



SAPIENZA
UNIVERSITÀ DI ROMA



CENTRO RICERCHE
ENRICO FERMI

Luminarie

Time Of flight Plastic Scintillators and Hi-Z Organic Scintillators

11/11/2021 - Rome



Main Task

- Fast Timing Plastic Scintillators **Particle Physics**
 - 3DIT (3D printed scint.)
- Hi-Z Plastic Scintillators **Imaging (SPECT, etc.)**
- Additional ideas.. (not discussed today)
 - particle identification (gamma/neutron)
 - ... **Particle Physics**

Main Links:

- LEOS Group for the chemistry development
- FBK Team for the readout
- Partner of the EIC (Molecubes, Synective, Univ. Utrecht)

TOPS: Time Of flight Plastic Scintillator

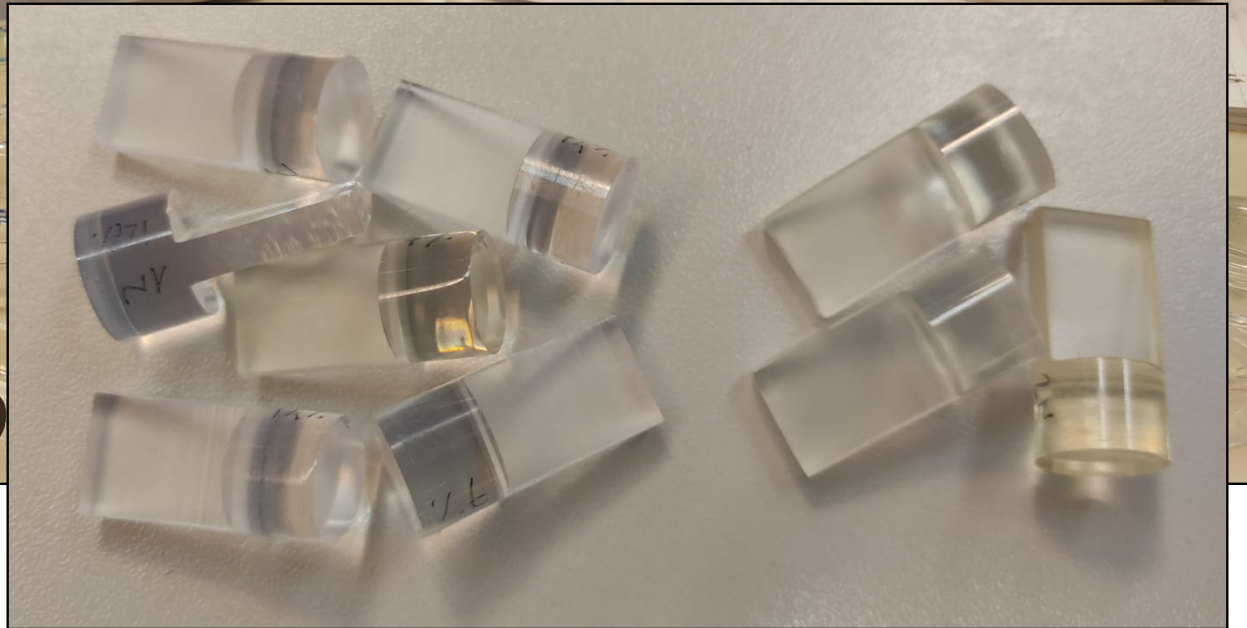
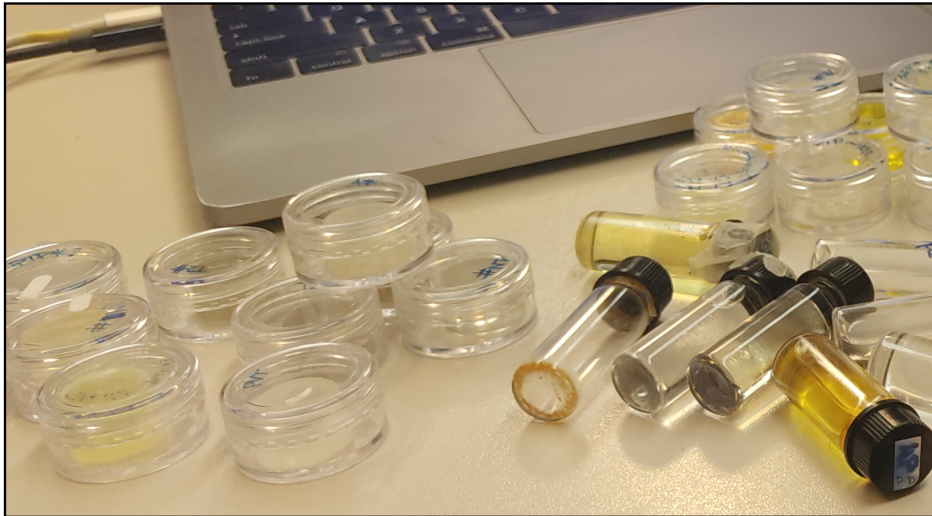
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This has become ...

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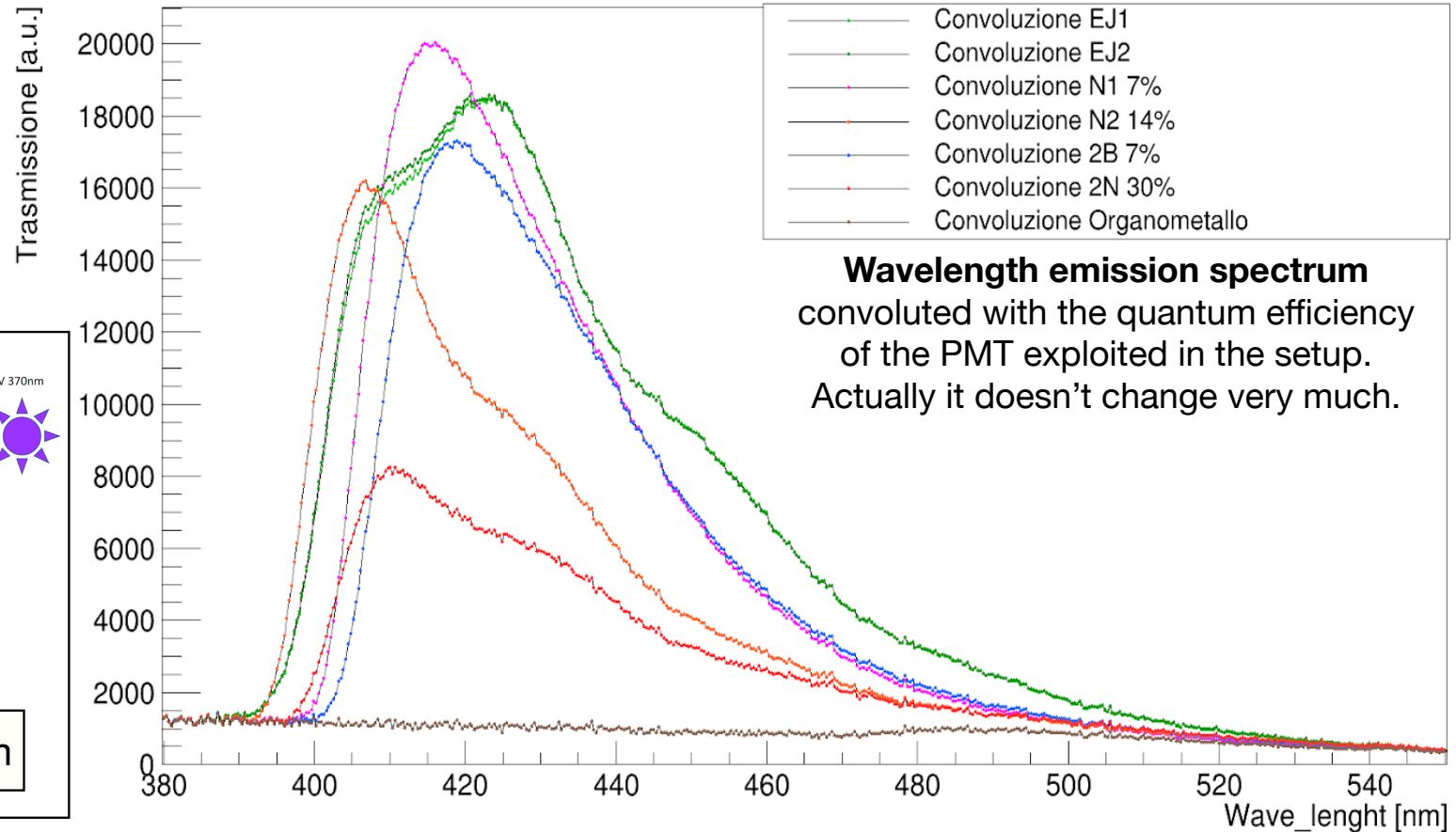
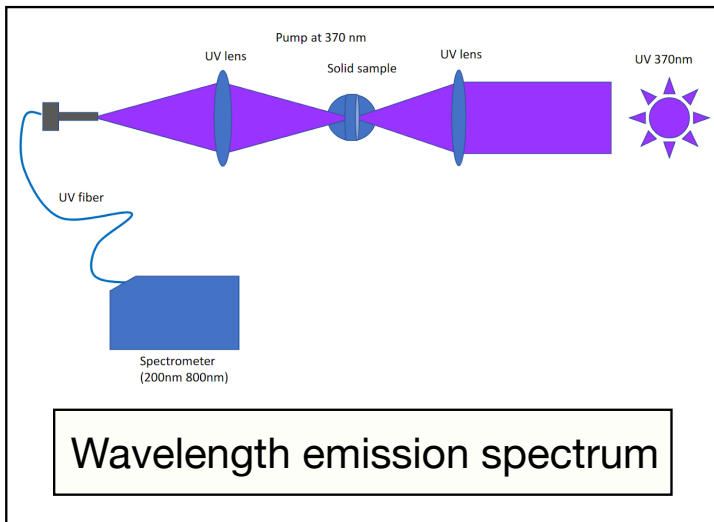
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This has become ... just that..

TOPS

We select therefore the 4 new fluorophores that show the best performances in terms of scintillation light spectrum, sample transparency as a function of concentration, overall light output and time response.



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MICHELA

<p>back and forth at the same s radiation from atoms s work. ed classical expectatio</p> <p>2N 7%</p>	<p>back and forth at the same s radiation from atom s wor The occurrence of d classical expectatio</p> <p>2N 14%</p>	<p>back and forth at the same s therefore radiation from atoms work. d classical expectatio</p> <p>2N 30%</p>
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TOPS

We performed test with cosmics, protons and carbon ions beams. The most recent results have been obtained with cosmic rays at SBAI.

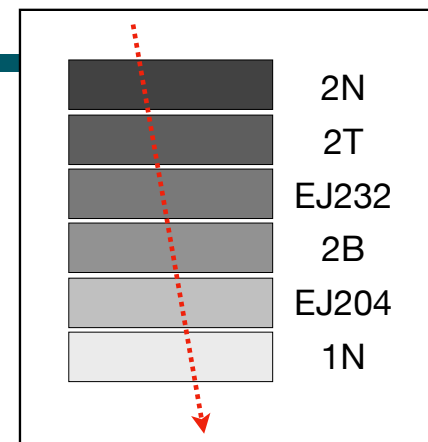
Readout system:

- PMT H10721-20
 - quantum efficiency impacts on the final light output (QE peak at 400nm)
 - rise time (from datasheet) 0.57 ps

DAQ system:

- WaveDAQ

Experimental SETUP



Samples	Primary Dopant	Wavelength emission	Light Output* % EJ232	Rise-Time [ns]	Width [ns]	Time Resolution [ps]
	%	[nm]	<i>systematic and statistics error 10%</i>			
EJ-232	-	370	100	2	9	123
EJ-204	-	408	200	2.5	11	211
2N	14%	405	110	2	12	81
2T	14%	-	240	3	18	97
1N	14%	415	155	3	17	102
2B	14%	420	160	2.5	14	110

Best performances have been obtained with samples of a concentration of fluorophores at 14%.

TOPS

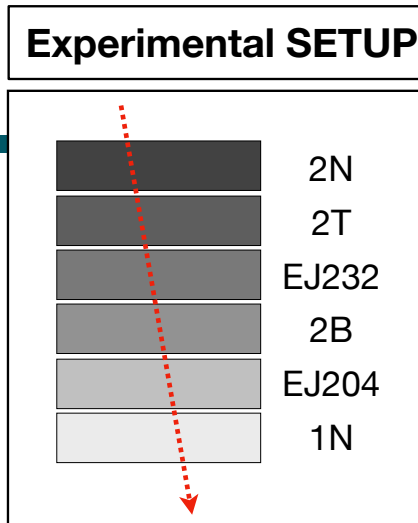
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Increase of 55% the light output wrt the most performing commercial scintillator in terms of LY

35% better than faster commercial scintillator

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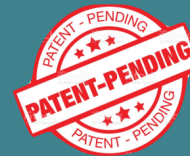
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Possible Applications:

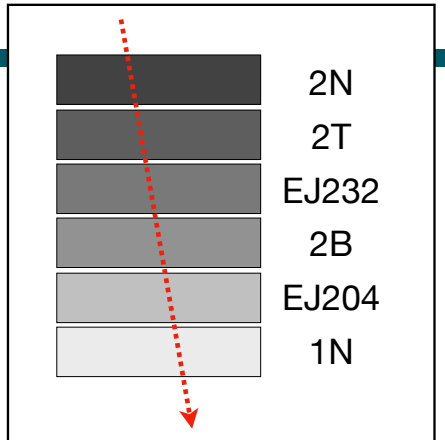
- Timing Detectors
- dE/dx Detectors
- Combination of the two



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the light
most
commercial
ns of LY

Experimental SETUP



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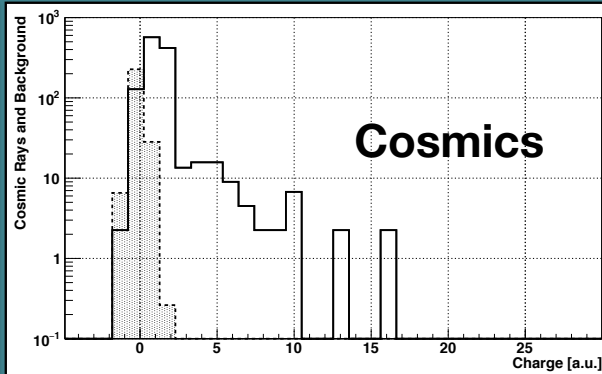
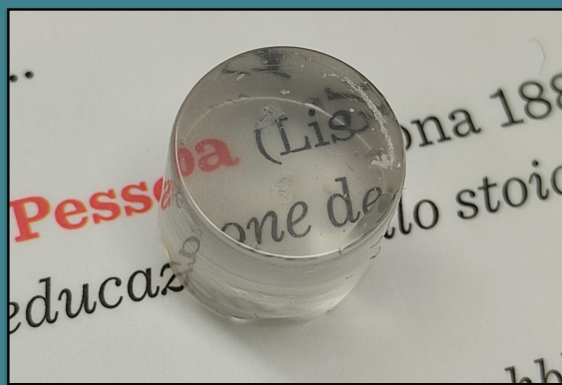
Best performances have been obtained with samples of a concentration of fluorophores at 14%.

EDIT: 3D plastic scintillator

Funded by a small Bando di Ateneo 2021-2022 (L.Mattiello)

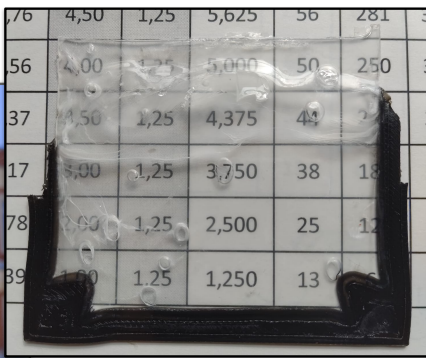
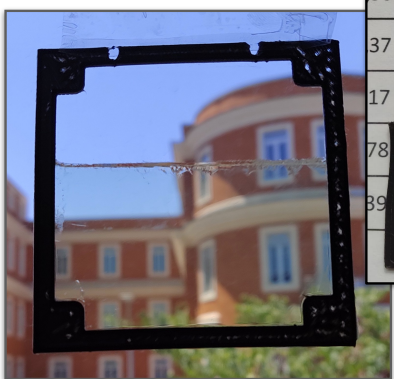
- CREF (MM) and INFN (Silvio M., Valerio P., Silvia M.)'in kind'
- LEOS (chimici) and SBAI

The idea is to exploit the *veroclear* material of the 3D printers and try to integrate in the resin the scintillator.

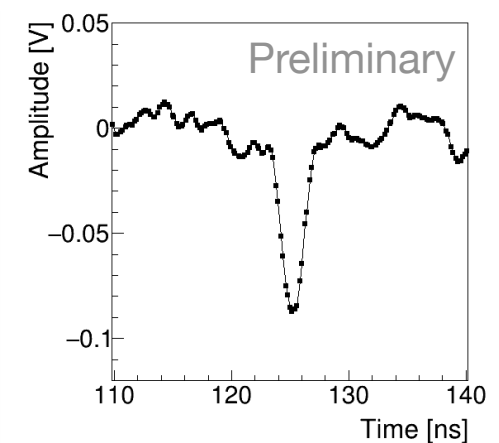
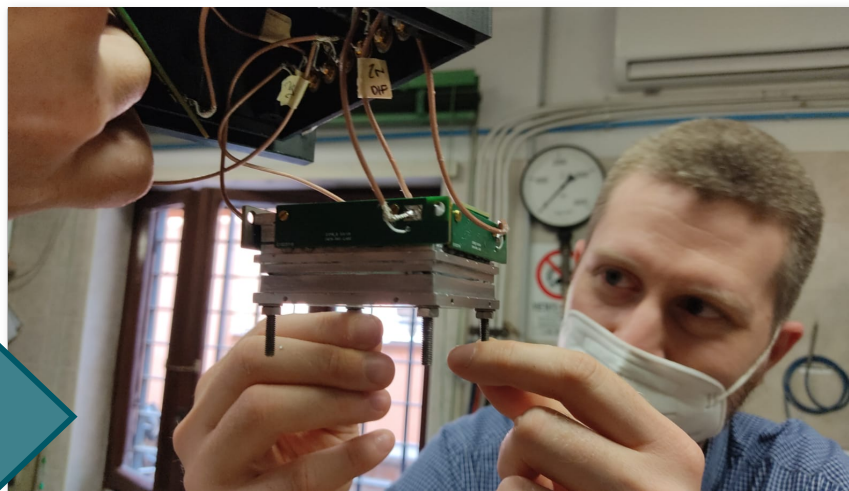


The samples of scintillator dissolved in *VeroClear* liquid and polymerised by UV, have been irradiated with minimum ionising particles (m.i.p, cosmic rays). The light output of the first prototype obtained with m.i.p. irradiation is shown. The background contribution has been superimposed (dashed line) to the signal (black line). The energy loss (dE/dx) of the muon is clearly contributing to the scintillation response with its typical landau shape.

Several Prototypes



Nice pictures but bad performances for now



MICHELA

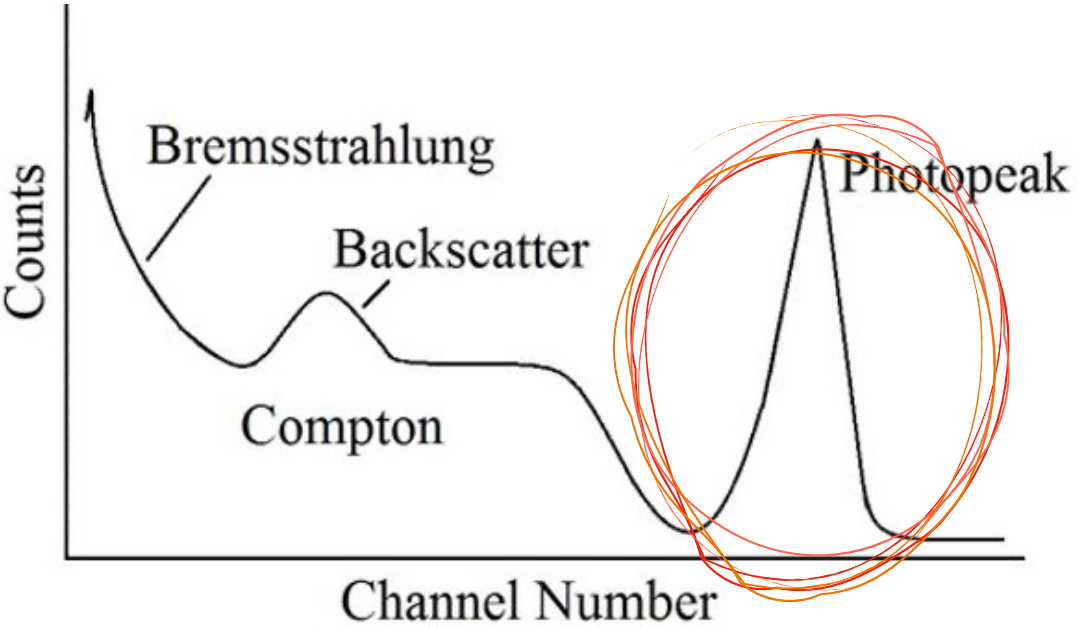
Fast Scintillators

We are starting understanding and really characterising the samples

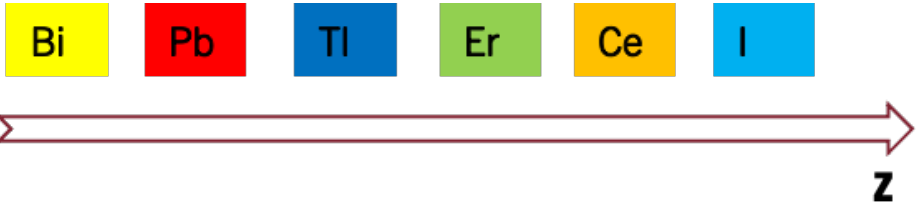
- ◆ We characterised the fluorophores from the emission spectra point of view
- ◆ We are able to produce samples of scintillators faster than commercial one
- ◆ We can also exploit the light output performances, thanks to the high concentration that we can reach with this fluorophores
- ◆ Concentration up to 30 %: we need to understand if fluorophore saturates or the transparency decrease the light transmission..
- ◆ the 3D potentiality is very interesting.. we have to work..
- ☑ Sometimes we find impurity in the samples (in the fluorophores) that decreases the performances.

Hi-Z Scintillators

The idea (2020) is to work on the R&D of a hi-Z element enriched plastic scintillator, always with the chemistry LEOS group of SBAI (L.Mattiello, D.Rocco). The main goal is to obtain a plastic scintillator in which low energy photons (100-500 keV) interact via photoelectric effect.



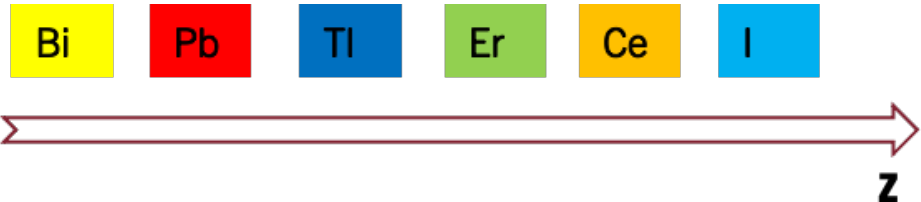
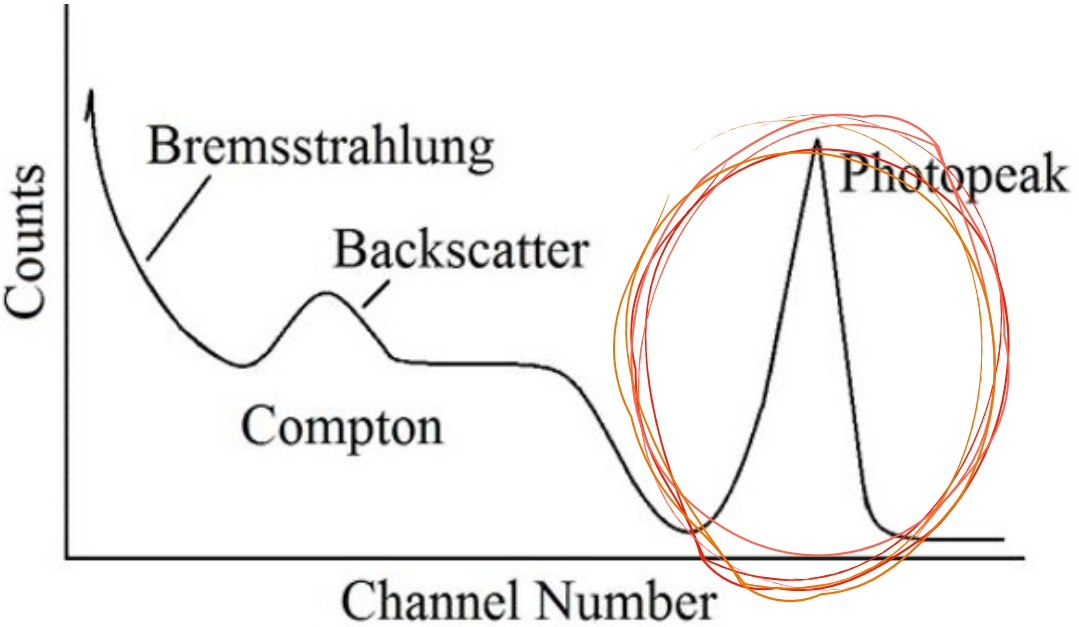
The first application we are working on is the realisation of a SPECT based on hi-Z plastic scintillators.



Several elements have been studied via MC and investigated from a chemistry point of view as a function of concentration (2%-5%-10%-20%-30%-50%)

Hi-Z Scintillators

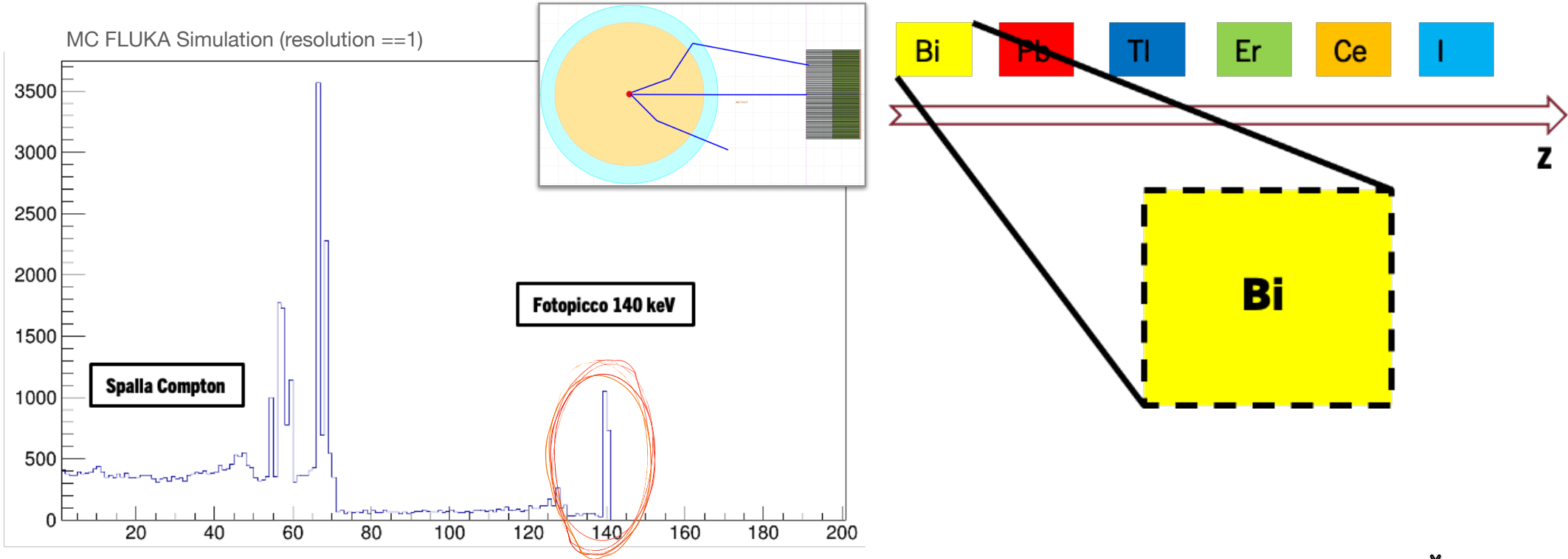
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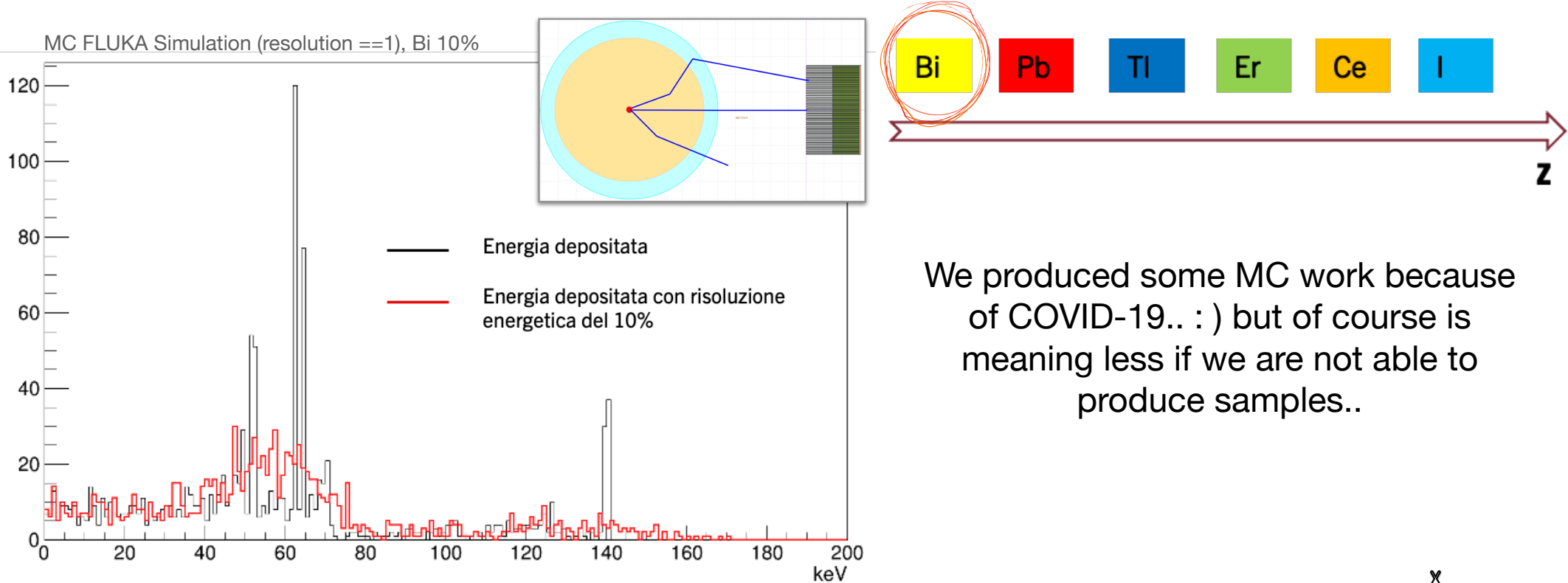
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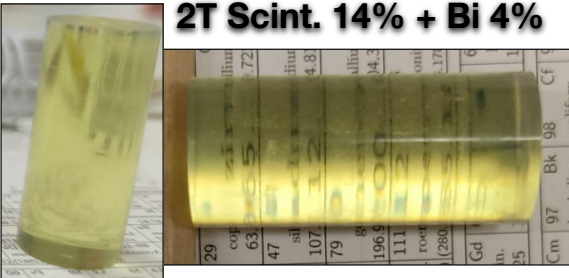
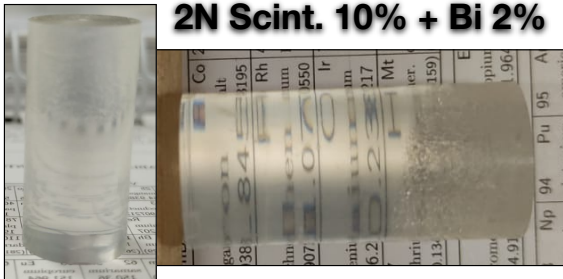
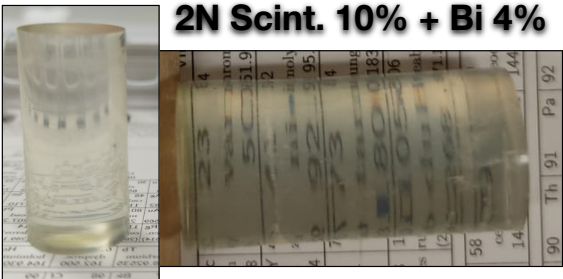
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We produced some MC work because of COVID-19.. :) but of course is meaning less if we are not able to produce samples..

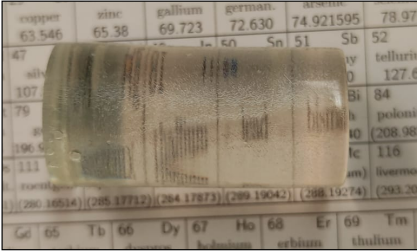
Hi-Z Scintillators

We started with some very bad tentative.. after almost an year we 'end up' with nice samples:

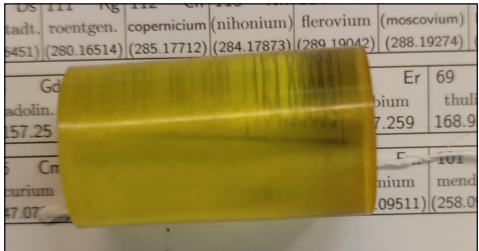


standalone hi-Z element

Bi pivalato 5%



Er chinolina



Hi-Z Scintillators

Unfortunately we do not have a 144 keV photon source.. but..

Rif. vostro ordine: Trattativa 1854286 - Ns. rif.: 877-2021MN

Descrizione sorgente	Quantità	Attività sorgente
BDR8122 Ba-133 Gamma Reference Activity tolerance: + 30 %, - 10 % Activity calibrated, DAkkS certificate Drawing: VZ-0477-001 Active diameter: 1 mm Overall dimensions: Ø 25 mm x 3 mm	1	37 kBq

80 keV @ 36%
356 keV @ 69%

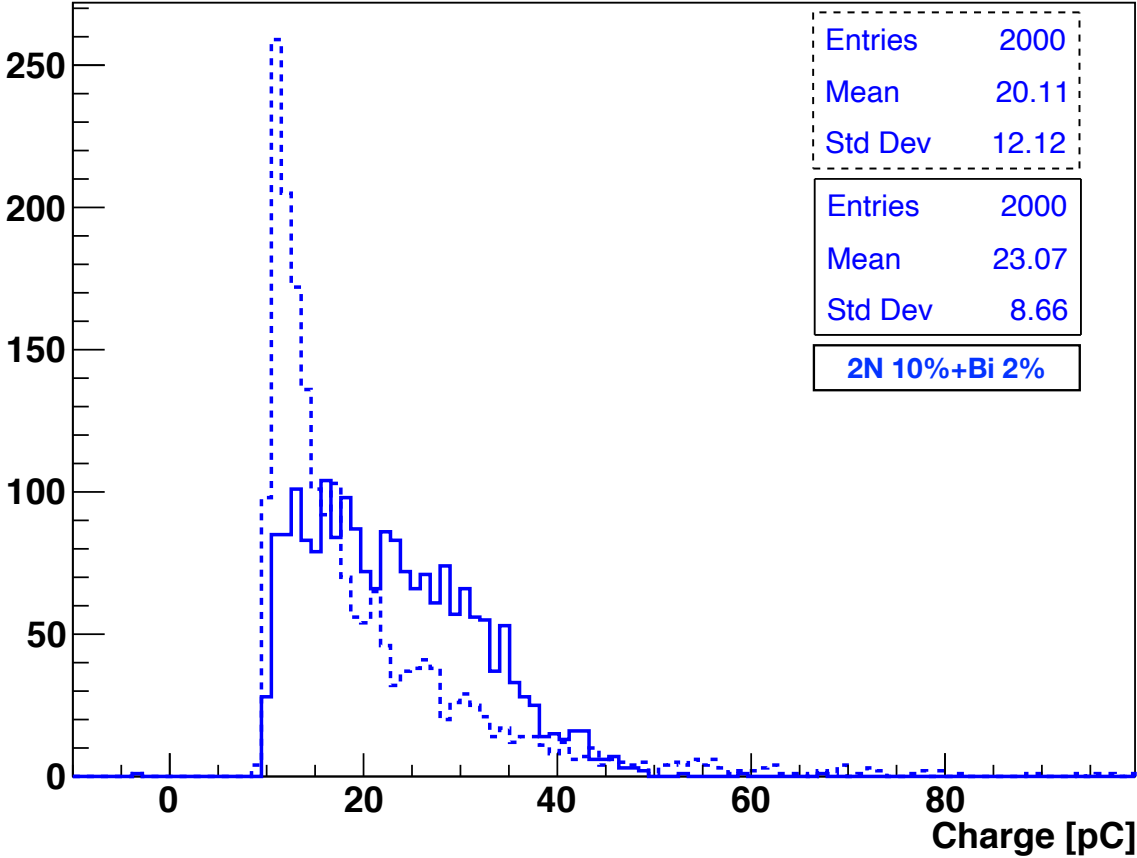
Salvo imprevisti, saremo in grado di consegnarvi il materiale tra fine novembre e inizio dicembre. Sarà mia cura contattarla all'arrivo della sorgente per prendere accordi sulla consegna. Rimango a disposizione per eventuali necessità di chiarimento. Cordiali Saluti

In the mean wile we are testing at least the light output of the samples..

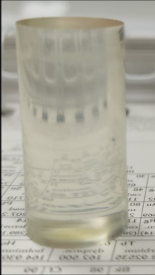


Hi-Z Scintillators

Test of light output with and without 90Sr source



EJ204/BC400



2N 10%+Bi 4%



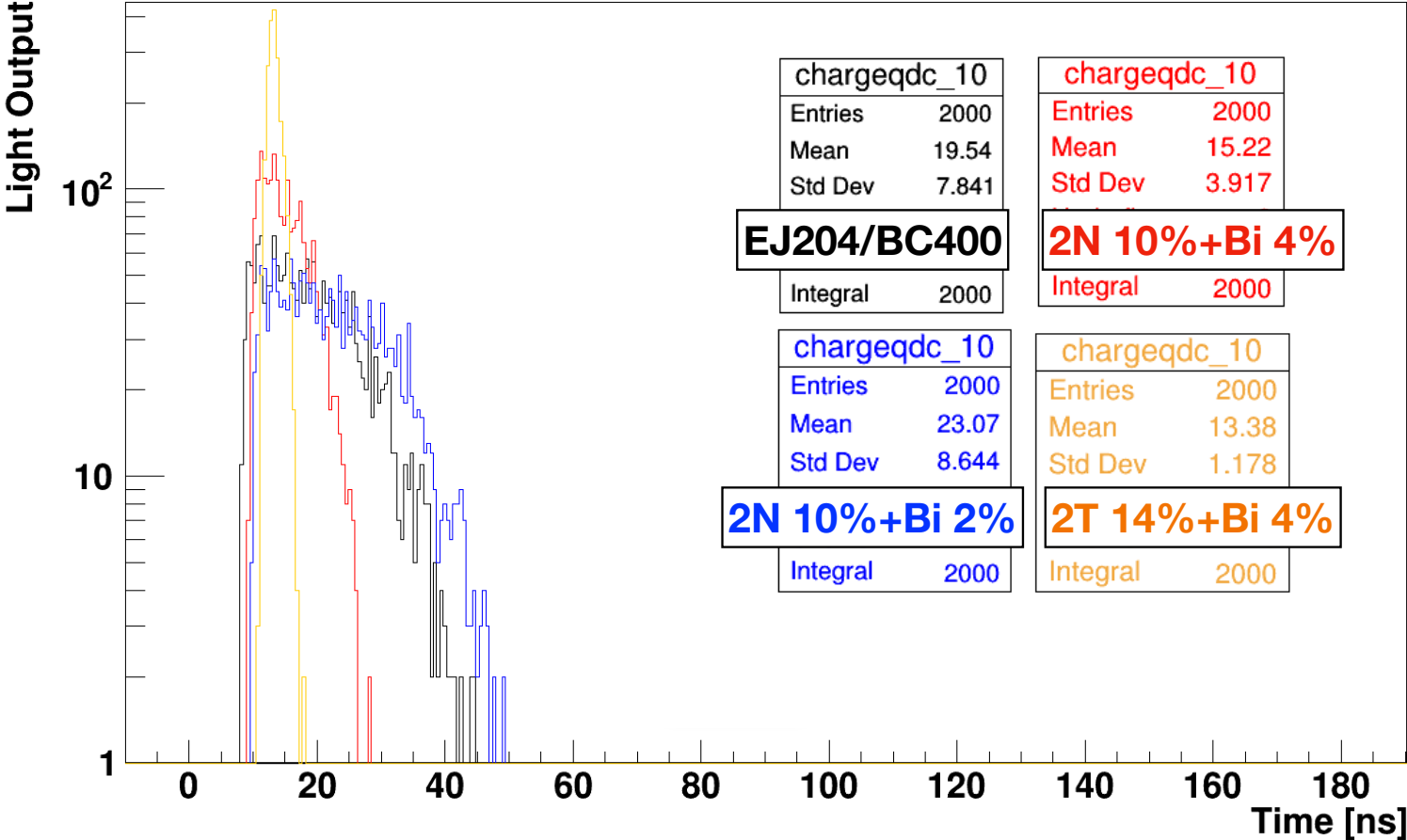
2N 10%+Bi 2%



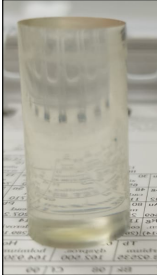
2T 14%+Bi 4%

Hi-Z Scintillators

Test of light output with and without 90Sr source



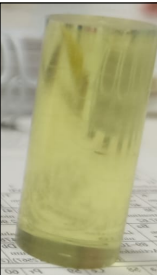
EJ204/BC400



2N 10%+Bi 4%



2N 10%+Bi 2%



2T 14%+Bi 4%

Hi-Z Scintillators

We are far from understanding if stuff are working.. but at least:

- ◆ We are able to produce samples of enriched hi-Z organic scintillators
- ◆ Exploiting our scintillators allows to mix staff easily
- ◆ Up to 4% we have no transparency problem
- ☑ There is an impurity in half of the Bi pivalato that we produced that has to be removed before producing more samples.

A new master student (Biomedica), Eleonora is working on it..

So.. at the end of the story

• Fast Timing Plastic Scintillators:

Patent under submission

Paper in preparation

Measurements at CNAO (November 2022)

I am my own master student.. can I have one? (Physics)

3DIT (3D printed scint.): no student but it is ok for now

• Hi-Z Plastic Scintillators

Work in progress


A new master student (Biomedica), Eleonora is working on it.

¹³³Ba source will arrive soon

• Additional ideas.. (not discussed today)

▶ particle identification (gamma/neutron): we have no time.. next in fashion

Poster IEEE2021



The 3DIT project: development of new plastic scintillator 3D printed

D. Rocco, Patrizia De Maria, Micol De Simoni, Marta Fischetti, Gaia Franclosini, Marco Magi, Leonardo Mattiello, Silvia Milana, Sivio Morganti, Vincenzo Petera, Valerio Pattrinacci, Daniele Rocco, Alessio Sartì, Adalberto Scubba, Marco Toppi, Giacomo Traini, Antonio Triglio, Angelo Schiavi, Michele Marafini

1 Milano, Istituto della Fisica e Centro Studi e Ricerche E. Fermi, Roma, Italy
2 Napoli, Università di Napoli, Dipartimento di Fisica, Napoli, Italy
3 Padova, Università di Padova, Dipartimento di Fisica e Astronomia
4 Dipartimento di Scienze e Ingegneria, Università degli Studi di Bari, Bari, Italy
5 Università di Firenze, Firenze, Italy

Organic scintillators consist of organic molecules and eventually a wavelength shifter (primary and secondary dopants) respectively, homogeneously dispersed in a transparent polymeric matrix, generally consisting of polyvinyltoluene (PVT) or polystyrene (PS). The main advantages of organic materials are fast time response, flexibility in manufacturing and low cost. Nevertheless, commercial plastic scintillators are not suited for very customized thin structures while, as to know, the 3D printer technique (laser, ceramic and polymer) exploited for the mechanical structures of the detectors, allows for high precision manufacturing (tolerances of few tens of μm).

The 3DIT project is a feasibility study dedicated to the R&D of fast plastic scintillators in polymeric matrices obtained by means of additive manufacturing.

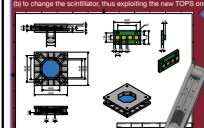
Scintillating materials, when crossed by ionising particles produce a scintillation light, generally proportional to function on the energy of the interacting particles, that can be detected with proper photodetectors. In order to match the photodetector optical detection efficiency the scintillators are tuned to produce light typically in the ultraviolet and/or visible energy range. Here in general, according to the applications, the materials are chosen in order to maximise different parameters, such as time response, and yield, detection probability, shape and cost.

The Time of Flight Plastic Scintillators (TFPS) is a new class of fast plastic scintillators [1]. The possibility of developing plastic scintillators with new resins has been demonstrated using a system of 4kV polymer matrix, loaded with various concentrations of scintillating compounds. Both liquid and solid compounds have been characterised in terms of transmittance and absorption with photoluminescence spectroscopy measurements. The samples of plastic scintillators showed excellent optical transparency, even at high concentrations. The samples of scintillators realised have been equipped with fibre photodetector tubes (PMT) and characterised in terms of light output and scintillation time with cosmic rays. A time resolution of ~30% better than commercial plastic scintillator (EJ232) has been obtained for the tested samples (see table below). Both liquid and solid samples have been tested with several sources of radiations (cosmic rays, gamma sources and ion beams) in order to characterise the light output of the scintillators coupled with commercial photomultiplier tubes. The samples show promising light output and excellent timing properties.

In the FDOT experiment the start detector for the time of flight (ToF) measurement is made of an ultra-thin plastic scintillator. The intrinsic time resolution is dominated by the scintillator characteristics. The nowadays best (fastest) plastic scintillators are EJ-232 (EJ) and BC-408 (BC) resin (Cobalt).


Up to now the performance obtained with an ultra-thin EJ-232 of 200 μm with an Oxygen beam of 400 MeV are a time resolution in ToF measurement of 25 ps. In the picture the start detector is shown, the scintillator in the center and its readout electronics.

In order to overcome the intrinsic limits it is possible to change the plastic of the detector (to optimize the efficiency in the light collection (see the geometry below), to change the scintillator, thus exploiting the new TFPS resin.

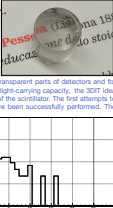


TFPS samples performances, readout with PMT H10721-20

Sample	Chemical	Concentration	Time Res. (ps)	Time Res. (%)	Light Yield (ph)
1	PS	0.05	2.5	15	231
2	PS	0.1	2.5	15	231
3	PS	0.2	2.5	15	231
4	PS	0.5	2.5	15	231
5	PS	1.0	2.5	15	231
6	PS	2.0	2.5	15	231
7	PS	5.0	2.5	15	231
8	PS	10.0	2.5	15	231
9	PS	20.0	2.5	15	231
10	PS	50.0	2.5	15	231
11	PS	100.0	2.5	15	231



First samples of this 3D printed plastic scintillator. The photo shows the 3D printed samples, which are transparent and easy to manipulate as they keep the fundamental characteristics of the 3D resin. The work is in progress.



Currently, means that can be processed through 3D printing and integrated according to the mechanical/physical constraints. These peculiarities are fundamental to ensure the optimisation in terms of detector and geometry efficiencies. The characterization studies of the 3D transparent resin base are of great interest to the resin and 3D printer manufacturer, who already see a considerable market prospects that could be further extended. The definition of optimised chemistry and geometry, supported by a complete thermo-mechanical and radiation hardness characterisation would open new frontiers both from an experimental and industrial point of view. The feasibility of an additive manufacturing of plastic scintillators will be investigated by 3DIT. It will be possible to imagine a multi-material 3D process, opening the way to multiple applications, from the particle physics full detector up to military, security and medical devices radiation.

From mechanical material is generally required to realise 3D print transparent parts of electronics and for prototyping, as it has interesting optical properties with good light carrying capacity, the 3DIT idea is to exploit it as a transparent material that simulates the solvent of the scintillator. The first attempts to dissolve the fast organic scintillator in the MecChar material have been successfully performed. The samples have been polymerised by UV irradiation.

The samples of scintillators obtained in MecChar liquid and polymerised by UV, have been matched with minimum losses (partially in MecChar resin). The light output of the first prototype obtained with multi-irradiation is shown in Figure. The background contribution has been superimposed (dashed line) to the signal (black line). The energy loss (Edep) of the muon is clearly contributing to the scintillation response with its typical ionisation shape.

Acknowledgement: The project has been supported by INFN University 2020 call for research, F4N, INFN, Sapienza University of Rome.

References: [1] Misabel, R., Belandier, A., Mattiello, L., Marafini, M., Rocco, D., Sartì, A., Scubba, A., Ribba, C., Traini, G., Petera, V. TFPS project: Development of fast timing plastic scintillators. In: NUOVO CIMENTO C, 2020 - ISBN: 2527-4009 - (presented at: FATA 2019, Acqueve, Italia) [1] www.mstbary.com/mattiello/scaricaveriscint

MICHELA

