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Detectors for mammography: Introductory Seminar

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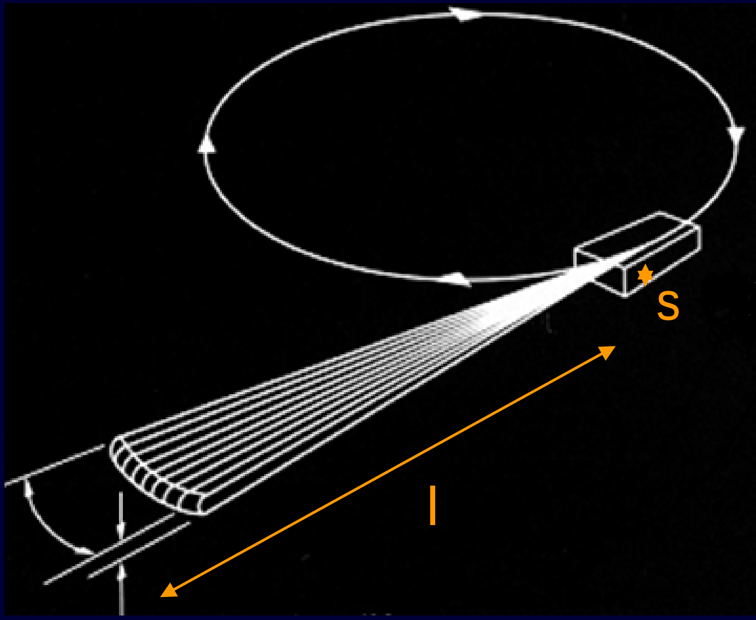
elettra

Outline

- Mammography with Synchrotron Radiation
  - The SYRMEP (SYnchrotron Radiation for MEdical Physics) beamline
  - The mammography clinical program
- The PICASSO (Phase Imaging for Clinical Application with Silicon detector and Synchrotron radiation) detector
  - Requirements of a digital detector for mammography
  - PICASSO microstrip silicon detector characteristics
  - Single photon counting electronics
  - Imaging results: planar and tomographic imaging
- Conclusions

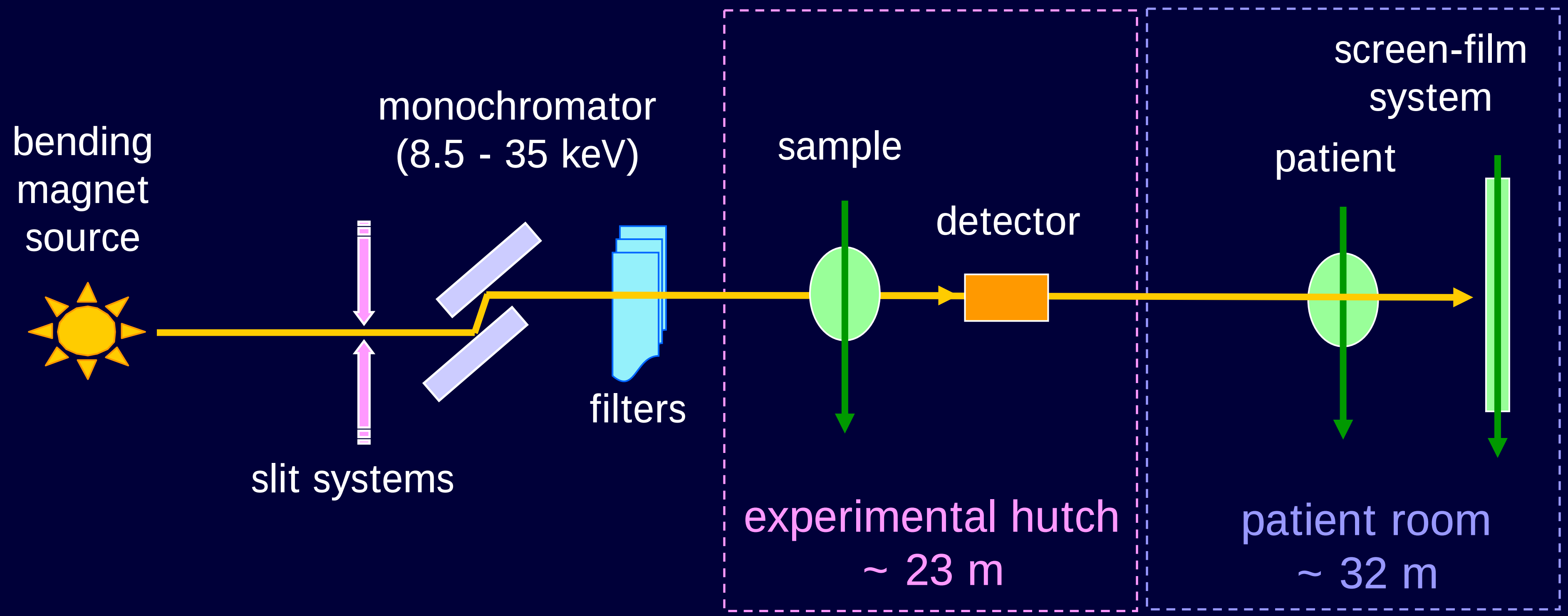
Characteristics of synchrotron radiation (SR)

- High x-ray intensity on a broad energy range
  - Tunable monochromatic beam
    - Choose the optimum energy for a specific examination
    - Dose optimization/reduction
    - No beam hardening effects (in tomography)
- Laminar beam geometry (the beam is naturally collimated)
  - Images are acquired by scanning the object/patient through the fan beam
  - High scattering rejection
- Small source size and large source-to-sample distance
  - High degree of lateral coherence
  - Phase-sensitive techniques



Suitable for mammography
Improving image and diagnostic quality
Dose reduction

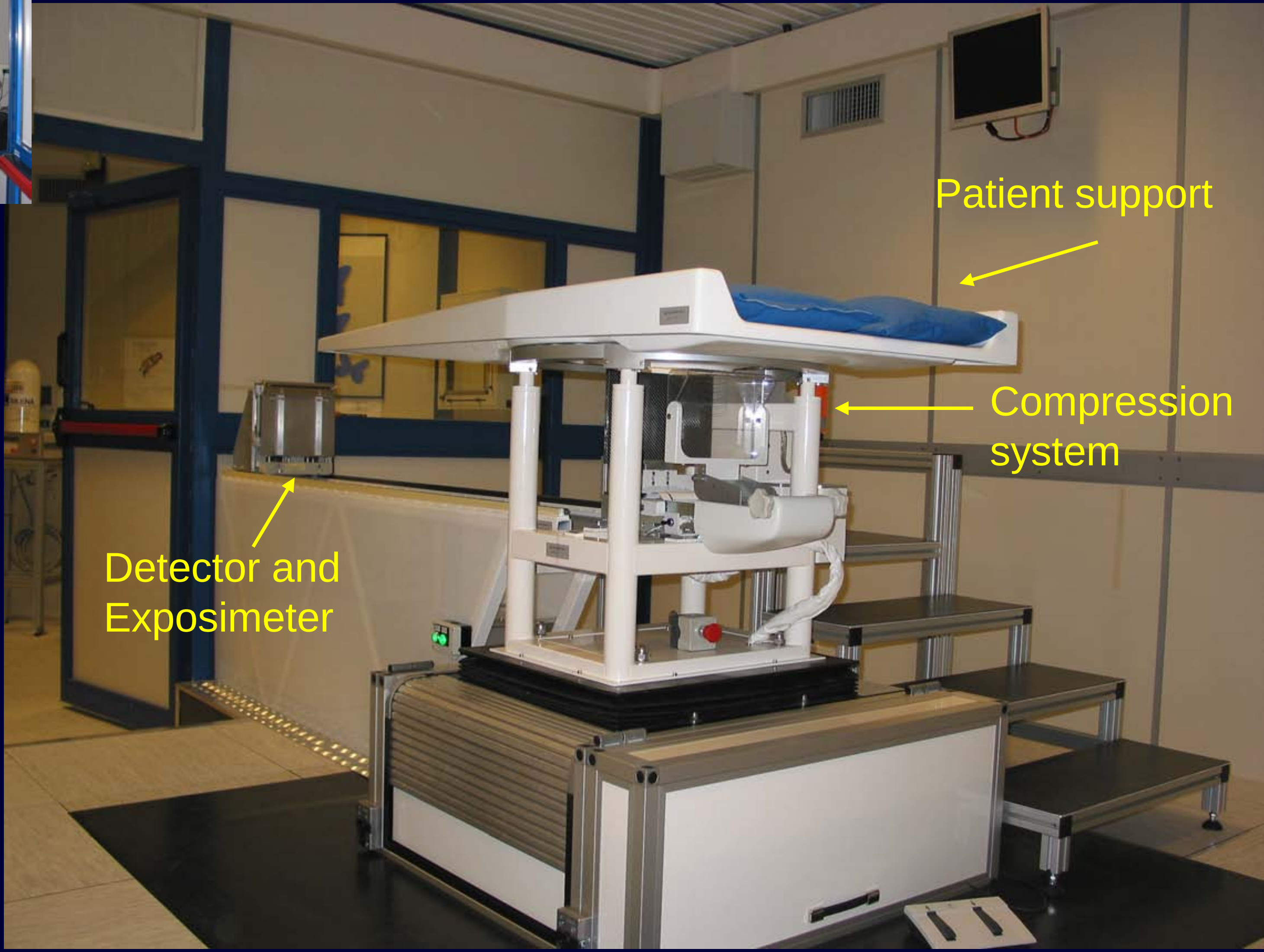
The SYRMEP beamline (I)



- Source size ~ 1.1 (horizontal) x 0.1 (vertical) mm^2
- Divergence: ~ 7 mrad (horizontal) x 0.2 mrad (vertical)
- Laminar beam: 4 x 150 mm^2 (exp hutch) – 4 x 210 mm^2 (patient room)
- Flux at 17 keV (Elettra operated at 2.4 GeV, 140 mA ring current): 10^8 ph/mm^2/s

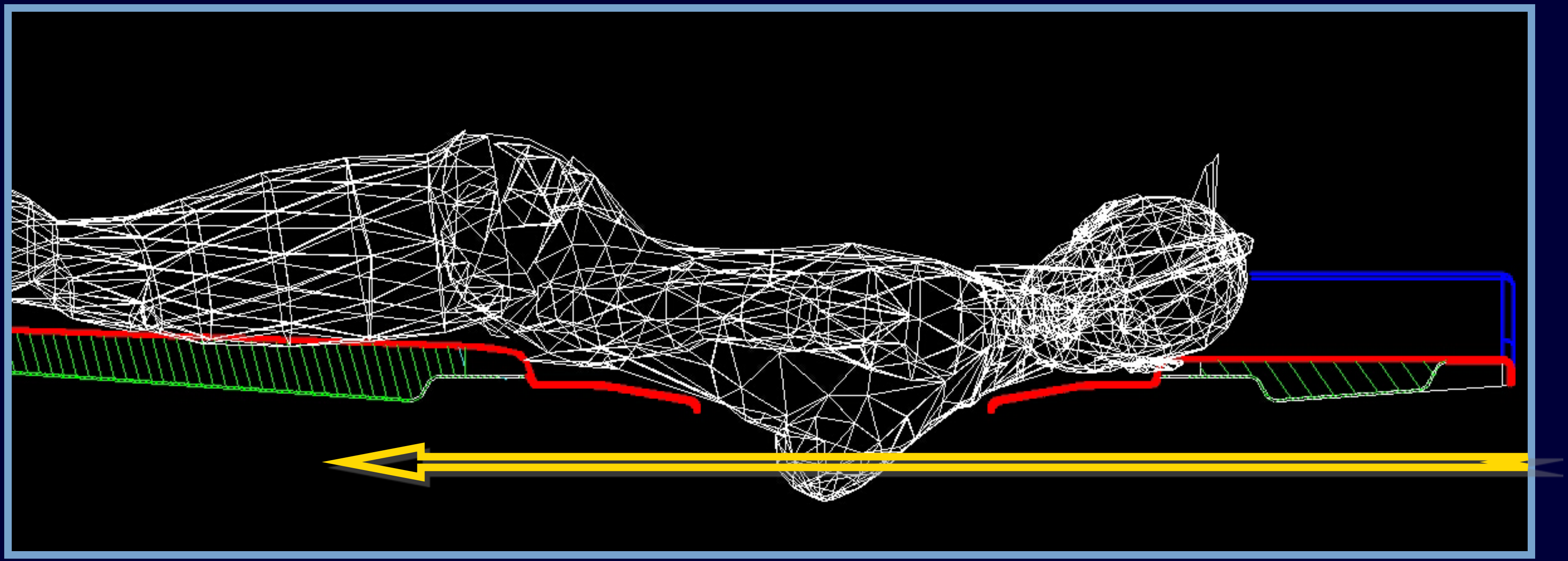
Vertical scan of the sample through the beam

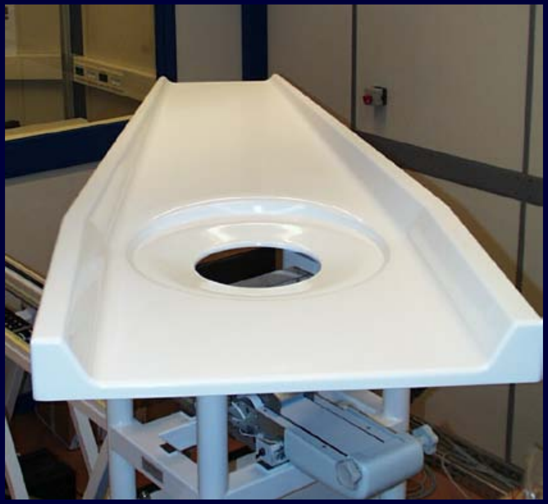
Examination room

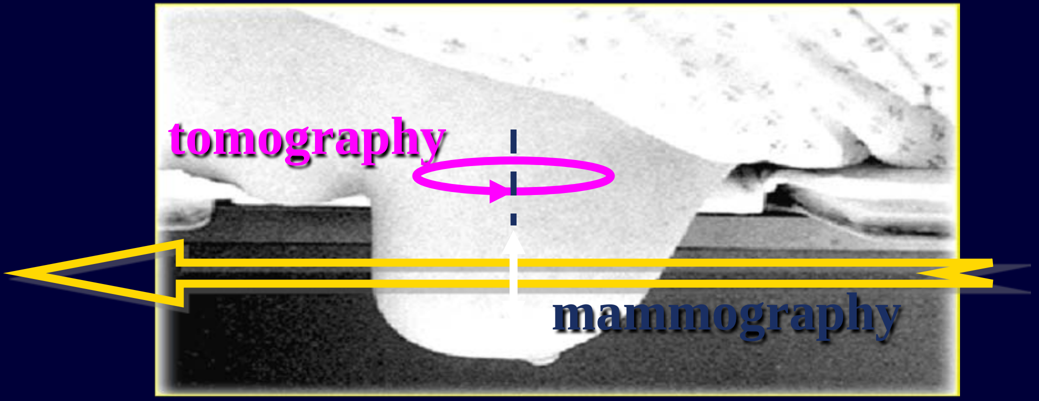


Patient positioning

Size and shape of the opening are consistent with the chest anatomy



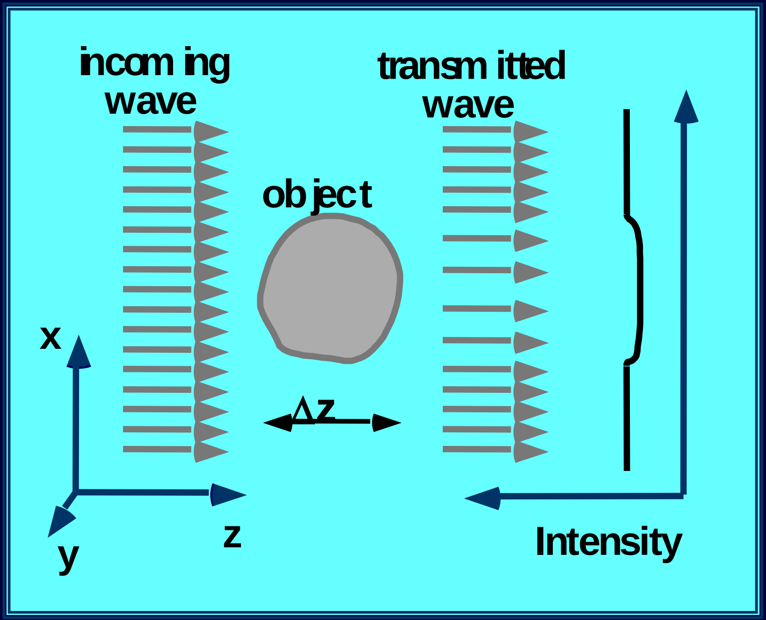


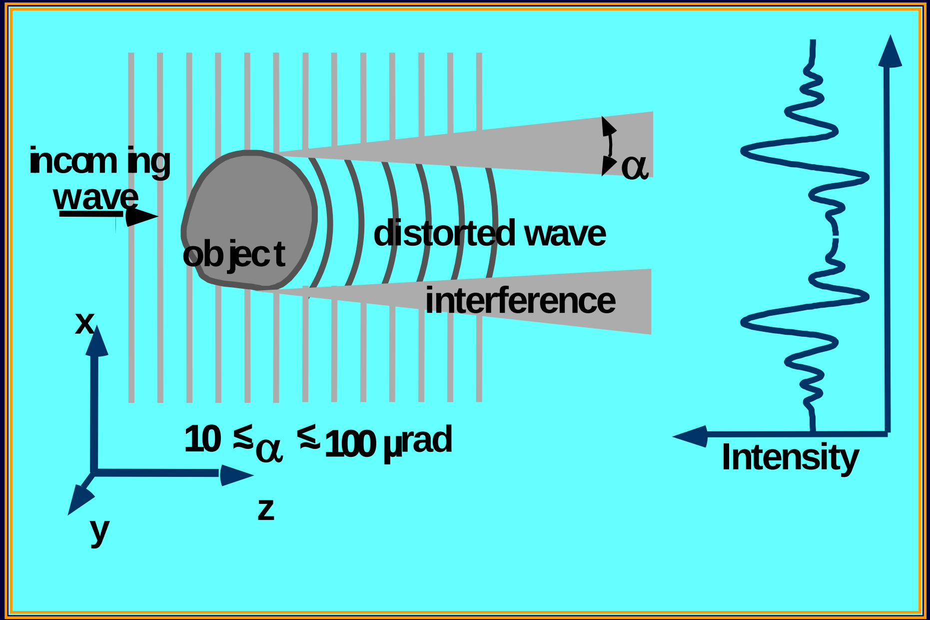


Mammography with SR: clinical program

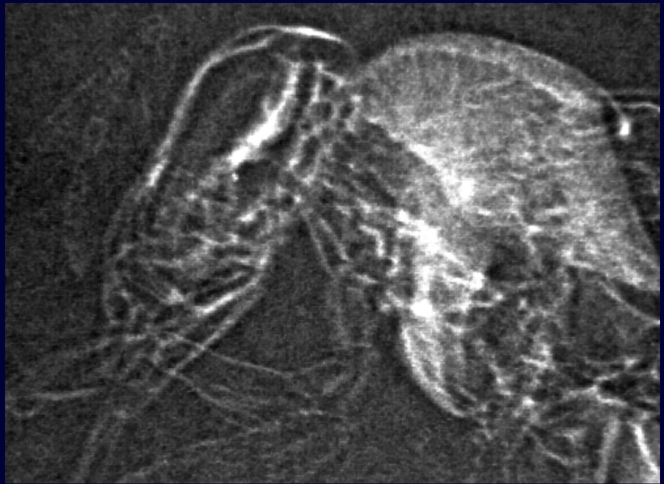
- Our goal
  - Improving the diagnostic quality of conventional mammography without increasing the dose delivered to the patient
- 3 Phase program
  - Phase I: Phase contrast MSR with screen-film system
    - Completed with 71 patients (2006-2009)
    - Encouraging results: MSR outperforms conventional mammography
  - Phase II: Phase contrast MSR with digital detector
    - Feasibility study by using FUJIFILM Fuji CR for Mammography PROFECT ONE
    - Development of our custom digital detector (PICASSO)
  - Phase III: new techniques (CT and/or tomosyntesis)

Phase Contrast Imaging





- Phase shift of X-ray wavefront when crossing a detail
- Interference pattern between refracted and unrefracted waves produces intensity variations on the detector (if the source is coherent)
- Sample-to-detector distance (about 2 m) is optimized to detect the interference pattern

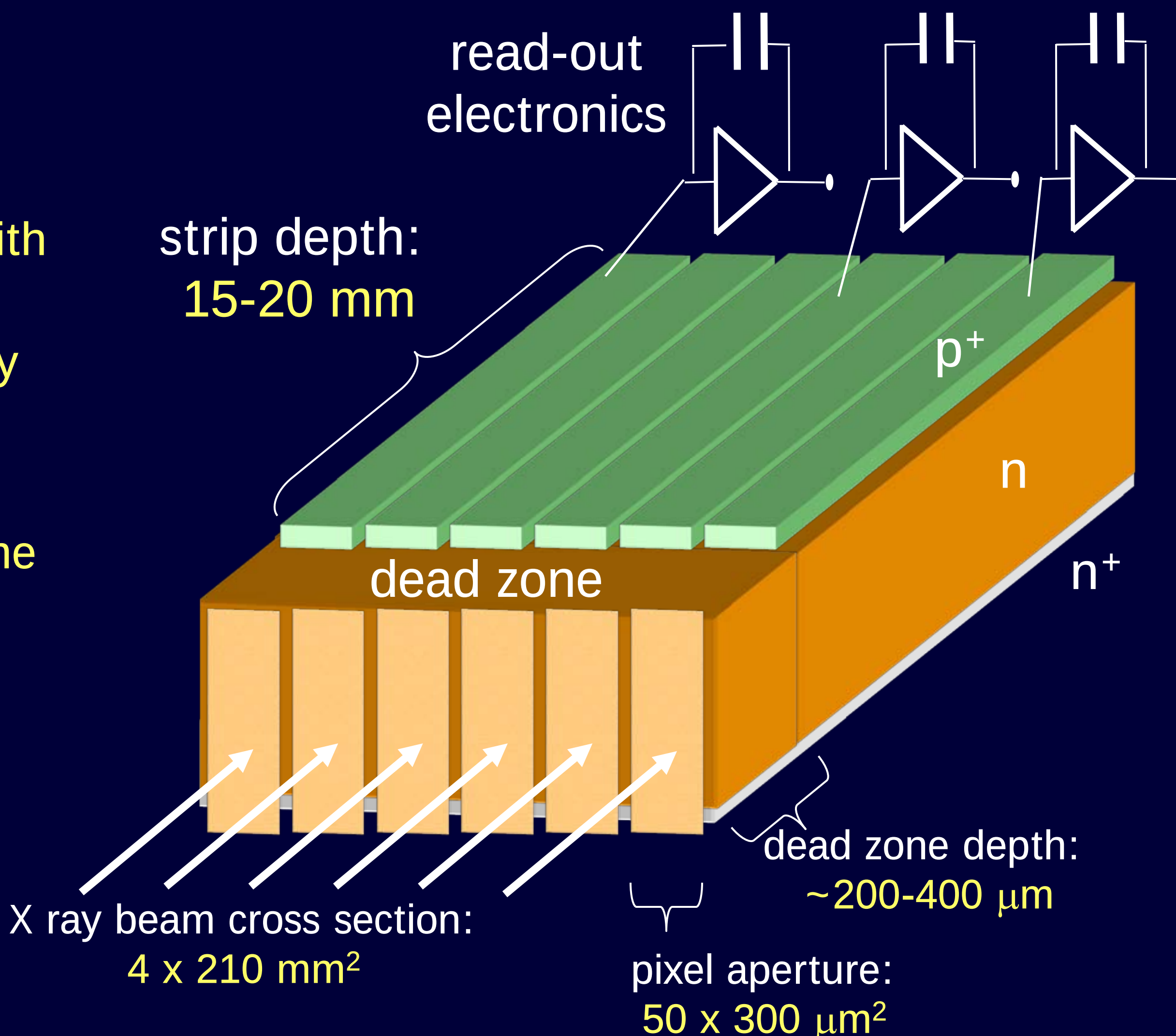


PICASSO Digital Detector Requirements

- High efficiency
  - Low dose
- High spatial/contrast resolution
  - Detect micro-calcifications/nodules
  - Detect phase contrast effects
- Wide dynamic range
- Fast Rate Capabilities and Read-Out
  - Take a mammogram in a few seconds
- Laminar geometry
  - Matching beam cross section
  - Scatter Rejection

The silicon micro-strip detector: “edge-on” geometry

- Advantages of “edge-on” geometry:
  - Matching the laminar geometry of the beam with a natural pixel array
  - High absorption efficiency
- Problems:
  - Dead (undepleted) volume in front of the sensitive region that reduces the detection efficiency (~70-85% @ 20keV)

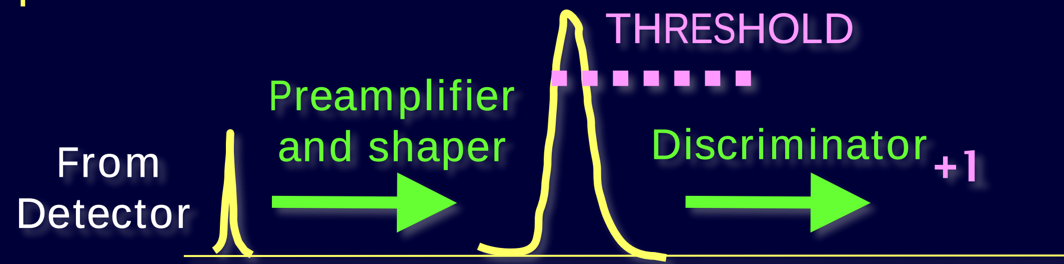


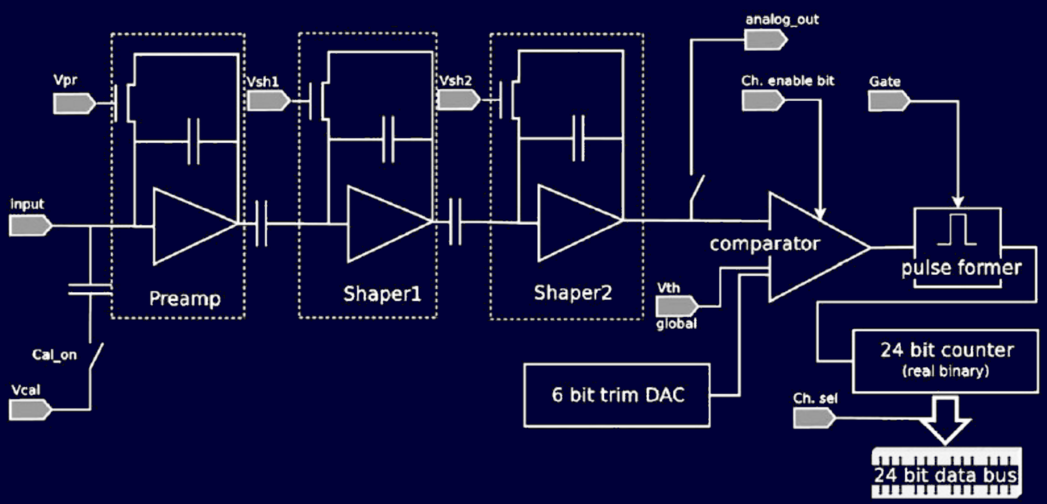
Single Photon counting

- Advantages
  - The quantum nature of the information carried by the photon beam is preserved (only Poisson noise, no quantization error typical of charge integration devices)
  - High (virtually infinite) dynamic range
- Challenges
  - Can we have a uniform response over all channels?
  - Can we have a low noise AND high acquisition speed (~MHz)?
  - Can we have all channels (pixels) counting simultaneously at full rate (when contrast is in the order of 1%)?

Single Photon Counting

- Each strip is bonded to a channel of the read-out electronics. Each channel features:
  - Charge sensitive preamplifier
  - Shaper
  - Discriminator
  - Counter

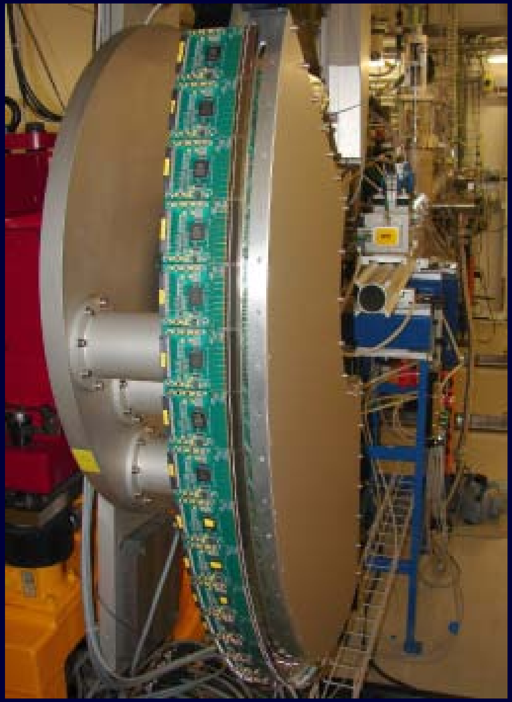




A. Mozzanica et al ,Nuclear Instruments and Methods in Physics Research A 607 (2009) 250–252

PICASSO Single Photon Counting: Mythen-II

- Mythen-II ASIC developed by detector group of the Paul Scherrer Institut (PSI) for photon counting ASIC for powder diffraction studies
- Widely used powder diffraction detectors and other applications
  - SLS, Australian Synch, DESY, Diamond, Spring-8
- Characteristics:
  - 0.25 µm UMC technology
  - 128 channels
  - 50 µm pitch
  - 24-bit counter
  - low noise preamplifier (noise about 230 e-)
  - 6-bit threshold trim DAC to obtain uniform response over all channels
  - Single photon counting at 1 MHz



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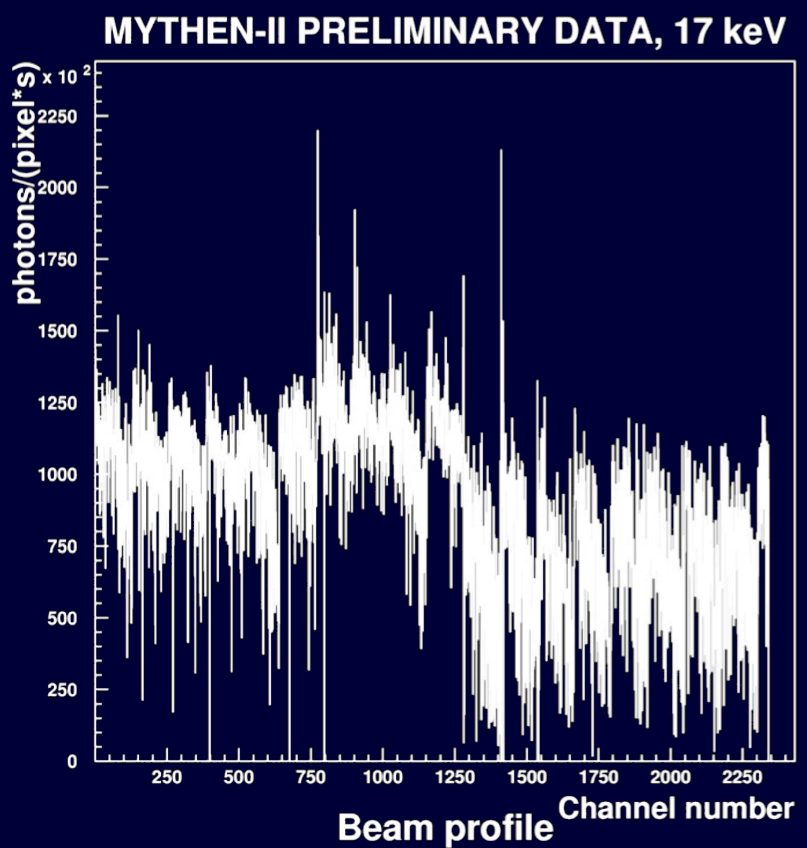
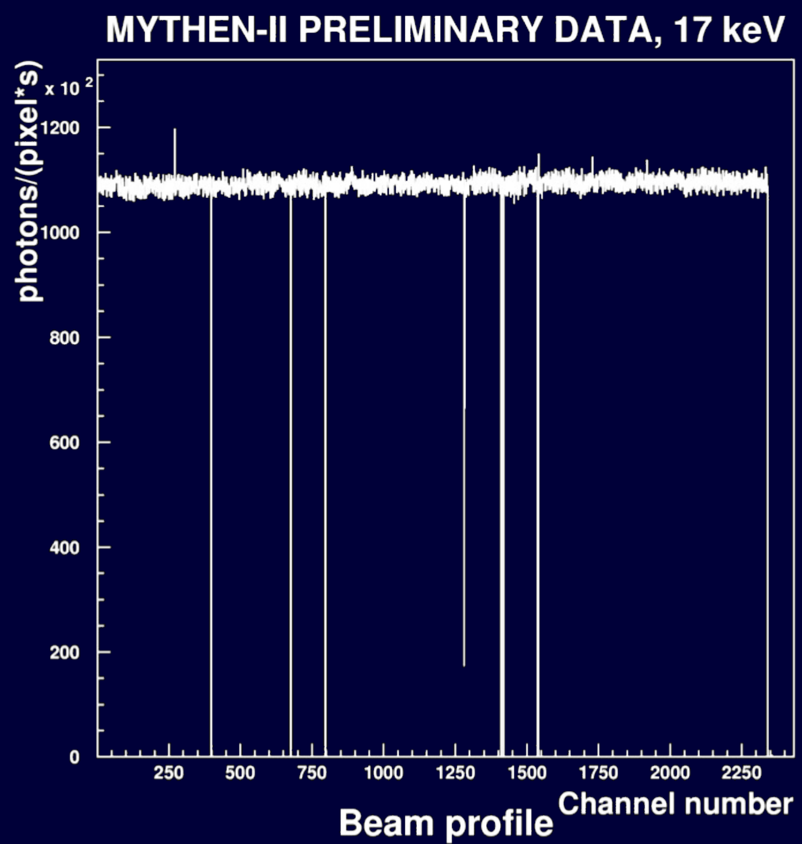
Mozzanica, A. et al., Nucl. Instrum. Meth. A , 2009. 607. 1. 250-252

6-bit threshold trim DAC

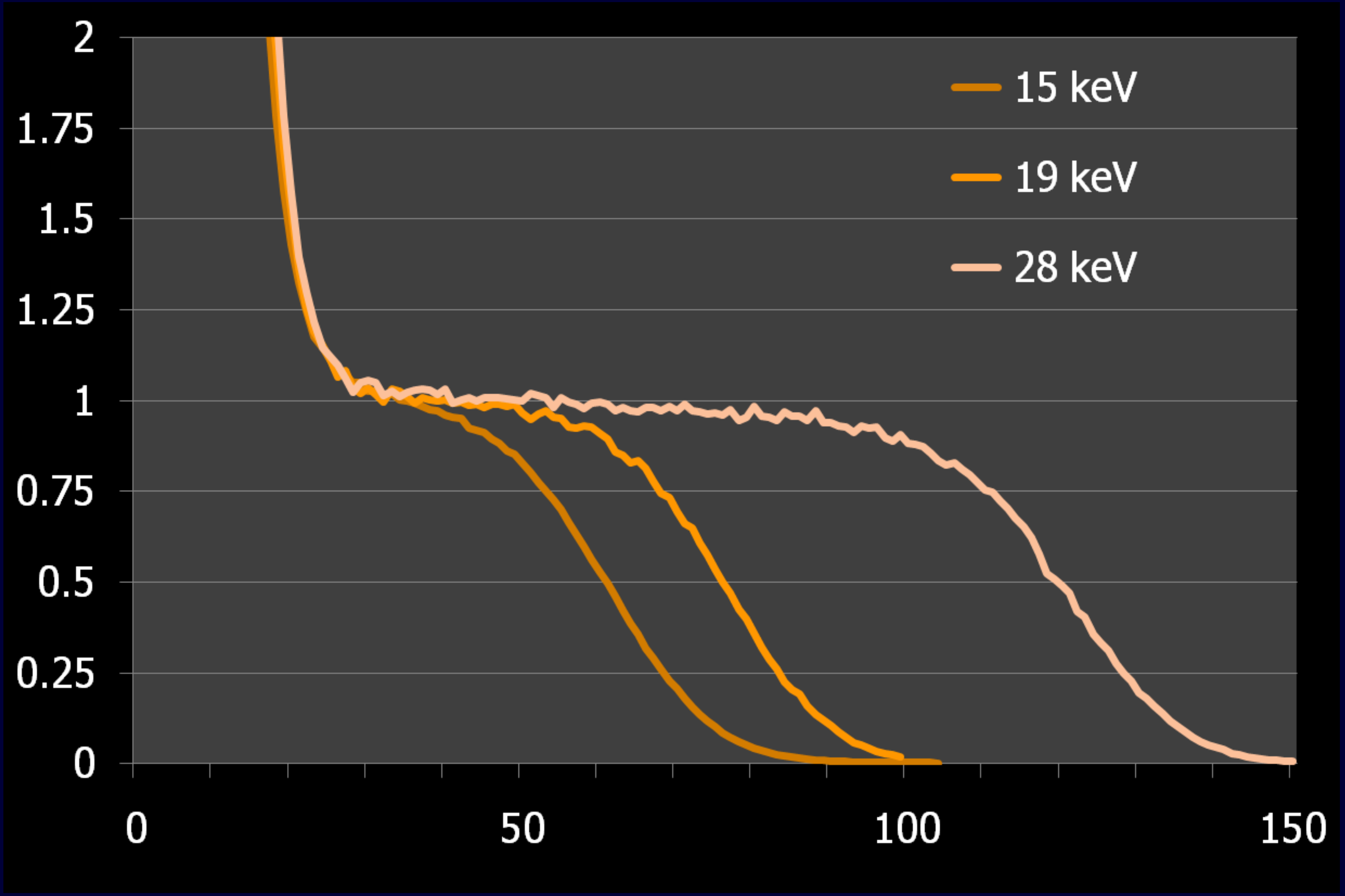
- Equalizing the response of the different channels
  - Without trim DAC
  - With trim DAC





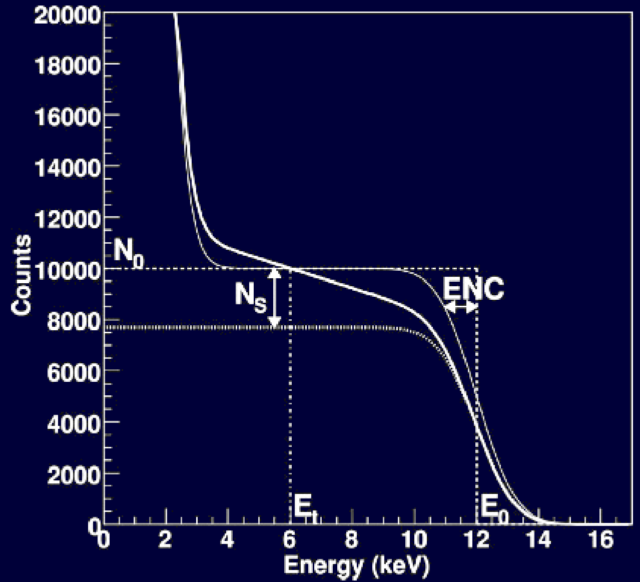
Threshold scan

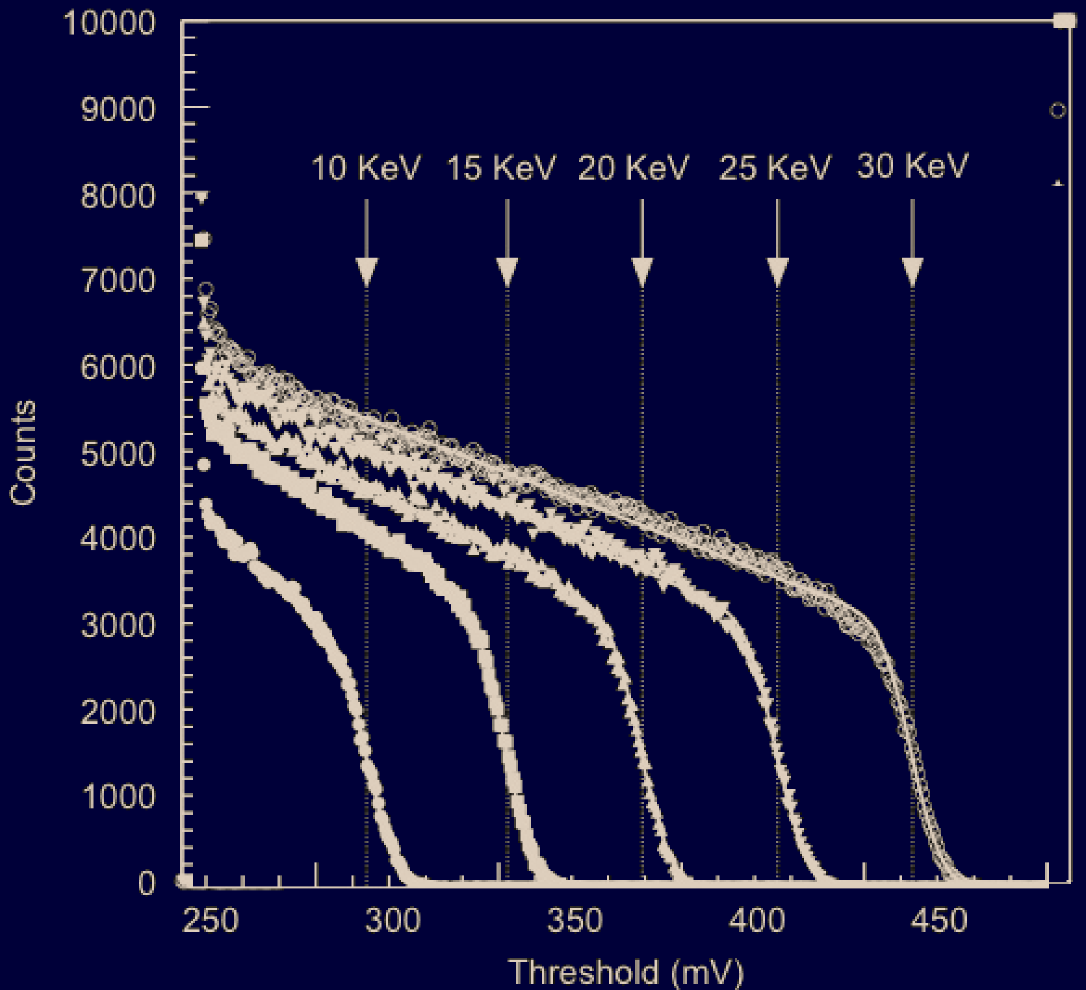
- Pencil beam 10 μm wide to avoid charge sharing effects



*Rigon, L. et al., Nucl. Instrum. Meth. A , **617** (2010) 244-245*

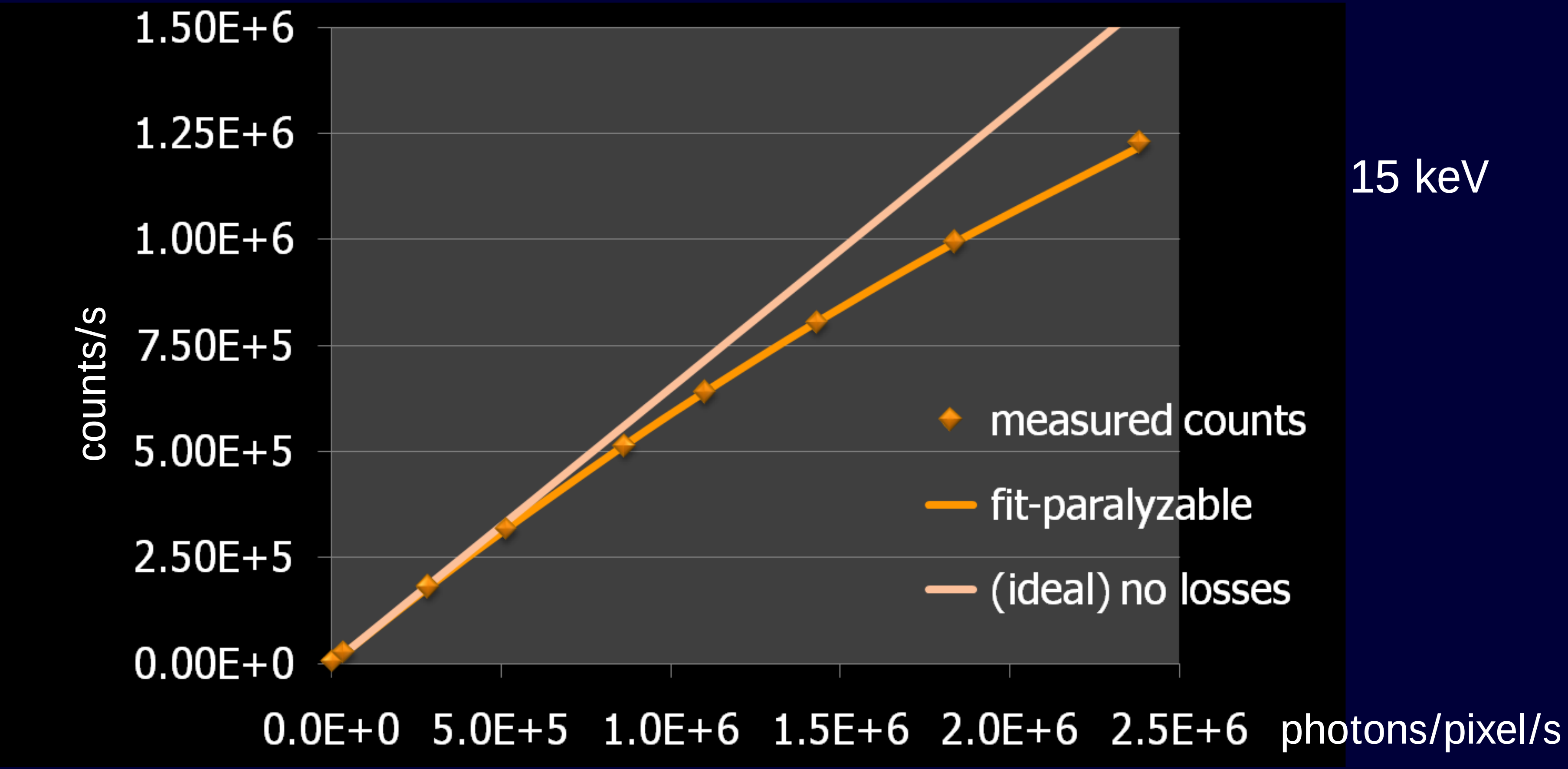
Charge sharing





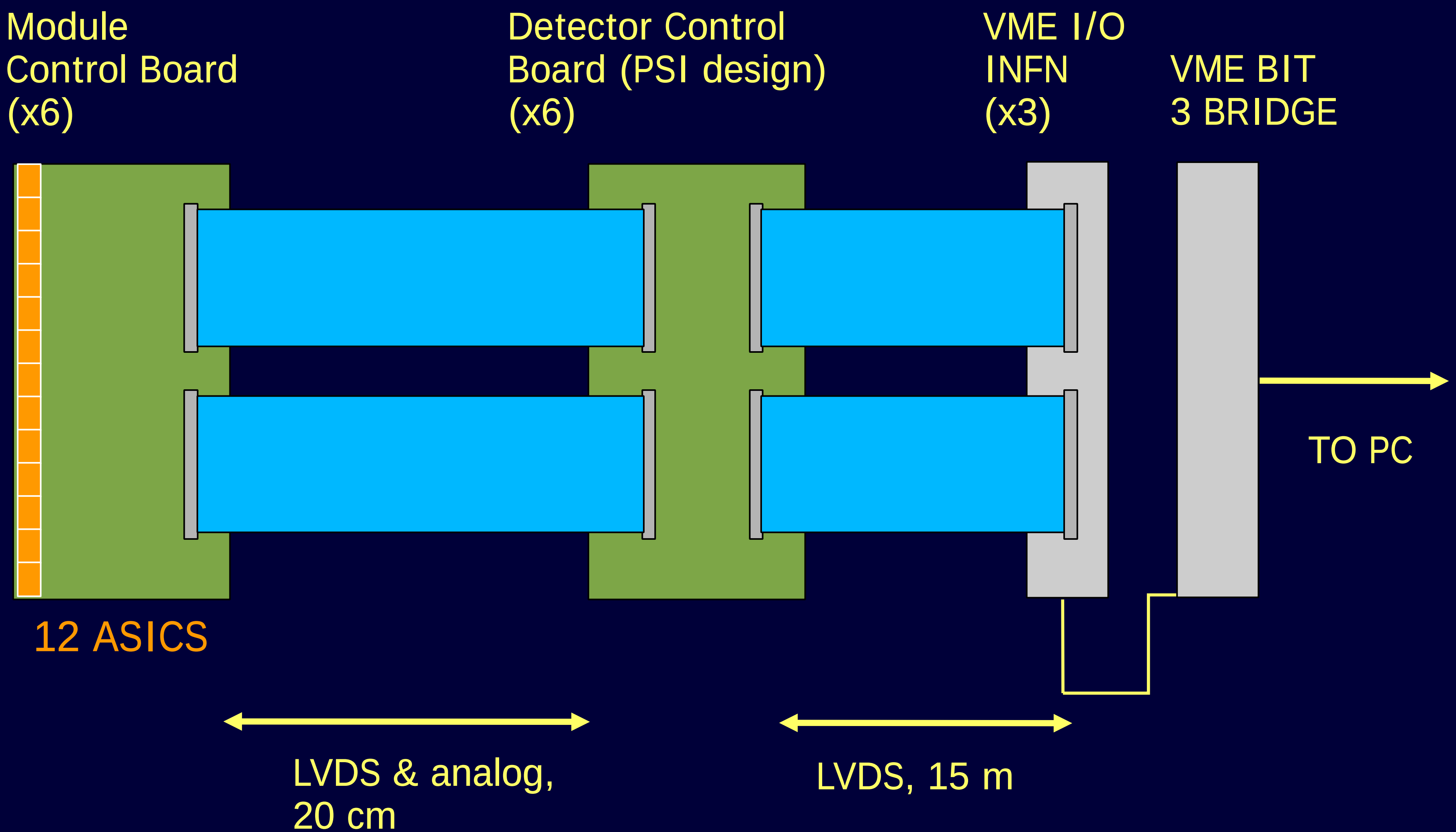
Mozzanica, A. et al., Nucl. Instrum. Meth. A , 2009. 607. 1. 250-252
A.Bergamaschi et al, J. of Synchrotron Rad., , 2010, 17, 653-668

PICASSO Counting Rate Capabilities



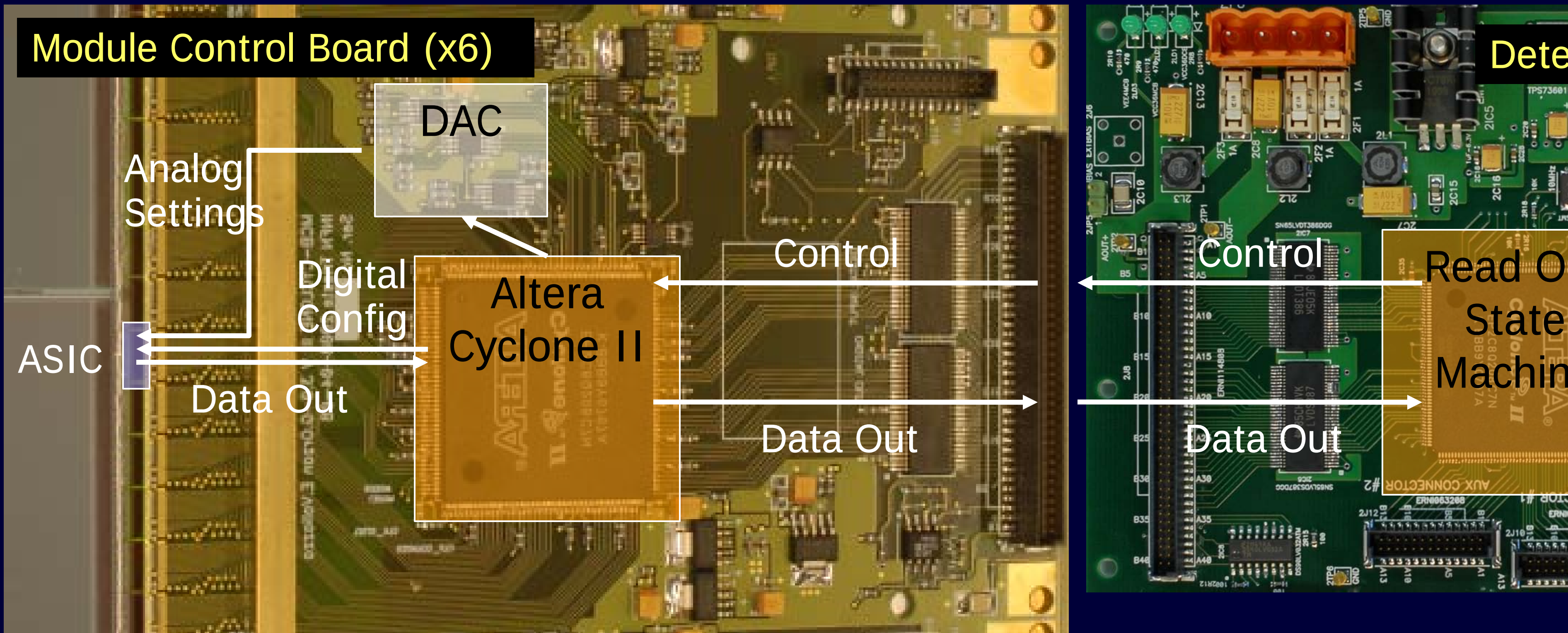
- Compatible with a paralyzable model with
  - Efficiency 65.1 % (compatible with ~ 200 µm dead zone)
  - Dead Time 0.16 µs
- Almost negligible losses (< 10%) up to 1.2 MHz

Read-out Electronics



Vallazza, E. et al. Proceedings of 10th ICATPP Conference, 700-705 World Scientific Publishing Co.

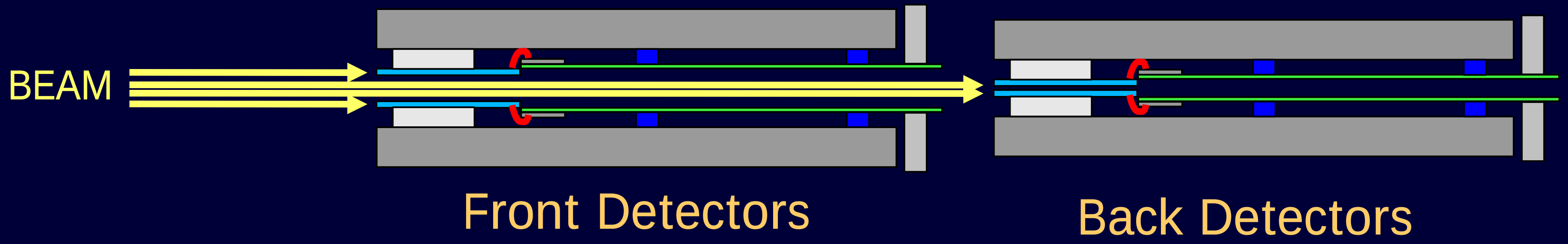
Read-out Electronics (II)



- Designed an improved version of the VME I/O with local memory board to buffer the frames during the scan

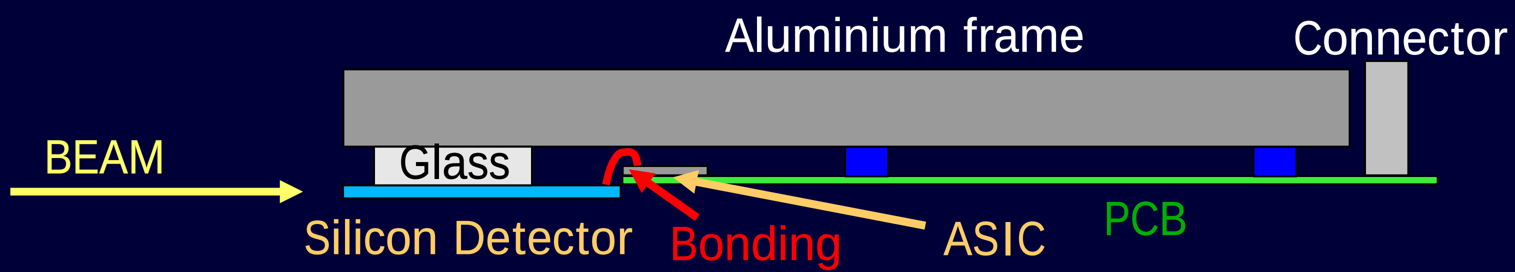
The PICASSO detector assembly

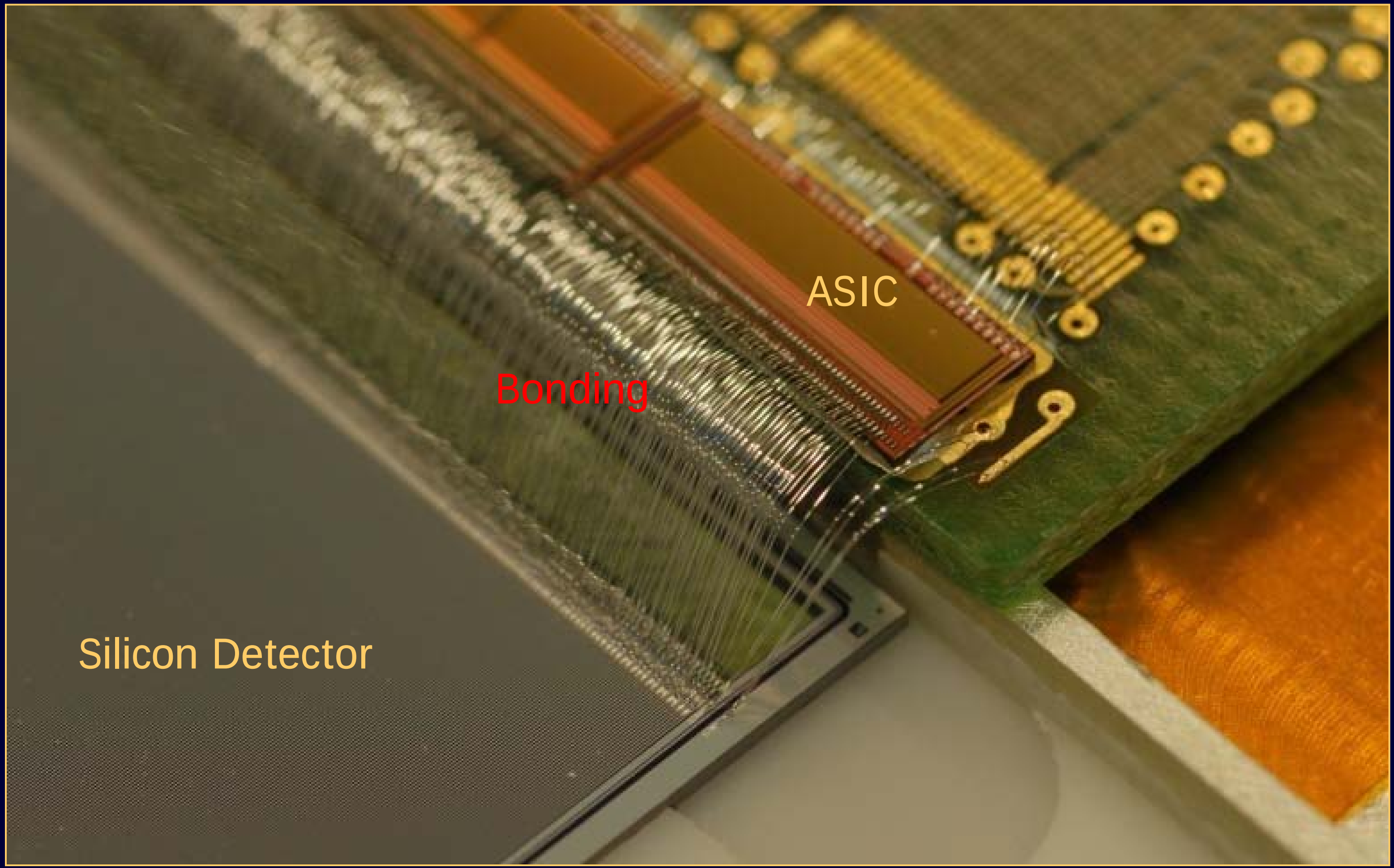
- A 4-layer detector to successfully exploit the beam size
- Tight requirements
  - coverage of the beam width (210 mm)
  - silicon detector planarity about 10-20 µm
  - very small spacing between layers
- Our solution
  - modular design
  - displacement of the modules along the beam propagation direction



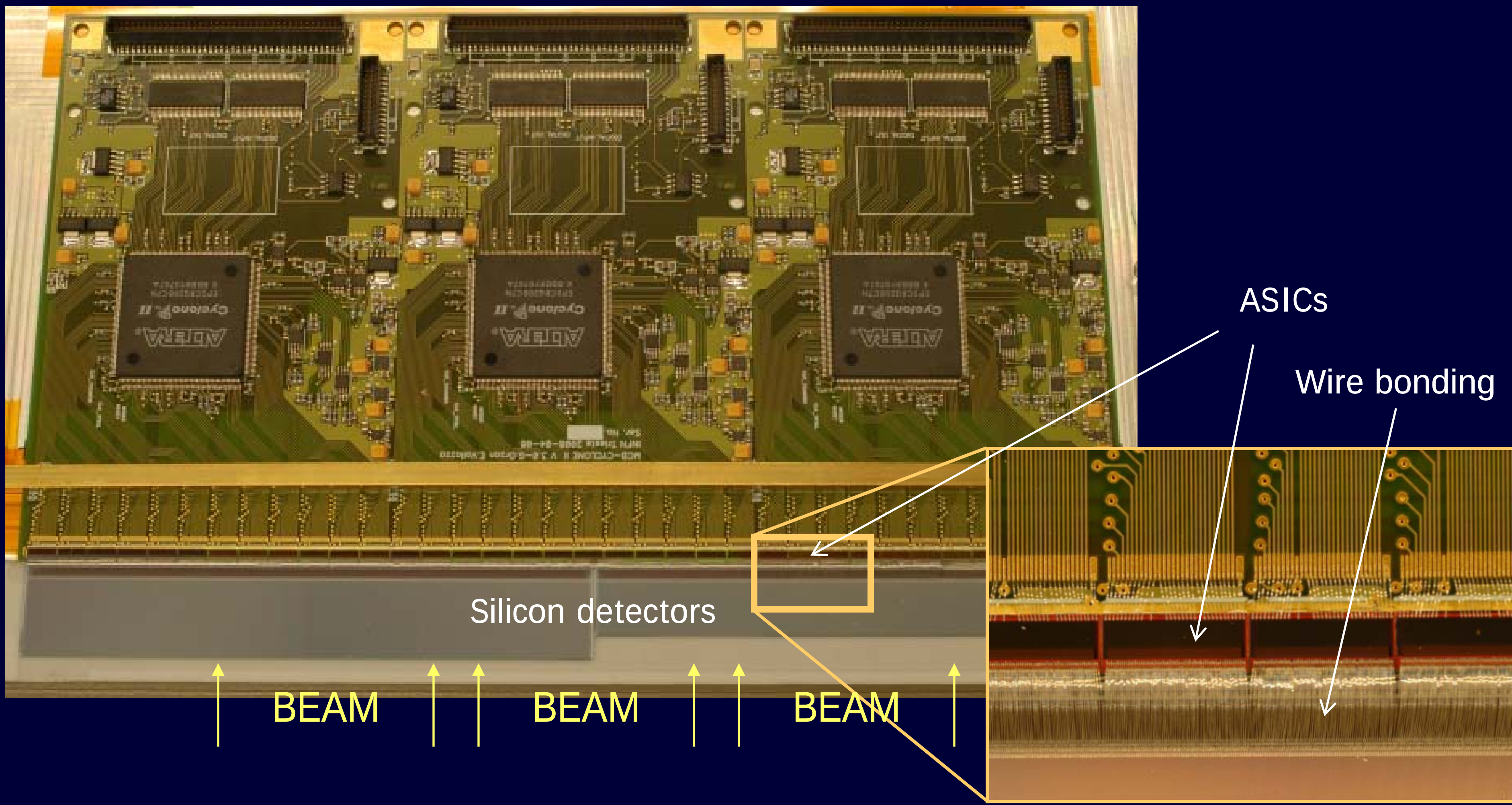
Vallazza, E. et al. Proceedings of 10th ICATPP Conference, 700-705 World Scientific Publishing Co.
Rigon, L. et al. IEEE Nuclear Science Symposium Conference, 2008, 1536

Modular design



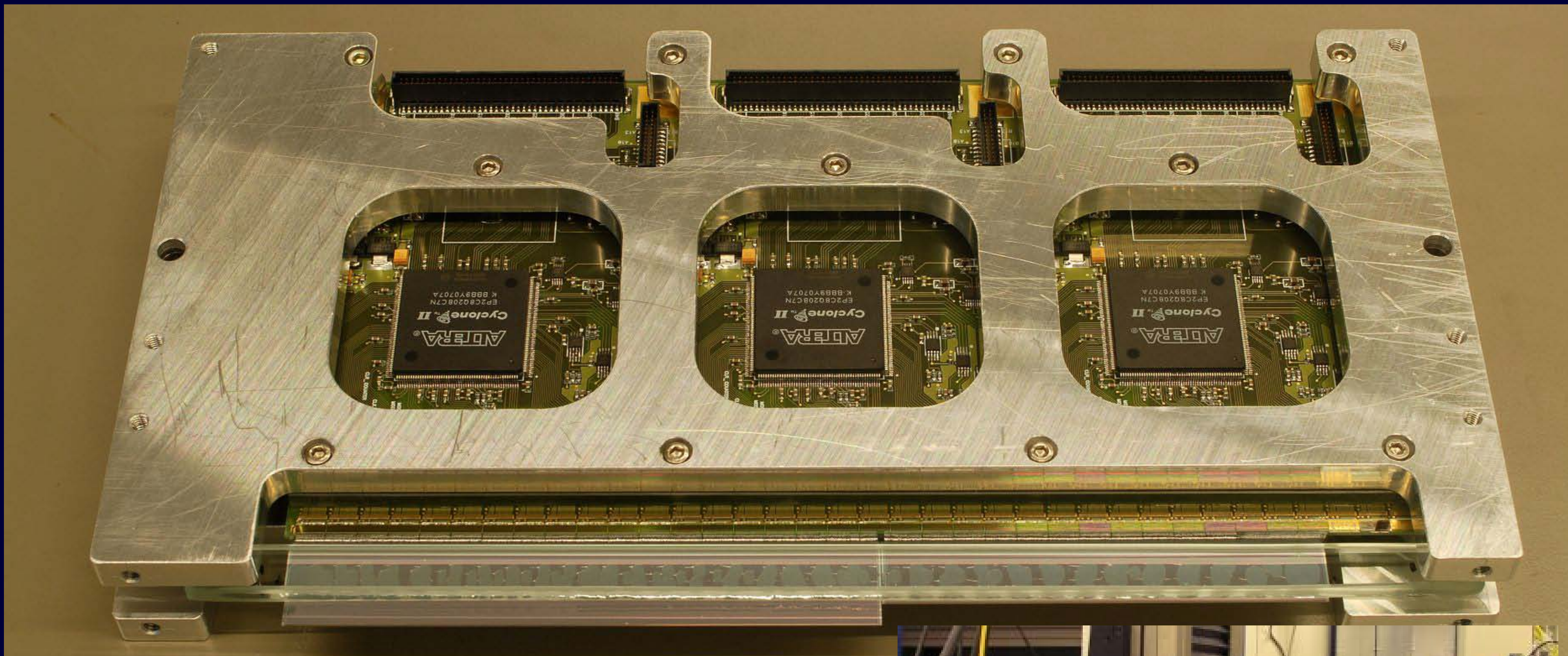


Single layer full size prototype

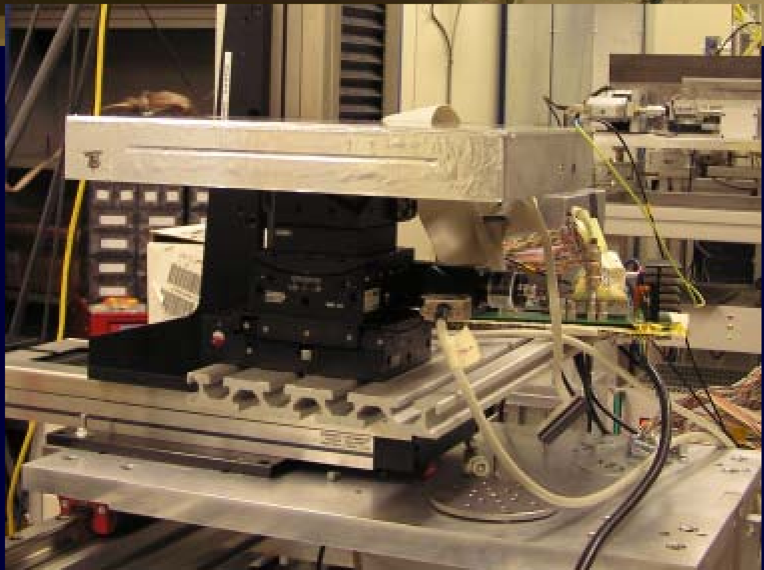


- Single layer 210 mm silicon detector
  - Use of two modules (120 mm+90 mm), 33 ASICs (4224 channels)
  - PCB hosts 3 Altera Cyclone-II FPGA for ASIC control
  - Assembled and bonded at Mipot SpA (Cormons, Italy)

Double layer prototype

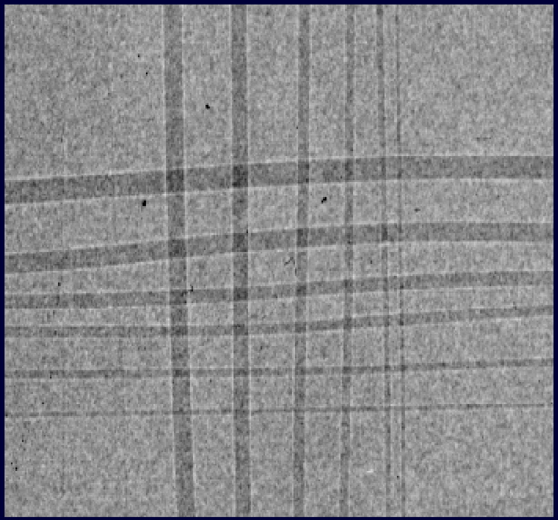


- Double layer 210 mm silicon detector
  - Detectors glued to the glass bar and fixed in the aluminum frame
  - Assembly system developed by the mechanical workshop of INFN
  - Tested at the SYRMEP beamline

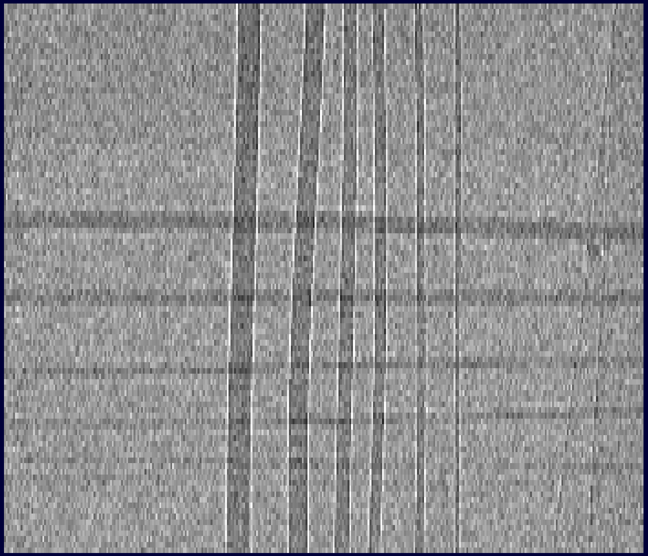


Wire Phantom

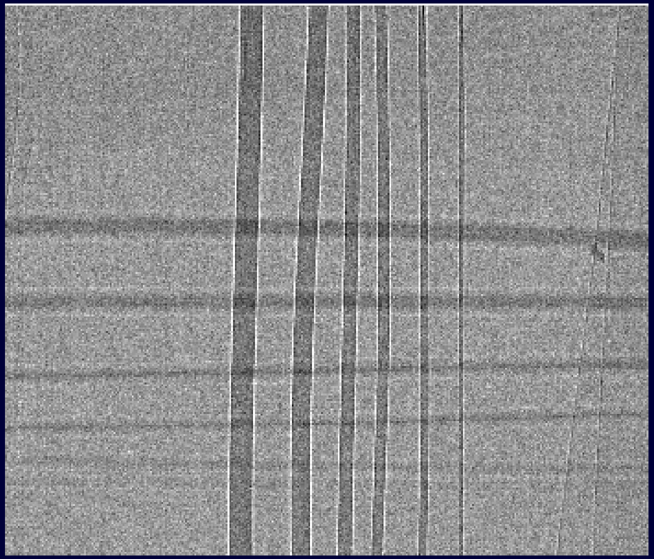
- Wire Phantom + 3cm thick Lucite slab, 17 keV



Film-screen system
Air dose 1.5 mGy



PICASSO
150 µm scan step
Air dose 0.9 mGy

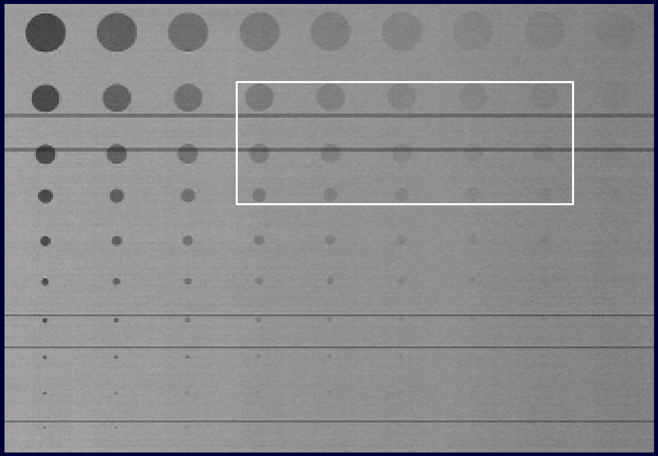


PICASSO
50 µm scan step
Air dose 2.53 mGy

Experimental results: CD Phantom detail

Gammex RMI 180
Constrast Detail (CD) Phantom

19 keV
Scanning step 100 µm
0.015 s per step



Air Entrance dose
8.1 mGy

Contrast
[%]

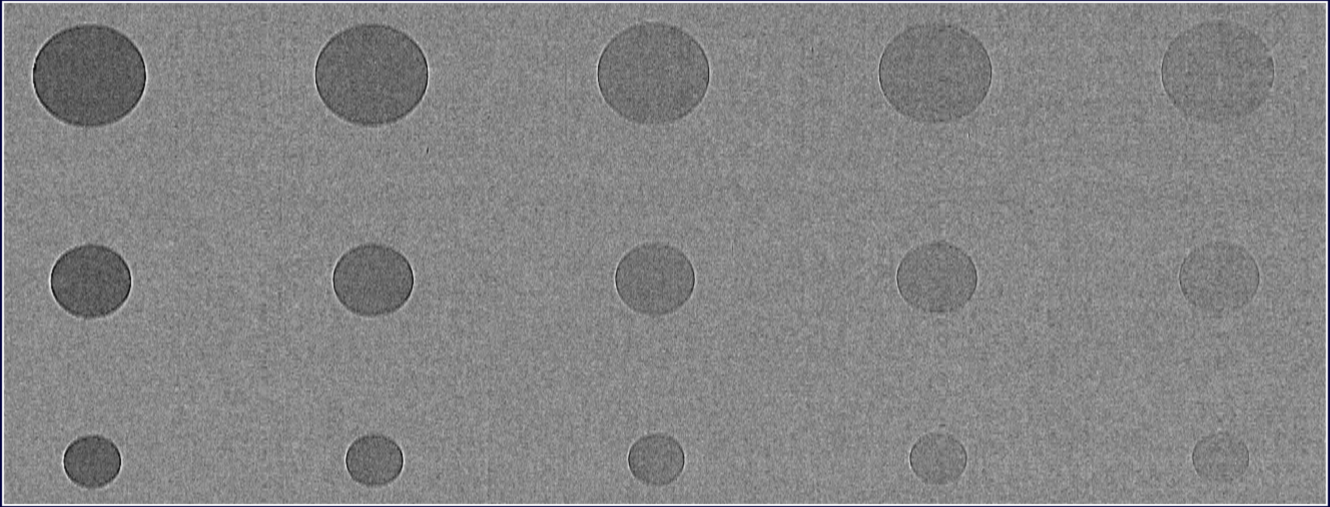
2.50 1.77 1.26 0.89 0.63

Diameter
[mm]

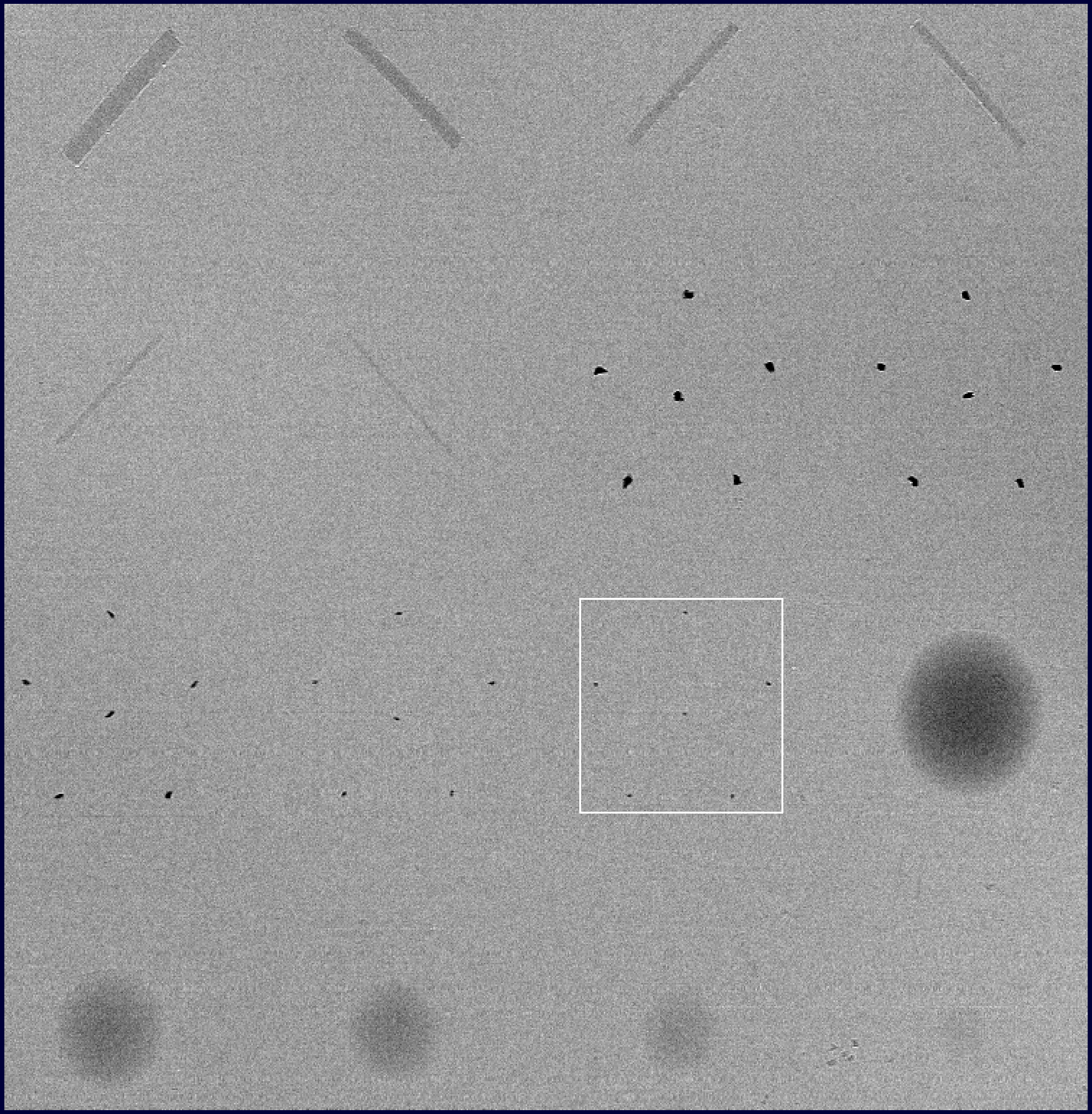
5.00

3.54

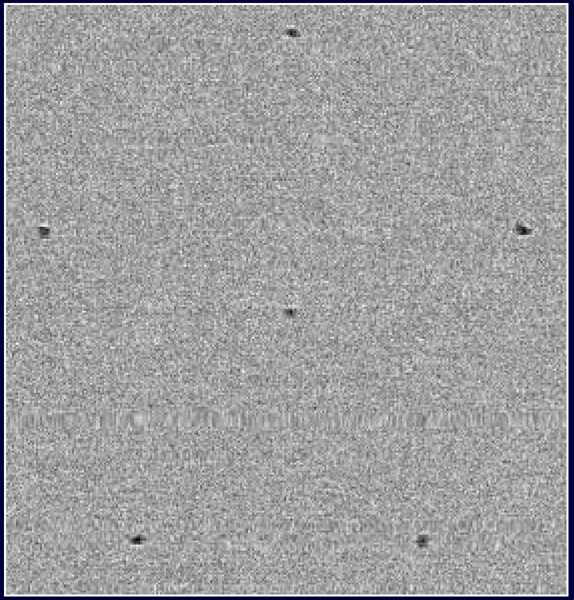
2.50



ACR (American College of Radiology) Phantom



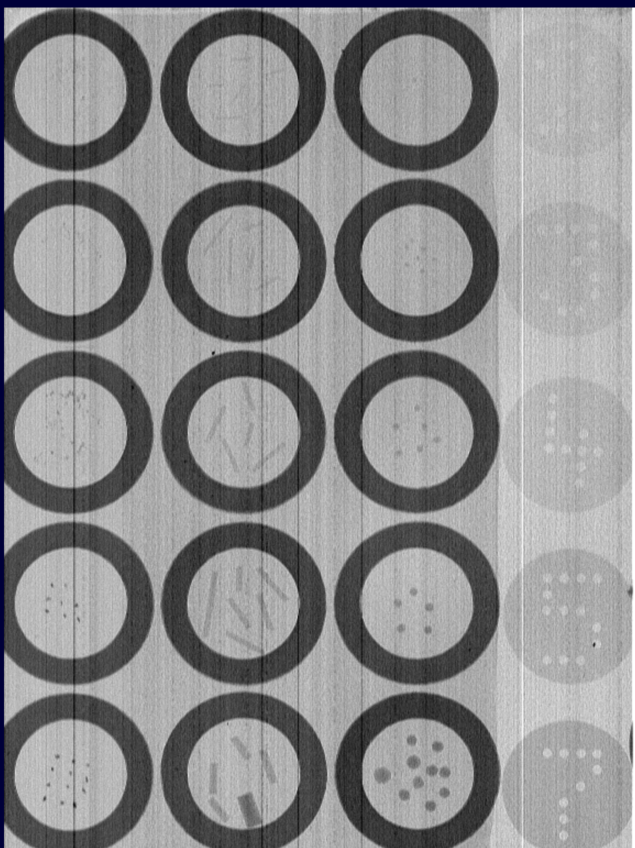
19 keV
Scanning step
50 µm
0.2 s per step
Air Entrance dose
8.5 mGy



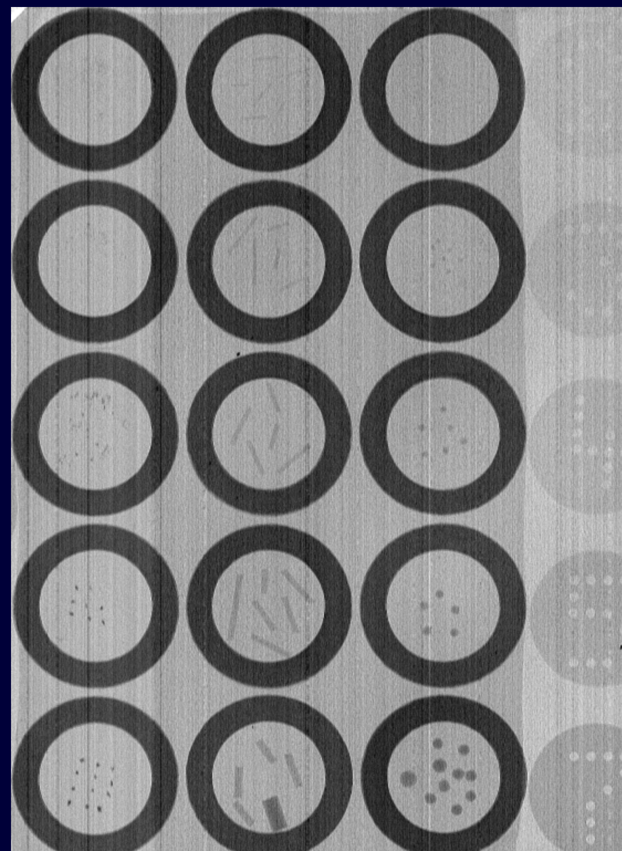
Rigon, L. et al. Nucl. Instrum. Meth. A 2009, 608. 1. S62-S65

Gammex RMI 160 “Ackermann” Phantom detail

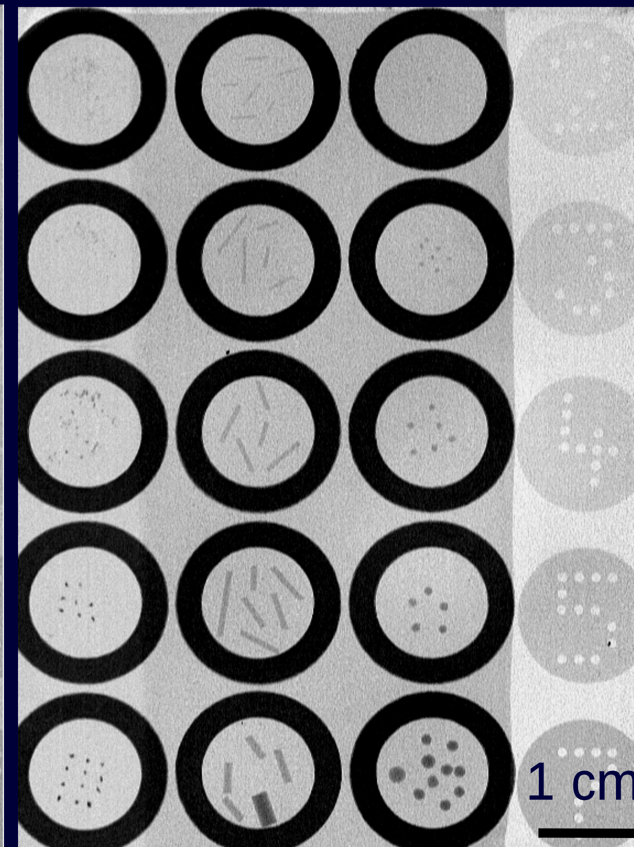
- Phantom + 30 mm Plexiglas acquired at 19.5 keV
  - Scanning step 100 µm, 0.100 s per step
  - Air Entrance dose 1.75 mGy



Top layer
Raw image



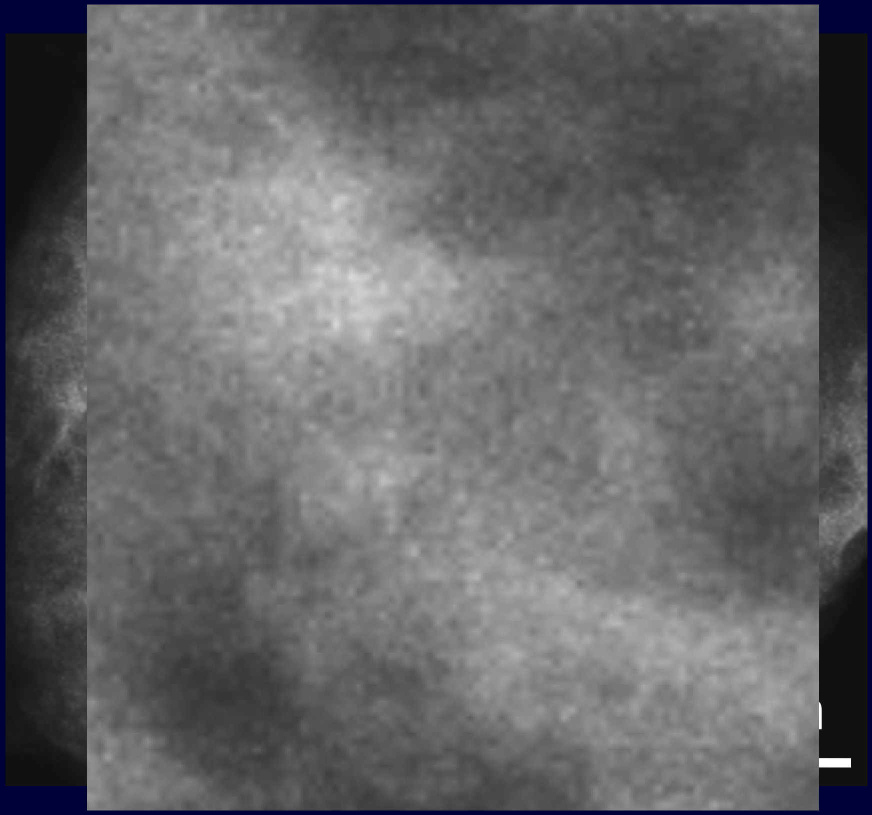
Bottom layer
Raw image



Summed and normalized image

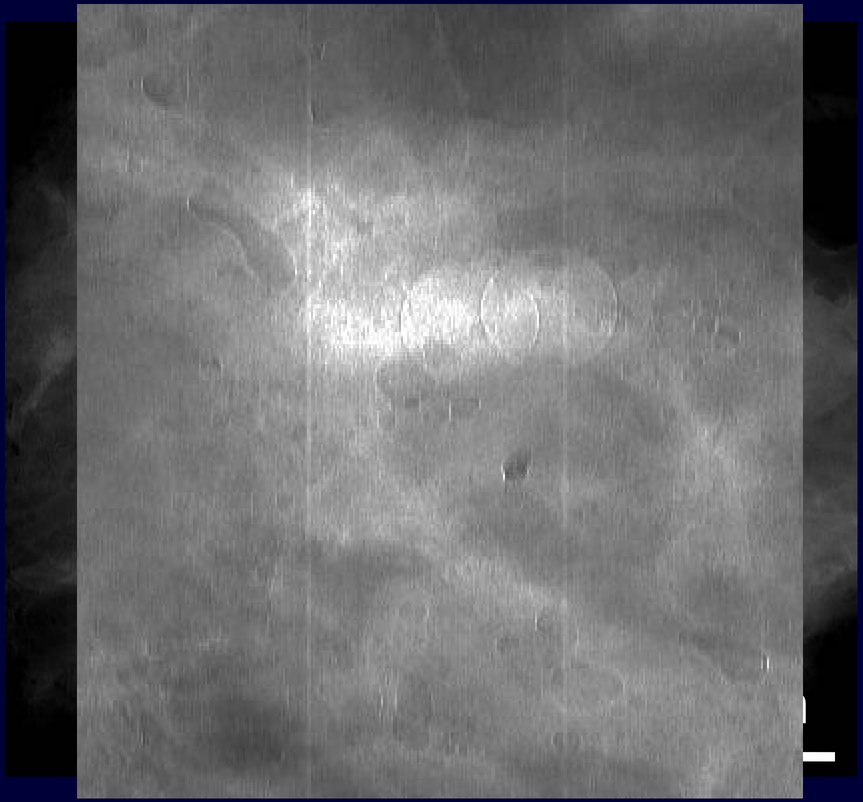
In vitro breast tumor tissue

Agfa Image Plate mammographic system



Ro/Ro Anode/Filter
7 mAs, 28 kVp
Air entrance dose ~ 0.6 mGy

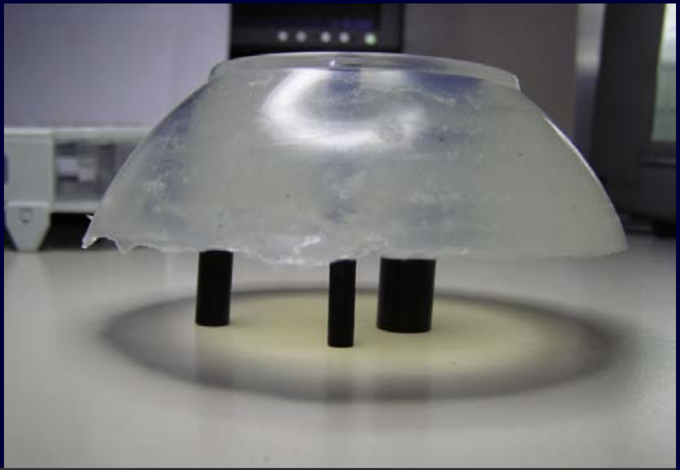
PICASSO single layer detector

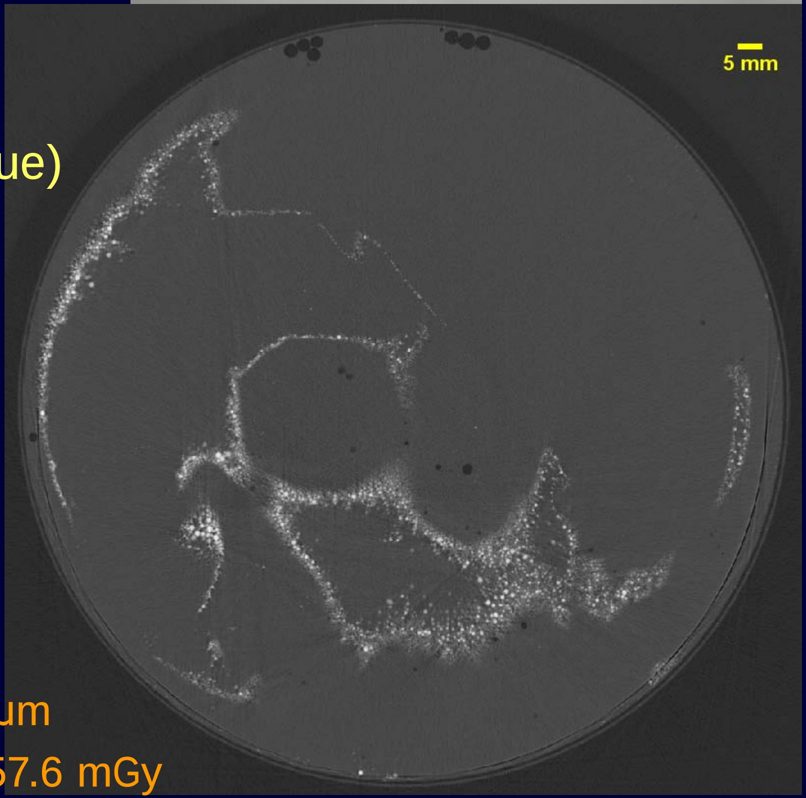


Energy 23 keV
Scanning step 200 µm
Exposure time 80 ms/step
Air entrance dose ~ 0.4 mGy

Custom-made PhC-Tomography Breast Phantom

- Shape: to mimic uncompressed breast
  - Diameter: 8-12 cm
- Composition
  - Glycerol
    (same attenuation as glandular tissue)
  - 3 Delrin rods
    (same attenuation as breast-tumor tissue)
  - Quartz microspheres
    (diameter 100-800 µm)
    to mimic microcalcifications





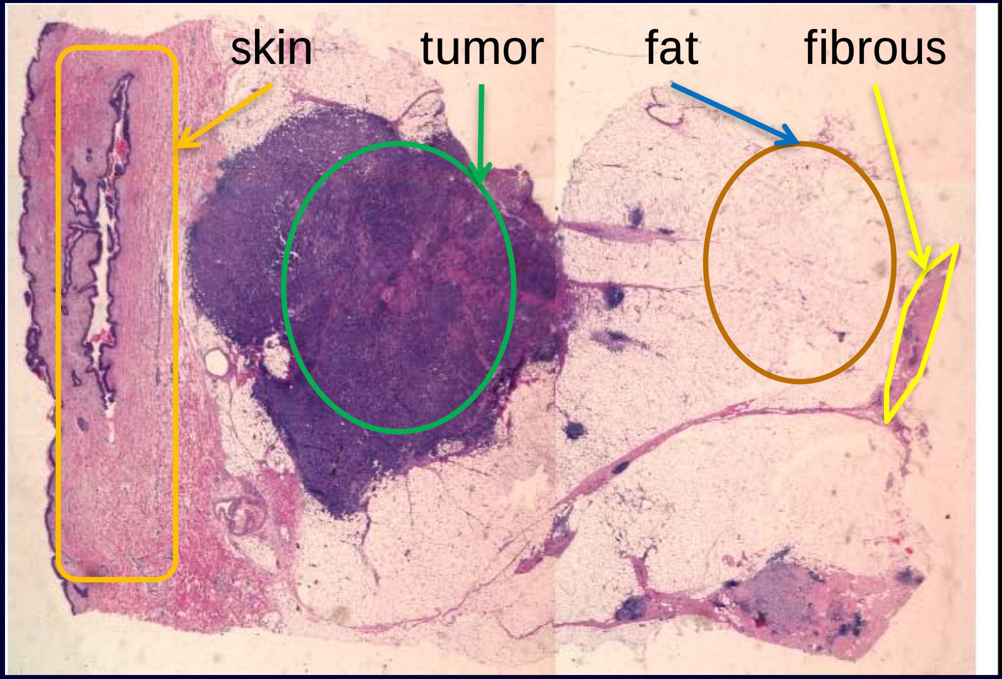
90 projections

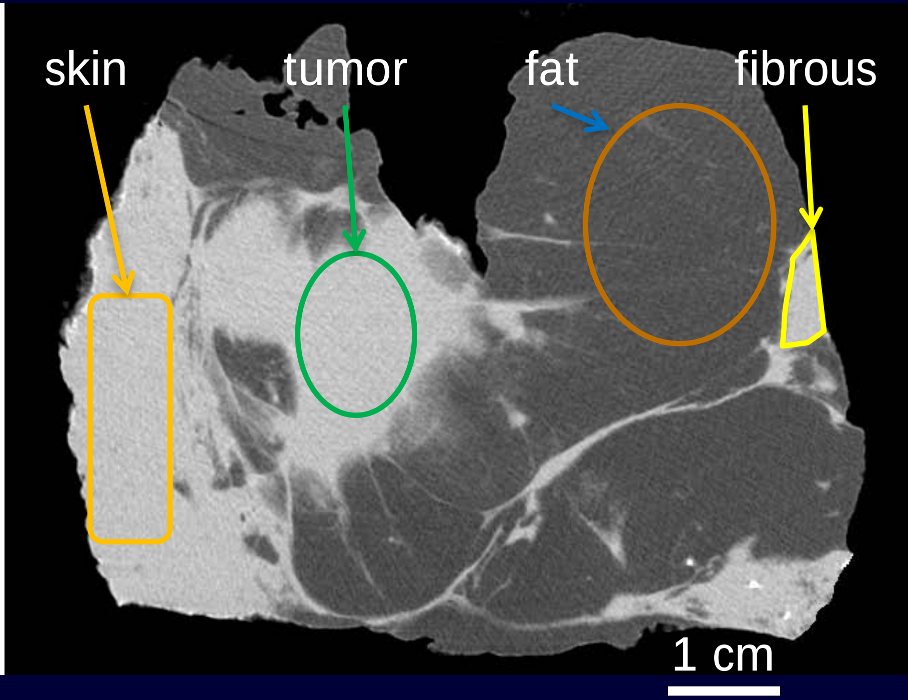
Pixel aperture: 100 µm

Air entrance Dose: 57.6 mGy

Breast Tissue Tomography

- Characterization and accurate measure of linear attenuation coefficient of breast tissue
  - Slice reconstructed from 2400 projections on 180° (angular step 0.075°)
  - Energy 23 keV
  - Exposure time 1s per projection
  - High dose





Chen, R. C. et al. Phys. Med. Biol., 55 (2010) 4993- 5005

Concluding Remarks

- The SYRMEP group is operating a beamline dedicated to *in-vivo* mammography at ELETTRA . In the first clinical project using a conventional screen-film system.

- The PICASSO collaboration has developed a silicon microstrip detector. Phantom and *in-vitro* studies have shown:
  - High efficiency
  - Remarkable spatial and contrast resolution
  - Single photon counting capability up to ~1 MHz
  - Excellent uniformity over ~ 2 x 4200 channels counting simultaneously

- Future Work
  - Construction of the 4 layer detector
  - Implementation of the new TCP-IP based read-out electronics
  - Integrating the PICASSO system on the patient beamline

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