Fully 3D-printed plastic scintillator particle detector prototype

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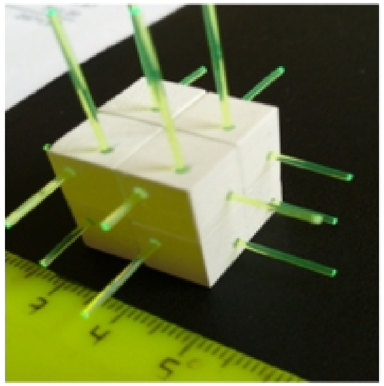
Why 3D Printing?

- In the last years more and more experiments started to develop massive plastic scintillator detectors with more complex and fine-granularity geometries;
- Neutrino detector, sampling calorimeters, neutron detectors, etc.
  - Case study: example from the new neutrino plastic scintillator detector at the T2K experiment (~2,000,000 scintillator cubes)



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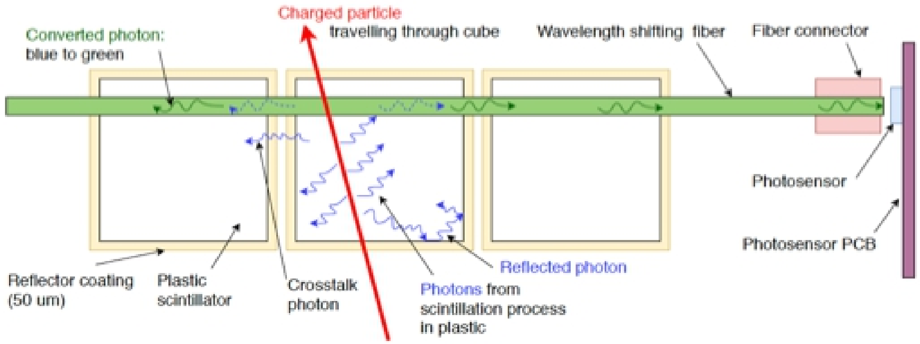
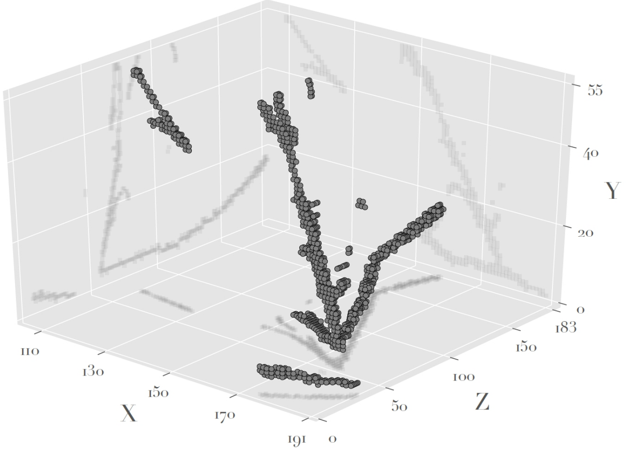
NIM A936 (2019) 136-138

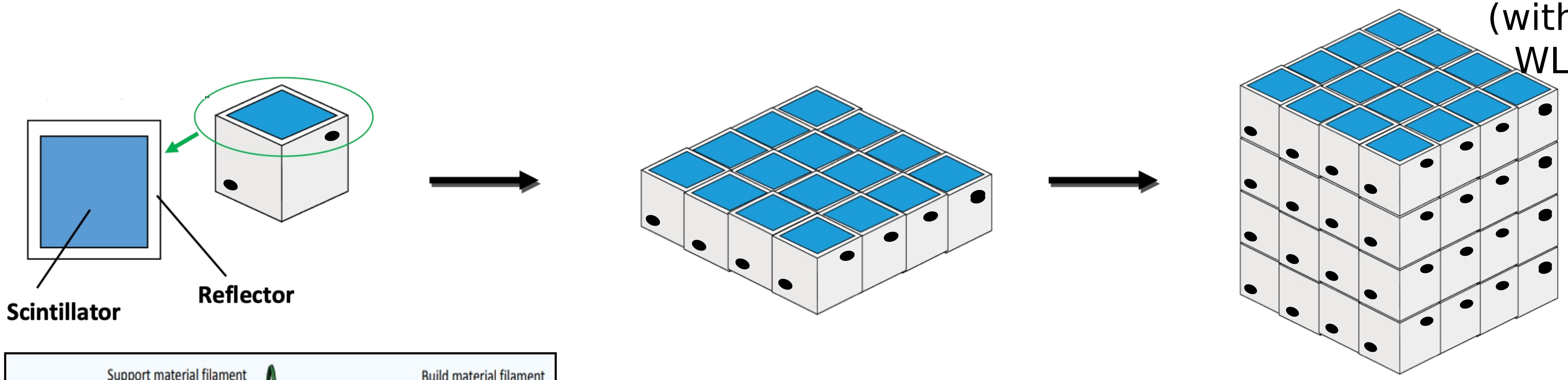


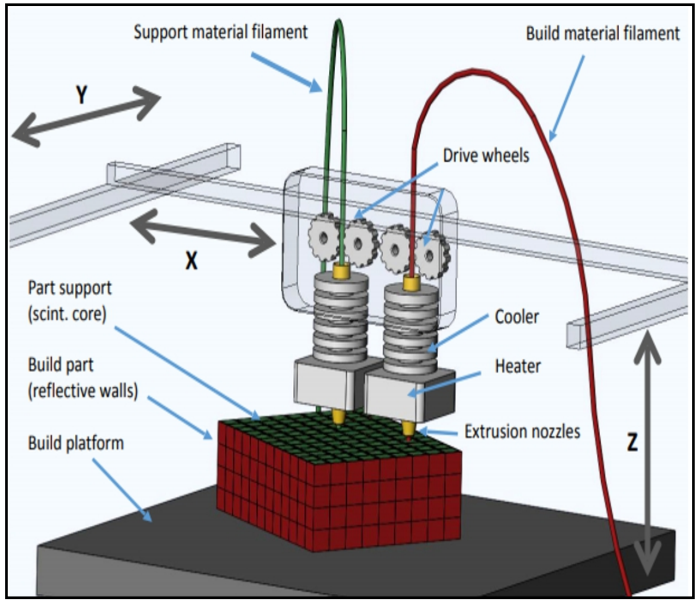


- Not easy to build and assemble these detectors with traditional techniques (e.g. injection moulding), that involve many different steps involving subtractive processes

Additive Manufacturing may be a viable and cheap solution

3D printing a scintillating "SuperCube"





Fused Deposition Modeling (FDM) is a promising solution

Need a technology that can:

- Achieve good scintillation performance and high transparency in the scintillator core.
- 3D print big volumes in relatively short time and cheap processes and avoid multiple steps (manufacturing and assembly)
- 3D print simultaneously more materials.
- Hollow objects, e.g. holes for WLS fibers

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

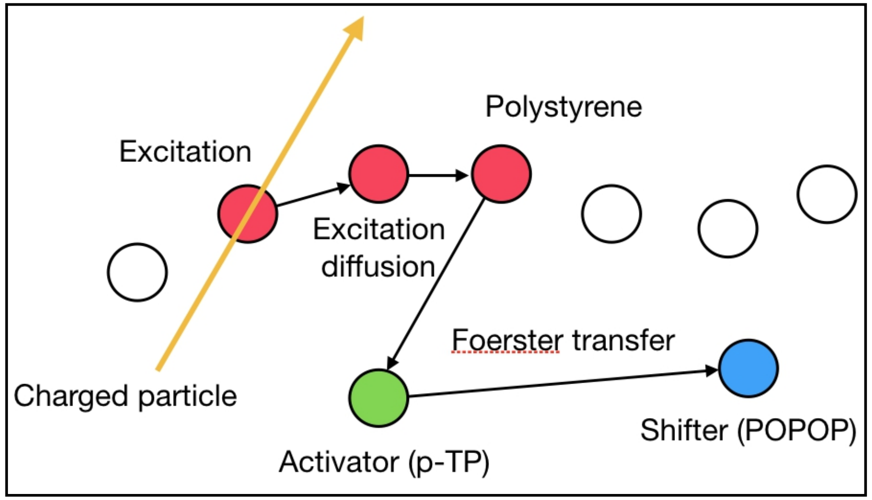
- General purpose R&D towards the first 3D printed particle detector with performances comparable to the state of the art

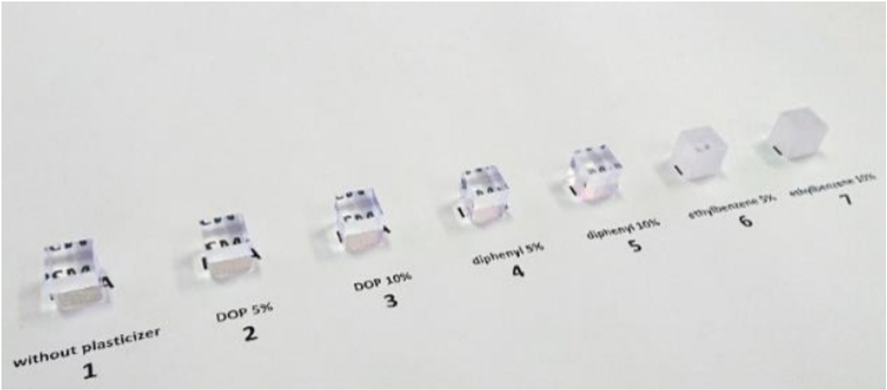
3DET comprises CERN, ETH Zurich, HEIG-VD, ISMA

- The collaboration can profit from expertise in particle detector development, scintillator materials and additive manufacturing
- Started a new collaboration with Ip2I Lyon on muon tomography with 3D printed detectors
- Open to extend the collaboration to new institutes dedicated to particular developments

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

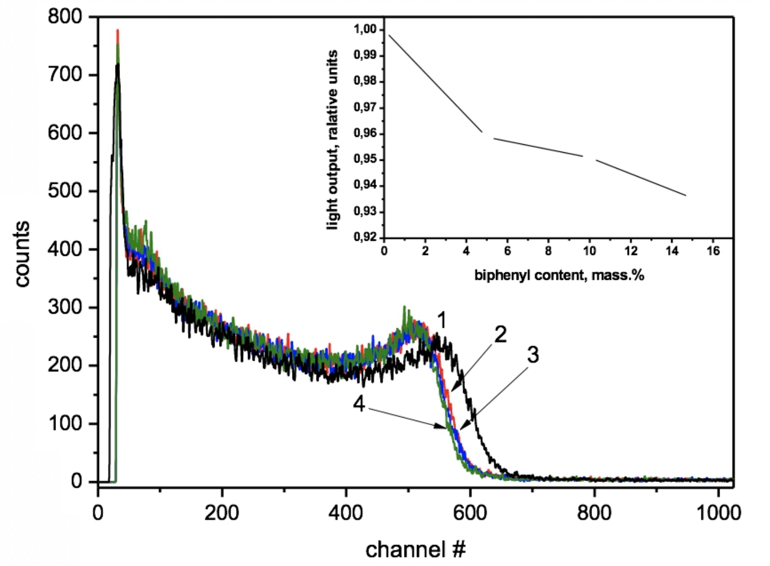
The proof of the concept





Optimal composition is a standard polysterene based one, i.e. polystyrene + pTP + POPOP (same as UPS-923A produced by ISMA, NIMA 555(1):125–131, 2005)

Polystyrene is well known => No need to "invent" a new chemical composition !



Tested both w/ and w/o 5% biphenyl as plasticizer
(in later prototypes we also dropped biphenyl out)

The proof of the concept

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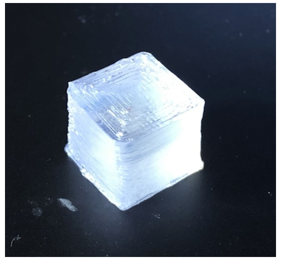
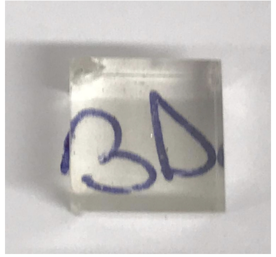
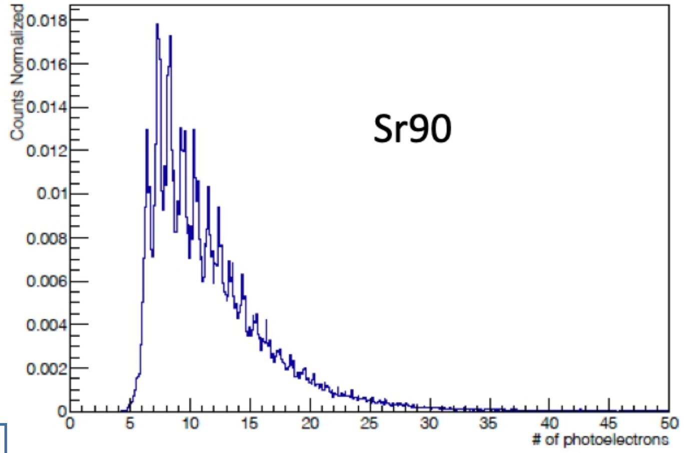


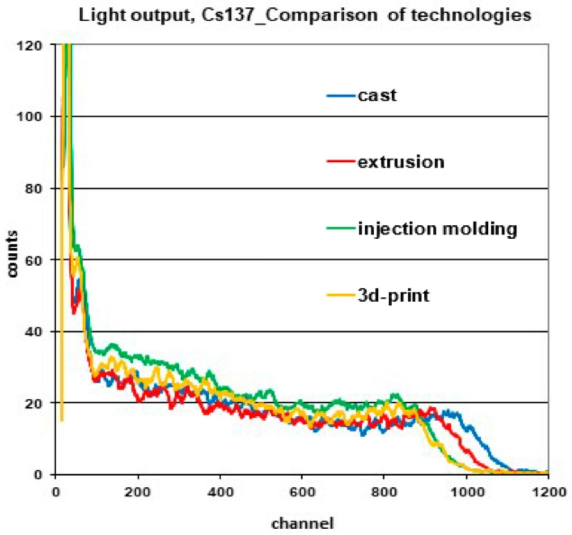
*printed with CreatBot Dx2

The outermost surface is always opaque. Characteristic of FDM

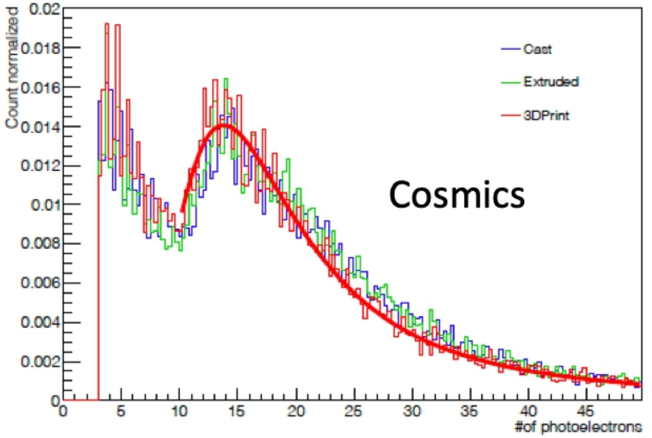




Results confirmed with PMT on Cs^{137} source (with reflector envelope)

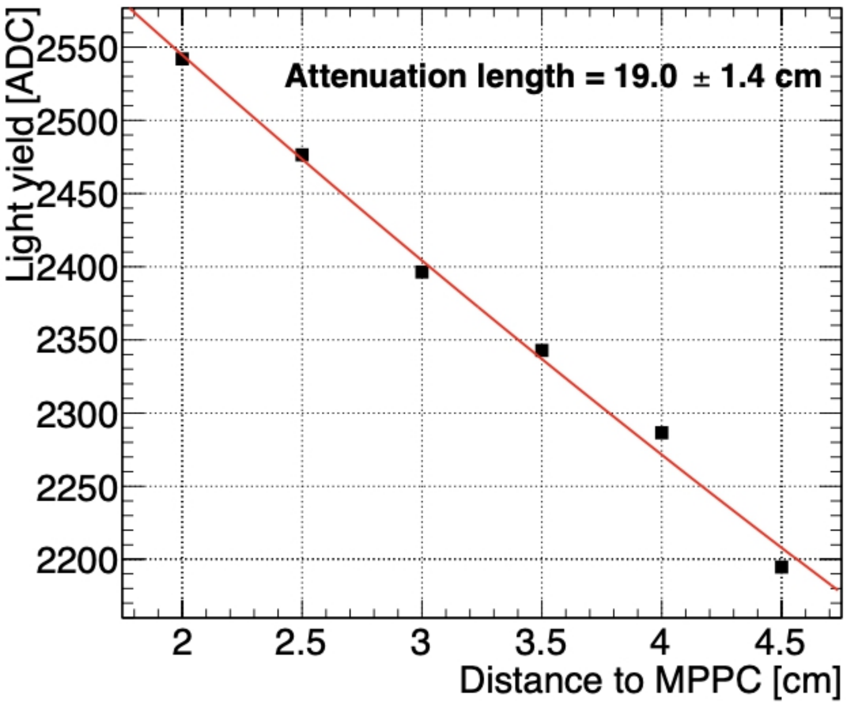


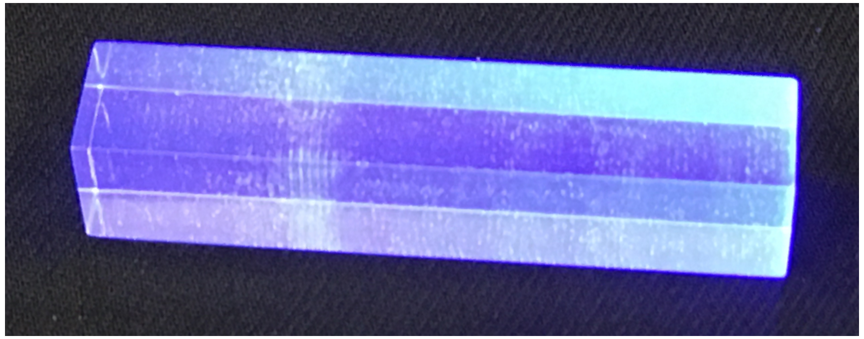
MPPC coupled directly with scintillator cube in black connector (no white reflector envelope)



Attenuation length (technical)

Transparency measured from 5 cm-long bar





- Polished on the outermost surface and covered with white teflon.
- SiPM on one end + Sr^{90}/Y^{90} source moving at different positions
- Sparse presence of small air bubbles

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

3D printed optical reflector

Polymer pellets

+

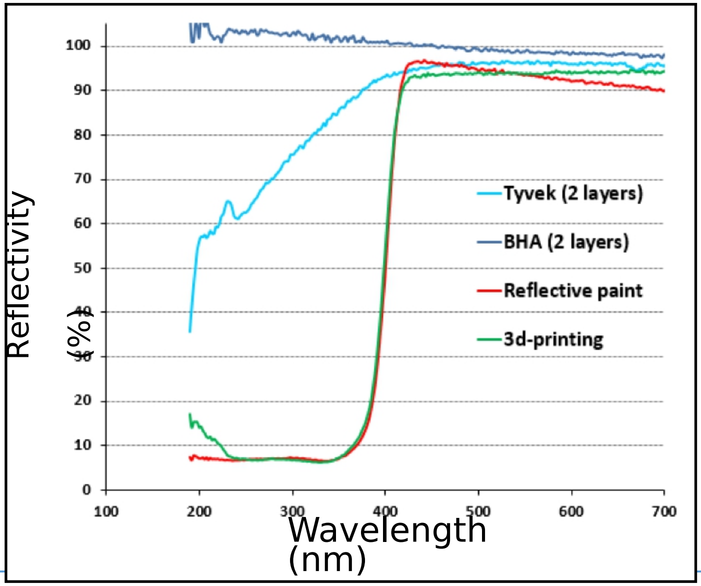
Reflective pigment TiO2 (or BaSO4, MgO…)

=

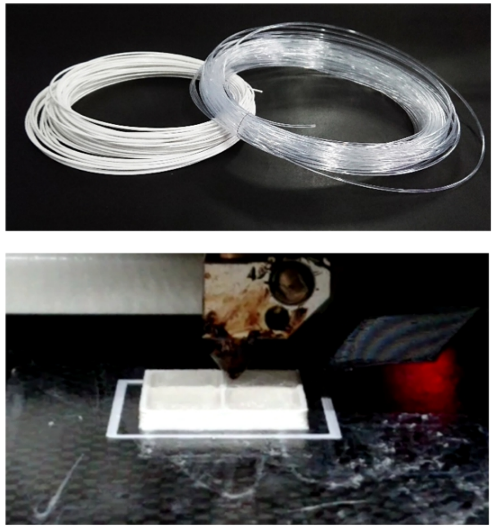
Reflective filament

Polymer mixed with TiO_2	Reflectivity at λ = 420 nm (%)
ABS	87.5
HIPS	87.1
PC	76.1
PMMA	90.6
PS	91.1

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



Multi material printing:



Optically-isolated scintillator cubes

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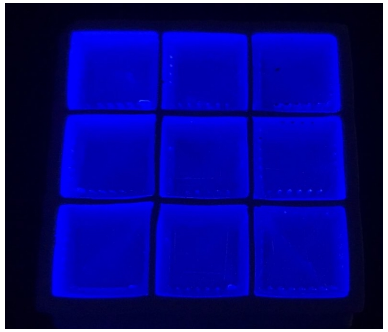
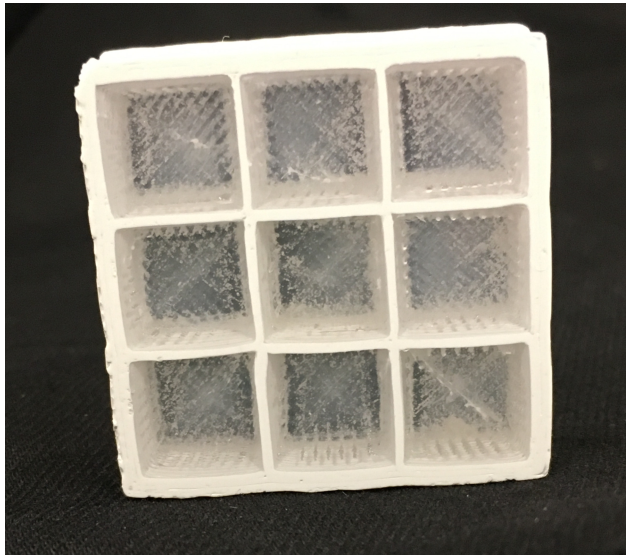
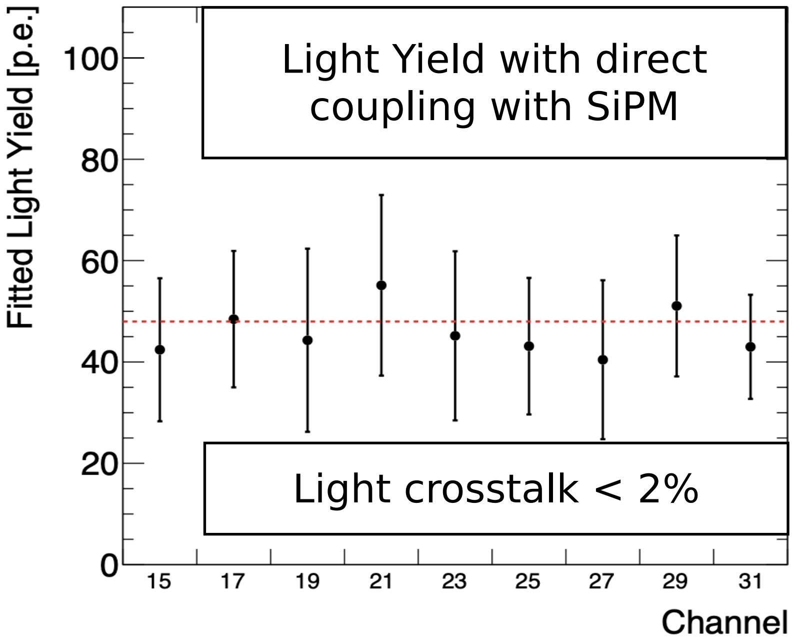
Succeeded to 3D print a matrix of optically-isolated scintillator cubes using a 2- nozzel printer (CreatBot F430)







- Good scintillation performances
- Outermost surface not perfect due to the melting of the material at high temperatures
- Tolerance on reflector thickness ~0.5 mm
- White remnants in the scintillator (extruder could not move up/down before changing material)
- Top and bottom surfaces had to be polished and no holes could be printed.

Heat resistant reflector

The optical performance of white reflector filament was excellent but needed to be more heat resistant to better preserve the geometry

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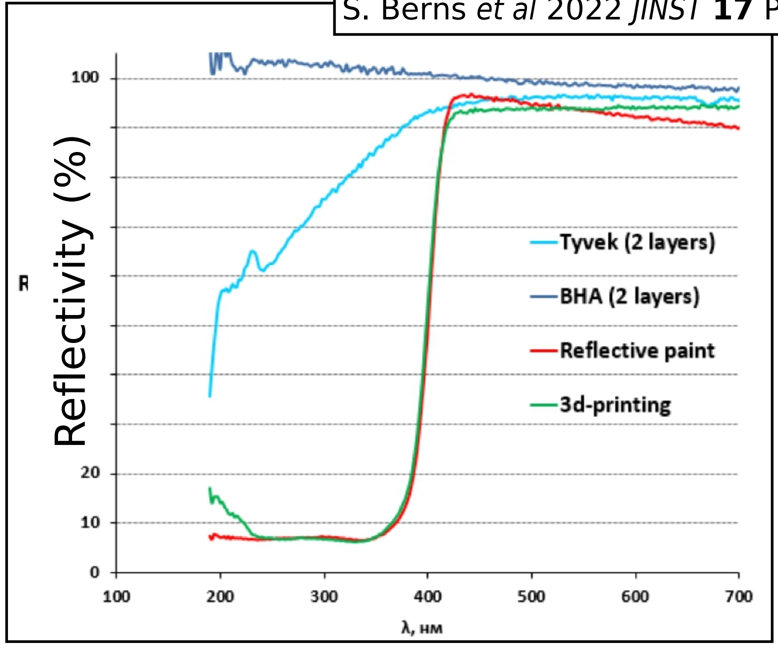
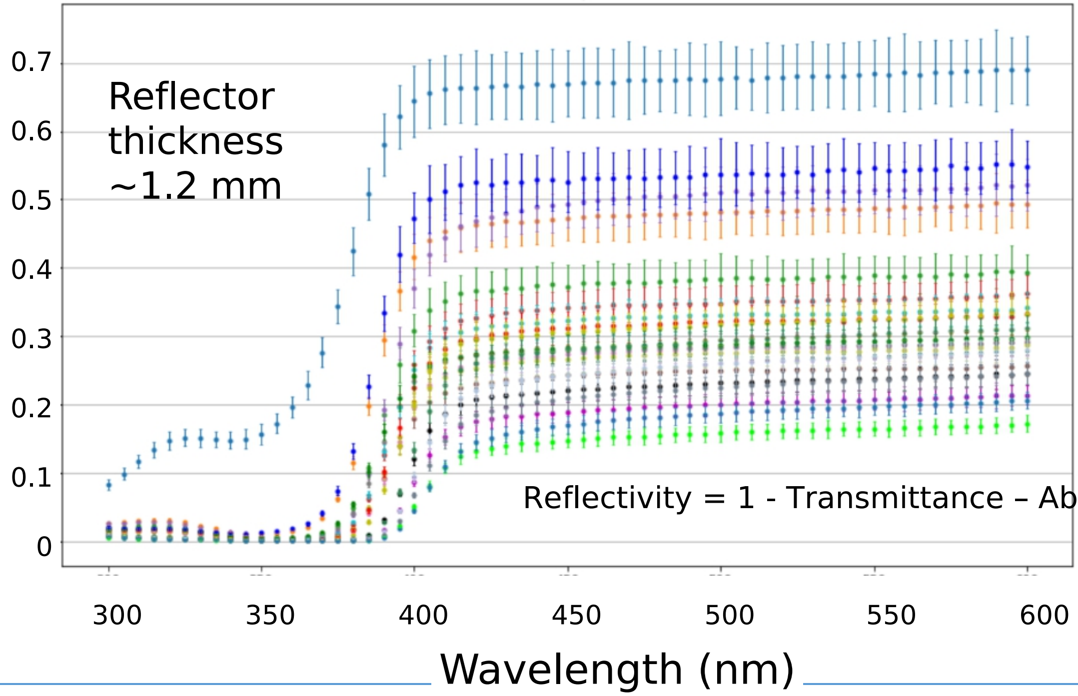


- Light transmittance is worse than our custom filament (~15% vs ~8% @420 nm)
- Expect a bit higher cube-to-cube light crosstalk
- **Heat resistant**

Tested several white filaments on the market resistant to heat up to 270℃ (FDM reaches up to ~220℃)

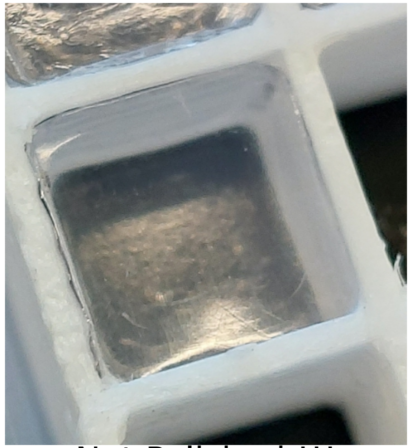
⇒ Polycarbonate (PC) + polytetrafluoroethylene (PTFE)



Towards a 3D printed SuperCube

It had to be polished...

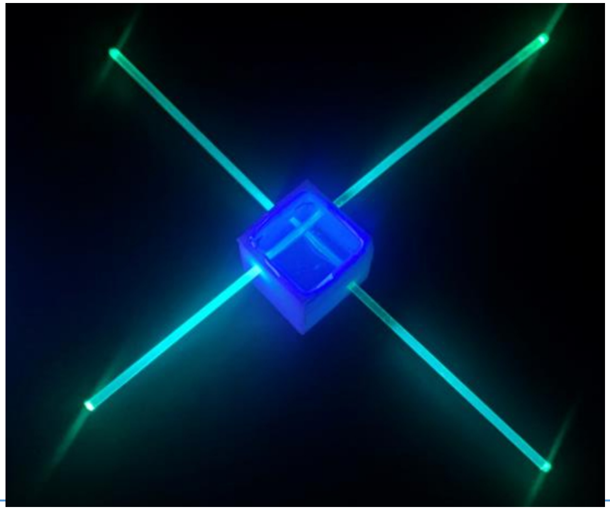
After improving the 3D printing technique



Not Polished !!!

Very transparent and no airbubbles

Managed to make 1.1 mm diameter holes to host the WLS fibers

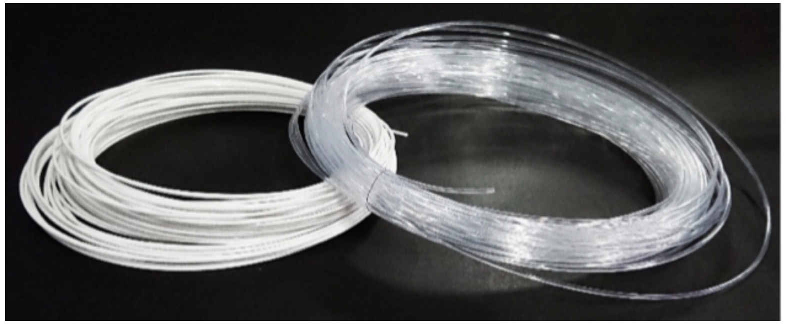


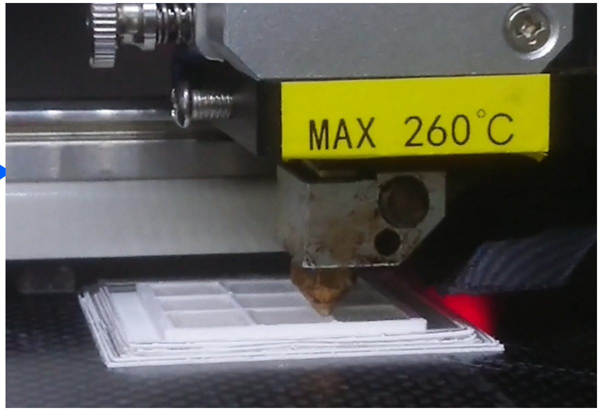
No post-polishing needed !

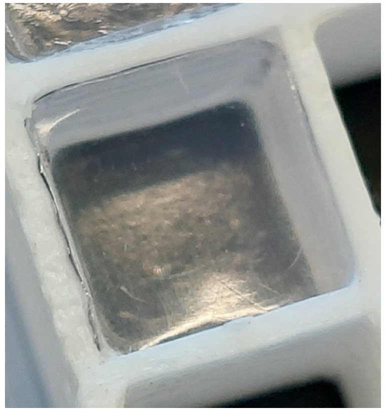
WLS fibers can be inserted directly!

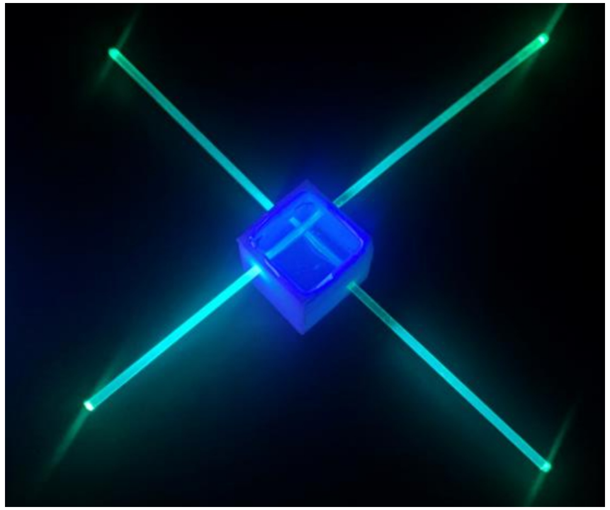
Ready to collect data !

The 3D printed SuperCube

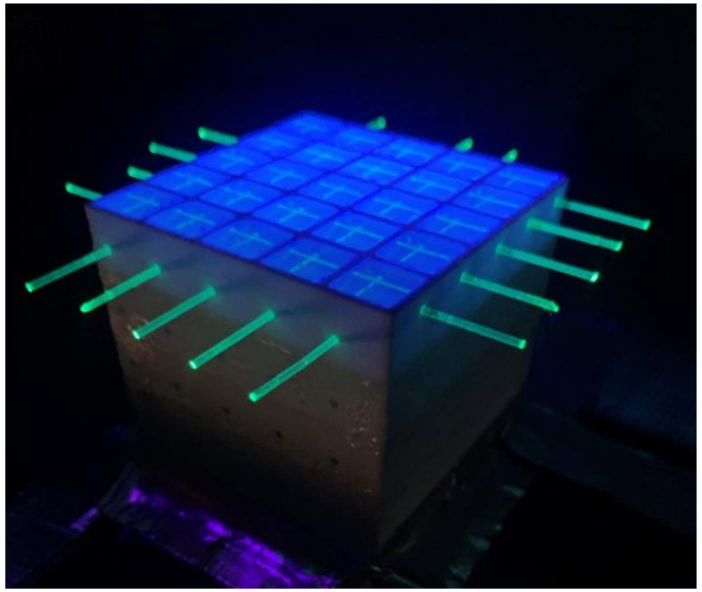








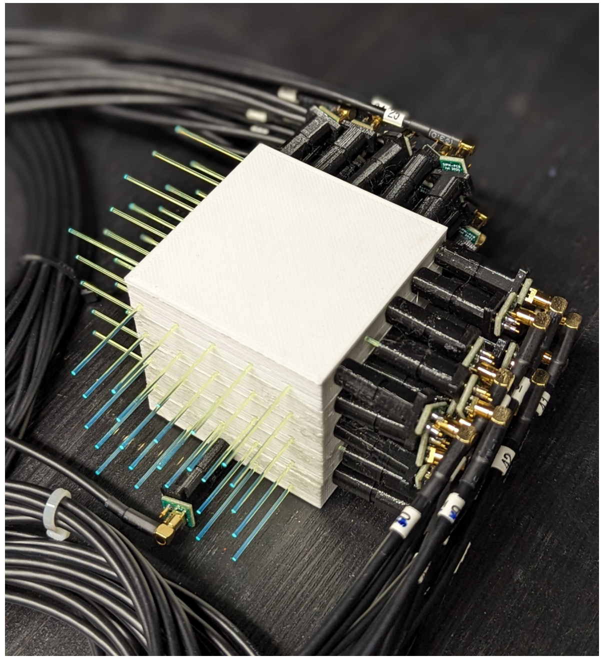
Single cube with two WLS fiber readouts



Complete 5th layer, UV-light exposed.

Complete 5x5x5 super-cube.

The 3D printed SuperCube

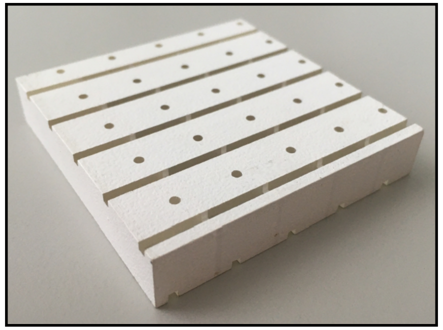


2 channels per cube

Read out with Hamamatsu SiPM S13360-1325CS (PDE~25%)

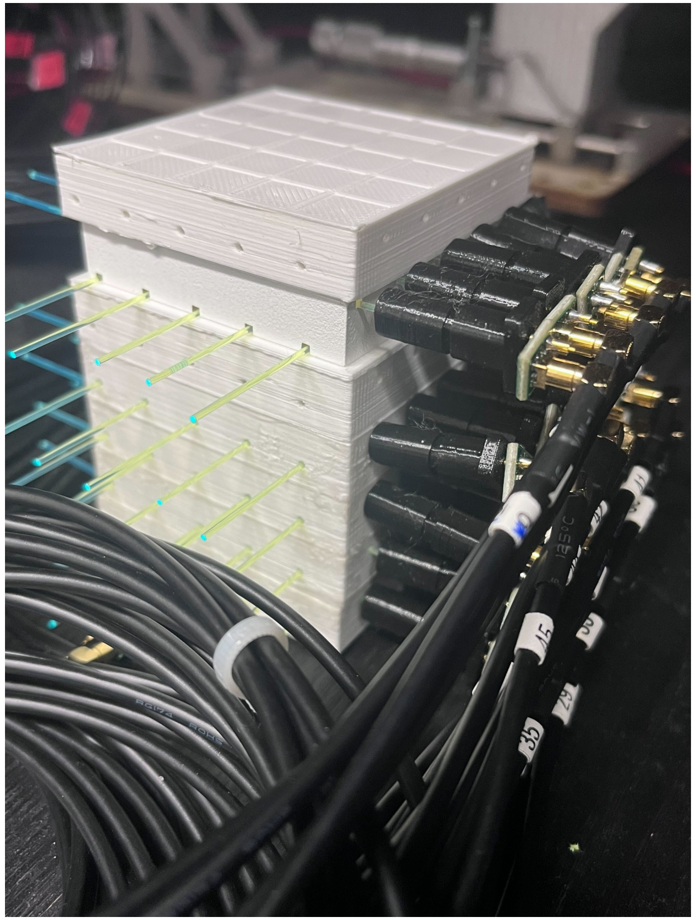
Electronics readout with CAEN FEB 5702 (CITIROC ASIC)

*A. Boyarintsev *et al* 2021 *JINST* **16** P12010

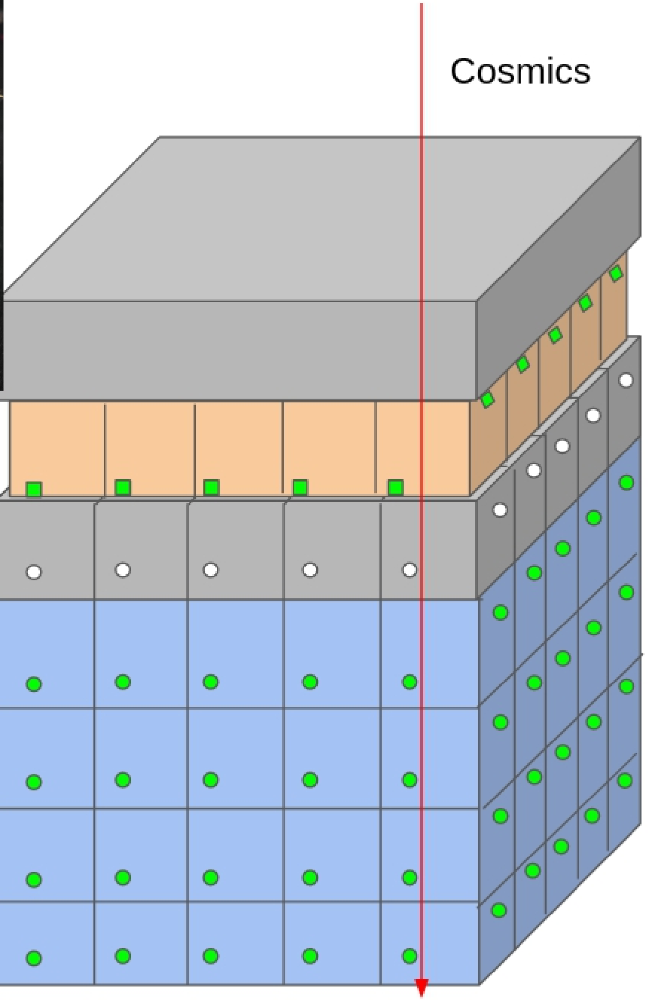


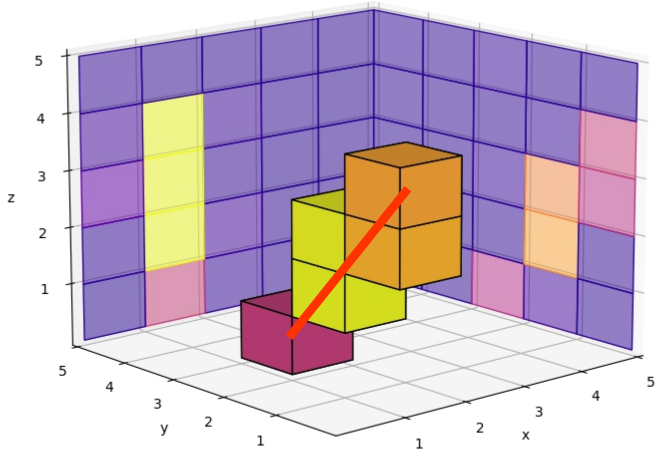
Compared with a layer of standard scintillator cubes produced with injection moulding and glued together, optically-isolated with epoxy+TiO2)

An extra layer of cubes on the top to provide a reflective cover

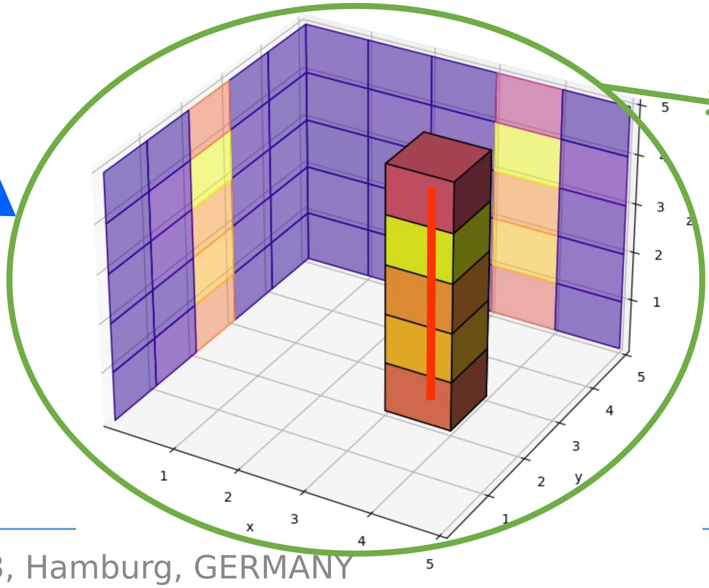


The 3D printed SuperCube



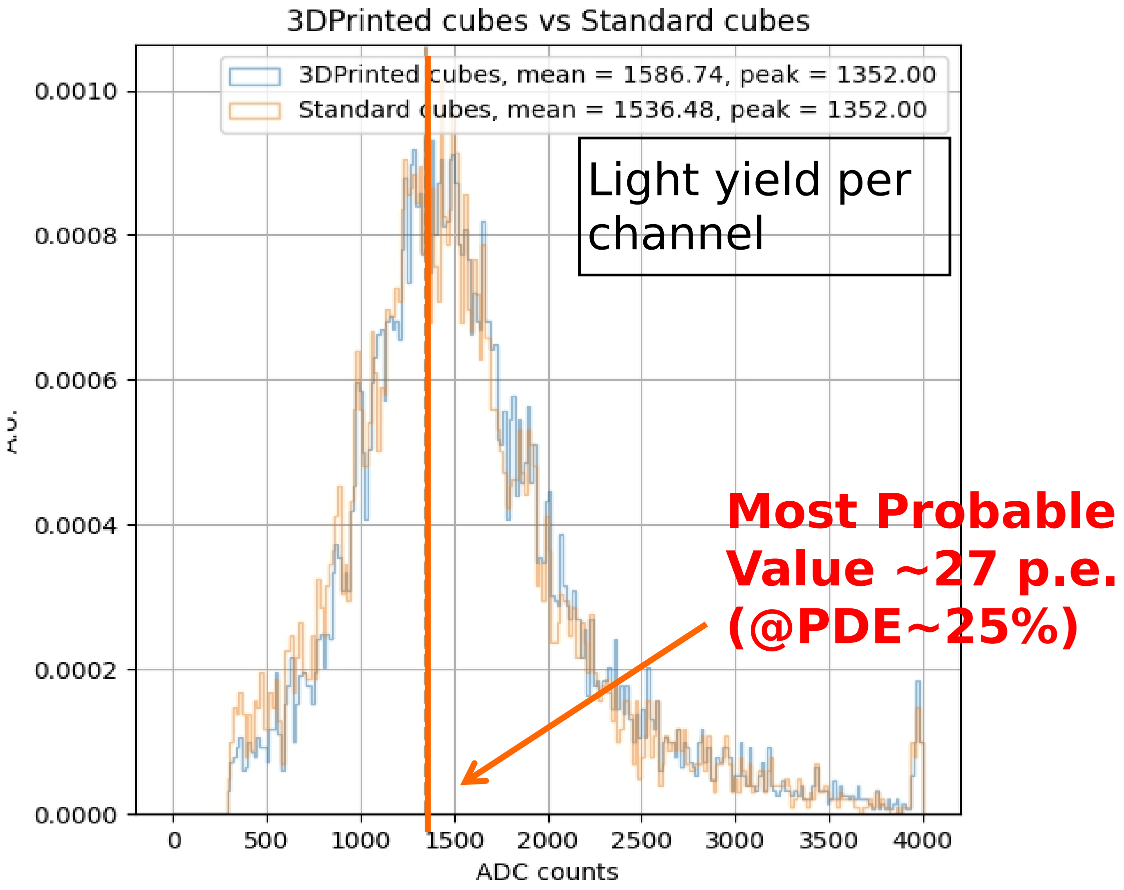


Cosmic data

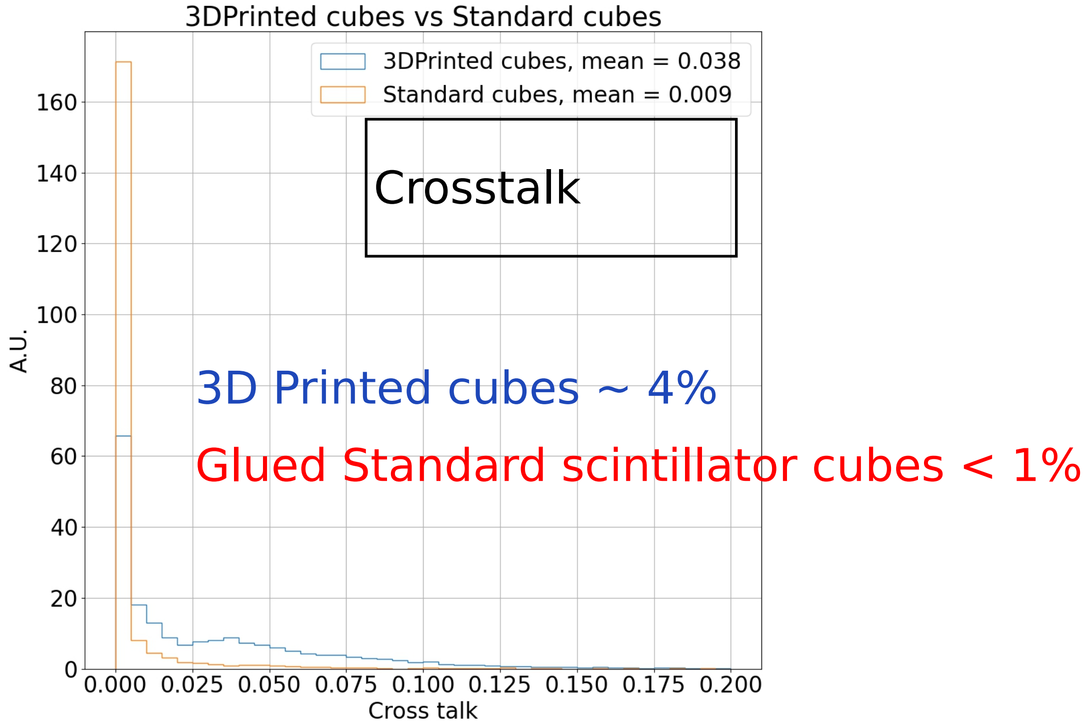


- Vertical cosmic tracks were selected to have a relatively consistent path length within the cobe volume.

The 3D printed SuperCube

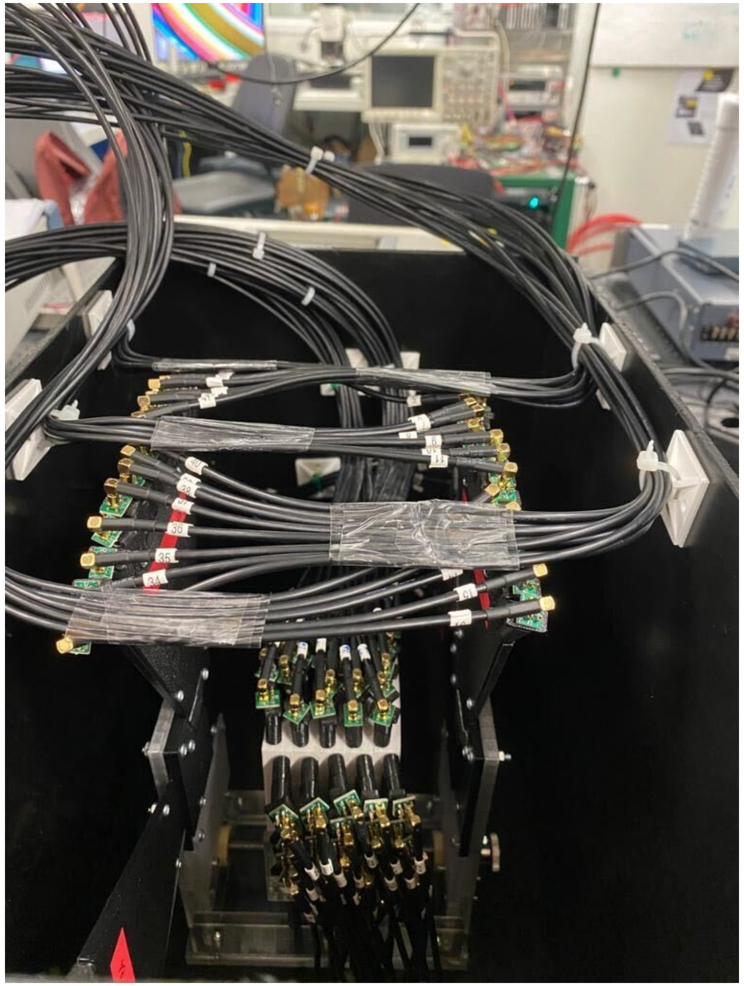


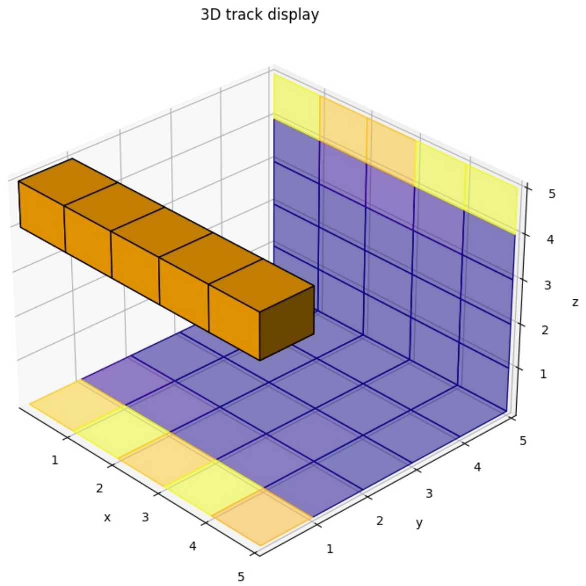
Tested with cosmic, light yield ~ 27p.e./channel/cosmic

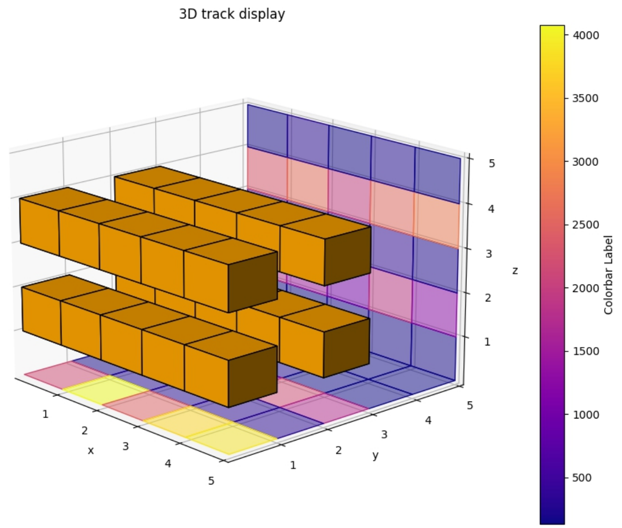


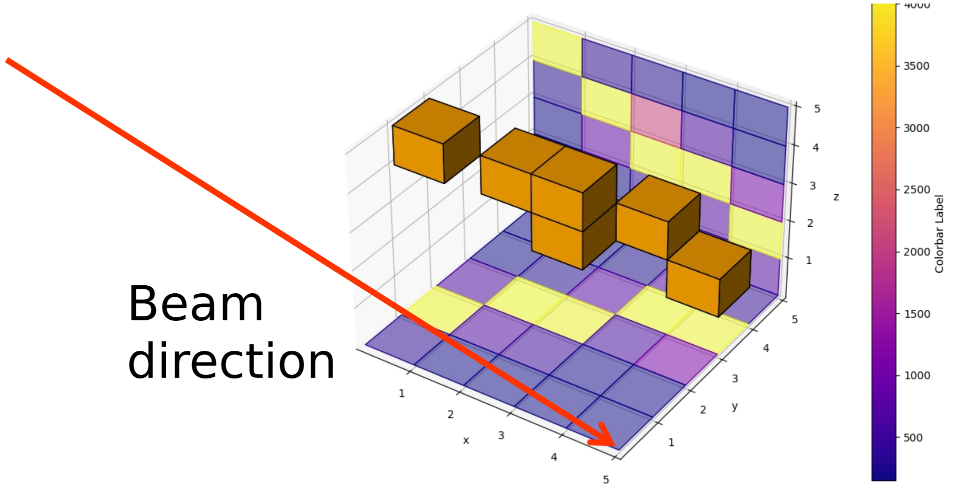
Successfully tested for the first time a totally 3D printed "final" plastic scintillator detector (no post-processing) with performance acceptable for a particle physics experiment

The 3D printed SuperCube









Conclusion and Future plans

- **We demonstrated the feasibility of 3D printing plastic scintillator detectors with complex and 3D geometries with performance analogous to traditional manufacturing processes. No subtractive processes needed.**

- **To optimize the 3d-printed scintillating cube matrix, work in progress to further improve the reflector filament.**
  - **heat resistent and high reflectivity**
  - **thinner reflector walls**
- **Beam test at CERN is on-going.**

- **Writing an article where details about the AM process implementation and final performances are described.**

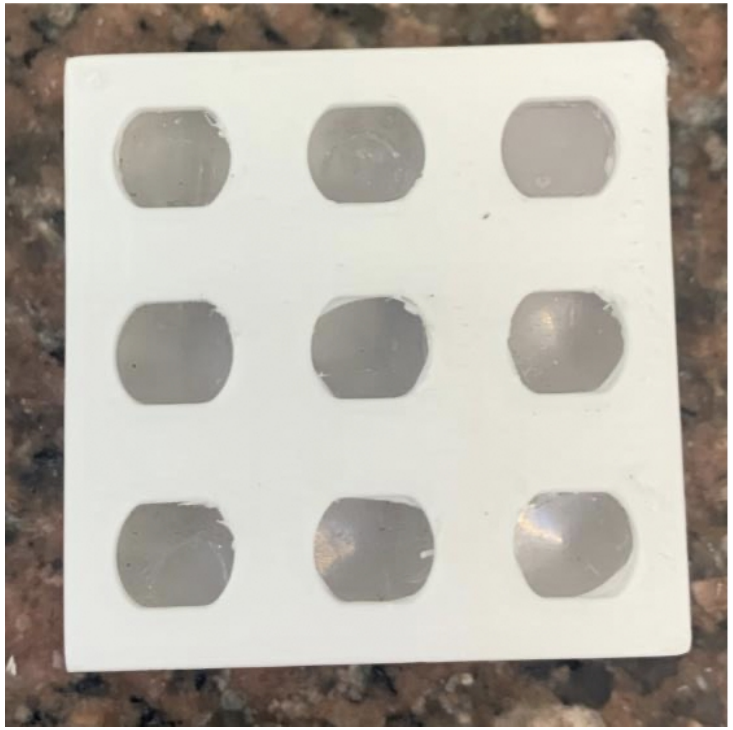
- **Developed also 3D printing for inorganic materials (see backup).**

If interested in such R&D, we are open to set collaborations for applications and projects (https://threedet.web.cern.ch)

Backup

Towards a 3D printed SuperCube

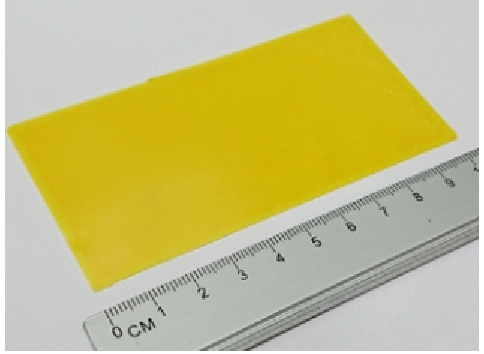
9 optically isolated cubes ready to be directly coupled to SiPM
(no post-processing)

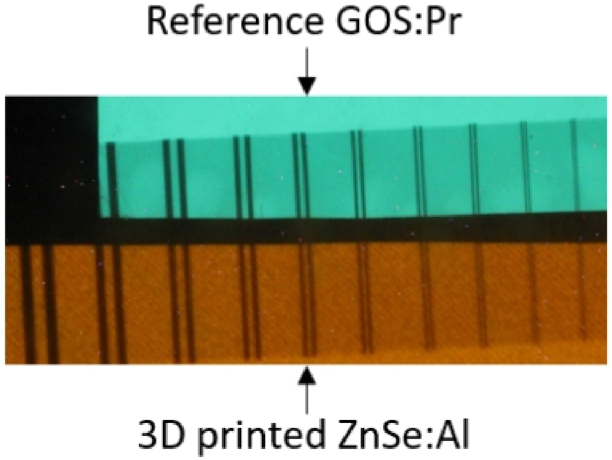


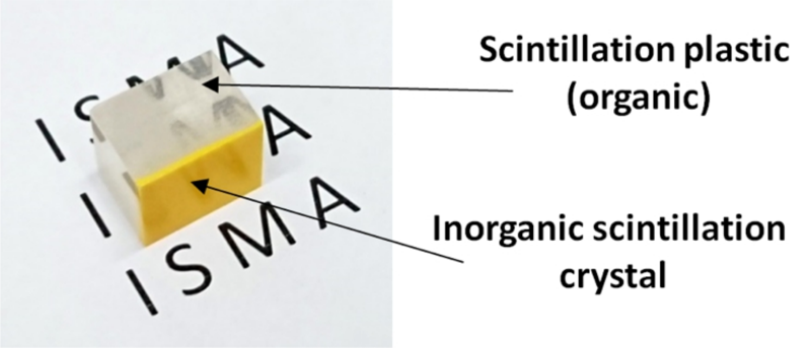
Ready to be instrumented with photosensors and electronics
→ particle detector

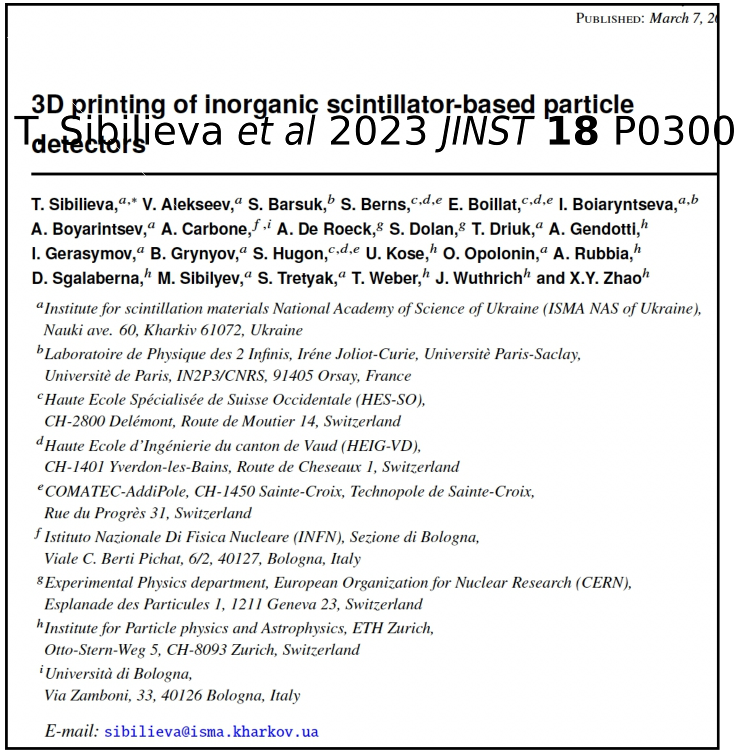
Inorganic scintillator

We 3D printed inorganic scintillator for registration of Ionizing and X-ray radiation









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3D printing of inorganic scintillator-based particle detectors

T. Sibilieva *et al* 2023 *JINST* **18** P03007

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Possibility to further develop the technology even for sampling calorimeters