Fully 3D-printed plastic scintillator particle detector prototype

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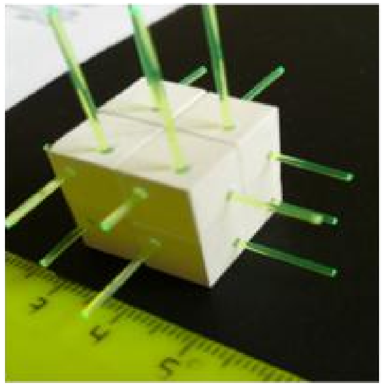
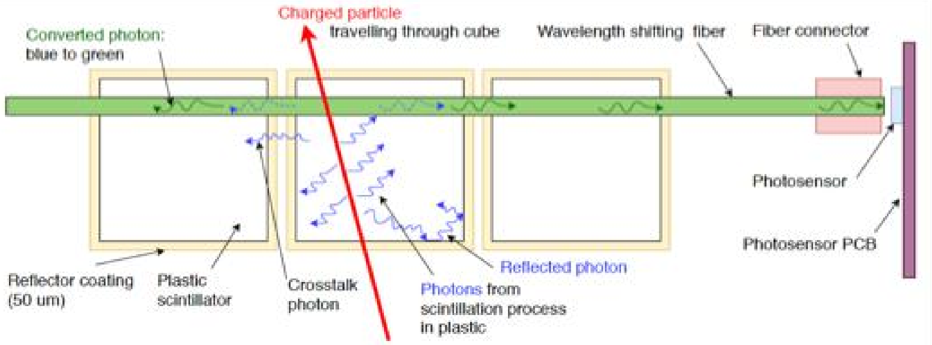
CALOR 2024, Tsukuba, JAPAN

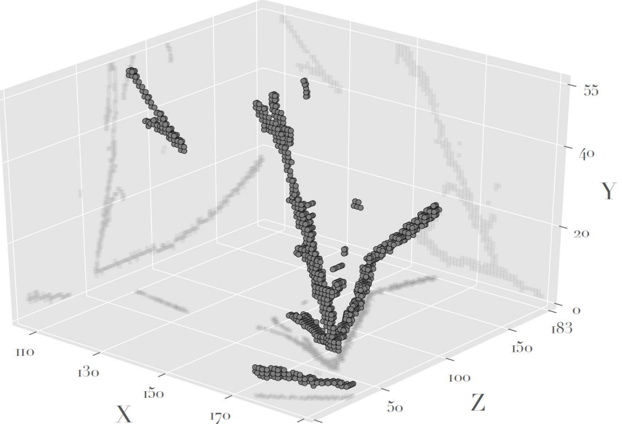
Why 3D Printing?

- 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)



JINST 13 (2018) 02, P02006
NIM A936 (2019) 136-138



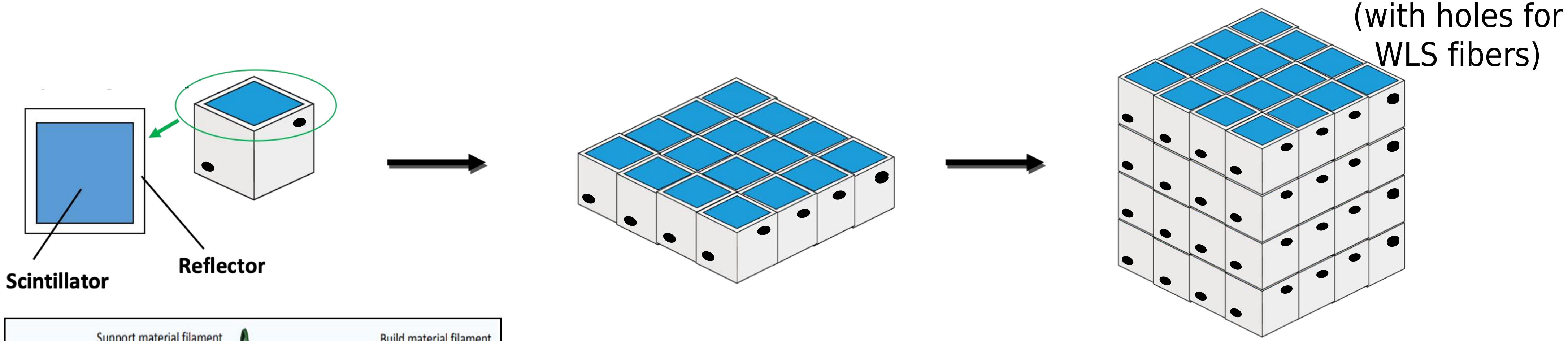


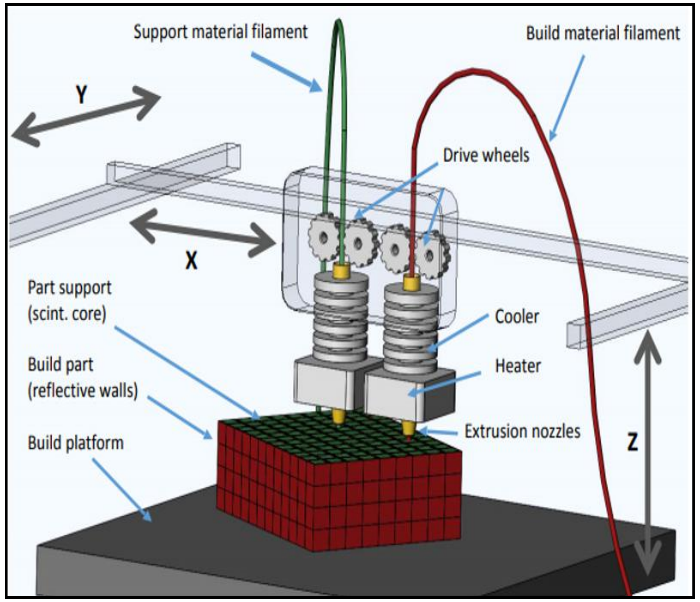
Phys. Rev. D 103, 032005 (2021).

- 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 for the scalability towards a multi-ton detector.

3D printing a scintillating “SuperCube”



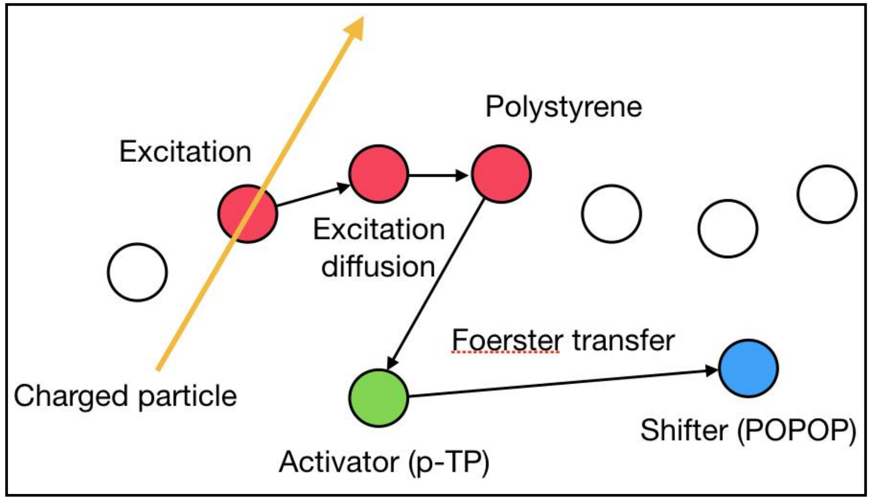


Fused Deposition Modeling (FDM) is a promising solution

Need a technology that can:

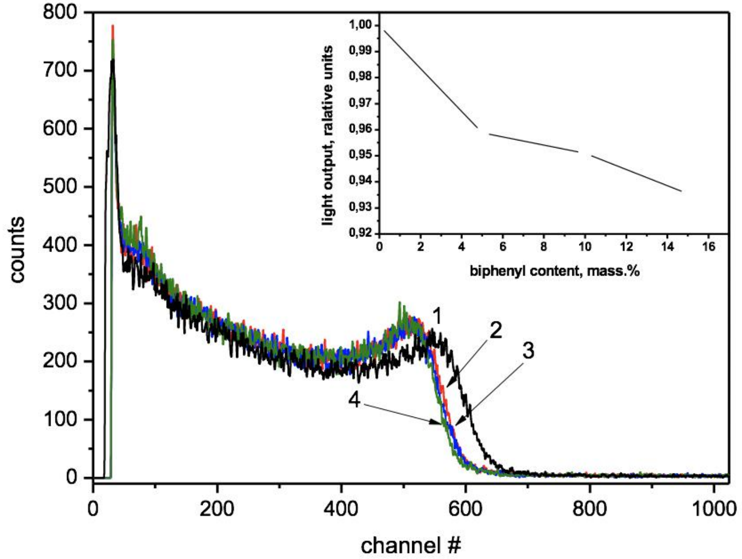
- Achieve good scintillation performance and high transparency in the scintillator core.
- 3D print big volumes in relatively short time and cheap processes and avoid multiple steps (manufacturing and assembly)
- 3D print simultaneously more materials.
- Hollow objects, e.g. holes for WLS fibers

The 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)

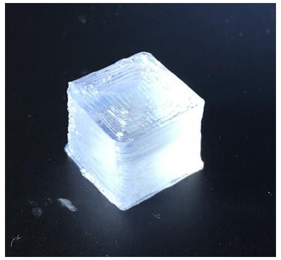
Polystyrene is well known => No need to "invent" a new chemical composition !



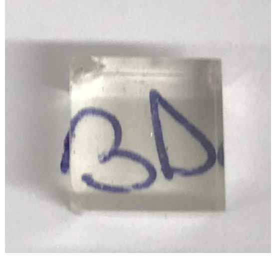
Tested both w/ and w/o 5% biphenyl as plasticizer
(in later prototypes we also dropped biphenyl out)

The proof of the concept

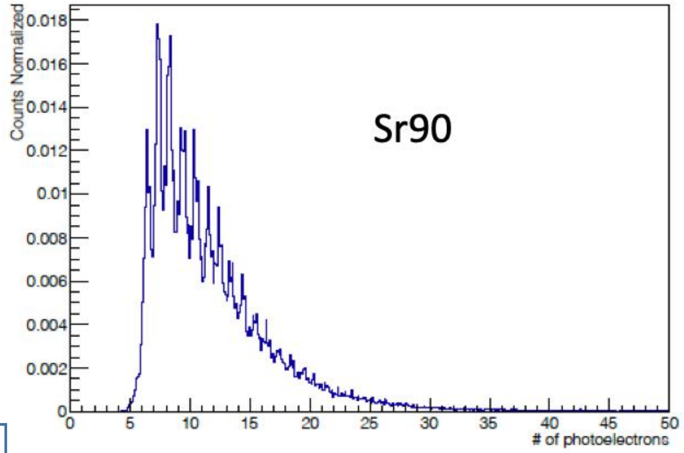
S.Berns *et al.* 2020 *JINST* **15** P10019



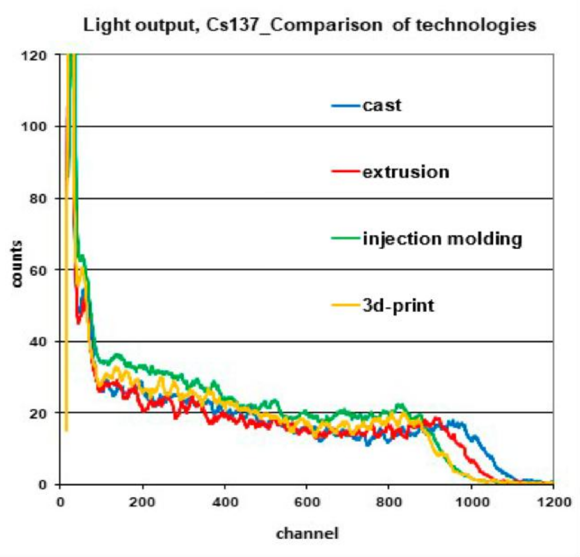
The outermost surface is always opaque. Characteristic of FDM



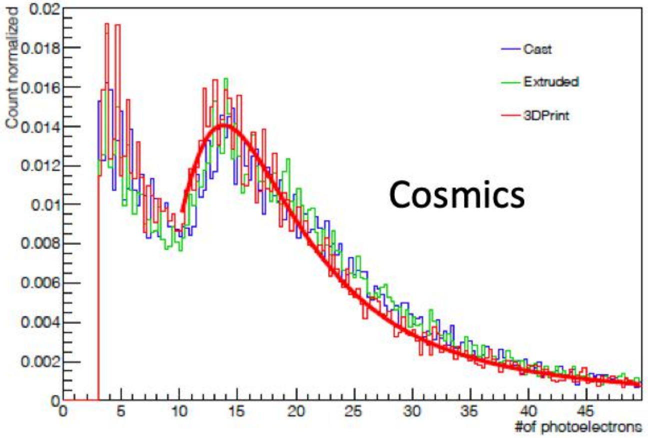
**printed with CreatBot Dx2*



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

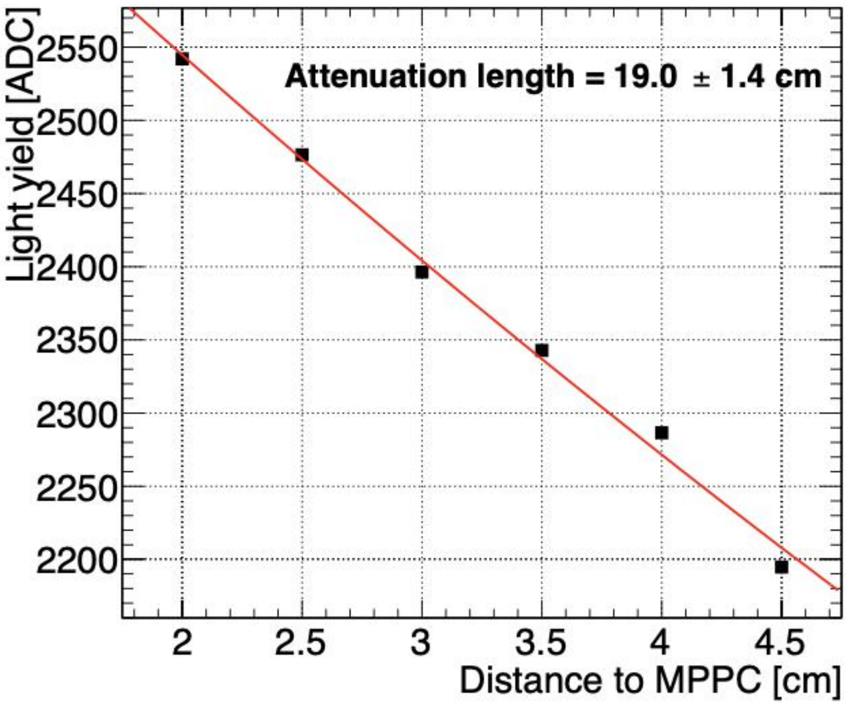


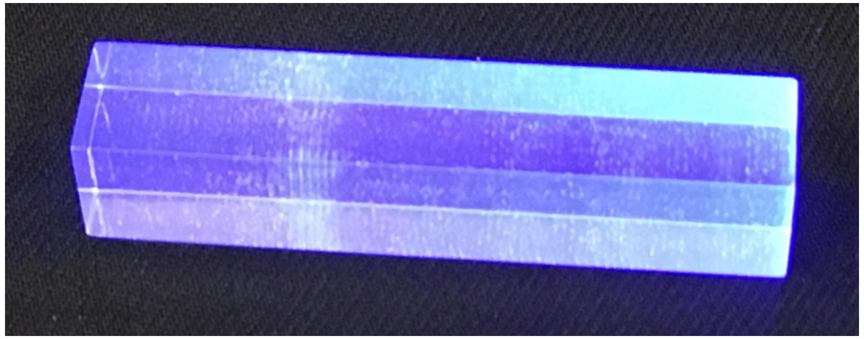
MPPC coupled directly with scintillator cube in black connector (no white reflector envelope)



Attenuation length (technical)

Transparency measured from 5 cm-long bar





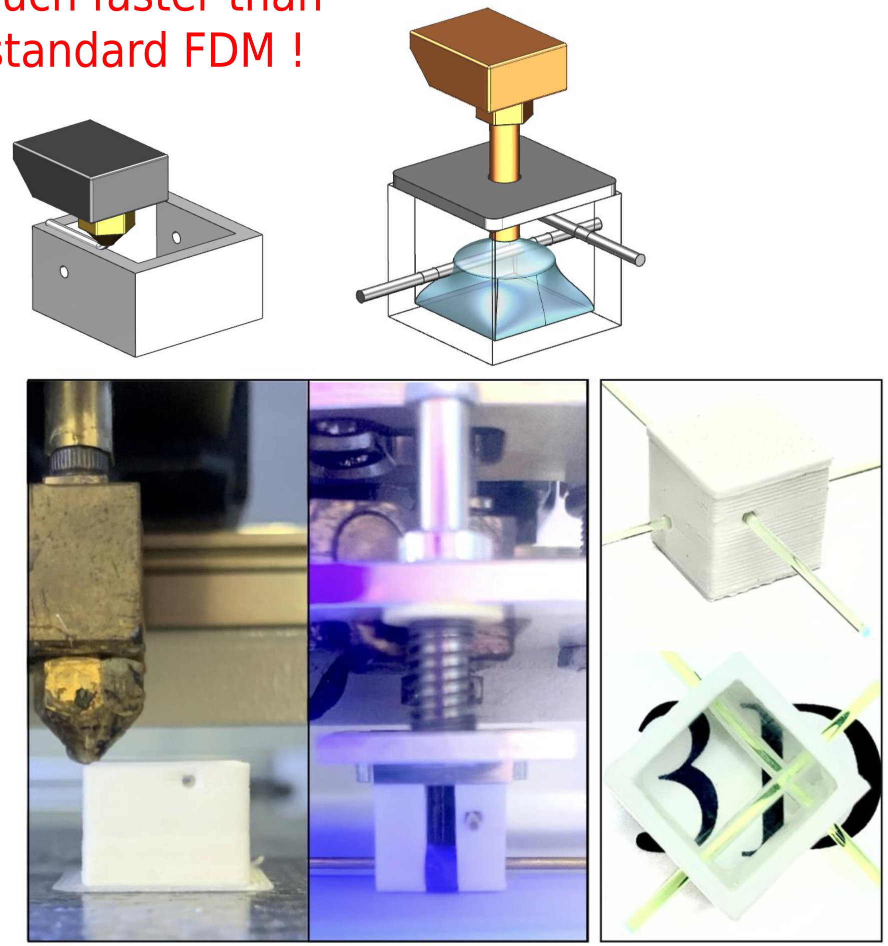
- Polished on the outermost surface and covered with white teflon.
- SiPM on one end + Sr^{90}/Y^{90} source moving at different positions
- Sparse presence of small air bubbles

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

Fused injection modeling

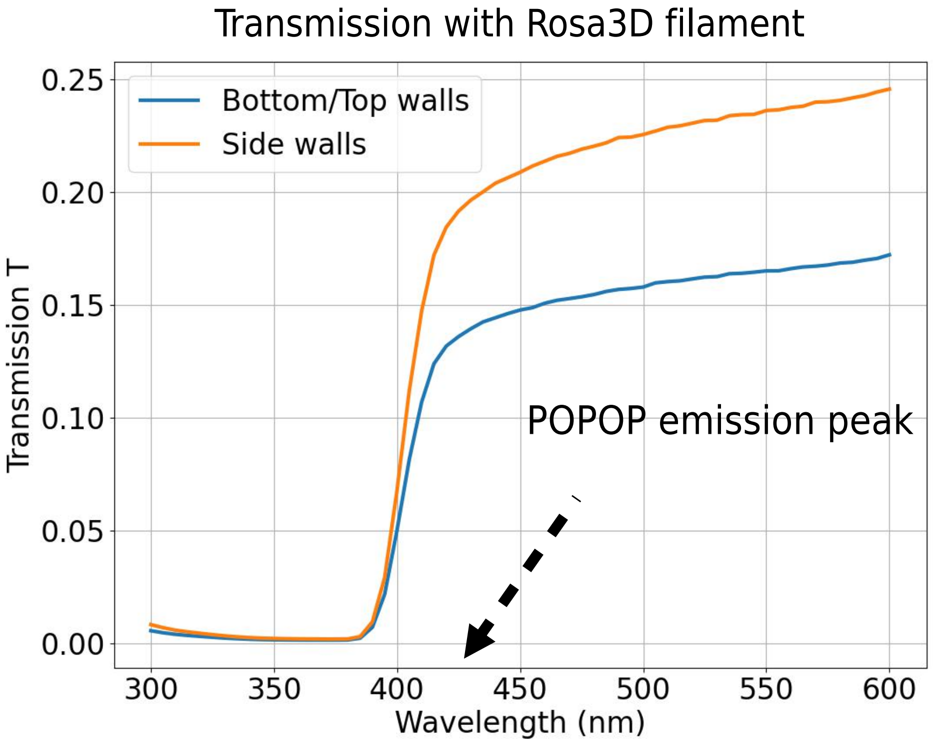
3D print the mould and quickly inject melted plastic scintillator

Much faster than standard FDM !

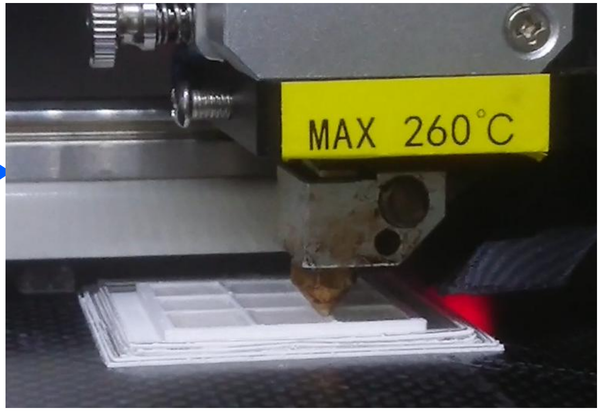


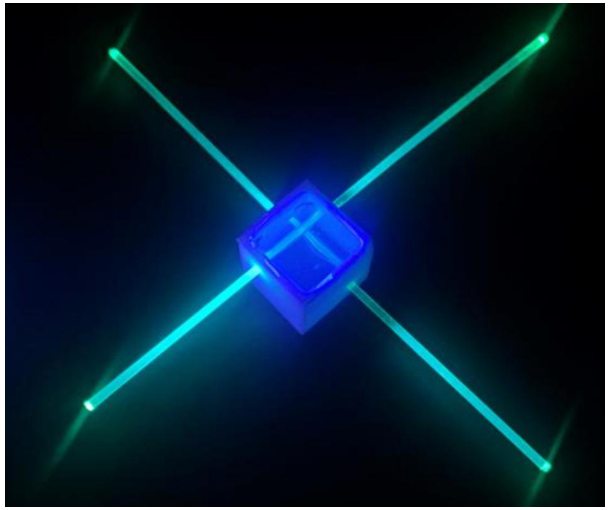
arXiv:2312.04672

The desired geometrical shape is preserved by a reflective polycarbonate + PTFE heat-resistant (~300℃) filament

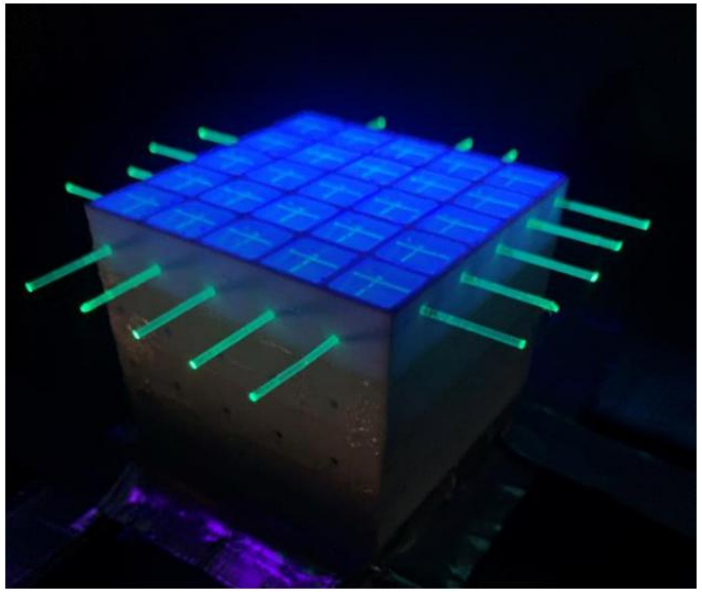


The 3D printed SuperCube





Single cube with two WLS fiber readouts



Complete 5th layer, UV-light exposed.

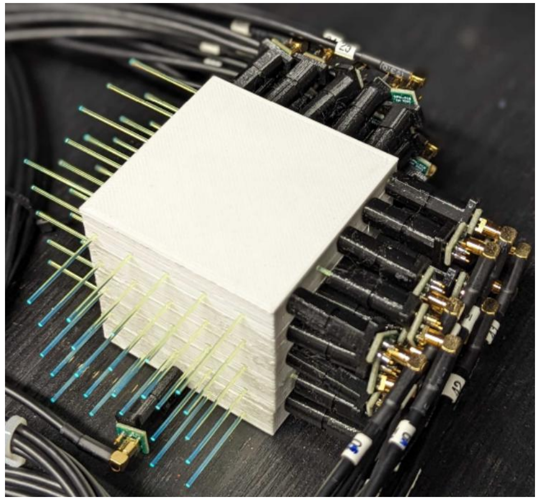
Complete 5x5x5 super-cube.

The 3D printed SuperCube

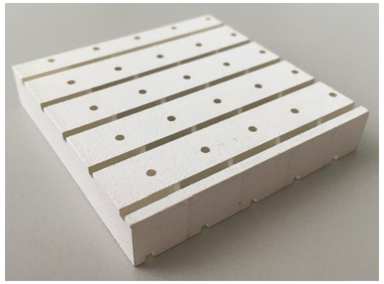
arXiv:2312.04672

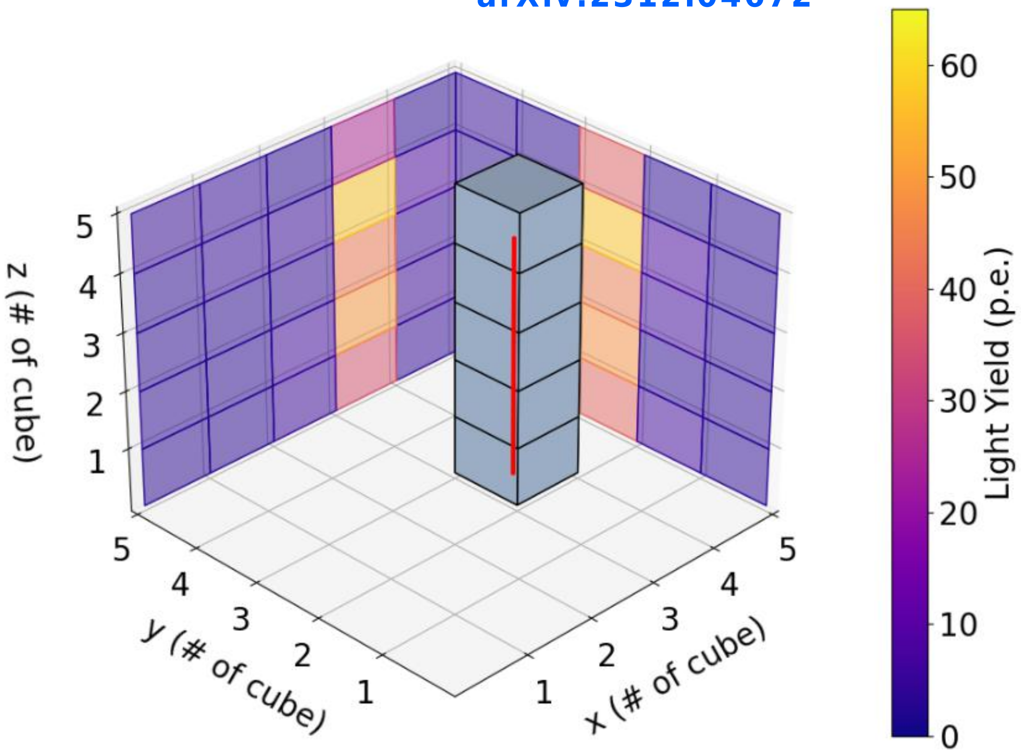
Tracking of cosmic rays in a 5x5x5 cubes prototypes

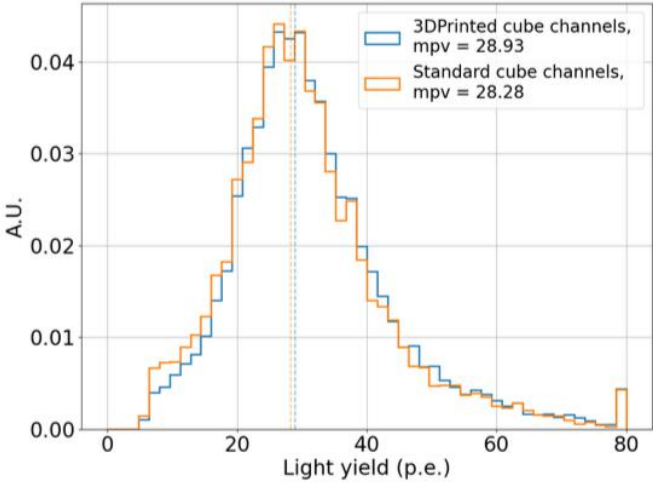
- ✓ Hamamatsu S13360-1325CS SiPM (PDE~25%)
- ✓ CAEN FEB 5702 (CITIROC ASIC) front-end

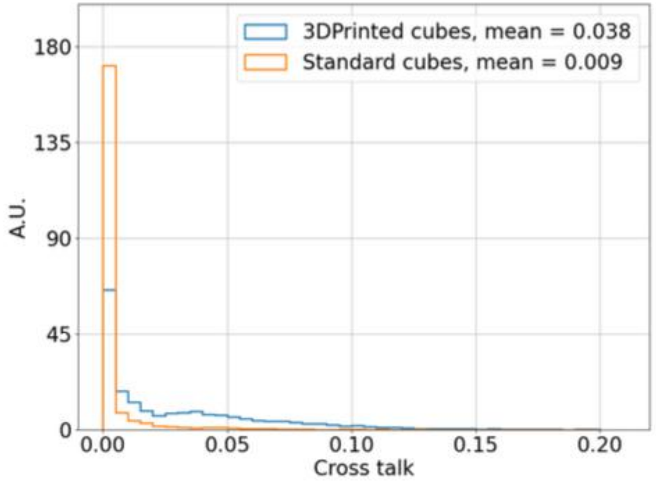


Compared with cast scintillator (both filament and cast produced by ISMA)





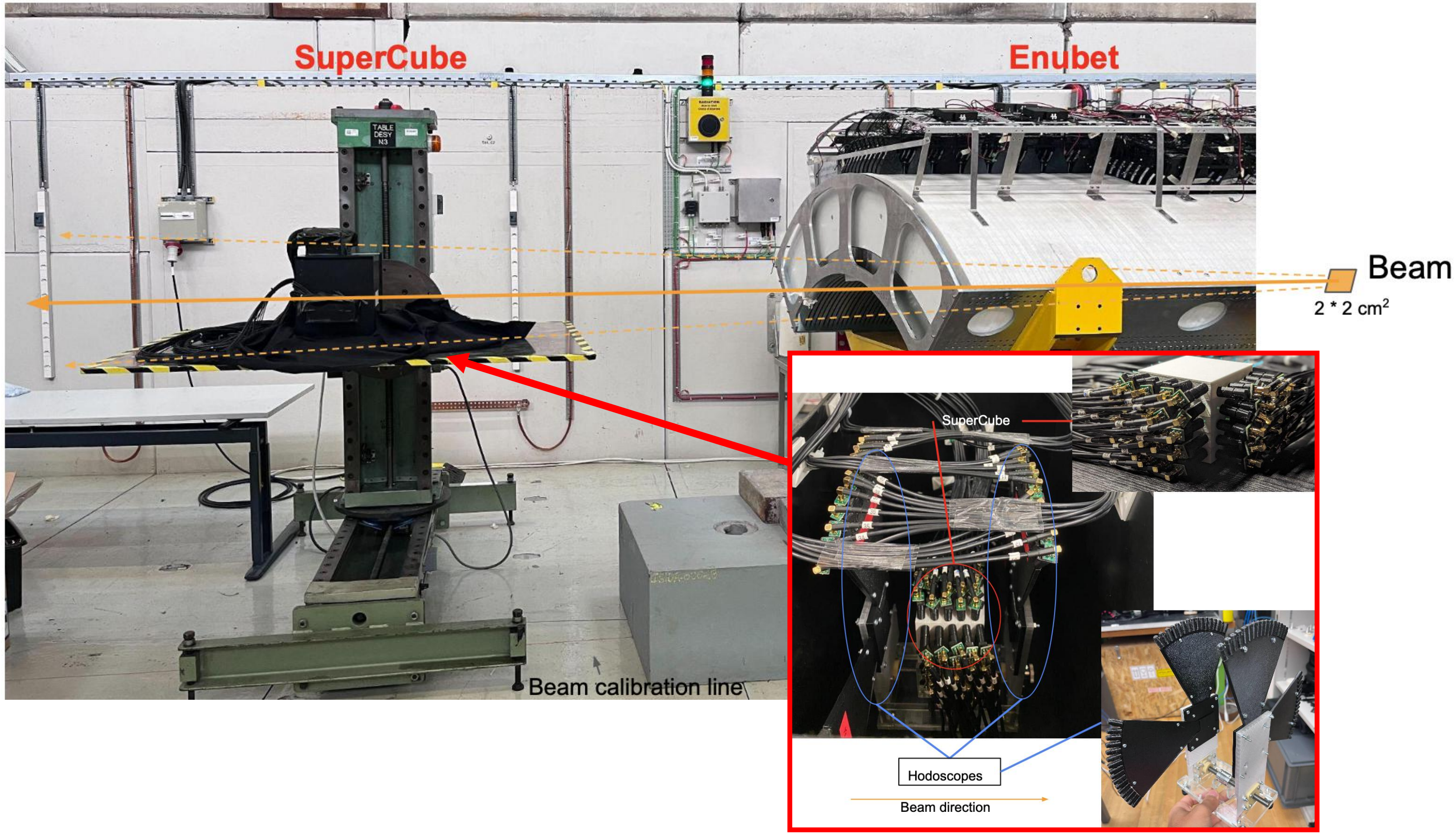




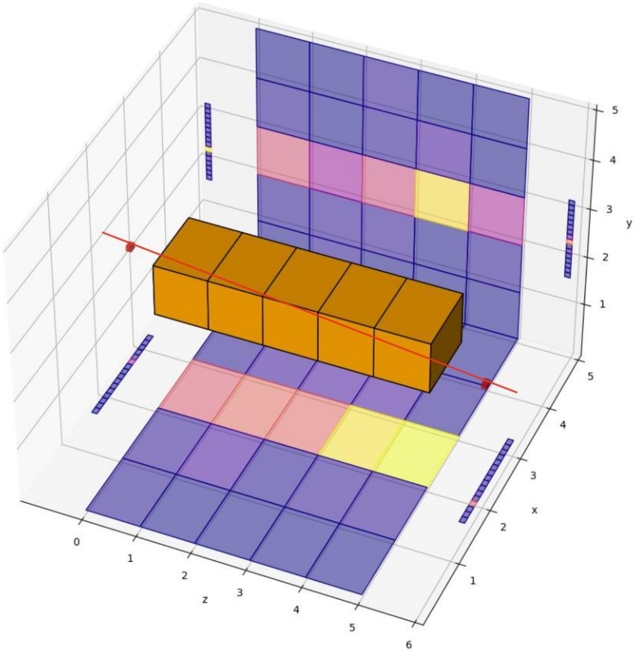
Scintillator light yield same as standard scintillator (MPV ~ 29 p.e. / MIP / cm)

Cube-to-cube crosstalk ~4% ⟶ slightly higher but OK for neutrino detection

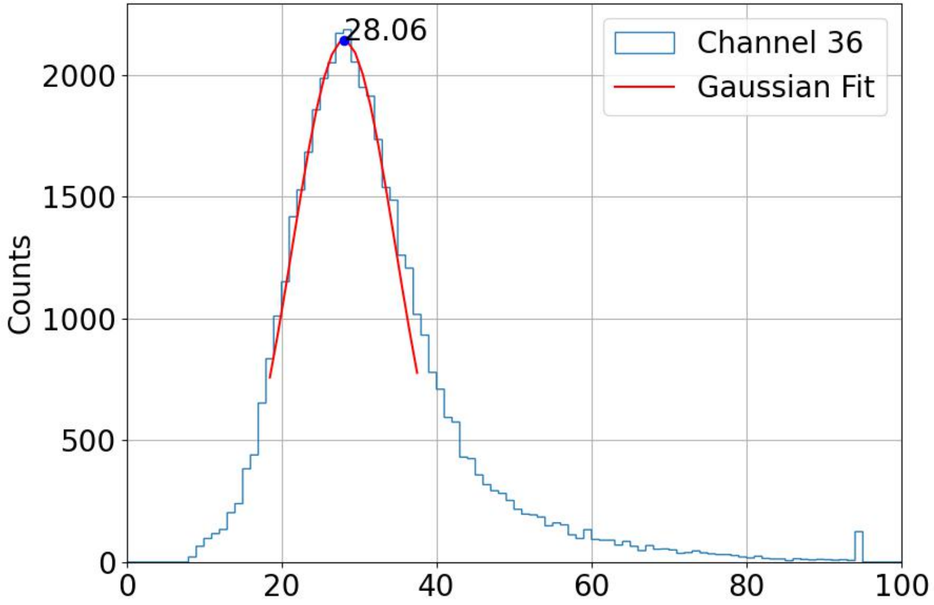
SuperCube Beam test

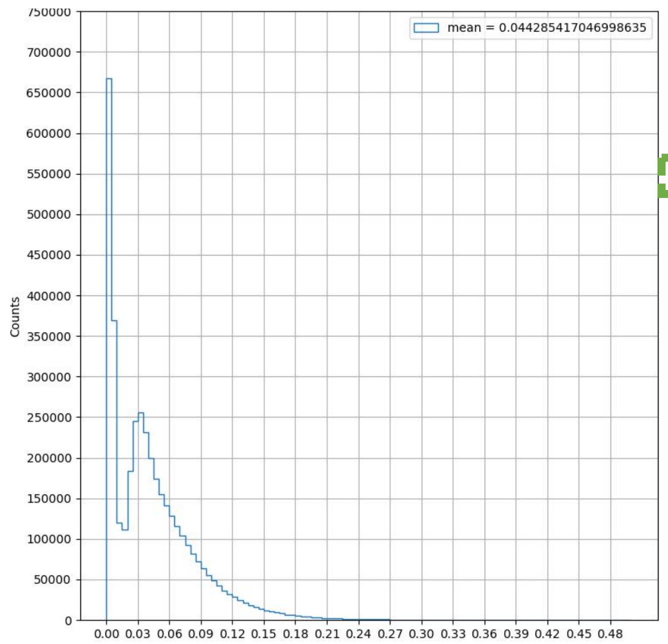


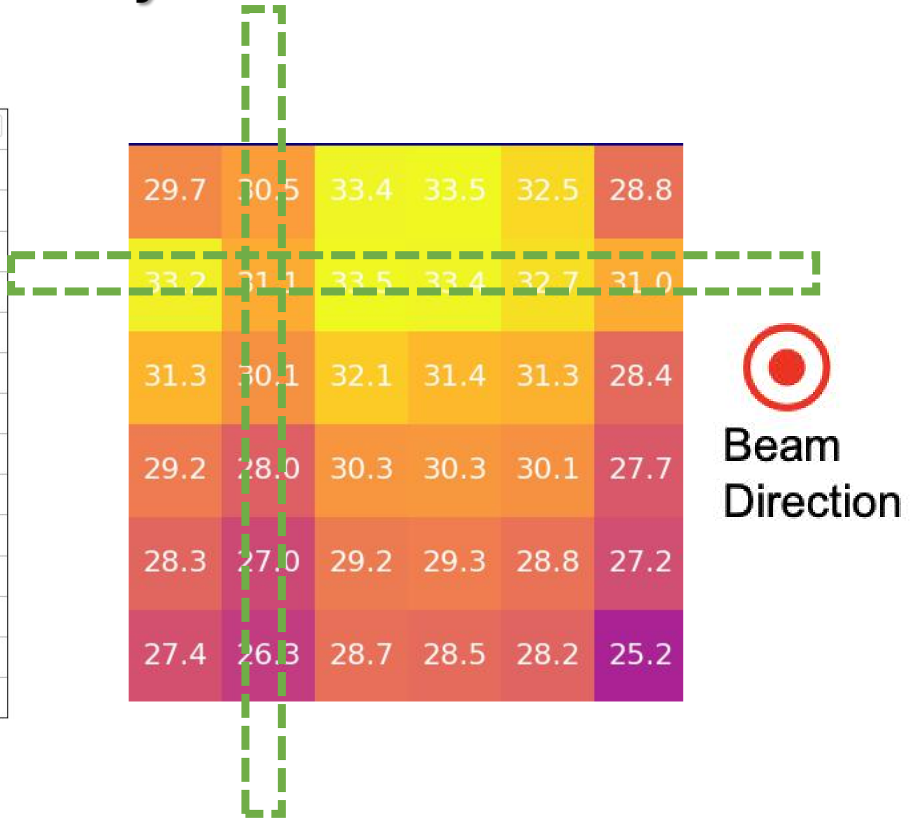
- Beam tests at CERN in T9 from Proton Synchrotron
- Hodoscope of 16(X)+16(Y) 1mm scintillating fibers (Kuraray SCSF-78 square)



SuperCube Beam test - LY & Xtalk & Nonuniformity







- **Average light yield ~28 p.e.**
- **crosstalk peak at 3%, 4% in average**
- **Light yield variance within a single cube of ~7%**

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**

- **Working towards fully automatic printer, sampling calorimeter.**

- **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)

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

Backup

3D printed optical reflector

Polymer pellets

+

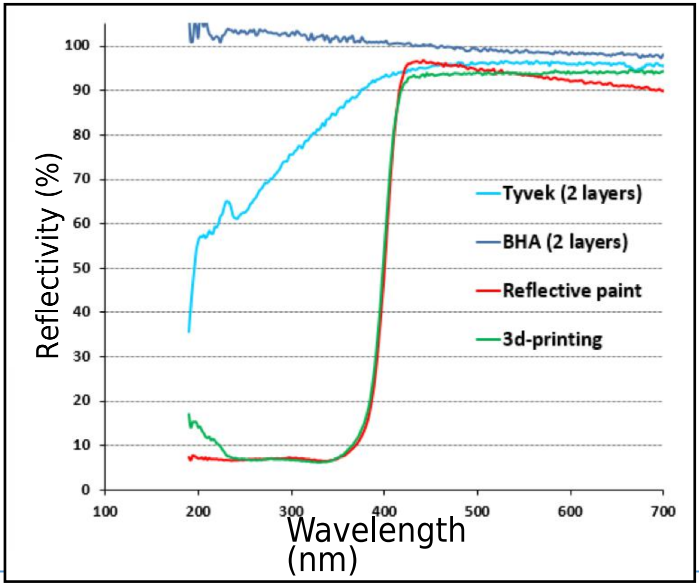
Reflective pigment TiO2
(or BaSO4, MgO…)

=

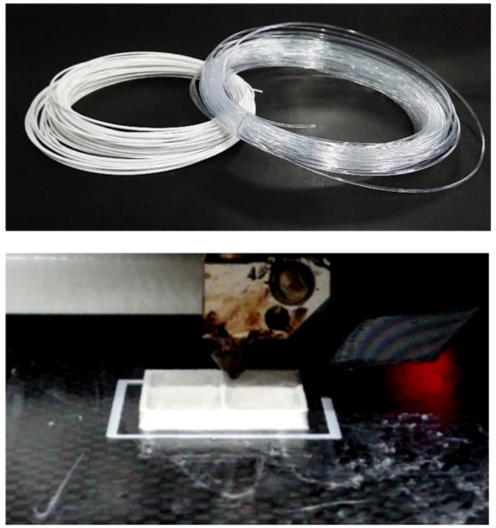
Reflective filament

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:

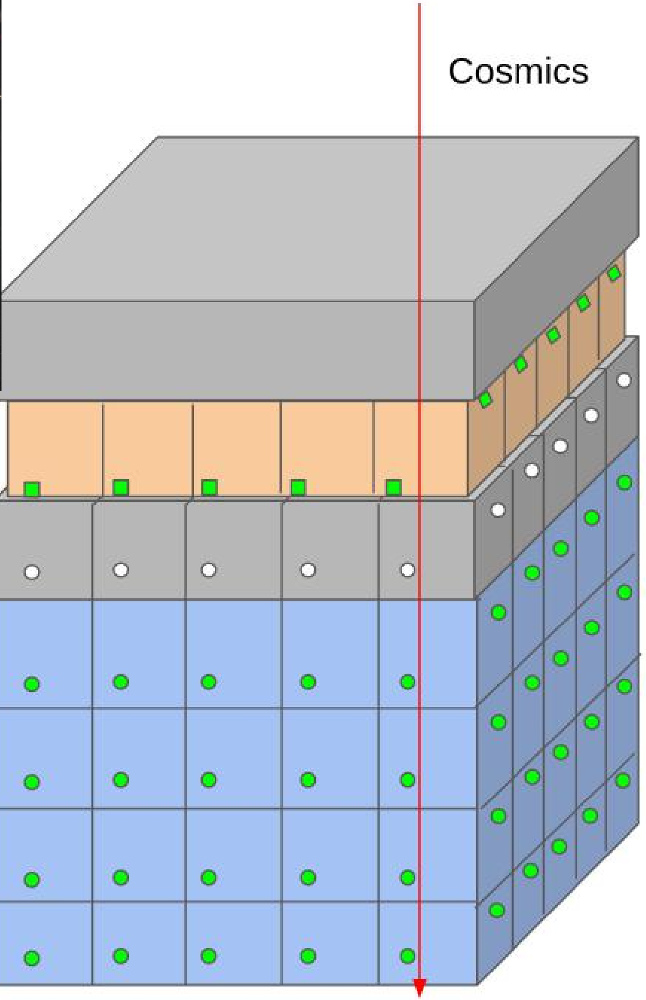


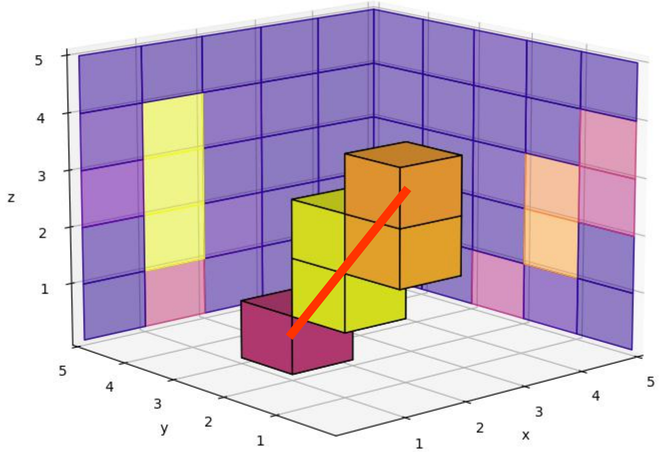
Towards a 3D printed SuperCube

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

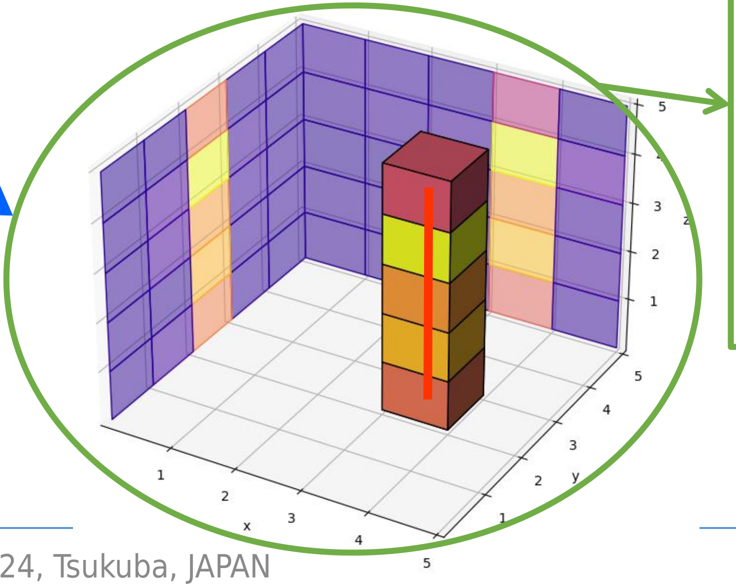
Ready to be instrumented with photosensors and electronics
→ particle detector

The 3D printed SuperCube





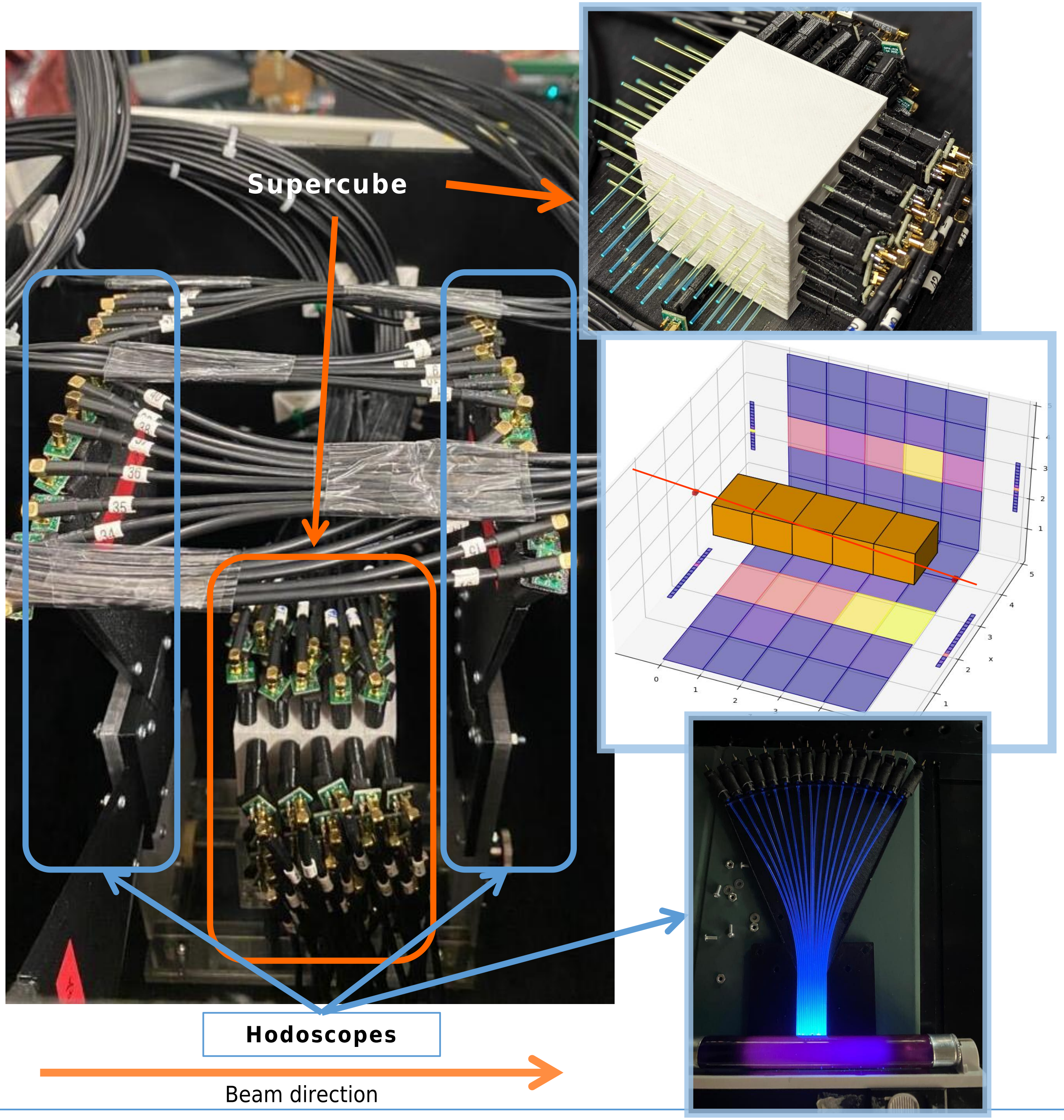
Cosmic data



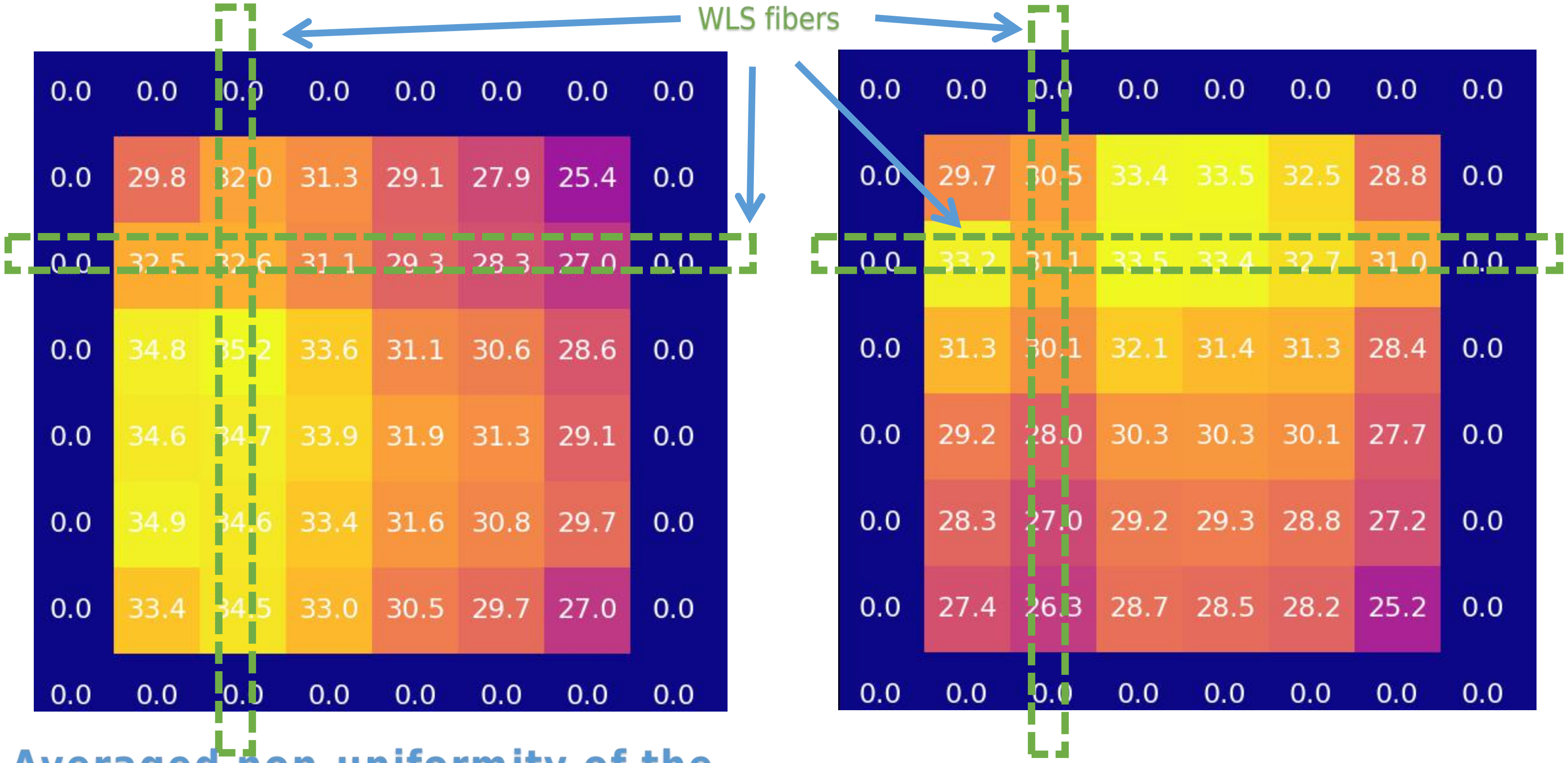
- Vertical cosmic tracks were selected to have a relatively consistent path length within the cobe volume.

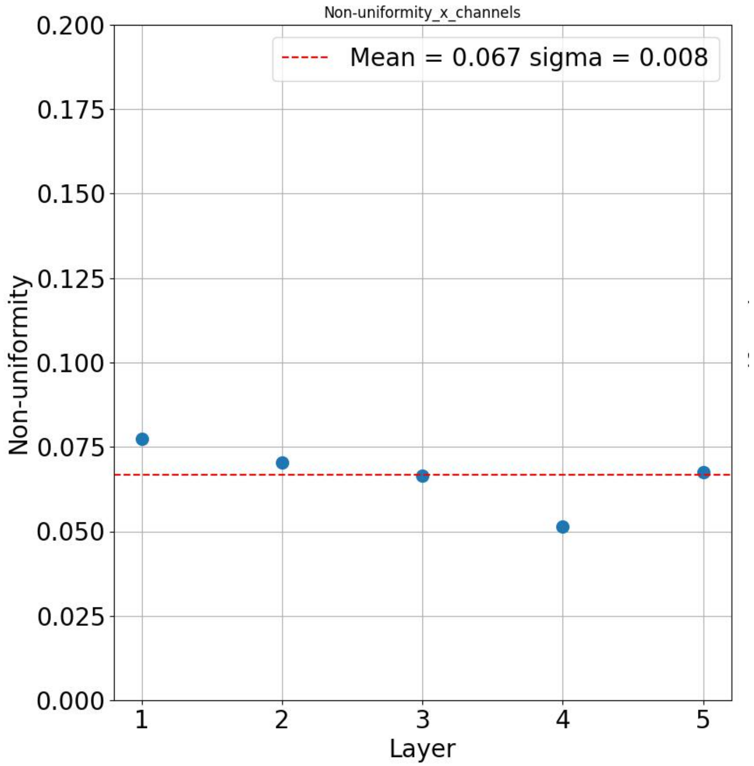
SuperCube Beam test

- Cube channels:
  - 5*5 X + 5*5 Y channels
  - Read out with Hamamatsu SiPM S13360-1325CS (PDE~25%)
- Hodoscope channels:
  - 16 X + 16 Y Kuraray square scintillating fibers of 1mm.
  - covering 1.6 cm * 1.6 cm area of the supercube center.
- Beam component:
  - CERN T9 from Proton Synchrotron
  - Downstream of calormeter -> mainly MIPs.



SuperCube Beam test - Non-uniformity





- Same map can be taken for each of the 5 cubes in the center column of the SuperCube.
- Std. of each map was taken and plotted above to show the non-uniformity between different cubes.

- **Averaged non-uniformity of the center cubes (average of 5 cubes in the center covered by the hodoscopes)**
- **High light yield region around the fibers can be seen clearly**

X channel:

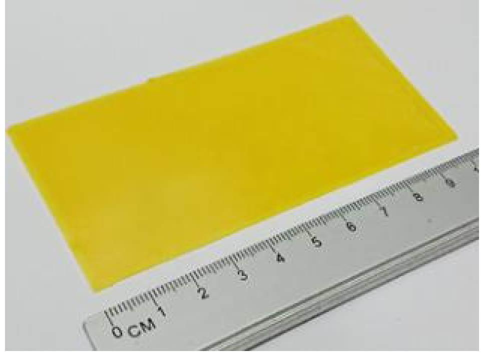
- Max non-uniformity: -19% ~ 12%

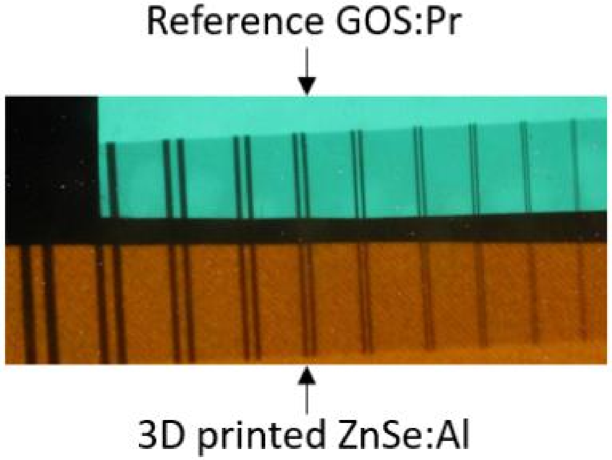
Y channel:

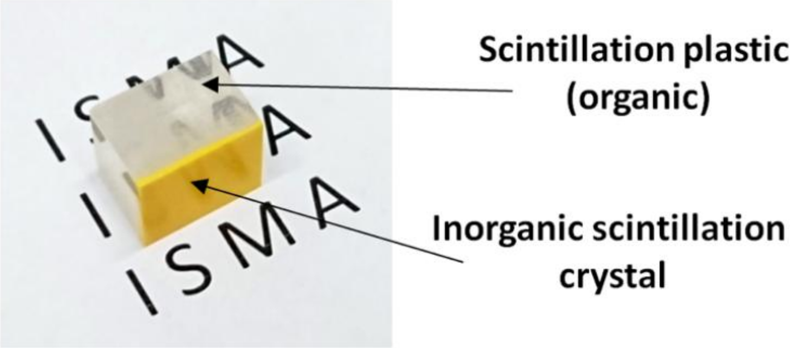
- Max non-uniformity: -16% ~ 12%

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

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Possibility to further develop the technology even for sampling calorimeters