Proportional Counters

Introduction

Before we can look at individual radiation processes, we need to understand how the radiation is detected:

- Non-imaging detectors

  Detectors capable of detecting photons from a source, but without any spatial resolution

  $\Longrightarrow$ Require, e.g., collimators to limit field of view.

  Example: Proportional Counters

- Imaging detectors

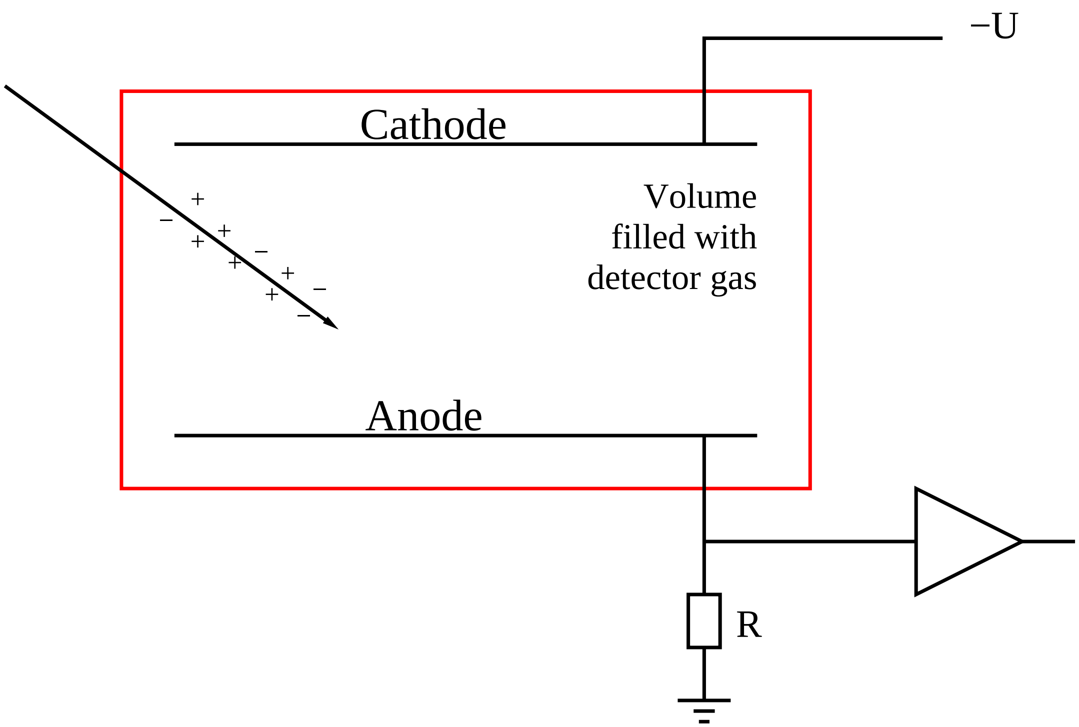
  Detectors with a spatial resolution, typically used in the IR, optical, UV or for soft X-rays.

  Generally behind some type of focusing optics.

  Example: Charge coupled devices (CCDs)

Here: will concentrate on detectors for X-rays and optical light, starting with non-imaging detectors.

Ionization chamber



Simplest gas detector: gas-filled capacitor (ionization chamber)

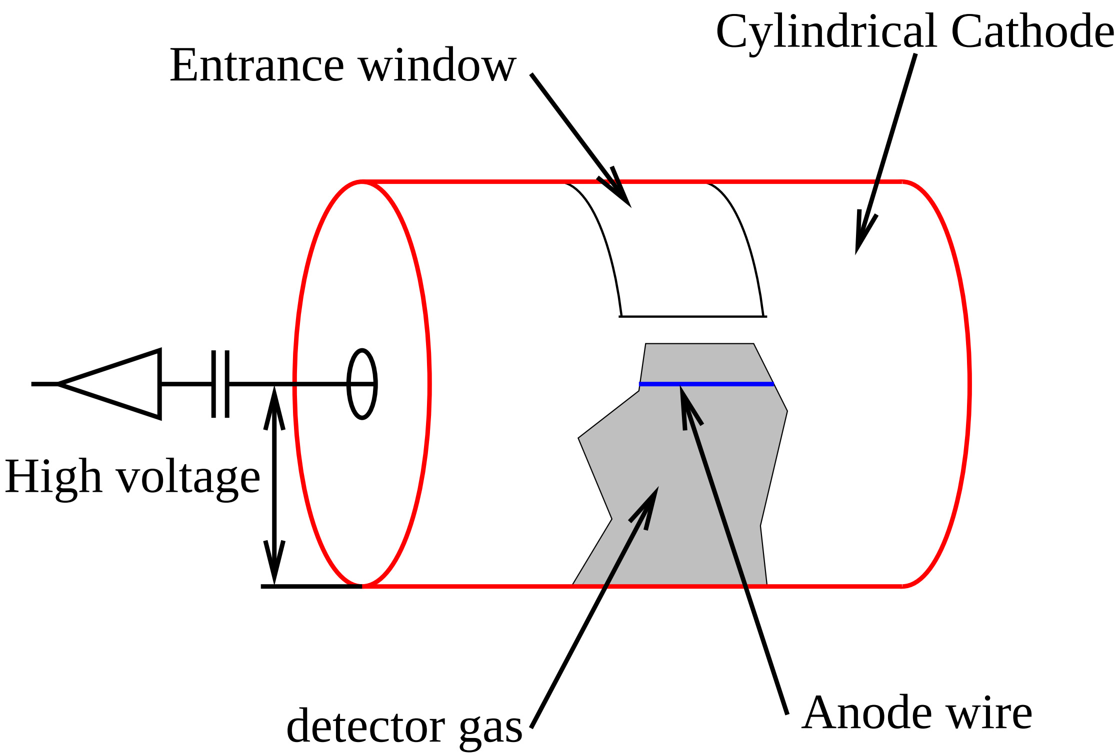
- photon is photo absorbed in detector gas
- K-shell electron ejected with energy $\propto$ initial E
- through collisional ionization N charges are produced
- Electrostatic induction induces charge on capacitor plates
- Charges drain via $R \Longrightarrow$ Measurement

Pulse height: $\Delta Q = -Ne = C\Delta U \Longrightarrow \Delta U = -Ne/C$

Typical magnitude of signal: $C = 20\,\text{pF}$, $Ne = 2 \times 10^5\,\text{e}^- \cdot e \Longrightarrow \Delta U = 1.6\,\text{mV}$.

Problem: Pulse very weak since only primary charge measured.

Proportional Counters



Solution: amplify charge

Close to Anodewire:

$E(r) = V/(r\ln(b/a))$ (b radius of cathode, a radius of anode)

$\Longrightarrow$ Strong acceleration of ionized particles

$\Longrightarrow$ collisional ionization of gas

$\Longrightarrow$ cascade!

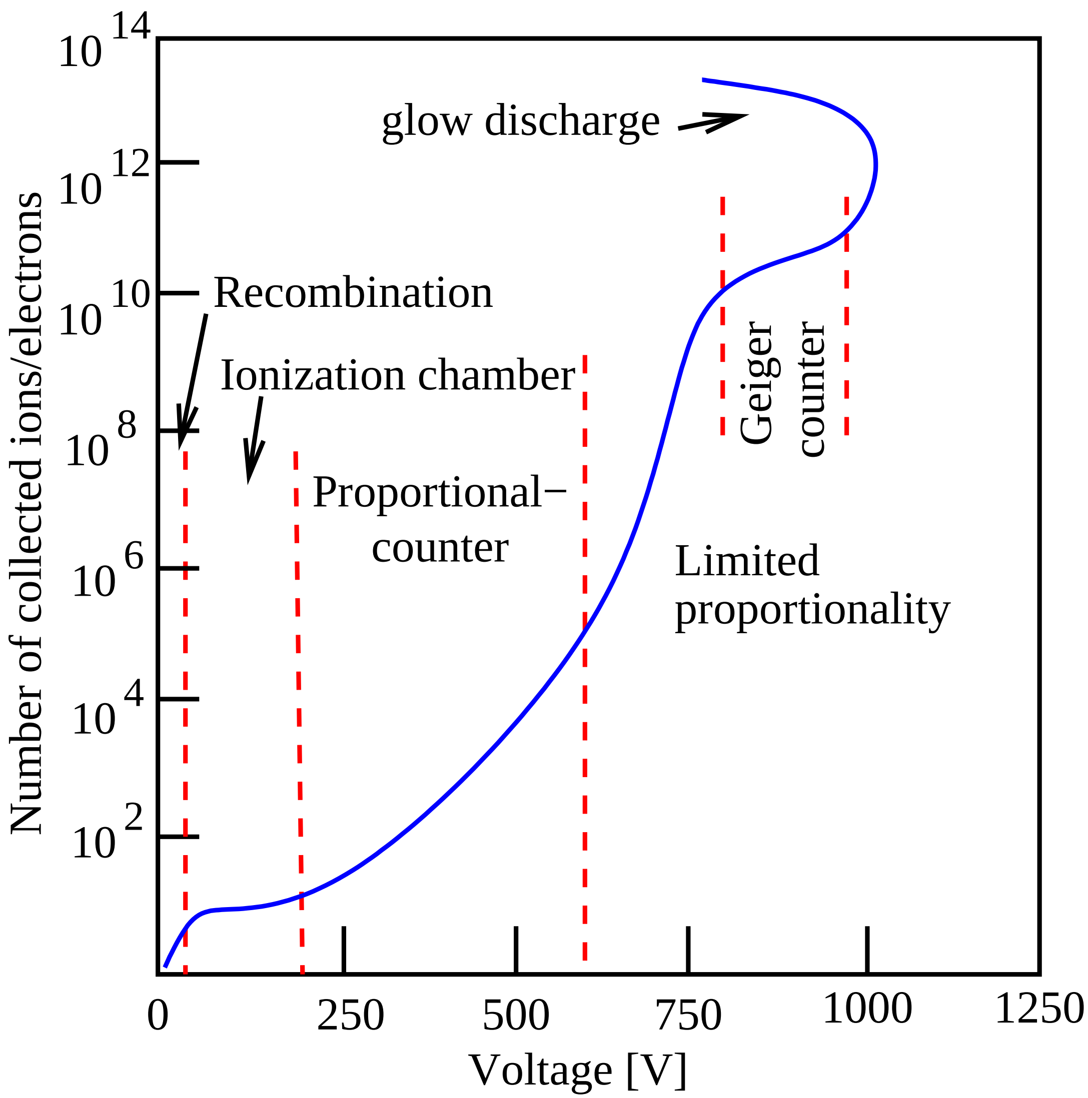
Measured voltage:

$$\Delta U = -\frac{eN}{C} \cdot A$$

where A: amplification factor (typical: $A = 10^4 \dots 10^6$).

Since $A \sim$ const.: Voltage pulse $\propto N$, and therefore Voltage pulse $\propto$ detected X-ray energy! and therefore: “proportional counter”

Pulse Amplifi cation



Pulse amplifi cation in detector as a function of anode voltage.

Typical proportional counter voltages are several 100 to 1000 V (depending on detector gas).

(after Grupen, Fig.4.21)

Detector Gas

Use inert gases, e.g., Ar or Xe, since required voltage smallest and only low losses due to excitation of the gas atoms.

Number of ions produced: $N = E/\omega$, where ω is given by:

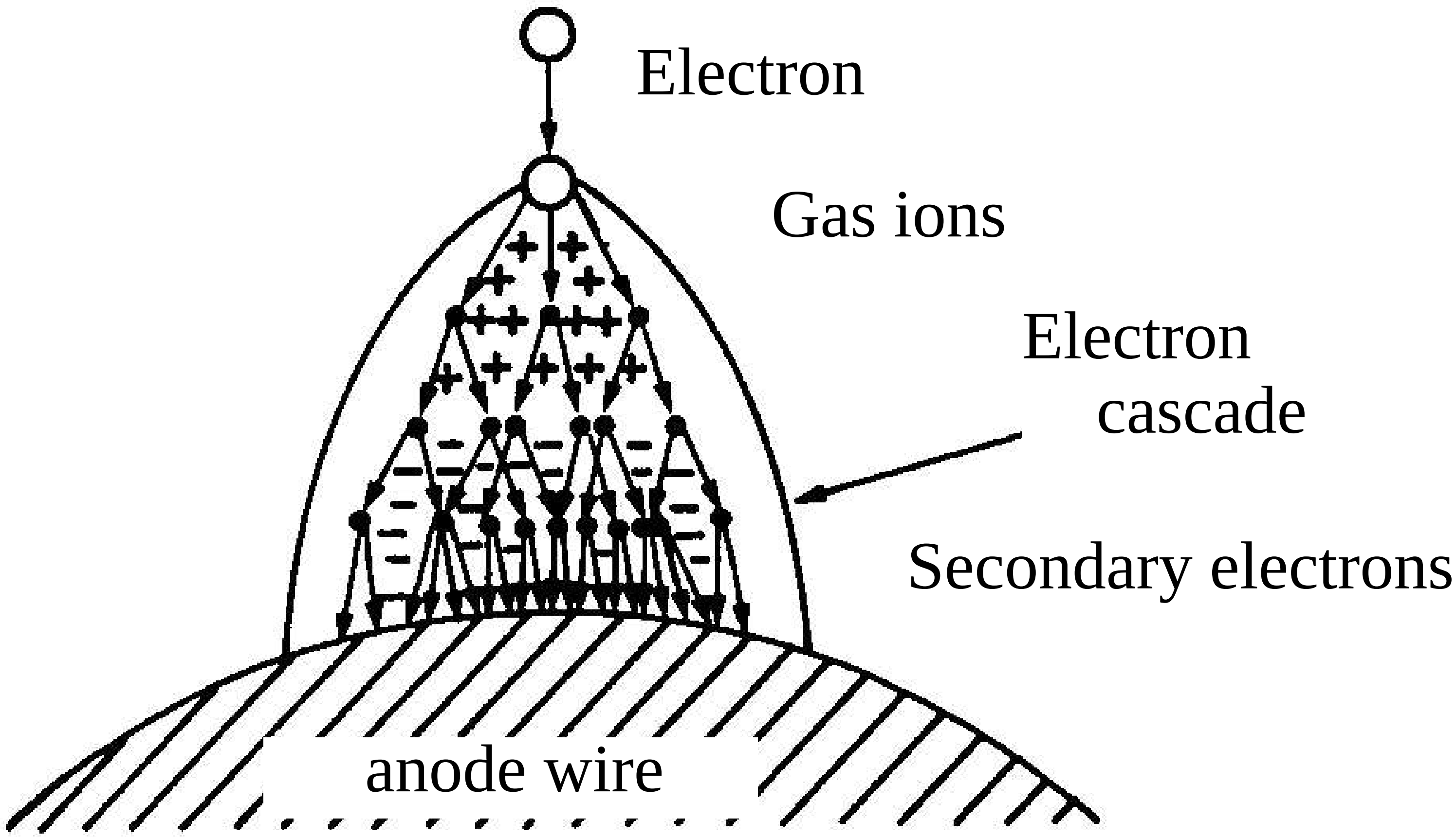
Gas	H	He	Ne	Ar	Kr
ω [eV]	36.6	44.4	36.8	26.25	24.1
Gas	Xe	Air	CO_2	CH_4	
ω [eV]	21.9	35.2	34.2	29.1	

$\Longrightarrow$ Typically $N \sim$ 1000 electron-ion pairs per 20 keV photon.

Note:

- probability for absorption $\sigma_{\text{bf}} \propto Z^{4\ldots5} \Longrightarrow$ use Xenon ($Z = 54$) for astronomical detectors
- since $\sigma_{\text{bf}} \propto E^{-3} \Longrightarrow$ proportional counters limited to $E < 100$ keV.

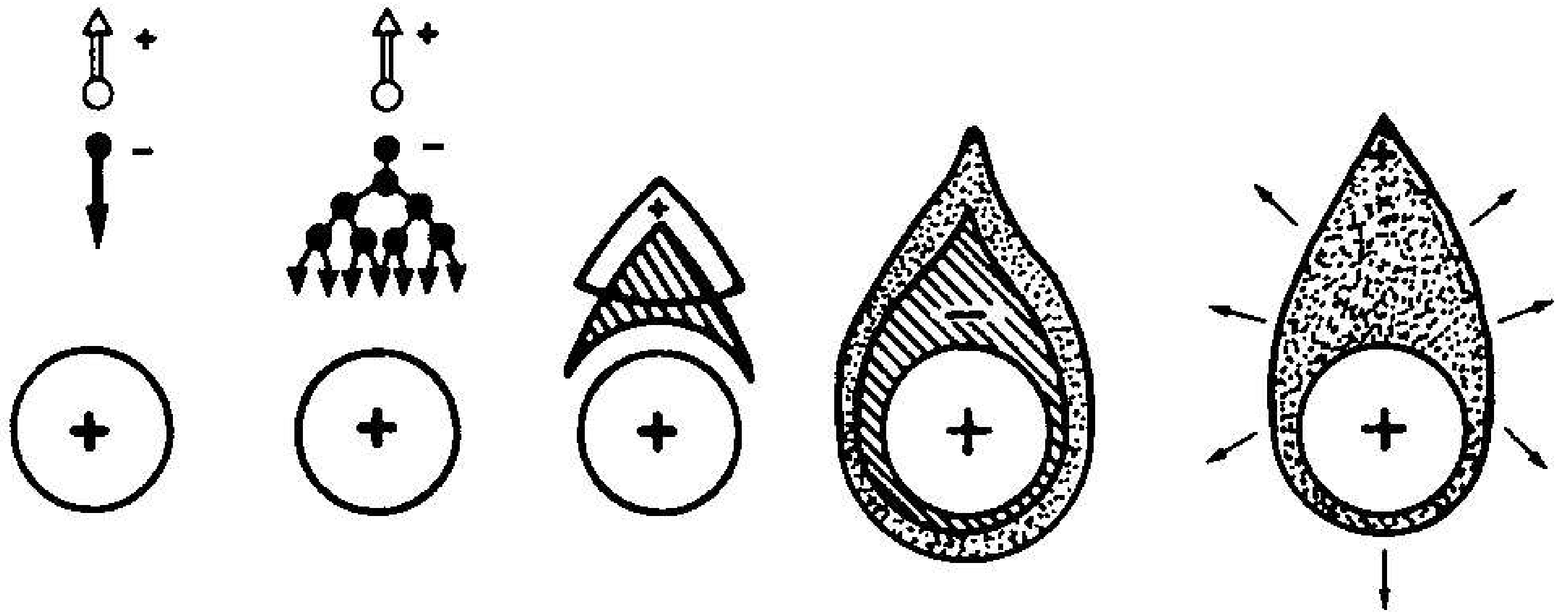
Cascade, I



Grupen (Fig. 4.9)

Typical electron paths $\approx \mu$m $\Longrightarrow$ Cascade happens very close to anode wire

Cascade, II



Grupen (Fig. 4.27)

Electrons are accelerated to very high speeds towards wire, Ions are accelerated away from wire

$\Longrightarrow$ Main signal from ions, *not* electrons, since ions have larger potential difference

typical duration of signal $\sim$ 100 μs, can reach higher time resolution by differentiating the signal

Energy Resolution

Measured signal: pulse height $\Longrightarrow$ Energy of the X-ray

Resolution: ΔE: Width (=FWHM, Full Width at Half Maximum) of the distribution of measured energies.

Poisson statistics (N discrete Electron-Ion pairs!):

$$\Delta E \propto 2.35\sqrt{N} \propto 2.35\sqrt{E}$$

Typically one uses $\Delta E/E$

Slight correlations due to amplifying discharge $\Longrightarrow$ Width of distribution somewhat smaller than expected from Poisson statistics $\Longrightarrow$ Fano Factor F:

$$\frac{\Delta E}{E} = 2.35 \left(\frac{F}{N}\right)^{1/2}$$

where for gas detectors $F \sim 0.2$–0.3

More detailed theory yields

$$\frac{\Delta E}{E} = 2.35 \left(\frac{W\,(F+A)}{E}\right)^{1/2}$$

W: mean energy to produce a pair (26 eV for Ar+Methane), $F \sim 0.2$, $A \sim 0.6$

$\Longrightarrow$ up to 14% at 5.9 keV doable.

Quenching

Problem: Excited ions emit UV photons $\Longrightarrow$ formation of new cascades due to photo effect $\Longrightarrow$ Total cascade takes a long time $\Longrightarrow$ large dead time.

Solution: Absorption of UV photons in "quenching gas", which is added to primary photomultiplier gas $\Longrightarrow$ cascade $< 1\,\mu\mathrm{s}$

Energy of excited quenching gas is dumped later via inelastic collisions within the gas

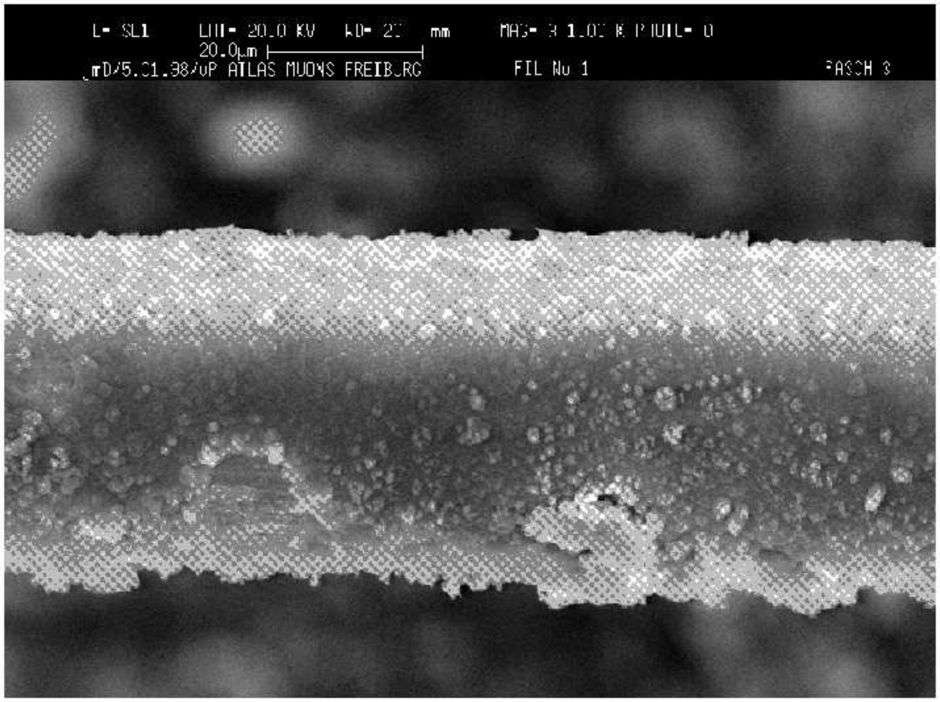
Also direct quenching of cascade, e.g., via

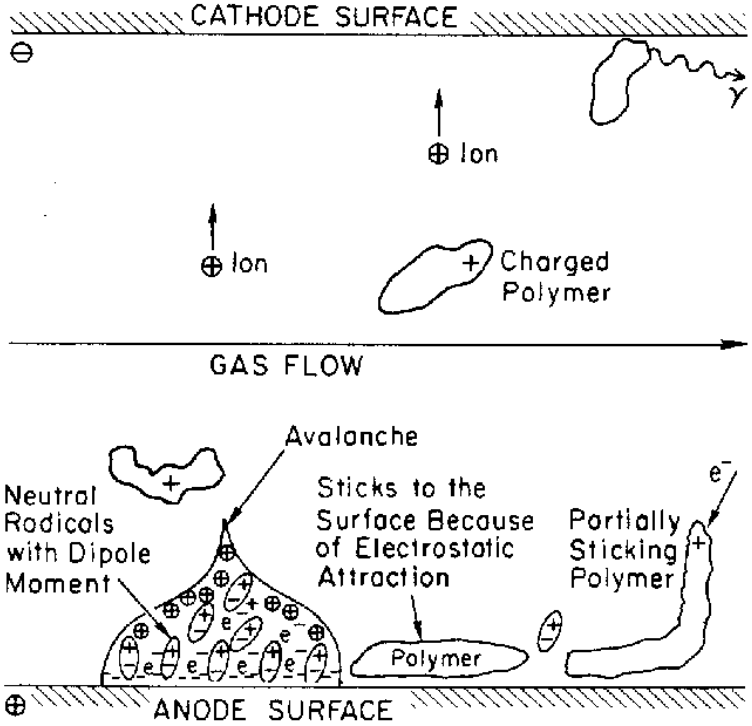
$$\mathrm{Ar}^{+} + \mathrm{CH}_4 \longrightarrow \mathrm{Ar} + \mathrm{CH}^{+}$$

Typical quenching gases: CH_4, alcohol (C_2H_5OH), CO_2, BF_3, ... (about $\sim 10\%$ of total gas pressure).

Often used: "P10-gas" (90% Ar and 10% CH_4)

Ageing





Marko Spegel, 1999 (Diss. Uni Wien), J. Vavra, SLAC-3882

Cascade: plasma discharge $\Longrightarrow$ Destruction of gas contaminants $\Longrightarrow$ formation of free radicals $\Longrightarrow$ polymerization

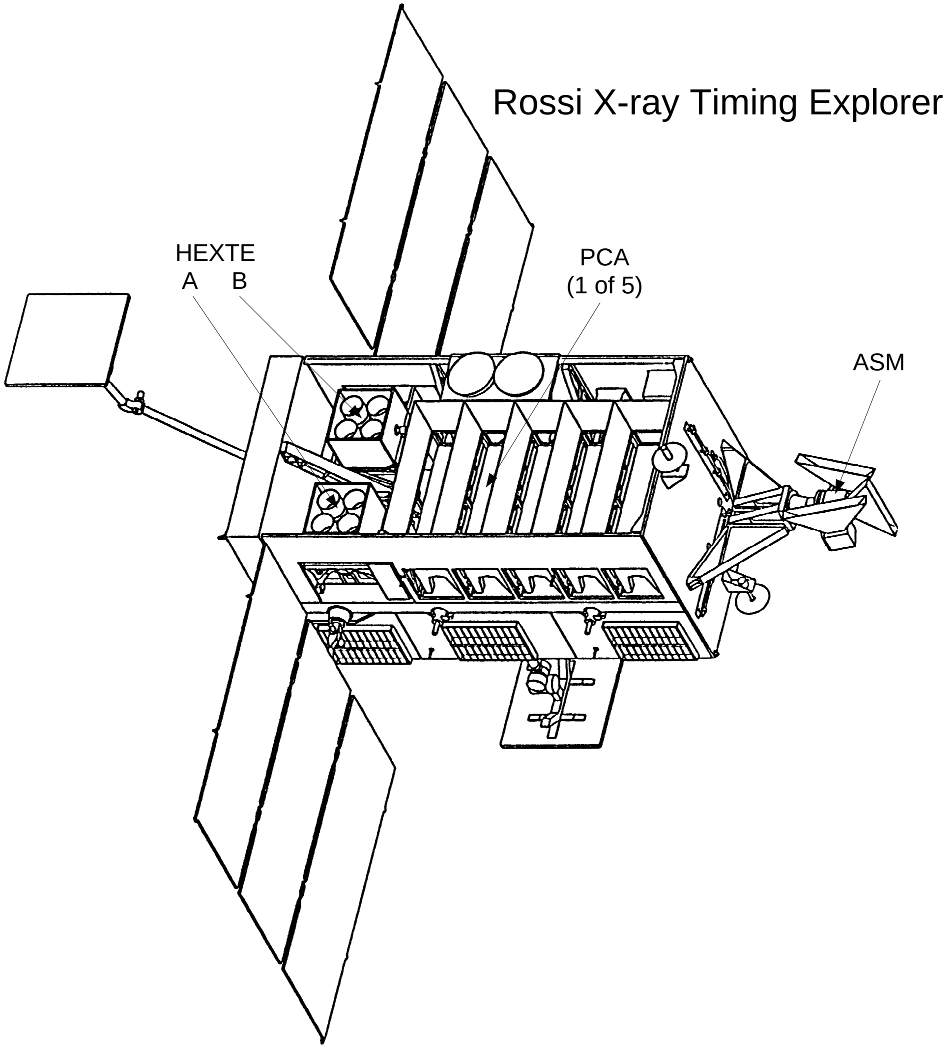
Polymers have high dipole moment $\Longrightarrow$ attach to electrodes $\Longrightarrow$ Reduction of pulse charges $\Longrightarrow$ "Ageing"

Typical contaminants: carbon, oxide-layers, silicates, e.g., from oil, finger grease, Silan (SiH_4), solvents in vacuum sealants,. . .

Results in field electron emission through photo-effect $\Longrightarrow$ discharge $\Longrightarrow$ wire destroyed ("Malter-Effekt")

Most sensitive proportional counter gas: Ar/CH_4. . .

Example: RXTE-PCA

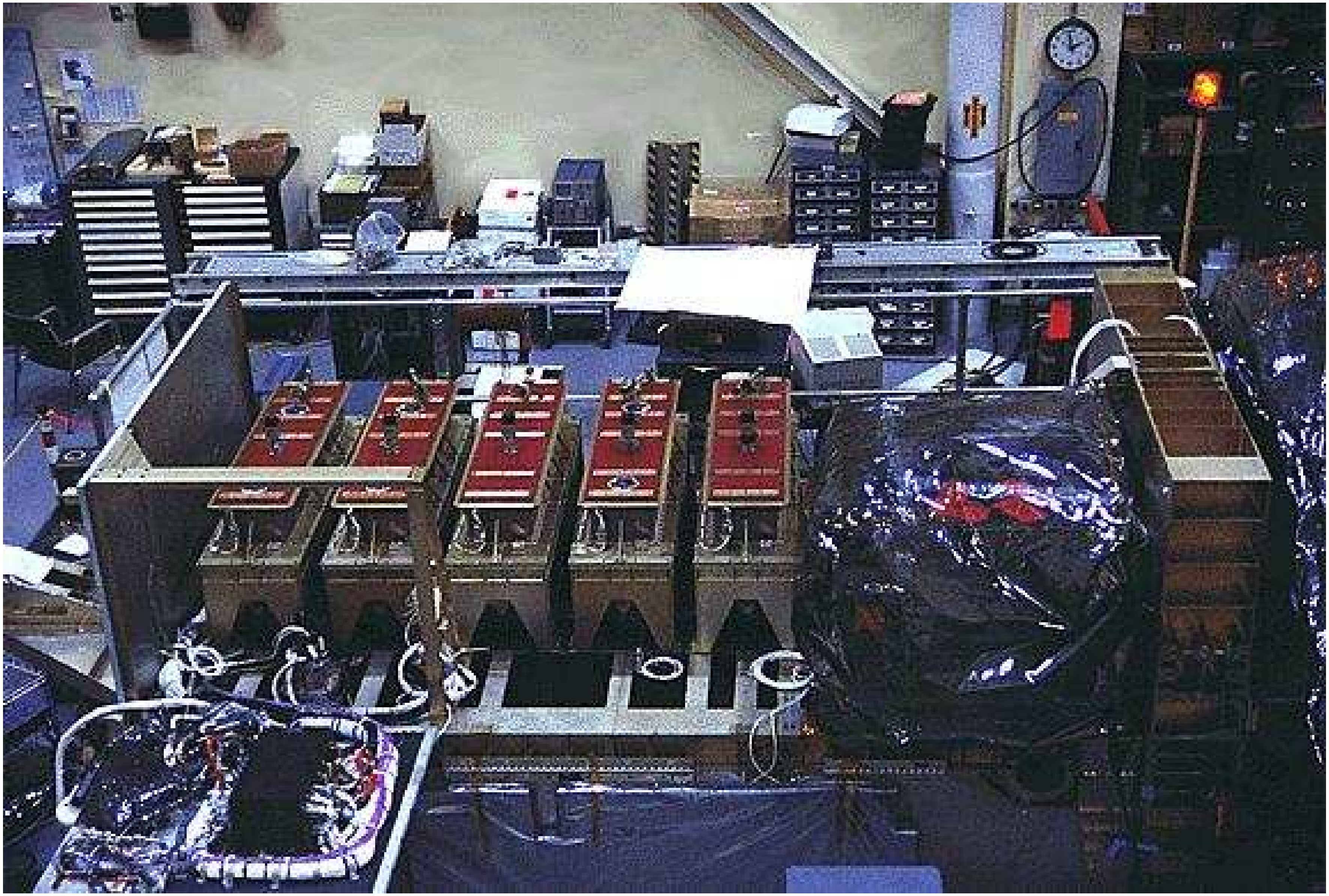


Rossi-X-ray Timing Explorer, Launch 30.12.1995, 3 instruments:

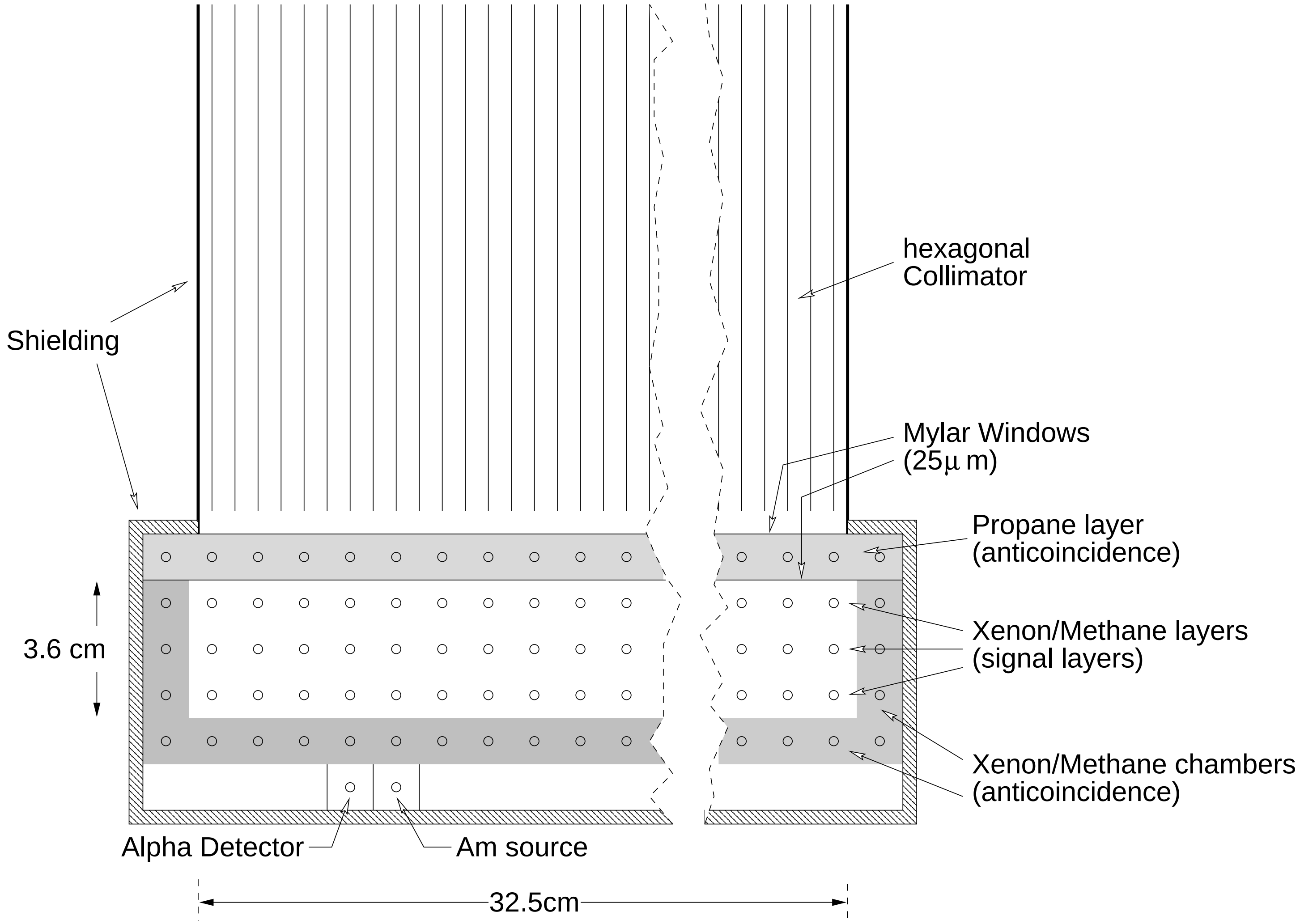
- Proportional Counter Array (PCA, 2–100 keV),
- High Energy X-ray Timing Experiment (HEXTE, 15–250 keV),
- All Sky Monitor (ASM, 2–10 keV)

PCA and HEXTE have μsec timing resolution

Example: RXTE-PCA



Example: RXTE-PCA



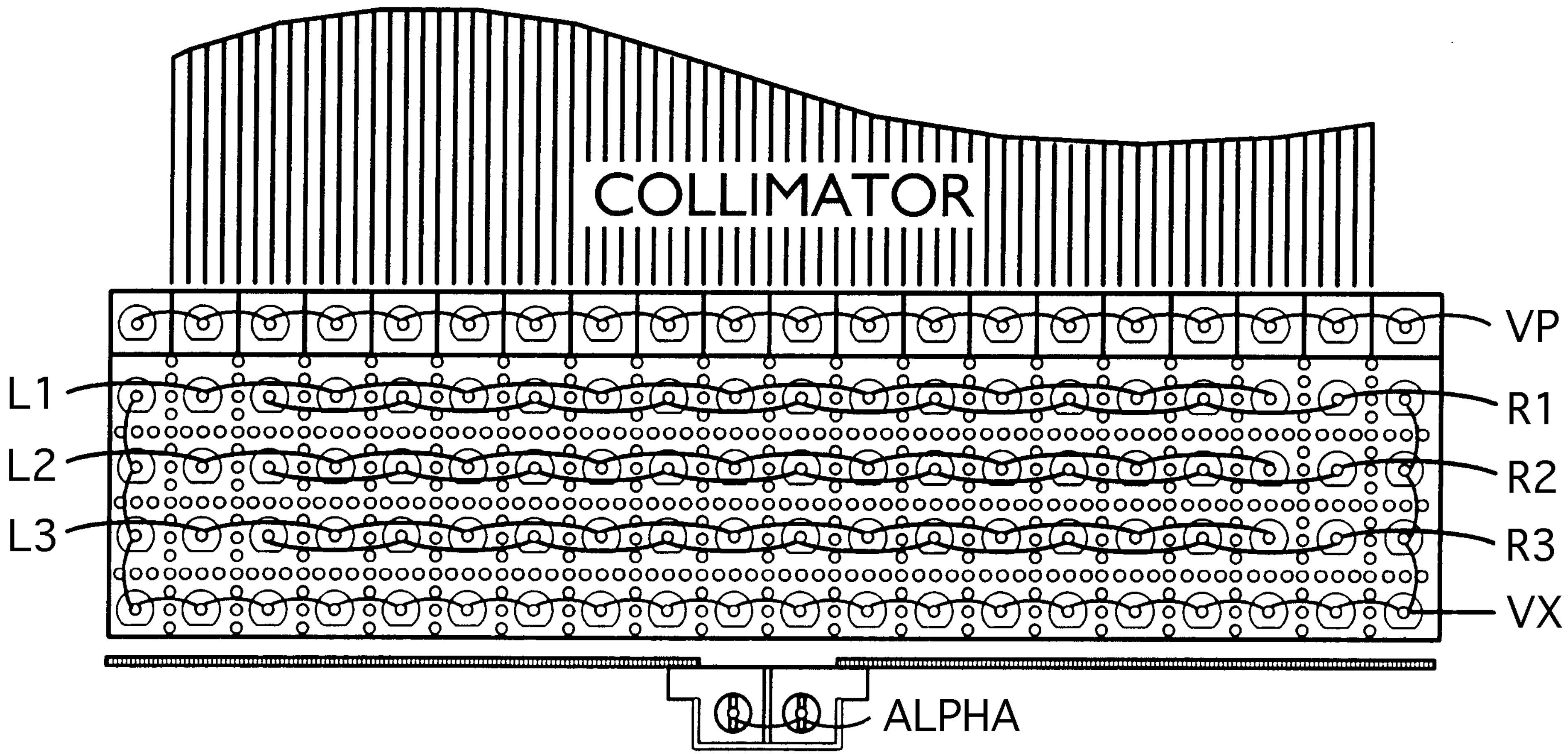
PCA consists of 5 Proportional Counter Units (PCUs), 1 atm pressure

Propane and outer anodes in Anti-Coincidence $\Longrightarrow$ Background reduction

BeCu-Collimator to limit field of view to $\sim 1^\circ$

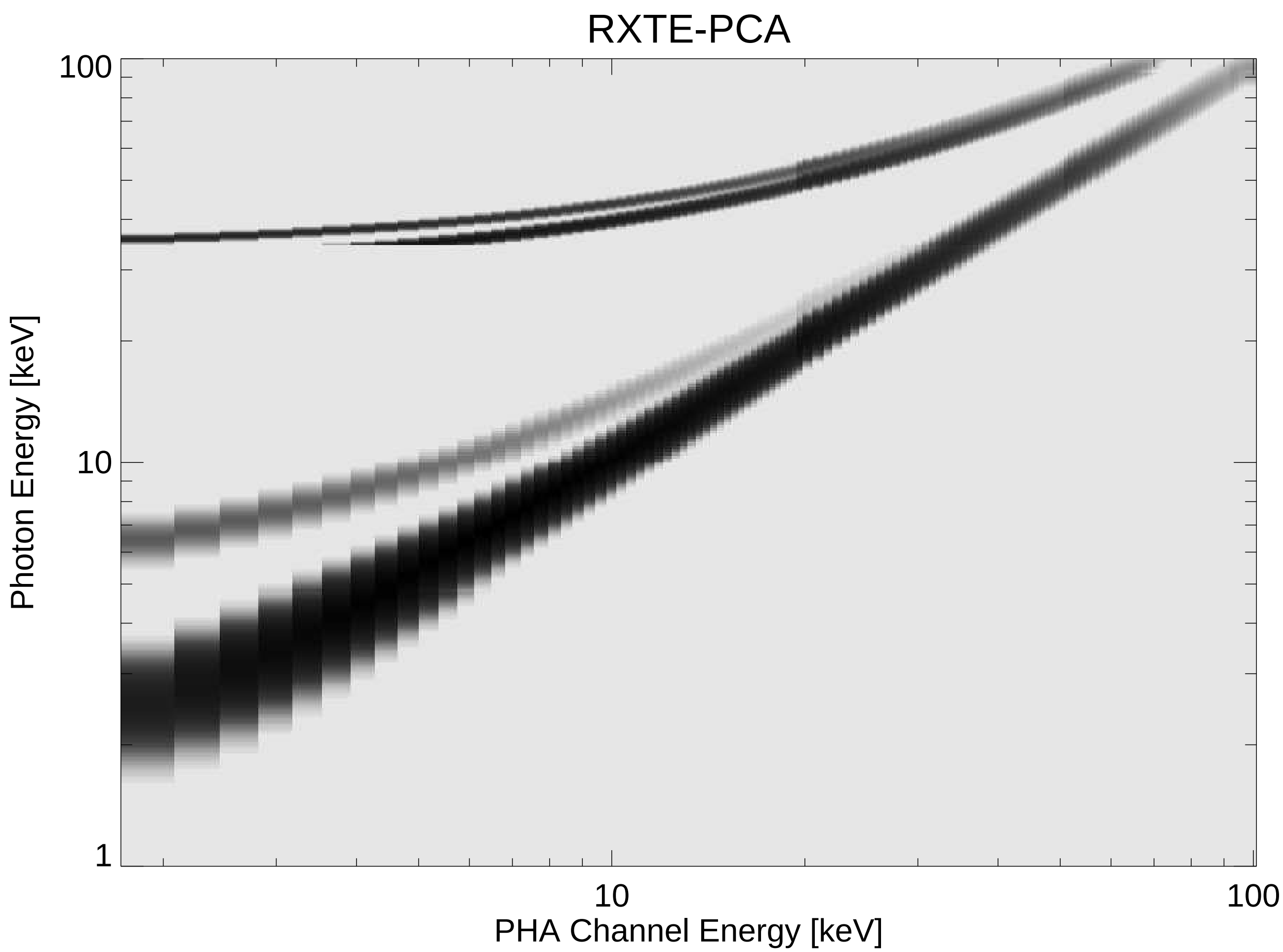
^{241}Am-source for energy calibration (simultaneous emission of 59.6 keV γ's and α-particles $\Longrightarrow$ coincidence measurements).

Example: RXTE-PCA



Design of the PCA (NASA/GSFC)

Example: RXTE-PCA

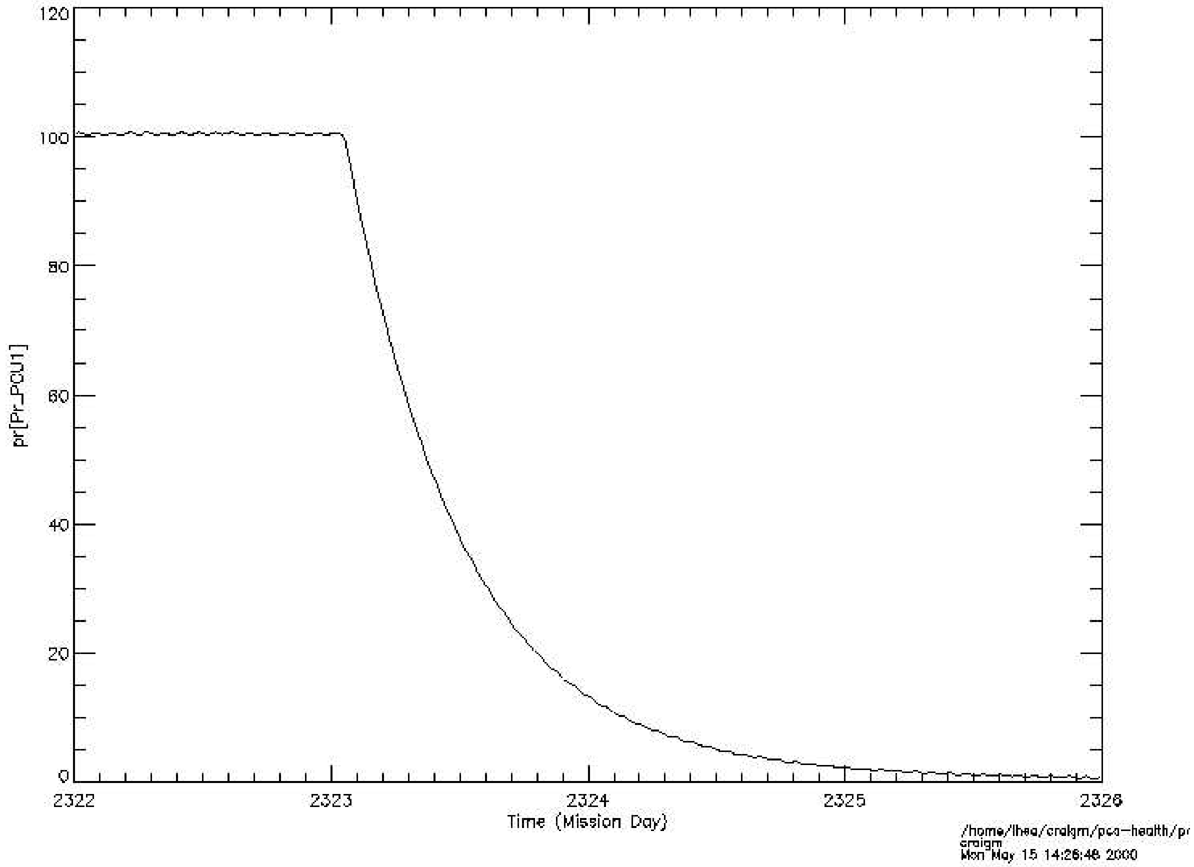


Response matrix: Relation between incident photon energy and detection channel.

Resolution: 18% at 6 keV

Escape-Peaks caused by Xe Kα ($E = 29.46$ keV) and Xe Lα ($E = 4.11$ keV) photons leaving the detector without being detected.

Example: RXTE-PCA



. . . this is what happens once a Mylar window starts having a hole in space

In addition ageing $\Longrightarrow$ Reduction of high voltage, alternate use of different PCUs.