

A Single Photon Emission Computer Tomograph for breast cancer imaging

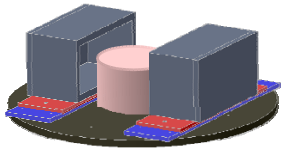
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^c *University of Bologna and INFN-Bologna, Bologna, Italy*





MammoSPECT

MammoSPECT

Design

Head design

Reconstruction

Monte Carlo

Readout

Results

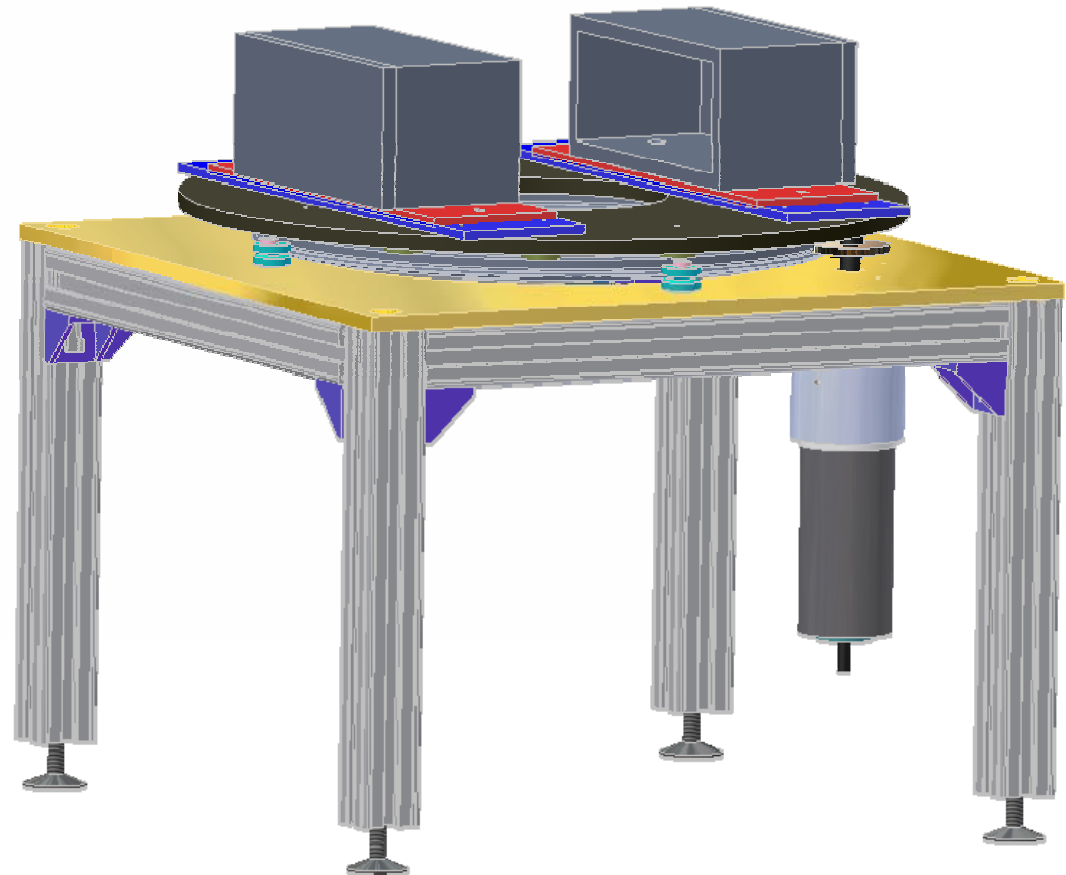
Conclusion

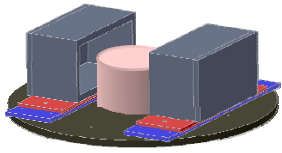
Single photon emission imaging (SPECT) of the breast for the detection of small size tumors.

Aim: to overcome the present clinical sensitivity limit (1 cm \emptyset) for the detection of small size tumors.

Imaging of the cellular steady state model, which would confirm the presence of higher radioactivity uptake from malignant lesions.

Future perspective: analysis of ^{99m}Tc radiopharmaceutical perfusion uptake due to neoangiogenesis generated from the presence of the lesion.





MammoSPECT Design

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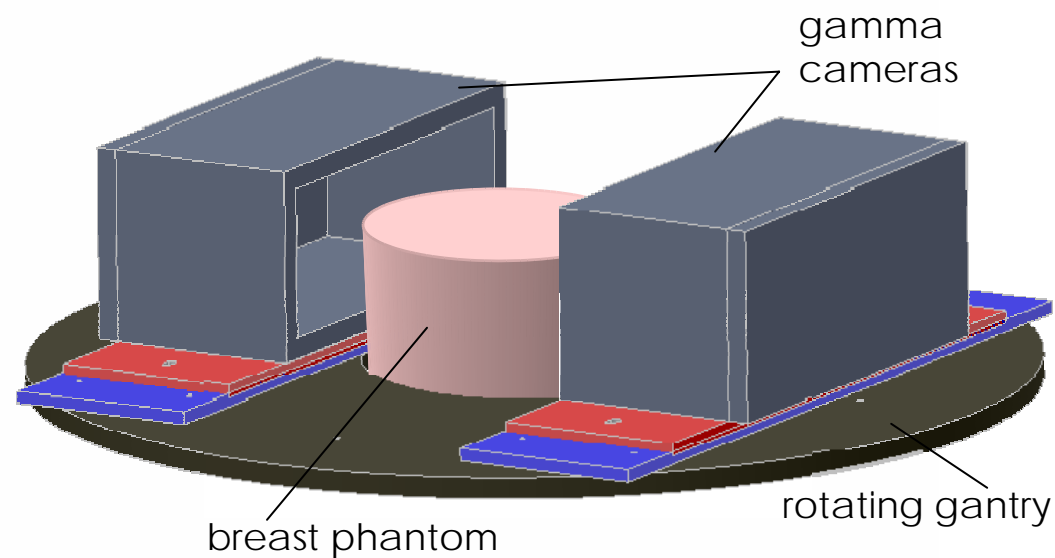
Monte Carlo

Readout

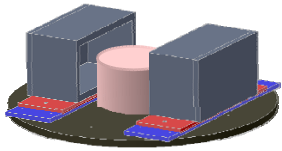
Results

Conclusion

- Two gamma cameras, each about 15 cm x 5 cm wide.
- The SPECT is mounted on a ring that will be rotating around the breast.
- The patient is prone with a pendulous breast.



- Radius of rotation: 6.5 cm.
- Field of View (FOV): 13 cm \varnothing x 5 cm h



MammoSPECT Head Design

MammoSPECT
Design

Head design

Reconstruction

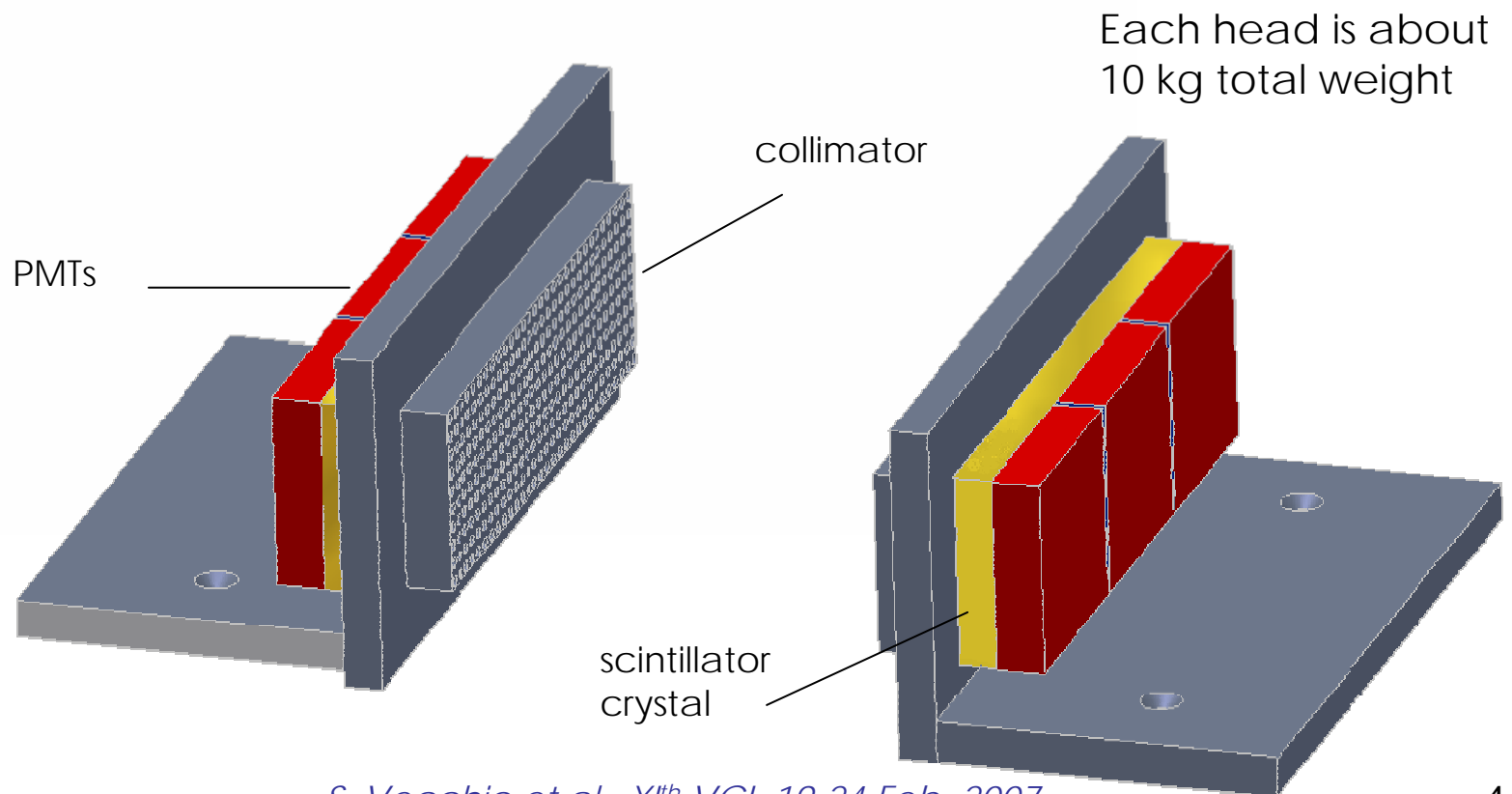
Monte Carlo

Readout

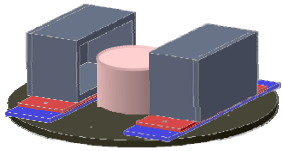
Results

Conclusion

- 3 Hamamatsu 64-anode PMT H8500 (5 cm x 5 cm) .
- large NaI(Tl) scintillator crystal (75 cm²).
- "General Purpose" lead collimator.



S. Vecchio et al., XIth VCI, 19-24 Feb. 2007



MammoSPECT

MA-PMT: Hamamatsu "Flat Panel" PMT H8500

MammoSPECT

Design

Head design

MA-PMT

crystal

Collimator

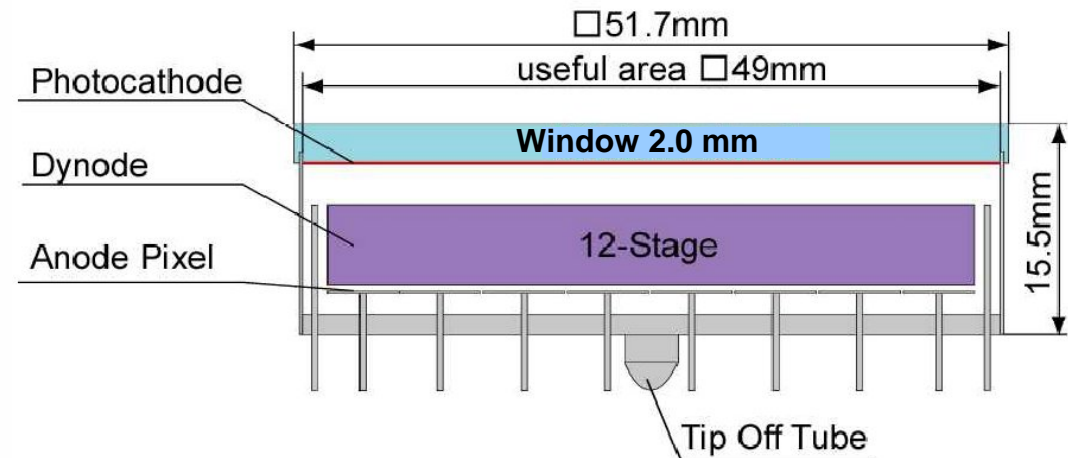
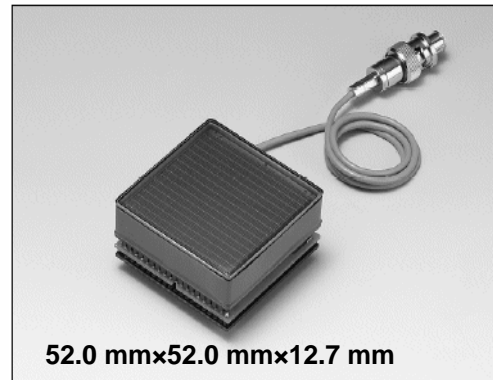
Reconstruction

Monte Carlo

Readout

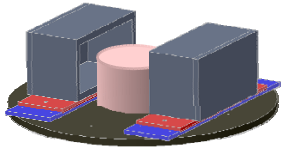
Results

Conclusion



Parameter		Description	Unit
Spectral Response		300 to 650	nm
Peak Wavelength		420	nm
Photocathode Material		Bialkali	—
Window	Material	Borosilicate glass	—
	Thickness	2.0	mm
Dynode	Structure	Metal channel dynode	—
	Number of Stage	12	—
Number of Anode Pixels		64 (8 × 8 matrix)	—
Pixel Size / Pitch at Center		5.8 × 5.8 / 6.08	mm

- Typical anode luminosity is 55 A/lm
- Typical anode gain spread is about 3:1



MammoSPECT

MA-PMT: Hamamatsu "Flat Panel" PMT H8500

MammoSPECT
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Reconstruction

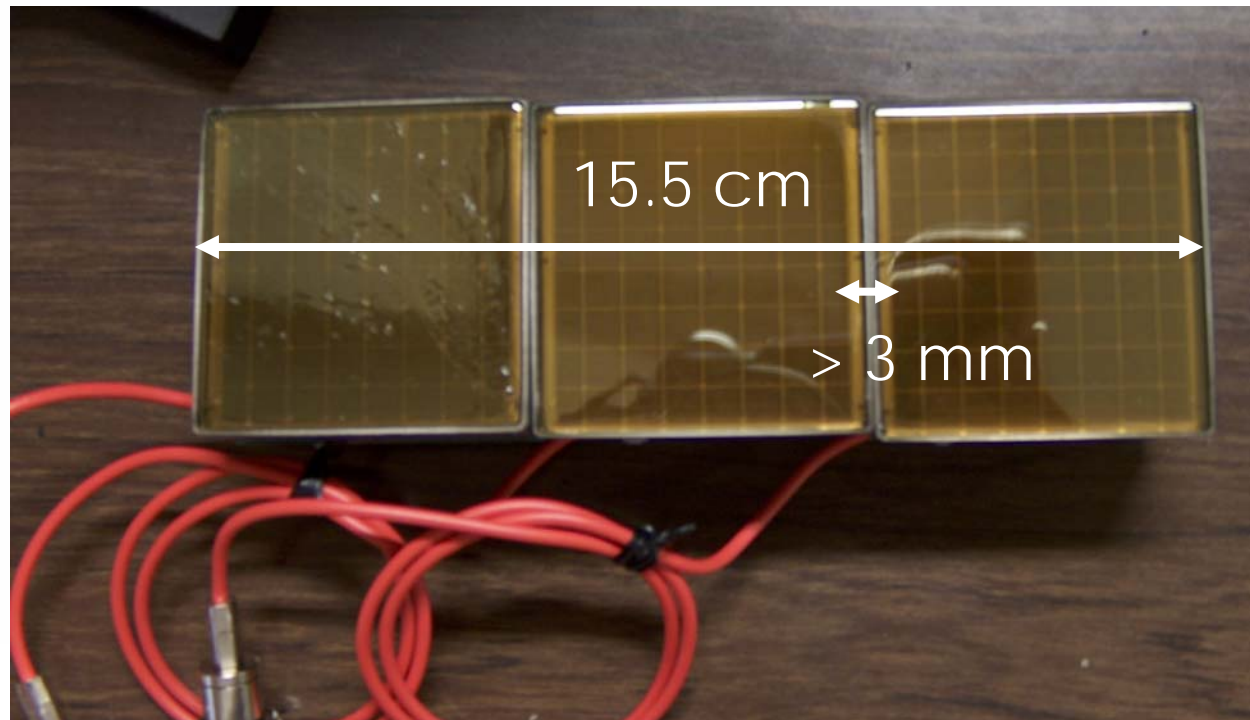
Monte Carlo

Readout

Results

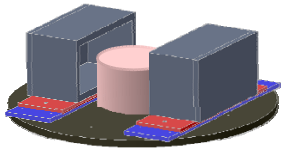
Conclusion

Effective Area	49 × 49	mm
Dimensional Outline (W × H × D)	52 × 52 × 28	mm
Packing Density (Effective Area / External Size)	89	%



Total Active Area : 138 × 46 mm² (79%)
Recovered detector area: 150 × 46 mm² (85%)

S. Vecchio et al., XIth VCI, 19-24 Feb. 2007



MammoSPECT

NaI(Tl) Crystal (Saint Gobain)

MammoSPECT

Design

Head design

MA-PMT

crystal

Collimator

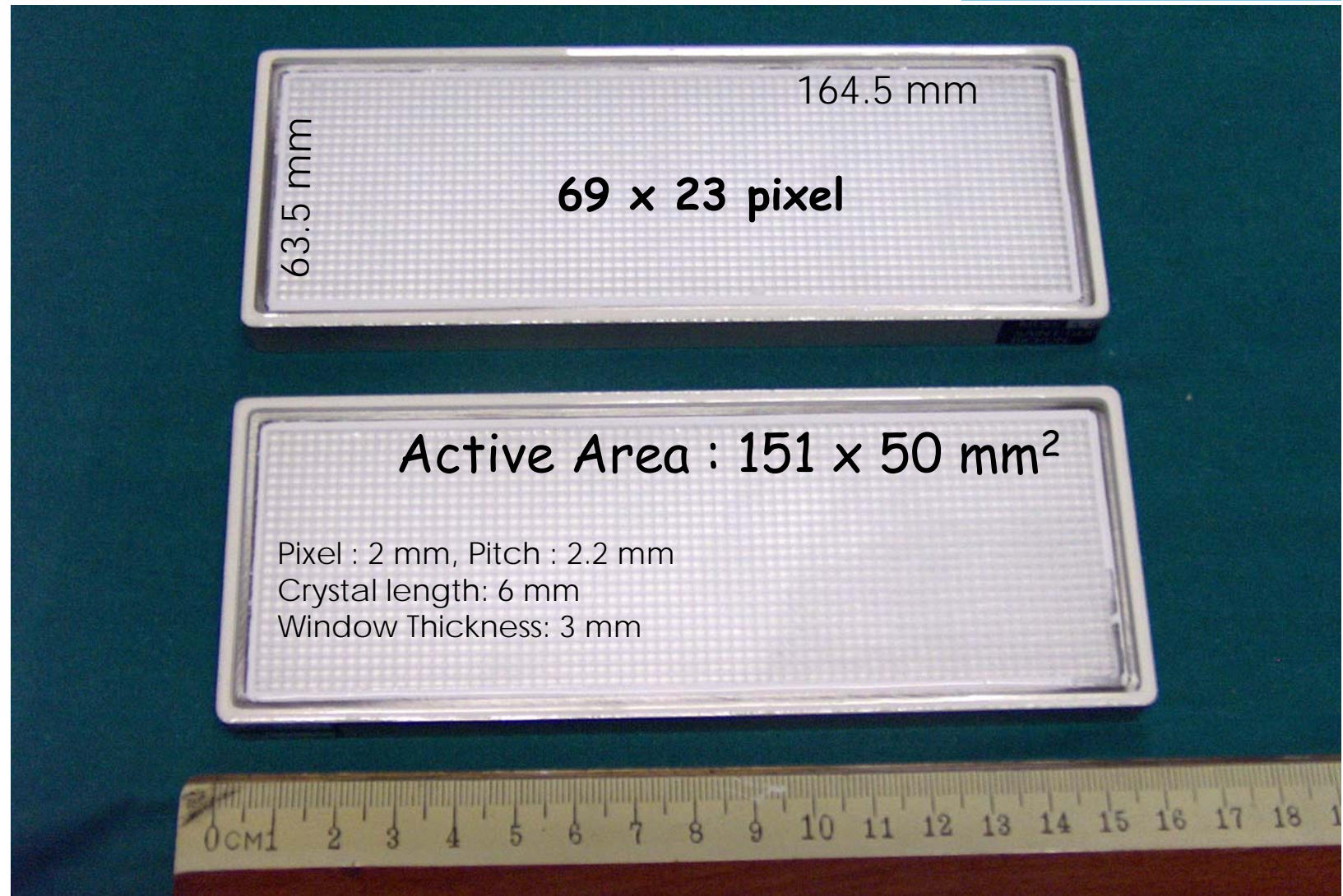
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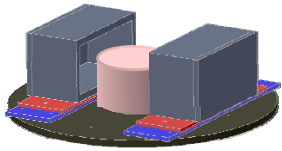
Monte Carlo

Readout

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MammoSPECT

Collimator

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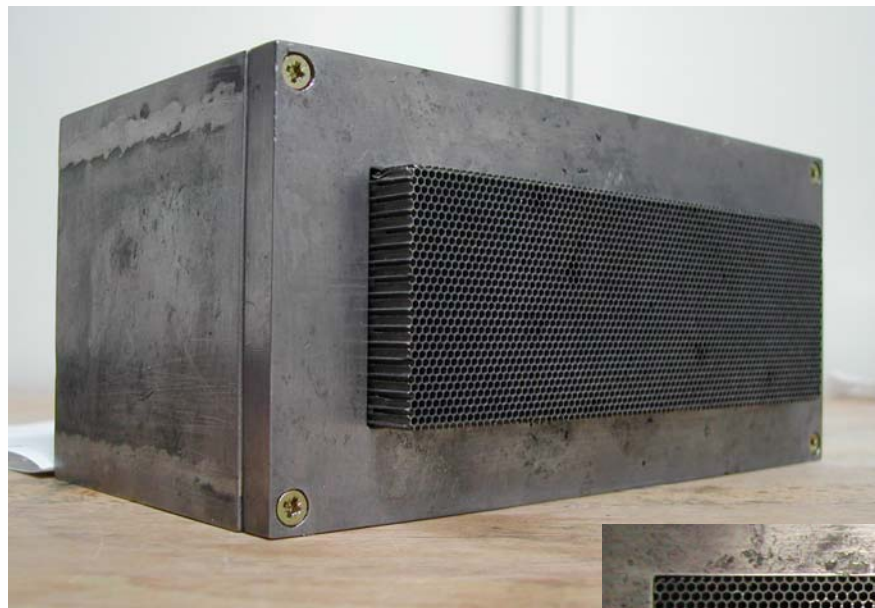
Monte Carlo

Readout

Results

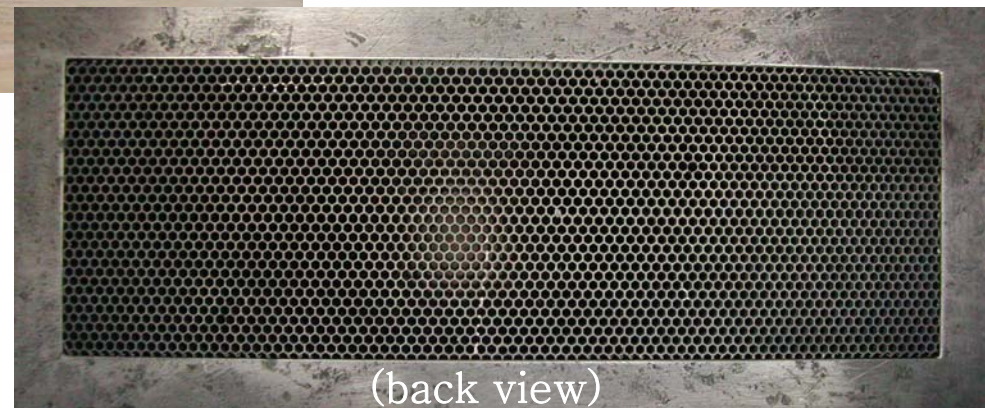
Conclusion

- Lead collimator
- Compromise between sensitivity & resolution @ 140 keV

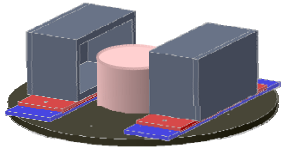


Holes diameter	1.5 mm
Septa thickness	0.2 mm
Length	22 mm
Efficiency [cpm/uCi]	508
Resolution (FWHM @ 10 cm)	8.1 mm

Chosen on the basis of dedicated simulations to compare the best alternatives



(back view)



MammoSPECT Reconstruction algorithm

MammoSPECT

Design

Head design

Reconstruction

Monte Carlo

Readout

Results

Conclusion

- Iterative reconstruction

- Simulated annealing

- Minimization of a cost function:

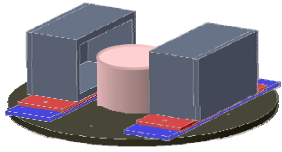
$$E = S \cdot \sum_{j=1}^{N_p} |A_j - A_{ave,n}| + (1-S) \cdot \frac{\sum_{k,m} (P_{k,m} - P_{k,m}^{rec})^2}{K \cdot M}$$

- N_p : number of image pixels;

- $A_{ave,n}$: average activity in a region $n \times n$ around the pixel of interest;

- S : smoothing parameter;

- $P_{k,m}$ $P_{k,m}^{rec}$: measured projections and pseudo-projections for the k^{th} detection element at angle m .



MammoSPECT

Correction factors for reconstruction

MammoSPECT

Design

Head design

Reconstruction

Monte Carlo

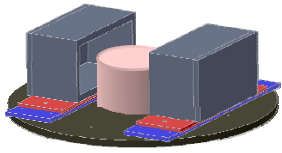
Readout

Results

Conclusion

Corrections are incorporated directly in the projector and used for calculating the pseudo-projections at each iteration of the reconstruction procedure

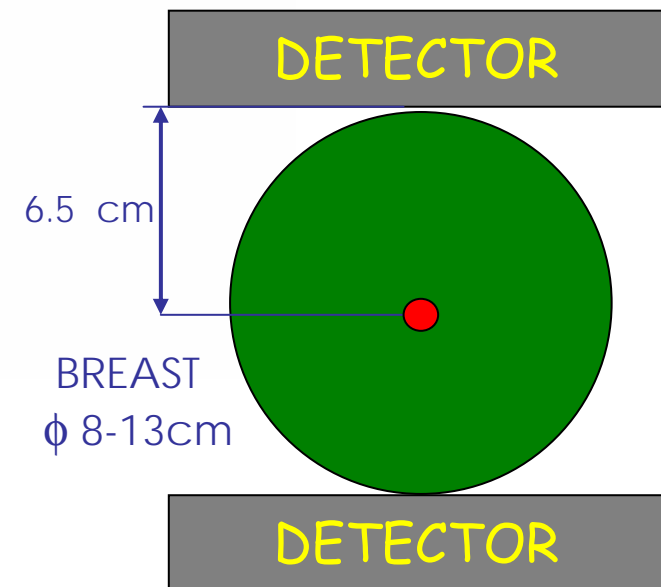
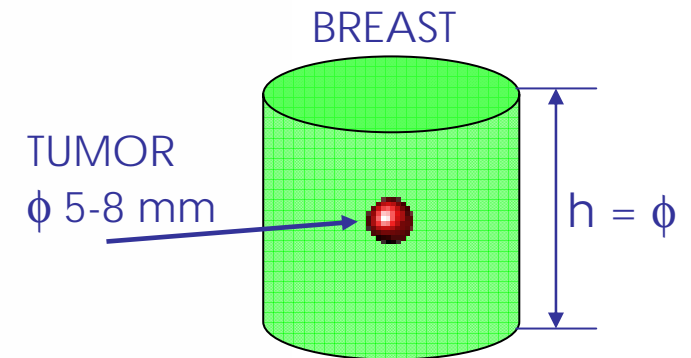
- Collimator response
- Variable spatial resolution
- Attenuation due to breast tissue
- Scattering due to breast tissue

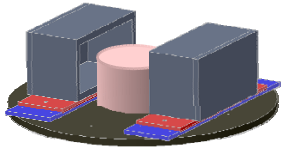


MammoSPECT Monte Carlo simulation

EGSnrc code

- Radionuclide: ^{99m}Tc (140 keV)
- Detector:
 - NaI(Tl) crystal matrix
 - 50x150x6 mm³, 22x68 pixel.
- Phantom:
 - breast tissue, cylindrical,
 - \varnothing 8 cm, 10 cm, 13 cm.
 - specific activity: 100 nCi/cc
- Tumour:
 - spherical
 - \varnothing 5 mm, 8 mm
 - specific activity: 1 $\mu\text{Ci}/\text{cc}$,
(0.5 $\mu\text{Ci}/\text{cc}$, 1.5 $\mu\text{Ci}/\text{cc}$)
- **T/B = 10:1, (5:1, 15:1)**





MammoSPECT Reconstruction details

MammoSPECT

Design

Head design

Reconstruction

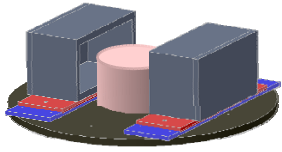
Monte Carlo

Readout

Results

Conclusion

- Rotation radius: 6.5 cm
- 36 projection on 360°
- Total scan duration: 20 minutes
- Selected event: $E > (E_{\text{photopeak}} - 2 \cdot \sigma_E)$
- Iterative reconstruction
 - Reconstructed FOV: 15 cm x 15 cm x 5 cm
 - Reconstructed image: 69 x 69 pixel
 - Image voxel: 2.2 x 2.2 x 2.2 mm³



MammoSPECT

Figures of merit for reconstructed images

Signal to Noise Ratio (SNR) and Image Contrast (IC) formulas for tomographic images:

$$SNR = \frac{\Sigma_{ROI} - BKG}{\sigma_{BKG}}$$

Region of Interest (ROI) :
3 x 3 pixels (6.6 x 6.6 mm²)

$$IC = \frac{\Sigma_{ROI} - BKG}{\Sigma_{ROI}}$$

- *BKG*: background average
- σ_{BKG} : background standard deviation
- Σ_{ROI} : average over a ROI centered on the tumour

MammoSPECT

Design

Head design

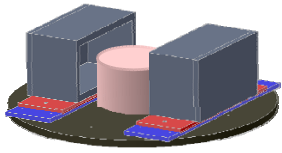
Reconstruction

Monte Carlo

Readout

Results

Conclusion



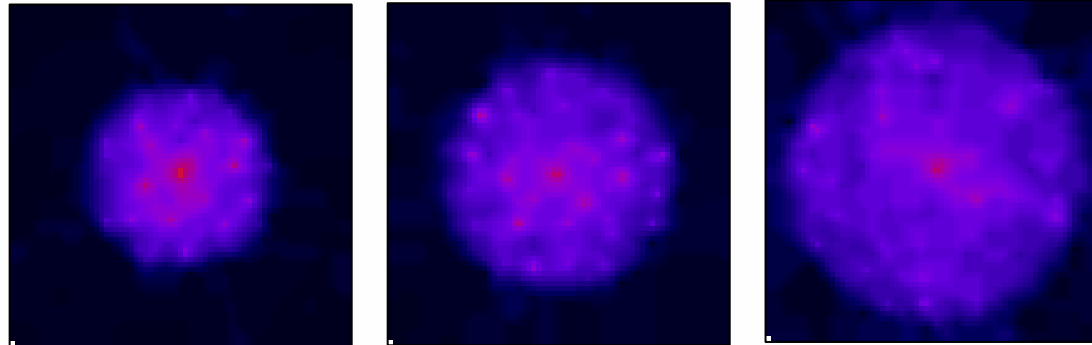
MammoSPECT

Results for 5 mm \emptyset tumour

- MammoSPECT
- Design
- Head design
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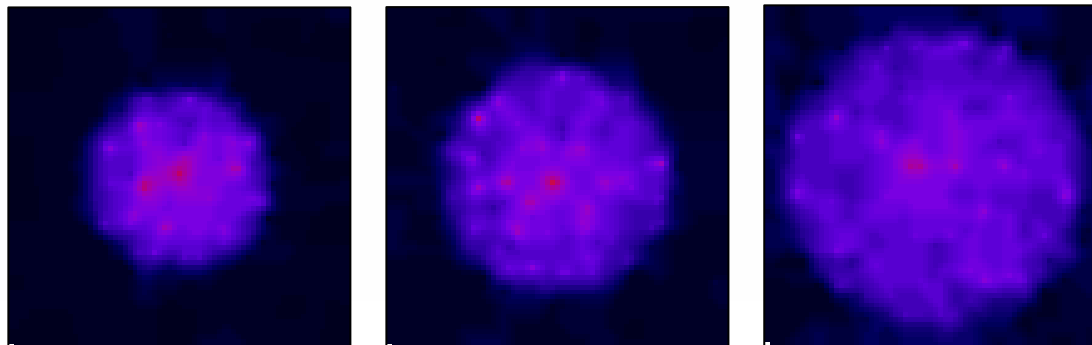
breast 8 cm 10 cm 13 cm

T/B 15:1

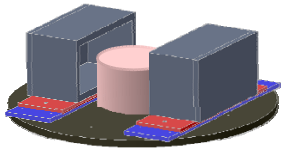


SNR	5.6	5.8	5.2
IC	36%	39%	37%

T/B 10:1



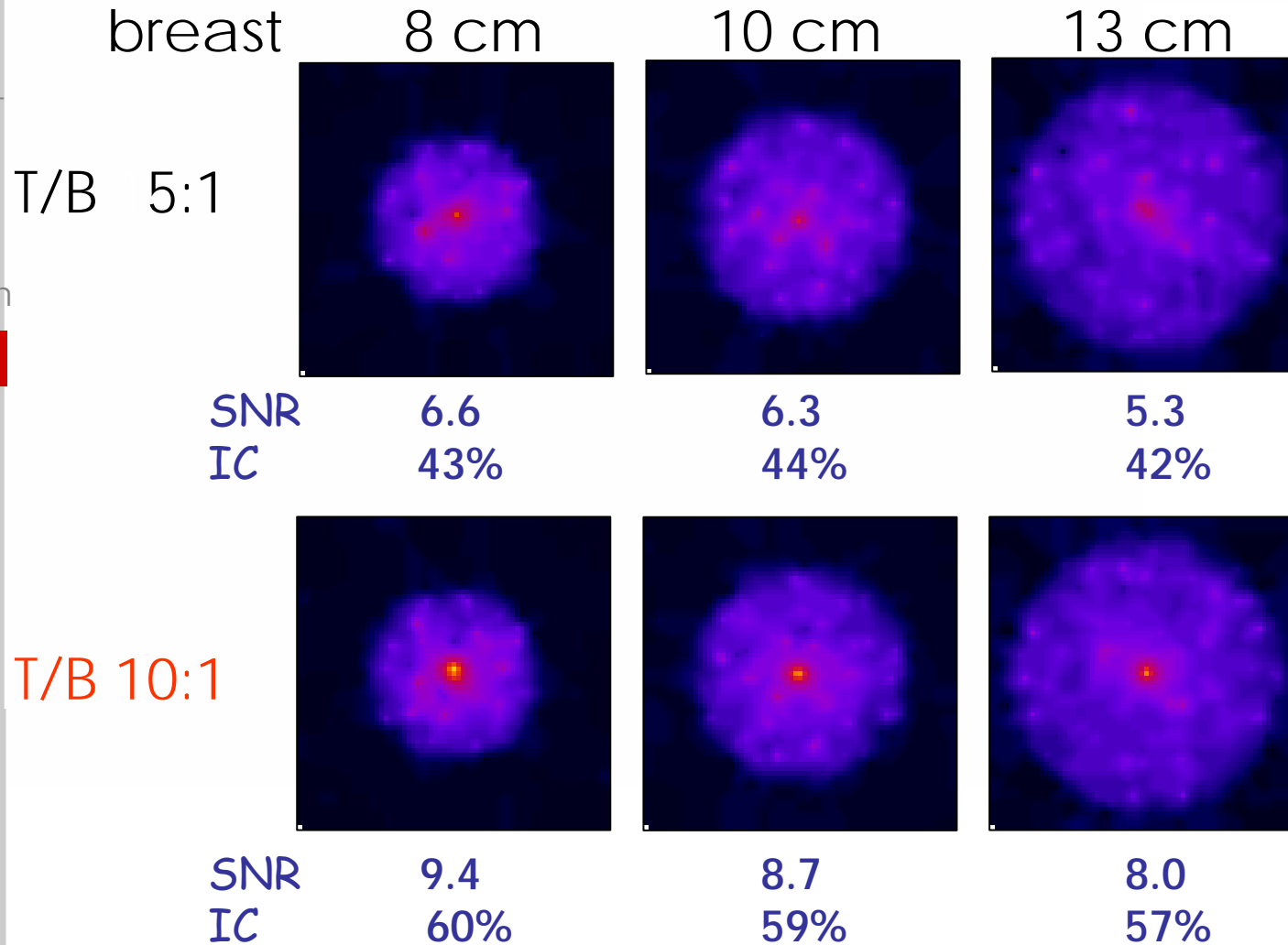
SNR	4.9	4.7	4.6
IC	34%	38%	30%

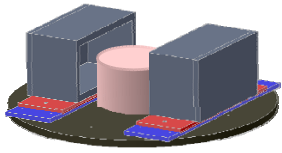


MammoSPECT

Results for 8 mm \emptyset tumour

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MammoSPECT

Results for 8 mm \varnothing tumour

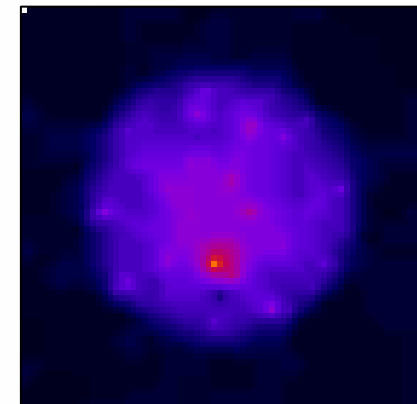
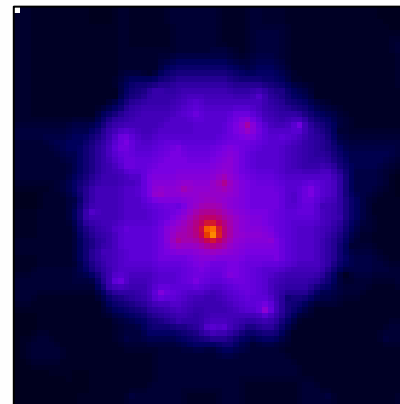
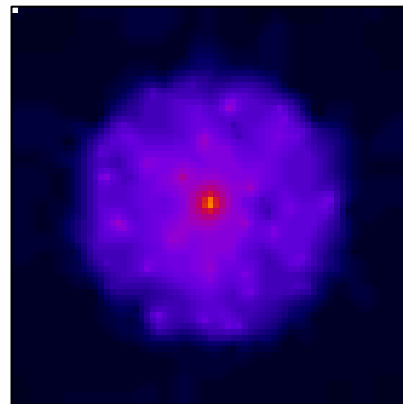
MammoSPECT
Design
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10 cm breast - T/B 10:1

Centered

1 cm

2 cm

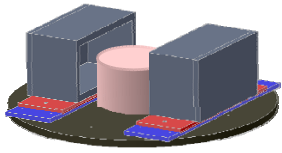


SNR
IC

8.7
59%

8.6
56%

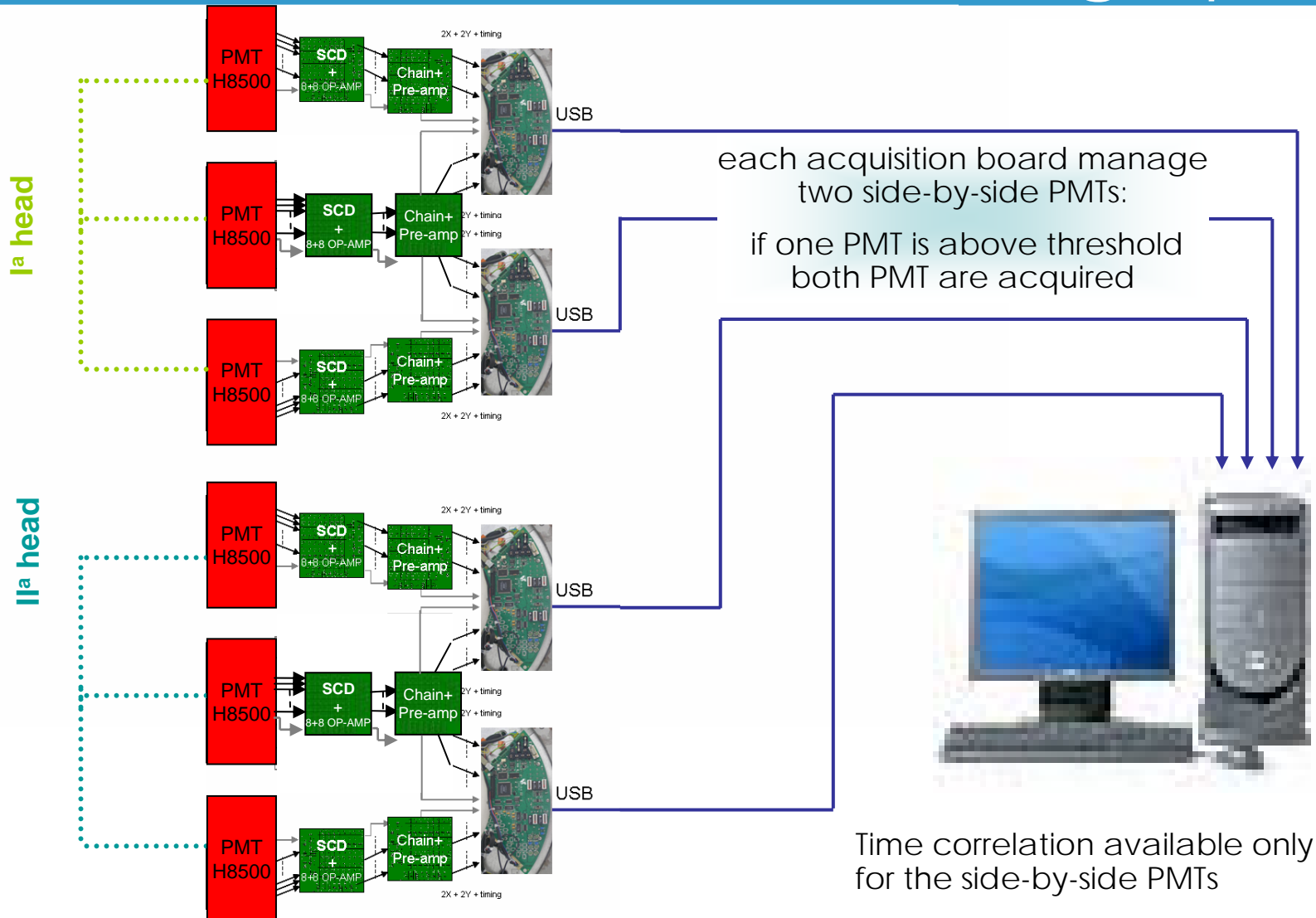
8.5
52%

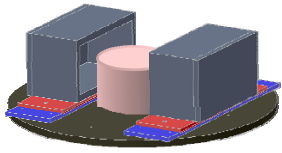


MammoSPECT

Readout for the entire tomograph

- MammoSPECT Design
- Head design
- Reconstruction
- Monte Carlo
- Readout**
- Results
- Conclusion

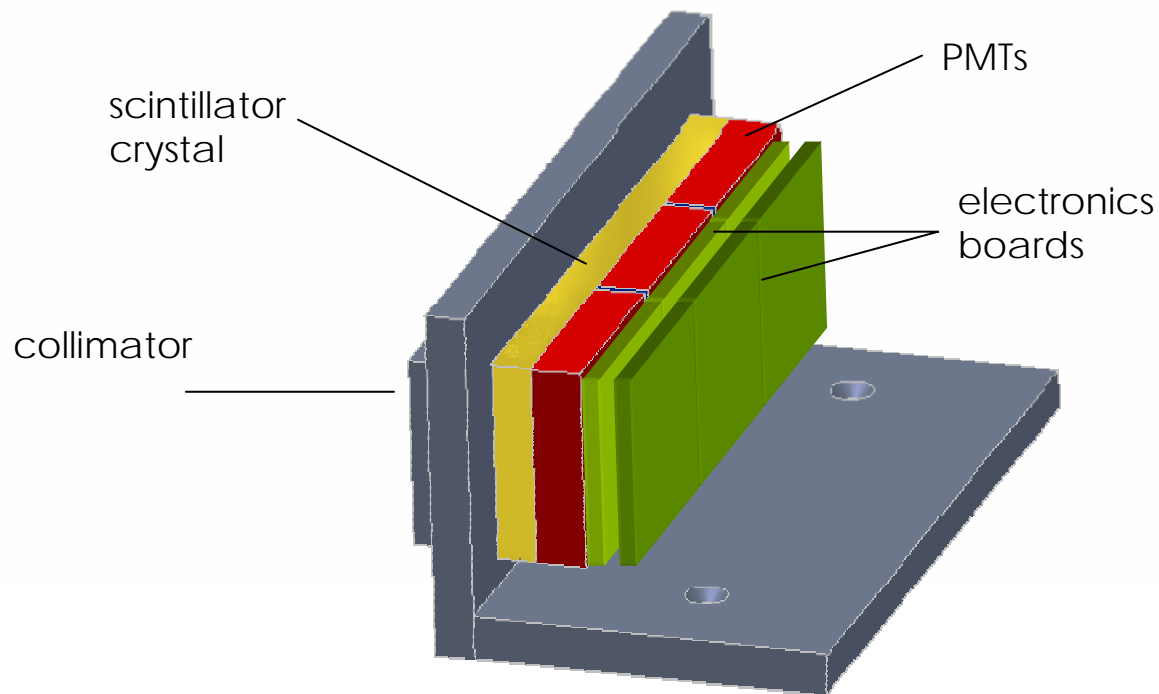


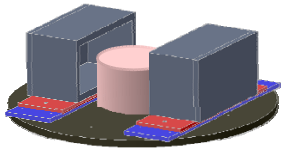


MammoSPECT Head Design (2)

3 Hamamatsu 64-anode PMT H8500 (5 cm x 5 cm) :
the readout of each head manages $3 \times 64 = 192$ channels.

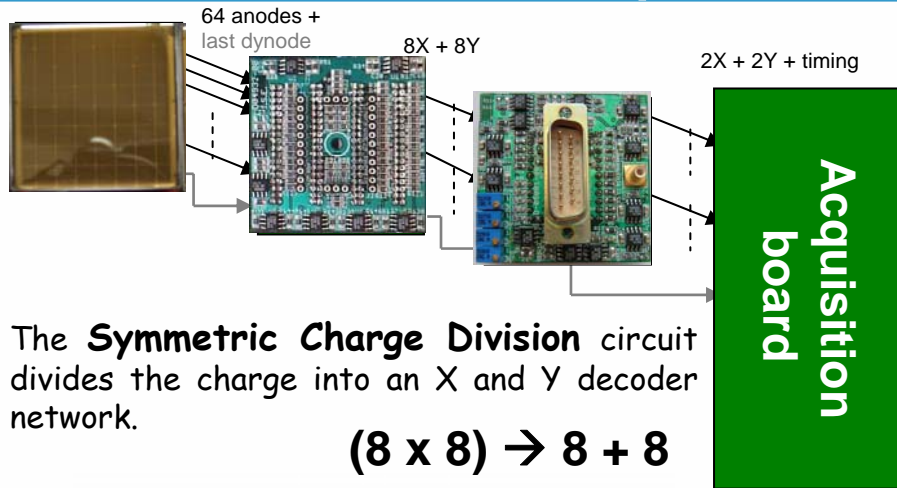
MammoSPECT
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Head design
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MammoSPECT PMT multiplexed read-out

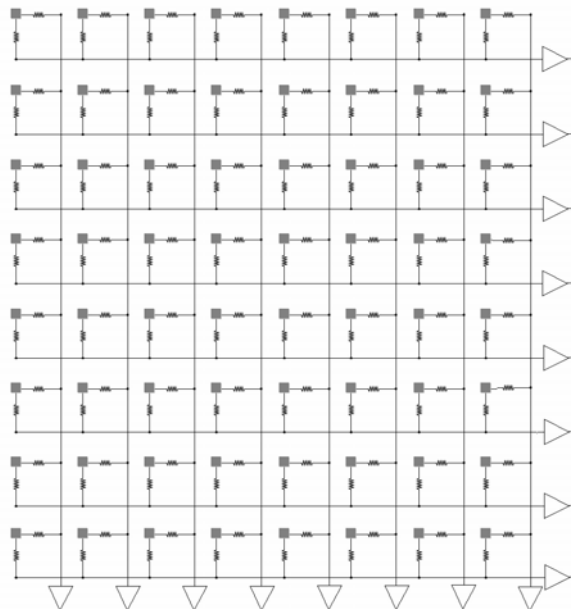
- MammoSPECT
- Design
- Head design
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Electronics partially inherited from YAP-(S)PET Small Animal Scanner

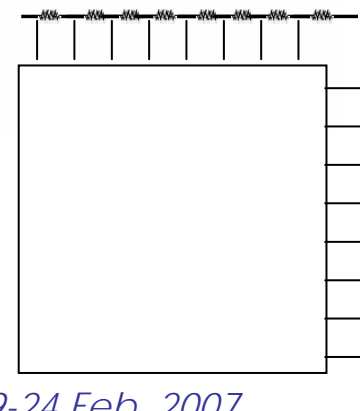
The **Symmetric Charge Division** circuit divides the charge into an X and Y decoder network.

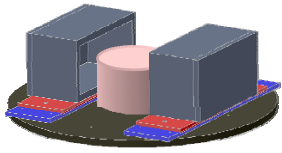
$$(8 \times 8) \rightarrow 8 + 8$$



The **SCD** is followed by simple resistive chains to further reduce the number of signals to two for each direction.

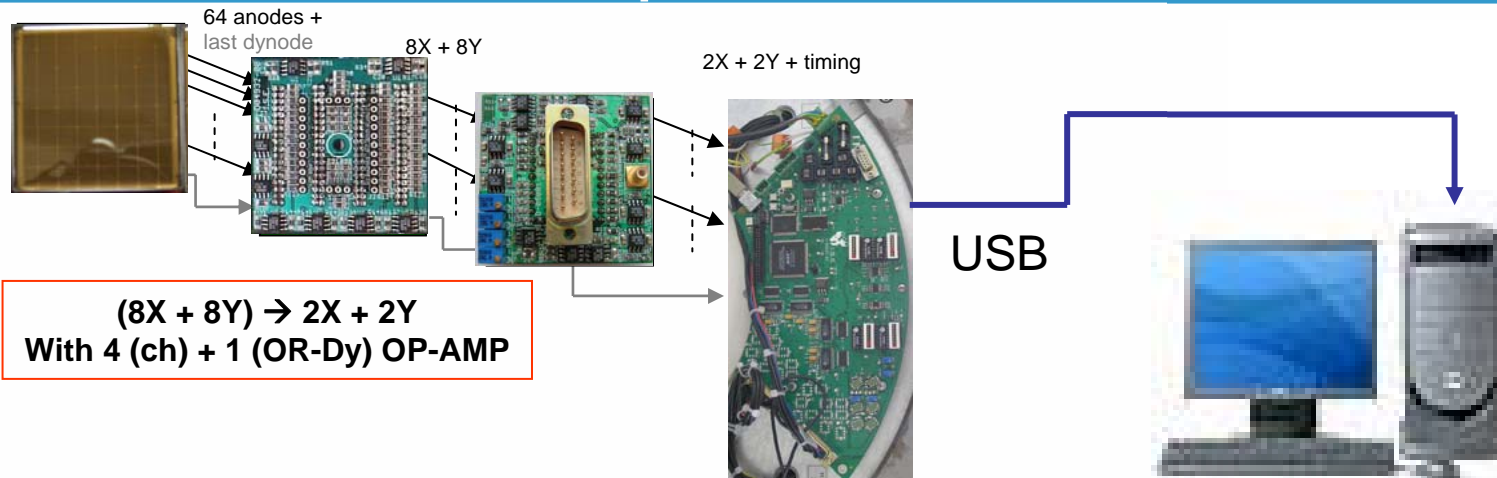
$$(8+8) \rightarrow 2 + 2$$





MammoSPECT PMT multiplexed read-out

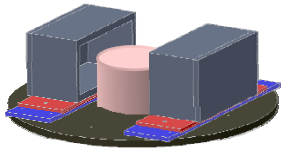
MammoSPECT
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- Constant fraction discrimination
- Energy threshold: about 50 keV
- Max acquisition rate per board: 100 kHz
 \Rightarrow up to 300 kHz can be managed by the whole acquisition system

$$X_{position} = \frac{V_{x+} - V_{x-}}{V_{x+} + V_{x-}}$$

$$Y_{position} = \frac{V_{y+} - V_{y-}}{V_{y+} + V_{y-}}$$

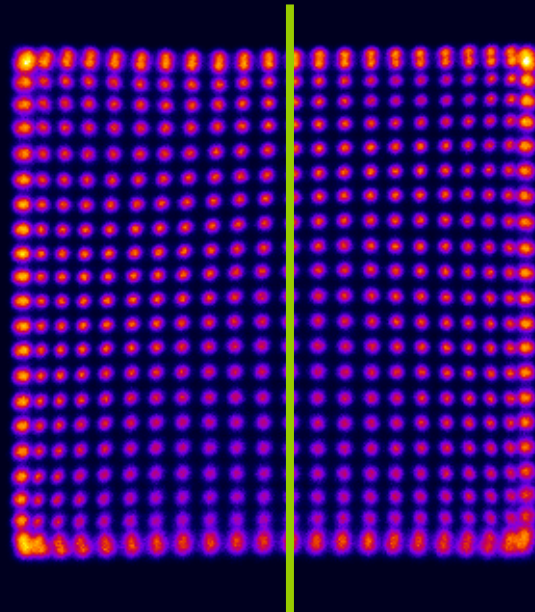


MammoSPECT

SCD-based multiplexed readout for a single PMT

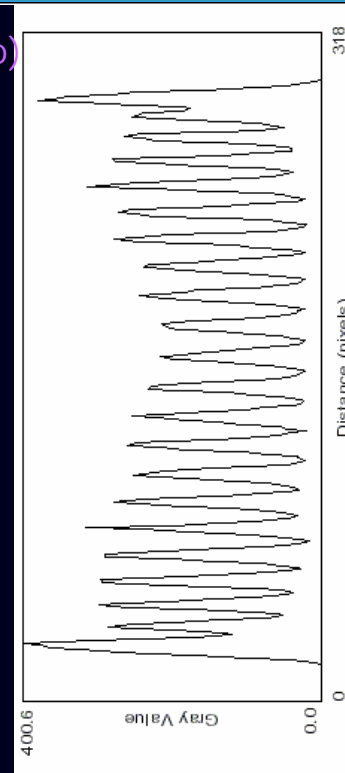
- MammoSPECT
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n° AA0325, 1.5 mm window, 122 keV (^{57}Co)

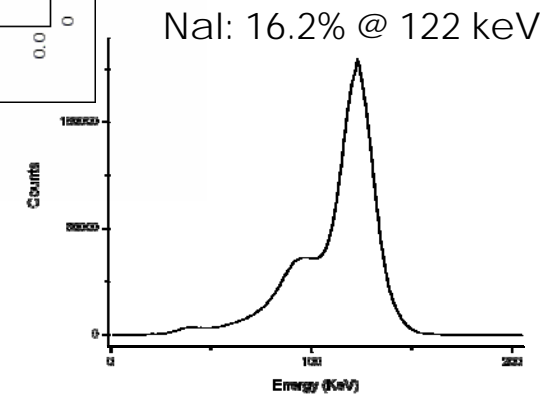


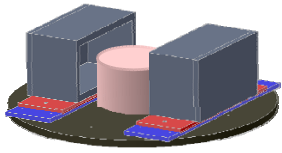
NaI:TI 23x23 matrix

1.8 mm x 1.8 mm side
Separated by 200mm epoxy
45.8 mm x 45.8 mm area



Resolution (mm)	0.8
Peak/Valley	6.8

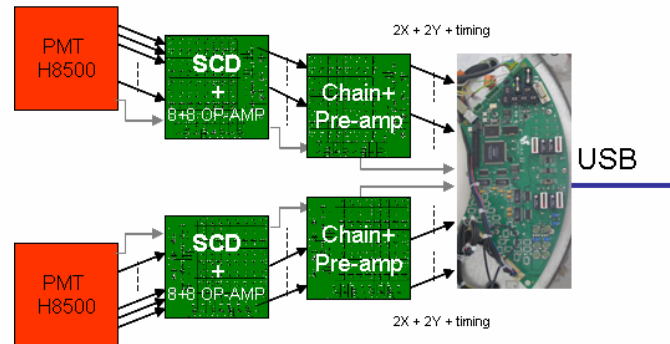




MammoSPECT

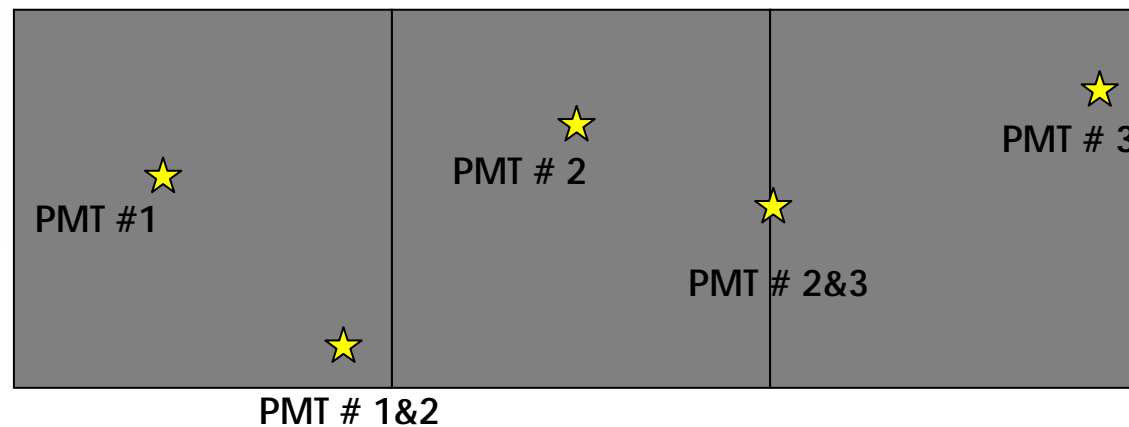
Readout for a 3-PMTs assembly

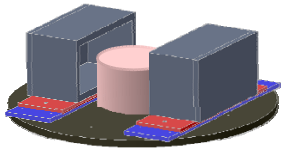
- MammoSPECT
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- Conclusion



Time correlation between each side-by-side PMT pair. The PMT in the center can be separately correlated with both the other ones.

The event reconstruction never involves more than two PMT of one head:





MammoSPECT

Recover of the dead area

MammoSPECT

Design

Head design

Reconstruction

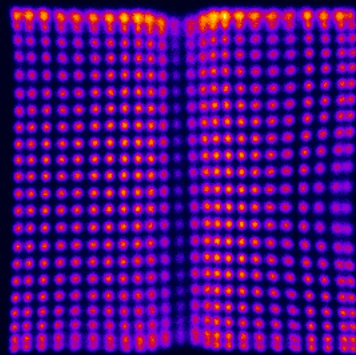
Monte Carlo

Readout

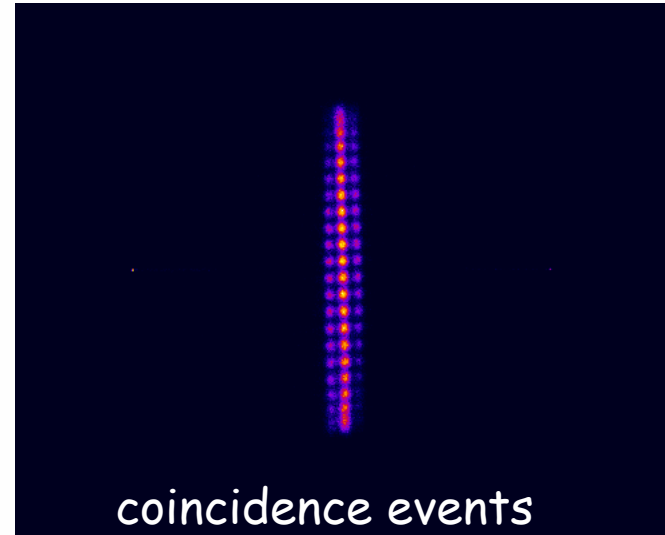
Results

Conclusion

1.5 mm window, 122 keV (^{57}Co)



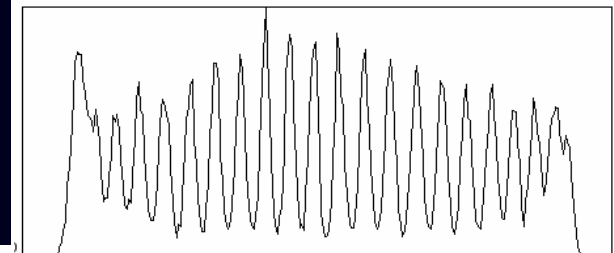
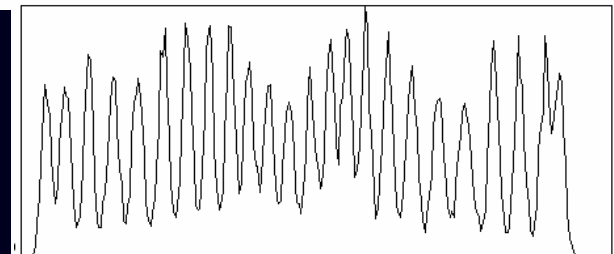
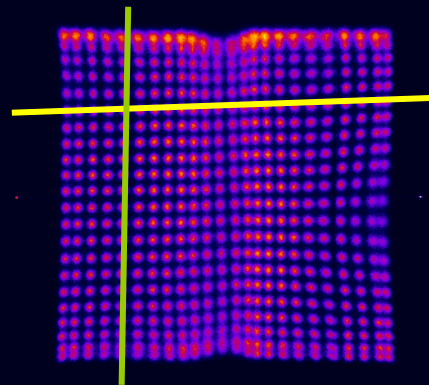
anticoincidence events

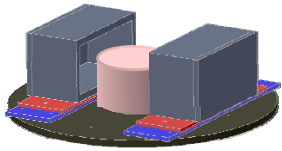


coincidence events

NaI:Tl
23x23 matrix
1.8 mm side,
2 mm pitch

total events

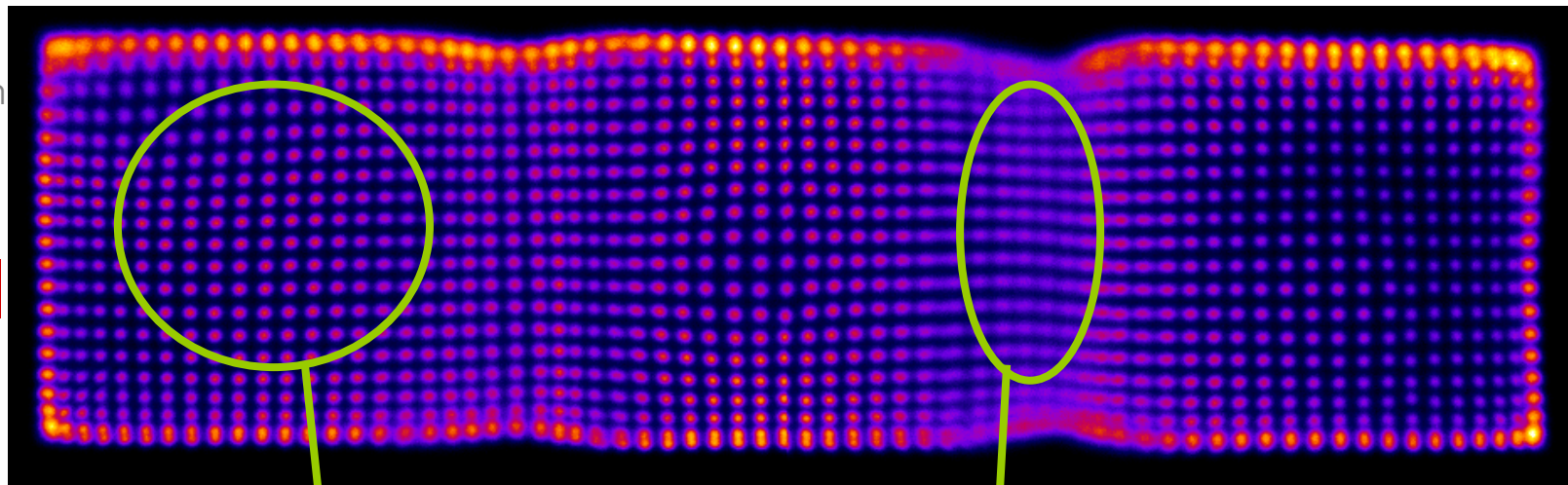




MammoSPECT Imaging performance

- MammoSPECT
- Design
- Head design
- Reconstruction
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- Results**
- Conclusion

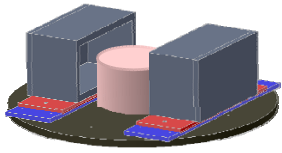
**^{57}Co flood field irradiation
(no collimator)**



Energy resolution
@ 122 keV:

16 %

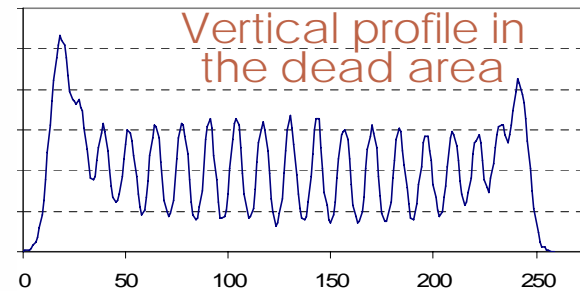
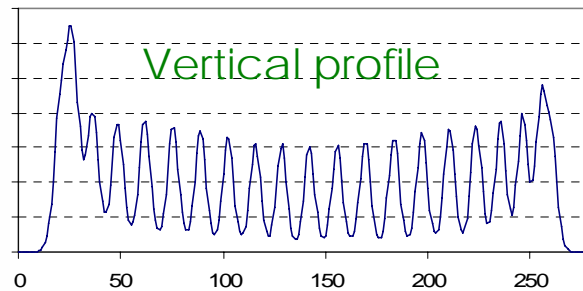
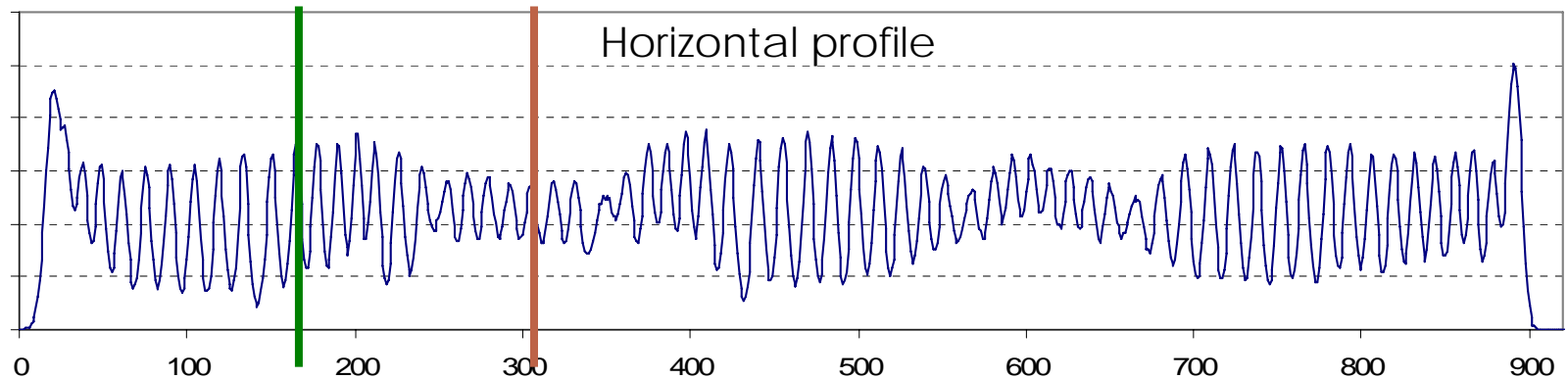
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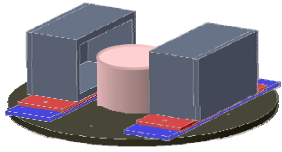
MammoSPECT Imaging performance

- MammoSPECT
- Design
- Head design
- Reconstruction
- Monte Carlo
- Readout
- Results
- Conclusion

^{57}Co flood field irradiation



	Vertical profiles		Horizontal profiles
	detector area	dead area	total area
Resolution (mm)	1,1	1,2	1,3
Peak/Valley	4,6	3,2	2,5



MammoSPECT

Summary and future work

MammoSPECT

Design

Head design

Reconstruction

Monte Carlo

Readout

Results

Conclusion

- The dead area in the H8500 PMT triplet assembly is successfully recovered with reasonable values of P/V and energy resolution
- Measurements of detection efficiency are coming soon
- MC simulation estimate a sensitivity limit of 8 mm \varnothing tumour (T/B 5:1) in 13 cm breast
- The realization of the rotating ring has being completed
- The SPECT ring will be transferred at the Nuclear Medicine Division of University of Pisa for the validation on breast phantoms.

This work is developed within the framework of the PRIN2004 Italian project: "New Techniques for Breast Cancer Imaging".