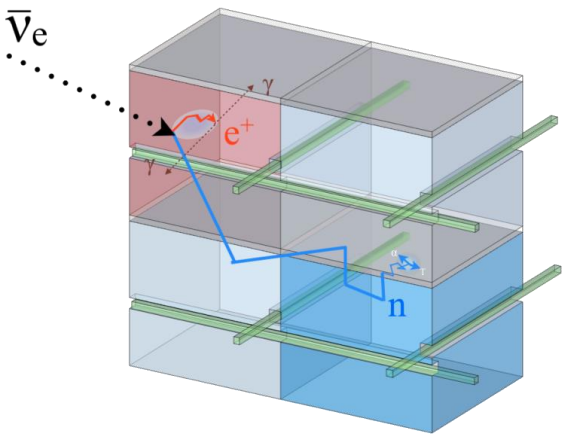
A polystyrene-based scintillator production process involving additive manufacturing

Stephen Dolan
For the 3DET Collaboration

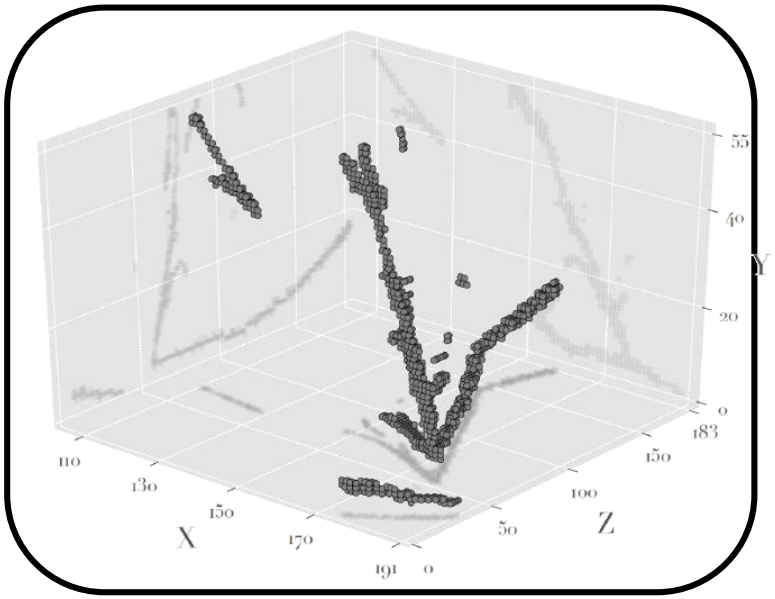
stephen.joseph.dolan@cern.ch

The Scintillator Detector Frontier

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



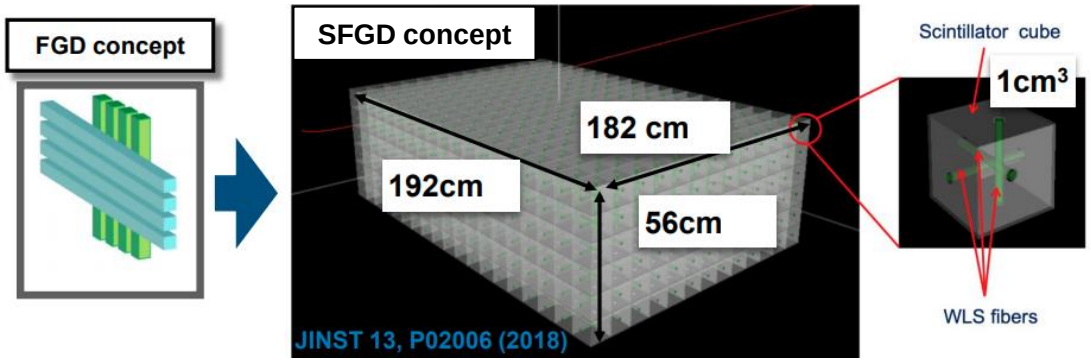
- Examples
  - T2K ND "SFGD" *JINST* **13** P02006 (2018)
  - SoLid *JINST* **12** P04024 (2017)
  - CALICE *JINST* **5** P05004 (2010)
  - DUNE ND calorimeter *Instruments*, 5(4), 31 (2021)



The Scintillator Detector Frontier

Example: The SFGD concept

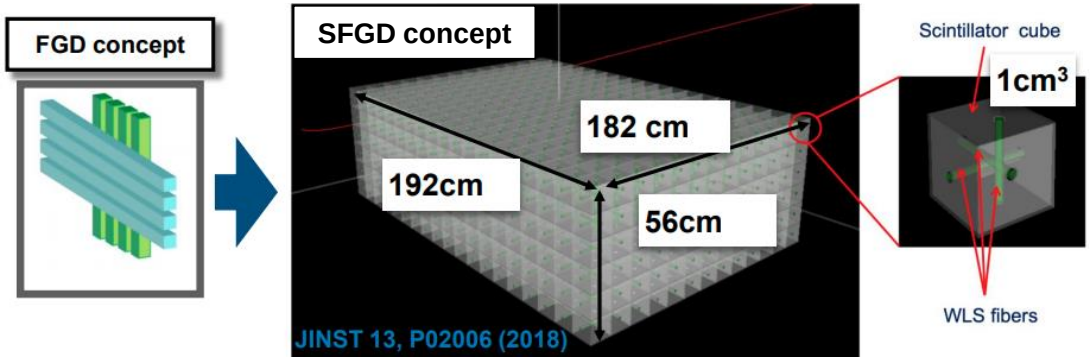
- 4π acceptance
- Better tracking thresholds
- Improved resolution
- Enables measurements of neutron kinematics

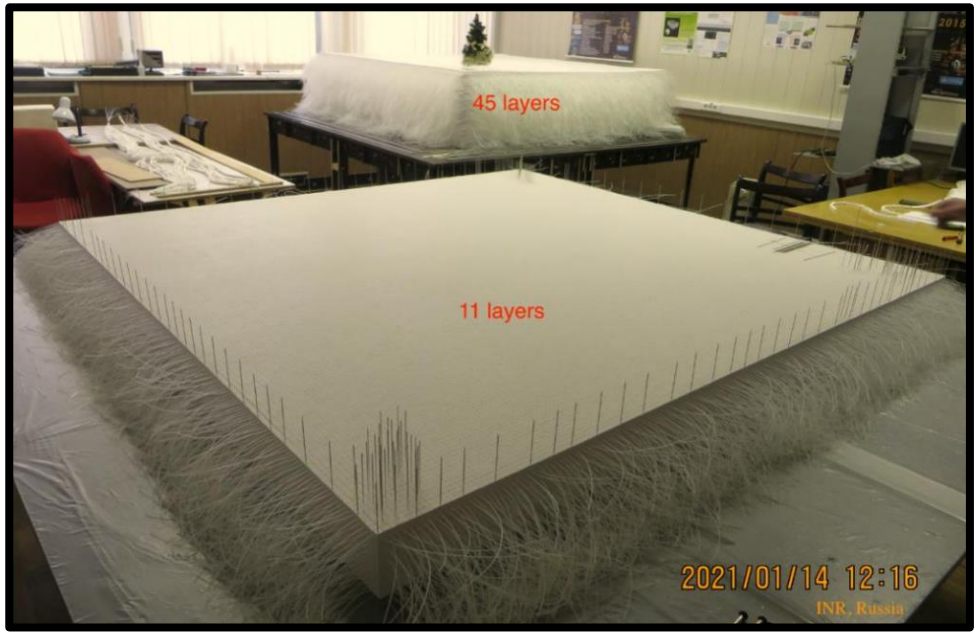


The Scintillator Detector Frontier

Example: The SFGD concept

- 4π acceptance
- Better tracking thresholds
- Improved resolution
- Enables measurements of neutron kinematics





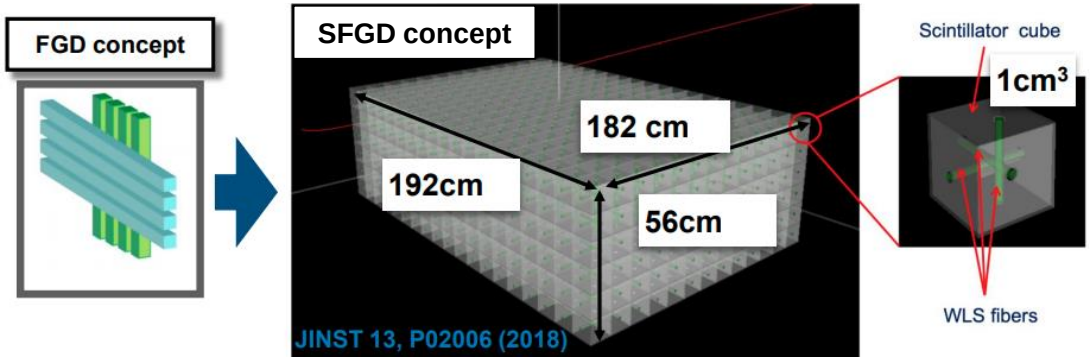
- Two million scintillator cubes
- 58,000 wave length shifting fibres
- ~ 2 tons of target mass

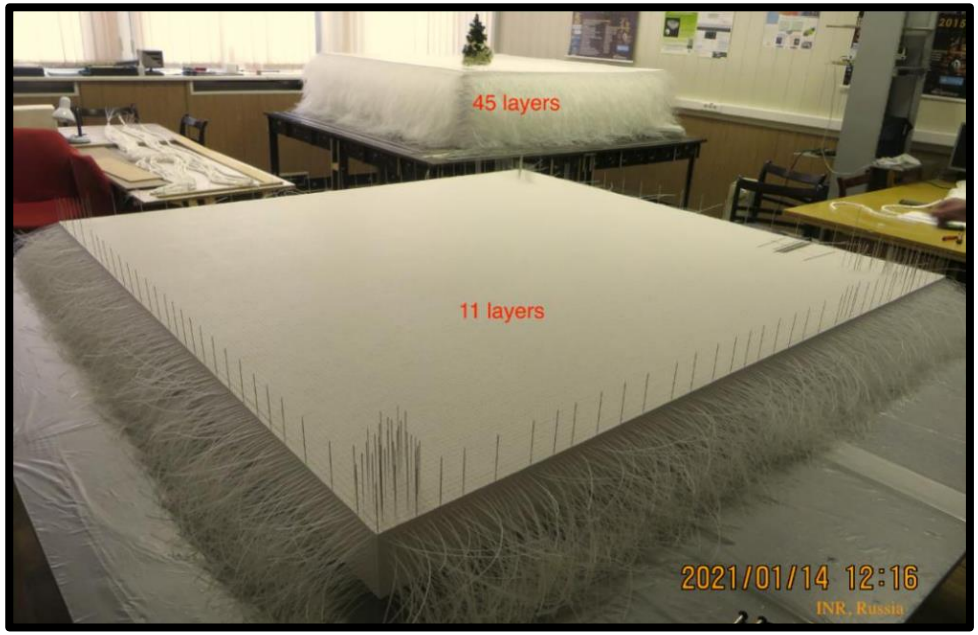
Challenging to assemble using standard techniques, especially if we ever need to go larger!

The Scintillator Detector Frontier

Example: The SFGD concept

- 4π acceptance
- Better tracking thresholds
- Improved resolution
- Enables measurements of neutron kinematics





- 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!

Additive manufacturing may provide a viable means to produce future large detectors

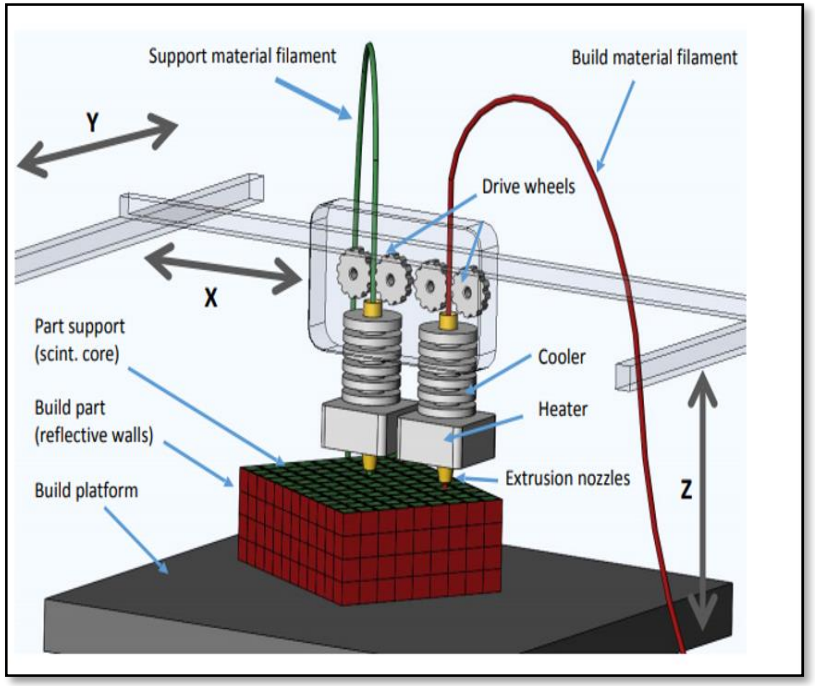
The 3DET Collaboration

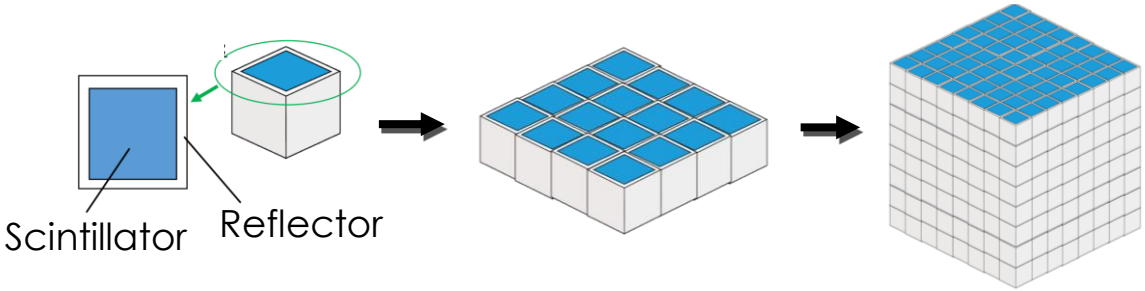
- The 3D printed DETector (3DET) collaboration is **investigating and developing additive manufacturing as a new production technique** for future scintillator particle detectors
  - General purpose R&D towards the first 3D printed particle detector with performances comparable to the state of the art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

Printing a Large Scintillator Detector

Use "Fused Deposition Modelling" (FDM)

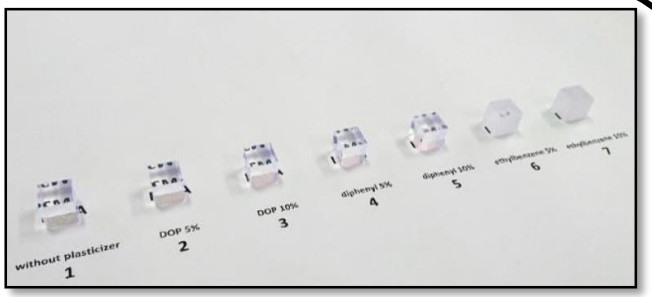
- Line by line assembly using filaments fed into extrusion nozzles
- 3D print large volumes quickly using multiple materials
- Robust (and relatively cheap)
- Allows a high transparency

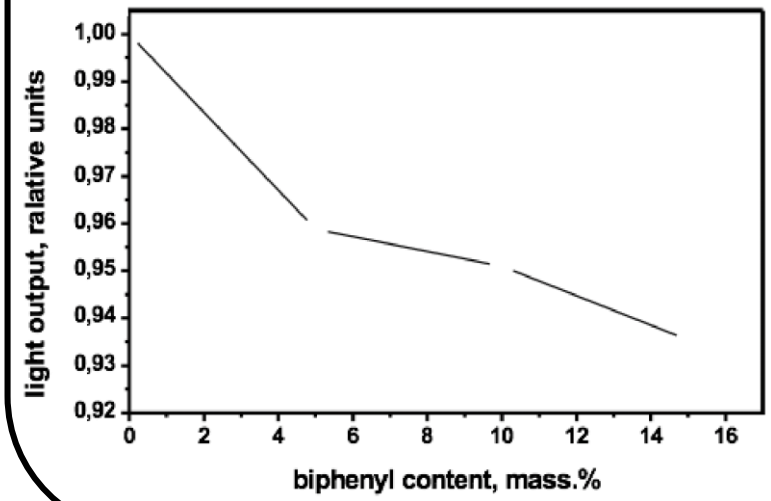




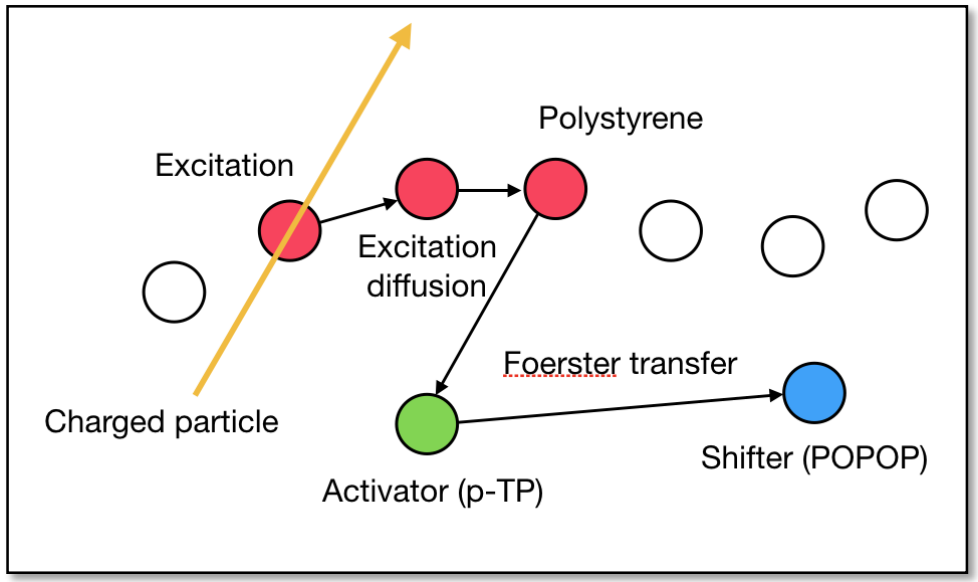
The Scintillator Filament

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





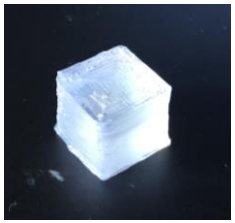
- No need to invent a new chemical composition: polystyrene has well known scintillating properties



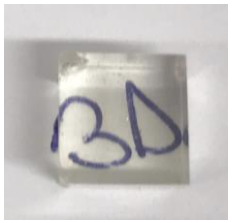
The Proof of Concept

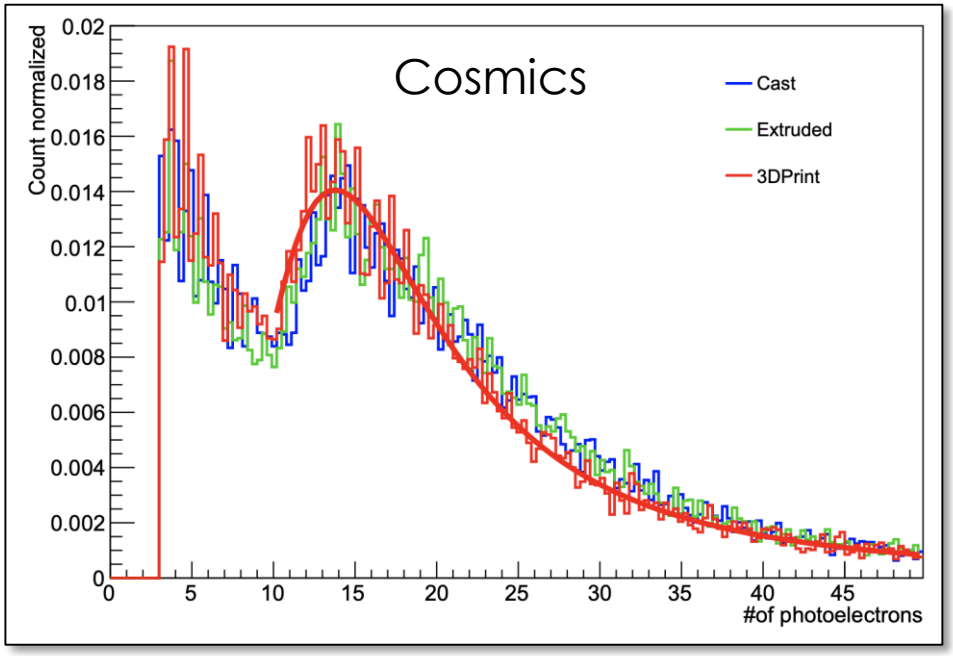
- Produce scintillator cubes using FDM as well as with standard techniques
- Compare light yield using cosmic and source exposure.
- Photosensor is coupled directly with the cubes

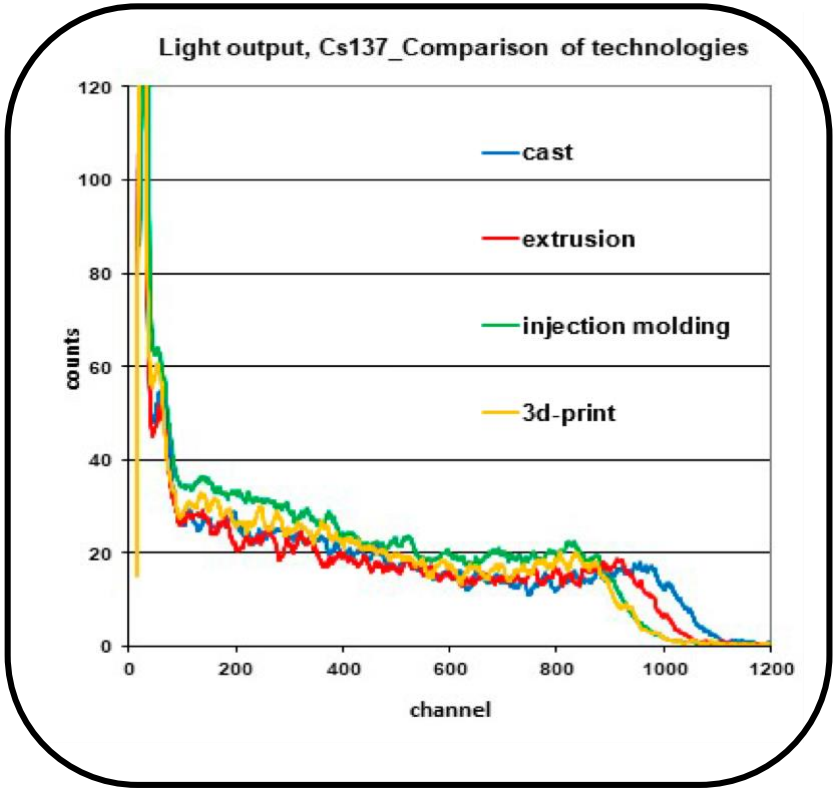
The outermost surface is always opaque. Characteristic of FDM.



Polishing the cube







The Proof of Concept

- Produce scintillator cubes using FDM as well as with standard techniques
- C
- F

The outermost surface is always opaque. Characteristic of FDM.

A novel polystyrene-based scintillator production process involving additive manufacturing

S. Berns et al 2020 JINST 15 P10019

S. Berns,[a,b,c] A. Boyarintsev,[d] S. Hugon,[a,b,c] U. Kose,[e] D. Sgalaberna,[e,*,1] A. De Roeck,[e] A. Lebedynskiy,[d] T. Sibilieva,[d] P. Zhmurin[d]

[a] *Haute Ecole Spécialisée de Suisse Occidentale (HES-SO), CH-2800 Delémont, Route de Moutier 14, Switzerland*

[b] *Haute Ecole d'Ingénierie du canton de Vaud (HEIG-VD), CH-1401 Yverdon-les-Bains, Route de Cheseaux 1, Switzerland*

[c] *COMATEC-AddiPole, CH-1450 Sainte-Croix, Technopole de Sainte-Croix, Rue du Progrès 31, Switzerland*

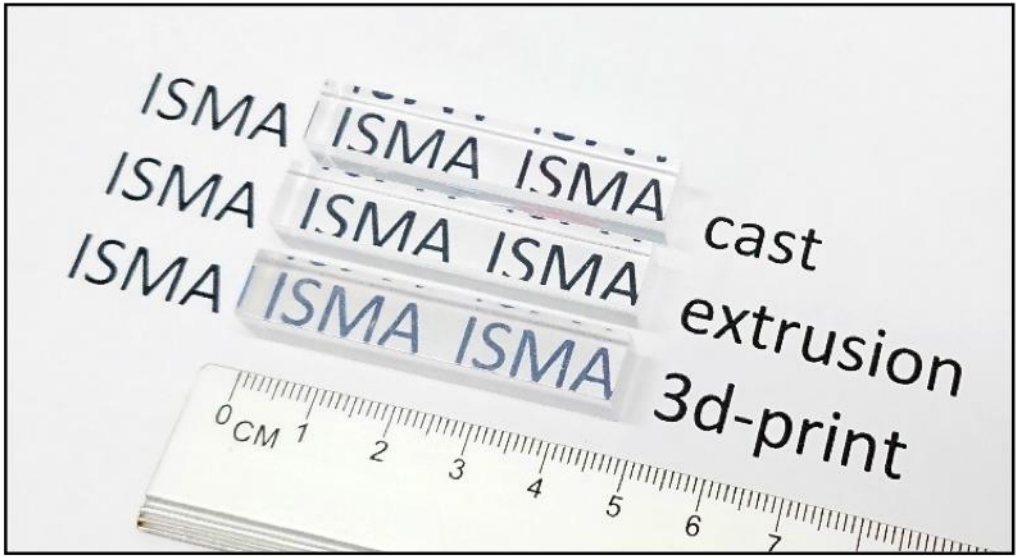
[d] *Institute for Scintillation Materials NAS of Ukraine (ISMA), Kharkiv 61072, Ukraine*

[e] *European Organization for Nuclear Research (CERN), 1211 Geneva 23, Switzerland*

[*] *Now at ETH Zurich, Institute for Particle Physics and Astrophysics, CH-8093 Zurich, Switzerland*

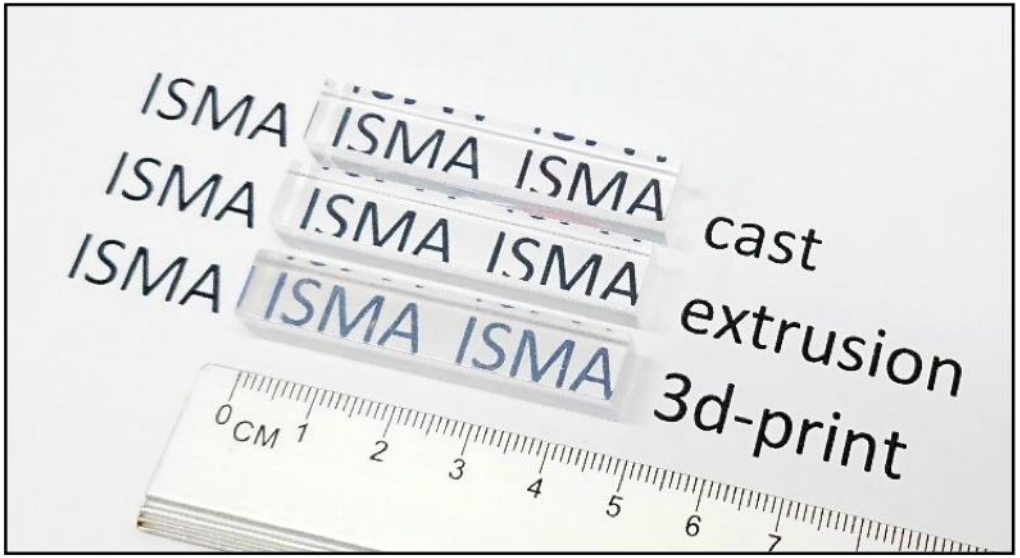
The attenuation length

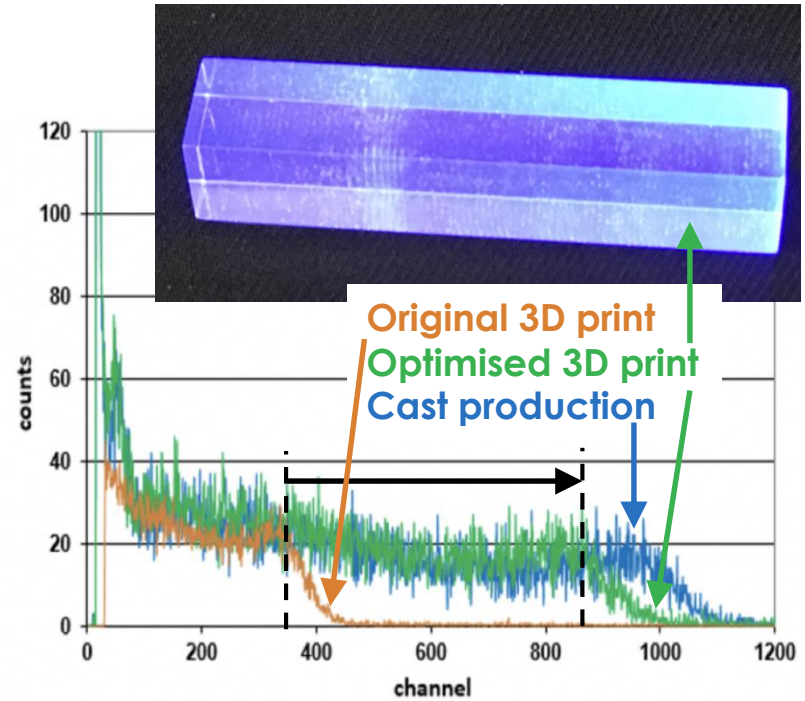
- Can also print long bars of scintillator



The attenuation length

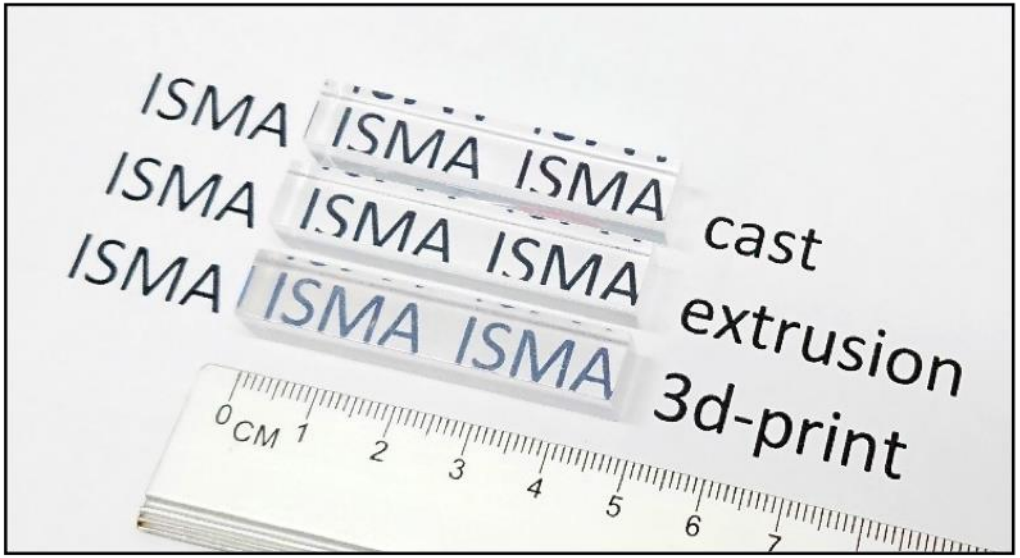
- Can also print long bars of scintillator
- Optimise the attenuation length by adjusting the printing parameters. Optimised bar achieves a ~20 cm attenuation length.

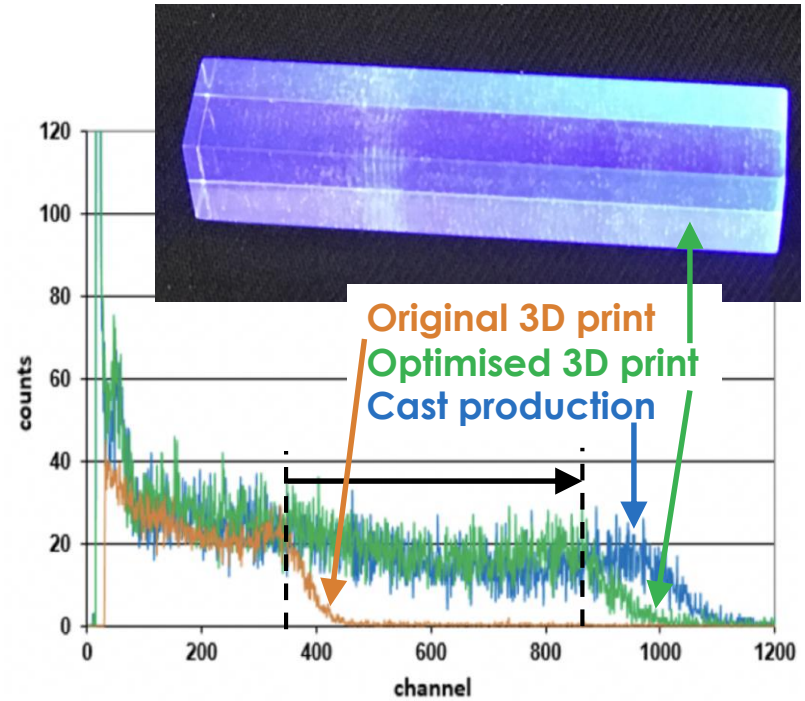




The attenuation length

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

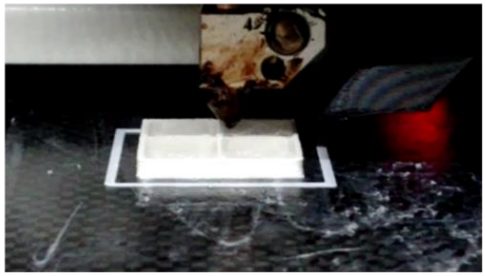




The 3D printed optical reflector

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

Multi material printing:



Polymer pellets

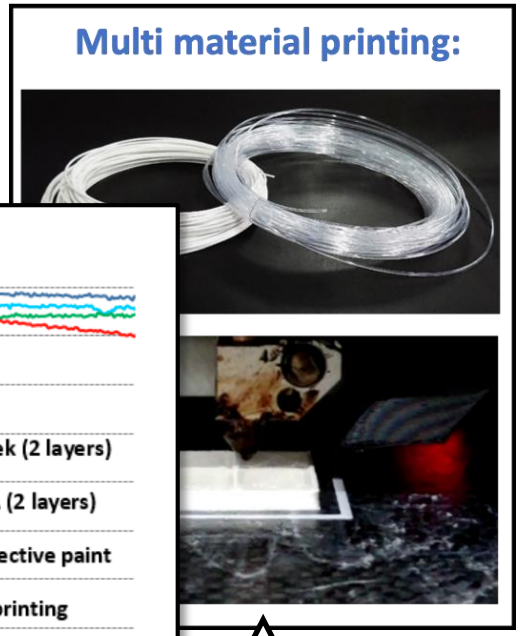
+

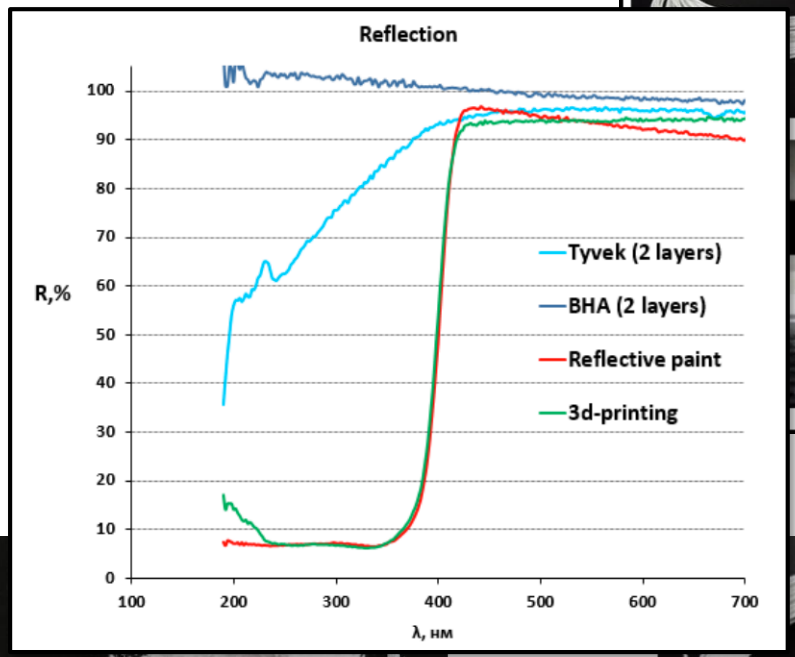
Reflective pigment TiO2 (or BaSO4, MgO…)

Reflective filament

The 3D printed optical reflector

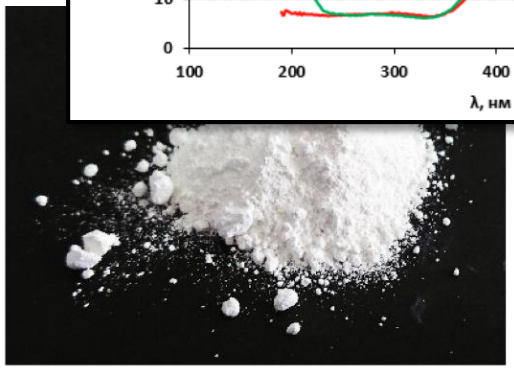
- Using FDM we can simultaneously print the Scintillator and an optical reflector
- 10 mm thick scintillator, 1mm thick reflector



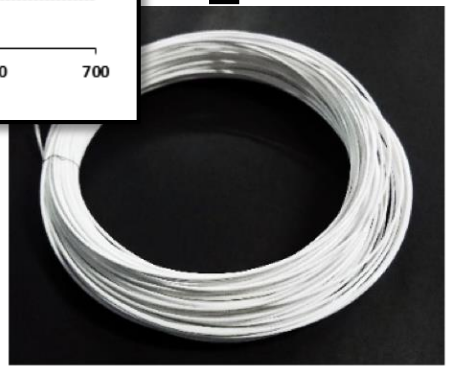


Polymer pellets

+



Reflective pigment TiO2 (or BaSO4, MgO…)



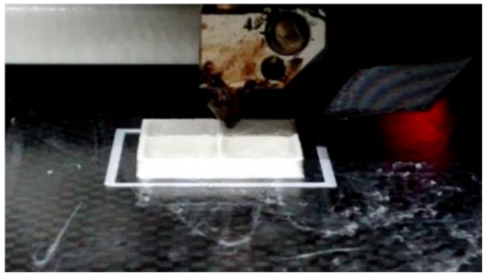
Reflective filament

The 3D printed optical reflector

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

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

Multi material printing:



Polymer pellets

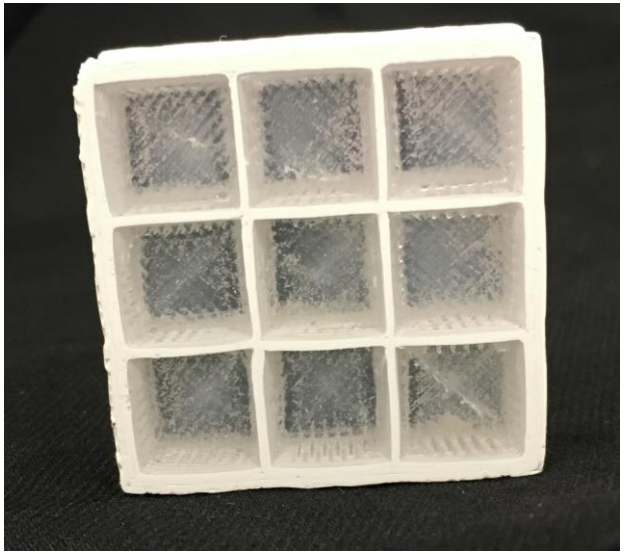
+

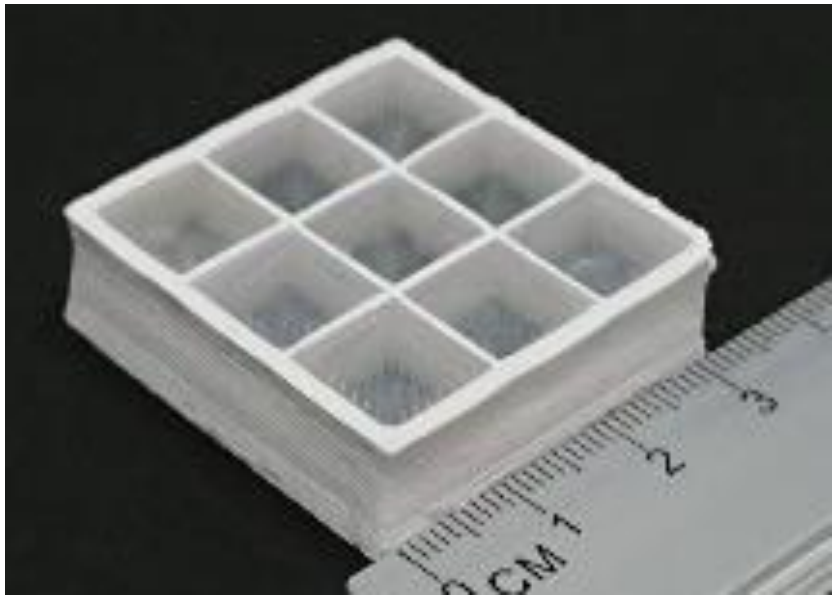
Reflective pigment TiO2 (or BaSO4, MgO…)

Reflective filament

The 3D printed scintillator matrix

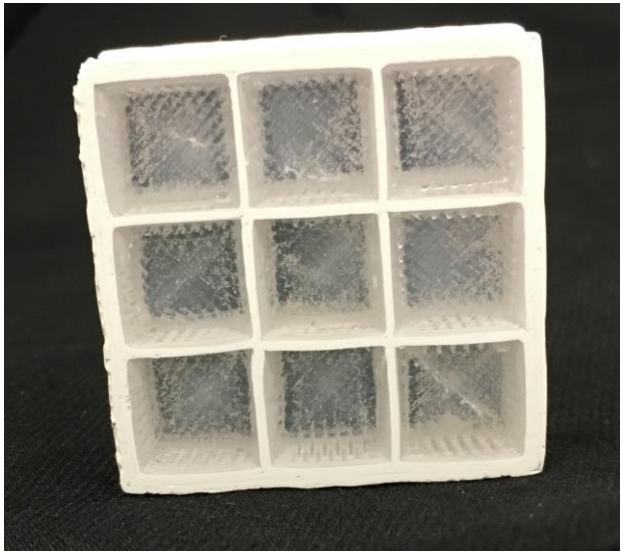
- **Successfully 3D printed matrices of optically isolated scintillator cubes**

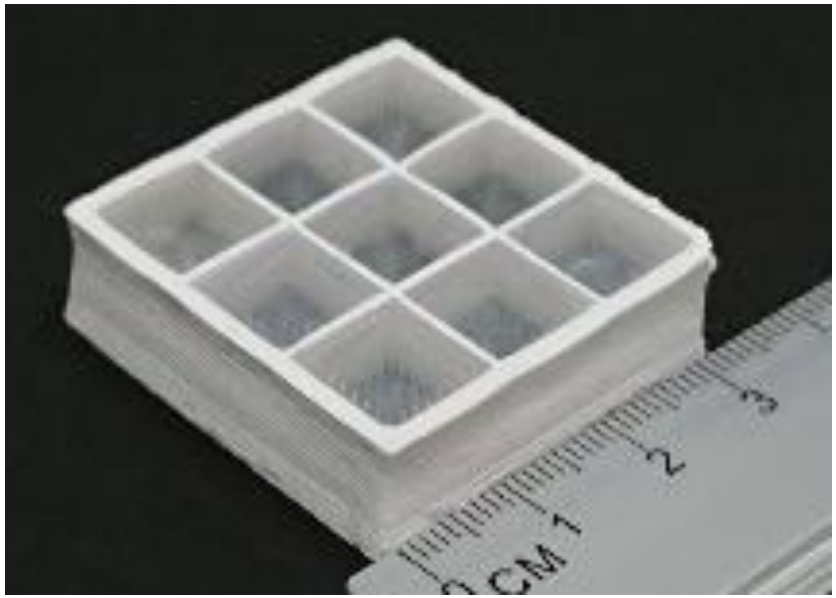




The 3D printed scintillator matrix

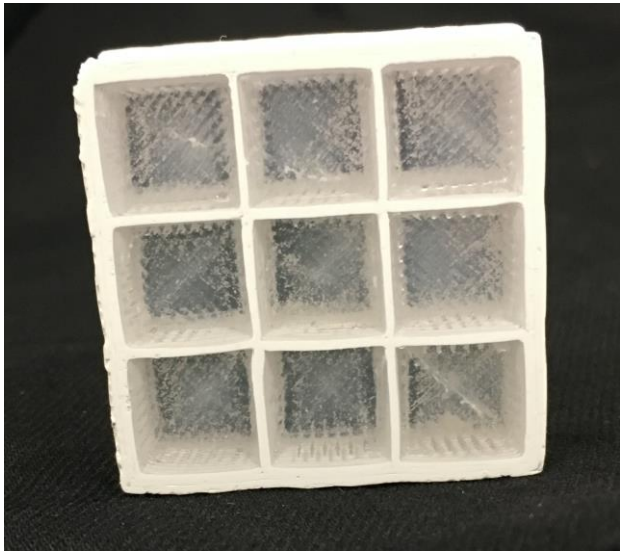
- **Successfully 3D printed matrices of optically isolated scintillator cubes**
- Outermost surface has non-uniformities due to the high temperature printing, but this is not critical (it's the inner part that will matter for physics performance)
  - Tolerance of reflector thickness and cube shape ~0.5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

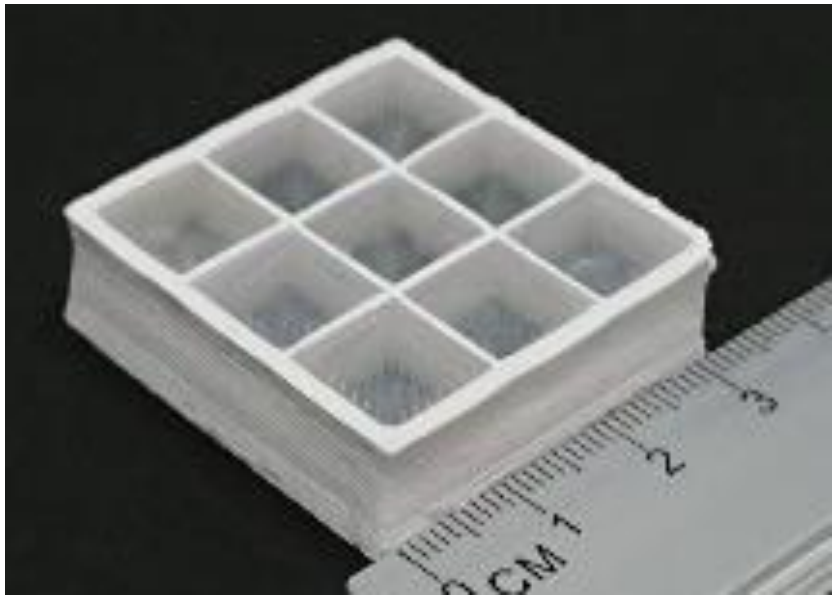




The 3D printed scintillator matrix

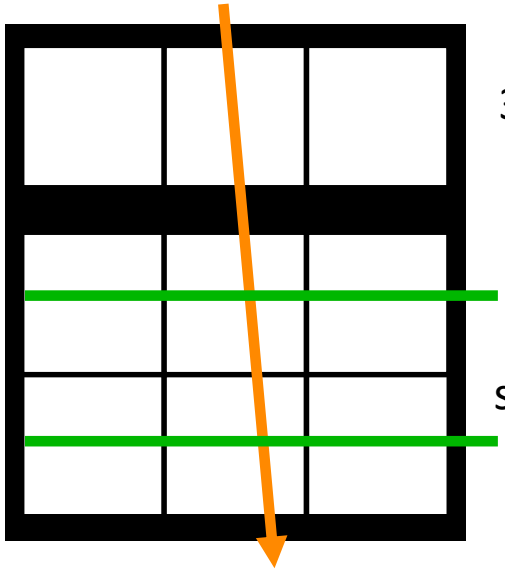
- **Successfully 3D printed matrices of optically isolated scintillator cubes**
- Outermost surface has non-uniformities due to the high temperature printing, but this is not critical (it's the inner part that will matter for physics performance)
  - Tolerance of reflector thickness and cube shape ~0.5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

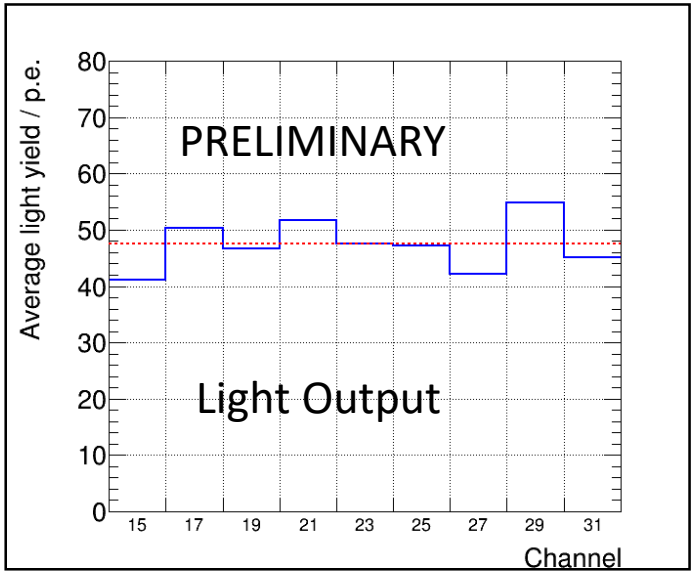


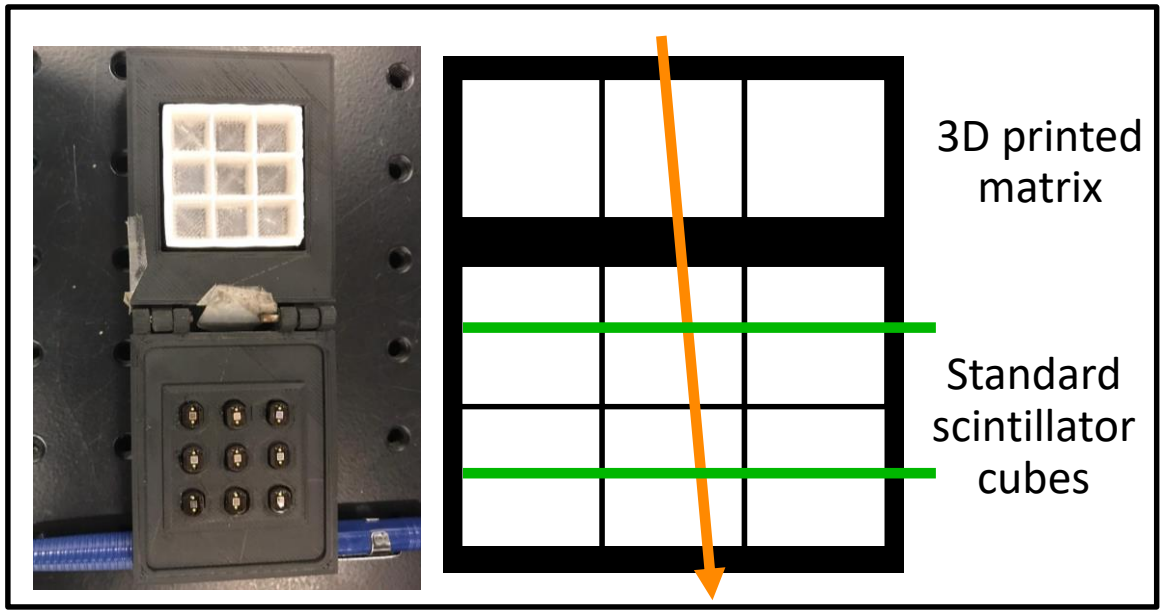
3D printed matrix

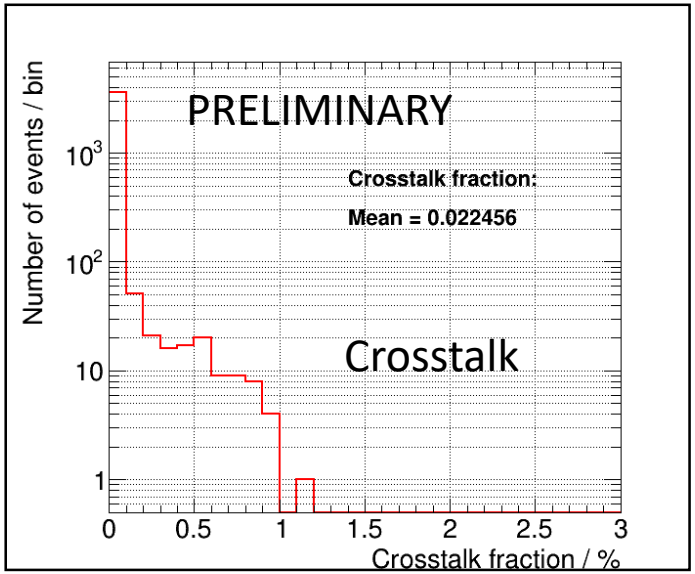
Standard scintillator cubes

The scintillator matrix performance

- 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%







Summary and future plans

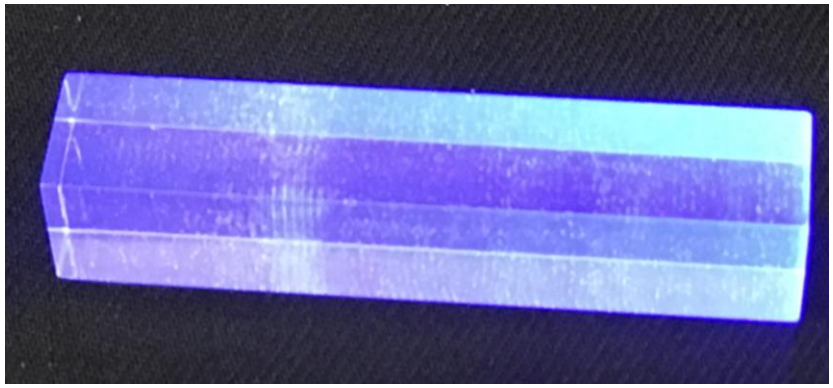
- Demonstrated the feasibility of 3D printing plastic scintillator detectors, using Fused Deposition Modelling to simultaneously print both the scintillator and the optical reflector
- With further R&D, 3D printing may allow an easier (and potentially cheaper) realisation of complex detector geometries 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

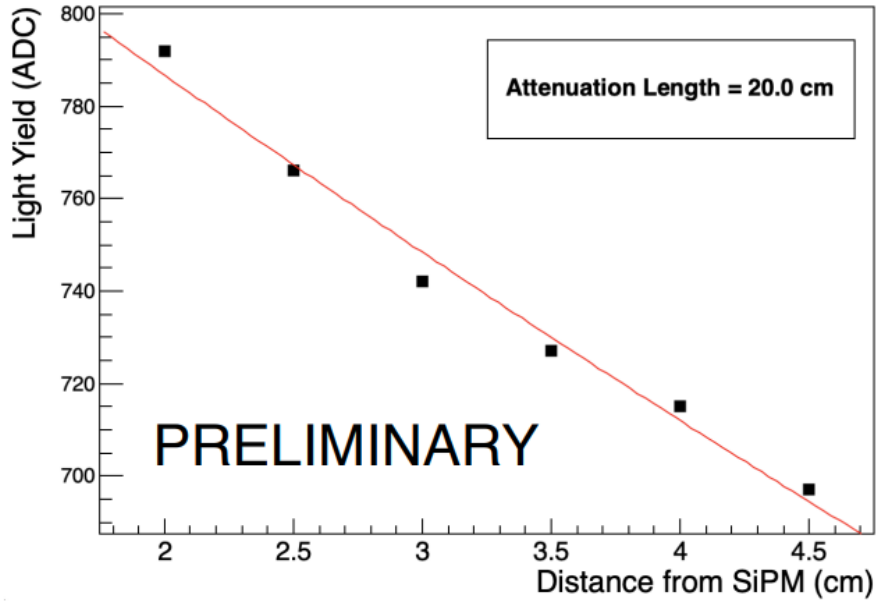
BACKUP

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

Attenuation Length ~ 20 cm
Acceptable for detectors with fine segmentation

End