# Optical readout of gaseous detectors: new developments and perspectives

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[4] CEA, IRFU, Gif-sur-Yvette, France
[5] C-rad, Uppsala, Sweden

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# Content

**Optical readout of gaseous radiation detectors**

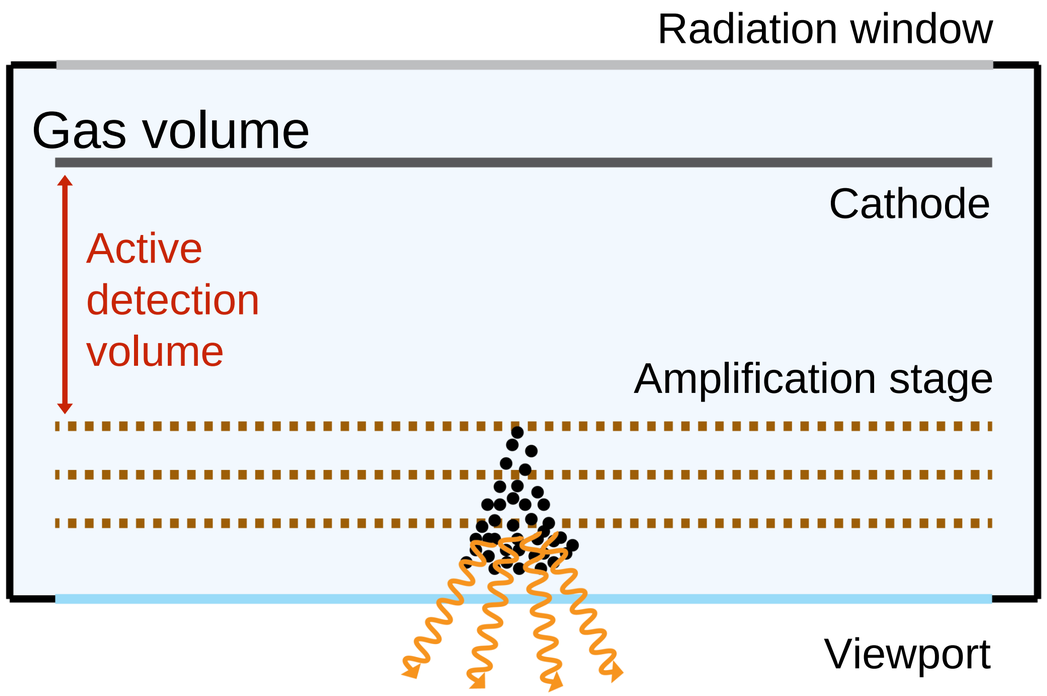
**New developments**

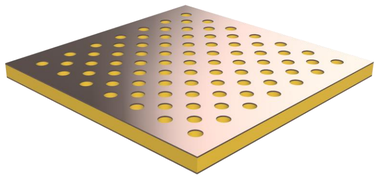
Low material budget beam monitoring
Optical readout of MicroMegas detector

**Ultra-fast optical readout**

X-ray fluoroscopy and fluorescence
3D track reconstruction in optical TPCs

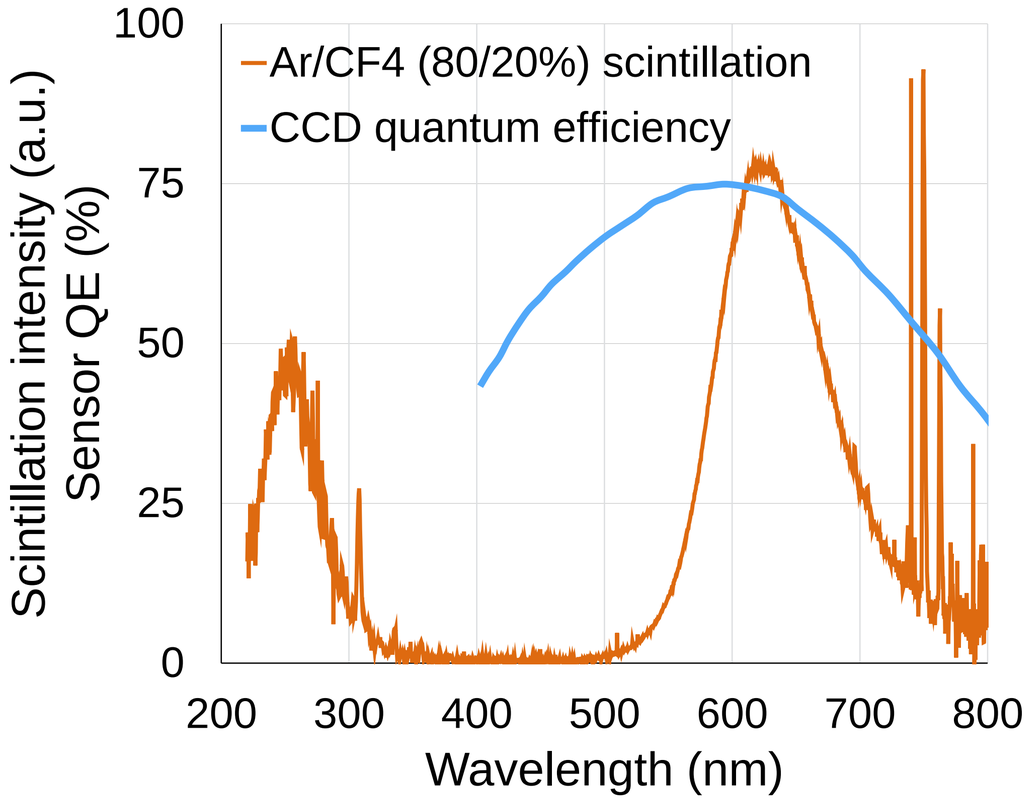
# Gaseous radiation detectors optical readout



Gaseous Electron Multiplier (**GEM**)

Camera




Schematics not drawn to scale

# Gaseous radiation detectors optical readout

**Integrated** imaging approach

**Megapixel** imaging sensors for high **spatial resolution**

**Optical components** for adjustable magnification

Limited **frame rate**

**Radiation hardness** of imaging sensors

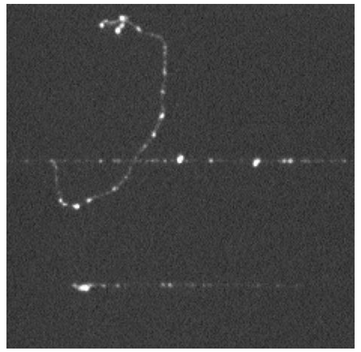
Need of **$CF_4$**-based gas mixtures or wavelength shifters

# Gaseous radiation detectors optical readout

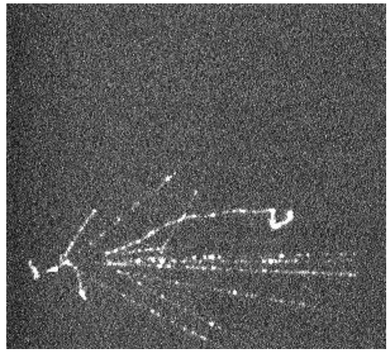
## at the Gaseous Detector Development lab at CERN

X-ray photons

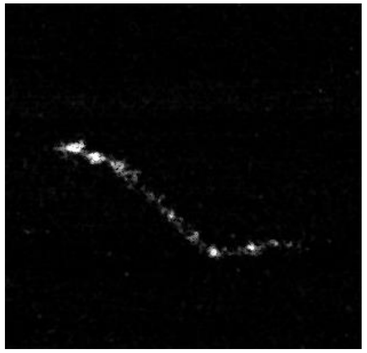
Alpha track



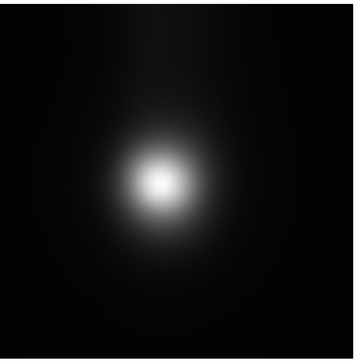
Muon tracks with δ-ray



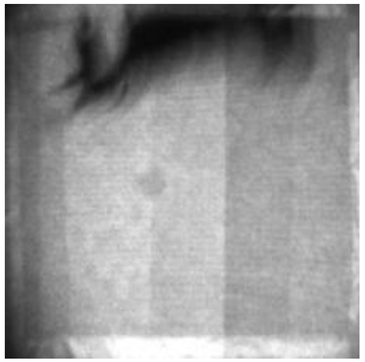
Hadronic shower



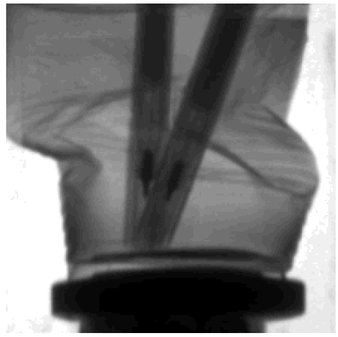
Cosmic event



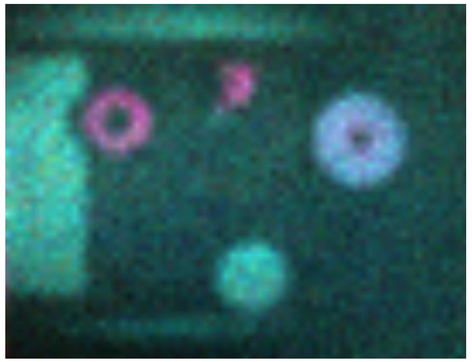
Proton beam profile



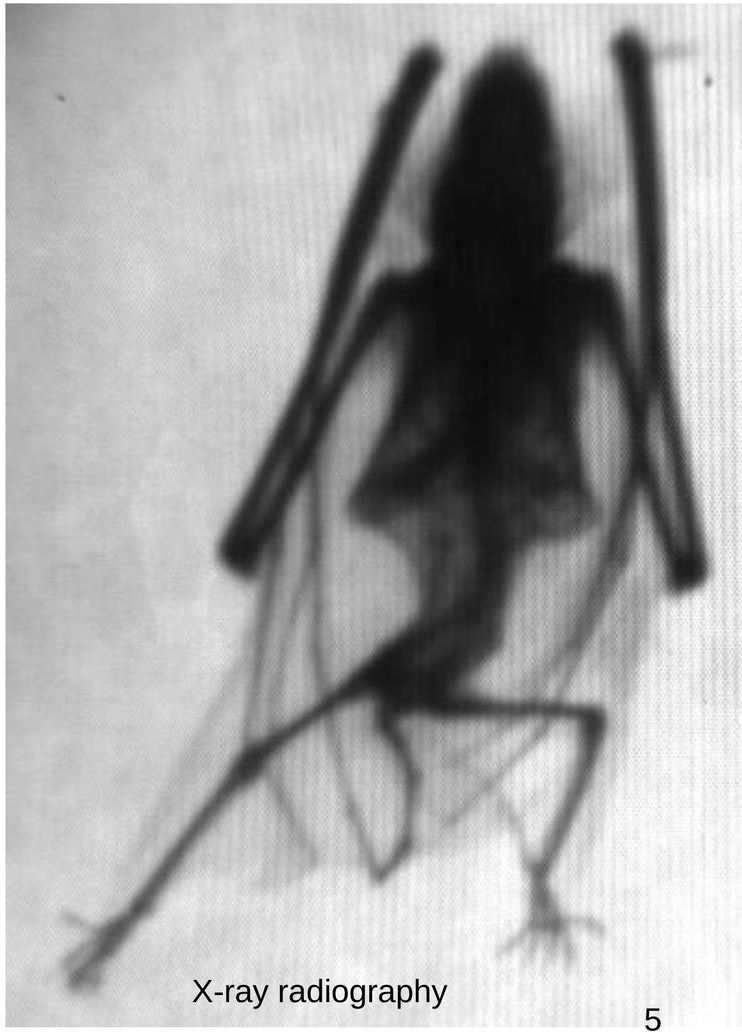
X-ray fluoroscopy



X-ray tomography



X-ray fluorescence



X-ray radiography

# New developments
# Low material budget beam monitoring

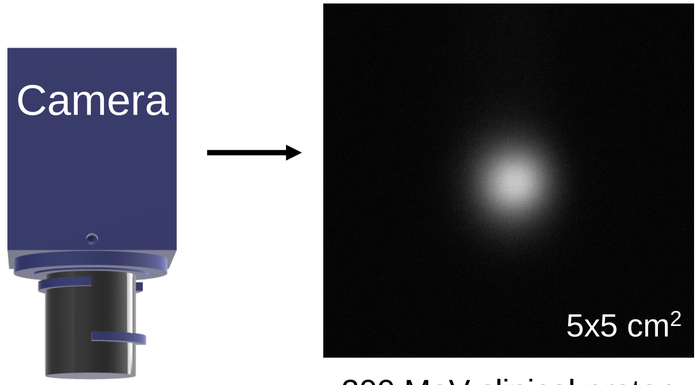
# Beam monitoring

**Guiding light out of beam path with thin mirror**

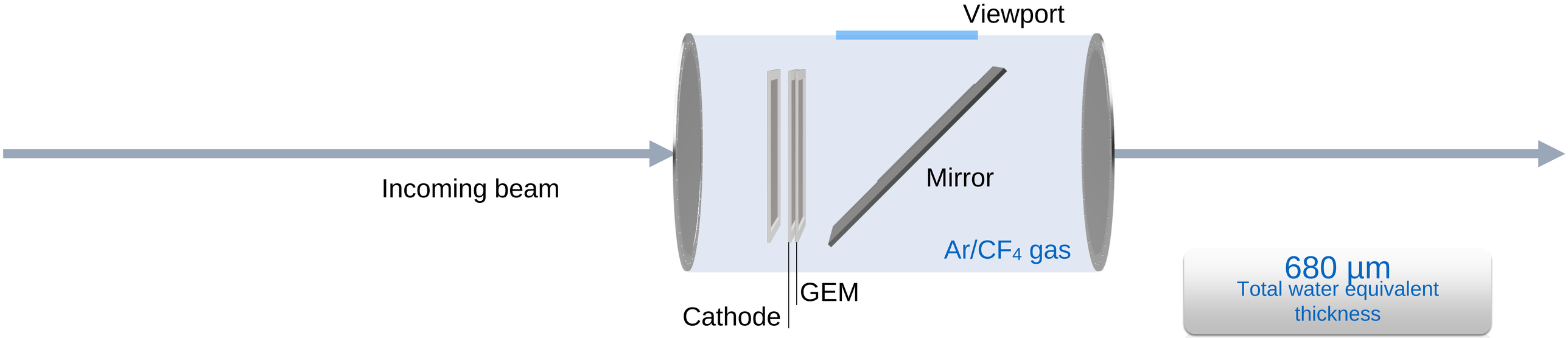
**Low material budget** due to use of gas and thin foil detector components

**High spatial resolution pixelated readout**

**Minimise radiation exposure** of camera



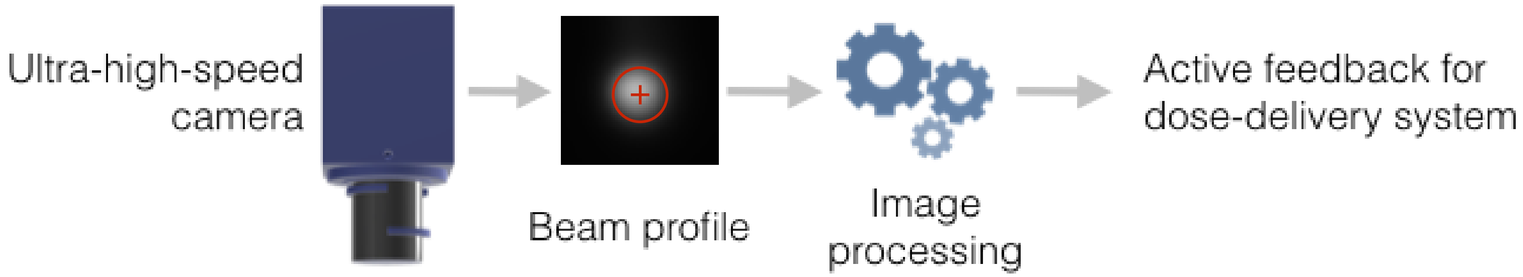

200 MeV clinical proton beam

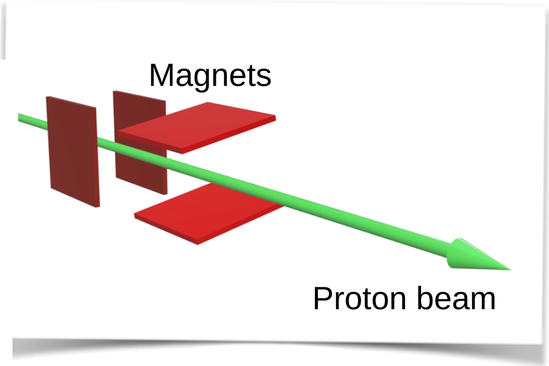


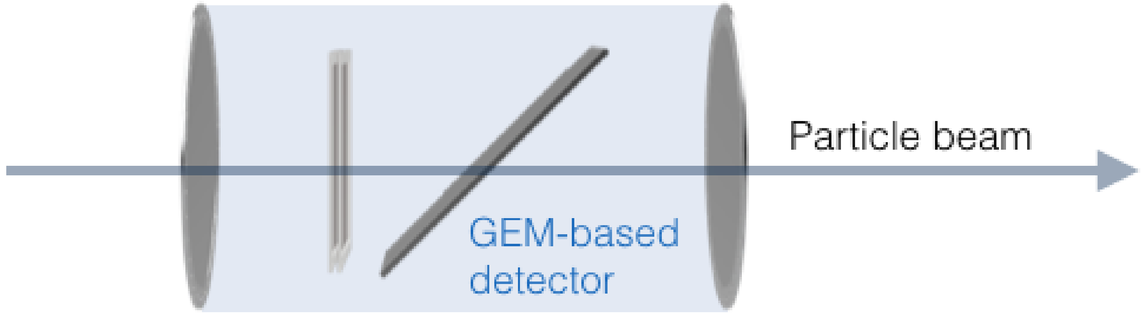

680 µm
Total water equivalent thickness

Schematics not drawn to scale

# Beam monitoring for active feedback



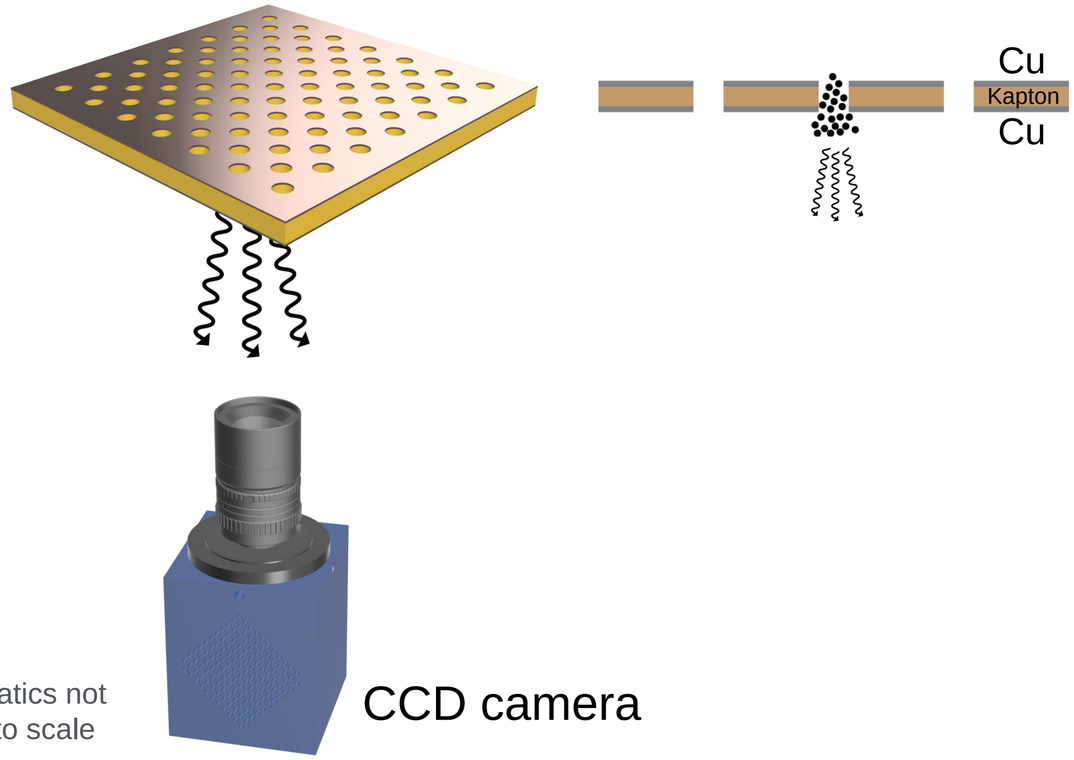




Schematics not drawn to scale

# New developments
# Optical readout of MicroMegas detector

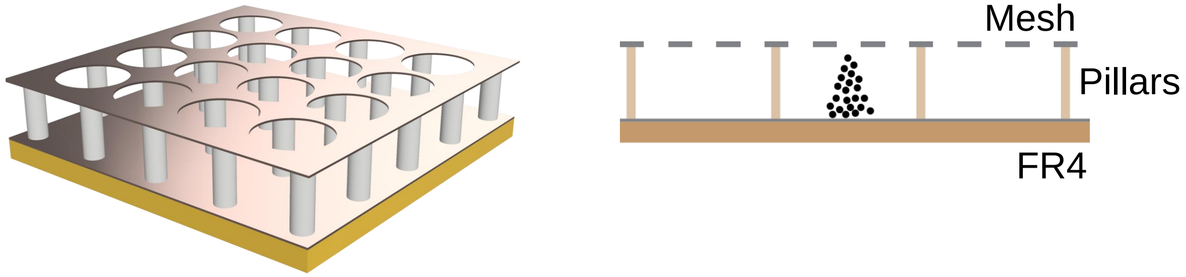
# Optical readout of gaseous detectors

Gaseous Electron Multiplier (**GEM**)




Schematics not drawn to scale

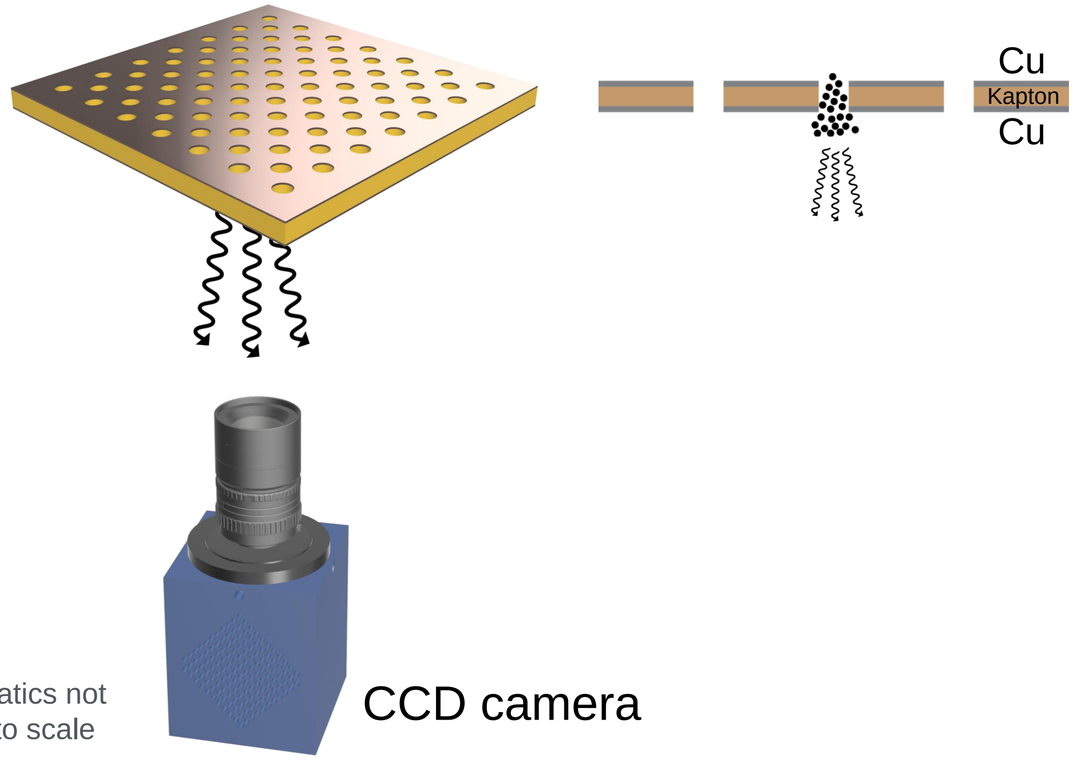
Micro-Mesh Gaseous Structure (**MicroMegas**)



# Optical readout of gaseous detectors

**Exploiting uniform amplification region of MicroMegas detectors**

Gaseous Electron Multiplier (**GEM**)

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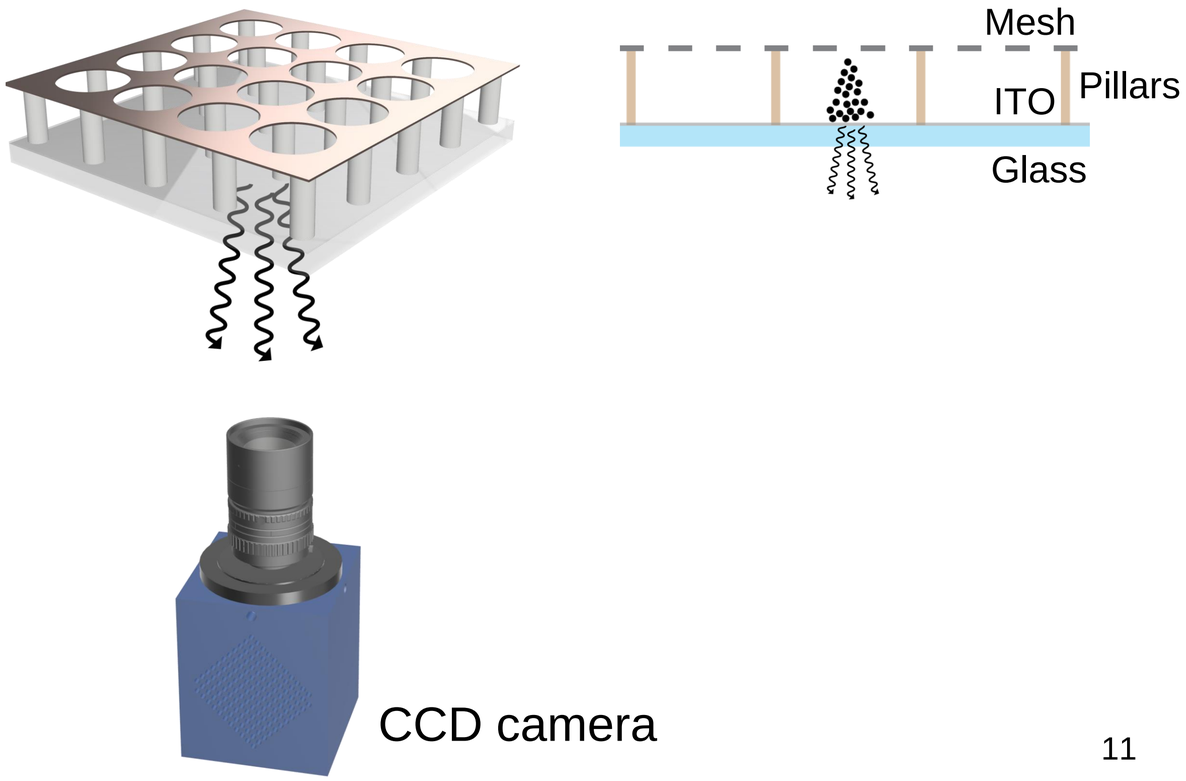


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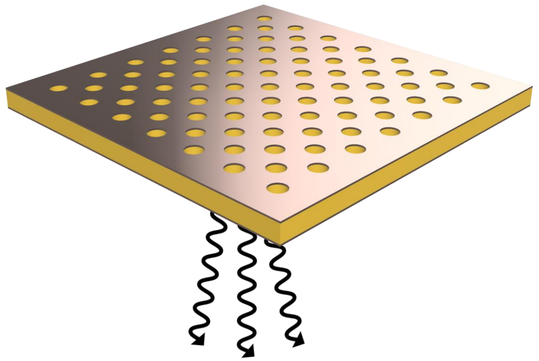
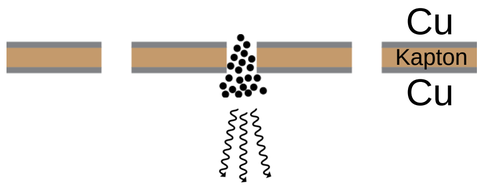
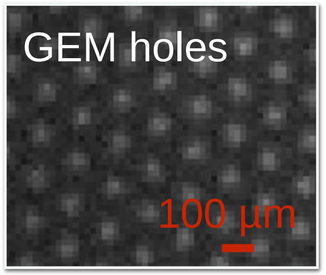


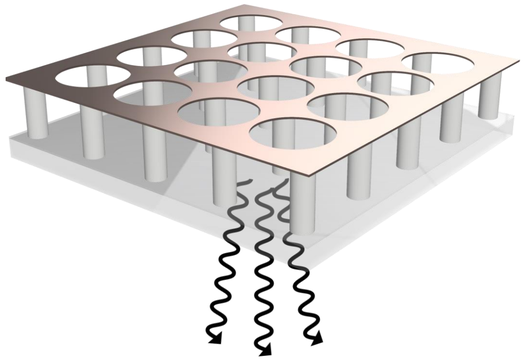


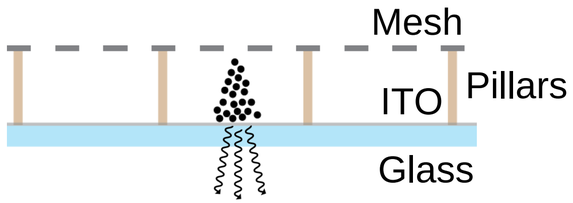




CCD camera

Schematics not drawn to scale

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






CCD camera

**Potential advantages:**

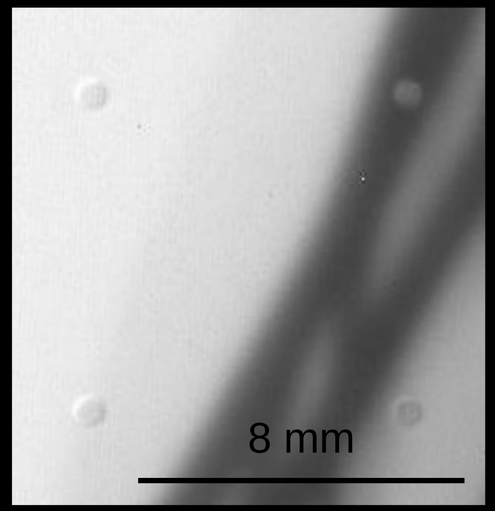
- Better energy resolution
- Higher uniformity for imaging (no hole structure)

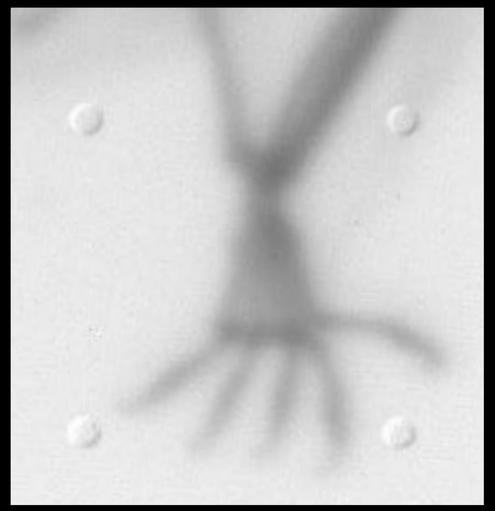
# X-ray radiography imaging with glass Micromegas


Optically read out **glass Micromegas** detectors are well suited for X-ray radiography.

They appear to permit higher spatial resolution than optically read out GEMs.

Pillars are visible as inefficient areas in background subtracted, beam-shape corrected images.



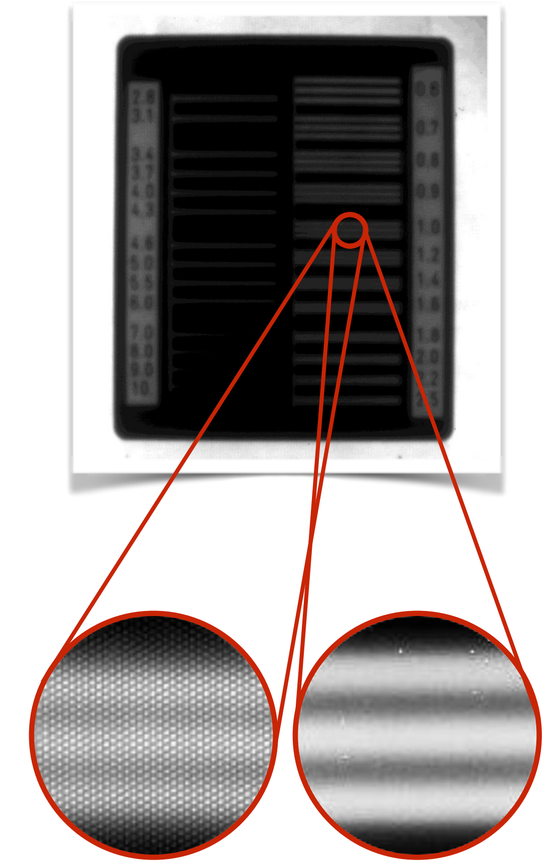
# Spatial resolution comparison

Line pair phantoms were used to measure the spatial resolution and compare it to the one achievable with an optically read out triple-GEM.

**Spatial resolution:**

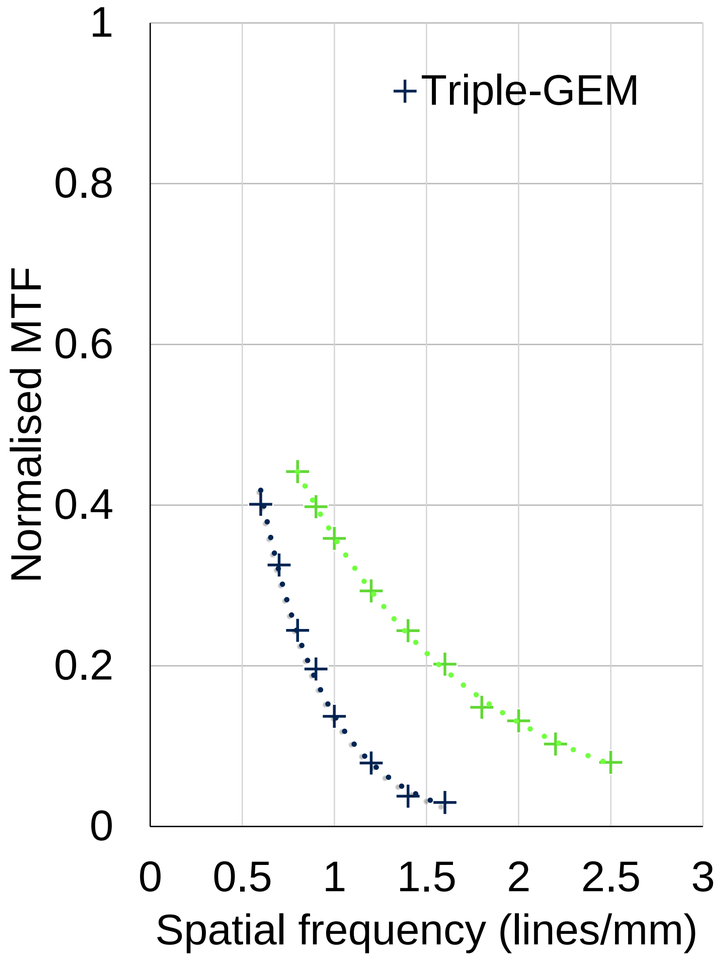
Triple-GEM: **≈890 µm** (1.11 lines/mm)

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



Triple-GEM
Hole structure

Micromegas
Uniform



# Next steps
# Ultra-fast optical readout

# Optical readout

Integrated imaging approach

Megapixel imaging sensors for high spatial resolution

Optical components for adjustable magnification

**Frame rate**

Radiation hardness of imaging sensors

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

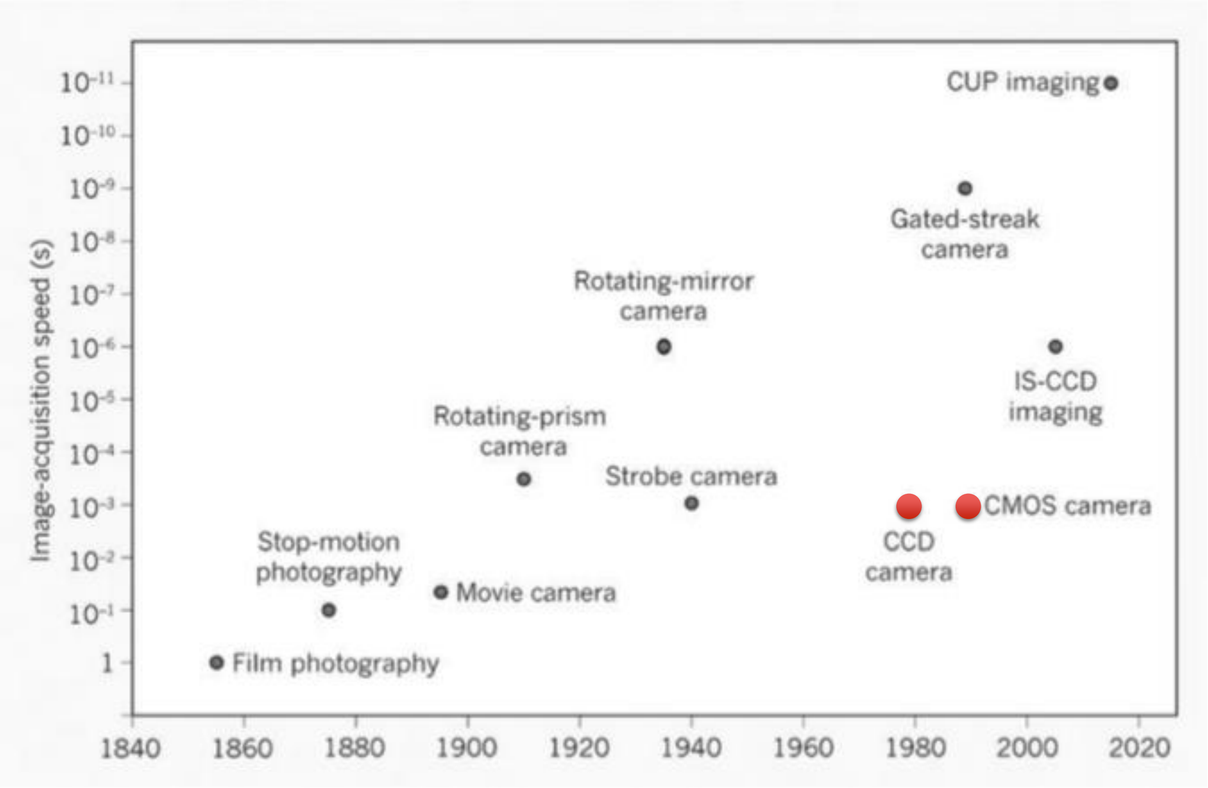



Image adapted from: B. Pogue, Nature 516 (2014) 46–47

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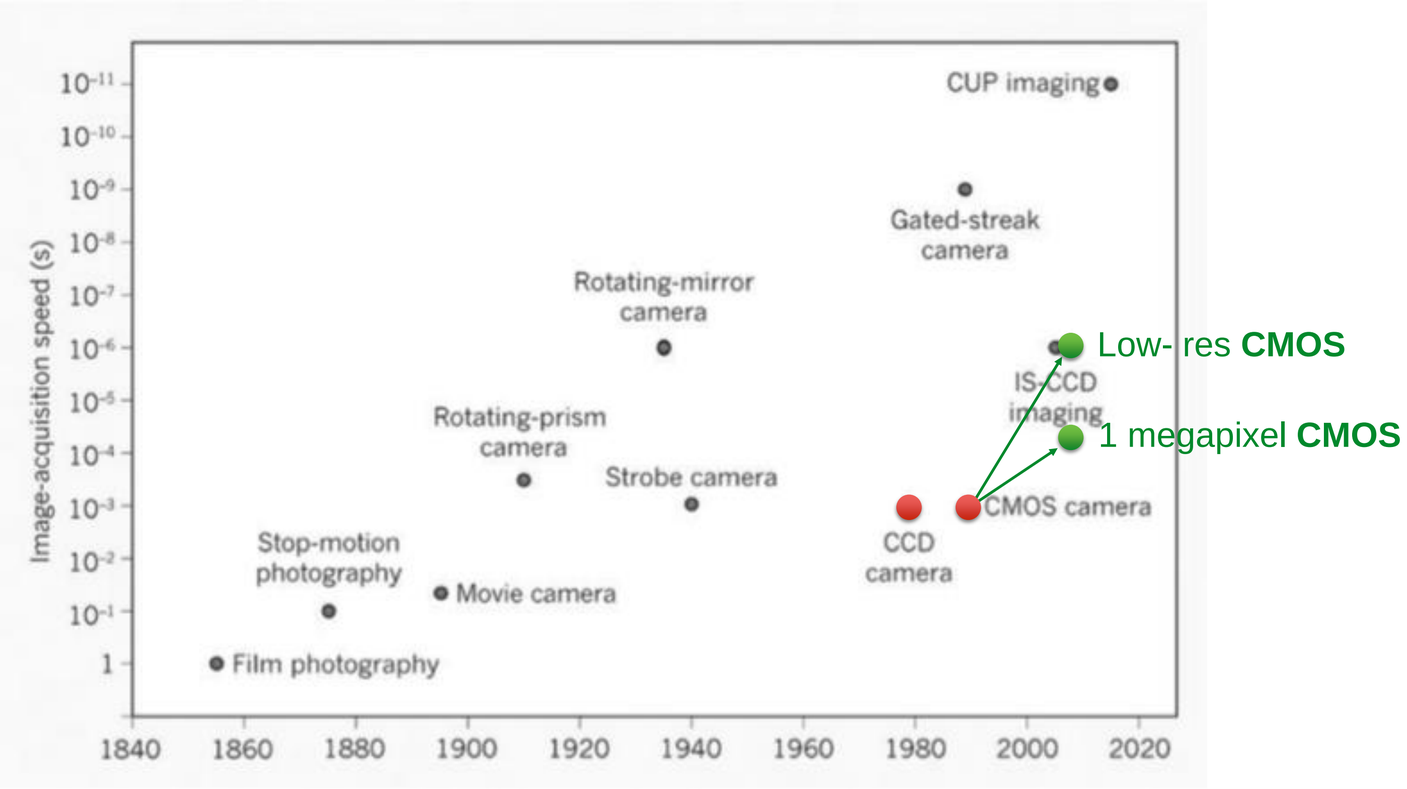



Image adapted from: B. Pogue, Nature 516 (2014) 46–47

# Optical readout

Integrated imaging approach

Megapixel imaging sensors for high spatial resolution

Optical components for adjustable magnification

**Frame rate**

Radiation hardness of imaging sensors

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

**Photron FASTCAM SA-Z**

- 1 megapixel CMOS sensor
- 12 bit depth
- **20 kfps** at 1024x1024
- **2.1 Mfps** at 128x8
- ISO 50,000 sensitivity

**Phantom v2512**

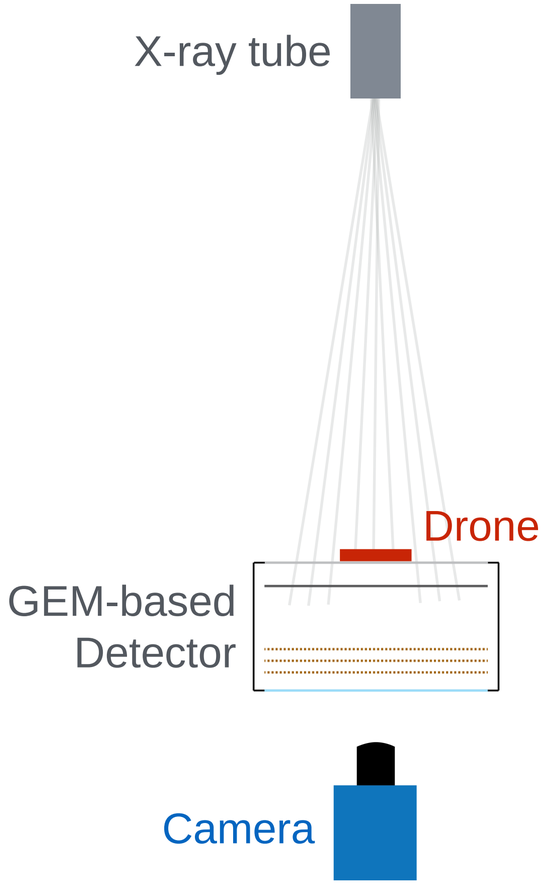
- 1 megapixel CMOS sensor
- 12 bit depth
- **25 kfps** at 1280 x 800
- **1 Mfps** at 128x32
- ISO 100,000 sensitivity

Ultra-fast optical readout

X-ray fluoroscopy and fluorescence

# High-speed X-ray fluoroscopy

**Integrated readout approach** and **high-rate compatible MPGDs** permit short exposure imaging



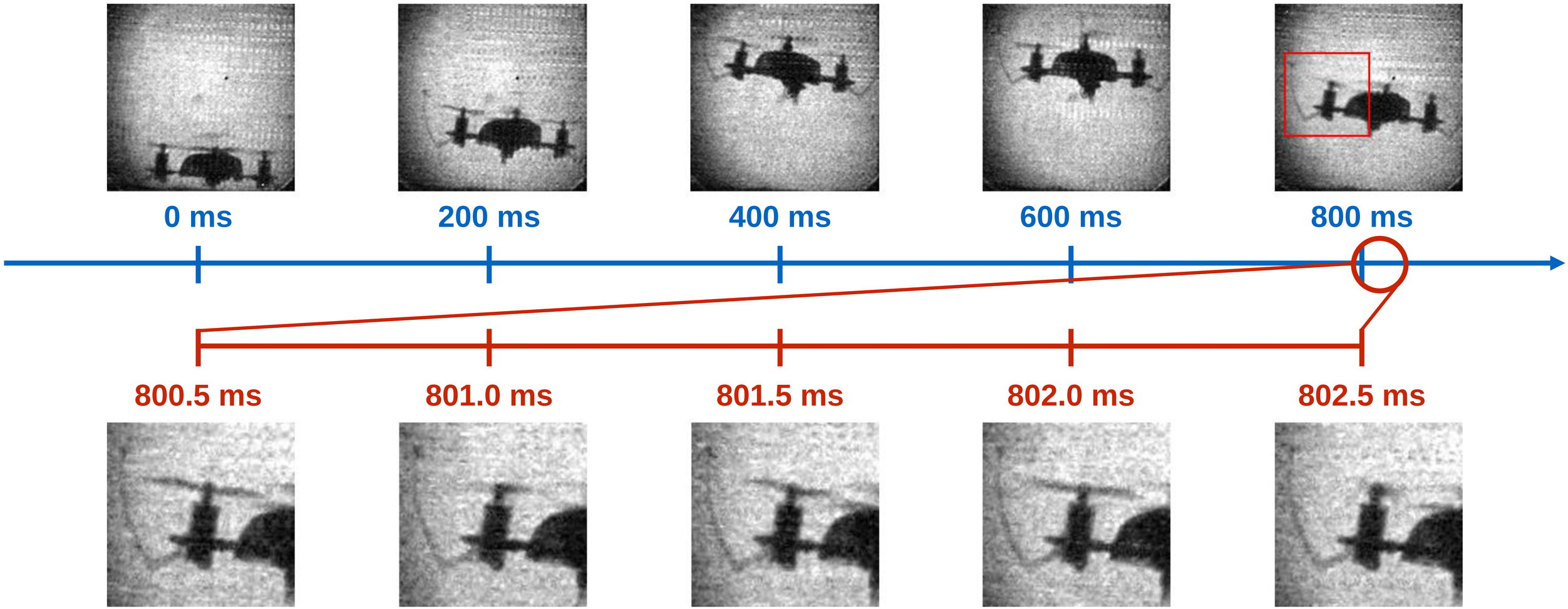

**Minimising motion blur** and enabling fast radiography due to fast sensor readout and high sensitivity

Schematics not drawn to scale

# High-speed X-ray fluoroscopy

0 ms | 200 ms | 400 ms | 600 ms | 800 ms

# High-speed X-ray fluoroscopy



# Full-field X-ray fluorescence

**High-frame rates** may enable **rapid full-field X-ray fluorescence** imaging

Individual $^{55}$Fe X-ray photons in short exposure image

F.M. Brunbauer et al. JINST (13) 2018.

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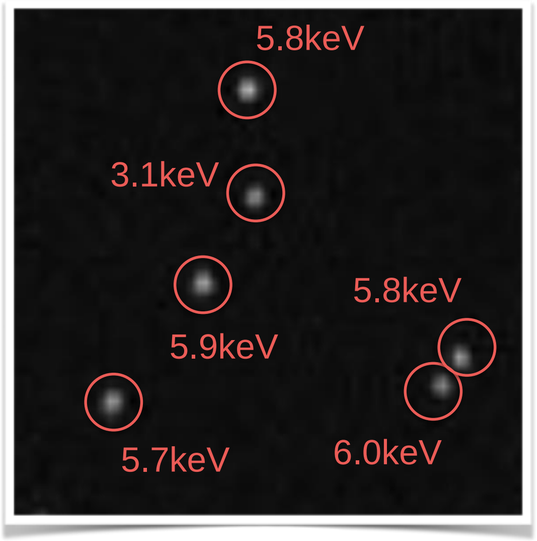
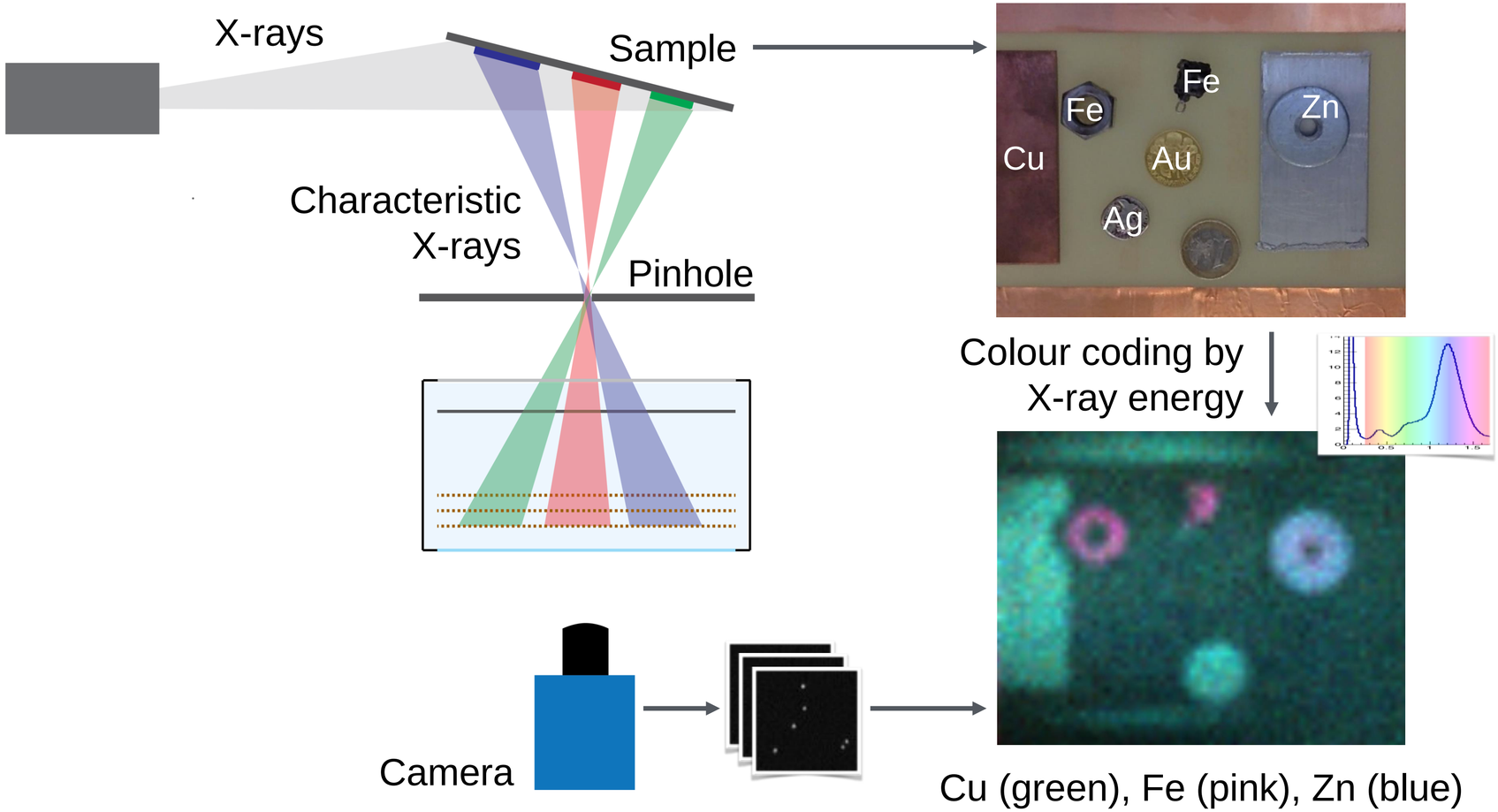



Individual $^{55}$Fe X-ray photons in short exposure image

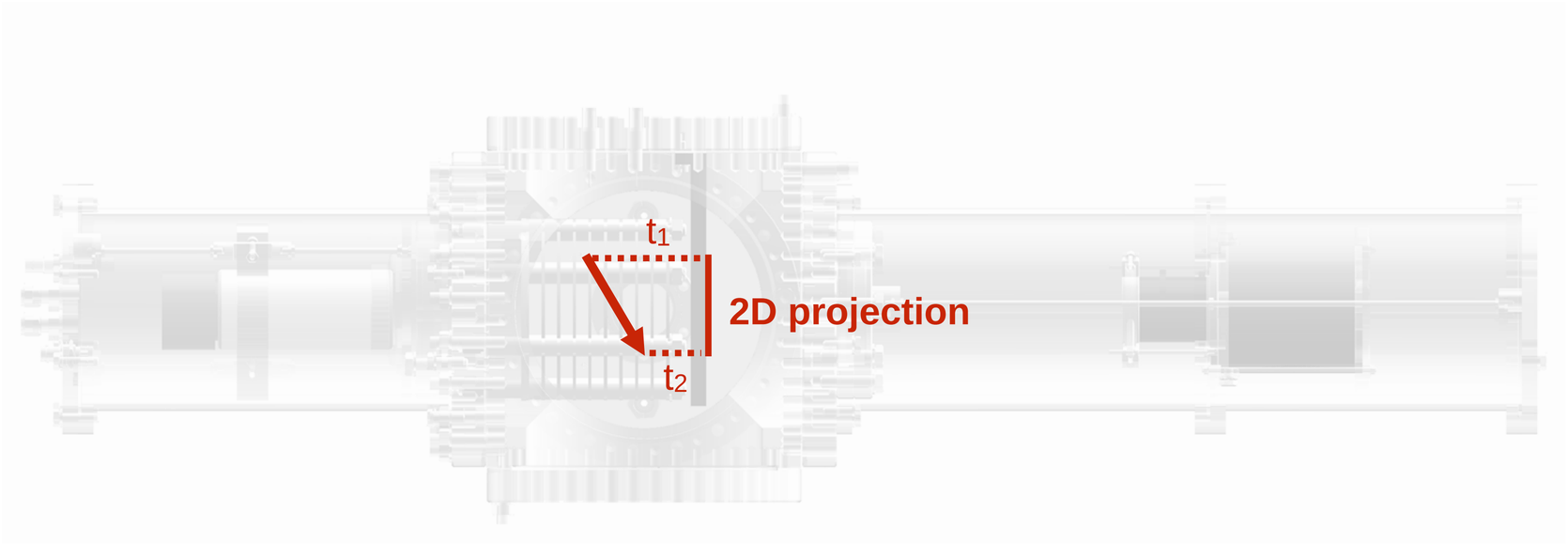



Schematics not drawn to scale

F.M. Brunbauer et al. JINST (13) 2018.

# Ultra-fast optical readout
# 3D track reconstruction in optical TPCs

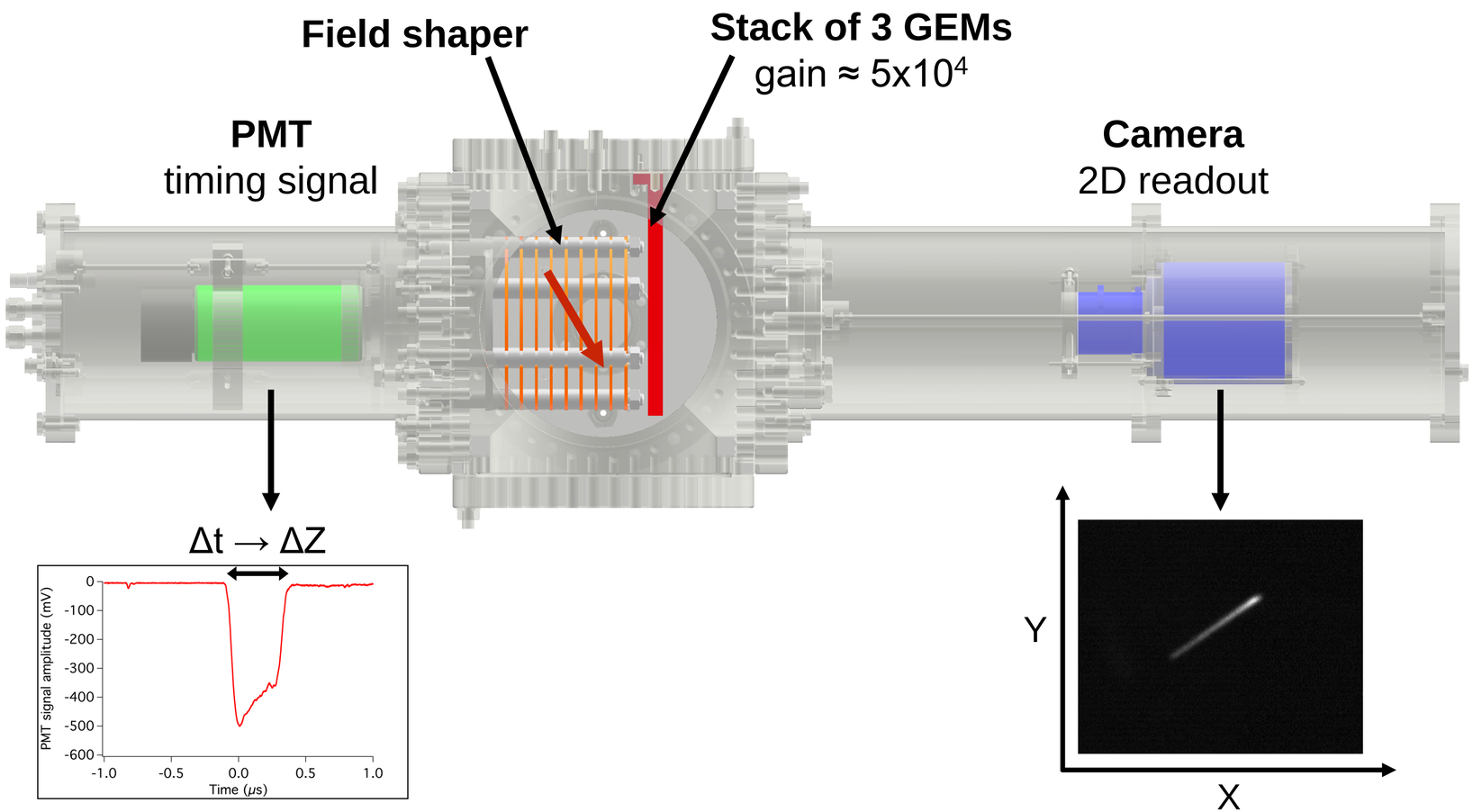
# Optically read out TPC

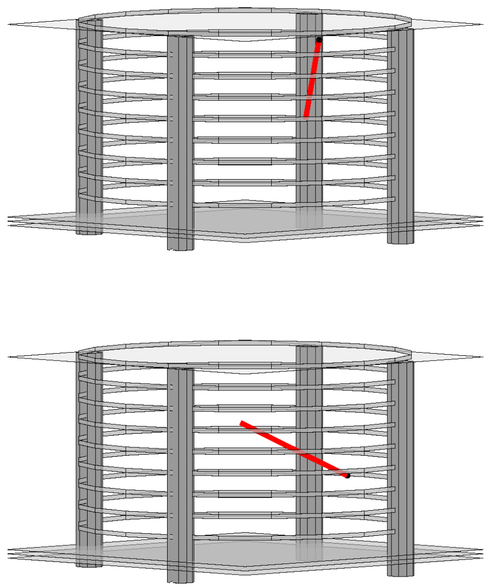



$\Delta t = t_1 - t_2 \rightarrow \mathbf{\Delta Z}$

Schematics not drawn to scale

# Optically read out TPC CCD + PMT

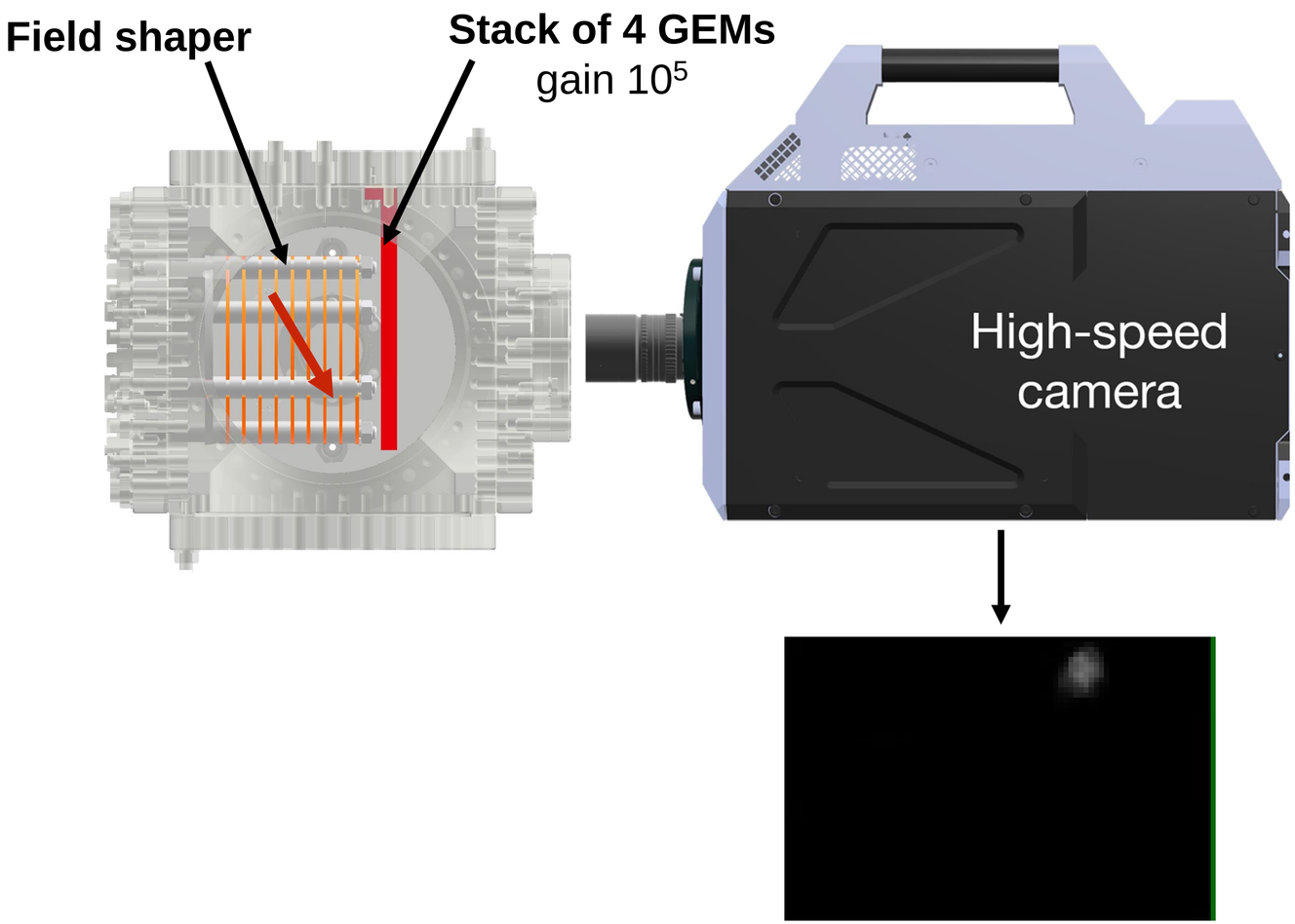


F. M. Brunbauer et al., **Live Event Reconstruction and Scintillation Studies in an optically read out GEM-based TPC**, IEEE NSS 2016

Schematics not drawn to scale

# Optically read out TPC Ultra-fast CMOS




Schematics not drawn to scale

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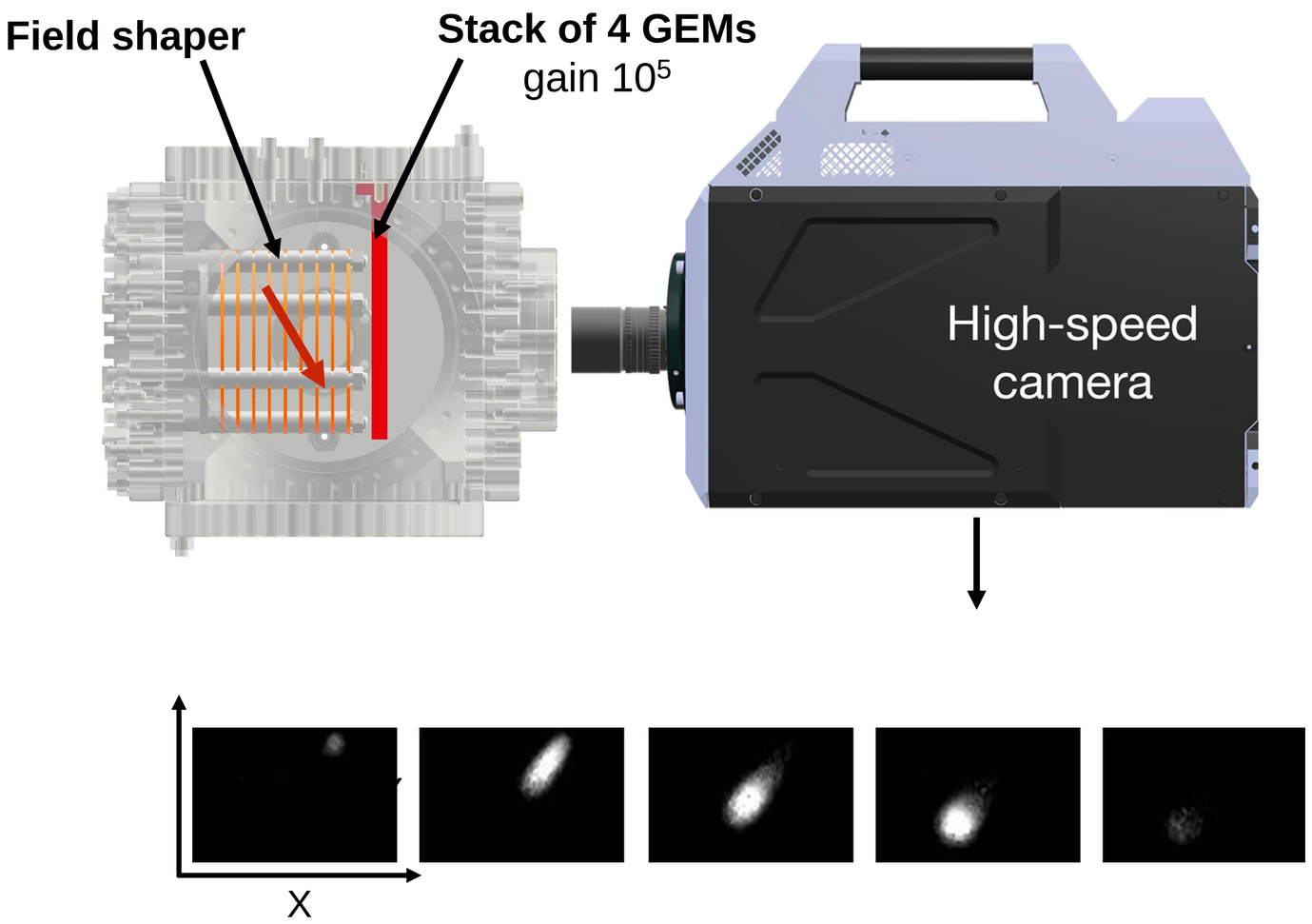
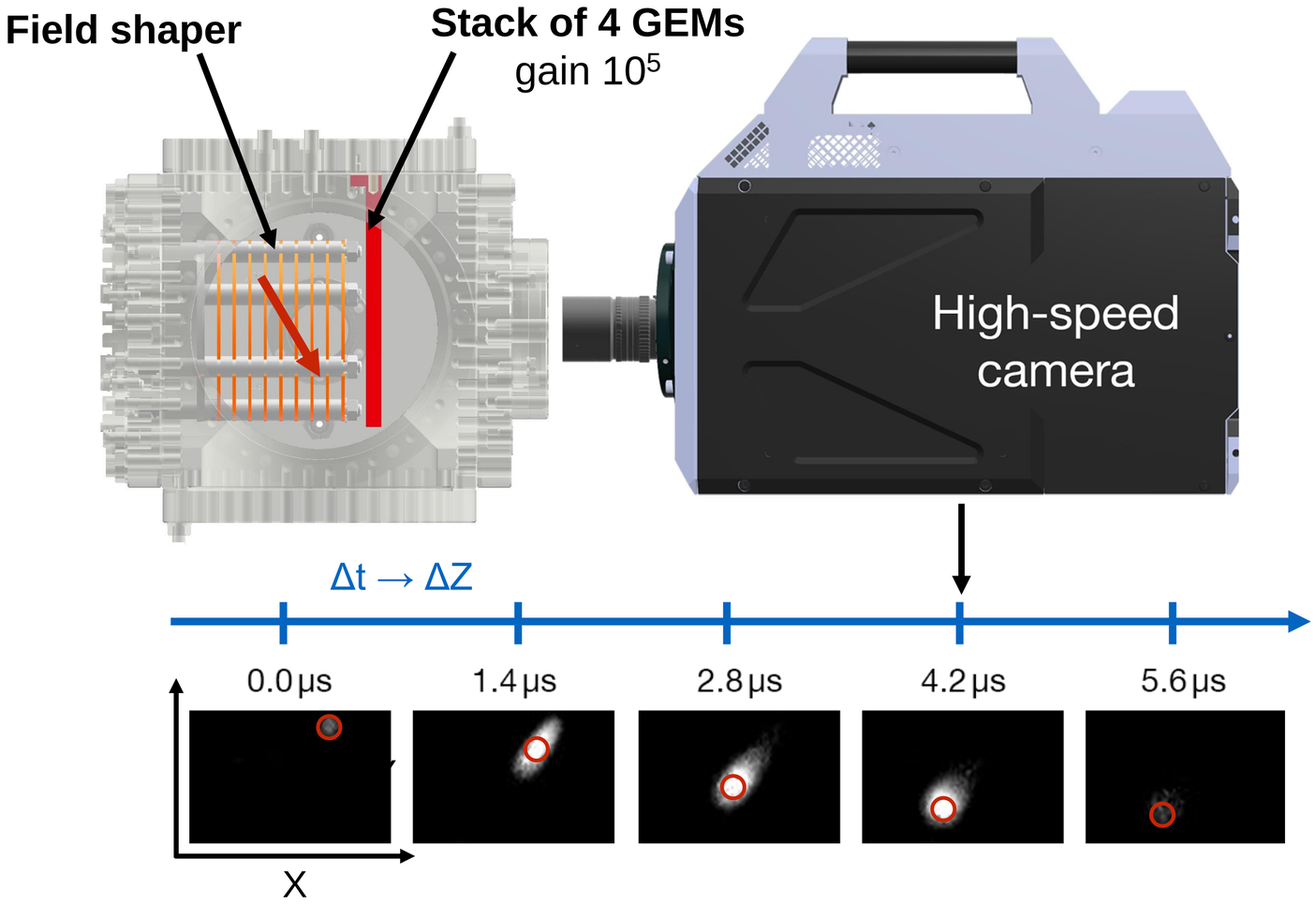
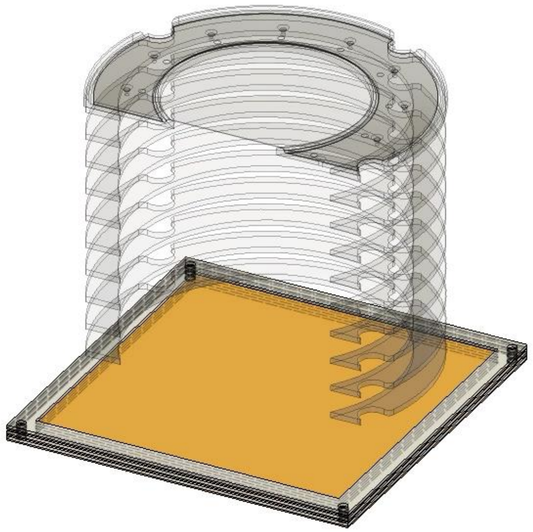



Schematics not drawn to scale

# Optically read out TPC Ultra-fast CMOS




Recorded with 10 V/cm drift field corresponding to ≈0.5 cm/μs in $Ar/CF_4$



3D alpha track reconstruction (schematic)

Schematics not drawn to scale

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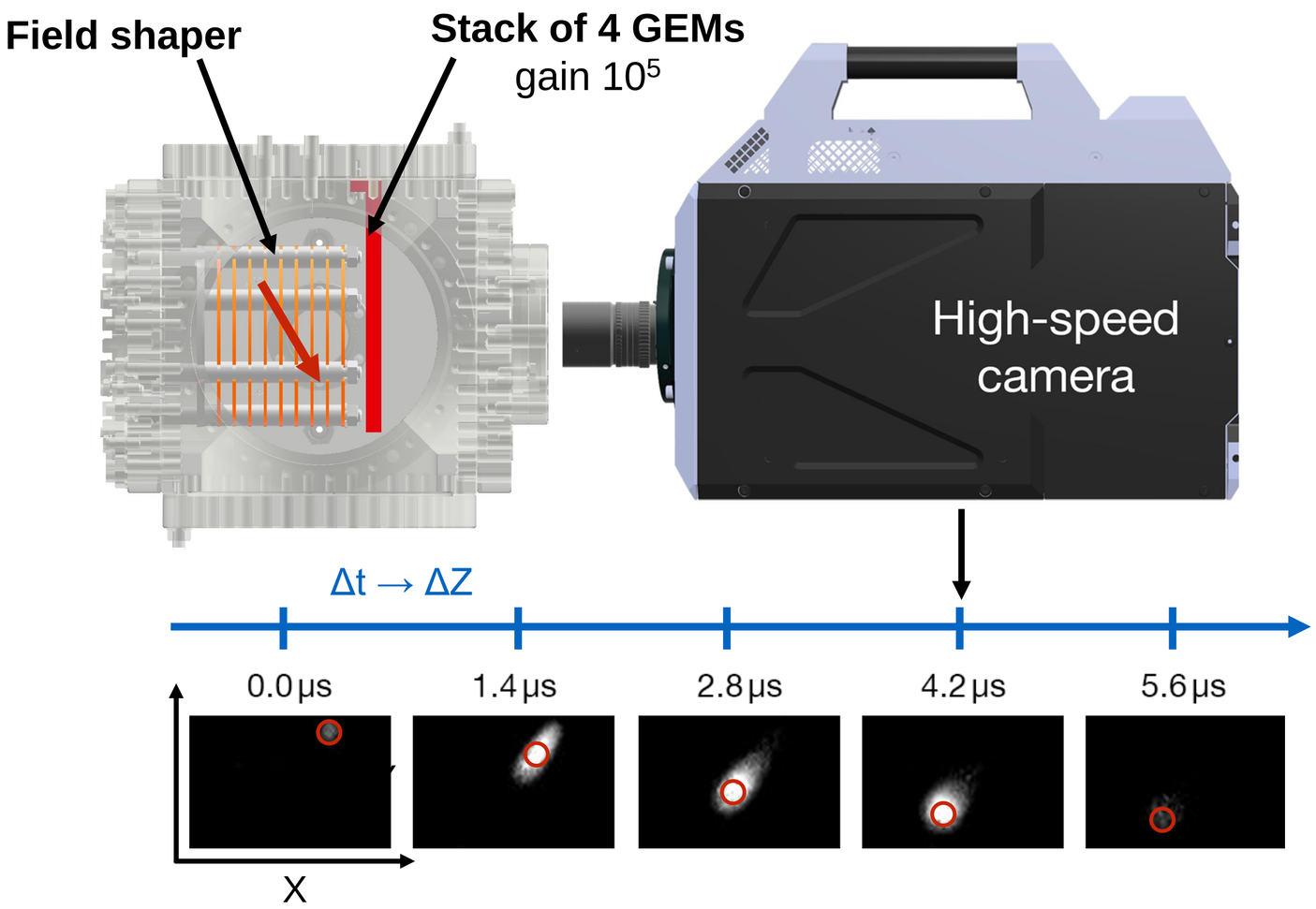


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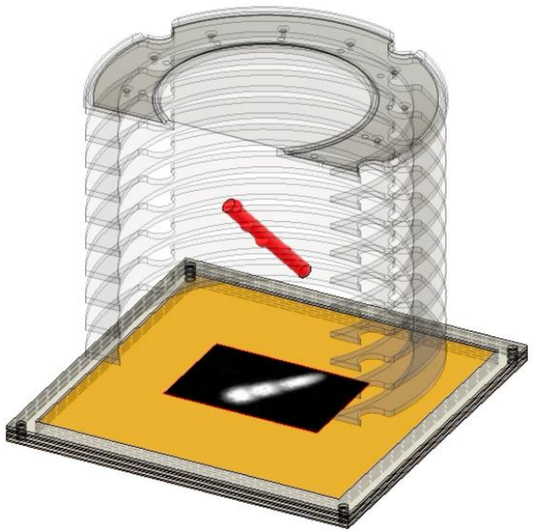


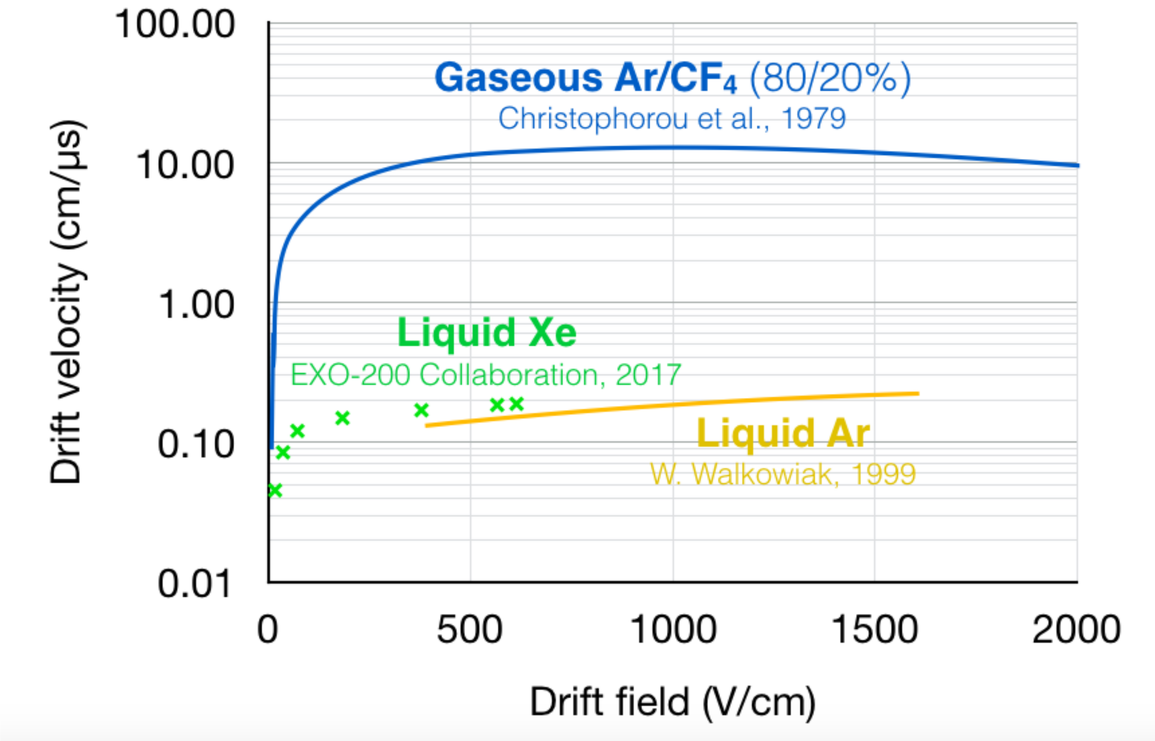
3D alpha track reconstruction (schematic)

Schematics not drawn to scale

# Optically read out TPC Ultra-fast CMOS

At **low drift fields**, the arrival time of primary electrons at the GEM in a TPC setup can be resolved in **individual image frames**. **Sub-mm depth resolution** with microsecond inter-frame intervals may be achievable in **liquid TPCs** or **negative-ion TPCs**.

## Electron-drift TPCs




## Negative-ion TPCs

Drift times on the order of **0.1 mm/μs** at 1 bar in gaseous Xe

Martoff et al., NIM A 440, 355 (2000)
Nygren, Journal of Physics: Conference Series 65 (2007) 012003

# Conclusions

Optical readout is a **versatile readout approach** for gaseous detectors. The use of optical components makes it adaptable for varying detector geometries and requirements.

Using gas as active medium and thin foil detector components, **low-material budget detectors** can be realised. Optical readout devices can be placed outside of the beam path to minimise exposure and scattering.

Integrating MPGDs on a transparent substrate enables optical readout. **Glass-based Micromegas** were operated and shown to provide good spatial resolution.

**Ultra-fast CMOS cameras** enable novel applications for optically read out detectors.
X-ray fluoroscopy under strong irradiation is enabled by the integrated imaging approach.
Rapid **full-field X-ray fluorescence** may be possible with high-speed cameras.

Microsecond inter-frame intervals permit sequence imaging for **3D track reconstruction in optical TPCs**.