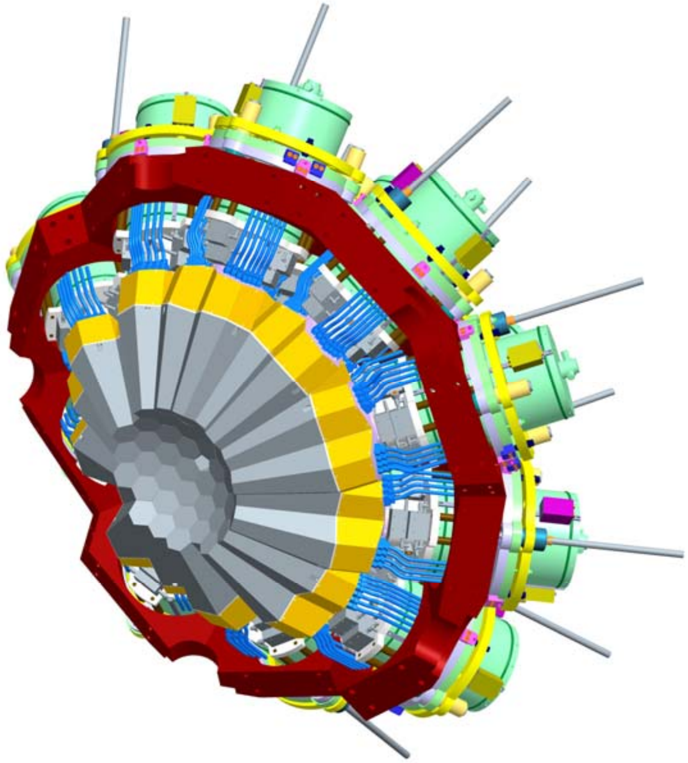
Advances in HPGe technology
The new AGATA triple cluster

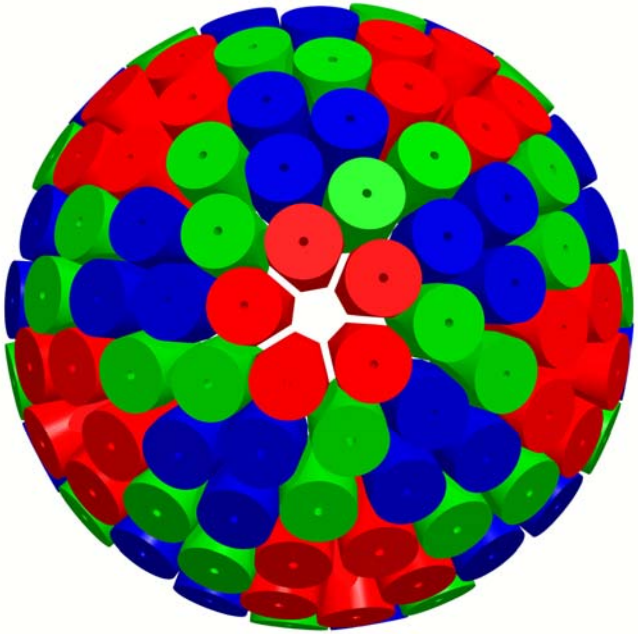


- ❑ Requirements for AGATA
- ❑ AGATA triple cluster
- ❑ Core preamp & pulser
- ❑ Triple cluster: resolution
- ❑ Cross talk studies
- ❑ Triple cluster: cross talk
- ❑ Summary / Outlook

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
EGP workshop, Paris 29/5/08

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

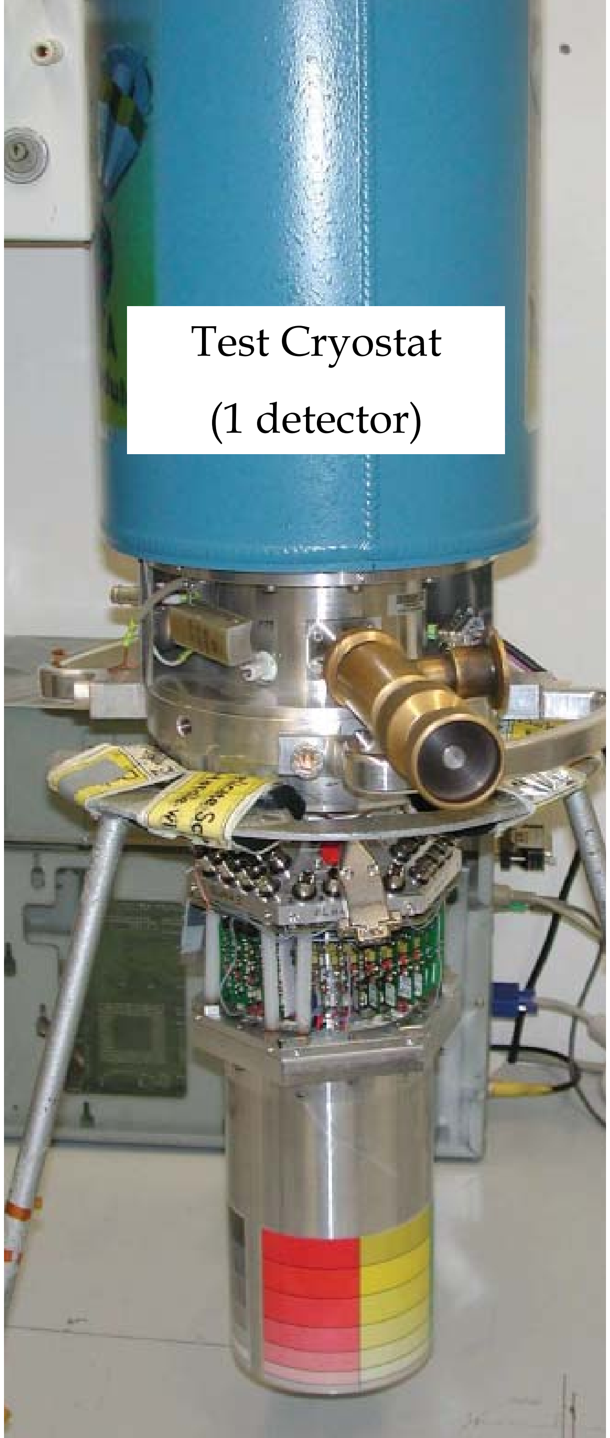
Rates: 3 MHz (M_γ=1) 300 kHz (M_γ=30)
today 1 MHz 20 kHz

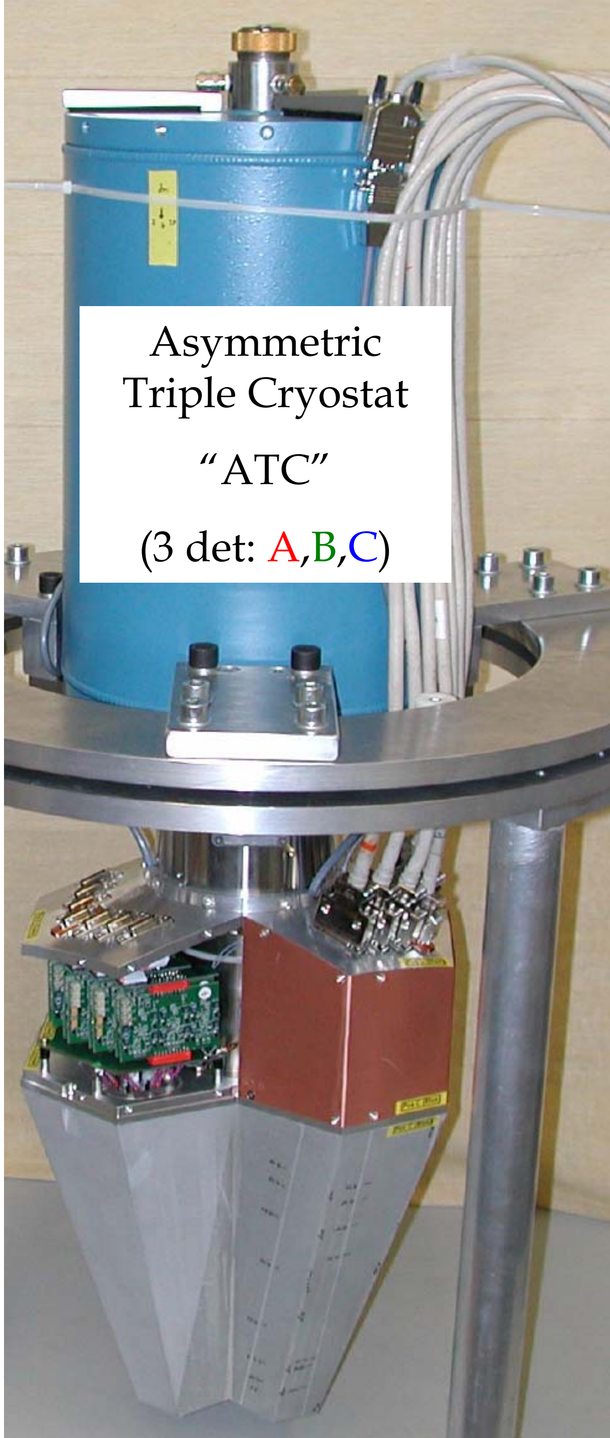
- 180 large volume 36-fold segmented Ge crystals in 60 triple-clusters
- Digital electronics and sophisticated Pulse Shape Analysis algorithms allow
- Operation of Ge detectors in position sensitive mode → γ-ray tracking

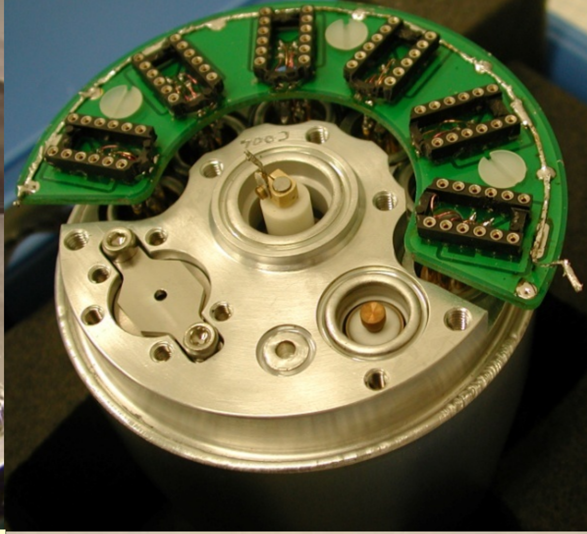
Acceptance test (CAT)
IKP / Saclay

Characterization
Liverpool / GSI / Orsay

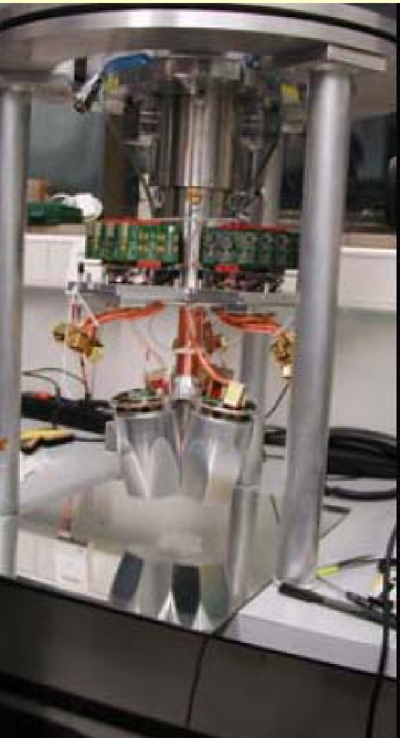
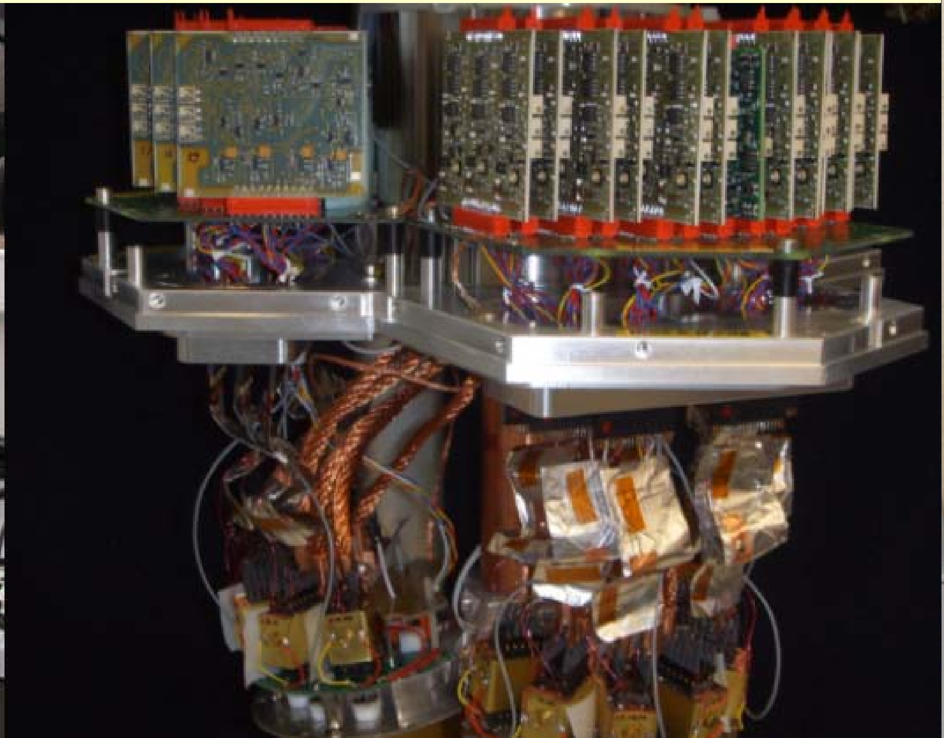
Assembly in ATC



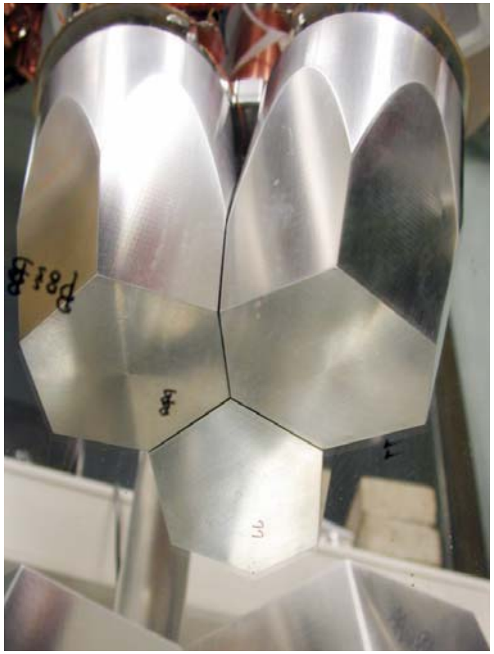


First AGATA triple-detector @ IKP Cologne


Asymmetric AGATA Triple Cryostat

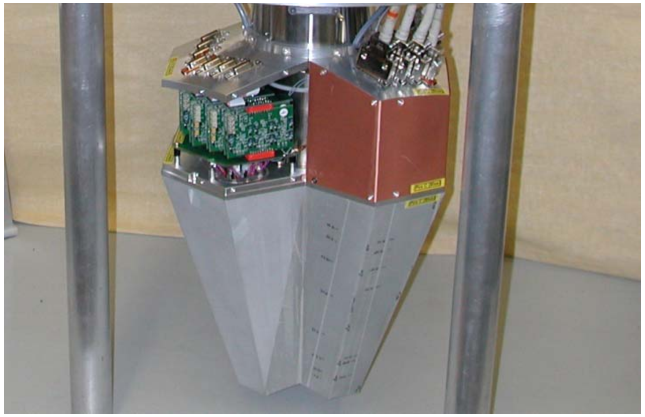


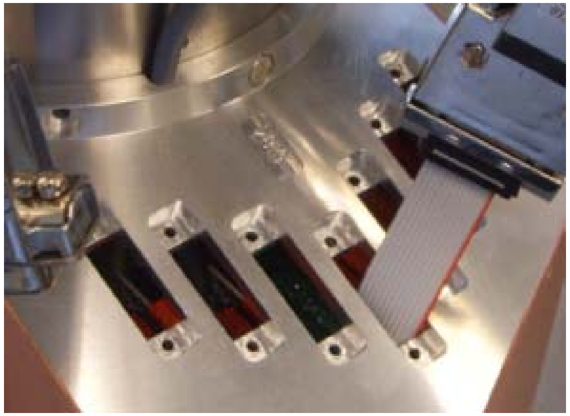
Mechanical precision of the end caps
(bending under vacuum within tolerances)

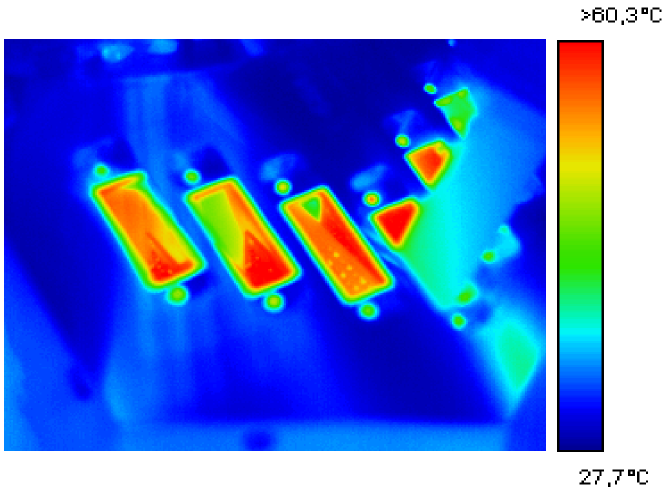
Exact positioning of the detectors
inside the triple
Spacing 0.5 mm

Heat development of
111 spectroscopic channels
(Limit 65°C not exceeded)

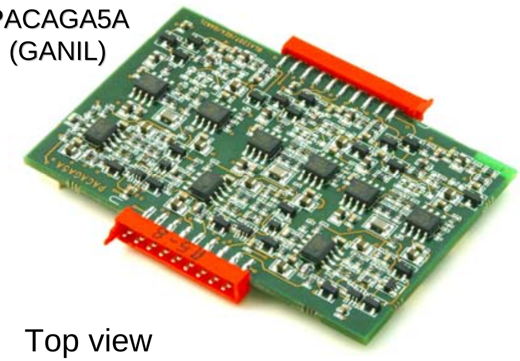
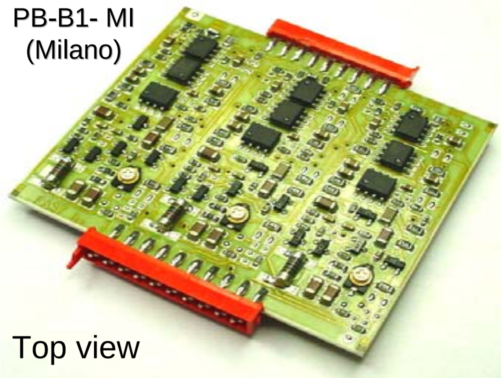
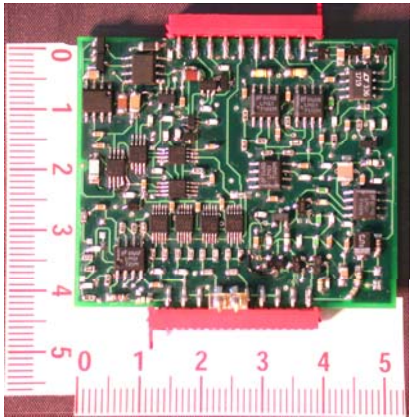
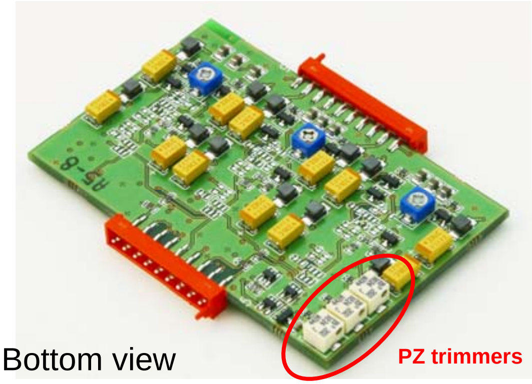
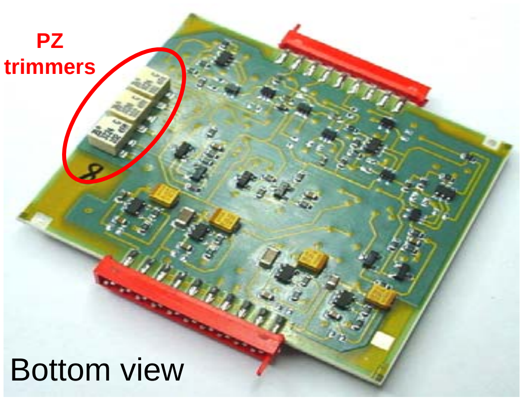
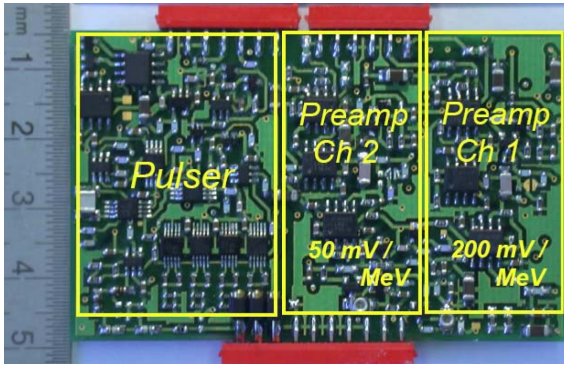
Low LN2 consumption







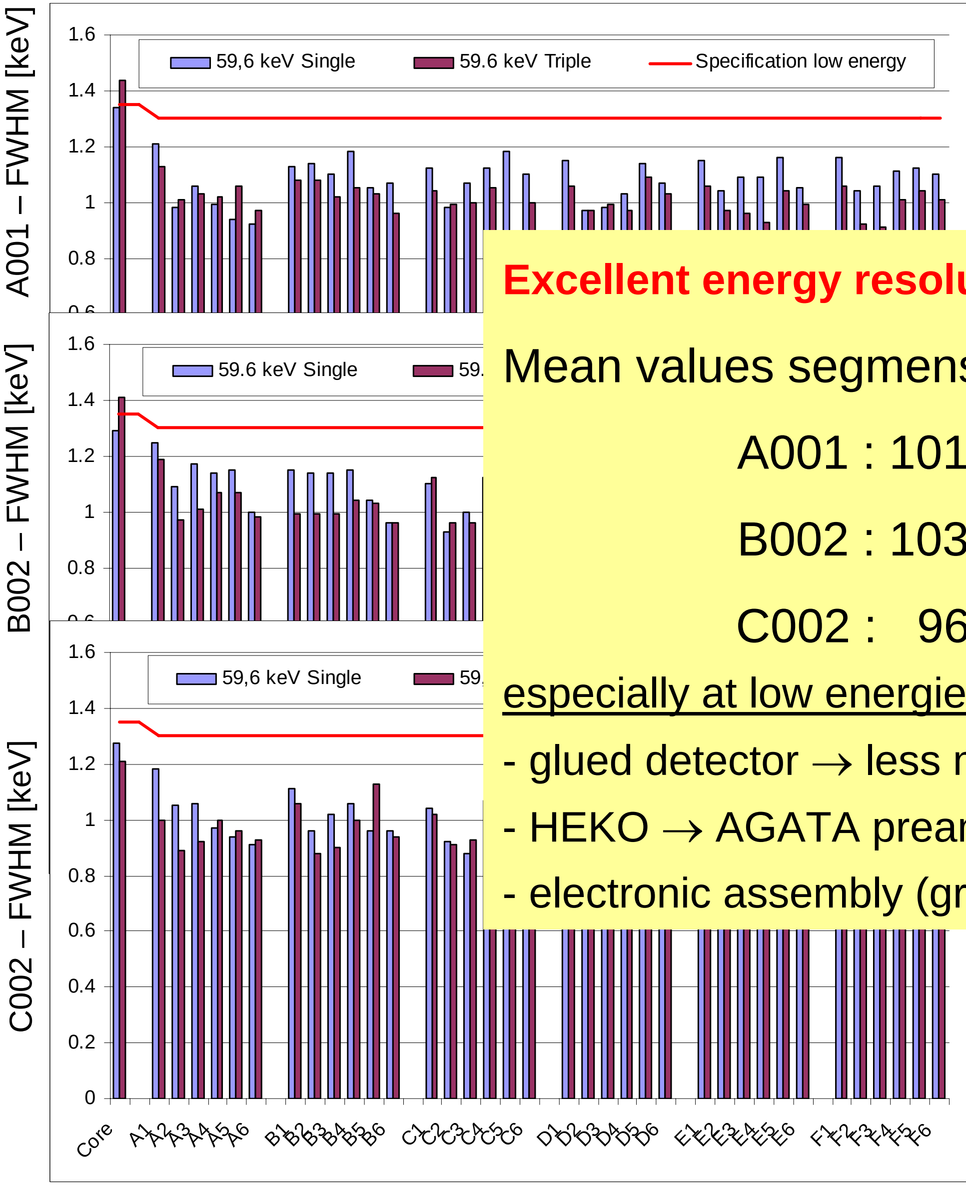
Developed preamplifiers

PACAGA5A (GANIL)  Top view	PB-B1- MI (Milano)  Top view	AGATA_ core-pulser (Koeln)  1 Channel version
 Bottom view	 Bottom view	New version: "Dual Core" 
<u>Triple segment preamp</u> **on FR4 substrate** **Mod. "PACAGA5A" – GANIL** B. Cahan et al.	**<u>Triple segment preamp</u>** **on alumina substrate** **Mod. "PB-B1 MI" – Milano** A. Pullia et al.	**<u>Core preamplifier & built-in pulser</u>** **on FR4 substrate** **Mod. "AGATA core-pulser" – Koeln** G. Pascovici et al.

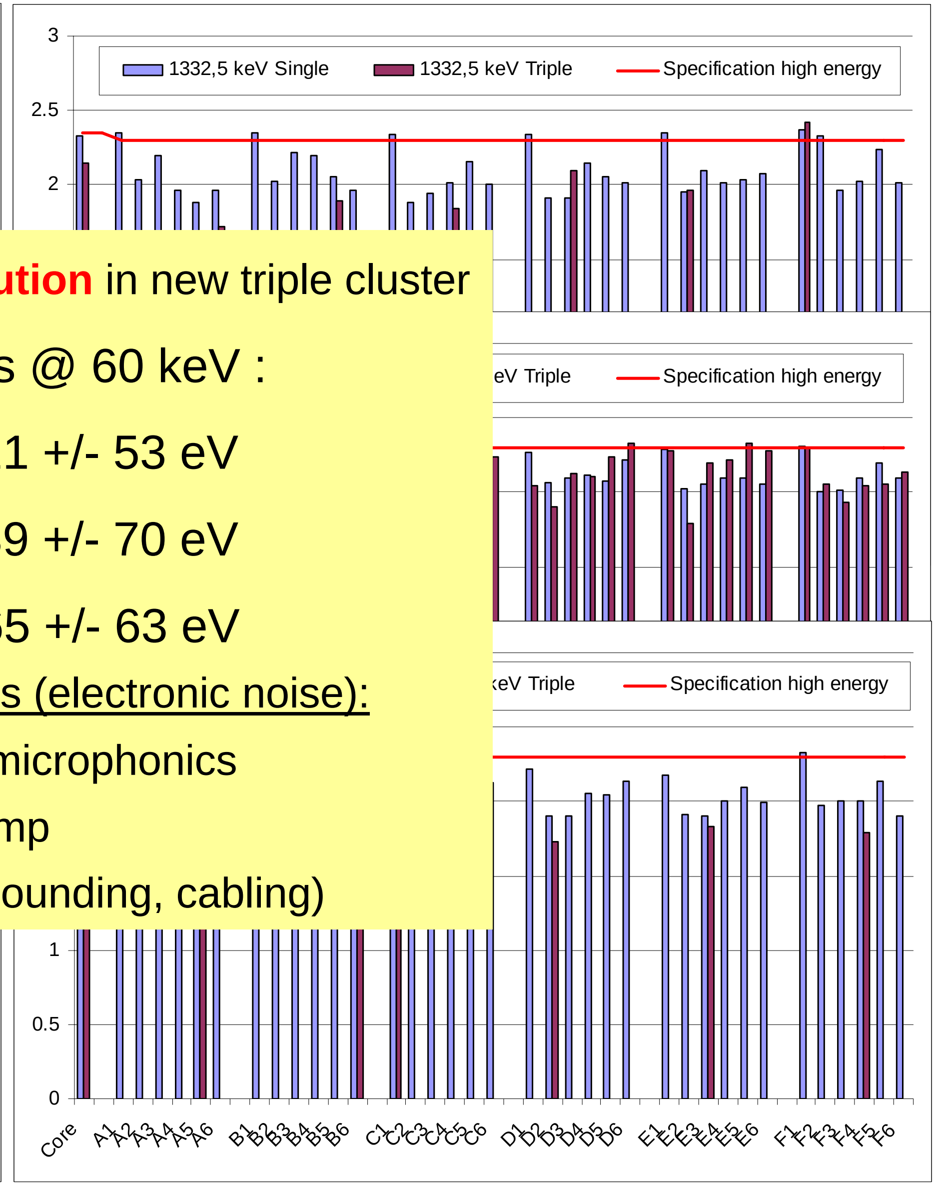
A. Pullia, G. Pascovici, B. Cahan, D. Weisshaar, C. Boiano, R. Bassini, M. Petcu, F. Zocca, "**The AGATA charge-sensitive preamplifiers with built-in pulser and active-reset device**", Proc. Nucl. Sci. Symp., October 16-22, 2004, Rome, Italy

Tripel Cluster Energies: Single vs Triple cryostat

Resolution 60keV line



Resolution 1.33MeV line



Excellent energy resolution in new triple cluster

Mean values segmens @ 60 keV :

A001 : 1011 +/- 53 eV

B002 : 1039 +/- 70 eV

C002 : 965 +/- 63 eV

especially at low energies (electronic noise):

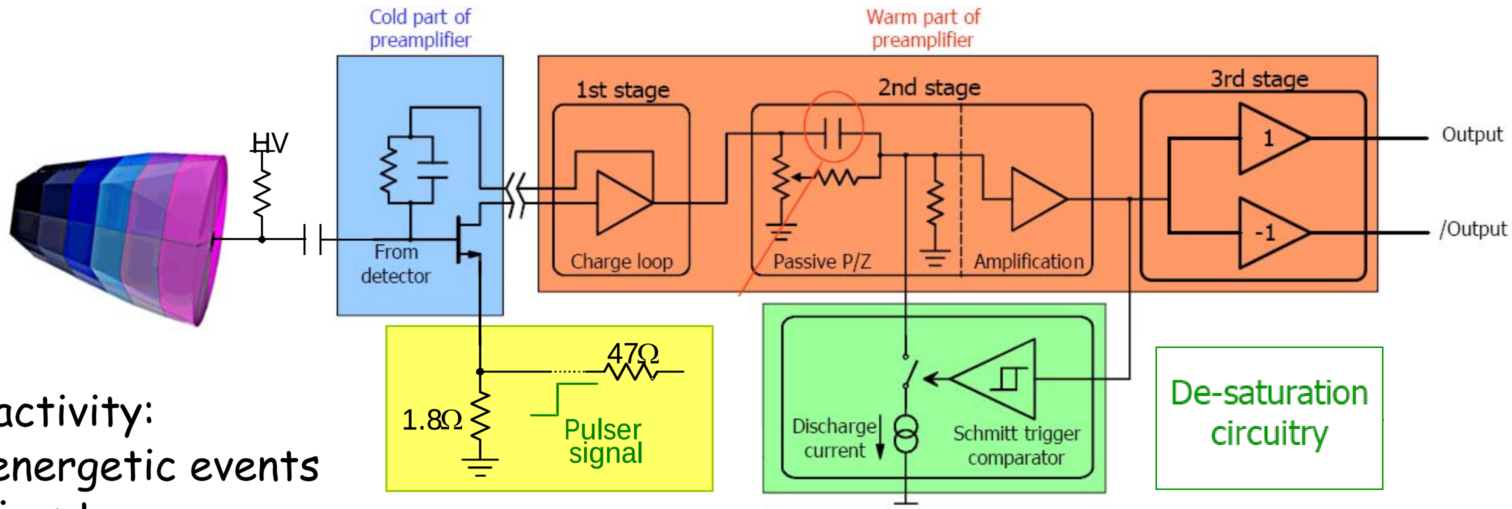
- glued detector → less microphonics
- HEKO → AGATA preamp
- electronic assembly (grounding, cabling)

AGATA DUAL core preamplifier

γ (≈ 1-10MeV)

$p^{\pm}$ $K^{\pm}$

(≈ 10-100 MeV)



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

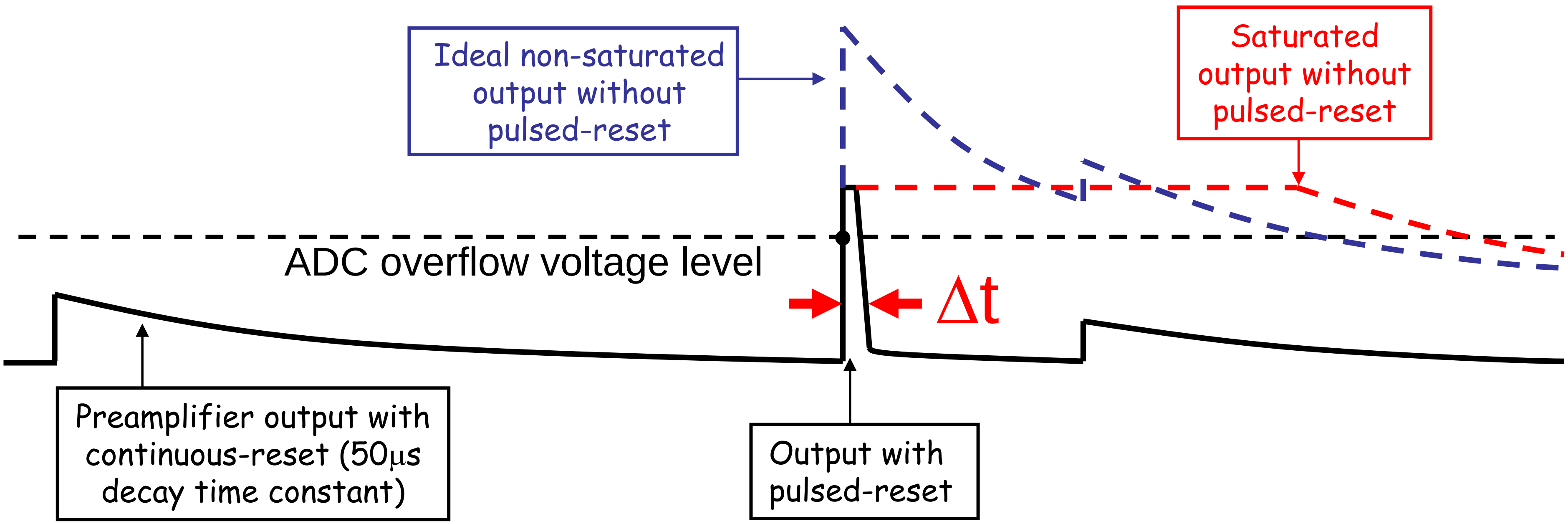
Requirement core preamp:

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

"Low noise, dual gain preamplifier with built in spectroscopic pulser for highly segmented high-purity germanium detectors"

G. PASCOVICI et al. - WSEAS Conference, Bucharest, Romania, June 24-26, 2008

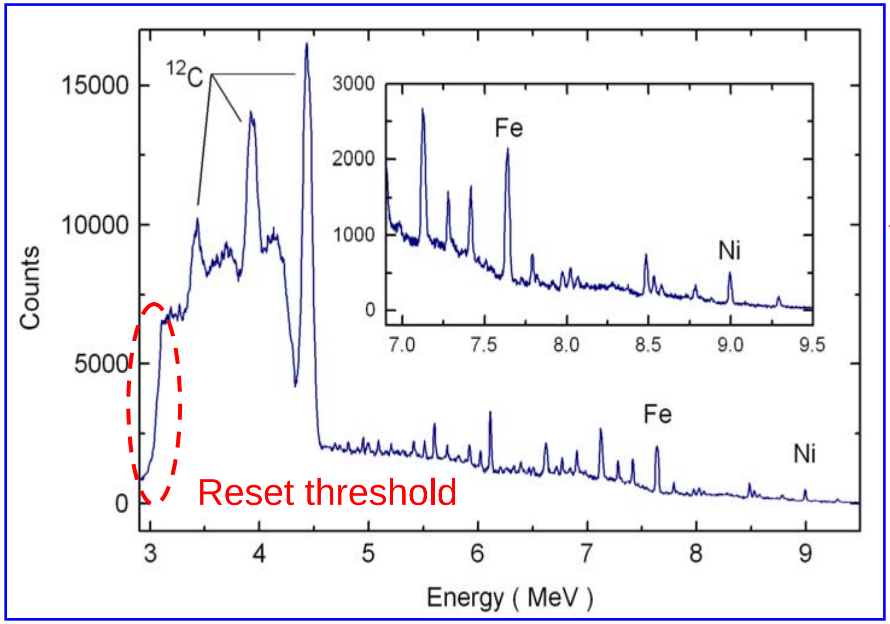
Mixed reset technique: continuous + pulsed



An ADC overflow condition would saturate the system for a long while ➡ Pulsed-reset mechanism allows fast recovery of the output (upto x4/x5 in throughput)

"Time Over Threshold" (T.O.T) : $\Delta t \propto E$

^{241}Am+Be spectrum

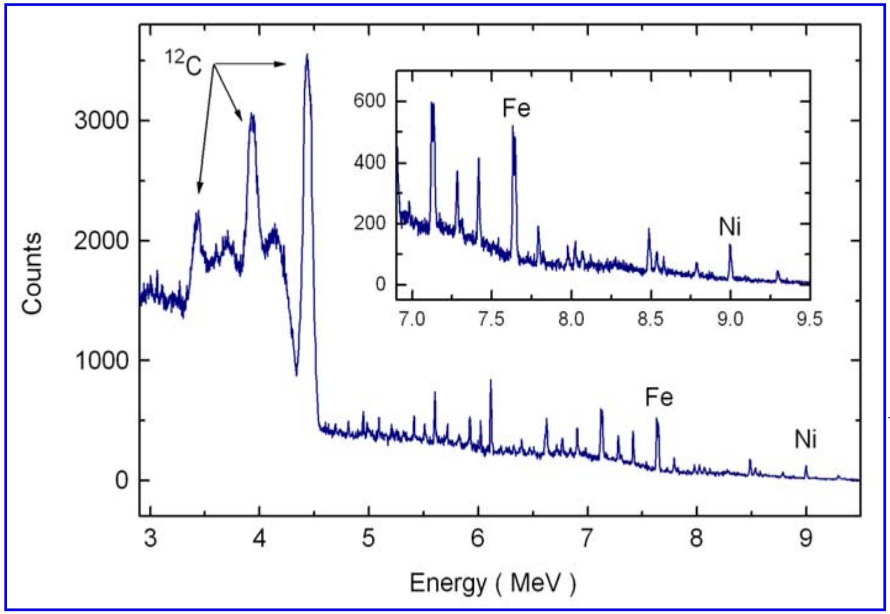


"reset" mode (by TOT technique)

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 %**

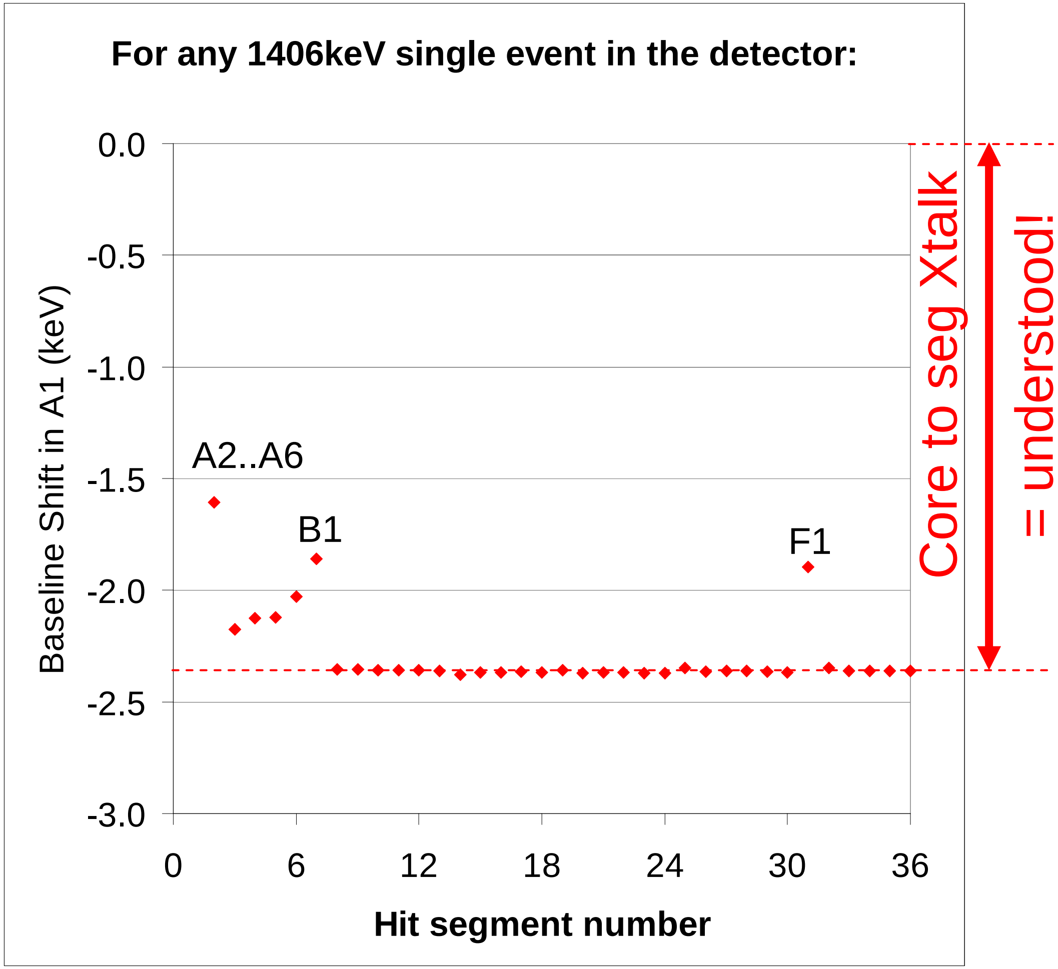
At high energies (> 10 MeV)

TOT mode ~ pulse-height mode

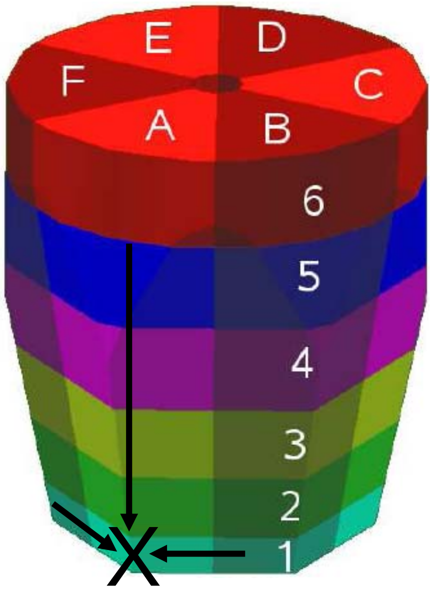


"pulse-height" mode

Cross talk : intro



Segment labeling:



Sectors: A...F

Rings: 1...6

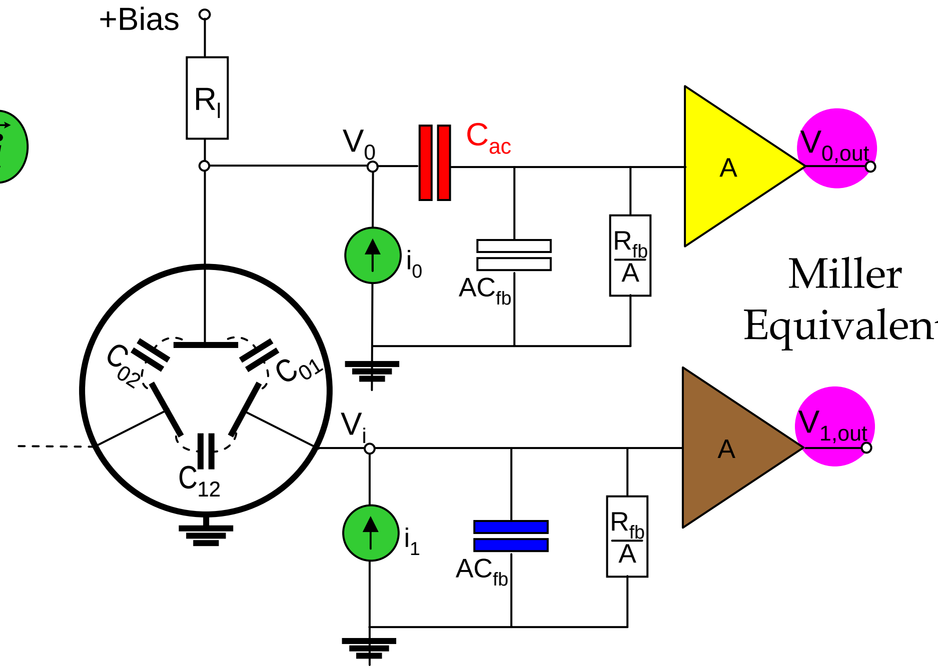
A model to describe cross talk

Segment-to-Core

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

Core-to-Seg | Segment-to-Segment

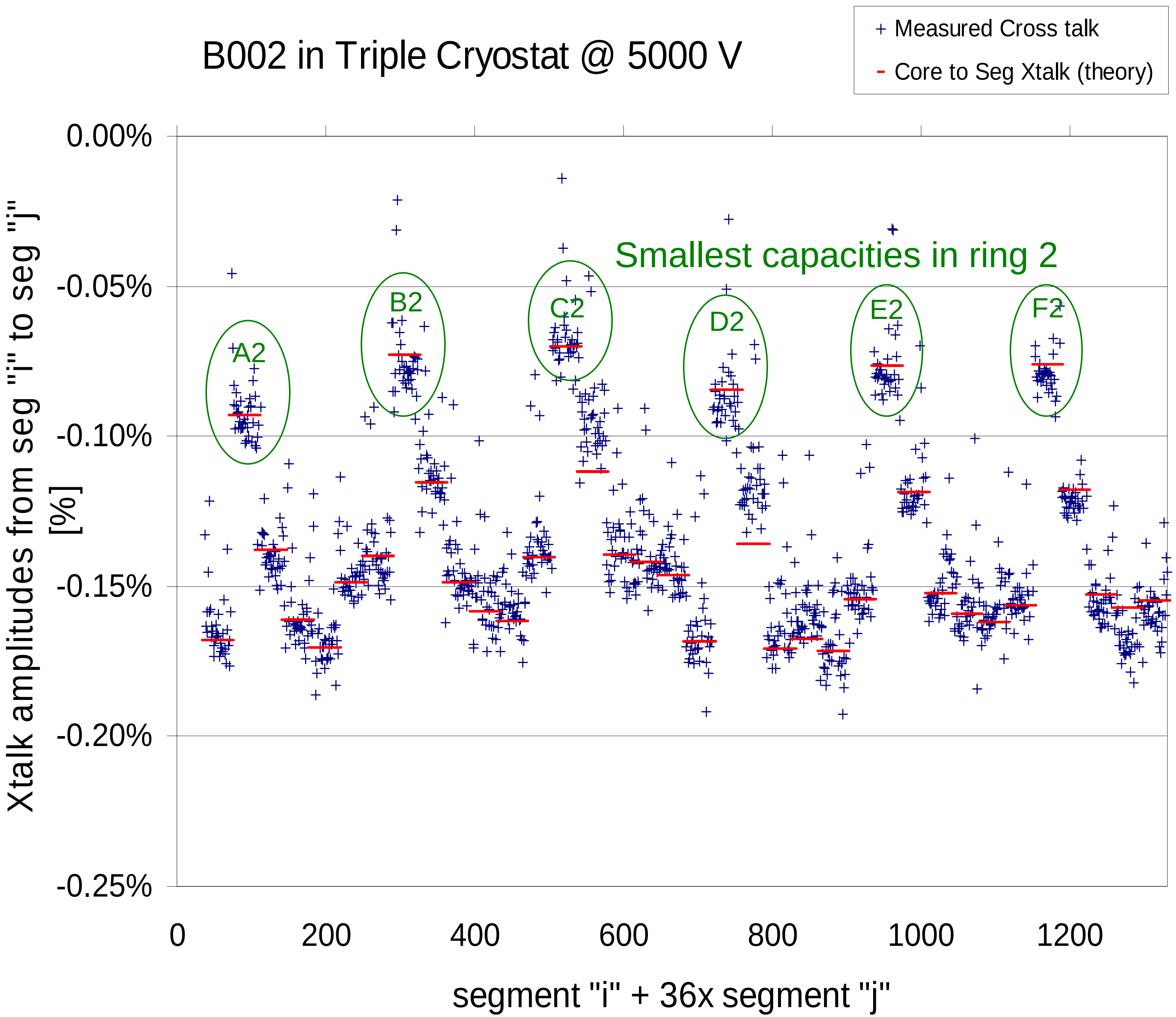
~ 1pF/1000pF | ~1pF/(10000 · 1pF)



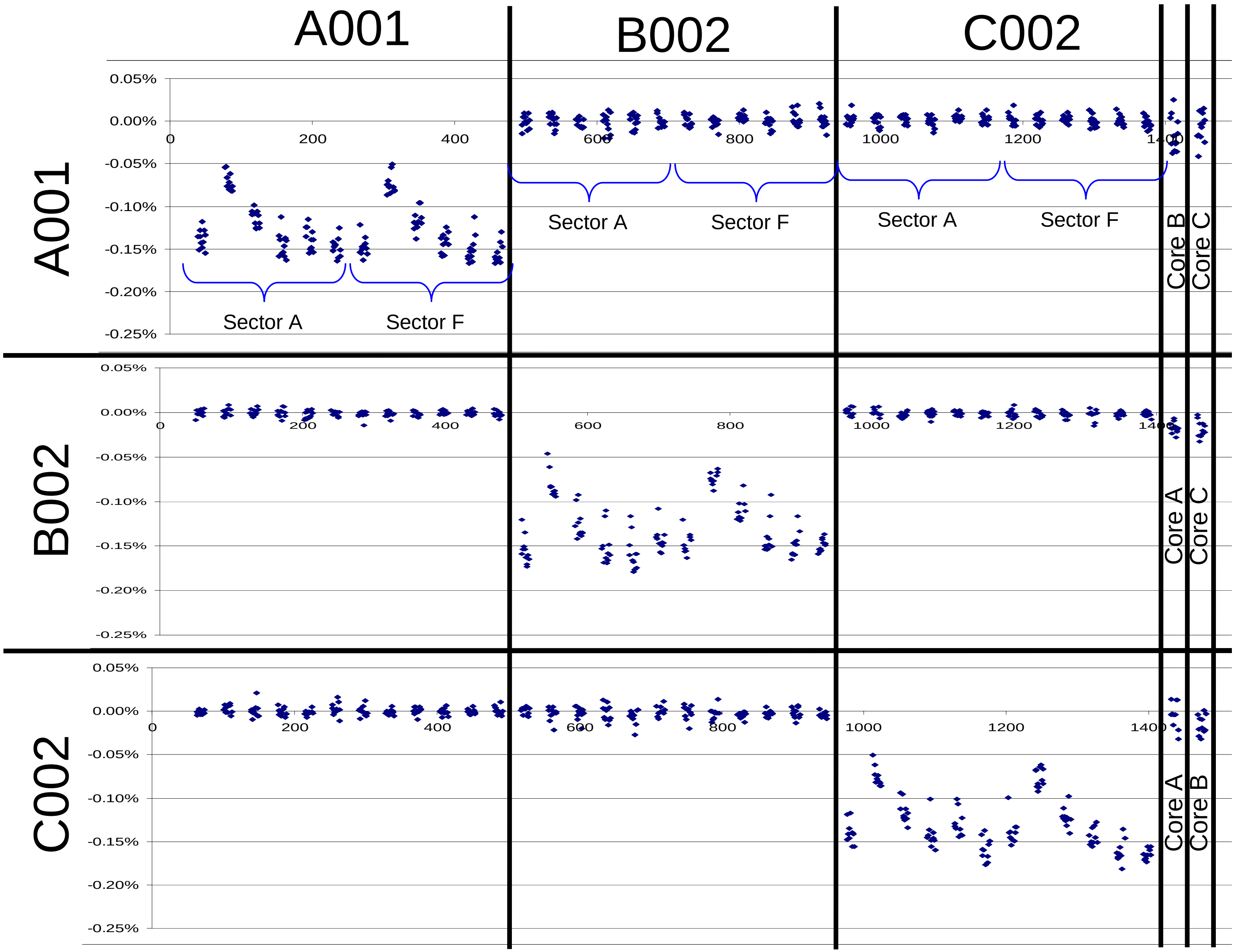
Crosstalk is intrinsic property of segmented detectors !

B. Bruyneel et al – to be submitted to NIM

E. Gatti et al – NIM 193 (82) p. 651

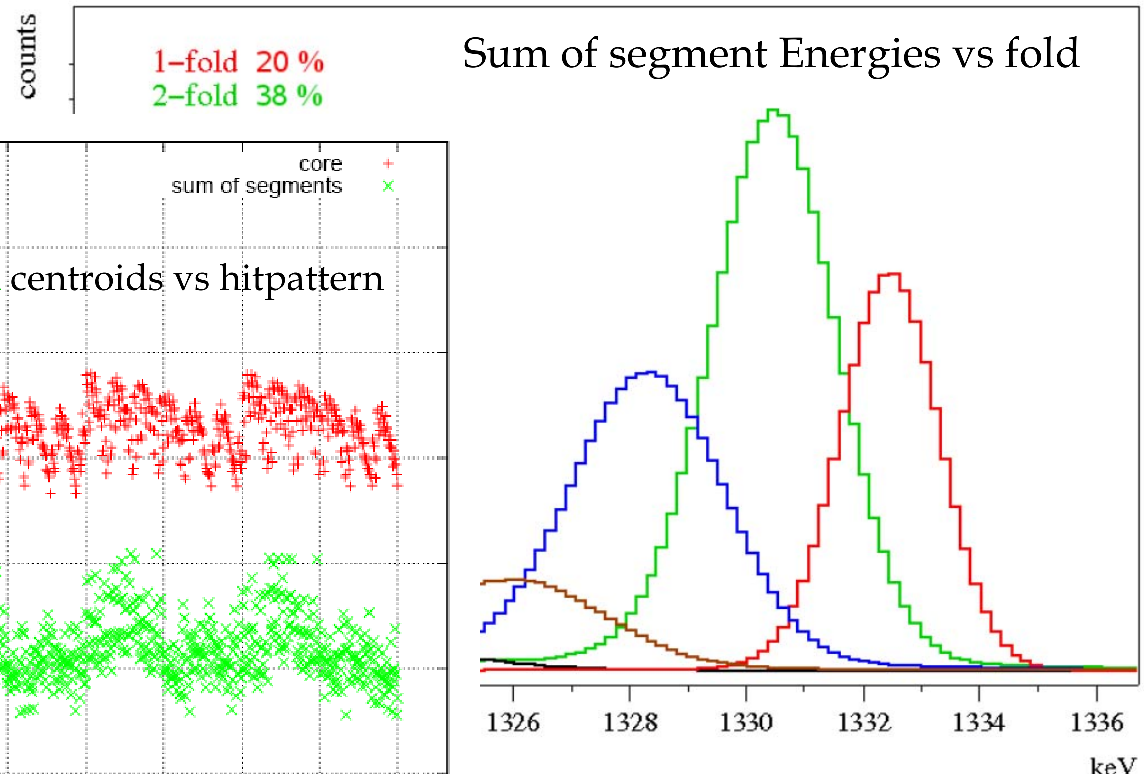

B002 in Triple Cryostat @ 5000 V
Measured Cross talk
Core to Seg Xtalk (theory)
Smallest capacities in ring 2
A2
B2
C2
D2
E2
F2
0.00%
-0.05%
-0.10%
-0.15%
-0.20%
-0.25%
0
200
400
600
800
1000
1200
Xtalk amplitudes from seg "i" to seg "j" [%]
segment "i" + 36x segment "j"

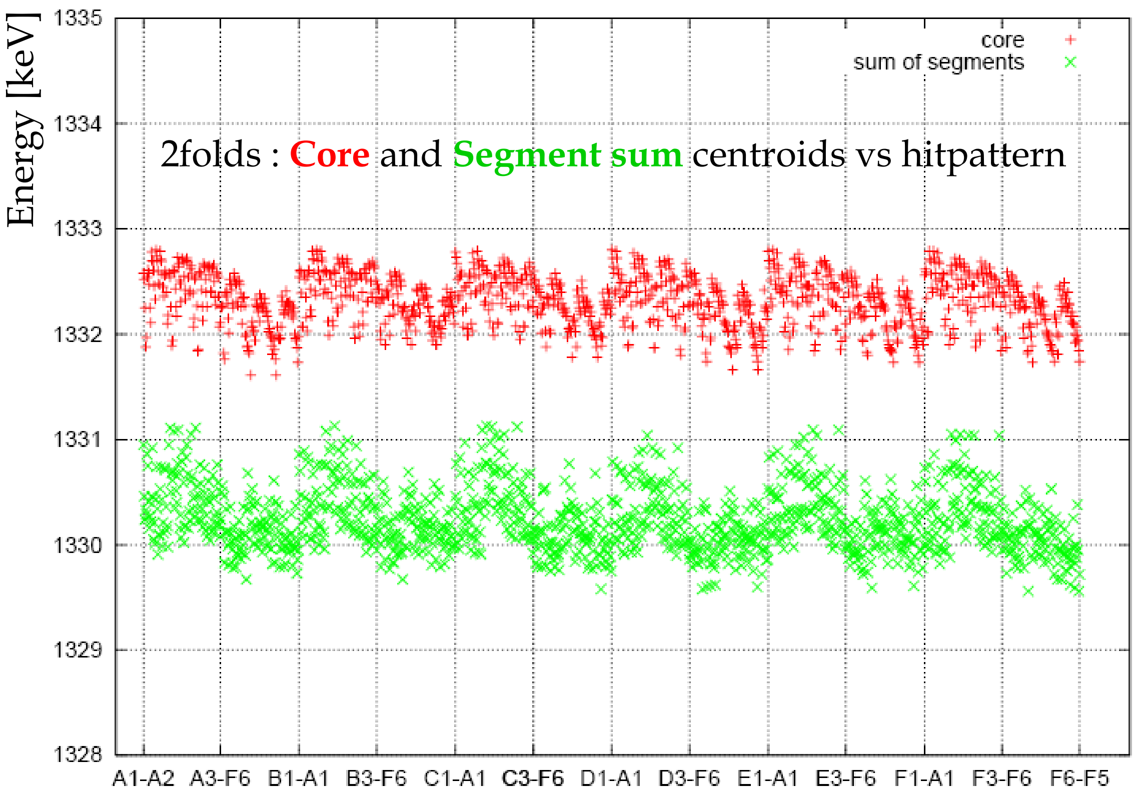
Cross talk in Triple Cryostat



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> !

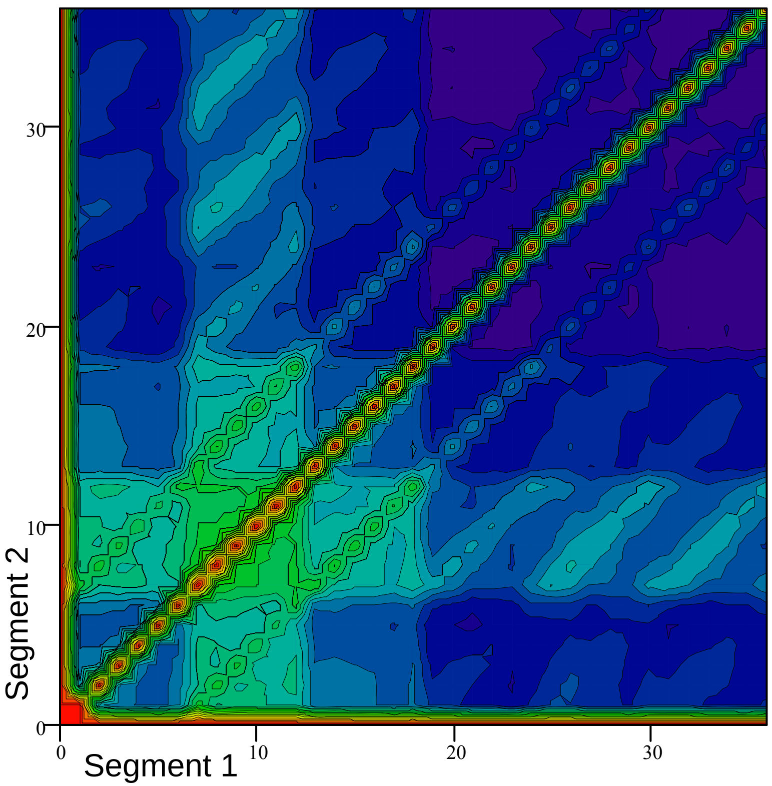




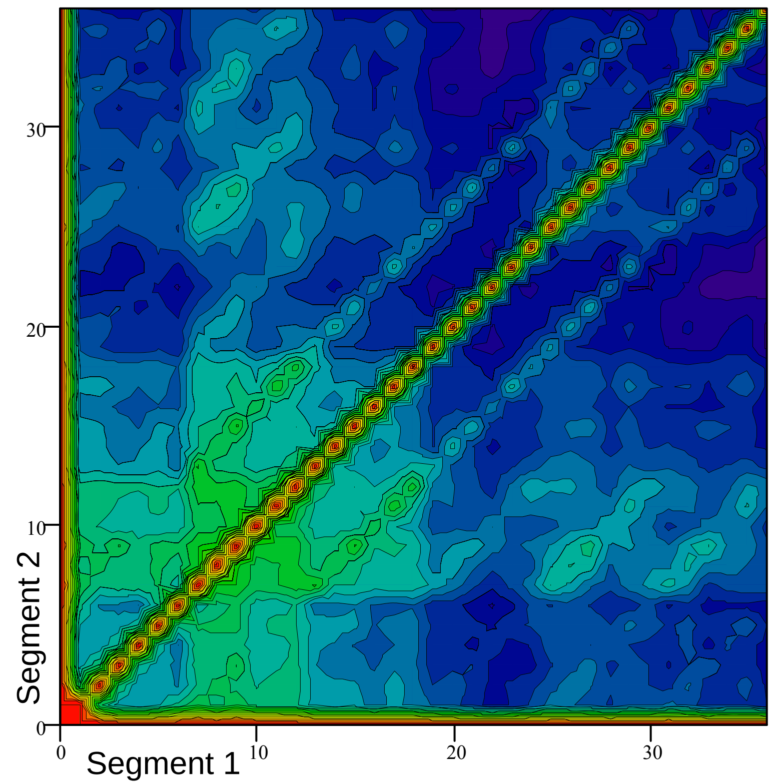
…All possible 2fold combinations

Core to segment crosstalk in 2folds

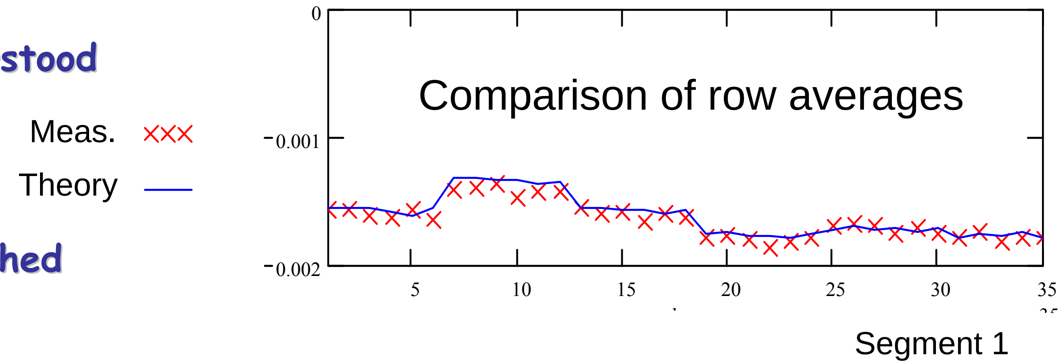
Simulation



Measured (S001)



- Core to segment cross talk understood
- Quantitative agreement between theory and observation
- Fundamental cross talk limit reached



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:*

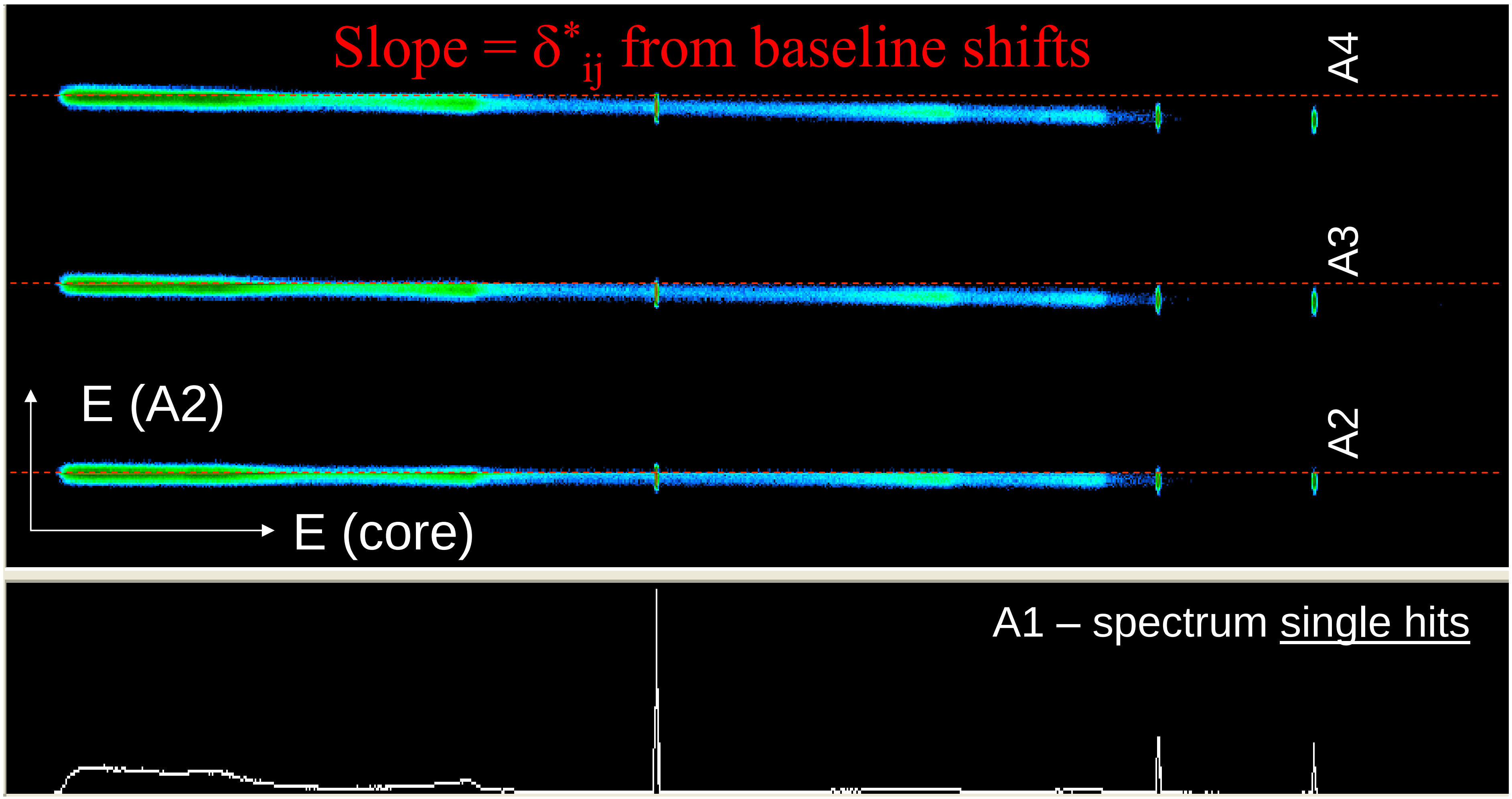
$$\begin{bmatrix} E_{core} \\ \hdashline E_{seg1} \\ E_{seg2} \\ E_{seg3} \end{bmatrix}_{meas} = \begin{bmatrix} 1+\delta_{01}^{*} & 1+\delta_{02}^{*} & 1+\delta_{03}^{*} \\ \hdashline 1 & \delta_{12}^{*} & \delta_{13}^{*} \\ \delta_{21}^{*} & 1 & \delta_{23}^{*} \\ \delta_{31}^{*} & \delta_{32}^{*}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

All matrix elements measured

Measuring the cross talk parameters

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

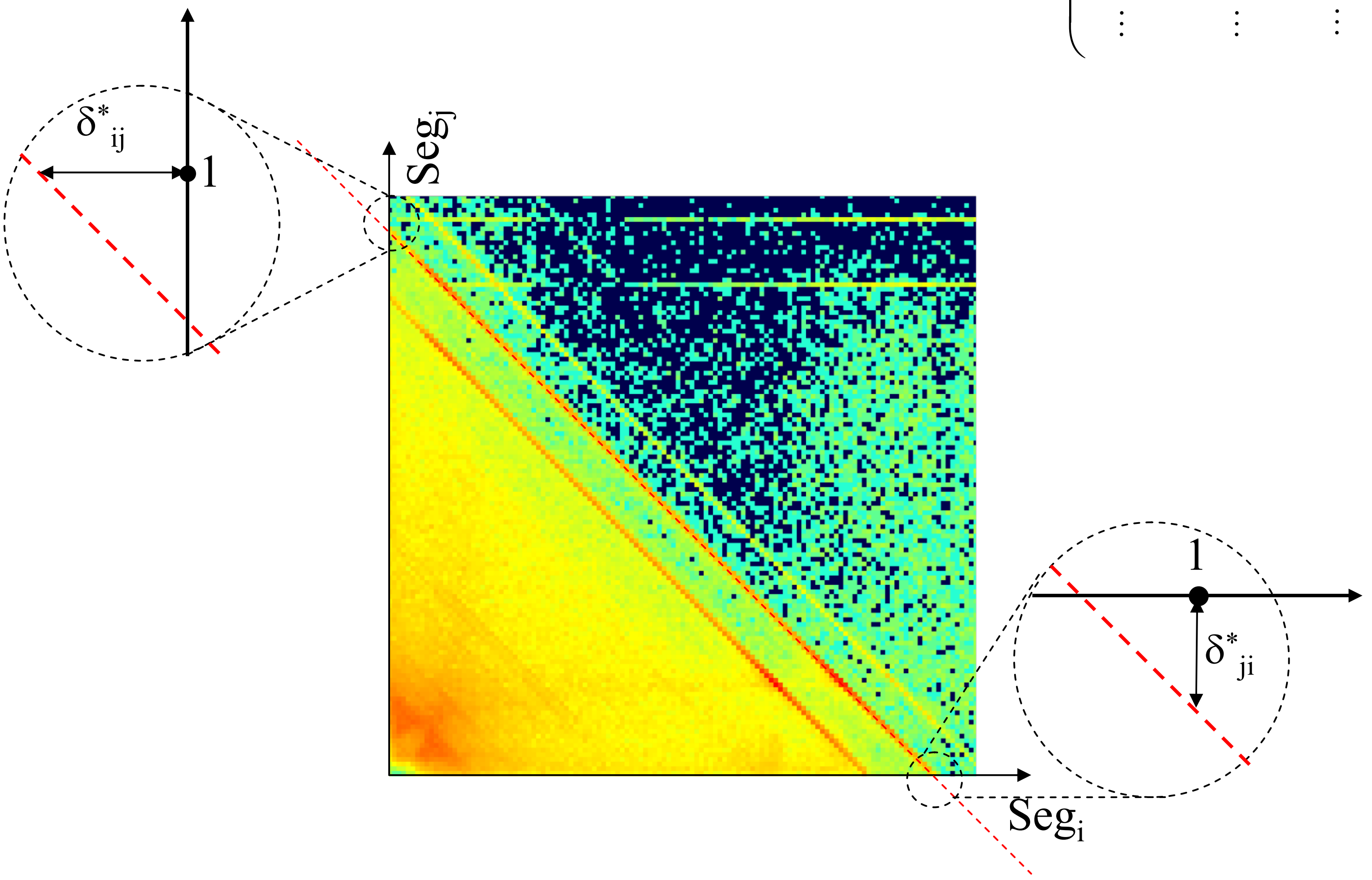
a) From singles:



Measuring the cross talk parameters

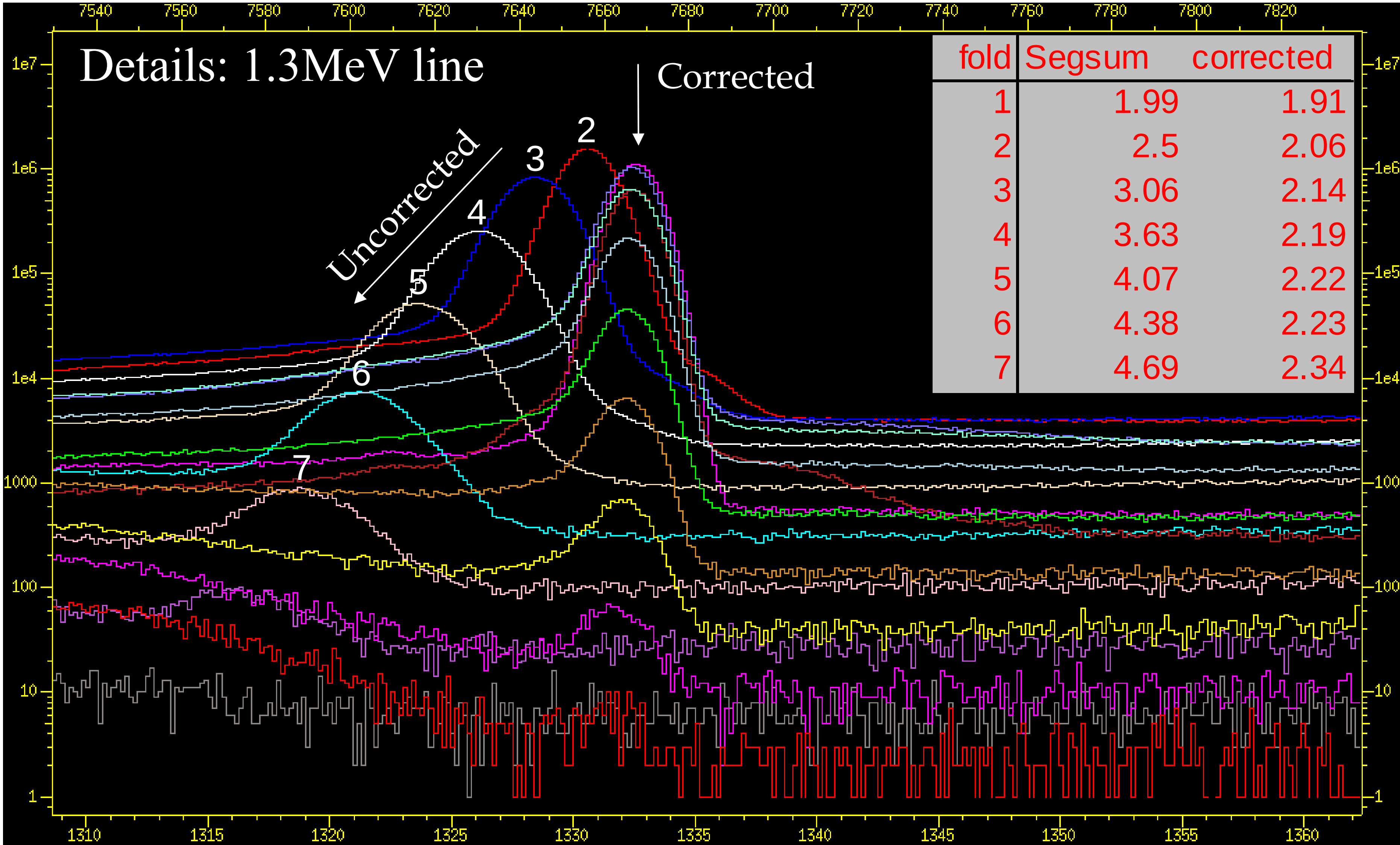
$$\begin{pmatrix} 1+\delta^*_{01} & 1+\delta^*_{02} & 1+\delta^*_{03} & \cdots \\ 1 & \delta^*_{12} & \delta^*_{13} & \cdots \\ \delta^*_{21} & 1 & \delta^*_{23} & \cdots \\ \delta^*_{31} & \delta^*_{32} & 1 & \\ \vdots & \vdots & \vdots & \ddots \end{pmatrix}$$

b) From doubles:



Cross talk correction: Results

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

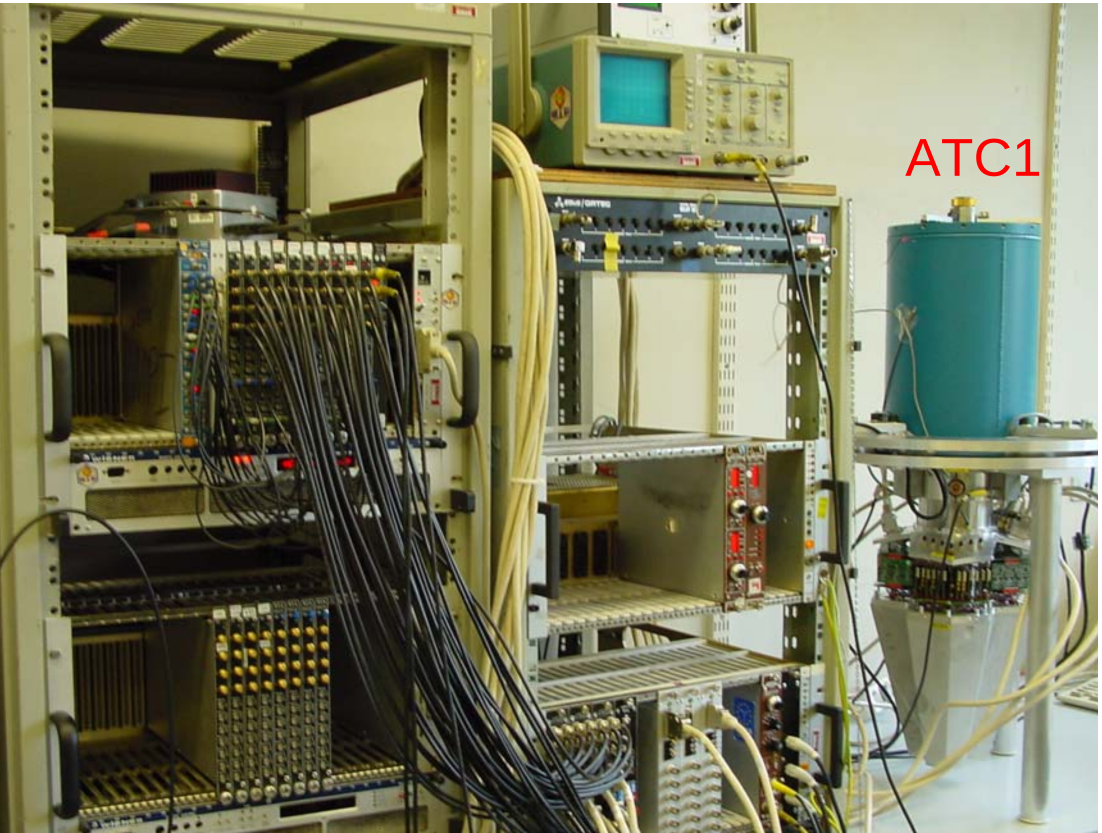
AGATA Triple Cluster: Summary and outlook

AGATA Triple Cluster Detectors operational:
- first triple: cryostat, mechanics, vacuum o.k.
  thermic properties of preamps o.k.
  seg-preamps, core preamps & pulser o.k.
  High dynamic range
  energy resolution o.k.
  no cross talk between detectors –
  (fundamental xtalk limit reached)

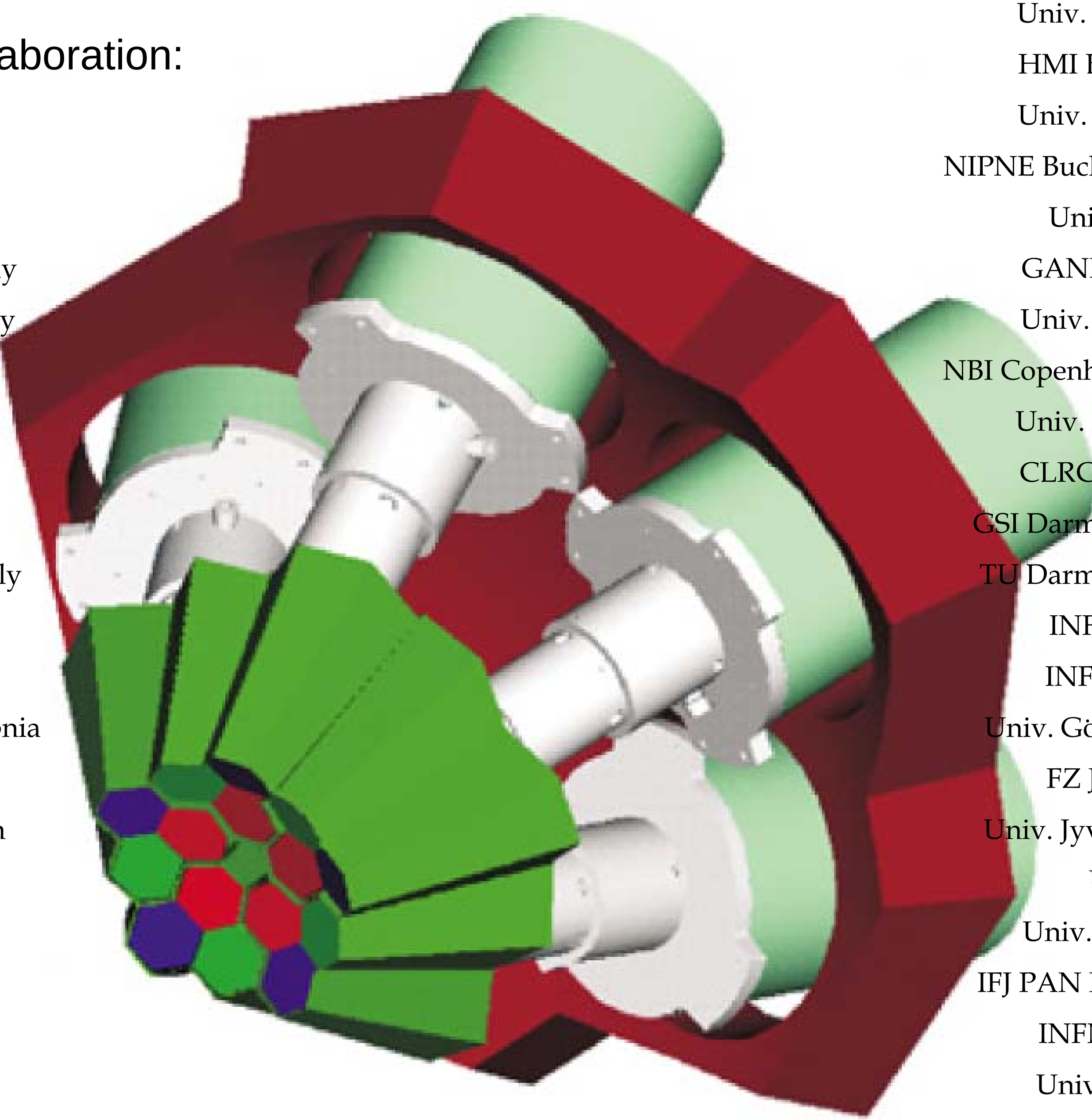
Outlook: Demonstrator at Legnaro:

- transport to Legnaro and first tests with digital electronics at Legnaro June/July 2008

- assembly constrained by available detectors



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

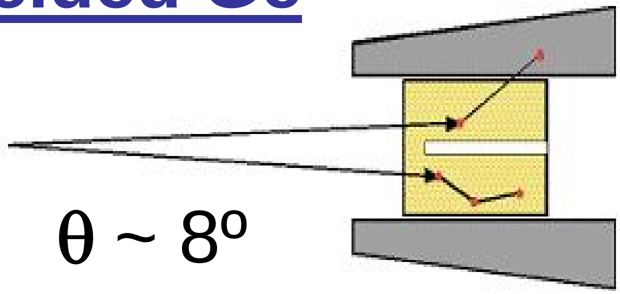
Univ. Ankara, Turkey
HMI Berlin, Germany
Univ. Bonn, Germany
NIPNE Bucharest, Romania
Univ. Brighton, UK
GANIL, Caen, France
Univ. Camerino, Italy
NBI Copenhagen, Danmark
Univ. Cracow, Poland
CLRC Daresbury, UK
GSI Darmstadt, Germany
TU Darmstadt, Germany
INFN Firenze, Italy
INFN Genova, Italy
Univ. 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/

Idea of γ-ray tracking

Compton Shielded Ge

ε_{ph}	~ 10%
N_{det}	~ 100
Ω ~40%	

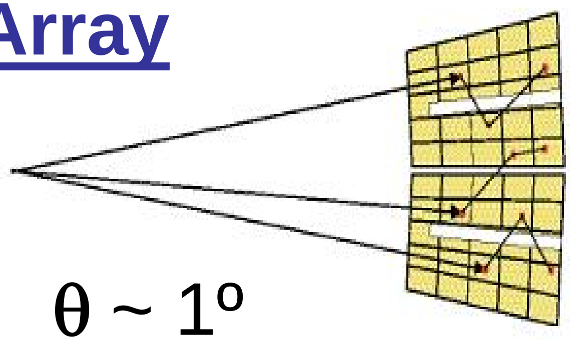


large opening angle means poor energy resolution at high recoil velocity.

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

Ge Tracking Array

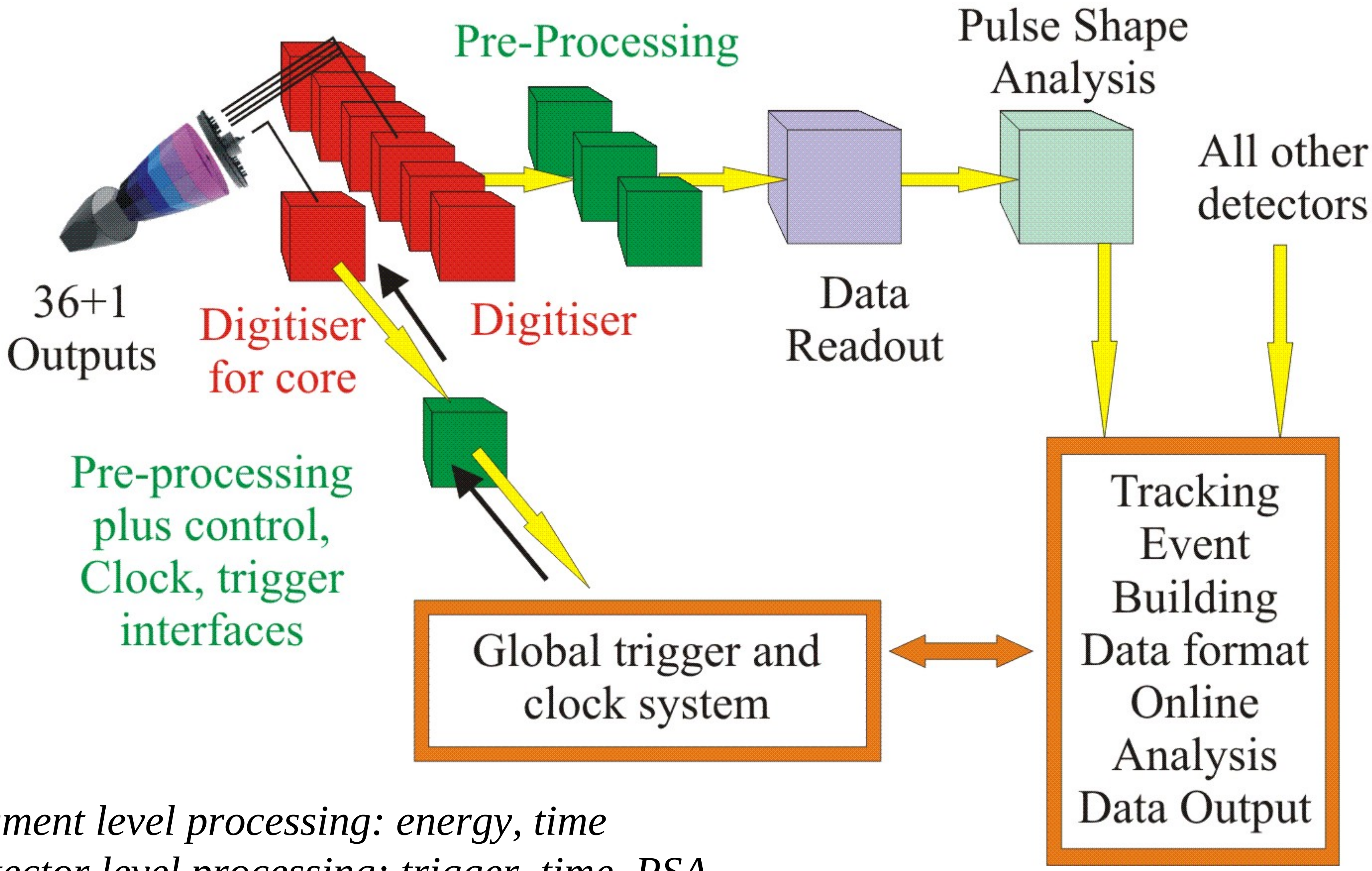
ε_{ph}	~ 50%
N_{det}	~ 100
Ω ~80%	



Combination of:

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

Schematic of the Digital Electronics and Data Acquisition System for AGATA

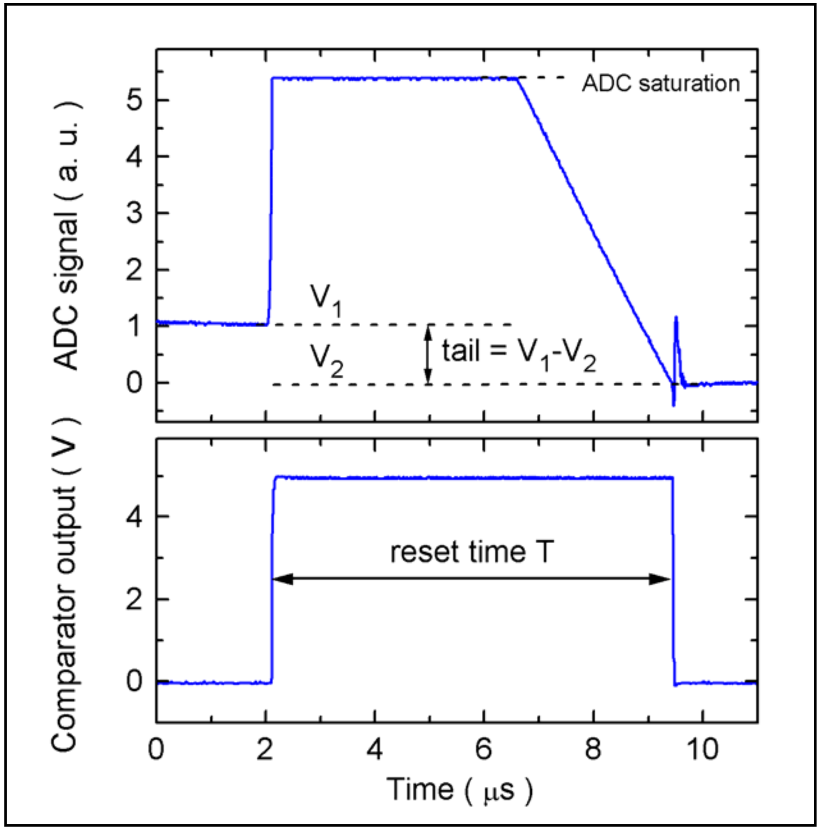


Segment level processing: energy, time

Detector level processing: trigger, time, PSA

Global level processing: event building, tracking, software trigger, data storage

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

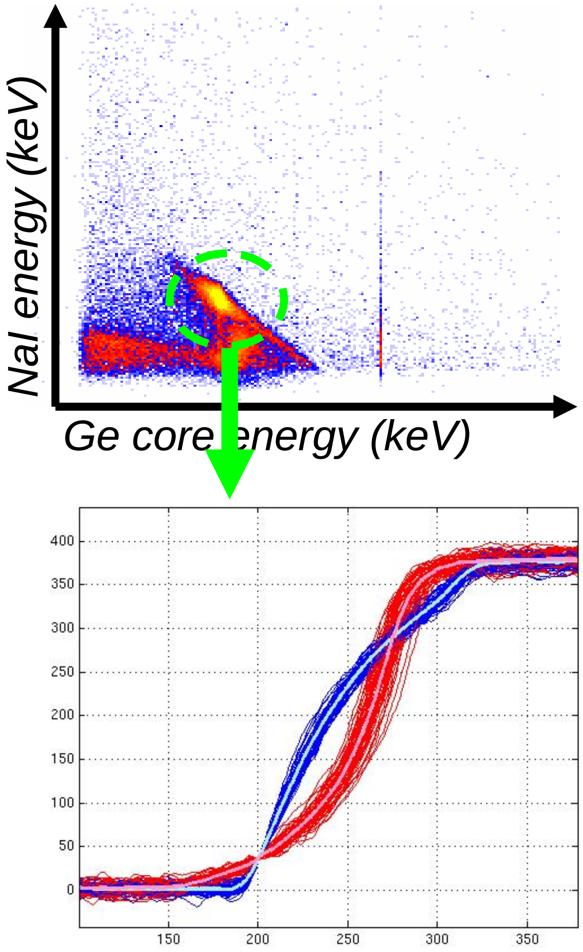
b_1, b_2, k_1, E_0 = fitting parameters

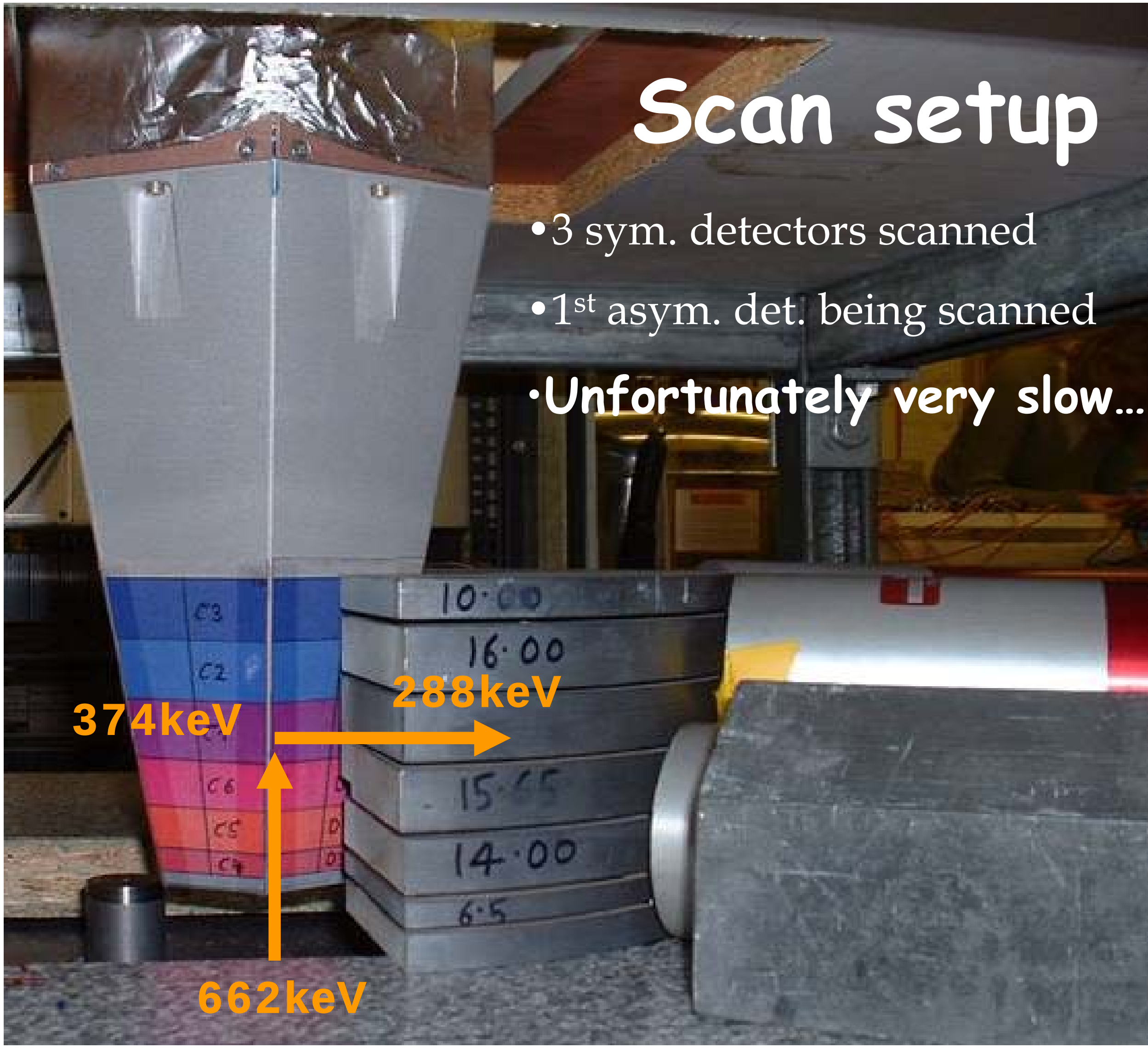
Within ADC range → standard "pulse-height mode" spectroscopy

Beyond ADC range → new "reset mode" spectroscopy

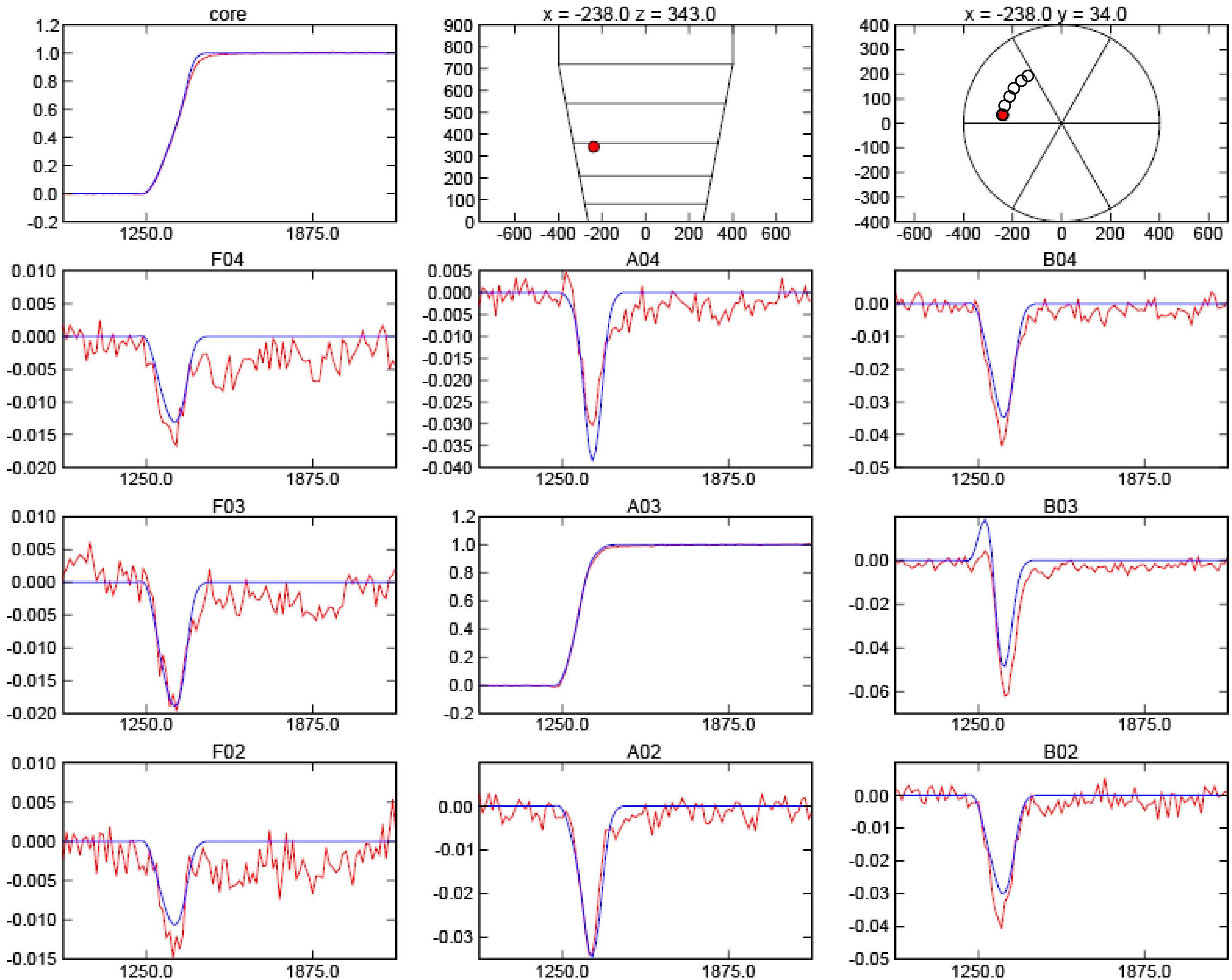
Coincidence measurement = Position selection

THE UNIVERSITY of LIVERPOOL

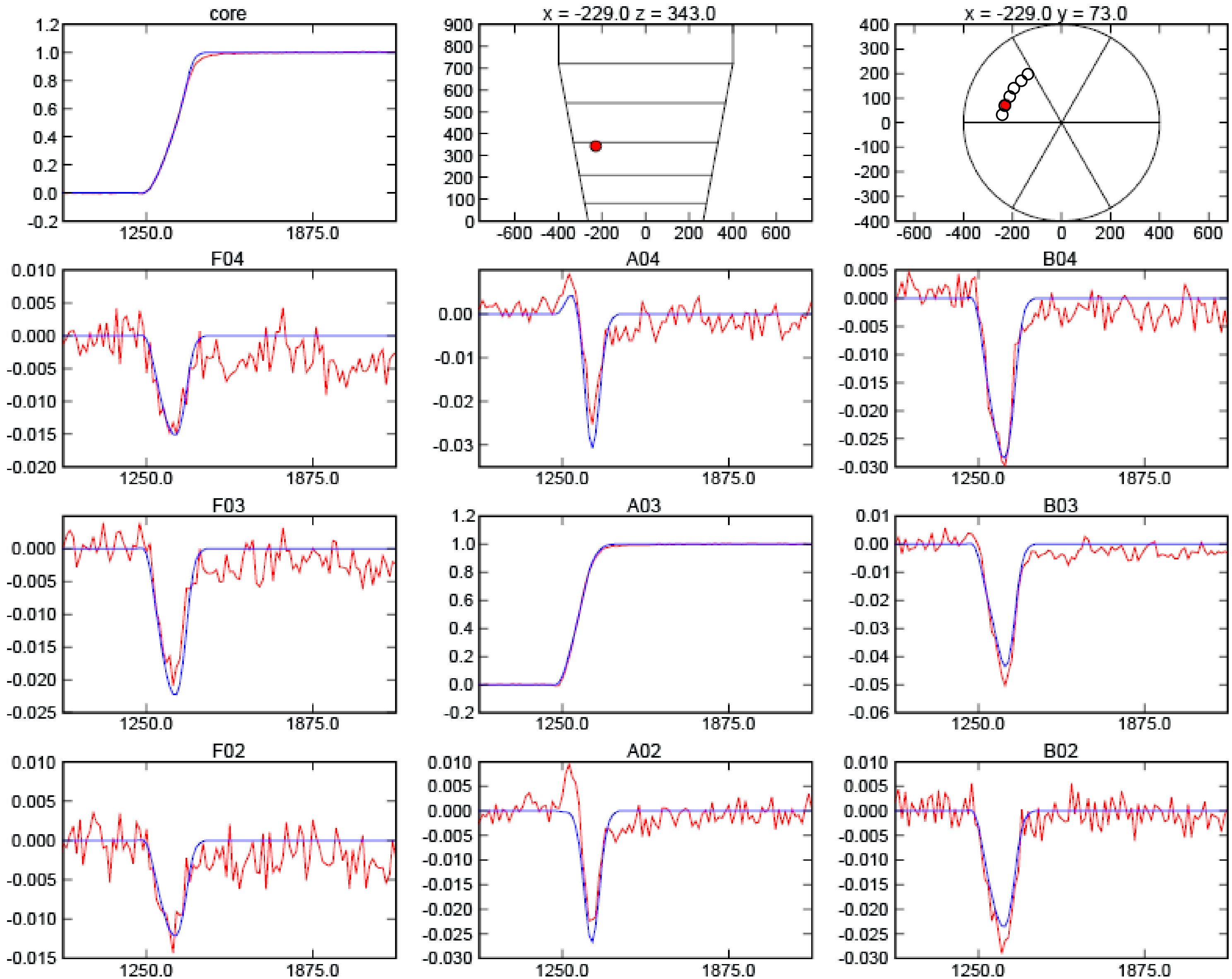




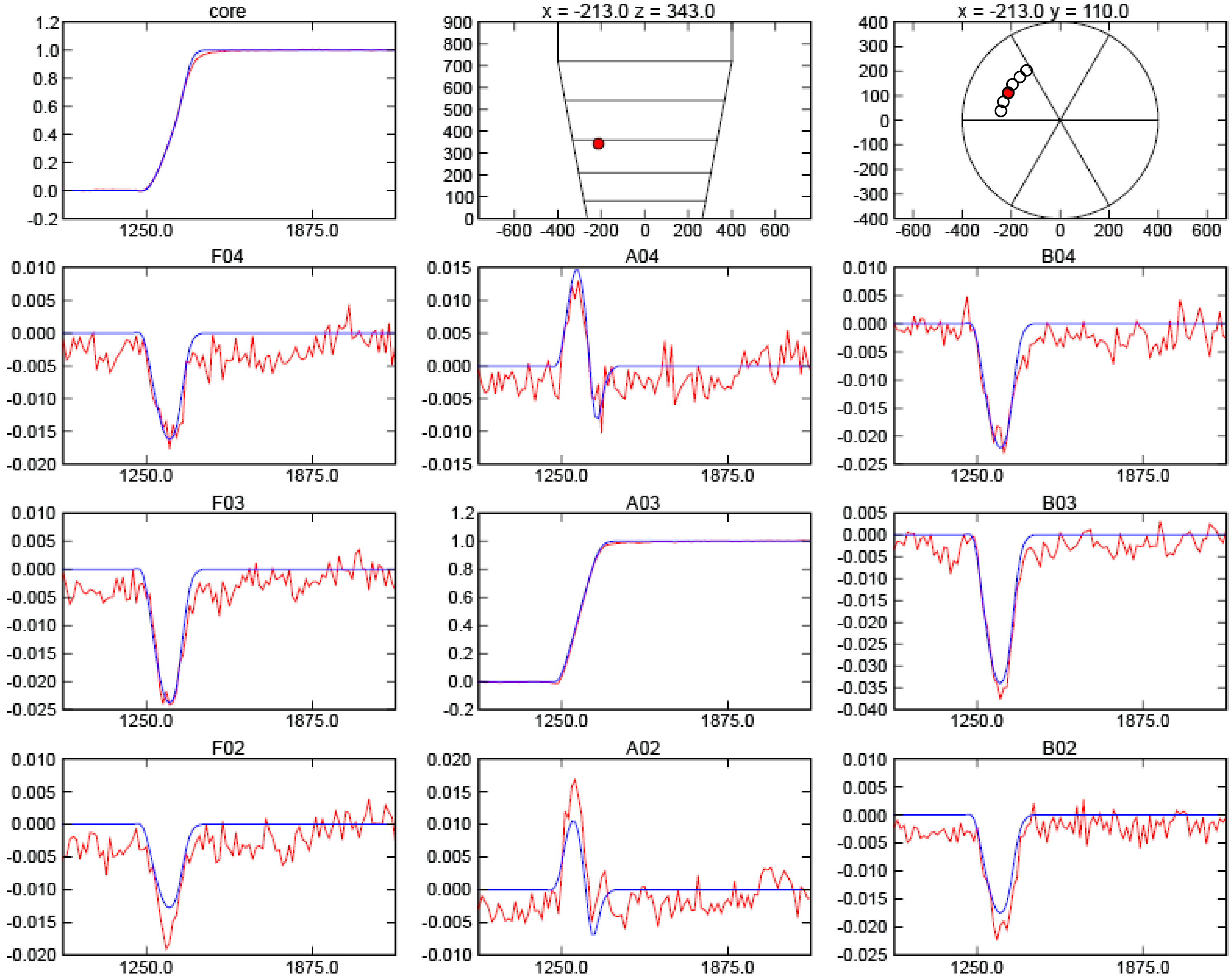
Scanning - examples



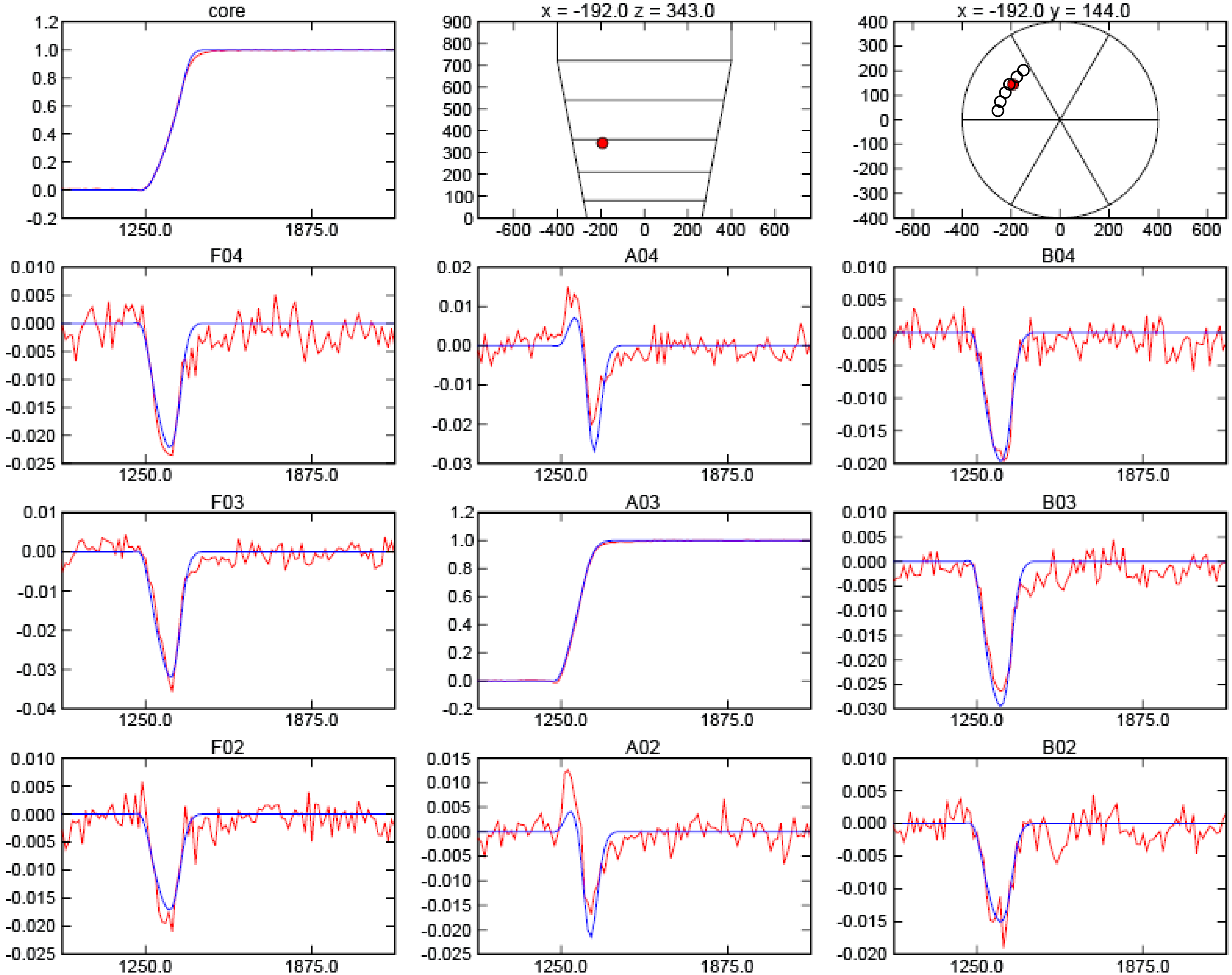
Scanning - examples



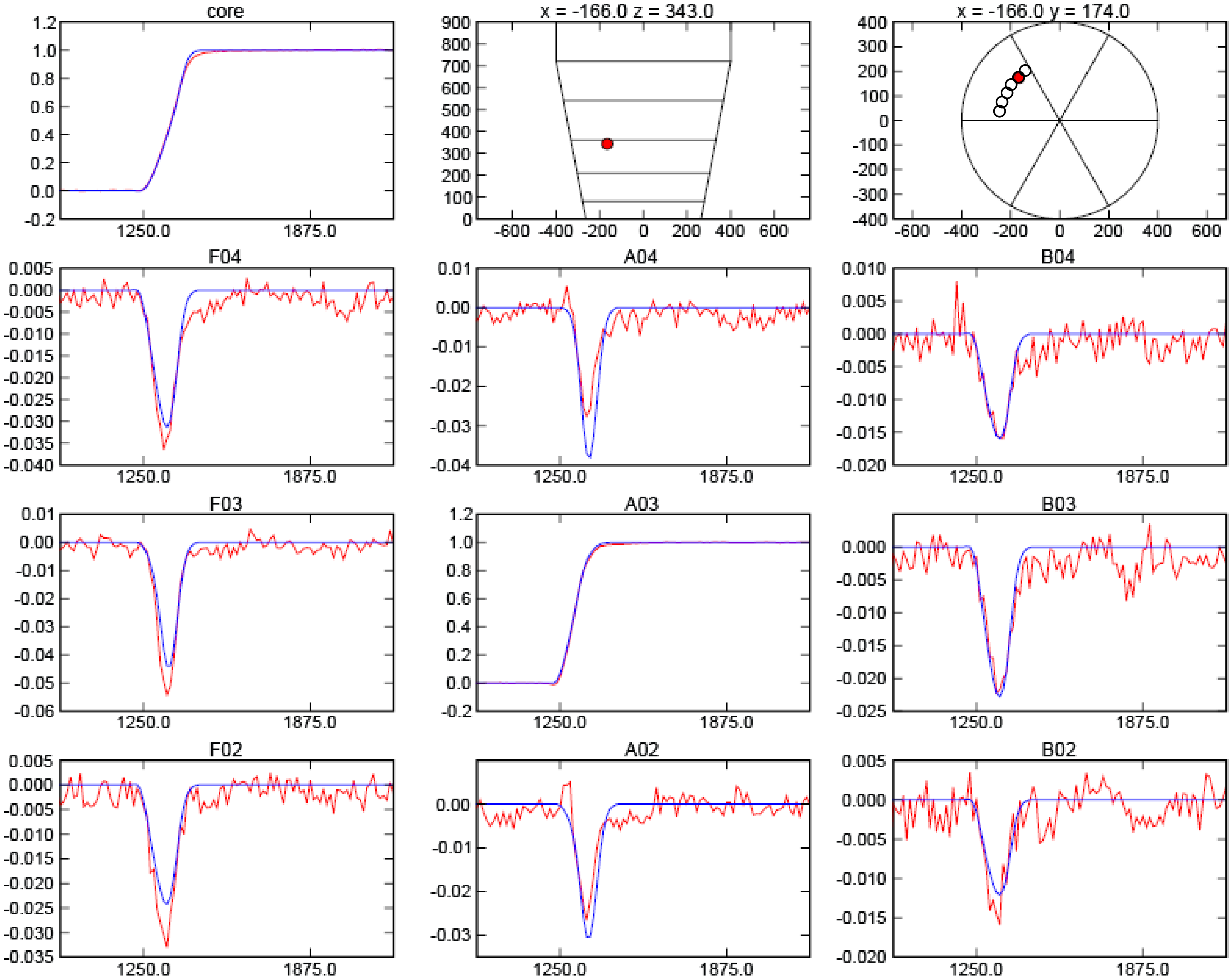
Scanning - examples



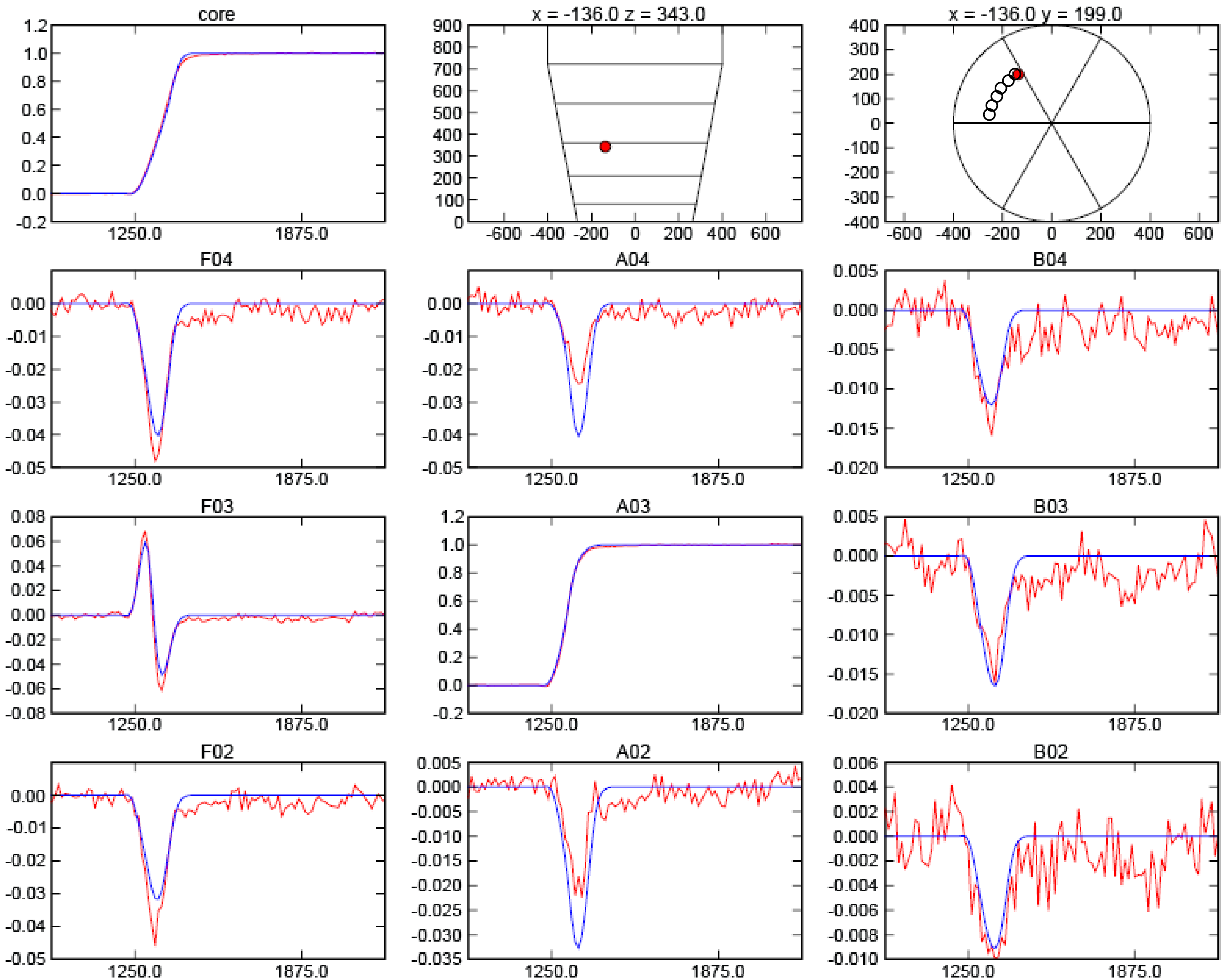
Scanning - examples



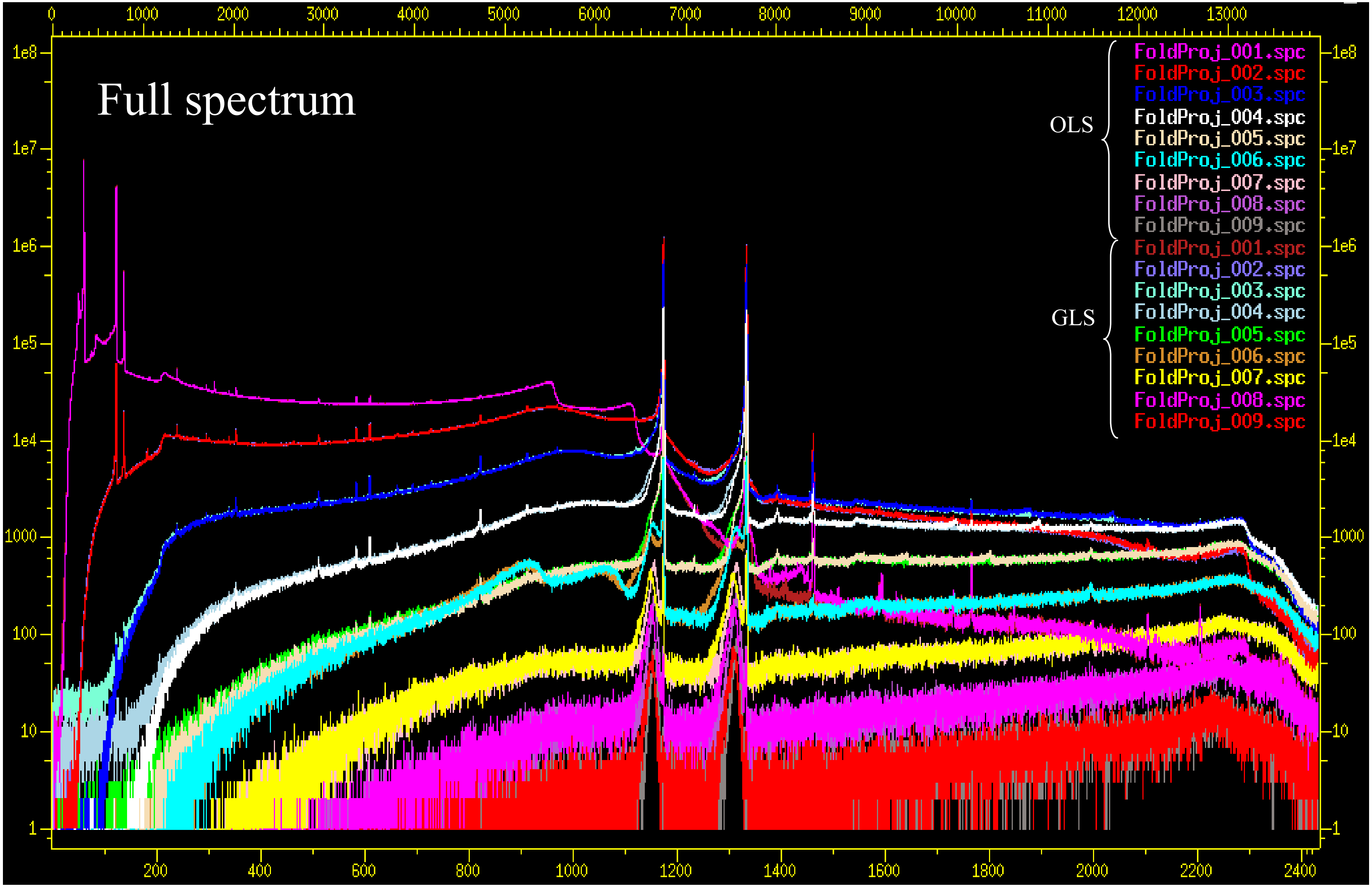
Scanning - examples



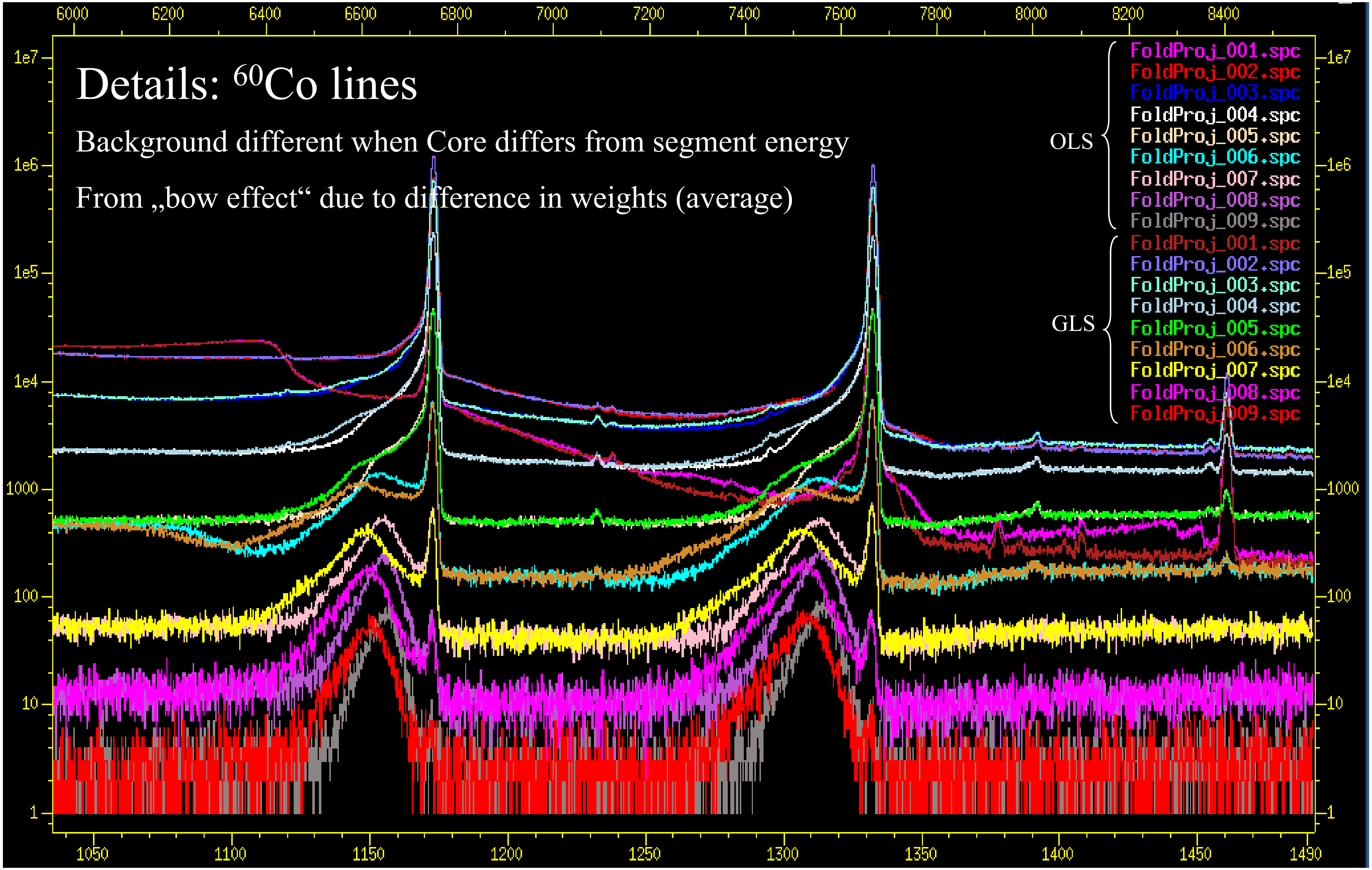
Scanning - examples



Results in pictures

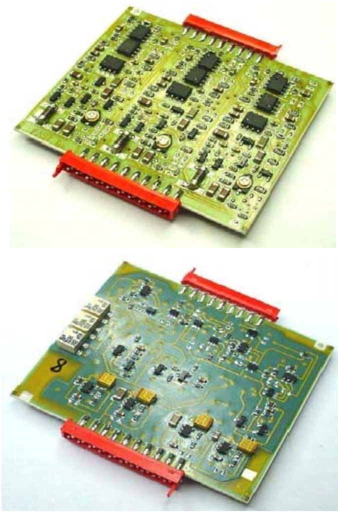


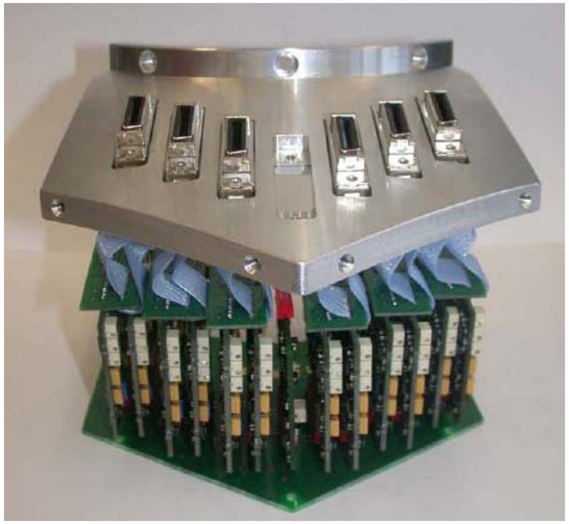
Results in pictures



AGATA : A complete new development…

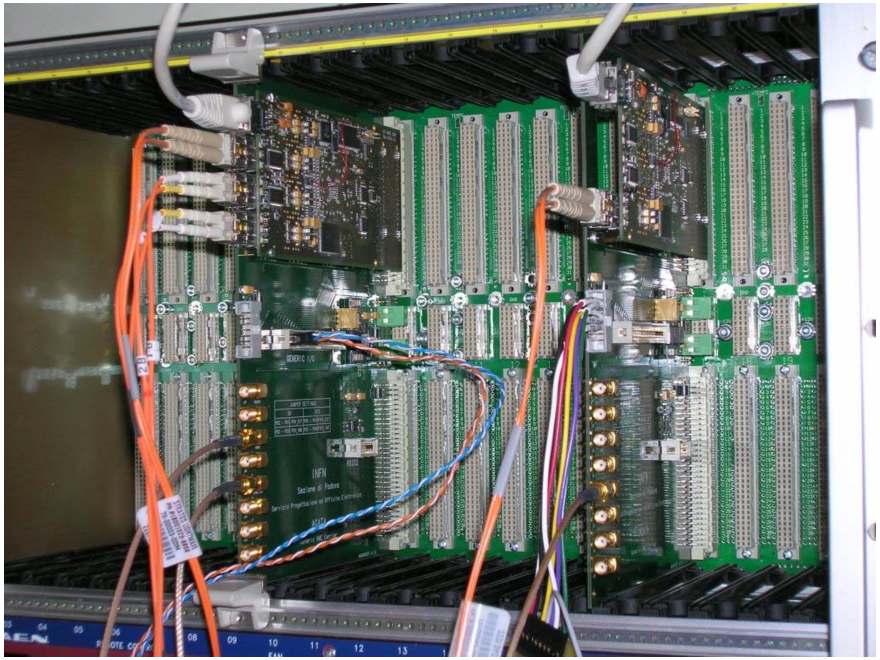
Preamplifiers (Milano, GANIL, Köln)



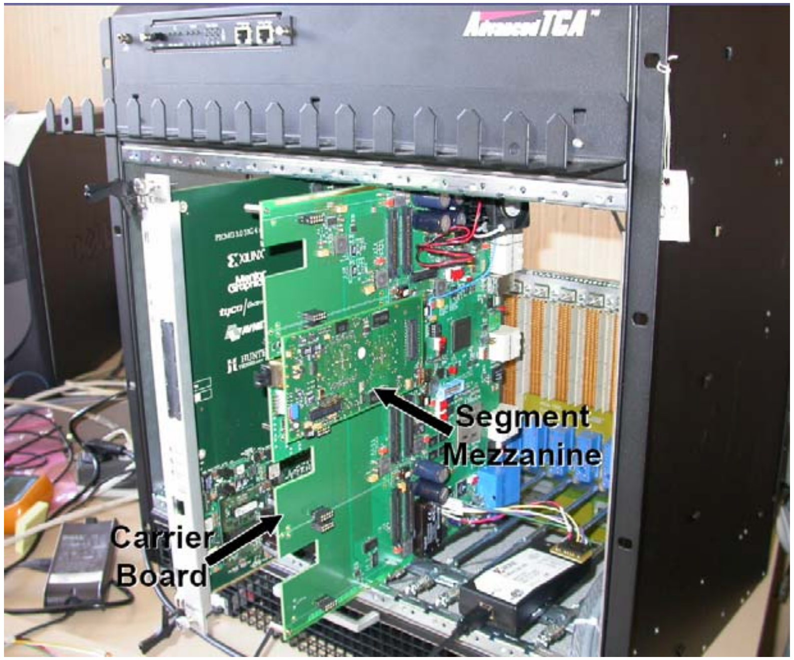


Digitisers (IReS, CCLRC, U-Liv.)

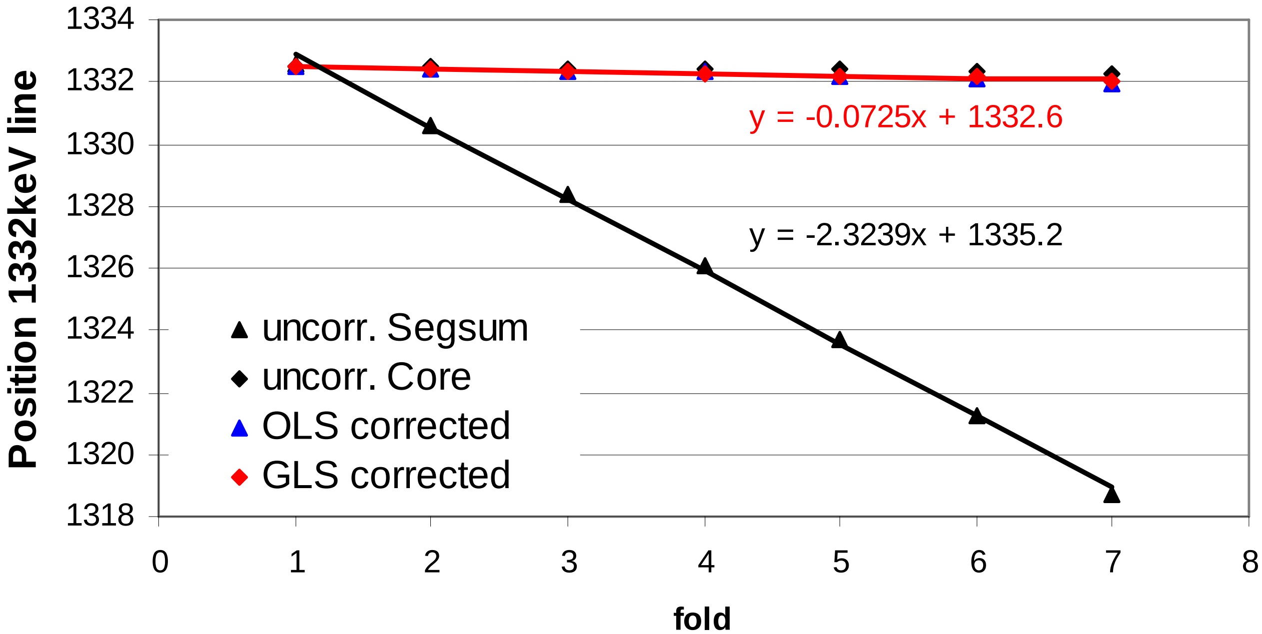
Global Trigger and Synchronization (Padova)

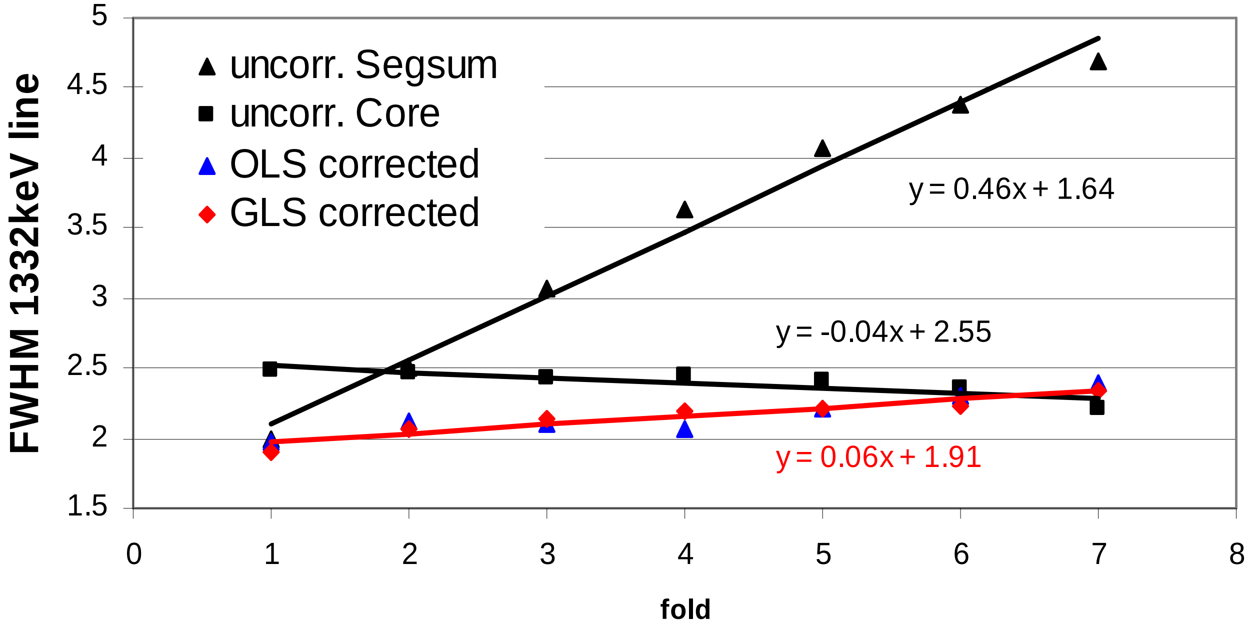


Preprocessing (Orsay)

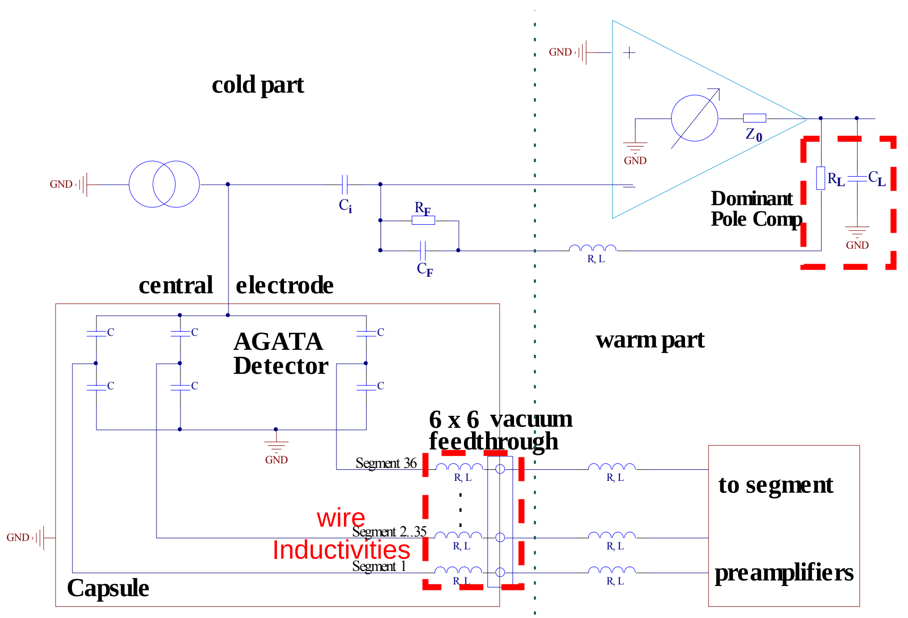


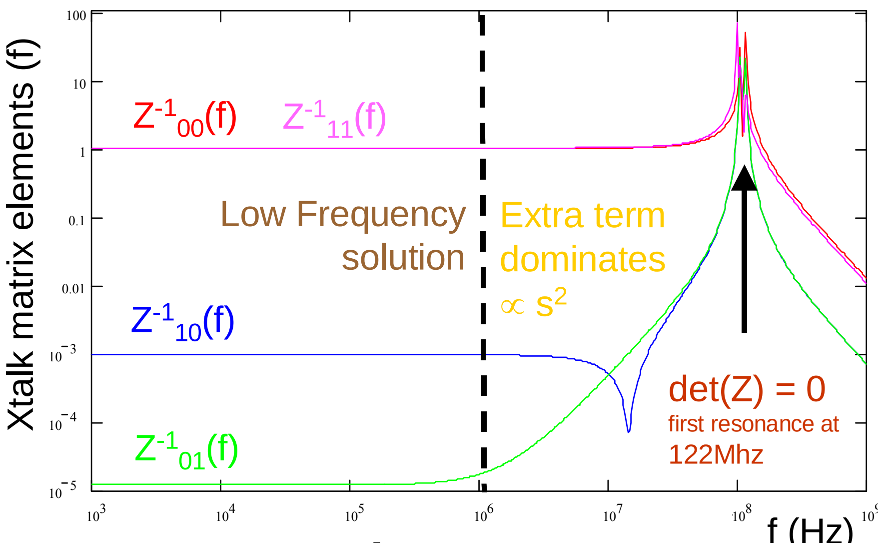
Results in values

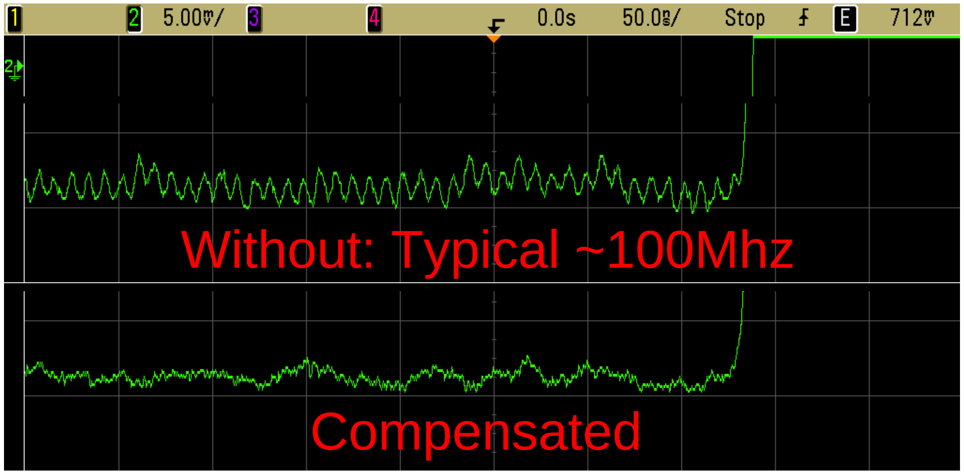


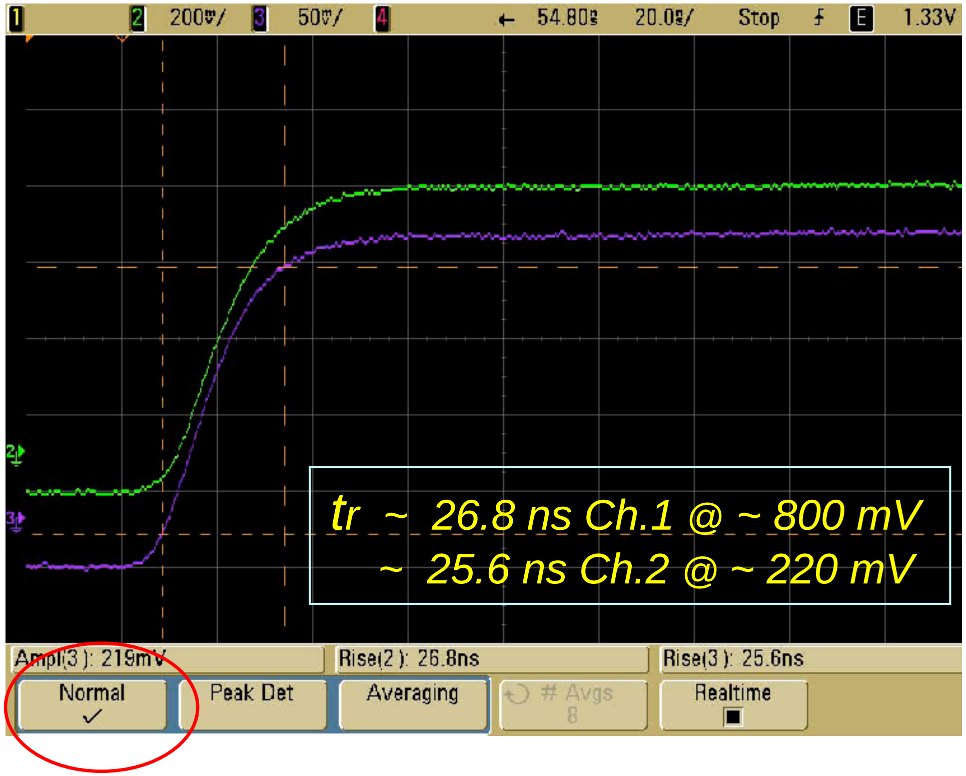


Dominant Pole Compensation

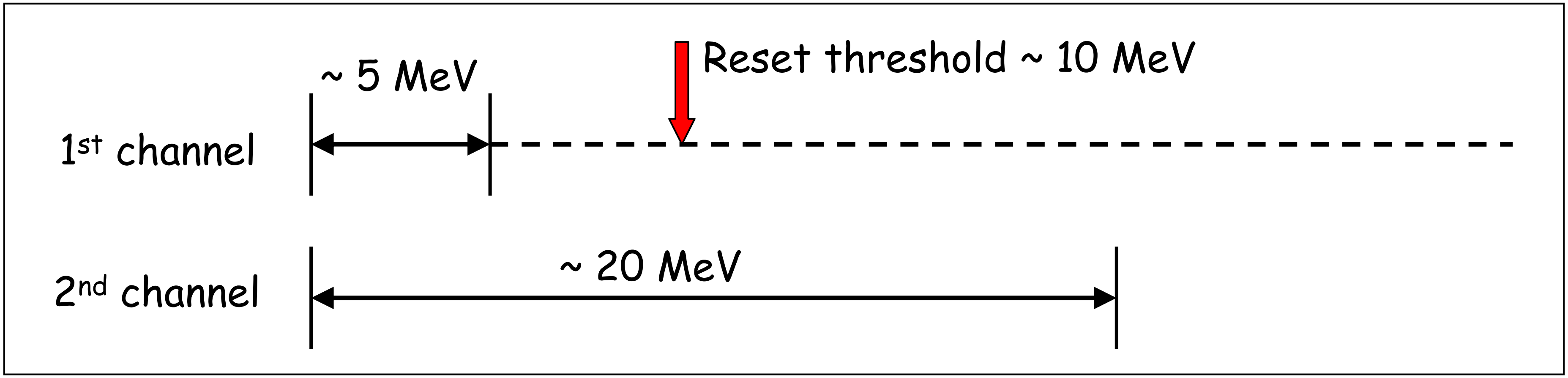


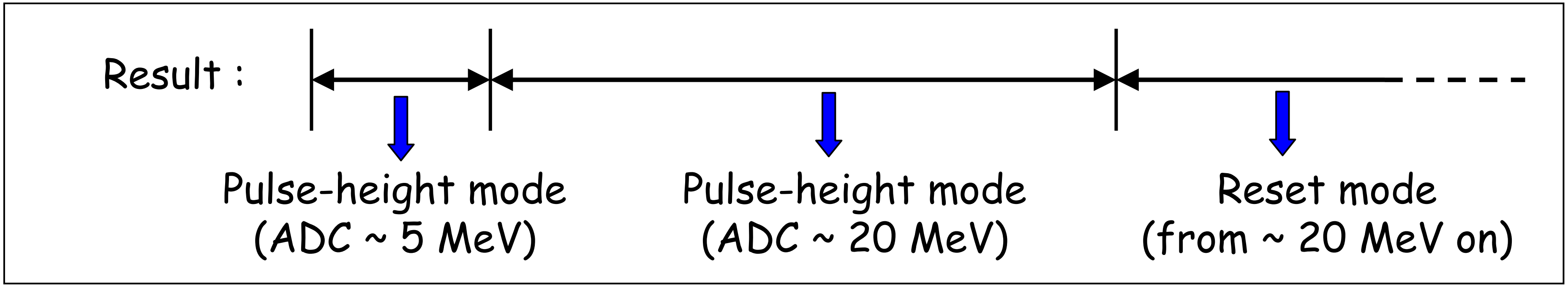






The ideal acquisition chain: "dual-channel" core preamplifier





Optimum energy resolution at all ranges

A model to describe crosstalk

AC equivalent detector model:

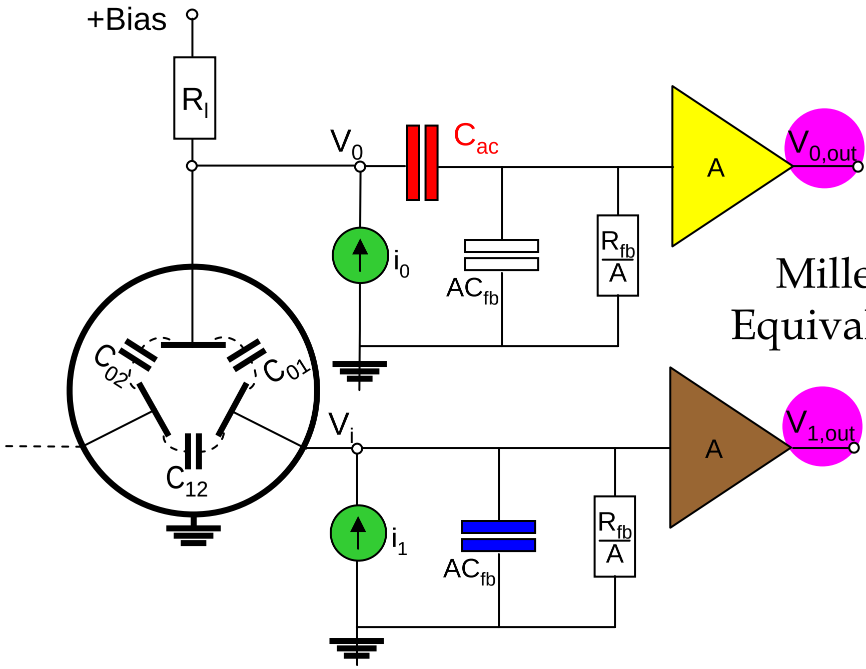
$$i_h = \underbrace{\sum_{i=1}^{N} q_i \mathbf{v}_i(\mathbf{r}_i) \cdot \mathbf{F}'_{1h}(\mathbf{r}_i)}_{\text{Ramo theoreme}} - \underbrace{\sum_{k=1}^{n} C_{hk} \frac{\partial V_k}{\partial t}}_{\text{Extension}}$$

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 !

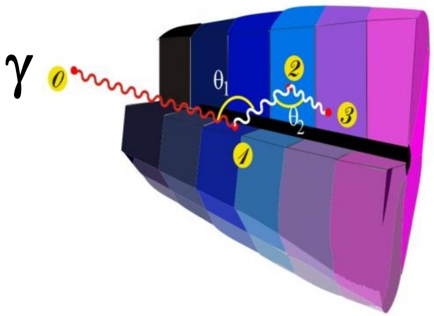


Miller Equivalent

Ingredients of γ-Tracking

1

Highly segmented HPGe detectors



2

Digital electronics to record and process segment signals

3

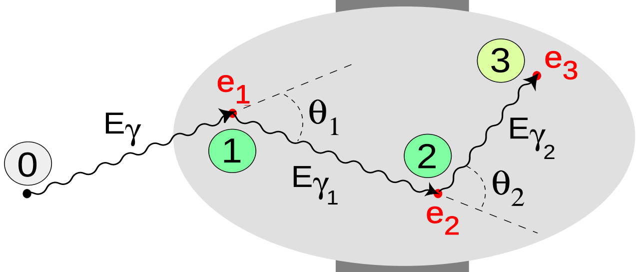
Pulse Shape Analysis to decompose recorded waves

Identified interactions

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

4

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



reconstructed γ-rays