X-ray Polarimetry
— a new window ready to open

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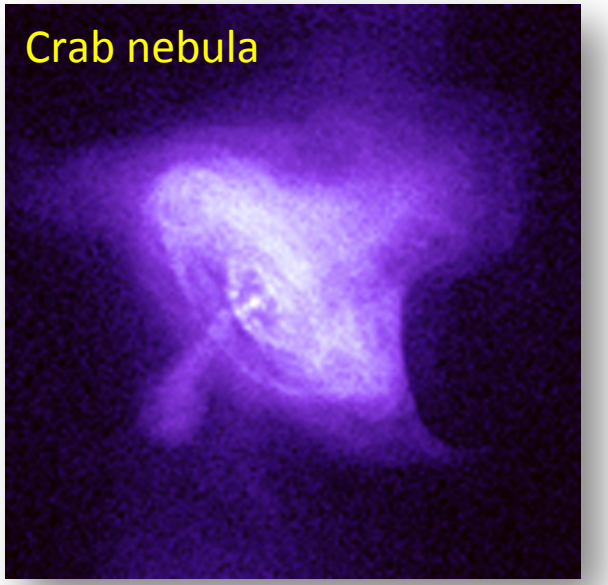
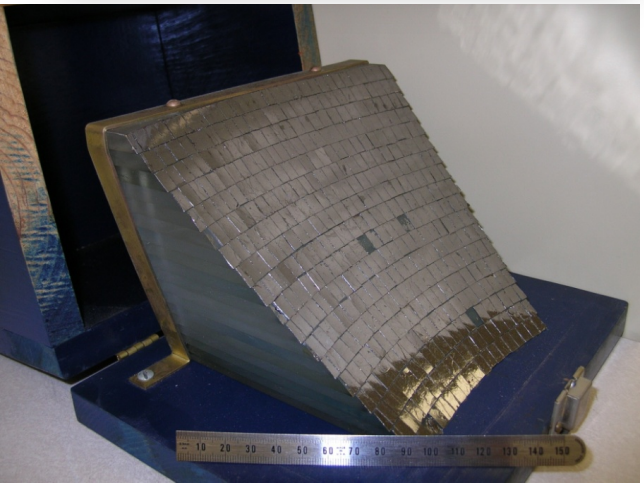
Science with X-ray polarimetry

- ✓ Acceleration Mechanisms
  - ✓ Pulsar Wind Nebulae
  - ✓ Supernova Remnants
  - ✓ Relativistic jets
  - ✓ Active galactic nuclei
- ✓ Magnetic fields in compact objects
- ✓ Scattering in aspherical geometries and accretion physics
- ✓ Fundamental Physics

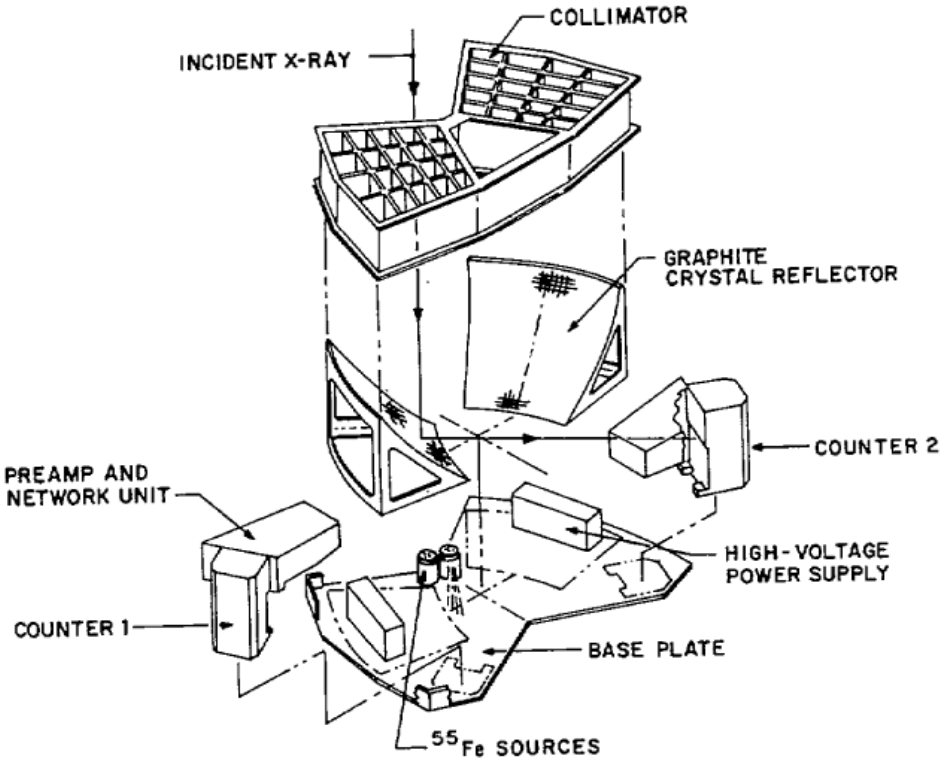
First positive detection in X-ray polarimetry

and last





- 1975 OSO-8
  - Crab Nebula
  - $P = 19.2\% \pm 1.0\%$
  - $\varphi = 156.4° \pm 1.4°$
  - Weisskopf et al. (1976, 1978)



1975 - 2015

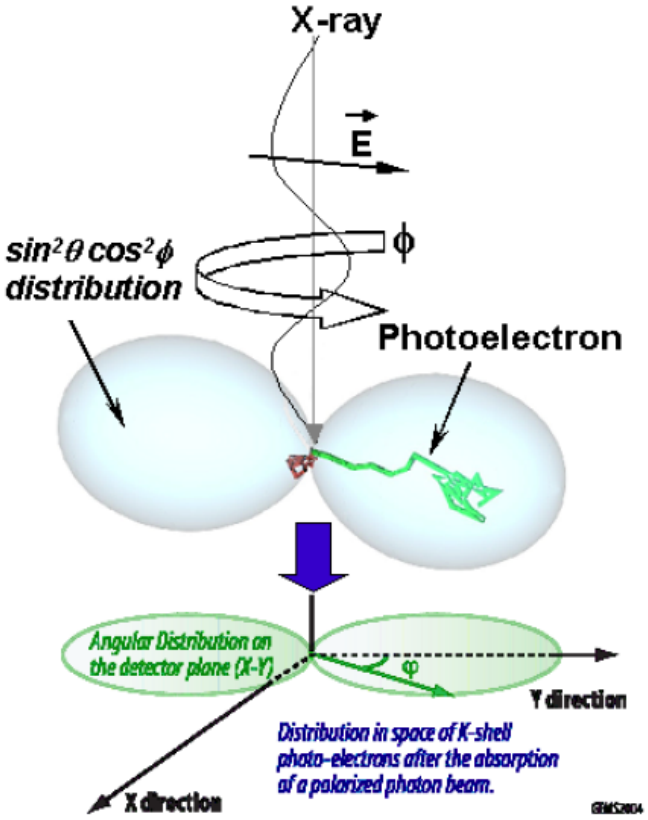
- No observation for 40 years
- Because the sensitivity of the polarimeter onboard OSO-8 is too low
  - Narrow energy band & low efficiency
  - Time averaged upper limits
    - 1–3 per cent for Sco X-1
      (Weisskopf et al. 1978; Long et al. 1979)
    - a few per cent for Cyg X-1 and X-2
      (Long et al. 1980; Hughes et al. 1984)
    - 10% or above for other sources
      (Hughes et al. 1984)

~keV band: photoelectric effect

Cross-section of photoelectric effect

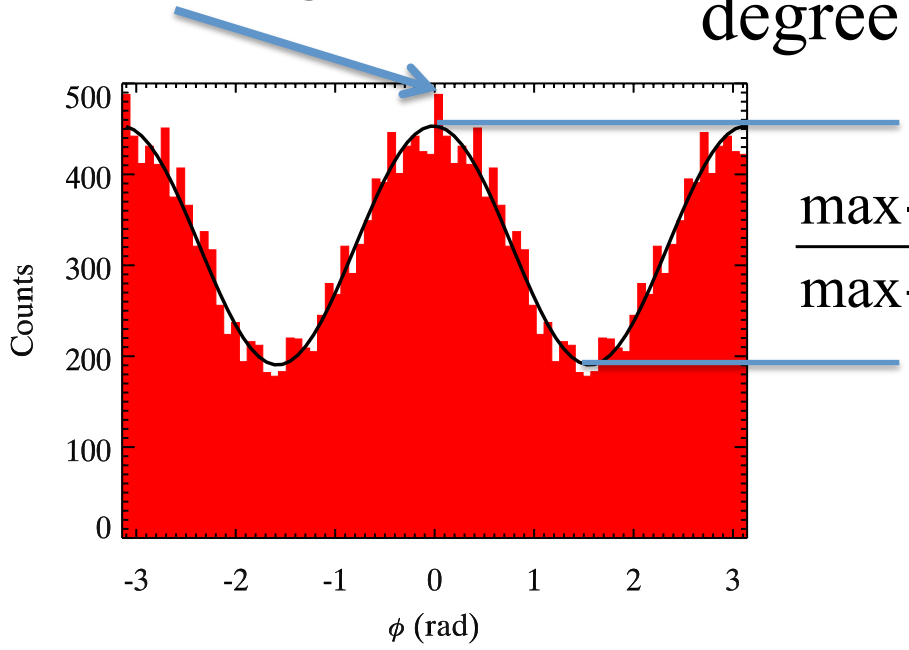
$$\frac{\partial\sigma}{\partial\Omega} = r_0^2 \frac{Z^5}{137^4}\left(\frac{mc^2}{h\nu}\right)^{7/2} \frac{4\sqrt{2}\sin^2(\theta)\cos^2(\varphi)}{(1-\beta\cos(\theta))^4}$$

$$\frac{d\sigma}{d\Omega} \propto \cos^2\varphi$$



position angle

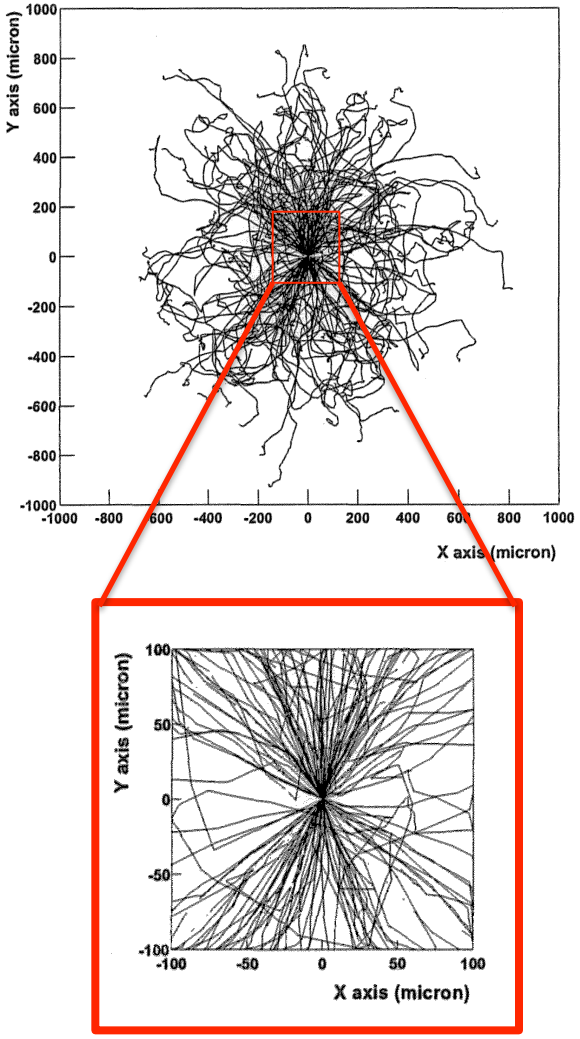
degree of pol



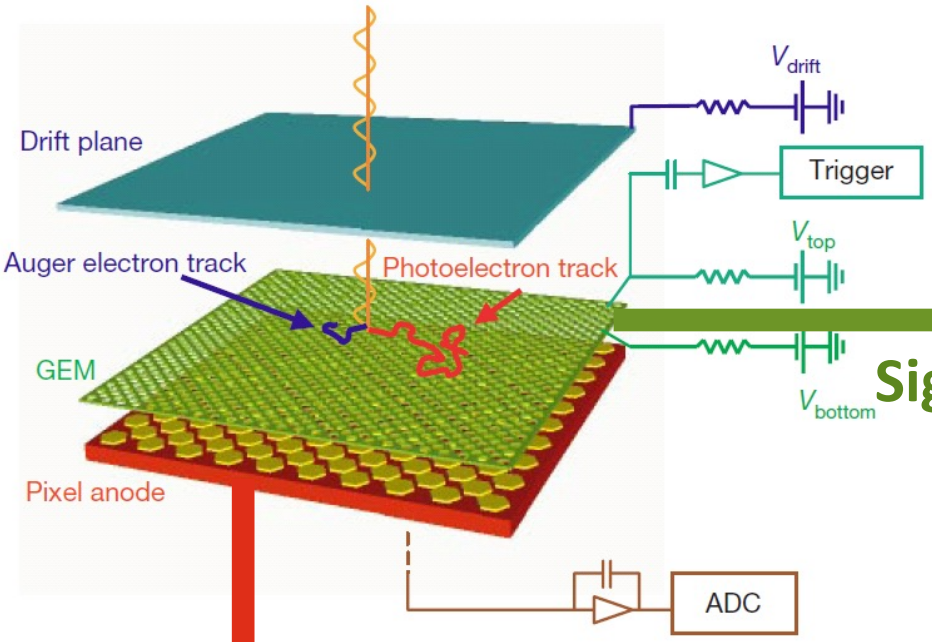
$$\frac{\max-\min}{\max+\min}$$

Technical difficulties

- Short range for electrons of a few keV
  - in silicon: ~μm
  - in gas: ~mm
- Electron tracks are not straight during ionization
- Challenge for nuclear detector
  - Require 2D imaging device
  - Resolution < 100 μm

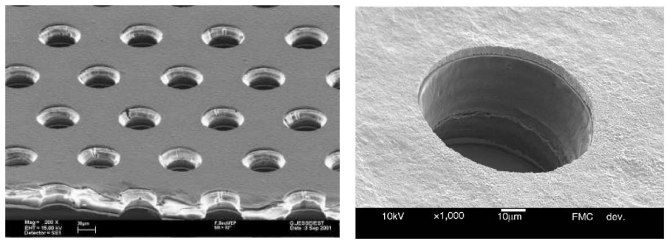


Micro-Pattern Gas Detector (MPGD)



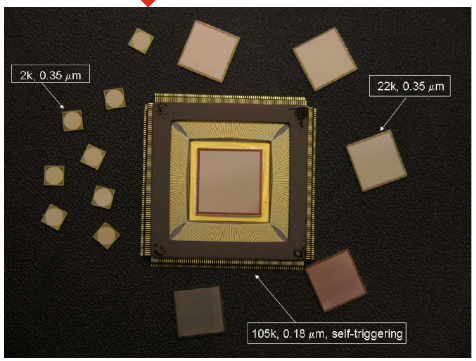
GEM

50µm-pitch

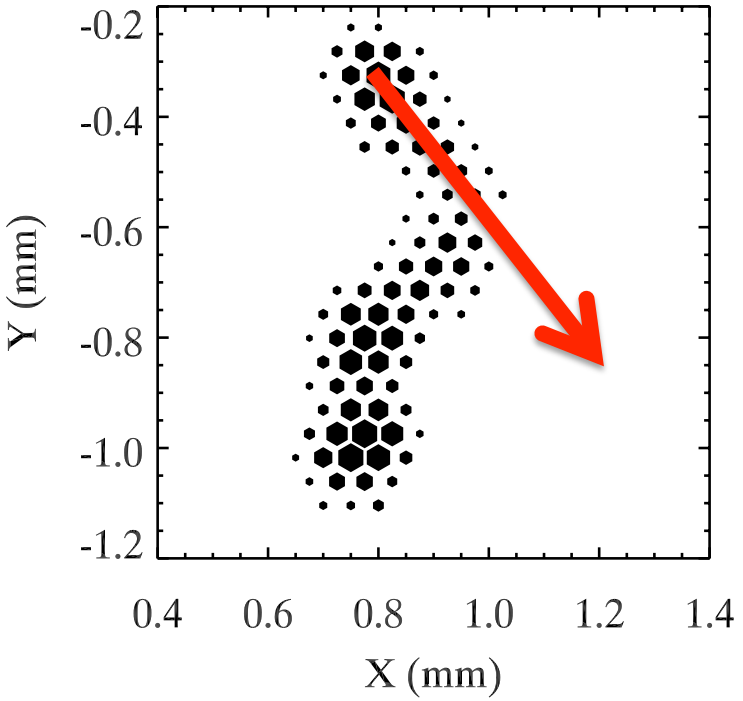


Signal amplification

2D pixel readout



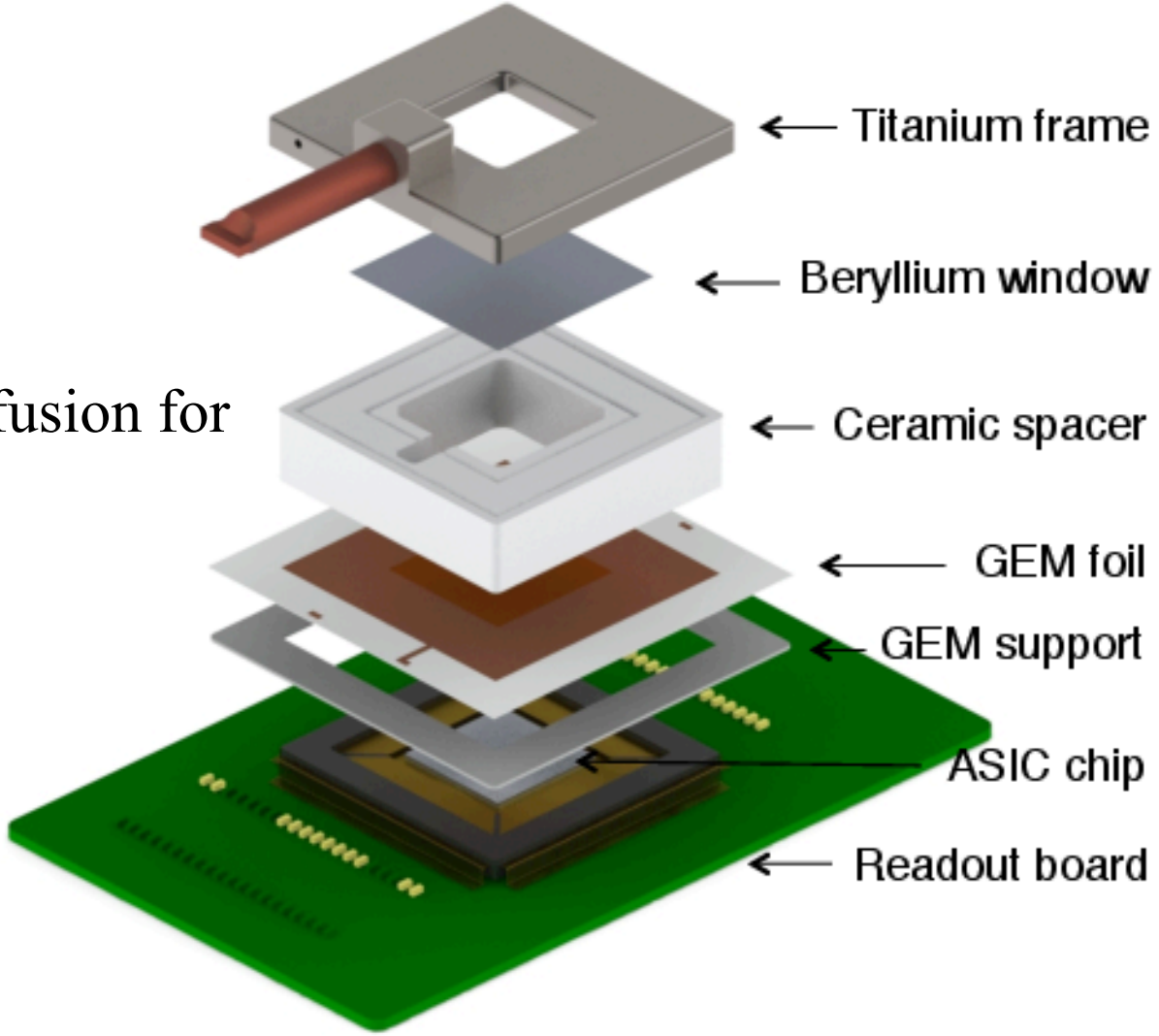
50µm-pitch, 105k
1.5cm * 1.5cm



First demonstrated by Costa, Bellazzini et al

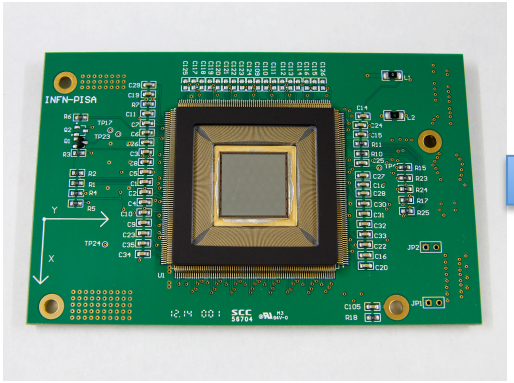
Detector design – sealed gas chamber

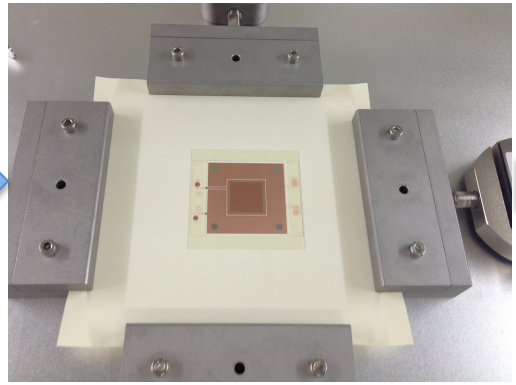
Gas mixture
DME (CH_3-O-CH_3)
Lowest transversal diffusion for electrons during drift

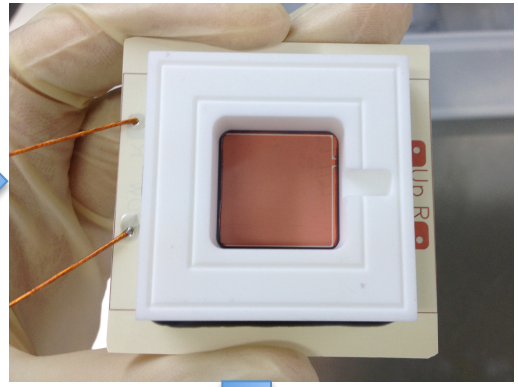


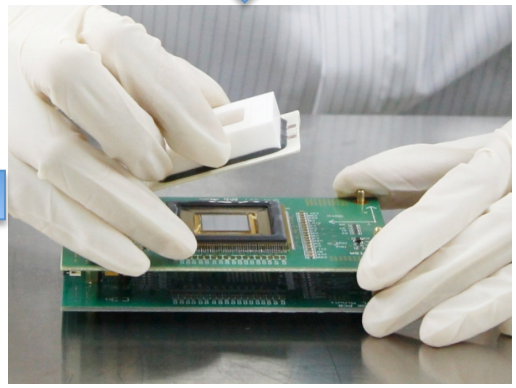
Following the design by Bellazzini et al. (INFN-Pisa)

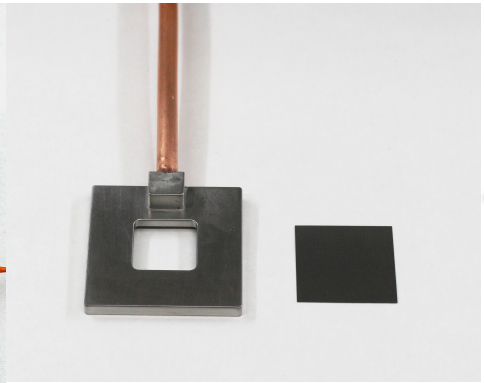
Detector assembly at Tsinghua University

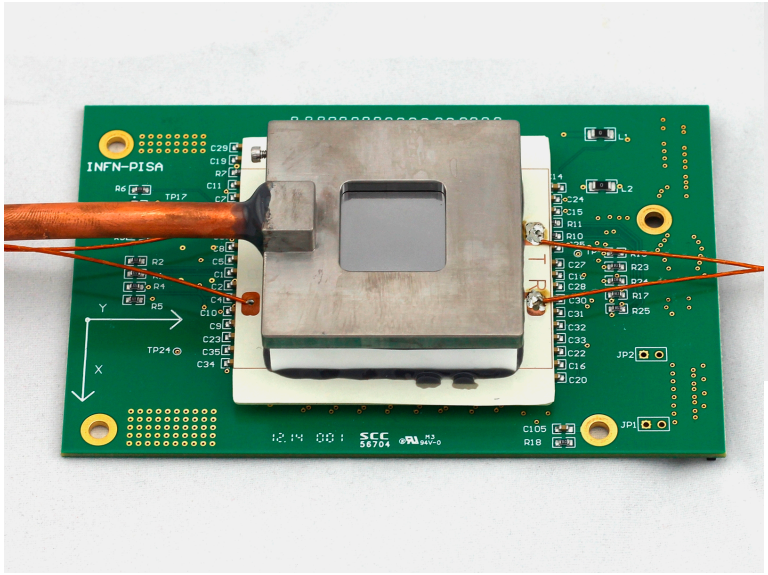




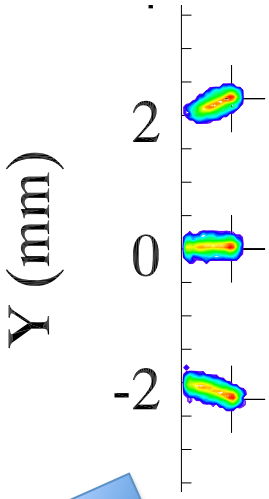


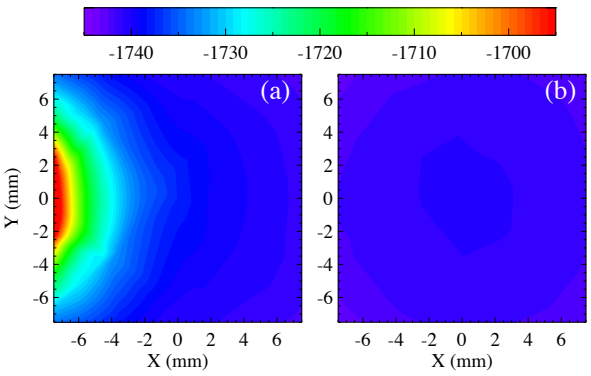


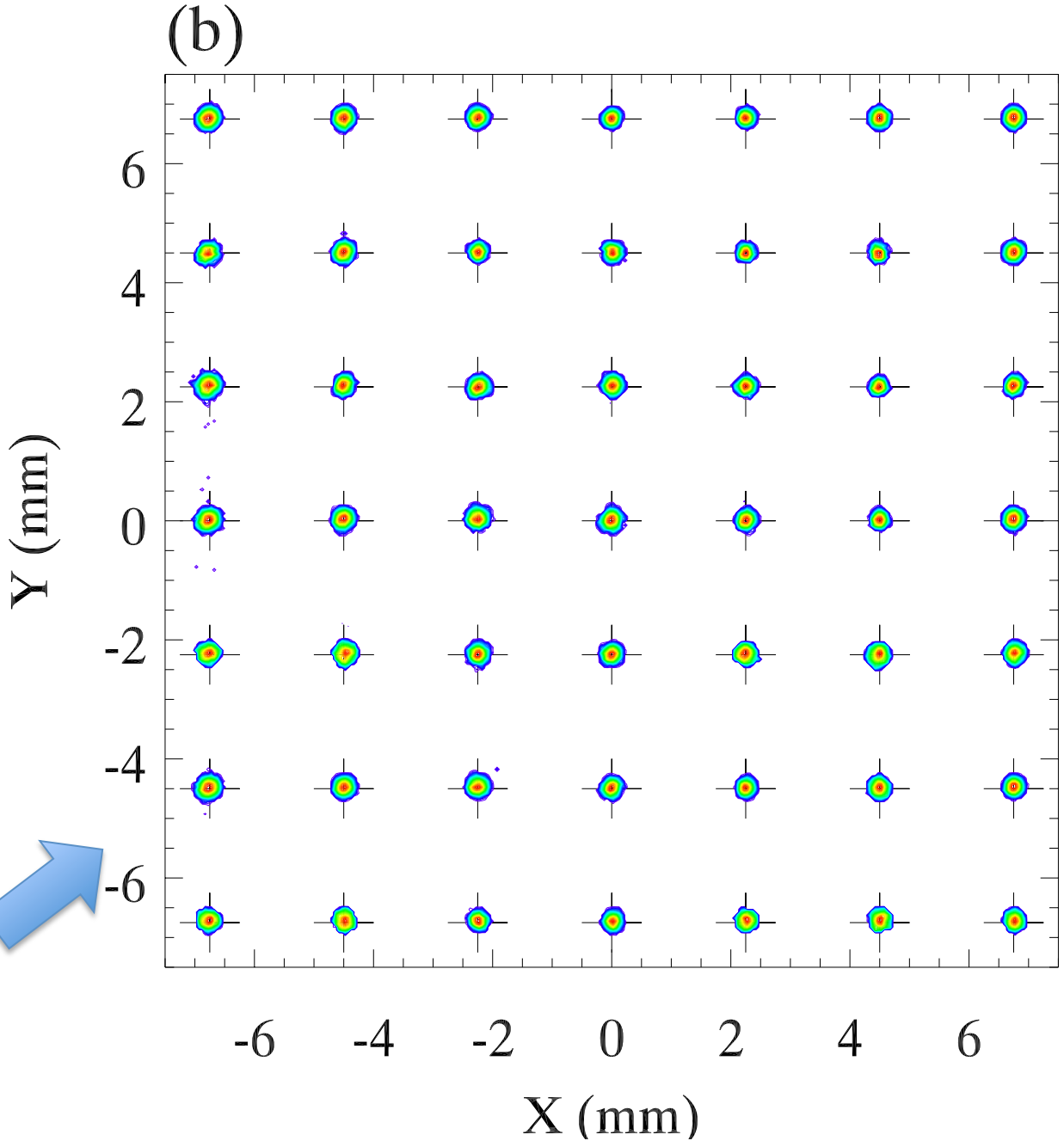




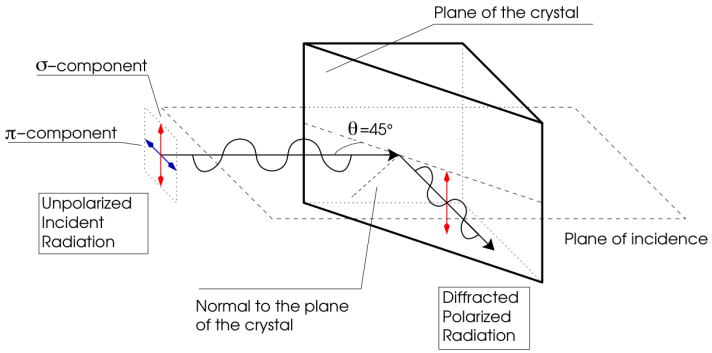
Electric field uniformity



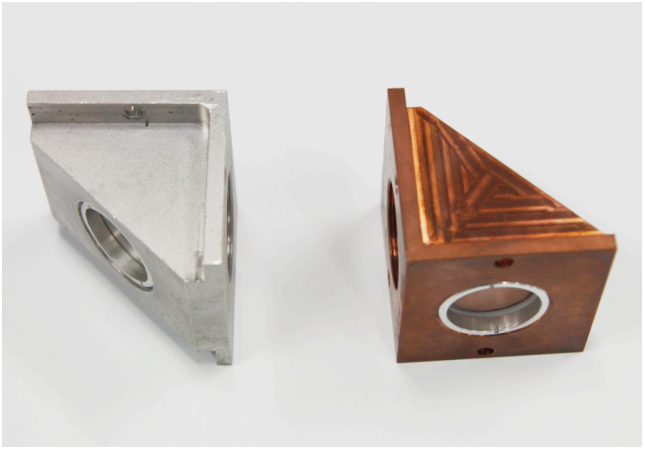


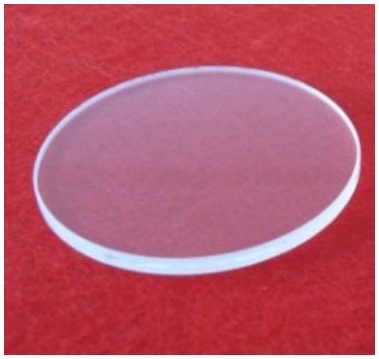


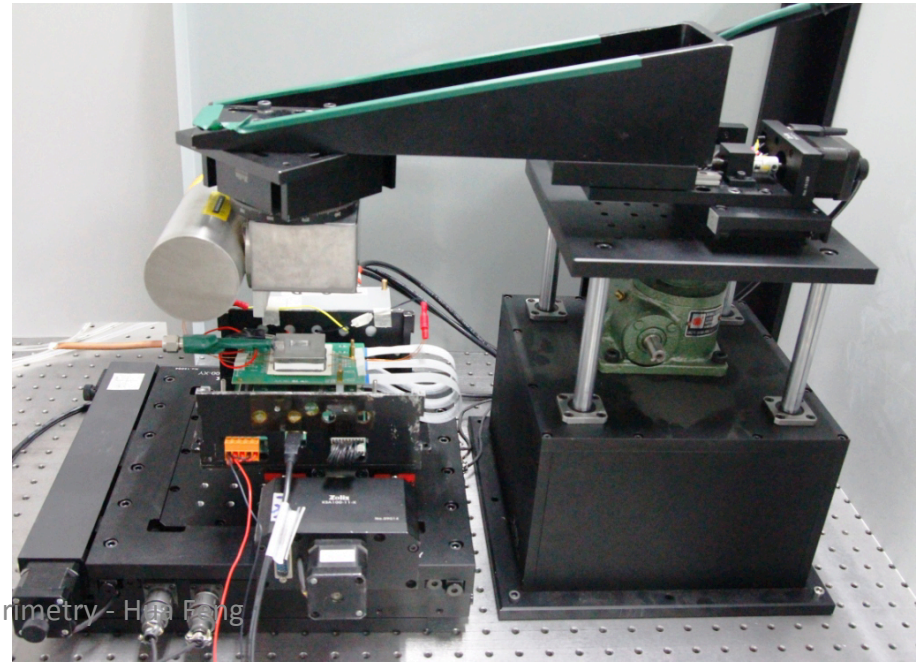
Fully polarized X-ray beams in the lab



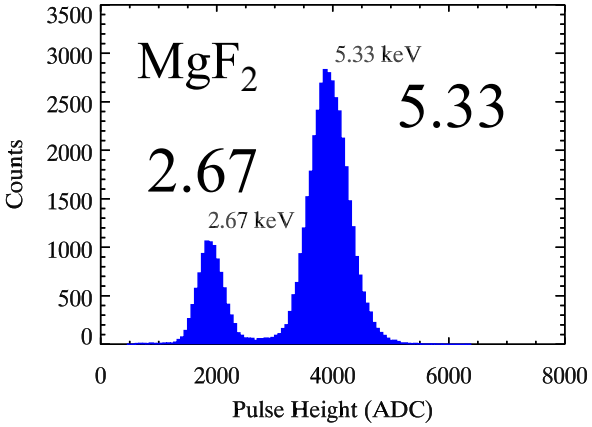
E (keV)	crystal	order
2.67	MgF_2	1st
3.74	Al	1st
5.33	MgF_2	2nd
6.09	LiF	2nd
7.49	Al	2nd

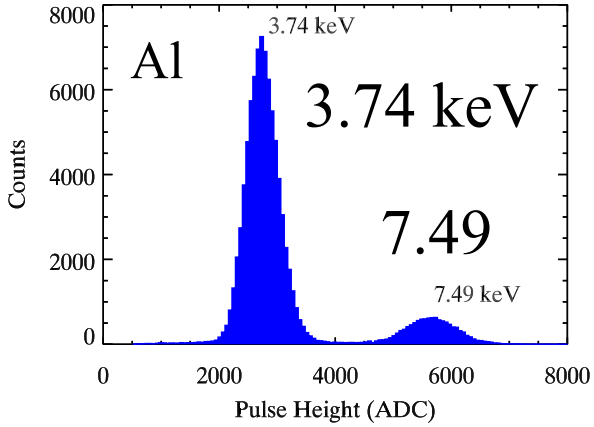


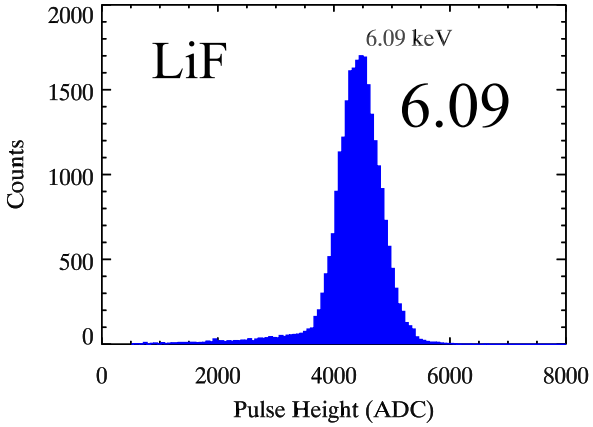


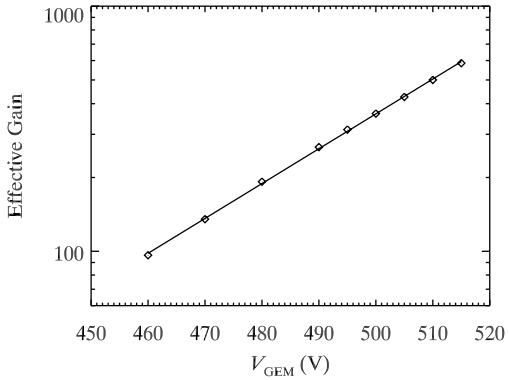


Energy spectra

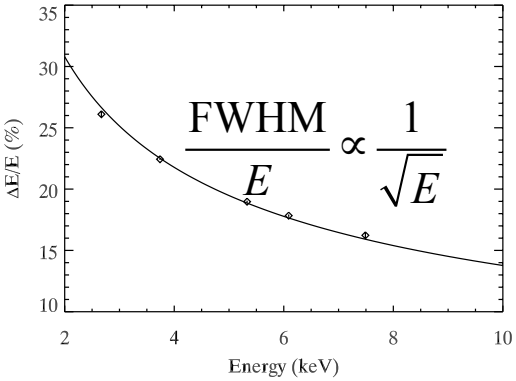








Effective gain



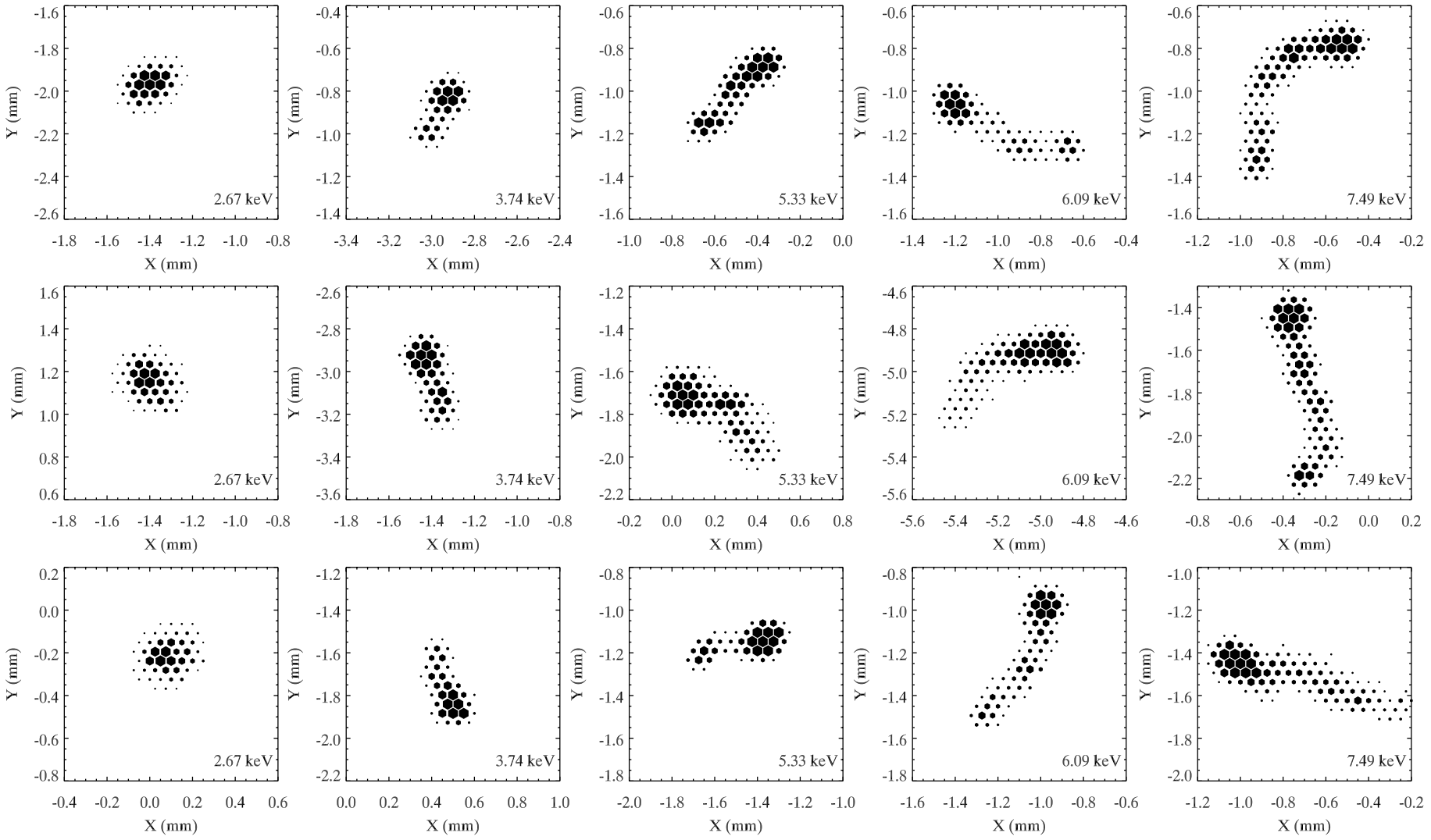
Energy resolution

18% at 6 keV

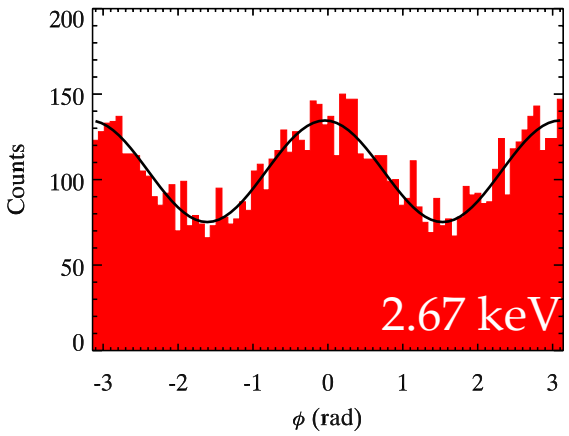
GEM: 50μm-thick

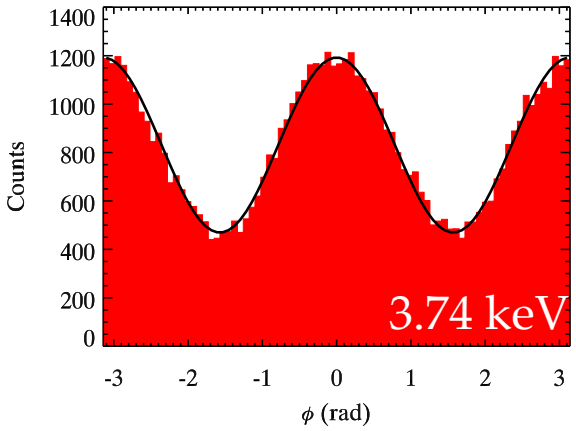
Gas: DME at 0.8 atm

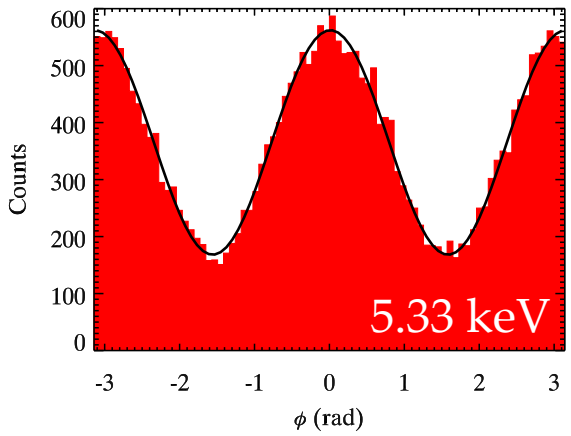
Photoelectron Tracks

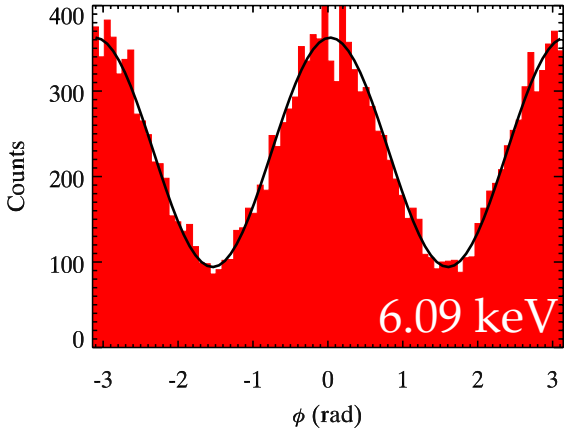


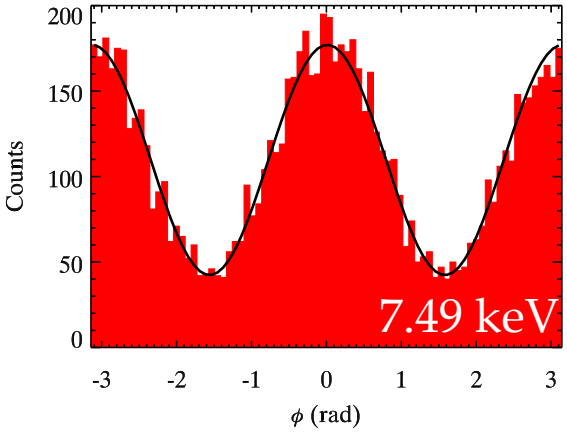
Modulation curves





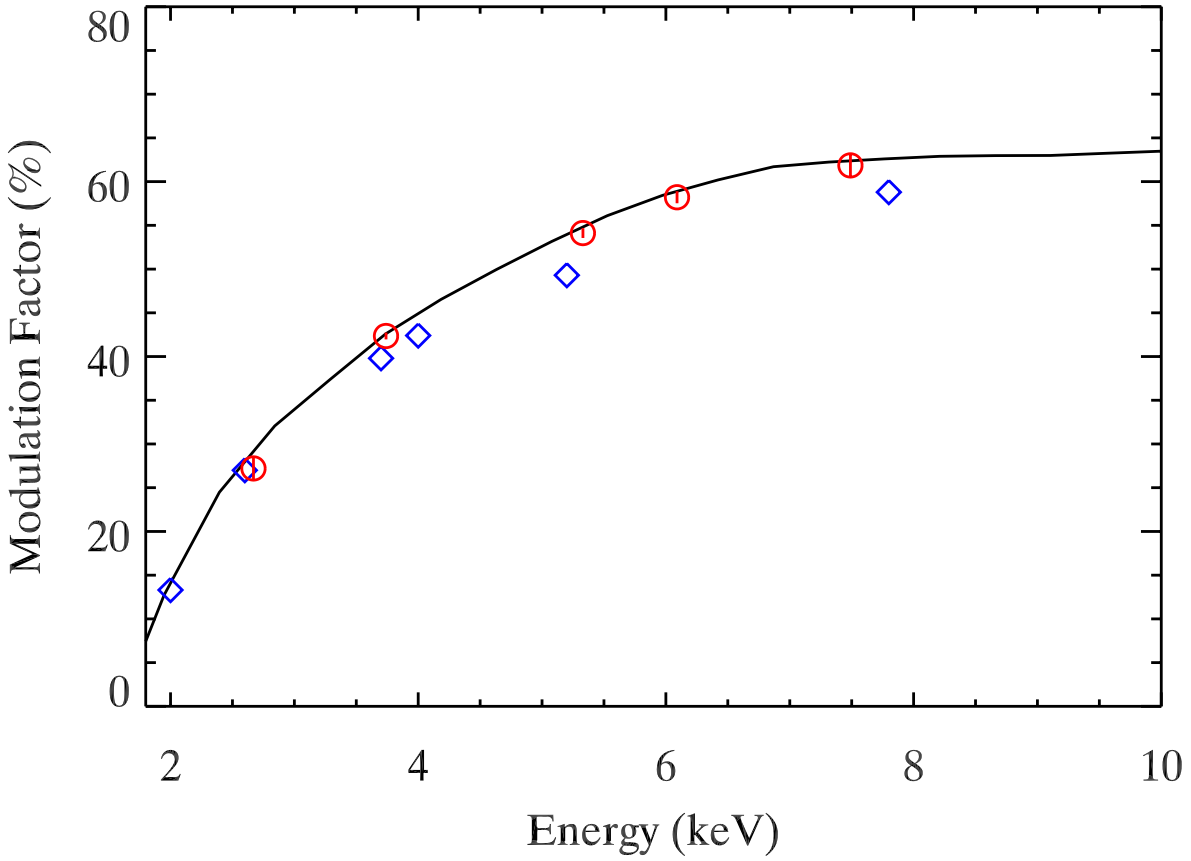






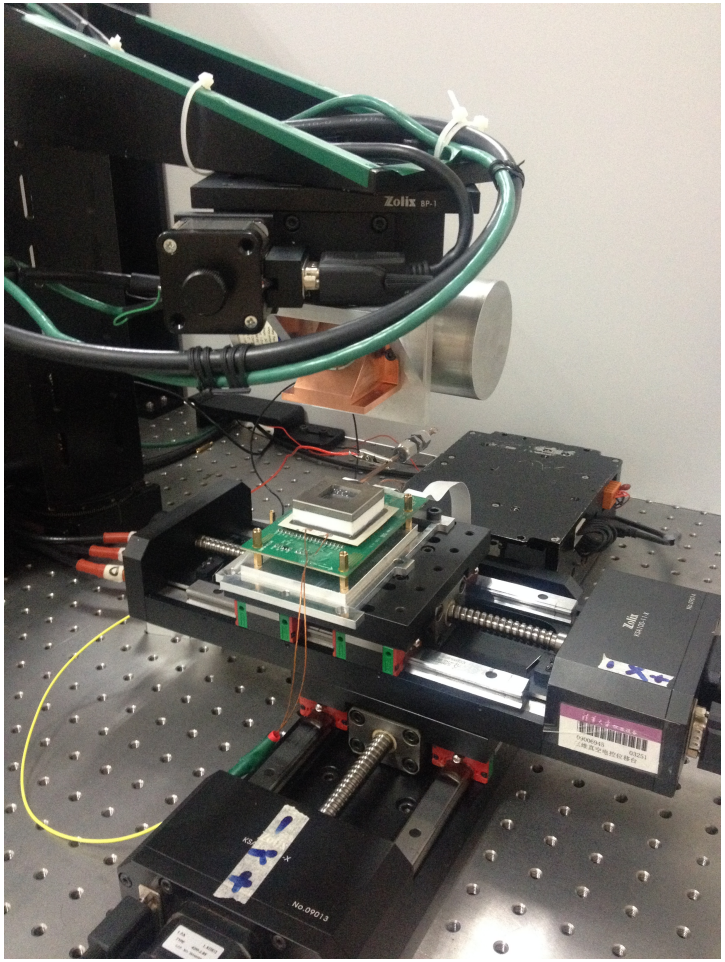
Modulation Factor

- Degree of modulation in response to 100% polarized X-rays

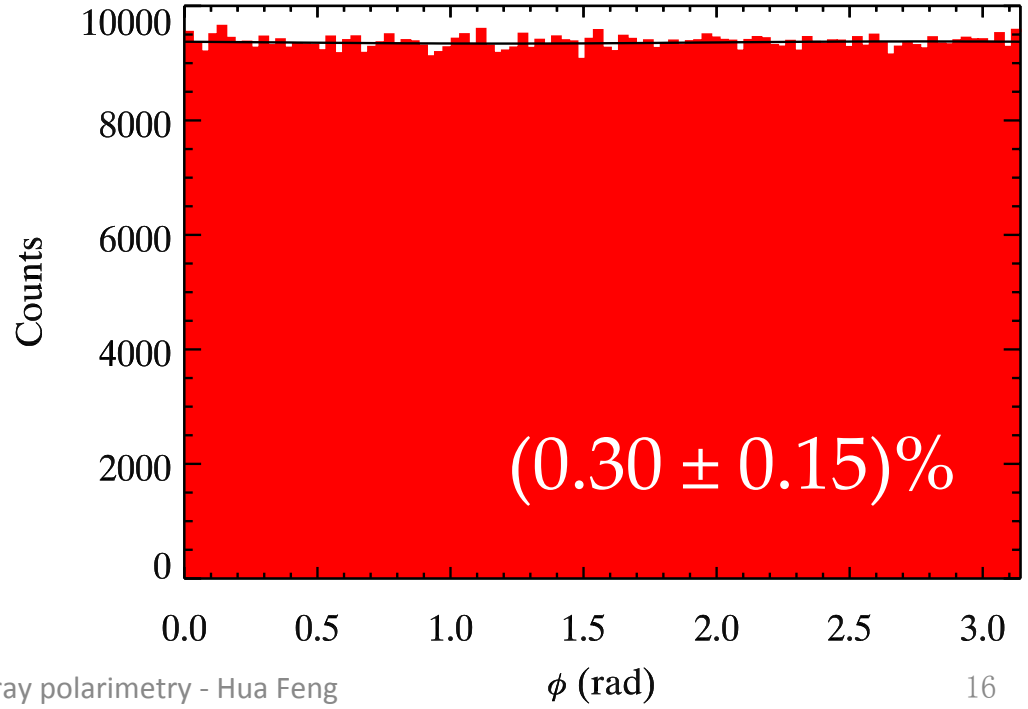


Systematic error

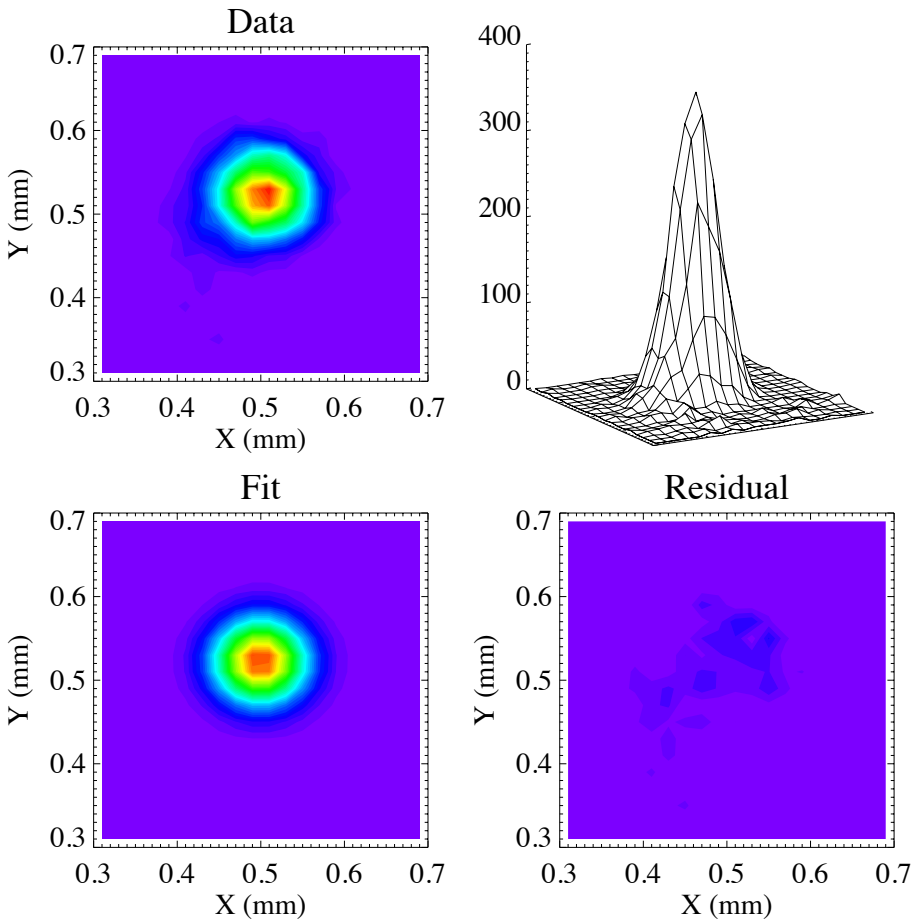
- Residual modulation from unpolarized X-ray beam

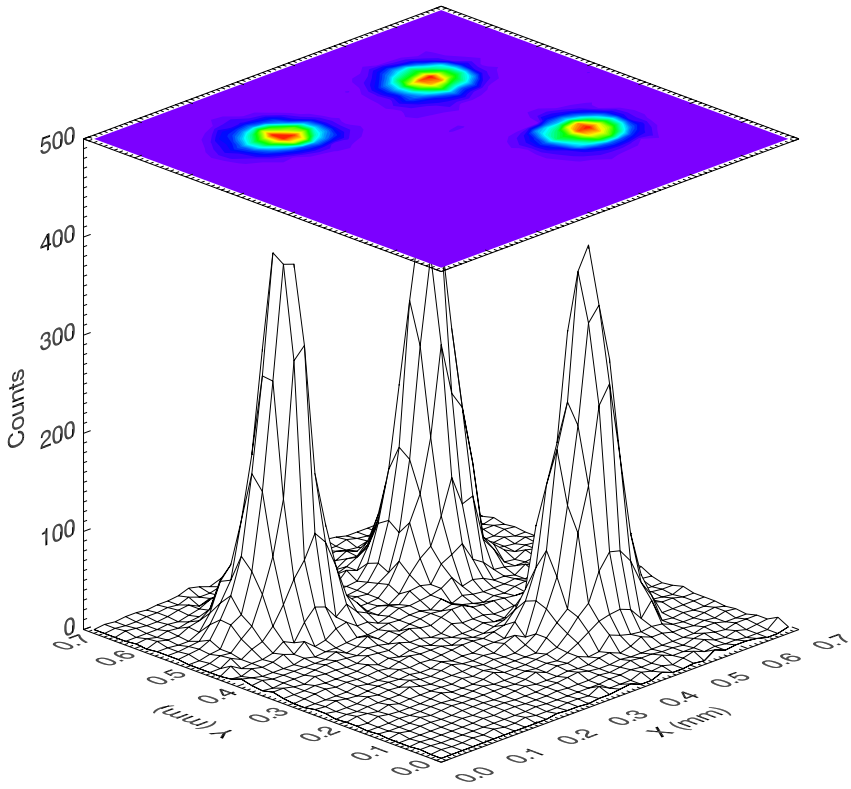


- DoP = 0.94% (99% upper limit)



Imaging – focal plane detector for grazing incident telescopes





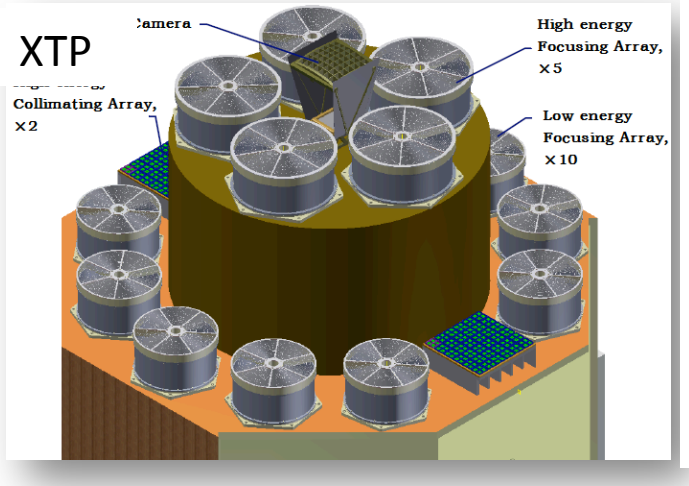
- FWHM: ~ 80 μm
- 300 μm apart in X and Y

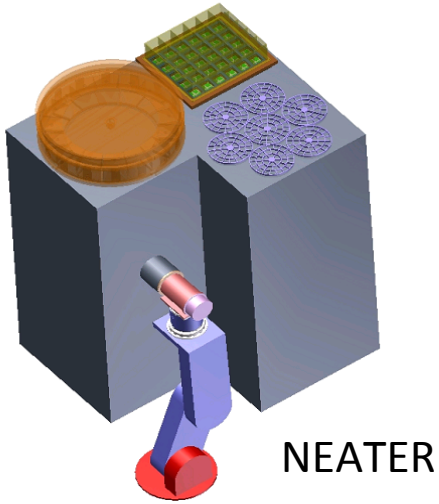
Technical difficulty: detector sealing

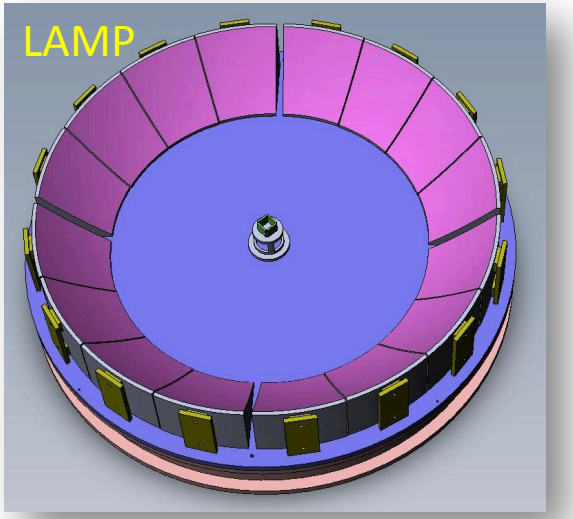
- Long lifetime sealed proportional counters
  - NASA/Goddard Space Flight Center
  - Oxford Instrument Analytical Oy
- Outgassing of materials decreases electron transportation rate
  - High vacuum technology + nuclear detector technology
  - Our detectors are now approaching a lifetime of 5-10 years

Future Missions with X-ray Polarimetry

- In China
  - X-ray Timing and Poalrization (XTP)
  - NEATER on Chinese space station
  - LAMP: micro-polarimeter for soft X-rays



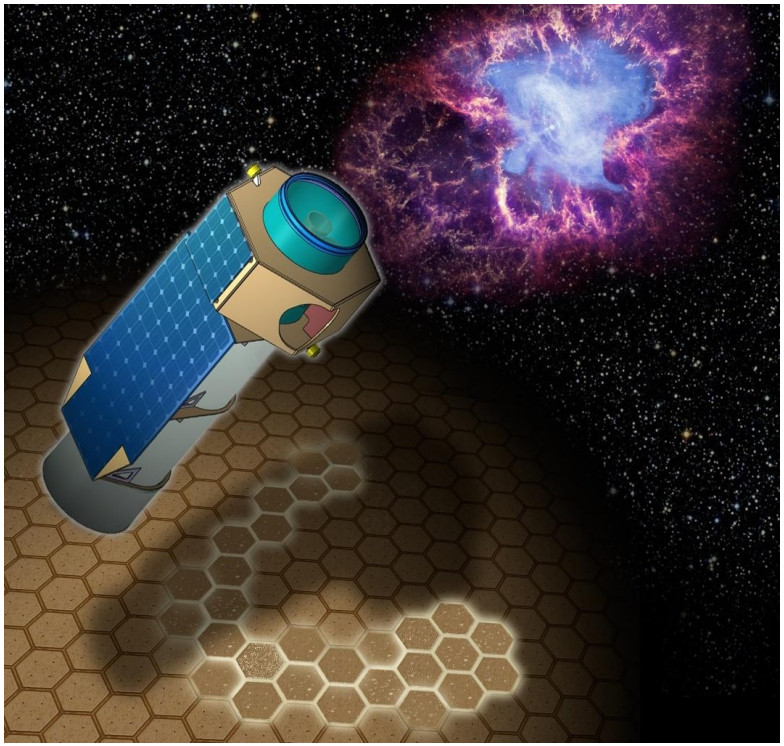




The X-ray Imaging Polarimetry Explorer XIPE

Proposed by

Paolo Soffitta, Ronaldo Bellazzini, Enrico Bozzo, Vadim Burwitz, Alberto J. Castro-Tirado, Enrico Costa, Thierry J-L. Courvoisier, Hua Feng, Szymon Gburek, René Goosmann, Vladimir Karas, Giorgio Matt, Fabio Muleri, Kirpal Nandra, Mark Pearce, Juri Poutanen, Victor Reglero, Maria Dolores Sabau, Andrea Santangelo, Gianpiero Tagliaferri, Christoph Tenzer, Martin C. Weisskopf, Silvia Zane



Approved by ESA in July 2015
Down-selection in May 2017

NASA selected two SMEXes in August 2015

Phase A study; down-selection in early 2017

summary

- 2015
  - year for X-ray polarimetry
- 2020-2025
  - Astronomical X-ray polarimetry will become true
- Detector technology
  - ready in the lab, almost space qualified
  - Assembly in house at Tsinghua