New Fast Timing Plastic Scintillators with the TOPS Project

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Fast Timing Applications
for Nuclear Physics and Medical Imaging
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Time Of flight Plastic Scintillators: TOPS

- **TOPS project** joint effort of chemistry, physics and engineering researchers of SBAI departments. Development of a new class of plastic scintillators;

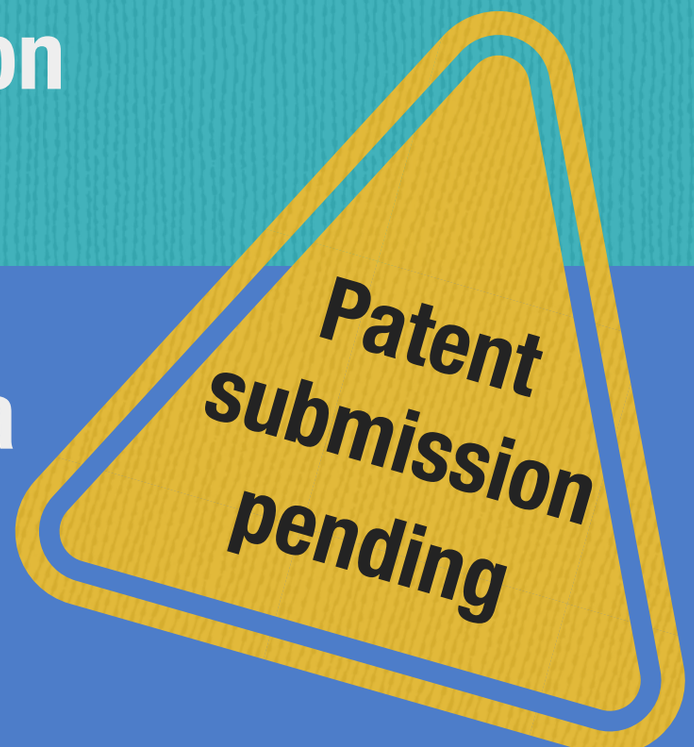
- Comparison of the light output and timing properties with cosmic rays. A commercial plastic scintillator BC-412 and an antracene samples have been used as a reference;

- Two TOPS samples have been irradiated with protons at different energies (70-220 MeV) at CNAO;

- First concentration studies and calibration with sources with one of the most promising new scintillator.

Time Of flight Plastic Scintillators: TOPS

- New TOPS molecules are under submission for a patent application.

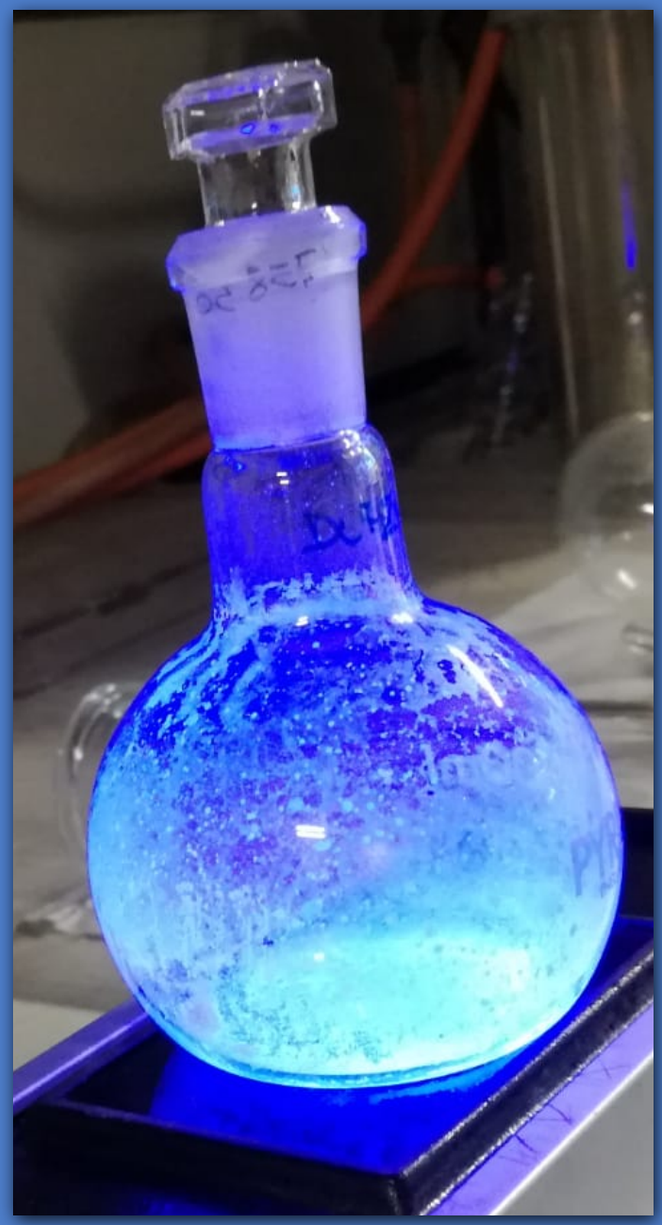


- The composition and the chemical formula of the new organic molecules can’t be shown.

- In this presentation, the scintillators are been named with a code (letter+number) without any meaning!
  Ex: 2N, 2B, T2, 1N, P2…

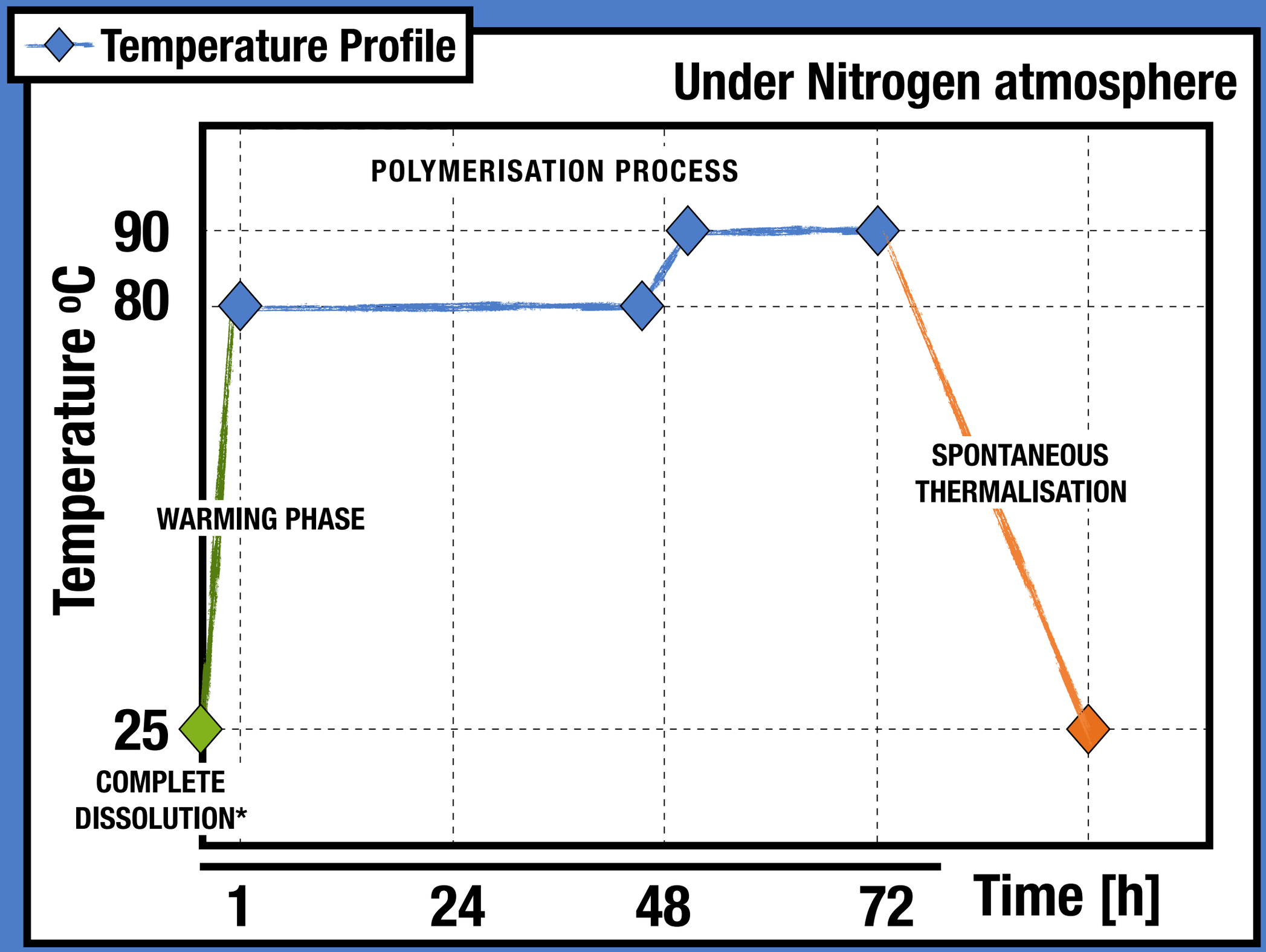
Plastic Preparation

New organic molecules, containing aromatic fragments, have been synthesised as organic scintillators. The scintillator molecules have been tested by Nuclear Magnetic Resonance (NMR) in order to confirm the intrinsic structure of the samples.



The possibility of developing plastic scintillators with our molecules was demonstrated using a system of a polyvinyl-toluene (PVT) polymer matrix loaded with various concentrations of scintillating compounds.

Plastic Preparation

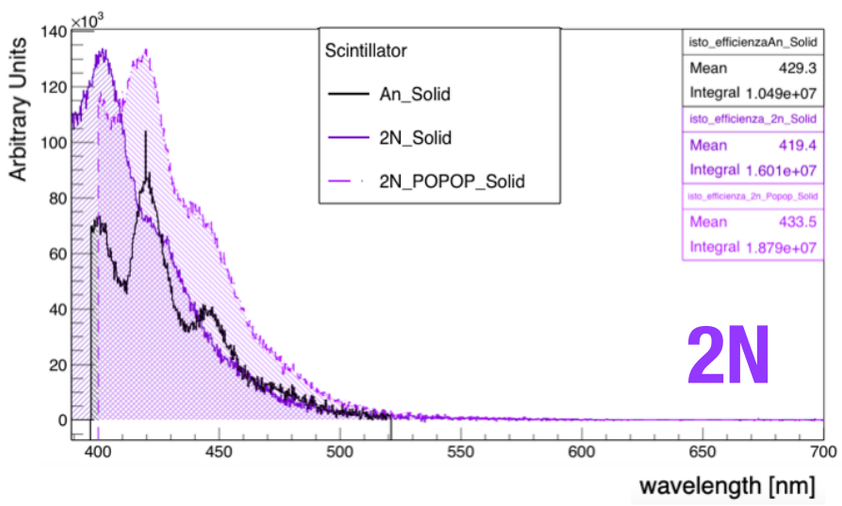


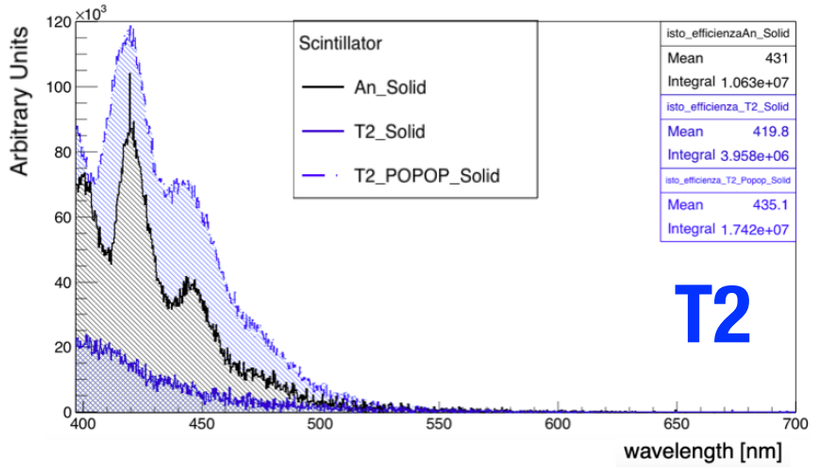
* the dissolution occurs at room temperature

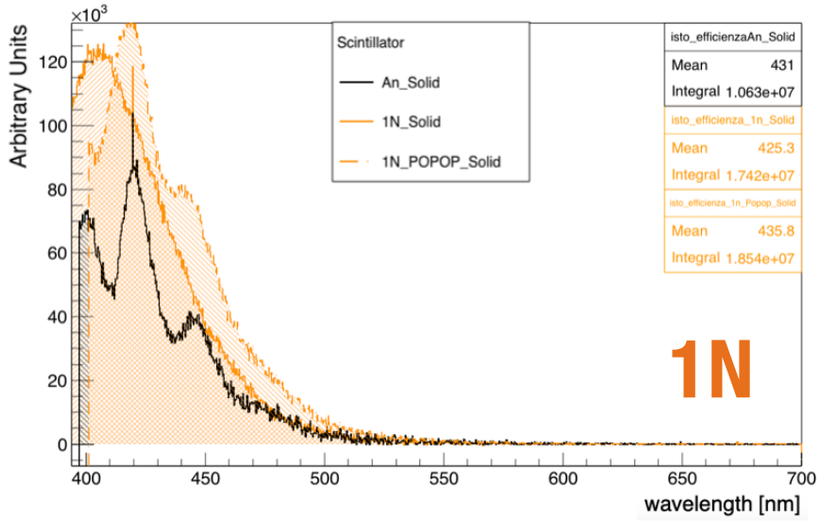
Plastic Preparation

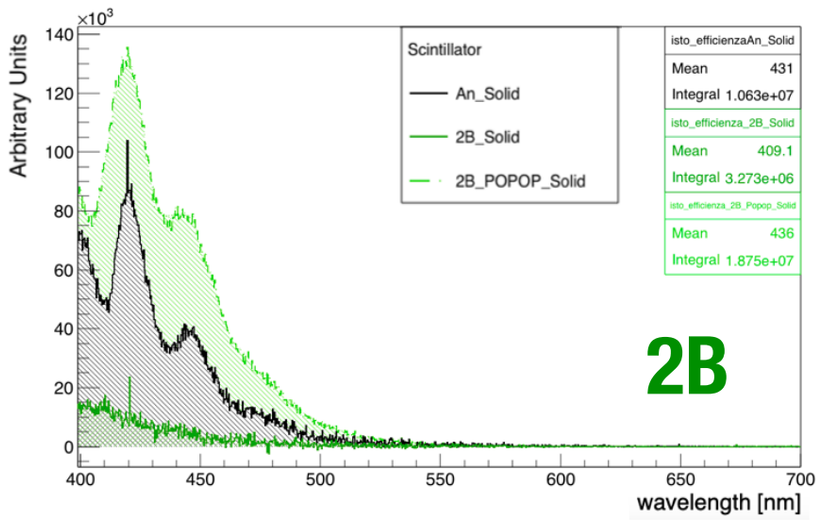
In order to improve the matching between the emission/absorption spectra of the scintillators, doping materials have been added as a wave-shifters, DPB and POPOP). For a fraction of the new scintillators the POPOP doping improved the performances in terms of light output.

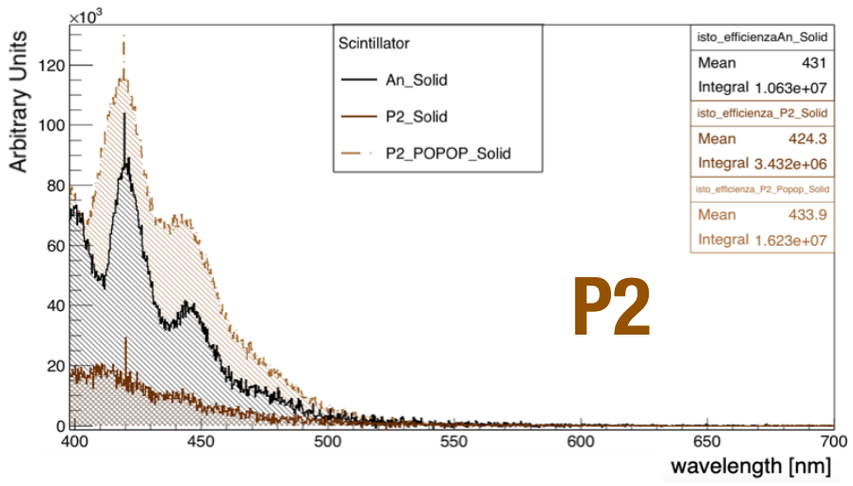
- **DPB (1,4-Diphenyl-1,3-butadiene)**
- **POPOP (1,4-Bis(5-phenyl-2-oxazol-2-yl)benzene**

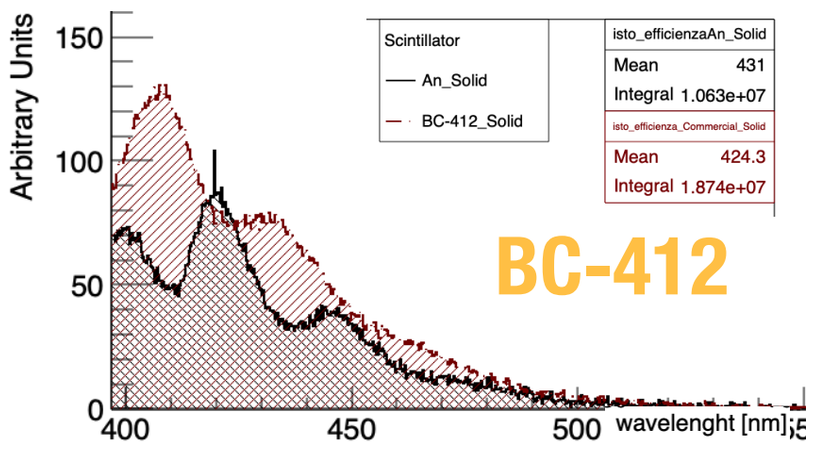












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The new plastic scintillator samples have been characterised in terms of transmittance and emission with photoluminescence spectroscopy measurements.

Plastic Preparation

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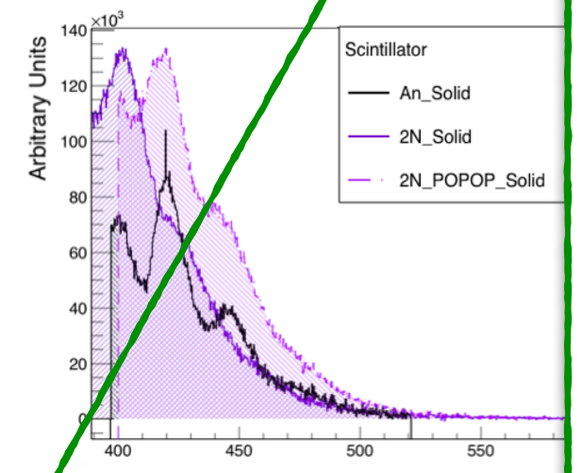

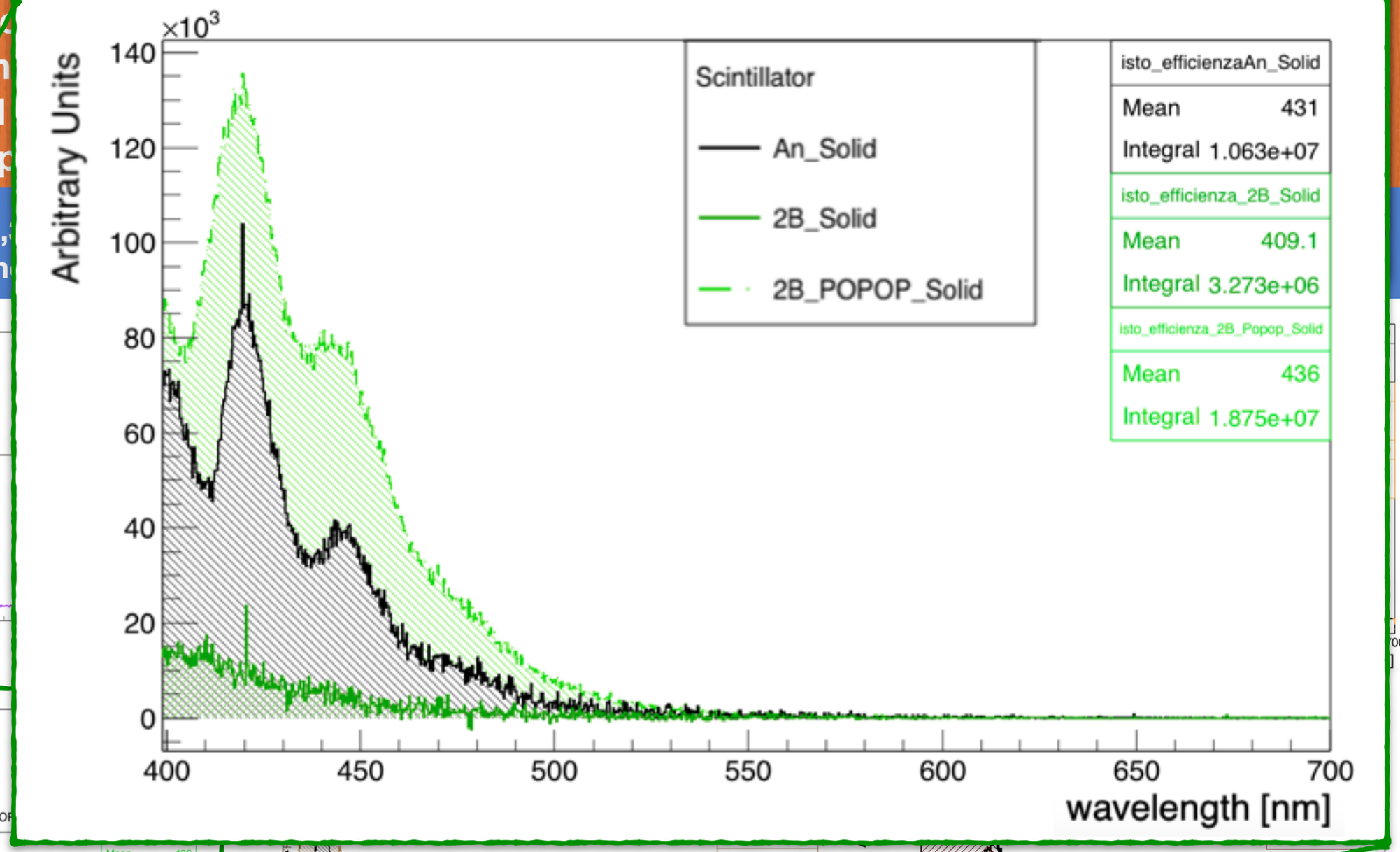

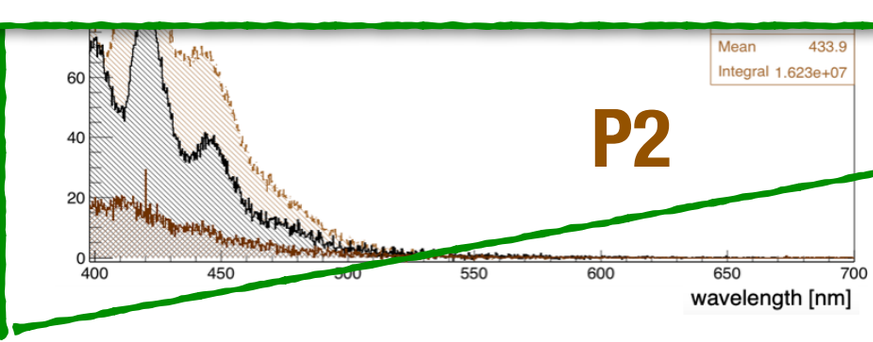

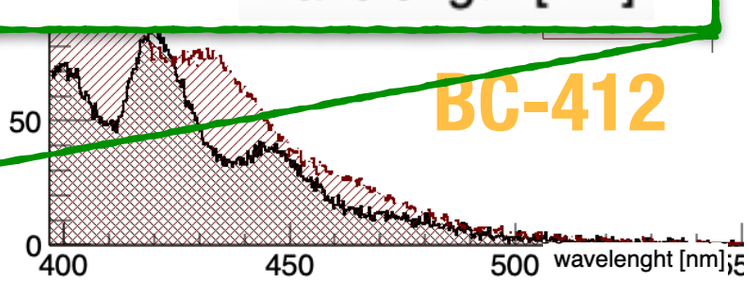

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The new plastic scintillator samples have been characterised in terms of **transmittance** and **emission** with photoluminescence spectroscopy measurements.

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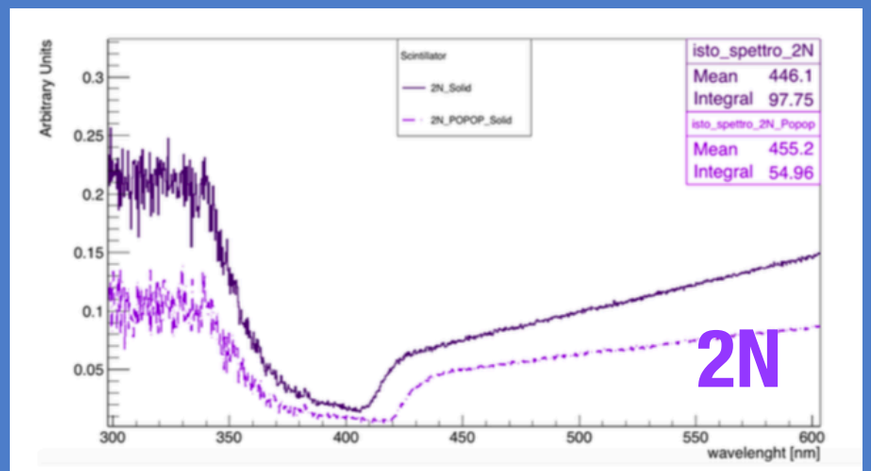

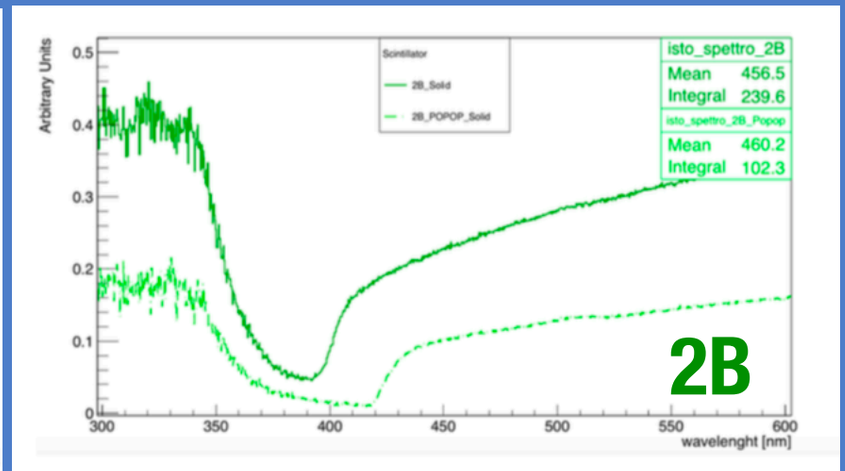

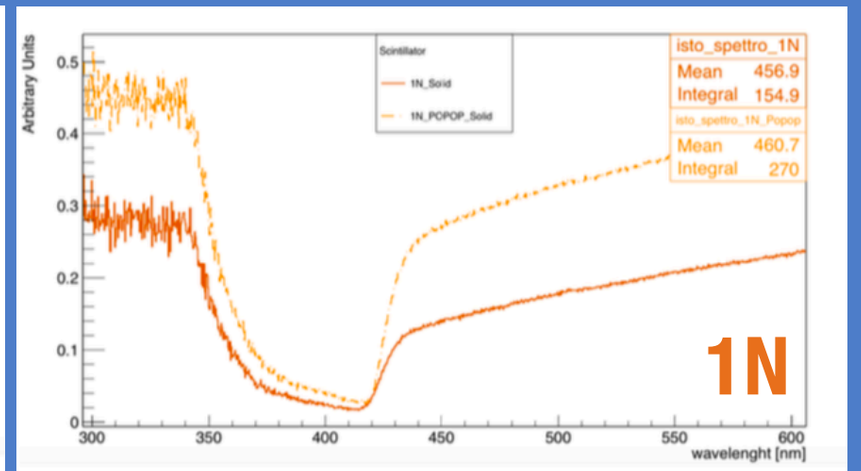

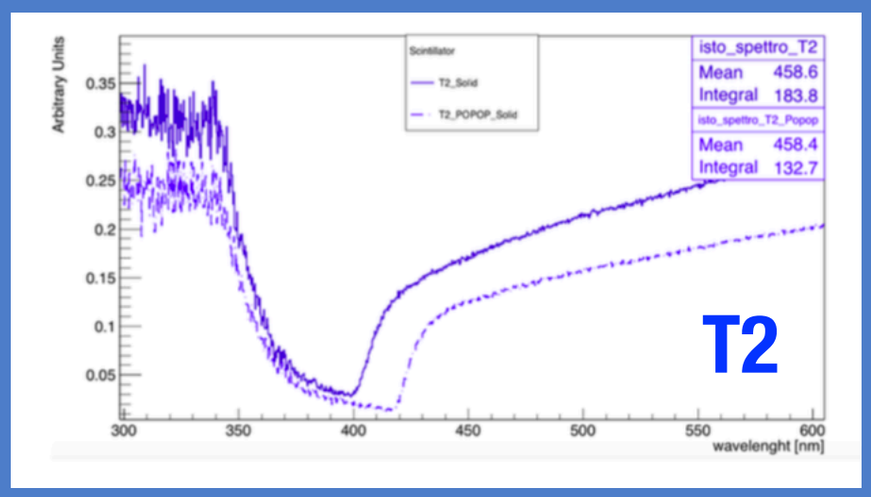

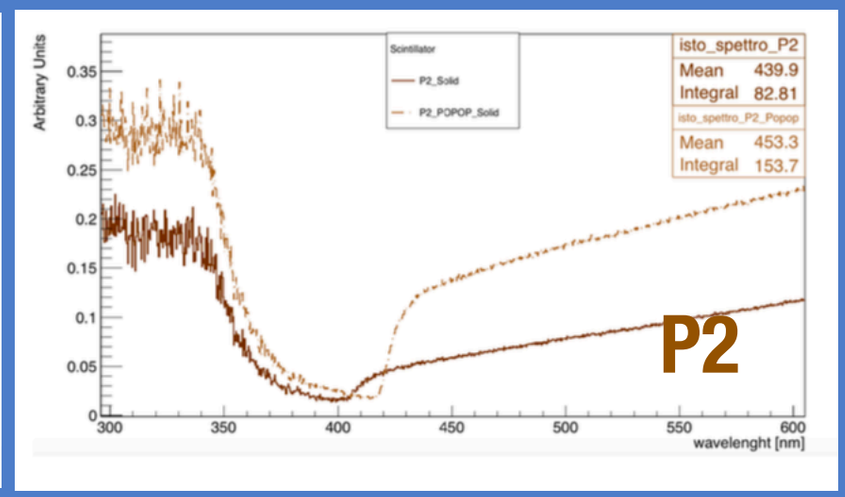

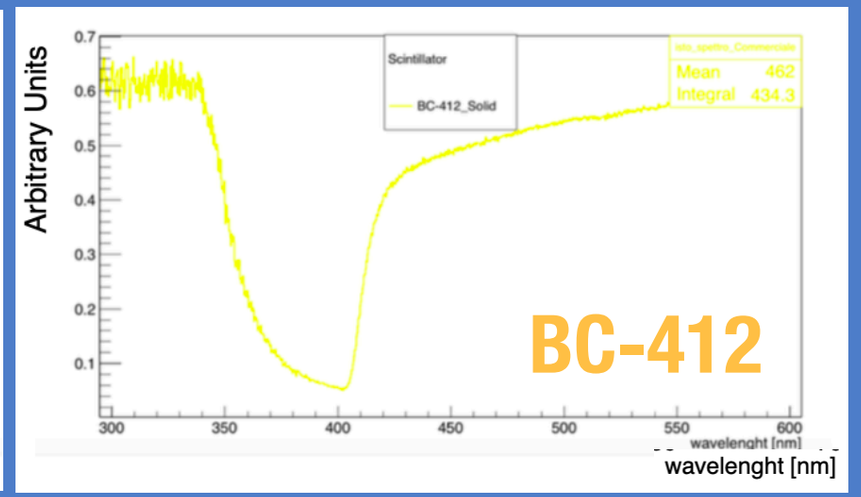

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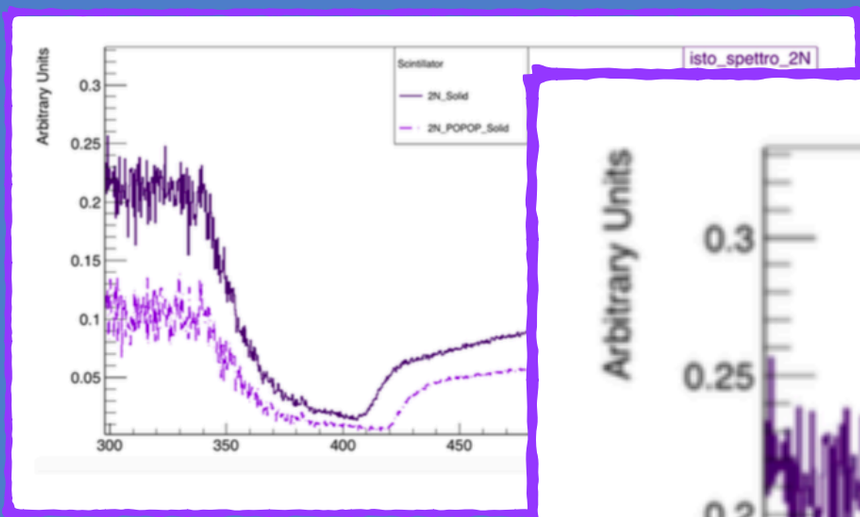

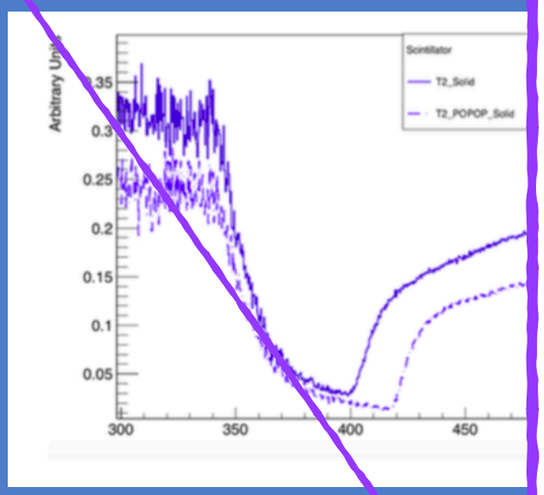

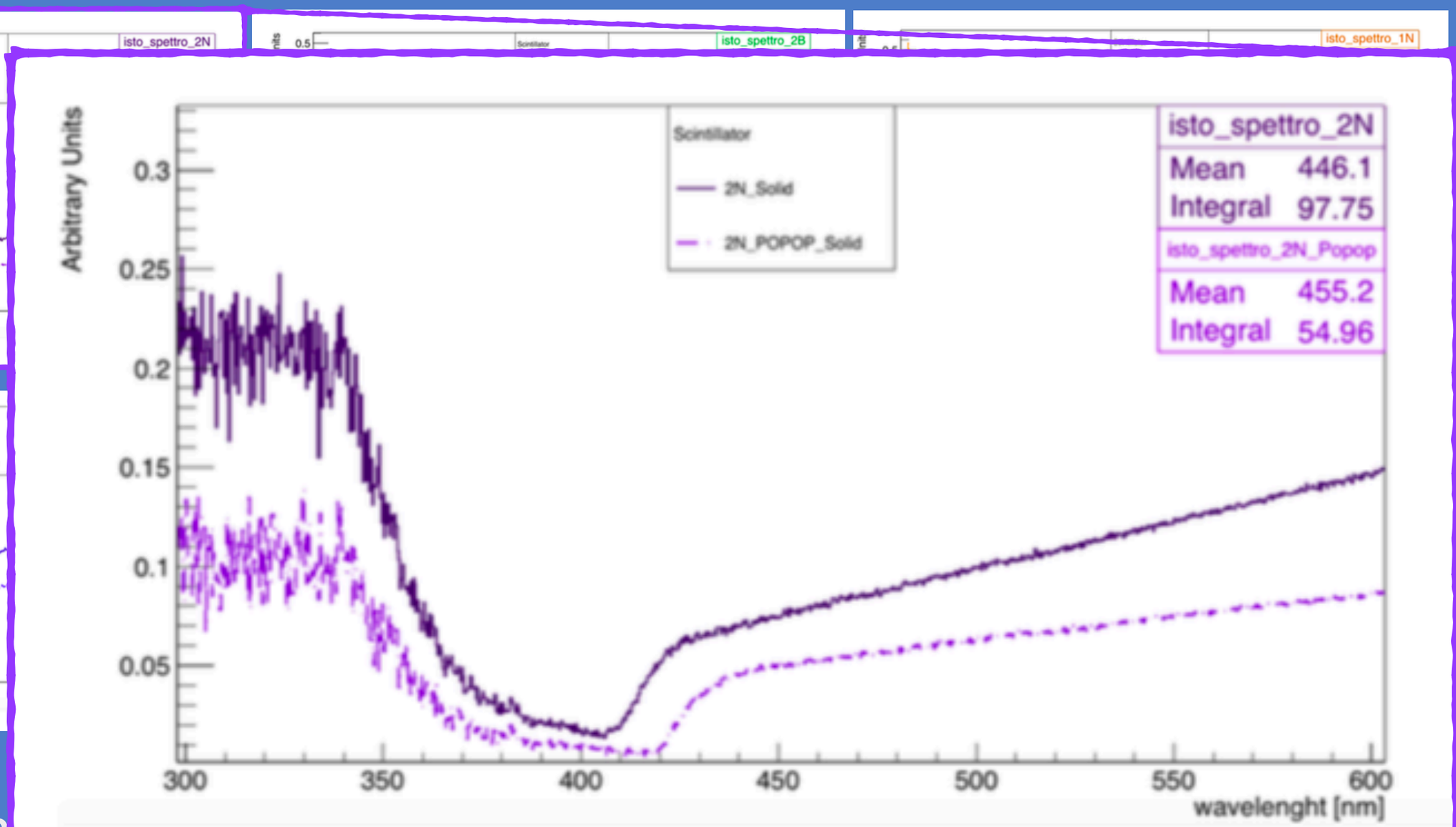

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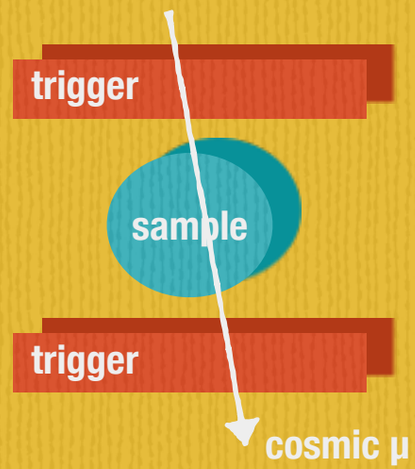
and emissi

Sample characterisation

Both liquid and solid samples have been tested with cosmic rays (mip) and the light output produced by ionisation in the scintillators has been collected with a commercial PMT.
Cosmic rays has been chosen for preliminary characterization because represent the worst situation in term of ionization.



Measurement performed:

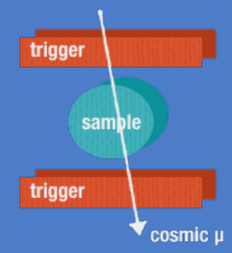
- Light Output
- Time resolution
- samples comparison

Experimental Setup

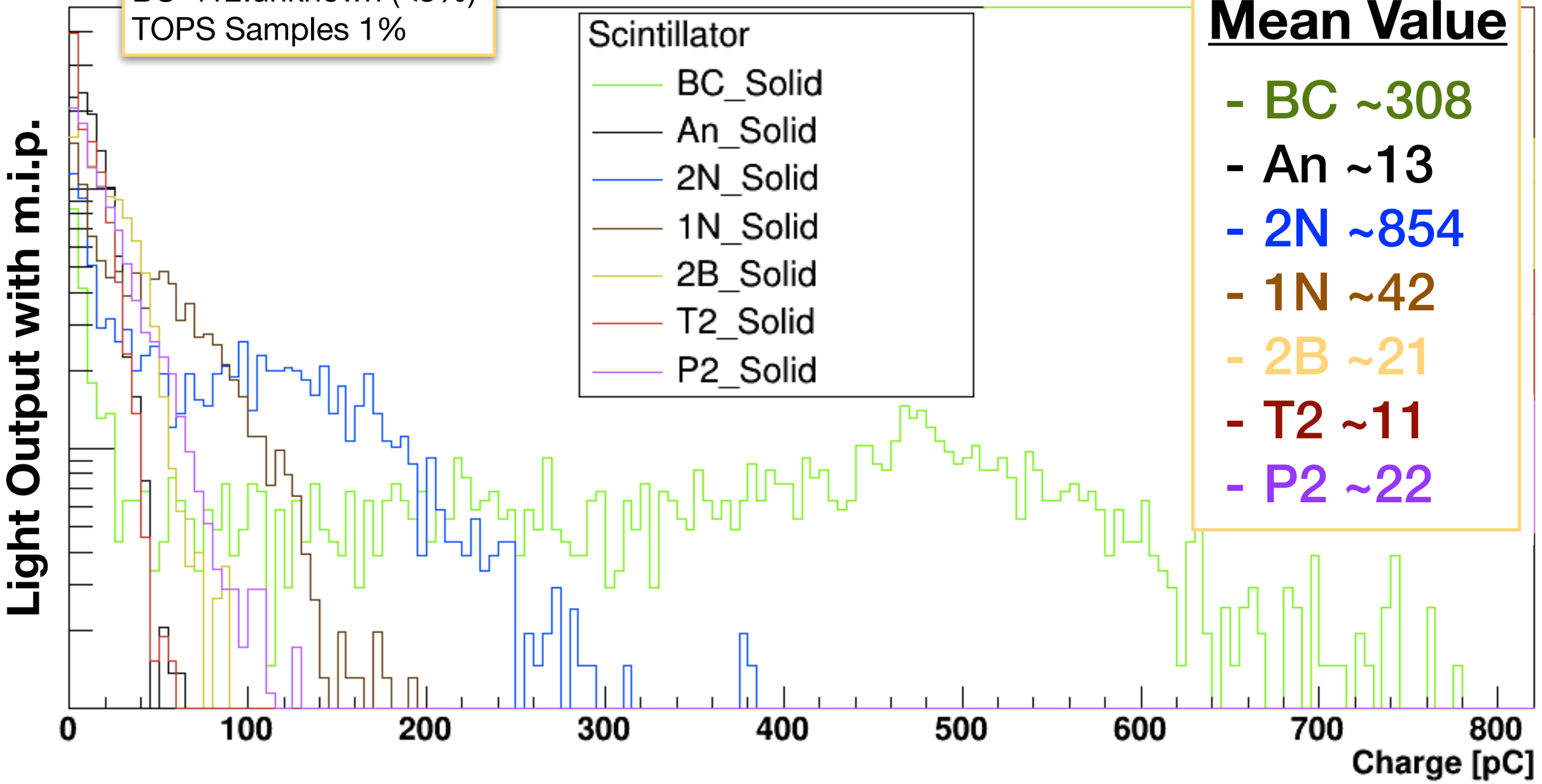
- External trigger for cosmics
- Daq VME:
  - ✦ QDC V792N (12 bit)
  - ✦ TDC V1290N (25ps)
  - ✦ Waveform Digitizer V1742 (2.5Gs/s)
- PMT XP1911 PHOTONIS risetime ~2.3 ns

On going work .. the samples characterisation is still in progress!!

Light output evaluation



Concentration:
BC-412:unknown (<3%)
TOPS Samples 1%

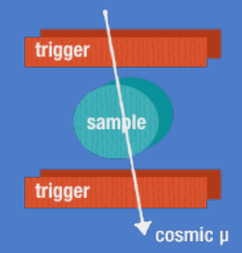


Mean Value

- BC ~308
- An ~13
- 2N ~854
- 1N ~42
- 2B ~21
- T2 ~11
- P2 ~22

As expected the commercial scintillator shows much better performances, however it has to be stressed that the TOPS scintillators are not jet optimised in terms of concentration and transparency.

Light output evaluation



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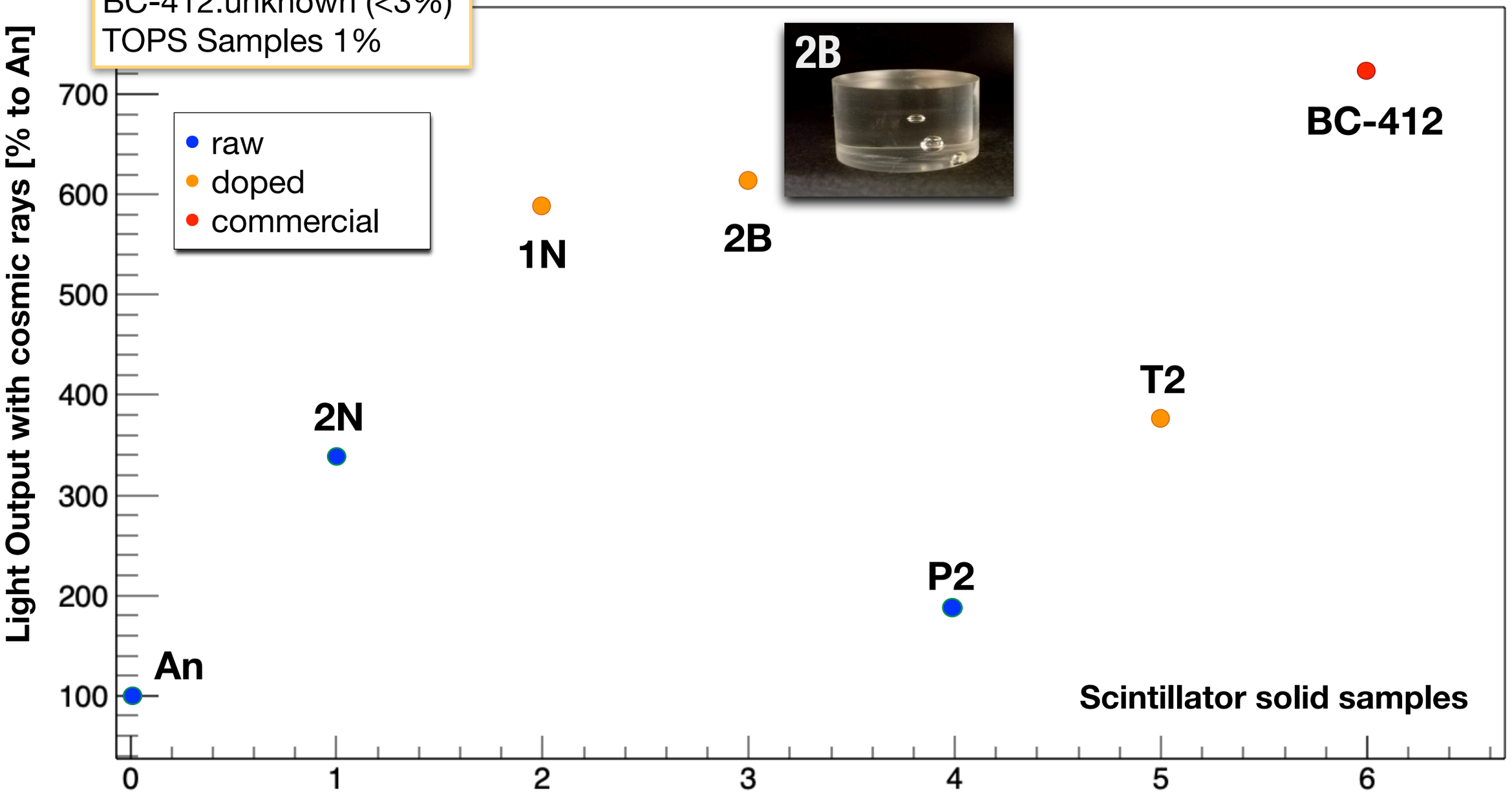
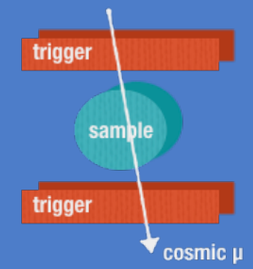


The 2N sample is less transparent than, for example the 2B, however it doesn't need any dopant to reach important light output values. A concentration study has been then performed.

Timing properties evaluation



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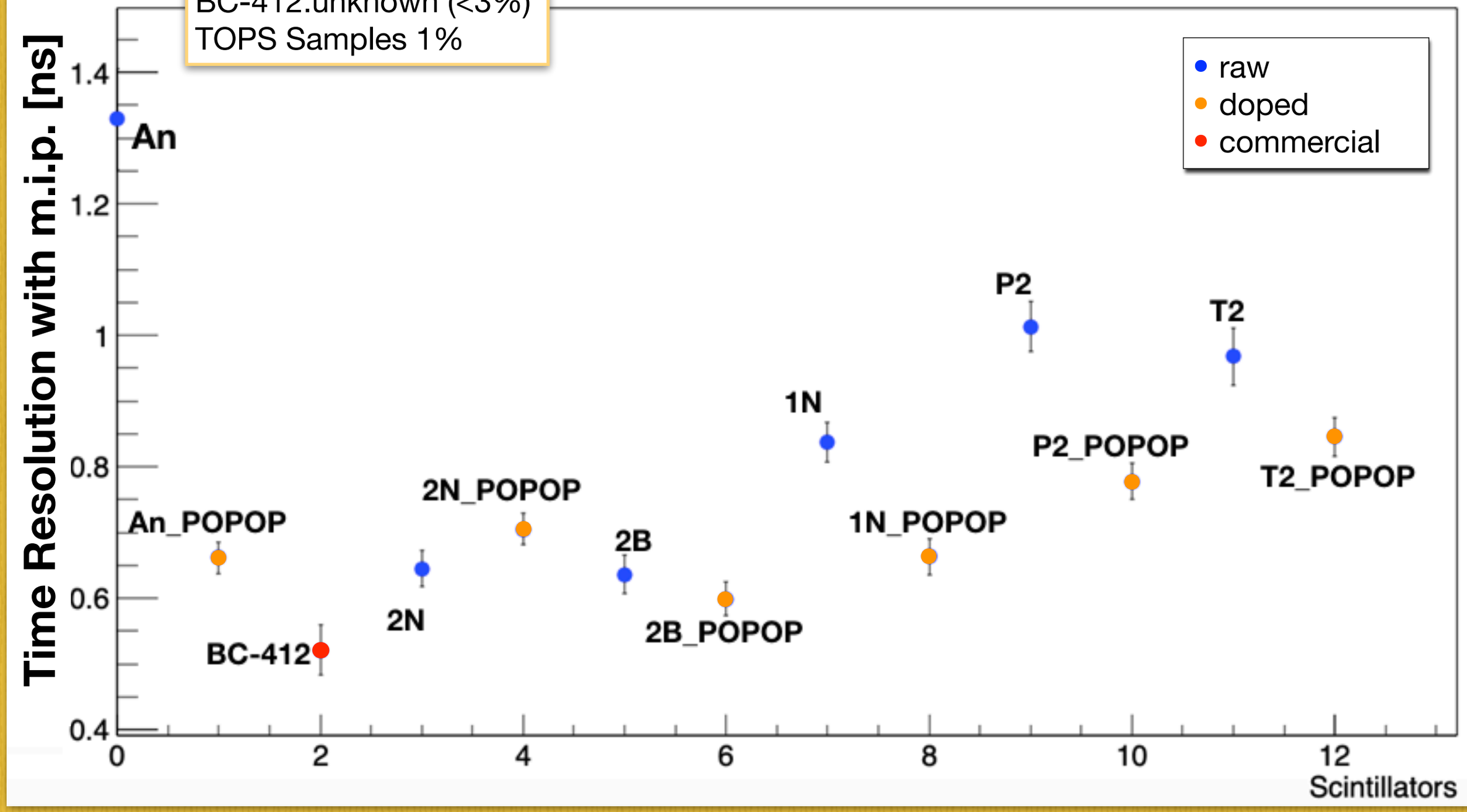
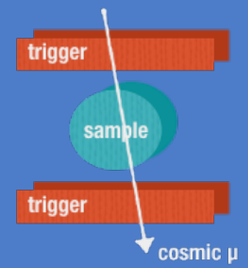


A very promising time resolution of ~ 600ps for 2N e 2B (BC-412 500ps) is obtained with this readout and setup. A preliminary time characterisation has been performed for those two samples.

Timing properties evaluation



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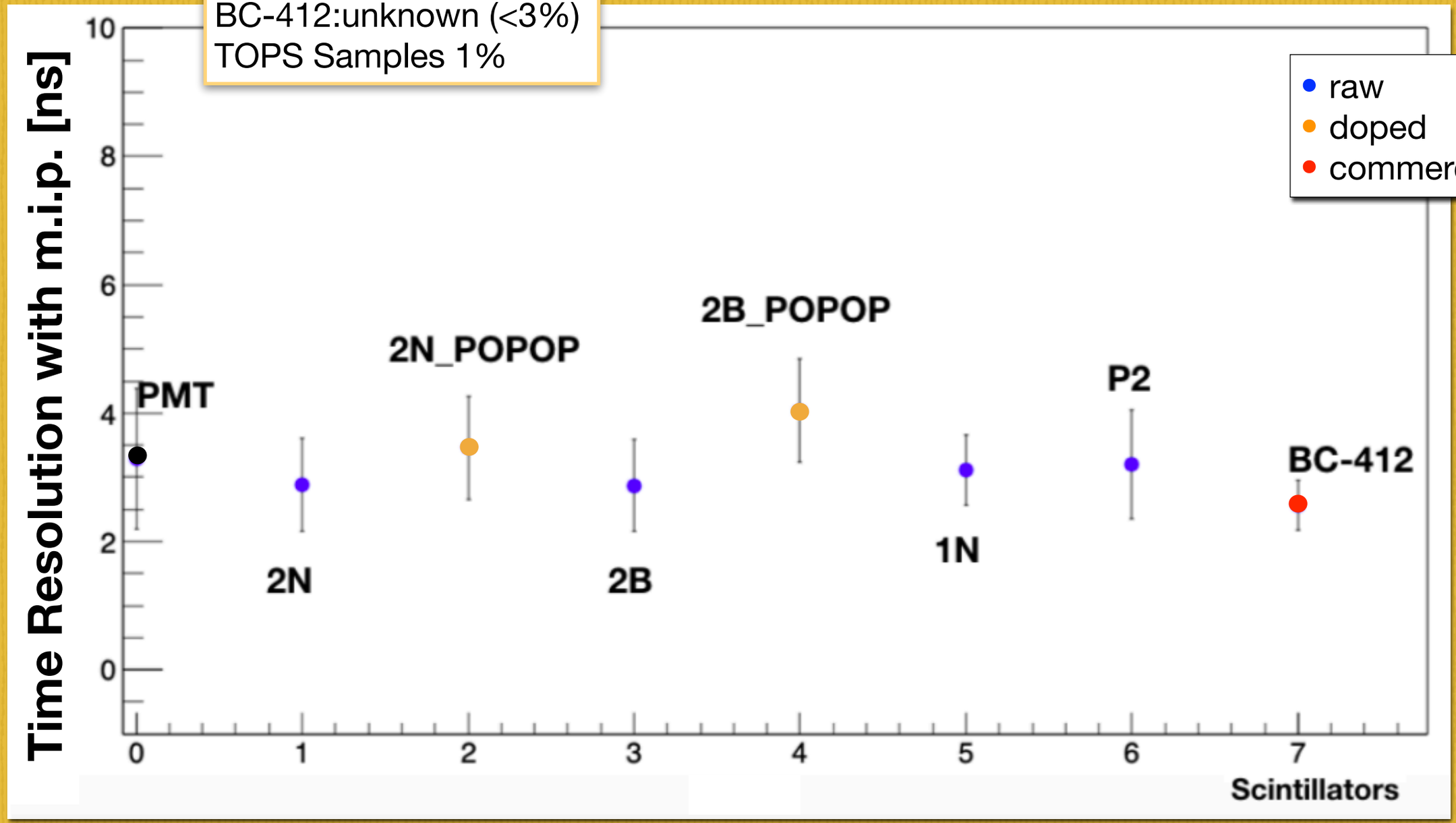
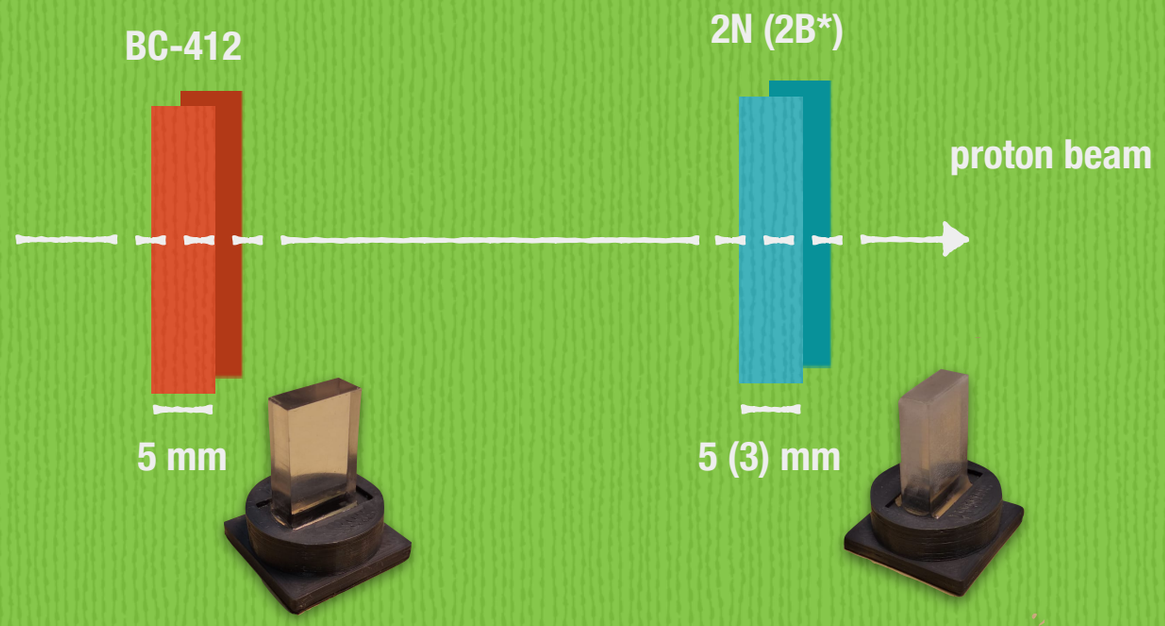


The waveform analysis shows that the rise times of the samples were dominated by the electronics capability (i.e. the pmt rise time) => for further analysis a more performing PMT will be employed.

Test Beam with protons

- 2N and 2B* has been tested with proton at CNAO
- Time measurement with a more ionising particle at different energies in order to study an higher energy release in the samples

Test Beam with protons

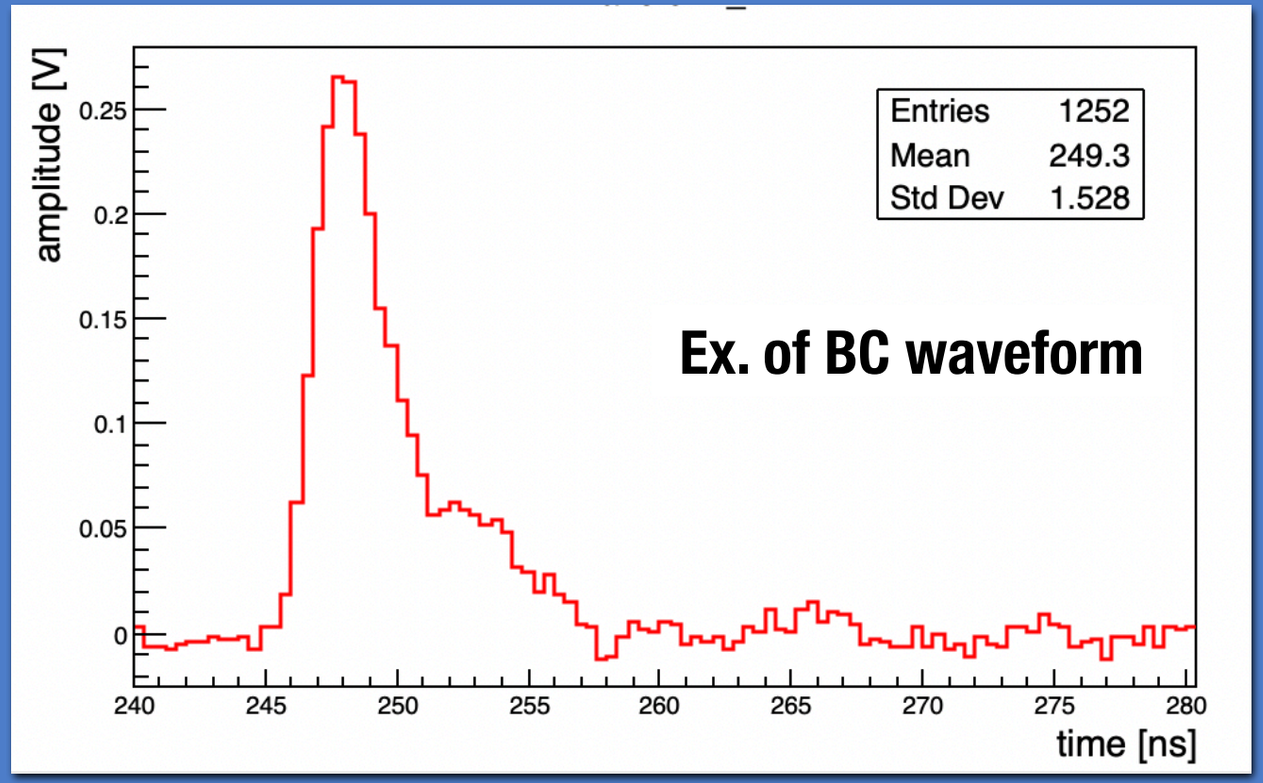


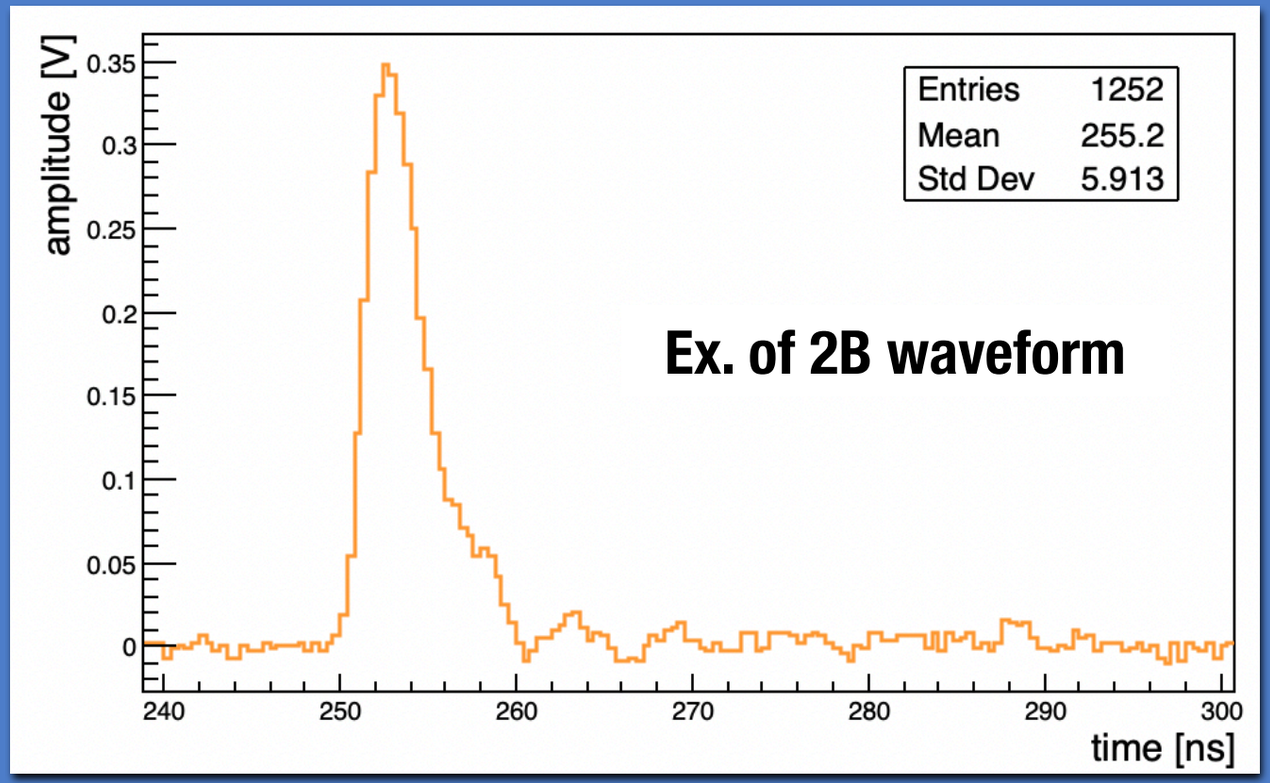
Proton beam@CNAO:

- energy 70- 220 MeV
- sigma ~1cm

Experimental SETUP:

- PMT H10721-210, risetime ~0.57ns
- DAQ LeCroy HD06104-MS 2.5Gs/s





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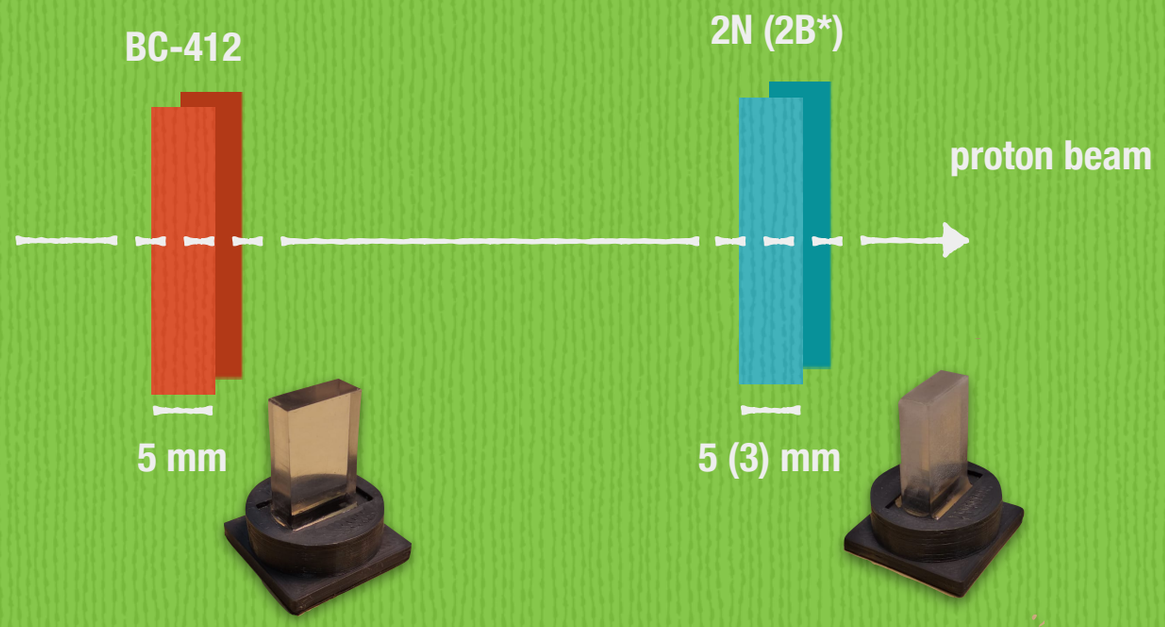

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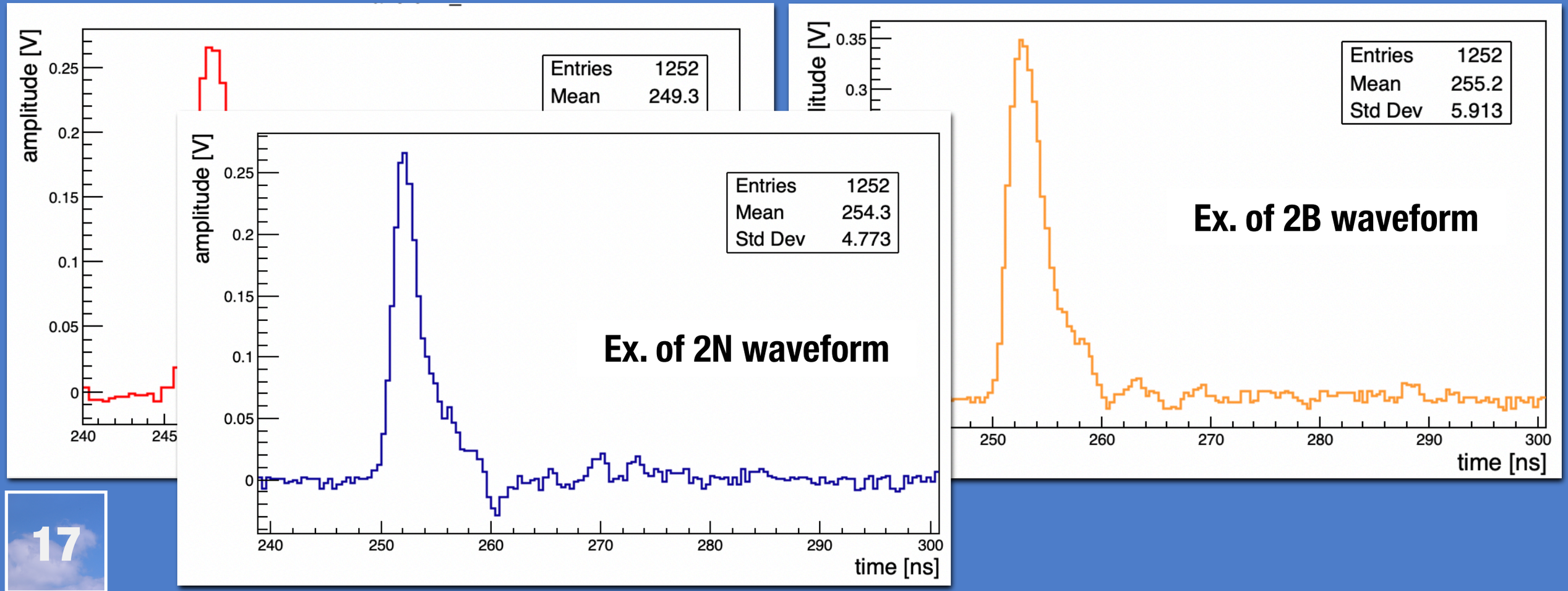

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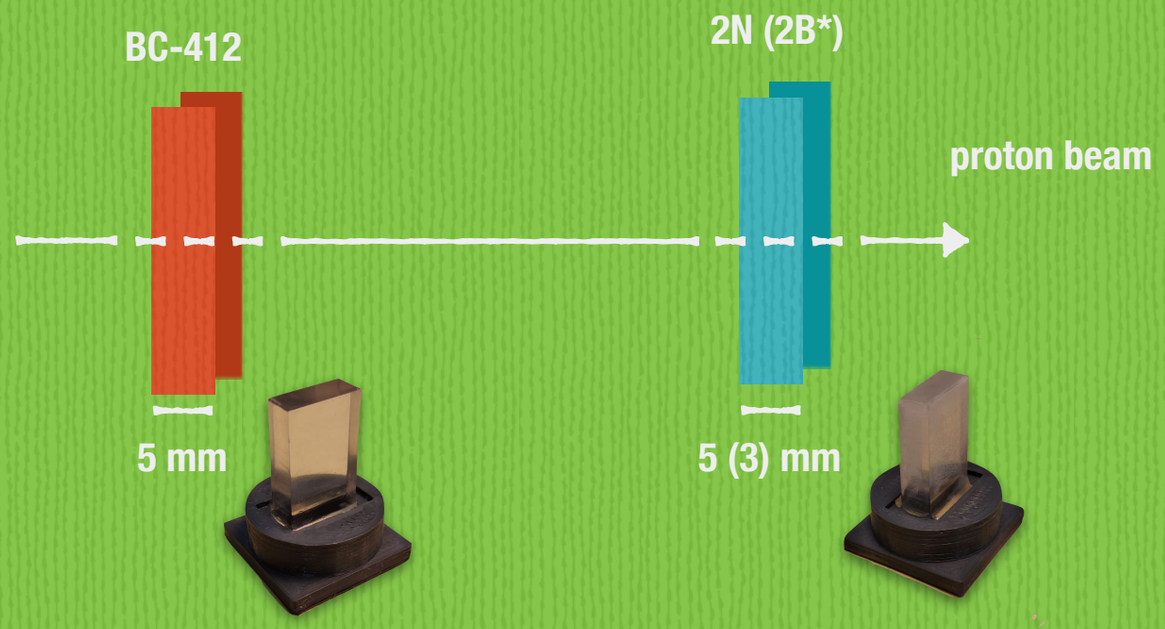

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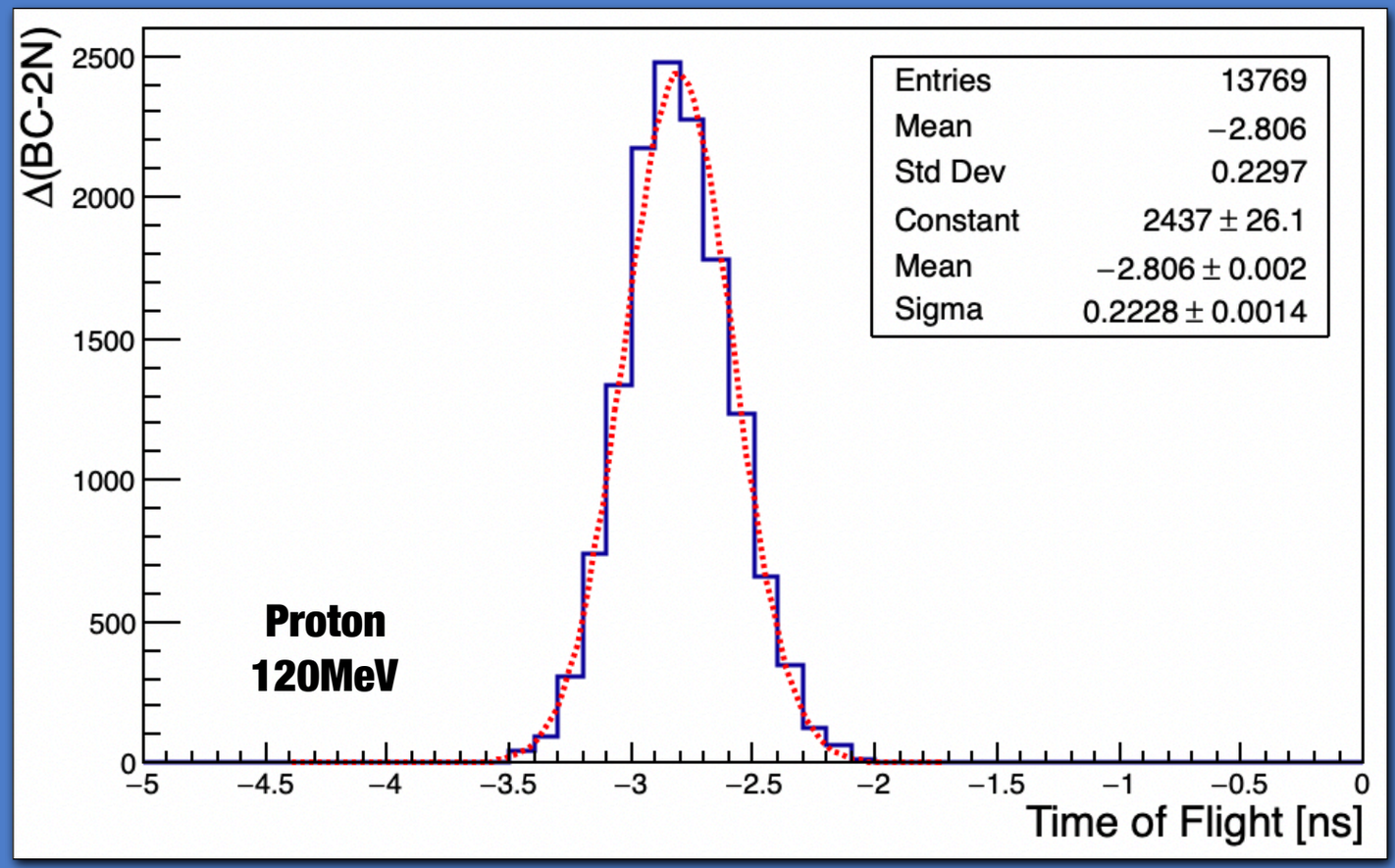
Measurement of Time Resolution in proton Time of Flight (ToF)

$$\sigma_\Delta = \sqrt{\sigma_{BC}^2 + \sigma_{2N(2B)}^2}$$

Upper limit on the new scintillators ToF resolution



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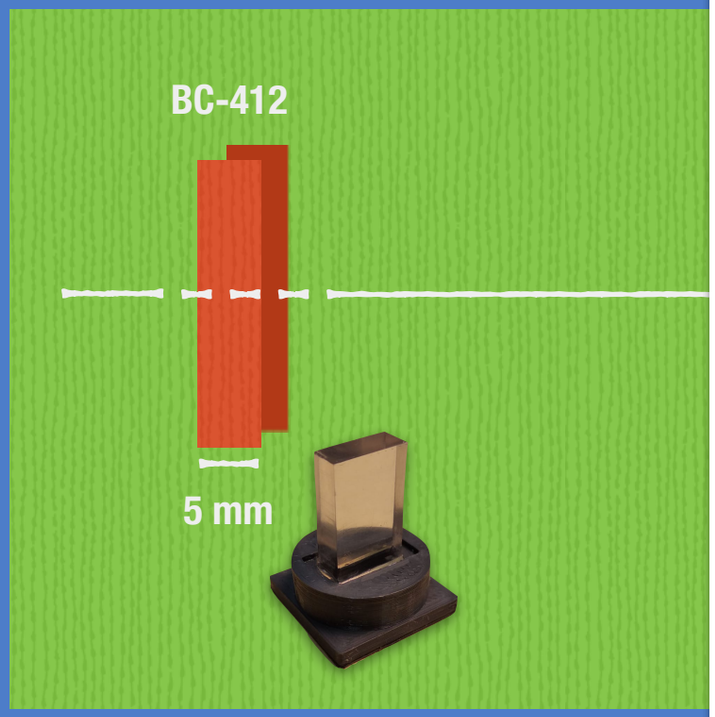

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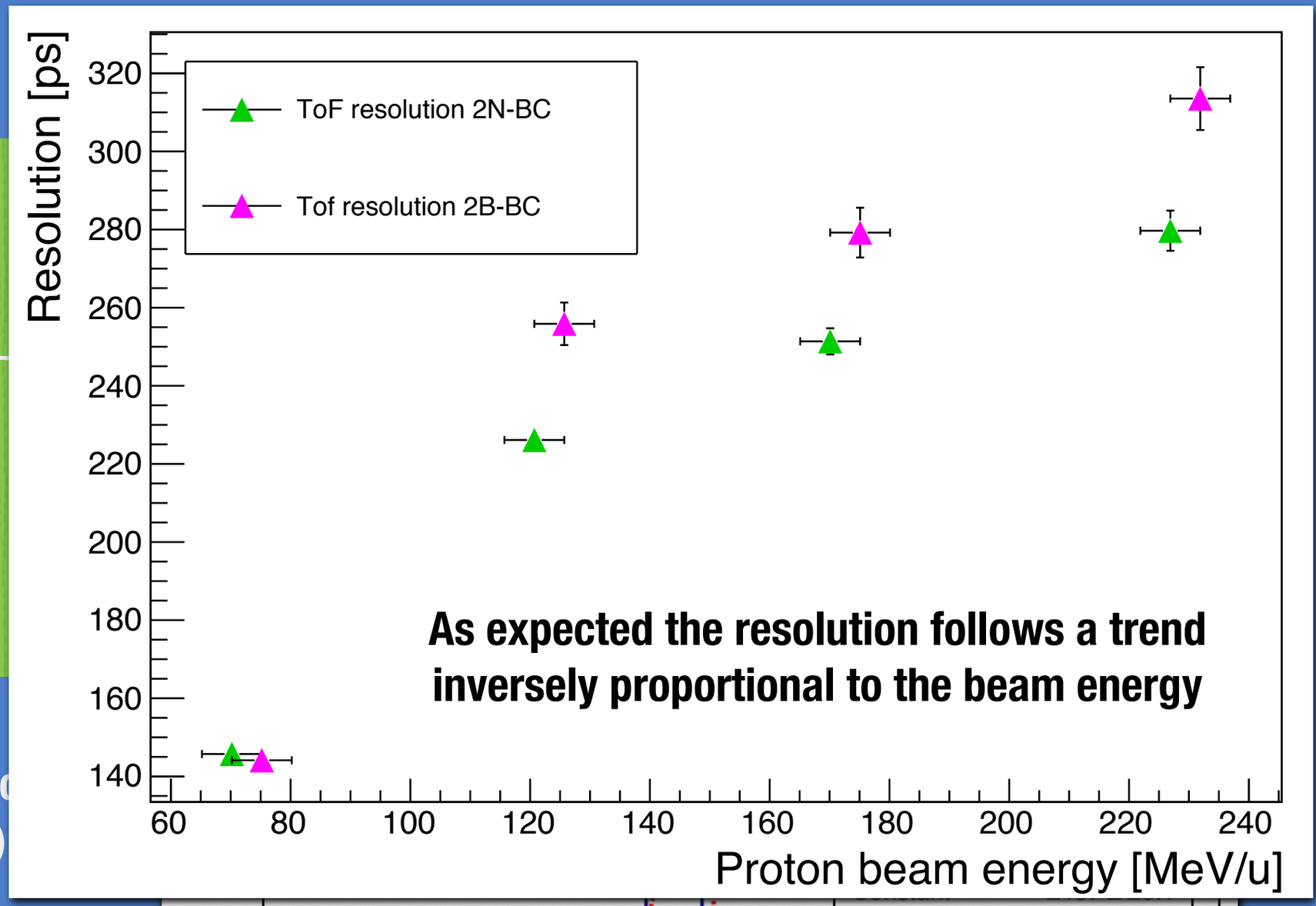

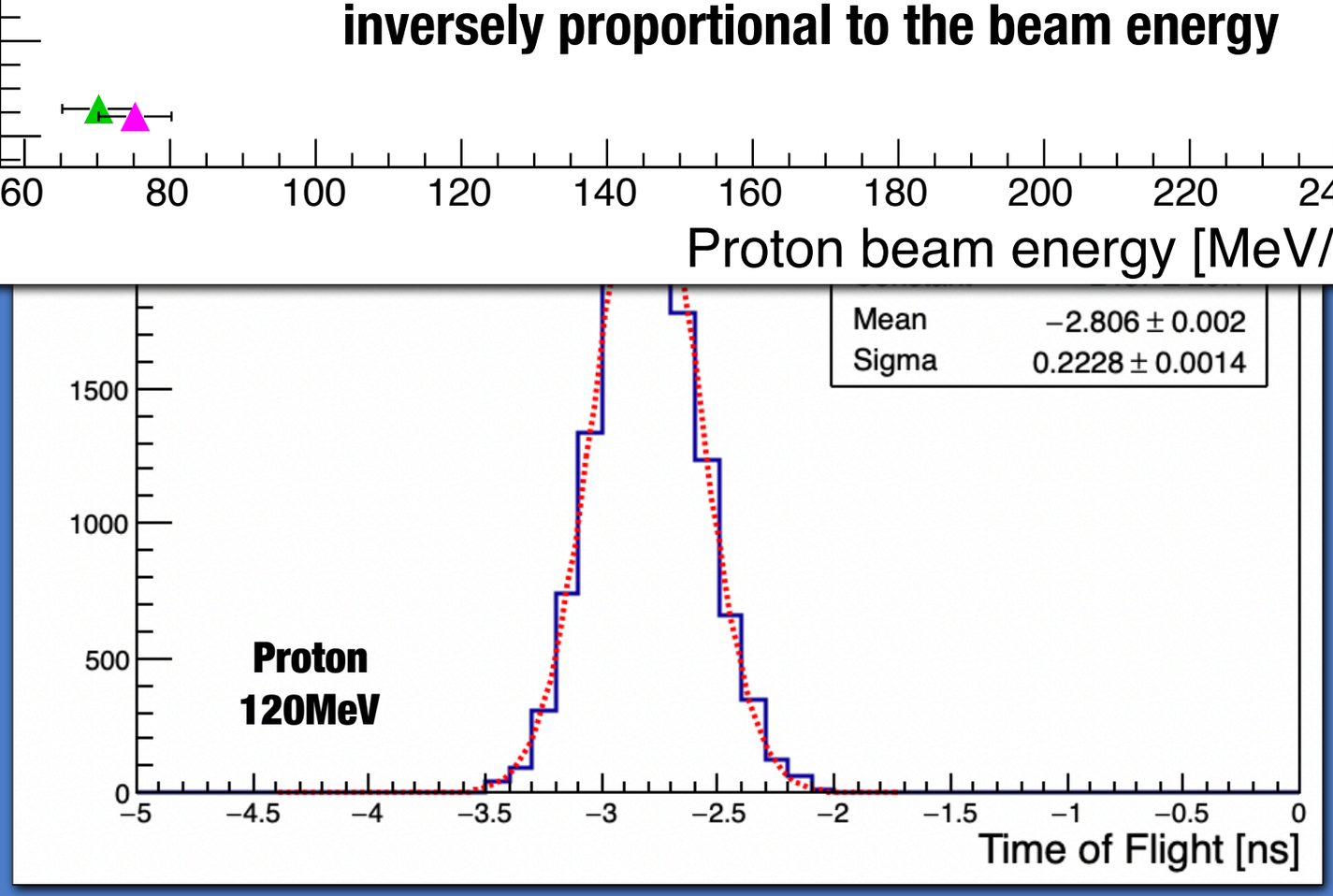

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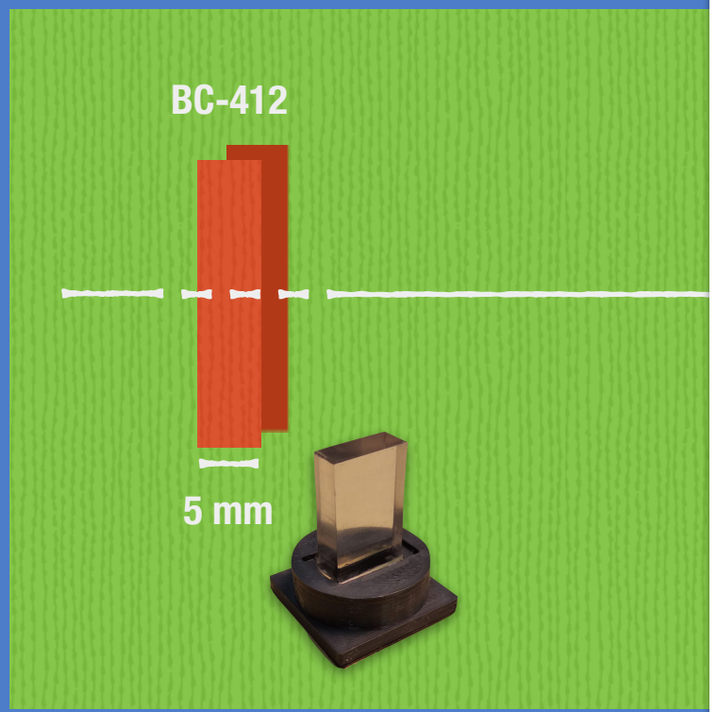

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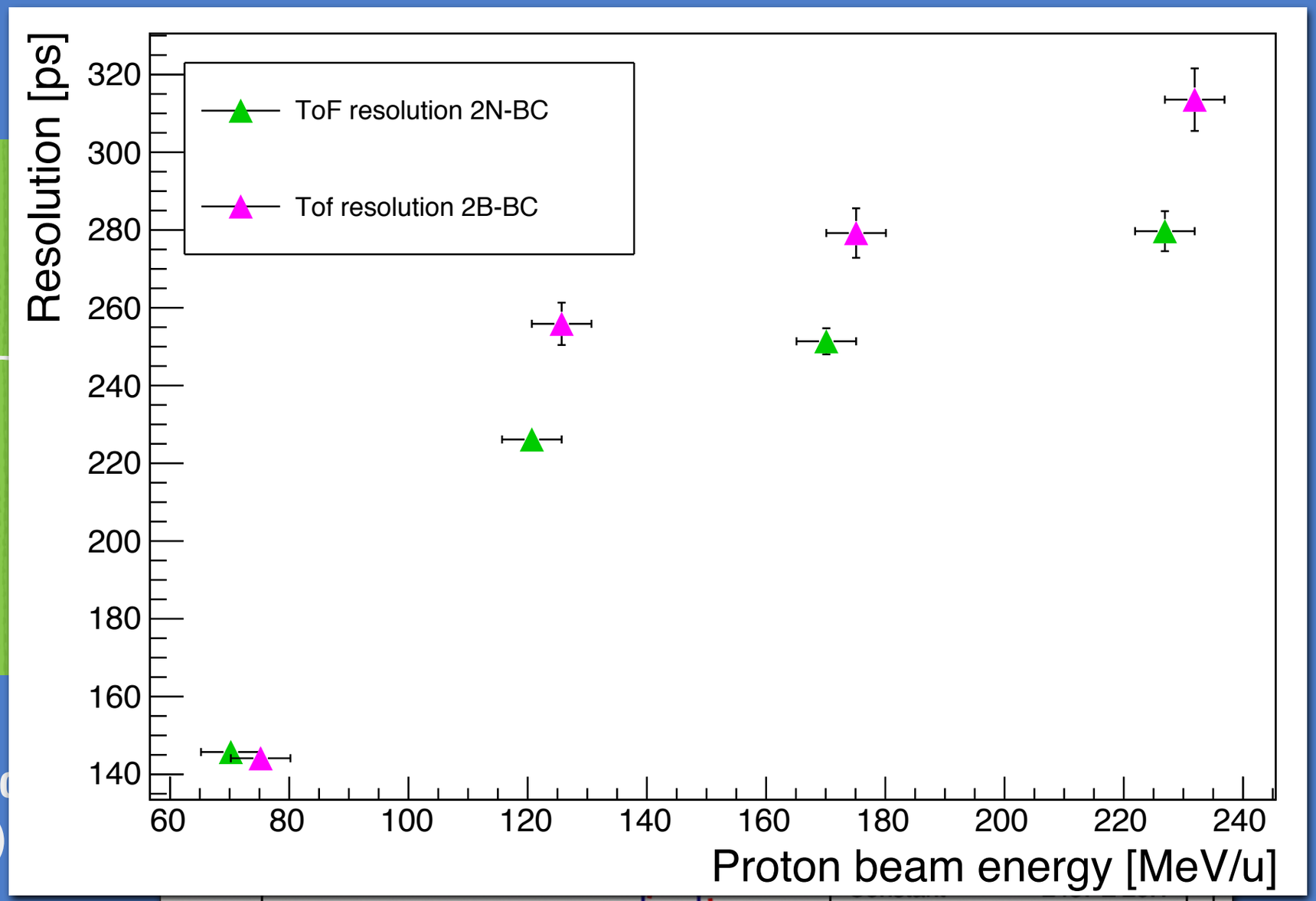

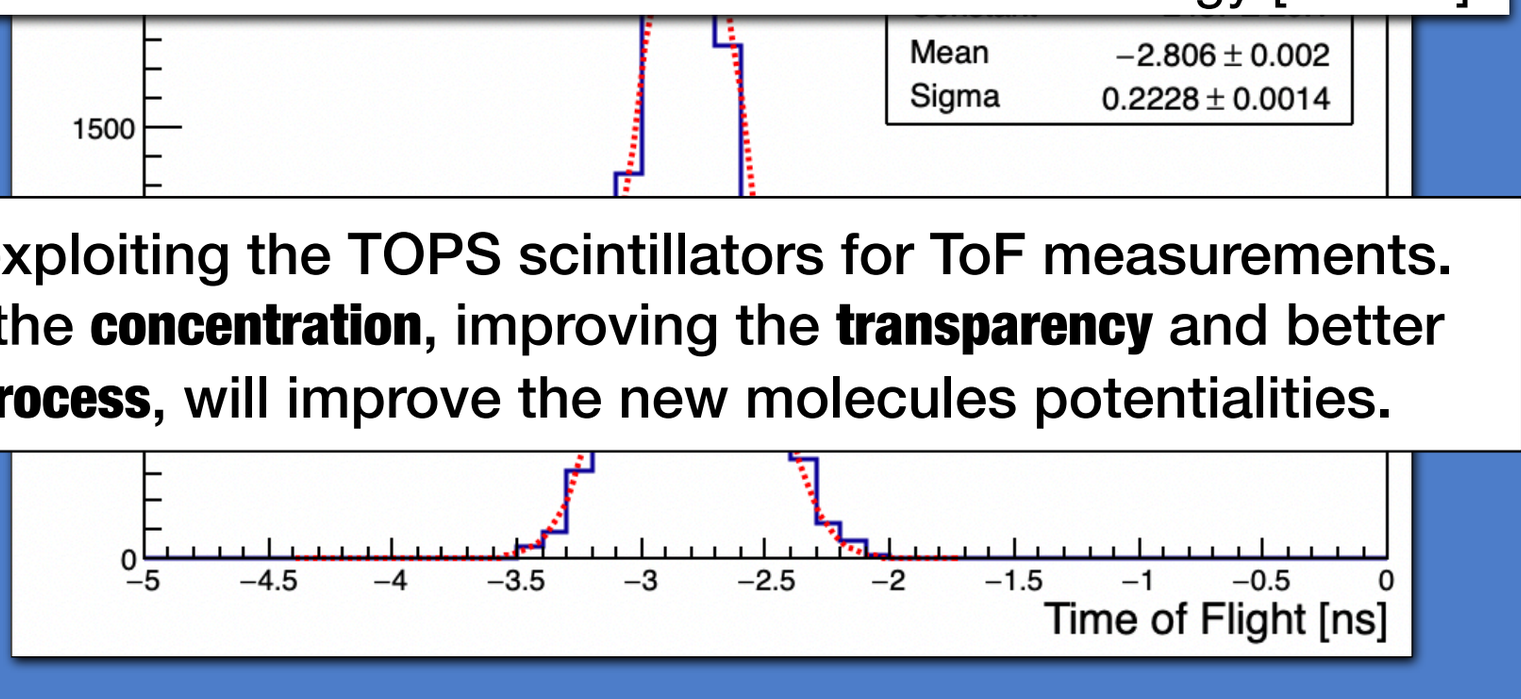

This result is the **first attempt** of exploiting the TOPS scintillators for ToF measurements. Further optimisation, balancing the **concentration**, improving the **transparency** and better controlling the **polymerisation process**, will improve the new molecules potentialities.

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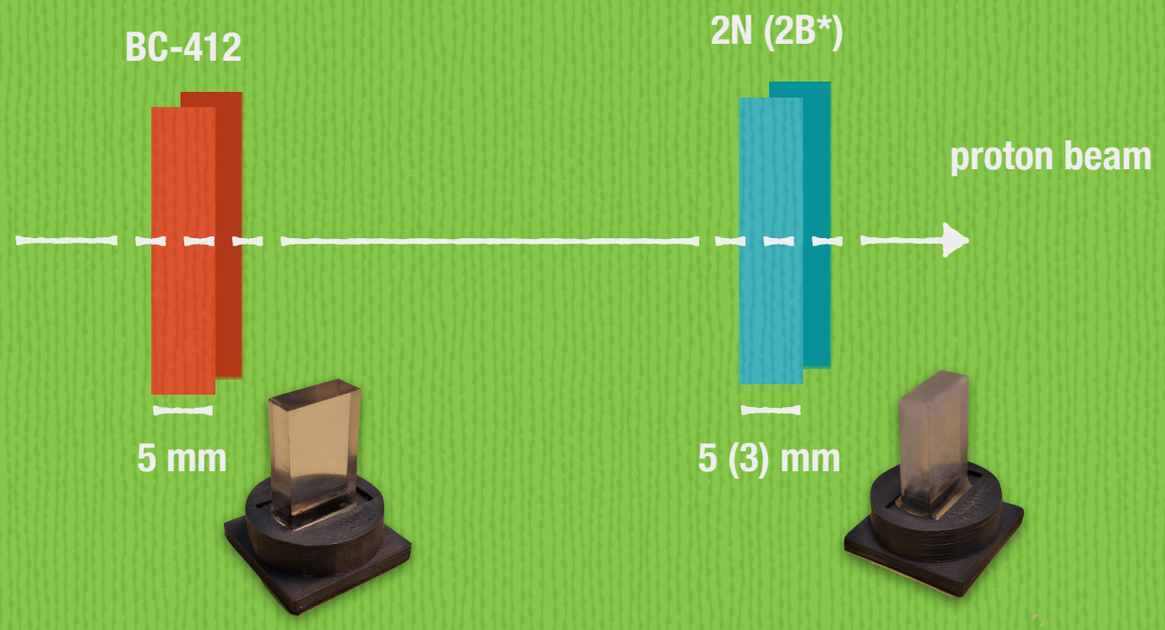

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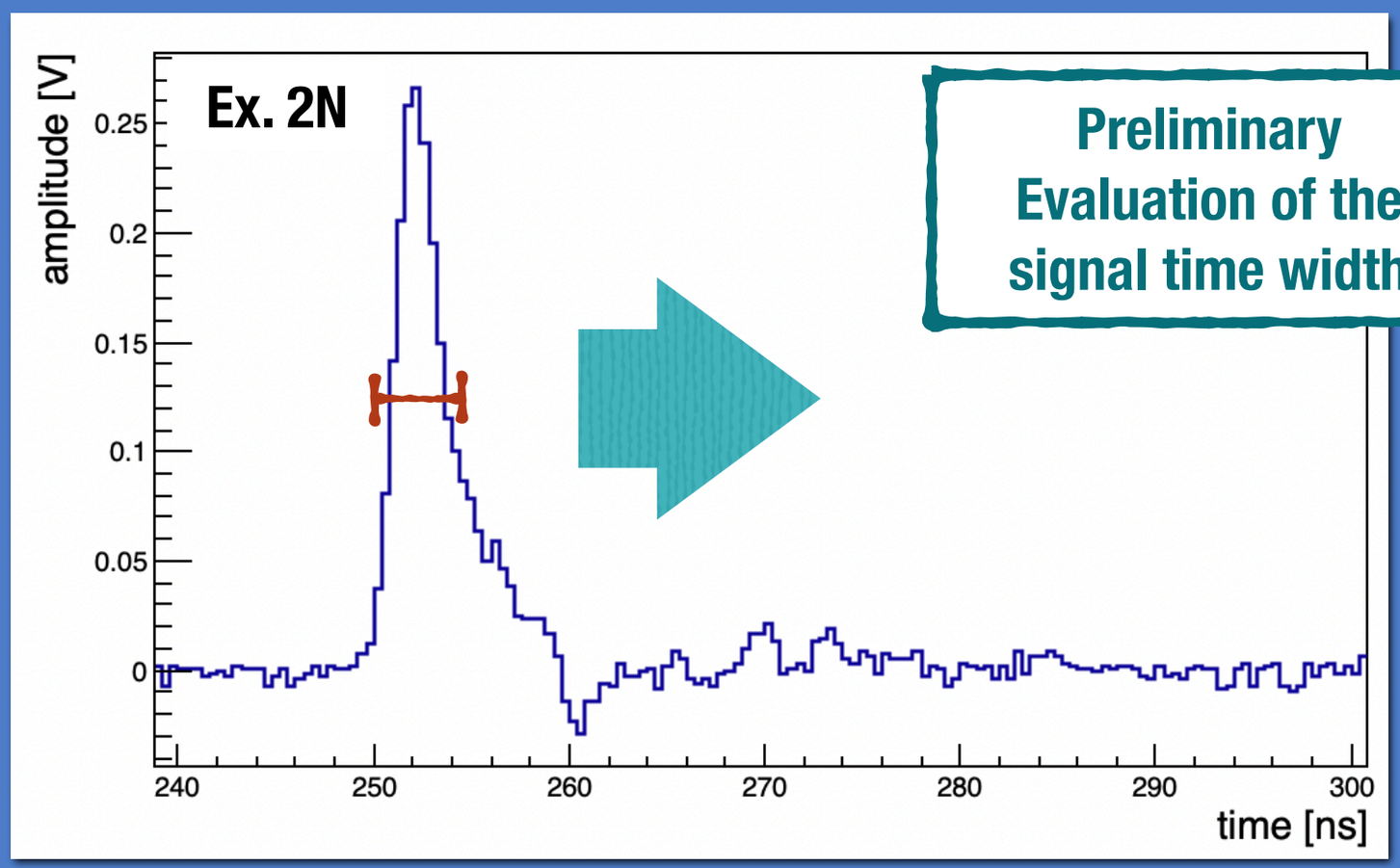
- DAQ LeCroy HDO6104-MS 2.5Gs/s

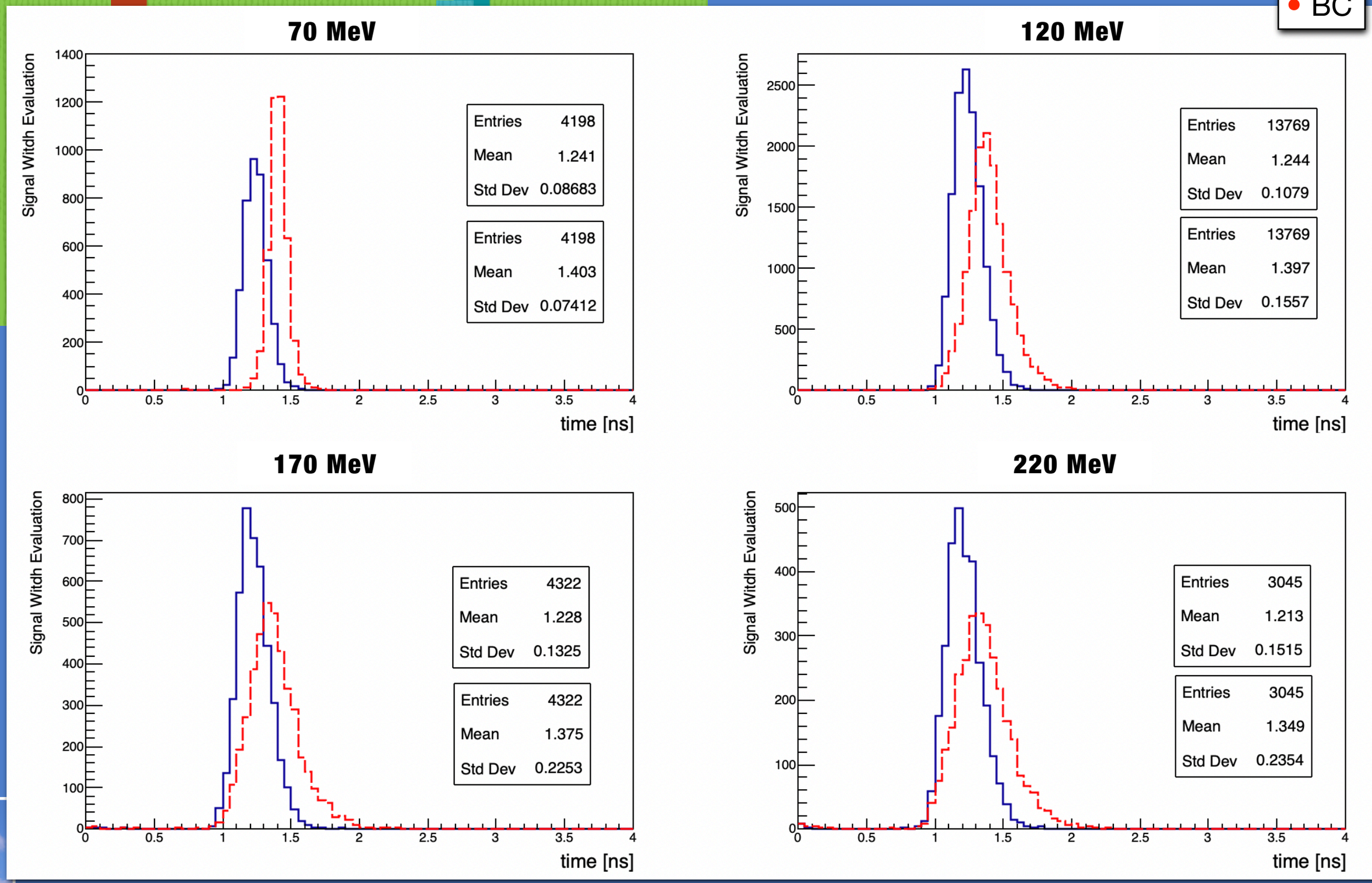


Preliminary Evaluation of the signal time width

Test Beam with protons

BC-412

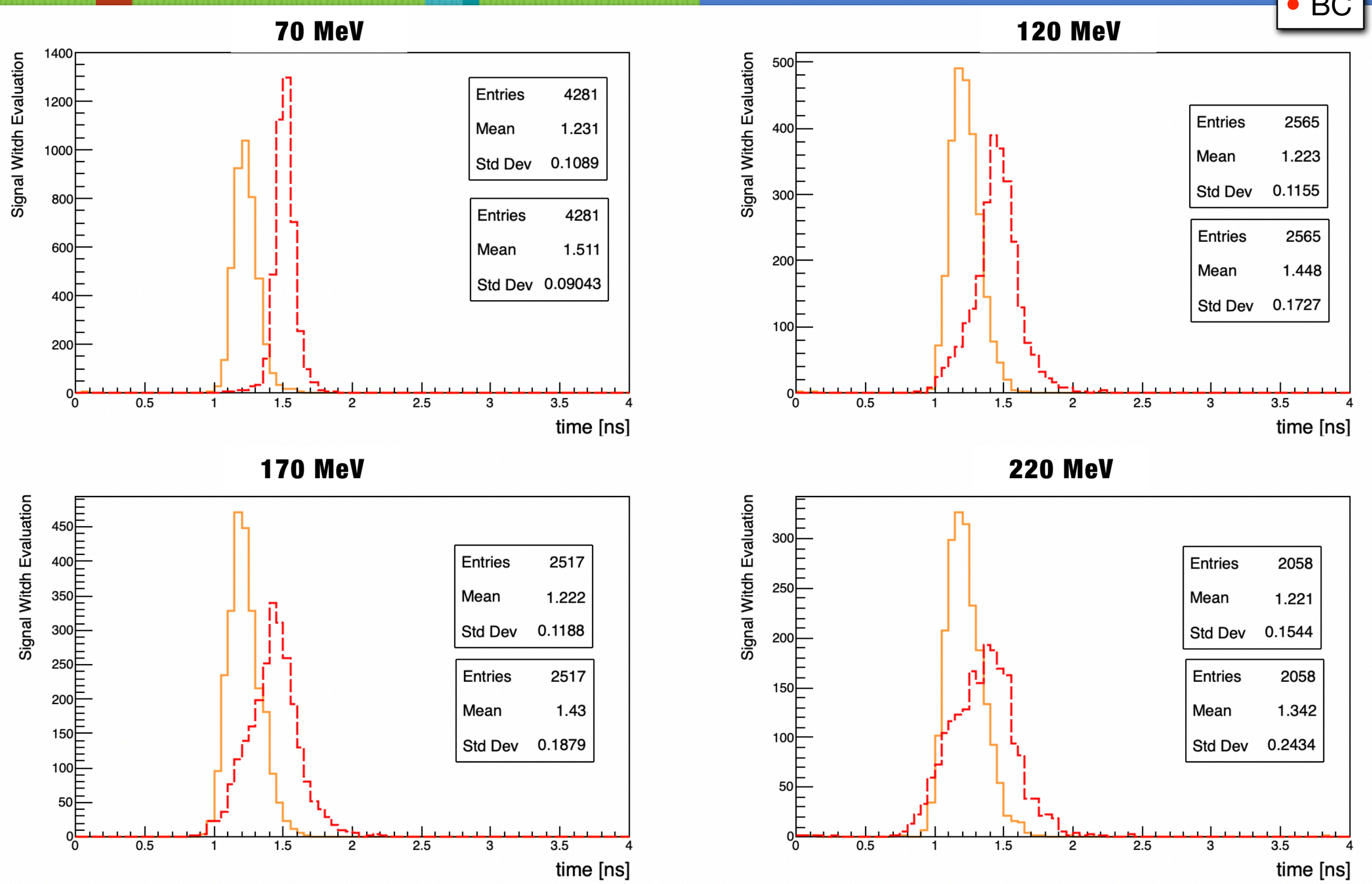
2N (2B)



Test Beam with protons

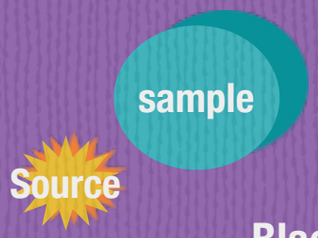
BC-412

2N (2B)

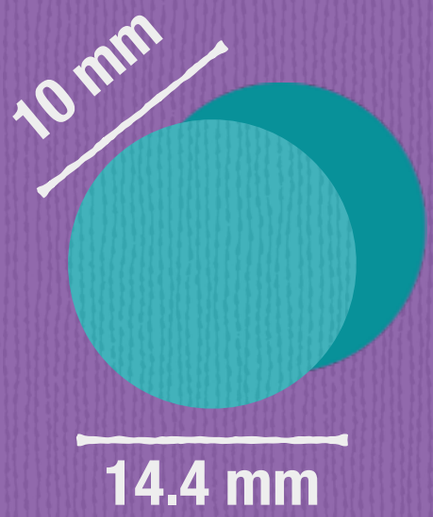


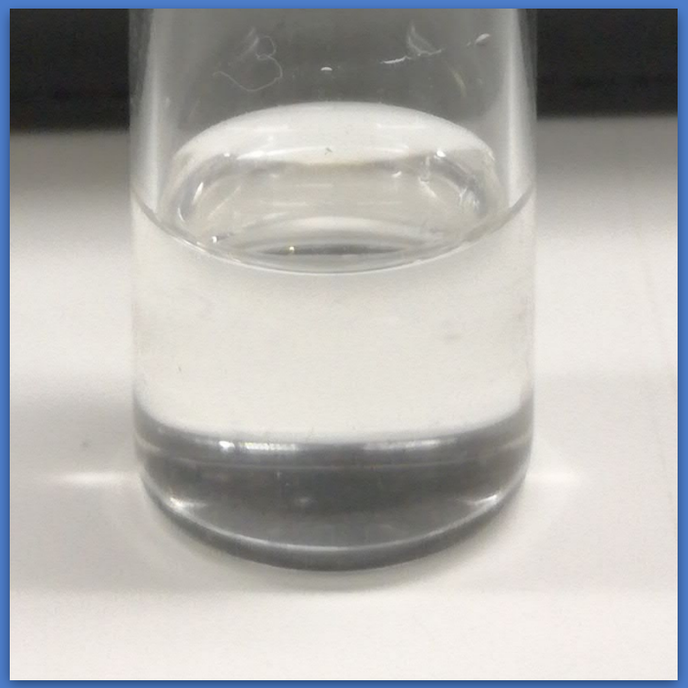
Concentration study on the 2N scintillator

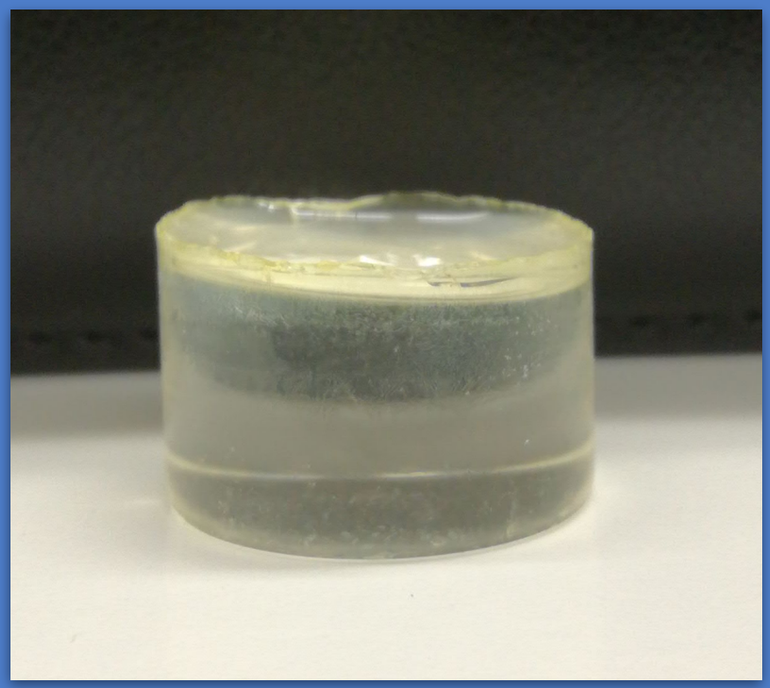
Experimental SETUP:

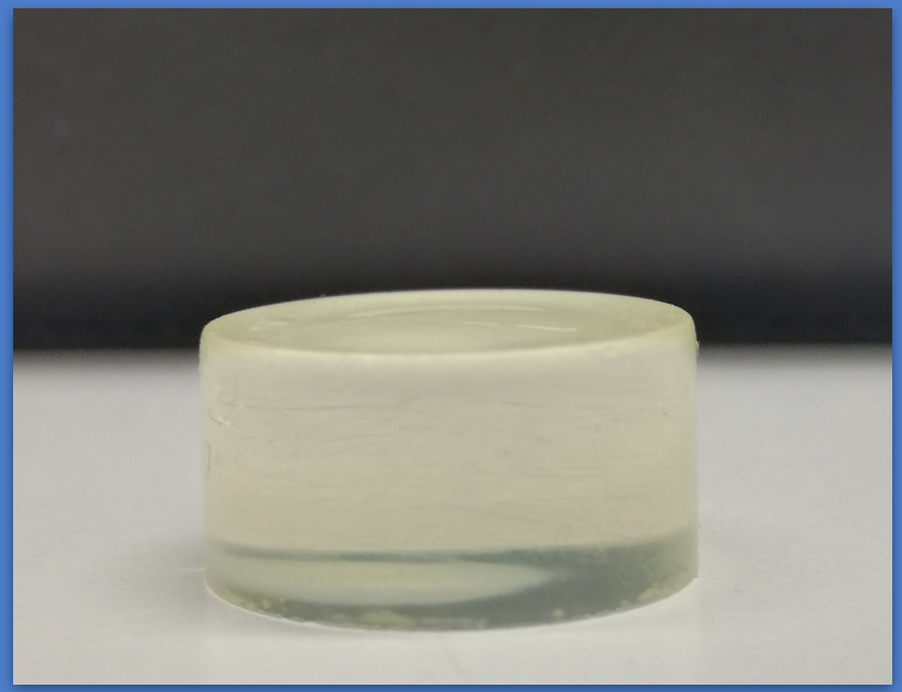


- PMT XP1911 PHOTONIS
- Daq: VME QDC (12 bit) and TDC
- sources: ^{137}Cs, ^{22}Na, ^{60}Co, ^{90}Sr



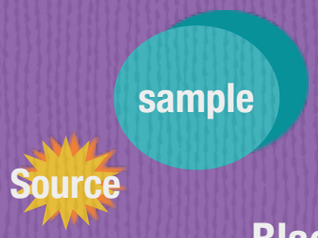


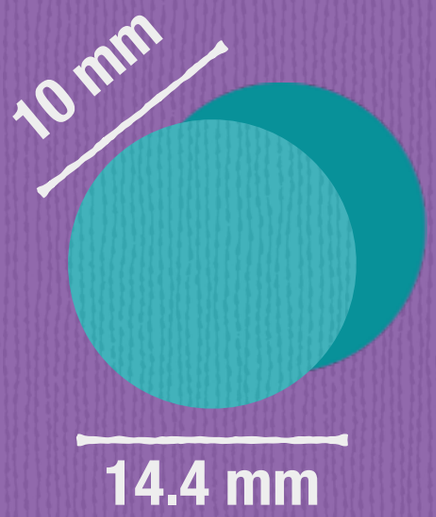




Concentration study on the 2N scintillator

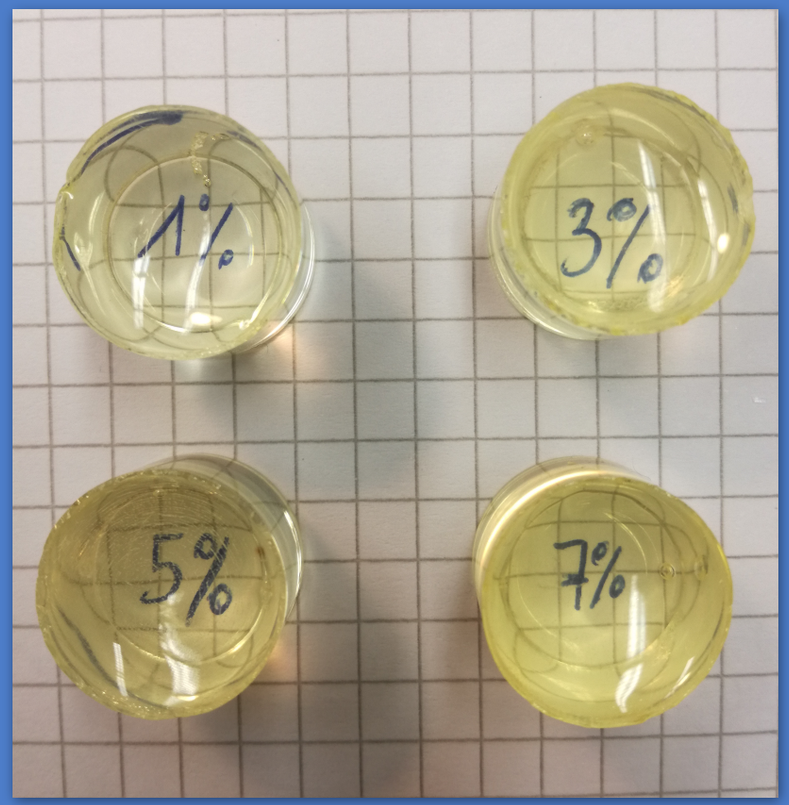
Experimental SETUP:





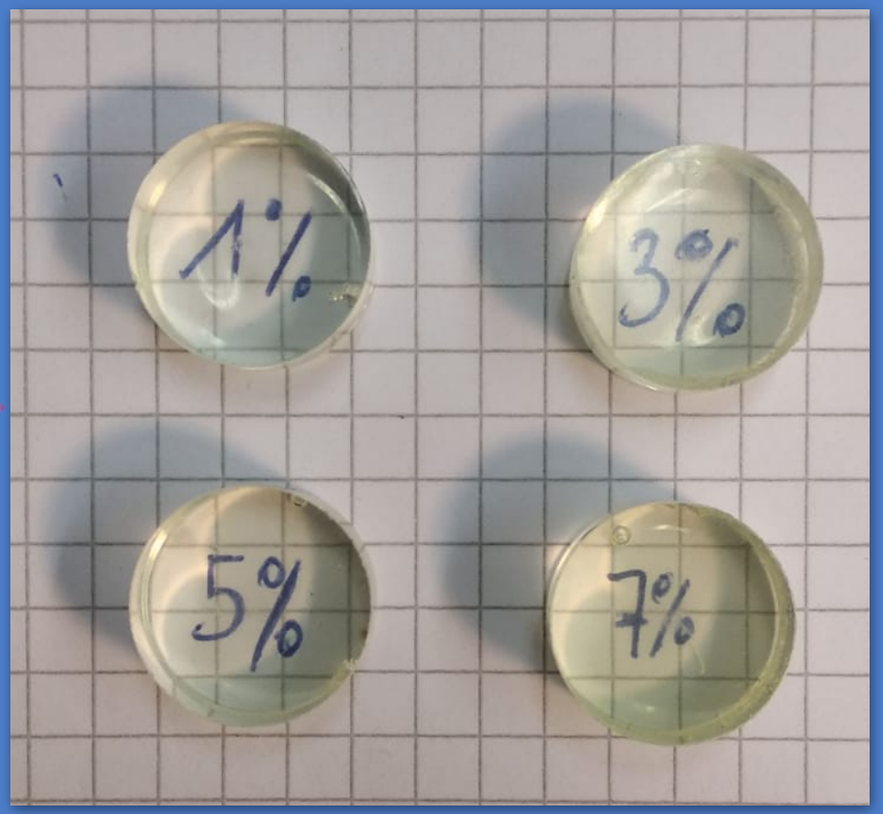
- PMT XP1911 PHOTONIS
- Daq: VME QDC (12 bit) and TDC
- sources: ^{137}Cs, ^{22}Na, ^{60}Co, ^{90}Sr

Before



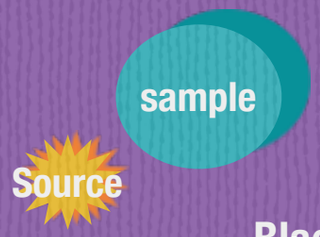
mechanical cutting

After



Concentration study on the 2N scintillator

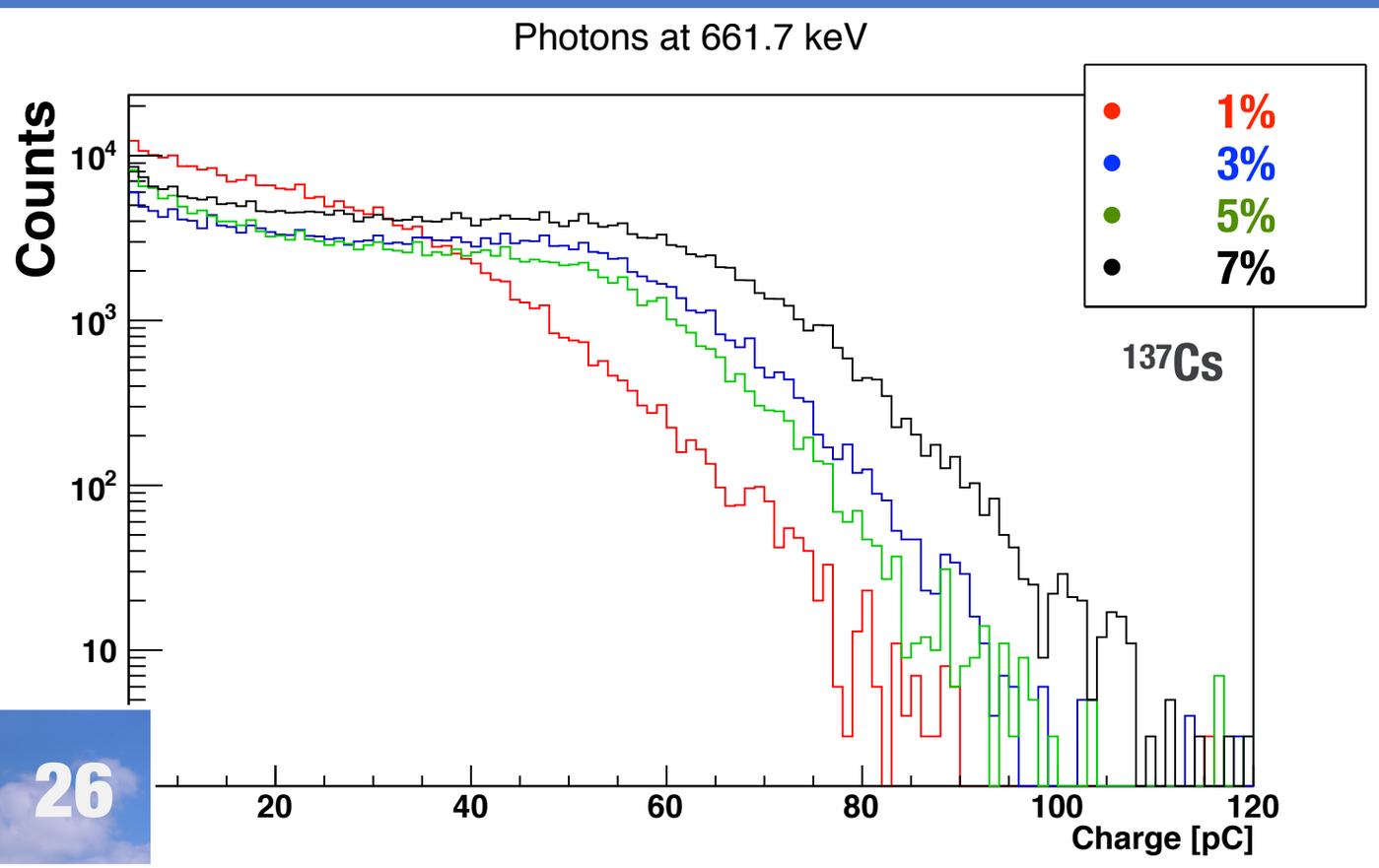
Experimental SETUP:

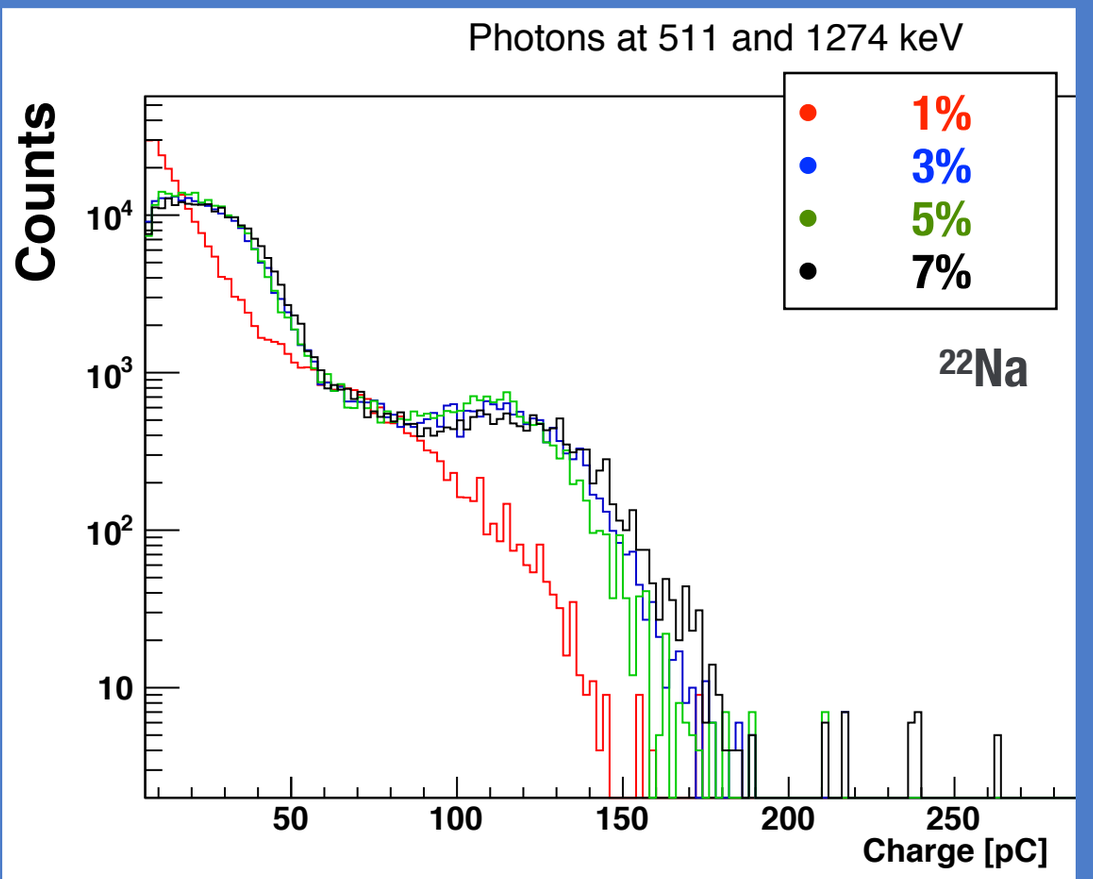


Black Box

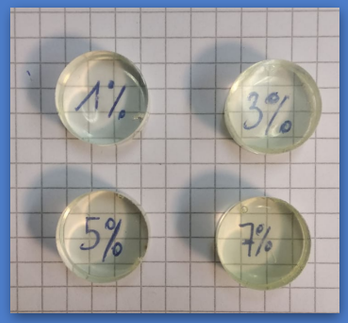
- PMT XP1911 PHOTONIS
- Daq: VME QDC (12 bit) and TDC
- sources: ^{137}Cs, ^{22}Na, ^{60}Co, ^{90}Sr

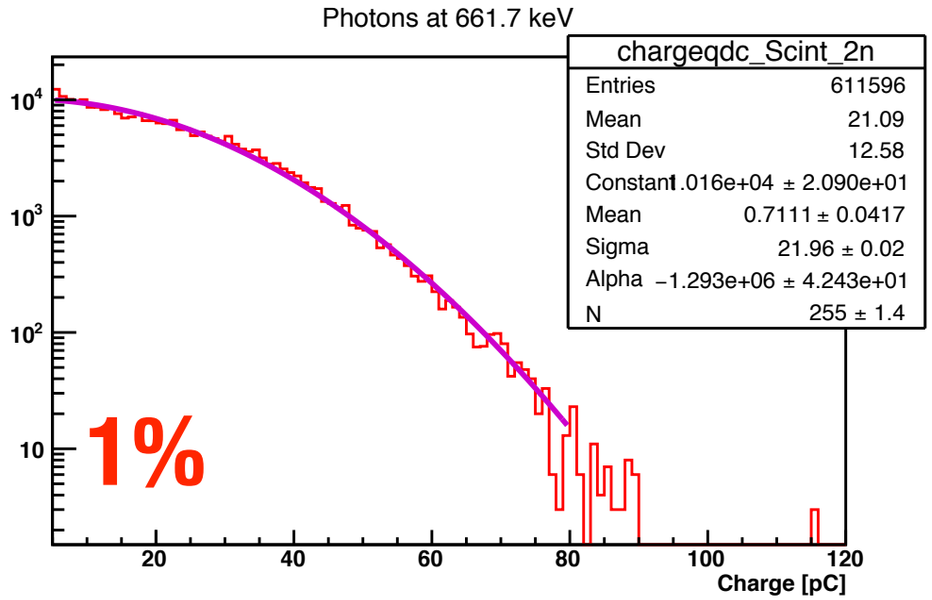
From this analysis is it possible to study the charge response as a function of the scintillating concentration in the samples. The aim is to identify the most favourable concentration and possible saturation.

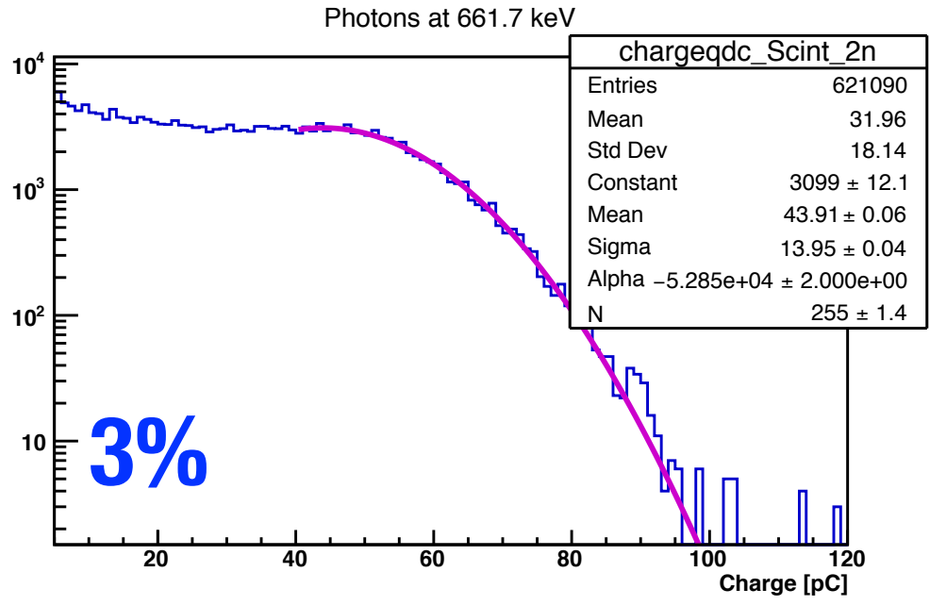


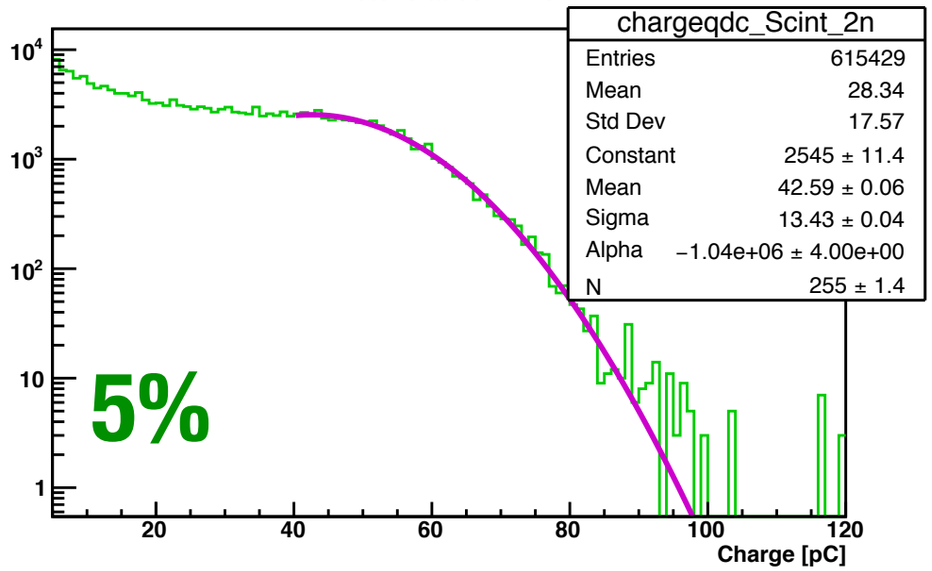


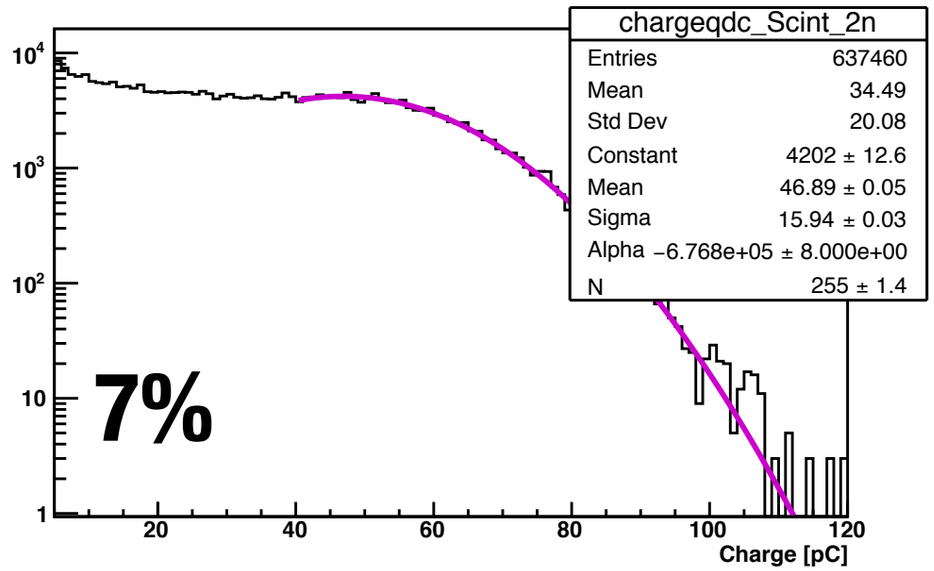
Concentration study on the 2N scintillator





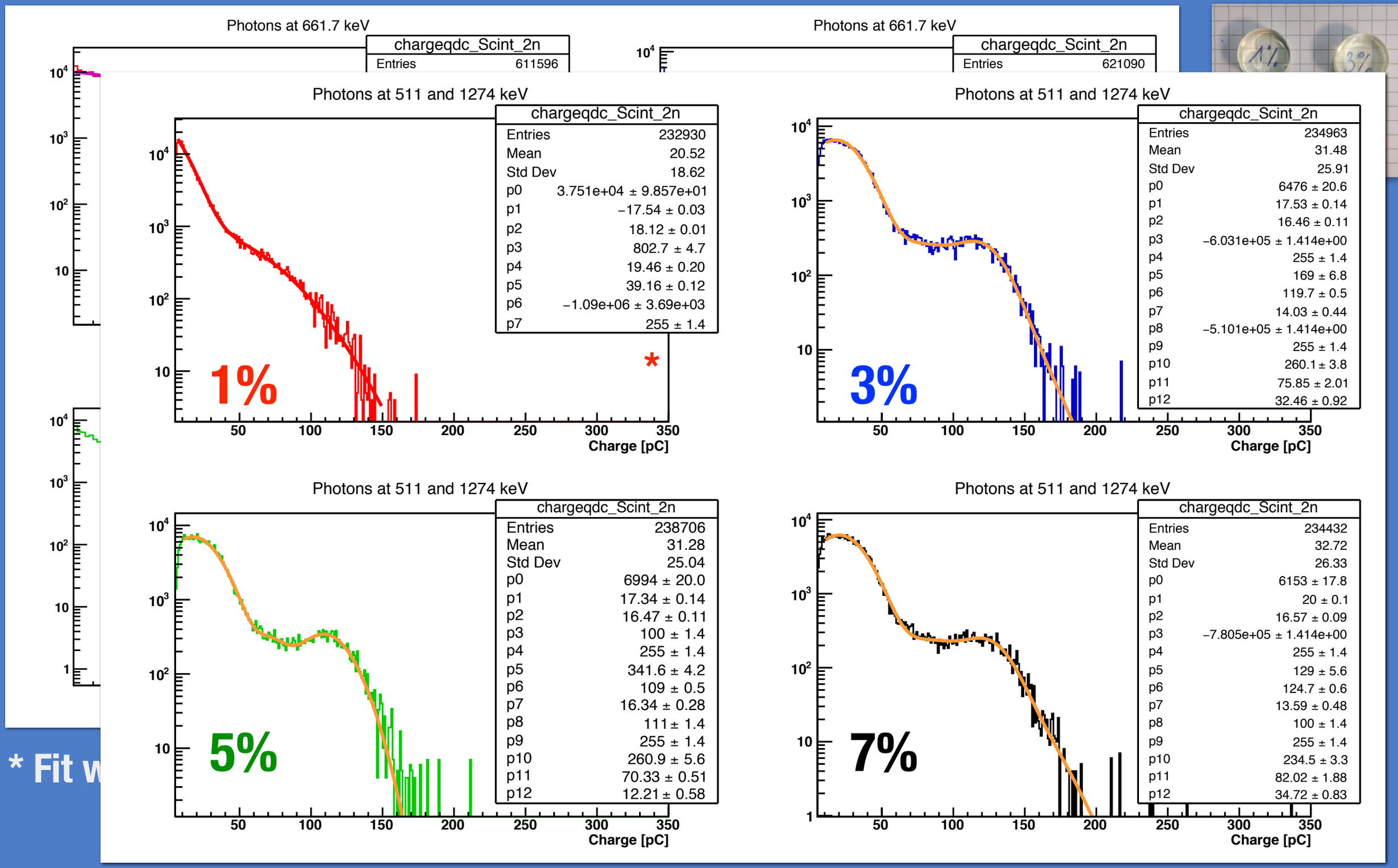






* Fit with a sigle crystal ball

Concentration study on the 2N scintillator

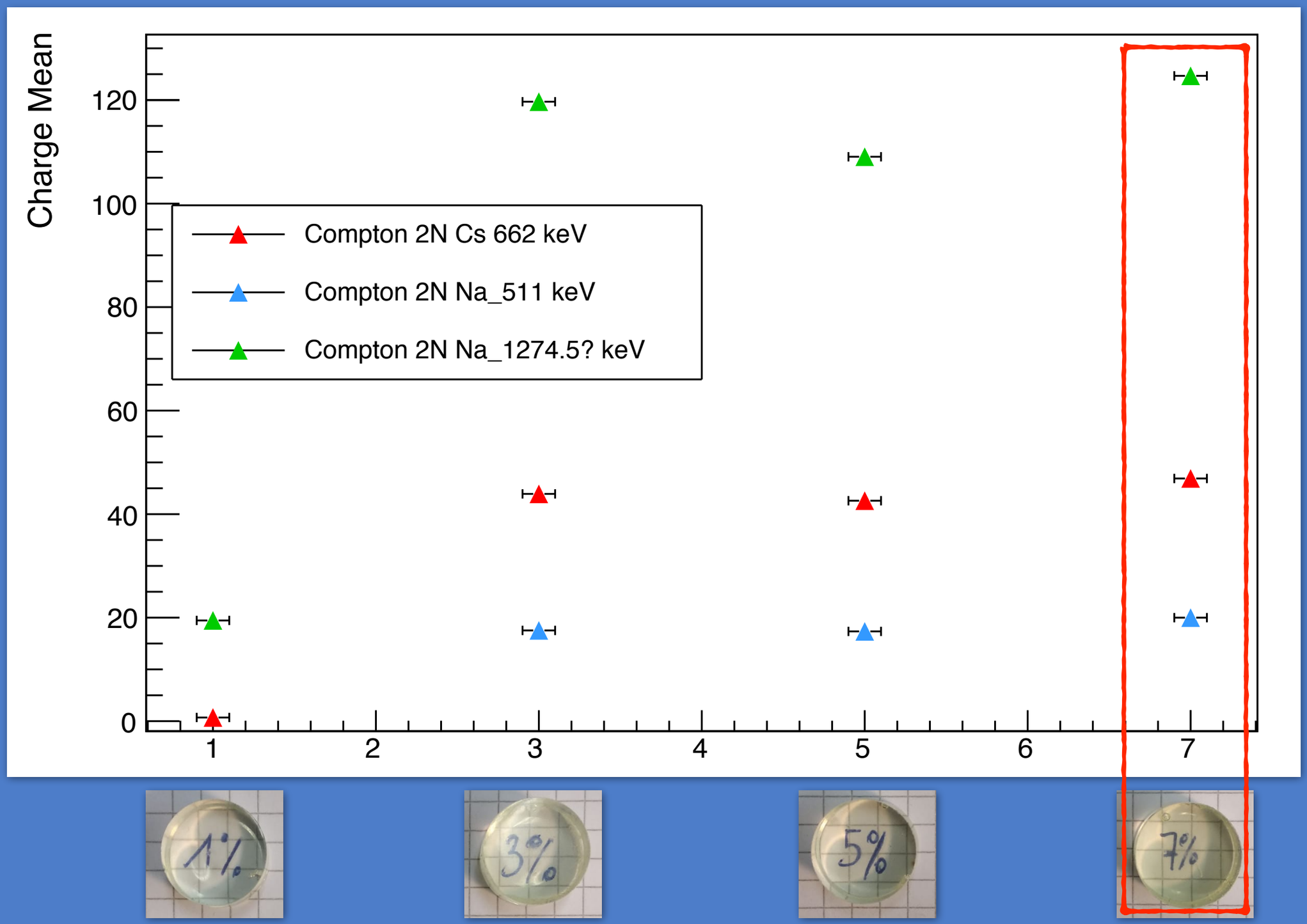


* Fit w

* Fit with a crystal ball and a gaussian for the background

* Fit with a two crystal balls and a gaussian for the background btw the Comptons

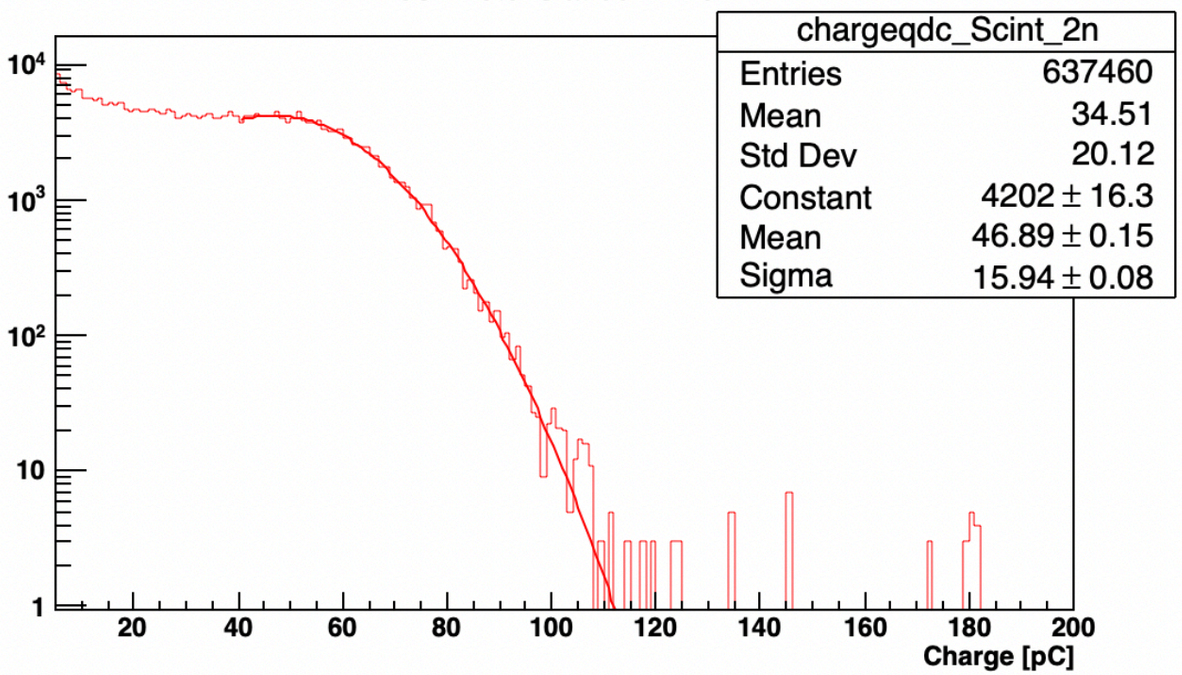
Concentration study on the 2N scintillator



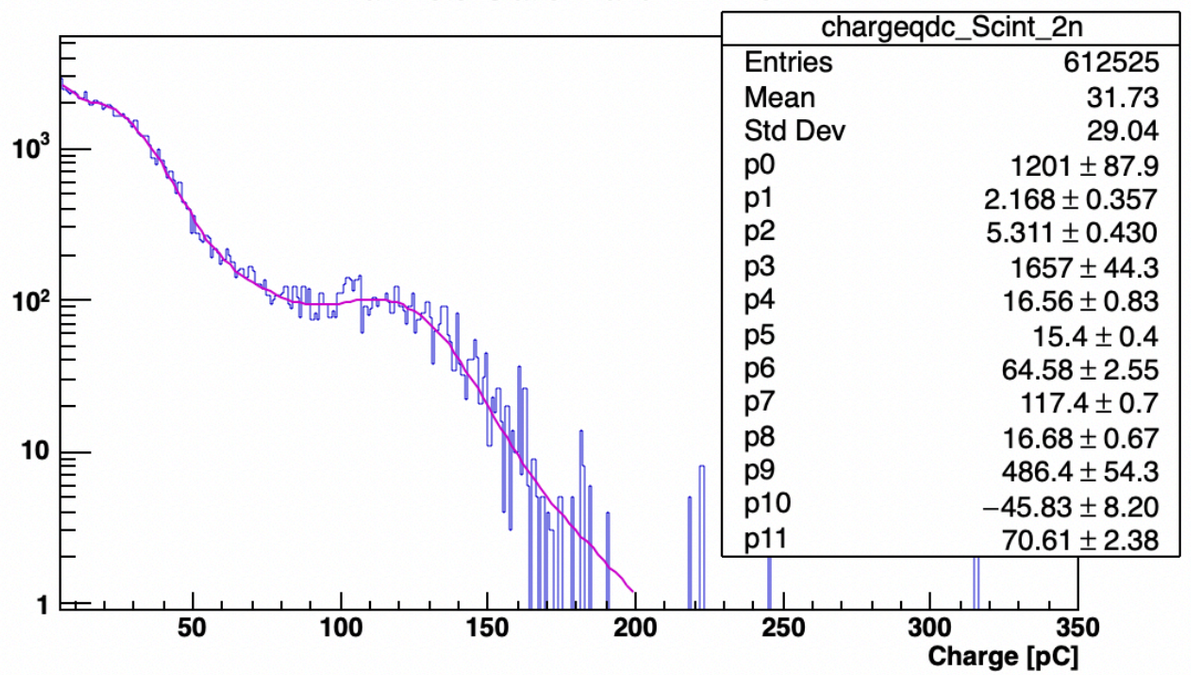
A concentration of at least 3% is preferable. The 5% sample is probably suffering of some polymerisation effect. The 7% concentration is the most favourable one. A time dependent analysis will be performed in next month.

Calibration for 2N at 7%

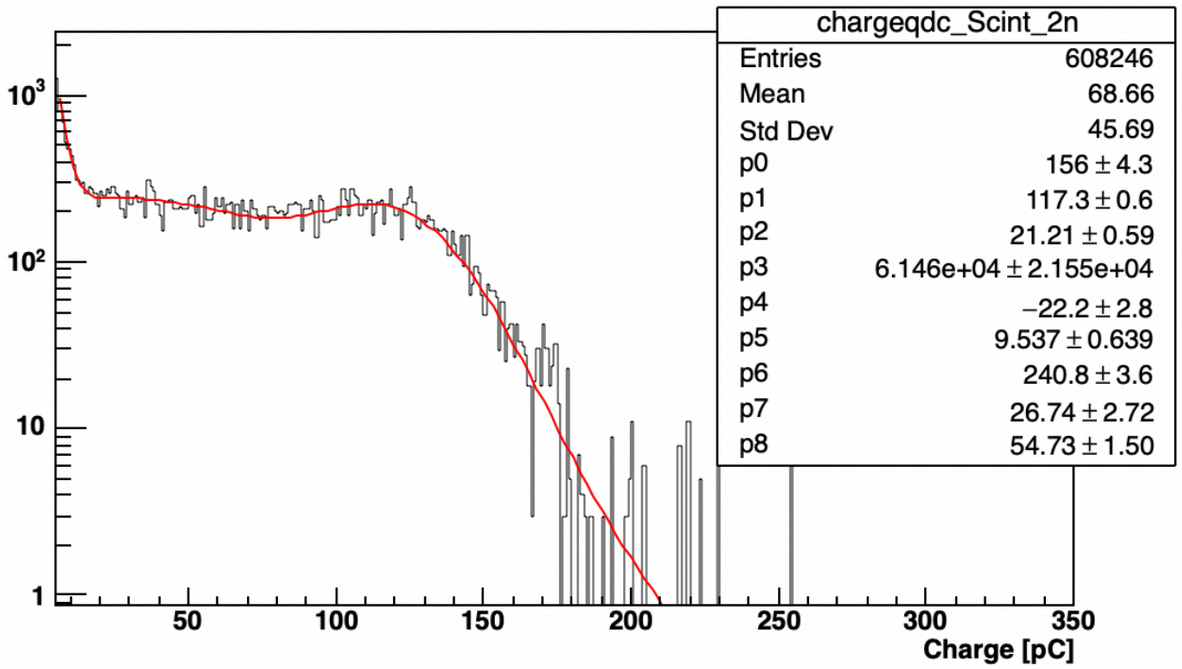
Cs Photons at 661.7 keV



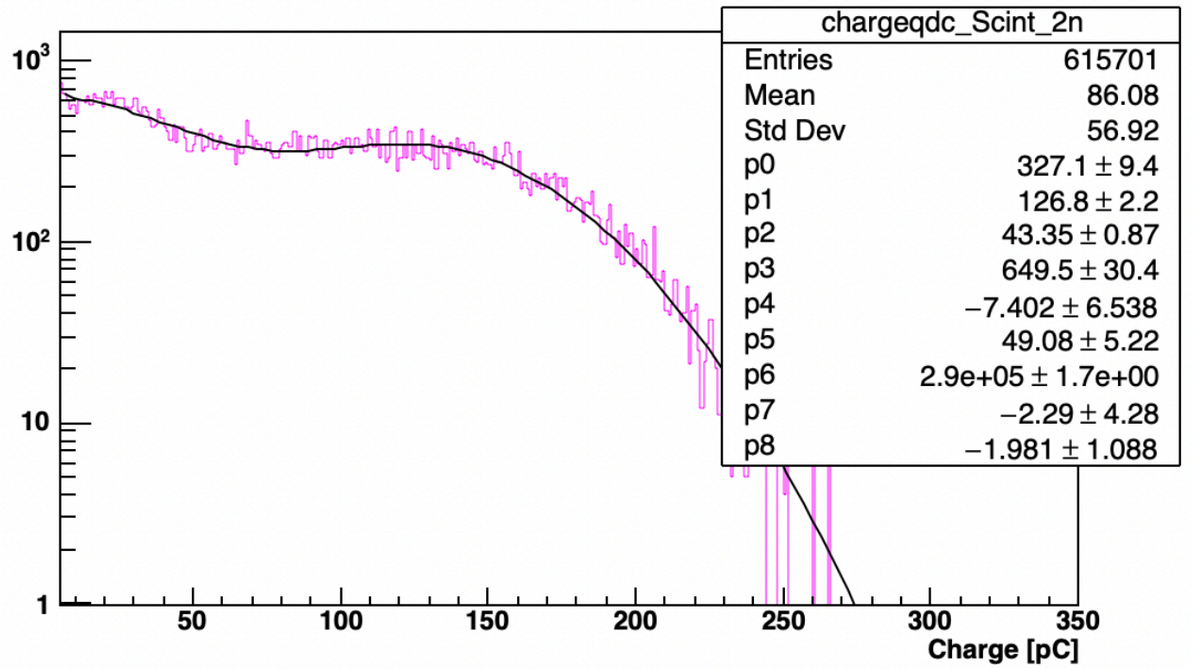
Na Photons at 511 and 1274 keV



Co Photons at 1173.2 and 1332.5 keV, Average 1252.86 keV

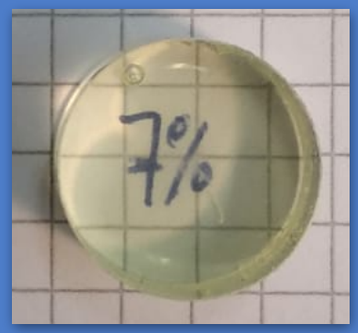


Sr Beta- decay electrons 546 keV and 2.28 MeV



* Fit with a gaussian for each Compton spectra and with a gaussian for pedestals and background

Calibration for 2N at 7%



137Cs:

Photopeak, Eγ = 661.66 keV; Compton edge, Ee = 477.34 keV

22Na:

Photopeak, Eγ = 511 keV; Compton edge, Ee = 340.67 keV

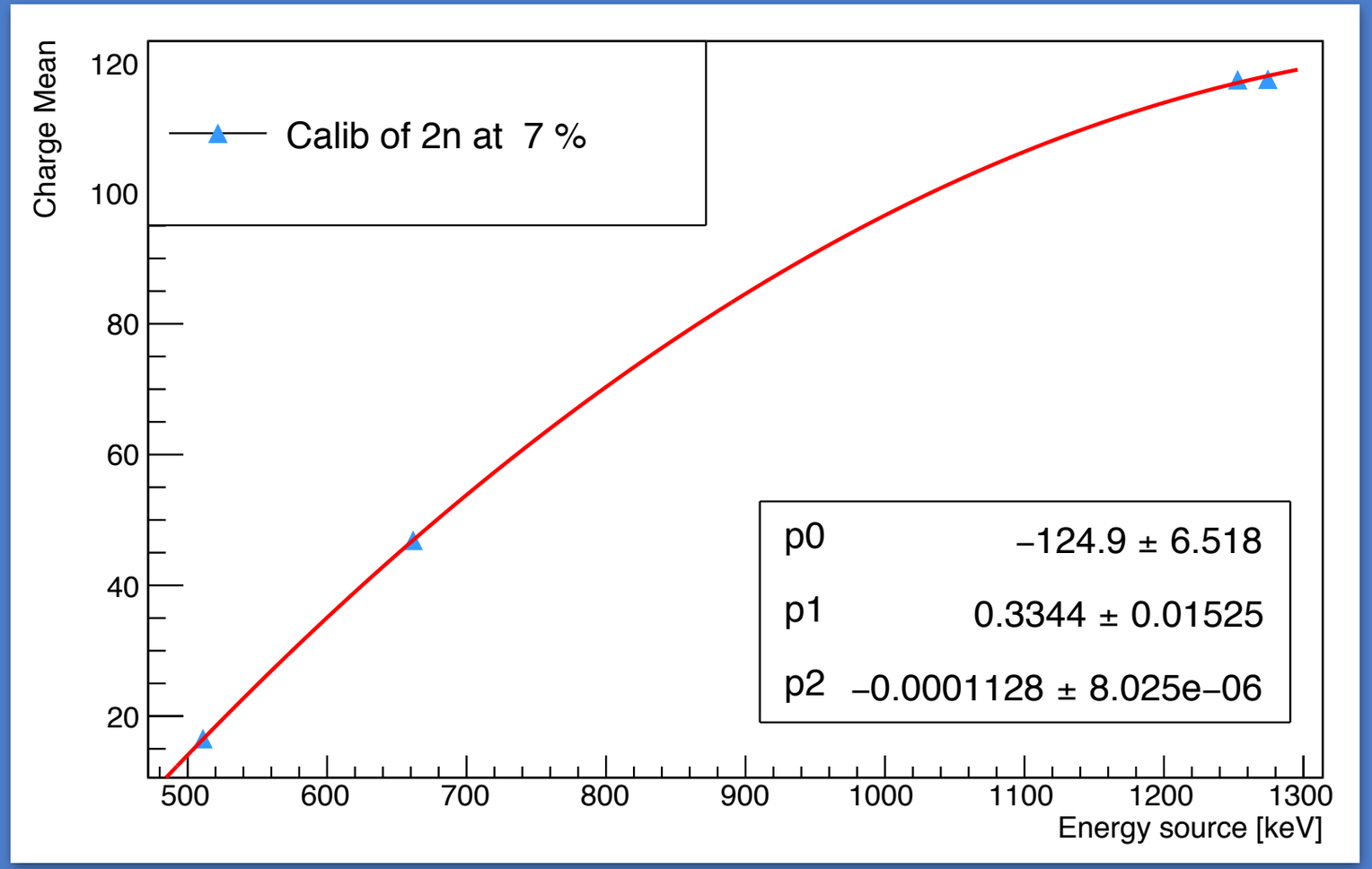
Photopeak, Eγ = 1274.54 keV; Compton edge, Ee = 1061.71 keV

60Co:

Photopeak, Eγ = 1173.2 keV; Compton edge, Ee = 963.39 keV

Photopeak, Eγ = 1332.5 keV; Compton edge, Ee = 1118.11 keV

Average 1252.86keV; Compton edge 1040.79



Summarising…

- Plastic scintillators are relatively cheap, easy to manipulate and light (low density) with respect to conventional crystal scintillators
  => precise measurements of particle Time of Flight (ToF).

- In the framework of the **TOPS project** tens of new scintillators, in liquid and solid samples, have been prepared and characterised in therm of light output and timing properties with cosmic rays.

- Some molecules shows promising time resolution performance. Samples have been irradiated with proton beam at CNAO performing ToF measurements reaching very good results.

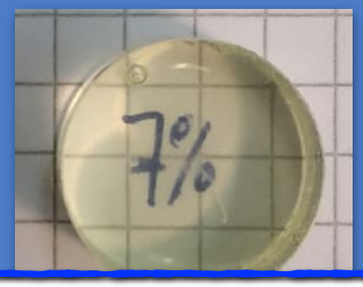
- For the 2N studies on the light output as a function of different concentrations have been performed as first input for a concentration optimisation.

… TOPS Next Steps

- Better performances can be reached improving:
  - transparency and dopant mix choice
  - concentration of the scintillators
  - preparation stability and polymerisation process
- Further test beam with charged beam will be performed in next month
- The ageing stability and the mechanical properties of the samples have to be studied for the solid sample
- Possible neutron/gamma PSD will be investigated

THANKS

Calibration for 2N at 7%



Cs Photons at 661.7 keV

chargeqdc_Scint_2n	
Entries	637460
Mean	34.51

Na Photons at 511 and 1274 keV

chargeqdc_Scint_2n	
Entries	612525
Mean	31.73
Std Dev	29.04
p0	1201 ± 87.9
p1	2.168 ± 0.357
p2	5.311 ± 0.430
p3	1657 ± 44.3
p4	16.56 ± 0.83
p5	15.4 ± 0.4
p6	64.58 ± 2.55
p7	117.4 ± 0.7
p8	16.68 ± 0.67
p9	486.4 ± 54.3
p10	−45.83 ± 8.20
p11	70.61 ± 2.38

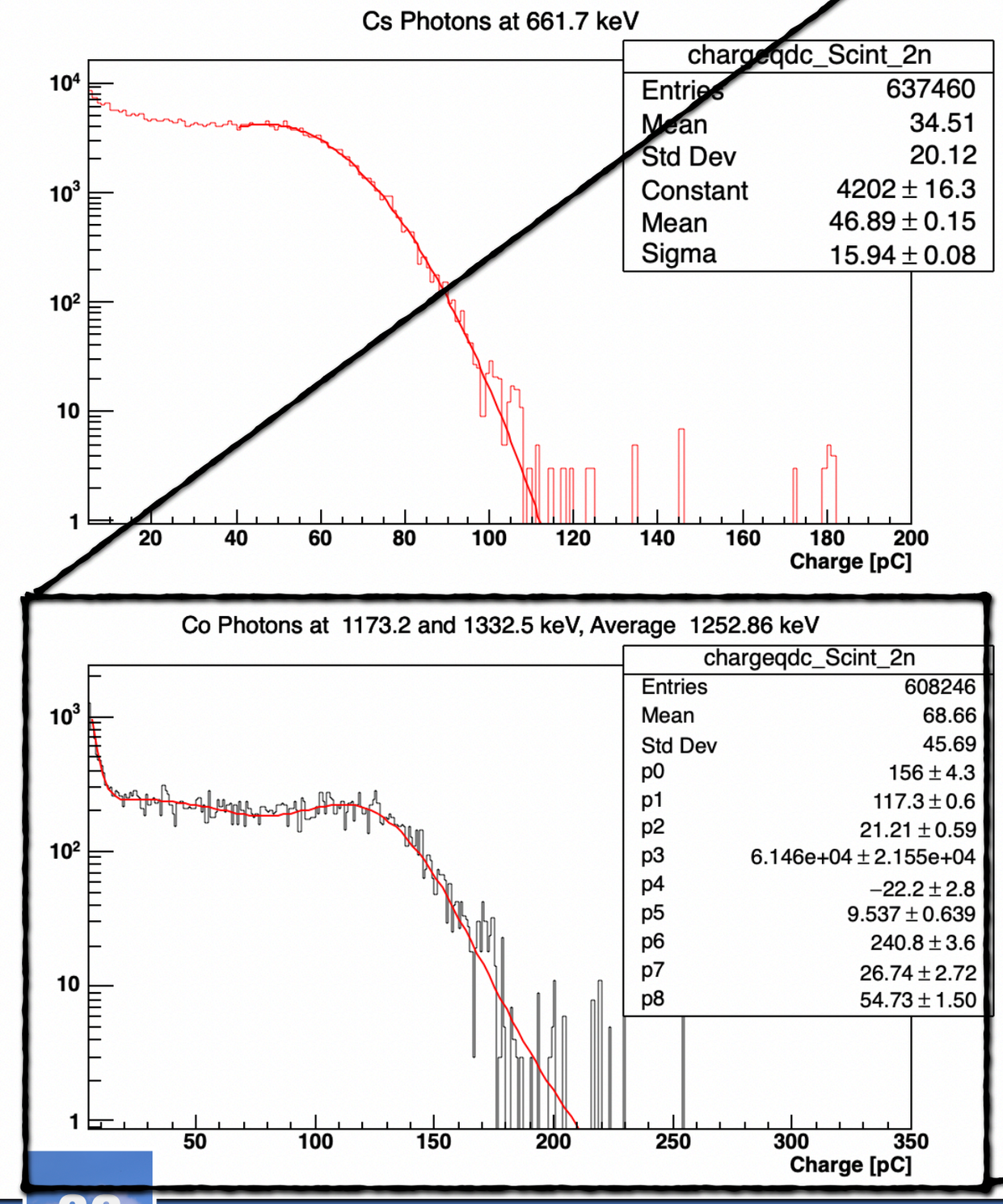
Charge [pC]

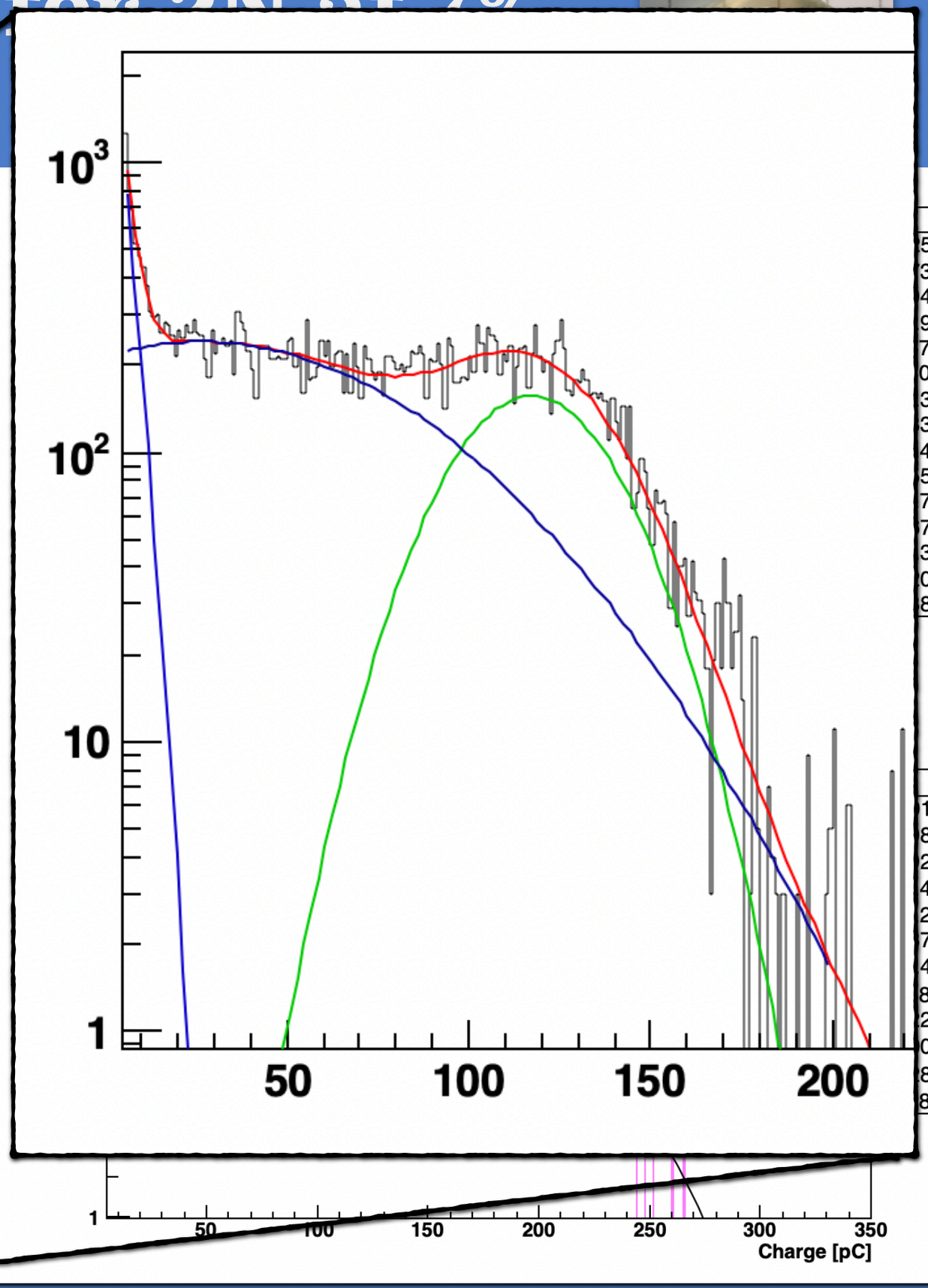
Sr Beta- decay electrons 546 keV and 2.28 MeV

chargeqdc_Scint_2n	
Entries	615701
Mean	86.08
Std Dev	56.92
p0	327.1 ± 9.4
p1	126.8 ± 2.2
p2	43.35 ± 0.87
p3	649.5 ± 30.4
p4	−7.402 ± 6.538
p5	49.08 ± 5.22
p6	2.9e+05 ± 1.7e+00
p7	−2.29 ± 4.28
p8	−1.981 ± 1.088

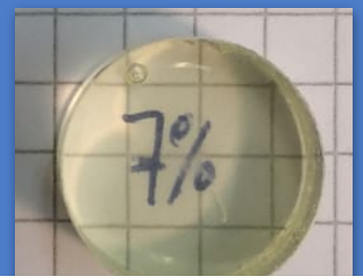
Charge [pC]

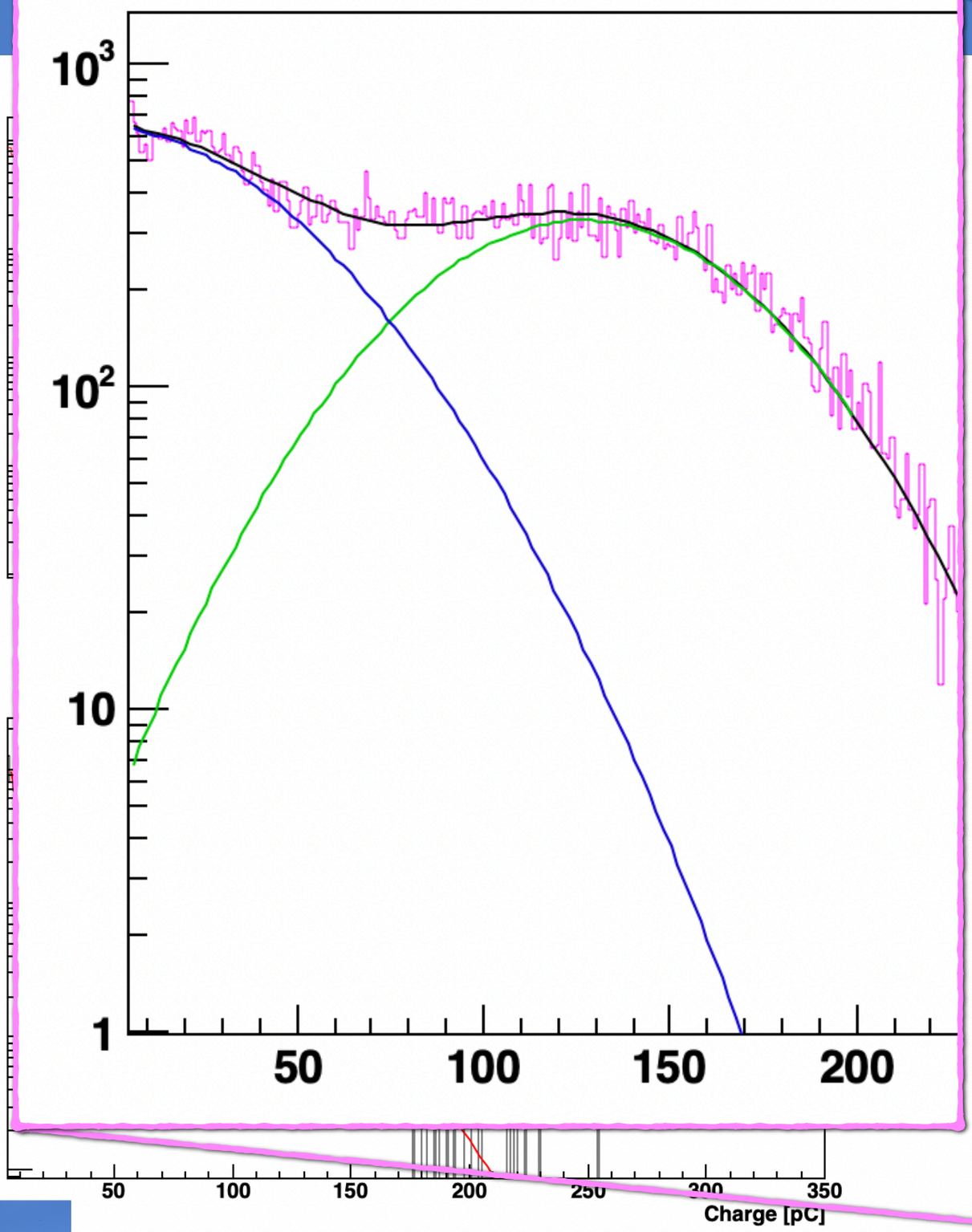
Calibration for 2N at 7%

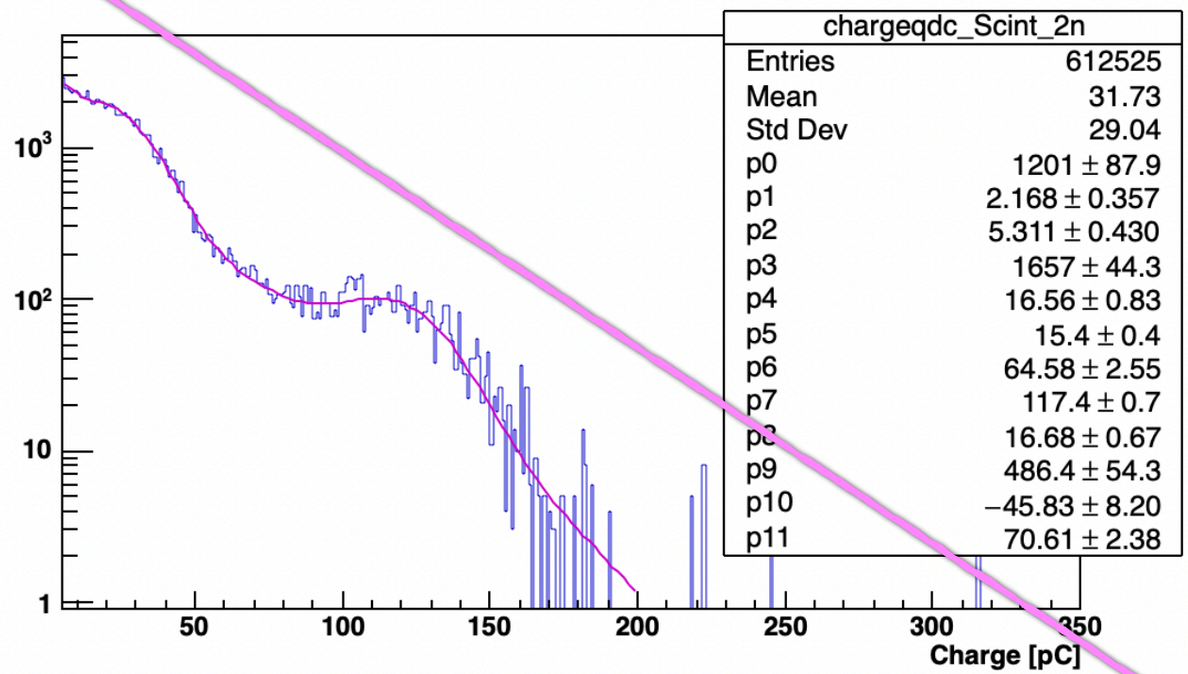


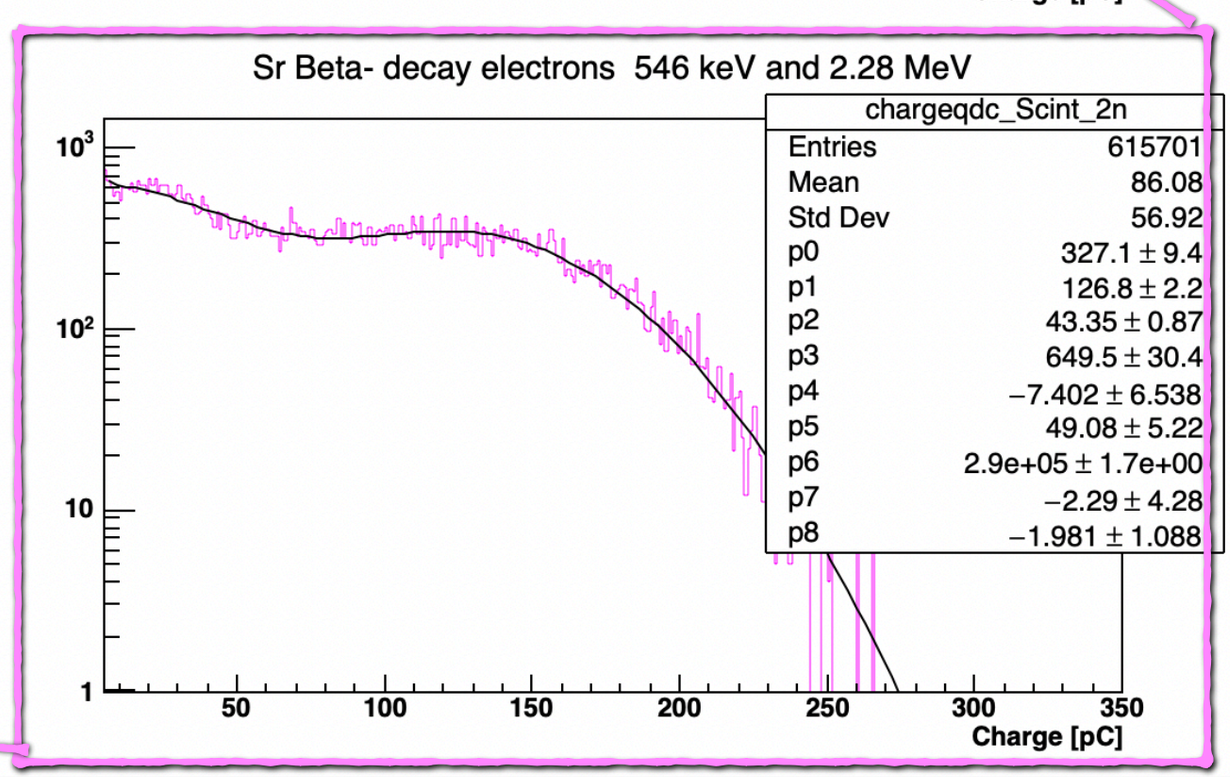


Calibration for 2N at 7%

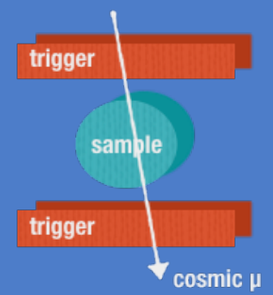


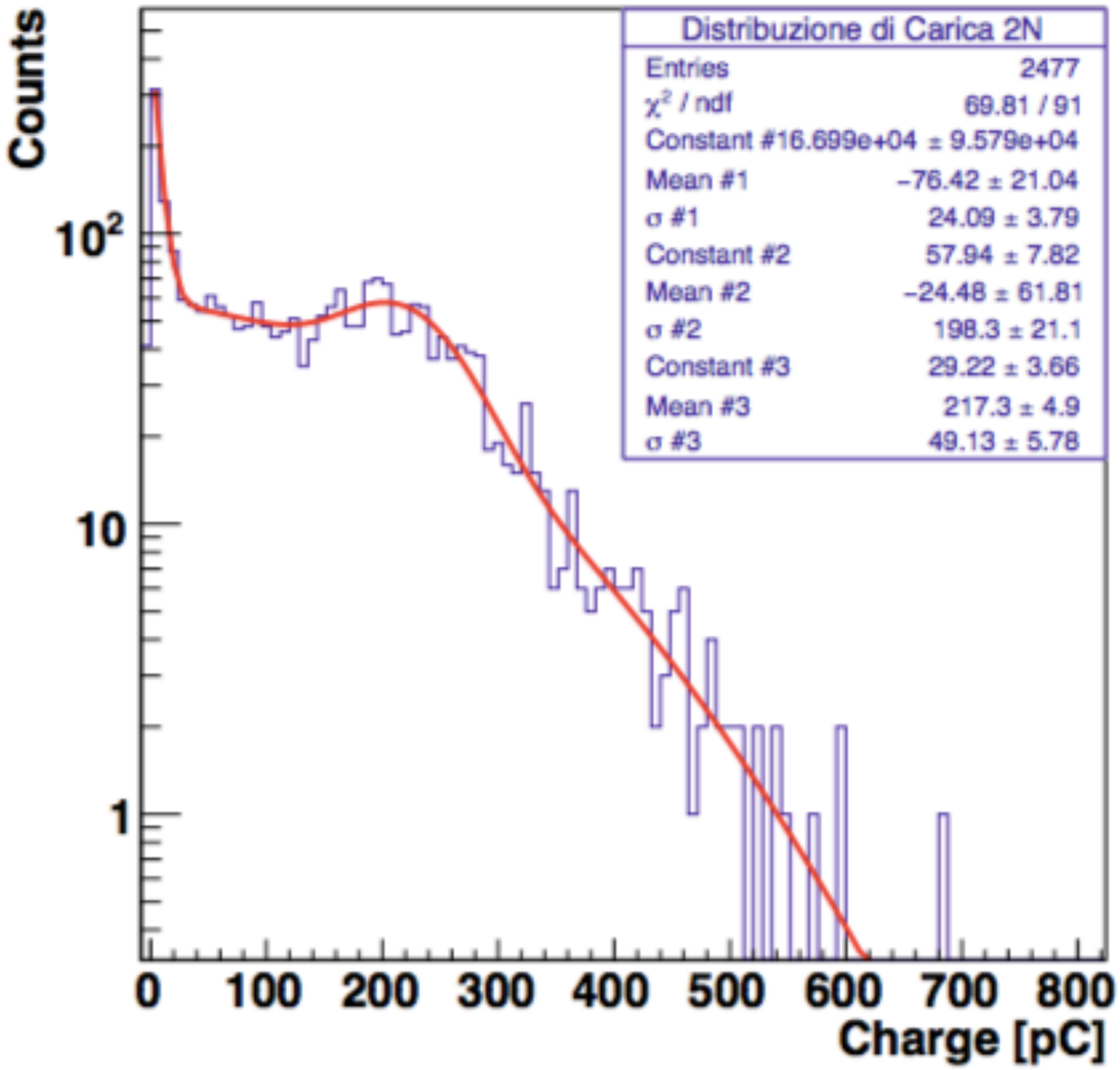


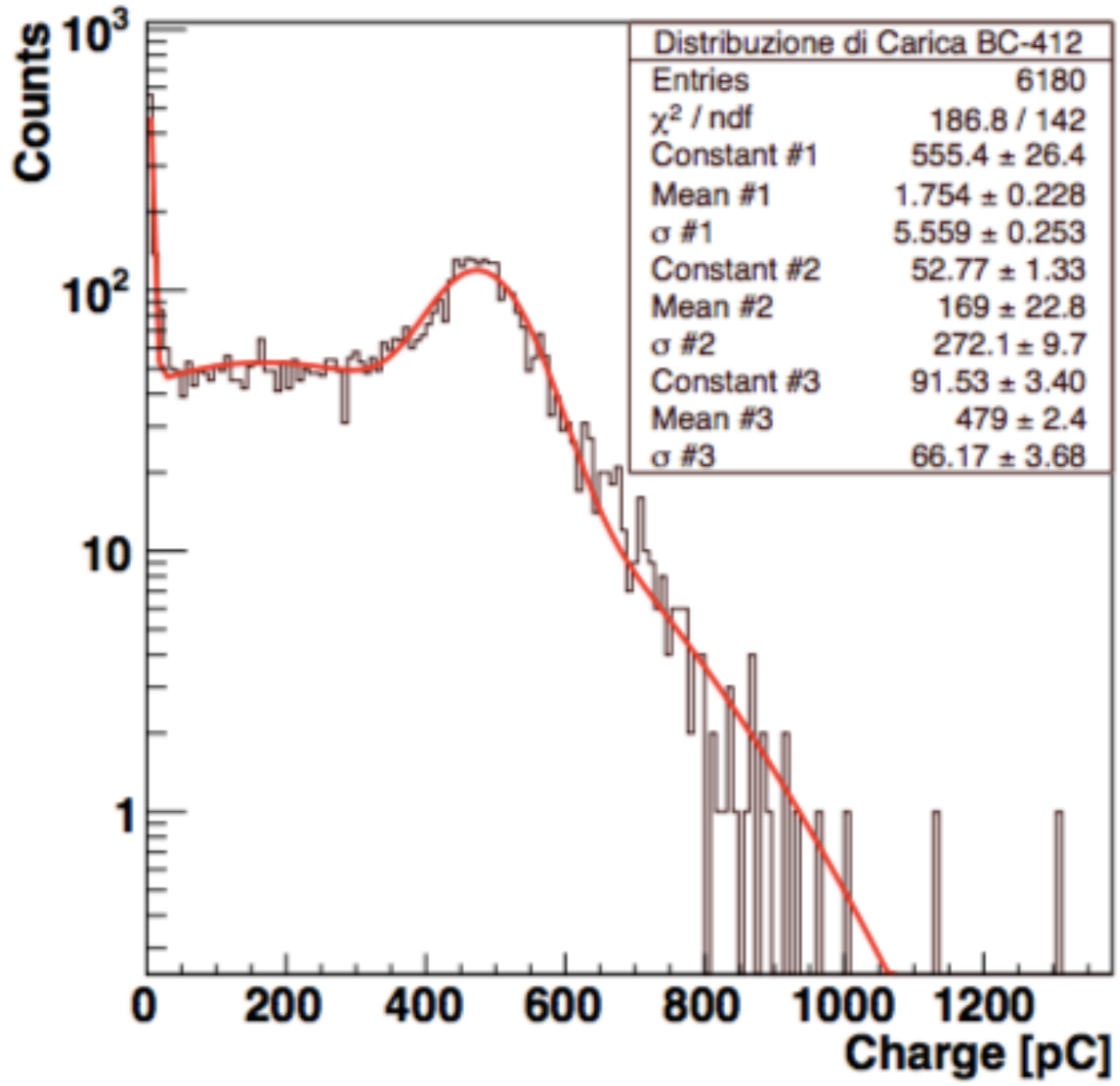




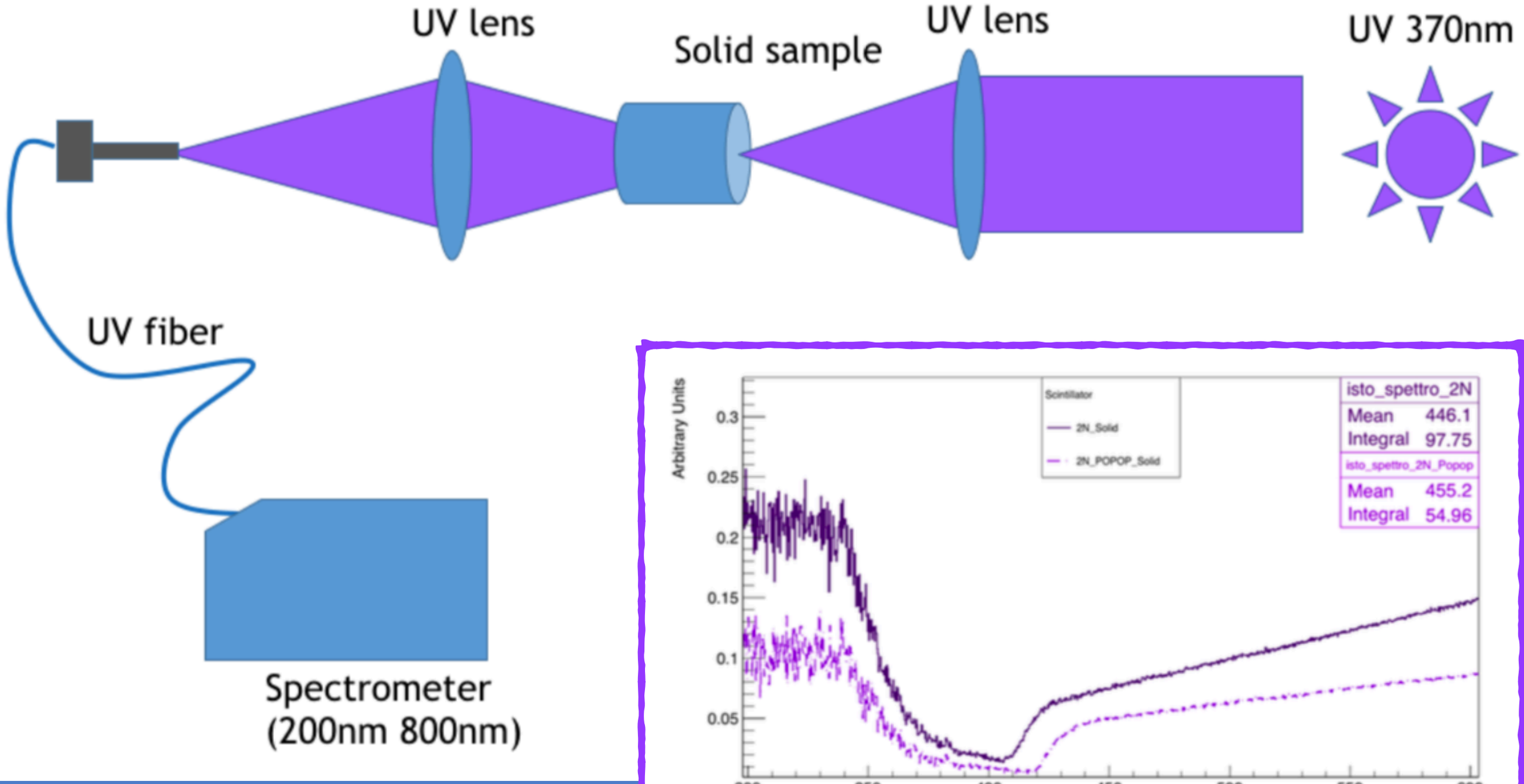
Light output evaluation







Trasmittance measurement



Emission measurement