GRAiNITA status report

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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:

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

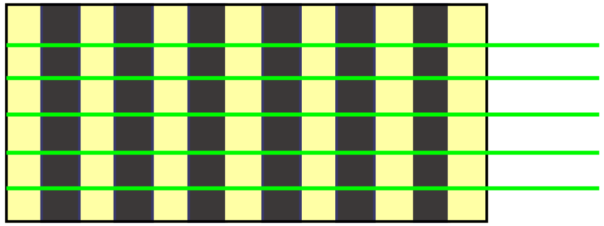
Crystal calorimeters :

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

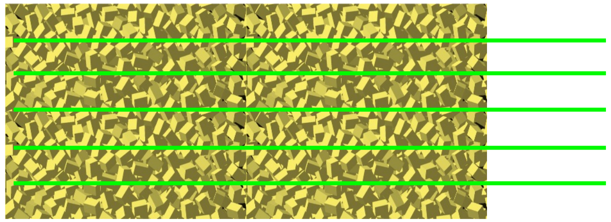
Requirements:

- fine sampling
- scintillation light locally contained

Shashlyk-type calorimeter



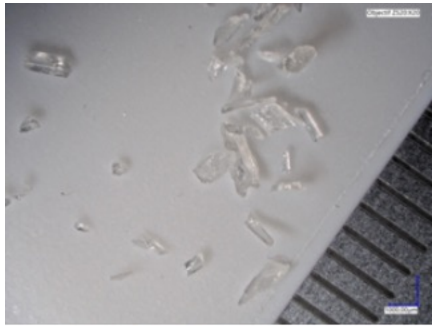
GRAiNITA

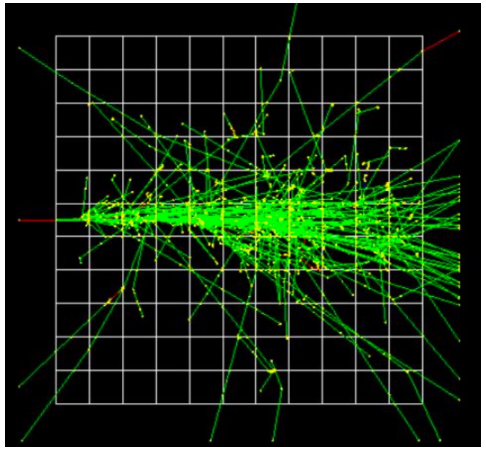


$ZnWO_4$

$ZnWO_4$ possible candidat:

- LY= 10kph/MeV
- Density 7.62
- Index n=2.1
- τ = 20 μs
- λ_{max} = 480 nm
- grain size : 0.5 mm - 1 mm





GEANT4 simulation
ZnWO4 + CH2I2 cubes
(random position)

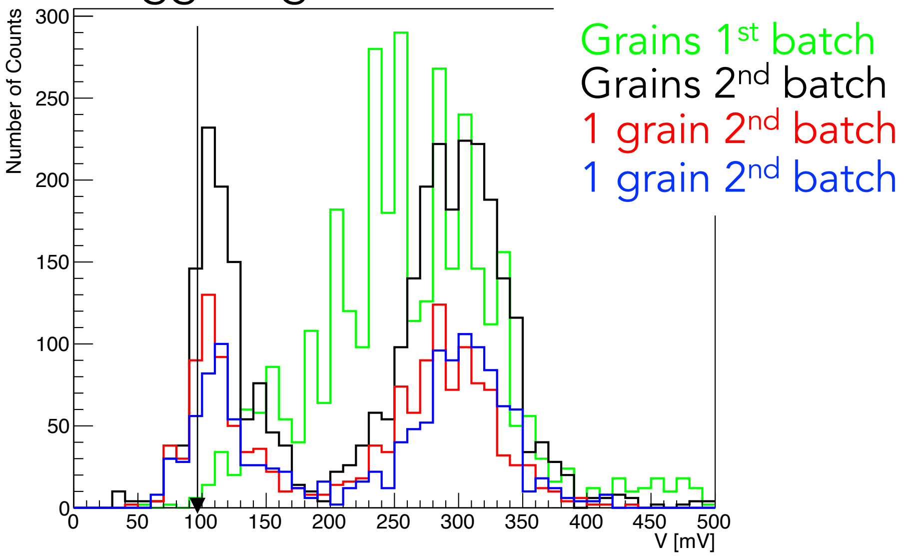
1mm cubes $\frac{\sigma_E}{E} \sim \frac{2\%}{\sqrt{E}}$

ISMA has done specific R&D and has produced grains & plates of $ZnWO_4$
At hand:

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

New

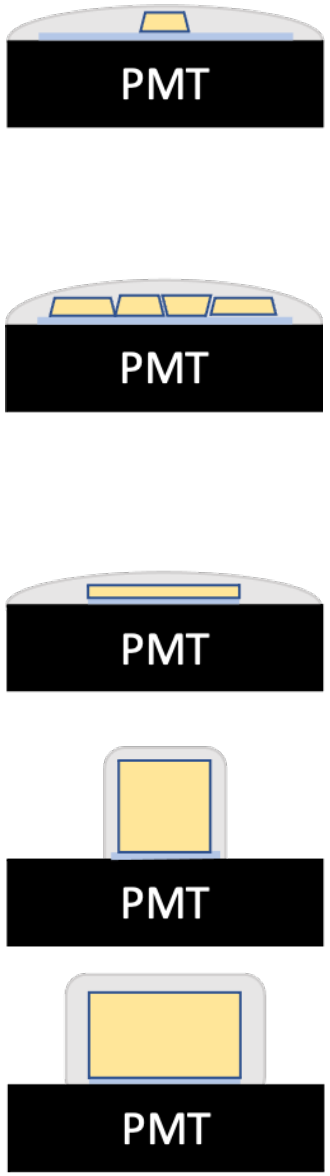
^{241}Am spectra for $ZnWO_4$ grains



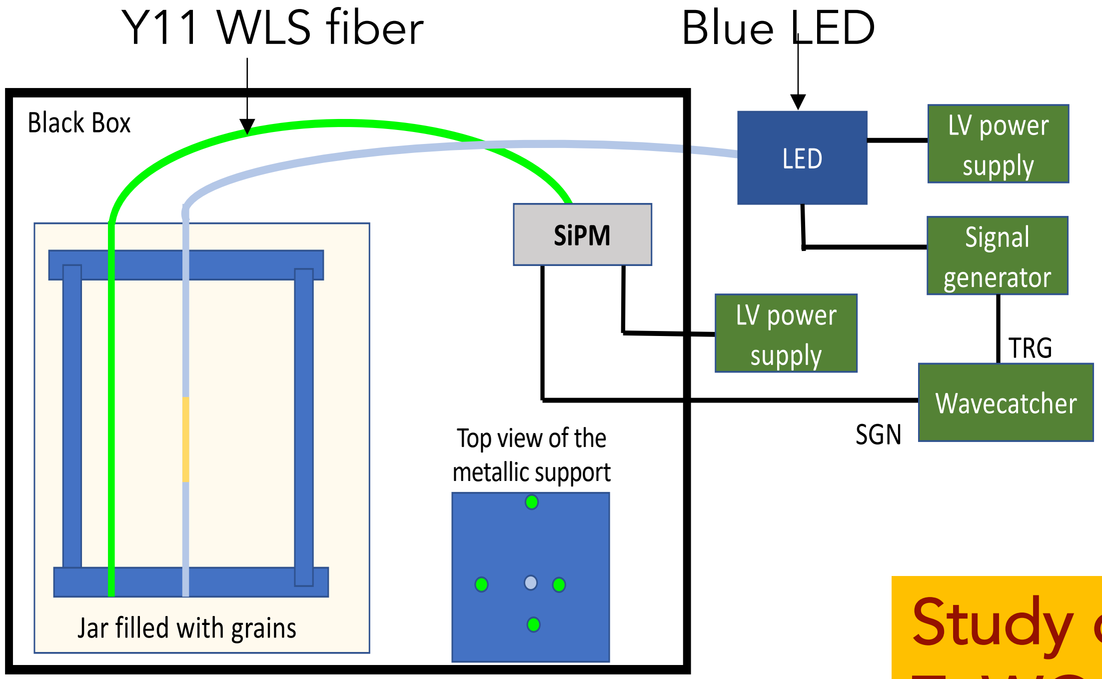
Better homogeneity in the grains light yield of the second production

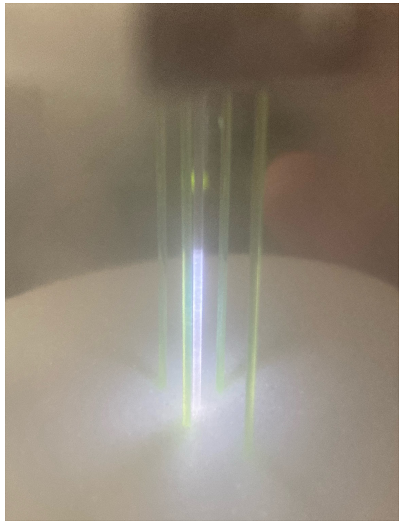
Production under control:
- grains are similar to larger crystals
- homogenous production

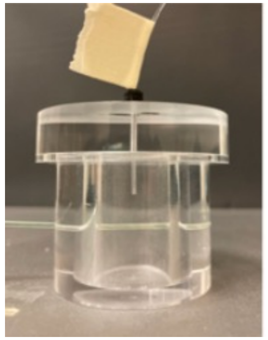
Crystals	Max Amp [mV]	Sigma [mV]
1 grain 1st batch	257.1	36.1
1 grain 1st batch	307.7	34.9
1 grain 2nd batch	302.5	32.9
1 grain 2nd batch	290.2	36.6
Grains 1st batch	260.7	59.2
Grains 2nd batch	292.7	43.1
0.85 mm plate	298.2	36.9
1.03 mm plate	300.3	34.0
2.14 mm plate	284.2	36.6
3.14 mm plate	266.9	35.1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



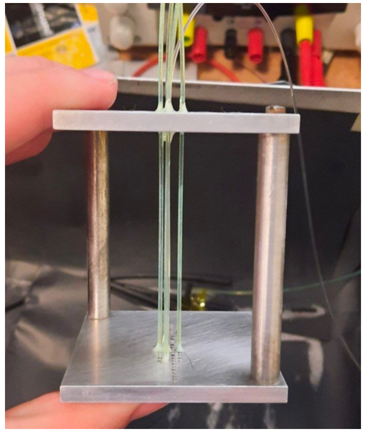
First test bench results







< 50 g of $ZnWO_4$



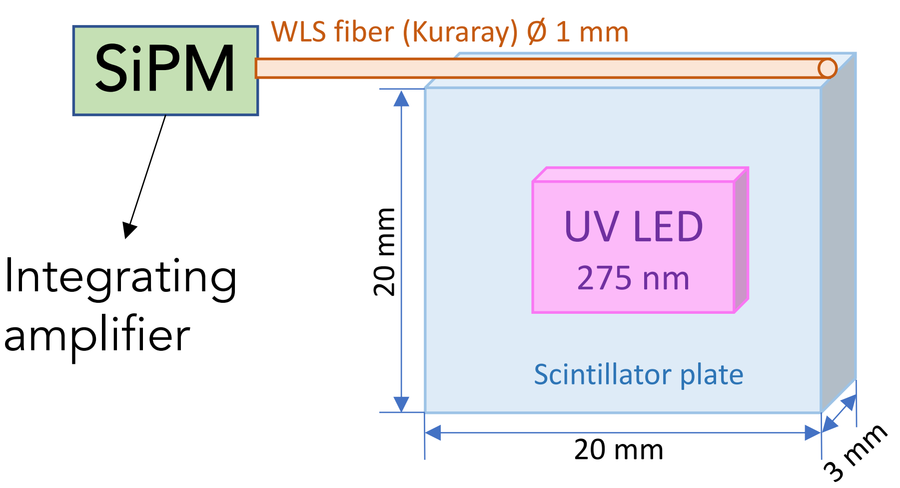
Study of the pulse time delay: average light path in $ZnWO_4$ + propanol ~ 17 cm

Light absorption too large (wrt to kitchen salt test)

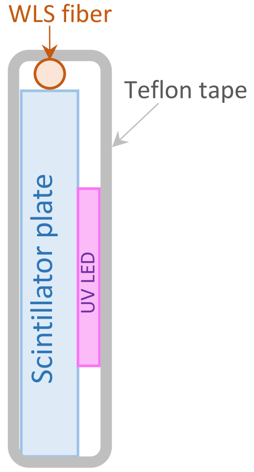
→ new studies with the new $ZnWO_4$ grains, a green LED and a better matched WLS fiber

Which fibers work better for $ZnWO_4$?

New



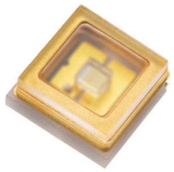
Front view



Side view

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

UV LED :

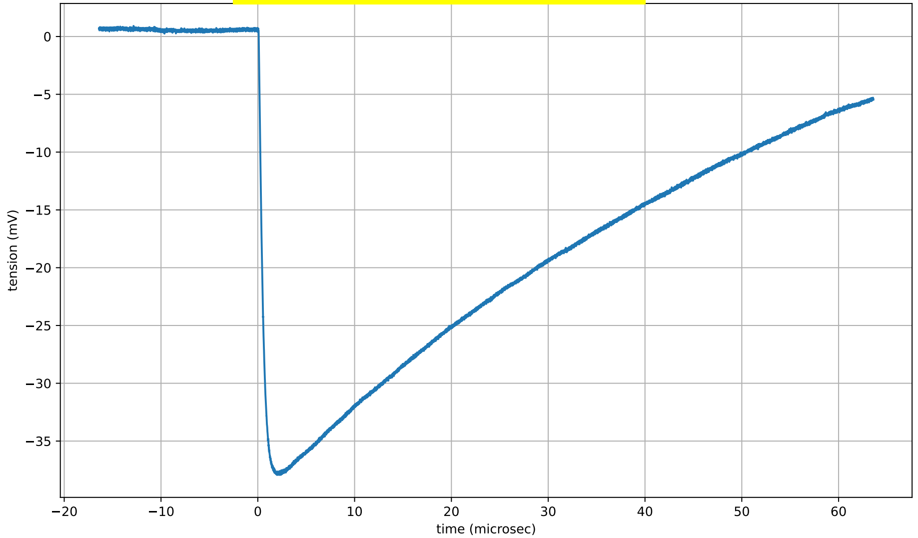


VLMU35CB2.-275-120
λ: 270 – 280 nm

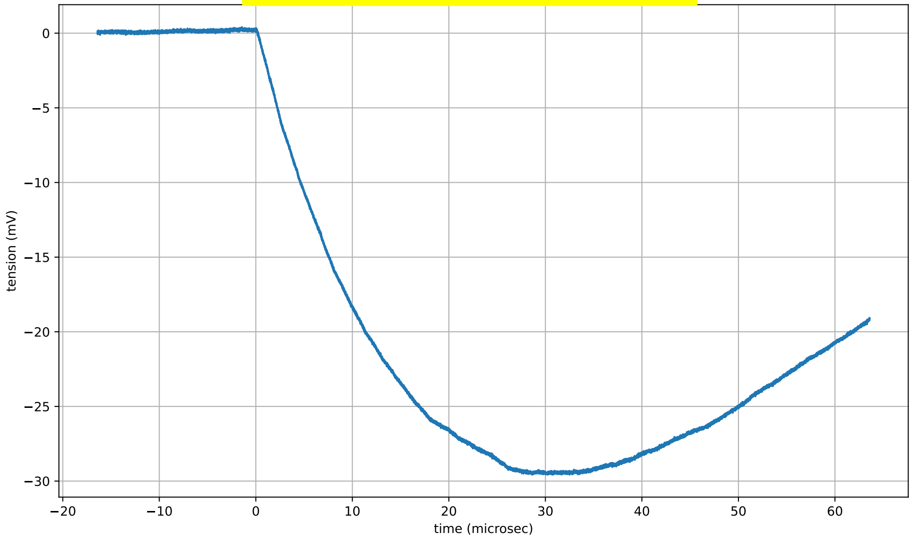
A set of different fibers provided by Kuraray:

- Y11 (200)
- O2(100)
- O2(300)
- R3(300)

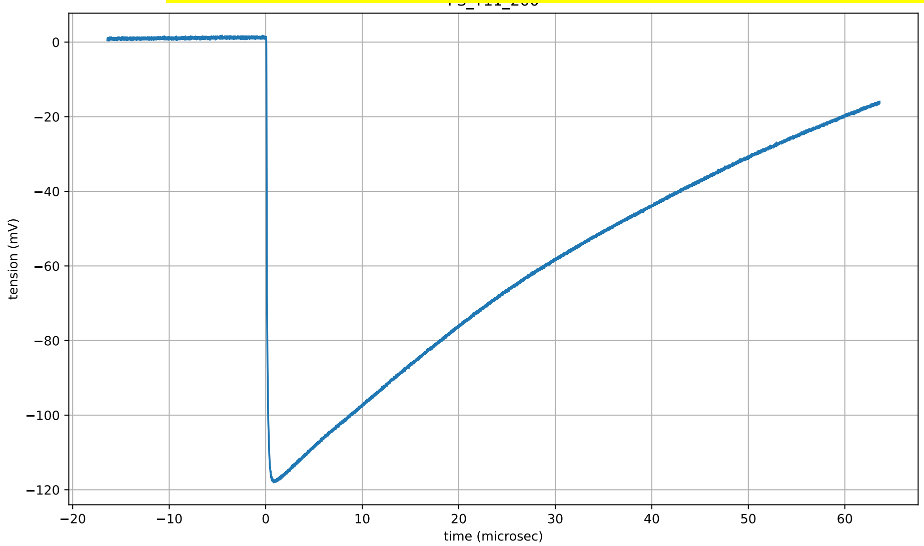
BGO + O2(100)



$ZnWO_4$ + O2(100)



Plastic Scintillator+ Y11(200)



\+ amplifier integrator with long time constant, amplitude

➔ charge

➔ Number of photo-electrons

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

Sci + Fiber	Amplitude (pc)	Corrected RMS (pc)	N_{phe}	Comment
$ZnWO_4$ + O2(100)	325	61.33	28.1	Best configuration
$ZnWO_4$ + Y11(200)	237	48.65	23.8	
$ZnWO_4$ + O2(300)	203	49.9	16.5	
$ZnWO_4$ + R3(300)	290	57.0	25.9	
Plastic + Y11(200)	994	72.3	189	SiPM saturation (600 cells)
BGO + Y11(200)	288	46.9	37.7	
BGO + O2(100)	334	55.7	35.9	

RMS corrected for the dark current

SiPM # of phe (LED OFF measurements)

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

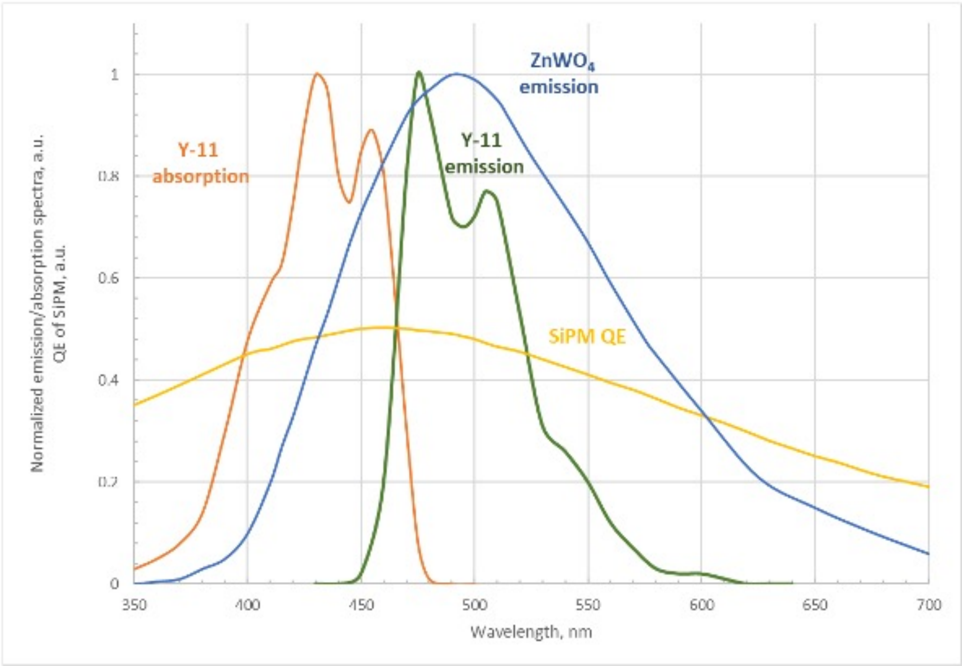
O2(100) best fiber for $ZnWO_4$, well working also for BGO

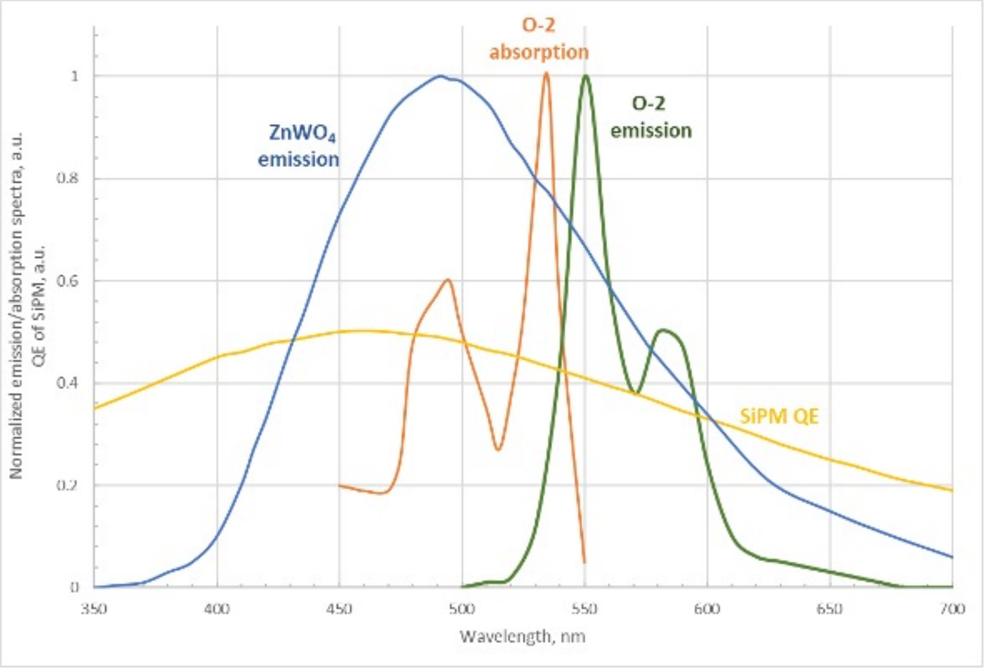
Higher light yield from plastic scintillator compared to $ZnWO_4$: due to UV excitation ? (it is the same for ionizing particles) . Seems to be the case for a scintillator + PMT read-out (back-up).

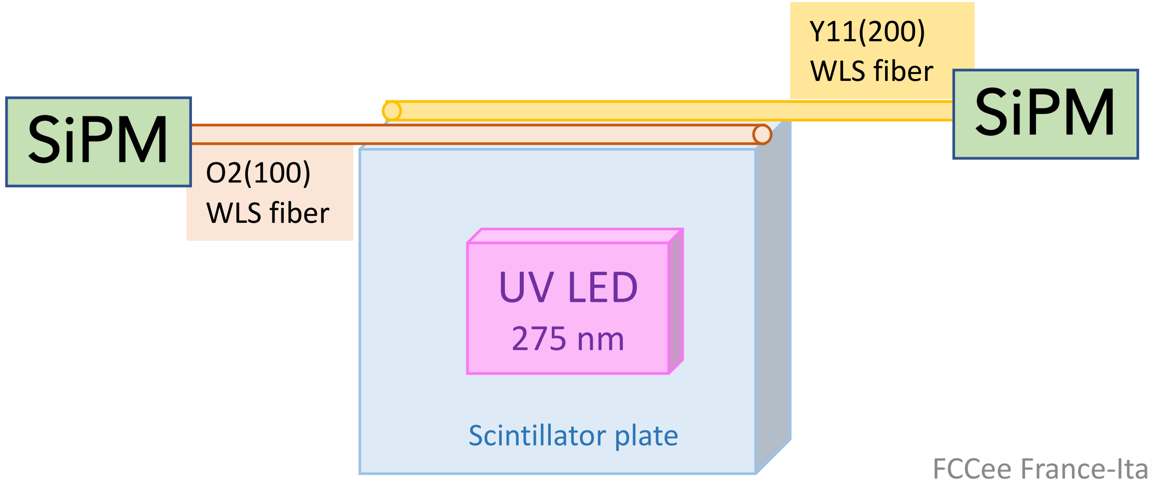
Try with 2 types of fibers ?

New

$ZnWO_4$+ Y11(200) or O2(100) WLS fiber (Kuraray)+SiPM (Hamamatsu S13360-3075CS)

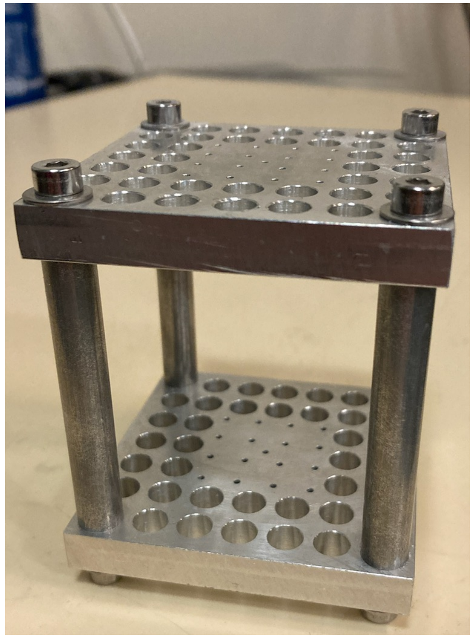






No obvious significant gain with respect to two identical fibers : at most 10%
→ not considered further

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

What will we learn ?

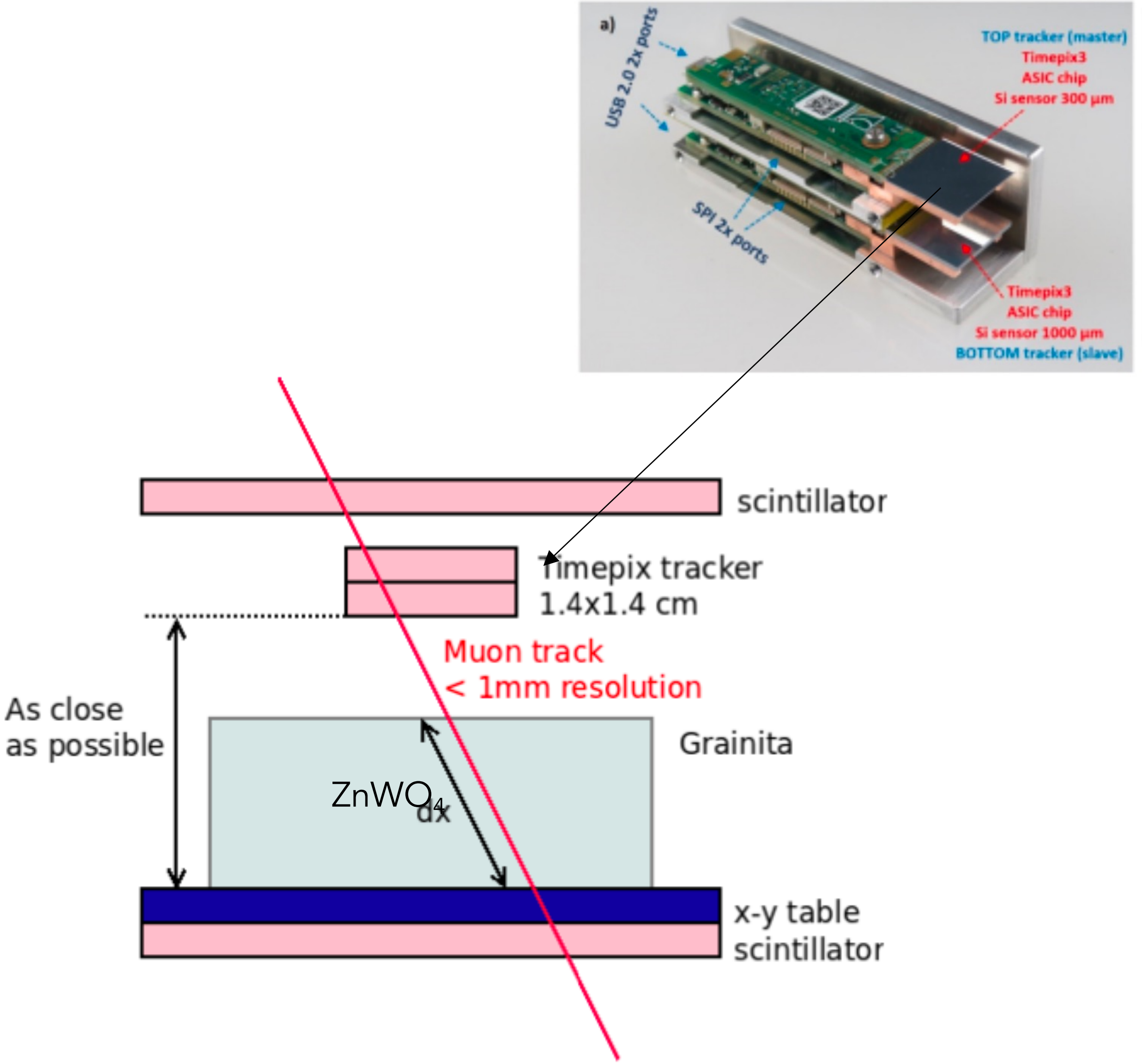
- Number of photo-electrons par GeV
- Study the uniformity response (μ close to a fiber or half-way)

Cosmic rays test bench design

Proposal:

- Upper sensor: 2 layers of TimePix3
  - 0.3° angular resolution
  - Perform the track reconstruction
  - 2 cm^2 (!)
- Lower sensor: 2 scintillator tiles
  - Detect stopping muons
  - Timing

Expected yield $\approx$ 1800 muons/day



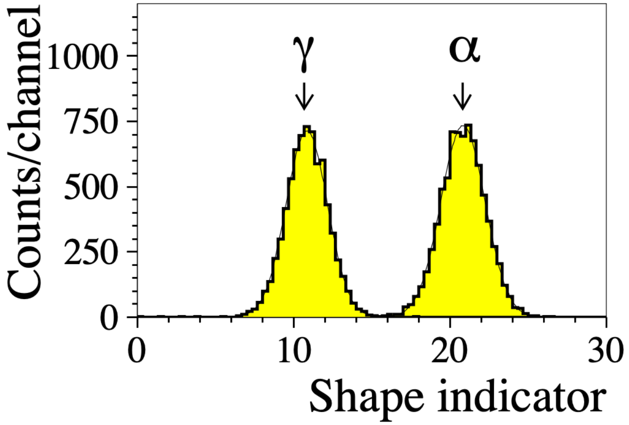
Pulse Shape Discrimination

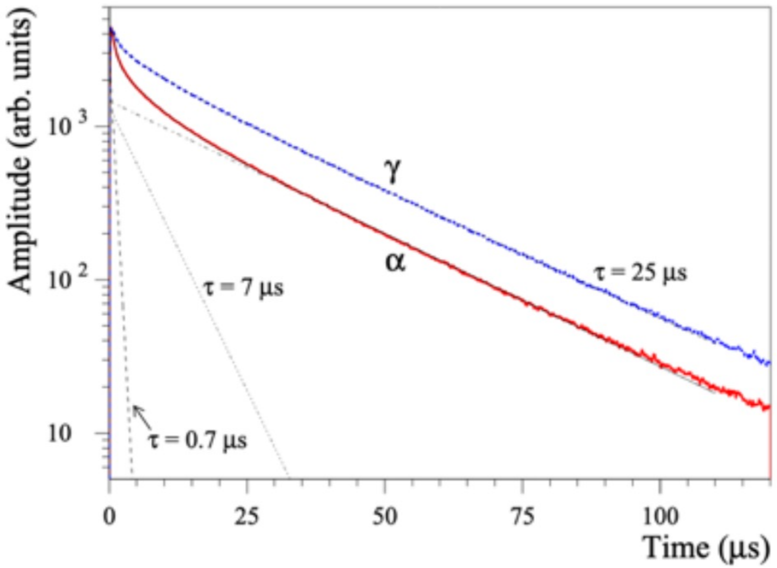
Two components (one fast, one slow) for the scintillation decay time in inorganic crystal

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

With ZnWO4: clear difference between γ and α (https://arxiv.org/pdf/nucl-ex/0409014.pdf)

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%)





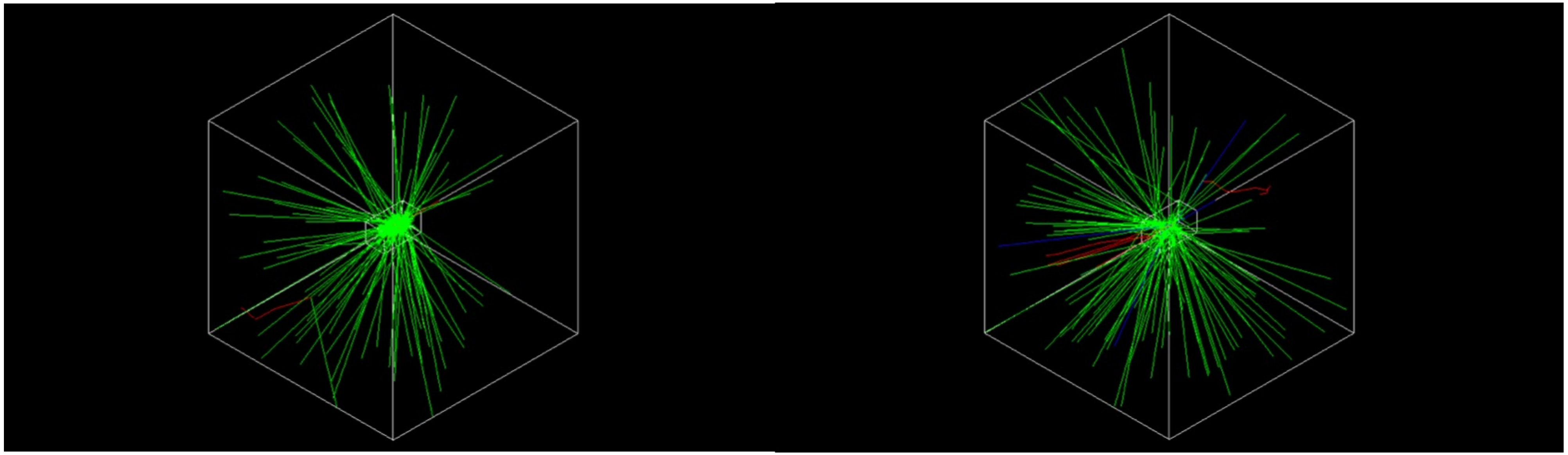
First step : different responses of electrons and pions

Starting a Geant4 simulation

Starting

$ZnWO_4$ / CH_2I_2 homogenous volume:

10 GeV electron | 10 GeV pion



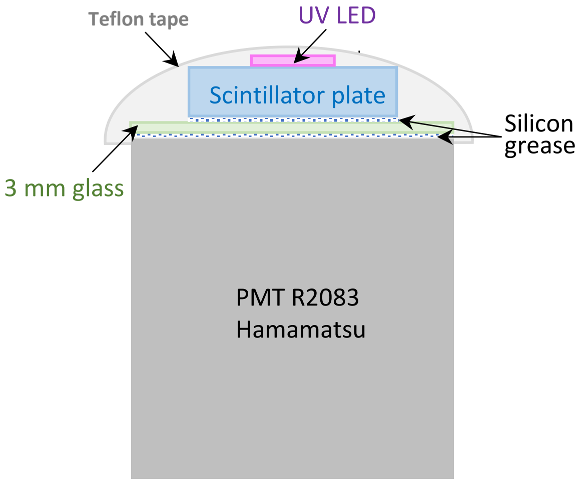
What's next ?

- Building and analyzing the 16-fibers prototype
- Build a calorimeter module (~ 35 kg $ZnWO_4$) with horizontal fibers
- Could we still improve the grains technology ?
- What about further fiber development ?
- Beam test

Stay tuned !

backup slides

Test of scintillators: reference point



UV LED
VLMU35CB2.-275-120
λ: 270 – 280 nm

Scintillator type	Pulse maximum	Average PMT QE
$ZnWO_4$ 4mm plate	0.35 V	14%
$ZnWO_4$ 2mm plate	0.34 V	14%
BGO 2mm plate	0.25 V	16.5%
Plastic Sci 3mm plate	1.25 V	25%

Issue do the the very long signal (not fully integrated) → lower voltage

13% of the light is trapped in BGO due to its refractive index wrt to grease

Ratio of BGO wrt Plastic : $\frac{0.25\ V}{1.25\ V} \times 1.13 \times 1.51 = 0.34$

ratio of QE

$ZnWO_4$+R-3 WLS fiber (Kuraray)+SiPM (Hamamatsu S13360-3075CS)