The GRAiNITA Project

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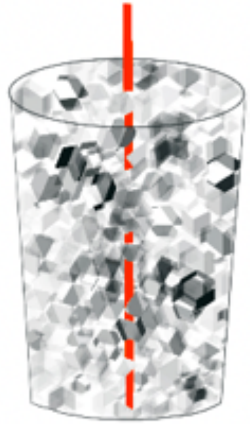


There will be 3 parts in the presentation

1) **A brief reminder of the GRAiNITA project ideas (formerly called Powder_O) and previously presented in IEEE (20/10/2021) and at the Annecy FCC-France meeting (01/12/2001)**
2) **An update on the more recent test results obtained**
3) **Presentation of a recent idea of using the pulse shape discrimination capabilities of crystal scintillator to correct the e/h effect and improve Jet energy resolution for a crystal ECAL in front of a Dual Readout HCAL**

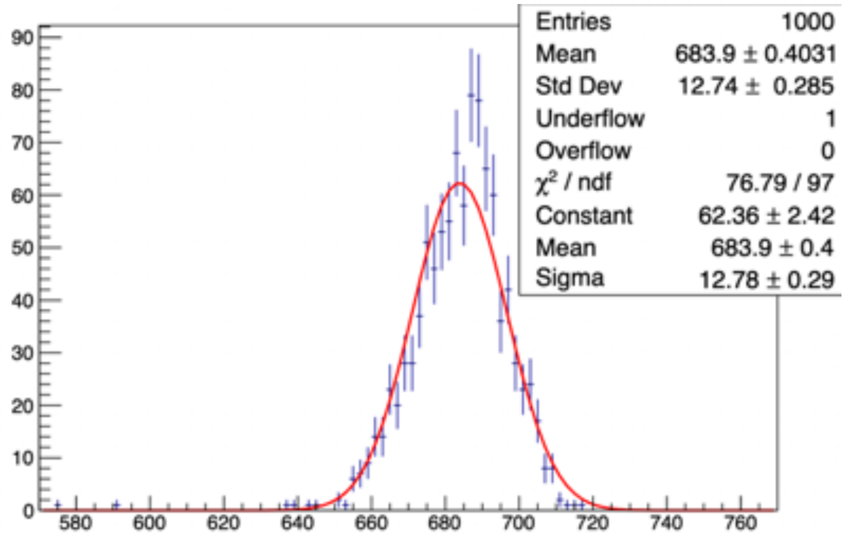
The GRAiNITA idea

The idea behind GRAiNITA => instead of sampling with plates and scintillator as in Shashlik and reading out the scintillator light with WLS fibers => use small grains for scintillators (grain density ≈ ½ solid density) add heavy liquid and use WLS fibers every 7mm.

GEANT4 simulation with Scintillator =ZnWO4 liquid= CH2I2 Grains simulated by random choice of 1mm cubes ZnWO4 or CH2I2 (random probably pessimist) (other cubes'sizes also tested)

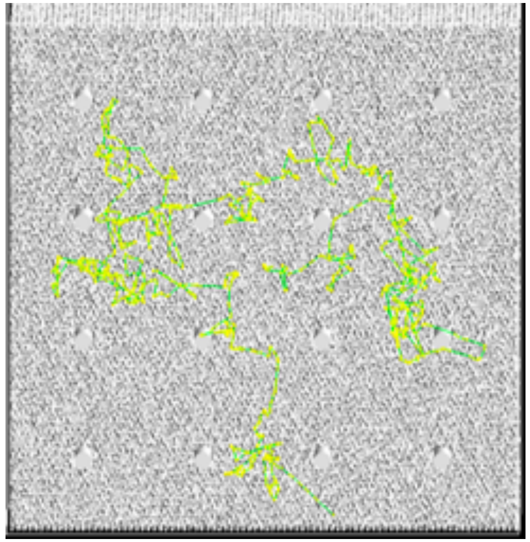
Energy resolution at 1 GeV : 1.87% vs 10%/sqrt(E) for typical Shaslik => satisfactory resolution for 0.5mm-1mm grains.

For this mixture of ZnWO4 and CH2I2 the density is d=5.47 X0=1.65cm and Rm=2.77cm

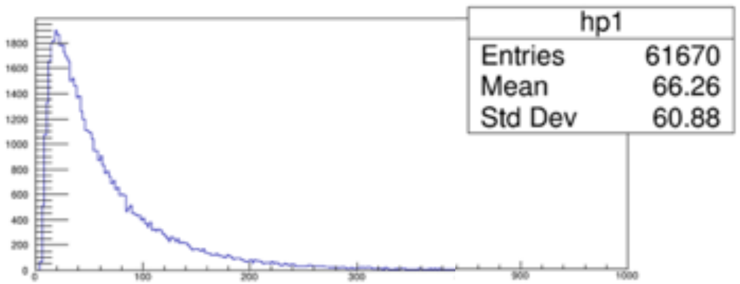


Light propagation

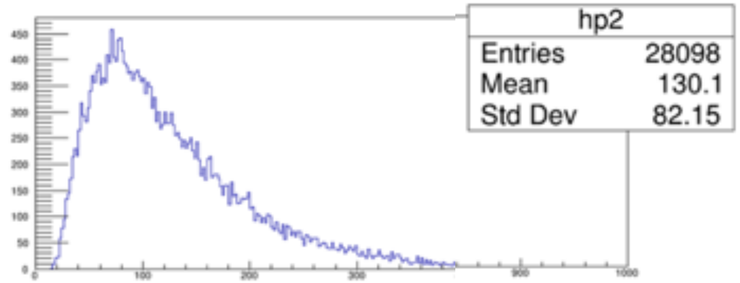
A simulation of light propagation was done for a module, with =1mm WLS fibers every 7mm, light produced in the center => follow the light path until reaches fibers. Light direction changes due to reflection and refraction Calculate path length. (path length => absorption?)



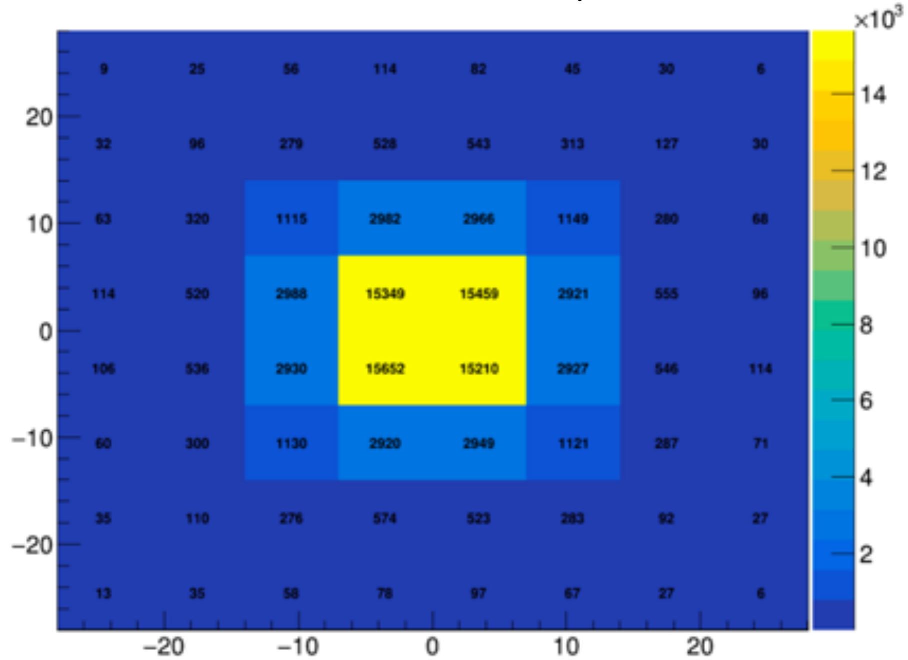
Central 4 fibers



12 next fibers



Number of Photons absorbed by each fiber



Properties of ZnWO4

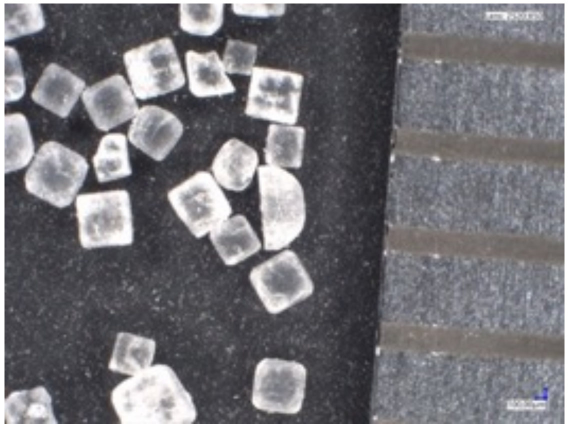
Density= 7.62 n=2.1

Light Yield 10Kphotons/MeV comparable to plastic scintillator (but more MeV deposited in high density ZnWO4 than in plastic)

melting point 1875°C High for Czochralski method (but works!).

But small crystal can be obtained by "spontaneous crystallisation from flux melt" (as salt dissolved in water and water evaporated from the sun!)

Our collaborators from ISMA UKRAINE have obtained such grains 2 productions with different solvent

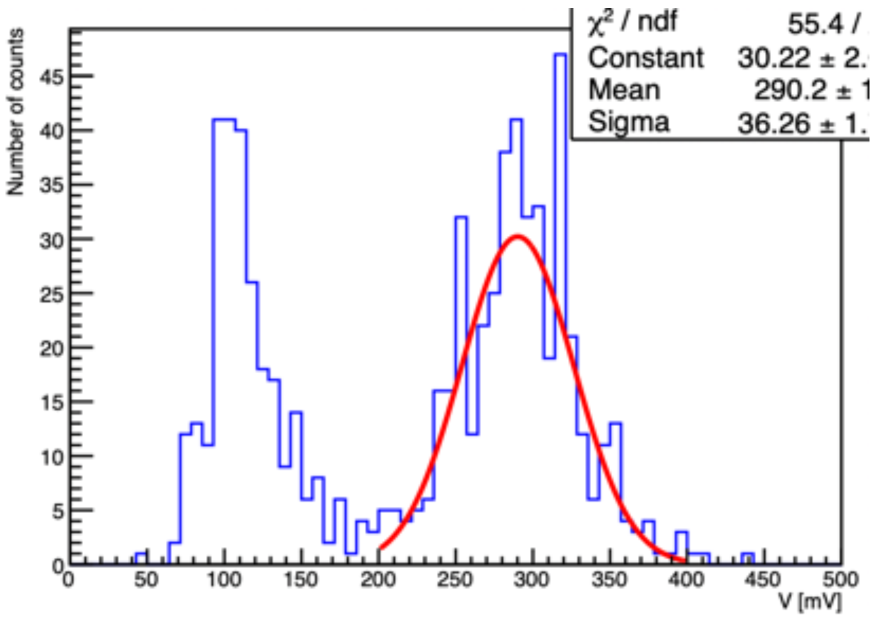


For comparison kitchen salt 0.5mm

Test of Grains scintillation efficiency (I)

The scintillation efficiency of grains were measured with a 60KeV Am 241 γ-source and a PMT and compared to plates or cubes of single crystals grown by the Czochralski method. The 60 KeV recoil electrons have a path length in ZnWO4 of about 60 microns << the grain size. Using the reference 10000 photons/MeV and a 15% average photocathode quantum efficiency for the ZnWO4 emission wavelength 90 photoelectrons (PhE) would be expected if the photon coupling would be perfect.

Typical charge pulse height for one grain.
If one assumes sigma/signal =1/sqrt(NPhE) Typical charge pulse height => 64 PhE



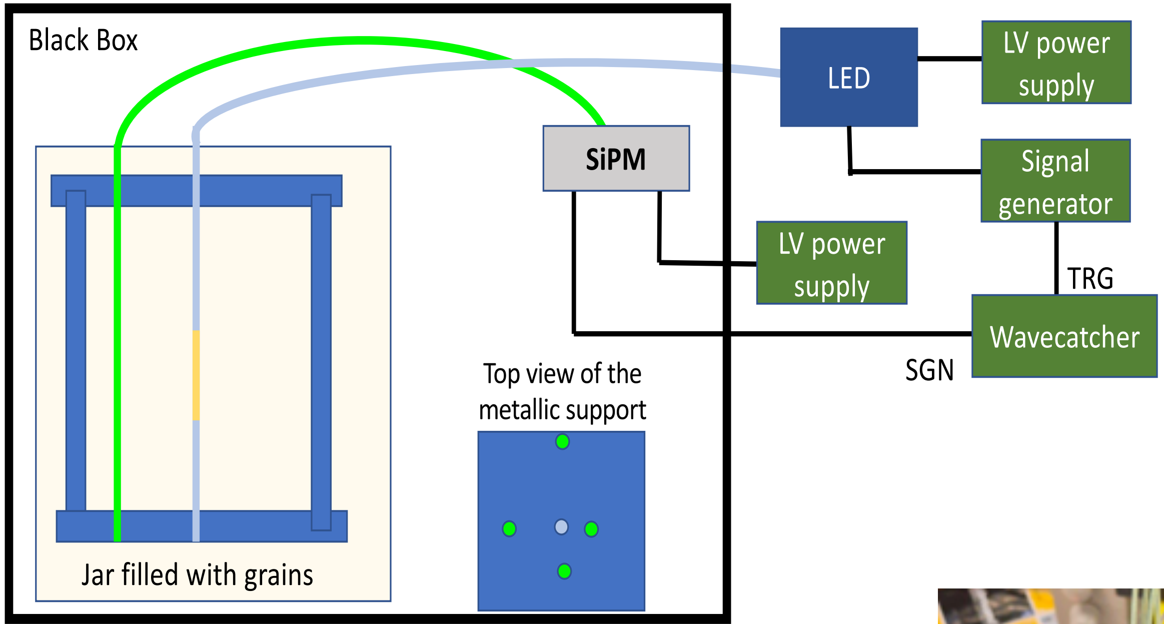
Test of Grains scintillation efficiency (II)

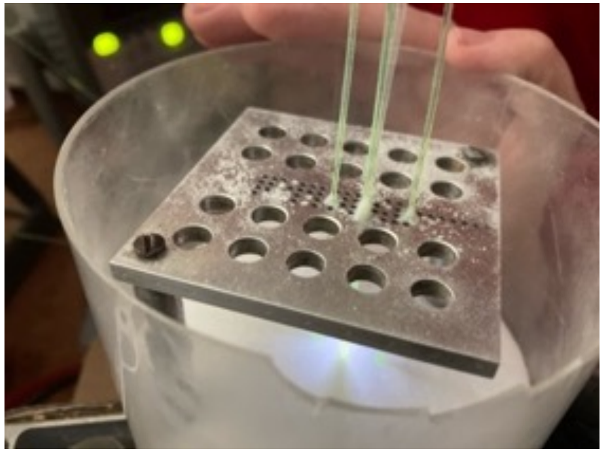
Very similar mean values are observed for plates and grains of both productions (old =first ,new = second). Perhaps some ensemble of grains of the first production (6 items or collection in frame) show a greater sigma due to different light efficiency?

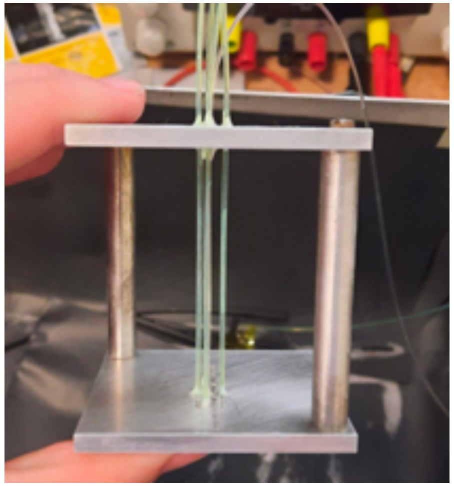
Sample name	Mean	Sigma	N phe
1 grain B old	307.7	34.88	77.82194
1 grain C new	302.5	32.91	84.48799
1 grain D new	290.2	36.26	64.05296
Grains free 6 items old	248.9	47.78	27.13673
Grains free 6 items new	298.3	35.69	69.85756
Grains in the frame old	260.7	59.24	19.36654
Grains in the frame new	292.7	43.11	46.09878
1 cm^3 cube	181.7	26.45	47.19093
2x2x0.085 cm plate (two measurements for reproducibility checking)	296.7 301.9	37.65 36.36	62.10193 68.94114
2x2x0.103 cm plate (two measurements for reproducibility checking)	300.7 298.3	35.32 36.21	72.48122 67.86556
2x2x0.214 cm plate (two measurements for reproducibility checking)	284.7 288.4	35.99 36.91	62.5765 61.05236

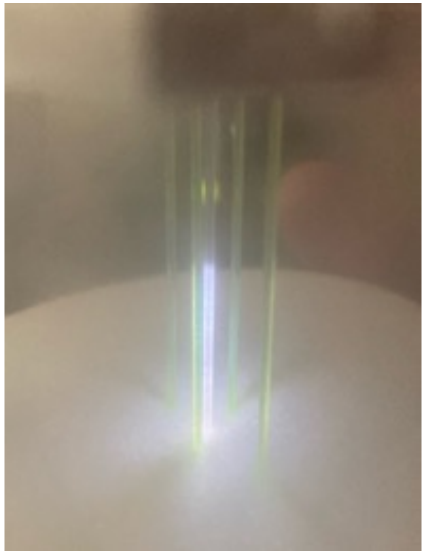
Light propagation experimental test

Used salt (0.5mm) (n=1.55) as powder + air or propanol (n=1.39) between grains



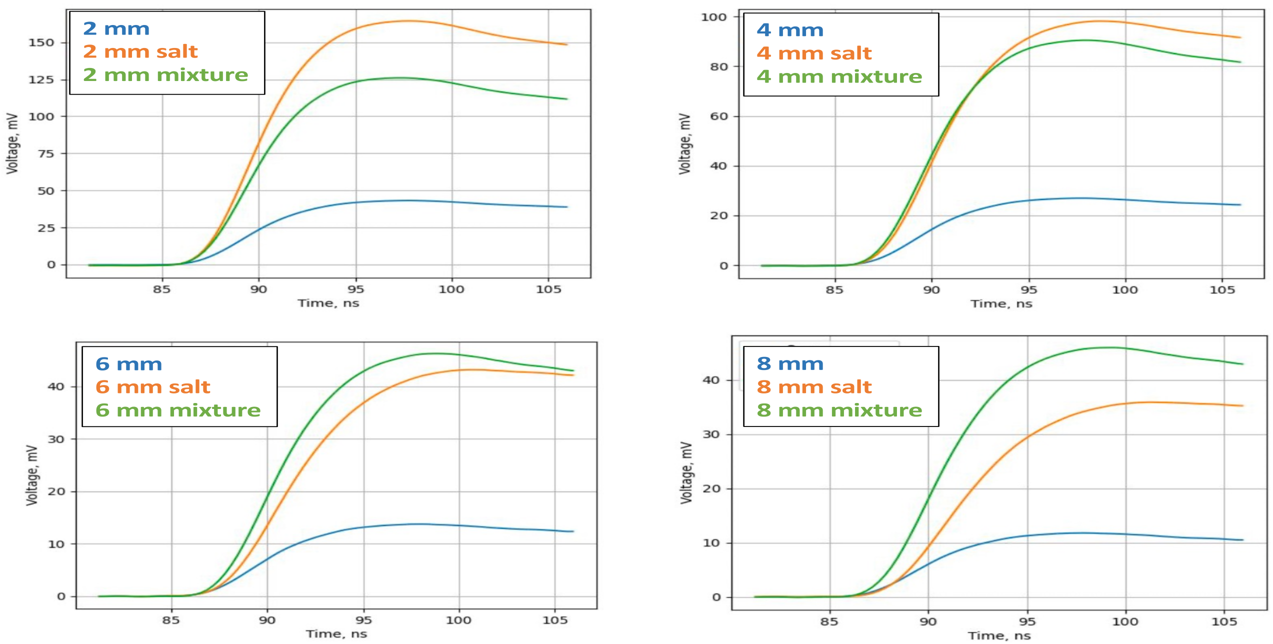






Blue LED light pulsewidth = 1.8 ns FWHM
Injection clear fiber unpolished 2cm
WLS fiber St Gobain 9929A
Wavecatcher digitiser @ 3.2 Gsample/s => pulse time delay => pathlength in powder

Light propagation: Salt test



For all cases we measure the amplitude (≃ the number of photons collected) and the half way up time => average photons time vs trigger. The reference point is time in air. The timing difference allows to obtain the average photon's total path from injection to WLS fiber

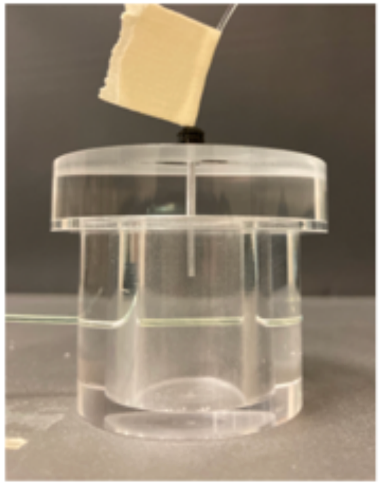
For all four WLS fibers position there is more light collected with the salt than air. If isopropanol (n=1.39) is added, light is less confined => 2, 4mm decrease 6, 8mm increase.

At 6mm the time difference with salt+air => is 1.4 ns => path ≃ 28cm

. with salt +isopropanol => is 0.6ns => path ≃ 12cm

Light propagation test with ZnWO4 (preliminary)

Because of the small quantities of ZnWO4 initially produced by ISMA a smaller light propagation test device was used. (<50g of ZnWO4) The injection fiber is 4mm from a WLS fiber. A VM1000 Al reflector is wrapped around the device to reinject escaping light.
Use propanol between grains => relative refractive index ZnWO4/propanol ≈ salt/air
Average light path in ZnWO4 + propanol 1.04ns ≈ 17cm
Light absorption still worse than salt by a factor ≈ 2
However a blue LED test is pessimistic for ZnWO4 (emits in the green) => future test green LED + new WLS fibers absorbing green



Use of Pulse Shape Discrimination for FCCee ECAL
Examples of PSD (I)

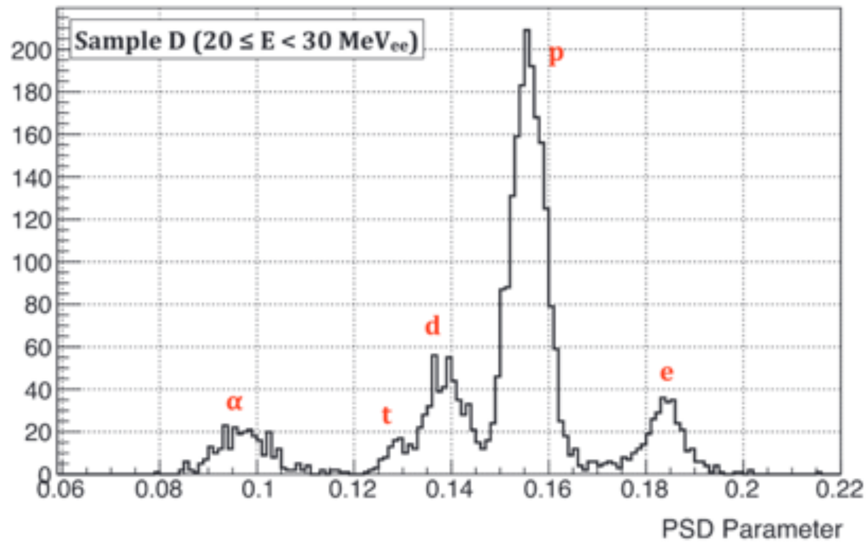
What is PSD?: It is a technique often used in nuclear physics (or double beta decay experiments). It corresponds to the observation that for crystal inorganic scintillator the scintillation decay time often has more than one exponential component.

Higher ionizing particles (low energy protons) are observed to have a very appreciable higher yield of the fast component. This is well documented for example for CsI(Tl) or ZnWO4 (but also known for BGO) For CSI for example in ref:

https://academic.oup.com/ptep/article/2018/4/043H01/4980960?login=false

$$\text{PSD parameter} = \frac{Q(T_2) - Q(T_1)}{Q(T_2)}.$$

Where Q =charge integrated from 0 to T and T1=2**μ**sec T2=4 **μ**sec
20-30 MeV electron and proton are easily identified

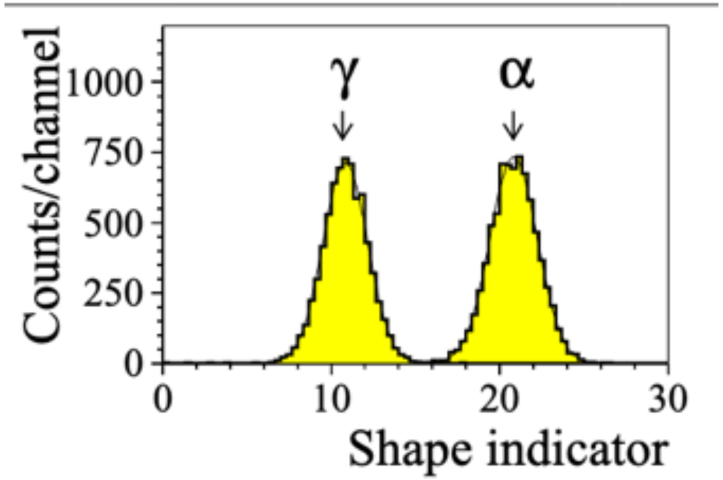


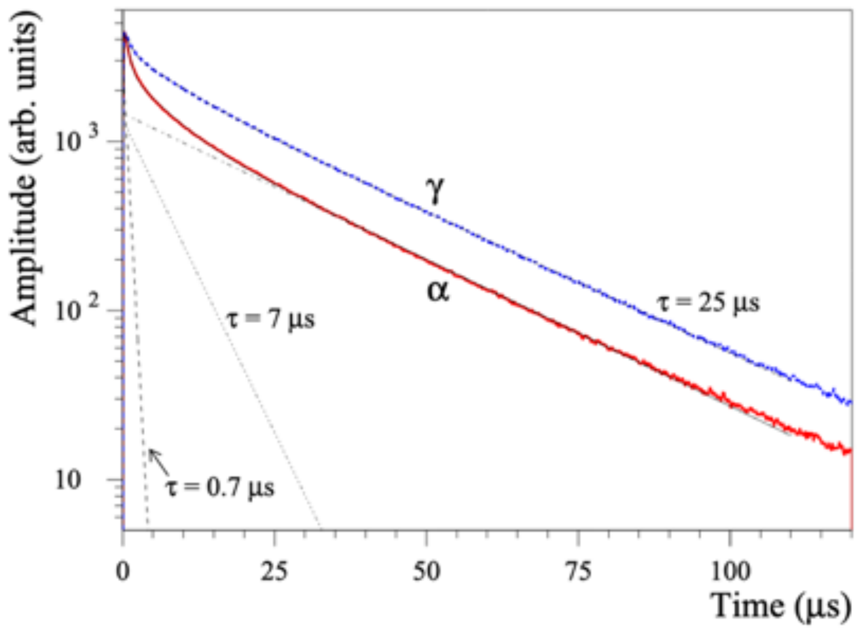
Examples of PSD (II)

Another example: for ZnWO4 https://arxiv.org/pdf/nucl-ex/0409014.pdf

The separation of signals from alpha or gamma ray (-> electron) is "perfect" using the PSD

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%)





Examples of PSD (III)

To our knowledge the use of PSD in particle physics at accelerator is very recent and the only example is an analysis performed on the CsI(Tl) ECAL of Belle II , the main aim being to identify clusters produced by a K0L interaction and separate them from the photon cluster background. The article dates from Sept 2020 https://arxiv.org/abs/2007.09642 Longo et all There is also a thesis by Longo https://dspace.library.uvic.ca/handle/1828/11301

Above 1GeV the identification of hadron cluster is still good with negligible photon (from pizero) contamination

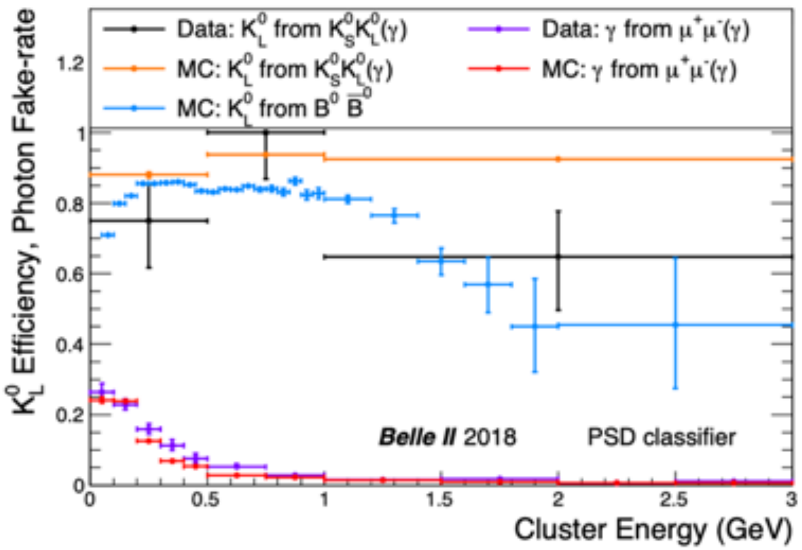


Figure 10: Measurement of the K_L^0 efficiency and photon-as-hadron fake-rate for the PSD classifier as a function of cluster energy for several control samples of K_L^0, and photons. Errors bars correspond to statistical errors.

Potential use of PSD for jet energy measurements in FCCee ECAL

Hadron energy measurements accuracy in calorimeter (or jet energy with a mixture of photons and hadrons) are much worse than photon because there is a sizeable e/h ratio (a typical average value is 1.8 in great part due to energy loss in breaking nucleus) The problem for the energy resolution is that the e/h ratio has a large variation from event to event because, for example, of the fluctuation in the first interaction of the ratio between pizero and charged pi created.

A possibility to recover the resolution is to evaluate the e/h by the measurement of the Cherenkov light yield in the same material => Dual Readout calorimeter, which is a very effective solution for HCAL but has a limited energy resolution for ECAL It has been suggested to use a crystal calorimeter for ECAL and evaluate its e/h by Cerenkov emission The Cerenkov light being separated by various mean (timing wavelength etc…) but the ratio (Cerenkov light / scintillation light) is typically less than a fraction of 1%

From the principle of PSD and observations at Belle II it seems very plausible that a similar evaluation of e/h can be performed by PSD in the ECAL if it contains crystal inorganic scintillator. This could be a rather simple process and the ratio of fast component is about 10% -20% of the light therefore easier to observe than Cerenkov

What next for PSD? Simulation?

Probably the most effective way to progress in evaluating the possibility of the use of PSD, is to perform first simulations.

The first idea could be to obtain (in Geant 4 event by event analysis) the correlation between the fraction of ionisation energy loss with high dE/dx particles (slow protons?, nuclei fragment? …) with the e/h ratio.

In a next step one could include in the simulation the pulse shape as function of the dE/dx and verify with the photoelectron statistics if e/h correction would be accurate enough.

Conclusion for GRAiNITA project

The next steps could be

1) **Perform needed simulations**
2) **Equip test device with “longer wavelength” WLS fibers**
3) **Perform test of light propagation**
4) **With a 16 fibers device perform a test with cosmic rays**