Plastic scintillator production involving Additive Manufacturing

Davide Sgalaberna (ETH Zurich) for the 3DET collaboration
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Why Additive Manufacturing?

• In the last years more and more experiments started to develop massive plastic scintillator detectors with complex geometries.

• Examples can be found in neutrino active targets, calorimeters, neutron detectors, etc.

• Not easy to build and assemble these detectors with standard techniques involving subtractive processes.

Additive Manufacturing may be a viable and cheap solution.
The 3DET collaboration

• The 3D printed DETector (3DET) collaboration aims at 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 can profit of expertise in particle detector development, scintillator materials and additive manufacturing

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3D printing a big plastic scintillator detector

Need a technology that can:

- Achieve good scintillation performance and high transparency in the scintillator core
- 3D print big volumes in relatively short time
- Robust (and relatively cheap)
- 3D print simultaneously more materials

Fused Deposition Modeling (FDM) is a promising solution
The scintillator filament

Optimal composition is polystyrene + pTP + POPOP with a 5% biphenyl as plasticiser.

No need to invent a new chemical composition: polystyrene is well known.
The proof of the concept

The outermost surface is always opaque. Characteristic of FDM

MPPC coupled directly with scintillator cube in black connector (no white reflector envelope)

Results confirmed with PMT on Cs\(^{137}\) source (with reflector envelope)

![Graph showing light output comparison](image-url)

![Graph showing Sr90 results](image-url)

![Graph showing Cosmics results](image-url)
The proof of the concept

A novel polystyrene-based scintillator production process involving additive manufacturing

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Scintillation Light Yield comparable with the one of standard production techniques
Printing of long bars is also possible.

The printing parameters have to be carefully tuned to achieve the required transparency and light output.

- After improving the printing parameters, an acceptable attenuation length was obtained.
The attenuation length

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 + Sr\textsuperscript{90}/Y\textsuperscript{90} source moving at different positions

- The scintillator is pretty transparent
- Sparse presence of small air bubbles
- Future improvements may be achieved by fine tuning the printing parameters in order to obtain a higher fill factor

**Attenuation Length ~ 20 cm**
Acceptable for detectors with fine segmentation
3D printing of the optical reflector

PRELIMINARY

<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>

Similar reflectivity to TiO\(_2\) paint but less than Tyvek and PTFE (no air gap, Lower reflection, Surface roughness)
The 3D-printed scintillator matrix

Succeeded to 3D print a matrix of optically-isolated scintillator cubes

Matrix configuration
- 10 mm cube edge
- 1 mm reflector thickness

- Outermost surface not very precise due to the melting of the material at high temperatures
  - Not a big concern, as long as the inner part provides good performance

- Tolerance of reflector thickness and cube shape ~0.5 mm

- Some reflector remnants in scintillator (extruder couldn’t move up/down before changing material)
The 3D-printed scintillator matrix

- 3D-printed matrix covered with white teflon and coupled directly to SiPM
- Cosmics are triggered with another matrix of cubes (standard production)
- Preliminary tests are promising: Measured Light Output ~ 45 p.e. Crosstalk probability ~ 2%
- Complementary tests with Cs$^{137}$: light output similar to injection moulding with TiO$_2$ reflector
Future Plans

• We demonstrated the feasibility of 3D printing plastic scintillator detectors (both the scintillator and the optical reflector) with the Fused Deposition Modelling

• More R&D is needed to further improve the 3D matrix:
  ♦ Geometrical tolerance and Transparency

• Future tests will aim at measuring time resolution and ageing effects

• Work ongoing also on 3D printing of inorganic materials (not reported in this talk)

• Plan to investigate other additive manufacturing technologies to overcome the weaknesses of Fused Deposition Modelling
If you are interested to collaborate with the 3DET collaboration please get in contact with:

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Thanks