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ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

IASF

Solid state Detectors
for telescope application

E.M.Quadrini on behalf of a large consortium

Foreword

After the IBIS success , the INAF-IASF, approved an R&D program to stimulate and support the birth of an Italian source for high quality CZT detectors.

Today, in consequence of a call for Ideas in March 05, the Italian Space Agency (ASI) is close to finance, among others R&D programs, an assessment study on the same matter.

In view of this opportunity a consortium between INAF-IASF, CNR-IMEM and Venezia Tecnologie has been formed and is already operative.

Thereafter there will be a short description of the consortium, its organisation, initial results and planned activities.

CZT features also @ room temperature:

- Good linearity versus temperature or bias
- Elevated Z
- Good spectral response

Our target is to enhance these features to:

- Modularity for large area detector planes (m^2)
- Energy range ~ 10-600 keV
- Stopping power at least 20% @ 600keV
- Pixels size selectable from 0.1 to 10 mm
- Energy resolution around 1% @ 100keV

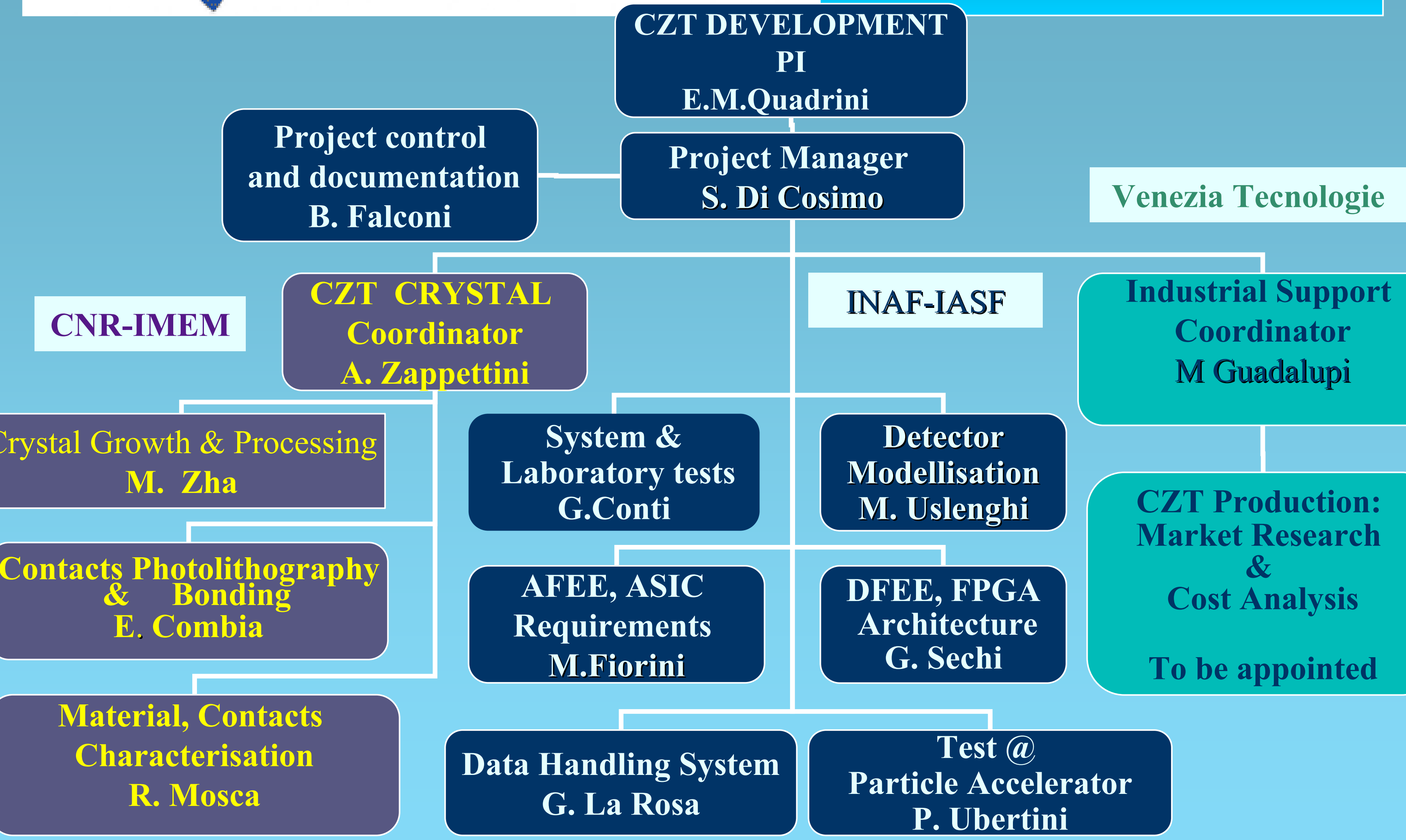
The target can be achieved through:

- Best quality crystals, contacts and bonding properties
- Optimised pixels geometry, crystal thickness and Electric field shape
- Deep knowledge of the carriers transportation rules
- Enhanced readout system
- Powerful on board data processing

The proposal for phase A study will follow three main lines.

- **Crystal growth and processing, contacts deposition**
- **Modellisation, Laboratory test, Readout electronics**
- **Market Research & Cost Analysis for next CZT mass production**

The responsibilities have been distributed according the following Management plan



CZT DEVELOPMENT
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Project Manager
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CNR-IMEM

CZT CRYSTAL
Coordinator
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INAF-IASF

Industrial Support
Coordinator
M Guadalupi

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M. Zha

Contacts Photolithography
& Bonding
E. Combia

Material, Contacts
Characterisation
R. Mosca

System &
Laboratory tests
G.Conti

Detector
Modellisation
M. Uslenghi

AFEE, ASIC
Requirements
M.Fiorini

DFEE, FPGA
Architecture
G. Sechi

CZT Production:
Market Research
&
Cost Analysis

To be appointed

Data Handling System
G. La Rosa

Test @
Particle Accelerator
P. Ubertini

Venezia Tecnologie (ENI)

It is committed to analyse possible industrial synergies for a mass production of CZT detector i.e crystal growth, processing and assembling in compact modules.

This implies extensive Market research and detailed Cost Analysis, evaluation of realistic production rate and of all commercial applications.

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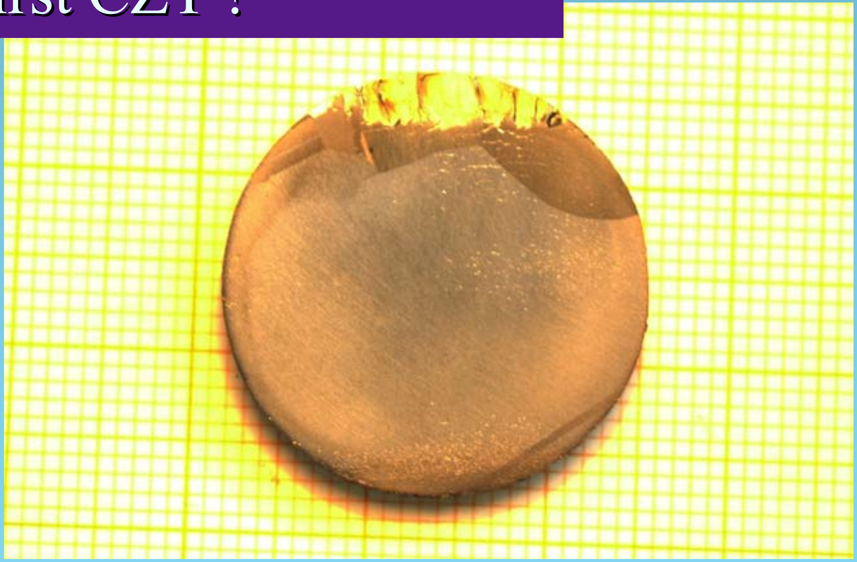
CNR-IMEM

Research Institute specialised in material science and crystal growth.

…and the first CZT !

2mm thick sample from a 2 inches crystal



Same sample, under different illumination

INAF –IASF
Involved in

- **procedures for crystals and electrical contacts fast qualification**
- **knowledge of detector response wrt background**
- **knowledge of detector response wrt interaction deep**
- **powerful Front End system**
- **advanced coincidence-anticoincidence rules for detector signals**
- **event reconstruction strategy**
- **background reduction strategy**

SIGNAL FORMATION IN CZT DETECTORS

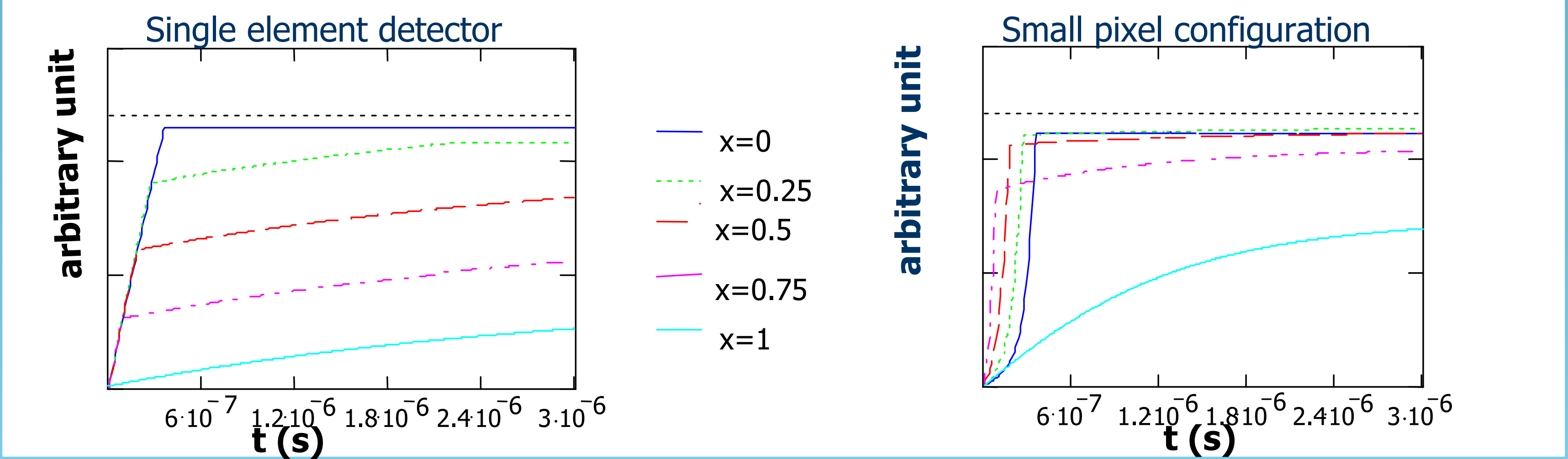
In a polarised CZT detector, Q charges are generated at some relative depth $0<x<1$ [$x=0$ @ cathode, $x=1$ @ anode] at any photon interaction. Correspondent charges are then induced at the electrodes, from where a two components current, due to electrons and holes respectively, is generated by integration.

During next hundreds of nanoseconds, the internal charges move in opposite directions and with different mobilities (μ_e and μ_h) until each current component ends when the respective charge carriers reach the electrode. Using a simplified model we analysed two cases:

"**Single pixel**" where a voltage V is applied to an uniform, planar detector of thickness d

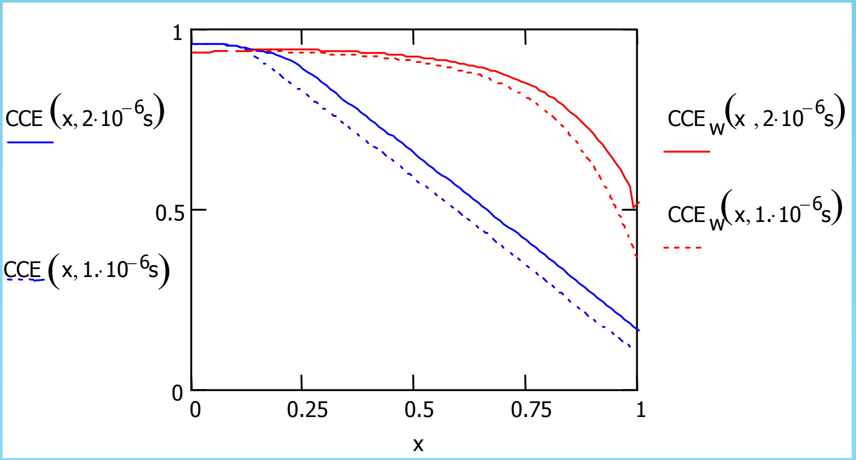
"**pixellated detector**" where a detector features a positive electrode finely segmented in pixel size smaller than the detector thickness, and a negative electrode common to all pixels. This is the case known as "**small pixel**" leading to the effect that each pixel become almost insensitive to holes drifting toward the negative electrode

MODEL RESULTS


Single element detector

Small pixel configuration

Signal shape for a various interaction depth. Single element detector (left) and 5 mm thick array with 2.46 mm pixels



Charge Collection Efficiency (CCE)

CCE vs relative depth interaction for small pixels (thickness/pixel =~ 2)[red]

and single element detector [blue].

Solid and dot lines refer to shaping time constants 1 and 2 μs, respectively

Digital Front End (DFE), USE OF FPGA

The knowledge of the signal shape is the starting point for a proper reconstruction of the detected photon.

Our detector electronics:

a charge pre-amplification, coupled to a flash ADC

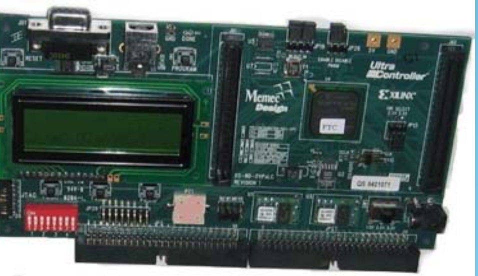
a powerful FPGA based digital processing unit for:

- **events time sorting**
- **electronic noise reduction,**
- **measurement of signal shape parameters**

the incoming events will be reconstructed in terms of total energy, interaction position, timing and coincidences.
This is for optimising the telemetry flux and allow polarimetry evaluation on multiple events.

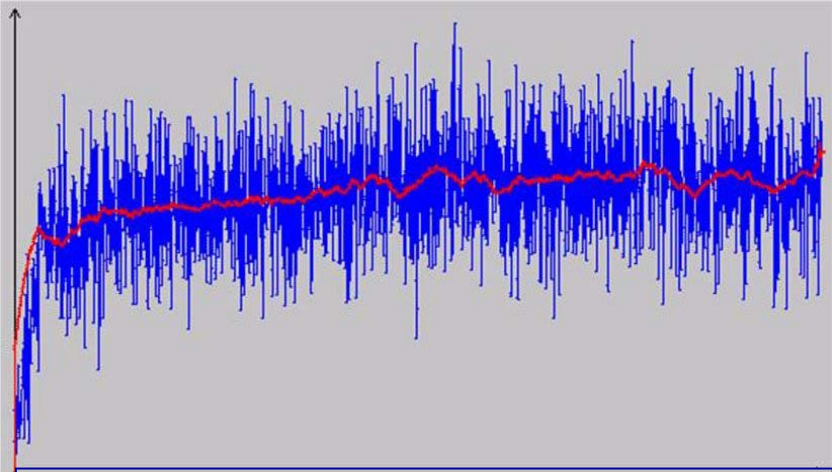
FPGA are high-performance devices for space applications featuring low power, low cost, high flexibility and reduced time to market.
Optionally a periodic refresh of the internal FPGA configuration during the normal operation phase, grant continuous and nominal behaviour ("Scrubbing")

The Mathematical model leads to algorithms for the best signal elaboration. These algorithms will be loaded in the DFE and performed in real time on the digital streams produced by the flash ADC.



The system used so far is based on the Xilinx XC2VP4 Virtex-II Pro FPGA embedding a PowerPC 405 processor. Signal processing algorithms are developed by C-language programs and compiled for the PowerPC.

At present, the FPGA board has been connected to a PC via the serial port, for algorithm evaluation purposes. In a second phase, the board will be connected directly to the digitalized output of the detector, for real-time analysis.



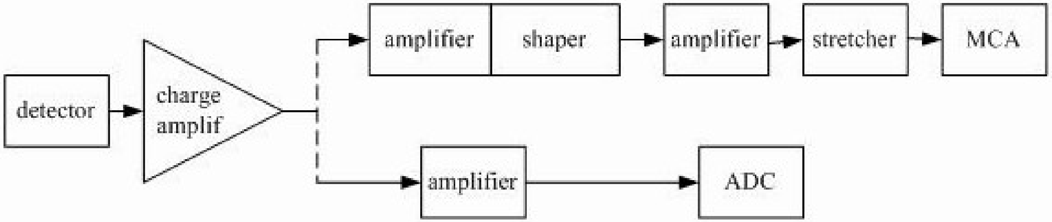
Moving average filter applied on a simulated input signal with superimposed noise.

TEST SETUP

Cal. source support and detector assembly on the optical bench

The detector array mounted on the AFEE board

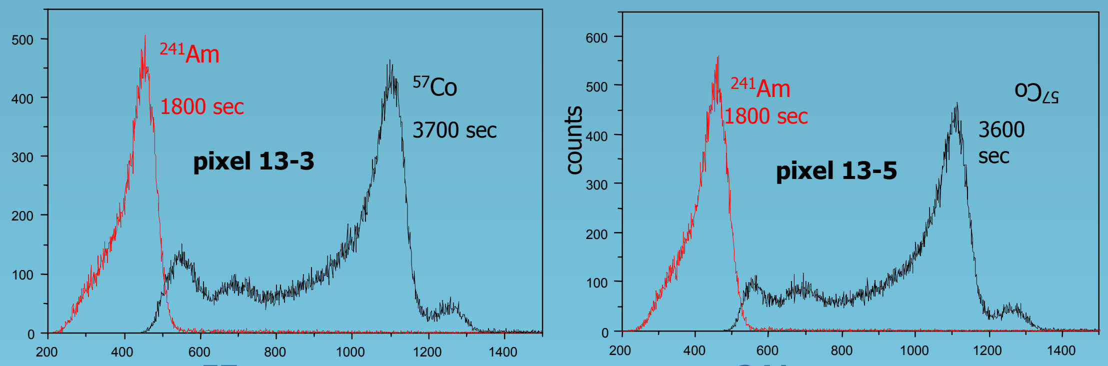
The signal analysis can b
performed via two
electronic chains



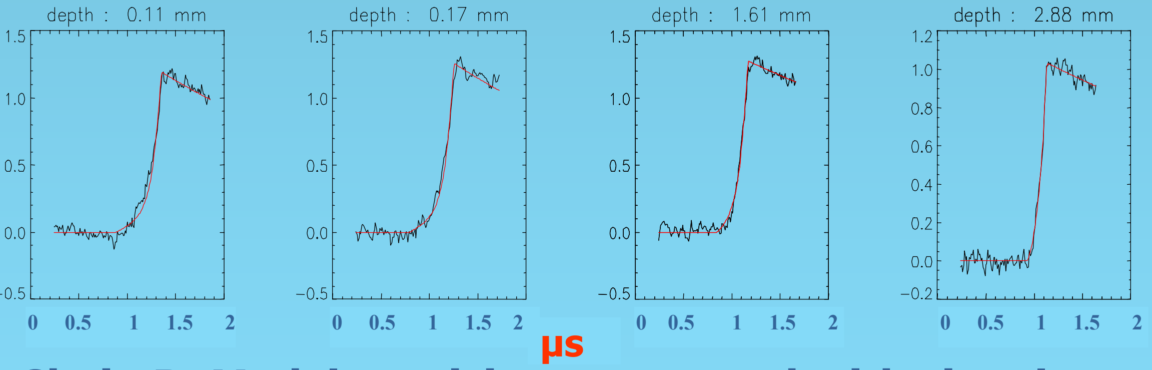
Performed tests:

- **collect reference spectr**
- **analyse AFEE behaviou**
- **compare flash ADC chai wrt classical nuclear electronics**
- **check the correction algorithm.**

TEST RESULTS



Chain A: ^{57}Co (122 and 136 KeV), ^{241}Am (60keV) collected spectra



Chain B: Model previsions compared with signals generated by pixel 13.5 under ^{57}Co irradiation

The analytical model has been fitted to the recorded waveforms. Fit parameters:

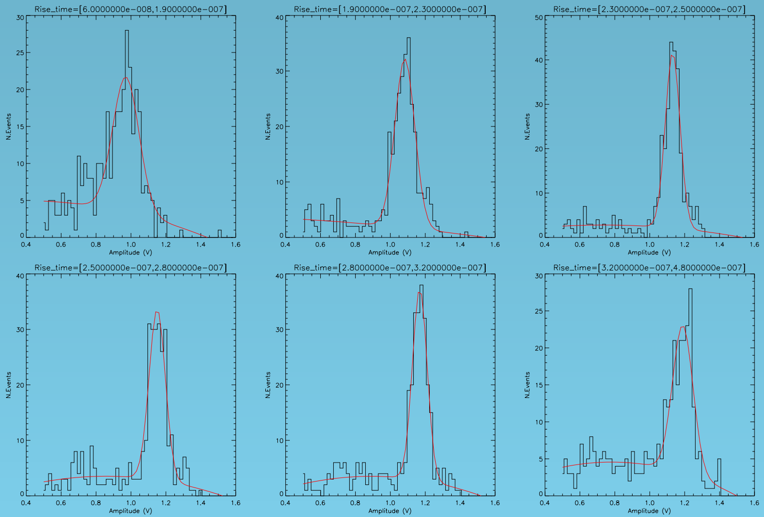
- **interacting photon energy**
- **interaction depth**
- **mobility lifetime ($\mu_e \cdot \tau_e$)**

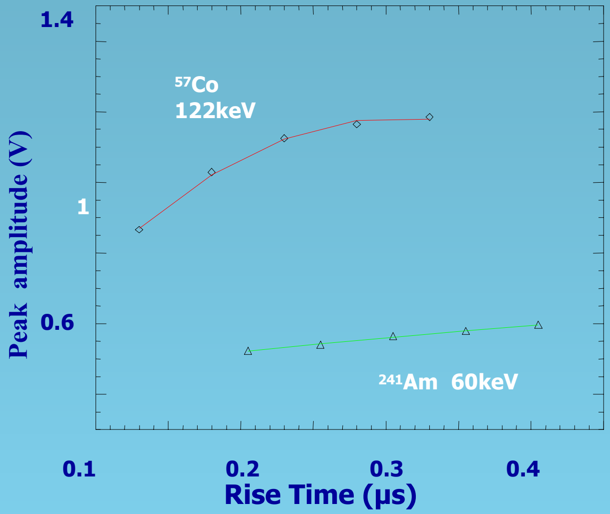
$$[\mu_h \cdot \tau_h = 1.2\ 10^{-4}]$$

Best fit leads

$\mu_e \cdot \tau_e = 3 \cdot 10^{-3}$ cm^2/V

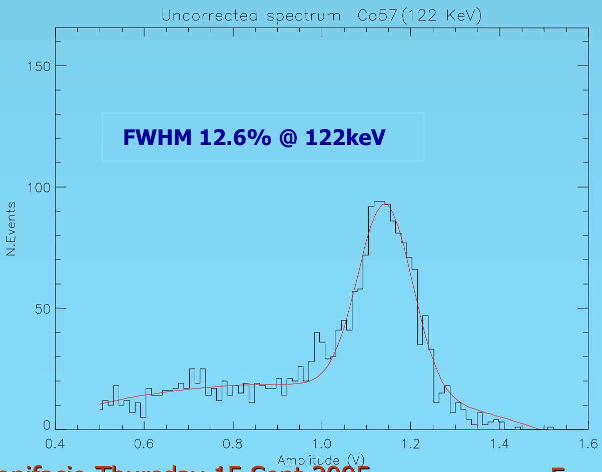
TEST RESULTS

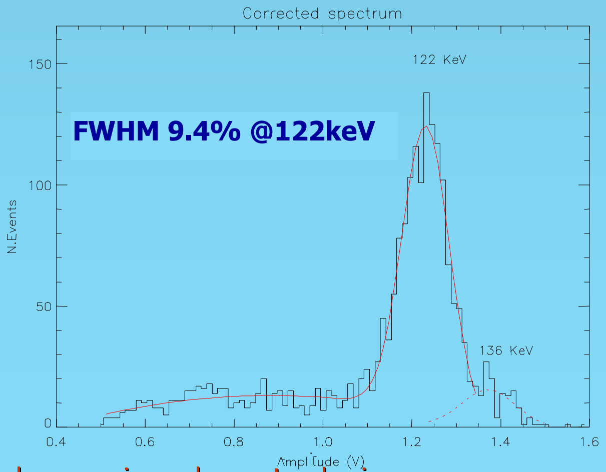




To correct the “tailing effect” we grouped wrt rise time the recorded waveforms.

The rise time binning has been chosen to have the same number of waveforms for each group, providing a proper SNR for each spectrum.





The dependence of the photo-peak centroid on the rise time has been used to correct the overall spectrum

Few Comments

At this early stage of our program we can dispose of:

an optical bench with motorized micrometric movements,
various options to set our Analogue Front End Electronics (AFEE),
a chain to directly collect the Front End signals,
to digitalise them,
to perform a computer based deep analysis and
to compare these results with a mathematical model.

Moreover we are already in condition to convert the elaboration algorithm in a real time process running in the Digital FEE and to archive all data for further analysis.

Result shown demonstrates that we can collect single signals and improve the detector response through a proper mathematical process. In this case, only the "tailing effect" was considered, leading to a corrections on the spectrum symmetry.

We plan to proceed in this direction.

PLANNED FUTURE ACTIVITIES I

We are going to start measurements on a crystal 5x5x20 mm with electrodes on the two smaller faces. This is to analyse photon interactions occurring at a fixed distance from anode (let say 20, 40, 60, 80% of detector thickness) and check our model on the dependence signal shape / interaction deep

Exploiting our "private" source we will dispose of various crystal samples grown at different purity levels and equipped with two or three diverse methods of contact deposition (e.g. gold, electroless, Sb_2Te_3).
Moreover we can select the best pixel geometry (square, hexagonal), size (from 0.1 to 10 mm) and configuration (with or without a guard ring)

In parallel, to reduce the electronic noise, a proper AFEE is under evaluation.
Namely, in the paper we present results obtained in a small pixel configuration using a single pixel surrounded by 8 polarized pixels.
The first evaluations for the DFEE architecture will follow.

PLANNED FUTURE ACTIVITIES II

Next step will be to bias all pixels and readout them all.
At that time there will be the possibility, among others, to work on cross talk, properly process single and multiple events, measure source polarisation, reject cosmic particles induced background.
All this in turn will reduce the unwanted events optimising the signal to noise rate.

Finally, this program will create the basis for the realisation of a working engineer model of our detector.
We aim to demonstrate the technical possibility to have in few years a new Gamma ray telescope performing in line with the future Astrophysics necessities.