Performances of different digital mammography imaging systems: evaluation and comparison

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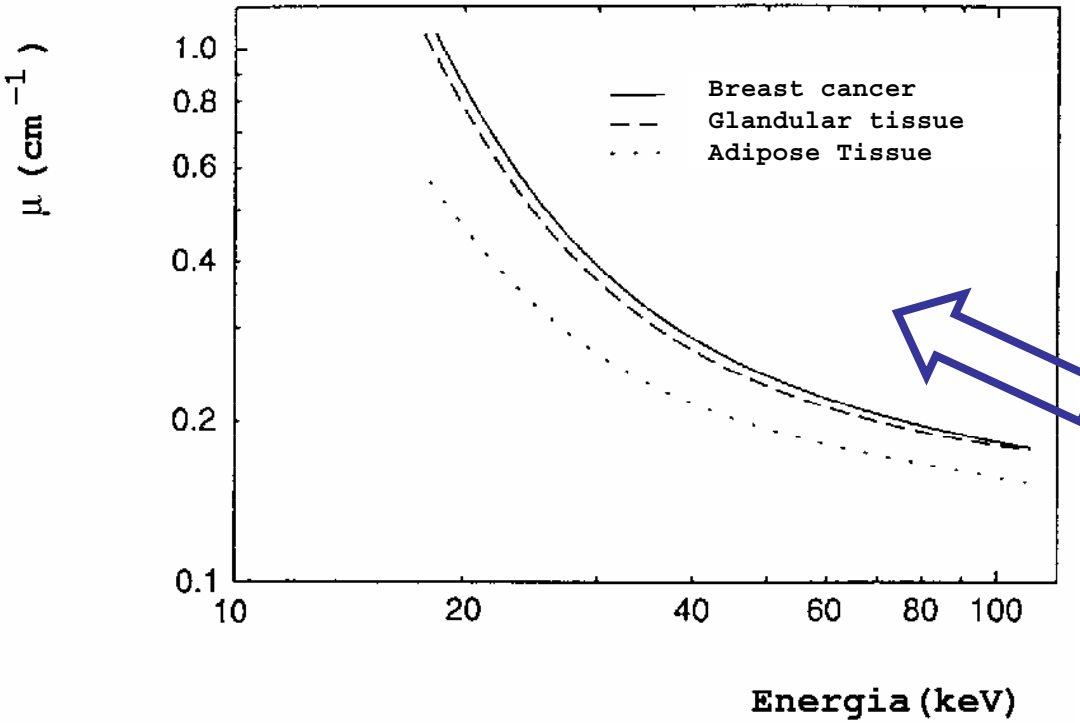
Outline

- ✓ Introduction
  - Mammography
  - Digital mammographic systems
- ✓ The MEDIPIX pixel detector for digital mammography
  - The assembly
  - Si and GaAs Detector development
- ✓ Imaging performance of the MEDIPIX pixel detector
  - Experimental set - up
  - Mammographic Phantom
  - Beam optimization
- ✓ Comparison with commercial digital systems
- ✓ MTF (Modulation Transfer Function) evaluation

The mammography challenge



Comparison between the linear attenuation coefficient of carcinoma, fat tissue and glandular tissue

- The problem for an early diagnosis: the X-rays attenuation of a pathological tissue is very similar to that of breast tissue.

- Typical lesions: masses (of the order of a cm and with low contrast) and clusters of microcalcifications (high contrast but small dimensions, of the order of hundreds of μm).

Digital Mammography (DM)

- ✓ Main features
  - Linear response with X-ray exposure
  - Wide dynamic range (10^4 – 10^5)
    - Mammography of dense breast
  - Reduced radiation dose
    - Exposure determined as a function of the Signal to Noise Ratio (SNR) not of the Optical Density of the film (OD)
    - Dose reduction from 20 to 80 %
  - Image processing
  - Time required for the examination (t_{exp}<1s; T_{proc}~minutes)

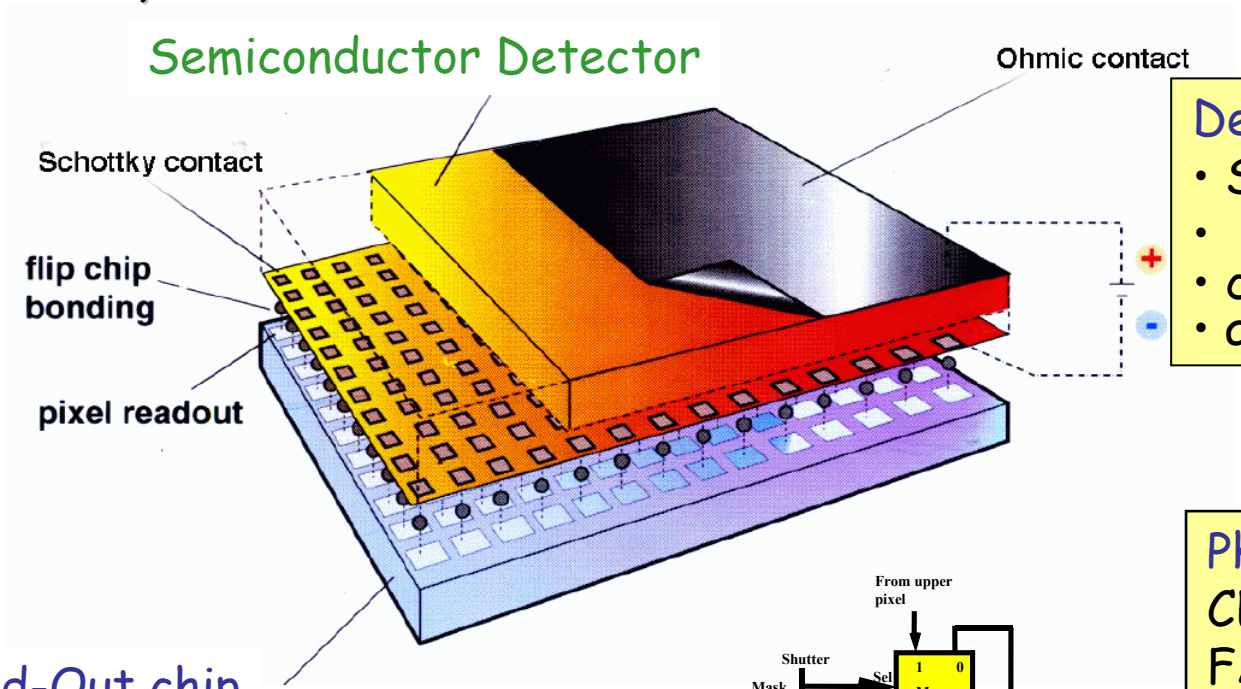
- ✓ Limits (?)
  - Spatial resolution
    - Film-screen systems ≥ 20 lp/mm
    - Digital systems ≤ 10 lp/mm
  - Costs

Digital systems

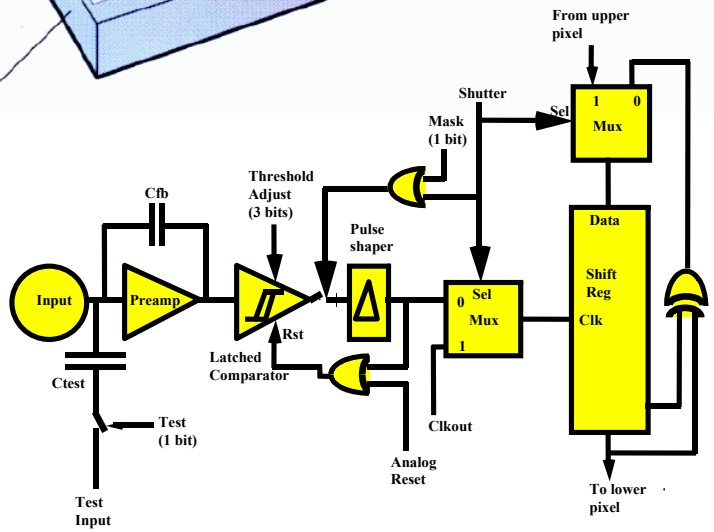
- ✓ Indirect integration detection systems
  - the X-rays are absorbed in a phosphor layer and produce light photons which convert into electric charges in a photo detector and then to an electric signal
    - Imaging Plates based on photostimulable phosphors
    - CsI(Tl) – aSi Flat Panels
    - Phosphor screen +OF taper+ CCD array (slot scanning)
- ✓ Direct integration detection systems
  - the X-ray photons directly convert into charges (electron-hole pairs) and thus to an electric signal in a photoconductor
    - aSe Flat Panels
- ✓ Direct photon counting systems
  - single photons are counted, i.e. the number of photons directly represent the intensity level in a pixel
    - Sectra Microdose Mammography (MDM) based on Si detectors
    - Xcounter based on gas avalanche photodiodes

The MEDIPIX1 Pixel detector for DM

http://medipix.web.cern.ch/MEDIPIX/

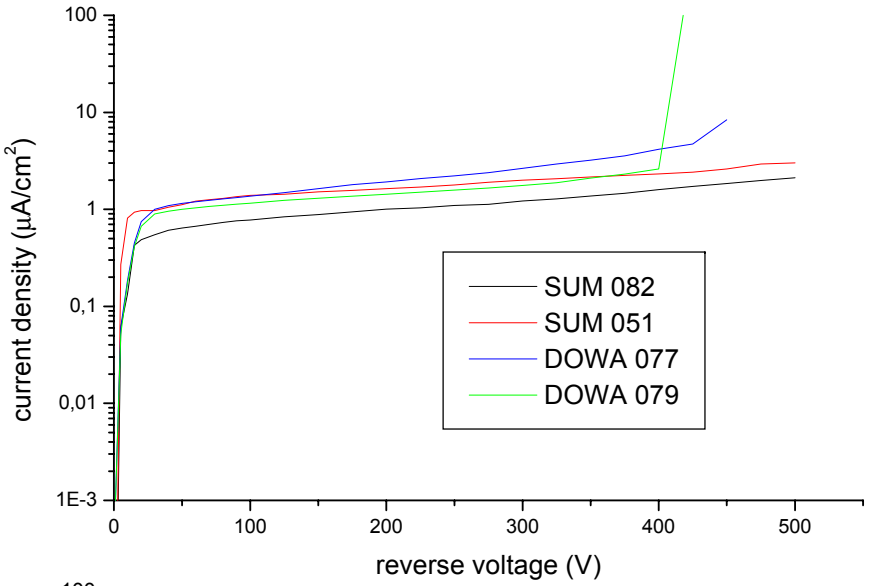


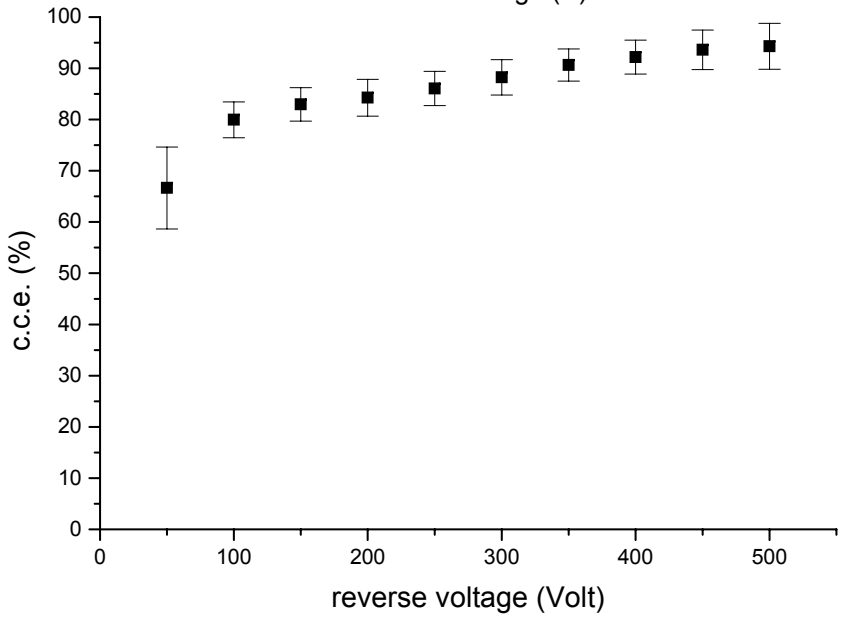
Detector
- Si, GaAs
- pixel 170 x 170 μm²
- channels 64 x 64
- area 1.2 cm²

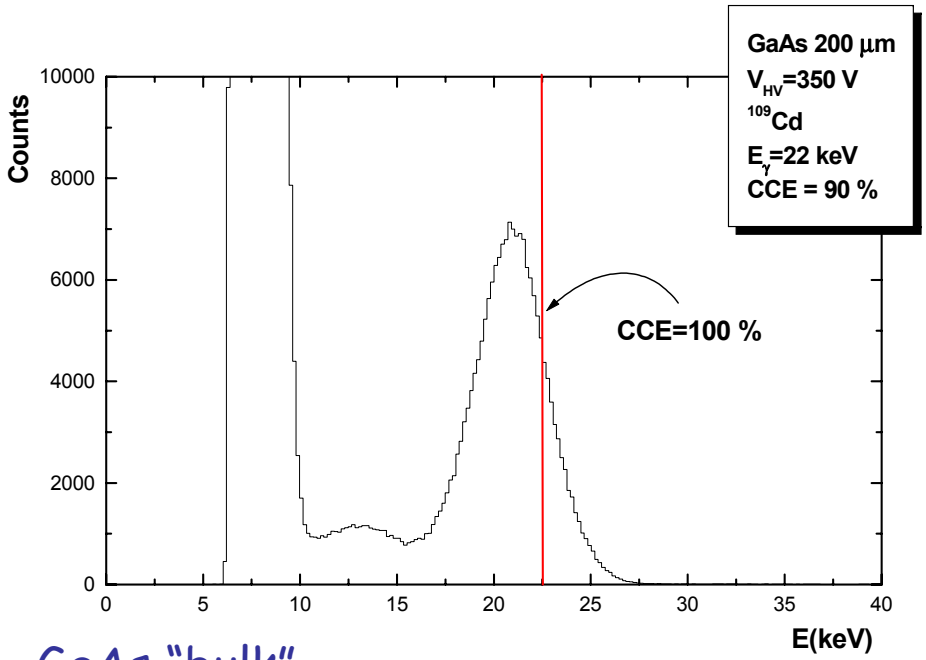


Photon Counting Chip (PPC)
CERN SACMOS 1 μm
FASELEC Zurigo
Pixel 170 x 170 μm²
Channels 64 x 64
Area 1.7 cm²
Threshold adjust 3-bit
Pseudo-random counter 15-bits

The GaAs pixel detector: material characterization







GaAs "bulk"

LEC (Liquid Encapsulated Chochralski),

Semi-insulating (SI)

Sumitomo

Resistivity = 10^8 Ohm cm

Contacts

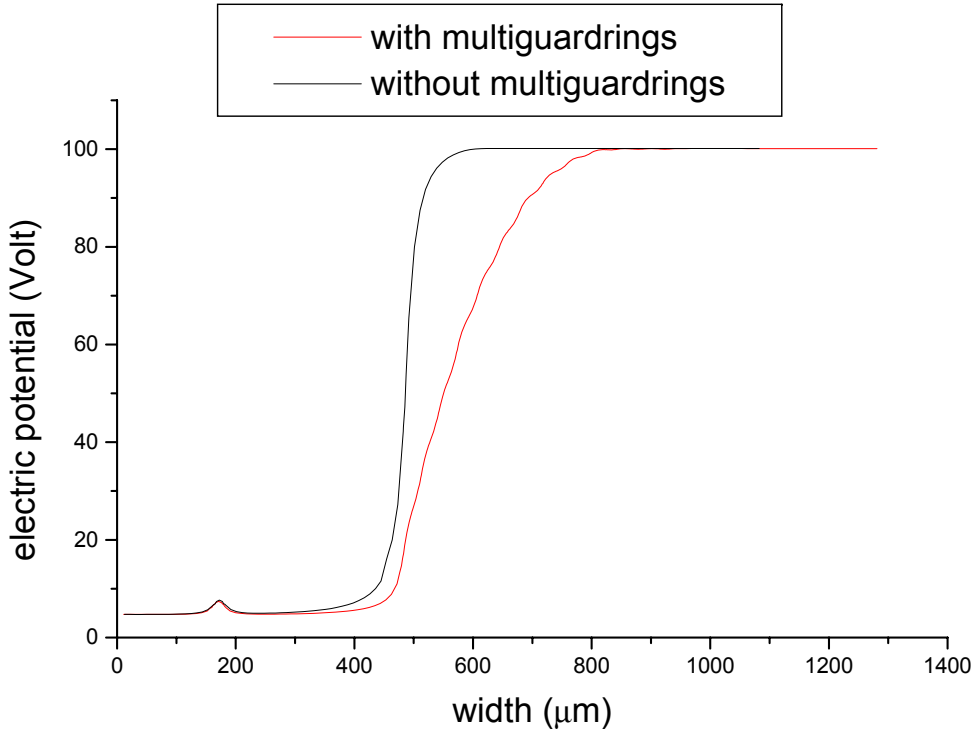
Schottky : multilayer Ti/Pd/Au

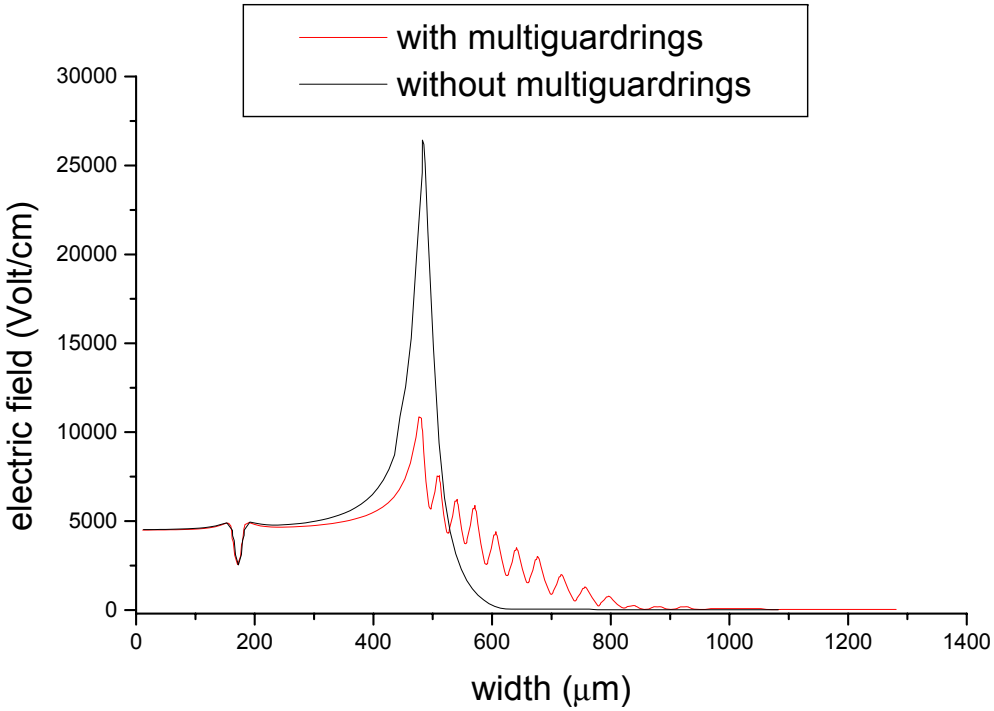
(AMS Roma)

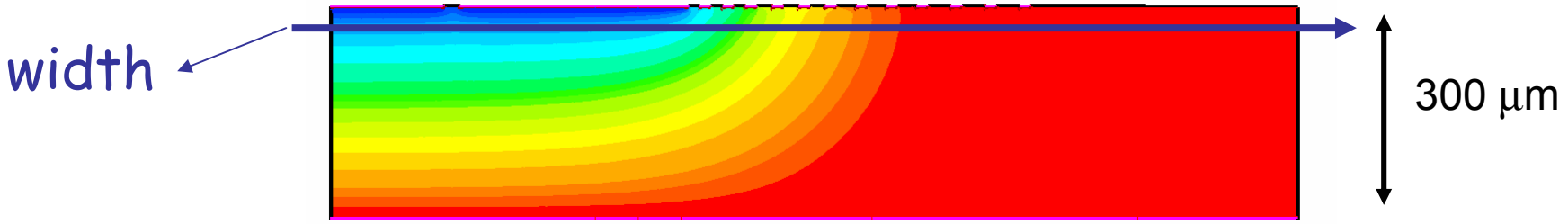
Thickness

200 μm

The Si pixel detector: geometry simulation





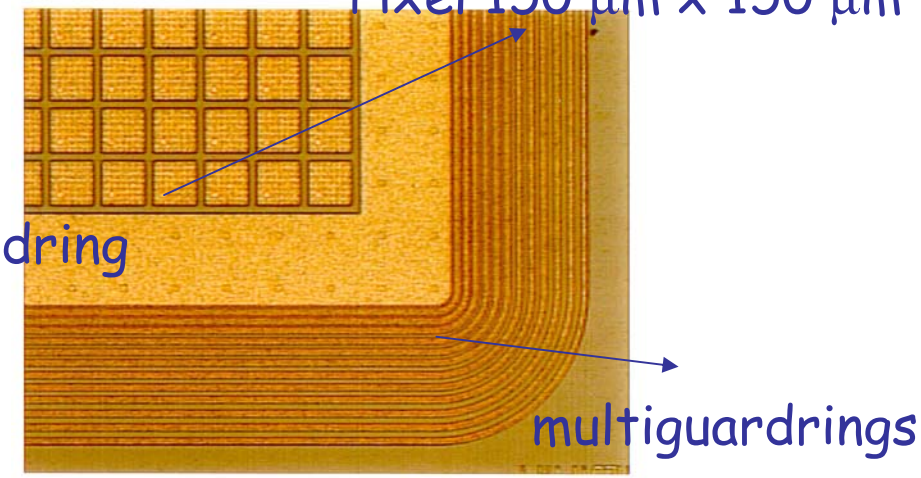


Simulation performed with the package ISE-TCAD

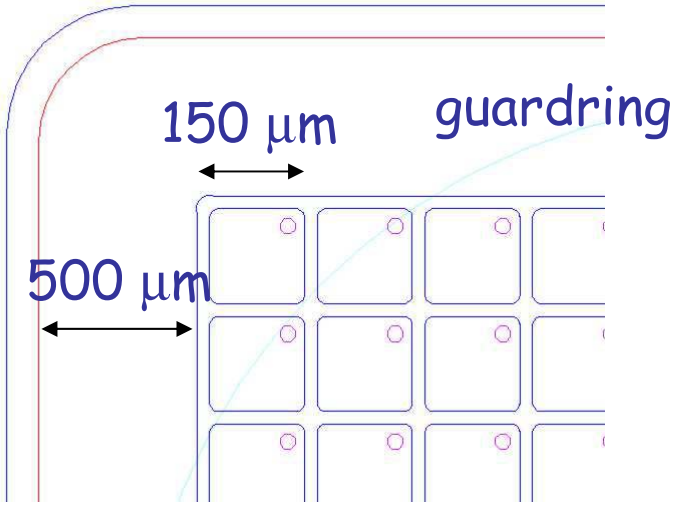
The pixel detectors

- ✓ Geometry
  - Pixel 150 μm, interpixel 20 μm
  - 64 x 64 pixels
  - Sensitive area 1.2 cm^2

- ✓ Si detectors
  - Produced by ITC-IRST (Trento, Italy)
  - Thickness 300, 525, 800 μm
  - p^+-n junction
  - Bump bonding by VTT (Finland)



- ✓ GaAs detectors
  - Produced by AMS (Italy)
  - Thickness 200 μm
  - Schottky contacts
  - Bump bonding by AMS



Detection efficiency @ 20 keV
- Si 300 μm 26 %
- Si 525 μm 40 %
- GaAs 200 μm 98 %

Experimental setup

Source: standard mammographic tube
(Instrumentarium Imaging Products Diamond)

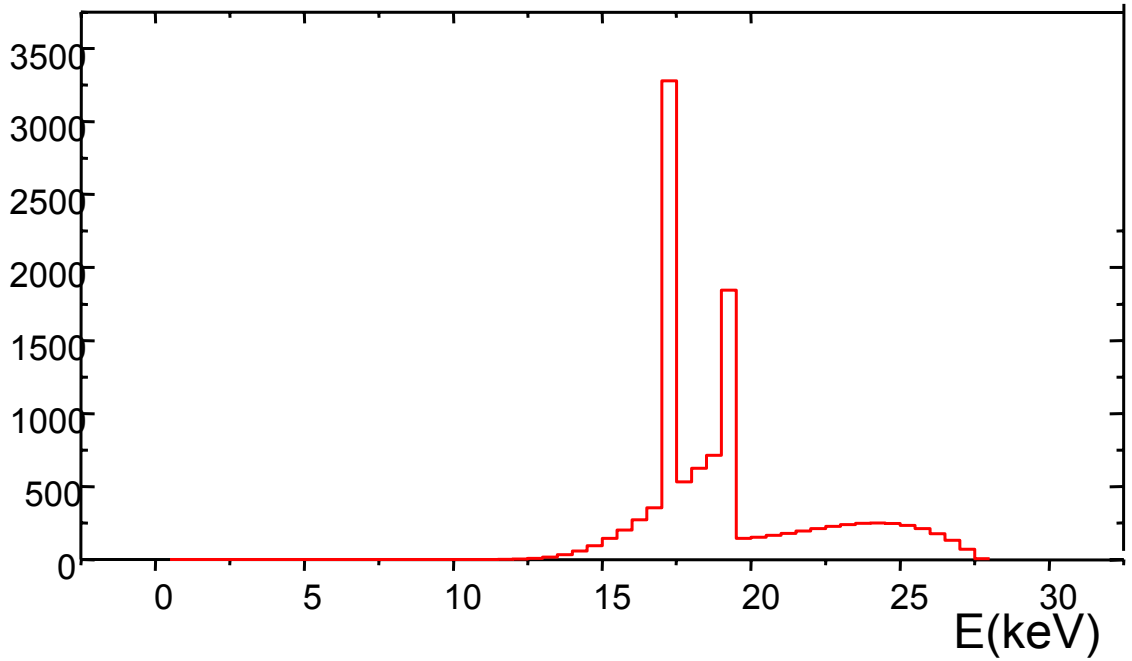
Molibdenum target

Mo (0.03 mm) and Be (1 mm) filters

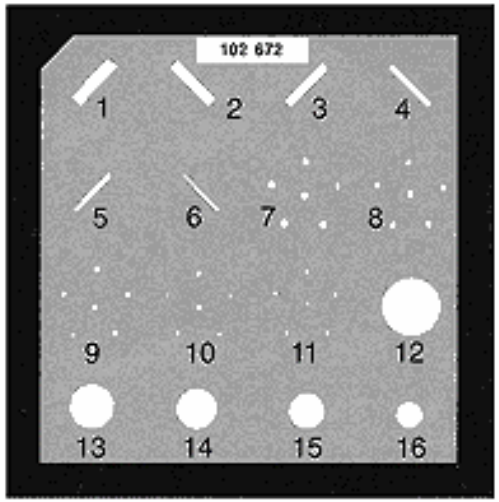
Distance between the beam focus and the detector = 64 cm

Mammographic facility of the Istituto di Radiologia, Ospedale S. Chiara, Pisa, Italy

mammographic spectrum (28 kVp)
After 4 cm Lucite
Simulated with the Program IPEM Report 78



Mammographic Phantom: RMI 156



RMI 156 phantom is recommended for quality checks in mammography (as suggested by American College of Radiology (ACR) Phantom)

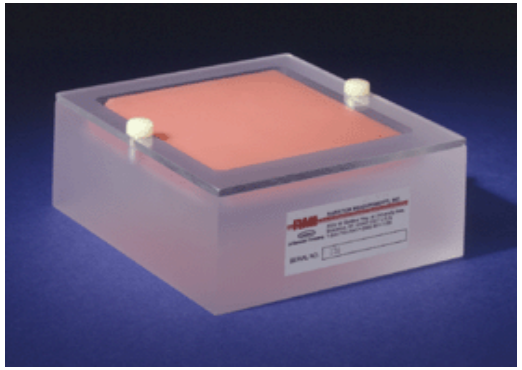
dimension : 8 x 8 cm^2

a Lucite block 3.3 cm thick
a wax block 0.6 cm thick
a 0.3 cm thick cover

It simulates a compressed breast (4.2 cm)

16 test objects embedded in wax:

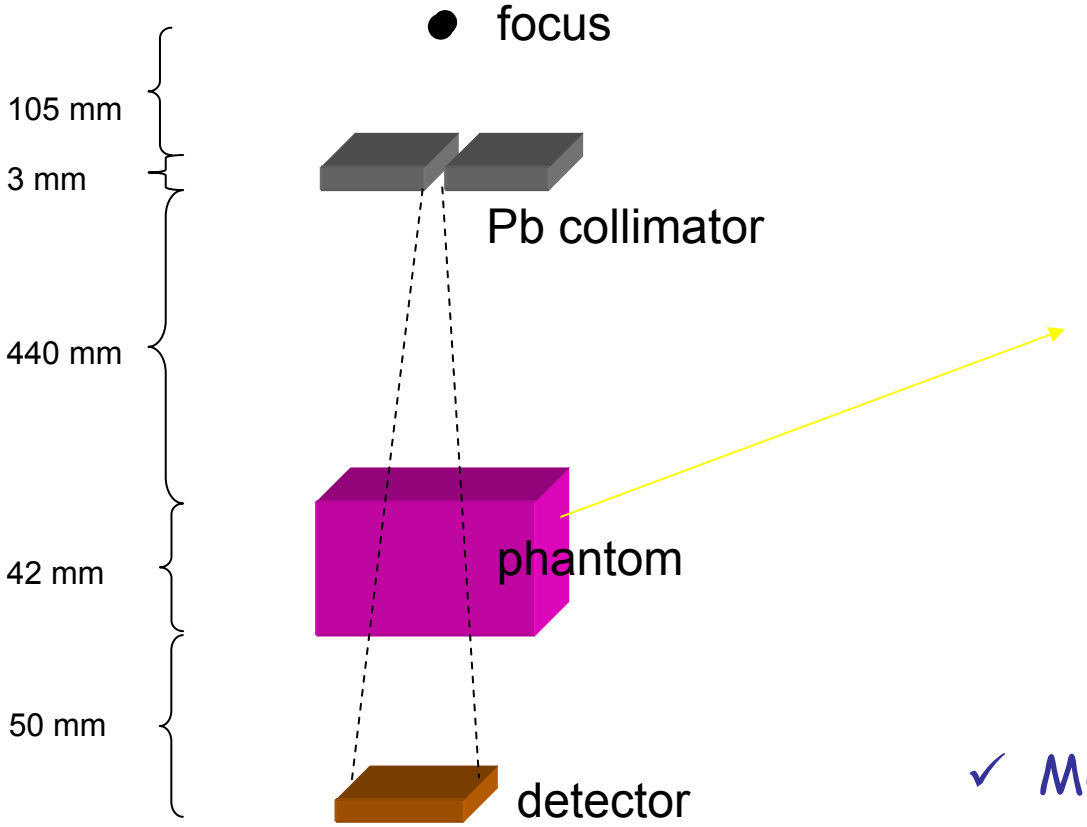
5 groups of simulated micro-calcifications of different diameter
(0.54 mm, 0.40 mm, 0.32 mm, 0.24 mm and 0.16 mm),

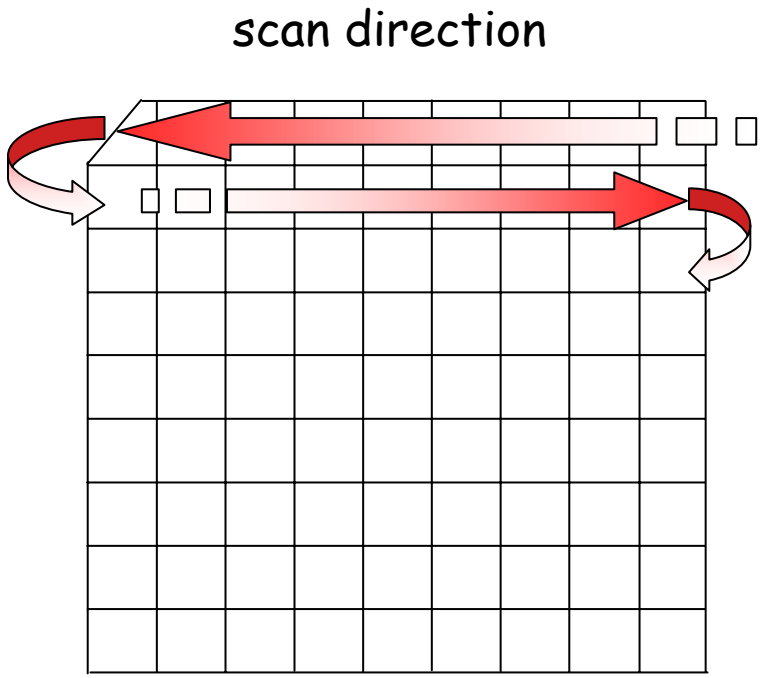


5 different thickness tumor-like masses
(2.00 mm, 1.00 mm, 0.75 mm, 0.50 mm and 0.25 mm)

6 different size nylon fibers that simulate fibrous structures
(1.56 mm, 1.12 mm, 0.89 mm, 0.75 mm, 0.54 mm and 0.40 mm)

Acquisition Geometry

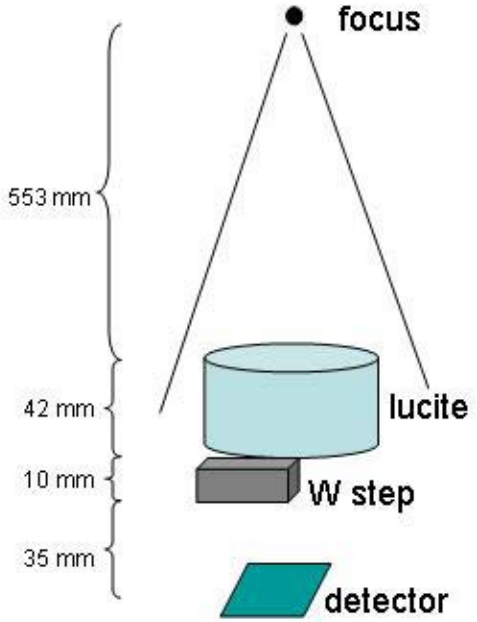


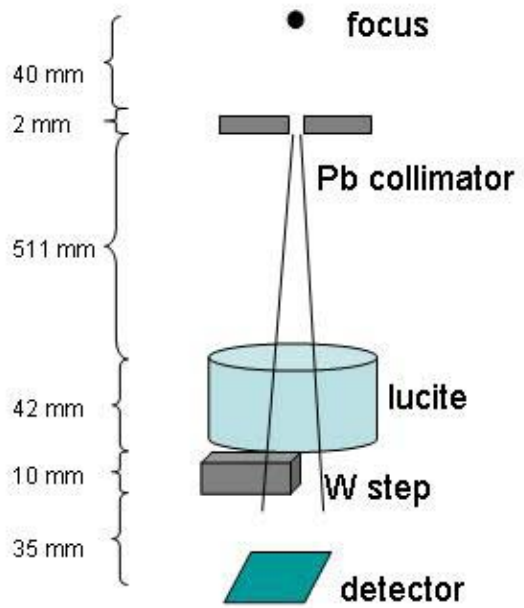


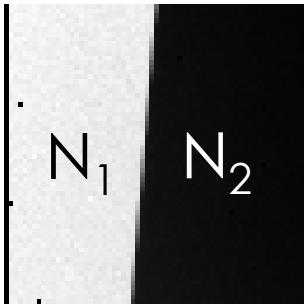
- ✓ Move and tile technique
- ✓ 72 different acquisitions
- ✓ scanning performed with stepper motors controlled by the PC

Exposure conditions optimization

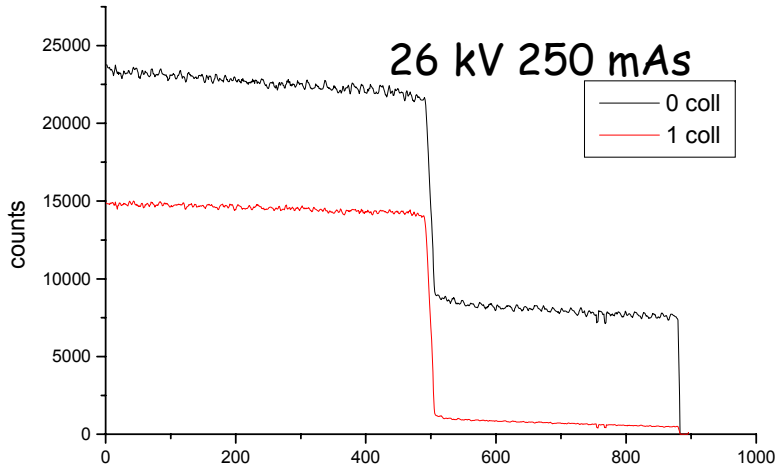
The effect of the collimator has been evaluated by measuring the contrast of a W edge with and without a collimator







With one collimator



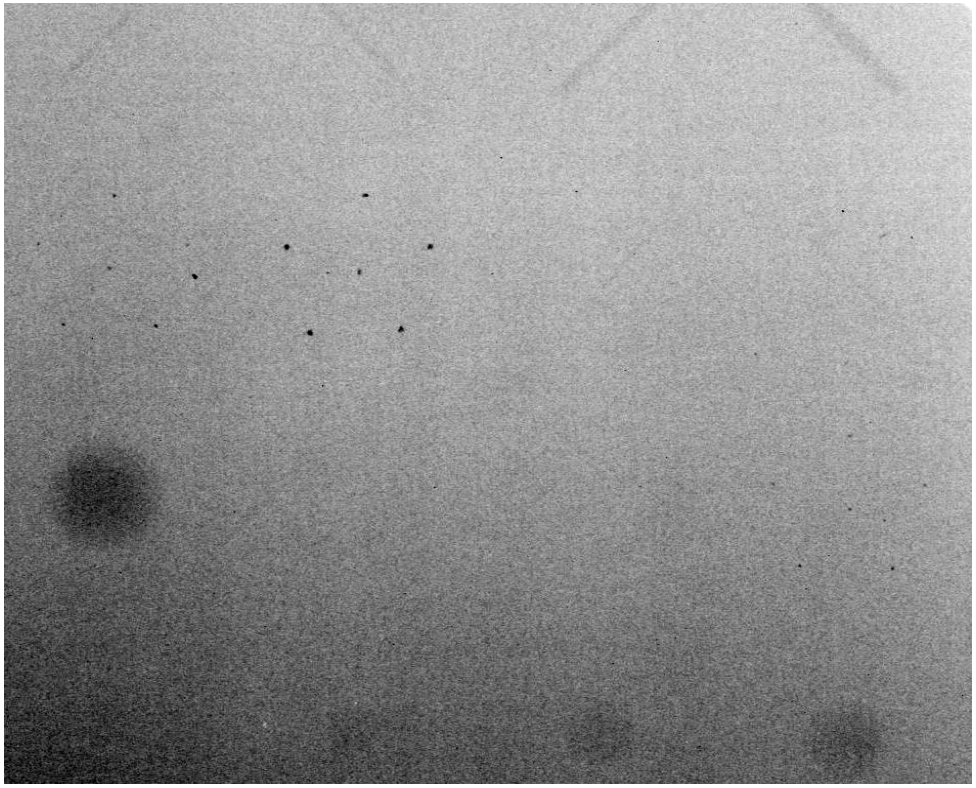
contrast

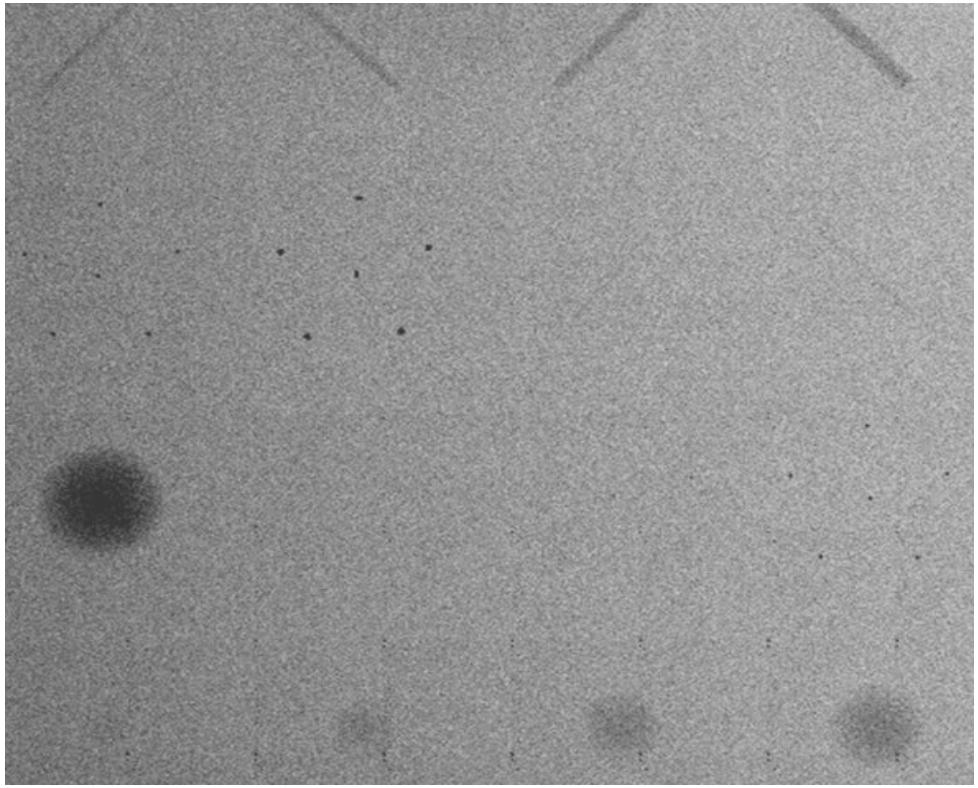
(65.0 ± 0.7) %

(95.11 ± 0.03) %

- The use of a collimator close to the beam focus allows a significant improvement in the detected contrast and therefore in the image quality.
- The system equipped with 2 collimators shows a slight contrast improvement (~ 0.6%).

MEDIPIX I –Film Images Comparison

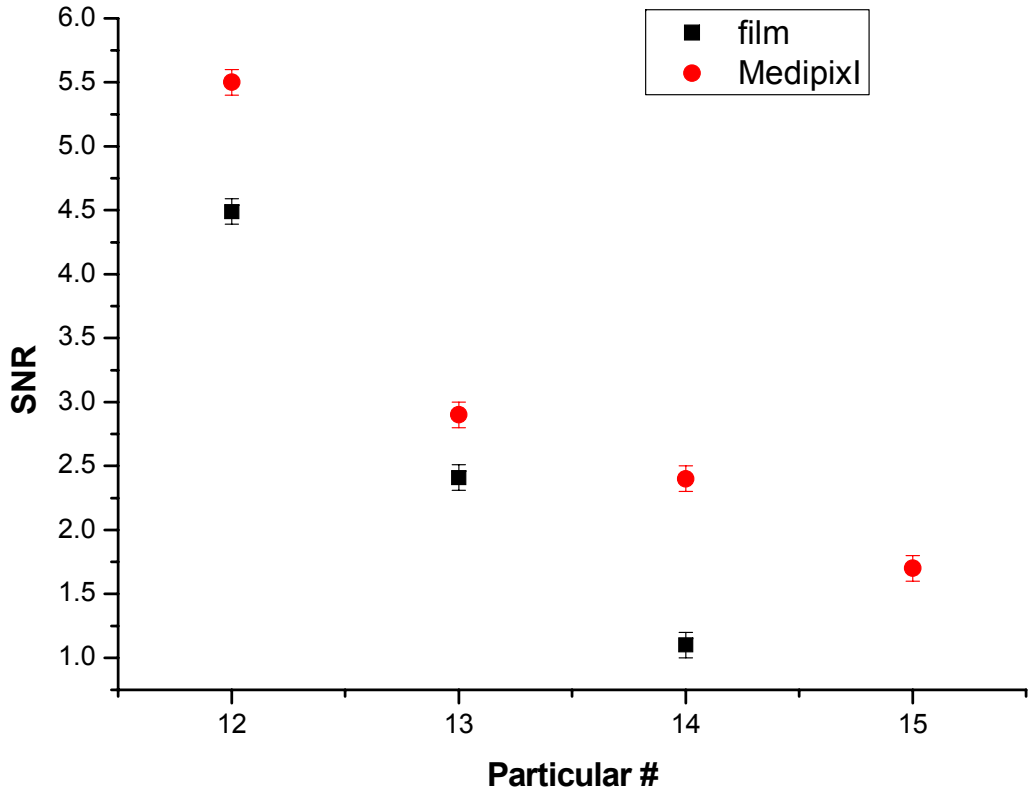




Tube settings
25 kV 80 mAs

- ✓ kodak trimatic film
  - kodak min-r 2190 screen
  - Digitized 12 bits, 85 μm pitch
- ✓ Medipix 1
  - Detector Si
  - 525 μm thick

MedipixI-Film SNR comparison



- ✓ The Signal to Noise Ratio (SNR) of the details imaged with the MEDIPIXI system is systematically higher than the SNR of the same details imaged by the film

- ✓ The SNR of the detail 15 (0.24 mm thick) is not measurable on film

The commercial digital systems

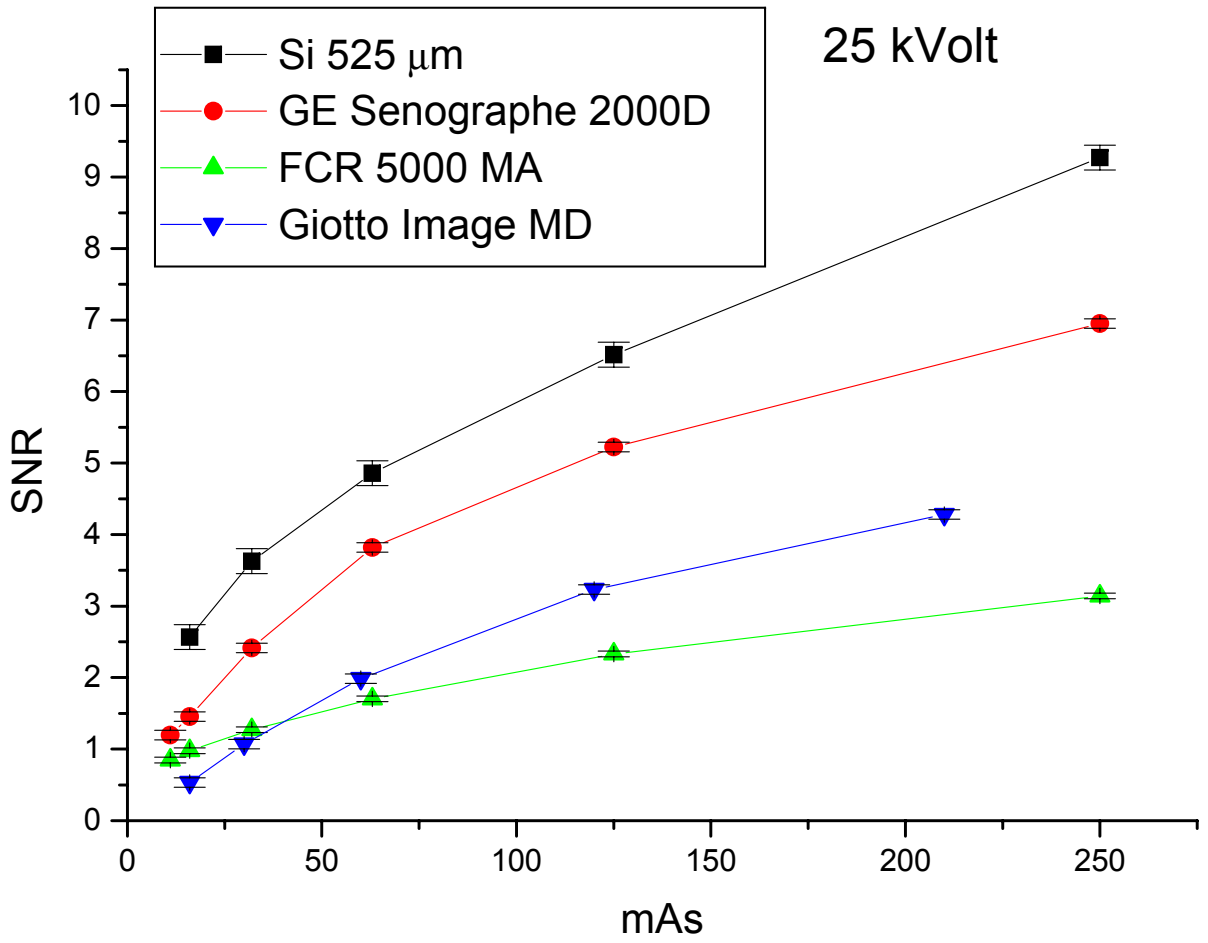
- GE Senographe 2000D based on CsI(Tl)-aSi
  - Diagnostic Centre Prevenia in Torino (Italy)
  - Ge Senographe 2000D is a full field digital mammography system:
  - 19 x 23 cm^2 amorphous silicon detector coupled to CsI (Tl) (flat panel) with a pixel size of 100 μm

- Fuji FCR 5000MA Computed Radiography (CR) based on imaging plates with a photostimulable phosphor screen
  - C.S.P.O. in Firenze (Italy)
  - Image Plate with a photostimulable phosphor screen
  - Senographe 800T X-ray unit:
  - 18 x 24 cm^2 with a pixel size of 50 μm

- Giotto Image MD Internazionale Medico Scientifica Srl (I.M.S. Bologna, Italy) based on aSe
  - Istituto di Radiologia APGD in Udine (Italy)
  - Amorphous selenium technology (flat panel)
  - active area 17.4 x 23.9 cm^2 with a pixel size of 85 μm
  - Mo and Rh filter

SNR comparison

•SNR as a function of the mAs for the detail 12 (2 mm thick tumor mass) of the RMI 156 phantom, obtained with the different acquisition systems

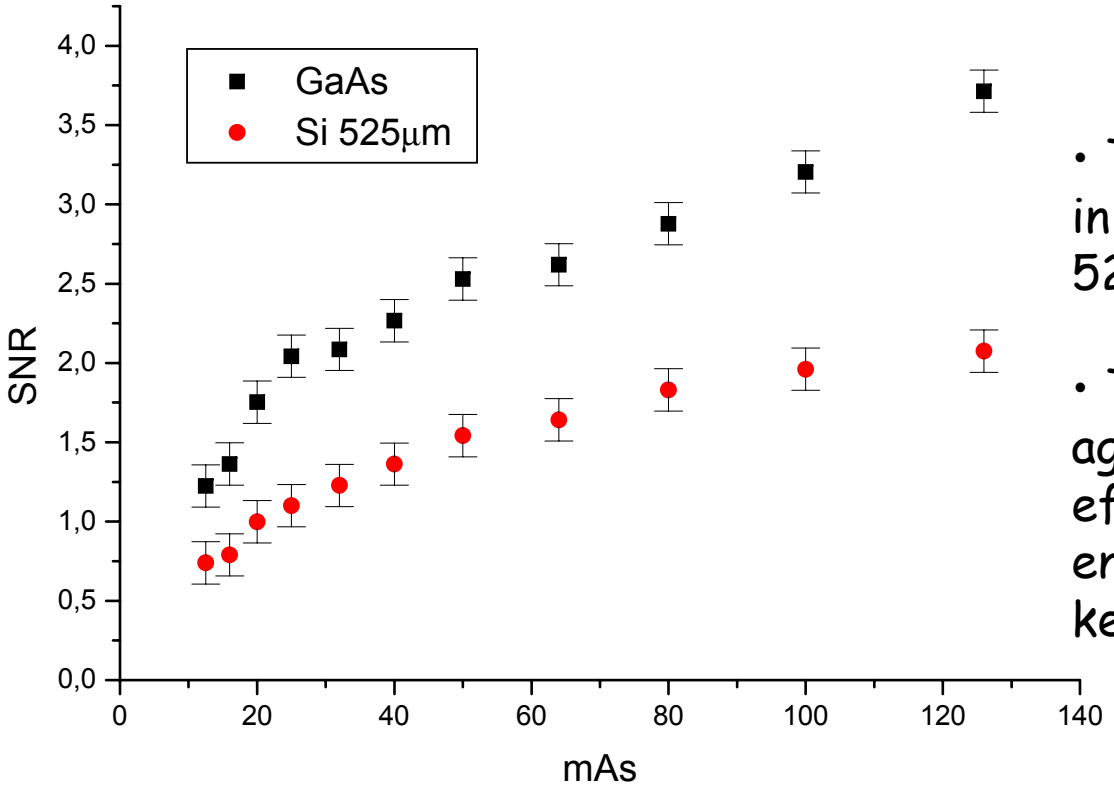


25 kVolt

GaAs- Si detectors SNR comparison

•SNR as a function of the mAs for the detail 12 (2 mm thick tumor mass) of the RMI 156 phantom with GaAs and Si 525 μm thick detectors.

•Tube for general radiography (W anode and an Al filter 2.5 mm)
•Tube settings: 40 kV and 16 - 125 mAs

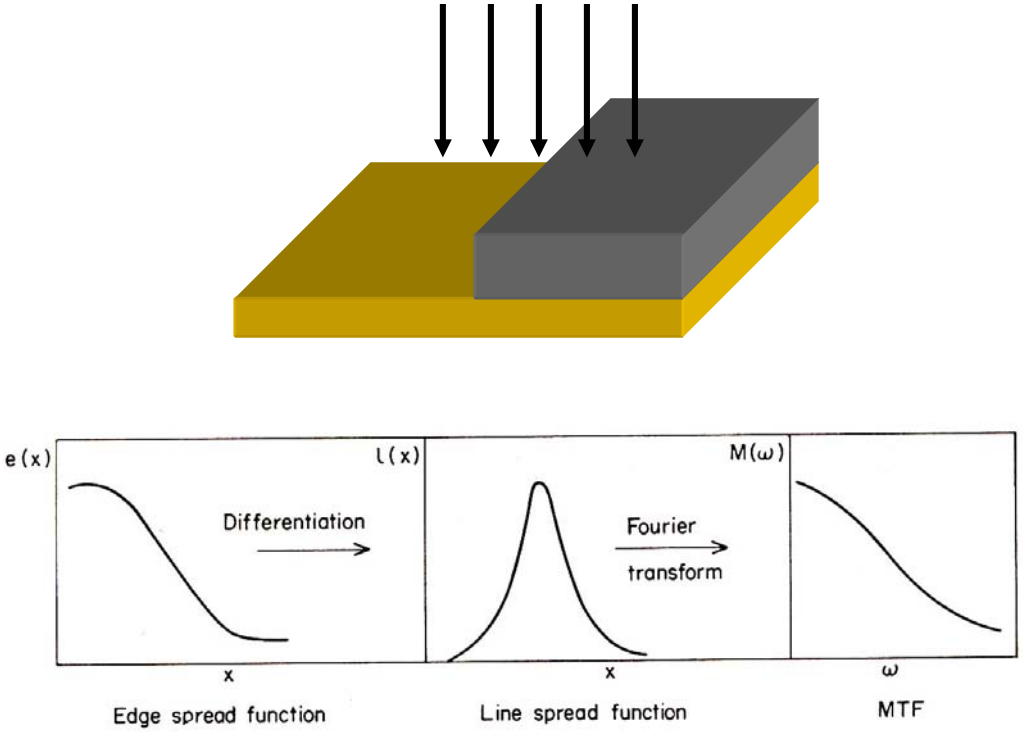


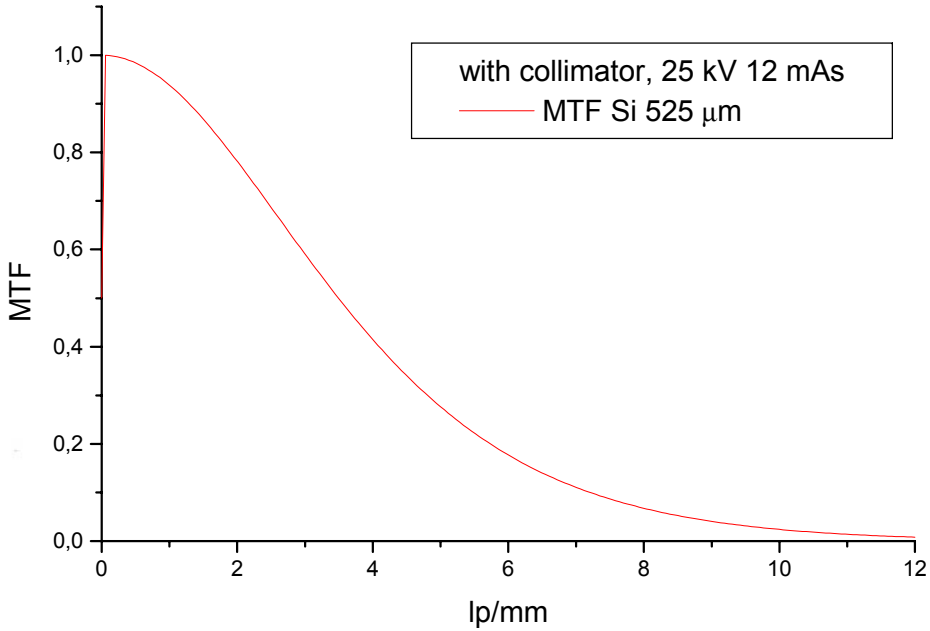
• The performance of the GaAs detector in terms of the SNR is superior to the 525 μm thick Si one

• The statistics on the images is in agreement with the different detection efficiencies of Si and GaAs at the energies of the X ray beam (average = 28 keV)

MTF evaluation: edge method

- The MTF of the system has been evaluated using the image of the W edge with the mammographic tube at 25 kV and 12 mAs.



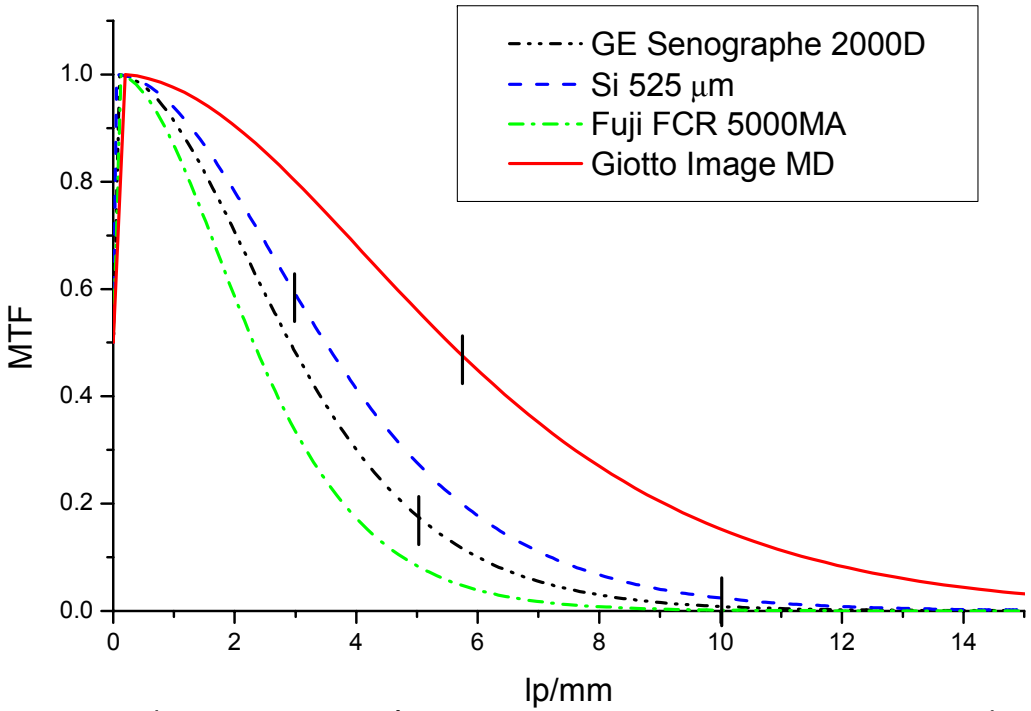


ESF: from the image of a W edge
LSF: the ESF' derivative
MTF: normalized Fourier Trasform of the LSF

At the Nyquist frequency (2.94 lp/mm) of the MedipixI the MTF is 60 %

MTF comparison

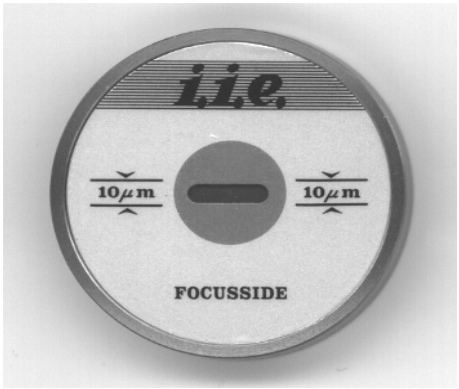
•Comparison among the MTF of the different digital systems is presented (the vertical lines represent the value of the Nyquist frequency for each system).

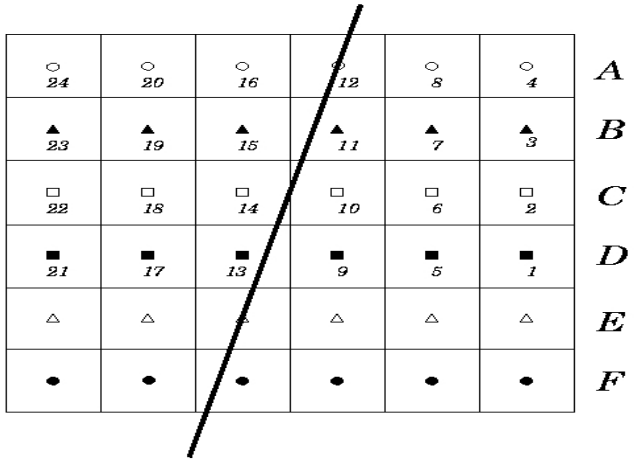


	Nyquist frequency	MTF
Giotto Image MD	5.88 lp/mm	46 %
Single photon counting	2.94 lp/mm	60 %
GE Senographe 2000 D	5 lp/mm	20 %
FCR 5000MA	10 lp/mm	1 %

These results are in agreement with data published in literature. Bloomquist et al. "Acceptance Testing of Digital Mammography Units for the ACRIN/DMIST Study", Proceedings of the IWDM 2002, Bremen, Germany, pp. 85-89

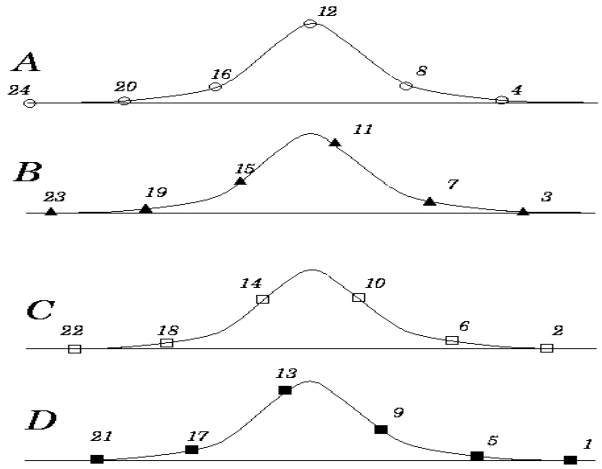
MTF evaluation: slit method



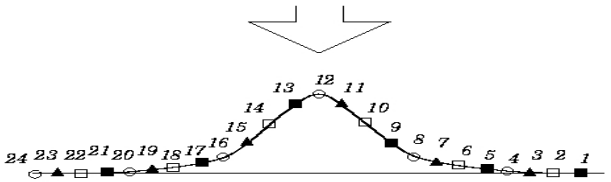


- ✓ Tantalum phantom, 1.5 mm of thickness, 10 μm width slit.

b)



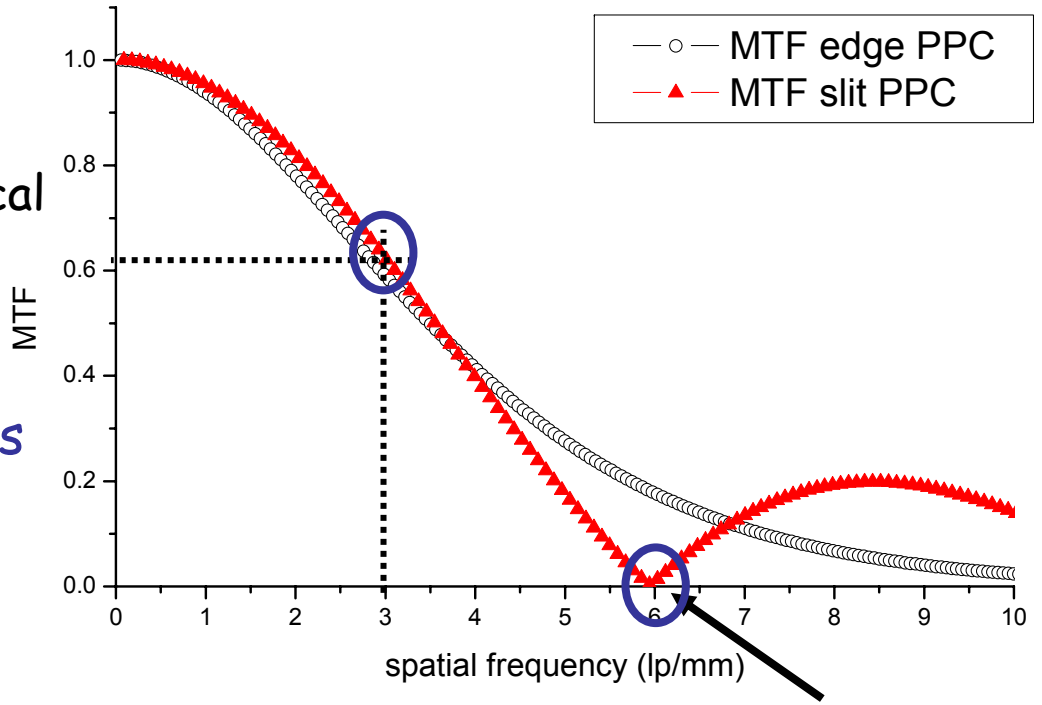
c)



- ✓ Presampling MTF
  - line slightly tilted with respect to the perpendicular to the pixel lines.
  - Composition of digital LSFs.
  - Computation of the FFT for the MTF

Edge –slit methods comparison

- ✓ The two curves have the same behavior up to the Nyquist frequency
- ✓ For higher frequencies the slit method is more accurate
  - Good agreement with the theoretical curve $\mathrm{sinc}(\pi f A)$ of an ideal imaging system of sampling aperture A
- ✓ The first minimum position provides the information on the sampling aperture A
  - For the PPC $A = 0.17$ mm which corresponds to the pixel dimension
- ✓ The MTF does not depend on the detector material and thickness



Conclusions

- Development of Si and GaAs pixel semiconductor detectors, which have been bump bonded to single photon counting chips (PCC-MedipixI system).

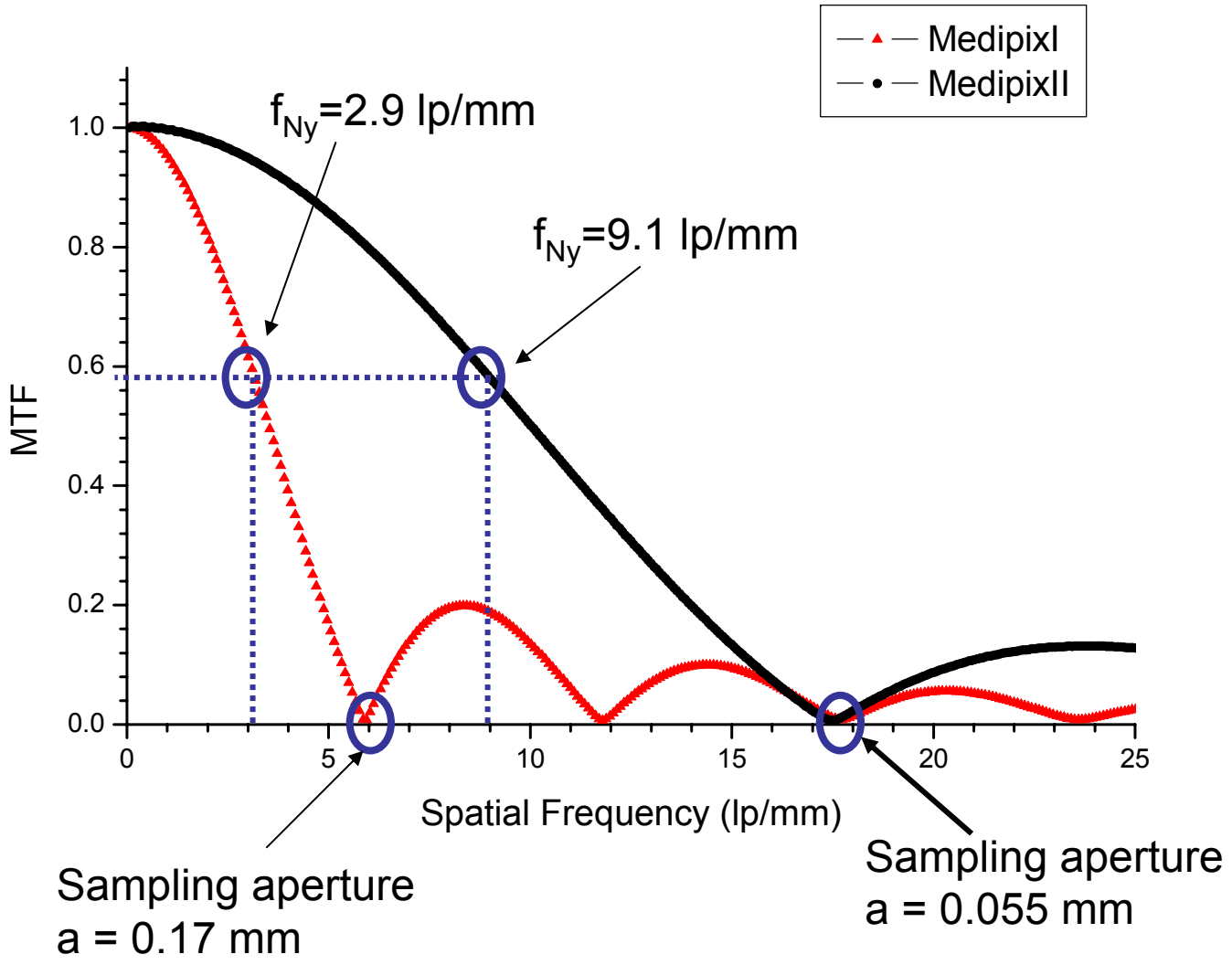
- These assemblies have shown very good imaging capabilities in terms of:

  SNR and MTF in comparison with commercial digital systems

- The MTF measurements with the slit method for the commercial systems have still to be done

- Assemblies based on Si pixel detectors and the new chip Medipix2 (256 x 256 pixel, 55 μm in side), are currently under test and an improvement in terms of SNR and MTF is expected

Medipix I -Medipix II MTF comparison



- ✓ MTF measured with the slit method
- ✓ W anode tube, 40 kV, 125 mAs