

SYRMA-CT

Tomografia mammografica con luce di sincrotrone, su
pazienti, in 2 anni

PARTECIPANTI e programma

- Bologna
- Ferrara
- Napoli
- Pisa
- Sassari (Cagliari)
- Trieste

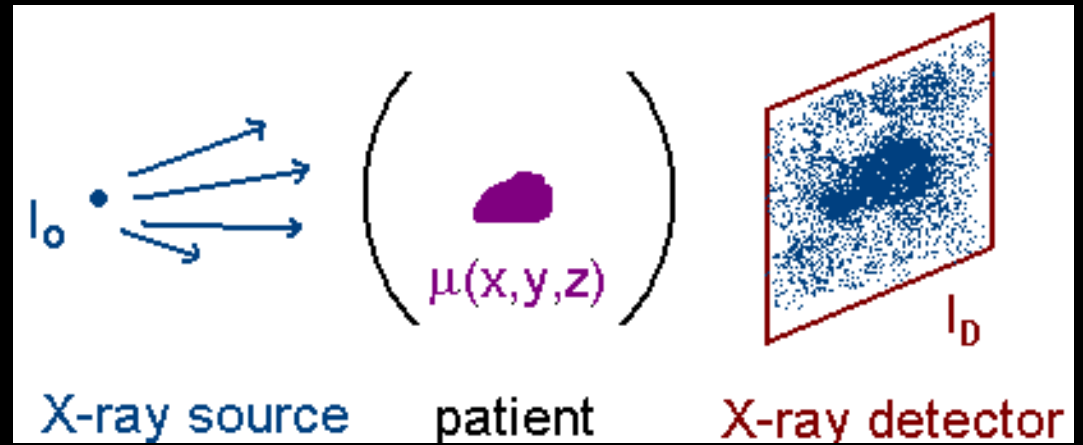
Milestone 2014:

Studio dettagliato di fattibilità e preparazione della richiesta al comitato etico

Milestone 2015:

CT con fascio monocromatico su alcuni pazienti

Imaging a raggi X



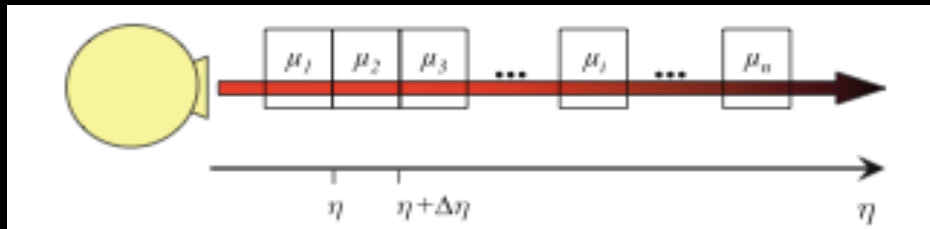
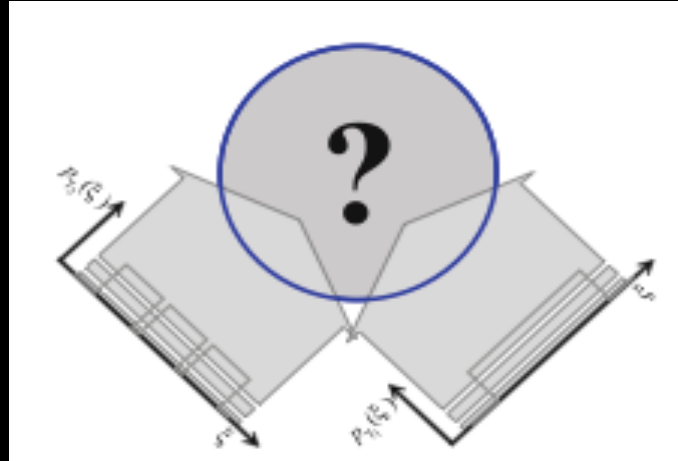
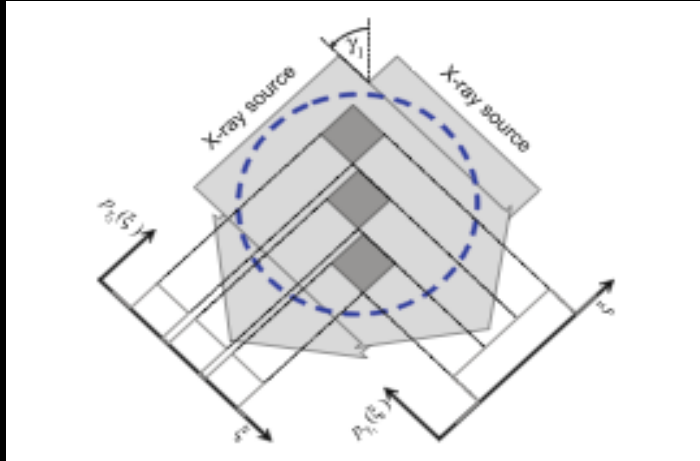
$$I_{out}(x, y) = I_0 \exp \left[- \int \mu(x, y, z) dz \right]$$

Caso di onda piana monocromatica

$$I_{out}(x, y) = \int I_0(E) \exp \left[- \int \mu(x, y, z, E) dz \right] dE$$

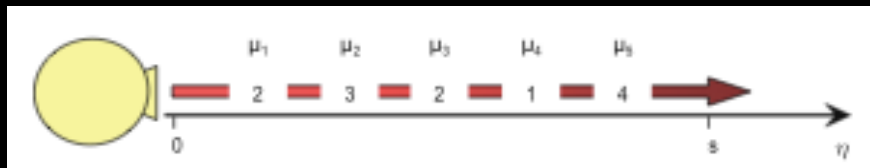
Caso di onda piana policromatica

CT: Ricostruzione di $\mu(x,y,z)$ a partire da misure di attenuazione



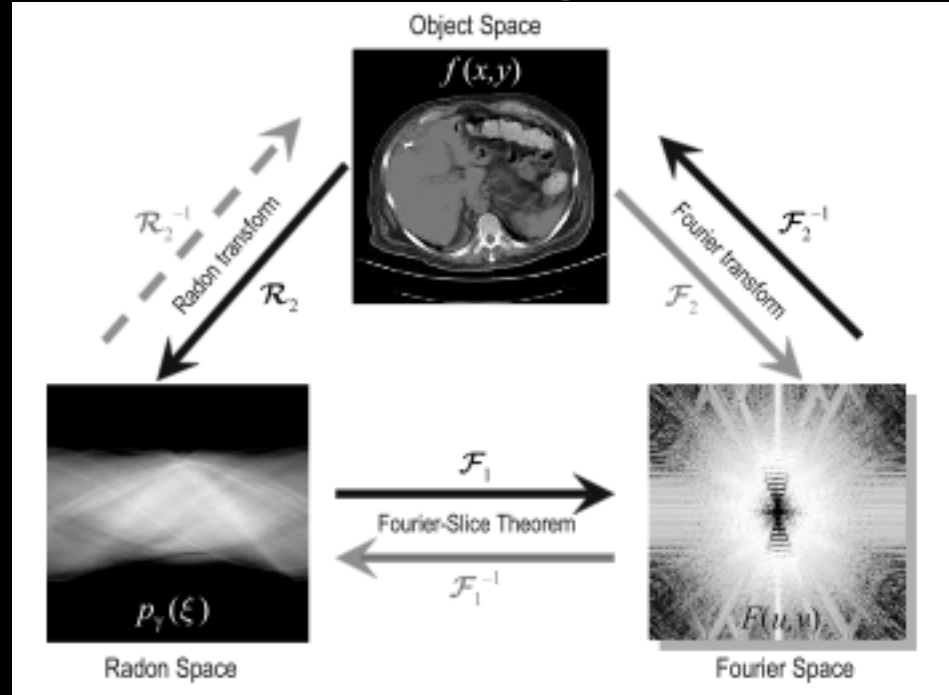
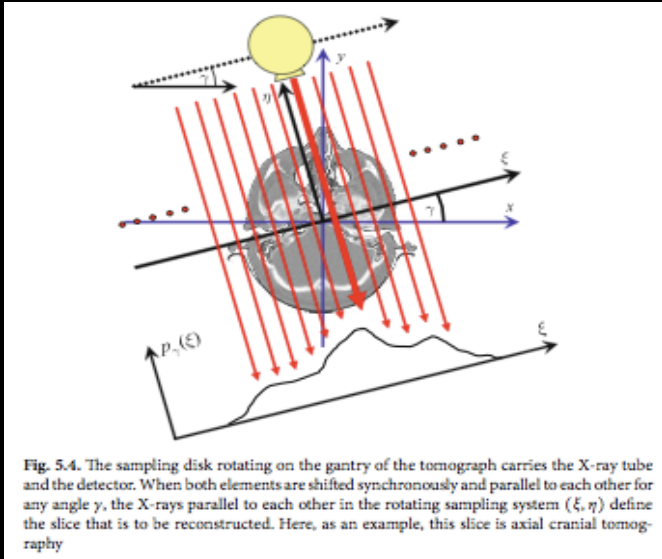
$$I_s = I_0 e^{-\int \mu(\eta) d\eta}$$

$$p(s) = -\ln\left(\frac{I_s}{I_0}\right) = \int \mu(\eta) d\eta$$



$$p(s) = \sum \mu_k \Delta\eta$$

Ricostruzione tomografica



$$p_{\gamma}(\xi) = \int_0^s \mu(\xi, \eta) d\eta$$

- Trasformata inversa di Radon
- Retroproiezione
- Metodi iterativi

Ricostruzione “esatta” possibile solo nel caso (analitico) di fascio monocromatico e geometria pencil o fan beam

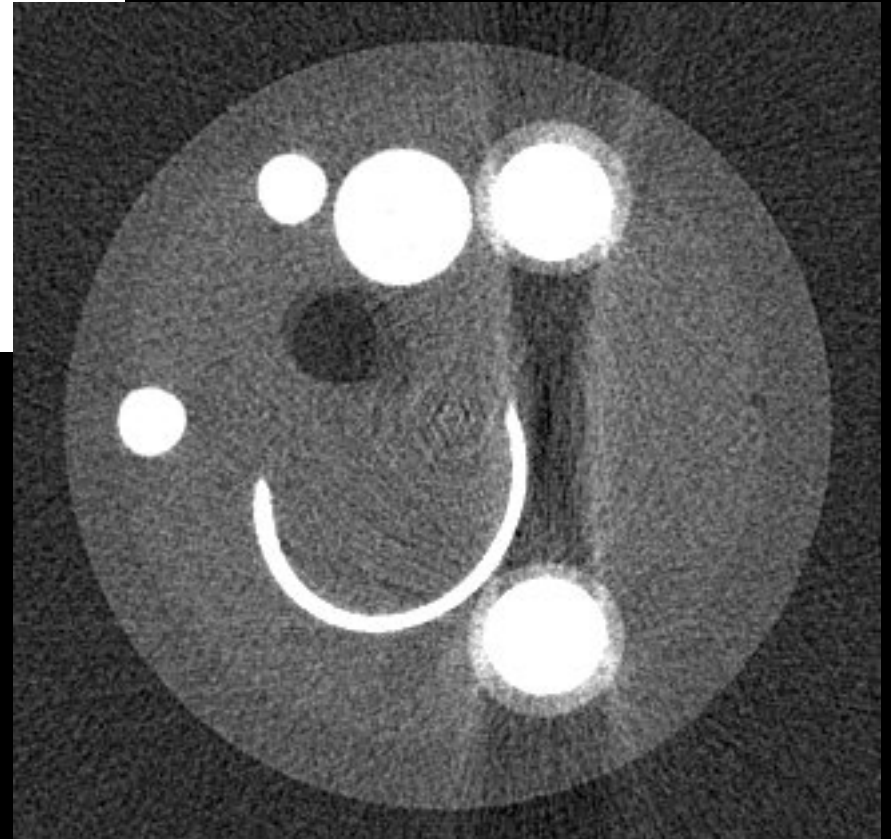
Tomografia policromatica

$$I_{out}(x, y) = \int I_0(E) \exp\left[-\int \mu(x, y, z, E) dz\right] dE$$

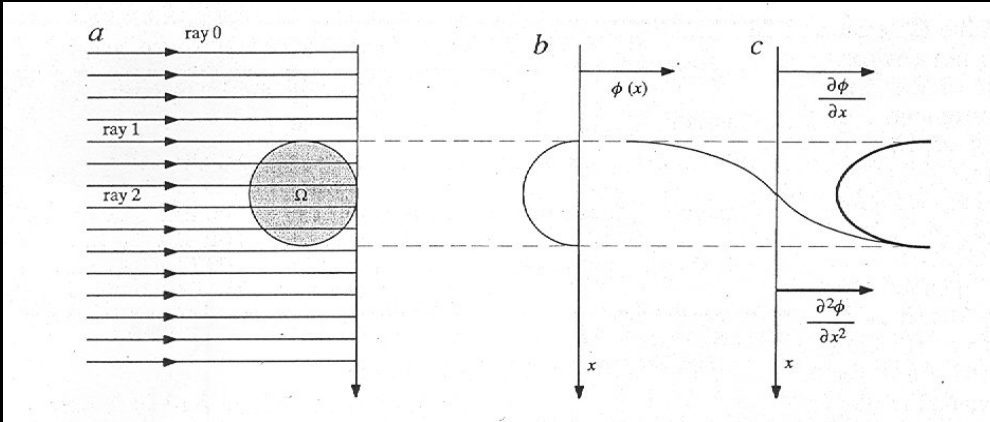
$$I_{out}(x, y) = I_0(\bar{E}) e^{-\int \mu(x, y, z, \bar{E}) dz}$$

$$p_\gamma(\xi) = -\ln\left(\frac{I_{out}}{I_0(\bar{E})}\right) = \int_0^s \mu(\xi, \eta, \bar{E}) d\eta$$

- Ricostruzione “approssimata”
- Artefatti da “beam hardening”



Phase contrast imaging



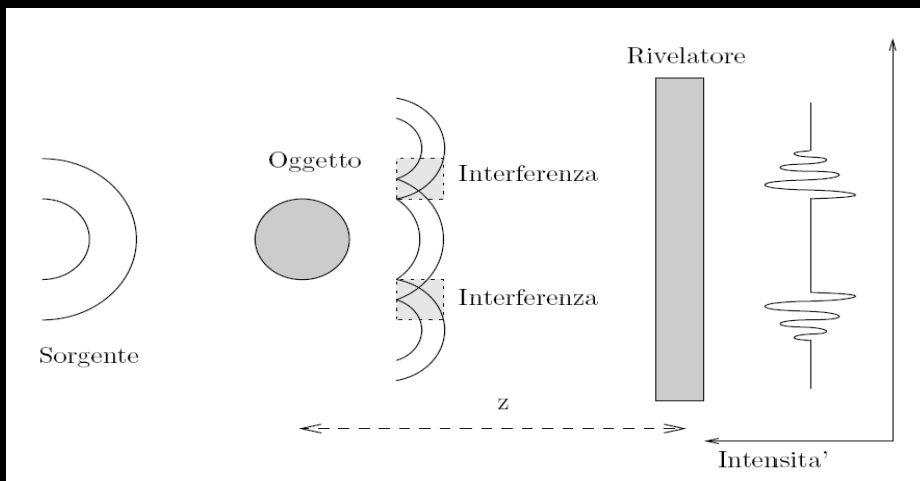
$$n=1-\delta-i\beta$$

$$\phi = -\frac{2\pi}{\lambda} \int \delta(s) ds$$

Possibile con sorgenti spazialmente coerenti

➔ Edge enhancement (gratis)

- Possibile il miglioramento della qualità dell'immagine (contrasto dei bordi delle strutture)



- Possibile (in principio) il phase retrieval
- Possibile (in principio) la ricostruzione della distribuzione spaziale di β e δ

Vantaggi del monocromatico

ENERGIA OTTIMALE

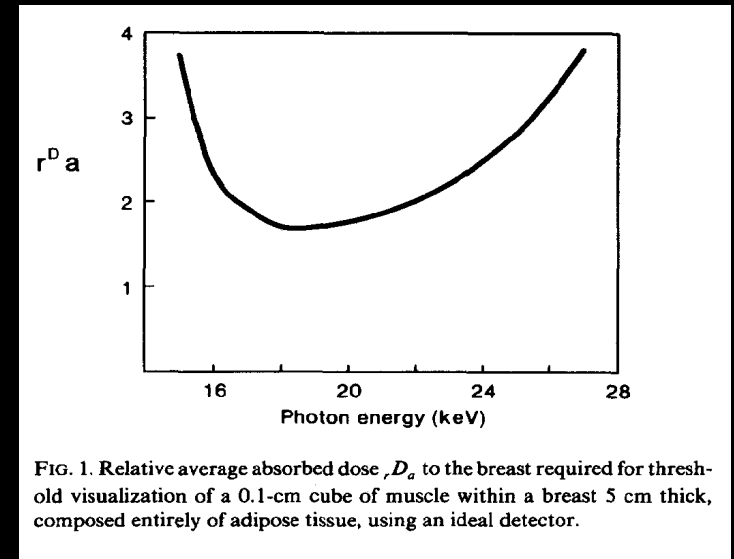
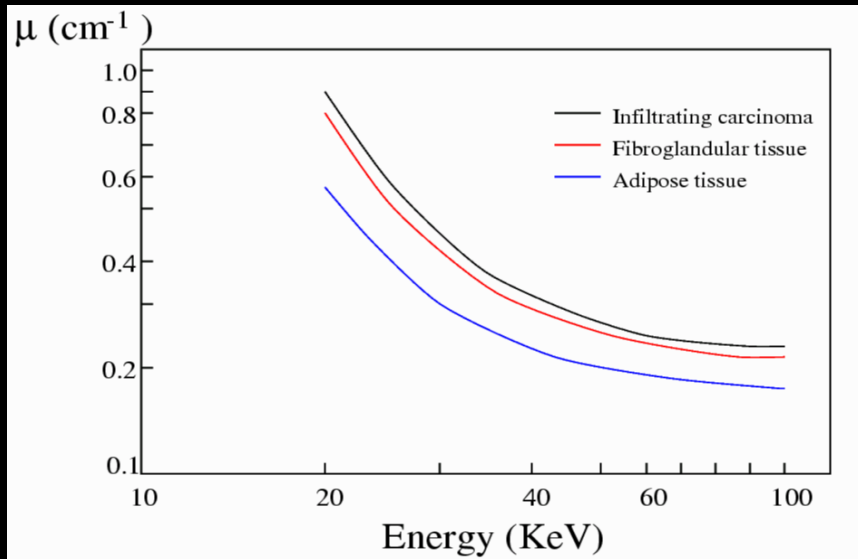


FIG. 1. Relative average absorbed dose, D_a to the breast required for threshold visualization of a 0.1-cm cube of muscle within a breast 5 cm thick, composed entirely of adipose tissue, using an ideal detector.

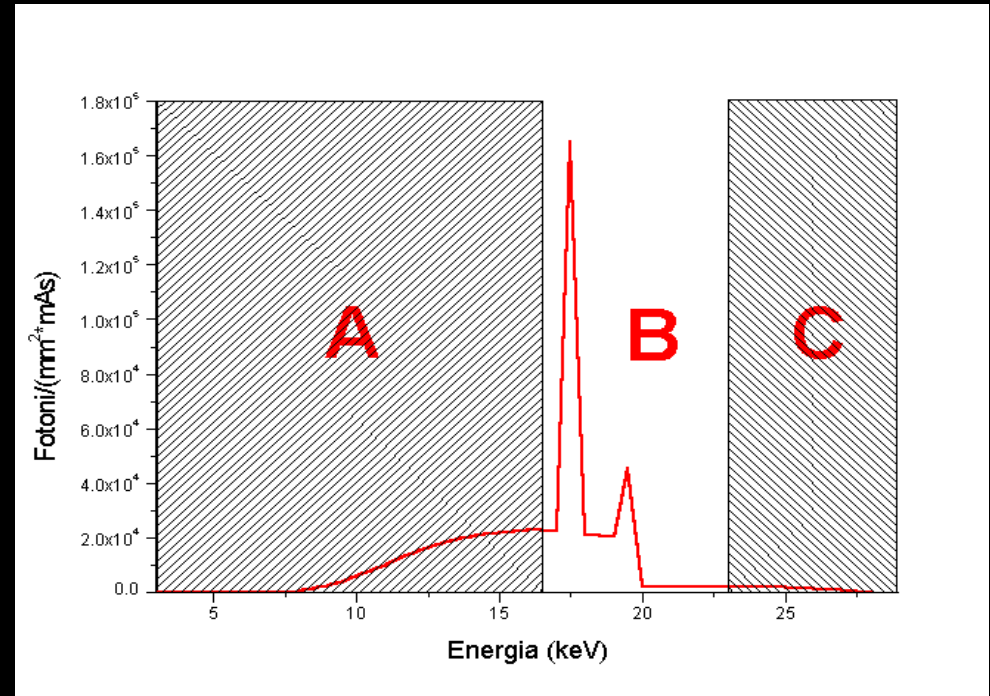
L'energia ottimale per l'imaging è un compromesso tra qualità dell'immagine e dose ceduta al paziente.

Dipende dallo spessore e dalla composizione del tessuto attraversato dalla radiazione e dall'efficienza del rivelatore.

ESEMPIO: MAMMOGRAFIA



Anode Material	Molybdenum
Anode Angle	12°
Anodic Voltage	28 kV
Filtrations	1 mm Be 0.03 mm Mo 600 mm Air



L'energia ottimale in mammografia è nell'intervallo 17keV - 25keV

Fluenza tipica: $10^7 \gamma / (\text{mm}^2 \text{s})$

Vantaggi del monocromatico in CT

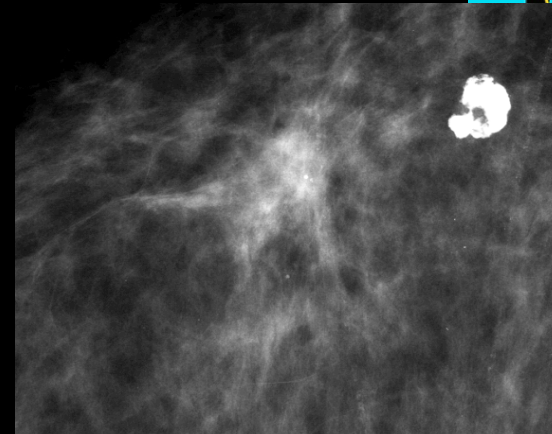
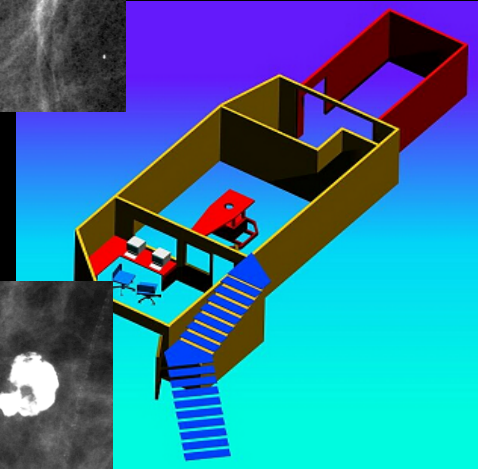
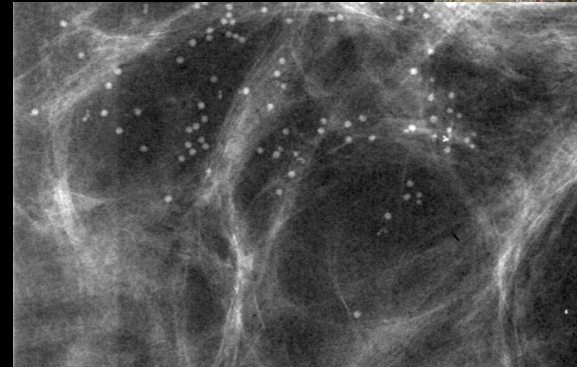
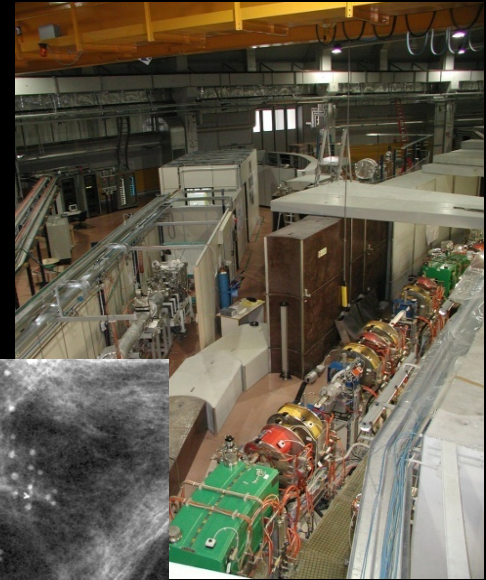
- Energia ottimale
- Imaging quantitativo
- No artefatti da “beam hardening”

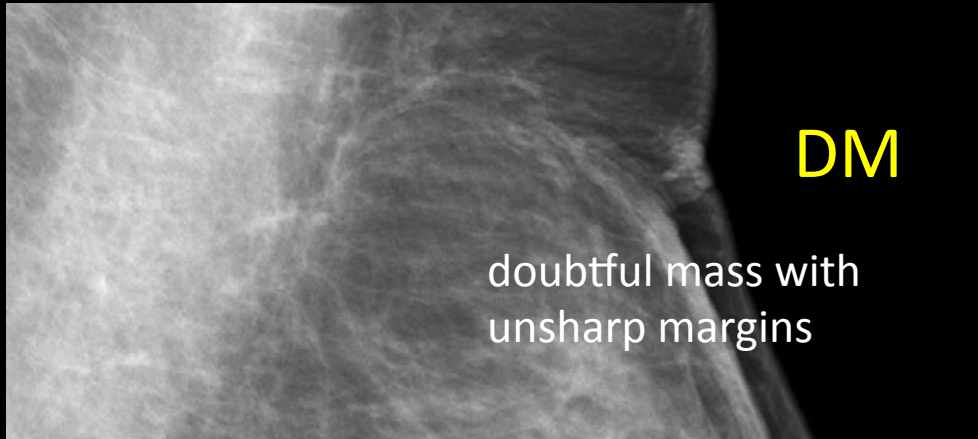
Cose fatte nel passato

SYRMEP @ ELETTRA
(Synchrotron Radiation for Medical Physics)

A brief history of the SYRMEP Beamline

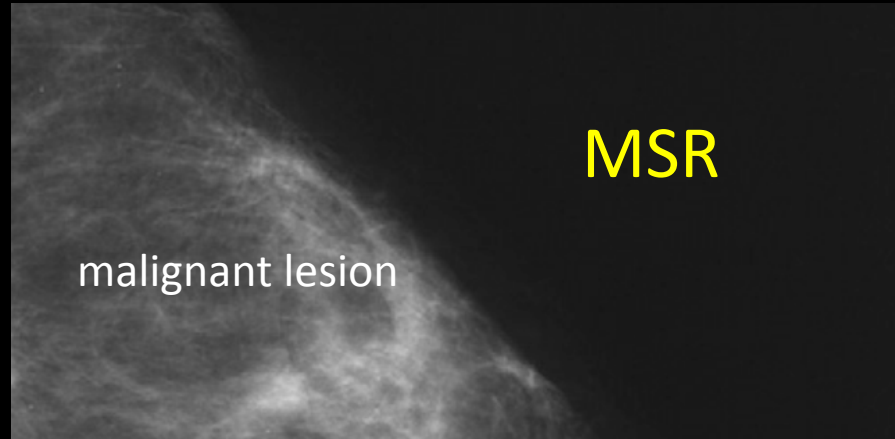
- 1996 First Photons
 - The SYRMEP beamline is devoted to *in vitro* medical imaging
- 1998 First low-dose PhC
- 2002 Upgrade beamline
 - A dedicated mammographic station is developed for the clinical program
- 2006-2009 Clinical Program
 - 71 patients have been examined
 - Castelli, E. et al. (2011). Mammography with synchrotron radiation: first clinical experience with phase-detection technique. *Radiology* 259, 684–694.





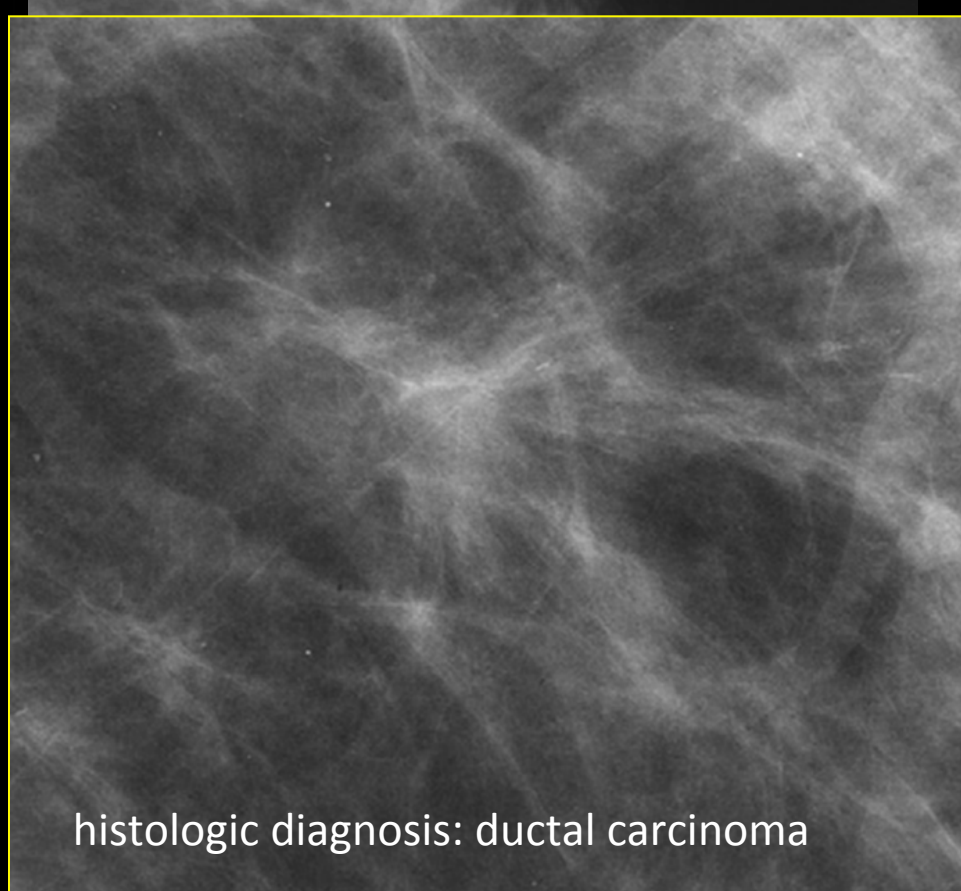
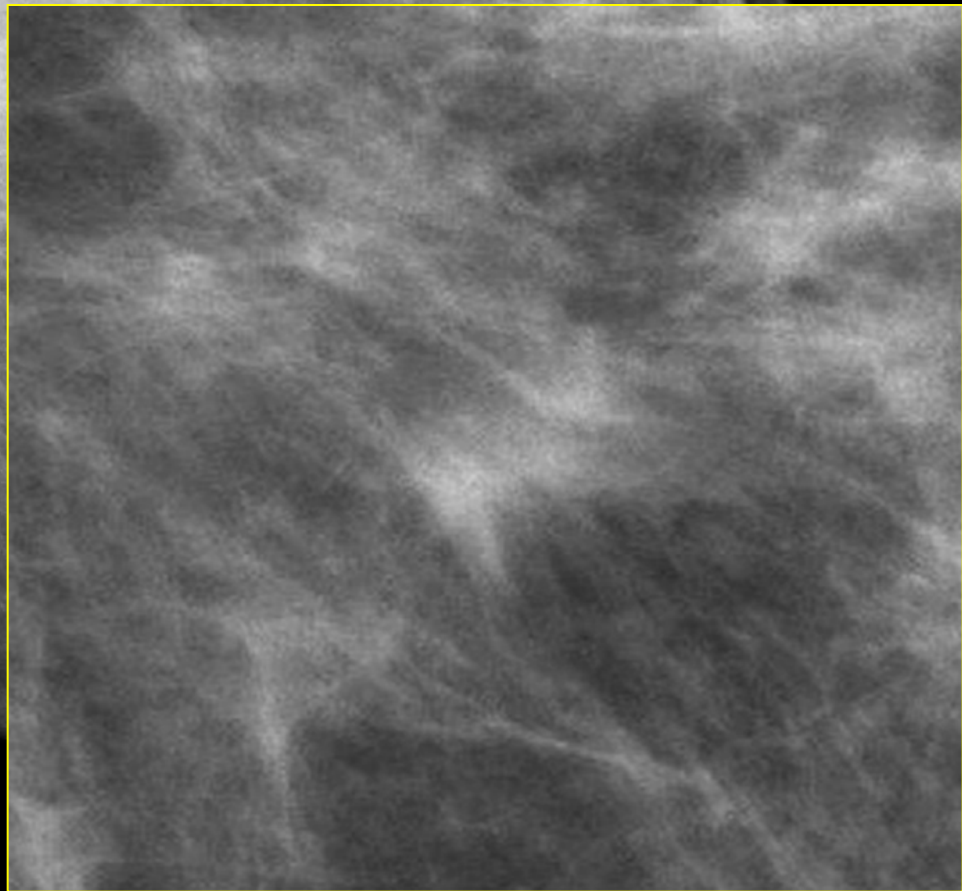
DM

doubtful mass with
unsharp margins



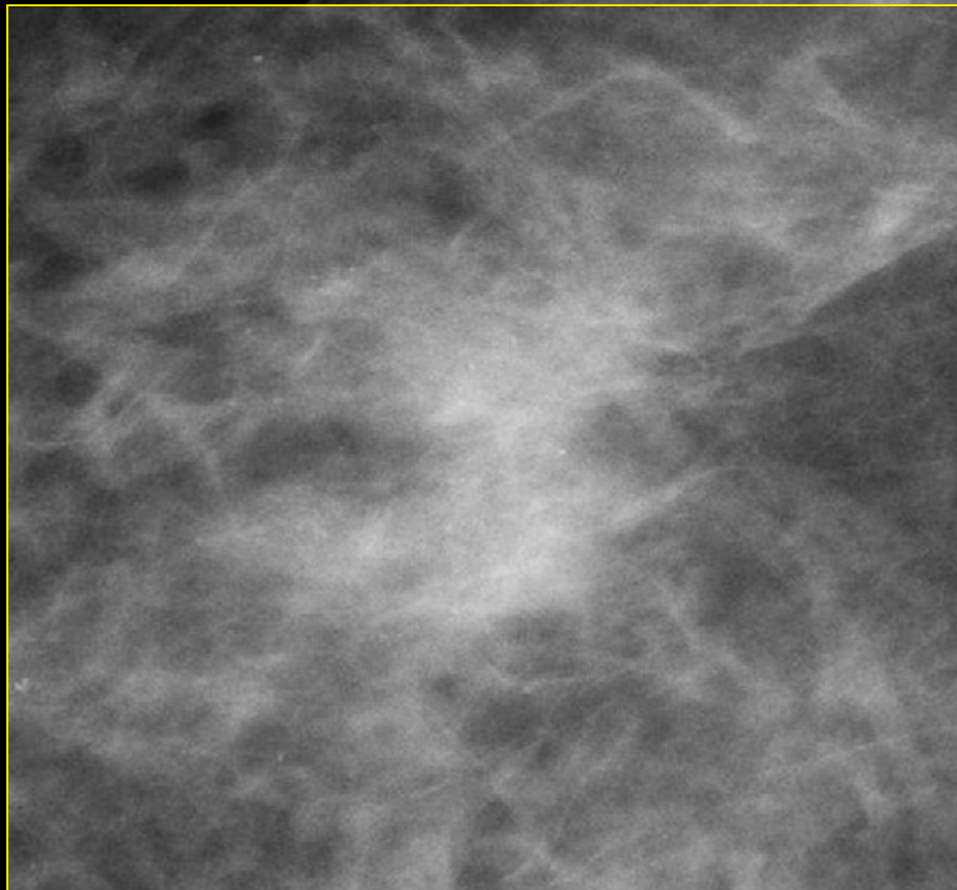
MSR

malignant lesion



histologic diagnosis: ductal carcinoma

DM



suspicious mass with architectural distortion

MSR



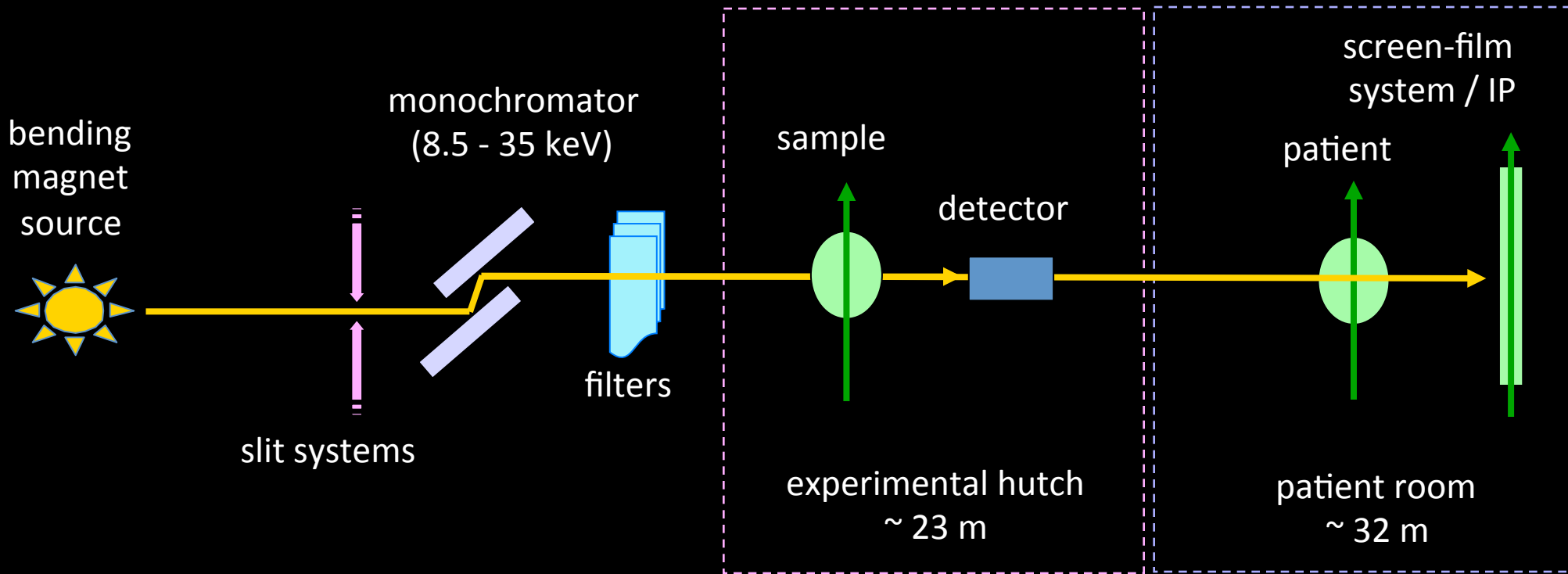
follow-up: no lesion

normal breast parenchyma

Sorgente e meccanica:

linea SYRMEP

The SYRMEP beamline (I)



Source size ~ 1.1 (horizontal) $\times 0.1$ (vertical) mm^2

Divergence: ~ 7 mrad (horizontal) $\times 0.2$ mrad (vertical)

Monochromatic beam with tuneable energy (8.5 - 35 keV)

Bandwidth: $\Delta\lambda/\lambda \sim 2 \times 10^{-3}$

Laminar beam cross section:

$4 \times 150 \text{ mm}^2$

$4 \times 210 \text{ mm}^2$

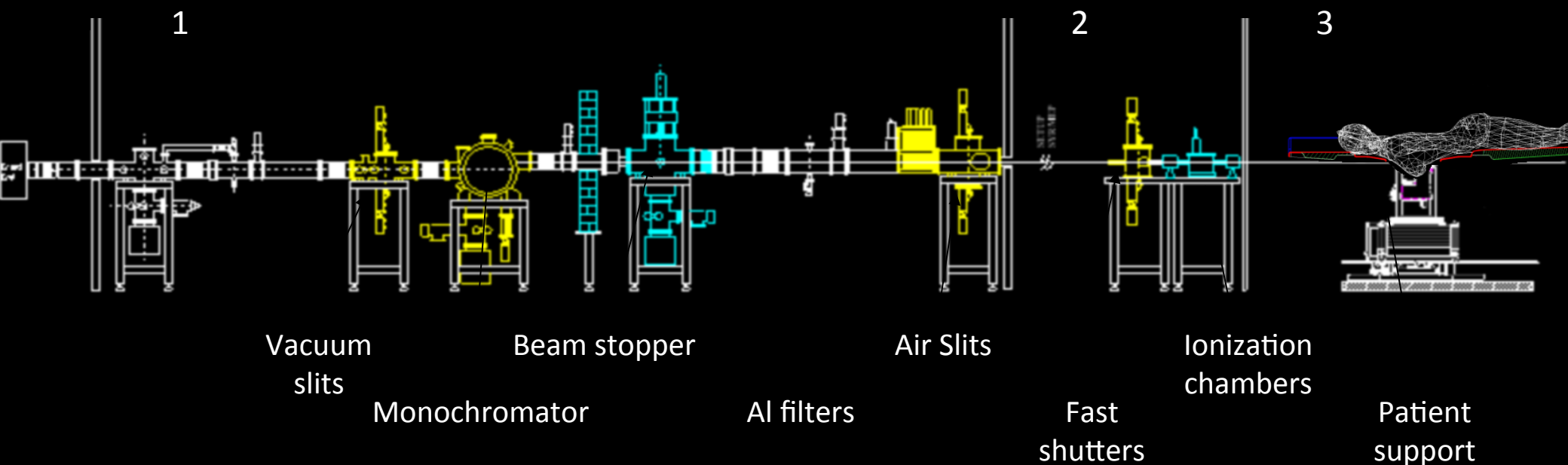
Flux available at 17 keV (Elettra operated at 2.4 GeV, 140 mA ring current):

$6 \times 10^8 \text{ ph/mm}^2/\text{s}$

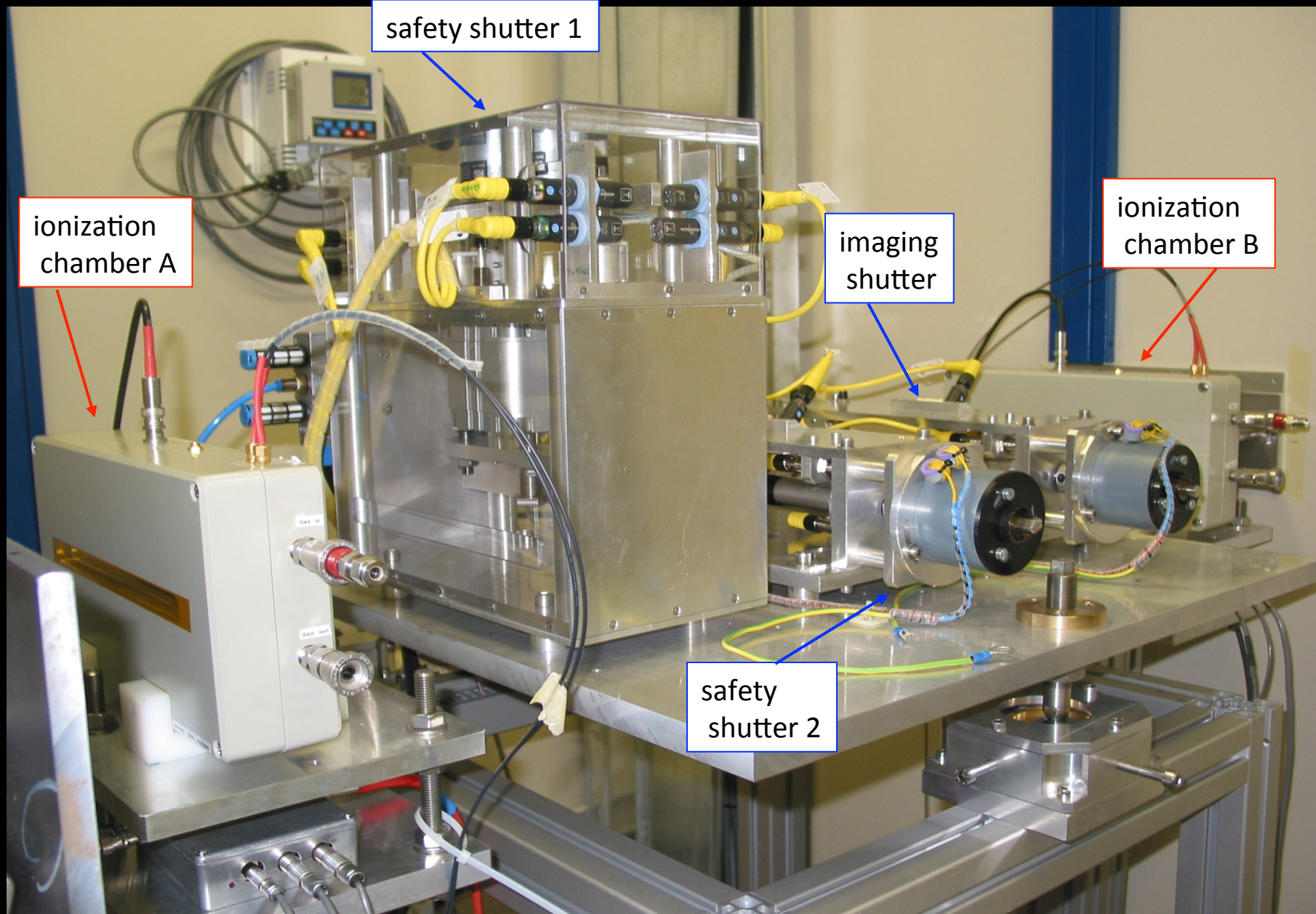
$2 \times 10^8 \text{ ph/mm}^2/\text{s}$

The SYRMEP beamline (II)

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



Dose control and safety system



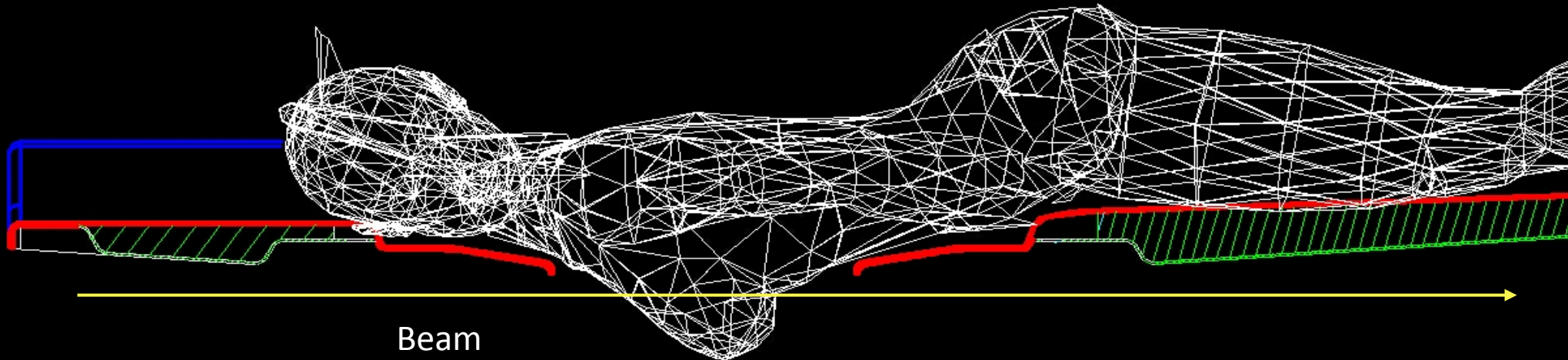
Patient support (I)

Prone position as used in stereotactic biopsy tables

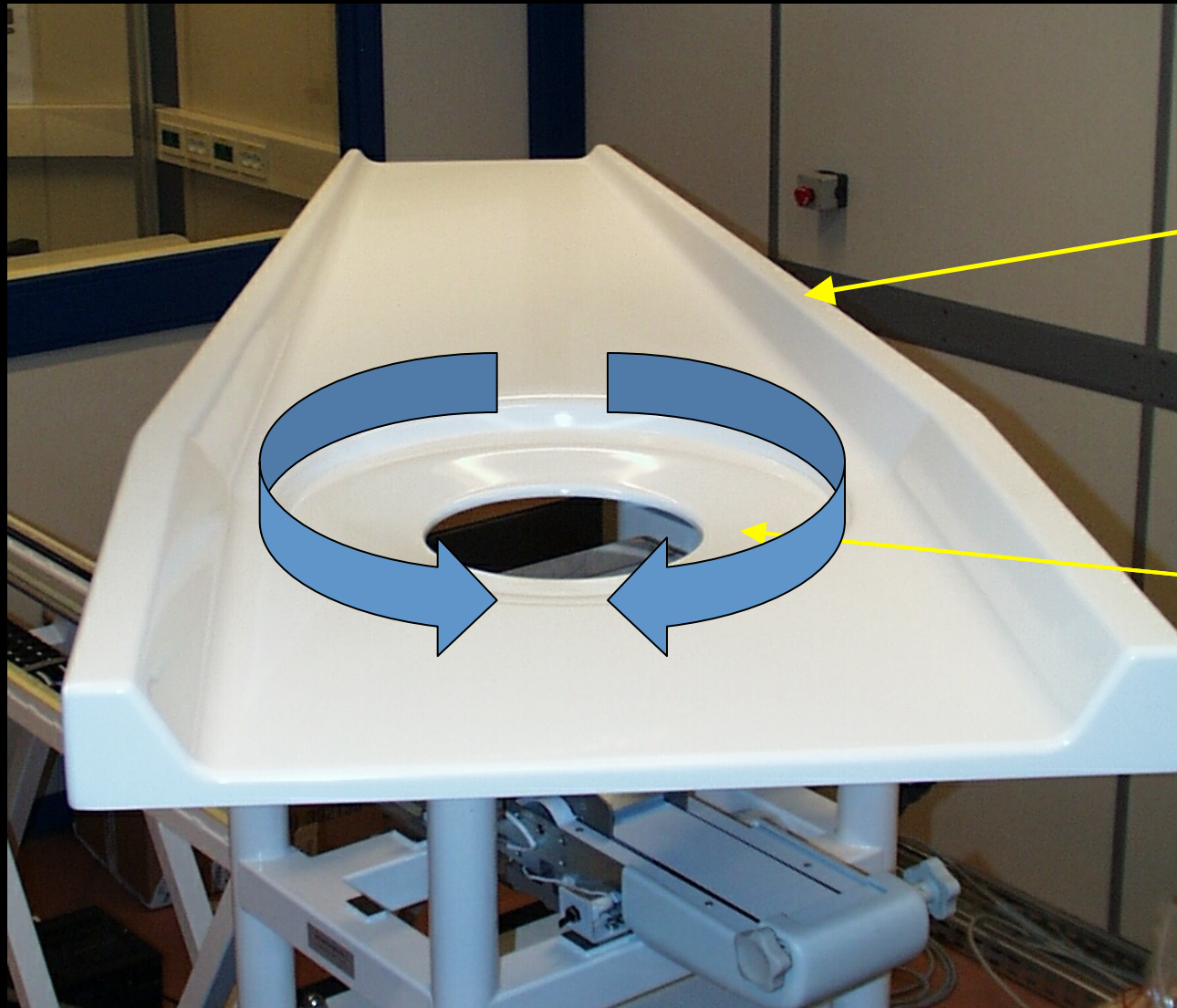
- Full Field Digital Biopsy system Giotto Image (IMS, Bologna, Italy)

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

- Good patient comfort



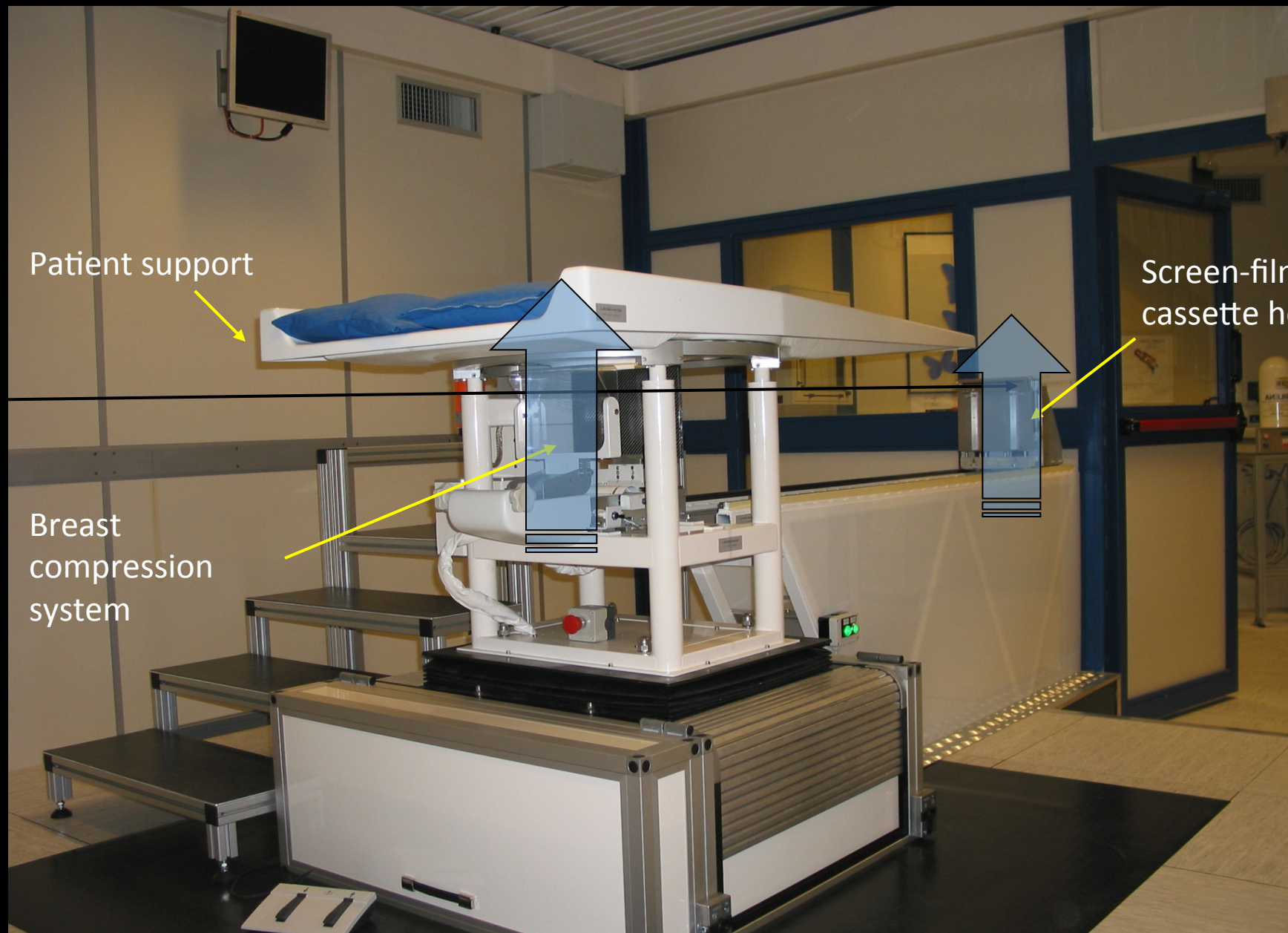
Patient support (II)



Carbon fiber support

26 cm Ø

Patient room



Patient support

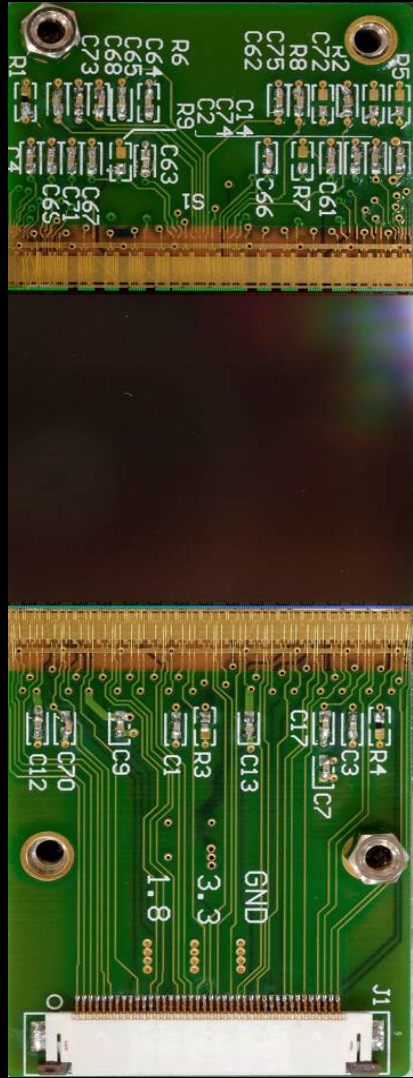
Screen-film / IP
cassette holder

Beam

Breast
compression
system

Rivelatore:
PIXIRAD

The building block of the X-ray Imaging Sensor



Base block of PIXIRAD.

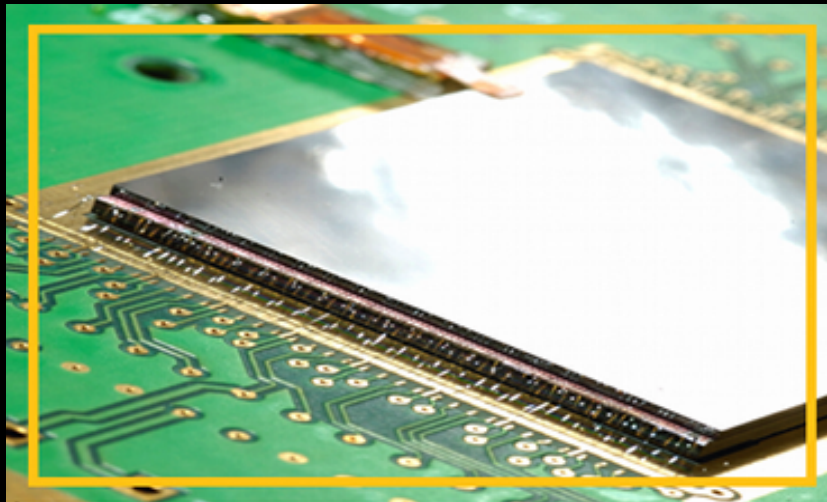
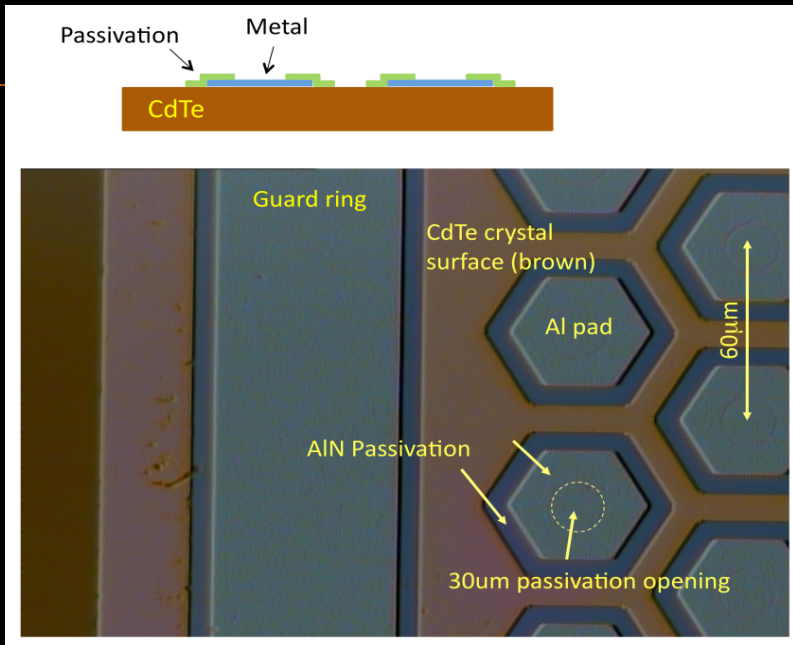
Hybrid architecture, obtained by coupling, with the *flip-chip bonding* technique:

- a CdTe X-ray sensor ($30 \times 25 \text{ mm}^2$, electron collection type)
- a pixellized CMOS ASIC (512×476 pixels, at $60 \mu\text{m}$ hex. pitch)

Main characteristics:

- color capability (2 counters / thresholds in each pixel)
- largest ASIC ever built on planet
- largest CdTe sensor with pitch finer than $100 \mu\text{m}$ ever built
- buttable on two sides
- very low global threshold
- automatic offset compensation

The CdTe Sensor



CdTe semiconductor characteristics:

Atomic numbers	48, 52
Effective atomic number	50
Density ρ (g/cm ³)	5.85
Band energy (eV)	1.5
Dielectric constant	11
Ionizing energy (eV)	4.43
Resistivity ρ (Ω cm)	10^9
Electron mobility μ_e (cm ² /Vs)	1100
Electrons mean lifetime τ_e (s)	3×10^{-6}
Hole mobility μ_h (cm ² /Vs)	100
Holes mean lifetime τ_h (s)	2×10^{-6}
$(\mu\tau)_e$ (cm ² /V)	3.3×10^{-3}
$(\mu\tau)_h$ (cm ² /V)	2×10^{-4}

The CdTe pixel sensor (ACRORAD Co., Ltd.) is a Schottky type diode with electron collection on the pixels
 Large area: 30.96 × 24.98 × 0.65 mm
 Pixel pitch: 60 μm (on hexagonal matrix)
 Very low leakage current @400-500V working voltage
 (5 nA/cm²)

The giant PIXIRAD-8

A 8 unit system 2M pixels, 4M counters
25x2.5 cm² active area

Sensor type:	CdTe, 650 μ m, 30.9 \times 25.0 mm ² Schottky type diode electron collection at pixel
ASIC+CdTe base block	512 \times 476 pixels
Number of blocks	8
Global active area	250 x 25 mm ²
Total number of pixels	1,949696
Total number of counters	3,899392
Pixel size	60 μ m hexagonal arrangement
Pixel density	323 pixels/mm ² , equivalent to 55 μ m on square arrangement
Pixel rate capability	10 ⁵ counts/pixel/s
Global rate capability	2x10 ¹¹ counts/s
Pixel dead-time	300 ns
Position resolution	11 line pairs/mm at MTF 50%
Reading while taking data	possible
Dead-space between blocks	2 columns (to be reduced to 1 column)
Energy range	1-100 keV
Detection efficiency at 50 keV	98%
Counters depth	15 bits
Read-out time at 50 MHz clock	0.073 s
Frame rate	13.6 fps
Minimum applicable global threshold	200 electrons
Cooling	liquid or forced air
Operating temperature	+40 -40 C
Sensor bias voltage	200 + 400 V
Leakage current density	5 nA /cm ² at 400 V, -30 C
Typical number of defective pixels	less than 10 ⁻²
Number of independent thresholds (colors)	2 set of two (swappable in real time)



PIXIRAD-8 application to digital mammography



Complete module includes;

- 8 unit sensor
 - 25×2.5 cm² active area
 - 2 M pixel – 4M counters
 - 2 pixel inter-modules spacing
 - almost edge less toward the breast
- DAQ electronics
- Cooling system
- 1 Gbit Ethernet connection

In sintesi

- conteggio di fotoni
- alto rate
- ampio range dinamico
- alta efficienza
- grande area
- DAQ affidabile

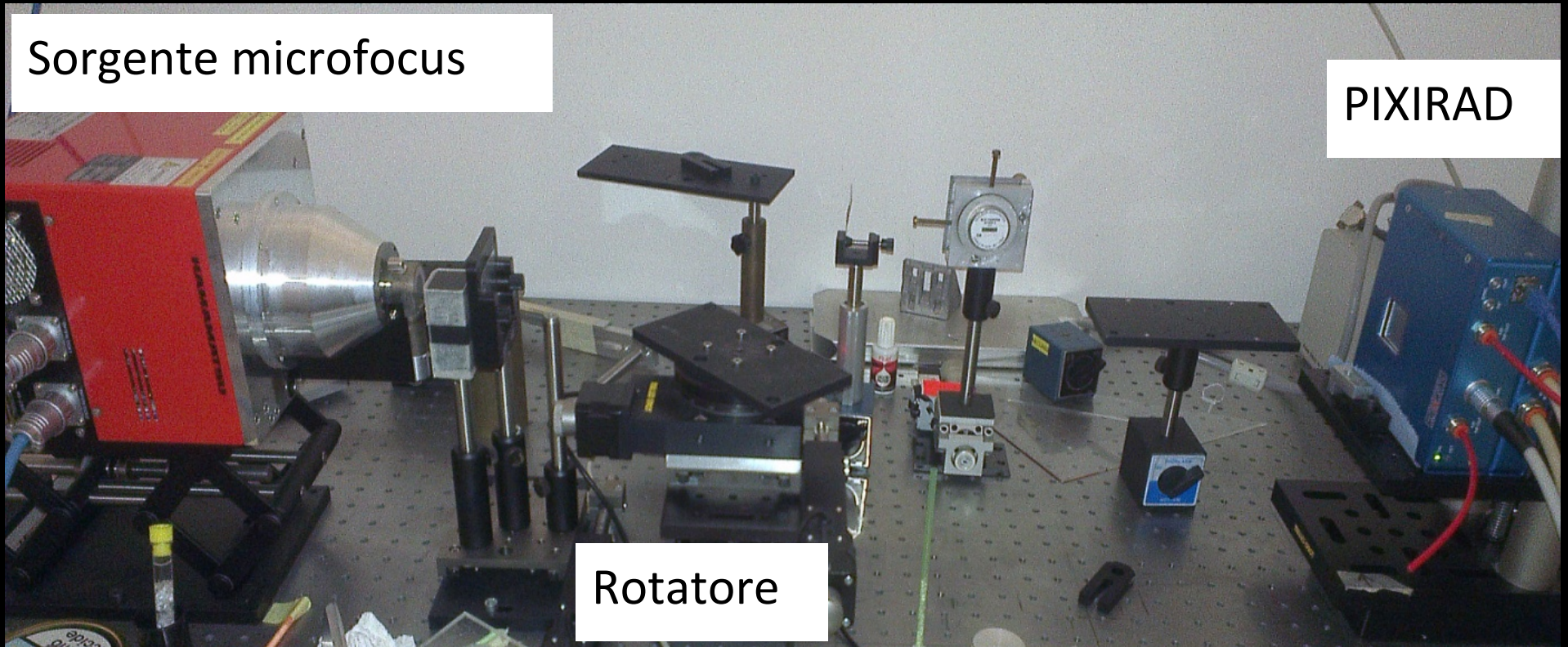
Laboratorio a PISA

Sistema per micro CT

Sorgente microfoco

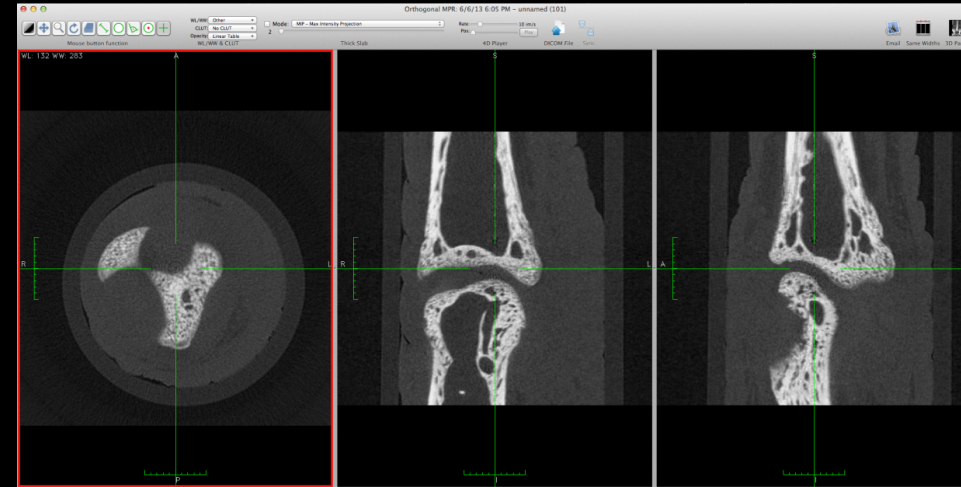
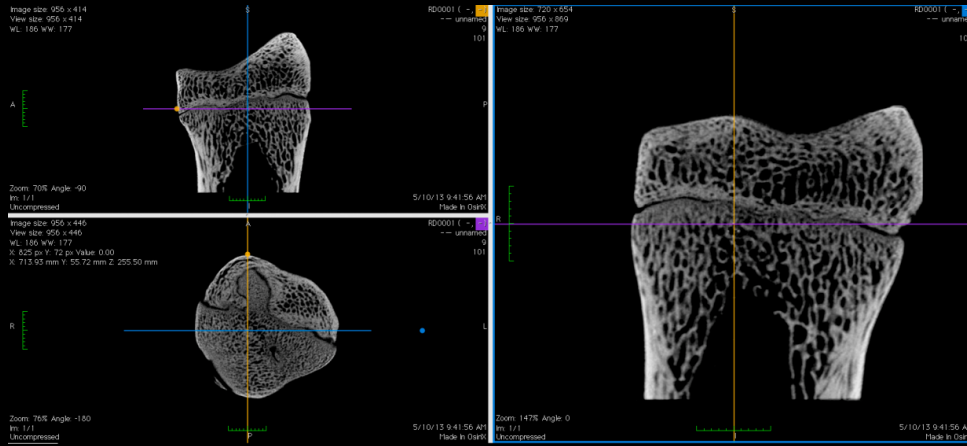
PIXIRAD

Rotatore



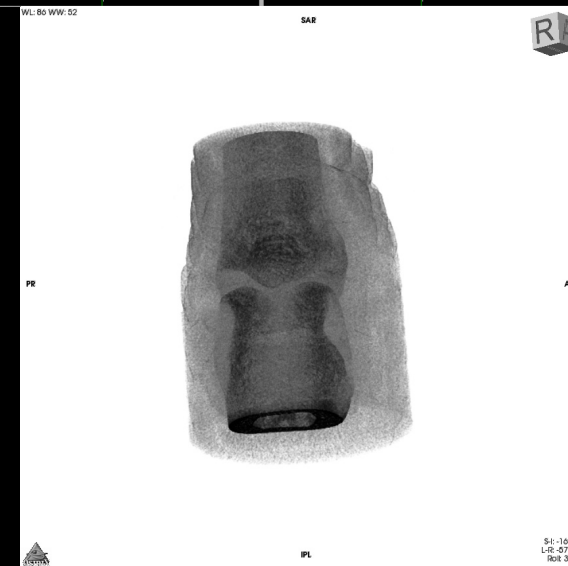
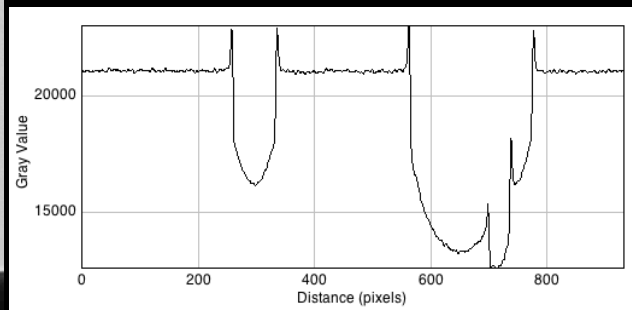
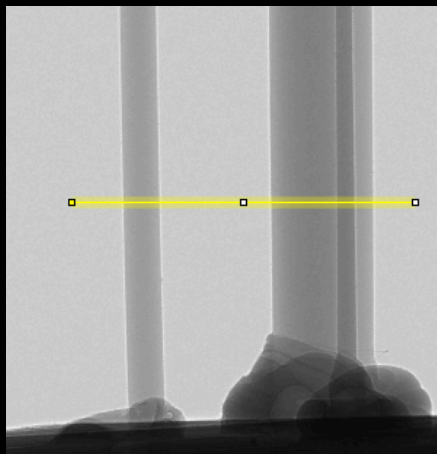
Micro CT

Alcuni risultati



720 projections, 0.5 degree, 55 kV, 160 μ A
Magnification factor:1.25

Phase contrast imaging



3 PMMA sticks, 27 kV, 200 μ A, Magnification factor:3
The detector is at 75 cm from the source.

Scopo dell'esperimento

La diagnostica senologica sta con forza muovendosi verso la tomografia sia con raggi X che con MRI.

La competizione internazionale nel campo della mammografia in contrasto di fase è vivace sia con luce di sincrotrone che con sorgenti convenzionali (con uso di gratings) con progetti di mammografia planare e tomografica.

L'obiettivo di SYRMA-CT è di estendere il programma clinico della linea SYRMEP alla tomografia della mammella e di mantenere la leadership italiana nella mammografia in contrasto di fase.

Cose da fare

WP1

Adeguamento della facility di mammografia

- calibrazione camera a ionizzazione ad alte energie
- adeguamento supporto paziente
- nuovo supporto per il seno in scansione
- nuovo supporto del detector e procedure di allineamento con l'asse di rotazione del letto
- nuovo programma di controllo esame

WP2

Detector

- Caratterizzazione con fasci monocromatici
- Adeguamento del sistema PIXIRAD-8 (Meccanica)
- Interfaccia con il sistema di acquisizione clinico
- Ottimizzazione dose-risoluzione spaziale (rebinning)

WP3

Algoritmi di ricostruzione

- CT spirale o roto-traslazione con fascio parallelo
- Algoritmi con ridotto numero di proiezioni
- Phase retrieval

WP4

Dosimetria

- simulazioni per ottimizzare energia e algoritmo di scansione al fine di ottenere acquisizioni alle dosi volute
- definizione delle grandezze dosimetriche di interesse per la domanda di autorizzazione al comitato etico
- misure di validazione delle simulazioni.

WP5

Misure in laboratorio e oggetti test

- generazione dati per testare gli algoritmi di ricostruzione (non sarà sempre possibile usare la linea SYRMEP)
- sviluppo oggetti test per dosimetria, per test performance e per i controlli di qualità.
- Reperimento di campioni “ex-vivo” da usare per test.

WP6

Richiesta di autorizzazione al comitato etico
(fine 2014/inizio 2015)

PISA

WP2:

- Caratterizzazione rivelatore con fasci monocromatici
- Adeguamento del sistema PIXIRAD-8 (Meccanica)
- Interfaccia con il sistema di acquisizione clinico
- Ottimizzazione dose-risoluzione spaziale (rebinning)

WP5:

- generazione dati per testare gli algoritmi di ricostruzione

Persone 2014 (provvisorio)

Nome		FTE
Bellazzini		0.2
Brez		0.2
Delogu		0.8
De Ruvo		0.5
Spandre		0.2

Richieste 2014

Tipo	Motivazione	kEuro
MI	Missioni a ELETTRA: 5 persone per 1 mese	20
ME	Partecipazione a 2 congressi	6
Meccanica	Allestimento telaio per il detector, possibile movimentazione motorizzata	10
Inventariabile	Sorgente fluoroscopica per calibrazione + computer di controllo	15 + 3
Trasporto	Spostamento di materiale Pisa-Trieste	2
Software		5
		TOT: 61

Richieste servizi: 1 mese uomo officina (realizzazione componenti meccanici)