36 fold segm. AGATA crystal

SIMULATION DES DETECTEURS GERMANIUM

Bart Bruyneel
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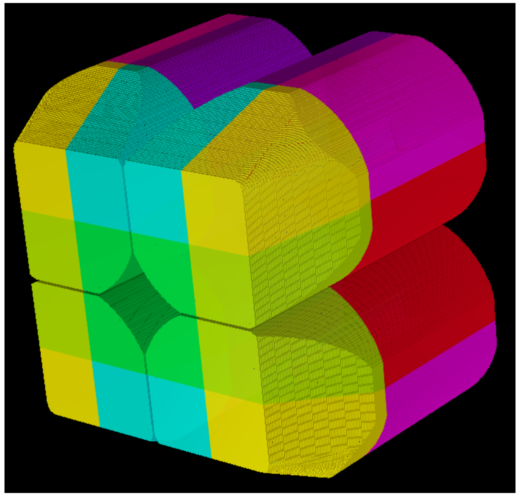
17/06/2013 la Journée de la simulation, Orsay

ADL 3.0



Segmented Clover detector

Overview

- Intro on AGATA & Tracking
- AGATA Detector Library « ADL 3.0»

- Weighting potential
  - Ramo Theorem
  - Time dependent weighting potentials
- Mobilities in Germanium

- Correction for neutron damage

WHY ADL ?

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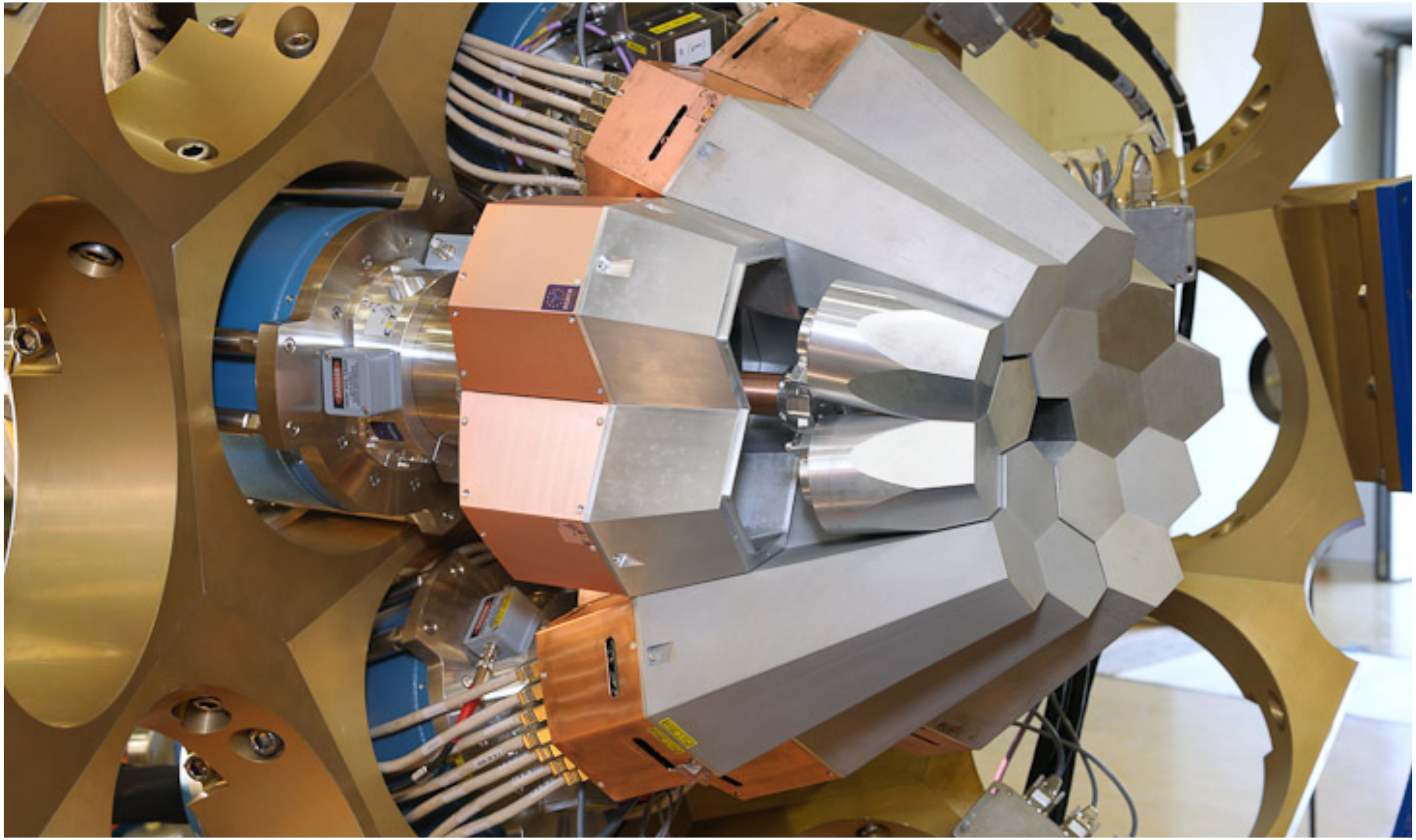
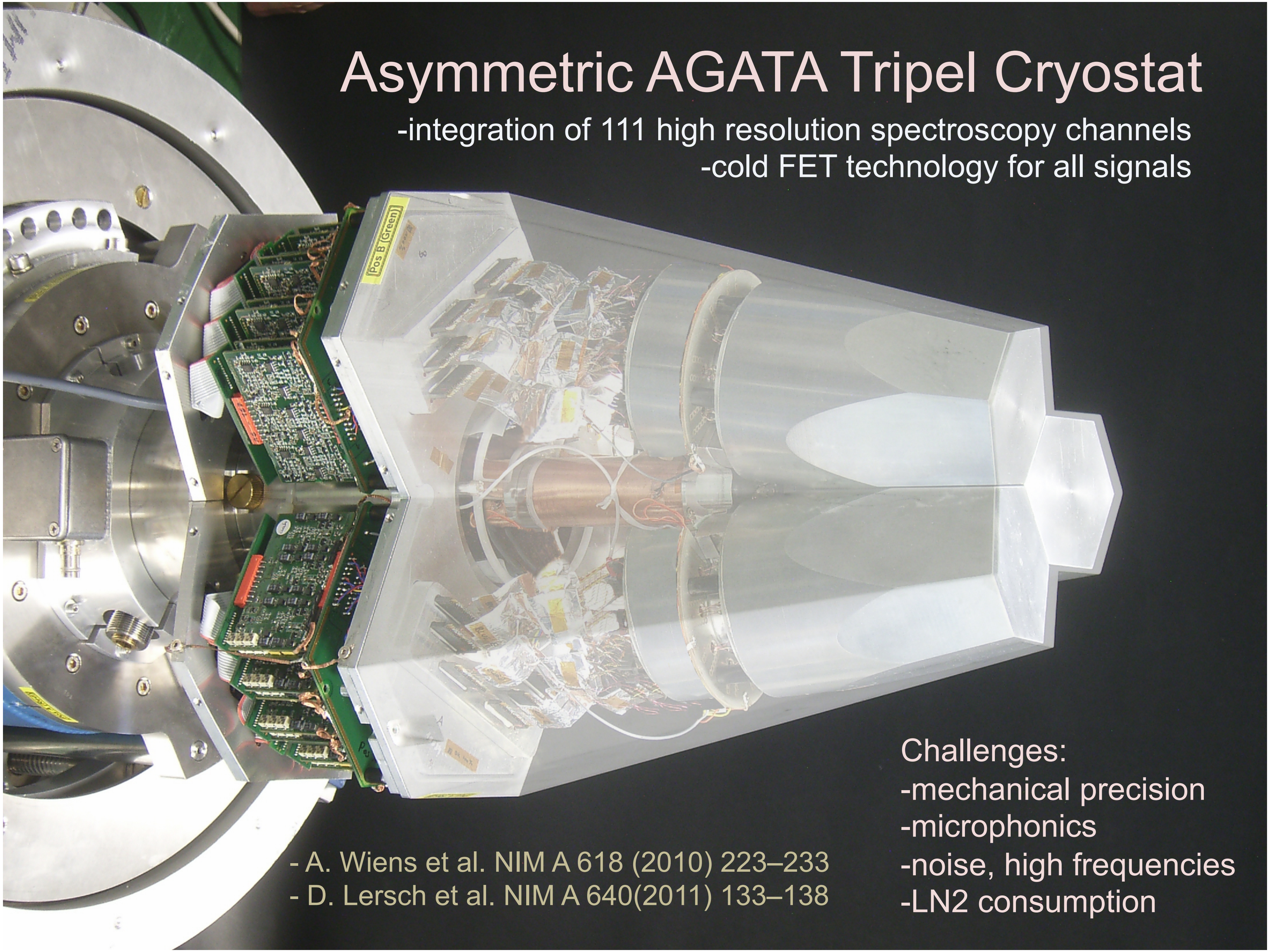
The Advanced γ Tracking Array “AGATA”



Asymmetric AGATA Tripel Cryostat

-integration of 111 high resolution spectroscopy channels
-cold FET technology for all signals



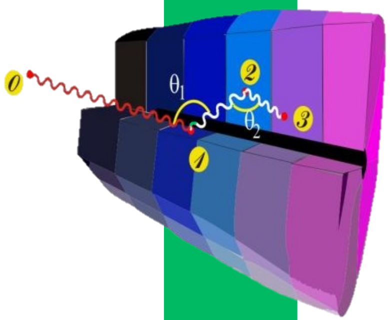
Challenges:
-mechanical precision
-microphonics
-noise, high frequencies
-LN2 consumption

- A. Wiens et al. NIM A 618 (2010) 223–233
- D. Lersch et al. NIM A 640(2011) 133–138

AGATA & TRACKING

1

Highly segmented HPGe detectors



2

Digital electronics to record and process segment signals

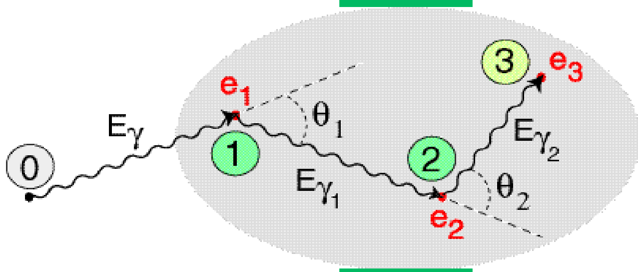
3

Pulse Shape Analysis to decompose recorded waves

Identified interaction points $(x,y,z,E,t)_i$

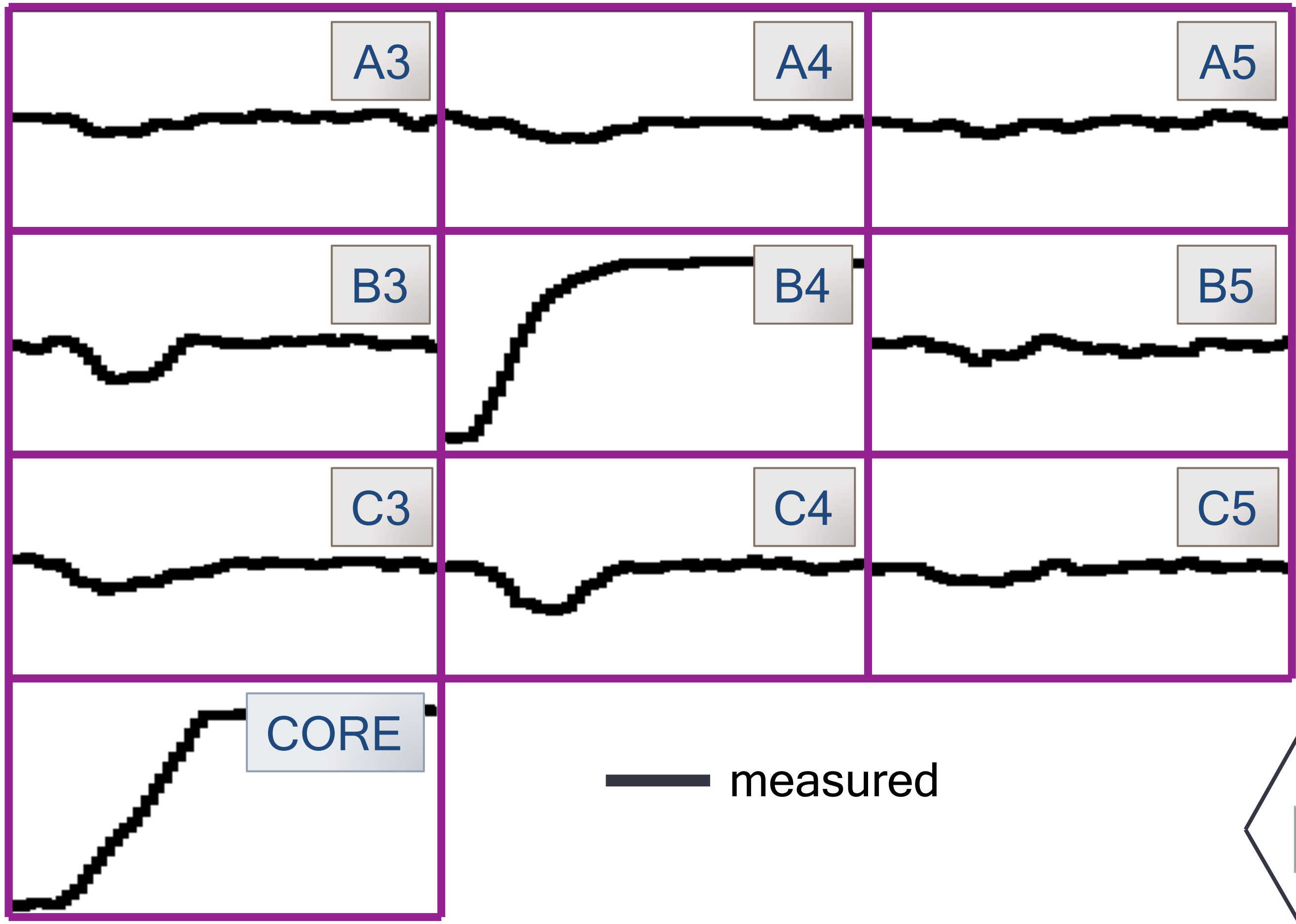
4

Reconstruction of tracks evaluating permutations of interaction points



Reconstructed gamma-rays

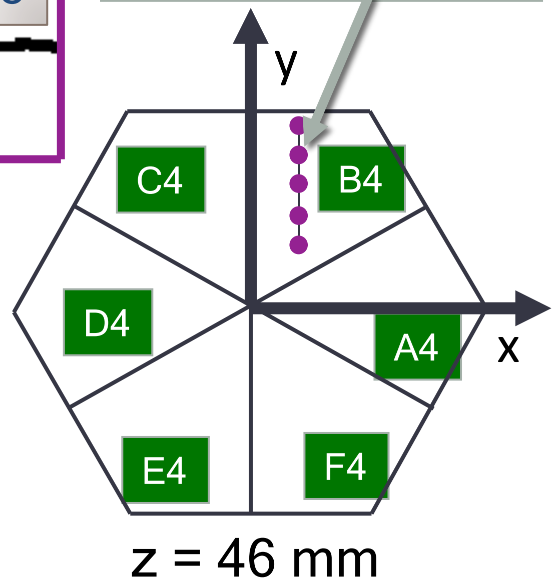
Pulse Shape Analysis Concept

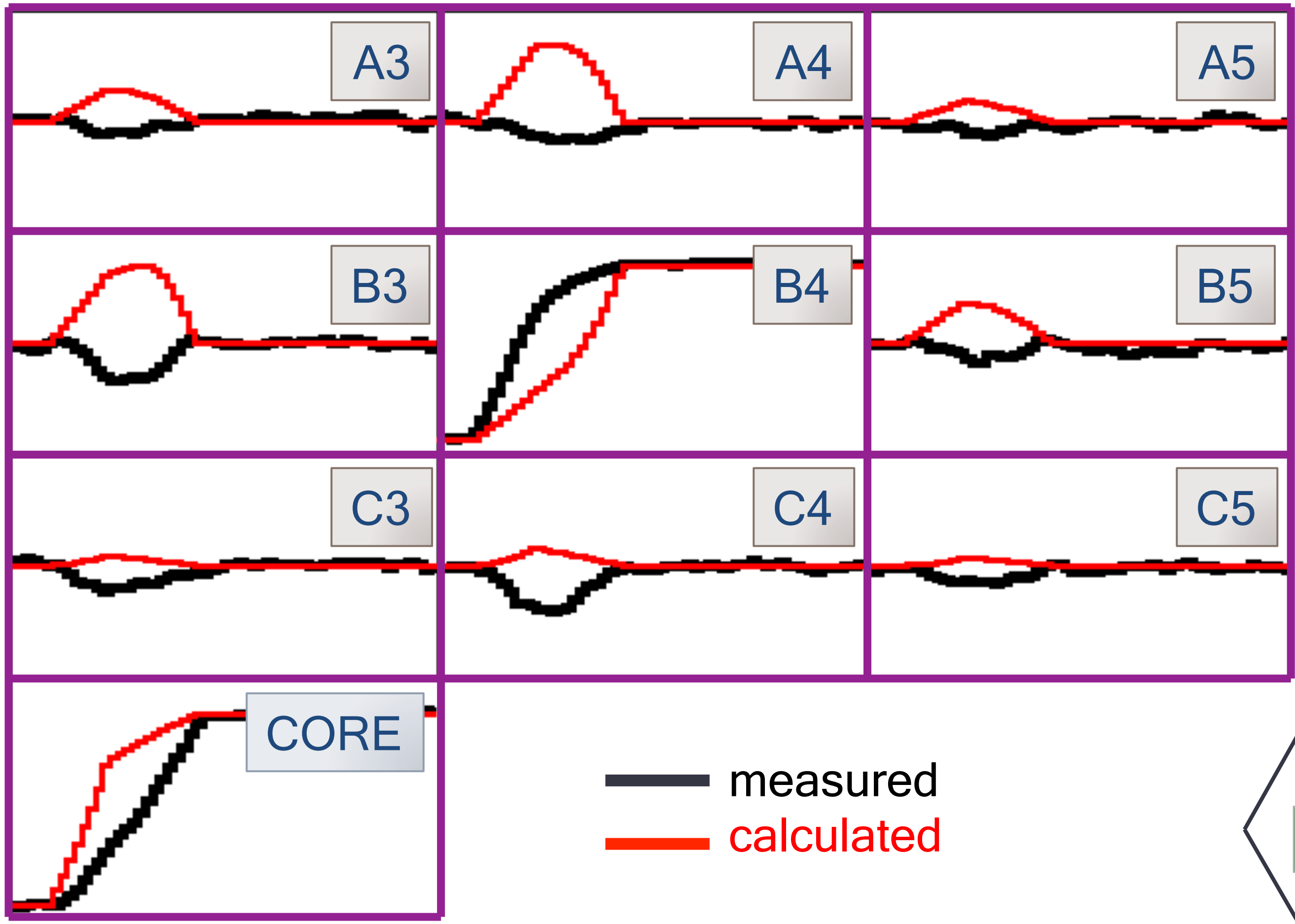


791 keV deposited in segment B4

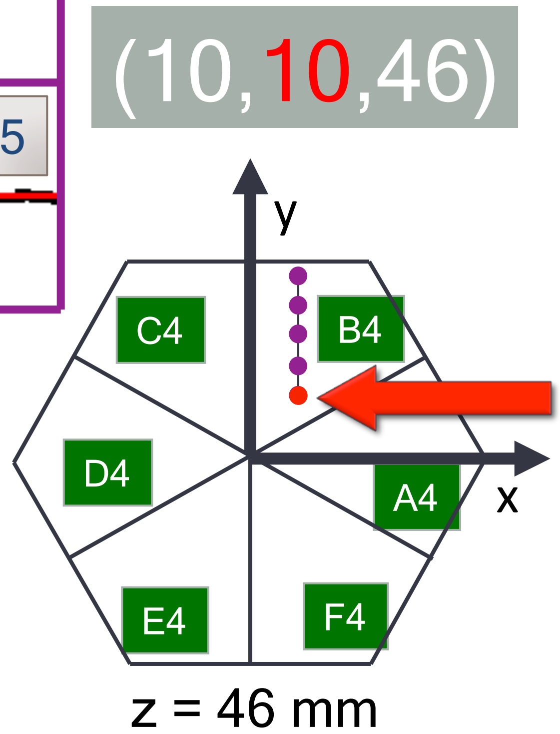
Library generation

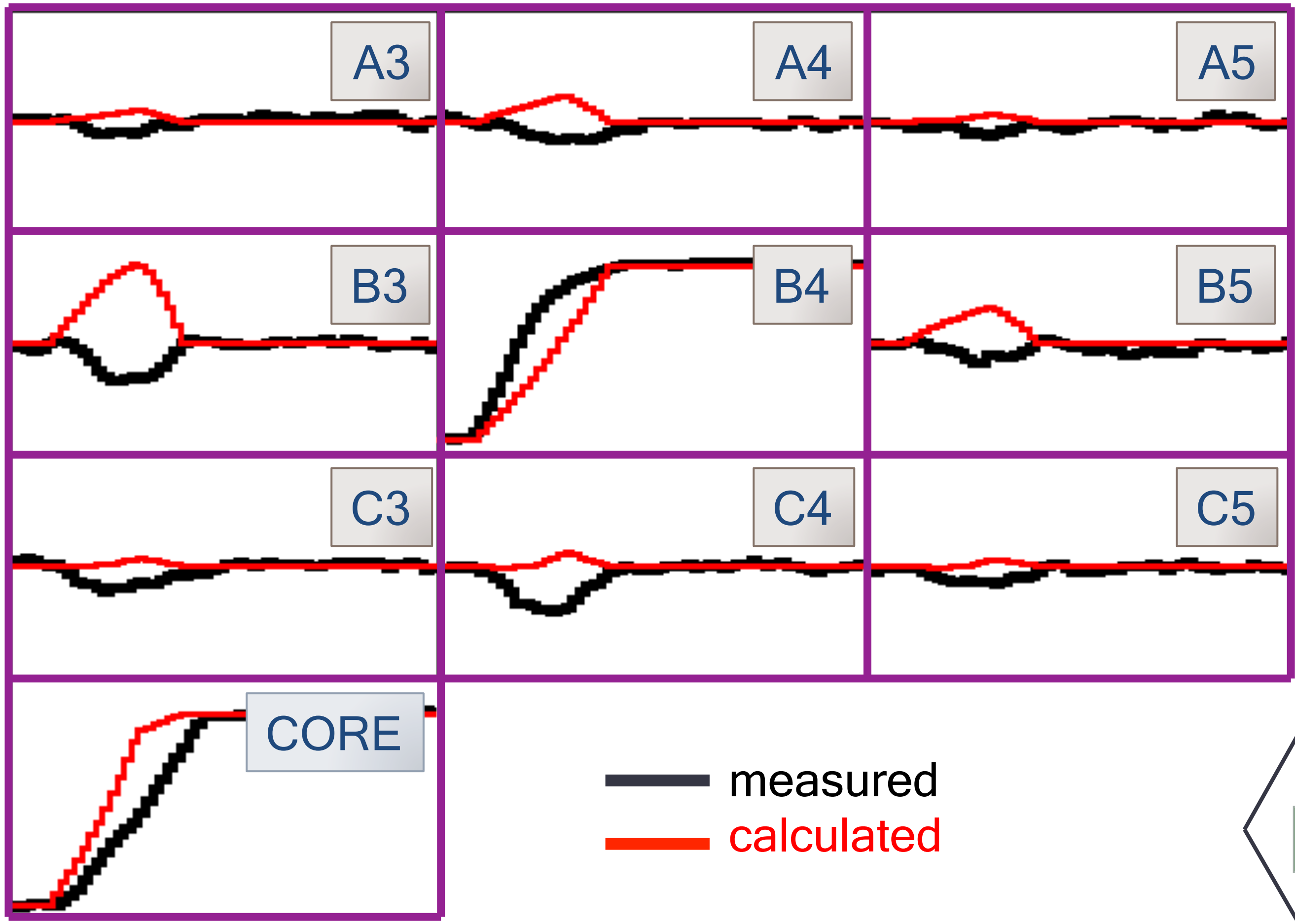
Different codes
ADL (C)
JASS (Java)
MGS (Matlab)





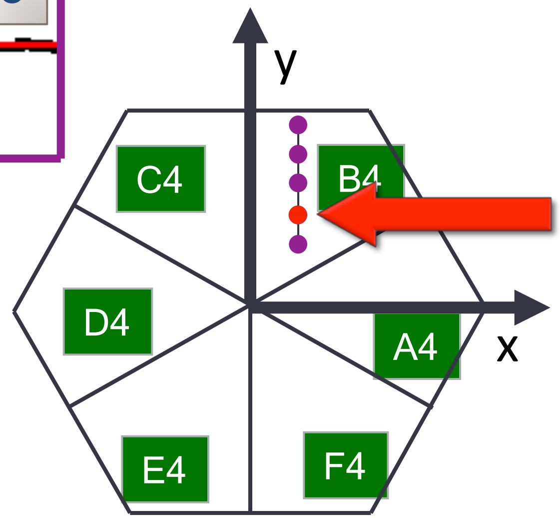
791 keV deposited in segment B4



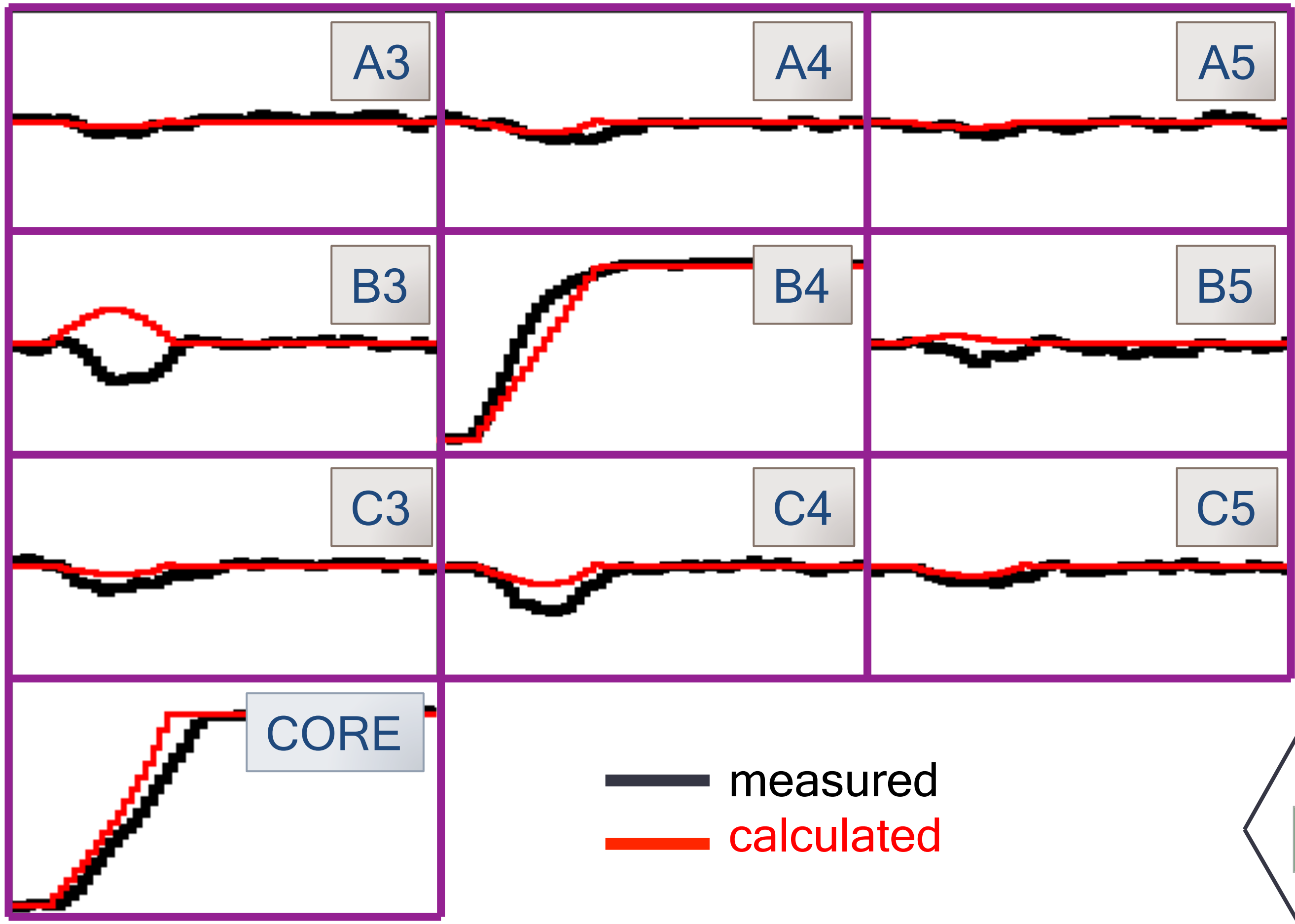


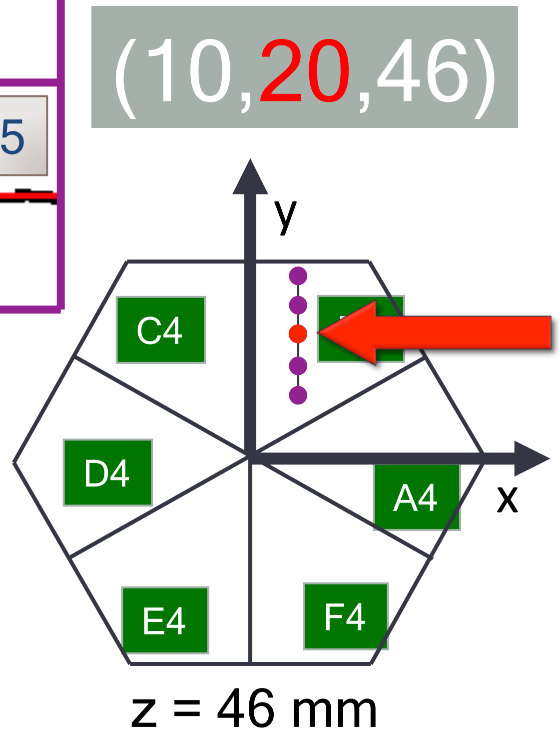
791 keV deposited in segment B4

(10,15,46)

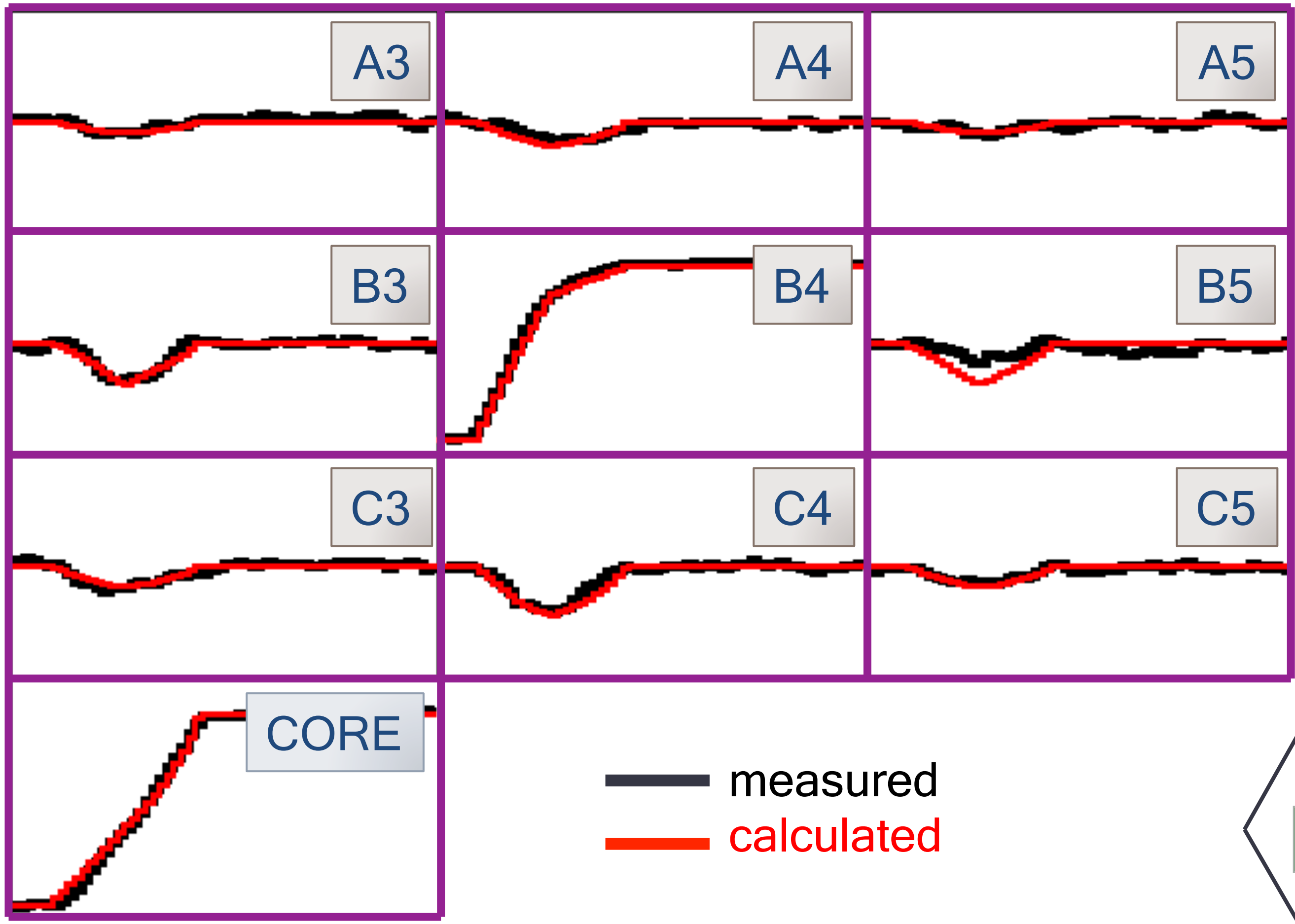


z = 46 mm

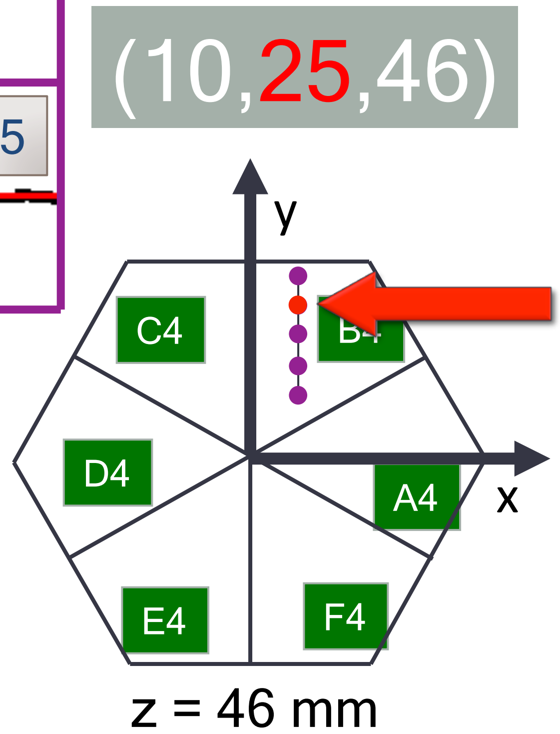


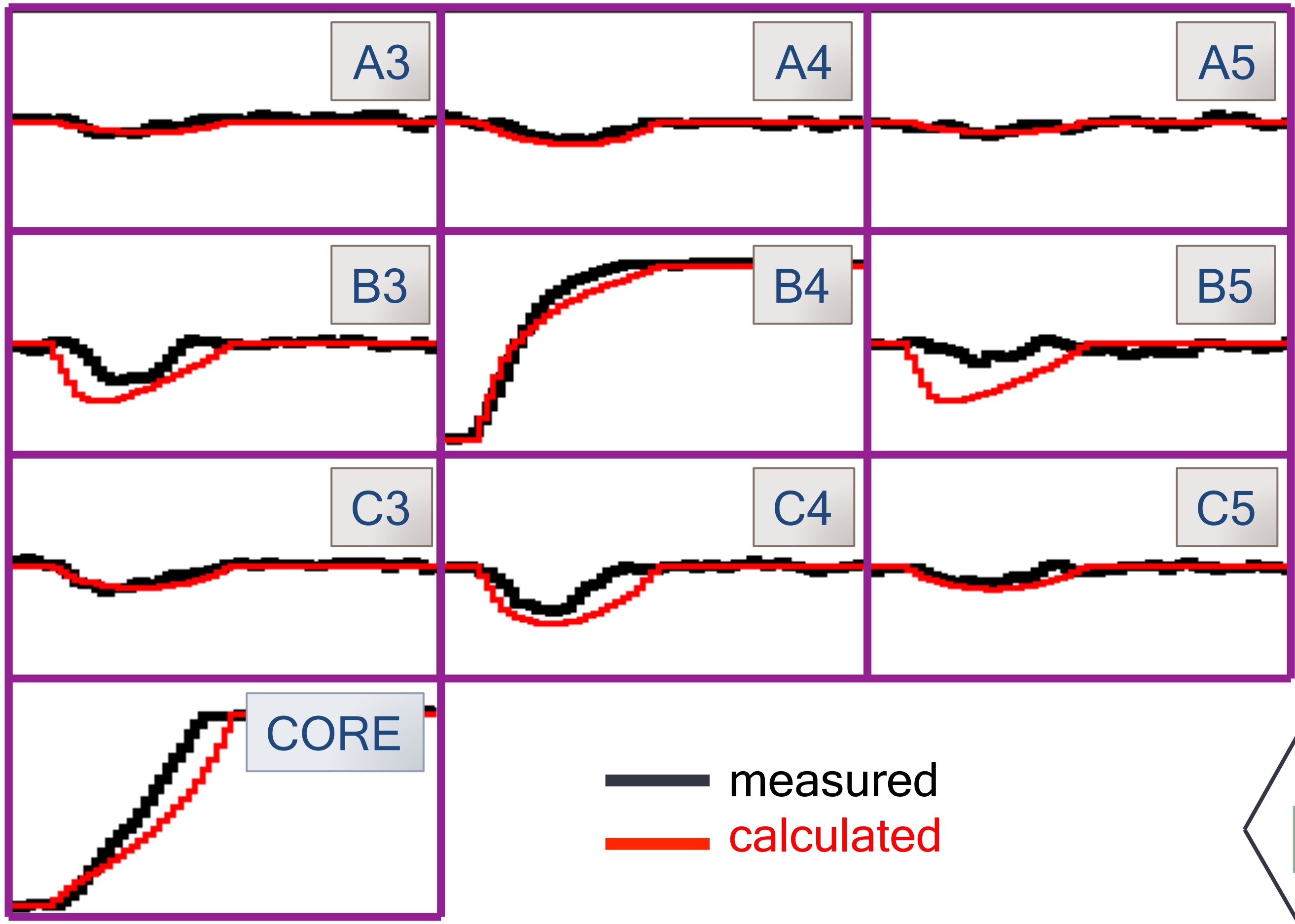


791 keV deposited in segment B4

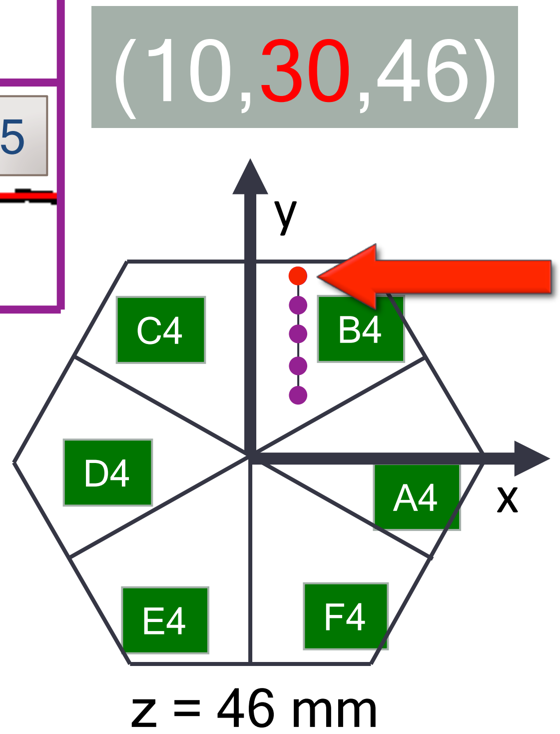


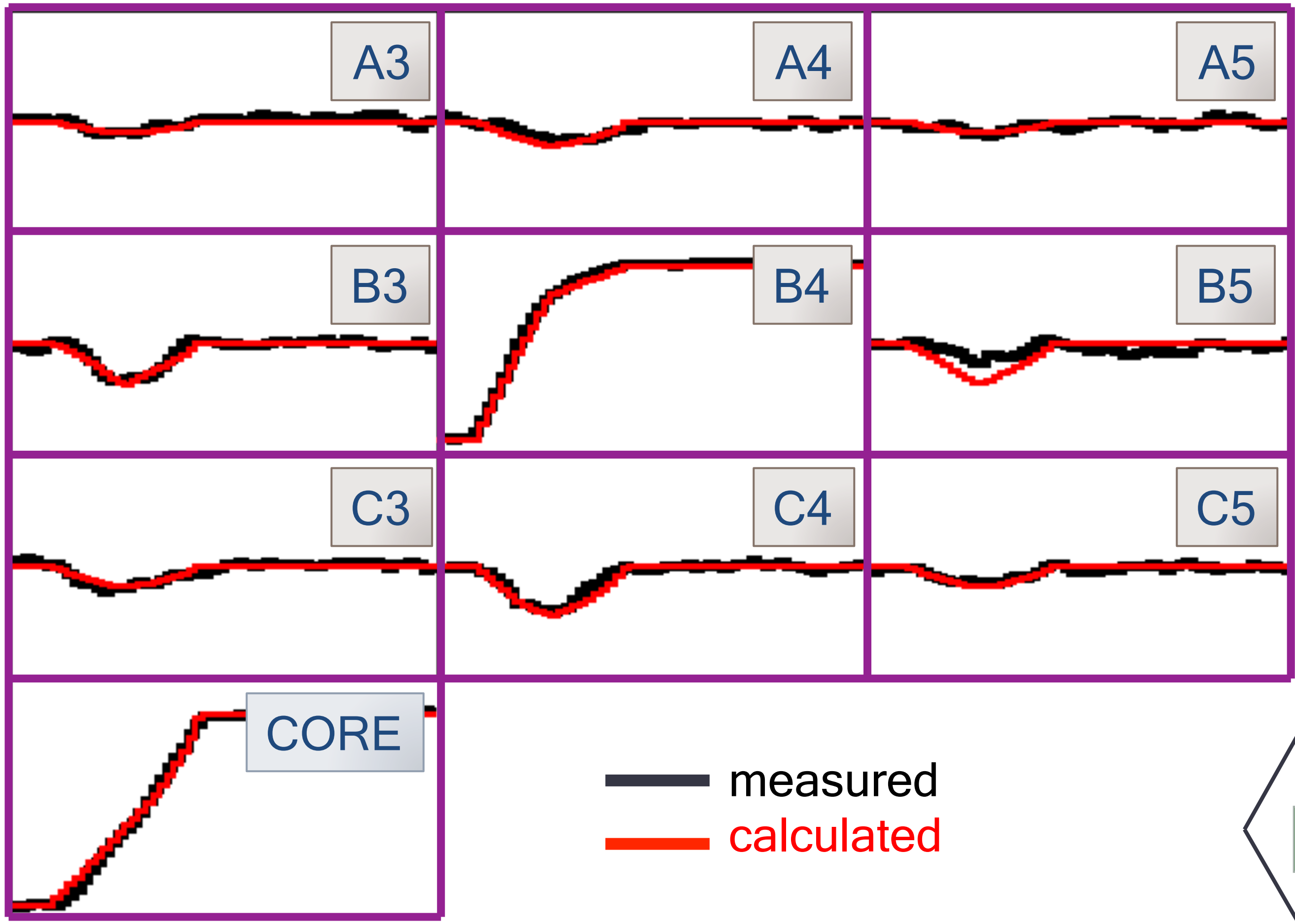
791 keV deposited in segment B4





791 keV deposited in segment B4

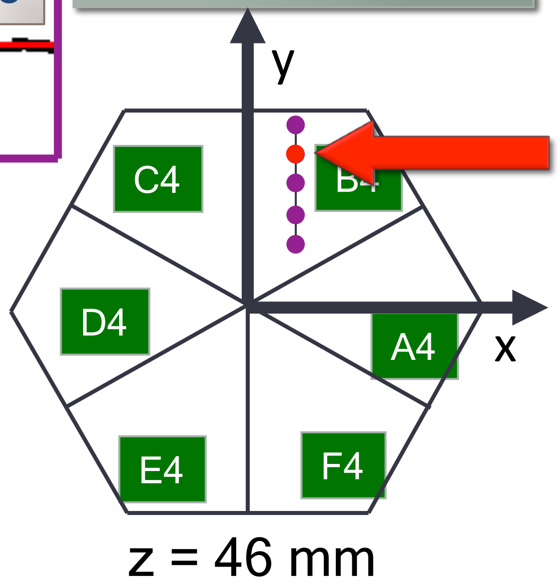




Result of *Grid Search* algorithm

R. Venturelli

(10,25,46)



791 keV deposited in segment B4

ABOUT ADL 3.0

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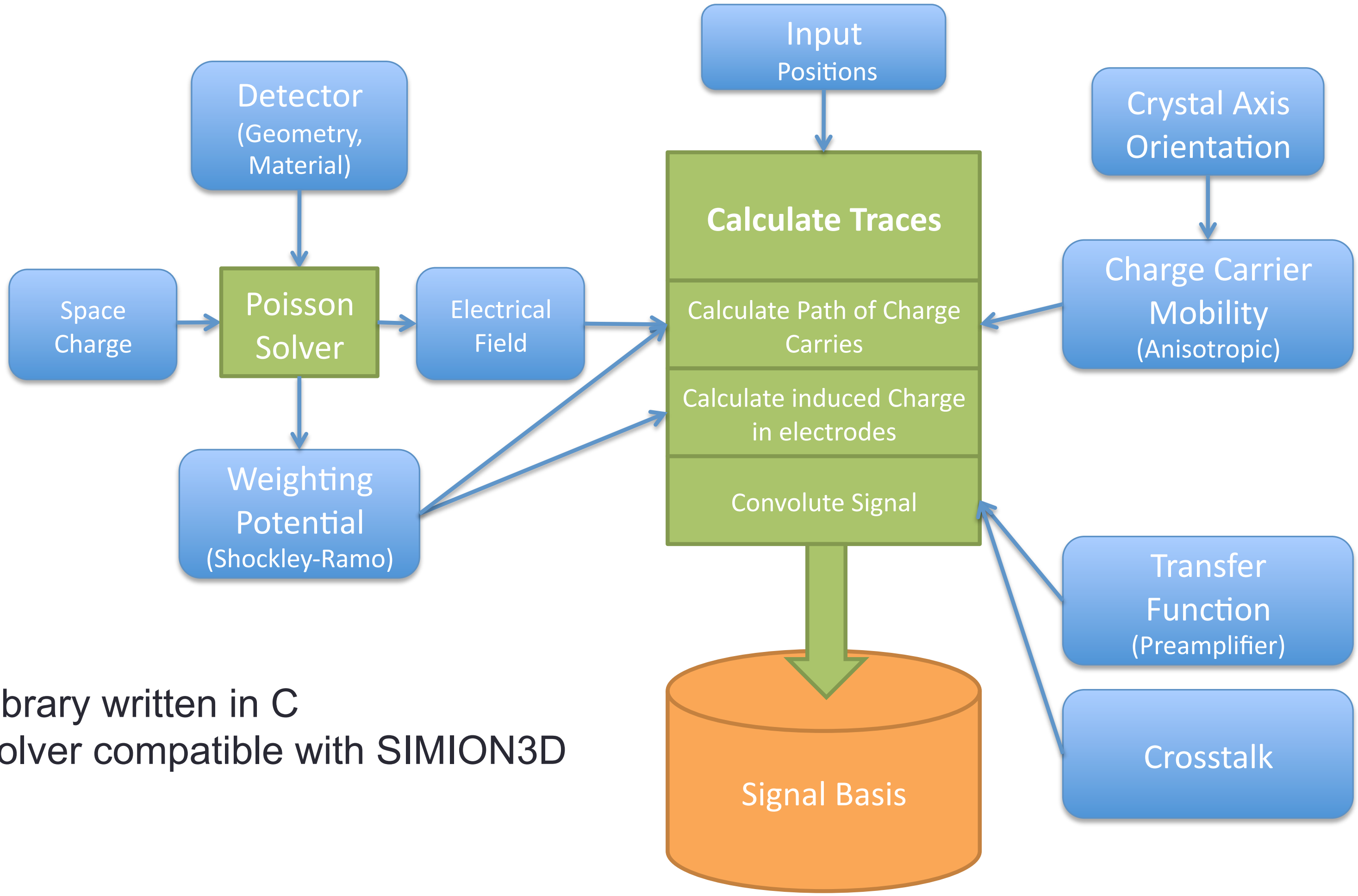
AGATA Detector Library “ADL”



- Library written in C
- Solver compatible with SIMION3D

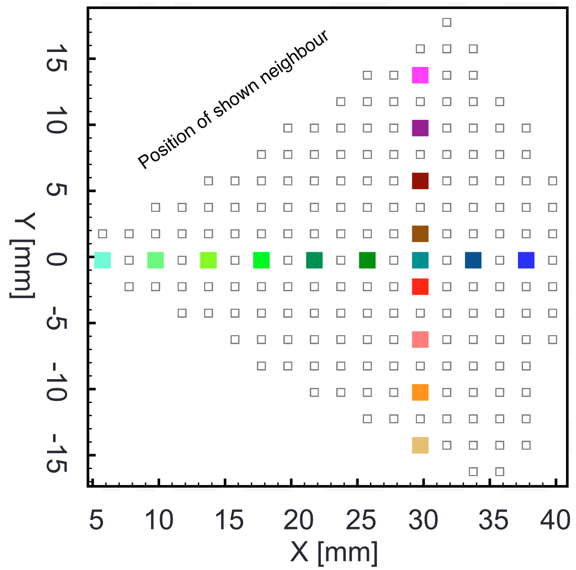
AGATA Detector Library “ADL”

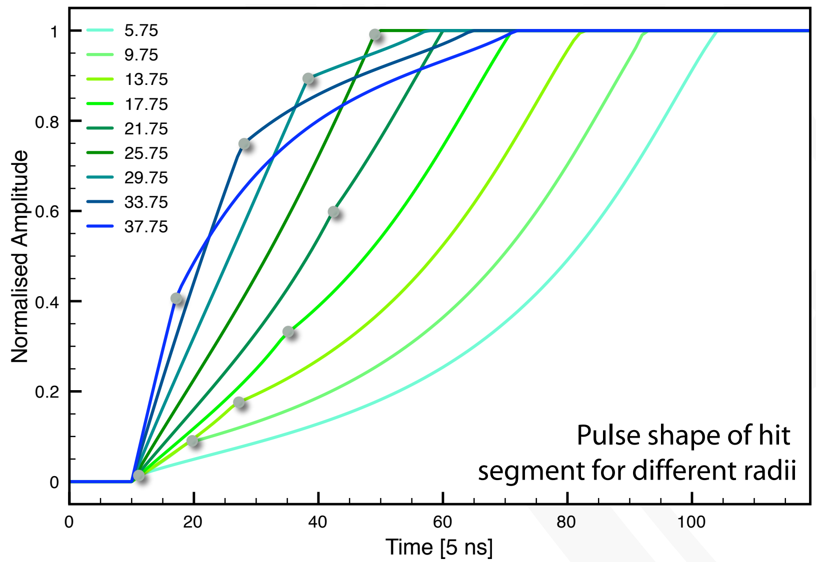
EXAMPLE PROGRAM

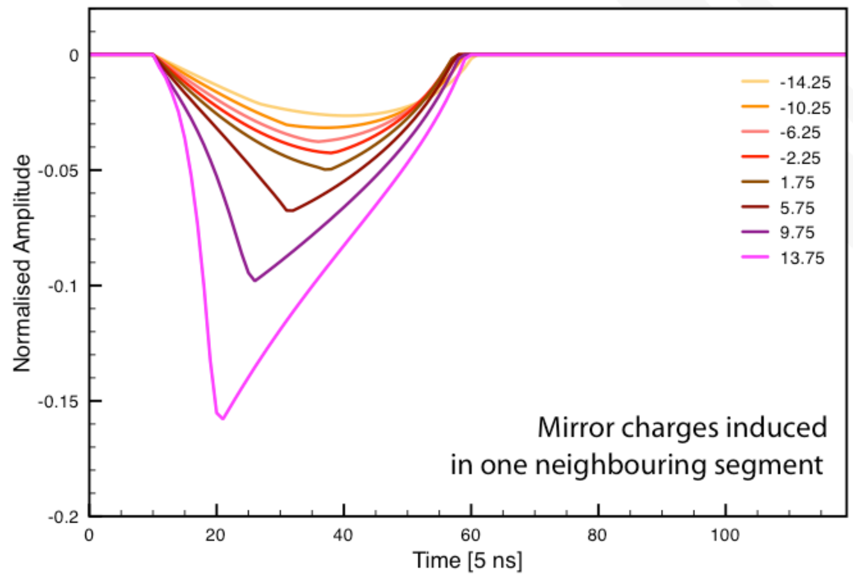
```c
#include "ADL.h"

int main (void) {
	FILE *output;
	struct ADL_EVENT *evt;

	ADL_Setup("/Volumes/BEAST/AGATA/Config/Template_ADL.txt");
	ADL_Status();

	//lets create a new event structure:
	evt = new_event();
	//Fill in the Hit Pattern (HP):
	evt->HP.Eint[0]=10.0;		//Energy of interaction 0 (we only simulate a single interaction here)
	evt->HP.T0= 0.010;		//Time the interaction occurs in the trace
	evt->HP.Pos[0][0]=2.0;		//Position where this interaction occures
	evt->HP.Pos[0][1]=2.0;
	evt->HP.Pos[0][2]=8.0;

	//On basis of the HP, here the traces are generated
	//Traces are stored in the Trace Data (TD) part of the event:
	ADL_G_CalculateTraces(evt);

	//Write the event to file:
	output = fopen("/Volumes/BEAST/AGATA/output.txt","w");
	ADL_G_WriteEvent(output,evt);
	fclose(output);
	return 0;
}
```

Examples: AGATA

- Signal shapes from AGATA detector as function of position
- Simulation using ADL
- (Steepest slope not always clear)
- (remark: segment preamps are inverting)







WEIGHTING POTENTIALS

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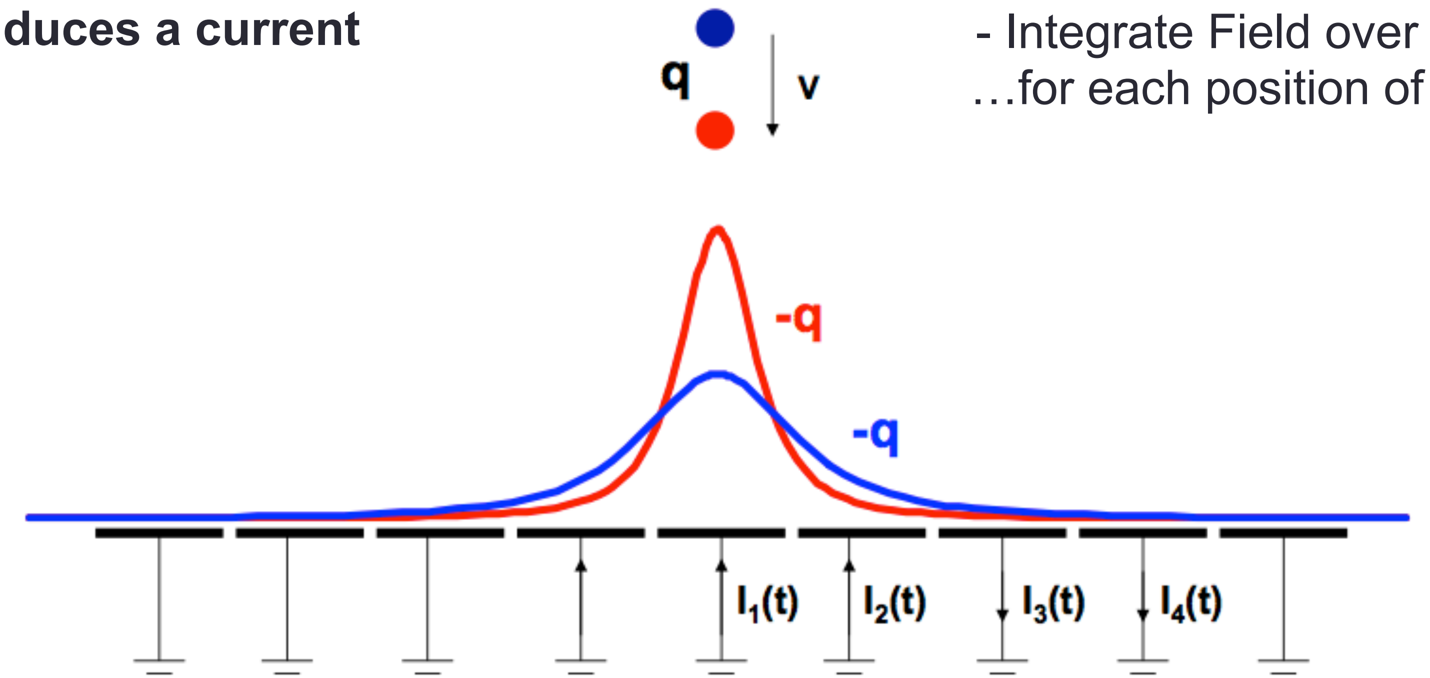
Principle of Signal induction

- A point **charge q at distance z_0** above a **grounded metal plate** induces an image charge

- If the plate is segmented, The **movement** of charge q **induces a current**

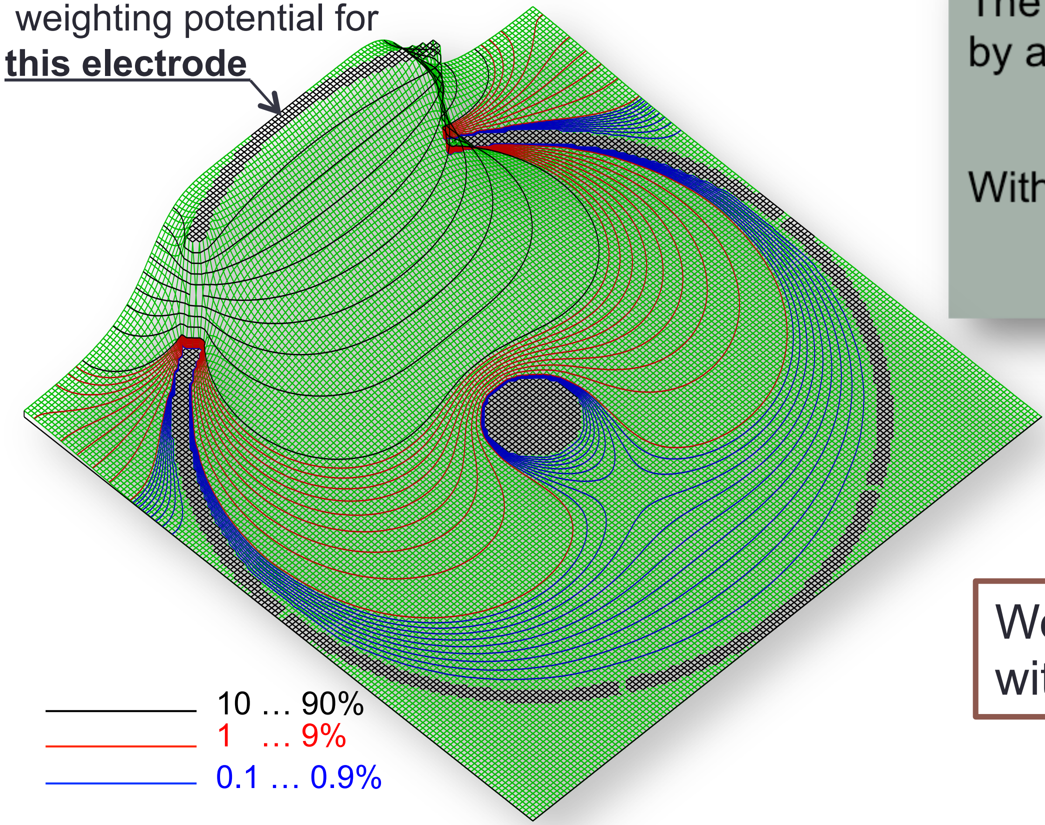
- To calculate Induced charge:
  - Solve Field for position of q
  - Integrate Field over surface

  …for each position of q… 🙁



Shockley – Ramo theorem

Example - 6x segm. coaxial detector:
weighting potential for
this electrode



The induced charge Q_{qi} on electrode i by a point charge q located at x_0 is

$$Q_{qi} = -q \cdot \psi_i(\vec{x}_0)$$

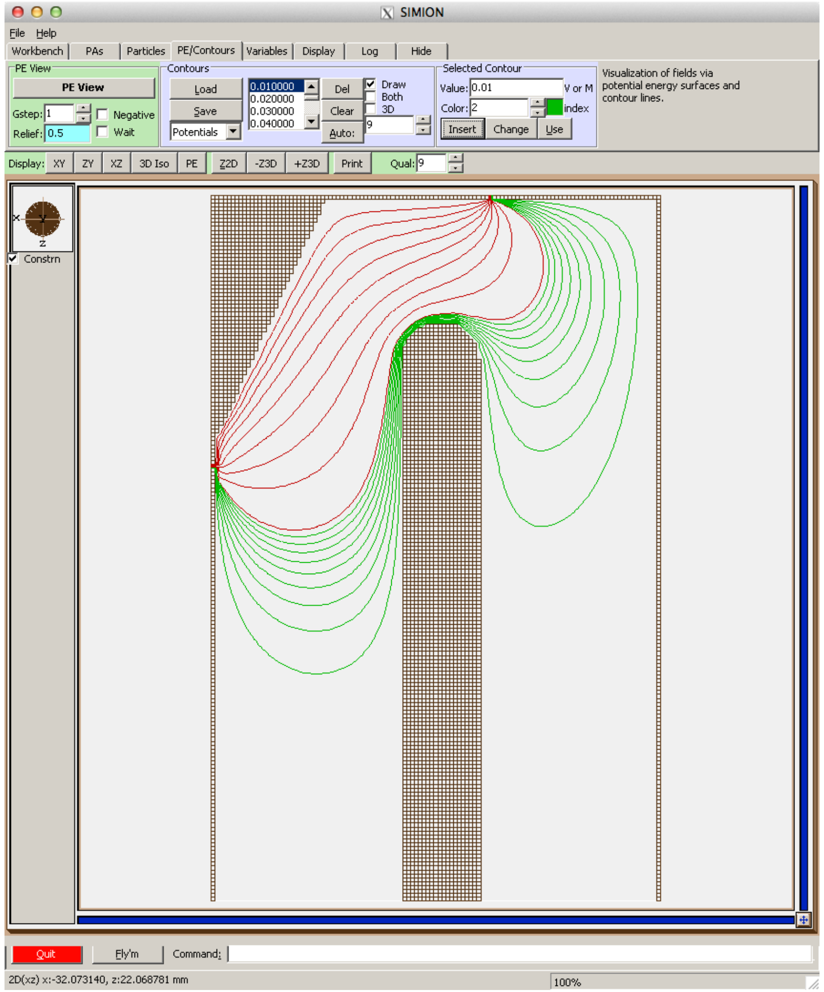
With **weighting potential** ψ_i defined by

$$\nabla^2 \psi_i(\vec{x}) = 0 \qquad \psi_i|_{S_j} = \delta_{i,j}$$

Weighting potentials dont change with the position of q…

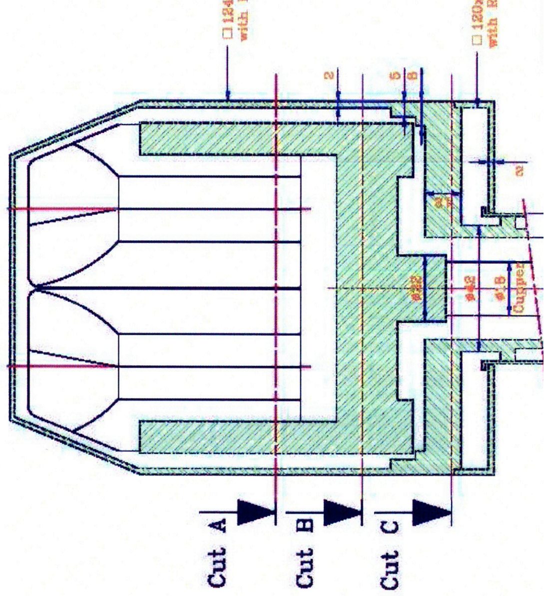
SIMION 8.0

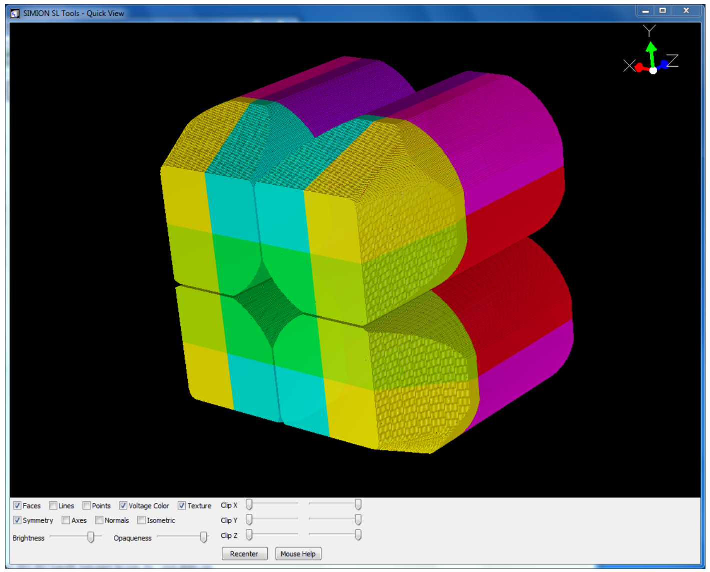
- Tool for Ion beam line development
- Used for visualisation in ADL
- import geometries e.g. from CAD files



Example: clover detector

(Itemba Labs – South Africa)

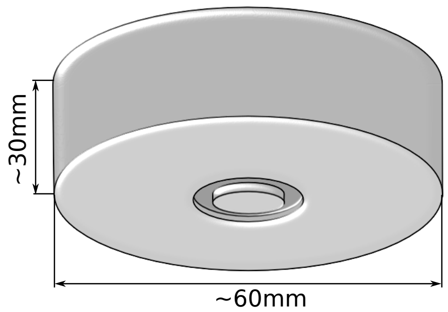


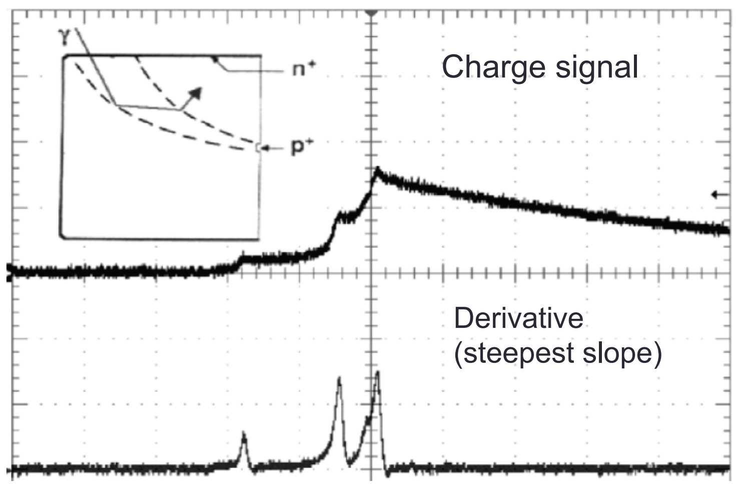


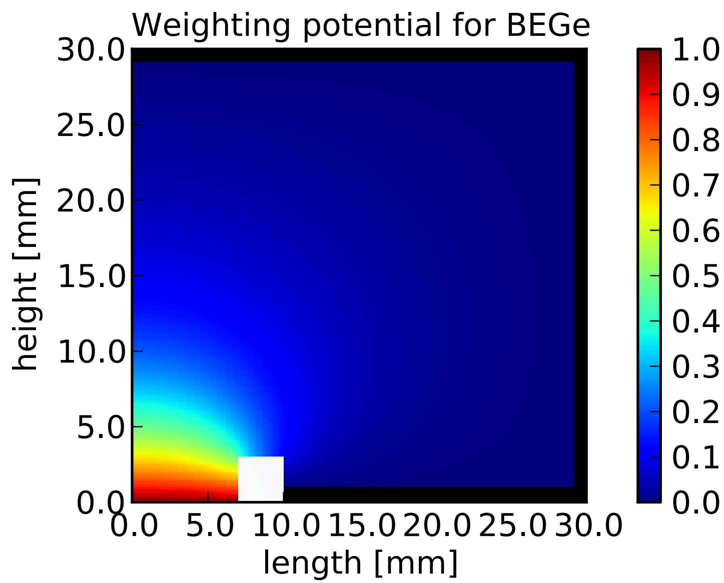
Examples: ADL + GERDA

BEGe Broad Energy Ge detector:

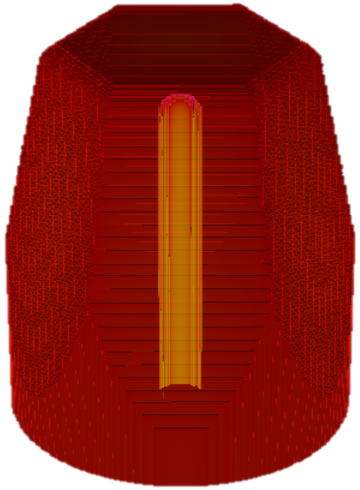
- have a very local weighting potential
- Identification of multiple hits via steepest slope method
- Very small capacity ➔low serial noise

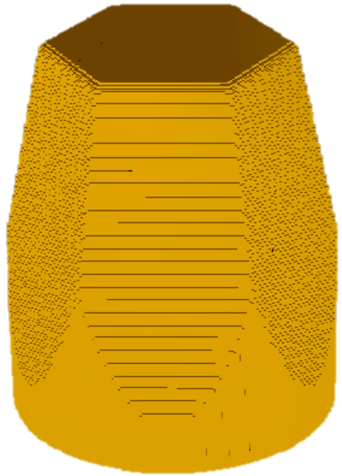


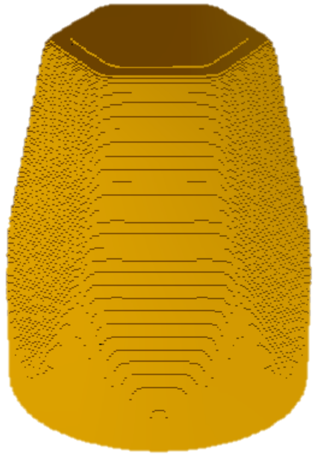




Depletion of a HPGe detector


B


C: HV = 10V


D: HV = 100V

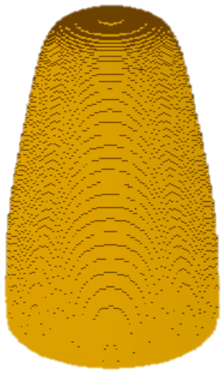
Depletion of a HPGe detector

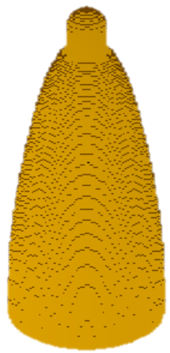
A: Bare HPGe germanium crystal
symmetric AGATA detector

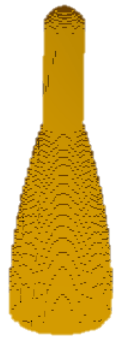
B: Geometry in simulation
The HV contact is colored yellow

C-G: Undepleted volume
as function of HV.

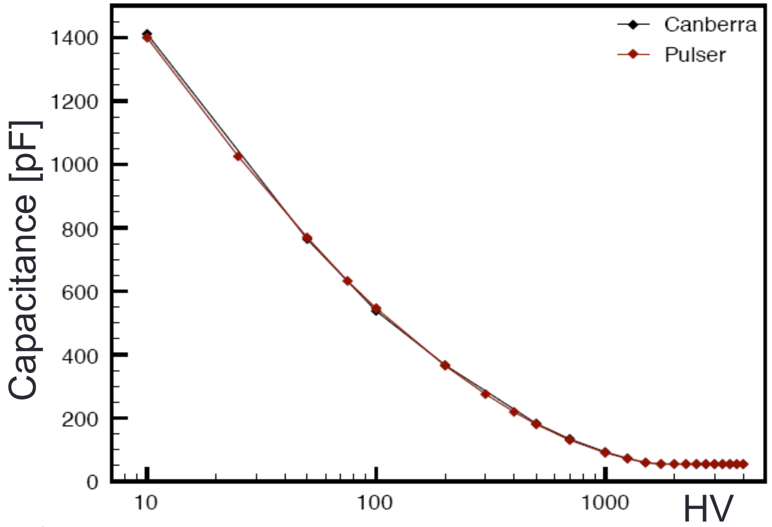
(assumption: 10^{10} impurities / cm^3)


E: HV = 1kV

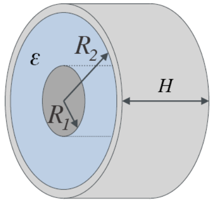

F: HV = 2kV


G: HV = 3kV

Impurity from C-V measurements



Reconstruction of impurity profile:

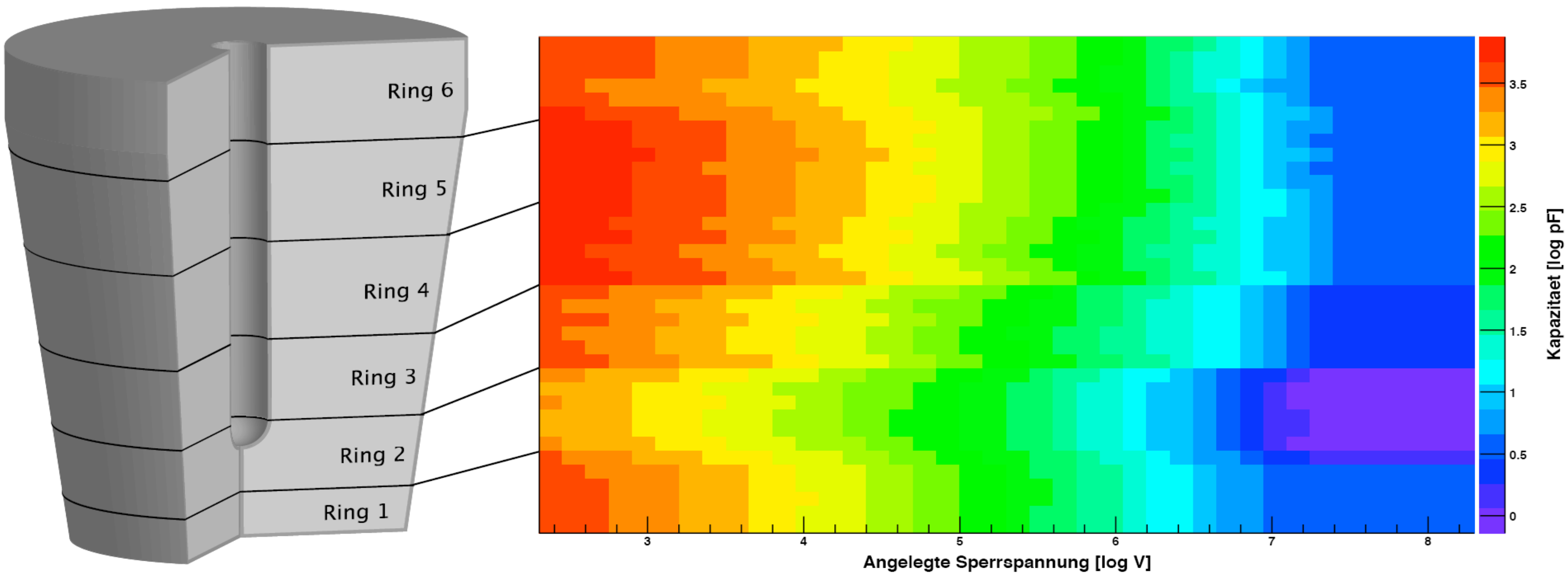


•*C(V)* gives depletion boundary R_1:

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

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

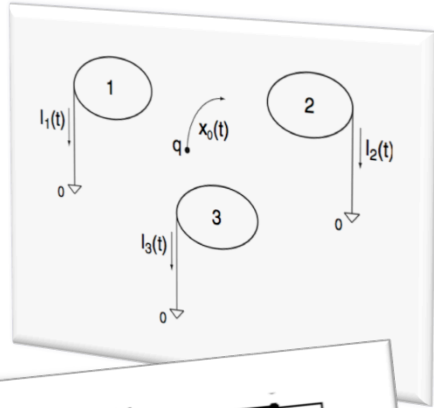
$$N_D(R_1) = -\frac{C^3 e^{\frac{4\pi\epsilon H}{C}}}{4e\pi^2 H^2 \epsilon R_2^2 \frac{dC}{dV}}$$



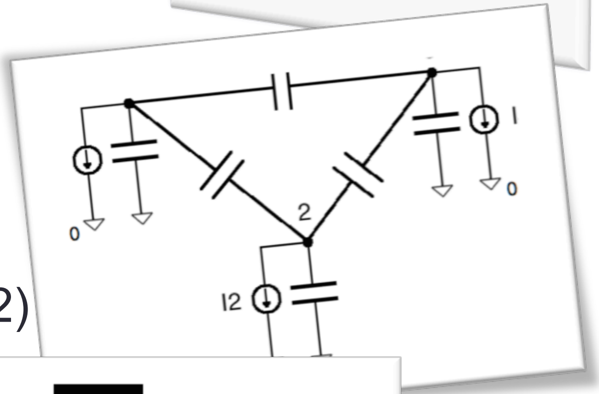
Extended Ramo theorem

- Describes detectors in a realistic electronic network.
- In 3 steps:
  - 1) Apply the Ramo theorem:
    Calculate the induced currents in each electrode
  - 2) Equivalent electronics scheme:
    Proof: see Gatti and Padivini, NIM 193 (1982) 651-653
    -Determine the capacitances of your detector,
    -Add the current sources found from 1)
  - 3) Realistic electronics scheme:
    Change the above simplified scheme
    into a realistic model
- Result = realistic signals

1)



2)



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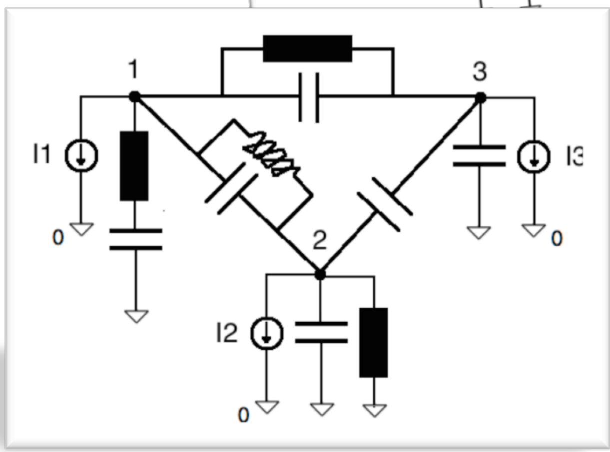
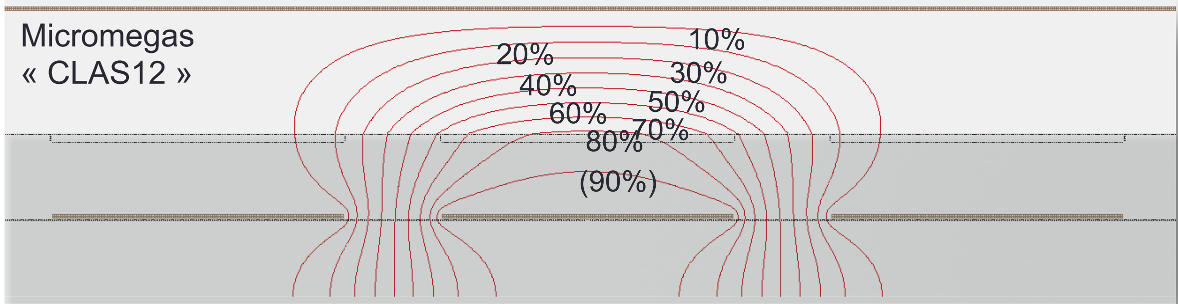


Time dependent weighting potentials



Equation to solve:

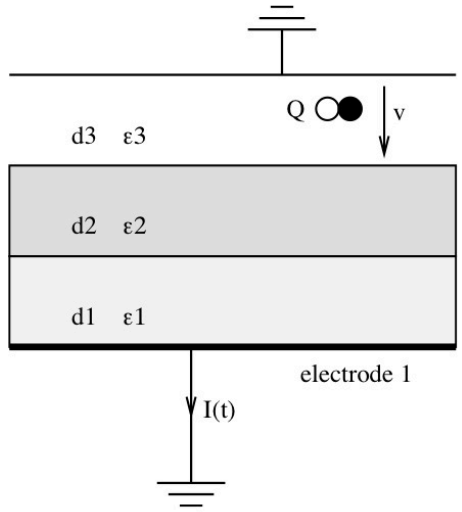
- Homogeneous dielectric medium: $$\nabla^2\phi(x) = 0$$
- Inhomogeneous medium: $$\nabla\varepsilon(x)\nabla\phi(x) = 0$$
- Including resistivity : $$\nabla(\varepsilon(x) + \sigma(x)/s)\nabla\phi(x,s) = 0$$

$\updownarrow$ Laplace Transform

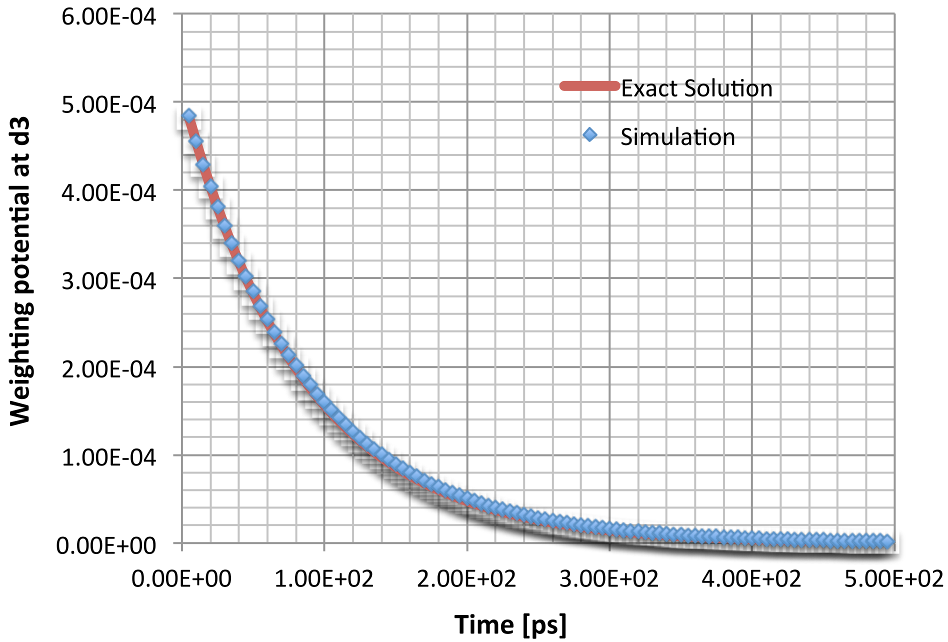
= Time dependent weighting potential $$\phi(x,t)$$

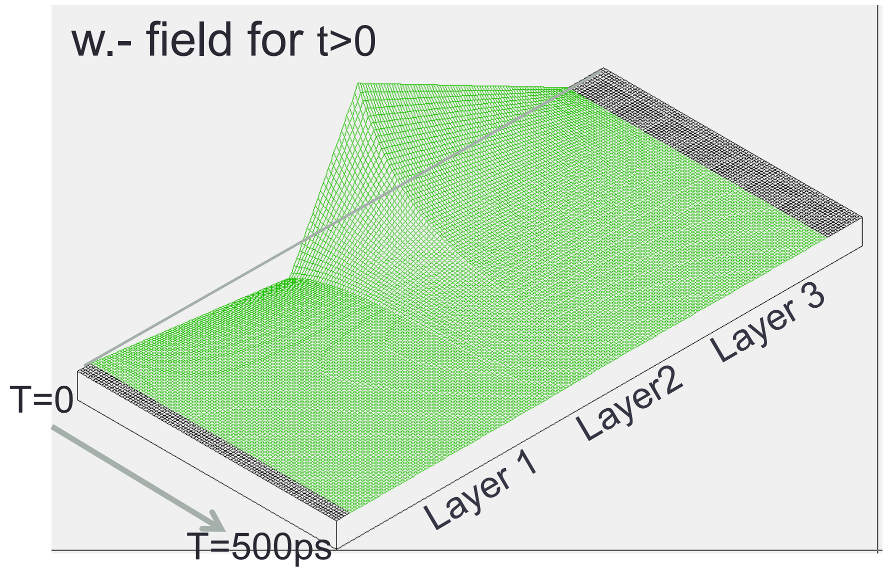
Ex: Astrobox

Astrobox	d [μm]	εr	σ [1/Ωm]
layer 3	80	1	0
layer 2	25	4.5	0.5
layer 1	75	4	0



$$V_3(x,t) = c(x)\,[\delta_t + (1/\tau_2 - 1/\tau)\exp(-t/\tau)]$$





MOBILITIES IN GERMANIUM

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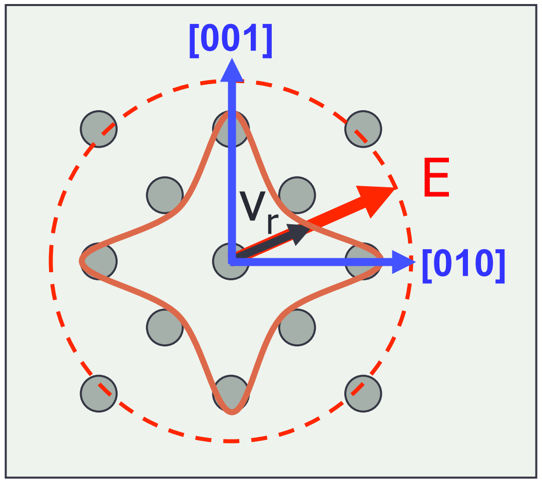
Anisotropic Mobility

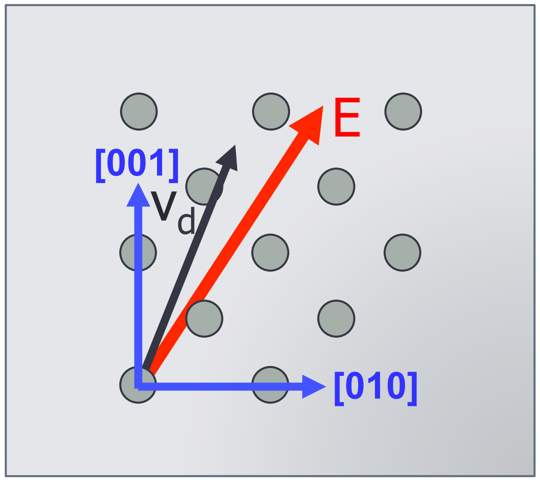
$$\vec{v}_d = \iiint \vec{v}(\vec{k}) f(\vec{k}) d\vec{k}$$

- At high fields, radial anisotropy is observed
- Radial anisotropy induces tangential anisotropy:
  a drift component towards the faster axis
- For fields along symmetry axis, no tangential drift components can exist:
  Crystal + E field are then invariant under certain rotations; so must be the drift

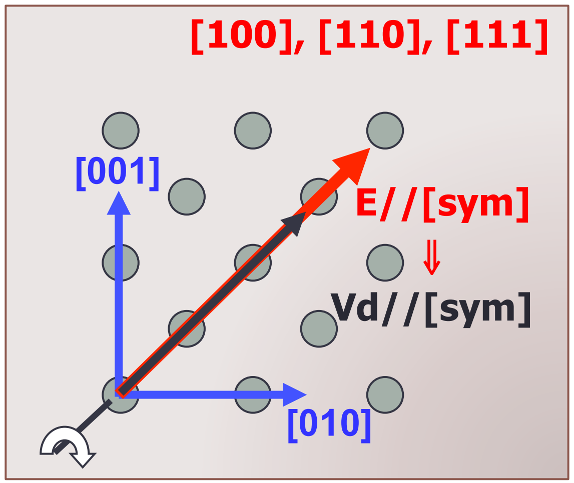
Radial anisotropy,



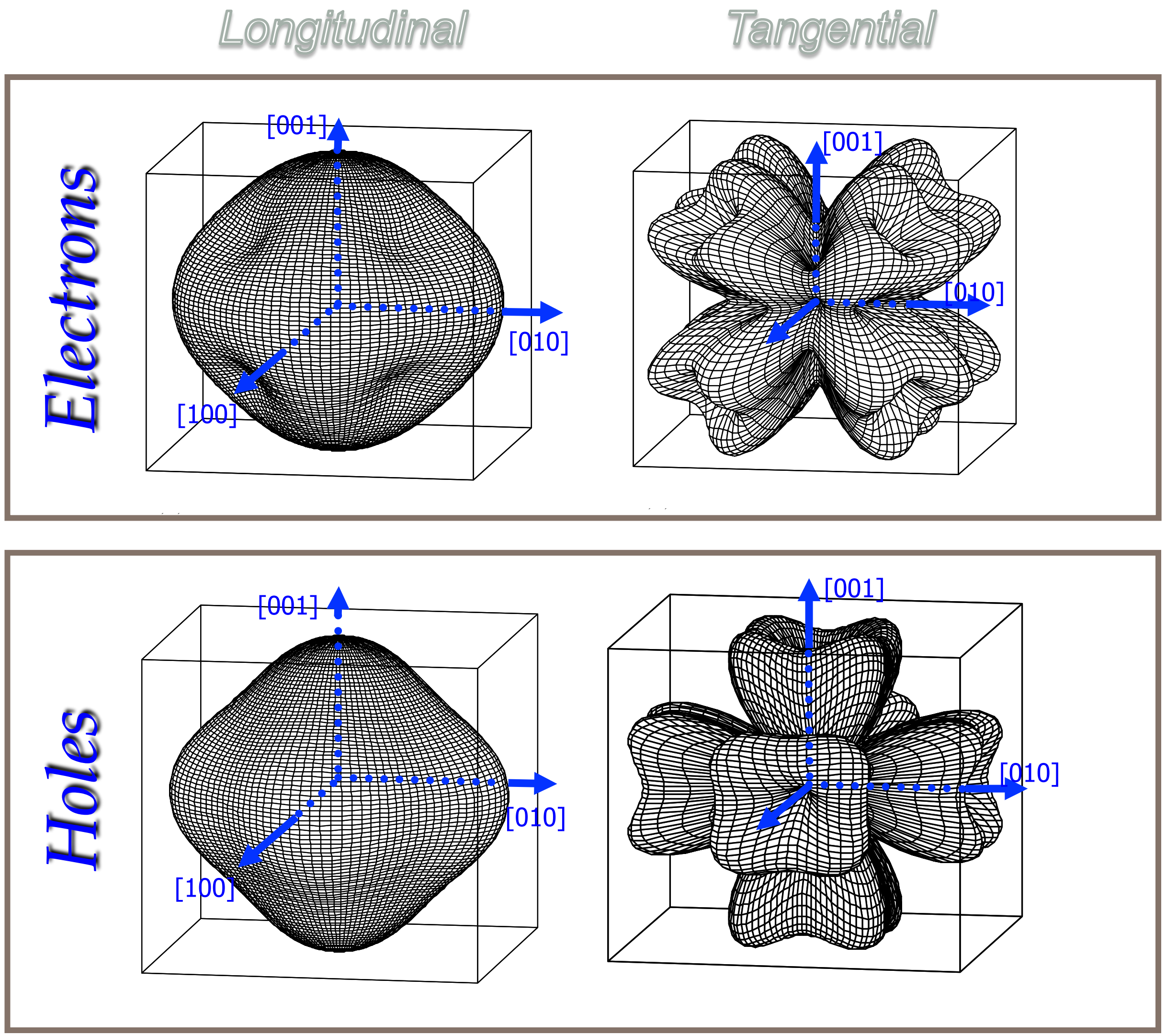
Tangential anisotropy,



except for E // symmetry axis



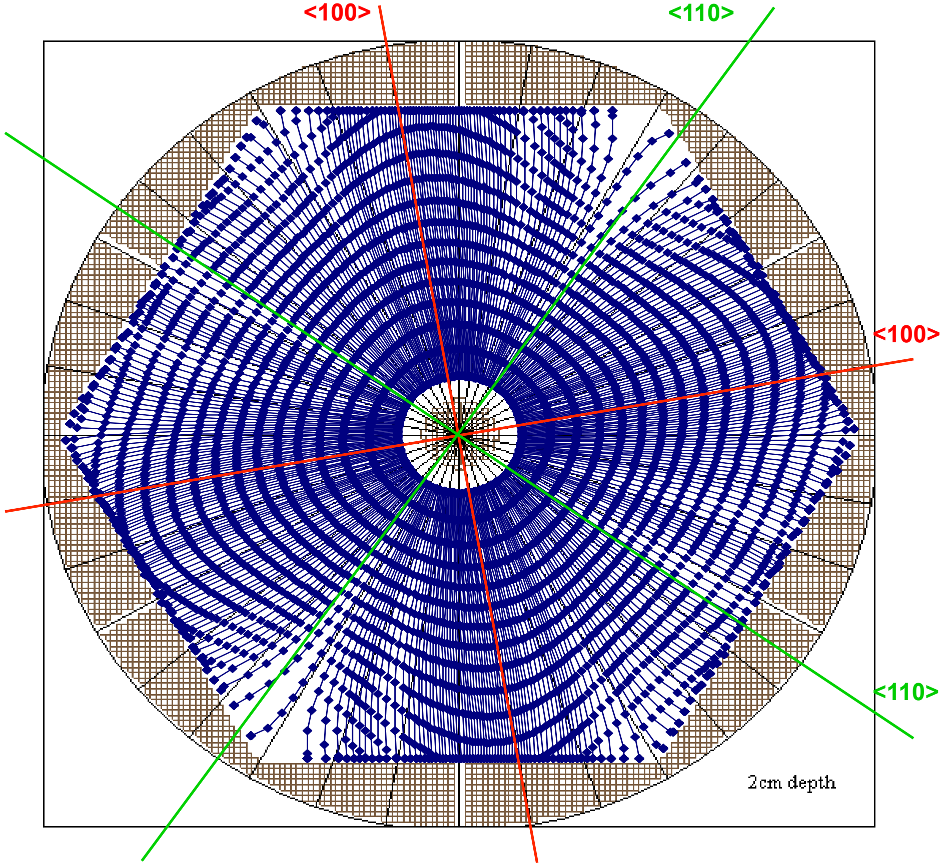
Anisotropy in mobility



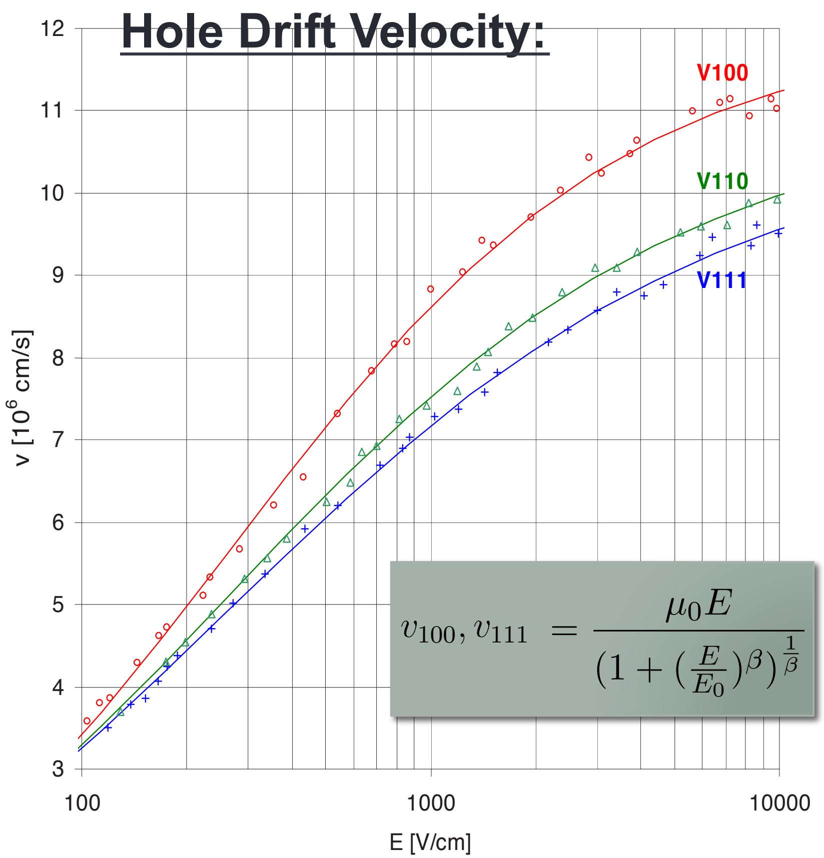
- Longitudinal and tangential components of drift velocity as function of orientation of the field (1200 V/cm)

- Electrons v_r mainly slower near [111],
- Holes v_r mainly faster near [100]
- Tangential components:
  -0 along symmetry axes
  -pointing towards nearest [100] axis

Example: Hole trajectories

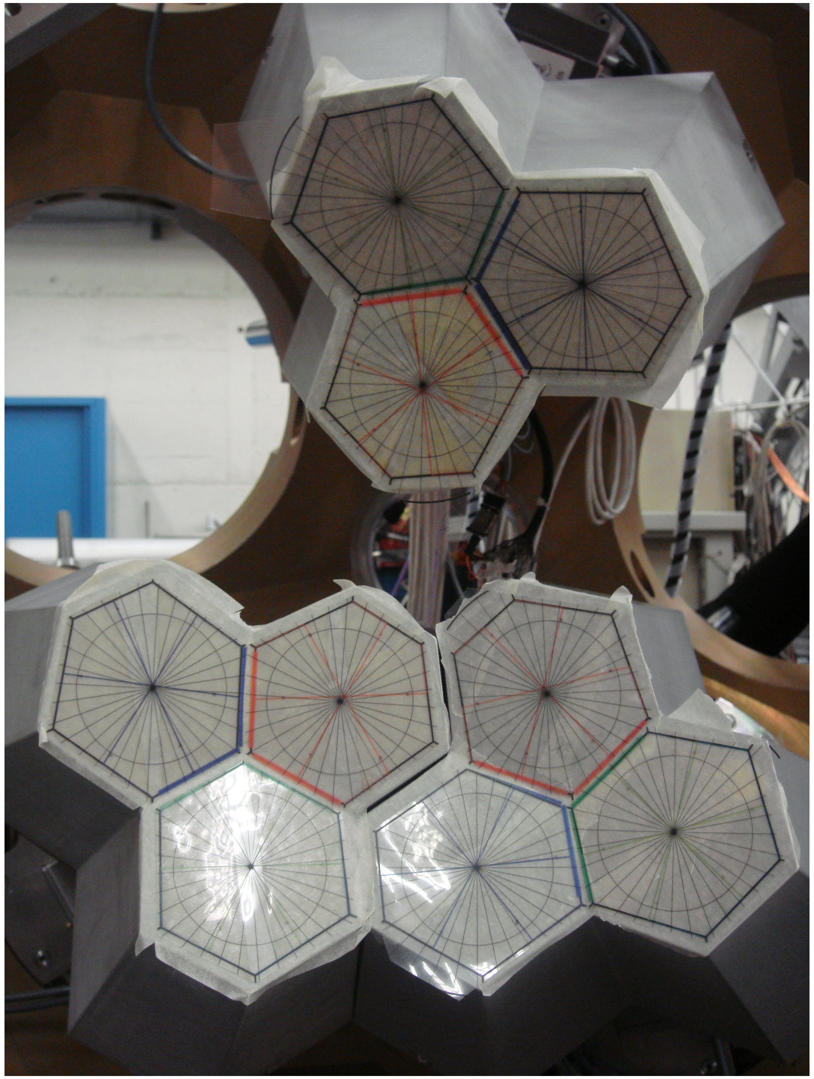


Hole trajectories for homogeneous starting positions around the core electrode. Every 25ns a point was plotted on the trajectory



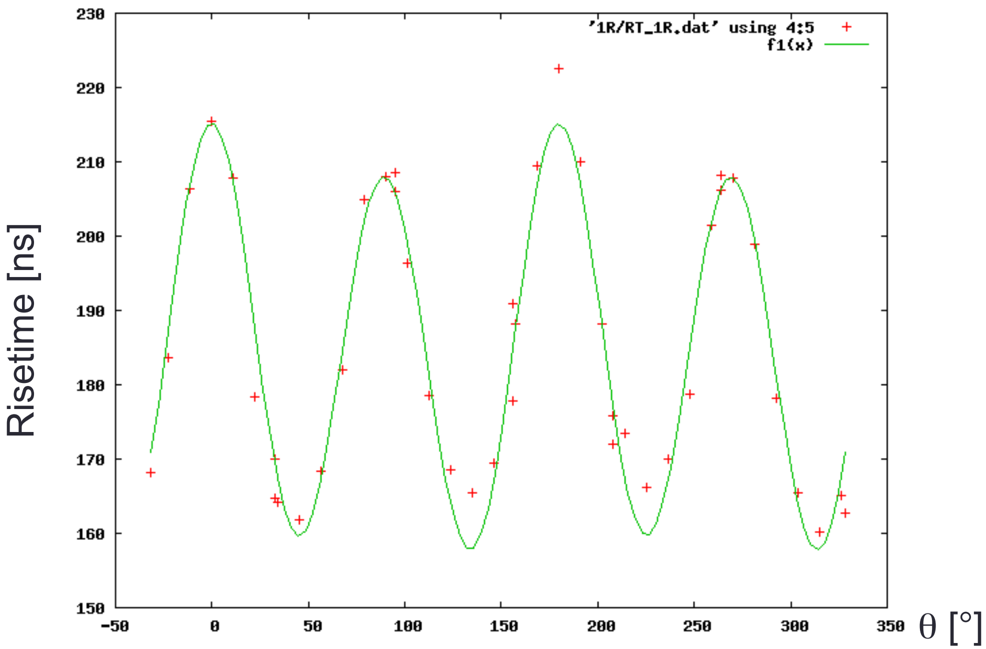
$$v_{100}, v_{111} = \frac{\mu_0 E}{(1 + (\frac{E}{E_0})^{\beta})^{\frac{1}{\beta}}}$$

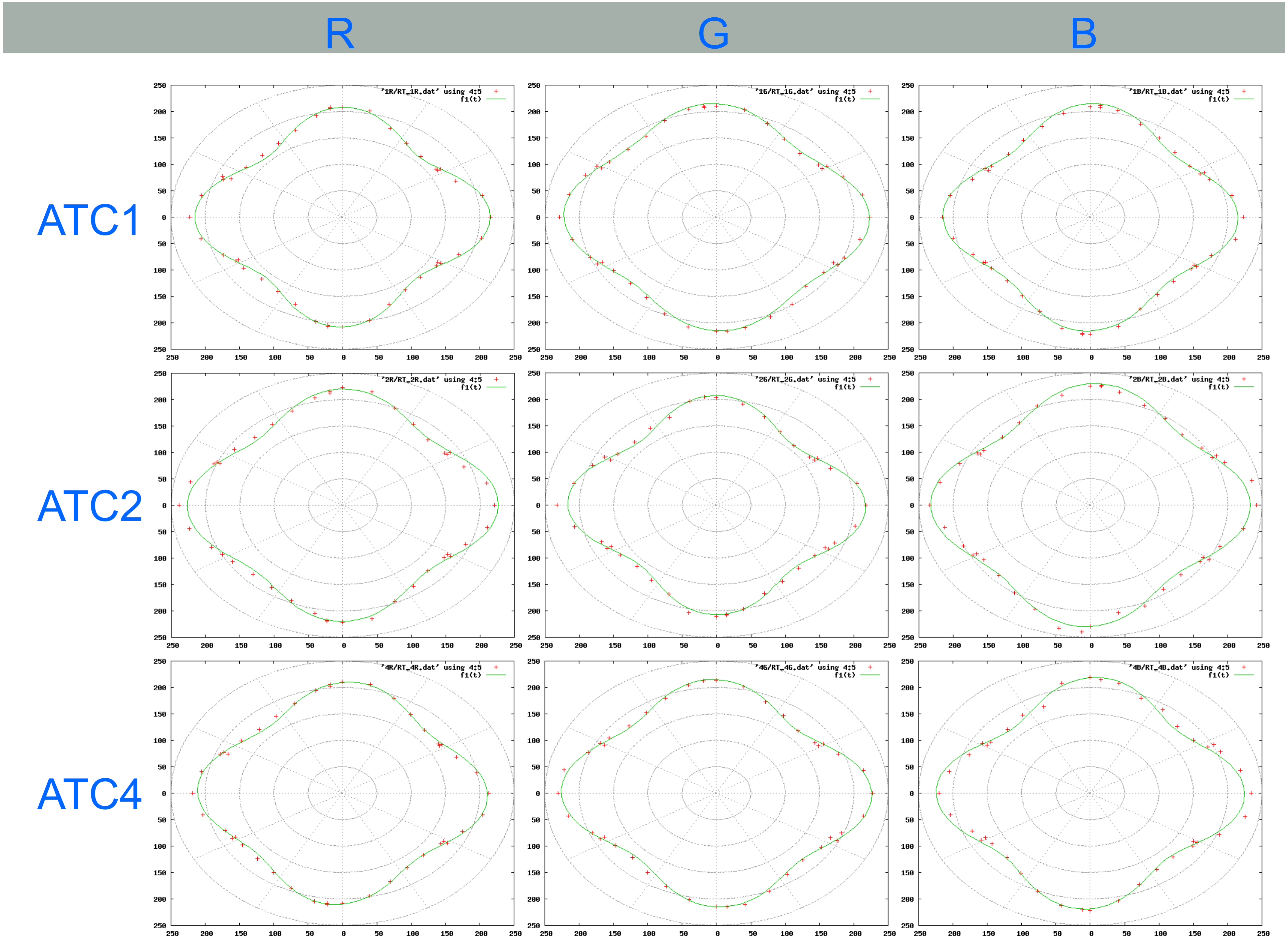
Measuring the crystal axis



- 400kBq Am source +
- Lead Collimator: ∅ 1.5mm X 1cm
- Front Scan at ∅ 4.7cm: 300 cts/s
- Fitfunction Risetime(θ) =

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

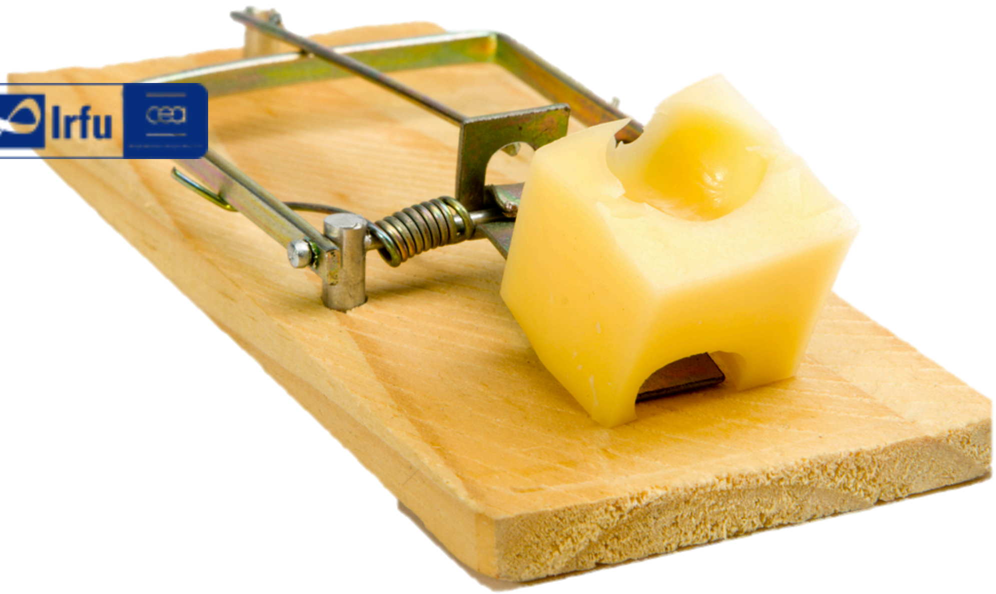



R
G
B
ATC1
ATC2
ATC4
'1R/RT_1R.dat' using 4:5
f1(t)
'1G/RT_1G.dat' using 4:5
f1(t)
'1B/RT_1B.dat' using 4:5
f1(t)
'2R/RT_2R.dat' using 4:5
f1(t)
'2G/RT_2G.dat' using 4:5
f1(t)
'2B/RT_2B.dat' using 4:5
f1(t)
'4R/RT_4R.dat' using 4:5
f1(t)
'4G/RT_4G.dat' using 4:5
f1(t)
'4B/RT_4B.dat' using 4:5
f1(t)

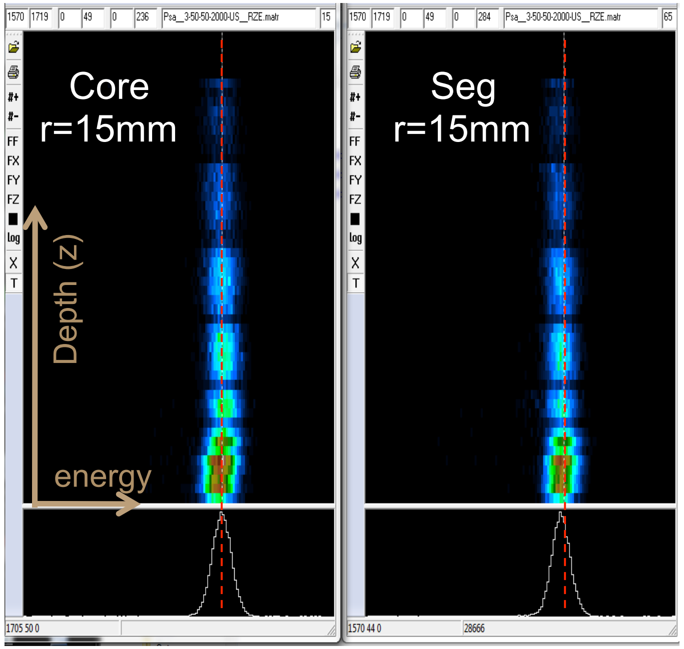
NEUTRON DAMAGE, TRAPPING AND CORRECTION

Bart Bruyneel

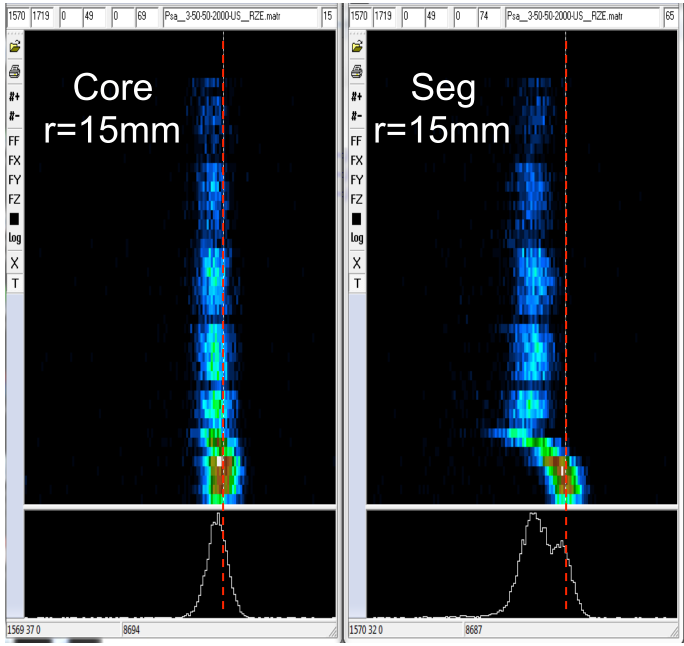
CEA Saclay, France

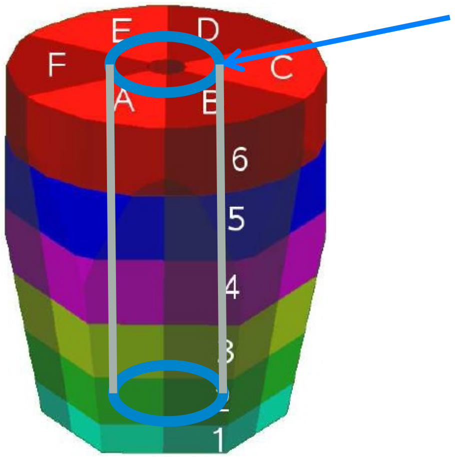


New detector…



after neutron damage





The 1332 keV peak as a function of crystal depth (z) for interactions at r = 15mm

The charge loss due to neutron damage is proportional to the path length to the electrodes. This is provided by the PSA, which is barely affected by the amplitude loss.

Knowing the interaction position,
the charge trapping can be modeled and corrected away

Collection Efficiency

T.W. Raudorf, R. H. Pehl – NIM A 255 (1987) 538-551
Bruyneel et al. – EPJ A (2013) 49:61

• Trapping rate of electrons / holes "q":

$$\frac{dq}{dt} = - < \sigma\, v > N_t q \quad \Leftrightarrow \quad q(t) = q_0 \cdot e^{-\int_0^t <\sigma v> N_t dt'}$$

σ : trapping cross section
v : microscopic velocity
<.>: average over ensemble
N_t : density of trapping centers

• Collection efficiency (position dependent) of electrons / holes for electrode "i":

$$\eta^i_{e,h}(\vec{x}_0) = - \int_0^{t_e} \left(\vec{\nabla}\phi_i \cdot \vec{v}_{e,h}\right) \cdot \frac{q(t)}{q_0} dt$$

x_0 : interaction position in detector
ϕ_i : weighting potential of segment i
$v_{e,h}$: drift velocity of electrons / holes
t_e : collection time

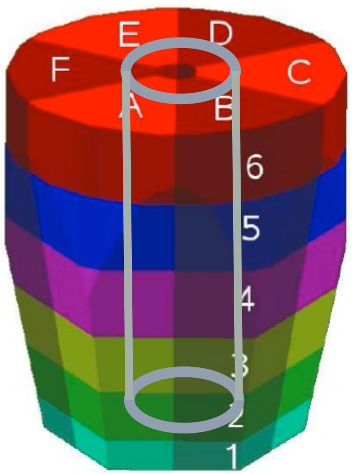
= Integral [current to seg i per unit charge]
= total recorded charge by e/h after collection

• Total collection efficiency allows reconstruction of original energy:

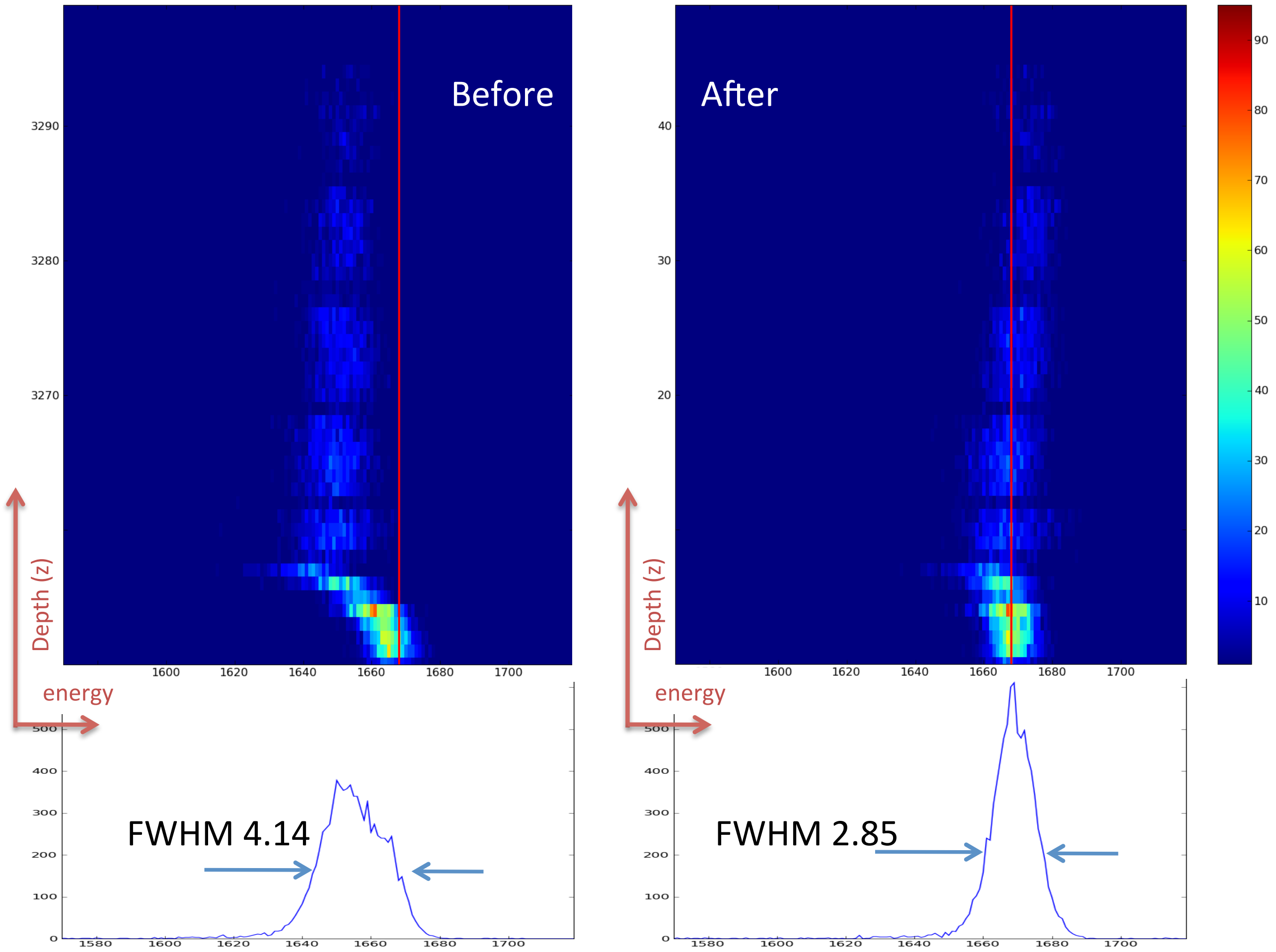
$$\eta^i_{tot}(\vec{x}_0) = \eta^i_e(\vec{x}_0) + \eta^i_h(\vec{x}_0)$$

Neutron Damage Correction

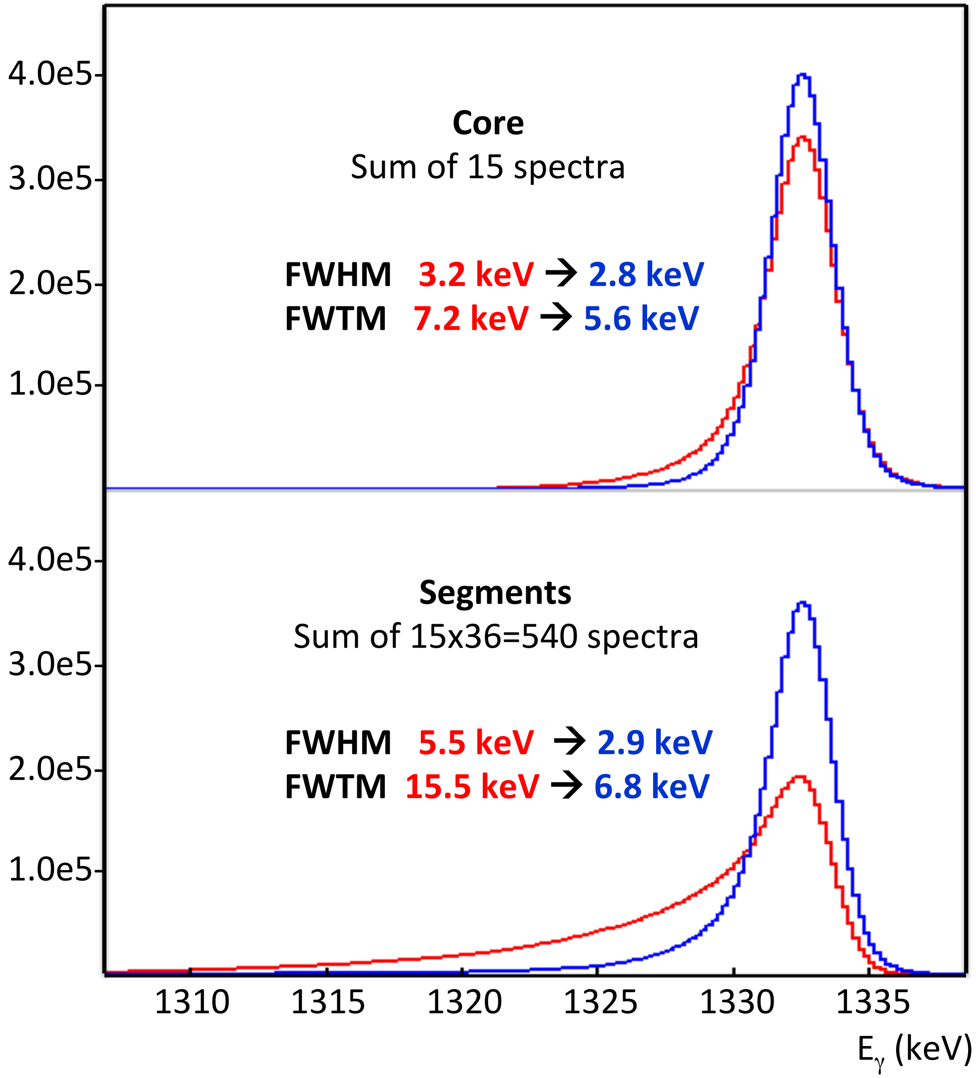
Selection of events using PSA



The 1332 keV peak as a function of crystal depth (z) for interactions at r = 15mm



Neutron Damage Correction



Line shape at the end of the AGATA @ LNL beam campaign

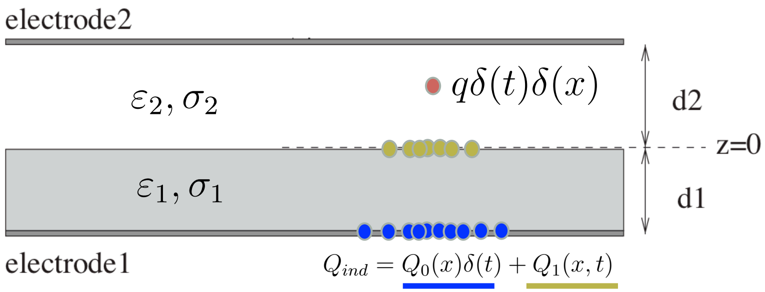
- Red = without correction
  Blue = with correction
- summed core line shape:
  Core is rather insensitive to neutron damage
- Summed segments line shape:
  Segments are more sensitive to neutron damage than core.

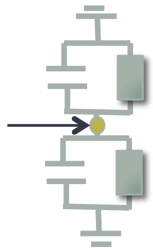
…FIN…

Bart Bruyneel
CEA Saclay, France

Time dependent weighting potentials

An example:





Equivalent scheme for decay constant

- Infinite short times: directly induced charges, time independent fraction of weighting potential $$\lim_{s\to\infty} \nabla(\varepsilon(x) + \sigma(x)/s)\nabla\phi(x,s) = 0$$
- q also charges the interface at z=0 : indirectly induces charges time evolution of the charges at interface
- Total Weighting potential $$\phi = \phi_0(x)\delta(t) + \phi_1(x,t)$$
- Time integrated charge: $$\phi_{int} = \int_0^\infty \phi \, dt \quad \leftrightarrow \lim_{s\to 0} \nabla(\varepsilon(x) + \sigma(x)/s)\nabla\phi_{int}(x,s) = 0$$

Example: Astrobox

Explicit solution for x<d3:

see e.g. W. Riegler, NIM A 491 (2002) 258

define

$$a = \varepsilon_1\varepsilon_2 d_3 + \varepsilon_2\varepsilon_3 d_1 + \varepsilon_3\varepsilon_1 d_2$$

$$b = \varepsilon_3\sigma_2 d_1 + \varepsilon_1\sigma_2 d_3$$

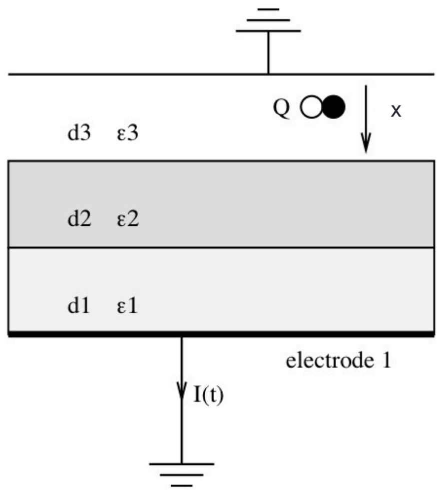
$$c(x) = \varepsilon_1\varepsilon_2 x/a$$

$$\tau_2 = \varepsilon_2/\sigma_2$$

$$\tau = a/b$$

$$V_3(x,s) = c(x)\frac{s + 1/\tau_2}{s + 1/\tau}$$

$$V_3(x,t) = c(x)\left[\delta_t + (1/\tau_2 - 1/\tau)\exp(-t/\tau)\right]$$

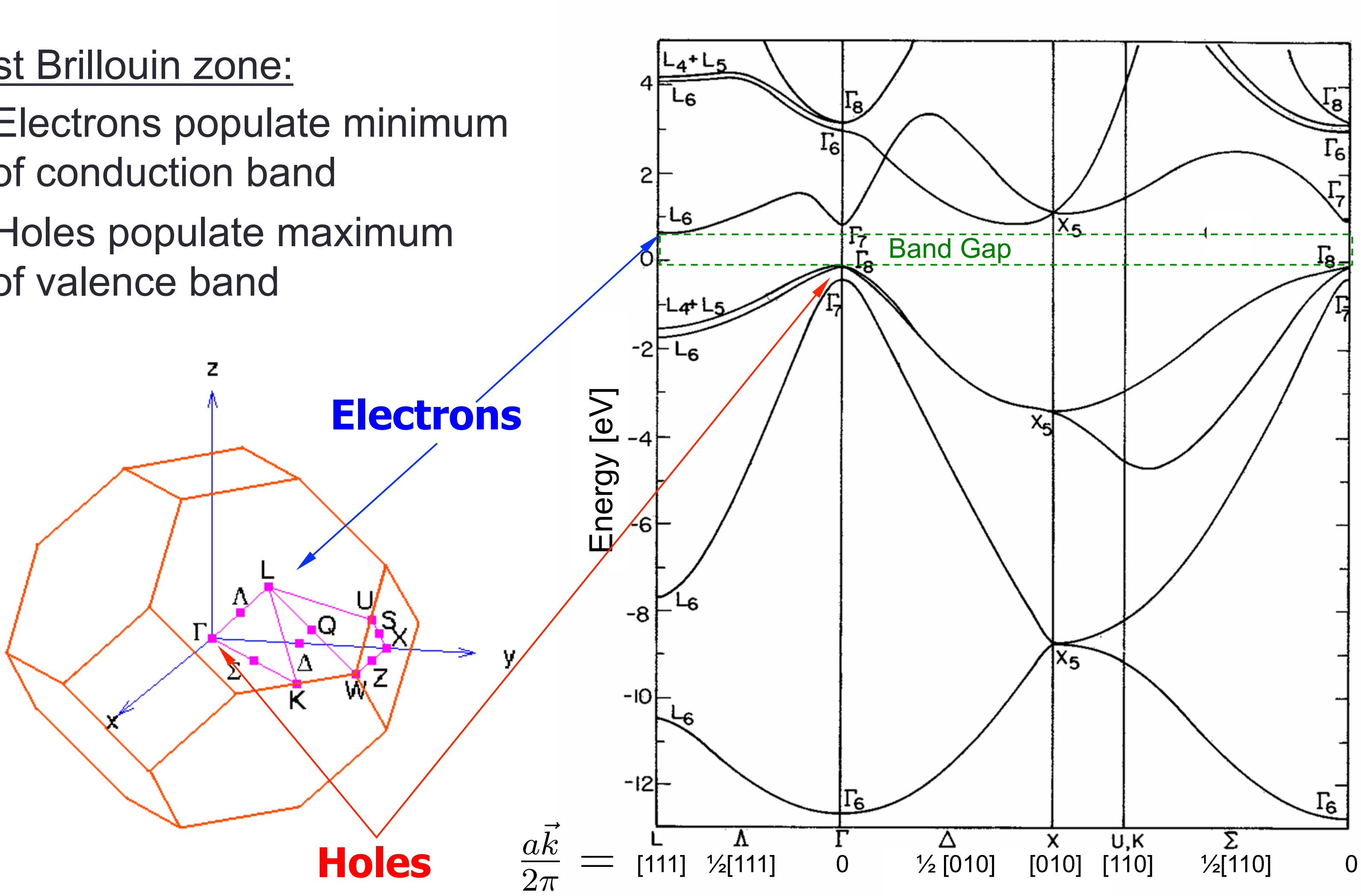


Astrobox	d [µm]	εr	σ [1/Ωm]
layer 3	80	1	0
layer 2	25	4.5	0.5
layer 1	75	4	0

Germanium Band structure

first Brillouin zone:

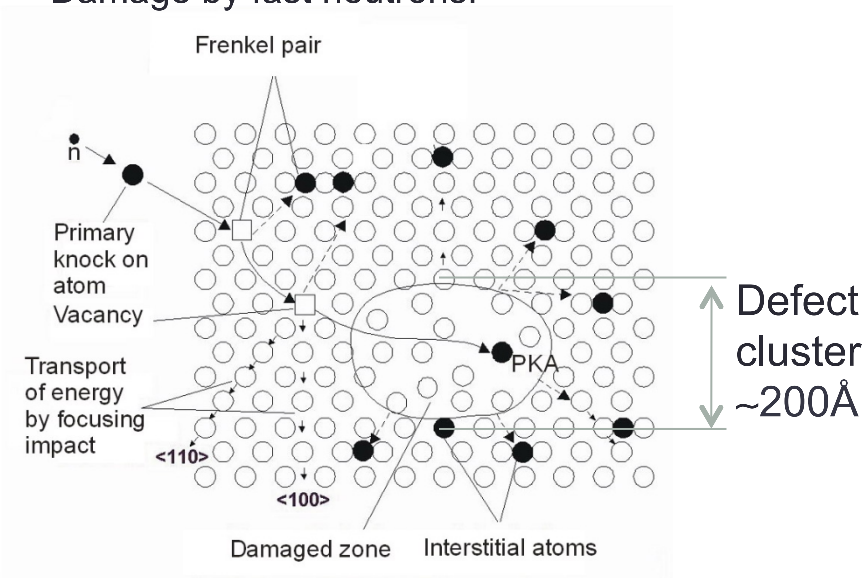
- Electrons populate minimum of conduction band
- Holes populate maximum of valence band



Trapping cross section

L. S. Darken et al. NIM 171 (1980)

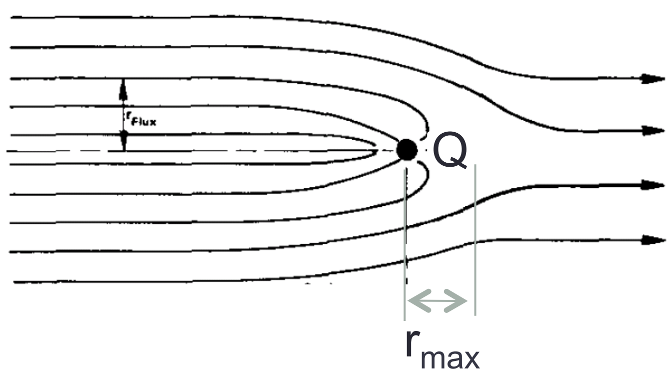
Damage by fast neutrons:



Cross section from field line disturbance:

Balance between E field and Coulomb force:

$$qE = \frac{Qq}{4\pi\varepsilon r_{max}^2} \quad \Leftrightarrow \quad \sigma \propto 4\pi r_{max}^2 = \frac{Q}{\varepsilon E}$$



<u>Assumptions:</u>

- Trapping only by disordered regions
- Macroscopic model: drift velocity!

Q ~ 100e equilibrium charge state

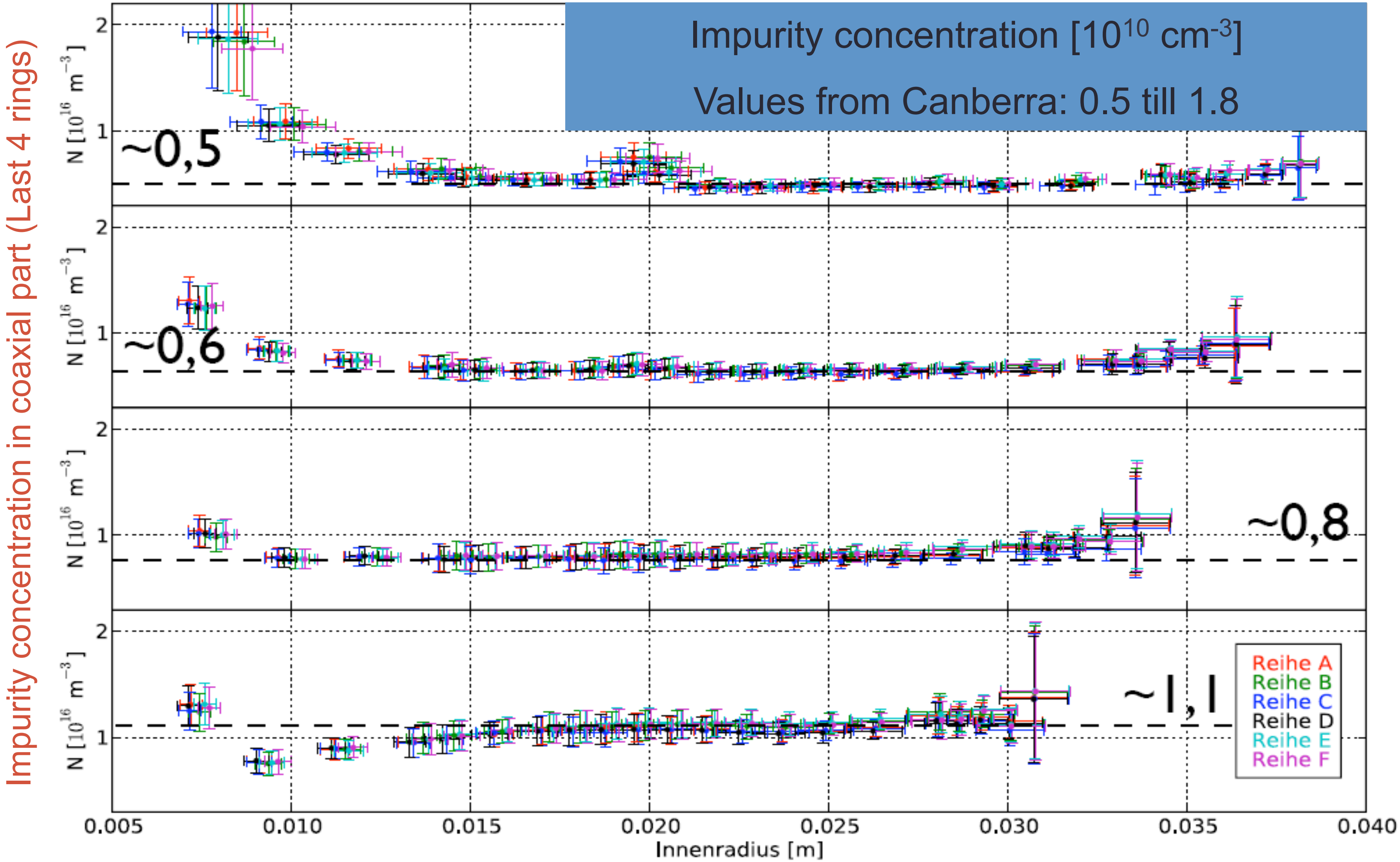
r_{max}~ 2 µm cross section (E=2kV/cm)

l_e ~ 0.2 µm dist. betw. optical phonon emission

Trapping rate (per hole):

$$< \sigma\, v > \propto \frac{v_d}{E}$$

Reconstructed Impurity Profile



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

Values from Canberra: 0.5 till 1.8