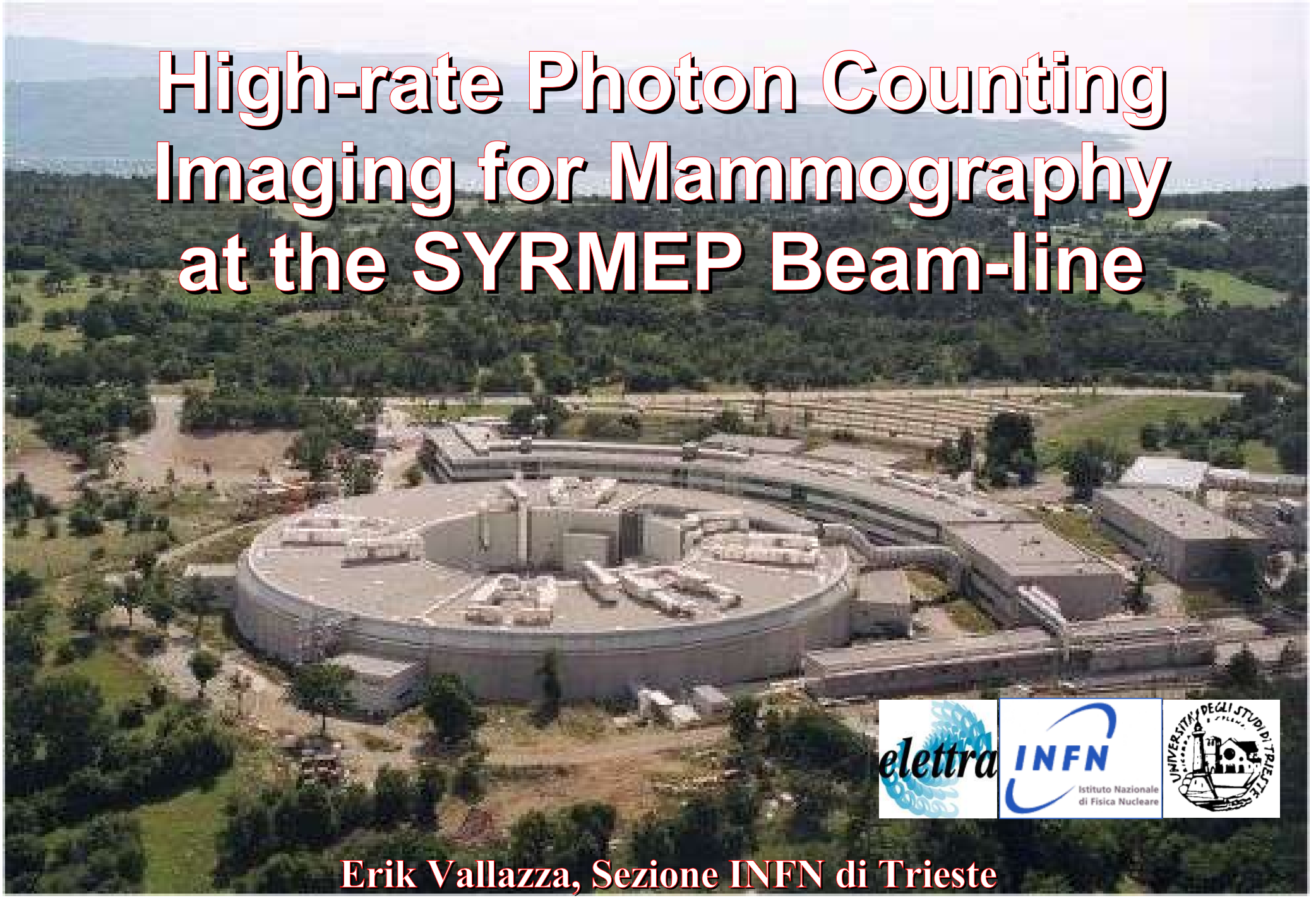
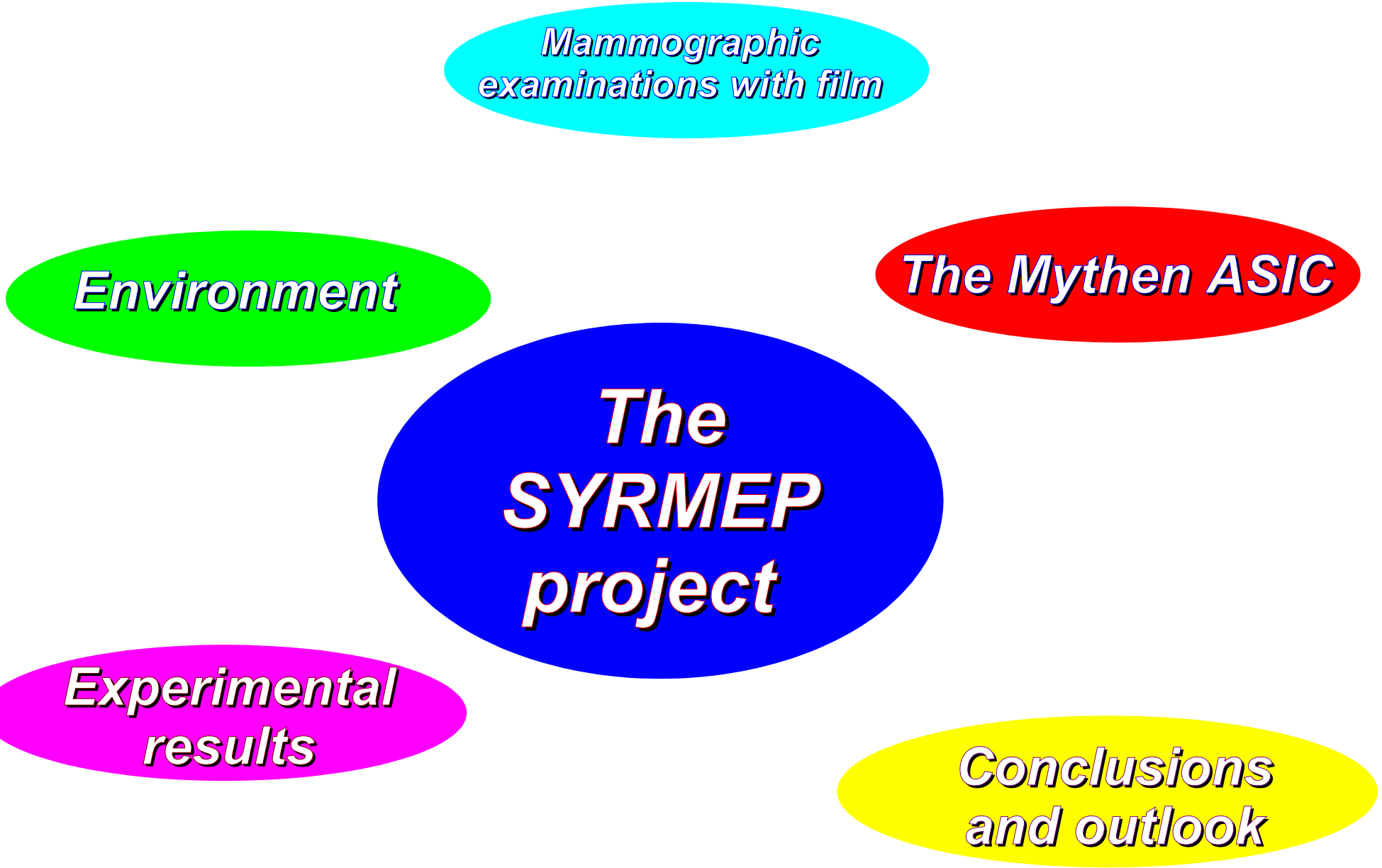
High-rate Photon Counting Imaging for Mammography at the SYRMEP Beam-line



Erik Vallazza, Sezione INFN di Trieste


Mammographic examinations with film
Environment
The Mythen ASIC
The SYRMEP project
Experimental results
Conclusions and outlook

Motivations

Mammography (and/or ultrasonography) is a first level exam.

Mammography is a typical example of extreme requirements on the X-ray source as well as on the detection system (detection of microcalcifications and low contrast masses, possible indicators of early breast cancer). Breast is one of the most radiosensitive organs

Over the past 10 years several improvements have been made on mammographic units and screen-film systems, including the widespread diffusion of digital systems based on flat panel technology, but there are still several limitations. Mammography is far from being perfect:

- sensitivity ranges from 75% to 90%
- specificity from 90% to 95%.

The SYRMEP project

The main goal of SYRMEP is the investigation and development of innovative techniques for medical imaging in order to improve the image quality

Synchrotron Radiation

- ✔ Monochromatic
- ✔ Energy-tunable
- ✔ Coherent
- ✔ Laminar

+

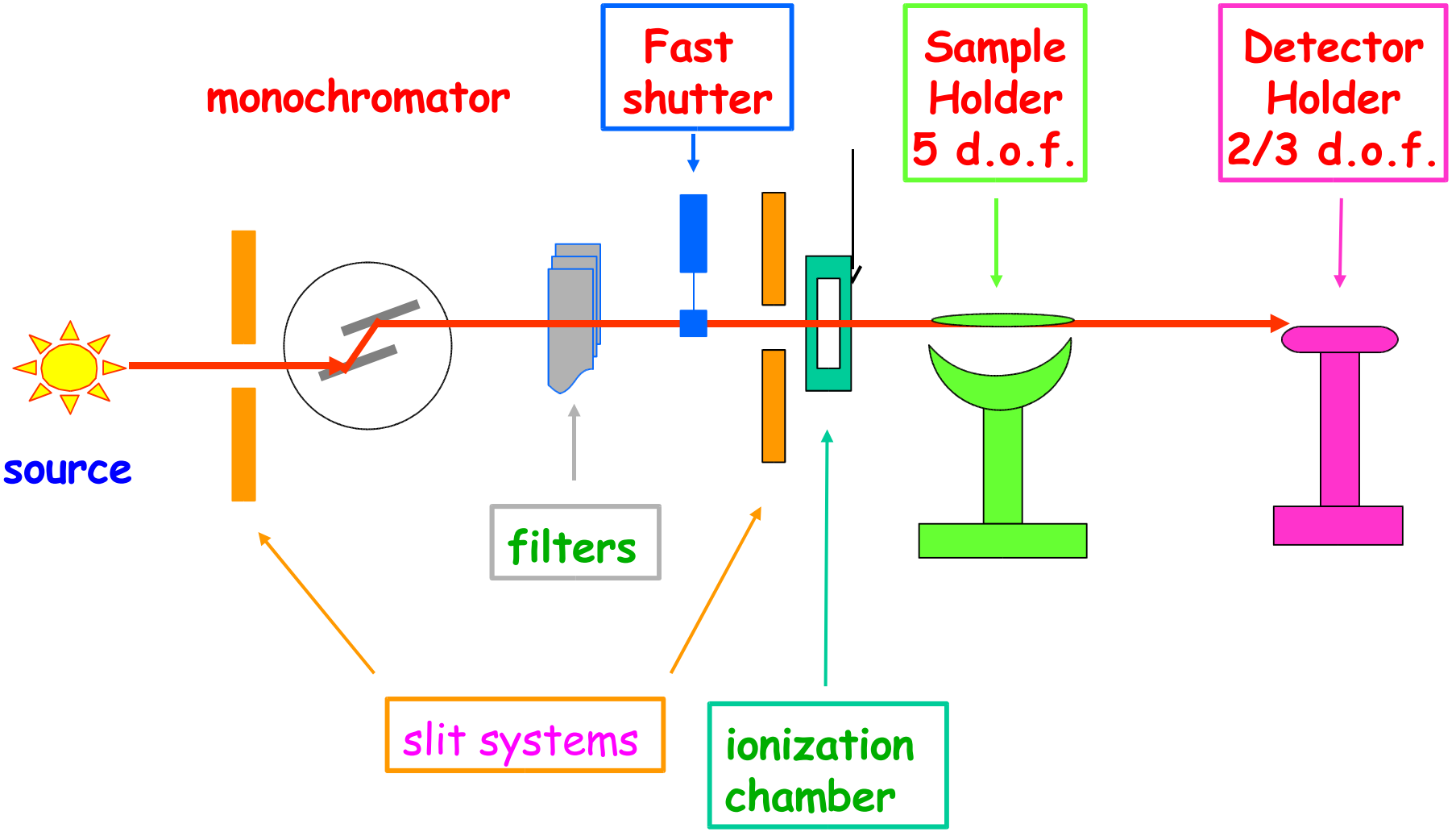
Detectors

- ✔ Film/Screen system
- ✔ Imaging Plate
- ✔ Si microstrip detector
- ✔ CCD

Techniques

- ✔ Conventional
- ✔ Phase Contrast
- ✔ DEI
- ✔ Tomography

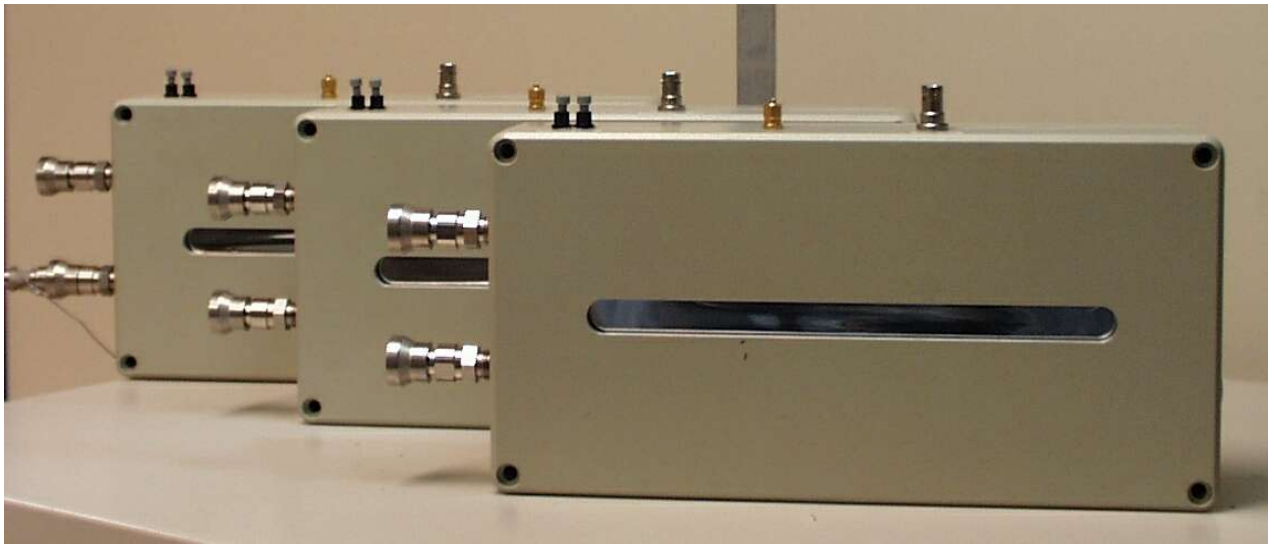
The Syrmep beamline



Beam parameters

- Source size @ 1100 μm x 100 μm
- Divergence : horizontal 7 mrad, vertical 0.155 mrad
- Cross-section at the Experimental Area: 140 x 4 mm^2, Radiological Area: 200 x 6mm^2
- Source-to-sample distance 21 m (EA), 30 m (RA)
- Energy range: 8 - 35 keV, Bandwidth $\Delta E/E=10^{-3}$
- Typical fluxes at 15 keV:
  - 2 * 10^8 phot./mm^2 s (@ 2 GeV, 300 mA)
  - 7 * 10^8 phot./mm^2 s (@ 2.4 GeV, 140 mA)

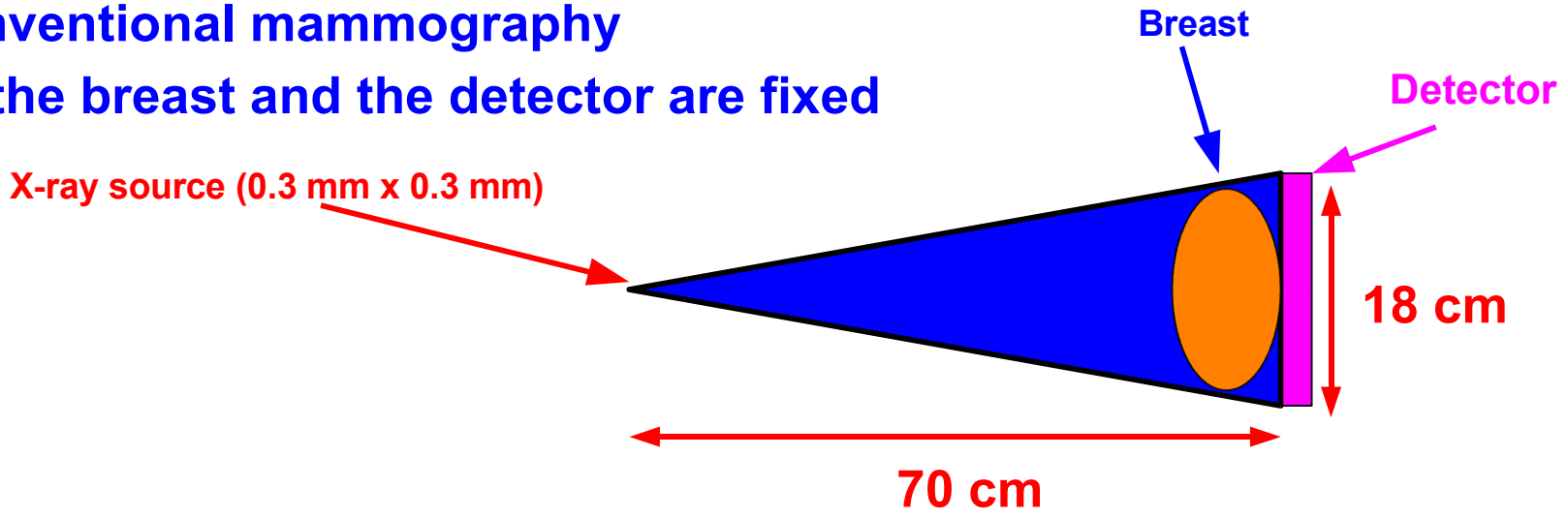
Beam flux monitors, developed and built by Sincrotrone Trieste



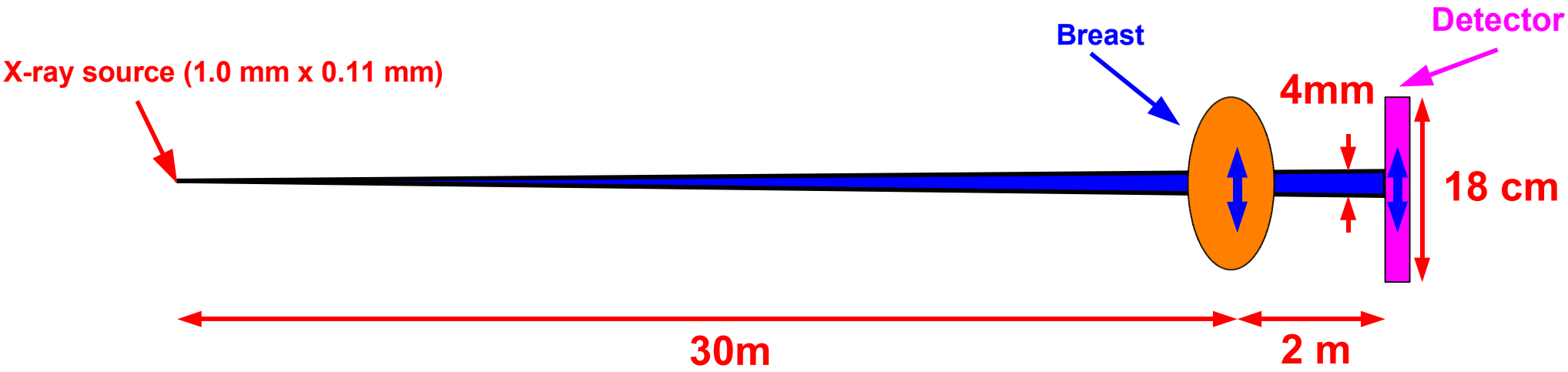
Phase contrast Imaging

Clinical conventional mammography

The beam, the breast and the detector are fixed

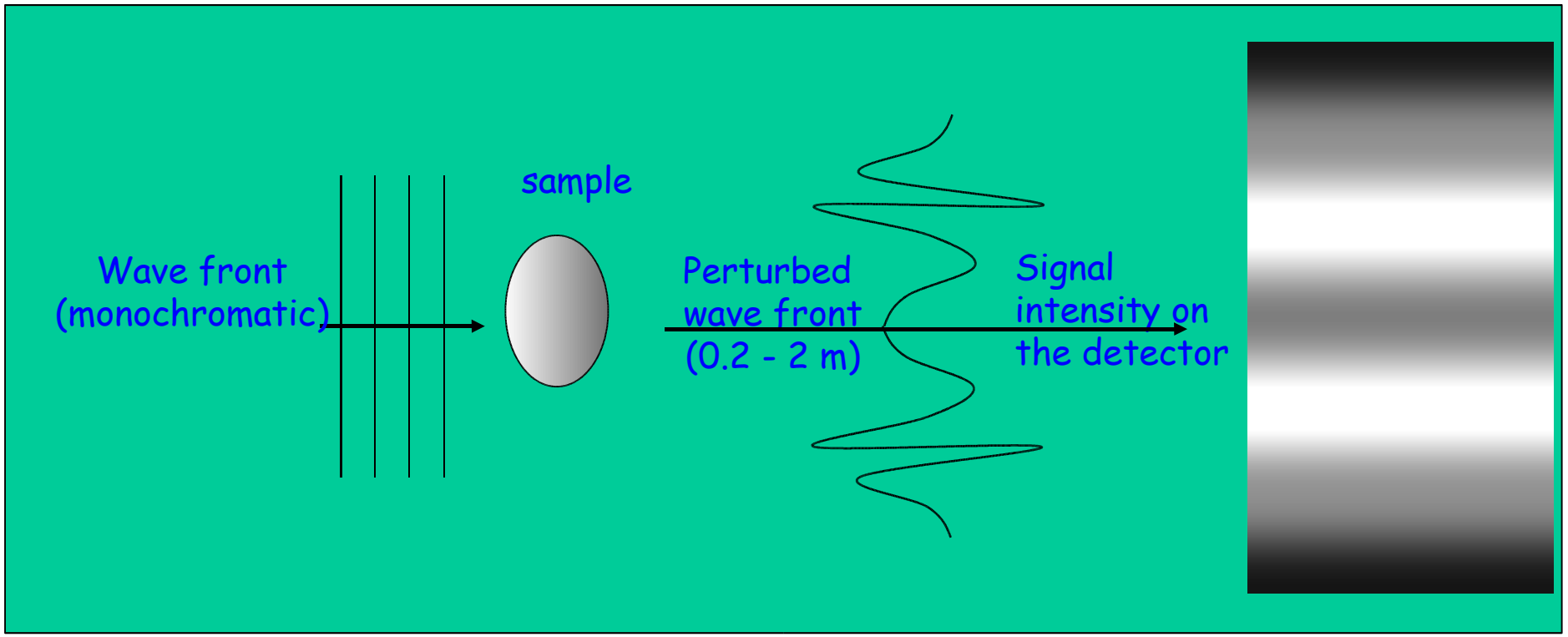


Synchrotron Radiation Phase Contrast mammography with screen-film
The beam is fixed; the breast and the detector move together



Important parameter: 18/70=0.26 (1); 0.004/32=0.00012 (2)

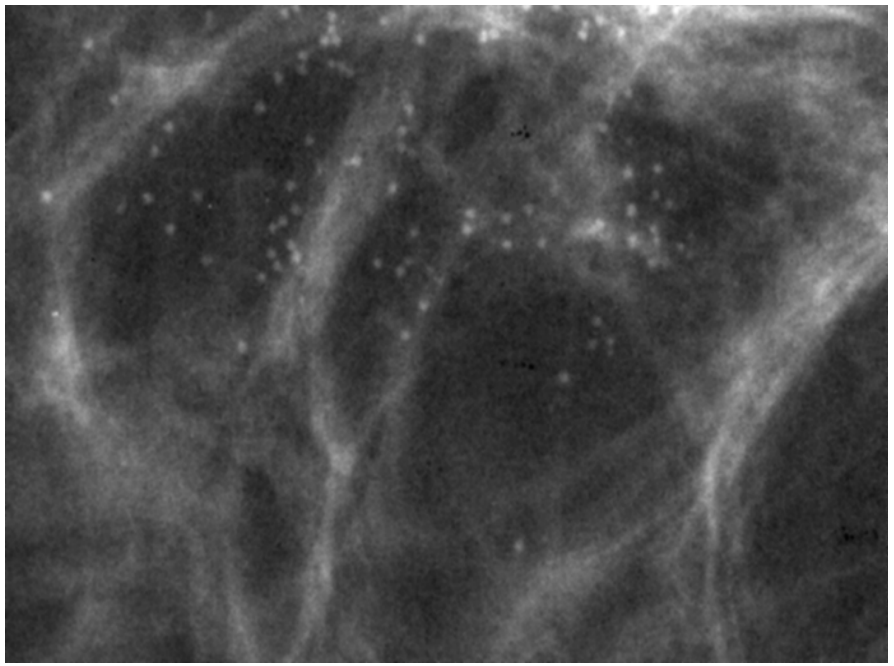
Phase contrast Imaging: physics principles



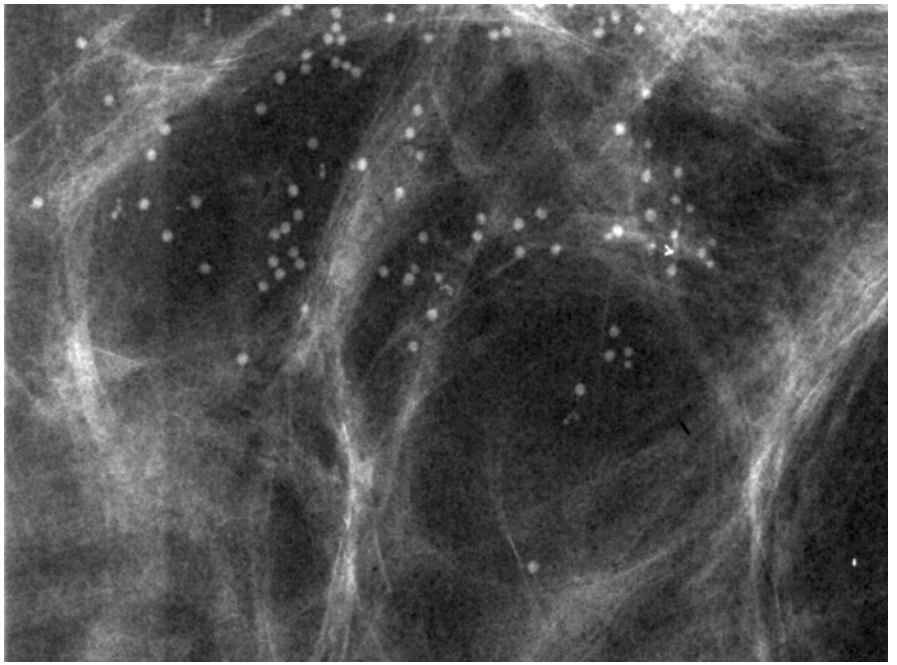
Very good detector spatial resolution required, about 50 μm

Previous results: phase contrast imaging of breast tissue with screen-film systems

Absorption



Phase Contrast

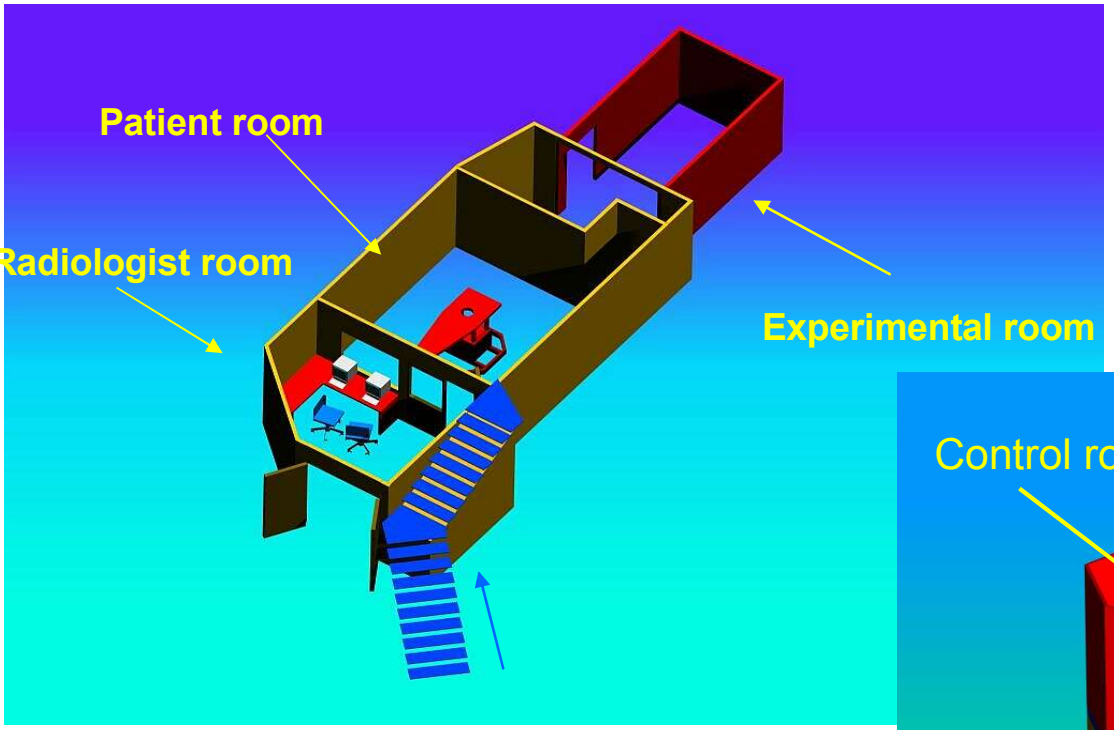


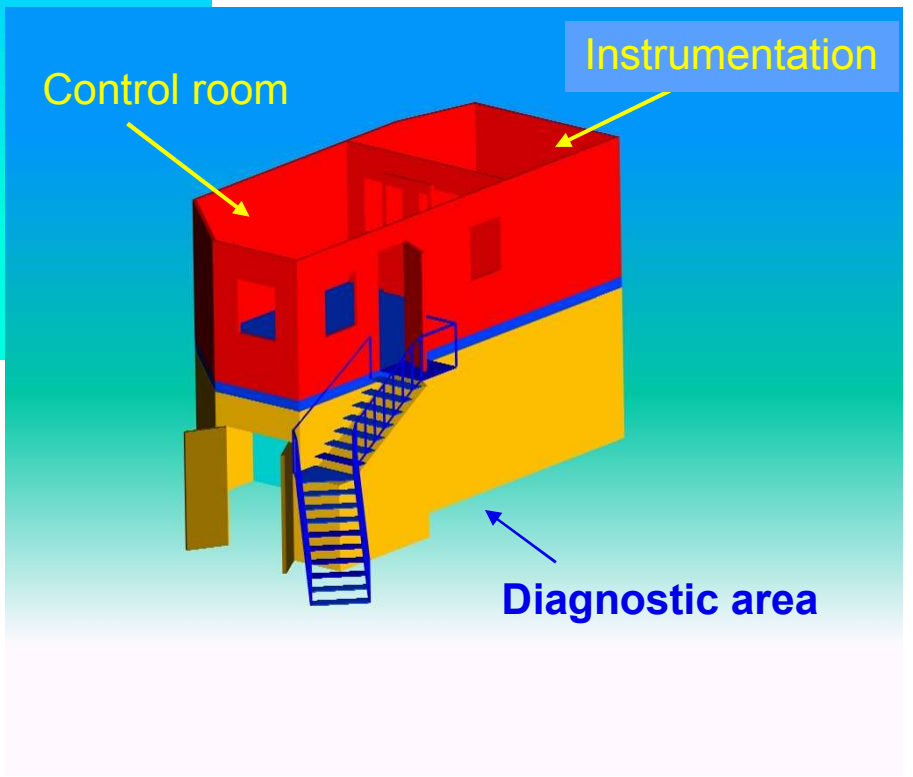
Thickness = 3 cm

Energy = 17 keV

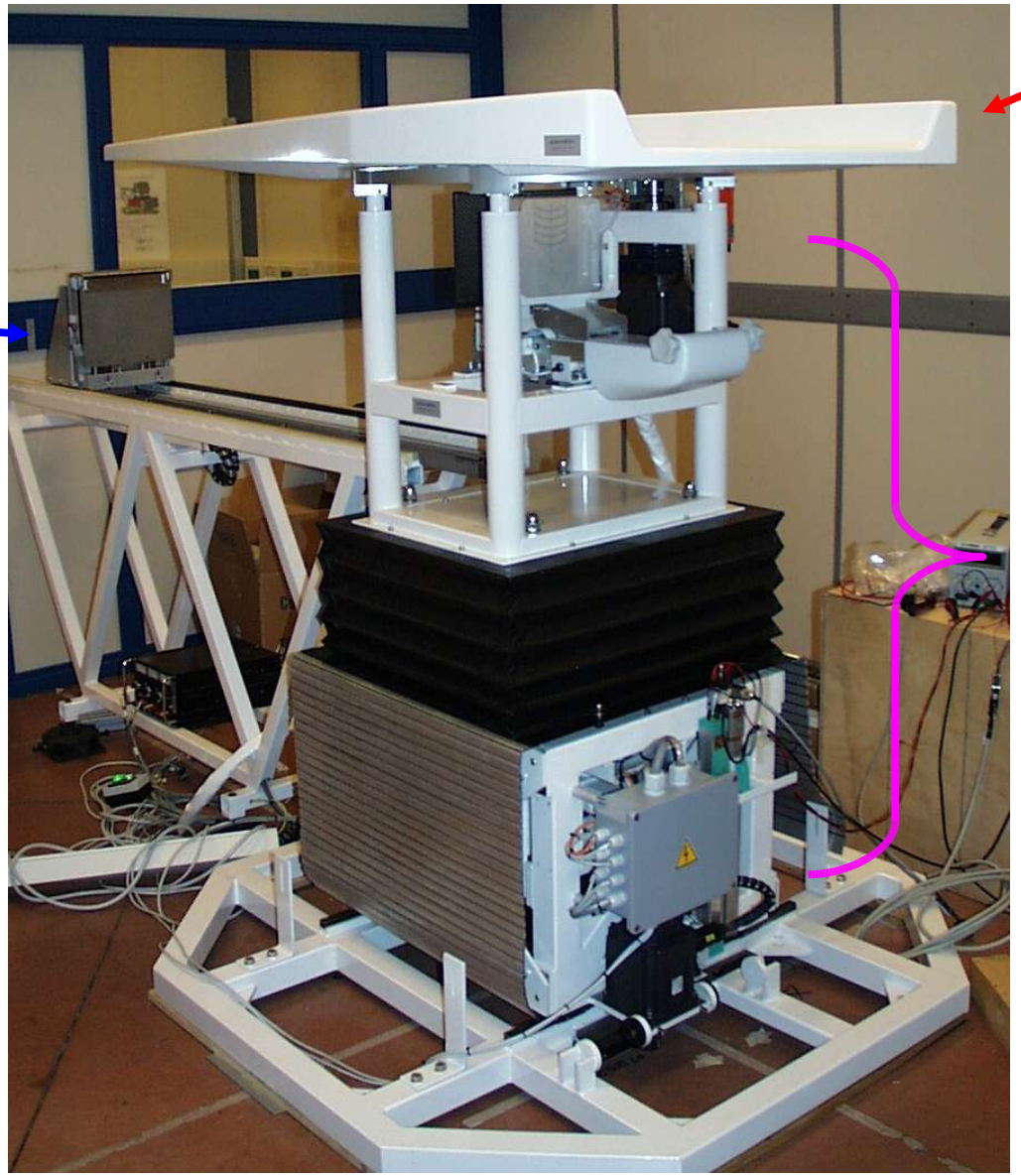
MGD = 0.5 mGy

The SR mammography system (I)



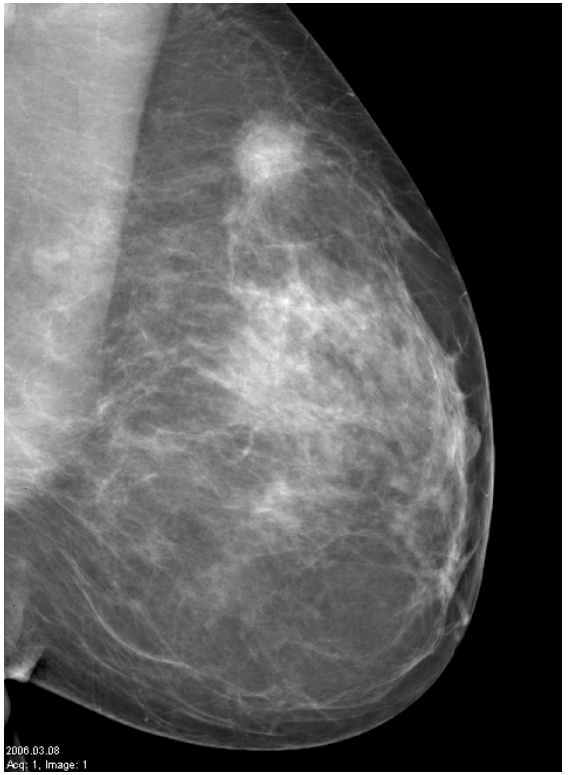


The SR mammography system (II)

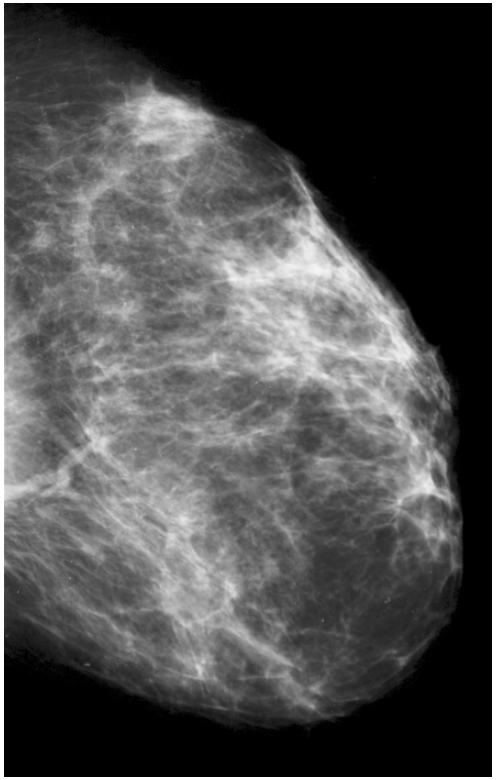


Clinical SR mammography: results

- Beamline commissioning started in 2000
- Approved for patients examinations in 2004
- First 28 patients examined in 2006 with screen-film technique with very good results



CONV obl



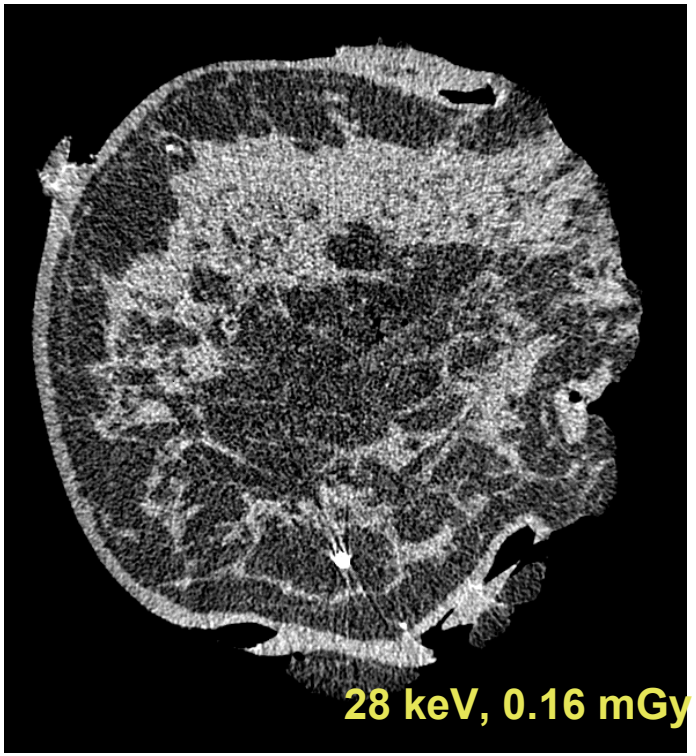
SR obl

Digital GE Senographe 2000D vs PHC SR

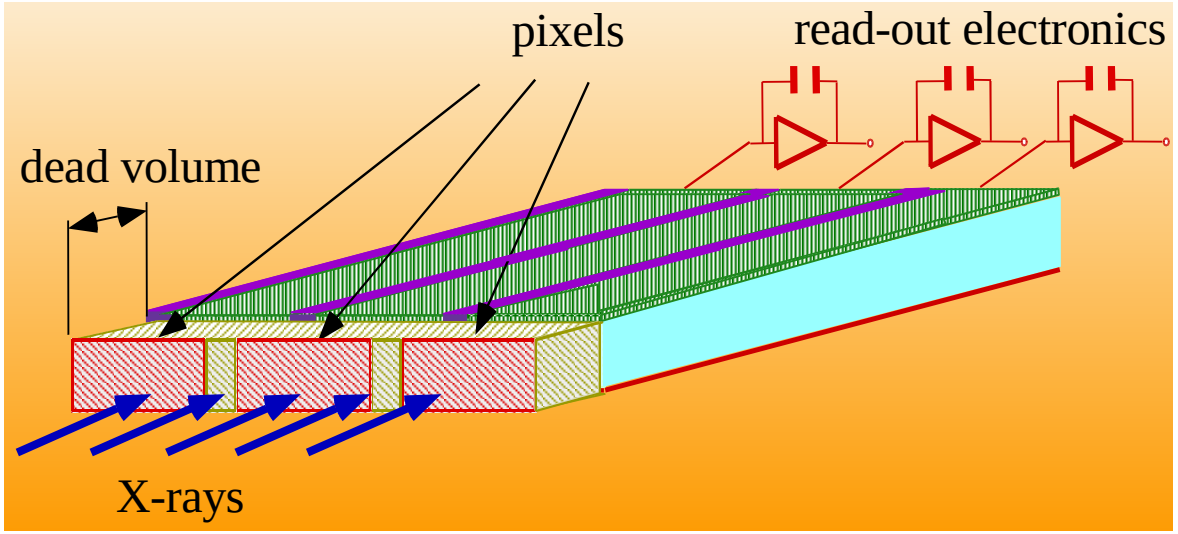
Next step: the digital system

- Edge-on technique pioneered by the SYRMEP collaboration
- Phase contrast techniques up to now used with screen-film seem feasible with Si microstrip detector
- Versatile system that can be used for absorption and tomographic imaging
- Complex mechanics to have a multi-layer system

Computed tomography of breast sample in-vitro



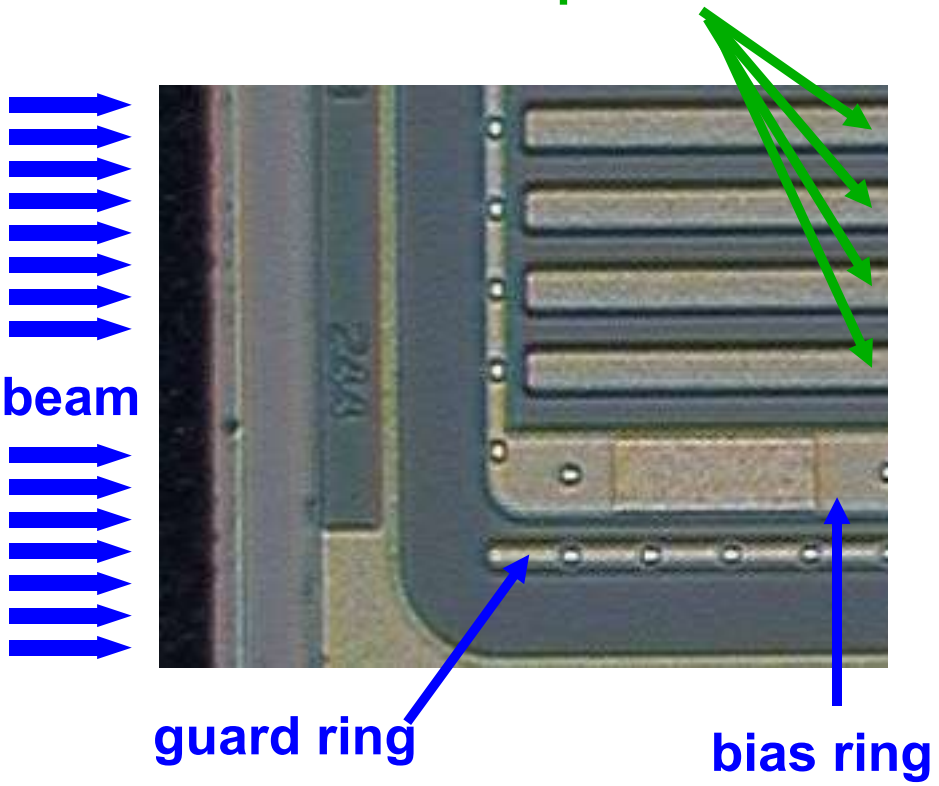
The edge-on technique



- A silicon microstrip detector is used in the so called ``edge-on'' geometry matching the laminar geometry of the beam
- The absorption length seen by the impinging radiation is given by the strip length (~ 100% in 1 cm of silicon for 20 keV photons)
- Almost complete scattering rejection
- The pixel size is determined by the strip pitch (H) times the detector thickness (V)
- Drawback: the dead volume in front of the strip

The microstrip silicon detector

- The guard ring is present on only 3 sides
- The distance between the bias ring and the scribe line is kept 200 μm shorter than the standard



- 256 to 1024 strips
- Strip length 2 cm
- 100 or 50 μm strip pitch
- Detector thickness: 300 μm

Pixel aperture: 100 or 50 x 300 μm²

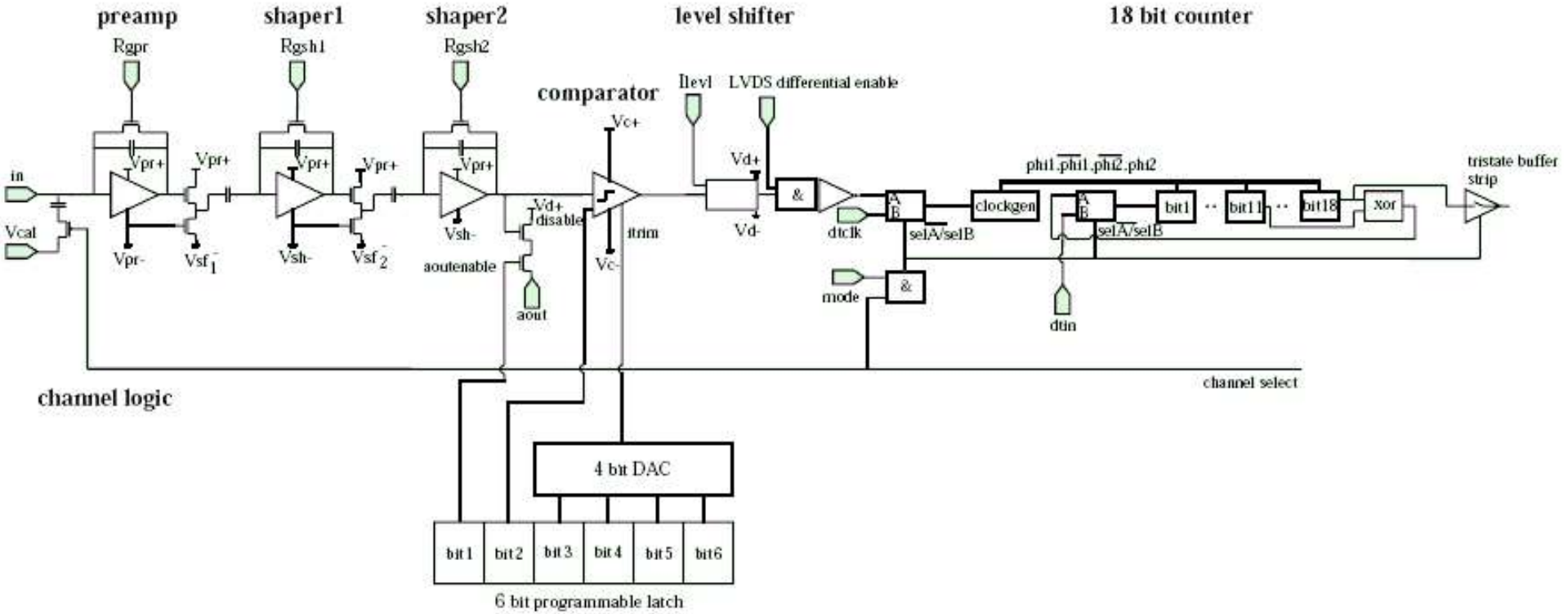
- Dead entrance window ~200 - 400 μm
- Detection efficiency: 80% (20 keV)

Produced by HAMAMATSU

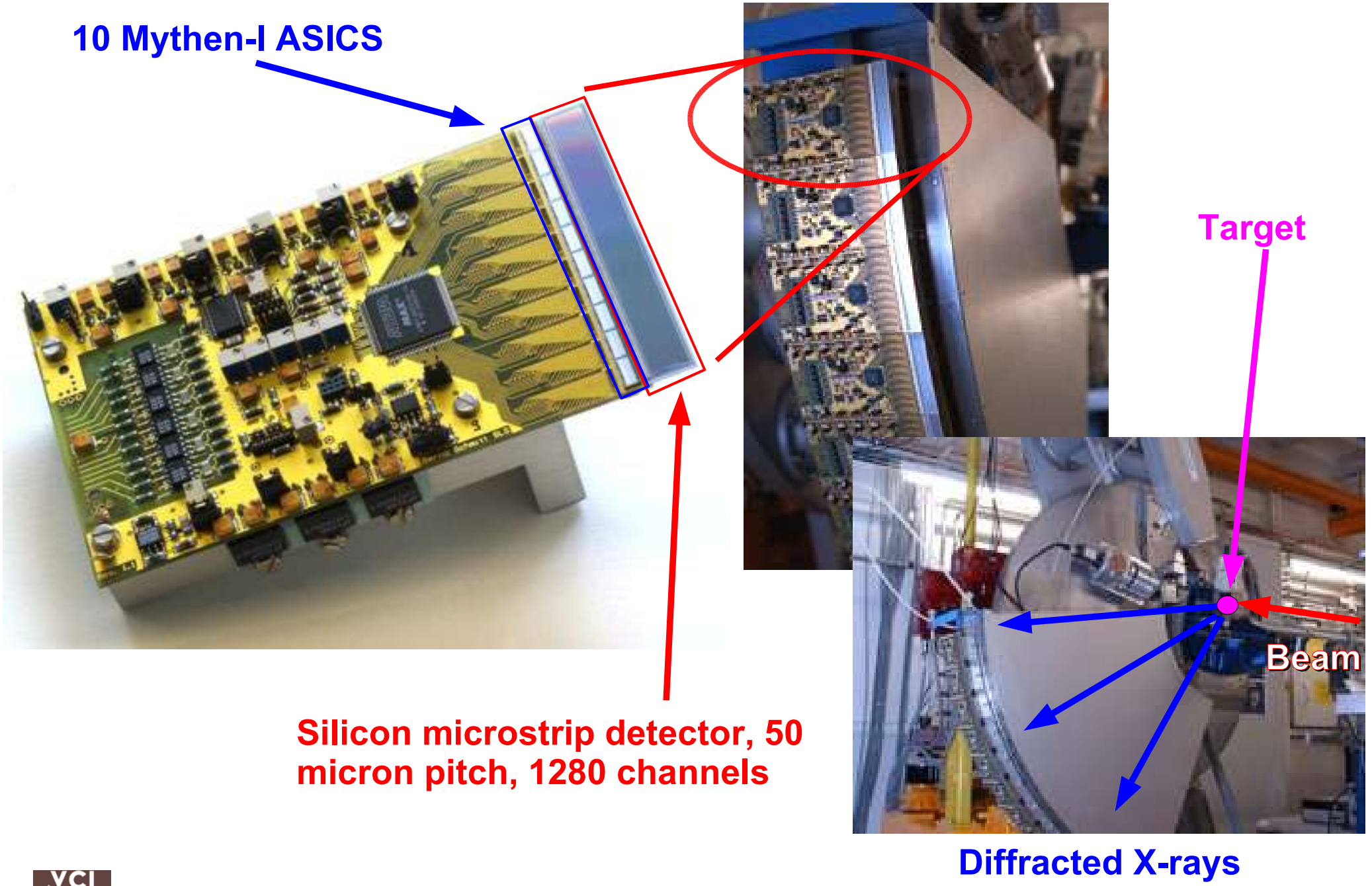
The Mythen ASIC

- Developed by the SLS detector group of the Paul Scherrer Institut, Villigen: photon counting ASIC for diffraction studies
- First version Mythen-I in DMILL 0.8 μm technology: deployed about 18k cnannels at the diffraction beamline of the SLS (Swiss Light Source), described in B. Schmitt et al., NIM A 501 (2003) 267·272
- Characteristics (Mythen-I)
  - 128 channels, 50 micron pitch
  - low noise preamp (noise about 230 e-)
  - 18 bit counter
  - Read-out time: 250 μs
  - Count rate: 1 MHz per channel

The Mythen-I ASIC architecture

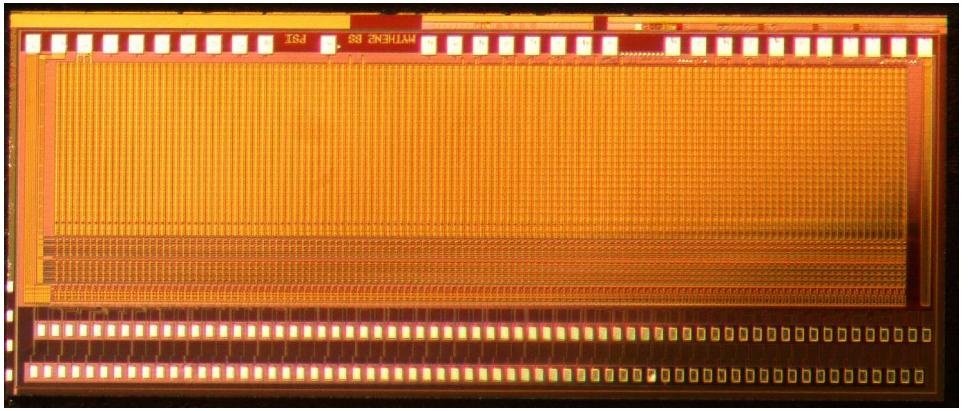


The Mythen readout system @ the SLS beamline



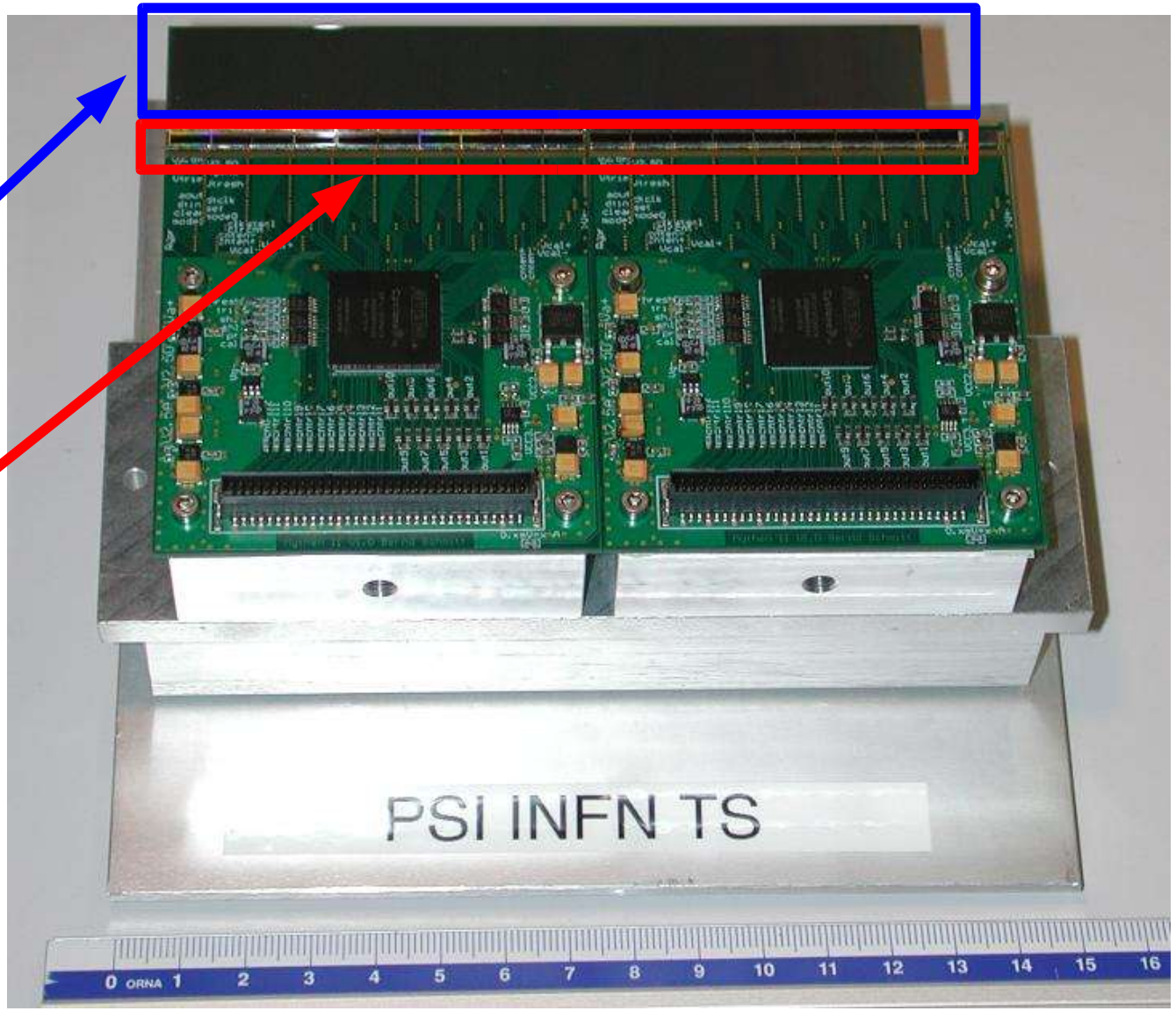
The Mythen-II ASIC: architecture and performance

- Evolution of the Mythen-I
- 0.25 μm UMC technology
- Upgrades:
  - 24 bit counter
  - re-design of the digital part
  - much better performance
  - 6-bit threshold trim DAC for each channel
  - with proper optimization usable up to 3 MHz (work in progress)

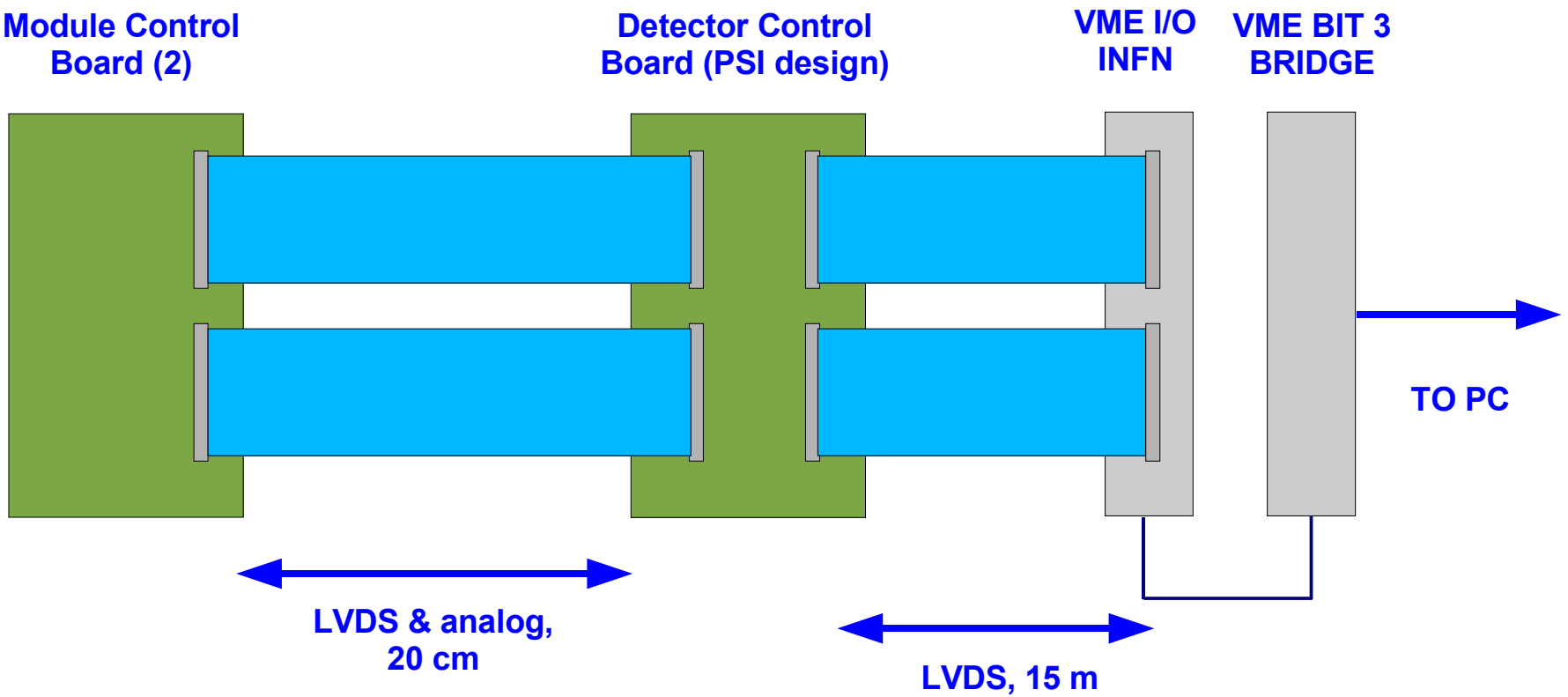


The PSI-TS module assembly

- Activated in 2006 a collaboration between INFN-TS and PSI (Anna Bergamaschi, Bernd Schmitt) to apply the Mythen modules to SR imaging
- One 12-cm Hamamatsu detector, 2368 strips
- Use of two ``standard'' PSI modules for a total of 19 ASICs, 2432 channels
- Assembled at PSI
- Three data taking periods in July, October and November 2006
- Very good performance (see later)

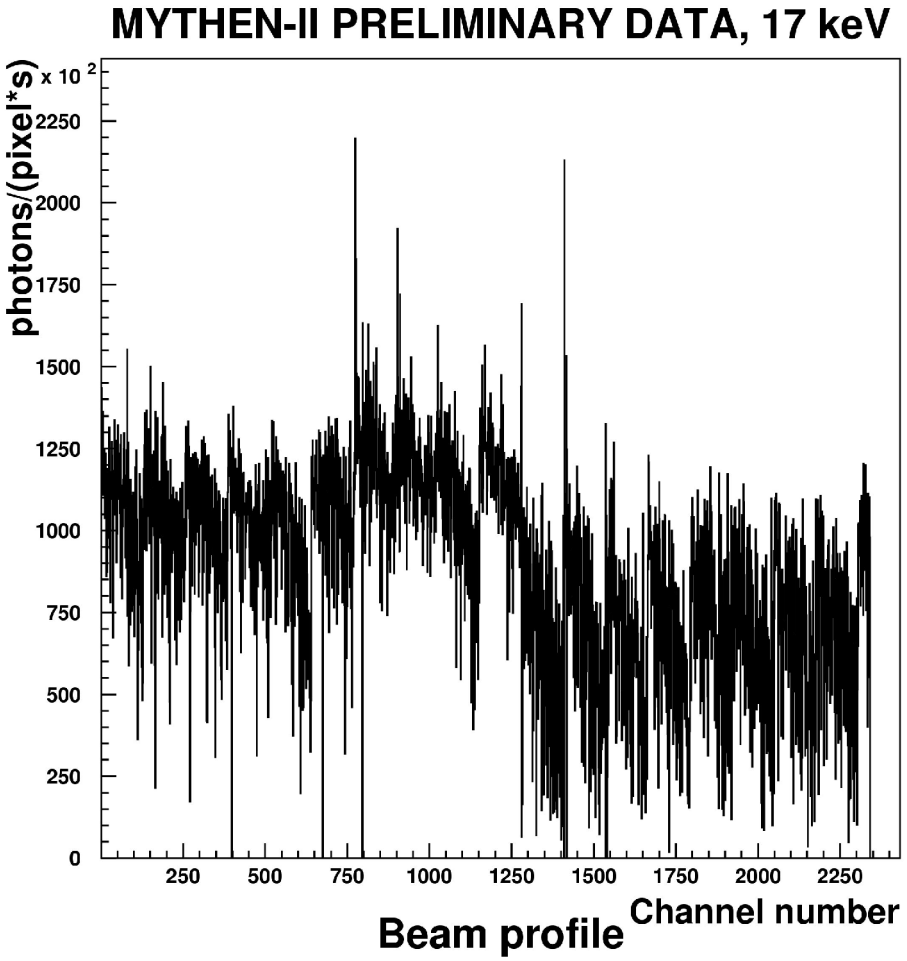


The PSI-TS readout

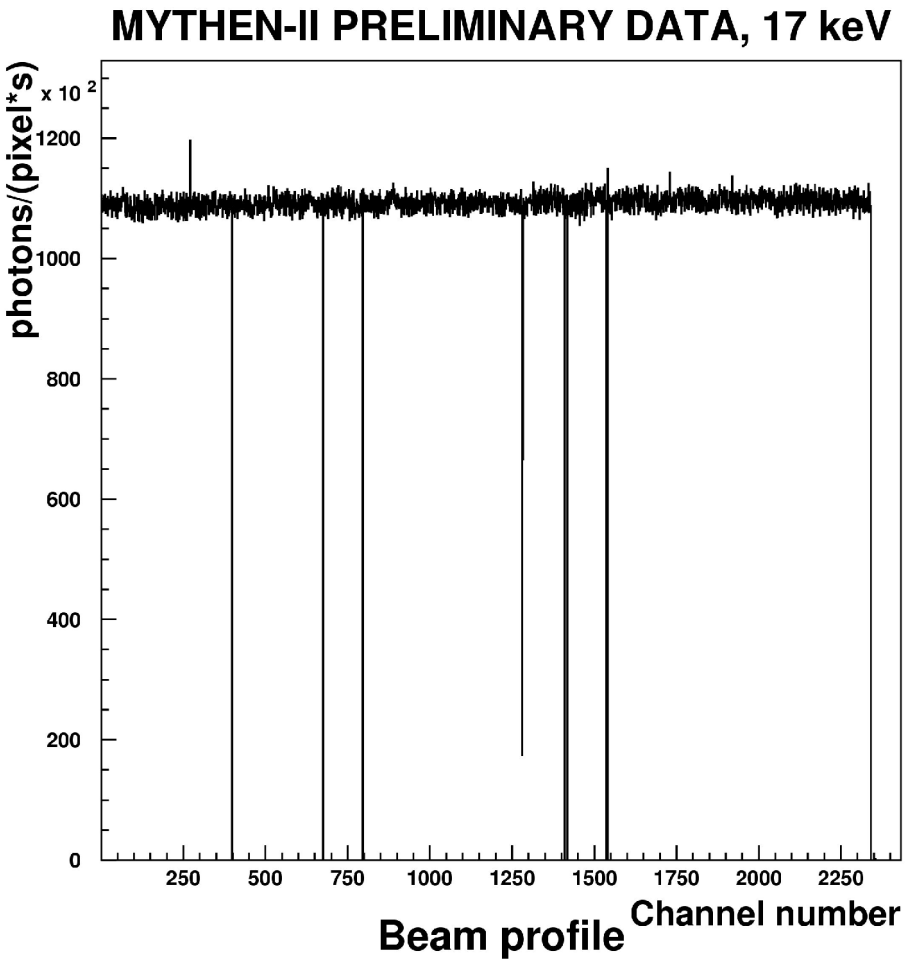


- Very simple readout
- Already designed an improved version of the VME I/O with an ALTERA Cyclone II FPGA and local memory to buffer the frames during the scan
- To control a single MCB the PSI SLS detector group has developed a compact board with a System-On-Chip ASIC controllable via ethernet (contact bernd.schmitt@psi.ch)

Experimental results: channel count equalization



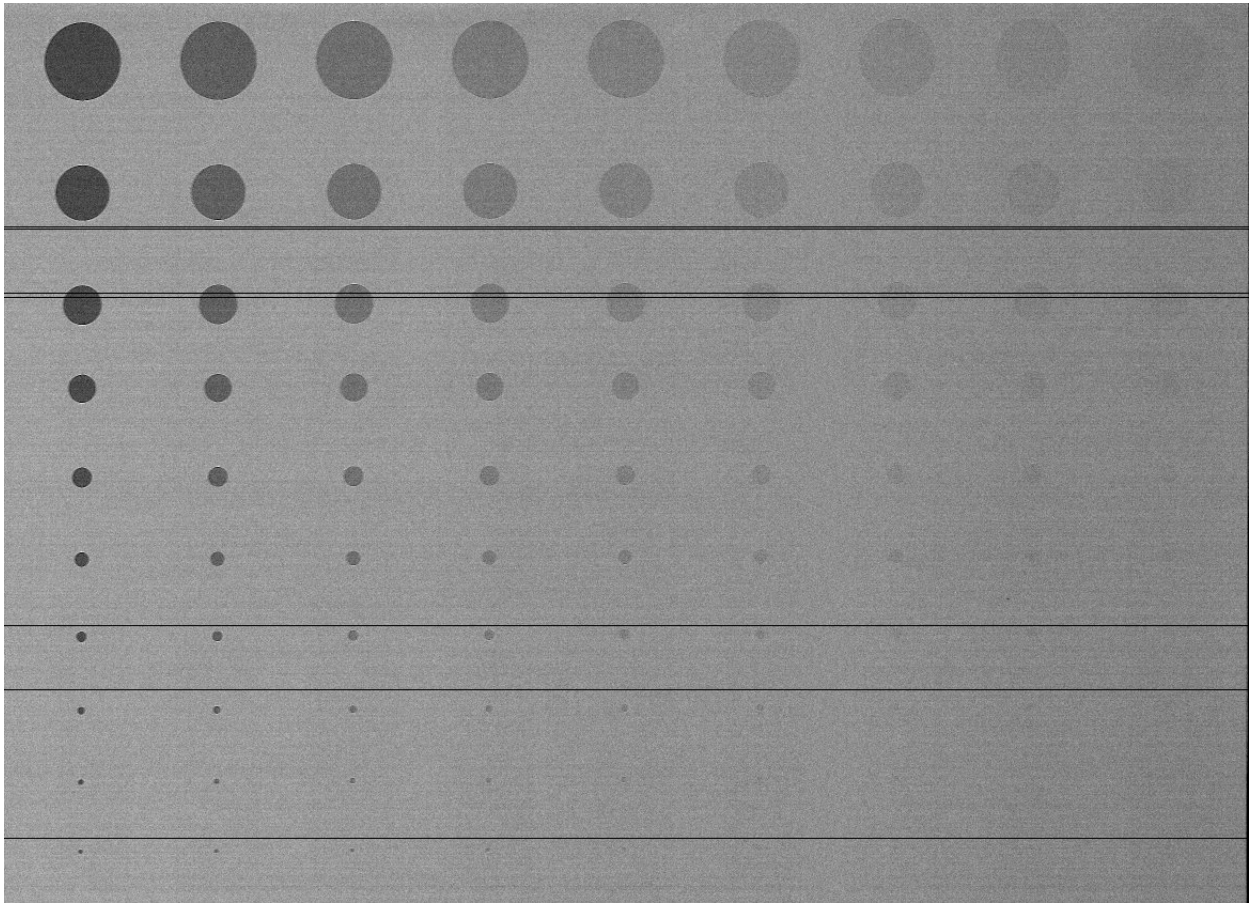
Before trim DAC adjustment



After trim DAC adjustment

Experimental results: contrast

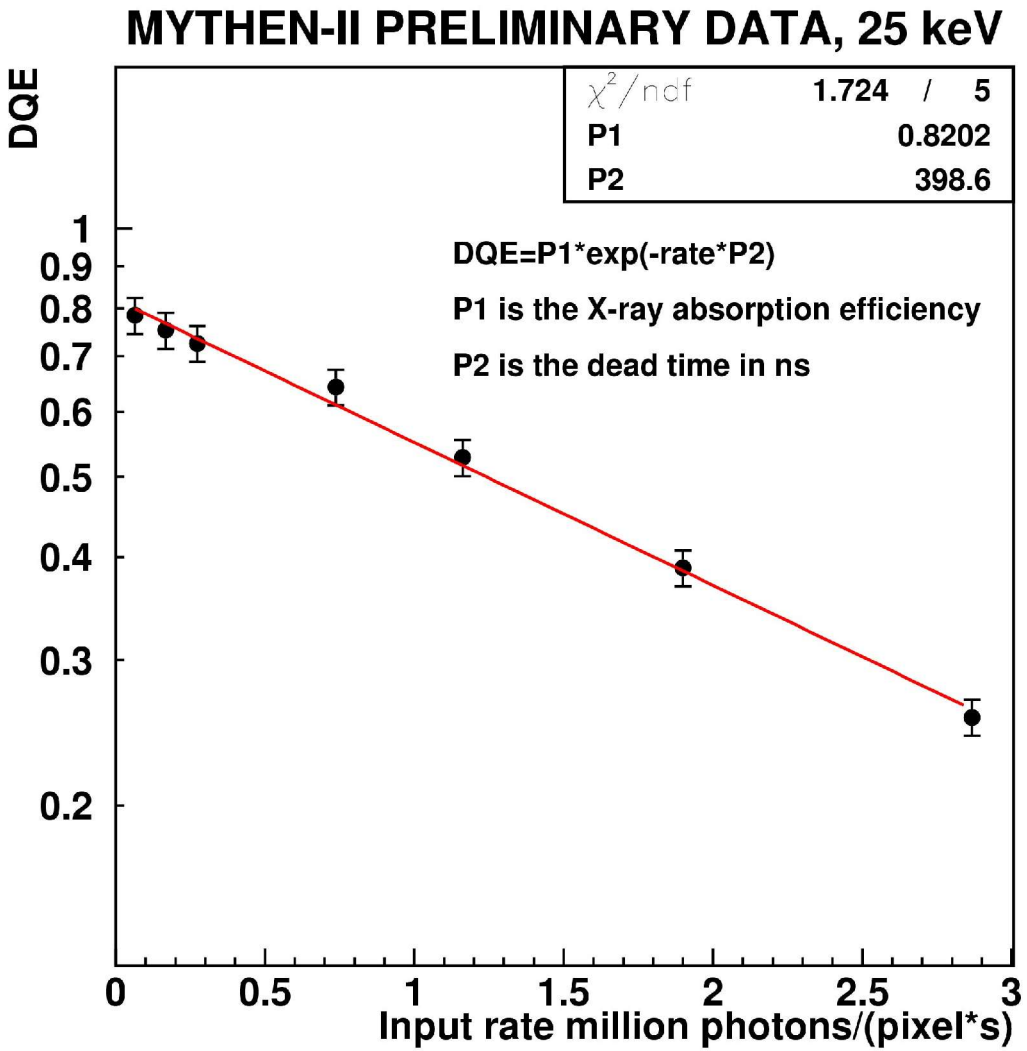
- **Contrast Phantom (Gammex RMI-180) data taken at 17 keV**



10k photons/pixel, acquisition rate 350 kHz, 20 keV

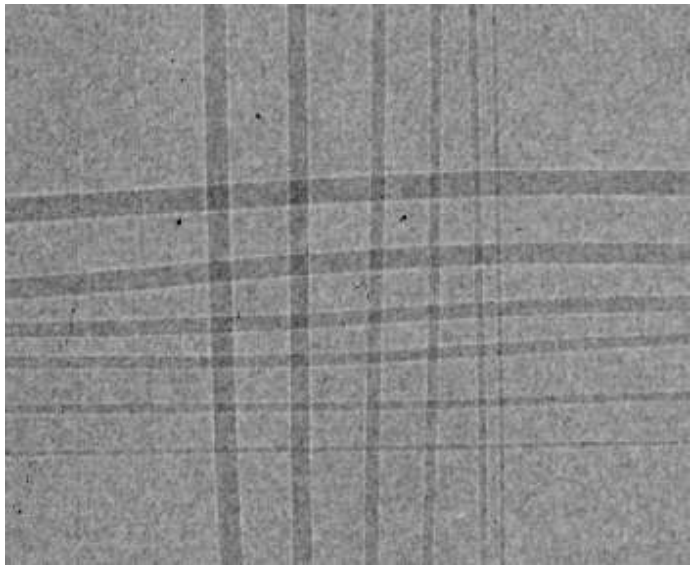
Experimental results: DQE

- Definition of DQE: output as a function of the input taking into account:
  - the X-ray conversion efficiency taking into account 400 μm of dead zone
  - the dead time of the detector
- Procedure: comparison of measured vs expected rate as a function of the thickness of the absorbing material in front of the detector
- Model for deadtime : paralysable counter out=exp(-in*deadtime)
- PRELIMINARY RESULTS: hard work on optimisation is going on

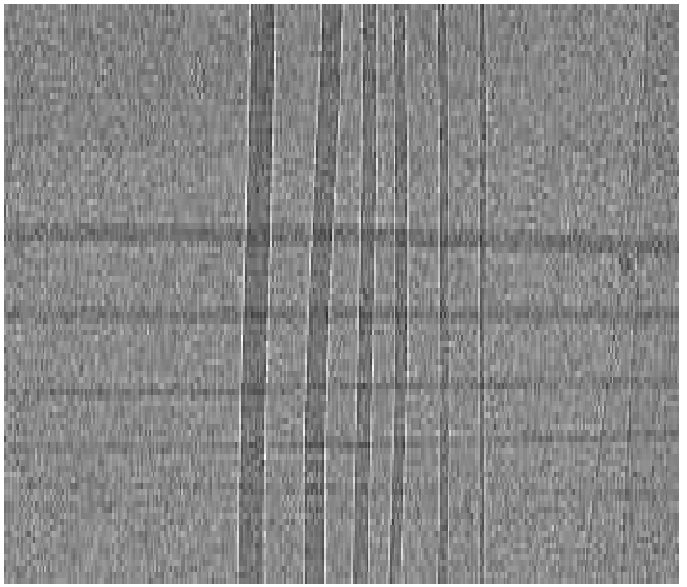


Experimental results: Phase Contrast imaging

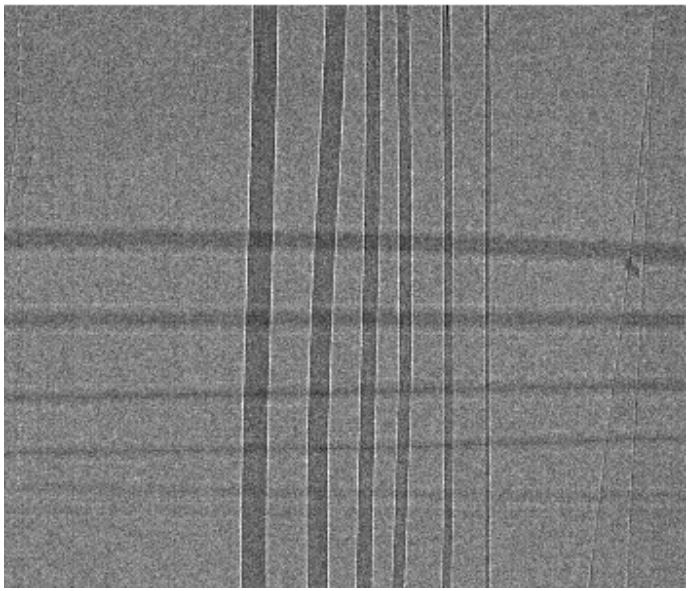
- **Images of nylon wires**



Film-screen image,
1.5 mGy dose



Mythen-II, 150 um scan step,
0.9 mGy Dose

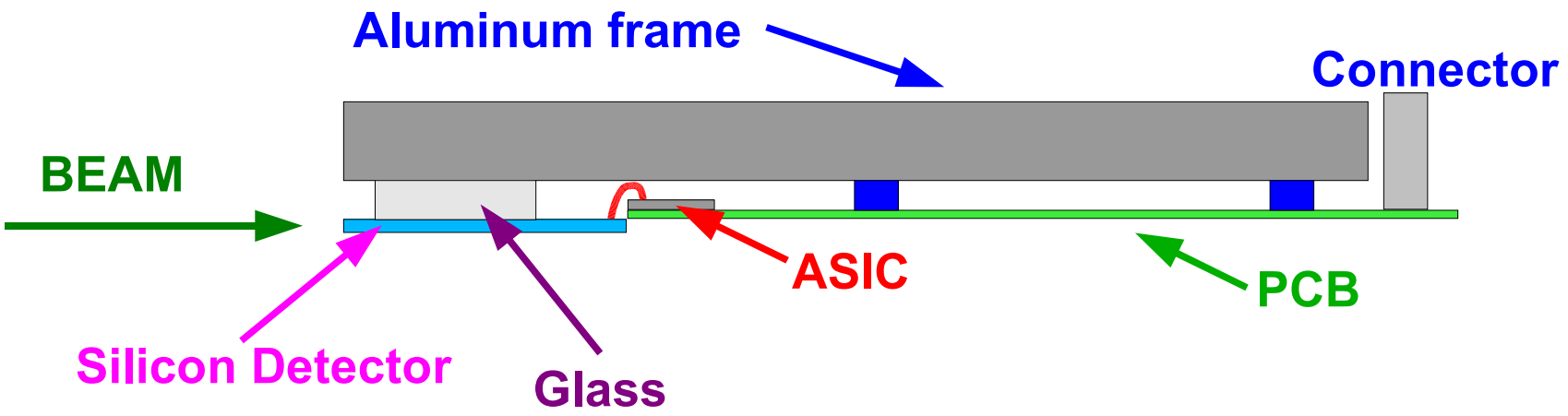


Mythen-II, 50 um scan step,
2.53 mGy Dose

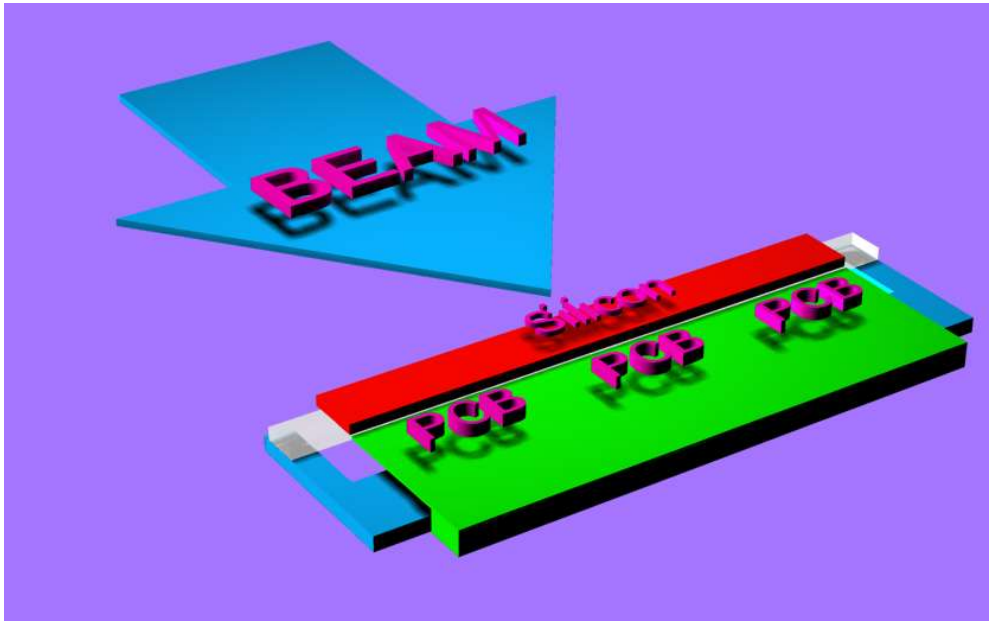
The PICASSO project

- To successfully exploit the beam size, a multi-layer (up to 4) should be built
- Development funded by INFN as the PICASSO project
- Tight requirements: very small spacing between layers, no aligned dead pixels, coverage of the beam width (21 cm), Silicon detector planarity about 10-20 μm
- The solution:
  - displacement in z along the beam of the various modules
  - gluing of two silicon detectors (9 and 12 cm wide) to a glass substrate
  - support of the PCB and the Silicon sensor by an Aluminum frame
- Complex mechanics

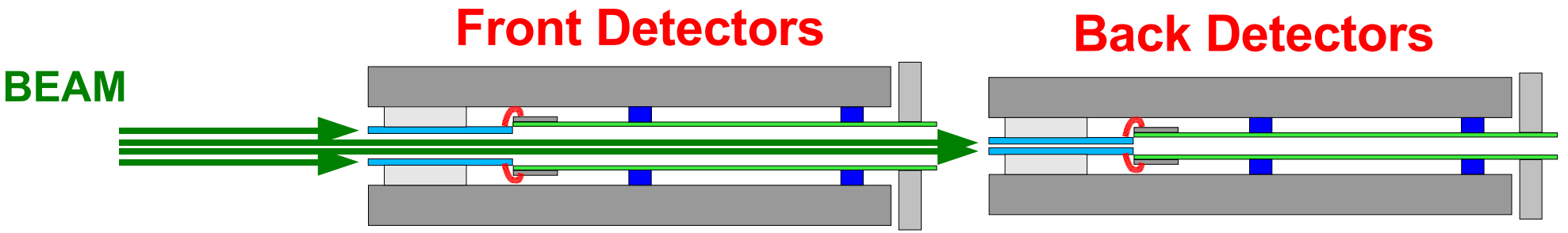
The single layer design



- Final PCB will host 33 Mythen-II ASICs for a total of 4224 channels
- On the PCB there will be 3 Altera Cyclone-II FPGA for ASIC control
- The two silicon detectors will be assembled in order to maintain the 50 μm pitch
- Assembly system developed by the mechanical workshop of INFN-TS



The multi layer design



- The mechanical tools are ready now
- A 12-ASIC PCB will be assembled with a silicon detector and will be tested in ELETTRA before Easter

Collaboration

- **PSI: Anna Bergamaschi, Bernd Schmitt**
- **INFN/University Trieste: Fulvia Arfelli, Edoardo Castelli, Renata Longo, Tatjana Rokvic, Erik Vallazza**
- **Sincrotrone Trieste: Diego Dreossi, Ralf Menk, Luigi Rigon**

Conclusions and outlook

- The SYRMEP beamline at the ELETTRA synchrotron fullfills now all the requirements for medical examinations
- A very promising detection system based on the Mythen-II ASIC has been developed
- Work is in progress to ensure the applicability of the microstrip detector for PhC imaging and tomography