Micro Pattern Gaseous Detectors and potential applications beyond fundamental Physics

Filippo Resnati[1,2]
on behalf of CERN EP-DT-DD Gaseous Detector Development team

[1]CERN, [2]ESS

ICHEP - Chicago - 6th August 2016

Outline

Brief overview of Micro-Pattern Gaseous Detectors

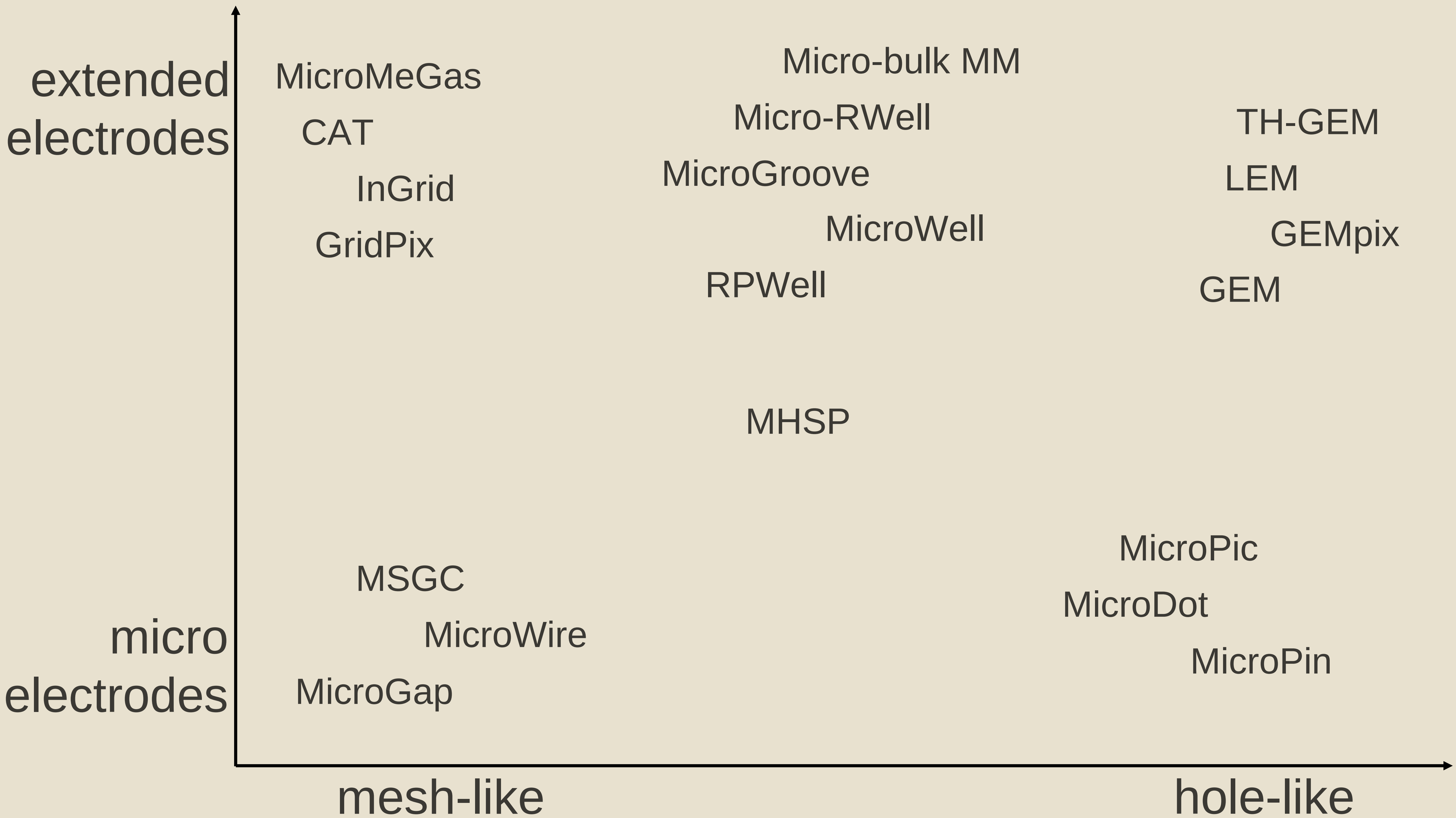
Four examples of their application beyond fundamental Physics

Intuitive, simple and versatile readout for MPGDs suitable for applications beyond HEP

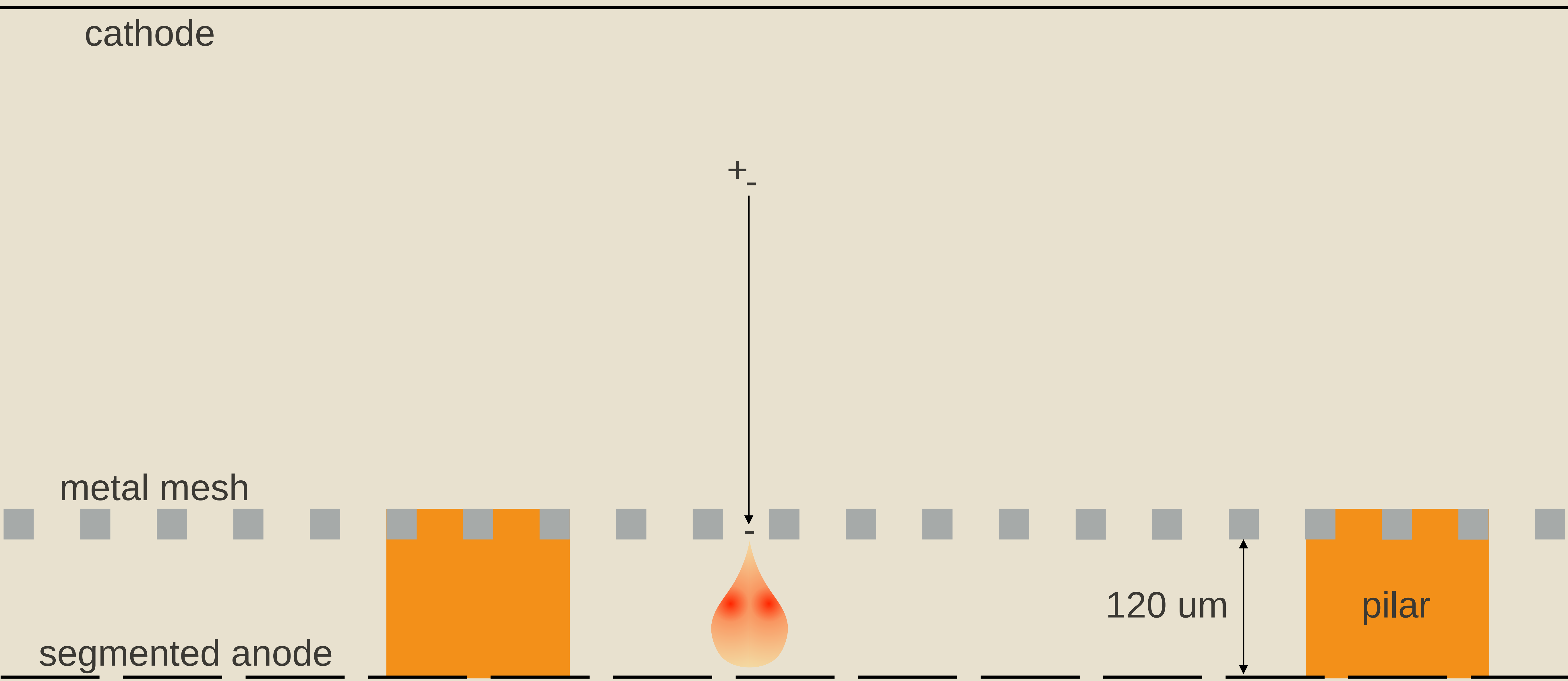
Micro-Pattern Gaseous Detectors

Structures to provide suitable electric fields in gas to amplify the otherwise small amount of ionisation charge produced by the interacting particles

MPGDs: a rich family

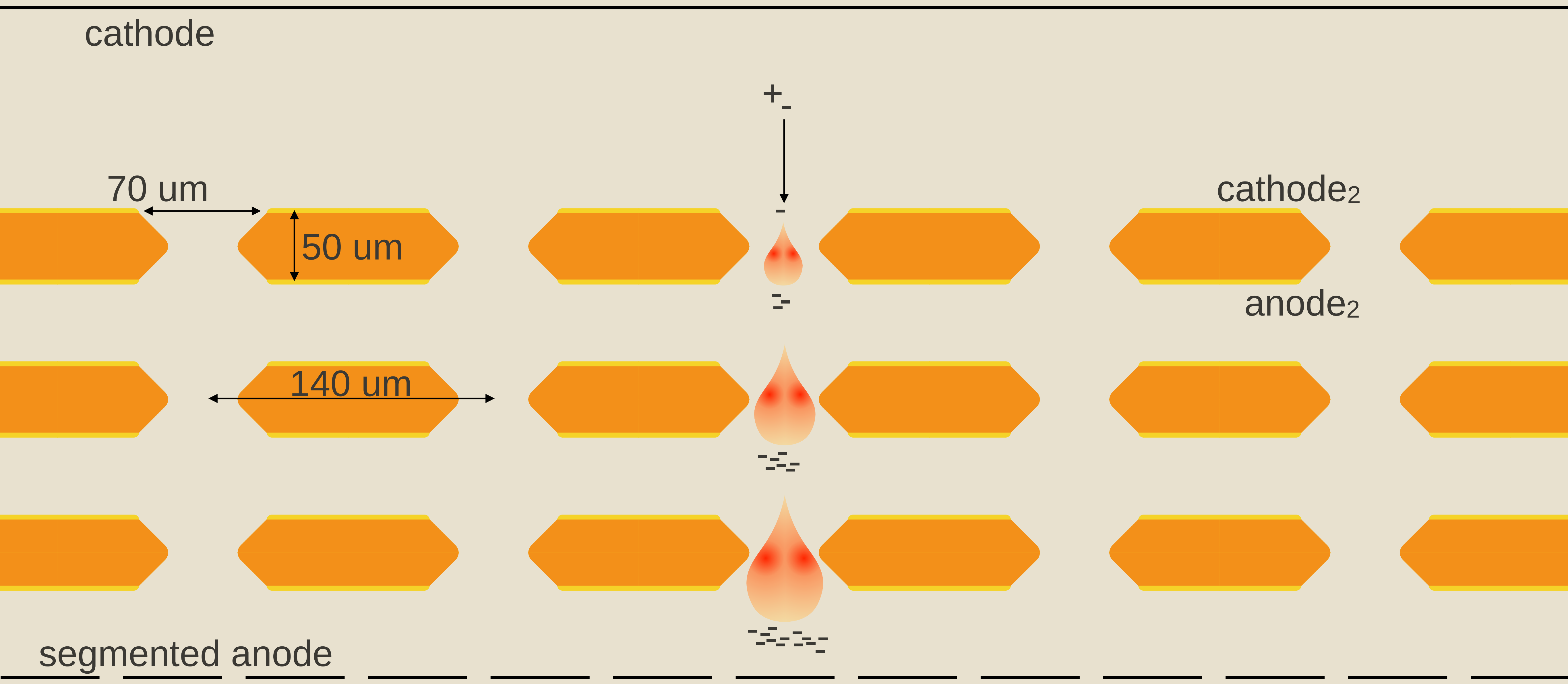


Micromegas



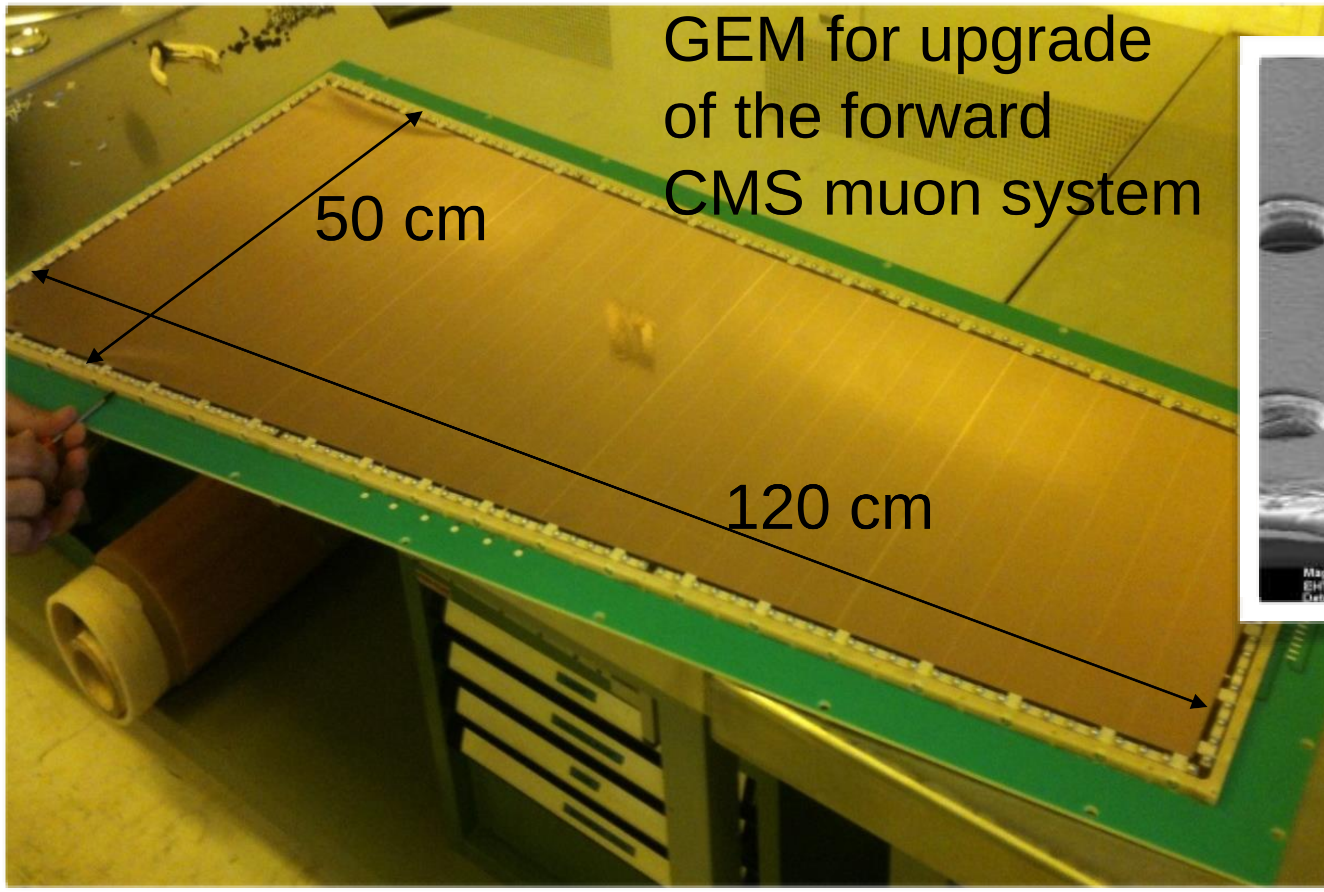
Anode can be made resistive to reduce the discharge effects

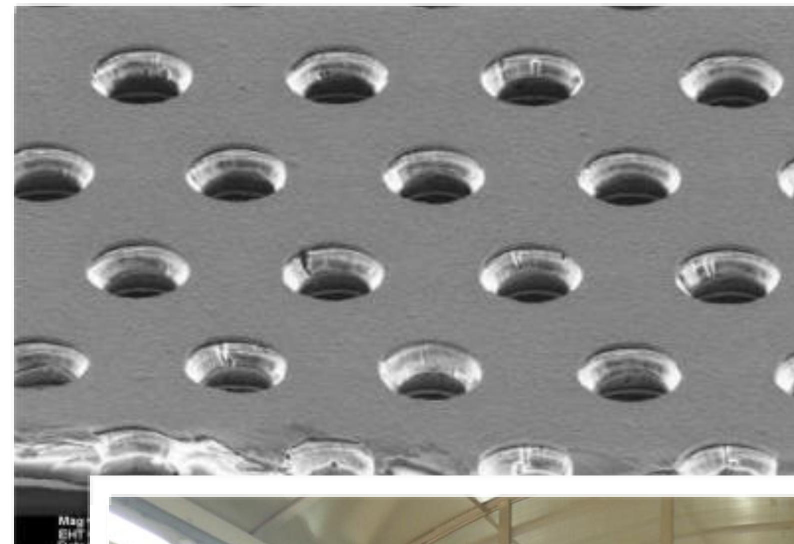
GEMs

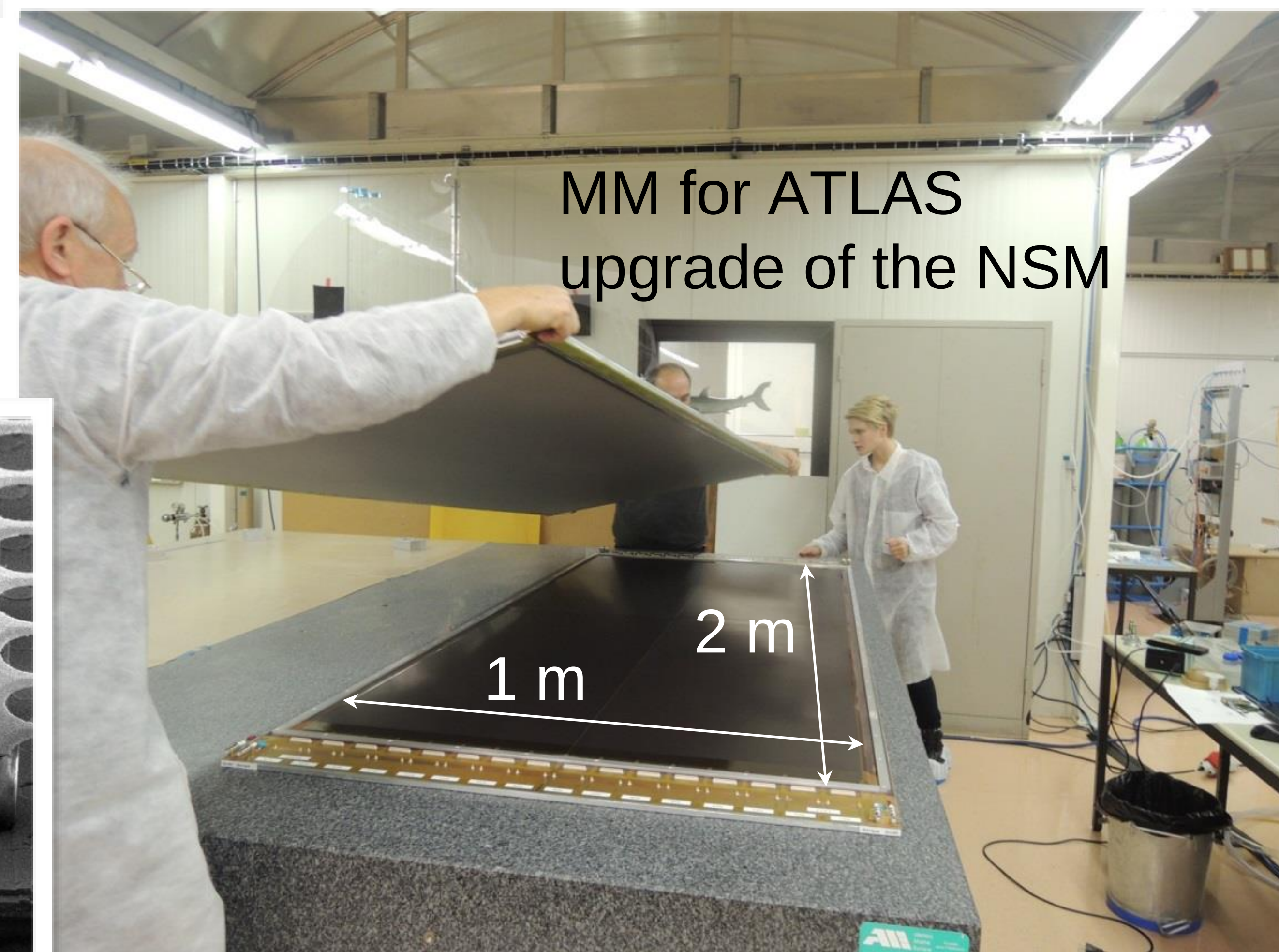


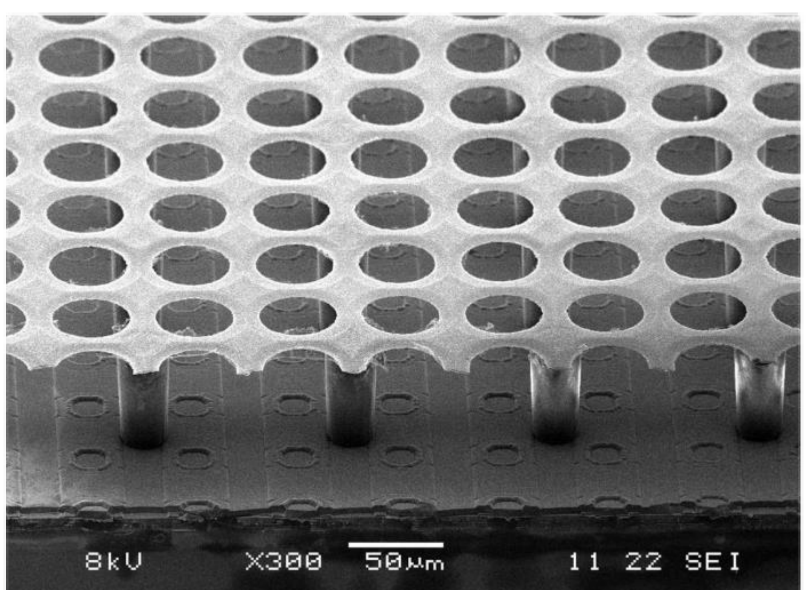
Small gain of each stage reduces the discharge probability

Two remarkable examples









Beyond fundamental Physics

MPGDs found (and still finds) applications beyond fundamental Physics mainly (but not only) due to their imaging capabilities and the advantageous size over price ratio

Some examples

C-RAD GEMINI:
developments to obtain a radiation-hard detector based on GEMs for imaging and dosimetry during γ-ray treatments

Static XRF:
GEM detector used for X-ray fluorescence of artworks in order to unveil underlying paintings over large surfaces

Multigen 2D:
portable and battery-driven muon telescope based on Micromegas used for cosmic muon tomography

NMX at ESS:
development of a GEM based neutron detector with gadolinium converter for NMX instrument at ESS

C-RAD GEMINI

A strong trend has recently developed for using Electronic Portal Imaging Device (EPID) for online verification of the actually delivered dose distribution (Portal Dosimetry), an application for which none of the standard EPID detectors was designed nor optimised.

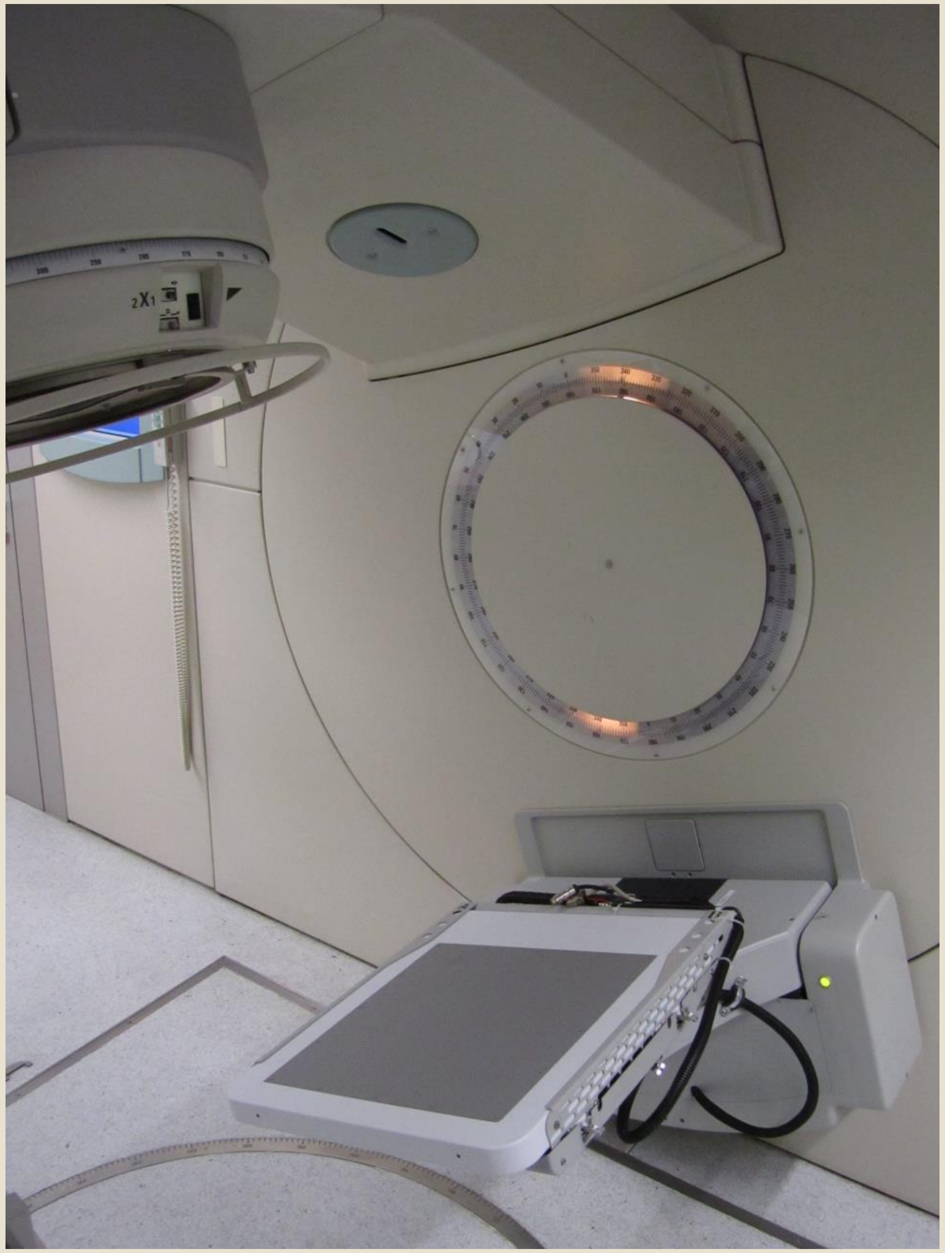
Detectors will be exposed to a very intense γ radiation.

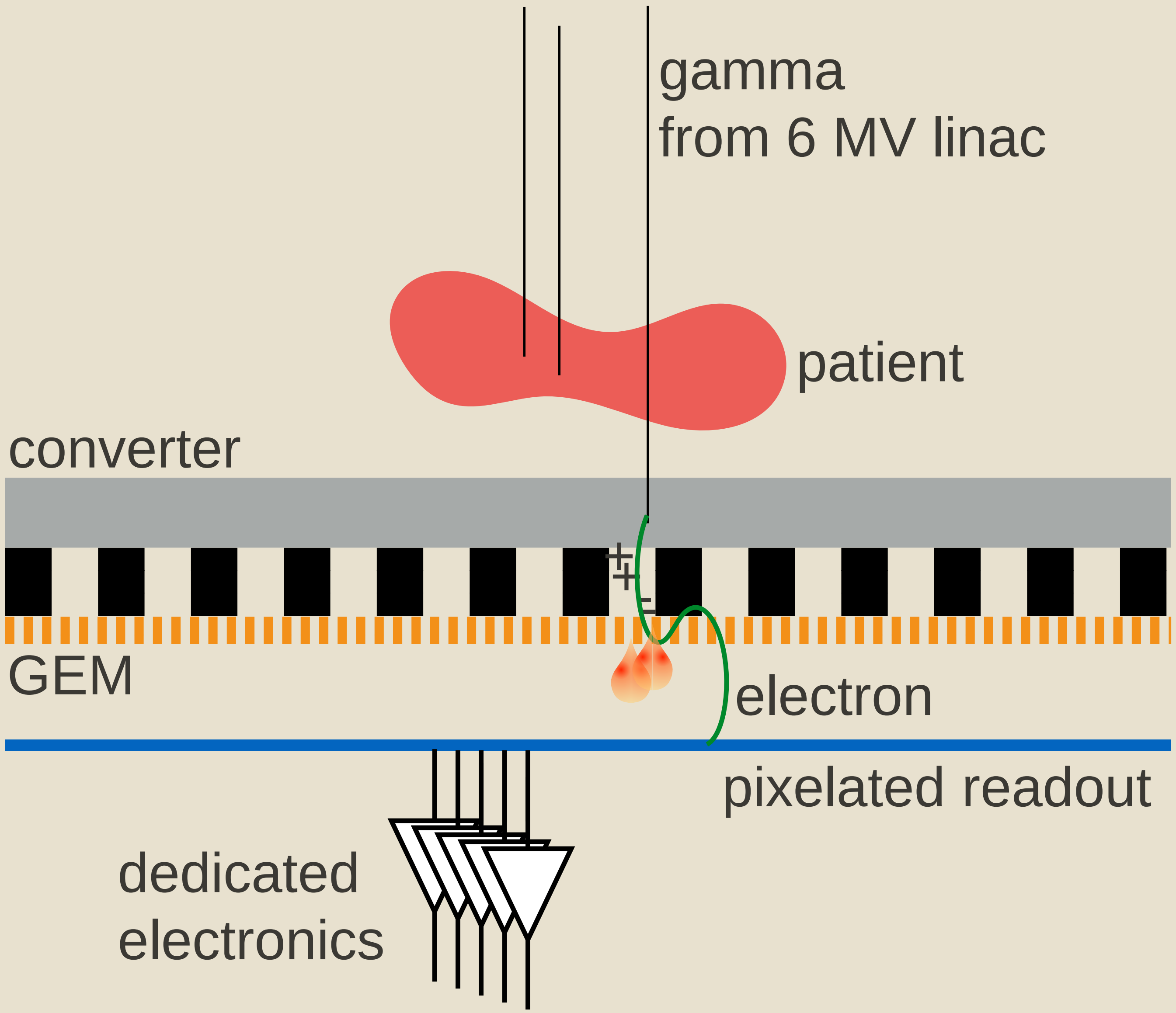
Goals of the development:
- superior radiation hardness
- dose rate independence
- dose linearity
- zero ghosting

C-RAD GEMINI

C-RAD: Swedish company developing and commercialising the detector

GEMs ensures high flux capability, linear response and radiation tolerance

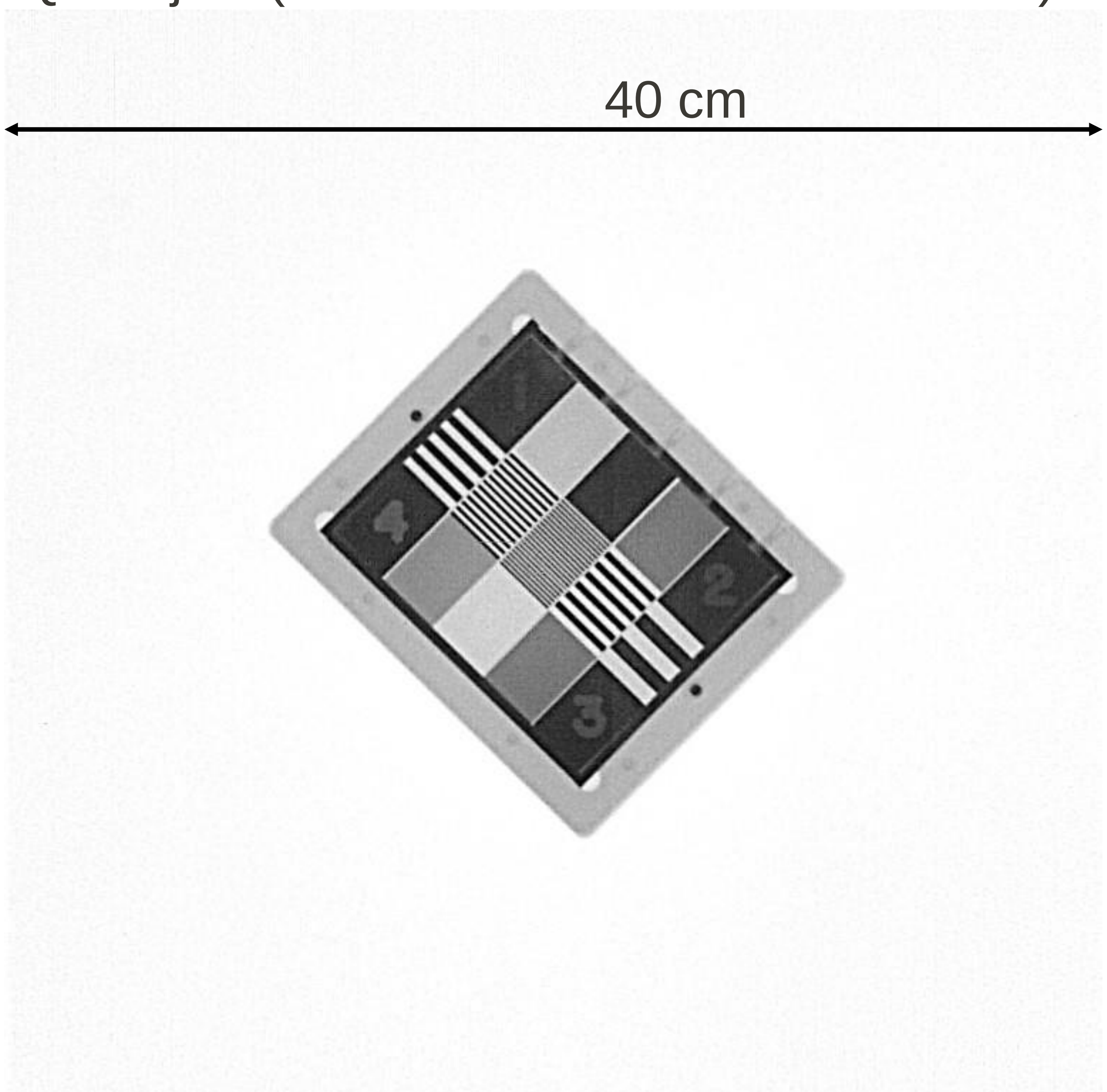




C-RAD GEMINI

6 MV linac, 1.5 MeV average gamma energy, 3 MU dose

QA object (resolution and contrast measure)



Pelvic phantom

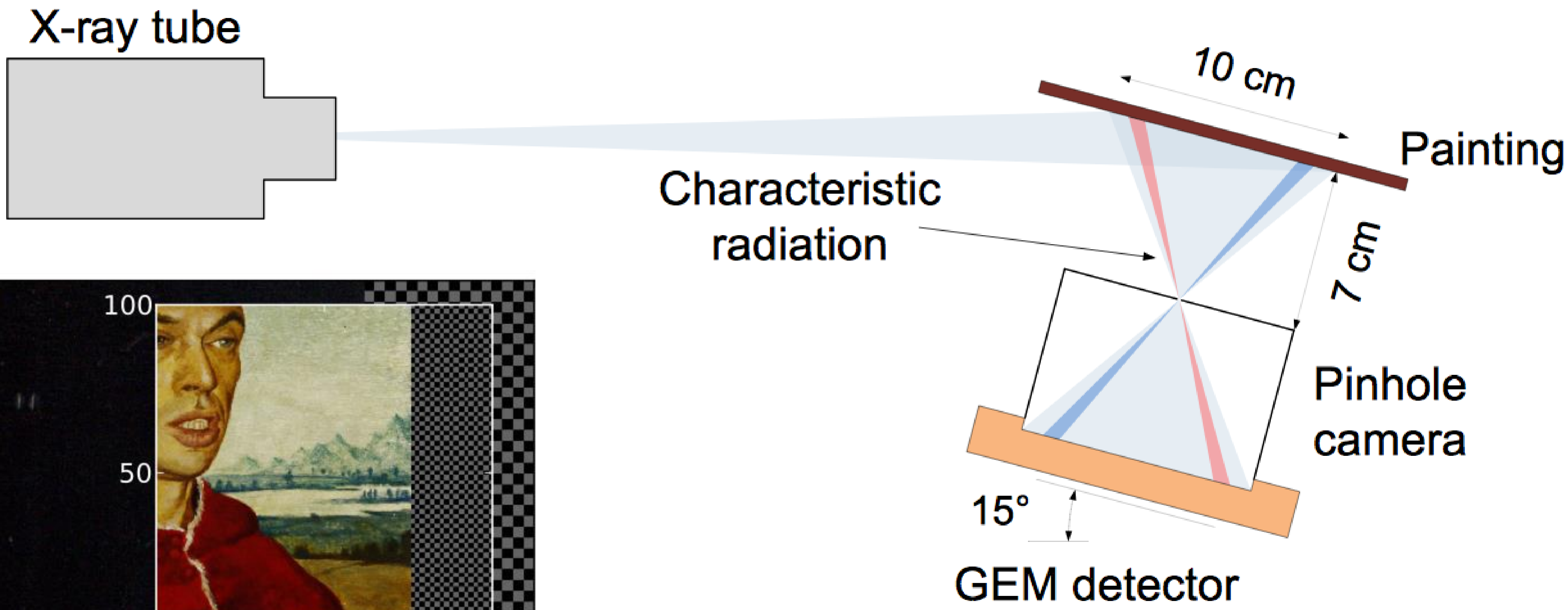
X-ray fluorescence

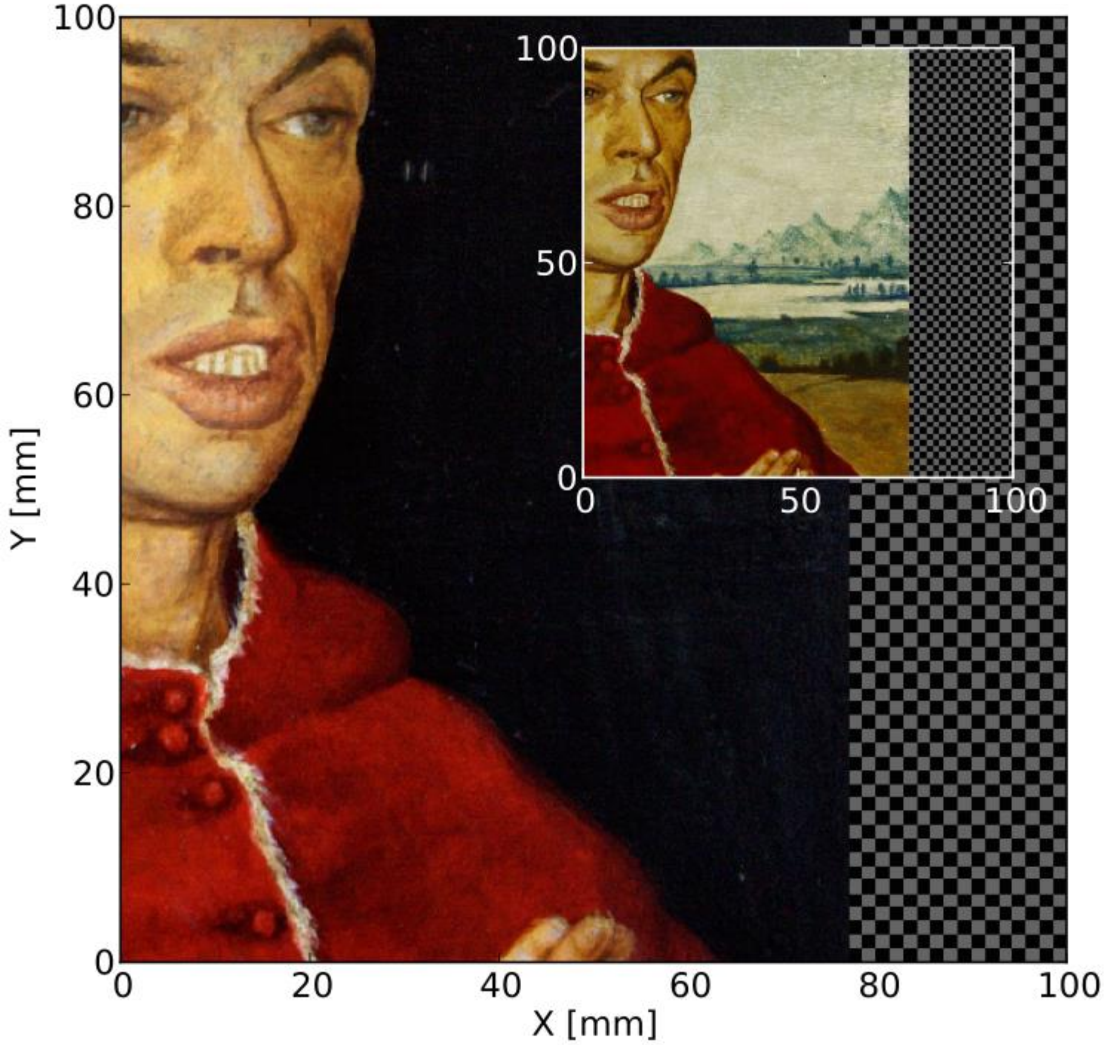
X-ray fluorescence can be used to unveil underlying paintings. Large surface can be achieved by scanning with extraordinary energy and position resolution.

Three main concerns:
- dangerous to move precious masterpieces
- dangerous to have moving parts near the masterpieces
- long time to scan

X-ray fluorescence

XRF imaging system for fast mapping of pigment distributions in cultural heritage paintings

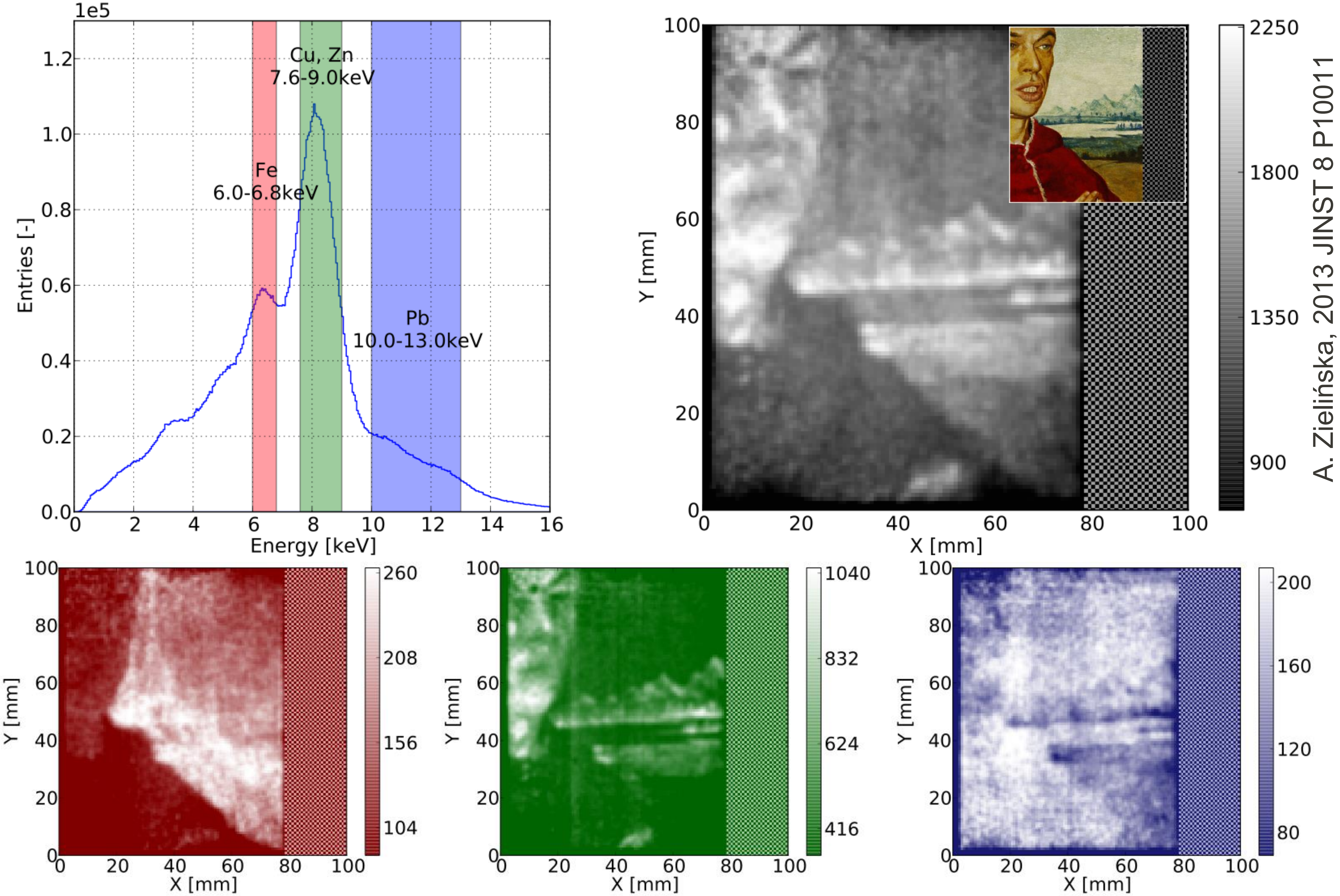




A. Zielińska, 2013 JINST 8 P10011

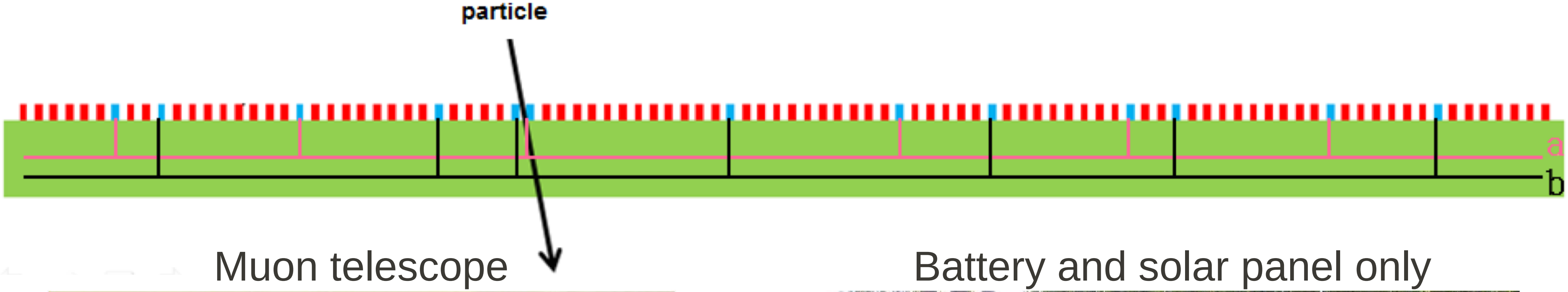
- Position and energy sensitive method
- No position scan required
- The system can be brought to the museum

X-ray fluorescence



MM Multigen 2D

Autonomous detector operation outside the laboratory: power consumption is a main issue.
Reduce the number of electronic channels with *genetic* multiplexing 1024 strips -> 61 channels

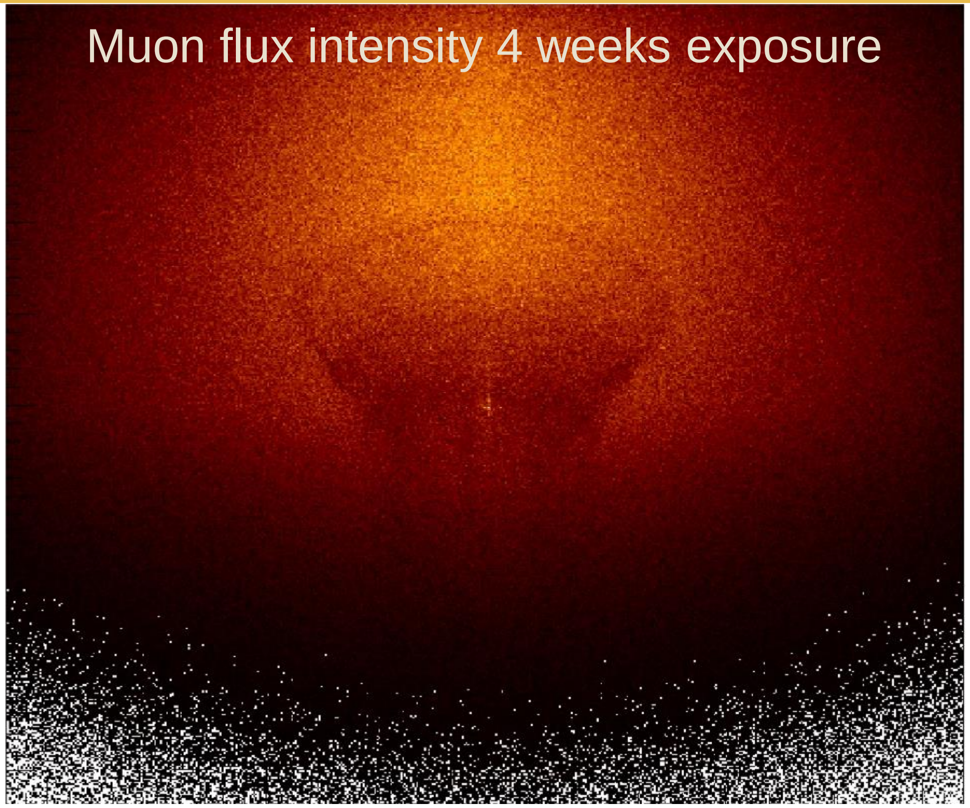


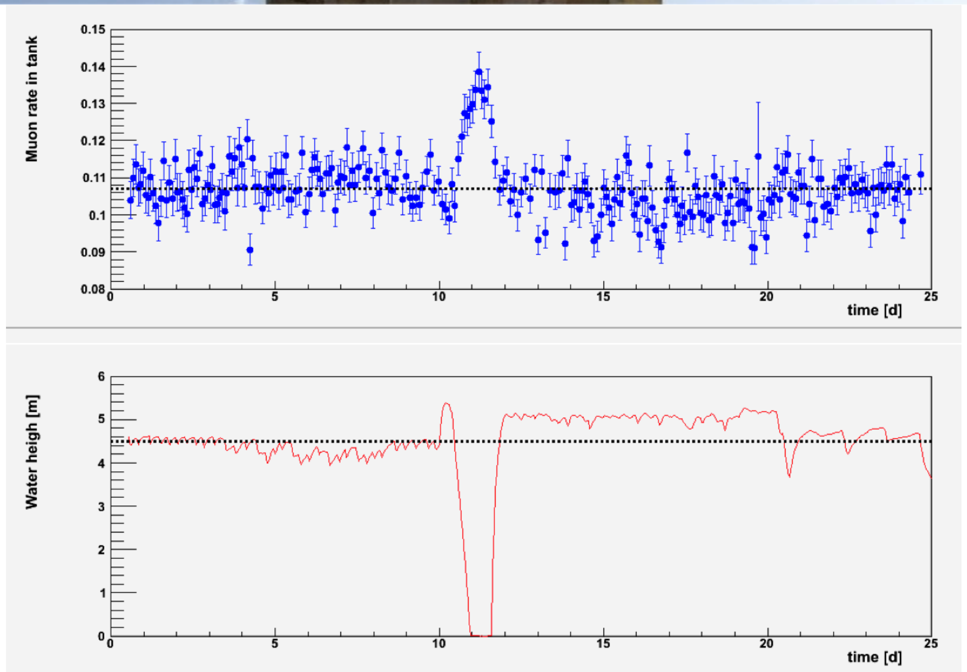
Muon telescope

Battery and solar panel only

S. Bouteille *et al.*, MPGD2015 contribution
https://indico.cern.ch/event/451078/contributions/1113856/attachments/1171977/1692457/RD51_SBouteille.pdf

MM Multigen 2D





Muon tomography of a water tower

Dynamic study of the water content

S. Bouteille *et al.*, MPGD2015 contribution
https://indico.cern.ch/event/451078/contributions/1113856/attachments/1171977/1692457/RD51_SBouteille.pdf

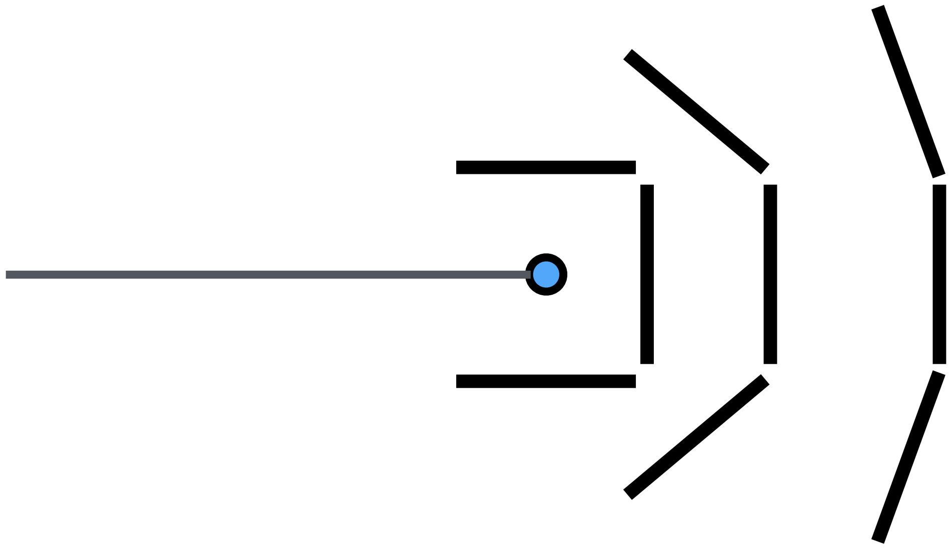
MM Multigen 2D

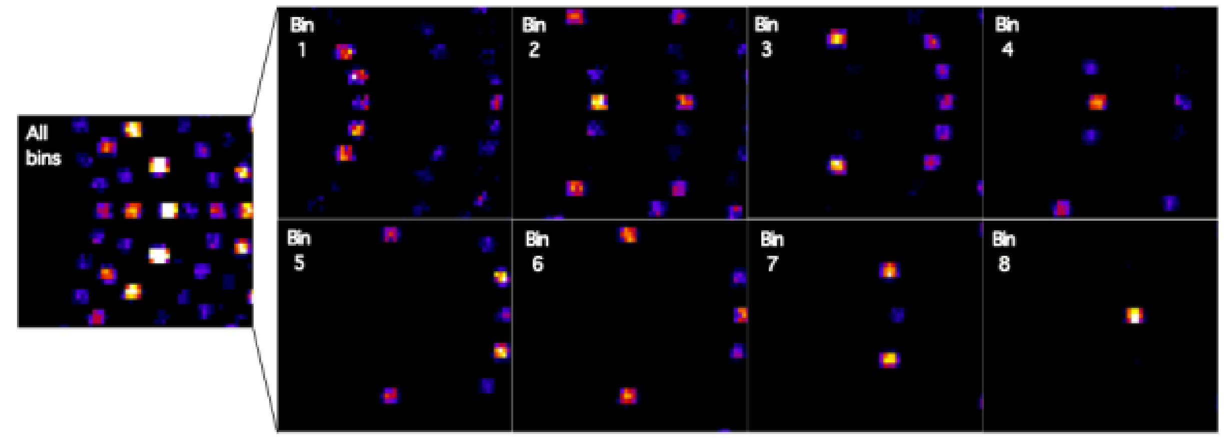
Muon tomography of the Cheops Pyramid is ongoing

S. Procureur *et al.*, 2016 RD51 Collaboration Meeting
https://indico.cern.ch/event/532518/contributions/2195610/attachments/1286182/1913223/2016-06-07_-_RD51.pdf

NMX at ESS

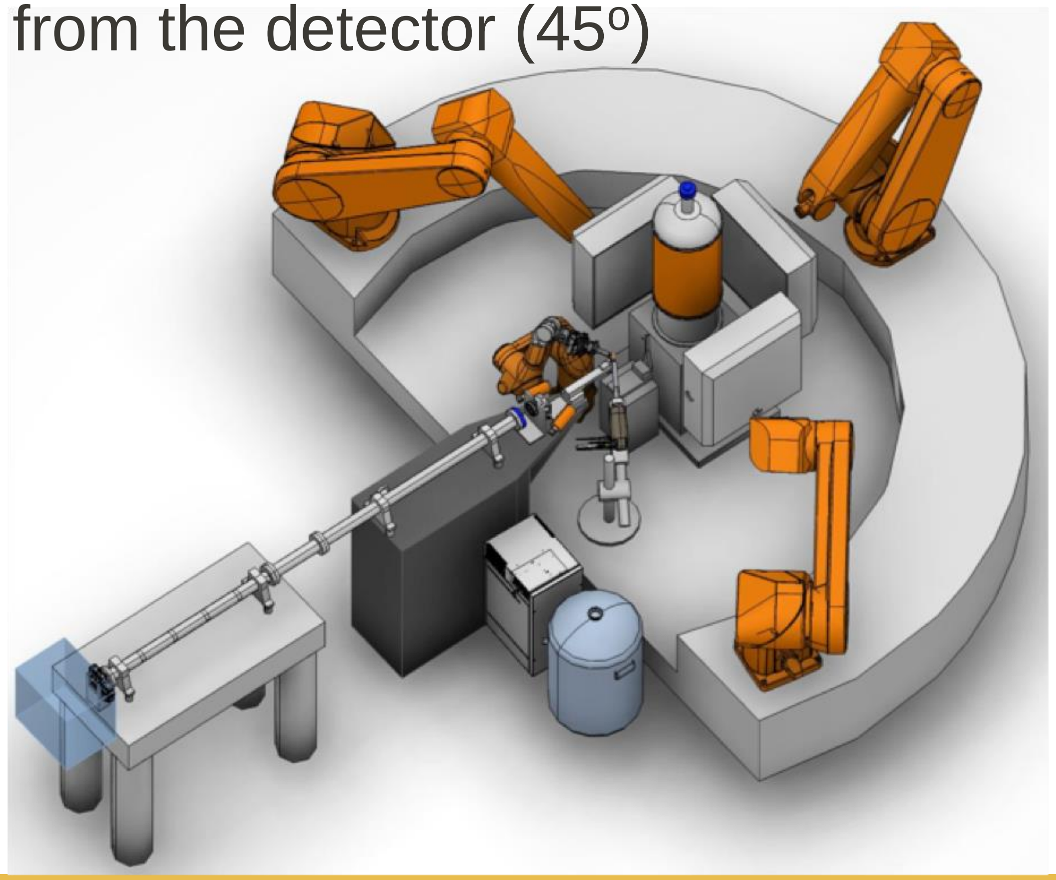
Neutron Macromolecular Crystallography instrument at ESS





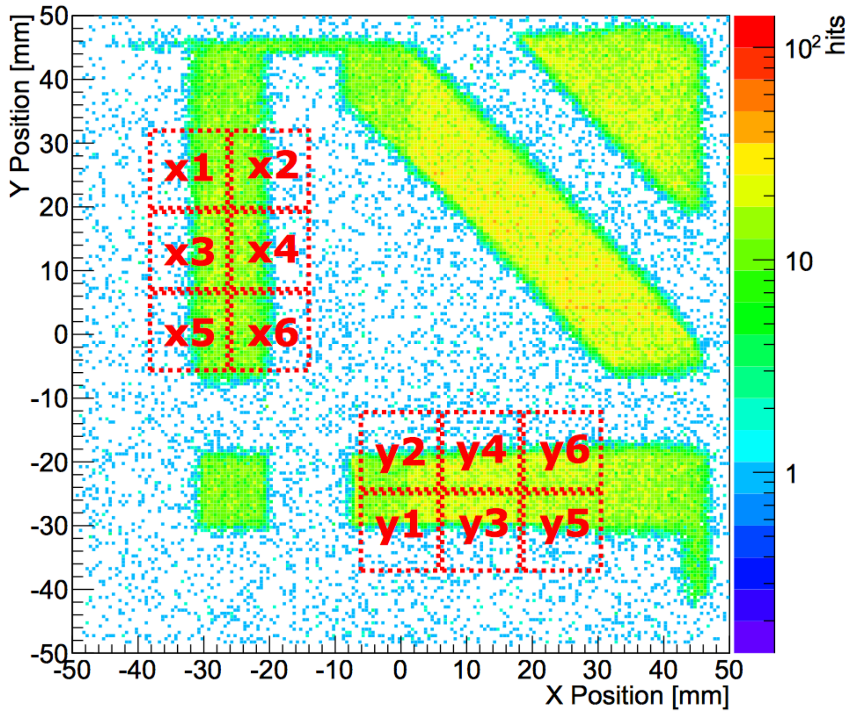
Time binned diffraction pattern (simulation) from a 5 mm crystal of perdeuterated rubredoxin at 20 cm from the detector (45º)

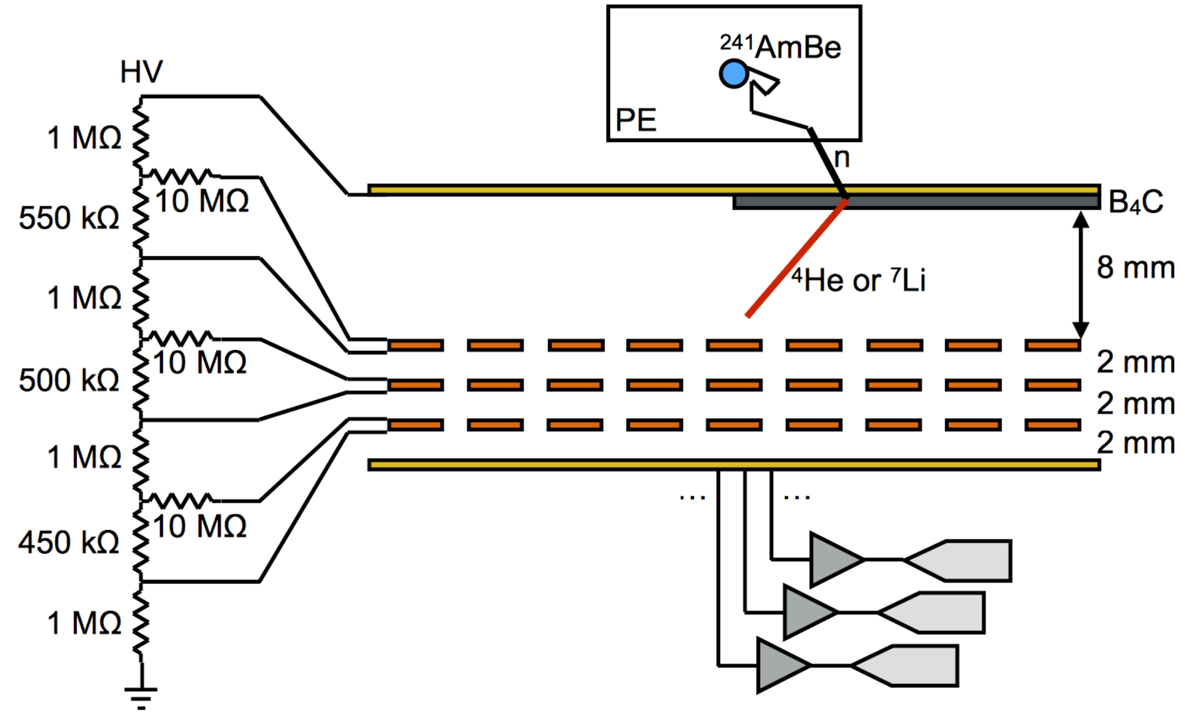
Detector requirements:
- 3x 60x60 cm^2 movable
- 20-100 cm operation distance
- time resolved (tens of us)
- <500 um X&Y spatial resolution
- <100 kHz/mm^2 local flux
- ~20% efficient
- γ rejection not critical

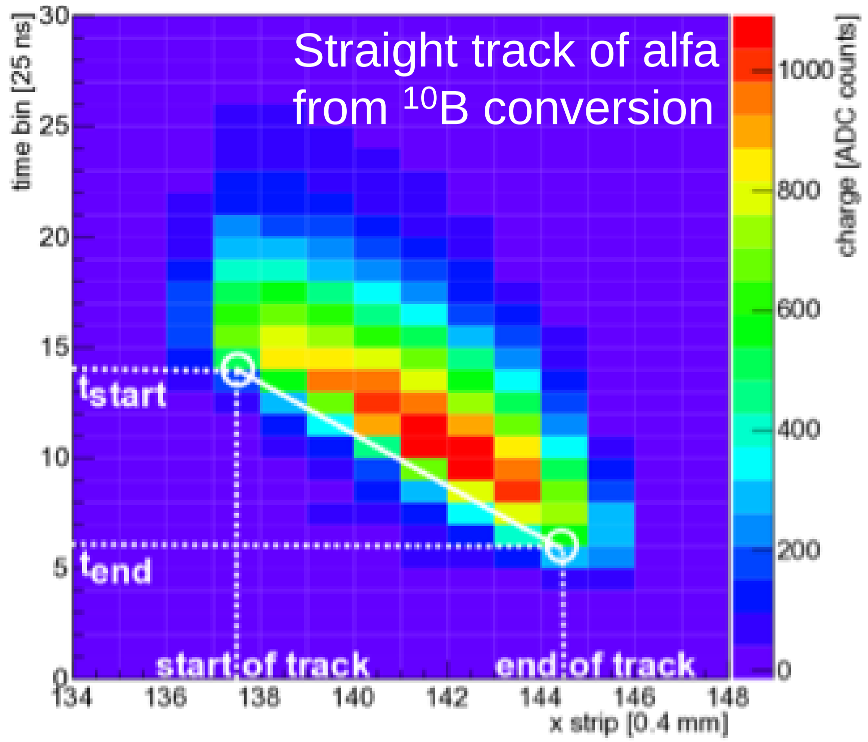


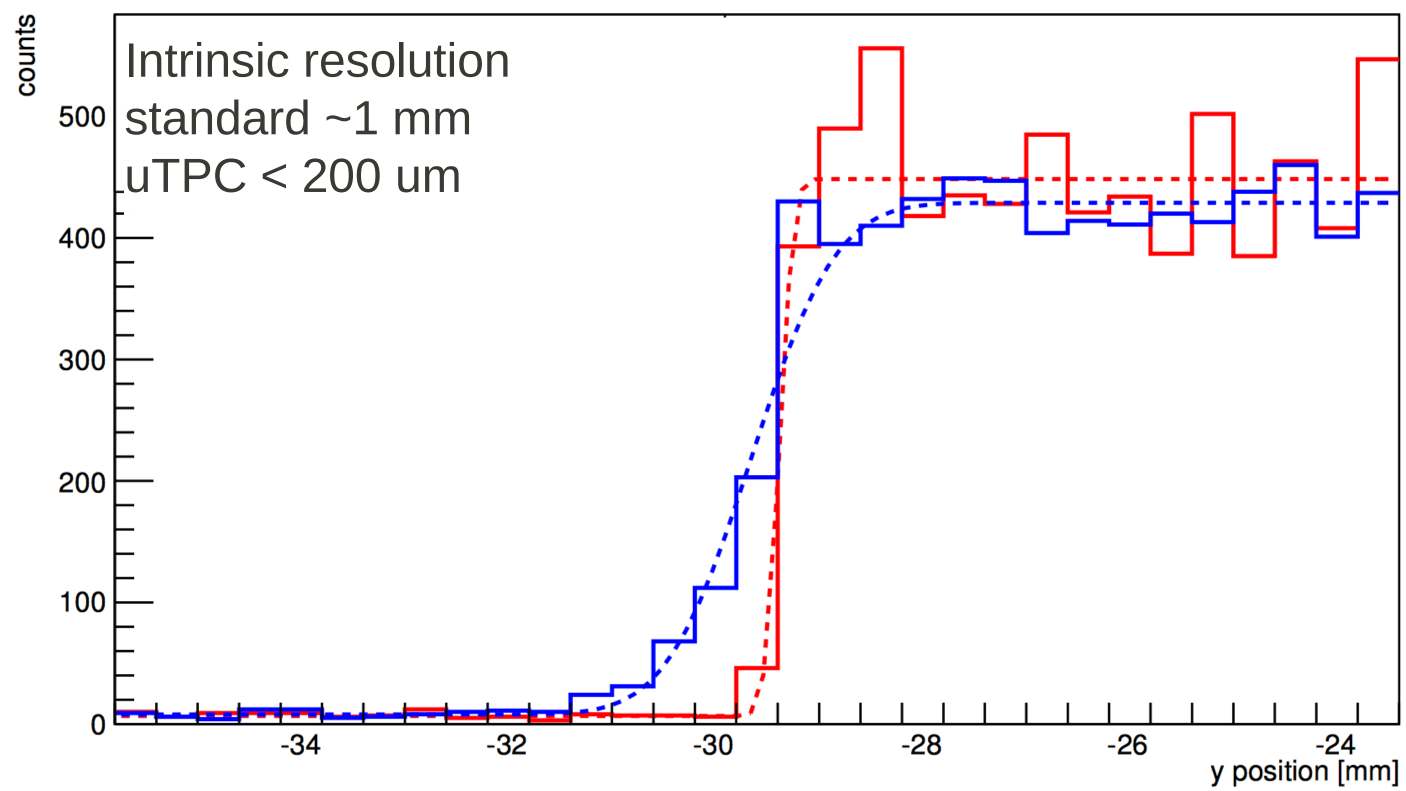
B-GEM & uTPC concept

D. Pfeiffer *et al*., JINST 10 (2015) P04004



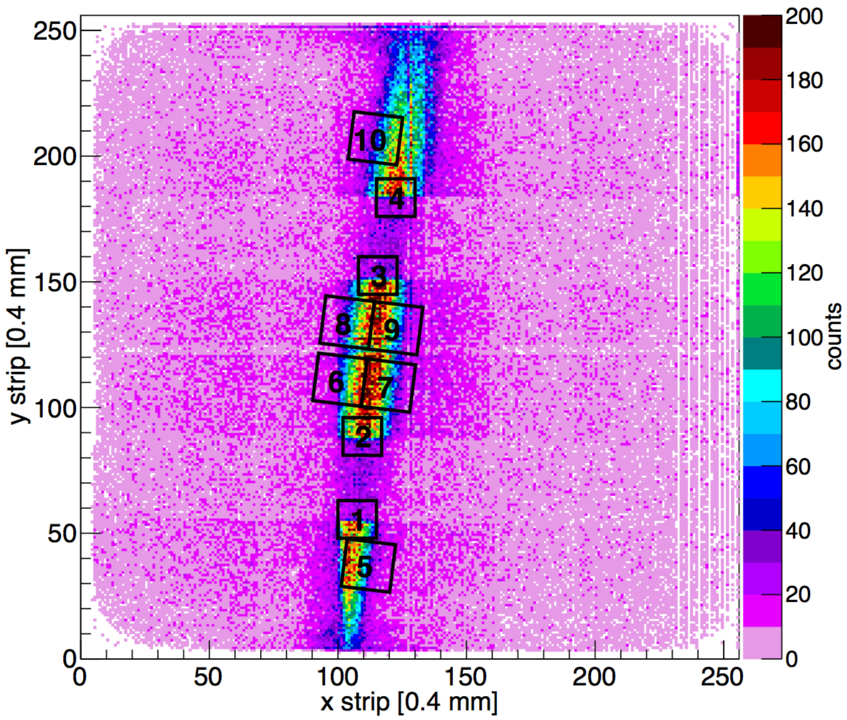






Gd-GEM & uTPC concept

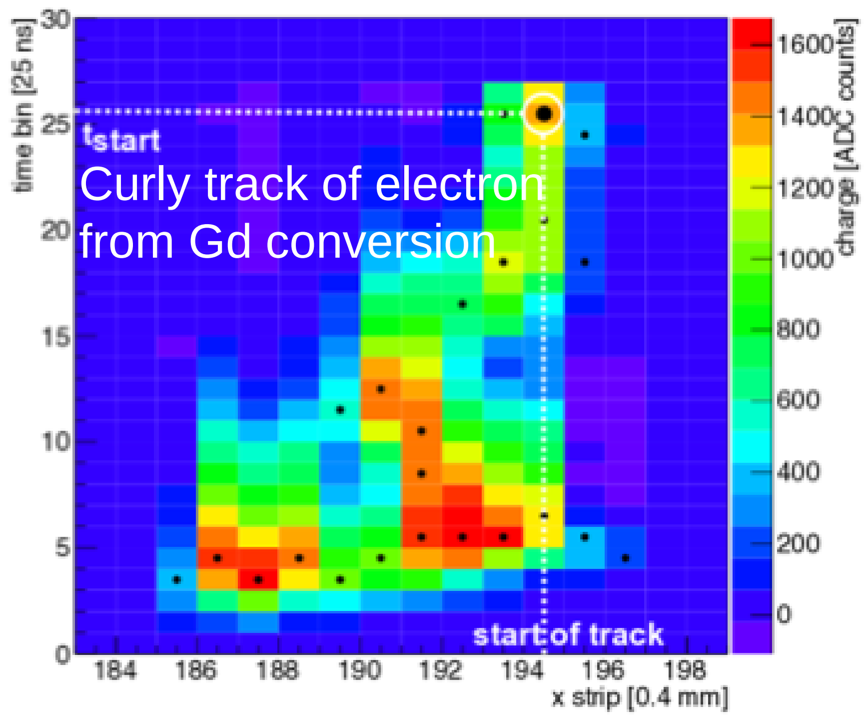
D. Pfeiffer *et al.*, JINST 11 (2016), P05011

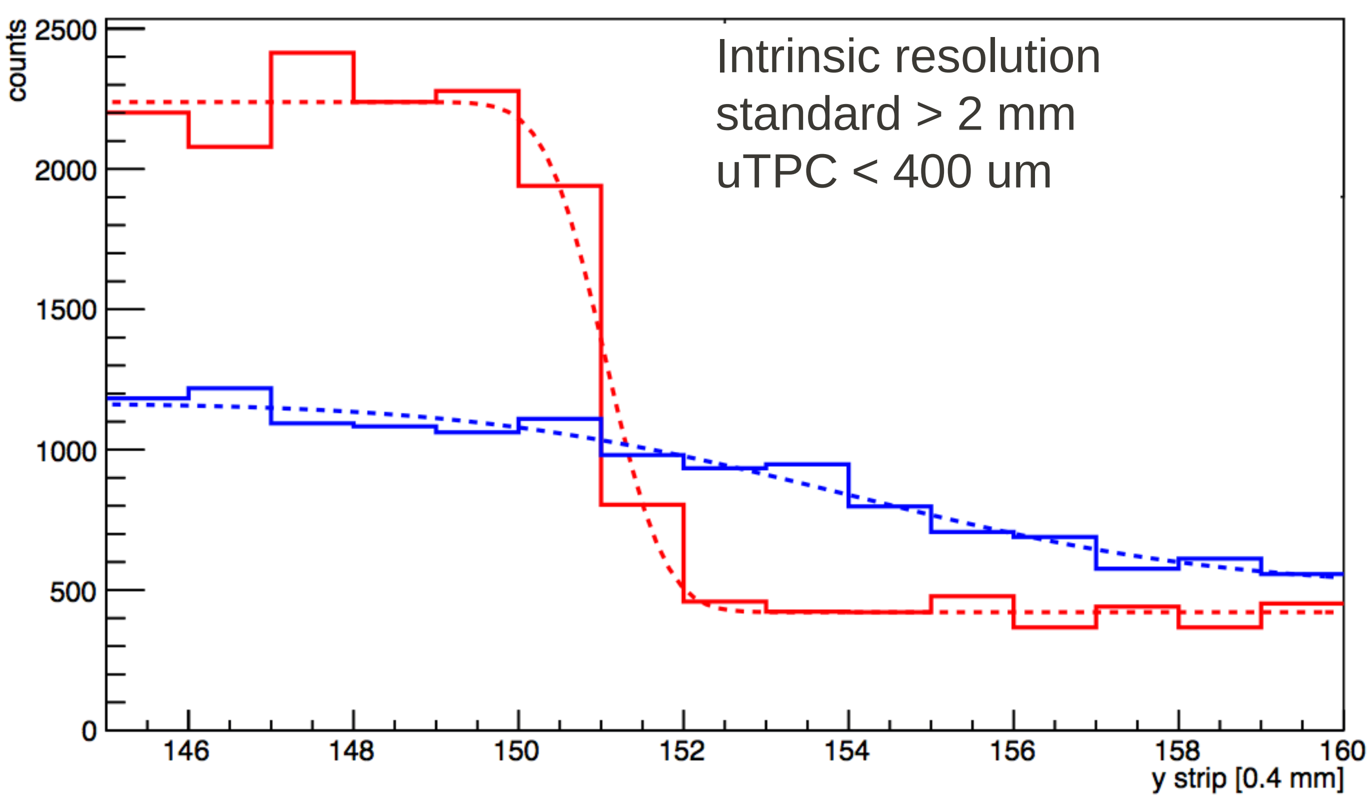


Larger absorption cross section of gadolinium enables the development of more efficient (*O*(15%)) detectors.

$^{X}Gd + n \rightarrow {}^{X+1}Gd^{+} + e^{-}$

Reconstruction of the curly tracks of the electron is more challenging, but the start of the track is well recognisable.





Other type of amplification

Almost unavoidably light is produced during charge avalanche.

Depending on the gas mixture, the scintillation can be copious and at the *right* wavelength.

Not many gas mixtures scintillate in the visible window, for which most of the light sensors are optimised.

CF_4 is one of them and noble gases with CF_4 admixtures are effective scintillators.

Light yield comparison
- common scintillator as NaI(Tl): ~40 ph/keV
- GEMs in Ar/CF4 (80/20) at a gain of 10^5: ~10^6 ph/keV

Optical readout

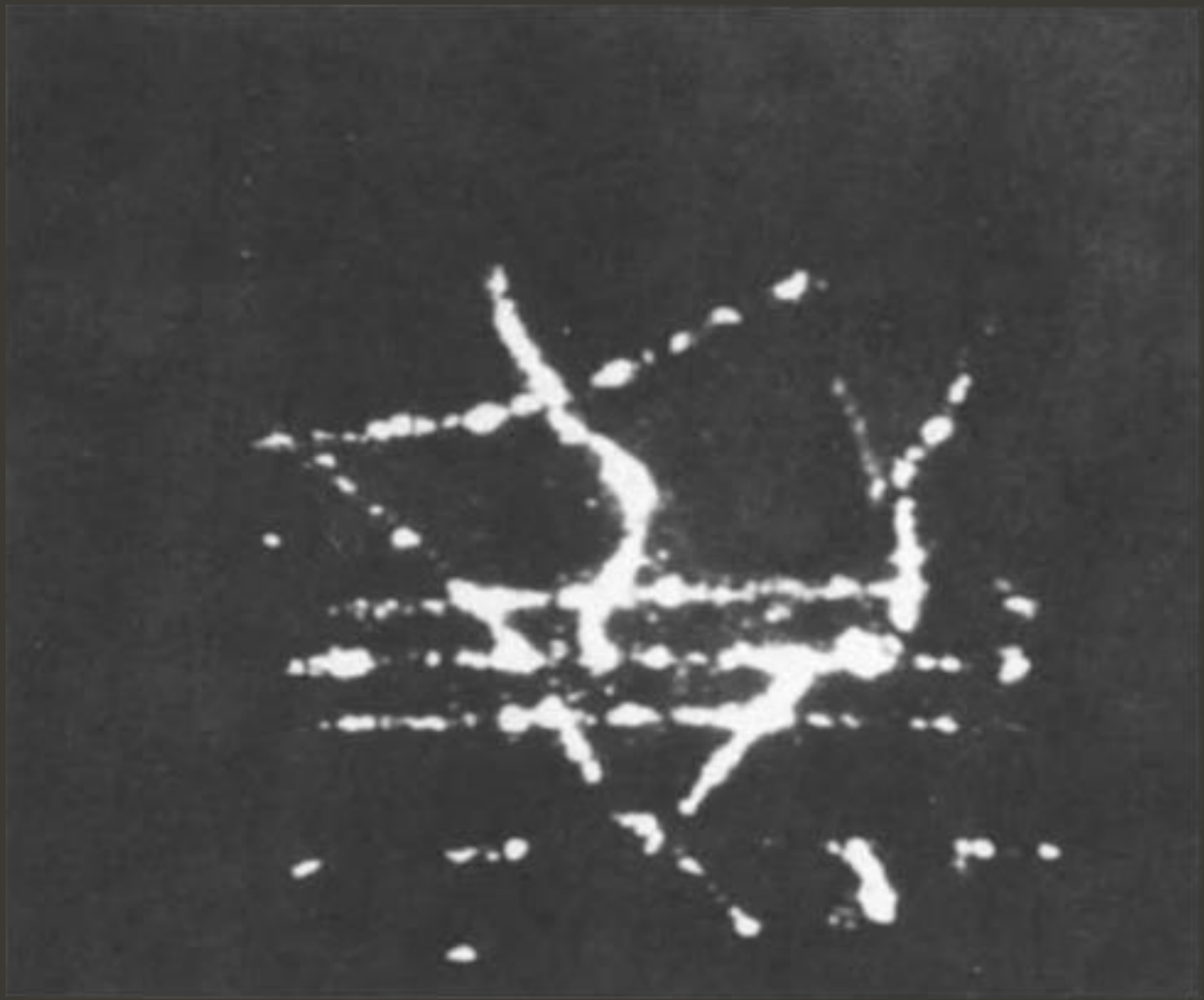
Record the light emitted during the Townsend avalanche with a camera using the detector as a scintillating plate

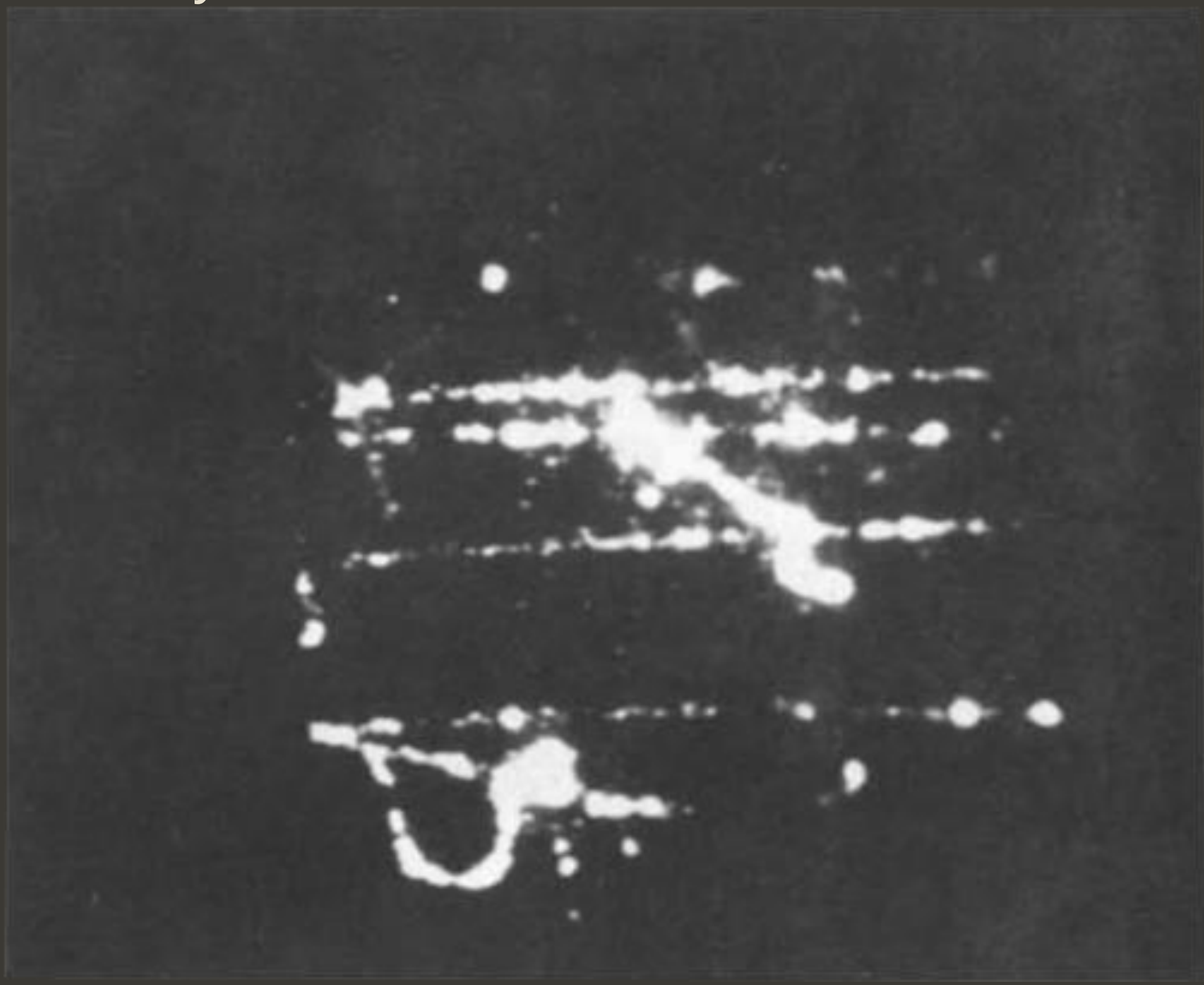
Advantages:
- Simplicity, like taking a picture
- Robustness, as a device off-the-shelf
- Versatility, several uses and environments

Only the techniques are new

Parallel mesh chamber filled with $Ar/CH_4/TEA$ 80%/8%/2% seen through an image intensifier and a camera

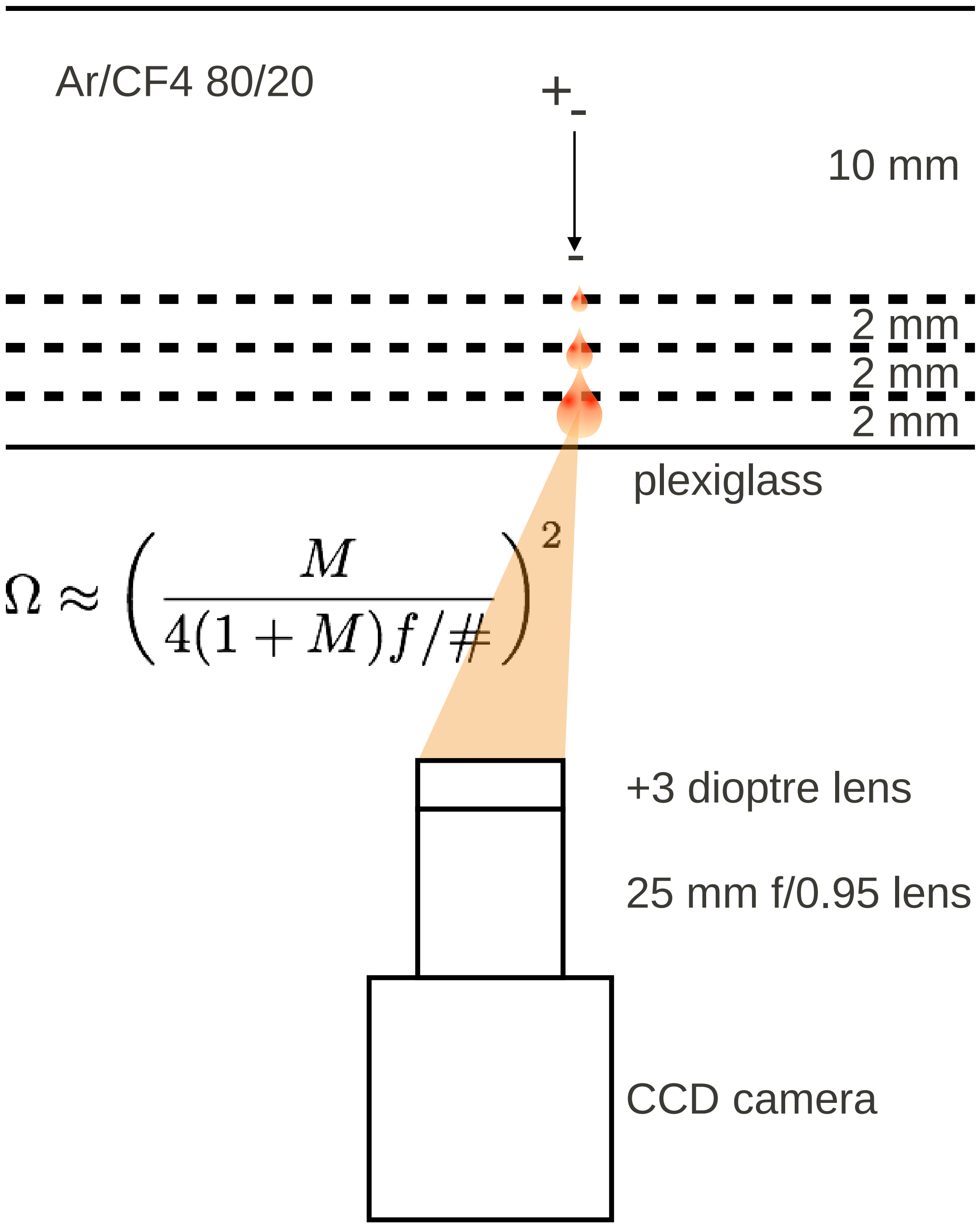
Muons and delta rays



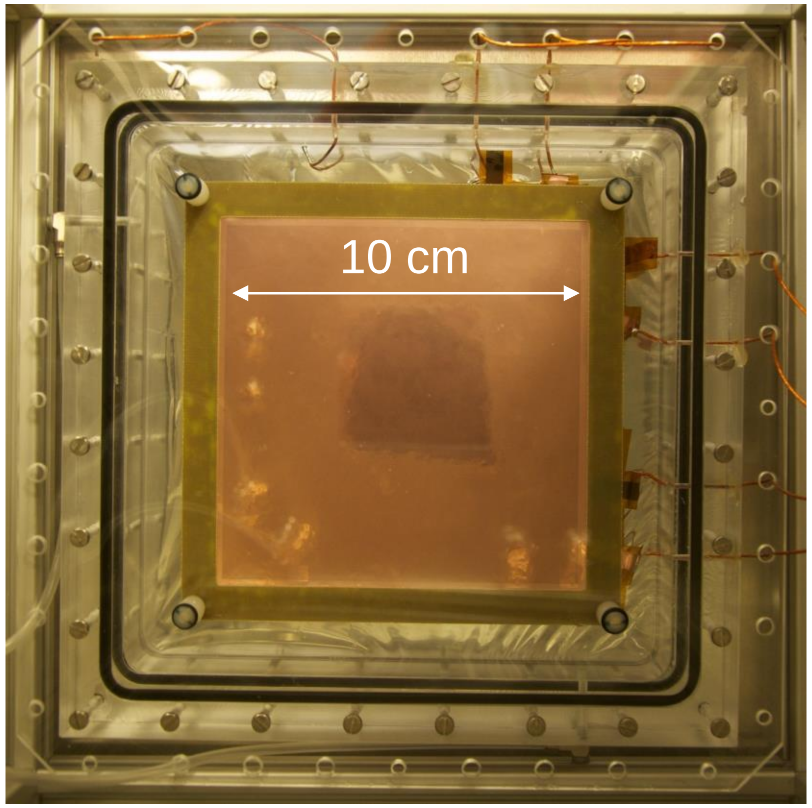


G. Charpak *et al*., NIM A258 (1987) 177

The setup



$$\Omega \approx \left(\frac{M}{4(1+M) f/\#} \right)^2$$

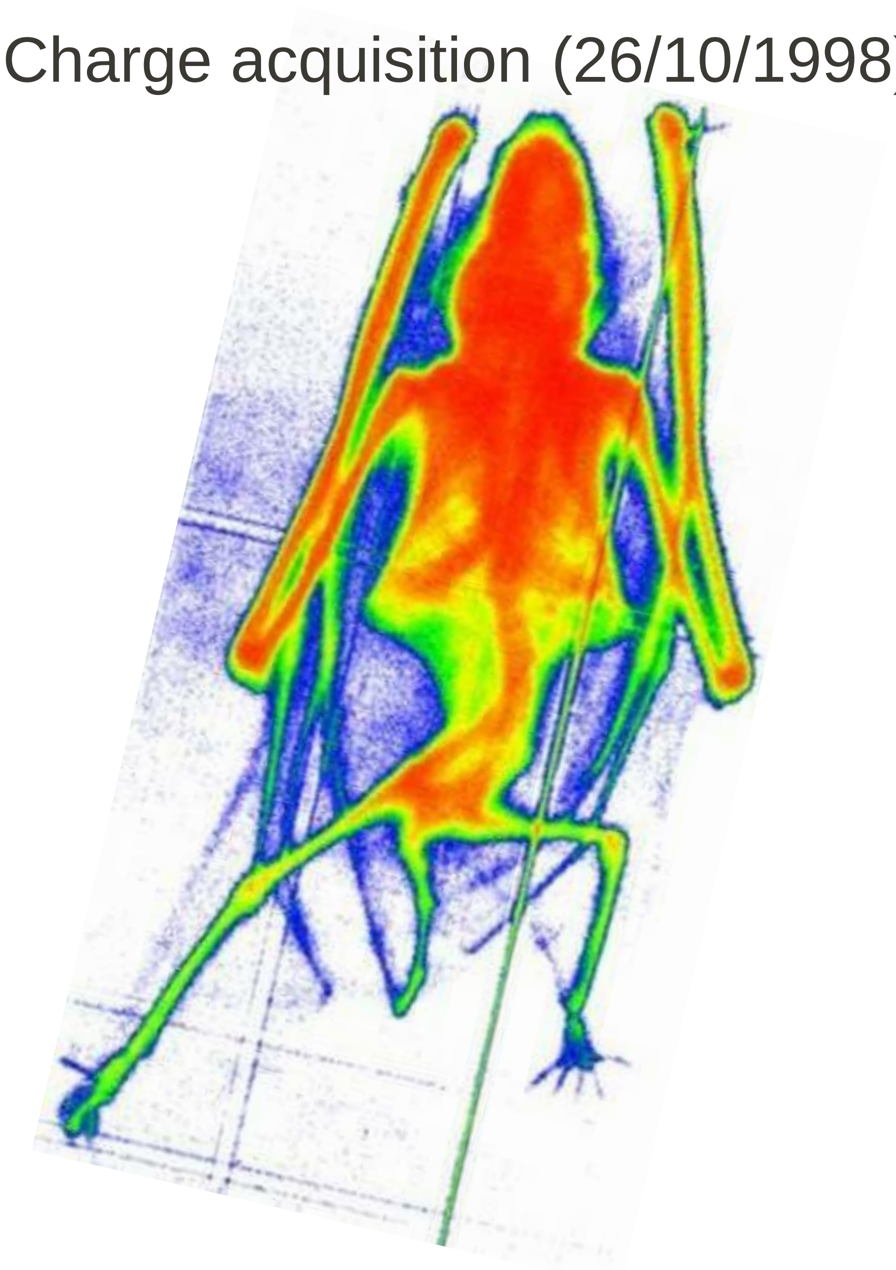


M = sensor size / image size
M ~ 0.1 -> Ω ~ 5x10-4
This implies:
large sensor, low noise,
fast lens and a lot of light

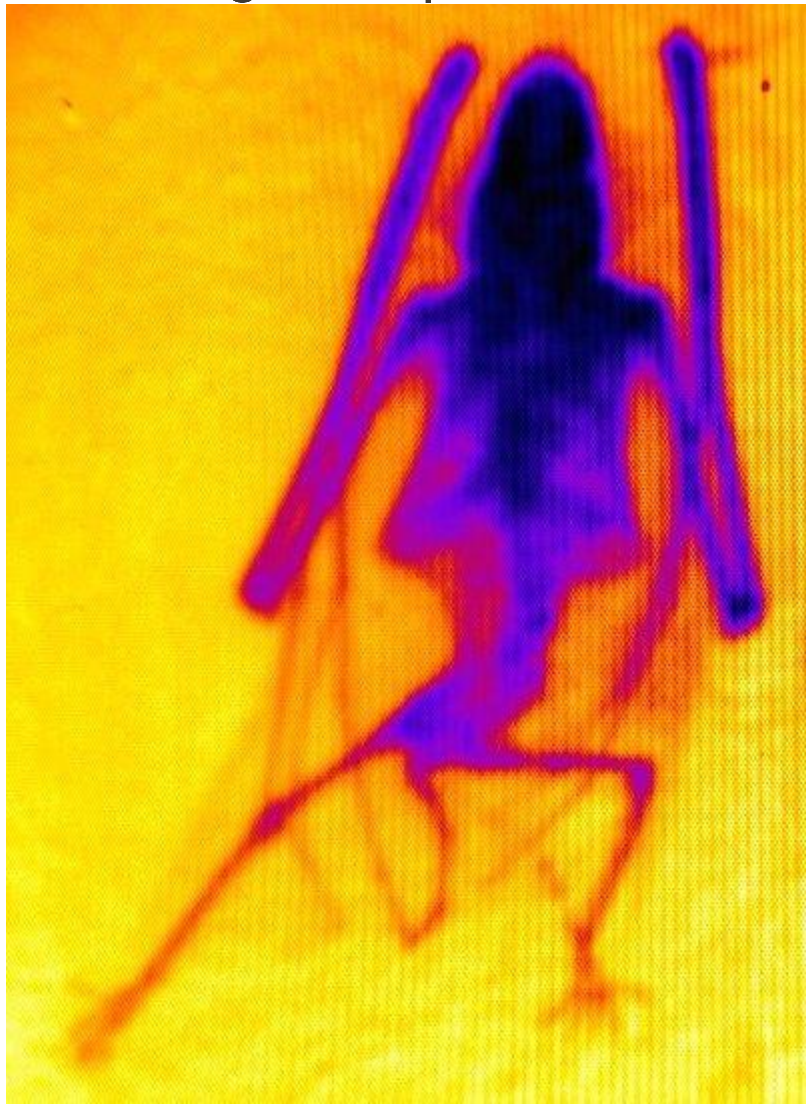
X-ray images

X-ray tube with W target at 20 kV - 40 kV at few mA

Charge acquisition (26/10/1998)



Light acquisition

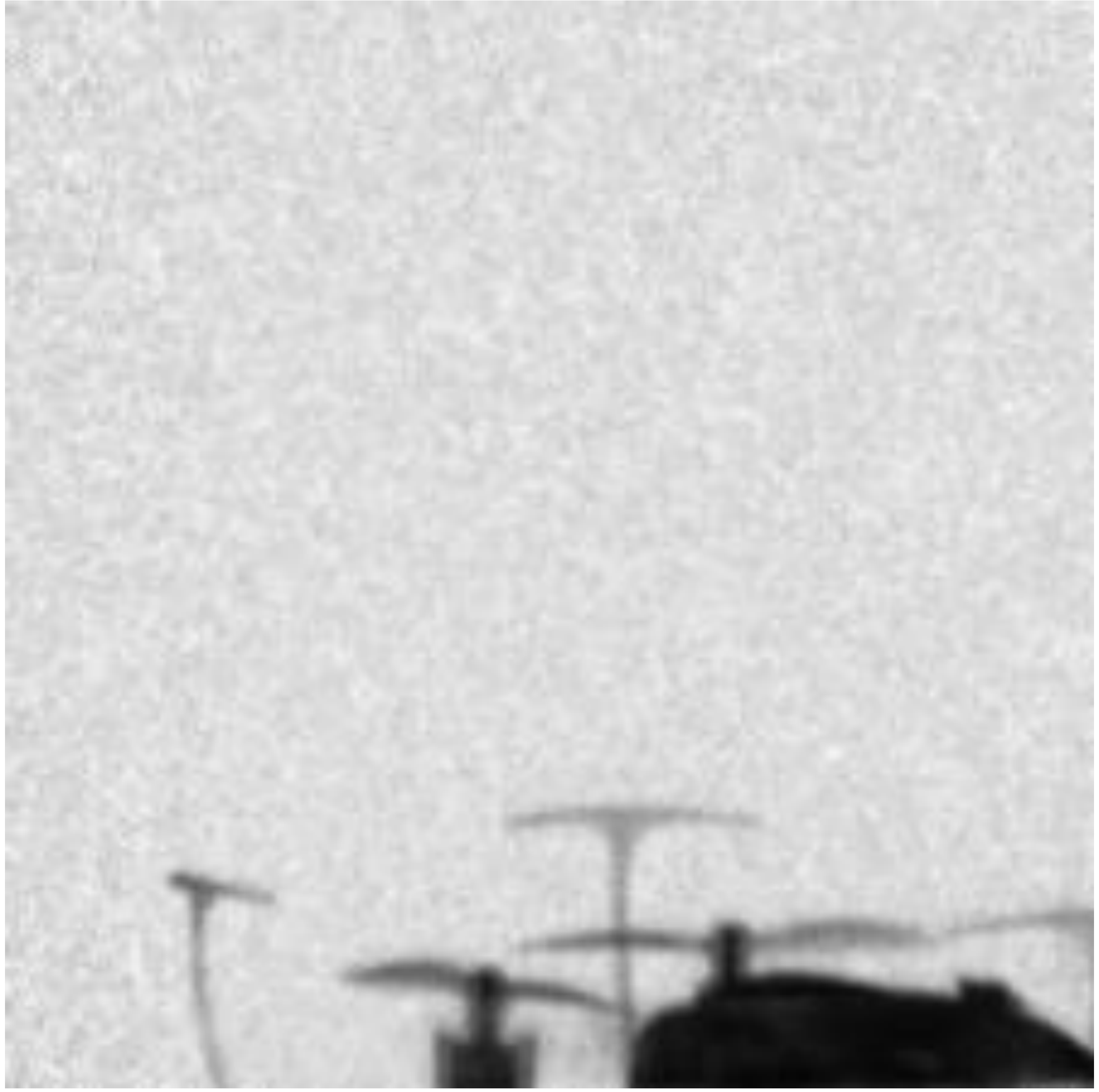


~7 cm

Raw data:
fast (<1 s) acquisition
and no processing time

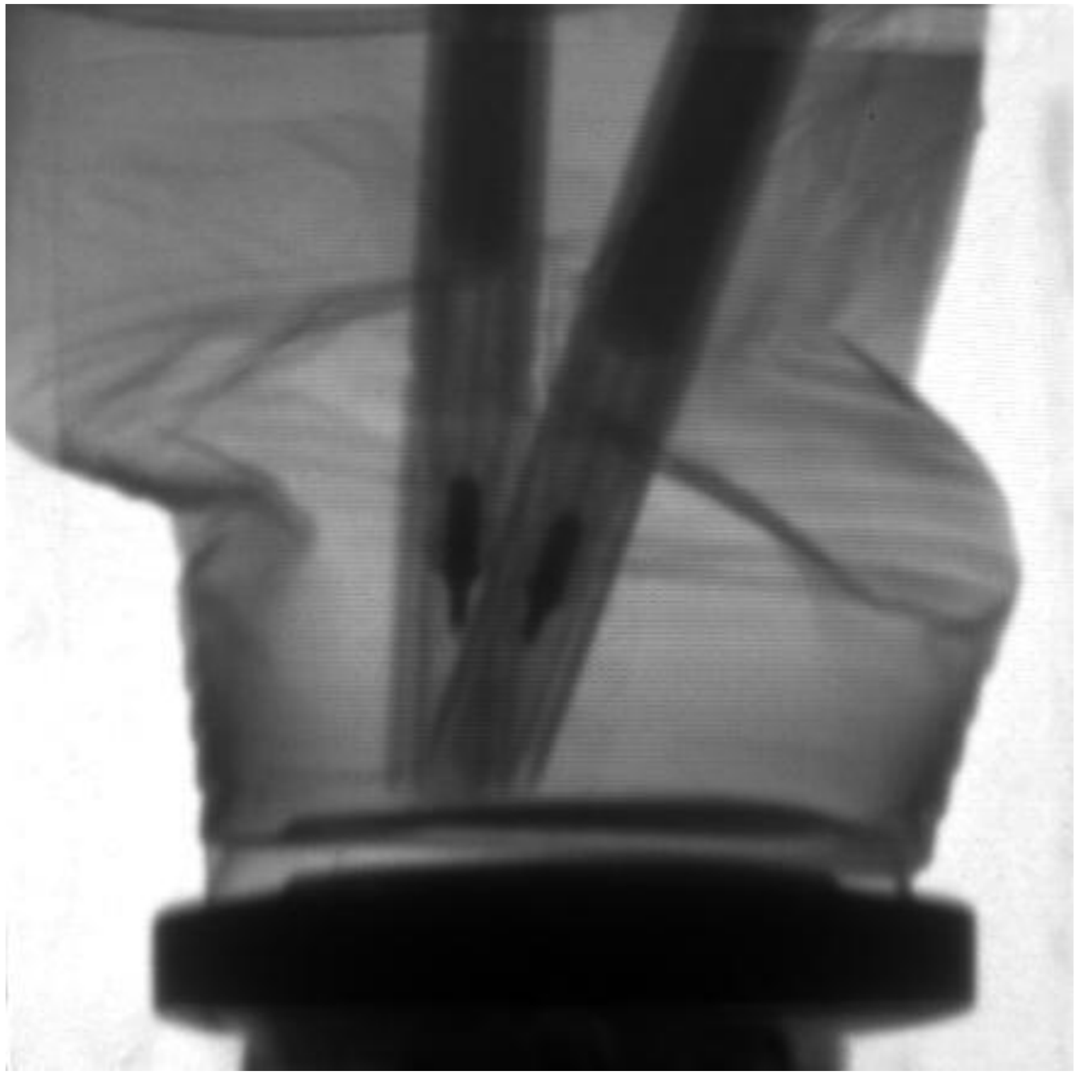
Fluoroscopy

50 ms exposure
10 Hz acquisition

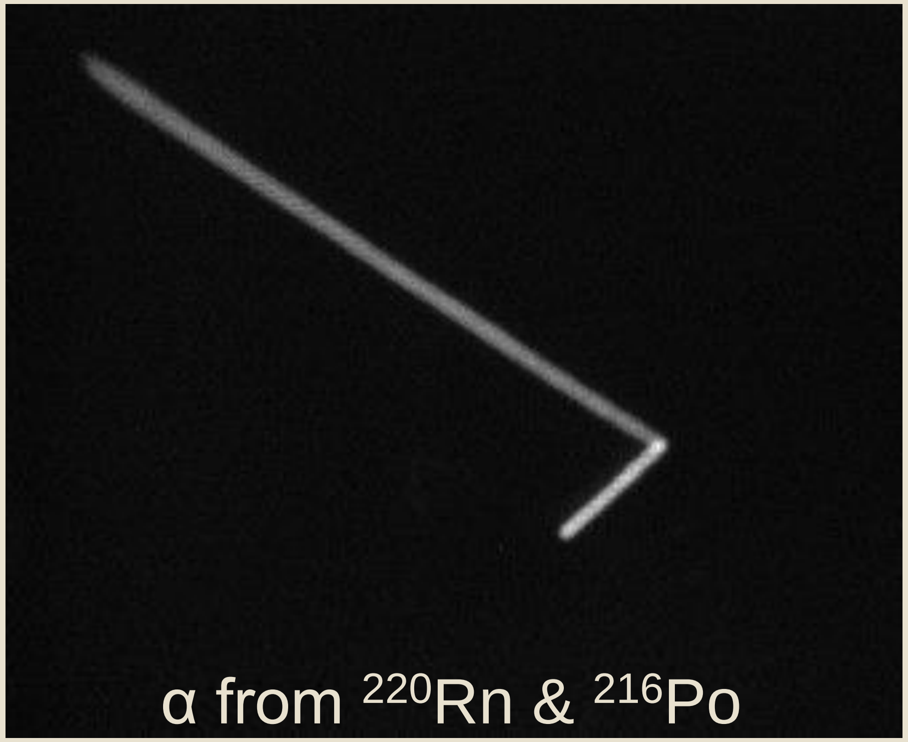


CT and 3D imaging

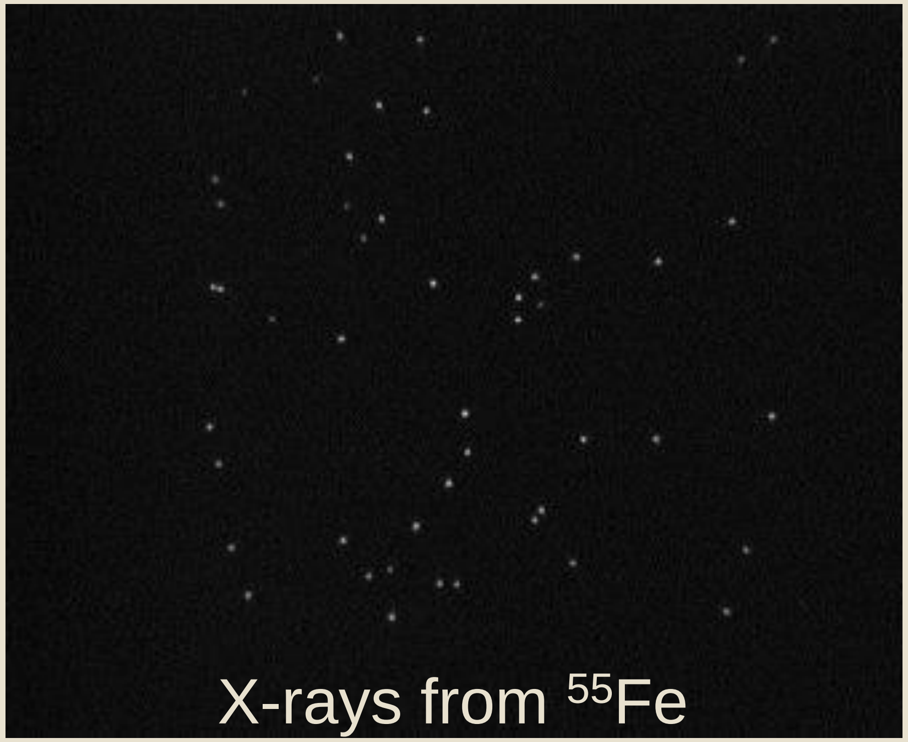
Image -> Sinograms -> Filtered Back Projection -> 3D image



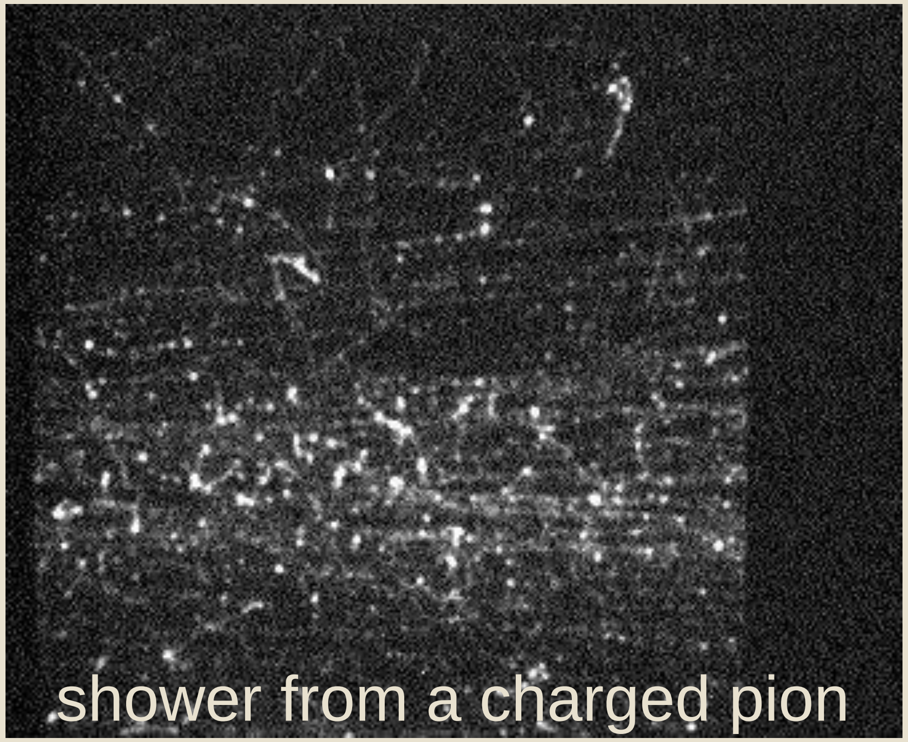
Single events



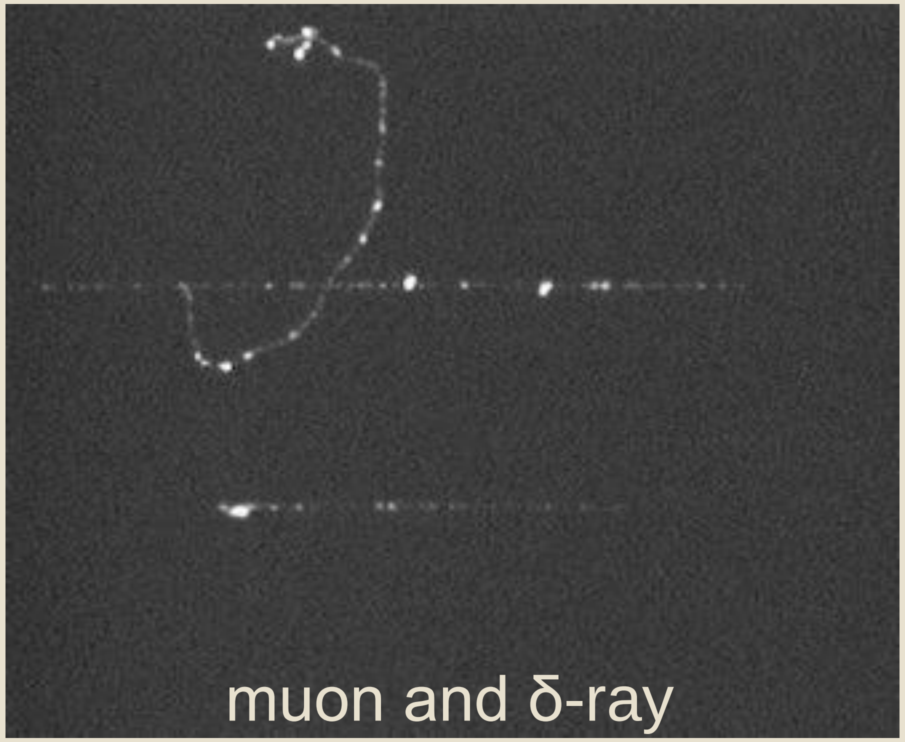
α from ^{220}Rn & ^{216}Po



X-rays from ^{55}Fe



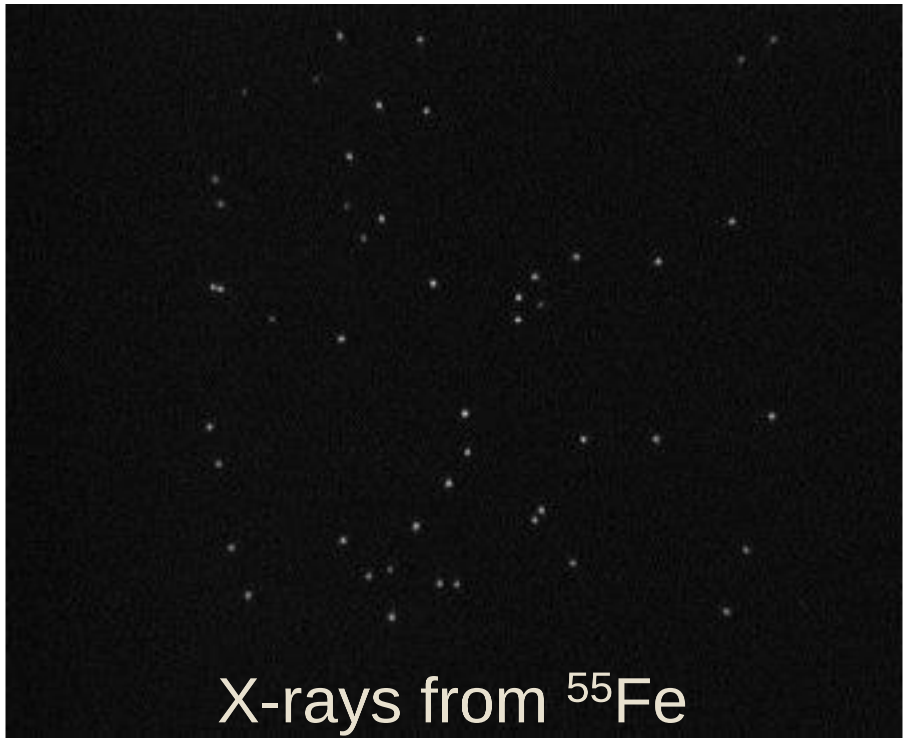
shower from a charged pion

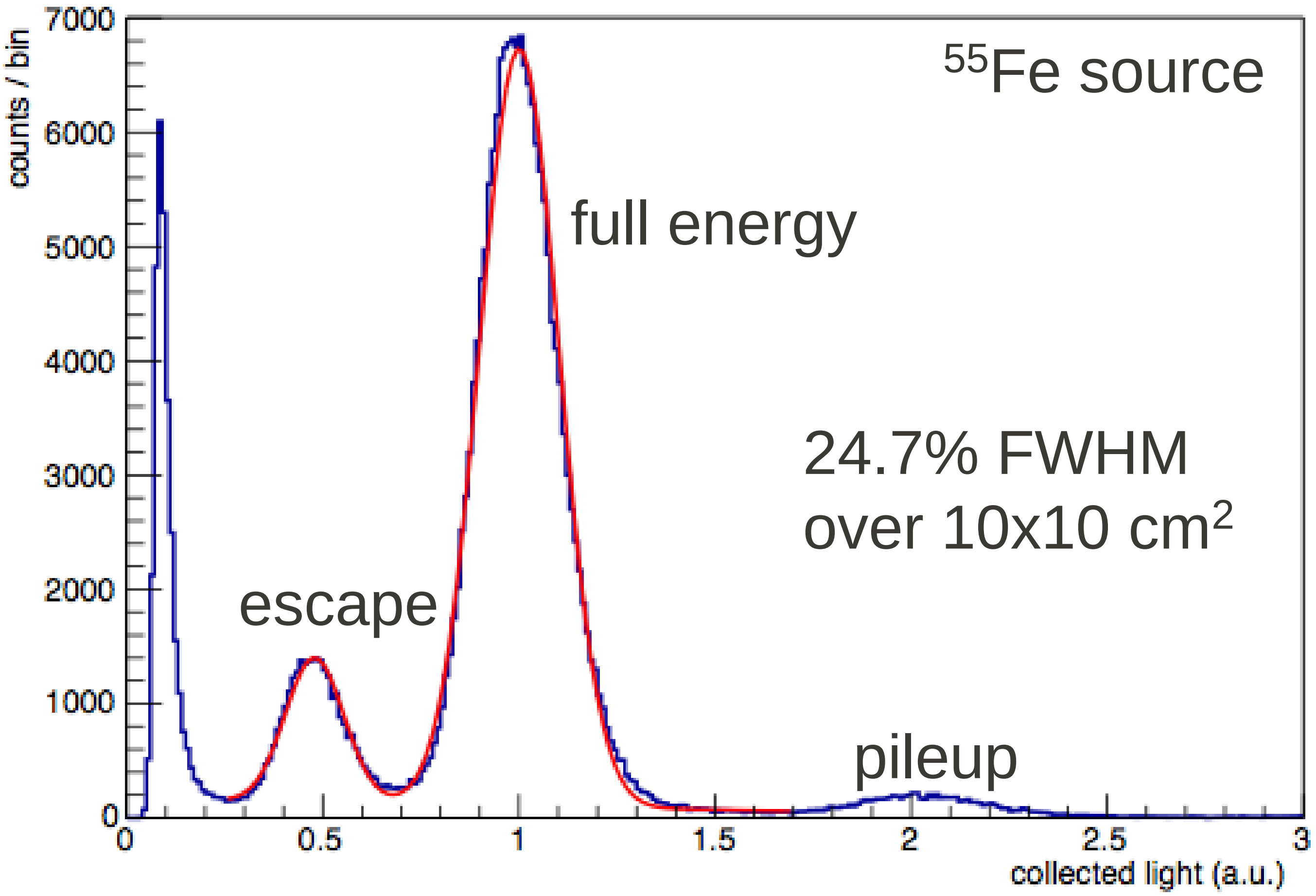


muon and δ-ray

For hours in sealed mode at test beam

Quantitative analysis

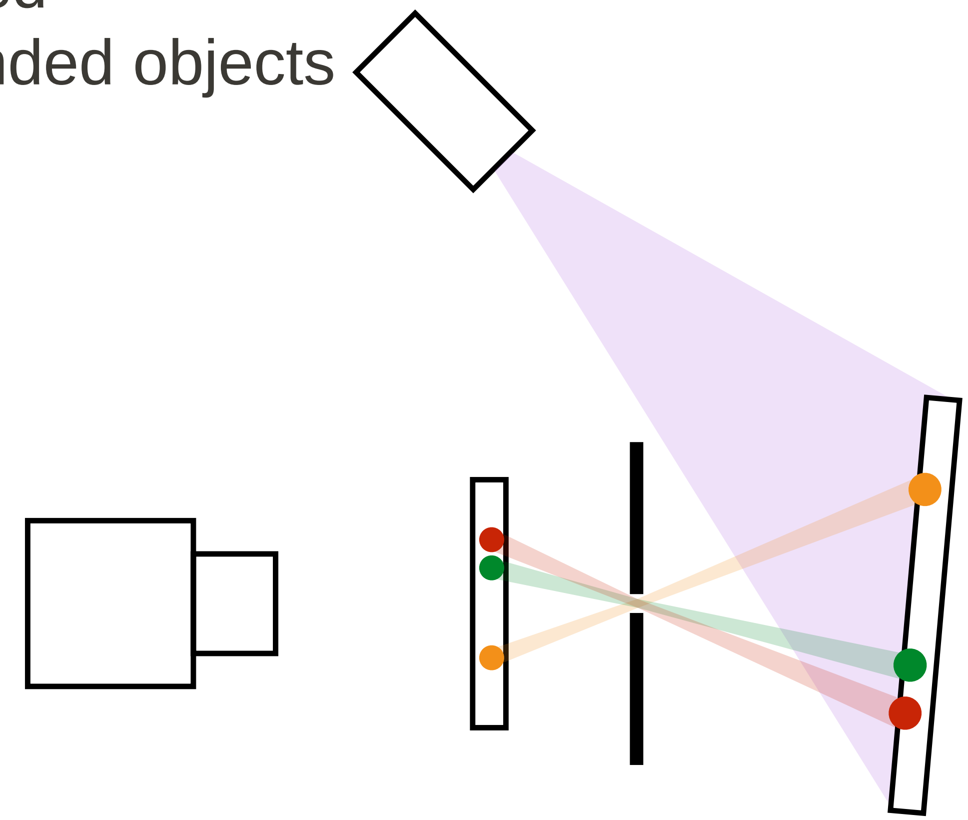




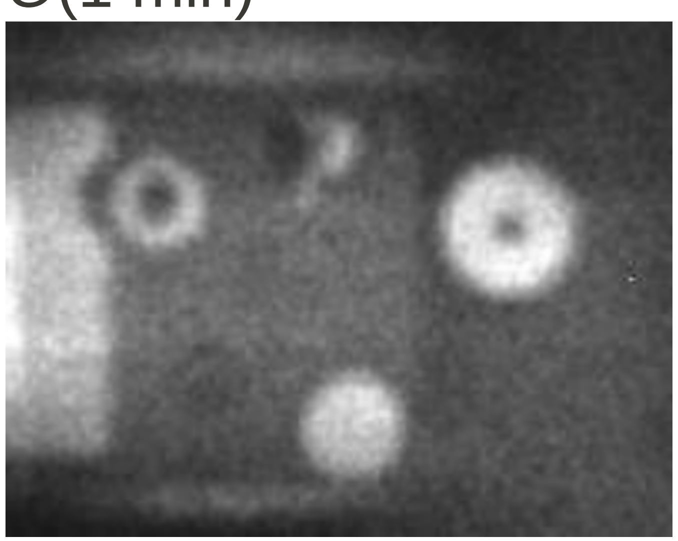
Fluorescence

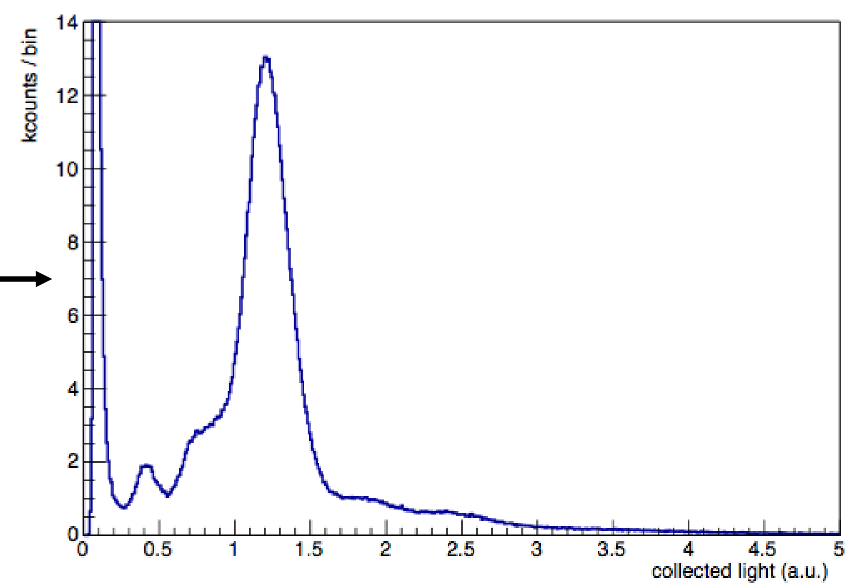
Spatial- and energy-resolved
X-ray fluorescence of extended objects

17 cm

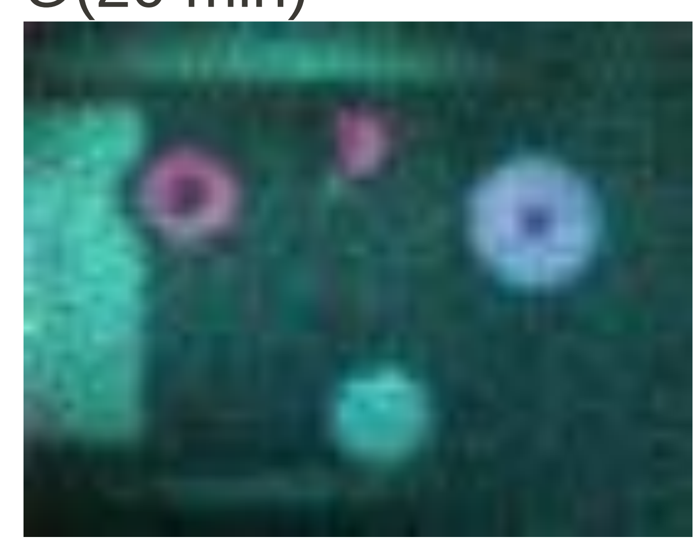


O(1 min)





O(20 min)



Applications under investigation

Optical readout may be also used for:

- X-ray crystallography
- UV imaging
- neutron imaging
- gamma imaging

…

Summary

Applications:
medical imaging in high dose treatments, nanodosimetry, X-ray fluorescence, cosmic muon tomography, radon detectors.

Fundamental research other than HEP:
neutron diffractometry, rare events searches (nuclear physics, dark matter, neutrino-less double beta, neutrino oscillation).

And possibly in the future:
X-ray crystallography over large surfaces, homeland security, online beam monitor for hadron therapy, …