Development of dual MCP x-ray imager for 40 ~ 200 keV region

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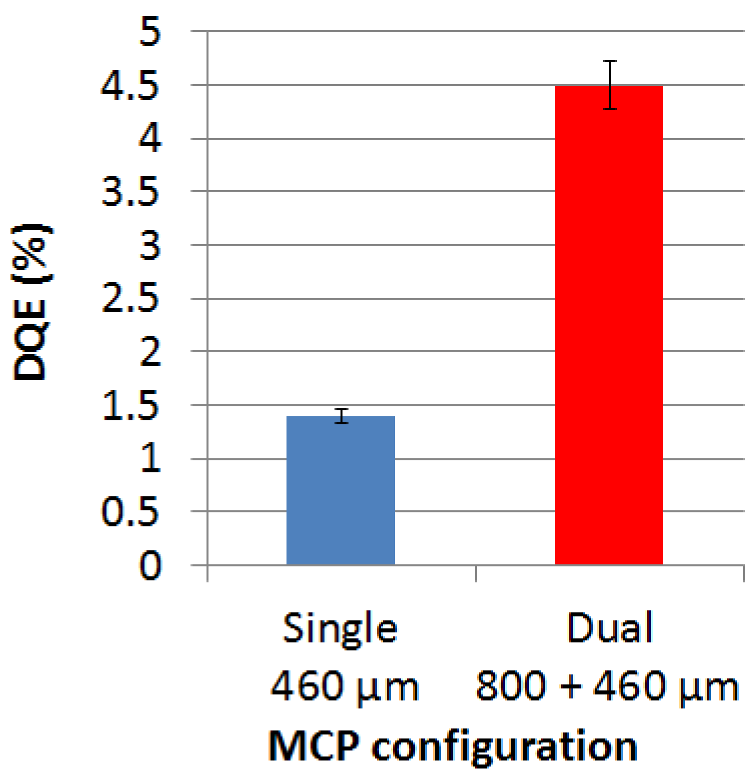
Summary

Using a novel dual MCP, we have demonstrated an imaging detector with 3.2x higher DQE @ 59 keV



MCP thickness	Bias (V)	DQE (%)	QE (%)
Single 460 µm	775	1.4	8.1
Dual 800 + 460 µm	625 + 600	4.5	13.3

(1) Compton radiography requires gated x-ray imager with DQE > 4%

(2) Single MCP camera becomes noisy over 30 keV due to depth dependent electron gain of MCP

(3) With using dual MCP, it is possible to suppress the noise due to depth dependent gain

(4) With using with dual MCP, DQE = 4.5% was achieved

(5) The 1st dual MCP camera AXIS is in its production phase

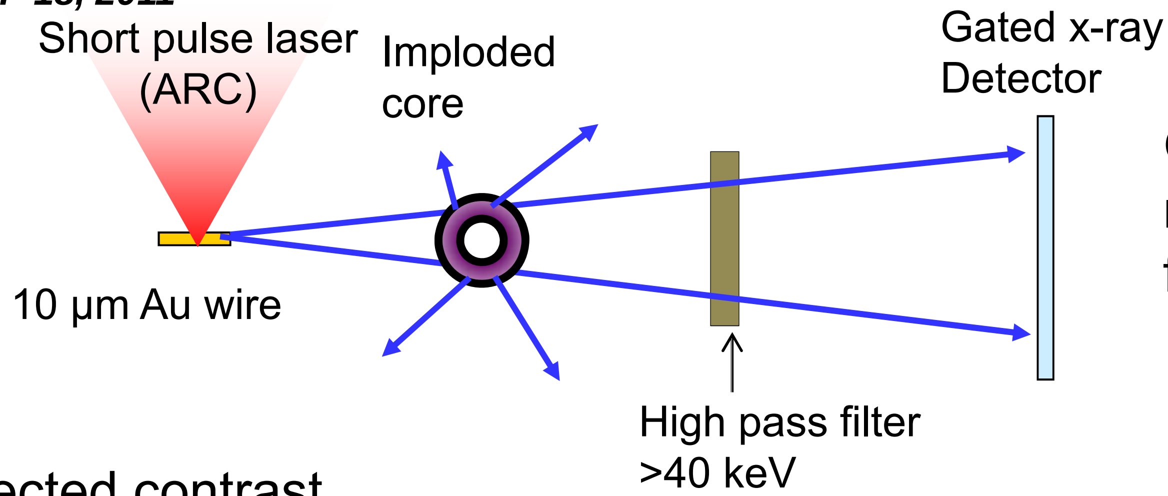
MOTIVATION

We need a gated imager for 40~200 keV x-rays

Compton backlight

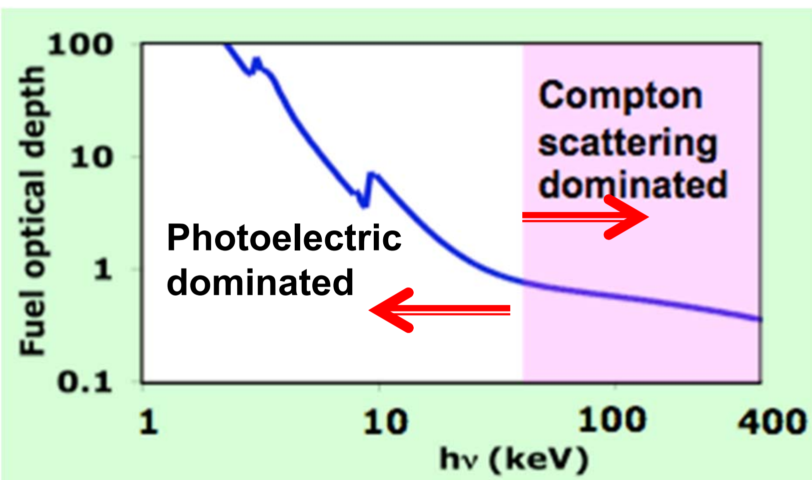
Radiography based on Compton scattering can reveal the DT fuel assembly near bang time

Tommasini, et al., PoP 18, 2011



Gating is essential to reduce background from hohlraum

Expected contrast



Ideal contrast (OD ~1) for high density DT fuel near maximum compression time

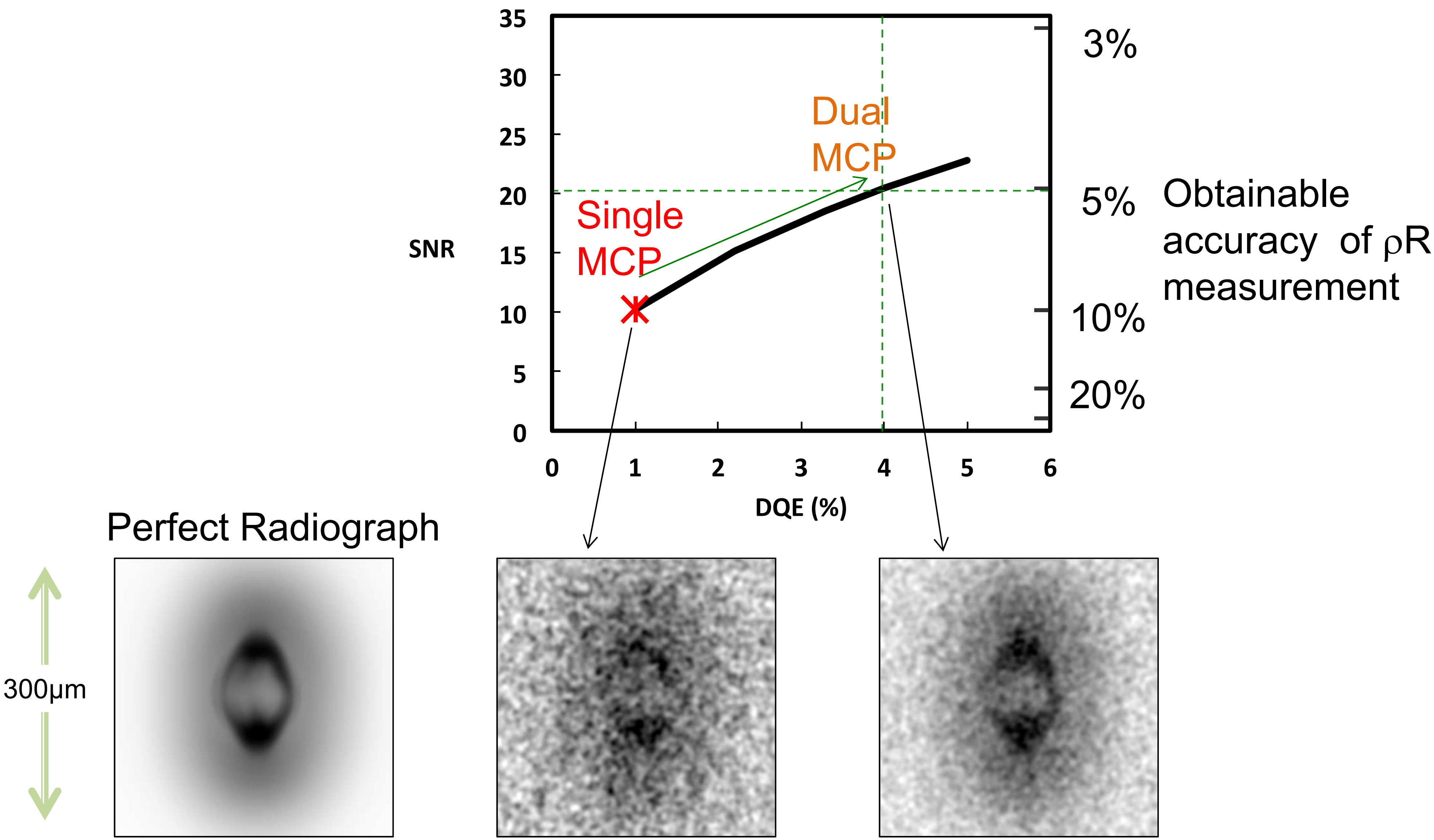
Flat cross section allows broadband radiography (40~ 200 keV)

10x-20x more signal than K-alpha

High-pass filtration suppress the background from core emission

Compton radiography requires gated imager which works well in 40~200 keV region

We need a DQE of 4% to achieve a SNR of 20 to measure fuel ρR with 5% rms accuracy

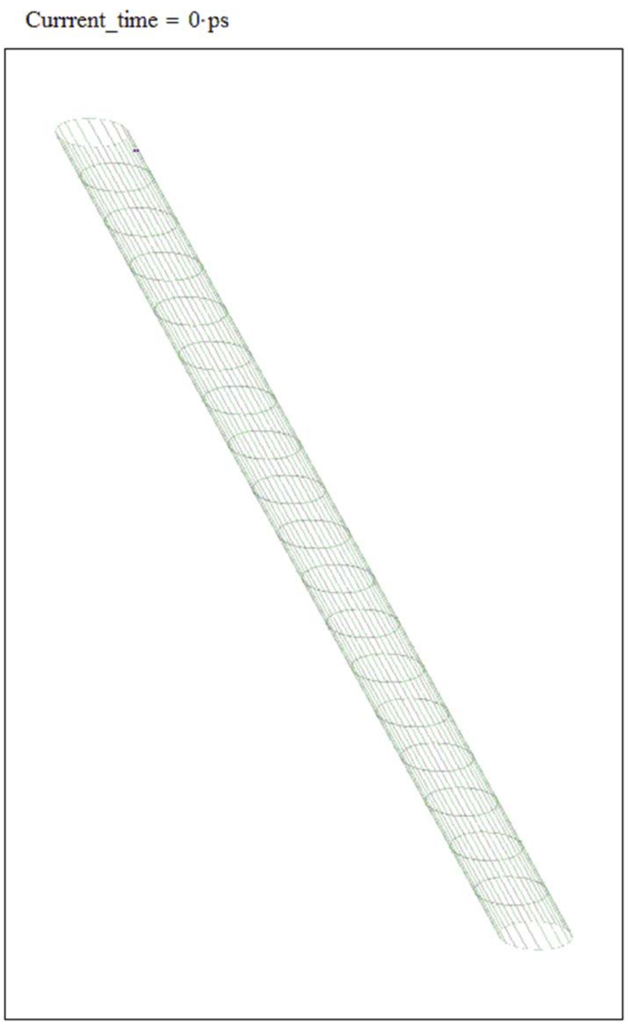


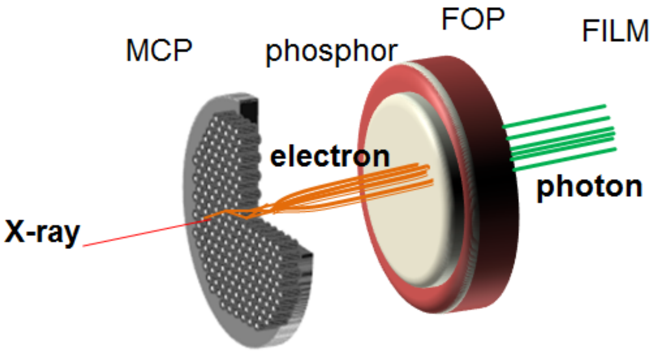
Why do we need a new detector?

Conventional MCP cameras becomes noisy in high energy regime

Standard MCP based camera becomes noisy for x-ray energy over 30 keV

Why does MCP image become noisy over 30keV?





(1) Stochastic behavior of avalanche stream
Multiplication has event-by-event variability

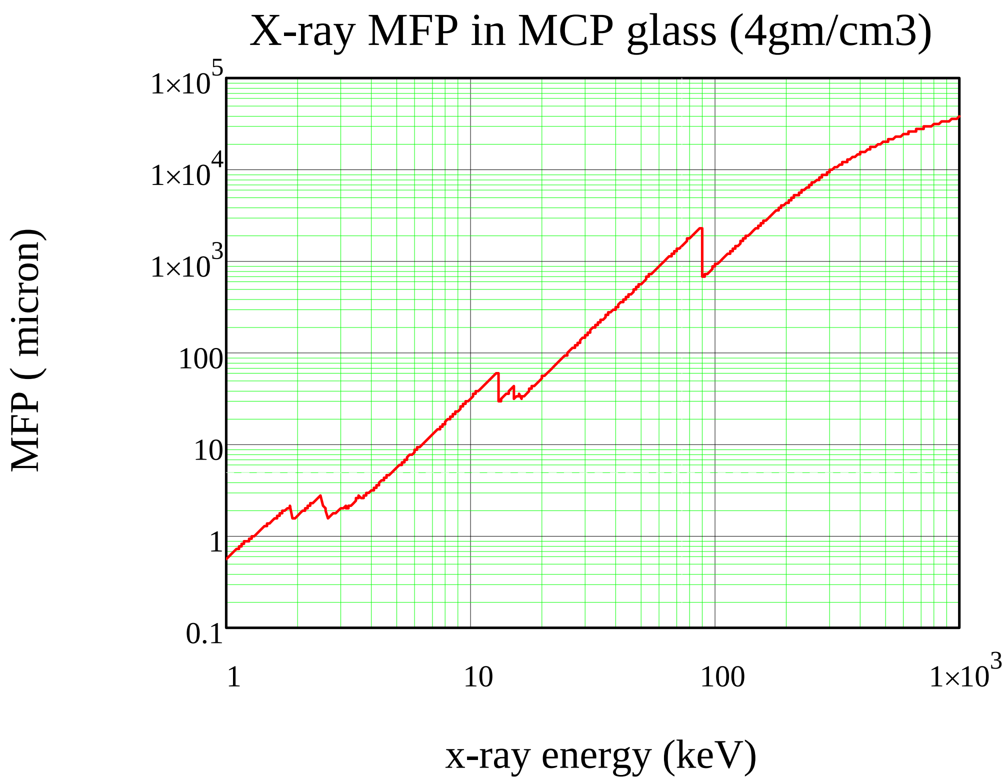
(2) Avalanche starts from few electrons

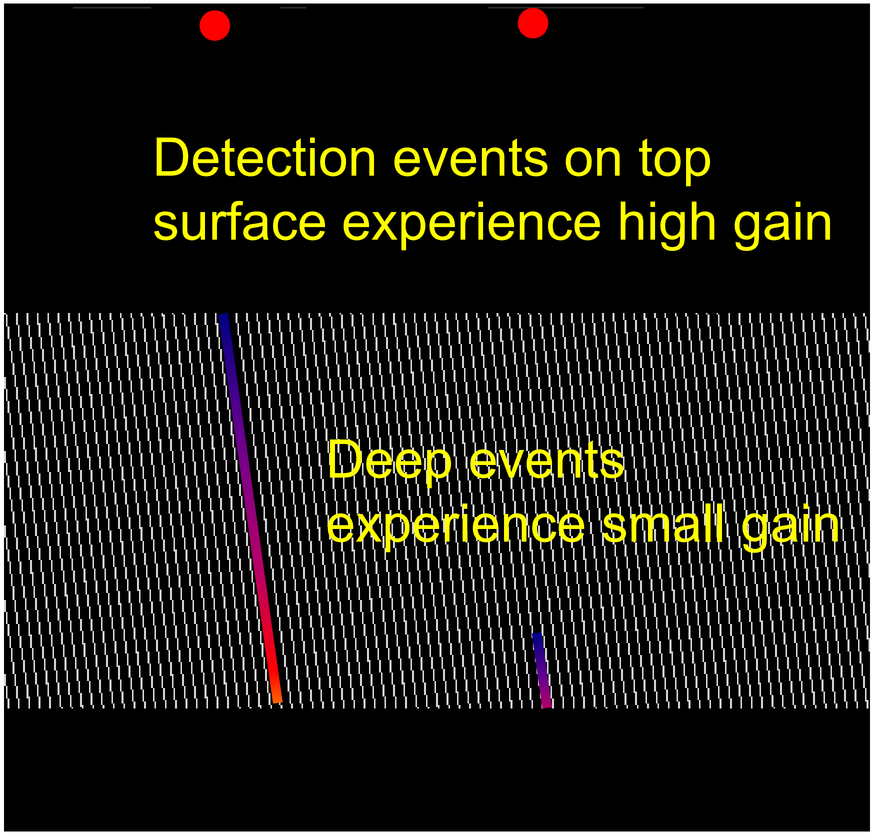
(3) Depth dependent MCP gain
High energy x-rays penetrate deep into MCP

➔ NEXT slide

MCP gain depends on the depth of the detection event

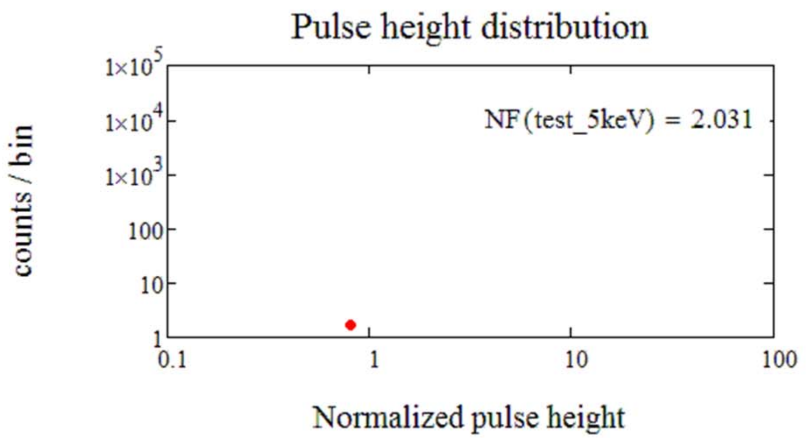
Depth effect is significant for high energy x-rays



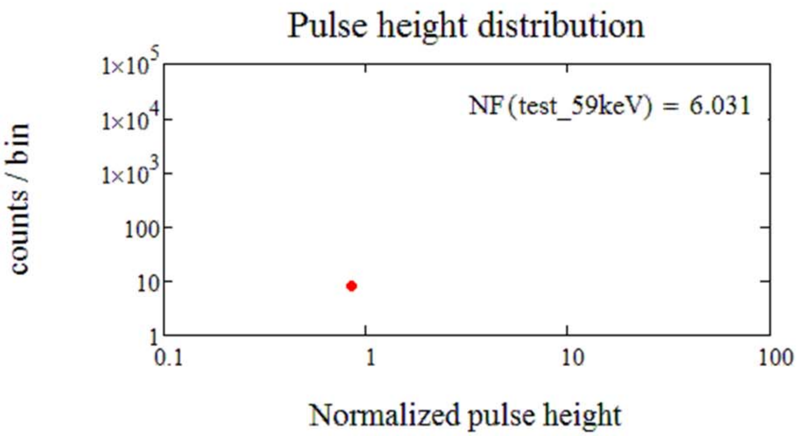


Due to this depth dependent gain, width of the pulse height response depends on x-ray energy

Narrow PHD for 5 keV photons



Broad PHD for 59 keV photons

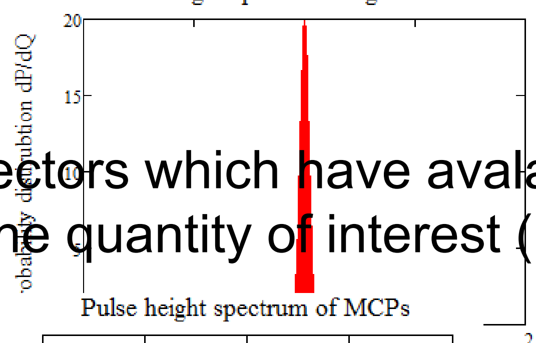


What is DQE?

High DQE = low NF

Detective Quantum Efficiency (DQE) is a useful metric to evaluate SNR of noisy detectors

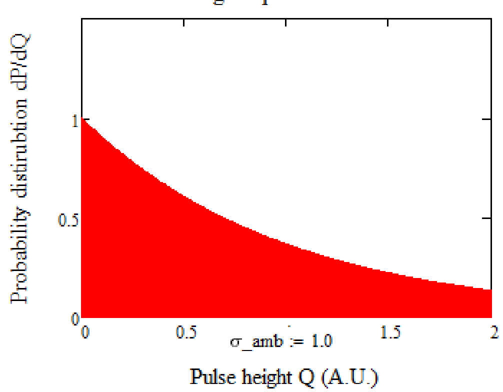
(1) Quantum efficiency (QE) is a good metric for detectors which have narrow pulse height distribution (e.g. CCD, HPGe)



$$QE \equiv \frac{N_{detected\_events}}{N_{incident\_photons}}$$

(2) For detectors which have avalanche amplification noise, DQE is the quantity of interest (e.g. Proportional counter, MCP)

$$SNR = \sqrt{QE \times N_{incident\_photons}}$$



$$DQE \equiv \left(\frac{SNR_{out}}{SNR_{in}} \right)^2$$

$$SNR_{out} = \sqrt{DQE \times N_{incident\_photons}}$$

Noise Factor (NF) is another useful metric which represents the relation of QE and DQE

(1) Quantum Efficiency

$$QE \equiv \frac{N_{detected\_events}}{N_{incident\_photons}}$$

(2) Detective Quantum Efficiency

$$DQE = \frac{QE}{NF}$$

$$where \quad NF = 1 + \frac{\sigma_{cl}^2}{<\xi>^2}$$

Cluster noise
Standard deviation of the ***pulse height distribution***

Average of the pulse height distribution

Narrower pulse height response

Lower NF

Higher DQE

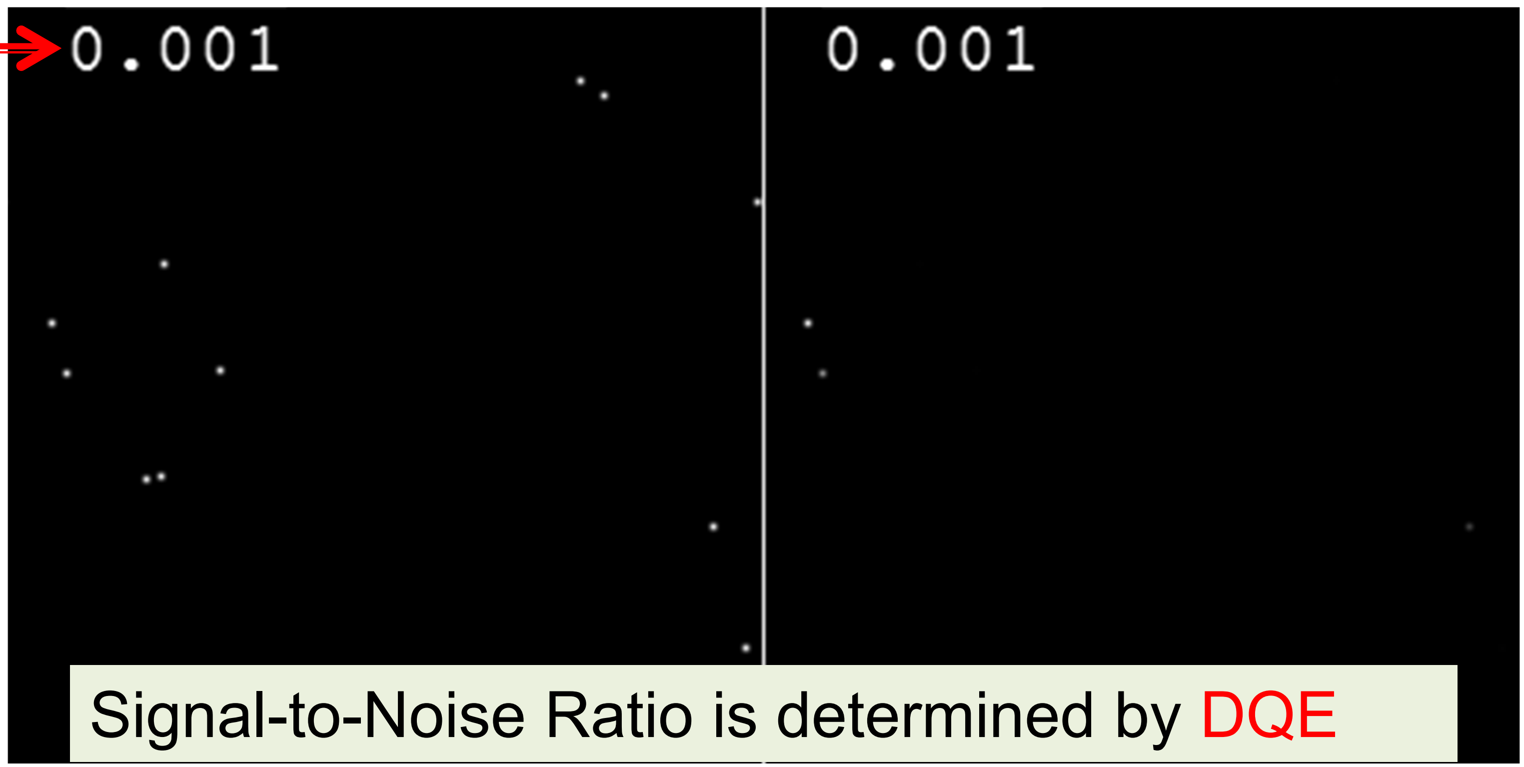
To achieve required SNR, we need a detector which has high DQE (small Noise Factor)

Comparison of two detectors with the same QE

High DQE detector
QE : 10%
NF : 1
DQE : 10%

Low DQE detector
QE : 10%
NF : 8
DQE : 1.25%

Detected events per resolution element



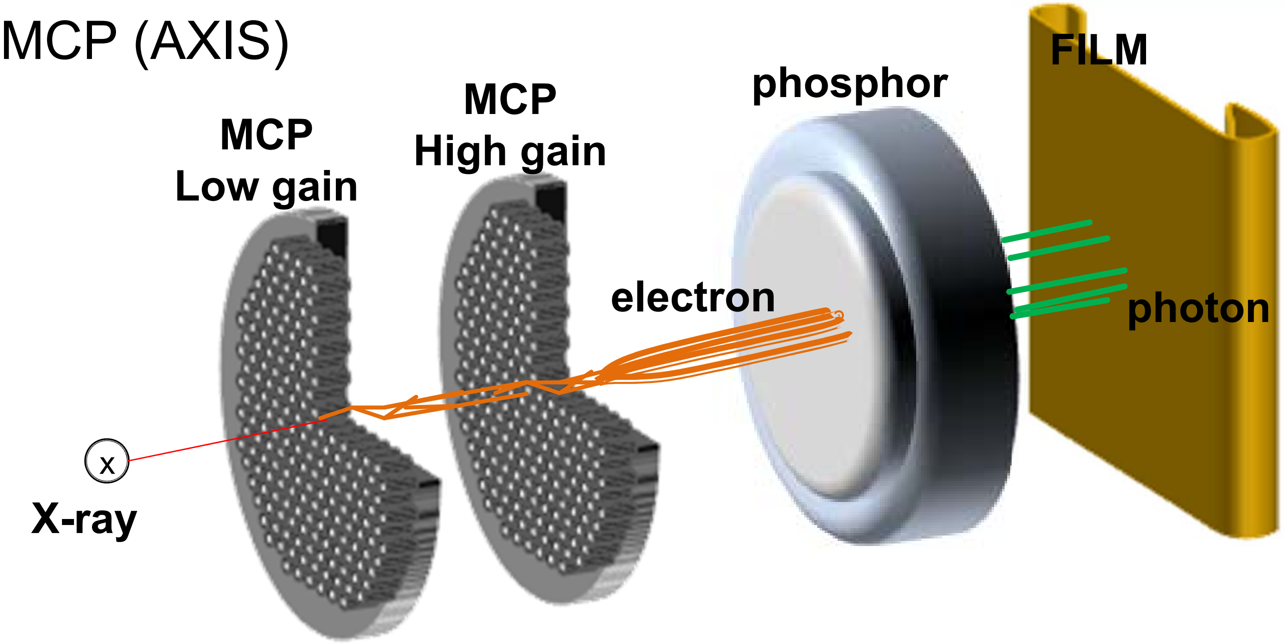
Signal-to-Noise Ratio is determined by DQE

CONCEPT

We can reduce noise using a dual MCP configuration

We are increasing DQE using a dual MCP configuration

Dual MCP (AXIS)



The 1st MCP (800 μm thick) is operated in low gain and works as **thick photocathode**

The 2nd MCP (460 μm thick) is operated in high gain and works as **main amplifier**

Because of low gain of the 1st MCP, the output is less sensitive to the depth of the detection ➔ high DQE

The dual MCP provides good performance regardless of gain setting

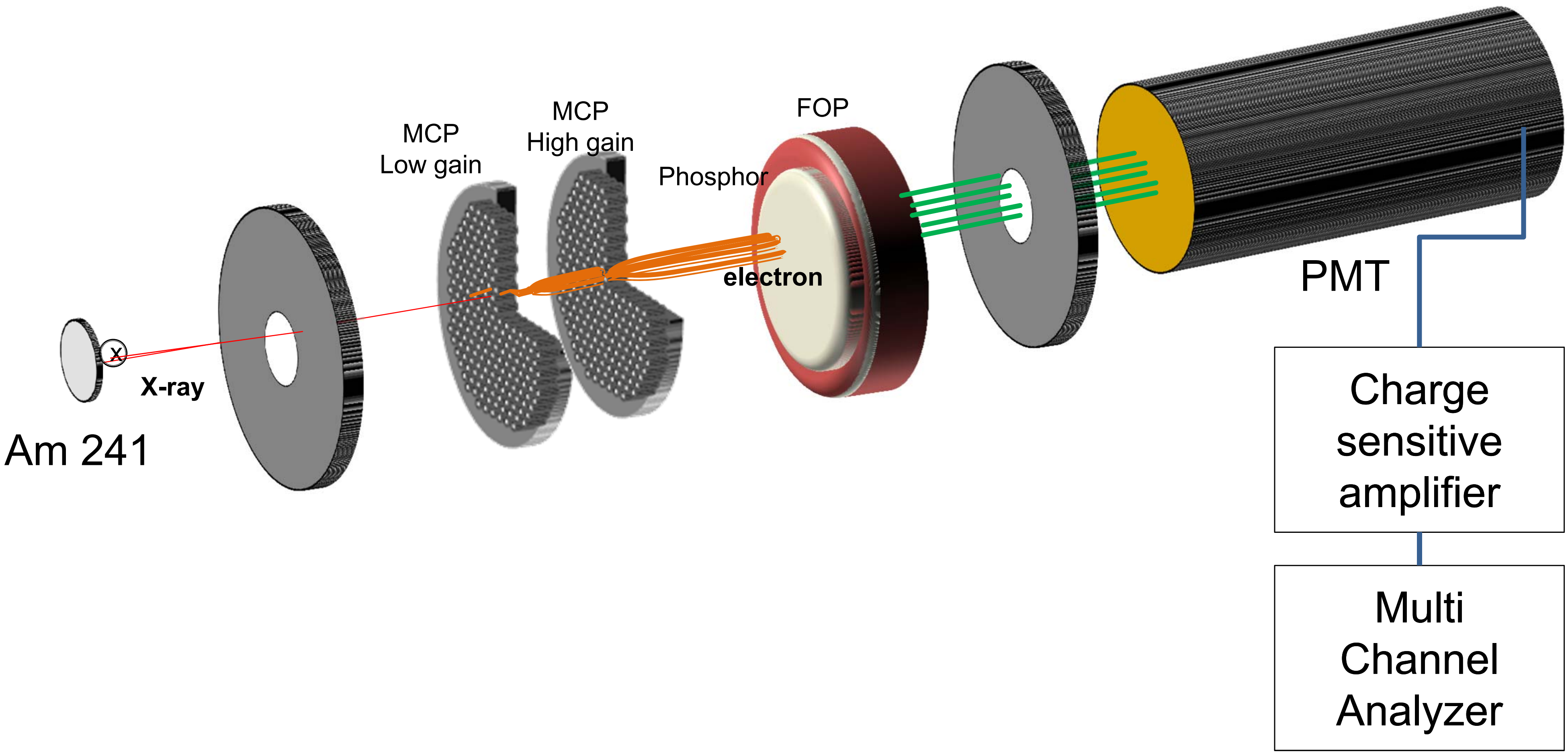
Expected performance for 60 keV x-rays (Gain ~1000x)

	Dual MCP 800 + 460 μm	Single MCP 460 μm
QE	13%	8 %
DQE	4 ~ 4.5% Independent to total gain	1.4 % Depends on MCP gain
Dynamic range	Expected to be wide because PHD is narrower	High-end tail of the PHD saturates first (Events near entrance)
Gate width	0.5 ~ 1ns Limited by electron transit time	70 ~ 100 ps Limited by electron transit time

EXPERIMENT

We measured DQE of MCPs

We measured QE and DQE of the dual MCP configuration camera using 59 keV RI source



Dual MCP

The pulse height response changes as a function of bias voltage given to the MCP1

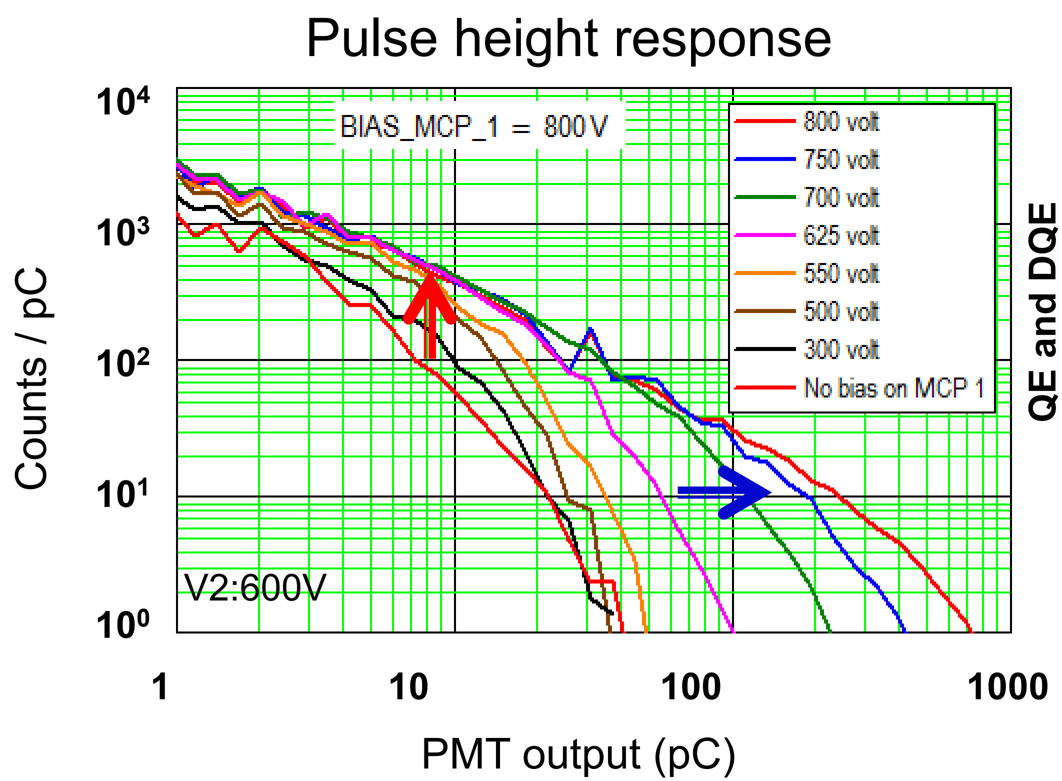
The maximum DQE = 4.5% was observed when MCP 1 bias = 625V

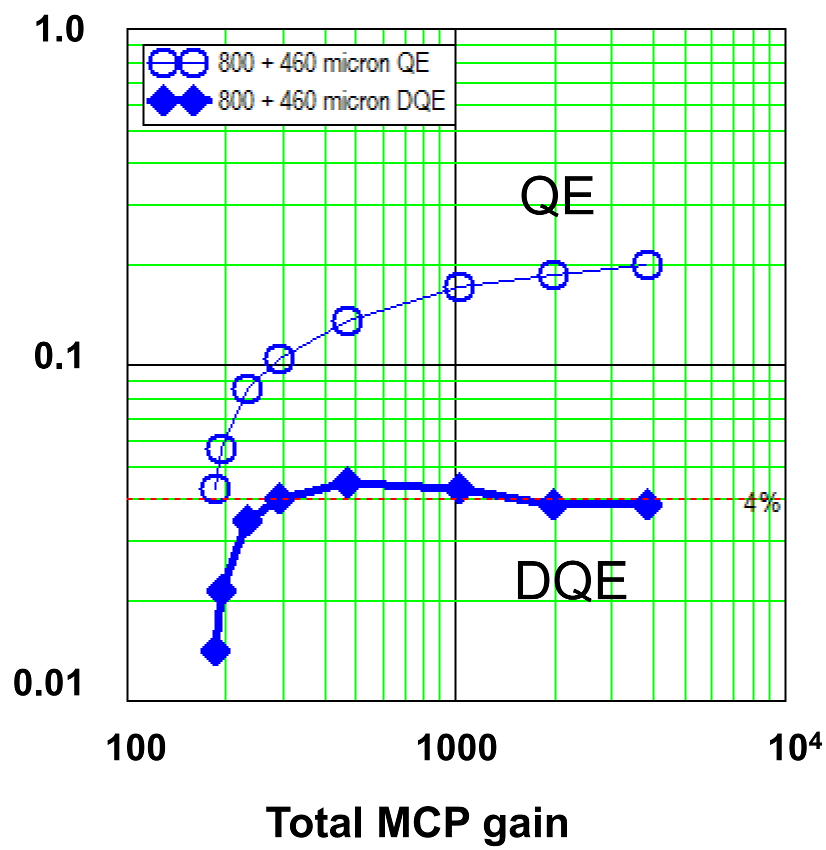
When 1st MCP is turned on, x-rays detected on 1st MCP start contributing the output

When the 1st MCP is not biased, all the events are coming from the 2nd MCP

Beyond this point DQE goes down because pulse height response is expanding (depth dependent gain effect)

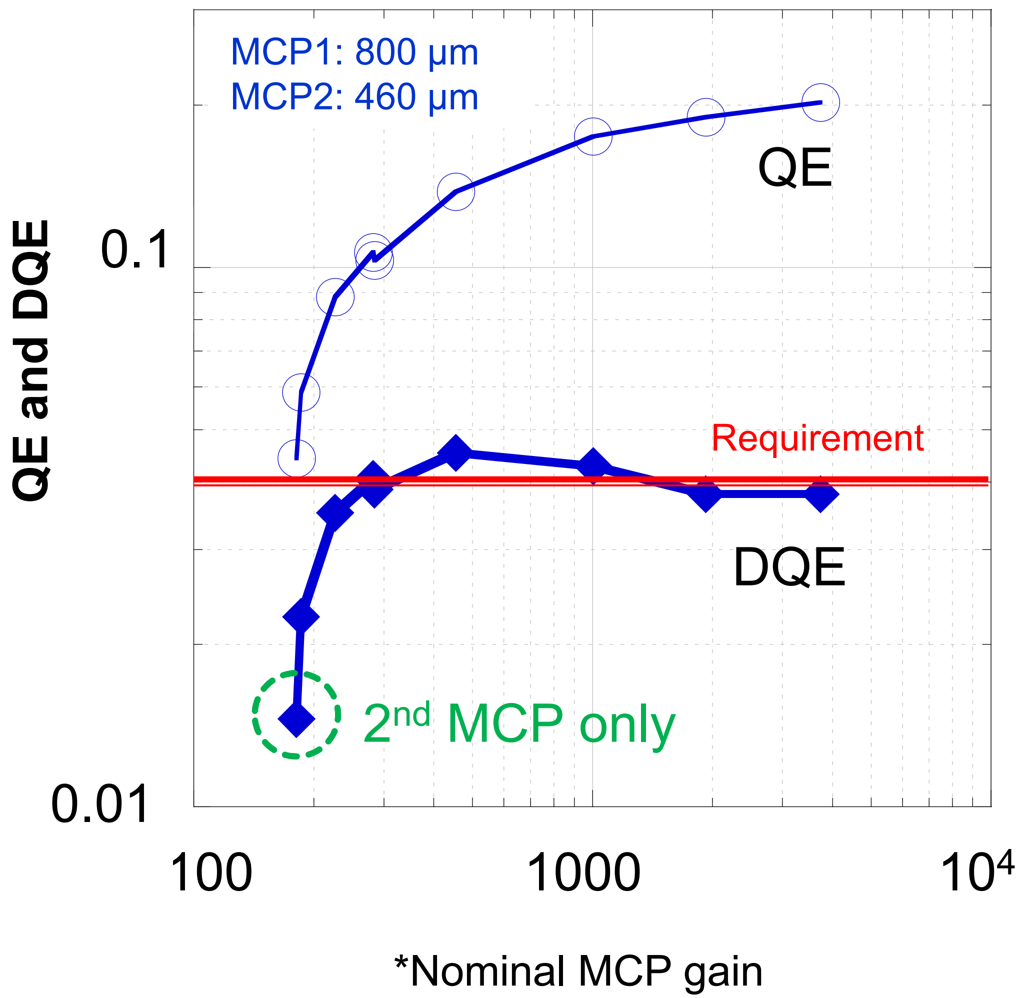
Both QE and DQE go up





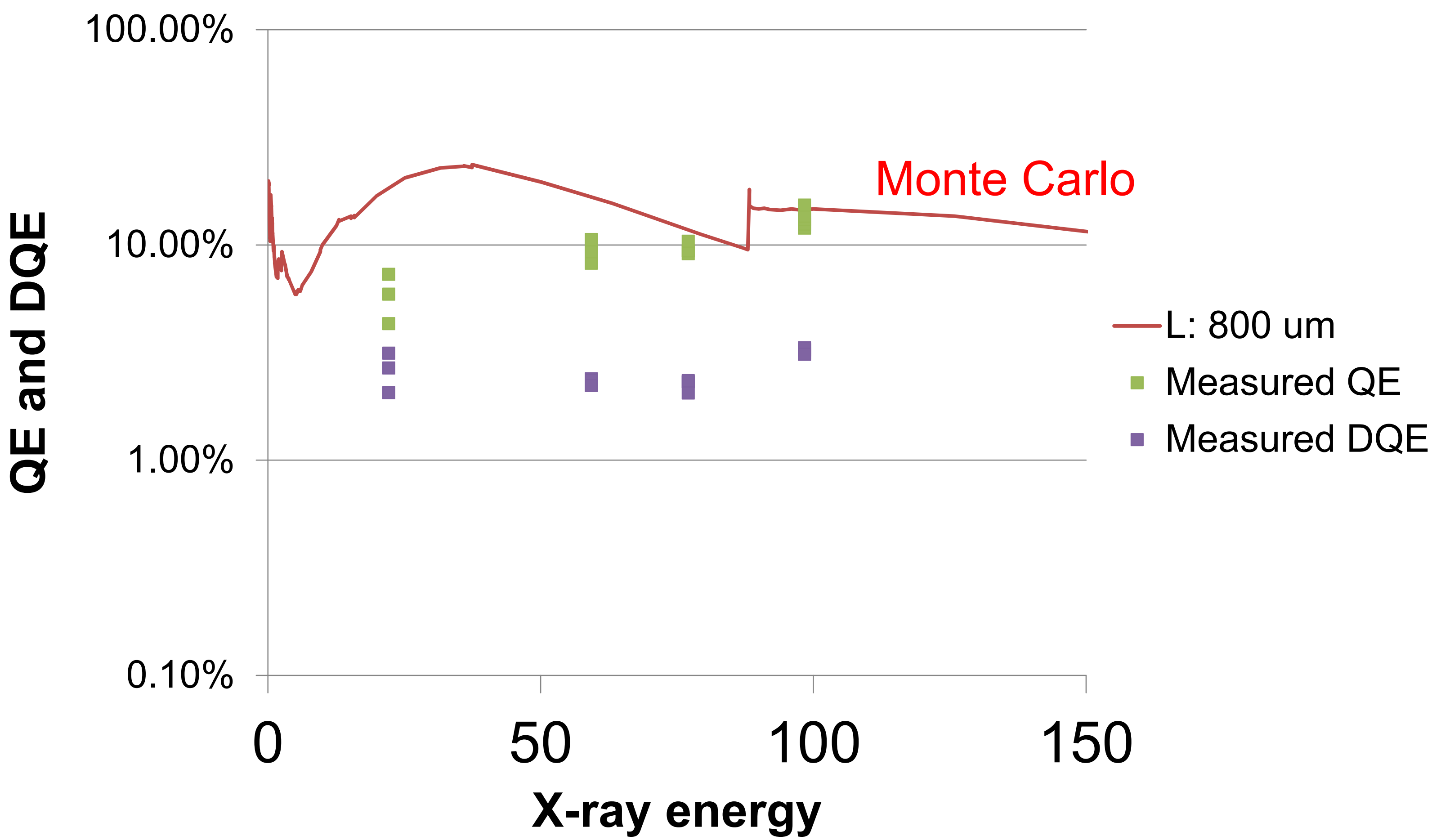
Dual MCP

We optimized the bias voltage of 1st MCP DQE = 4.5% was achieved successfully



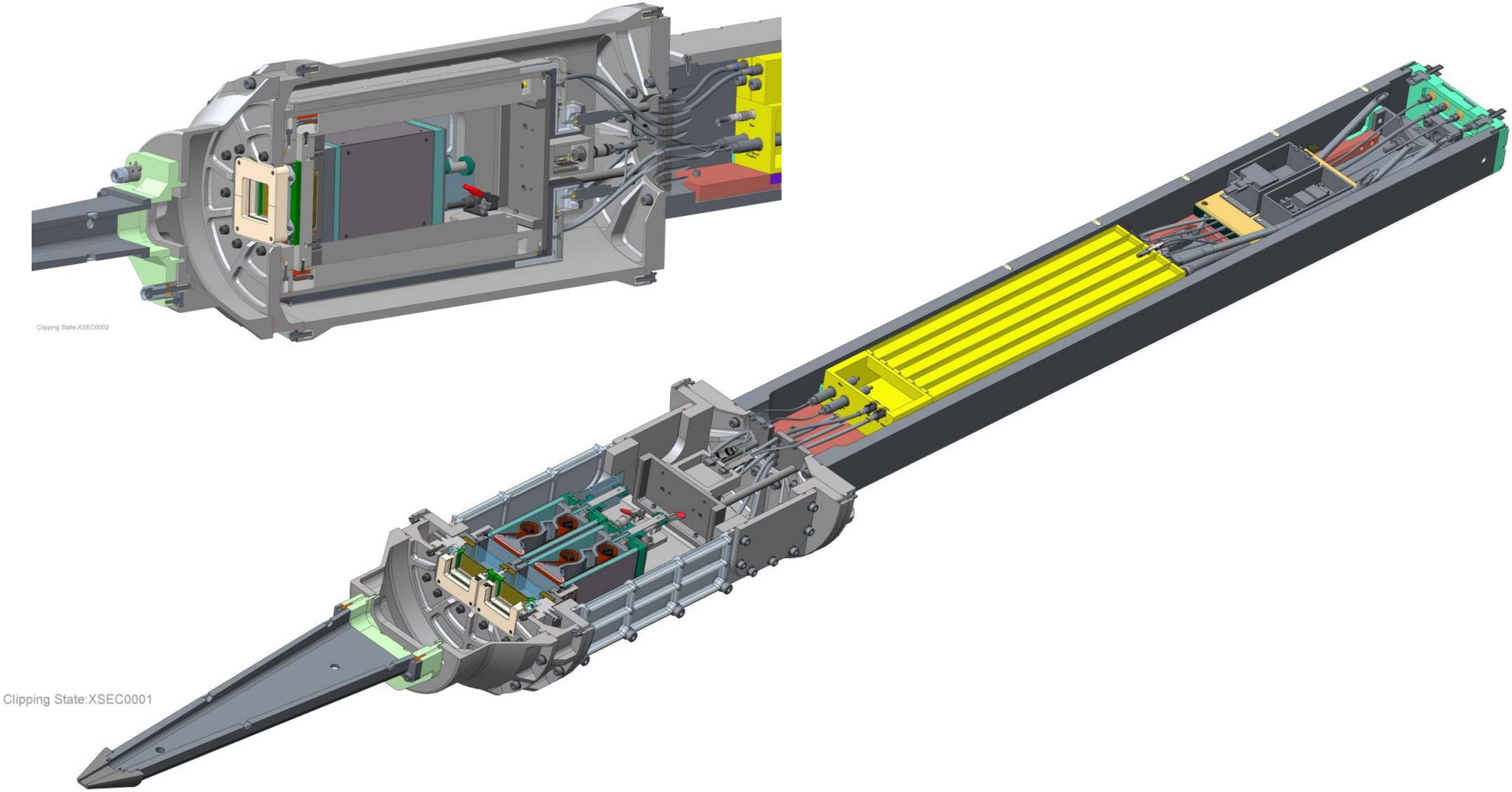
*Total MCP gain was changed by adjusting the bias voltage to MCP1

DQE of the dual MCP set us was measured at several energies using the same method

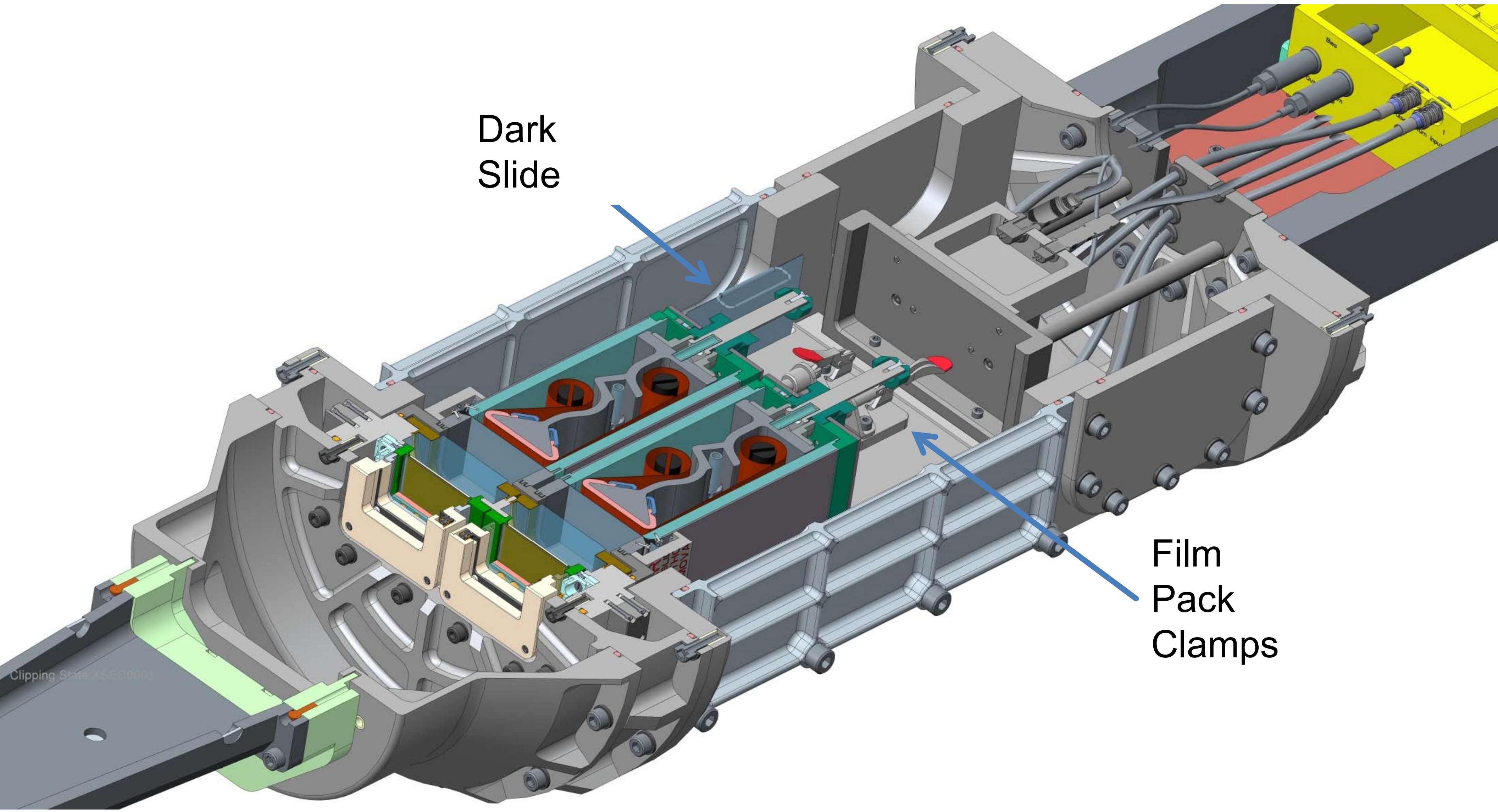


Current status of of AXIS

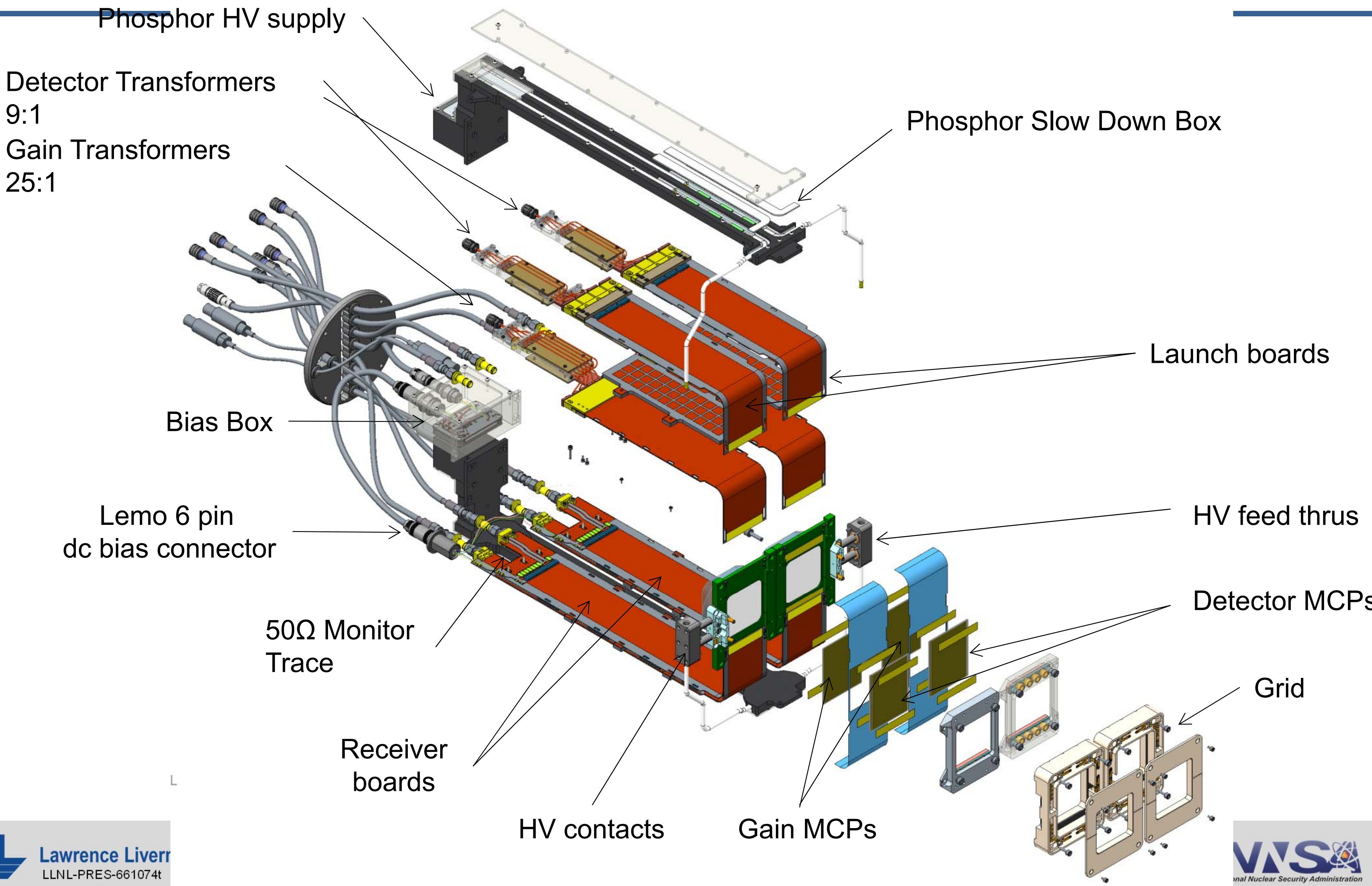
AXIS is DIM based x-ray framing camera with two 40 mm x 40 mm frames



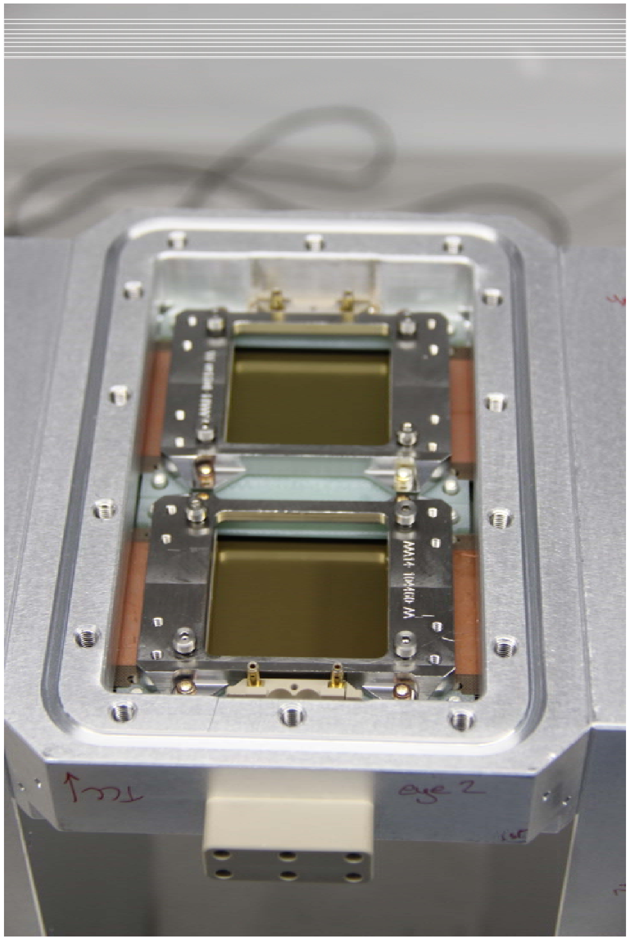
To use in harsh neutron background, KODAK TMAX 400 film is used for recording

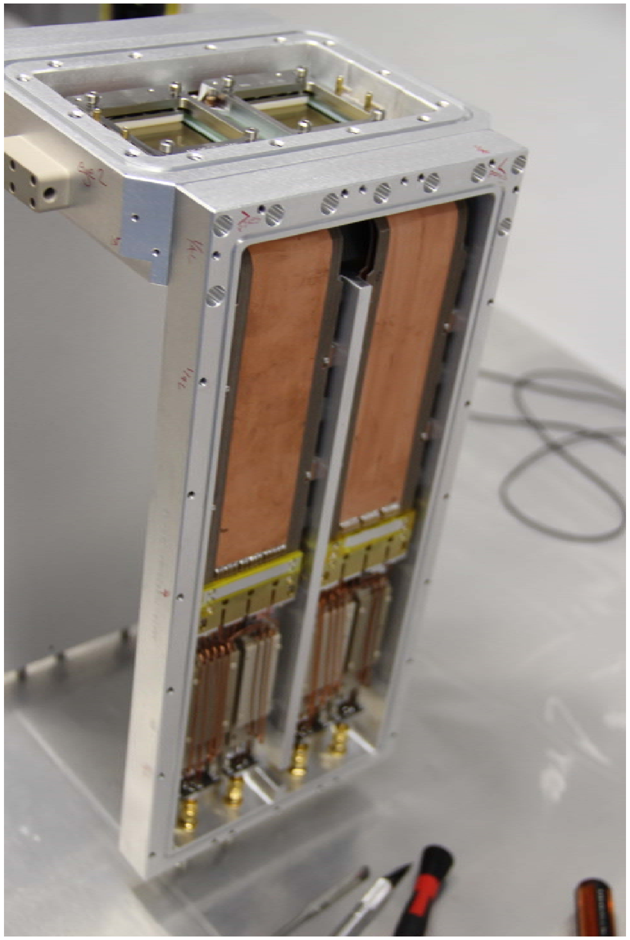


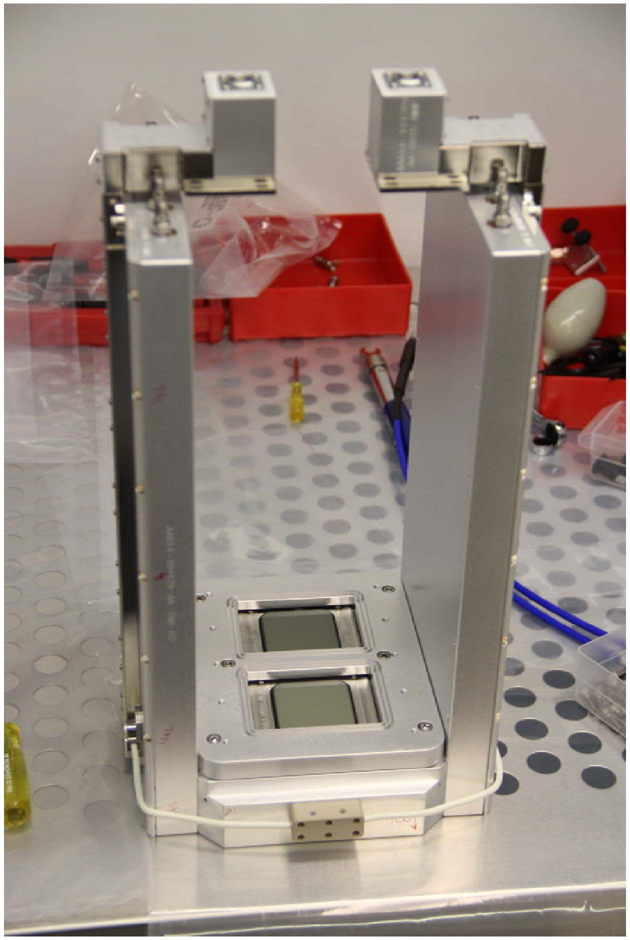
Assemble of MCP head is completed



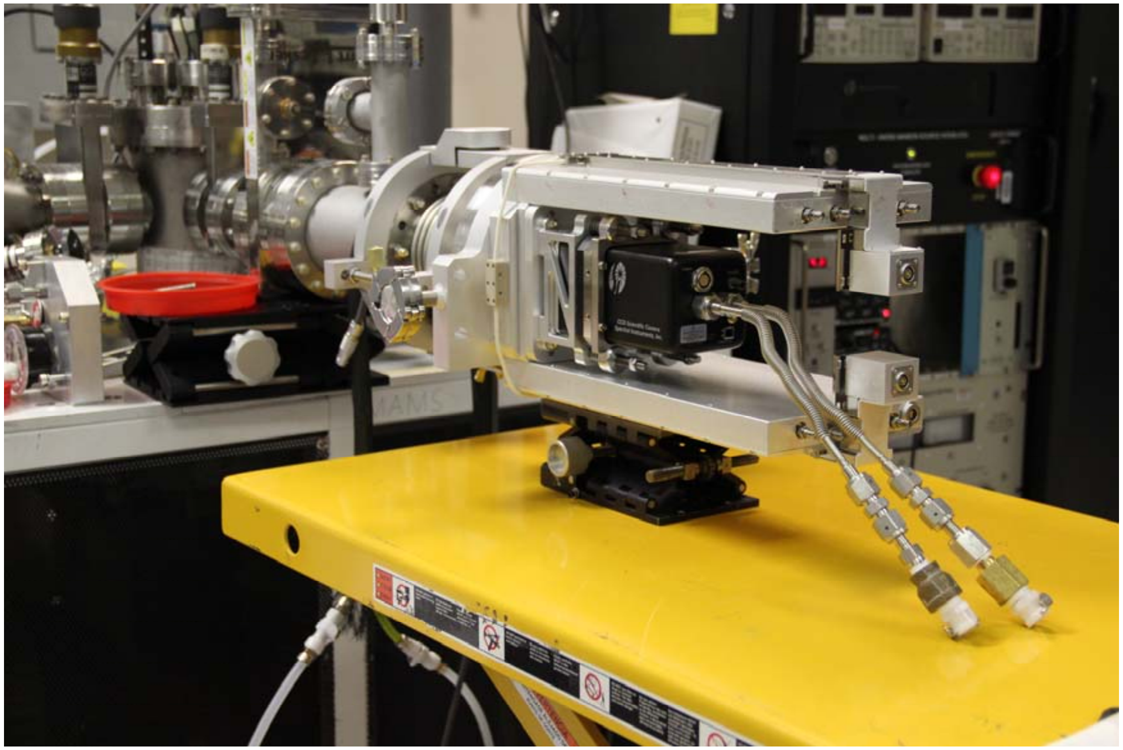
The AXIS head was assembled and currently being tested on HEX source at NSTec

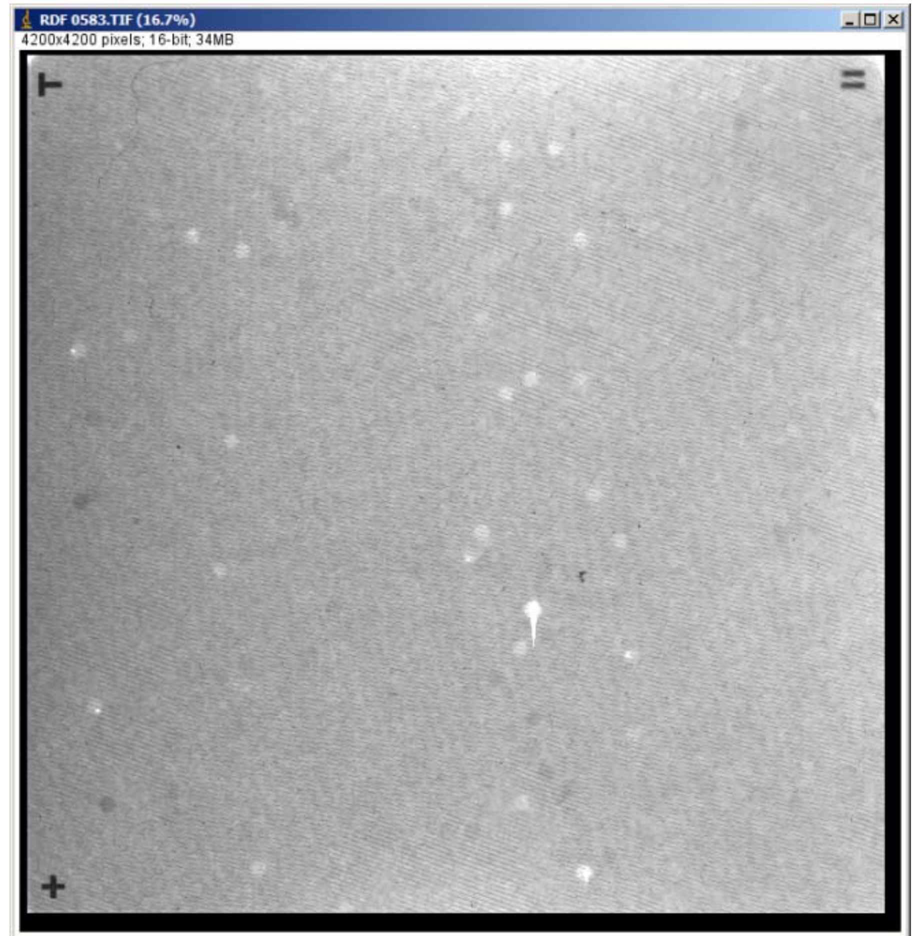






The first AXIS image was obtained with using Manson source





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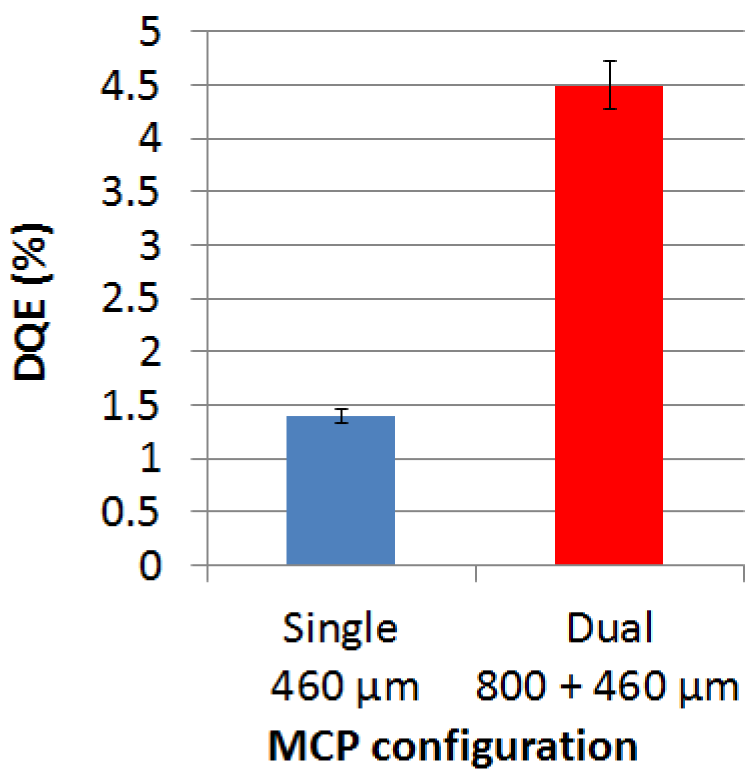

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