PICASSO
A Detector for Phase-Contrast Mammography with Synchrotron Radiation

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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
  - Geometrical characteristics
  - Single photon counting capabilities
  - Imaging results: planar and tomographic imaging
- Conclusions

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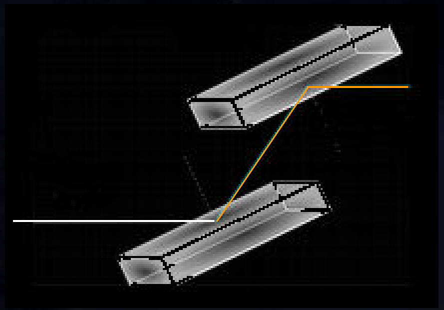
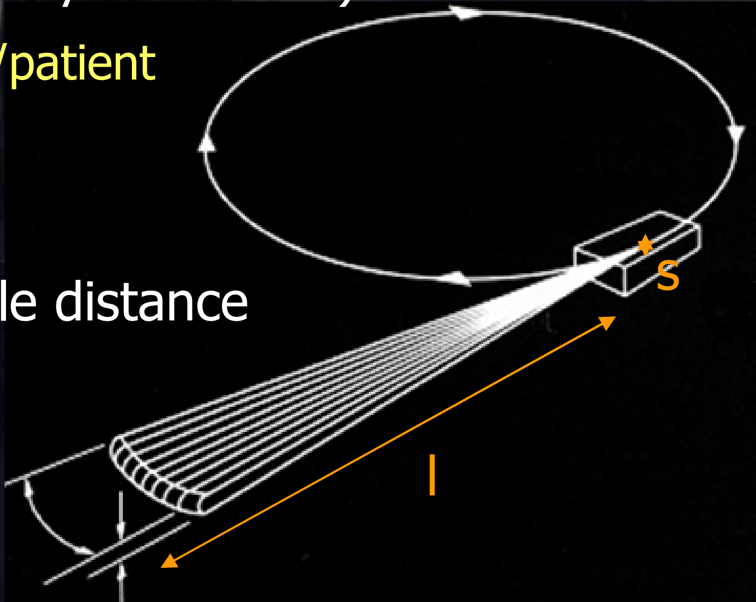
Characteristics of synchrotron radiation (SR)

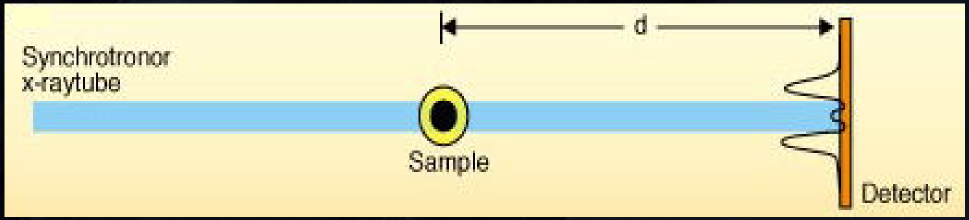


- High x-ray intensity on a broad energy range
  - Tunable monochromatic beam
    - Choose the optimum energy for a specific examination
    - Dose optimization/reduction
    - No beam hardening effects (in tomography)
- Laminar beam geometry (the beam is naturally collimated)
  - Images are acquired 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



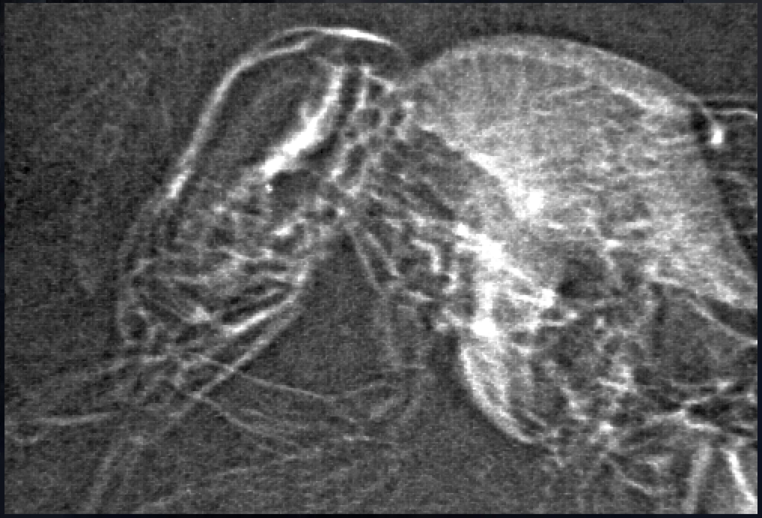
Phase Contrast (PhC)

- Phase effects → Modulation of X-ray intensity on the detector
- PhC is the simplest way
  - In line propagation
  - Edge enhancement $(\nabla^2\Phi(x,y))$



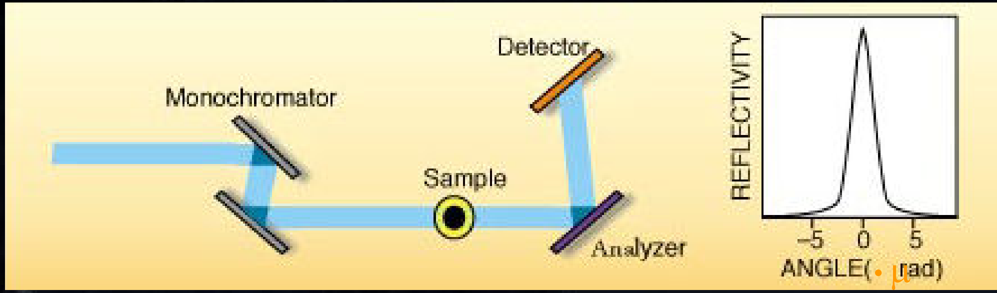
- Example:

absorption

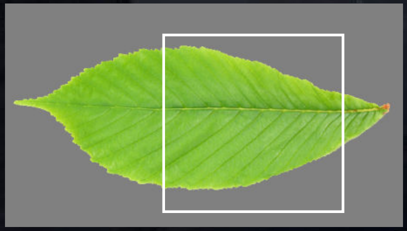


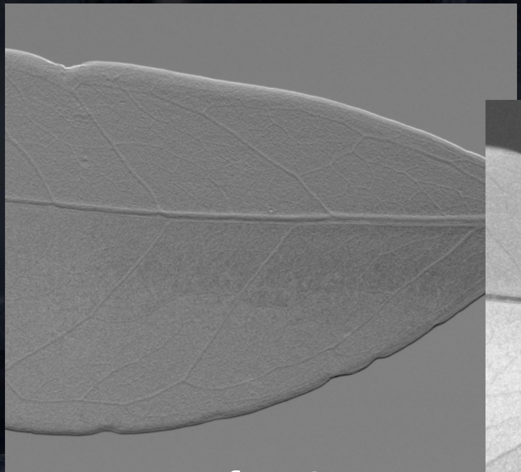
phase contrast

Diffraction Enhanced Imaging

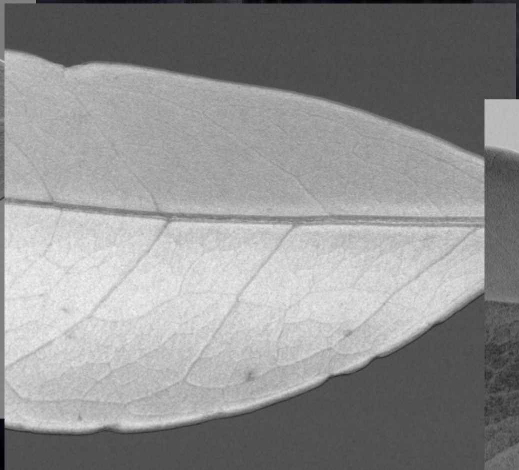


- A.k.a. Analyzer-based Imaging
  - Edge enhancement ($\nabla\Phi(x,y)$)
  - Can give images based on different physical effects
- Example:





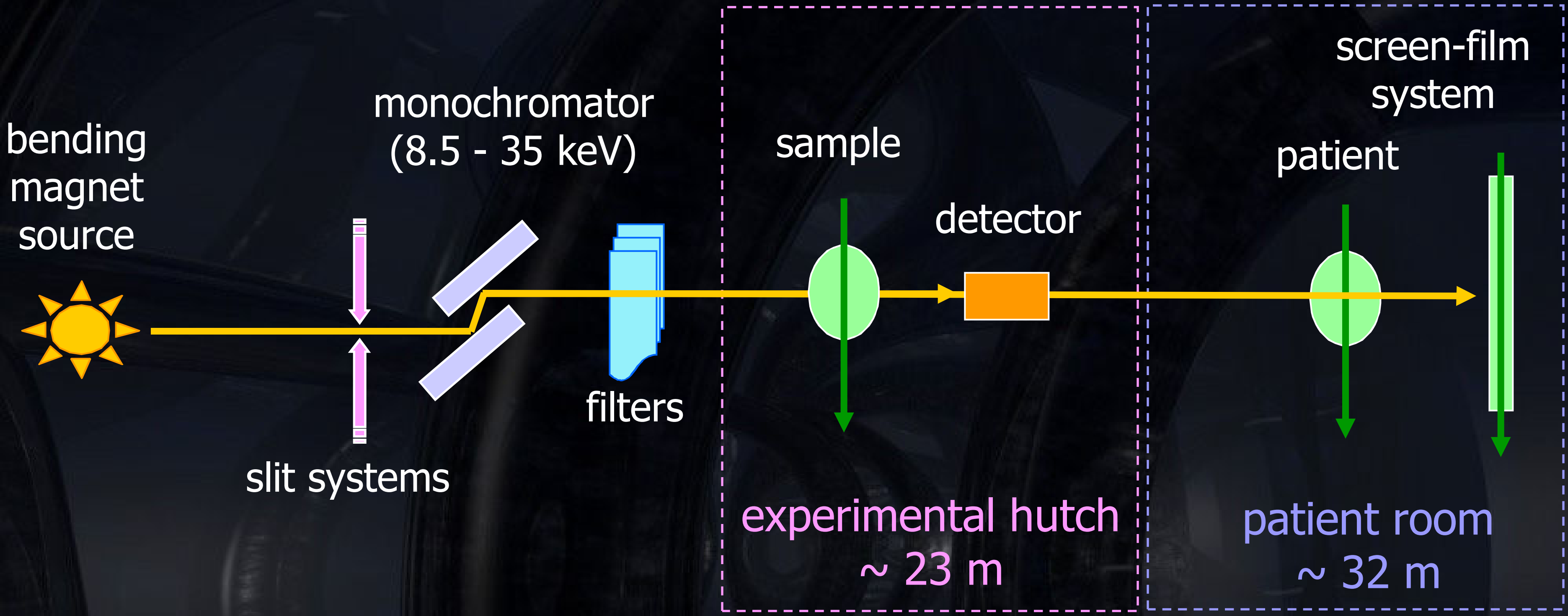
refraction



ultra-small angle scattering

absorption and extinction

The SYRMEP beamline (I)

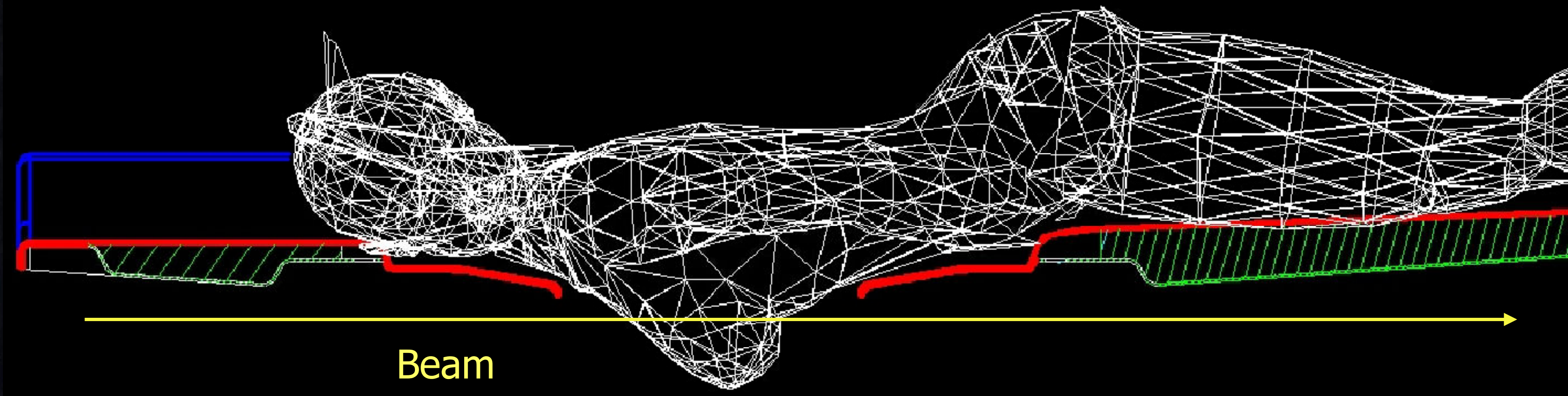


- Source size ~ 1.1 (horizontal) x 0.1 (vertical) mm^2
- Divergence: ~ 7 mrad (horizontal) x 0.2 mrad (vertical)
- Laminar beam cross section: 4 x 150 mm^2 4 x 210 mm^2
- Flux available at 17 keV (Elettra operated at 2.4 GeV, 140 mA ring current):

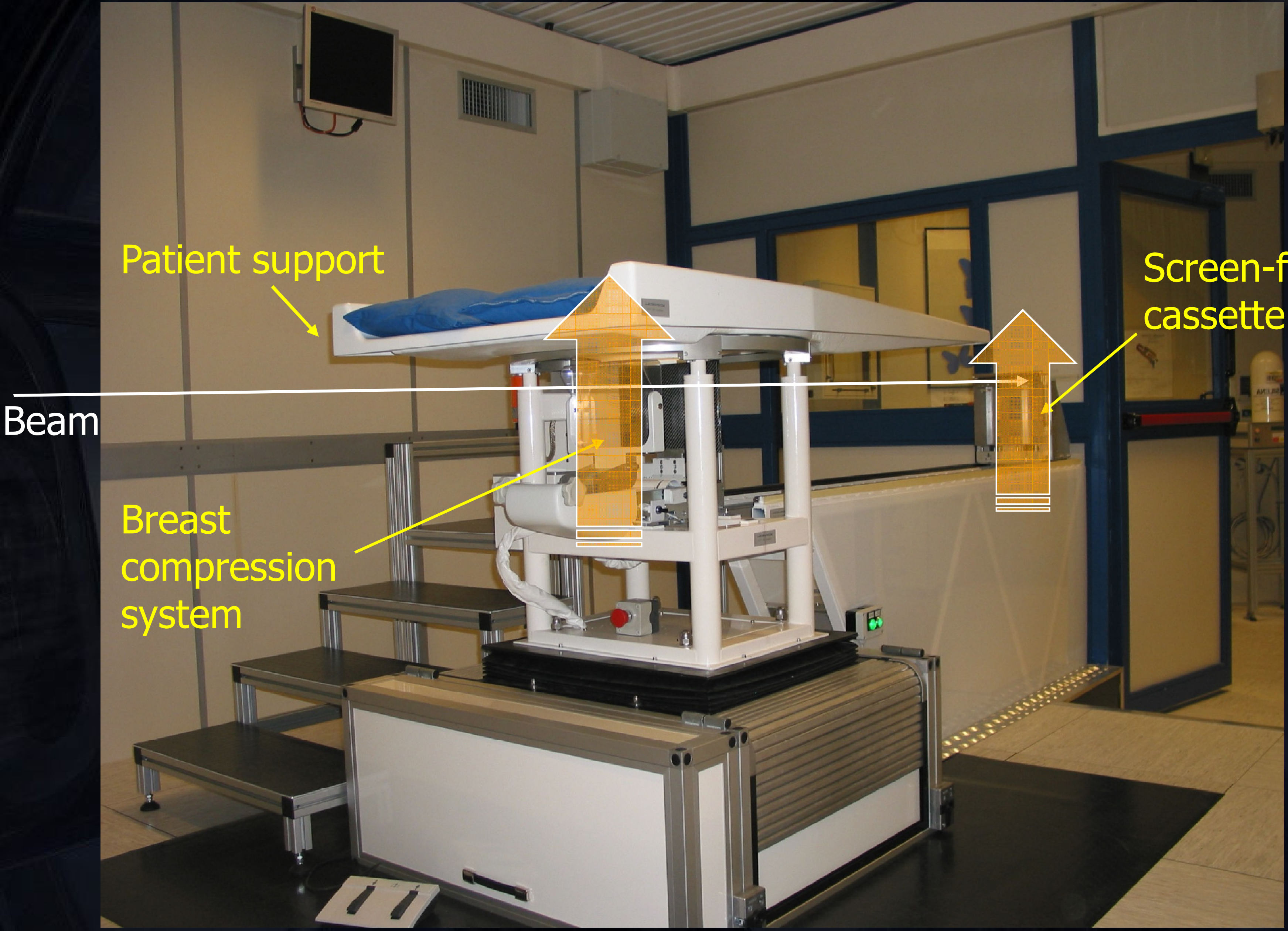
  $6\ 10^8$ ph/mm^2/s $2\ 10^8$ ph/mm^2/s

Patient support

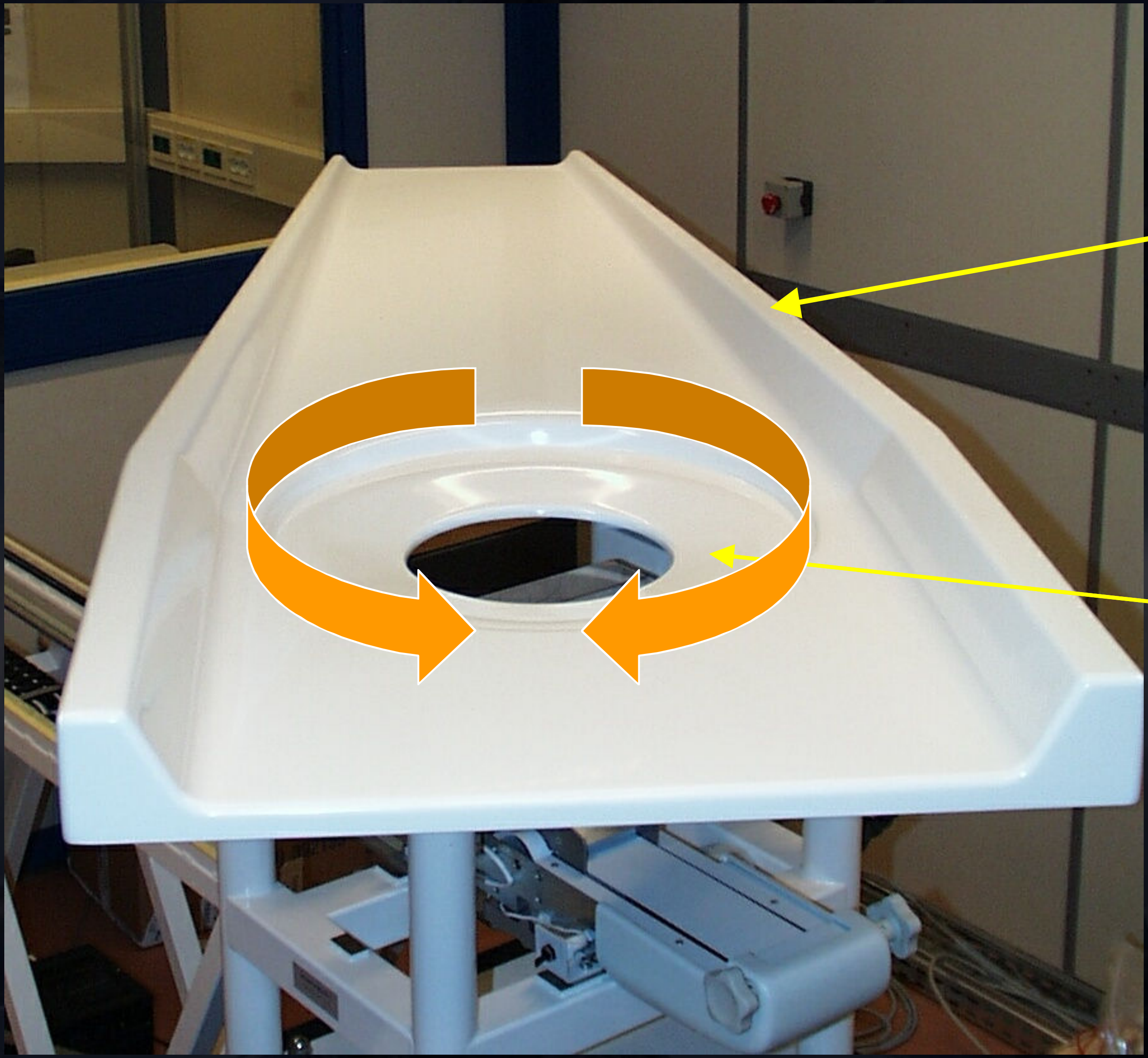
- Prone position as used in stereotactic biopsy tables
  - Full Field Digital Biopsy system Giotto Image (IMS, Bologna, Italy)
- Size and shape of the opening are consistent with the chest anatomy
  - Good patient comfort



Patient room



Patient support (II)



Carbon fiber support

26 cm Ø

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)

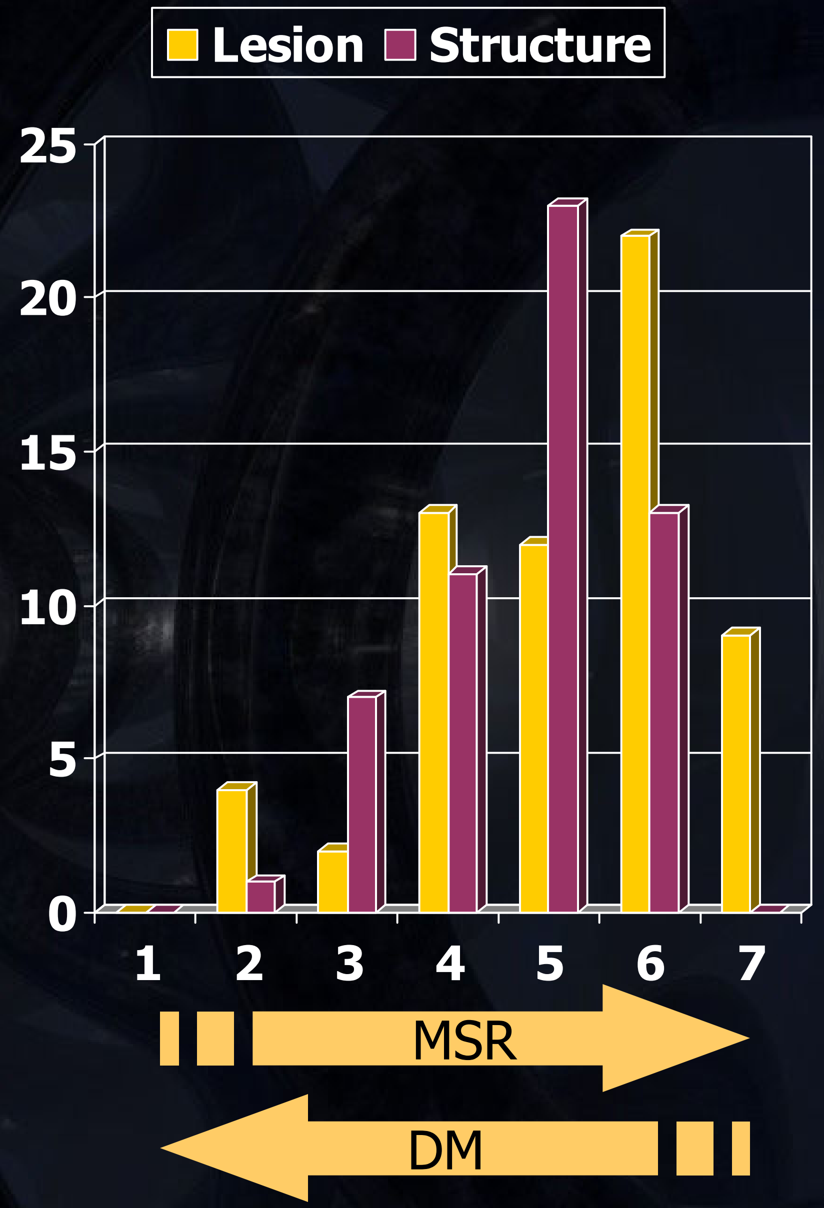
MSR: Clinical Program Preliminary Results (I)

- Data from the first 49 patients have been considered
- A comparison with conventional mammography is performed
  - The conventional system is a state-of-the-art Digital Mammography (DM) GE Senographe DS
  - An expert Radiologist compared MSR and DM images and evaluated them in terms of
    - Visibility of the lesion
    - Visibility of the glandular structure relevant to the diagnosis
  - In both cases the score ranged in a scale from 1 to 7, where
    - 7 excellent visualization with MSR and poor visualization with DM
    - 4 equal visualization for both modalities
    - 1 excellent visualization with DM and poor visualization with MSR

Castelli, E. et al. manuscript in preparation

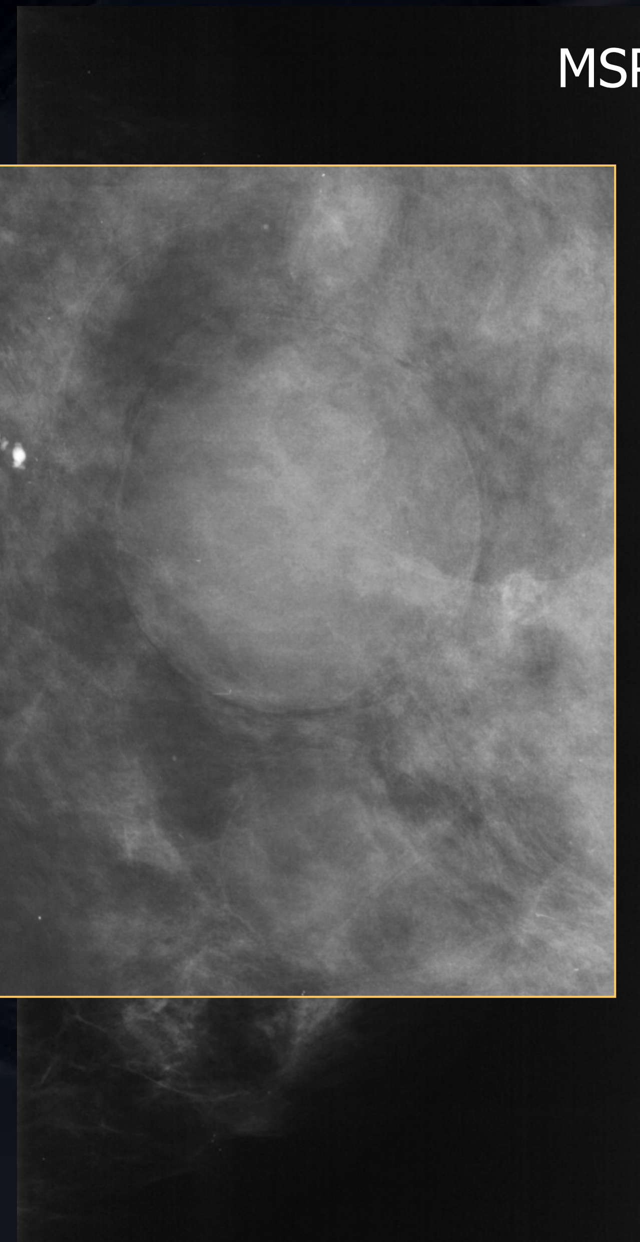
MSR: Clinical Program Preliminary Results (II)

- The histogram shows that MSR allows a better visualization, both for the lesions and for the glandular structure
- A Wilcoxon signed rank test rejects the null hypothesis of equal visualization
  - *P < 0.00001*
    both or lesions and for glandular structure



Castelli, E. et al. manuscript in preparation

Conventional (DM) Vs Synchrotron (MSR)



Dreossi, D. et al., Eur. J. Radiol. 68 S58 (2008)

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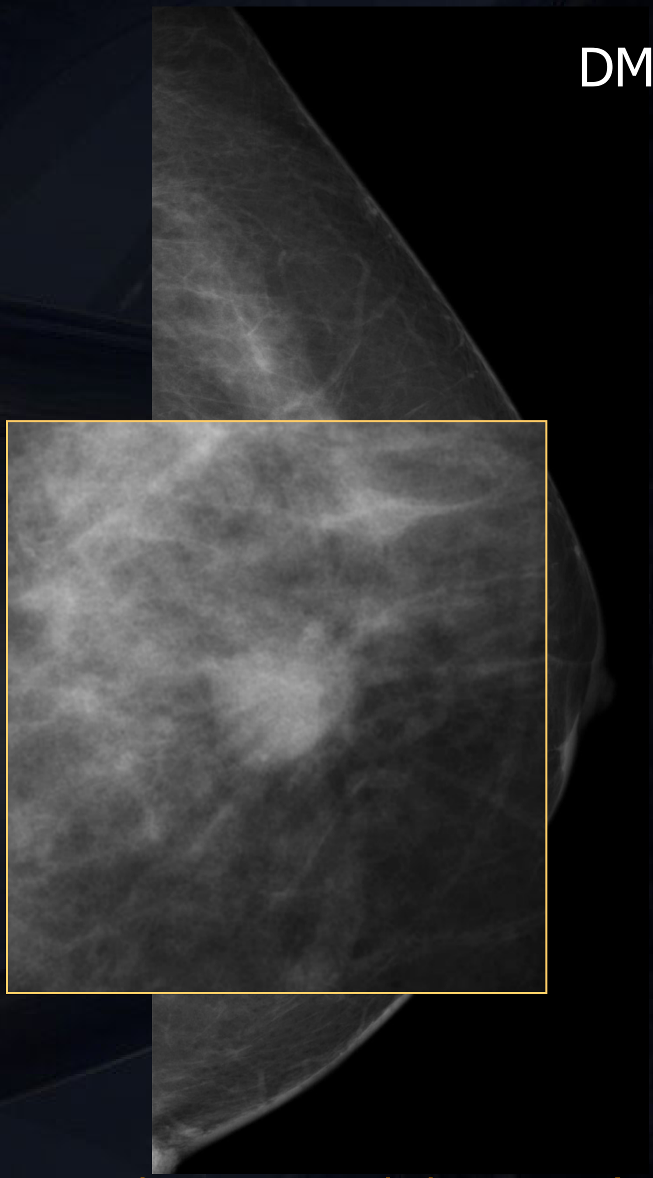

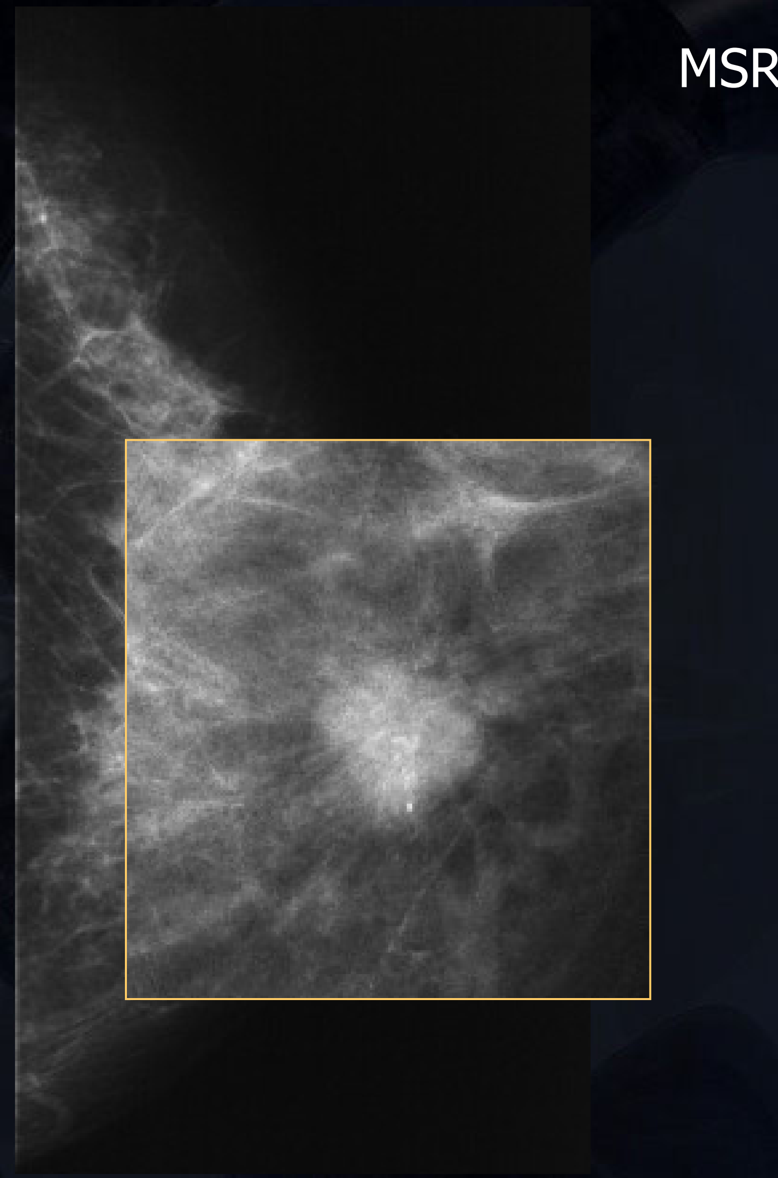

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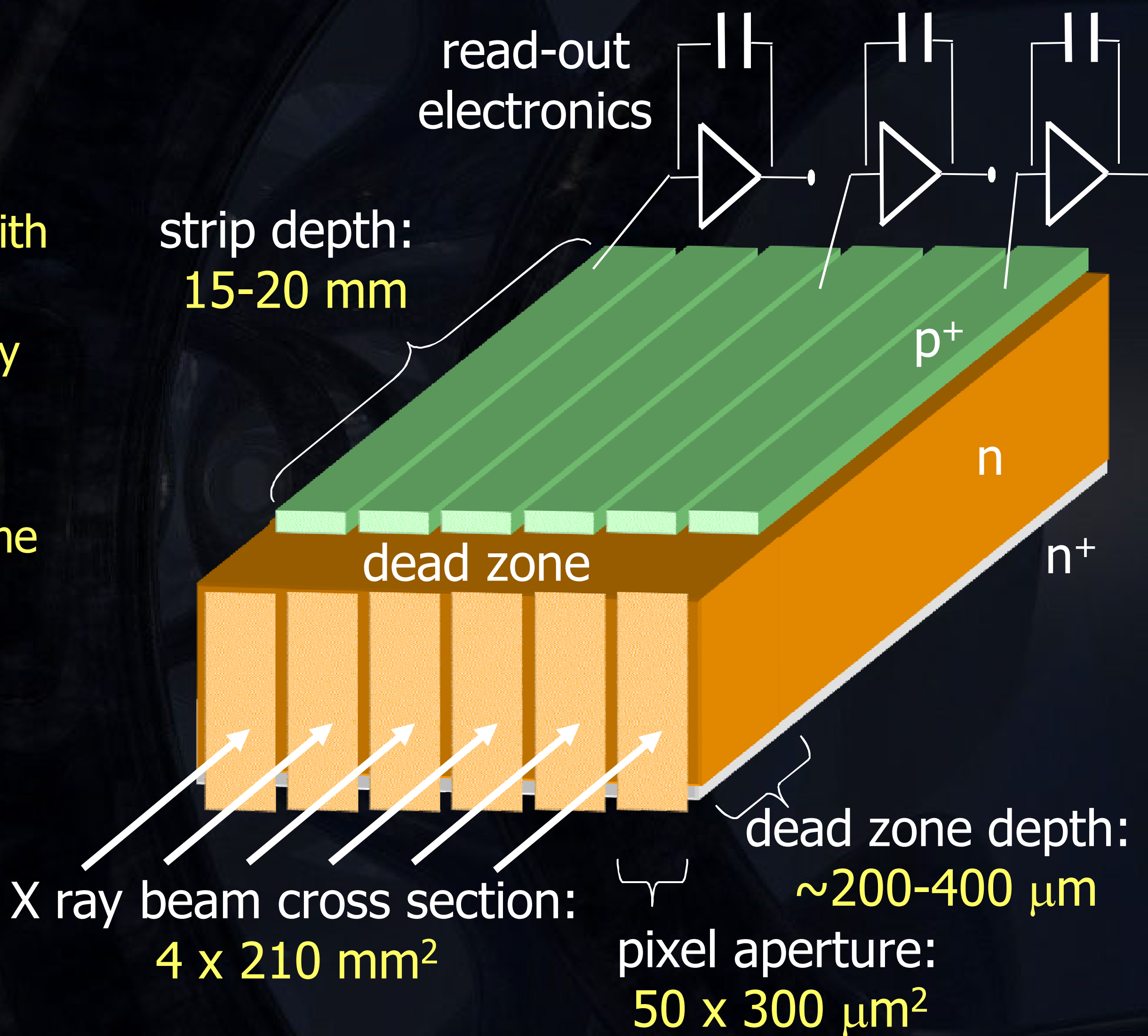
PICASSO Digital Detector Requirements

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

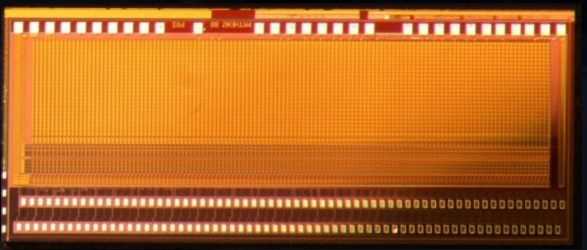
The silicon micro-strip detector: "edge-on" geometry

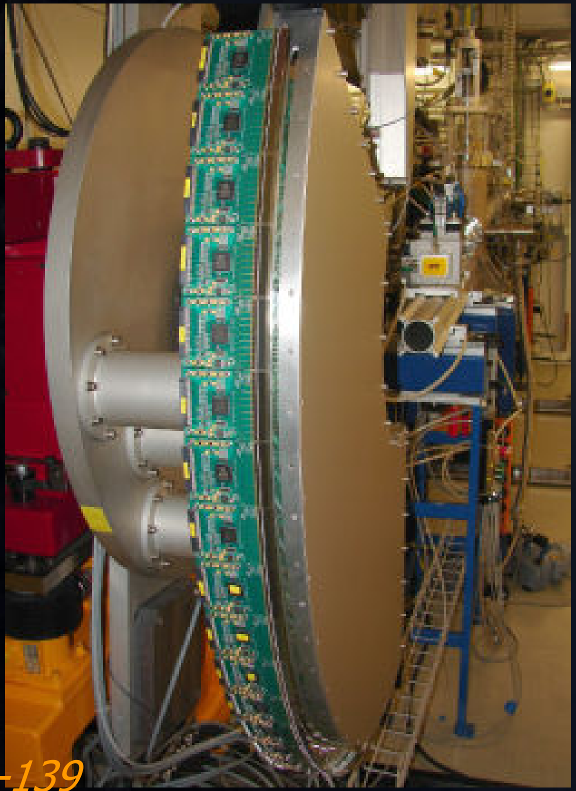
- Advantages of "edge-on" geometry:
  - Matching the laminar geometry of the beam with a natural pixel array
  - High absorption efficiency
- Problems:
  - Dead (undepleted) volume in front of the sensitive region that reduces the detection efficiency (~70-85% @ 20keV)



Single Photon Counting

- Mythen-II ASIC developed by PSI detector group
- Widely used in "face-on" 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
  - 6-bit threshold trim DAC to obtain uniform response over all channels
  - Single photon counting at 1 MHz





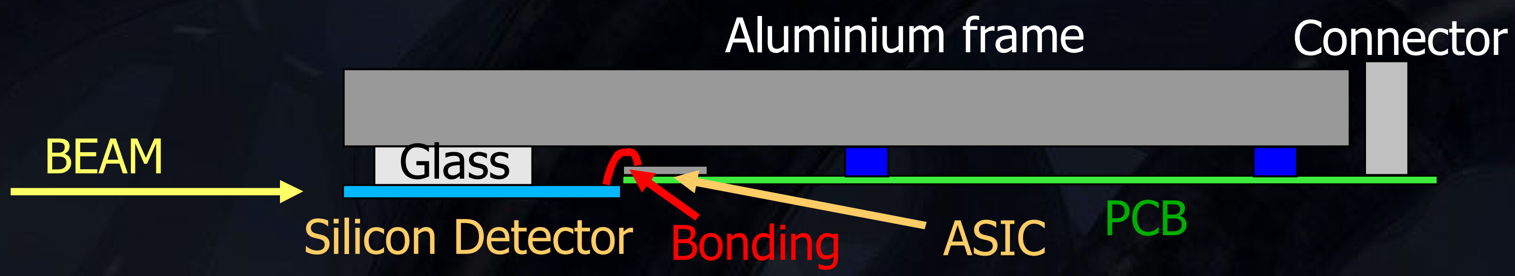
Bergamaschi, A. et al., Nucl. Instrum. Meth. A , 2009. 604. 1-2. 136-139
Mozzanica, A. et al., Nucl. Instrum. Meth. A , 2009. 607. 1. 250-252

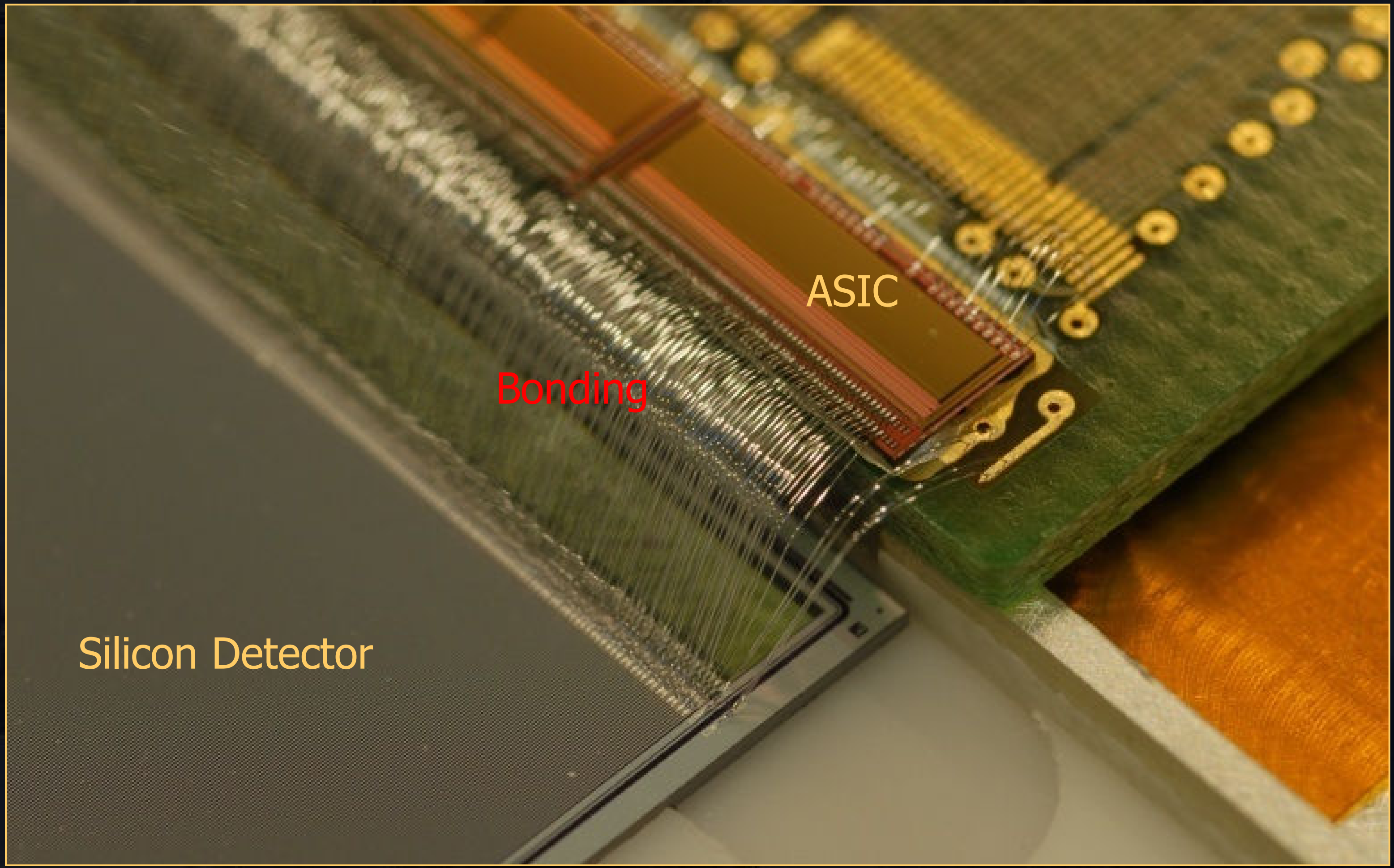
The PICASSO detector assembly

- 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

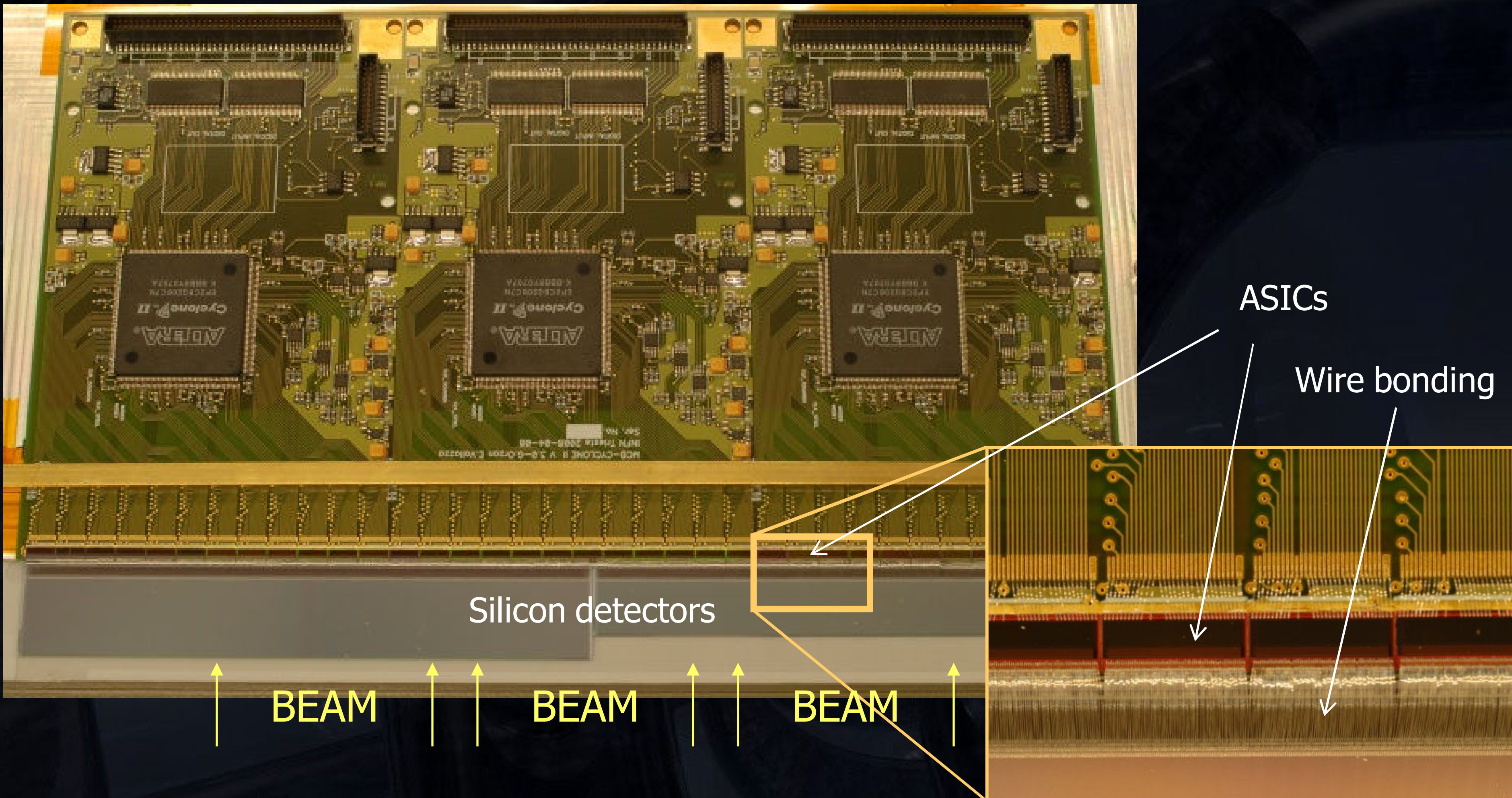
Vallazza, E. et al. Proceedings of 10th ICATPP Conference, 700-705 World Scientific Publishing Co.
Rigon, L. et al. IEEE Nuclear Science Symposium Conference, 2008, 1536

Modular design



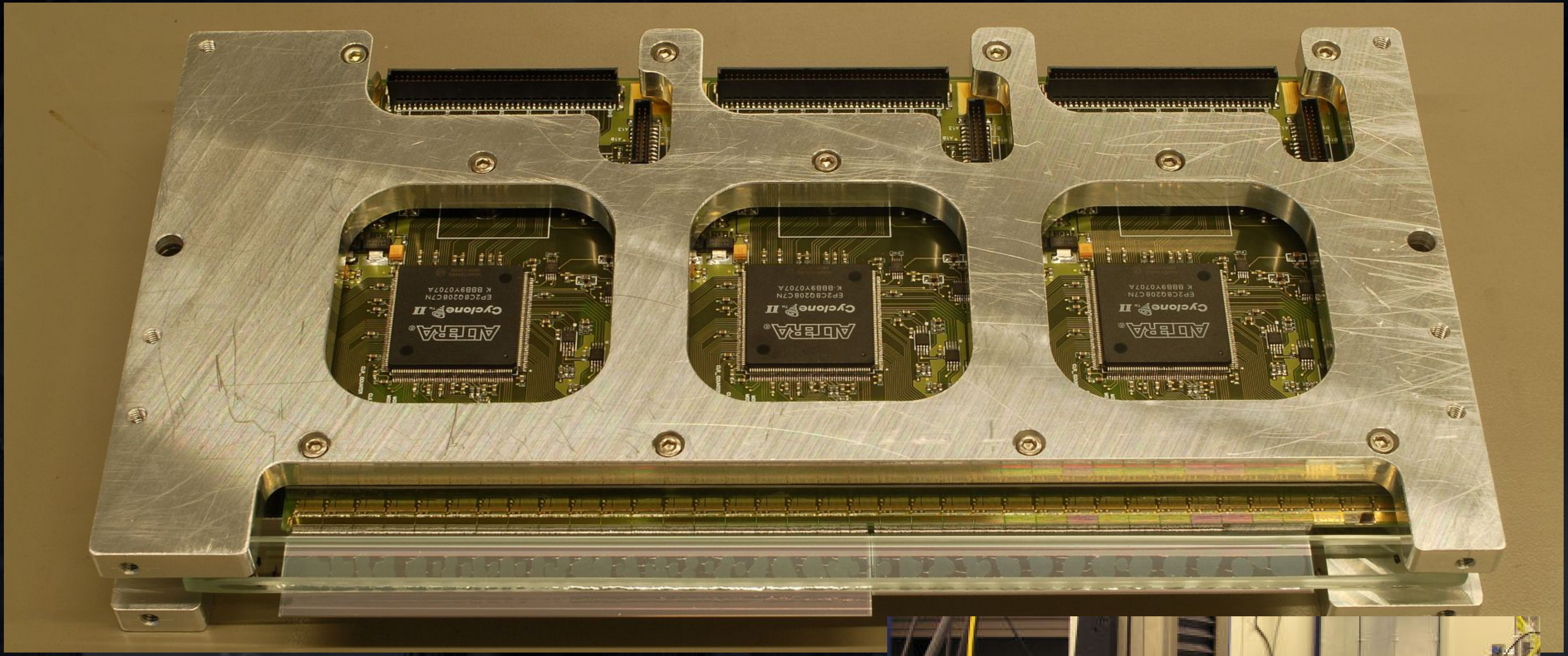


Single layer full size prototype

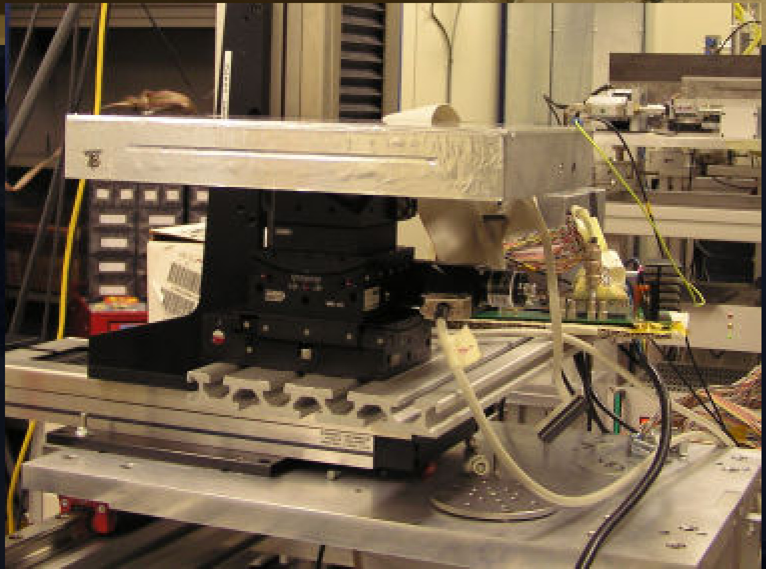


- Single layer 210 mm silicon detector
  - Use of two modules (120 mm+90 mm), 33 ASICs (4224 channels)
  - PCB hosts 3 Altera Cyclone-II FPGA for ASIC control
  - Assembled and bonded at Mipot SpA (Cormons, Italy)

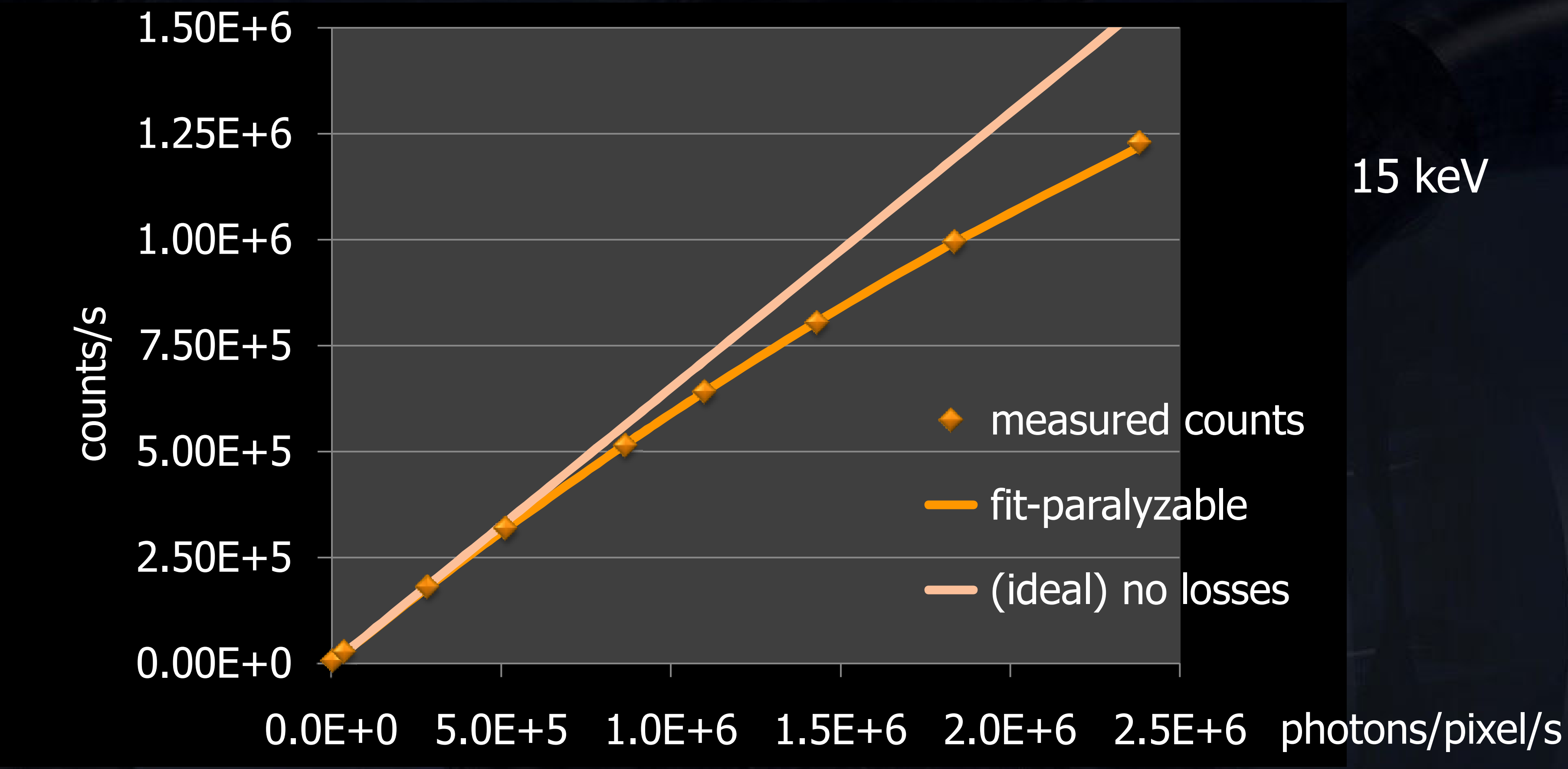
Double layer prototype



- 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

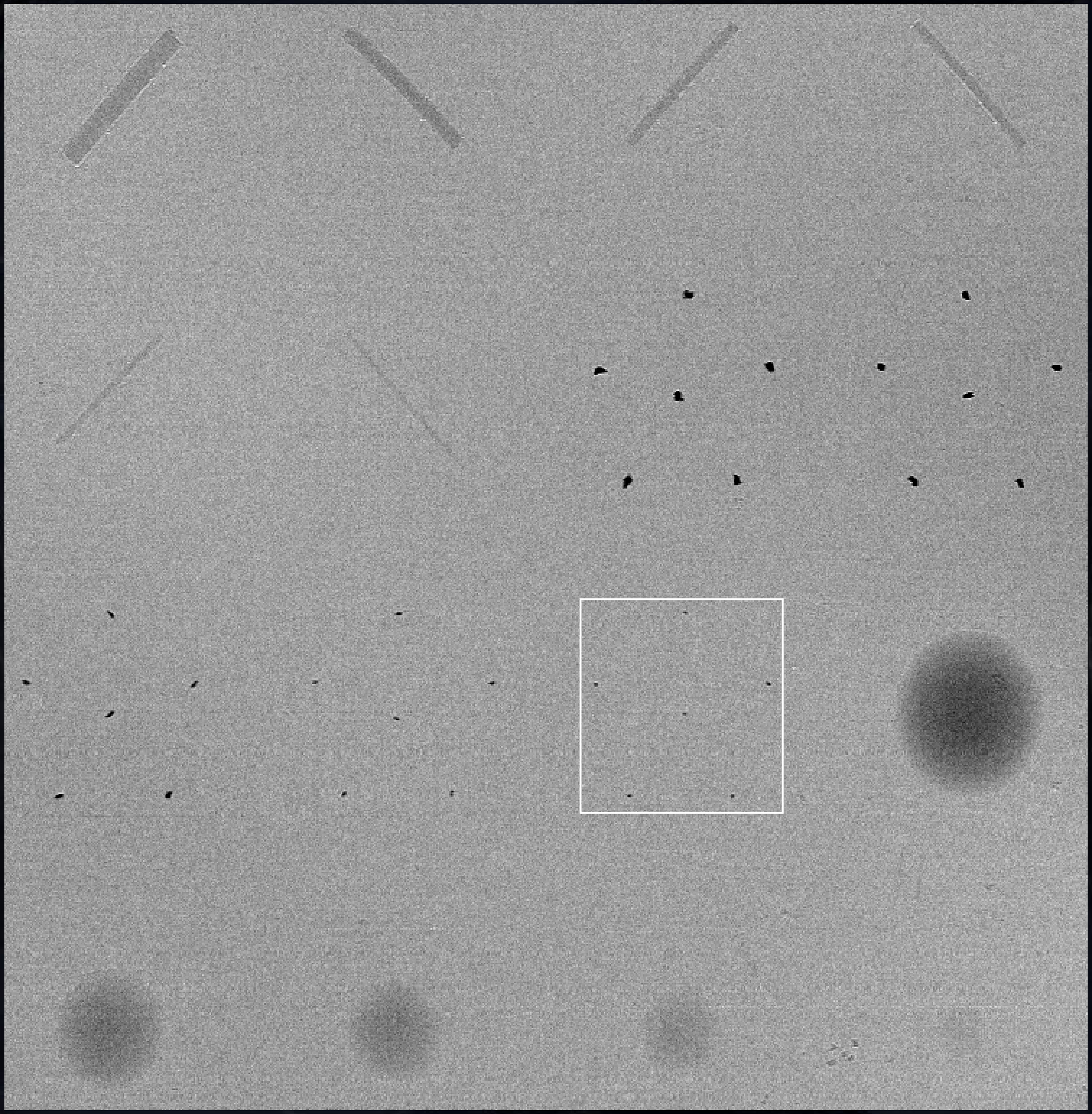


PICASSO Counting Rate Capabilities

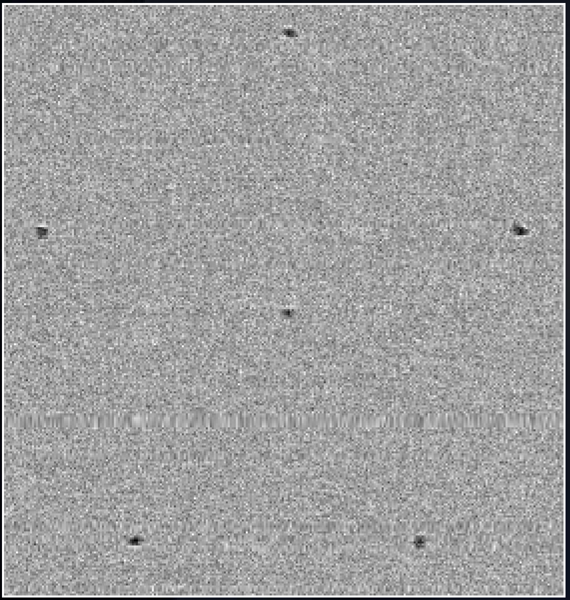


- Compatible with a paralyzable model with
  - Efficiency 65.1 % (compatible with ~ 200 μm dead zone)
  - Dead Time 0.16 μs
- Almost negligible losses (< 10%) up to 1.2 MHz

ACR (American College of Radiology) Phantom



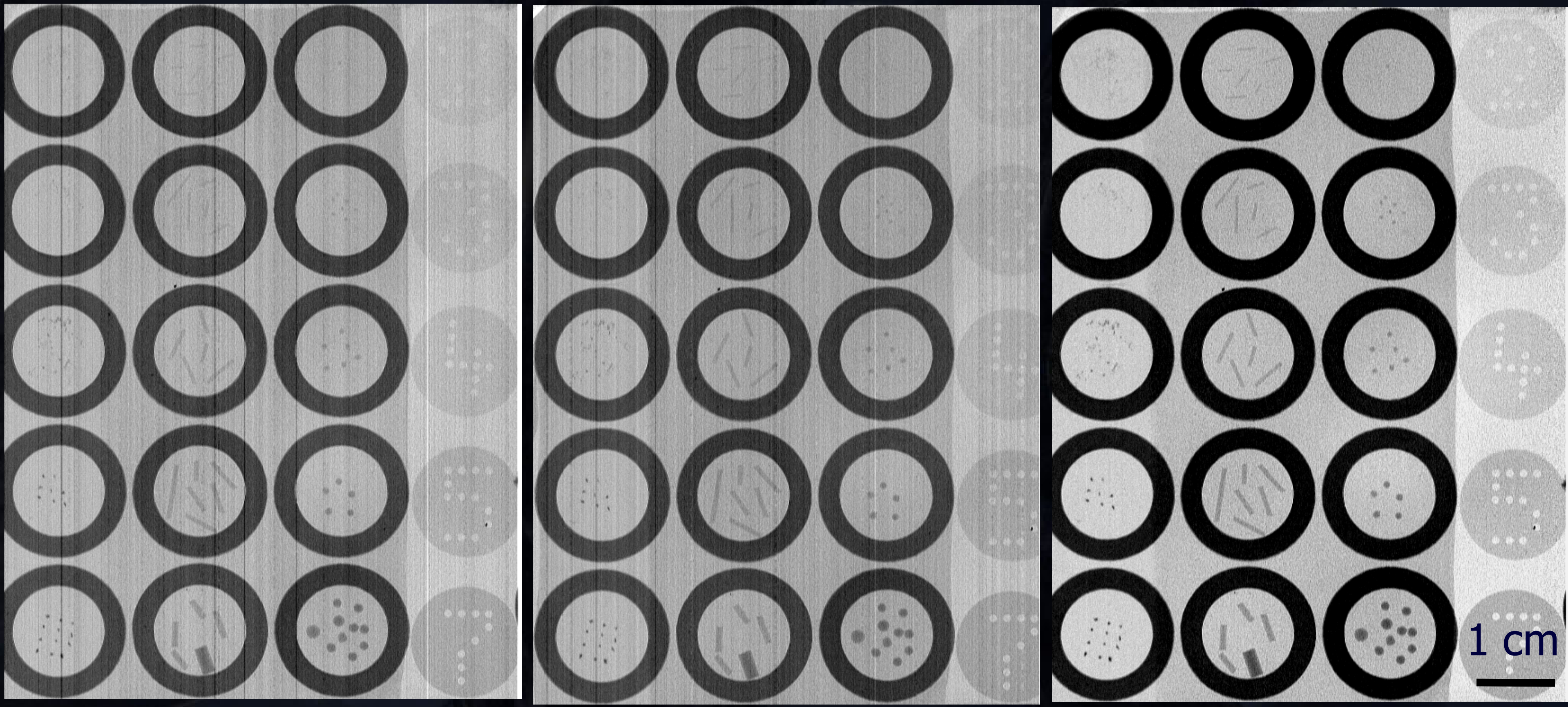
19 keV
Scanning step
50 µm
0.2 s per step
Air Entrance dose
8.5 mGy



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

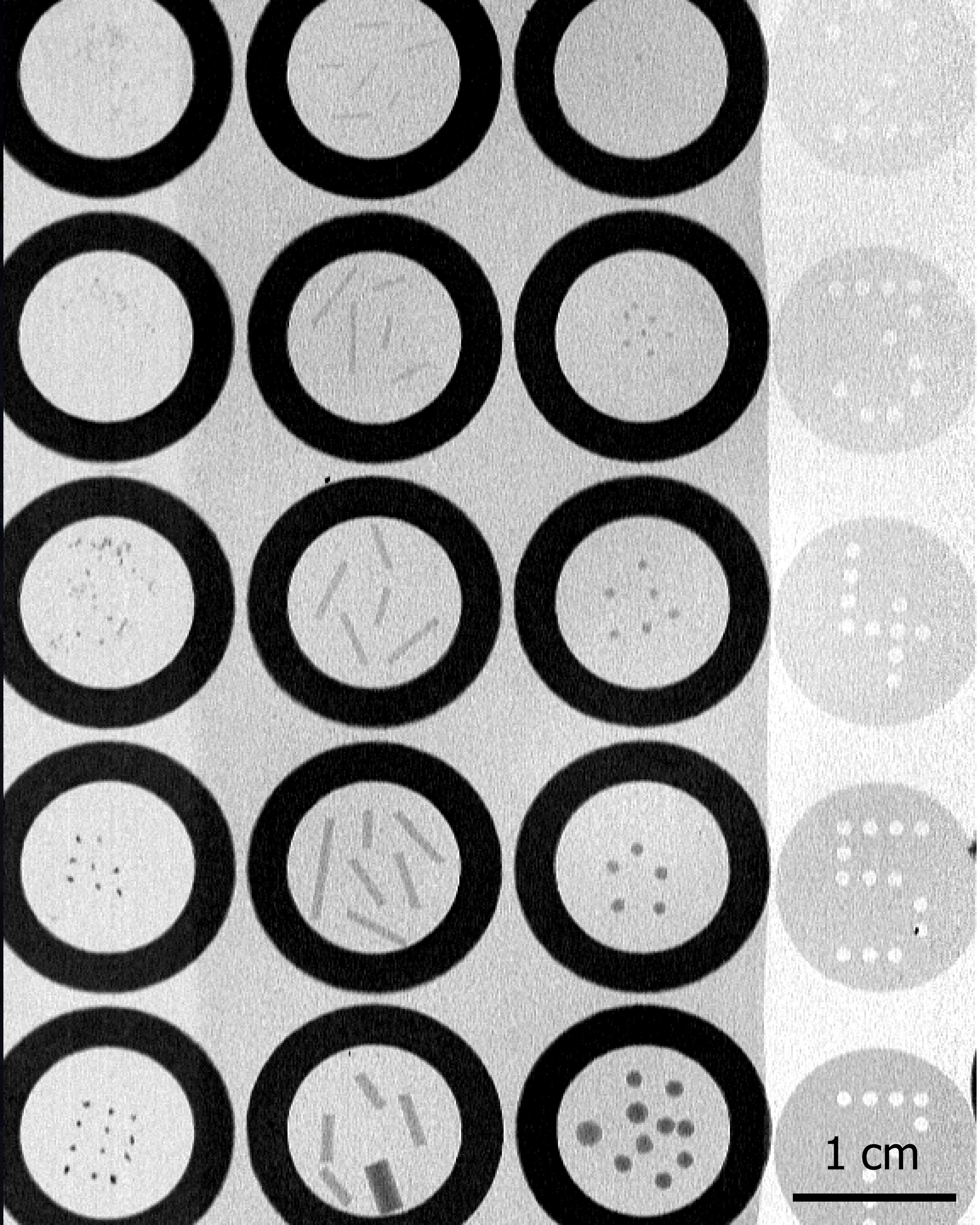
Gammex RMI 160 "Ackermann" Phantom detail

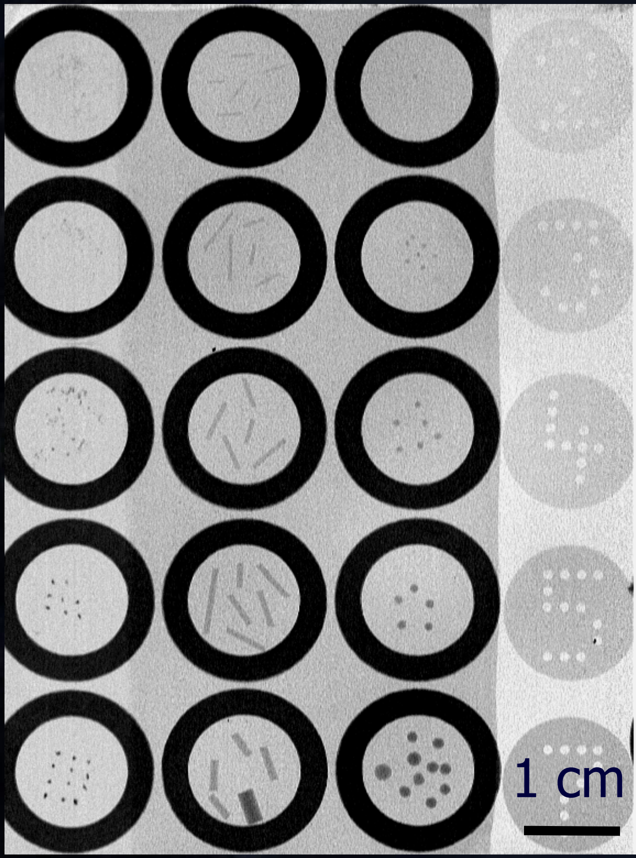
- Phantom + 30 mm Plexiglas acquired at 19.5 keV
  - Scanning step 100 μm, 0.100 s per step
  - Air Entrance dose 1.75 mGy



Top layer Raw image | Bottom layer Raw image | Summed and normalized image

Phantom detail

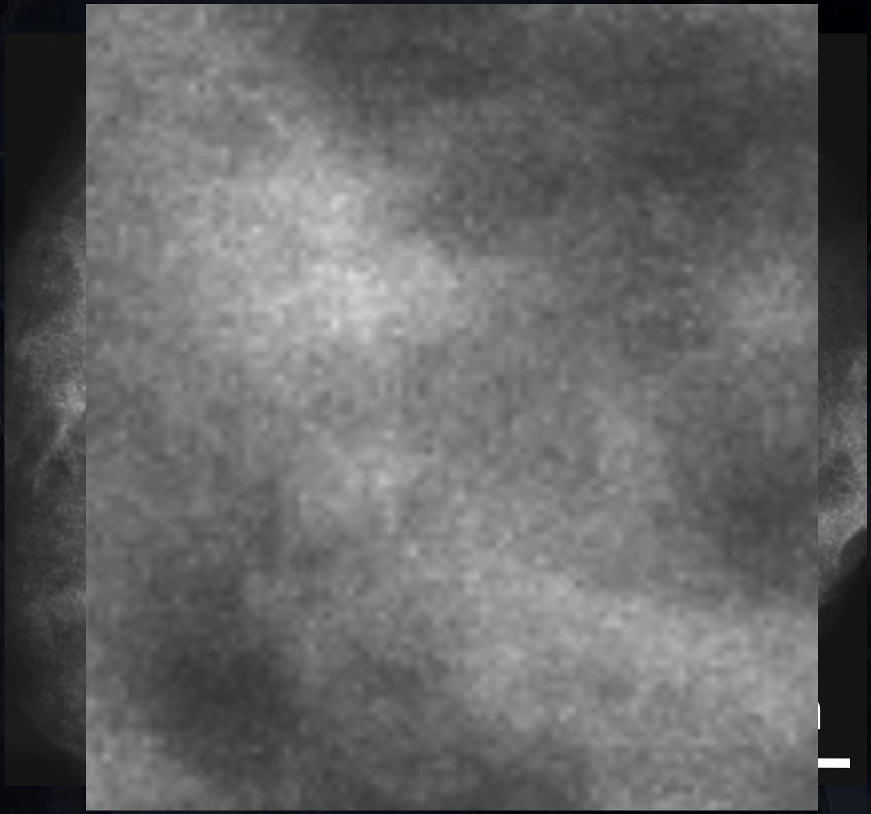




Summed and normalized image

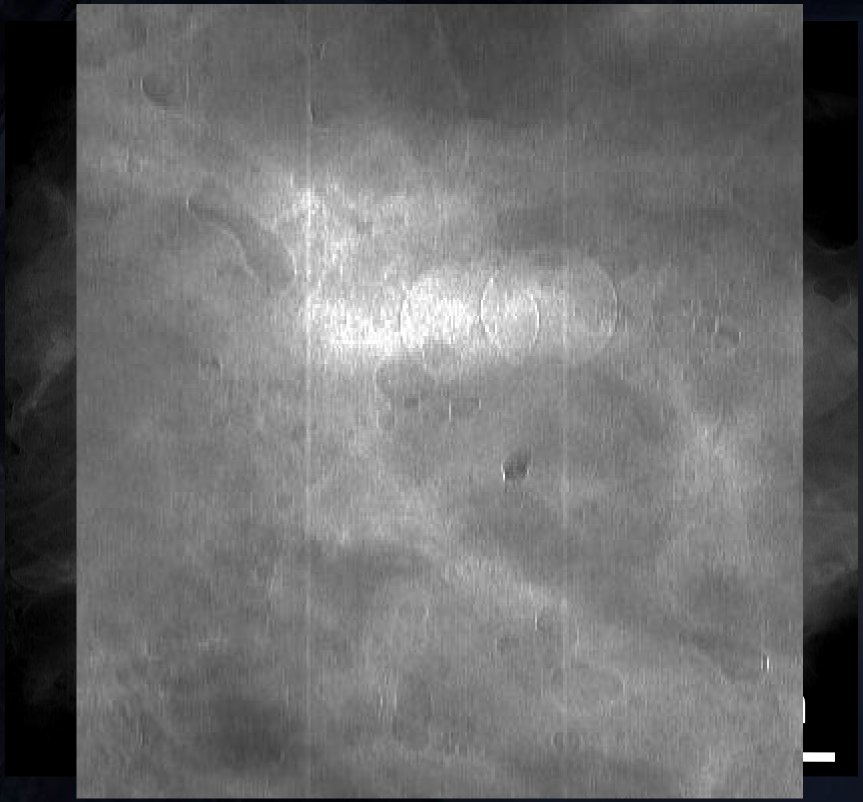
In vitro breast tumor tissue

Agfa Image Plate mammographic system



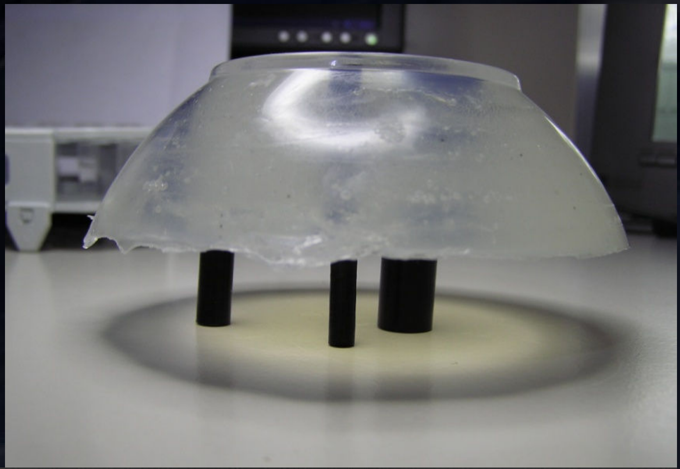
Ro/Ro Anode/Filter
7 mAs, 28 kVp
Air entrance dose ~ 0.6 mGy

PICASSO single layer detector

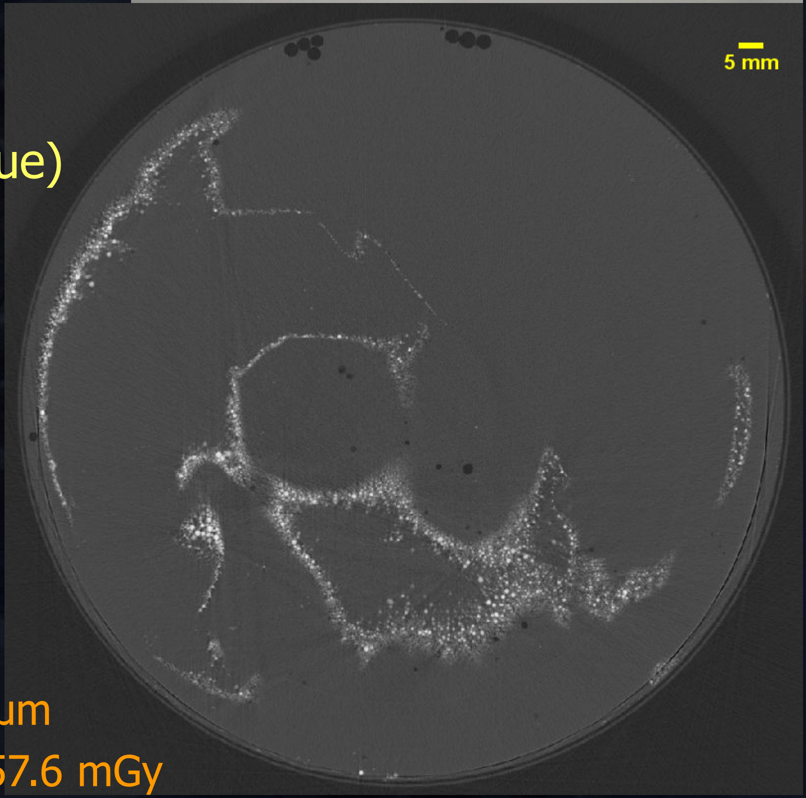


Energy 23 keV
Scanning step 200 μm
Exposure time 80 ms/step
Air entrance dose ~ 0.4 mGy

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



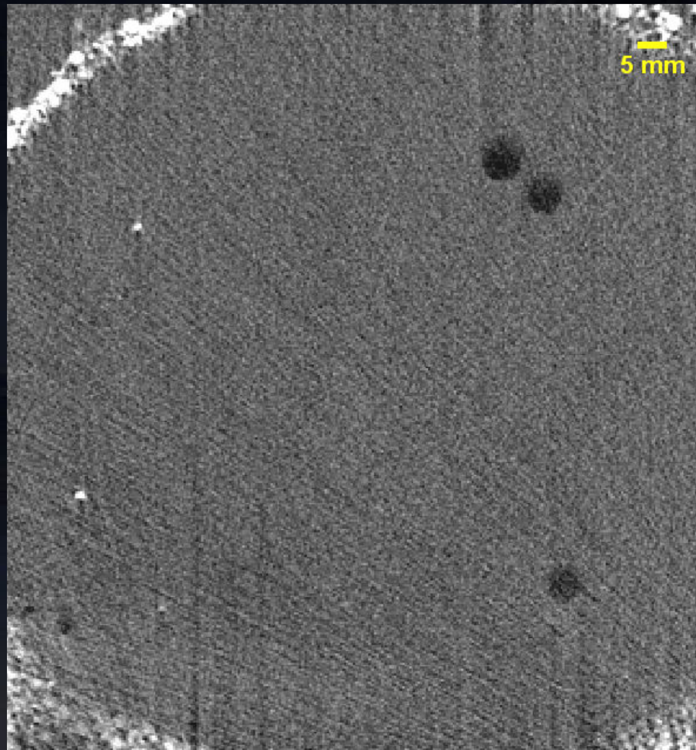
90 projections

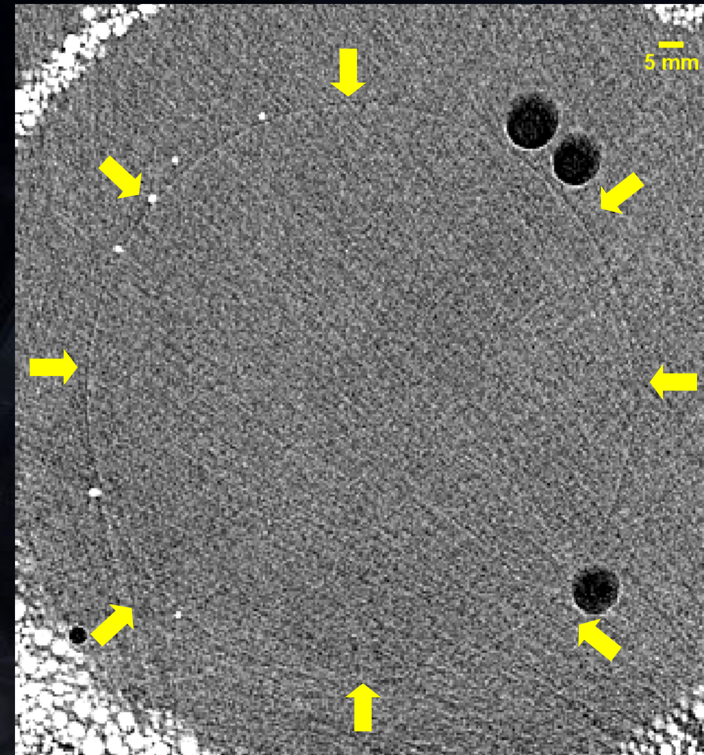
Pixel aperture: 100 μm

Air entrance Dose: 57.6 mGy

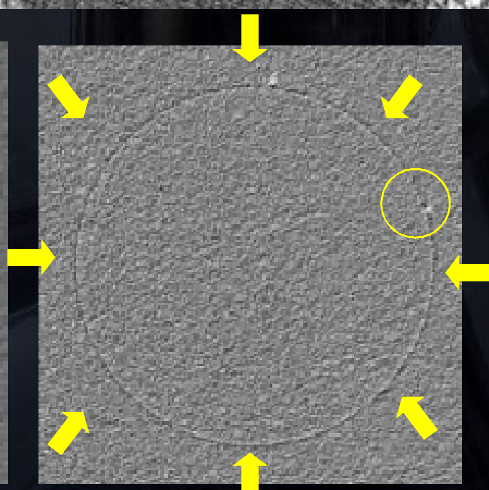
Custom-made PhC-Tomography Breast Phantom

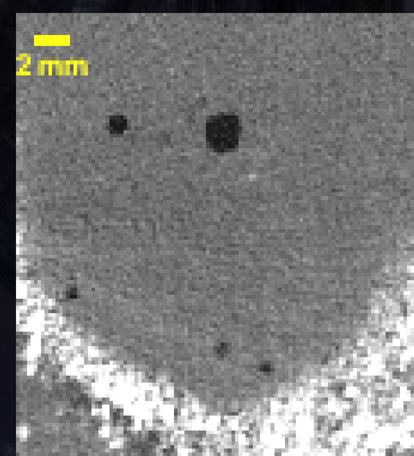
Absorption

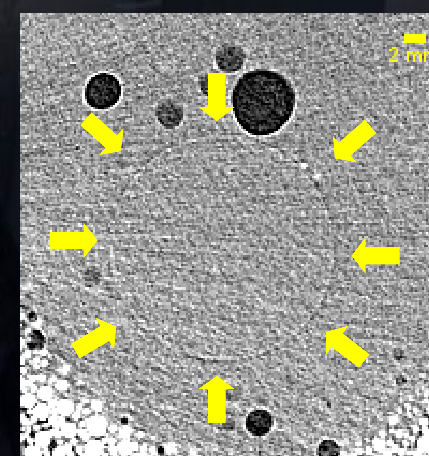




Phase Contrast





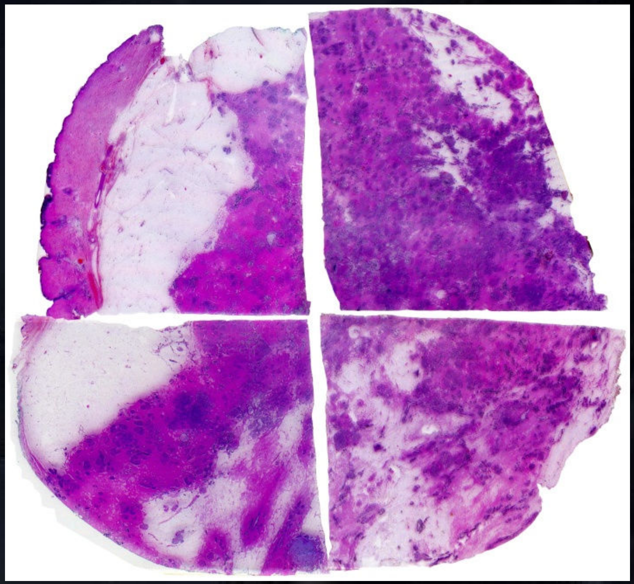


Absorption Phase Contrast

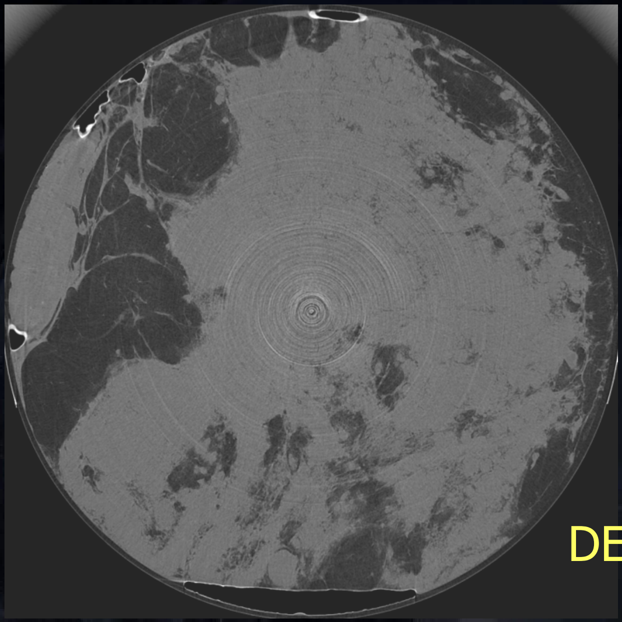
Absorption Phase Contrast

Breast Tissue DEI Tomography

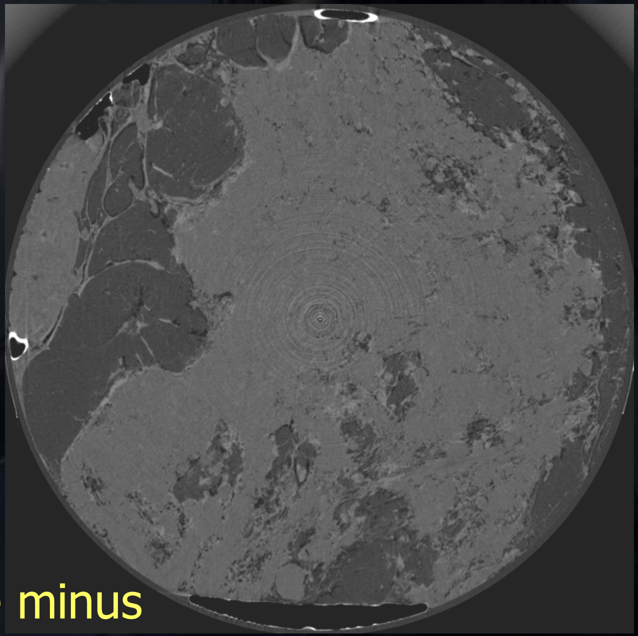
DEI
Tomography
21 keV



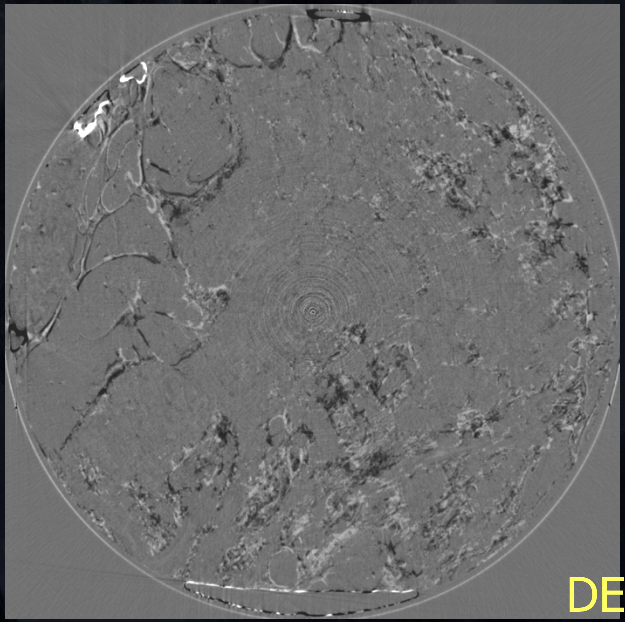
Histology



DEI - Top image

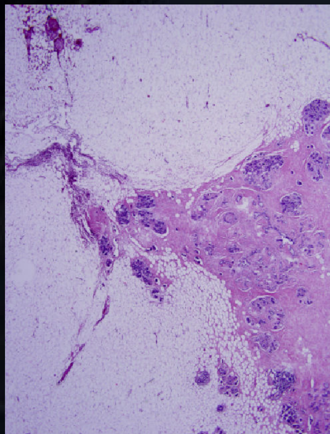


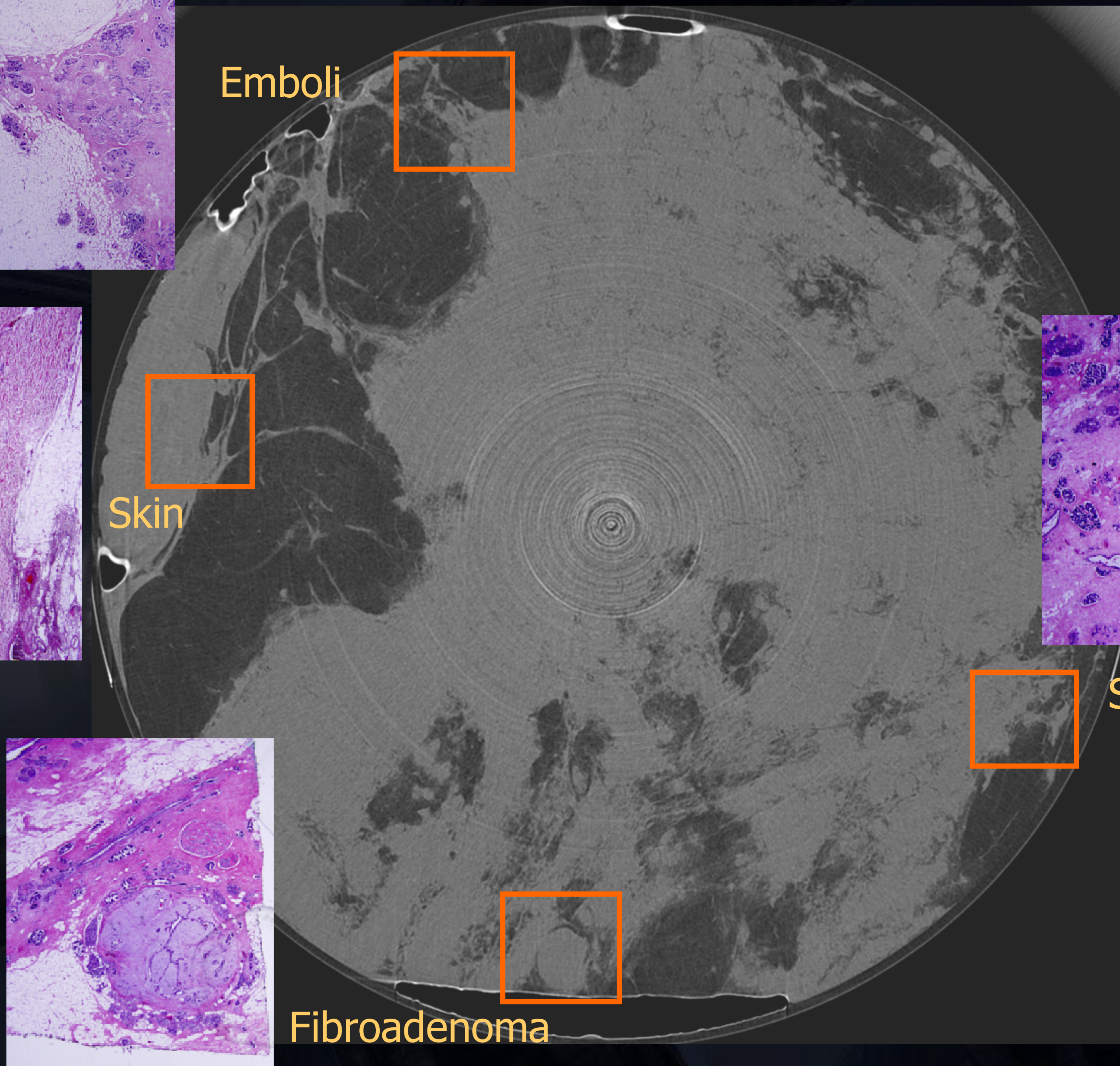
DEI - Slope minus

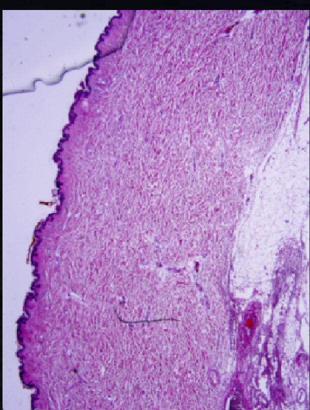


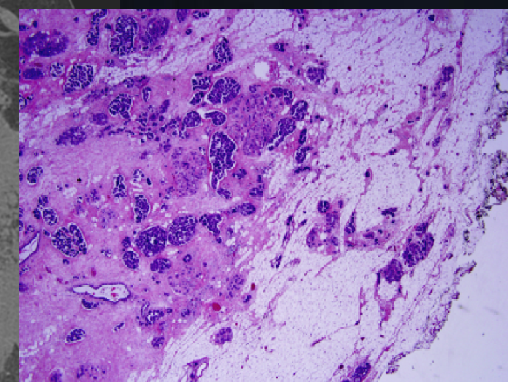
DEI -Refraction

Breast Tissue DEI Tomography



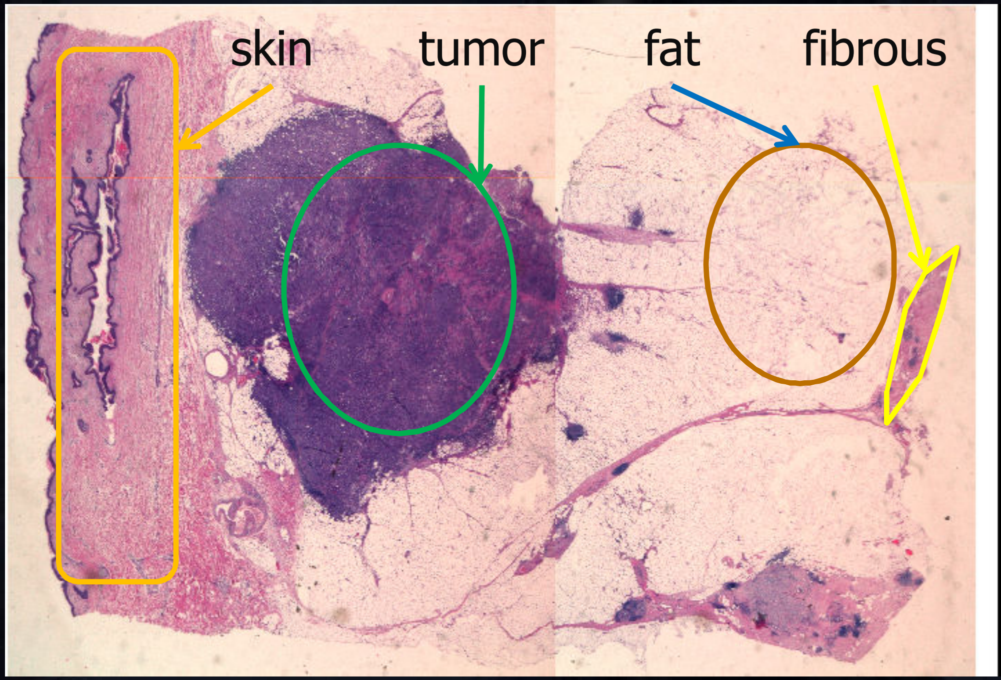


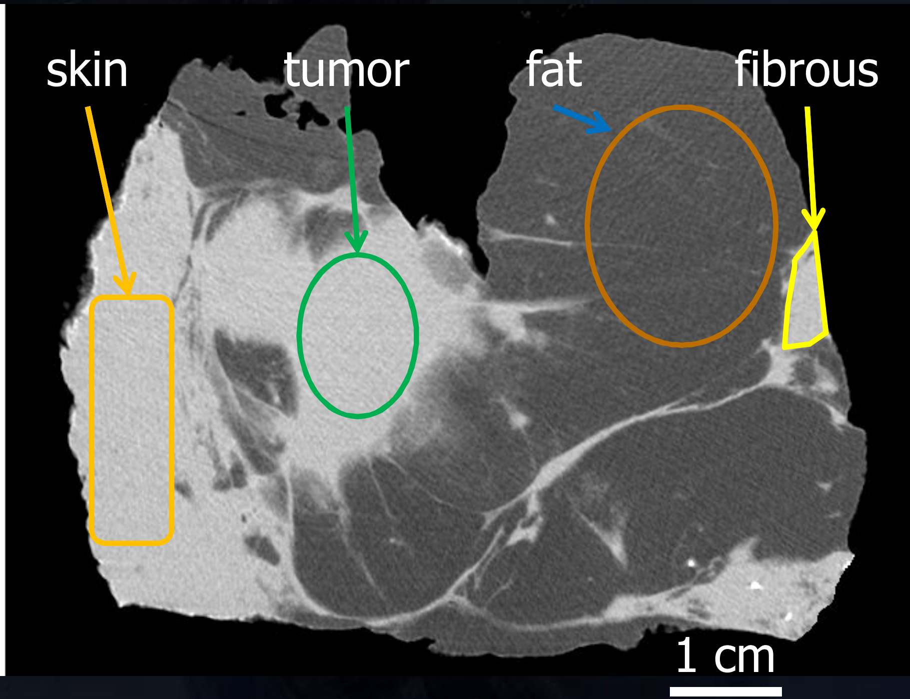




Breast Tissue Tomography

- 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





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Concluding Remarks

- The SYRMEP group is operating a beamline dedicated to *in-vivo* mammography at ELETTRA
- The first clinical mammography project provided excellent results
  - 71 patients have been examined by using a conventional screen-film system
  - evidence that MSR outperforms DM in visualizing lesions and glandular tissue
- 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
- These characteristics make PICASSO a unique tool for medical imaging and pave the way for its utilization in the next clinical trial

Thank you!

References

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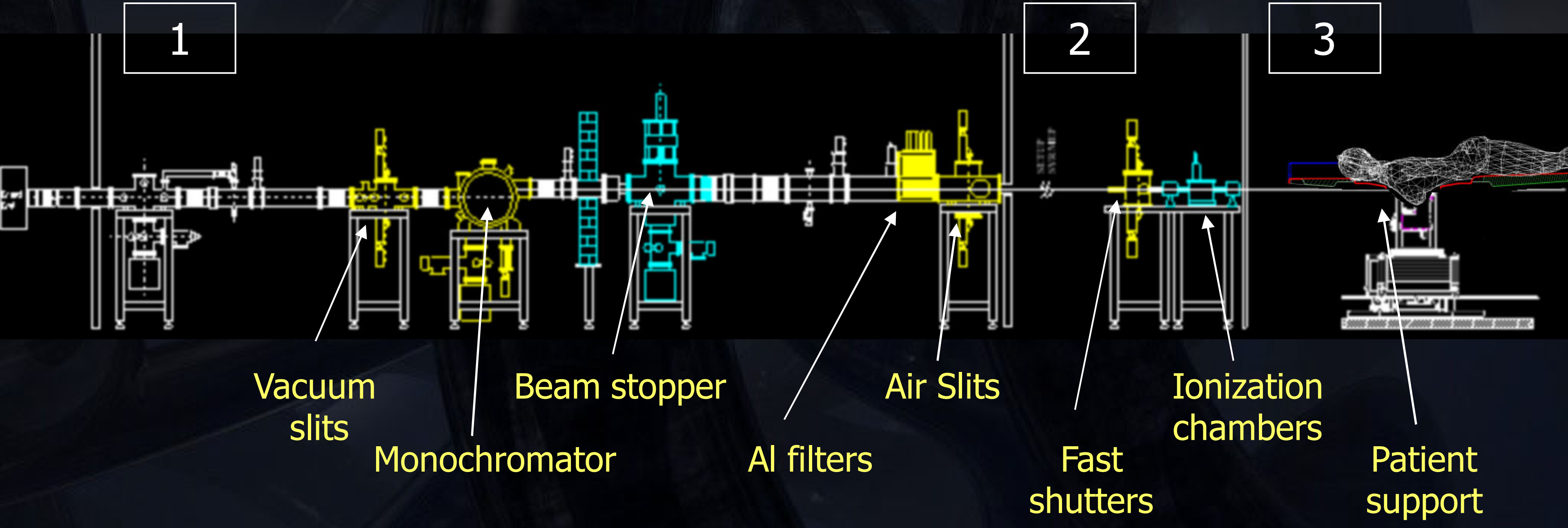
- E. Castelli et al., Nucl. Instrum. Meth. A **572** 237 (2007)
- D. Dreossi et al., Nucl. Instrum. Meth. A **576** (2007)
- D. Dreossi et al., Eur. J. Radiol. **68** S58 (2008)
- A. Bergamaschi et al., Nucl. Instrum. Meth. A **604** 136 (2009)
- A. Mozzanica et al., Nucl. Instrum. Meth. A **607** 250 (2009)
- E. Vallazza et al., Proc. of 10th ICATPP Conference, World Scientific Publishing 700 (2008)
- L. Rigon et al., IEEE Nuclear Science Symposium Conference 1536 (2008)
- L. Rigon et al., Nucl. Instrum. Meth. A **608** S62-S65 (2009)

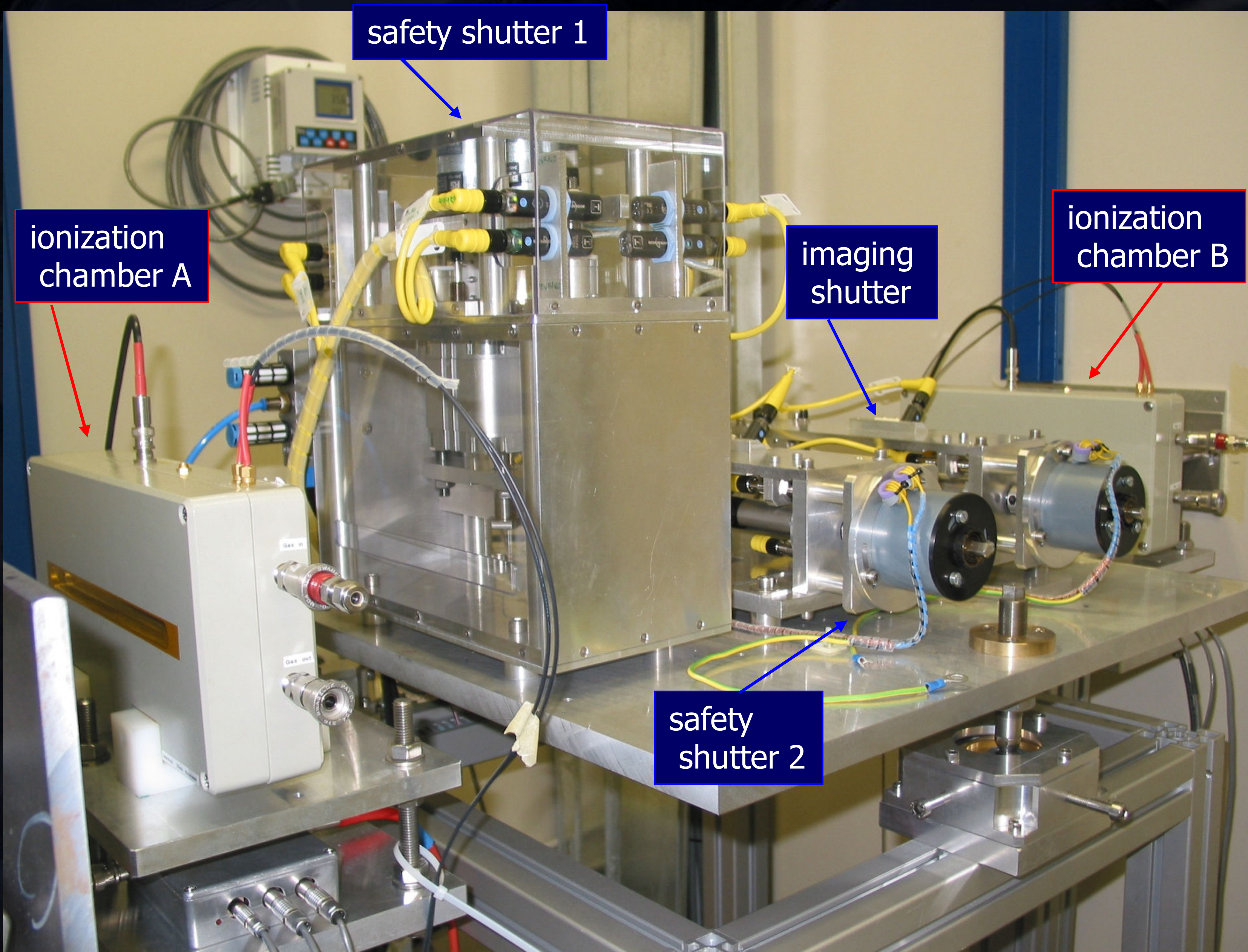
Extra time
(Back-up slides)

The SYRMEP beamline (II)

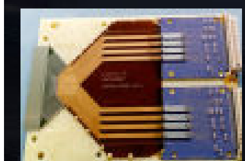
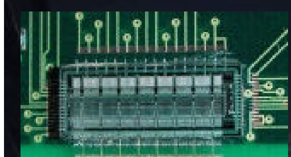
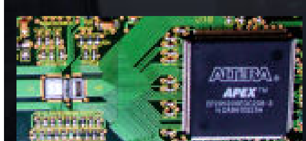
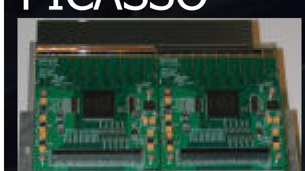
- 1 Beam preparation (energy, flux, geometry)
- 2 Beam monitoring (dose, exposure time, safety system)
- 3 Patient exposure



Dose control and safety system

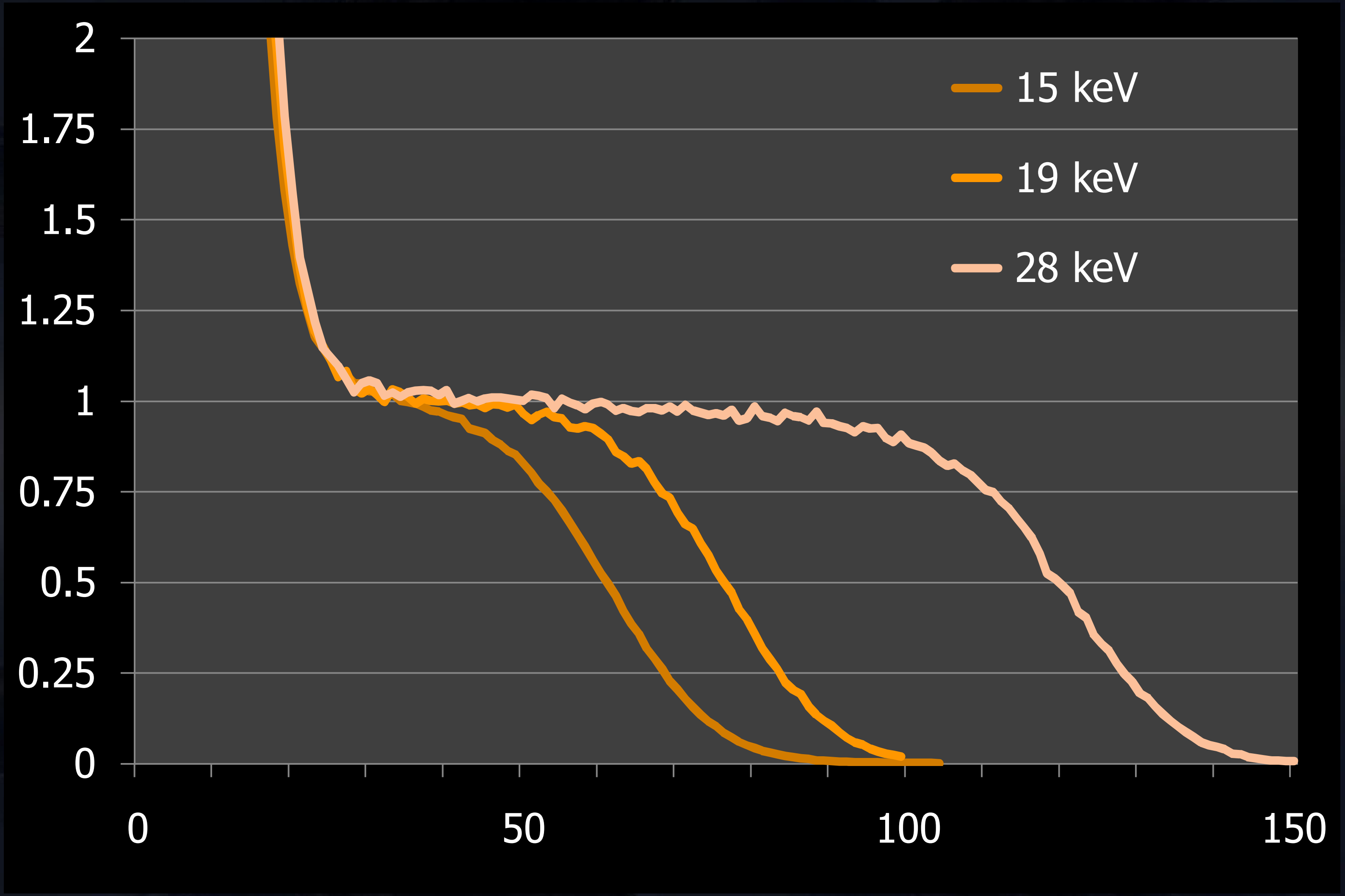


A decade of single photon counting

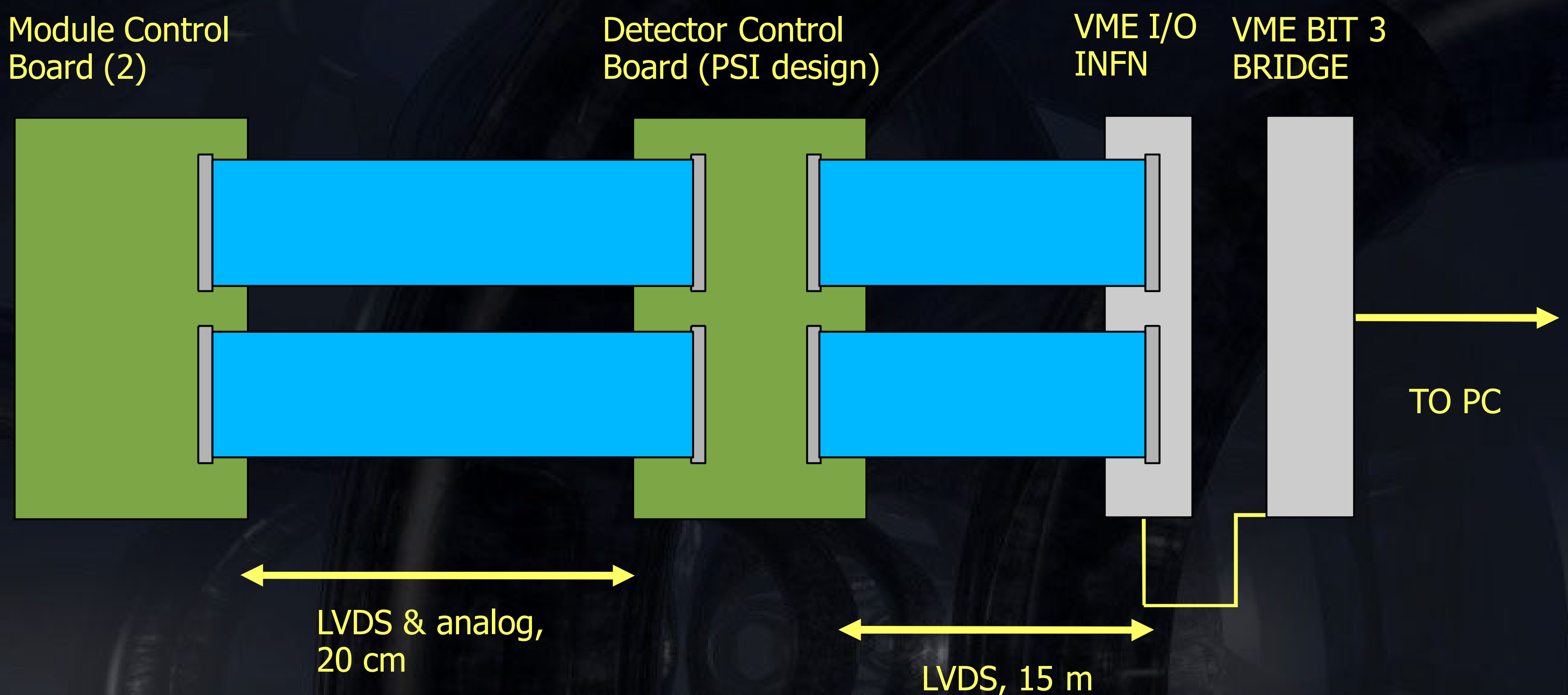
	ASIC	Channels per ASIC [total]	Pitch µm	Pixel Size µm x µm h x v	Gain mV/fC	Noise e- RMS	Max Rate MHz
SYRMEP 	CASTOR (Lepsi)	32 [764]	200	200 x 300	200	250	0.01
FRONTRAD 	FROST (Caen)	64 [64]	200	100 x 300	130	800	0.1
MATISSE 	VA64_TAP +LS64 (Ideas)	64 [64]	100	100 x 300	100	500	1
PICASSO 	Mythen II (PSI)	128 [8448]	50	50 x 300	110	240	1

Threshold scan

- Pencil beam 10 μm wide to avoid charge sharing effects



Read-out Electronics



- Very simple readout
- Already designed an improved version of the VME I/O with an ALTERA Cyclone II FPGA and local memory to buffer the frames during the scan

Read-out Electronics (II)