X−ray imaging with a silicon microstrip detector coupled to the RX64 ASIC

G. Baldazzi[a], D. Bollini[a], A.E. Cabal Rodriguez[b], W. Dąbrowski[c],
A. Diaz Garcia[b], M. Gambaccini[d], P. Giubellino[e], M. Gombia[a], P. Grybos[c],
M. Idzik[c,e], A. Marzari-Chiesa[f], L.M. Montano[g], F. Prino[h], L. Ramello[h],
M. Sitta[h], K. Swientek[c], A. Taibi[d], A. Tuffanelli[d], R. Wheadon[e], P. Wiacek[c]

[a] *Dipartimento di Fisica dell'Università di Bologna and INFN, Bologna, Italy;*
[b] *CEADEN, Havana, Cuba;*
[c] *Faculty of Physics and Nuclear Techniques, University of Mining and Metallurgy, Cracow, Poland;*
[d] *Dipartimento di Fisica dell'Università di Ferrara and INFN, Ferrara, Italy;*
[e] *INFN, Torino, Italy;*
[f] *Dipartimento di Fisica Sperimentale dell'Università di Torino and INFN, Torino, Italy;*
[g] *CINVESTAV, Mexico City, Mexico;*
[h] *Dipartimento di Scienze e Tecnologie Avanzate dell'Università del Piemonte Orientale and INFN, Alessandria, Italy*

Luciano Ramello, Universita' del Piemonte Orientale (Alessandria, Italy)

IWORID02, Amsterdam, 8−12 September 2002

Outline

- Motivation and intended applications
- System description
  - Microstrip detectors
    - *Good spatial resolution (100 μm pitch)*
  - RX64 readout chip for single photon counting
    - *Low noise (designed for cristallography @ 8 keV)*
    - *High counting rate*
- Measurements:
  - RX64 ***internal calibration***
    - Gain estimation
    - Noise measurement
  - ***Radioactive sources***
    - Gain measurement, absolute energy scale
  - ***Quasi−monochromatic X−ray beam***
    - Energy scans
    - Imaging tests

Motivation and applications

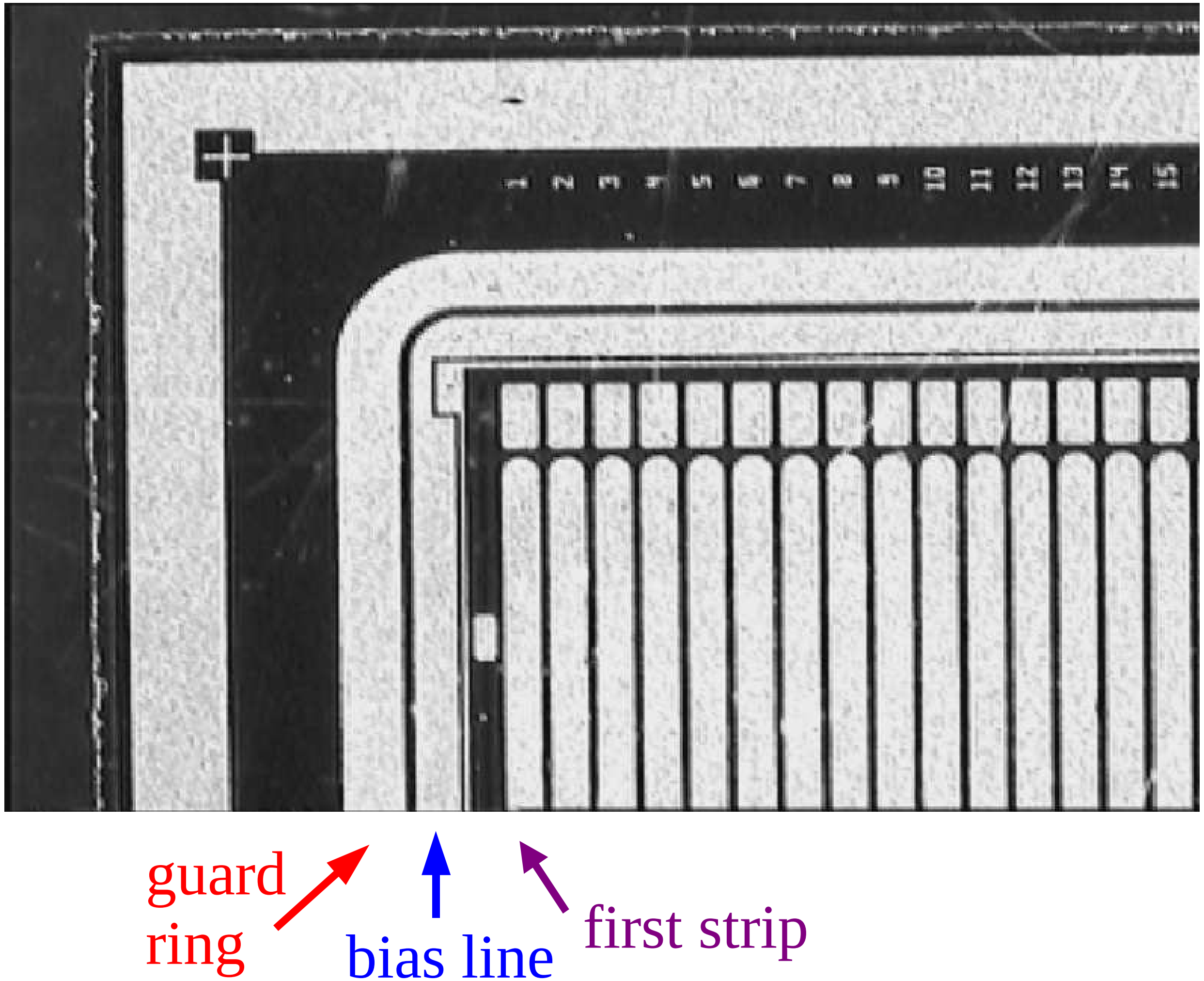
- One−dimensional silicon array for scanning mode imaging
  - Good spatial resolution with reduced number of channels
- Advantages of digital (single photon) X−ray imaging:
  - Higher detecting efficiency with respect to screen−film systems
    - *Edge−on orientation (parallel incidence) preferred for E>18 keV*
  - Possibility of processing and transferring digital data

<u>see also talk by P. Rato Mendes (normal incidence scanning)</u>

- Subtraction imaging: removes background structures
- Dual energy technique: isolates materials characterized by different energy dependence of linear attenuation coeff. μ
  - First application: angiography at iodine K−edge (33 keV)
  - Another application: dual−energy mammography (18+36 keV)
  - Suitable for small−scale installations

Silicon microstrip detectors

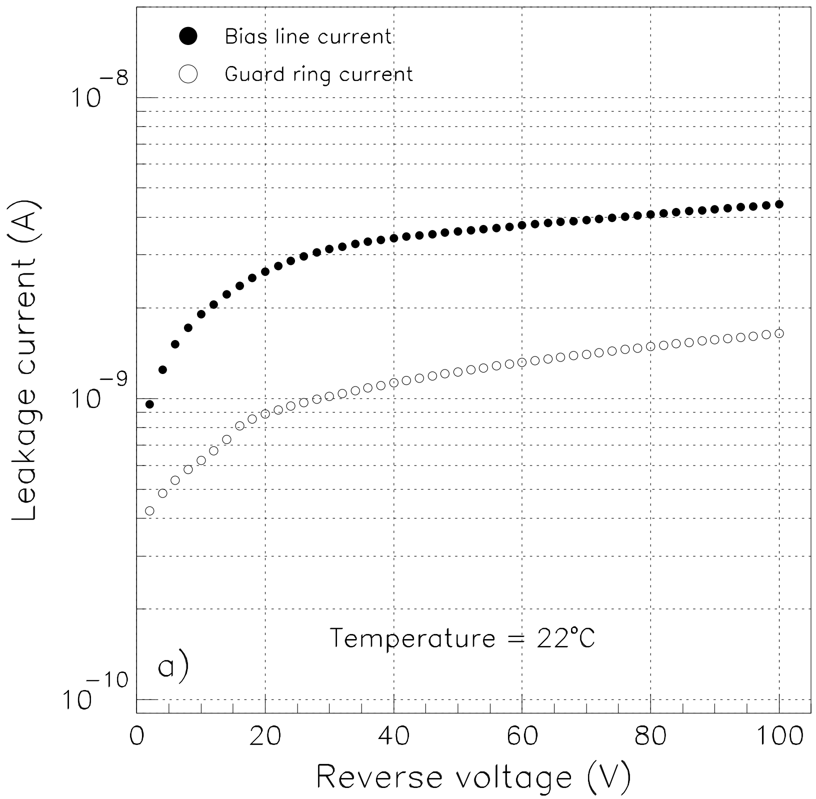
- 132 strip detector for 1st prototype (2 RX64 chips)
  - AC−coupled strips
  - FOXFET biasing
  - Depth = 300 μm
  - Strip pitch = 100 μm
  - Strip length = 10 mm
- 400 strip detector for 2nd prototype (equipped with 6 RX64 chips)



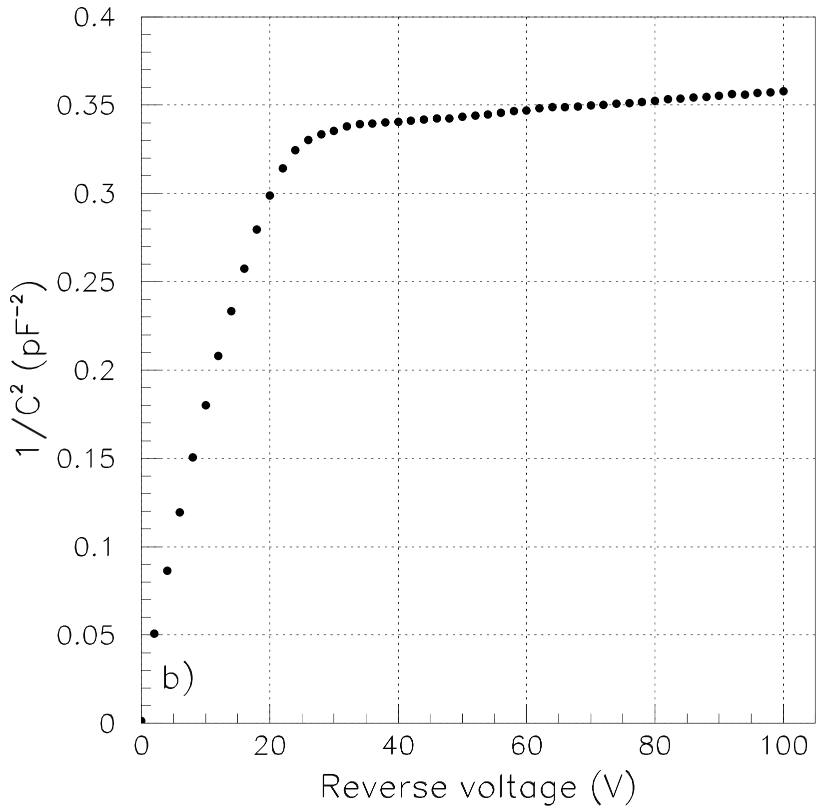
- Detectors developed by ITC−IRST, Trento, Italy

Detector characterization

132 strip detector



400 strip detector



I−V for bias line and guard ring

Leakage current (typ.) for 128−400 strip det.

at 30 V ≈ 24 − 33 pA/strip (22−25 °C)

at 60 V ≈ 28 − 44 pA/strip

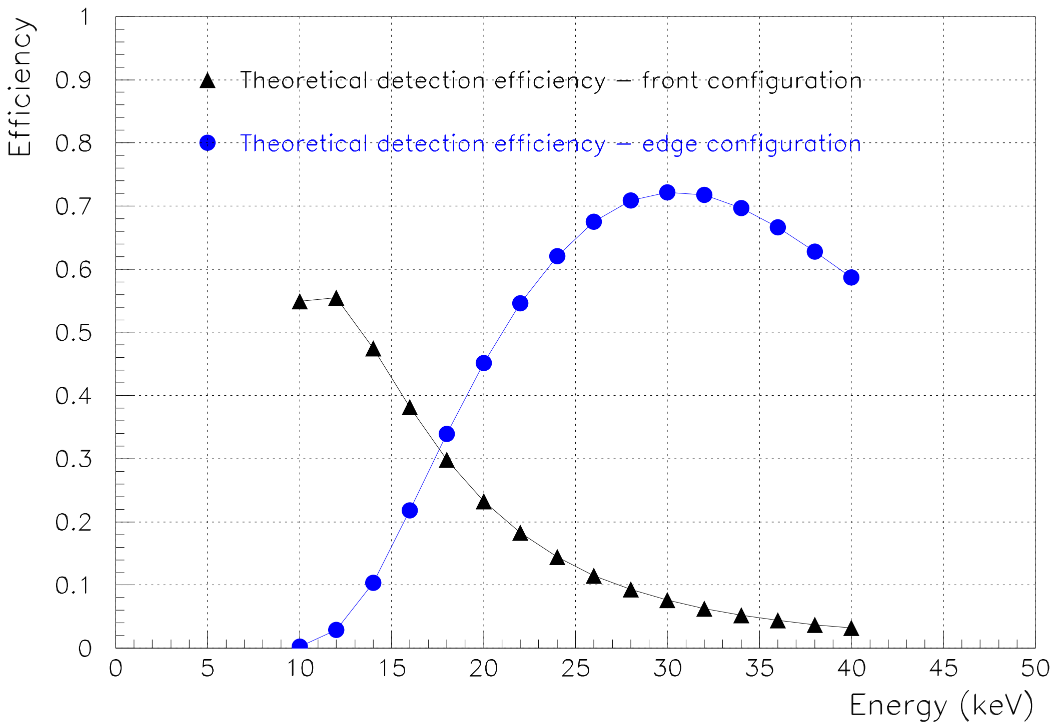
C−V for a group of 4 strips

Depletion voltage ≈ 25 V

Detecting efficiency

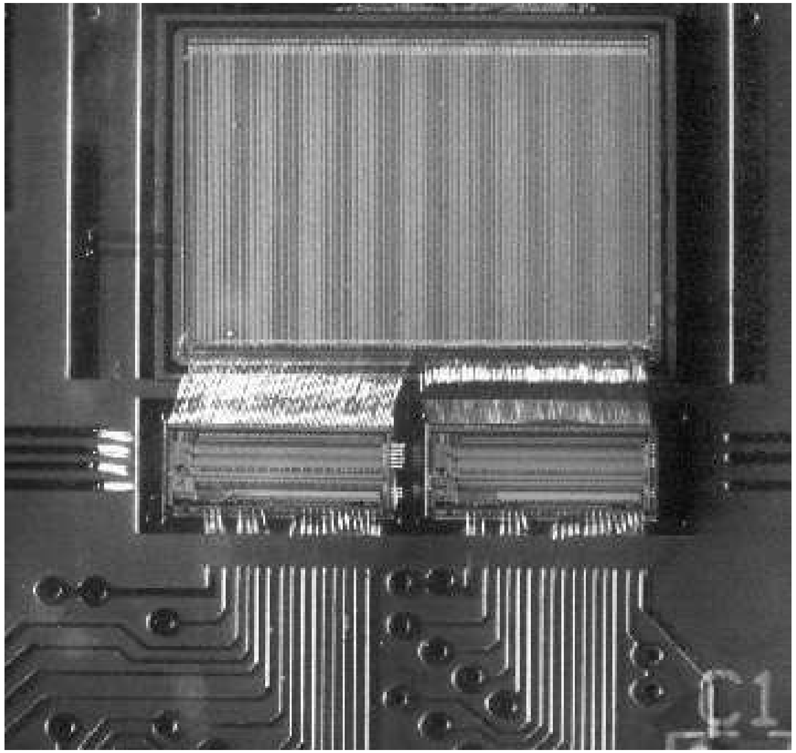
Efficiency for converting X−rays via photoelectric effect

- ***Front*** configuration
  - Strip orthogonal to beam axis
    - *70 μm of Al absorber*
    - *300 μm active length*
- ***Edge*** configuration
  - Strip parallel to beam axis
    - *765 μm of insensitive Si*
    - *10 mm active length*



The RX64 readout chip

- Binary architecture for readout electronics
  - preamp. + shaper (tunable peaking time) + discrim. + scaler : 1 bit information per strip
  - Single photon counting (up to 1 M per strip)
- 64 channels − AMS 0.8 μm technology
  - 2 chips (128 channels) in the 1st prototype, 6 chips (384 channels) in the 2nd prototype
  - ***Low noise (min. threshold 6 keV)***
  - ***Counting rate*** capability = 200 kHz/channel

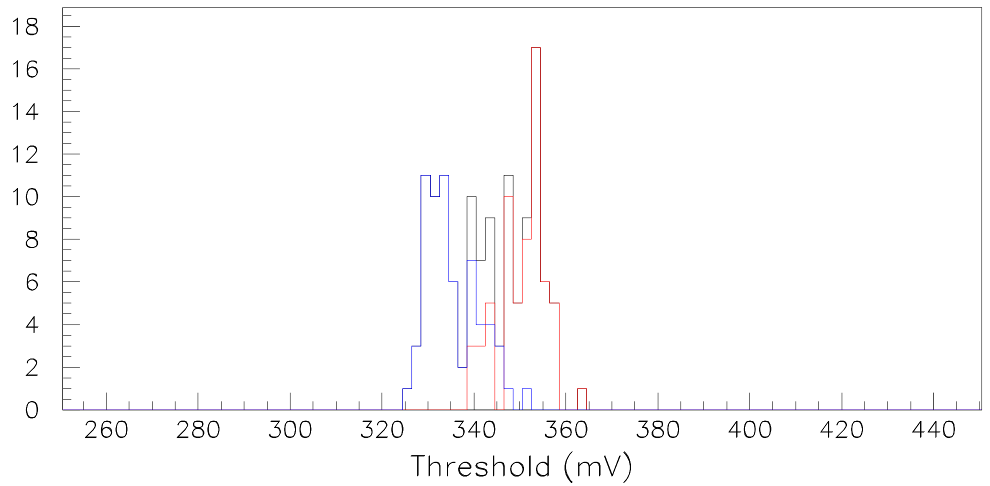


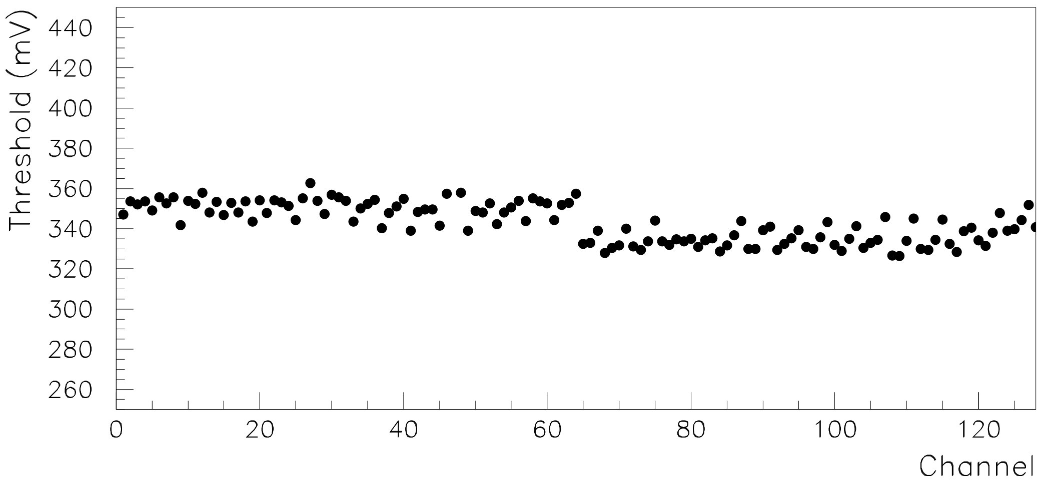
Parameter	Measured value
Gain	60-90 μV/electron
ENC (C_{det}=2.5 pF, I_{det}=100 pA)	167 el. RMS
Input range	up to 10000 el.
Peaking time	500-1000 ns
Counting rate	200 kHz/channel
Power consumption	2.5 mW/channel

Data Acquisition:

- NI's PCI−DIO−96 (desktop) or DAQCard−DIO−24 (portable)
- NI's LabVIEW 6i software

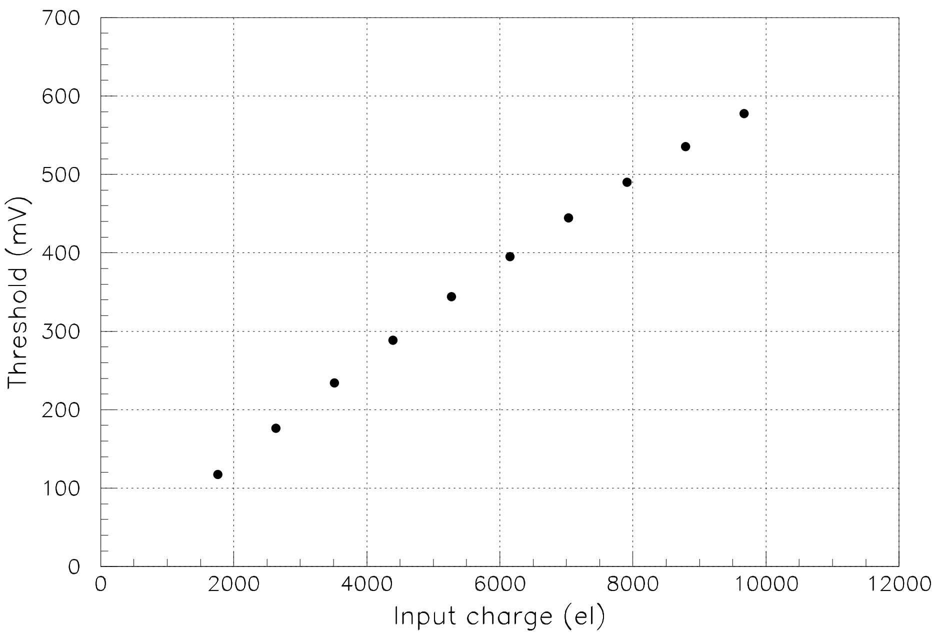
Measurements with internal calibration

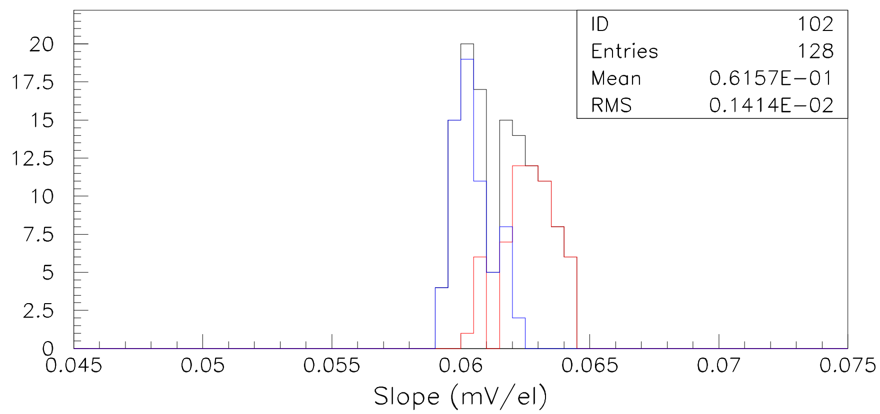


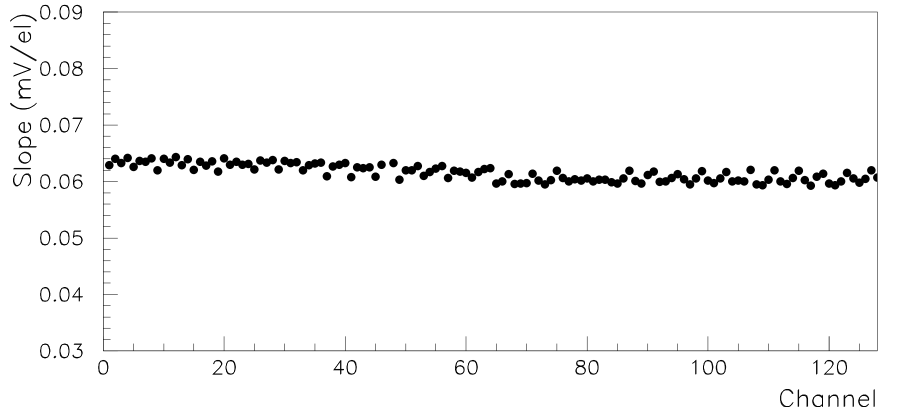


- Calibration pulse of ≈5300 electrons (internal voltage step applied to C_{test} = 75 fF)
- Measure counts vs. threshold (noise ends at 80 mV)
- Gaussian fit to differential distr. gives signal amplitude and noise at discrim. output
- Gaussian peak threshold distribution for 128 channels:
  - Threshold spread ≈ 8%
  - Small systematic difference (≈ 4%) between the chips

Response linearity, gain estimation







- Scan with 10 different amplitudes (4−22 mV)
- Circuit response linear up to 8000 electrons (30 keV) for T_{peak}= 1 μs
- Linear fit: gain and comparator offset

<***Gain***> = 61.6±1.4 μV/el.

Small (3.5%) systematic difference between chips

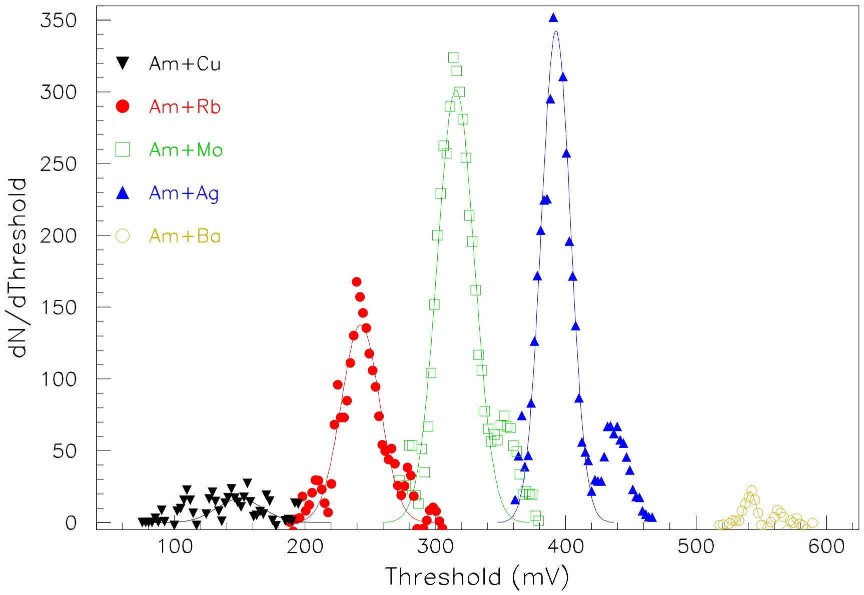
Noise measurements

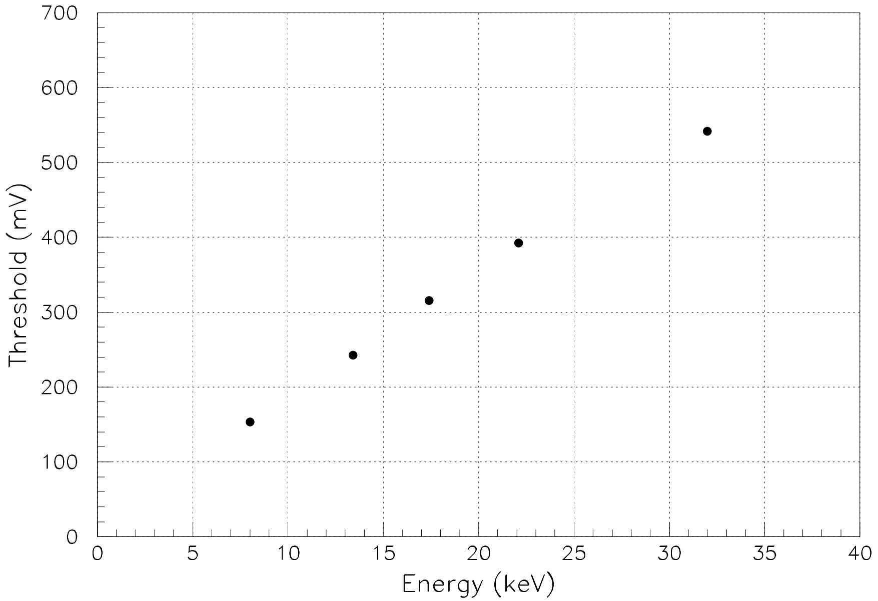
Detector with 128 equipped channels:

- ***RMS value of noise = 8.1 mV ⇒ ENC = 131 electrons***
- ***RMS of comparator offset distribution 3.2 mV: 2 times smaller than noise*** *(common threshold setting for all channels)*

Module	T(peak)	Gain (μV/el.)	ENC (electrons)
2xRX64+detector	LONG	61.6	131
6xRX64 alone	LONG SHORT	63.7 82.8	176 131
6xRX64+fanout (no detector)	LONG SHORT	63.7 82.8	184 148

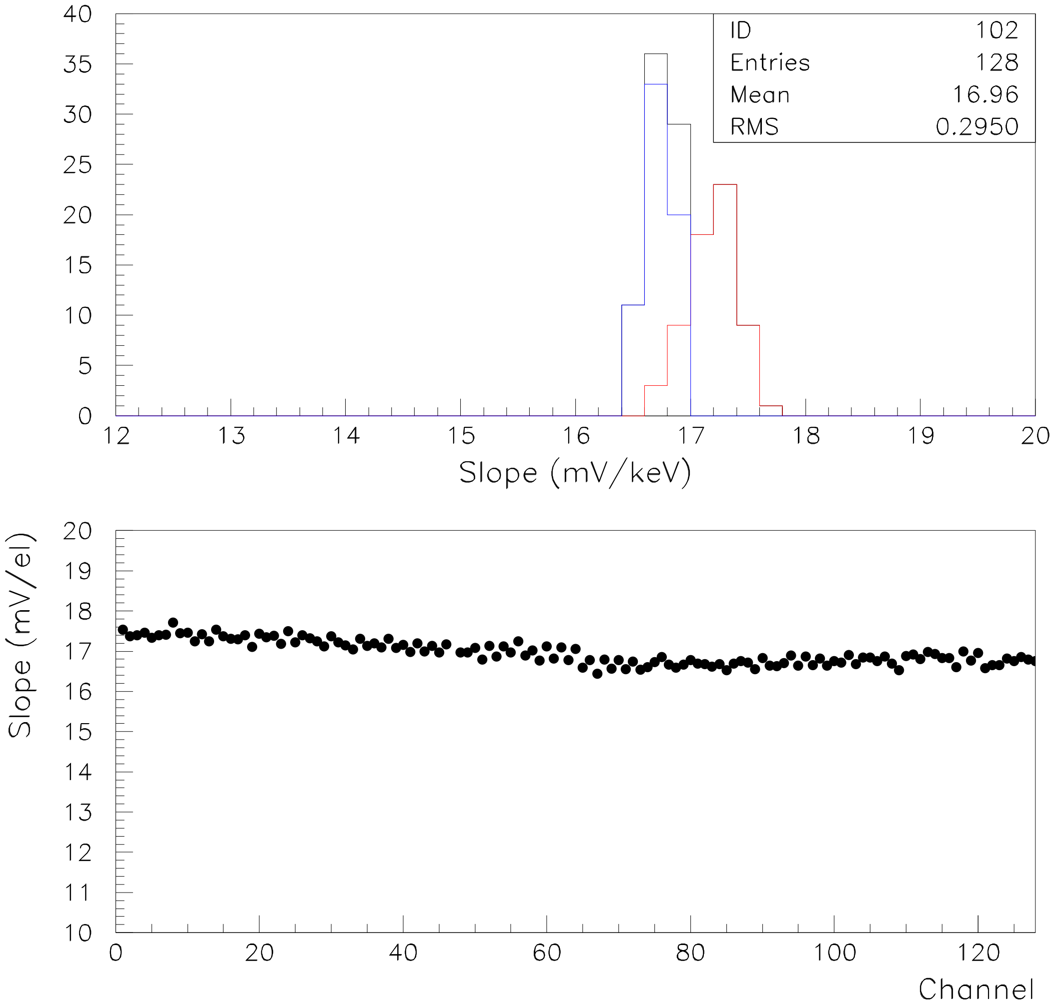
Results with ^{241}Am fluorescence source





- K_β peak clearly visible for Mo, Ag and Ba targets
- Gaussian fits to K_α peak give absolute energy calibration
  - RMS noise (from Ag) = 11.2 mV $\Rightarrow$ ENC $\approx$ 180 electrons
    - *Due to fluctuations in e−h pairs + higher strip bias voltage*

Gain evaluation with source



- Linear fit in the range 8<E<30 keV (excl. Am−Ba)
- Gain distribution for the 128 channels
  - ***<Gain>*** = 17.0 mV/keV

    $\Rightarrow$ 61.7 μV/el.
  - RMS gain= 0.3 mV/keV
  - Small (2.7%) systematic difference between the two chips
- Good agreement with the gain extracted using the internal calibration

Quasi monochromatic X−ray beam

- W−anode X−ray tube
- X−ray beam monochromatized by Bragg diffraction in a mosaic cristal
    - *$2.8 \times 6.0 \times 0.1\ cm^3$ highly oriented pyrolitic grafite crystal*

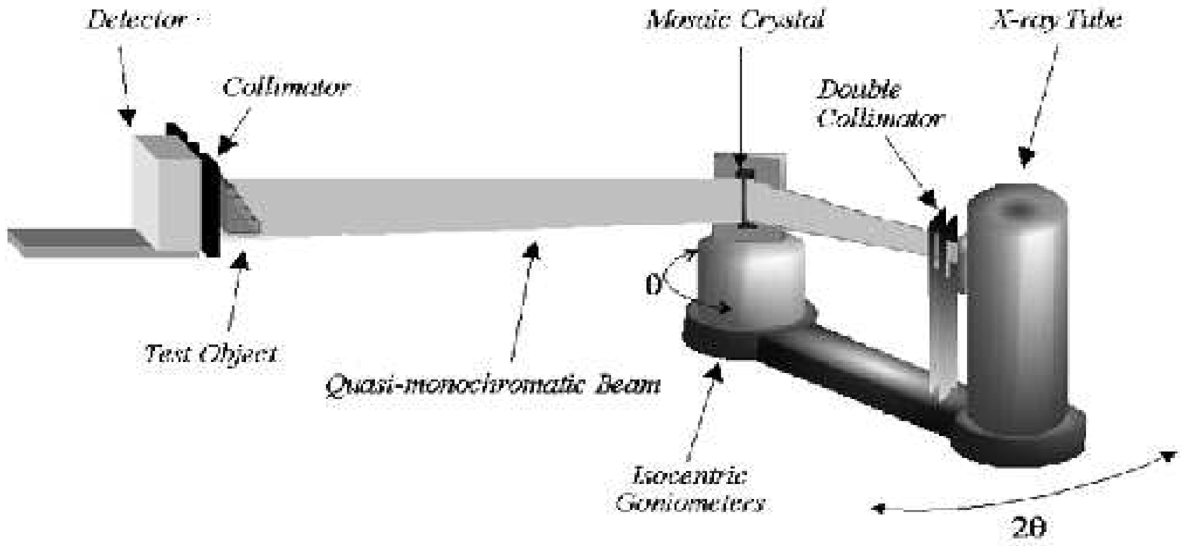
➨ X−ray tube mounted on a goniometer

→ X−ray energy selection

$$E_B = \frac{n \cdot h \cdot c}{2d \sin \vartheta_B}$$

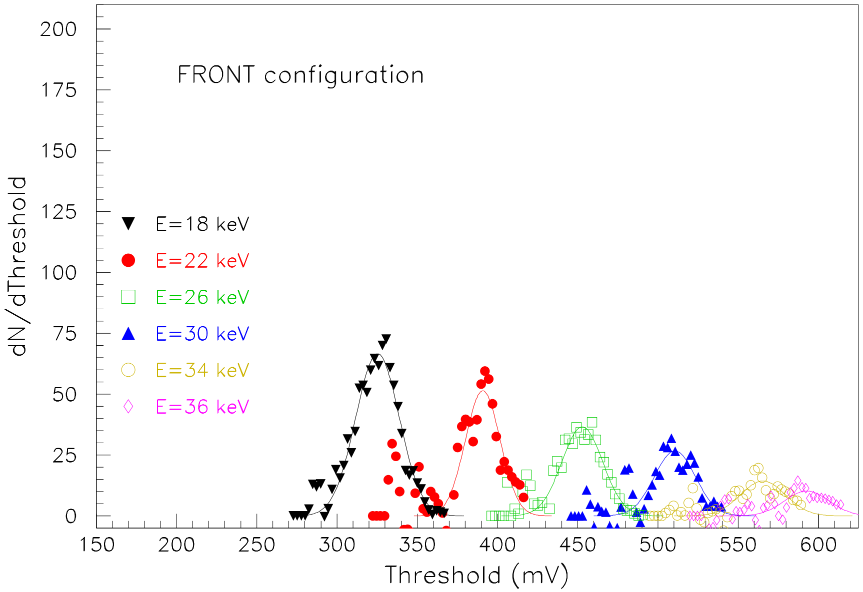
➨ Possibility of dual energy beams (using 2nd order Bragg diffraction)

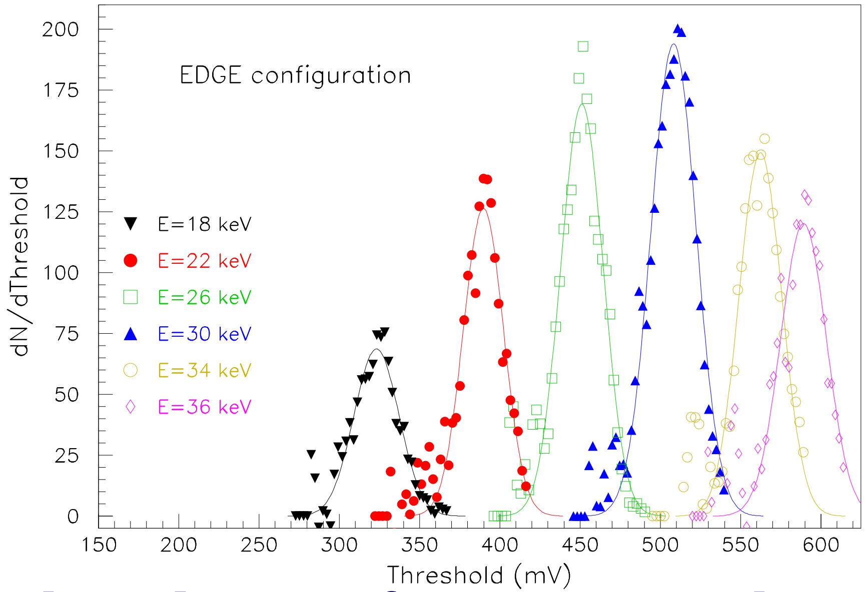
- Detector placed at ≈ 90 cm from the crystal
- 300 μm wide collimator upstream from the detector (FRONT config. only)



Energy scans with X−ray beam

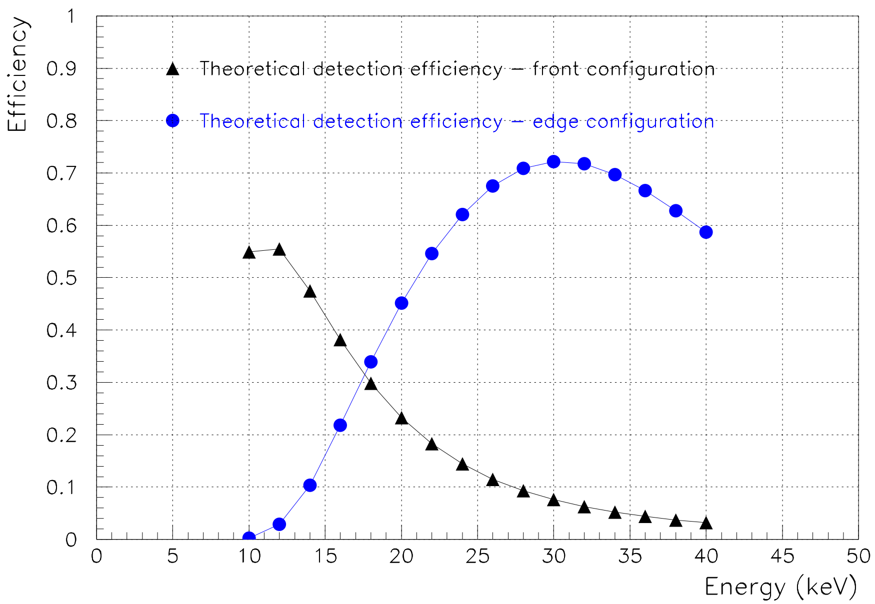
- Discriminator threshold scans taken with 6 different energies of the quasi−monochromatic X−ray beam





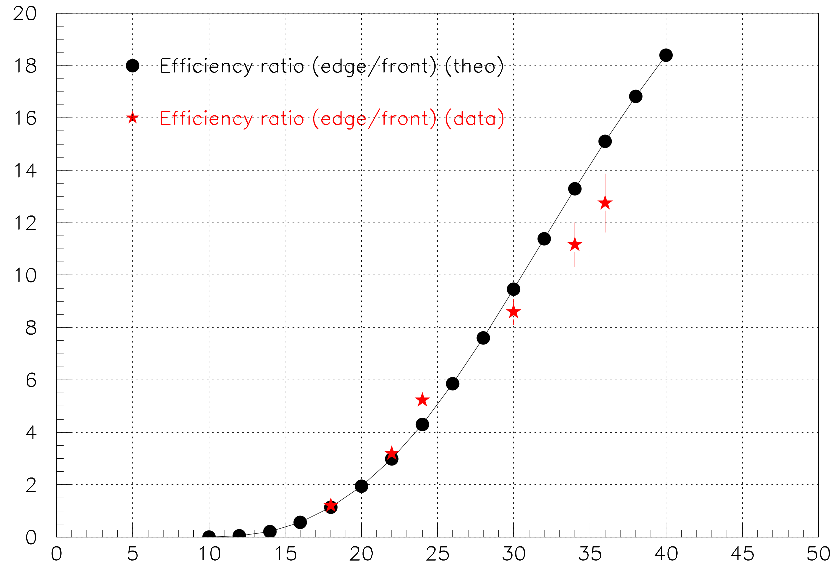
- Detector much more efficient in the edge configuration in the whole energy range considered (18−36 keV)
- Rate capability: at 20 keV, counts ∝ mAs (5−225 mAs), with at least a factor of 10 margin before saturation

Measured detector efficiency



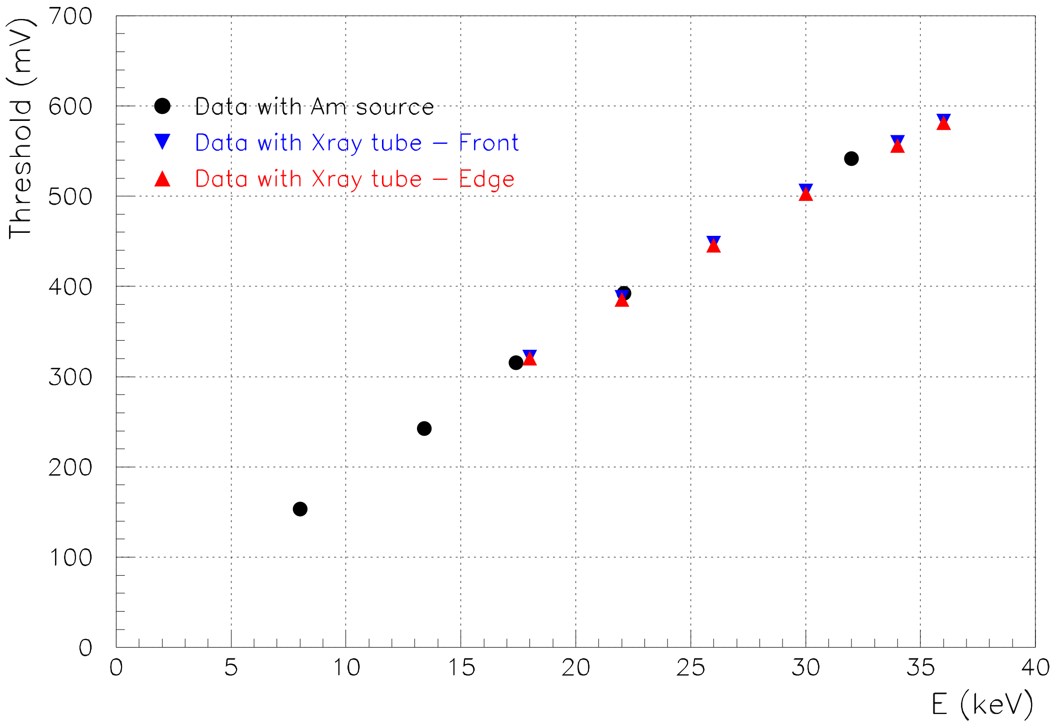
Theoretical efficiencies as a function of energy in front and edge configurations

Efficiency ratio Edge/front



- Acceptable agreement between data measured and theoretical expectations (Compton neglected)

Energy scan results



- Excellent agreement among the different data sets
  - ➔ Quality of the tuning of the quasi monochromatic X−ray beam
- Gaussian width ≈ 13.4 mV (was 11.2 mV with Am−Ag source)
  - *Enlargement reflecting the energy spread of the quasi−monochromatic beam*

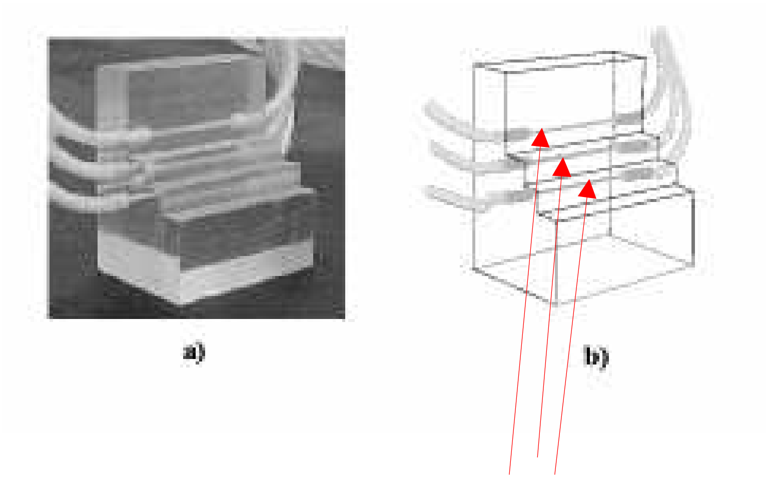
K−edge subtraction angiography

- Medical examination → visualization of occlusions in arteries
- Conventional procedure for angiography
  - Iodate contrast medium injected directly in the coronary arterial system
    - *Catheter fitted in the femural artery* → ***invasive procedure*** *(high risk)*
    - ***Long fluoroscopy exposure*** *time to manage the catheter up to the heart*
  - X−ray transmission image taken
    - *Iodine X−ray absorbtion coefficient different from the surrounding tissues*
- K−edge subtraction angiography (usually at synchrotron facility)
  - TWO images taken with two monochromatic beams
    - *1st BELOW and 2nd ABOVE the iodine K−edge (at 33.13 keV)*
  - Pixel by pixel subtraction of the two images to extract the iodine signal
    - ***Enhanced contrast:*** → *lower Iodine concentration needed*

      → *possible intravenous injection of the contrast agent*

Imaging test

- Detector in edge configuration
- Test object
  - plexiglass step wedge phantom
    - *40 mm high − 30 mm wide*
    - *Thickness ranging from 10 to 45 mm*
  - Three 1 mm diameter cylindrical cavities
    - *Filled with iodate solution*
    - *Solution concentration = 370 mg/ml*



- Images taken with quasi−monochromatic beam
  - First image at 31 keV
  - Second image at 35 keV
- Two dimensional image obtained by moving the object in the orthogonal direction

Single energy images

- Data corrected for X−ray beam intensity profile, flux differences at the two energies and detector efficiency

Image at 31 keV

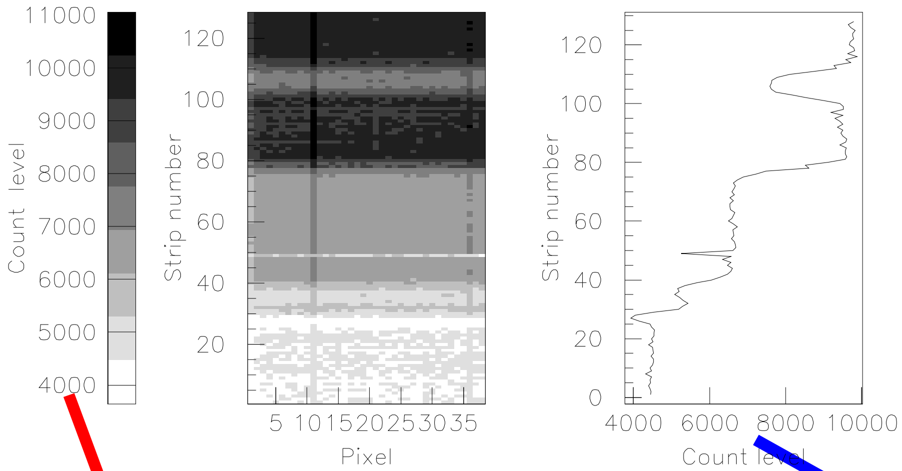
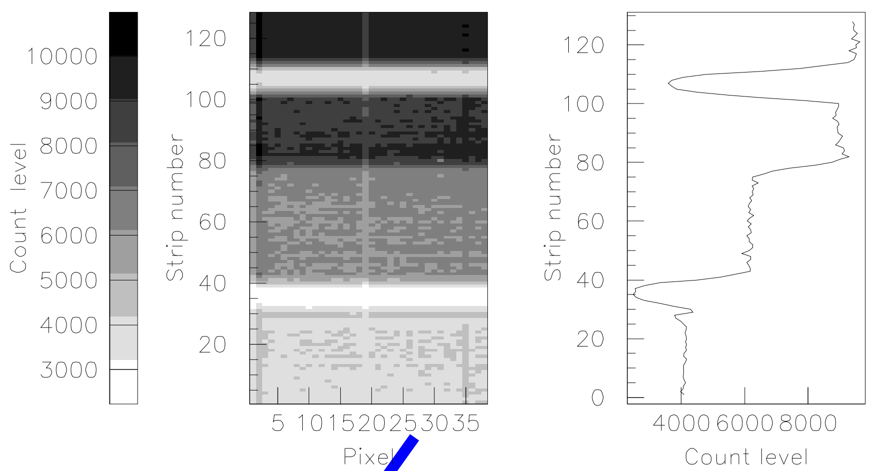


Image at 35 keV

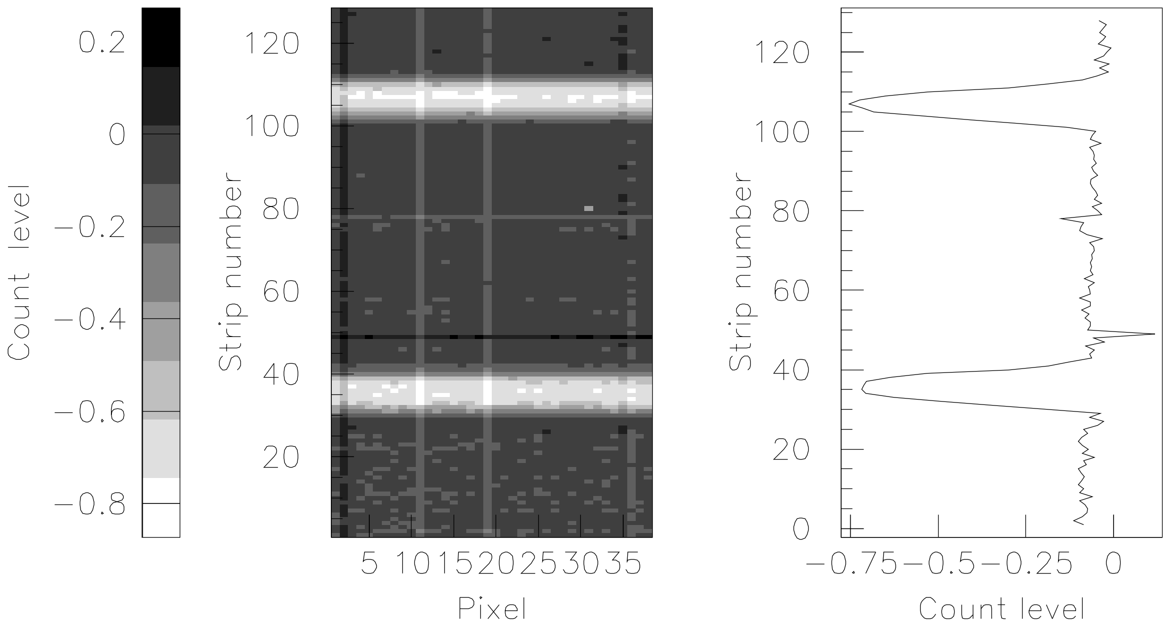


Iodine signal hardly visible at 31 keV

Presence of a vertical gradient due to the attenuation characteristics of the step−wedge phantom

K−edge subtraction image

Subtraction image = ln(Image35) − ln (Image 31)



- No gradient due to the attenuation characteristics of the phantom
- Iodine contrast enhanced
  - Detail visibility improved

Conclusions and outlook

- Detecting system for X−ray imaging (8−36 keV) developed and tested
  - Gain and noise measured with chip calibration and fluorescence sources
    - *<Gain>=17.0 mV/keV ⇔ 61.6 μV/el. @ T(peak) = 1 μs*
    - *Noise threshold ≈ 80 mV ⇔ 4.7 keV ⇒ operation with threshold as low as 6 keV*
    - *ENC ≈ 131 electrons (1 cm long strips, 128 equipped channels)*
- Energy scans with quasi−monochromatic X−ray beam
  - X−ray energy in excellent agreement with the expectations
  - Energy spread small with respect to the intrinsic noise of the system
- K−edge subtraction angiography test (128 equipped channels)
  - Contrast enhanced + background structure removed
- Work in progress towards clinical applications:
    - *Larger detectors (400 strips: under test; 4 cm length) + double threshold chips*
    - *Large field dichromatic X−ray source for clinical angiography*