Nuovi algoritmi di posizione con cristalli di scintillazione planari per SPET e PET

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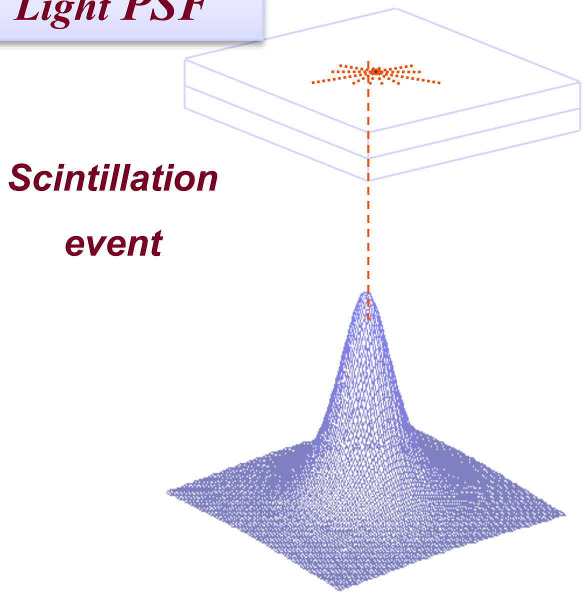
*Position arithmetic and **intrinsic spatial resolution** by light sharing*
Image and scintillation light PSF

Light PSF



$$X_C = \frac{\sum_j n_j k_j}{\sum_j n_j}$$

where

x_j represents the linear weight associated to the anode array

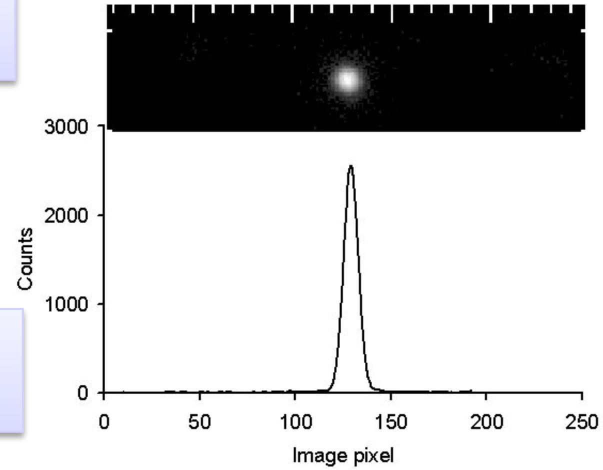
$$n_j = \sum_k n_{k,j}$$

is the projection of the charge collected along the J-th column

$$\sigma_x = \left(\sum_j k_j^2 \overline{n_j}\right)^{1/2} \Big/ \left(\sum_j k_j \frac{d\overline{n}_j}{dx}\right)$$

Image PSF

$$\sigma_{imm} \cong \frac{\sigma_{PSF}}{\sqrt{n_{phe}}}$$



Spatial Resolution

$$SR = PSF_{imm} / L \qquad L = \frac{dX_{measured}}{dx_{mech}}$$

L is ideally =1

Latest Technological Advances

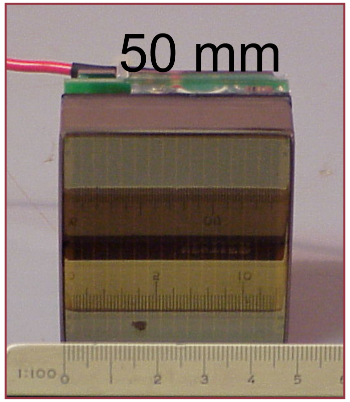
Hamamatsu H8500 segmented PMT (MAPMT) 38% QE

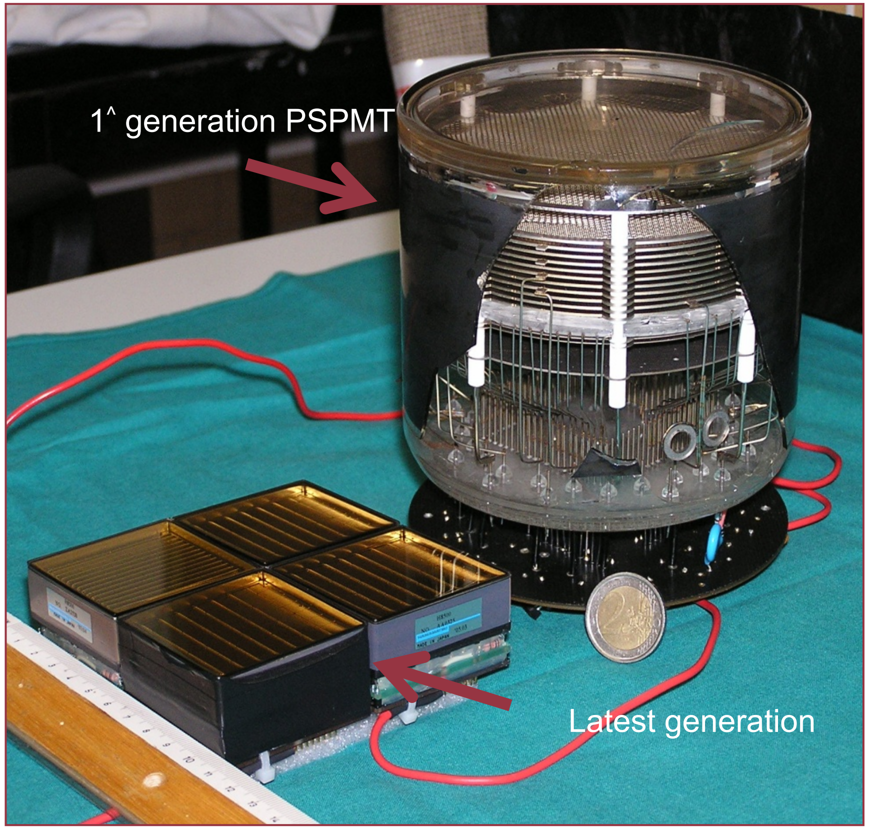
Gamma Camera Module

Photodetector: Position sensitive Flat Panel PMT H8500 Hamamatsu

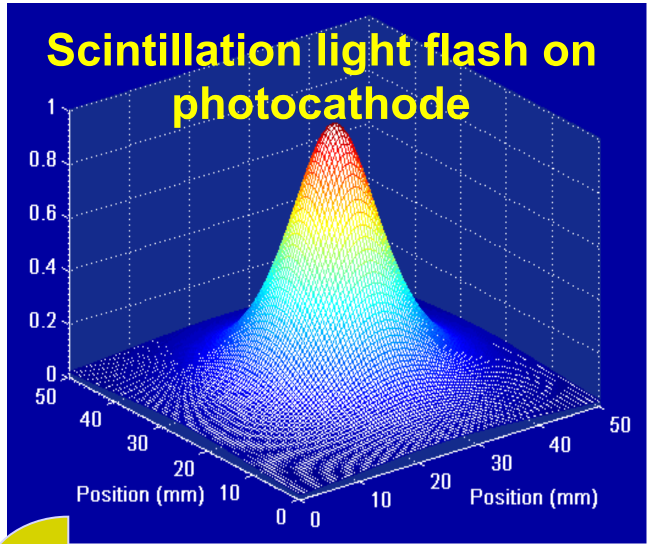
- Extremely compact (15 mm of thickness)
- Ideal for closely packing in array (1.5 mm edge dead zone)
- Intrinsic spatial resolution better than 0.5 mm

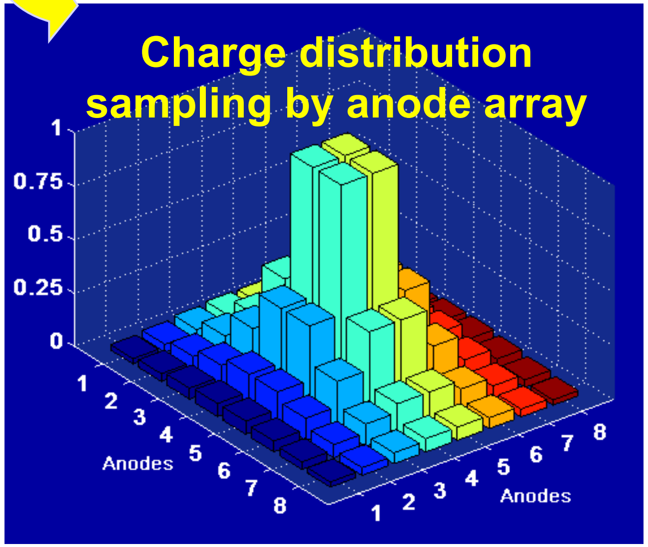
It allows large detection area modules for compact SPET system





Light sharing technique with Hamamatsu H8500 MA-PMT

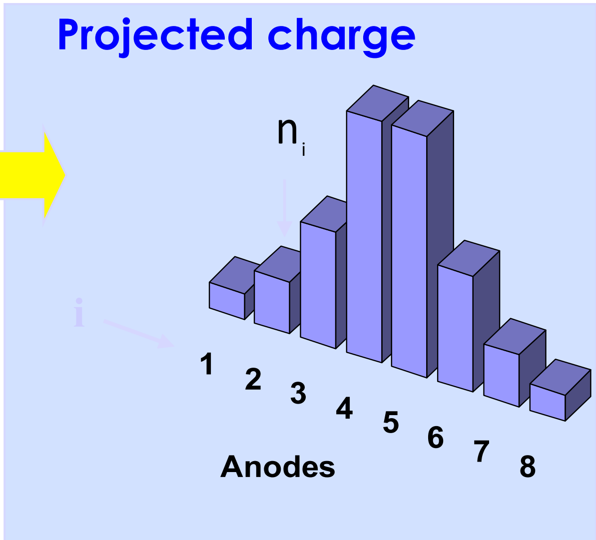




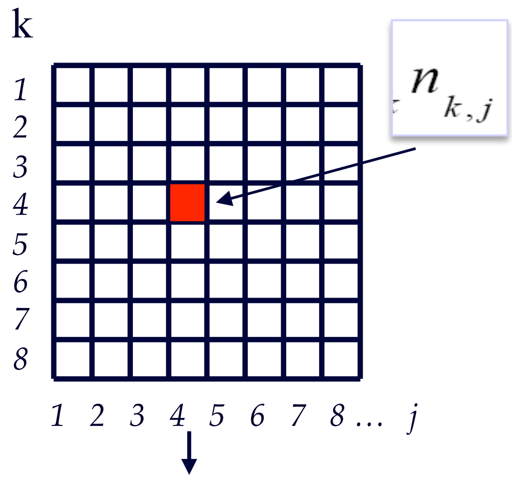
X & Y Position

Centroid Algorithm

$$X_C = \frac{\sum_j n_j k_j}{\sum_j n_j}$$

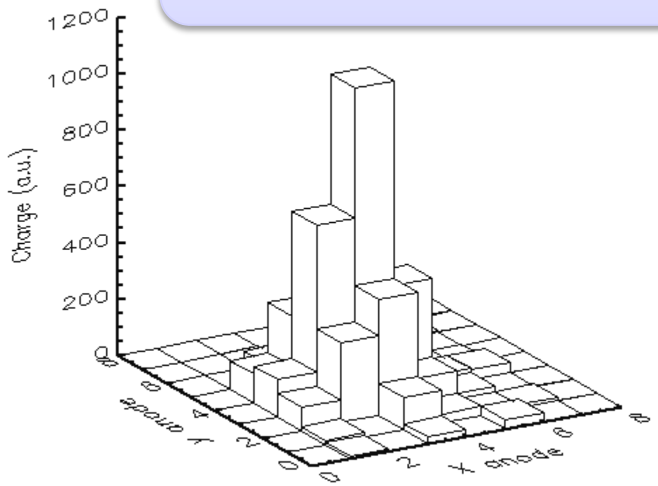


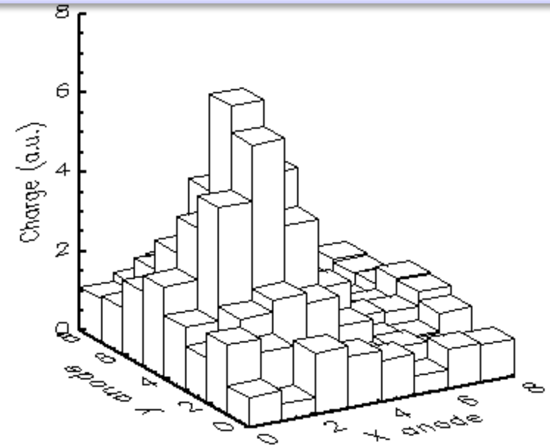
Anode array
(Hamamatsu H8500)



$$n_j = \sum_k n_{k,j}$$

Ideal Position linearity of Scintillation array with Linear Weight

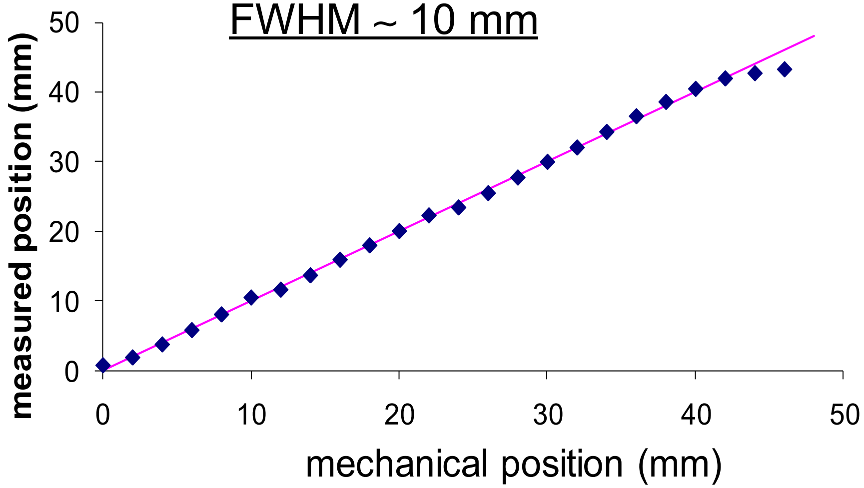




NaI:Tl *24x24 array*

1.8 x 1.8 x 6 mm³ pixel

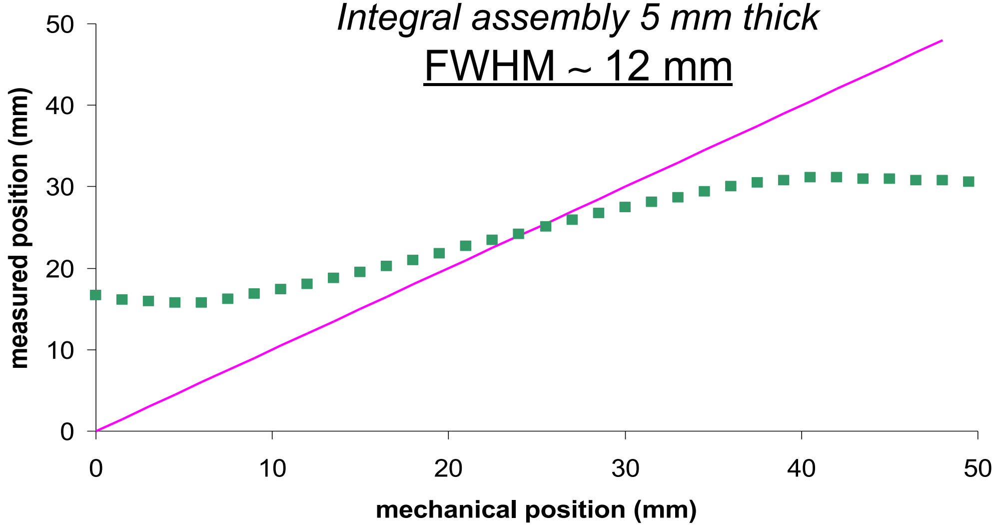
FWHM ~ 10 mm



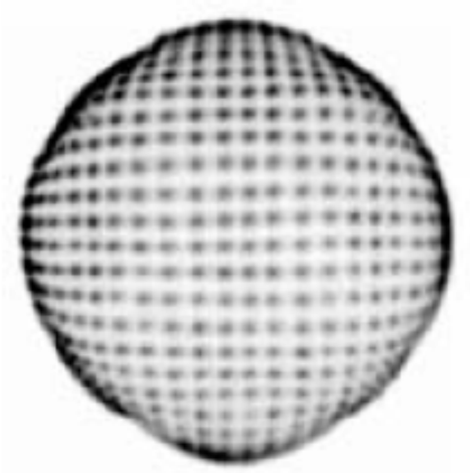
$LaBr_3$:Ce

Integral assembly 5 mm thick

FWHM ~ 12 mm

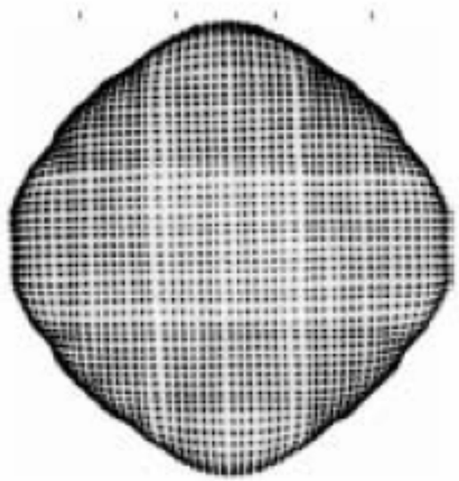


Single Crystal *vs* Pixels



Single Crystal Detector

- 120 mm diam × 6 mm thick NaI(Tl) plate
- 5″ PS-PMT
- Significant "barrel" distortion & non-linearity
- Good uniformity
- Edges difficult to recover
- Fair spatial resolution ~ 4 mm



Pixelated Detector

- 2 × 2 × 3 mm³ CsI(Tl) array, 120 mm diam
- 5″ PS-PMT
- Reduced distortion
- Better linearity
- Poor uniformity
- Artefacts due to readout
- Better spatial resolution ~ 3.5 mm

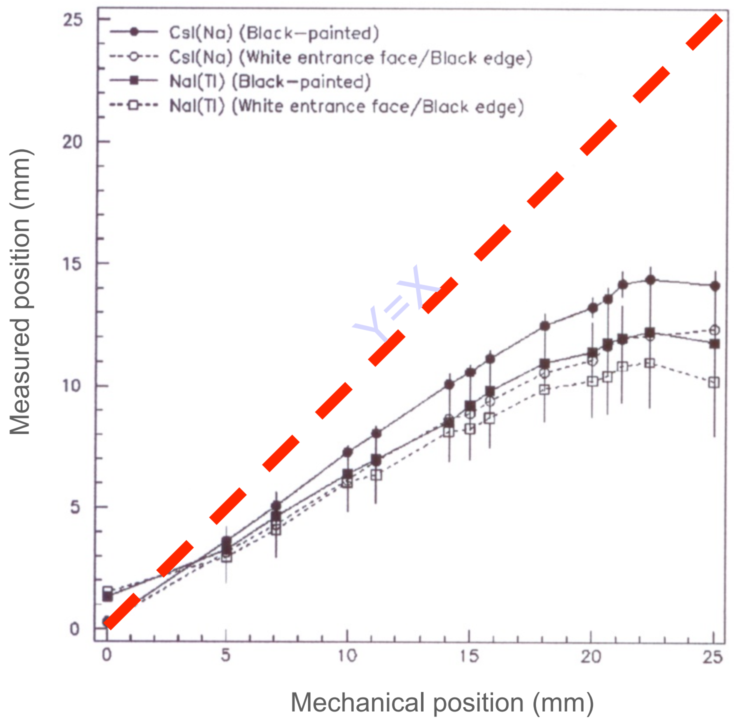
⇒ ***Most imperfections can be removed by signal/image correction algorithms***

Jeong et al, *NSS/MIC 2003*, M6-59

Université de Sherbrooke
Faculté de médecine et des sciences de la santé

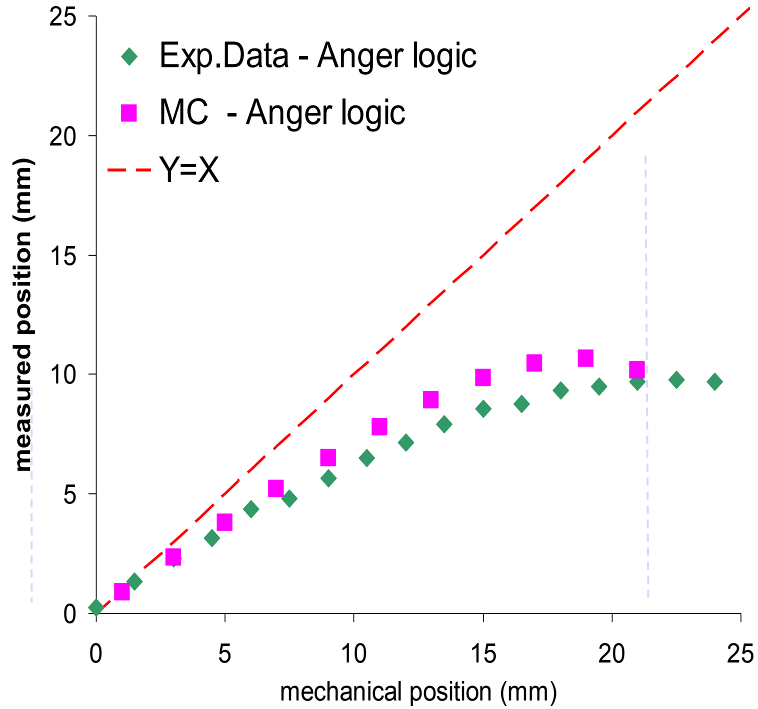
Intrinsic position non linearity continuous crystal

Literature data : Intrinsic loss of position linearity



Sanchez F. et al., *"Design and tests of a portable mini gamma camera"*, Med.Phys., Vol.31, June 2004

LaBr3:Ce 4mm thick



$$L_{meas} = \frac{dX_{measured}}{dx_{mech}} = 0.65$$

$$L_{MC} = 0.67$$

The optimum weight

From H.H.Barrett and W. Swindell "Radiological Imaging" 1981

$$\sigma_x = \left(\sum_j k_j^2 \overline{n}_j \right)^{1/2} \Big/ \left(\sum_j k_j \frac{d\overline{n}_j}{dx} \right)$$

Spatial resolution of the system in term of the phototube weights and the individual-tube spatial response functions

$$\sigma_{x,\min} = \left[\sum_j \frac{1}{\overline{n}_j} \left(\frac{d\overline{n}_j}{dx} \right)^2 \right]^{-1/2}$$

$$k_j(opt) = \frac{2k(x - x_j)}{(x - x_j)^2 + d^2}$$

It is seen that the optimum weight is strongly position dependent , but dependents only on the distance to the scintillation (x-x_j). To provide the minimum resolving distance, the optimum weights must be changed for each event according to the location of the event

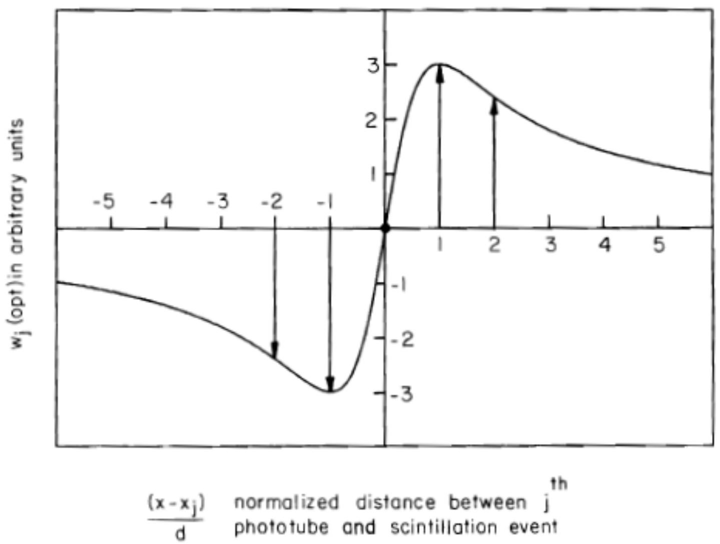


Fig. 5.49 Solid curve shows the optimum weighting factor for the jth tube located at x_j for a scintillation event positioned at x. For comparison with the fixed weights of the Anger camera, arrows show the set of fixed weights that would be used for an array of five tubes with uniform inter-tube separation equal to the height d of the tube above the crystal.

New position arithmetic for continuous Scintillators based on floating weights

$$X_C = \frac{\sum_j n_j k_j}{\sum_j n_j}$$

where

x_j represents the linear weight associated to the anode array

$$n_j = \sum_k n_{k,j}$$

is the projection of the charge collected along the J-th column

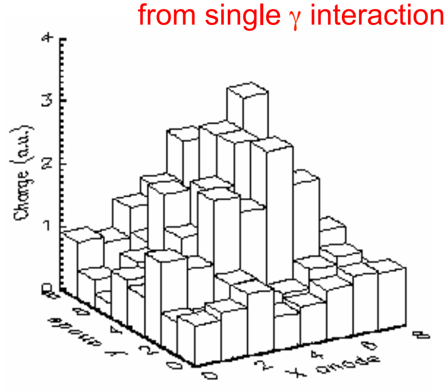
New algorithm:

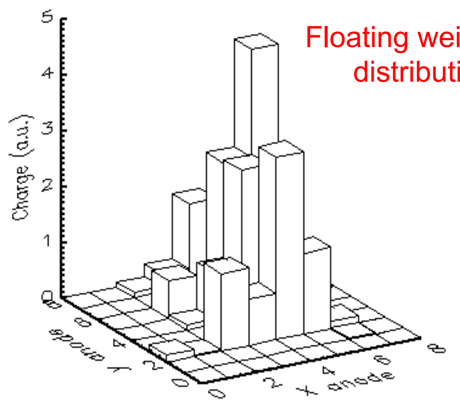
$$X_C = \frac{\sum_j n'_j k_j}{\sum_j n'_j} \quad \text{where} \quad n'_j = \sum_k \left(n_{k,j} \cdot w_{k,j}\right)$$

$w_{k,j} = n_{k,j}$ is the weight.

In general $w_{k,j}$ is a 2D array of weights strictly related to $n_{k,j}$
In this way the position information related to the anode position k_j is more *enhanced near the interaction point (maximum charge* = maximum weight) and depressed far from interaction location.

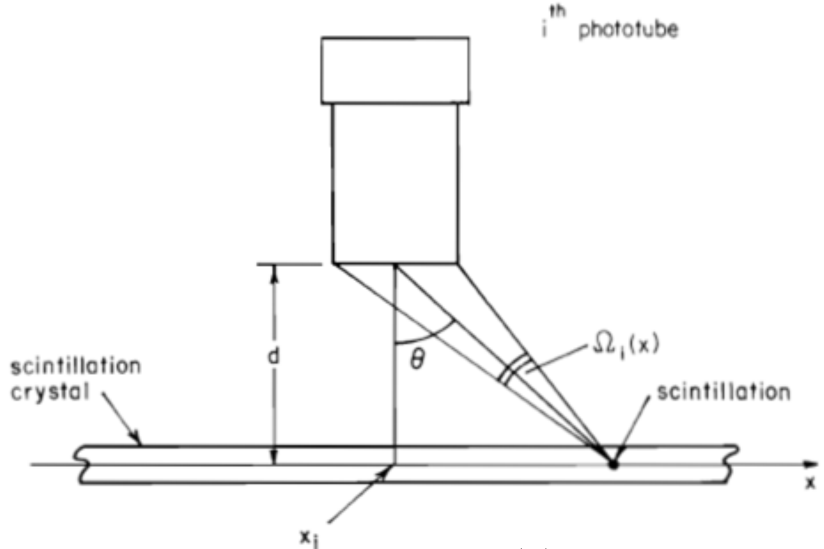
Original charge distribution from single γ interaction



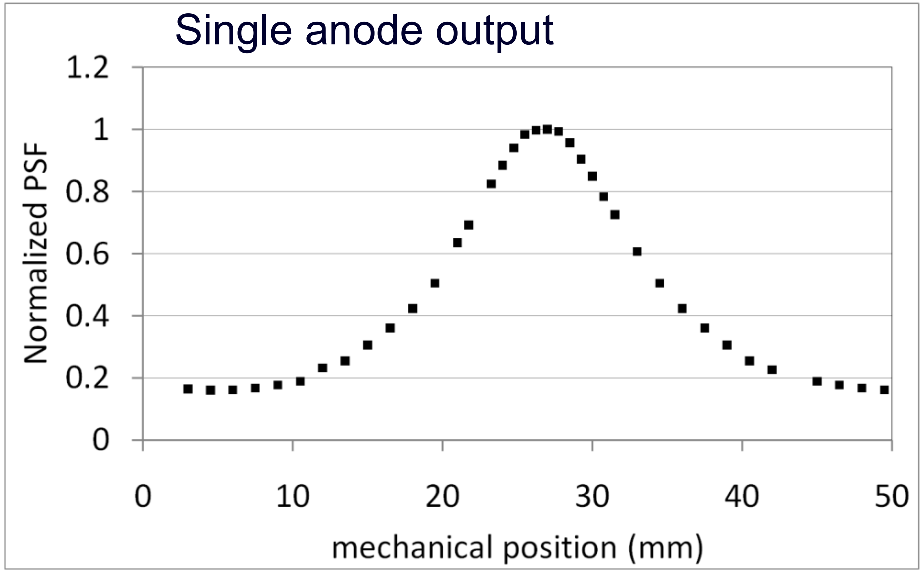


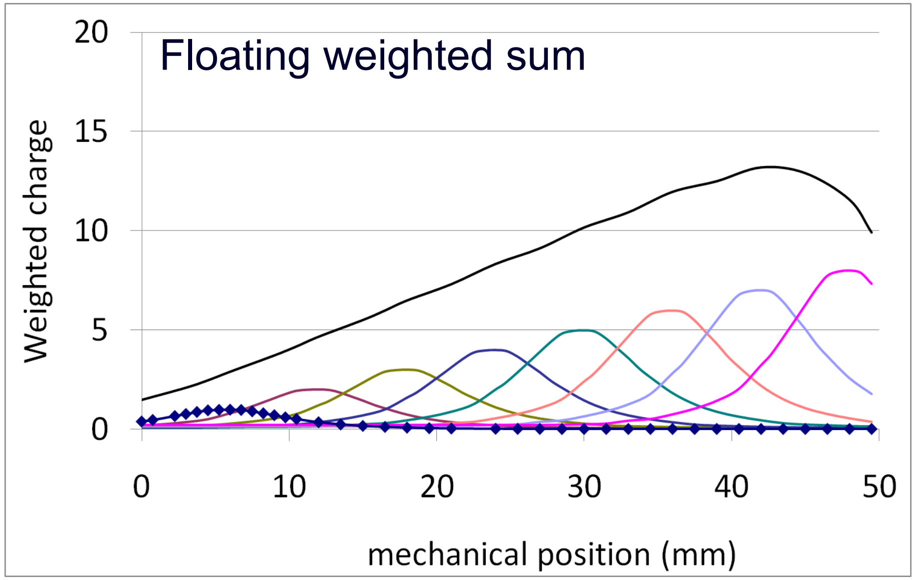
Floating weighted distribution

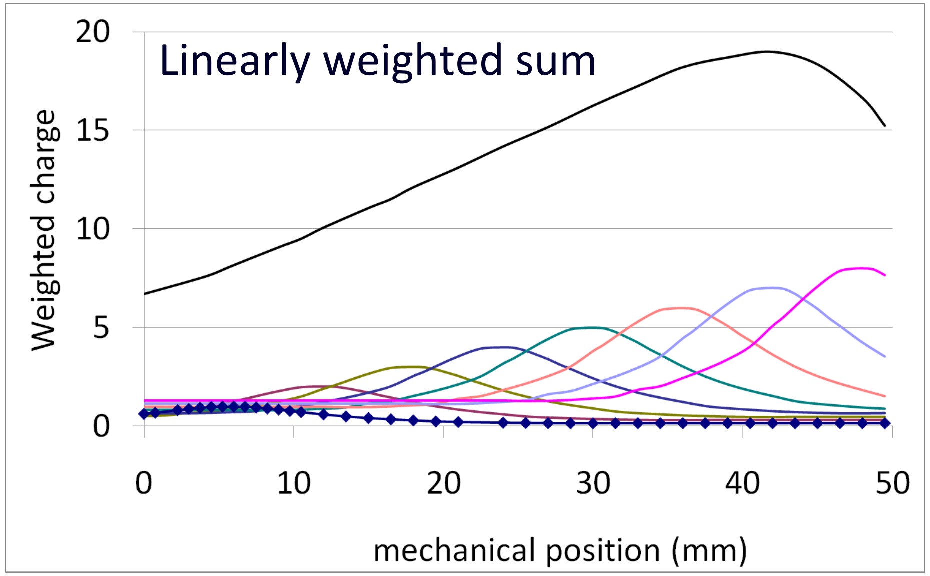
Continuous $LaBr_3$:Ce -4 mm thick – Linear scanning –



Geometry showing solid angle $\Omega_i(x)$ subtended by *i*-th phototube for scintillation located at x

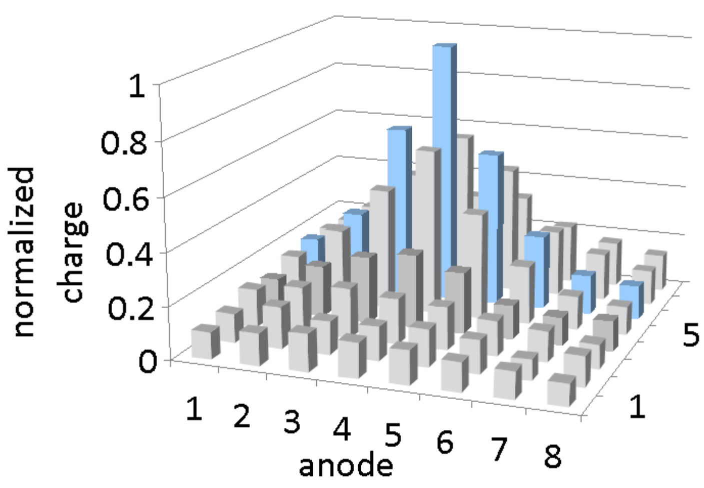


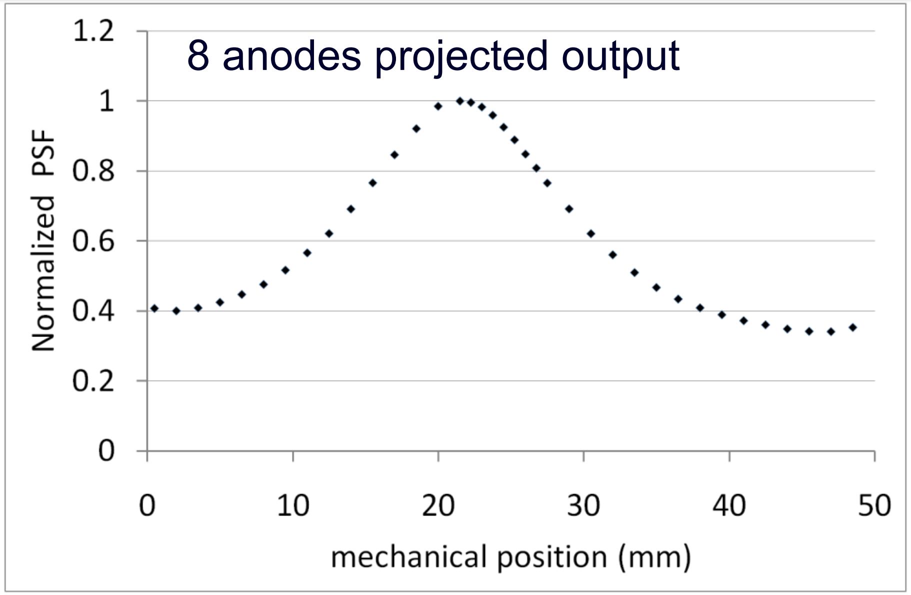


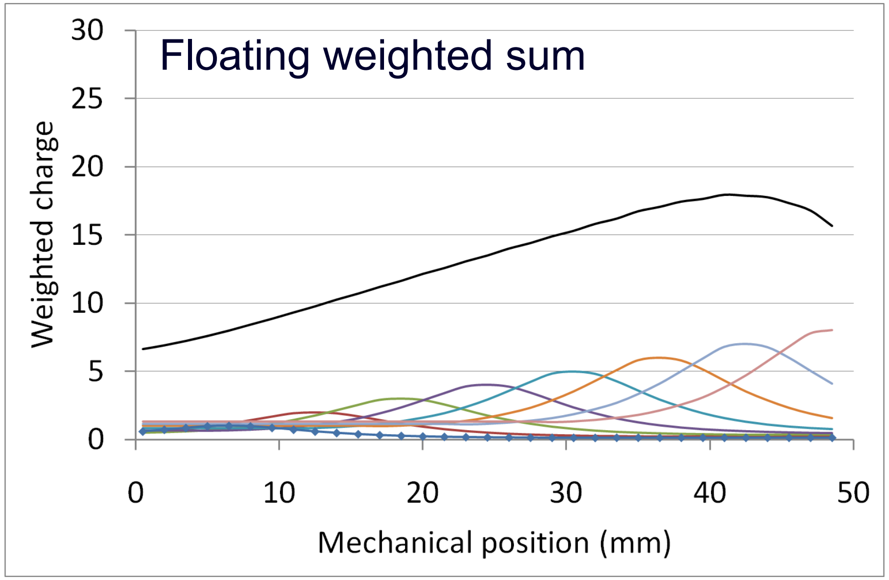


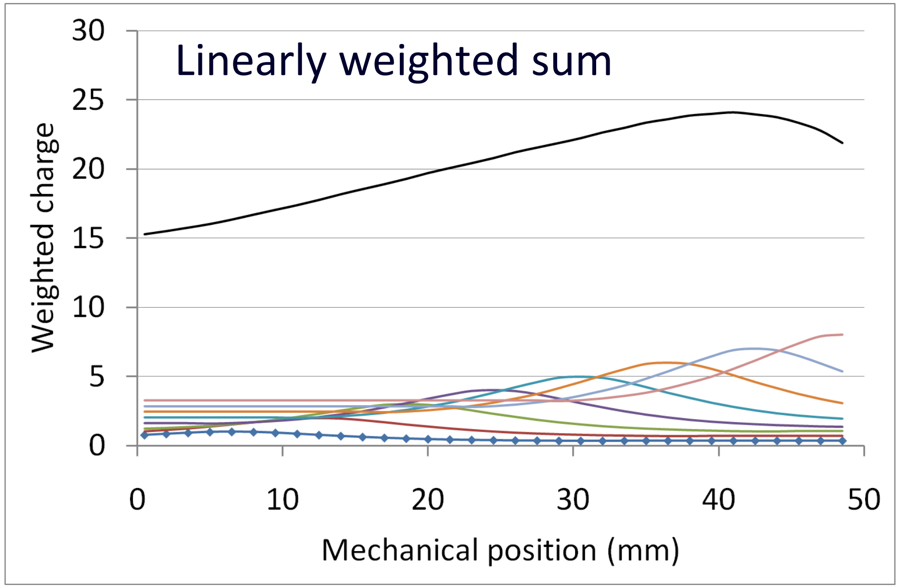
Continuous $LaBr_3$:Ce -4 mm thick – projected charge analisys – Experimental data –

Charge distribution – 6 mm anode size

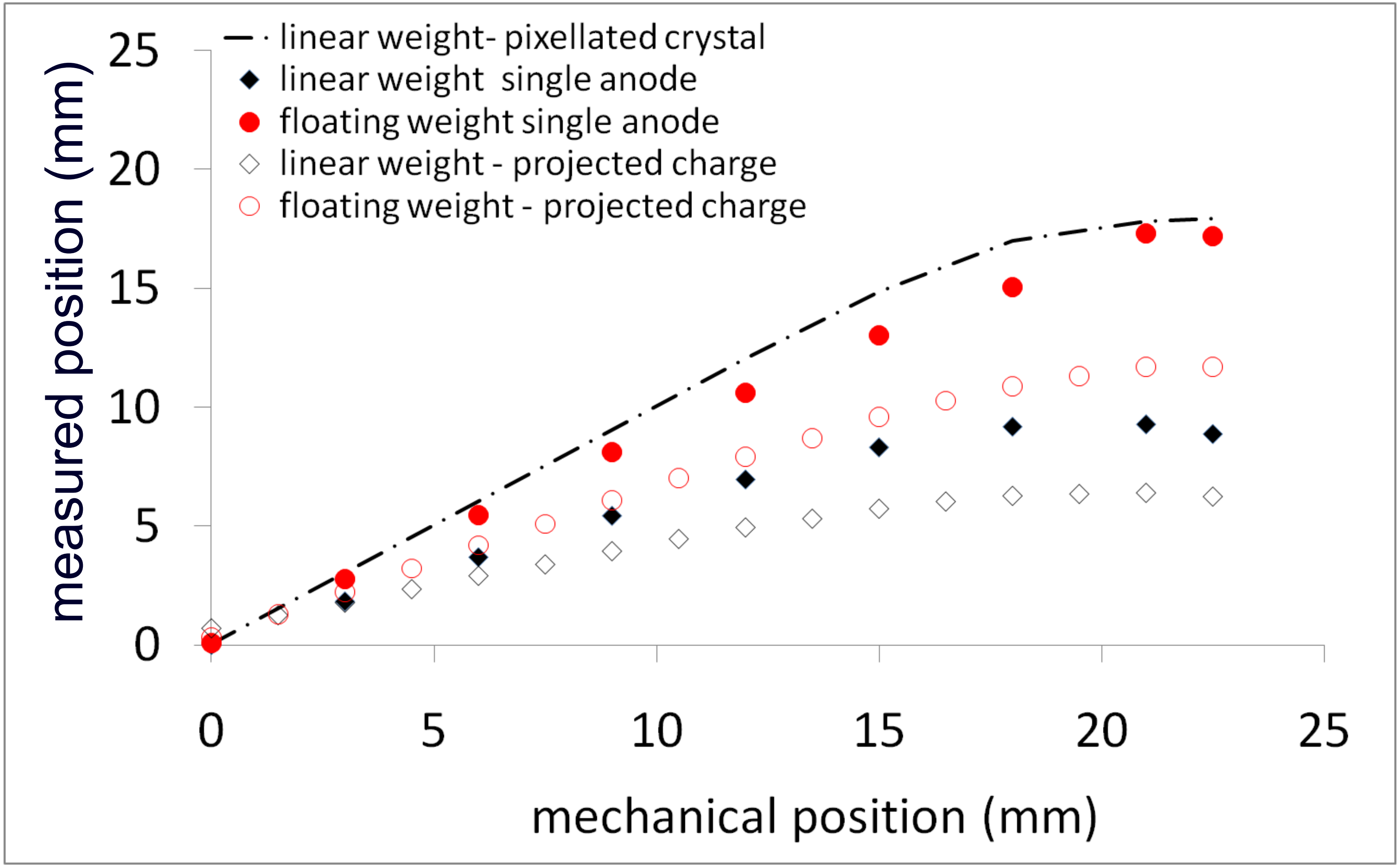






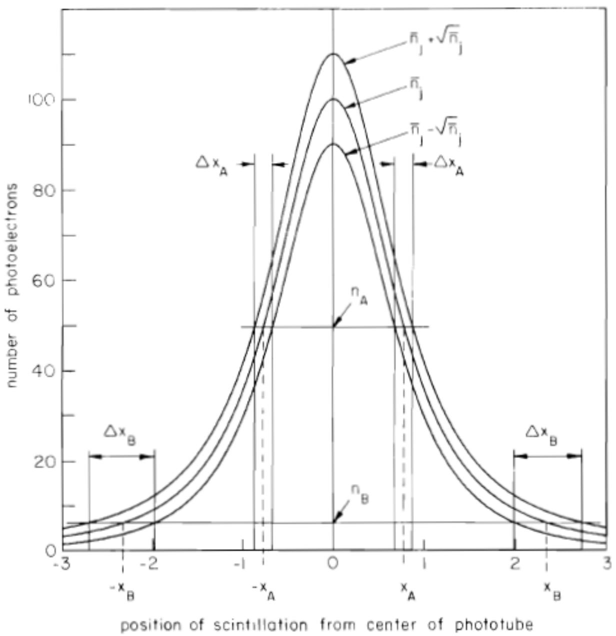


Continuous $LaBr_3$:Ce -4 mm thick – position linearity –

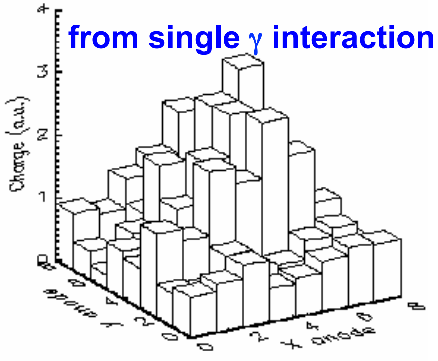


Single anode threshold

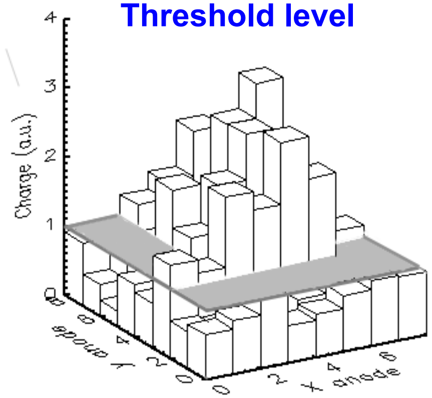
Single anode threshold reduces larger position uncertainty associated with weak pulses of charge distribution tails



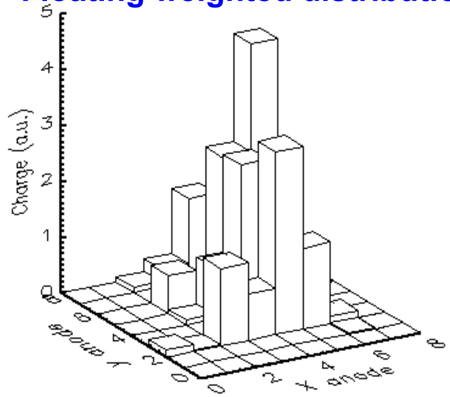
Original charge distribution from single γ interaction



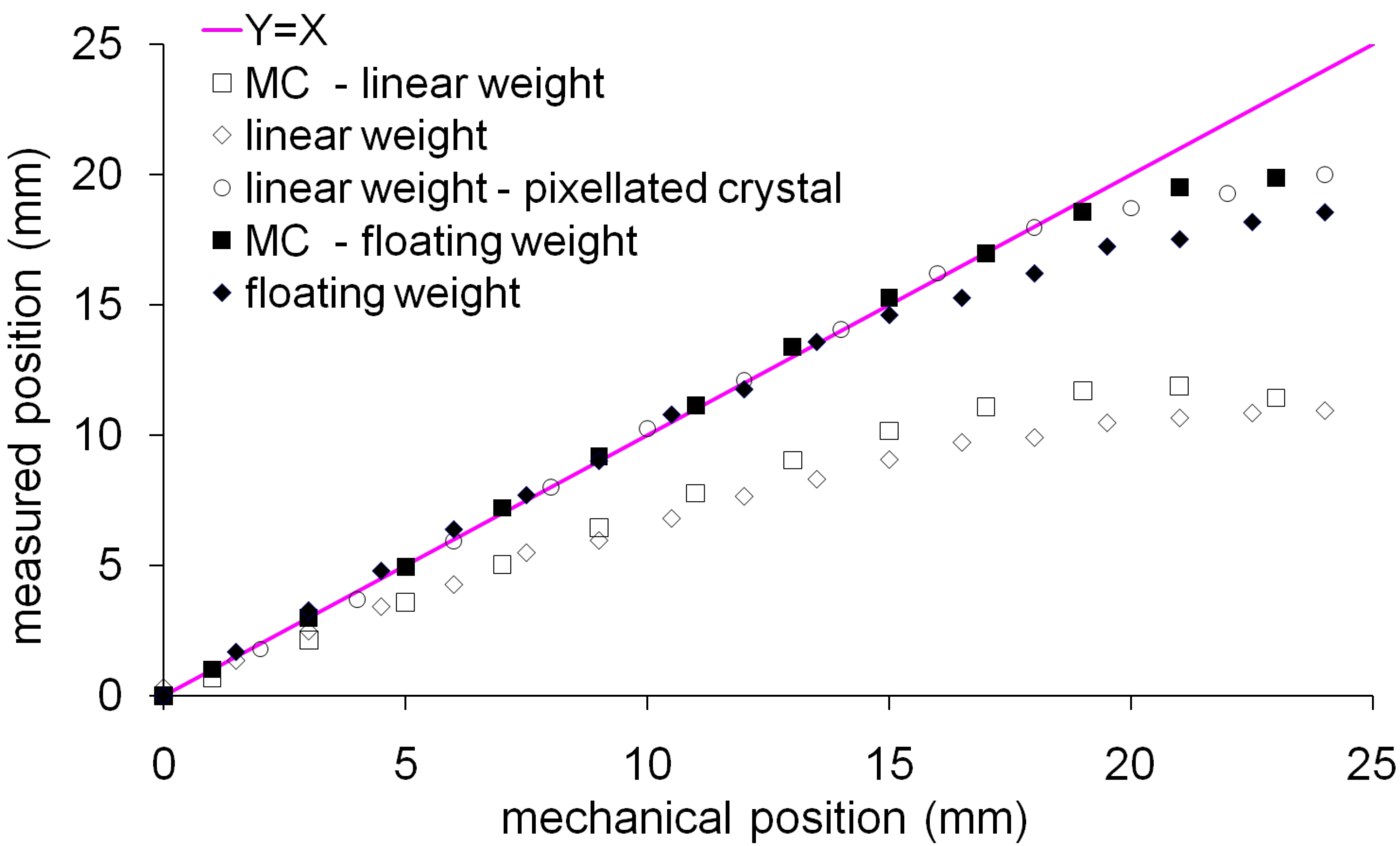
Threshold level



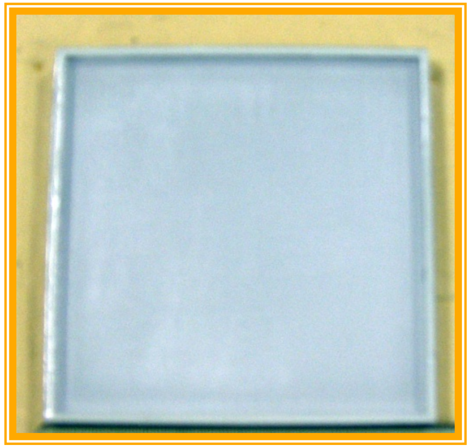
Floating weighted distribution



Continuous $LaBr_3$:Ce -4 mm thick – position linearity with threshold –

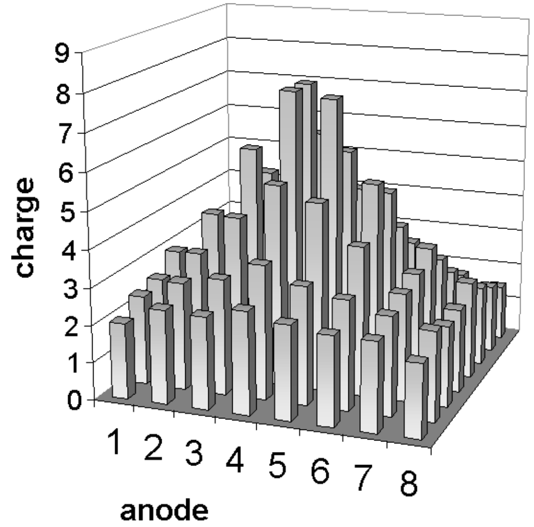


Continuous $LaBr_3$:Ce crystal 10 mm thick

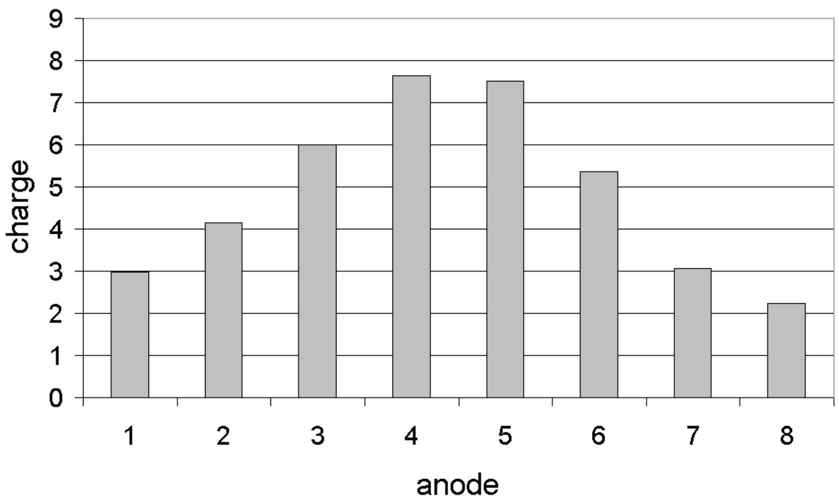


51 x 51 x 10 mm^3 size
3 mm glass window

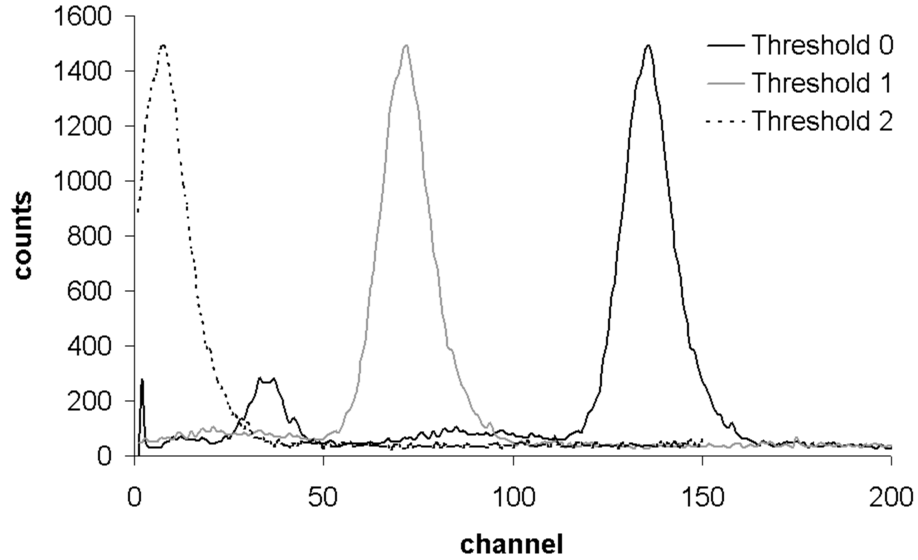
Charge distribution –
6 mm anode size



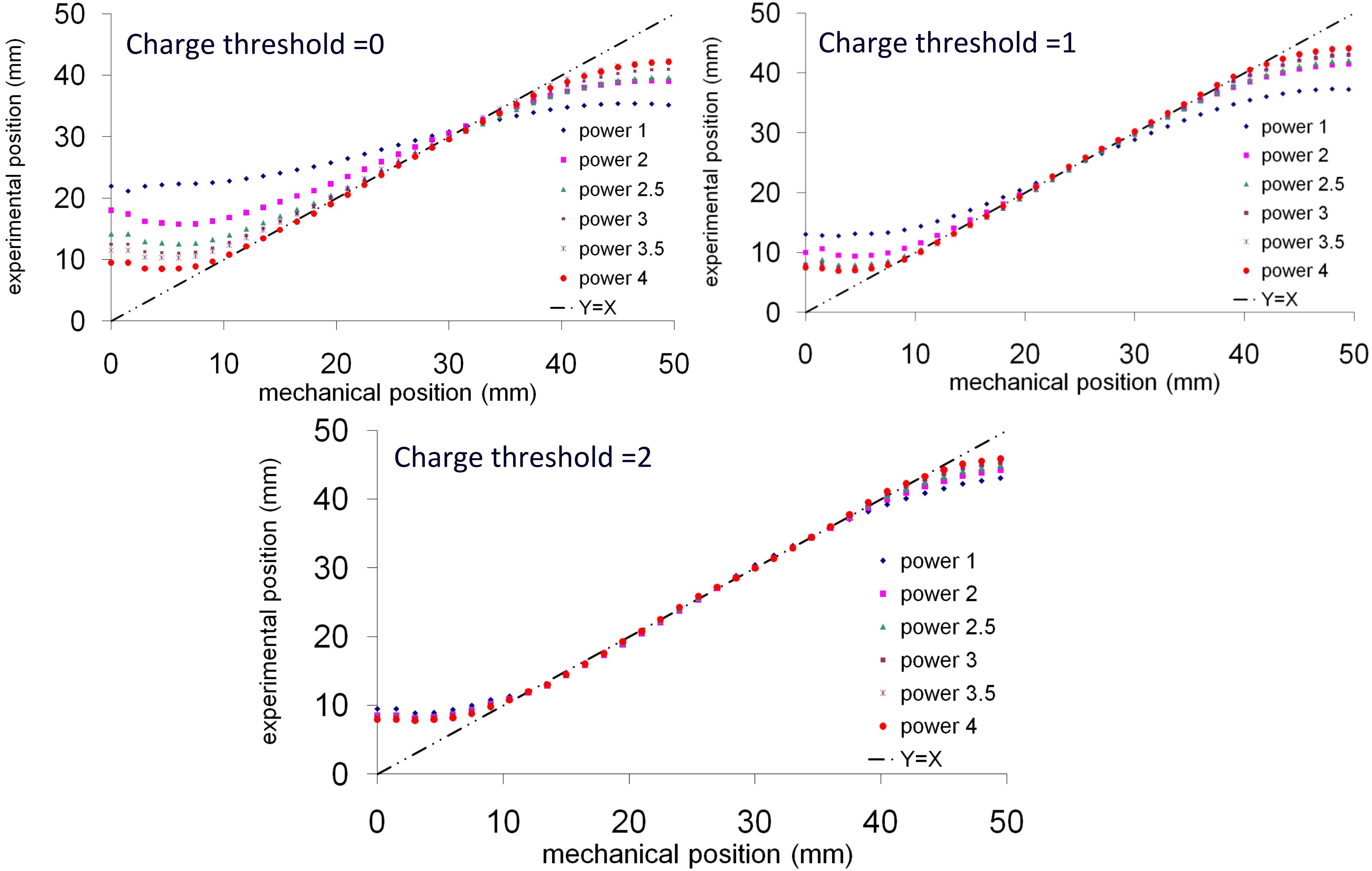
Light PSF 26 mm FWHM



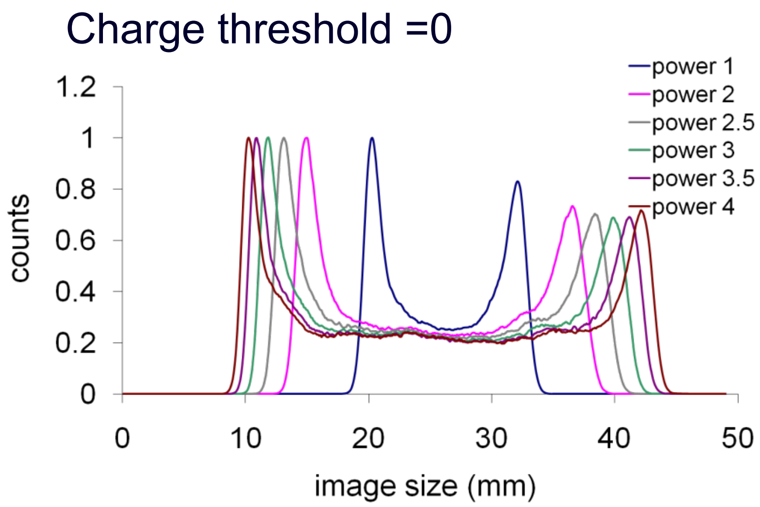
Pulse height distribution

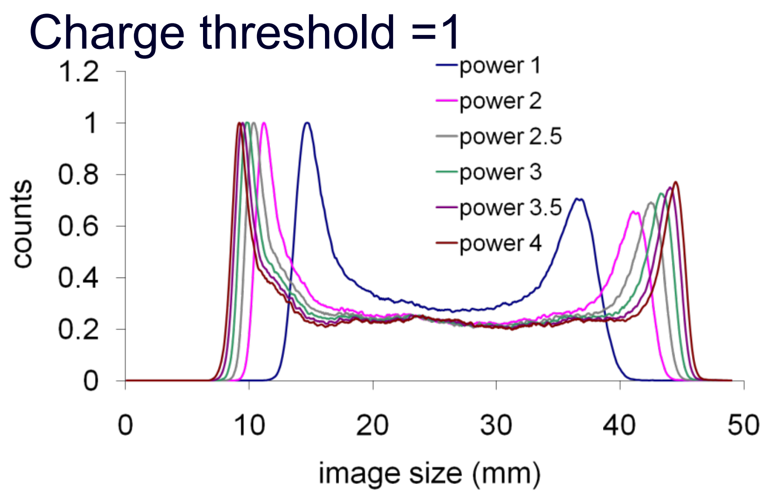


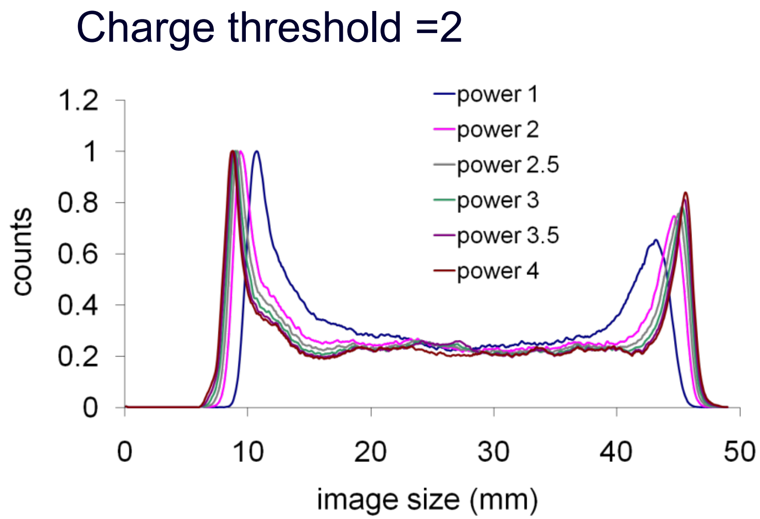
Charge threshold and RTP effect on position linearity

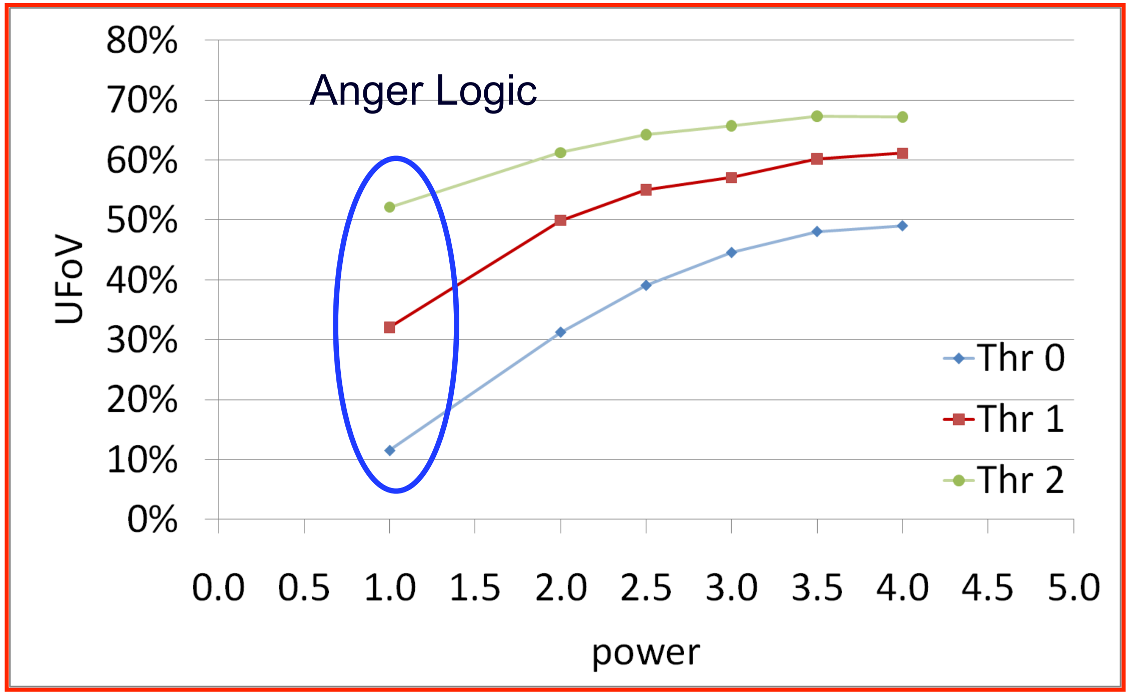


Charge threshold and RTP effect on FoV



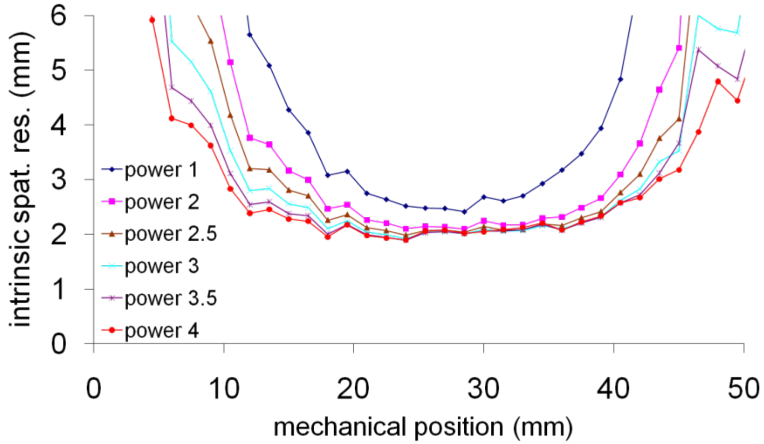




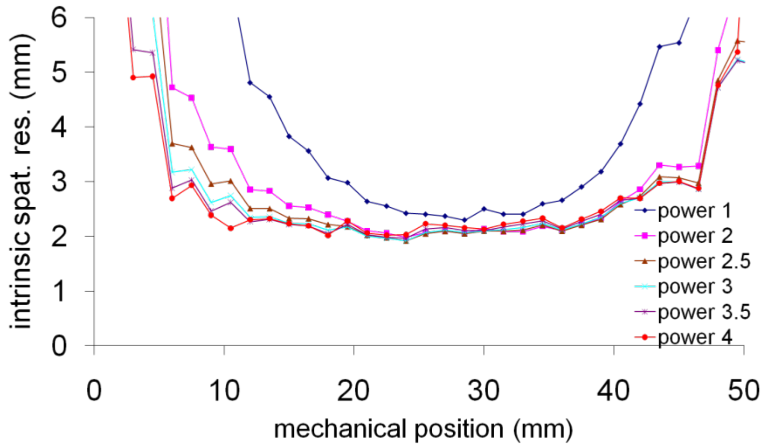


Charge threshold and RTP effect on spatial resolution

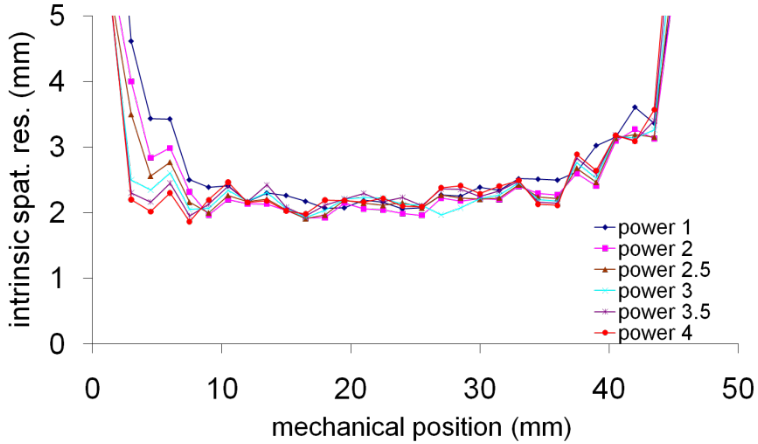
Charge threshold =0

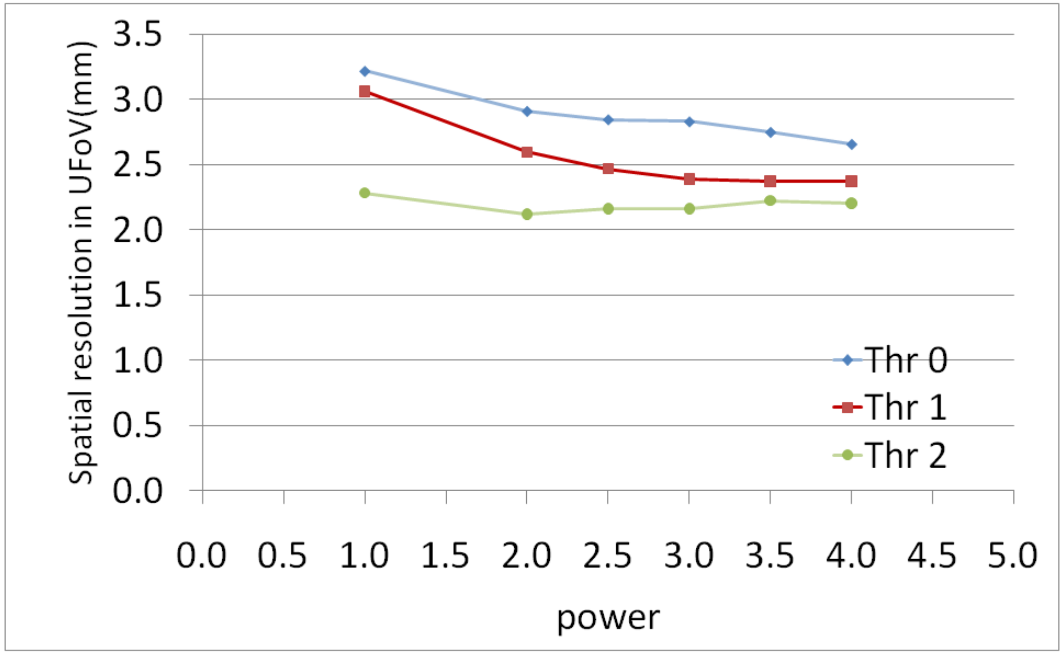


Charge threshold =1



Charge threshold =2

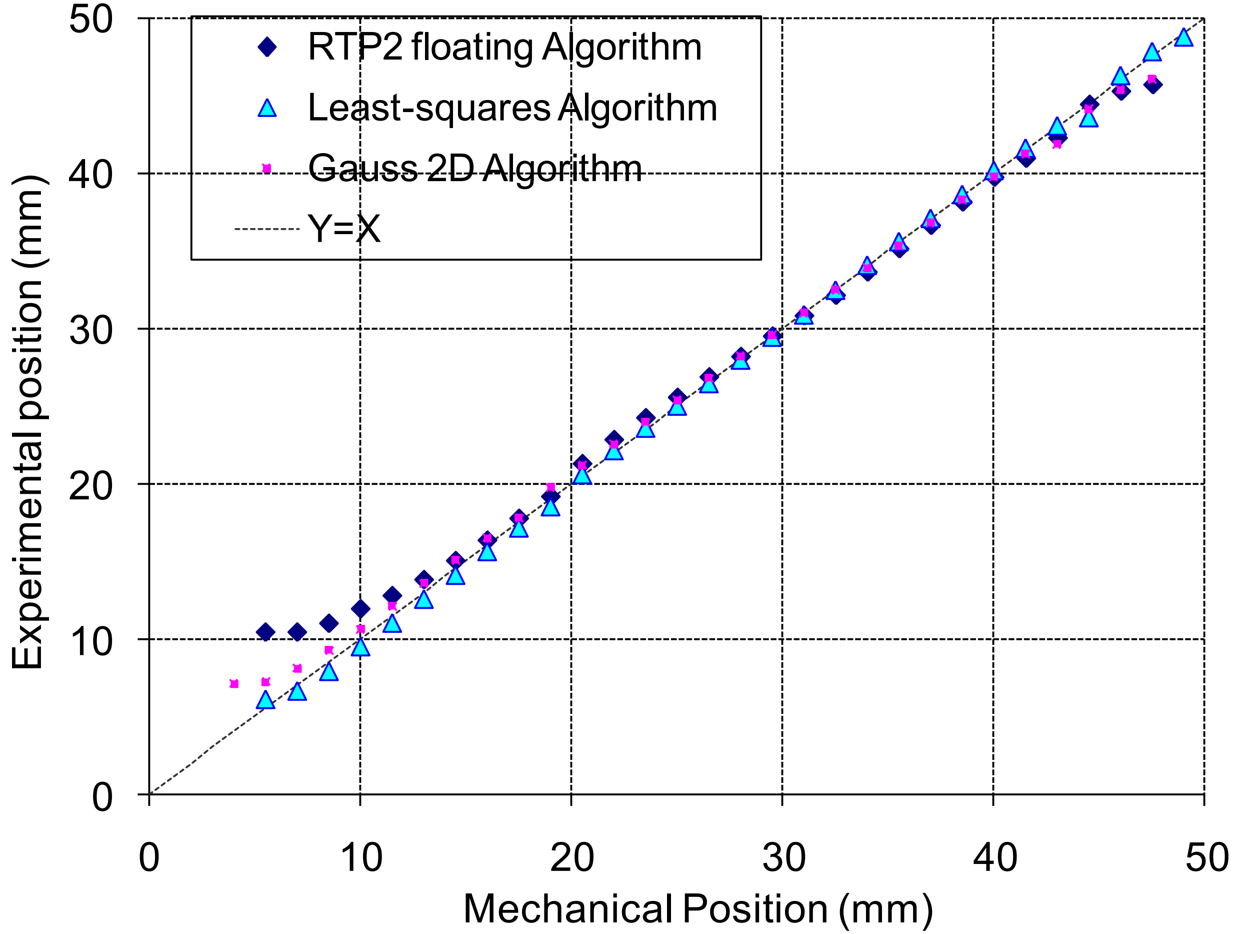




Position Algorithms Comparison

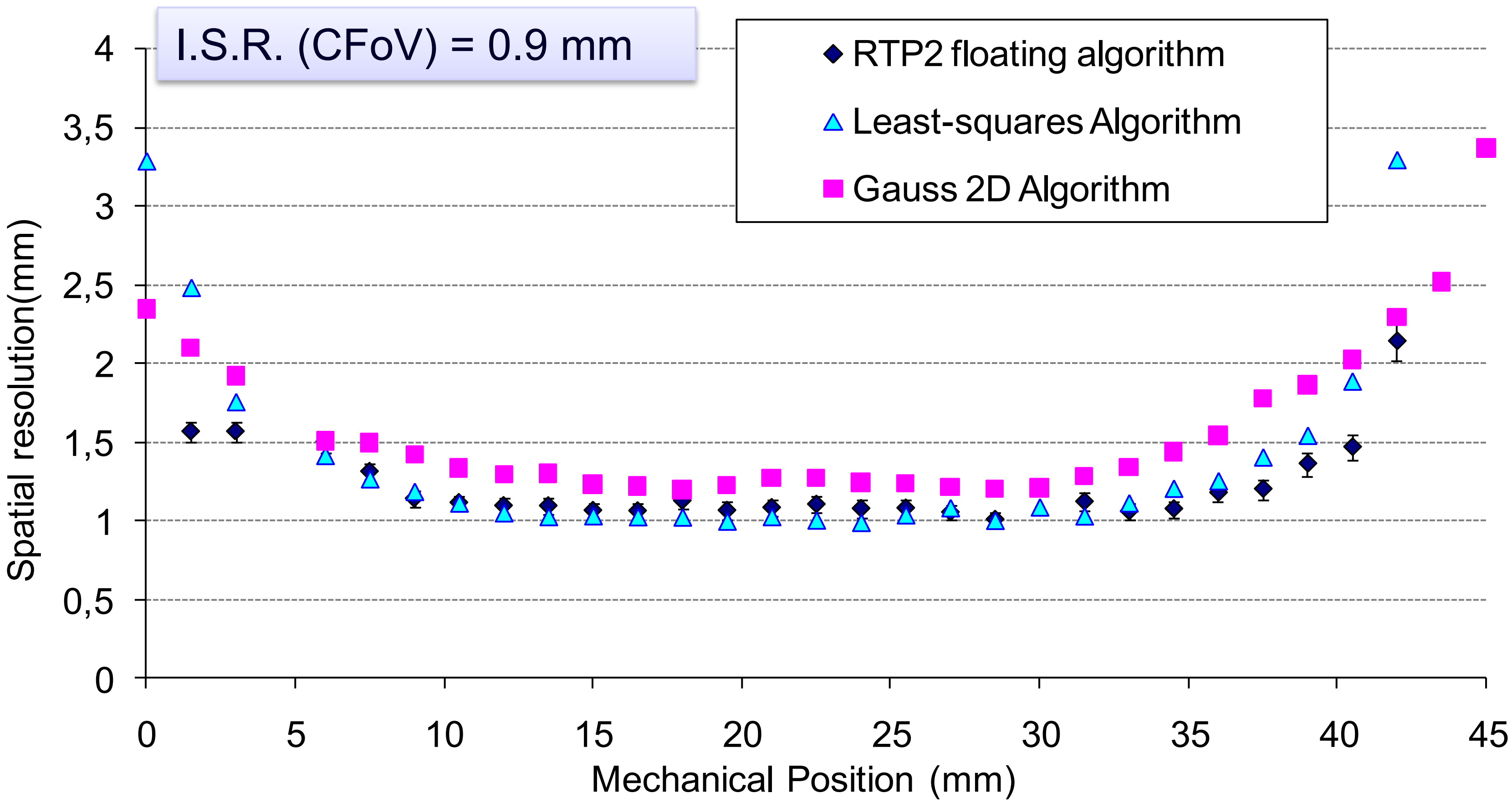
LaBr$_3$(Ce) *4 mm thick*

BA MA-PMT H8500



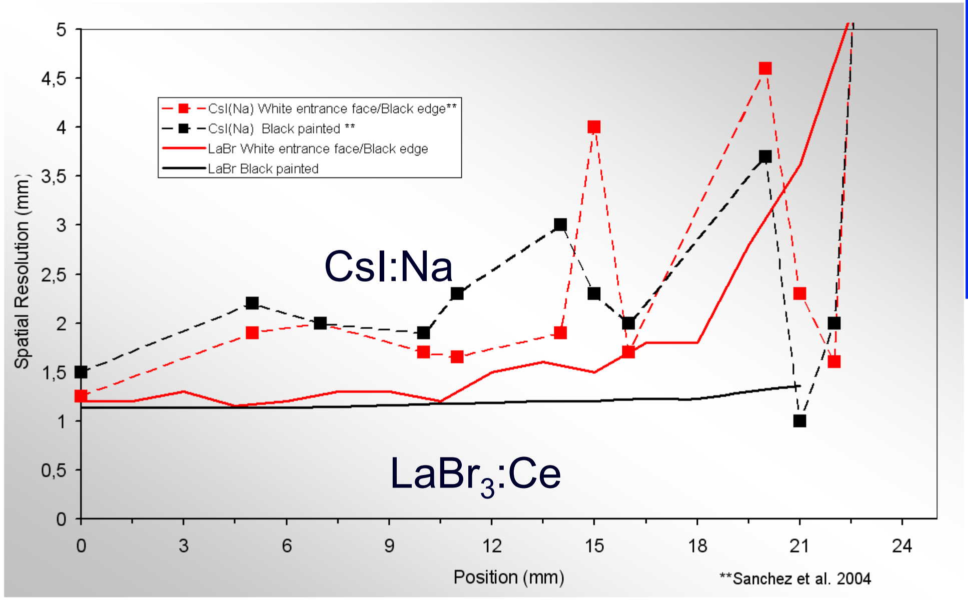
Position Algorithms Comparison

$LaBr_3(Ce)$ *4 mm thick*



Conclusions
Comparison with literature data

Spatial resolution



LITERATURE **Sanchez F. et al., Medical Physics, Vol.31, June 2004**
CsI(Na) 51 mm diam **4 mm thick 3 mm** opt. guide
3" PSPMT Hamamatsu R2486

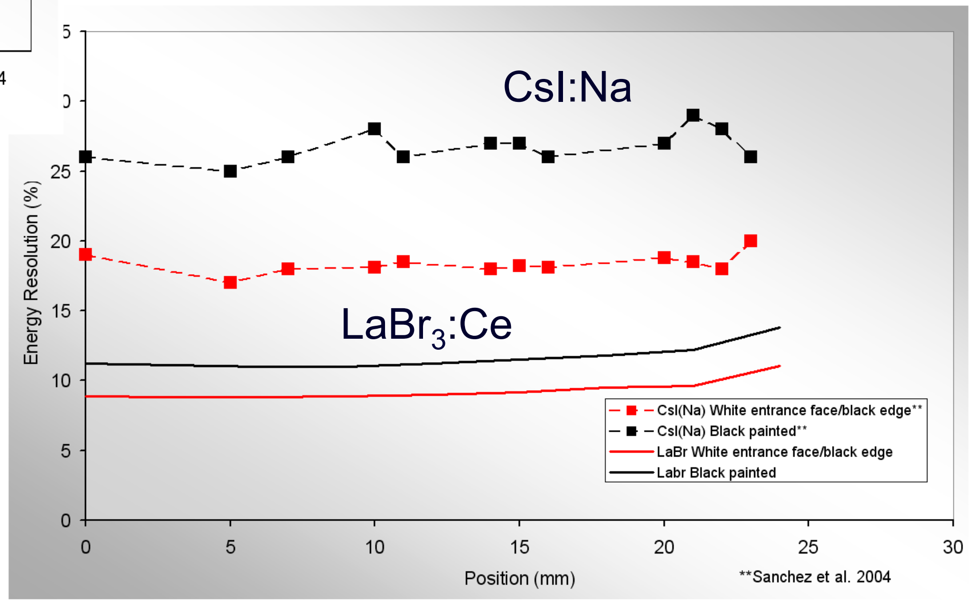
THIS WORK
$LaBr_3$:Ce 49 mm square **4 mm thick 4.5** opt. guide
2" MA-PMT hamamatsu H8500

Energy resolution

better than 50%!

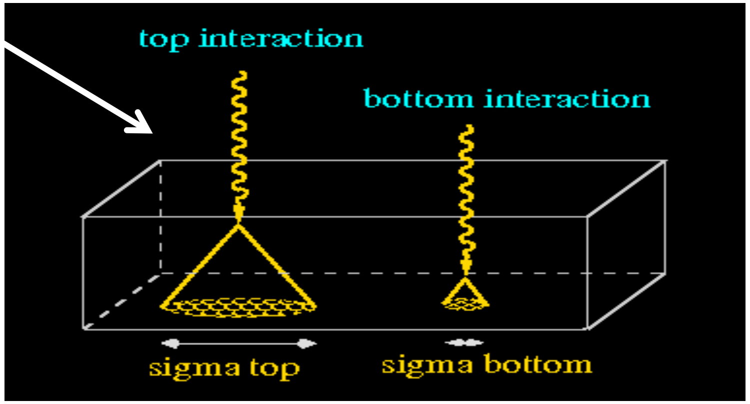
$LaBr_3$:Ce

Two times better!

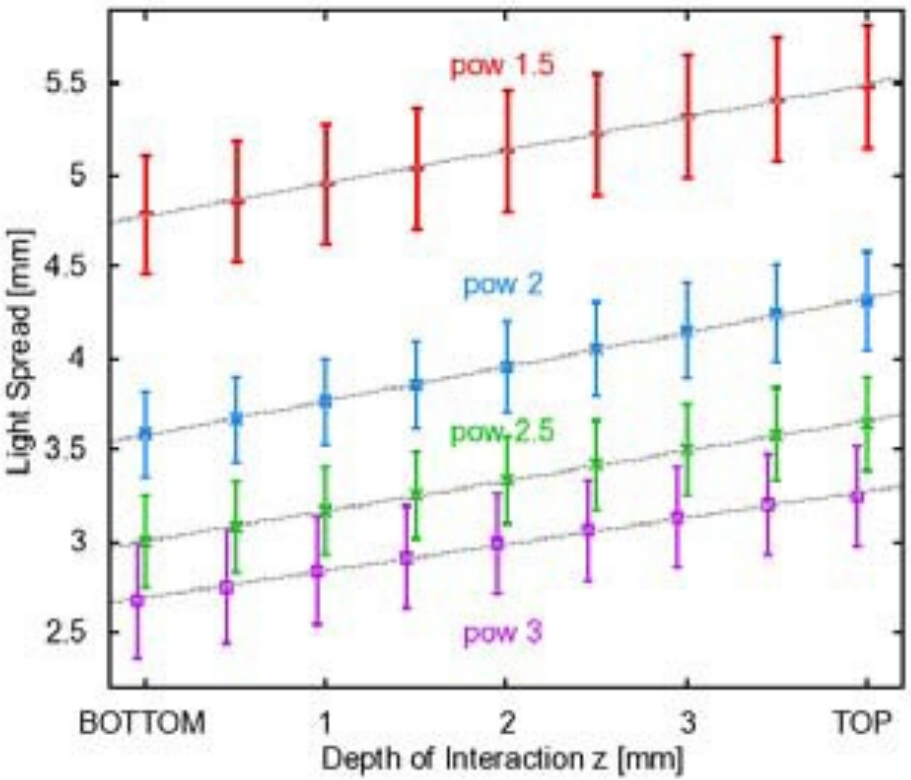


Future Perspective "fully 3D detector ……
"……1mm DOI resolution in PET ?

LaBr3:Ce continuous crystal



Preliminary results at 140 keV gamma ray energy



- ✓ Depth dependent response of continuous LaBr3:Ce crystals
- ✓ High photoelectron number reduces error on light spread discrimination

Simulazione Monte Carlo Geant4

INFN Bologna