



**PIXEL 2000**



International Workshop on Semiconductor  
Pixel Detectors for Particles and X-Rays

Genova - Porto Antico - Magazzini del Cotone (Sala Libeccio)

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I SPA-Tubes with YAP:Ce Active  
Windows for X and Gamma Ray  
Imaging.

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CERN

INFN-Roma III (HIRESPET\* Collaboration)

Institute of Physics, Academy of Sciences-Prague

Alice and LHCb exp. at CERN

EP-TA2 and EP-MIC groups at CERN

Industrial partners:  
D.E.P. (NL)  
Crytur Ltd. (CZ)  
Edgetek (FR)

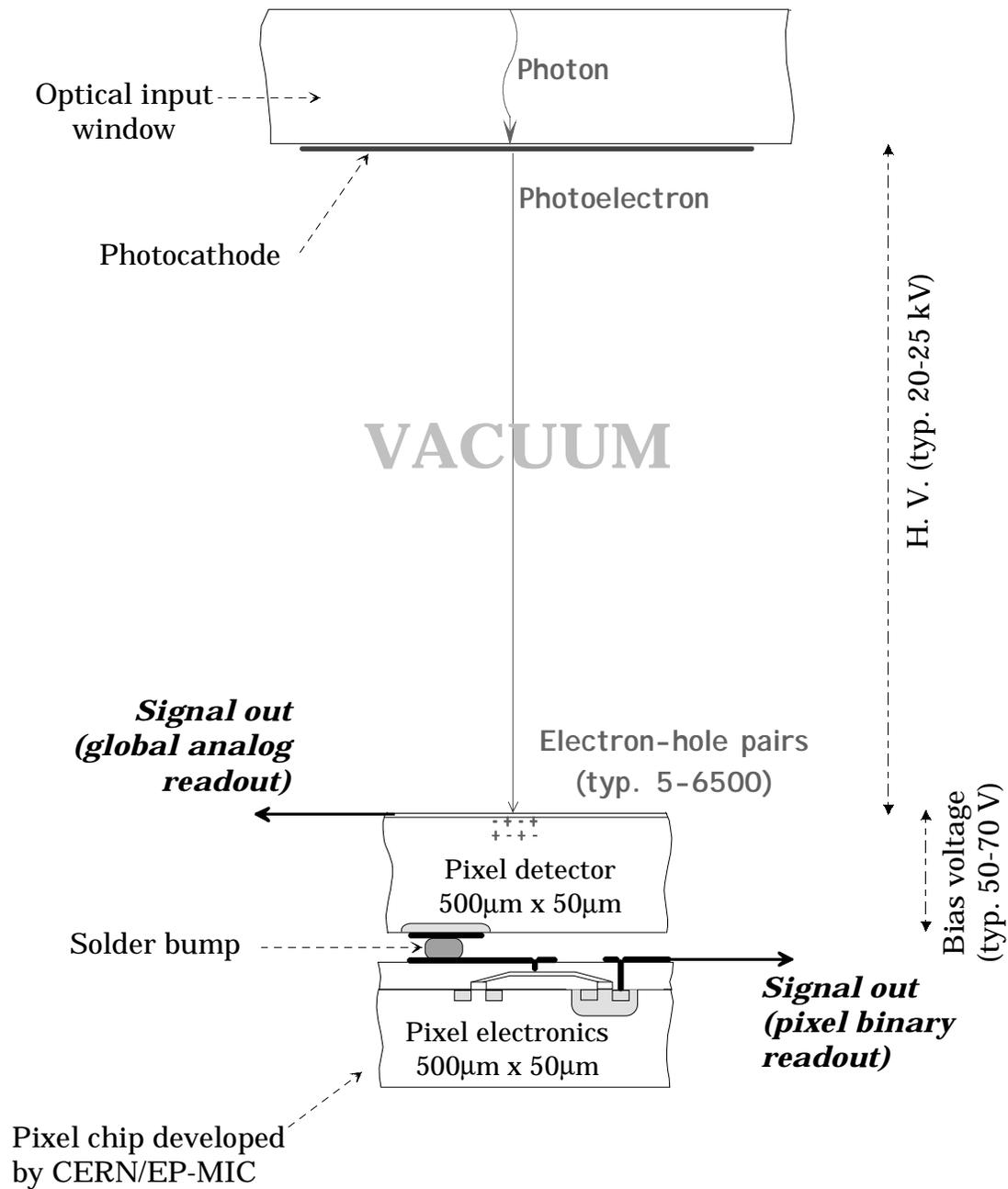
*<http://www.roma1.infn.it/~hirespet/index.html>*



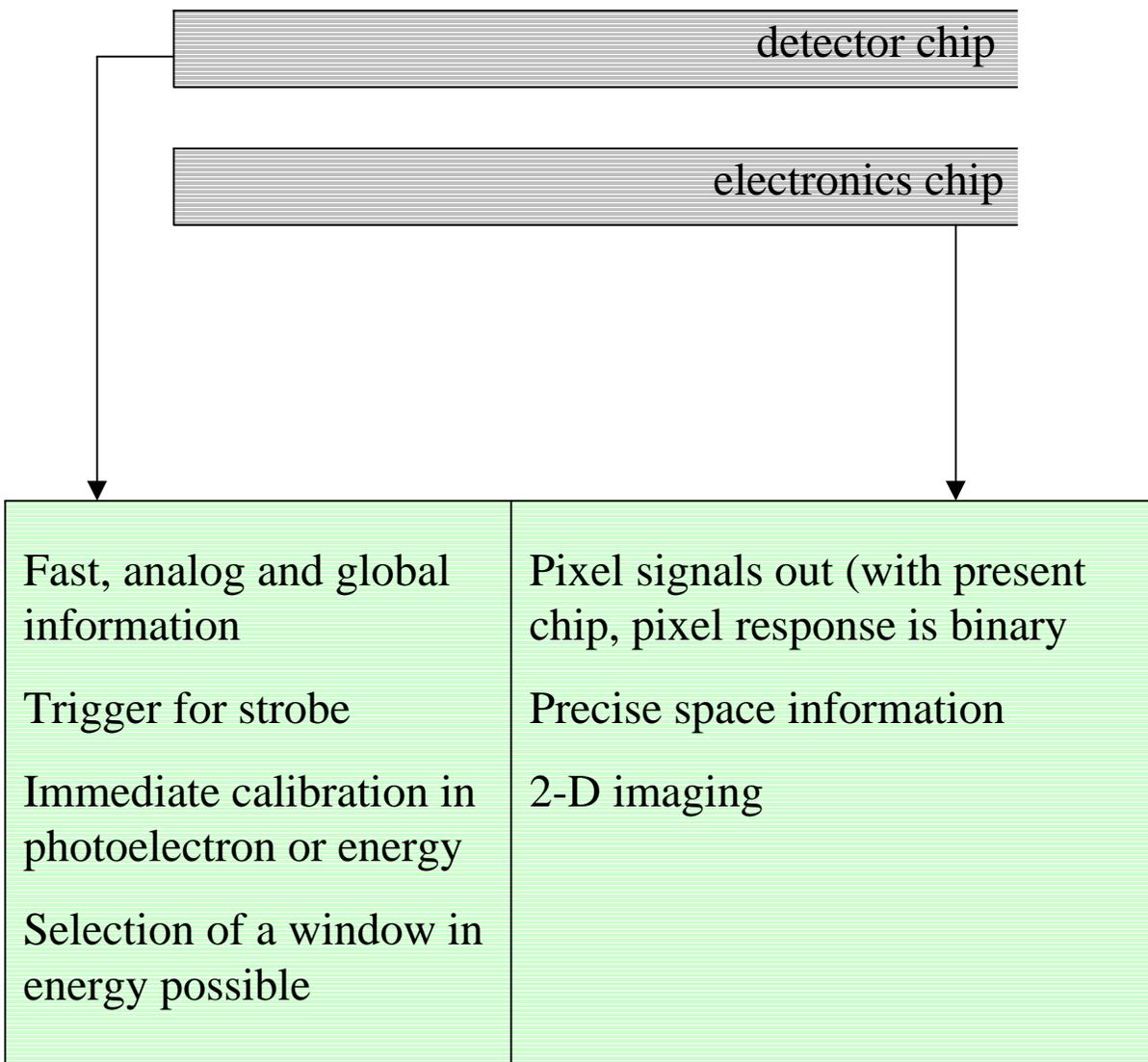
## OUTLINE

- \* Short introduction to the I SPA-tube
- \* "Conventional" designs of gamma cameras based on I SPA-tubes and results
- \* Present developments : scintillating windows (YAP:Ce)
- \* Conclusions and future outlook

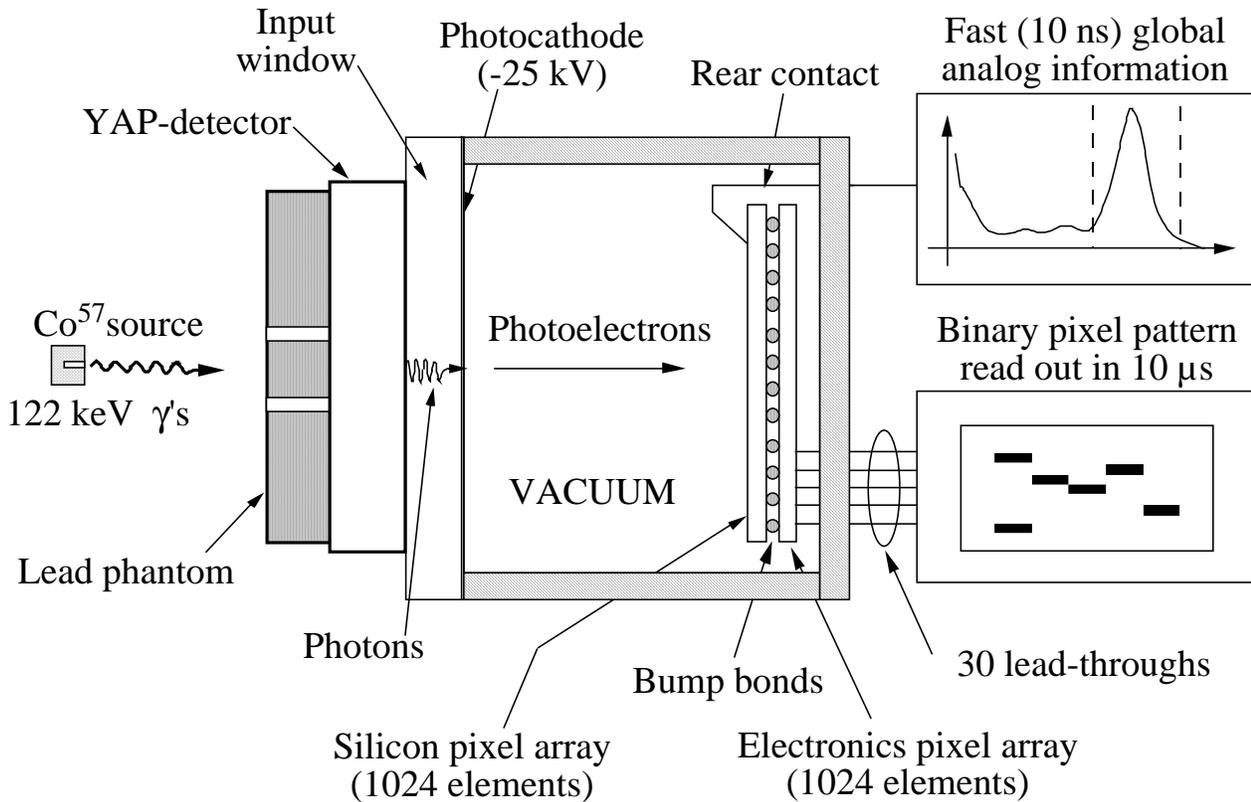
**Position-sensitive photon detection with an I SPA-tube**



## The self-triggering principle



## Detection of $\gamma$ -rays with an I SPA-tube



$\Omega$  chip assembly developed by RD19 collaboration  
Pixel size  $75\text{mm} \times 500\text{mm}$



## $\gamma$ -imaging with an I SPA-tube coupled to YAP:Ce crystal detectors \*

### Properties of pure YAP

Chemical formula	YAlO <sub>3</sub>	(inert, non <b>hygroscopic</b> )
Crystal structure	Orthorhombic	(no cleavage)
Density	g.cm <sup>-3</sup>	<b>5.37</b>
Molecular weight		168.88
Z <sub>eff</sub>		<b>34</b>
Hardness	Moh	<b>8.6</b>
Refractive index n	at 400 nm	1.97
	at 500 nm	1.95
Transparency	nm	240 to >1000

### Additional properties of YAP doped with Ce

Light emission peak	nm	<b>365</b>
Light decay (1/e)	ns	<b>27</b>
Radiation length	cm	2.7
Avr. K X-ray energy of Yttrium	keV	15.2
Refractive index n	at 400 nm	<b>1.92</b>
	at 500 nm	1.91

Due to its properties YAP can be easily machined and optically polished.  
Arrays of small individual elements (1mm<sup>2</sup> down to 300 $\mu$ m<sup>2</sup> can be assembled)

\* Our YAP crystal detectors are produced by Crytur Ltd, Turnov, Czech Republic



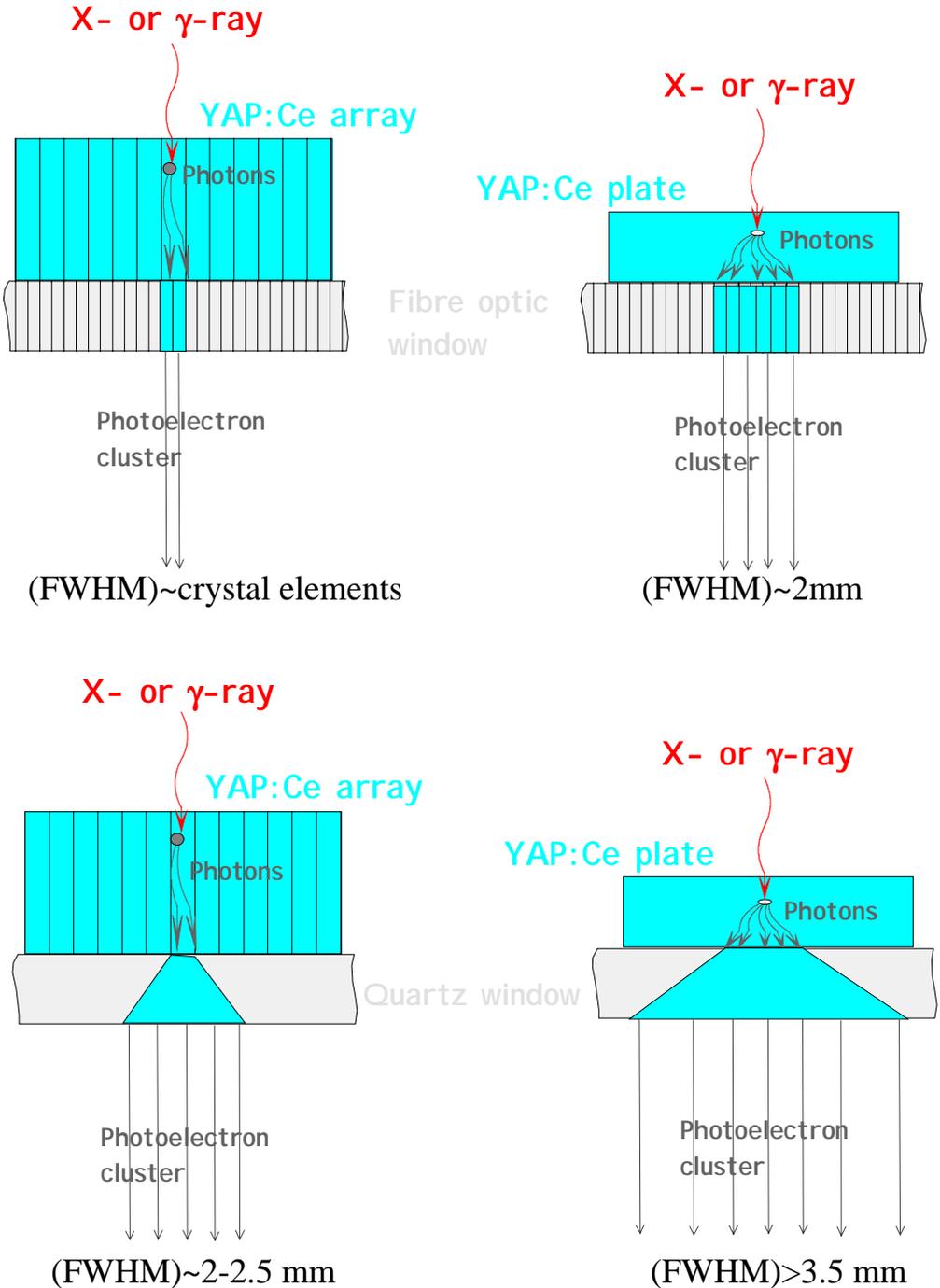
## Performances of I SPA-tubes in imaging

The overall performances of the I SPA-tube rely on both

**The input window arrangement:** the goal is to collect as many photoelectrons as possible while preserving the “localisation” of the gamma event

**The anode pixel chip:** the goal is to detect as many photoelectrons  $N_{pe}$  as possible on the detector plane (energy resolution considerations) and to get a binary pattern reproducing the light spot on the photocathode with a number of firing pixels  $N_{hit}$  ( $< N_{pe}$ ) allowing a precise c.o.g calculation (analysis event per event)

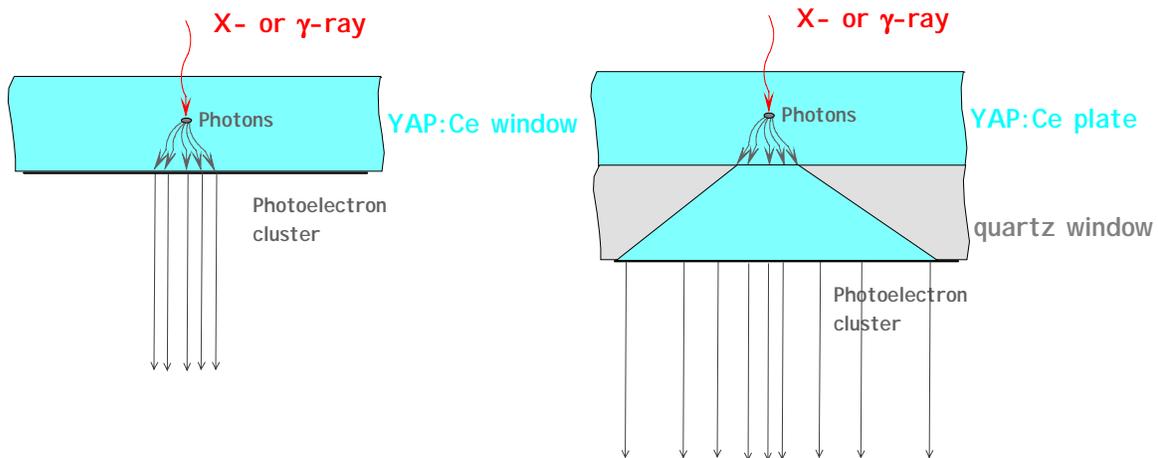
## Different possible configurations





## Current ISPA prototype

### YAP:Ce scintillating window

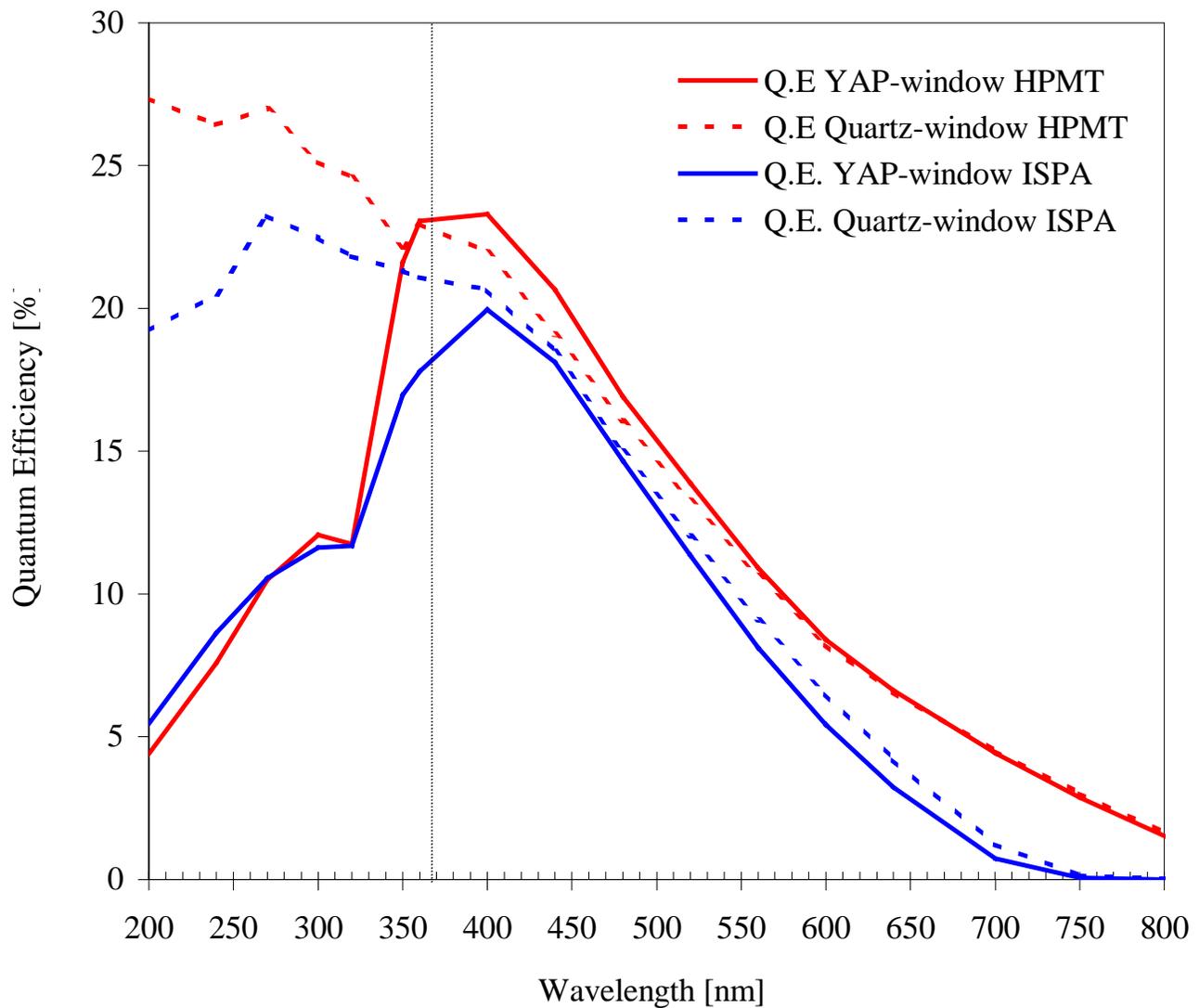


### LHC1\* chip implementation

- new electronics    ➡ amplifier 100 ns peaking time, globally adjustable threshold, adjustable delay line, coincidence logic and memory
- smaller pixel size    ➡ (50x500 $\mu$ m)
- Electrical tests    ➡ ~7.5% (150) pixels are masked (noisy)
- ➡ test input  $\sim 4900e^-$   $\gamma$  1710 ( $\sim 85\%$ ) pixels respond with an efficiency of  $\sim 95\%$

\* The LHC1 chip has been developed at CERN by the RD19 and the EP/MIC group

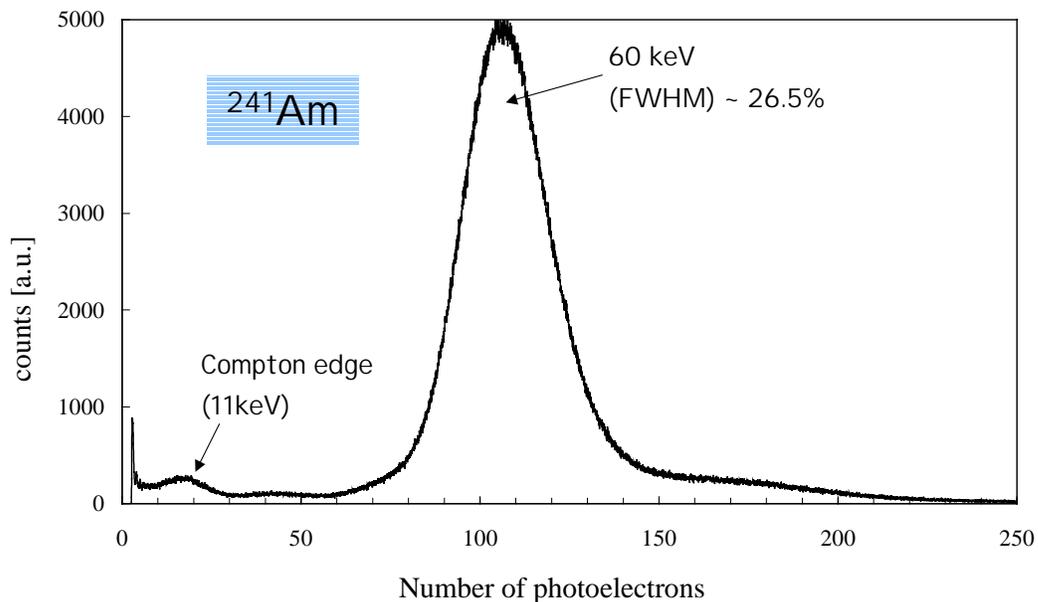
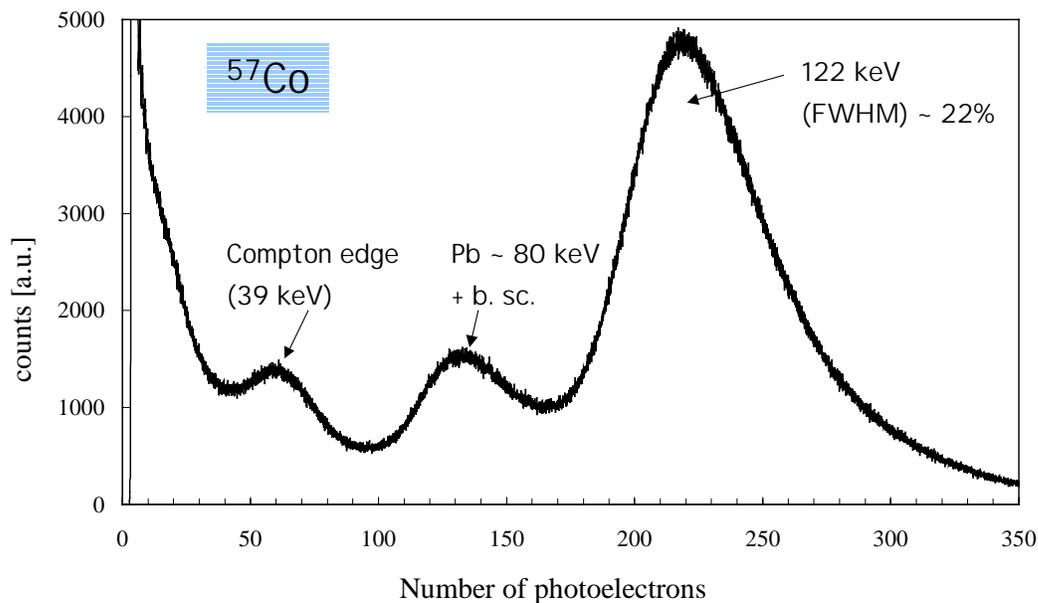
## Quantum efficiency of S20 photocathode on YAP:Ce scintillating window



Perfect stability observed over 2 years

## Energy spectra of some different sources

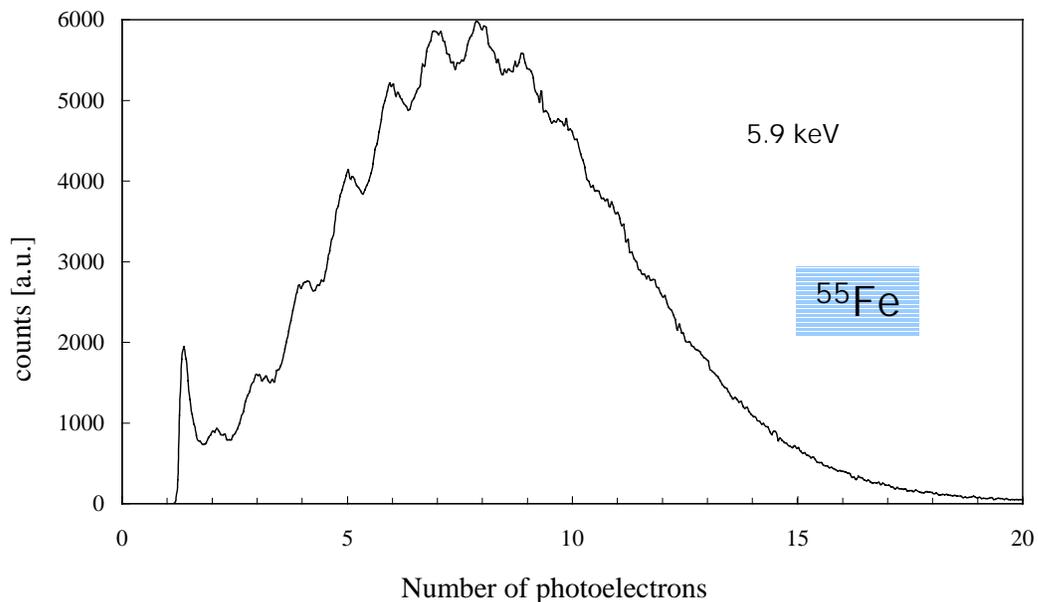
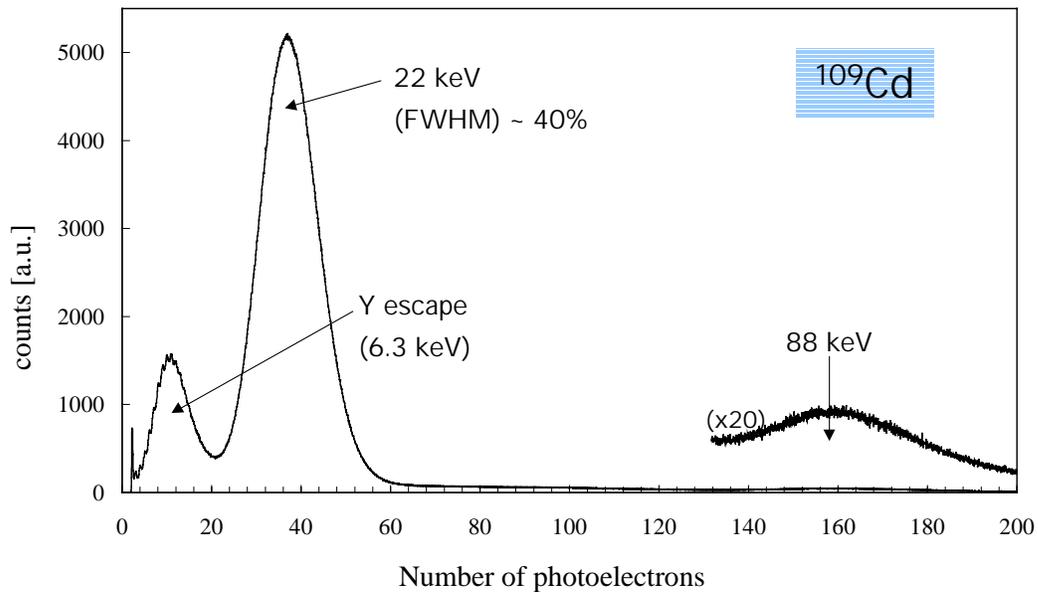
Emissions converted in the YAP:Ce window of the I SPA-tube  
Pulse height distributions measured on the silicon chip rear side





## Energy spectra of some different sources

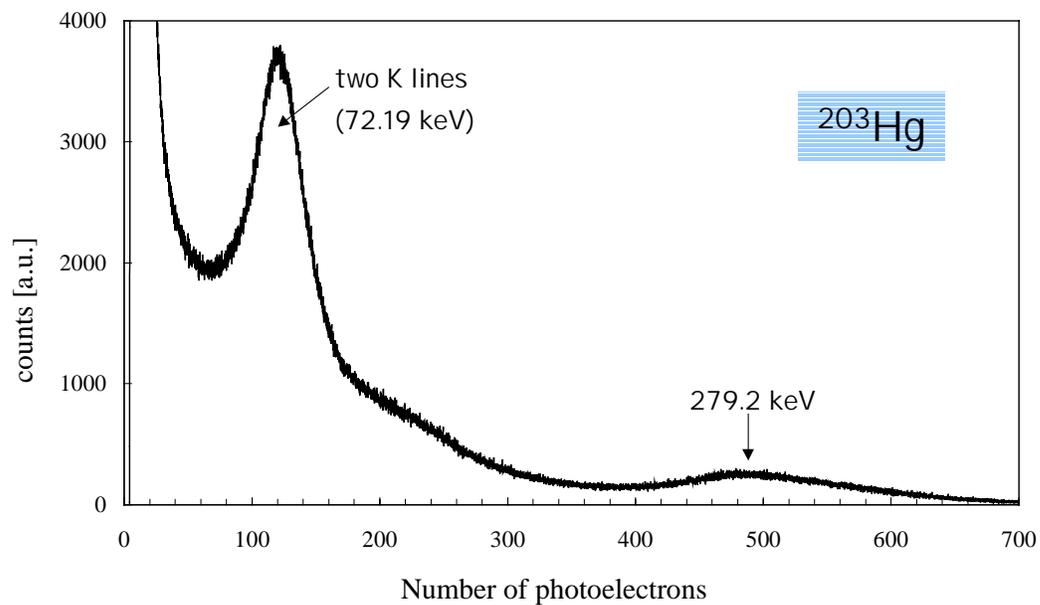
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## Photoelectron numbers versus the energies of total absorption peaks for several gamma sources measured with the YAP-window I SPA-tube

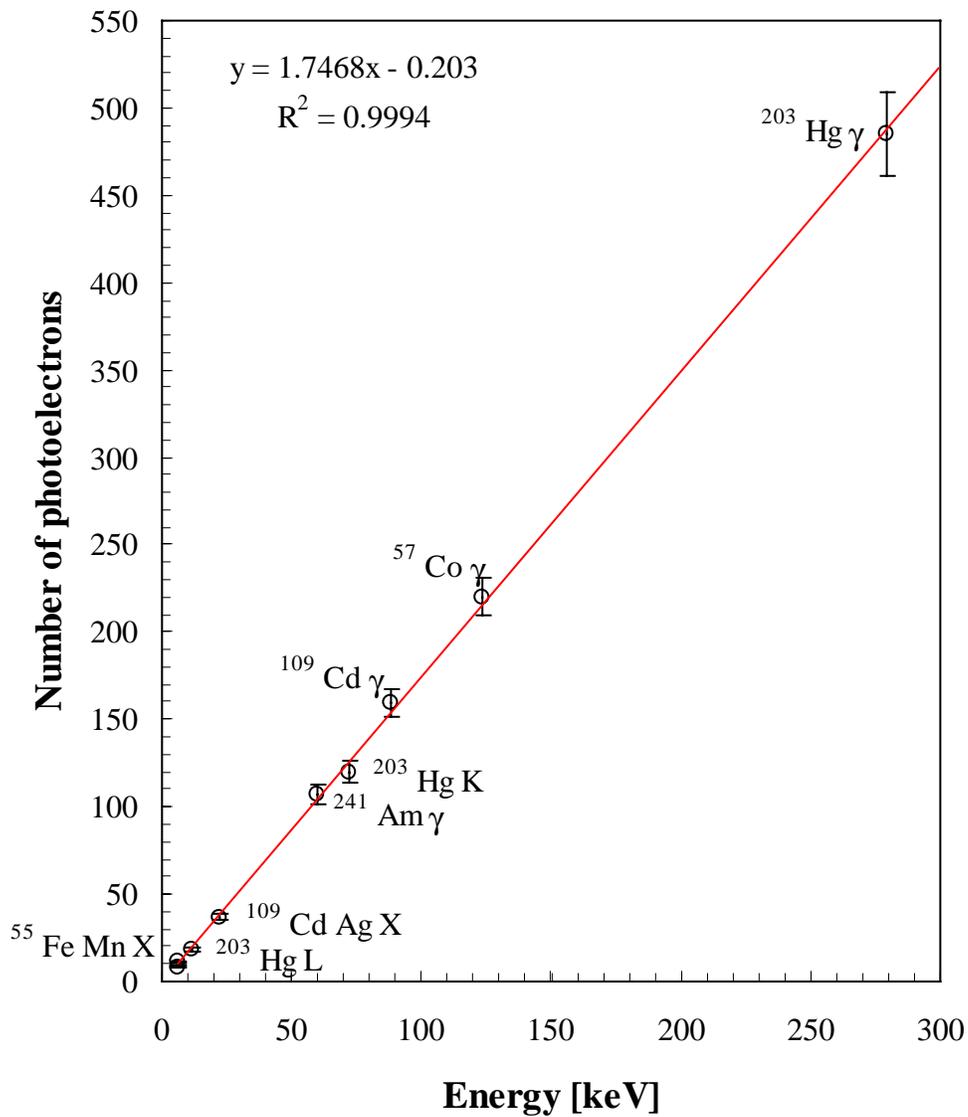
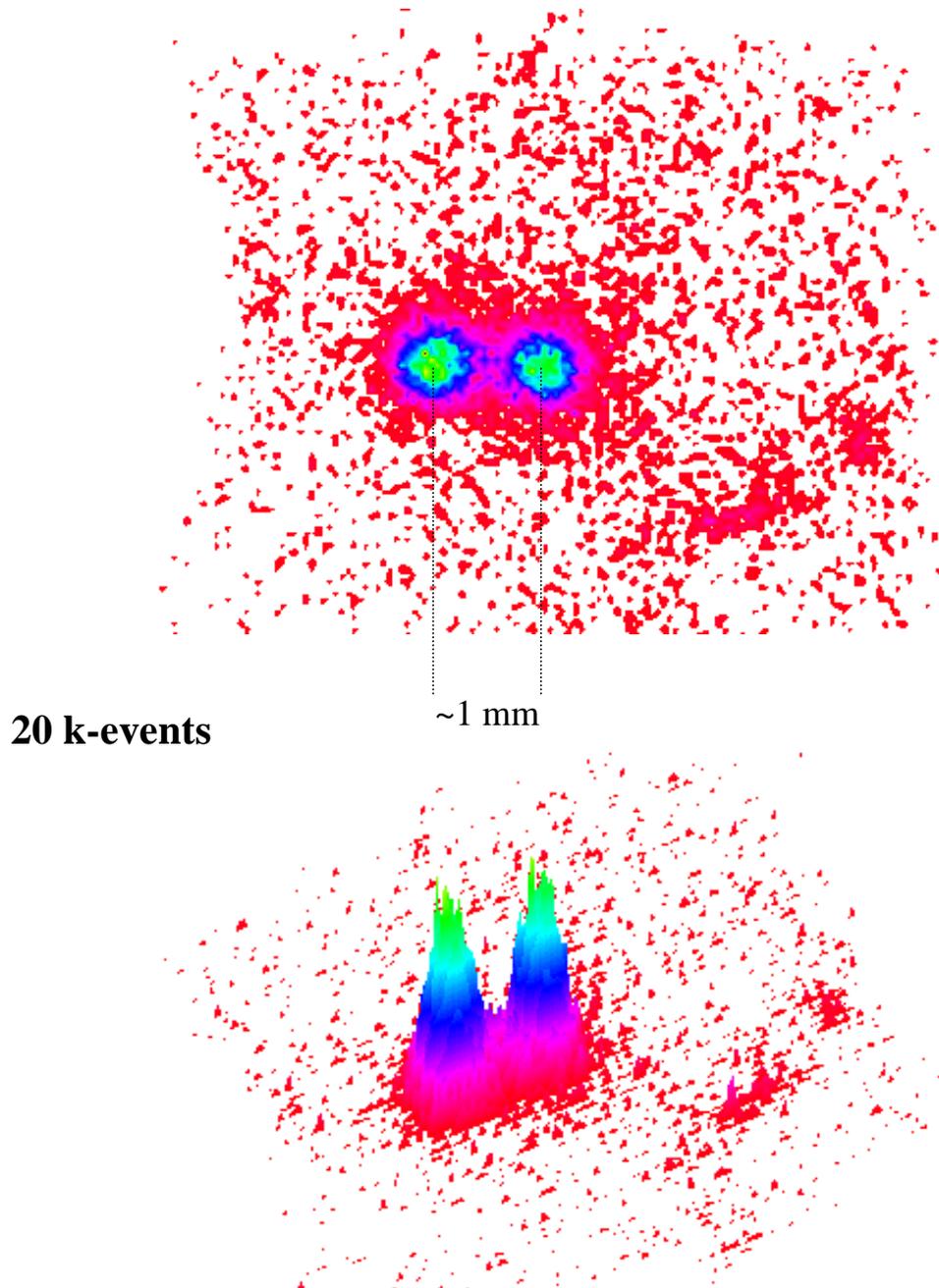


Image of a 60 keV  $\gamma$ -source ( $^{241}\text{Am}$ ) through a 2-holes (0.35 mm  $\phi$ ) lead collimator (5 mm thick)

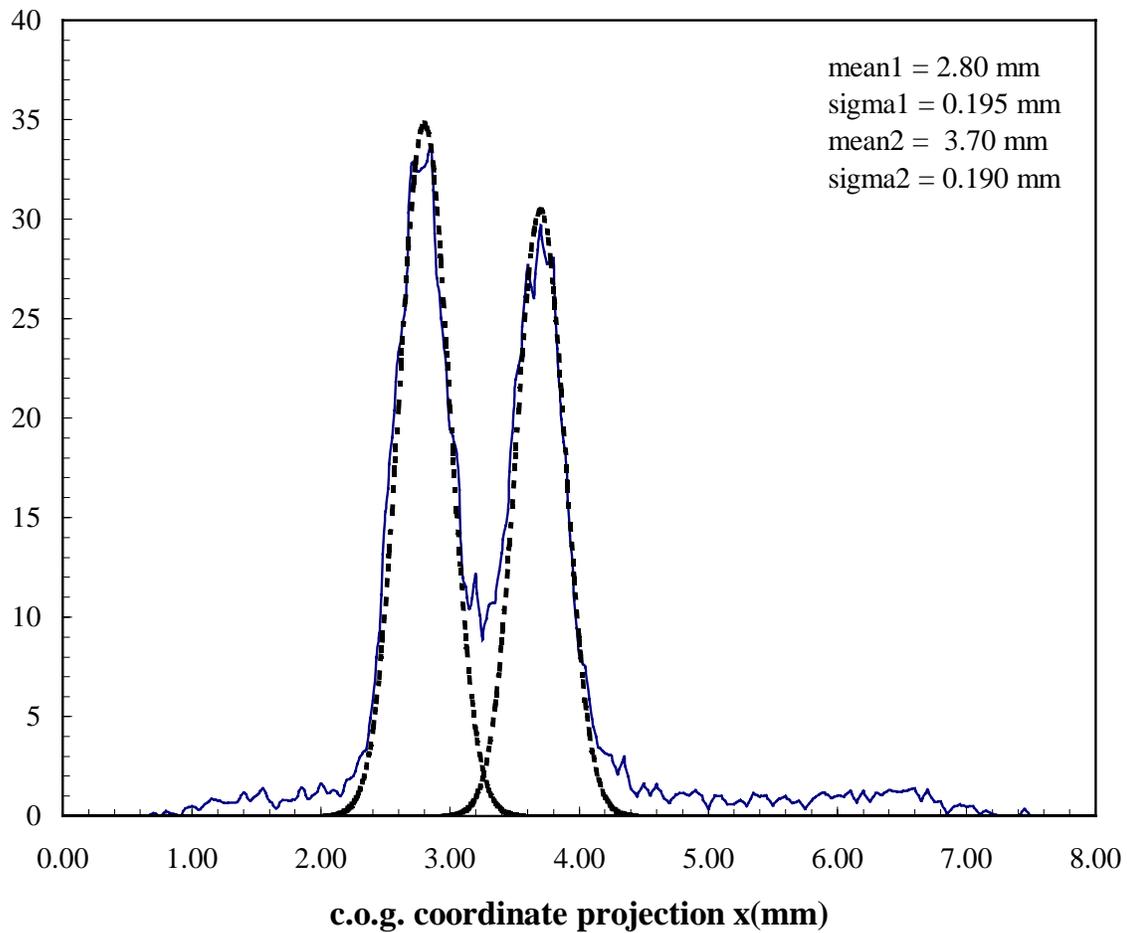




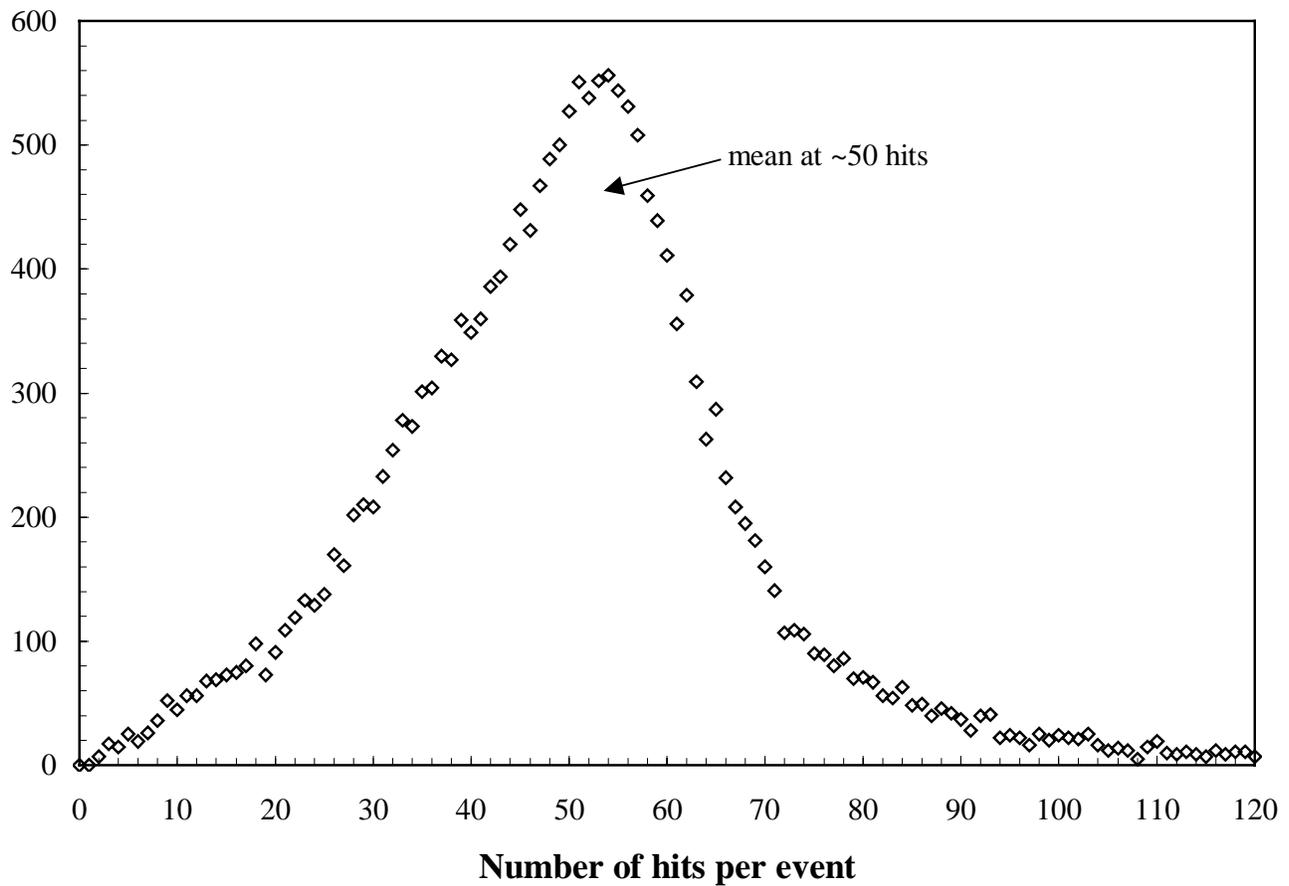
## Intensity profile of the two holes along the X-direction

distance of the two holes = 0.90 mm on chip

$$\text{FWHM}_{x_{\text{meas.}}} = 0.452 \text{ mm}$$



Average number of firing pixel per gamma event:  $N_{hit}$

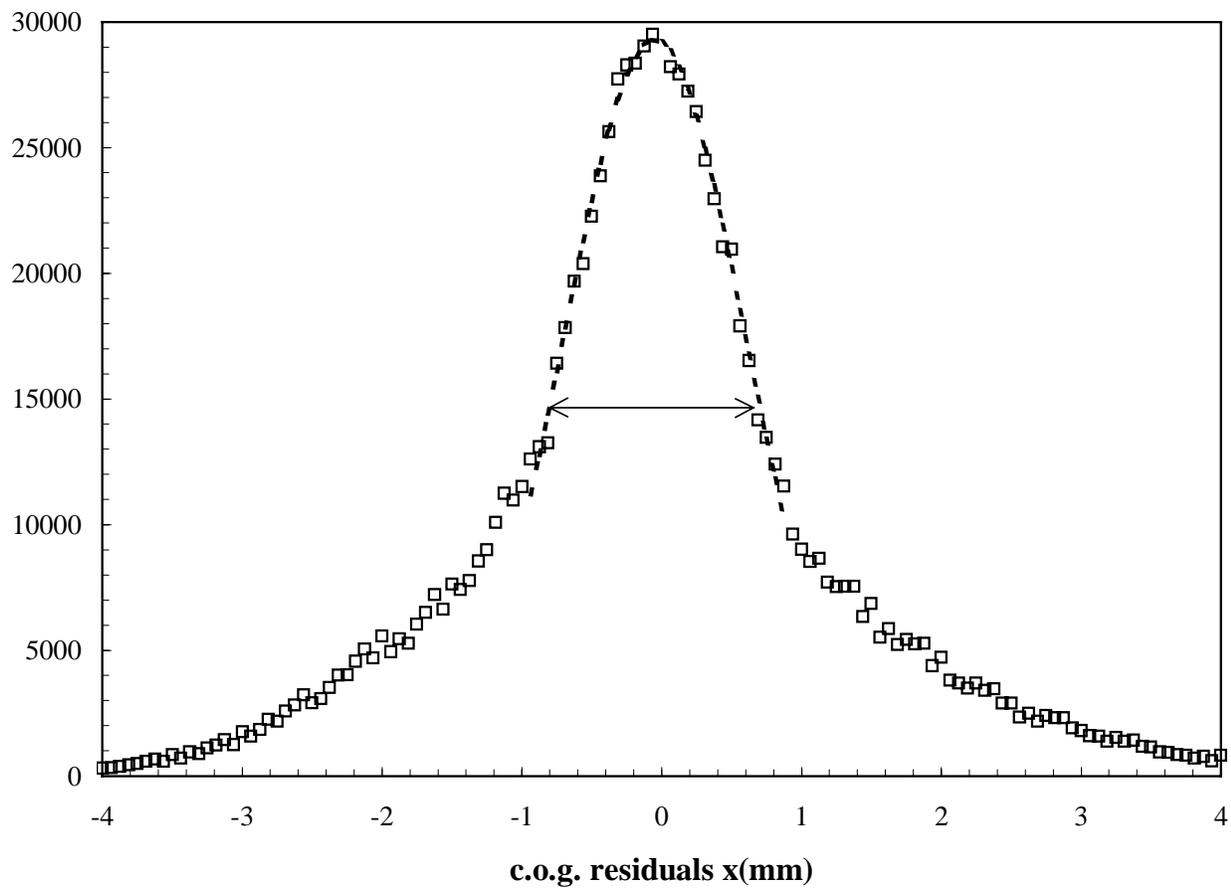


Note:  $N_{hit} \sim 50$  is  $<$  to  $N_{pe} \sim 100$ . The greatest part of the difference is due to "overlap" effect



## Center-of-gravity residual projection along the X-direction

$$(\text{FWHM})_{\text{resX}} = 1.50 \text{ mm on chip}$$





The estimation of the spatial resolution is simply given by:

$$\phi^2 + \left( \frac{FWHM_{res}}{\sqrt{N_{hit}}} \right)^2 = (FWHM)^2$$

$$(FWHM)_{resX} = 1.50 \text{ mm}; (FWHM)_{resY} = 1.46 \text{ mm}; N_{hit} \sim 50$$

$$x \quad \Rightarrow \quad 0.35^2 + 0.214^2 = 0.410^2 \quad \langle====\rangle \quad FWHM_{x_{meas.}} = 0.452 \text{ mm}$$

$$y \quad \Rightarrow \quad 0.35^2 + 0.206^2 = 0.406^2 \quad \langle====\rangle \quad FWHM_{y_{meas.}} = 0.435 \text{ mm}$$

The difference between the estimated values and the measured ones can be related to the tails in the residual distributions, which worsens the precision in the c.o.g. calculation.



## CONCLUSIONS

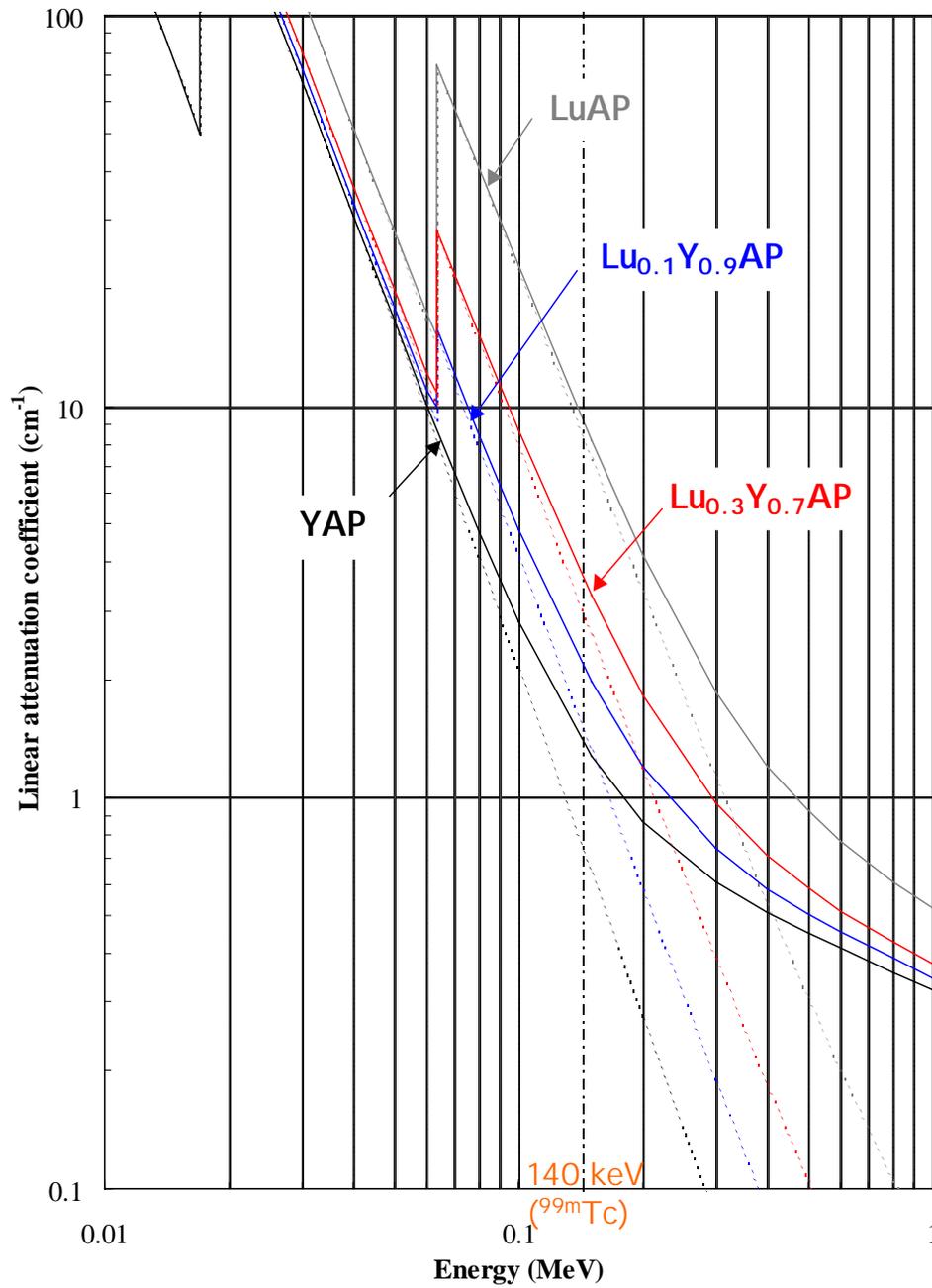
- \* First results with the YAP:Ce window I SPA-tube are very encouraging (cluster size  $\sim 2$ ,  $N_{pe} \times 1.2$ ).
- \* They can be used to detect a wide range of energies (window thickness can be adjusted).
- \* Better matching of refractive index if coupled to other standard crystals.
- \* The performances can be further improved with those of future pixel chip anode.



## FUTURE OUTLOOK

- \* Developments on heavier Ce-doped scintillators and of larger dimensions.
- \* Implementation of ALICE chip.
- \* Possible use of thinned detector unit.

## Attenuation coefficients of Cerium-doped RE<sup>3+</sup> perovskyte scintillators





## Some properties of Cerium-doped RE<sup>3+</sup> perovskite scintillators

	Rel. L. Y. %NaI (TI)	Density (g.cm <sup>-3</sup> )	Peak emission (nm)	Light decay (ns)
NaI (TI)	100	3.67	415	230
BGO	20	7.13	480	300
YAP:Ce	40	5.37	365	27
Lu <sub>0.1</sub> Y <sub>0.9</sub> AP:Ce	-	5.73	-	-
Lu <sub>0.3</sub> Y <sub>0.7</sub> AP:Ce	-	6.19	-	-
LuAP:Ce	20-50	8.34	360-370	<20

@ 140 keV with a 3-mm thick scintillating window:

YAP:Ce	~30% efficiency (~55% total absorption)
Lu <sub>0.1</sub> Y <sub>0.9</sub> AP:Ce	~45% efficiency (~70% total absorption)
Lu <sub>0.3</sub> Y <sub>0.7</sub> AP:Ce	~65% efficiency (~80% total absorption)
LuAP:Ce	~95% efficiency (~95% total absorption)