Proportional Counters

Some of what you should know in order to use proportional counters for Spectroscopy, Timing, Imaging and Polarimetry

Keith Jahoda

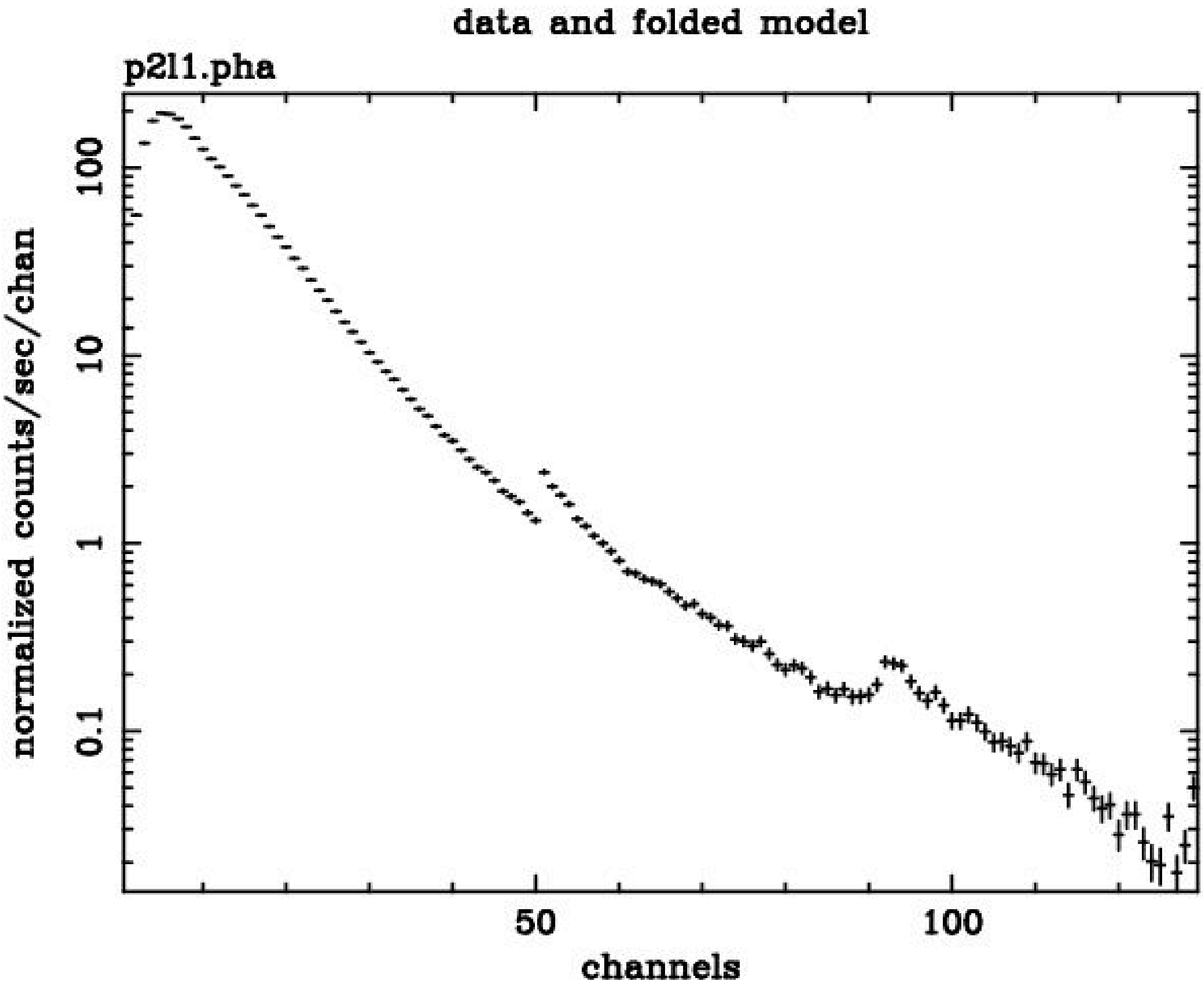
GSFC Laboratory for X-ray Astrophysics

Why Proportional Counters?

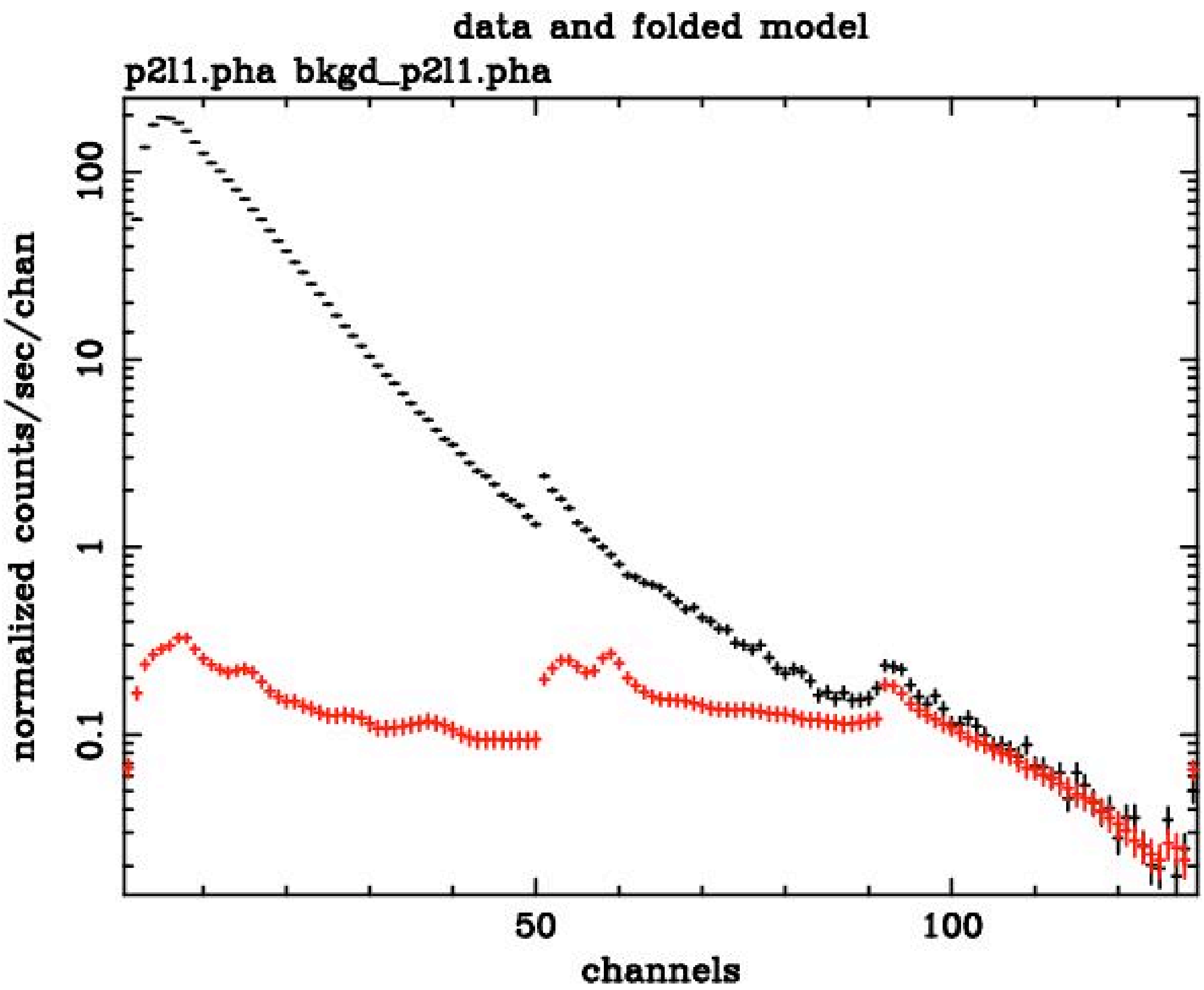
- Historical Work-horse
  - Sounding rockets, Uhuru, Ariel-5, HEAO-1, Einstein, EXOSAT, Ginga, RXTE …
- Still attractive for
  - Large area
  - Low power
    - Signal processing only, no cooling requirement
  - Low background
  - Broad band-pass
  - Unique capabilities, even now
    - Polarization, like imaging, spectroscopy, and timing, will begin with proportional counters.
  - Calibration
  - Low cost
  - Performance can be tuned for unique projects - polarimetry

What is a Proportional Counter?

- Executive Summary, (inspired by DAS)
  - An X-ray interacts with an atom of the prop counter gas. Photo-electric absorption is most important (or only important) mechanism below 100 keV
  - Charge is generated, proportional to the incident X-ray energy; (i.e., electrons and positive ions separated).
  - The charge is multiplied in a high field region.
  - The charge is collected, measured, digitized, and telemetered.



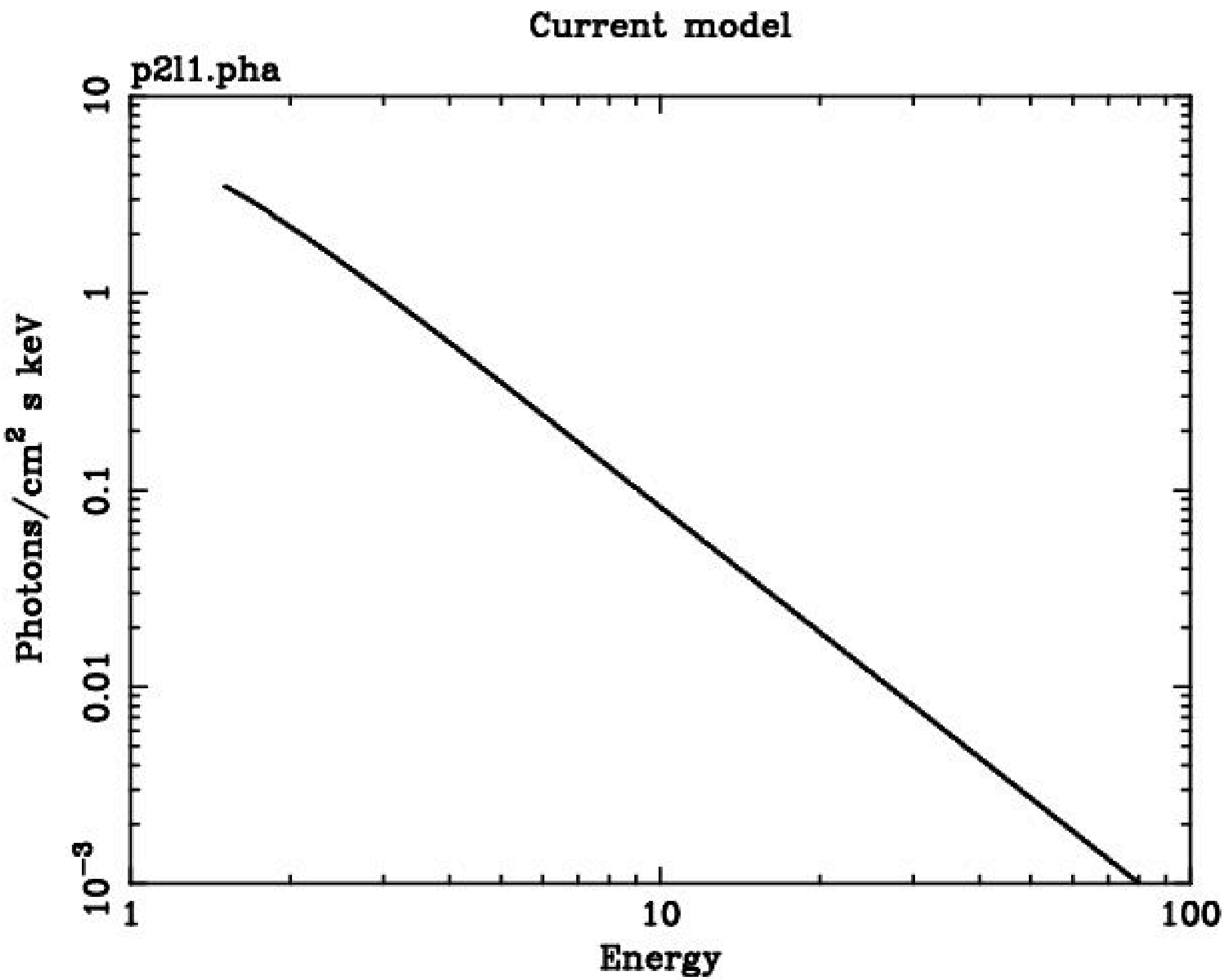
Output is “channel”, time, and possibly direction or polarization. Collapsed over time yields a Pulse Height Spectrum. Example from RXTE/PCA



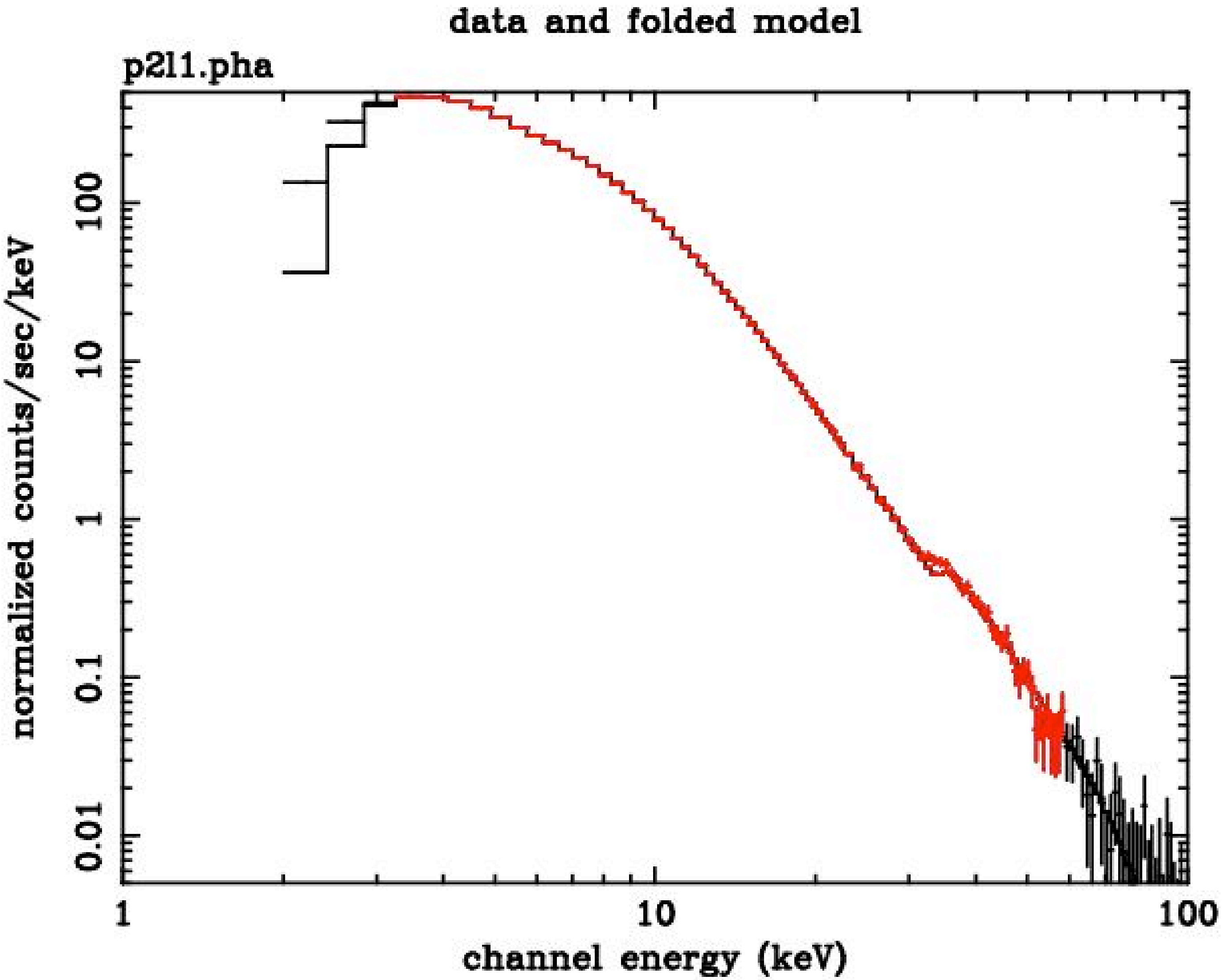
Pulse Height spectrum includes background. Individual photons are not identified as "signal" or "background"

Sources of Proportional Counter Background

- From sky (I.e. through collimator)
- From particles
  - Minimum ionizing particles deposit ~ 2keV/ mg per cm^2
  - Electrons with 10s of keV can penetrate window to deposit 1-10 keV
  - Secondaries from spacecraft, detector itself
- From photons
  - Forward Compton scattering of γ-rays
  - Flouresence from collimator or other detector material
  - Secondaries from Spacecraft or instrument



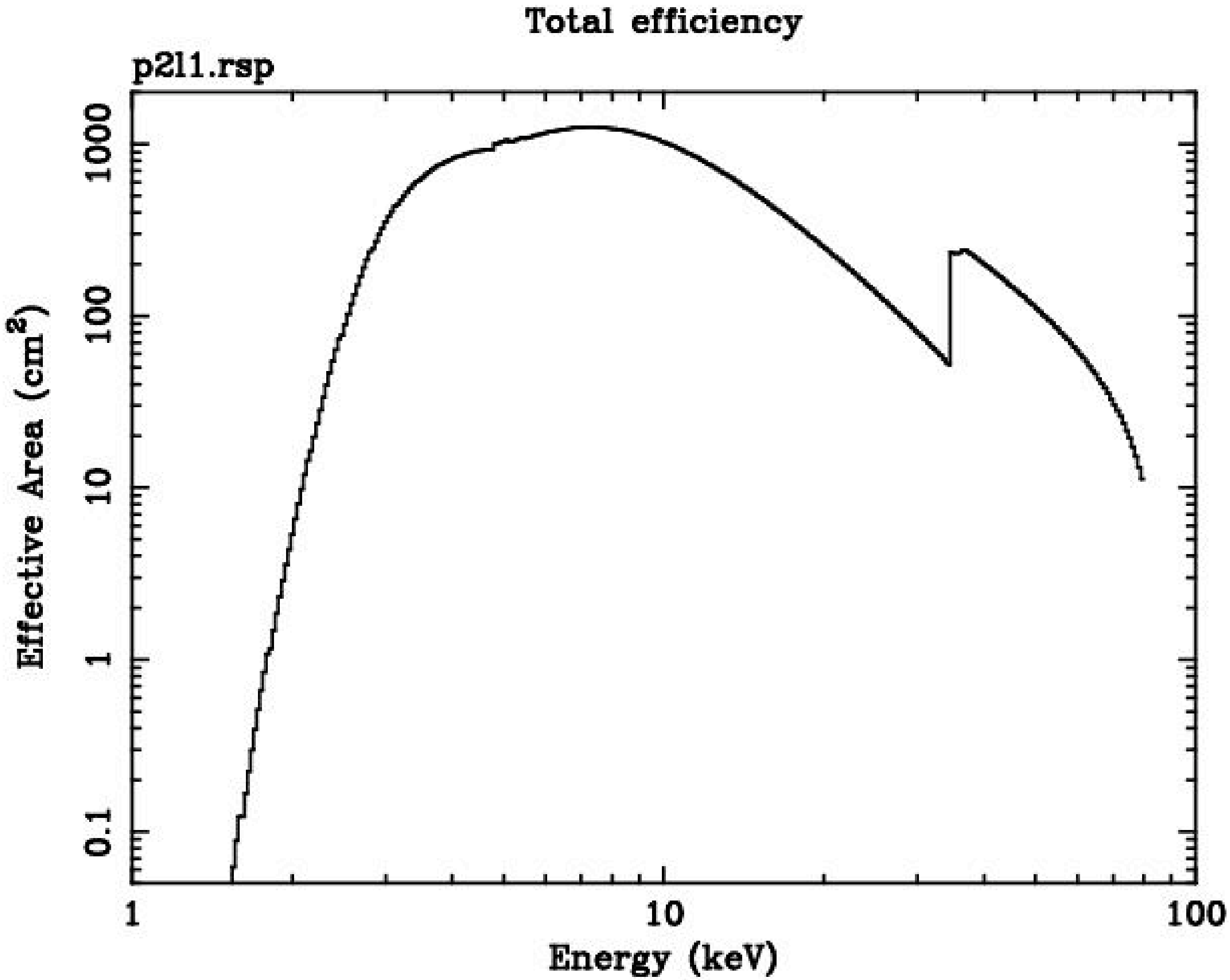
Knowledge (or intuition) about source yields estimate of input spectrum. (modestly absorbed power-law in this case)



Knowledge about detector (I.e. response matrix) allows comparison of model spectrum to data.

Between Model and Data

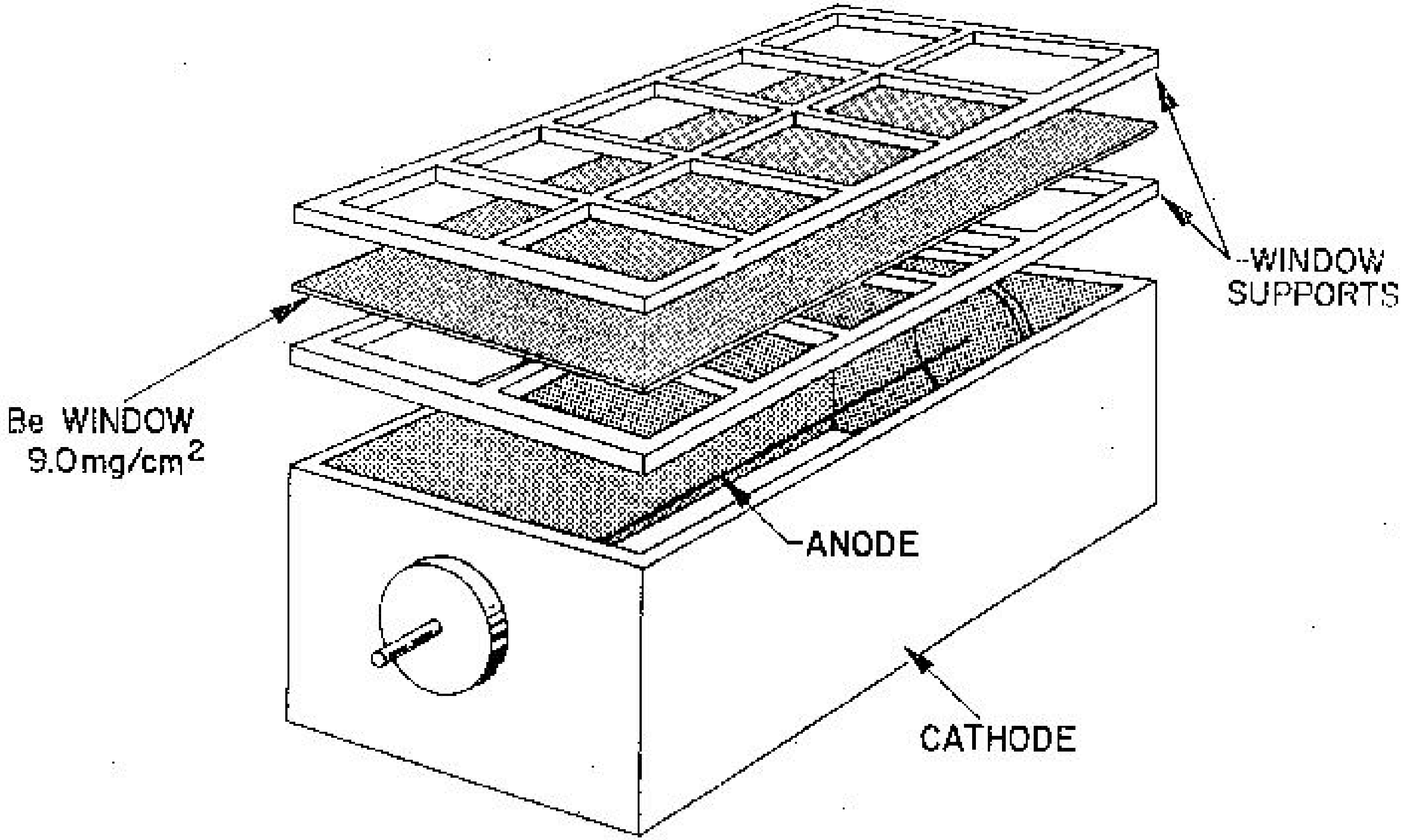
- Comparison already assumes that we can convert energy to channel
- "slope" in counts space (Δ cts/keV-s per keV) is steeper than in photon space (Δ photons/cm^2-s-keV per keV). Efficiency as a function of Energy must be understood
- Counts roll over at low energy (window)
- Obvious structure at 34 keV (K-edge in Xenon)
- Model is poor at extreme energies



Efficiency shows discontinuities at edges.

What is a Proportional Counter?

- Essential components:
  - Window
    - Defines low-end bandpass
  - Absorption/drift volume
    - Defines high end bandpass
  - Multiplication region
    - High field region
  - Readout
    - Electrodes may (or may not) be multiplication electrodes
- Essential Physics
  - Photo-electric cross section

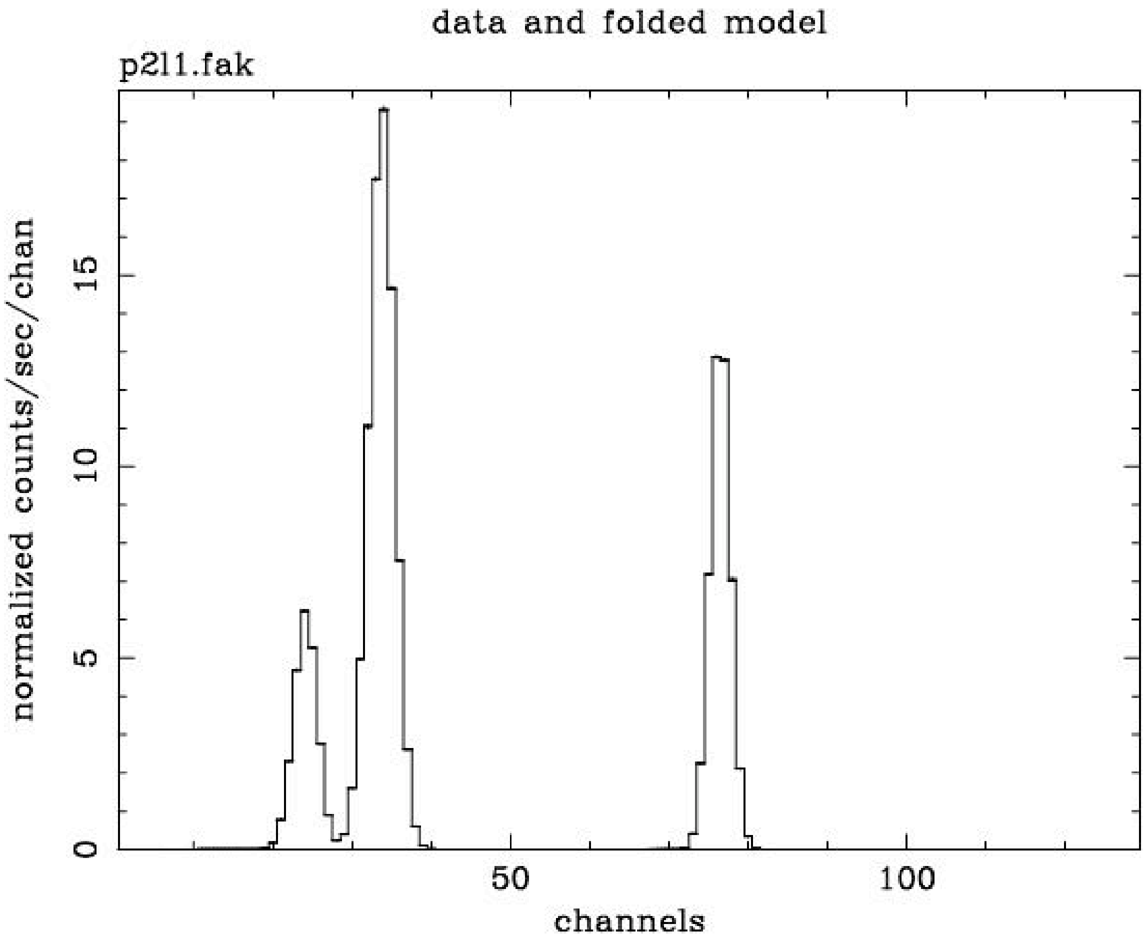


-WINDOW
SUPPORTS
Be WINDOW
9.0mg/cm²
ANODE
CATHODE

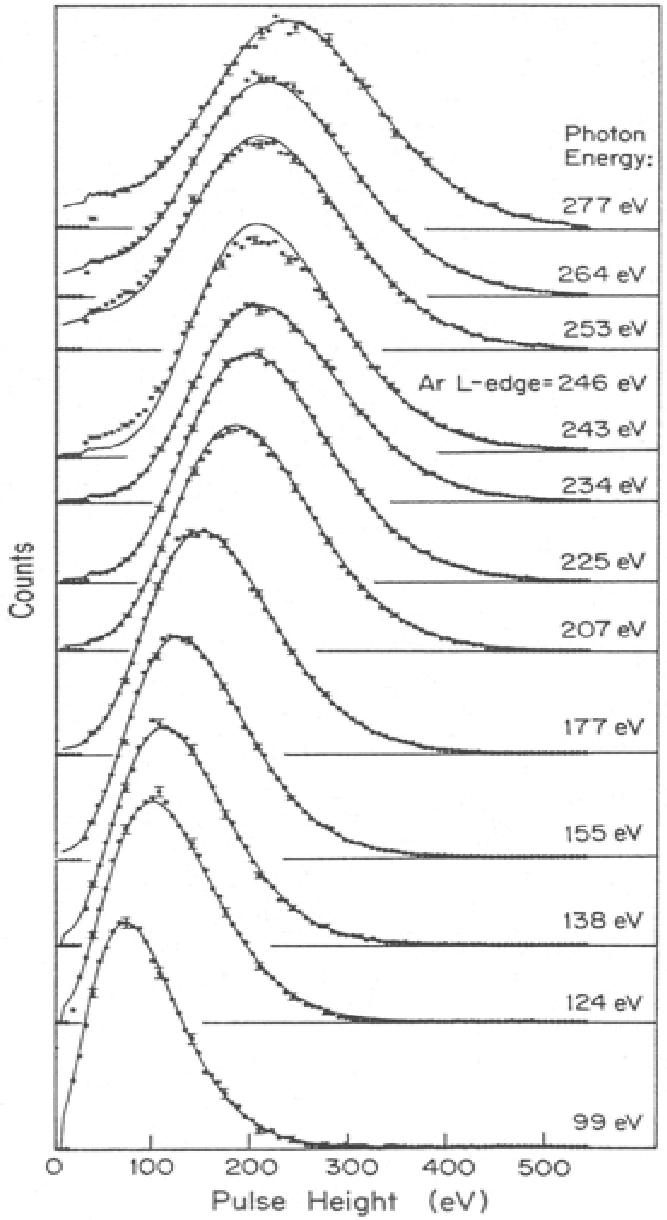
What is a Proportional Counter?

- Essential characteristics:
  - Photo-electric absorption
  - In a Gas
  - Followed by relaxation of the ion and secondary ionization
  - Amplification (see excellent talks by DAS, RJE in previous X-ray schools)
    - avalanche process in gas
    - electronic processing
- Resulting charge signal is proportional to photon-energy (with important exceptions)

An Exception



- RXTE/PCA response to 45 keV.
- "photo-peak" is in channel ~75

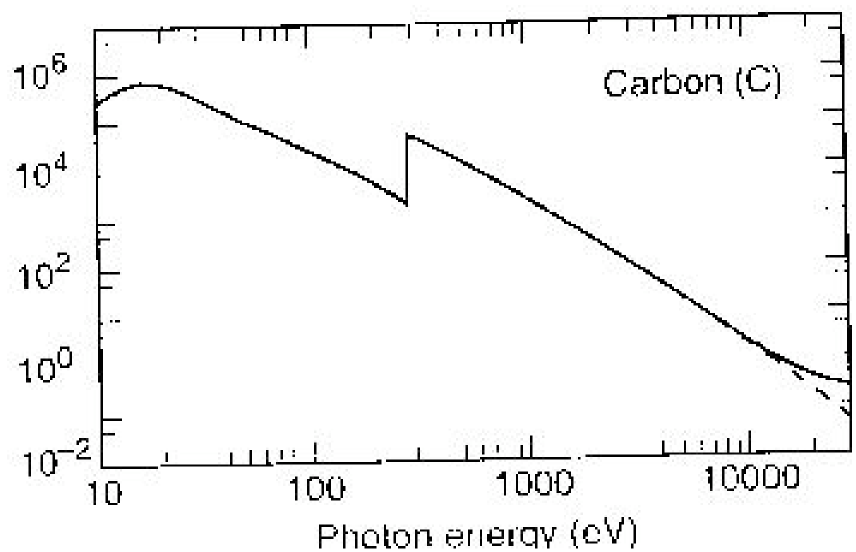


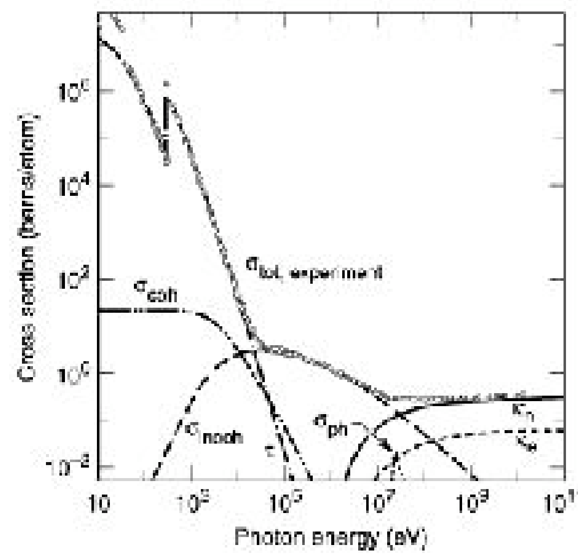
Another Exception

- Mono-chromatic input to Ar based proportional counter.
- Peak shifts and shape changes at Ar -edge

Jahoda and McCammon 1988, Nucl. Instr. Meth. A

Carbon mass attenuation and total cross-section





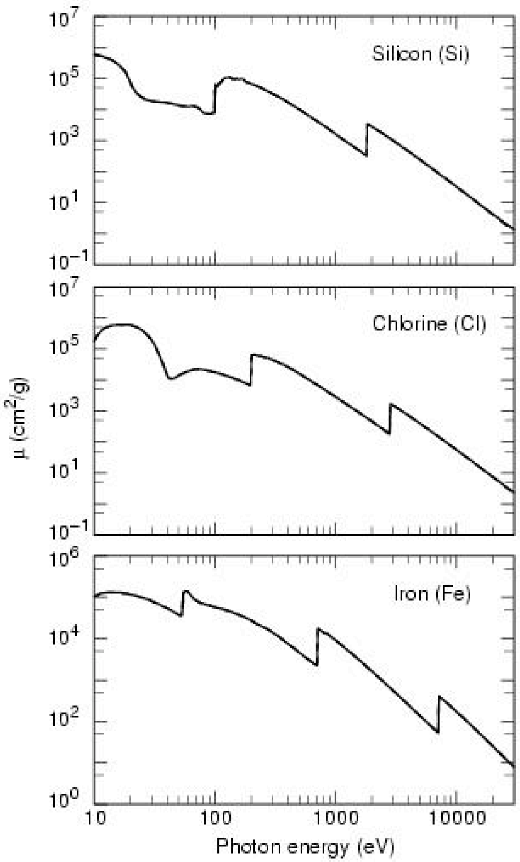
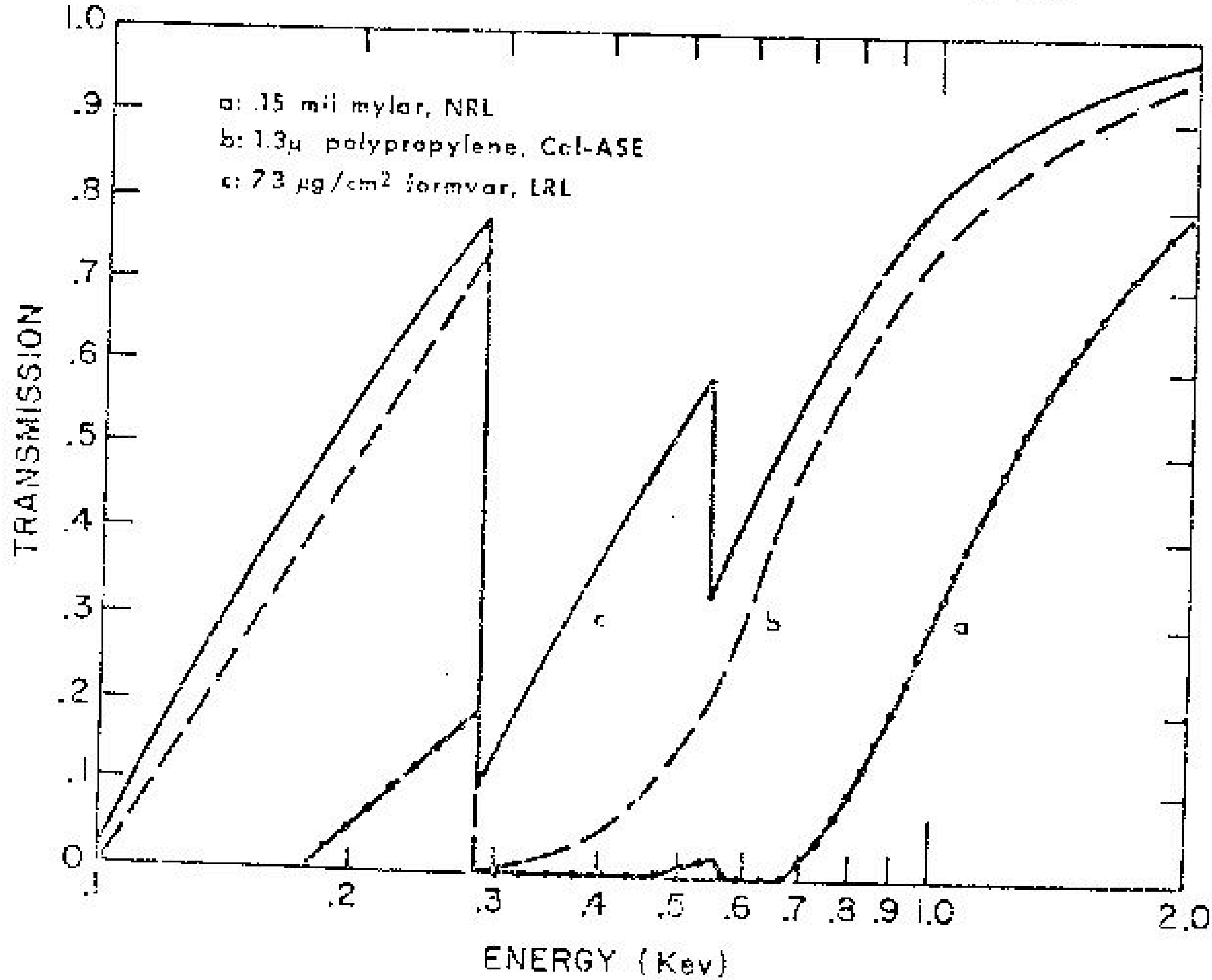
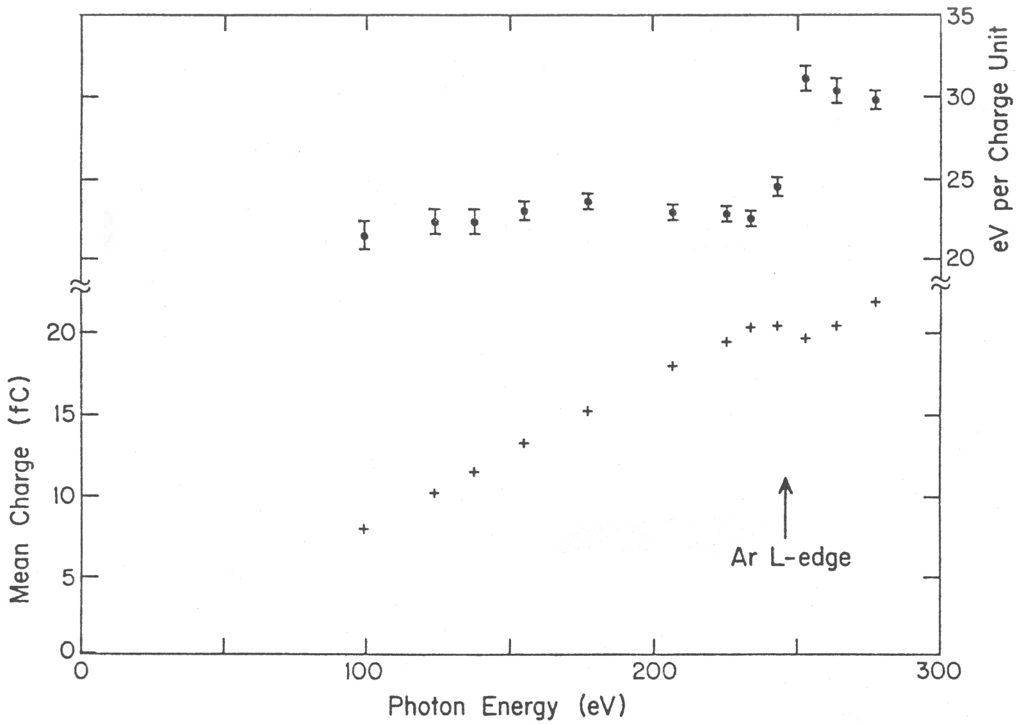


Fig. 1-5. *Silicon, chlorine and iron mass absorption coefficients.*

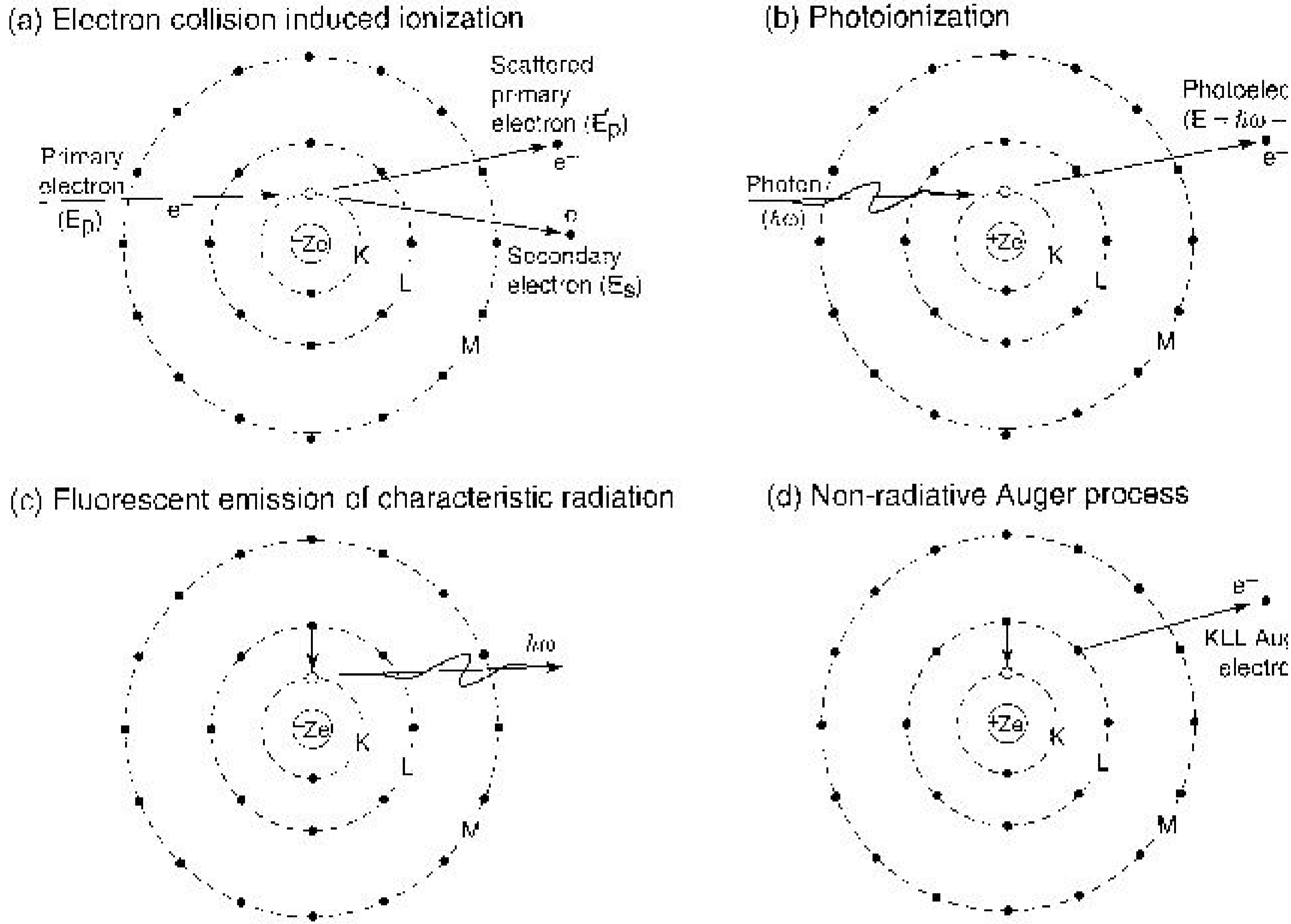
IRANSMISSION OF COUNTER WINDOWS

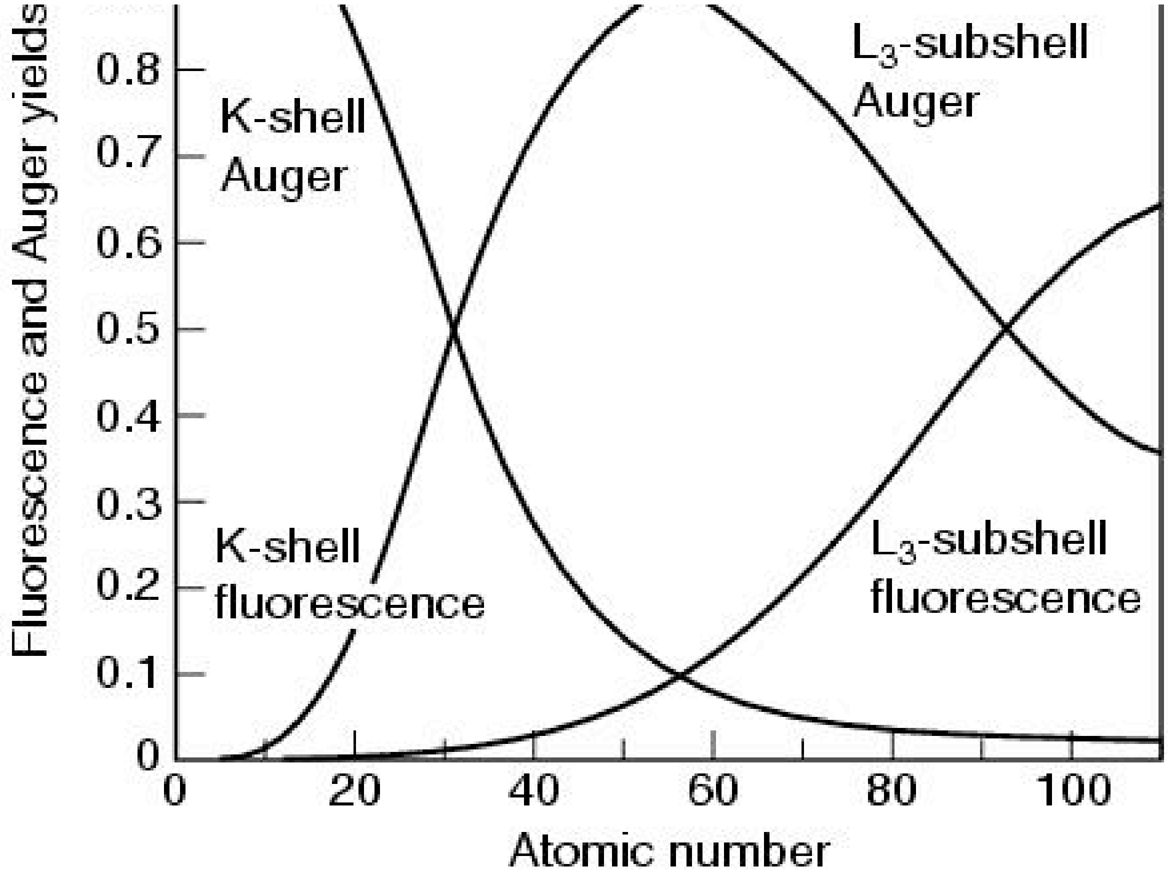




Discontinuity at the edge can be understood in terms of mean, final ionization state. Above the edge, the ion retains more potential energy

Basic Ionization and Emission Processes in Isolated Atoms

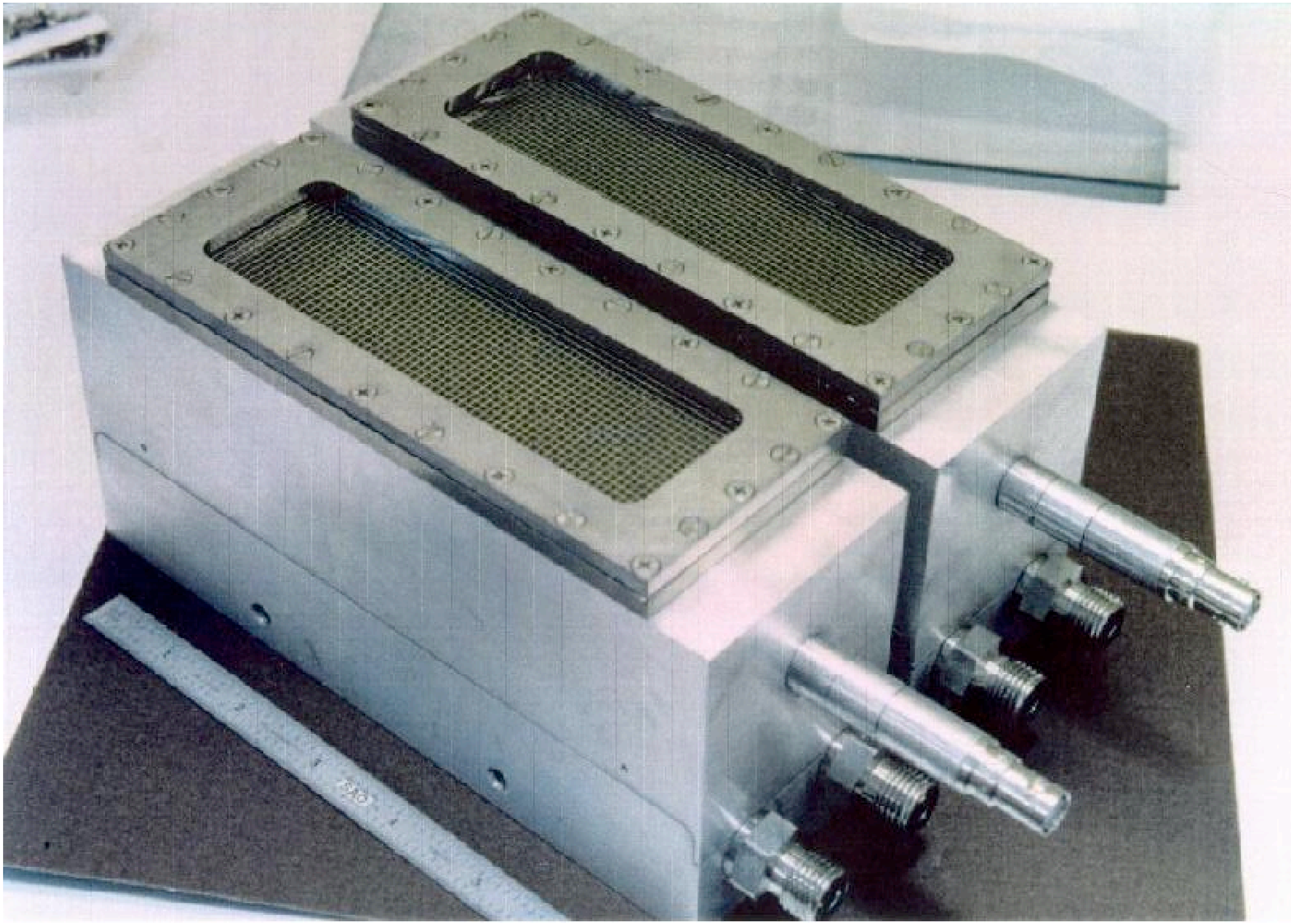




(Courtesy of M. Krause, Oak Ridge)

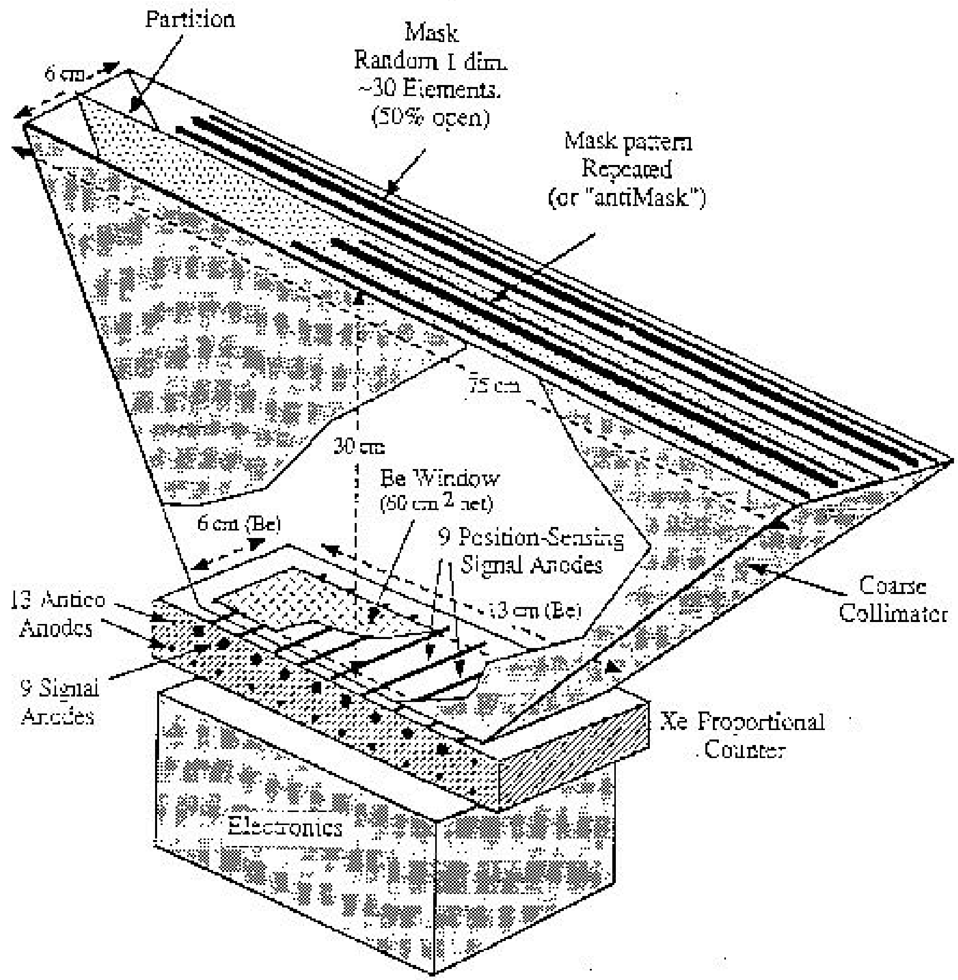
RXTE/ PCA

FPCS



K. Jahoda, 6 Aug 2007 X-ray School, GWU

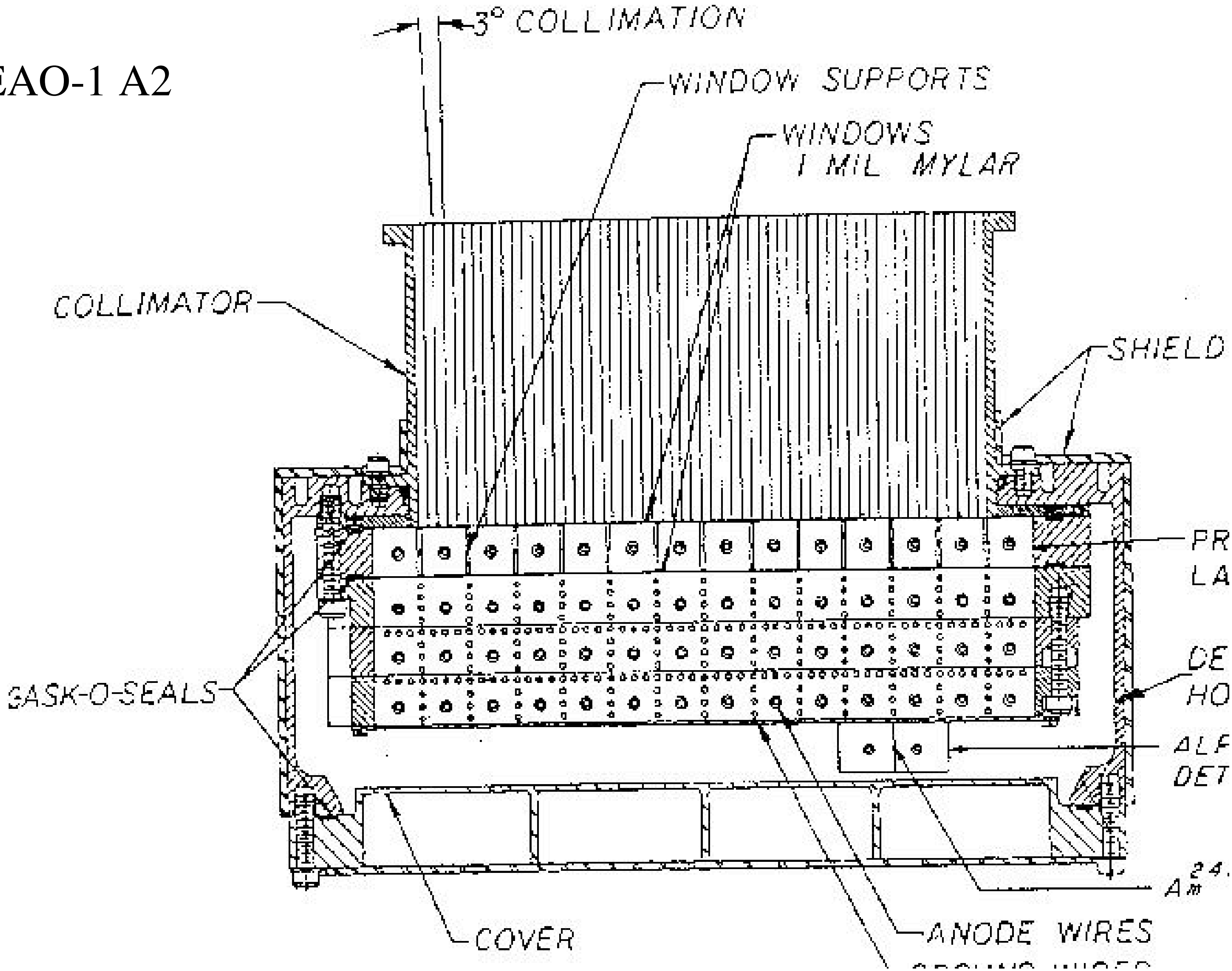
SHADOW CAMERA (1 of 3)*



*Not to scale; e.g. proportional counter drawn oversize.
Dimensions are approximate.

K.

HEAO-1 A2



3° COLLIMATION
WINDOW SUPPORTS
WINDOWS
1 MIL MYLAR
COLLIMATOR
SHIELD
PR
LA
DE
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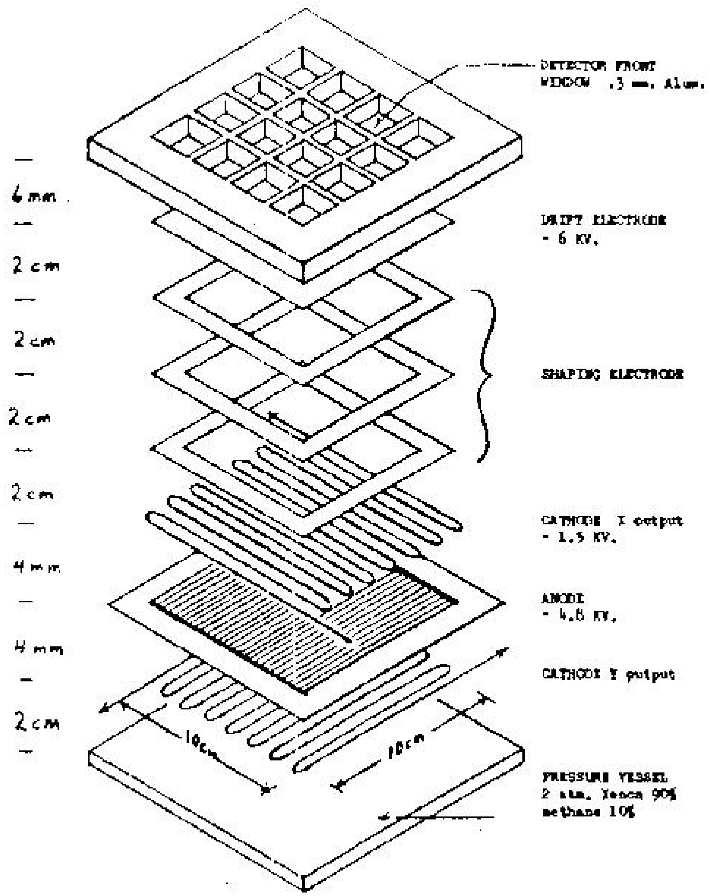
GASK-O-SEALS
ALF
DET
COVER
ANODE WIRES

EINSTEIN IPC



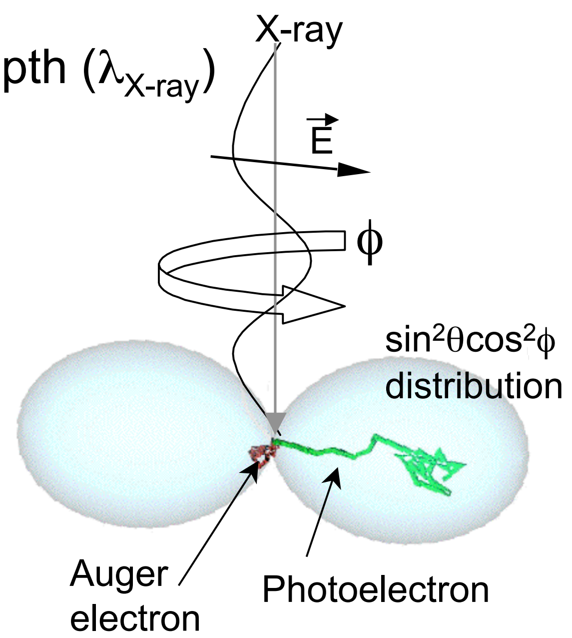
DETECTOR ELECTRODE ASSEMBLY

Future Uses

- Polarimetry
  - Gas detector allows images of the individual interactions.
  - Range of the photo-electron can be tuned

Photoelectric X-ray Polarimetry

- Exploits: strong correlation between the X-ray electric field vector and the photoelectron emission direction
- Advantages: dominates interaction cross section below 100keV
- Challenge:
  - Photoelectron range < 1% X-ray absorption depth ($\lambda_{X\text{-ray}}$)
  - Photoelectron scattering mfp < e^- range
- Requirements:
  - Accurate emission direction measurement
  - Good quantum efficiency
- Ideal polarimeter: 2d imager with:
  - resolution elements $\sigma_{x,y}$ < e^- mfp
  - Active depth ~ $\lambda_{X\text{-ray}}$
  - => $\sigma_{x,y}$ < depth/10^3

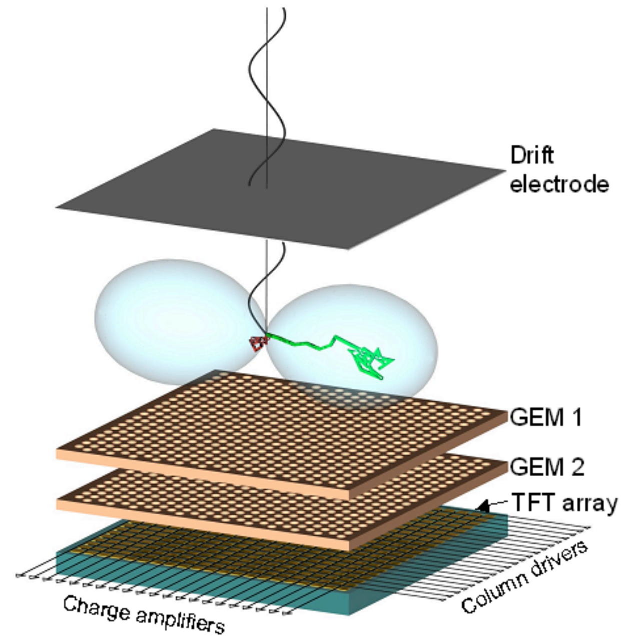


X-ray Polarimetry by Photoelectron Track Imaging

- First demonstrated in 1923 by C.T.R. Wilson in cloud chamber

- Modern track imaging polarimeters based on:
  1. Optical readout* of:
     - multistep avalanche chamber
     - GSPC
     - capillary plate proportional counter
  2. Direct readout# of GEM with pixel anode
     - resolution > depth/100
     - sensitive in 2-10 keV

- Active depth/$\sigma_{x,y}$ is limited by diffusion as primary ionization drifts through the active depth

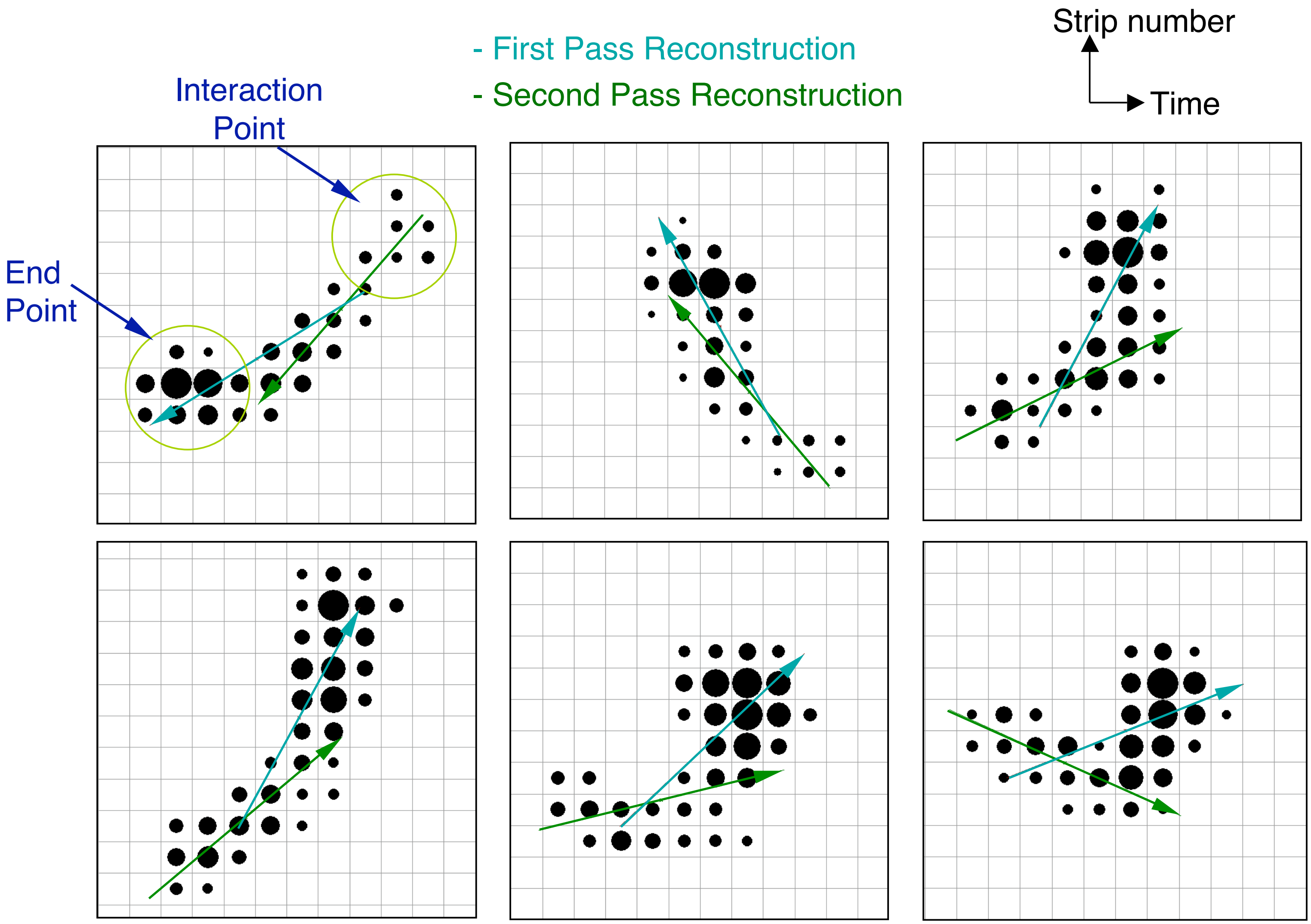


The geometry that affords the gas pixel polarimeter focal plane imaging limits its quantum efficiency

*Ramsey et al. 1992

#Bellazinni et al. 2003, 2006; Black et al. 2003

Typical Reconstructed Events



Analysis and Results

- Histograms of reconstructed angles fit to expected functional form: $N(\phi) = A + B\cos^2(\phi - \phi_0)$ where ϕ_0 is the polarization phase
- The modulation is defined as: $\mu = (N_{max} - N_{min})/(N_{max} + N_{min})$
- Results:
  - It's a polarimeter
  - Uniform response
  - No false modulation

unpolarized

polarized at 0^o

Polarization Phase	Measured Parameters		
	Modulation (%)	Phase (degrees)	χ_ν^2
unpolarized	0.49 ± 0.54	44.6 ± 28.7	1.2
0^o	45.0 ± 1.1	0.3 ± 0.6	1.1
45^o	45.3 ± 1.1	45.2 ± 0.6	1.0
90^o	44.7 ± 1.1	-89.9 ± 0.6	1.4

polarized at 45^o

polarized at 90^o