Optical readout of glass Micromegas: neutron imaging and DLC-coated meshes

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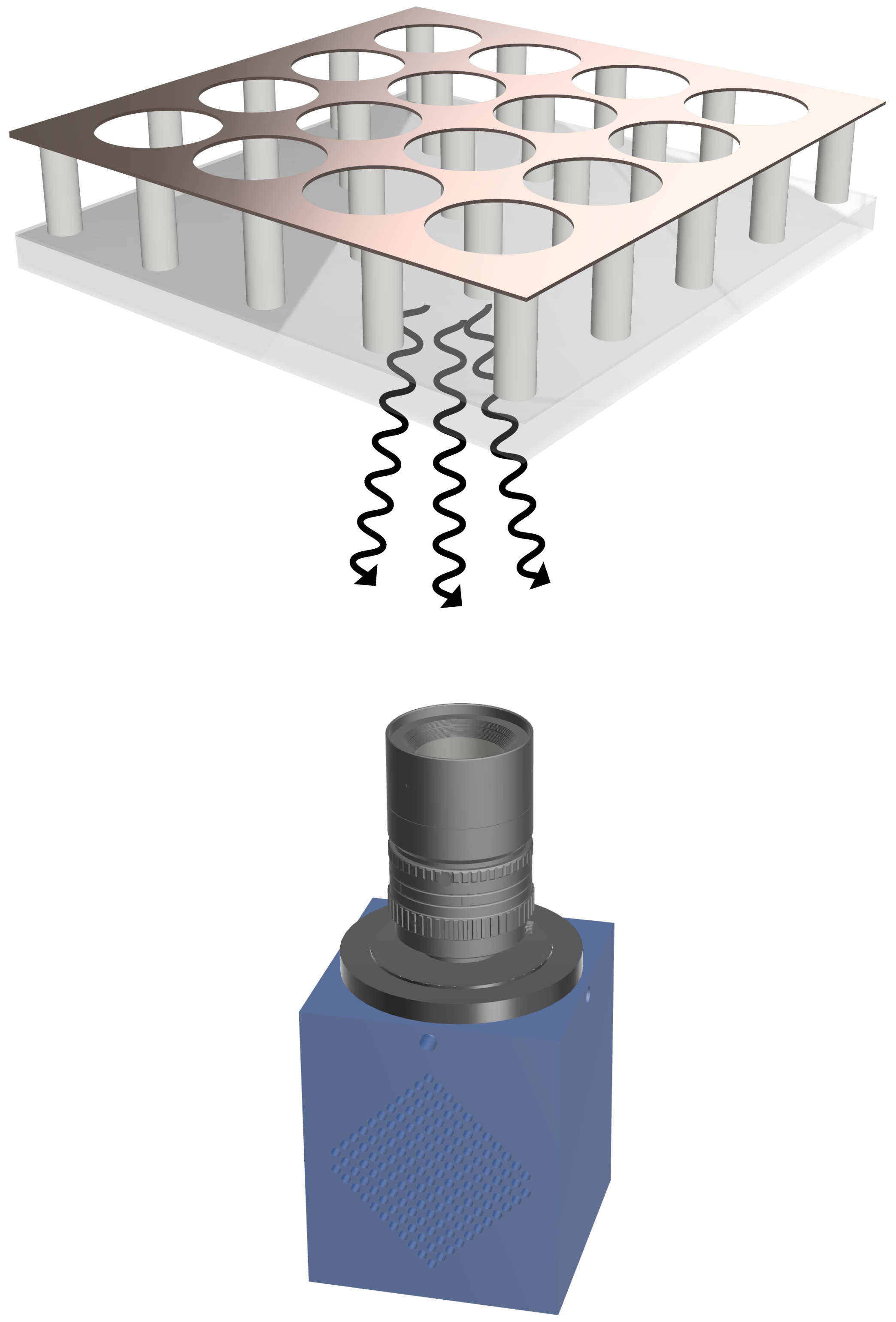
RD51 Mini-Week, February 17, 2021

Optical readout of Glass Micromegas

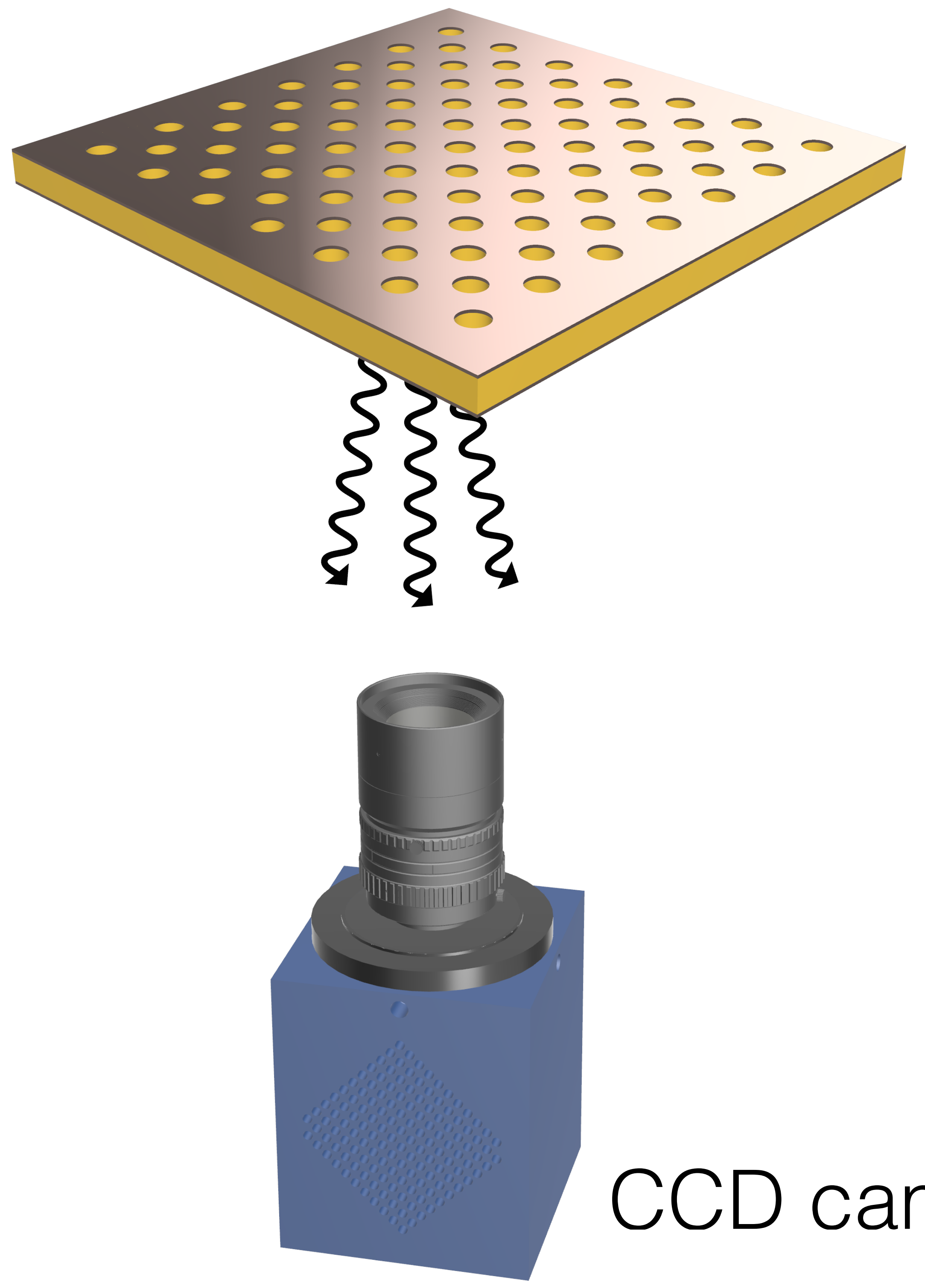
- Optical readout with Glass Micromegas
- Neutron imaging with B_4C cathode
- DLC-coated black meshes

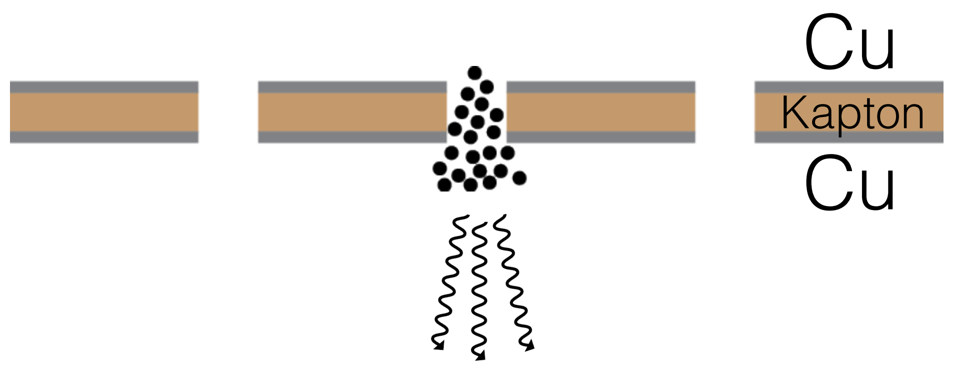


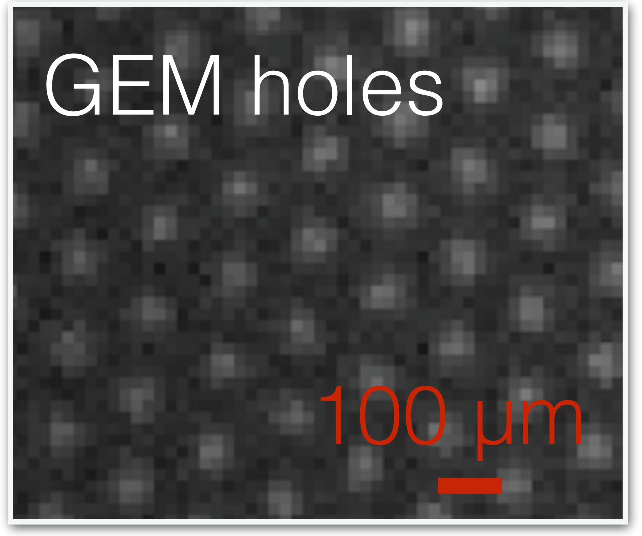
Optical readout of gaseous detectors

Employing high electric field regions for signal amplification by electron avalanche multiplication.
Scintillation light emitted during avalanche multiplication can be recorded with imaging sensors.

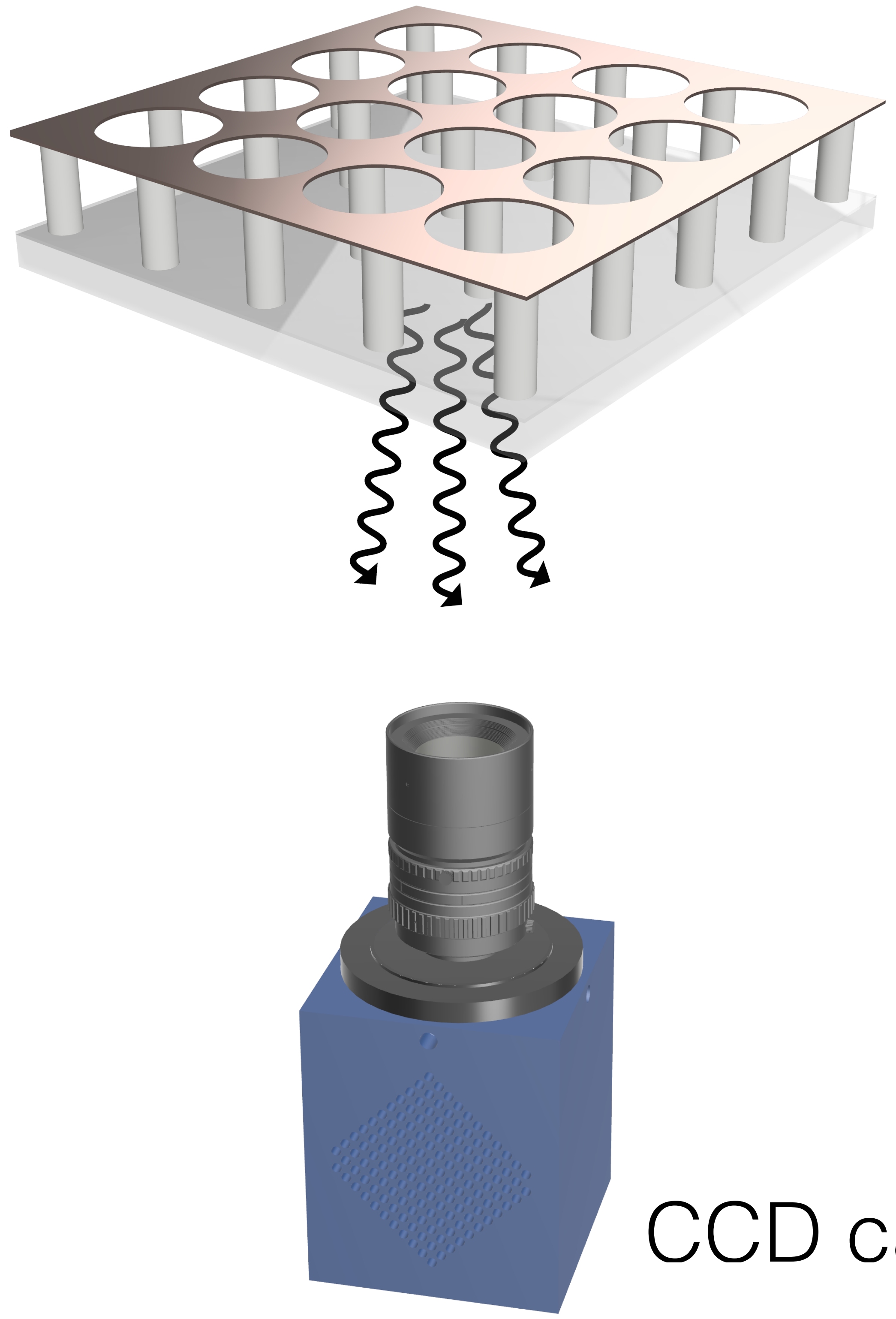
Gaseous Electron Multiplier (**GEM**)

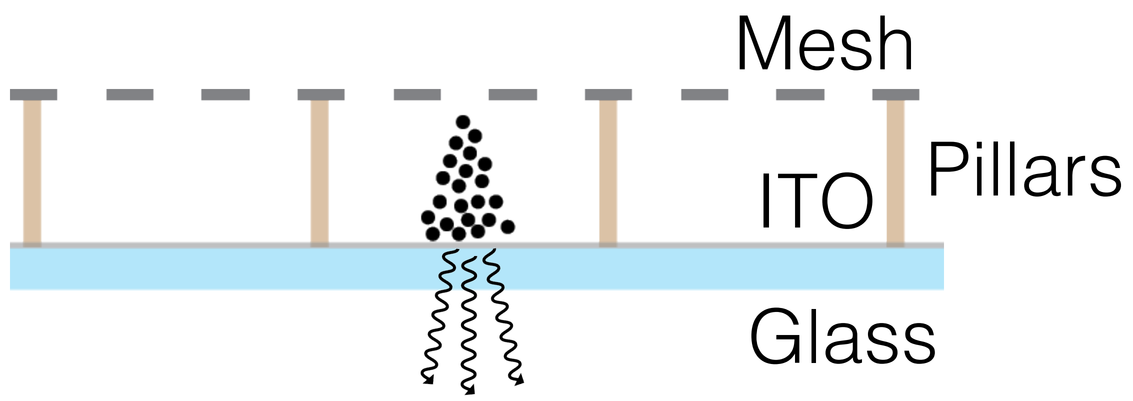






Micro-Mesh Gaseous Structure (**MicroMegas**)





Potential advantages:

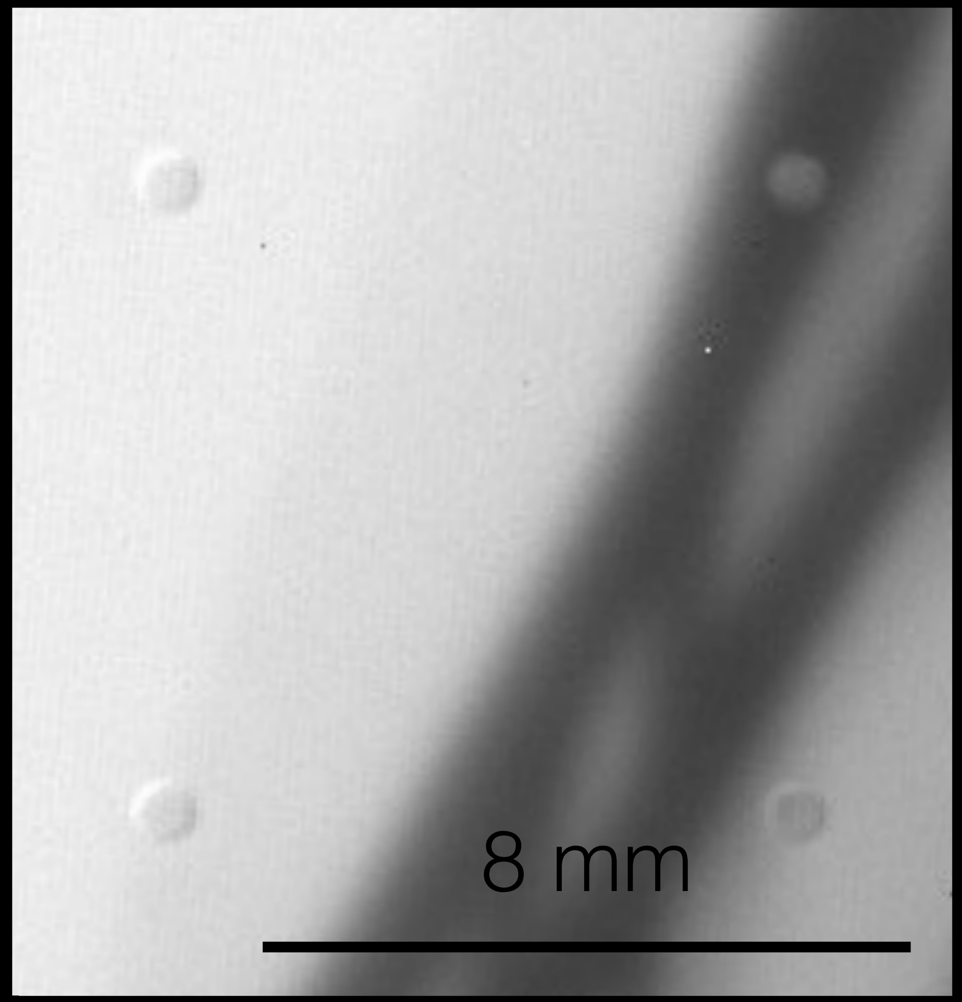
- Higher energy resolution
- Higher uniformity for imaging (no hole structure)

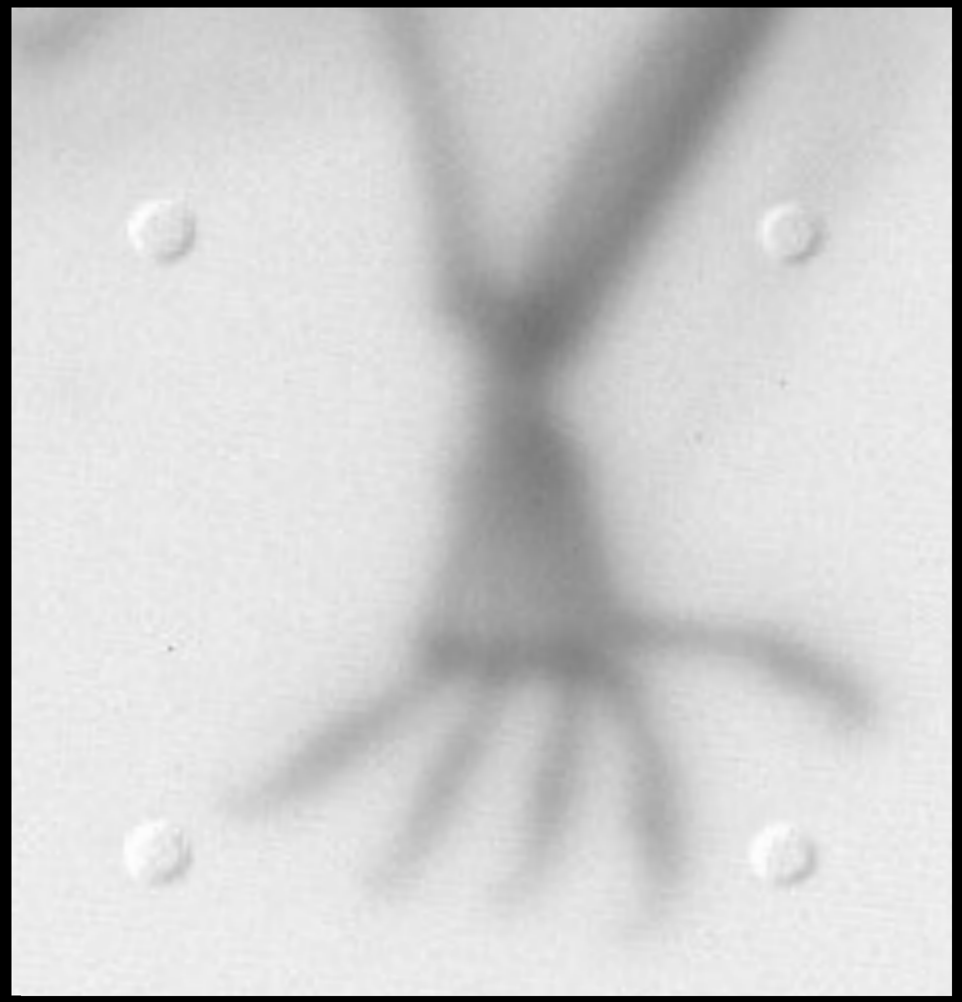
X-ray radiography images

X-ray radiography works well and appears to give higher resolution images than optically read out GEMs

Pillars are visible as inefficient areas

Image was recorded by 10x 10s exposures, BG subtracted, derided by “white” image to correct for beam profile





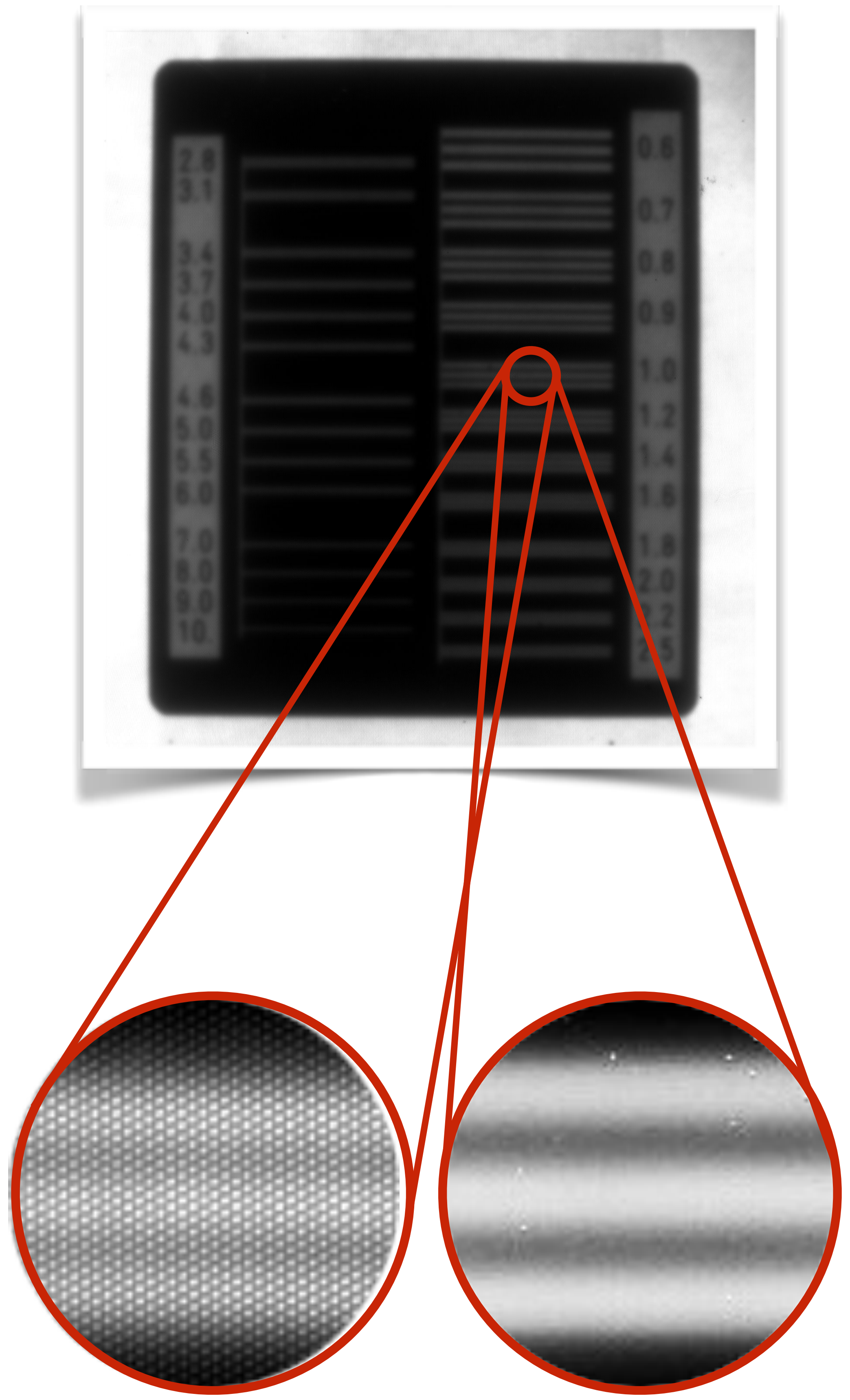
Spatial resolution comparison between GEM and optically read out Micromegas

Line pair phantoms were used to measure the spatial resolution and compare it to the one achievable with an optically read out triple-GEM. The normalised Modulation Transfer Functions (MTFs) were used to determine the resolvable spatial frequency. The spatial resolution was determined as the spatial frequency at which the normalised MTF falls below 10%.

Spatial resolution:

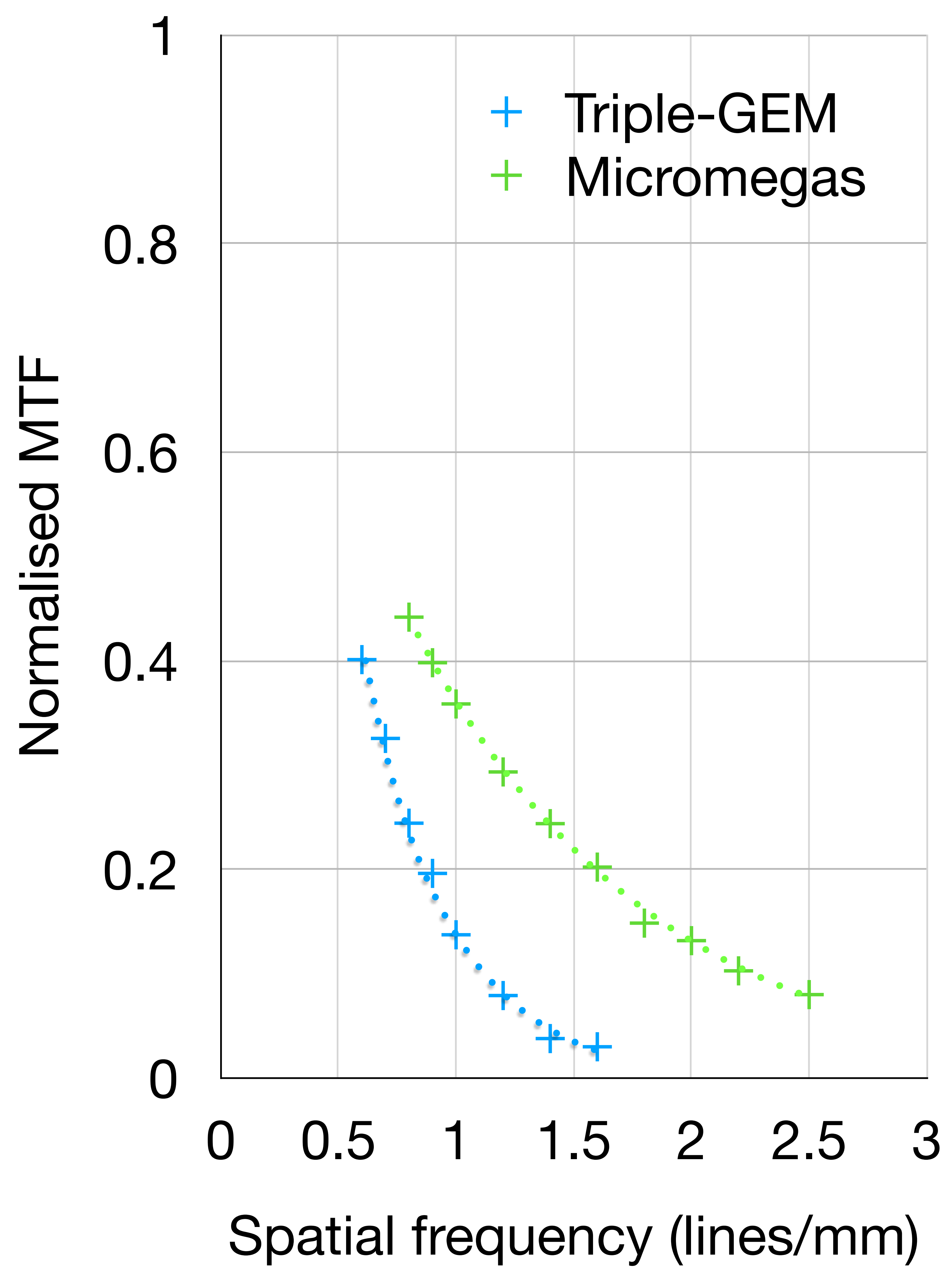
Triple-GEM: ≈**890 µm** (1.11 lines/mm)

Micromegas: ≈**440 µm** (2.25 lines/mm)



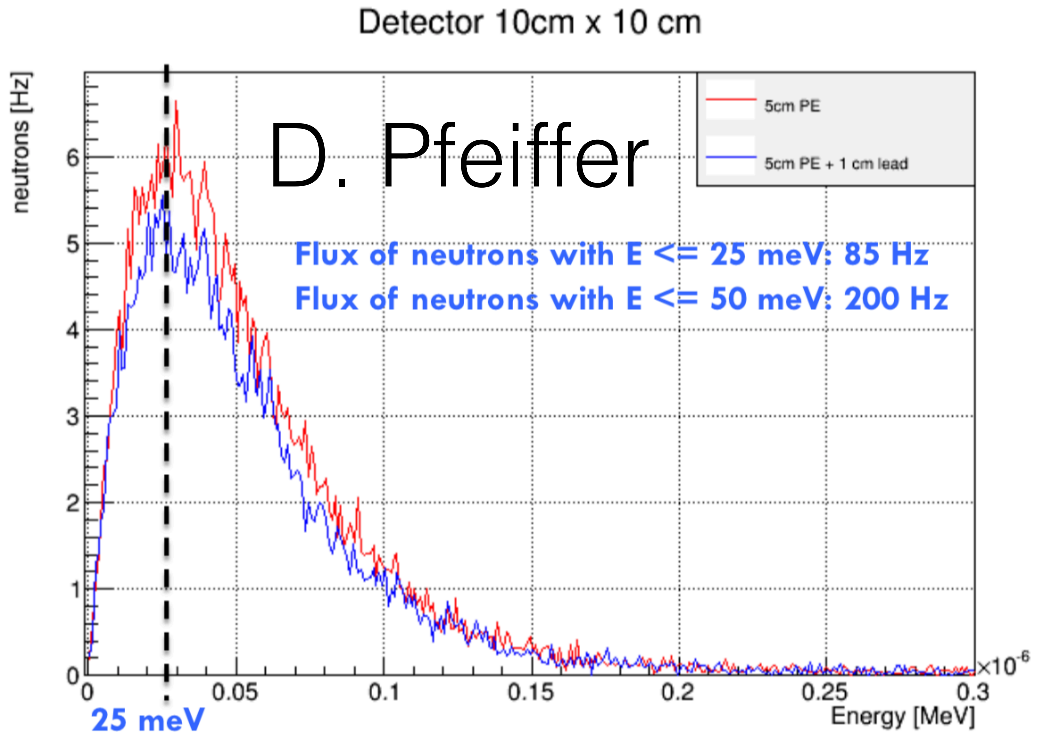
Triple-GEM
Hole structure

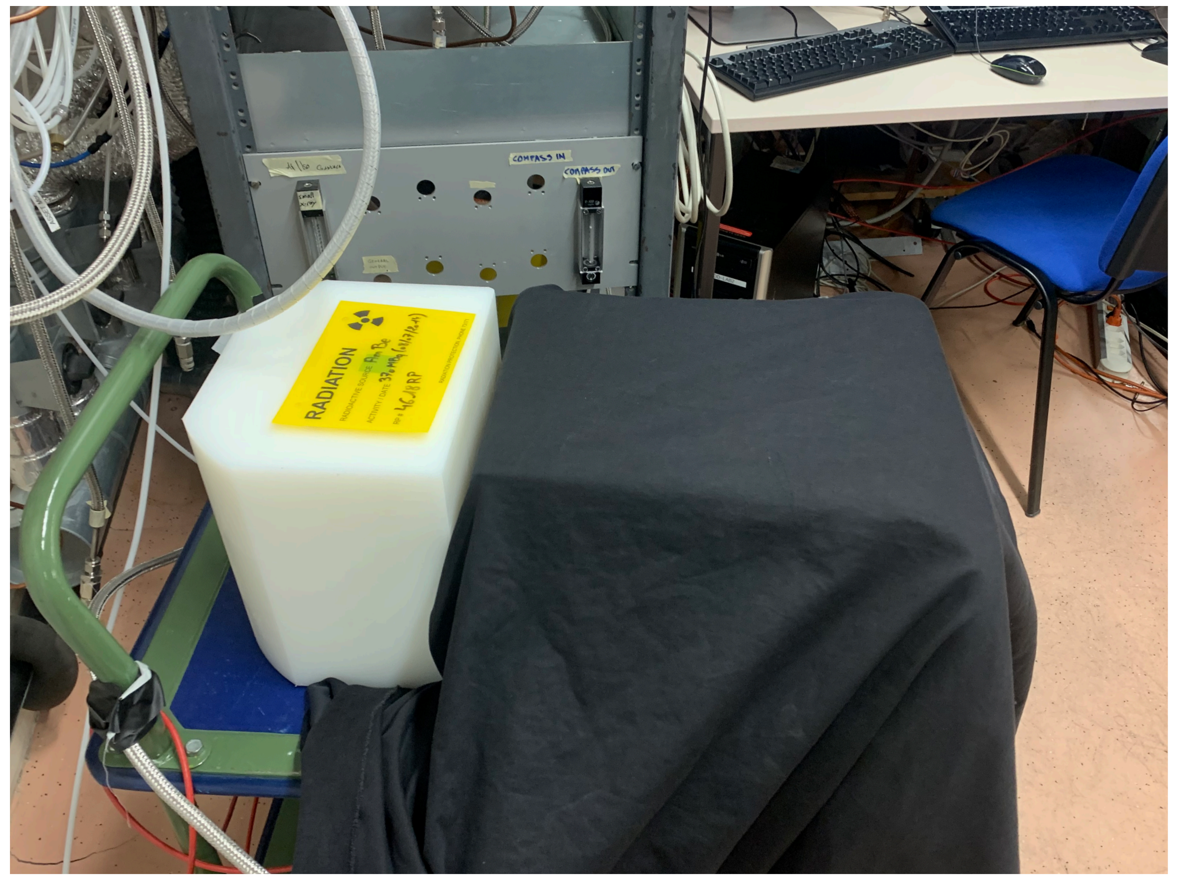
Micromegas
Uniform



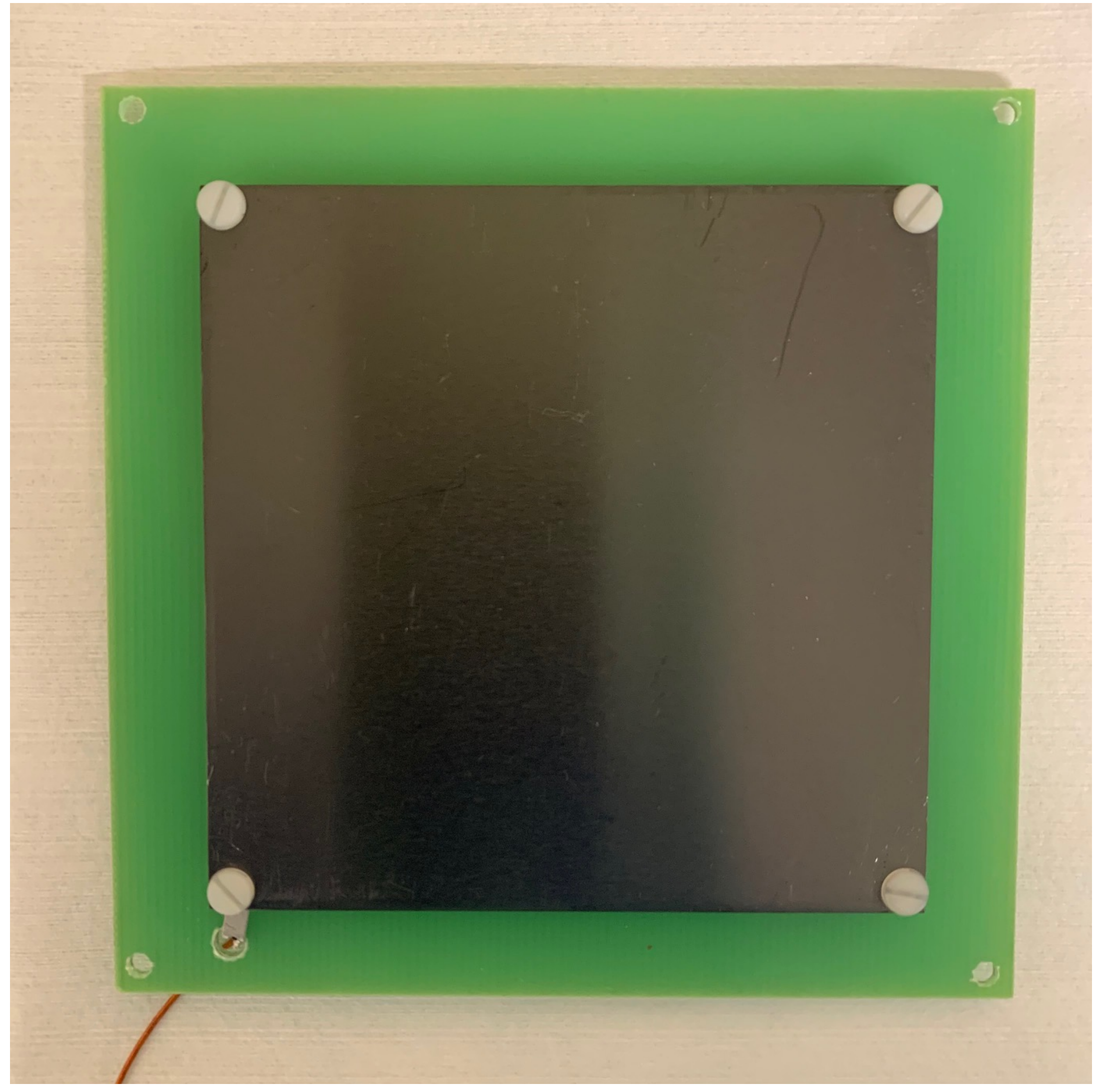
Neutron imaging with B_4C cathode

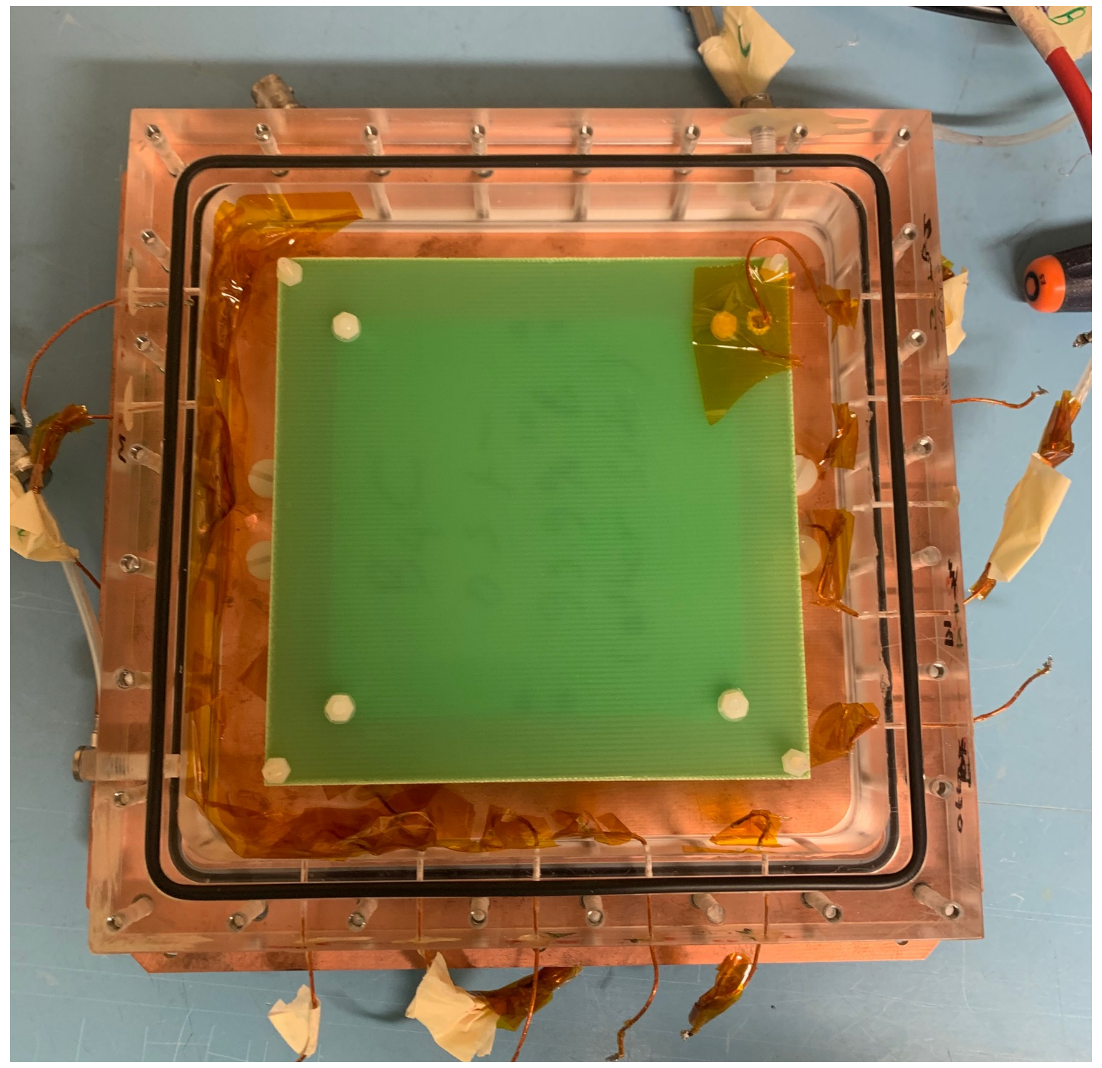
Setup

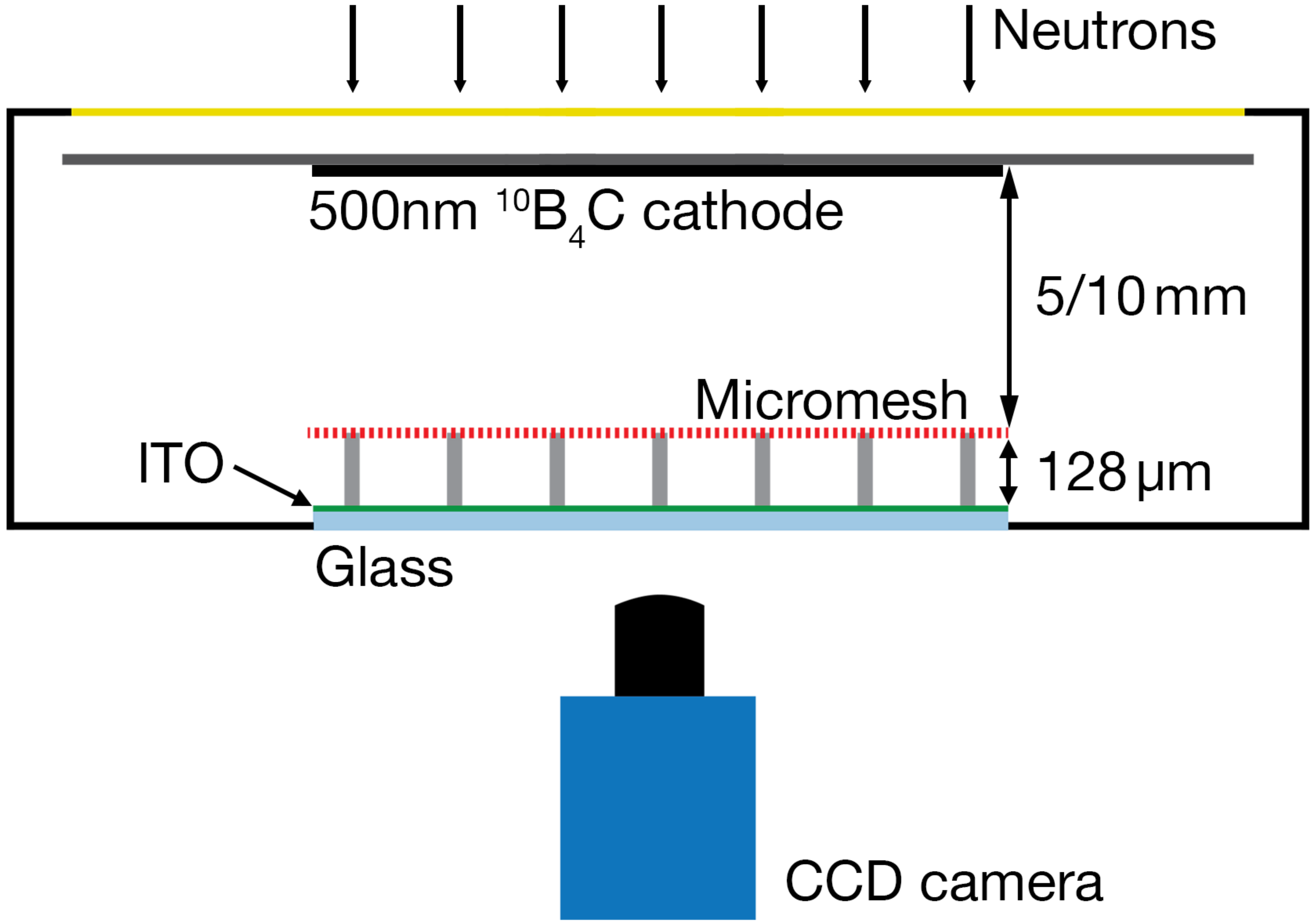




- Glass MM on ITO
- 500nm thick B_4C layer with 99.9% ^{10}B enriched on metal plate as cathode
- 5mm or 10mm drift region thickness
- 200 V/cm drift field, mesh at GND, 580V on anode
- AmBe neutron source in PE shielding, low rate
- Thermal neutrons, 2.3/2.8 MeV alpha emission
- Low light conditions, 8x8 binning, 1s exposures

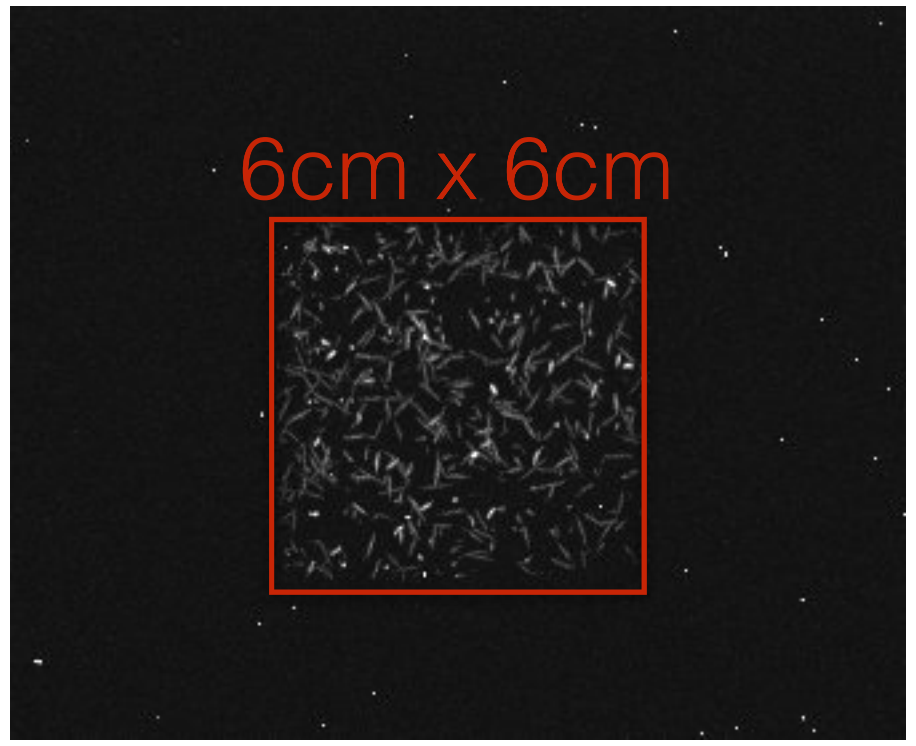






Short exposure images

Ar/CF4 (80/20%), 5l/h
200 V/cm drift field
Mesh at GND
580V at anode
1s exposure



2.6 px/mm -> 1px ≈ 384µm

5mm drift

10mm drift

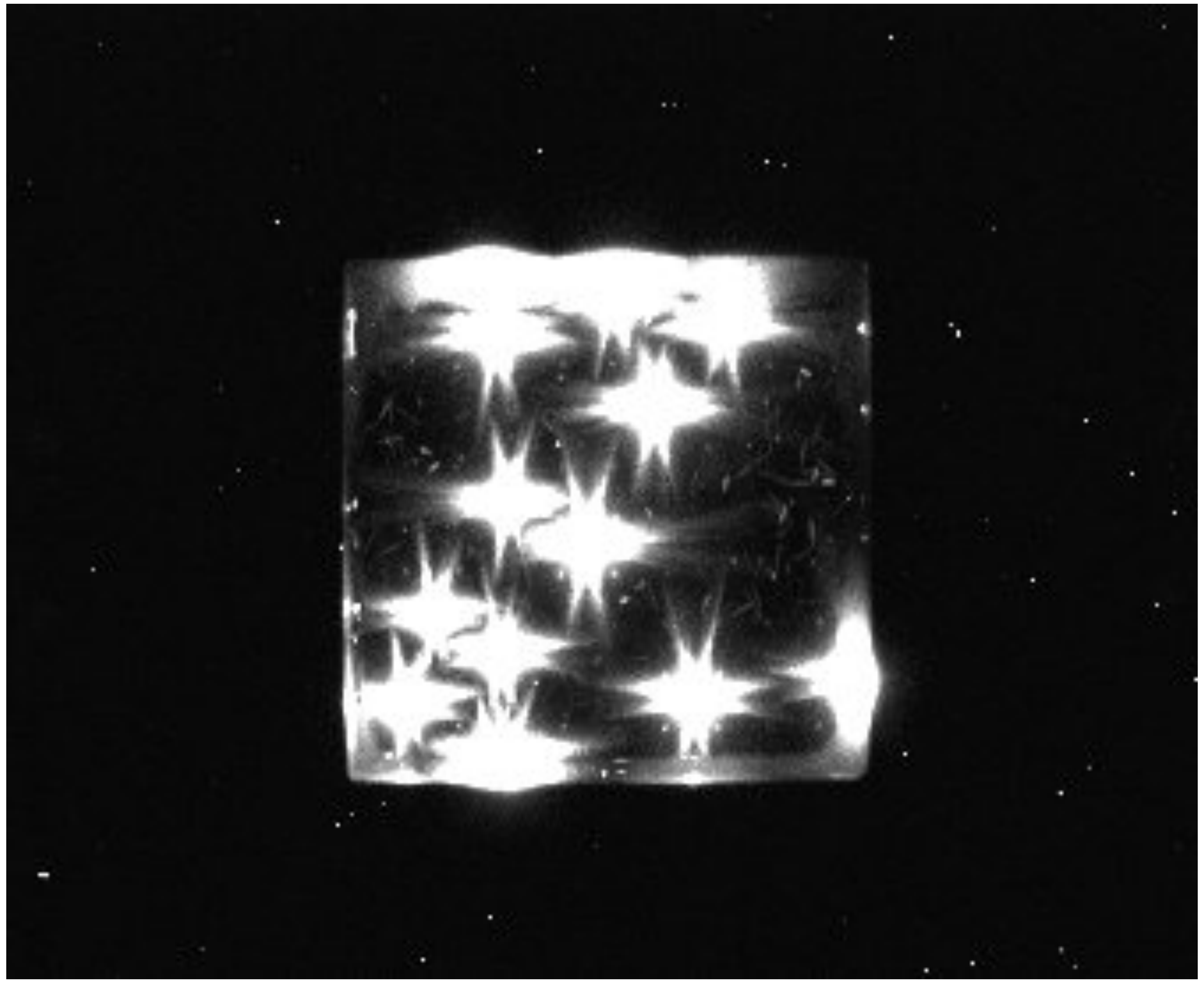
Sparks in 1000s

Ar/CF4 (80/20%), 5l/h
200 V/cm drift field
Mesh at GND
580V at anode

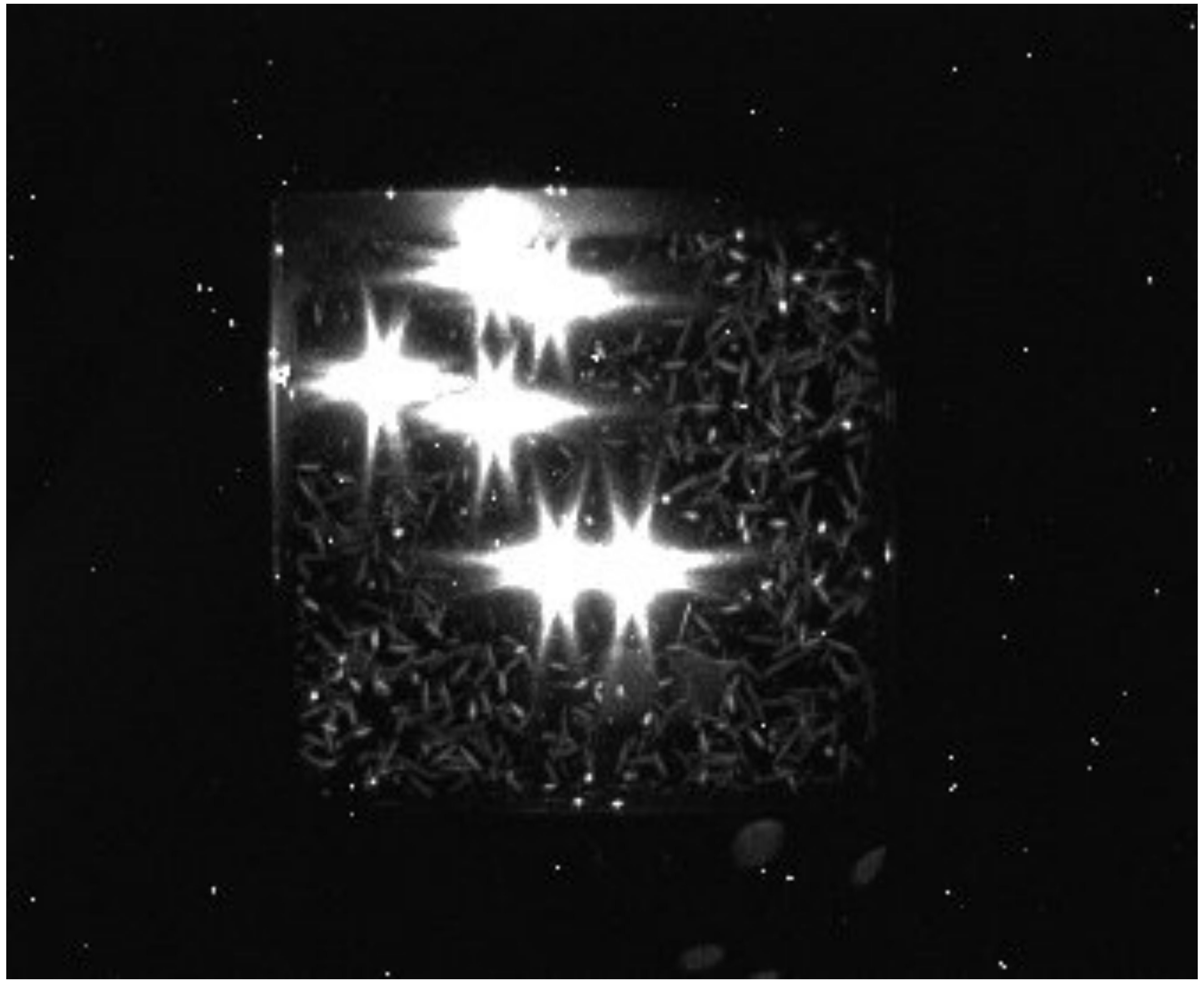
Occasional sparks in 1000s total exposure time are distributed across active area.

Lower spark rate with larger drift gap.

5mm drift



10mm drift



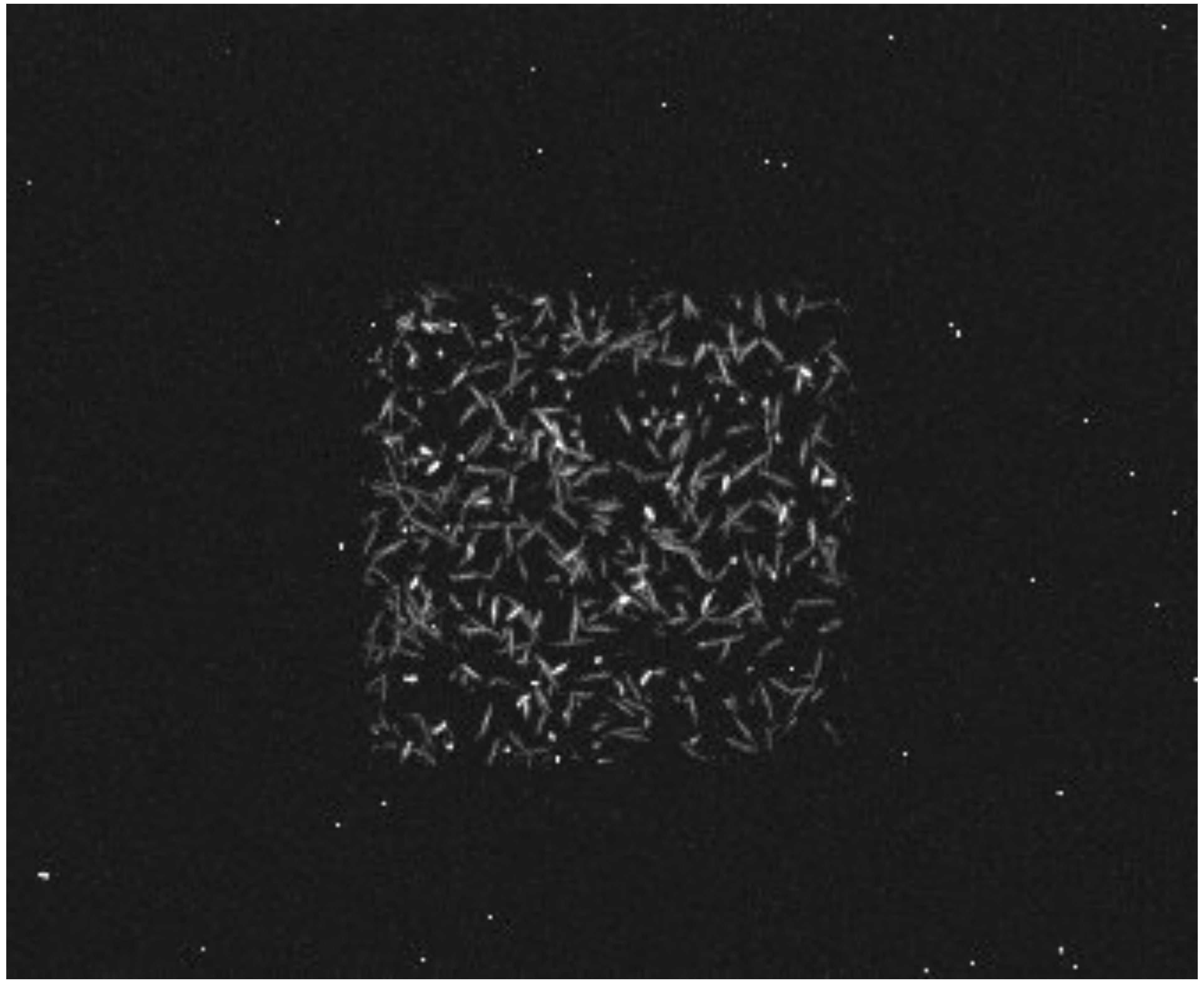
1000x 1s
BG subtracted
MAX intensity of stack

Long exposure

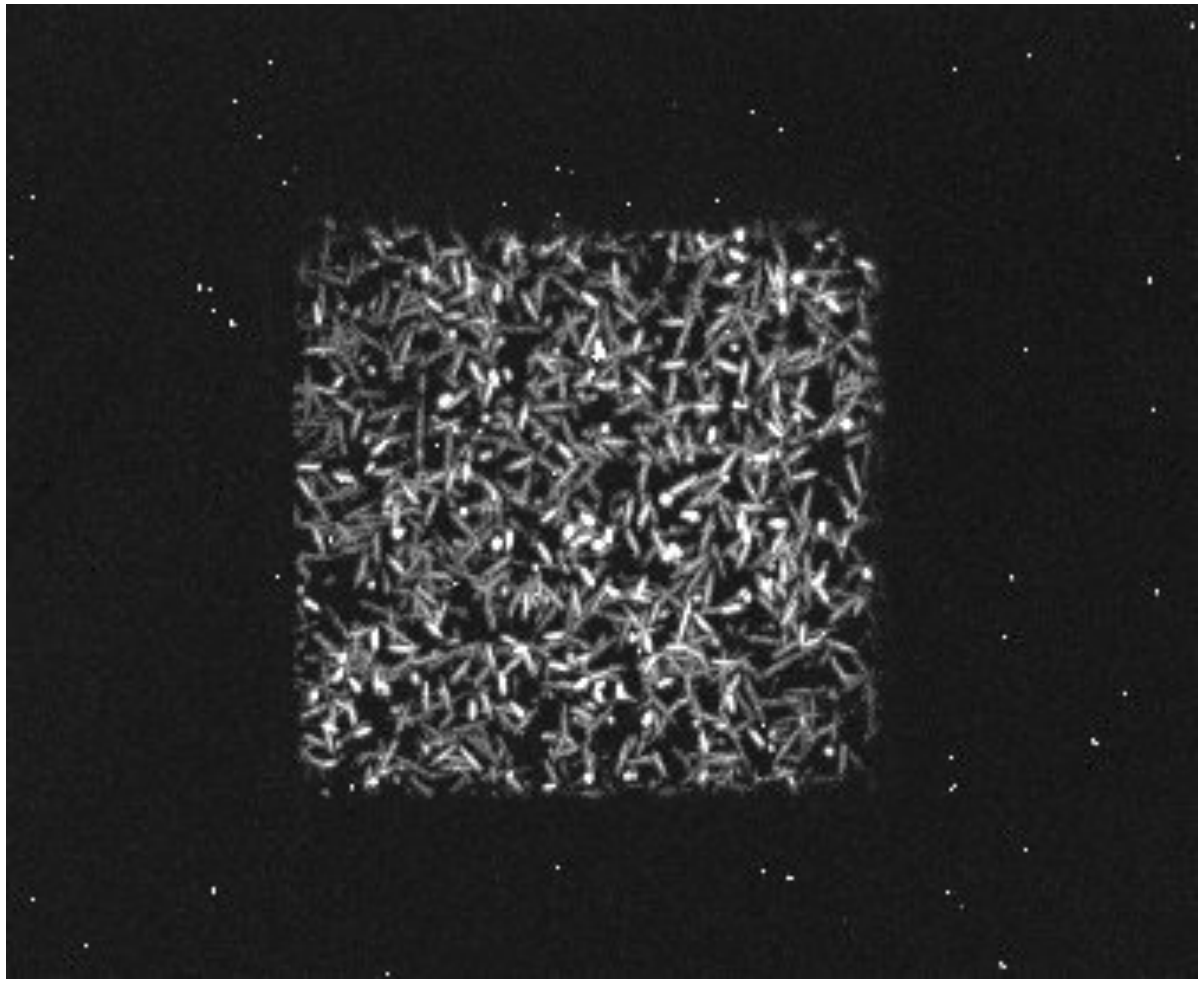
Ar/CF4 (80/20%), 5l/h
200 V/cm drift field
Mesh at GND
580V at anode

Max intensity of imaging stack shows extend of active area of detector - limited by low rate of source

5mm drift



10mm drift



1000x 1s
BG subtracted
MAX intensity of stack, sparks removed

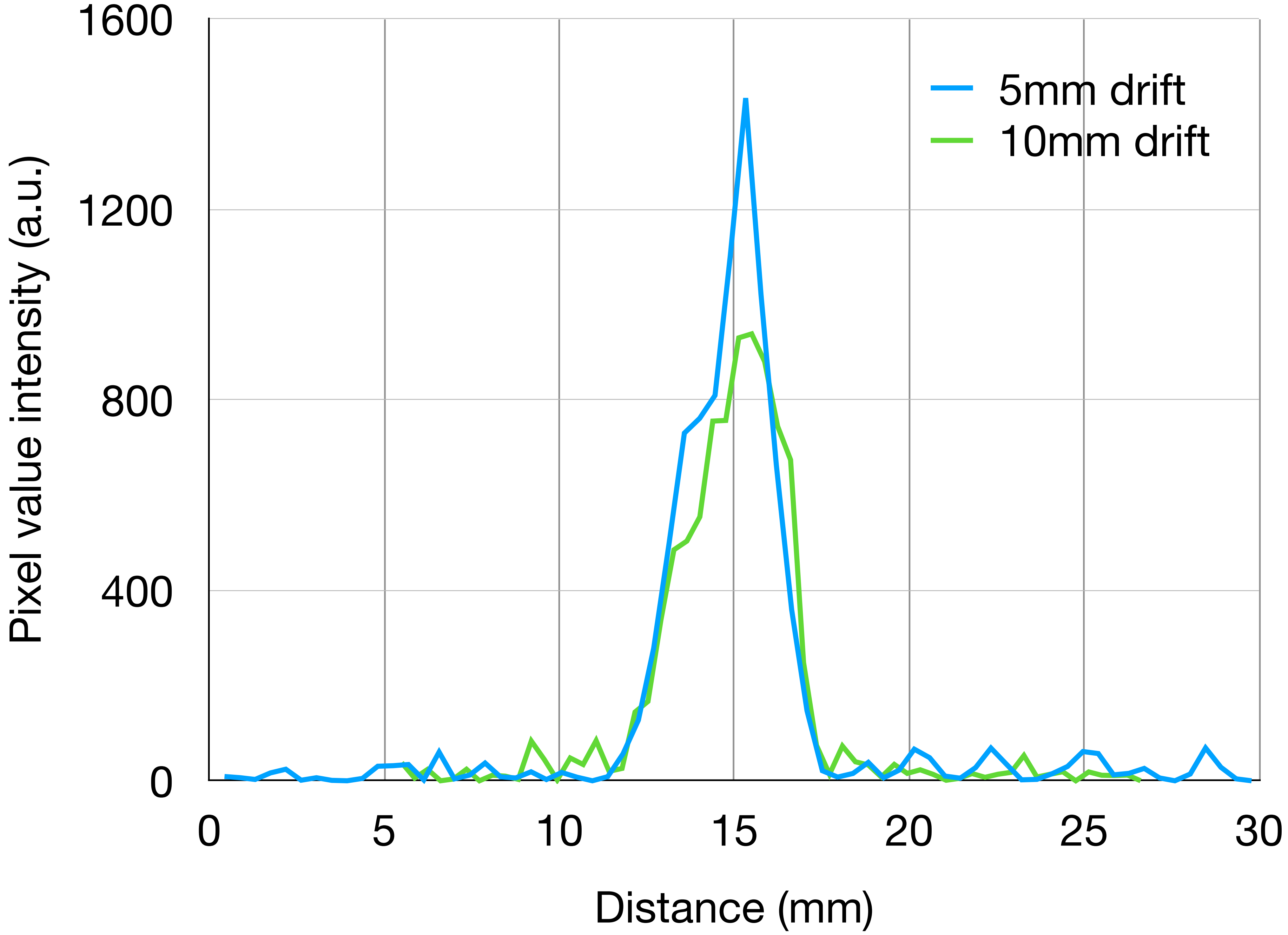
Line profile of alpha tracks

Ar/CF4 (80/20%), 5l/h
200 V/cm drift field
Mesh at GND
580V at anode

Line profile of pixel value intensity across tracks shows Bragg peak and therefore allows for head-tail discrimination for some tracks. Limited by low resolution.

5mm drift

10mm drift



Binning

Low resolution of CCD operating in 8x8 binning mode limits profile granularity.

Lower binning (higher resolution) decreases SNR. Limited by high ≈7e read noise of CCD.

CCD 8x8
336x275 px

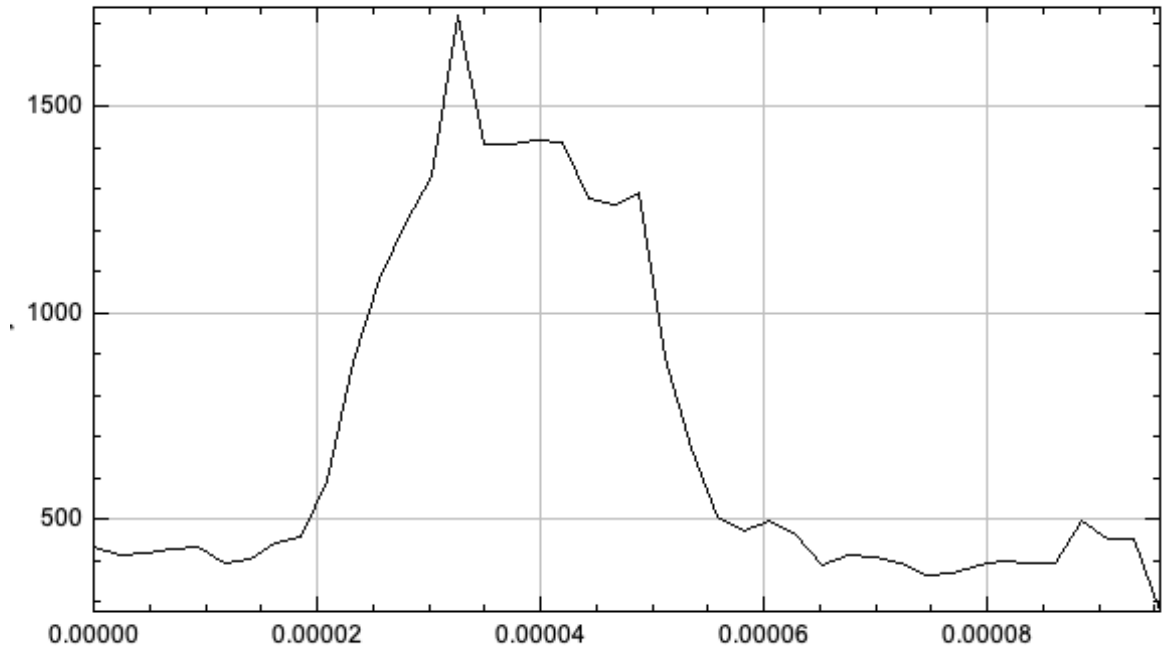
CCD 4x4
672x550 px

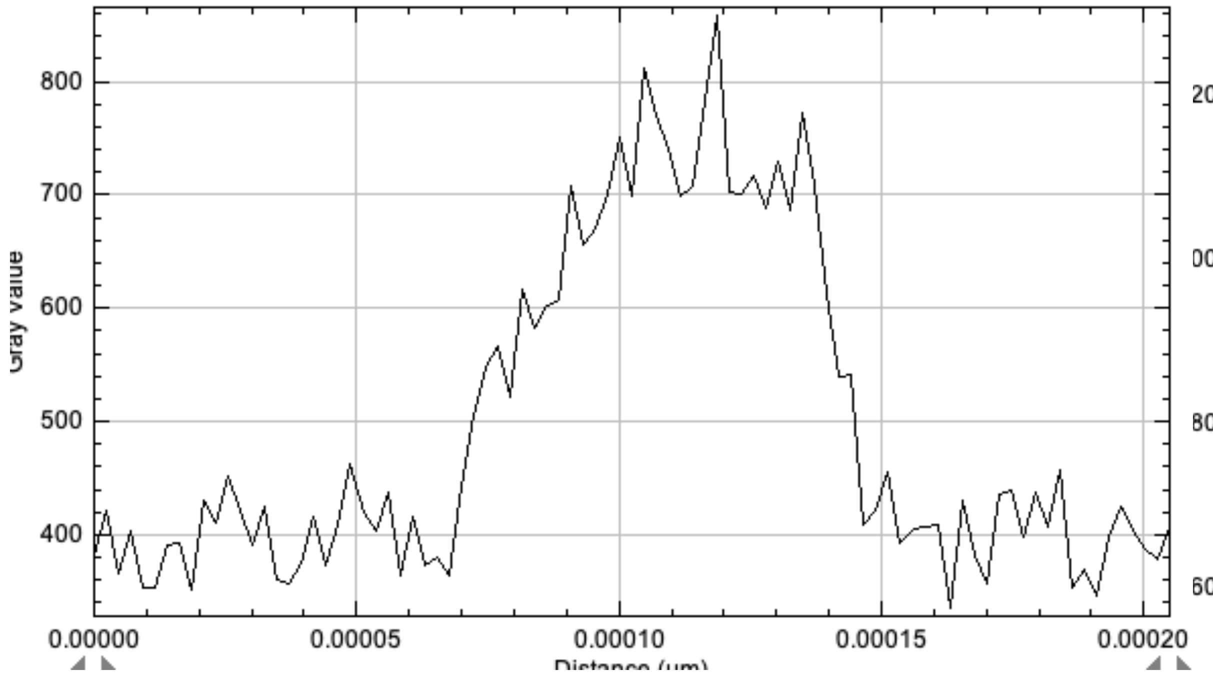
CMOS 4x4
576x576 px

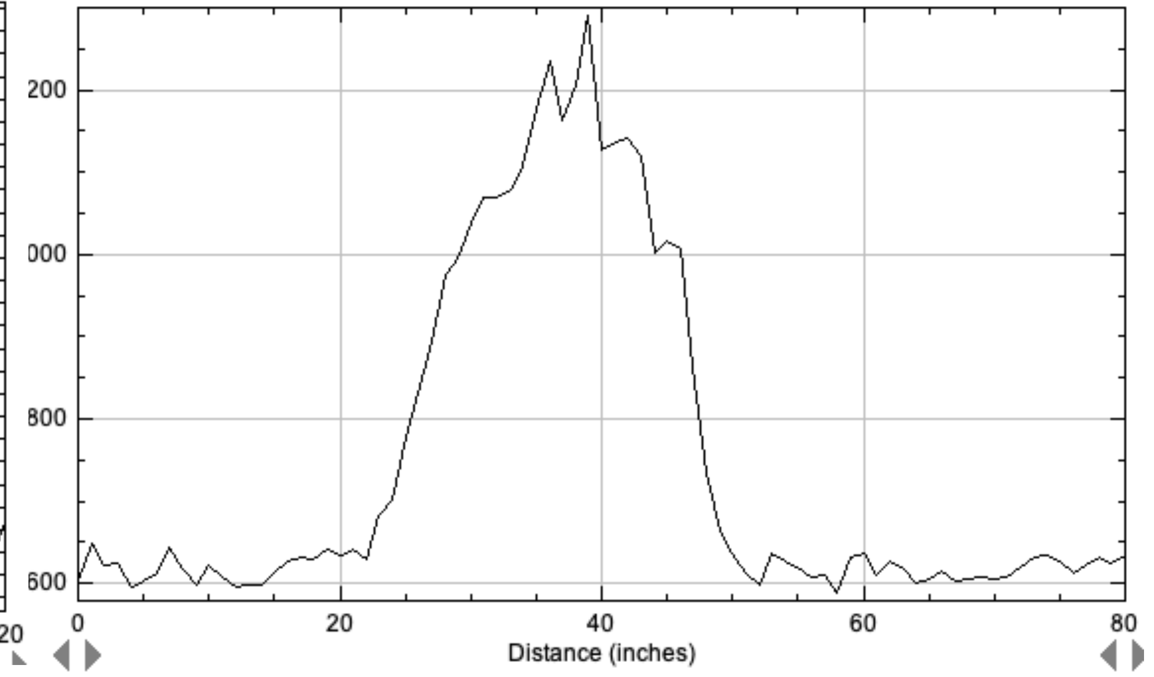
SNR 29

SNR 18

SNR 88







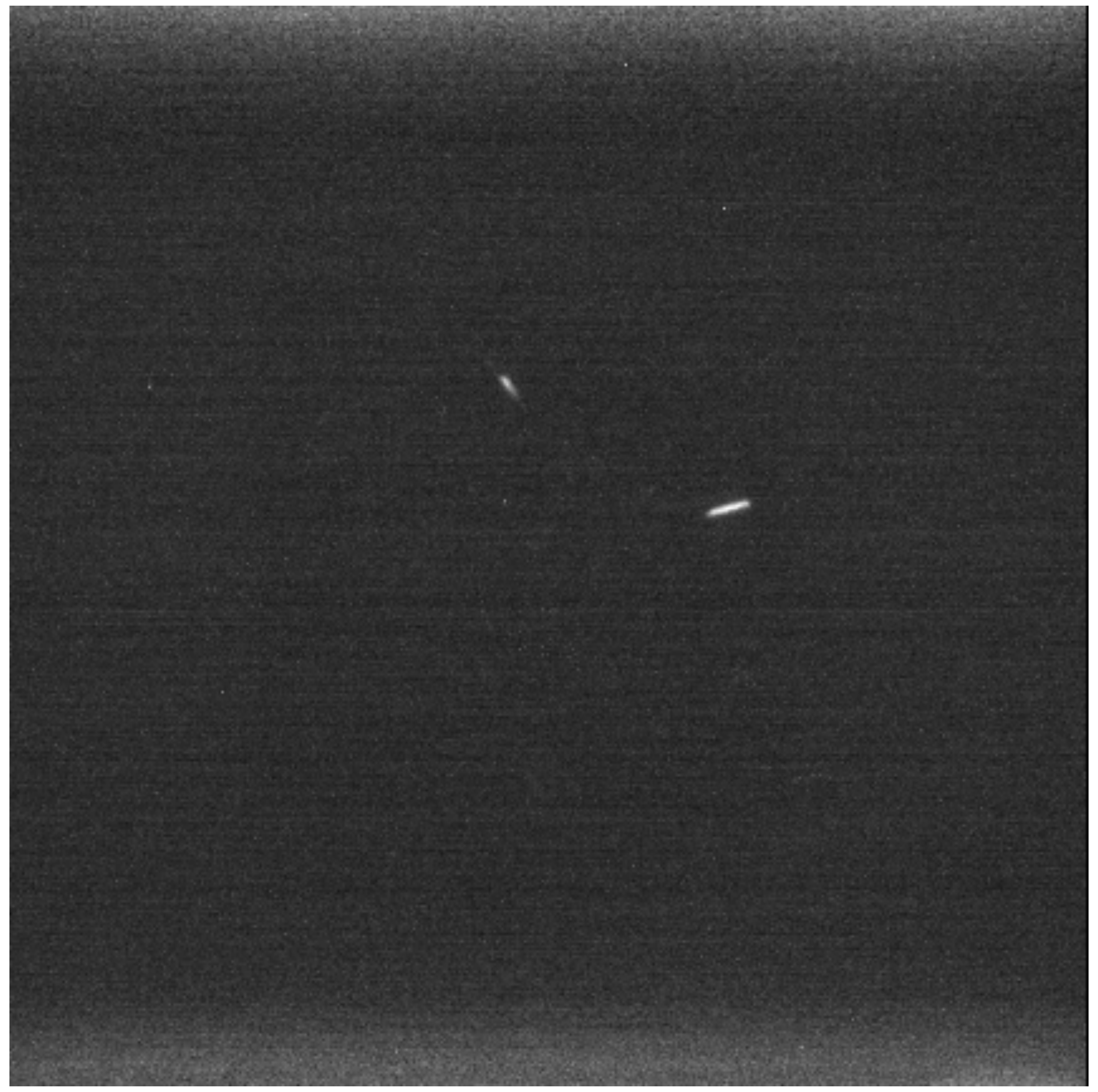
1s exposure
570V anode, Mesh GND, 200Vcm
10mm drift gap

Quiet scan

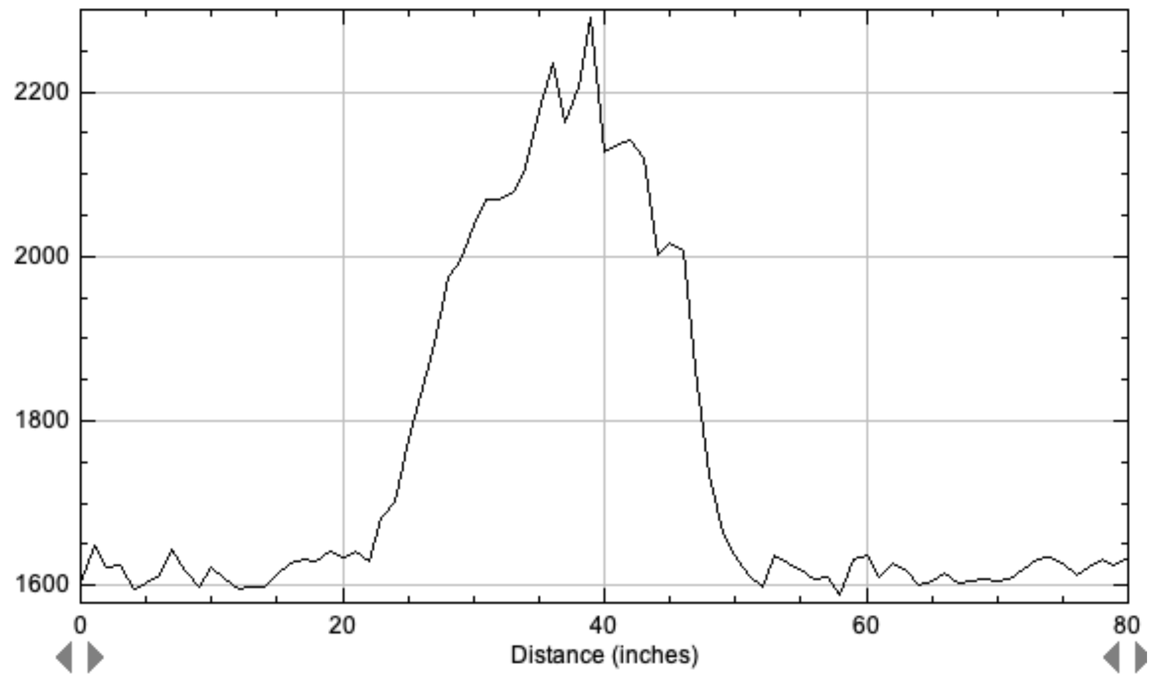
Binning

Low read noise (≈1e) CMOS (Hamamatsu Orca Fusion) allow for higher granularity images and better line profiles, even at full resolution.

4x4
576x576 px

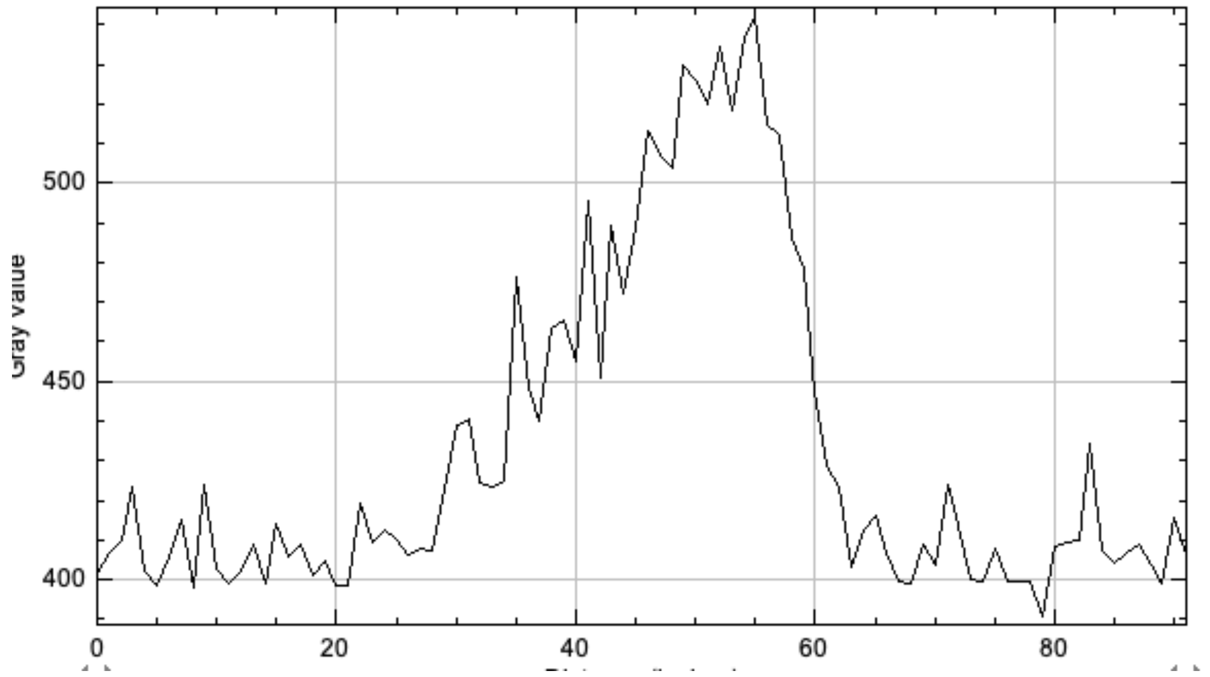


SNR 88



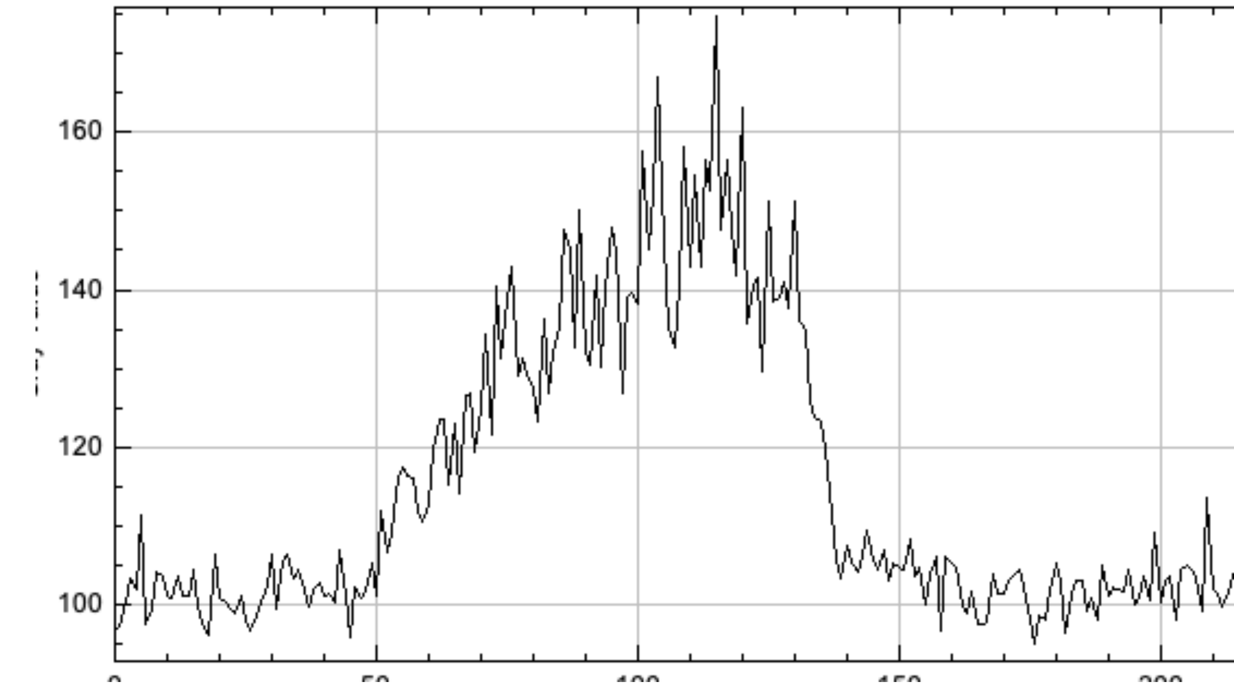
2x2
1152x1152 px

SNR 48



1x1
2304x2304 px

SNR 33



1s exposure
570V anode, Mesh GND, 200Vcm
10mm drift gap

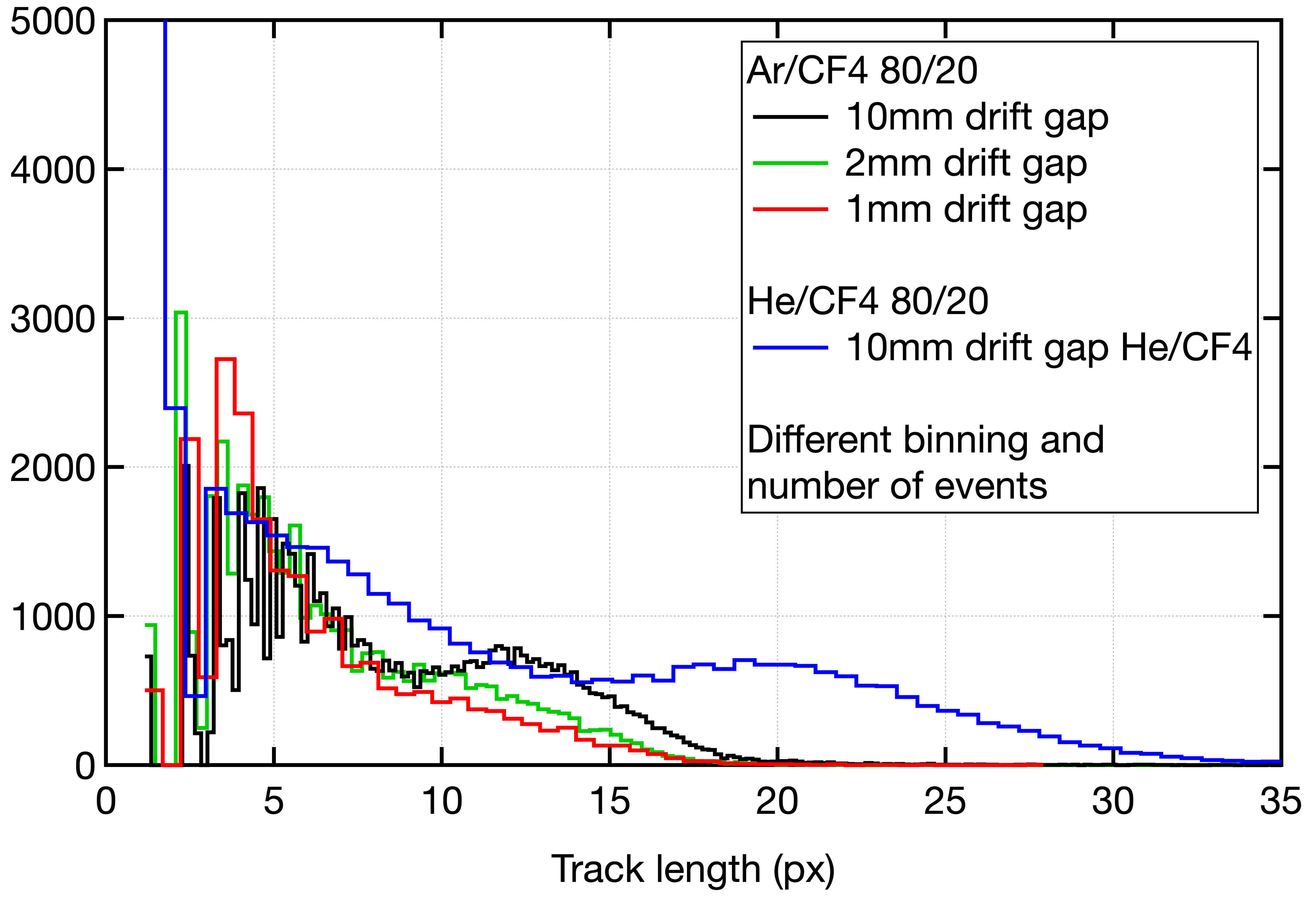
Quiet scan

Length of tracks

Major axis length plotted for different drift gap thicknesses

Many tracks partially contained

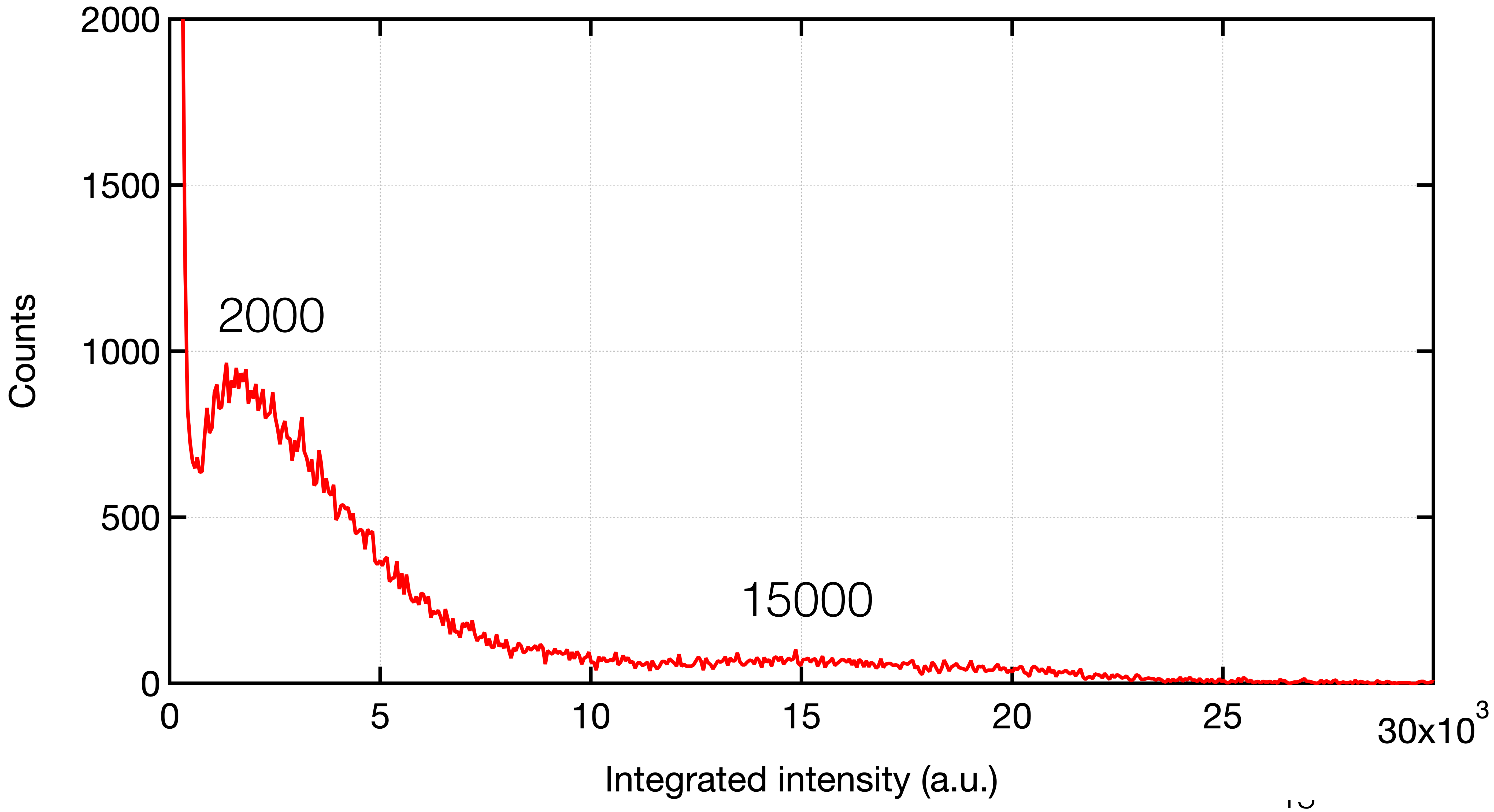
Longer tracks in thicker drift gaps and in He/CF4

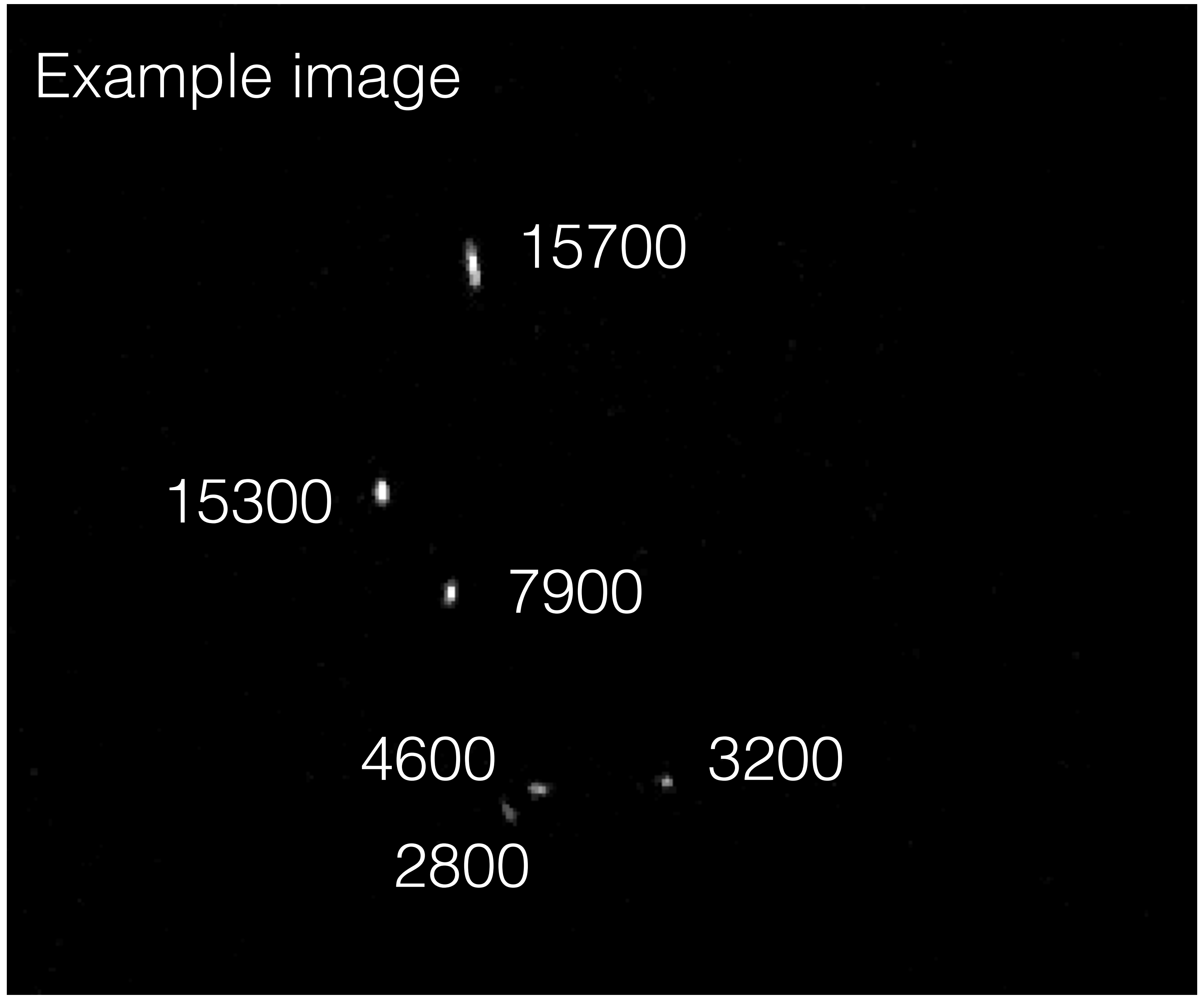


Energy spectrum

13h exposure with 5s frames was used to extract energy information from individual track events.

Main peak ≈2000 and larger energy events ≈15000 with very broad distribution observed. Rate too low for significant pile-up.





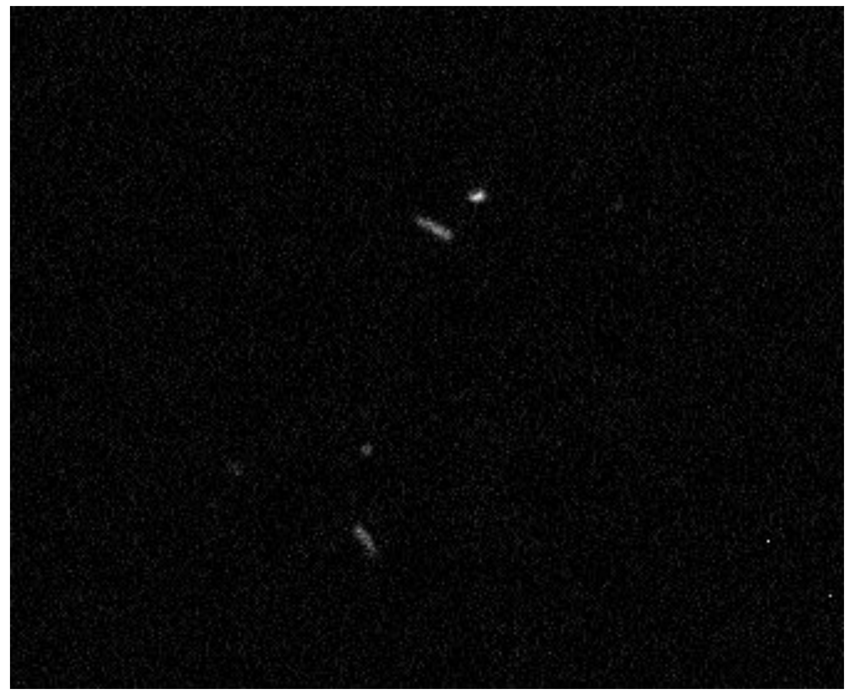
10mm drift
Threshold
BG subtract
identify events
Integrate
Histogram
570V

Drift field variation

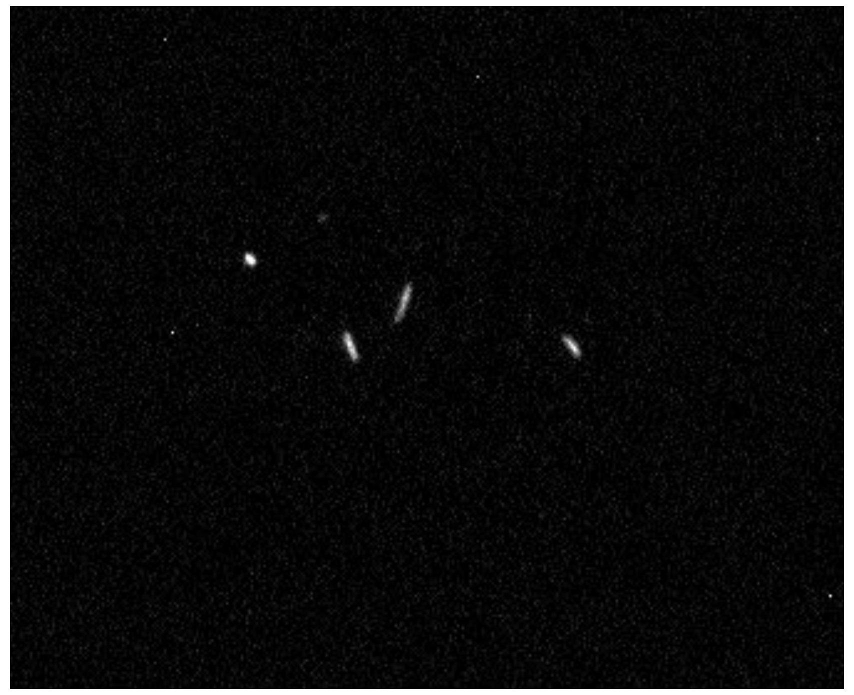
Higher drift fields decrease diffusion (track width) but increase sparking probability.

20 V/cm

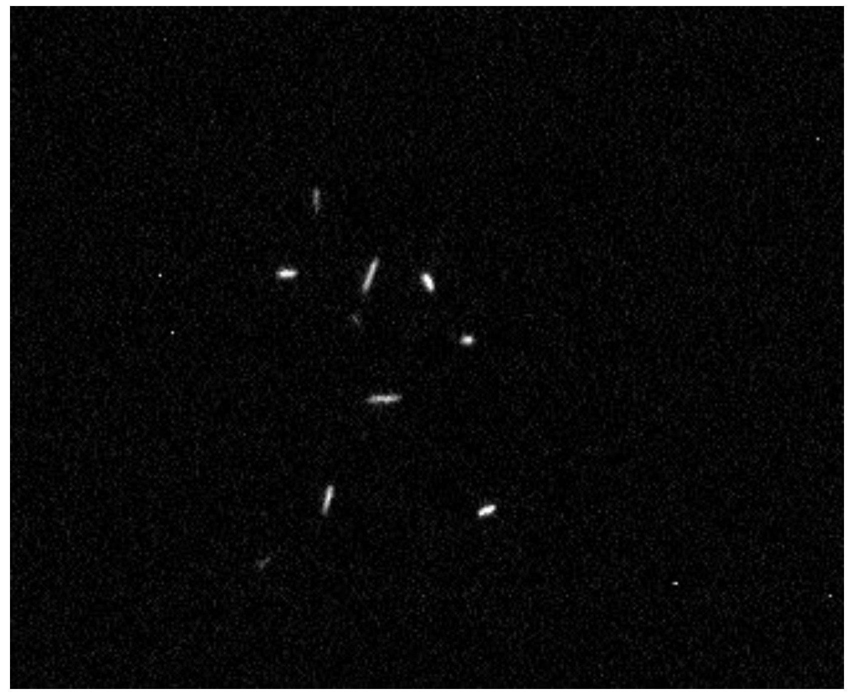
50 V/cm



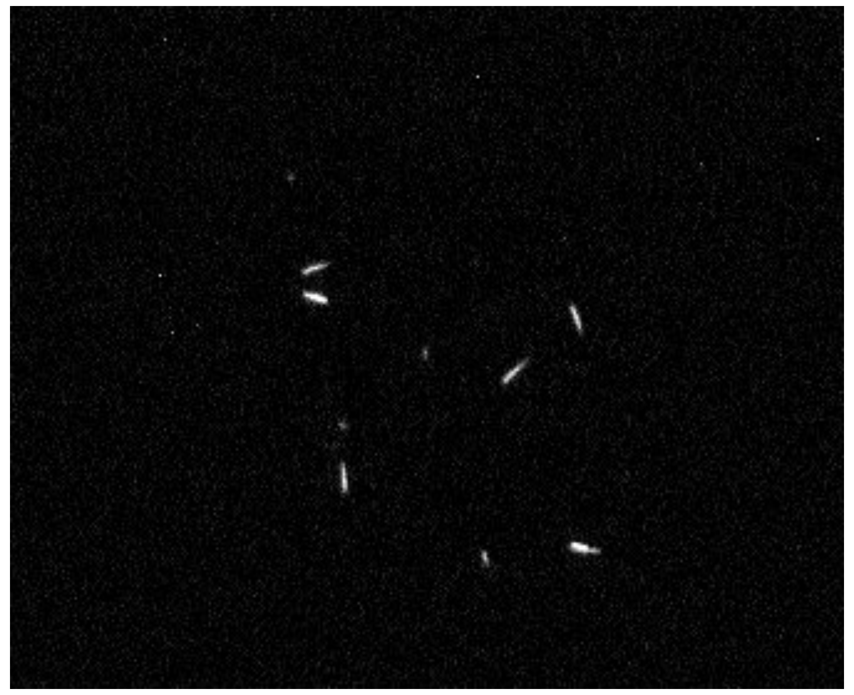
100 V/cm



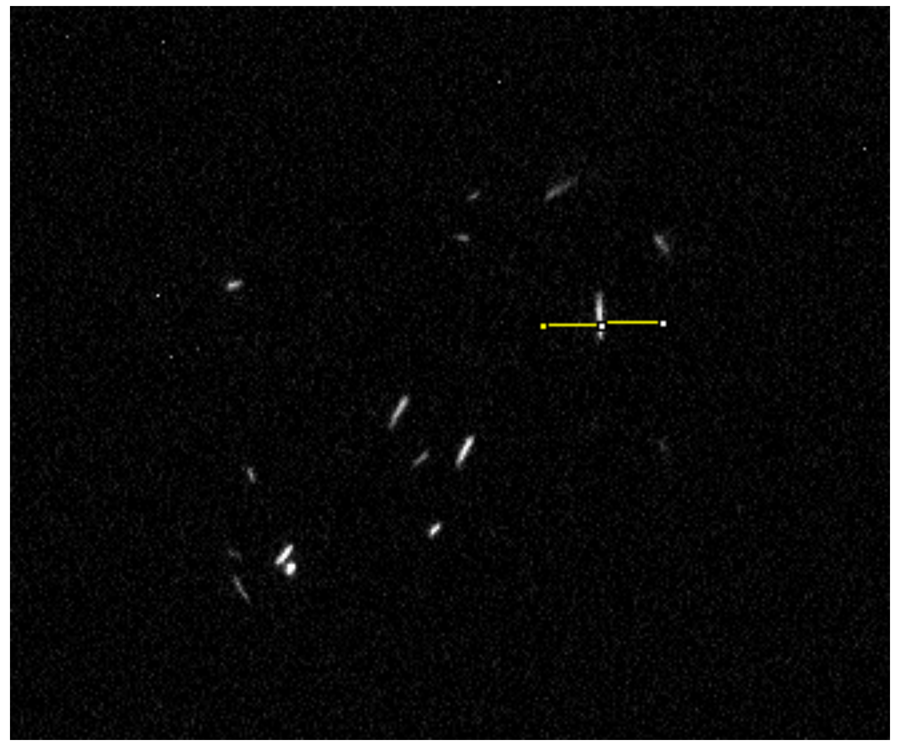
200 V/cm

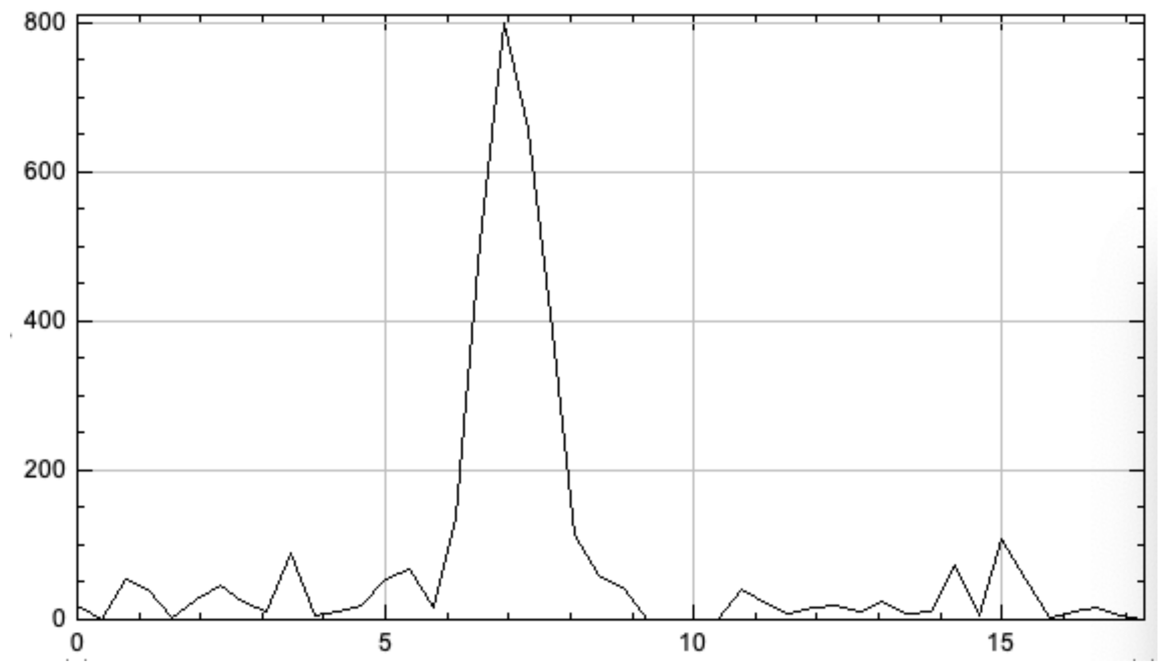


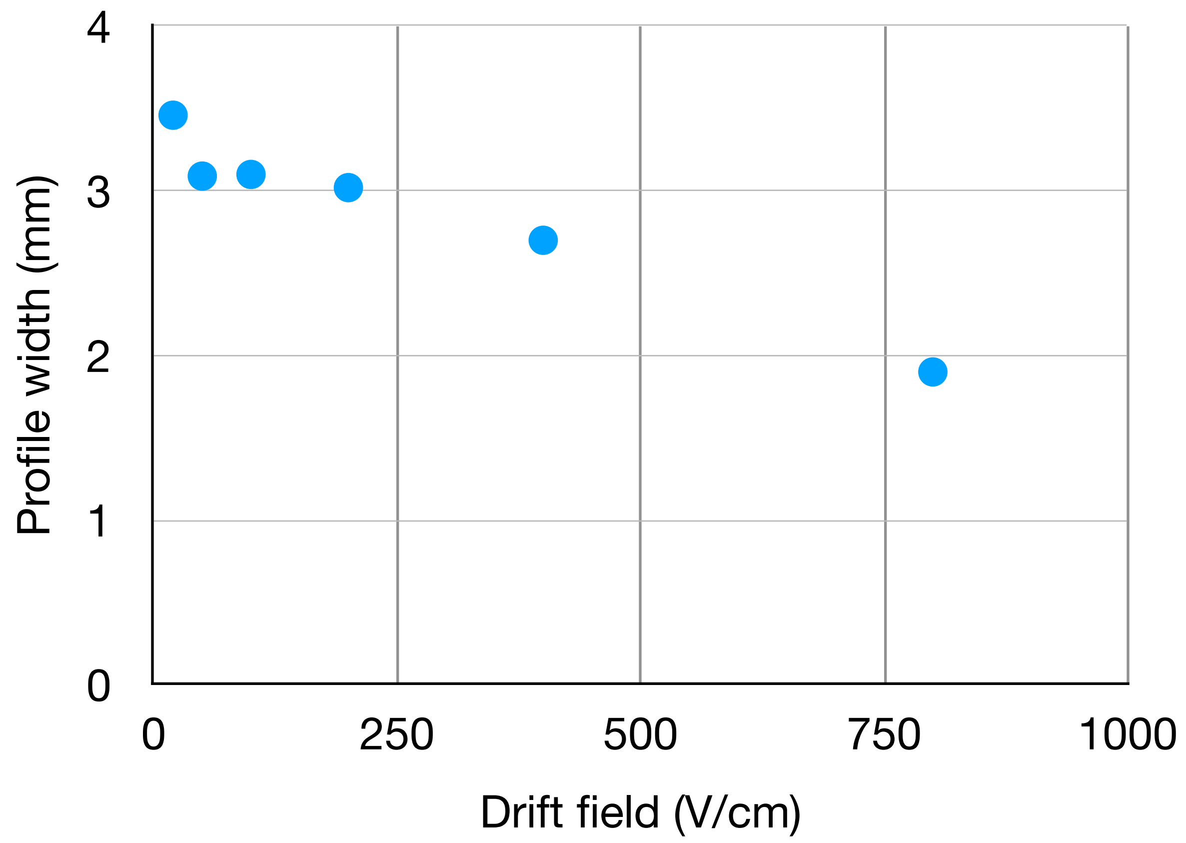
400 V/cm



800 V/cm



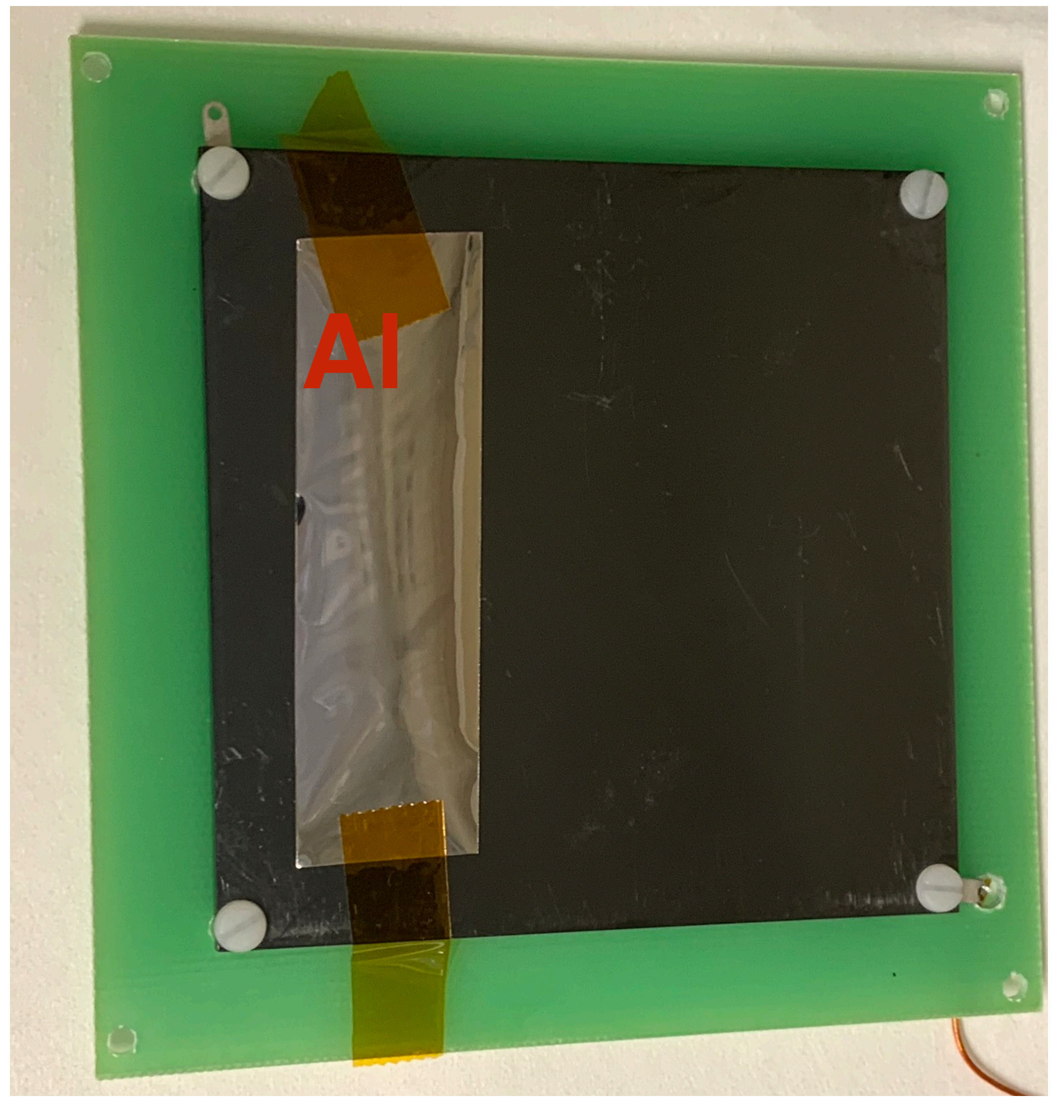


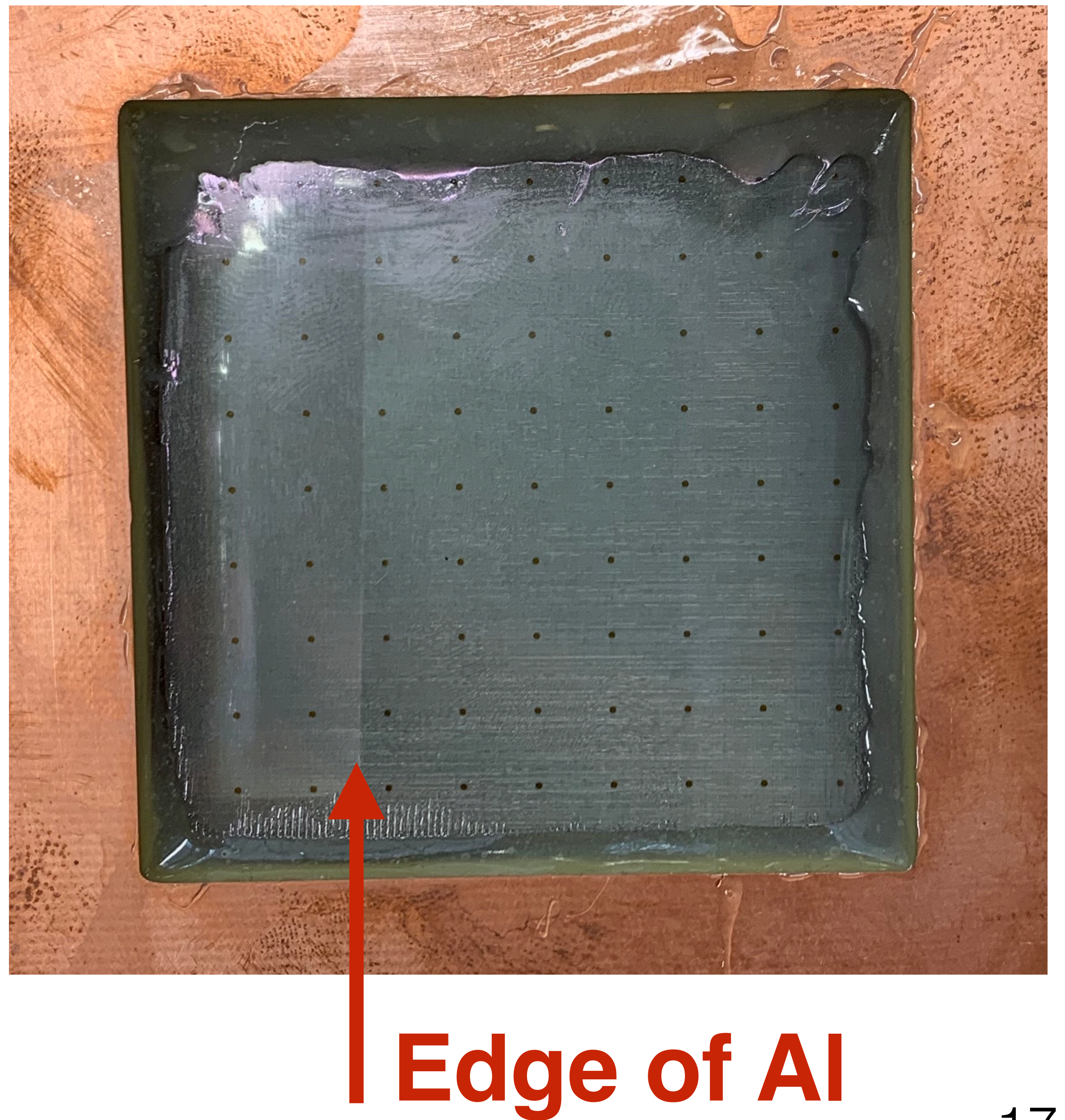


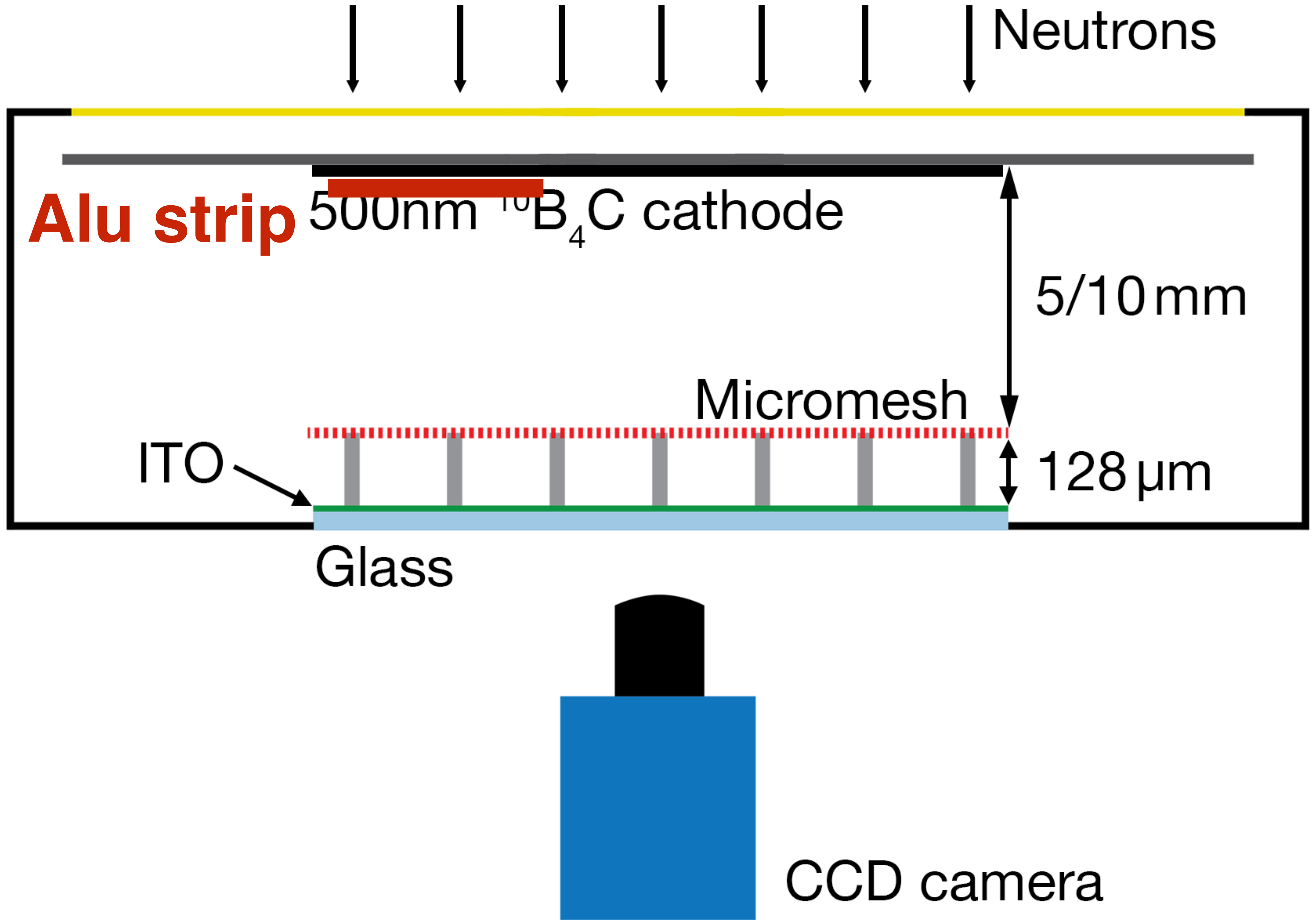
Ar/CF4 (80/20%), 5l/h
Mesh at GND
570V at anode
10mm drift

Spatial resolution measurement setup

- Glass MM on ITO
- 500nm thick B_4C layer with 99.9% ^{10}B enriched on metal plate as cathode **+ Alu strip on left part**
- 5mm or 10mm drift region thickness
- 200 V/cm drift field, mesh at GND, 580V on anode
- Am/Be neutron source
- Low light conditions, 8x8 binning, 1-5s exposures





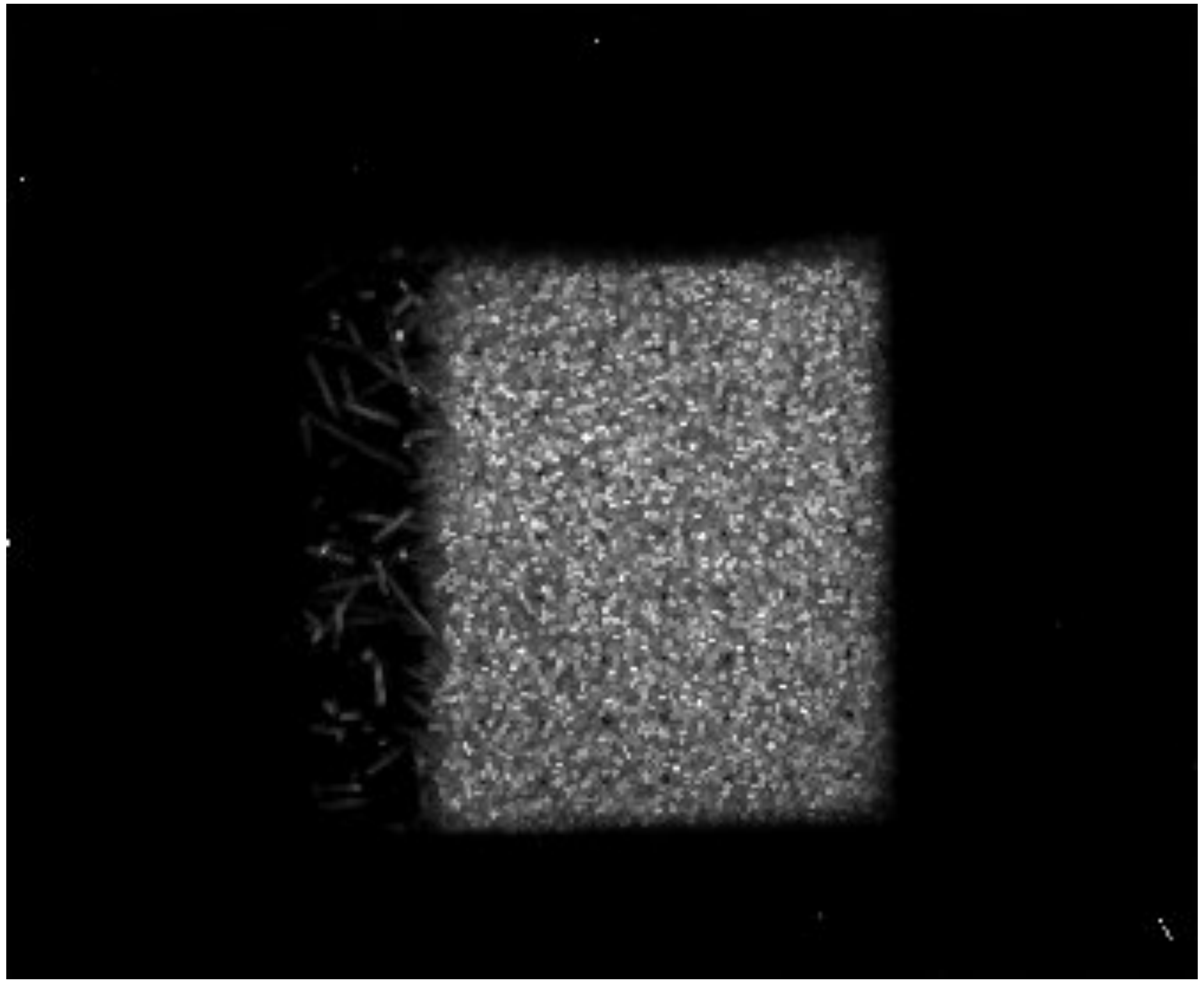


Spatial resolution

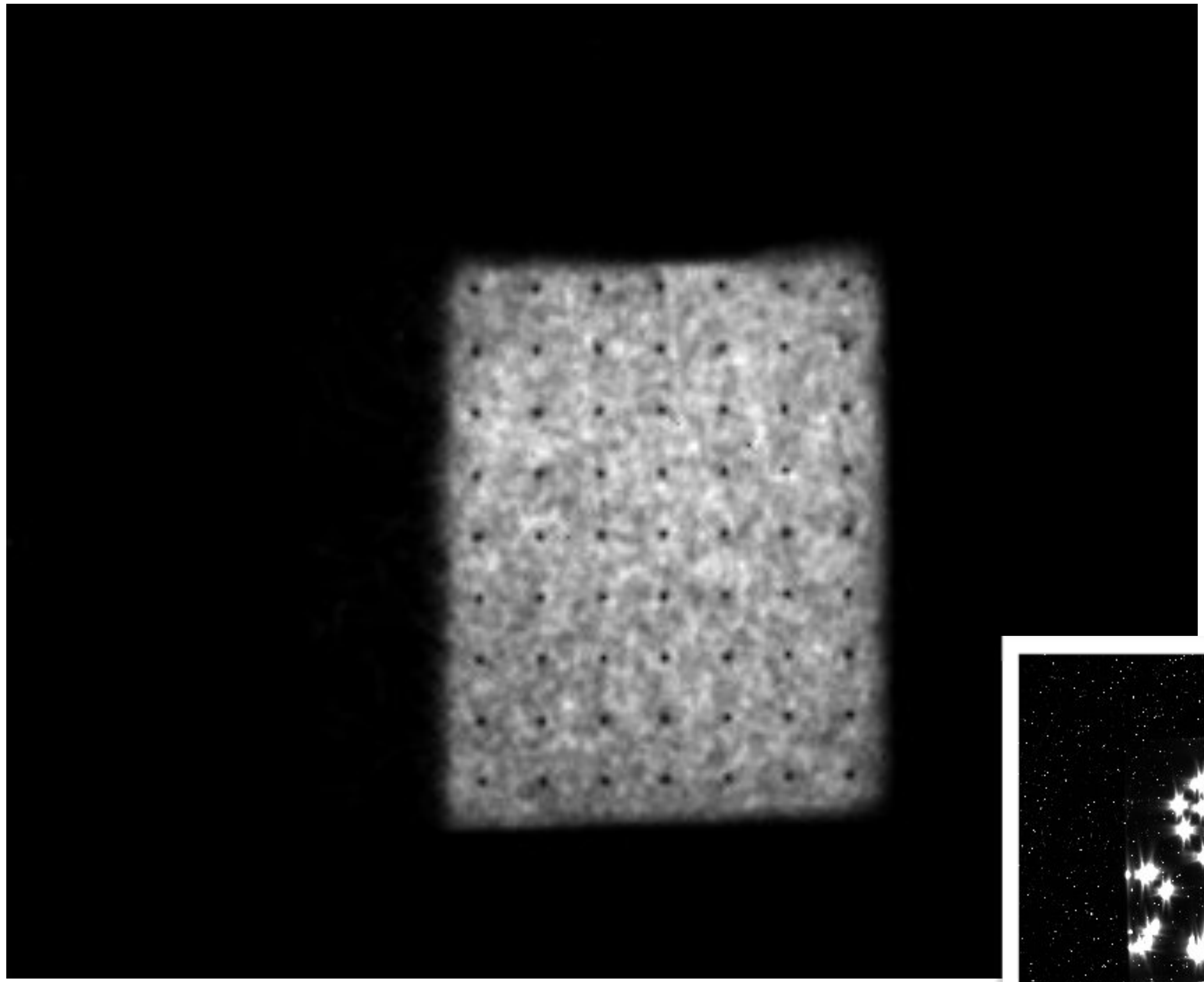
10mm drift region
11546x 5s = 16h
BG subtracted, sparks removed, Outlier filtered (r=1, th=5), 100 Subtracted

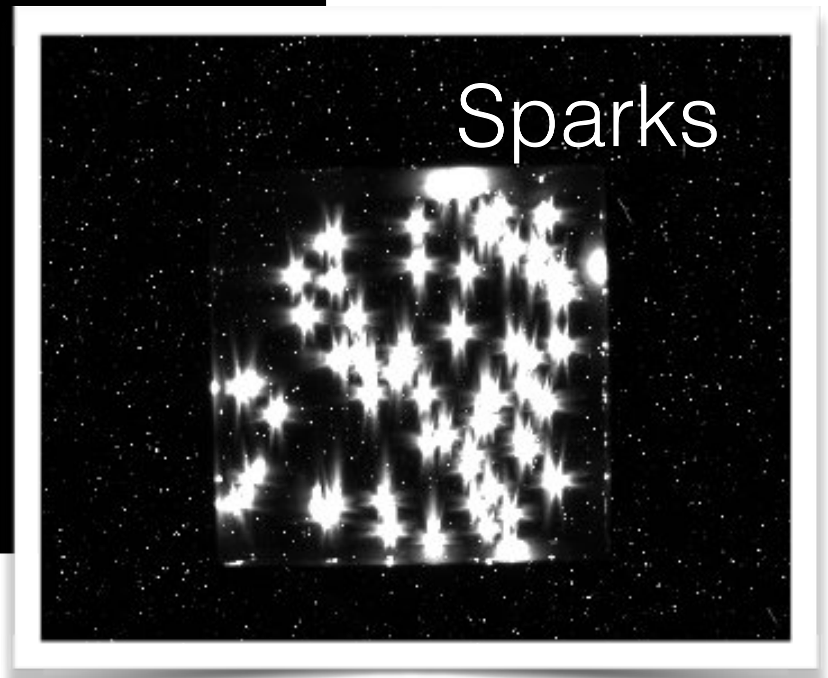
Edge of covered region visible in Max and summed images.

MAX intensity



SUM of intensity





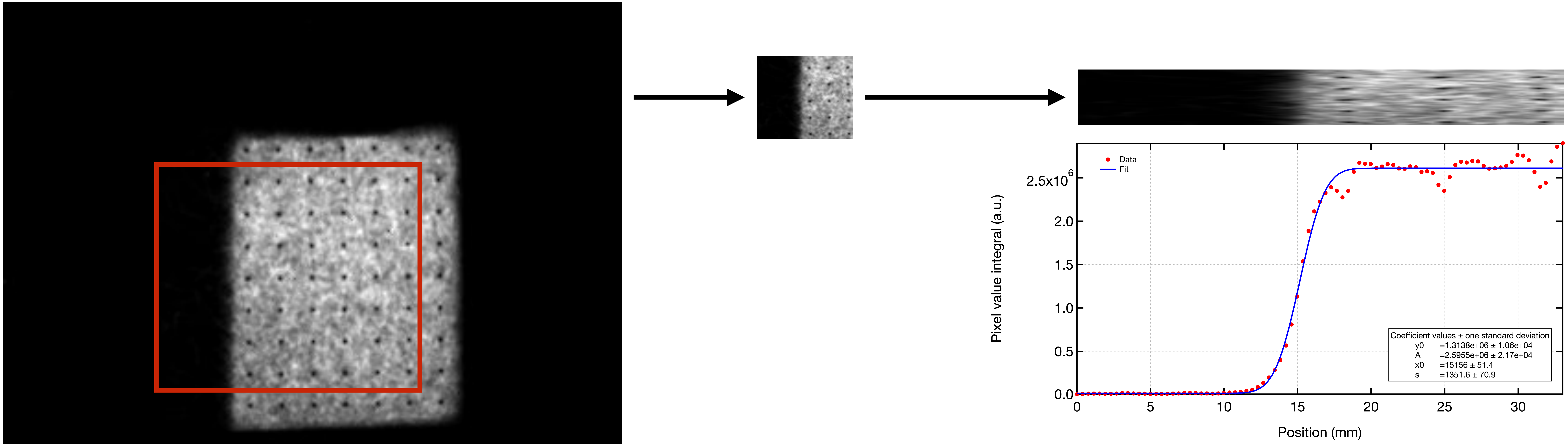
Ar/CF4 (80/20%), 5l/h, Partly covered
200 V/cm drift field, Mesh at GND, 570V at anode

Spatial resolution

10mm drift region
11546x 5s = 16h
BG subtracted, sparks removed, Outlier filtered (r=1, th=5), 100 Subtracted

1D projection of edge and fit with error function to extract spatial resolution.

SUM of intensity



Fit with error function:
y0 + (A/2)*erf((x-x0)/(sqrt(2)*s))

Spatial resolution: σ ≈ 1.3mm

Ar/CF4 (80/20%), 5l/h, Partly covered
200 V/cm drift field, Mesh at GND, 570V at anode

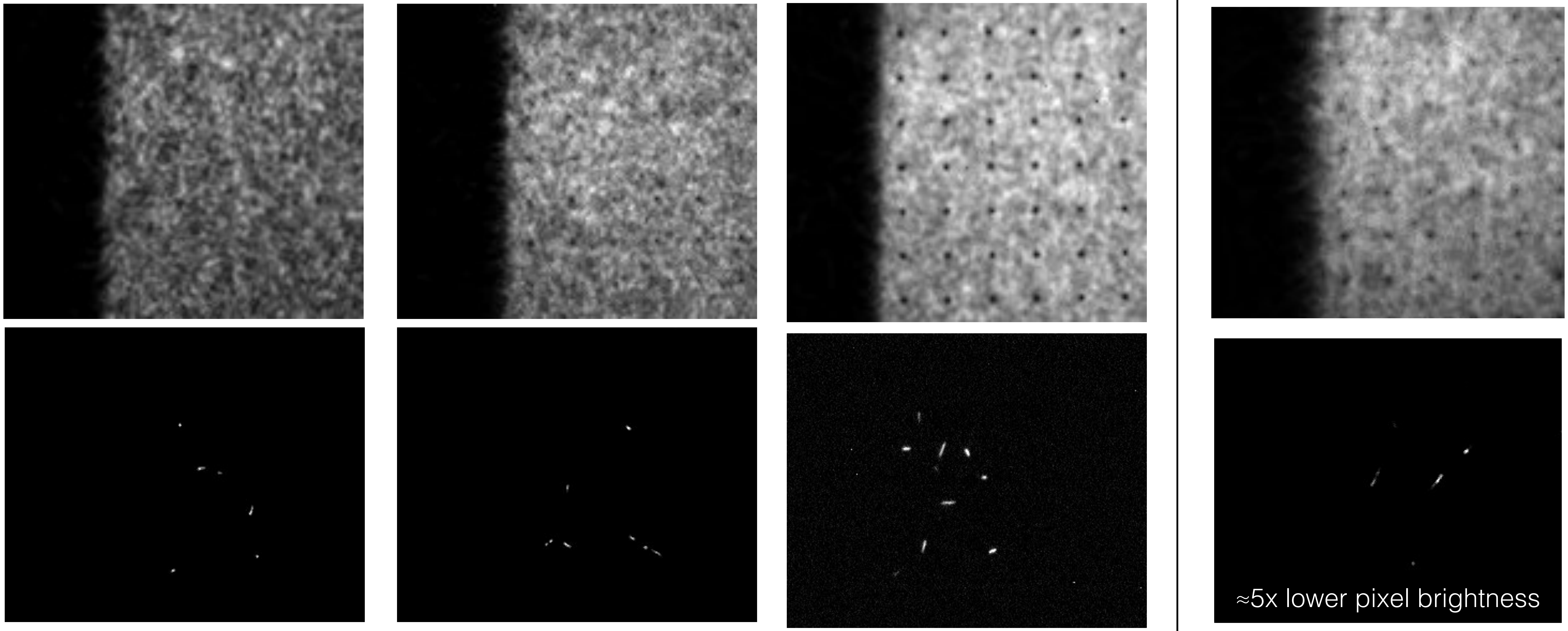
Spatial resolution - different drift gap

Ar/CF4 80/20 | **He/CF4 80/20**

1mm drift | 2mm drift | 10mm drift | 10mm drift

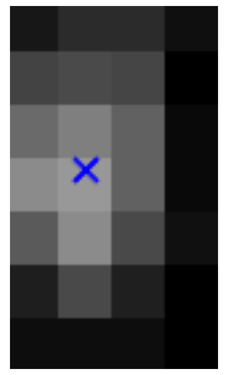
Image sum

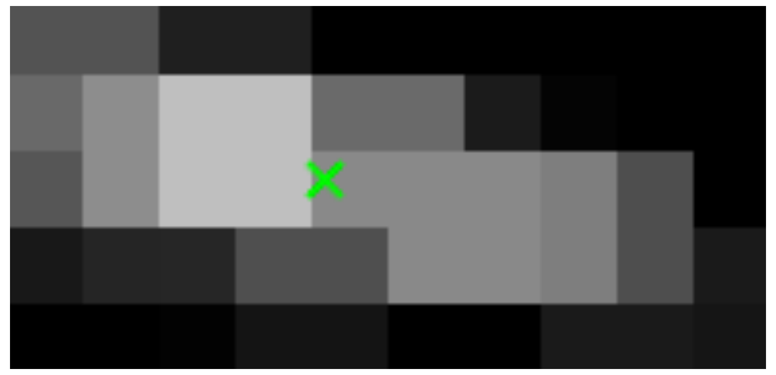
Example frame

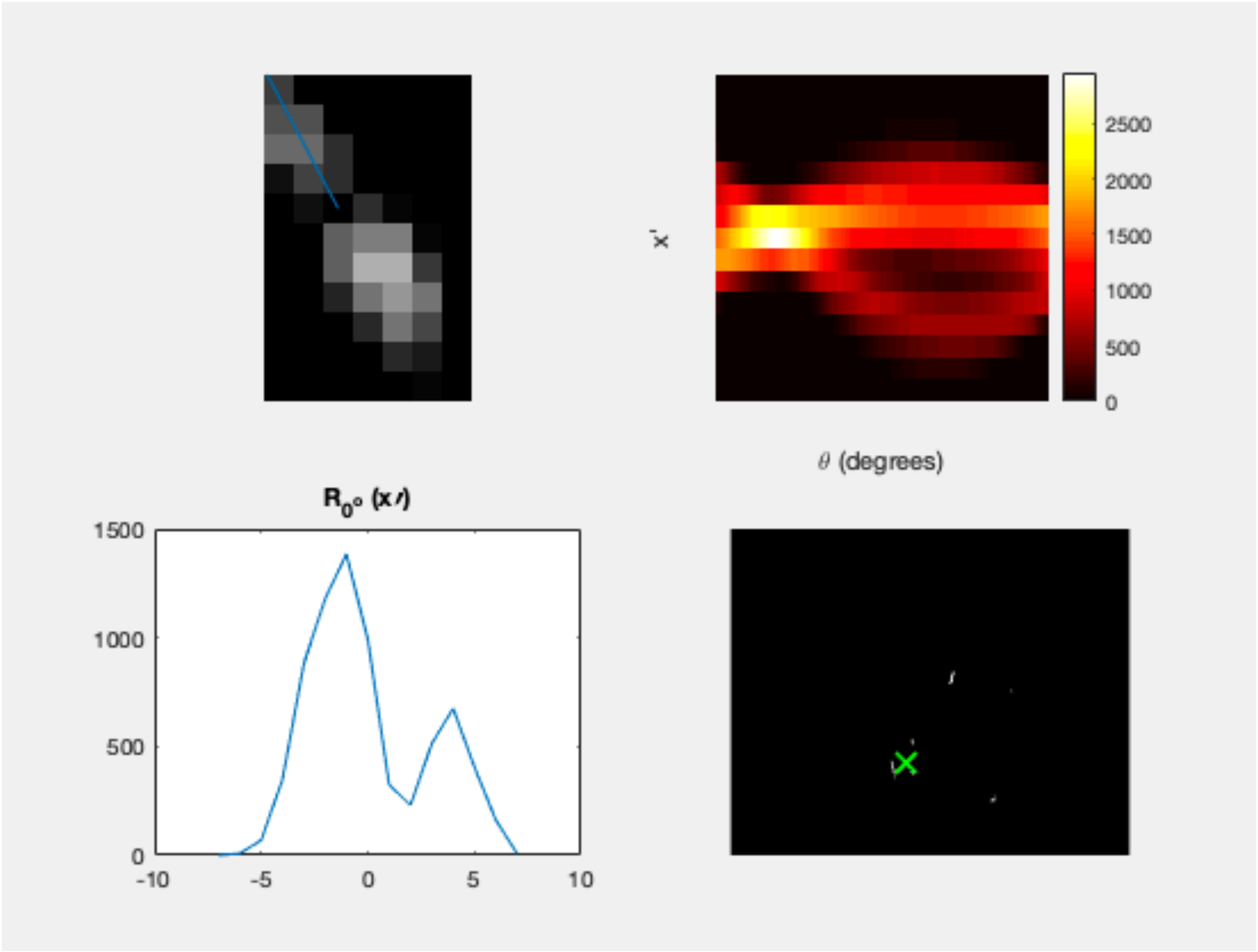


Ar/CF4 (80/20%), 5l/h, Partly covered
200 V/cm drift field, Mesh at GND, 560/570V at anode

Spatial resolution

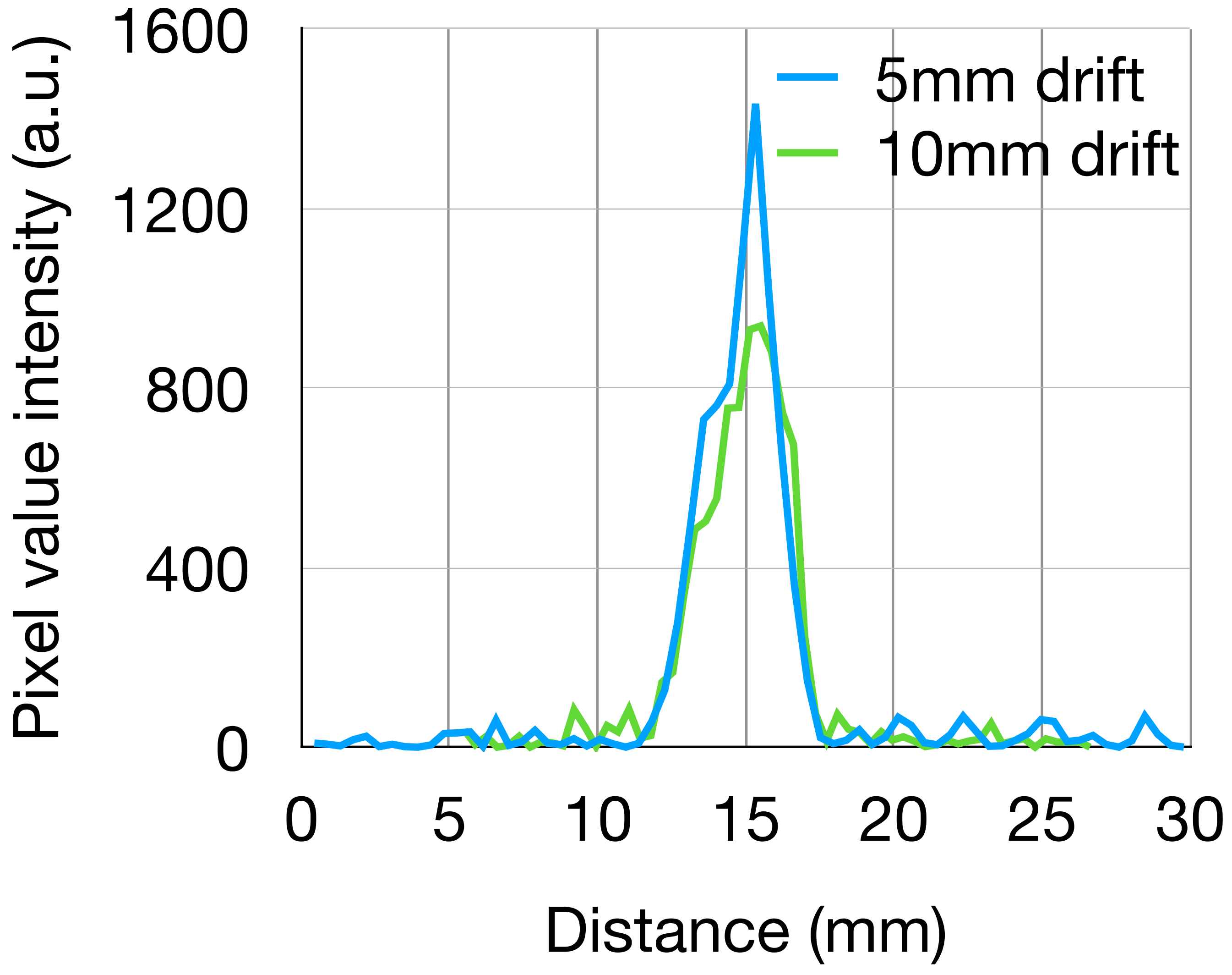


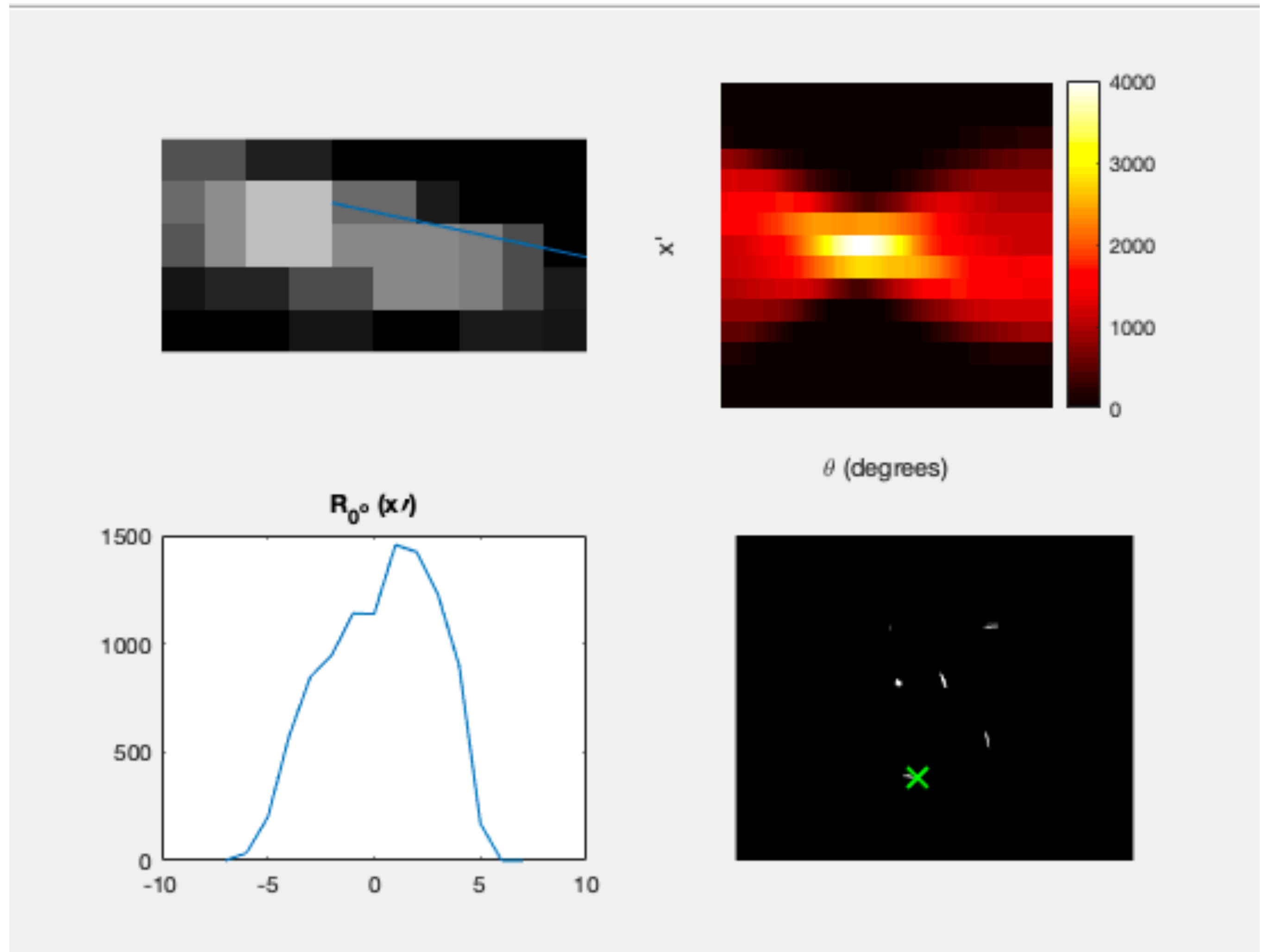




Used different reconstruction methods to determine hit location from same set of images

- Image sum: sum of intensity
- COG: all events (spot/track) with COG hotpoint determination
- COG+Tracks: identify tracks for longer (major axis) tracks, use min side



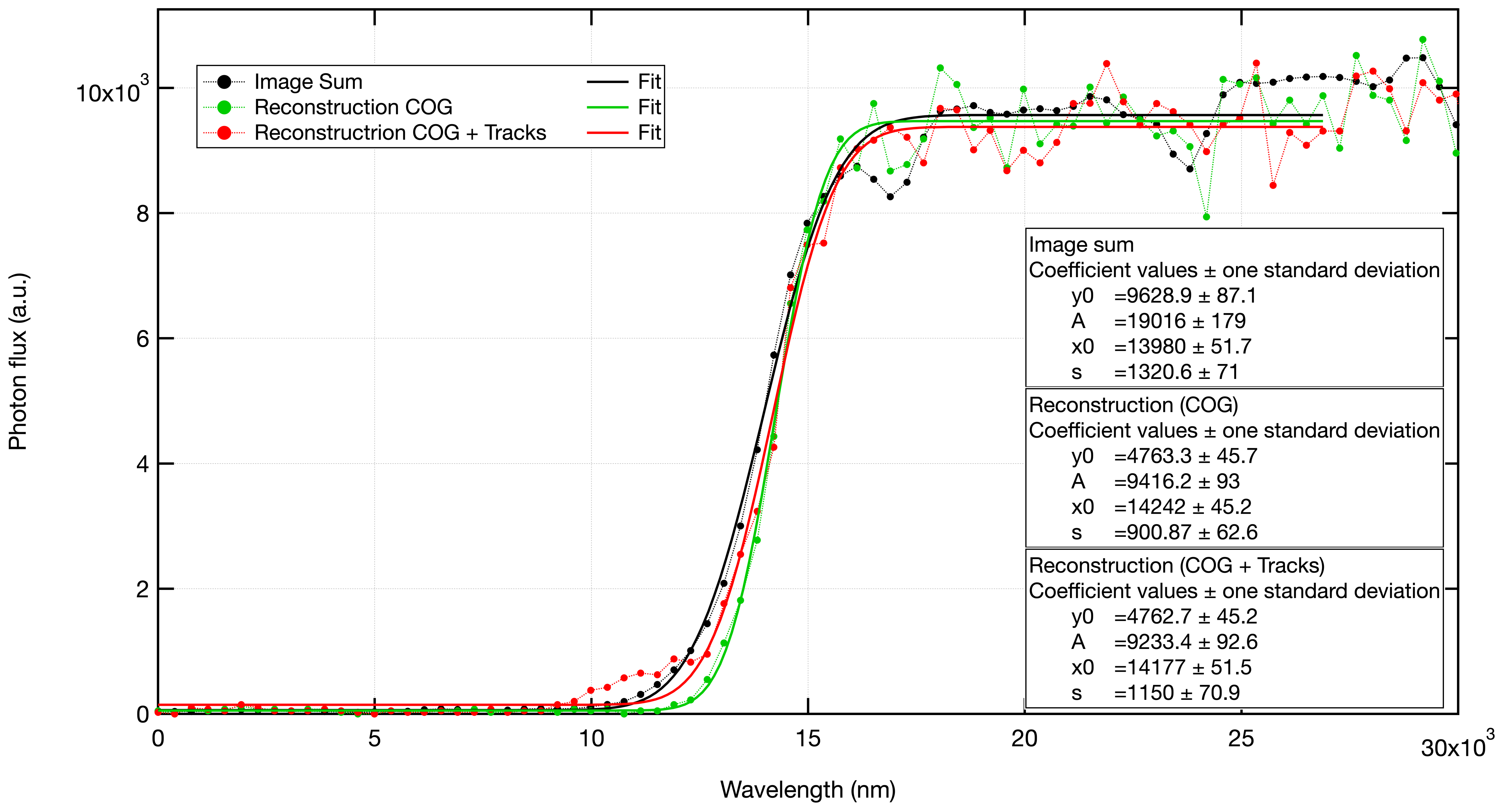


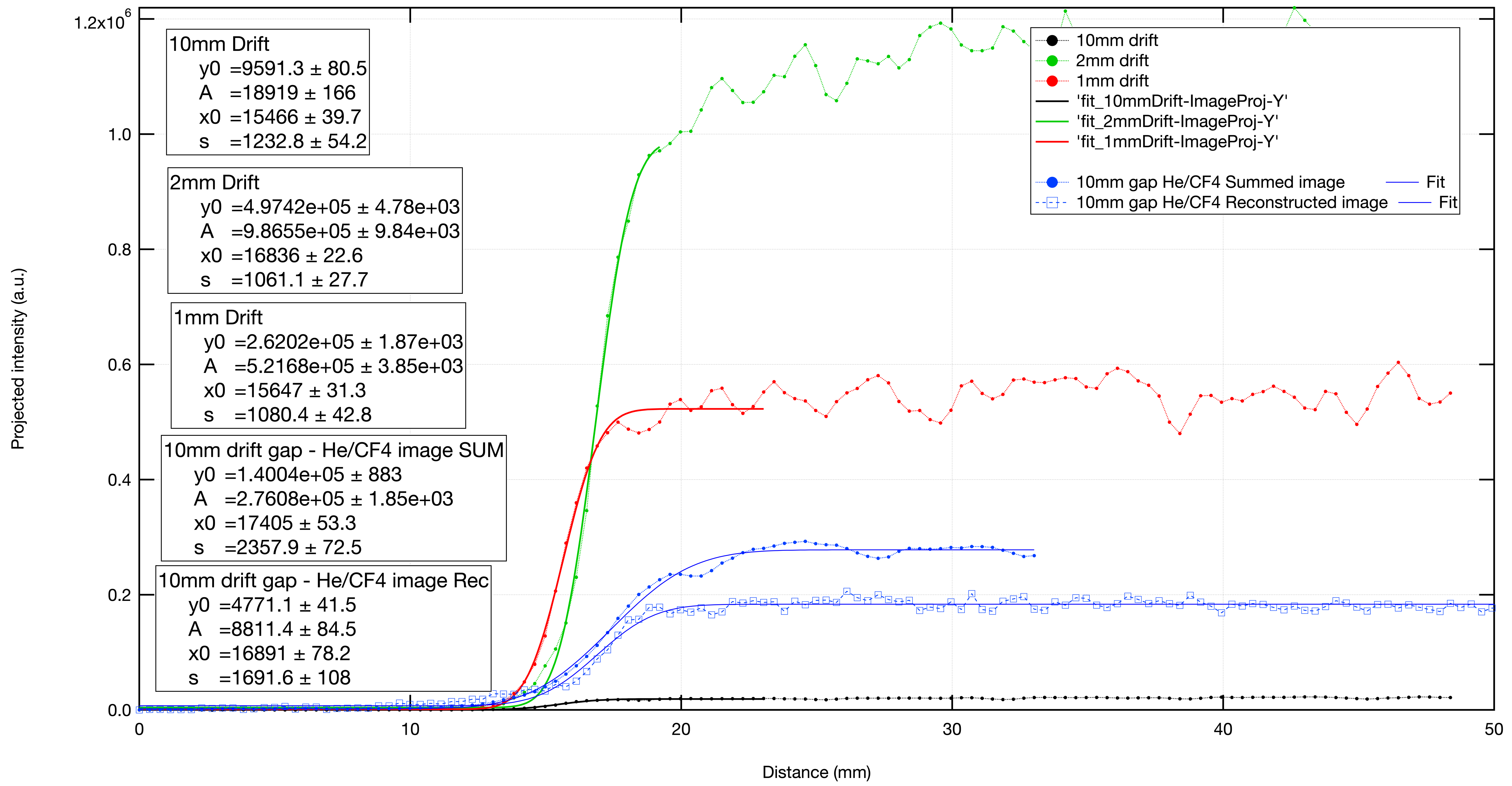
Spatial resolution

Reconstructed images provide higher spatial resolution than summed up (integrated) images.

Track finding and starting point determination algorithm to be improved and refined.

No significant improvement of spatial resolution observed with smaller drift gaps.





Ar/CF4 (80/20%)/HeCF4, 5l/h, Partly covered
200 V/cm drift field, Mesh at GND, 560/570V at anode (500V HeCF4)

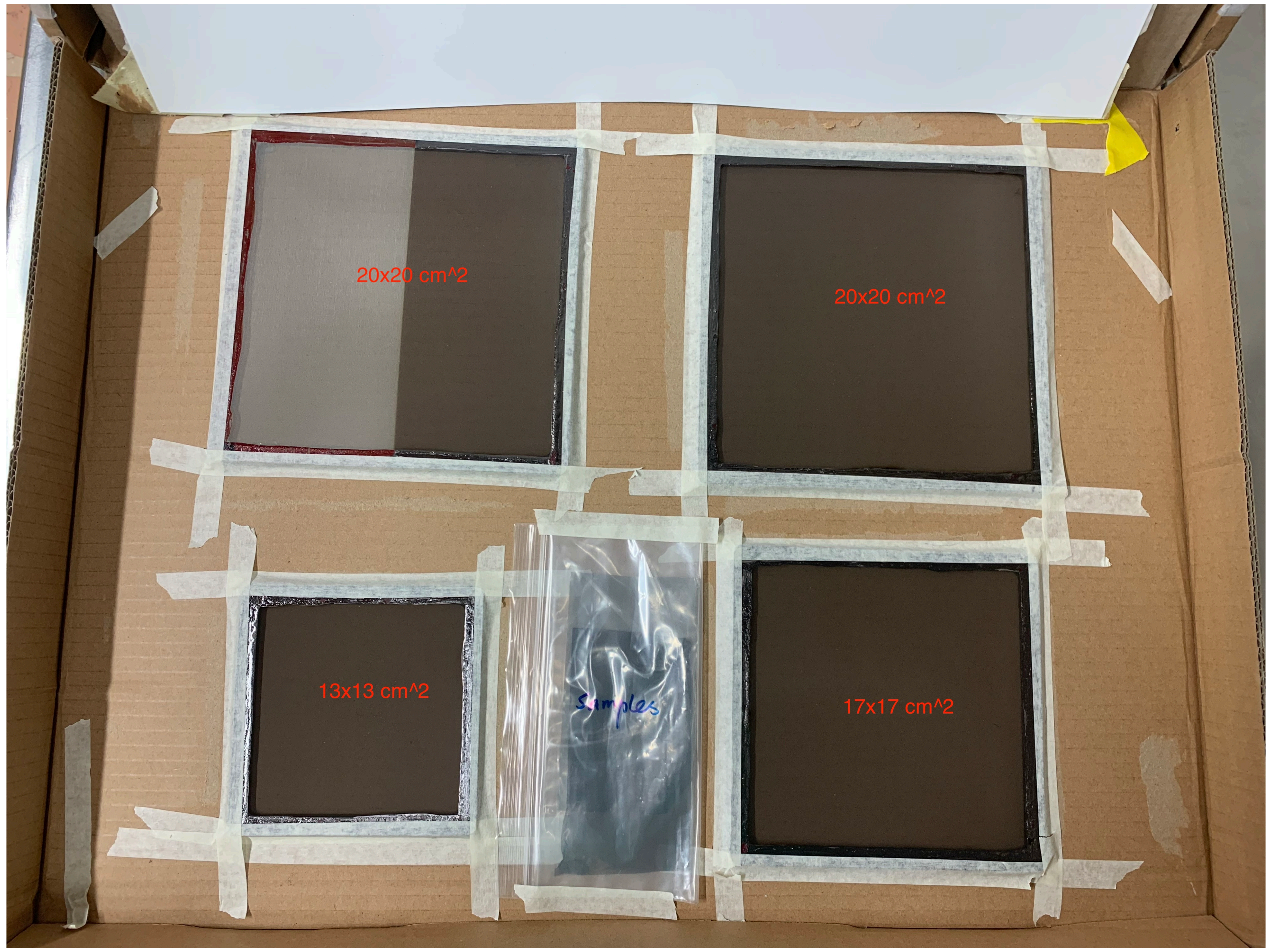
DLC-coated black meshes

DLC-coated meshes

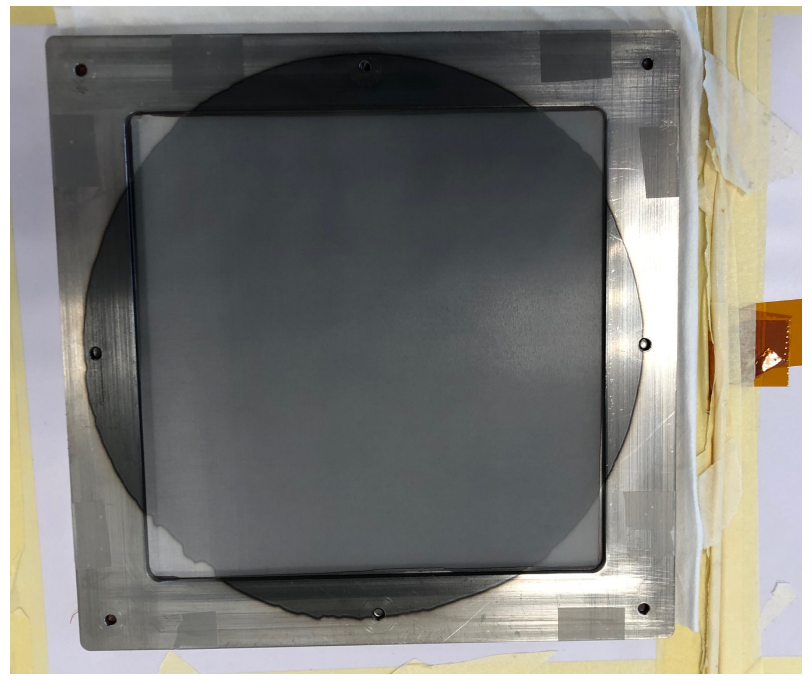
Several different DLC-coated meshes available from two difference sources

Integrated in bulk glass Micromegas and as exchangeable mesh on individual frames

Coated by Yi (USTC)

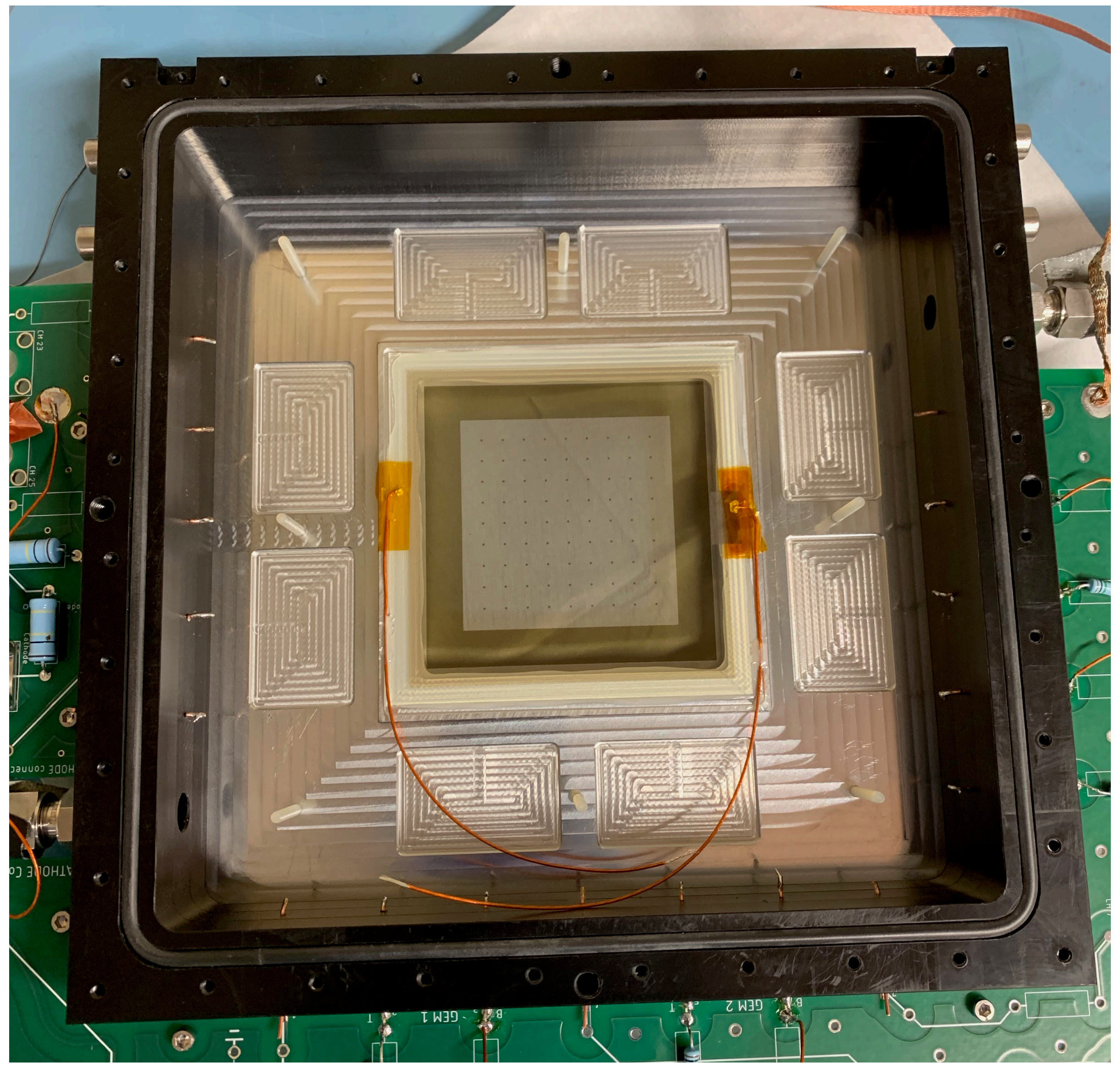


Coated by Australian company

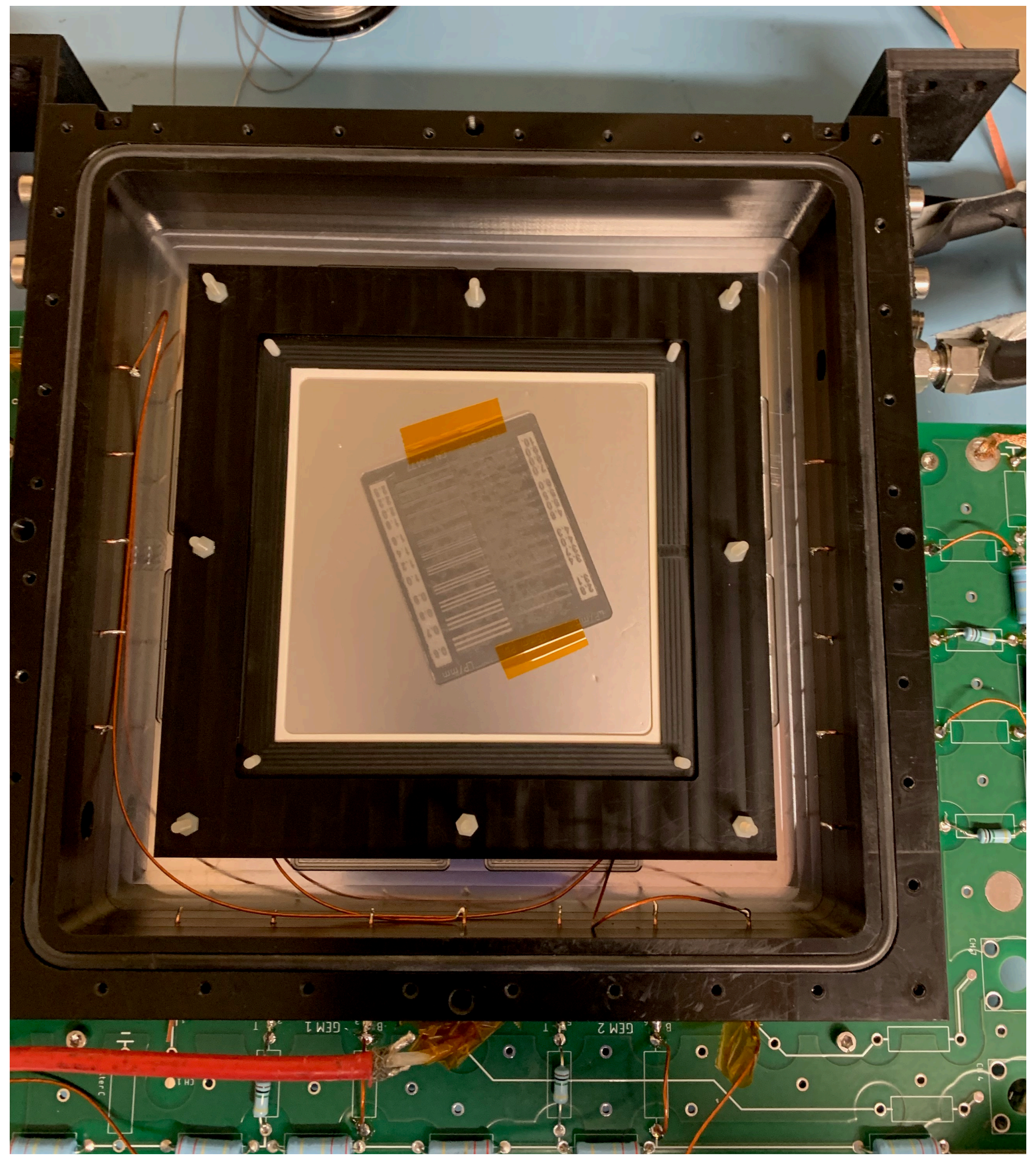


Setup

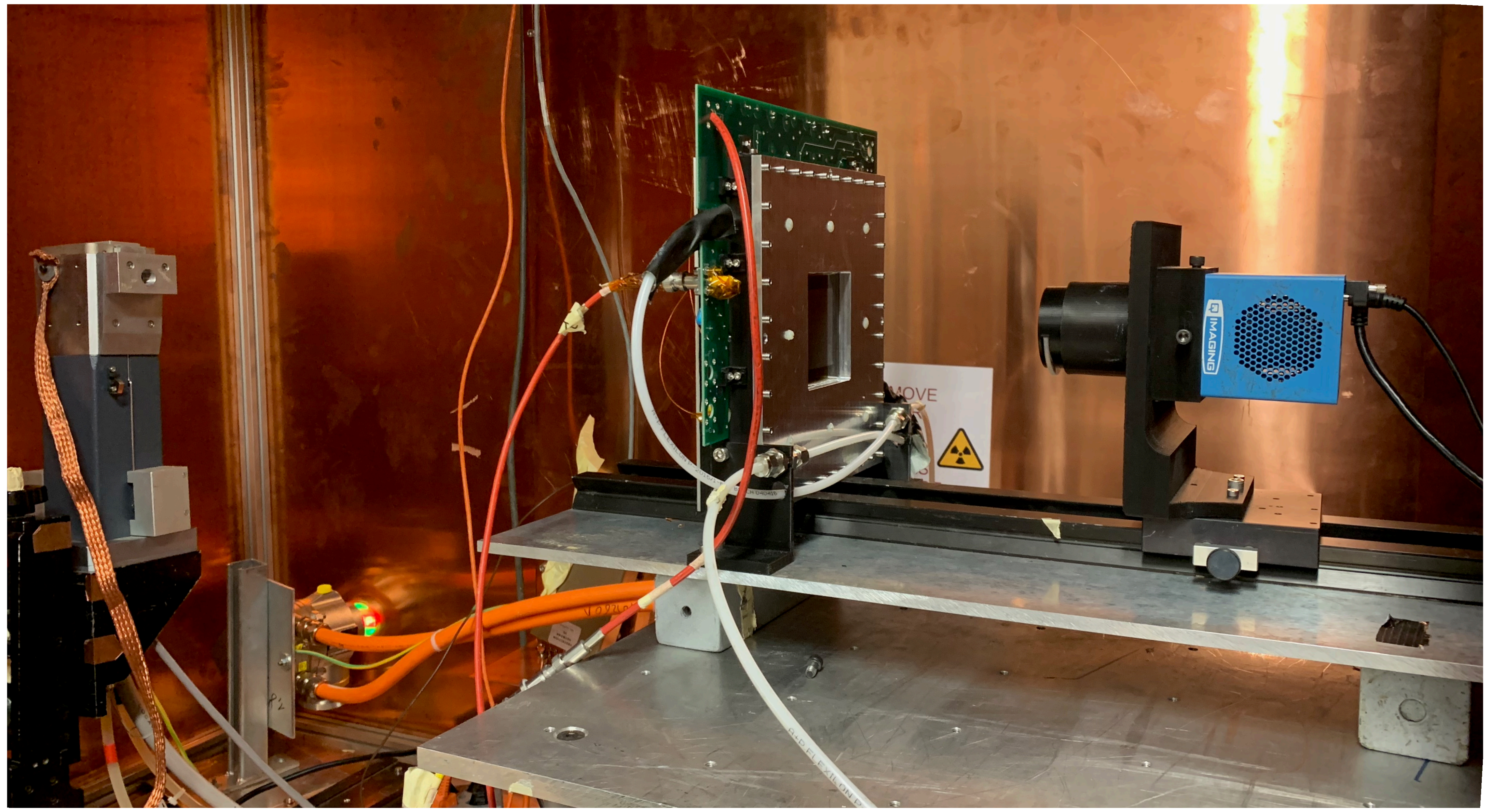
Bulk Glass MM mounted in chamber



Line mask mounted on Alu cathode

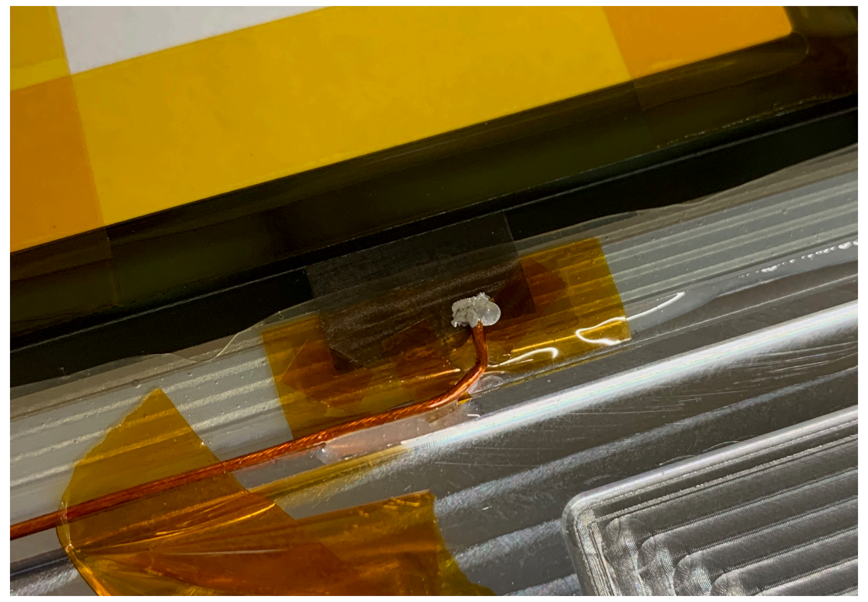


Detector in front of X-ray tube (70cm distance) and camera looking through glass substrate from behind

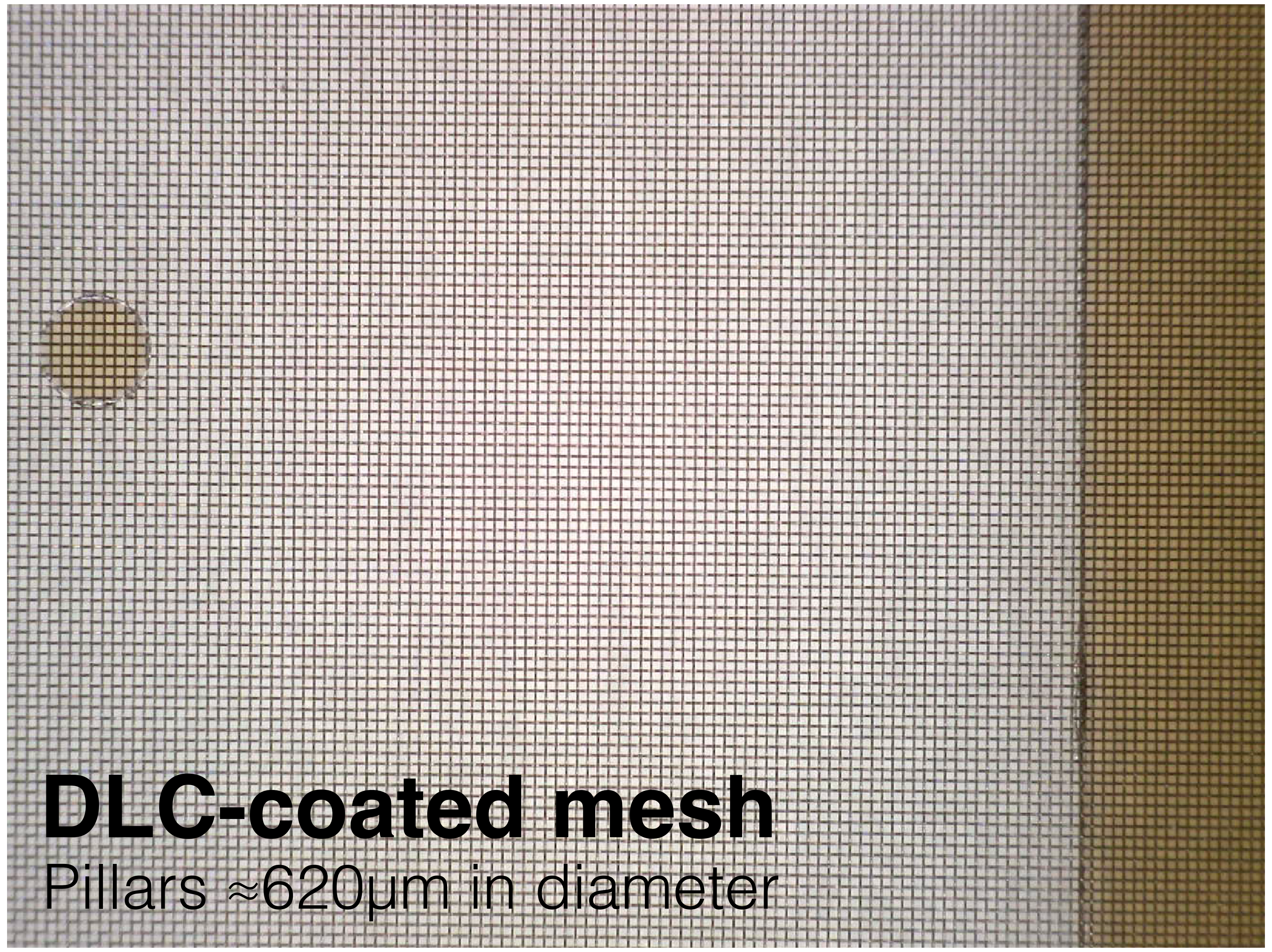


2mm drift gap, Alu cathode with mask phantom on top

Ar/CF4 80/20, 5l/h
X-ray tube, 70cm distance, 20kV, 3mA
For spatial resolution: 100V/cm drift, 530V on anode, mesh GND
1x1, gain 2, 30s exposure, AVG, BG subtracted, 17mm lens with +3 dioptre



Bulk Glass MM with standard and DLC-coated meshes



Microscope pictures of standard and DLC-coated meshes used in bulk glass MM

Pillars in DLC-coated mesh detector larger

DLC-coated mesh detector with mesh from Australian supplier

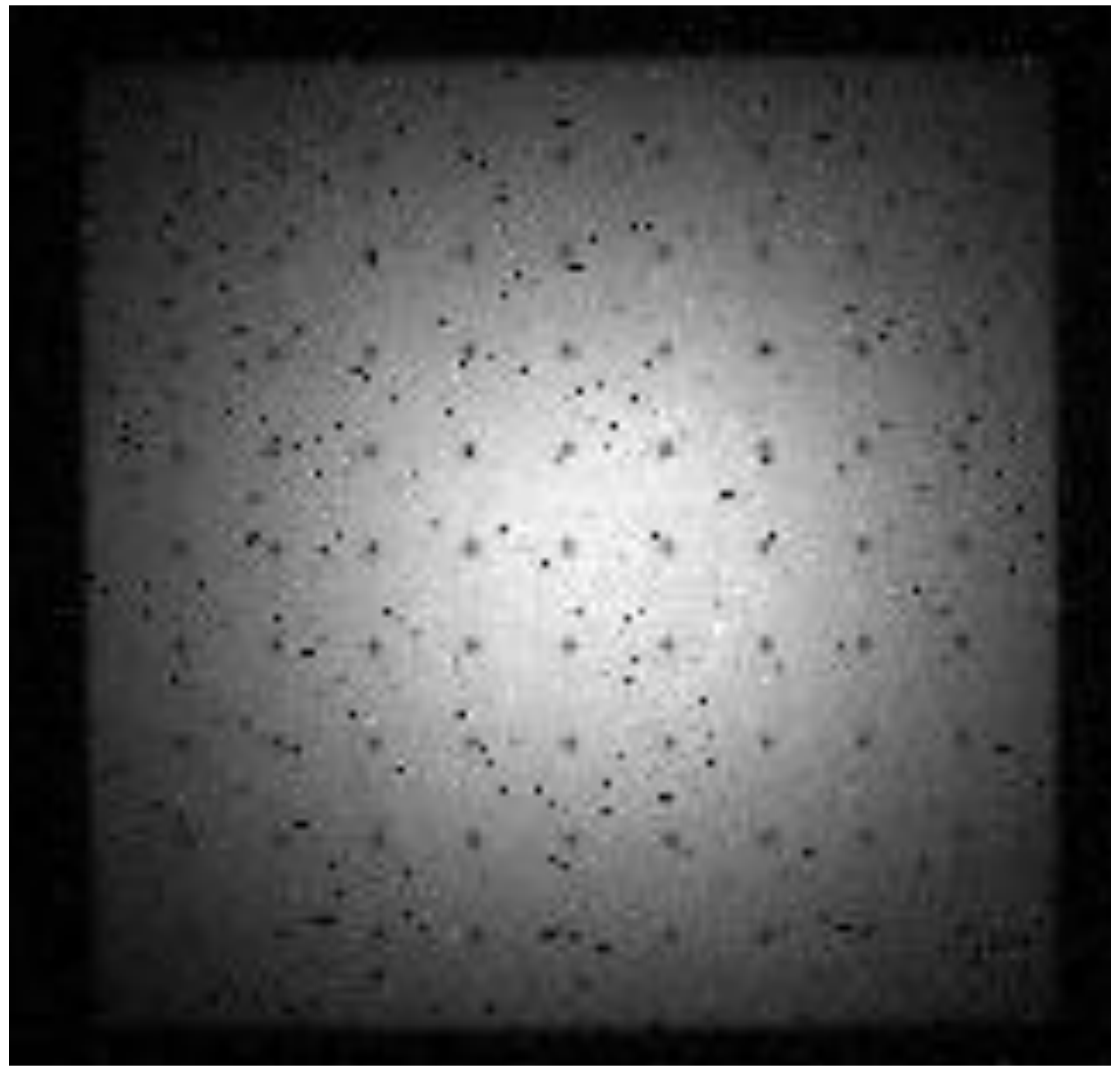
First operation with ^{55}Fe

First operation in He/CF4 80/20 with Fe55 source

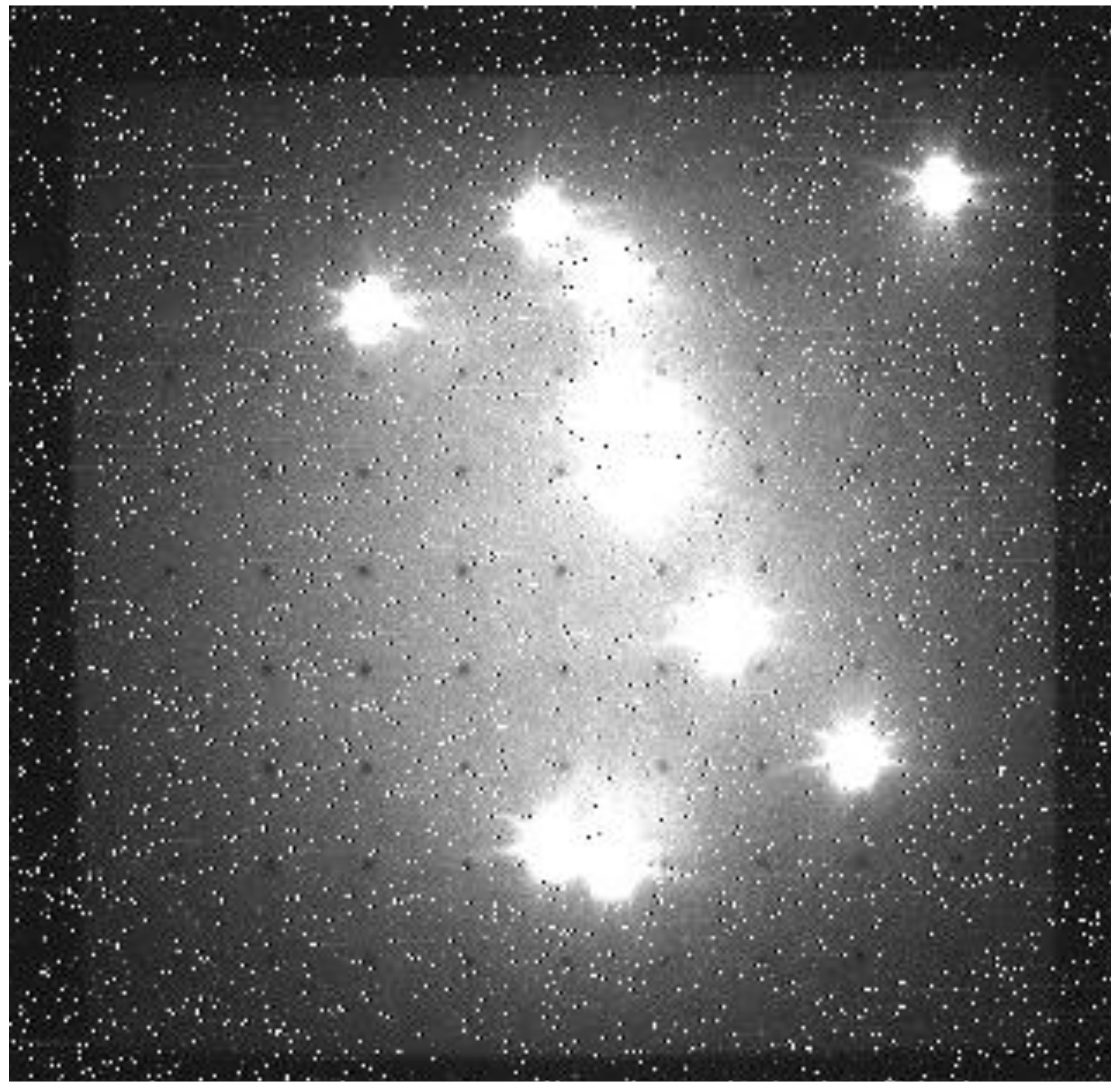
Low light output and limited gain

Possible to see Fe55 source profile for long exposures and with averaging

Fe55 source profile



Sparks (550V anode)



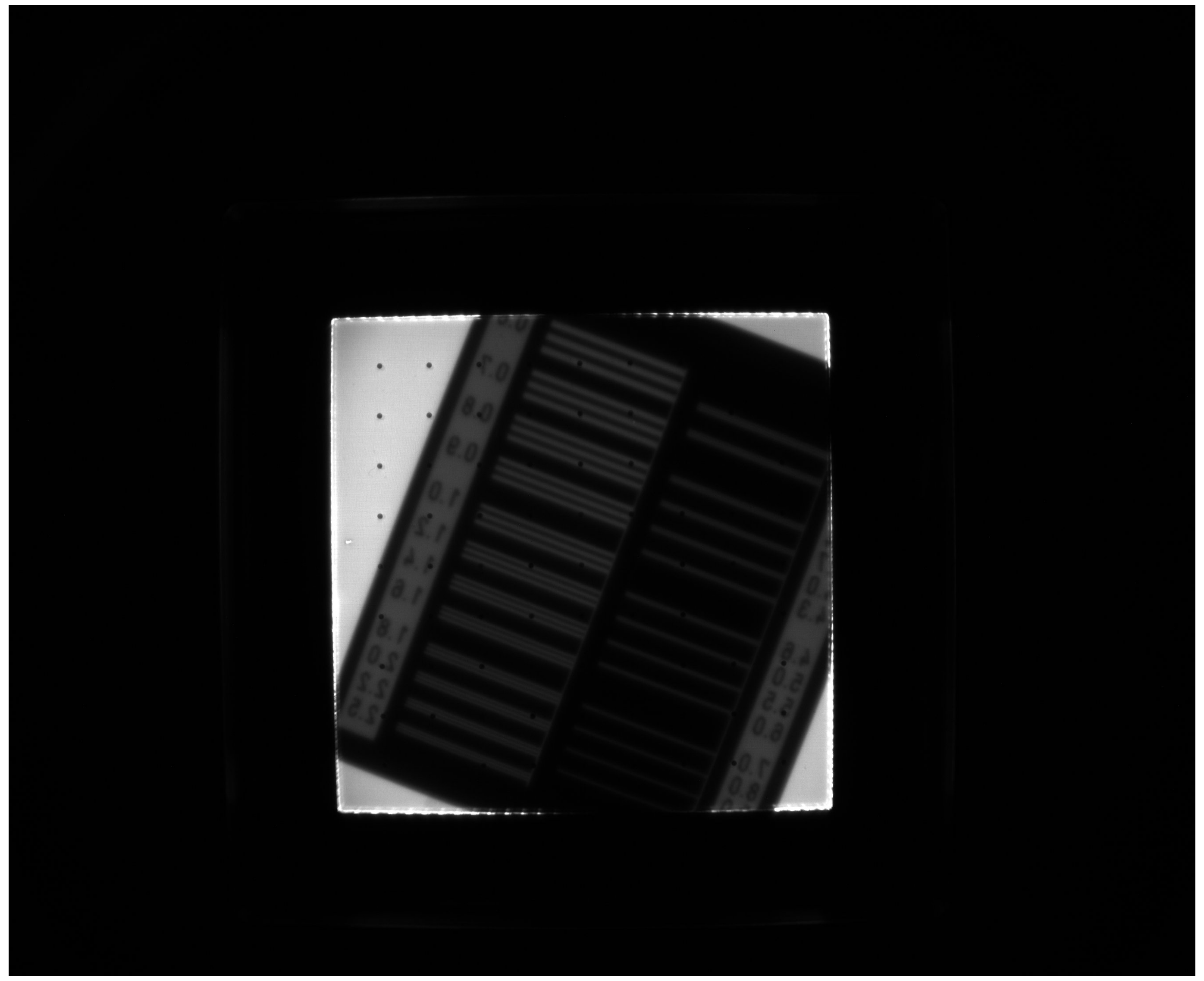
He/CF4 80/20, 5l/h
Fe55 source, 1cm drift, 500V/cm drift, Mesh GND, anode 540V
8x8, gain 2, 10s exposure,
AVG, BG subtracted, Outlier filtered

Bulk Glass MM with DLC-coated mesh

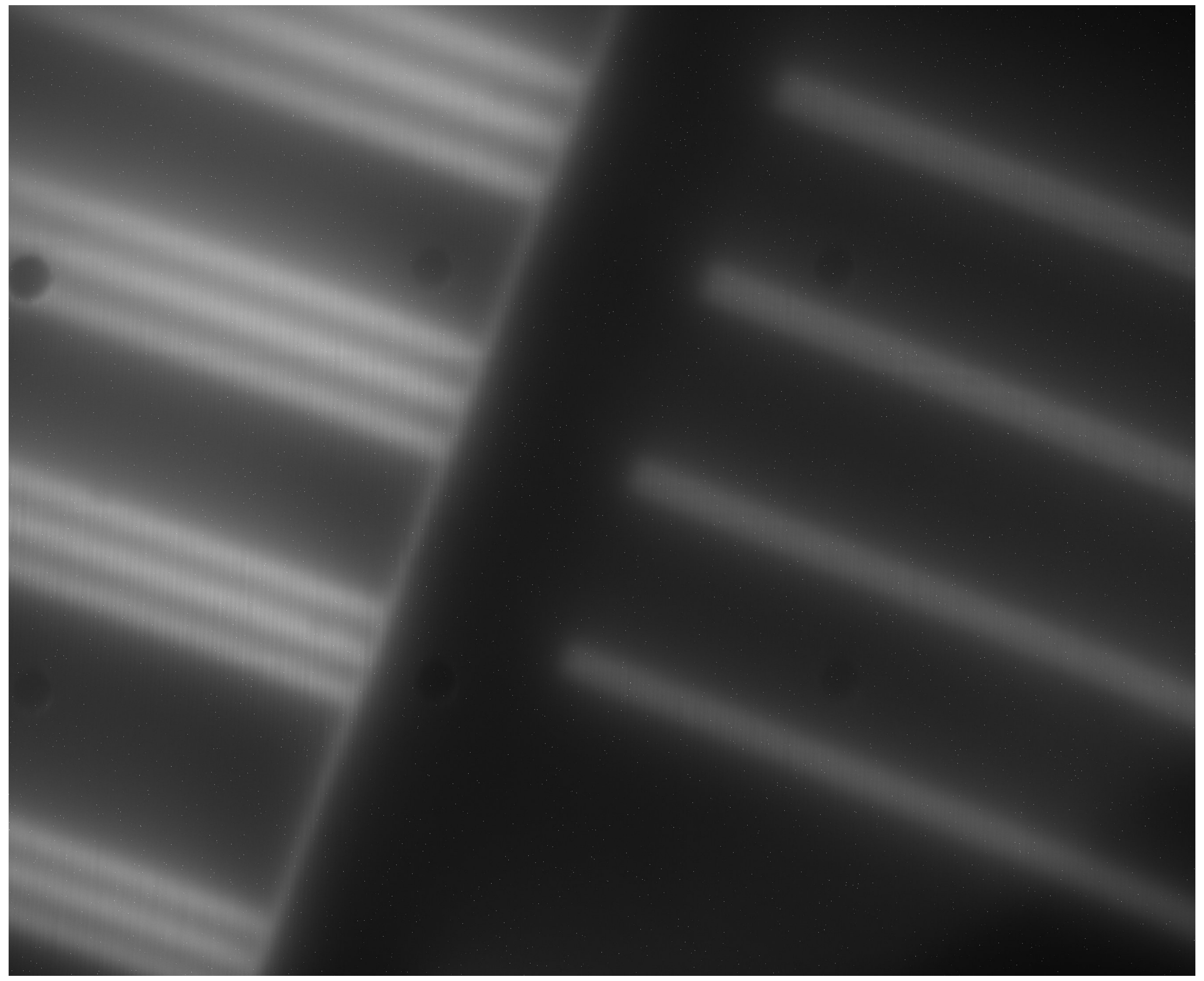
Recorded images of full view of detector and closeup images

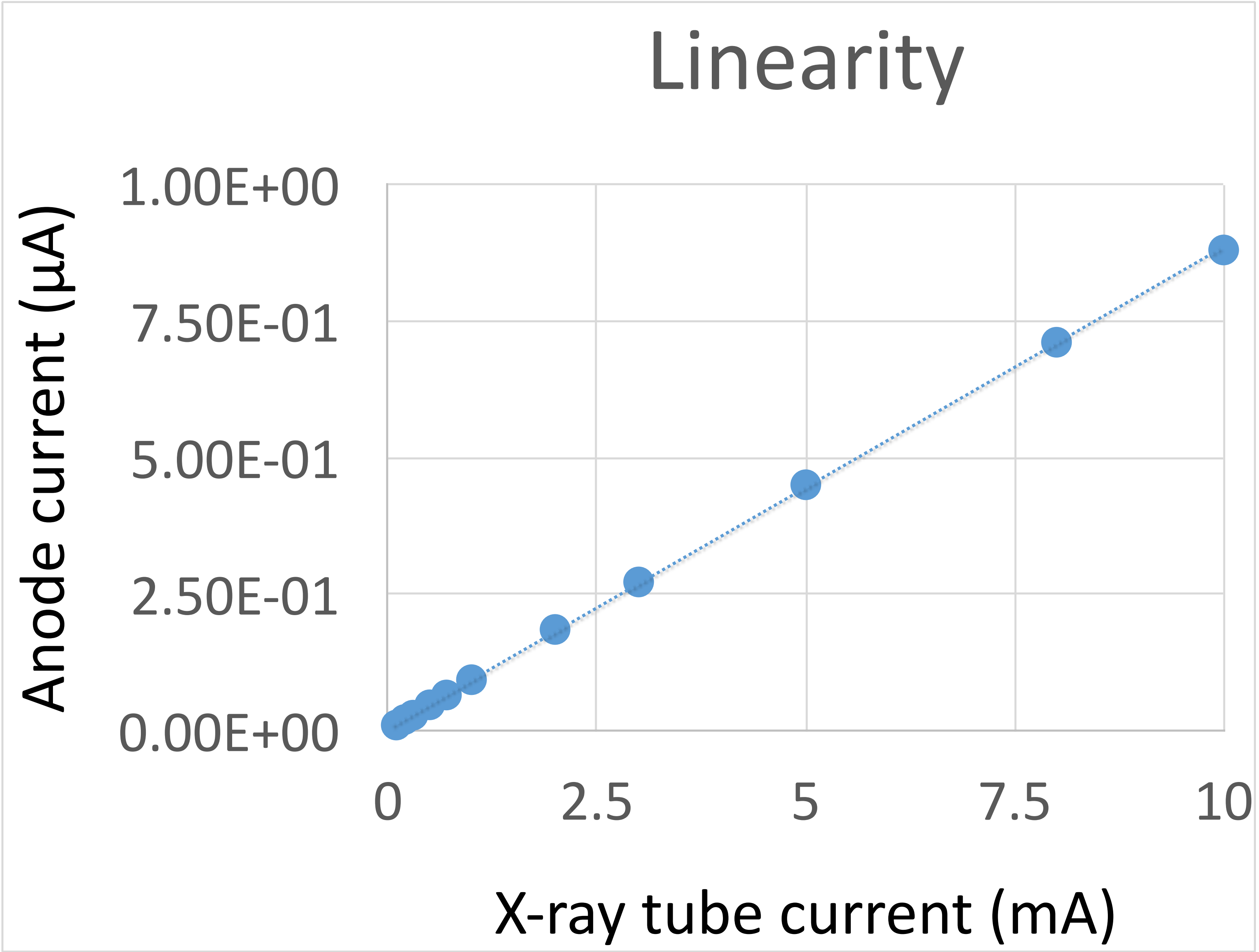
Verified linearity with increasing X-ray tube intensity

Full view recorded for spatial resolution measurement (17mm lens with +3 dioptre)



Full view recorded for closeup view (50mm lens with +3 dioptre)

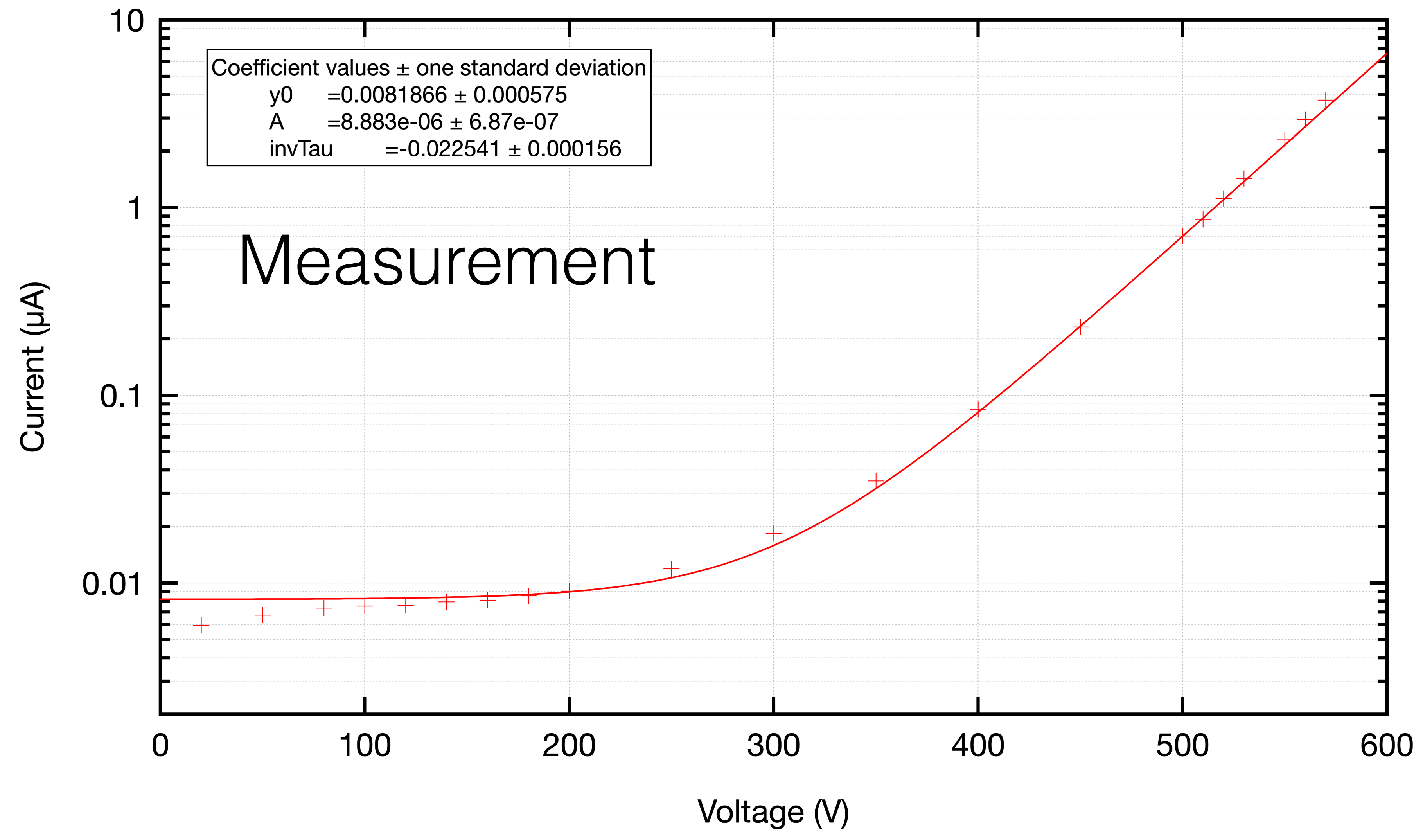




Bulk Glass MM with DLC-coated mesh

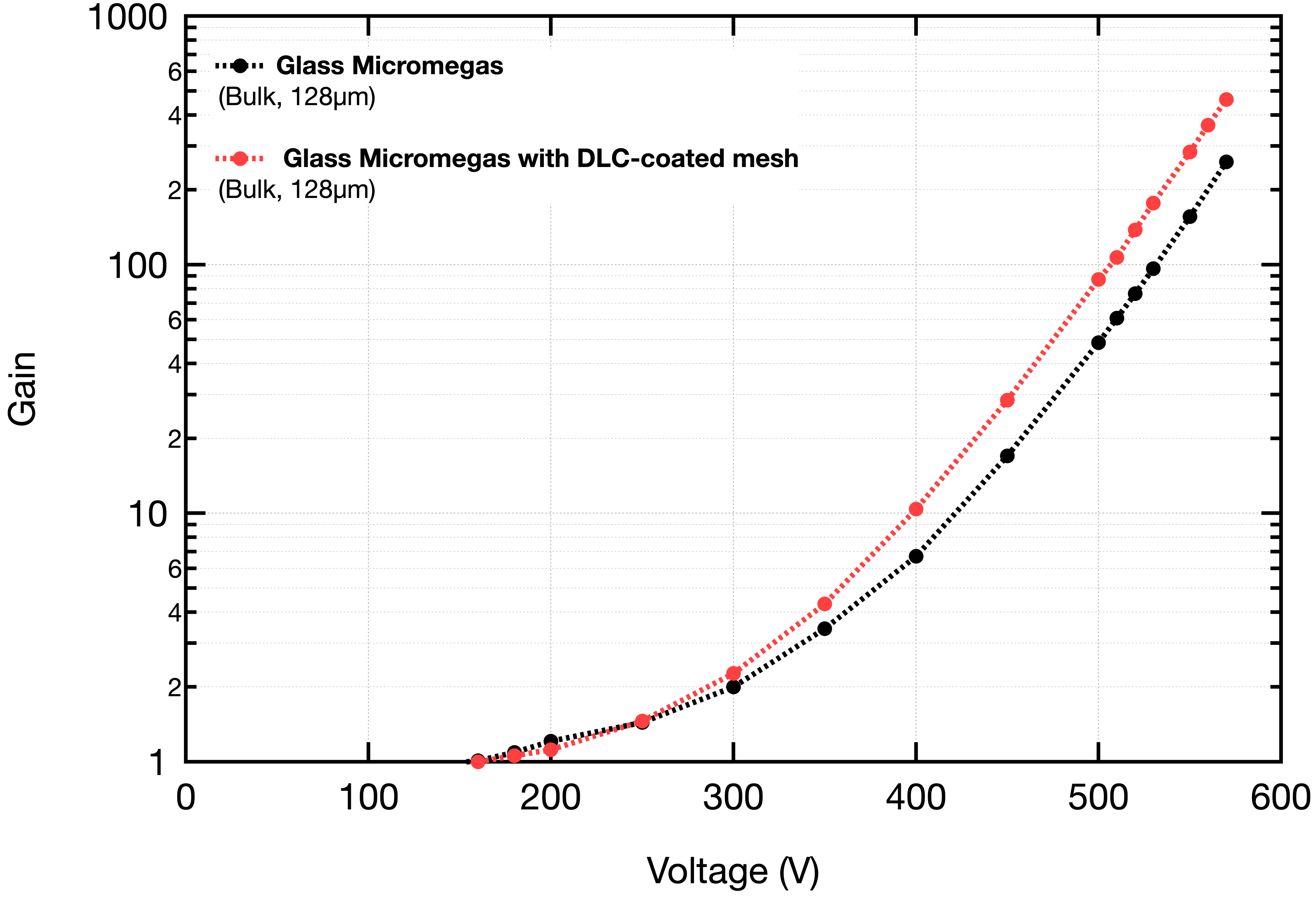
Gain measurement under strong X-ray irradiation
Record anode current as function of anode voltage

Determine primary current from plateau at lower voltages
Fit with exponential function
Device current by primary current for gain estimate



Comparison of gain of MM with standard mesh and DLC mesh

(both Ar/CF4 80/20%, flushed, comparable primary currents ≈8nA)

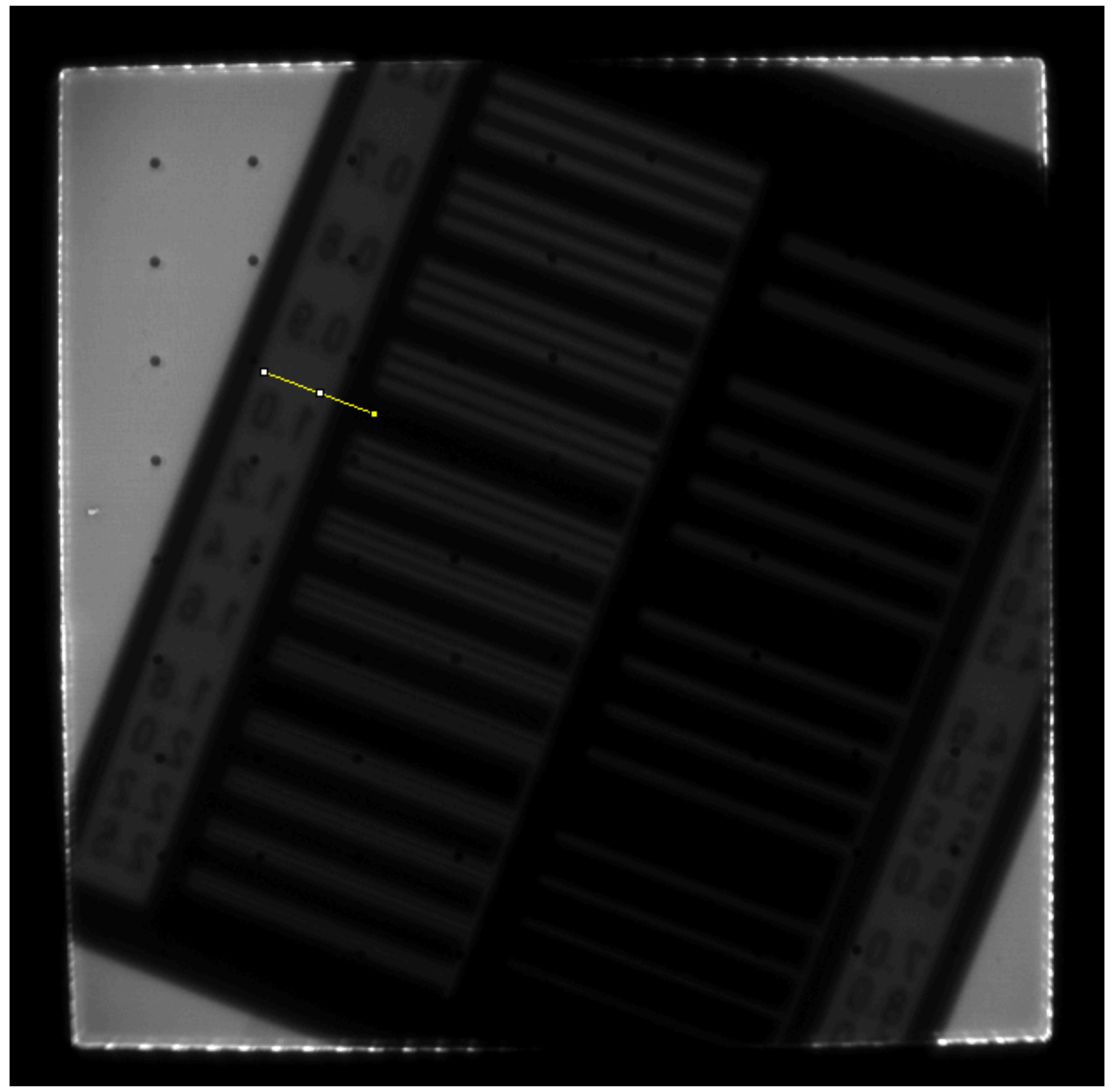


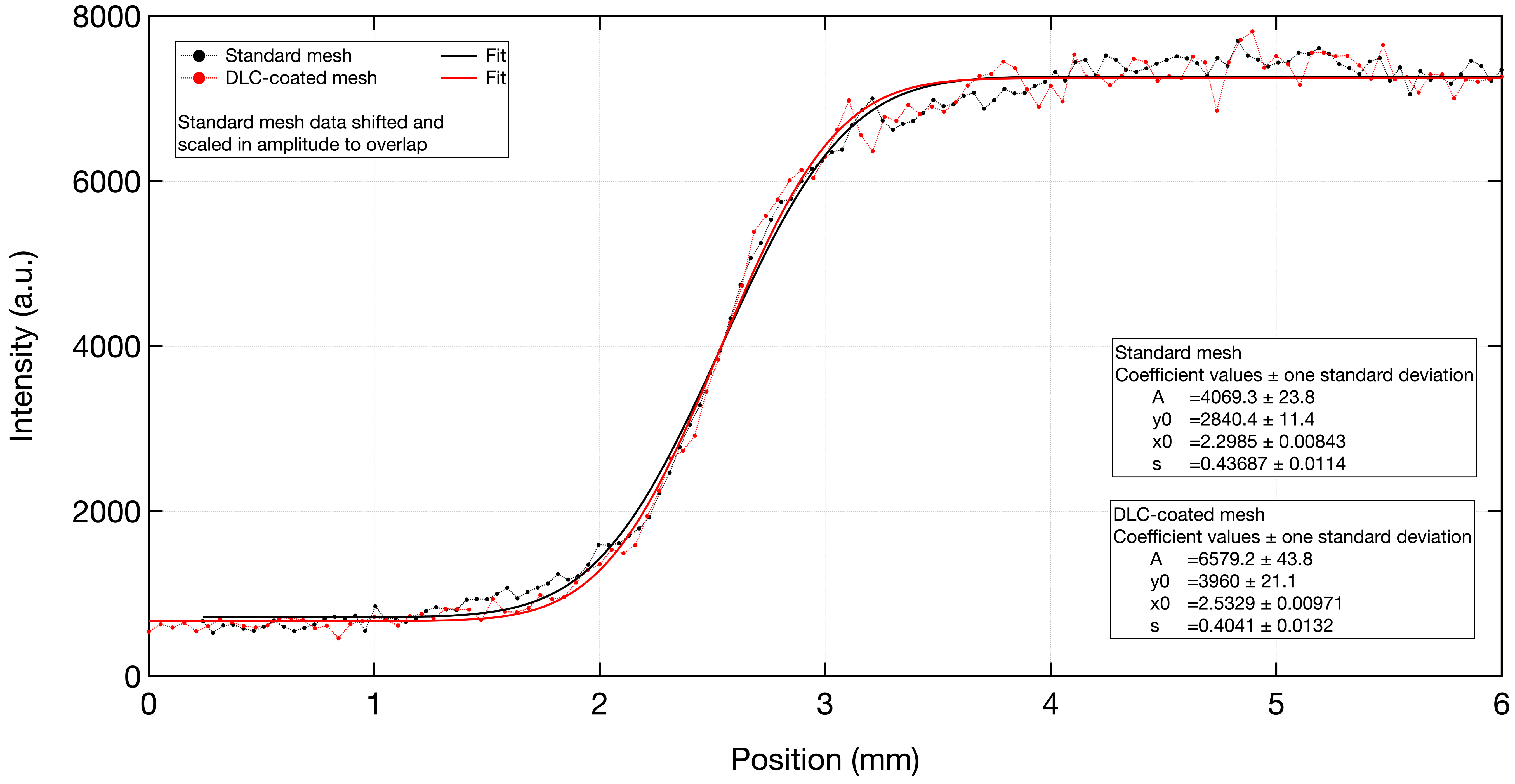
DLC-coated meshes spatial resolution

Line profile across edge of phantom
Fit with error function, std as quantitative measure of spatial resolution

Measured for standard mesh and DLC-coated mesh (in two different setups)
Mask in contact with cathode, 20kV X-ray tube, 70cm source to cathode

Edge recorded with DLC-coated mesh is ≈10% narrower than with standard mesh, to be confirmed in same setup with half-coated mesh

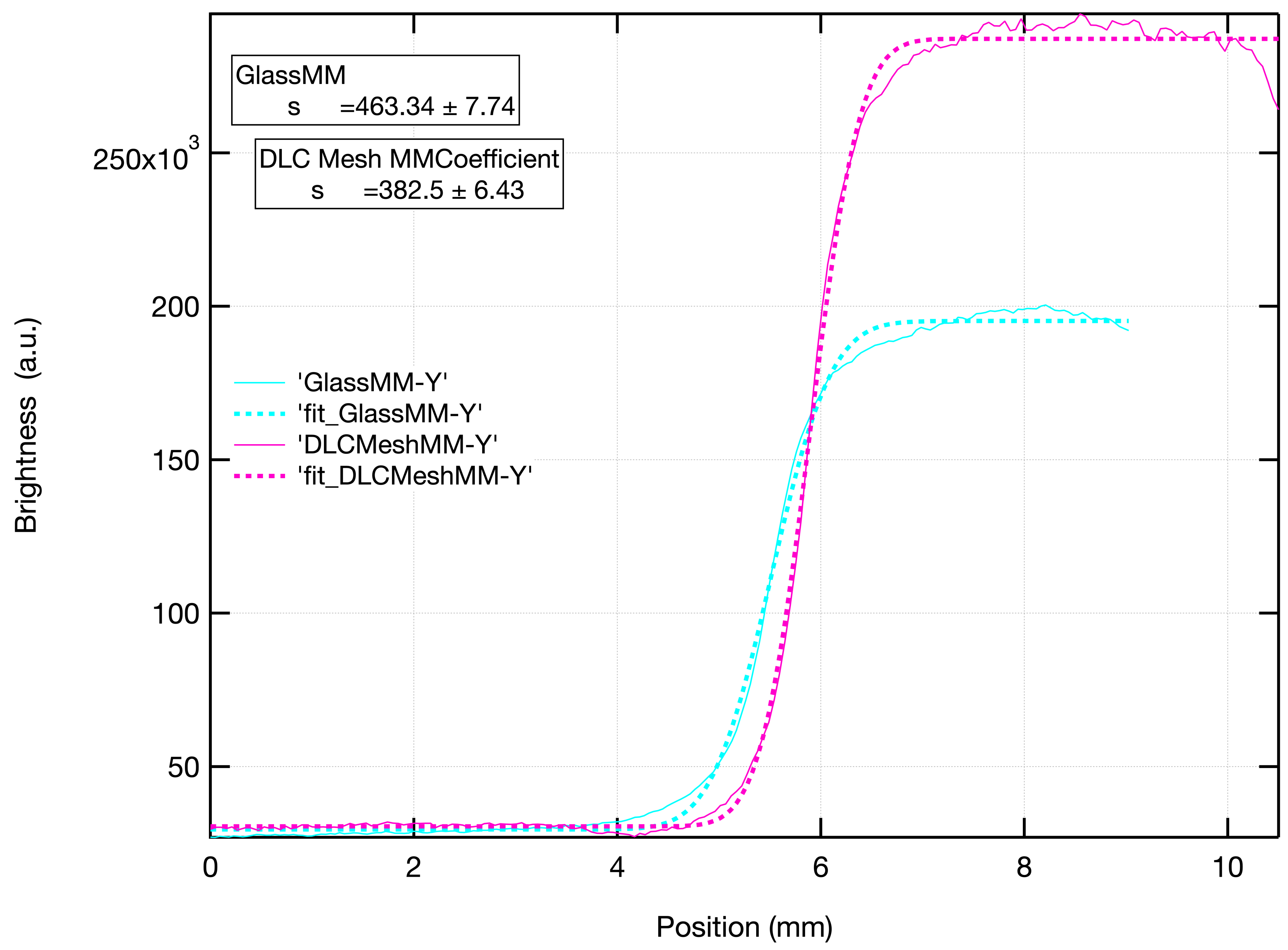




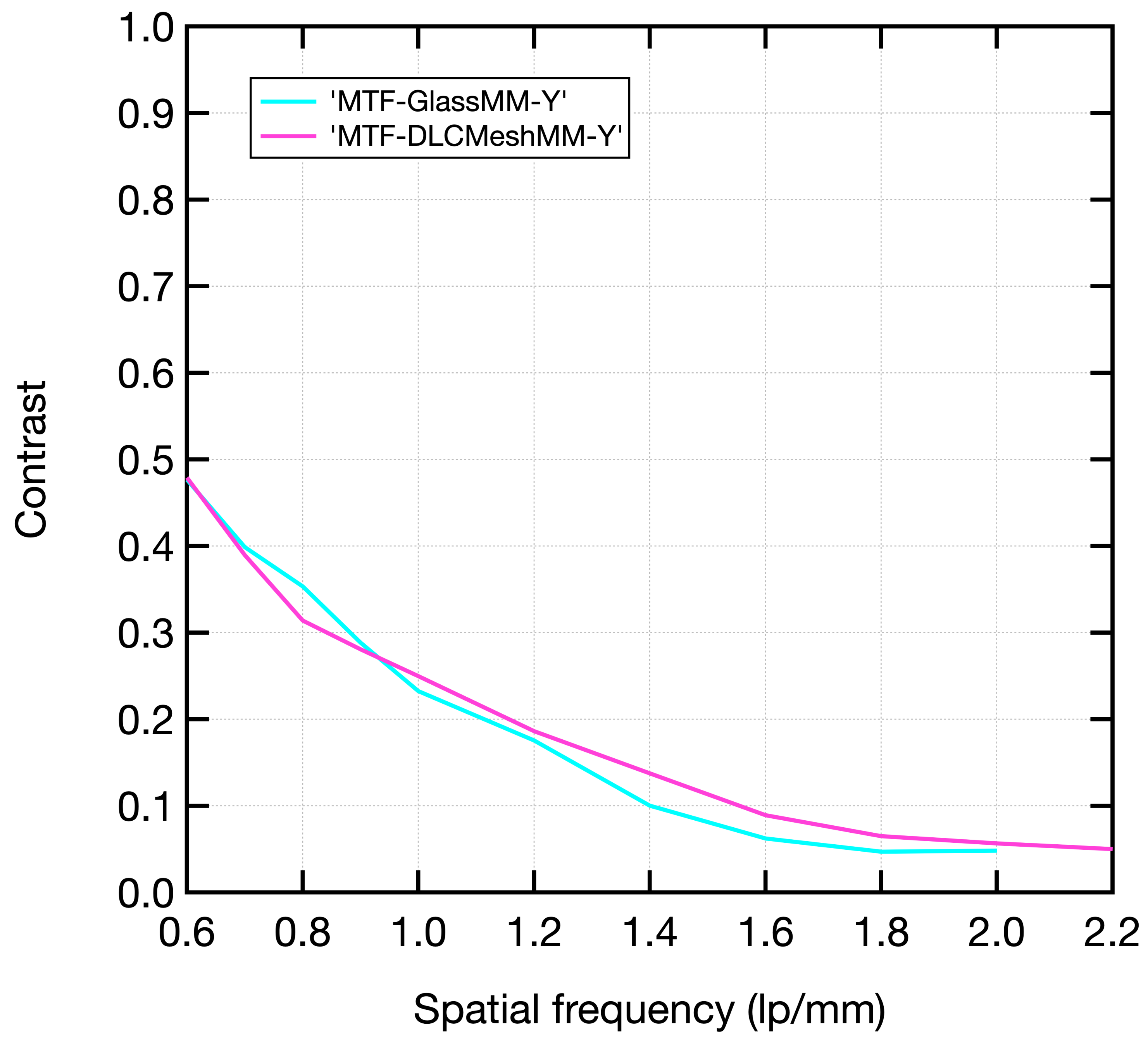
Effect of black electrodes on spatial resolution

Inconsistent results for spatial resolution of GEMs, GlassMM and black electrodes…

Edge profile (1D projection) comparison



MTF comparison



Conclusions

- Integrating Micromegas on **glass substrates** allows for scintillation light readout with high granularity imaging sensors.

- Glass Micromegas were operated with a **B4C neutron converter** used as cathode. Individual alpha tracks were recorded optically and **head-tail distinction** was possible.
- Summed images and reconstructed images of an edge phantom were used to measure the spatial resolution.

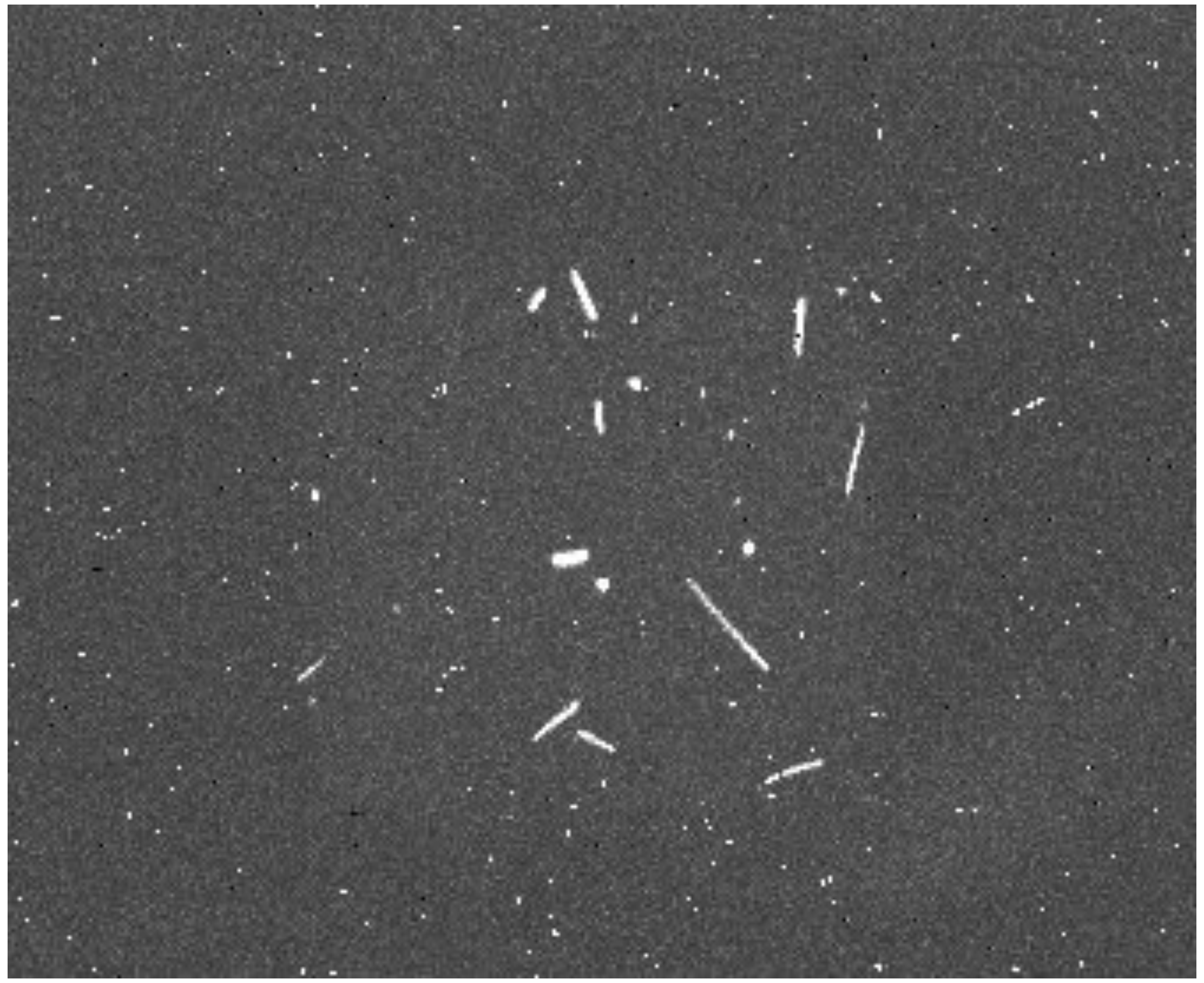
- **Dark meshes** were obtained by **DLC coating** and are being evaluated for possible effects on the achievable image quality in optically read out Micromegas for imaging with high spatial resolution.

Backup

Reversed cathode

Reversed cathode (metallic plate, B4C pointing outwards)
≈1.5-2h exposure

with Source



no Source

10Hz / kg
C
150 keV beta

10mm drift, 200V/cm
Threshold
BG subtract
MAX
570V