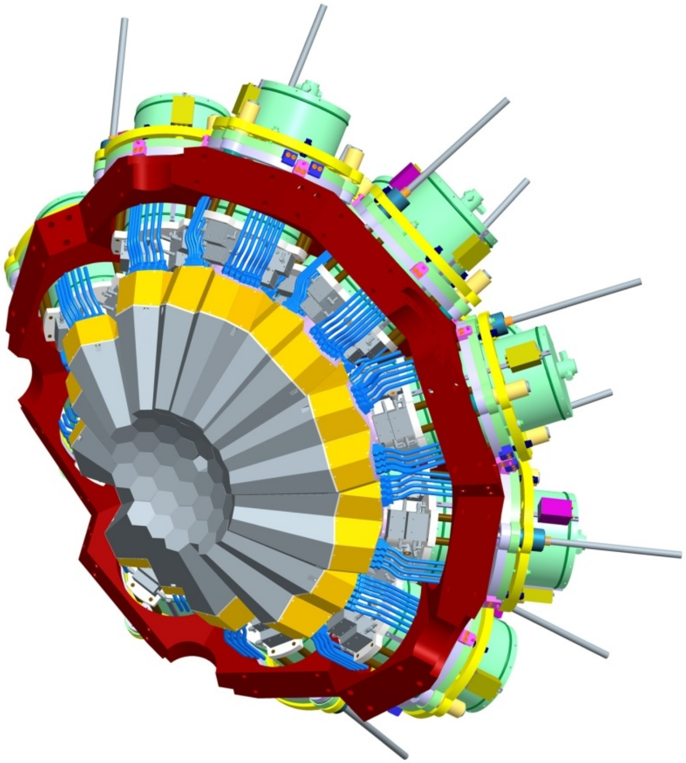
# Advances in HPGe technology The new AGATA triple cluster



- Requirements for AGATA
- AGATA triple cluster
- Core preamp & pulser
- Characterization & PSA
- Cross talk studies
- AGATA – present status

B. Bruyneel, B. Birkenbach, J. Eberth, H. Hess, D. Lersch, 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

Muenchen, 03/04/09

# 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

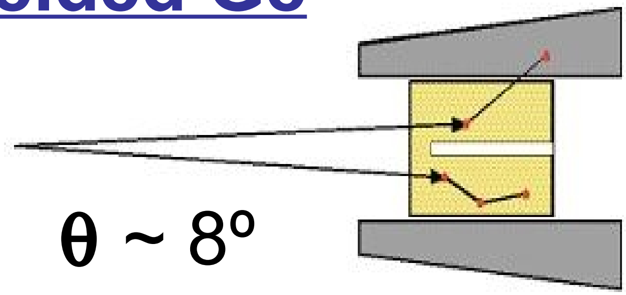
# Idea of $\gamma$-ray tracking

## Compton Shielded Ge

$\varepsilon_{ph}$ ~ 10%

$N_{det}$ ~ 100

$\Omega$ ~40%



$\theta \sim 8^{o}$

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

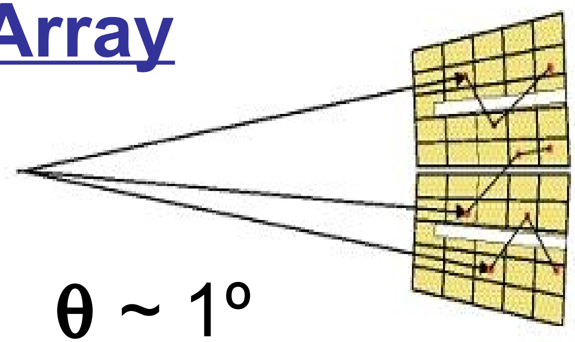
Previously we had to waste scattered gammas.
Technology is available now to track them.

## Ge Tracking Array

$\varepsilon_{ph}$ ~ 50%

$N_{det}$ ~ 100

$\Omega$ ~80%



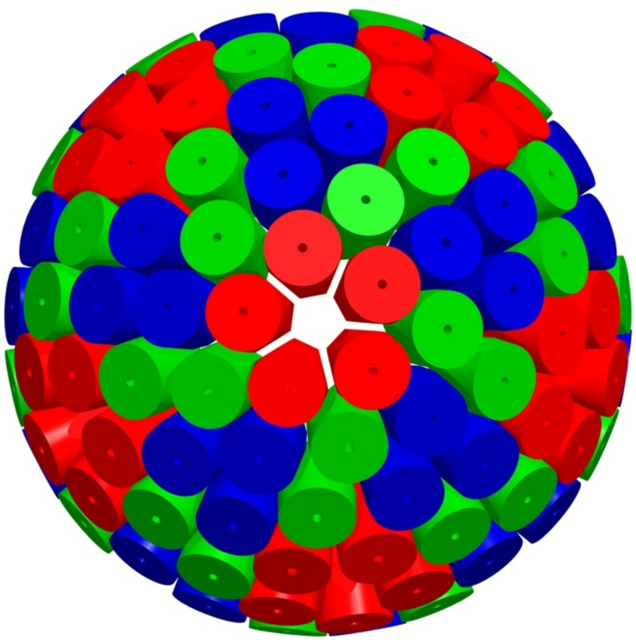
$\theta \sim 1^{o}$

Combination of:

- segmented detectors
- digital electronics
- pulse processing
- tracking the $\gamma$-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% ($M_\gamma$=1) 28% ($M_\gamma$=30)
today's arrays ~10% (gain ~4) 5% (gain ~1000)

**Peak/Total:** 58% ($M_\gamma$=1) 49% ($M_\gamma$=30)
today ~55% 40%

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

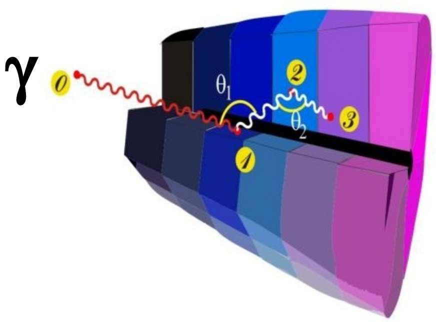
**Rates:** 3 MHz ($M_\gamma$=1) 300 kHz ($M_\gamma$=30)
today 1 MHz 20 kHz

- 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

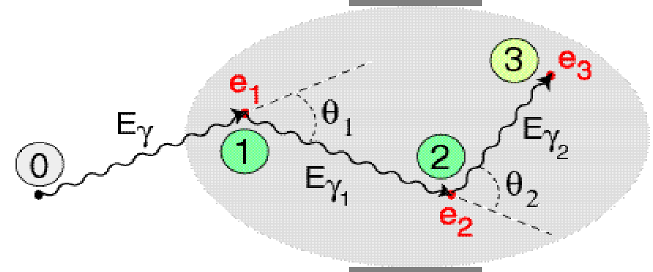
Pulse Shape Analysis to decompose recorded waves

Identified interactions

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

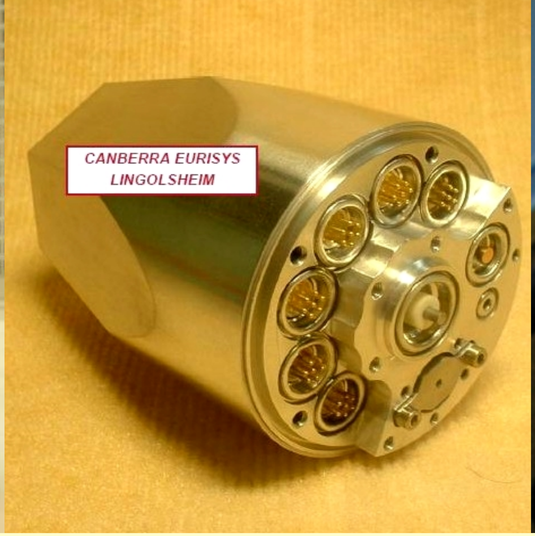
4

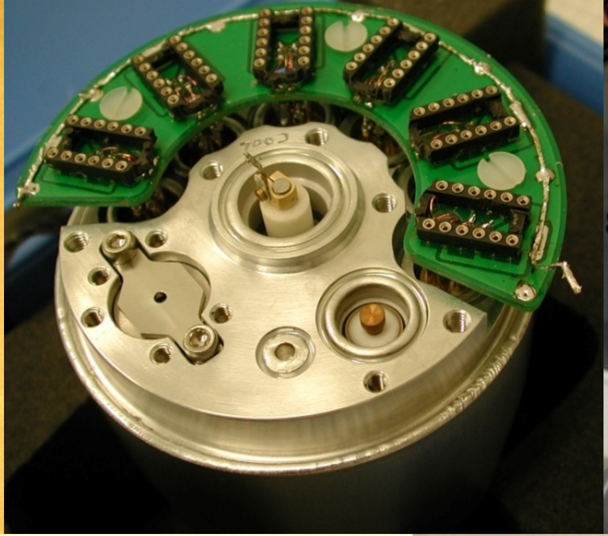
Reconstruction of tracks e.g. by evaluation of permutations of interaction points

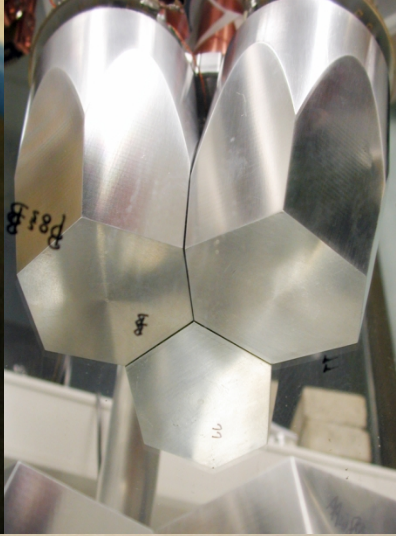



reconstructed γ-rays

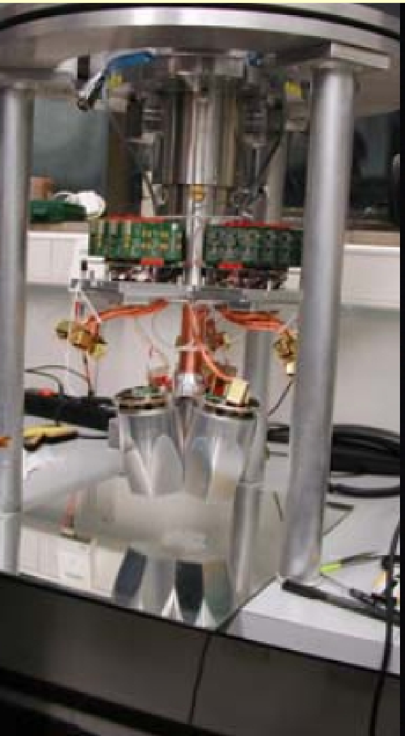
- AGATA Triple cluster

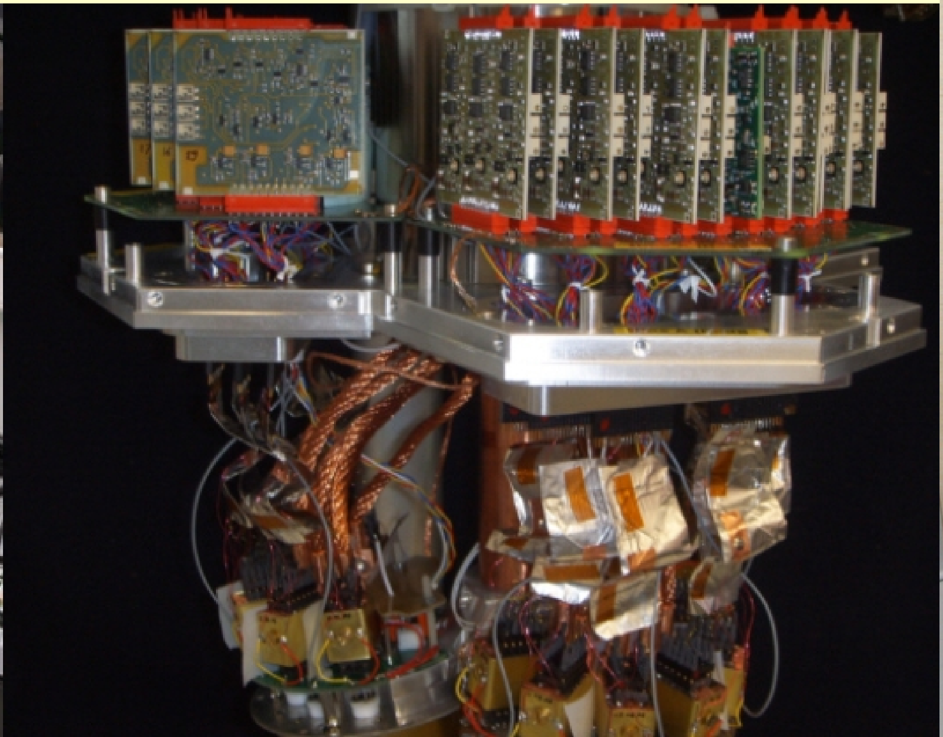





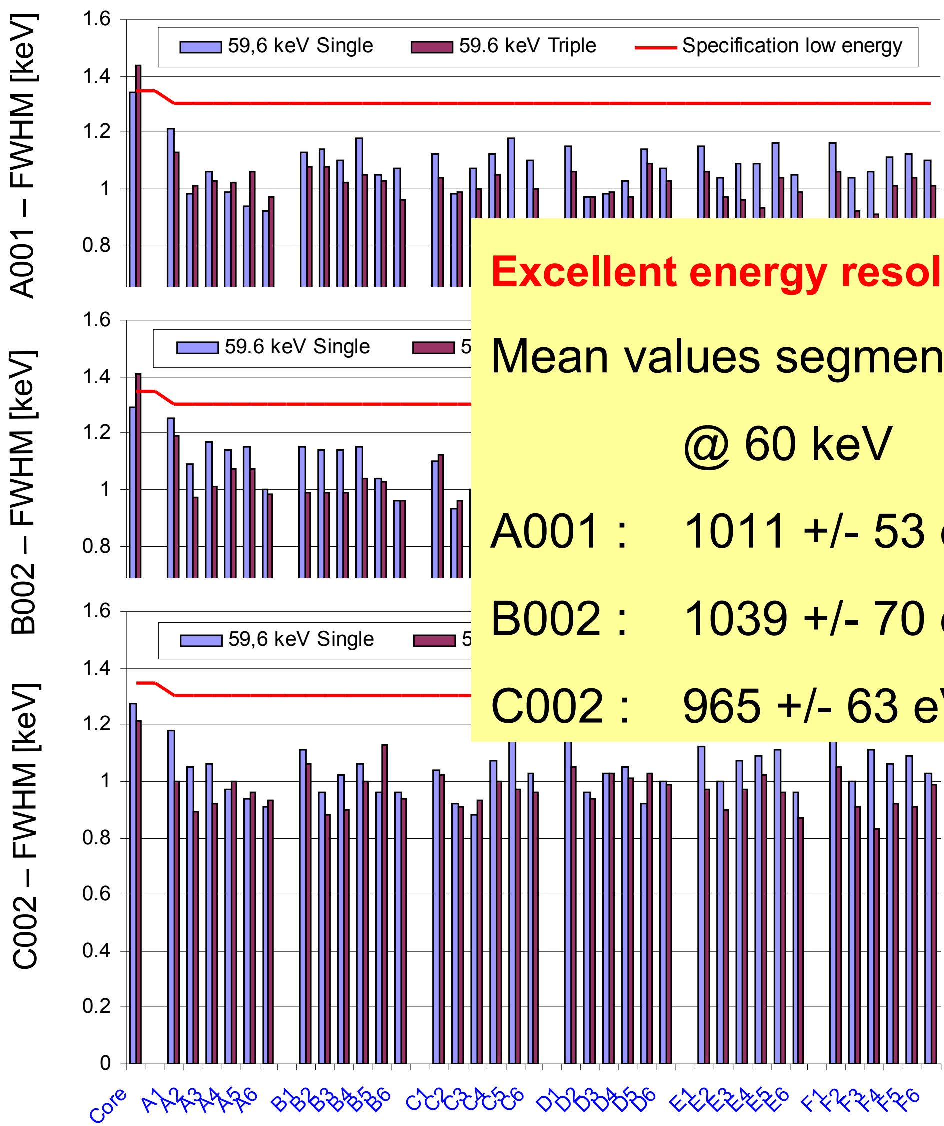
# First AGATA triple-detector @ IKP Cologne



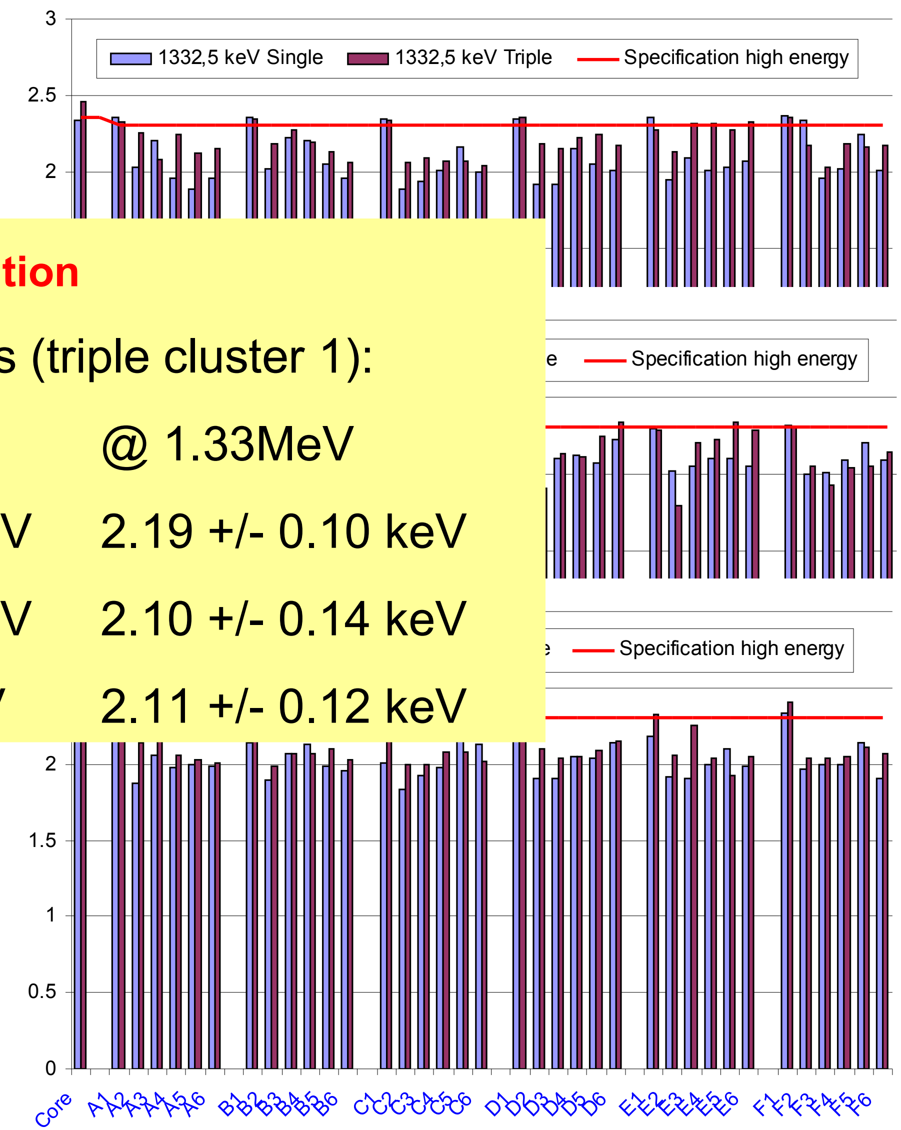


# Tripel Cluster: Energies of 111 channels

## Resolution 60keV line




## Resolution 1.33MeV line



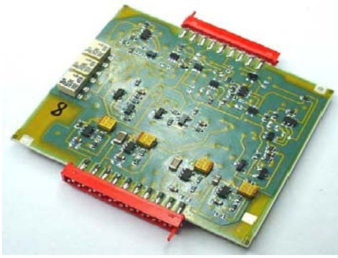

**Excellent energy resolution**

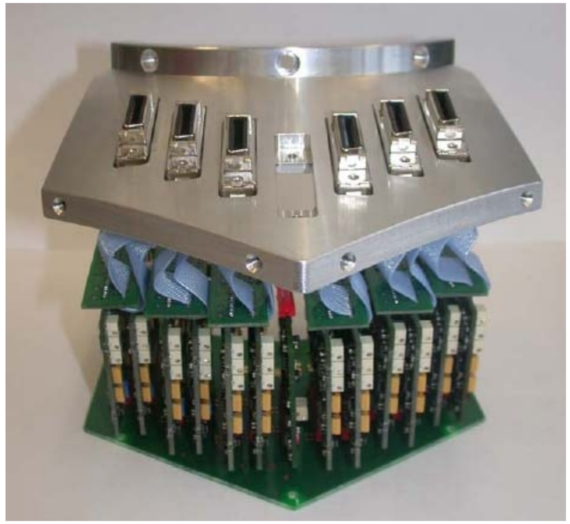
Mean values segments (triple cluster 1):

| | @ 60 keV | @ 1.33MeV |
|---|---|---|
| A001 : | 1011 +/- 53 eV | 2.19 +/- 0.10 keV |
| B002 : | 1039 +/- 70 eV | 2.10 +/- 0.14 keV |
| C002 : | 965 +/- 63 eV | 2.11 +/- 0.12 keV |

AGATA : A complete new development…

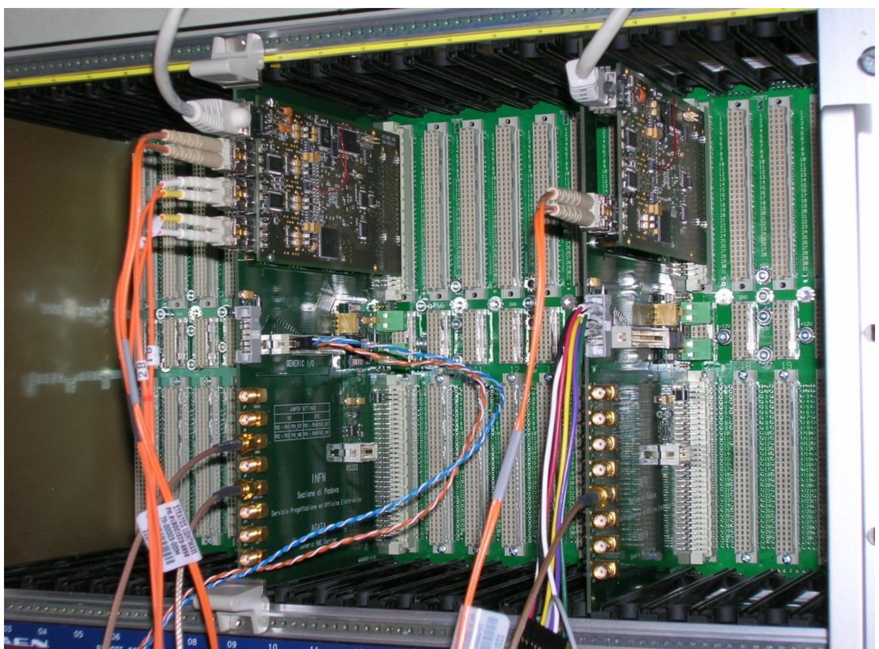
## Preamplifiers (Milano, GANIL, Köln)



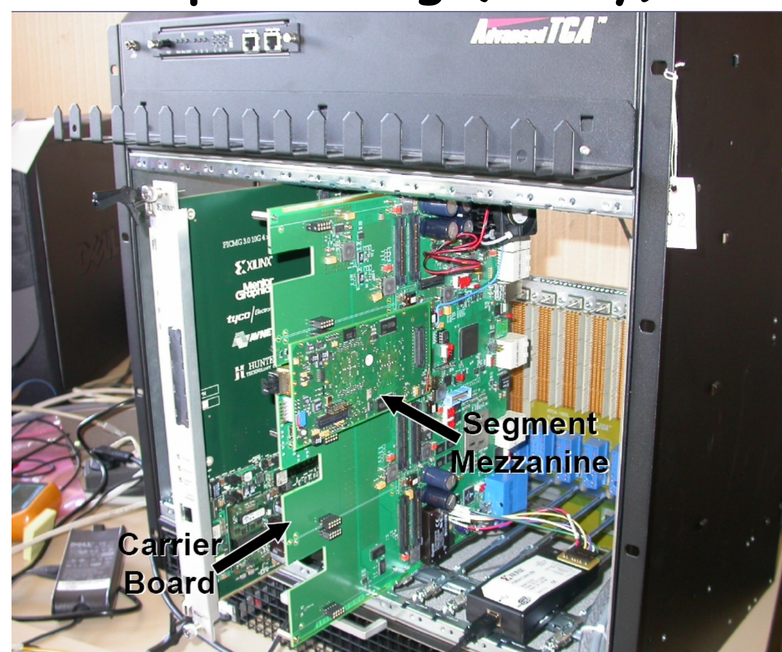


## Digitisers (IReS, CCLRC, U-Liv.)


## Global Trigger and Synchronization (Padova)

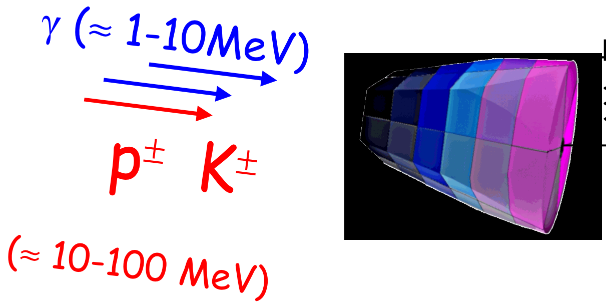


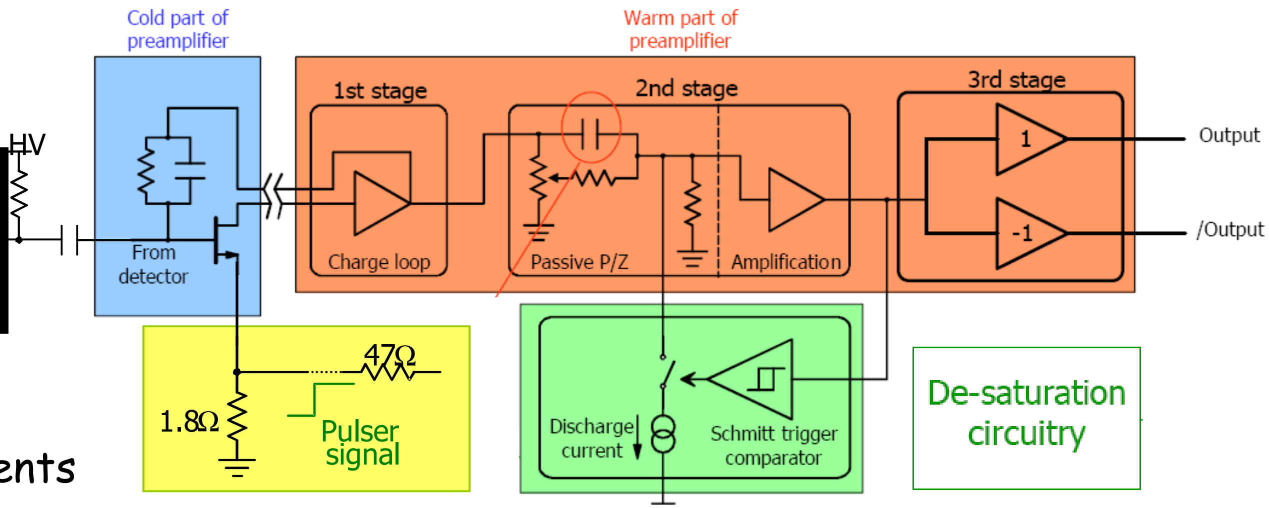
## Preprocessing (Orsay)



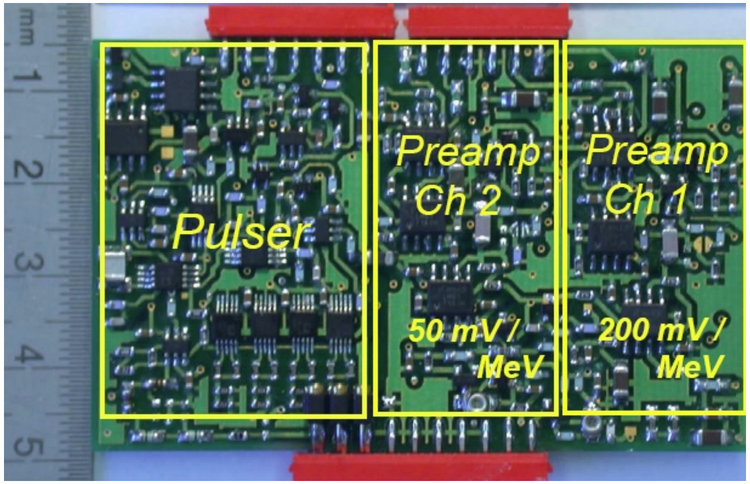
- Core preamp & pulser

# AGATA DUAL core preamplifier




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



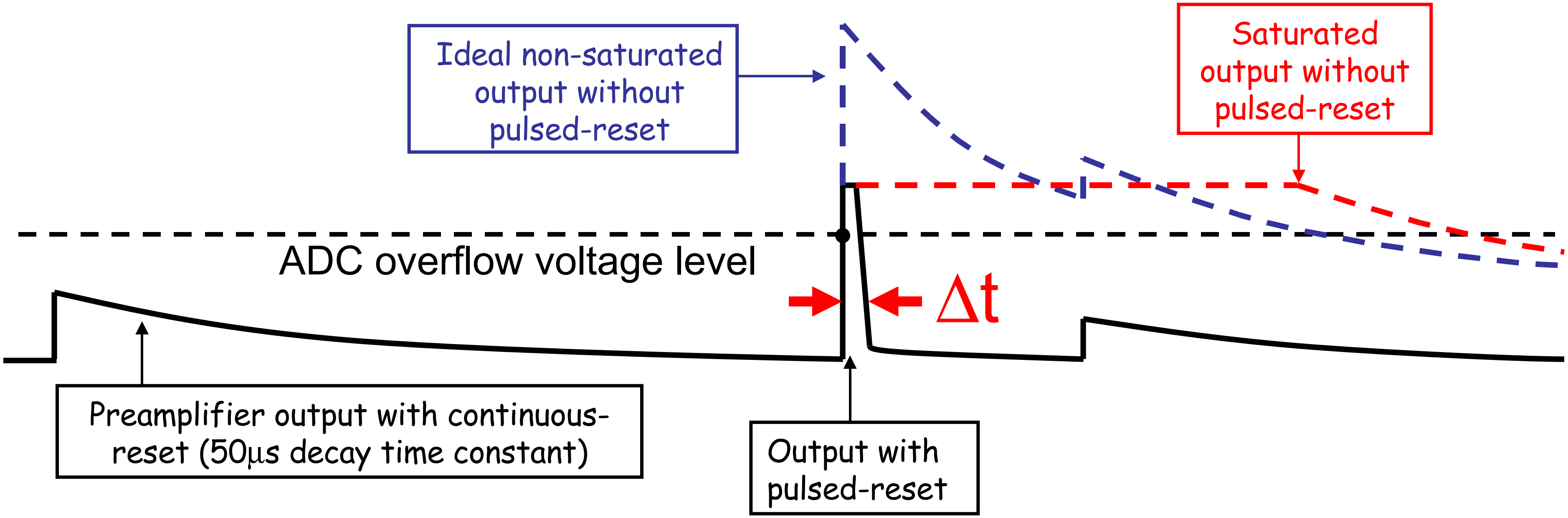

**Requirement core preamp:**

- 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

# New reset technique



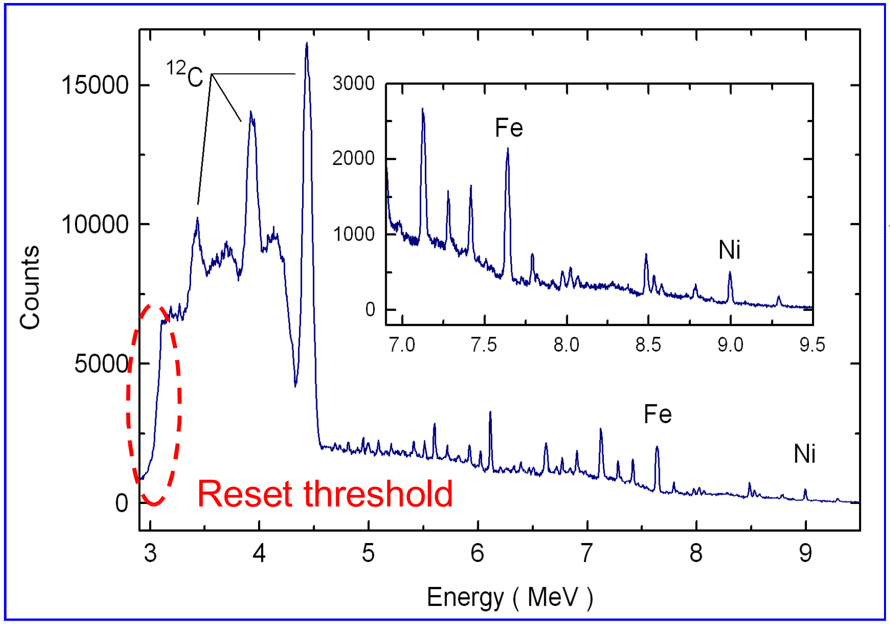

An ADC overflow condition would saturate the system for a long while

Pulsed-reset mechanism allows

- high countrates (throughput x 5)
- high energy detection (upto 200MeV)

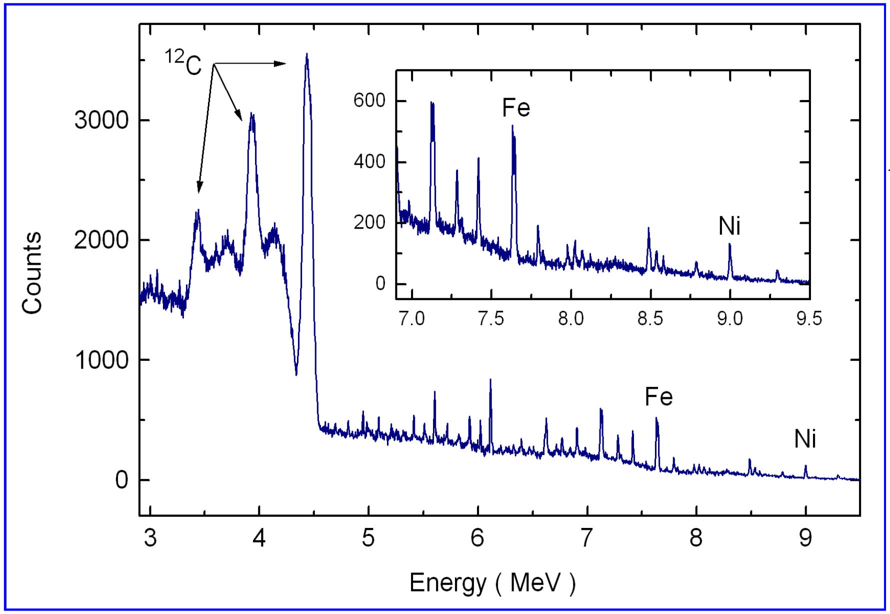
"Time Over Threshold" (T.O.T) : $\Delta t \propto E$

# $^{241}$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 %** |




"pulse-height" mode

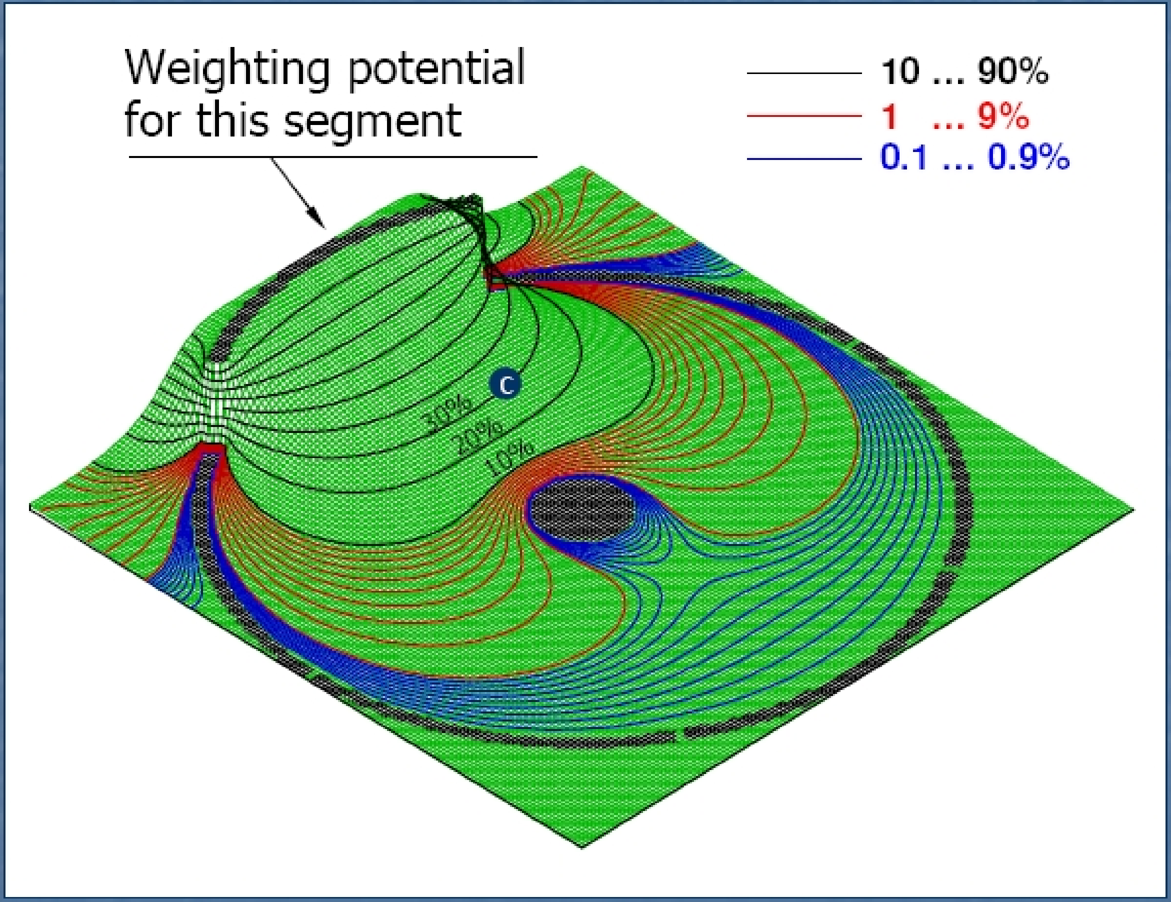
Universal instrument

Energy range 20keV-200MeV

Optimum resolution

- Characterization & PSA

# Weighting potentials



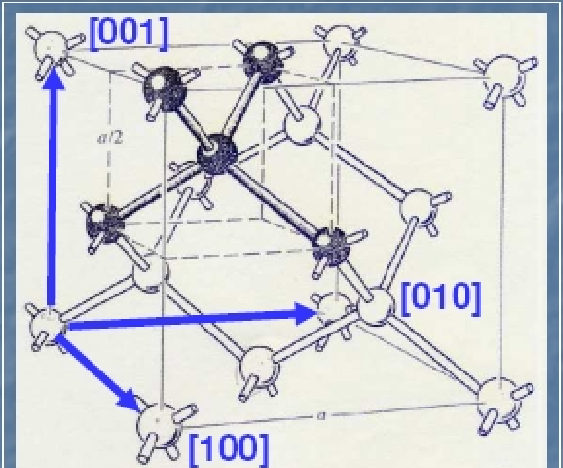

**Weighting potential:**

- Reveals amount of induced charge
- One for each electrode
- Laplace solution

**Observables:**

- Currents towards electrodes
- Depend on motion

# Mobilities : Intro



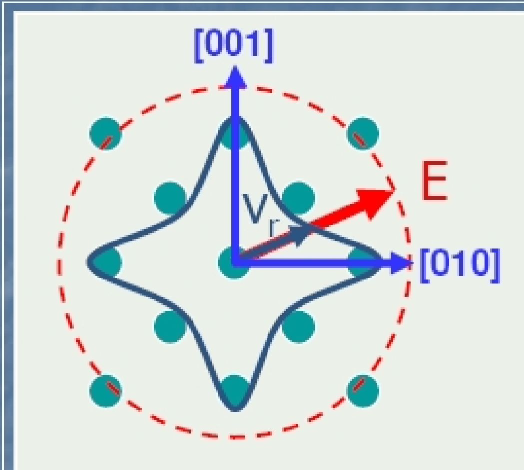

- Monocrystalline Ge
- Periodic potential

⇓

Bloch electrons:

$$\Psi_{n,\vec{k}}(\vec{r}),\ \varepsilon_{n,\vec{k}}$$

- Wave vector $\vec{k}$ in first Brillouin zone
- Band index n



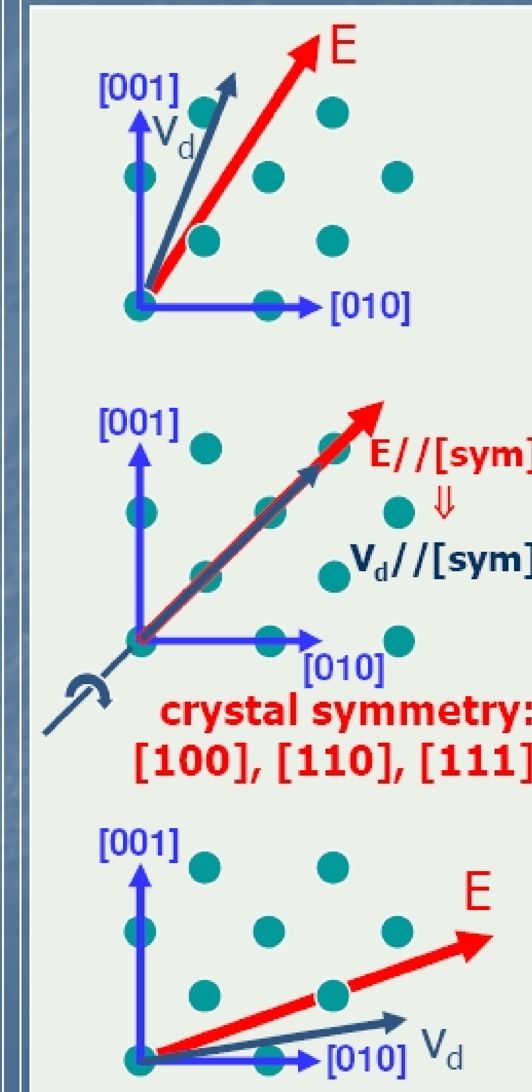

- Velocity:

$$\vec{v}_{n,\vec{k}} = \frac{1}{\hbar}\vec{\nabla}_{\vec{k}}\varepsilon_n(\vec{k})$$

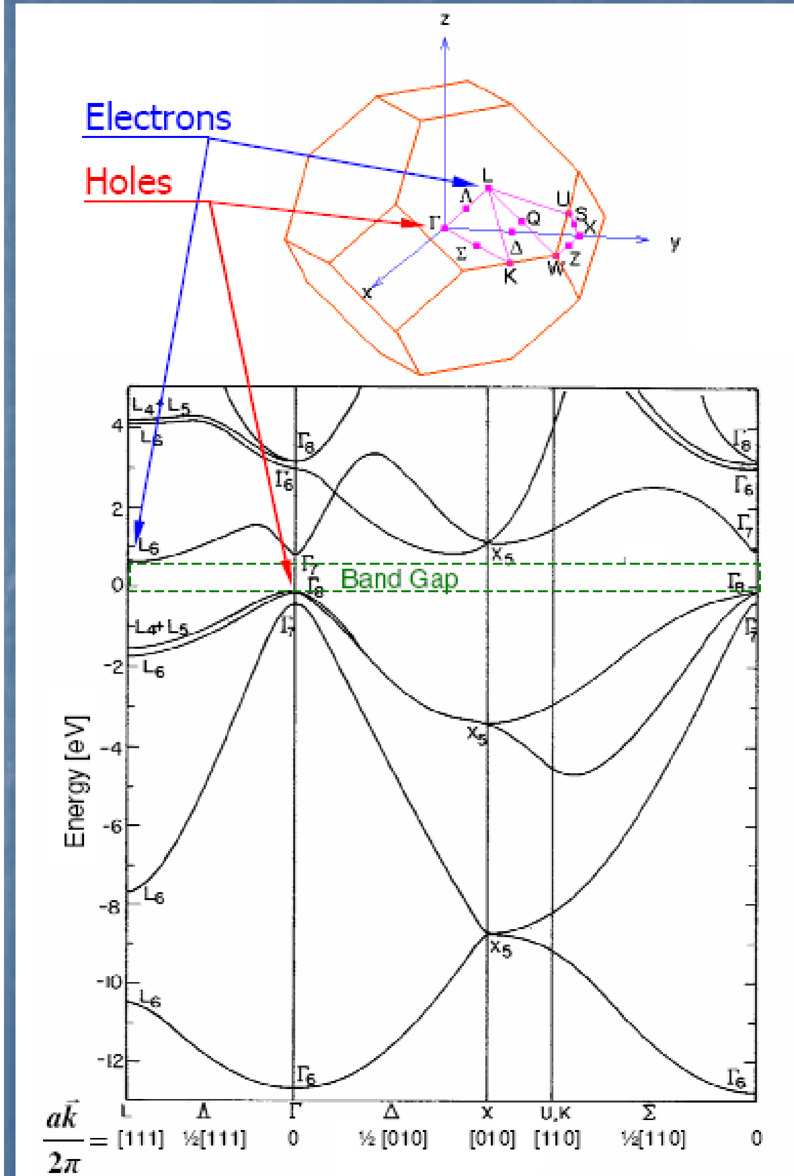
- Longitudinal anisotropy

$|v_r|$ angle dependent

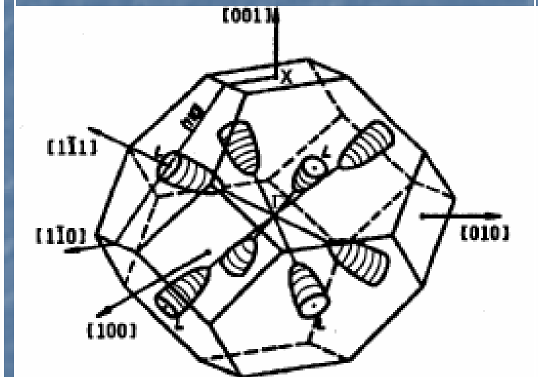
- Tangential anisotropy



# Electron and Hole Mobility in Ge

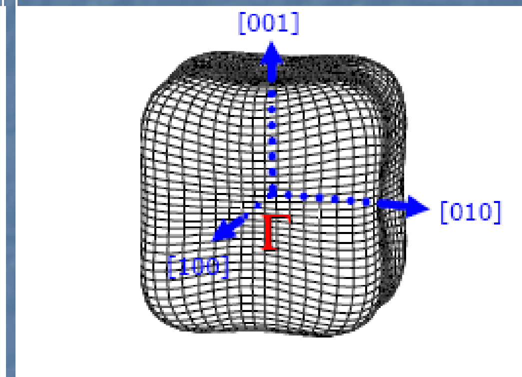



## Electrons




- Phys.Rev. 130(6):2201-2204,1963
- distributed over 4 ellipsoidal valleys
- each valley is Maxwell-Boltzmann distributed
- intervalley scattering defines valley population

## Holes



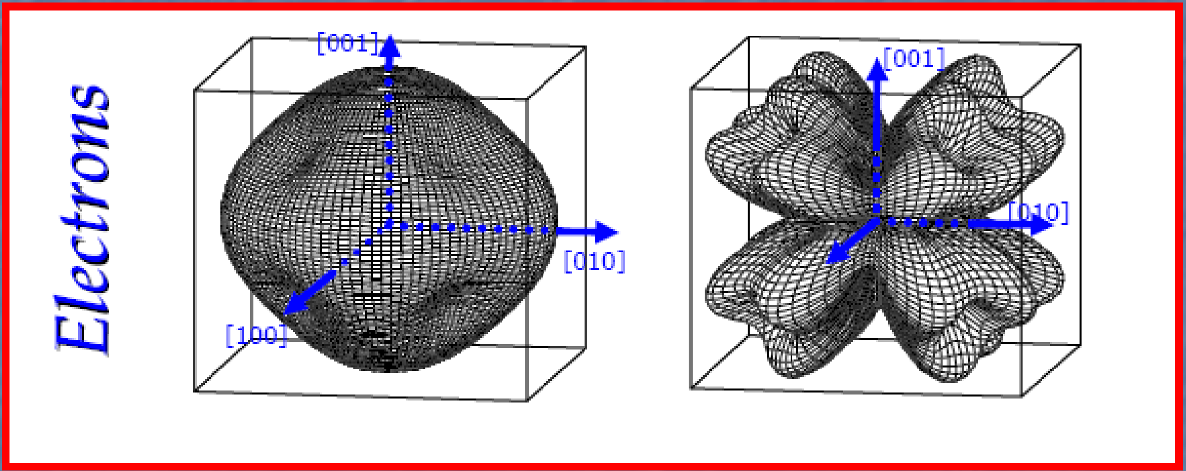

- no applicable model available. → own model:
- only "warped" heavy hole band is important
- "Streaming motion" → drifted Maxwell-Boltzmann distribution:

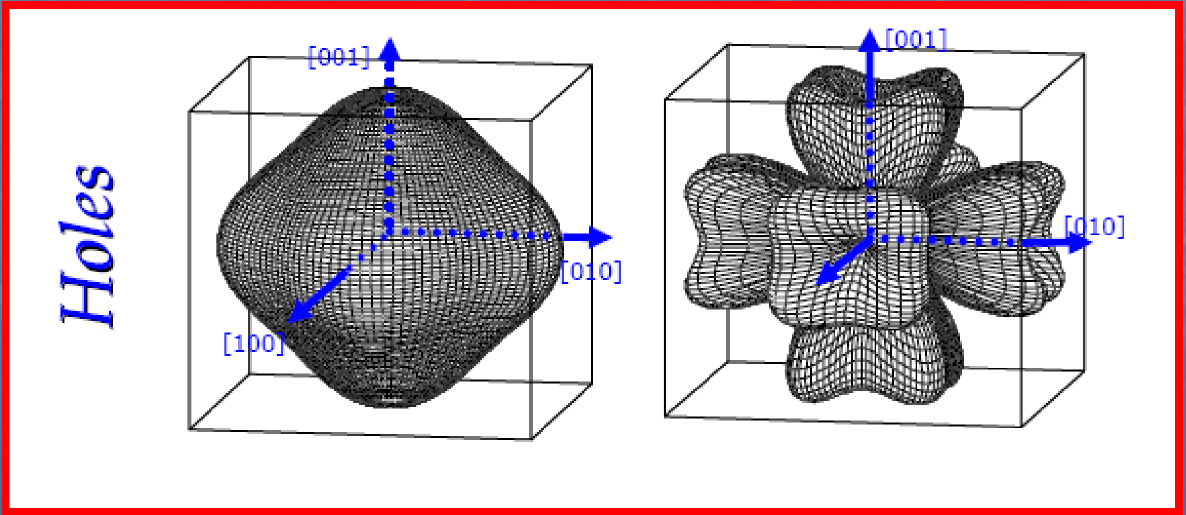
$$f(\vec{k}) \propto \exp\left(-\hbar^2(\vec{k}-\vec{k}_0)^2/2mk_bT_e\right)$$

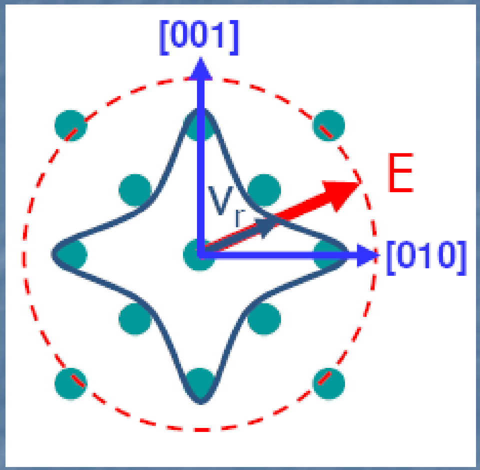
$$\vec{\mathbf{v}}_d = \int \mathbf{v}(\vec{k})\, f(\vec{k})\, d\vec{k}$$

# The anisotropic Hole mobility model

*Anisotropy: Radial velocity* *Tangential velocity*



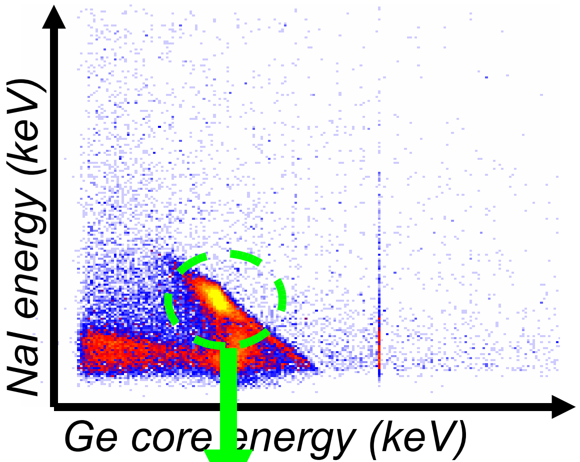



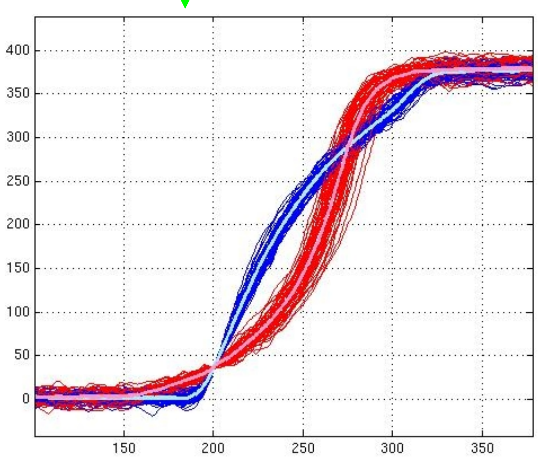



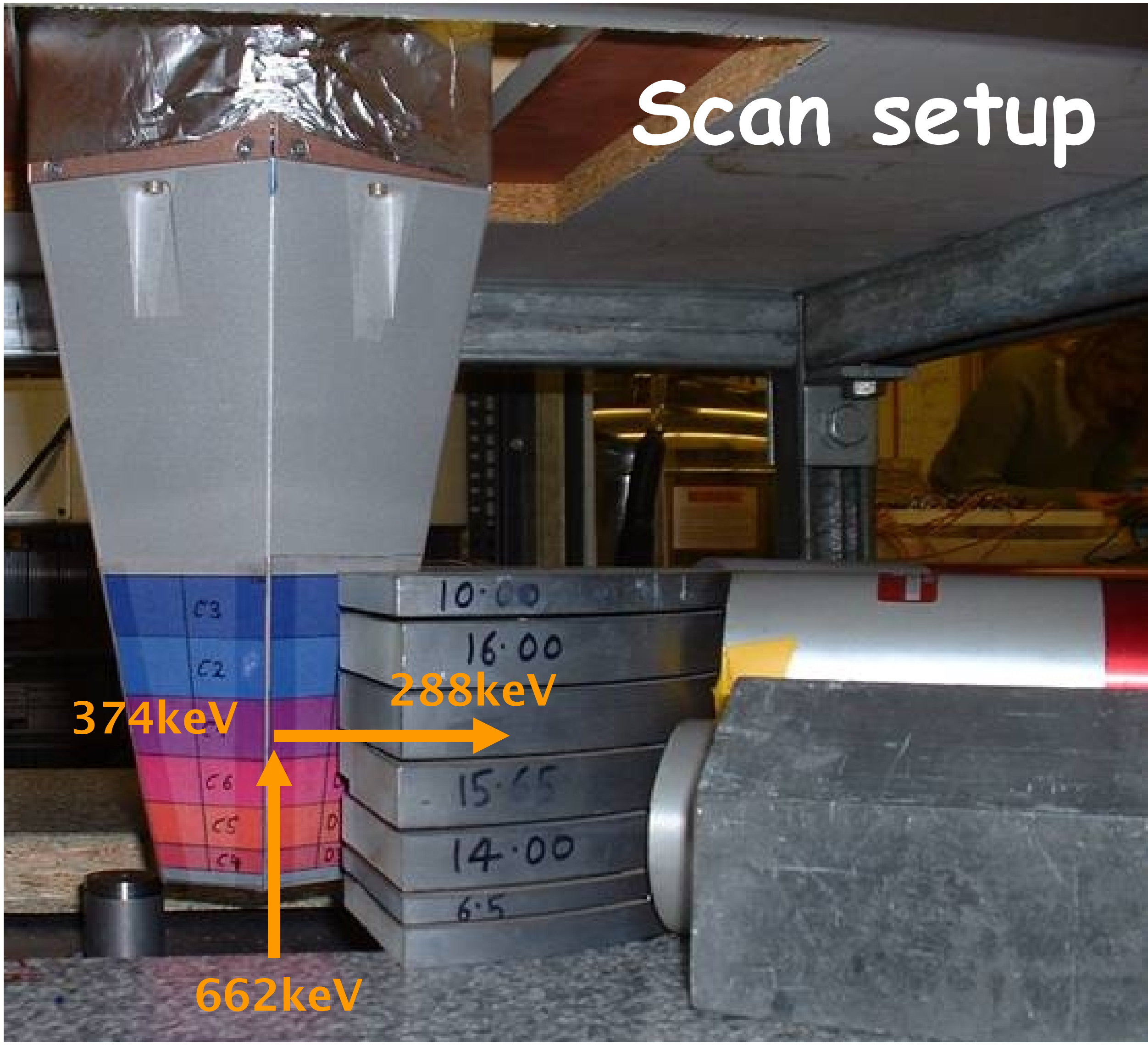

- Electrons $v_r$ mainly slower near [111], Holes $v_r$ mainly faster near [100]
- Tangential components 0 along symmetry axes and largest near directions of strongest longitudinal anisotropy

# Coincidence measurement = Position selection

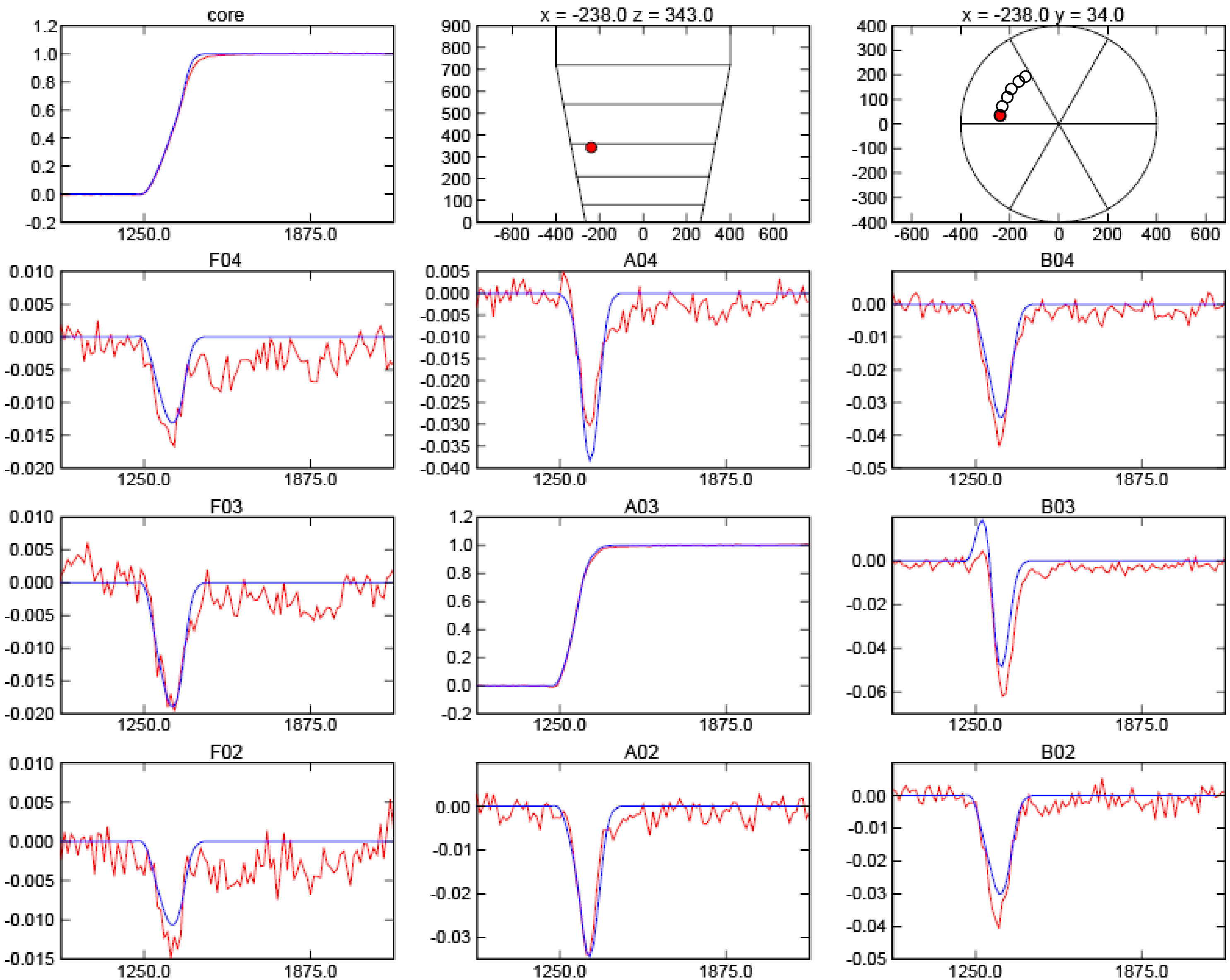
THE UNIVERSITY of LIVERPOOL



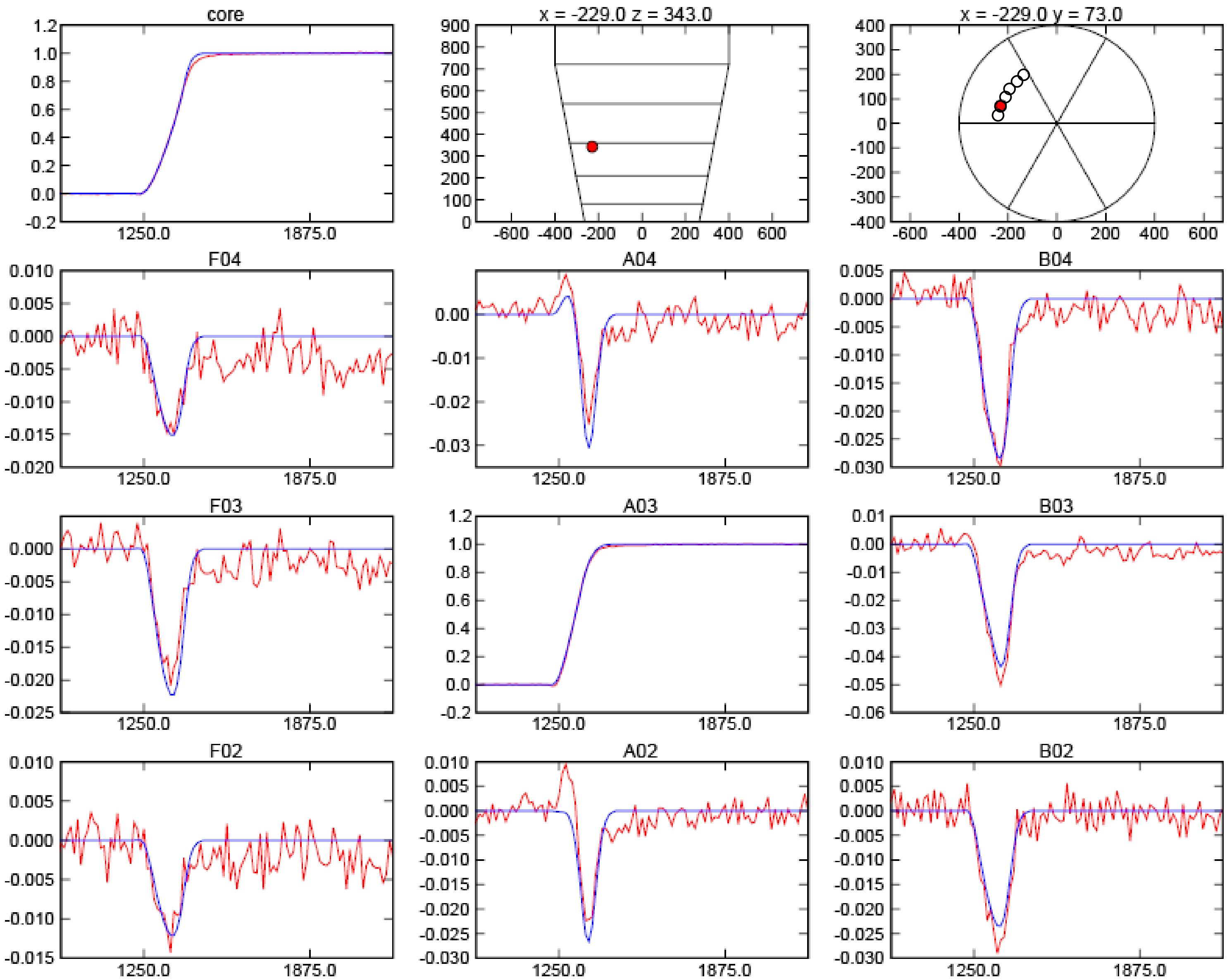



# Scanning - examples



# Scanning - examples



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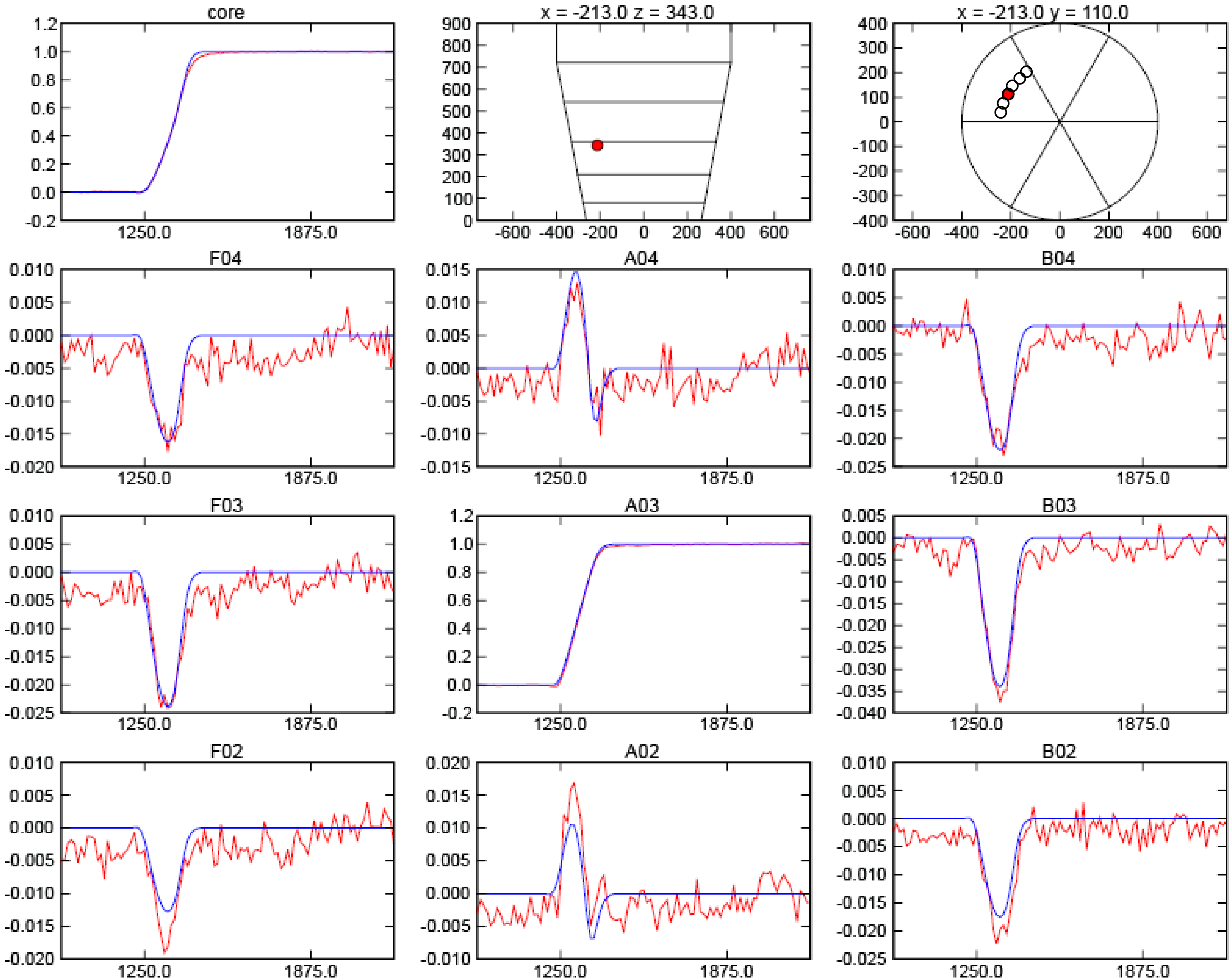

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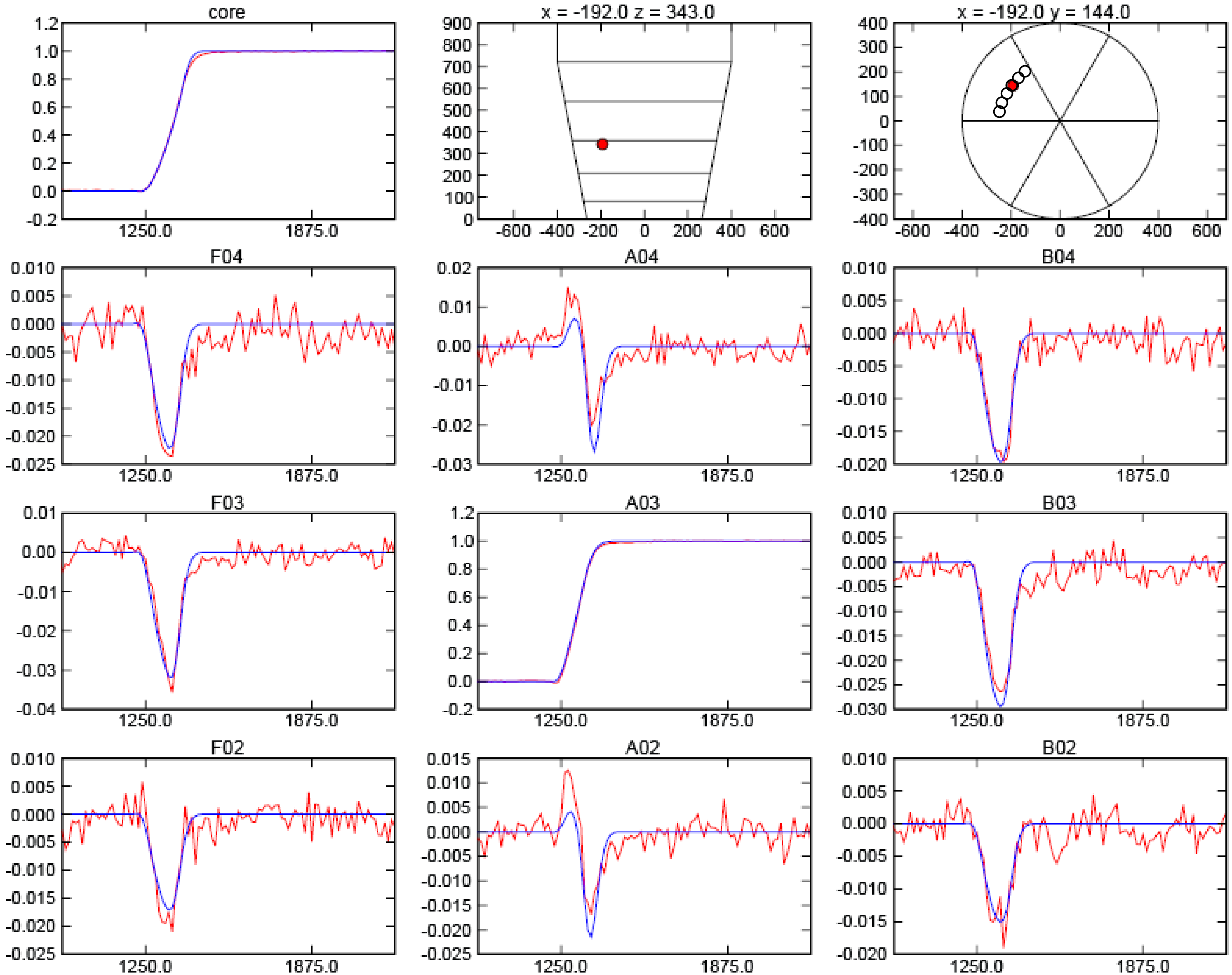

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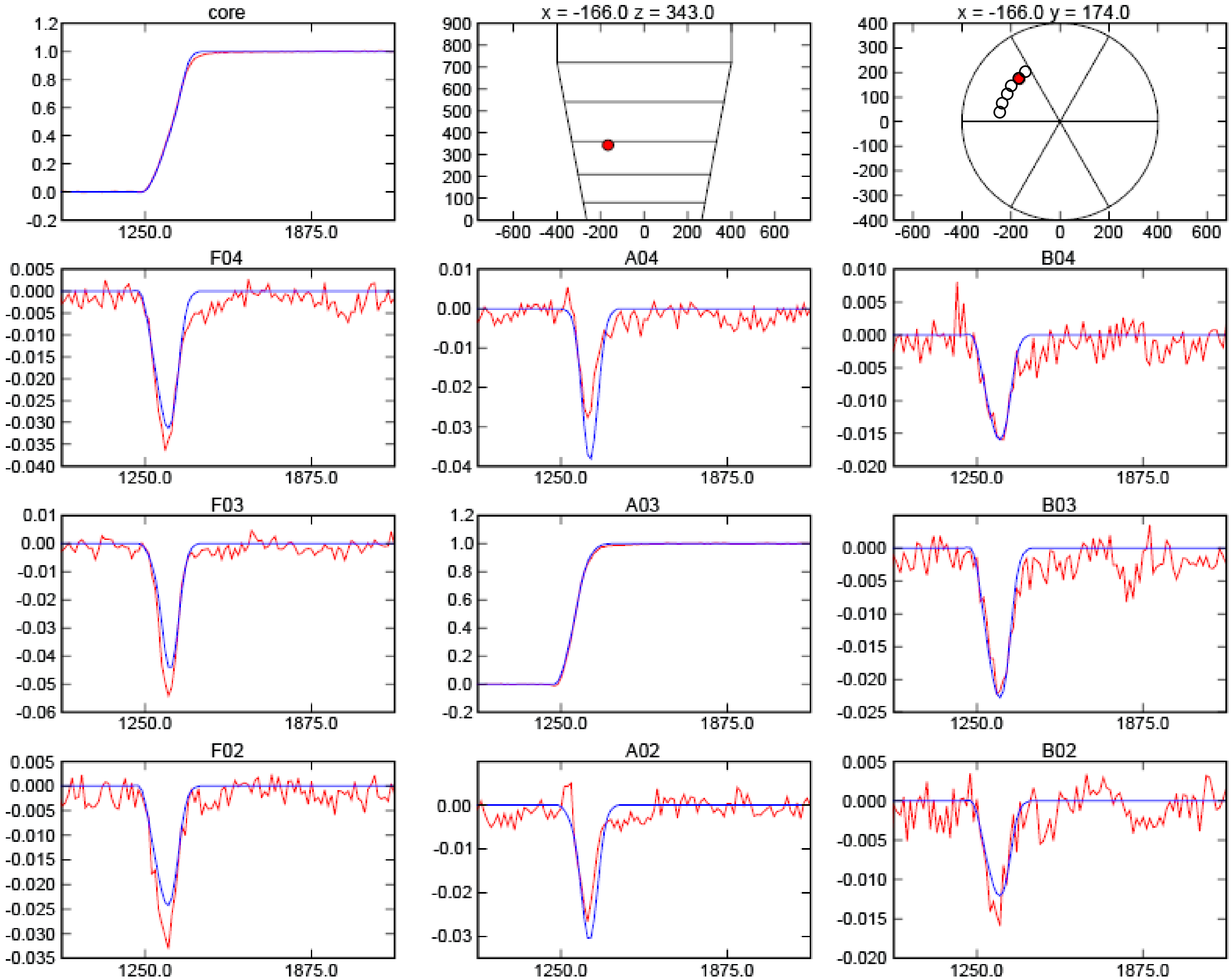
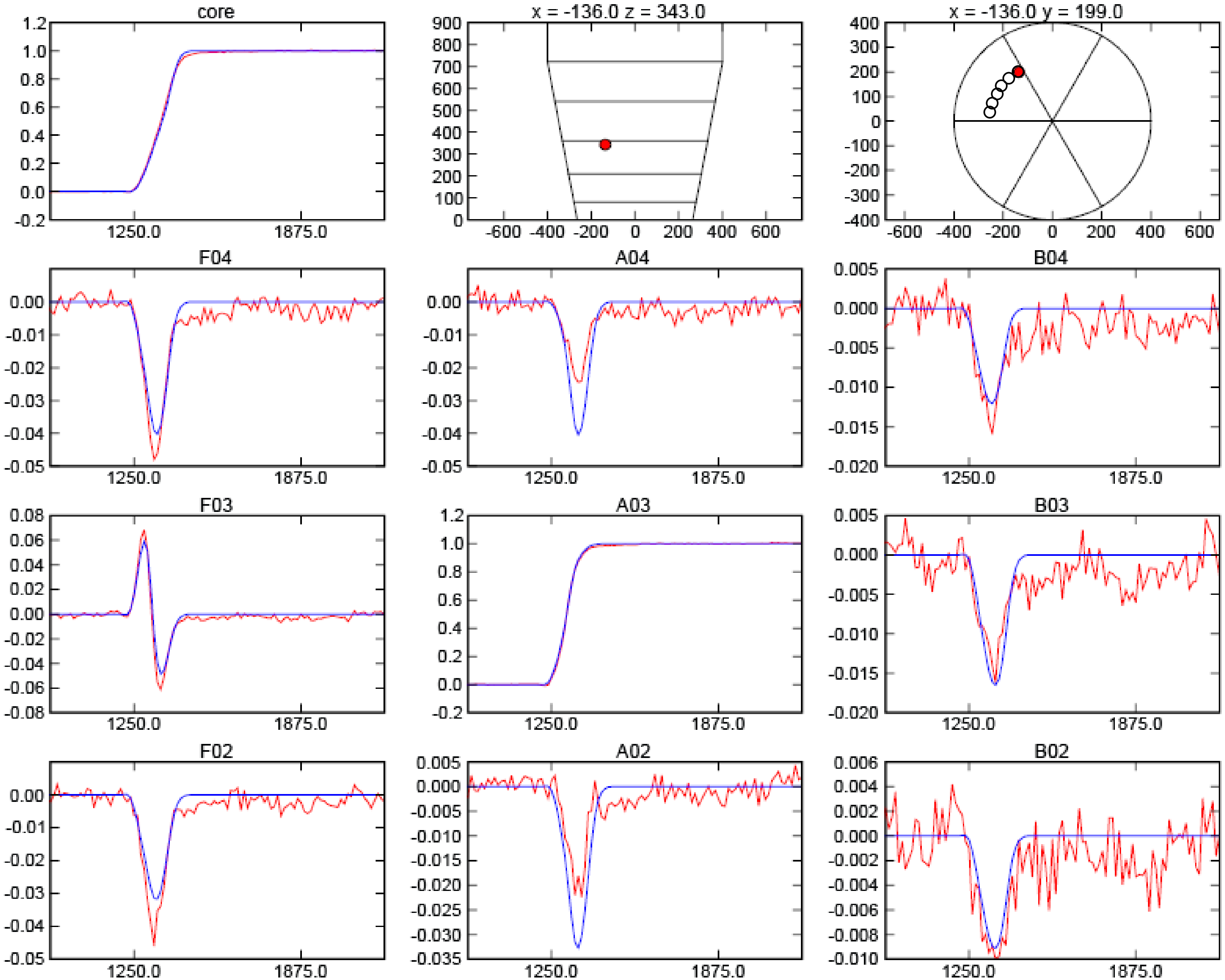


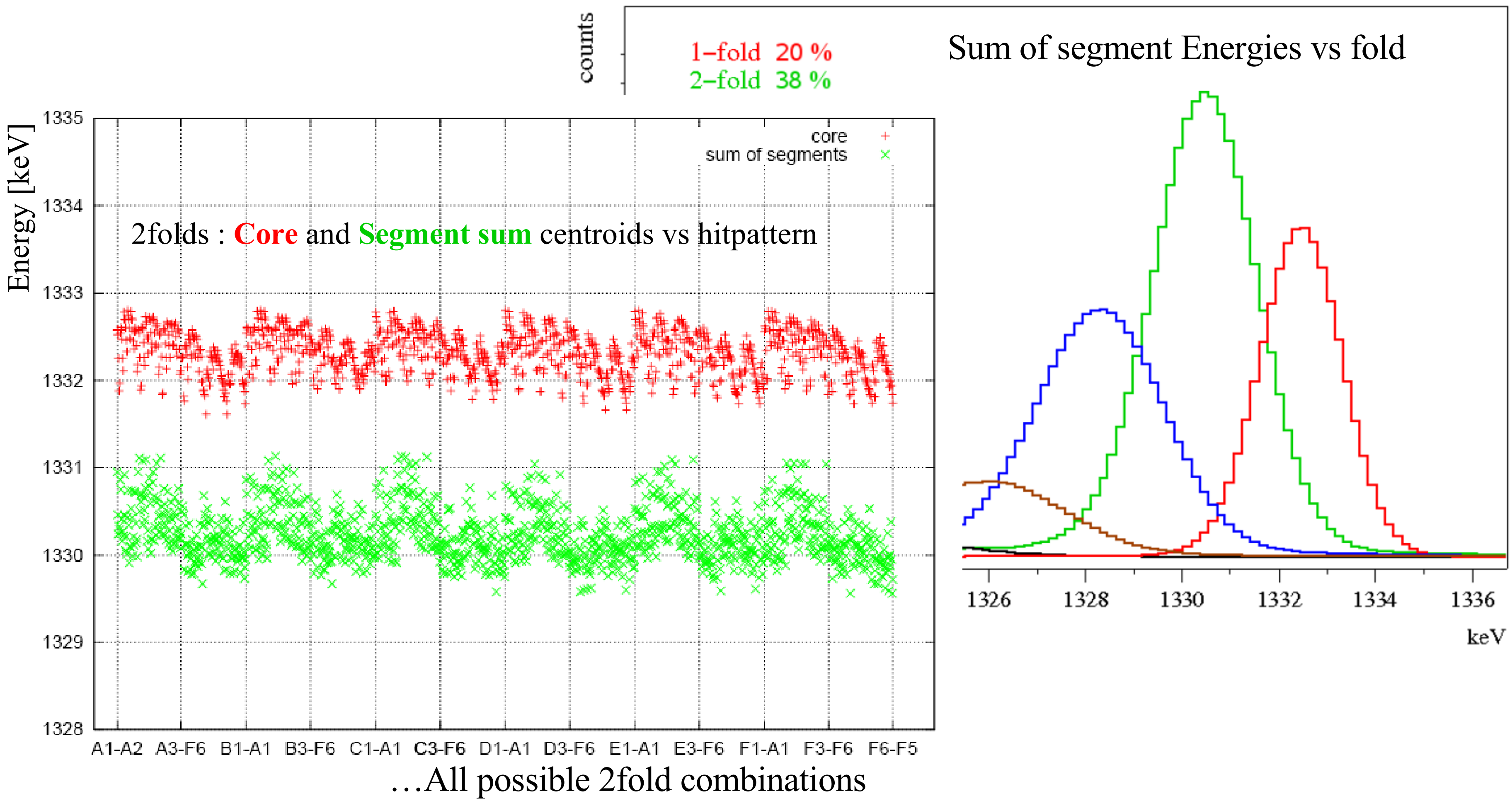
# Scanning - examples



- Crosstalk studies

# 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> !



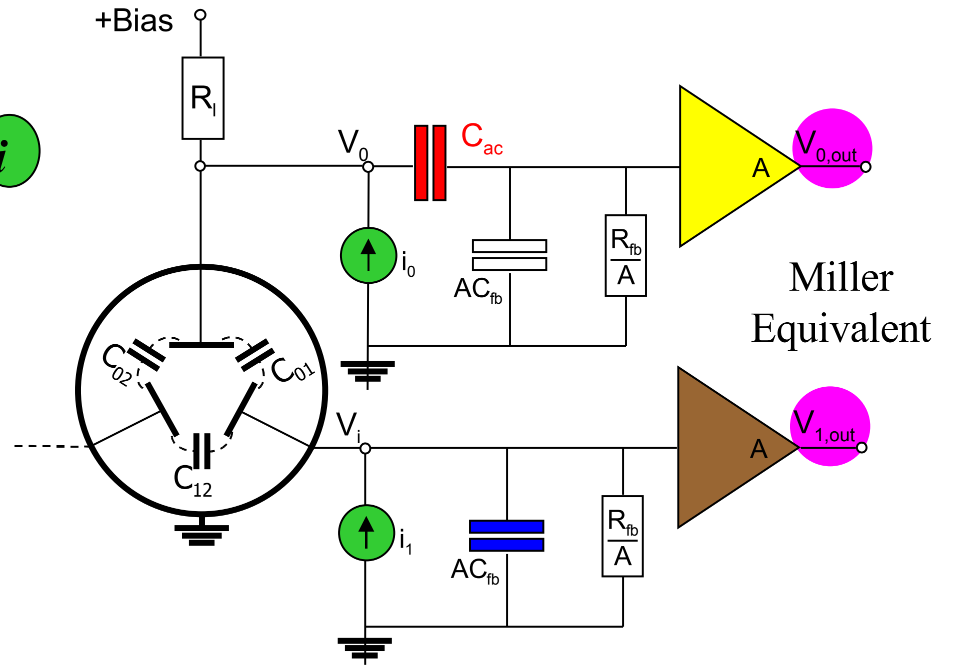
# A model to describe cross talk

Segment-to-Core

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

Core-to-Seg | Segment-to-Segment

~ 1pF/1000pF | ~1pF/(10000 · 1pF)




**Crosstalk is intrinsic property of segmented detectors !**


B. Bruyneel et al – NIM A 599 (2009) 196-208

E. Gatti et al – NIM 193 (82) p. 651

# 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

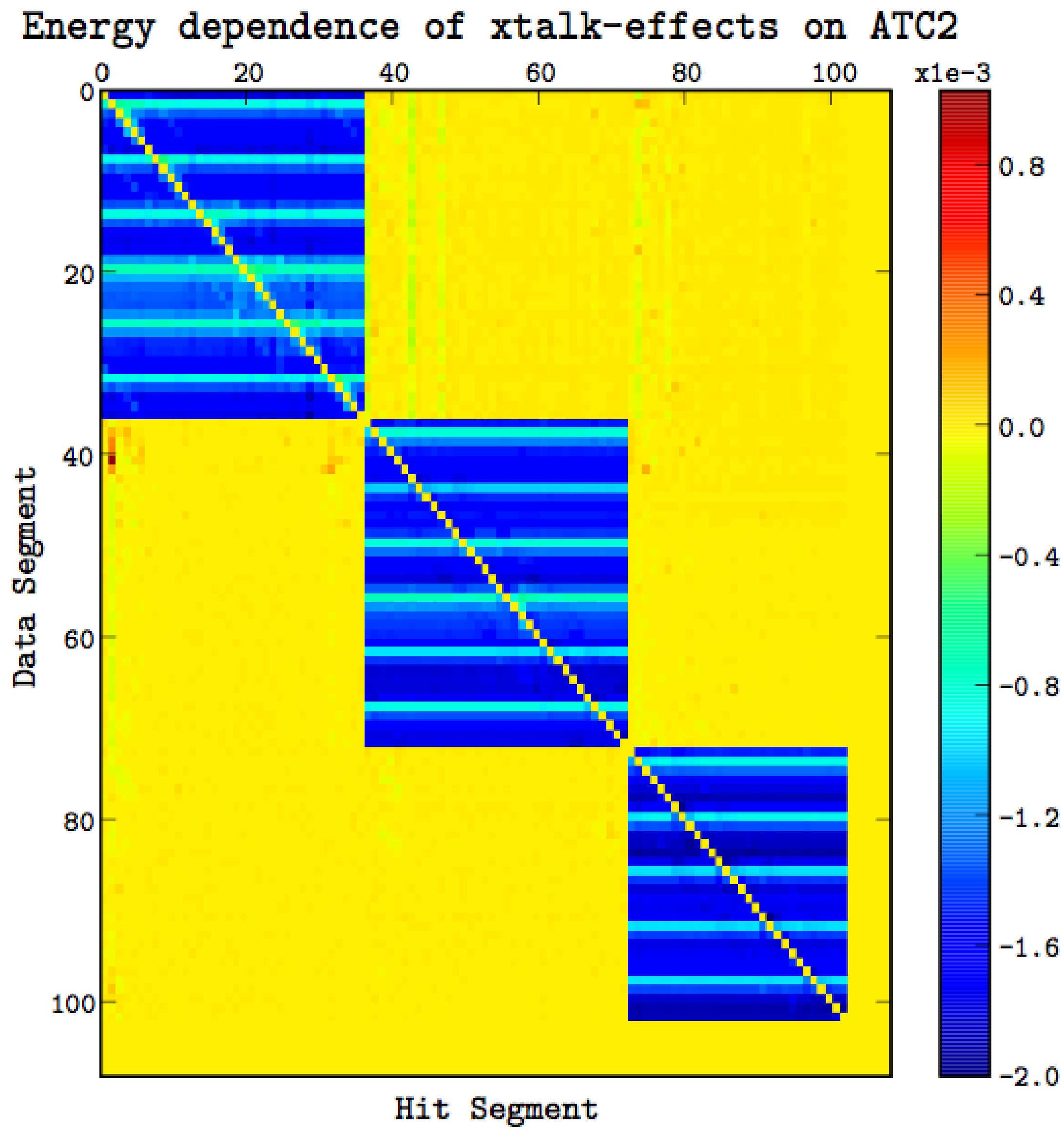
•*With cross talk:*

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

All matrix elements measured

# 2° AGATA triple cluster detector

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



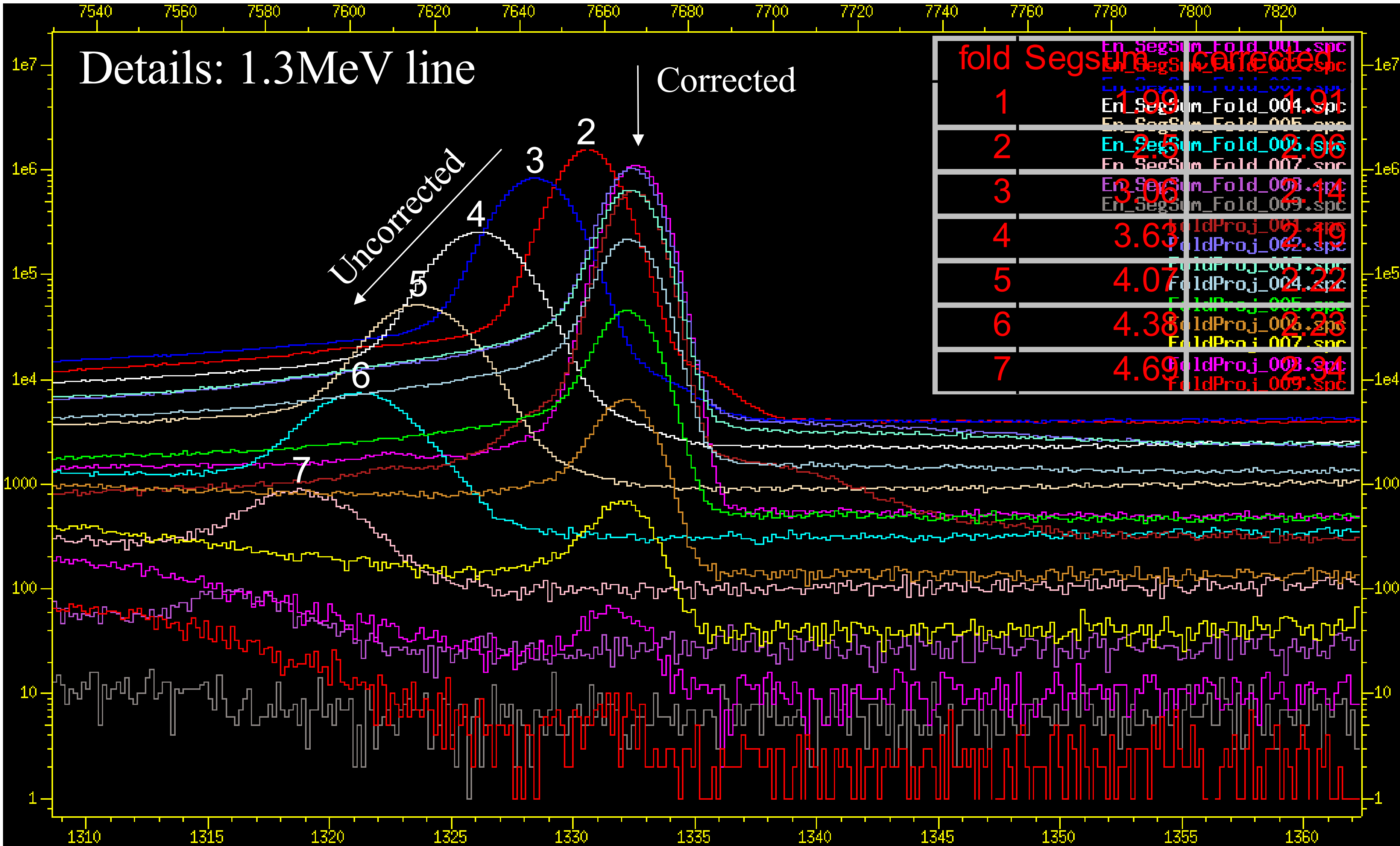

**<u>Crosstalk analysis of ATC2</u>**

cross talk contributions
~ $10^{-3}$ (blue areas)
within the detectors

cross talk level between
Different detectors
$<10^{-5}$ (yellow areas).

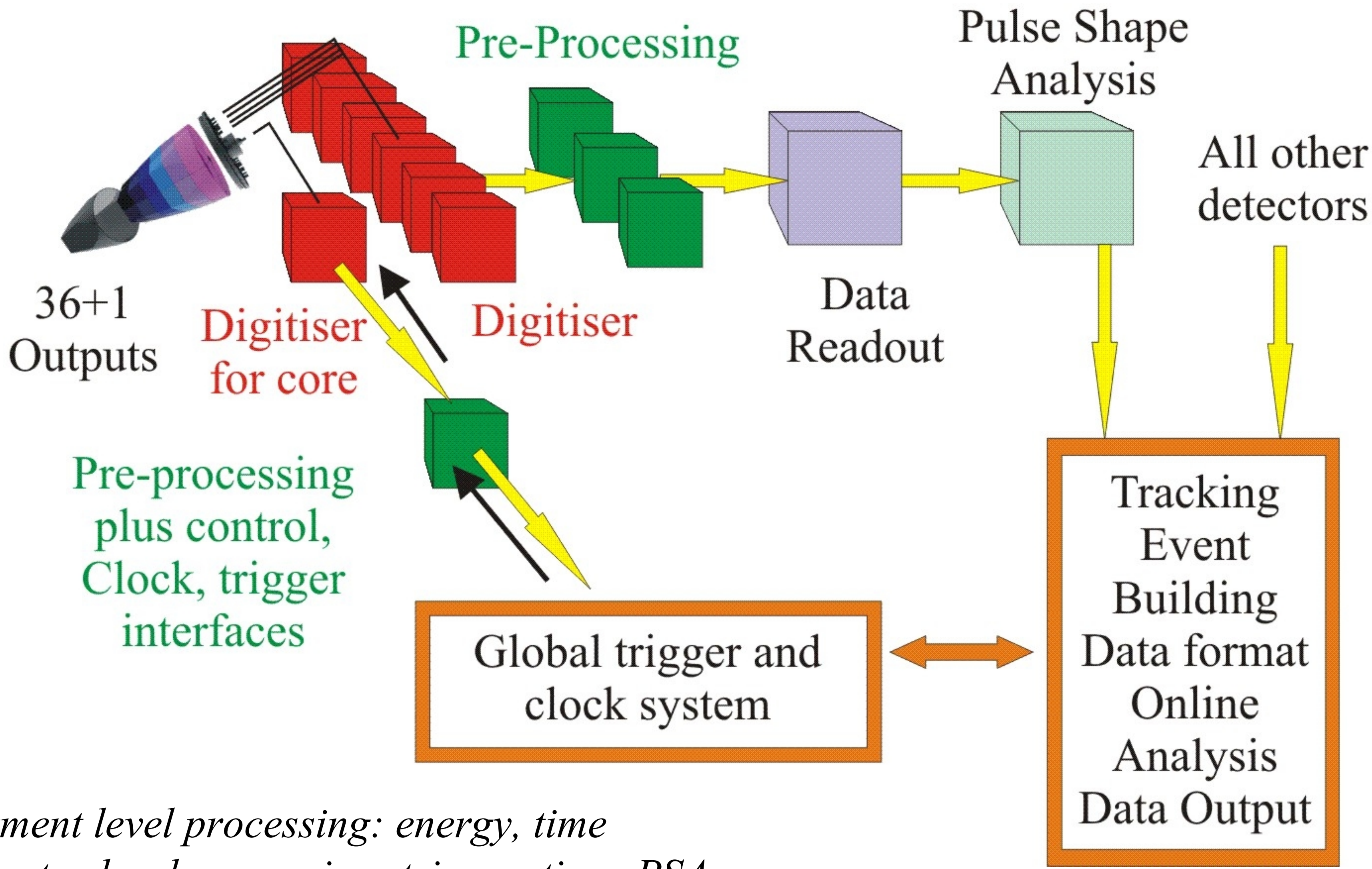
# Cross talk correction: Results

**FWHM 60keV: 1.20 → 1.02 !**



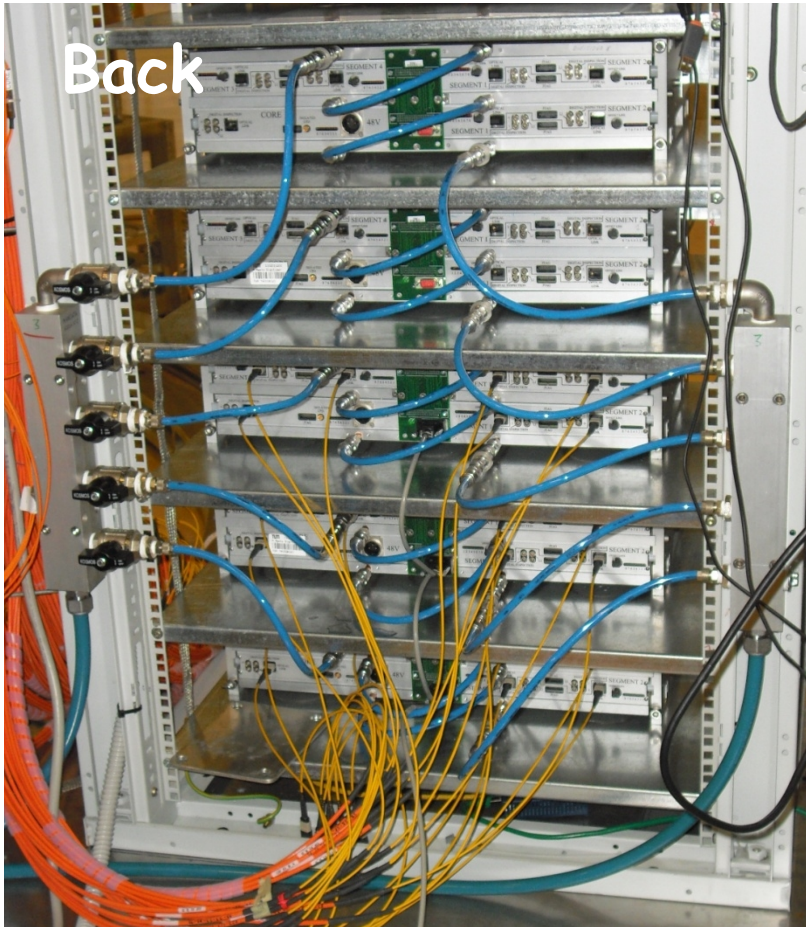
- AGATA – present status

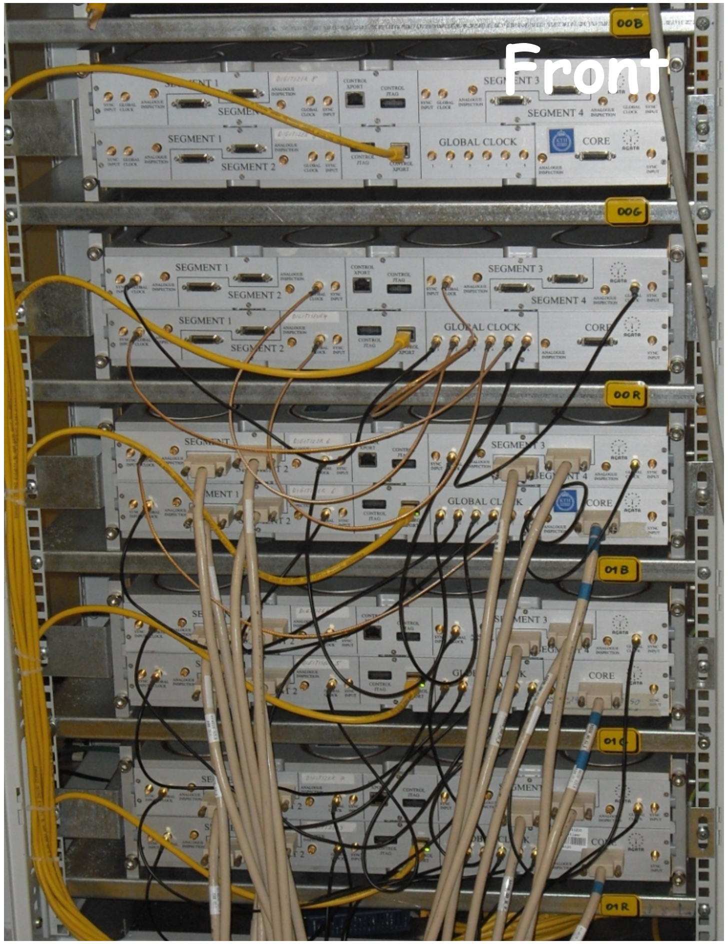
## *Schematic of the Digital Electronics and Data Acquisition System for AGATA*




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

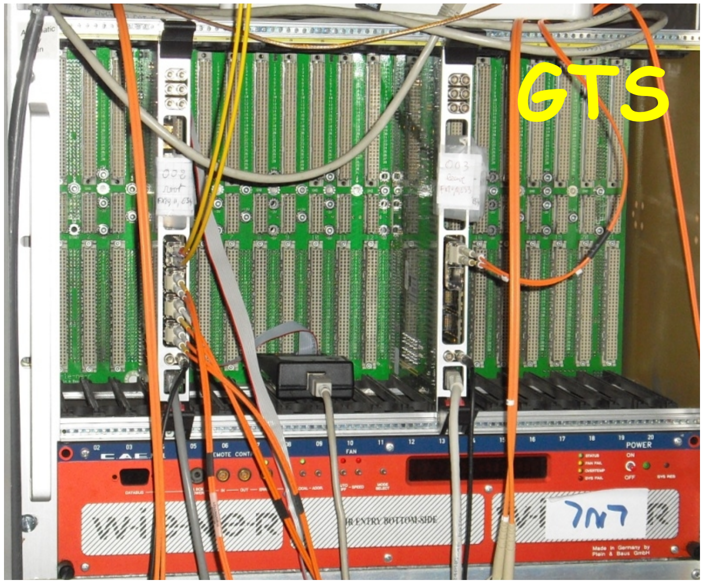
# Digitizers

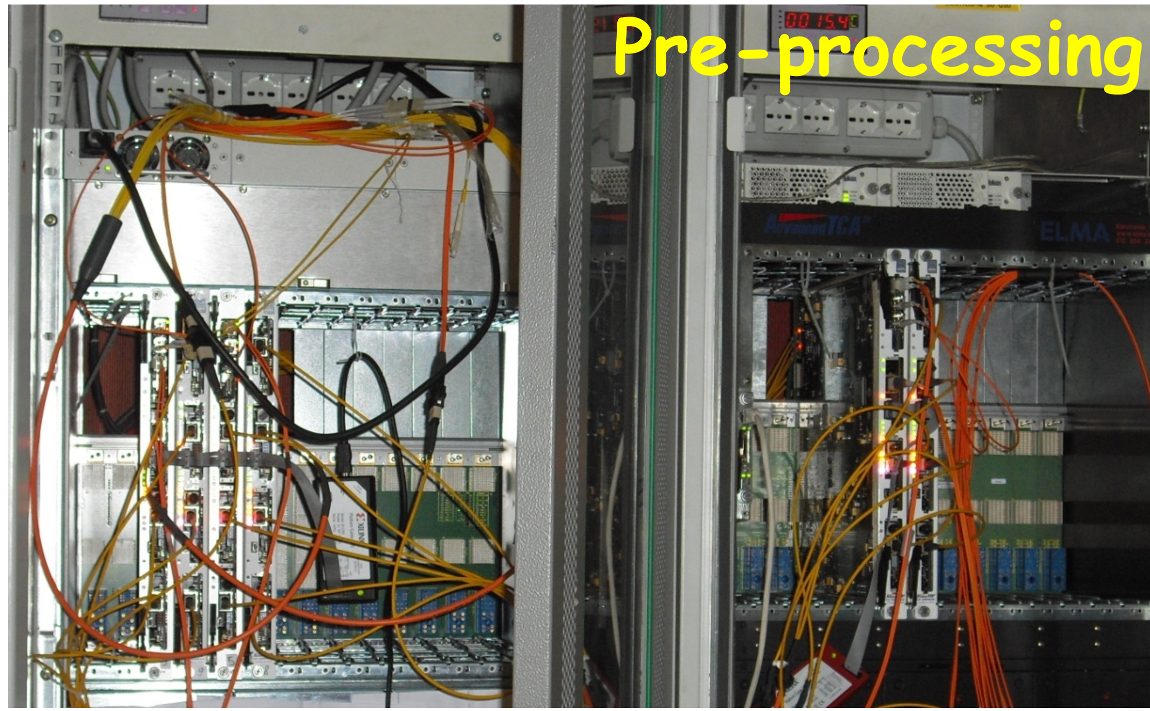



Six digitizers are placed in the structure and water cooled (power supply available for three of them only).

# GTS and pre-processing




6 carrier boards, 21 segment mezzanines, 5 GTS mezzanines available and working with preliminary version of slow control. Data from digitizers transmitted via optical fibres.

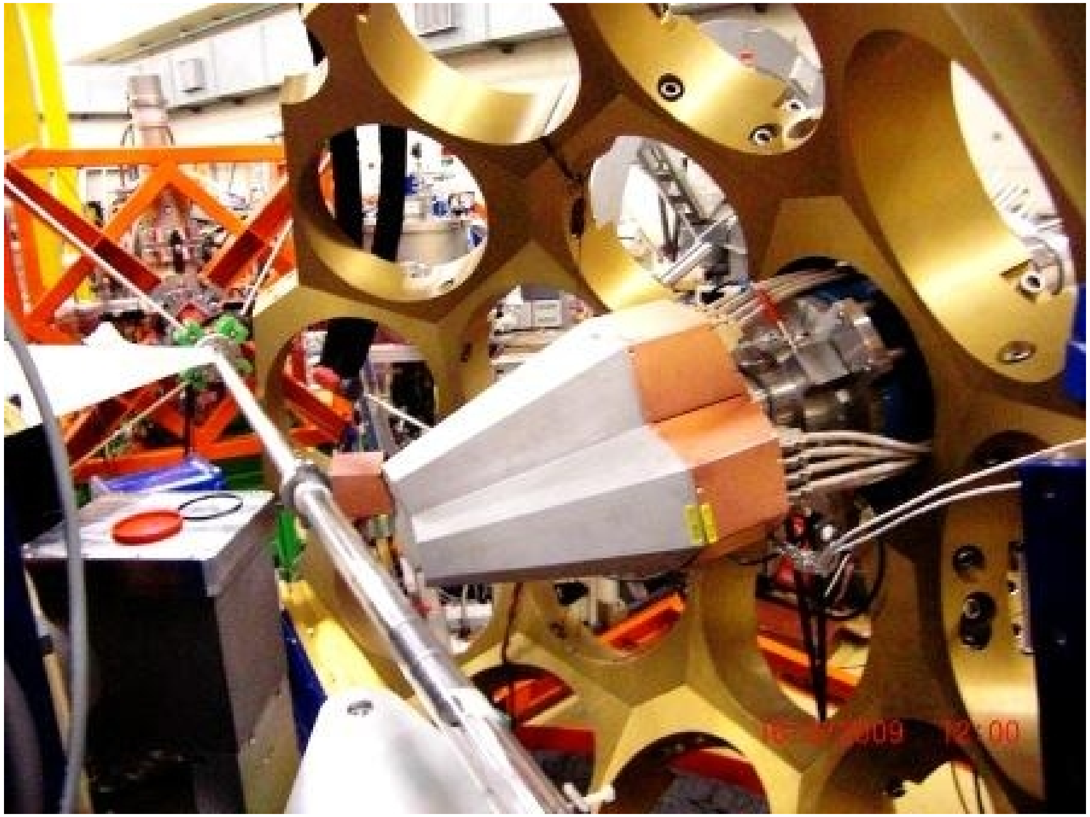
# Computing farm

PSA farm
with PCIe readout

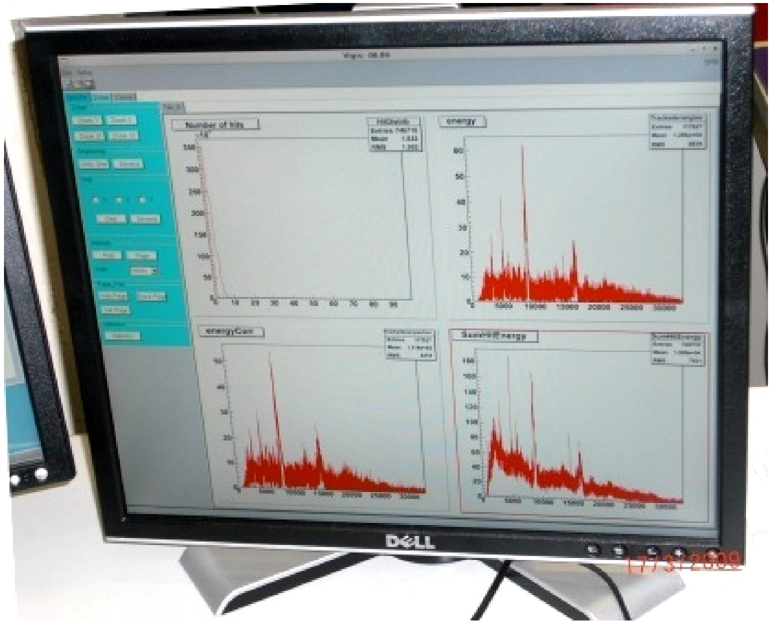

Disk server
(CMS/ALICE TIER-2)

Computing farm ("pizza boxes") for data acquisition with online (in real time) application of pulse shape analysis and $\gamma$-ray tracking.
Several TBs of disk space available at the LNL TIER-2 site.

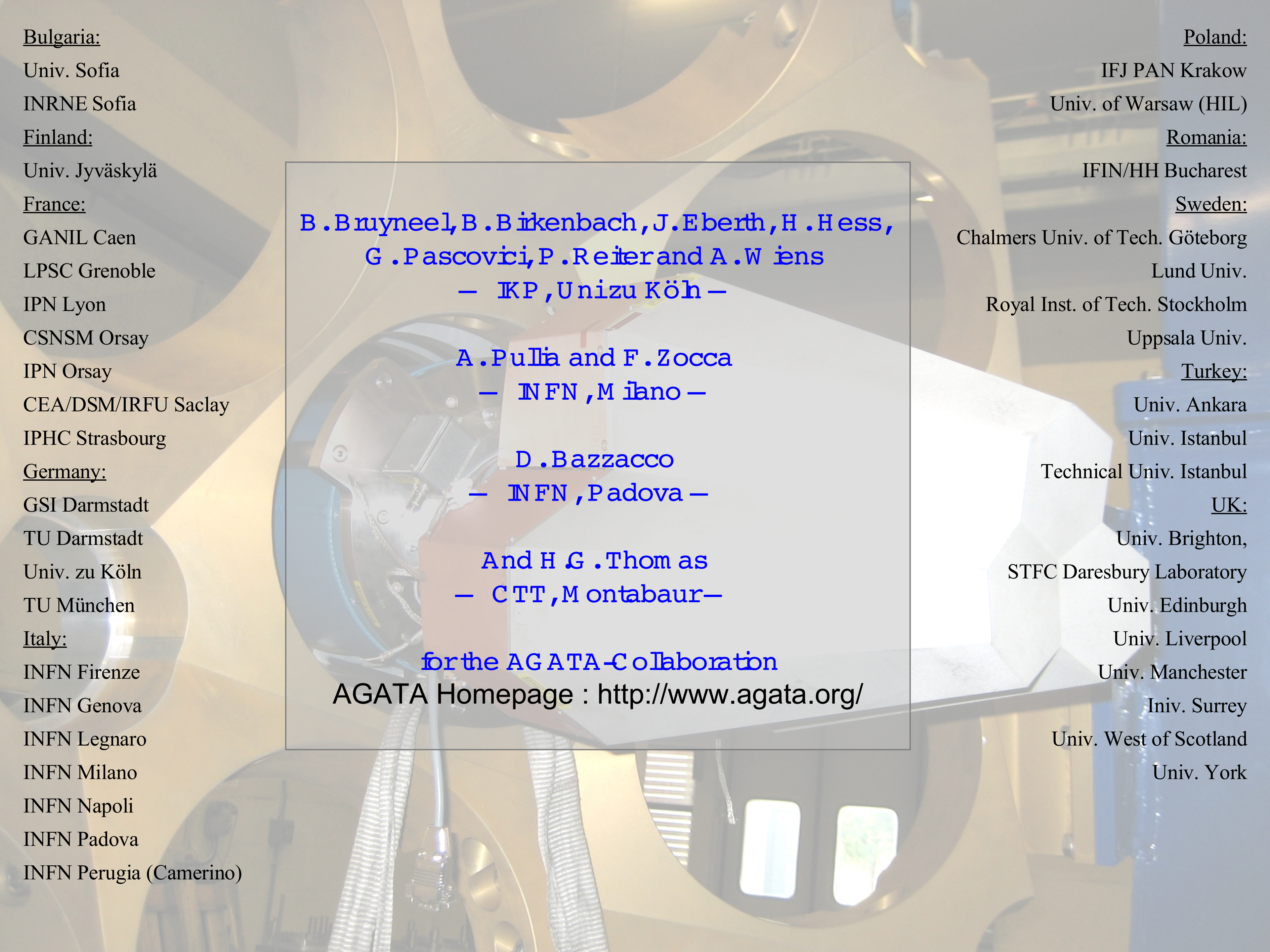
# AGATA is ALIVE !!!



11:42
17/03/2009



- **Pre-processing**
- **PSA**
- **Tracking**



<u>Bulgaria:</u>

Univ. Sofia

INRNE Sofia

<u>Finland:</u>

Univ. Jyväskylä

<u>France:</u>

GANIL Caen

LPSC Grenoble

IPN Lyon

CSNSM Orsay

IPN Orsay

CEA/DSM/IRFU Saclay

IPHC Strasbourg

<u>Germany:</u>

GSI Darmstadt

TU Darmstadt

Univ. zu Köln

TU München

<u>Italy:</u>

INFN Firenze

INFN Genova

INFN Legnaro

INFN Milano

INFN Napoli

INFN Padova

INFN Perugia (Camerino)


B.Bruyneel, B.Birkenbach, J.Eberth, H.Hess,
G.Pascovici, P.Reiter and A.Wiens
– IKP, Uni zu Köln –

A.Pullia and F.Zocca
– INFN, Milano –

D.Bazzacco
– INFN, Padova –

And H.G.Thomas
– CTT, Montabaur –

for the AGATA-Collaboration


AGATA Homepage : http://www.agata.org/

<u>Poland:</u>

IFJ PAN Krakow

Univ. of Warsaw (HIL)

<u>Romania:</u>

IFIN/HH Bucharest

<u>Sweden:</u>

Chalmers Univ. of Tech. Göteborg

Lund Univ.

Royal Inst. of Tech. Stockholm

Uppsala Univ.

<u>Turkey:</u>

Univ. Ankara

Univ. Istanbul

Technical Univ. Istanbul

<u>UK:</u>

Univ. Brighton,

STFC Daresbury Laboratory

Univ. Edinburgh

Univ. Liverpool

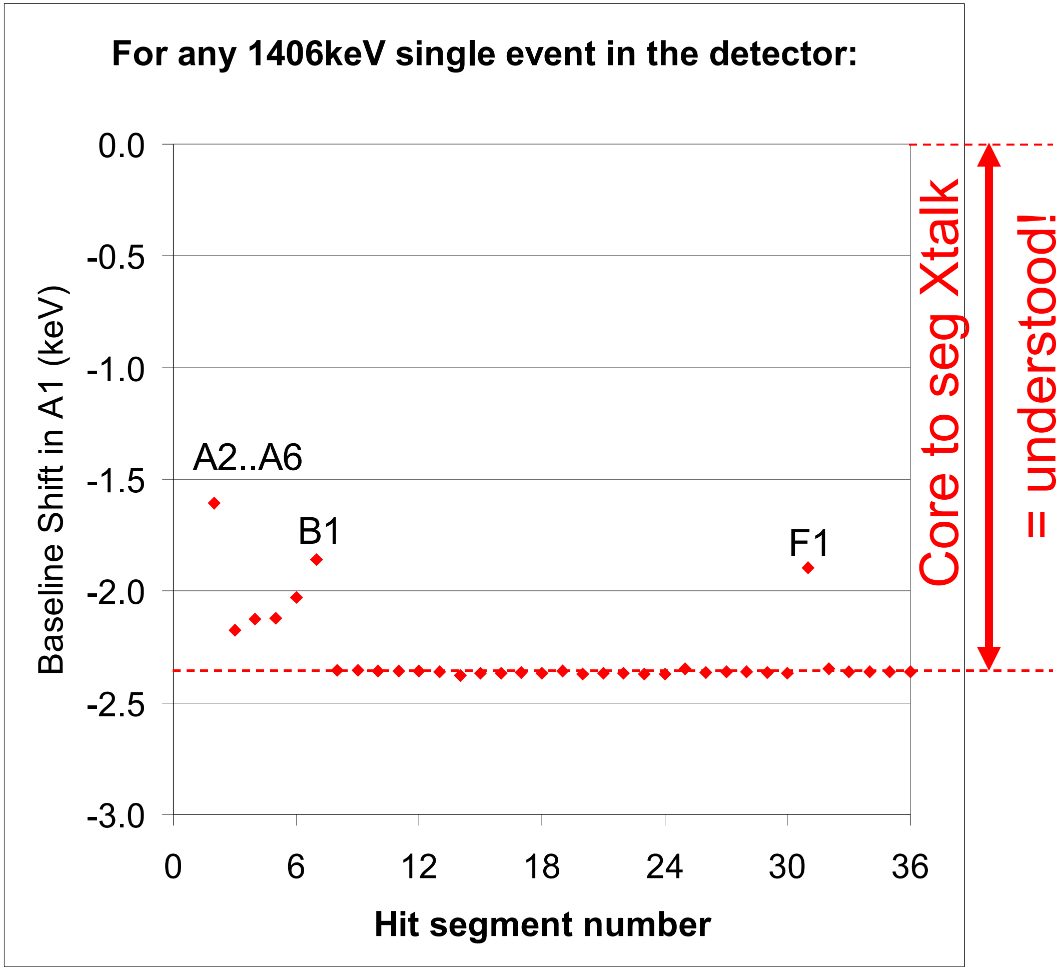
Univ. Manchester

Iniv. Surrey

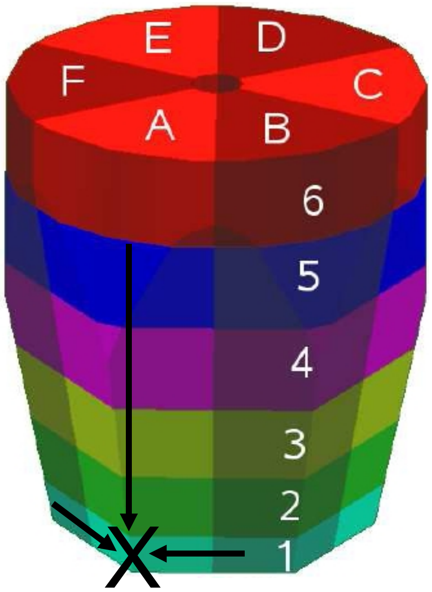
Univ. West of Scotland

Univ. York

# Cross talk : intro




Segment labeling:



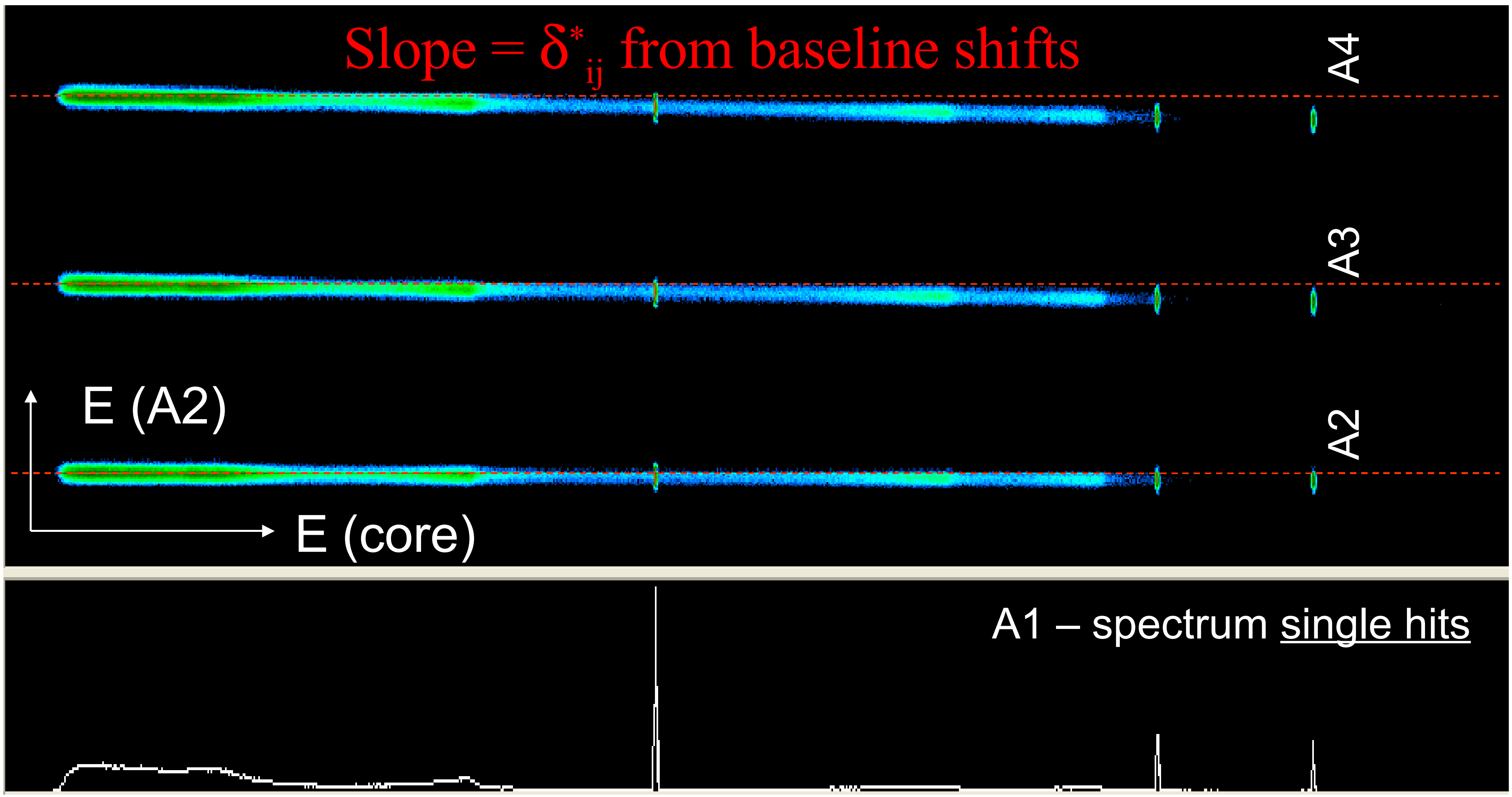

Sectors: A...F

Rings: 1...6

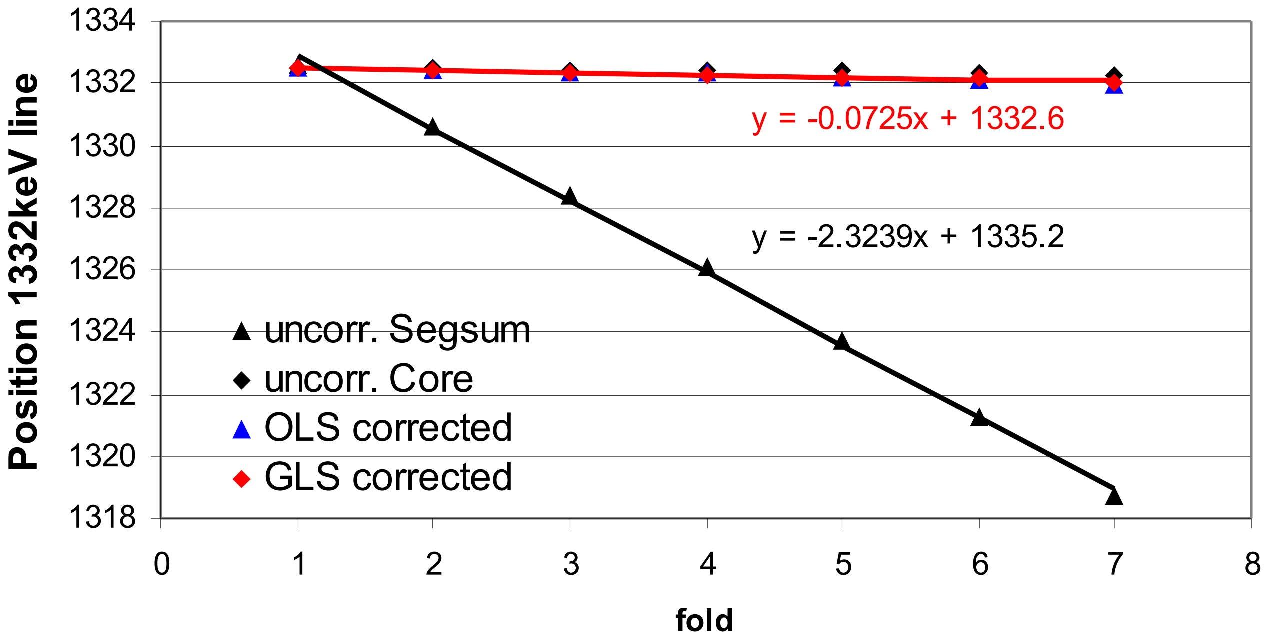
# Measuring the cross talk parameters

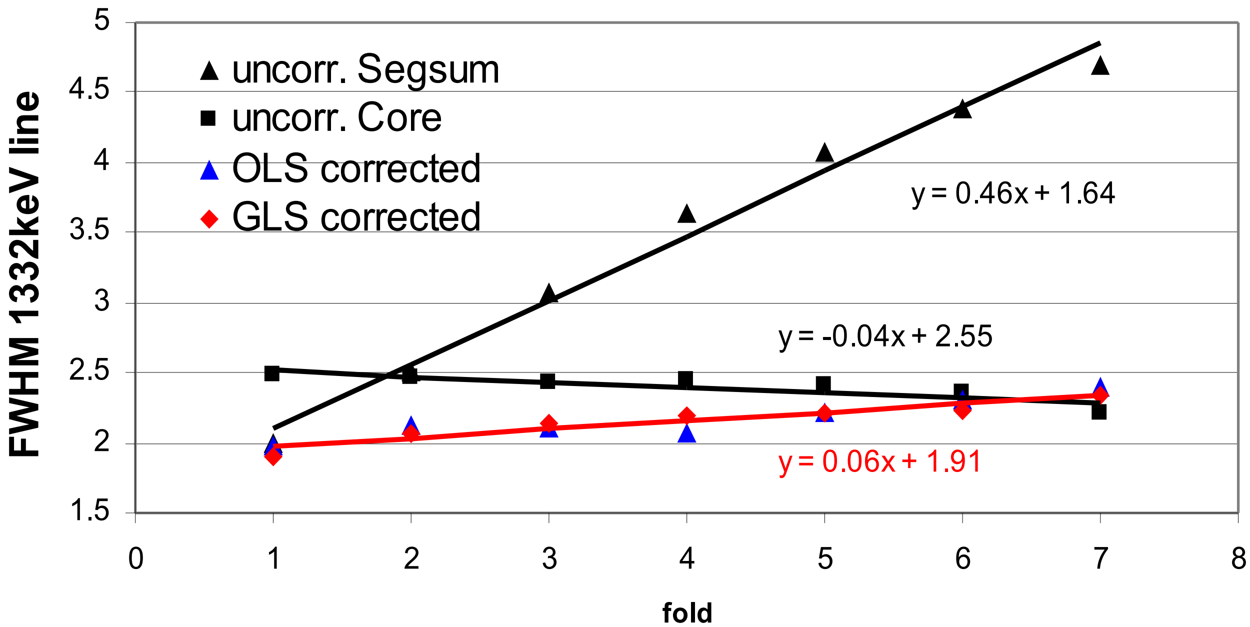
a) From singles:

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

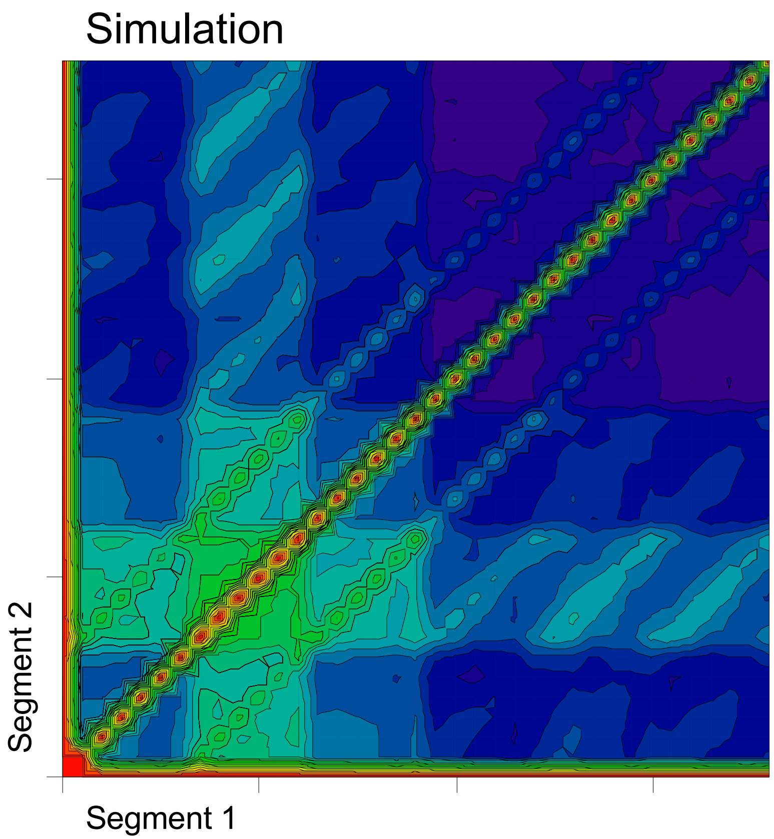


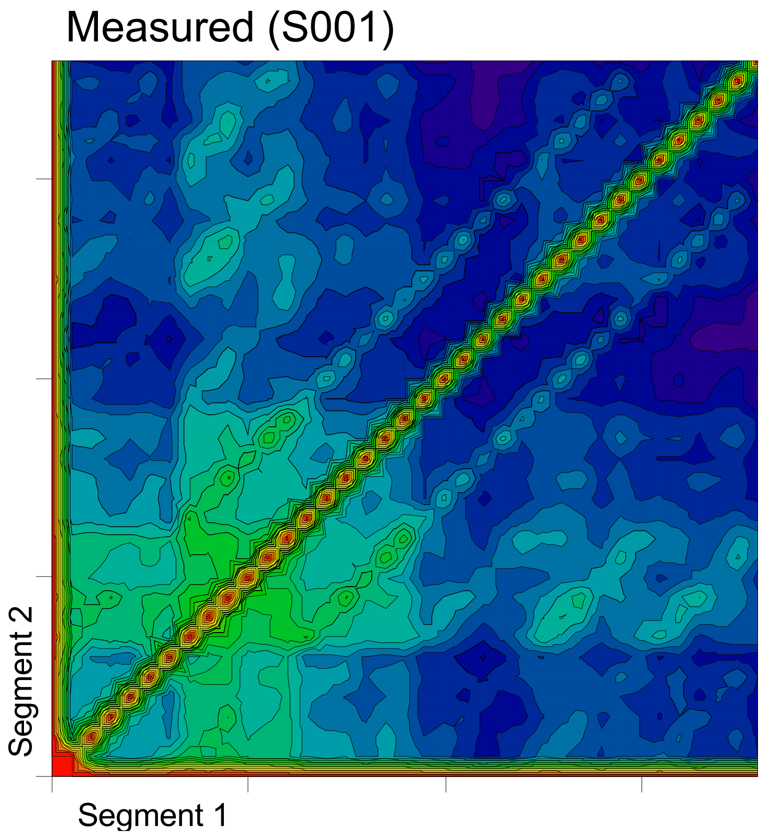
# Results in values



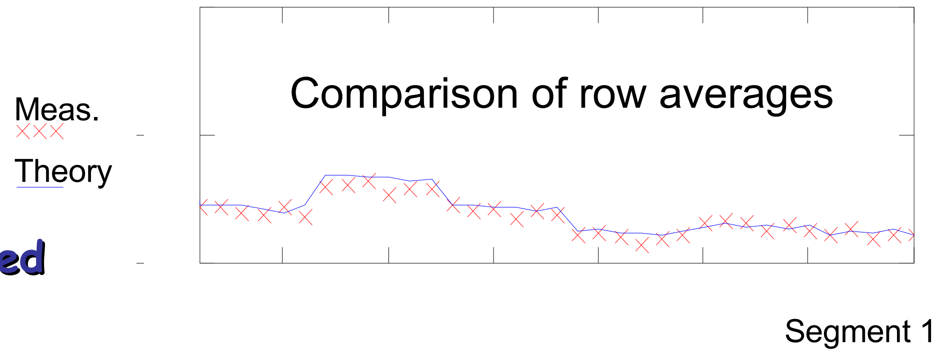



# Core to segment crosstalk in 2folds

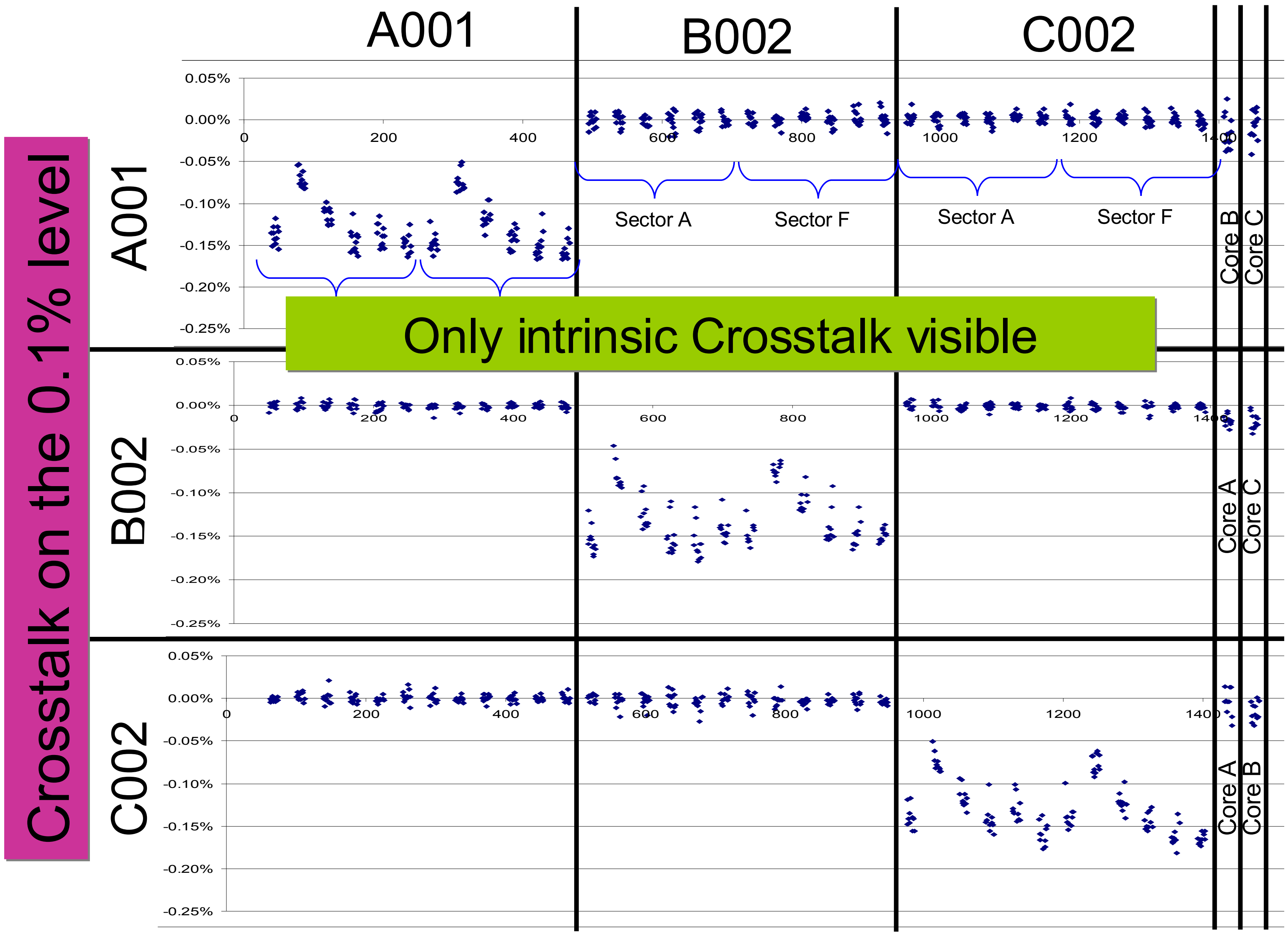


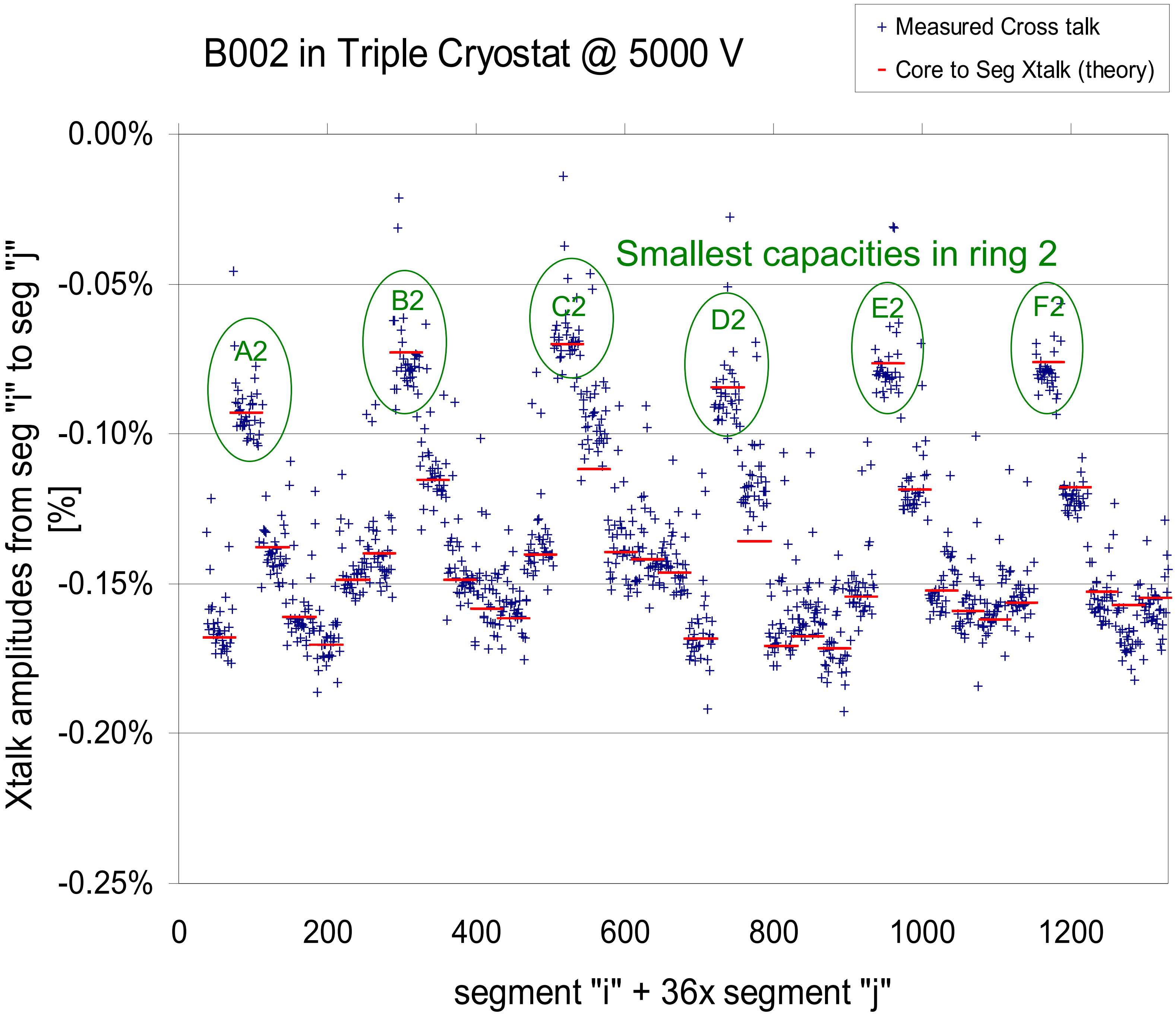




- Highly Quantitative agreement between theory and observation
- Fundamental cross talk limit reached



# Cross talk in Triple Cryostat

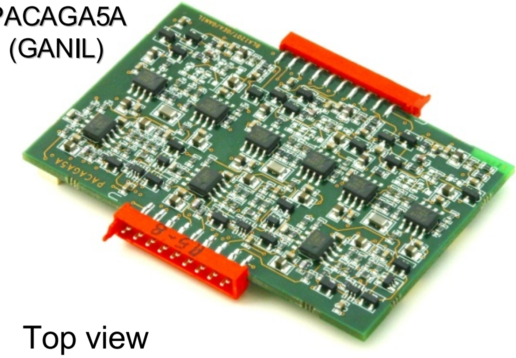




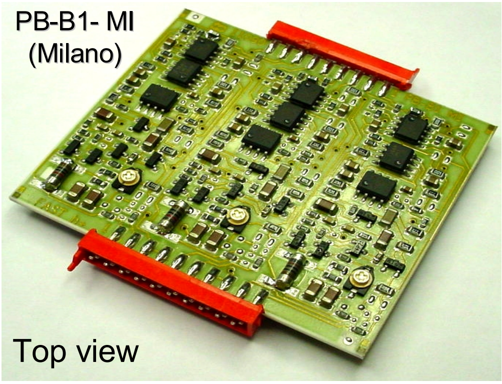
B002 in Triple Cryostat @ 5000 V
Measured Cross talk
Core to Seg Xtalk (theory)
Smallest capacities in ring 2
A2
B2
C2
D2
E2
F2
0.00%
-0.05%
-0.10%
-0.15%
-0.20%
-0.25%
Xtalk amplitudes from seg "i" to seg "j" [%]
0
200
400
600
800
1000
1200
segment "i" + 36x segment "j"

# Developed preamplifiers

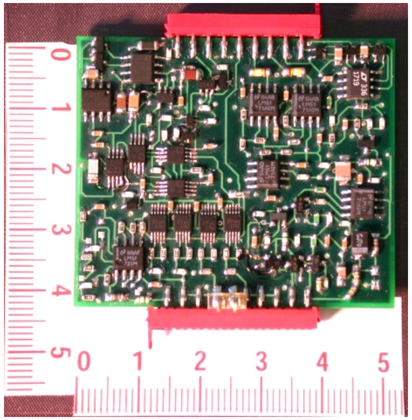
PACAGA5A
(GANIL)



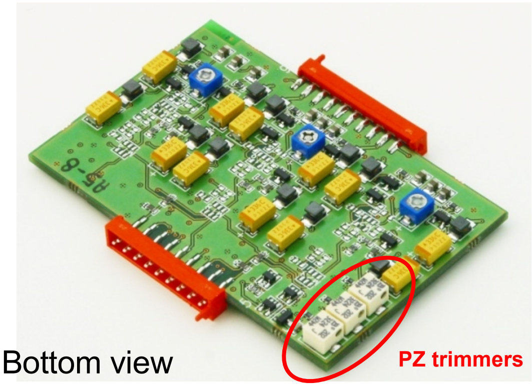
Top view

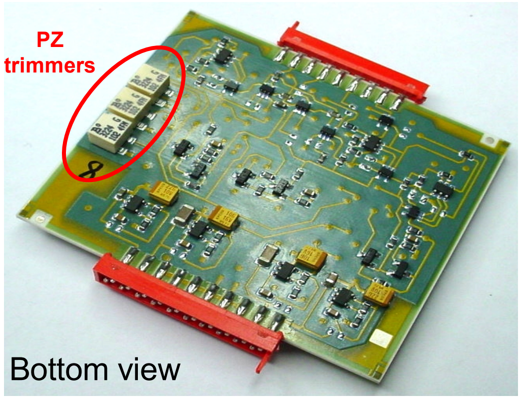



AGATA_
core-pulser
(Koeln)

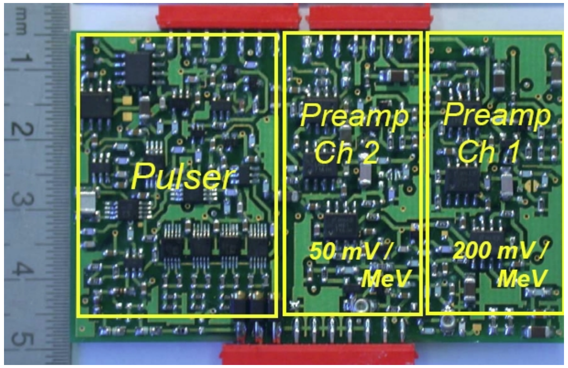



1 Channel
version



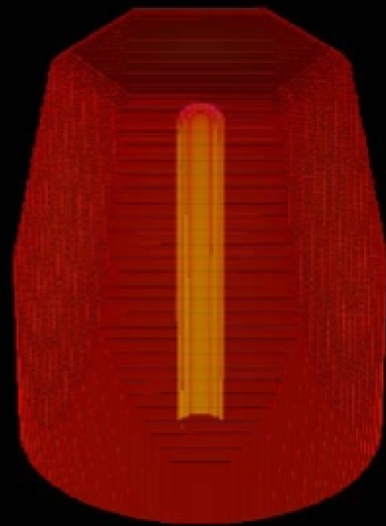

New version: “Dual Core“



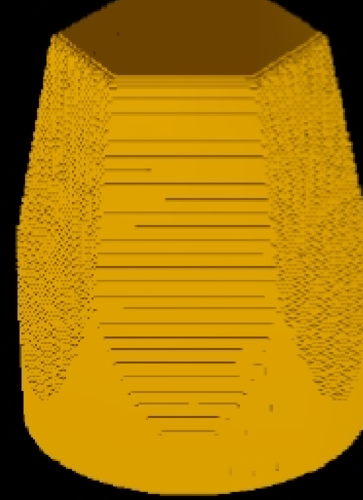

| | | |
|---|---|---|
| **<u>Triple segment preamp</u> on FR4 substrate**<br>**Mod. “PACAGA5A” – GANIL**<br>B. Cahan et al. | **<u>Triple segment preamp</u> on alumina substrate**<br>**Mod. “PB-B1 MI” – Milano**<br>A. Pullia et al. | **<u>Core preamplifier & built-in pulser</u> on FR4 substrate**<br>**Mod. “AGATA core-pulser” – Koeln**<br>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

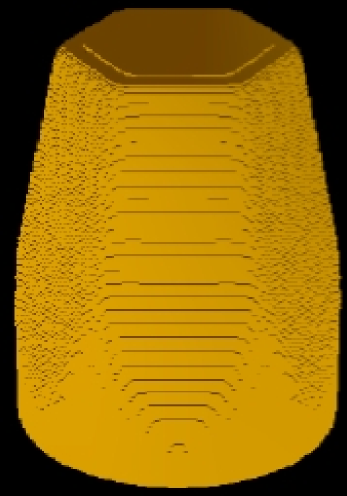

A



B



C: HV = 10V



D: HV = 100V

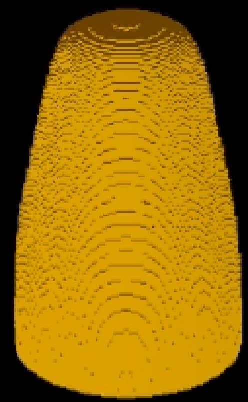
**Depletion of a HPGe detector**

A: Bare HPGe germanium crystal
symmetric AGATA detector

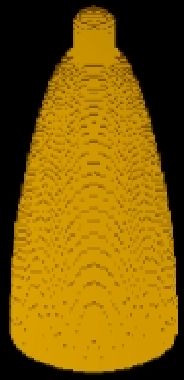
B: Geometry in simulation
The HV contact is colored yellow

C-G: Undepleted volume
as function of HV.

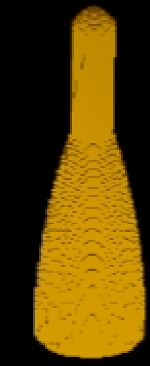
(assumption: $10^{10}$ impurities / $cm^3$)



E: HV = 1kV



F: HV = 2kV



G: HV = 3kV