X-ray polarimetry in Xenon gas filled detectors

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Motivation

- **Photoelectric effect is very sensitive to polarization since photoelectron angular distributions become preferentially aligned with the polarization vector;**

  - unpolarized X-rays: $\frac{d\sigma}{d\Omega} = \frac{\sigma}{4\pi}\left[1 - \frac{1}{2}\beta P_2(\cos\underline{\theta}) + (\delta + \frac{1}{2}\gamma \sin^2\underline{\theta})\cos\underline{\theta}\right]$

  linearly polarized: $\frac{d\sigma}{d\Omega} = \frac{\sigma}{4\pi}\left[1 + \beta P_2(\cos\theta) + (\delta + \gamma\cos^2\theta)\sin\theta\cos\varphi\right]$

  including 1st order non-dipole corrections δ and γ to the dipole approximation

($\underline{\theta}$ is the polar angle relative to the x-ray propagation direction, θ and φ are the polar and azimuthal angles relative to the polarization direction, β is the dipole asymmetry parameter and P_2 is the 2nd Legendre polynomial)

Derevianko *et. al.,* At.Dat.Nucl.Dat. Tables 73 (1999) 153

Trzhaskovskaya *et. al.,* At.Dat.Nucl.Dat. Tables 92 (2006) 245

Motivation

- **The profiles of the electron clouds produced by photo-ionization events can be used to probe the polarization;**

<u>Our Goal</u>: Observation of the polarization-induced anisotropy in the profiles of the electron clouds when polarized X-rays (~5-20 keV) are absorbed in xenon

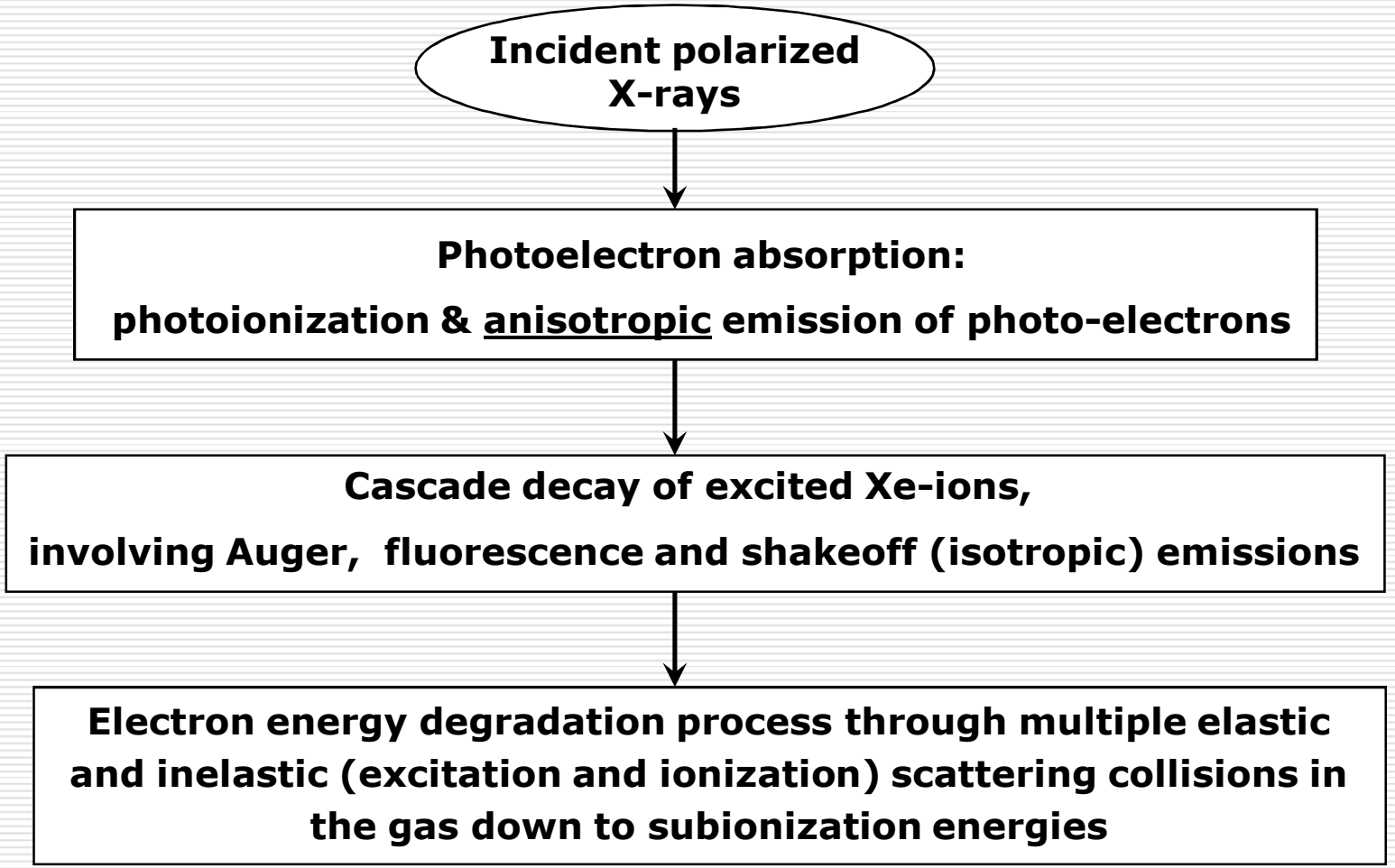
<u>Why?</u>: **great interest for x-ray astronomy & astrophysics**

- Polarization as a new observational parameter improves the characterization of astronomical x-ray emission sources

Summary

- **Monte Carlo simulation**
- **Experimental measurements**
  - **Polarized X-ray source**
  - **Gridded-Microstrip Gas Chamber (G-MSGC)**
  - **Micro-Hole & Strip Plate (MHSP)**
- **Conclusions**

Monte Carlo simulation: Model

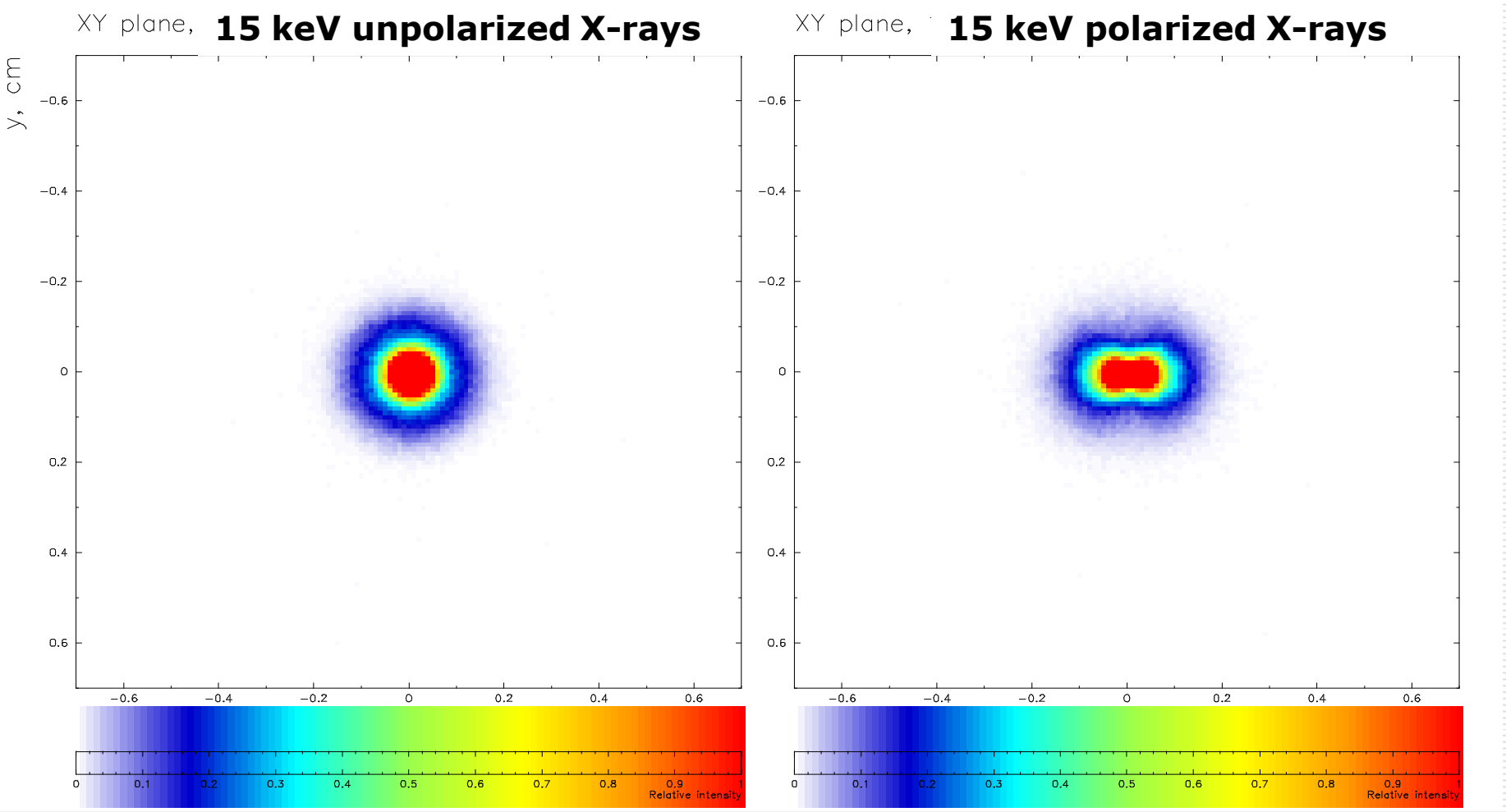


Dias *et. al.,* Phys.Rev. A48 (1993) 2887

Botte *et. al., IEEE NSS Conf.Rec.* (2008) 943 (submitted to IEEE-TNS)

Monte Carlo simulation: Results

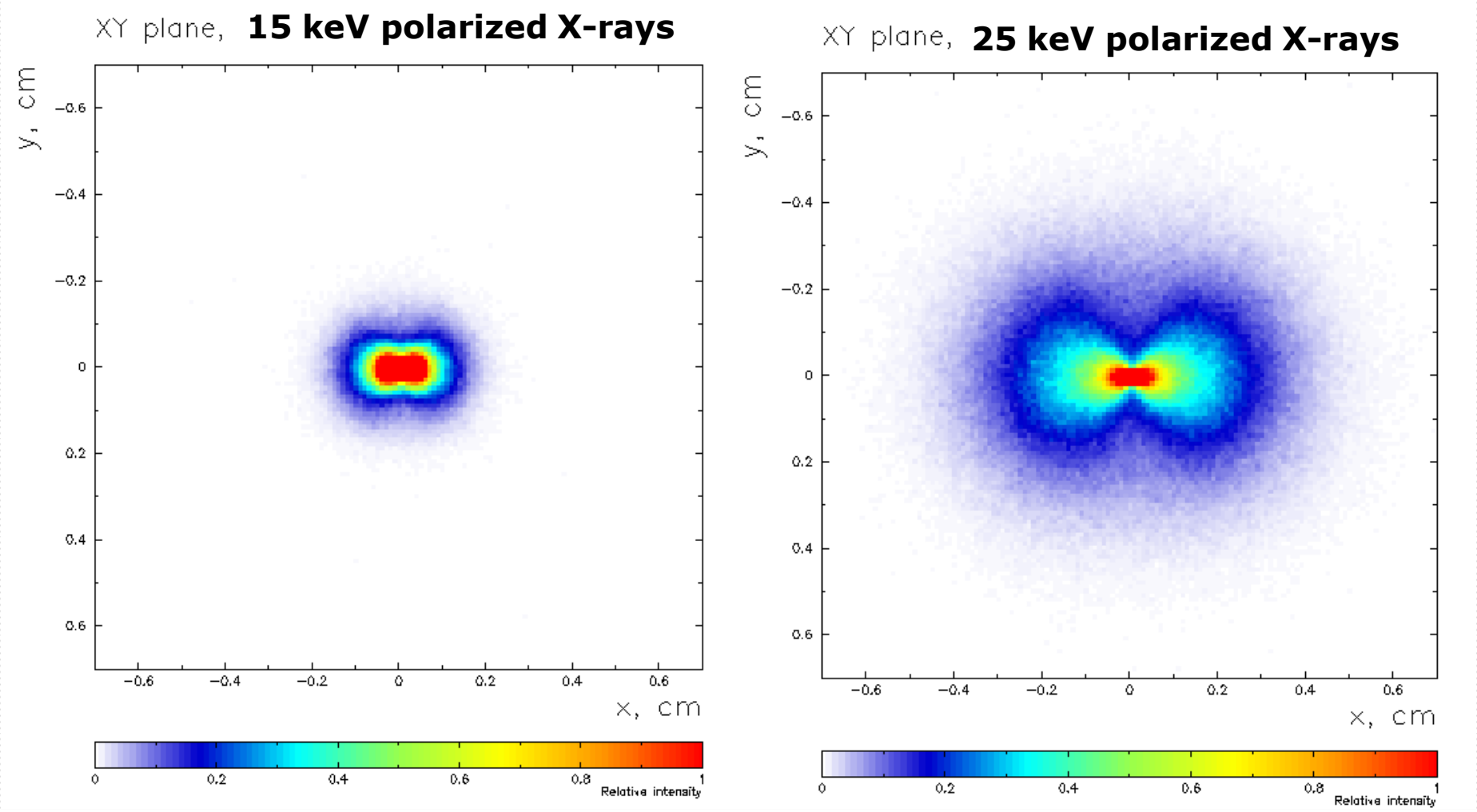
Xe @ 1 atm (Xe *E(L-edges)* ~ 5 keV)



incidence ⊥ XY plane, polarization ∥ X-axis

Monte Carlo simulation: Results

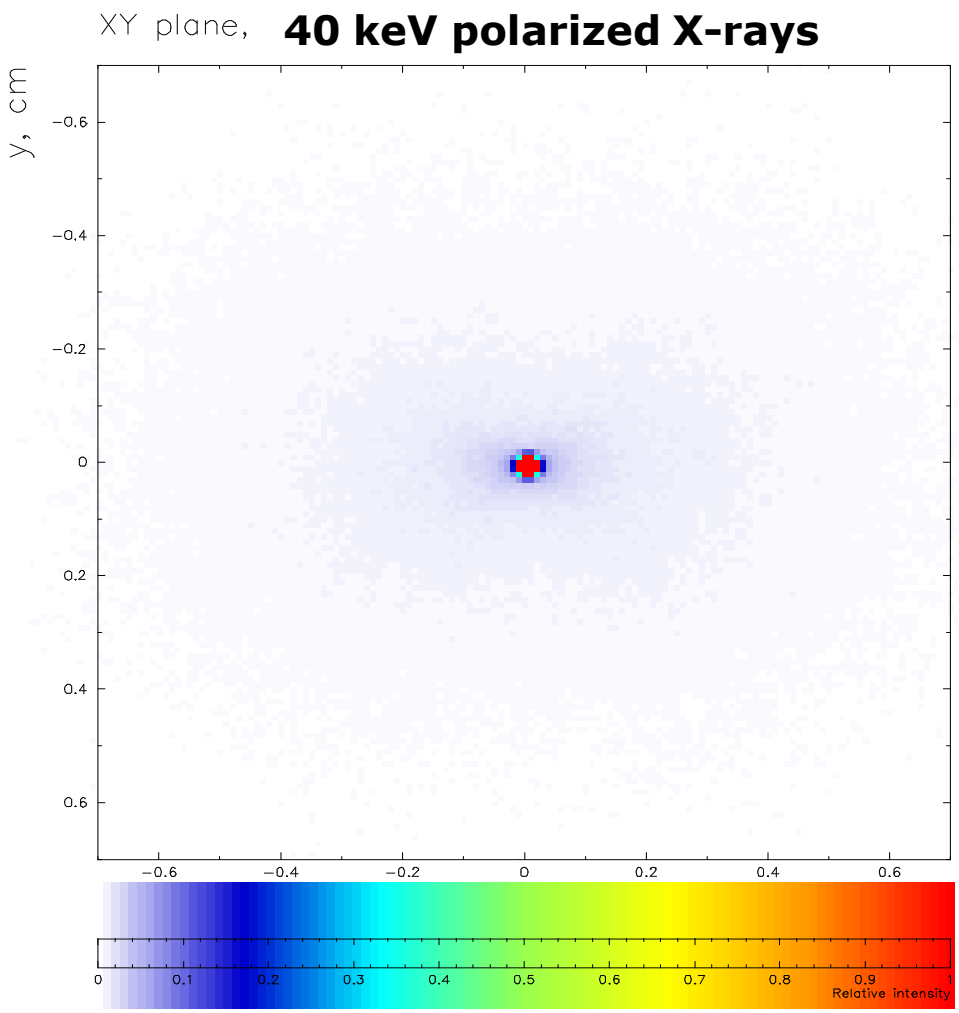
Xe @ 1 atm (Xe *E(L-edges)* ~ 5 keV)

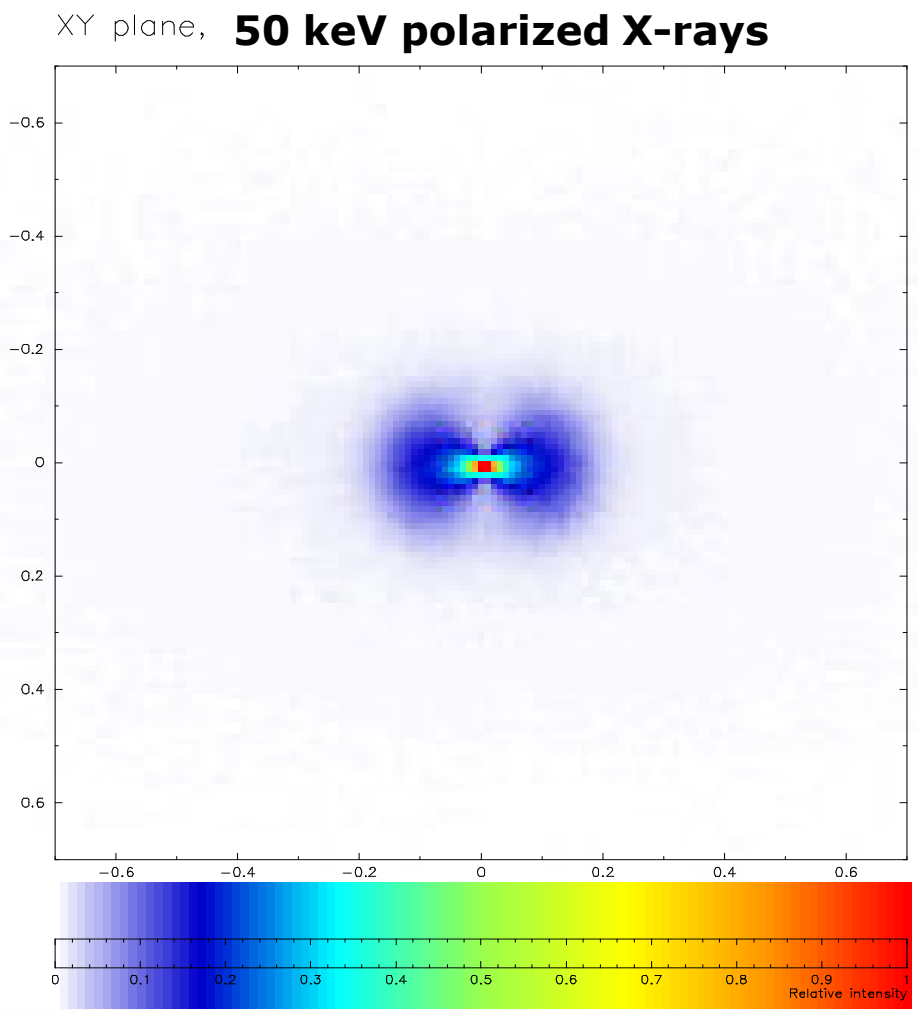


incidence ⊥ XY plane, polarization ∥ X-axis

Monte Carlo simulation: Results

Xe @ 1 atm (Xe *E(K edge)*=34.6 keV)

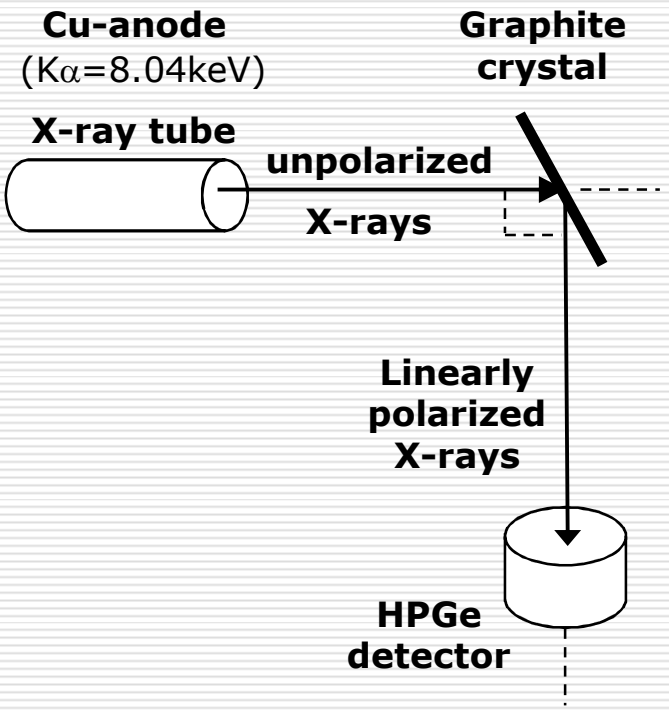


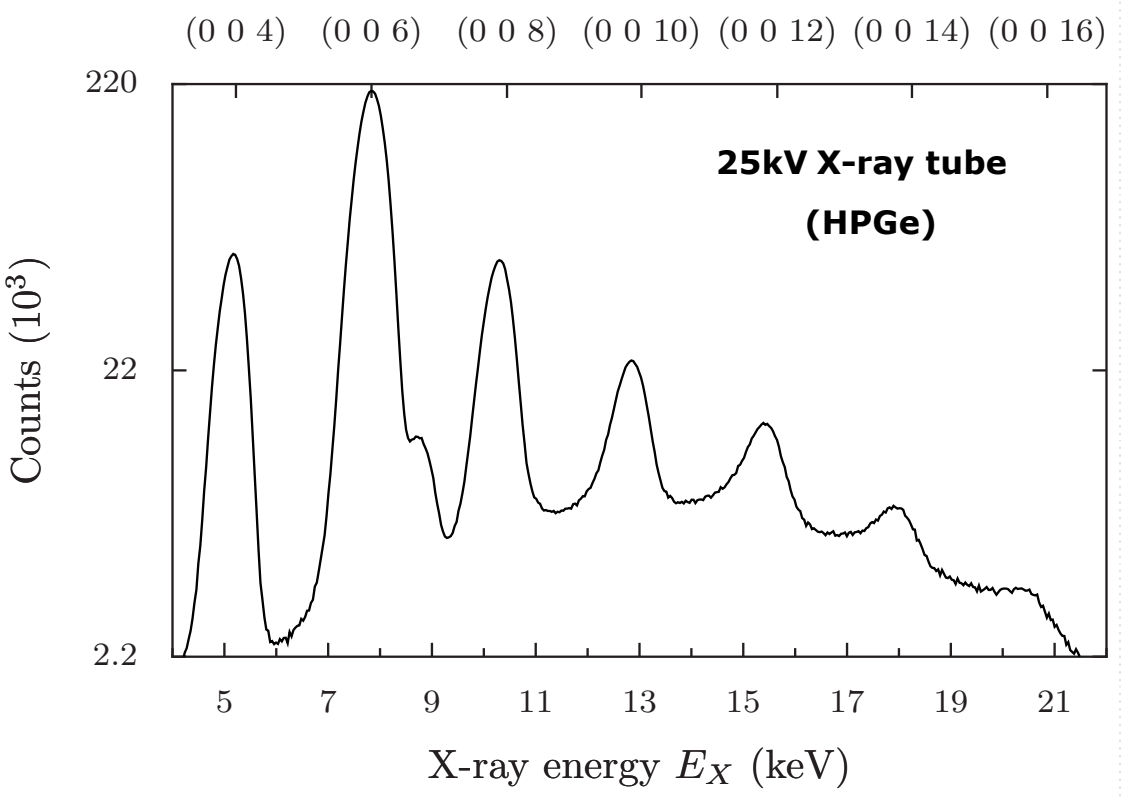


incidence ⊥ XY plane, polarization ∥ X-axis

Polarized X-ray source

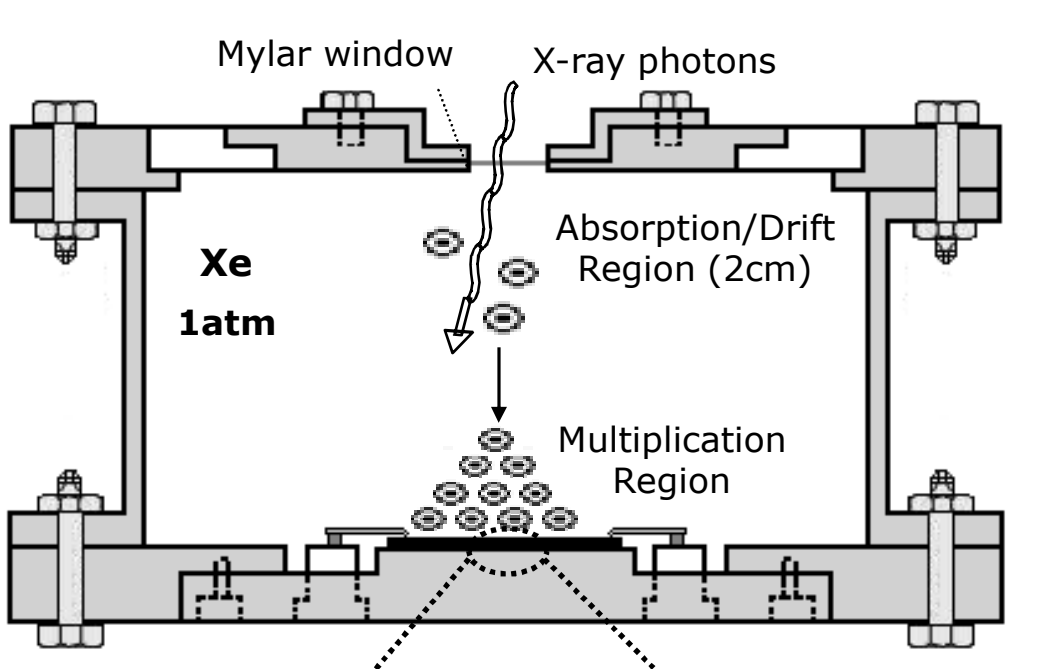
Polarized X-rays are obtained by Bragg reflection at 45º from unpolarized radiation generated with an X-ray tube



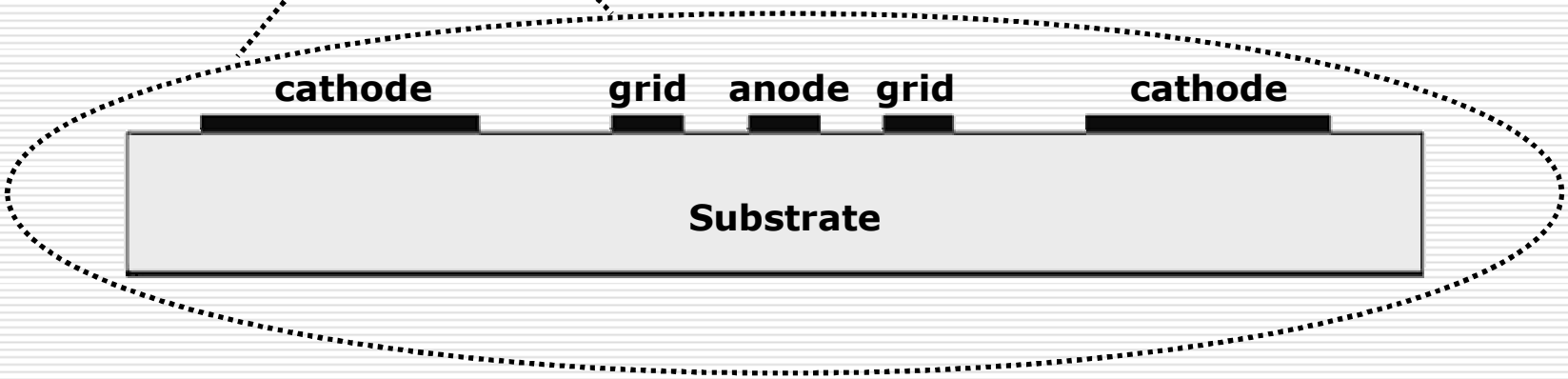


Linearly-polarized Bragg-reflection lines characteristic of graphite at E_x=5.22, 7.84, 10.45, 13.04, 15.66, 18.25, 20.86 keV

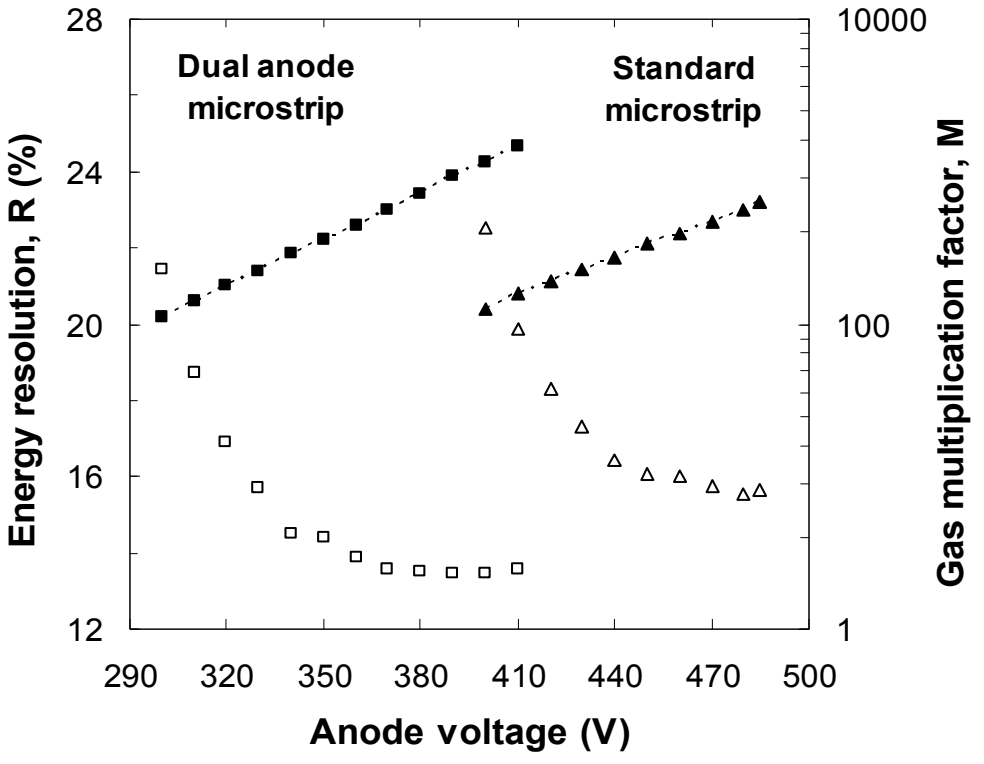
Gridded-MicroStrip Gas Chamber



Physical characteristics	
anodes and grids width	5 μm
cathodes width	90 μm
Anode-to-grid gap	12.5 μm
Cathode-to-grid gap	27.5 μm
pitch	185 μm



G-MSGC: Performance

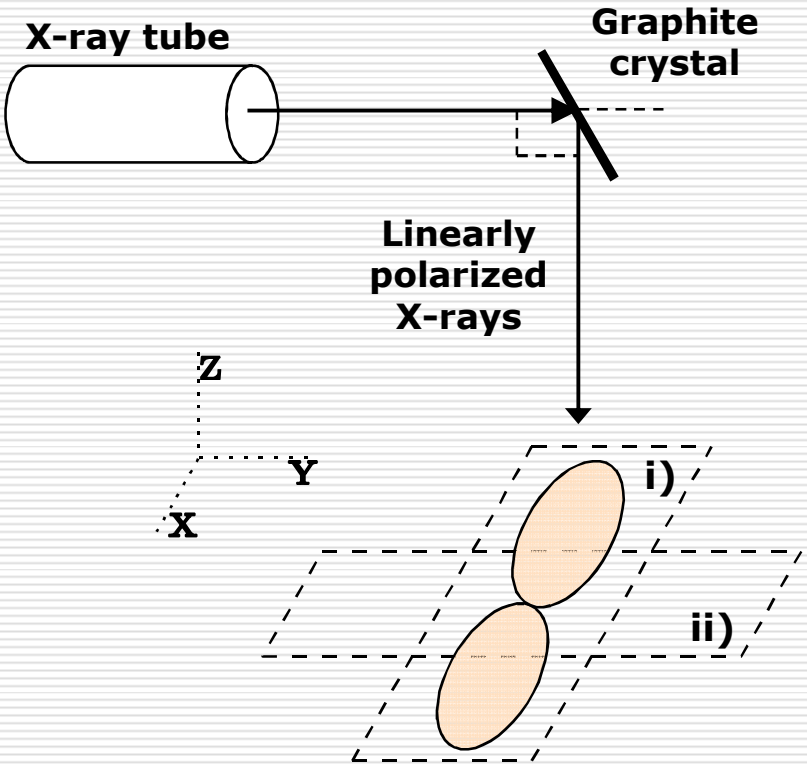


The anode is surrounded by a close-lying 2nd anode, playing the role of a grid at a potential between anode and cathode, allowing more accurate definition of the multiplication volume.

Carita *et. al.*,
IEEE TNS-54(5) (2007) 1779

Gas	Microstrip	Best R (%)	V_{anode} (V)	V_{grid} (V)	M
Xe	G-MSGC	13.4	400	100	1150
	Standard	15.6	480	-	560
P10	G-MSGC	12.6	415	150	590

G-MSGC: Experimental Setup



Polarization direction is //X-axis

Rectangular G-MSP orientations:

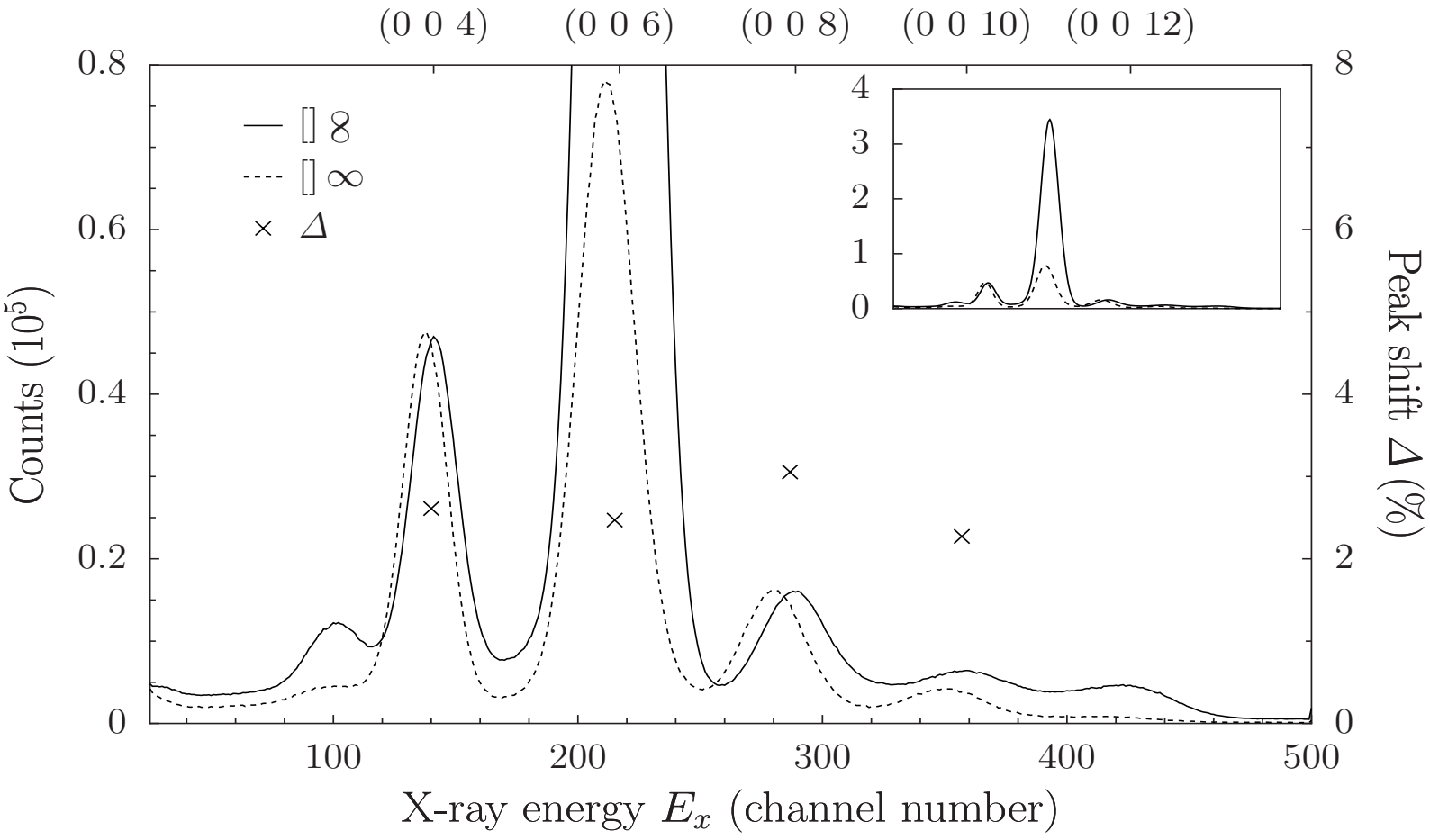
polarization vector is

i) parallel to the MSP **length** or

ii) parallel to the MSP **width**

G-MSP active area:
1.5 cm ×1 cm

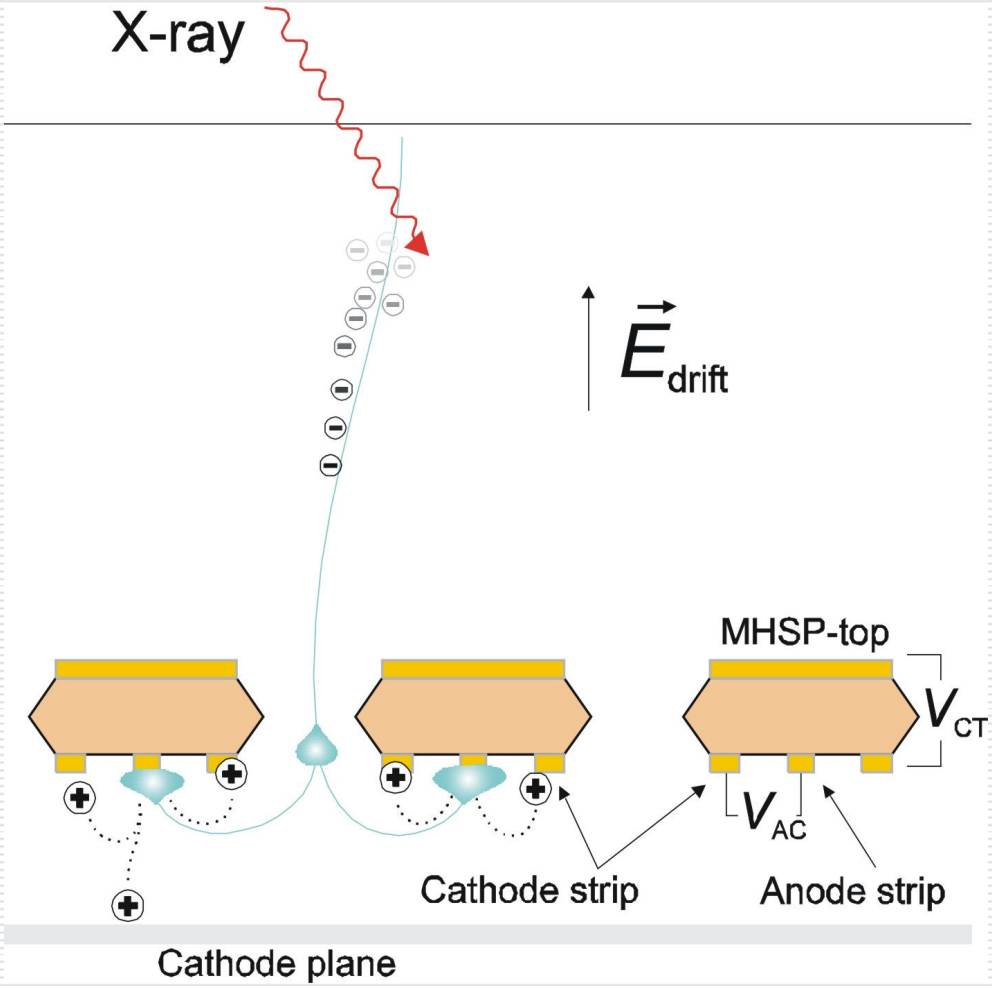
G-MSGC: Experimental Results



Energy spectrum, showing graphite x-ray lines

***Δ* is the observed shift of each peak to lower energies when the rectangular G-MSP orientation is changed from // to ⊥ to the polarization vector**

Micro-Hole & Strip Plate



Double-sided microstructure:

- **Perforated pattern of a <u>GEM</u>**
- **<u>Microstrip</u> pattern (bottom)**

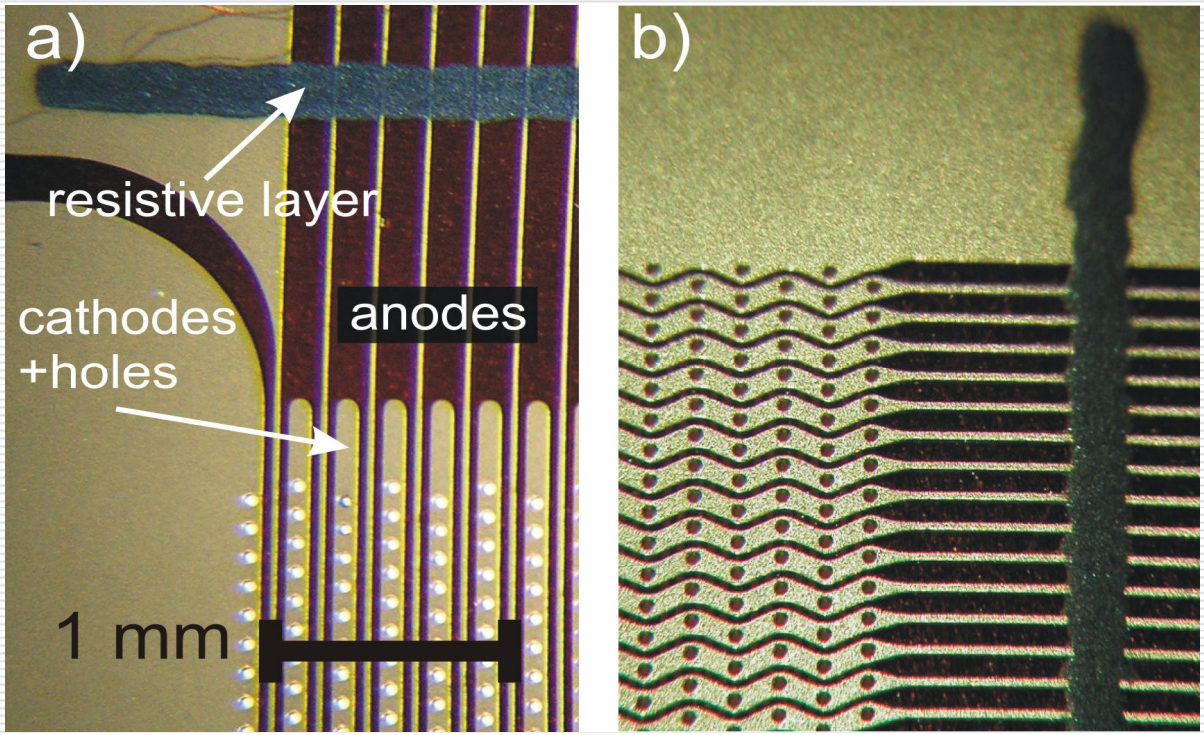
2 charge-multiplication stages:

✓ inside the holes and

✓in vicinity of the anodes

Veloso *et al.*, Rev.Sci.Instrum. 71 (2000) 2371

2D–Micro-Hole & Strip Plate



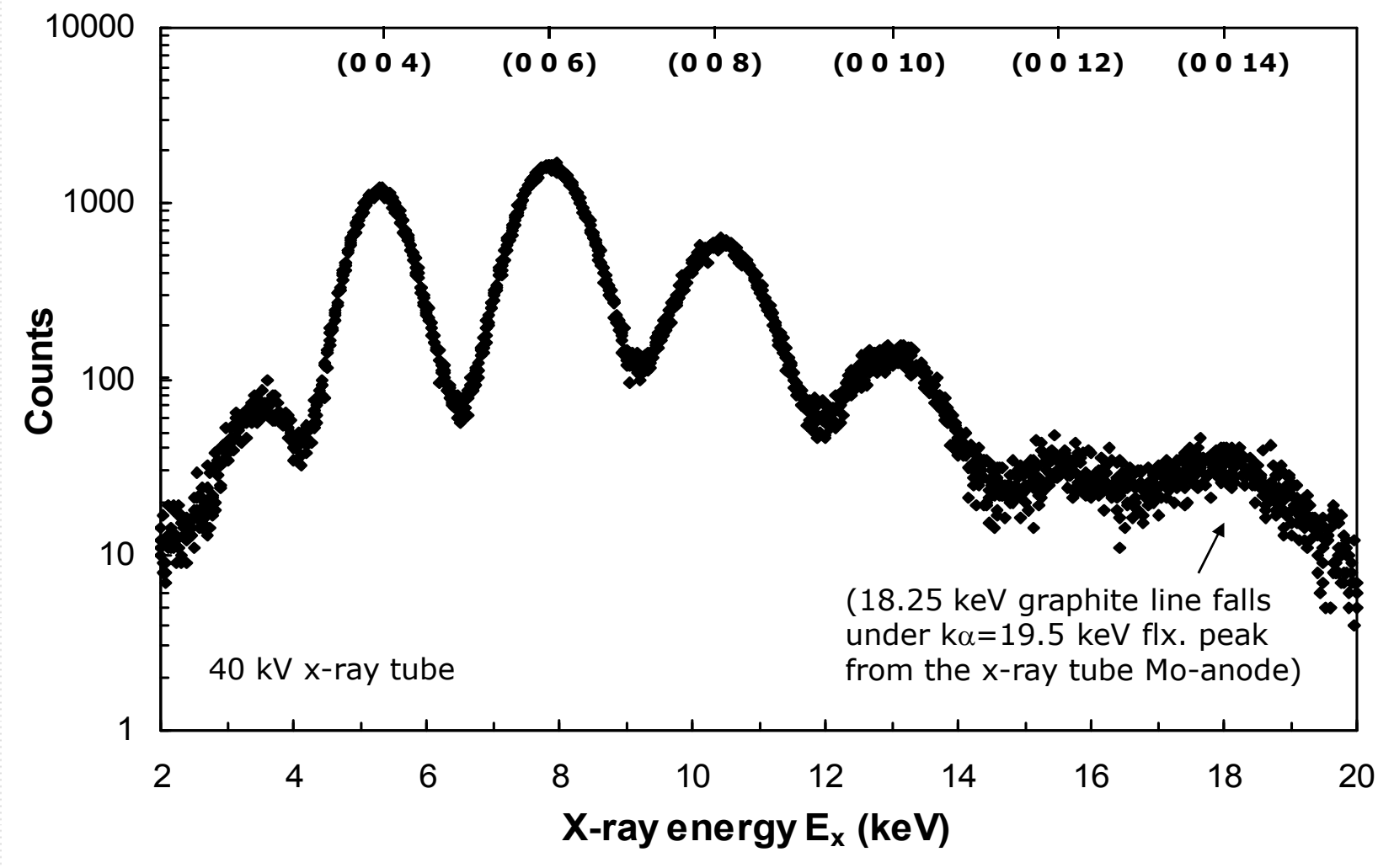
Physical characteristics and performances of the 2D-MHSP	
kapton foil thick	50 µm
holes diameter	50/60 µm
anodes with	20 µm
cathodes with	100 µm
pitch	200 µm
gas filling	Xenon
drift region	5 mm
FWHM (@5.9keV)	14%

X-ray imaging using the principle of resistive charge division

2D-imaging capability of the detector	
Position resolution - x dimension	130 µm (~300 µm FWHM)
Position resolution - y dimension	250 µm (~600 µm FWHM)
Field of view	2.5 cm x 2.5 cm

Natal da Luz *et. al.*,
IEEE TNS-55(4) (2008) 2341

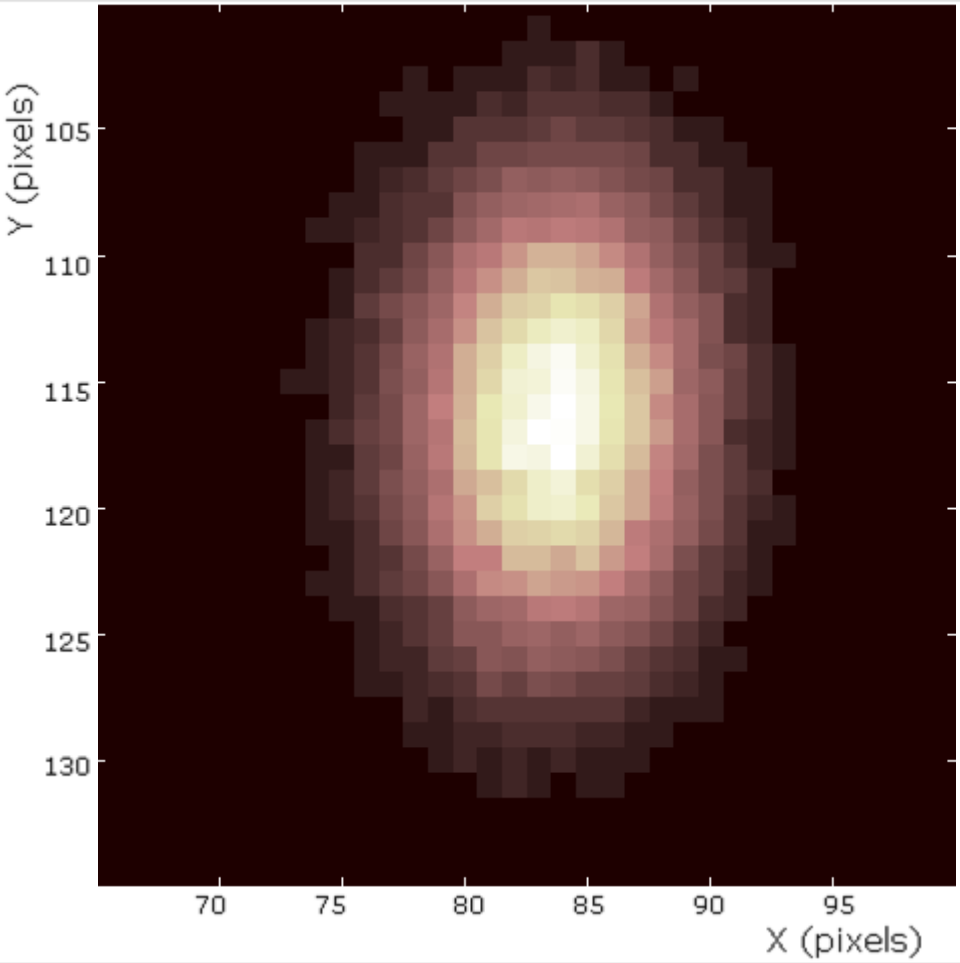
2D–MHSP: Experimental Results



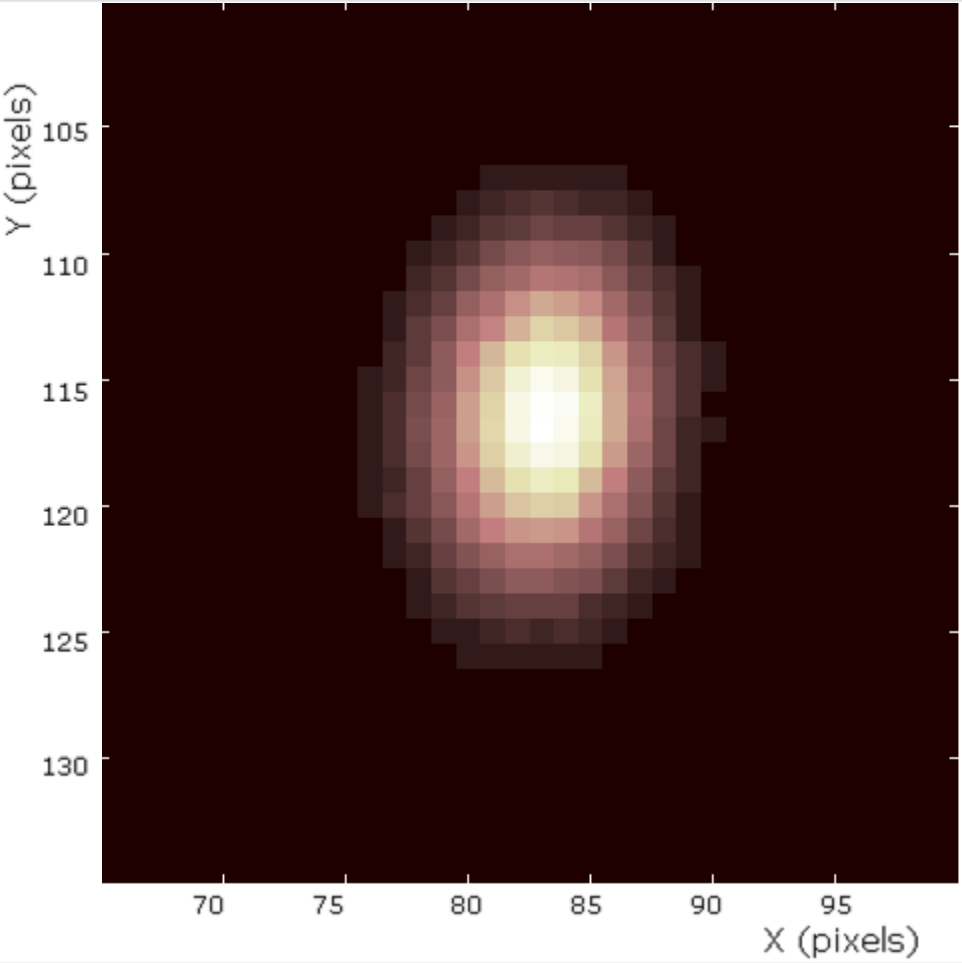
Energy spectrum, showing graphite x-ray lines

2D–MHSP: Experimental Results

5.22 keV polarized X-rays



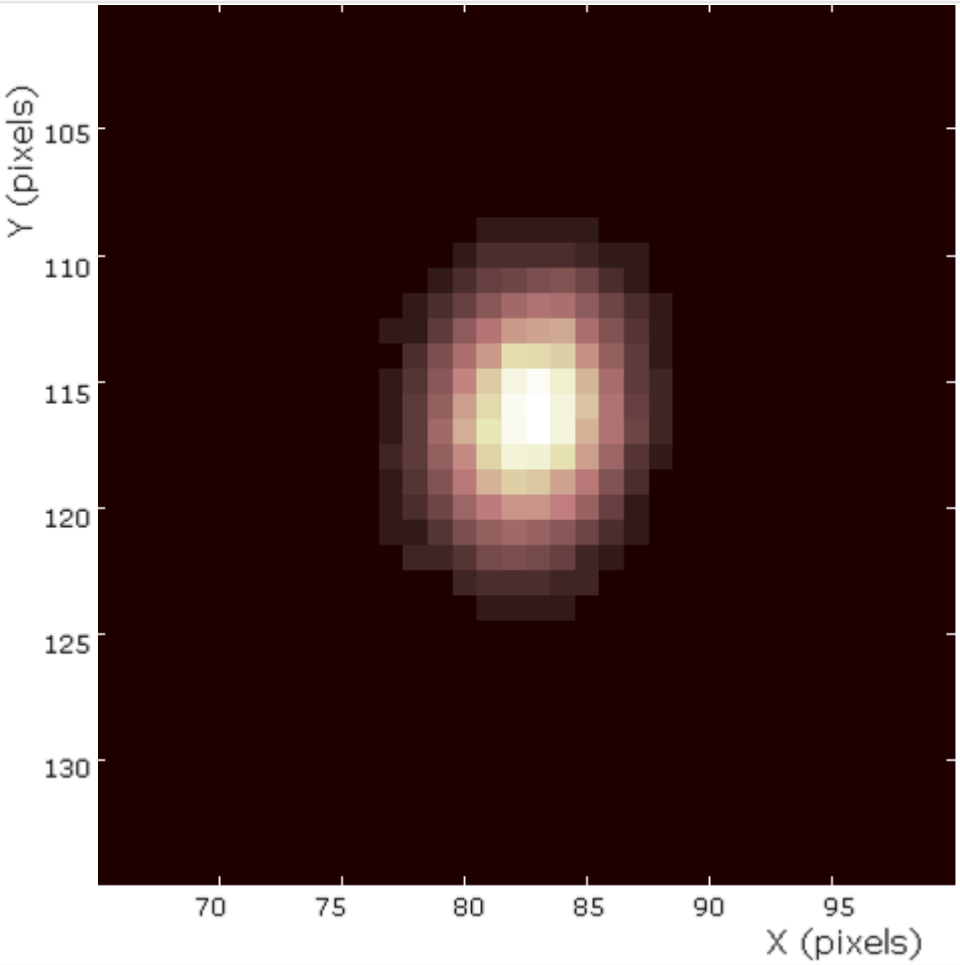
7.84 keV polarized X-rays



incidence ⊥ XY plane, polarization ∥ Y-axis

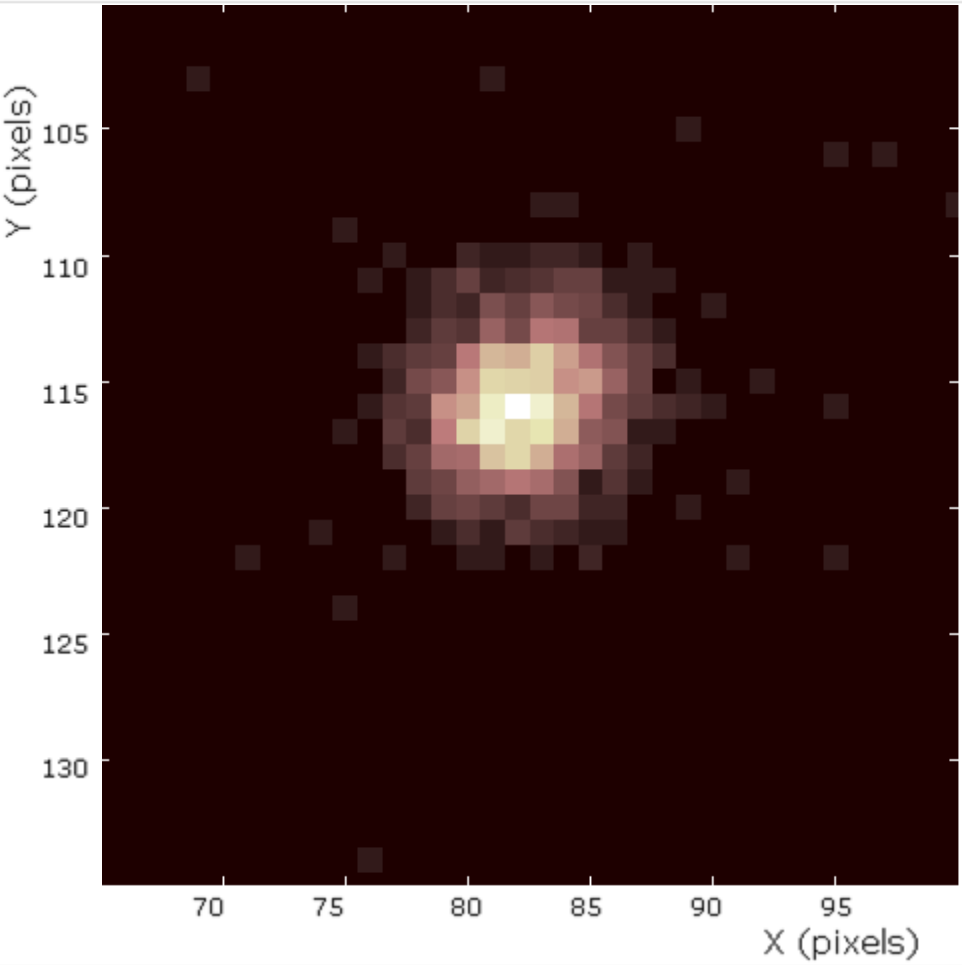
2D–MHSP: Experimental Results

10.45 keV polarized X-rays



polarization ∥ Y-axis

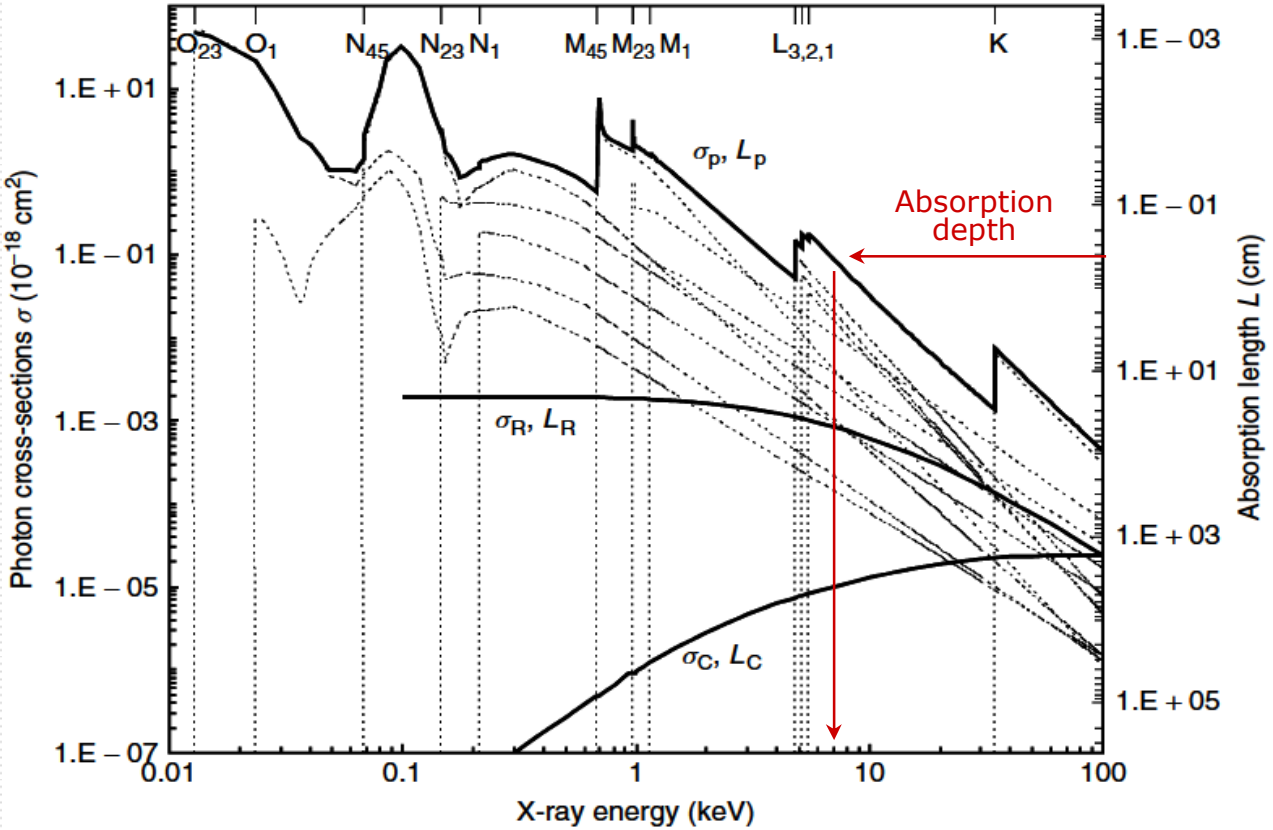
17.48 keV unpolarized X-rays



Kα fluorescence cloud profile from the X-ray tube Mo-anode

Future work

✓ optimization of the absorption region



Photoelectric σ_P, Rayleigh σ_R and Compton σ_C cross-sections for X-rays and corresponding absorption lengths-L in Xe at 760 Torr.

Conde, *X-ray Spectrometry: Recent Technological Advances*, John Wiley&Sons, 2004, ch.4

Conclusions

- Monte Carlo electron clouds reproduce the anisotropy of the photoelectron emission.

- G-MSGC: the shift observed in the peaks of the energy spectrum measured with a Gridded Microstrip Gas Chamber provide clear, albeit indirect, experimental evidence of the alignment of electron cloud profiles in Xe with x-ray polarization direction.

- 2D-MHSP:The images registered with a 2D position-sensitive detector based on the new Micro-Hole & Strip Plate structure further reinforce that evidence and confirm that a photoelectric polarimeter based on Micro Pattern Gas Chambers is a viable option for X-ray polarimetry.