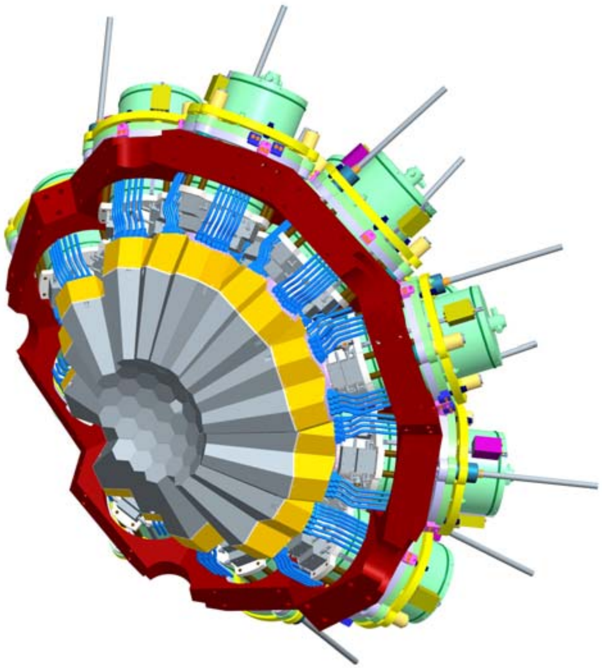
Position sensitive γ-ray detection with AGATA

Group Report - DPG, Darmstadt Mar. 2008



- ❑Introducing AGATA
  - Why AGATA?
  - Ingredients of γ-tracking
  - CAT – Characterization – assembly
- ❑Latest news on front end electronics:
  - Enhanced dynamic range with T.O.T. technique
  - Cross talk correction for segmented detectors
- ❑Summary / Outlook

B. Bruyneel, B. Birkenbach, J. Eberth, H. Hess, G. Pascovici, P. Reiter, A. Wiens — IKP, Uni zu Köln A. Pullia and F. Zocca — INFN, Milano and D. Bazzacco — INFN, Padova for the AGATA-Collaboration

New Facilities, New challenges

SPIRAL2 - HIE-ISOLDE - EURISOL - ECOS

Relativistic exotic beams ...

- Low beam intensity
- High backgrounds
- Large Doppler broadening
- High γ-ray multiplicities
- High counting rates

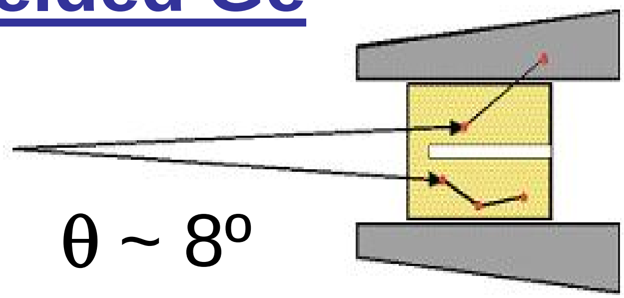
...Need:

- High efficiency
- High sensitivity
- High position resolution
- High Peak/Total
- High throughput

Idea of γ-ray tracking

Compton Shielded Ge

ε_{ph}	~ 10%
N_{det}	~ 100
Ω ~40%	



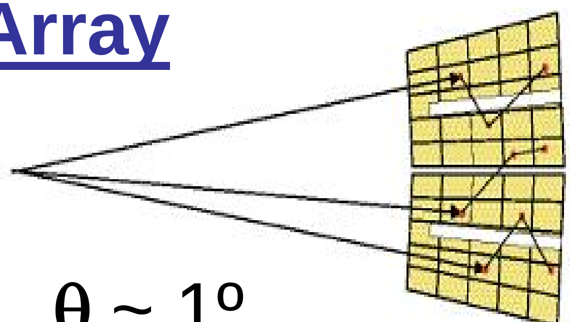
$\theta \sim 8^o$

large opening angle means poor energy resolution at high recoil velocity.

Previously we had to waste scattered gammas.
Technology is available now to track them.

Ge Tracking Array

ε_{ph}	~ 50%
N_{det}	~ 100
Ω ~80%	



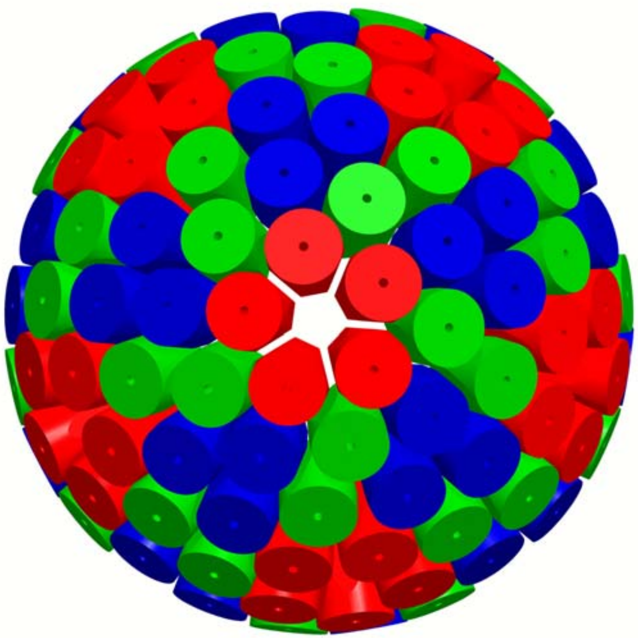
$\theta \sim 1^o$

Combination of:

- segmented detectors
- digital electronics
- pulse processing
- tracking the γ-rays

AGATA
(Design and characteristics)

4π γ-array for Nuclear Physics Experiments at European accelerators providing radioactive and stable beams



Main features of AGATA

Efficiency: 43% (M_γ =1) 28% (M_γ =30)
today's arrays ~10% (gain ~4) 5% (gain ~1000)

Peak/Total: 58% (M_γ=1) 49% (M_γ=30)
today ~55% 40%

Angular Resolution: ~1° →
FWHM (1 MeV, v/c=50%) ~ 6 keV !!!
today ~ 40 keV

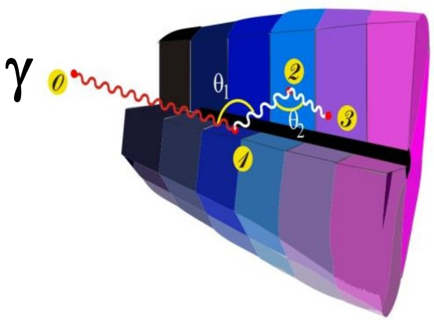
Rates: 3 MHz (M_γ=1) 300 kHz (M_γ =30)
today 1 MHz 20 kHz

- 180 large volume 36-fold segmented Ge crystals in 60 triple-clusters
- Digital electronics and sophisticated Pulse Shape Analysis algorithms allow
- Operation of Ge detectors in position sensitive mode → γ-ray tracking

Ingredients of γ-Tracking

1

Highly segmented HPGe detectors



2

Digital electronics to record and process segment signals

3

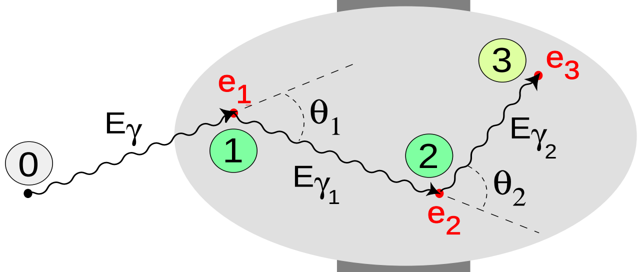
Pulse Shape Analysis to decompose recorded waves

Identified interactions

$(x,y,z,E,t)_i$

4

Reconstruction of tracks e.g. by evaluation of permutations of interaction points



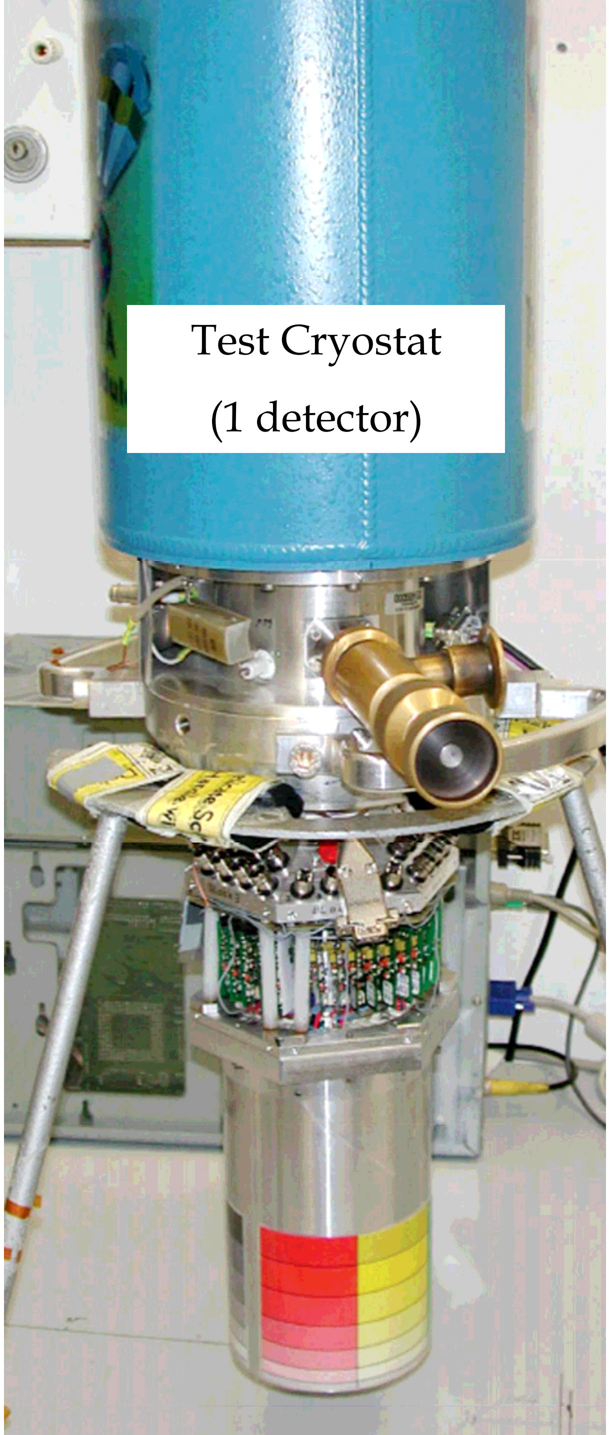
reconstructed γ-rays

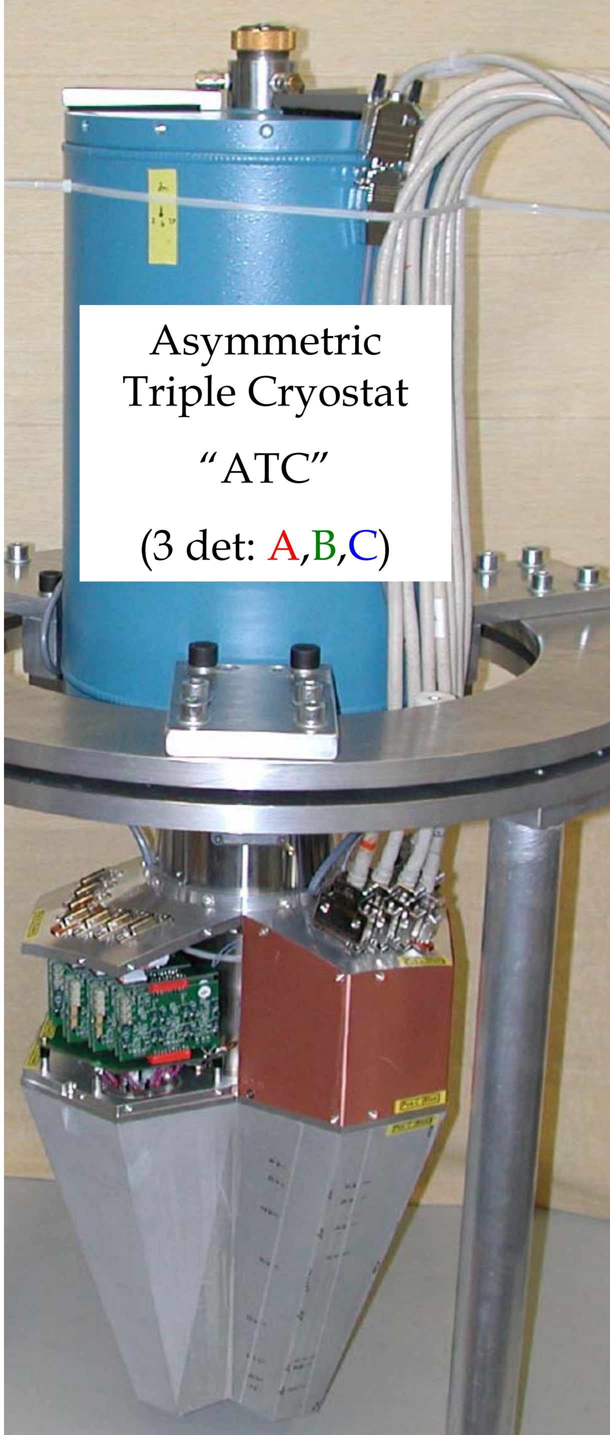
Acceptance test (CAT)
IKP / Saclay

Characterization
Liverpool / GSI / Orsay

Assembly in ATC

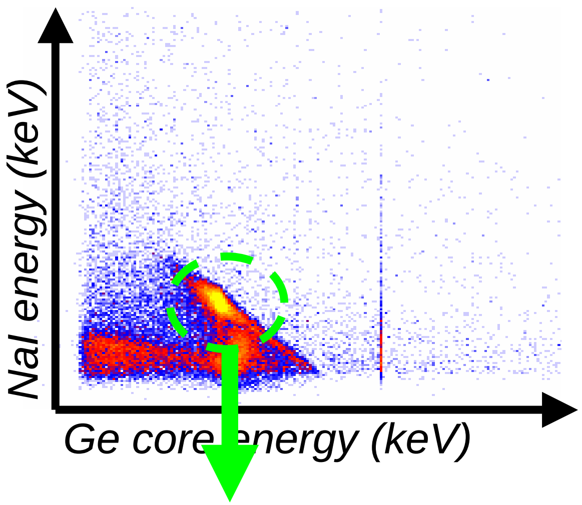
… see talk H. Hess

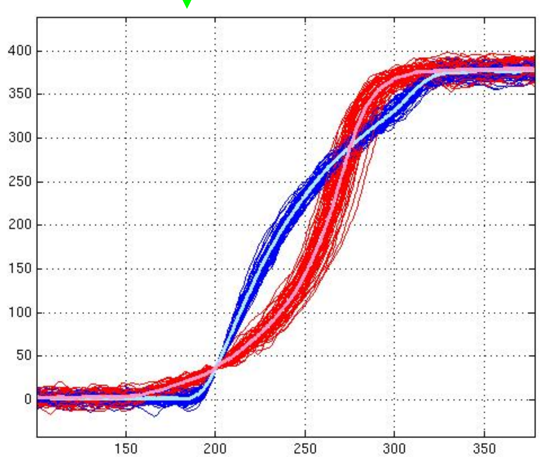


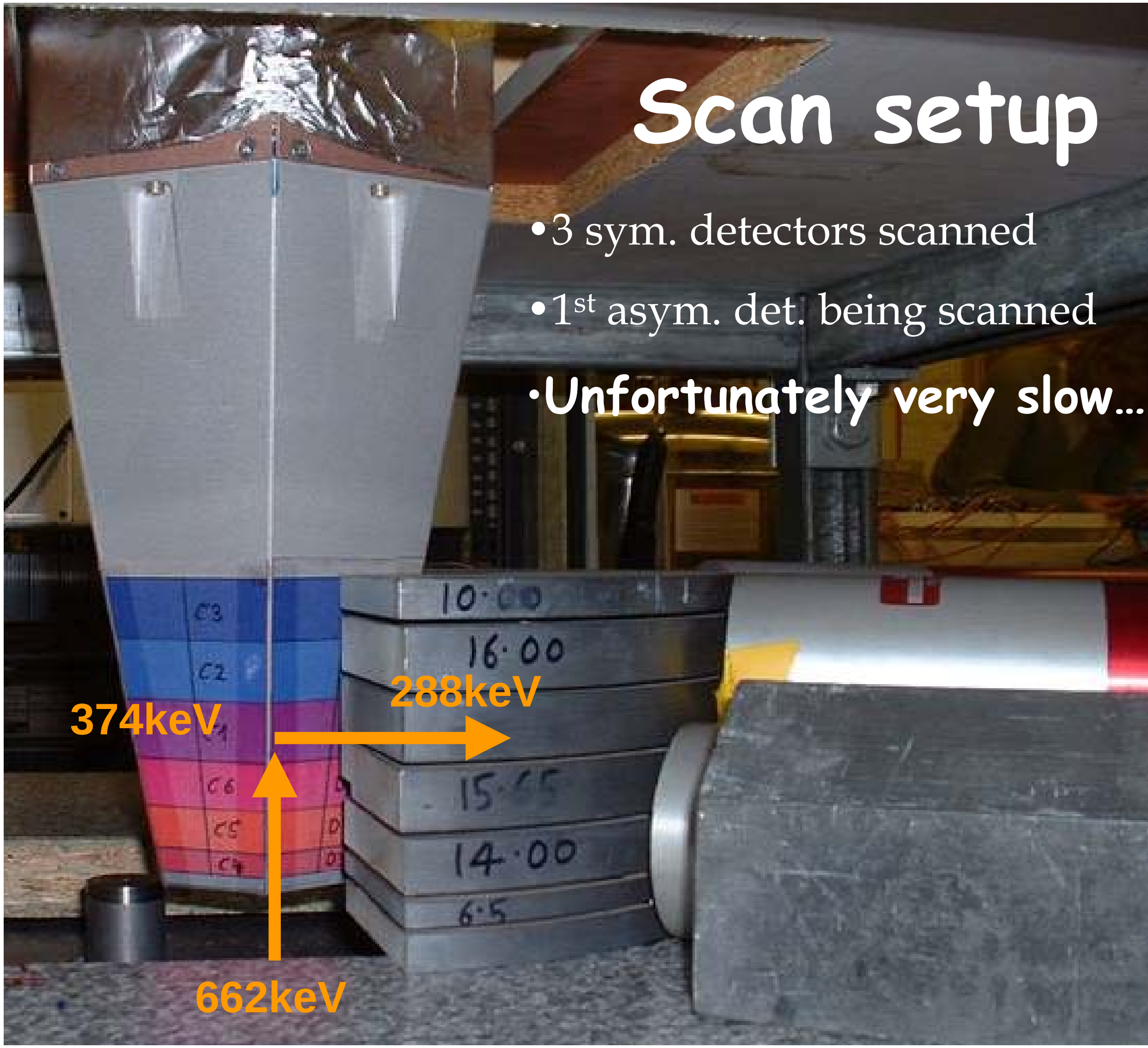


Coincidence measurement = Position selection

THE UNIVERSITY of LIVERPOOL



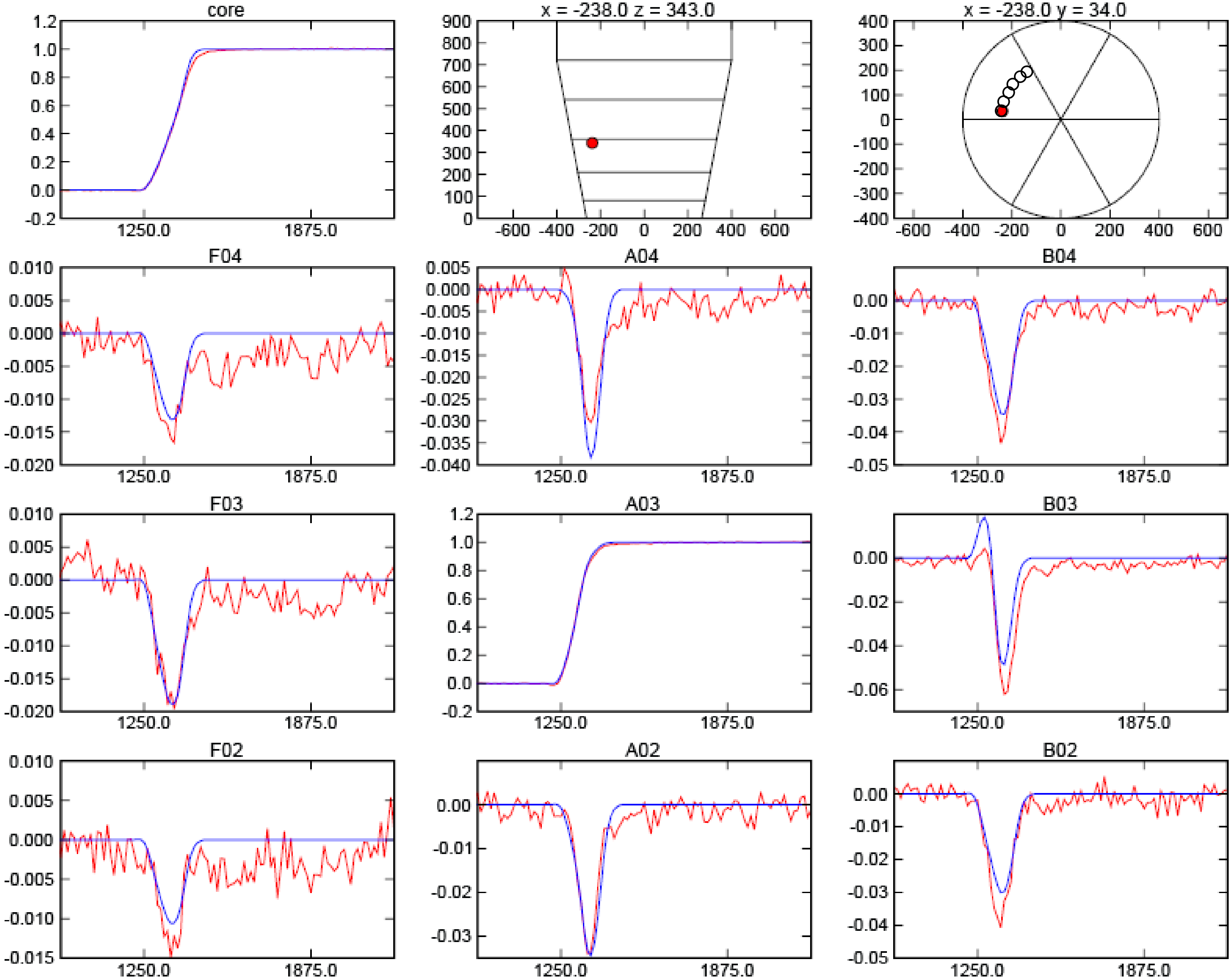




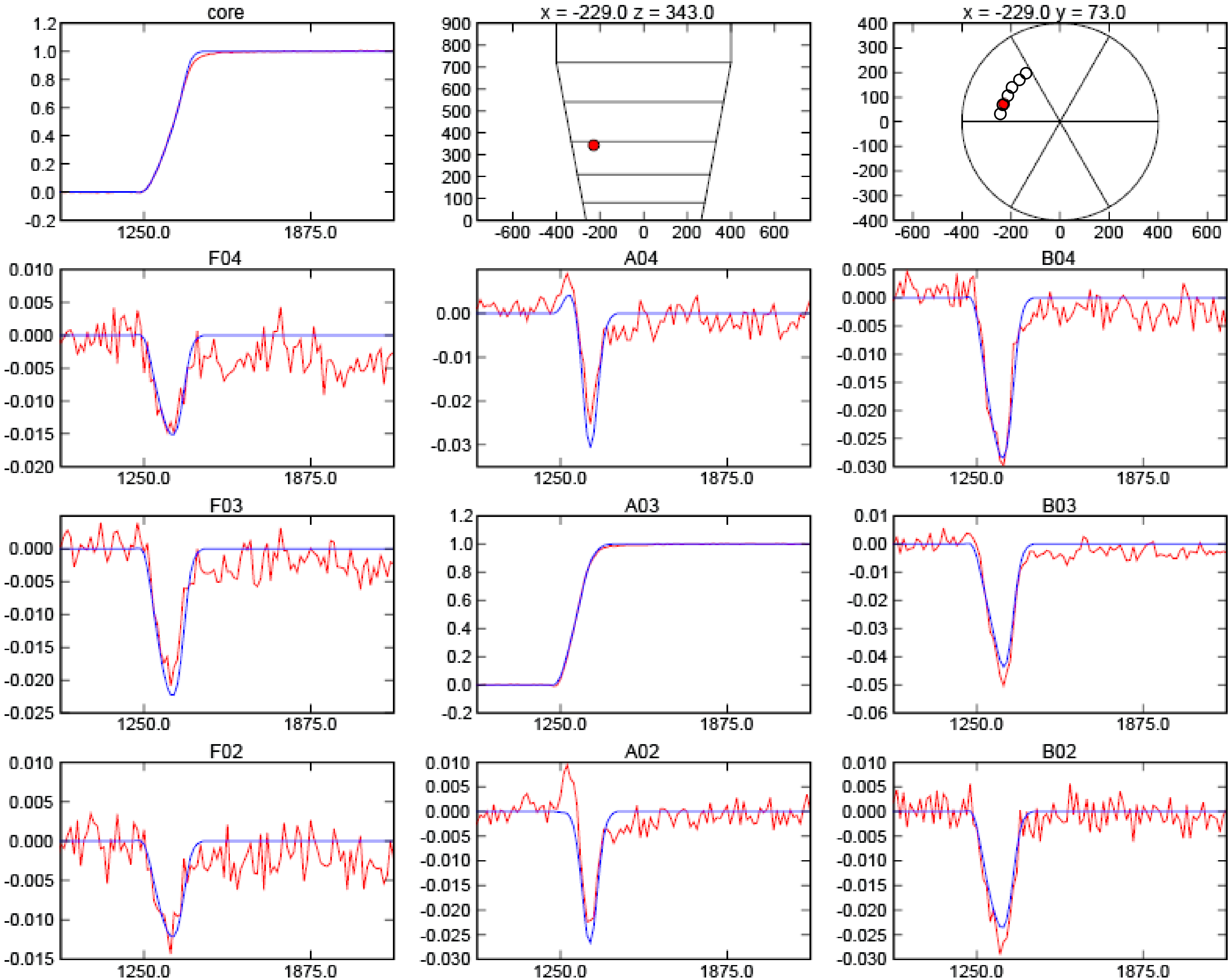
Scan setup

- 3 sym. detectors scanned
- 1st asym. det. being scanned
- **Unfortunately very slow…**

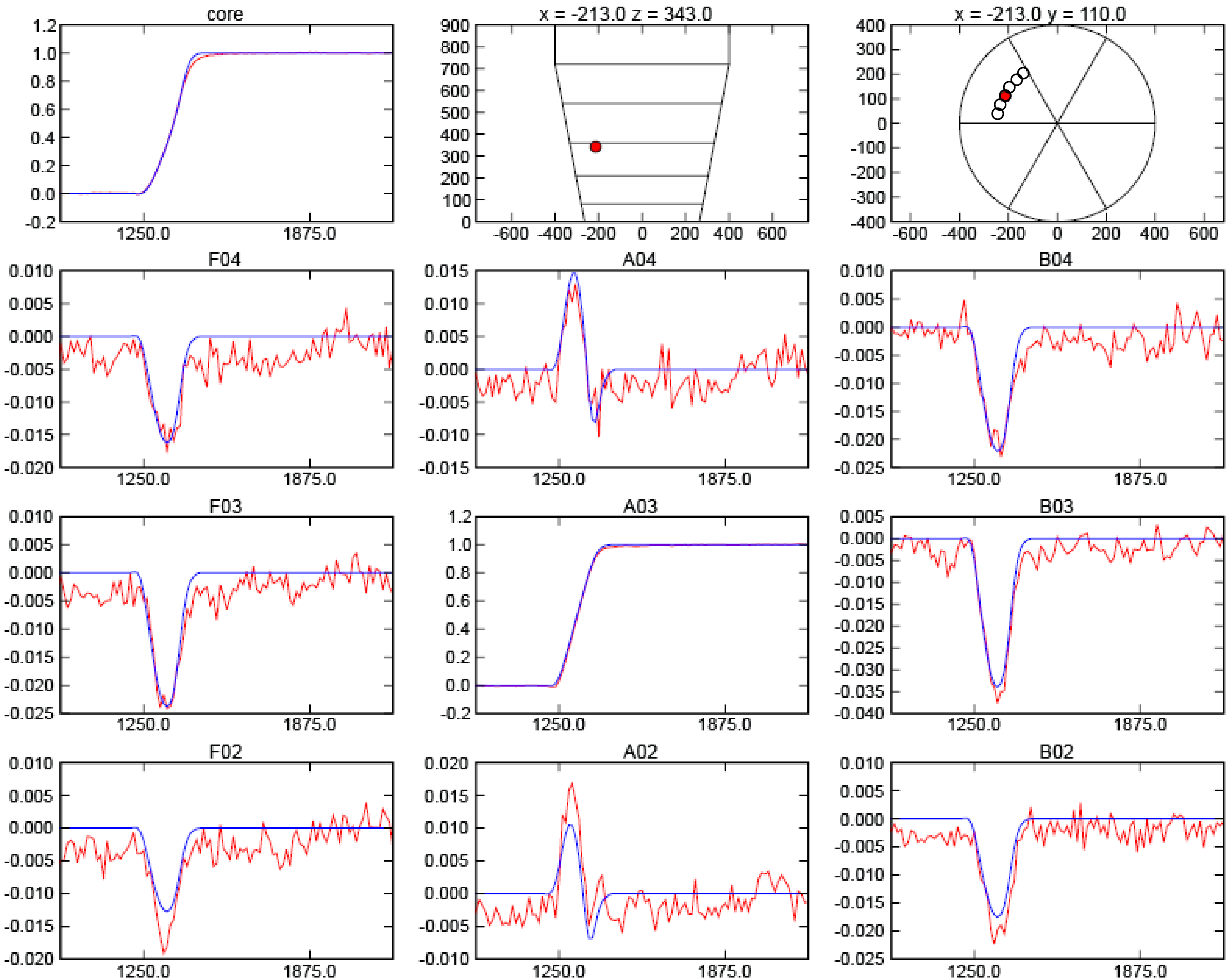
Scanning - examples



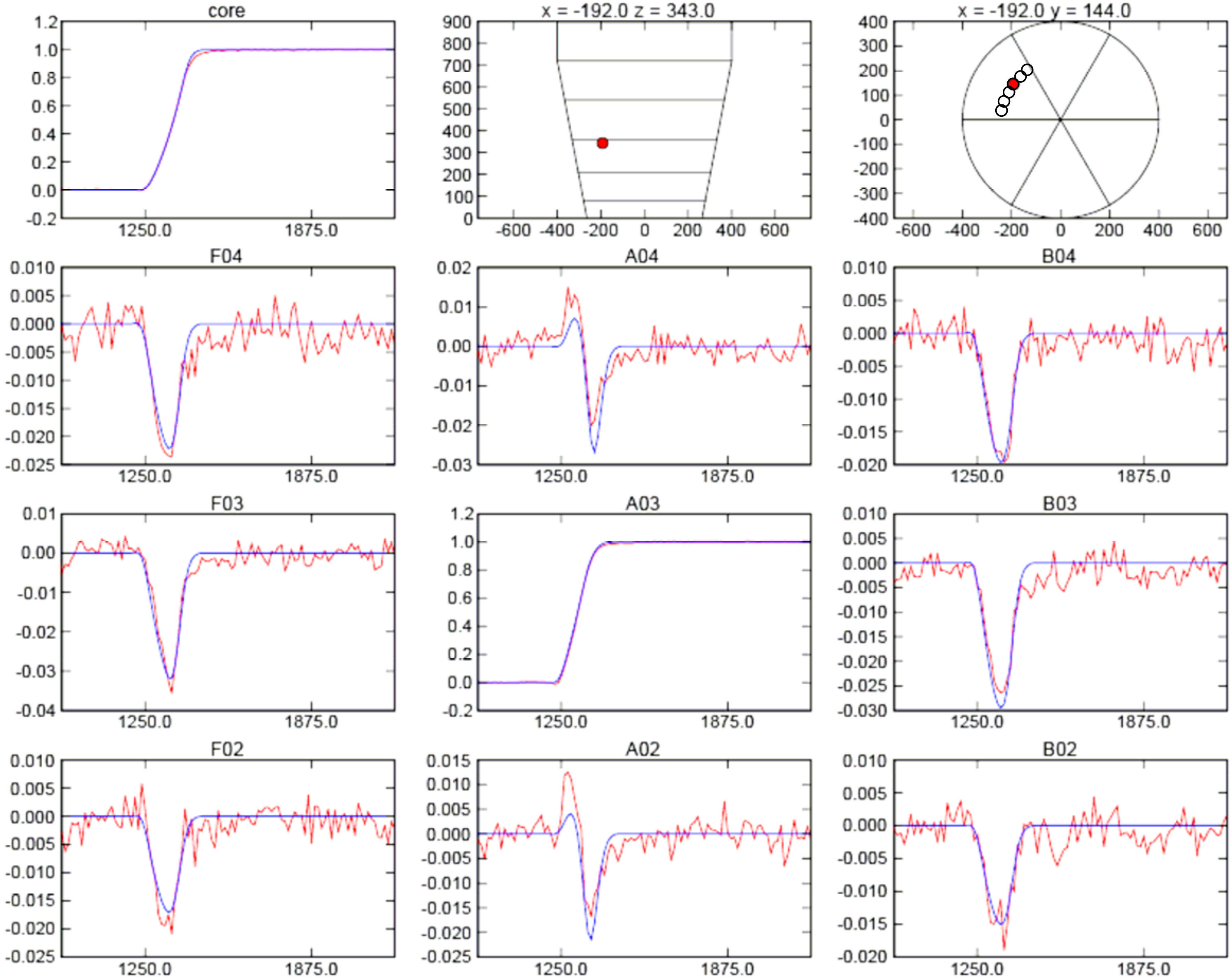
Scanning - examples



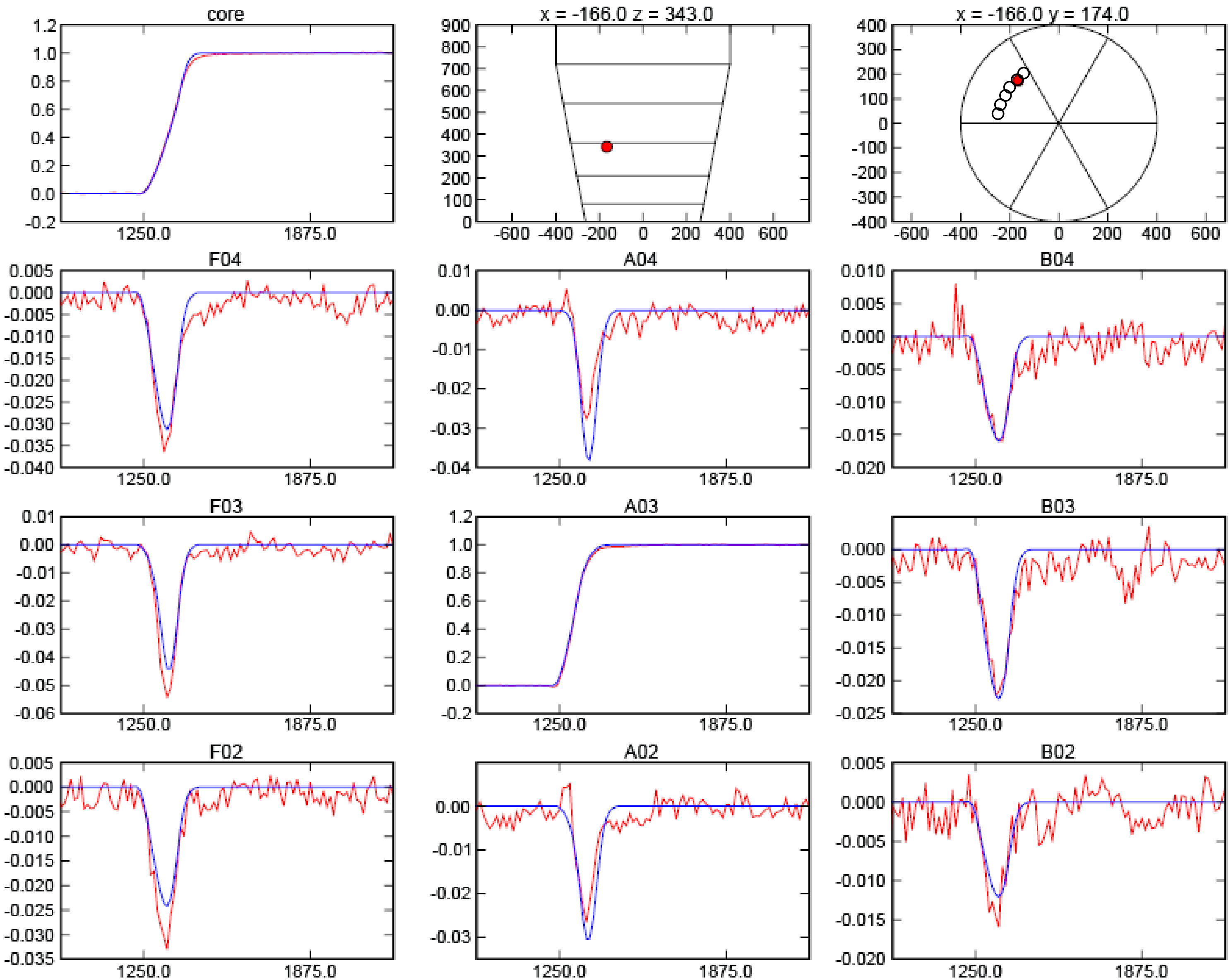
Scanning - examples



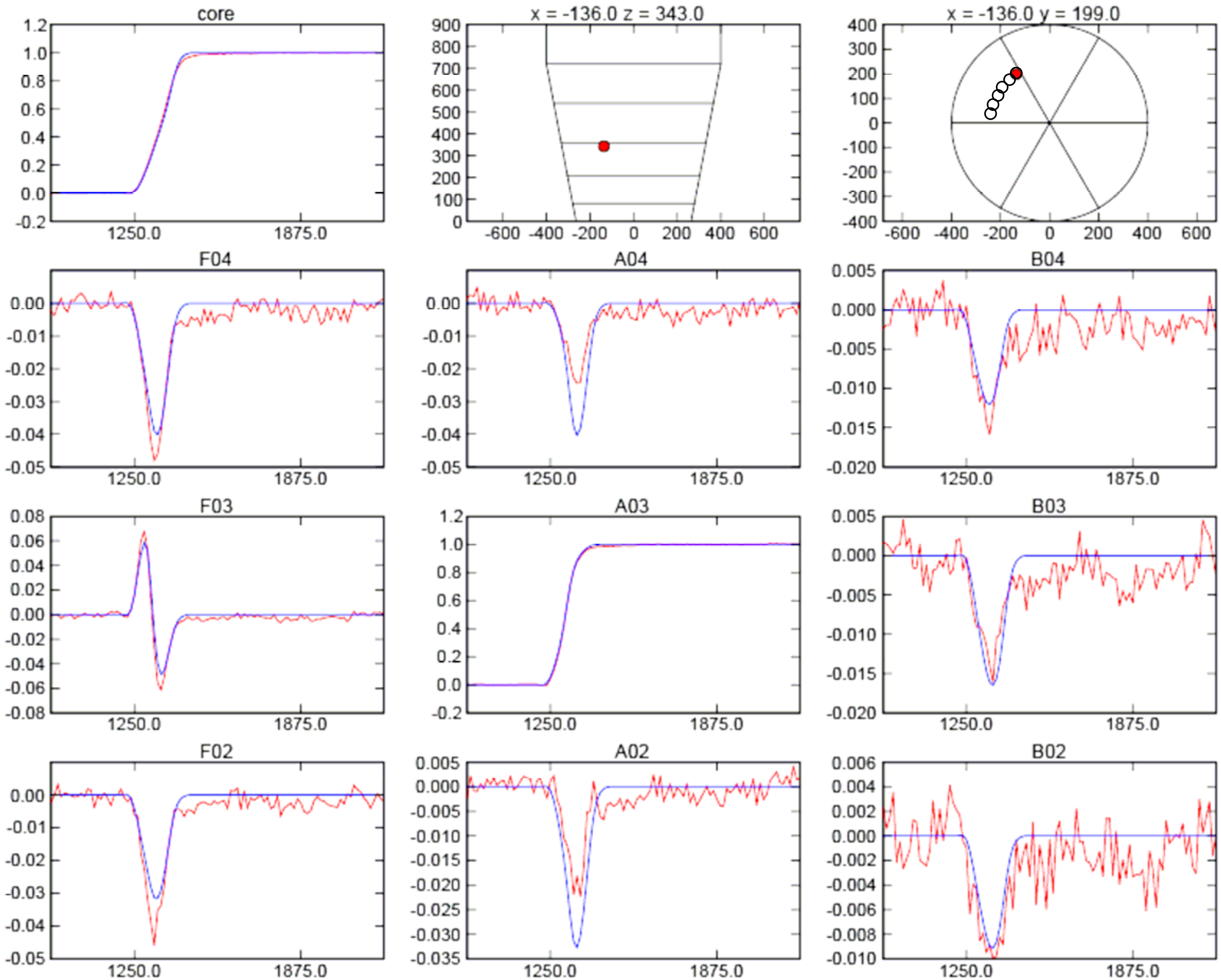
Scanning - examples



Scanning - examples



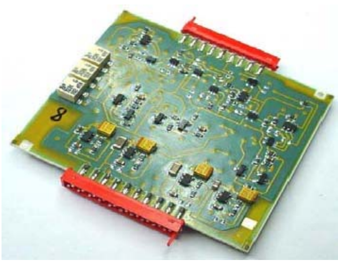
Scanning - examples

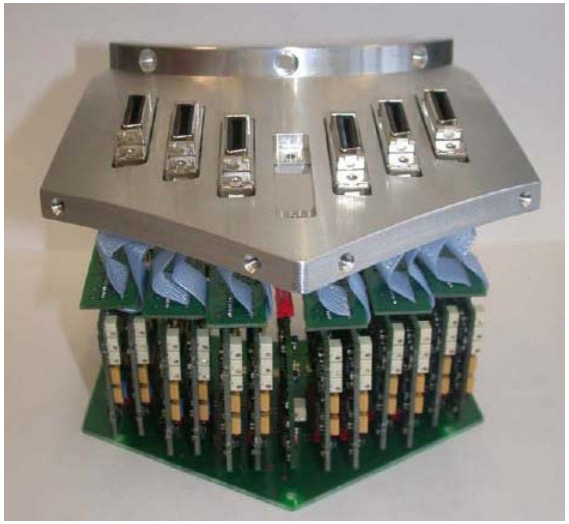


… see talk M. Schlarb

AGATA : A complete new development…

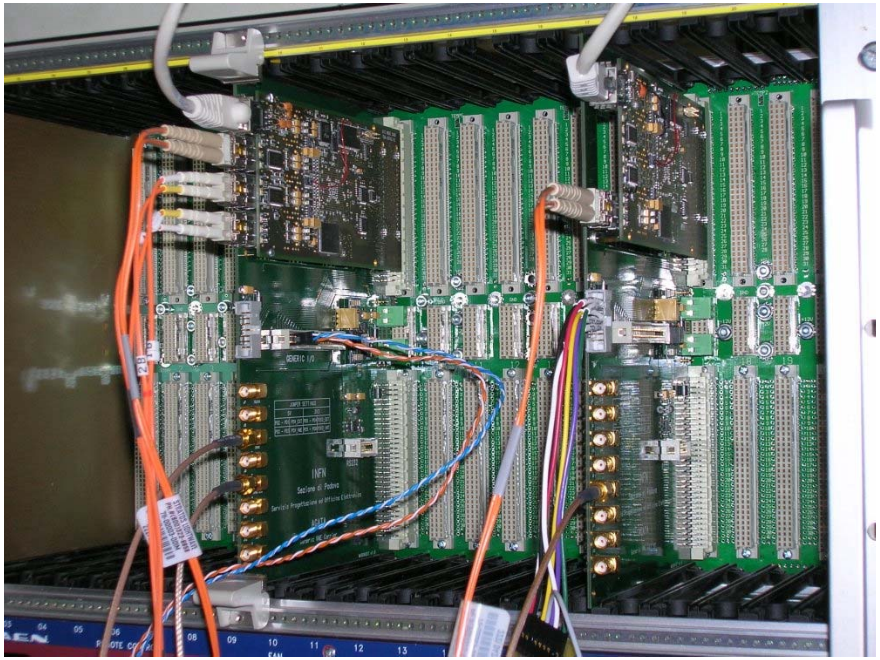
Preamplifiers (Milano, GANIL, Köln)



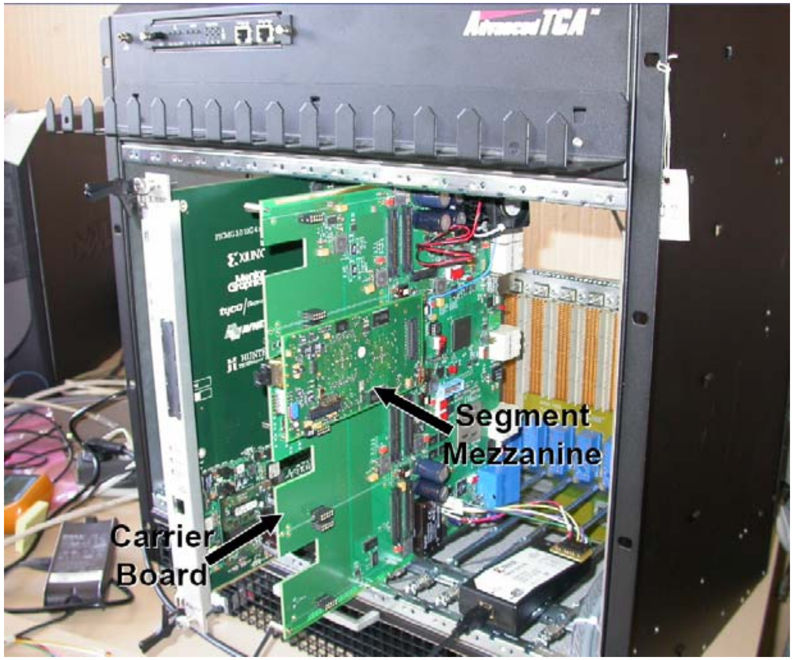


Digitisers (IReS, CCLRC, U-Liv.)

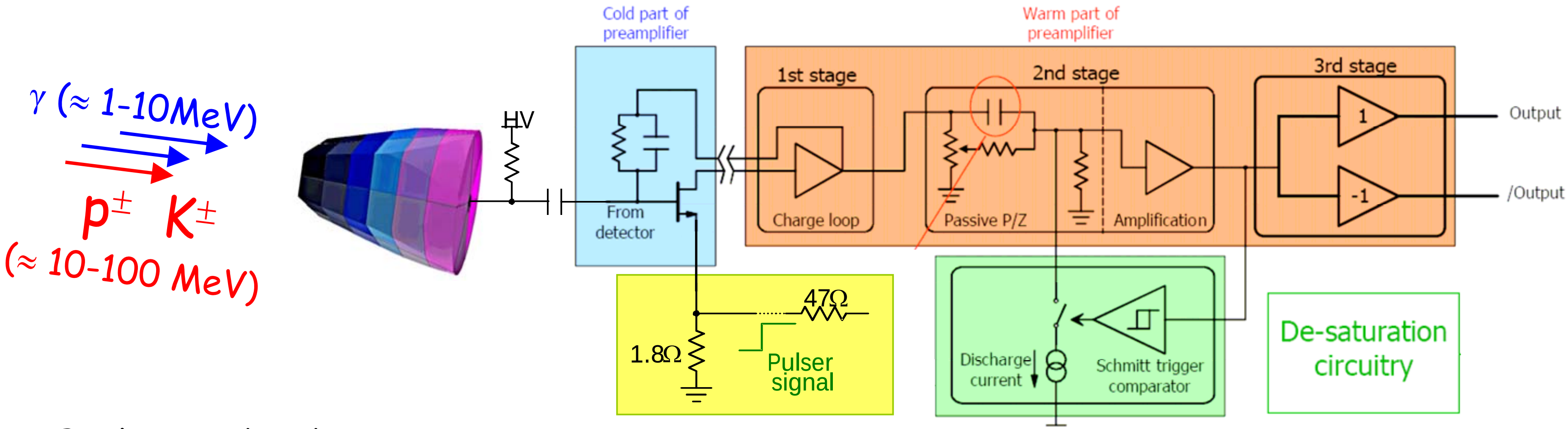
Global Trigger and Synchronization (Padova)



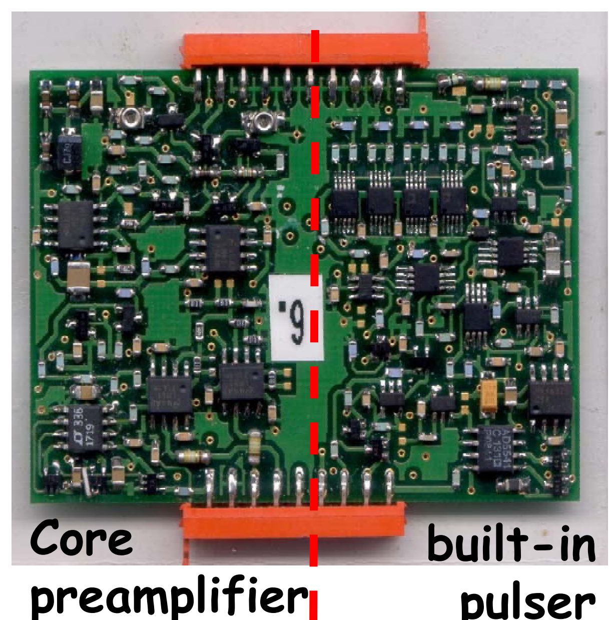
Preprocessing (Orsay)



AGATA core preamplifier and features



Background radioactivity:
Individual highly energetic events introduce a significant
SYSTEM DEAD TIME

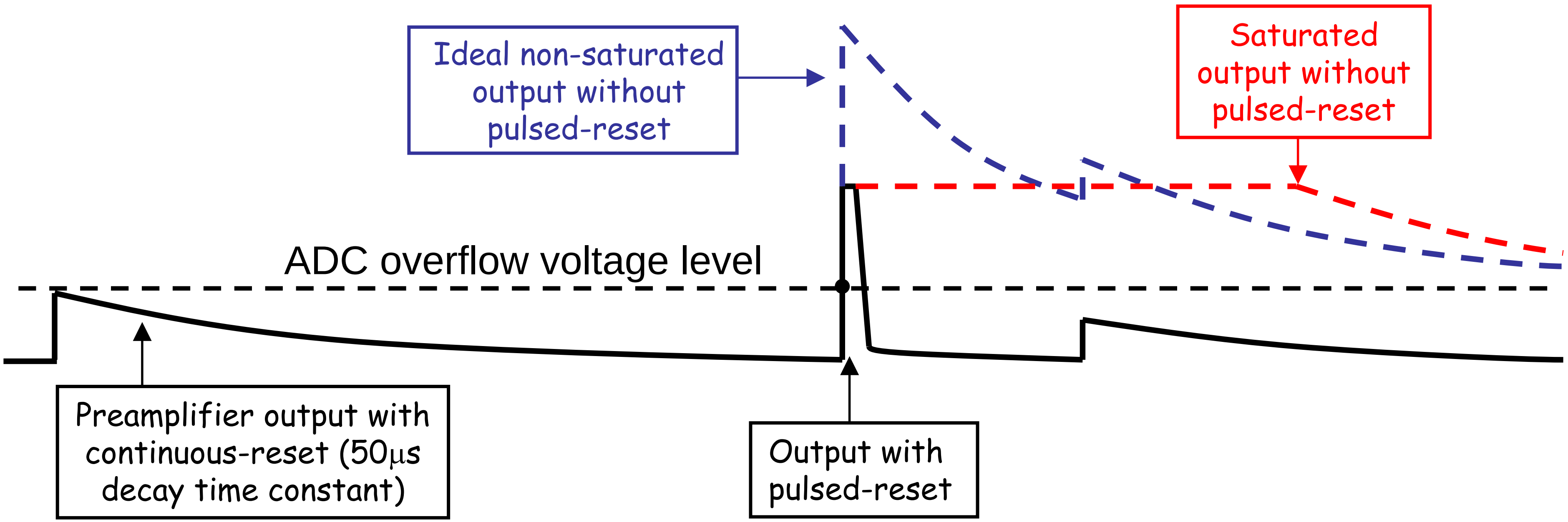


Development of IKP, cologne

Requirement core preamp:

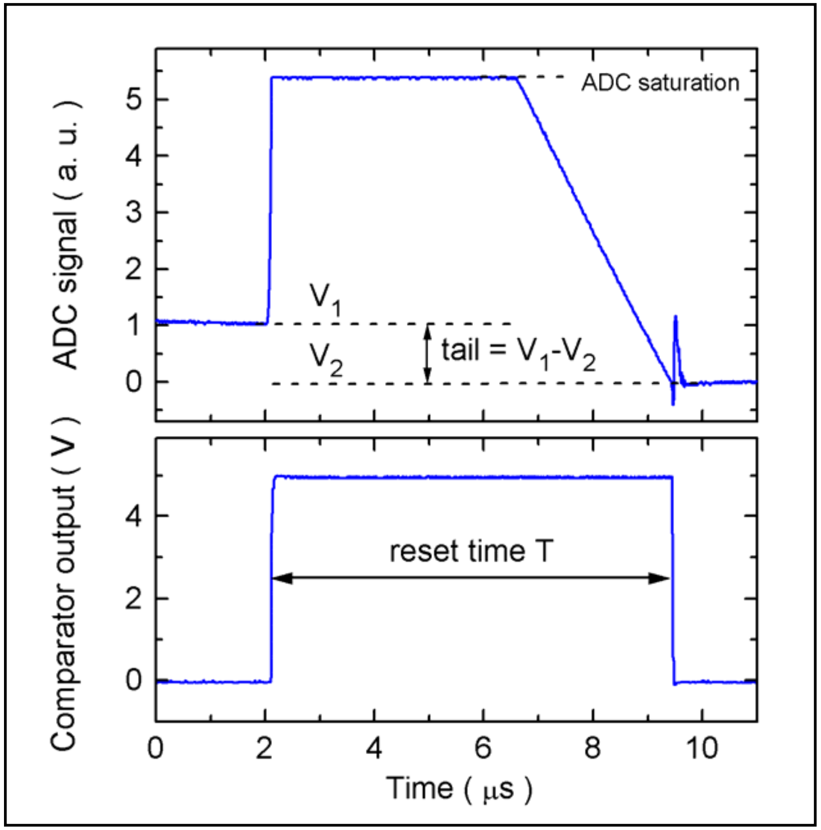
- low noise (energy + PSA)
- large bandwidth (PSA)
- WIDE DYNAMIC RANGE

Mixed reset technique: continuous + pulsed



An ADC overflow condition would saturate the system for a long while ➡ Pulsed-reset mechanism allows fast recovery of the output

Time-Over-Threshold (TOT) technique



second-order time-energy relation

$$E = E_O + b_1 T + b_2 T^2 - k_1 (V_1 - V_2)$$

contribution of the tail due to previous events

Calibration using built-in pulser:

E* = *energy of the large signal

T* = *reset time

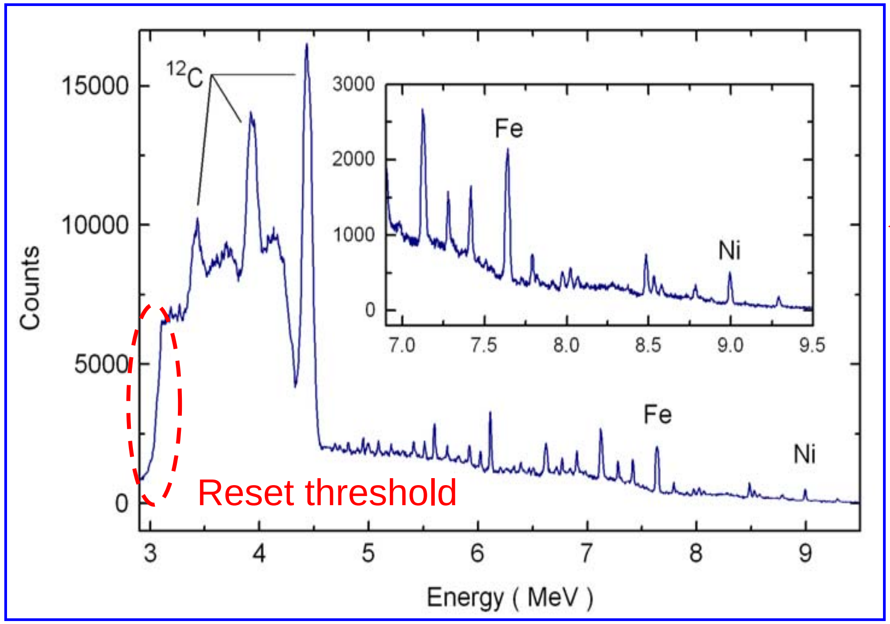
V_1, V_2* = *pre-pulse and post-pulse baselines

b_1, b_2, k_1, E_0* = *fitting parameters

Within ADC range → standard "pulse-height mode" spectroscopy

Beyond ADC range → new "reset mode" spectroscopy

^{241}Am+Be spectrum

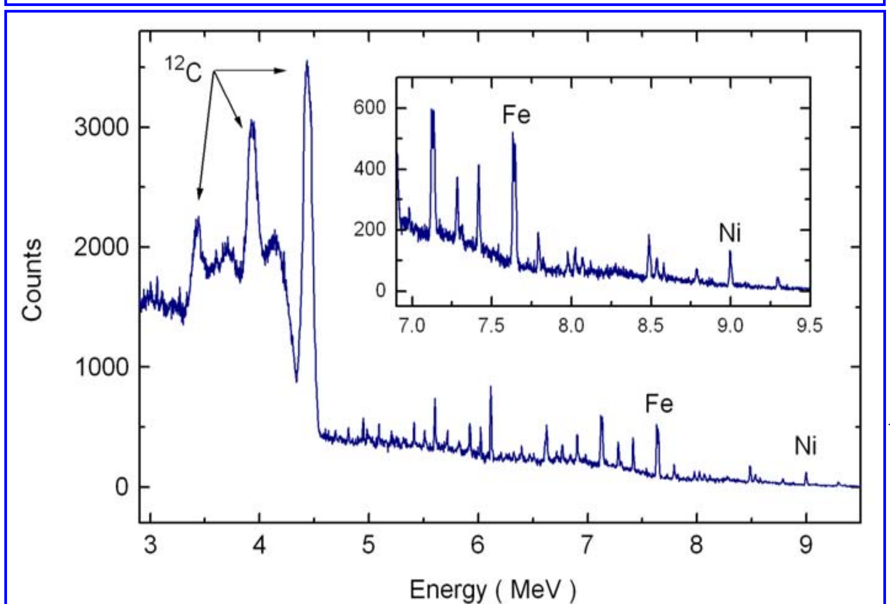


"reset" mode
(by TOT technique)

Energy	Resolution (fwhm) in pulse-height mode		Resolution (fwhm) in reset mode	
5.6 MeV	10.5 keV	0.14 %	18.8 keV	0.34 %
6.1 MeV	15.1 keV	0.17 %	17.1 keV	0.28 %
7.6 MeV	11 keV	0.14 %	18.8 keV	0.25 %
9.0 MeV	15 keV	**0.17 %**	18.9 keV	**0.21 %**

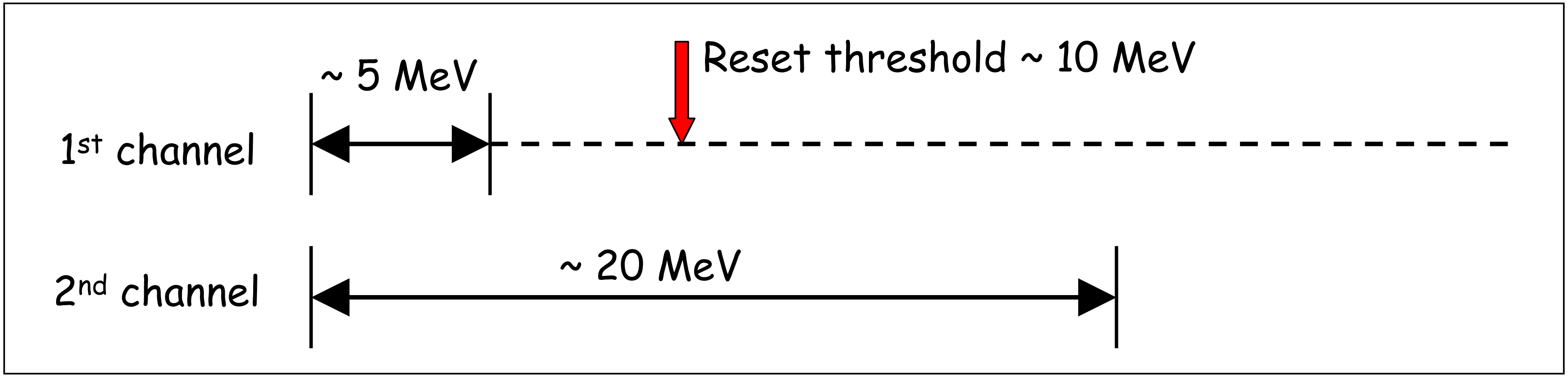
At high energies (> 10 MeV)

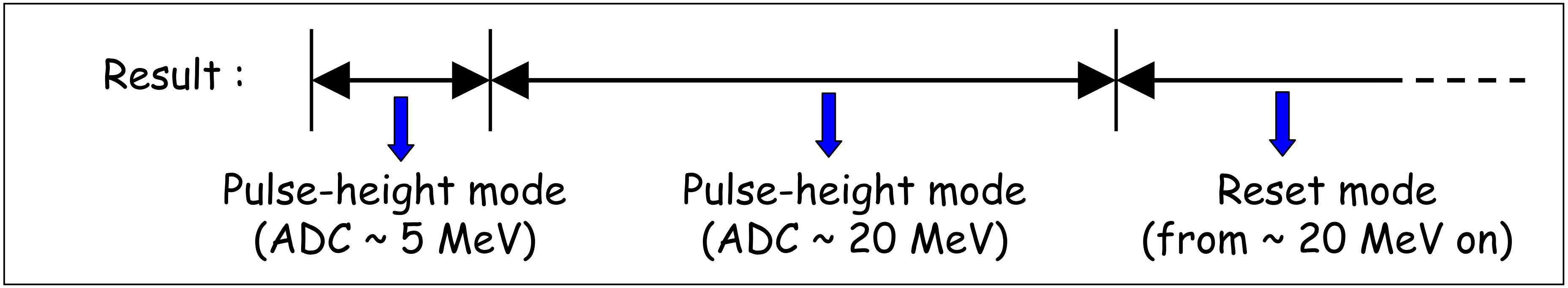
TOT mode ~ pulse-height mode



"pulse-height" mode

The ideal acquisition chain: "dual-channel" core preamplifier



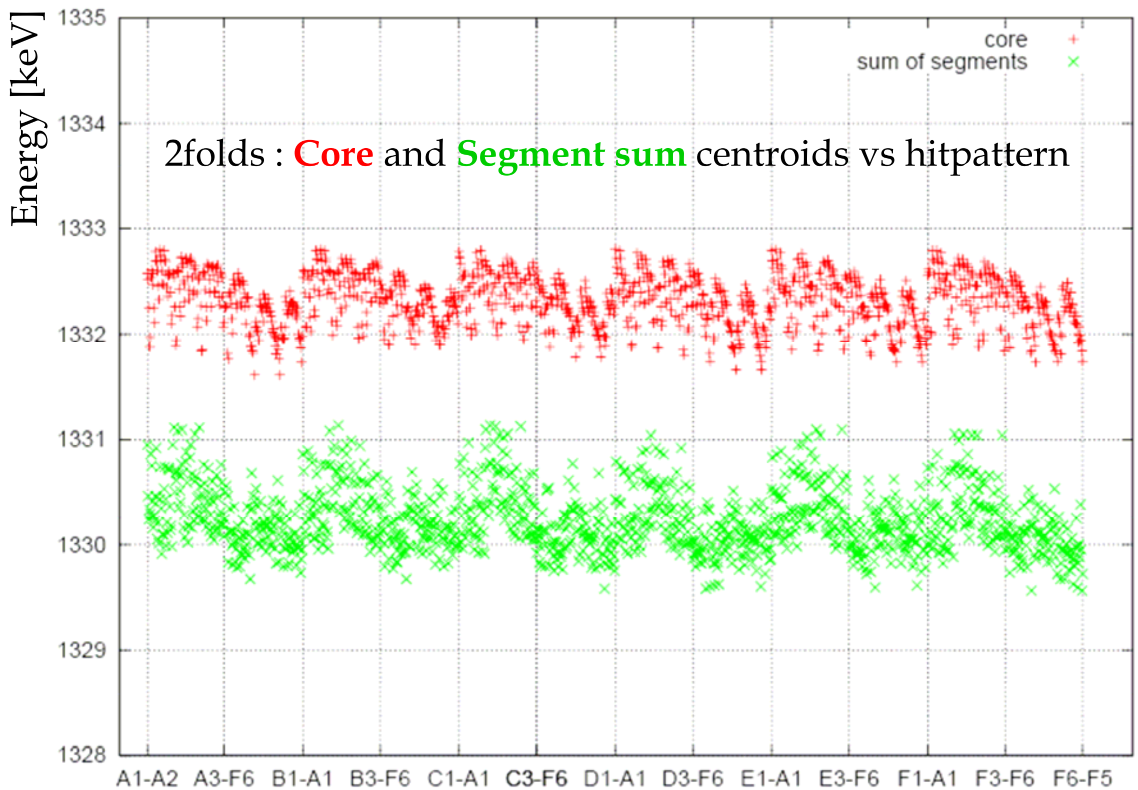


Optimum energy resolution at all ranges

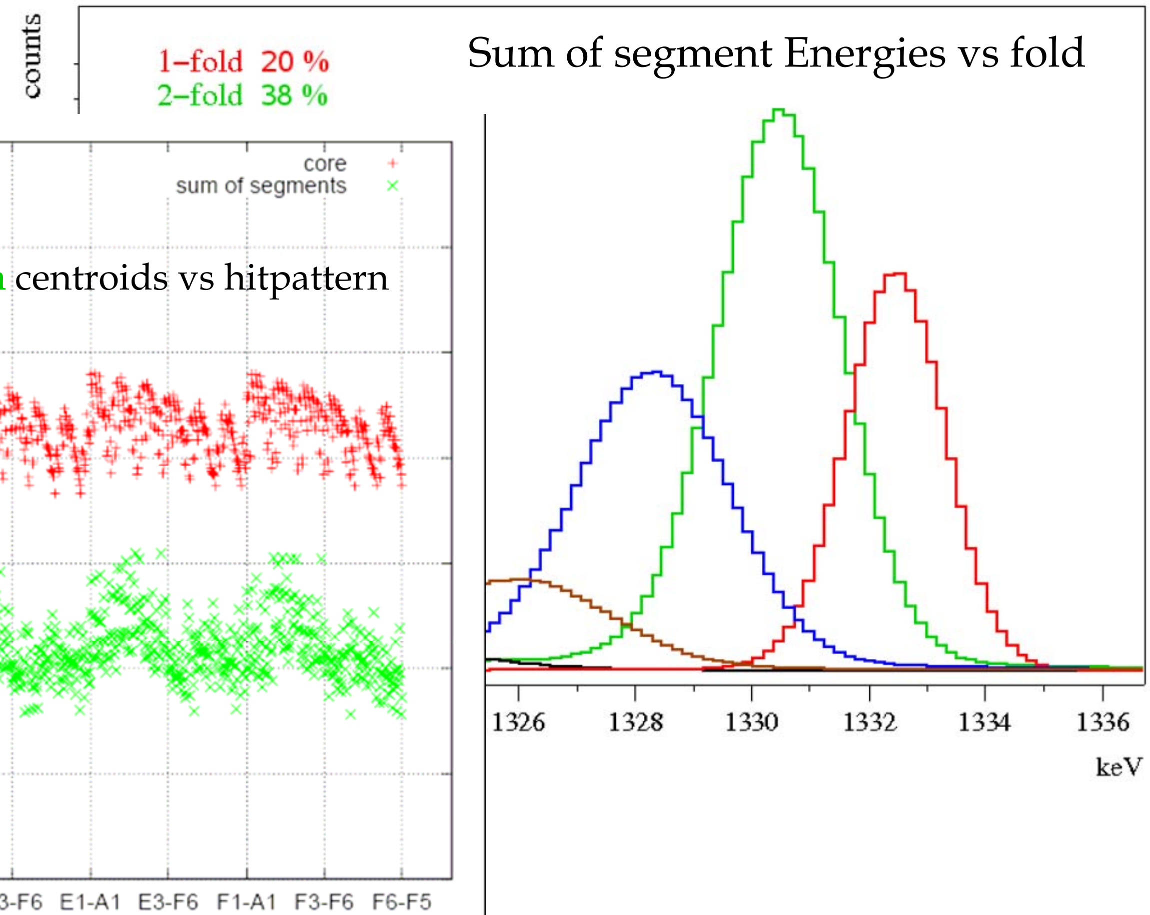
A **prototype** of the **dual core board** has already been realized and tests with the AGATA capsule ongoing.

Cross talk correction: Motivation

- Crosstalk is present in <u>any</u> segmented detector
- Creates strong energy shifts proportional to fold
- Tracking needs <u>segment energies</u> !



…All possible 2fold combinations



A model to describe crosstalk

AC equivalent detector model:

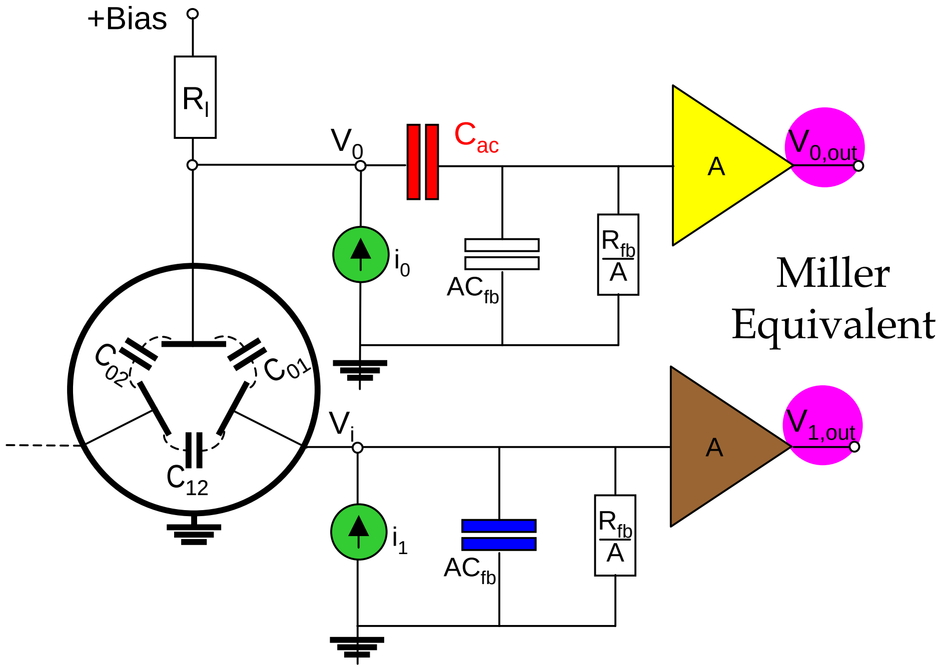
$$i_h = \underbrace{\sum_{i=1}^{N} q_i \mathbf{v}_i(\mathbf{r}_i)\cdot \mathbf{F}'_{1h}(\mathbf{r}_i)}_{\text{Ramo theoreme}} - \underbrace{\sum_{k=1}^{n} C_{hk}\frac{\partial V_k}{\partial t}}_{\text{Extension}}$$

Ramo theoreme - Extension

B. Pellegrini – Phys Rev B 34,8 (86) p. 5921

E. Gatti et al – NIM 193 (82) p. 651

Crosstalk is intrinsic property of segmented detectors !



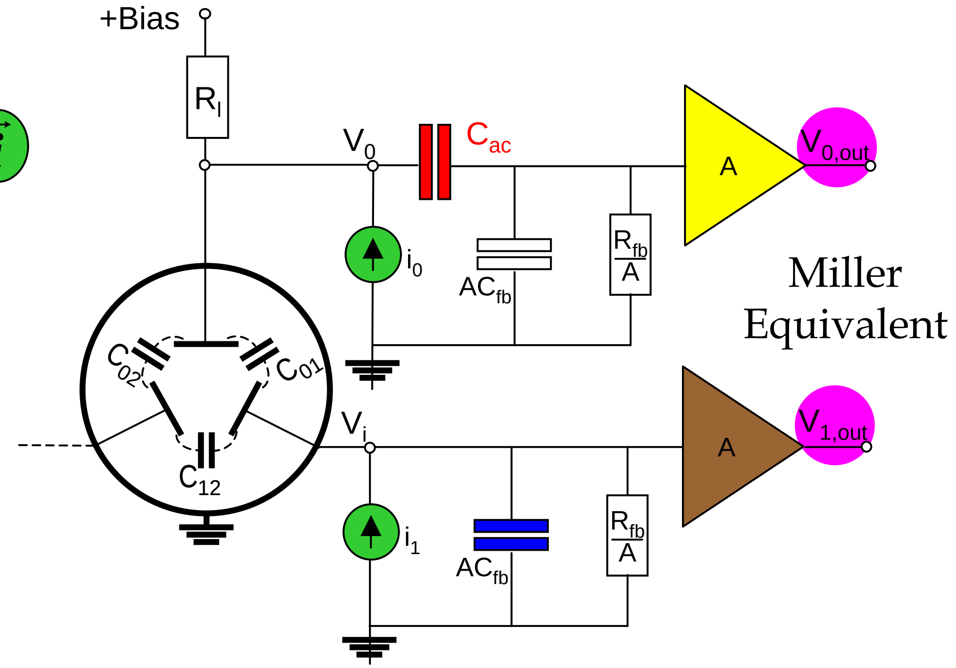
A model to describe crosstalk

Segment-to-Core

$$\vec{\mathbf{v}}_{out} \cong \frac{1}{sC_{fb}} \begin{pmatrix} 1 & -C_{01}/AC_{fb} & -C_{02}/AC_{fb} \\ -C_{01}/C_{ac} & 1 & -C_{12}/AC_{fb} \\ -C_{02}/C_{ac} & -C_{12}/AC_{fb} & 1 \end{pmatrix} \vec{i}$$

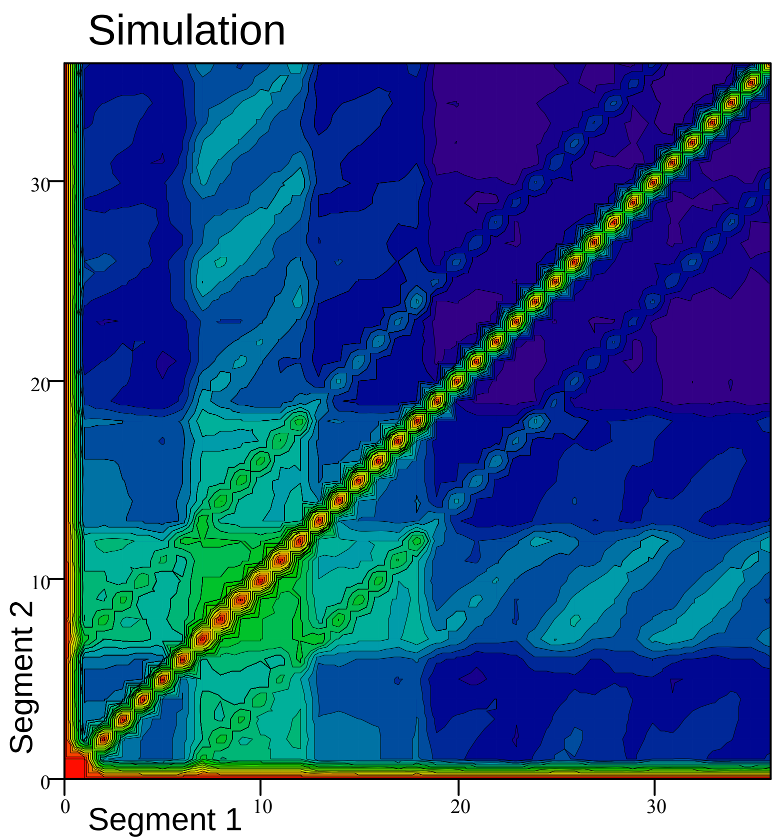
Core-to-Seg | Segment-to-Segment

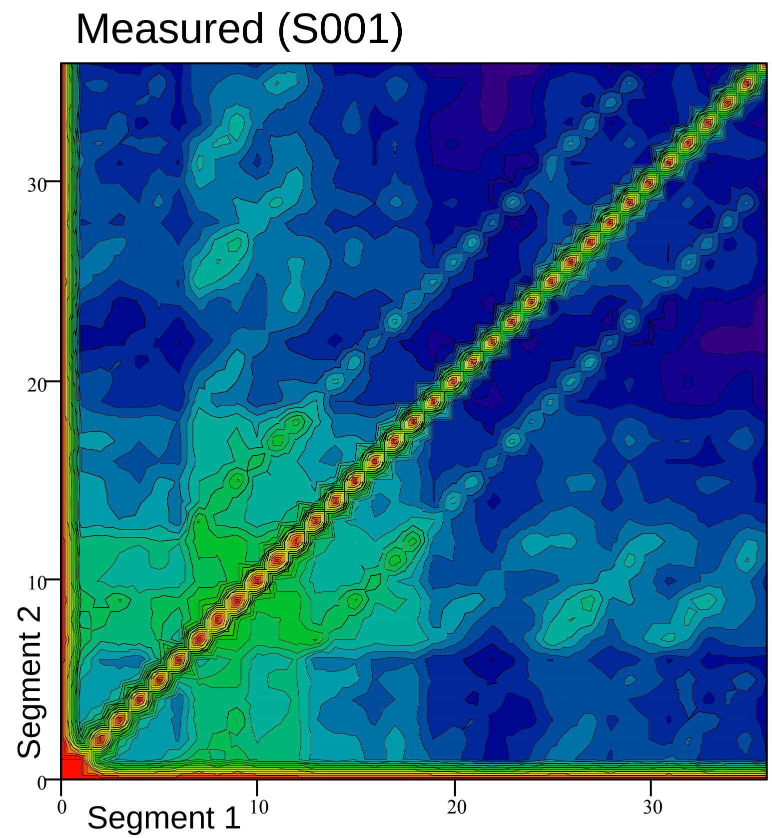
~ 1pF/1000pF | ~1pF/(10000 · 1pF)



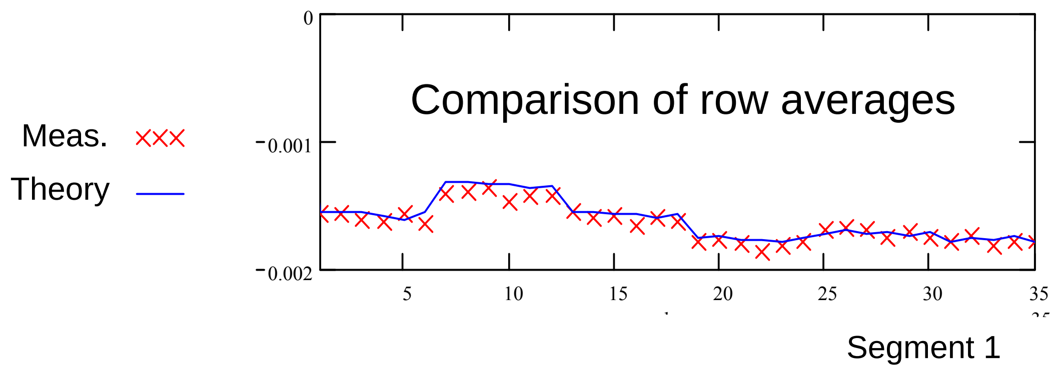
B. Bruyneel et al – to be submitted to NIM

Core to segment crosstalk in 2folds





Core to segment crosstalk is understood



Cross talk correction: strategy

•*Without cross talk:*

$$\begin{bmatrix} E_{core} \\ \hdashline E_{seg1} \\ E_{seg2} \\ E_{seg3} \end{bmatrix}_{meas} = \begin{bmatrix} 1 & 1 & 1 \\ \hdashline 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} E_{seg1} \\ E_{seg2} \\ E_{seg3} \end{bmatrix}_{true}$$

identity

•*With cross talk + <u>Conservation of calibration</u> :*

$$\begin{bmatrix} E_{core} \\ \hdashline E_{seg1} \\ E_{seg2} \\ E_{seg3} \end{bmatrix}_{meas} = \begin{bmatrix} 1+\delta_{01}^{*} & 1+\delta_{02}^{*} & 1+\delta_{03}^{*} \\ \hdashline 1 & \delta_{12}^{*} & \delta_{13}^{*} \\ \delta_{21}^{*} & 1 & \delta_{23}^{*} \\ \delta_{31}^{*} & \delta_{32}^{*} & 1 \end{bmatrix} \cdot \begin{bmatrix} E_{seg1} \\ E_{seg2} \\ E_{seg3} \end{bmatrix}_{true}$$

•*TO DO: Inverting non-square matrix = fitting (on event by event basis)*

OLS = Orinary Least Square fitting

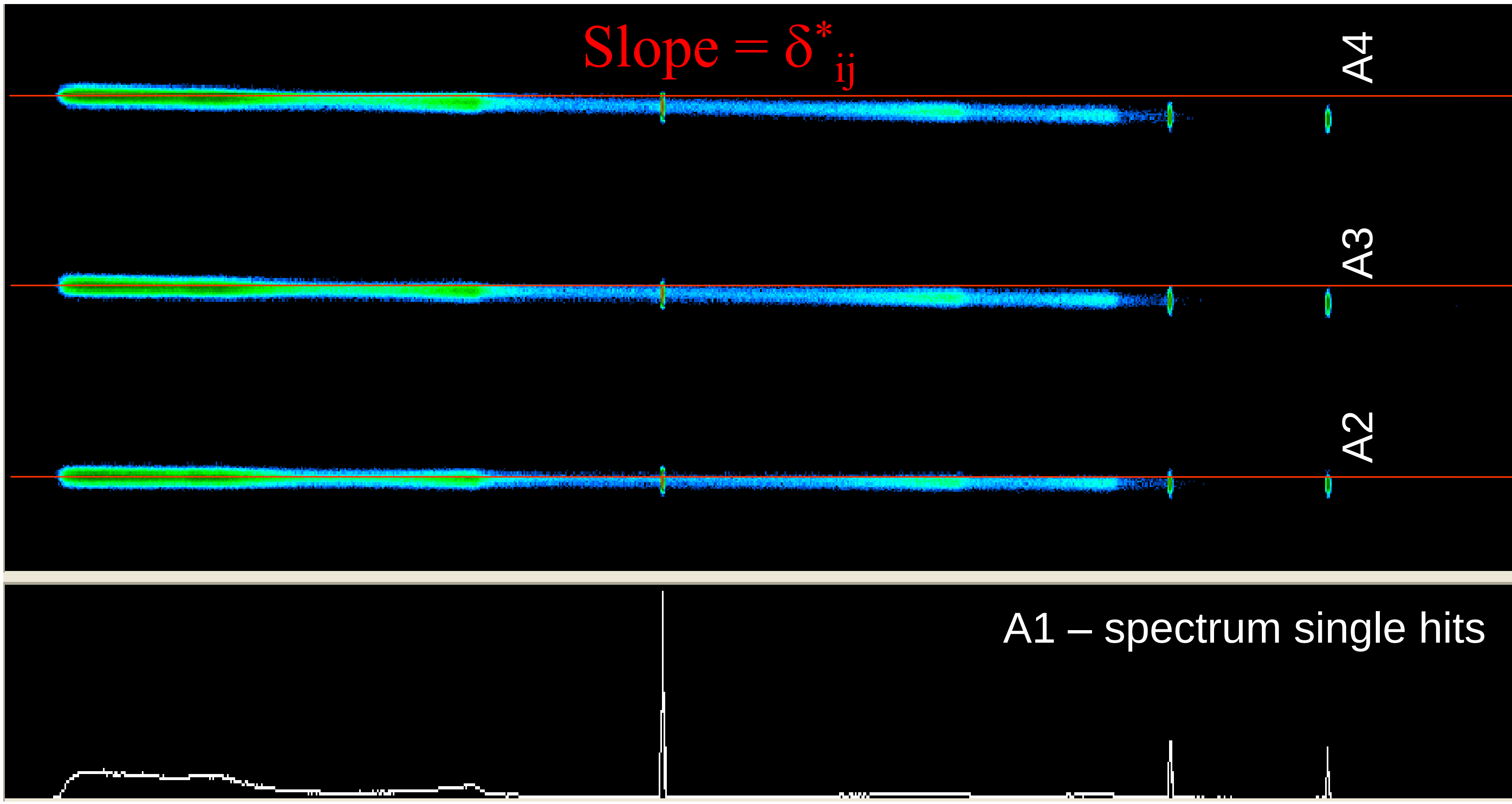
GLS = Generalized Least Square fitting

•*Fitting combines core + segment energies : **<u>increased resolution</u>***

Measuring the cross talk parameters

$$\begin{pmatrix} 1+\delta^*_{01} & 1+\delta^*_{02} & 1+\delta^*_{03} & \cdots \\ 1 & \delta^*_{12} & \delta^*_{13} & \cdots \\ \delta^*_{21} & 1 & \delta^*_{23} & \cdots \\ \delta^*_{31} & \delta^*_{32} & 1 & \\ \vdots & \vdots & \vdots & \ddots \end{pmatrix}$$

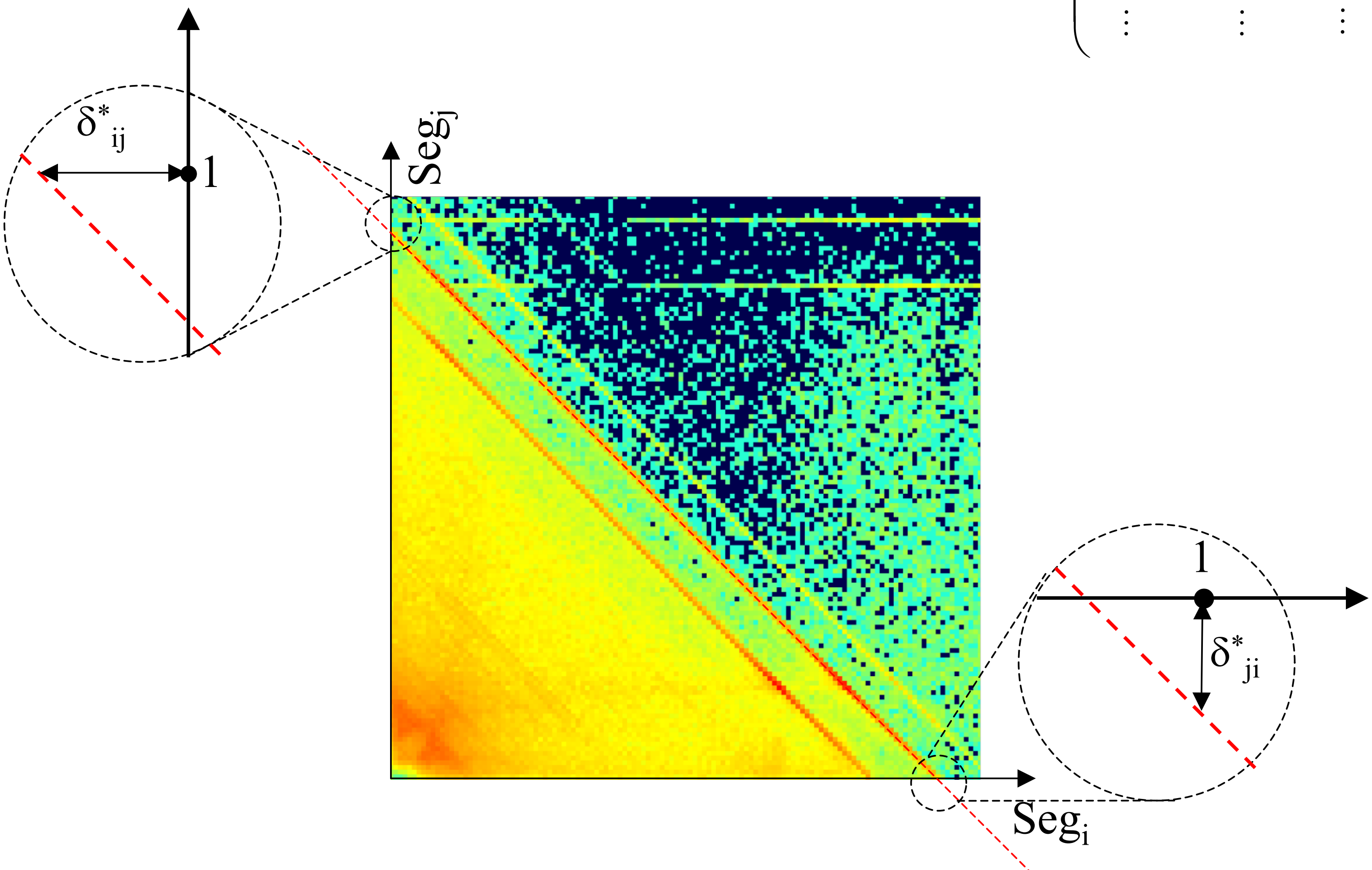
<u>a) From singles:</u>



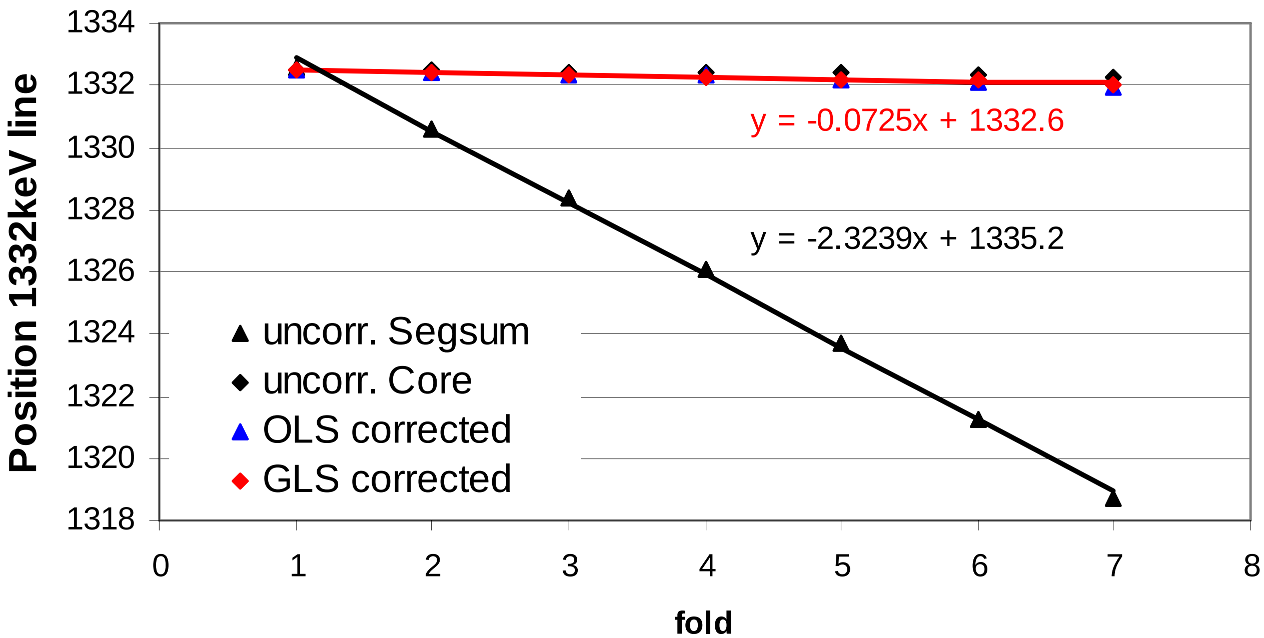
Measuring the cross talk parameters

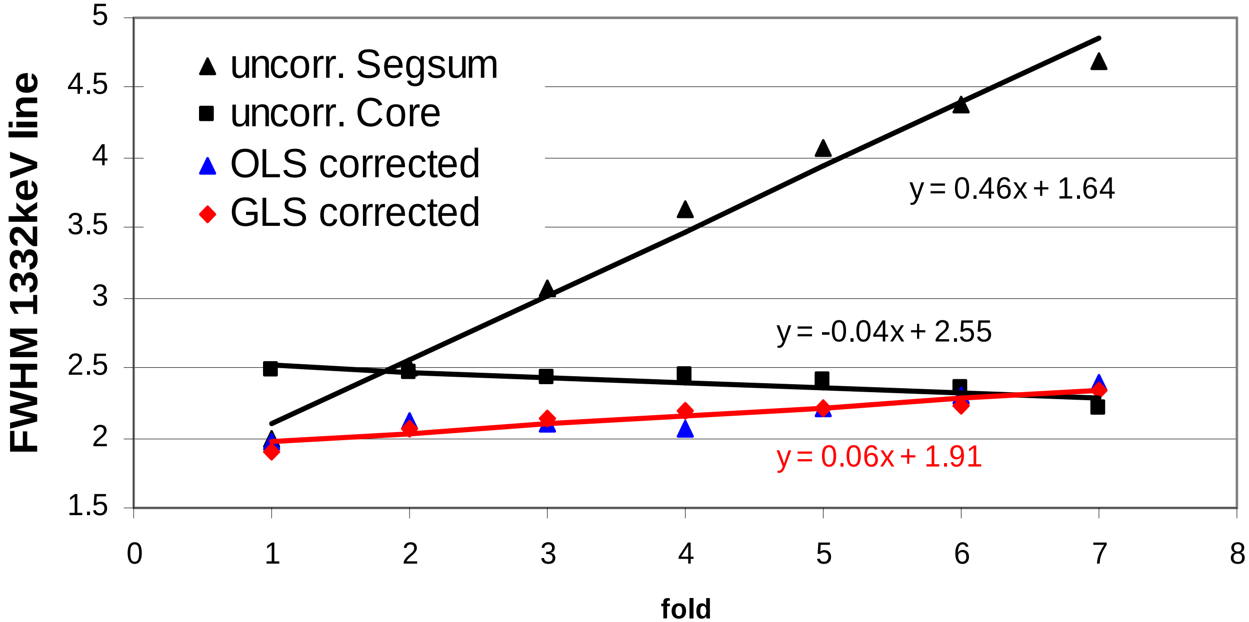
$$\begin{pmatrix} 1+\delta^*_{01} & 1+\delta^*_{02} & 1+\delta^*_{03} & \cdots \\ 1 & \delta^*_{12} & \delta^*_{13} & \cdots \\ \delta^*_{21} & 1 & \delta^*_{23} & \cdots \\ \delta^*_{31} & \delta^*_{32} & 1 & \\ \vdots & \vdots & \vdots & \ddots \end{pmatrix}$$

b) From doubles:

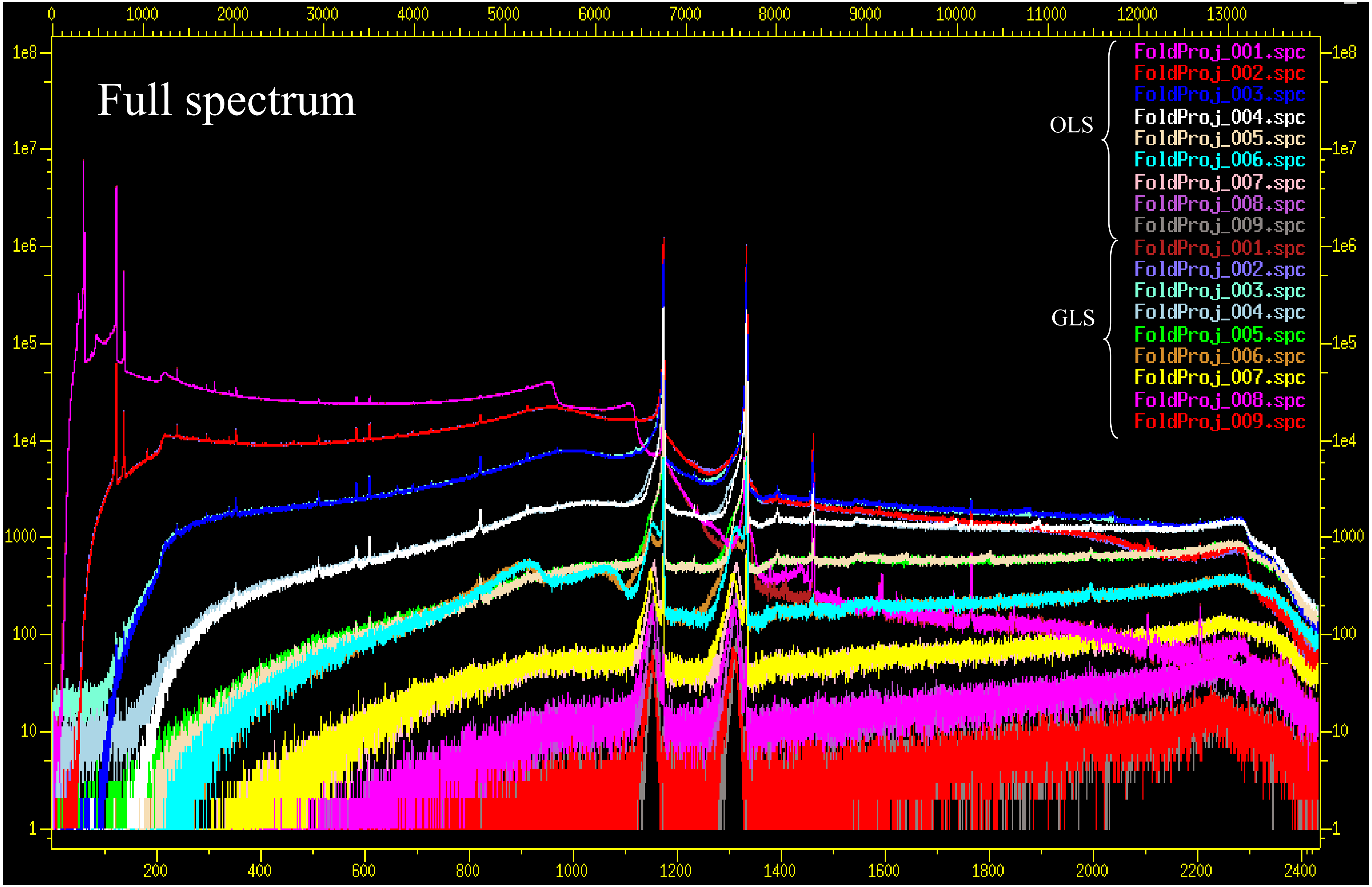


Results in values

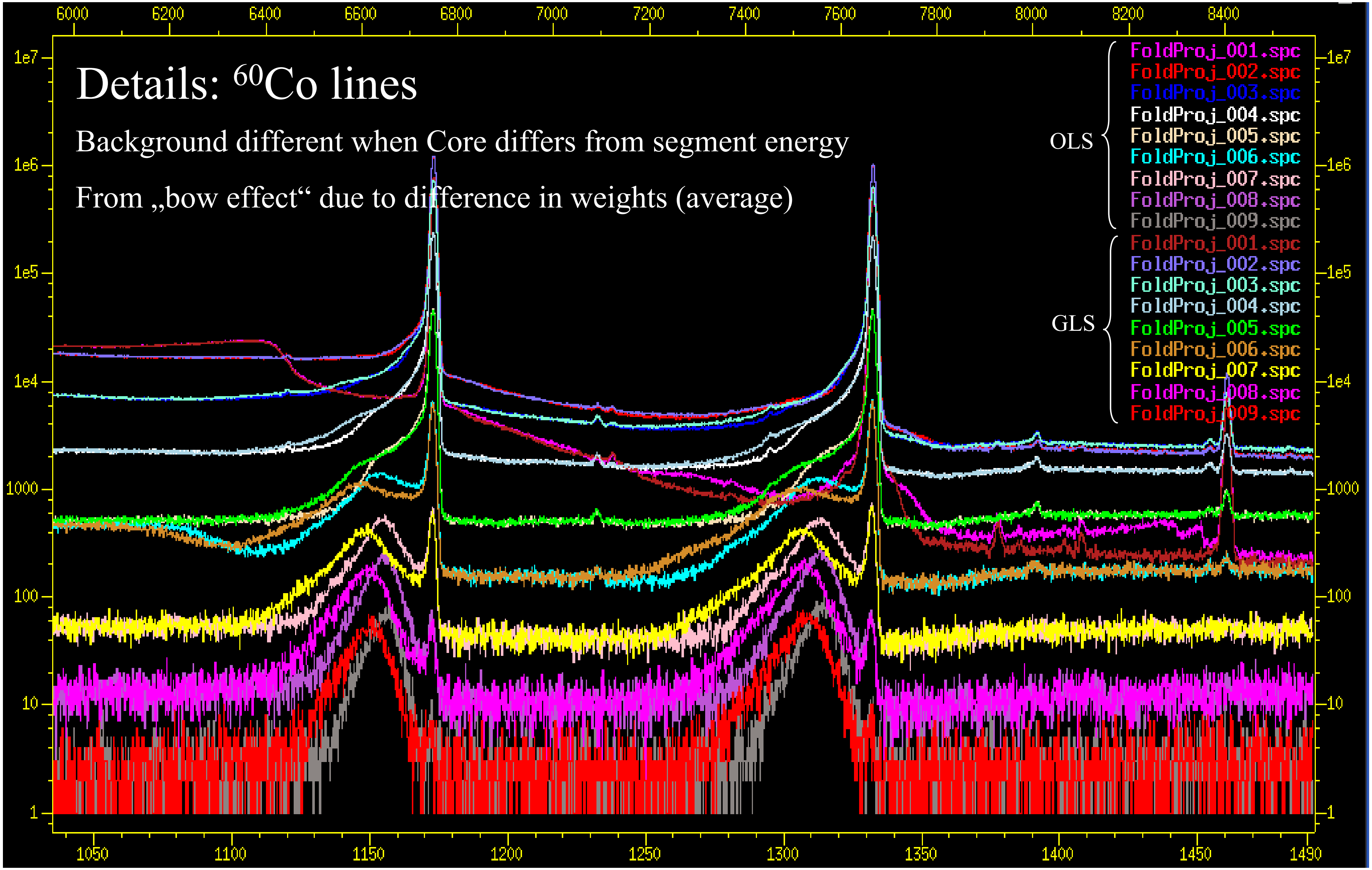




Results in pictures

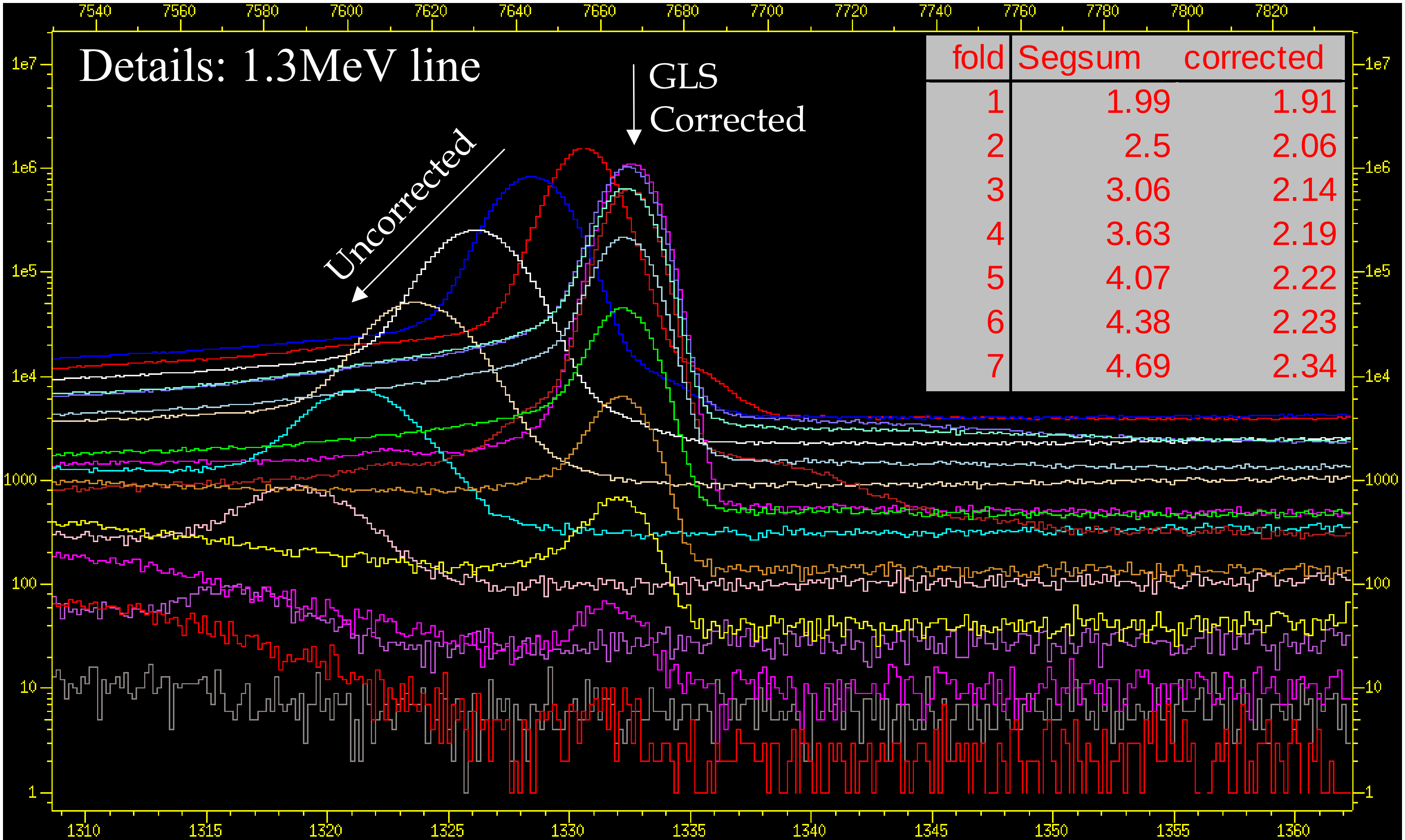


Results in pictures



Results in pictures

FWHM 60keV: 1.20 → 1.02 !



fold	Segsum	corrected
1	1.99	1.91
2	2.5	2.06
3	3.06	2.14
4	3.63	2.19
5	4.07	2.22
6	4.38	2.23
7	4.69	2.34

Summary

Time over Threshold technique

•A resolution of 0.21% was obtained at 9.0 MeV.

•TOT is to be applied BEYOND the range of the ADC in order to extend the energy measurement range (10MeV – 200MeV).

Crosstalk in Segmented Detectors

•The intrinsic cross talk limit in AGATA is reached

•A practical method for cross talk correction was presented

•Combination of Core + Segment = increased resolution.

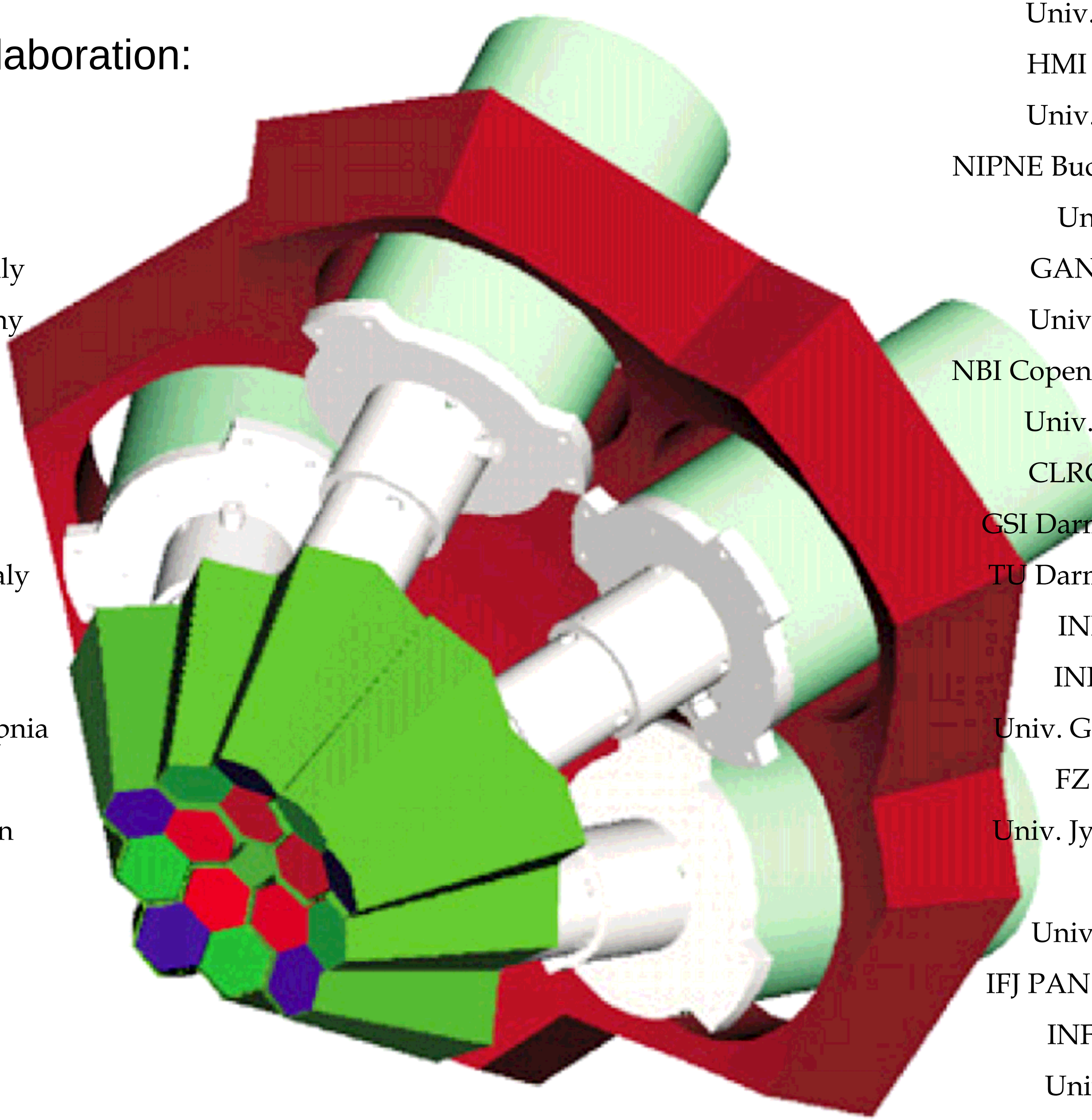
Outlook

•Start assembly AGATA DEMONSTRATOR (5ATC) @ Legnaro (2008)
... First AGATA-like operation

AGATA Homepage : http://www-win.gsi.de/agata/

The AGATA collaboration:

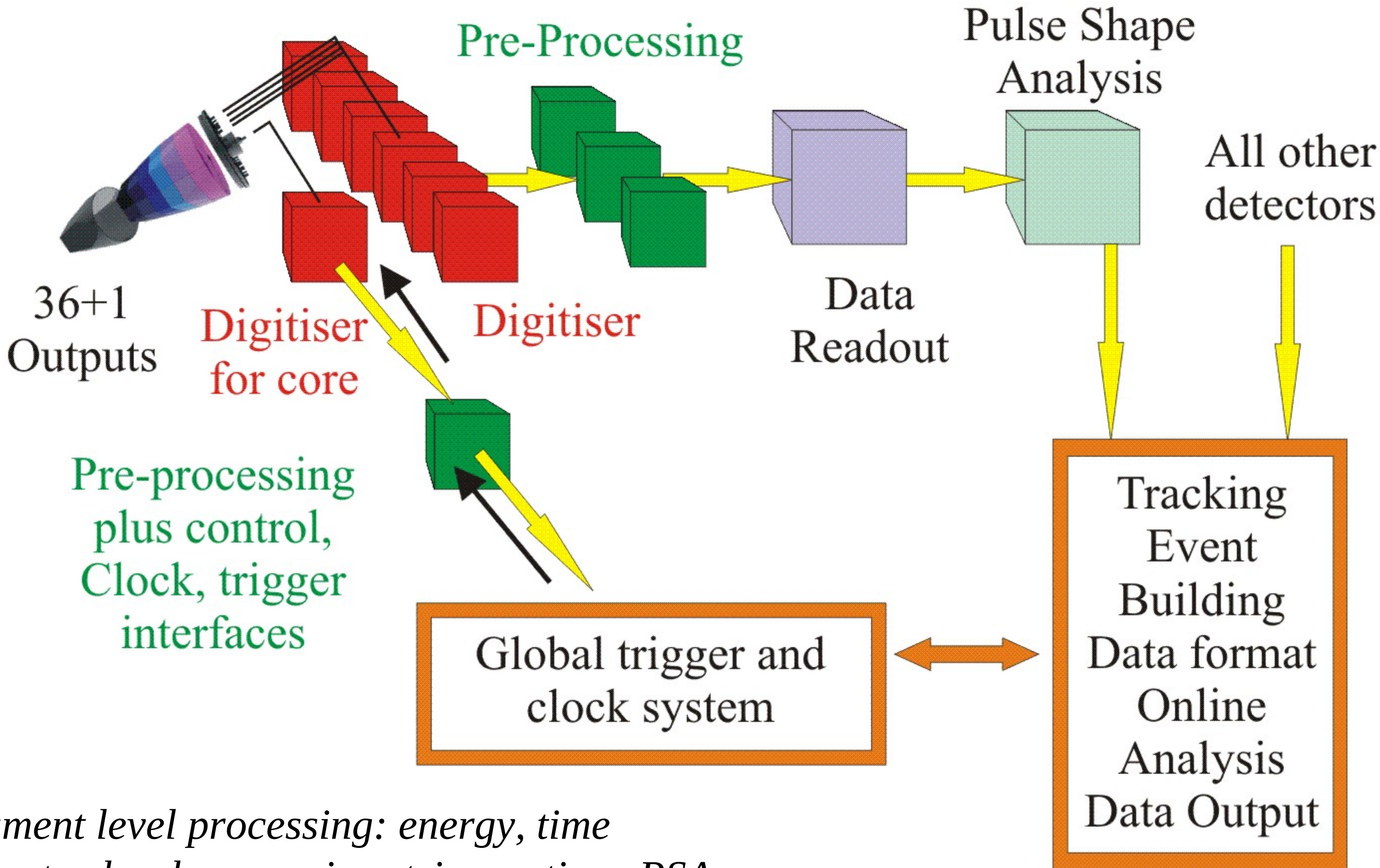
IPN Lyon, France
Univ. Lund, Sweden
Univ. Manchester, UK
INFN/Univ. Milano, Italy
LMU München, Germany
TU München, Germany
INFN Napoli, Italy
CSNSM Orsay, France
IPN Orsay, France
INFN/Univ. Padova, Italy
Univ. Paisley, UK
INFN Perugia, Italy
CEA Saclay, France, Dapnia
Univ. Sofia, Bulgaria
KTH Stockholm, Sweden
IreS Strasbourg, France
Univ. Surrey, UK
IPJ Swierk, Poland
Univ. Warsaw, Poland
Univ. Uppsala, Sweden
Univ. York, UK



Univ. Ankara, Turkey
HMI Berlin, Germany
Univ. Bonn, Germany
NIPNE Bucharest, Romania
Univ. Brighton, UK
GANIL, Caen, France
Univ. Camerino, Italy
NBI Copenhagen, Danmark
Univ. Cracow, Poland
CLRC Daresbury, UK
GSI Darmstadt, Germany
TU Darmstadt, Germany
INFN Firenze, Italy
INFN Genova, Italy
Univ. Göteborg, Sweden
FZ Jülich, Germany
Univ. Jyväskylä, Finland
Univ. Keele, UK
Univ. Köln, Germany
IFJ PAN Krakow, Poland
INFN Legnaro, Italy
Univ. Liverpool, UK
Univ. Istanbul, Turkey

AGATA Homepage : http://www-win.gsi.de/agata/

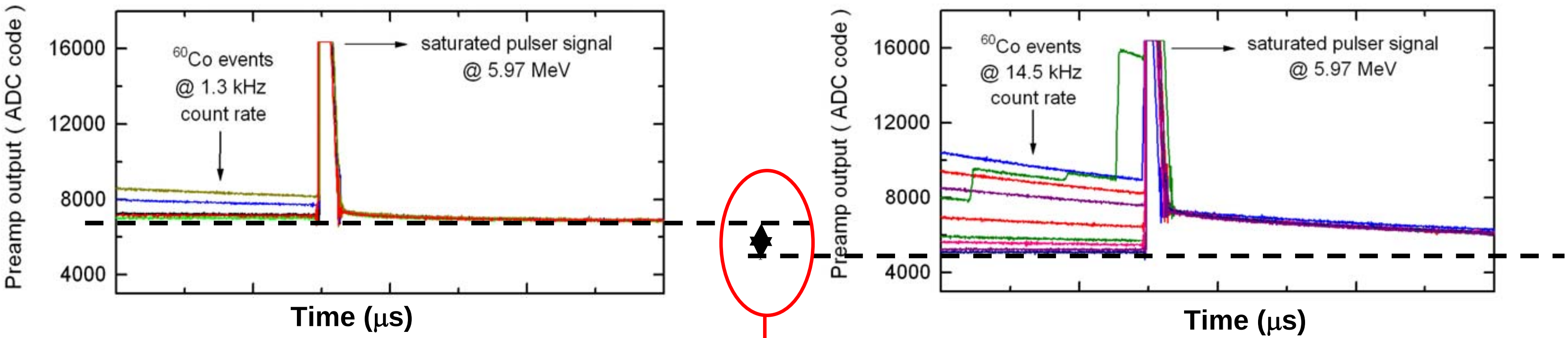
Schematic of the Digital Electronics and Data Acquisition System for AGATA



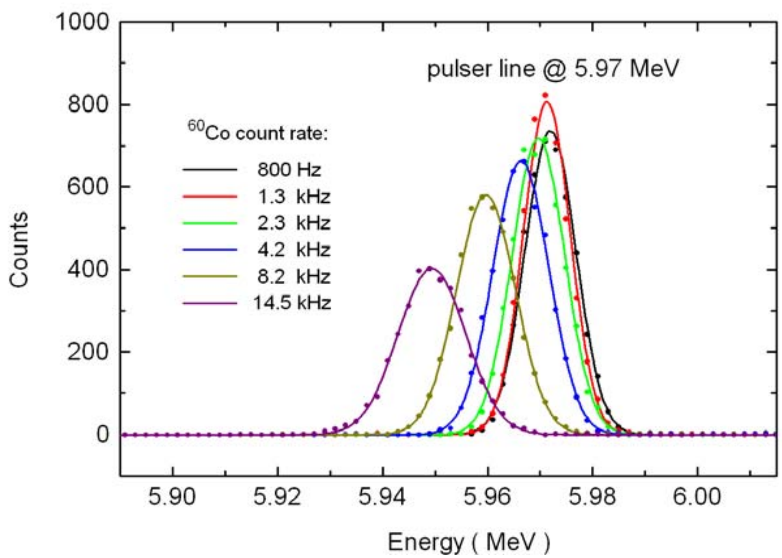
Segment level processing: energy, time
Detector level processing: trigger, time, PSA
Global level processing: event building, tracking, software trigger, data storage

Peak shift at increasing count rates

1.3 kHz count rate   14.5 kHz count rate



The baseline shifts downwards due to *AC*-coupled preamplifier



from Campbell's theorem :

$$\Delta E_{shift} = \lambda < E > T$$

λ = event rate

‹ E › = mean event energy

T = reset time