Performance of FlexToT Time Based PET Readout ASIC for Depth of Interaction Measurements

J.M. Cela[2], A. Comerma[1], L. Freixas[2], D. Gascon[1], R. Graciani[1], J. Marin[2], G. Martínez[2], R. Masachs[1], J.M. Perez[2], P. Rato[2], D. Sanchez[1], A. Sanuy[1], I. Sarasola[2], J. Trenado[1]

[1]Universidad de Barcelona, [2]CIEMAT, Madrid

Conference on Technology and Instrumentation in Particle Physics

Amsterdam, Holland
5th June 2014

ICCUB
Institut de Ciències del Cosmos

Si UB

GOBIERNO DE ESPAÑA
MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD
Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

1

Outline

- ✔ Behind FlexToT
- ✔ Depth of Interaction
- ✔ FlexToT system
- ✔ Phoswich
 - ➢ Setup
  - ➢ Measurements
- ✔ Summary

Behind FlexToT

- ICC-UB experimental HEP group is working in particle experiments (since mid 90s), astroparticle and medical imaging (more recently).

- Develops read out electronics for:
  - Calometers and Tracking (LHCb)
  - Cherenkov telescopes (CTA)
  - Silicon trackers (DEPFET-Belle and future colliders)

- Project with CIEMAT to develop and ASIC for SiPM/MPPC based PET
  - ICC-UB: expertise on electronics and microelectronics design
  - CIEMAT: expertise on PET and medical imaging instrumentation

http://icc.ub.edu/   **http://siub.ub.edu/**
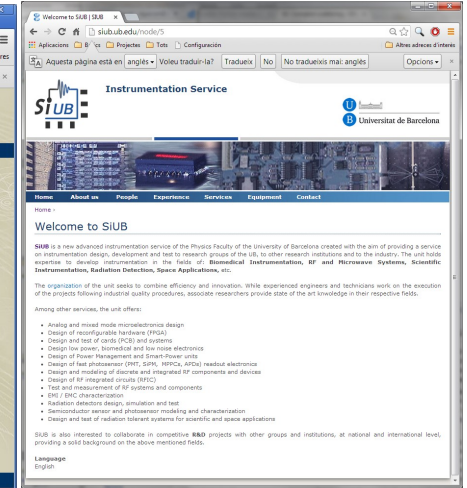
BrainPET Project
New generation PET equipment for functional studies of the human brain

MRI   ¹⁸FDG-PET   PET/MRI

Objective: Development of a prototype for clinical use
Collaboration with Puerta de Hierro Hospital – Majadahonda

Positron Emission Tomography + Magnetic Resonance
- Functional and Anatomic Imaging
- Reduced dose to the patient
- Better contrast for soft tissues

Technological advances
- Compatibility with magnetic fields
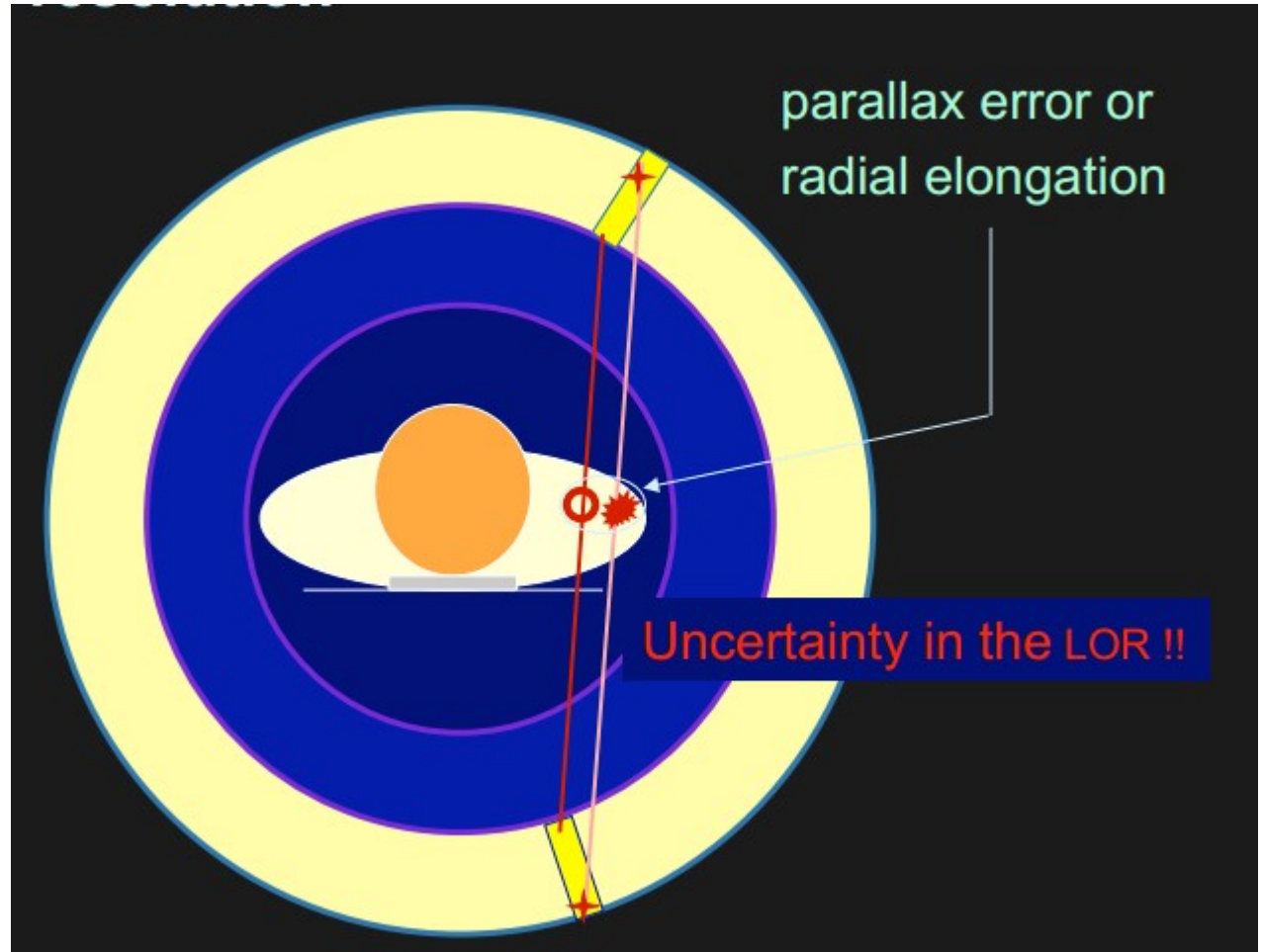- LYSO:Ce Monolithic Scintillators
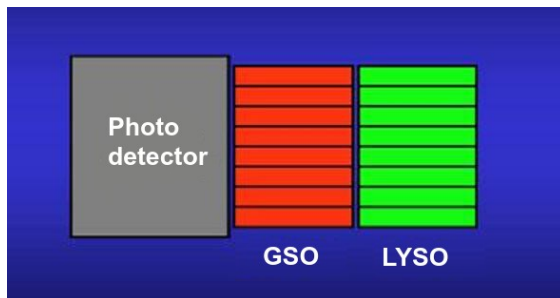- Integrated ASIC electronics readout
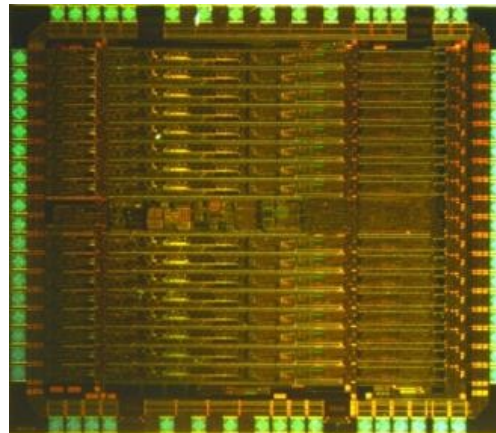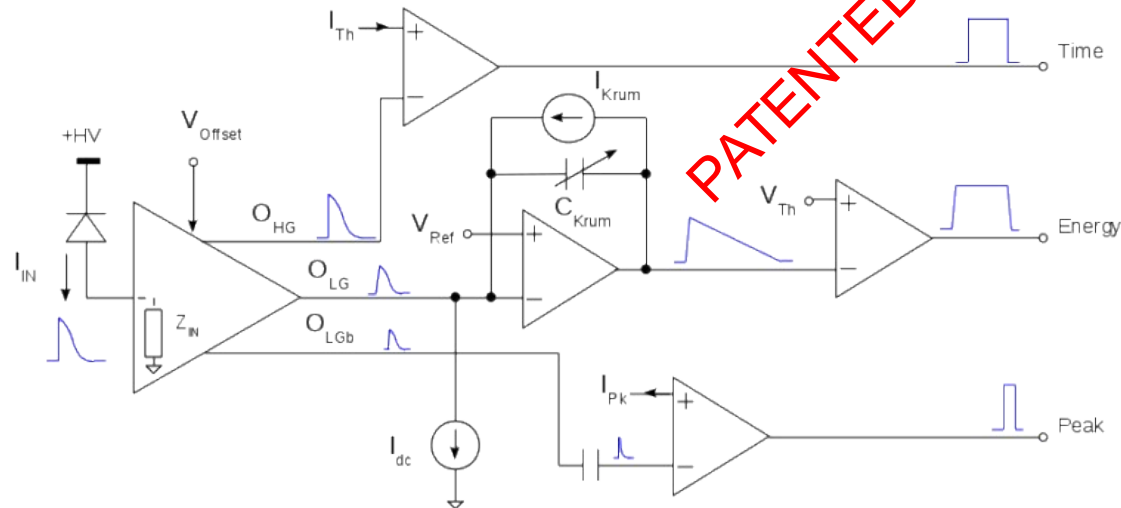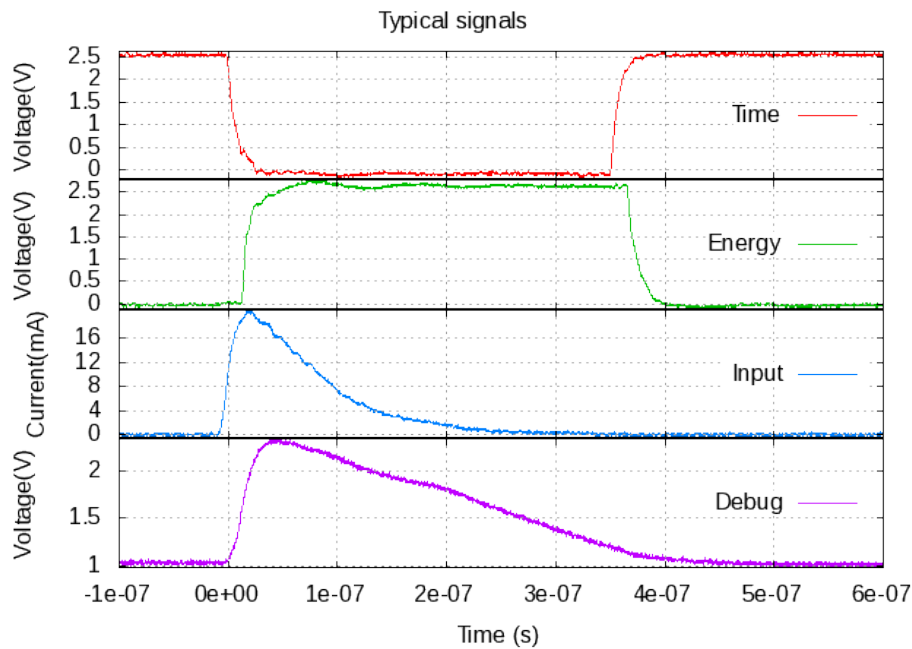
Institut de Ciències del Cosmos

Depth of Interaction

- Radiation emitted from non central region of the ring provoke parallax error in the reconstruction
- Using stacked scintillator crystals with different properties can reduce the error.

FlexToT (I)

- A Flexible ASIC for MPPC (PET, SPECT, Compton)   2 contributions in 2013 NSS

  - Novel current mode input stage

  - Time over Threshold RO

    - No ADC required

Typical signals

FlexToT
**16 channel
SiGe BiCMOS 0.35um
Austriamicrosystem
10 mm²
3.3 V (10 mW/ch)
QFN 64**

ICCUB

Institut de Ciències del Cosmos

Si UB

GOBIERNO DE ESPAÑA MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD Ciemat

FlexToT (II)

- Why **Flex**ToT?

  - Linear ToT can be adjusted to different scintillator time constants

  - High Dynamic Range: can be connected to different sensors with a wide range of overvoltages

  - Use of ToT digitalization allows trading-off resolution versus rate

  - Accurate analog processing directly connected to FPGA
    - TDCs and signal processing are in FPGA: reconfigurable!
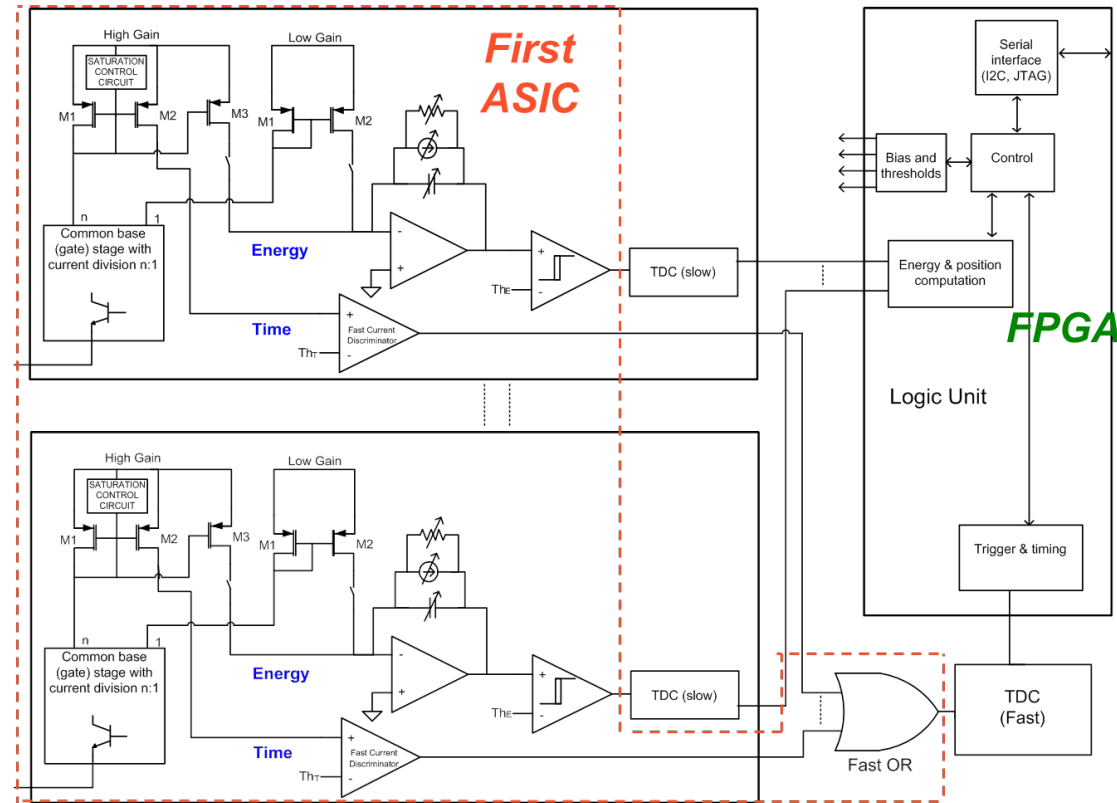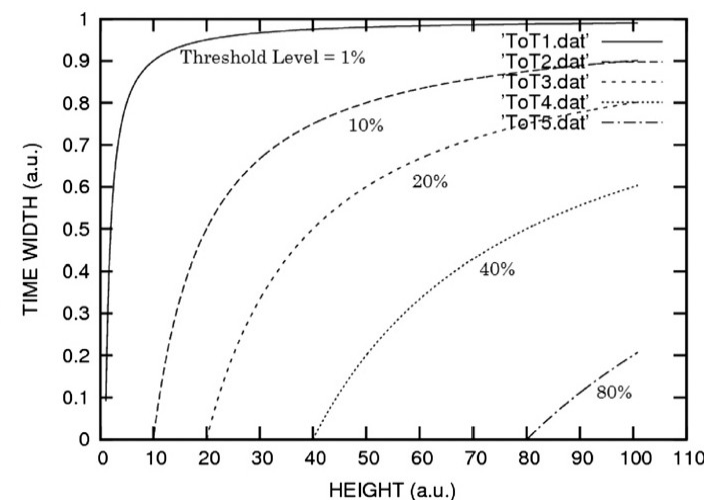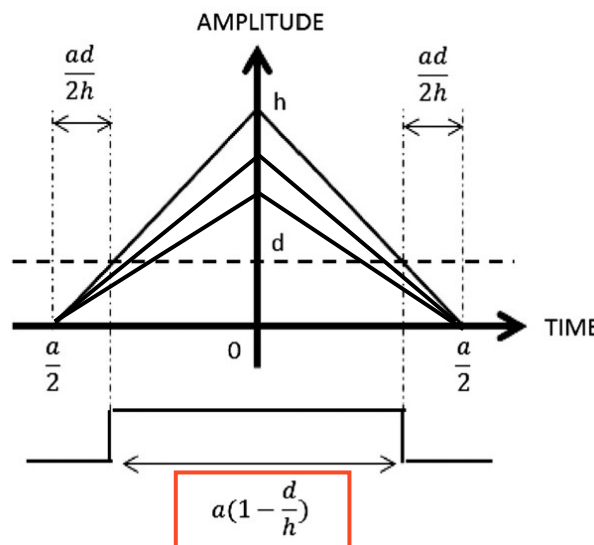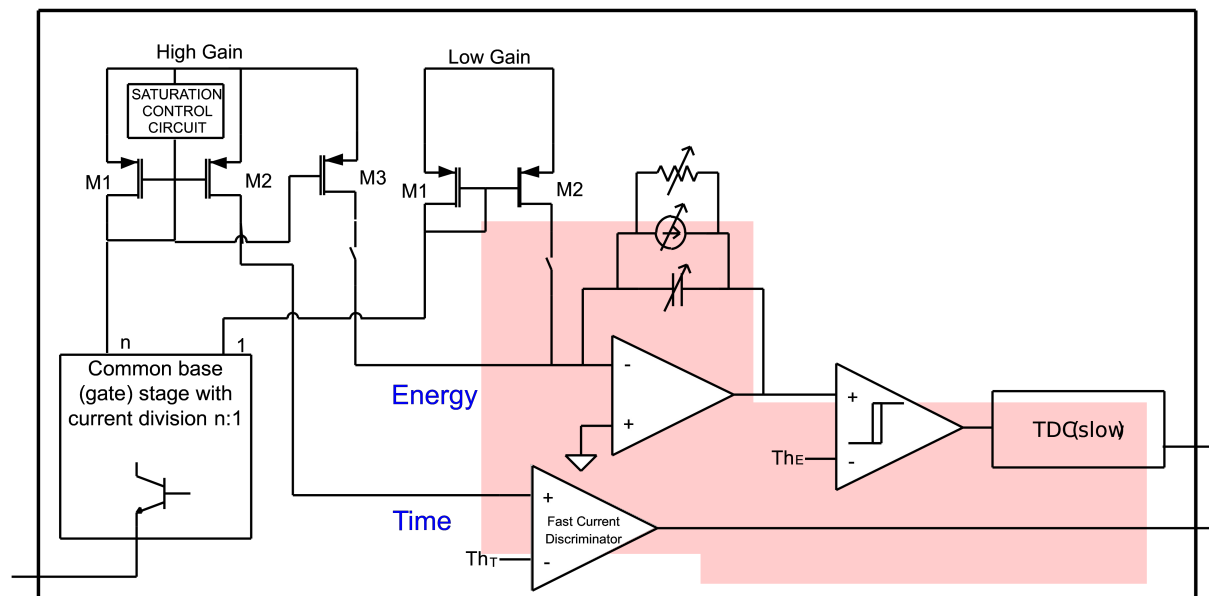
FlexToT (III)

- ### Why Flex**ToT**?
  - **Simple, robust & low power**
    - **NO ADC !**
  - Widely used in ASICs for tracking
  - Gathering interest for PET
    - > 10 proposals lasts NSS
    - Only moderate resolution is required

- ### Configurable ToT
  - Non-linear vs linear
  - Tuneable feedback current
    - Rate vs resolution

- ### Classical ToT is non-linear
  - CSP+Shaper+Discriminator


Orita, NIMA 648, S24-27, 2011

FlexToT: Test setup

- ASIC design test set-up at ICC-UB
  - 16 ch: 1 x SiPM Array + 1xASIC + 1xFPGA
  - Signal can be injected from arbitrary waveform generator (AWG) for electrical characterization.

- PET module design and test set-up at CIEMAT
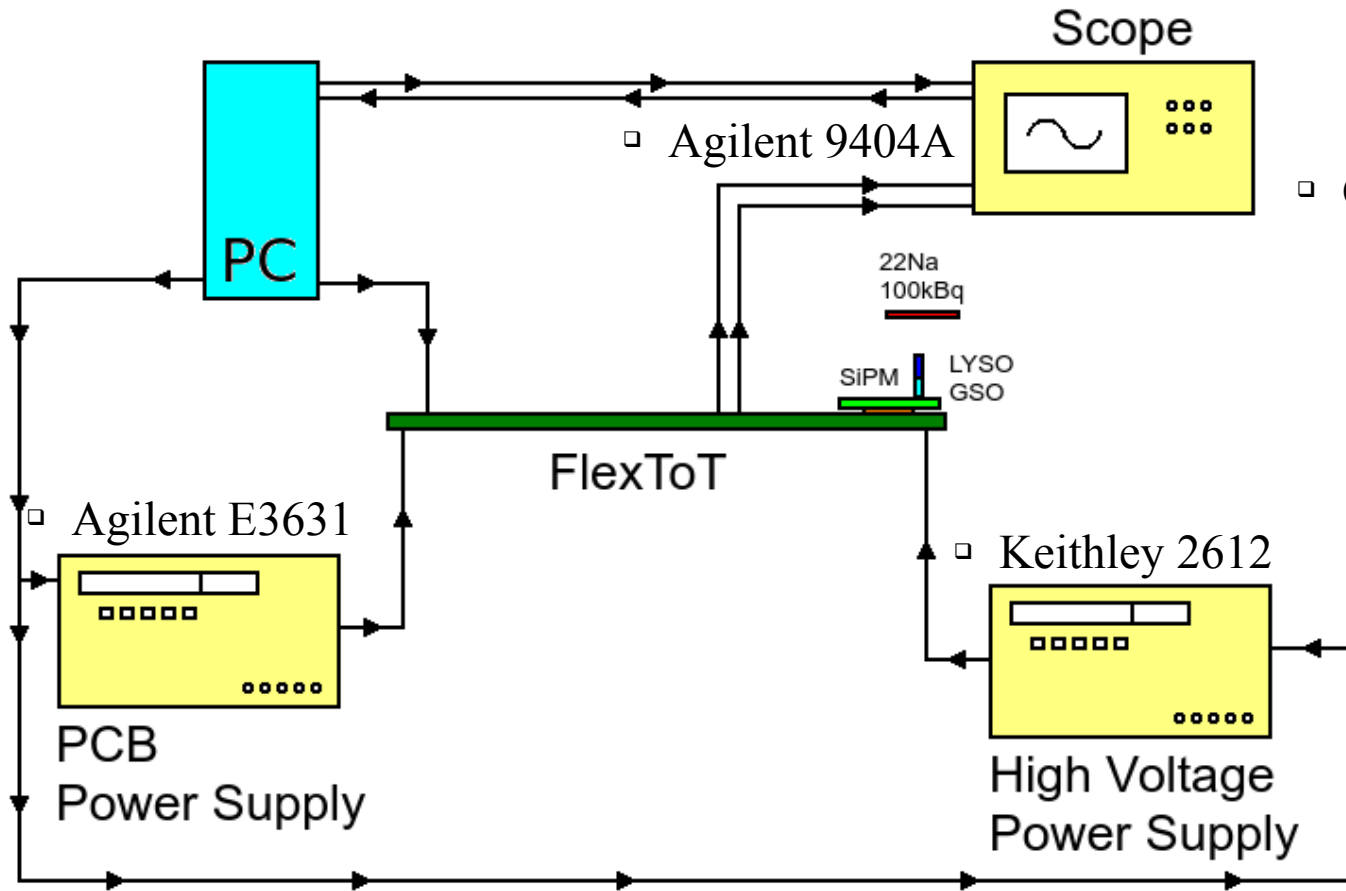 - 64 ch: 4x SiPM Array + 4xASIC + 1xFPGA
  - Several boards for coincidence

$\tau \approx 36ns$

$\tau \approx 110ns$

Institut de Ciències del Cosmos
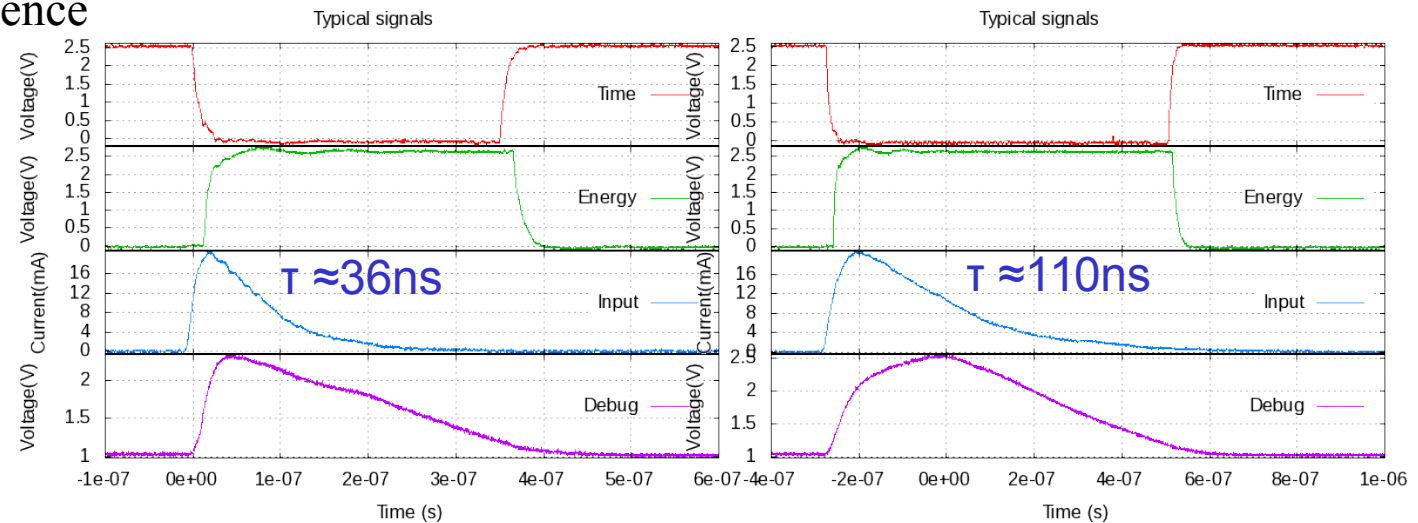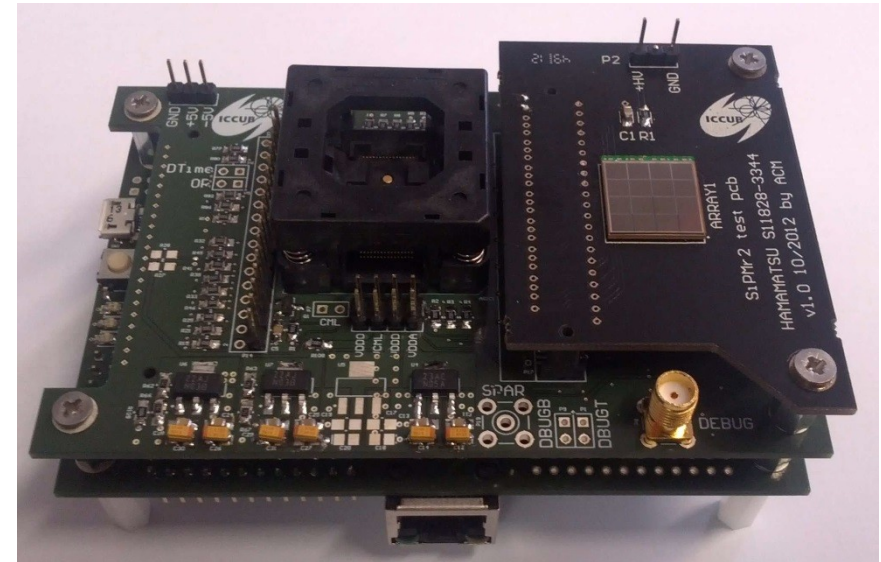
FlexToT: Calibration

- Linear ToT is studied with AWG generator

  - ASIC is adjusted to a specific system

    - Scintillator light yield

    - Scintillator + MPPC time constant

    - MPPC characteristics and overvoltage
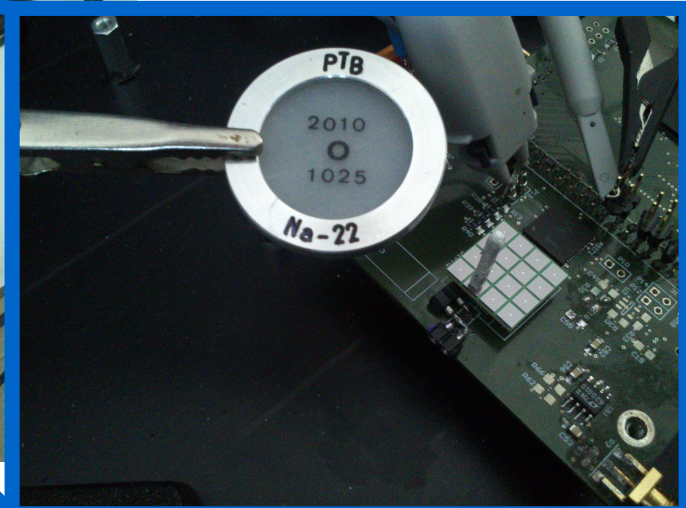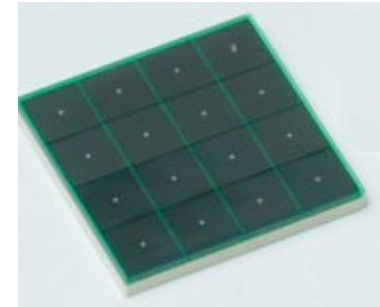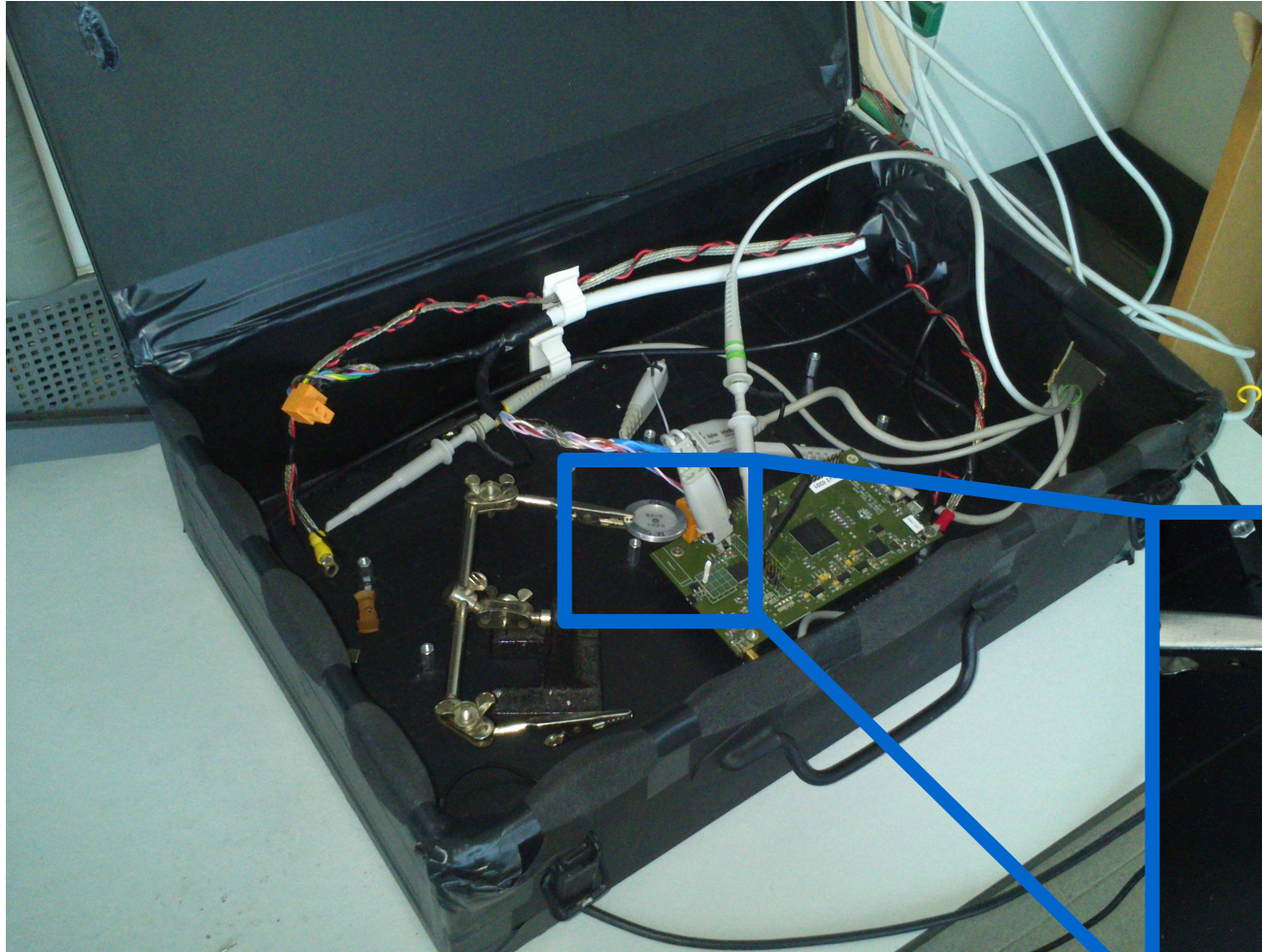
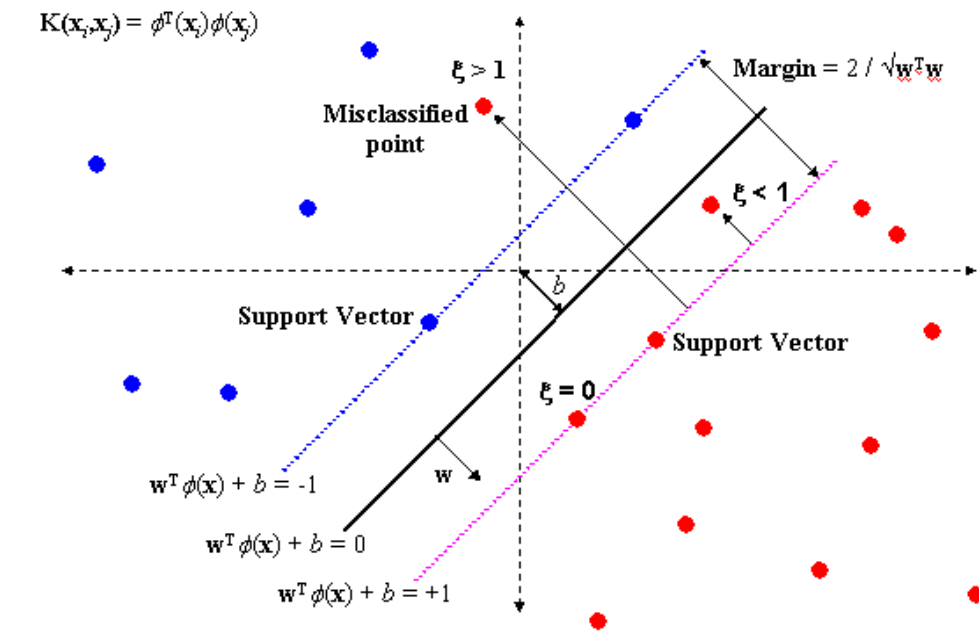 - We try to equalize channels
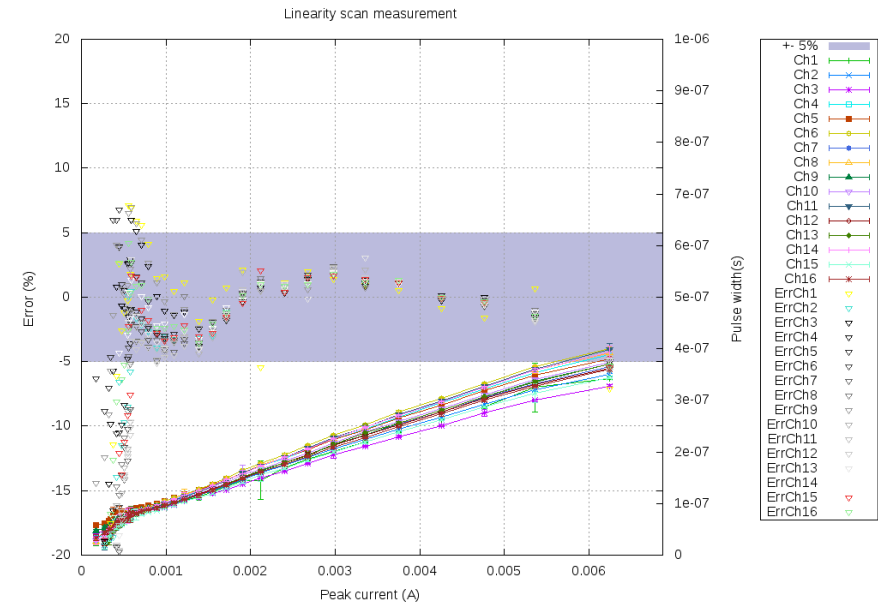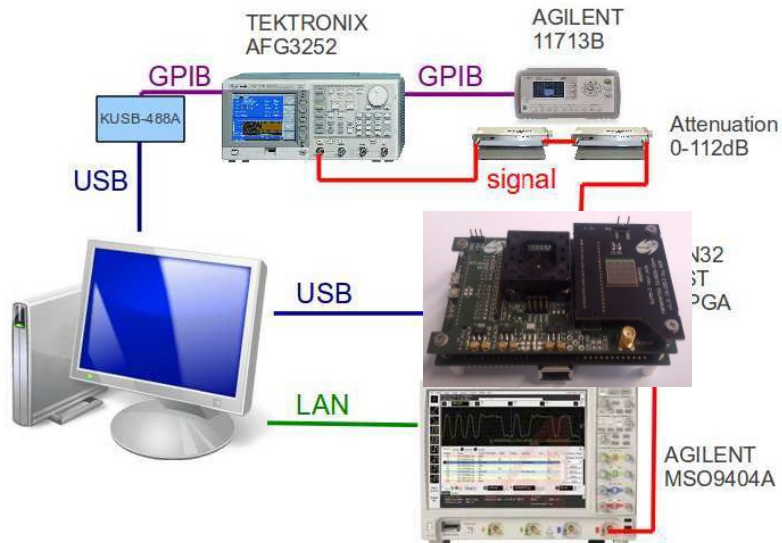
Phoswich: Setup

- Sensors:
  - Hamamatsu MPPC 16ch array
- Crystals:
  - LYSO: 1.35x1.35x7mm
  - GSO: 1.35x1.35x8mm

Institut de Ciències del Cosmos

Phoswich: Setup

Data Analysis: Algorithms

- Support Vector Machine (SVM) with Radial Function Basis(RFB) directly in the raw data.
  - System achieves a 98% of matching.

- Fit the 511keV peak for event selection previously to apply SVM
 - System achieves a 99% of matching.

$$K(x_i, x_j) = \phi^T(x_i)\phi(x_j)$$

Misclassified point

$\xi > 1$

Margin $= 2 / \sqrt{w^T w}$

$\xi < 1$

Support Vector

b

Support Vector

$\xi = 0$

$w^T \phi(x) + b = -1$

w

$w^T \phi(x) + b = 0$

$w^T \phi(x) + b = +1$
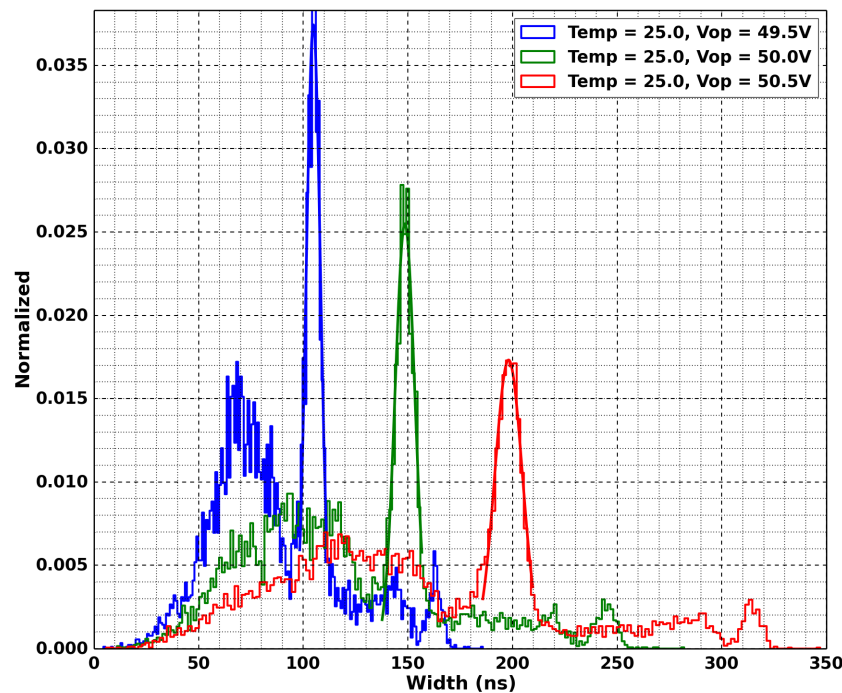
Measurements – Separated crystals

Measuring time signal over threshold we obtain different overlapping area between crystal responses.
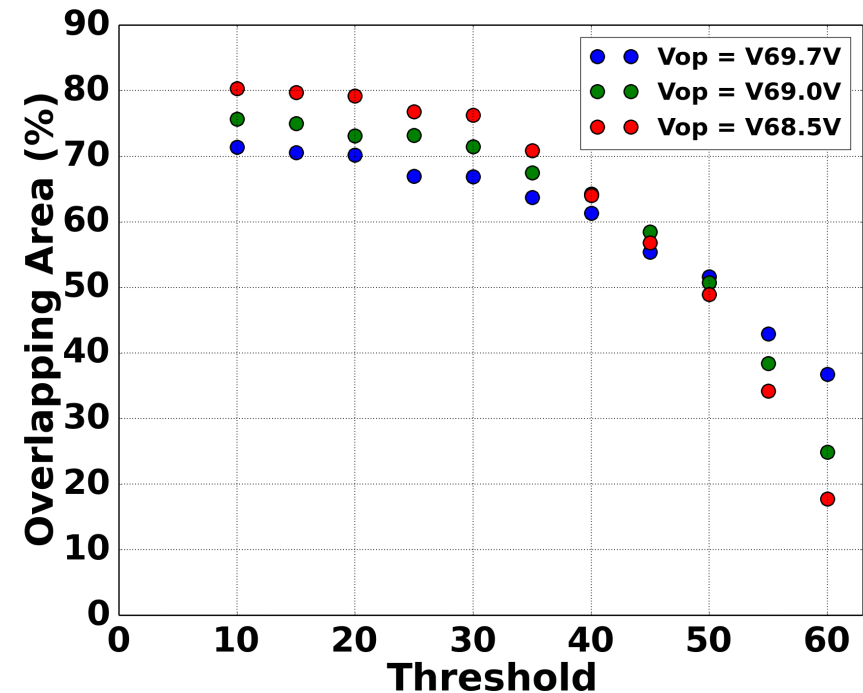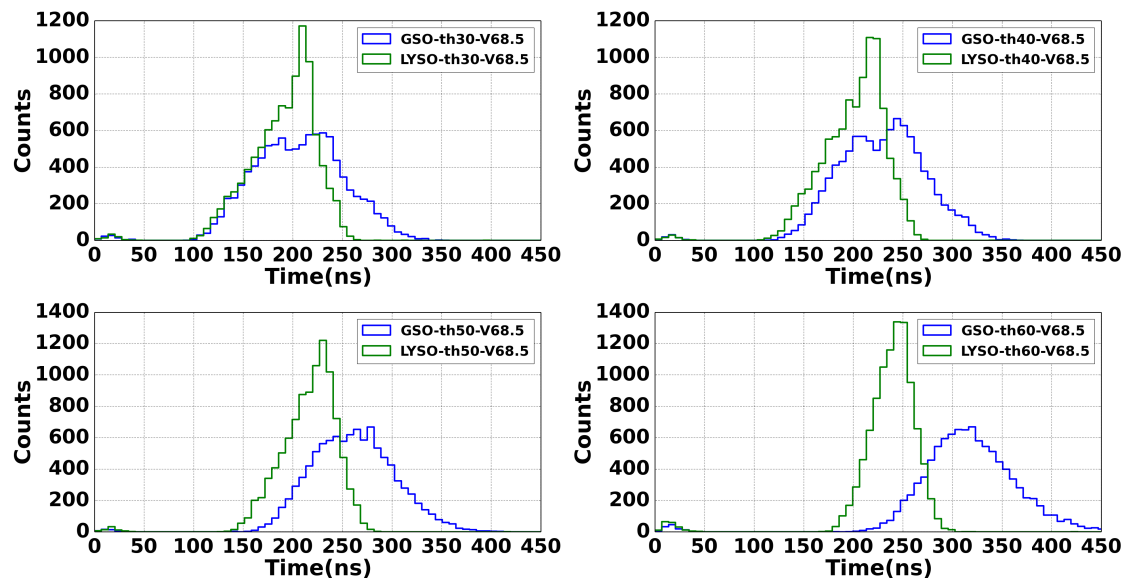
Working with low thresholds we obtain the best performance in time separation.
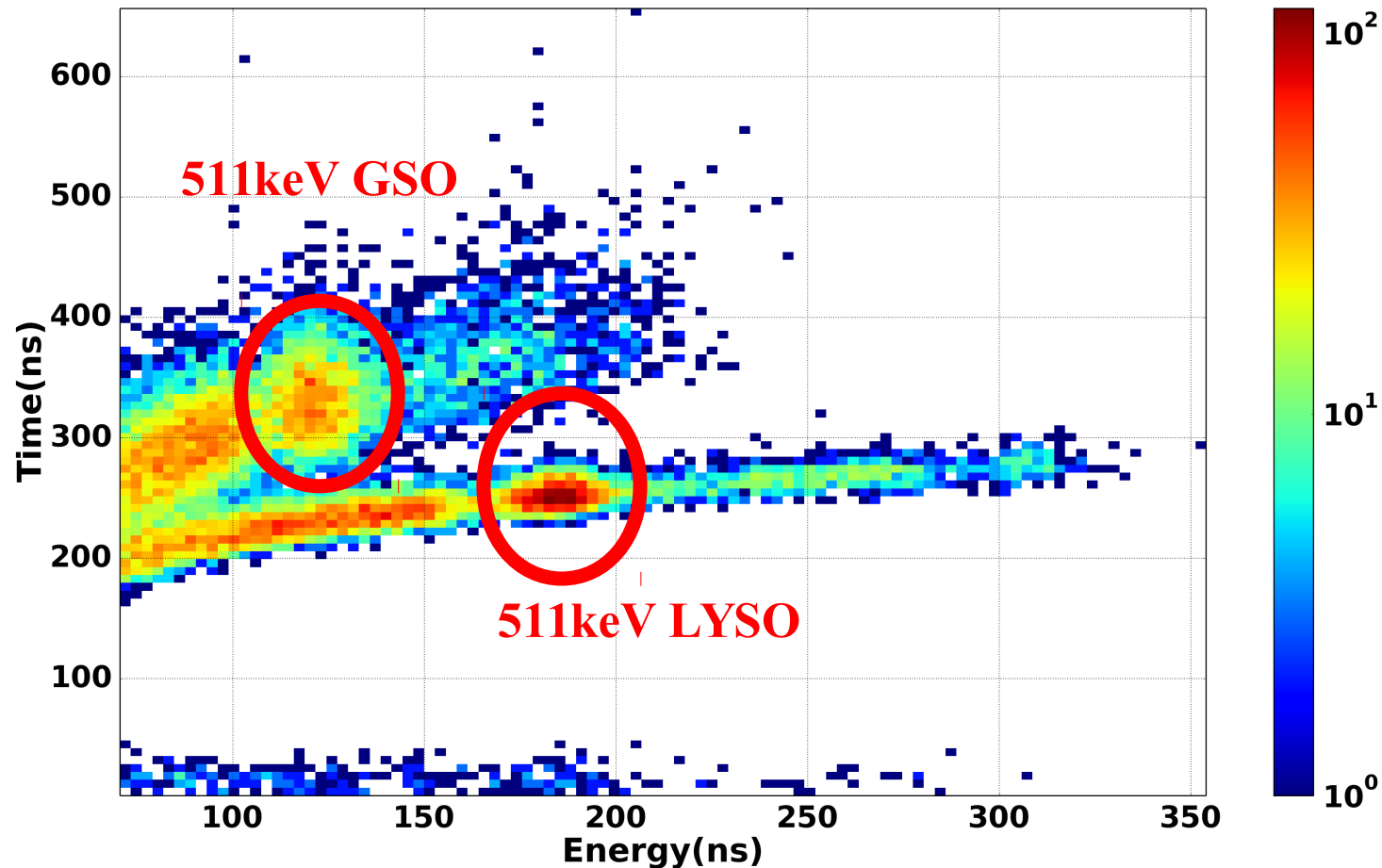
Measurements – Separated crystals

Measuring energy signals for different bias voltages we obtain different energy resolution in the 511keV peak.
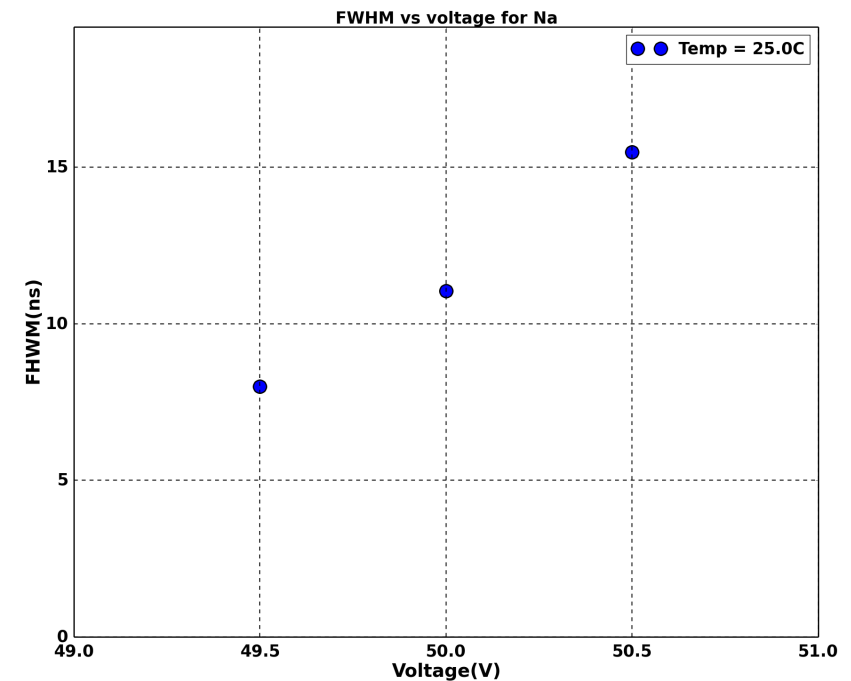
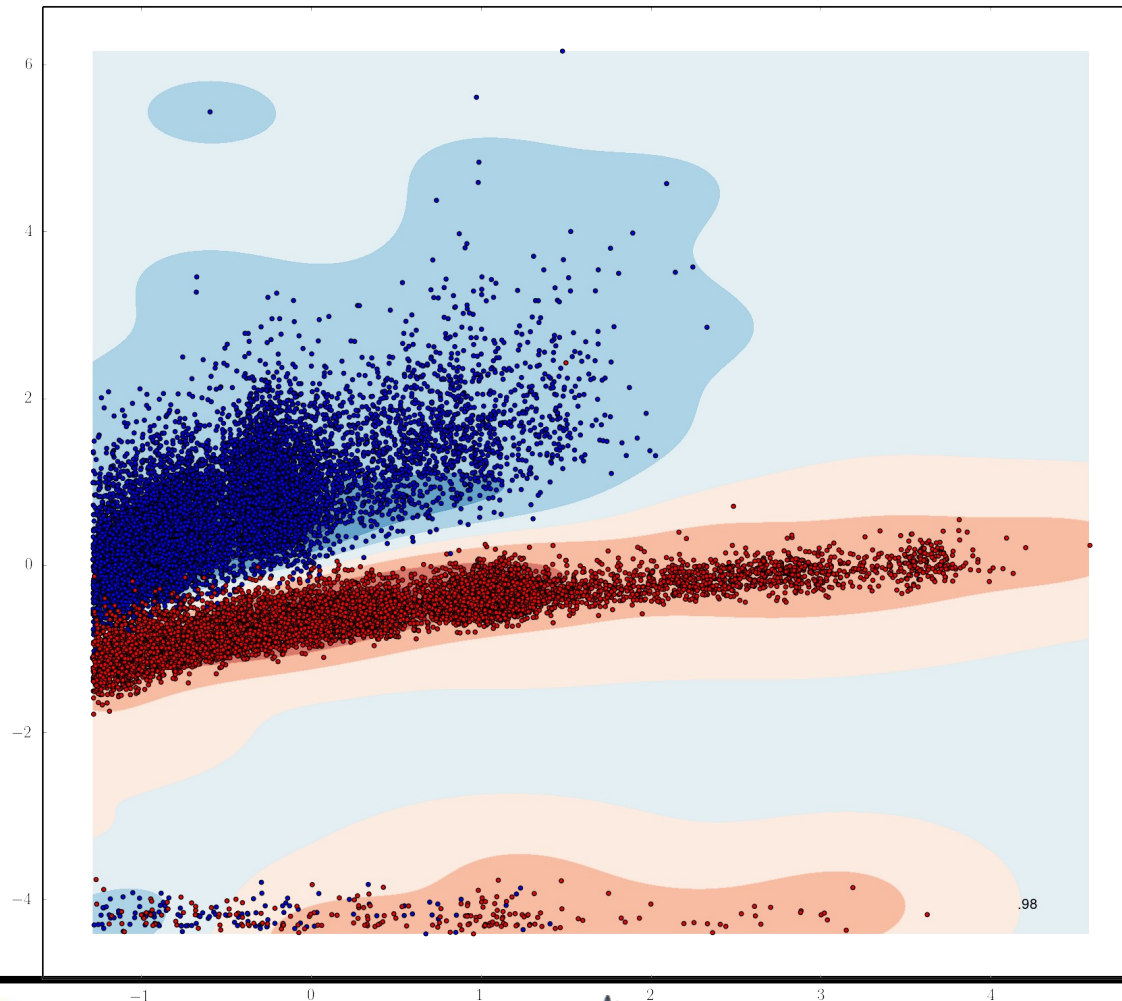*Working with low overvoltages we obtain the best performance in energy resolution.*

Measurements – Separated crystals
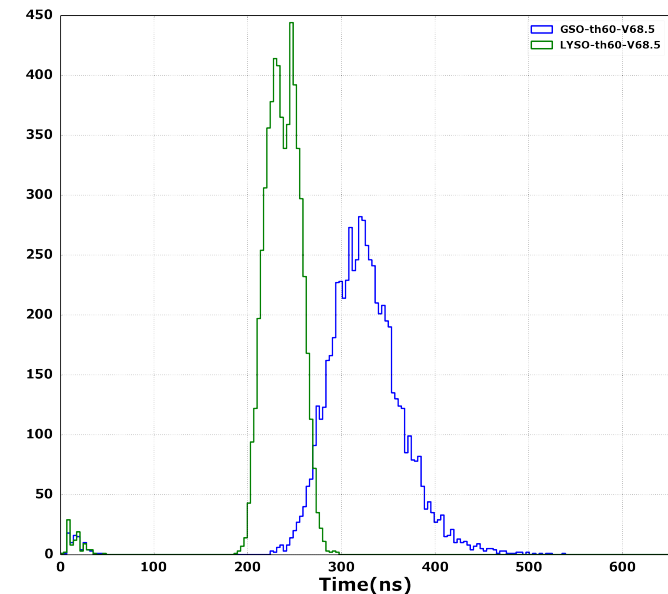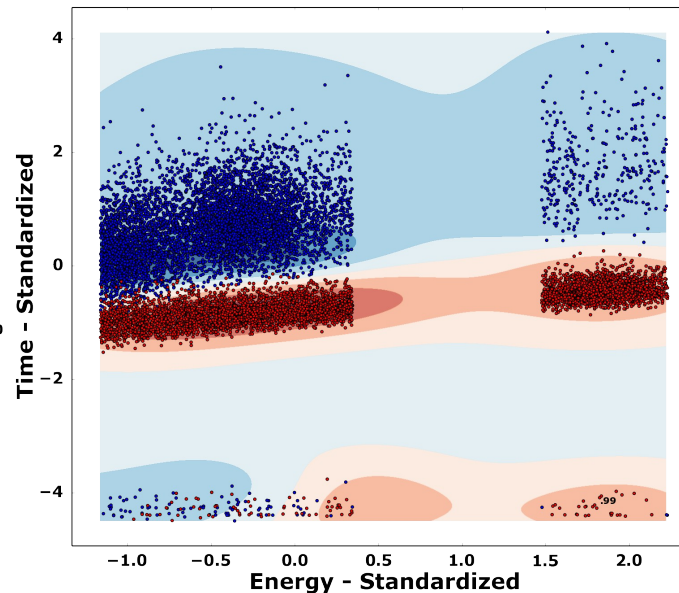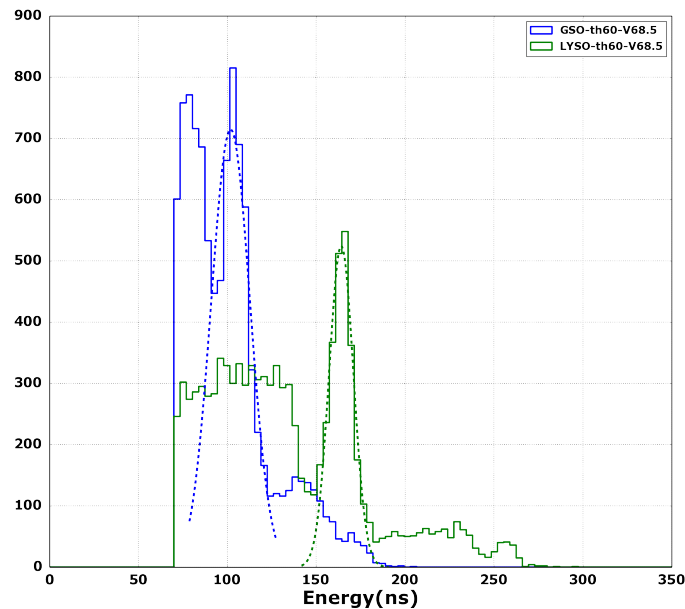
Measurements – Separated crystals

- SVM with RBF kernel

.98 of matching

Measurements – Separated crystals

- Event selection fitting the 511keV peak before applying SVM with RBF kernel
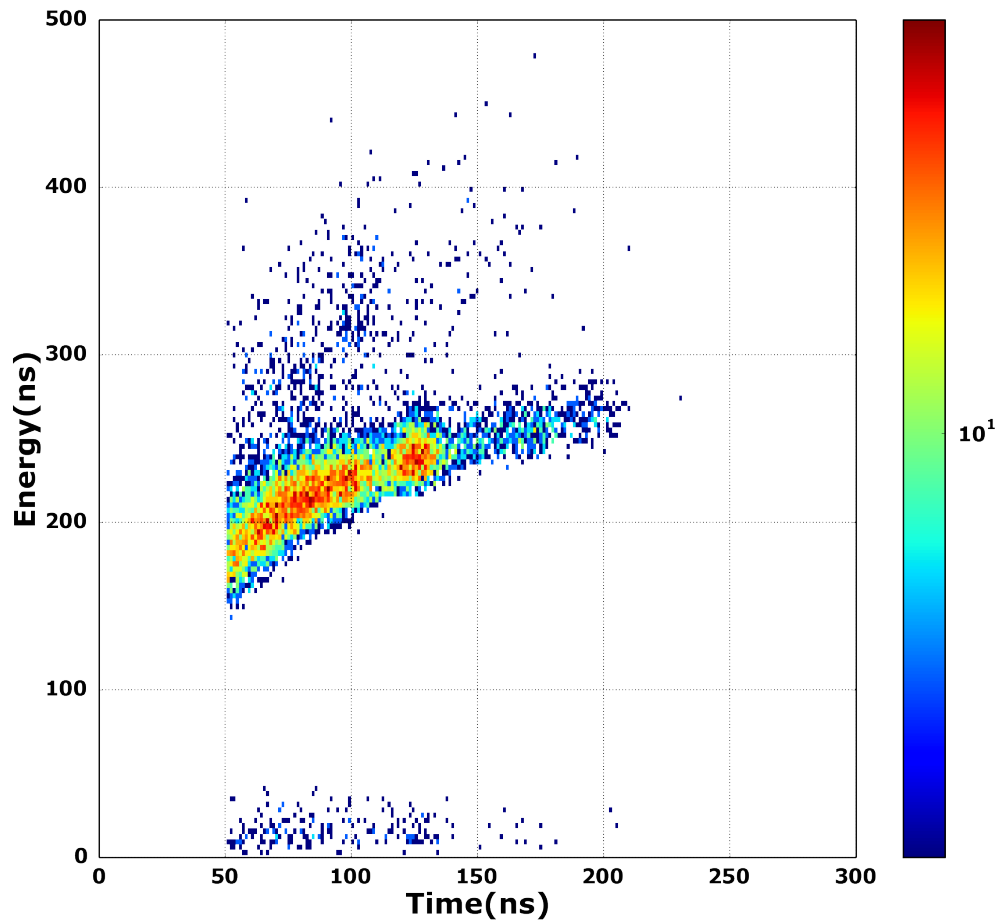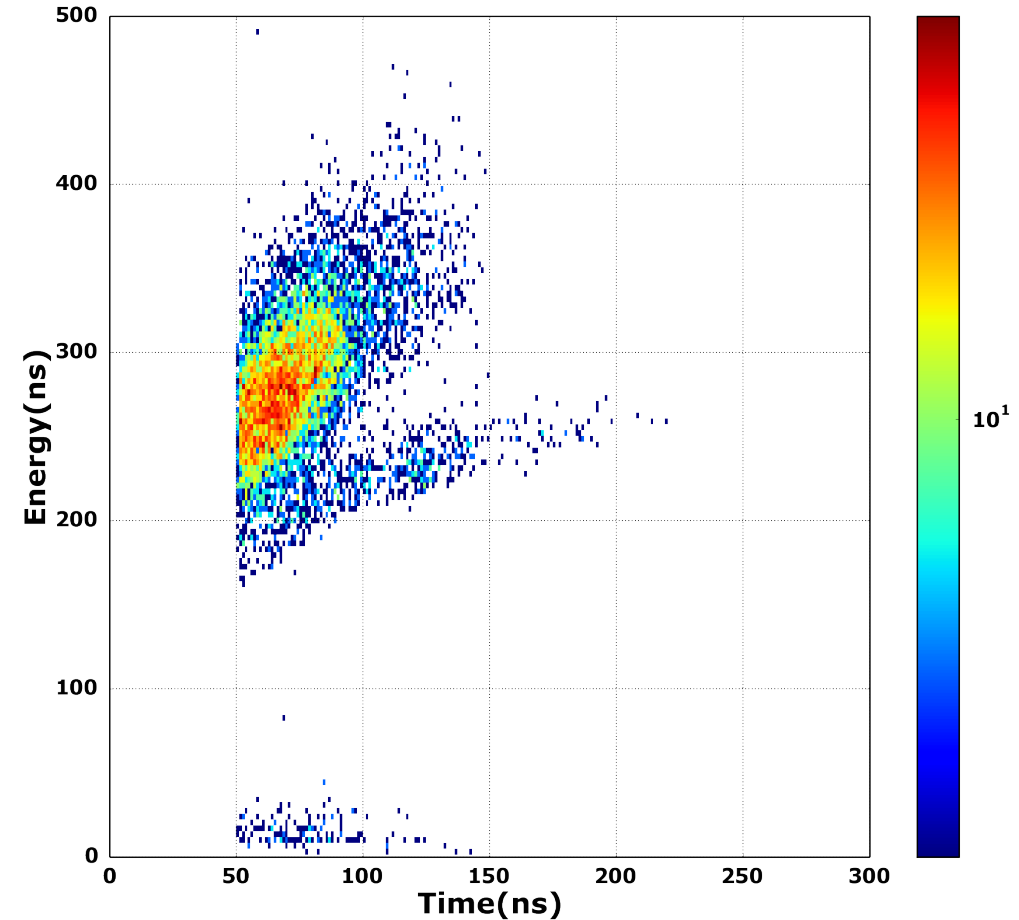

.99 of matching

Measurements – Stacked Crystals

- Without collimation
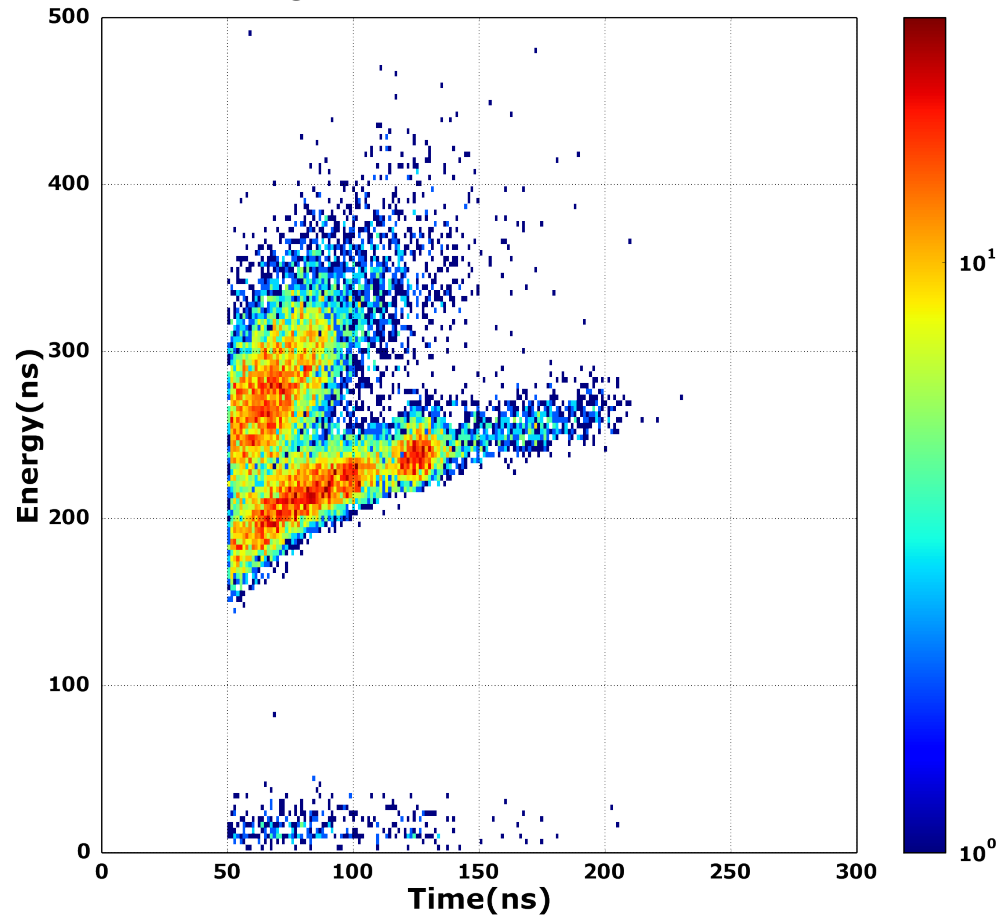
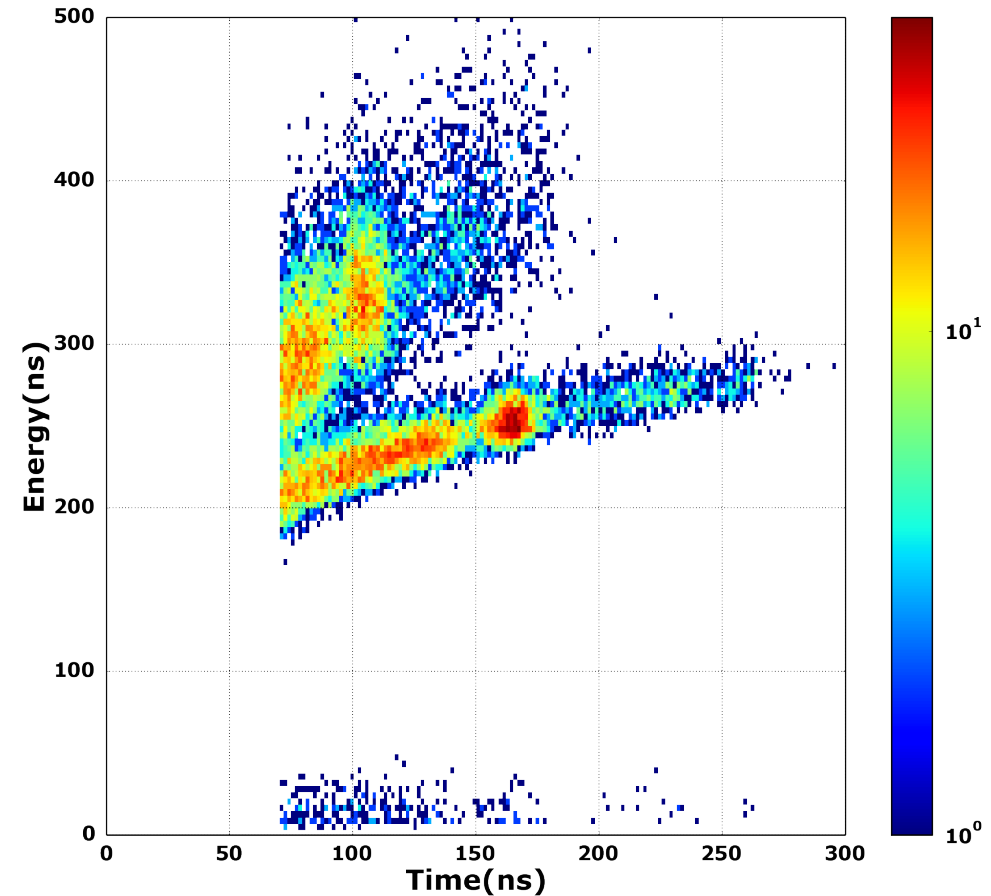Configuration: LYSO-GSO

Configuration: GSO-LYSO

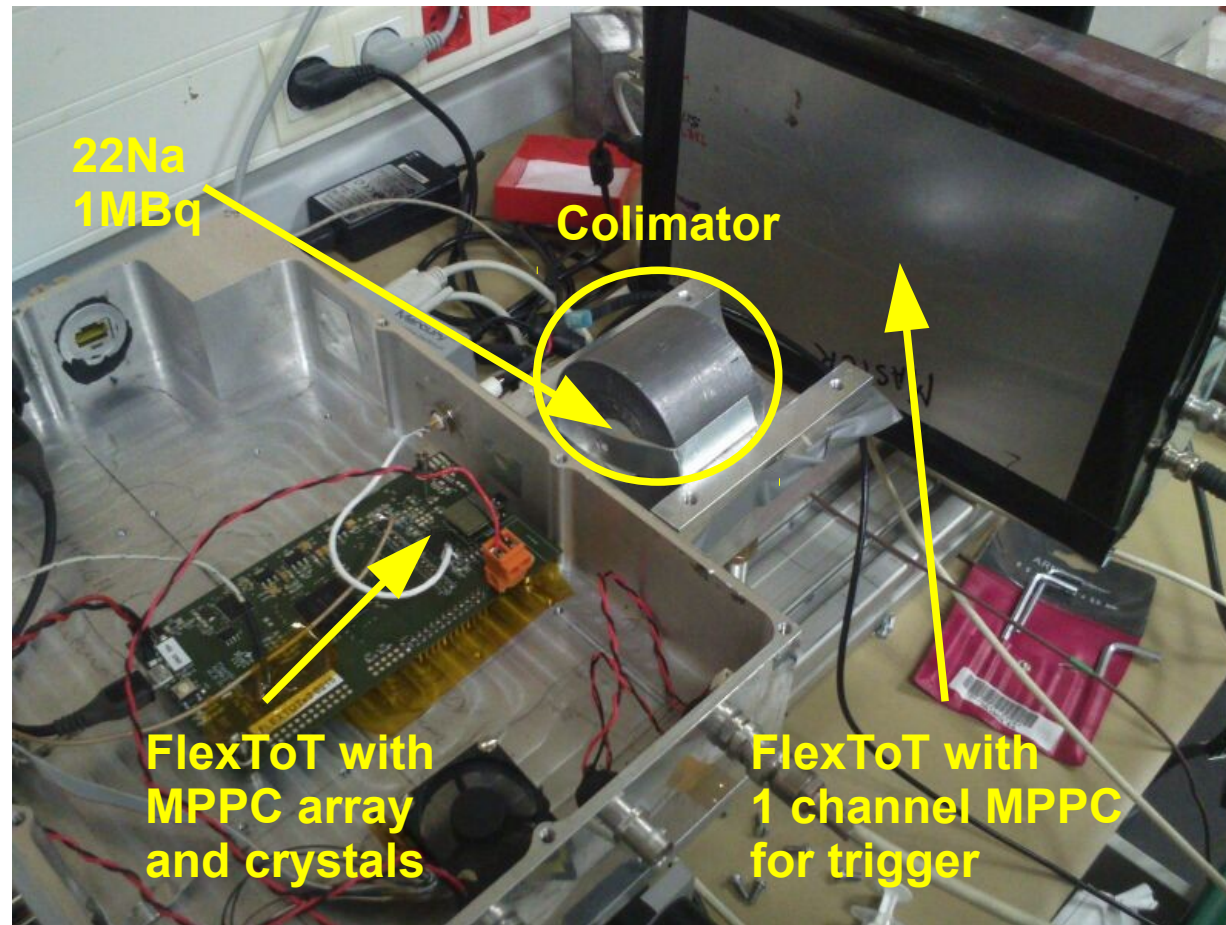# Measurements – Comparative

Configuration: Stacked

Configuration: Separated

Measurements – Stacked Crystals

Currently measuring with this setup in CIEMAT, Madrid

Summary

- HEP group of ICC have developed a flexible electronics that can be used for different variants of PET bringing ideas from particle physics designs.

- FlexToT with phoswich cristals have achieved a 99% of matching with separated crystals configuration.

- Right now CIEMAT is measuring the response of FlexToT with stacked crystals using a setup with lead collimators and electronic triggers.
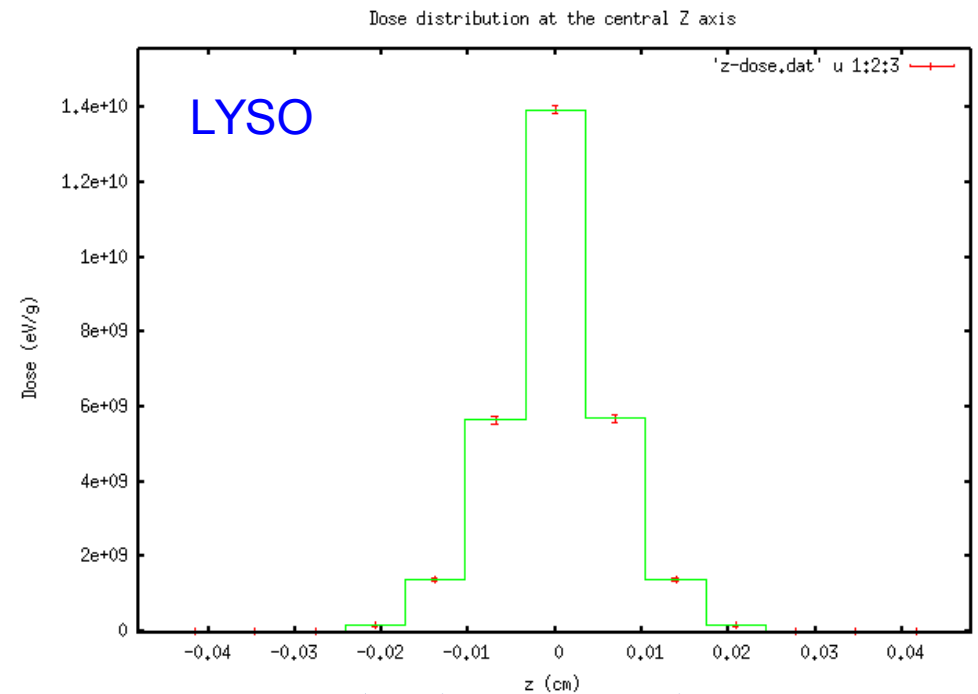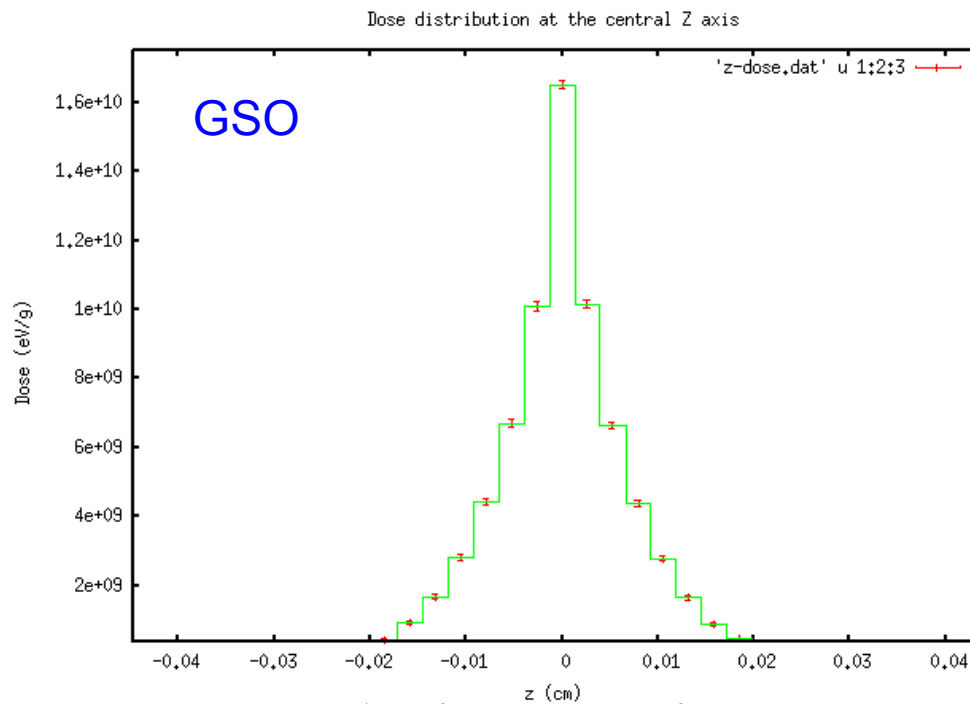
Thank you

Back up slides

Simulations

Simulations with Penelope 2014 of 511keV electrons inside a LYSO and GSO crystals. The dose deposited obtained by the electron is distributed in a few hundreds of microns around the absortion point.

Energy dose around the absortion point