A polystyrene-based scintillator production process involving additive manufacturing

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For the 3DET Collaboration

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The Scintillator Detector Frontier

- Massive scintillator detectors with complex geometries are becoming increasingly prevalent
  - Neutrino active targets
  - Neutron detectors
  - Calorimeters

- Examples
  - T2K ND “SFGD” *JINST* 13 P02006 (2018)
  - SoLid *JINST* 12 P04024 (2017)
  - CALICE *JINST* 5 P05004 (2010)
The Scintillator Detector Frontier

Example: The SFGD concept

- $4\pi$ acceptance
- Better tracking thresholds
- Improved resolution
- Enables measurements of neutron kinematics
The Scintillator Detector Frontier

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- Two million scintillator cubes
- 58,000 wave length shifting fibres
- ~ 2 tons of target mass

Challenging to assemble using standard techniques, especially if we ever need to go larger!
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Additive manufacturing may provide a viable means to produce future large detectors
The 3DET Collaboration

• The 3D printed DETector (3DET) collaboration is investigating and developing additive manufacturing as a new production technique for future scintillator particle detectors

  • General purpose R&D towards the first 3D printed particle detector with performances comparable to the state of the art

• 3DET comprises CERN, ETH Zurich, HEIG-VD, ISMA

  • The collaboration benefits from expertise in particle detector development, scintillator materials and additive manufacturing

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  Technical Coordinator: Umut Kose (umut.kose@cern.ch)
Printing a Large Scintillator Detector

Use “Fused Deposition Modelling” (FDM)

- Line by line assembly using filaments fed into extrusion nozzles
- 3D print large volumes quickly using multiple materials
- Robust (and relatively cheap)
- Allows a high transparency

https://makeagif.com/i/2ZQD2M
The Scintillator Filament

- Optimal composition found to be polystyrene + pTP + POPOP with a 5% biphenyl as plasticiser (needed to obtain a material suitable for FDM)

- No need to invent a new chemical composition: polystyrene has well known scintillating properties
The Proof of Concept

- Produce scintillator cubes using FDM as well as with standard techniques
- Compare light yield using cosmic and source exposure.
- Photosensor is coupled directly with the cubes

The outermost surface is always opaque. Characteristic of FDM.

Polishing the cube

Cosmics
The Proof of Concept

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A novel polystyrene-based scintillator production process involving additive manufacturing

*S. Berns et al 2020 JINST 15 P10019*


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The attenuation length

- Can also print long bars of scintillator
The attenuation length

- Can also print long bars of scintillator
- Optimise the attenuation length by adjusting the printing parameters. Optimised bar achieves a ~20 cm attenuation length.
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- Some air bubbles remain and reduce transparency
  - Scope for improvement by further fine tuning the printing process
The 3D printed optical reflector

• Using FDM we can simultaneously print the Scintillator and an optical reflector

• 10 mm thick scintillator, 1 mm thick reflector
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**Polymer pellets** + **Reflective pigment TiO2** (or BaSO4, MgO...) ➔ **Reflective filament**
The 3D printed optical reflector

- Using FDM we can simultaneously print the Scintillator and an optical reflector
- 10 mm thick scintillator, 1 mm thick reflector
- Reasonable reflectivity is achieved

<table>
<thead>
<tr>
<th>Sample</th>
<th>Reflection ($\lambda=420$ nm), %</th>
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<tbody>
<tr>
<td>PTFE</td>
<td>100</td>
</tr>
<tr>
<td>Tyvek</td>
<td>94</td>
</tr>
<tr>
<td>Reflective paint</td>
<td>93</td>
</tr>
<tr>
<td>3d-printing</td>
<td>91</td>
</tr>
</tbody>
</table>

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The 3D printed scintillator matrix

- Successfully 3D printed matrices of optically isolated scintillator cubes
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- Outermost surface has non-uniformities due to the high temperature printing, but this is not critical (it’s the inner part that will matter for physics performance)
  - Tolerance of reflector thickness and cube shape ~0.5 mm
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- Outermost surface has non-uniformities due to the high temperature printing, but this is not critical (it’s the inner part that will matter for physics performance)
  - Tolerance of reflector thickness and cube shape ~0.5 mm
- Some reflector elements found within the scintillator (scope for improvement)
The scintillator matrix performance

• The 3x3 matrix is coupled directly to photosensors
• Cosmics are triggered using another matrix of standard cubes
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- The 3x3 matrix is coupled directly to photosensors
- Cosmics are triggered using another matrix of standard cubes
- Preliminary measurements are promising:
  - Measured Light Output ~ 45 p.e.
  - Crosstalk probability ~ 2%

![Diagram showing 3D printed matrix and standard scintillator cubes]
Summary and future plans

• Demonstrated the feasibility of 3D printing plastic scintillator detectors, using Fused Deposition Modelling to simultaneously print both the scintillator and the optical reflector

• With further R&D, 3D printing may allow an easier (and potentially cheaper) realisation of complex detector geometries for future physics applications

• Performance of the 3D printed elements in the cube-matrix is comparable with that standard manufacturing techniques

• Further R&D is expected to improve performance
  • Better transparency
  • Improved geometrical tolerances
  • Investigating alternatives to FDM
  • Leaving holes for fibres as part of the printing
The attenuation length: details

In order to precisely quantify the attenuation length of the 3D printed scintillator, we obtained a sample after some improvements of the printing parameters:

- The 3D-printed sample was polished on the outermost surface
- SiPM on one end with SR$_{90}$/Y$_{90}$ source moving to different positions
- By eye: it looks transparent, but there’s a sparse presence of air bubbles – scope for improvement

**Preliminary**

Attenuation Length $\sim$ 20 cm
Acceptable for detectors with fine segmentation
End