CERN developments of an optical readout for MPGDs

Filippo Resnati (CERN)
on behalf of the GDD team

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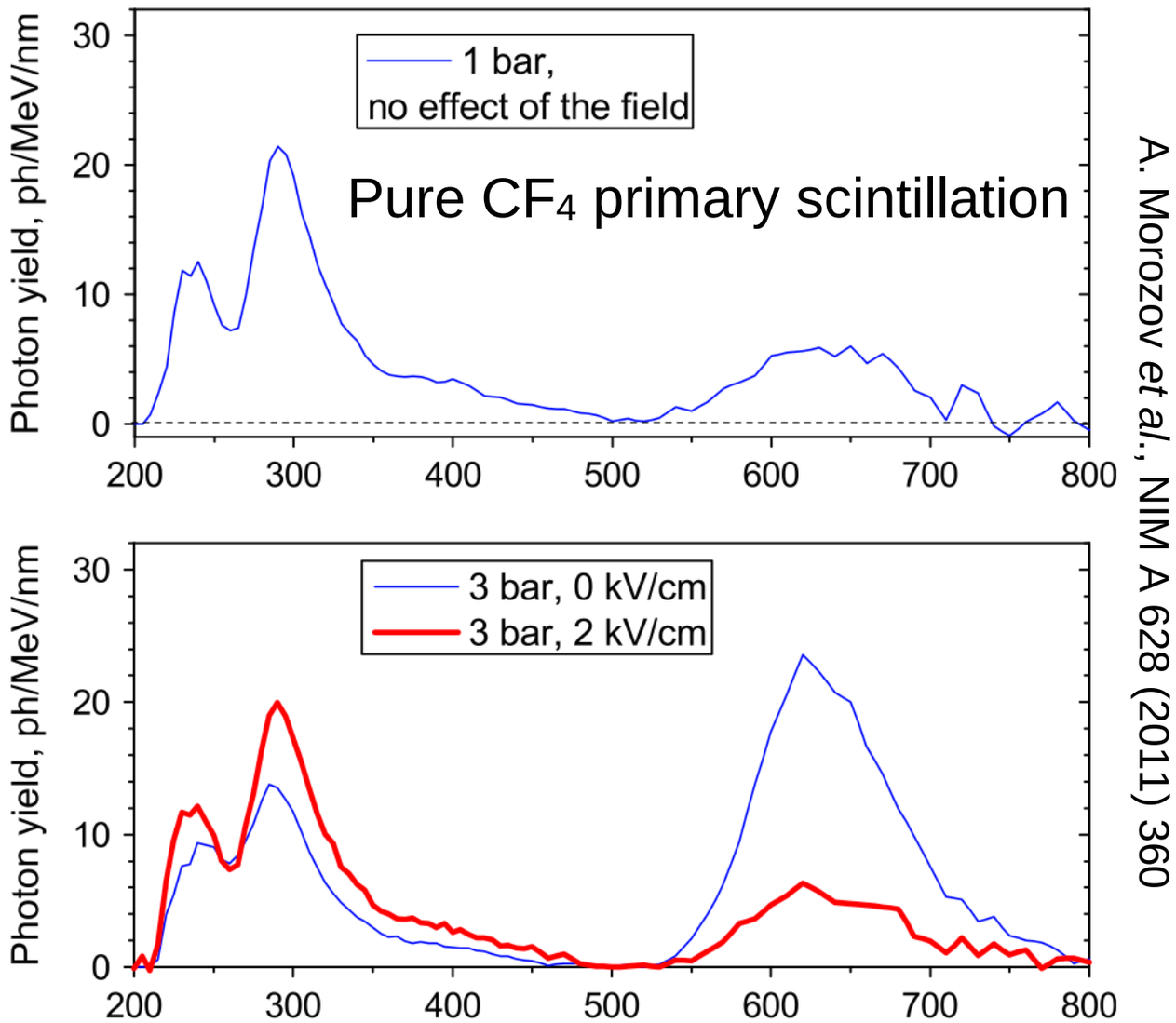
Where to get the light from

Almost the same spectra

Primary	Electroluminescence	Avalanche
Excitation and ionisation produced by the particle interacting with the gas. Some dependance with the electric field.	Scintillation without charge amplification. Increase linearly with the field. Easy in pure noble gases.	Exponential scaling with the field. *Proportional* to the charge gain. The extreme is the visible spark.

CF_4

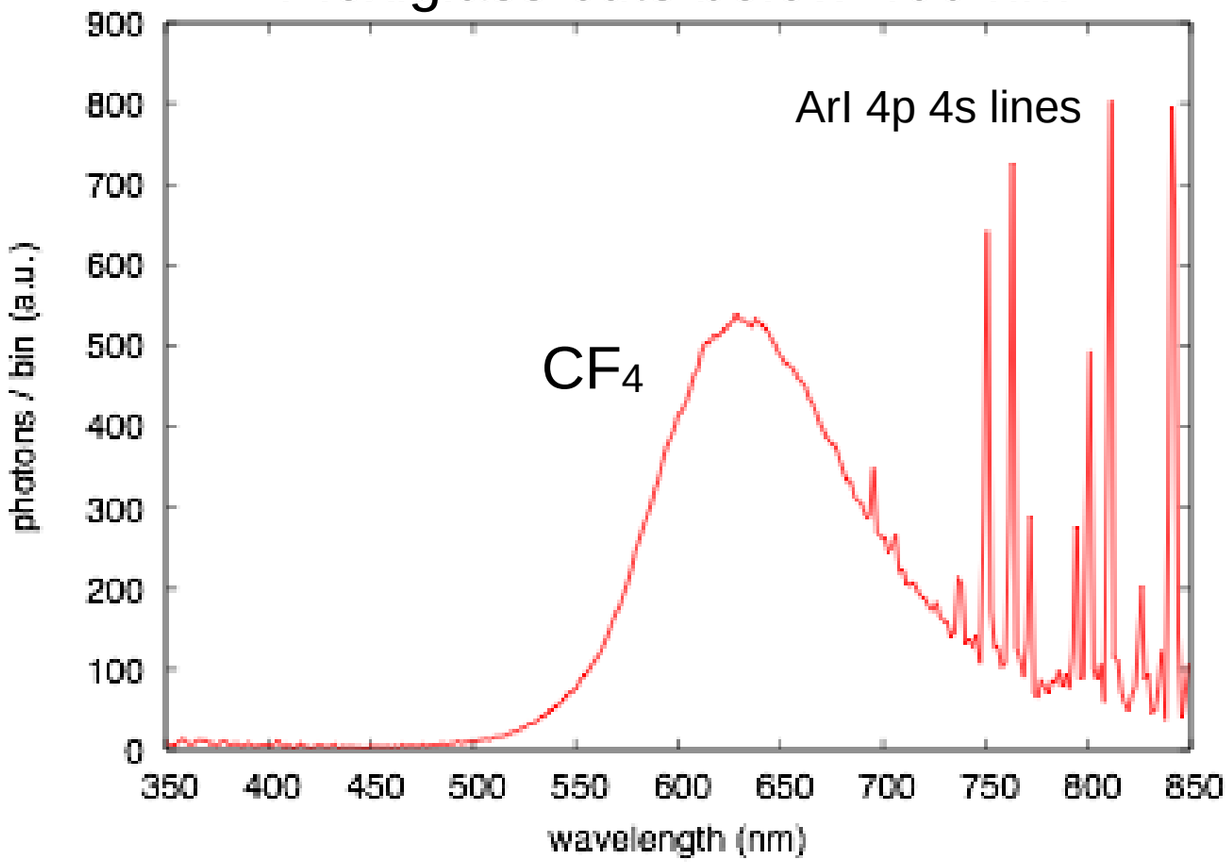
Admixtures which provide useful scintillation (enough and near the visible range) are rare.



CF_4 is not transparent to the CF_4 de-excitation to ground.
What scintillates must be something else: (CF_3^*), CF_3^{+*} and CF_4^{+*}

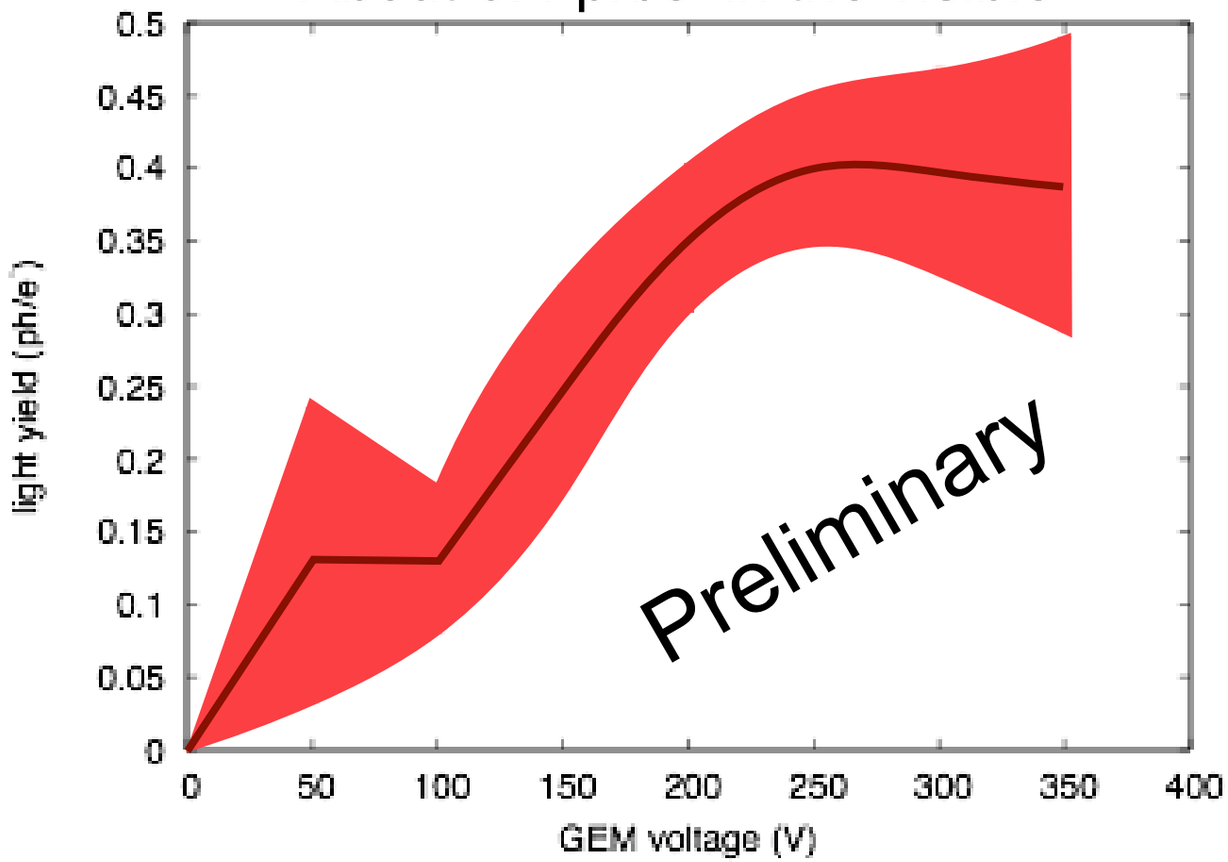
Ar/CF_4 80/20

Plexiglass cuts below 400 nm



Nicely matching the CCD efficiency curve

About 0.4 ph/e^- in the visible



High charge gain -> high light gain

Light yield comparison
NaI: ~40 ph/keV
GEM at a gain of 10^5: ~10^6 ph/keV

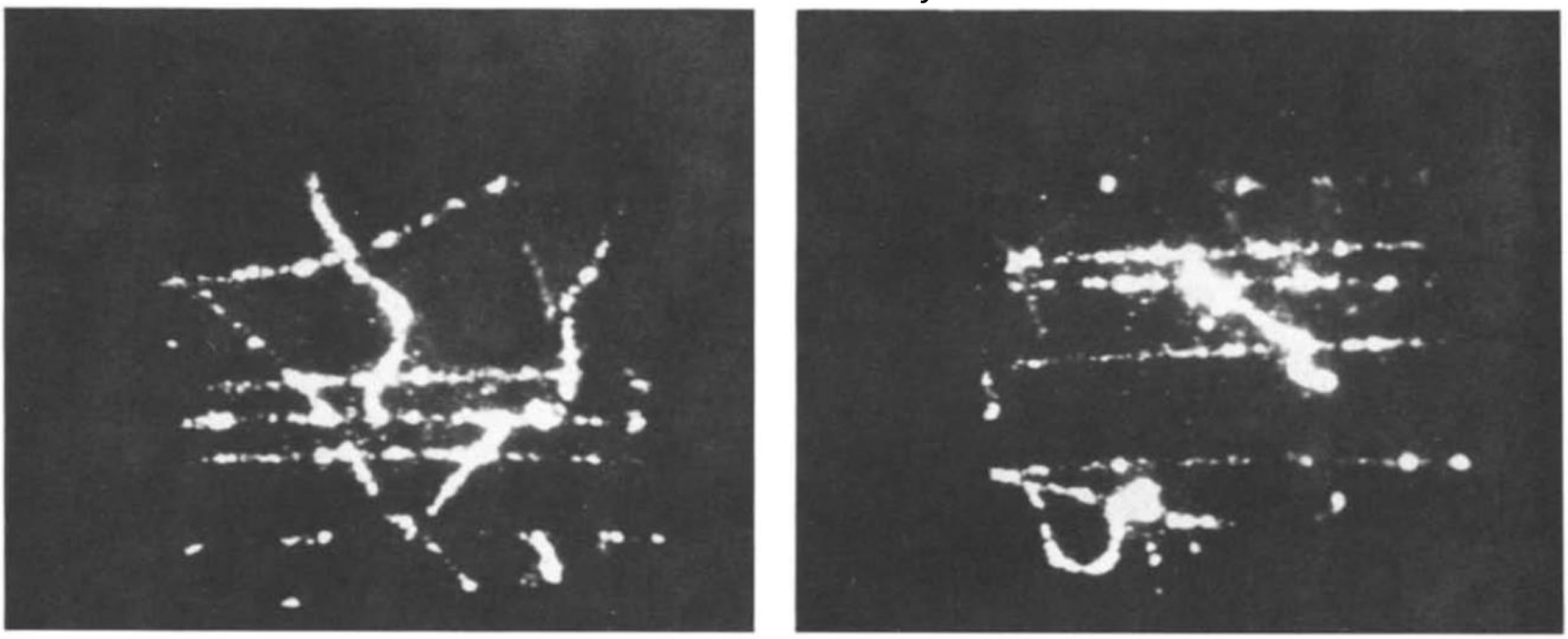
Optical readout

Record the light emitted during the Townsend avalanche with a camera: use the detector as a scintillating plate.

Only techniques are new

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

Muons and delta rays



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

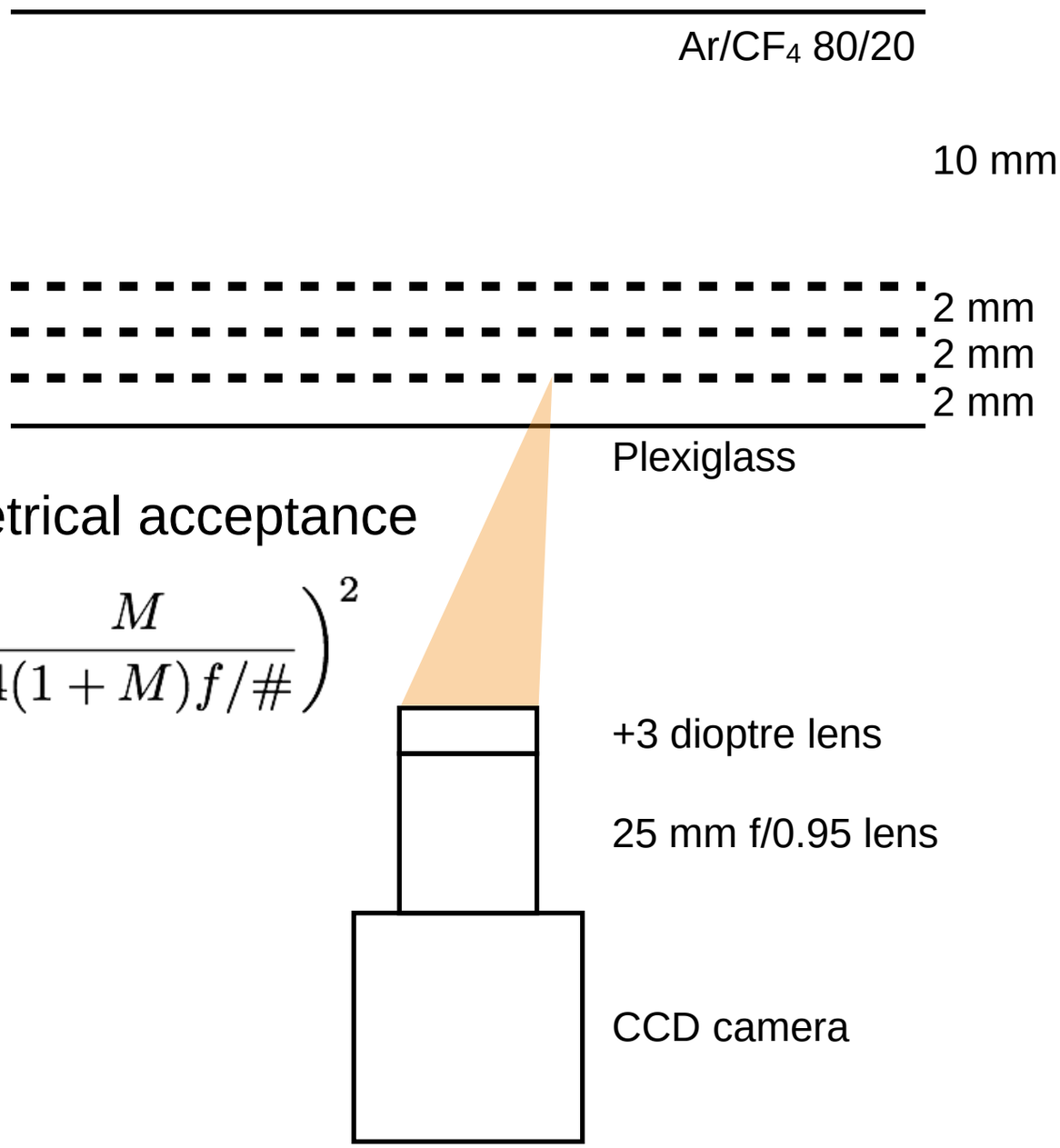
Advantages

Simplicity: like taking a picture

Robustness: as a device off-the-shelf

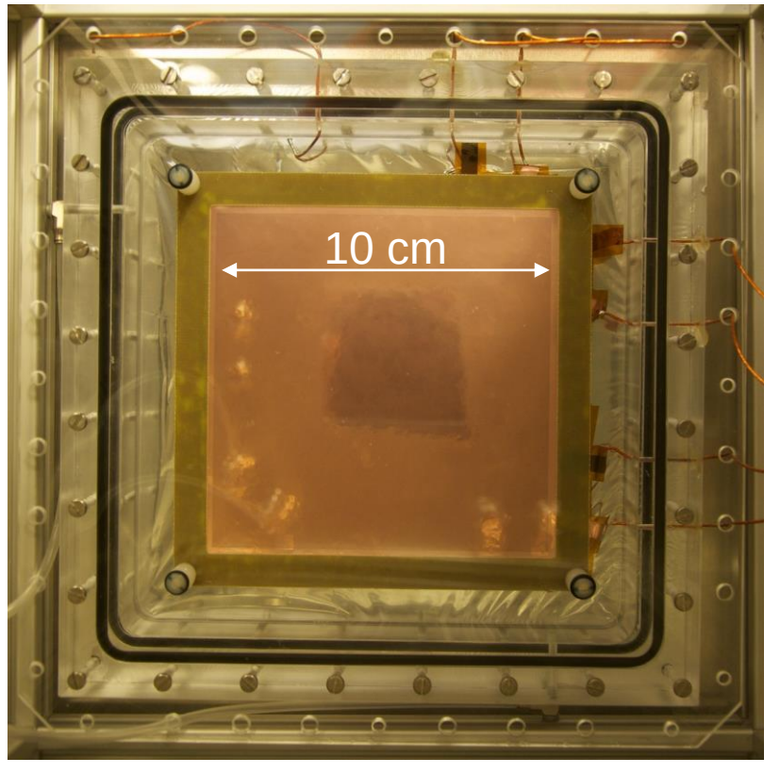
Versatility: several uses and environments

The setup



Geometrical acceptance

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



M = sensor size / image size
M ~ 0.1, Ω ~ 5×10^{-4}

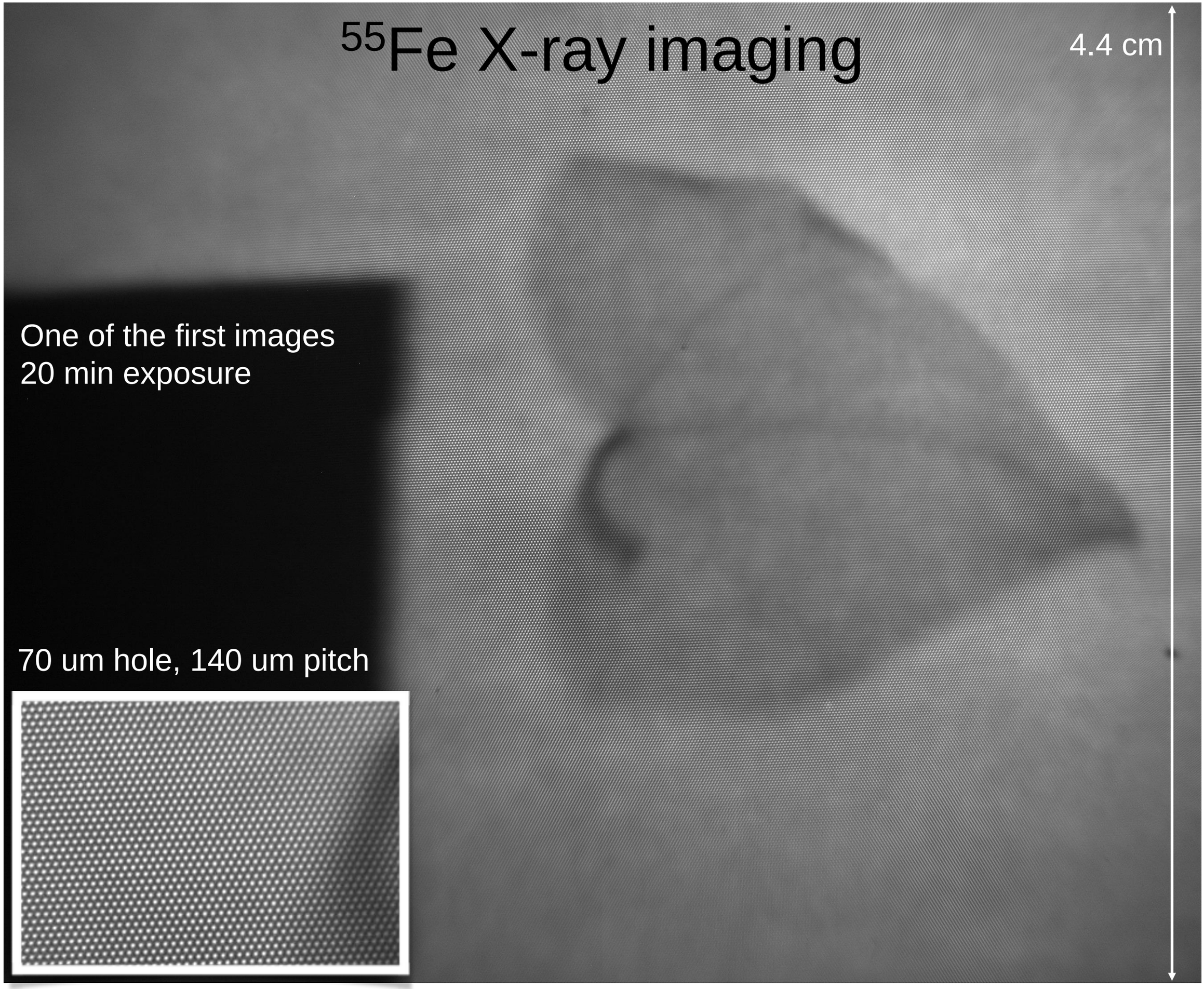
This implies:
- large sensor
- low noise
- fast lens
- a lot of light

Camera and lens

QImaging Retiga R6
CCD: 2688x2200 4.54x4.54 um^2 pixels
ADC: 14 bit
rate: 6.9 fps (20fps with binning)
read noise: 5.7 e^- RMS
dark current: 0.0002 e^-/p/s @ -20º C
trigger: external bulb + others

Navitar
focal length: 25 mm
aperture: f/0.95
Mount: C-Mount
Sensor type: 1’’ format

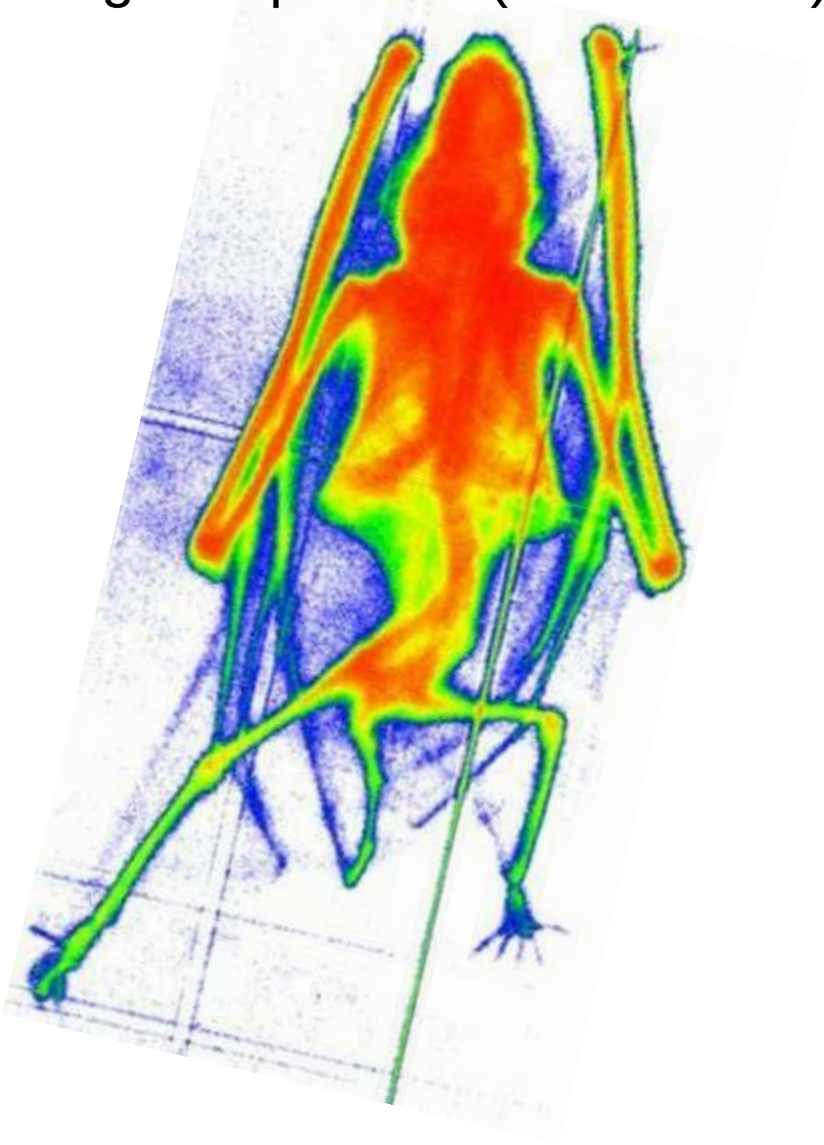
^{55}Fe X-ray imaging



X-ray images

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

Charge acquisition (26/10/1998)



Light acquisition

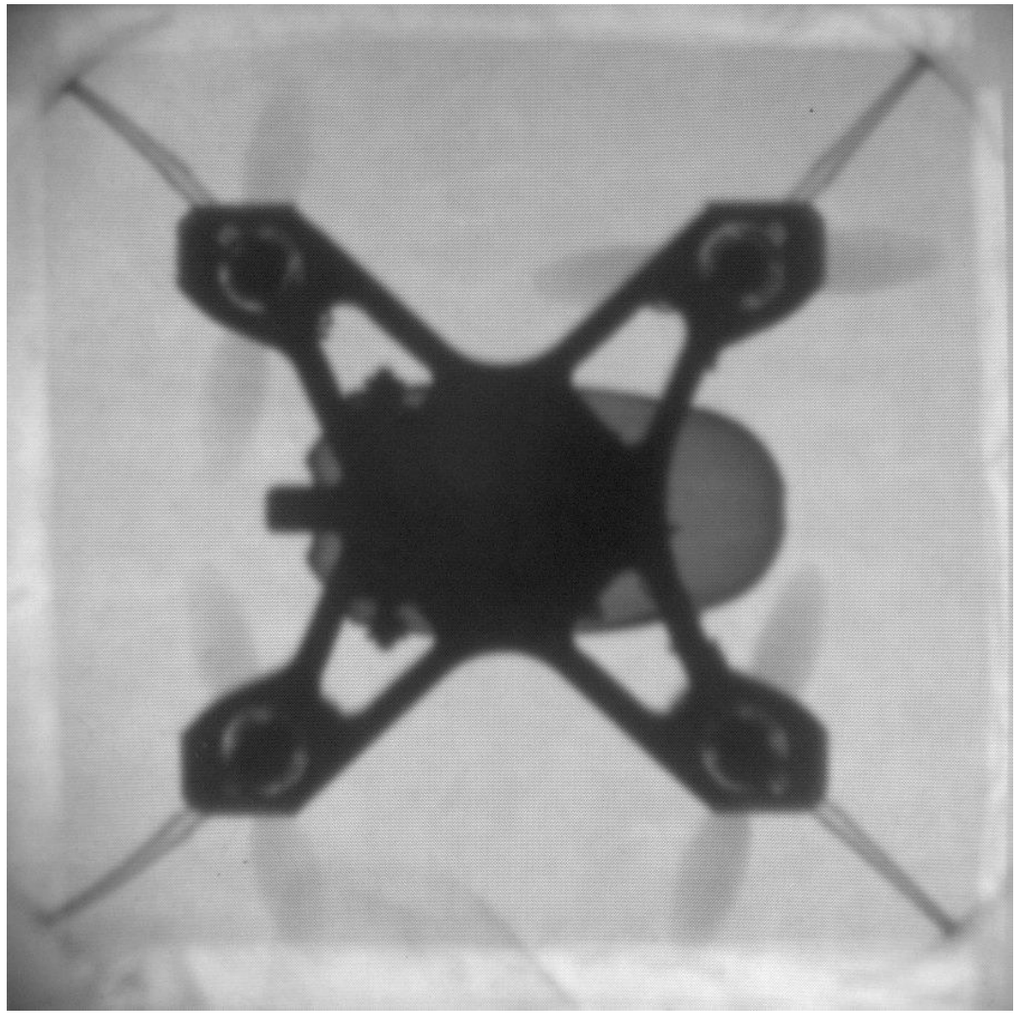
~7 cm

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

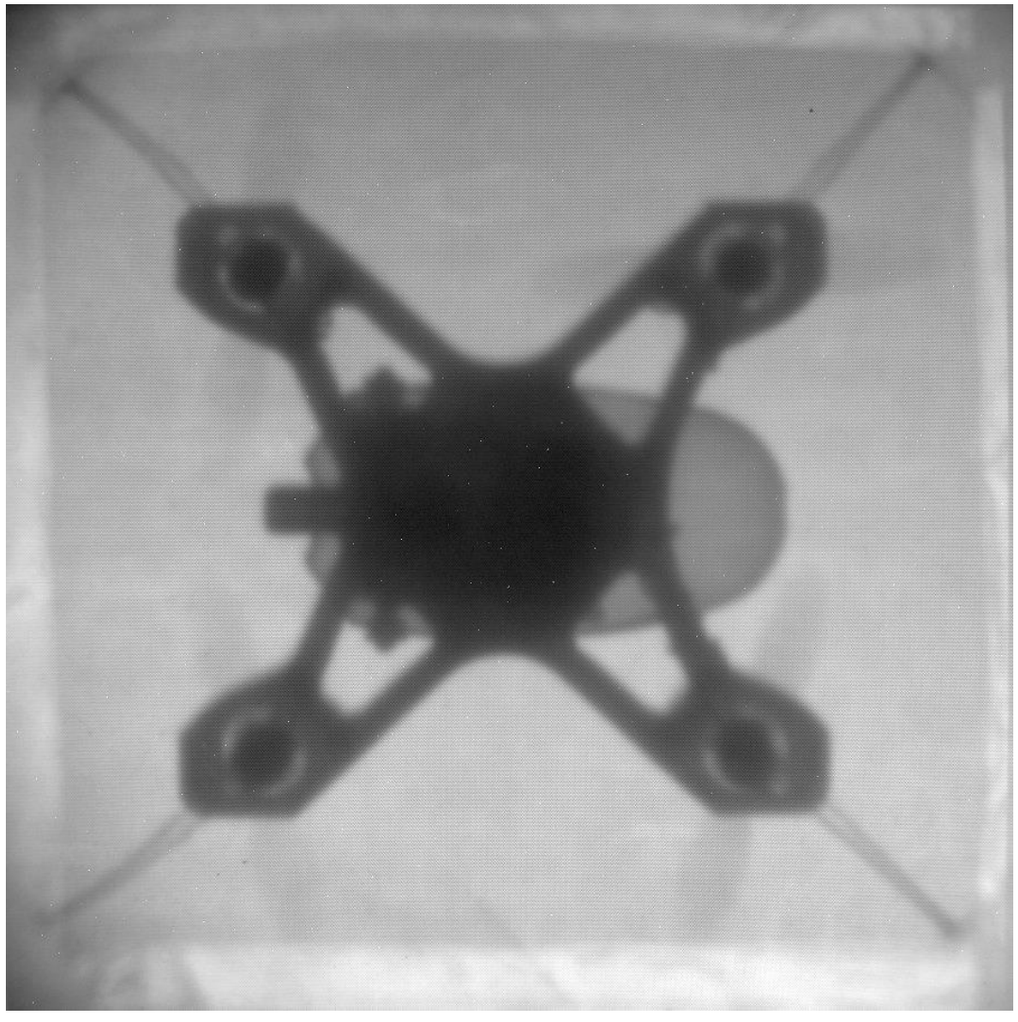
X-ray images

X-ray tube with W target

11 kV



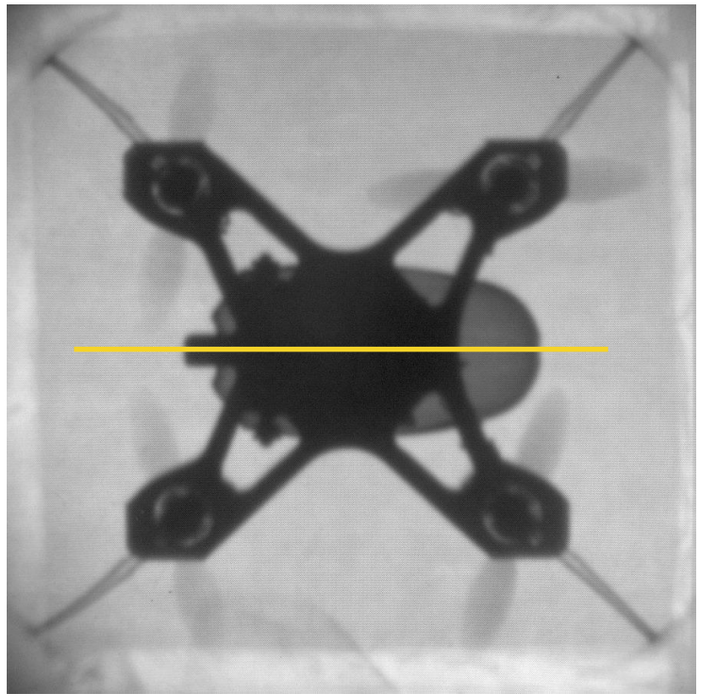
40 kV

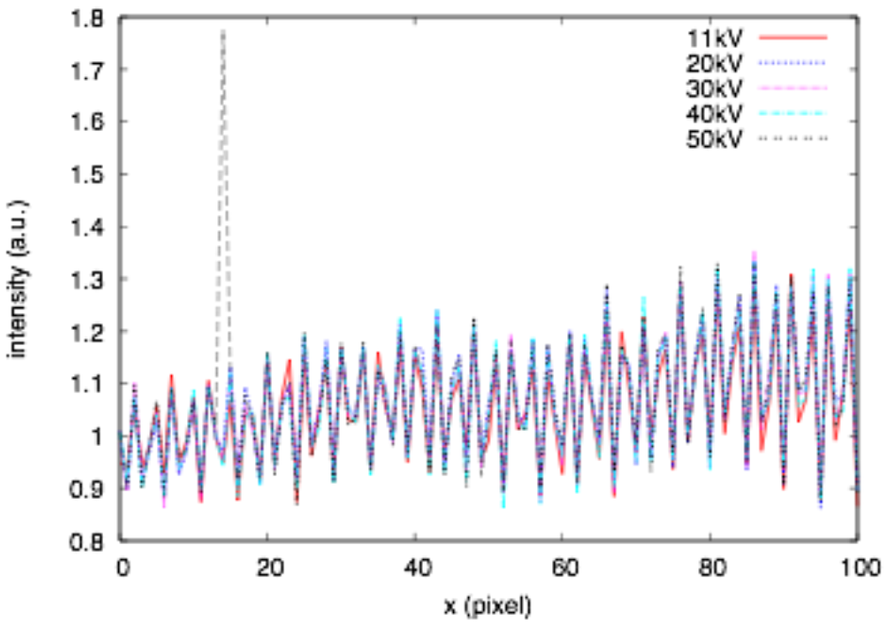


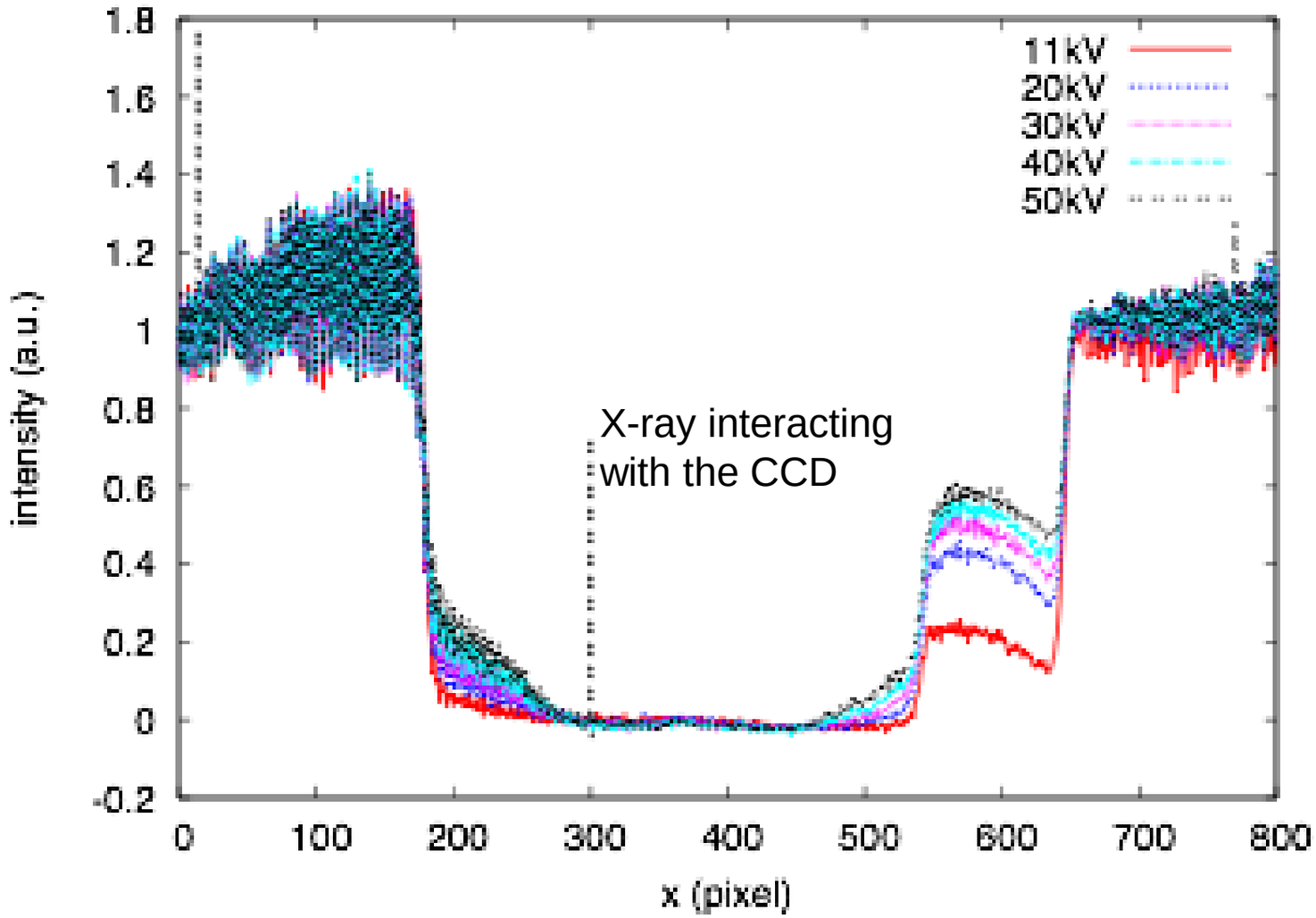
8 cm

Straight out from the camera, not even the flat field correction

X-ray images



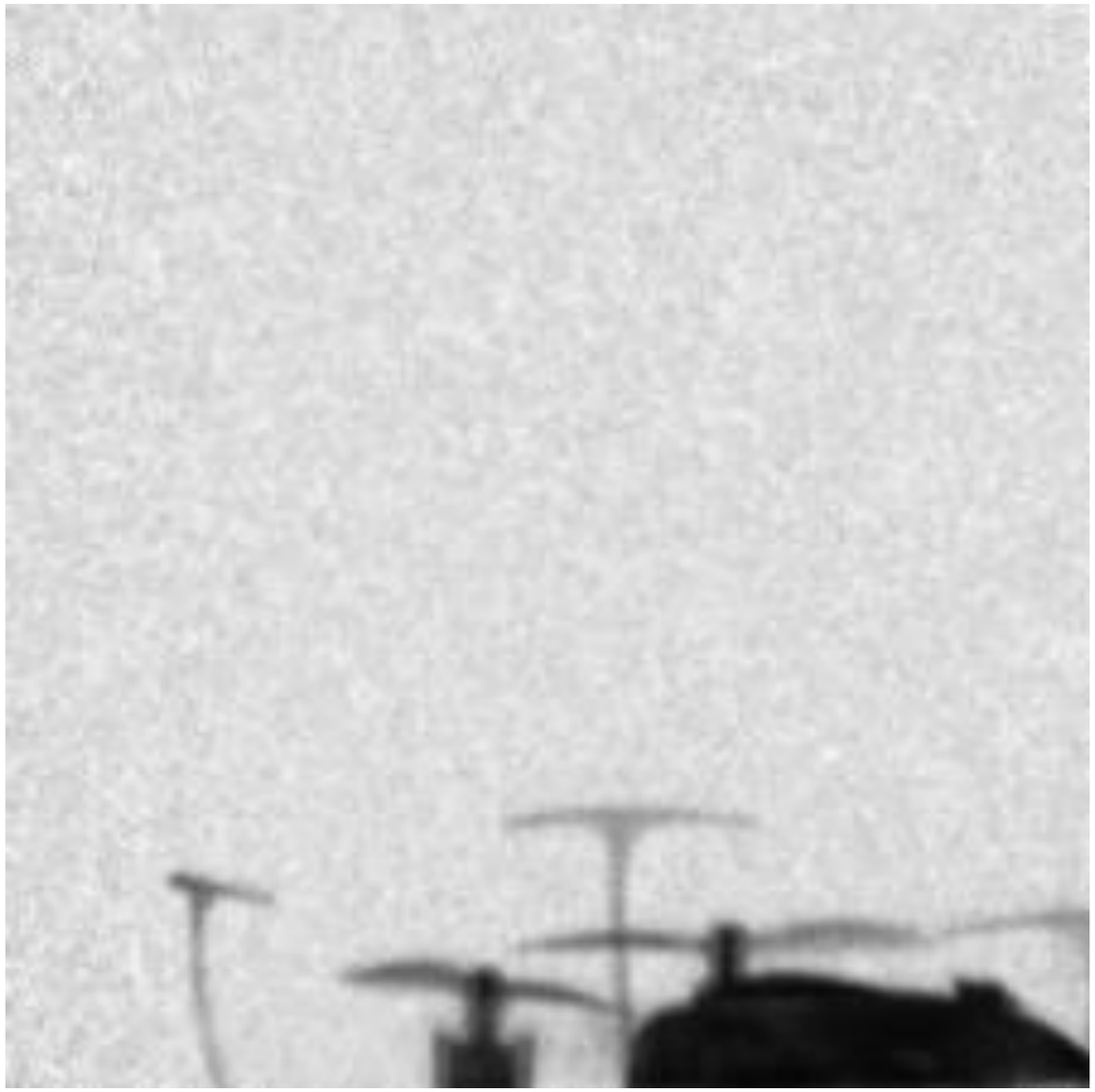




Increasing energy:
- X-ray more penetrating
- Worse position resolution (larger charge cloud)

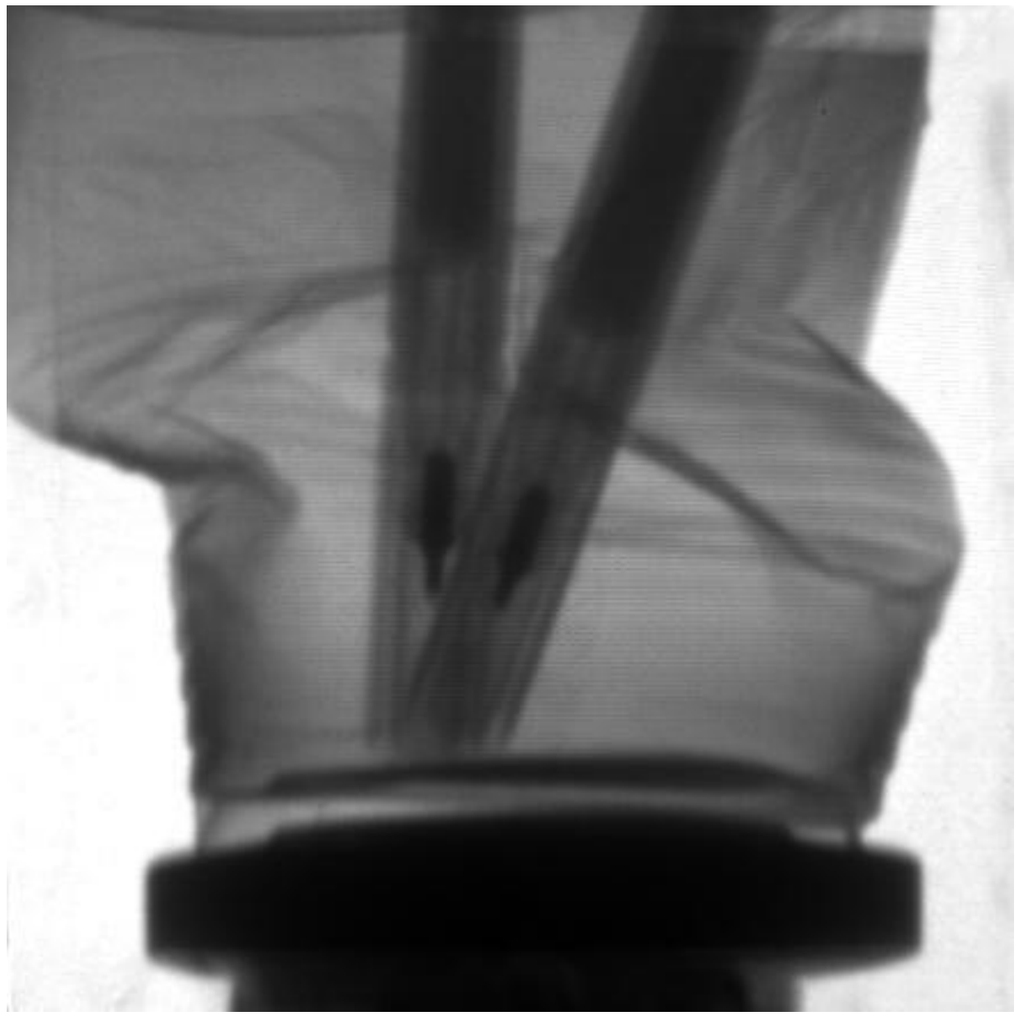
Fluoroscopy

50 ms exposure
10 Hz acquisition

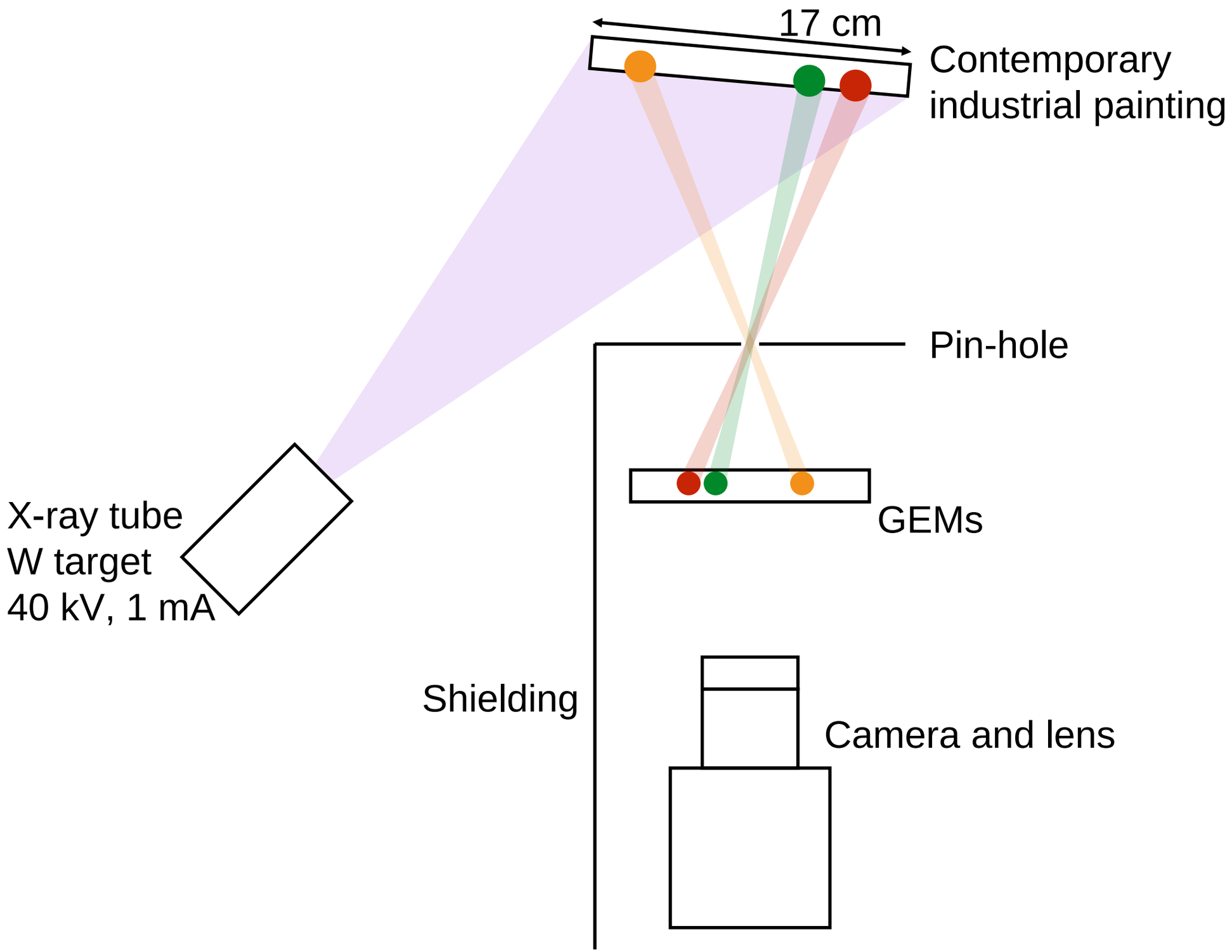


CT and 3D imaging

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

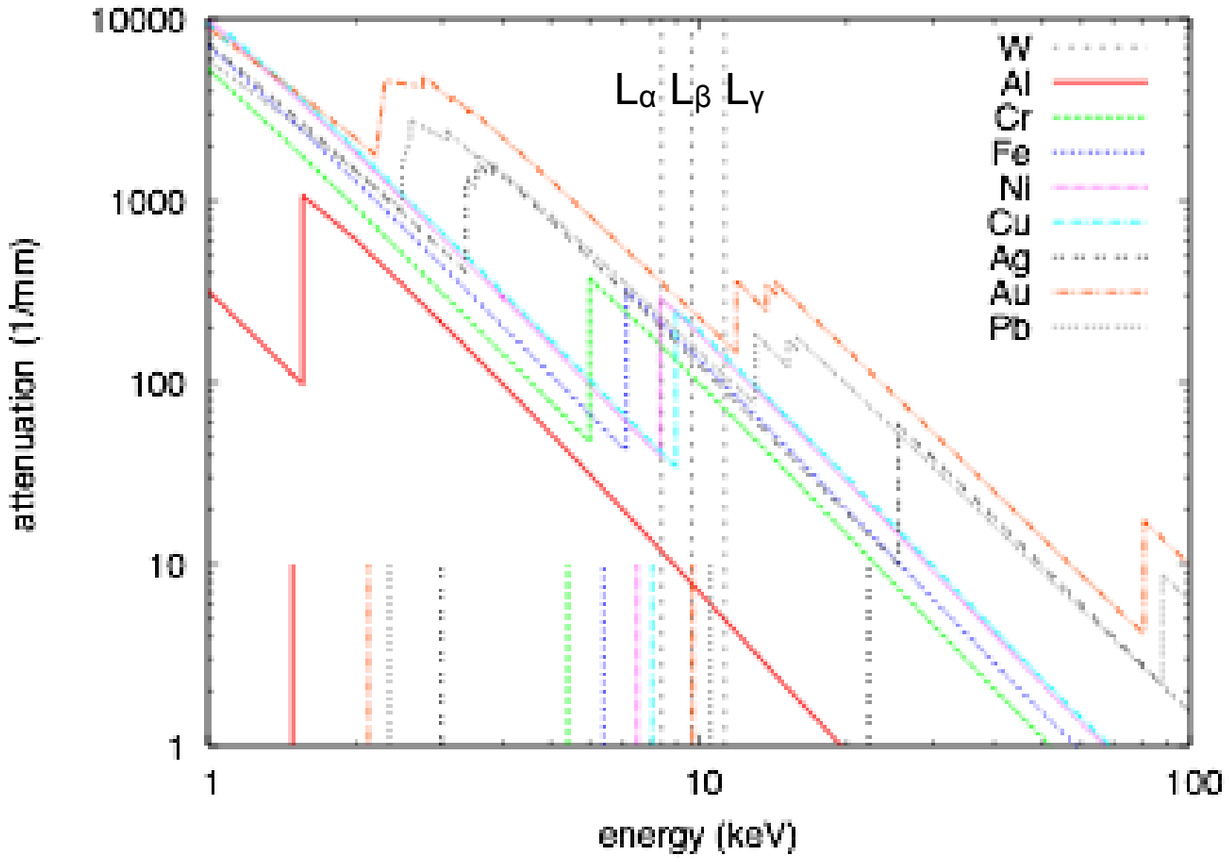


Fluorescence

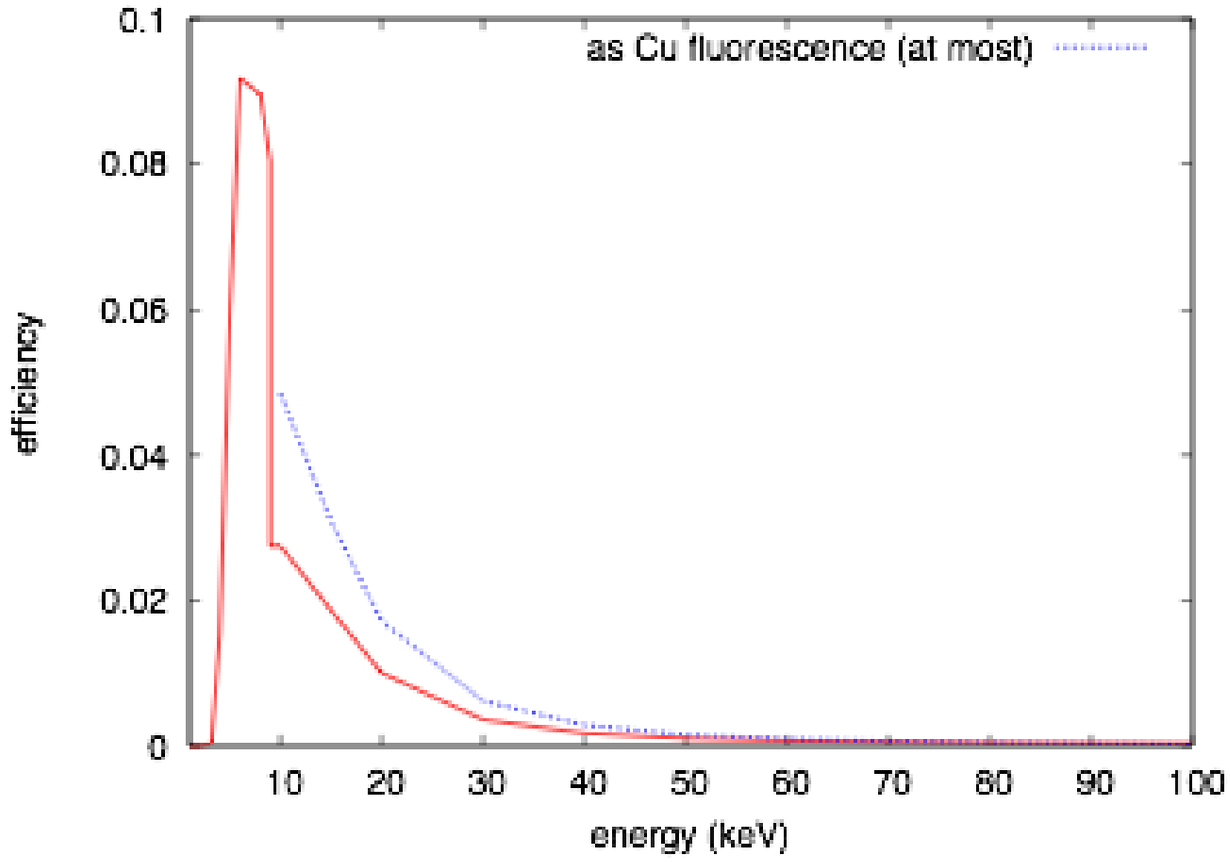


What should be expected

W target:
bremsstrahlung +
characteristic lines



Limiting factors (because not optimised):
- low energy -> window and cathode
- high energy -> gas

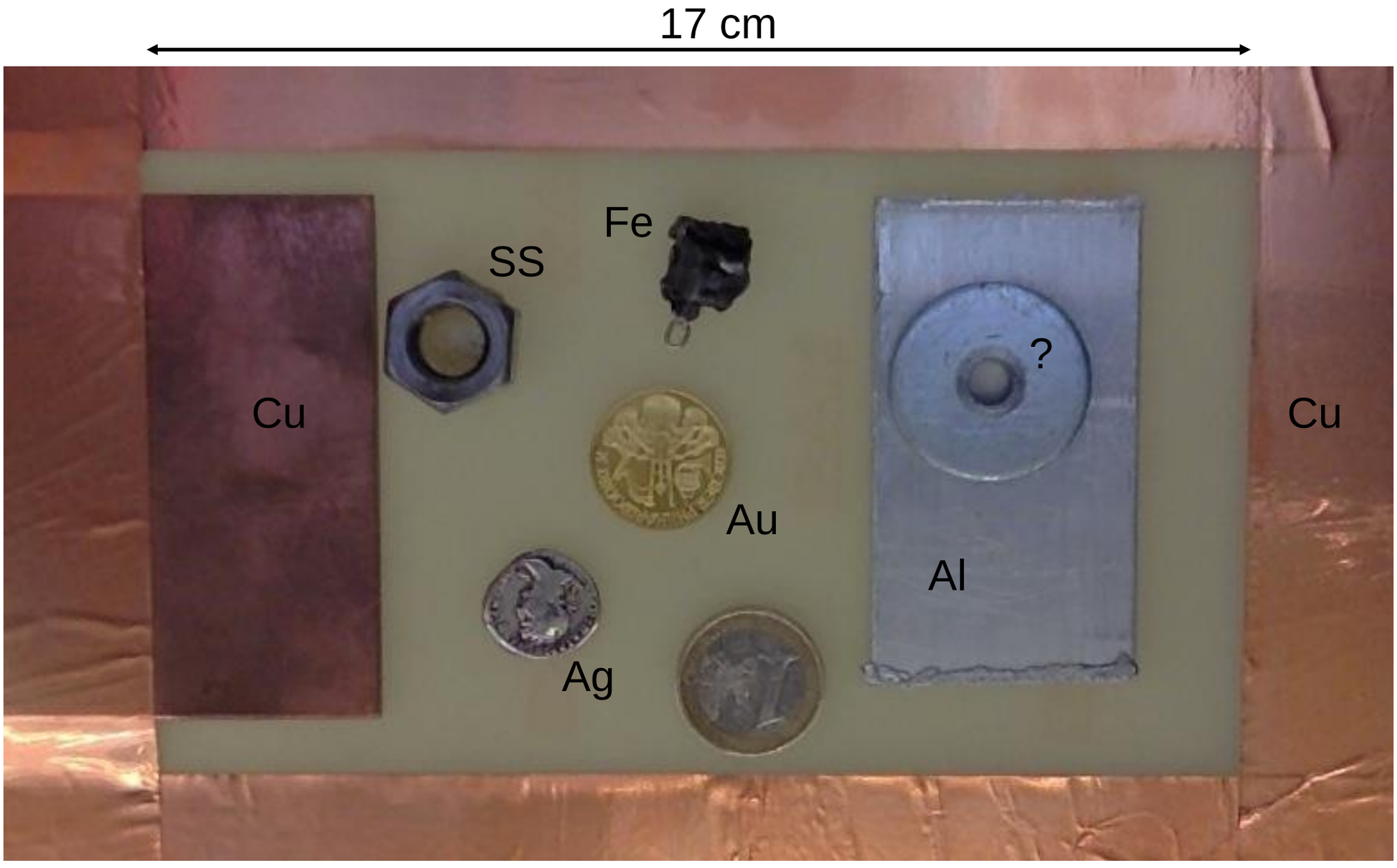


feasible:
Cr, Fe, Ni, Cu

difficult:
Au, Pb

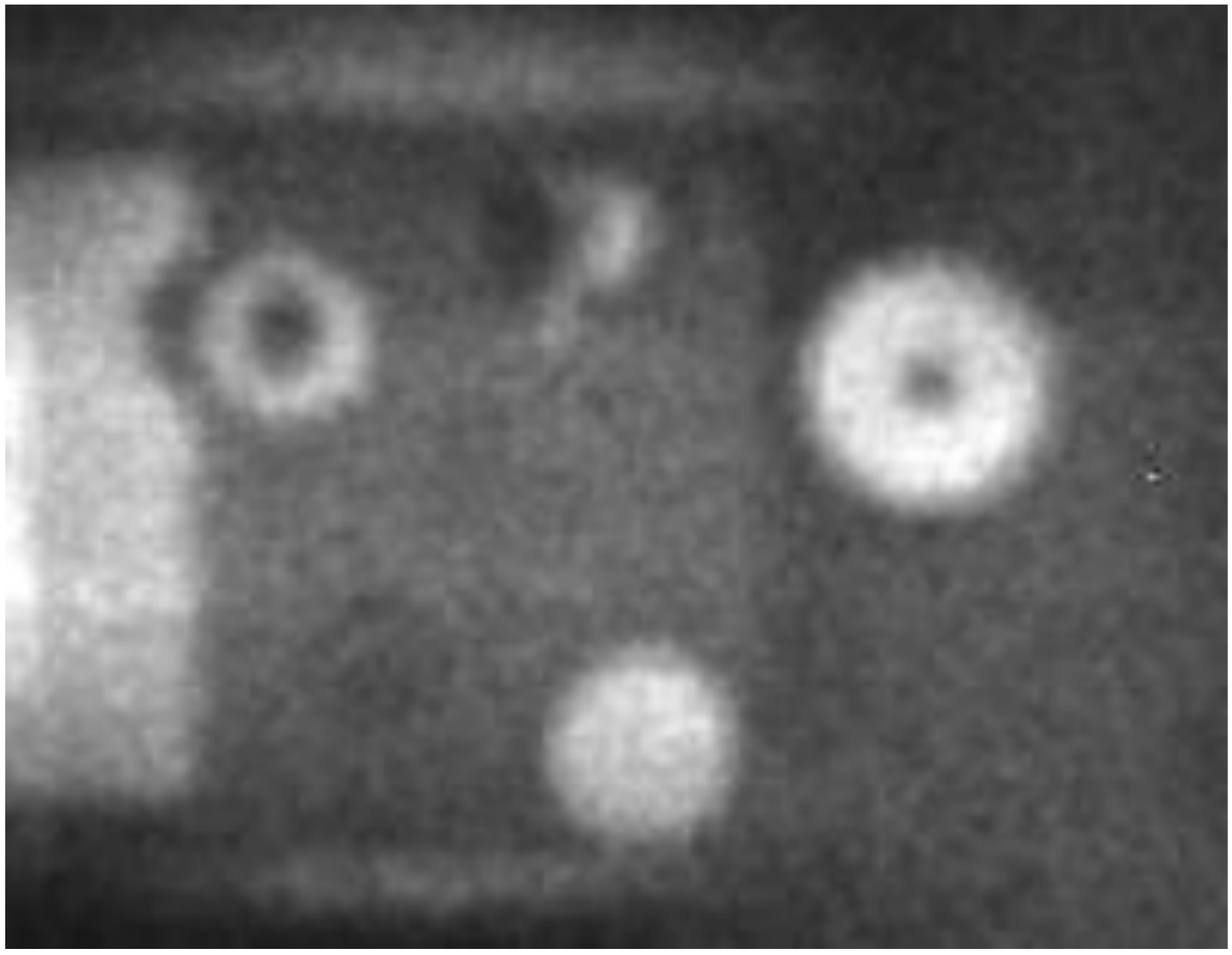
more difficult:
Al, Ag

The painting (visible)

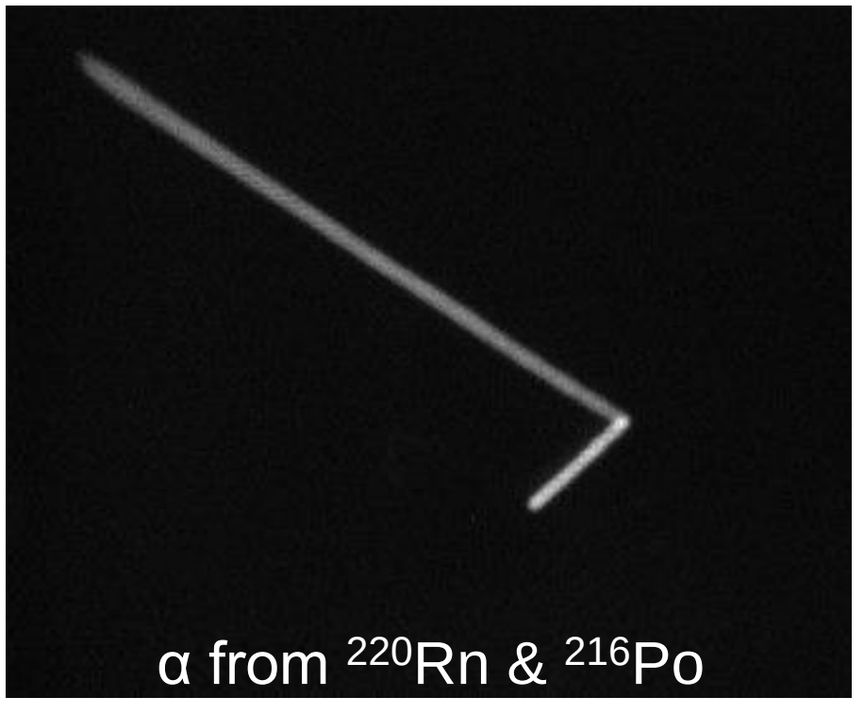


The painting (X-rays)

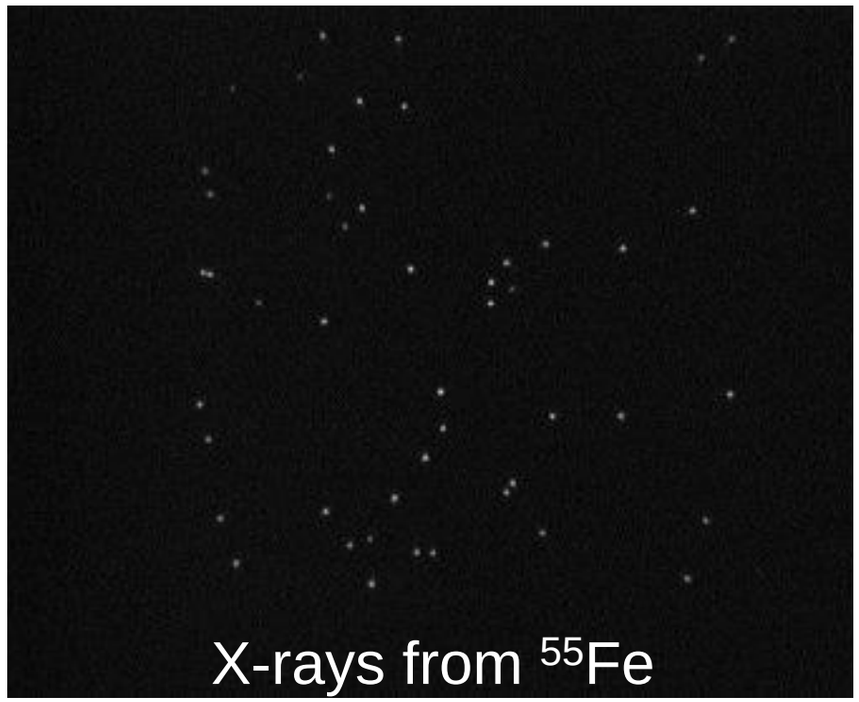
O(1 kHz) in 500 s exposure



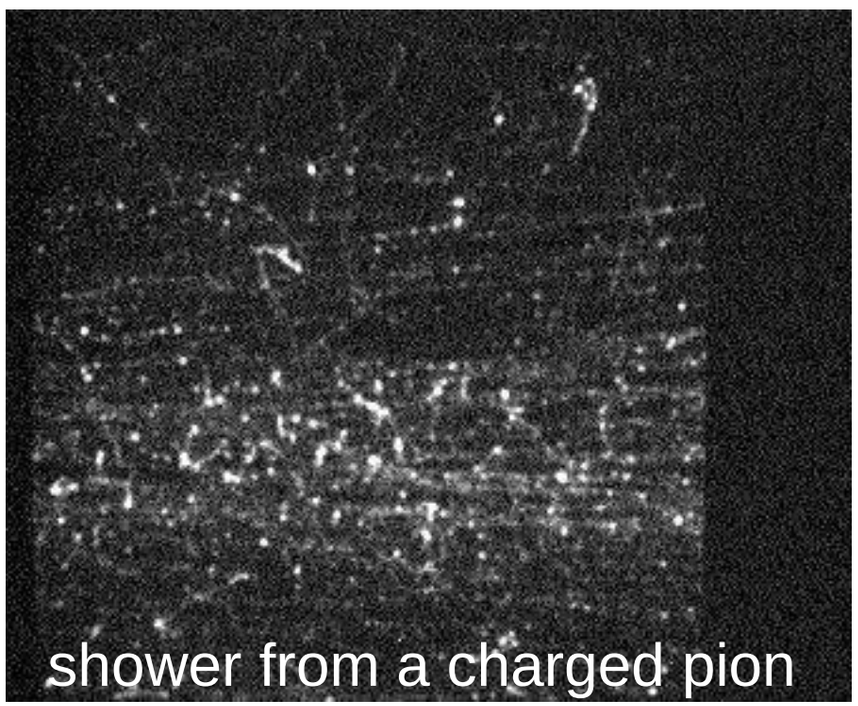
Event by event



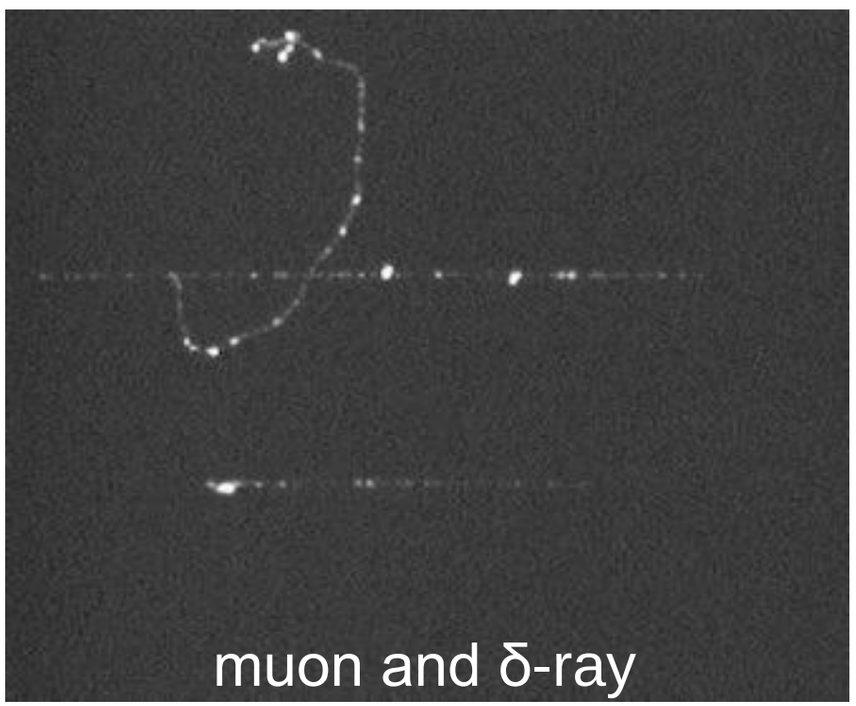
α from ^{220}Rn & ^{216}Po



X-rays from ^{55}Fe



shower from a charged pion

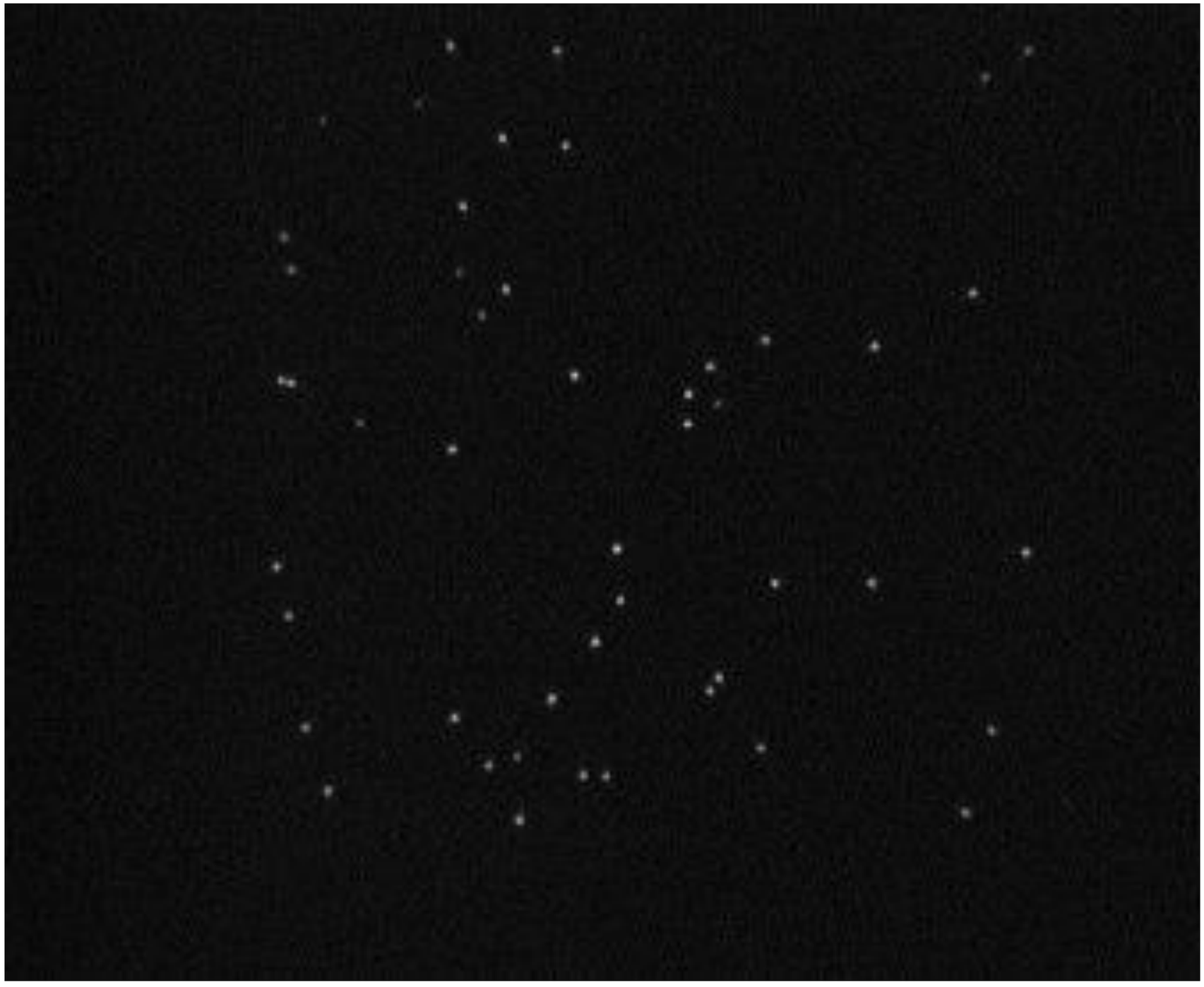


muon and δ-ray

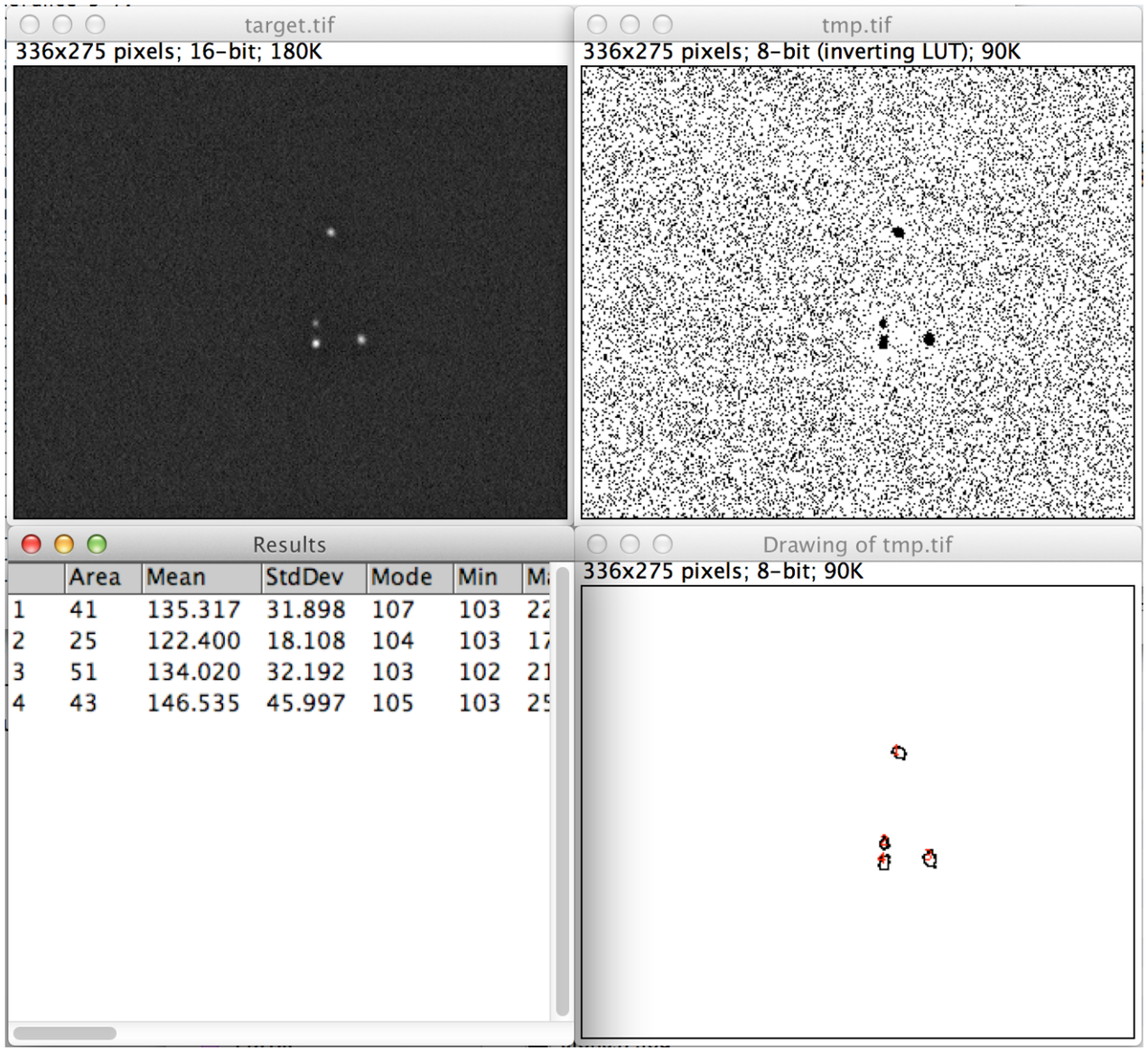
For hours in sealed mode at test beam

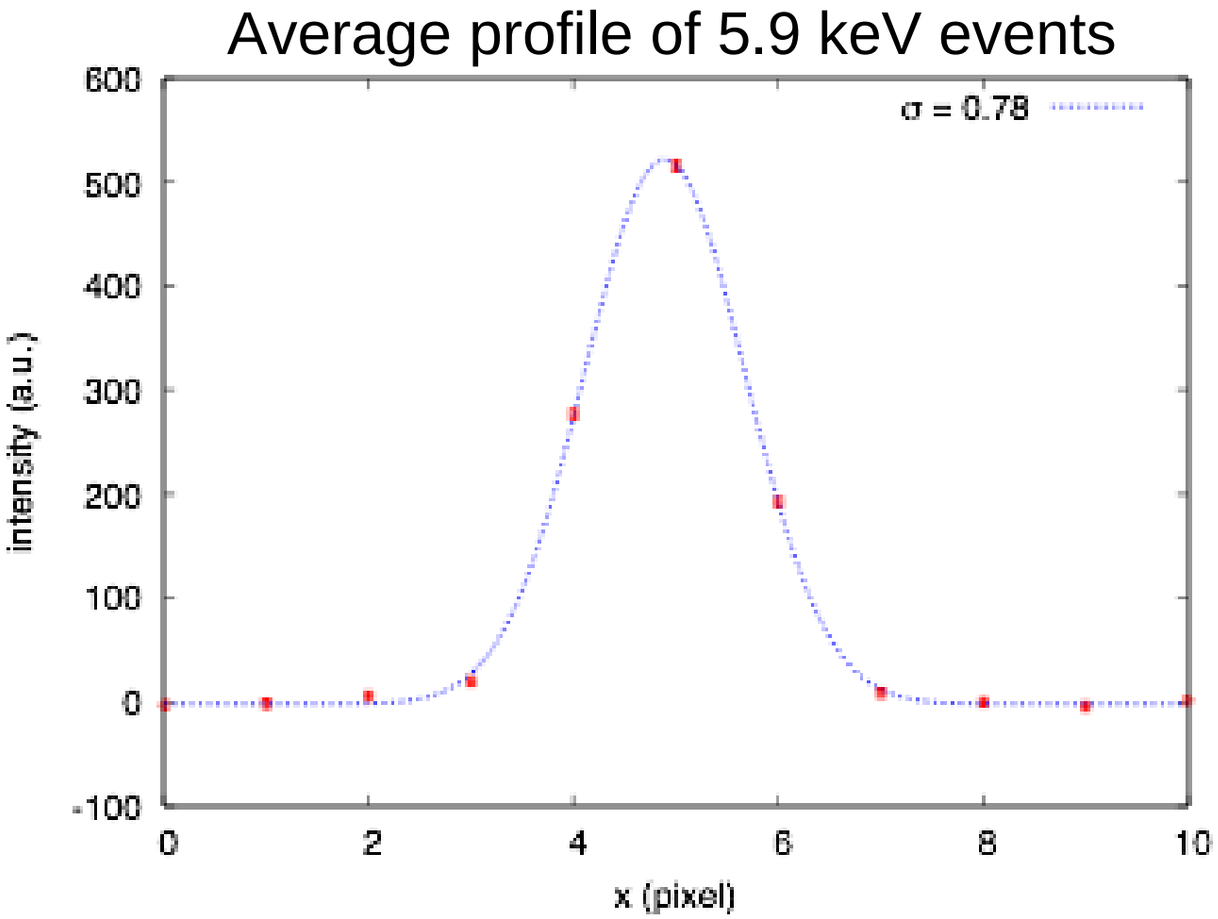
Event by event: X-rays

X-rays from ^{55}Fe source



Analysis of single clusters





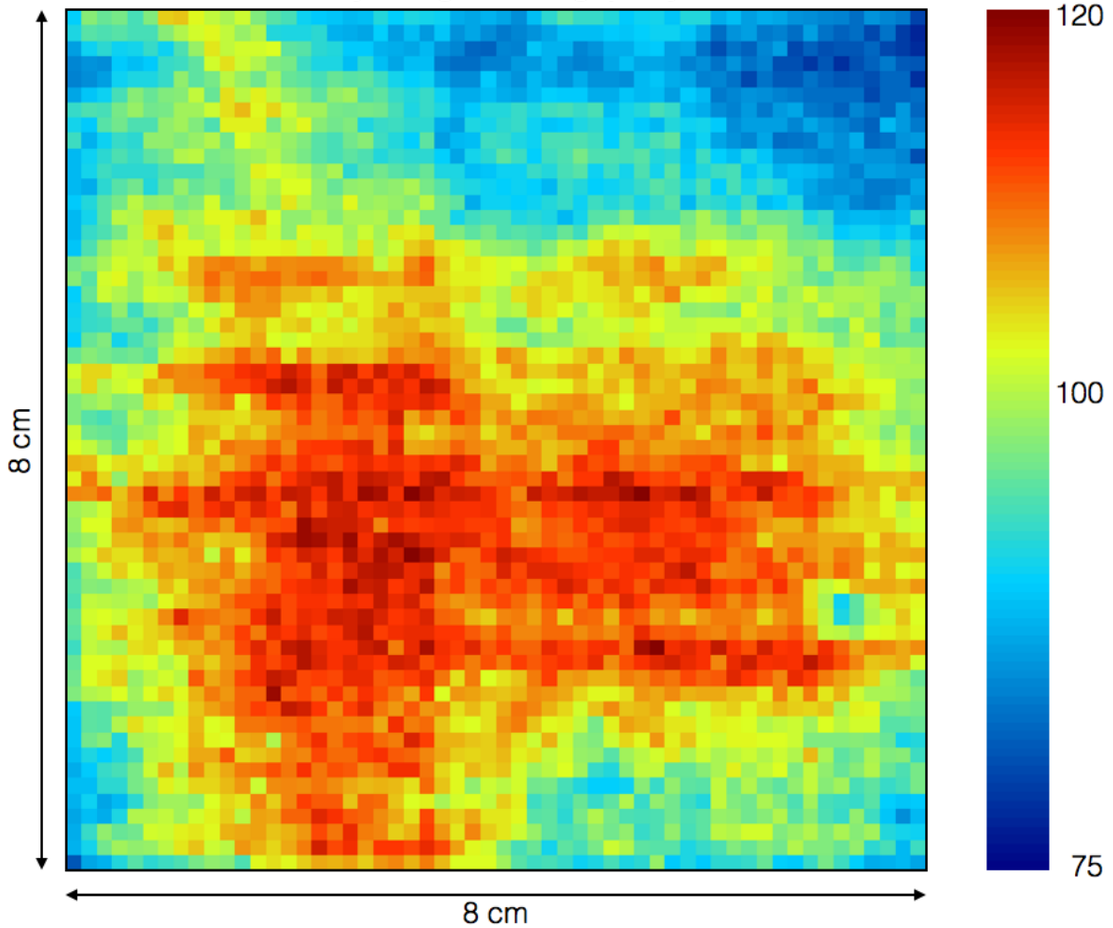
Spatial resolution in the limit of long exposure: 280 um for 1 cm drift and 5.9 keV X-rays. Dominated by e^- diffusion and cluster size.

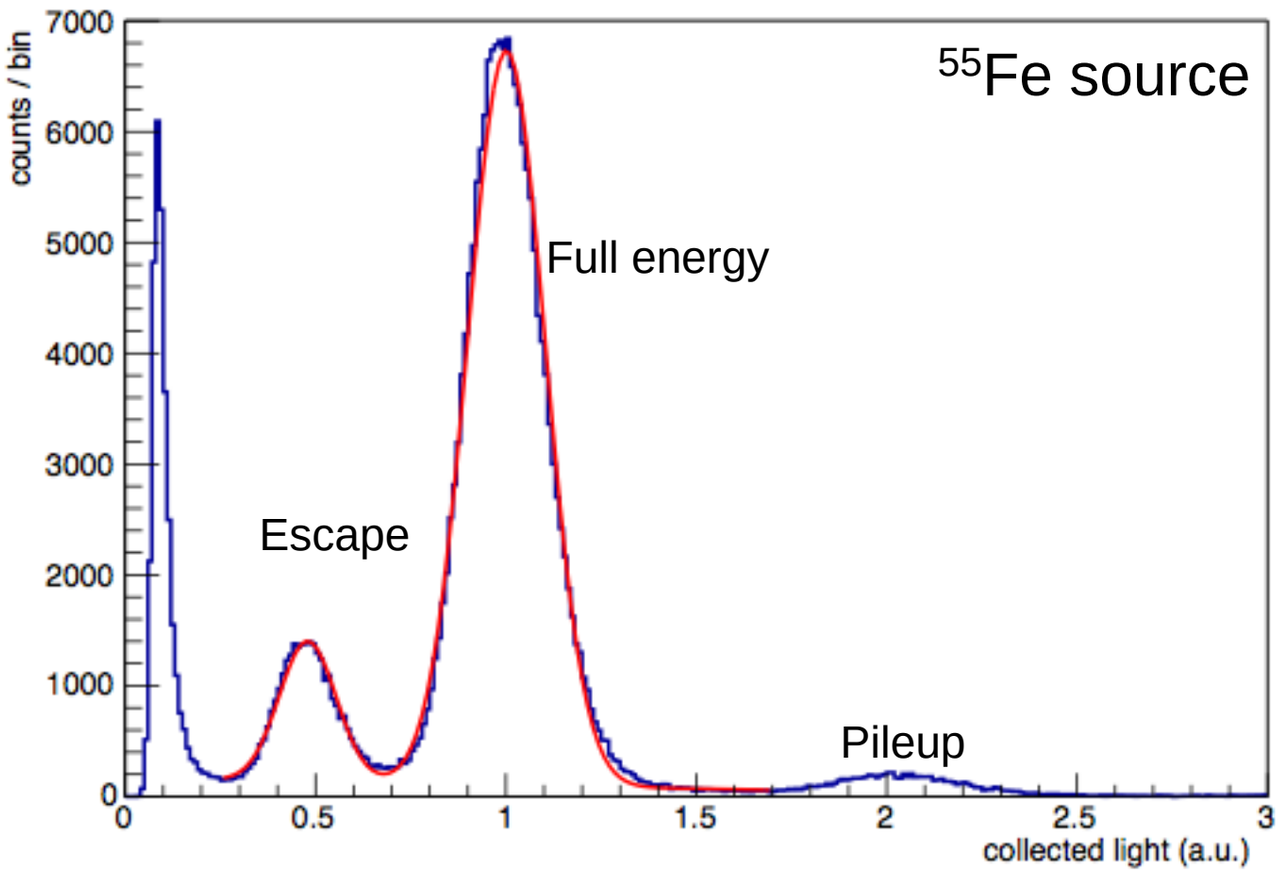
Spatial resolution improves using the barycentre of the cluster

The spectrum

from CCD images

Gain uniformity, vignetting plays a role too



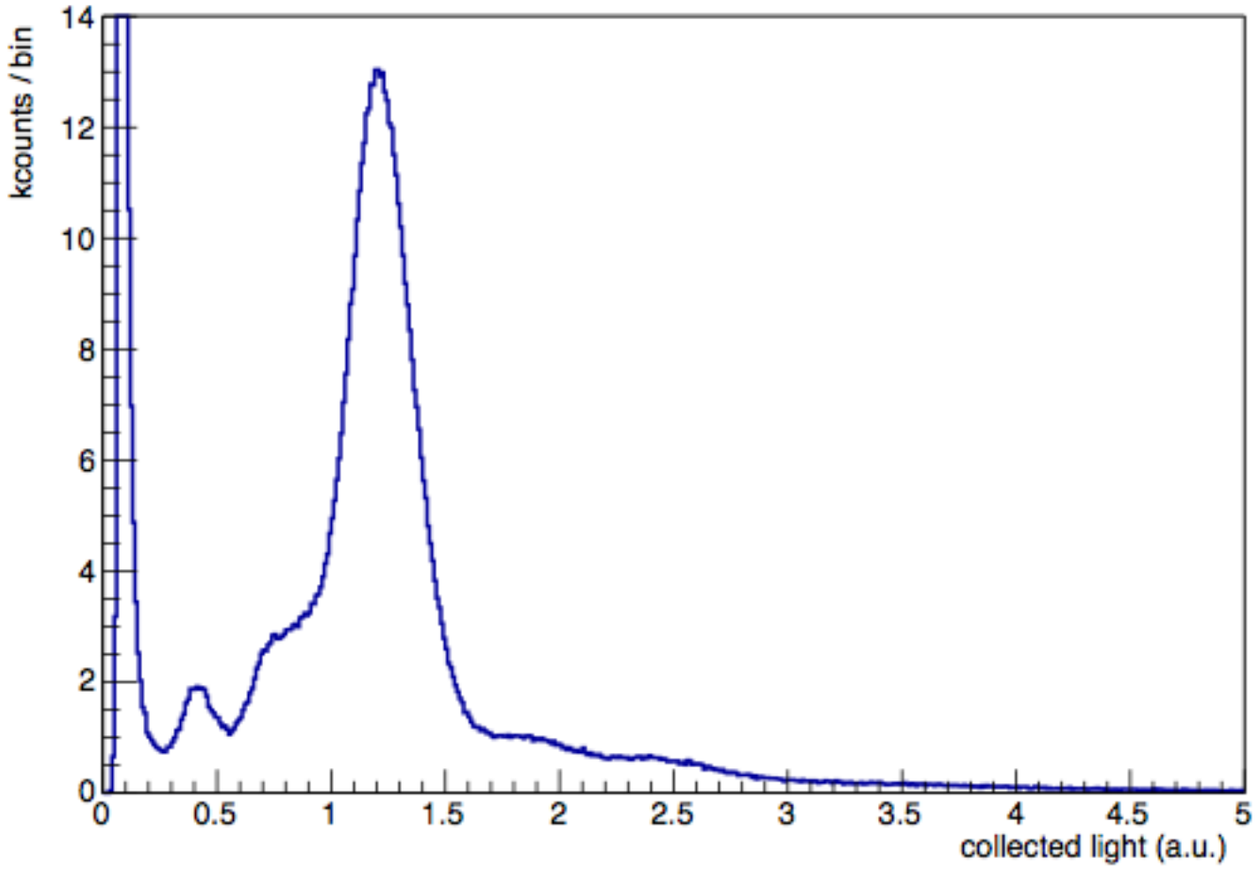


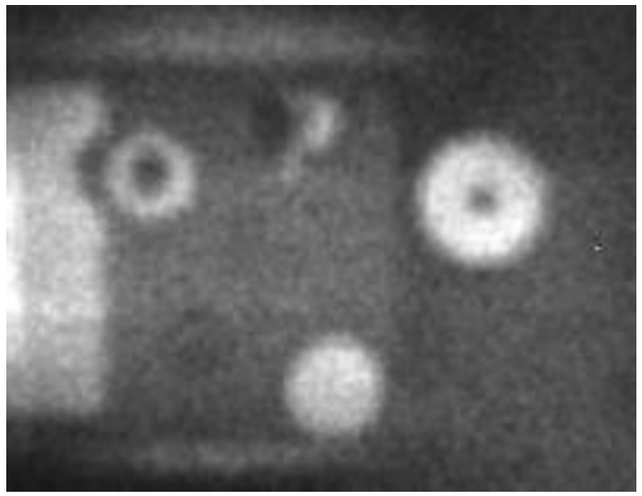
FWHM at 5.9 keV over 8x8 cm^2

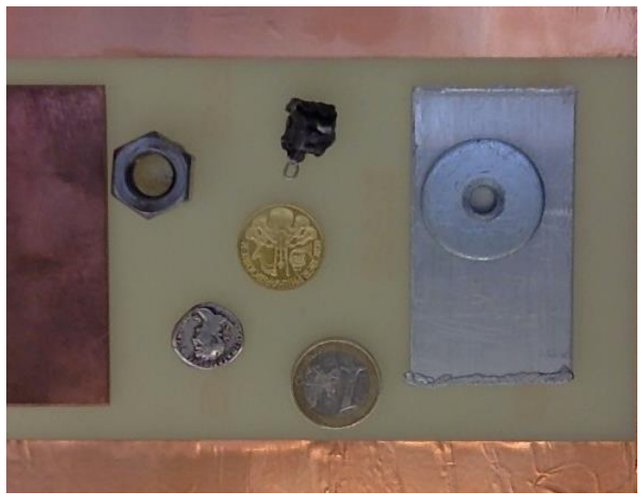
~36% before gain uniformity correction

24.7% after gain uniformity correction

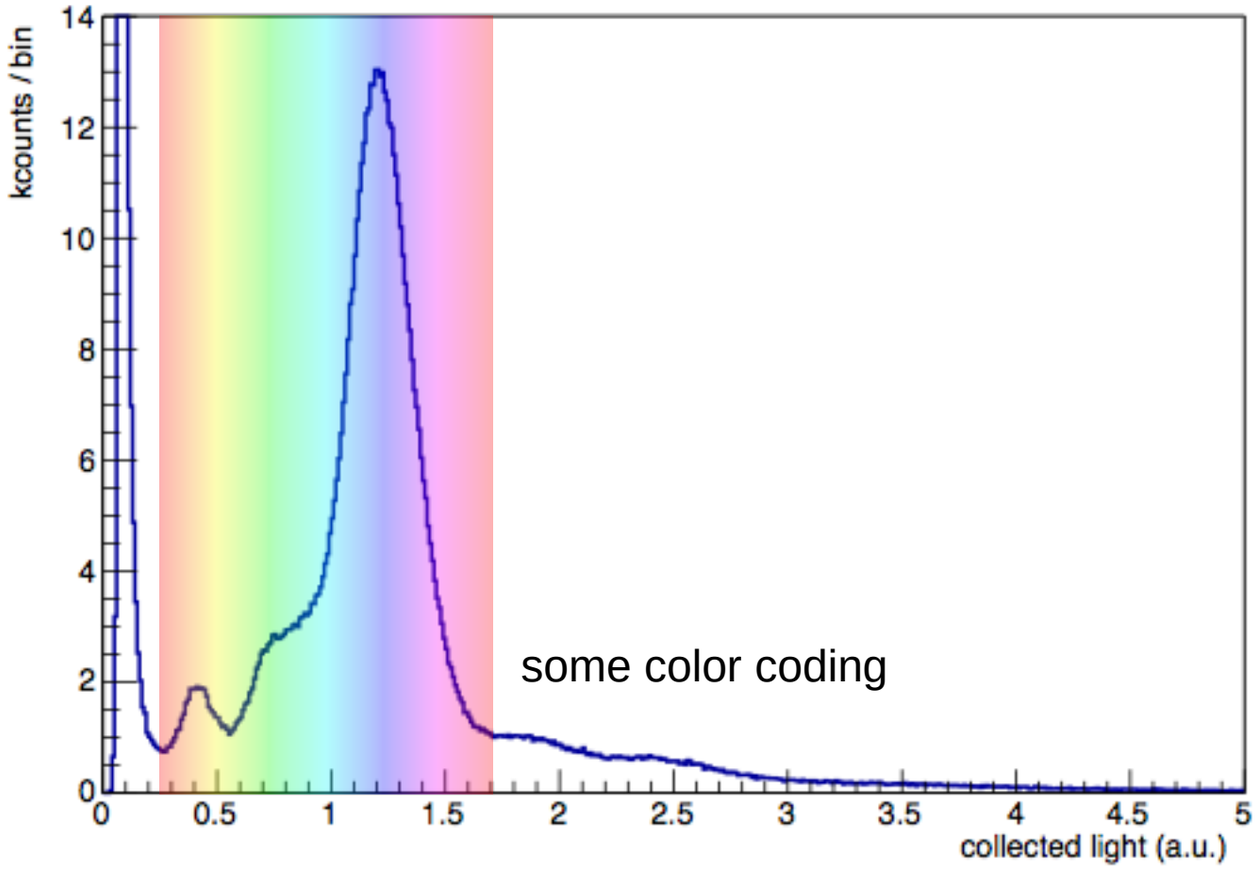
Fluorescence event by event

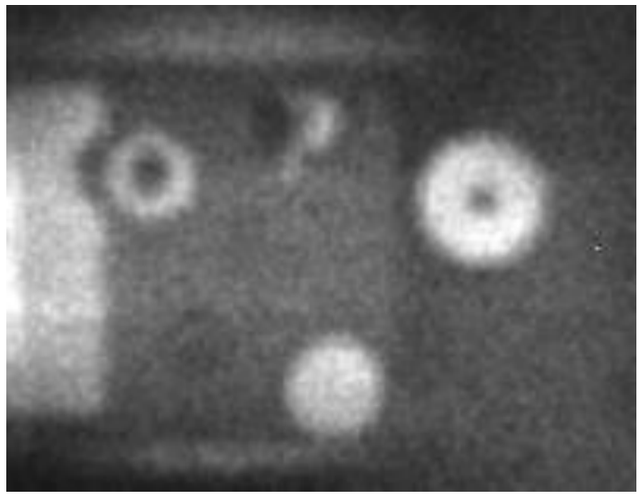


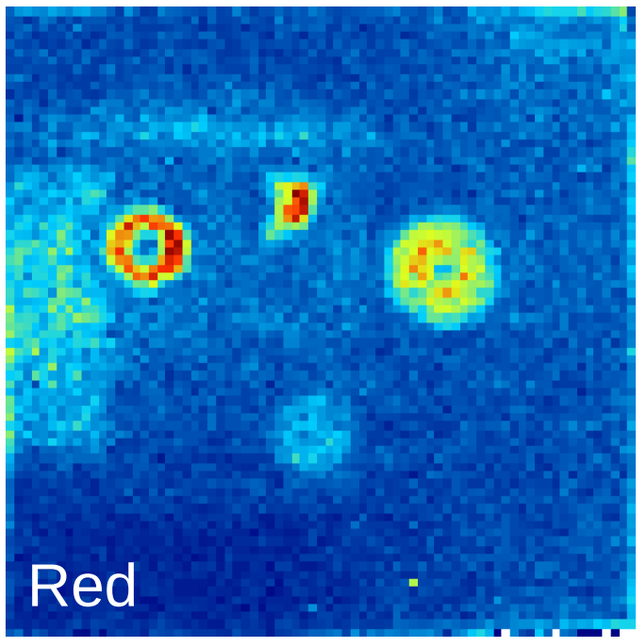


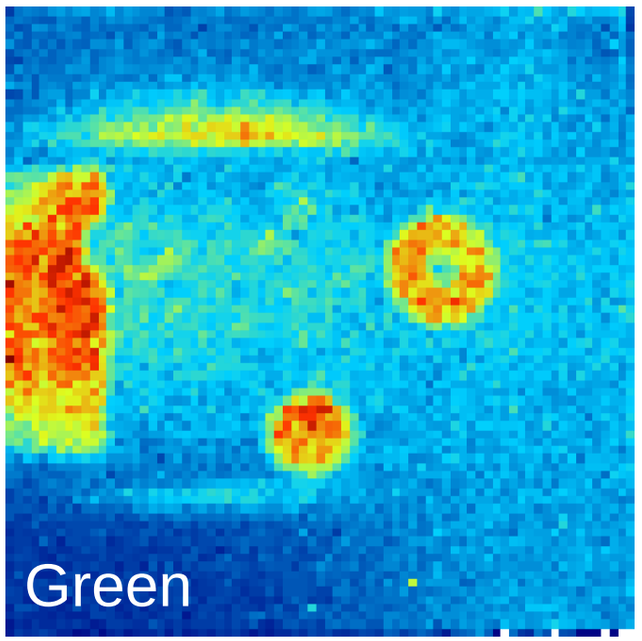


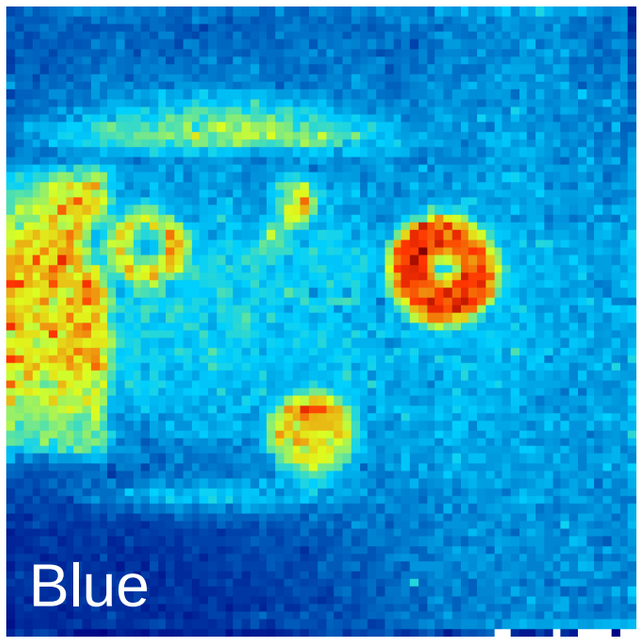
Fluorescence event by event



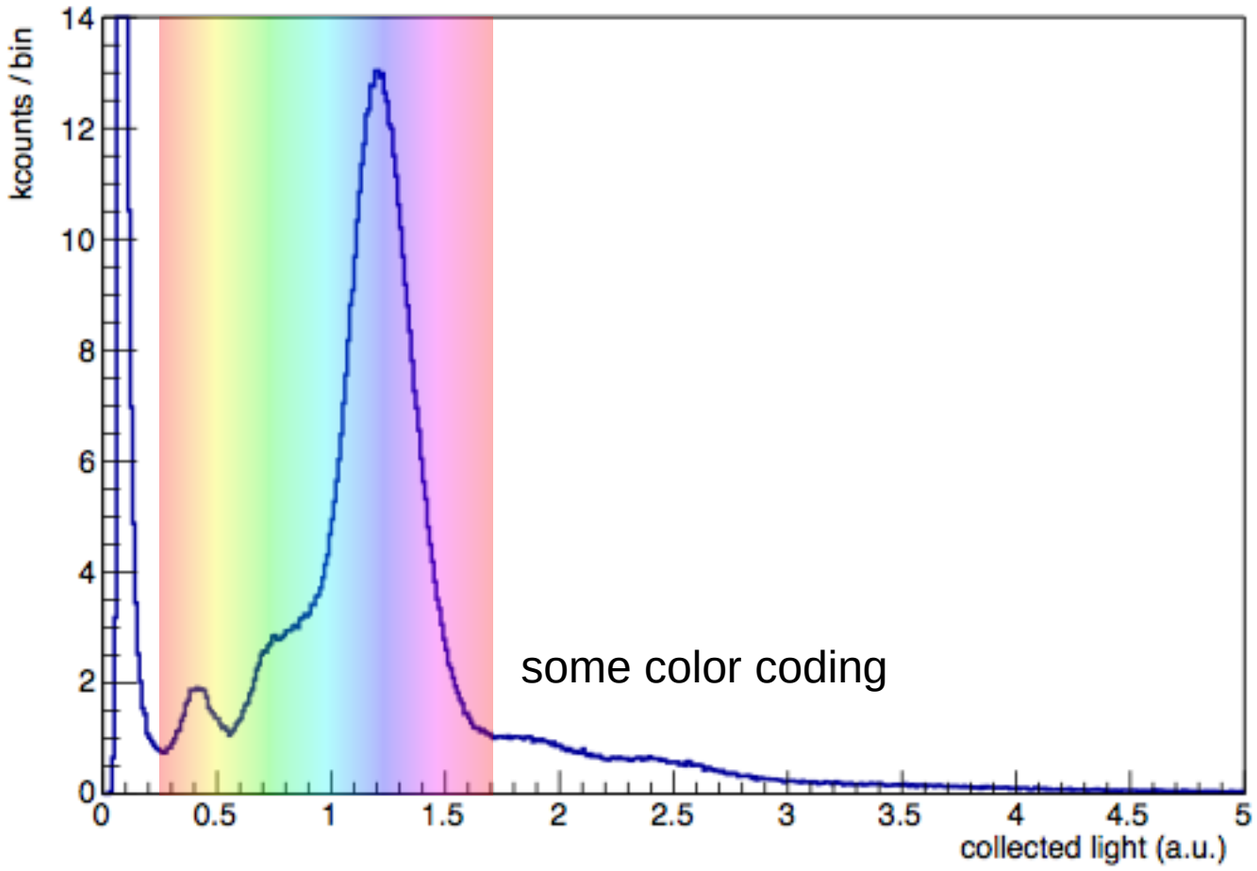


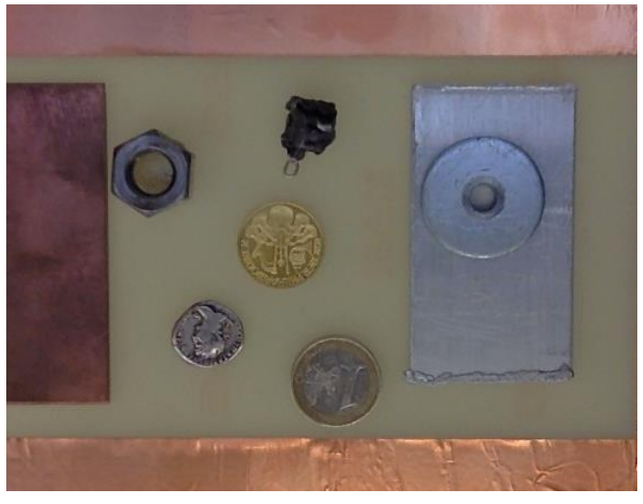




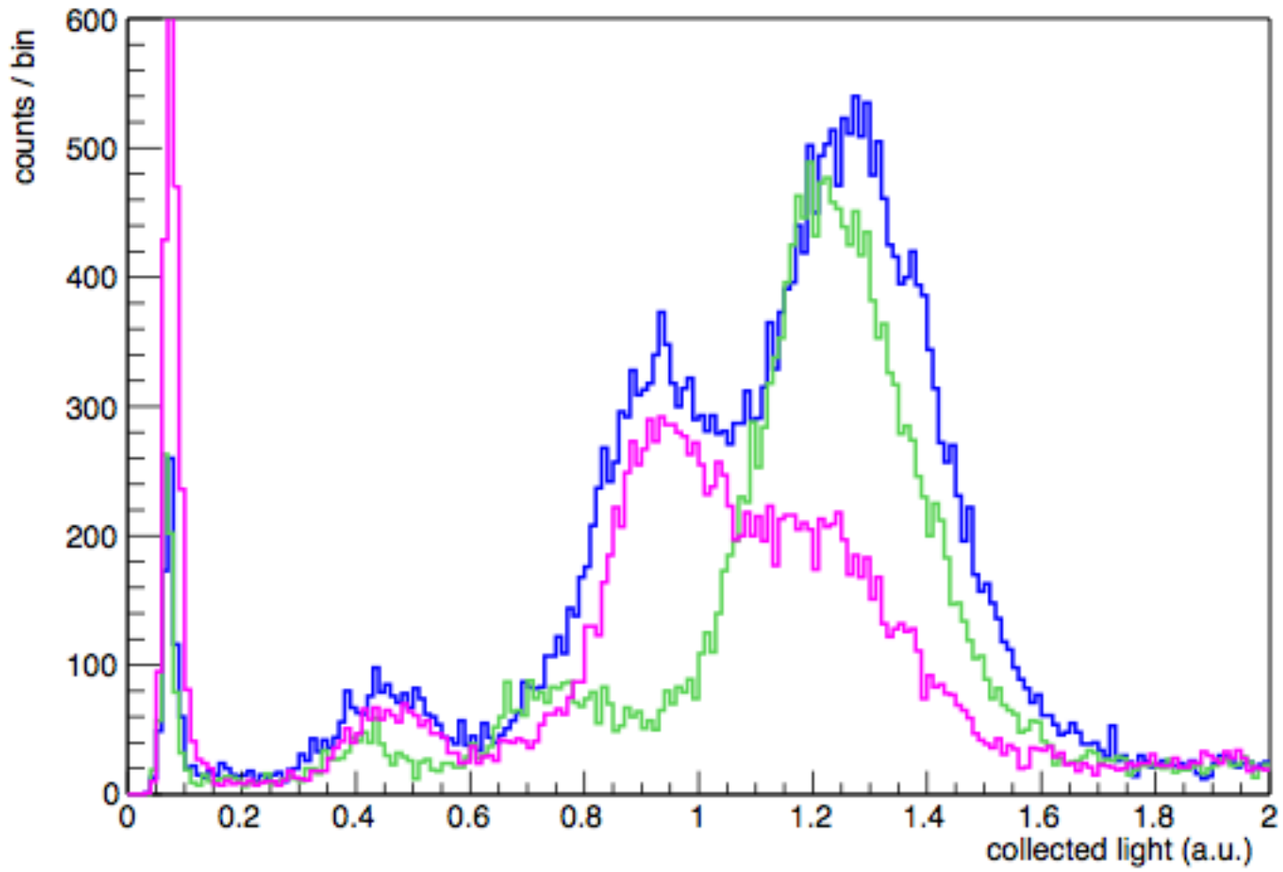


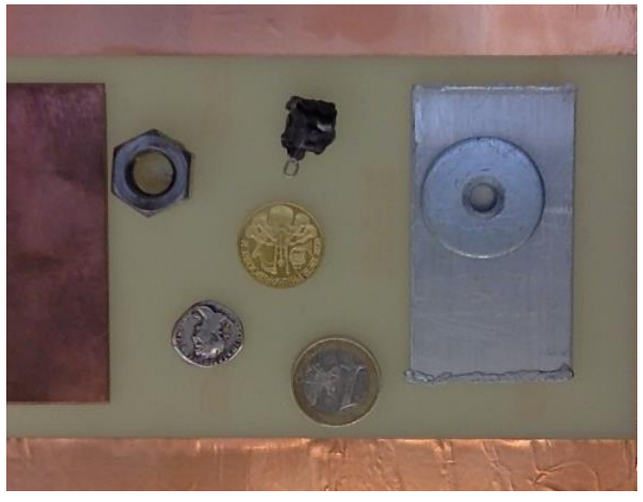
Fluorescence event by event





Fluorescence event by event





It’s Zinc

Possible other application

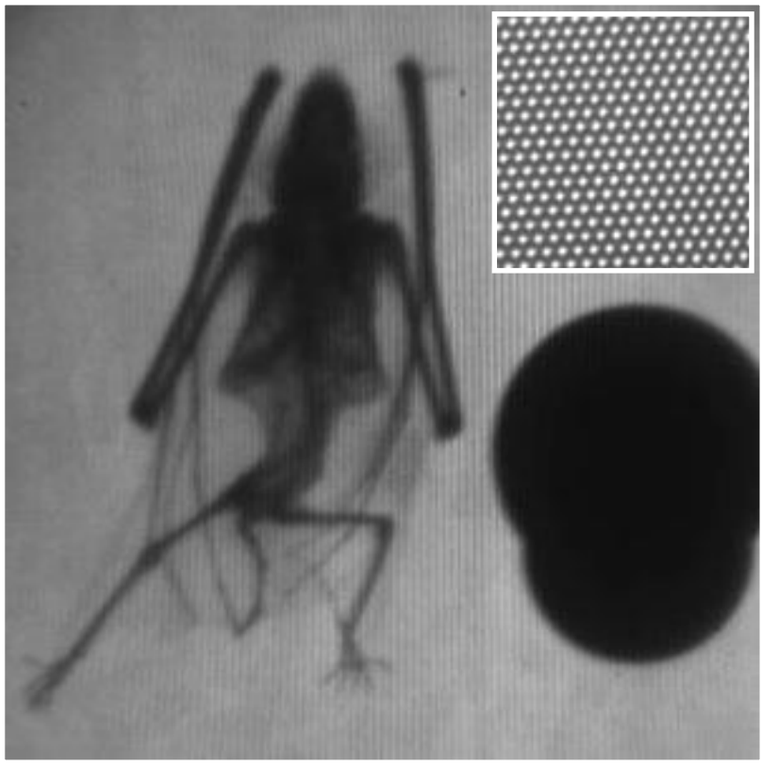
X-ray crystallography

UV imaging

Neutron imaging

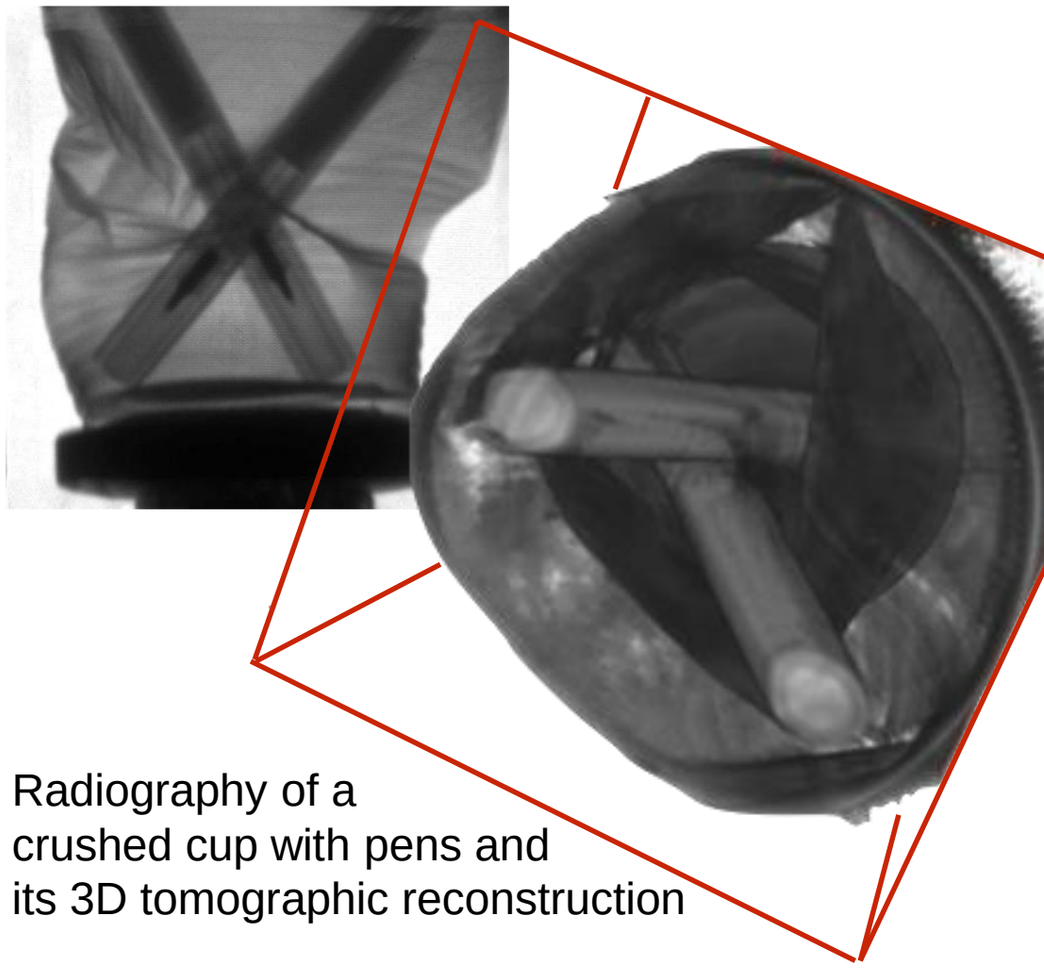
Gamma imaging

…

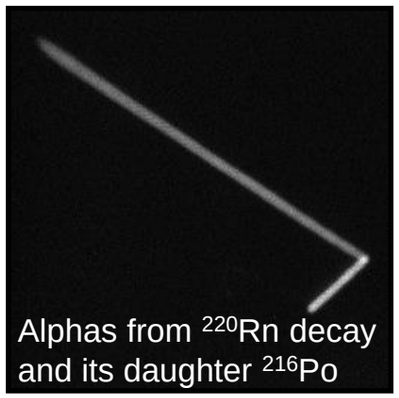


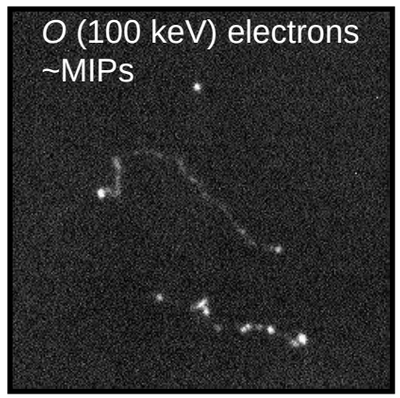
Radiography of a bat
and closeup of the GEM holes

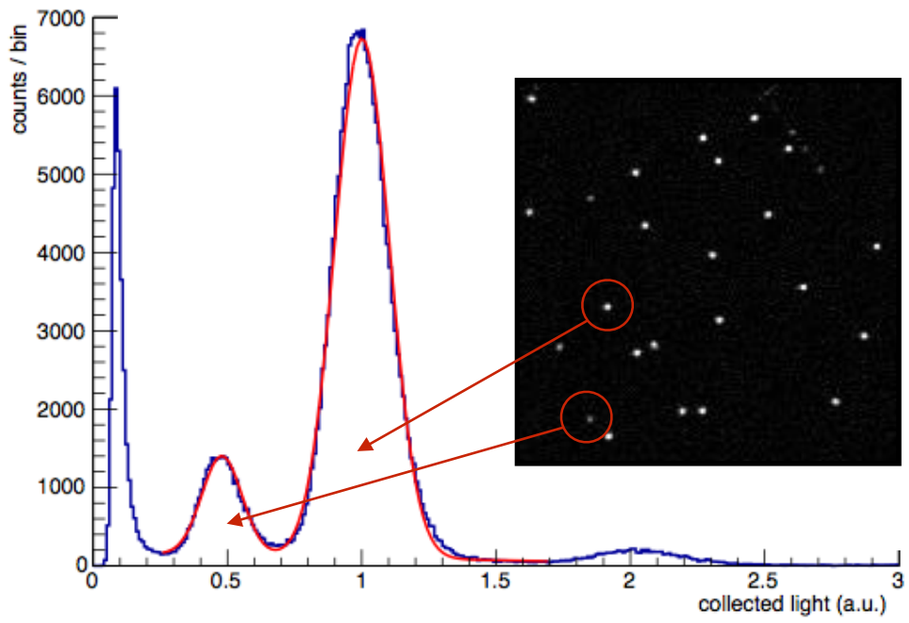
Freeze-frame of an X-ray
movie of a flying drone



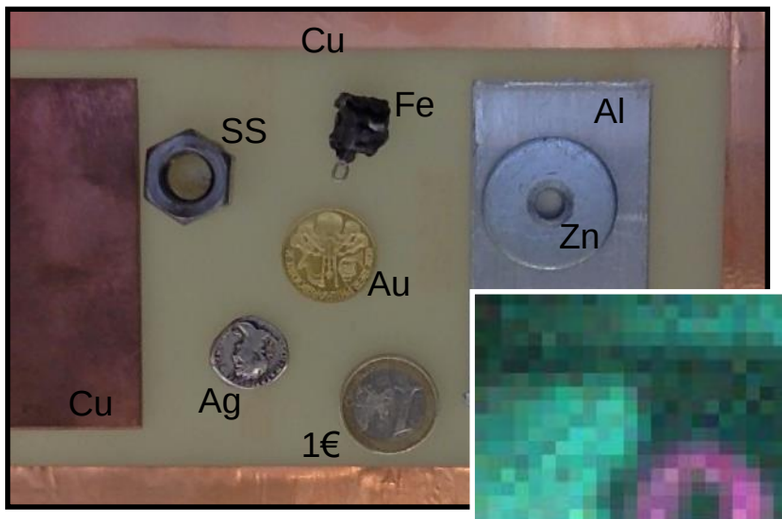
Radiography of a
crushed cup with pens and
its 3D tomographic reconstruction







Single X-rays from ^{55}Fe
and the energy spectrum
extracted from the images



Visible picture of a *painting*
and its X-ray fluorescence image.
Different colours refer to different
materials (energy resolved)