosmic test !

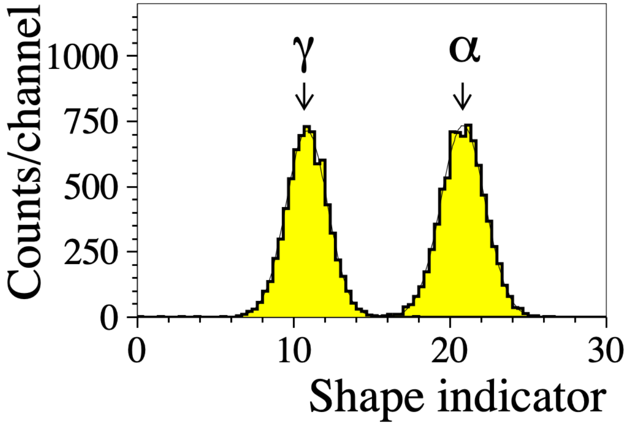
# Studies for the Pulse Shape Discrimination

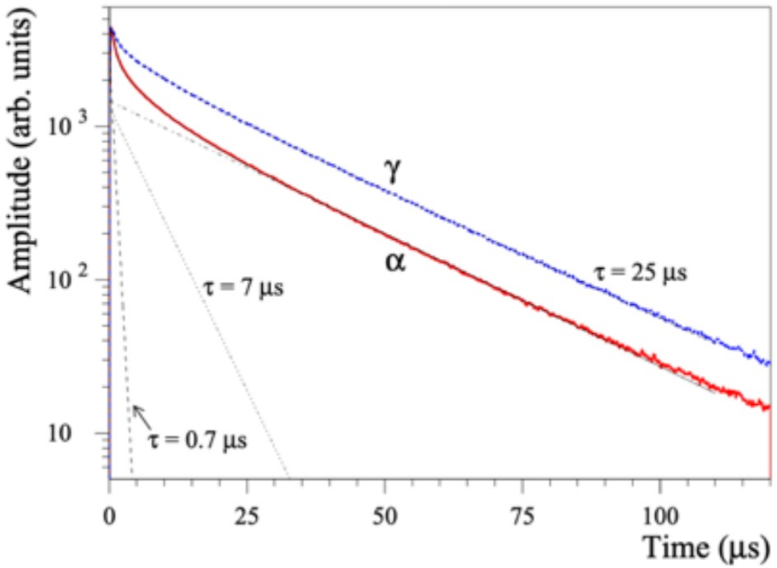
Two components (one fast, one slow) for the scintillation decay time in inorganic crystal

Higher ionizing particles (low E proton) : higher fraction of fast component

With $ZnWO_4$: clear difference between $\gamma$ and $\alpha$ (https://arxiv.org/pdf/nucl-ex/0409014.pdf )

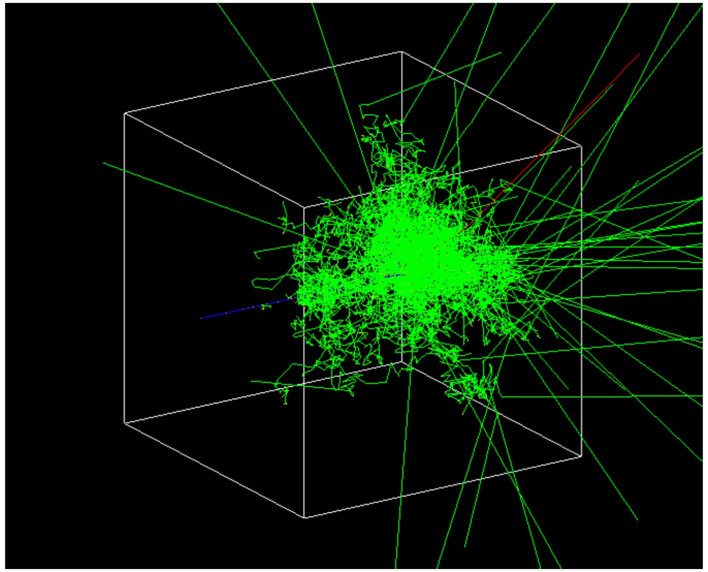
| Type of irradiation | Decay constants, $\mu s$ | | |
|---|---|---|---|
| | $\tau_1$ ($A_1$) | $\tau_2$ ($A_2$) | $\tau_3$ ($A_3$) |
| $\gamma$ ray | 0.7 (2%) | 7.5 (9%) | 25.9 (89%) |
| $\alpha$ particles | 0.7 (4%) | 5.6 (16%) | 24.8 (80%) |



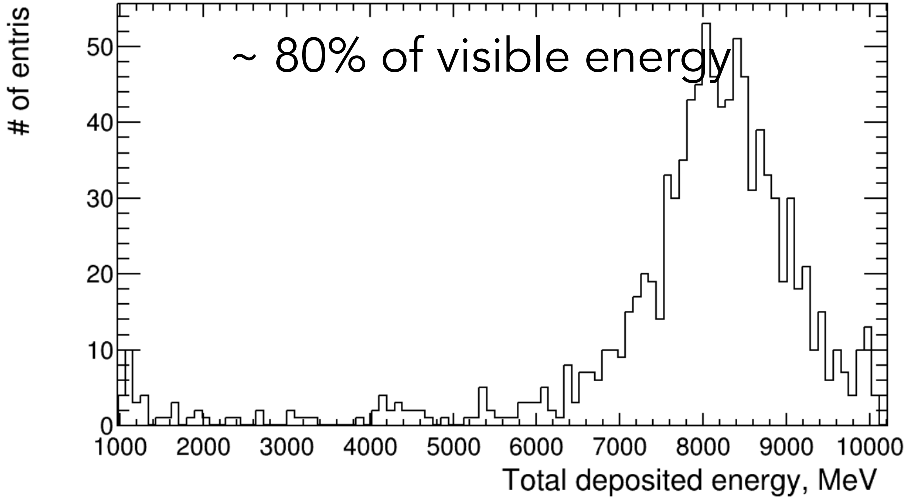



# GEANT4 simulation

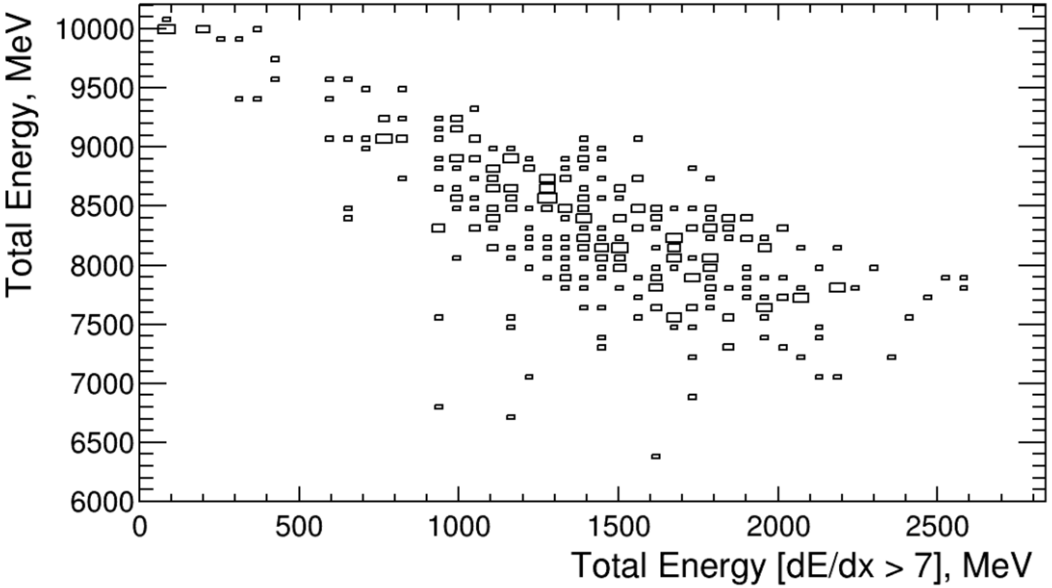
$1m^3$ of BGO



An example of the 10 GeV $\pi^+$ cascade




- Electromagnetic [$e^-$, $e^+$, $\gamma$] - on average 53.7% of the total energy;
- Hadronic [all the rest] - on average 46.2% of the total energy;




correlation is present !

# Conclusion

- A cosmic rays test should be done before the end of 2023

  ⇒ a more complete proof of concept

- Started the study of potential PSD

# backup slides

# With VM2000

‘Higher’ LED intensity

| | Charge [pC] | RMS [pC] | # Phe (estimate) |
|---|---|---|---|
| Air | 197 | 21 | 77 |
| BGO | 202 | 23 | 67 |
| ZnWO4 | 188 | 24 | 57 |

‘Standard’ LED intensity

| | Charge [pC] | RMS [pC] | # Phe (estimate) |
|---|---|---|---|
| Air | 127 | 19 | 41 |
| BGO | 133 | 19 | 44 |
| ZnWO4 | 121 | 21 | 33 |

‘Low’ LED intensity

| | Charge [pC] | RMS [pC] | # Phe (estimate) |
|---|---|---|---|
| Air | 63 | 16 | 17 |
| *BGO* | *64* | *14* | *20* |
| ZnWO4 | 63 | 16 | 16 |

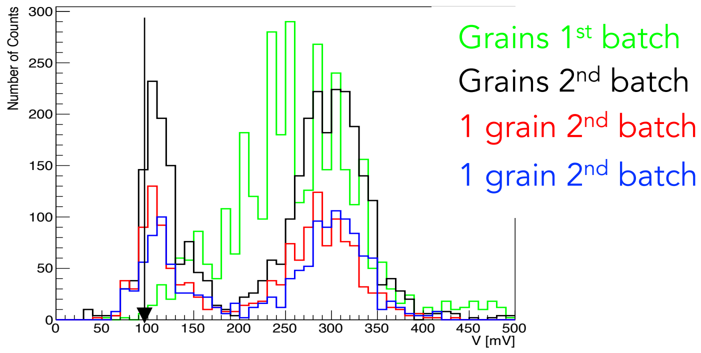
# $ZnWO_4$ production

Two methods to produce the grains:

- from large crystals obtained using the Czochralski method
- crystalisation from dissolved ZnWO4: "flux method" (much cheaper)

$^{241}$Am spectra for $ZnWO_4$ grains

triggering th.

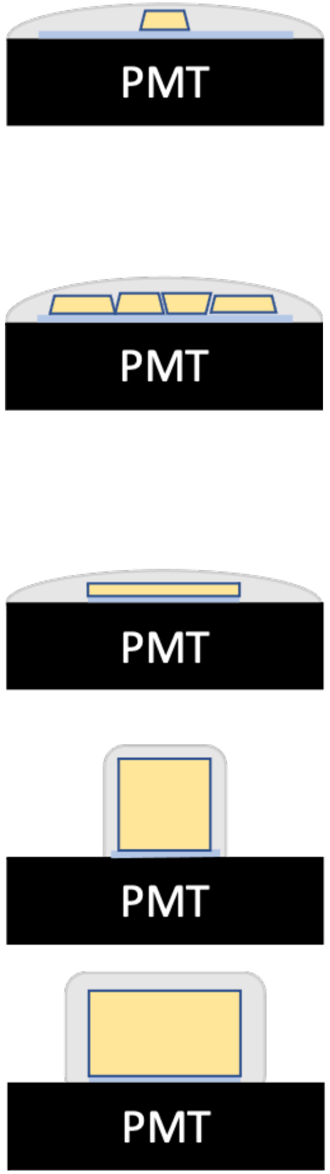



Better homogeneity in the grains light yield of the second production

| 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 $cm^3$ crystal | 181.4 | 26.7 |
| | | |
| 2x2x4 $cm^3$ crystal | 125.9 | 23.2 |

2

1




Production under control:

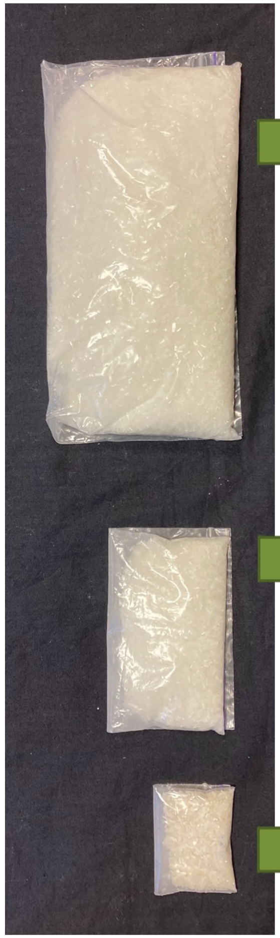
1. grains are similar to larger crystals (crystalisation works !)
2. homogenous production

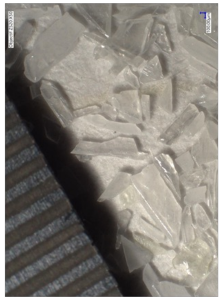
# $ZnWO_4$ single crystal grains obtained via the flux method

**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**





**$Na_2WO_4$ as a solvent + $ZnWO_4$ salt**:
$ZnWO_4$ grains yield ≈ 85 wt %, colorless and transparent, average size of grains ≈ 1 mm lateral size.

**$Na_2WO_4$ as a solvent + ZnO and $WO_3$** :
$ZnWO_4$ grains yield ≈ 25 wt % but brownish color

| Sample name | Mean | Sigma |
|---|---|---|
| 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 |

Test bench for the $ZnWO_4$ characterization