Gas detectors for X-rays

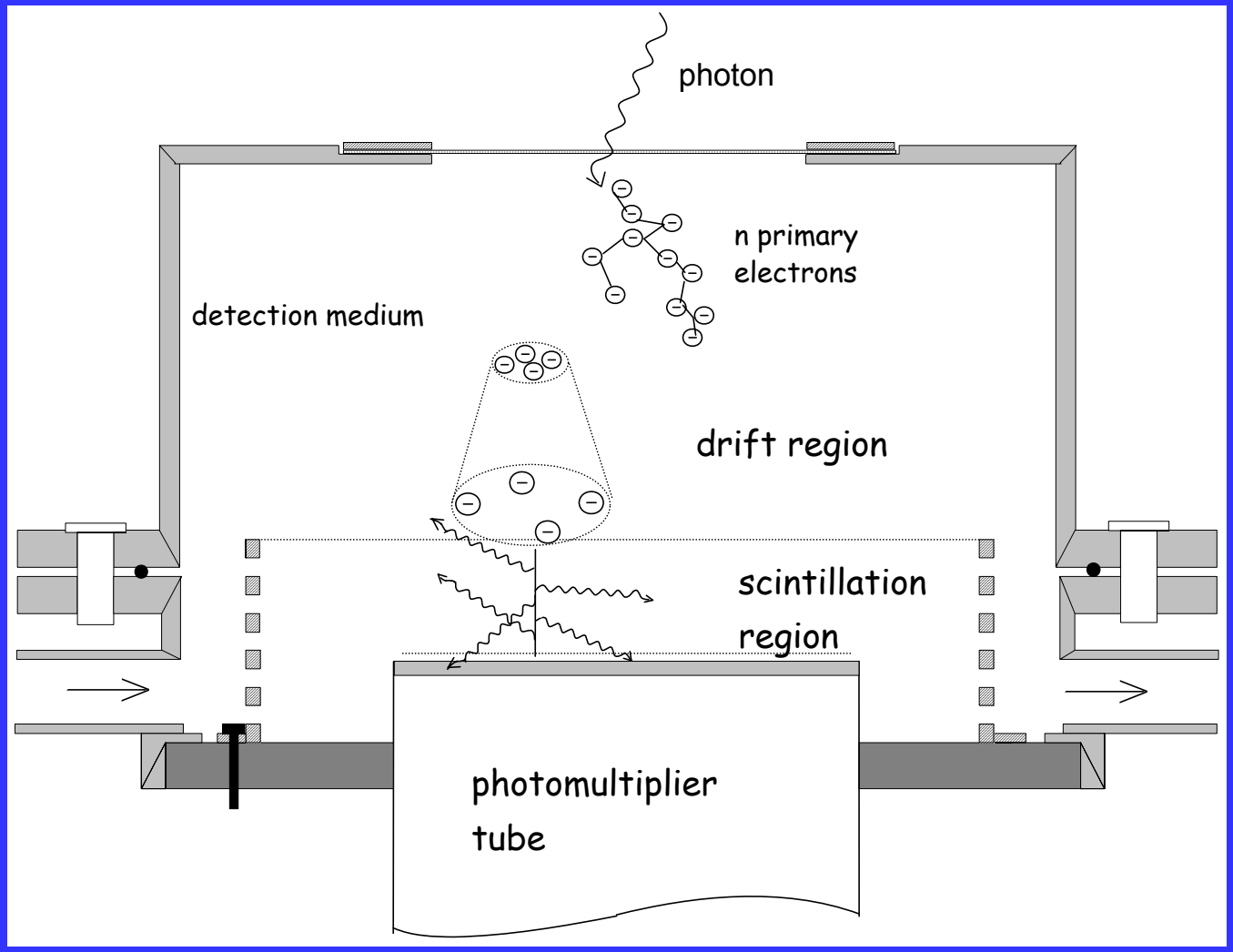
- Overall good energy resolution (<8% @ 5.9keV)
- Low cost
- Easy to operate (room temperature)
- Large detection areas
- Good radiation resistance

Gas detectors are based on the conversion of incident radiation in electric charge which is then converted into an electrical pulse.

Signal amplitude is proportional to the number of electrons produced.

Our attention at GIAN (Nuclear and Atomic Instrumentation Group) has been mainly drawn to Gas Proportional Scintillation Counters and Gas Proportional Ionization Counters.

Gas proportional scintillation counter



Amplification stage: scintillation produced in the deexcitation of electron impact excited atoms of the medium

Recent investigation in gas detectors

GPSC

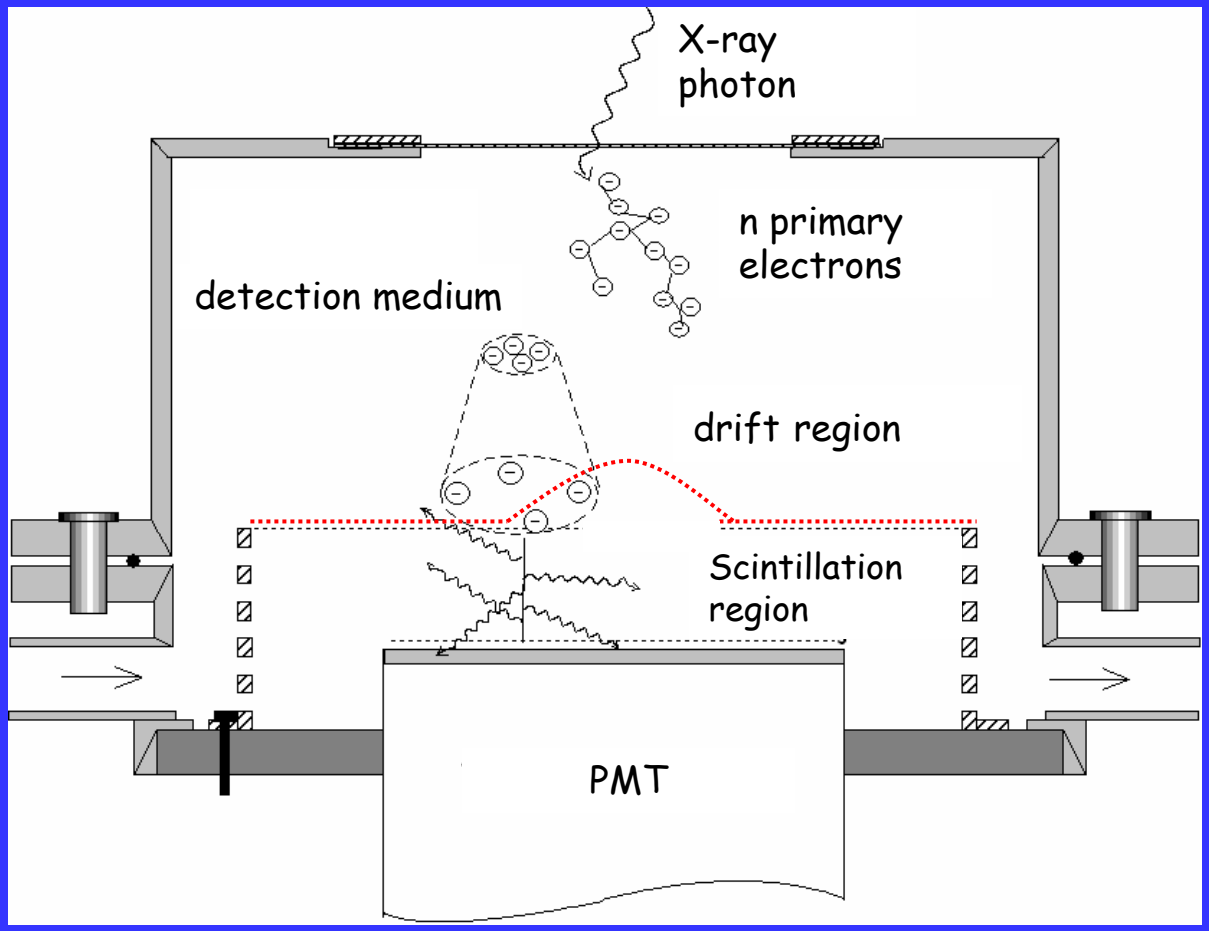
Problem: window Φ > 5mm - energy resolution degradation

Cause: Events off axis (with low solid angle)

Solution: exclude these events or compensate intensities.

1) Curved grid (@5,9 keV Φ = 25mm R from 10,5 to 8%)
2) Mask at photossensor window (@5,9keV Φ = 38mm R from 18 to 10%)
3) Digital signal processing (R improves 1% for E_{xr} < 10 keV)

Curved Grid Gas Proporcional Scintillation Counter (compensate intensities)

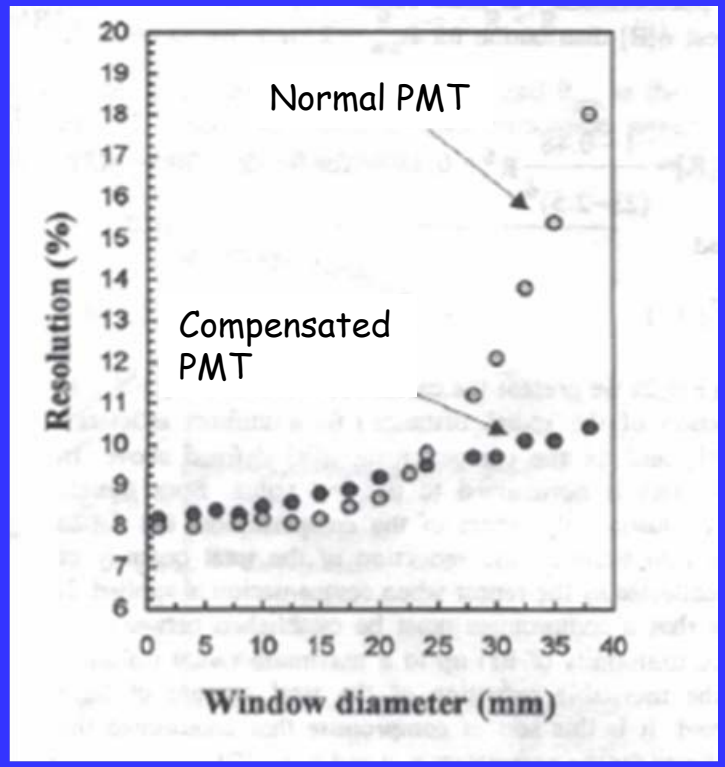


J.M.F.dos Santos, A.C.S.S.M.Bento, C.A.N.Conde

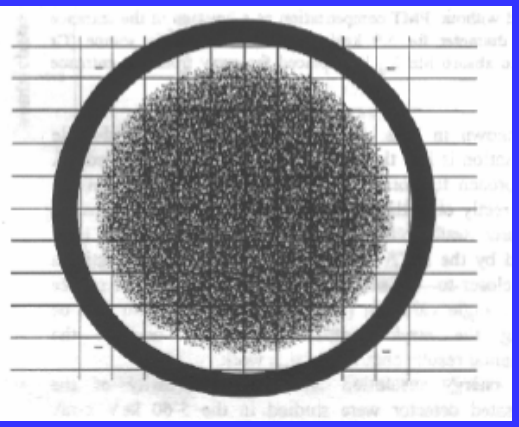
Nucl.Intr,&Meth.A 337(1994)427

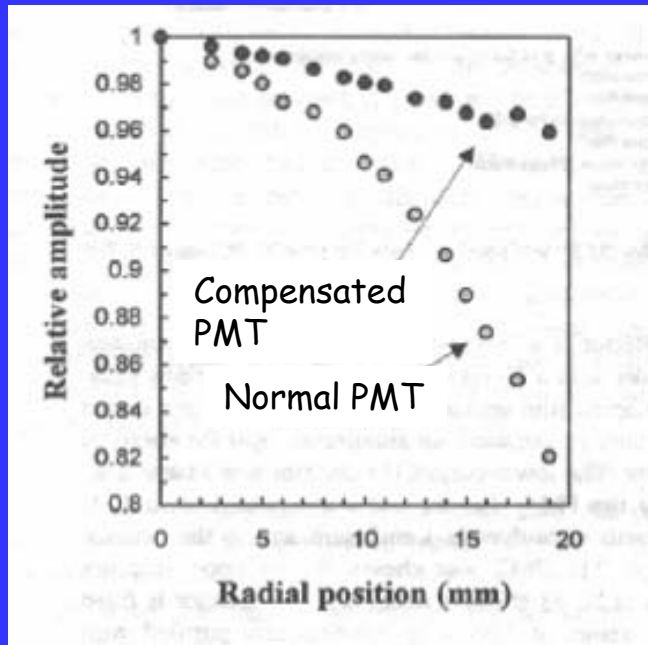
8% (from 10.5%) @ 6 keV Φ=25mm
Φ up to 40mm R~8%

Photosensor deposited mask (compensate intensities)



10% (from 18%)
@ 6 keV
Φ=38mm

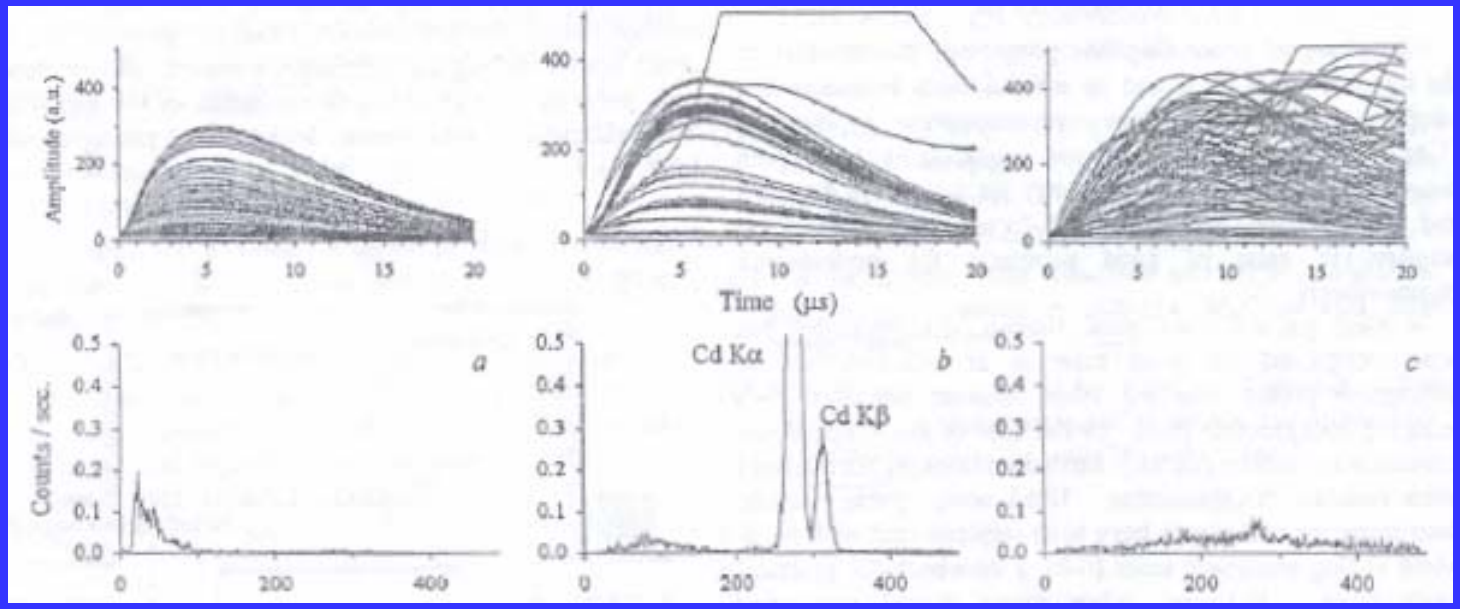




J.F.C.A.Veloso,J.M.F.dos Santos C.A.N.Conde

IEEE Trans.Nucl.Sci.42(1995)369

Digital signal processing (excluding events)

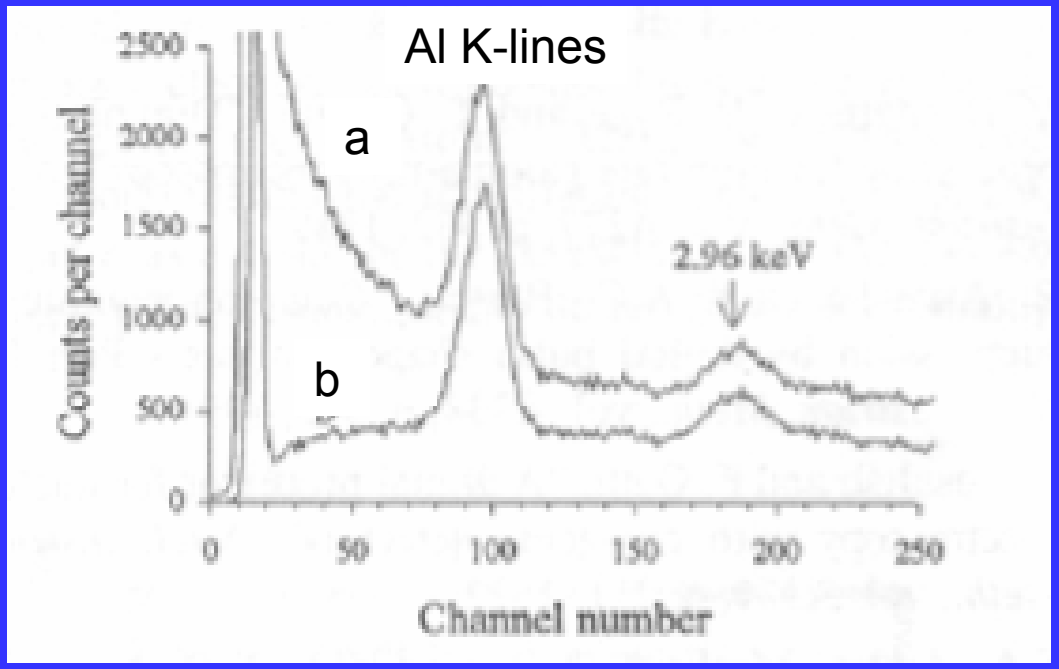


Signals from a ^{109}Cd source and corresponding spectrum with absorption events

a) in the scintillation region
b) in the scintillation/drift region with rise time discrimination
c) in the scintillation/drift region with long rise times (>4μs)

P.C.P.S.Simões, J.M.F.dos Santos, C.A.N.Conde,,Nucl.Intr,&Meth.A 422(1999)341

Digital signal processing (excluding events)



Al spectrum (^{244}Cm)
a) direct spectrum
b) rise time discriminated spectrum

P.C.P.S.Simões, J.M.F.dos Santos, C.A.N.Conde,,Nucl.Intr,&Meth.A 422(1999)341

Recent investigation in gas detectors

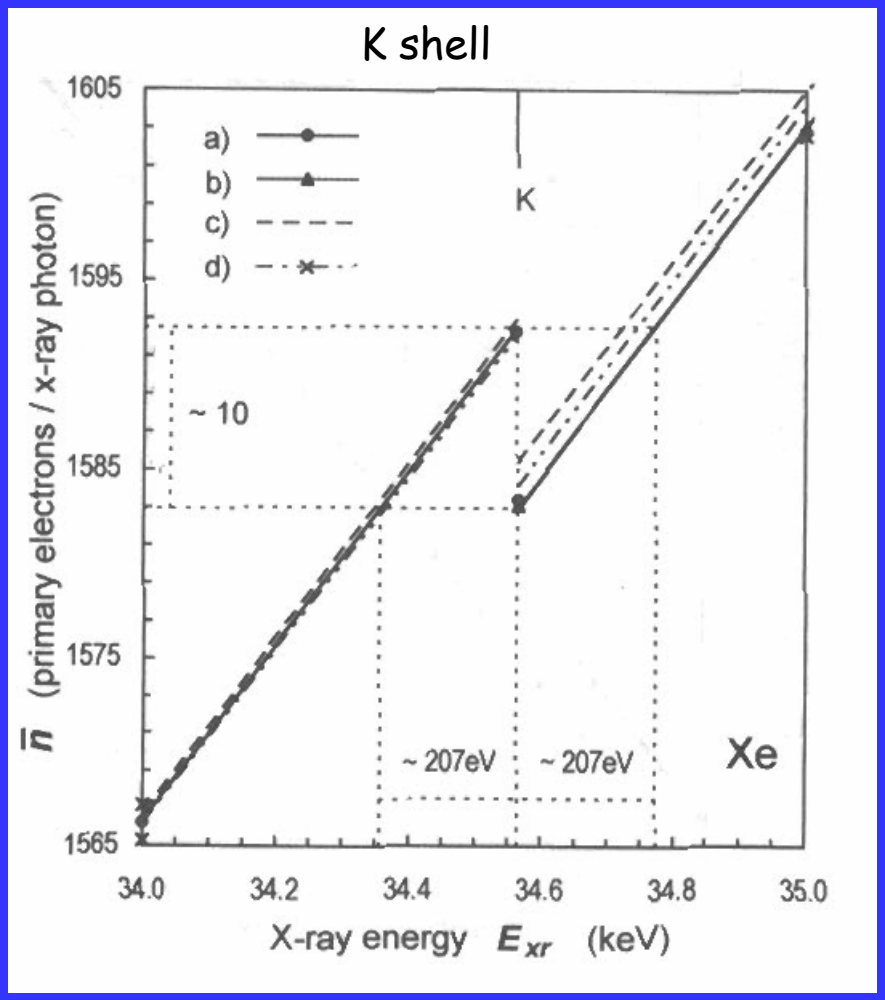
Xenon filled detectors

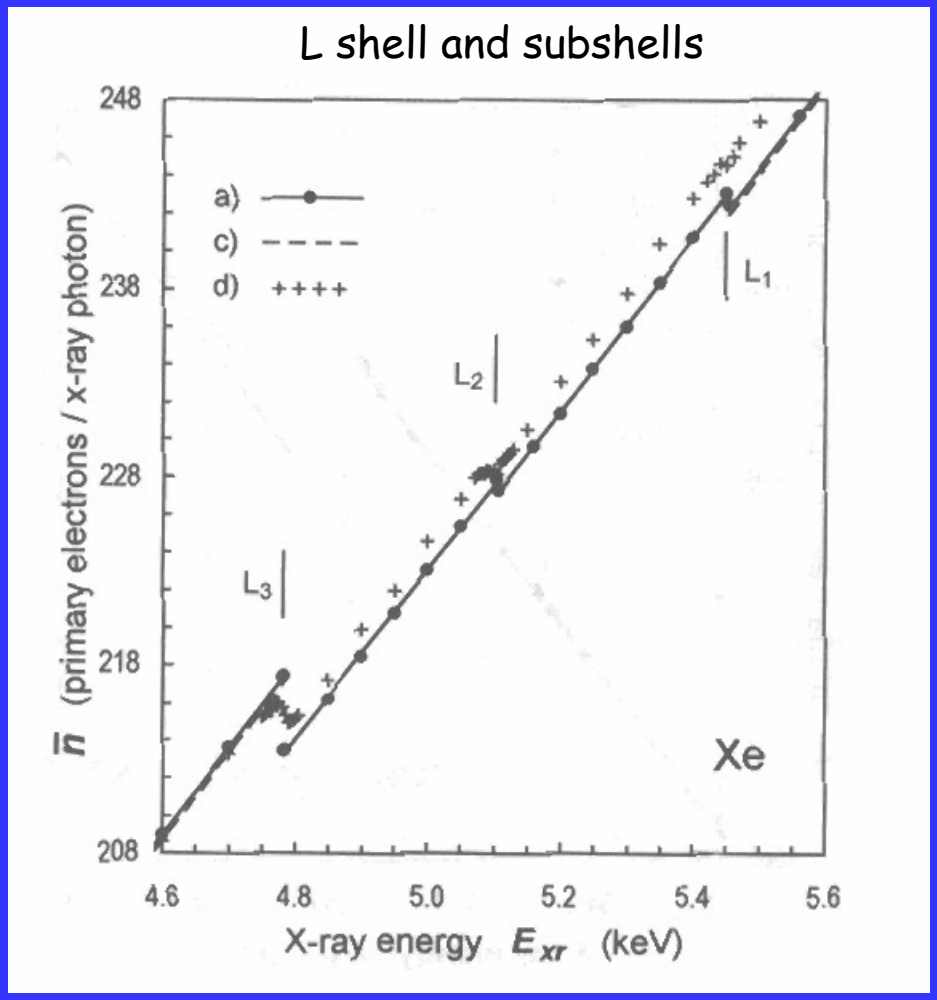
Monte Carlo simulation study

Problems detected and explained:

1) Energy non-linearity at absorption edges
2) Fano factor and w–value discontinuities at absorption edges

Break in energy linearity in Xe filled detectors: Monte Carlo simulated and experimental results

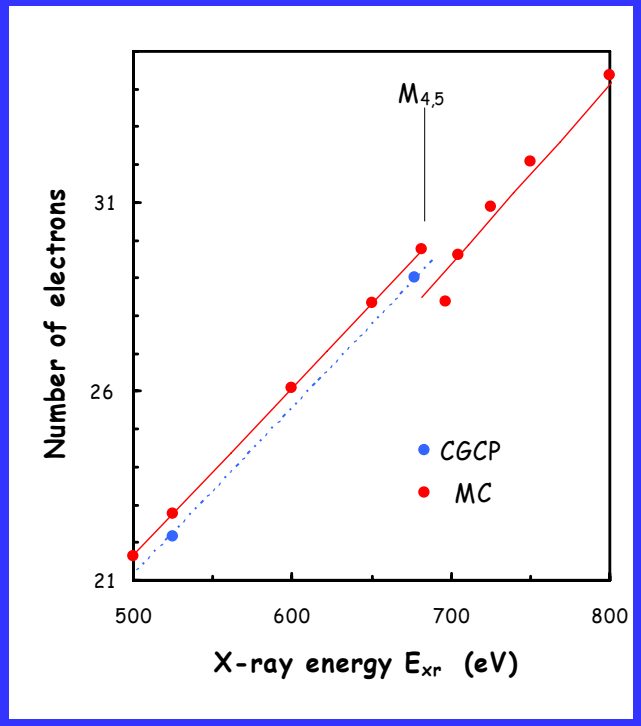


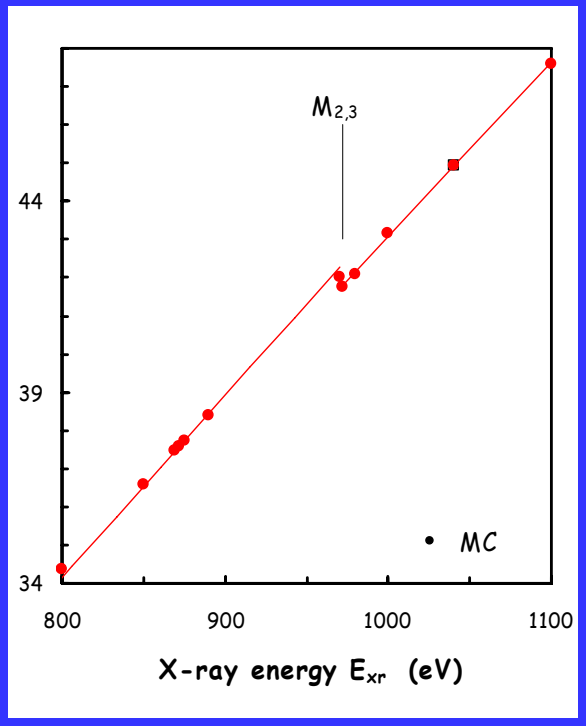


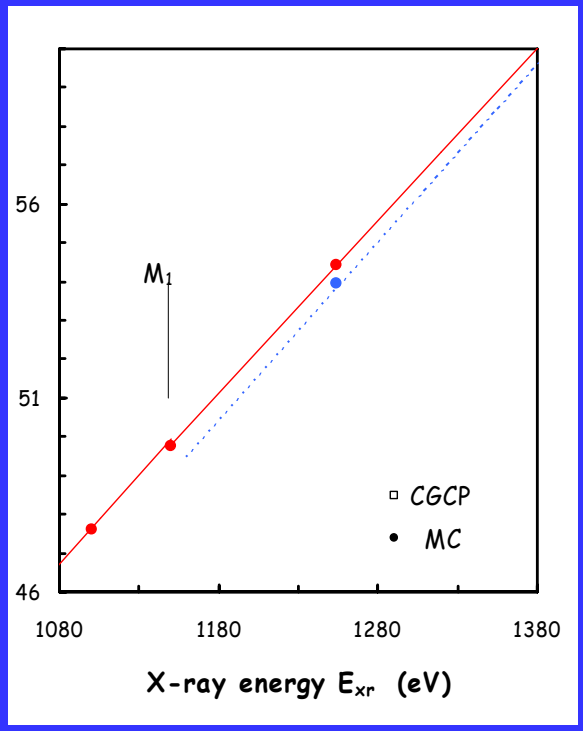
a), b) Monte Carlo
c) Experimental (with CPSC)
d) Experimental MSGC-based results

Break in energy linearity in Xe filled detectors: Monte Carlo simulated and experimental results

M shell and subshells







Recent investigation in gas detectors

Xenon filled detectors

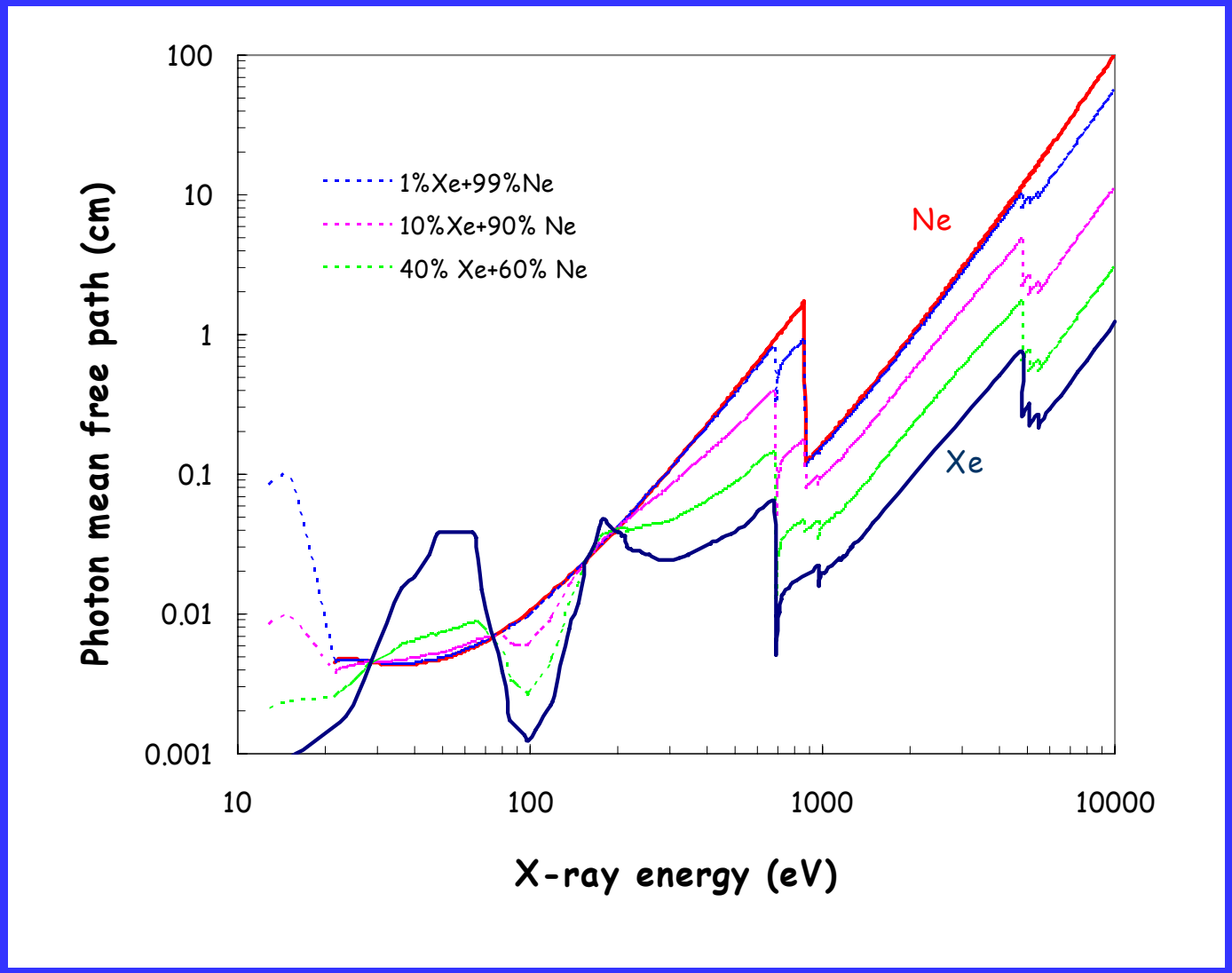
Known problem:
Pulse height distortion caused by electron loss to the entrance window

Cause: low photon absorption depth at specific photon energies

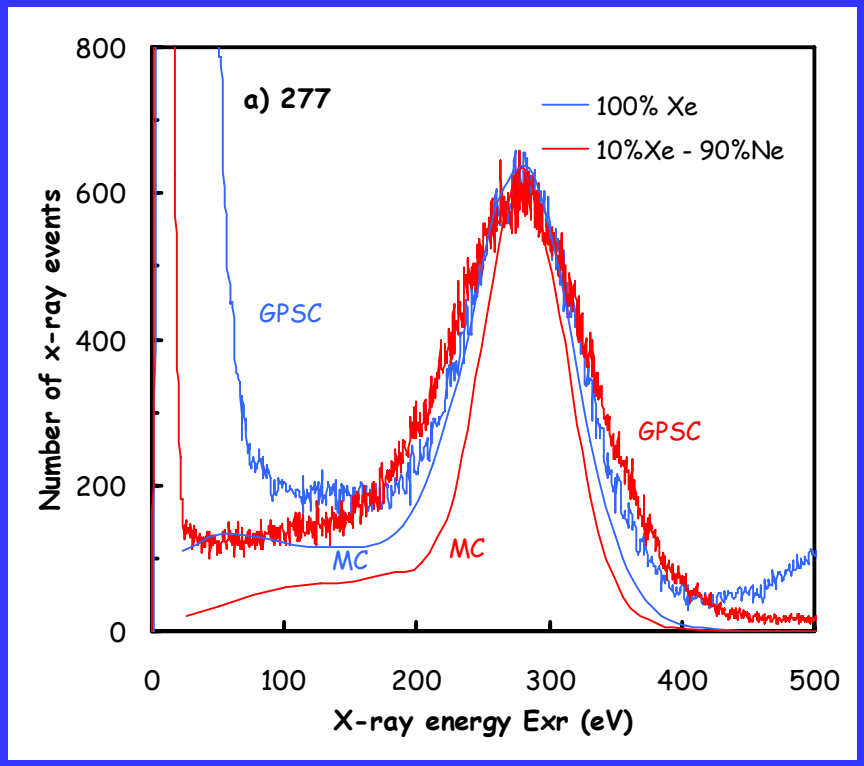
Solution:
Lighter absorption media – e.g. Xe-Ne mixtures to increase absorption depth

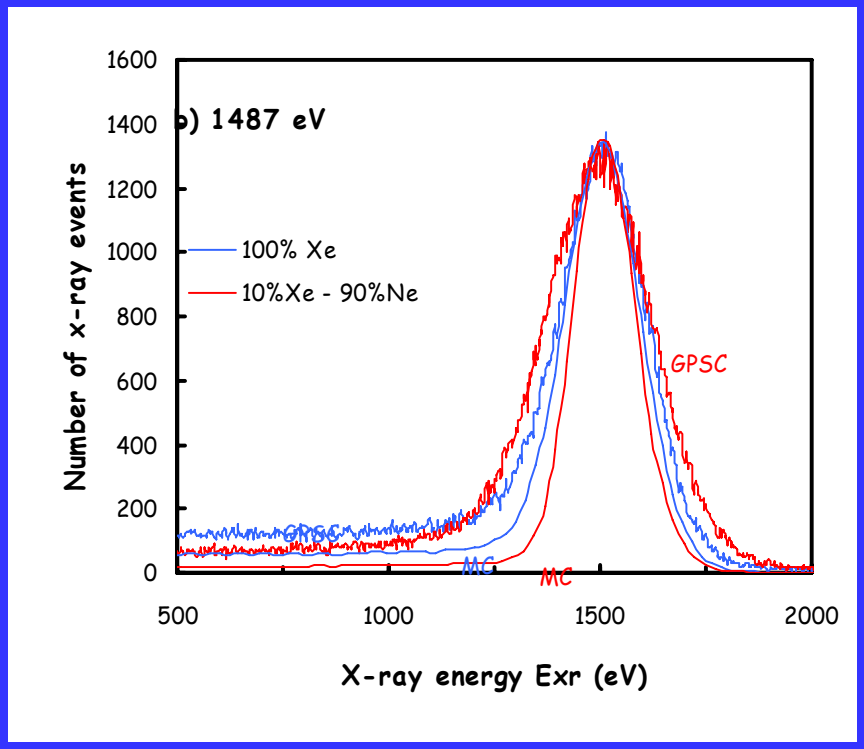
Monte Carlo simulation study of Xe-Ne mixtures

Photon mean free path in Xe, Ne and Xe-Ne mixtures at atmospheric pressure



GPSC experimental and Monte Carlo results with Xe-Ne mixtures

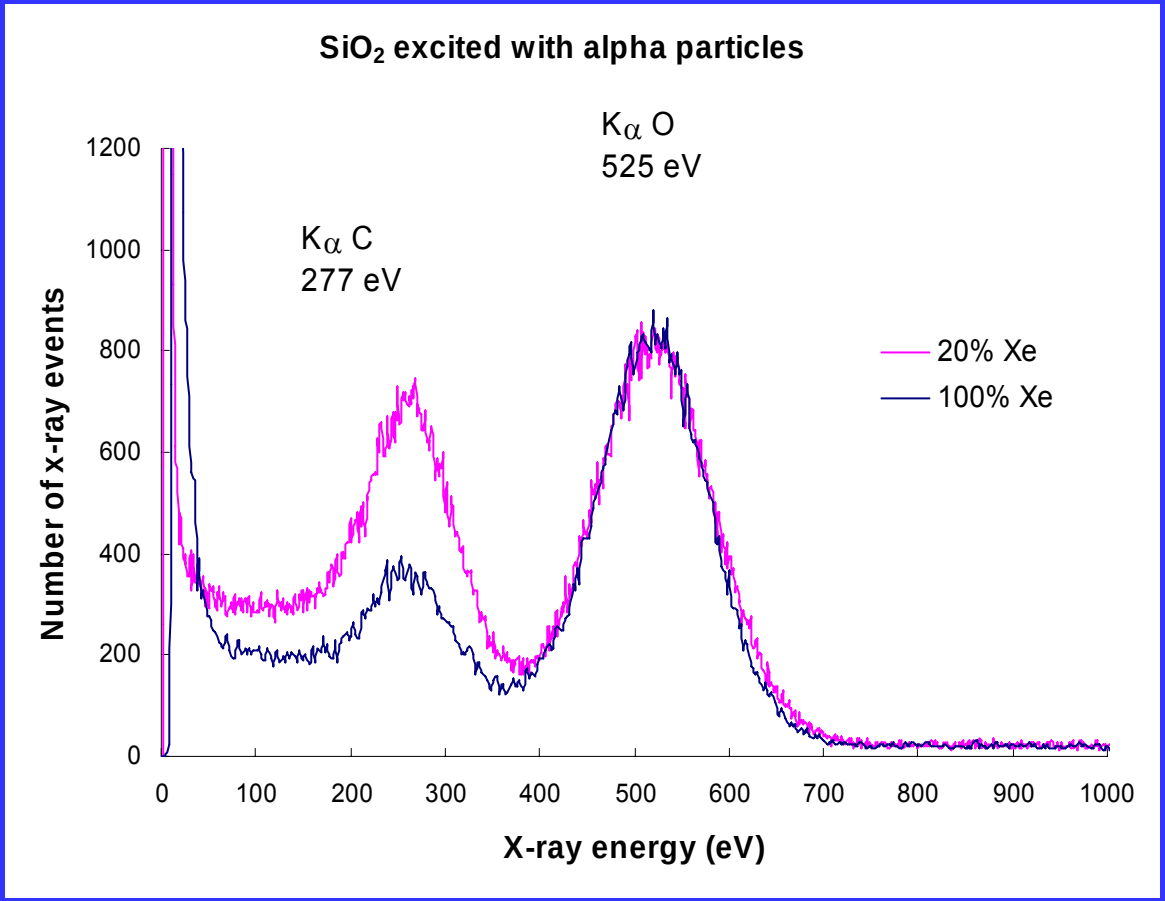




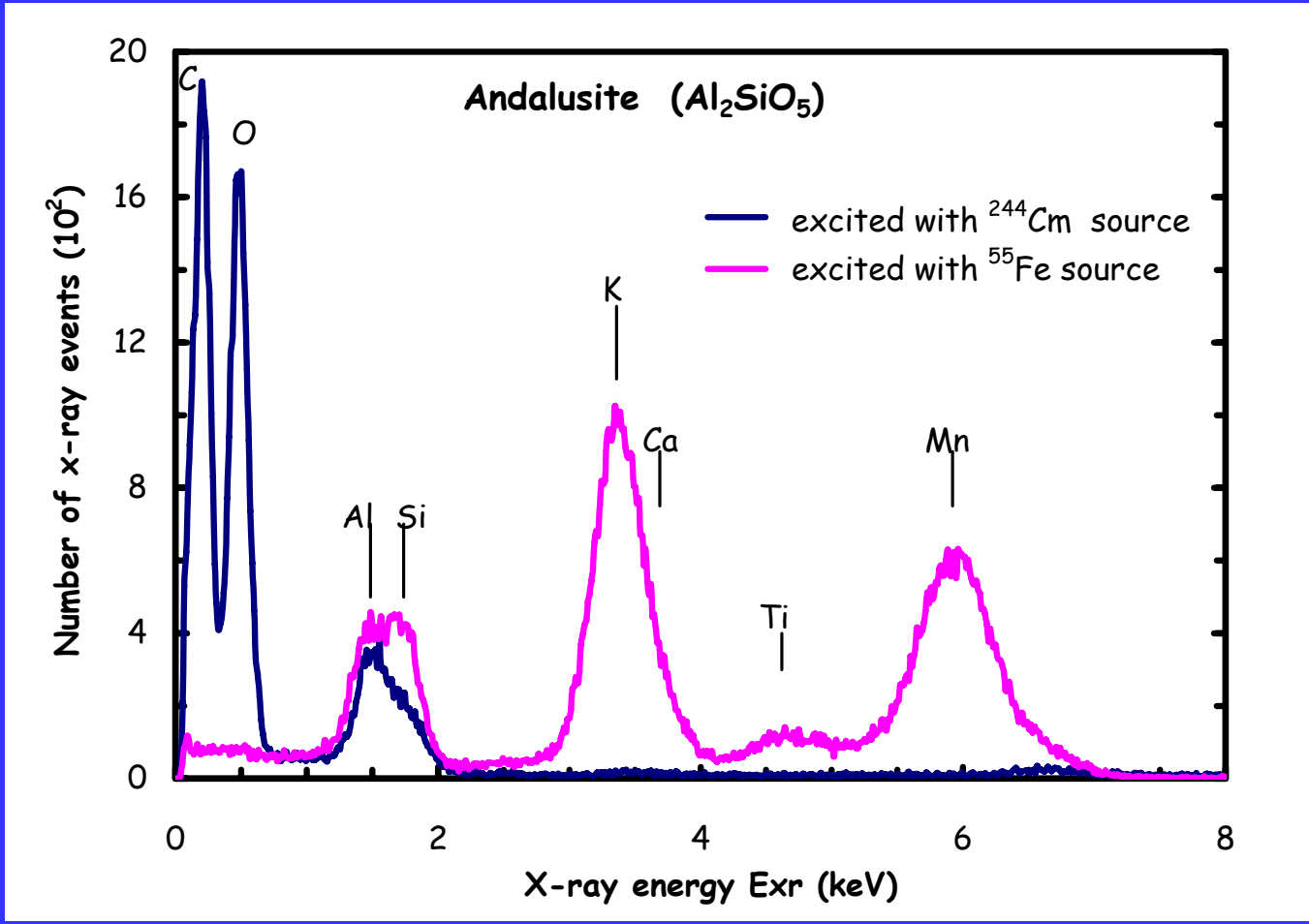
R= 35.3% in pure Xe
R= 44.5% in 10%Xe-90%Ne

Behaviour of pure Xe and 10%Xe-90%Ne mixture

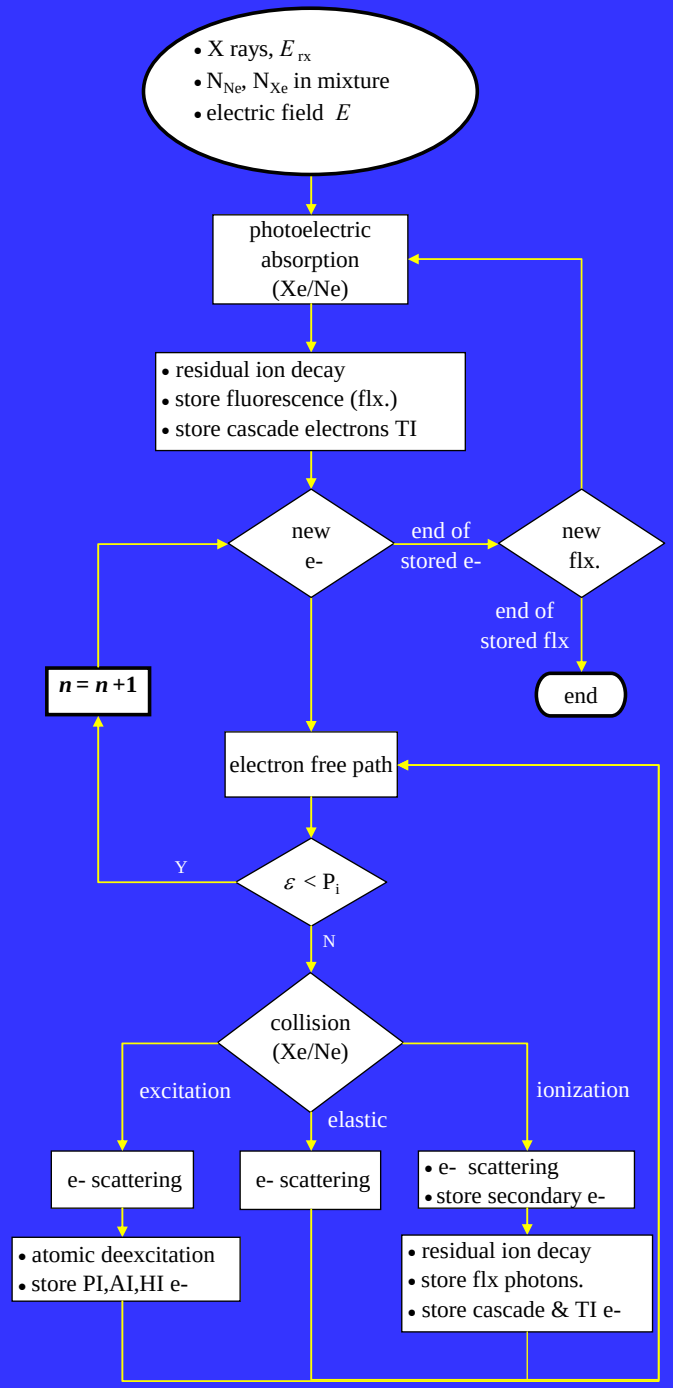
GPSC experimental and Monte Carlo results with Xe-Ne mixtures



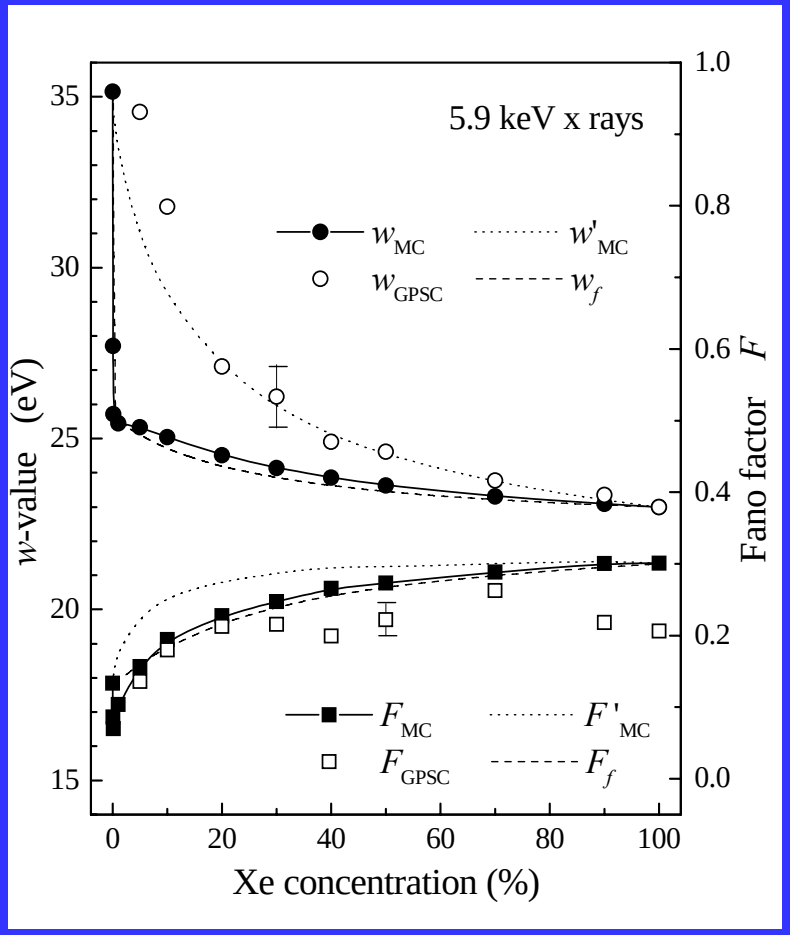
GPSC experimental results with Xe-Ne mixtures

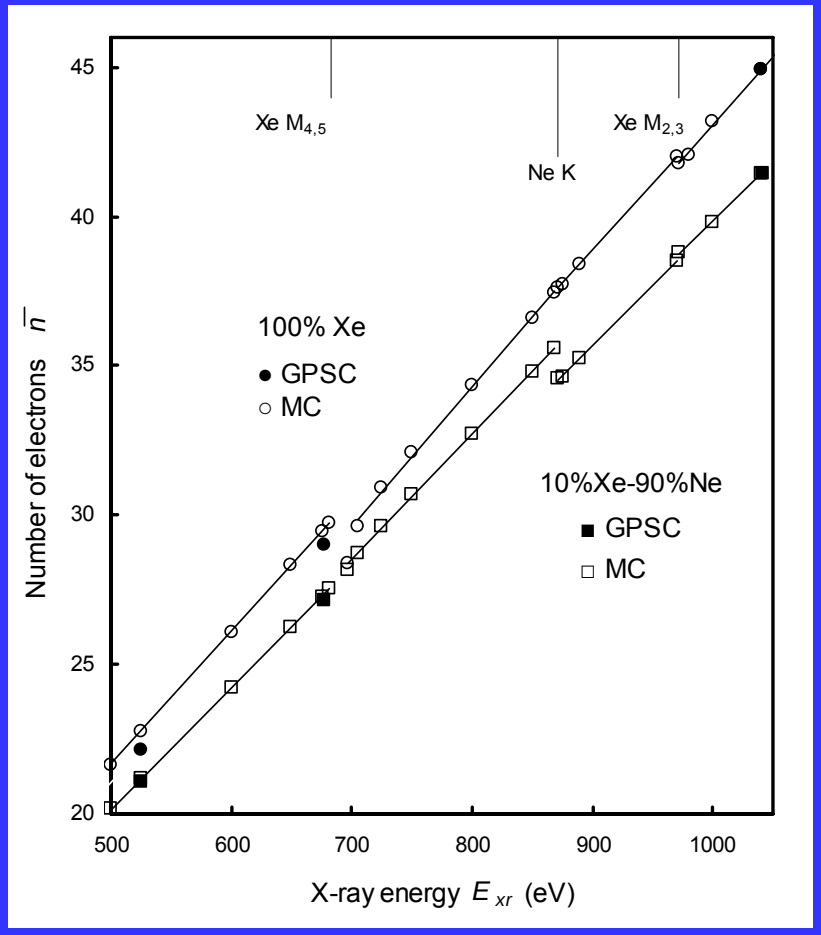


X-ray absorption flowchart in Xe-Ne mixtures



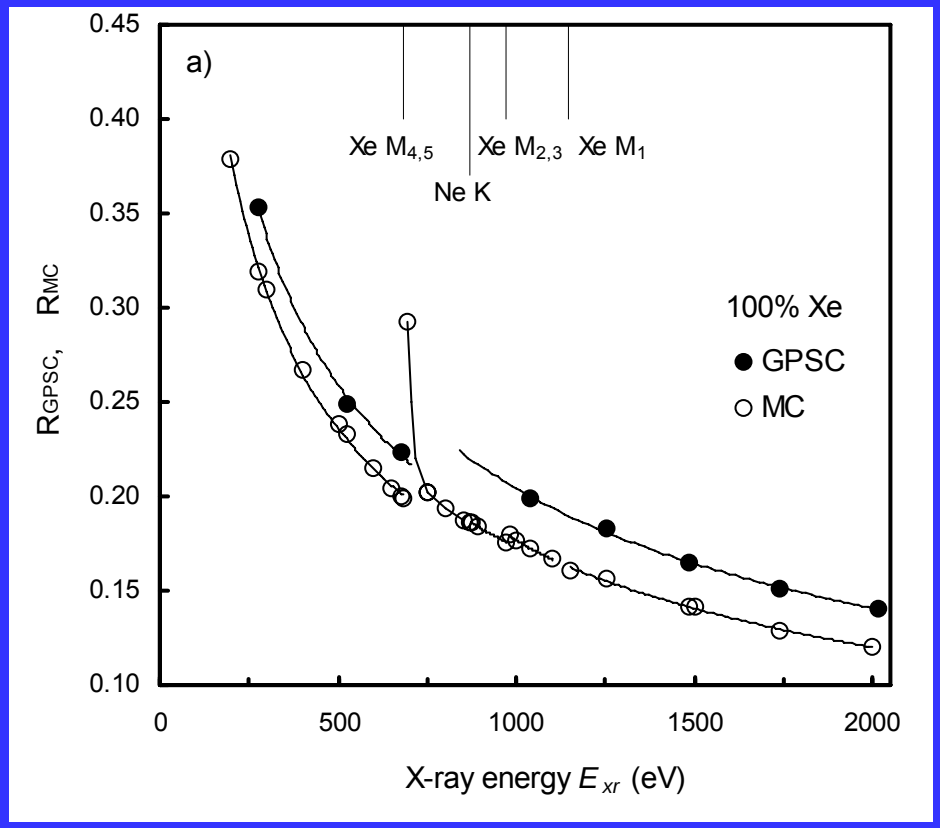
GPSC experimental and Monte Carlo study of Xe-Ne mixtures

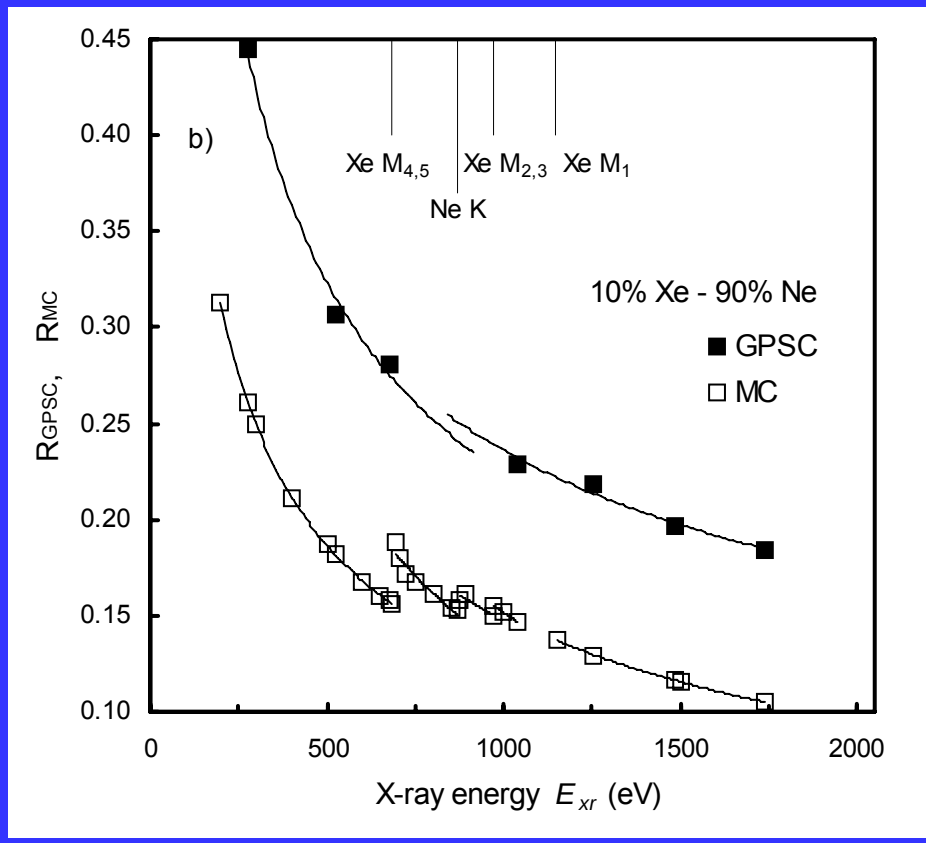




Behaviour of pure Xe and 10%Xe-90%Ne mixtures
Left – w-value and Fano factor as a function of Xe concentration
Right - mean number of electrons at Xe and Ne absorption edges

GPSC experimental and Monte Carlo study of Xe-Ne mixtures





Experimental and Monte Carlo calculated energy resolution as a function of the X-ray energy

On-going investigation in GPSC

Known problem:

The PMT makes the GPSC bulky, somewhat fragile and more expensive

Solution:

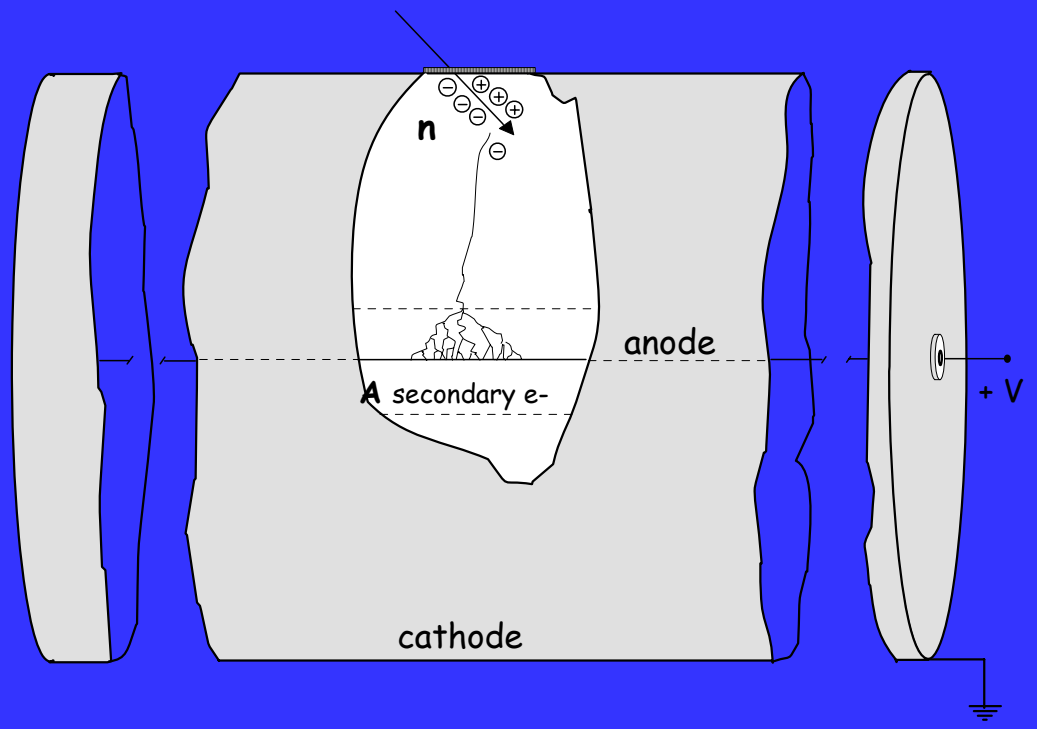
Find an alternative to the PMT

Fields under investigation:

CsI covered microstructures in different gas atmospheres (Monte Carlo simulation and experimental studies)

Photo-photomultiplier (simulation and experimental work)

Gas proportional ionization counter



Amplification stage : charge multiplication close to the anode

Recent investigation in gas detectors

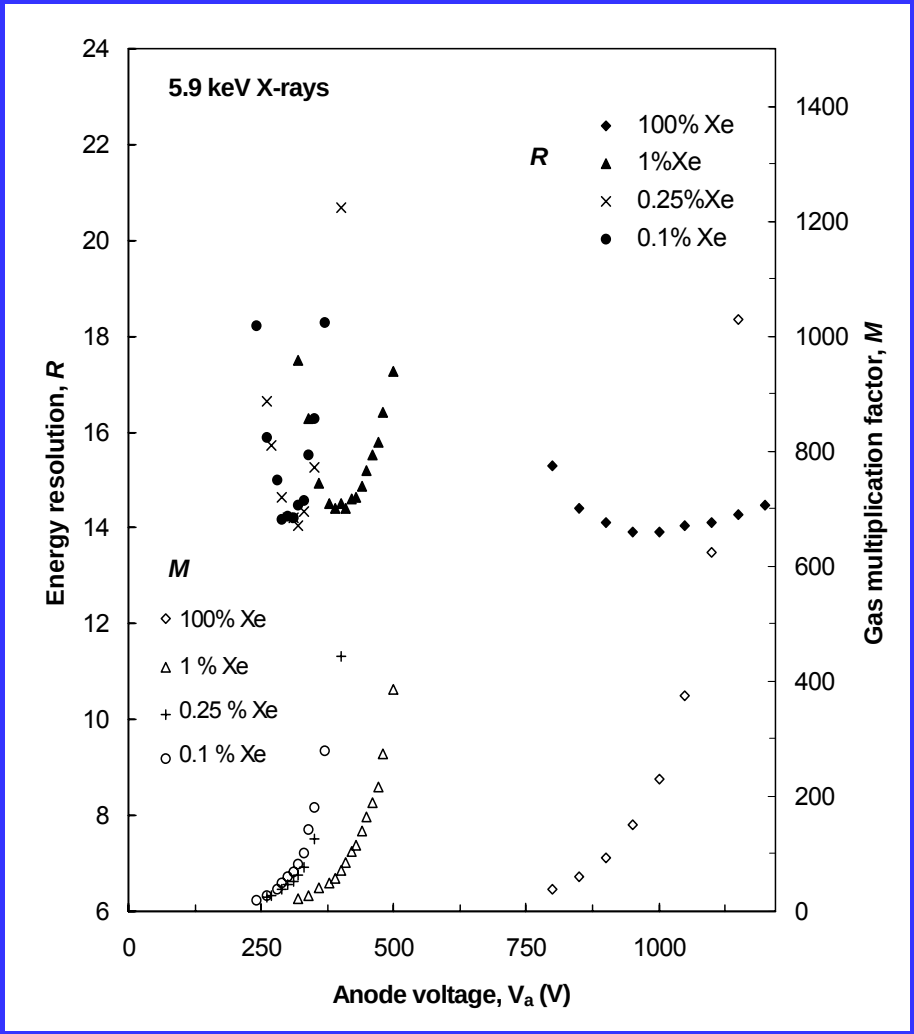
CGIP

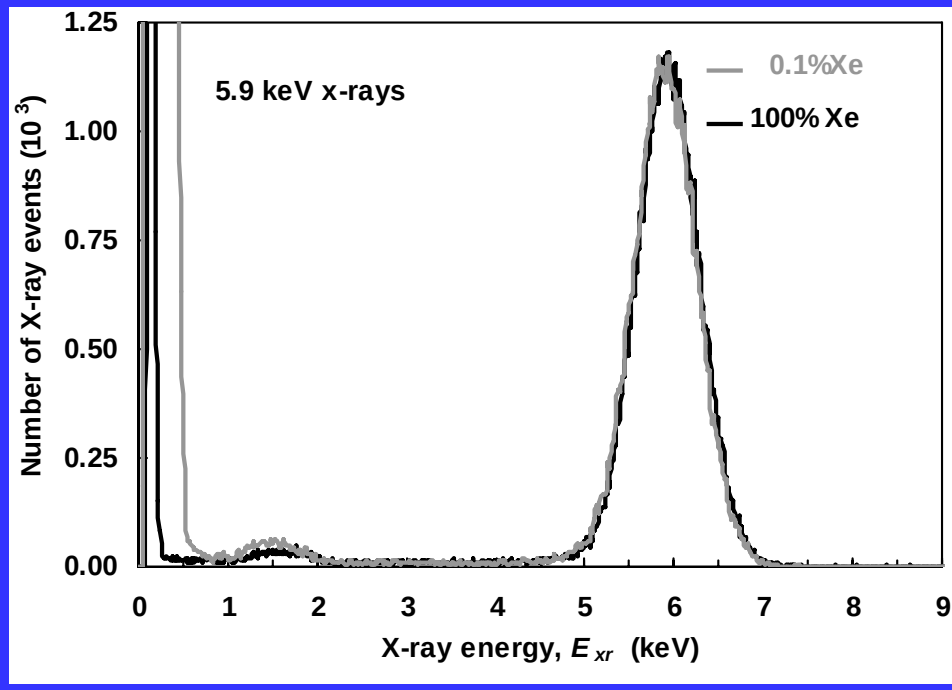
Problem: improve energy resolution

Solution:

- Use of Penning mixtures to increase the number of ion pairs
- Precise definition of the multiplication volume

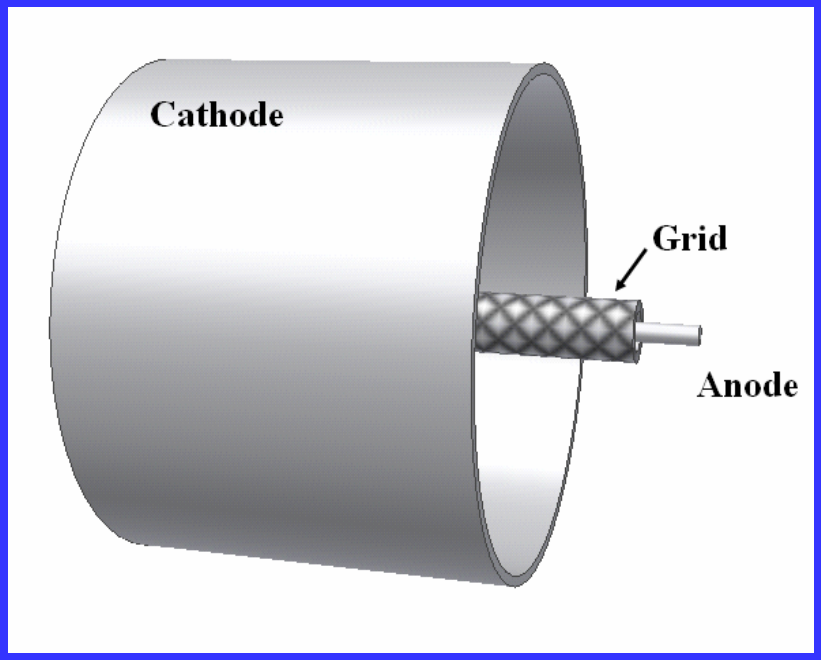
GPIC experimental results for Xe-Ne mixtures

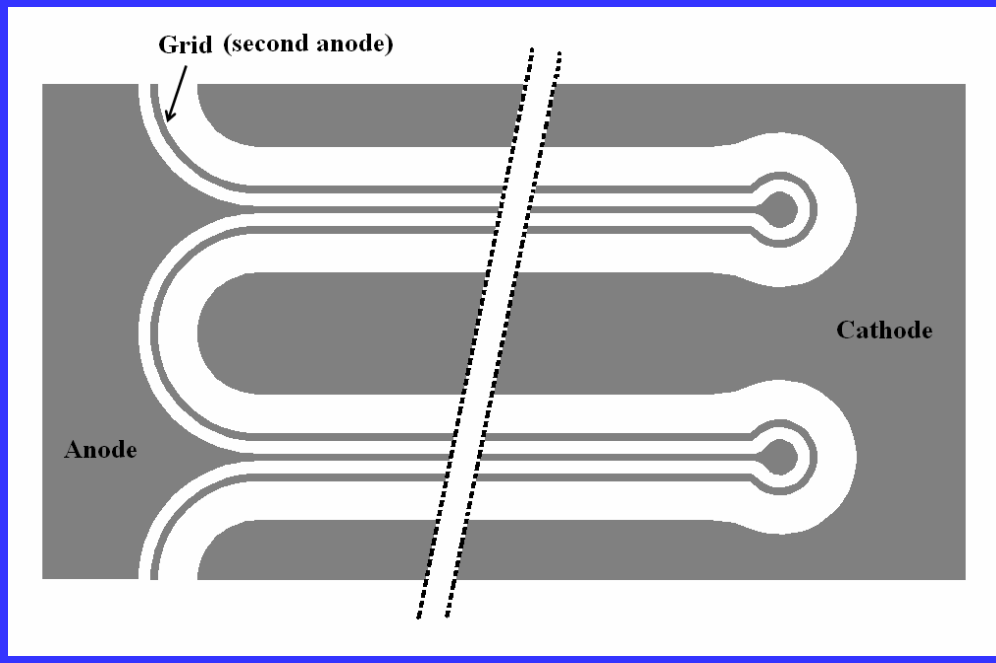




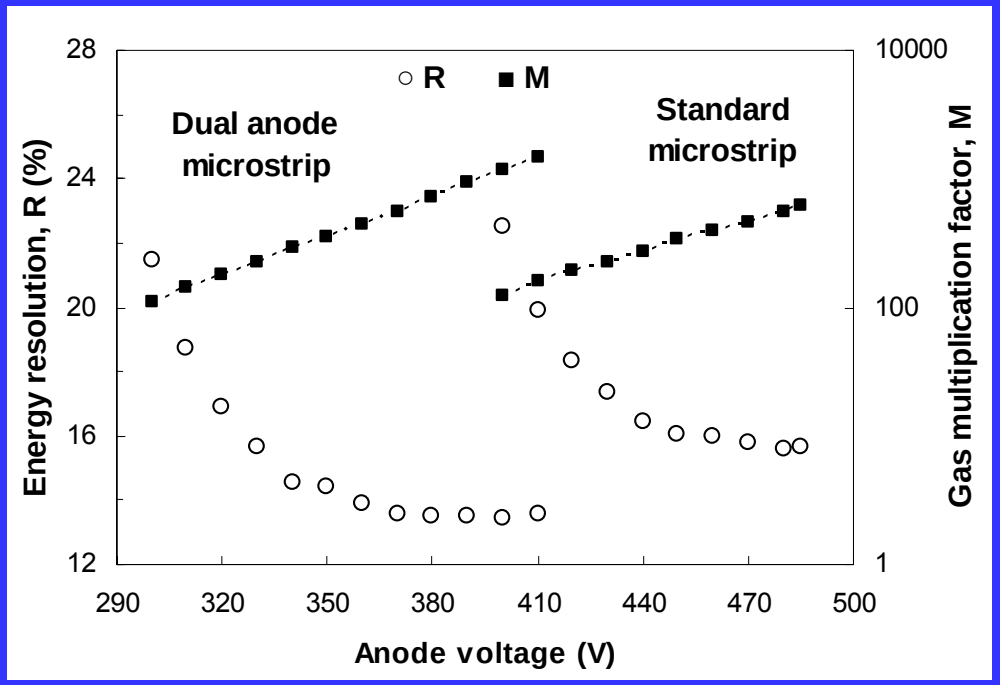
R= 13.9% in pure Xe
R= 14.2% in 0.1%Xe-99.9%Ne

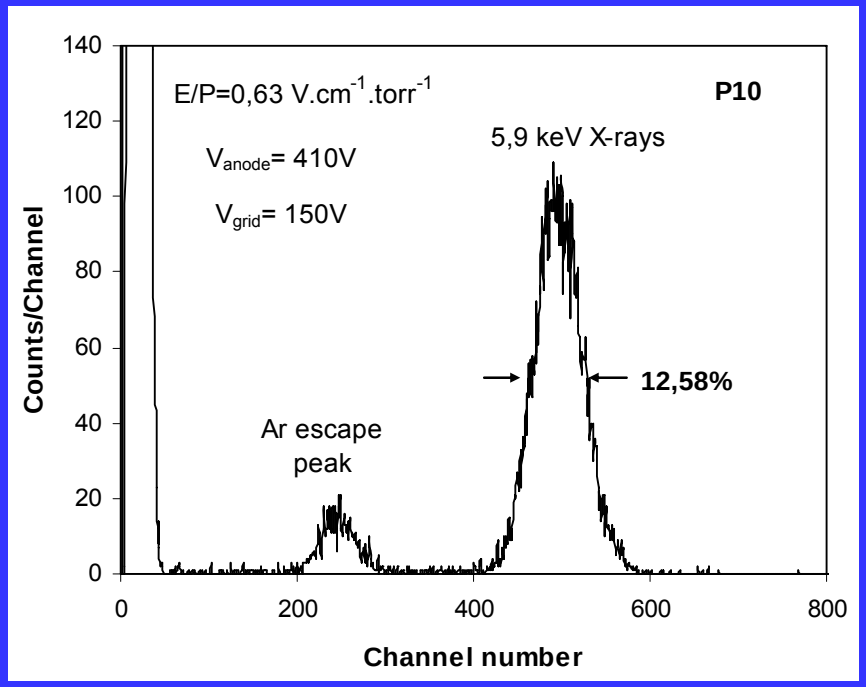
Precise definition of the multiplication volume: the gridded GPIC





Experimental results with gridded GPIC





Gas	Microstrip	Best R (%)	V_{anode} (V)	V_{grid} (V)	M
Xe	MS2	13.4	400	100	1150
	Standard	15.6	480	-	560
P10	MS2	12.6	415	150	590
	Standard	13.6	480	-	490

Other on-going fields of research at GIAN

Effect of the polarization of absorbed X-rays on the final profile of the electron cloud

Study of Astrophysical polarized γ-rays with pixelated CZT detectors (with ESA & Italian group in a consortium)

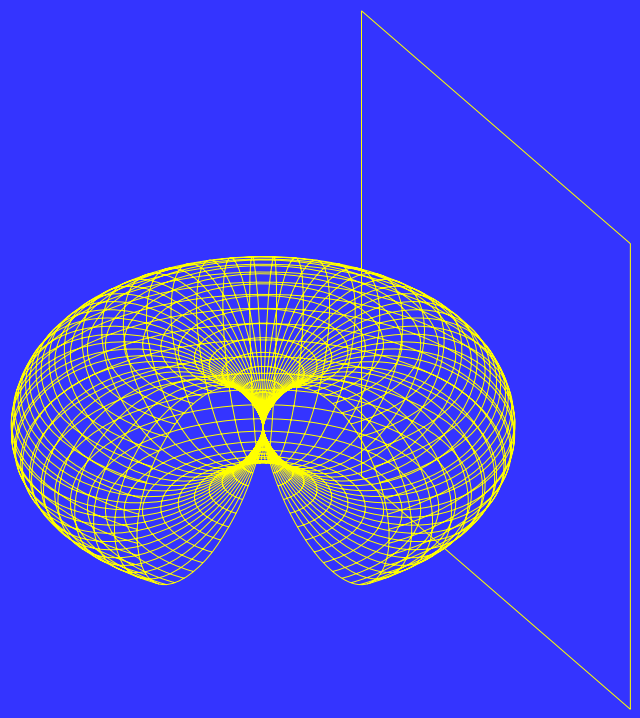
Study of solar x-ray physics in satellite-born detectors (with China)

Exotic atoms (muonic hydrogen Lamb shift measurements) (with PSI CH)

Experimental measurements and Monte Carlo calculation of transport parameters of noble gas ions (Ar+, Ar++, … in Ar)

Effect of the polarization of X-rays on the angular distribution of photoelectrons

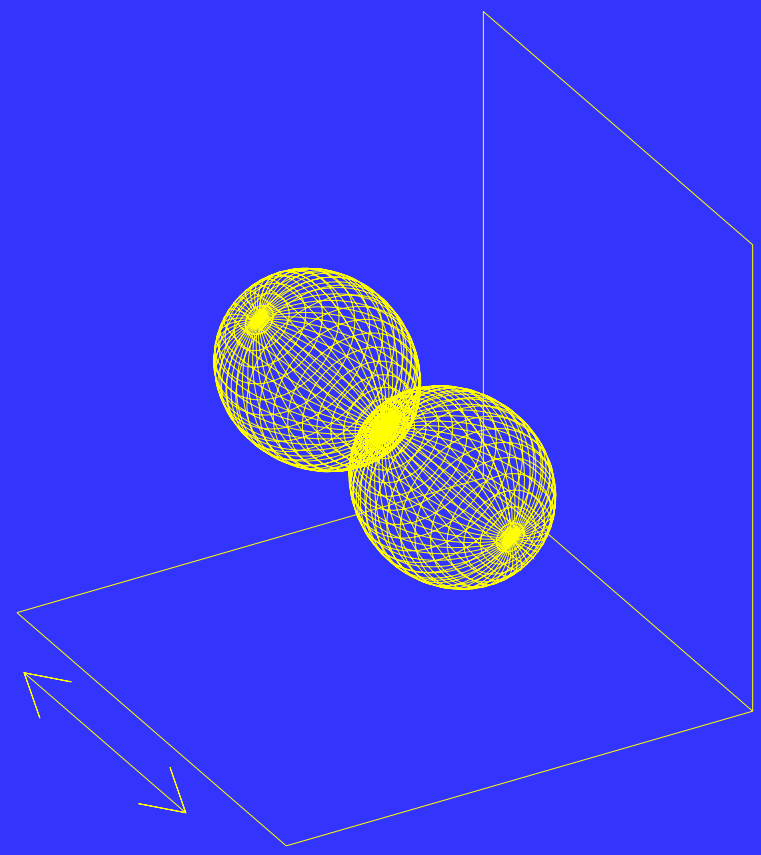
Unpolarized photons



$$\frac{d\sigma}{d\Omega} = \frac{\sigma}{4\pi}\left[1 - \frac{1}{2}\beta P_2(\cos\underline{\theta})\right]$$

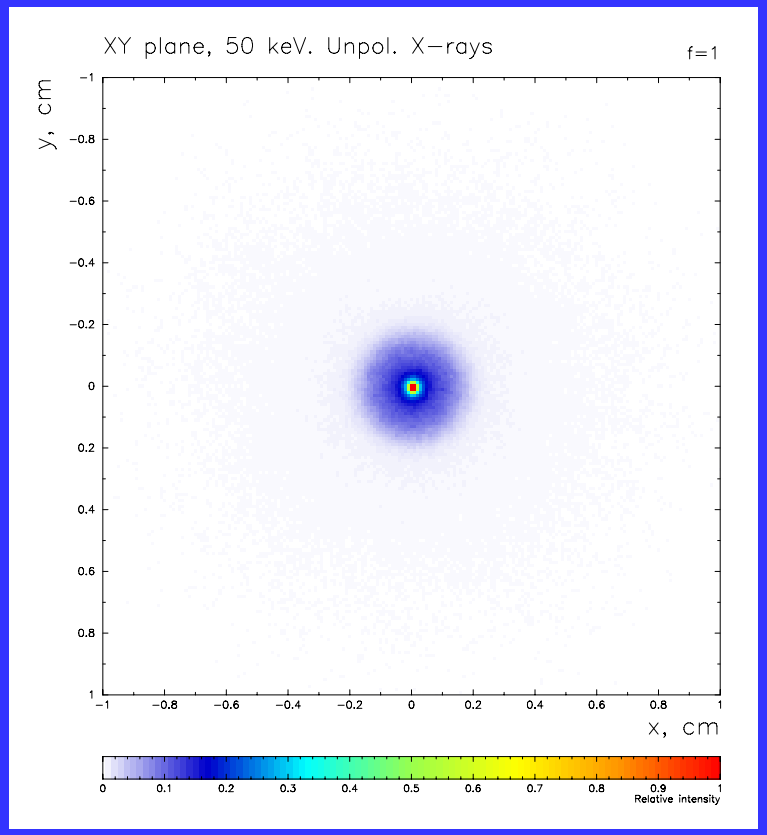
Photon direction

Polarized photons

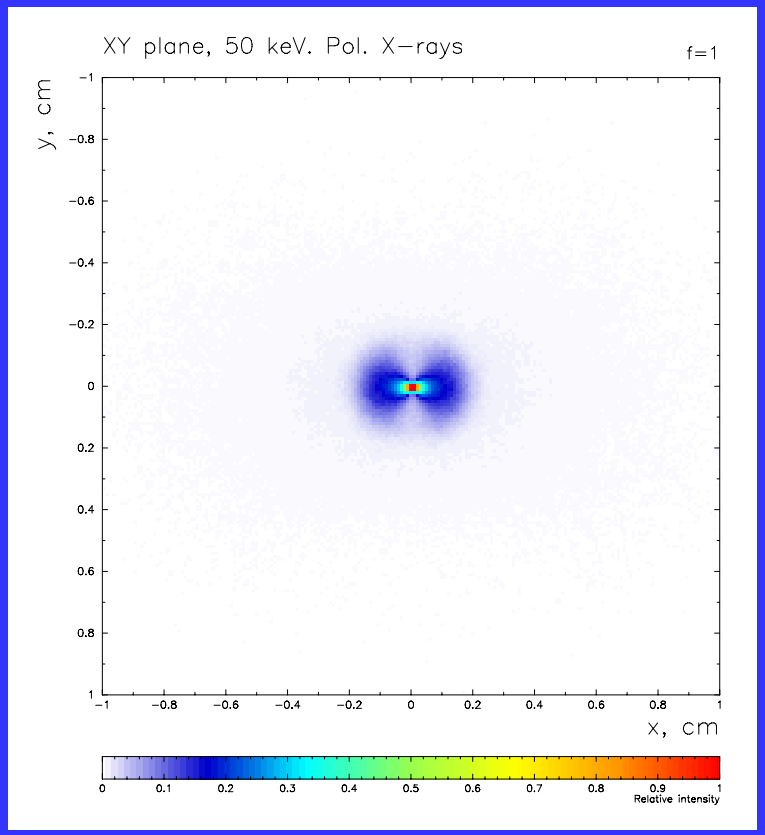


$$\frac{d\sigma}{d\Omega} = \frac{\sigma}{4\pi}\left[1 + \frac{1}{2}\beta P_2(\cos\theta)\right]$$

Monte Carlo calculated effect of the polarization of X-rays on the final profile of the electron cloud

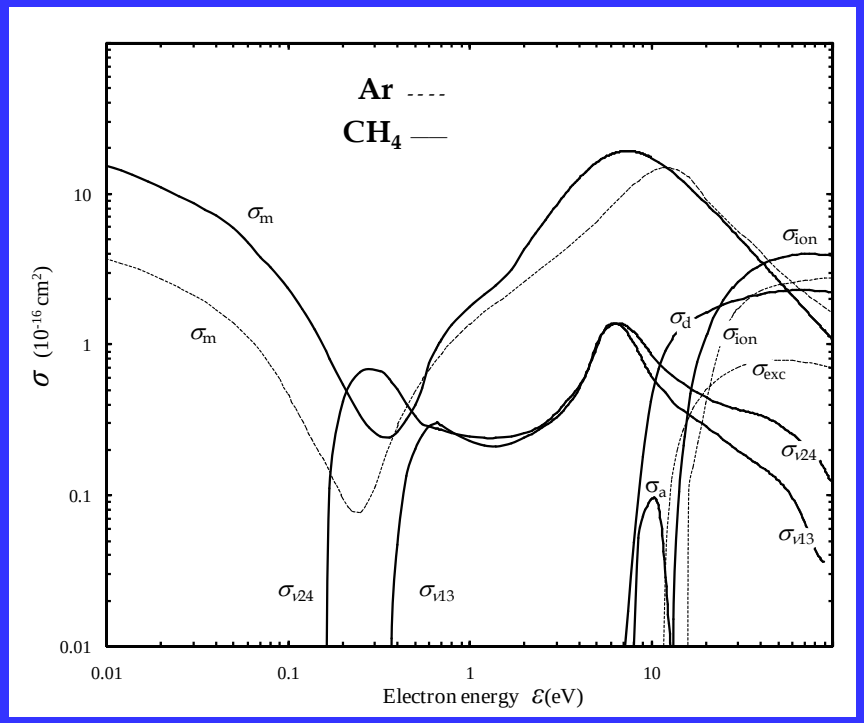


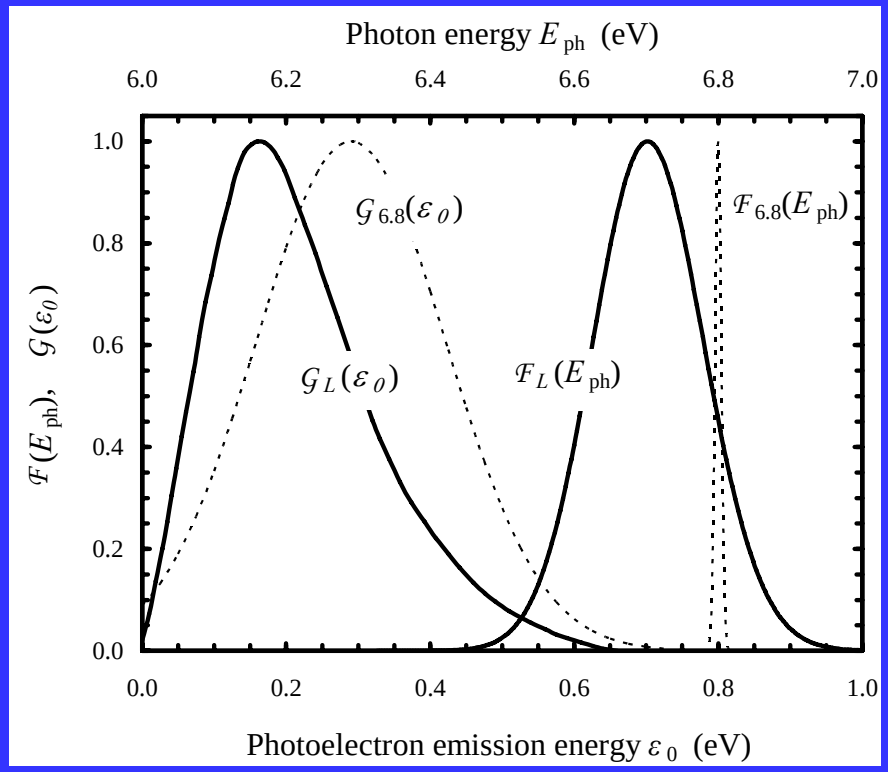
Unpolarized photons



Polarized photons

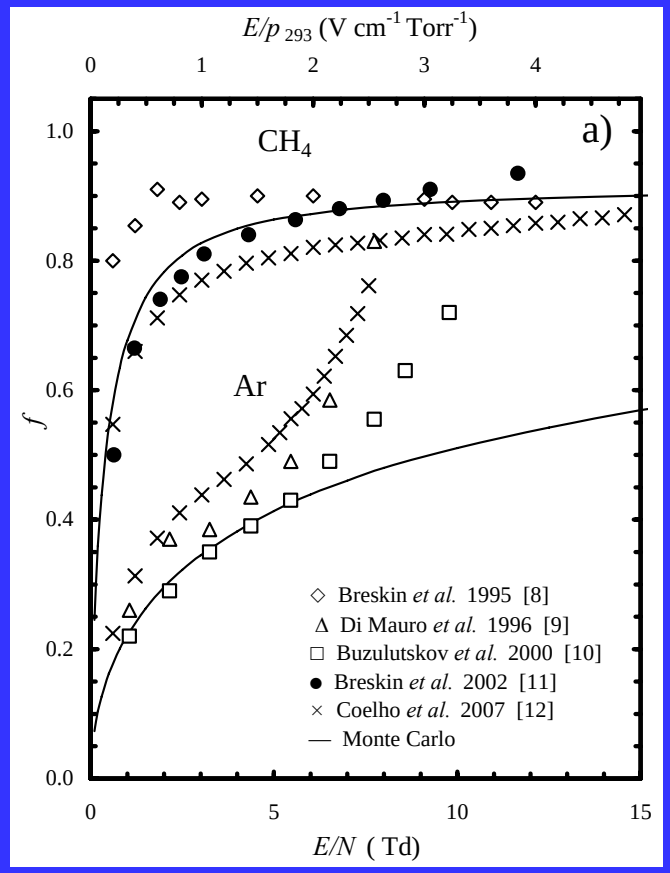
Transmission of photoelectrons emitted from a CsI photocathode into pure and mixed noble gases [Xe, Ar, Ne] and their mixtures with CF4 or CH4

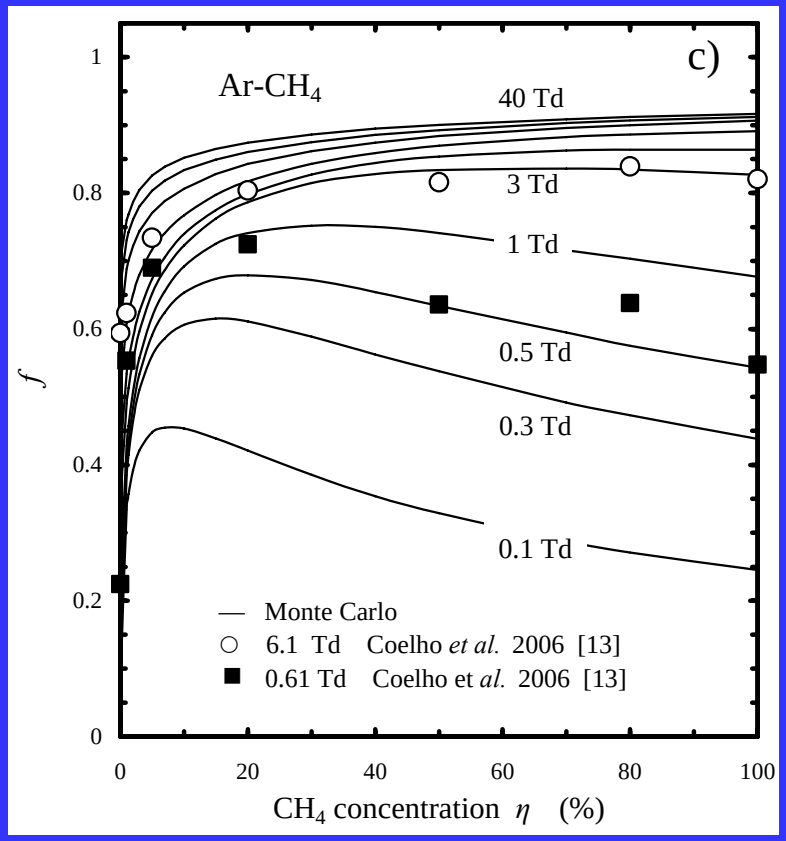




$F_L(E_{ph})$ is the photon emission from a continuous VUV Hg(Ar) lamp. The $G_L(\varepsilon_0)$ describes the initial energies of the photoe- emitted from CsI when irradiated with $F_L(E_{ph})$ photons.

Irradiation of CsI with continuous VUV Hg(Ar) lamp





Monte Carlo transmission efficiency *f* for the photoelectrons from CsI irradiated with photons from the distribution F*L*(*E*ph) of a Hg(Ar) lamp

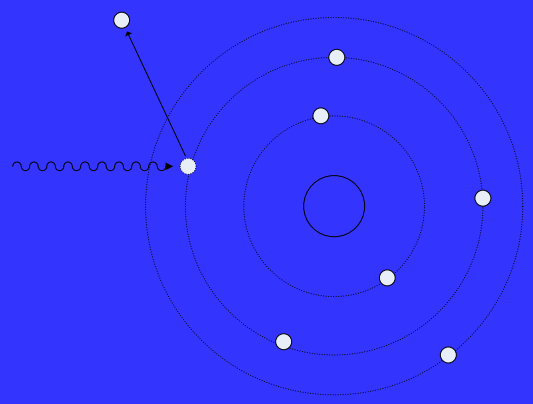
a) as a function of *E/N* in CH4 and in Ar,

b) as a function of *η* for *E/N* = 0.1, 0.3, 0.5, 1, 3, 5, 10, 20, 30 and 40 Td (*E/N* in Td = 3.034 *E/p* in V cm-1 Torr-1 at 293 K).

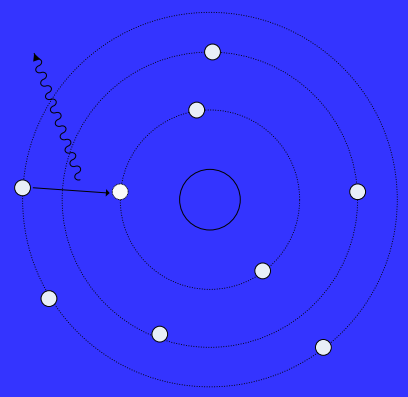
Radiation interaction and electron transport

Photon interaction { photoelectric effect, Compton effect, Rayleigh scattering }

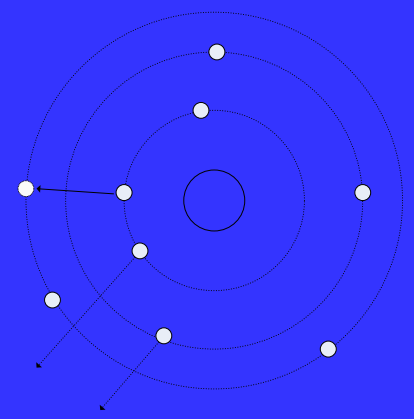
Electron interaction { elastic collision, excitation, ionization }



Photoelectric effect
(Excited ion)



Radiative decay



Auger/Coster-Kronig effect

Electron production – primary electron cloud formation

Through a sequence of the processes referred above the energy of the incident photon is converted intoa number of electrons whose energies are below the ionization porencial of the abosrbing medium => the primary electron cloud

The number N of electron produced per incident X-ray photon varies.

Causes
- external (associated electronics, drifts)
- internal (statistical fluctuations due to the discrete nature of the signal)

Internal or intrinsic causes set a limit to the detector performance

This limit is know as intrinsic energy resolution.

Energy Resolution

$$R_{GPSC} = 2.355\sqrt{\frac{Fw}{E_{rx}} + \frac{k}{A}}$$

Best achieved value for 5.9 keV – ~8%

$$R_{GPIC} = 2.355\sqrt{\frac{(F+f)w}{E_{rx}}}$$

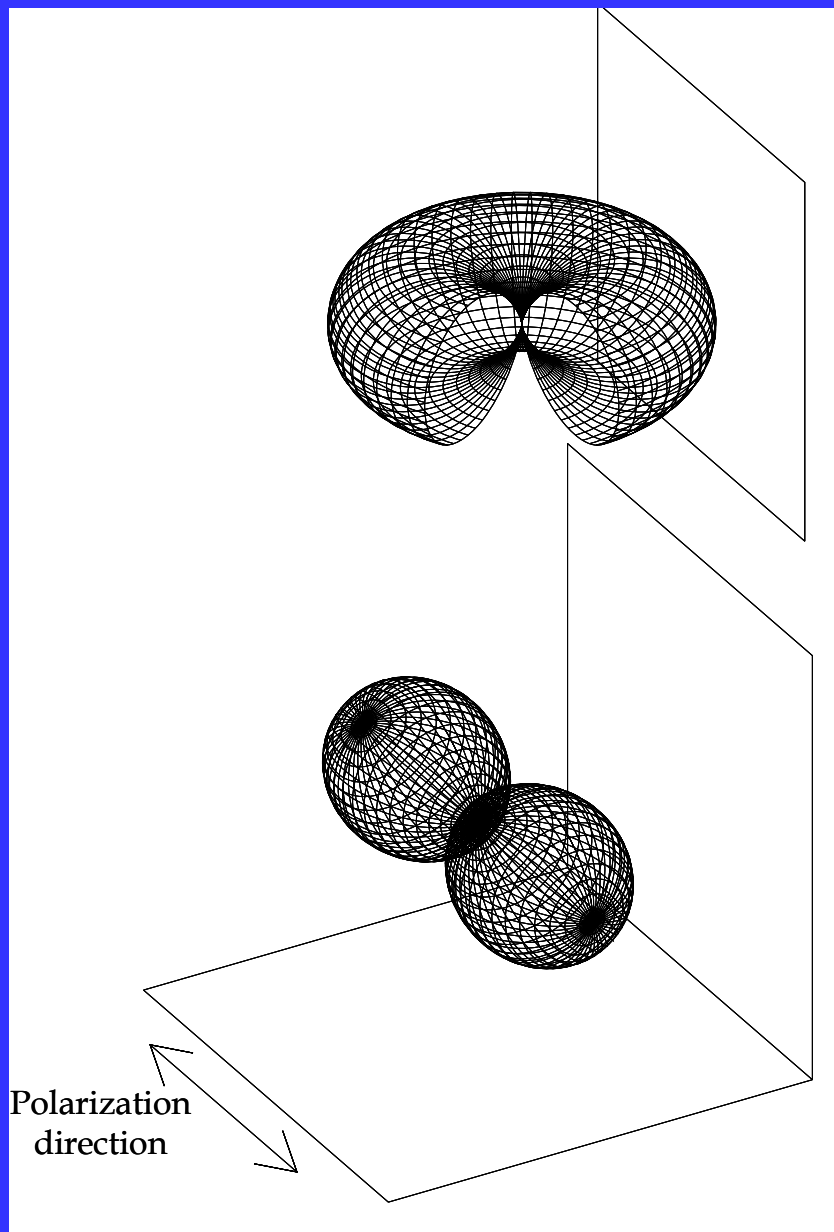
Best achieved value for 5.9 keV – 13%

Effect of the polarization of X-rays on the angular distribution of photoelectrons

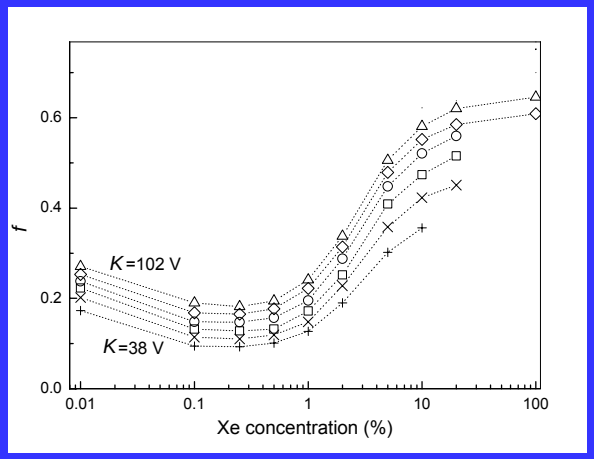
Angular differential photoionization cross-section for the emission of s-photoelectrons (ß=2)

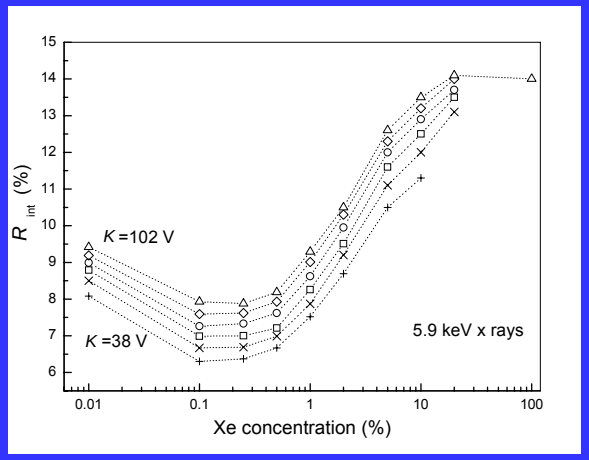
a) by unpolarized photons $$\frac{d\sigma}{d\Omega} = \frac{\sigma}{4\pi}\left[1 - \frac{1}{2}\beta\, P_2(\cos\underline{\theta})\right]$$

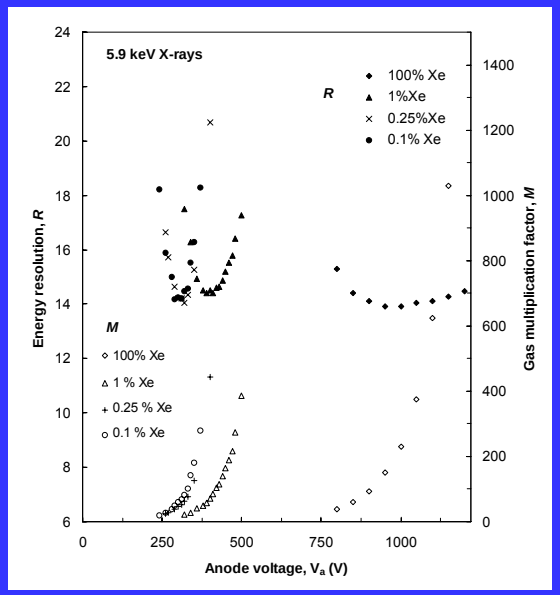
b) by linearly polarized photons $$\frac{d\sigma}{d\Omega} = \frac{\sigma}{4\pi}\left[1 + \beta\, P_2(\cos\theta)\right]$$



GPIC experimental and Monte Carlo results for Xe-Ne mixtures

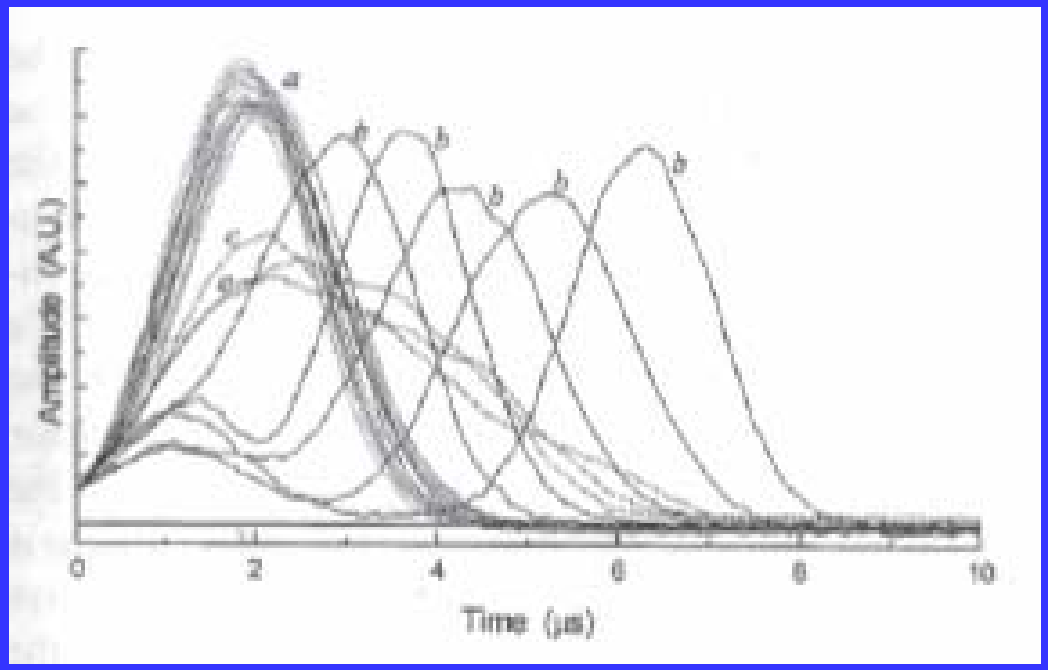






K=V/(ln(c/a))

Digital signal processing (excluding events)



^{109}Cd source 22.1keV events

a) absorbed in the drift region

b) whose "components" arrive at the scintillation region in separate times

c) absorbed near the detector walls.