the performances of compact gamma-cameras

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1. Introduction

2. Simulation

3. Measurements

5. Conclusions and outlook

Motivation

- **Early breast cancer detection**

Anger Camera --> Compact discrete gamma-camera

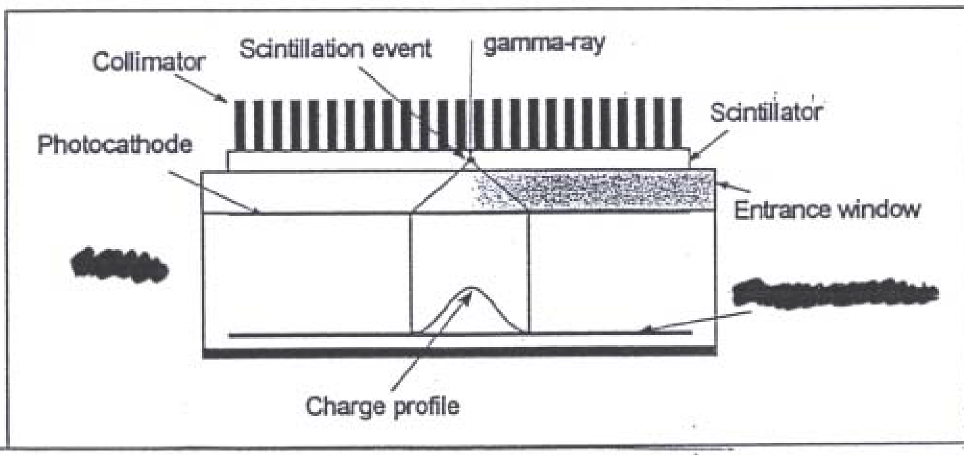
- **Enough sensitivity only for**

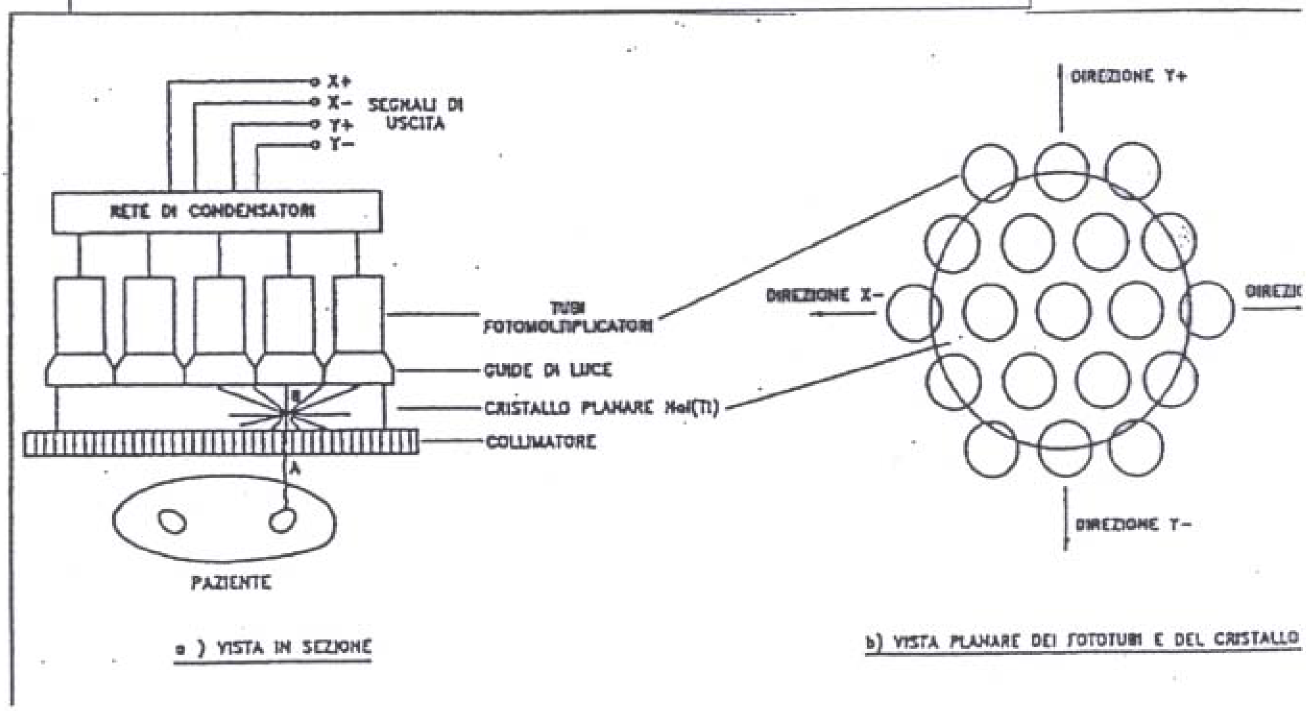
  T_{1b} tumors (> 5mm)

- **Optimization is needed**

Anger camera principle

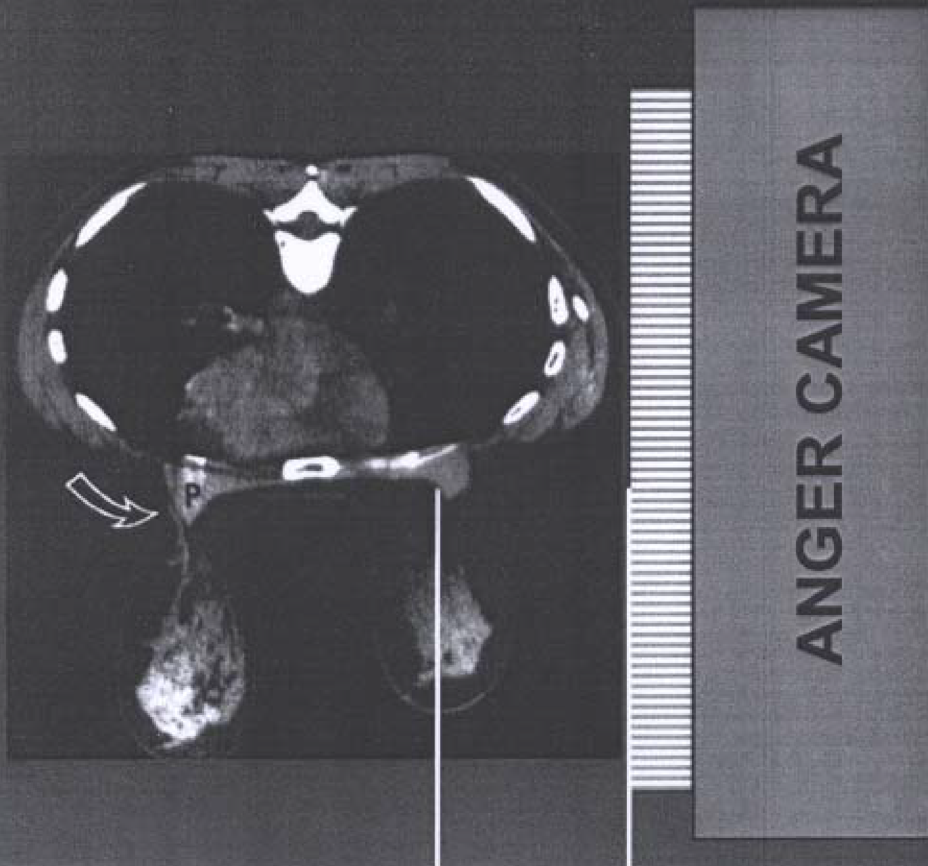
- Continuous scintillation crystal, light sharing across pixels
- Use centroiding algorithm to locate position





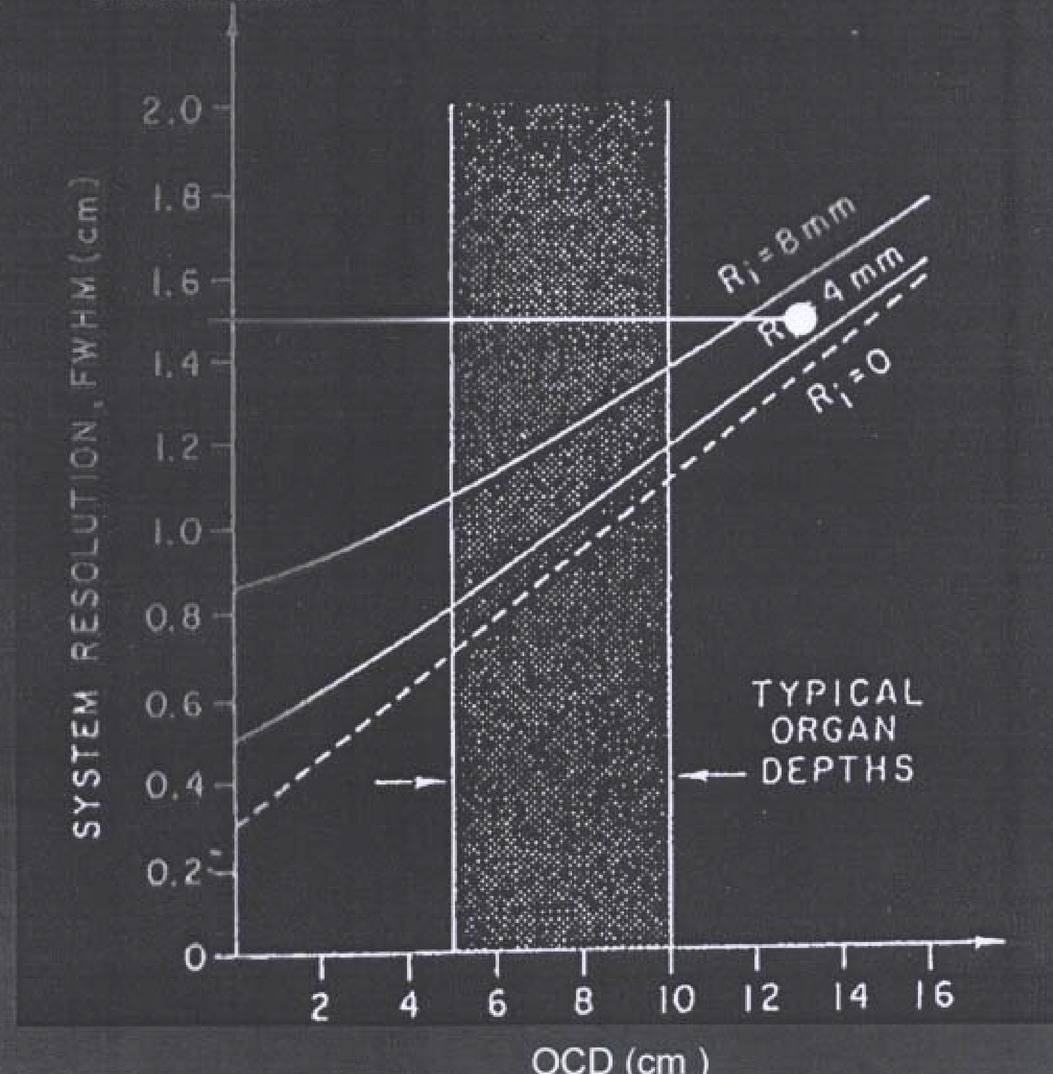
Spatial resolution in PSM

From: J.A.Sorenson and M.E.Phelps "Physics in Nuclesr Medicine" Grune & Strattom

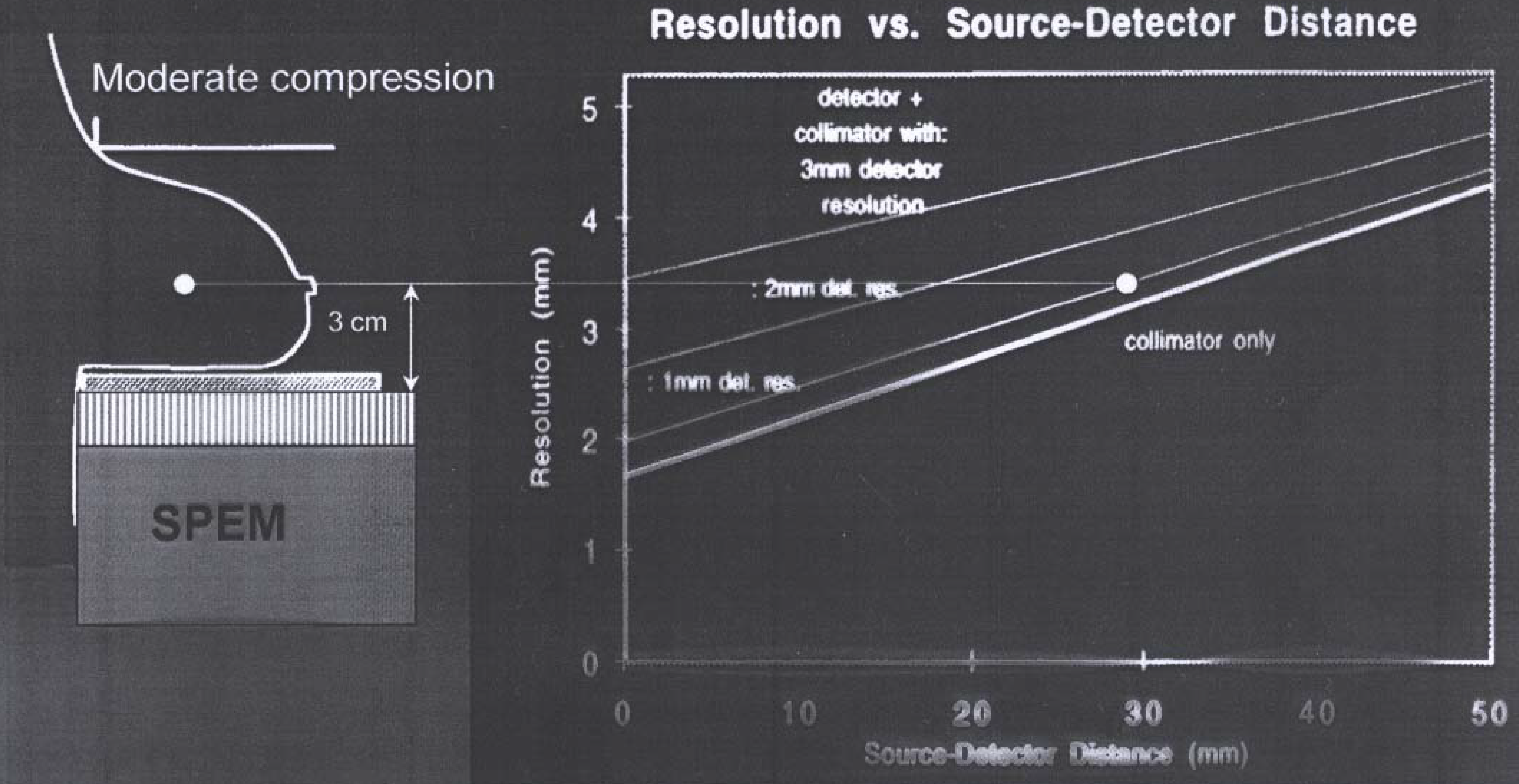


10 -15 cm

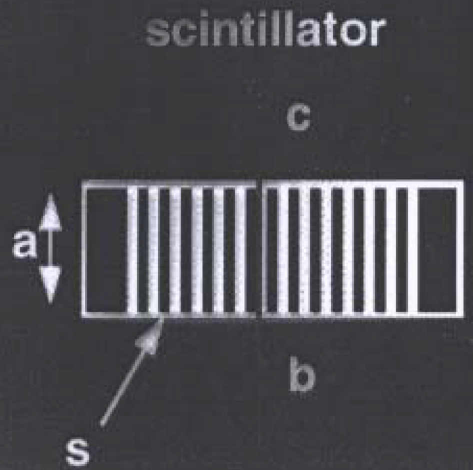
Object – collimator distance



Spatial resolution in SPEM



Collimator Design



Resolution (FWHM)

$$Rc = d(a_e + b + c) / a_e$$

$$a_e = a - 2/\mu$$

$$Rs = (R_c^2 + R_i^2)^{1/2}$$

Geometric Efficiency

$$g = k^2 \{ d^2 / [a_e (d + s)] \}^2$$

k = 0.263 for hexagonal,
0.282 for square

1 cm thick

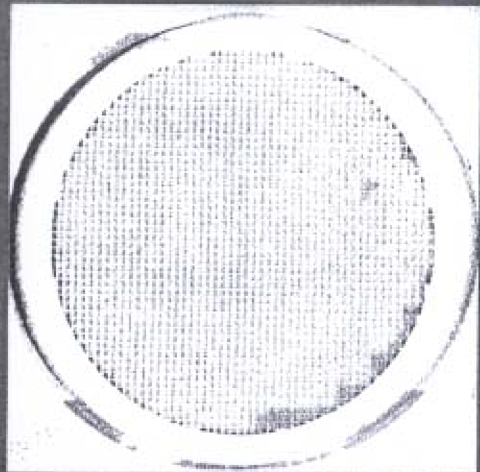
1.27 mm openings

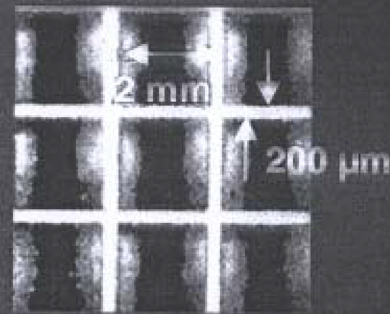
0.15 mm septa

resolution at 1.5 cm is 3.5 mm

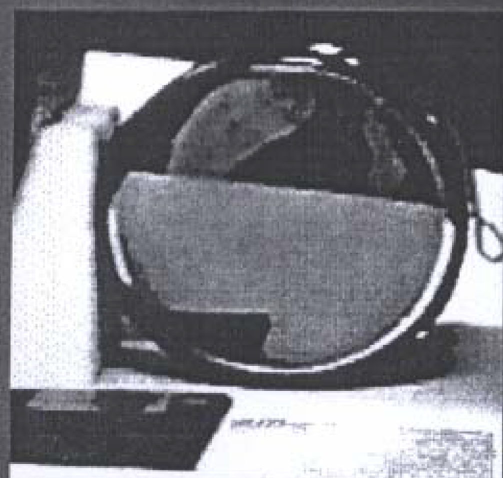
366 cpm/μCi

Rome - Italy
Dept. Experimental Medicine

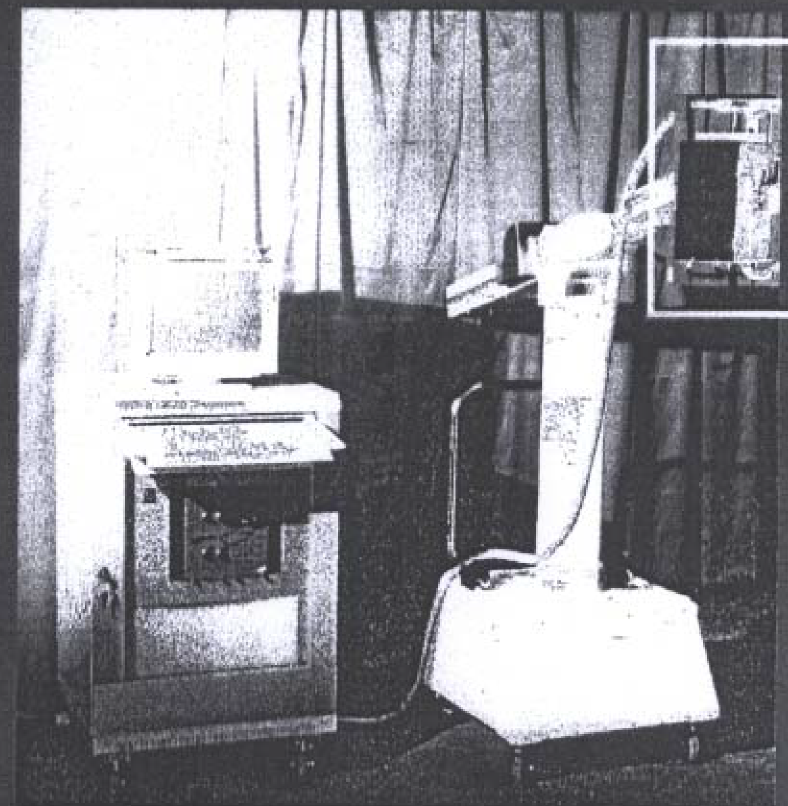




CRYSTAL ARRAY

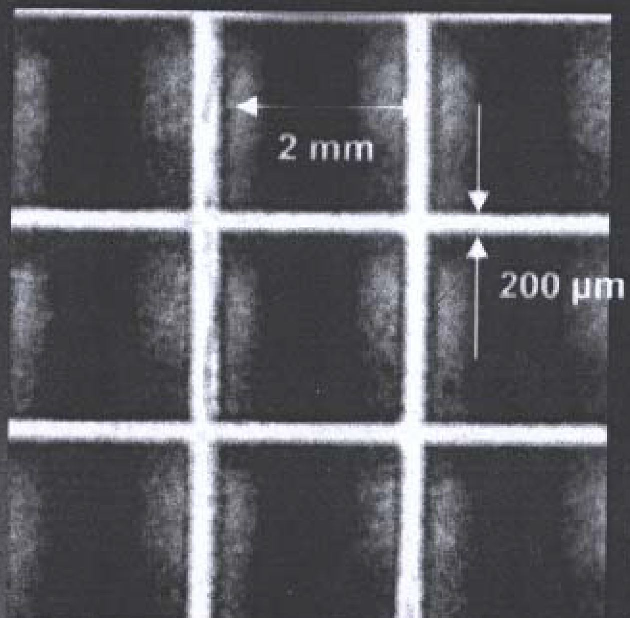


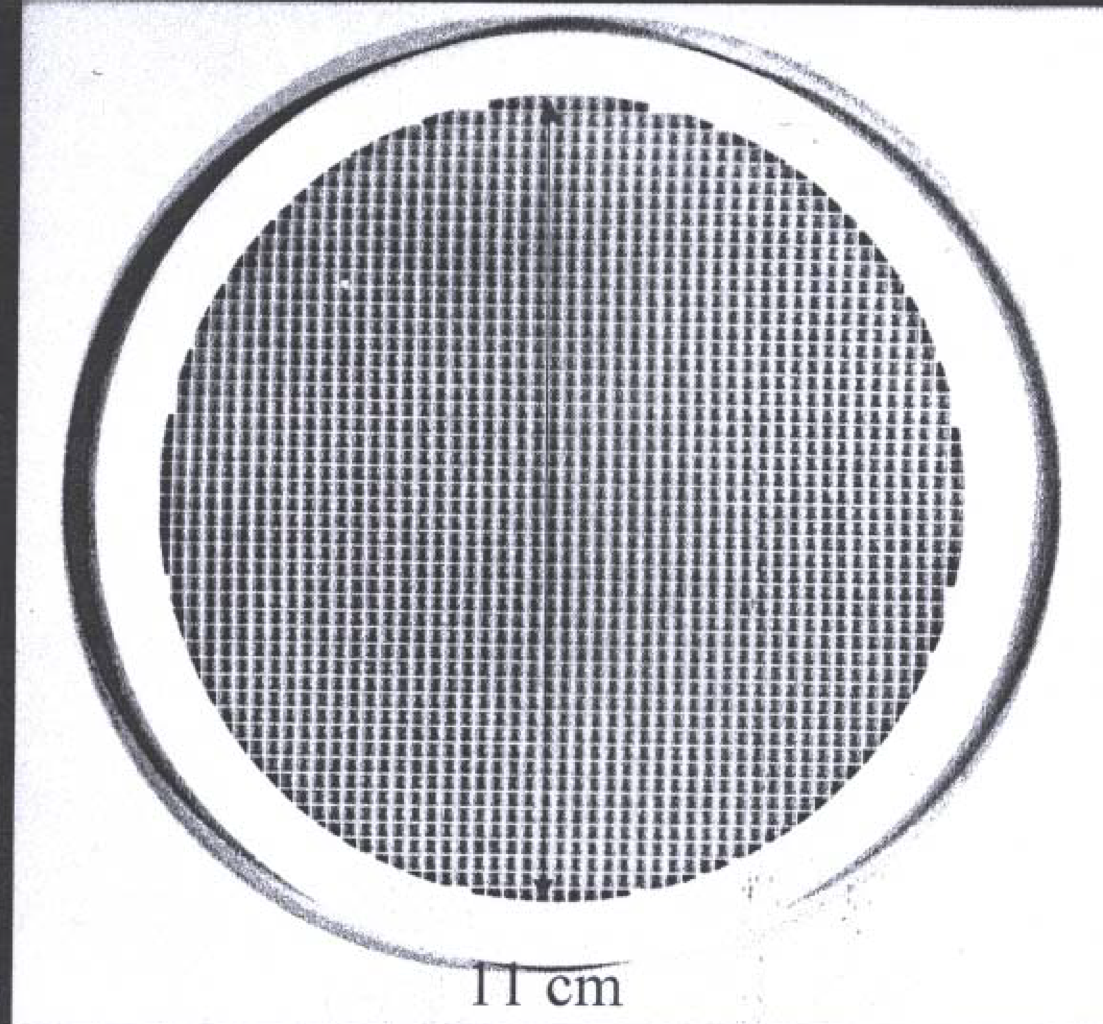
PSPMT



CsI(Tl) Scintillating array

produced by Hilger Analytical





and position linearity

- light spread
- light sampling

light spread

- scintillator thickness (planar
- granularity
- optical guide

light sampling

- photodetector (anode) segmentation
  - R5900 M64 — 18 x 18 mm² — 2x2 mm² pixels.
  - R5900 M16 — 18 x 18 mm² — 4 x 4 mm² pixels.
  - R5900 C8 — 22 x 22 mm² — stripes 5.5 mm

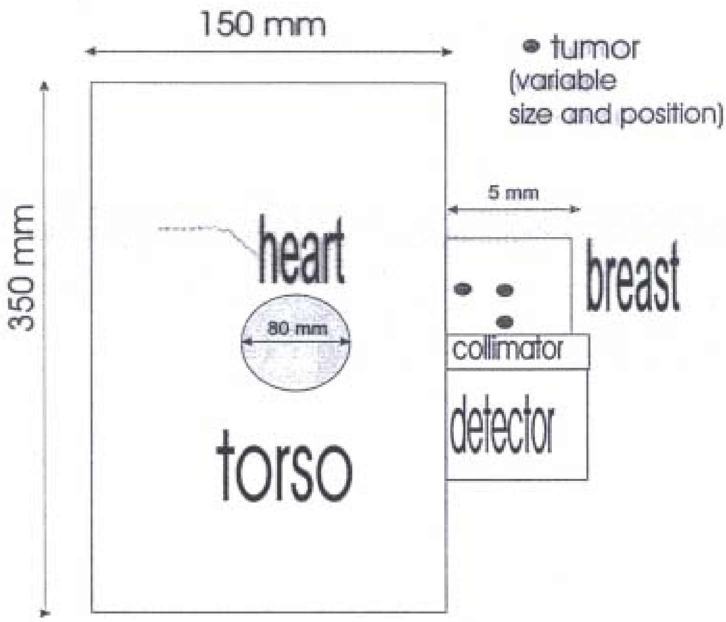


Figure 1: The scintimammography problem and our simulation

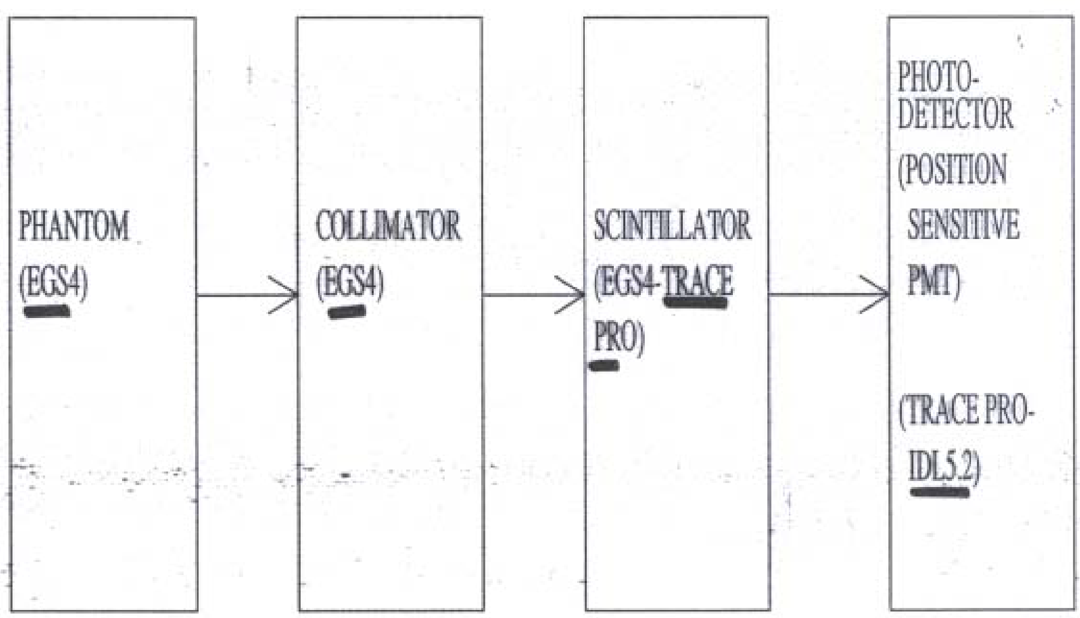


Figure 2: Block diagram simulation

Detector	Surface properties	Spatial resolution FWHM (mm)	Energy resolution FWHM [redacted] (%)
continuous CsI(Tl), 3 mm, 0.8 mm quartz	Diffusive white	1.3	11
CsI(Tl) pixel $2 \times 2 \times 3\ mm^3$, 0.8 mm quartz	Diffusive white	0.4	13
CsI(Tl) pixel $2 \times 2 \times 3\ mm^3$, 1.3 mm quartz	Diffusive white	0.5	13
CsI(Tl) pixel $2 \times 2 \times 3\ mm^3$, 3.8 mm quartz	Diffusive white	0.8	13
CsI(Tl) pixel $2 \times 2 \times 3\ mm^3$, 5.8 mm quartz	Diffusive white	0.9	13
CsI(Tl) pixel $4 \times 4 \times 3\ mm^3$, 0.8 mm quartz	Diffusive white	0.5	11
CsI(Tl) pixel $4 \times 4 \times 3\ mm^3$, 3,8 mm quartz	Diffusive white	0.8	11
CsI(Tl) pixel $4 \times 4 \times 3\ mm^3$, 3.8 mm quartz	Flat white paint	0.8	14
CsI(Tl) pixel $2 \times 2 \times 3\ mm^3$, 3.8 mm quartz	Flat white paint	0.9	17
CsI(Tl) pixel $1 \times 1 \times 3\ mm^3$, 3.8 mm quartz	Diffusive white	0.7	18
0.8mm 1×1×3		0.2	13%

Table 1: Gamma ray beam (1 mm diameter) reconstruction

PSF

light spread

Detector	Surface properties	FWHM (mm)	Light collected (u. a.)
continuous CsI(Tl), 3 mm, 0,8 mm quartz, surface event	Diffusive white	4,4	100
continuous CsI(Tl), 3 mm, 0,8 mm quartz, deep event	Diffusive white	2,4	$100 \pm 1,3$
CsI(Tl) pixel $2 \times 2 \times 3\ mm^3$, 0,8 mm quartz	Diffusive white	2,9	$86 \pm 1,2$
CsI(Tl) pixel $2 \times 2 \times 3\ mm^3$, 1,3 mm quartz	Diffusive white	3,1	$85 \pm 1,2$
CsI(Tl) pixel $2 \times 2 \times 3\ mm^3$, 3,8 mm quartz	Diffusive white	3,3	$85 \pm 1,2$
CsI(Tl) pixel $2 \times 2 \times 3\ mm^3$, 5,8 mm quartz	Diffusive white	4,4	$80 \pm 1,2$
CsI(Tl) pixel $4 \times 4 \times 3\ mm^3$, 0,8 mm quartz	Diffusive white	4,1	$94 \pm 1,1$
CsI(Tl) pixel $4 \times 4 \times 3\ mm^3$, 3,8 mm quartz	Diffusive white	6,3	$93 \pm 1,1$
CsI(Tl) pixel $4 \times 4 \times 3\ mm^3$, 3,8 mm quartz	Flat white paint	6,5	$60 \pm 1,5$
CsI(Tl) pixel $2 \times 2 \times 3\ mm^3$, 3,8 mm quartz	Flat white paint	3,7	$36 \pm 2,0$
CsI(Tl) pixel $1 \times 1 \times 3\ mm^3$, 3,8 mm quartz	Diffusive white	2,6	$57 \pm 1,6$
0.8 mm $1 \times 1 \times 3\ mm^3$		2.2	60 ± 1.5

Table 1: The "light" results

Simulations

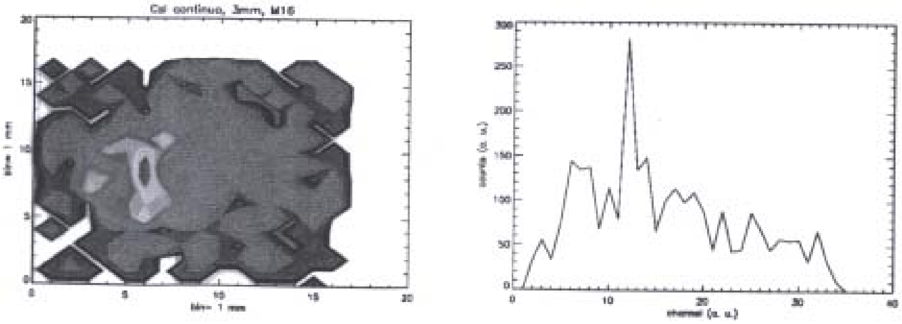


Figure 9: Continuous crystal image (at left) and one profile (at right)

C.S(Te)

$2 \times 2 \times 3\ mm^3$

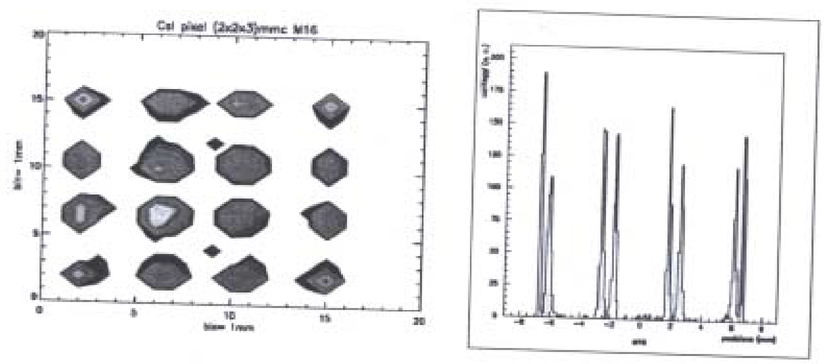


Figure 10: Image with M16 (without glass, only the PMT-window) and one image profile (at right)

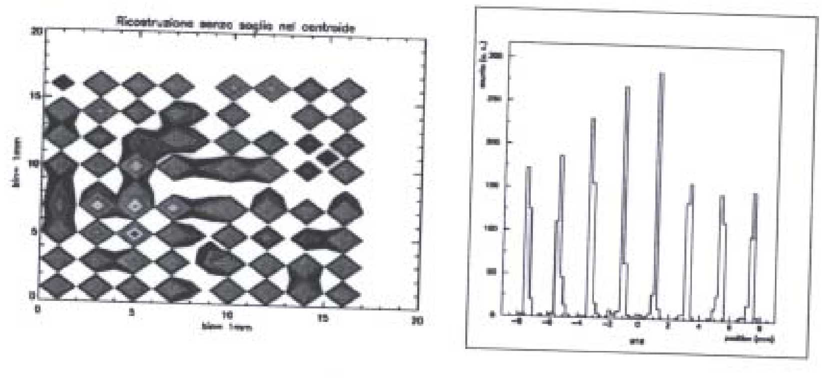


Figure 11: Pixel $2 \times 2 \times 3\, mm^3$ image (M64) and one image profile (at right)

Segmented scintillator, 2 x 2 x 3 mm^3 pixel size, M16, simulation

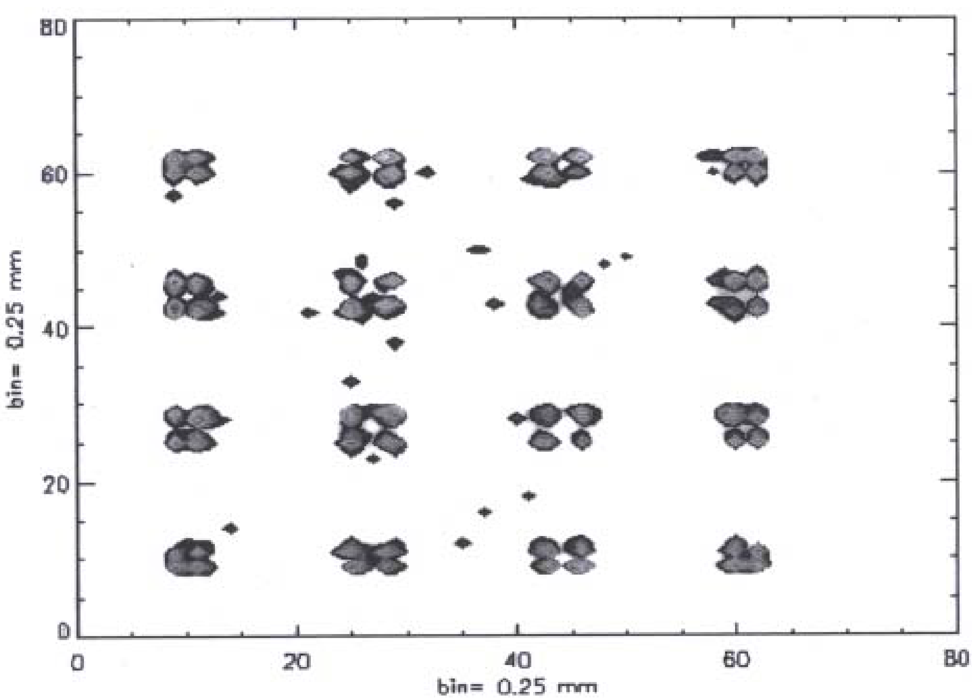


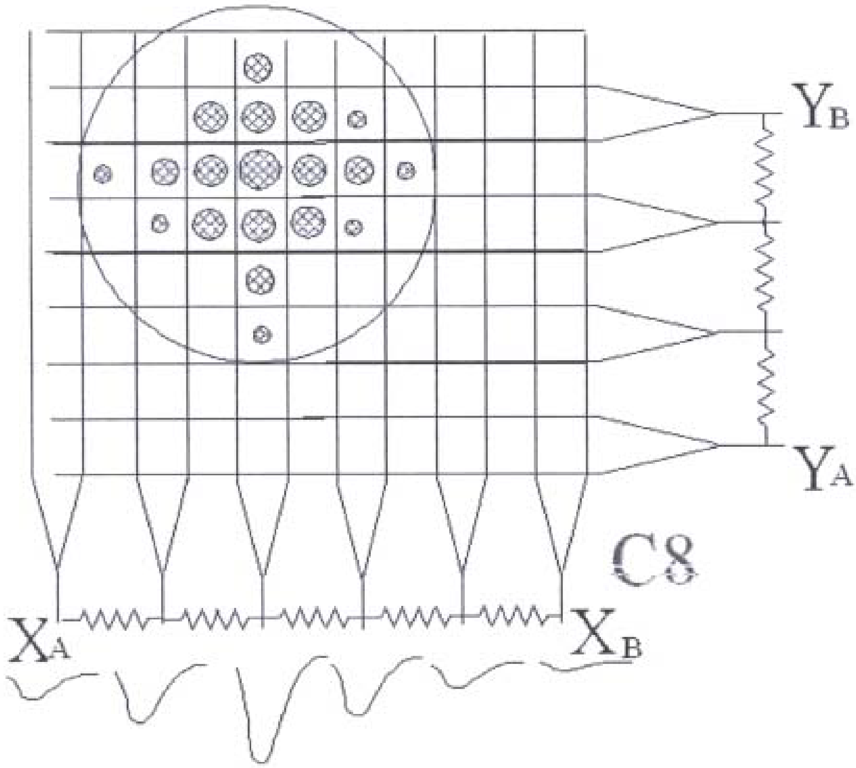
Image bin size = 0.25 x 0.25 mm^2
(1/64 pixel side)

- *Standard Nim and Camac readout + PC*
- *Kmax (Sparrow) Software DAQ*
- *PSPMT's: H6568-M16, R5900U-C8 (Hamamatsu)*
- *LED*
- *^{57}Co (122 Kev) rad. source*
- *3 segmented crystals arrays (CsI (Tl)*

  4.2x4.2x3 mm^3

  2.5x2.5x3 mm^3

  1.5x1.5x3 mm^3

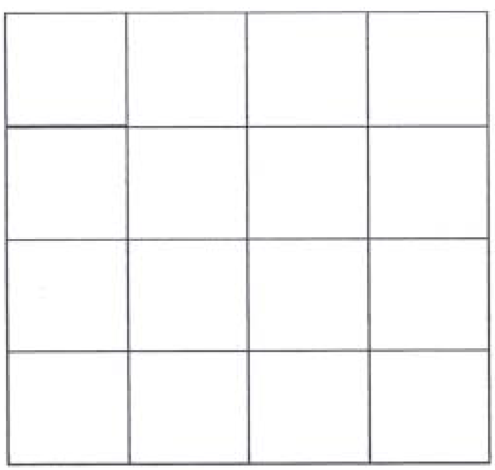


C8

CENTROID POSITION

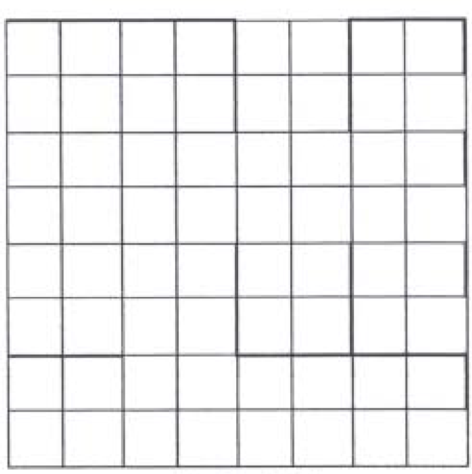
$$\Delta X = \frac{X_B - X_A}{X_B + X_A}$$

$$\Delta Y = \frac{Y_B - Y_A}{Y_B + Y_A}$$

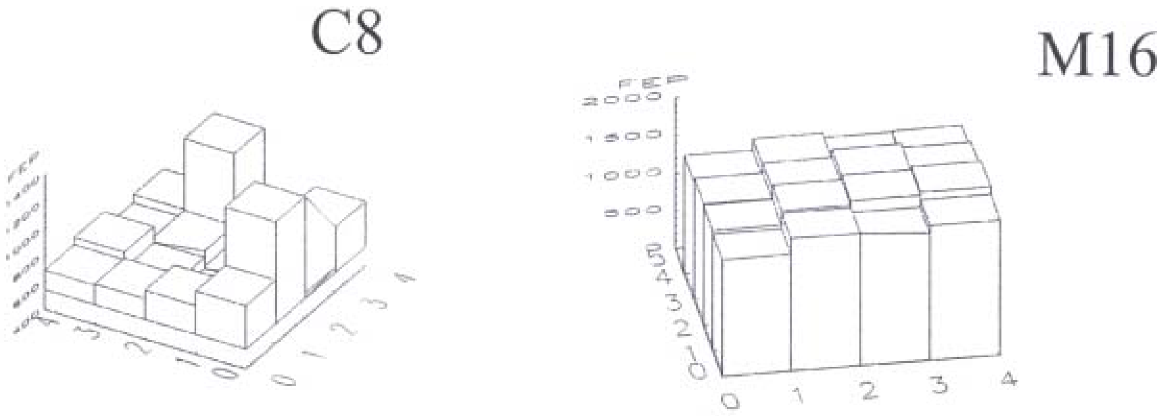


M16

MULTICHANNEL READOUT



M64



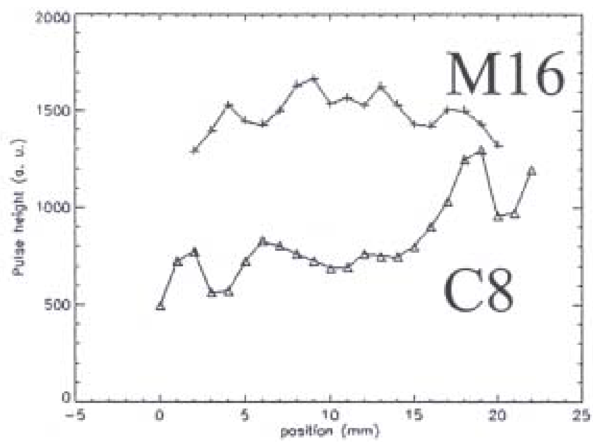


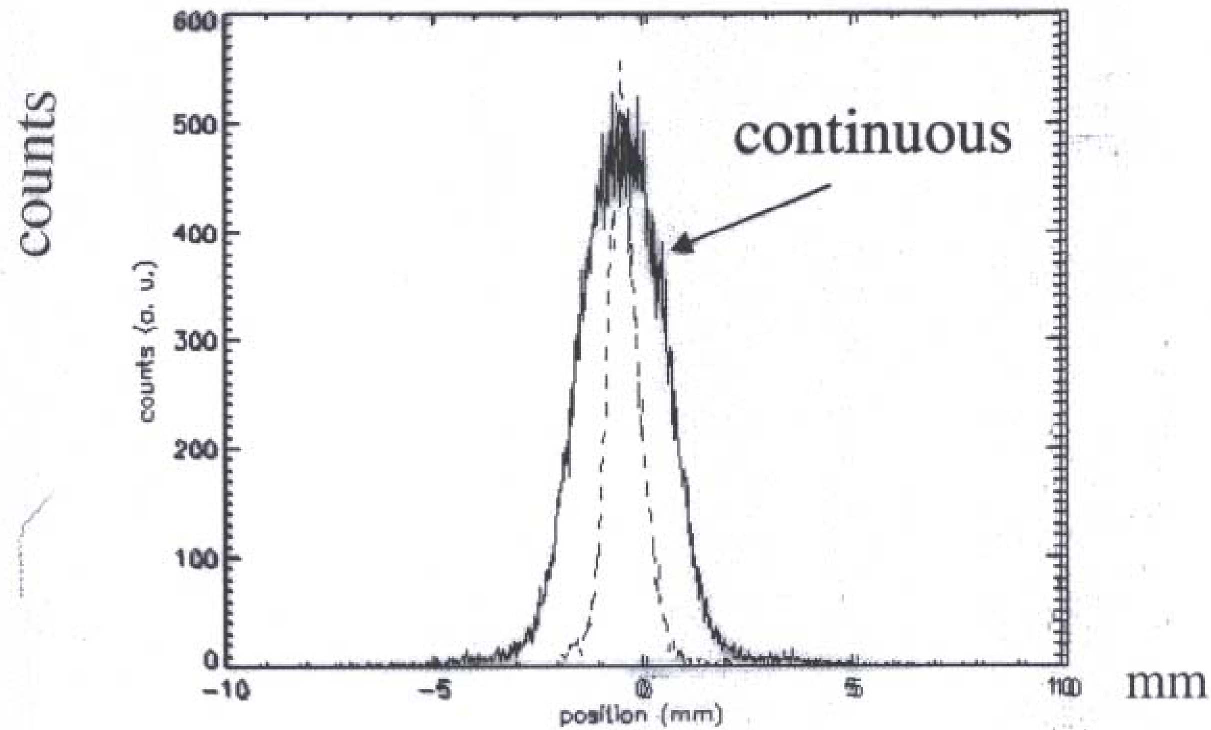
Table 1

	C8					M16	
Position	Ph X(u.a.)	S.D. (%)	Ph Y (u.a.)	S.D. (%)	X / Y	Ph (u.a.)	S.D. (%)
1	310	10	380	11	0.82	1580	6
2	330	15	410	15	0.80	1730	5
3	270	15	350	14	0.77	1670	6
4	290	14	390	13	0.74	1690	5
5	300	6	398	5	0.75	1620	5
6	271	3	350	3	0.77	1750	5
7	285	2	384	3	0.74	1860	4
8	488	4	720	6	0.68	1810	5
9	336	6	421	6	0.80	1610	4
10	246	11	295	8	0.83	1800	5
11	247	3	308	5	0.80	1860	5
12	299	8	412	4	0.73	1900	7
13	410	24	450	24	0.91	1560	6
14	590	10	710	11	0.83	1770	4
15	260	23	320	19	0.81	1700	9
16	380	16	500	16	0.76	1800	5

C8 Pulse height standard dev. 29 % (max variation 58 %)
M16 Pulse height standard dev. 6 % (max variation 18 %)

Spatial Resolution

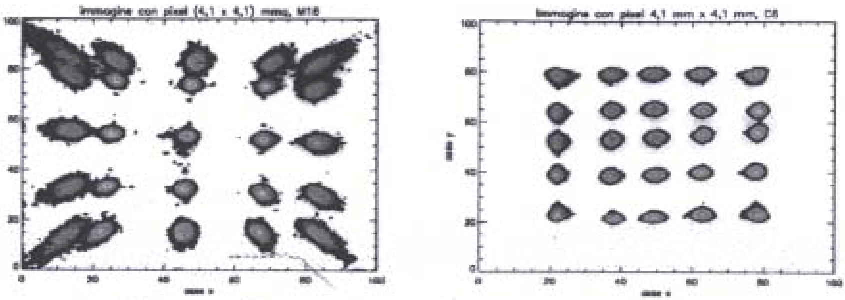
continuous (CsI(Tl) 3 mm) *vs*
segmented array (CsI(Tl) 4.2 x 4.2 x 3 mm^3)



Measurements with collimated (2 mm diam.)
^{57}Co (122 keV) source

measurements

18 x 18 mm² 22 x 22 mm²



M16 C8

4 x 4 mm² pixels.

Figure 26: H6568-M16 image with the $4.2 \times 4.2\ mm^2$ pixels, H6568-M16 (at left) and R5900U-C8 (at right)

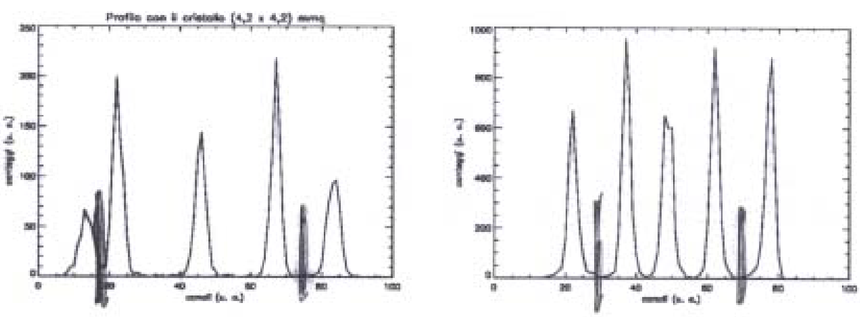


Figure 27: Images profiles

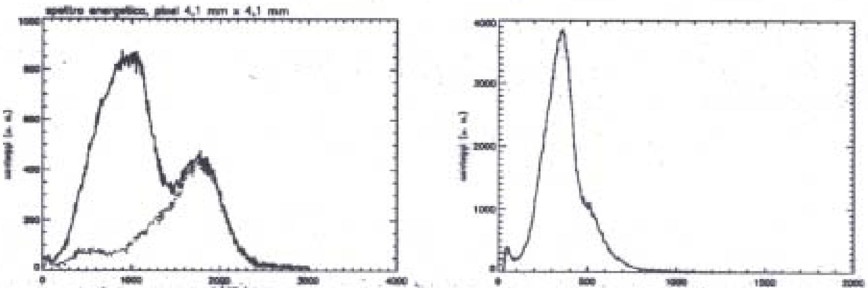


Figure 28: Spectrum with the $4.2 \times 4.2\ mm^2$ pixels, H6568-M16 (at left) and R5900U-C8 (at right)

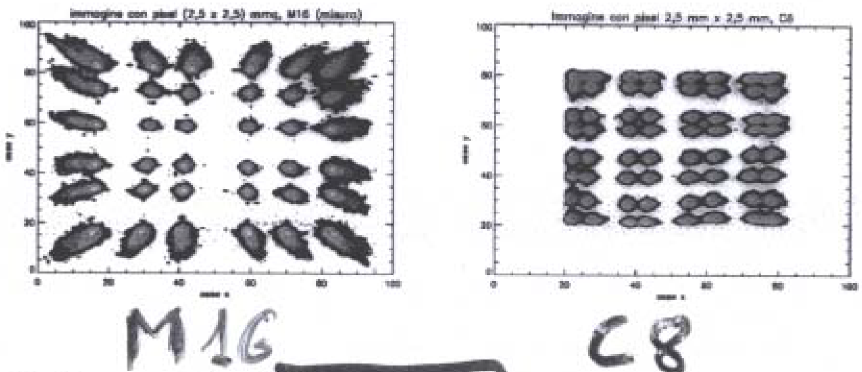


Figure 29: Images with the $2.5 \times 2.5\ mm^2$ pixels, H6568-M16 (at left) and R5900U-C8 (at right)

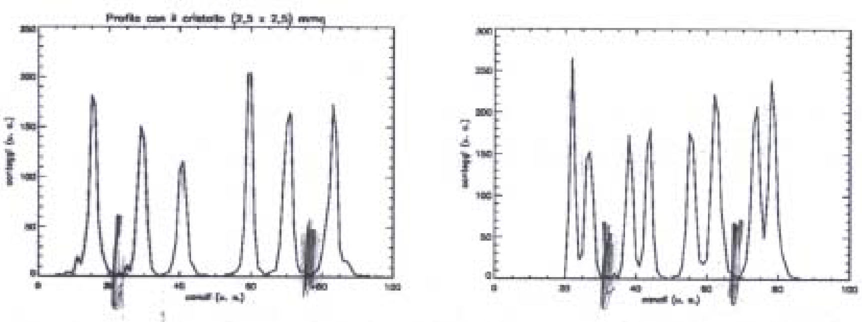


Figure 30: Images profiles

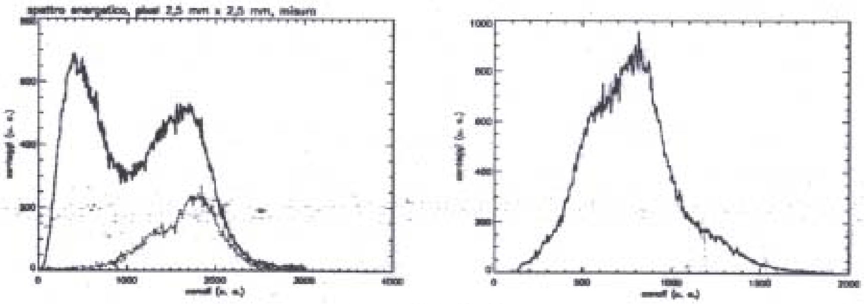


Figure 31: Spectrum with the $2.5 \times 2.5\ mm^2$ pixels, H6568-M16 (at left) and R5900U-C8 (at right)

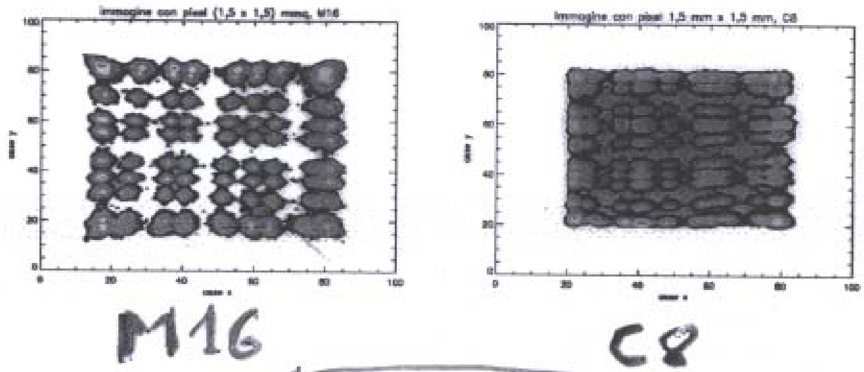


Figure 32: Images with the 1.5 × 1.5 mm^2 pixels, H6568-M16 (at left) and R5900U-C8 (at right)

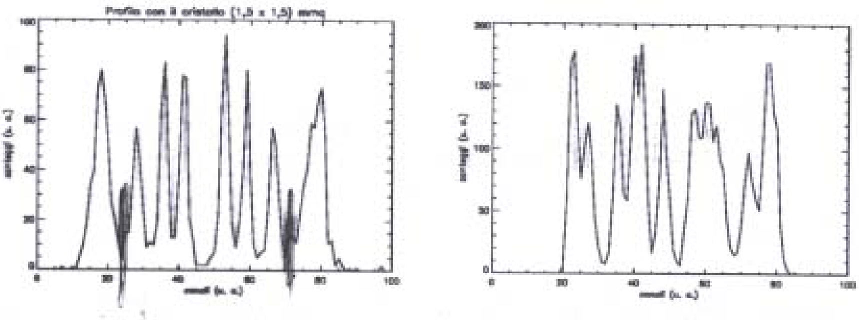


Figure 33: Images profiles

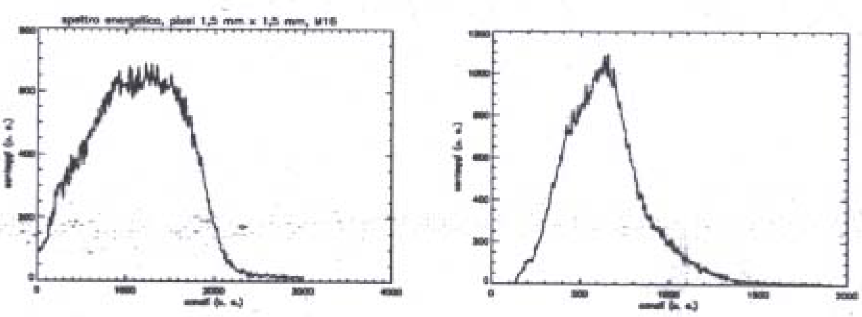
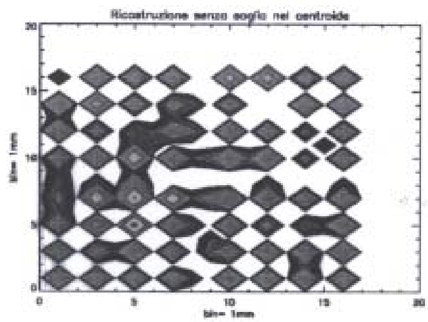


Figure 34: Spectrum with the 1.5×1.5 mm^2 pixels, H6568-M16 (at left) and R5900U-C8 (at right)



M6A

SIMULATION

$2 \times 2 \times 3$ mm^3

2×2 mm^2 anode pixel size

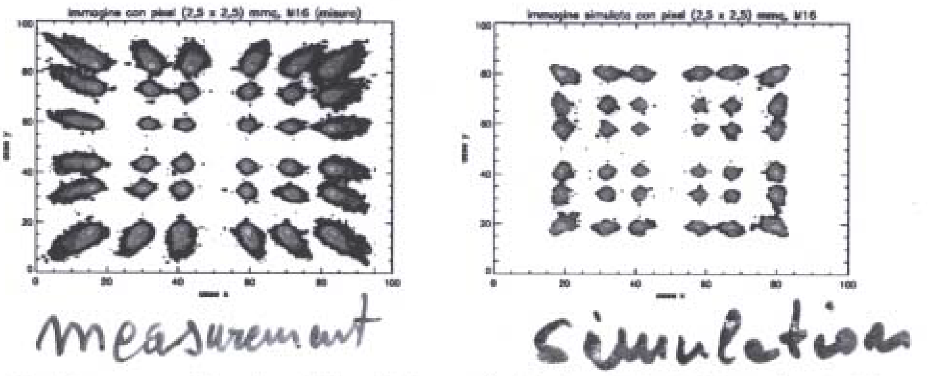


Figure 35: Images with the $2.5 \times 2.5\ mm^2$ pixels, H6568-M16 (at left) and simulation (at right)

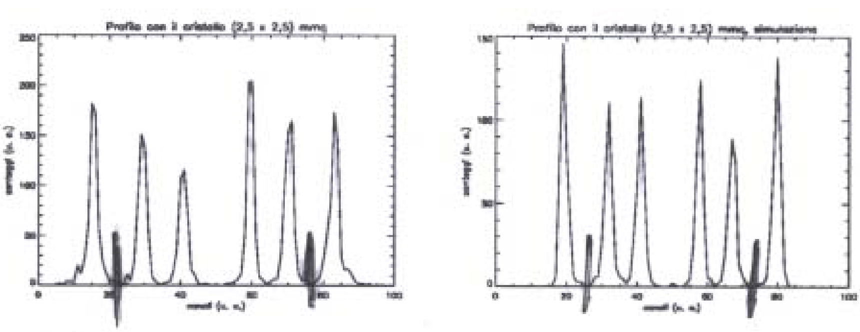


Figure 36: Images profiles

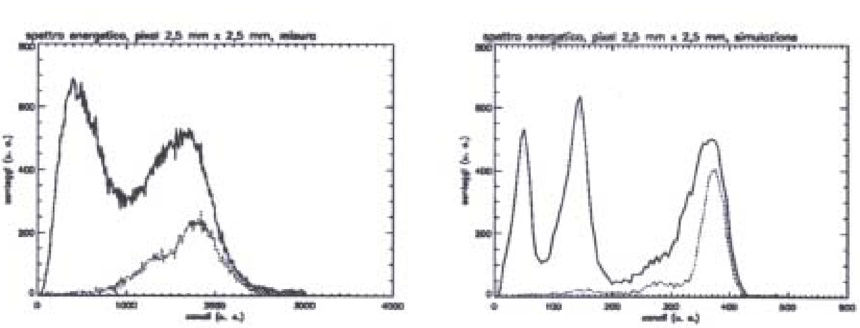


Figure 37: Spectrum with the $2.5 \times 2.5\ mm^2$ pixels, H6568-M16 (at left) and simulation (at right)

pixel size	Spatial resolution FWHM (mm)
4.2x2.4.2x3 mm^3, M16 measurement	0.61±0.08
4.2x2.4.2x3 mm^3, C8 measurement	0.74±0.11
2.5x2.5x3 mm^3, M16 measurement	0.48±0.12
2.5x2.5x3 mm^3, M16 simulation	0.44±0.10
2.5x2.5x3 mm^3, C8 measurement	0.82±0.17
1.5x1.5x3 mm^3, M16 measurement	0.57±0.16
1.5x1.5x3 mm^3, C8 measurement	

Conclusions

- **Compact discrete gamma-cameras are needed**
  (Segmented scintillators coupled to segmented photodetectors)

- Optimization is needed for careful **compact** gamma-cameras design.

- ***The segmentation of scintillator and photodetector are strictly correlated***

- **Possible Improvements**
  - **scintillators type and geometry**
  - **different photodetectors (HPD, Si diodes, SDD,CZT)**