Imaging with optically read out Micromegas

F. M. Brunbauer, A. Cools,
Thomas Papaevangelou, Emmanuel Pollacco (IRFU, CEA, University Paris-Saclay), Filippo Resnati (CERN), Francisco Jose (Paco) Iguaz Gutierrez (IRFU, CEA, now at Synchrotron SOLEIL), Esther Ferrer Ribas (IRFU CEA), Eraldo Oliveri (CERN), Leszek Ropelewski (CERN)

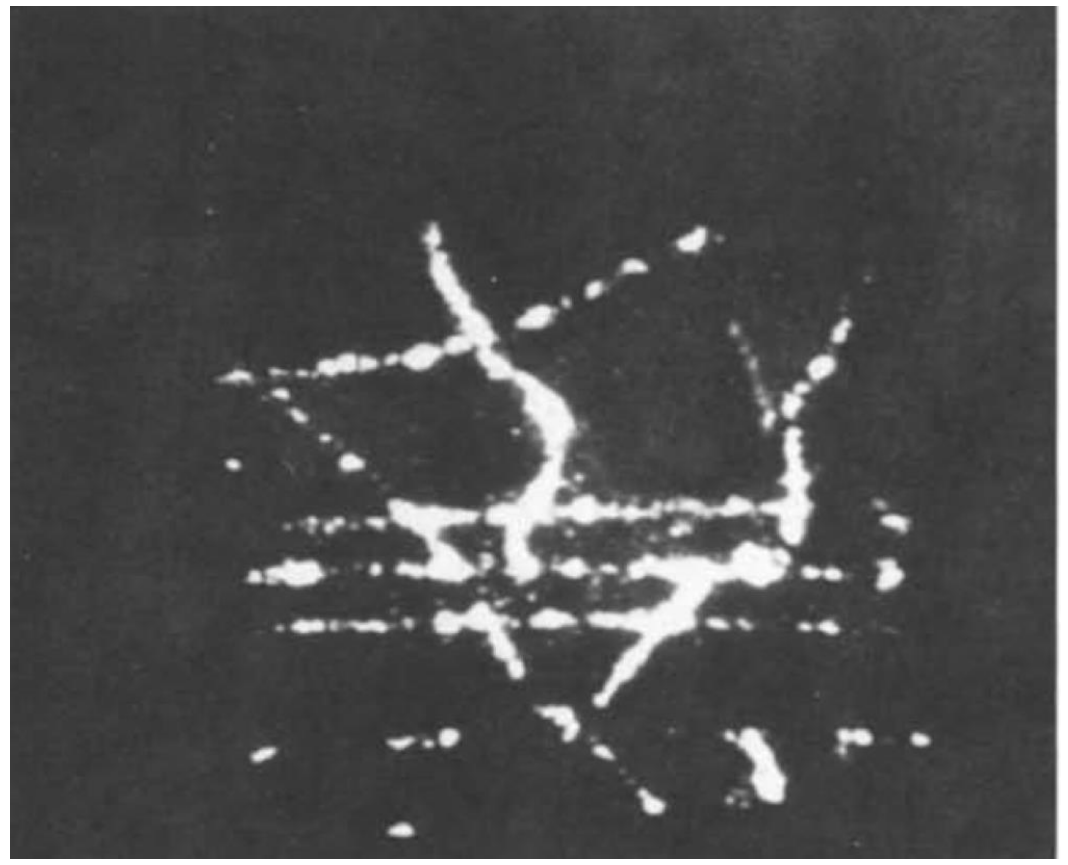
on behalf of CERN GDD team and IRFU/DEDIP Micromegas team

October 5, 2023

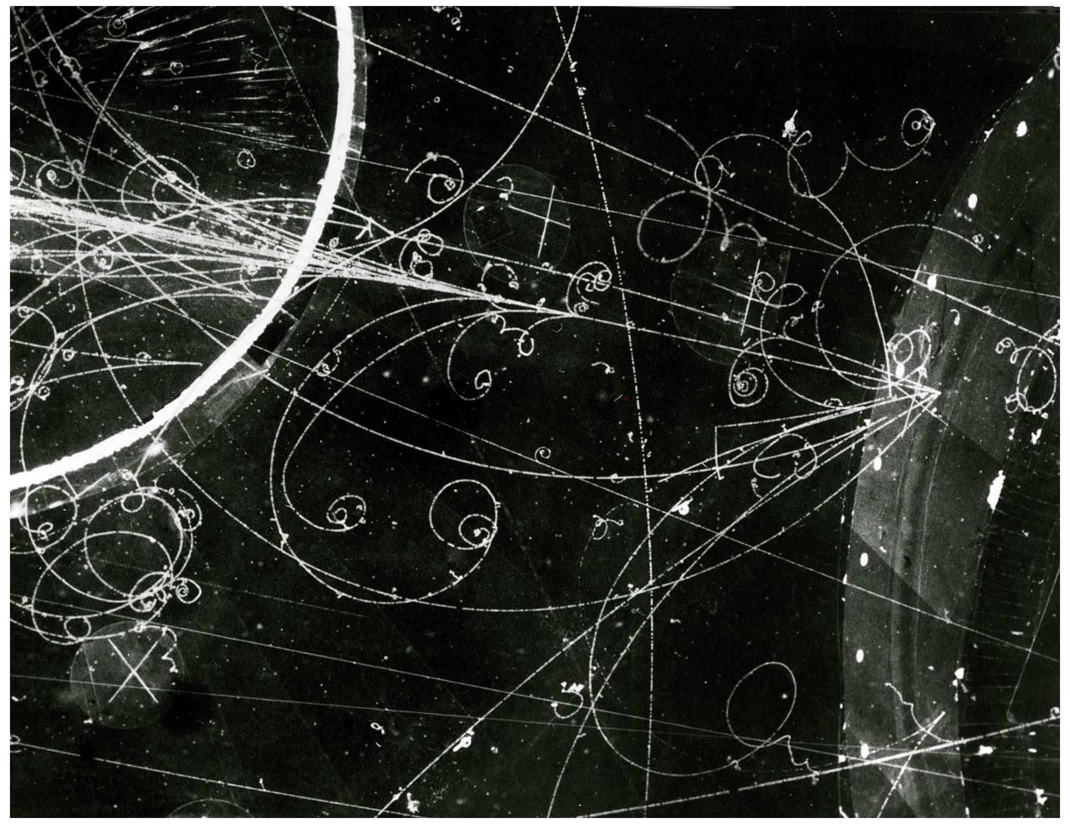
Contents

Optical readout

- Readout of detectors with imaging sensors or fast photon detectors
- Modern CCD and CMOS sensors allow high resolution and low readout noise
- Inherent stability to electronic readout noise
- Wide range of optical elements (mirrors, lenses, fibers) available



G. Charpak et al., NIM A258 (1987) 177

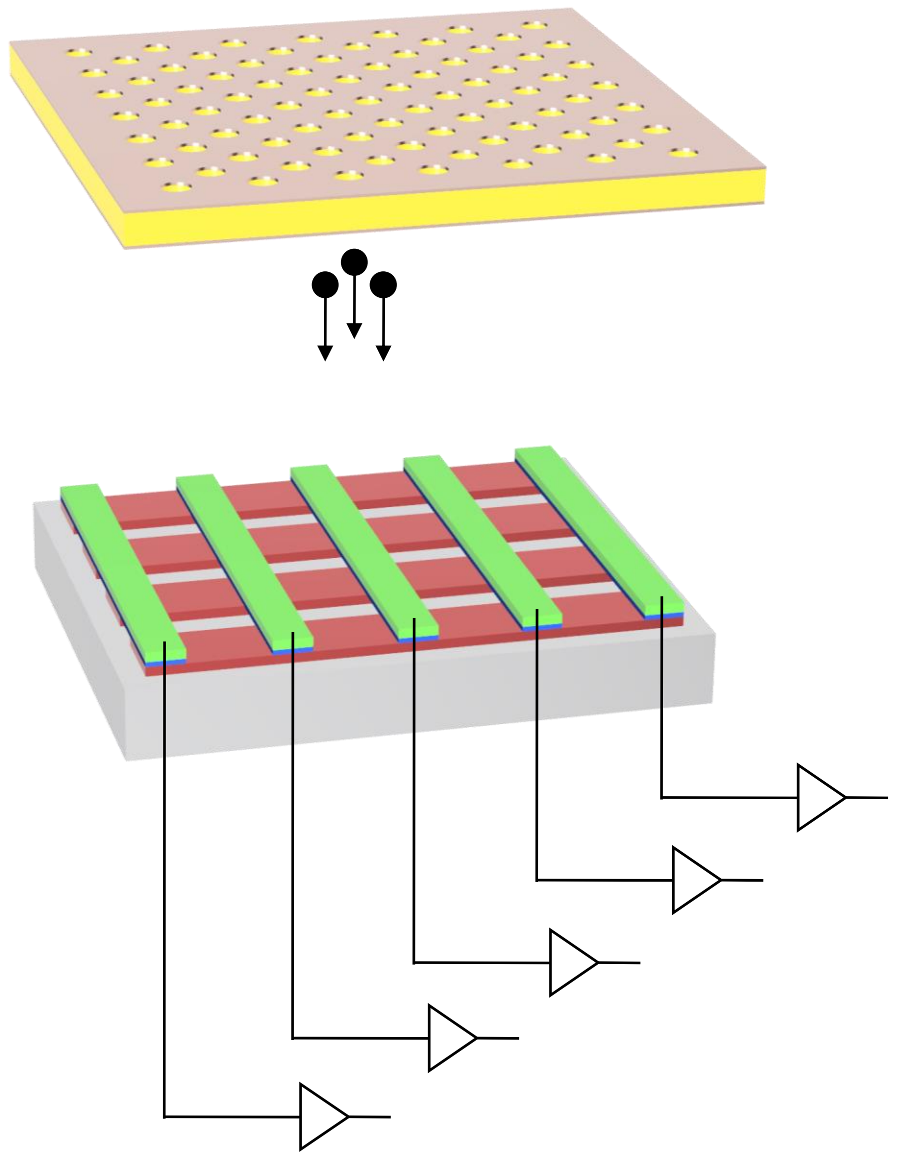


Courtesy of Brookhaven National Laboratory

Readout of MPGDs

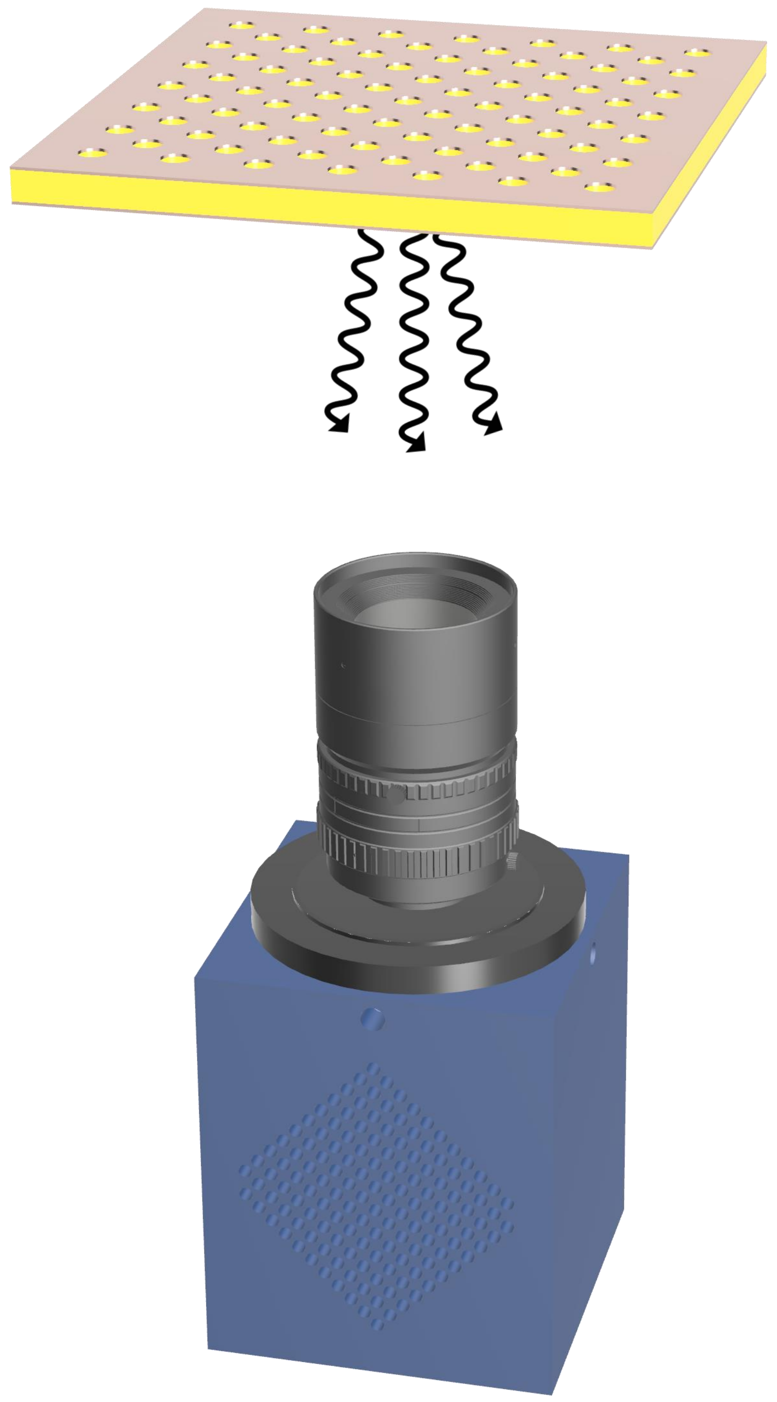
Electronic readout

Recording induced electronic signals with readout electronics



Optical readout

Recording scintillation light with imaging sensors



Schematics not drawn to scale

Optical readout

Integrated imaging approach

Intuitive pixelated readout with
megapixel imaging sensors

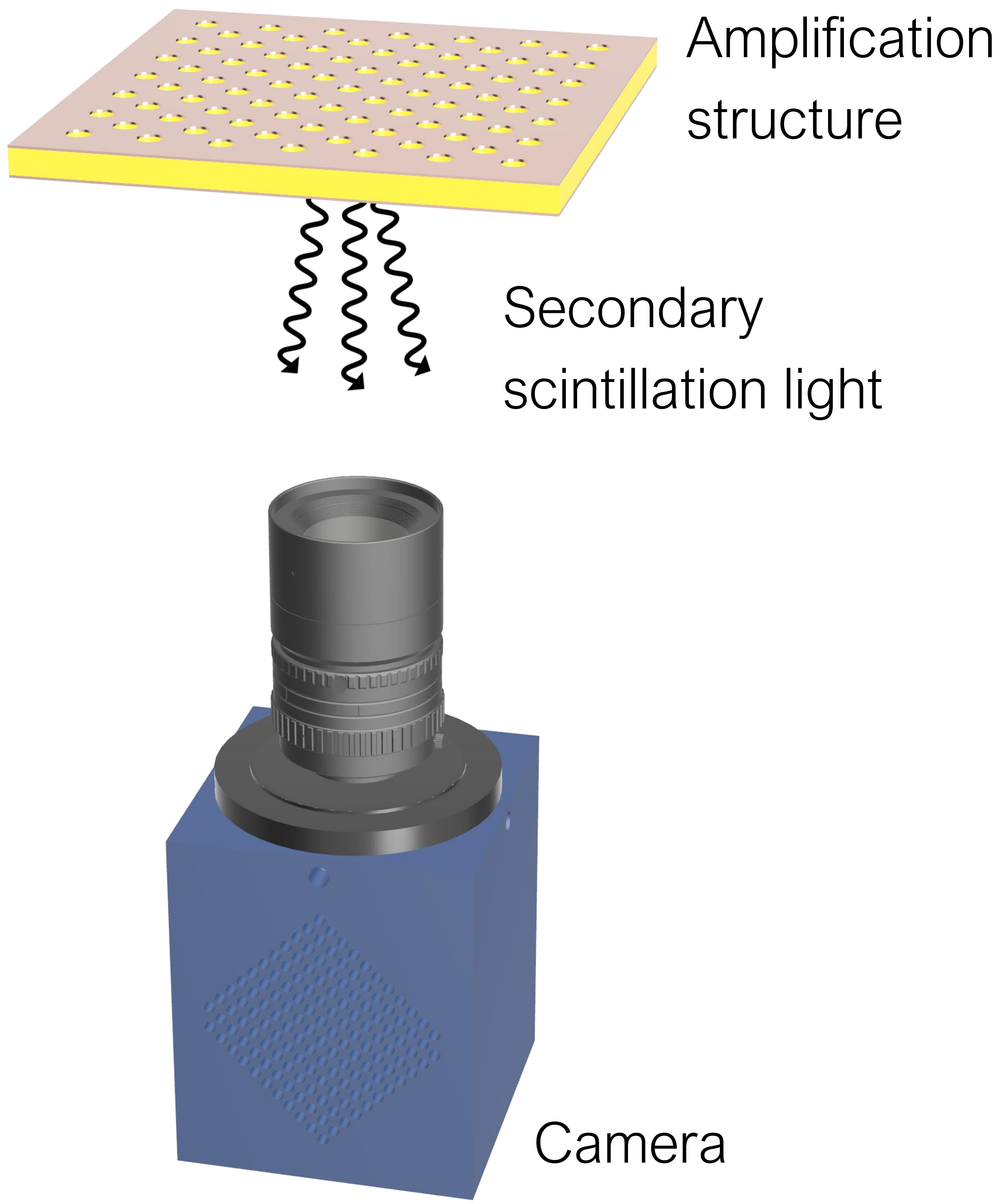
High spatial **resolution**

Lenses and mirrors to enable
adjustable magnification and camera location

Frame rate

Radiation hardness of imaging sensors

Need of **CF_4**-based gas mixtures
or wavelength shifters



Schematics not drawn to scale

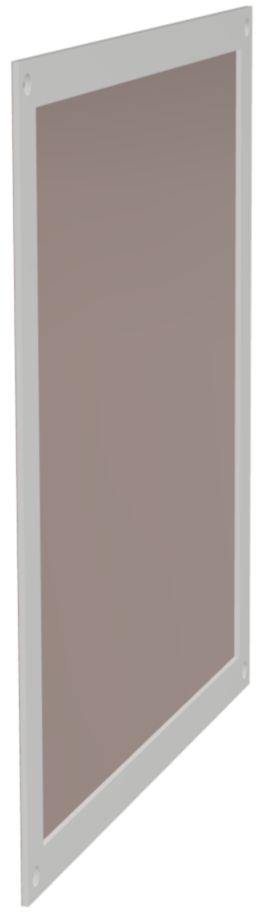
Optical readout

Image immediately available without need for reconstruction.

Two acquisition approaches:

- **Integrated imaging** collects all light within exposure time **without deadtime** with long exposure time
- **Event-by-event** recording with short exposure time for track reconstruction

Detector
(amplification and scintillation)



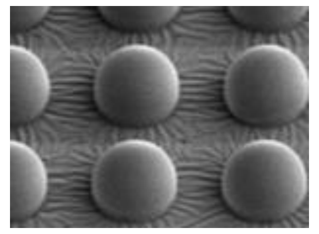
High gain MPGDs

Optics
(coupling)

Lenses, mirrors,
intensifiers, (tapered) fibers, Microlenses

photonis.com

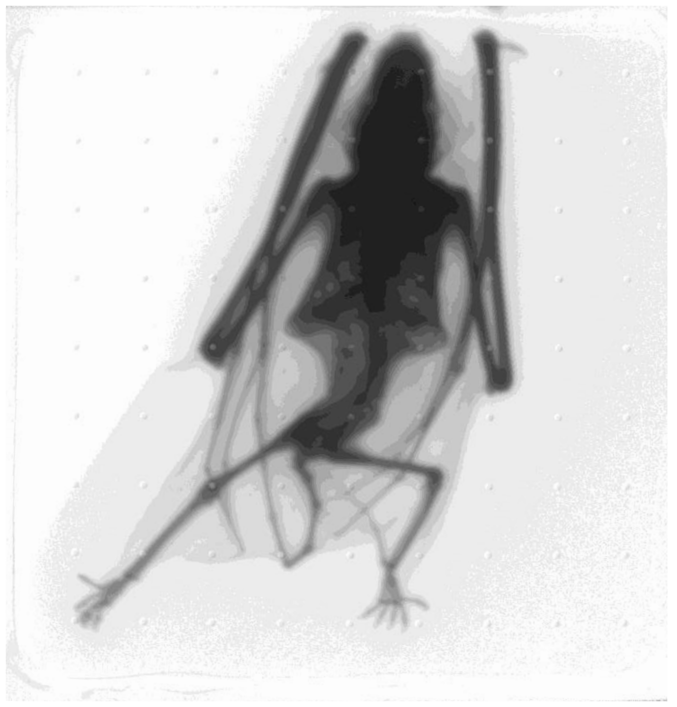
szphoton.com



10.1016/j.apsusc.2018.01.253

Imaging sensor
(camera)

CCD, CMOS, ASICs



X-ray radiography
(Glass Micromegas)

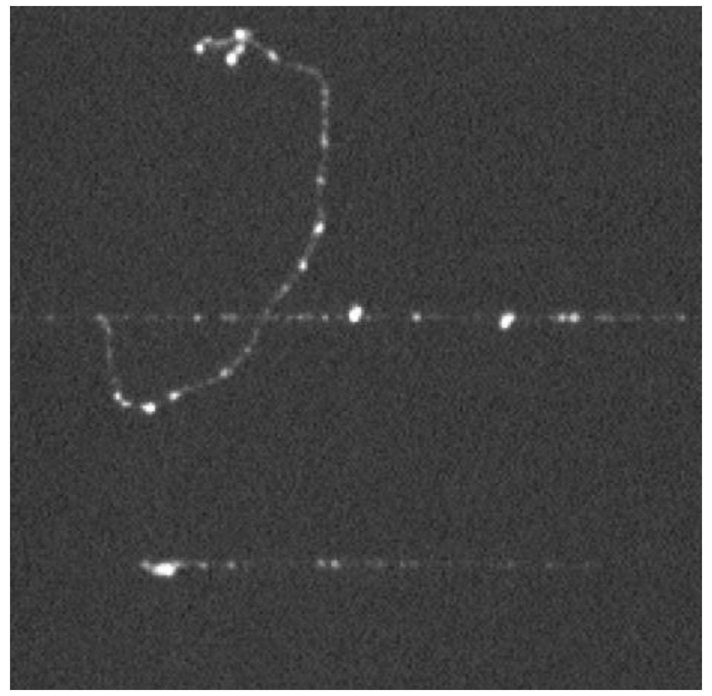
F. Brunbauer et al., Radiation imaging with glass Micromegas, https://doi.org/10.1016/j.nima.2019.163320

Radiation imaging with optically read out MPGDs

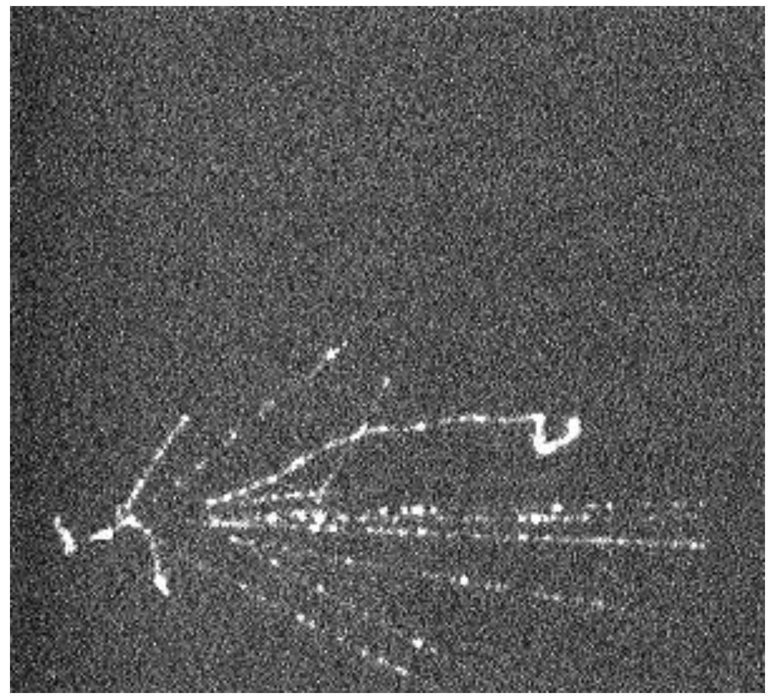
Visualising tracks, events & imaging

X-ray photons

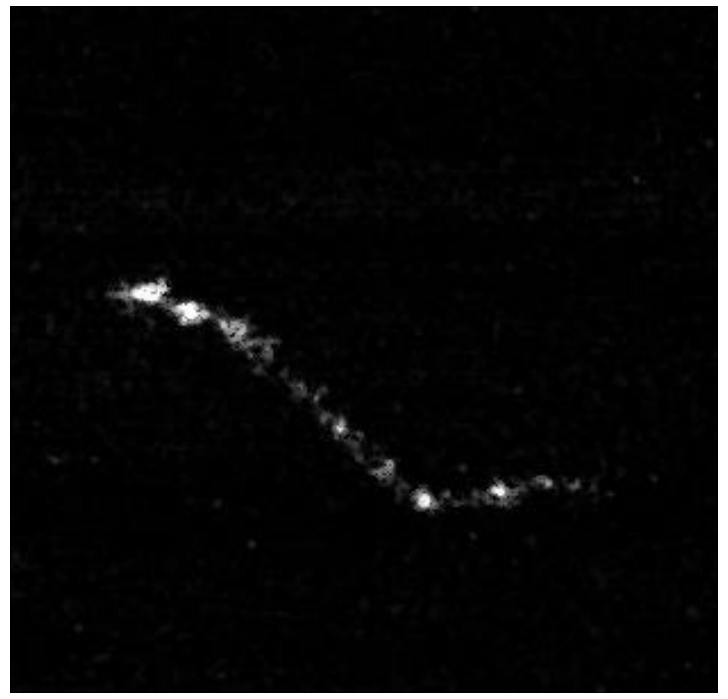
Alpha track



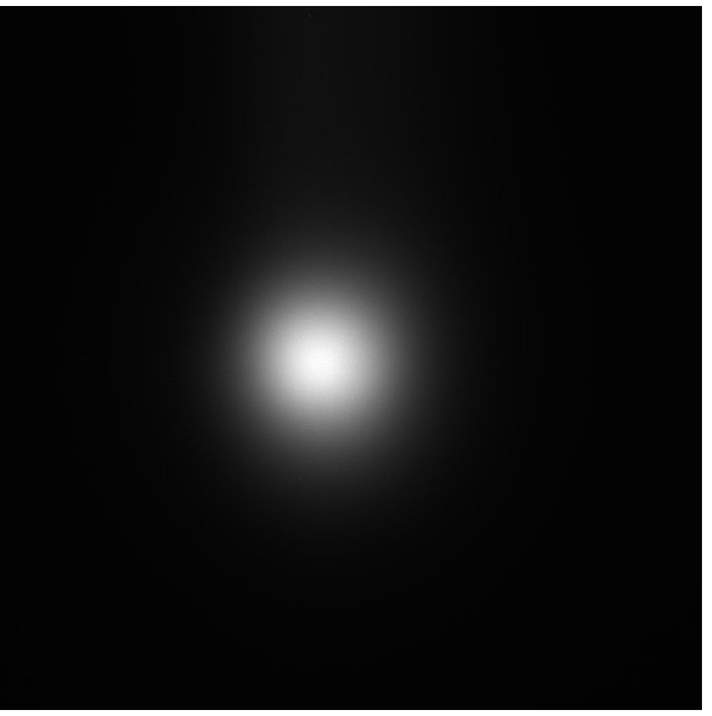
Muon tracks with δ-ray



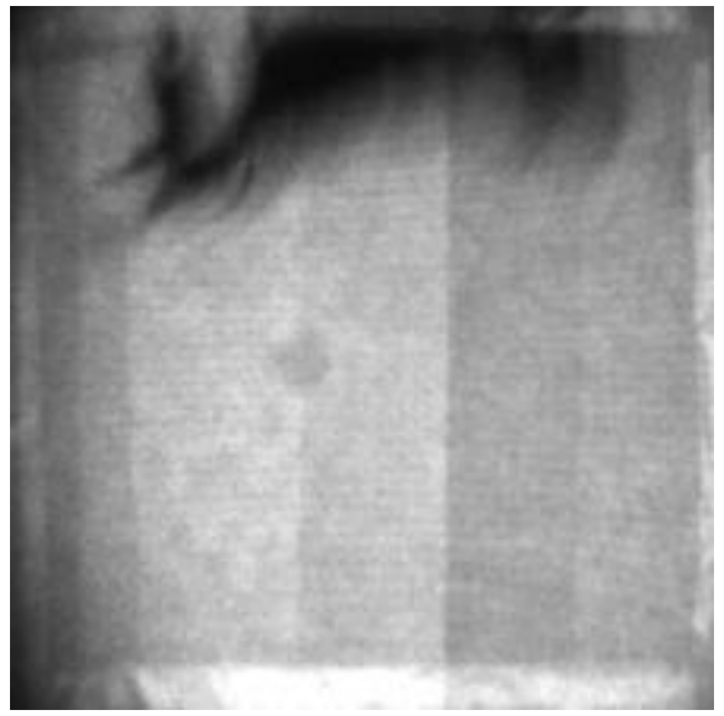
Hadronic shower



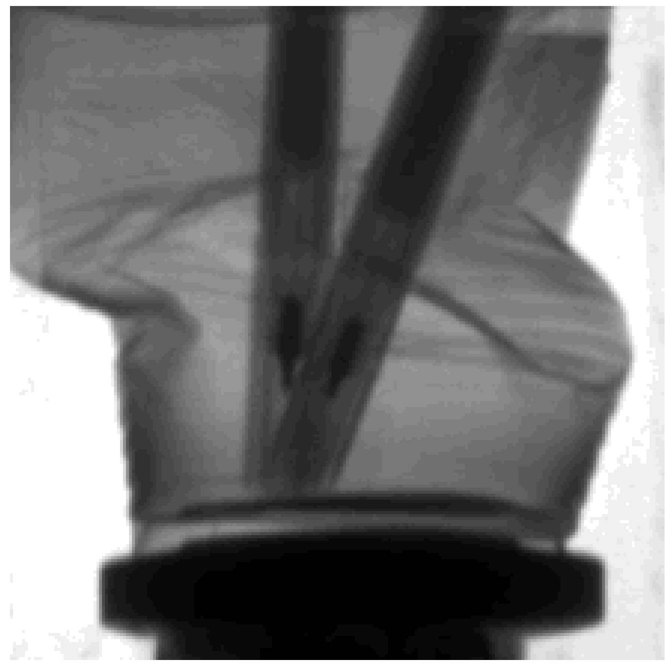
Cosmic event



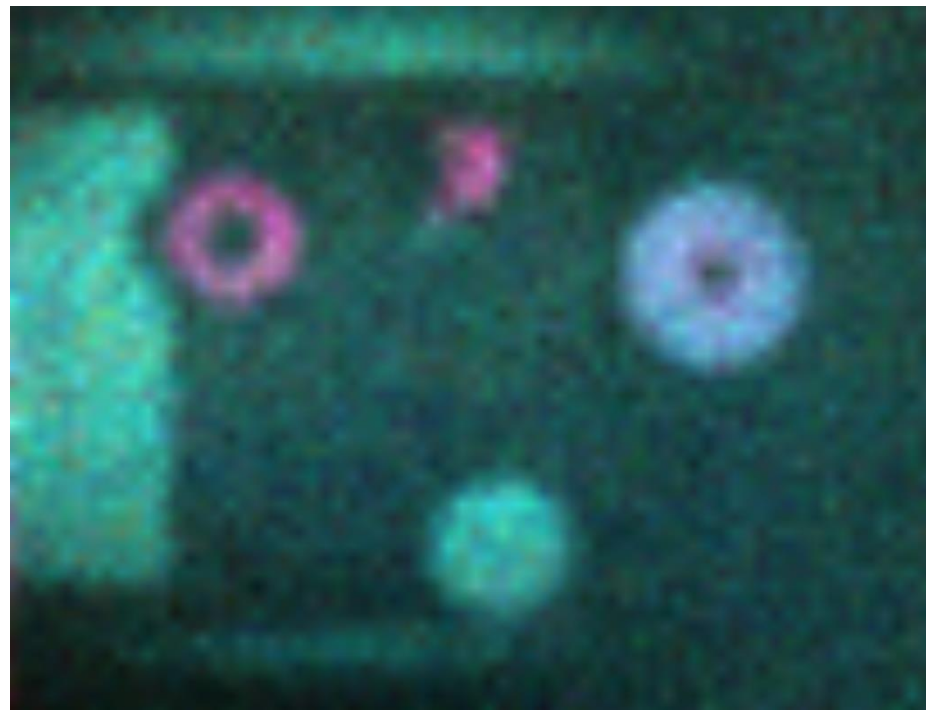
Proton beam profile



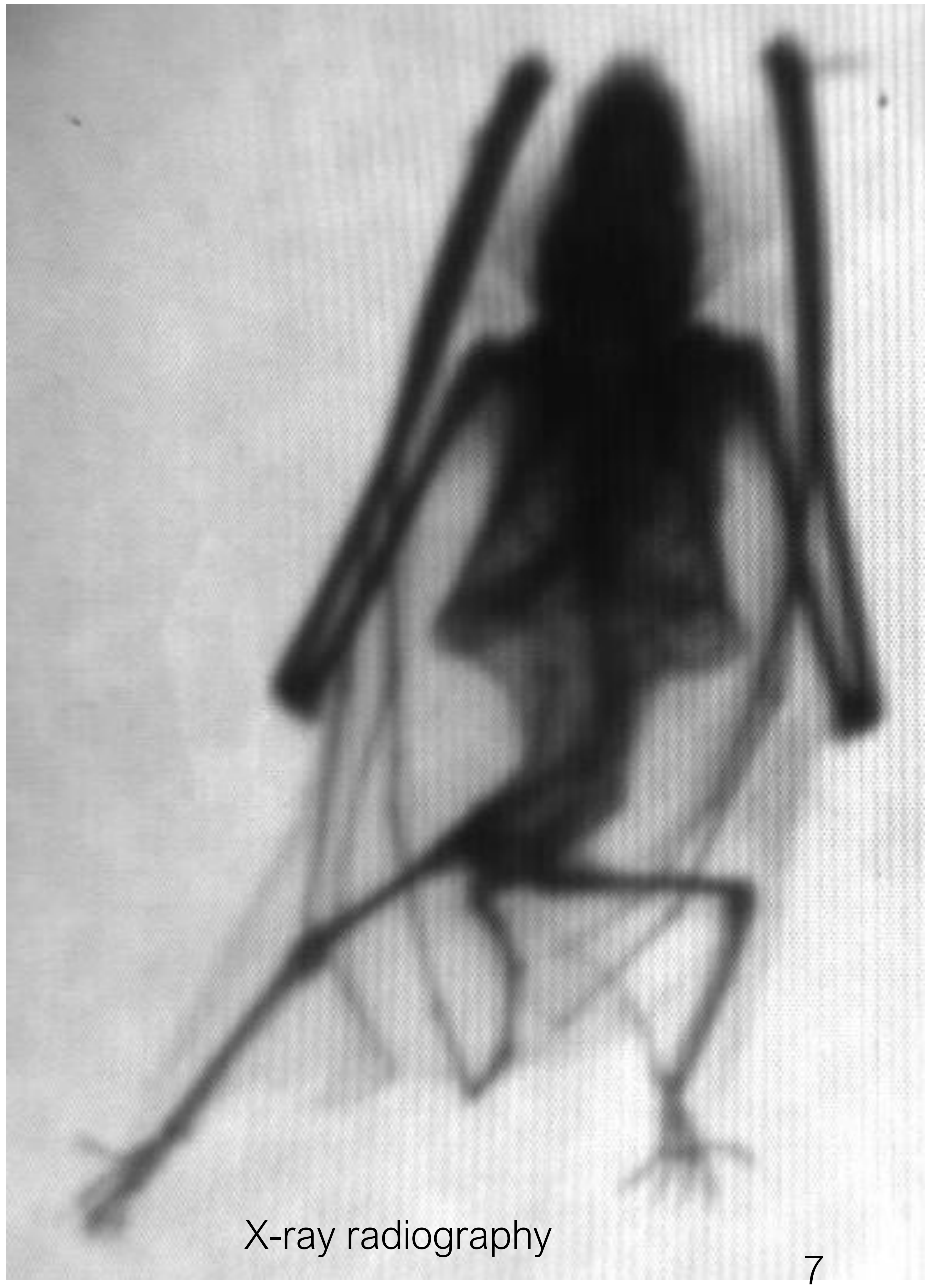
X-ray fluoroscopy



X-ray tomography



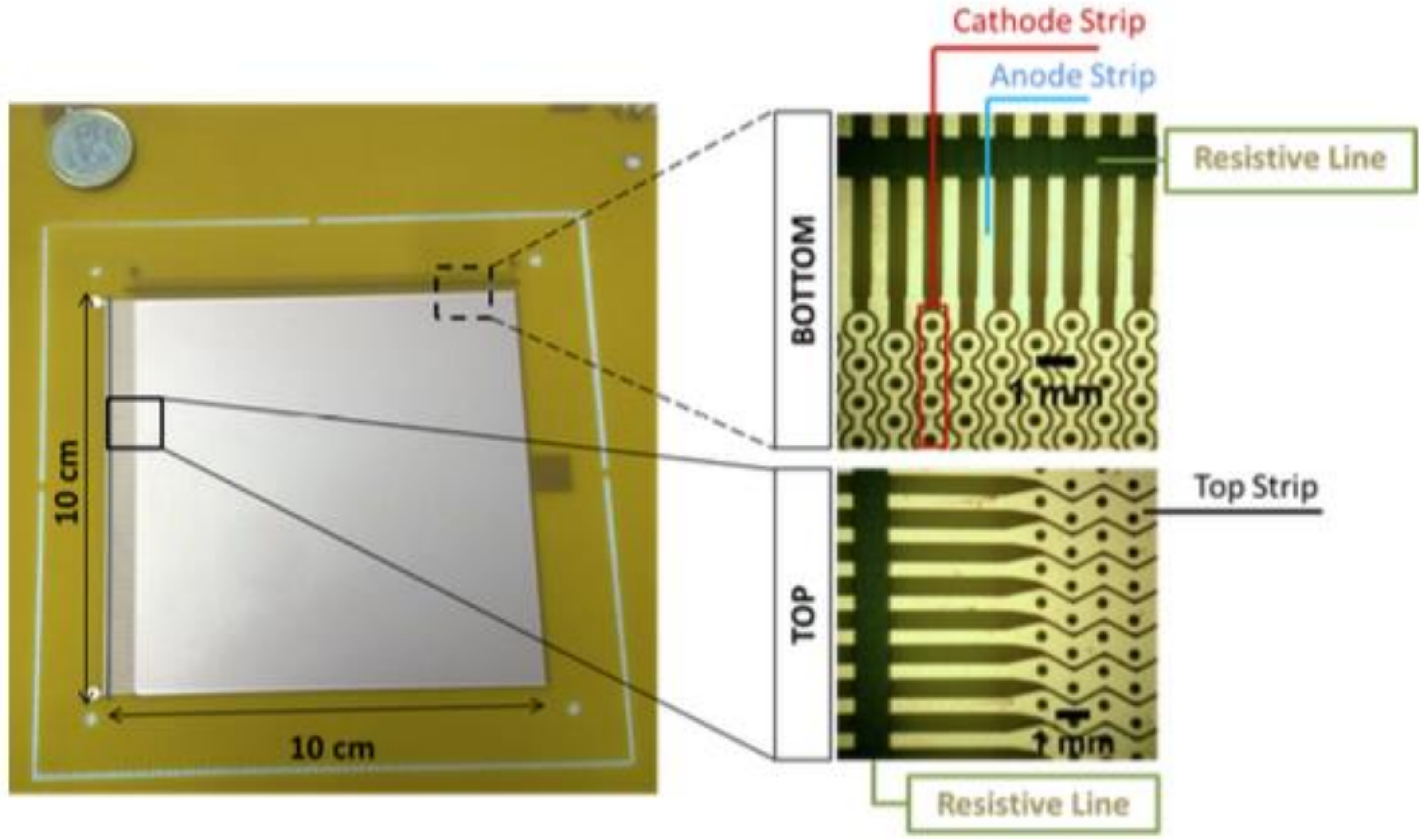
X-ray fluorescence

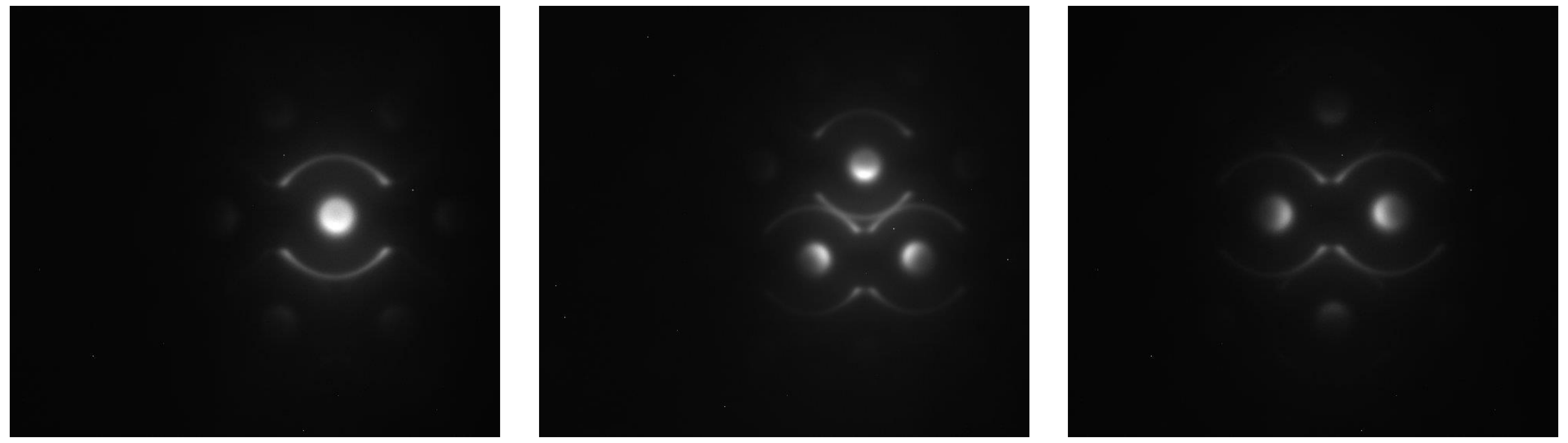


X-ray radiography

Optical readout as a tool for detector R&D

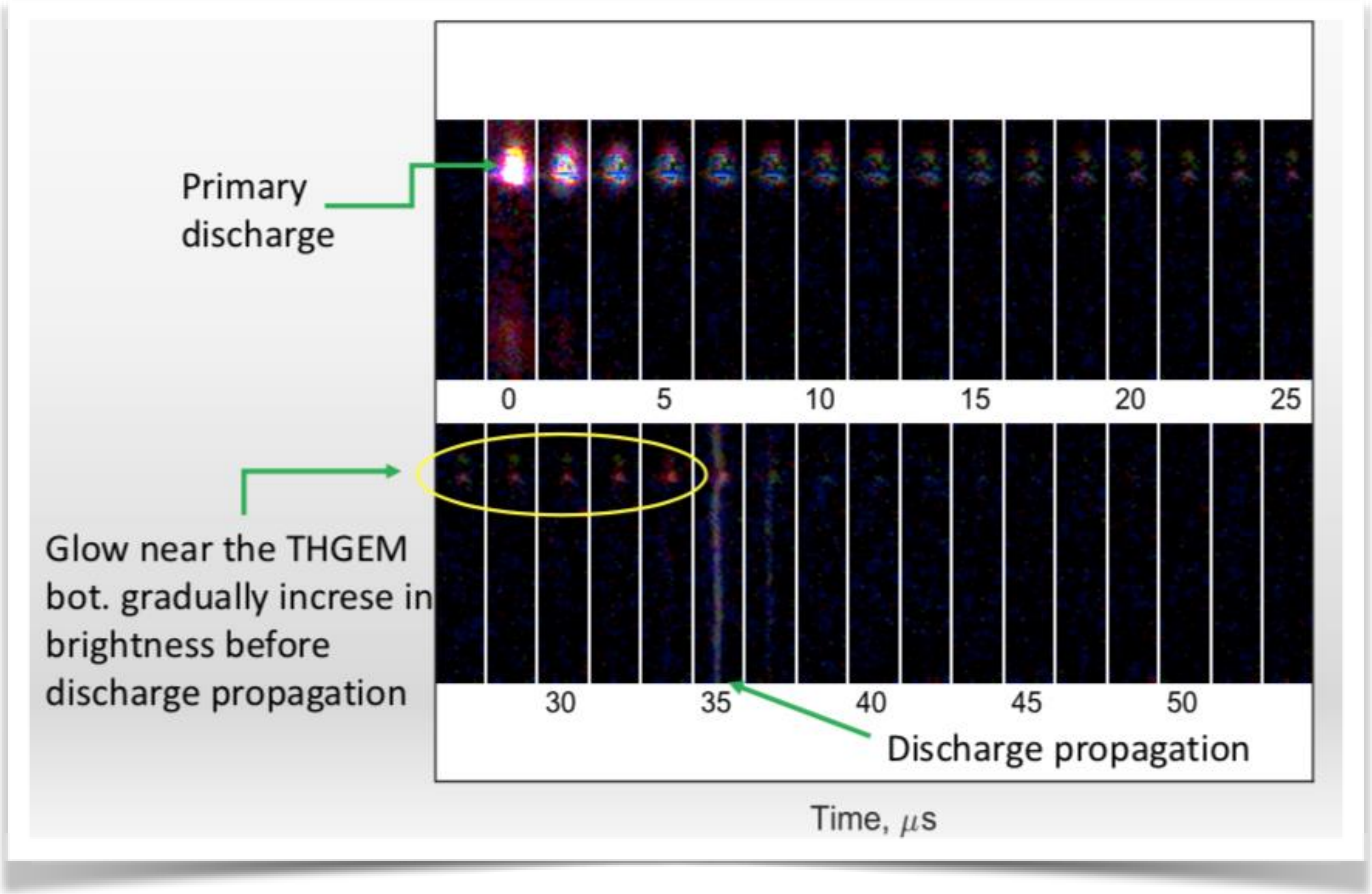
Visualising amplification in MPGD varieties





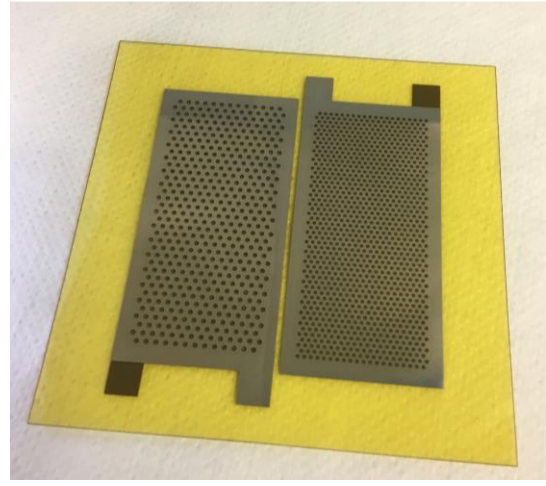
F. Amaro et al., JINST 5(2010);

Observing propagated discharges

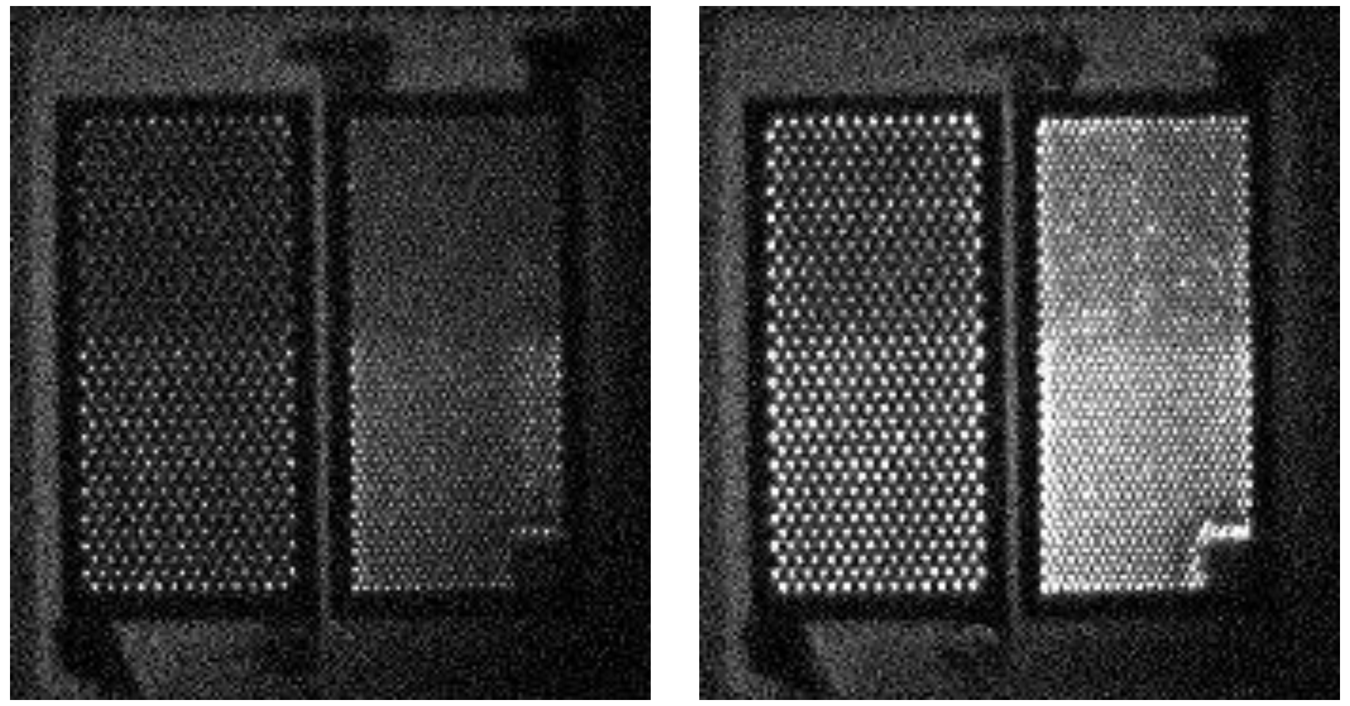


Utrobičić et al., MPGD stability workshop, Munich, 2018

Uniformity maps of gain



3D printed sample as received

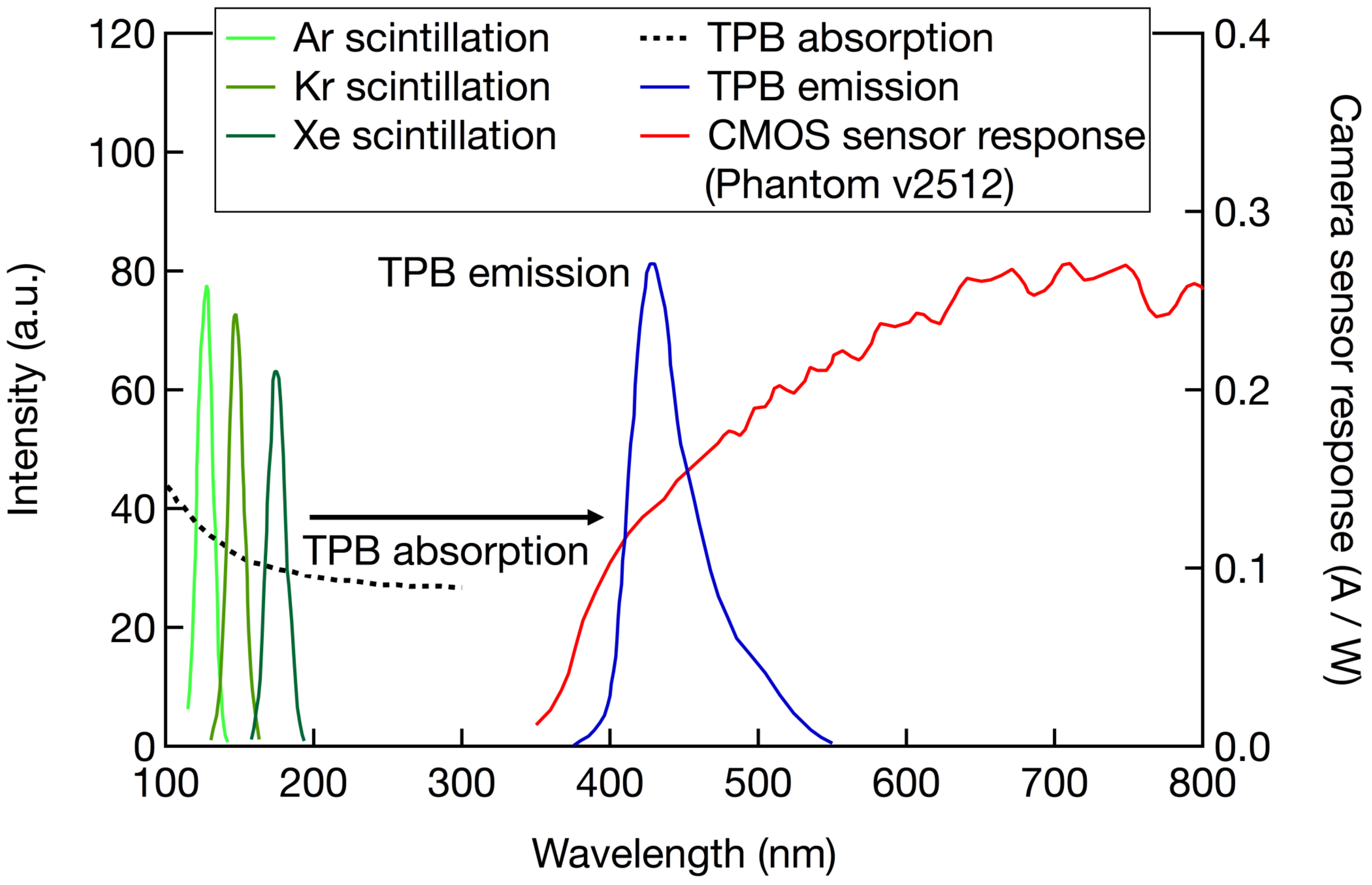


Schematics not drawn to scale

Secondary scintillation light emission

Optical readout scintillation spectra

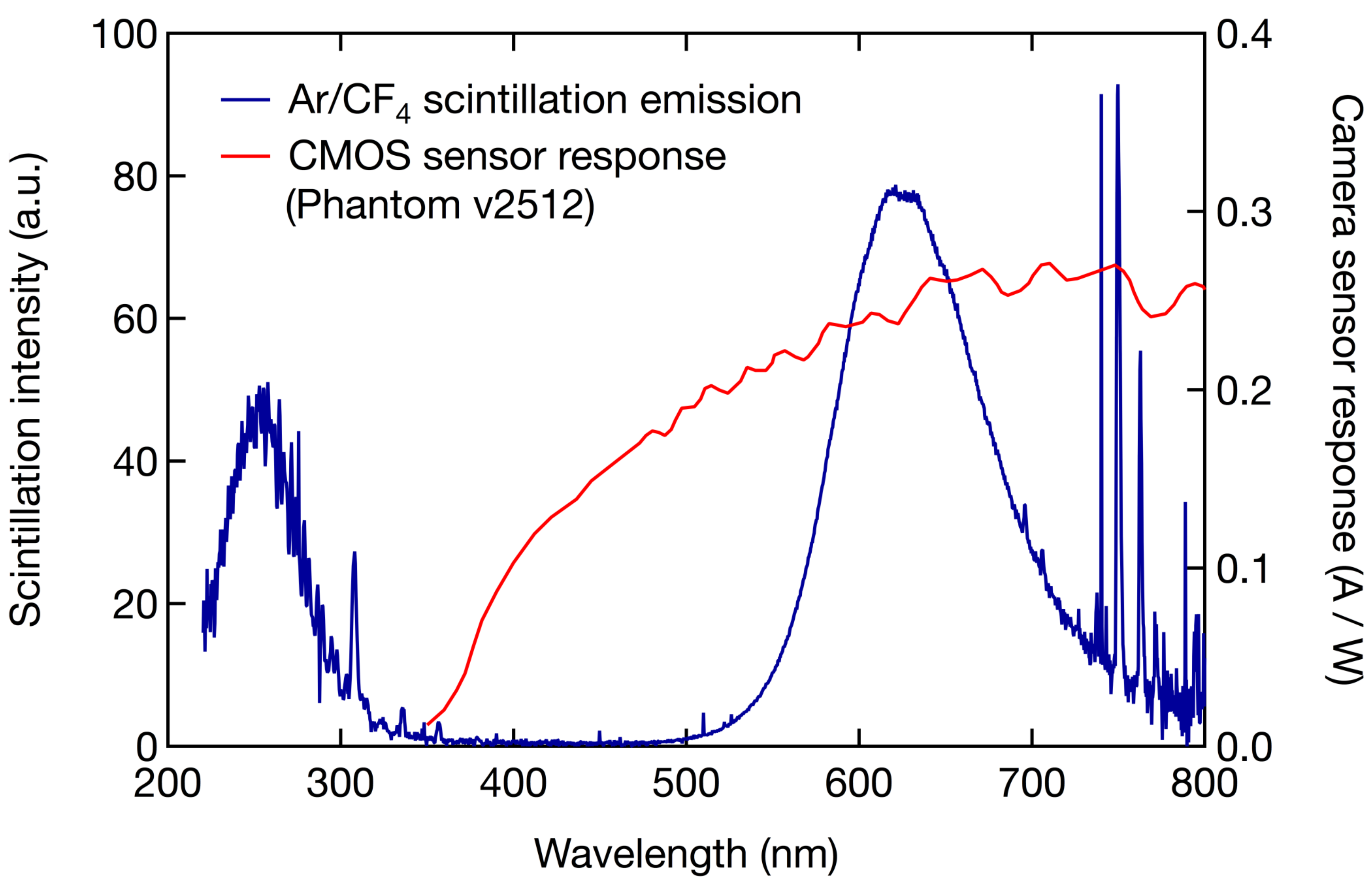
Using wavelength shifters



Data from: Ignarra, C.M. Physics Procedia 37 (2012): 1217–1222.
Scintillation data from: V. M. Gehman et al. NIM A 654 (2011) 1.

Wavelength shifters such as tetraphenyl butadiene (**TPB**) can be used to shift scintillation light spectrum to visible range with peak around **425 nm**

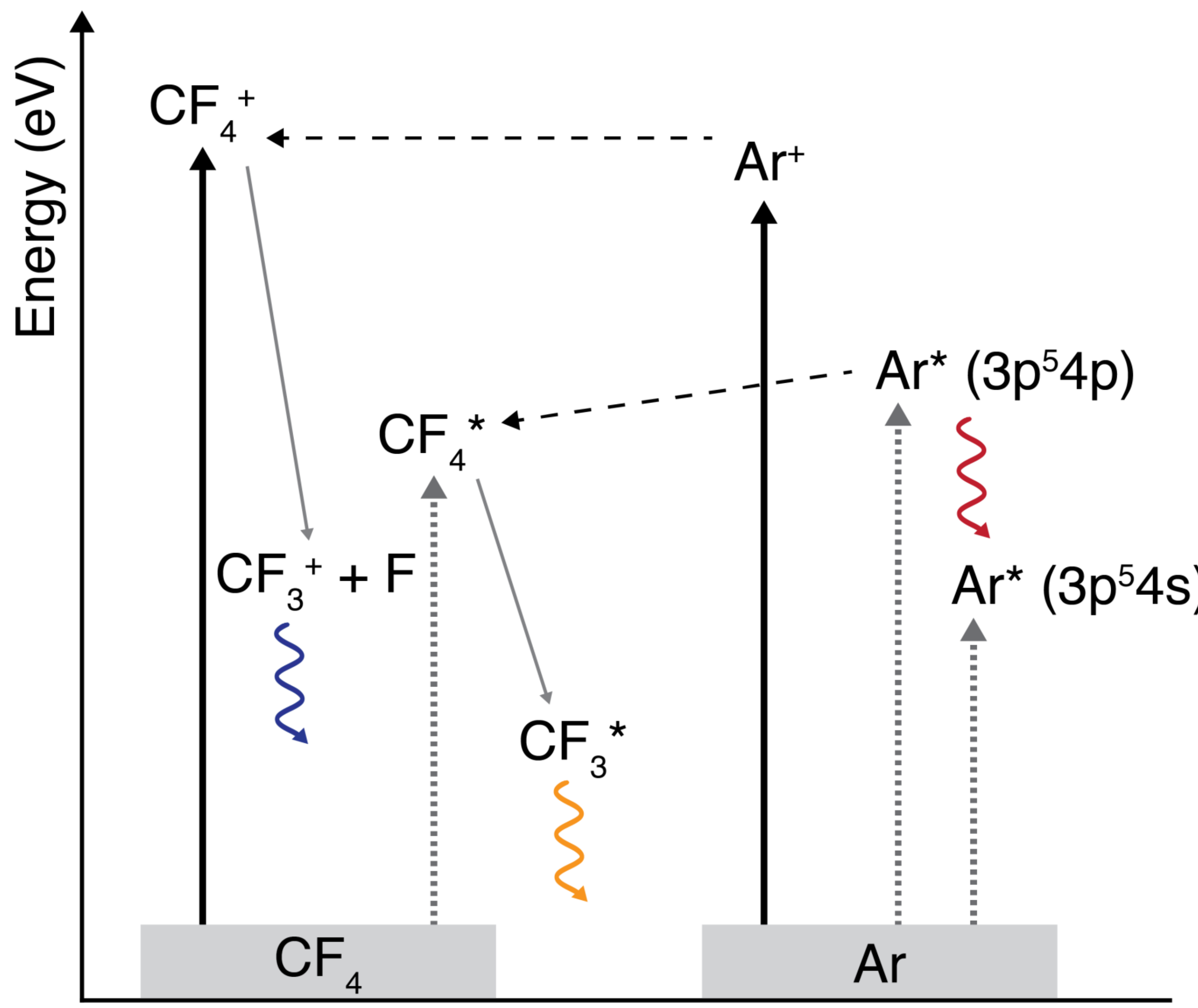
Using CF_4-based gas mixtures



Ar/CF_4 gas mixtures feature ample visible scintillation light emission with a peak around **630 nm**

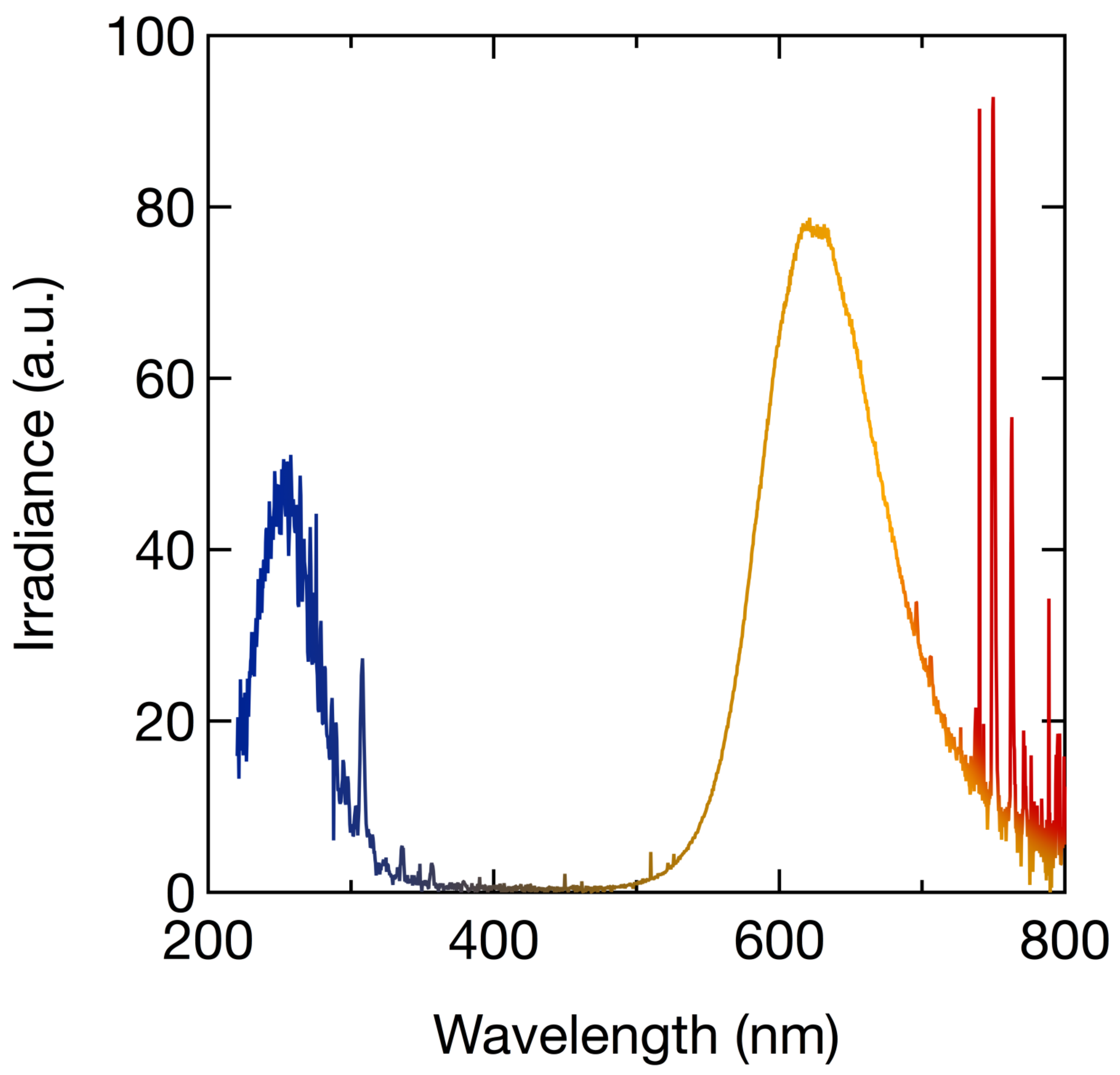
Optical readout scintillation spectra

Scintillation mechanism

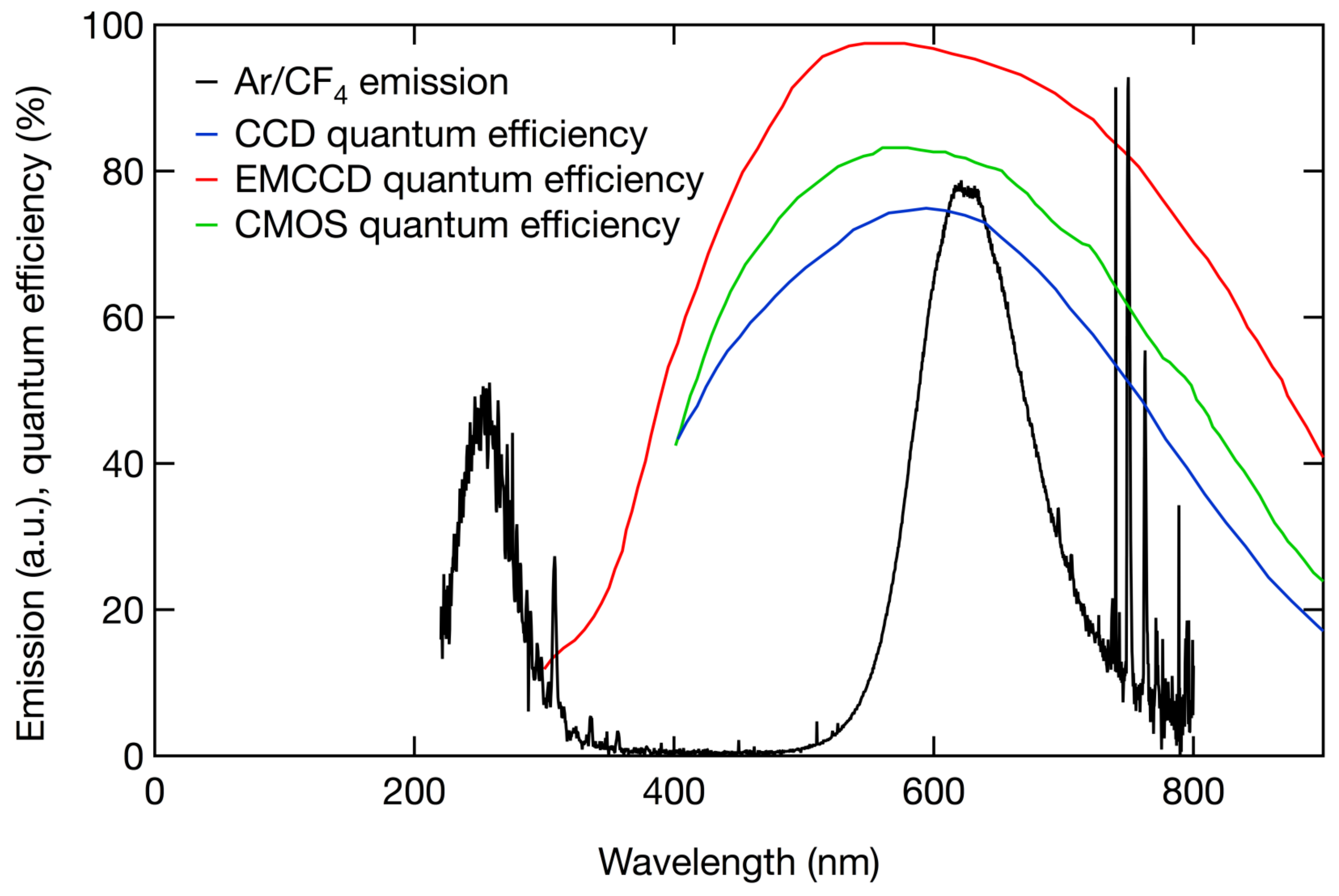


Adapted from Seravalli, E., PhD thesis, 2008

Scintillation spectrum



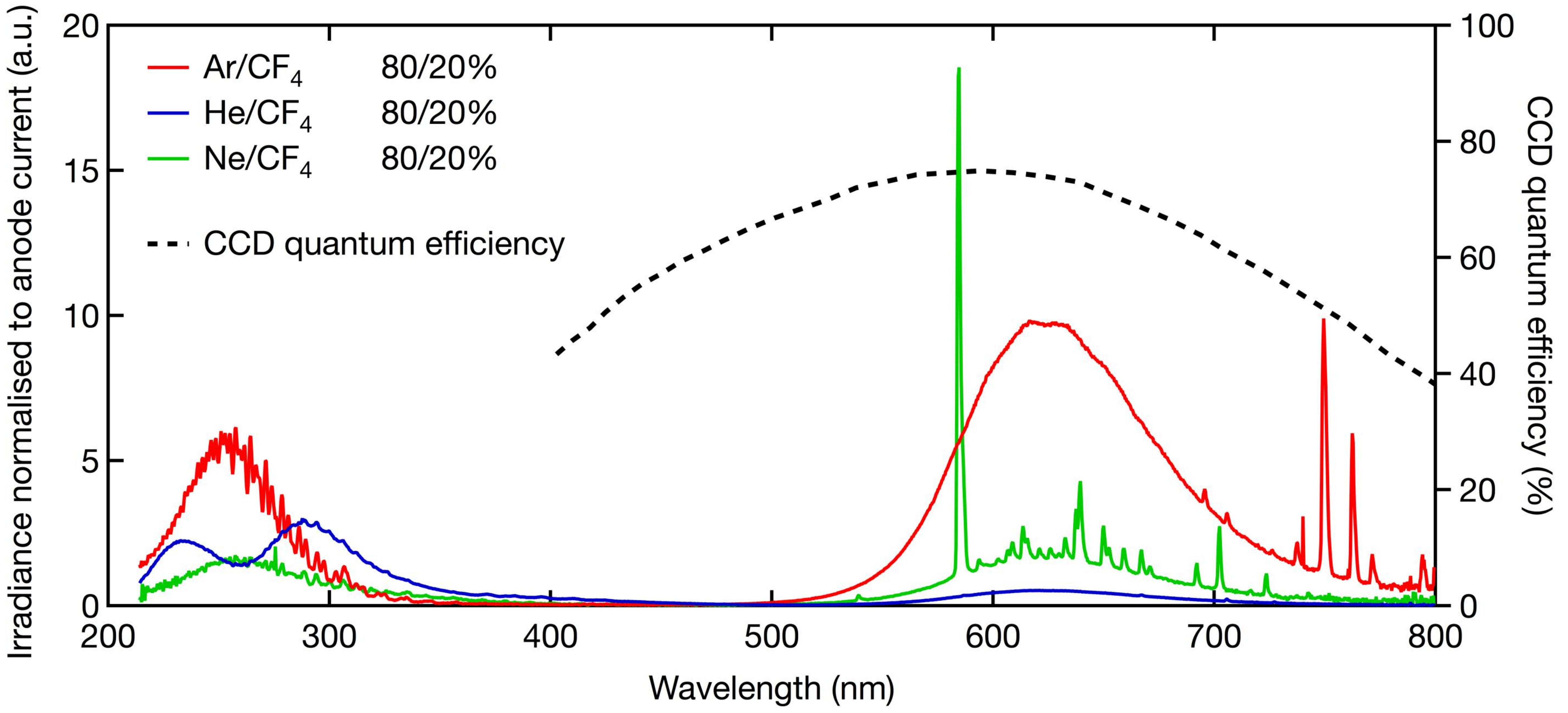
CF4 emission matched senstive wavelength range of most conventional imaging sensors



Schematics not drawn to scale

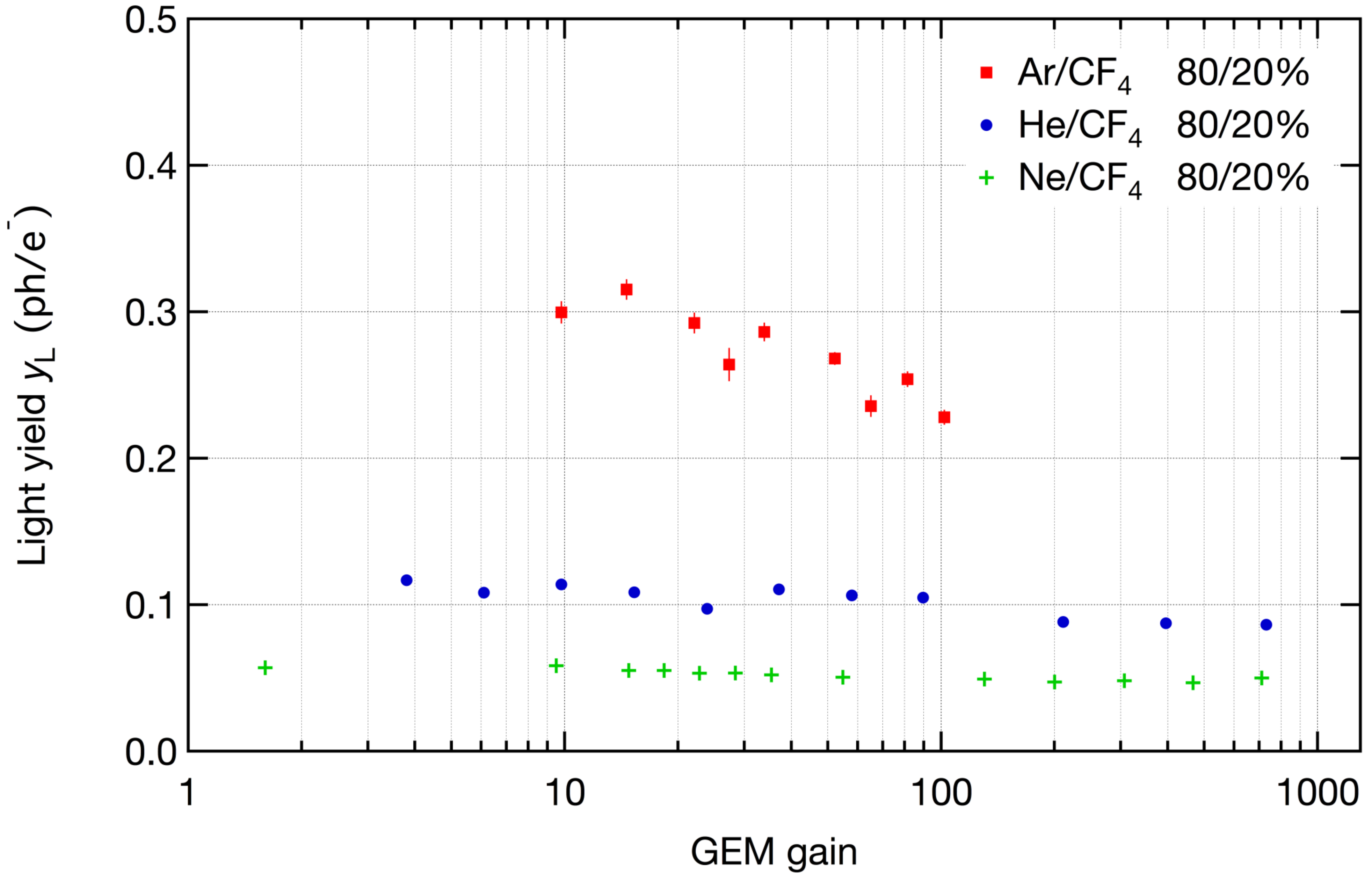
Optical readout scintillation spectra

Scintillation light spectra of different gas mixtures match CCD quantum efficiency



Intensity of emitted scintillation light

$$y_L = \frac{N_{ph}}{N_e}$$

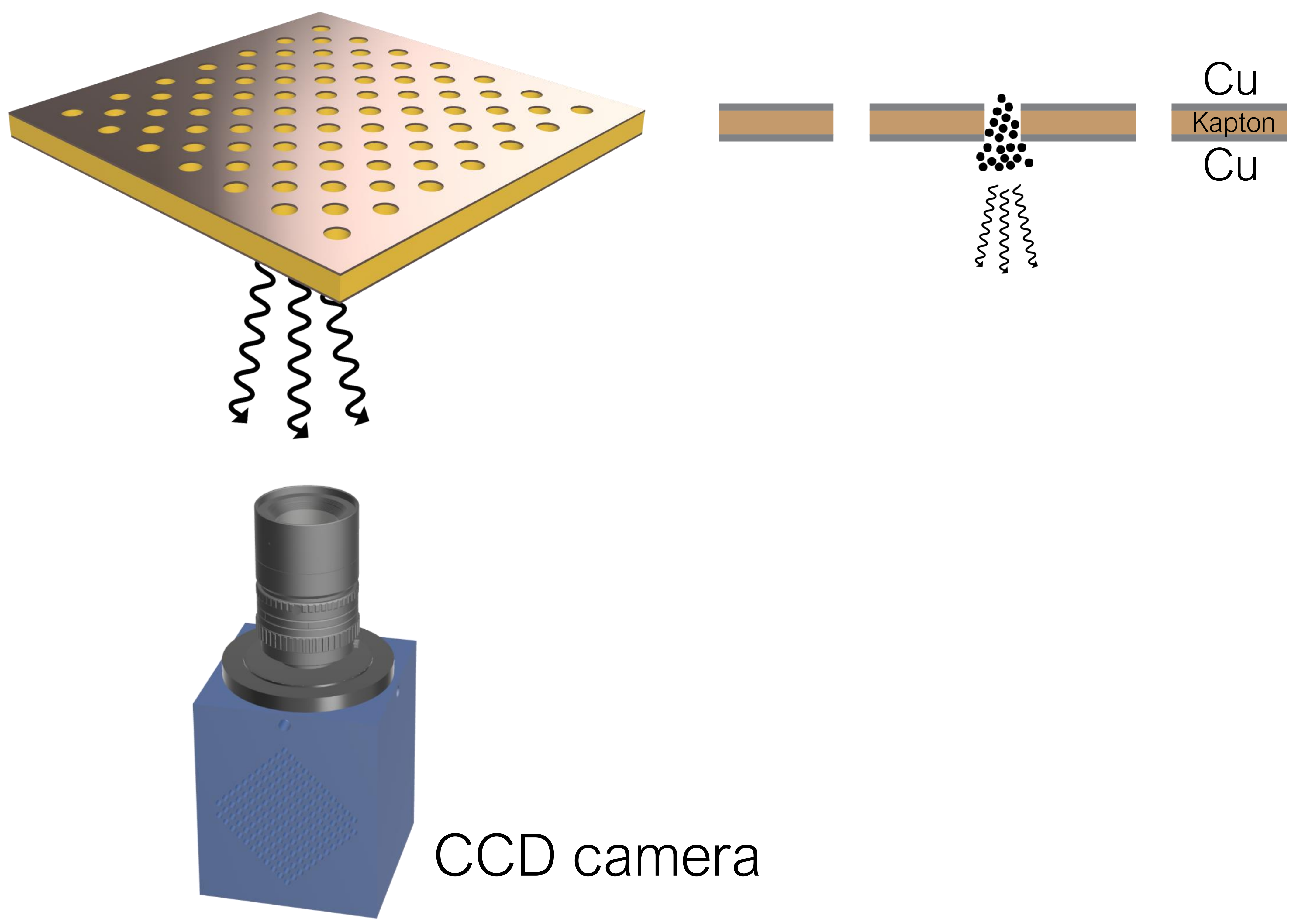


Micromegas on glass
Enabling optical readout

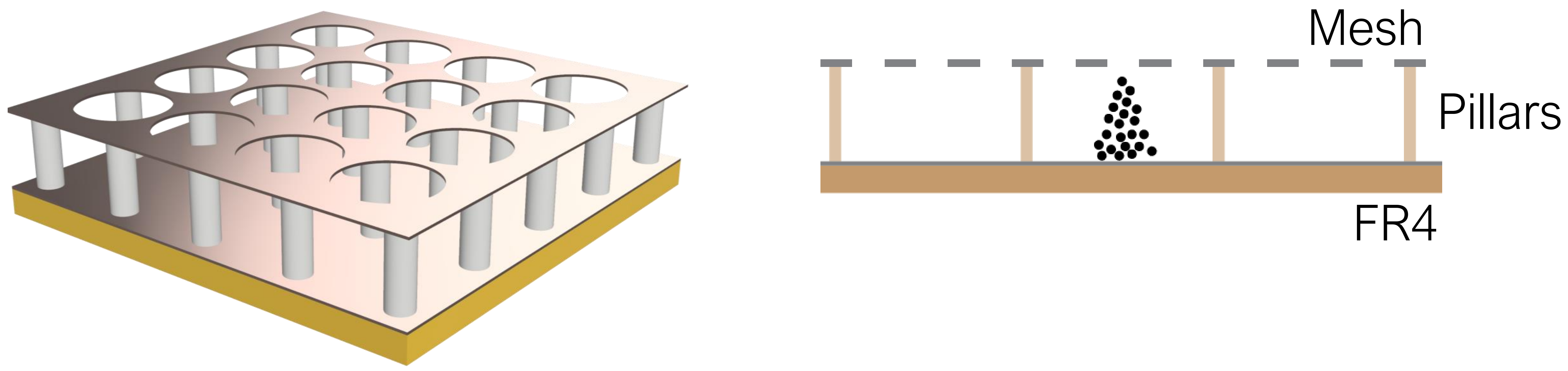
Optical readout of gaseous detectors

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**)



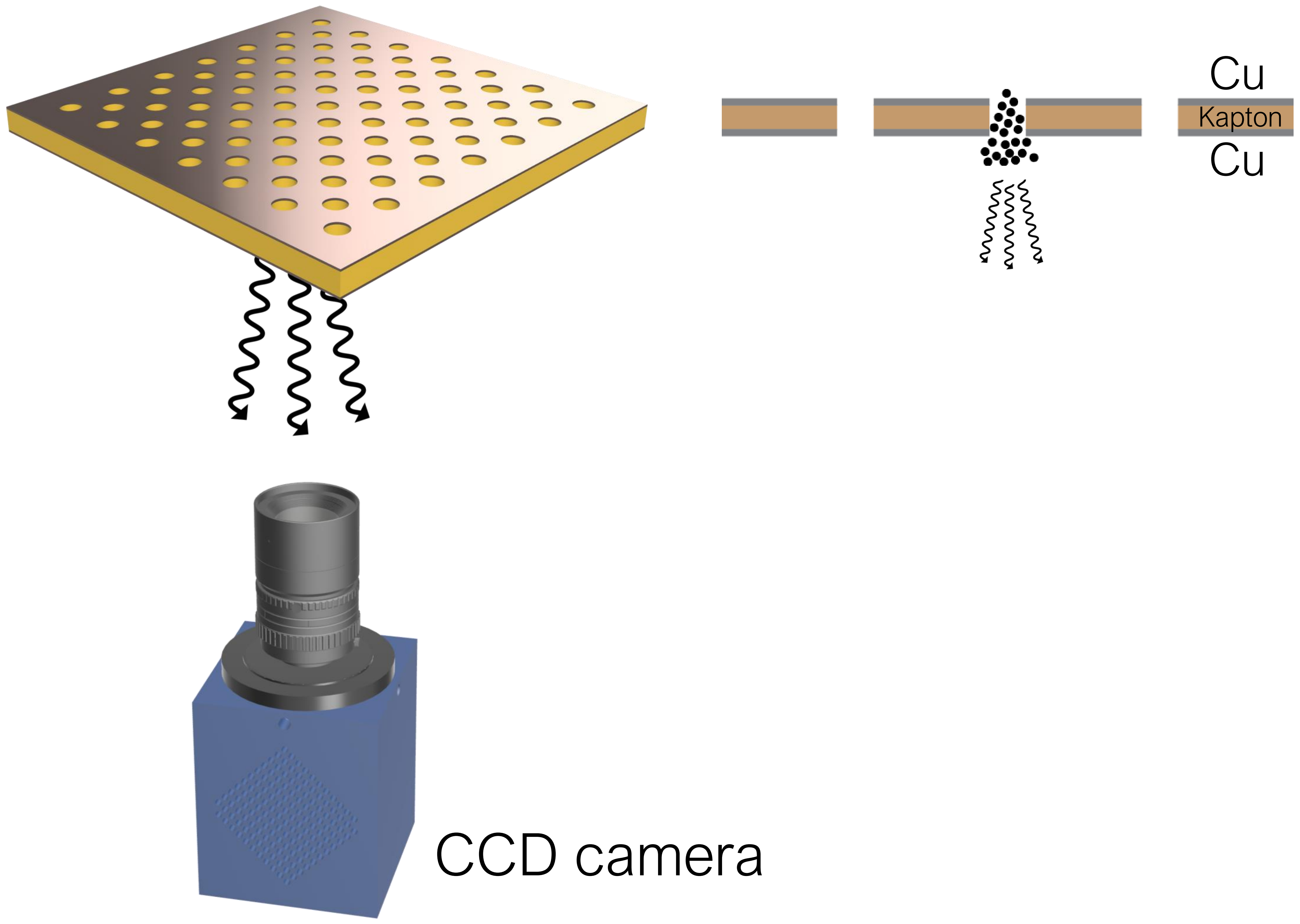
Micro-Mesh Gaseous Structure (**MicroMegas**)



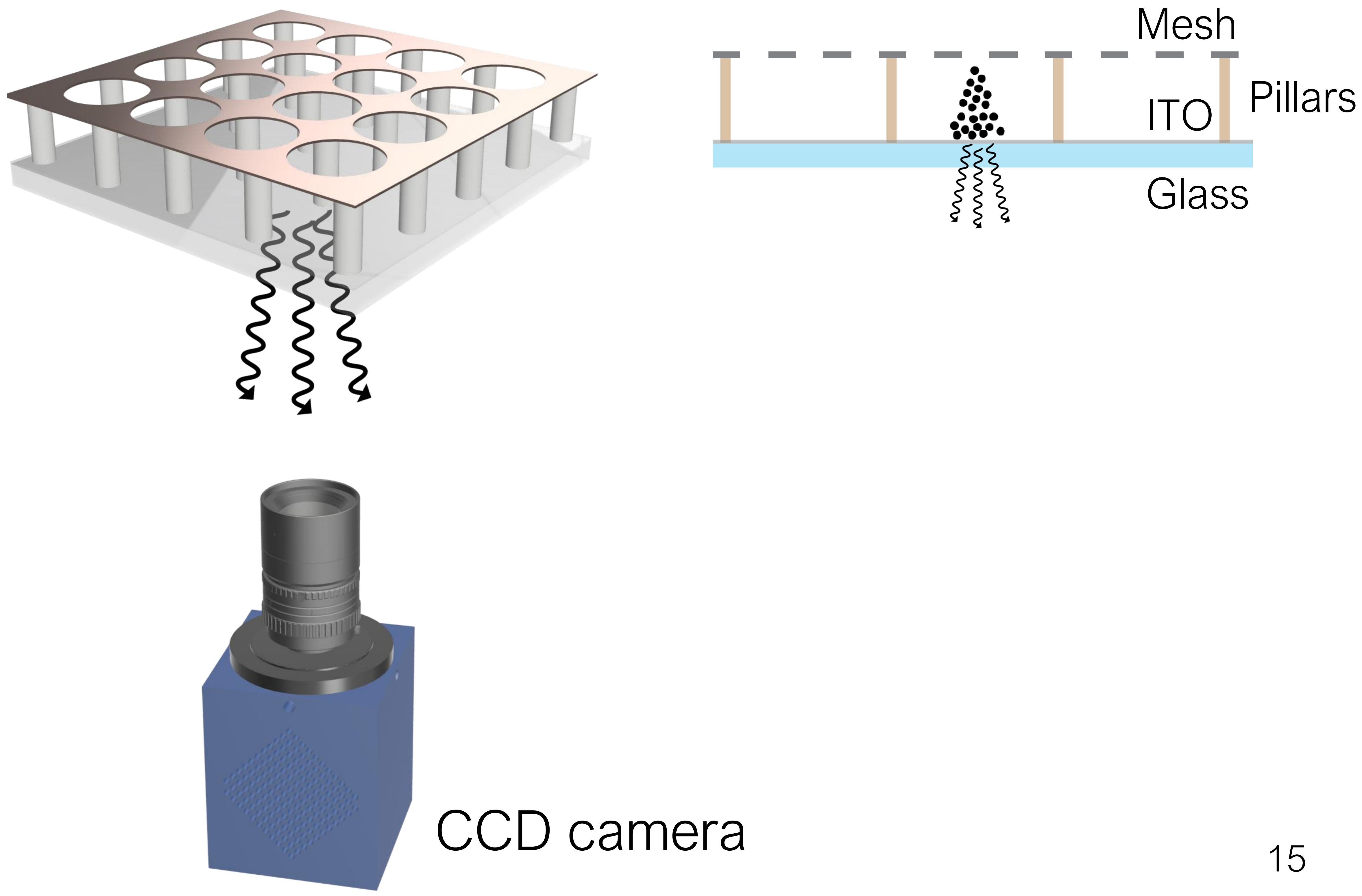
Optical readout of gaseous detectors

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

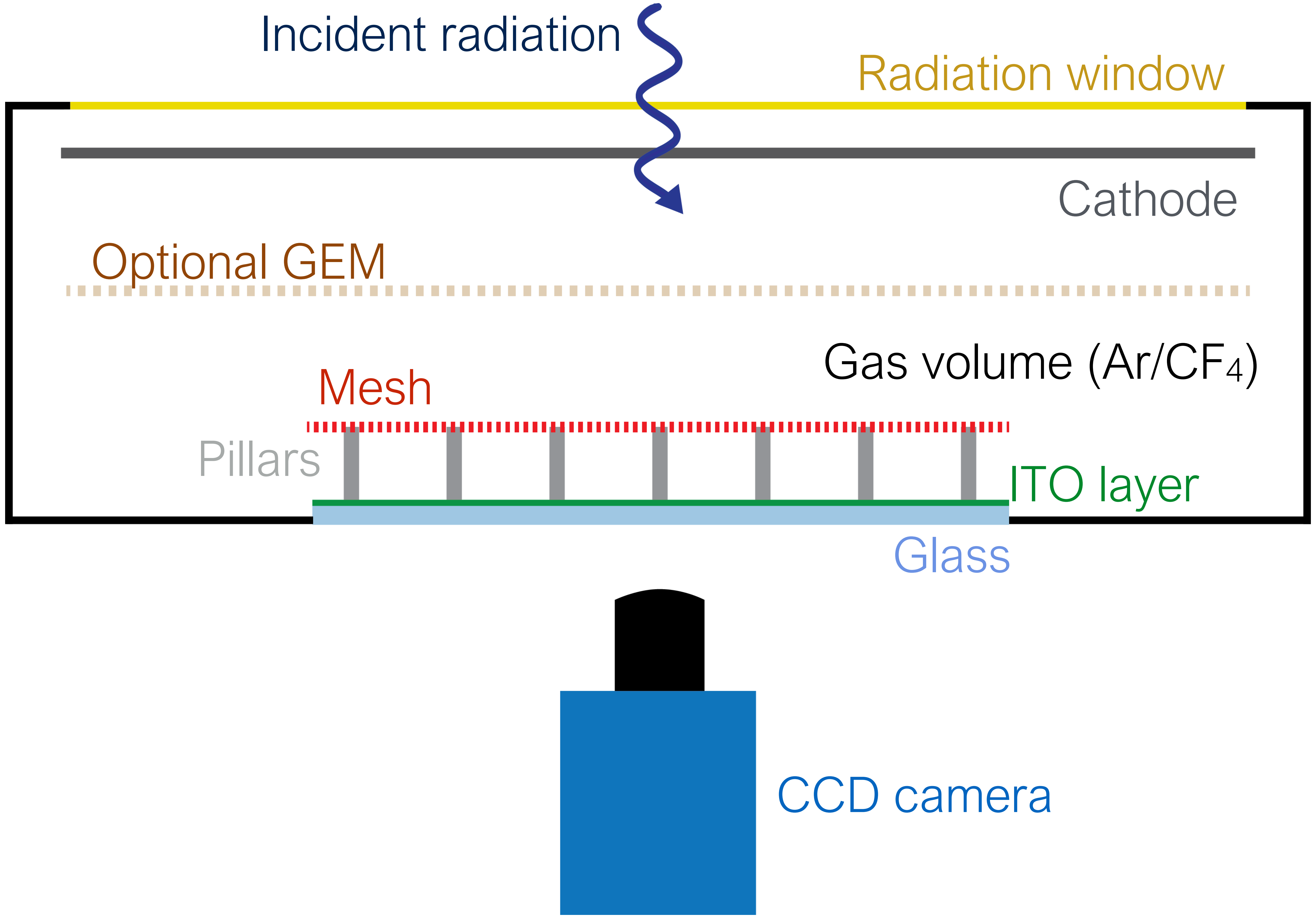
Gaseous Electron Multiplier (**GEM**)



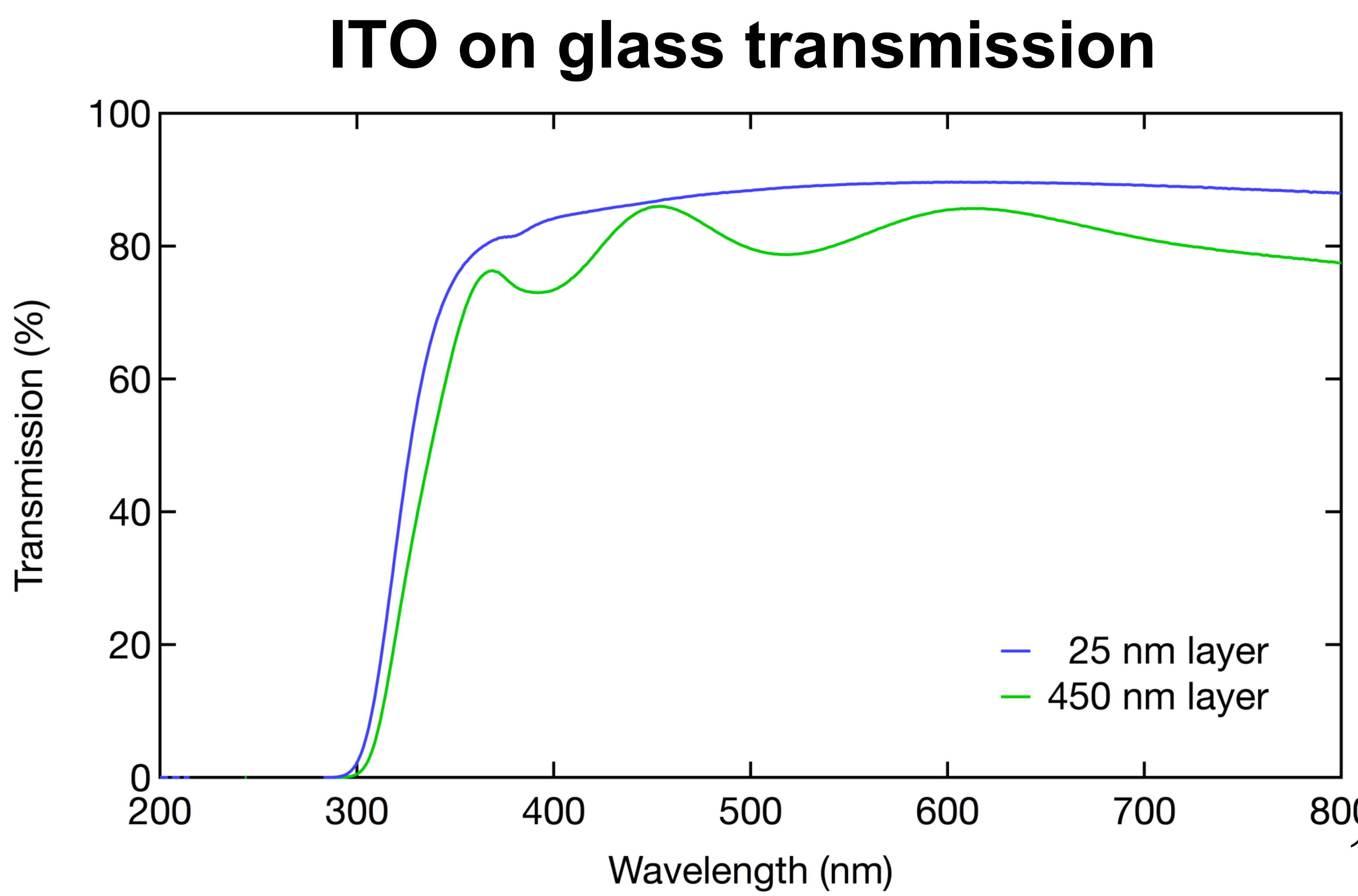
Micro-Mesh Gaseous Structure (**MicroMegas**)



Optical readout of Micromegas **setup**



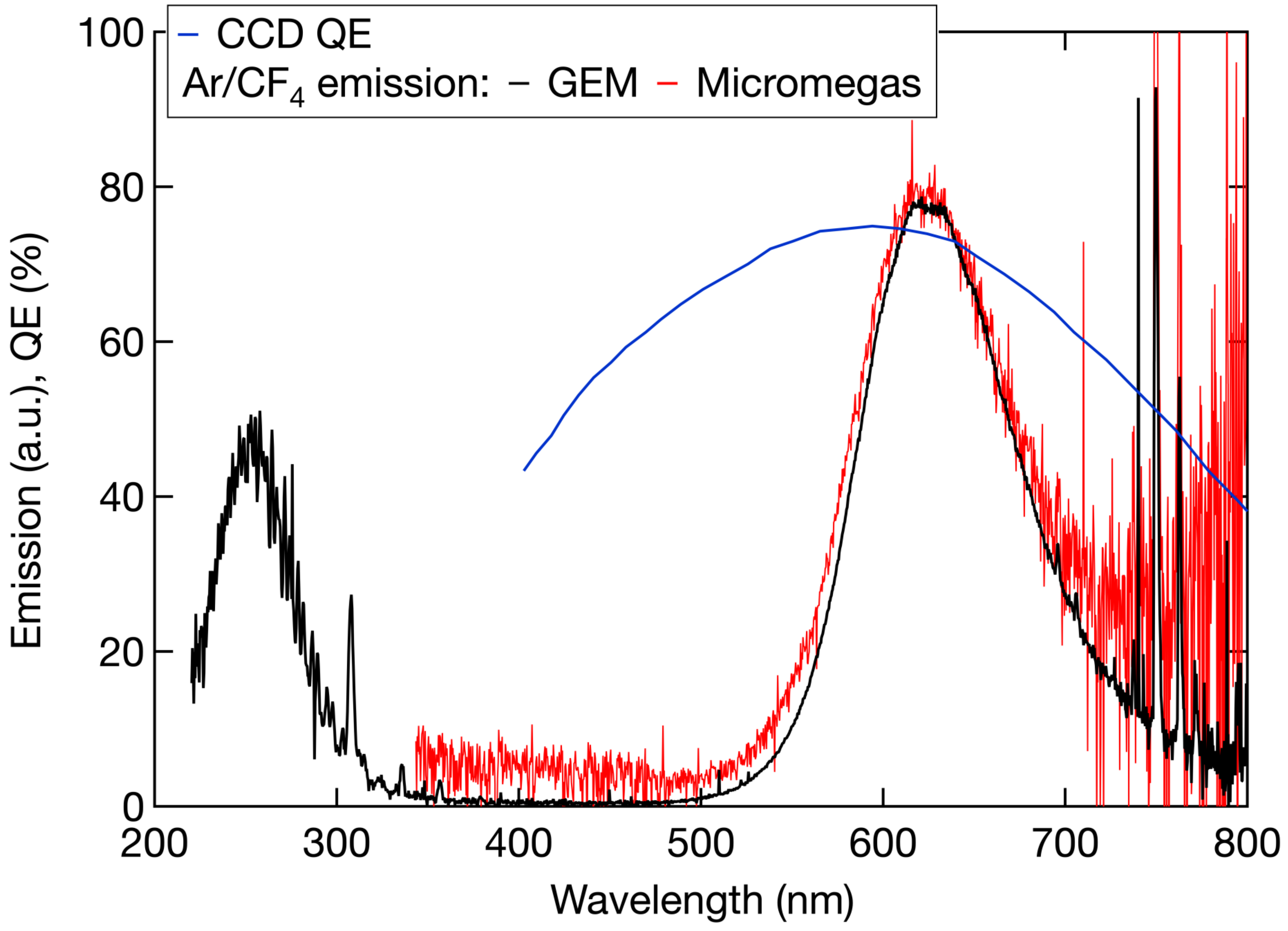
By integrating Micromegas on a transparent glass substrate with an ITO layer as anode, scintillation light emitted during electron avalanche multiplication can be recorded



Scintillation light from Glass Micromegas

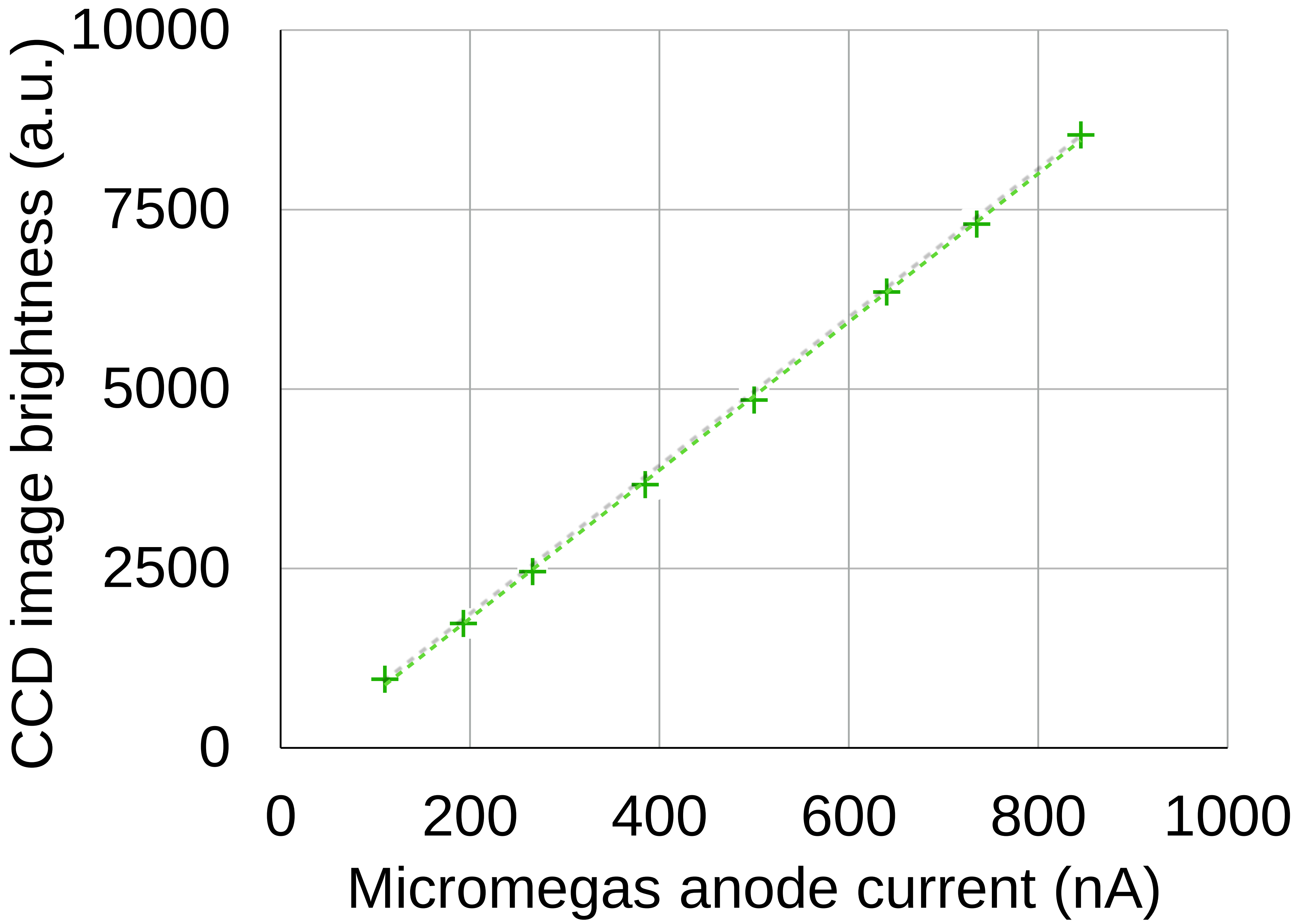
Secondary scintillation spectrum

Visible scintillation spectrum (VIS + NIR lines) are comparable for GEMs and Glass MM. Light below ≈300nm is suppressed in Glass MM due to ITO anode and glass substrate.



Constant light yield

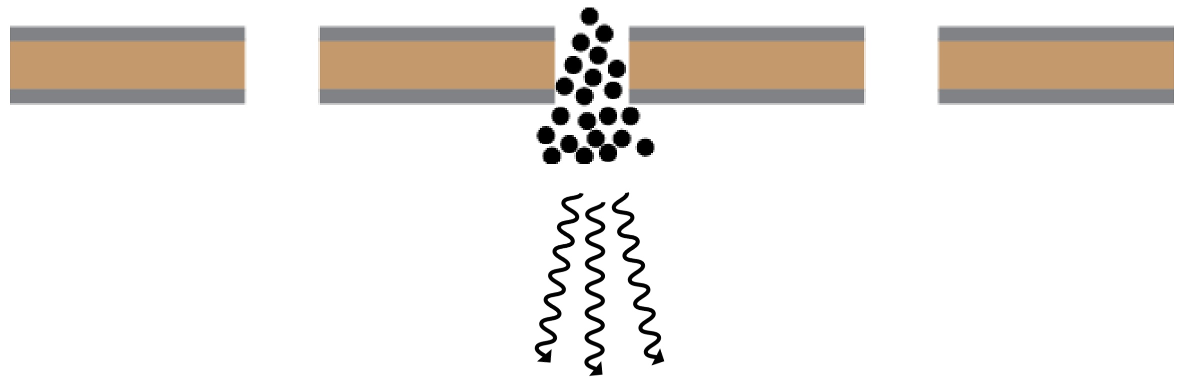
Brightness in CCD images is directly proportional to Micromegas anode current

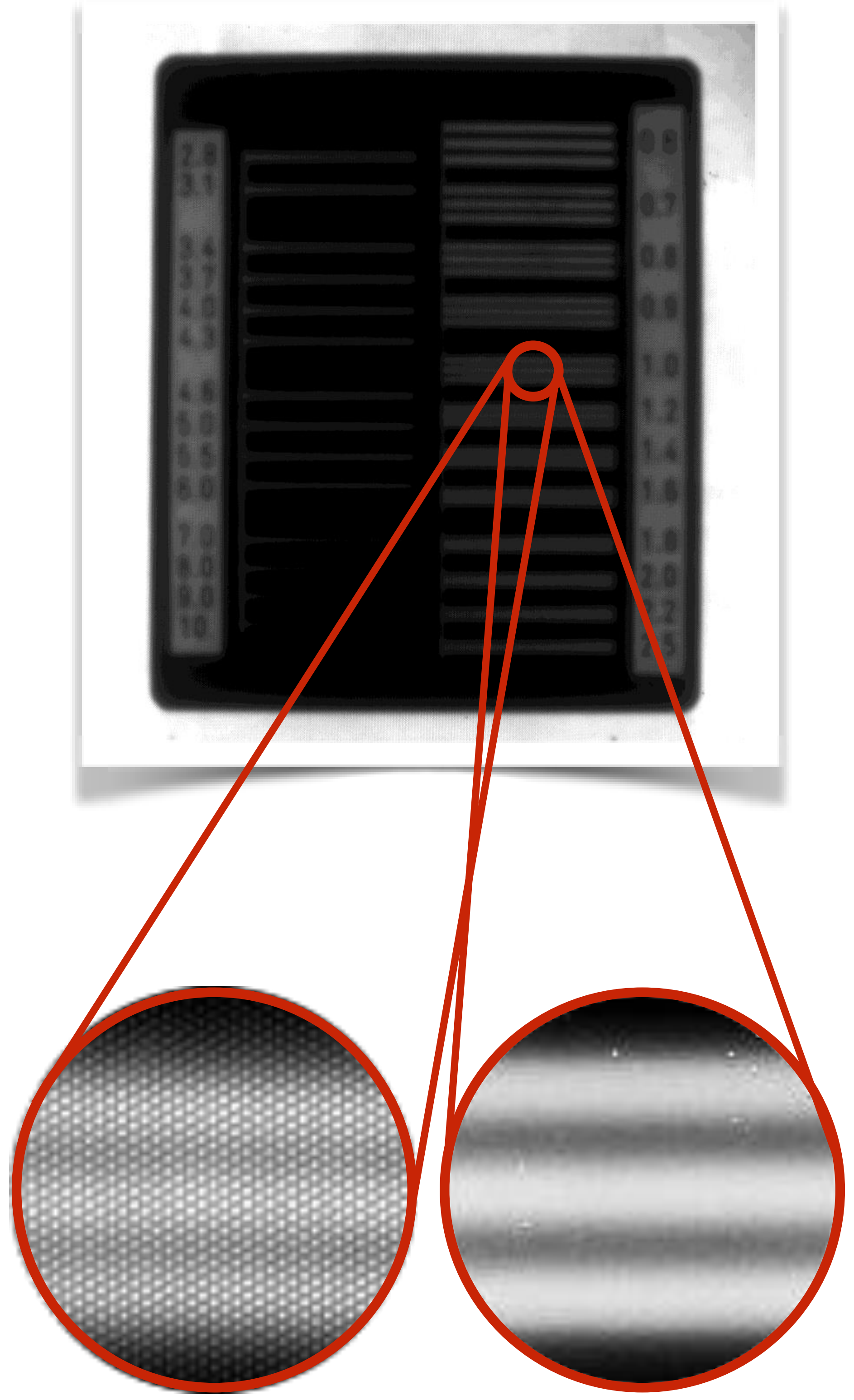


Light emission profile

Uniformity of amplification region determined light emission profile and achievable spatial resolution of optically read out MPGDs.

Gaseous Electron Multiplier (**GEM**)

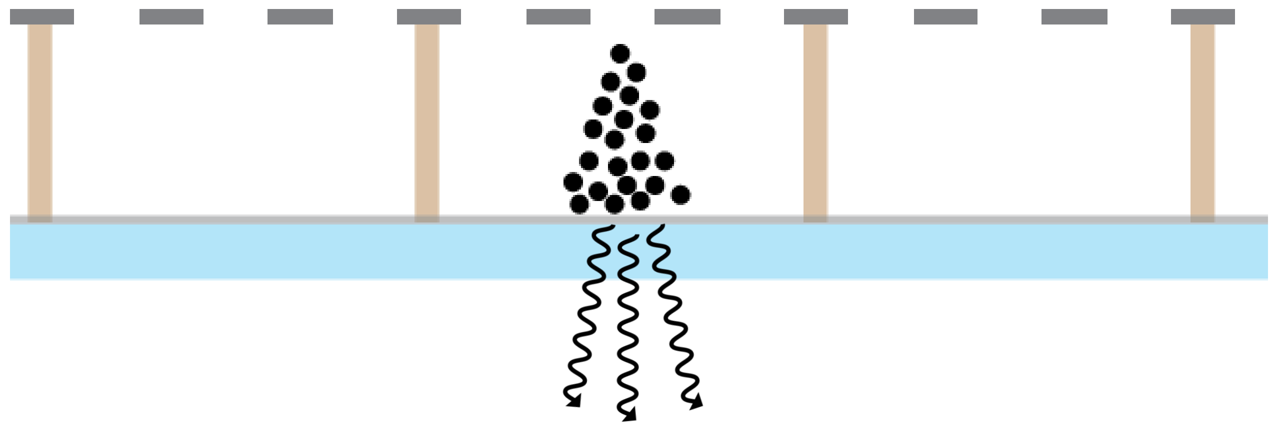




Triple-GEM
Hole structure

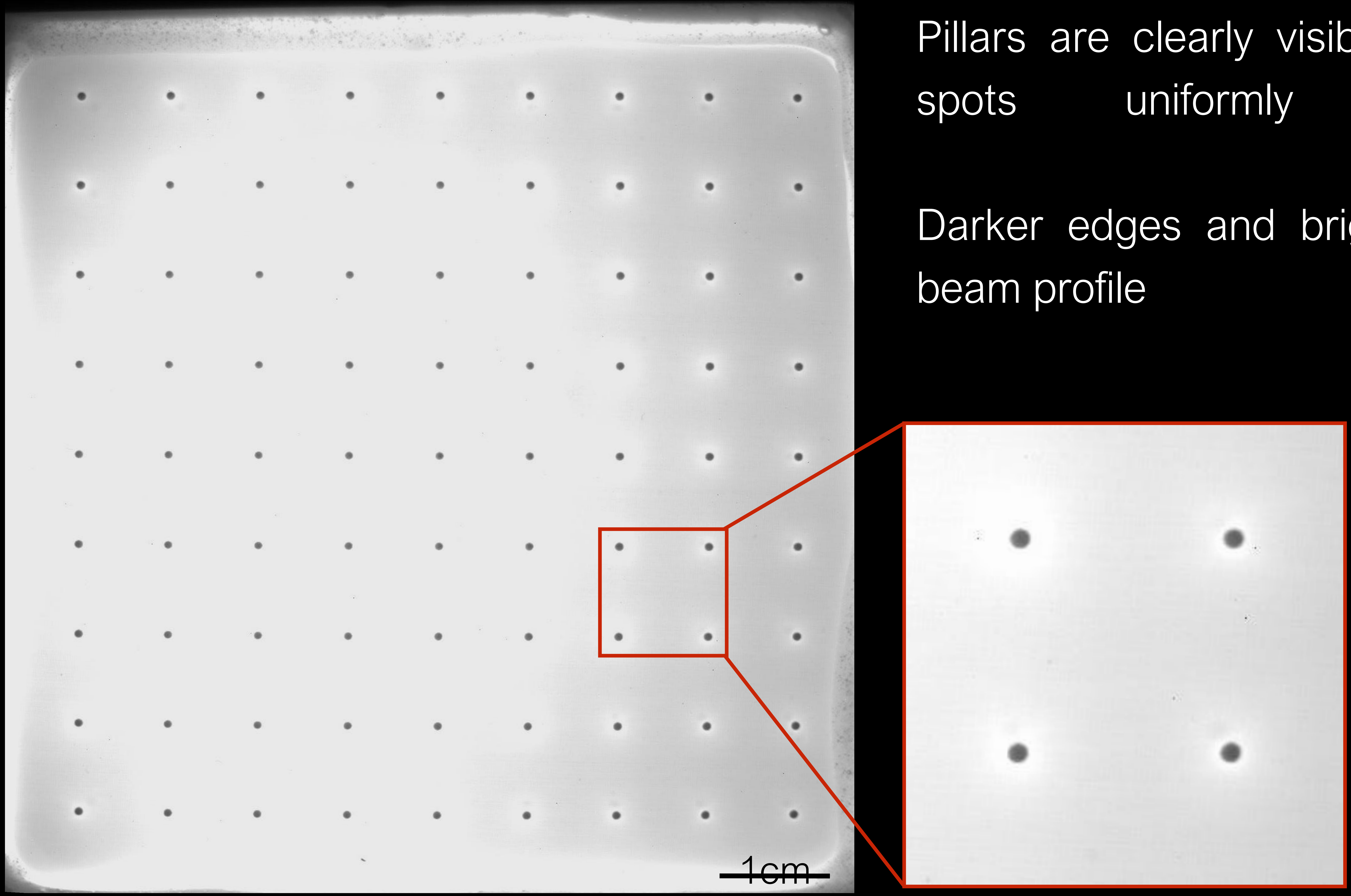
Micromegas
Uniform

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



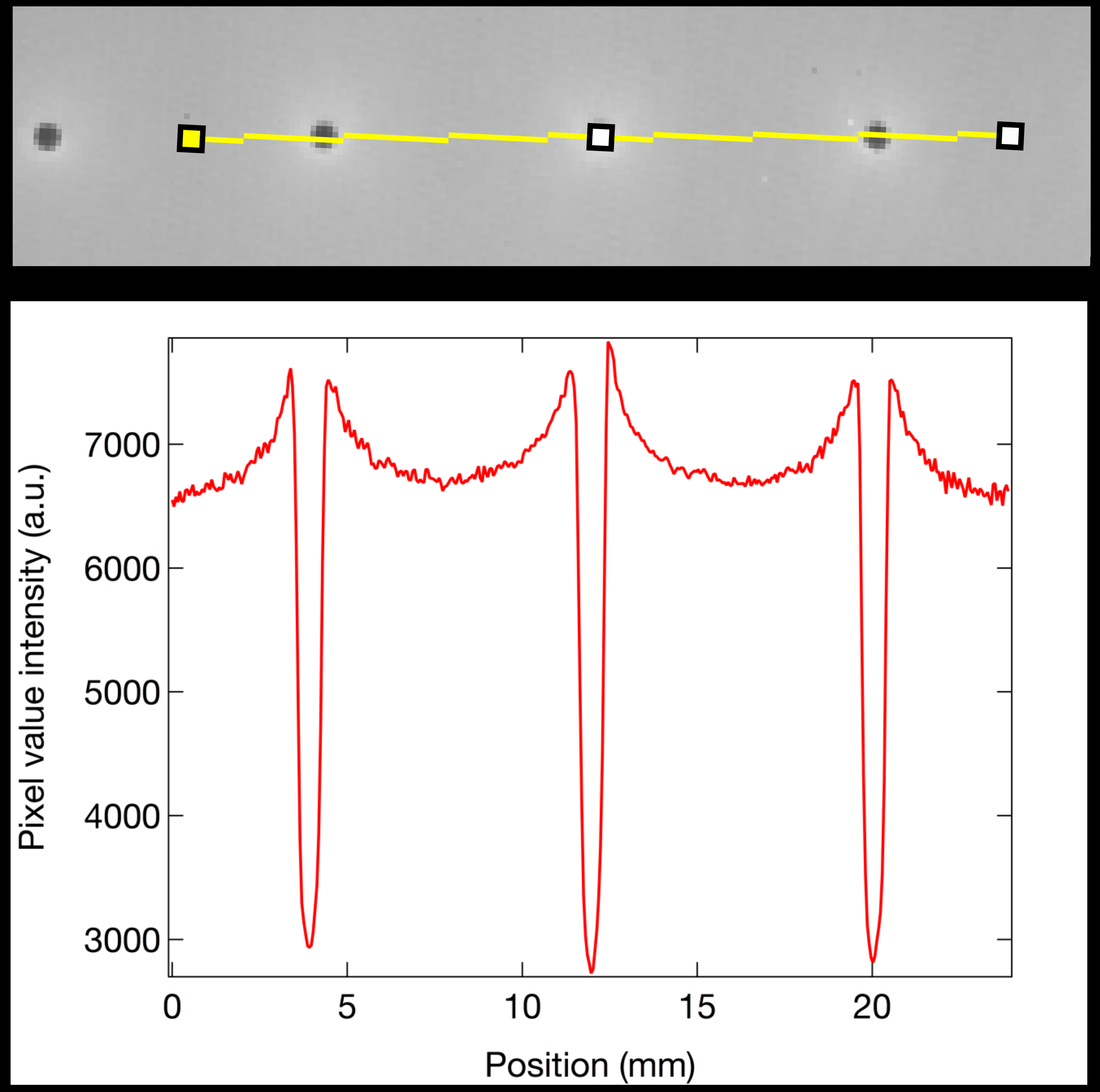
Imaging and spatial resolution

Optical response of Micromegas detector to X-rays



Pillars are clearly visible in flood exposure images as dark spots uniformly spaced at 8mm pitch

Darker edges and brightness variations attributed to X-ray beam profile

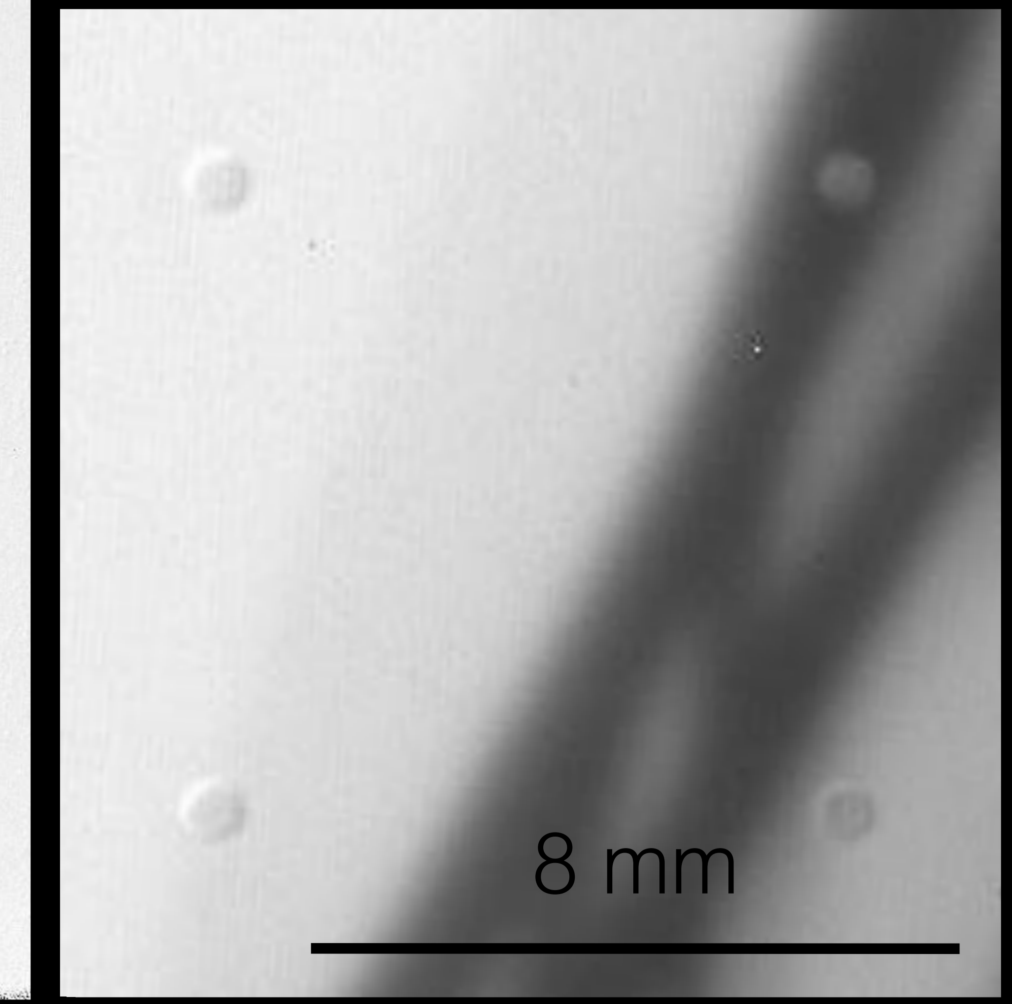


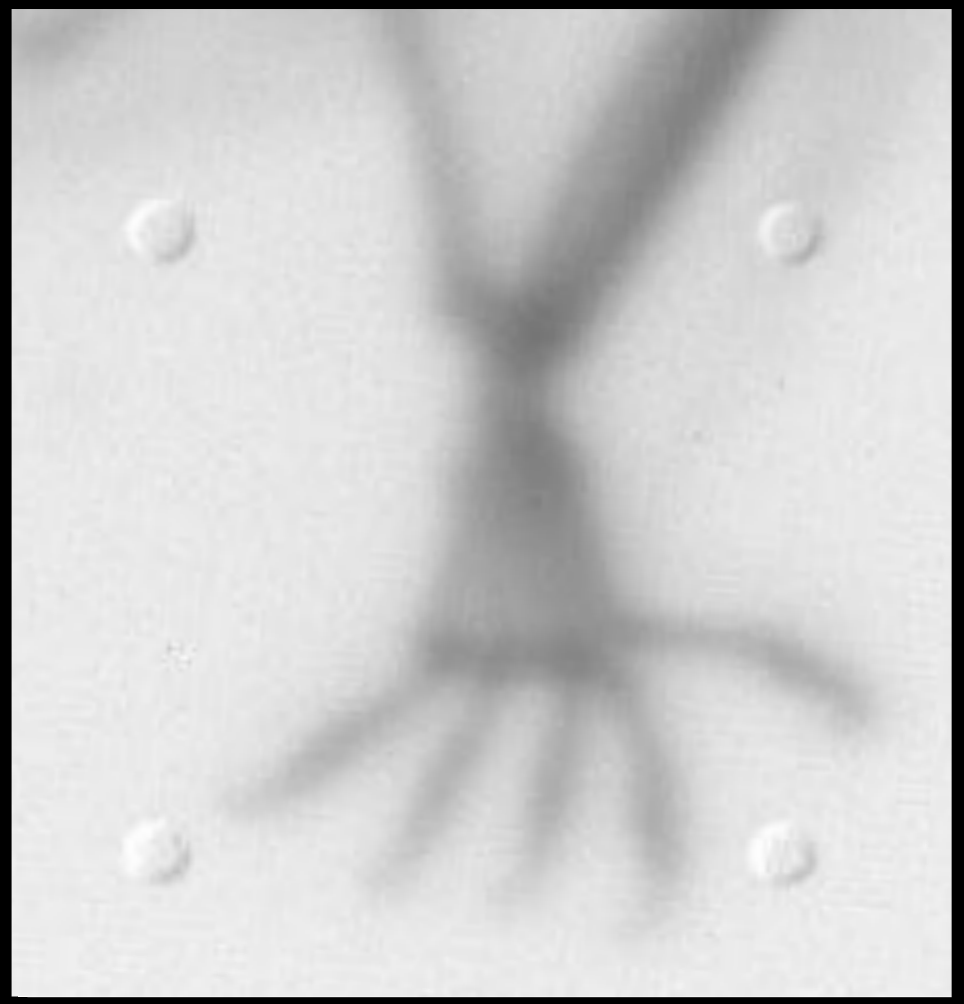
X-ray radiography with Glass MM

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

Pillars are visible as inefficient areas

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





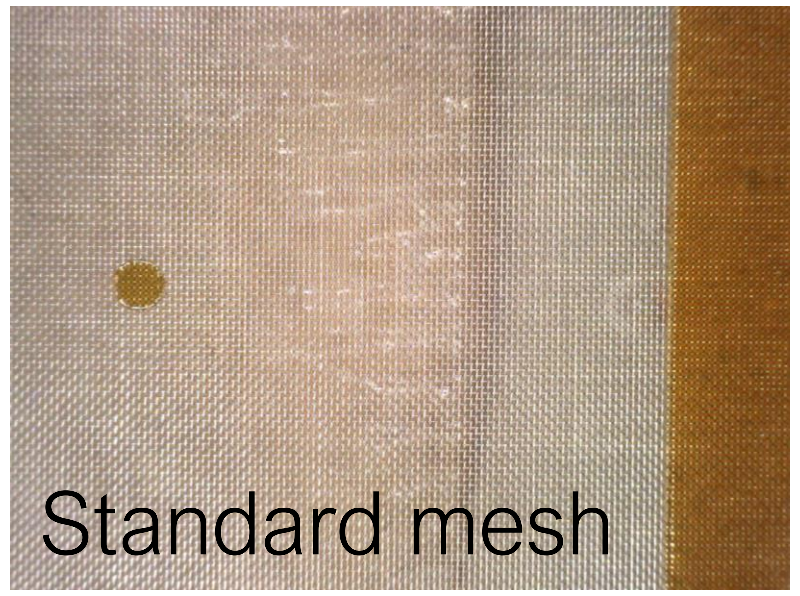
Triple GEM

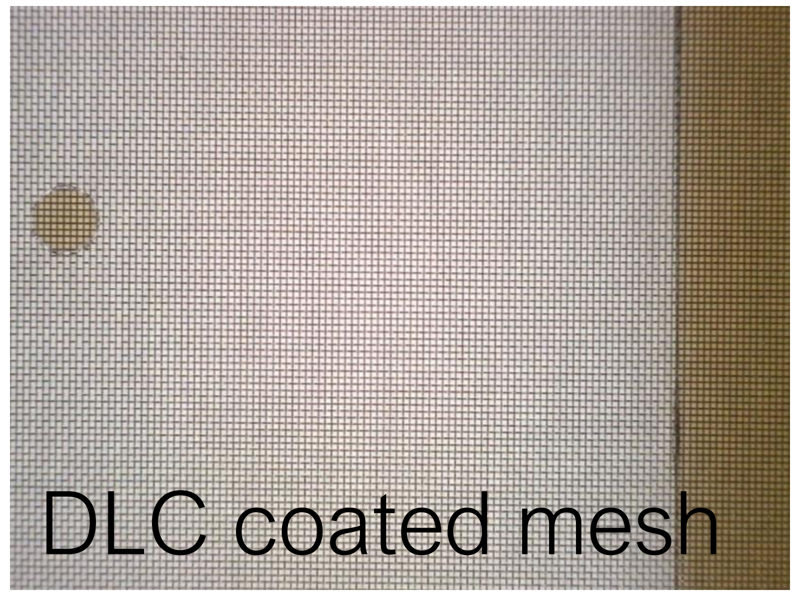
Glass Micromegas developments

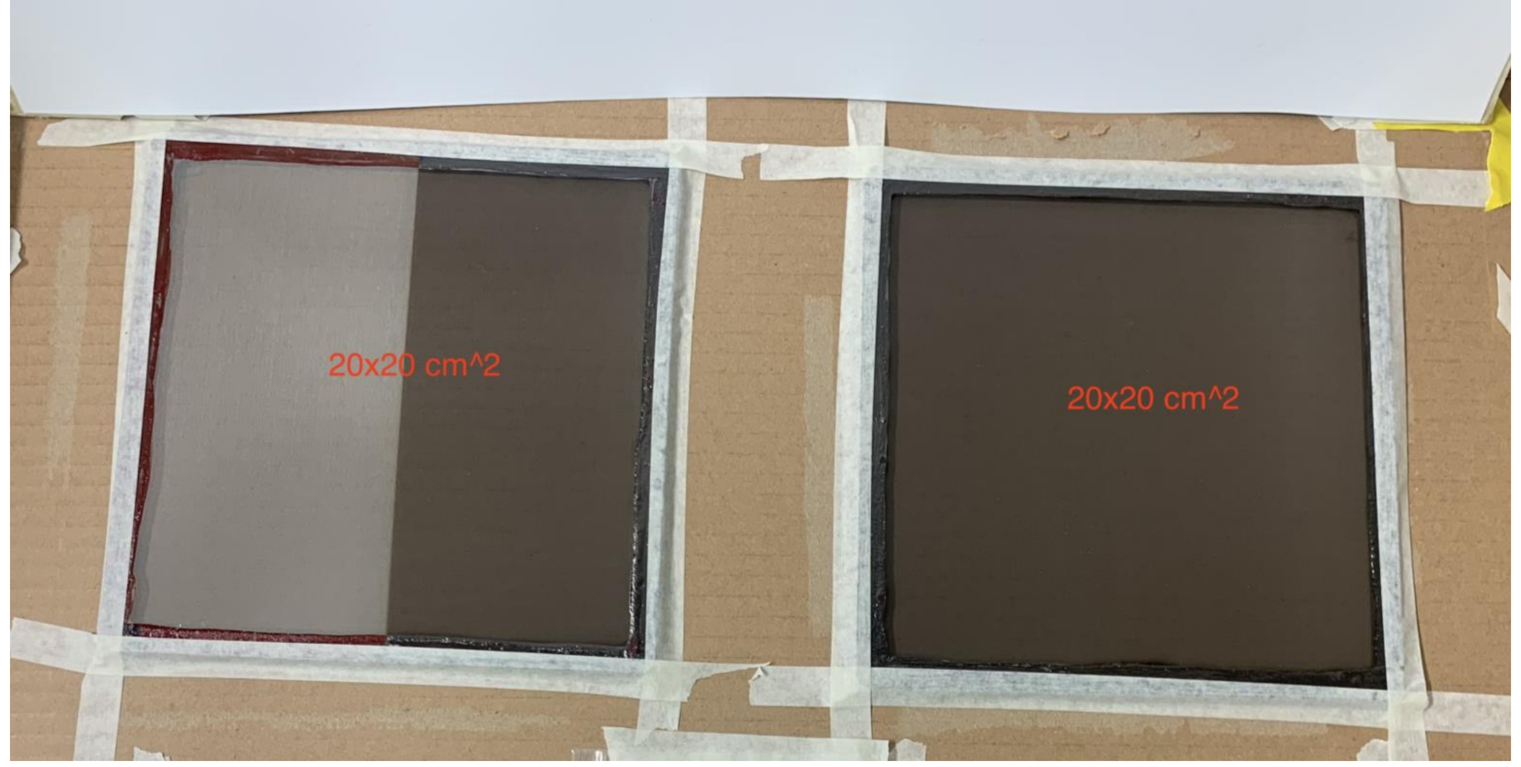
DLC-coated meshes

Reflections of scintillation light on the mesh may degrade spatial resolution. DLC-coated (darkened) meshes could be used to minimise reflections.

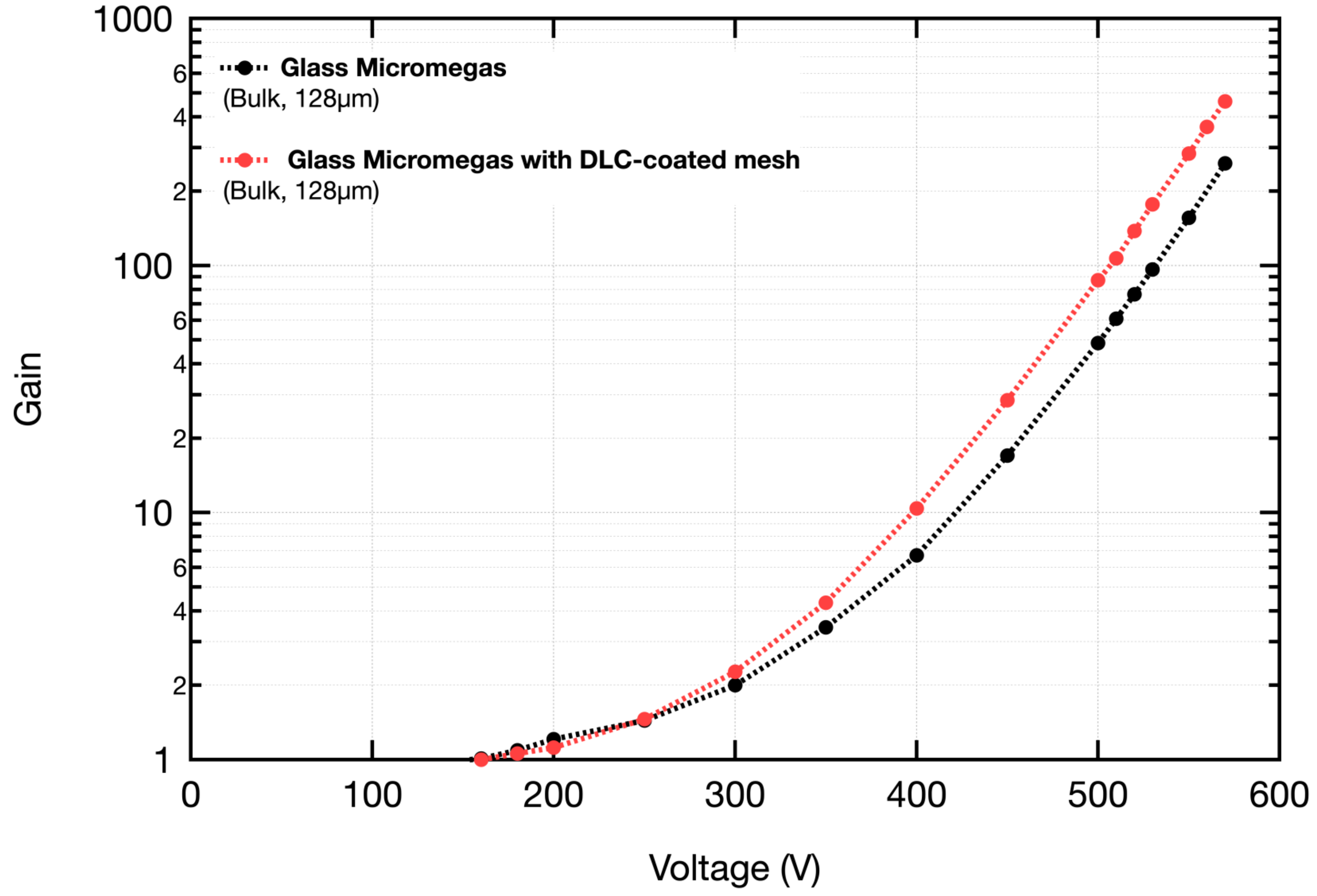
Similiar performance and potentially minor improvement of spatial resolution was observed comparing glass Micromegas with standard vs. DLC-coated meshes.

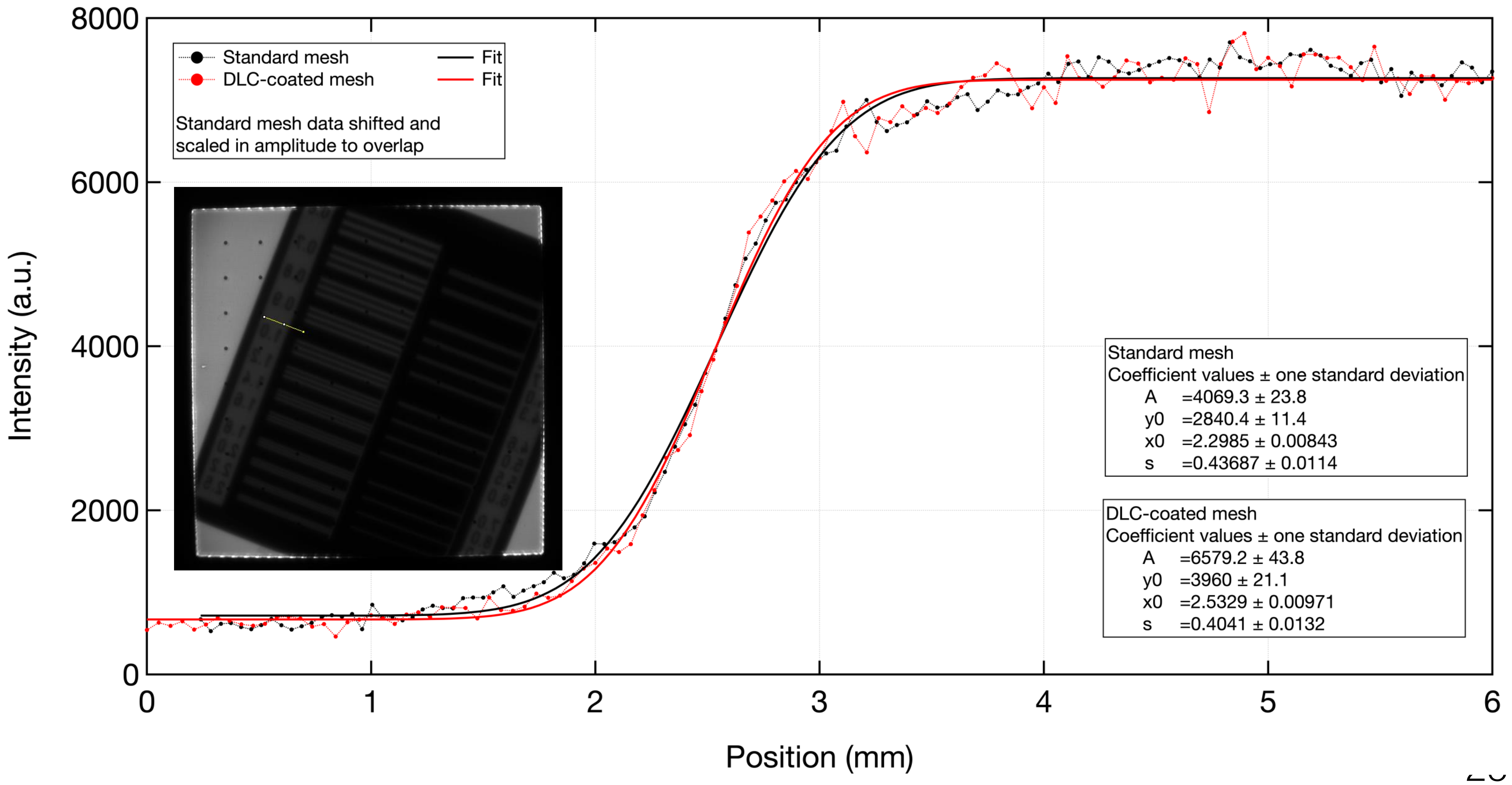






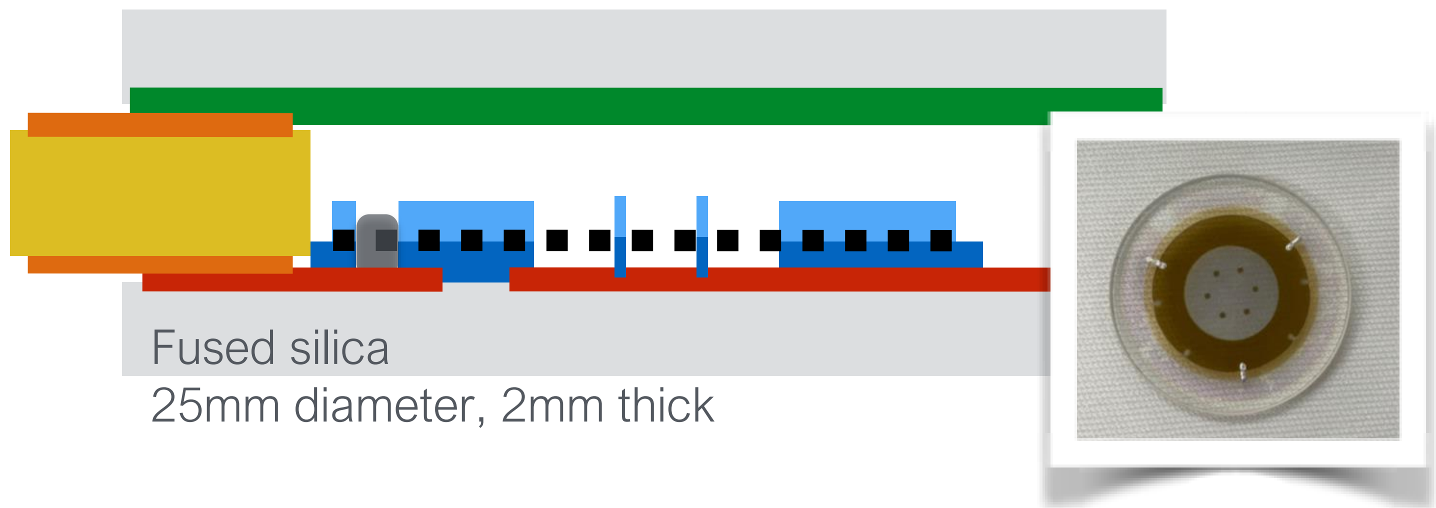
DLC coated at USTC

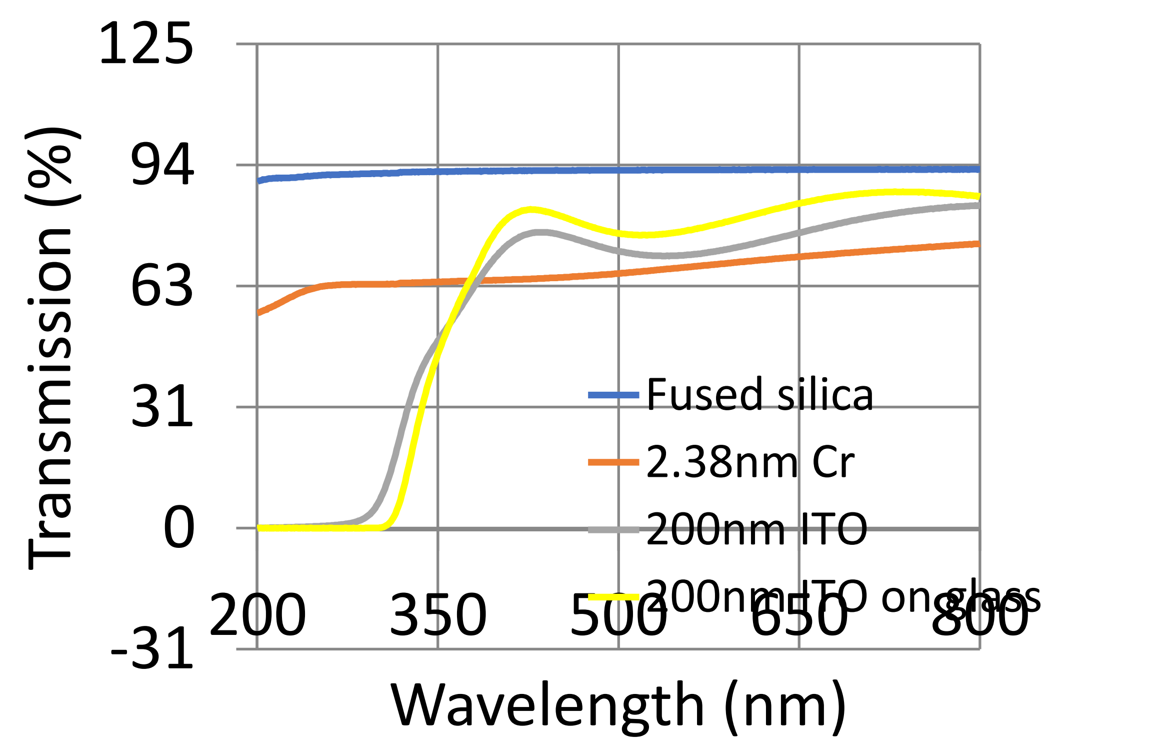




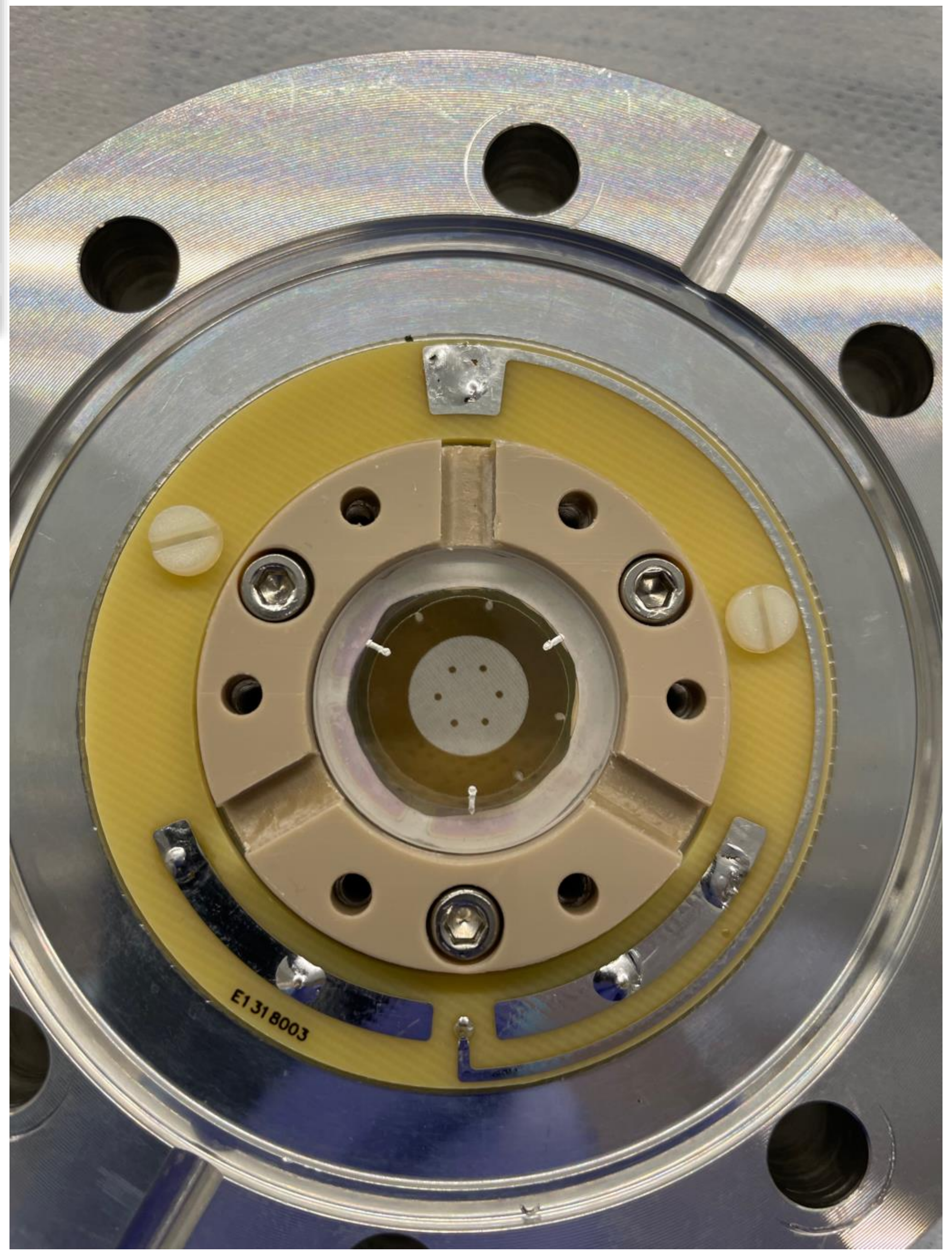
SiPM readout of Glass Micromegas

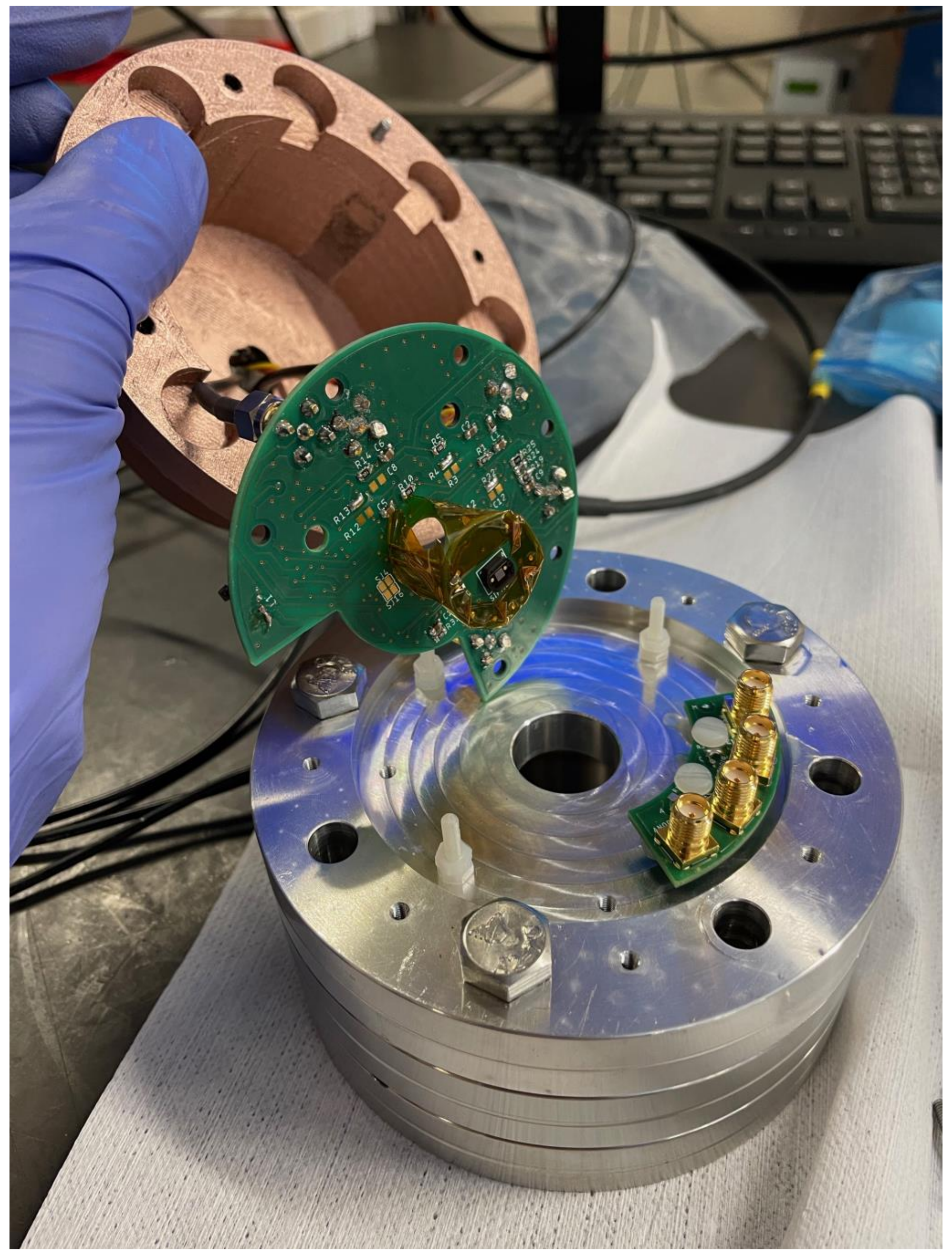
- Read out scintillation light from glass Micromegas with SiPM to profit from high time resolution and (limited) granularity
- Reconstruction of hit position from SiPM array



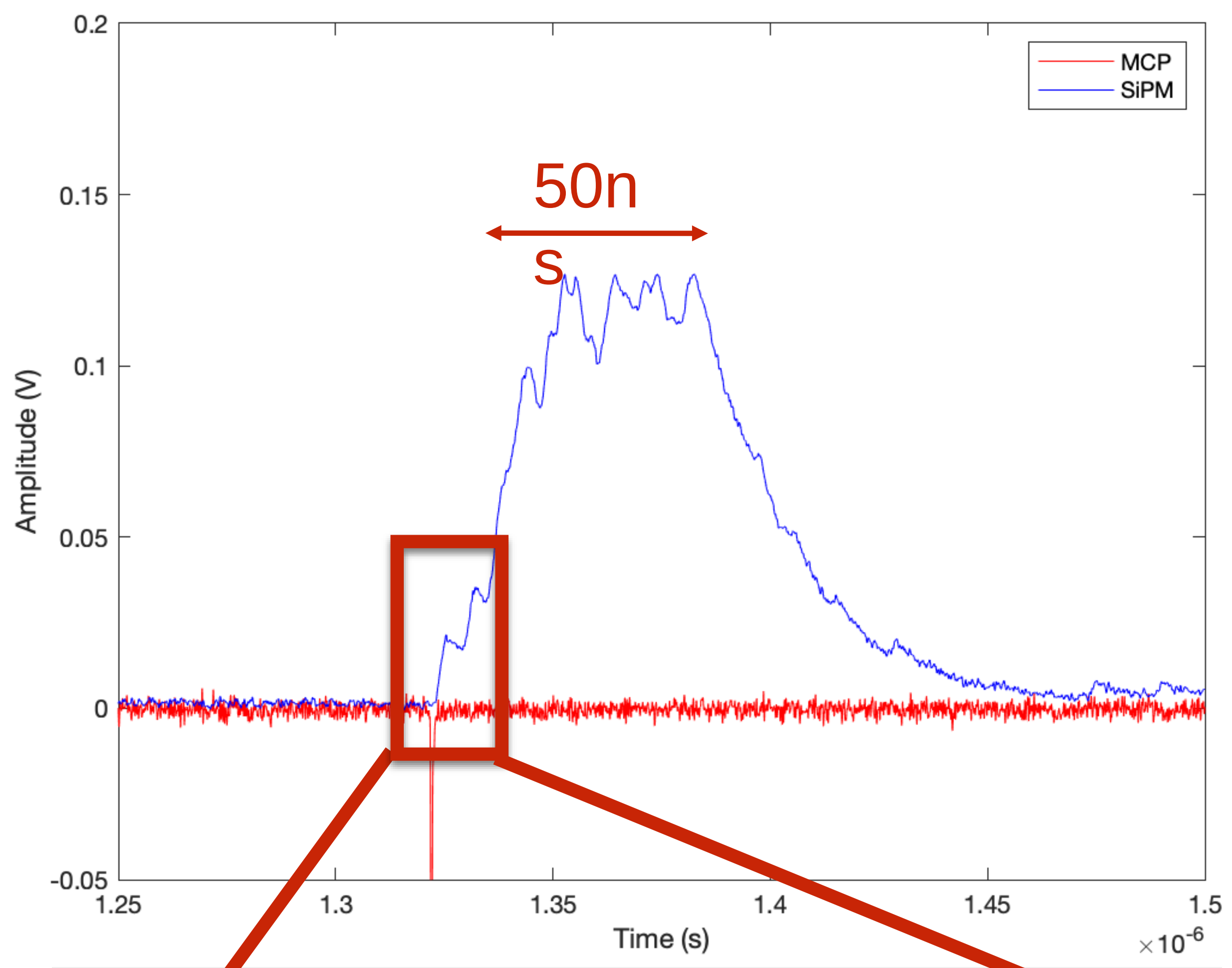


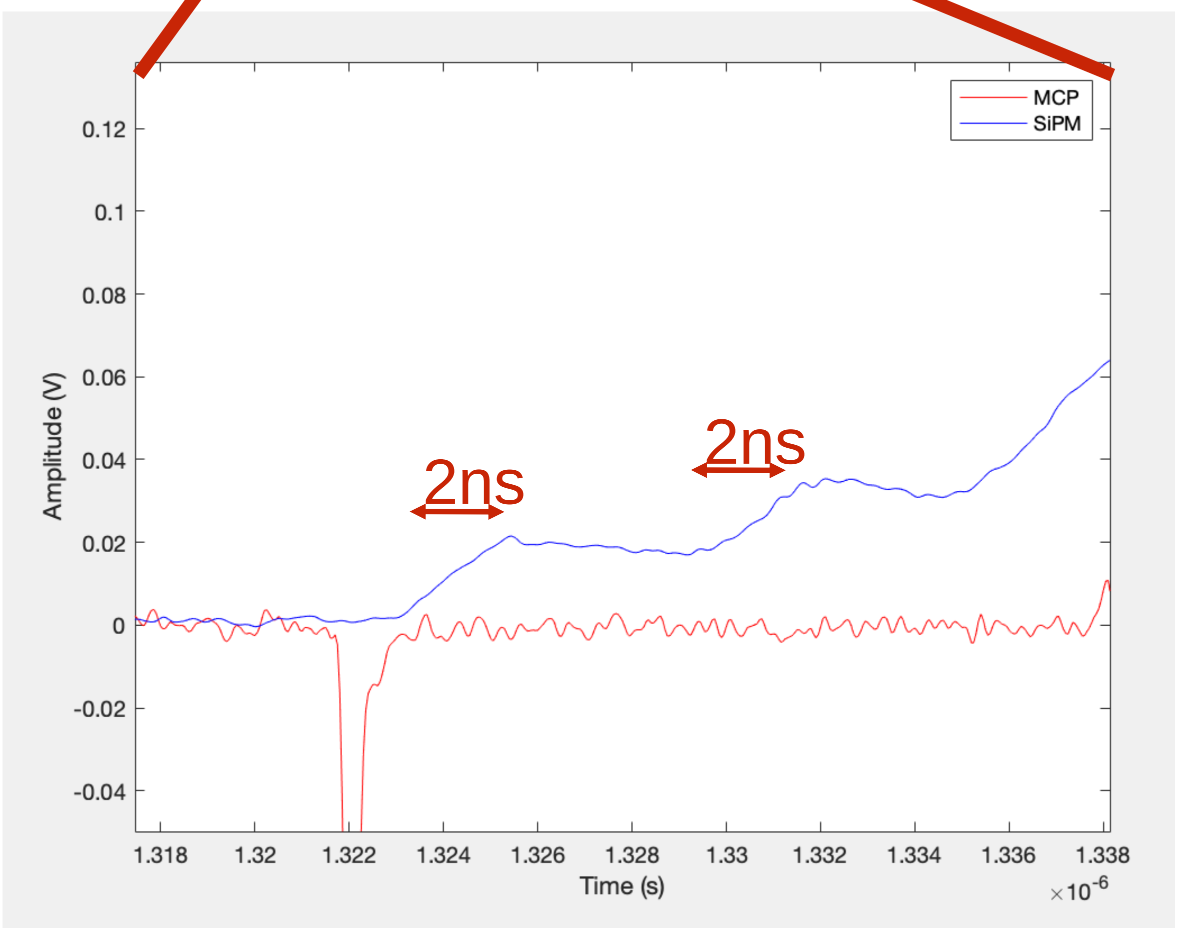
M. van Stenis





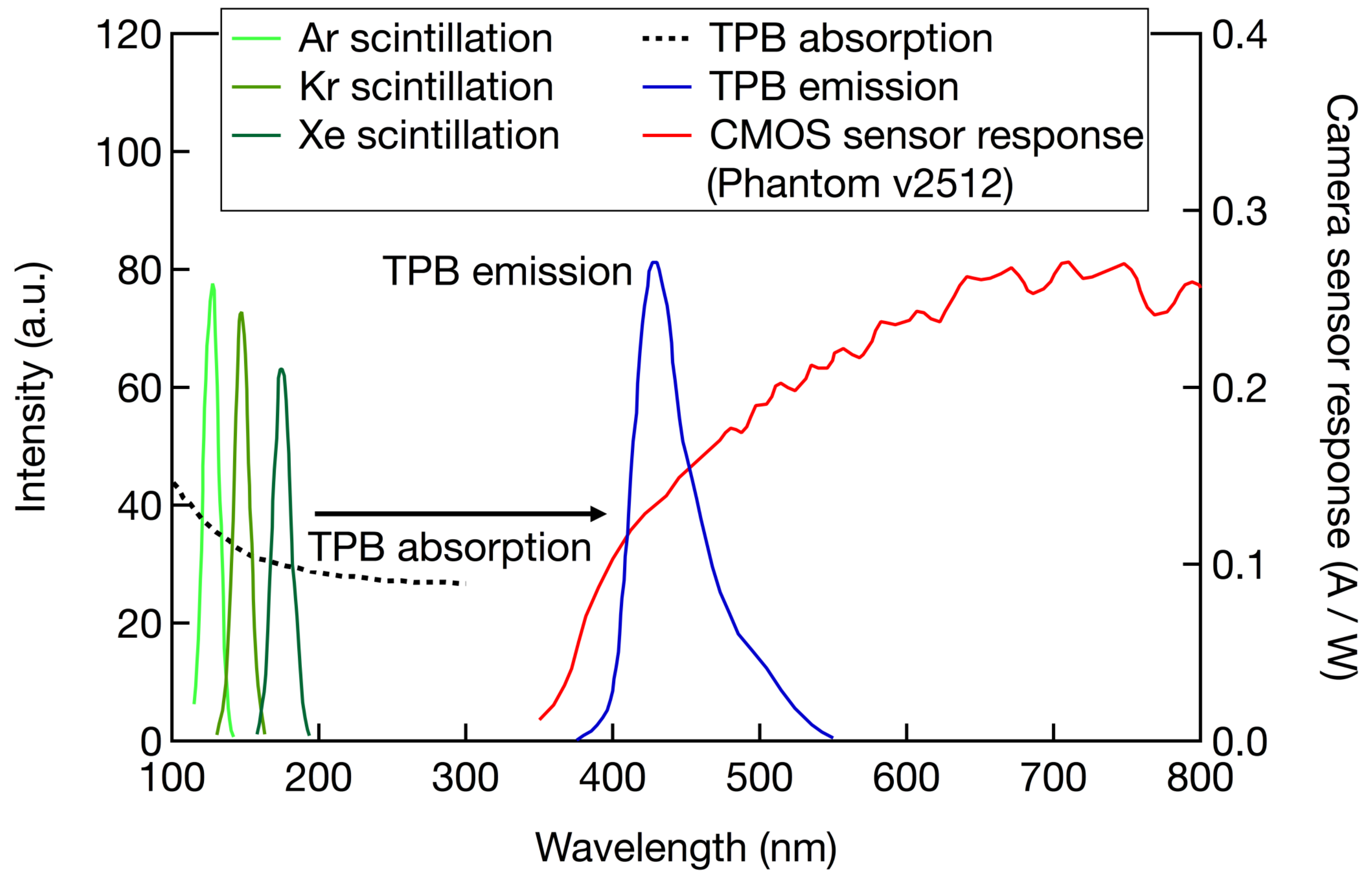
Ar/CF4 scintillation emission with over tens of ns



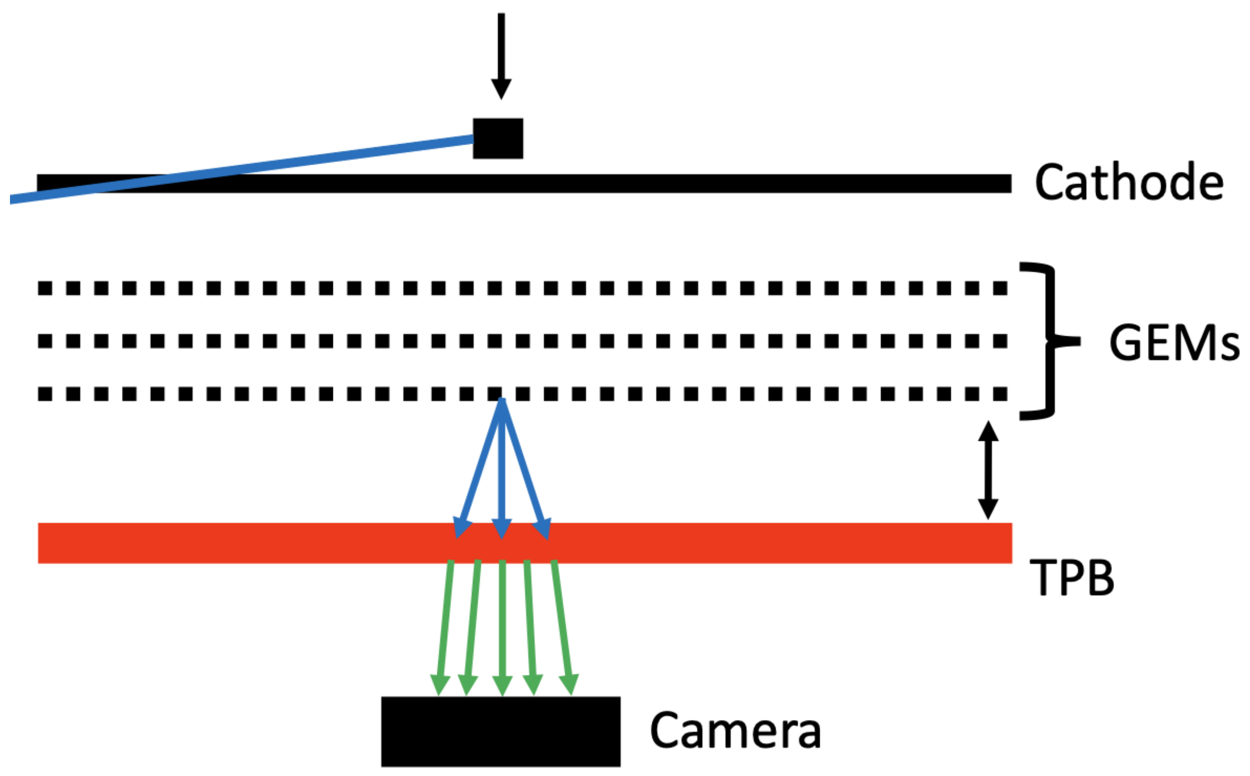


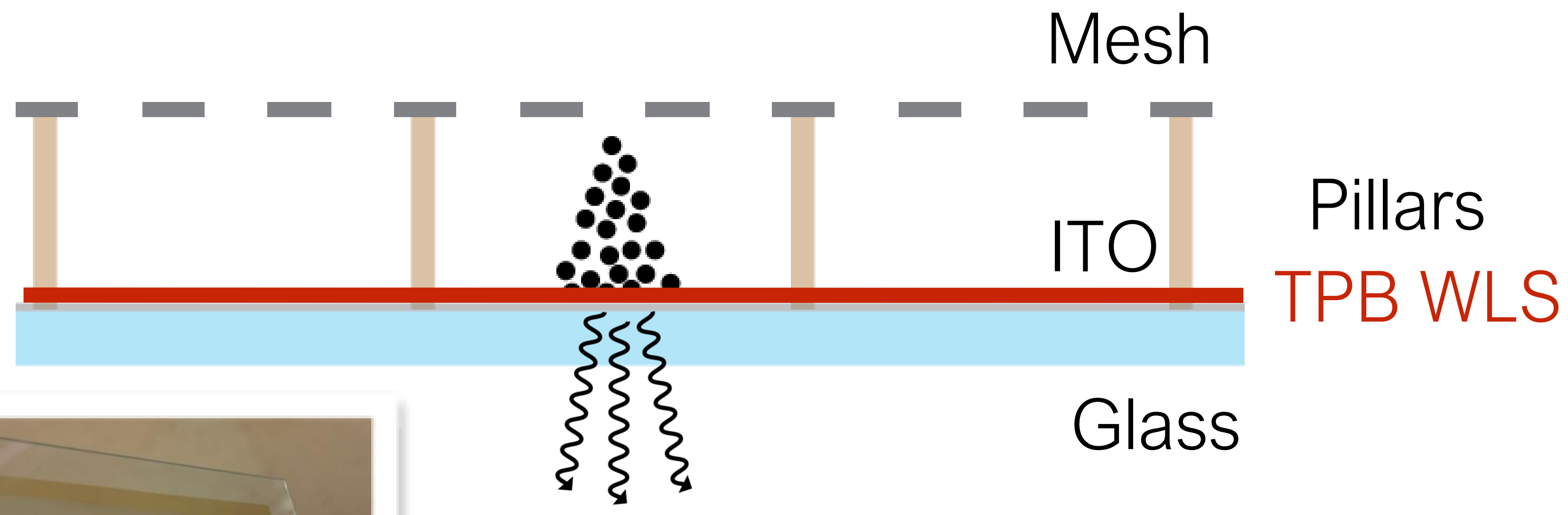
Wavelength shifting in Glass MM

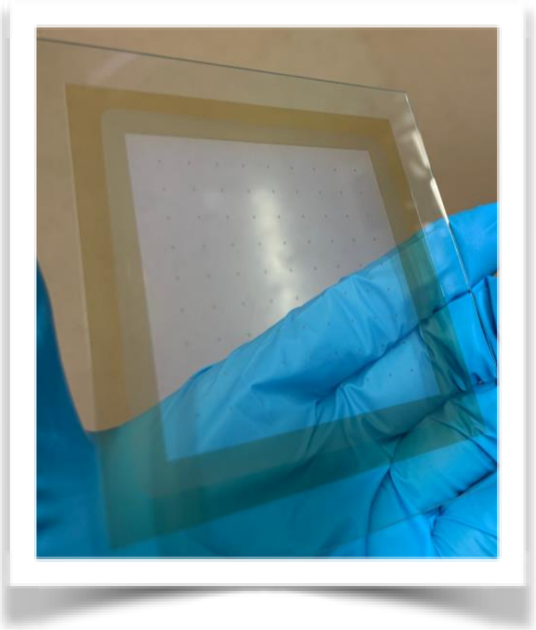
- Optical readout of MPGDs relies on CF4 for visible light emission
- Wavelength shifters (e.g. TPB layer) may be used to convert VUV light to visible light to allow optical readout in wider range of gases and operating conditions
- Study of light yield, spectroscopy and spatial resolution when using WLS



Influence of WLS placement on spatial resolution



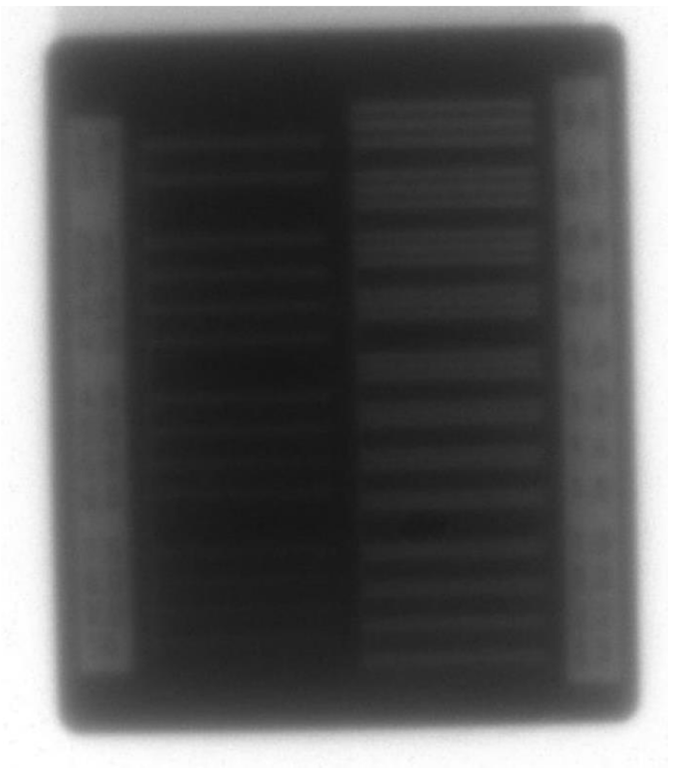




Juha Nummi (HIP), GDD summer student 2023

Use of line-pair mask to determine spatial resolution

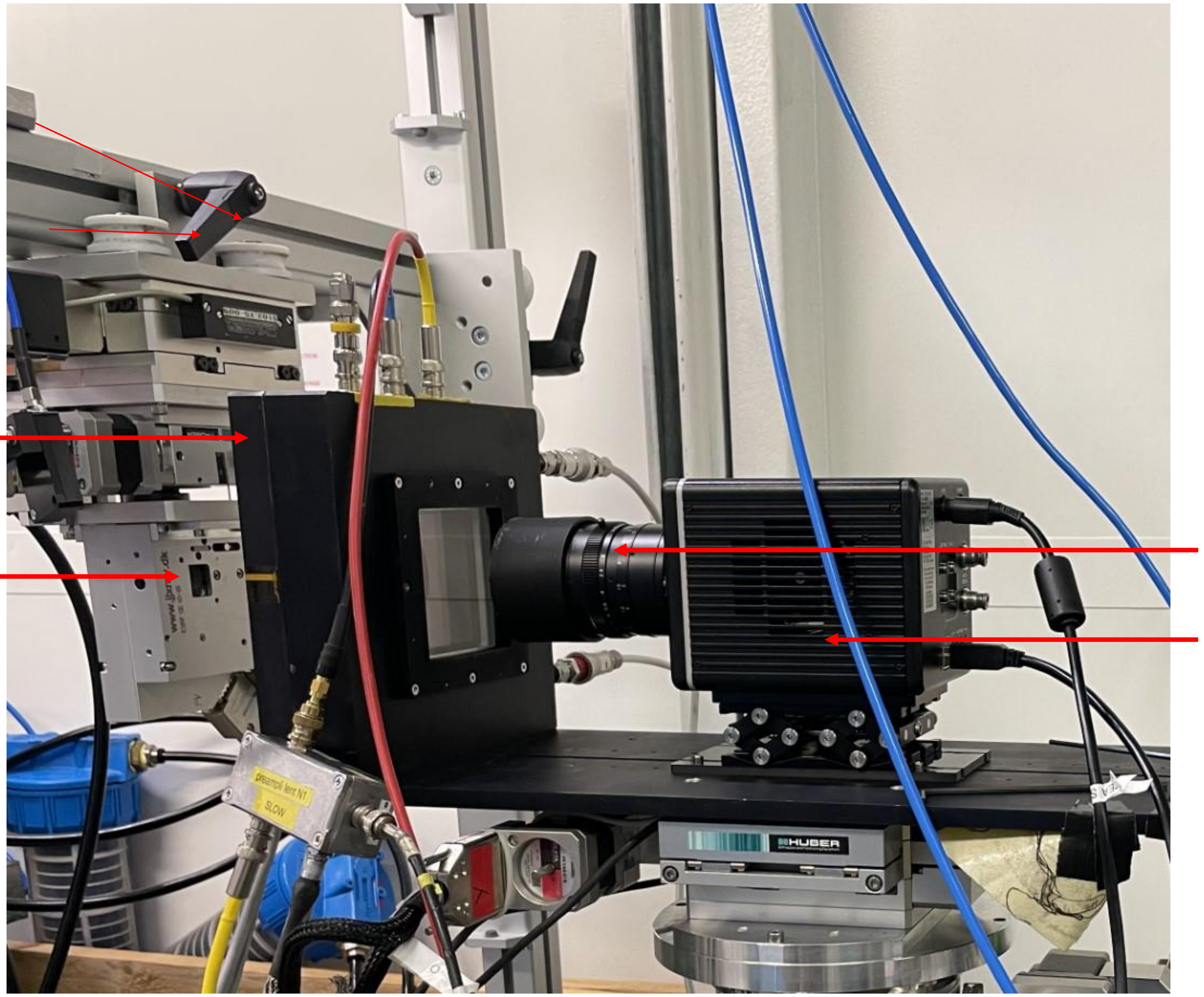
Line pair mask

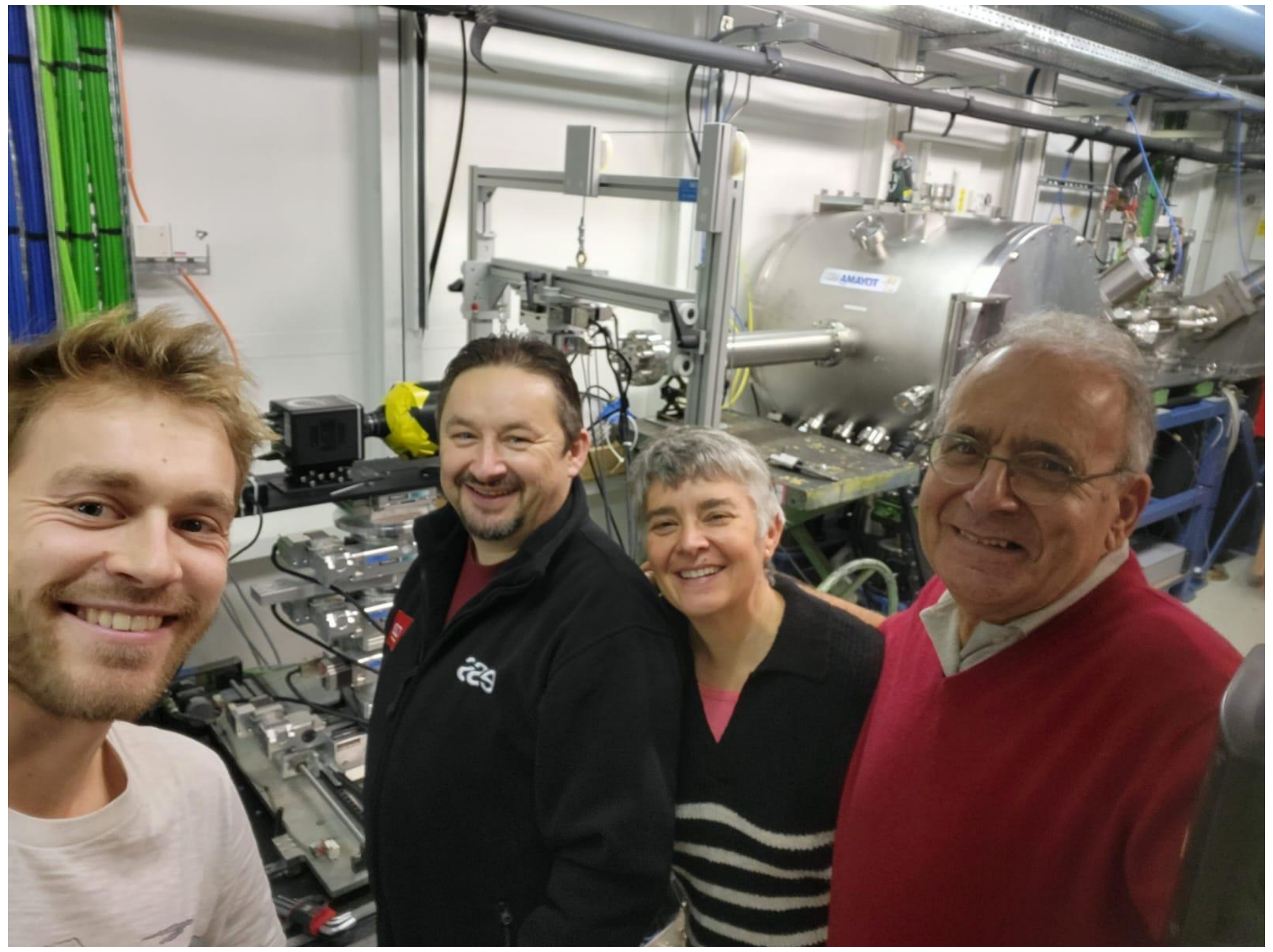


X-ray radiography with TPB at 2mm from GEM

Point Spread Function measurement

Soleil Synchrotron





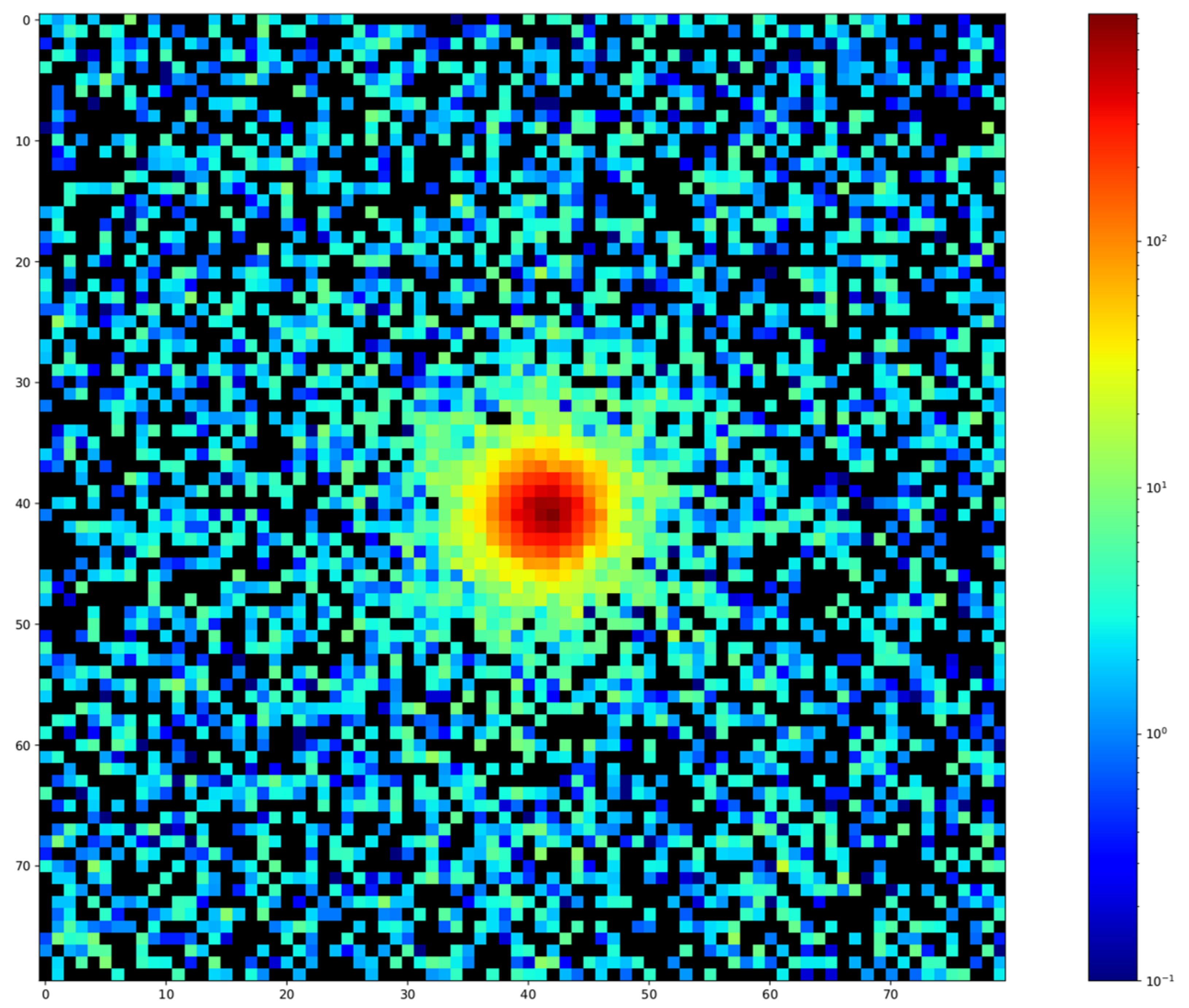
Soleil Synchrotron

<u>X-ray beam - 6keV - 50x50 µm²</u>

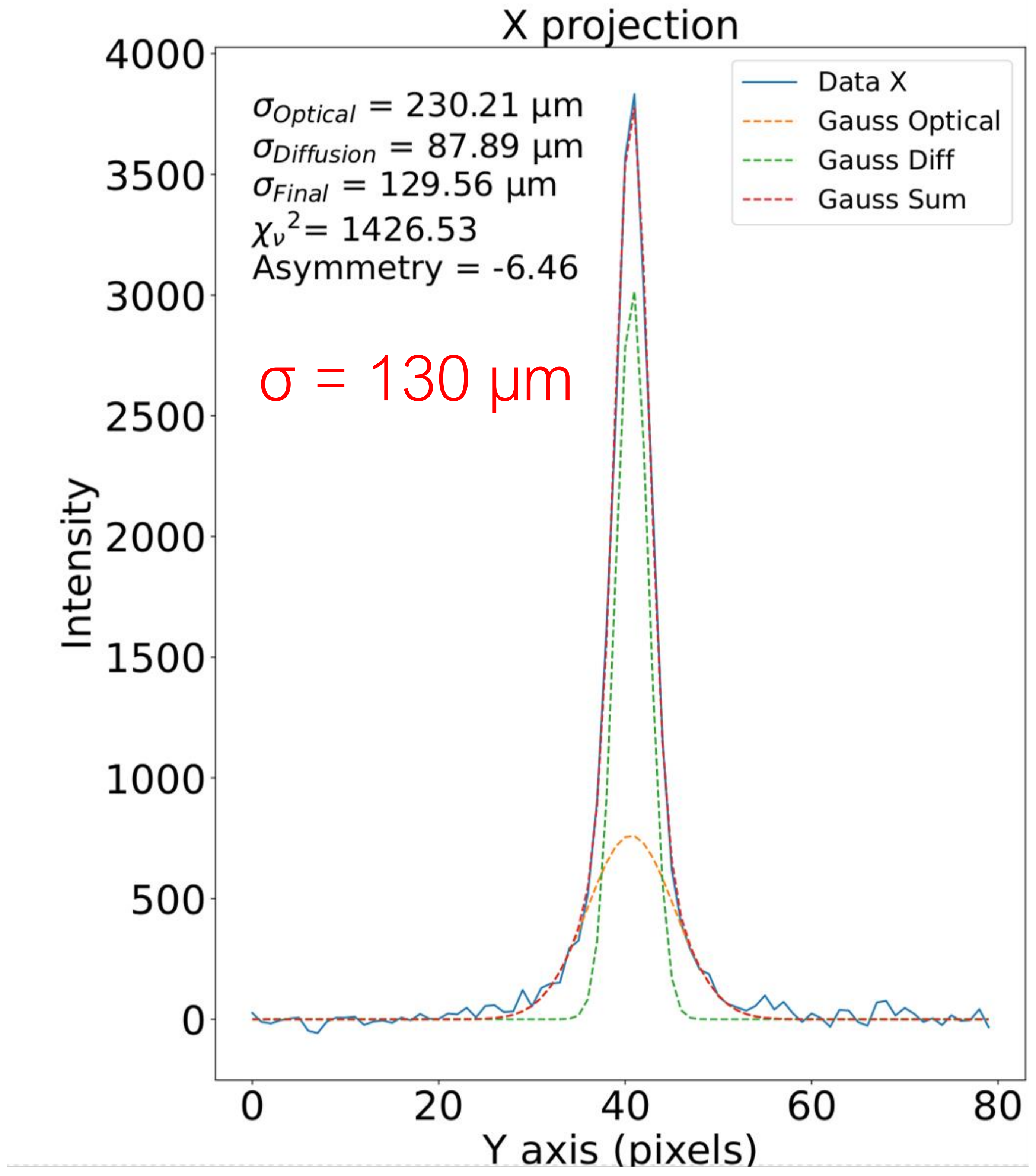
Measurement of Point Spread Function (PSF)

Spreading origins : diffusion and optics

1 mm



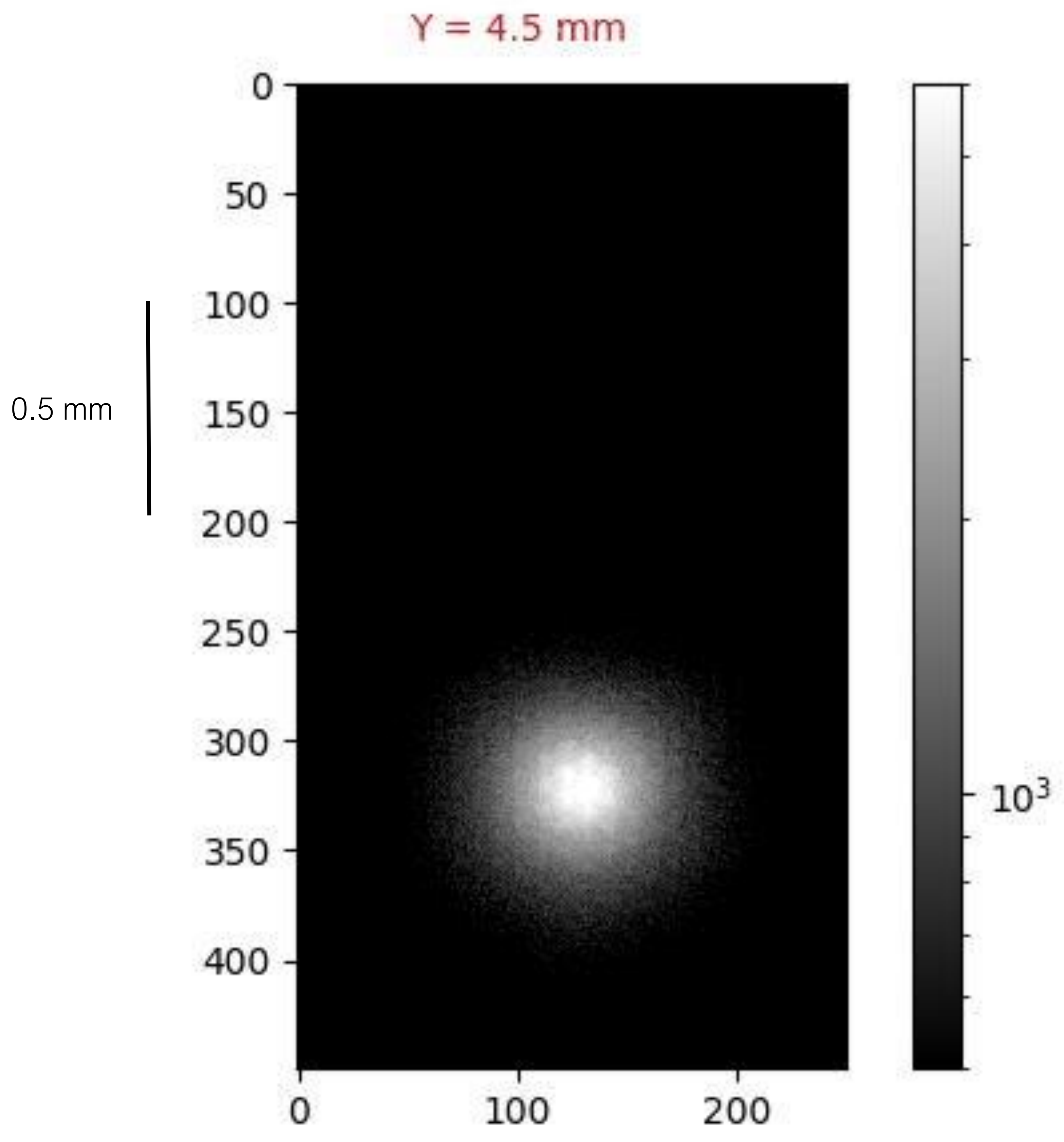
2D light intensity profile
50 x 50 µm beam (Va=36 kV/cm, Vd= 350V/cm)



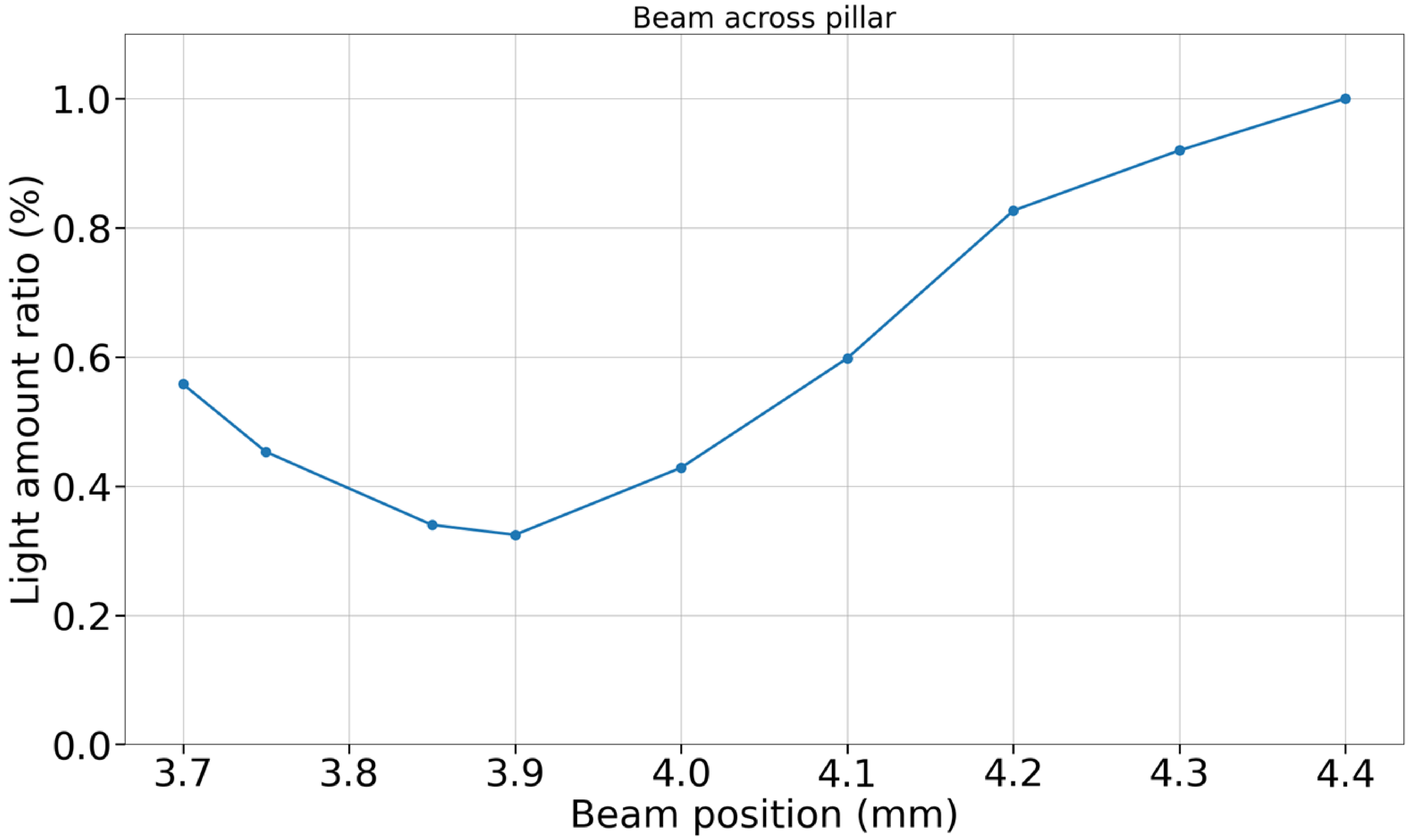
1D projection

Soleil Synchrotron

Micromegas **pillar** study

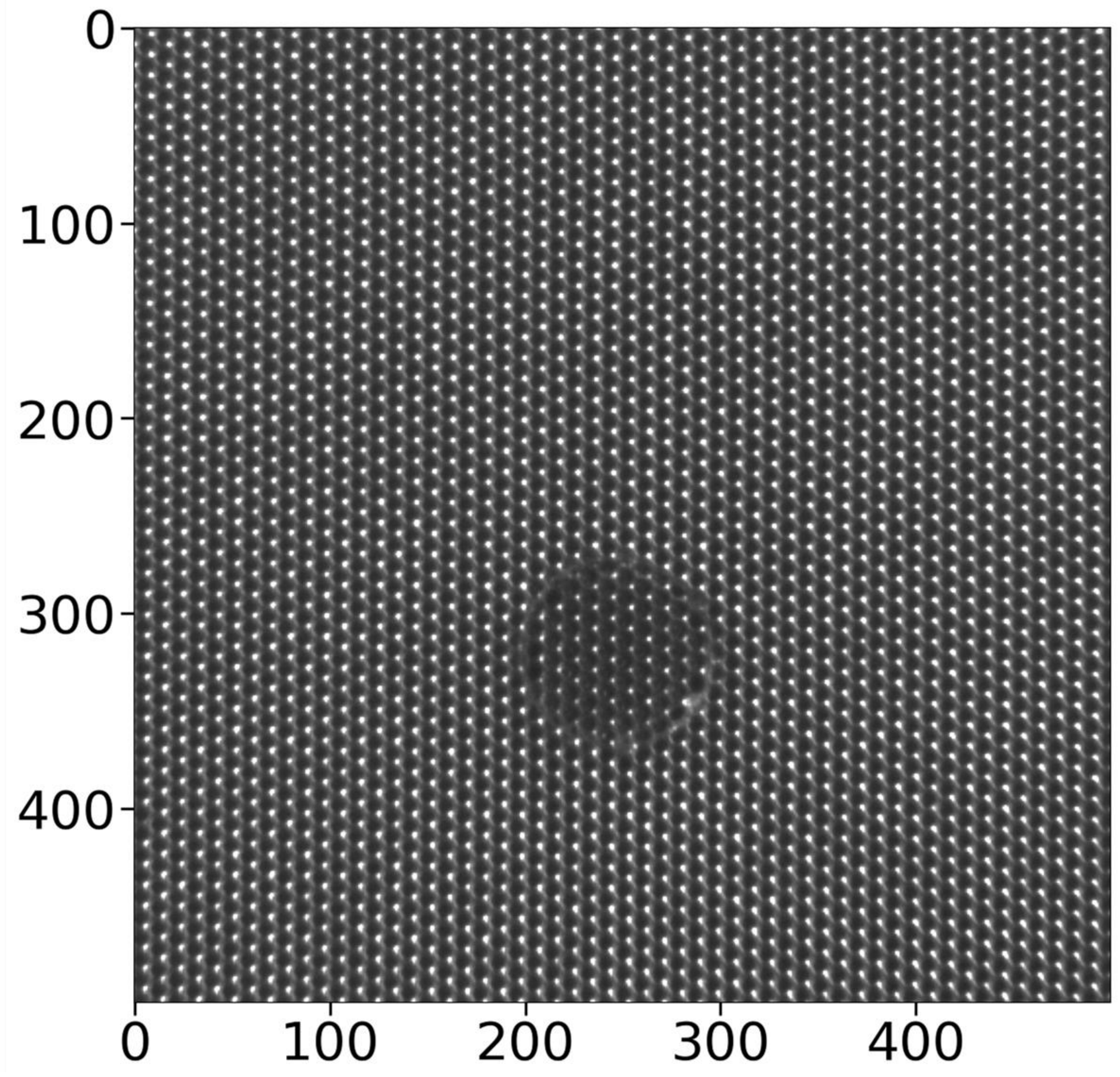


Glass Micromegas hexagonal mesh
(50x50 µm x-ray beam)



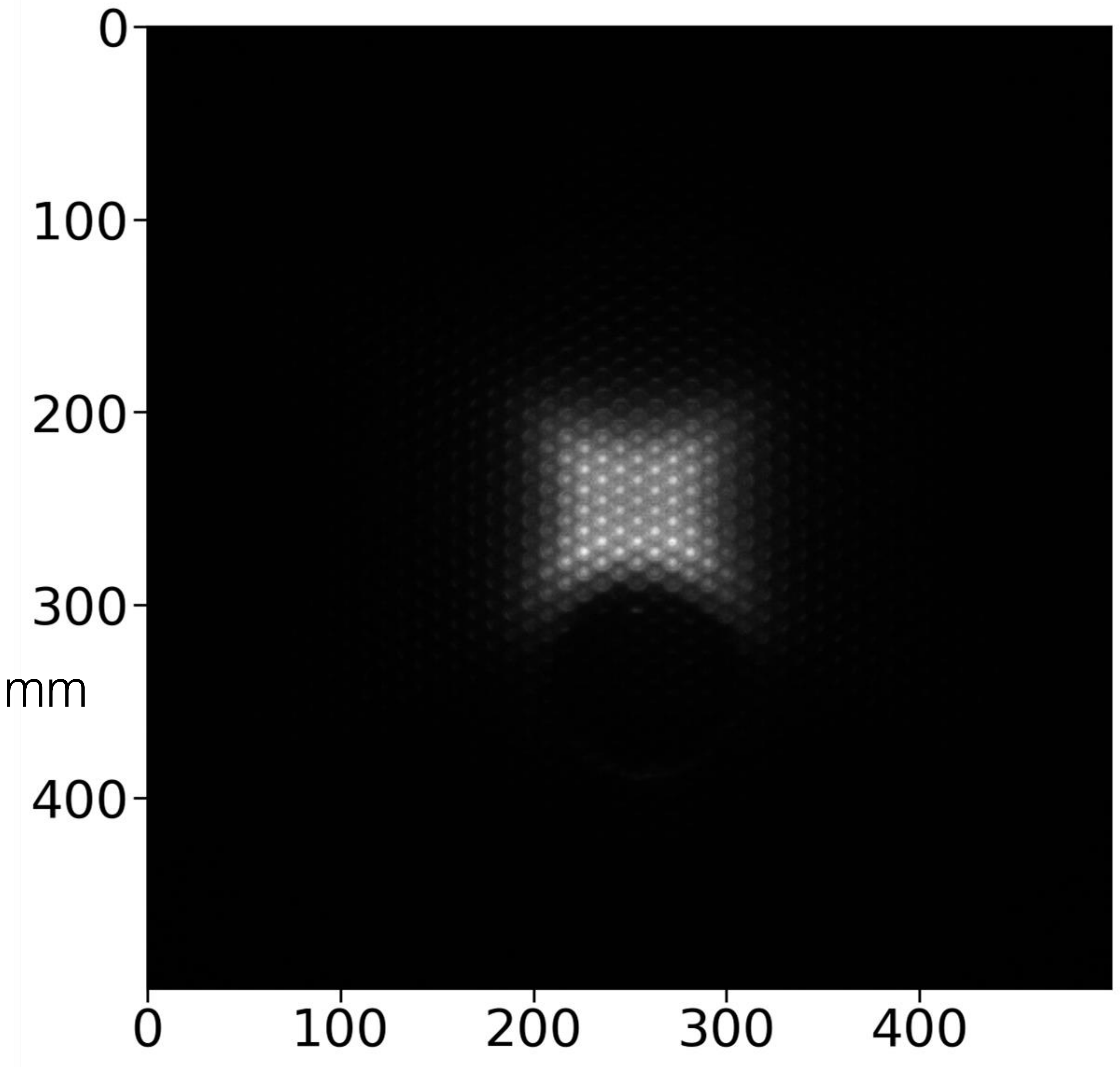
Soleil Synchrotron

Micromegas **mesh** study

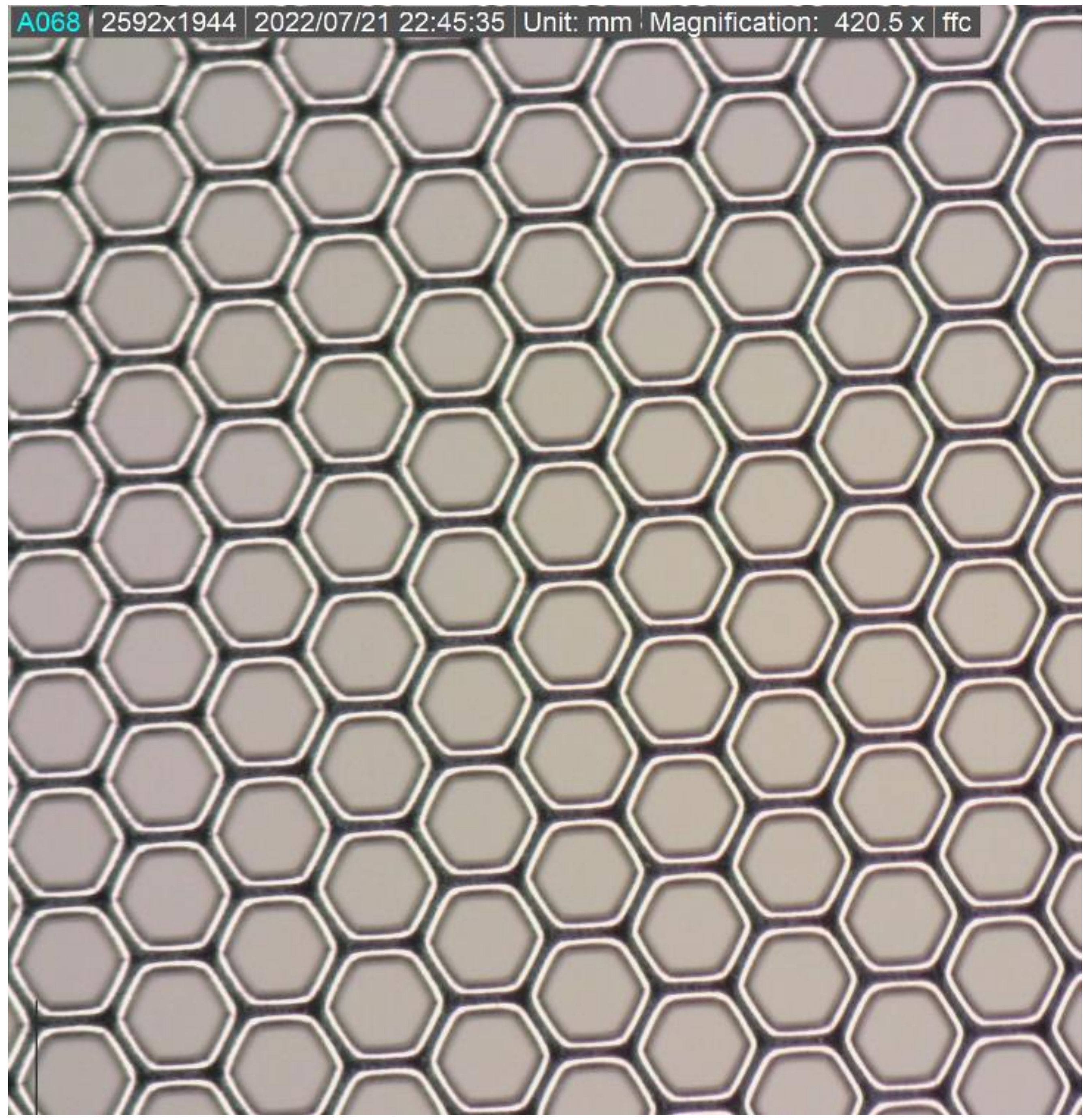


0.5 mm

Glass Micromegas Beta mesh
(0.1x0.1 mm X-ray beam)



Glass Micromegas Beta mesh (Ambient light)

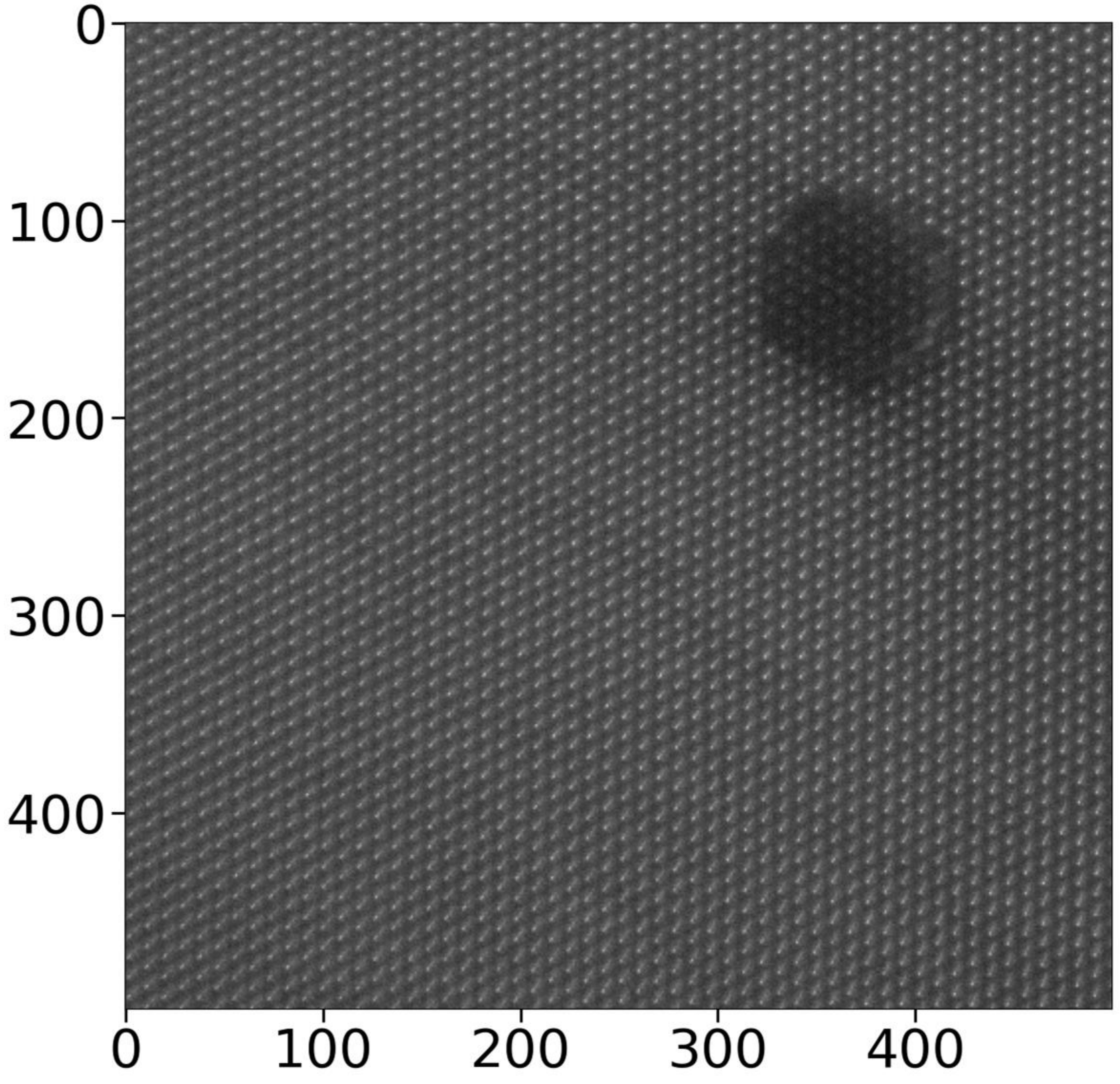


50 µm

Beta mesh (Microscope)

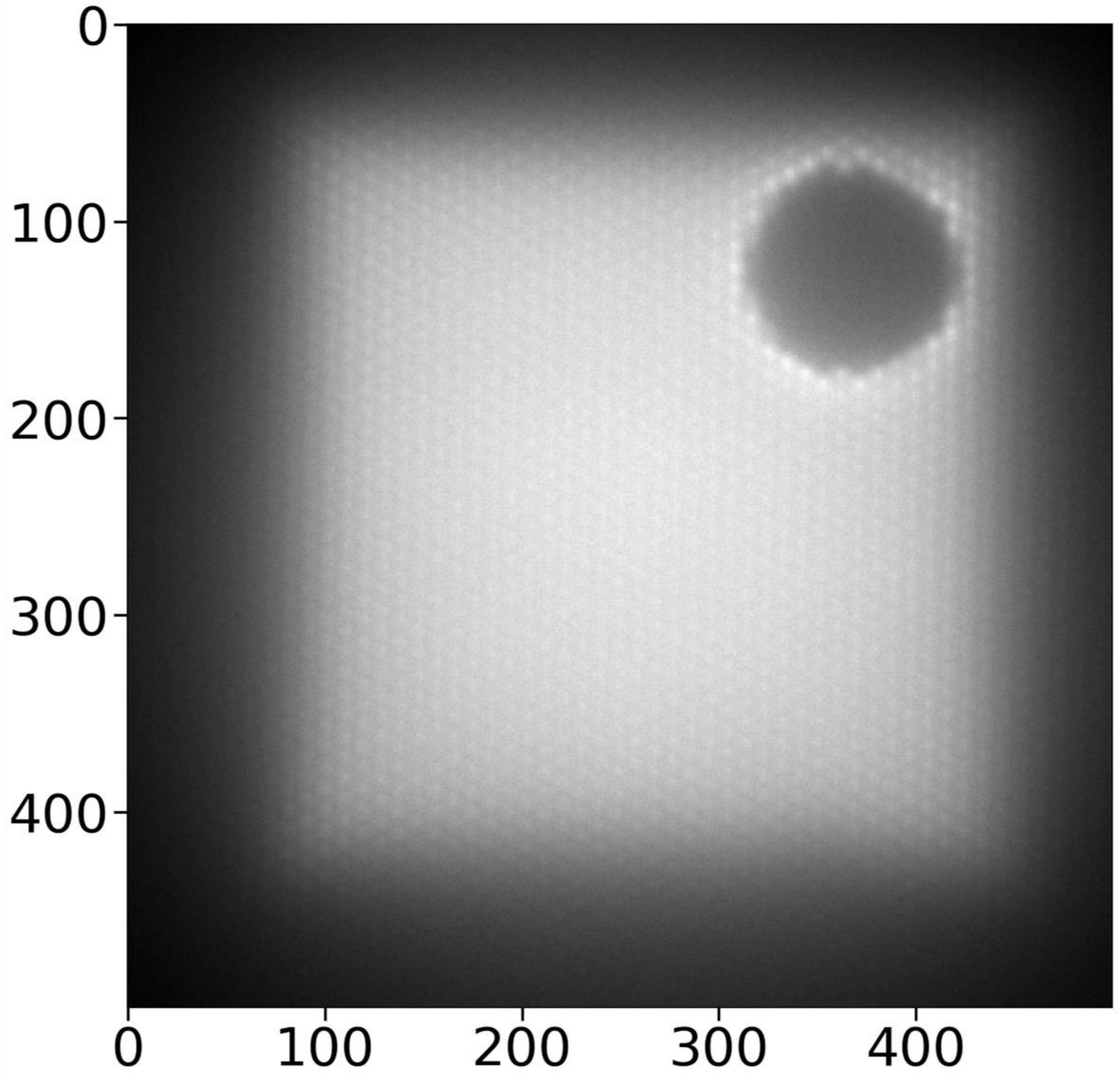
Soleil Synchrotron

Micromegas **mesh** study



Glass Micromegas Beta mesh (Ambient light picture)

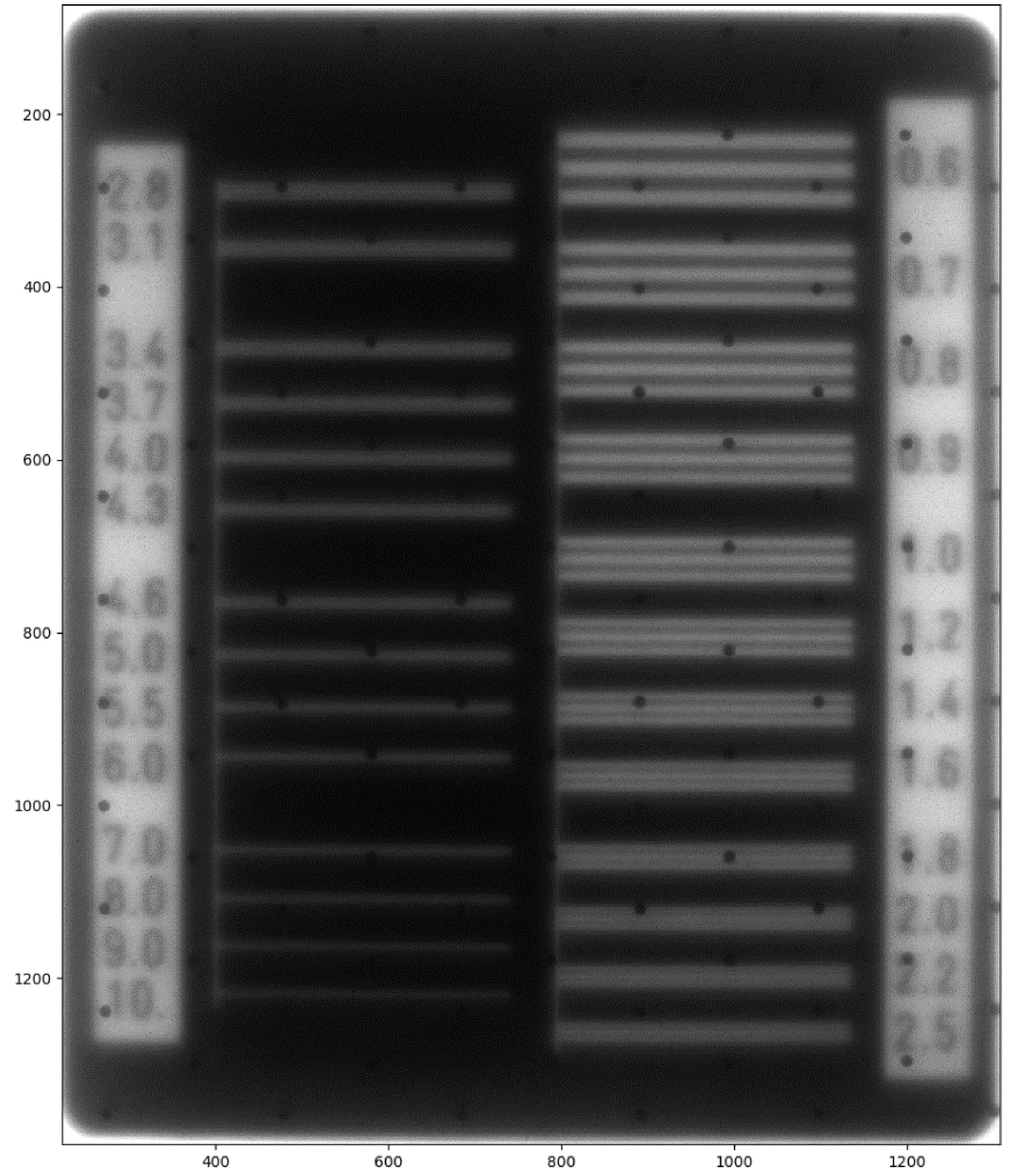
0.5 mm



Glass Micromegas Beta mesh (1x1 mm X-ray beam)

X-ray imaging

Micromegas **mesh** study

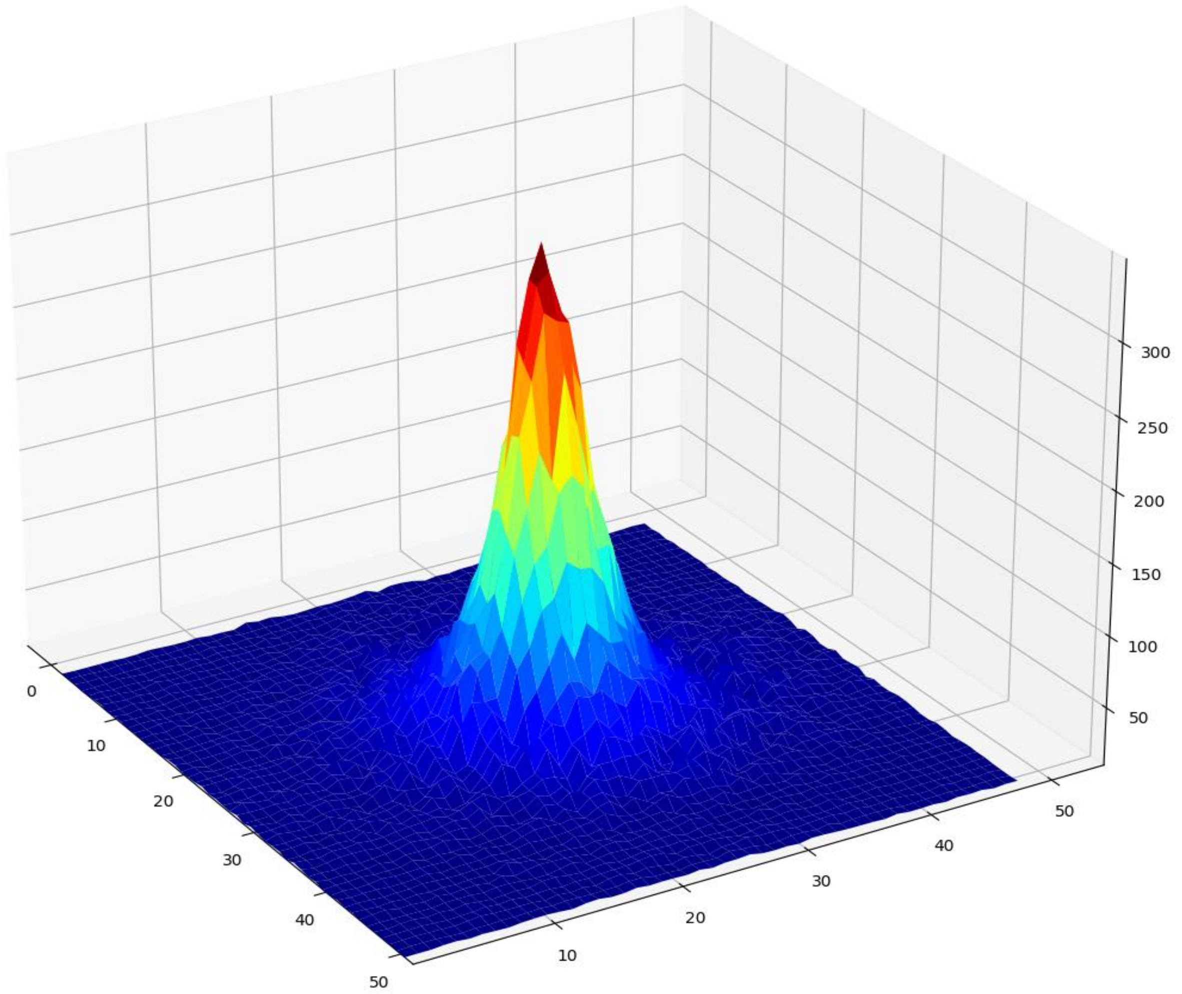


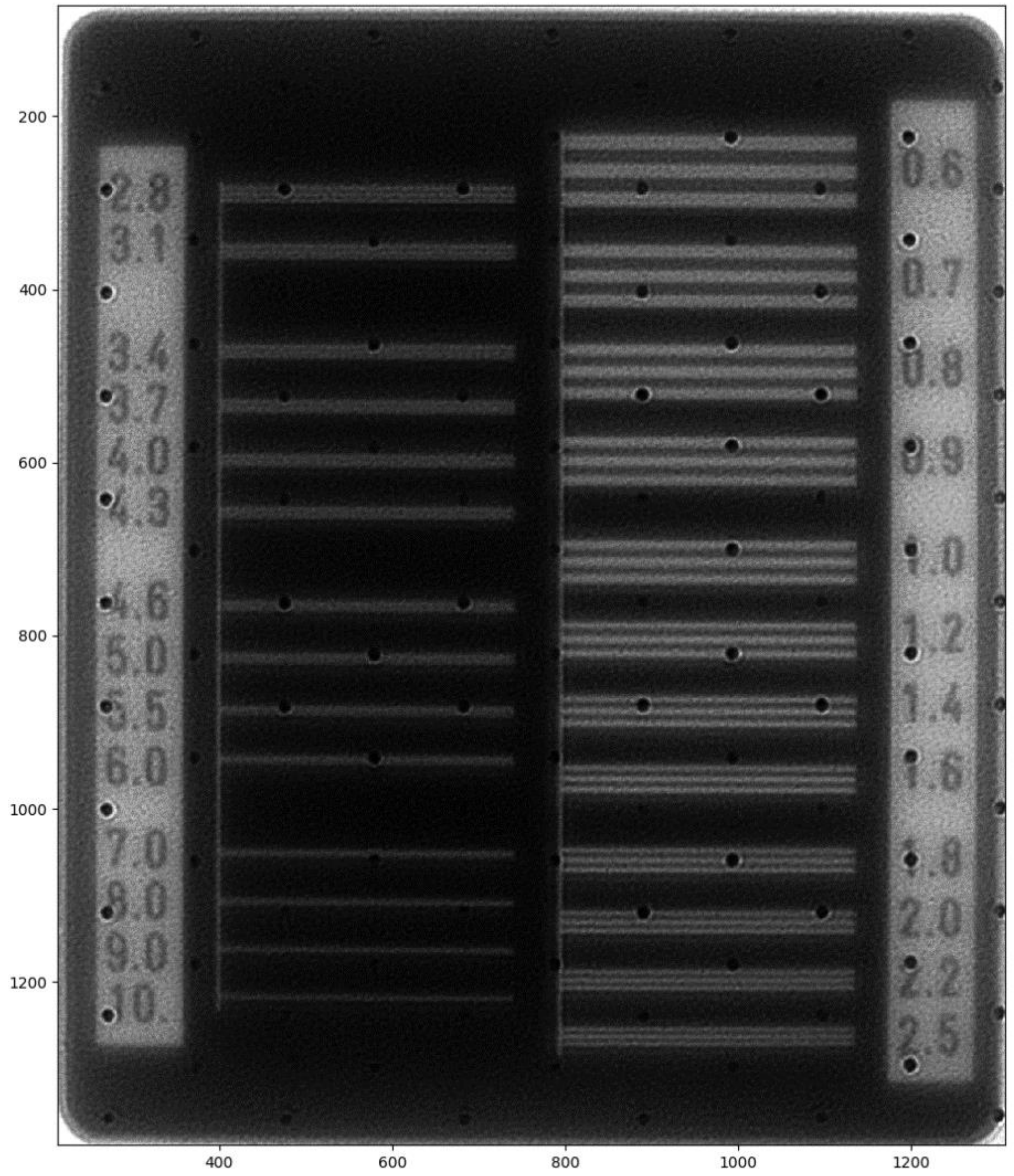
10 mm

MTF (10%) : 800 μm

Deconvolution

PSF from experimental data (σ = 280 μm)

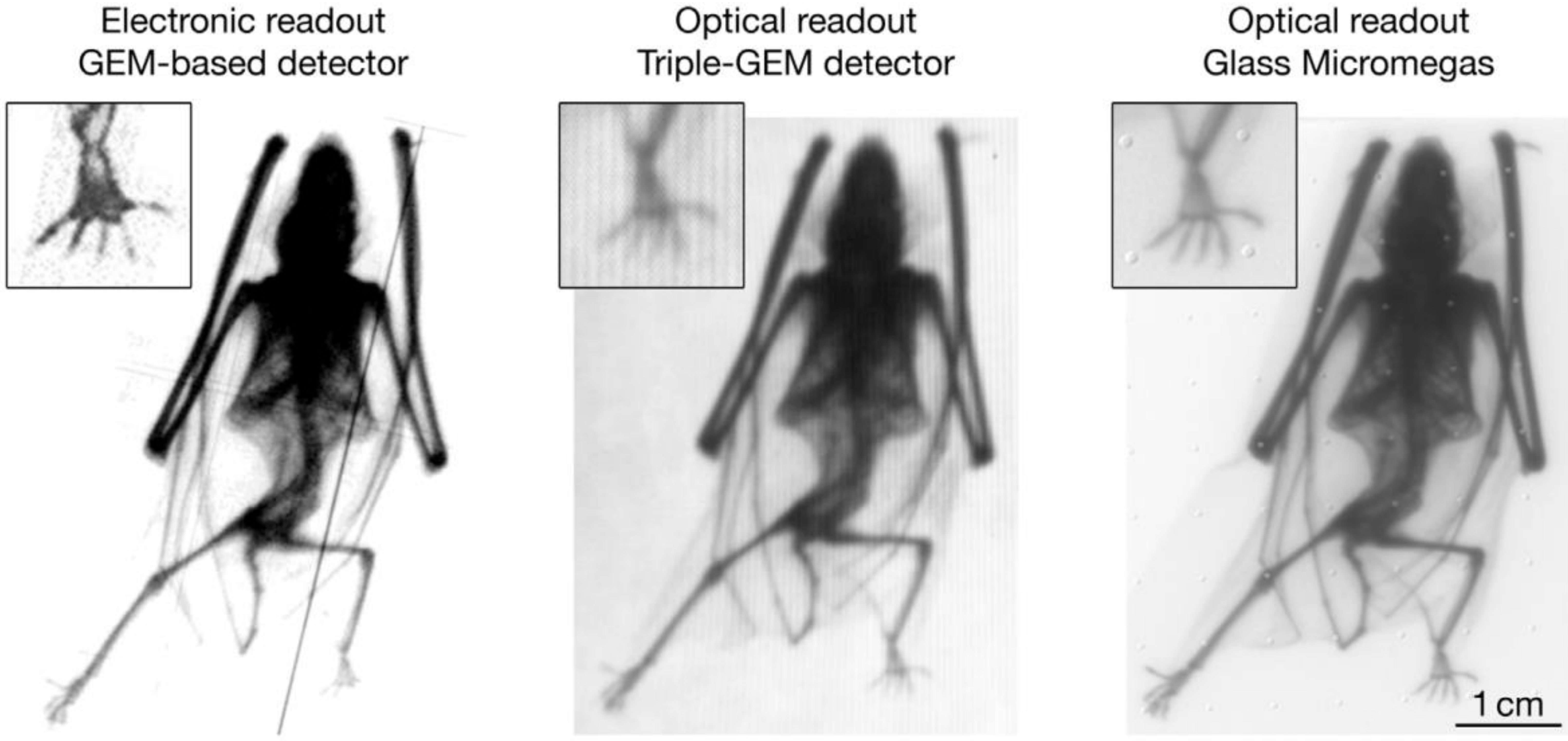




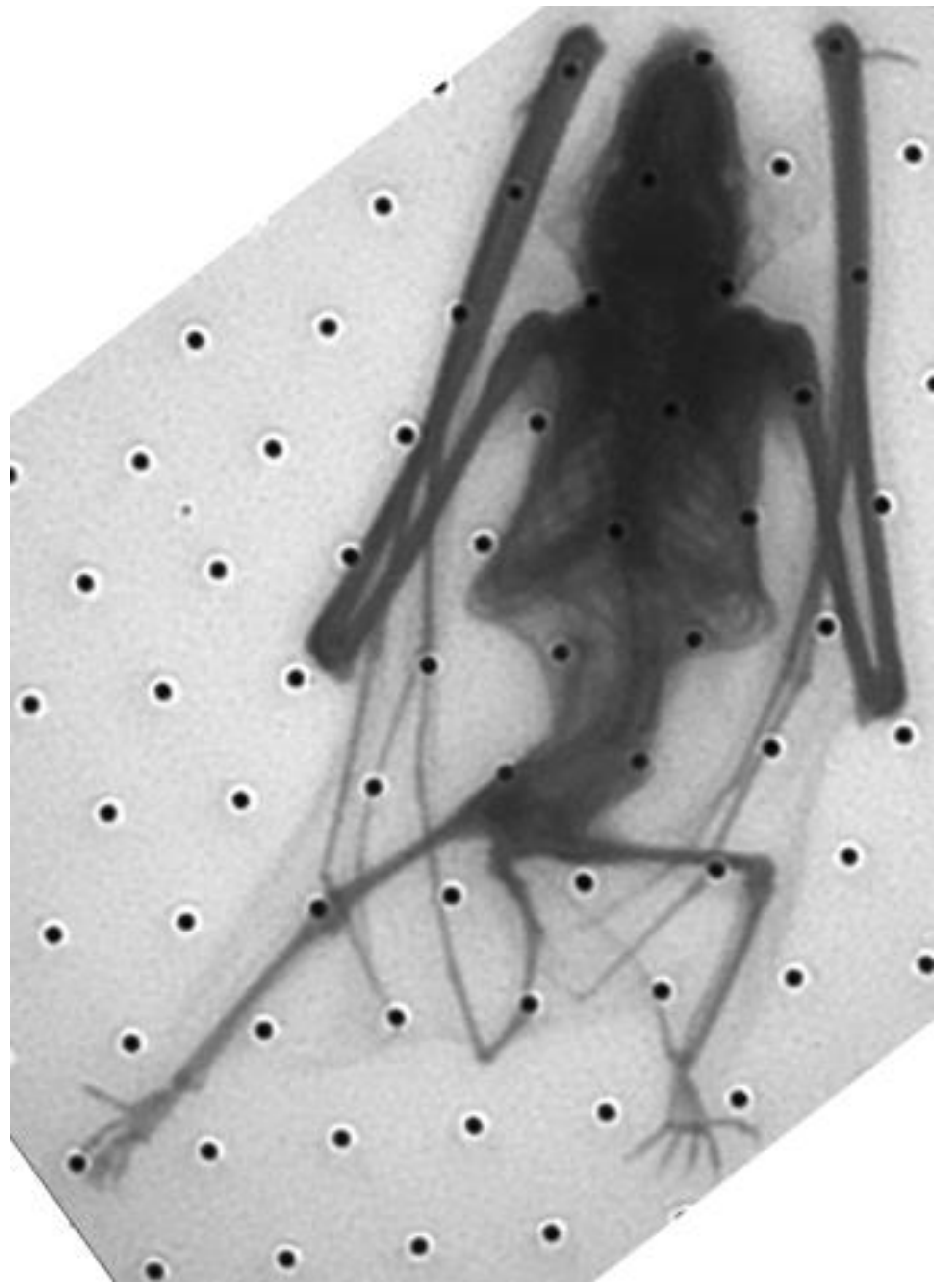
MTF (10%) : 281 μm

X-ray imaging

History of imaging with MPGDs



Glass Micromegas, Optical readout, deconvolution

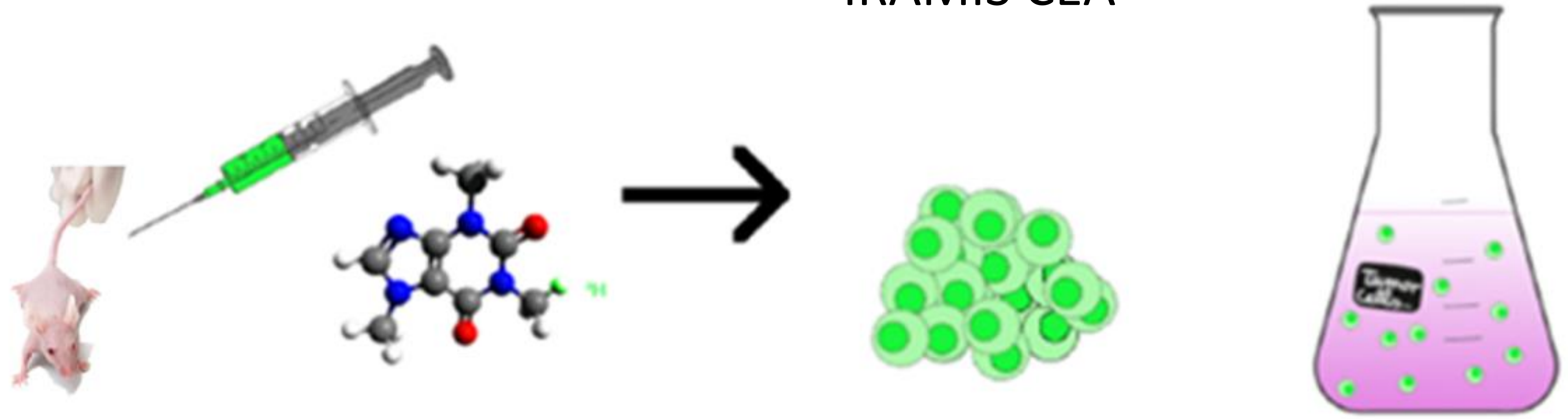


Activity measurement on tritiated cells

Beta imaging

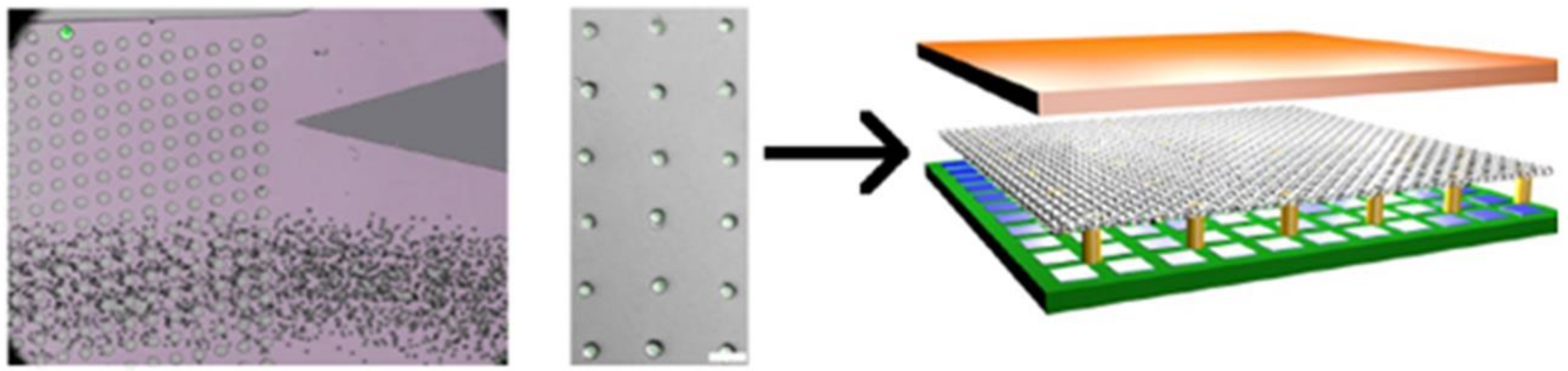
Joliot institut

IRAMIS CEA



Tumoural cells collected from an animal – Tritium tracking

Cellular culture



Cell deposit by microfluidics techniques

Tritium activity counting with gaseous detector

Tumor heterogeneity: different cell types inside a tumor

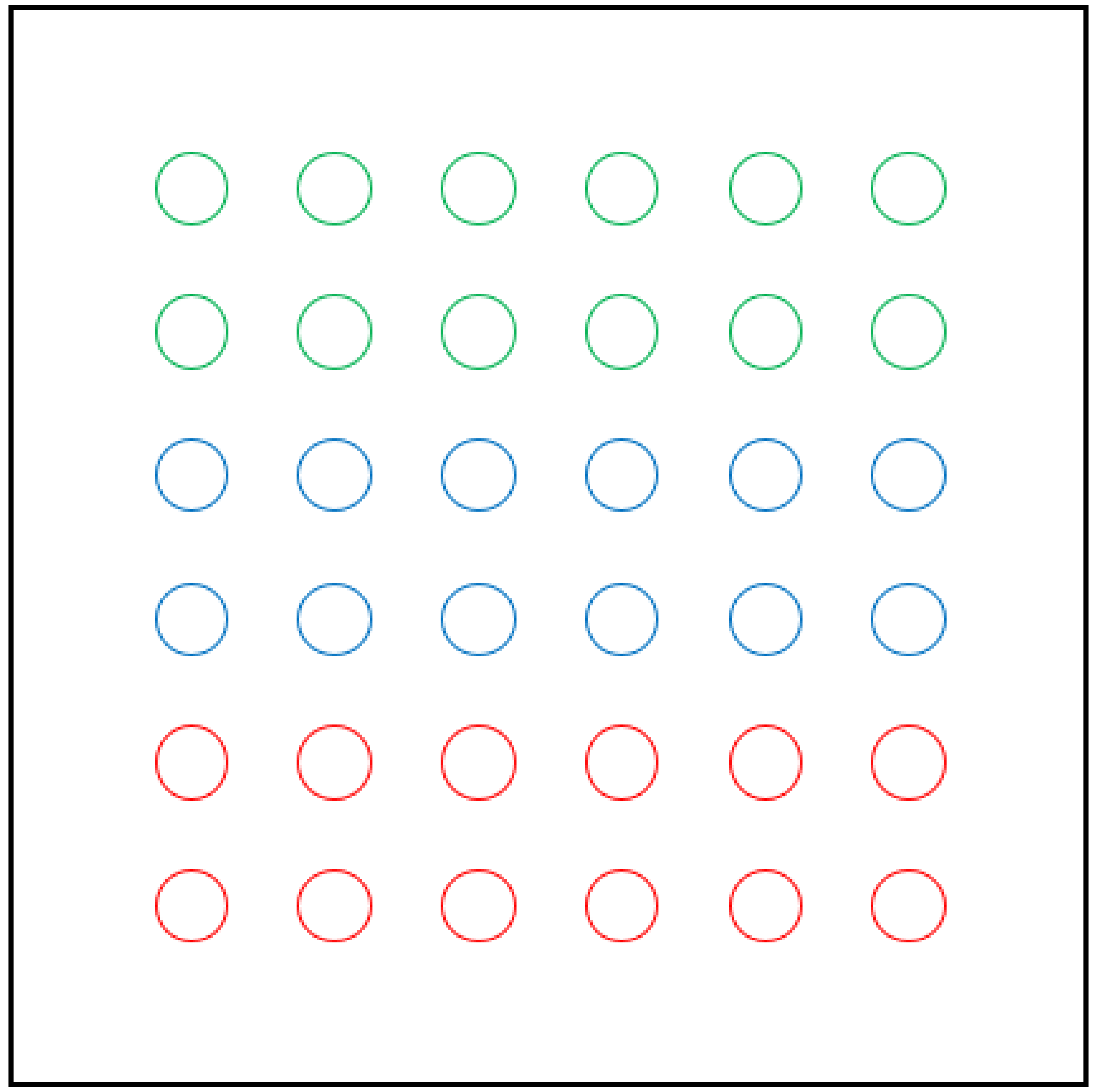
- Heterogeneity effect on drug targeting?
- Develop more efficient drugs
- Requires better detection sensibilities

Pharmaceutical needs at the cell level for drug development:

- Assess the **drug distribution** among cells
- At the cell level: Quantification of ^3H concentration in **single cell** samples

Beta imaging

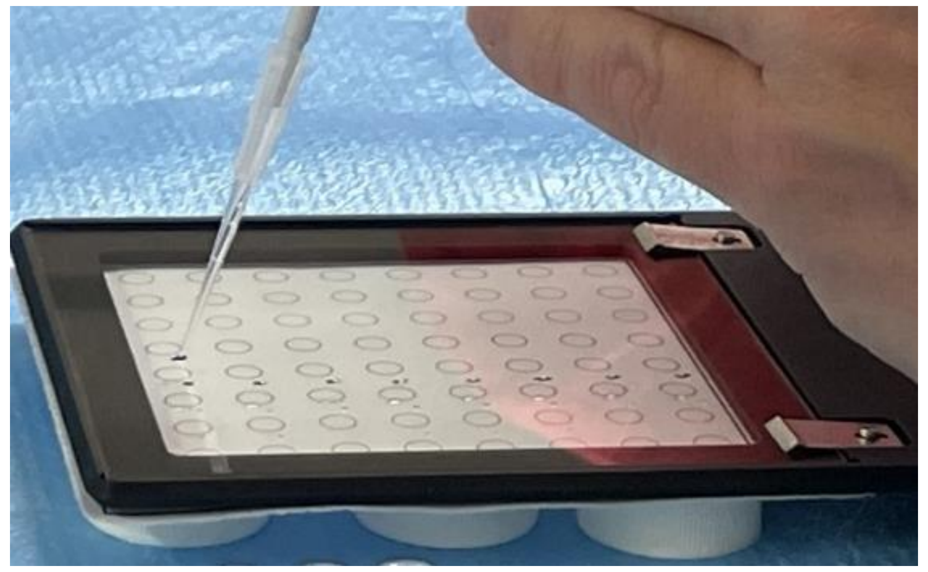
First deposit : tritiated glucose

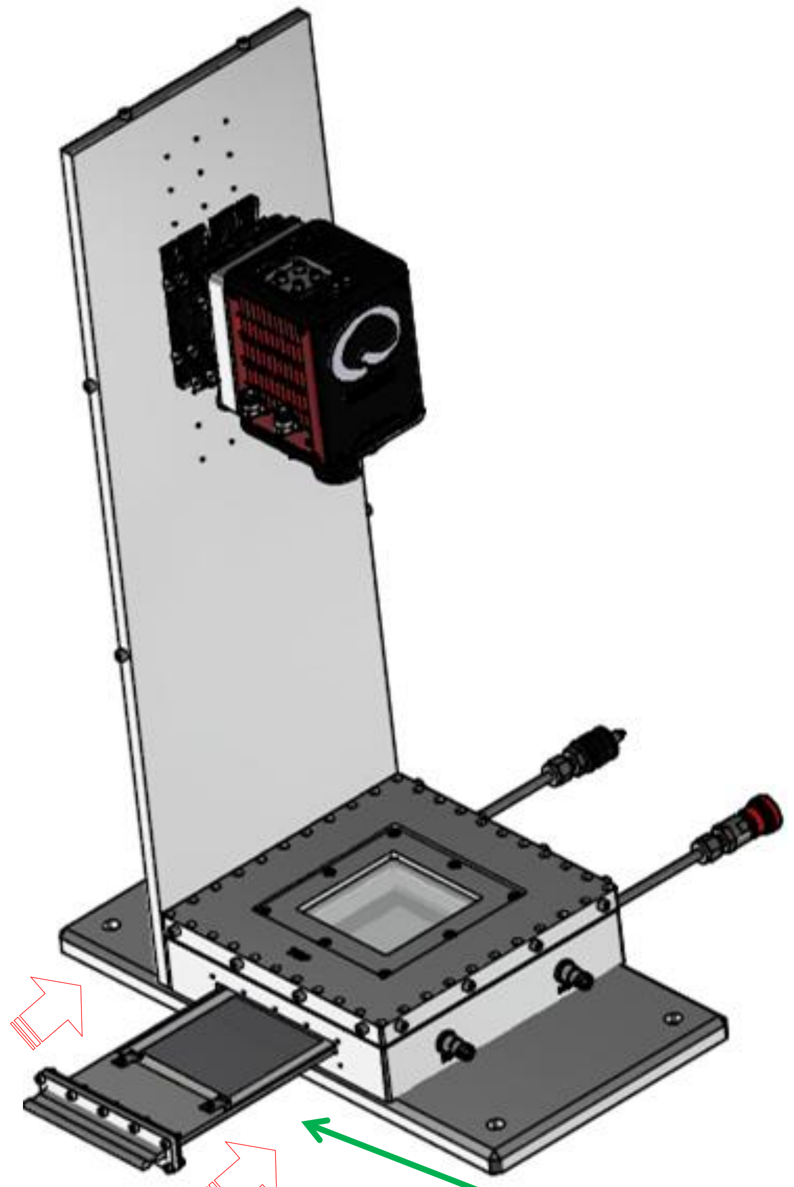


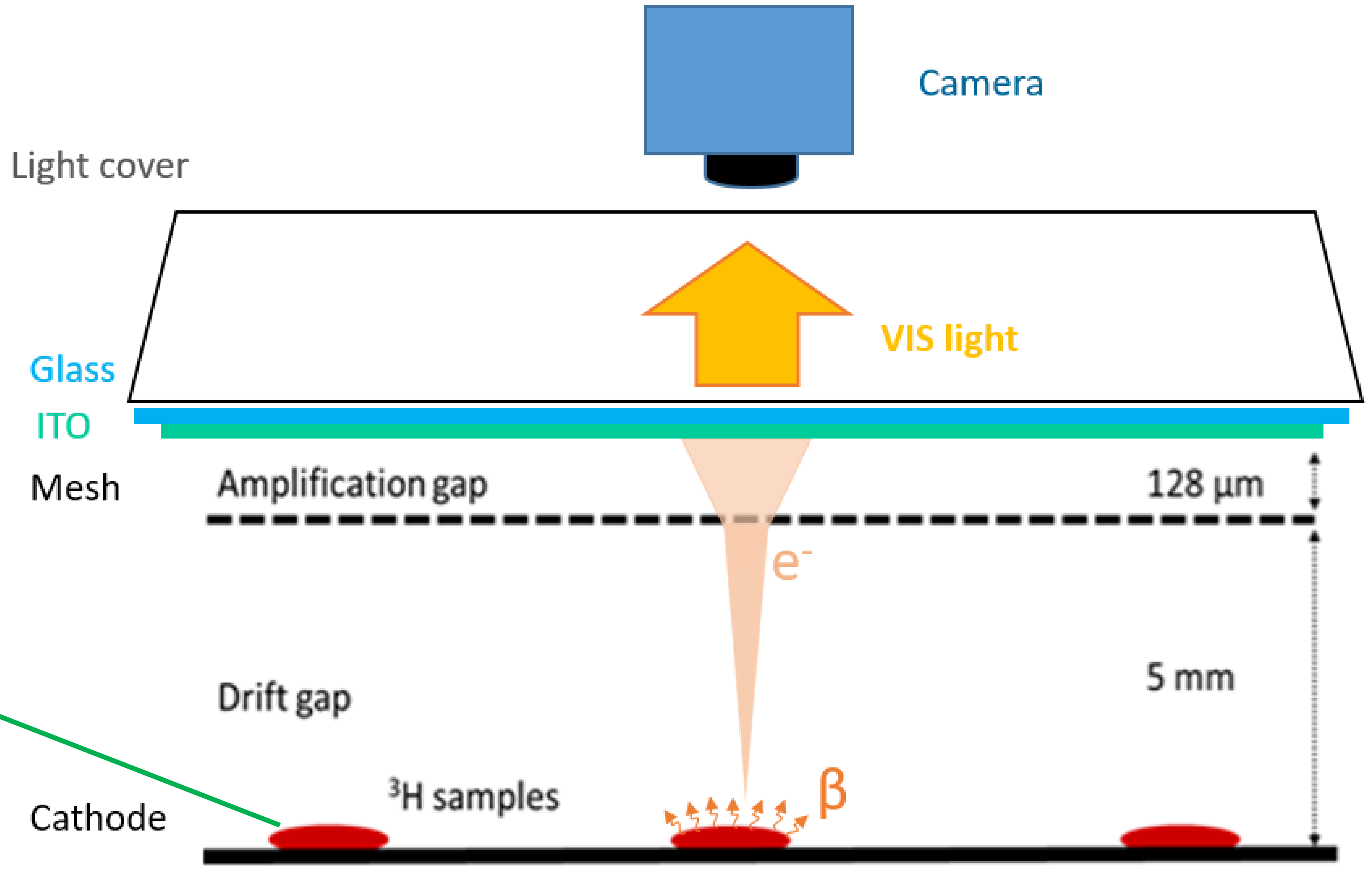
0.1 Bq

1 Bq

10 Bq







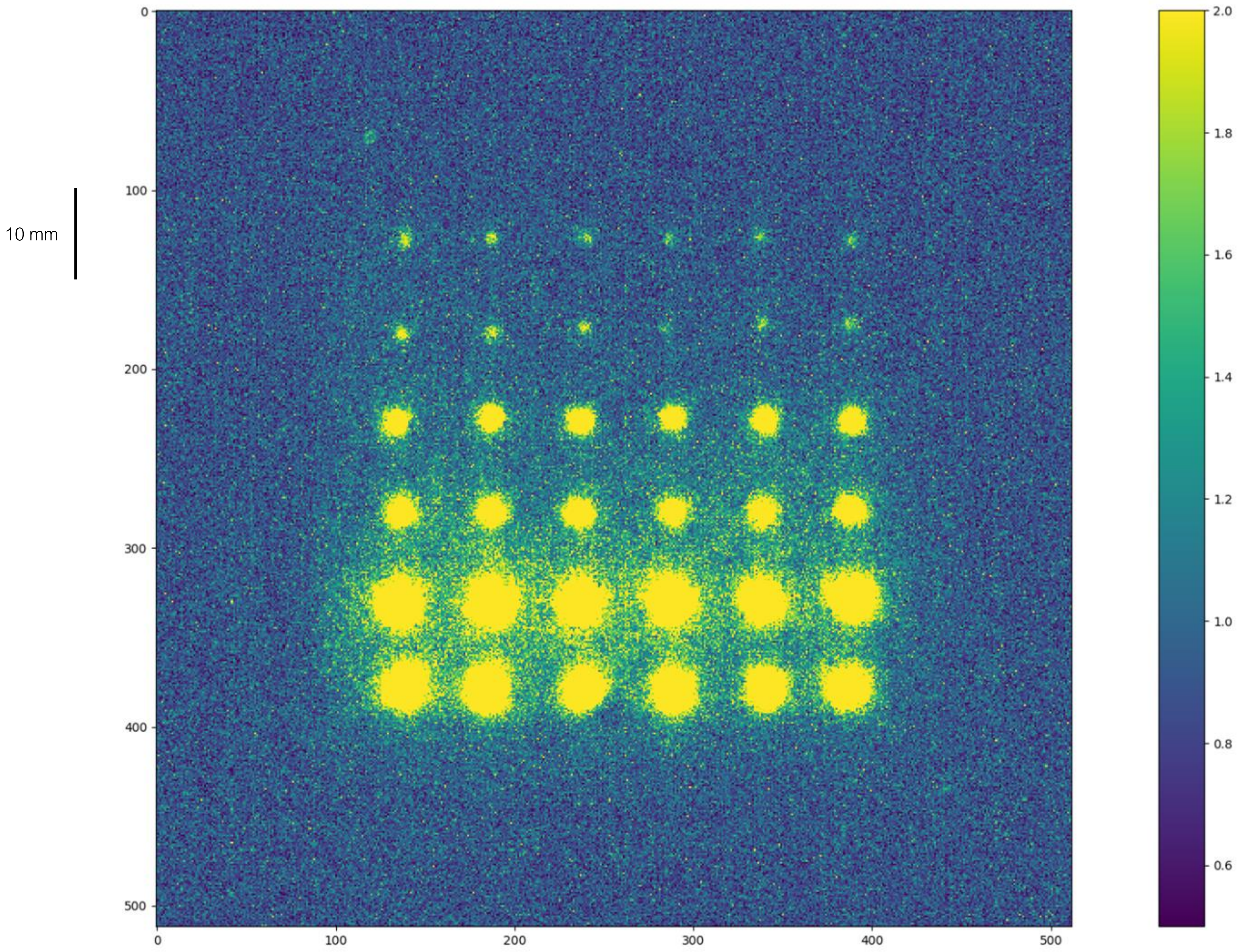
OPTIMED-BETA set-up scheme

Drug concentration ↔ sample activity (Bq)

Activity measurement limits and dynamic range → Activities: 0.1 Bq, 1 Bq and 10 Bq

Beta imaging

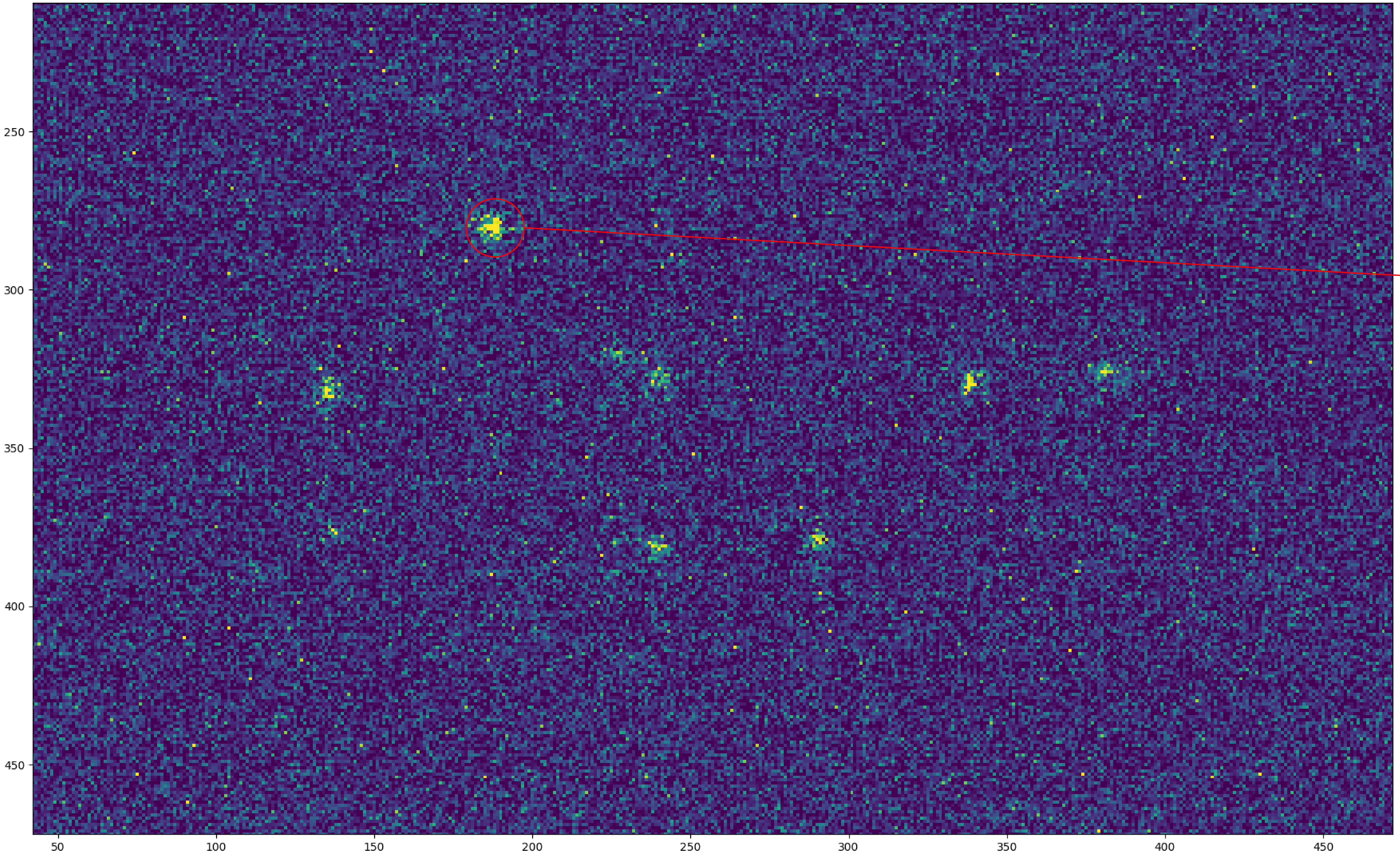
Integration

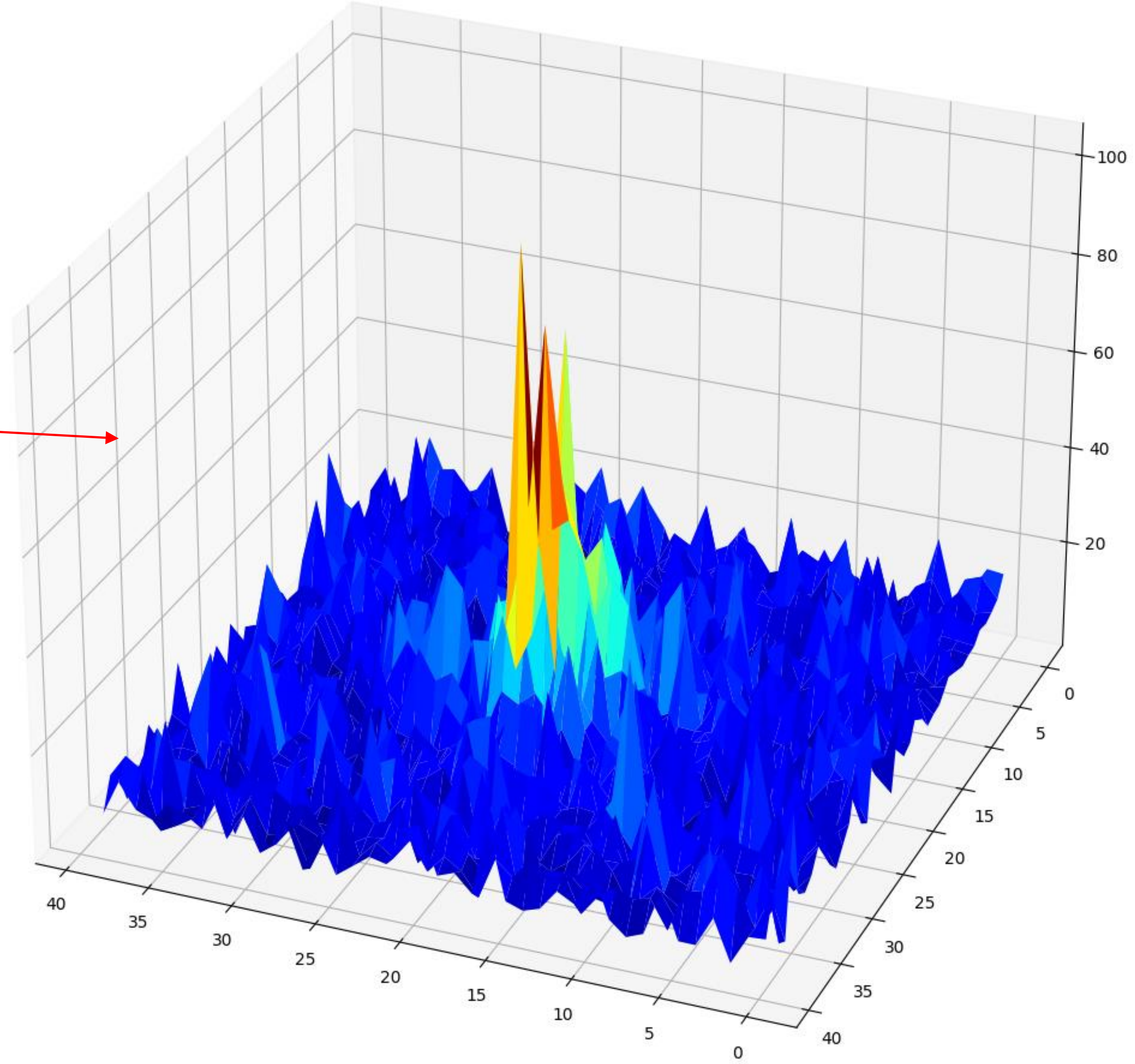


Light intensity profile
720 frames of 5 s (60 min) - 20% of CF4

Beta imaging

<u>Clustering</u>

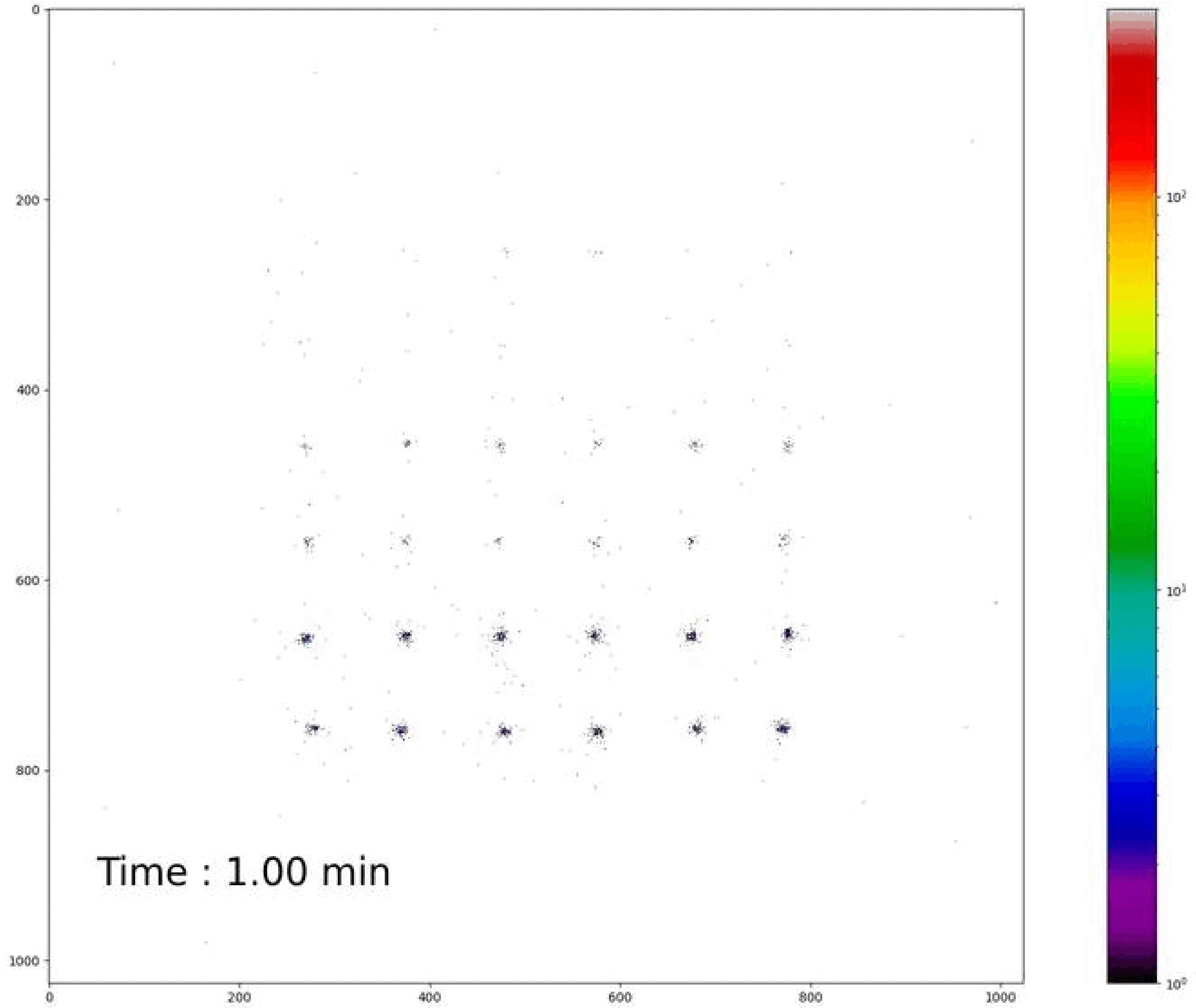




200 ms frame with single beta events

Beta imaging

Clustering



Cluster centroid histogram
20000 frames of 200 ms (64 min, 20% of CF4

Neutron imaging

Neutron imaging

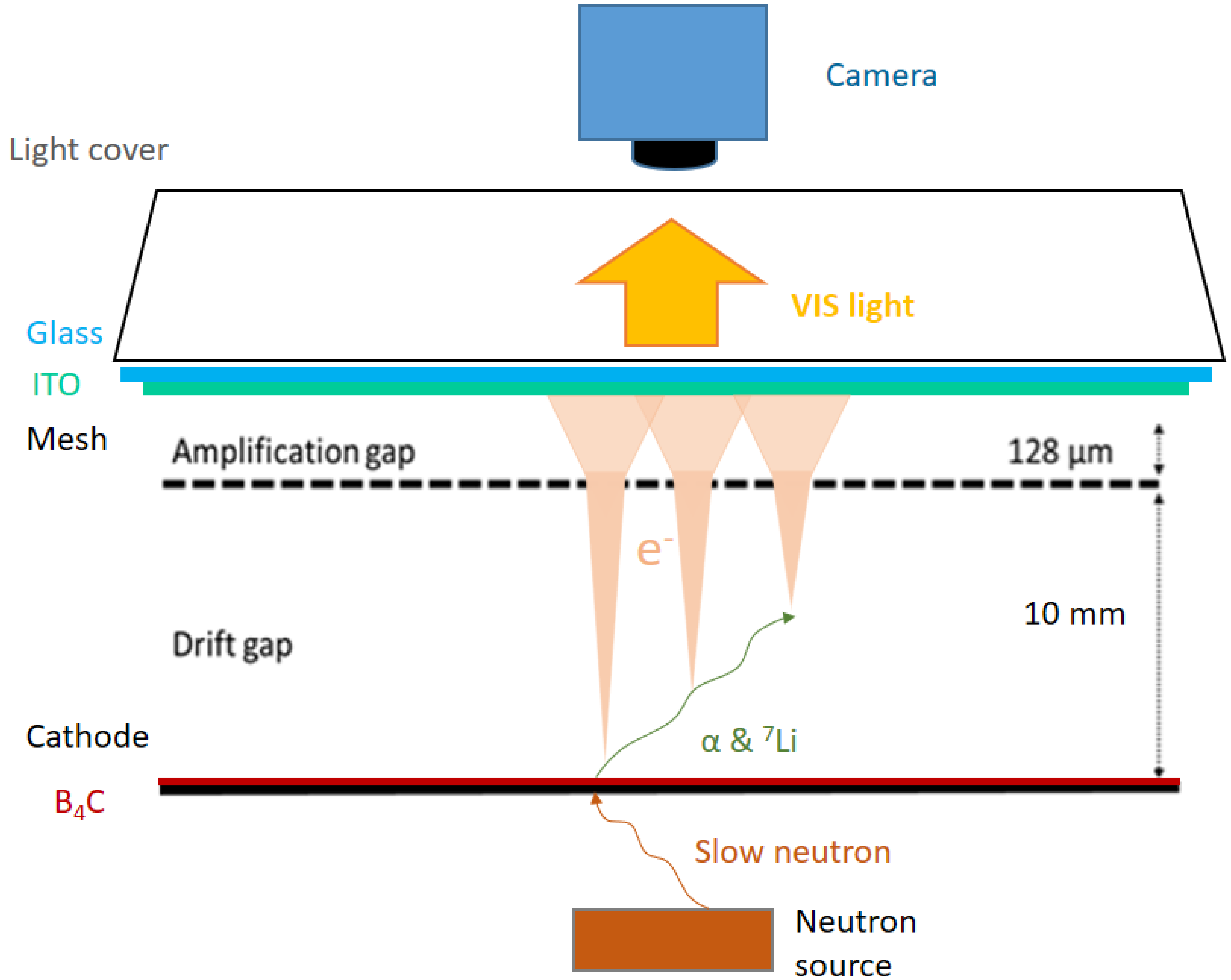
Cathode : $^{10}B_4C$ neutron-to-charge converter

Thermal neutrons absorbed by 2 µm thin $^{10}B_4C$ layer

Conversion efficiency: 5%

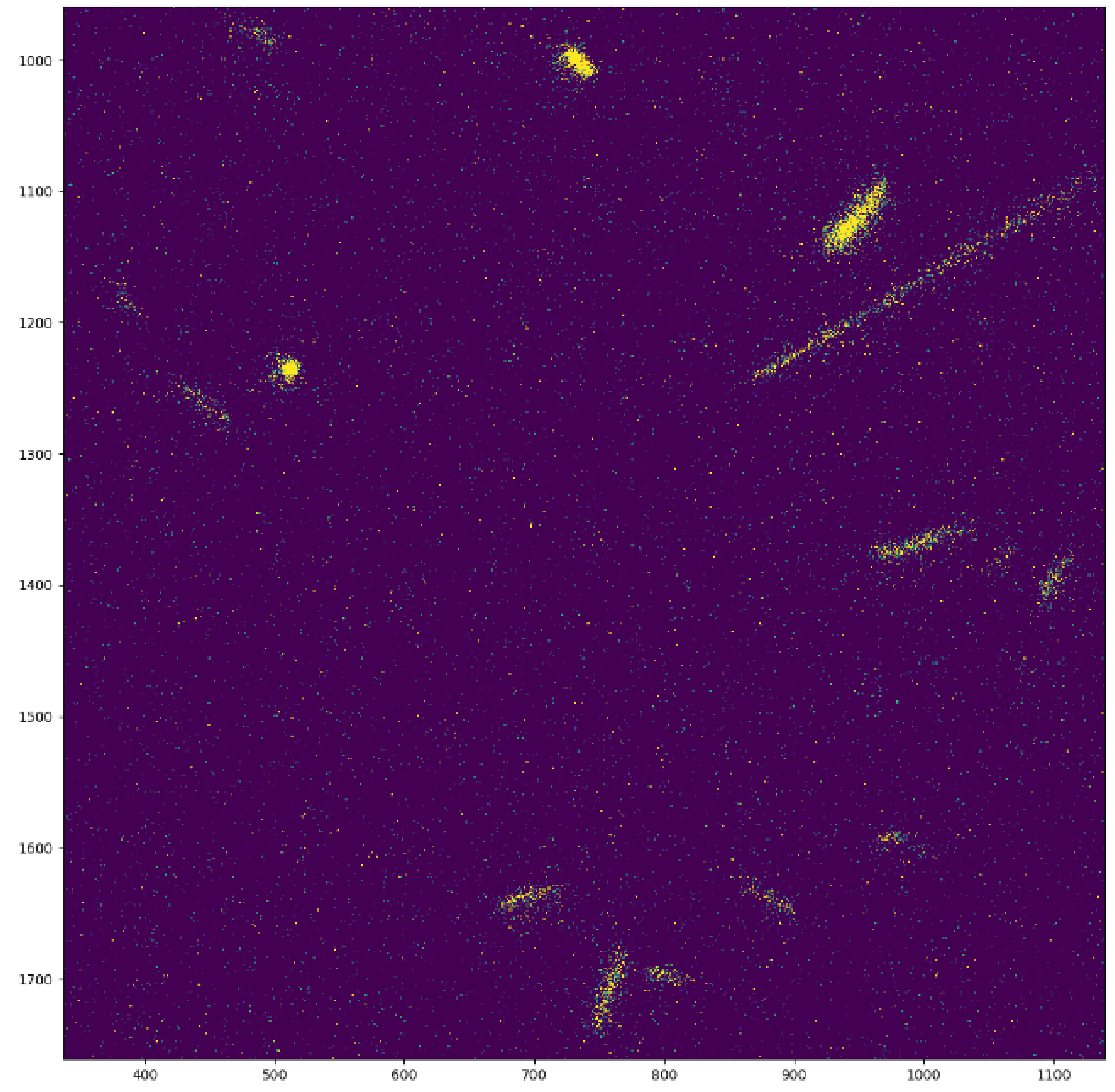
(α or Li) fragments cause strong ionisation

Drawback: fragments long range in the gas (5 mm)

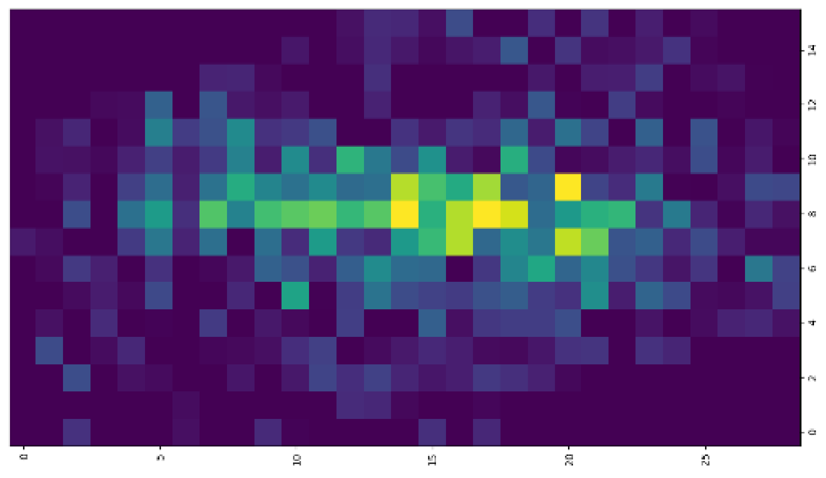


Neutron imaging

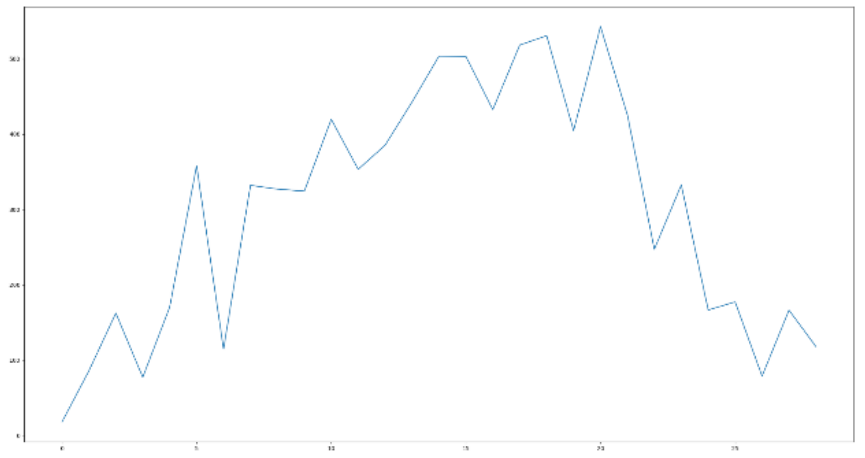
5 mm



800 V/cm drift field, 3 events/s



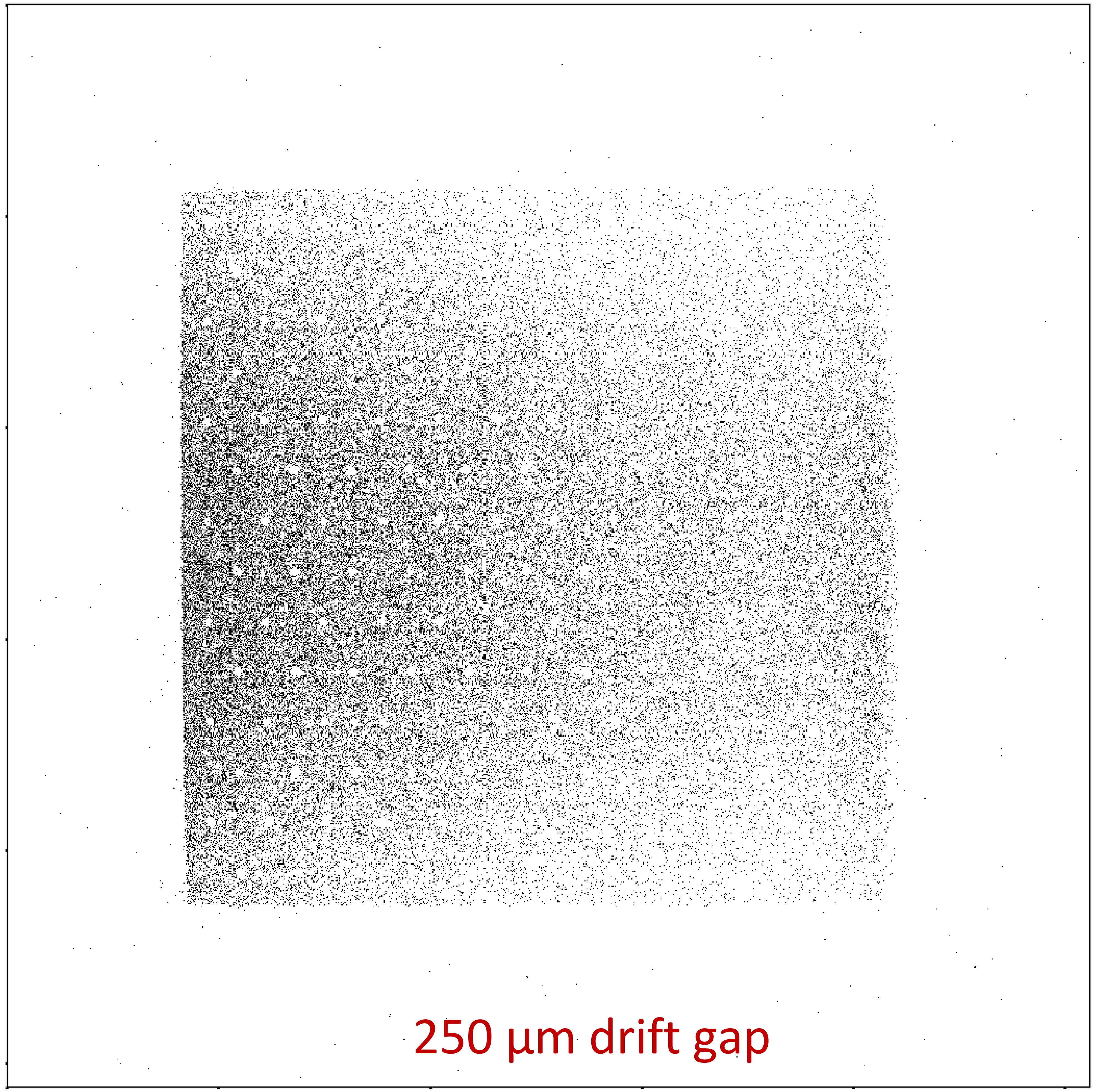
α track light intensity profile



Bragg curve

Clusters centroid Histo

1 cm



Perspectives

Simultaneous activity measurement with 14C and 3H

Single cell activity measurement

High flux neutron facility

THANK YOU