Additive Manufacturing of polystyrene based plastic scintillator

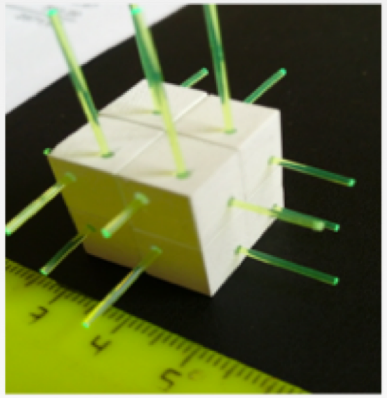
Umut KOSE (CERN) on behalf of 3DET Collaboration

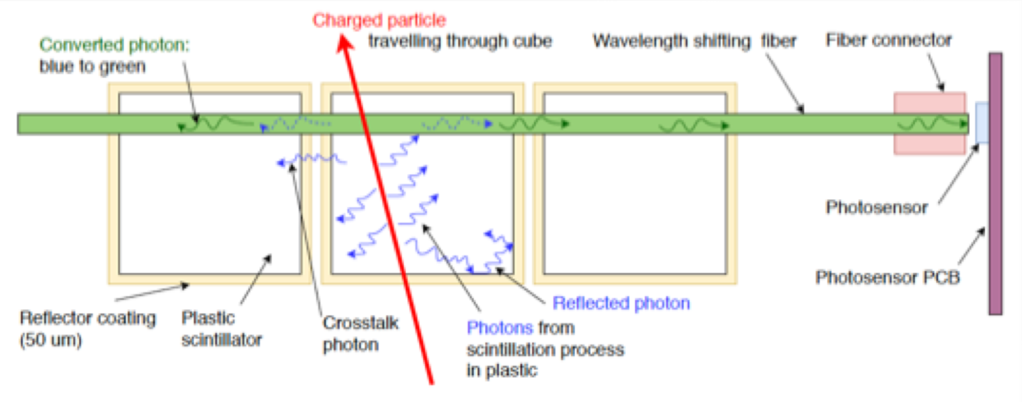
PANIC 2021, 5-10 September 2021, Lisbon, Portugal

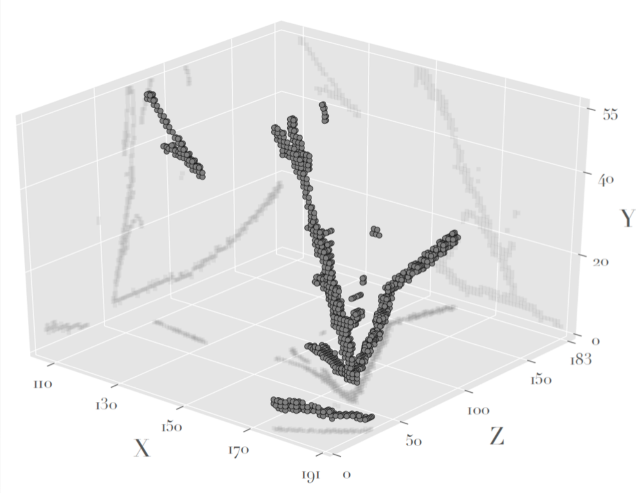
Why Additive Manufacturing?

- **Plastic scintillator detectors** can be found in a wide variety of scientific and industrial applications: for tracking and calorimetry in high energy physics, for diagnostic imaging in medicine, for beam monitoring in hadron therapy, and for many security applications.

- In the last years more and more experiments started to **develop massive plastic scintillator detectors with complex geometries**; such as neutrino active targets, fine grained calorimetry, neutron detectors, etc.







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

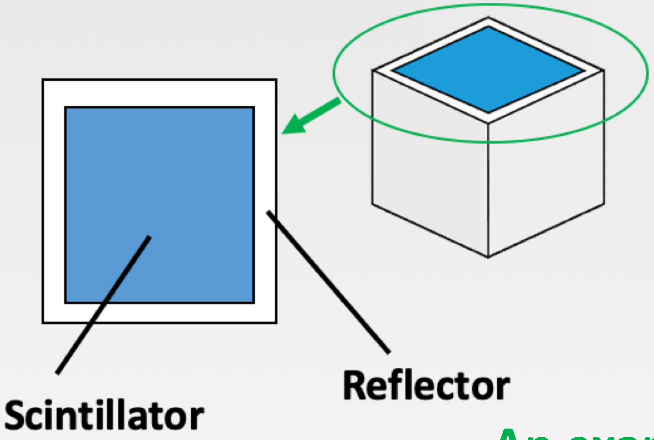
Additive Manufacturing technique may be a viable and cheap solution

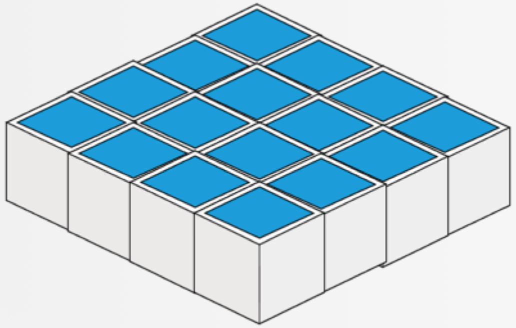
The 3DET Collaboration

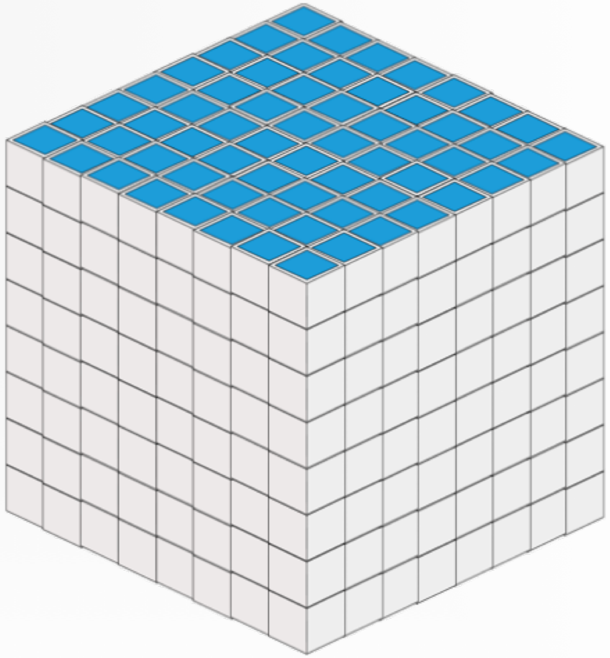
- The **3D printed DETector (3DET) collaboration** aims at **investigating and developing additive manufacturing as a new production technique for future scintillator particle detectors**
  - **General purpose R&D towards the first 3D printed particle detector with performances comparable to the state of the art**
- **3DET composes of CERN, ETH Zurich, HEIG-VD, ISMA**
  - **The collaboration can profit of expertise in particle detector development, scintillator materials and additive manufacturing**
  - **Contact Person**: Davide Sgalaberna (davide.sgalaberna@cern.ch)
    Technical Coordinator: Umut Kose (umut.kose@cern.ch)

Benchmark of 3D printing model

<u>Aim to 3D print simultaneously many optically-independent plastic scintillator volumes</u>







An example case study to apply AM techniques

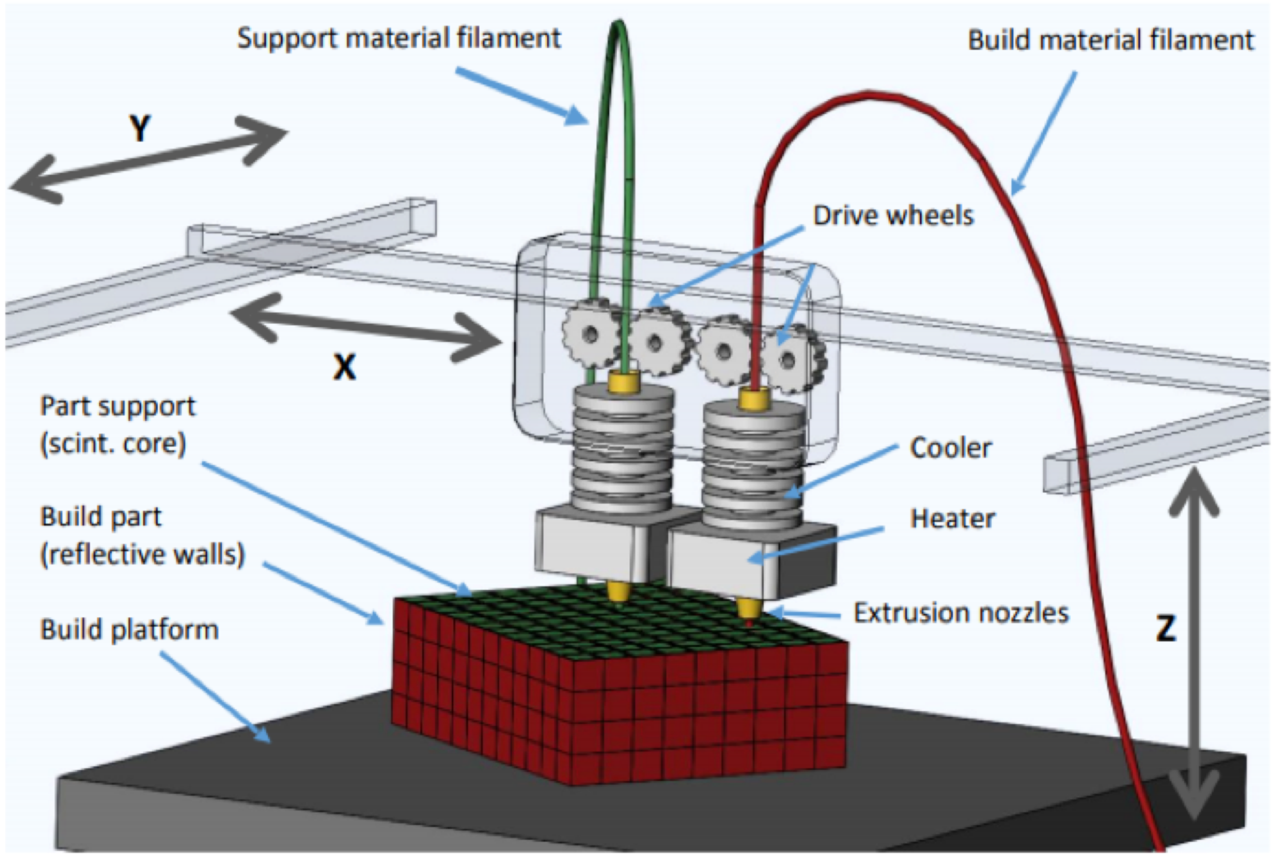
Need a technology that can:

- 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

3D printing plastic scintillator detector

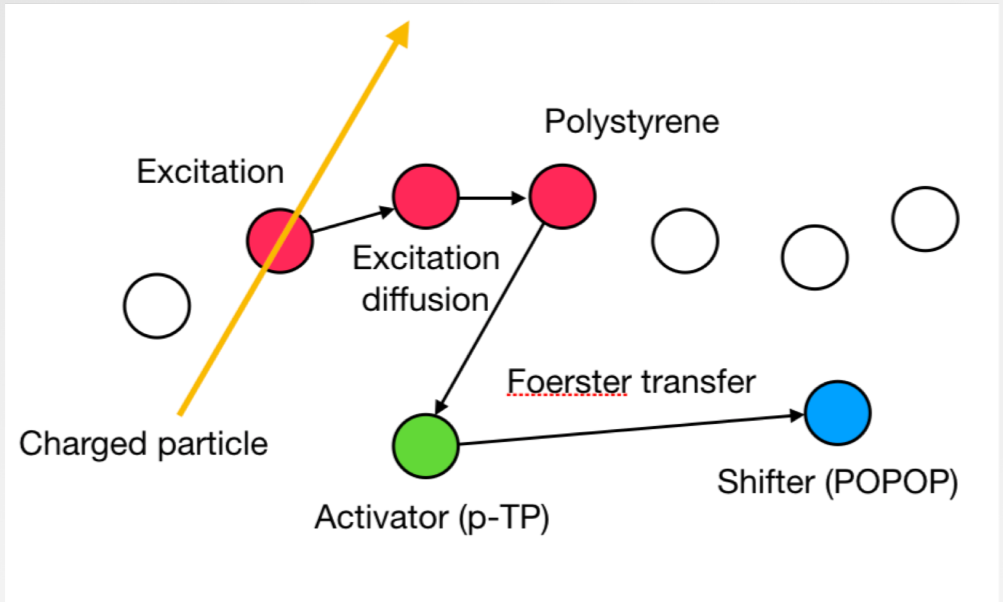
Fused deposition modelling, FDM, is very well established and the most widely used additive manufacturing technique:

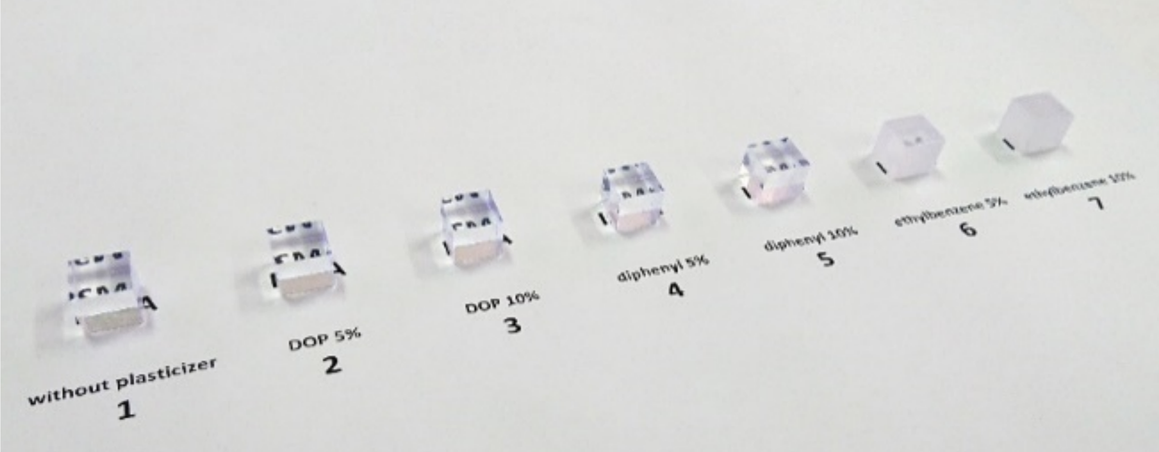
- Versatile in application,
- Rapid prototyping of specific shape and pattern,
- Cost effectiveness
- Multi material



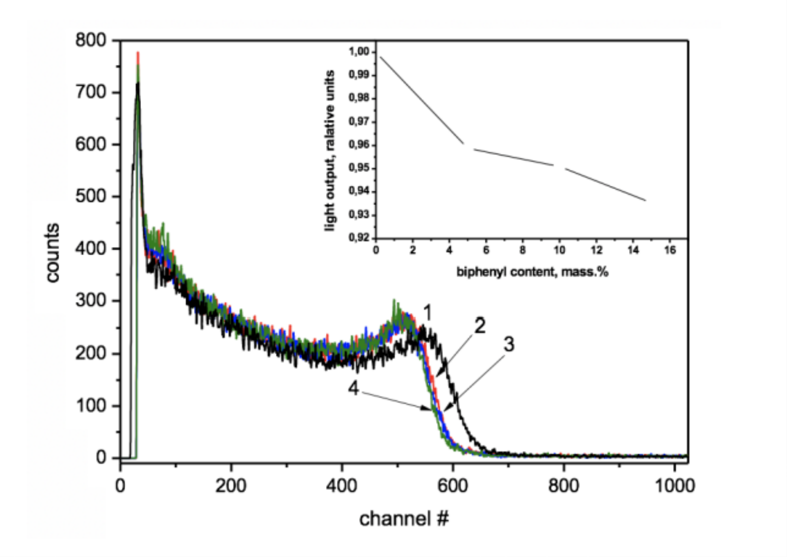
Fused Deposition Modeling is a promising solution

The scintillator filament





Scintillation polystyrene samples 10*10*10 mm with plasticizers

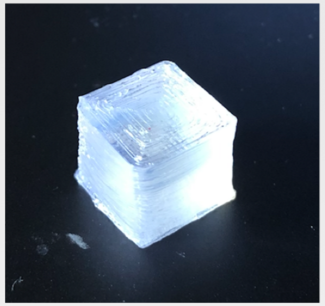


Requirements:

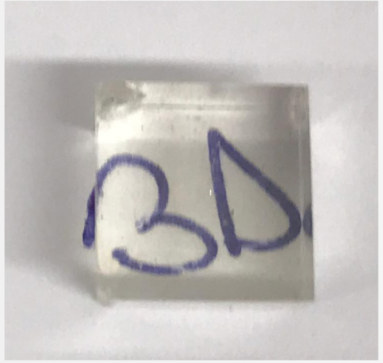
- **Transparency**
- **Dimensional uniformity**
- **Uniform distributions of the scintillation additives**
- **Flexibility: by adding plasticizer to polystyrene**

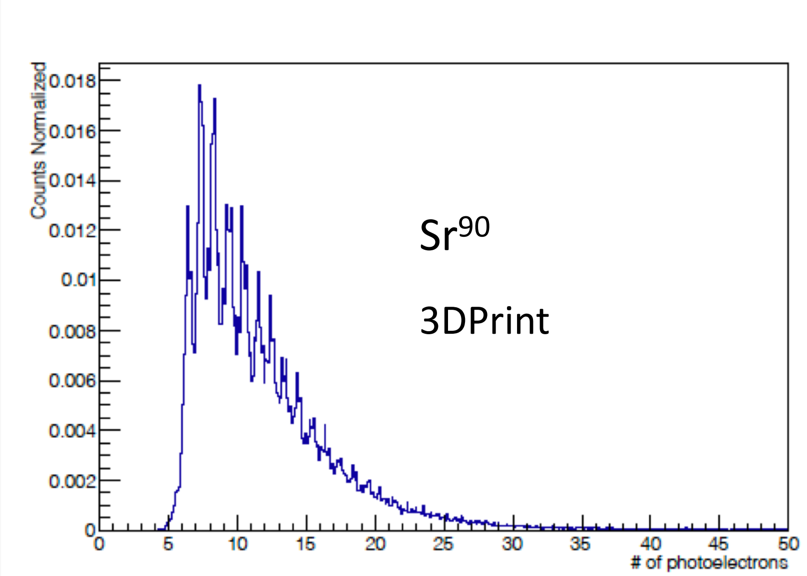
Optimal composition is polystyrene + pTP + POPOP with a 5% biphenyl as plasticizer

The proof of concept

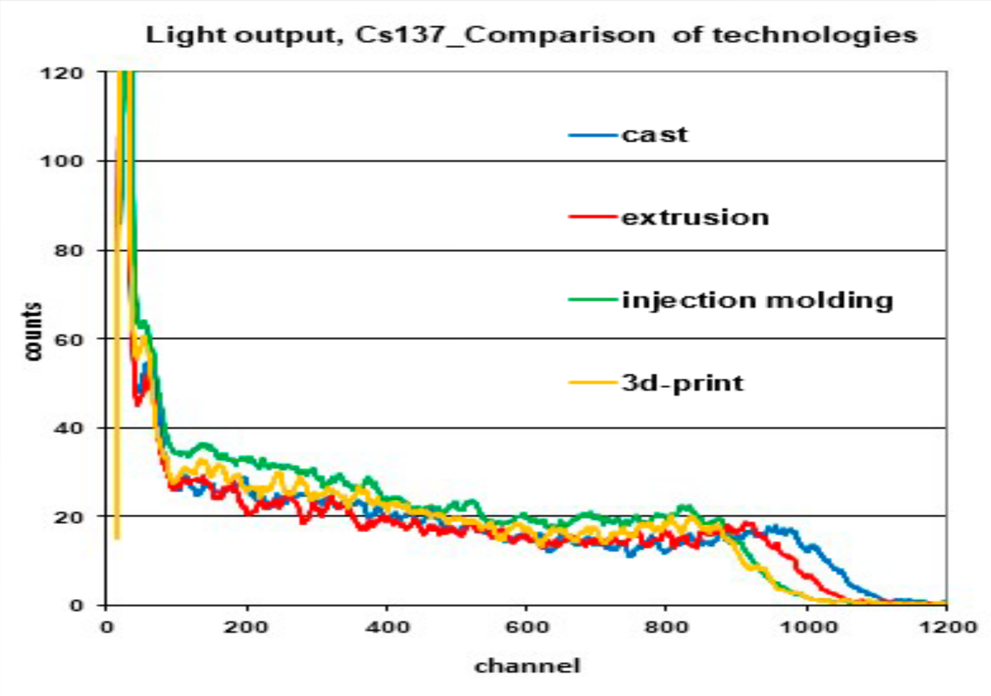


The outermost surface is always opaque. Characteristic of FDM

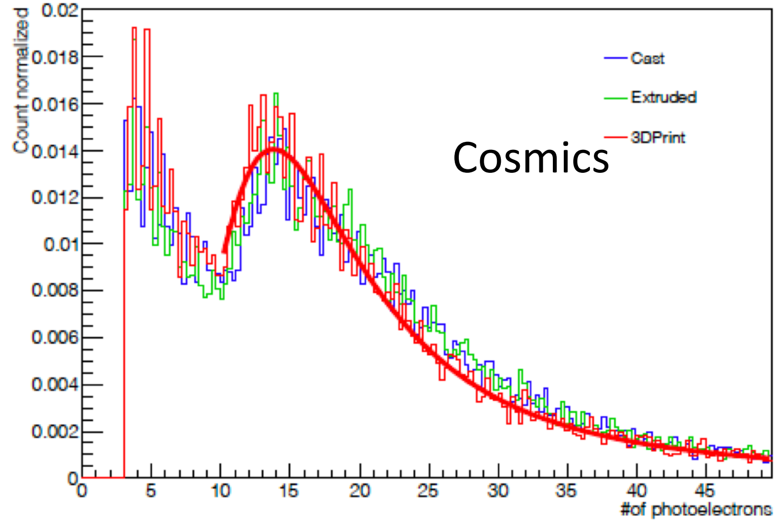




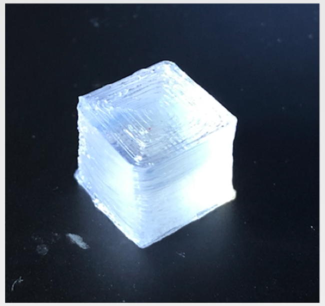
MPPC coupled directly with scintillator cube in black connector (no white reflector envelope)



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



The proof of concept



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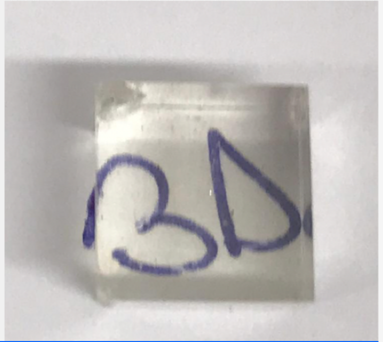

A novel polystyrene-based scintillator production process involving additive manufacturing

S. Berns et al 2020 JINST 15 P10019

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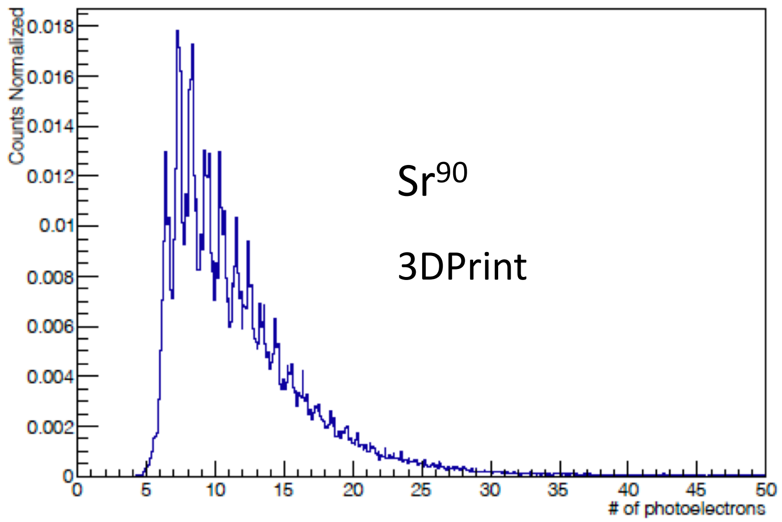
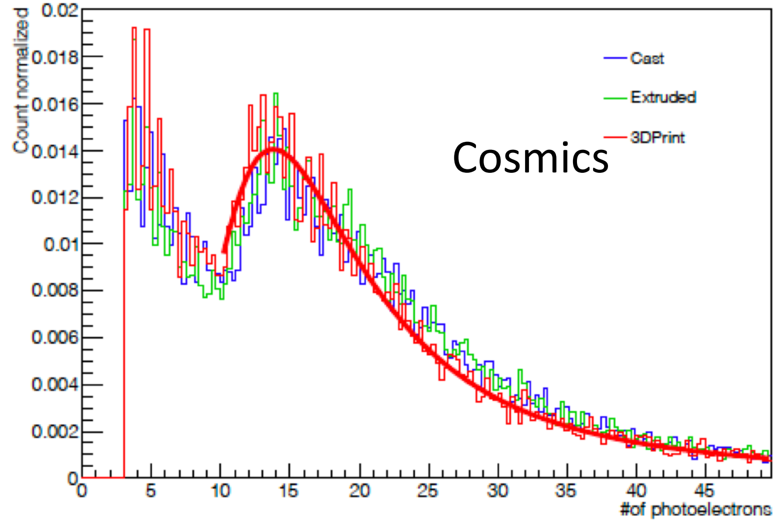
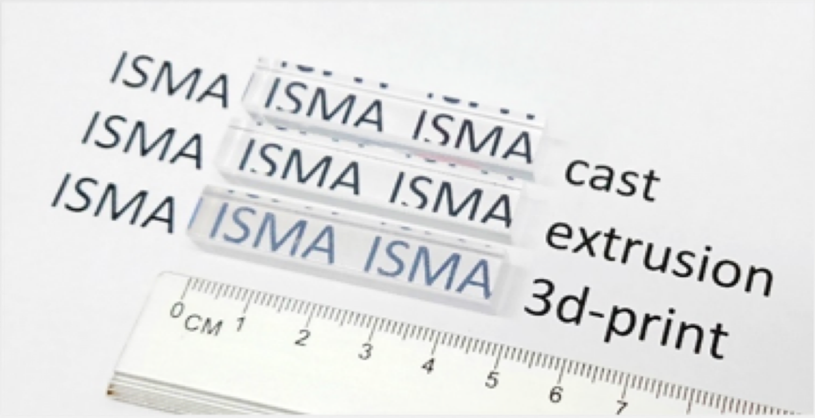
Scintillation light yield comparable with the one of standard production techniques



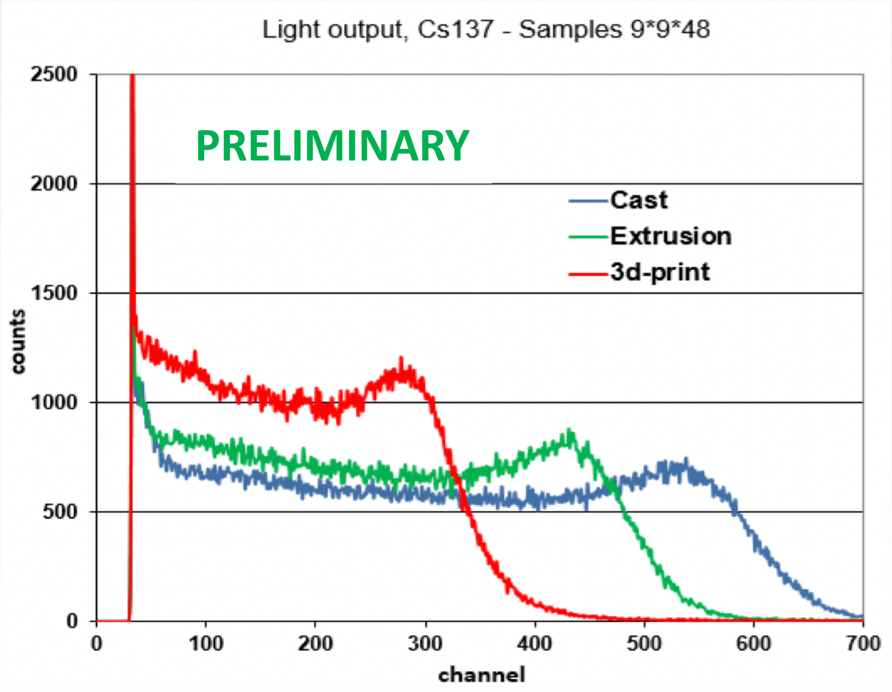
MPPC coupled directly with scintillator cube in black connector (no white reflector envelope)

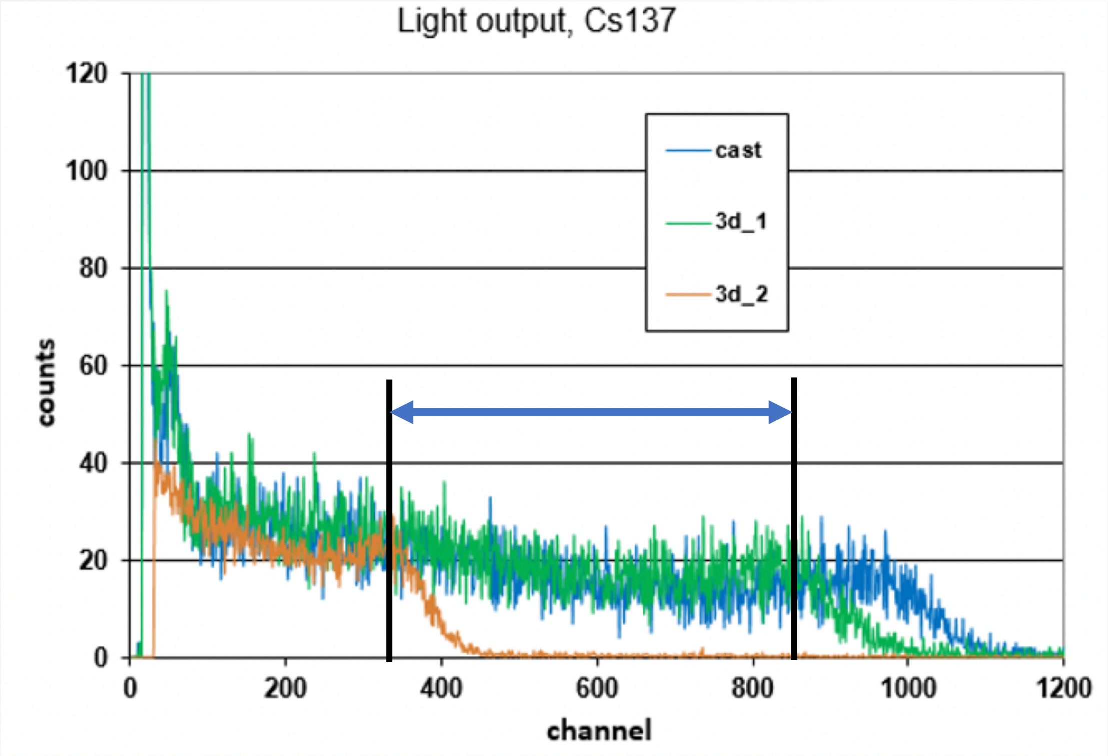


The attenuation length



Long bar sample 10 mm x 10 mm x 50mm





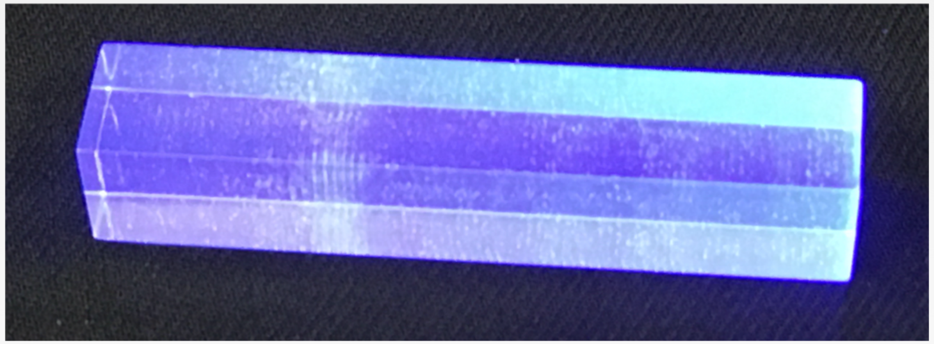
The printing parameters have to be carefully tuned to achieve the required transparency and light output

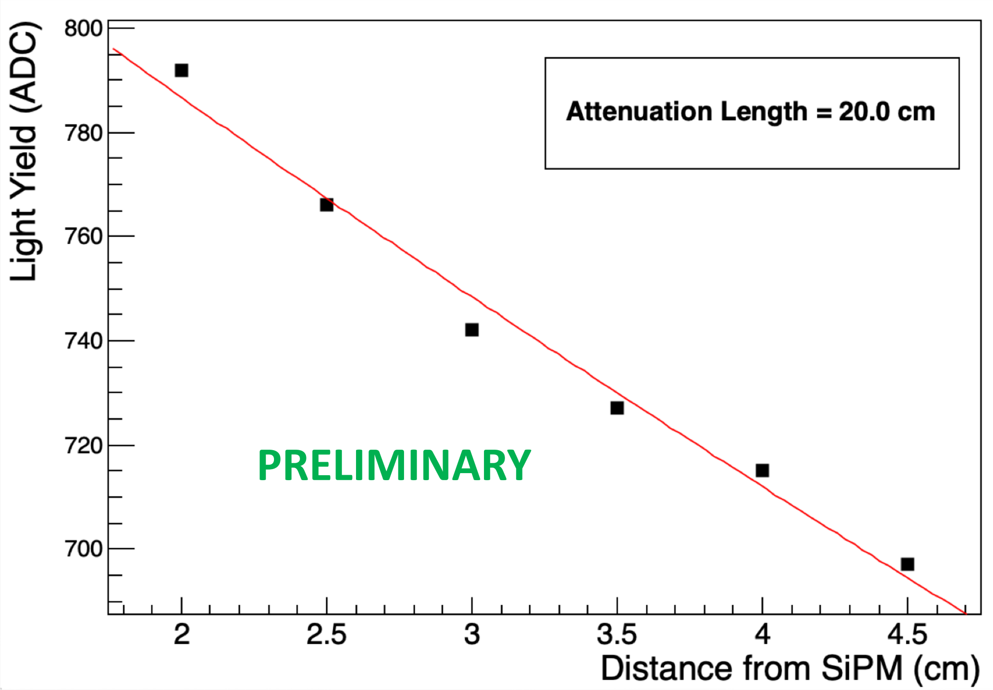
- After improving the printing parameters, an acceptable attenuation length was obtained

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 (10 mm x 10 mm x 50 mm) was polished on the outermost surface
- SiPM directly coupled on one end and Sr^{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 of ~20 cm obtained
Acceptable for detectors with fine segmentation

3D printing of the optical reflector

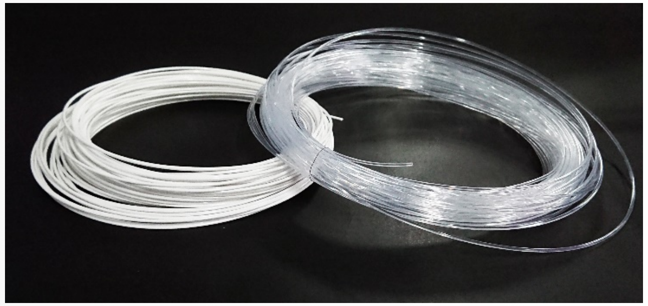
Polymer pellets

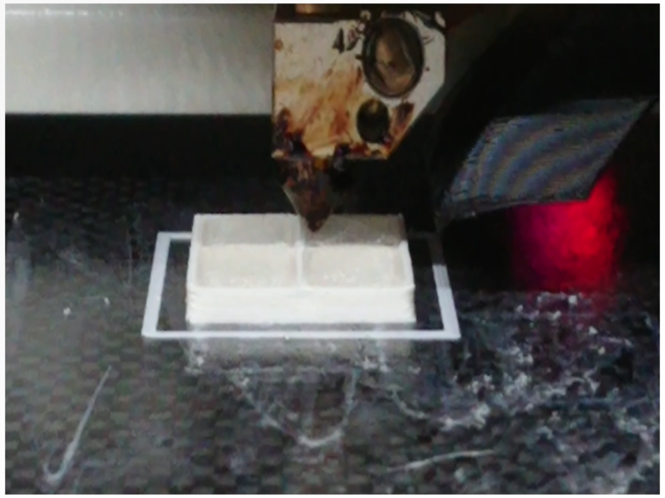
+

Reflective pigment TiO2
(or BaSO4, MgO…)

Reflective filament

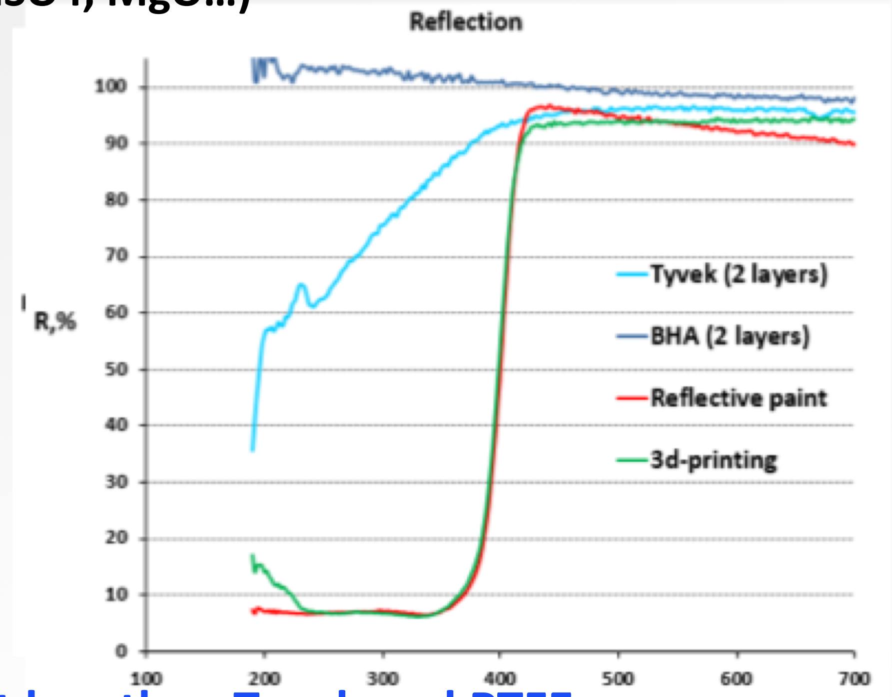
Multi material printing





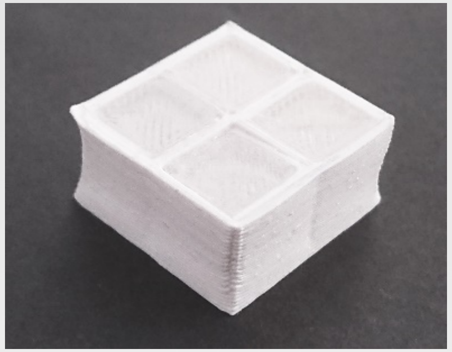
PRELIMINARY

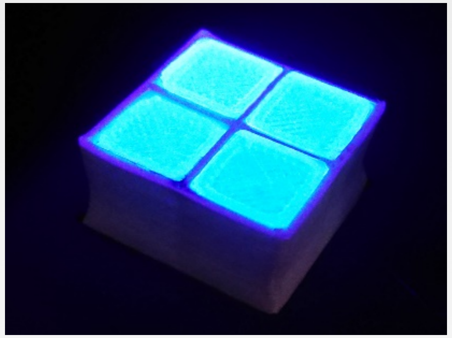
Sample	Reflection (λ=420 nm), %
PTFE	100
Tyvek	94
Reflective paint	93
3d-printing	91

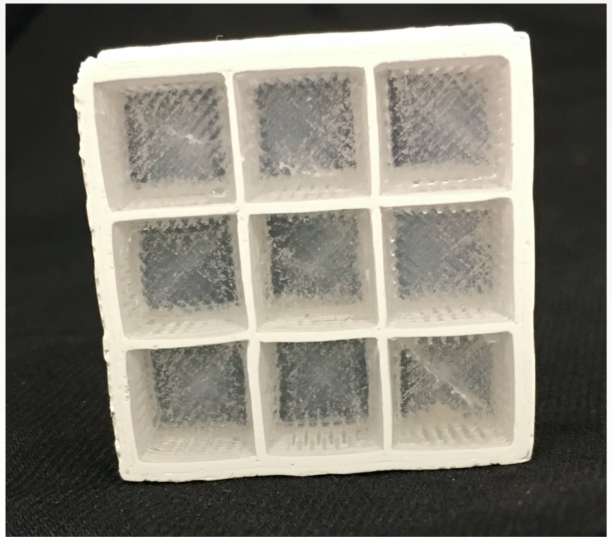


Similar reflectivity to TiO2 paint but less than Tyvek and PTFE
(no air gap, low reflection, surface roughness)

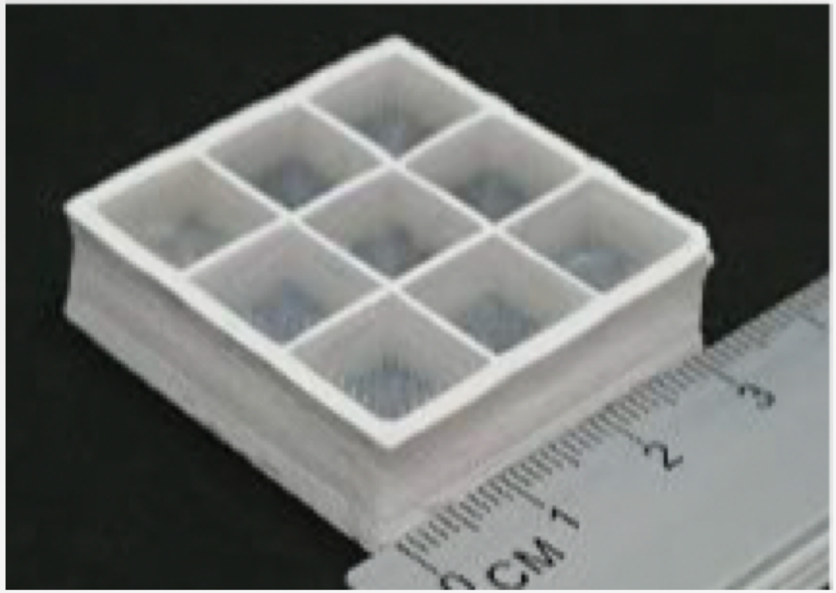
The 3D-printed scintillator matrix







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

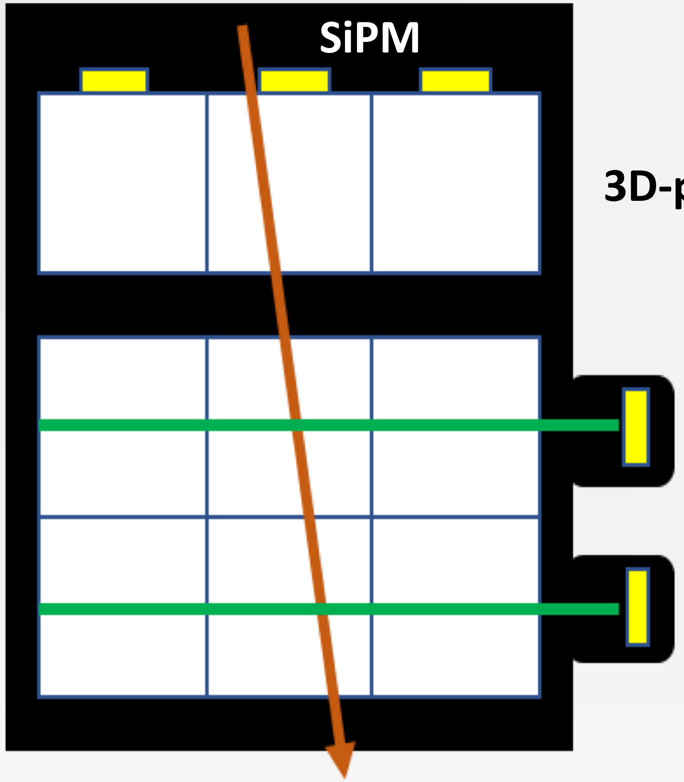


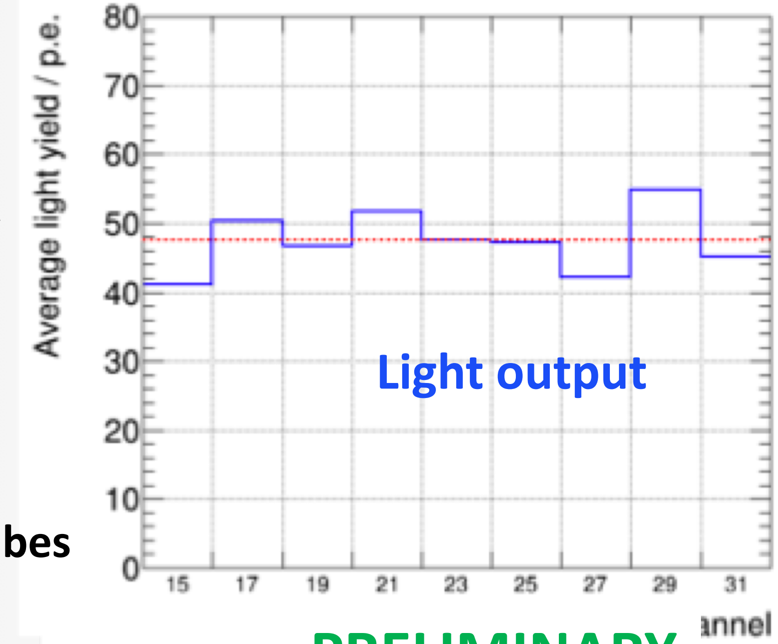
Matrix configuration:

- 10 mm cube edge
- 1 mm reflector thickness

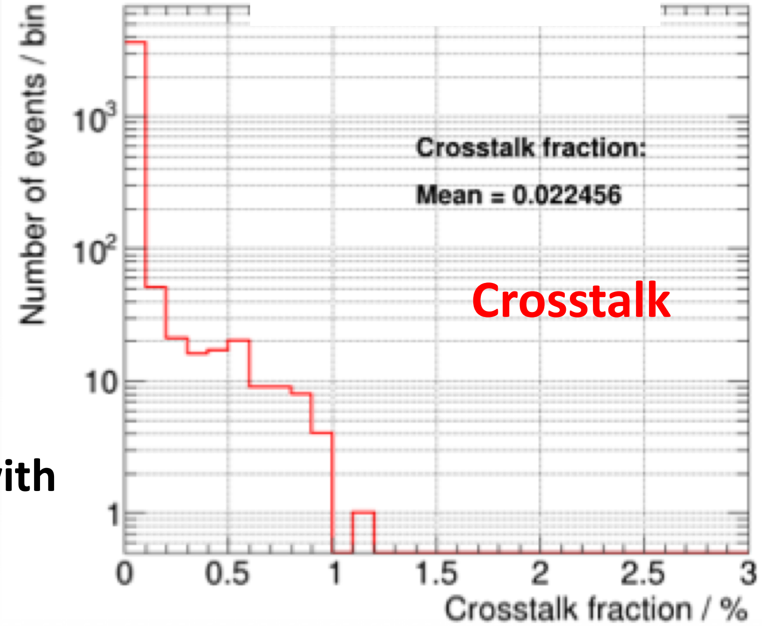
- Outermost surface not very precise due to the melting of the material at high temperatures
  - Not a big concern, as long as the inner part provides good performance
- Tolerance of reflector thickness and cube shape ~0.5 mm
- Some reflector remnants in scintillator (extruder couldn't move up/down before changing material)

The 3D-printed scintillator matrix





PRELIMINARY



- 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} show light output similar to injection molding with TiO2 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 of 3D printed sample and ageing effects

- Work on going 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

Thank you

If you are interested to collaborate with 3DET collaboration please get in contact with:

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