Plastic scintillator production involving Additive Manufacturing

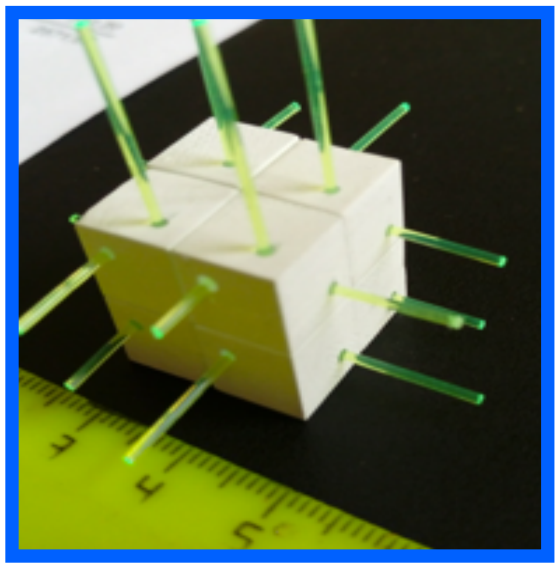
Davide Sgalaberna (ETH Zurich)

for the 3DET collaboration

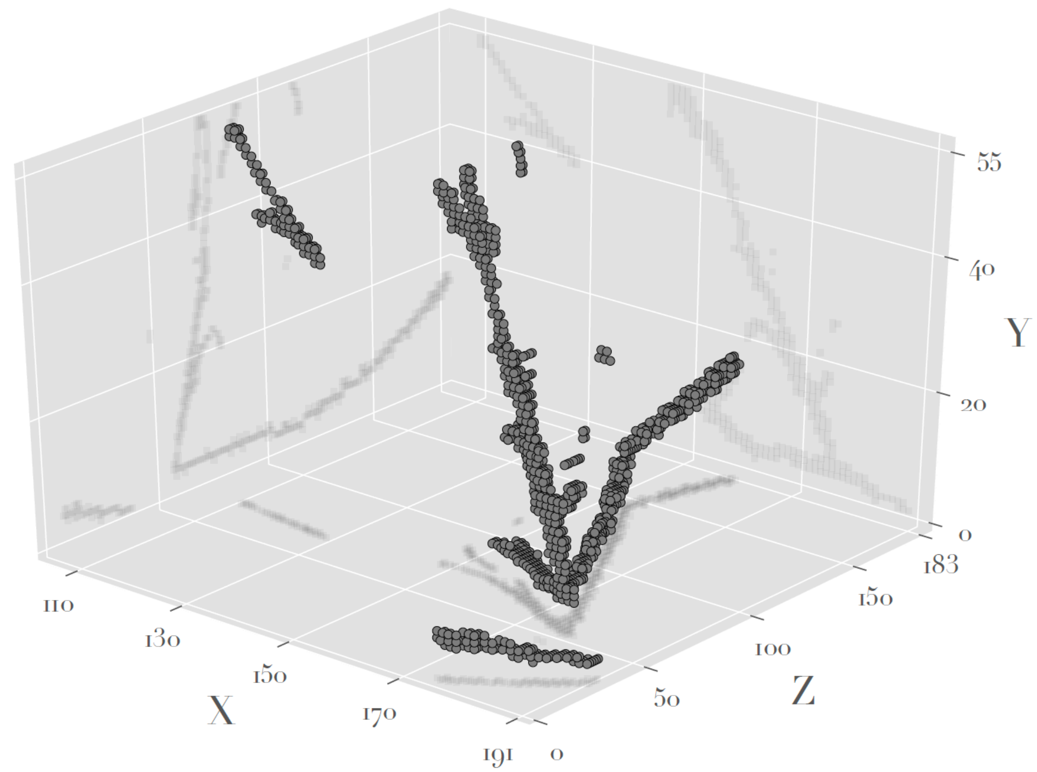
16th Vienna Conference on Instrumentation 2022

Why Additive Manufacturing ?

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



2018 *JINST* **13** P02006
NIM A936 (2019) 136-138



2018 JINST 13 P05005

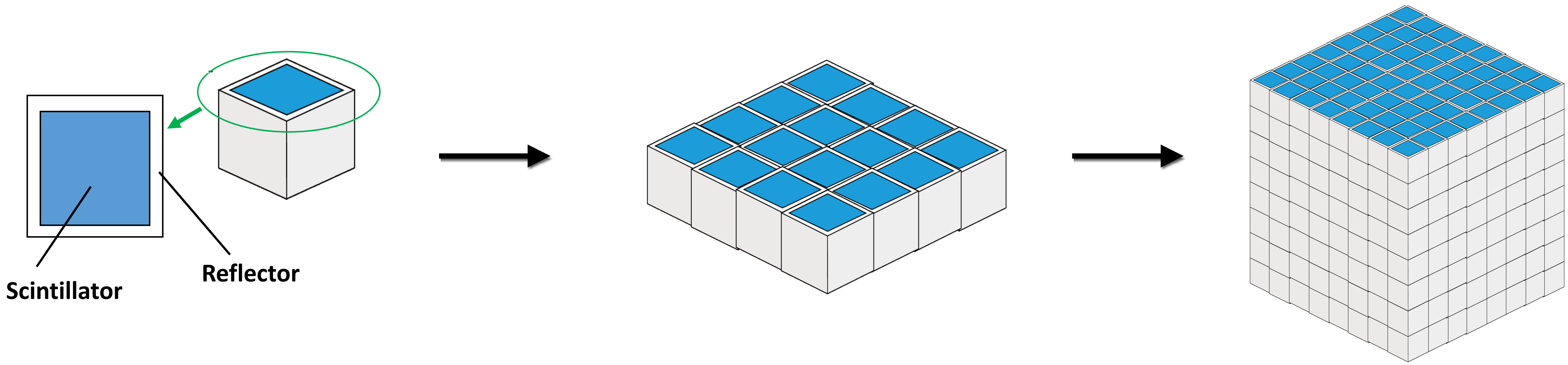
- Examples can be found in neutrino active targets, calorimeters, neutron detectors, etc.
- Not easy to build and assemble these detectors with standard techniques involving subtractive processes

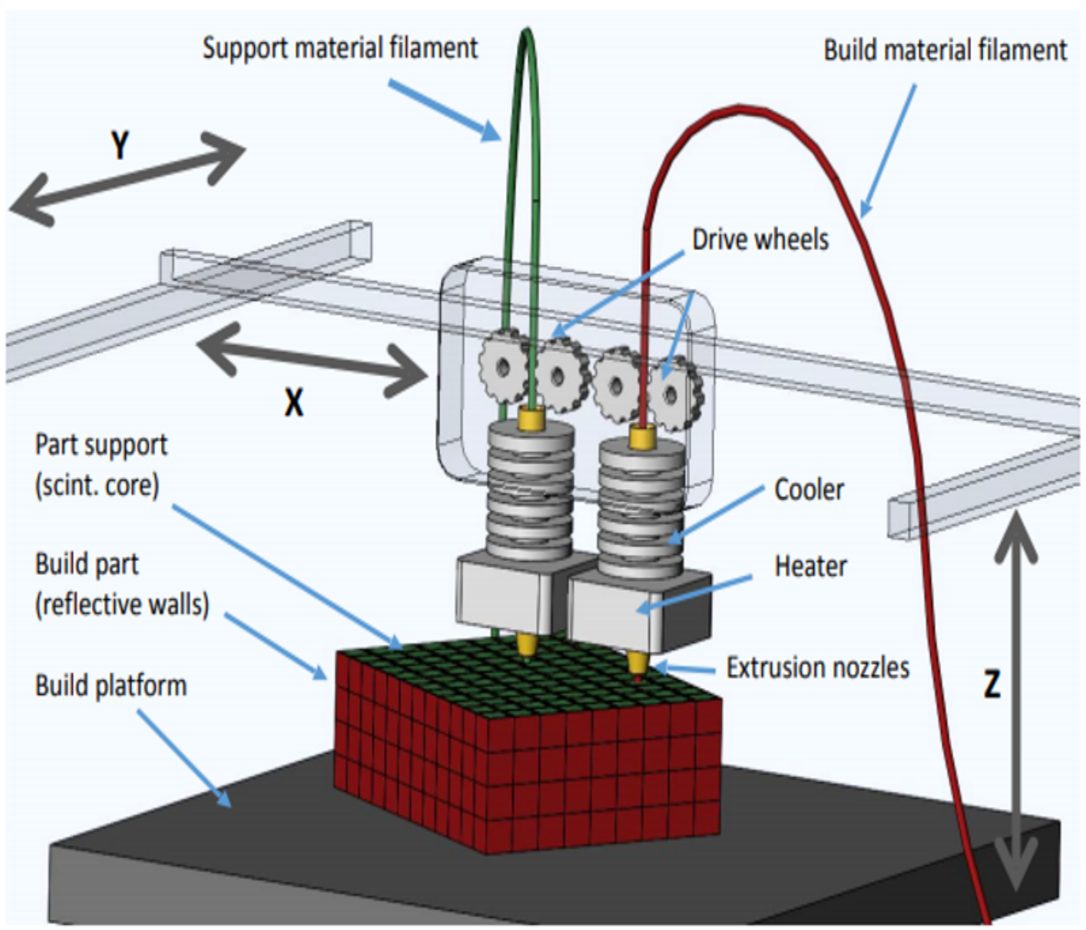
Additive Manufacturing may be a viable and cheap solution

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
    - ✦ More informations can be found at https://threedet.web.cern.ch

3D printing a big plastic scintillator detector



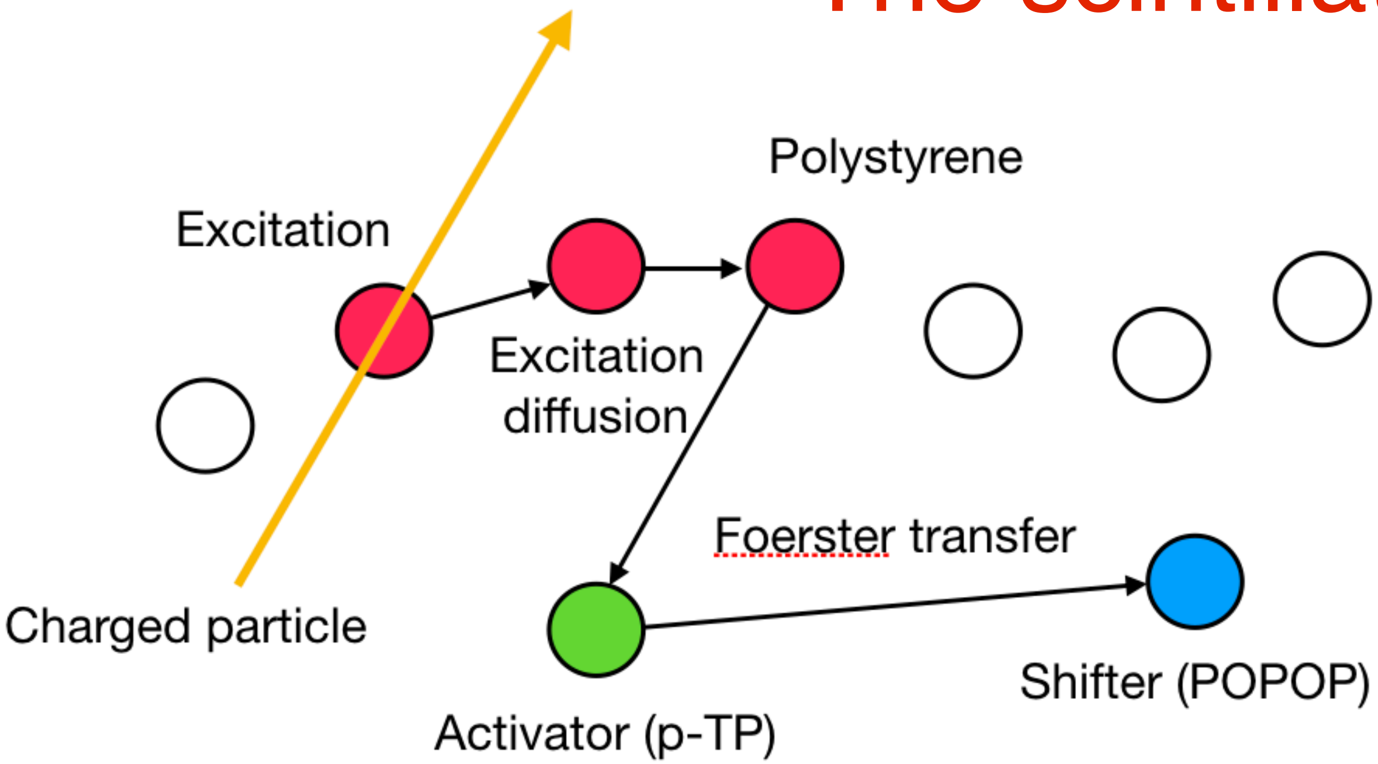


Need a technology that can:

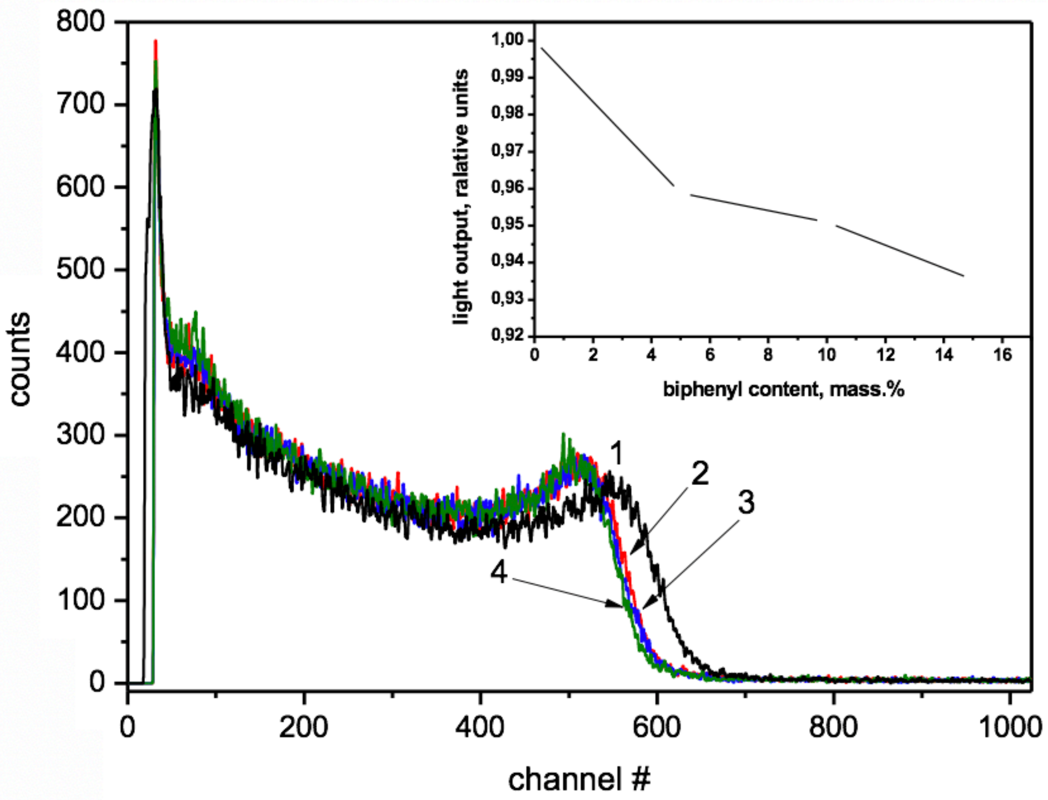
- Achieve good scintillation performance and high transparency in the scintillator core
- 3D print big volumes in relatively short time
- Robust (and relatively cheap)
- 3D print simultaneously more materials

Fused Deposition Modeling (FDM) is a promising solution

The scintillator filament

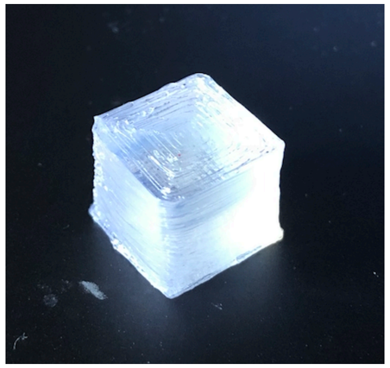


Optimal composition is polystyrene + pTP + POPOP with a 5% biphenyl as plasticiser

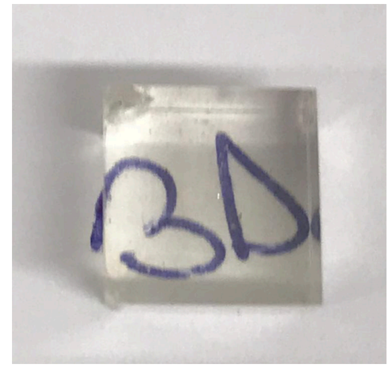


No need to invent a new chemical composition: polystyrene is well known

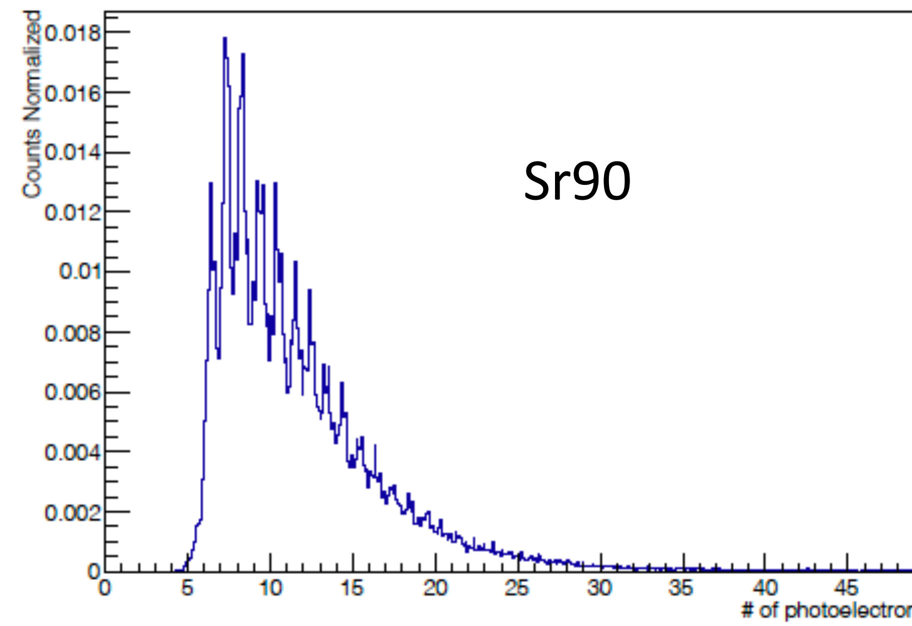
The proof of the concept



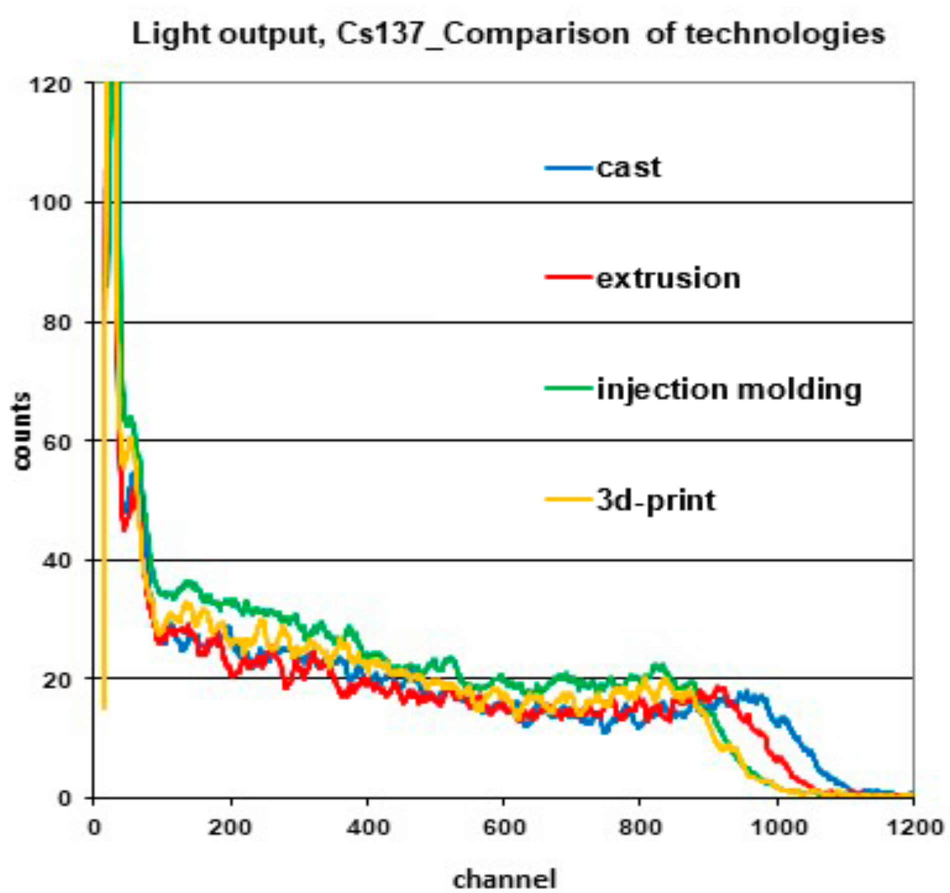
The outermost surface is always opaque. Characteristic of FDM

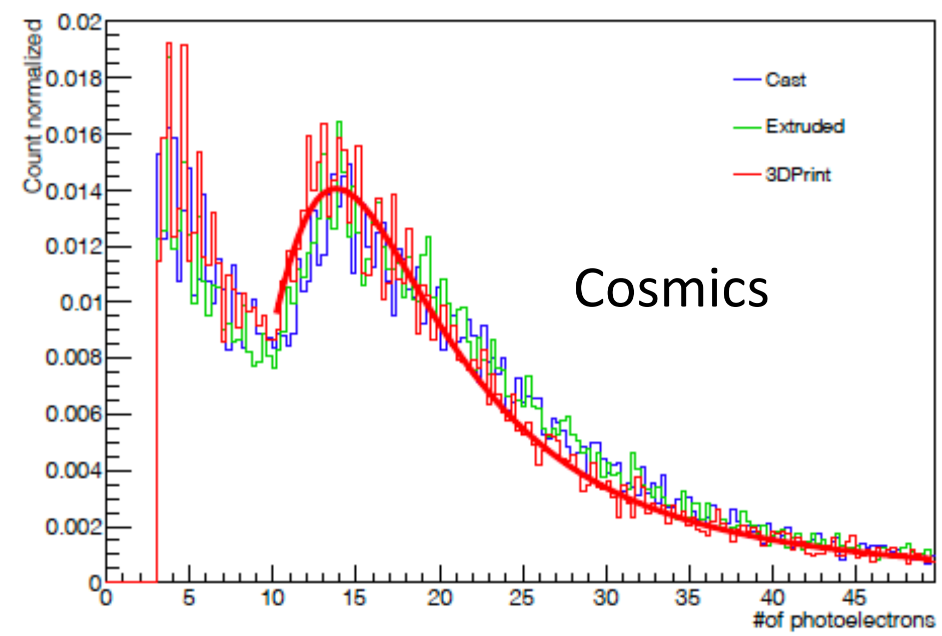


MPPC coupled directly with scintillator cube in black connector (no white reflector envelope)



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





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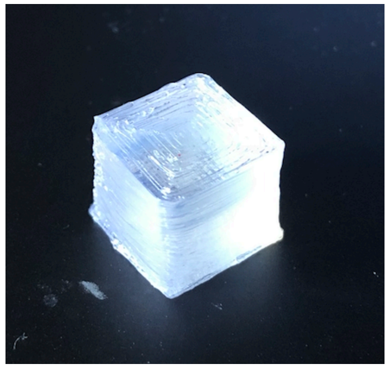

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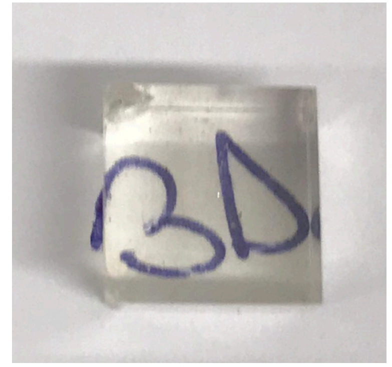

A novel polystyrene-based scintillator production process involving additive manufacturing

S. Berns et al 2020 JINST 15 P10019

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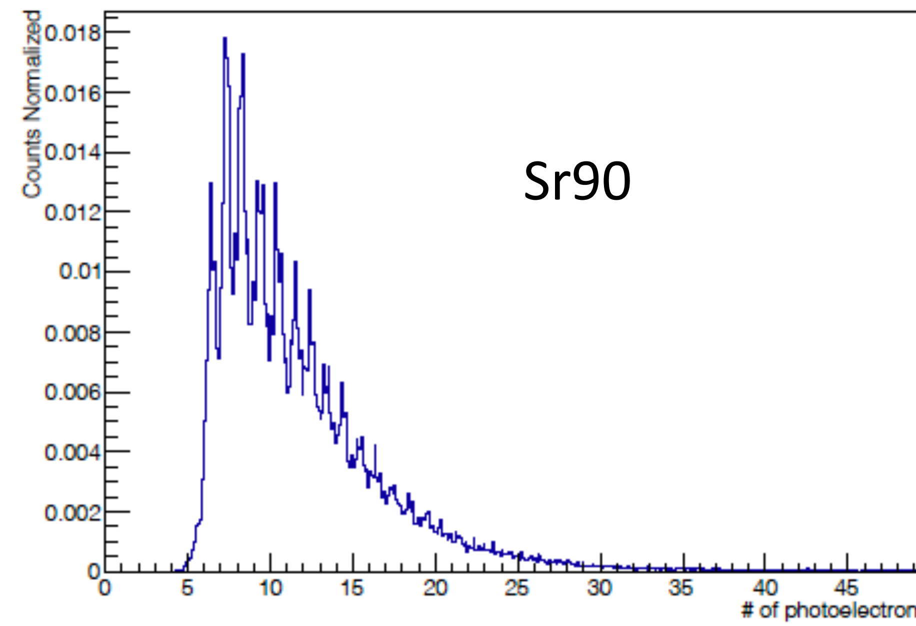
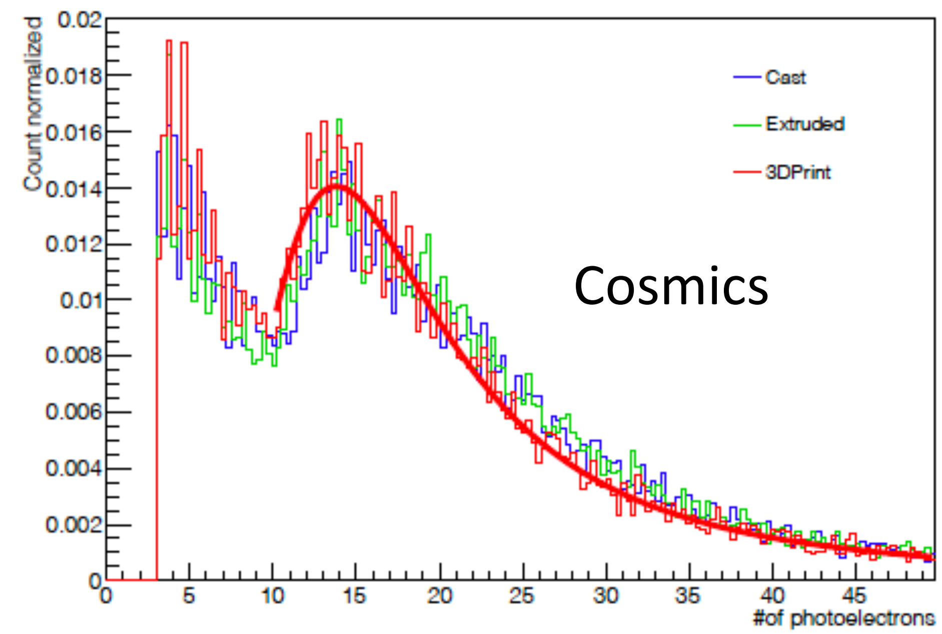
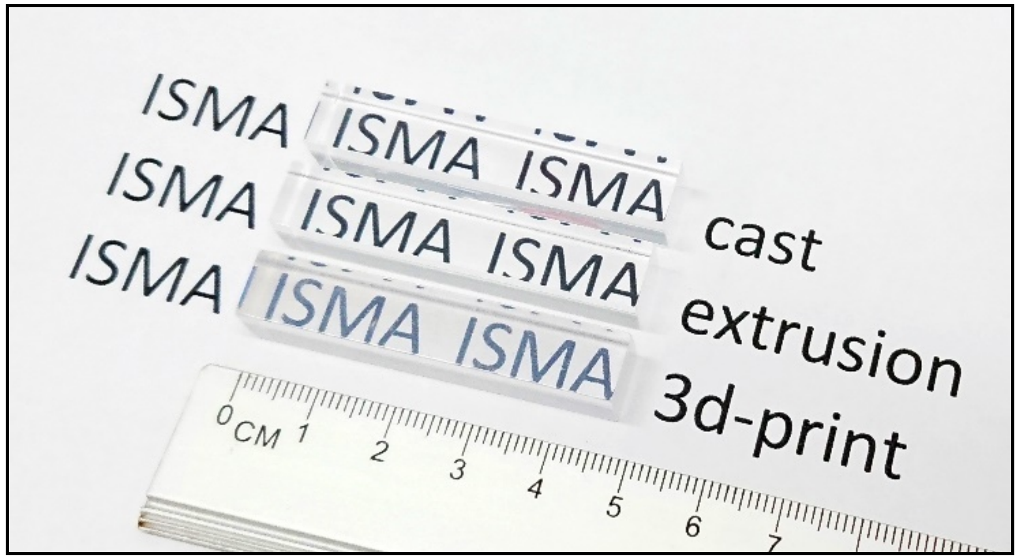
Scintillation Light Yield comparable with the one of standard production techniques

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

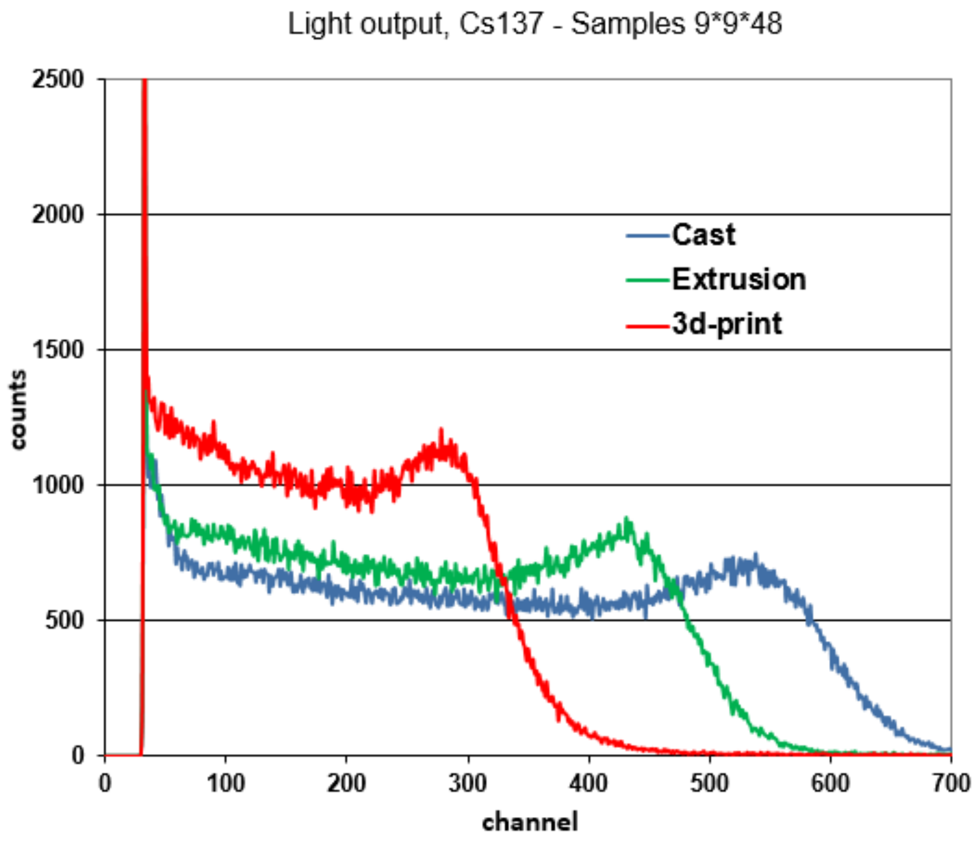


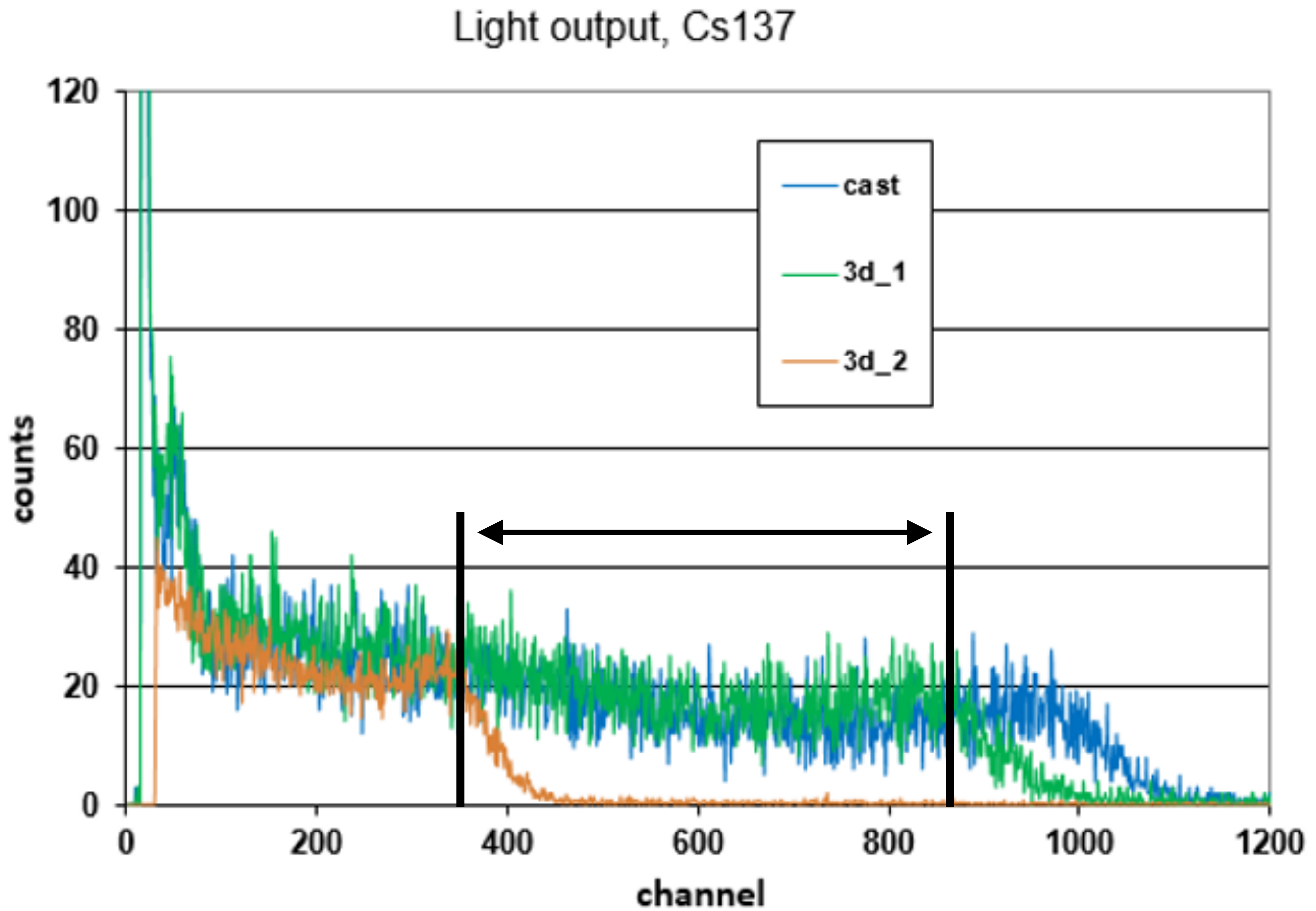


The attenuation length



Printing of long bars is also possible.



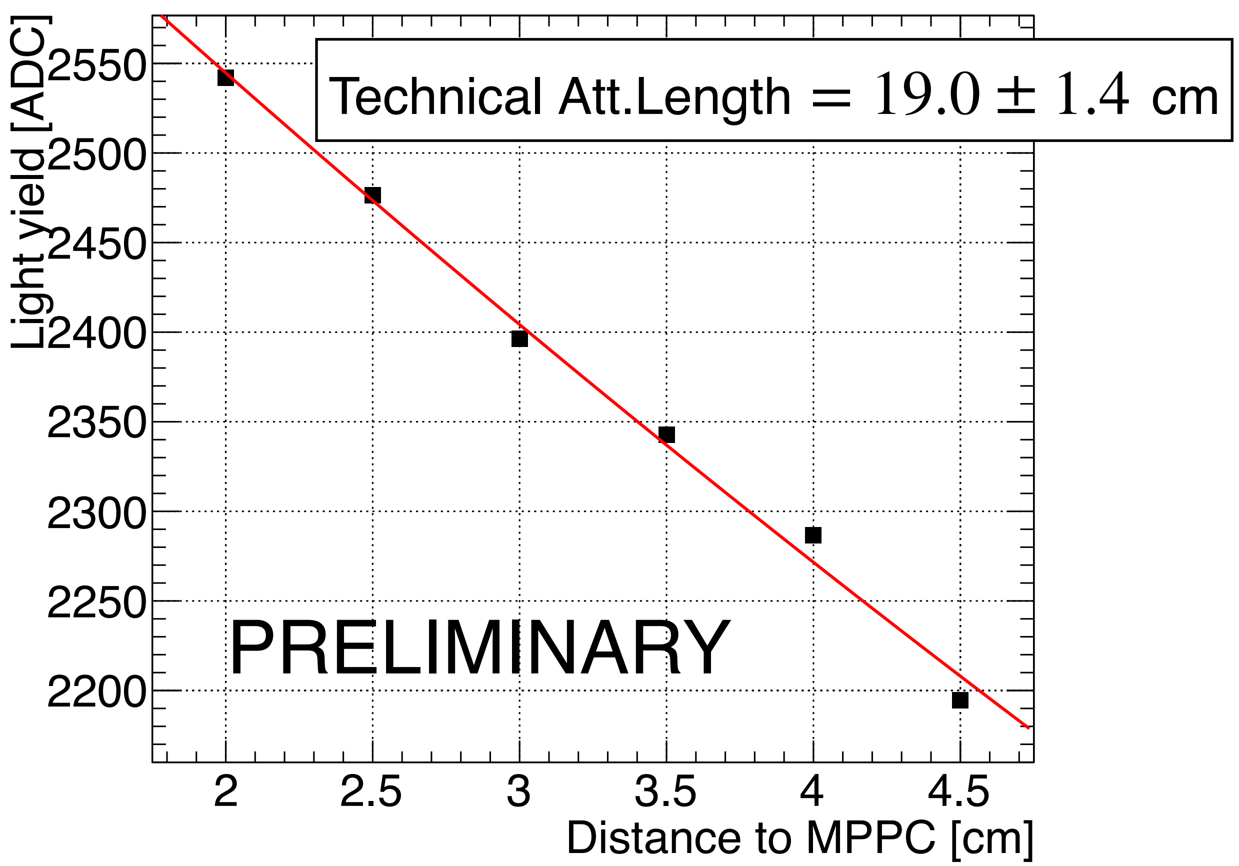


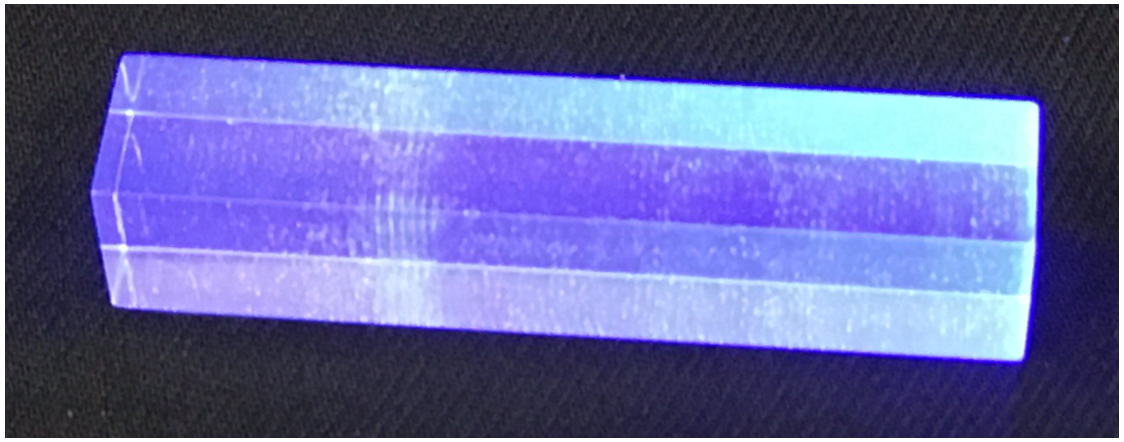
The printing parameters have to be carefully tuned to achieve the required transparency and light output

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

Scintillator transparency

Transparency measured from 5 cm-long bar





The scintillator transparency was found to be sufficiently good for few-cm granularity detectors

- Polished on the outermost surface and covered with white teflon. Tests performed also with black cover.
- SiPM on one end + Sr^{90}/Y^{90} source moving at different positions
- Sparse presence of small air bubbles
  - ✦ Aim at improving a higher fill factor to remove air bubbles

3D printing of the optical reflector

Polymer pellets

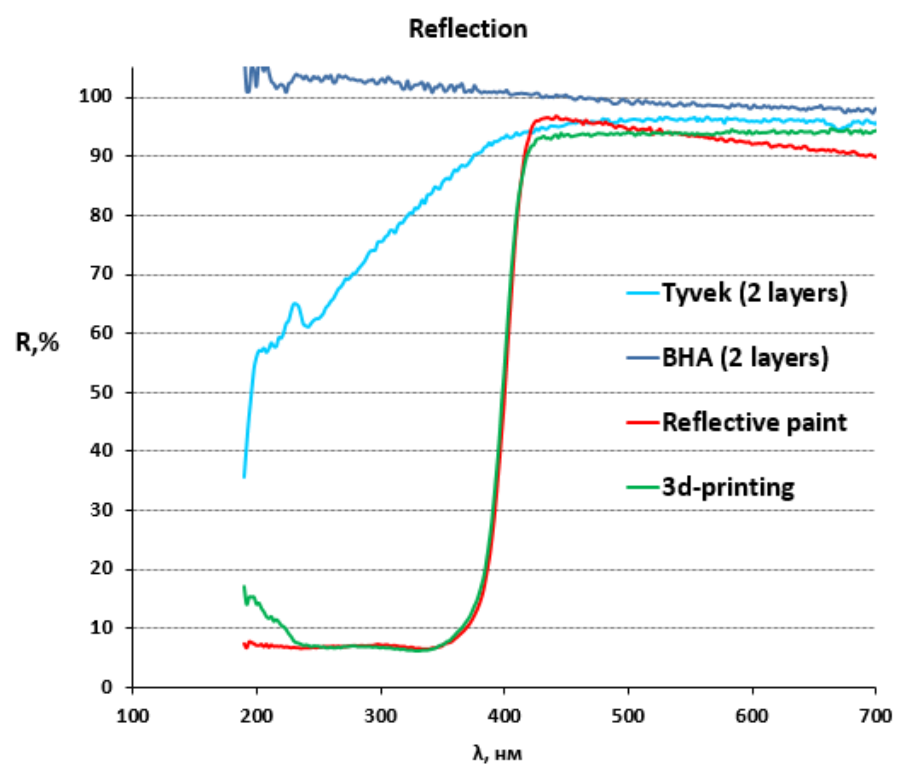
+

Reflective pigment TiO2 (or BaSO4, MgO…)

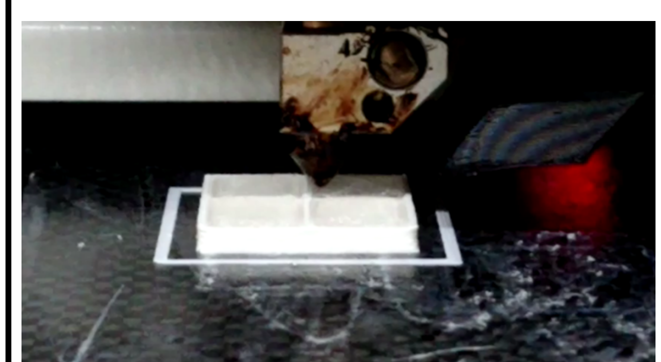
Reflective filament

PRELIMINARY

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

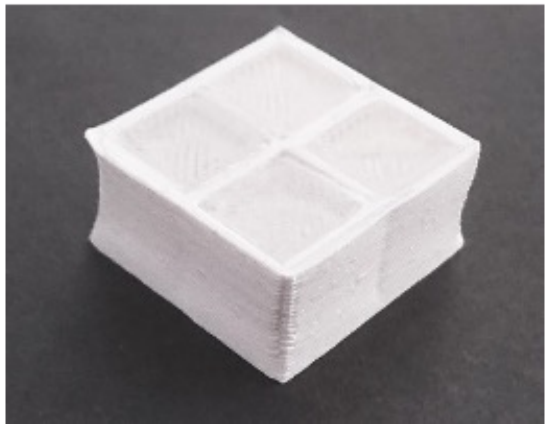


Multi material printing:

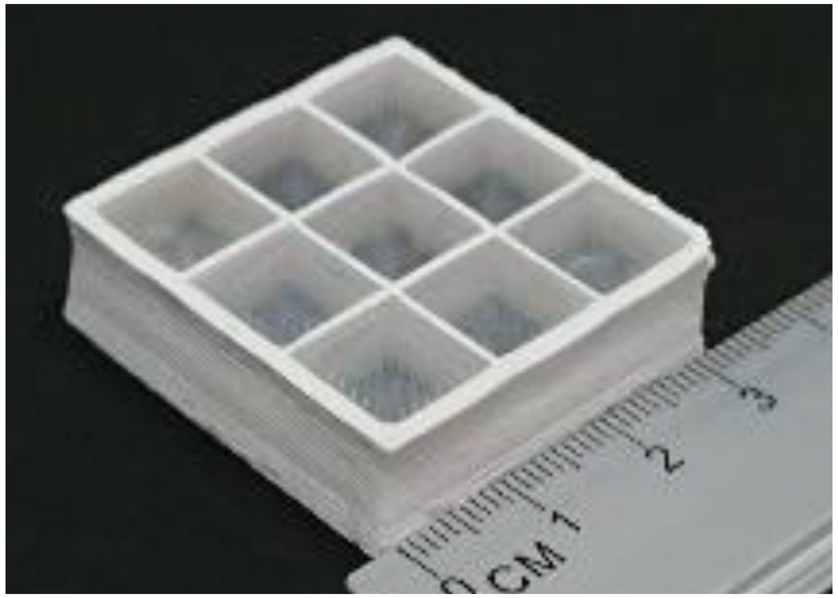


Similar reflectivity to TiO_2 paint but less than Tyvek and PTFE (no air gap, Lower reflection, Surface roughness)

The 3D-printed scintillator matrix

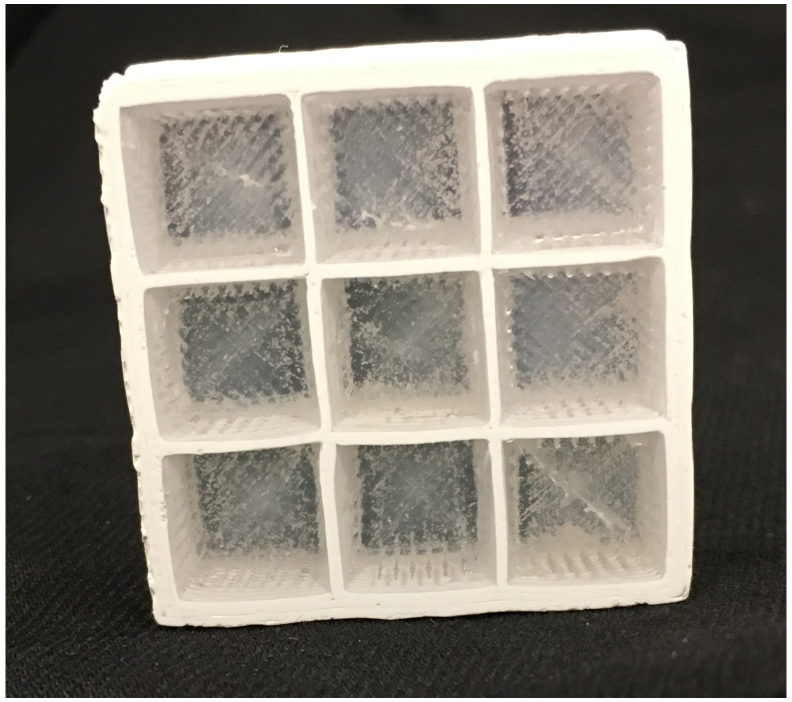


Succeded to 3D print a matrix of optically-isolated scintillator cubes



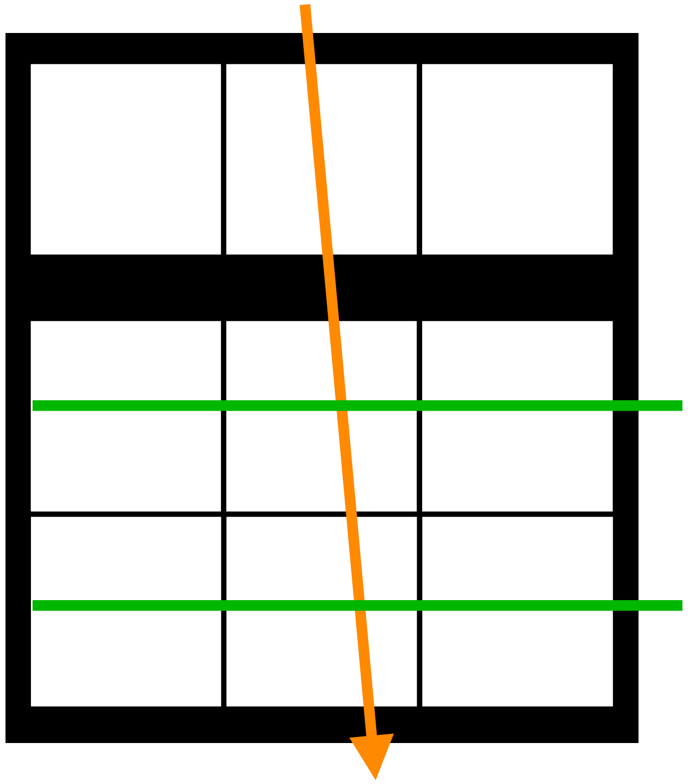
Matrix configuration

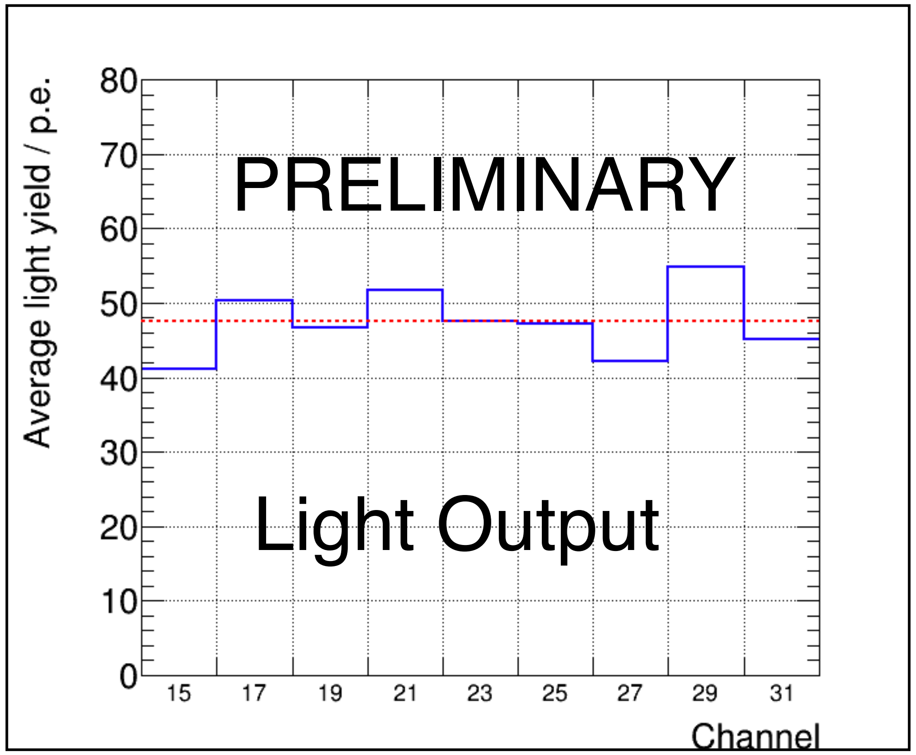
- 10 mm cube edge
- 1 mm reflector thickness

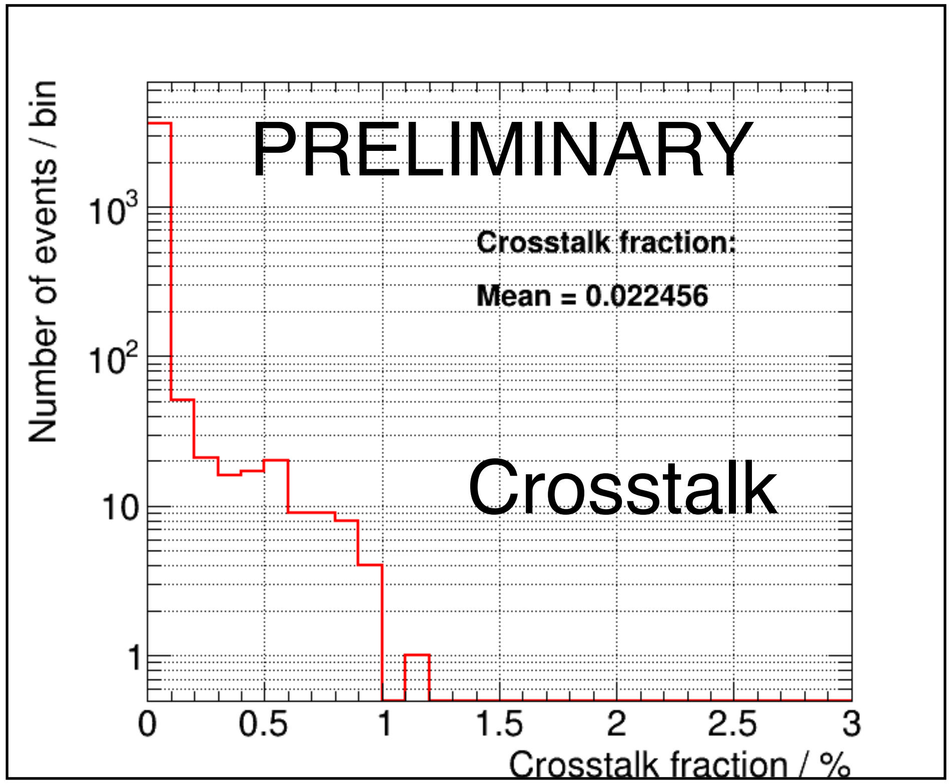


- Outermost surface not very precise due to the melting of the material at high temperatures
  - ✦ Not a big concern, as long as the inner part provides good performance
- Tolerance of reflector thickness and cube shape ~0.5 mm
- Some reflector remnants in scintillator (extruder couldn't move up/down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

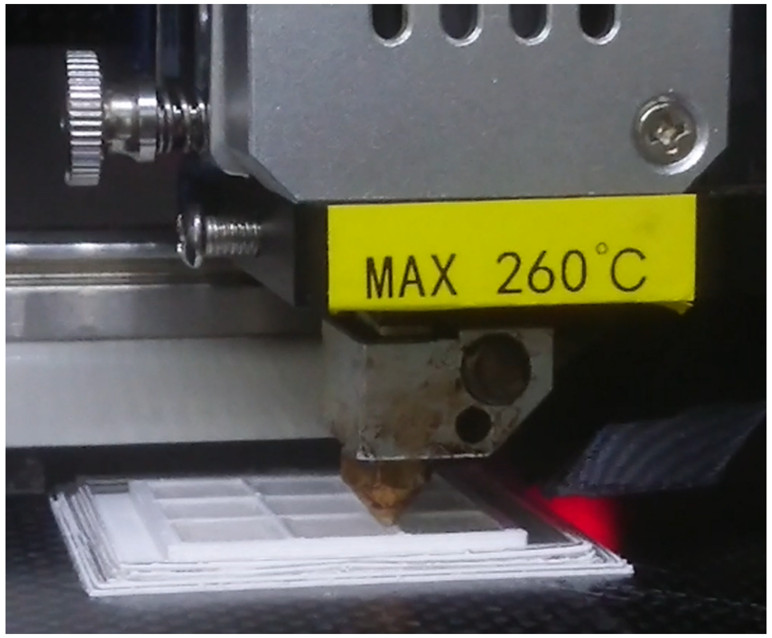
Future Plans

- We demonstrated the feasibility of 3D printing plastic scintillator detectors (both the scintillator and the optical reflector) with the Fused Deposition Modelling
  - ✦ More details can be found in arXiv:2202.10961

Additive manufacturing of fine-granularity optically-isolated plastic scintillator elements

The 3DET collaboration, S. Berns,[a,b,c] E. Boillat[a,b,c] A. Boyarintsev,[d] A. De Roeck,[e] S. Dolan,[e] A. Gendotti,[f] B. Grynyov,[d] S. Hugon,[a,b,c] U. Kose,[e,1,2] S. Kovalchuk,[d] A. Rubbia,[f] T. Sibilieva[d] D. Sgalaberna,[f] T. Weber,[f] J. Wuthrich,[f] X. Y. Zhao,[f]

- More R&D is needed to further improve the geometrical tolerance and transparency of the 3D-printed matrix
- Work ongoing also on 3D printing of inorganic materials (not reported in this talk)
- Future plans:
  - ✦ Characterization of the scintillator: time resolution and ageing effects
  - ✦ Working on new FDM-based strategies to improve the geometrical tolerance and achieve a faster 3D printing
  - ✦ investigate other additive manufacturing technologies to overcome the weaknesses of Fused Deposition Modelling



Thanks

If you are curious about the 3DET project and interested to try 3D printing on new applications check https://threedet.web.cern.ch and contact us

CERN

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ISMA
institute for scintillation materials