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TOPS project: Development of new fast timing plastic scintillators

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Summary. — In particle physics charged particles are measured exploiting many different detection strategies. The plastic scintillators are cheap, versatile and show good time response, thus are traditionally employed as timing detectors. TOPS (Time Of flight Plastic Scintillators) is an R&D project devoted to the synthesis and characterization of a novel class of plastic scintillators. Liquid and solid samples of tens of new scintillators have been tested and characterized. Some of them (2N, 1N, 2B, P2, T2) have shown a larger light output with respect to antracene, a standard benchmark material, and good timing properties. In order to improve the matching between the scintillators emission and the optimal trasmittive region in the absorption spectra, a doping material has been added as wave-shifter. The use of POPOP as doping improved the performances of a fraction of the scintillator samples. Based on the comparison of the light output values in measurements with cosmic rays, a selection of the most promising scintillators has been investigated also from the timing point of view. The scintillation time characteristics of the TOPS plastic samples have been studied with minimum ionizing particles using a commercial plastic scintillator BC-412 as a reference. The light output and timing properties have been also investigated with proton beams at different energies (70, 120, 170, 220 MeV) and show promising results providing a time of flight measurements accuracy of 150–300 ps. In this contribution, preliminary results obtained with this new class of scintillators developed in the TOPS project will be presented.

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1. – Introduction

Organic scintillators are largely exploited in a wide range of detectors application due to their capability to yield very good time resolutions. Plastic scintillators are also relatively cheap, easy to manipulate and light (low density) with respect to conventional crystal scintillators and one of their main application is, for example, the very precise measurements of particles Time of Flight (TOF). The research and development of organic scintillators is always active and in this framework our collaboration is involved in the TOPS project (Time Of flight Plastic Scintillators) focused on the study and characterisation of a new class of plastic scintillators tailored for fast timing application.

2. – New scintillators

New organic molecules containing aromatic fragments have been designed and synthesized as organic scintillators. The scintillator molecules have been characterised by means of Nuclear Magnetic Resonance in order to confirm the intrinsic structure of the samples. The developing of plastic scintillators with our molecules was demonstrated using a system of a polyvinyl-toluene (PVT) polymer matrix loaded with various concentrations of scintillating compounds [1]. Figure 1 shows the temperature profile during the polymerisation process. After the complete dissolution occurring at room temperature, the PVT matrix loaded with scintillators is warmed up in a nitrogen atmosphere.

Both liquid and solid compounds have been developed and tested. Figure 2 shows the steps for the realisation of solid samples of standard dimensions (diameter = 14.4 mm, thickness = 10 mm), starting from the polymerisation of a liquid solution. All the samples have been characterised in terms of transmittance and absorption with photoluminescence spectroscopy measurements.

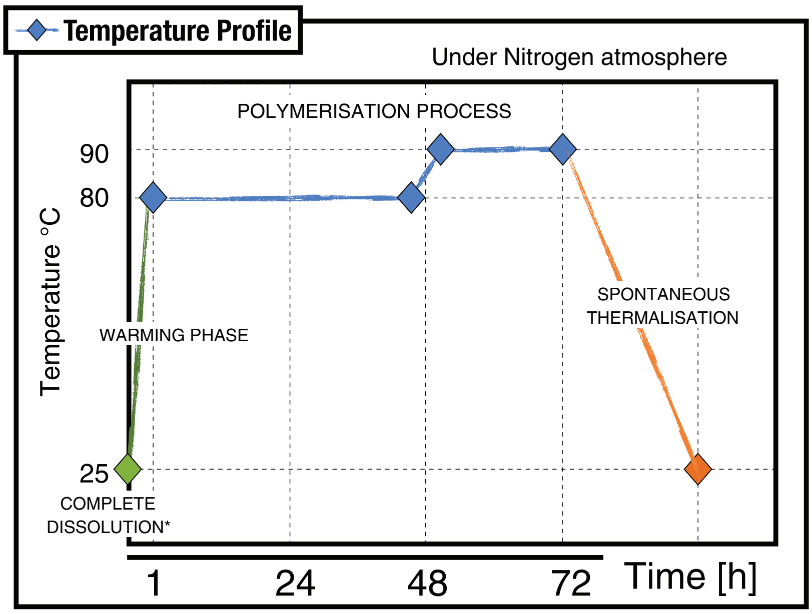

Fig. 1. – Temperature profile of the polymerisation process.

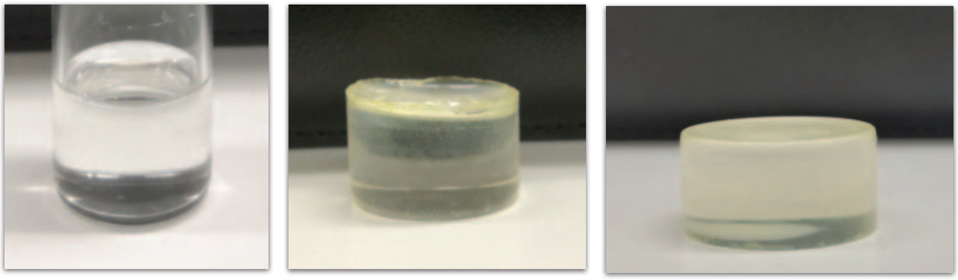

Fig. 2. – Example of a scintillator sample development. The scintillators polymerisation occurs in a glass vial. At the end of the polymerisation processes, the solid sample is extracted from the vial and is cut in order to have standard sized samples.

The scintillators emission/trasmission spectra matching has been improved with the introduction of doping materials as a wave-shifters (DPB([1]), POPOP([2])). For a fraction of the new scintillators the POPOP doping improved the performances in terms of light output. The samples have been tested with cosmic rays (CR) and the light output produced by CR ionisation in the scintillators has been measured using a commercial photo-multiplier tube (PMT, XP1911). Cosmic rays have been chosen to perform a preliminary characterization because they represent the worst situation in term of ionisation. The obtained results in terms of light output and timing properties are presented hereafter.

3. – Light output measurements

The light output, normalized to the anthracene, has been measured for the most promising samples. The values are reported in fig. 3 where the results obtained with a sample of BC-412 commercial plastic scintillator([3]) has been added as a reference. The orange dots refer to TOPS samples doped with POPOP while the green ones refer to the not-doped samples. Notice that the TOPS scintillators used in this study have been produced with a concentration of organic molecules of 1%, while the commercial plastic scintillator has a concentration (from the data-sheet) of $\leq 3\%$. The TOPS plastic scintillators showed also excellent optical transparency, even at high concentrations: the scintillator indicated as 2N has been produced at different concentrations, from 1% up to 7% and the samples did not show evident transparency or solubility problems. Figure 4 shows the 2N samples at different concentrations.

4. – Time response results

The timing properties of the 2B (doped) and the 2N new scintillators have been investigated with proton beams of different energies (70, 120, 170, 220 MeV). In order to study the timing resolutions a PMT H10721-210 (Hamamatsu, risetime ∼0.57 ns)

([1]) 1,4-Diphenyl-1,3-butadiene.
([2]) 1,4-Bis(5-phenyl-2-oxazol-2-yl)benzene.
([3]) `https://www.crystals.saint-gobain.com/products/bc-408-bc-412-bc-416`.

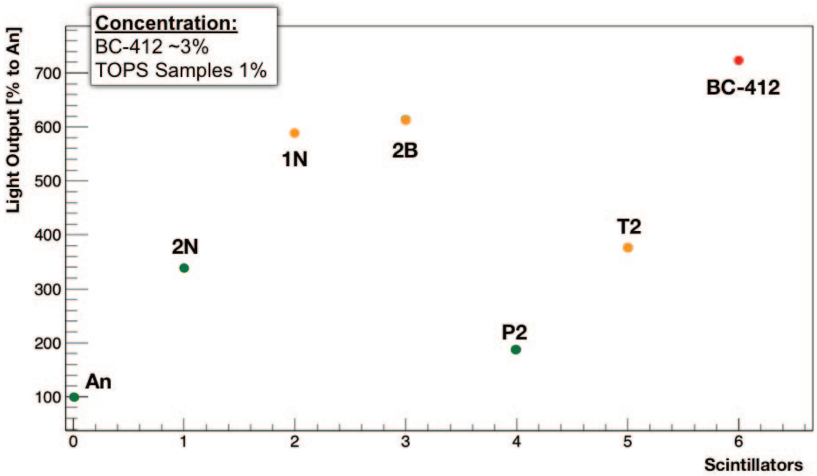

Fig. 3. – Measurements (normalized to the Antracene output, shown as the first entry in the plot) of the light output produced by cosmic ray in the TOPS samples and in a commercial scintillator (BC-412). The orange dots refer to samples in witch a wavelength shifter has been added as doping component. Only uncertainties included (the uncertainties are smaller than the marker size).

has been coupled to the samples. A schematic representation of the setup is reported in fig. 5: the BC scintillator has been used as a reference. The same PMT has been employed to instrument the BC sample in order to perform time of flight measurements. It must be noticed that the 2N and the 2B samples have different thicknesses, 5 mm and 3 mm, respectively. The new scintillators used in this test have a 1% concentration.

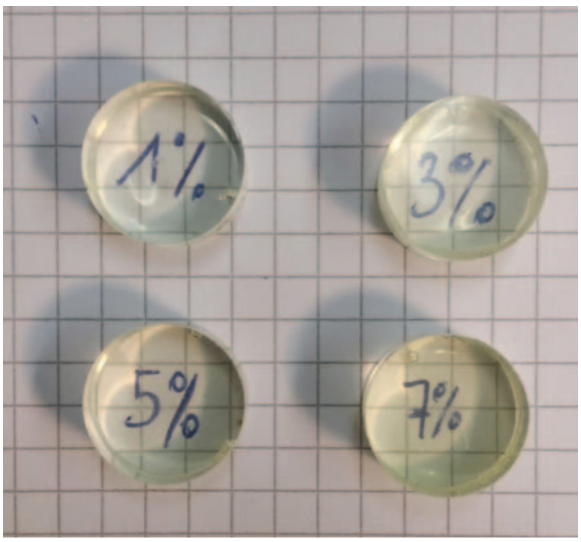

Fig. 4. – The 2N samples at different concentration, from 1 to 7%, are shown.

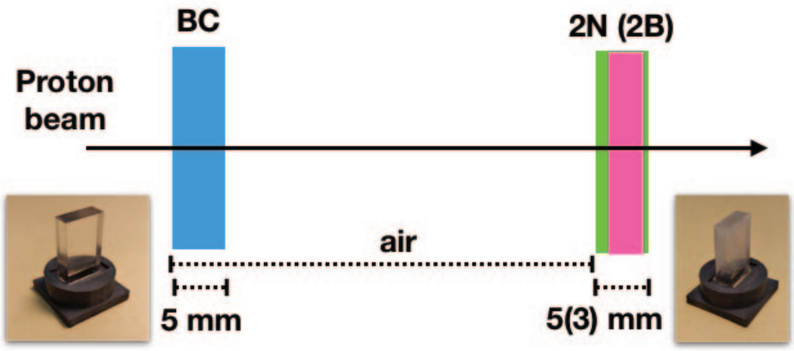

Fig. 5. – Schematic representation of the setup: the 2N and 2B samples are shown in green and pink while the BC, used as a reference, is shown in light blue.

Two different TOF measurements have been acquired using two combinations of detectors: BC-2N and BC-2B. The waveforms of all the PMT signals have been acquired with a digital oscilloscope (LeCroy HDO6104-MS 2.5 Gs/s). The time difference between the signals of the BC-2N and BC-2B couples has been studied. Figure 6 shows the TOF distribution obtained from a 120 MeV proton beam impinging on BC and 2N plastic scintillators. The single detector resolution (σ_i) is not available, while the combination of the two intrinsic resolutions has been measured: $\sigma_\Delta = \sqrt{\sigma_{BC}^2 + \sigma_{2N}^2}$. In fig. 7 the time resolution of the ToF measurement obtained with the different proton beams is reported; notice that for the BC-2B measurements the proton energy is shifted of 5 MeV in order not to overlap the markers at low energy.

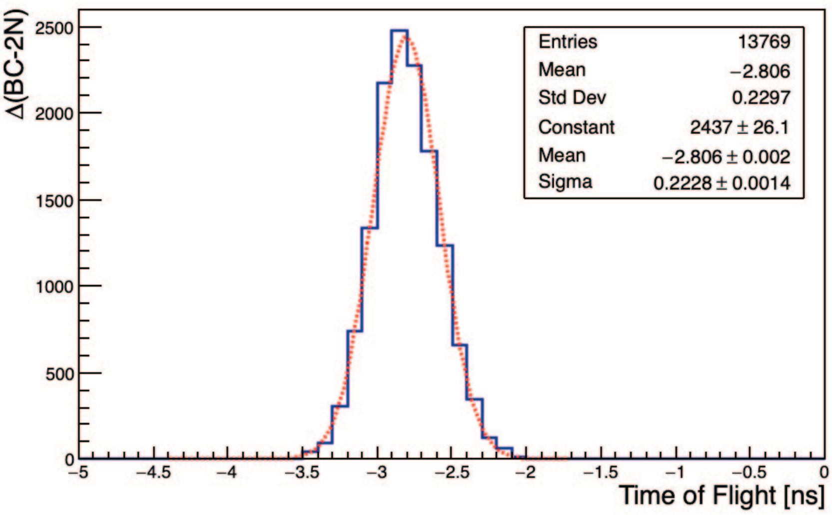

Fig. 6. – Distribution of the measured time of flight for 120 MeV protons for the BC-2N setup. The Gaussian fit function is superimposed.

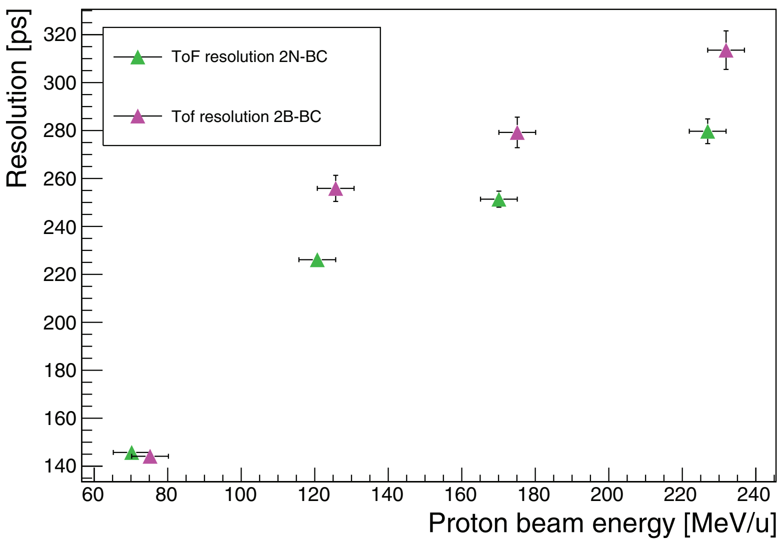

Fig. 7. – The time resolution obtained by the BC-2N and BC-2B couples of detectors are shown as a function of the proton kinetic energy. For the BC-2B measurements the markers positions are shifted in order to better compare the results at low energy.

For both configurations, with 2N and with 2B, the time of flight of the protons is measured with a resolution in the range of 150–300 ps. The 2B results suffer from the reduced thickness of the sample, compared with the 2N sample, that induced a lower energy deposition in the scintillator.

The resolutions obtained with protons confirm that the TOPS new molecules have a promising potential to implement new fast scintillators. Such preliminary results are also indicating that there is still room for improvement, and that an optimized balancing of the concentrations and a better transparency and control of the polymerization process will help improve the performances.

5. – Conclusions

The aim of the TOPS project is to develop new fast plastic scintillator materials with the main goal of improving the fast timing detectors landscape. The first preliminary tests of the new TOPS scintillators performed with mono-energetic proton beams in the energy range of 70–220 MeV showed promising results providing time of flight measurements with an accuracy of 150–300 ps.

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REFERENCES

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