3D inkjet printing of functional detector structures

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Additive manufacturing potential

High spatial resolution (≈hundreds of μm) multi-material fabrication by 3D printing could allow intricate structures for gaseous detectors. Insulating and conductive printed plastics could enable the fabrication of fully 3D printed radiation detectors.

Powering and readout electrodes

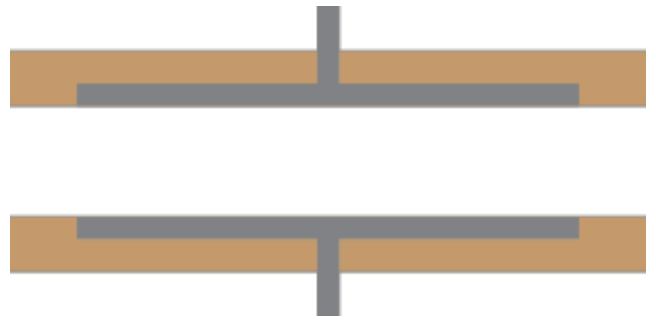
Feedthroughs

Embedded resistors

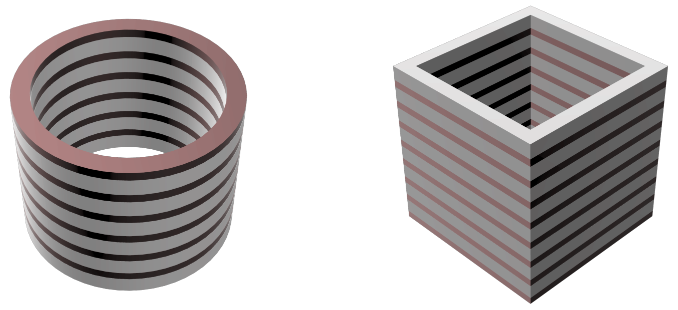
Capacitively coupled pads

Spherical readout structures

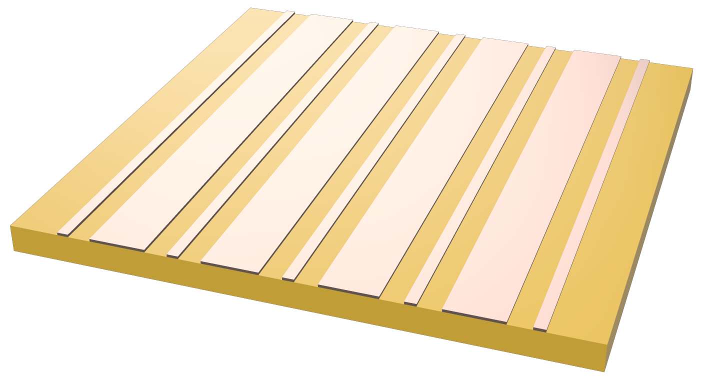
Gaseous radiation detectors and components



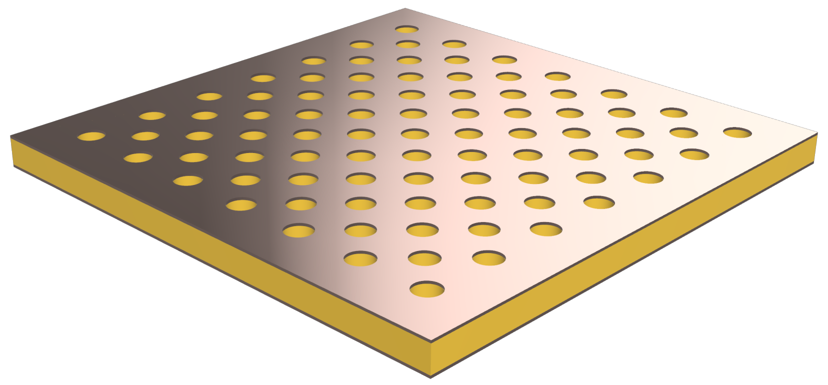
Ionisation chamber



Arbitrary field shaper geometries



MicroStrip Gaseous Counter



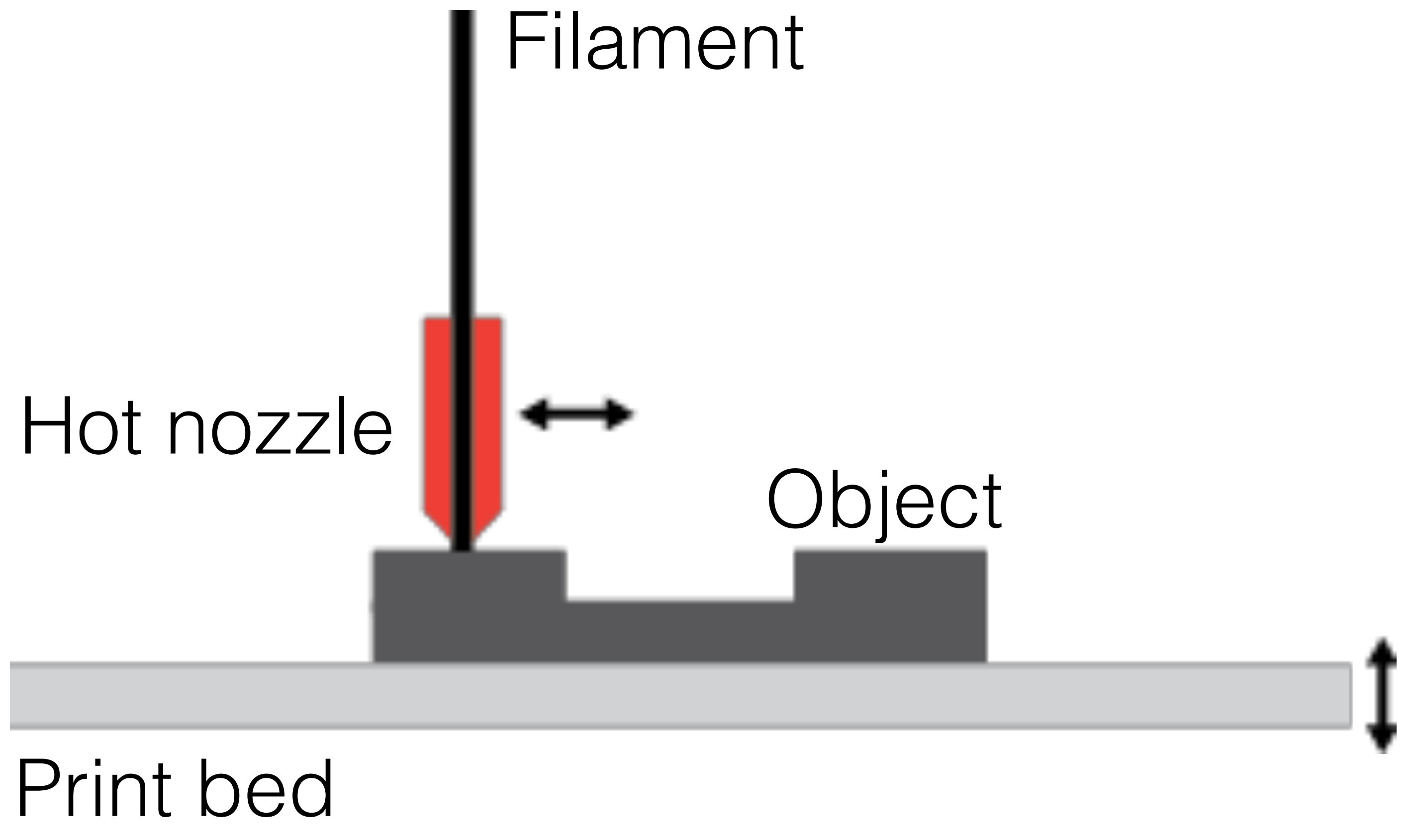
Thick Gaseous Electron Multiplier (**THGEM**)

Schematics not drawn to scale

Additive manufacturing techniques

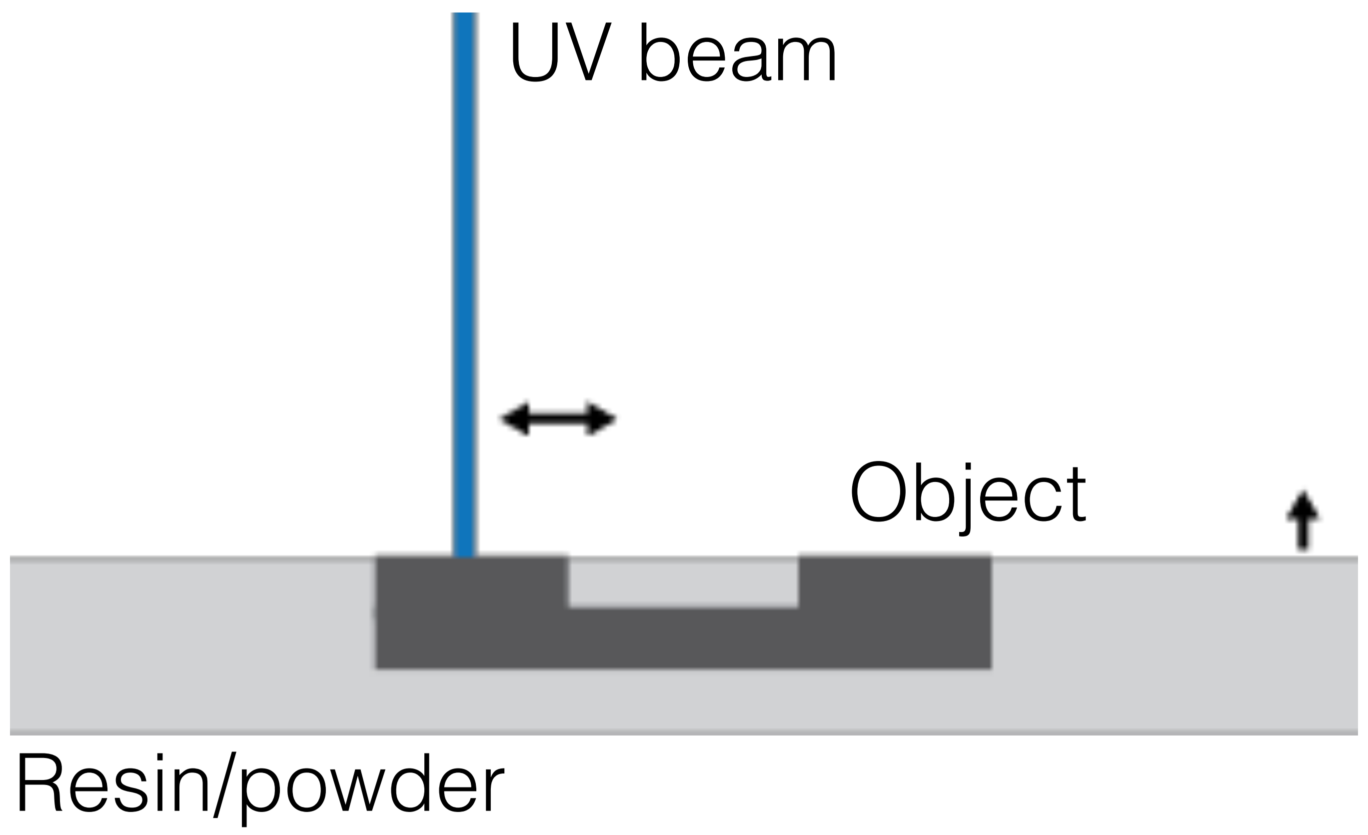
Available 3D printing techniques offer a wide range of spatial resolution and material capabilities. Multi-material fabrication including electrically conductive and insulating materials is crucial for fabricating functional structures.

Fused deposition modeling (FDM)



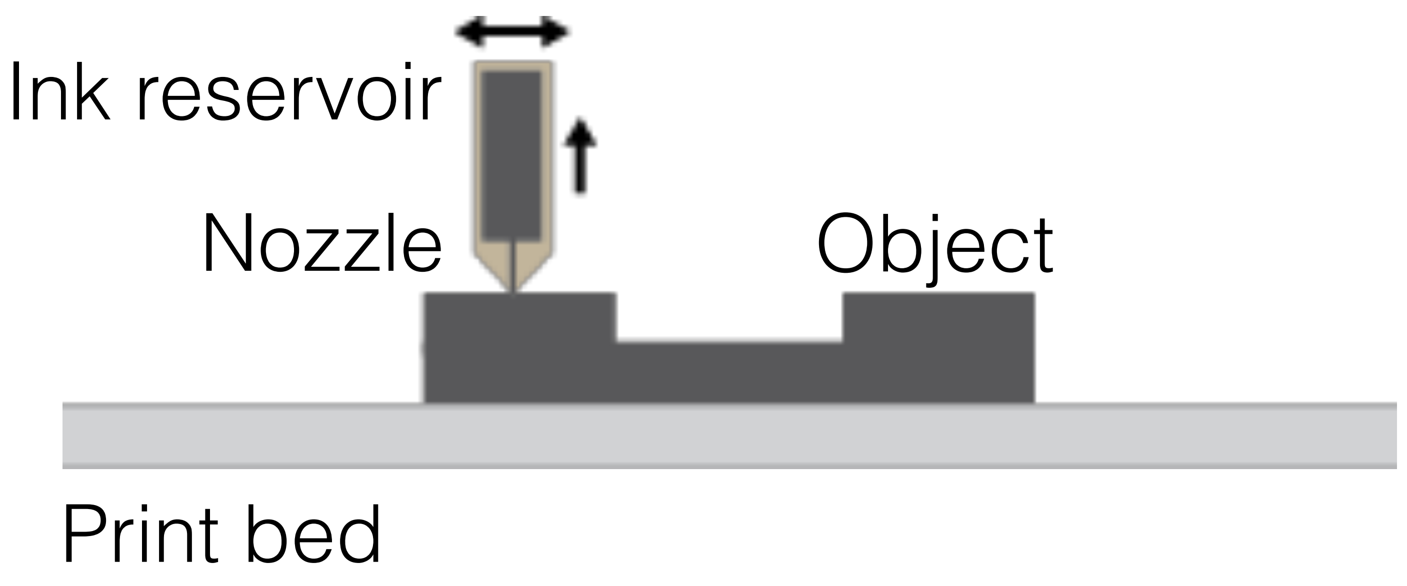
- Hundreds of micrometer resolution
- Conductive and insulating material available

Stereolithography



- Tens of micrometer resolution
- Insulating material only

Inkjet printing



- Tens of micrometer resolution
- Conductive and insulating material available

Schematics not drawn to scale

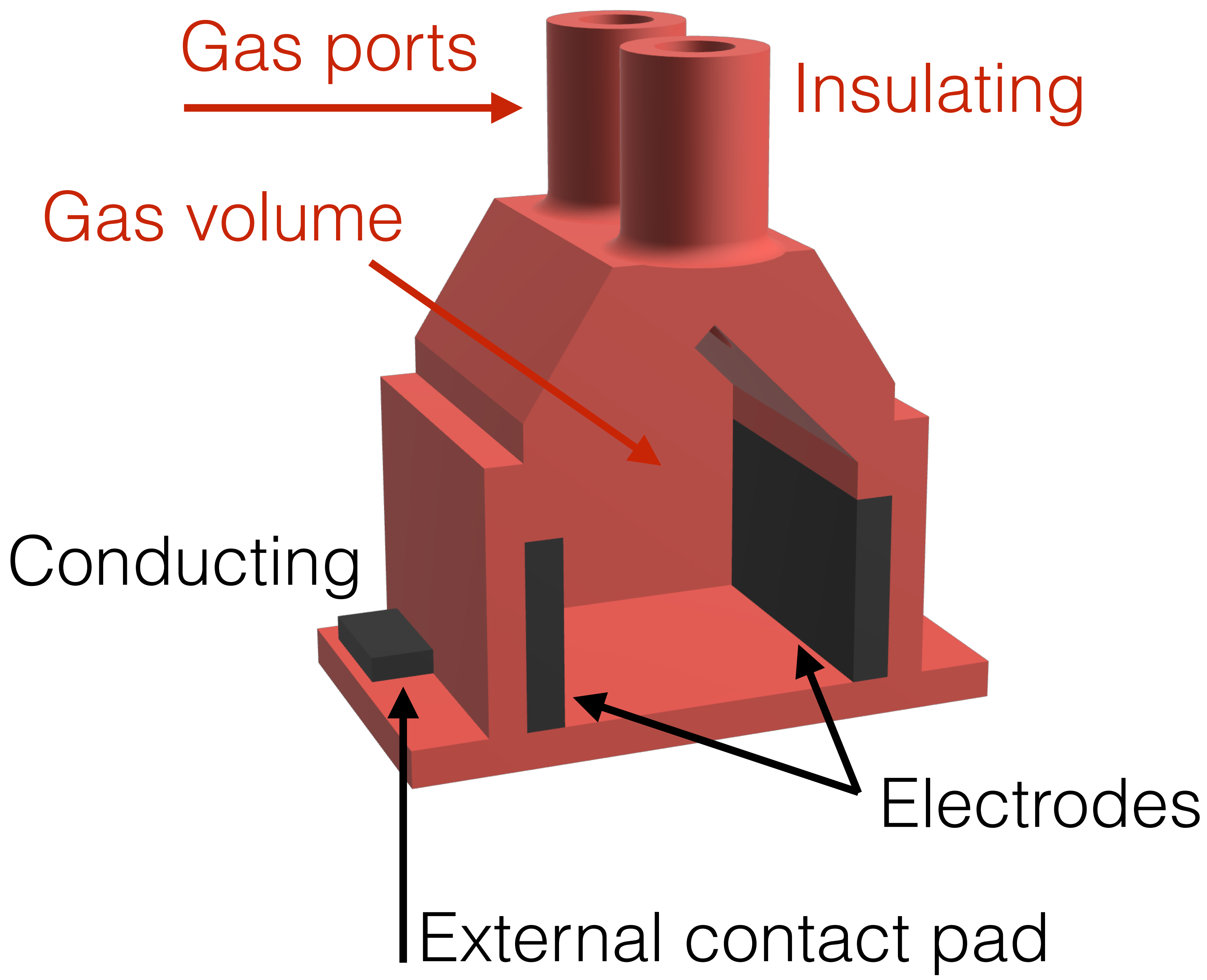
Fused deposition modeling

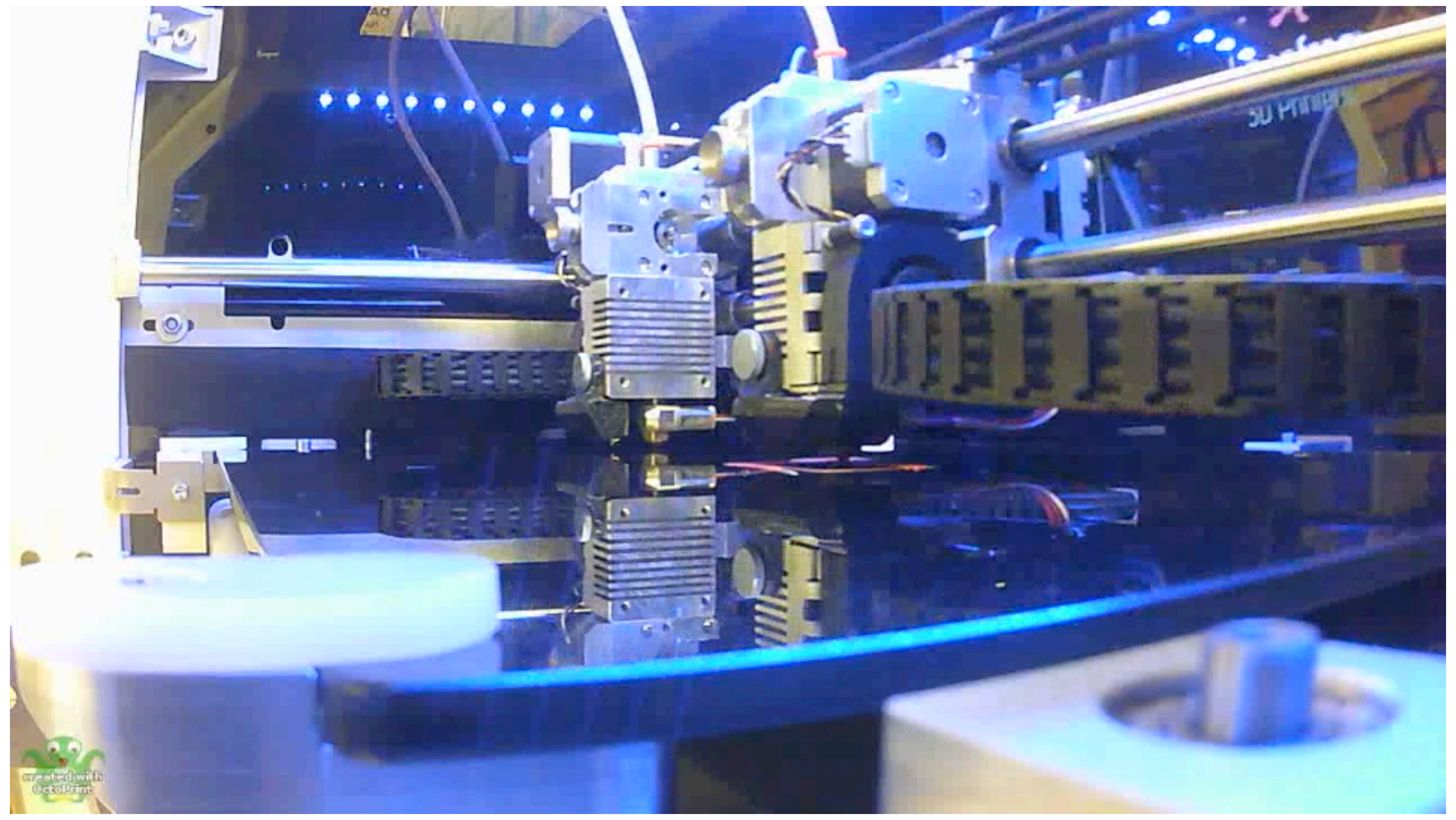
3D printed ionisation chamber and strip anode

Ionisation chamber

Gas volume with embedded plate electrodes with 2.4 cm separation was printed. Conductive structures were used to electrically contact electrodes from outside of the gas volume.

CAD model → **3D printing** → **Prototype**

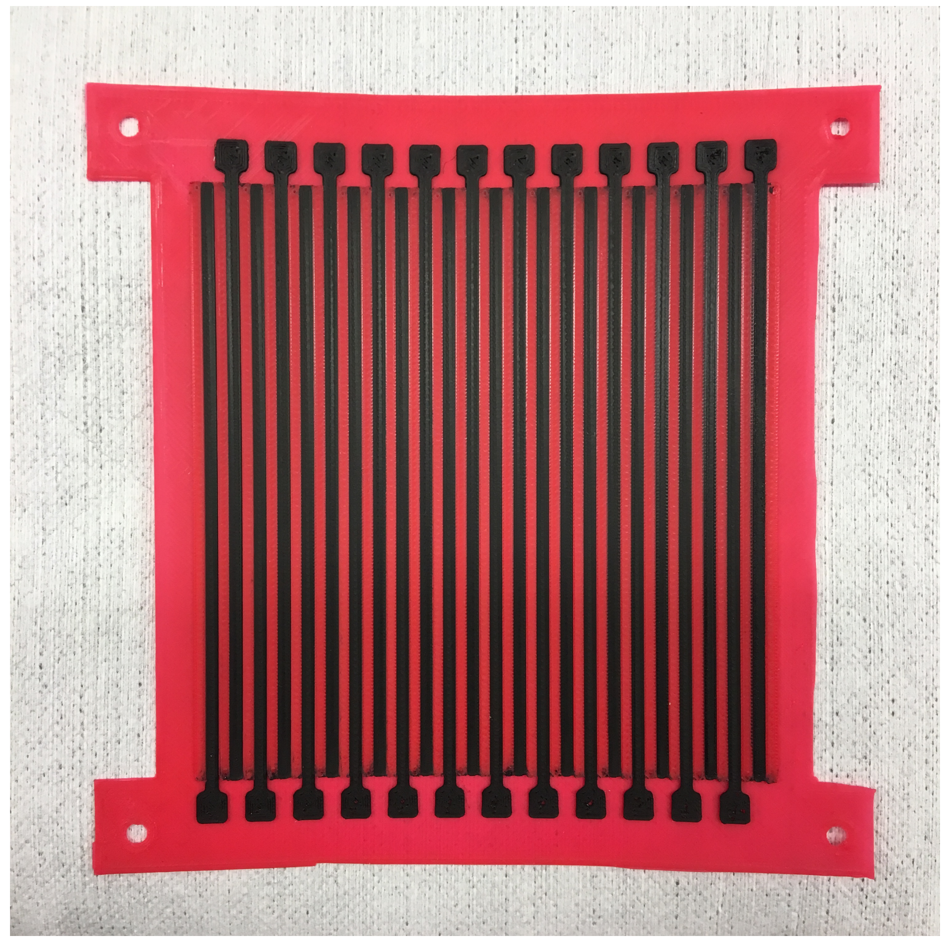




Strip anode

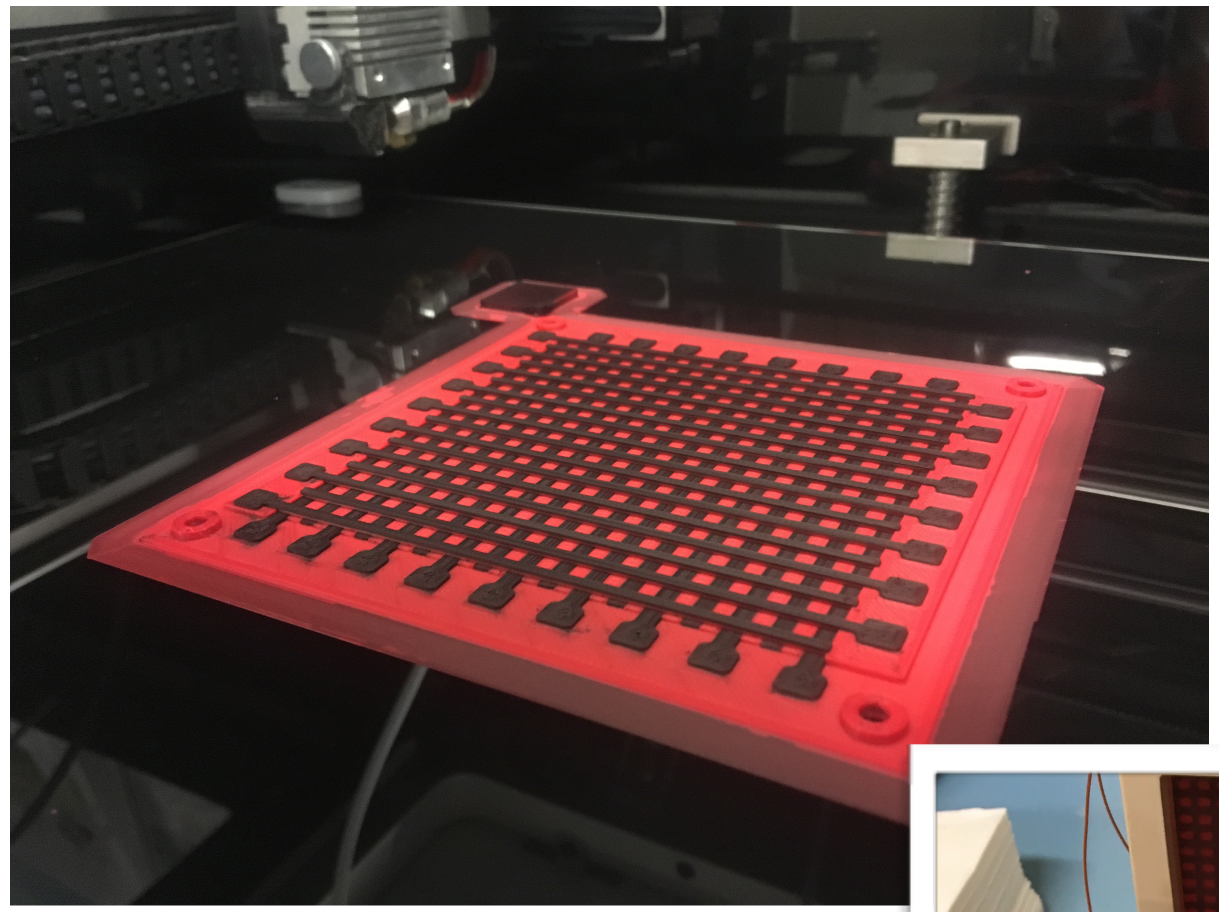
A strip anode with an active area of 10x10 cm^2 was 3D printed with conductive strips of 0.5 mm thickness on an insulating substrate. Electrical contact was made through the structure for easier contacting from the back.

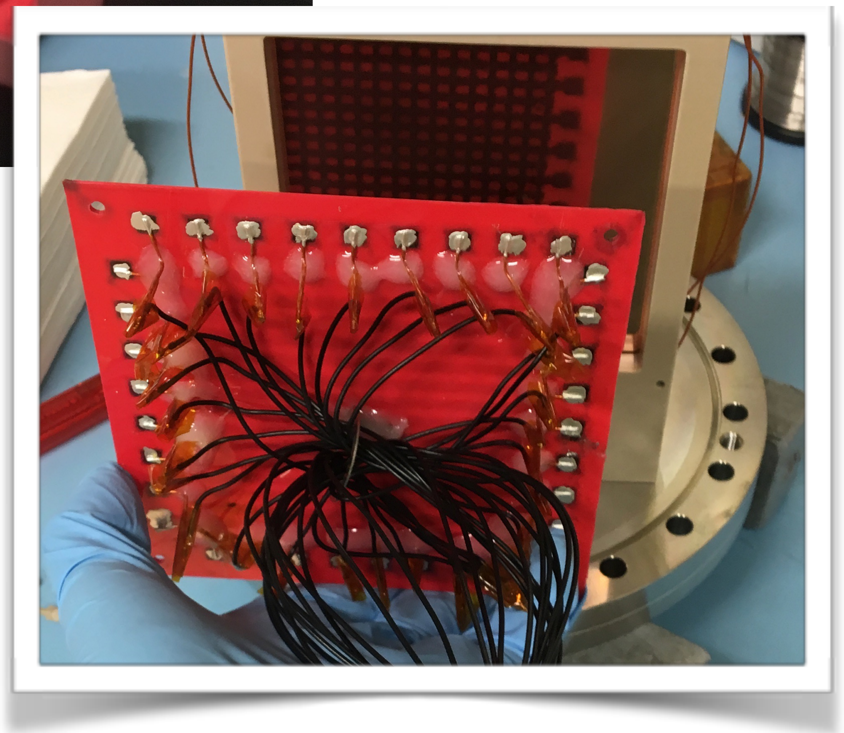
1D strip anode



2 mm strips
Pitch: 4 mm

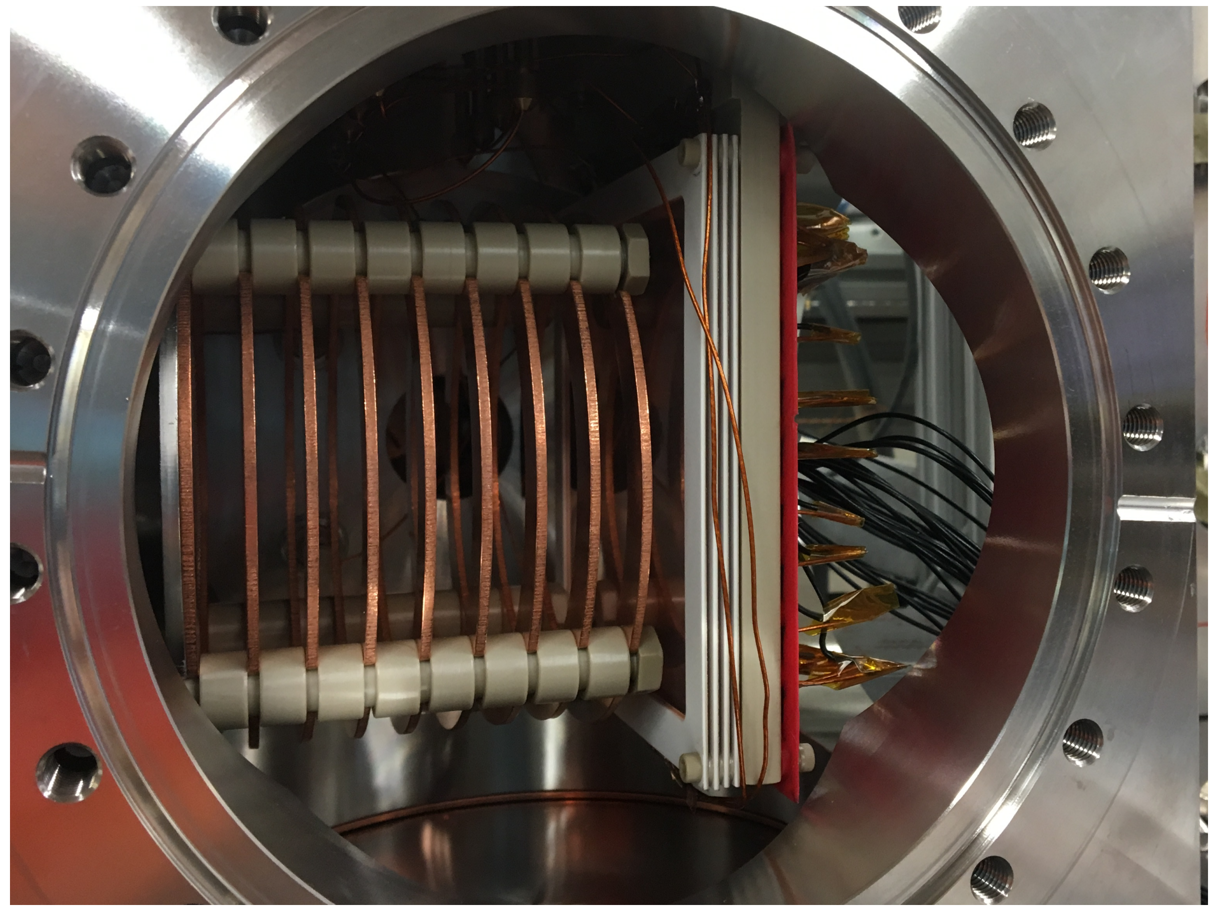
2D strip anode





Bottom: 3 mm strips
Top: 2 mm strips
Pitch: 6 mm

Test in TPC based on Gaseous Electron Multiplier (GEM)



Below triple-GEM stack with
1 cm induction gap

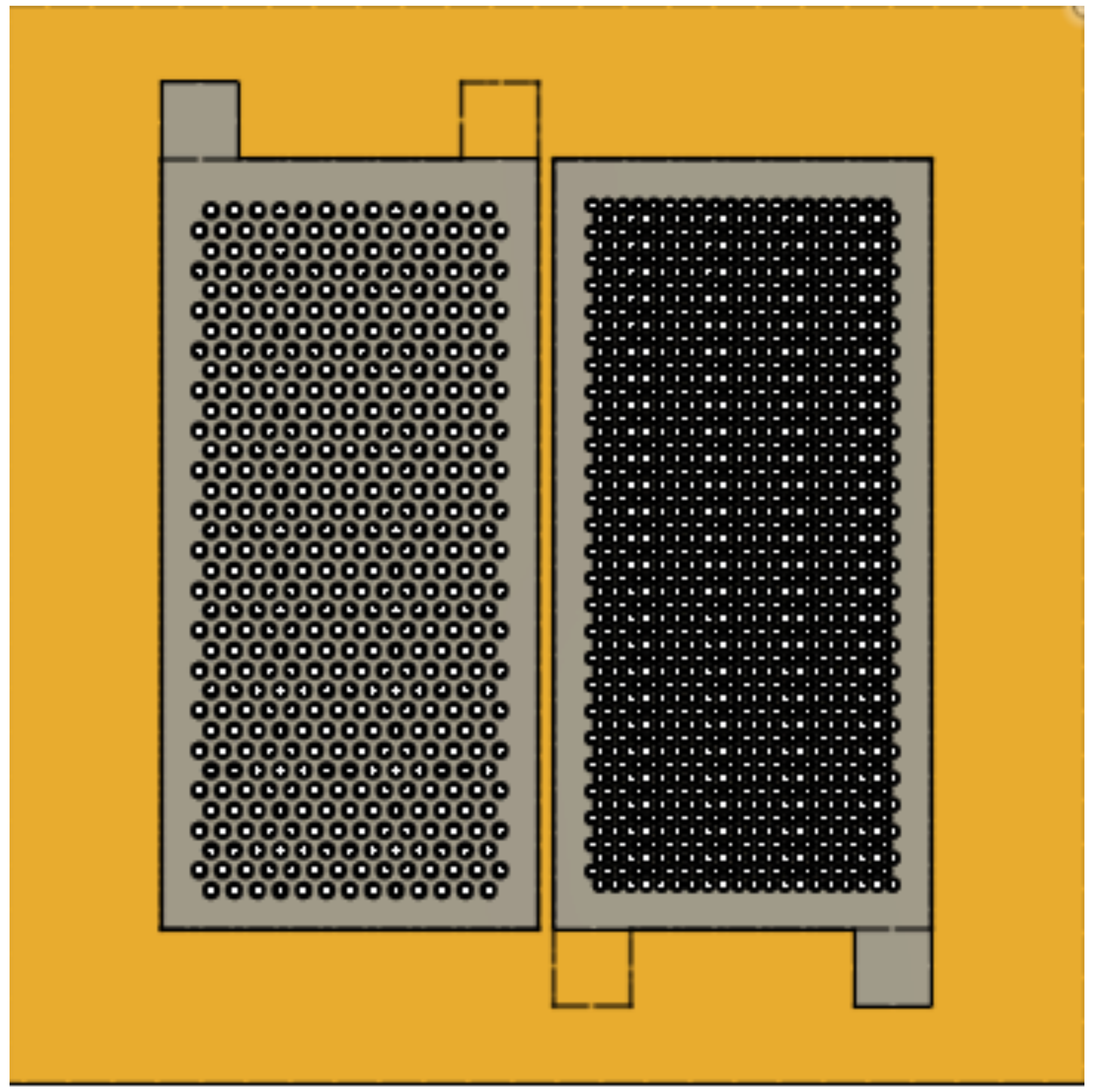
Inkjet printing

3D printed THGEM structure

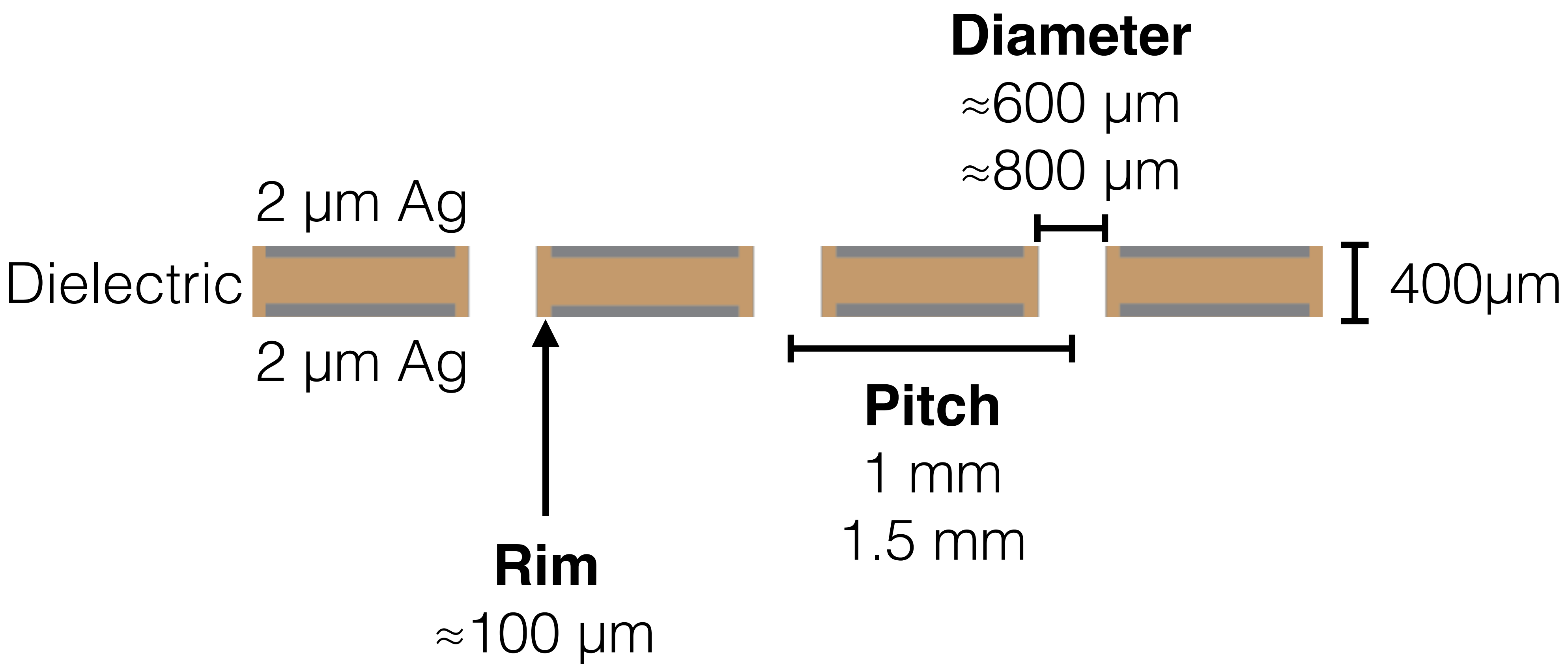
3D printed THGEM

A Thick Gaseous Electron Multiplier (THGEM) detector prototype was 3D printed with dual-material inkjet technology. The device features two sectors with different hole diameter and pitches and an active area of approximately 5x5 cm^2.

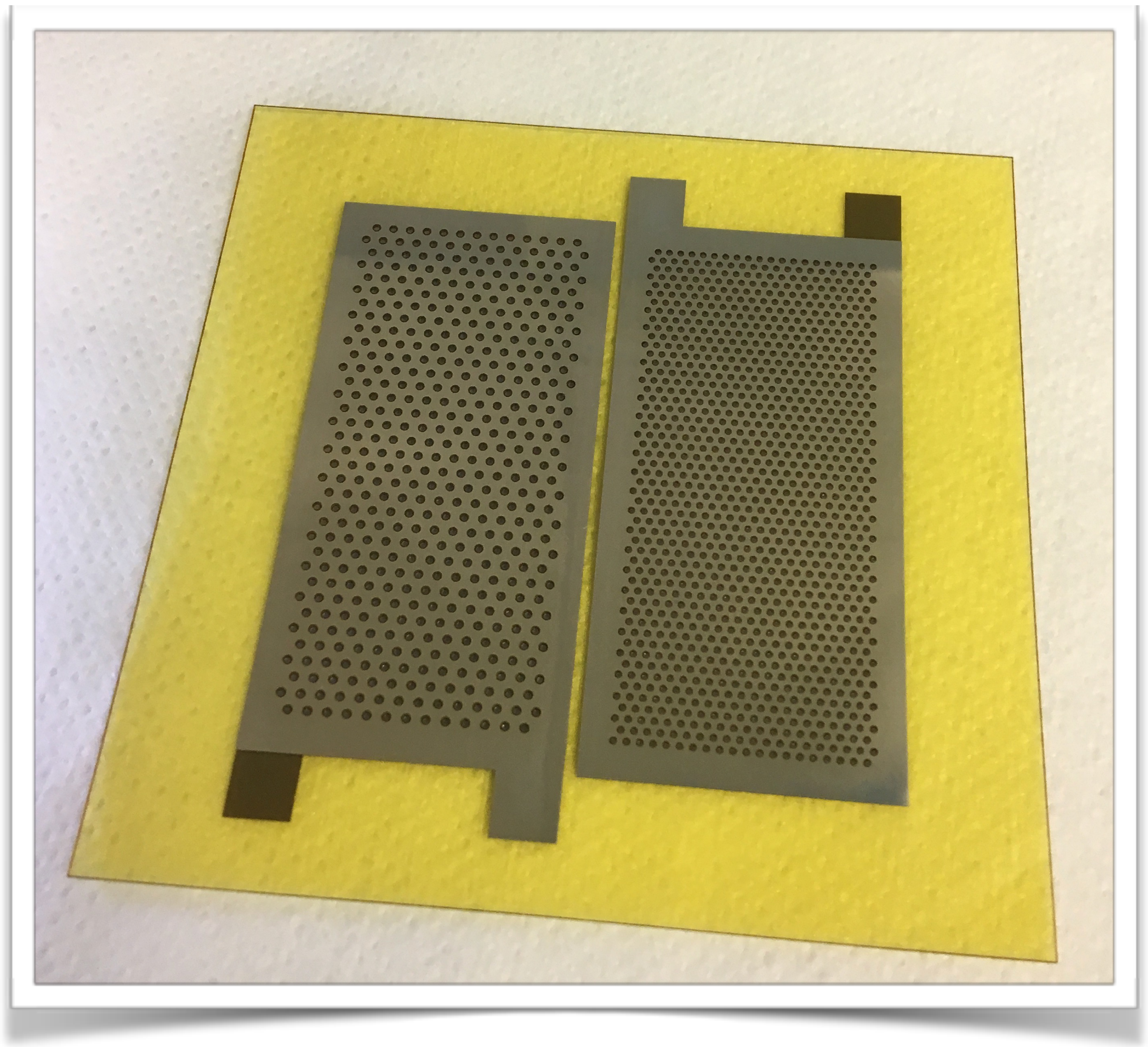
CAD design



Cross-section



3D printed THGEM



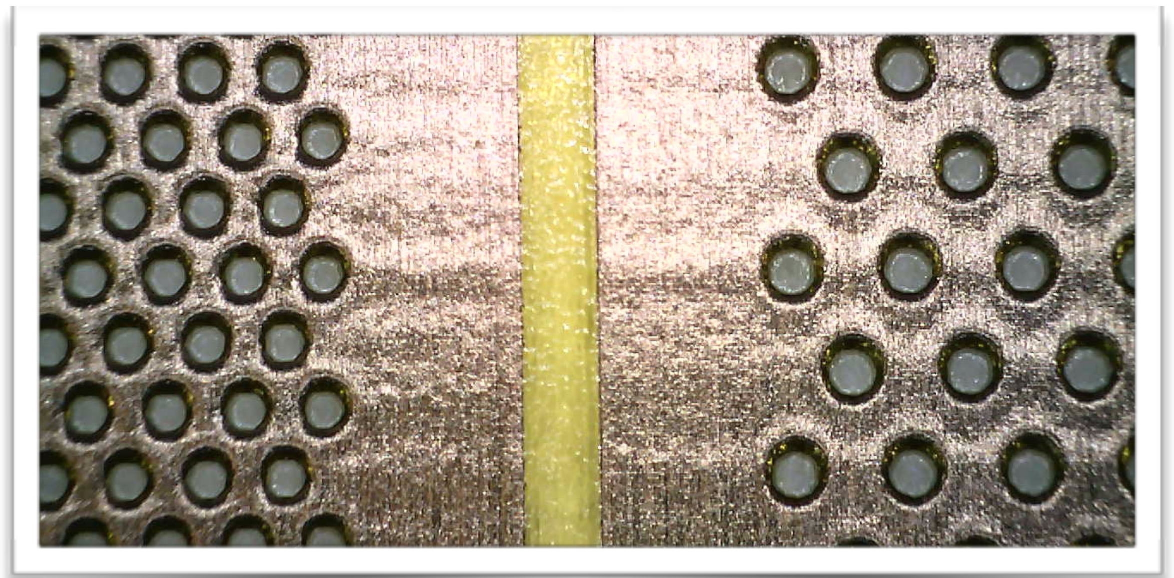
Schematics not drawn to scale

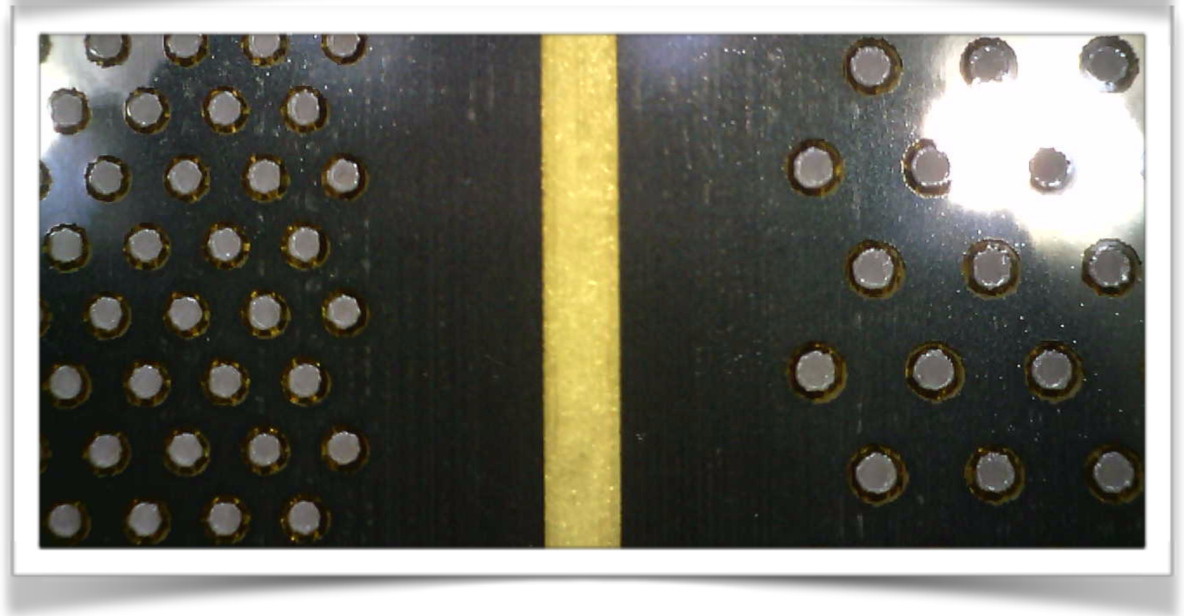
3D printed THGEM hole quality

The quality of the holes of the 3D printed prototype was different for the top and bottom sides. Additionally, varying misalignment of the holes in the conductive and insulating materials across the surface was observed.

Top / bottom difference

Top side

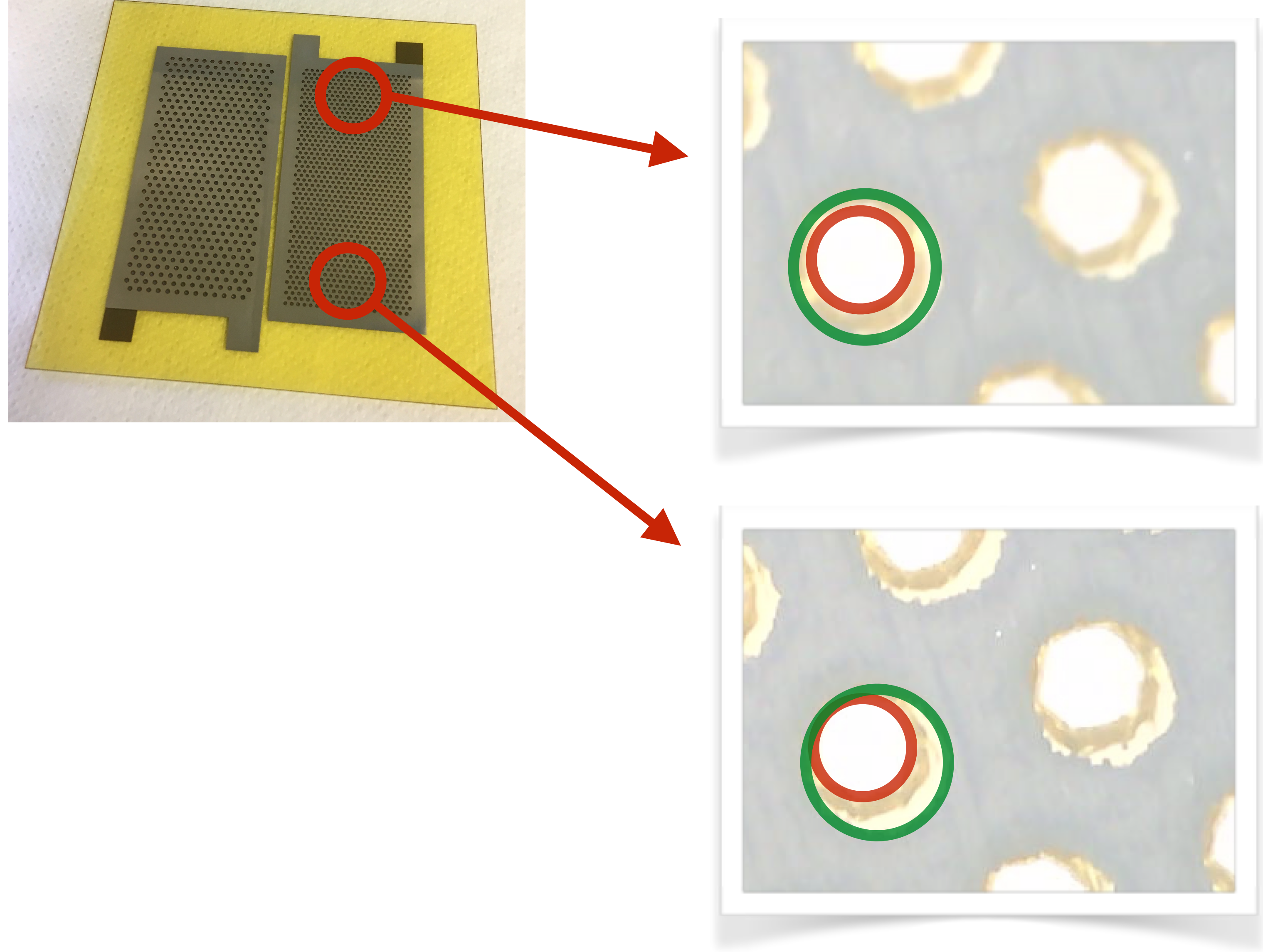




Bottom side

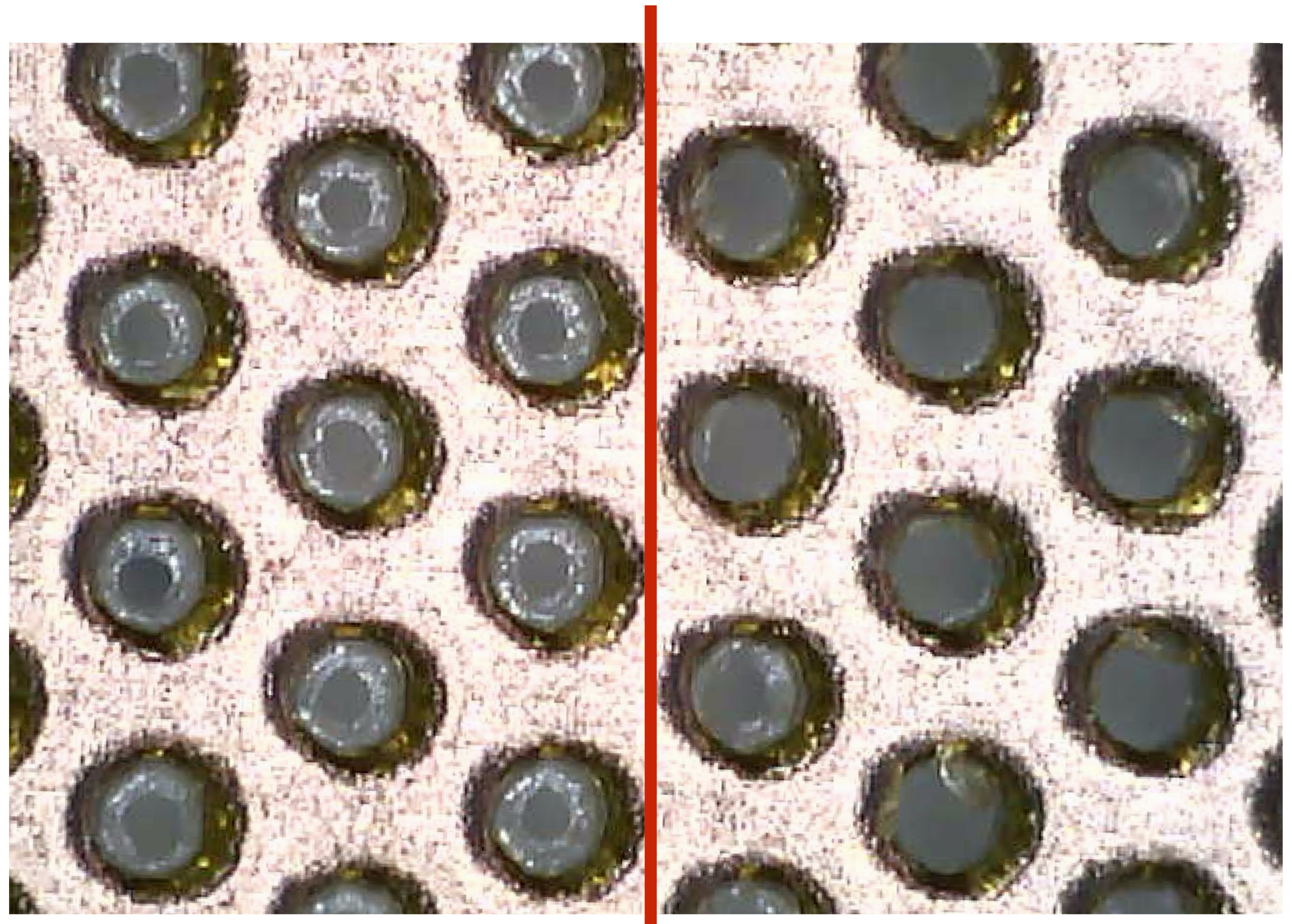
Misalignment

Minor misalignment



Stronger misalignment

Dielelectric residue in holes



Uncleaned | Cleaned

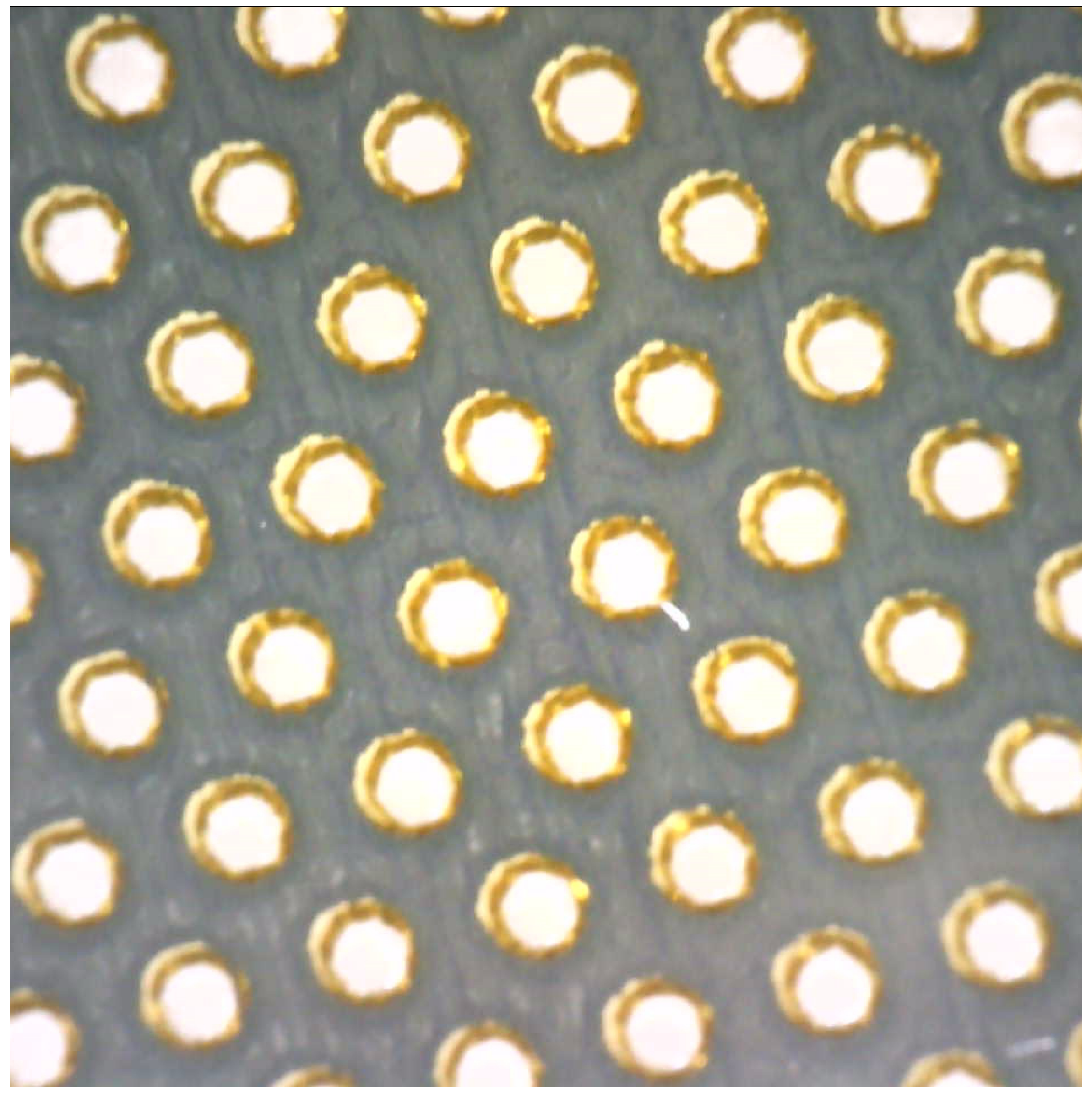
Bottom view

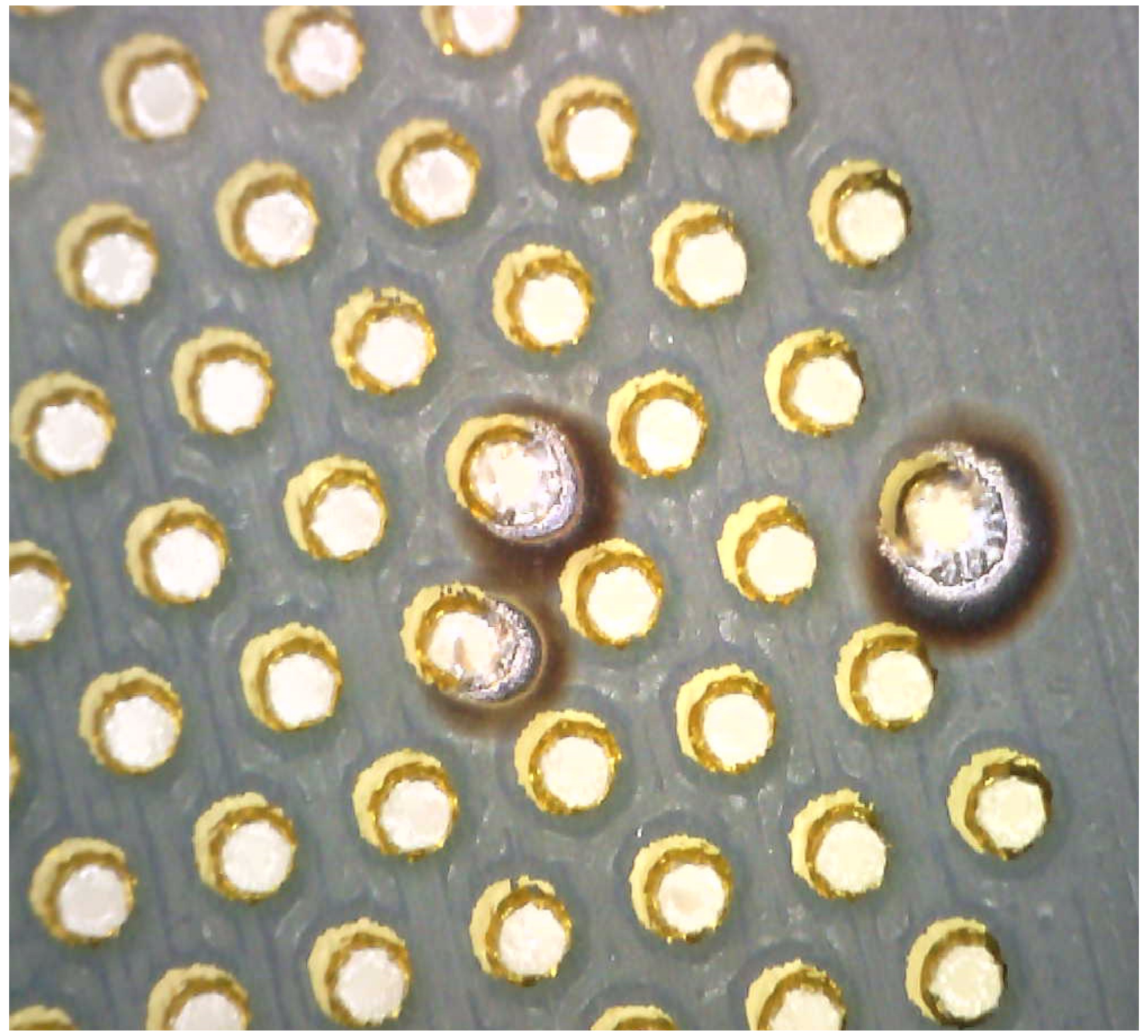
3D printed THGEM electrical testing

The two conductive electrodes are electrically separated with high impedance.
Applying excessive voltage differences between the two electrodes leads to destructive discharges which can have permanent effects.

<1 Ω across electrode	>100 GΩ between layers
≈ 110 pF capacitance	1600 V in air

Effect of discharges



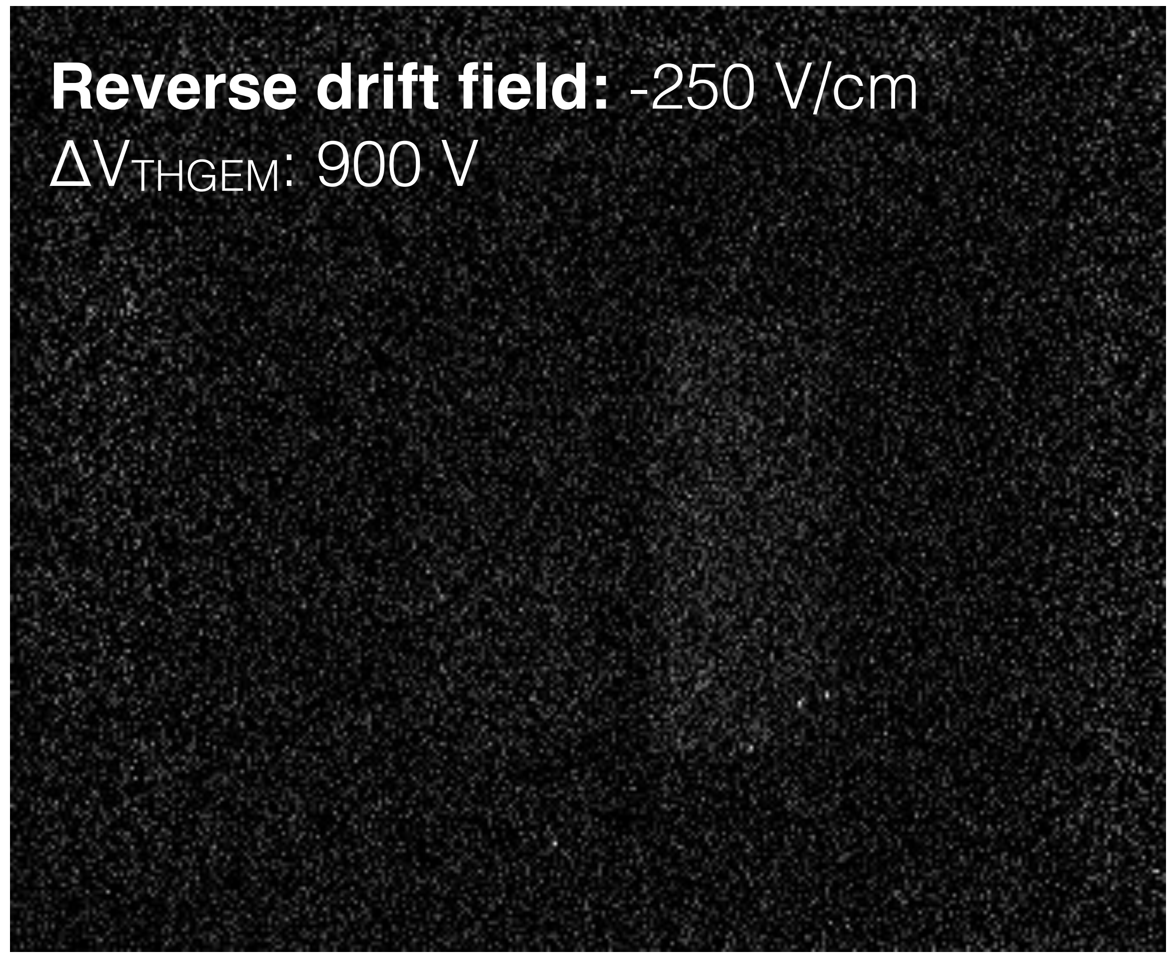


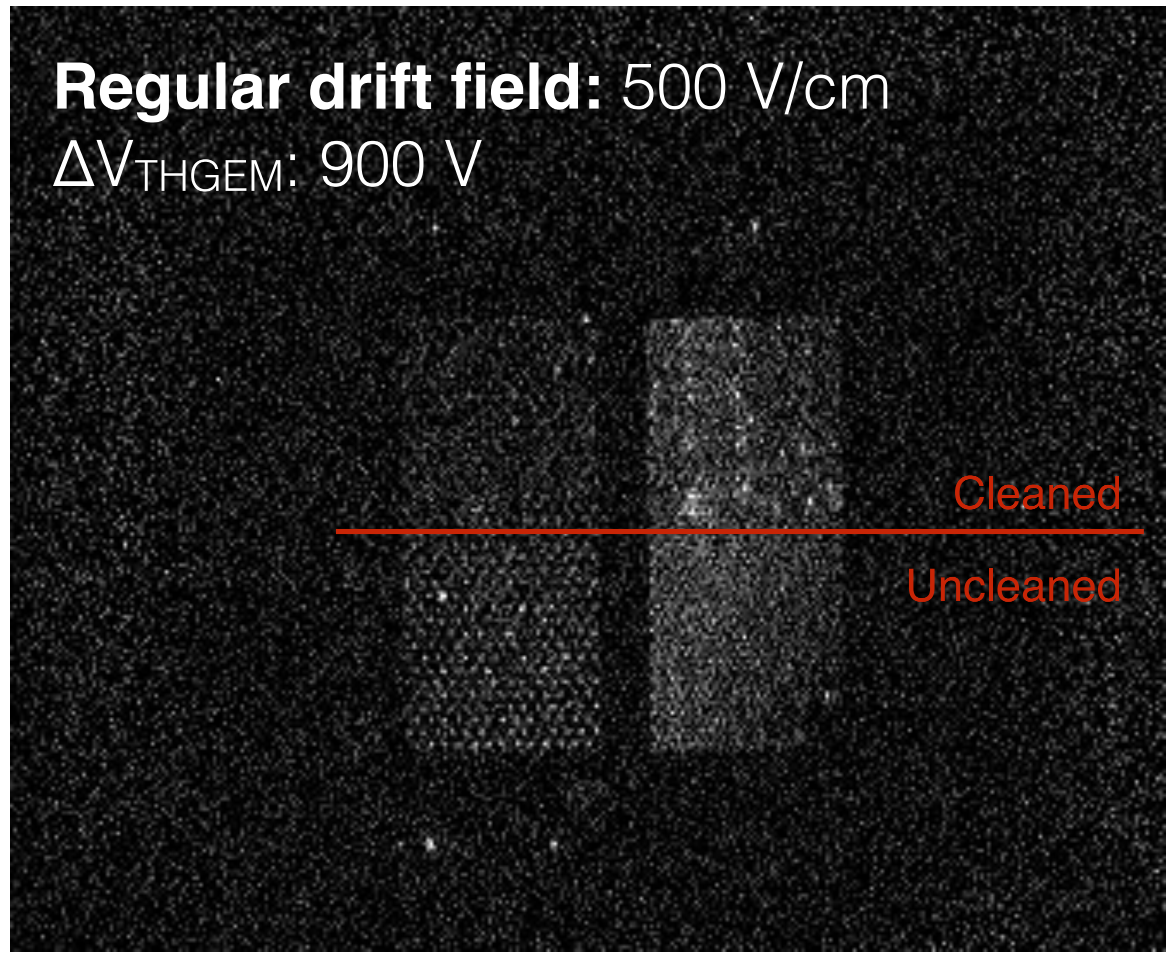
Discharges at ≈1600 V in air localised at misaligned holes.
Some had destructive effect leading to leakage current.

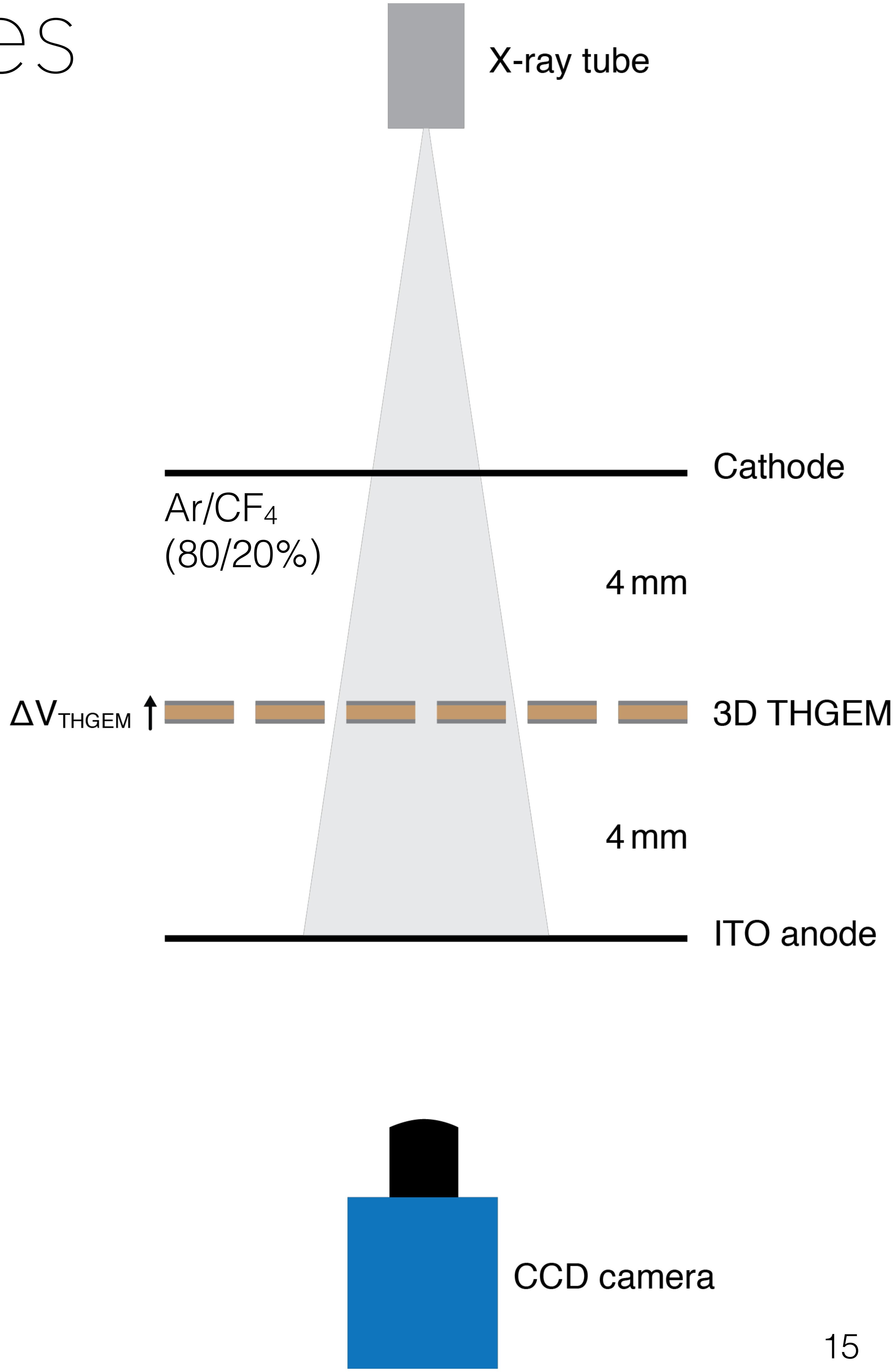
3D printed THGEM optical images

Reading out scintillation light produced in electron avalanche multiplication in the holes of the 3D printed THGEM, an image of the THGEM under X-ray irradiation can be recorded.

If using a reverse drift field in the conversion region (no electrons collected into THGEM), only weak primary scintillation is visible. If applying a forward drift field in the conversion region, primary electrons are collected into the THGEM and undergo avalanche multiplication leading to increased scintillation light intensity.

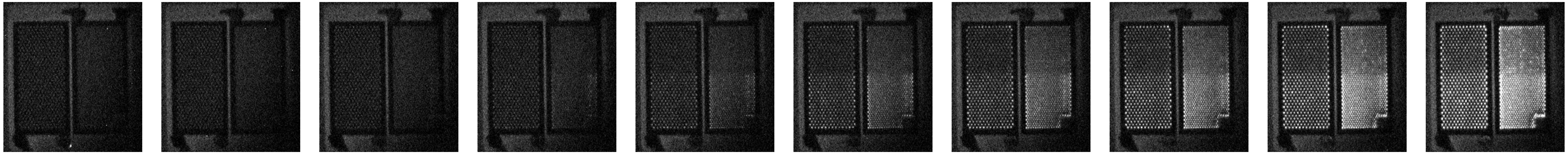






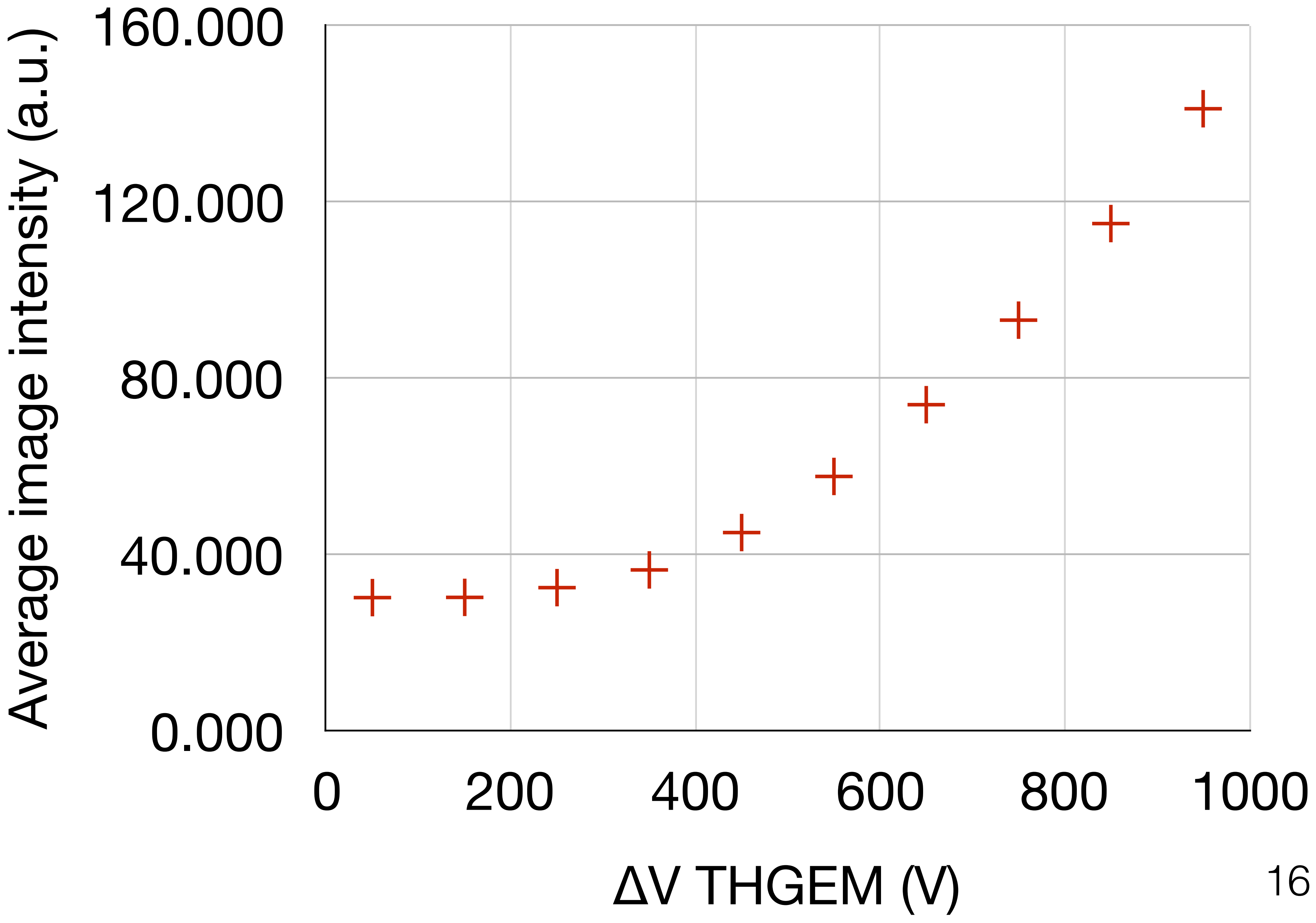
Schematics not drawn to scale

3D printed THGEM optical images



50 V	**150 V**	**250 V**	**350 V**	**450 V**	**550 V**	**650 V**	**750 V**	**850 V**	**950 V**
ΔV_{THGEM}	ΔV_{THGEM}	ΔV_{THGEM}	ΔV_{THGEM}	ΔV_{THGEM}	ΔV_{THGEM}	ΔV_{THGEM}	ΔV_{THGEM}	ΔV_{THGEM}	ΔV_{THGEM}

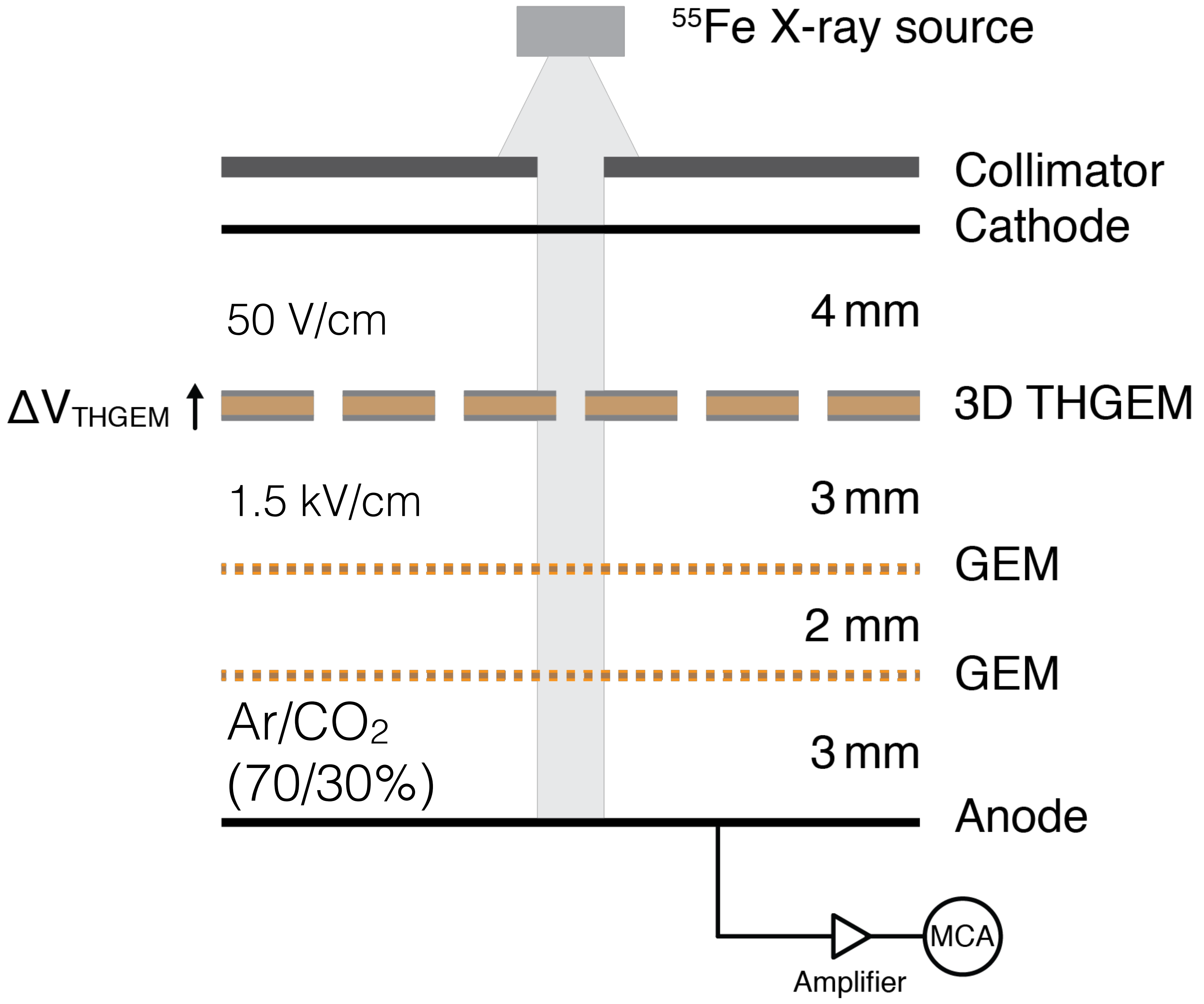
With increasing potential different between the top and bottom electrodes of the THGEM, electron avalanche multiplication sets in and leads to increasing scintillation light emission.



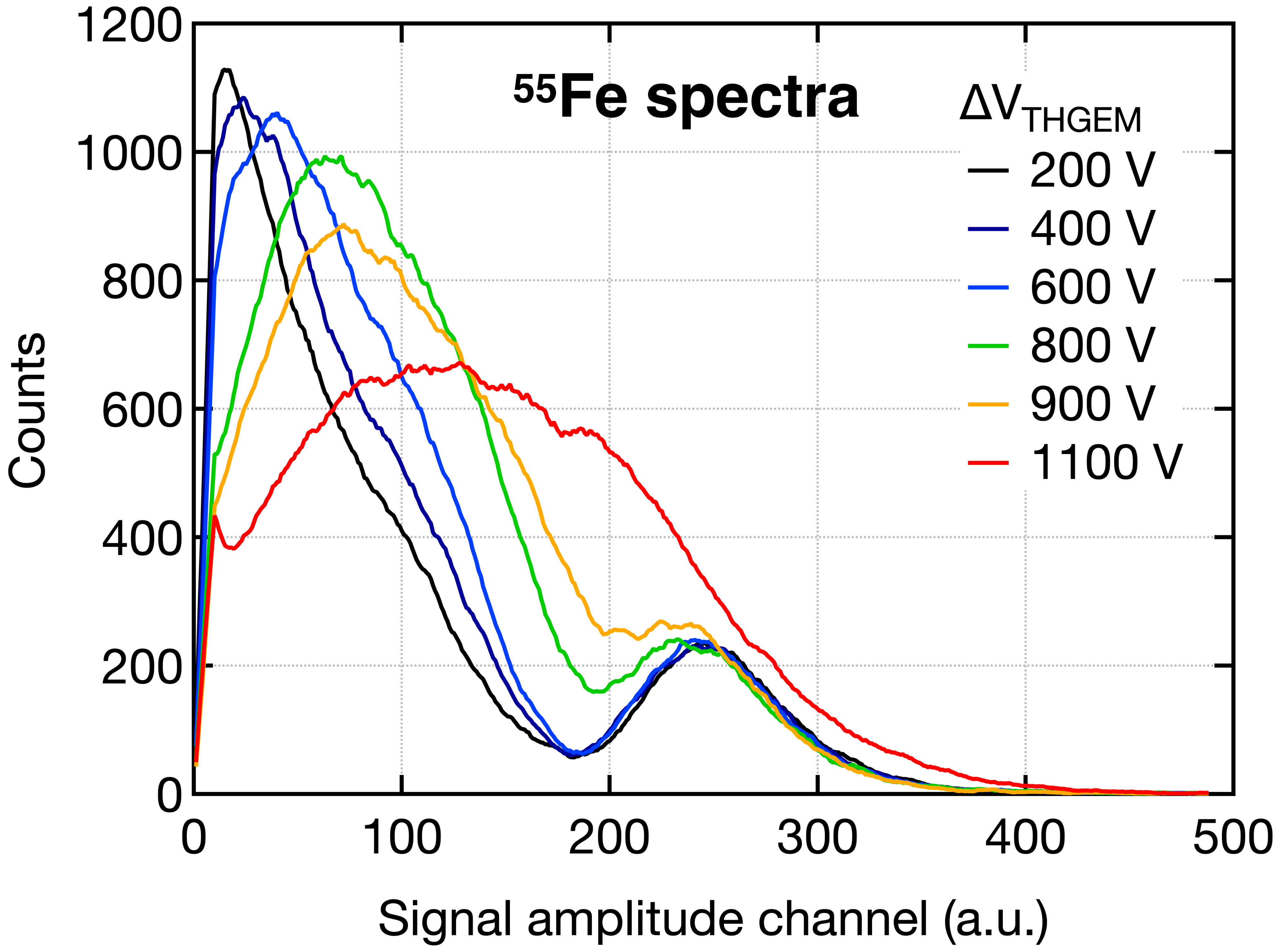
3D printed THGEM electrical signals

Operating the 3D printed **THGEM** as preampfification stage above a **double-GEM** detector, pulse height spectra of X-ray events from an ^{55}Fe source were recorded.

The acquired spectra show that there is transmission of electrons through the THGEM and a trend towards higher signal amplitudes for higher voltage drops across the THGEM. However, both **transparency** and **charge gain** are low for the achievable potential difference between the top and bottom electrodes of the THGEM before discharges set it.



Schematics not drawn to scale



Conclusions

Additive manufacturing techniques may enable **novel detector geometries** and approaches to detector development. Resolution and **multi-material capabilities** are key requirements for 3D printing function radiation detectors.

Fused deposition modeling permits **composite conductive and insulating structures** but the achievable spatial resolution is low. A **2D readout strip anode** was 3D printed and used in a GEM-based TPC.

Inkjet 3D printing with nanoparticle inks offers high spatial resolution and conductive inks enable printing of low-impedance conductive structures. High-impedance insulation between separated electrodes was achieved.

First functional radiation detector prototype was 3D printed and operated. Using an Ar/CF_4 gas mixture, a 3D printed THGEM prototype was optically read out.