Institute for Scintillation Materials
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3D printing scintillation detectors

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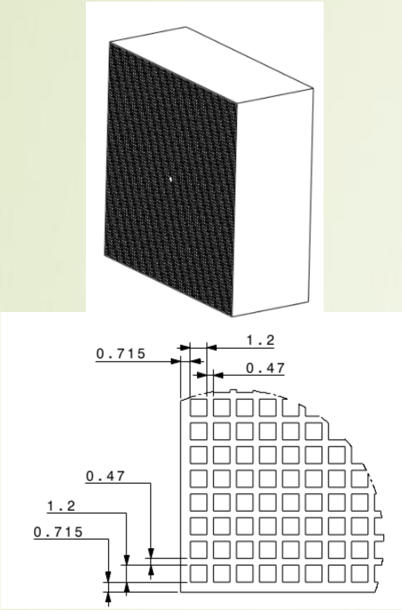
The 10th French-Ukrainian workshop on the instrumentation developments for HEP, IJCLab, June 10-12, 2025 is dedicated to the memory of Mykola F. Shulga

New technology for absorbers for SpaCal and Shashlyk production

CERN, IJCLab Orsay, INFN Bologna, ISMA Kharkiv

Main requirement for absorber: Material density not less than 11.3 g/cm^3



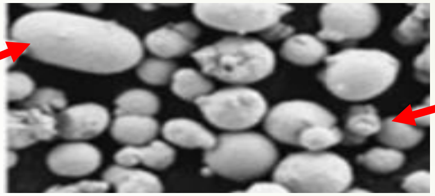
Absorbers

Bulk materials:

Lead…………………….. Density 11.3 g/cm^3; T_{melt} 327 °C
Tungsten…………….. Density 19.2 g/cm^3; T_{melt} 3422 °C

Alternatives:

Tungsten granules



Binder: organic or inorganic (metal, glass, other ideas?)

Tungsten powder…... Density (theory) up to 14 g/cm^3; in practice ~10.5 g/cm^3;
Tungsten powder with binder (11 - 14)? g/cm^3 clarification is required

Suitable absorber production technologies

Molding and CNC processing
+ Good quality
- Perfection achieved
- Environmental hazards

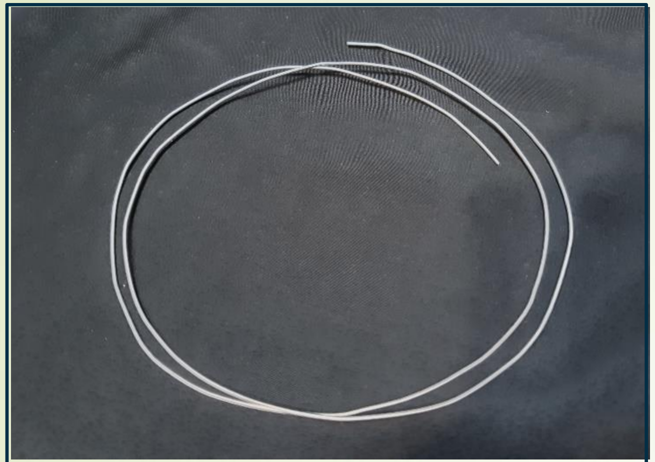
3D laser processing

+ Good quality
- Expensive

3D printing tungsten granules with binder
+ Promising for next-generation devices
+ Cost-efficiency and flexible
- Technology adaptation is required

Development (adaptation) of 3D printing technology based on W granules (filaments) is required

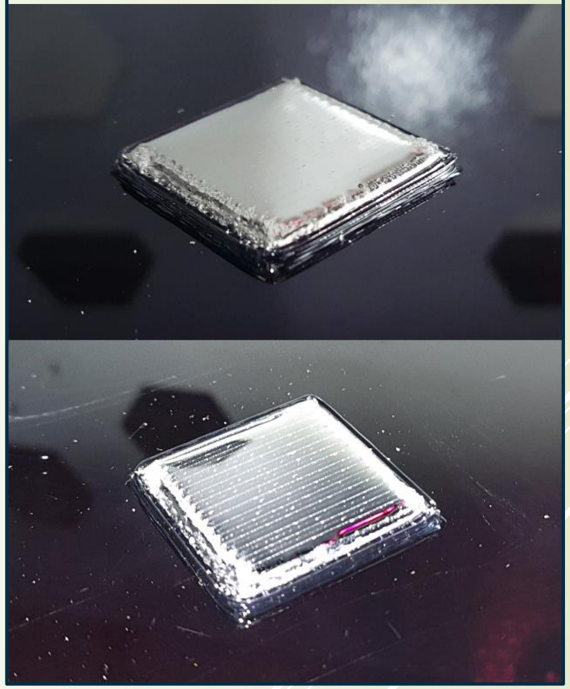
New technology: adaptation of FDM 3D printing for metal alloy filament



Filament made of eutectic alloy No.1

#	% (mass)			Density, g/cm^3	Z_{eff}/A	Radiation length, cm	T_{melt}, ^0C
	Sn	Pb	Bi				
1	**0,160**	**0,320**	**0,520**	**9,7**	**0,424**	**0,629**	**98**
2	-	0,455	0,545	11,23	0,397	0,558	124
3	Pb 100 %			11,34	0,396	0.556	327
4	W 100 %			19,2	0.403	0.351	3422
5	Cu 100 %			8.96	0.457	1.468	1084

Testing of double printing metal over plastic



Prospects for further research on the use of low-temperature eutectic alloys

Absorber prototype

FDM-metal-printing

+

- + Low metal melting point does not damage plastic
- + Homogeneous distribution inside the absorber
- + Production of layers from different materials in one technological process
- + No air entrapments

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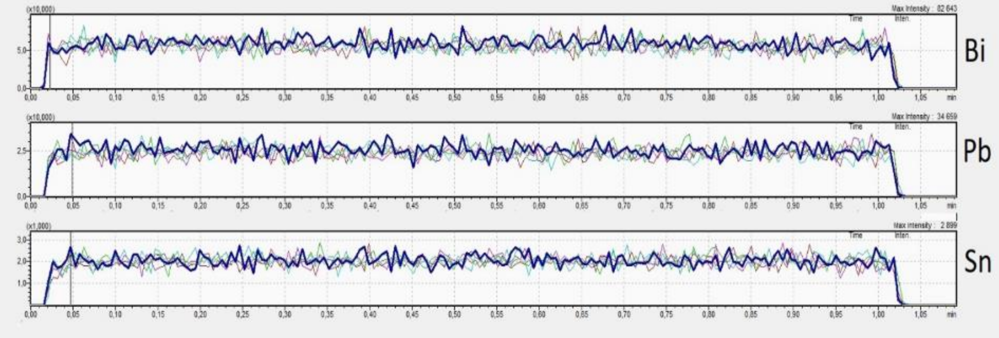
- - No studies of alloy reaction to radiation exposure
- - Difficulty creating objects with complex geometry.
- - New technology - equipment modification

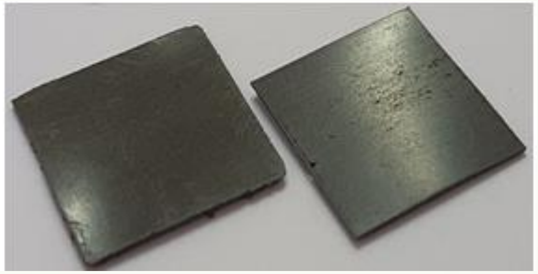


Measuring homogeneity of element distribution in an alloy

Absorber creation technologies: 3D printing based on tungsten powder

Fused Deposition Modeling (FDM)

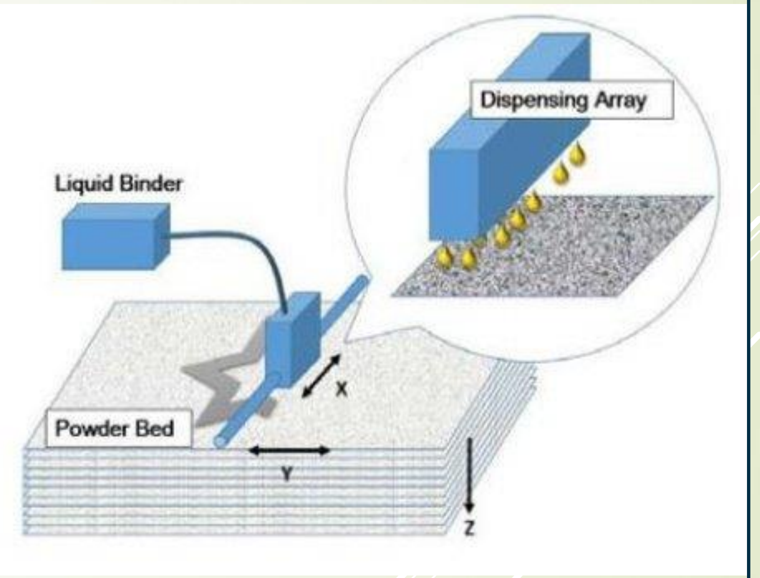
Parameters / Raw material	Filler to binder volumes ratio (%, vol)	Estimated material density, g/cm^3	Practical material density, g/cm^3	Product density using FDM technology, g/cm^3	Estimated Z-effective of material
Commercially available analogue Filament (W+PLA)	**40 to 60**	**8,6**	**7,8**	**6.8**	**35.4**
ISMA experiment results (W+TPU)	**45 to 55**	**9,3**	**8,3**	**7,5**	**38.9**



- Not high density compared to the absorber materials used
- Insufficient homogeneity of material in the product
- Insufficient geometric accuracy
- Low radiation resistance of plastics
- Filament is porous, fragile, with heterogeneous structure

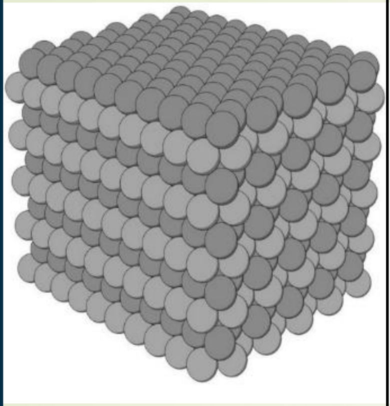
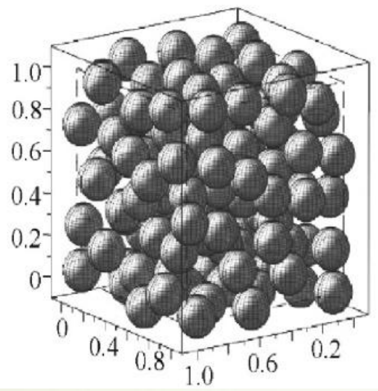
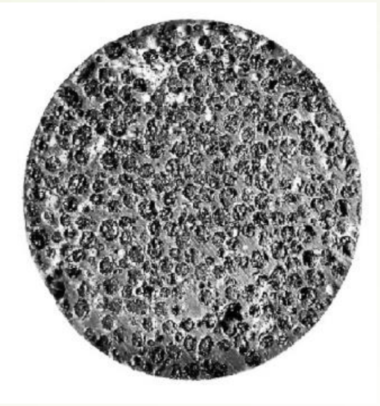
Metal Binder Jetting (MBJ)

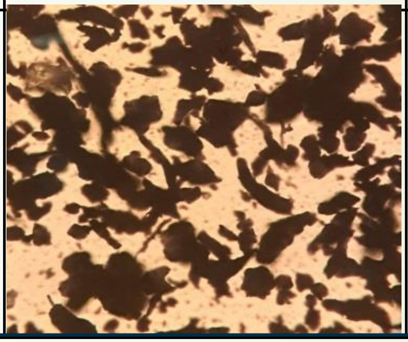
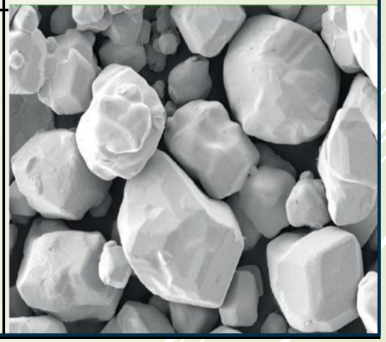
Research is currently underway

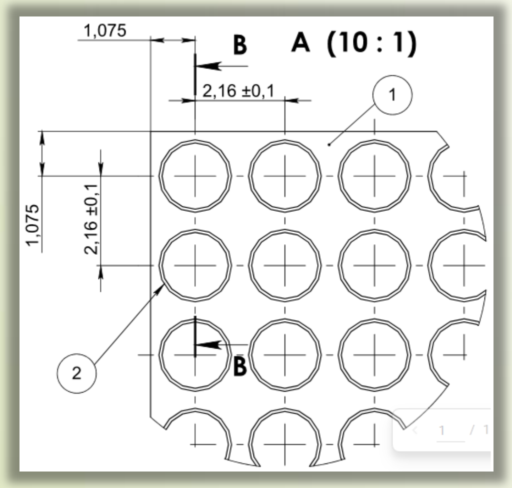


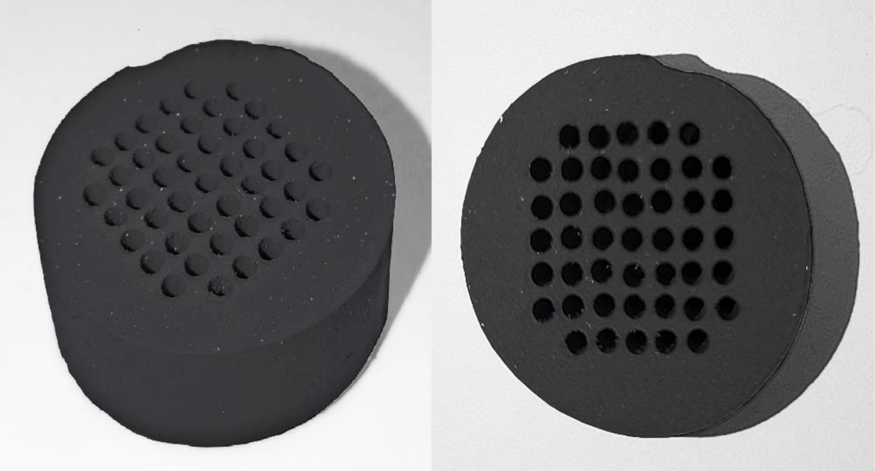
+ High density (up to **10,5 g/cm^3**)
+ Homogeneity of Z_{eff} in volume
+ High accuracy, surface quality
+ Any possible geometric shapes

Absorber creation technologies: Tungsten-filled composite molding

		
perfect densest packing (74.05% by volume)	random close-packed system (60% by volume)	real particle distribution in composite material (45% by volume)

Fillers / Parameters	Angular particles (previous work)	Spherical particles (used now)
Particle size, µm	**1-6**	**10-50**
Bulk Density, g/cm^3	**6,3**	**9**
Tap Density, g/cm^3	**8,2**	**11**
Composite Material Density, g/cm^3	**9**	**11,5**
Appearance of tungsten powder particles		





Absorber prototype made by composite molding technology

Tungsten angular powder, % vol.	Radiation-resistant binder, % vol.	Estimated density, g/cm^3	Practical density, g/cm^3
45	55	9,2	**9,0**

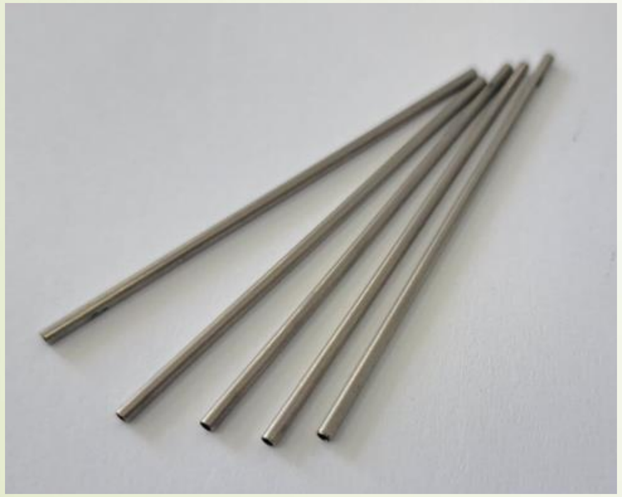
Disadvantages of the recent version of the composite absorber

Low mechanical strength - due to the elastic glue and high density the absorber was compressed like a sponge.
The weight of the absorber 100x100x100 mm is about 10 kg!!!

Potential action:

Mechanical strength:

1. Transition to a rigid binder. Replacing elastic adhesives to epoxy resin
2. Mechanical support of holes by steel capillary tubes



Previous version of the absorber

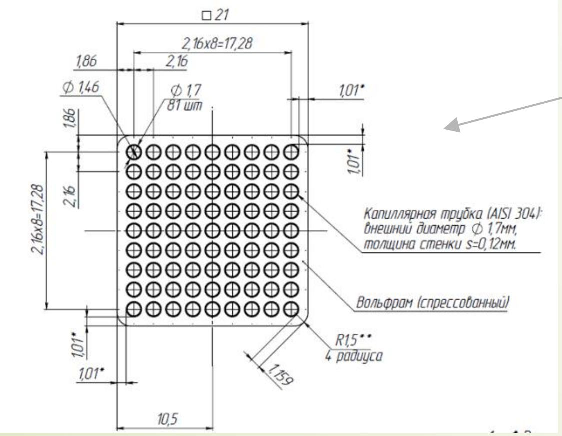
New version

The density of the absorber

Tungsten Powder Selection

tungsten brand	binder	mass of binder , g	mass of tungsten , g	composite density, g/cm³	mass content of tungsten, %	volume content of tungsten, %
ПВ-1 (Ukraine)	polydimethylsiloxane	3,96	51,3	8,8	92,83	42,52
ПВ-1 (Ukraine)	epoxy resin	3,69	45,49	8,6	92,5	41,34
SR-828	**epoxy resin**	**3,69**	**70,00**	**10,55**	**95**	**52,05**
ST-633	**epoxy resin**	**3,69**	**71,50**	**10,64**	**95,1**	**52,59**
C60-1362	epoxy resin	3,69	56,76	9,59	93,5	46,8
C80-601H	epoxy resin	3,69	56,39	9,59	93,5	46,8

Material samples for density measurement



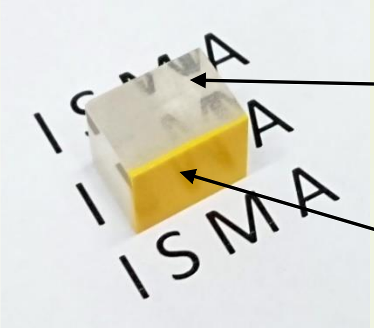
Sample size 20x20x50 mm – in progress.
Expected density 10.5 g/cm³
Binder – epoxy resign
Capillary tube outside dia 1.7mm, inside dia 1.46mm (s=0.12mm)
Use of material compaction technologies to ensure minimum micropores in absorber

SR-828 powders – provides absorber density of around 10.5 g/cm³

3D-Printing technology application

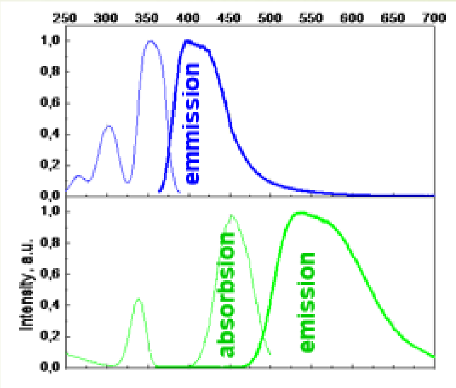
What could be 3d-printed:

1. Detector prototypes for laboratories and R&D groups;
2. Scintillation elements with complex geometry (high granularity volume 3D detectors for neutrino physics);
3. Scintillators for registration of alpha- and beta-particles and gamma-photons;
4. Thin layer scintillation films for X-ray imaging screen;
5. Combination of scintillators: inorganic/organic materials with overlapping emission and absorption spectrum.

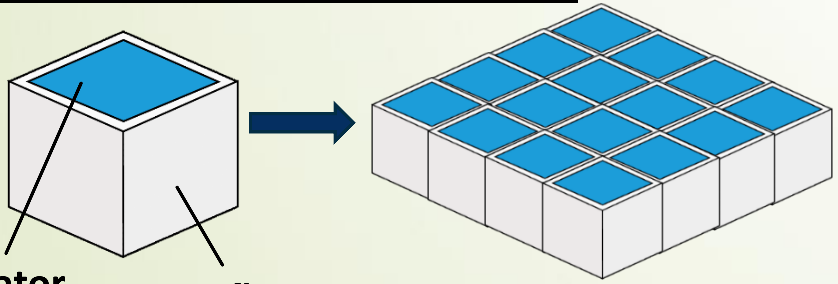


3d-printed combined scintillator

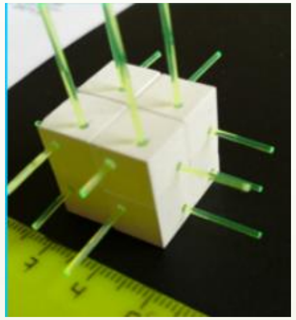
Overlap of the emission spectrum YSO:Ce and absorption spectrum YAG:Ce or YAGG:Ce



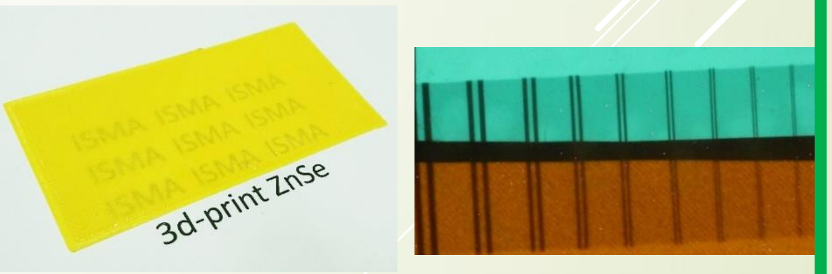
Aim to 3D print simultaneously many optically-independent plastic scintillator volumes



JINST 13 (2018) 02, P02006



Scintillator Array



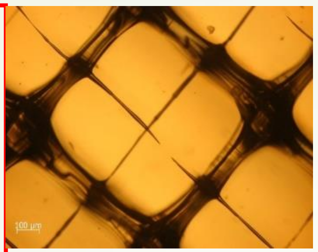
3d-printing of scintillators for x-ray imaging

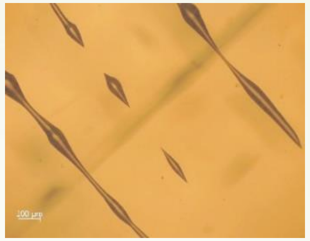
The light transmittance of a 3D-printed plastic scintillator

Problem: Opacity at recommended print settings

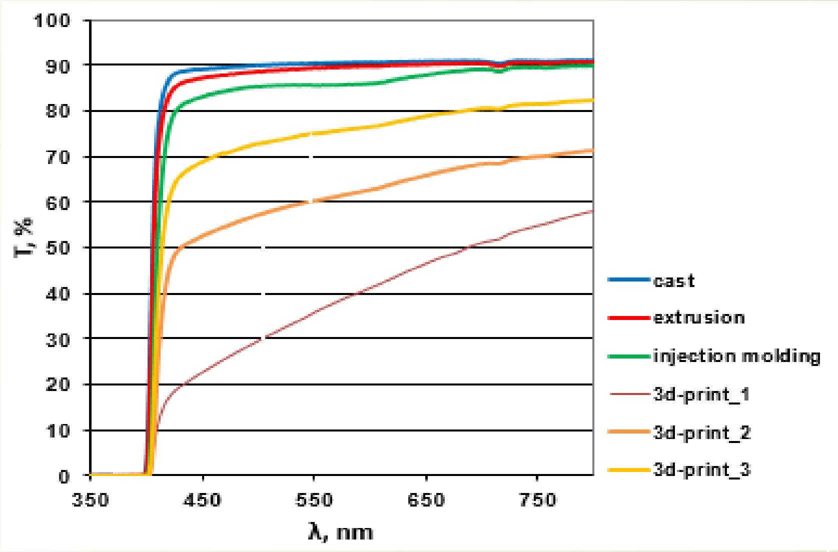
Leading causes of light transmittance degradation:

- Gas formation between layers
- Formation of a crystalline phase in polystyrene





Мікрофотографії 3D-друкованих зразків

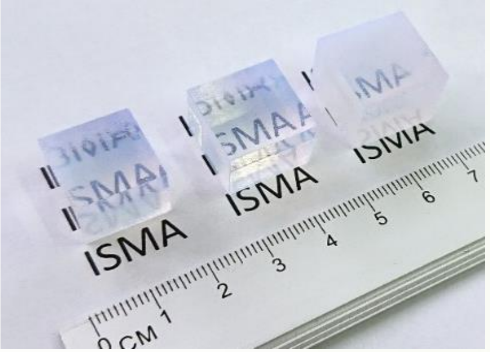


Light transmittance of samples 10 mm x 10 mm x 10 mm

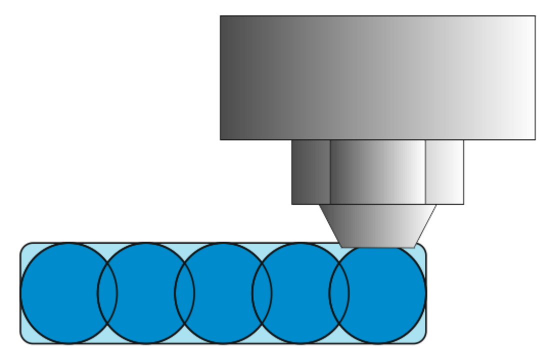
Solution in settings

Optimal mode for 3D printing of transparent elements:

- Increase extrusion temperature
- Increase material flow
- Percentage of overlap of filling of the formed layer: 10-15%
- Working platform temperature 100-110 °C
- Printing speed, 25-35 mm/sec
- Height of the formed layer 0.2 mm
- Without cooling



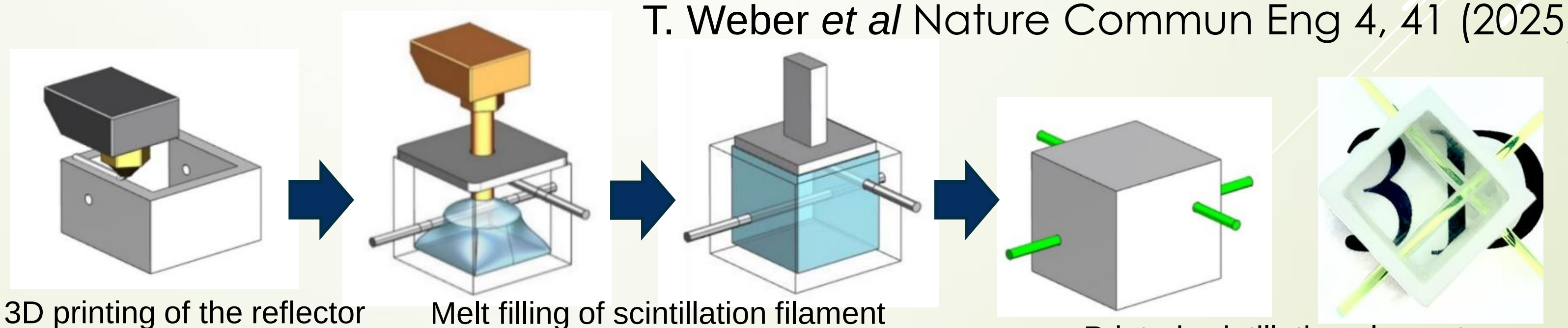
Регулювання прозорості



Schematic representation of 3D printing

Modified 3D printing technology

T. Weber *et al* Nature Commun Eng 4, 41 (2025)

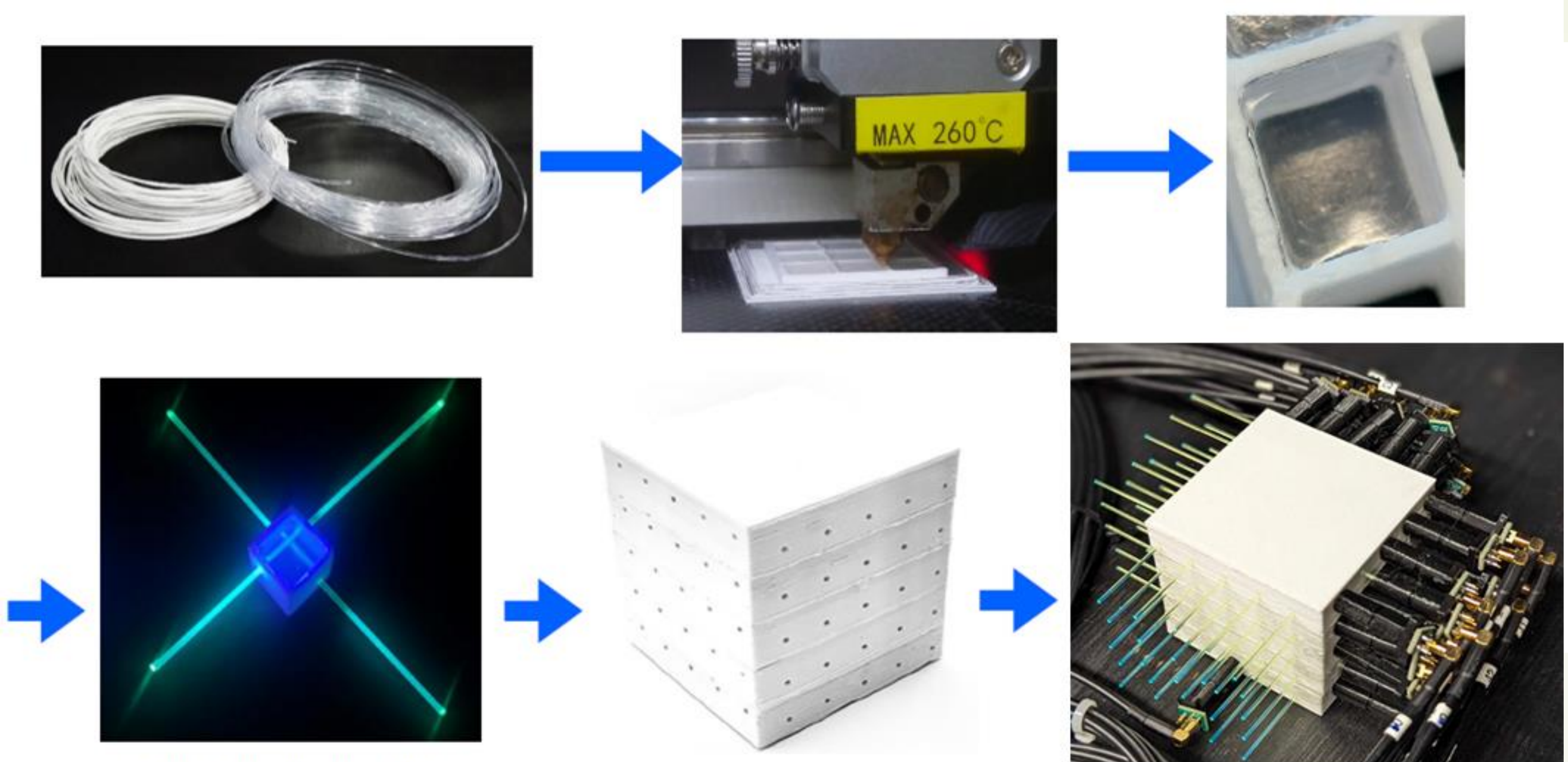


3D printing of the reflector using FDM technology

Melt filling of scintillation filament

Printed scintillation element

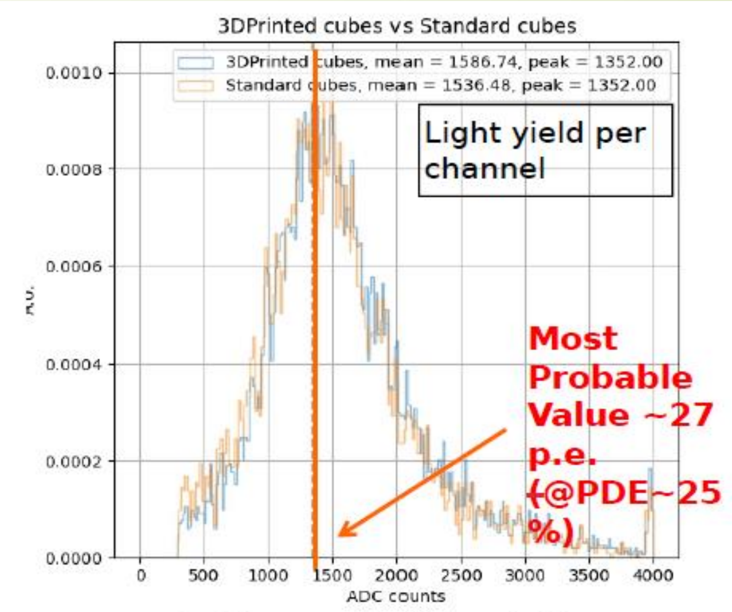
Super-Cube



Single cube with two WLS fiber readouts

Complete 5x5x5 super-cube.

Super-cube measurement



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

Fully 3D printed detector was created and successfully tested with performance acceptable for a particle experiment

Work is ongoing…

- improving mechanical properties of the reflector
- reducing the thickness of the reflector

Conclusion and Future Plans

Thus, our research opens up the possibility of creating a special unified tool based on all the 3D printing technologies considered, based on which it is possible to produce all three layers of a heterogeneous detector in a single technological cycle.

What is next?

1) Continued development and research of the absorber element for use by additive technologies. The results shown in this study indicate the promise of these materials for use in detectors.
2) Development of neutron-sensitive scintillation filaments and 3D-printing of the scintillators, investigation of their characteristics.
3) Development and investigation of the 3D-printing radiation-resistant scintillators for High-energy physics.

Thank you for your attention!

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Conclusions

1) Several technologies for creating absorbers using additive technologies are proposed.
2) Filaments for FDM technology have been developed and studied:
   - We proposed to create a filament based on the eutectic metal alloy Sn+Pb+Bi, with a density of 9.7g/cm^3, and a melting point of only 98 ^{0}C, which can be used with simultaneous printing of a plastic part of the detector;
   - Created filament, in which Tungsten powder is introduced into polymer bases like TPU, PLA, etc. Future work is required;
   - We proposed a composite molding technology for absorber production consisting of Tungsten spherical particles. The density of these materials was around 10.5 g/cm^3.
3) Promising technologies for further research and use for today are Fused Deposition Modeling by eutectic metal alloys, Composite Molding Technology, and Metal Binder Jetting.

Thank you for your attention!

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