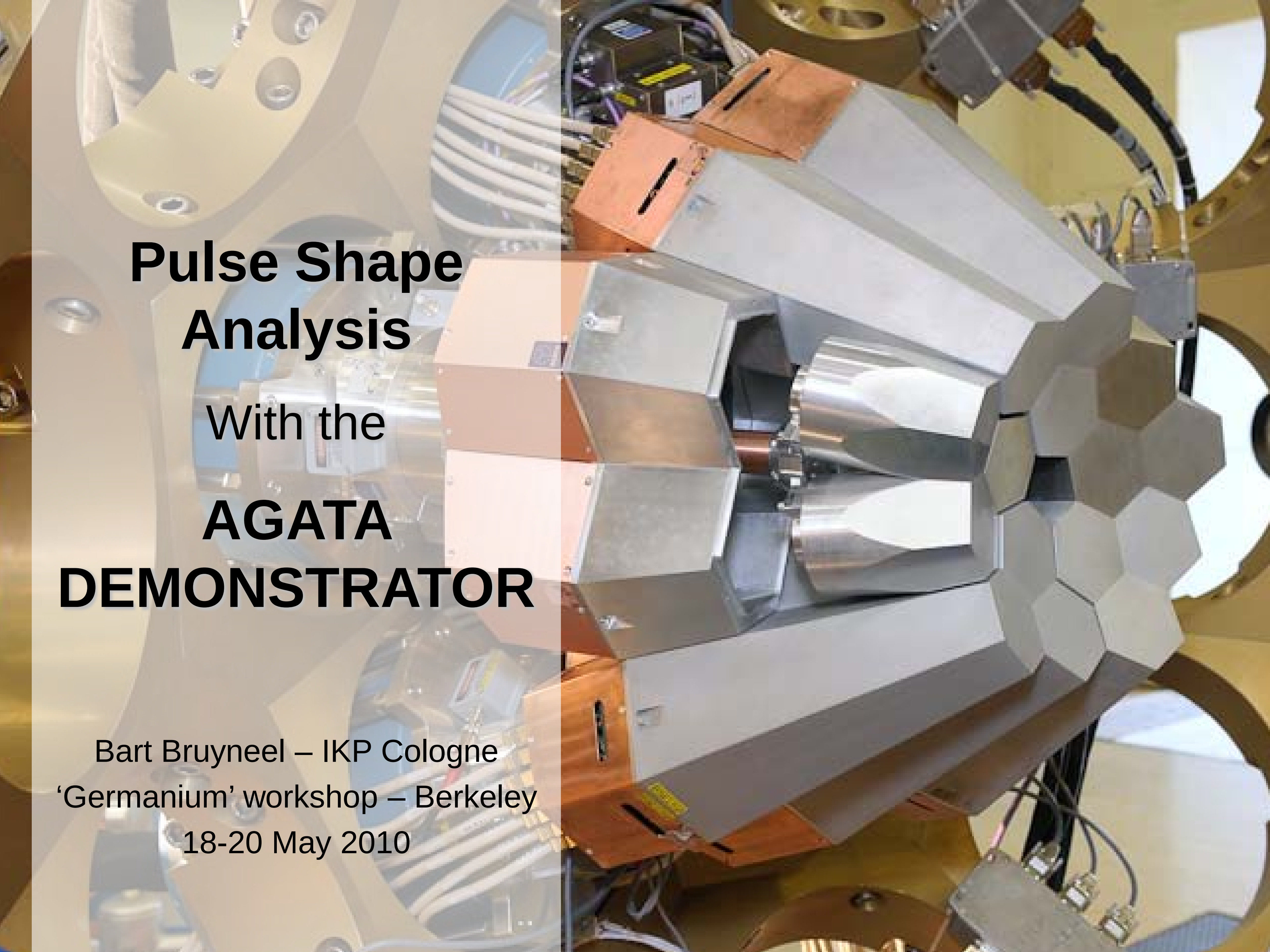


Pulse Shape Analysis

With the

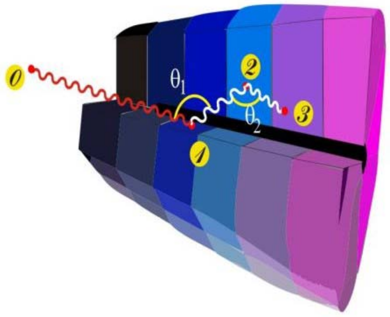
AGATA DEMONSTRATOR

Bart Bruyneel – IKP Cologne
‘Germanium’ workshop – Berkeley
18-20 May 2010

Ingredients of Gamma-Ray Tracking

1

Highly segmented HPGe detectors



2

Digital electronics to record and process segment signals

```
Infinium has finished acquiring your waveform!
1.00 GSa/s
```

```
              current      mean          std dev      min          max
Fall time(1+) 190.39 ns  ? 186.169 ns  ? 43.023 ns  ? 19.35 ns  ? 305.71 ns
```

3

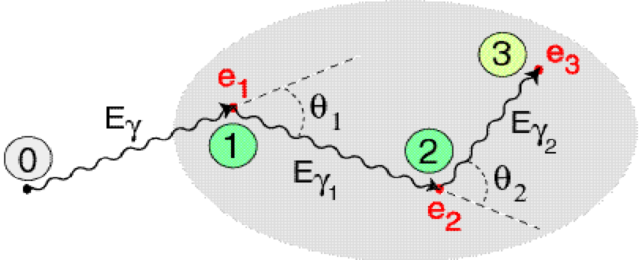
Pulse Shape Analysis to decompose recorded waves

Identified interaction points

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

4

Reconstruction of tracks evaluating permutations of interaction points



Reconstructed gamma-rays

PSA with the AGATA demonstrator

- How to simulate detector responses
- PSA methods used for AGATA
- First PSA results
- Optimisation:
  - Crystal orientation measurements
  - Response function of electronics
  - Derivative crosstalk analysis
  - CV measurements for doping profile

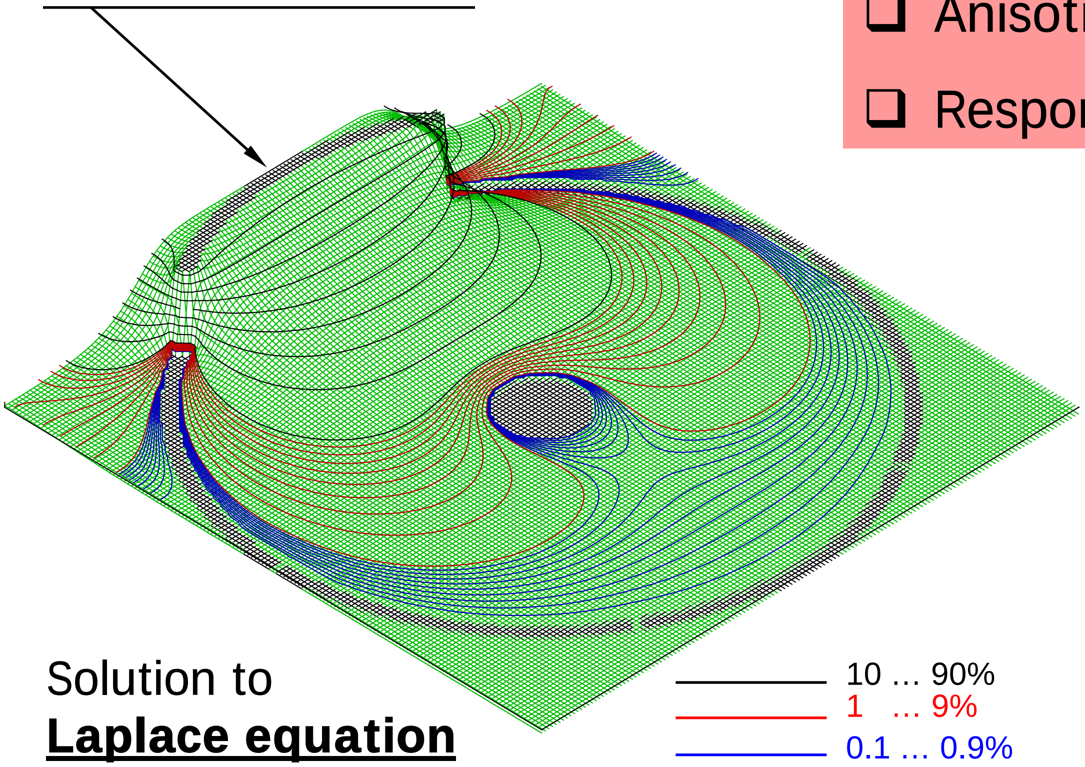
Preliminary

How to simulate detectors

Requirements:

- ☐ Weighting potentials
- ☐ Electrical field ↔ space charge
- ☐ Anisotropic Mobility
- ☐ Response of electronics

Weighting potential for this segment

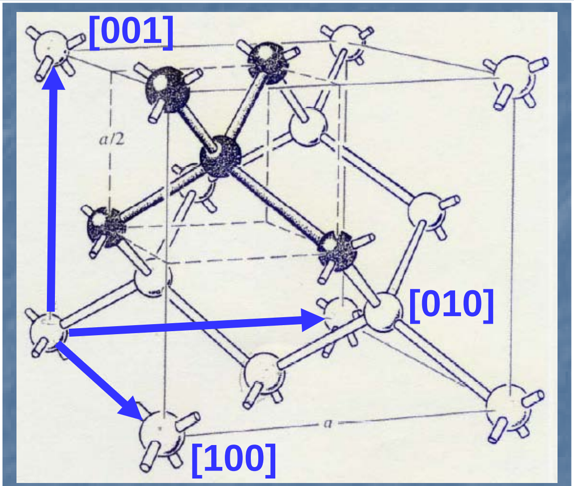


Solution to **Laplace equation**

B. Bruyneel NIMA 569 (2006) 764-773

B. Bruyneel NIMA 569 (2006) 774-789

Mobilities : Intro



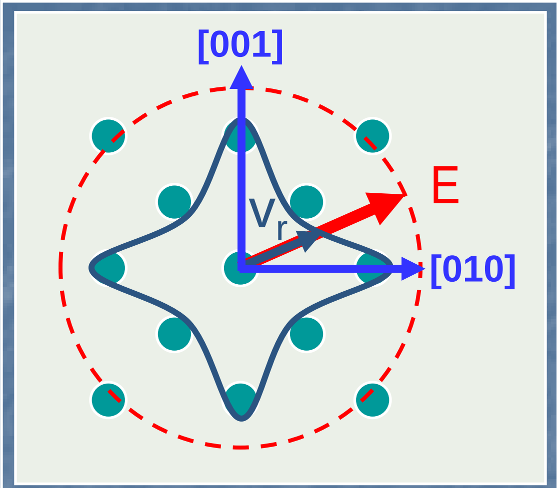
- Monocrystalline Ge
- Periodic potential

⇓

Bloch electrons:

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

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



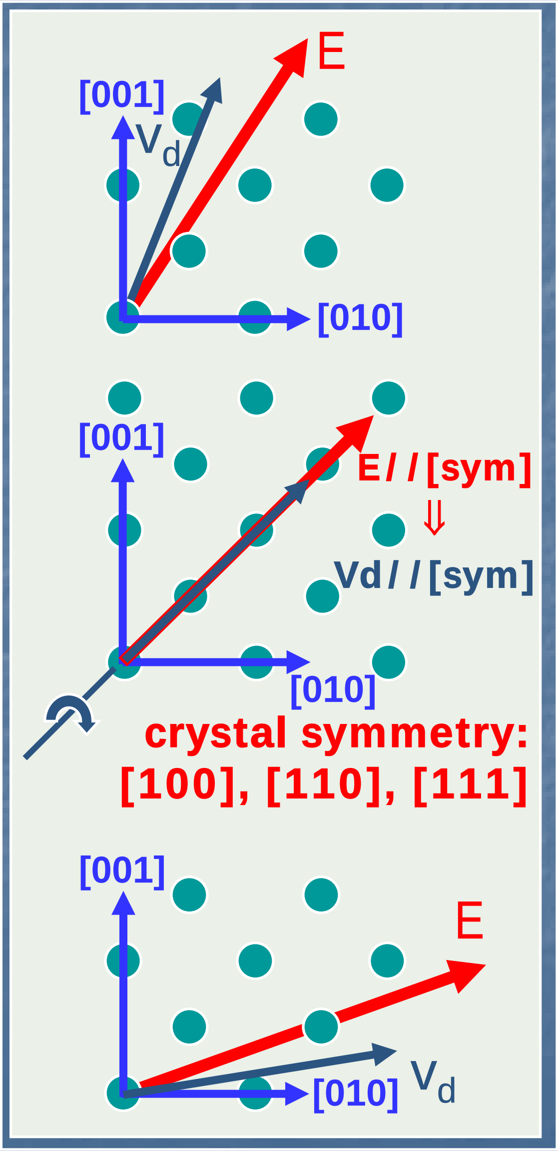
- Velocity:

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

- Longitudinal anisotropy

$|v_r|$ angle dependent

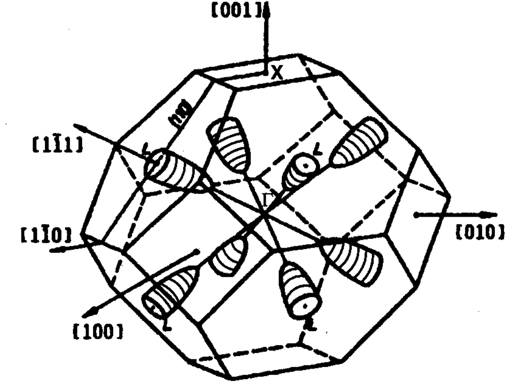
- Tangential anisotropy



crystal symmetry:
[100], [110], [111]

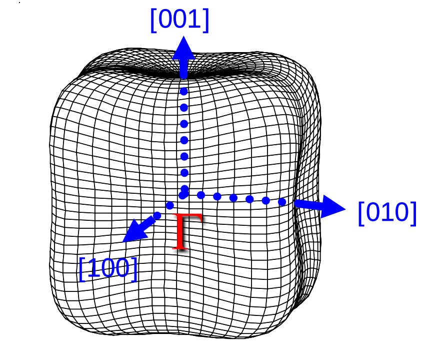
Electron and Hole Mobility in Ge

Electrons

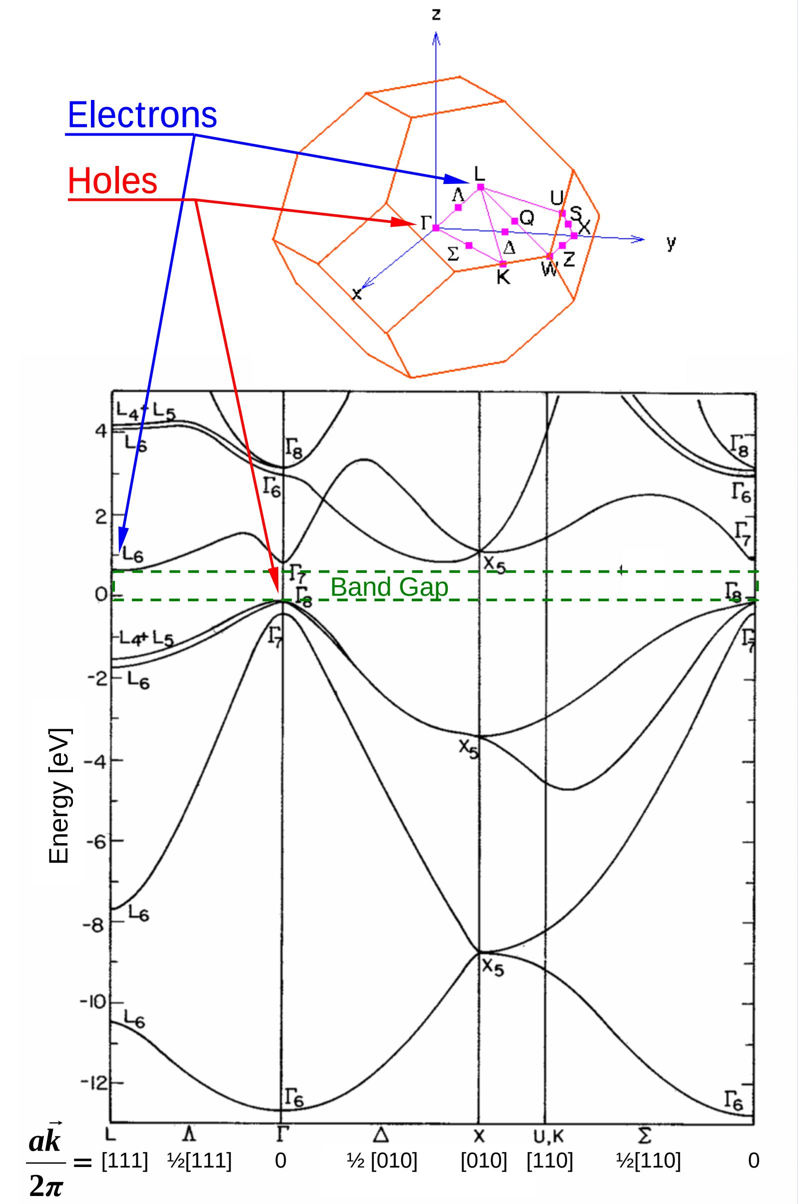


- L. Mihailescu et al. NIM A 447 (2000) 350
- distributed over 4 ellipsoidal valleys
- each valley is MB distributed, T(E)
- intervalley scattering ν(E) defines valley population
- v_{100}(E) and v_{111}(E) defines all.

Holes

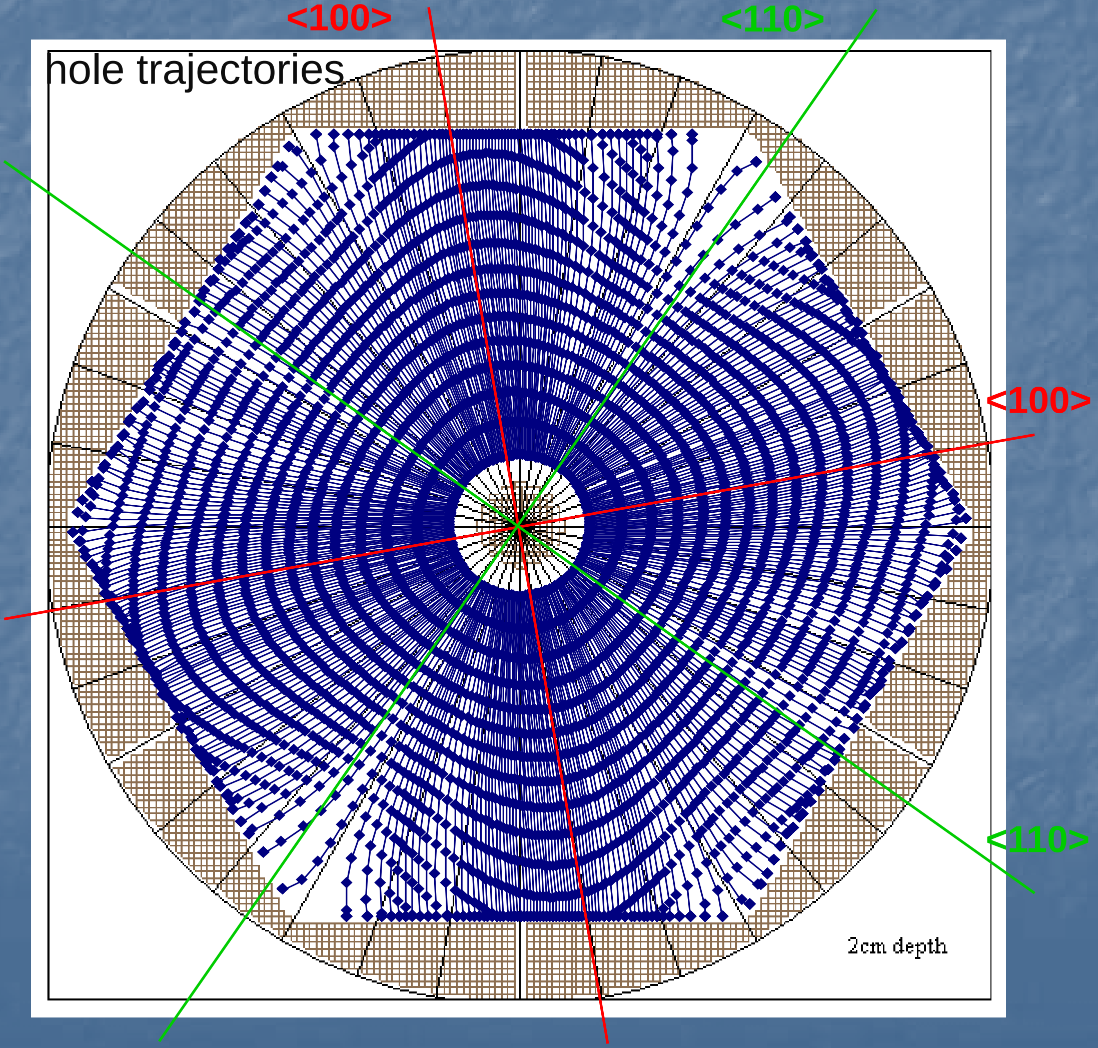


- B. Bruyneel et al. NIM A 569 (2006) 764-773
- only “warped” heavy hole band is important
- “Streaming motion” → drifted MB distribution:
- v_{100}(E) and v_{111}(E) defines all.



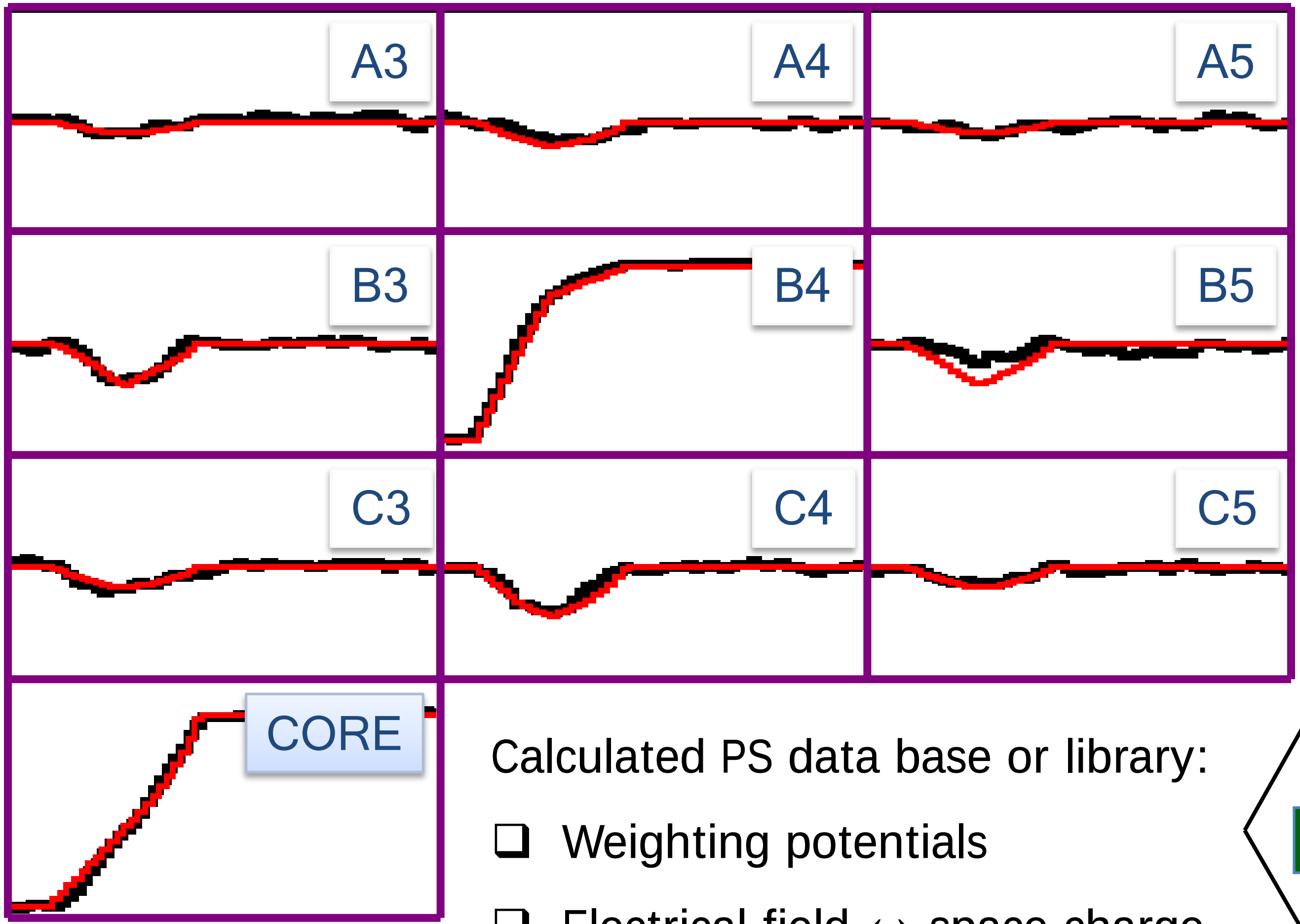
The anisotropic Hole mobility model

Electrons and holes have different longitudinal and tangential velocity anisotropy components.



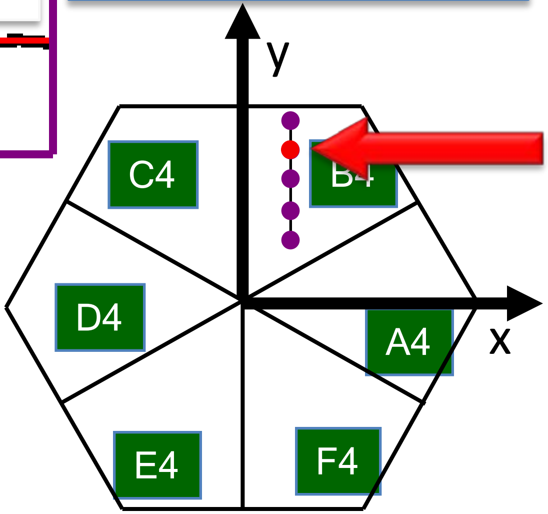
- Electrons v_r mainly slower near [111],
- Holes v_r mainly faster near [100]
- Tangential components 0 along symmetry axes and largest near same directions of largest v_r differences

Pulse Shape Analysis Concept



▬ measured
▬ calculated

Result of *Grid Search* algorithm *R. Venturelli*



z = 46 mm

Calculated PS data base or library:

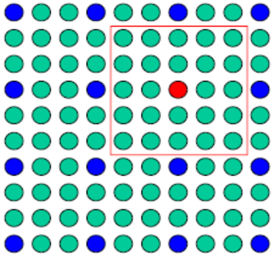
- ☐ Weighting potentials
- ☐ Electrical field ↔ space charge
- ☐ Anisotropic Mobility
- ☐ Response of electronics

PSA Codes within AGATA

The classical PSA scheme consists of 3 components:

- Figure of Merit (FOM) e.g. $\sum_{i \in \mathrm{ROI}} |\mathrm{event1}_i - \mathrm{event2}_i|^n$ (n=0.3)

A. Grid search:



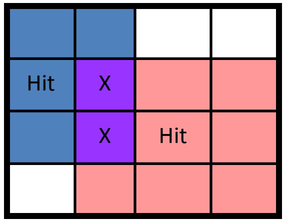
- Search Routine: optimization of FOM over library

implemented

- Adaptive Grid Search (A. Venturelli, INFN Padova)
- Particle Swarm Optimization (M. Schlarb, TU Munich)

- Decomposition strategy for multiple interactions:
  - assuming maximum 1 hit per segment
  - segments influenced by multiple hits excluded

A. Grid search:



PSA Codes within AGATA

Other PSA schemes

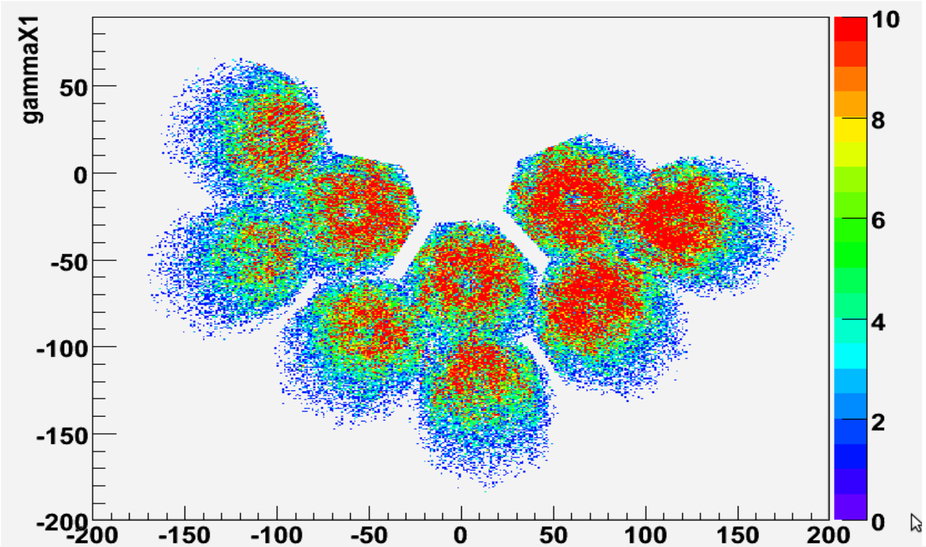
- Matrix method (A. Olariu, P. Desesquelles, CSNSM Orsay)

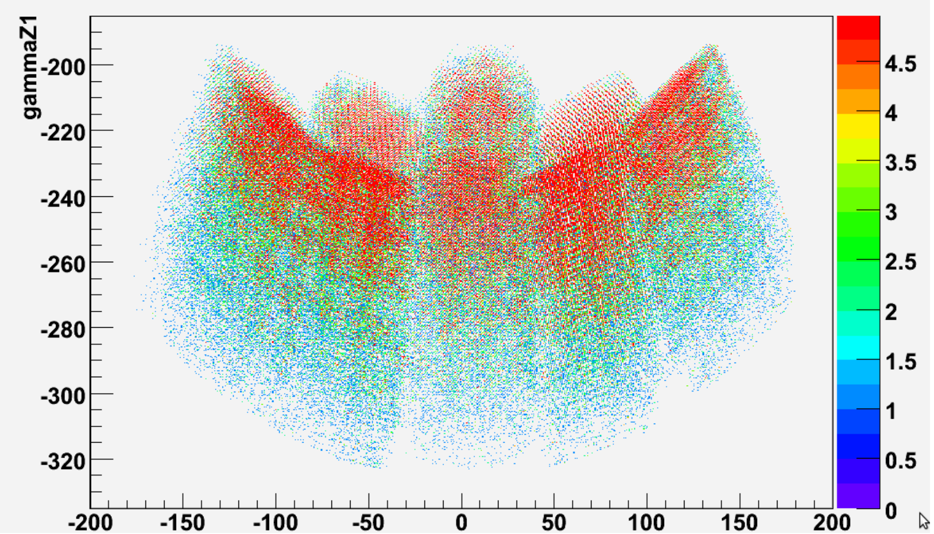
$$[\text{library}]\ .\ [\vec{x}] = [\overrightarrow{\text{event}}]$$

Partial PSA information

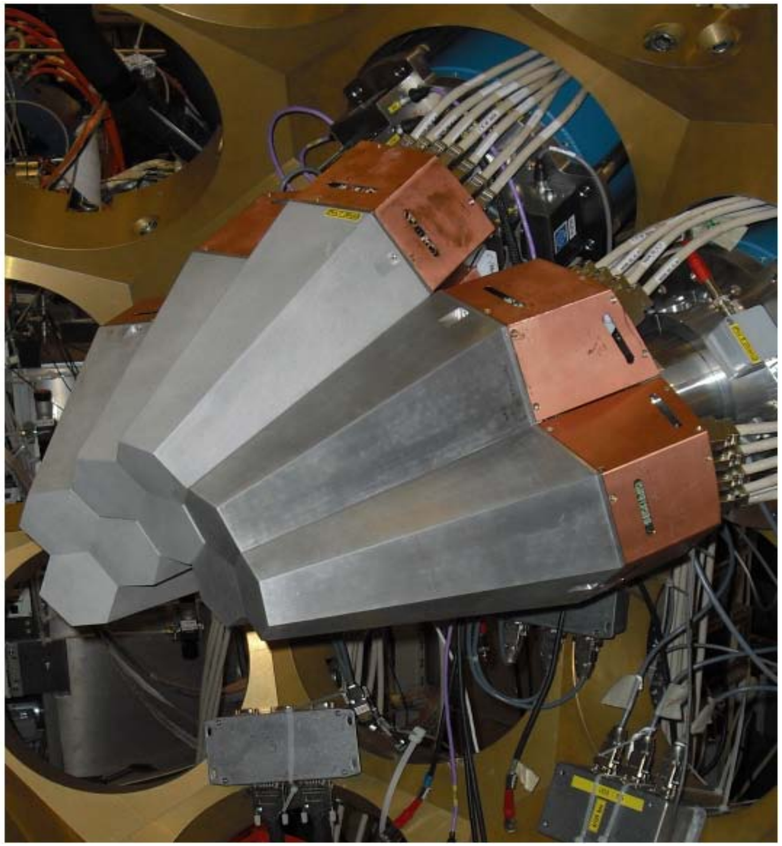
- Recursive Substraction algorithm (Fabio Crespi, INFN Milan)
  Gets radial coordinates & # interactions (~ steepest slope)

AGATA online



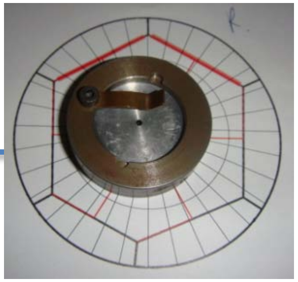


1st experiment with AGATA (18/02/10)



- < 5mm resolution deduced from Doppler shift correction (D. Bazzacco)
- psa online at rates > 5kHz per crystal

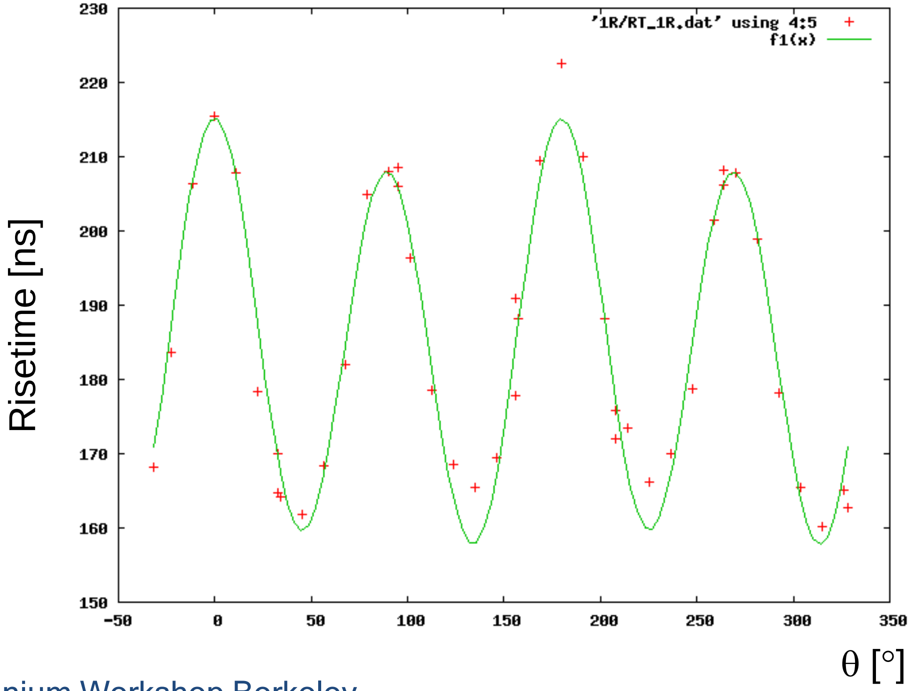
Optimisation: Crystal orientation

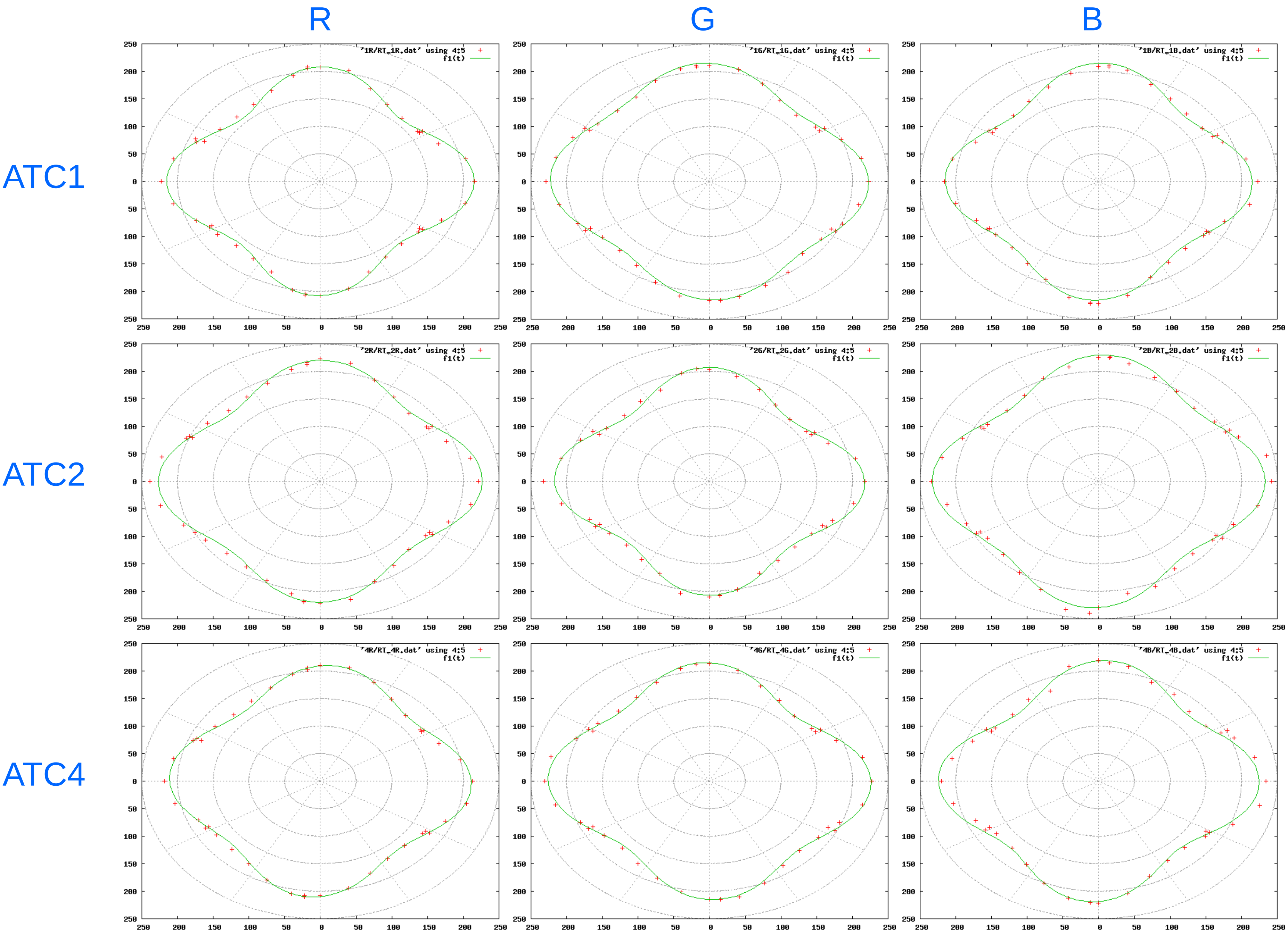


- 400kBq Am source +
- Lead Collimator: ∅ 1.5mm X 1cm
- Front Scan at ∅ 4.7cm: 300 cts/s

- Fitfunction Risetime(θ) =

$$A.[1+R_4\cos(\theta- \theta_4)].[1+R_2\cos(\theta- \theta_2)]$$



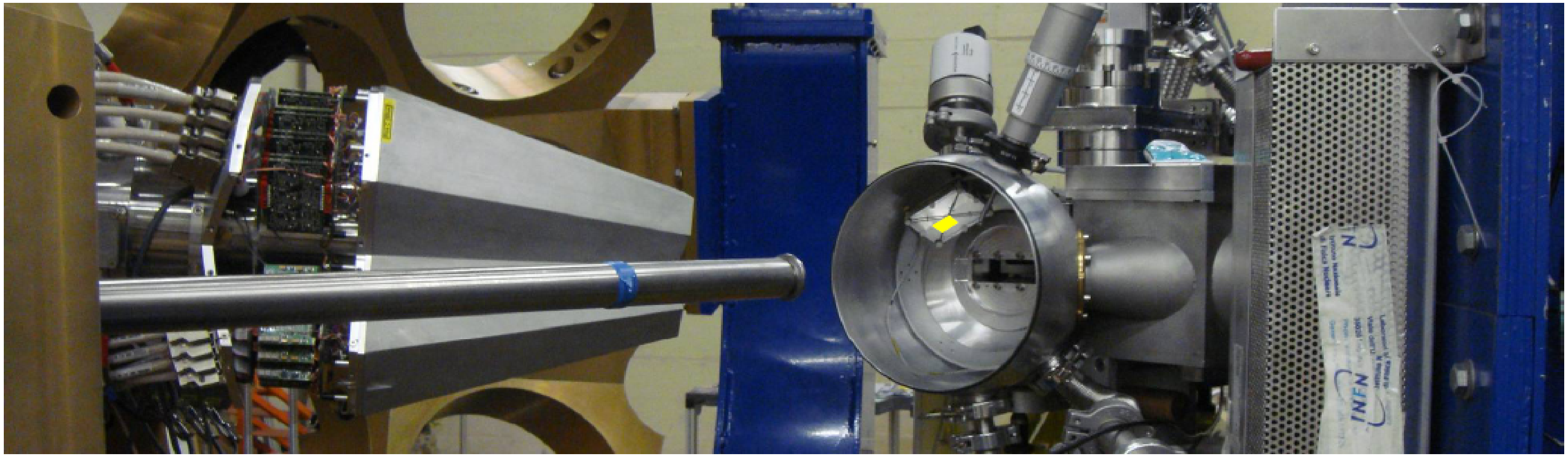

R
G
B
ATC1
ATC2
ATC4
'1R/RT_1R.dat' using 4:5
f1(t)
'1G/RT_1G.dat' using 4:5
f1(t)
'1B/RT_1B.dat' using 4:5
f1(t)
'2R/RT_2R.dat' using 4:5
f1(t)
'2G/RT_2G.dat' using 4:5
f1(t)
'2B/RT_2B.dat' using 4:5
f1(t)
'4R/RT_4R.dat' using 4:5
f1(t)
'4G/RT_4G.dat' using 4:5
f1(t)
'4B/RT_4B.dat' using 4:5
f1(t)
250 200 150 100 50 0 50 100 150 200 250

Commissioning experiment Week 27 2009

The reaction : ^{56}Fe at 220 MeV → ^{197}Au recoils with β ~ 8% E_γ = 847 keV (^{56}Fe)

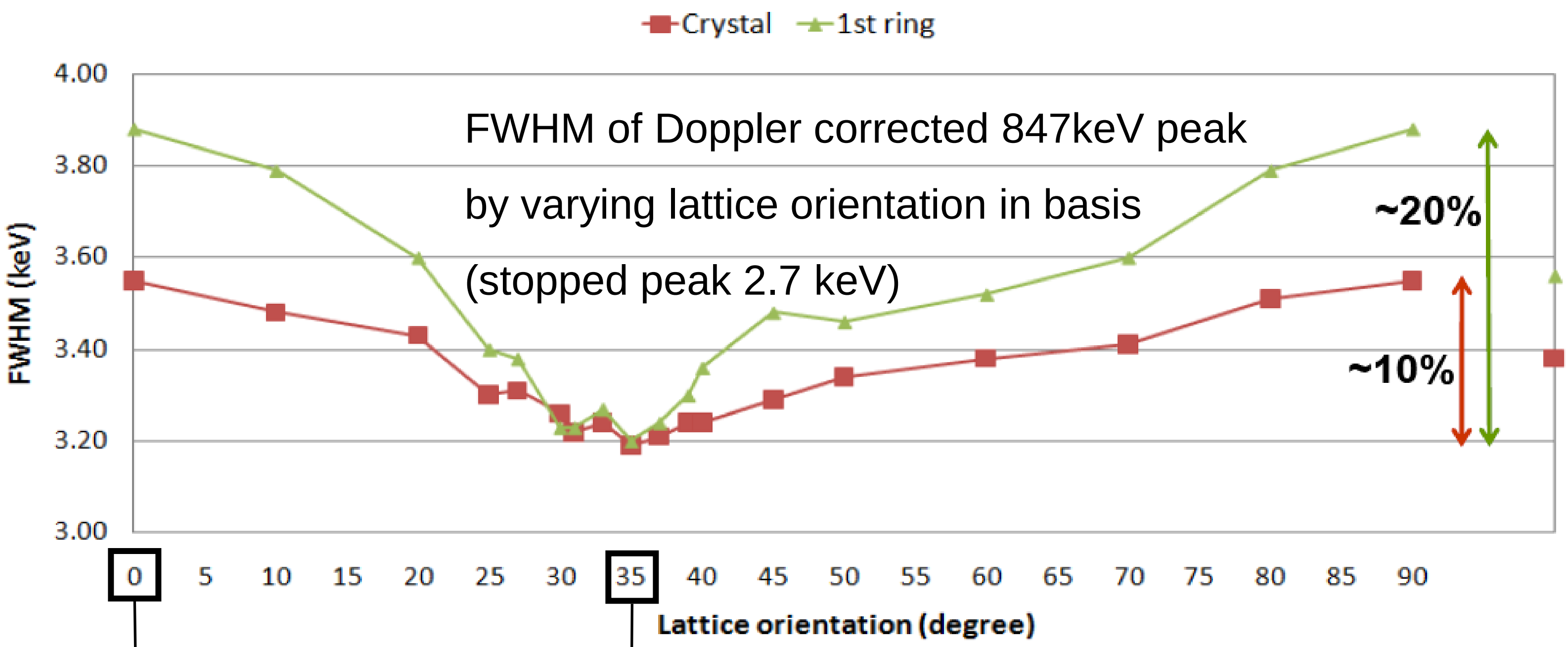
The detectors: γ detection with ATC1 in coincidence with DANTE for scattered ions

Experimental setup:



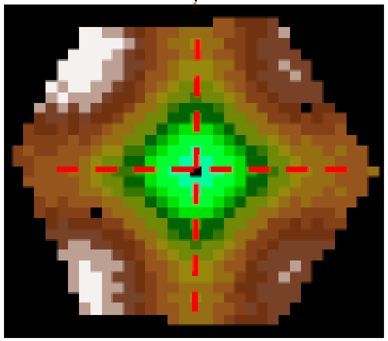
On-line event rate: 250 Hz of coincidences
Statistics: 150 Mevents for 2 Tbyte of saved traces

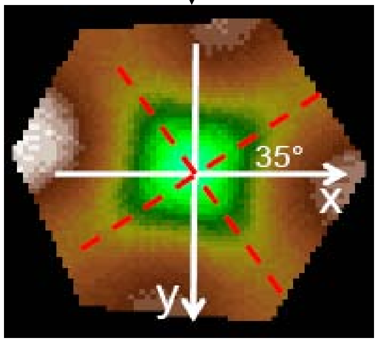
Influence of crystal orientation


FWHM of Doppler corrected 847keV peak

by varying lattice orientation in basis

(stopped peak 2.7 keV)



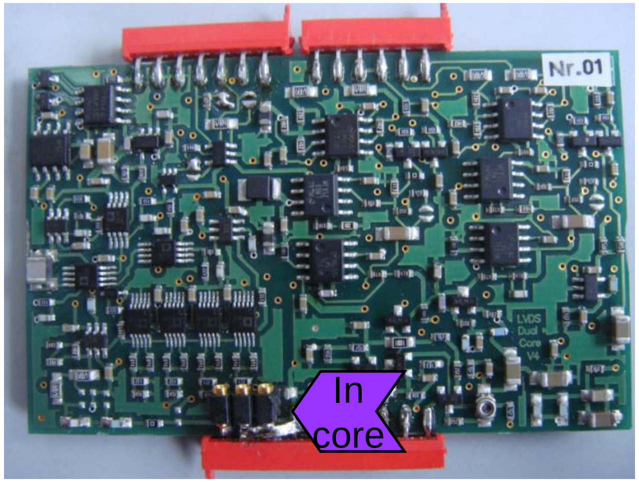


Main improvement from 1st ring

Front view of $T_{10\text{-}90}$ simulations

Angles with respect to x-axis

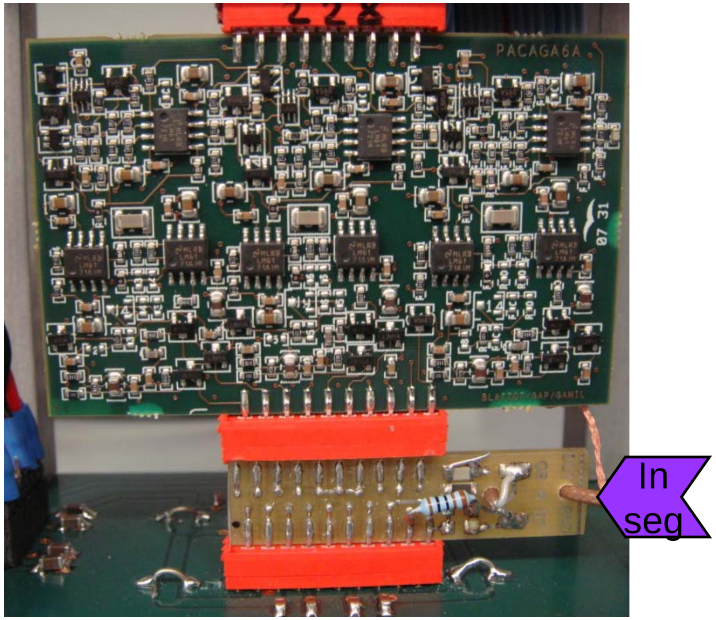
Optimisation: Electronics & Response

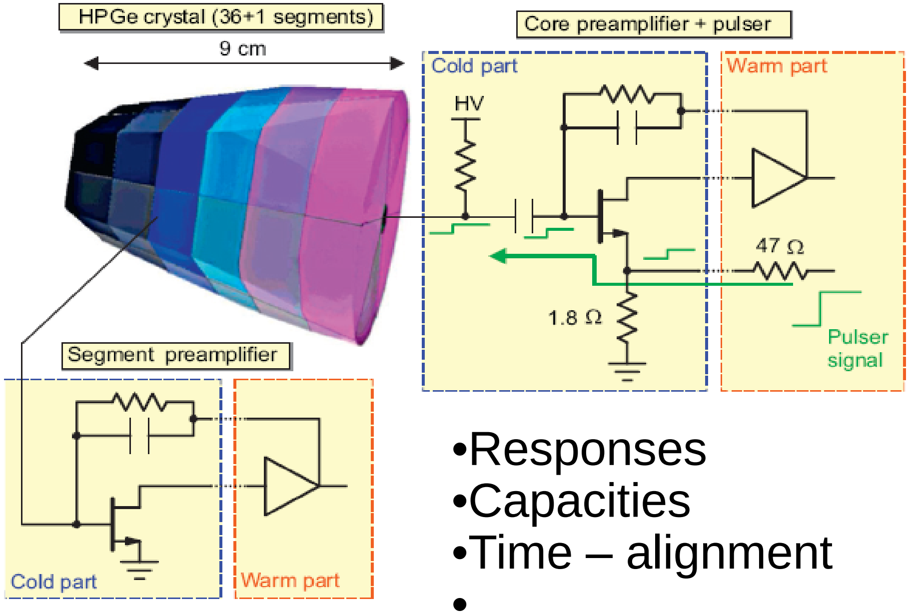


Rectangular wave

1ns rise time

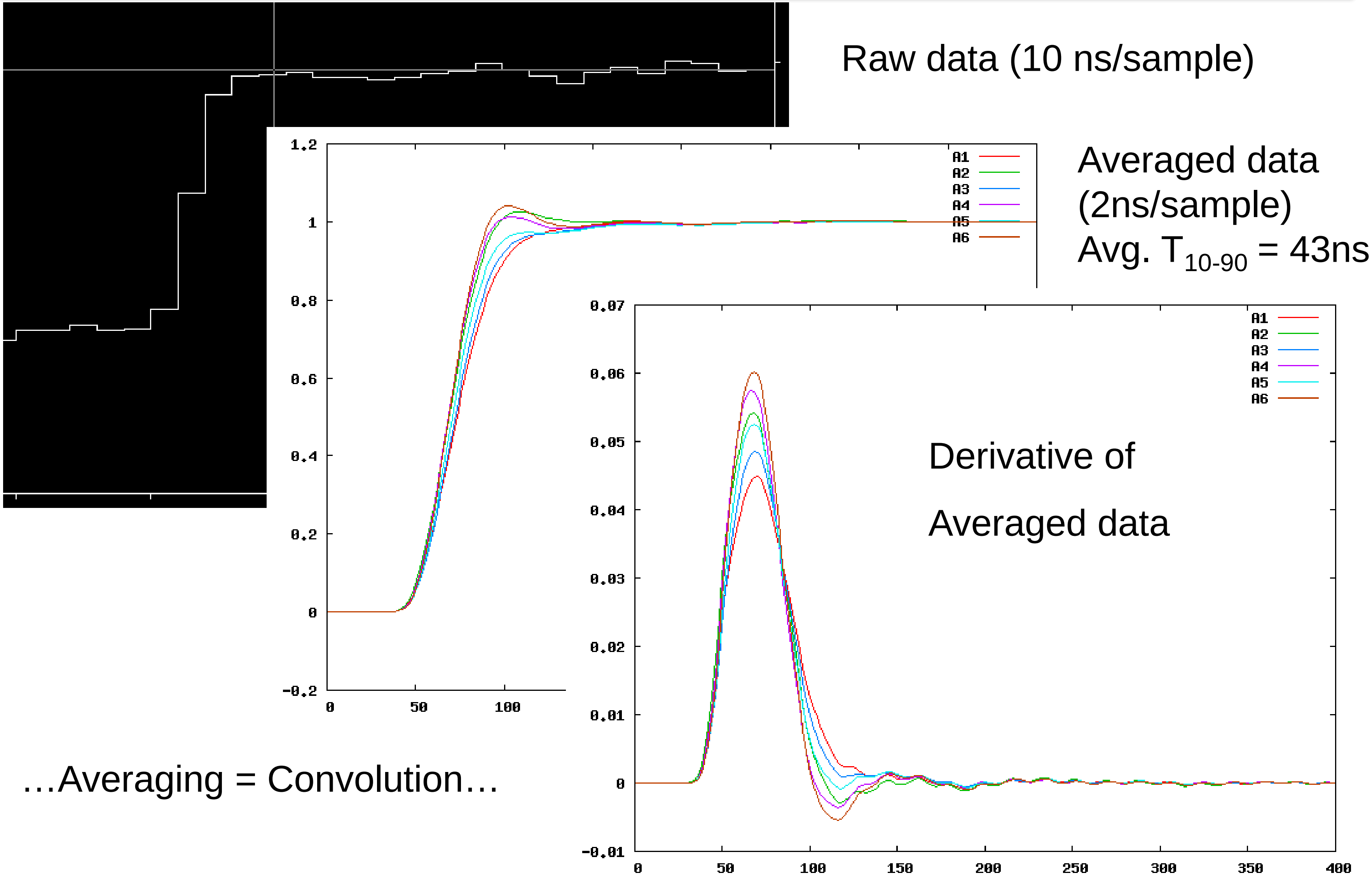
- Preamps 30-35ns rise time
- Core - built in progr. pulser ~ 60ns
  - bypass for fast 1ns pulser
- Segment pulser input (non-standard)





- Responses
- Capacities
- Time – alignment
- …

Response function



Raw data (10 ns/sample)

Averaged data (2ns/sample)
Avg. $T_{10\text{-}90}$ = 43ns

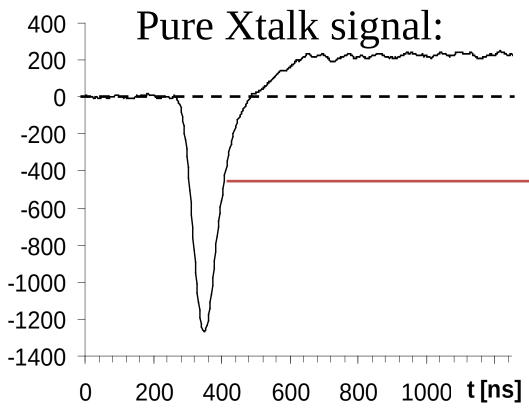
Derivative of

Averaged data

Time [ns]

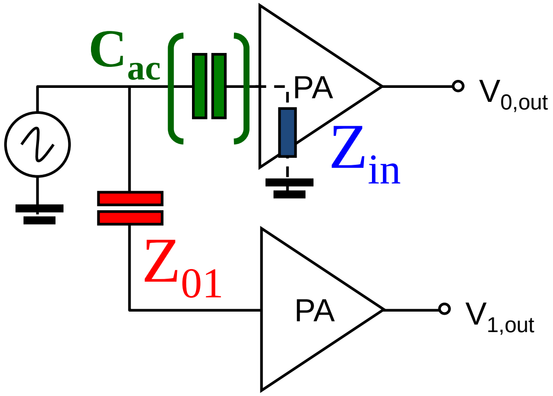
…Averaging = Convolution…

Optimisation: Origin of Crosstalk



Proportional Xtalk (50µs decay) → **Energy**

Differential Xtalk (only during risetime) → **PSA**



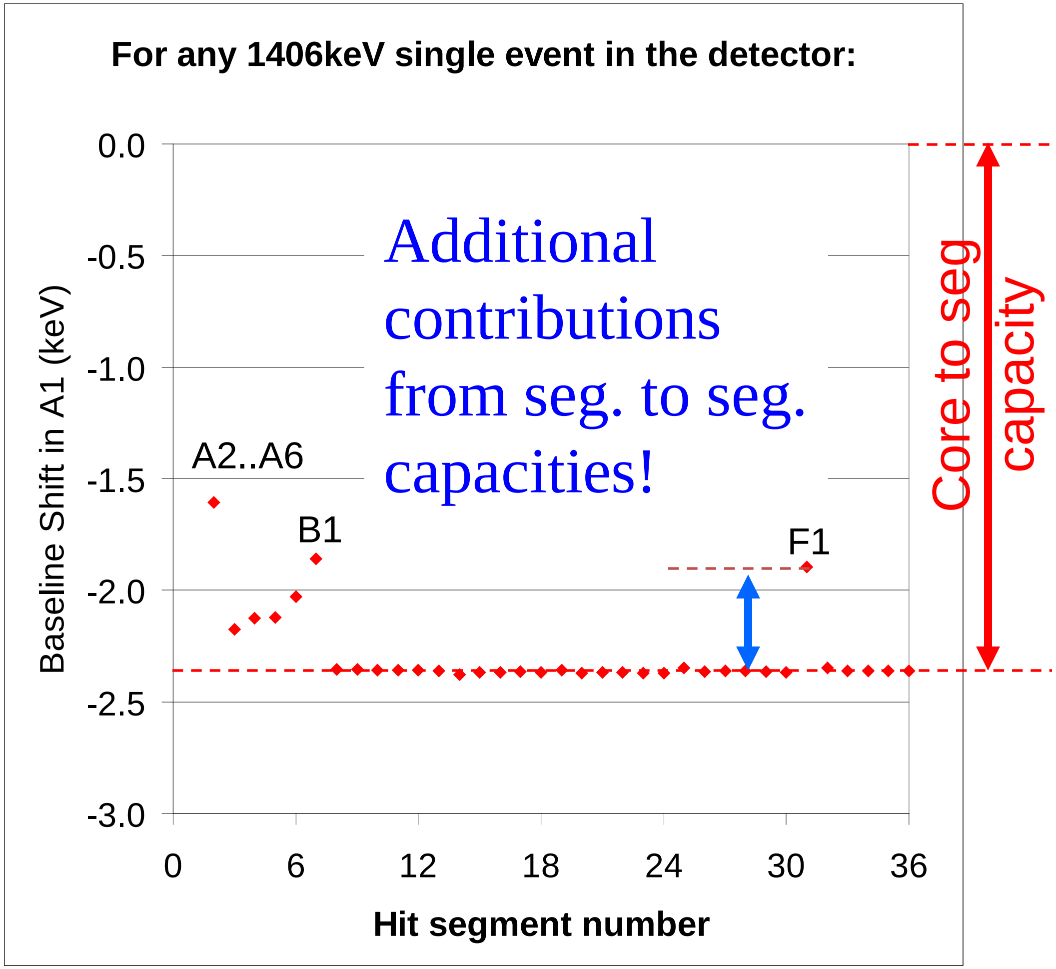
With $Z_{in} = 1/sAC_{fb} + (1/sC_{ac}) + R_{cold}$

Xtalk ~ Z_{in} / Z_{01}

$$\begin{aligned} &\sim \underbrace{C_{01}/AC_{fb} + (C_{01}/C_{ac})} + \underbrace{s \,.\, R_{cold}\, C_{01}} \\ &= \quad \text{Proportional} \quad + \text{Differential Xtalk} \end{aligned}$$

!!! Proportional and Differential Xtalk are related !!!

Proportional Xtalk measurement

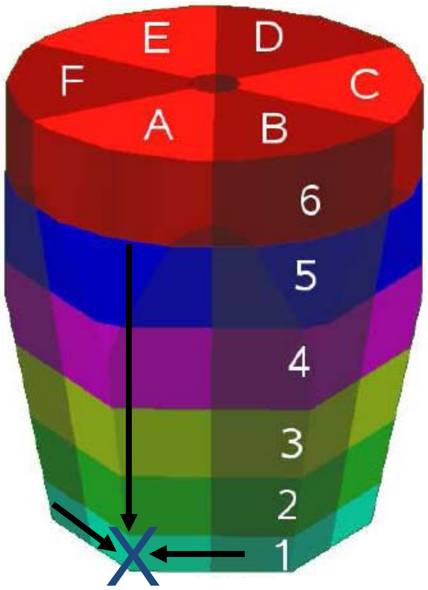


For any 1406keV single event in the detector:

Additional contributions from seg. to seg. capacities!

Core to seg capacity

Segment labeling:



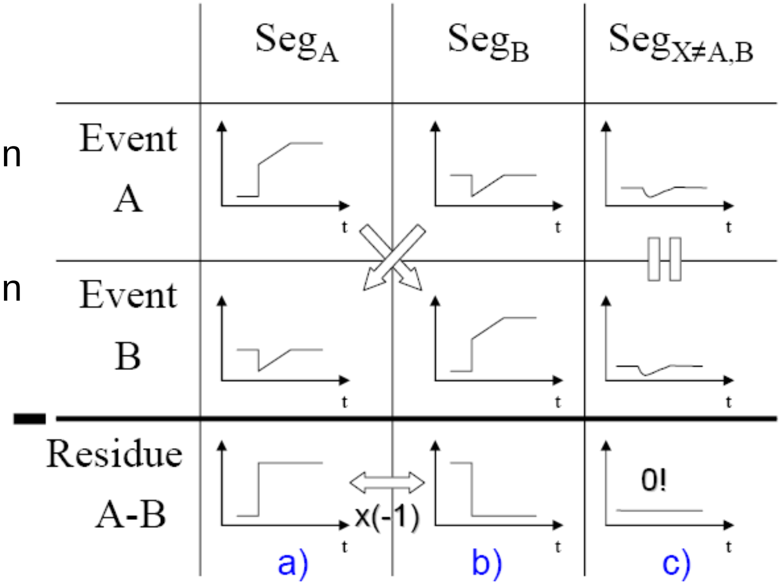
Sectors: A...F

Rings: 1...6

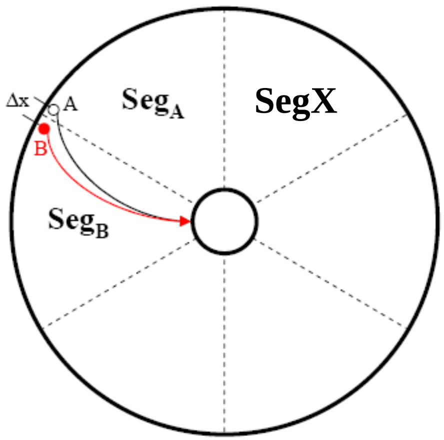
How to measure derivative Xtalk?

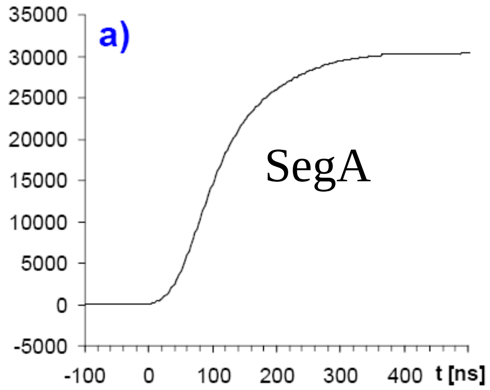
Energy deposition in segment A

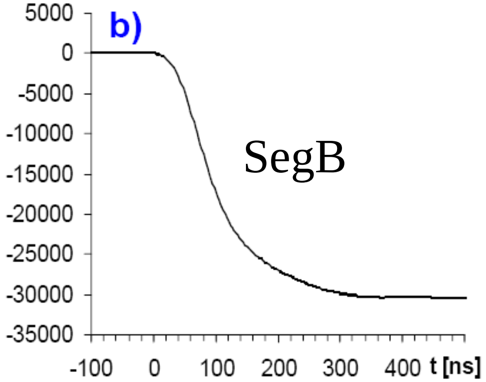
Energy deposition in segment B



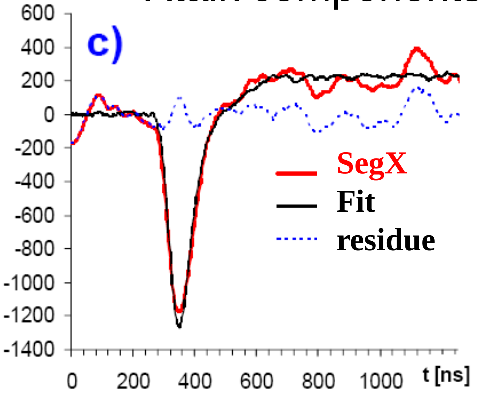
Source position at segmentation line





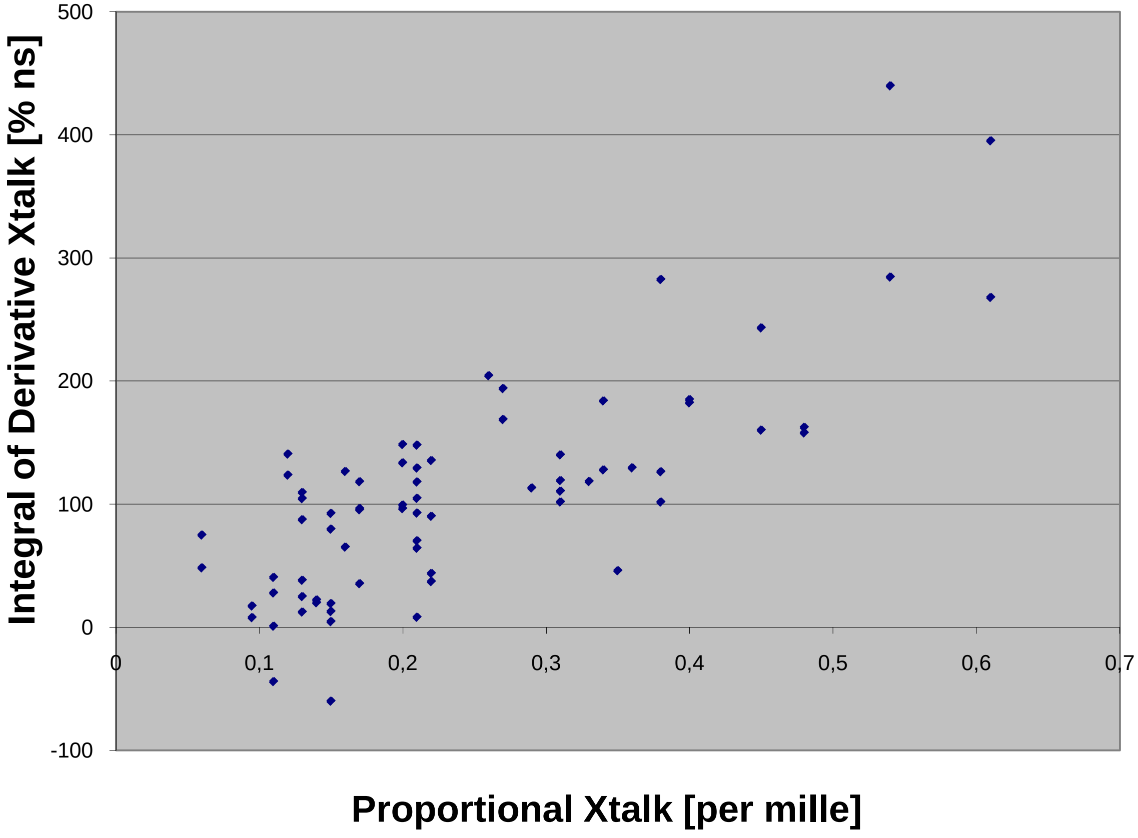


Xtalk components

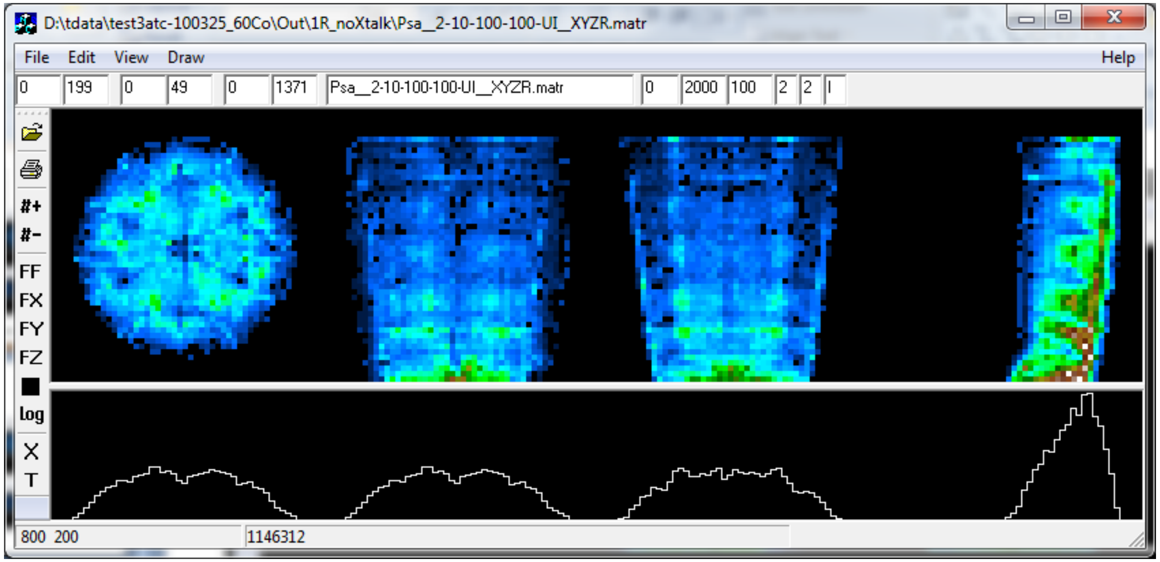


(1) B. Bruyneel et al. NIM A 569 (2006) 774-789 / MGS workshop (April 2005) / AGATA week (Nov 2005)

Derivative vs Proportional Xtalk

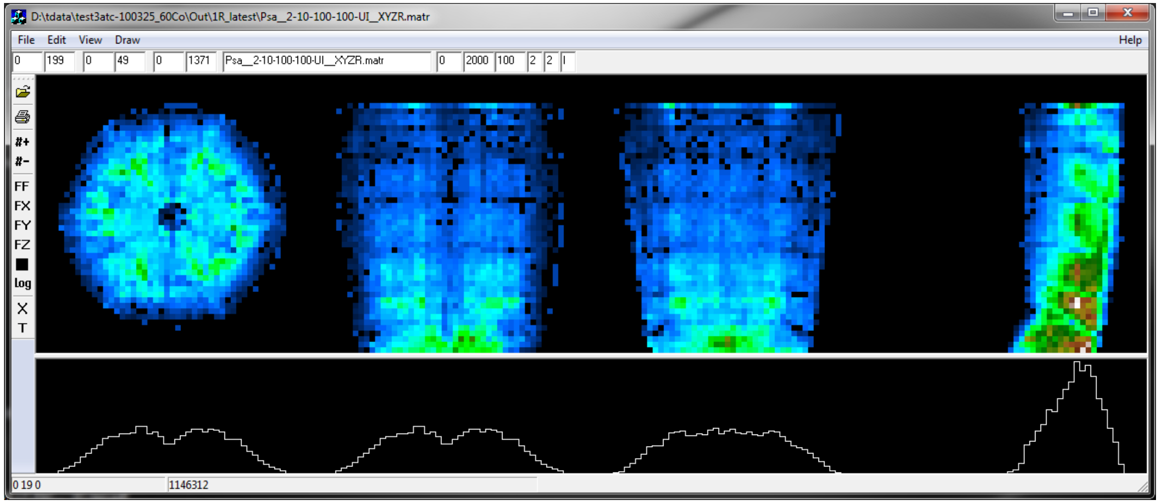


Impact of Xtalk – First results


D:\tdata\test3atc-100325_60Co\Out\1R_noXtalk\Psa__2-10-100-100-UI_XYZR.matr

0 | 199 | 0 | 49 | 0 | 1371 | Psa__2-10-100-100-UI__XYZR.matr | 0 | 2000 | 100 | 2 | 2 | l

800 200 | 1146312


D:\tdata\test3atc-100325_60Co\Out\1R_latest\Psa__2-10-100-100-UI_XYZR.matr

0 | 199 | 0 | 49 | 0 | 1371 | Psa__2-10-100-100-UI__XYZR.matr | 0 | 2000 | 100 | 2 | 2 | l

0 19 0 | 1146312

ATC1-R

Same data,

Same analysis

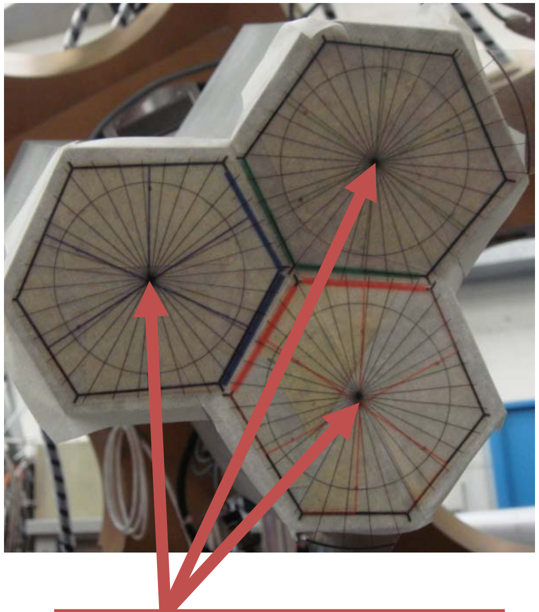
BEFORE…

and

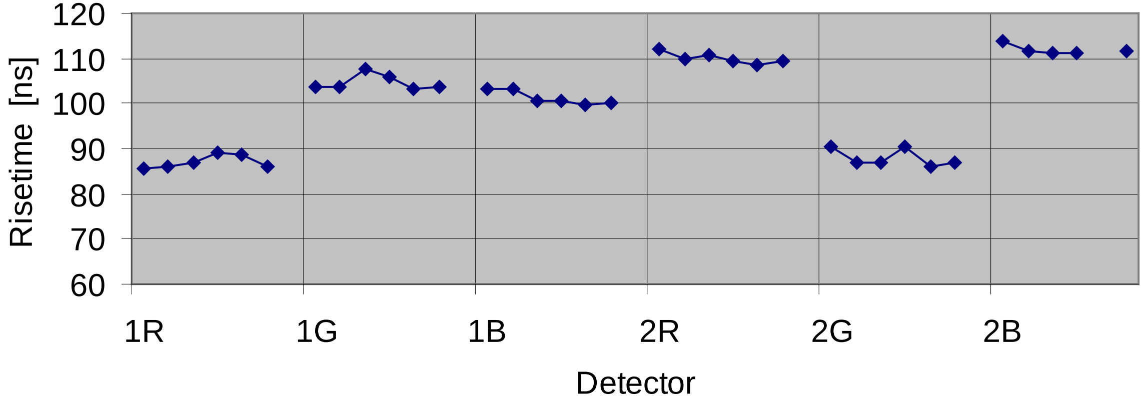
AFTER

implementation of crosstalk correction

The impact of the field strength



Coordinate (0,0,0)



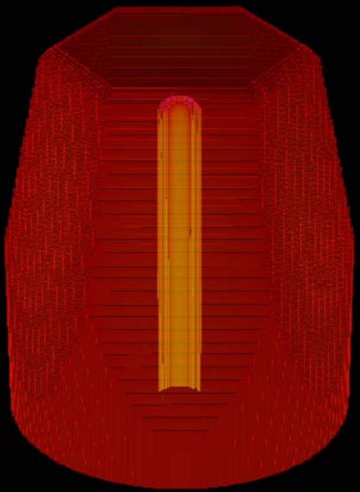
Core $T_{10\text{-}90}$ for position (0,0,0) for different detectors

(values from full energy gates on six front segments)

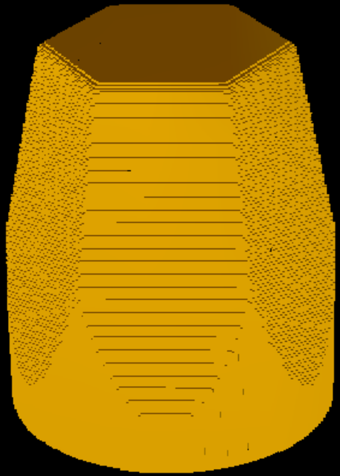
Impurity concentration and bias voltage (source Canberra)

Detector	**1R**	**1G**	**1B**	**2R**	**2G**	**2B**
Bias voltage [V]	5000	5000	5000	4500	4500	4000
Imp. Front [10^{10}cm^{-3}]	0.50	1.22	0.54	0.48	1.12	1.15

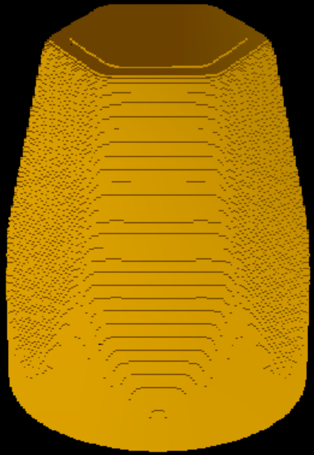
A



B



C: HV = 10V



D: HV = 100V

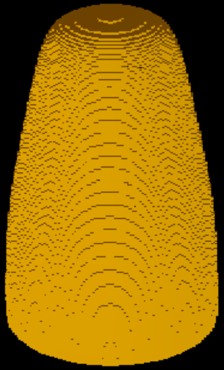
Depletion of a HPGe detector

A: Bare HPGe germanium crystal
symmetric AGATA detector

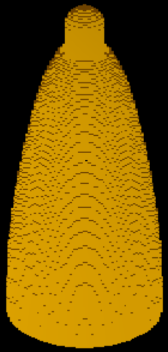
B: Geometry in simulation
The HV contact is colored yellow

C-G: Undepleted volume
as function of HV.

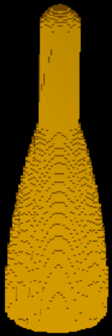
(assumption: 10^{10} impurities / cm^3)



E: HV = 1kV

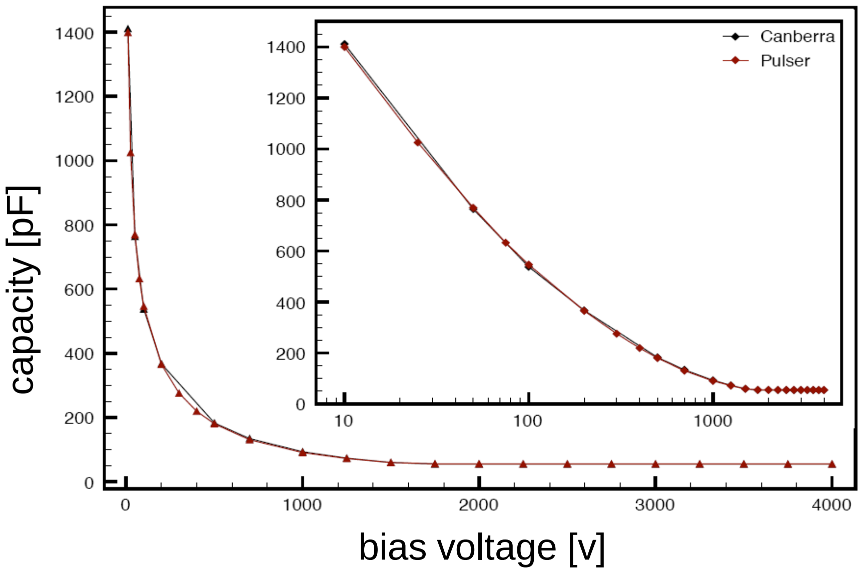


F: HV = 2kV



G: HV = 3kV

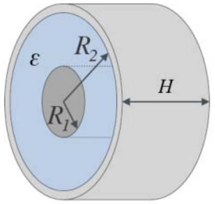
Impurity from C-V measurements



How it works (e.g. cylindrical geometry):

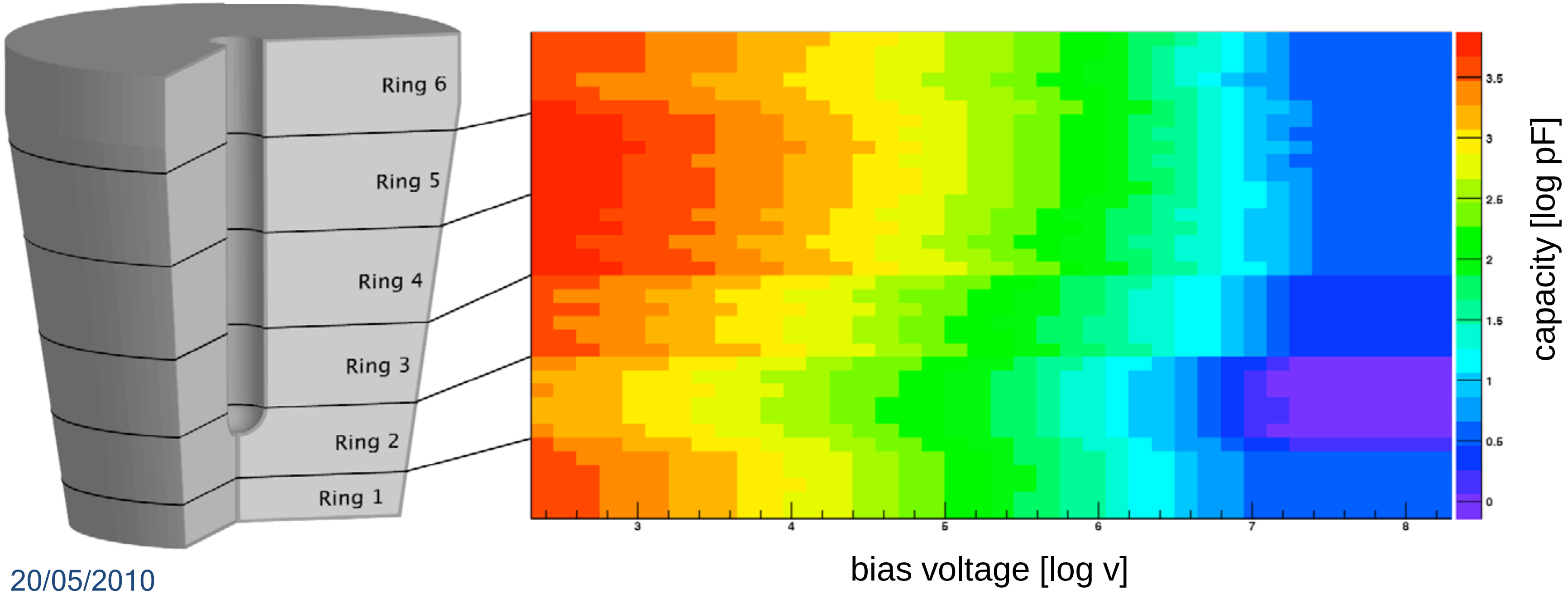
- *C(V)* gives depletion boundary *R_1*:

$$C = \frac{2\pi\epsilon H}{\ln\frac{R_2}{R_1}}$$



- *C(V), dC/dV* give impurity concentration at *R_1*

$$N_D(R_1) = -\frac{C^3 e^{\frac{4\pi\epsilon H}{C}}}{4e\pi^2 H^2 \epsilon R_2^2 \frac{dC}{dV}}$$

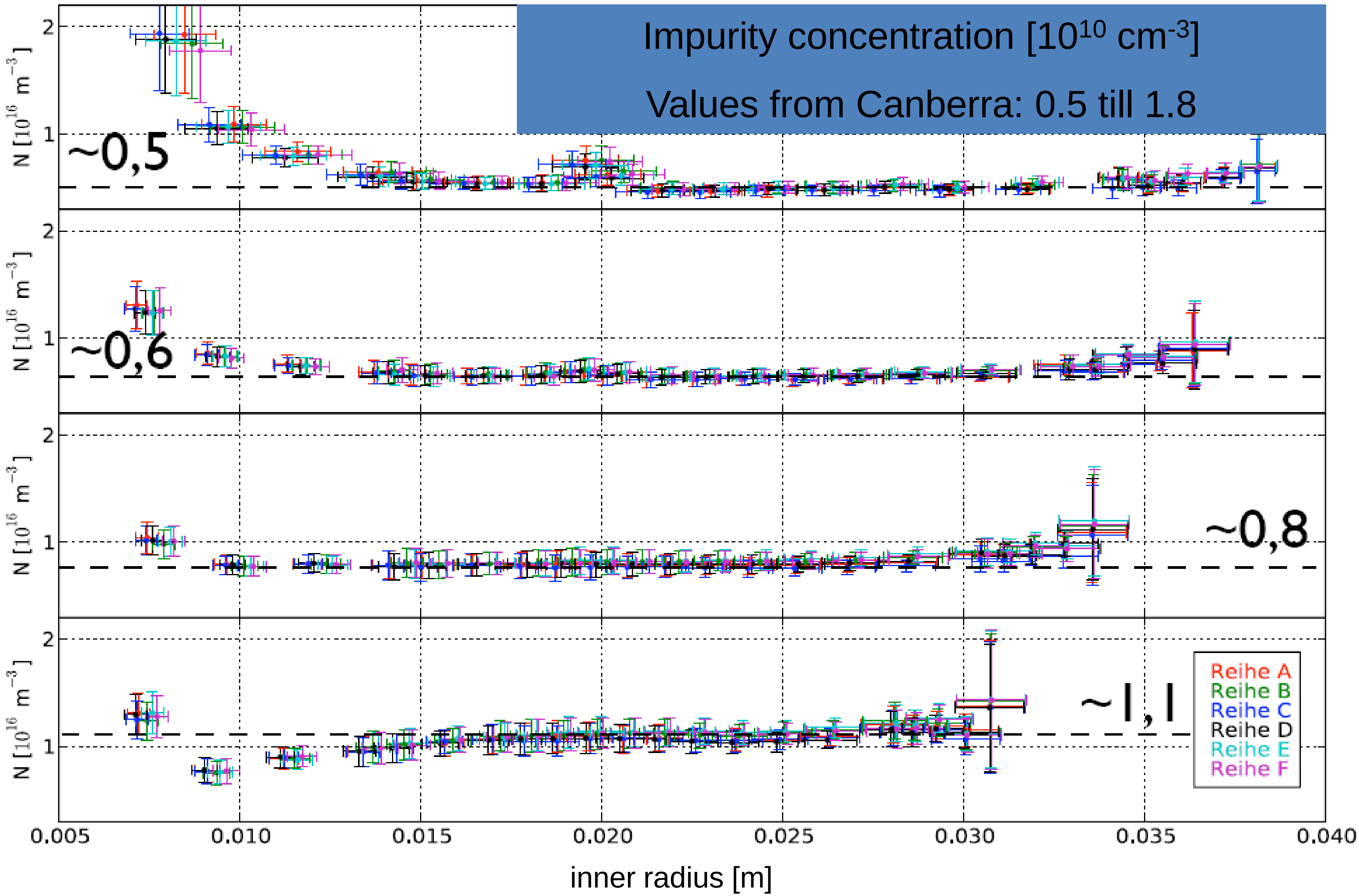


Results with the cylindrical approximation

Impurity concentration in coaxial part (Last 4 rings)

Impurity concentration [10^{10} cm^{-3}]

Values from Canberra: 0.5 till 1.8



Summary & Outlook

First in-beam- and source measurements show position resolution of ~ 5 mm

Value is in line with the design assumptions of the AGATA spectrometer, feasibility of γ-ray tracking is confirmed

PSA is based on calculated pulse shape libraries

Optimisation and tests with data sets from first experiments

-crystal properties
-response functions
-cross talk
-impurity concentration

Compare with pulse shape data from scanned detectors