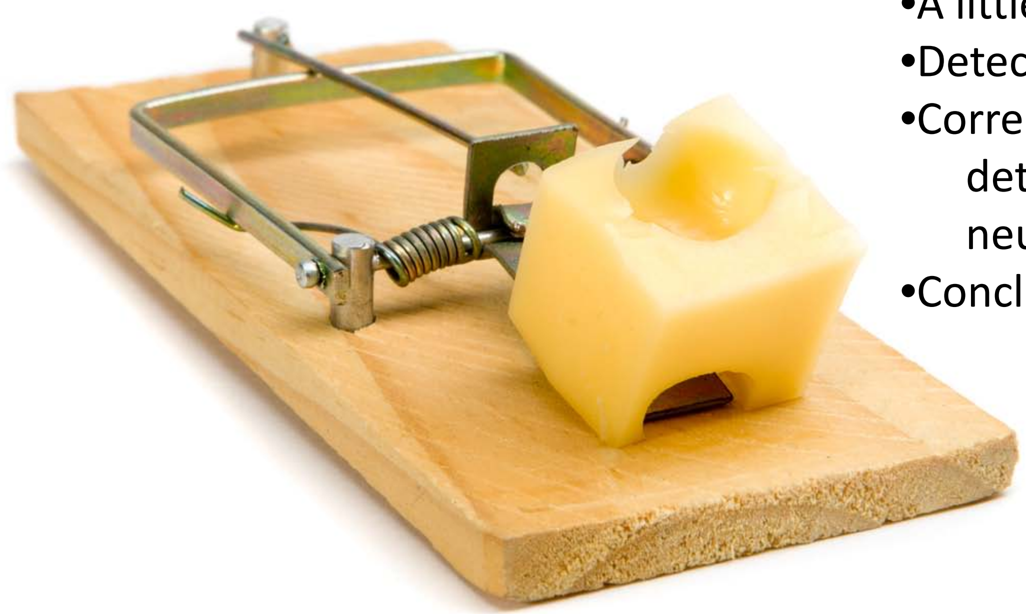
Neutron damage and trapping effects



- Why this talk?
- Trapping cross sections
- A little theory
- Detector "sensitivity" to trapping
- Correction of trapping:
  - detectors w/o damage
  - neutron damaged detectors
- Conclusion & ideas for the future

Analysis by A. Wiens & D. Bazzacco

Bart Bruyneel, Andreas Wiens, Dino Bazzacco

for the AGATA collaboration – 10th AGATA week Lyon, 22-26nov 2010

Why this talk?

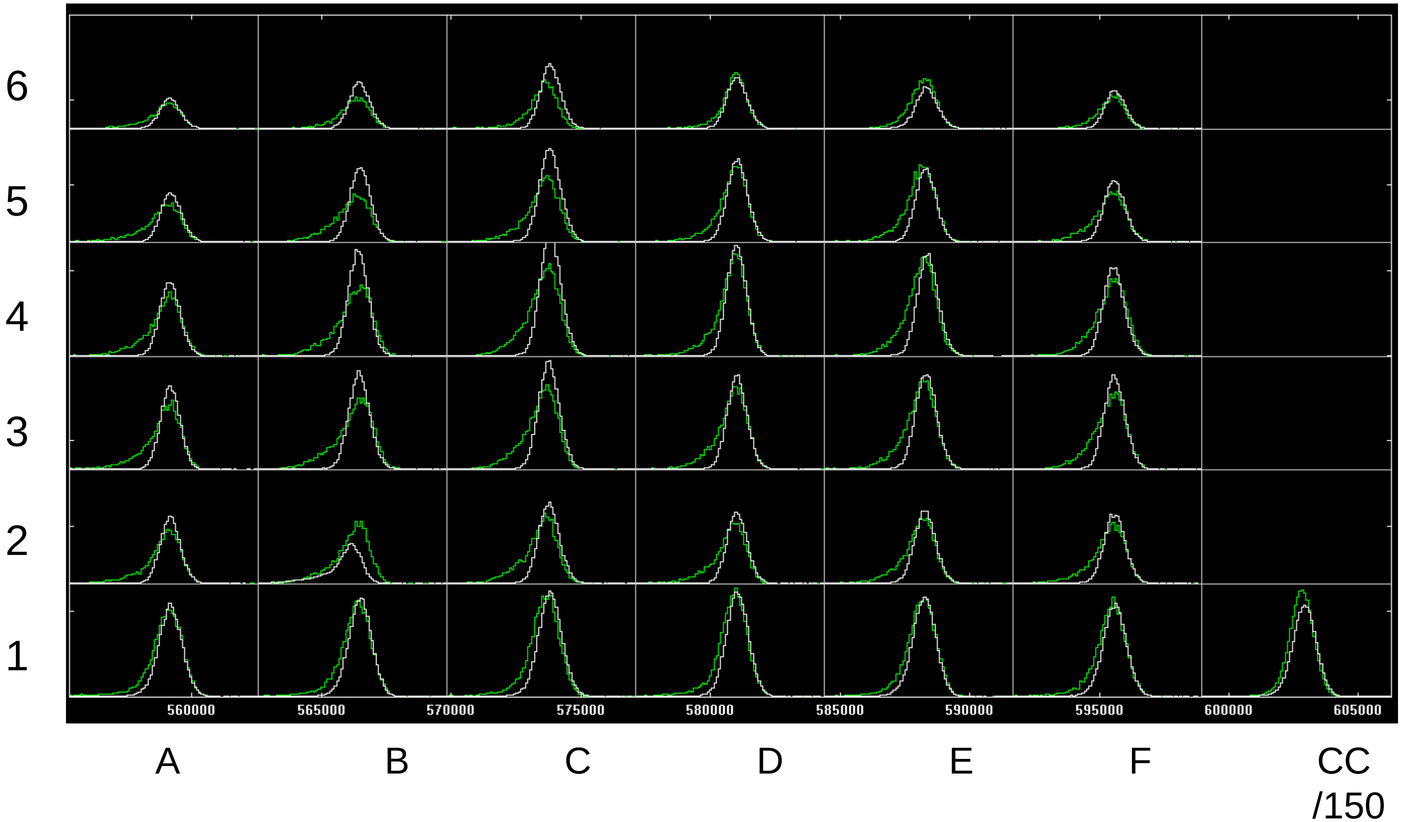
AGATA

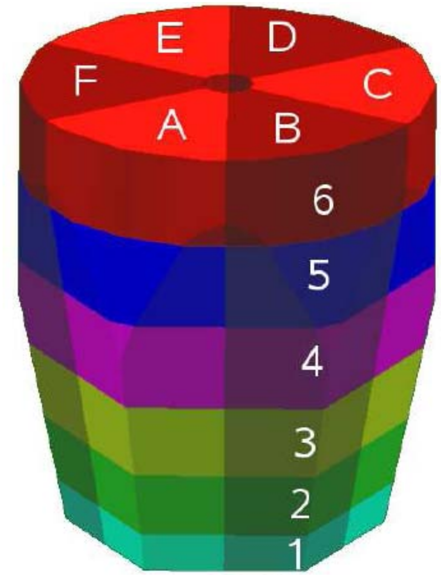
- Large volume detector: large radius = higher sensitivity for trapping
- Segments more sensitive to neutron damage than core (n-type)
- High count rate capability ("Yes, we can…")
- High efficiency … also for neutrons …
- …

Neutron damage is observed

Need a correction to delay annealing

Det. 1B - Shape of the 1332 keV line



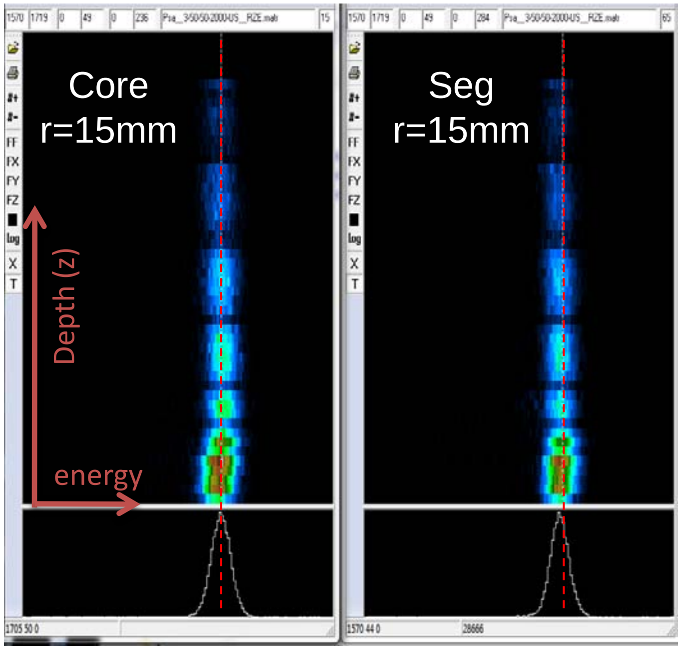


White: April 2010 → FWHM(core) ~ **2.3 keV** FWHM(segments) ~**2.0 keV**
Green: July 2010 → FWHM(core) ~**2.4 keV** FWHM(segments) ~**2.8 keV**
Damage after 3 high-rate experiments (3 weeks of beam at 30-80 kHz singles)

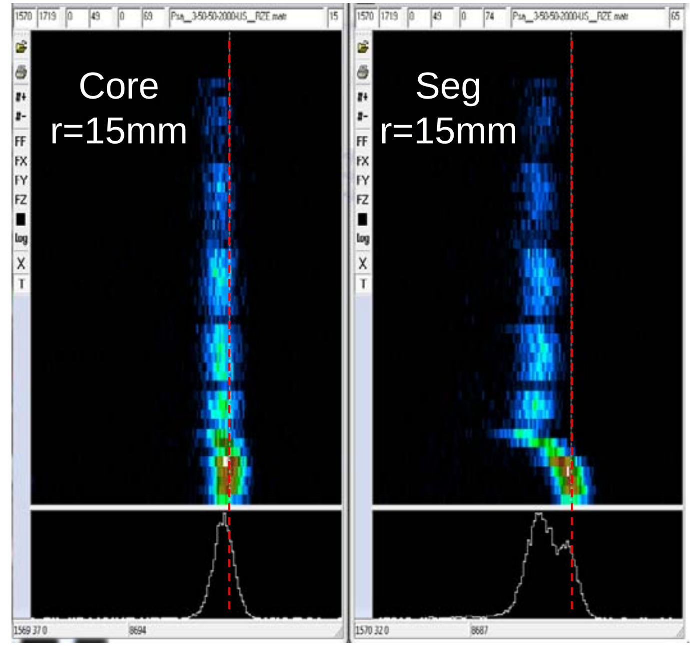
Worsening seen in most of the detectors; more severe on the forward crystals;
segments are the most affected, cores almost unchanged (as expected for n-type HPGe)

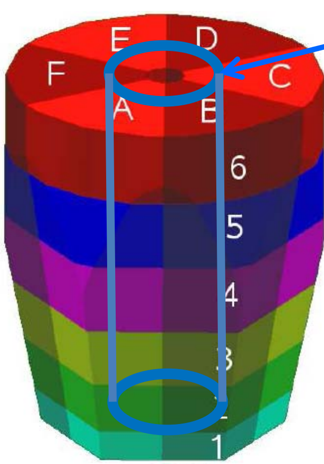
Crystal 1B (C002)

April 2010



July 2010





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

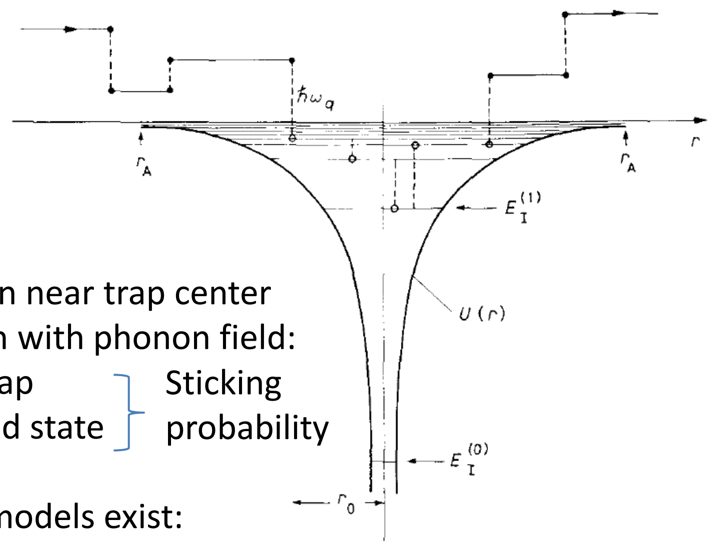
The charge loss due to neutron damage is proportional to the path length to the electrodes. This is provided by the PSA, which is barely affected by the amplitude loss.

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

Trapping cross sections

L. Reggiani – Rev. del Nuovo Cimento 12 nr 11 (1989)

Most popular is model by Lax:
Cross sections are **velocity** dependent



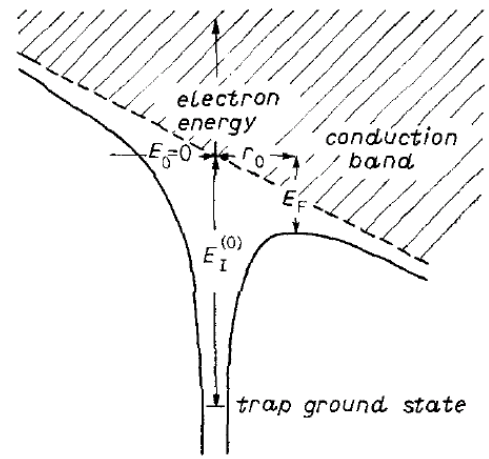
Lax: cascade model

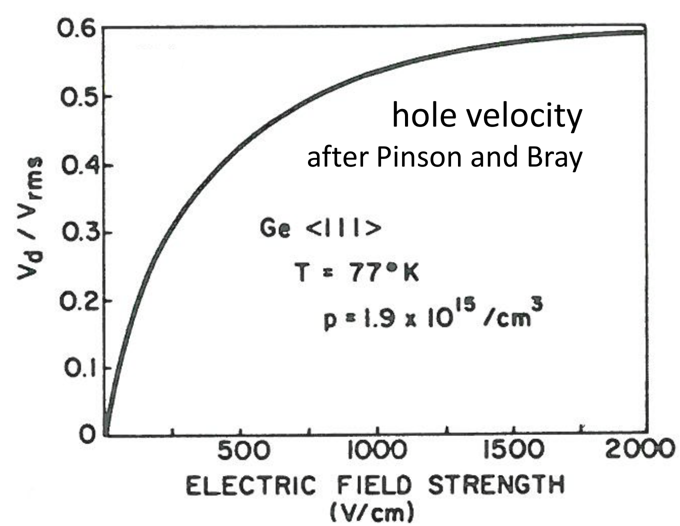
1) electron emits phonon near trap center
2) electron in interaction with phonon field:
   - or: struggles out of trap
   - or: collapses to ground state

} Sticking probability

But also other (recent) models exist:
e.g. L. S. Darken – PRL 69 (1992) 19 p 2842

Cross sections are **field dependent** -
e.g. Poole – Frenkel effect





$$< \sigma v > \propto E^x < v^y >$$

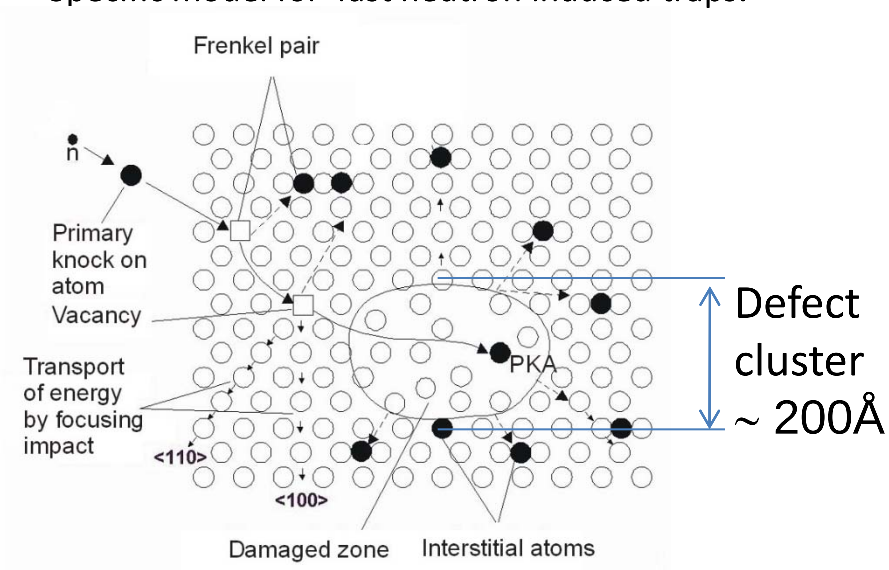
- data on <v^y> basically not existing
- difficult to know which model to use

only data →

Trapping cross section: neutron damage specific

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

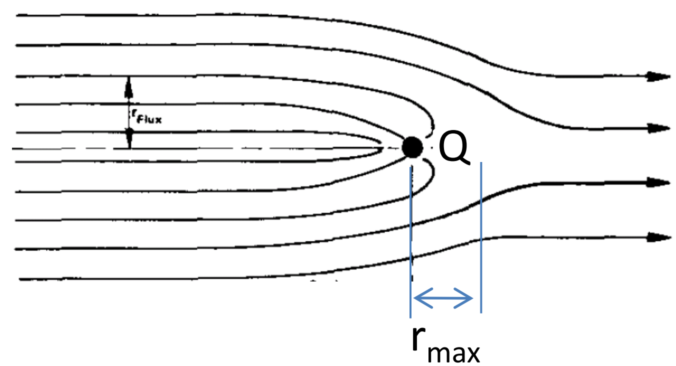
Specific model for fast neutron induced traps:



Cross section from field line disturbance:

Balance between E field and Coulomb force:

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



Assumptions:

- 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

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

Some theory: collection efficiency

T.W. Raudorf, R. H. Pehl – NIM A 255 (1987) 538-551

- 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

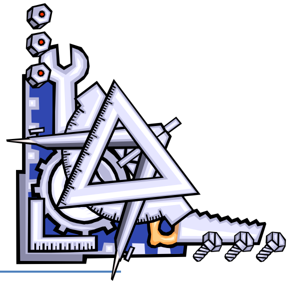
- Total collection efficiency for electrode "i" at position x_0 :

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

$$\simeq \phi_i(\vec{x}_0) + [1 - \phi_i(\vec{x}_0)] \cong 1$$

Partial collection efficiencies mainly report on weighting potential

Trapping sensitivity*



(*personal definition – don’t google!)

•DEFINITION: electron / hole sensitivity of electrode i to trapping

$$s^i_{e,h} = \frac{d\eta^i_{e,h}}{dN_t}\Big|_{N_t=0}$$

= fraction missing due to trapping
+ induced charge due to trail of trapped charges

•Relation to total collection efficiency:

$$\eta^i_{tot}(\vec{x}_0) = 1 + \left[N_e s^i_e(\vec{x}_0) + N_h s^i_h(\vec{x}_0)\right] + O(2)$$

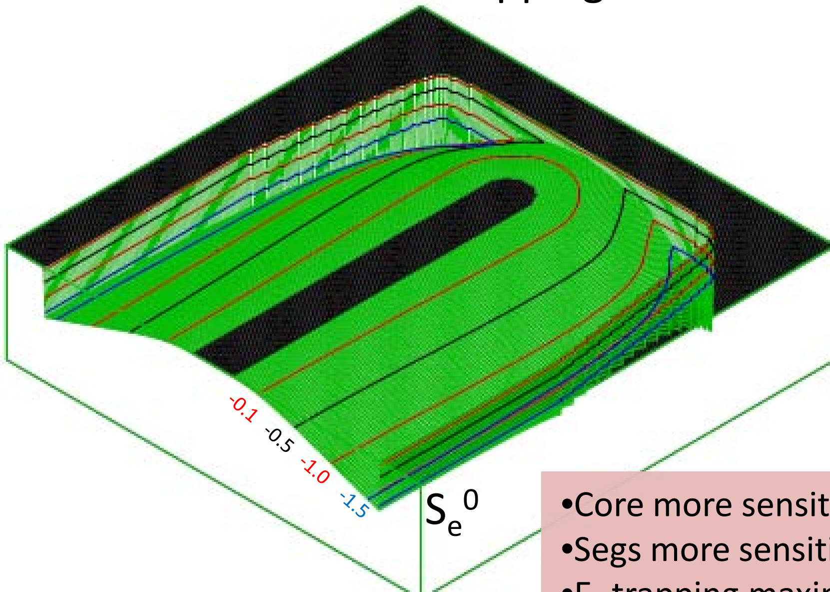
•Ne : density of electron traps, Nh: density of hole traps
•O(2) – higher order terms in taylor expansion - negligible
•sensitivities can be calculated in advance
•Ne, Nh are fit parameters

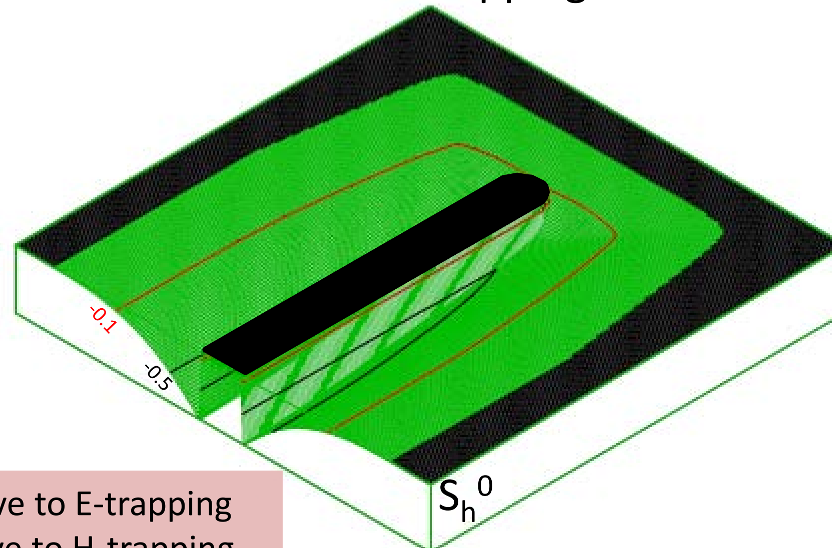
Sensitivity $s^{i}_{e,h}$

To electron trapping

To hole trapping

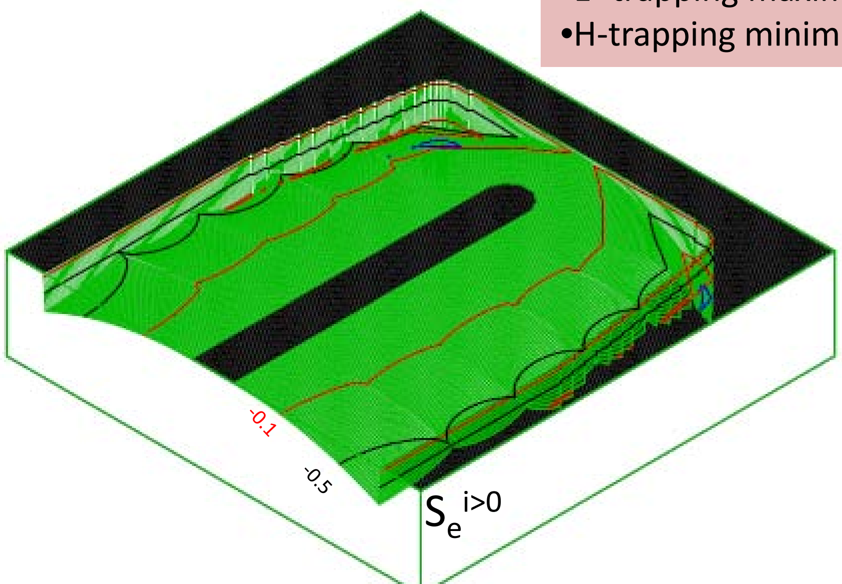
For Core

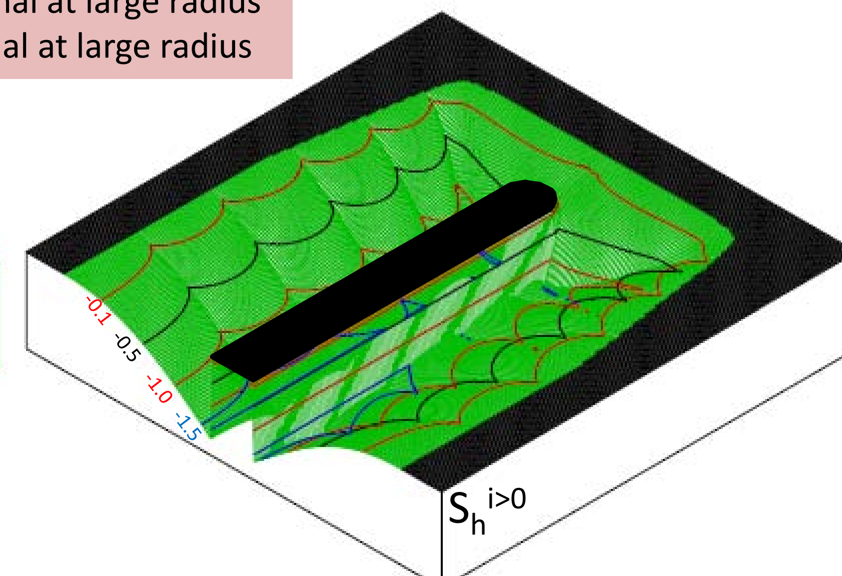




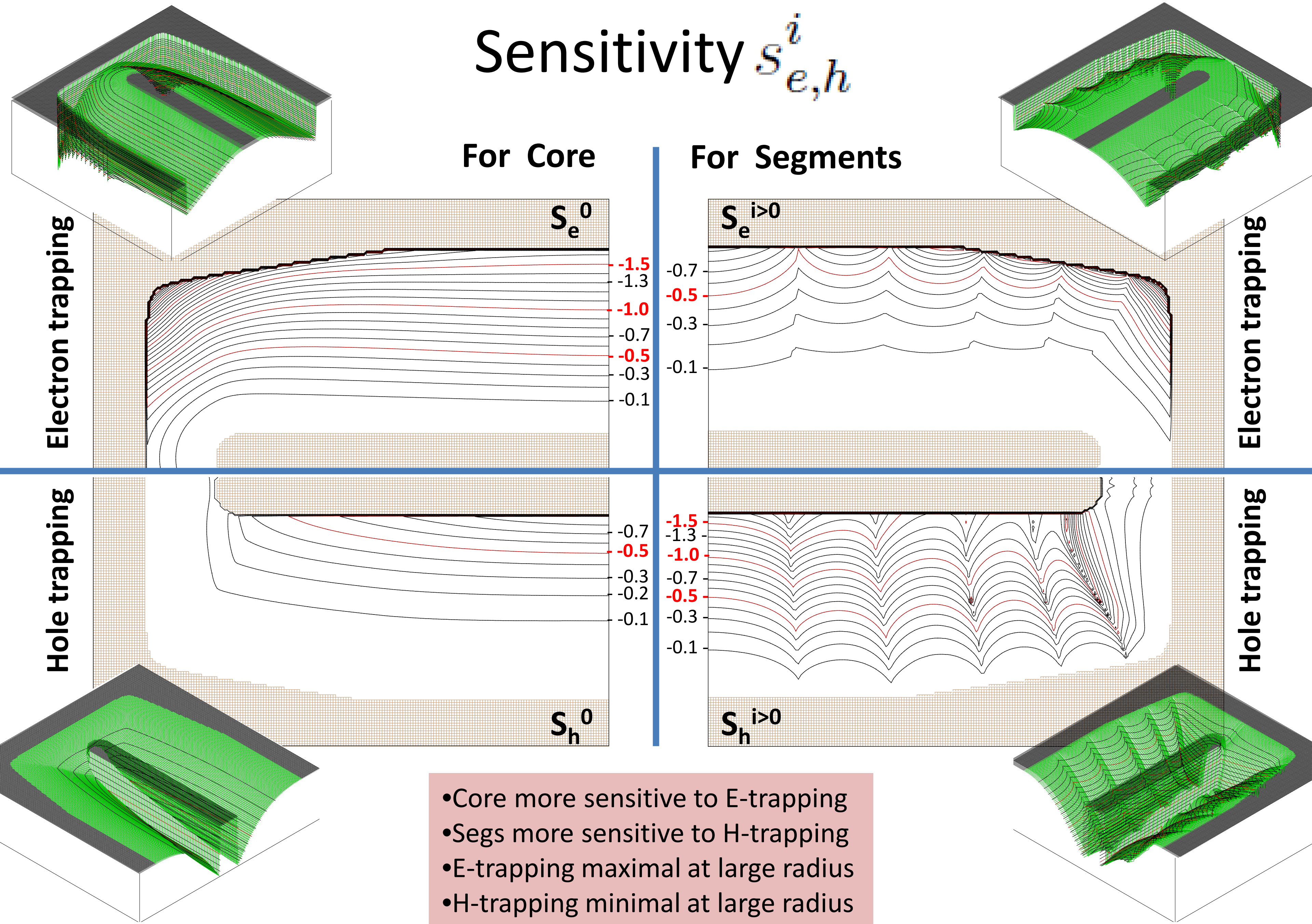
- Core more sensitive to E-trapping
- Segs more sensitive to H-trapping
- E- trapping maximal at large radius
- H-trapping minimal at large radius

For Segments





Sensitivity $s^i_{e,h}$

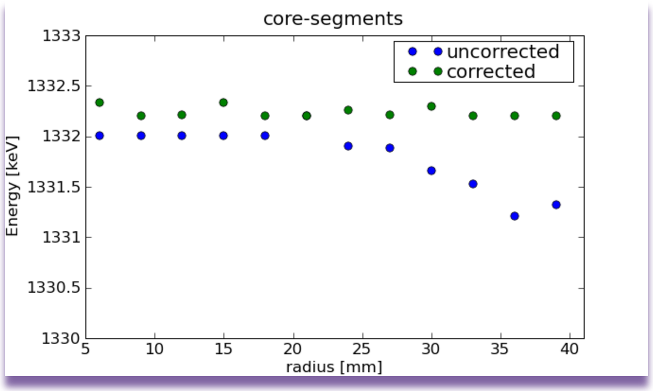


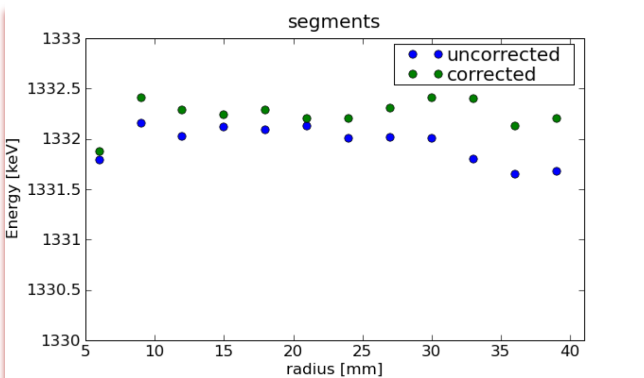
- Core more sensitive to E-trapping
- Segs more sensitive to H-trapping
- E-trapping maximal at large radius
- H-trapping minimal at large radius

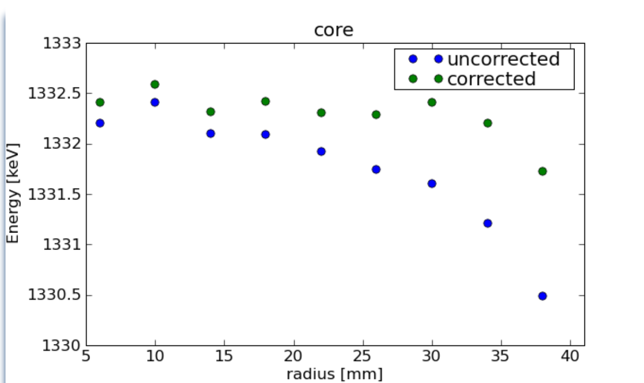
Trapping in new detectors

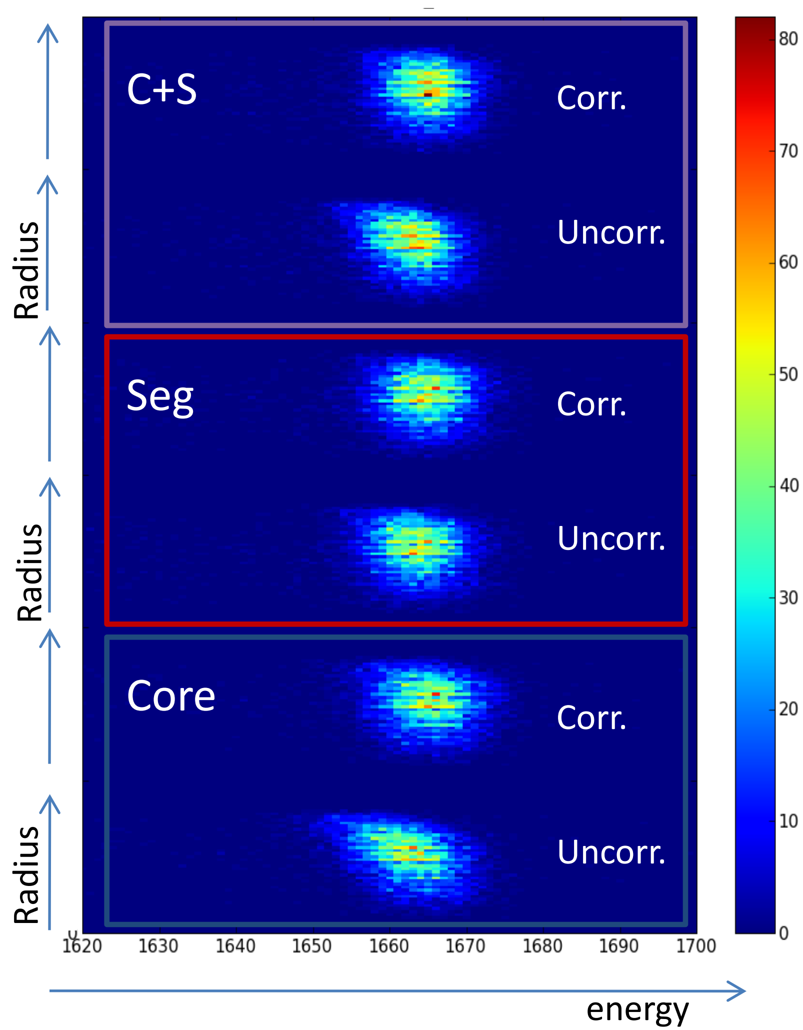
(A. Wiens)

- Electron trapping present in any detector
- Source of scattering on Fano factors



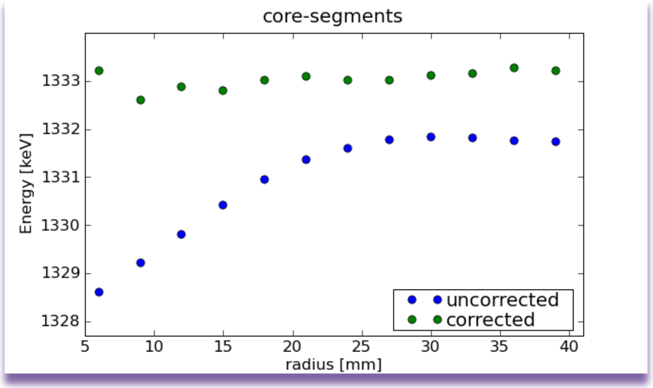


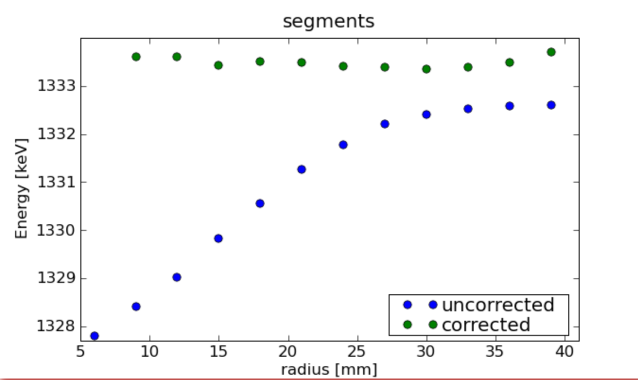


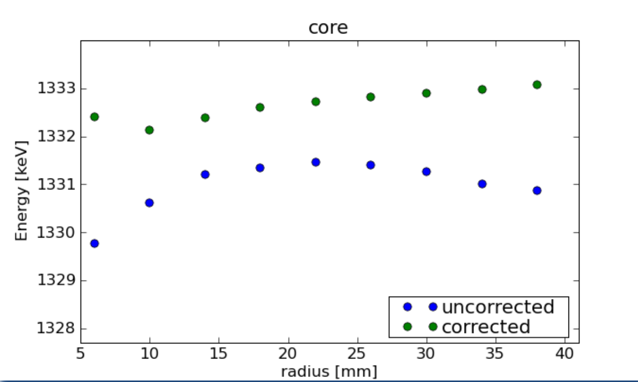


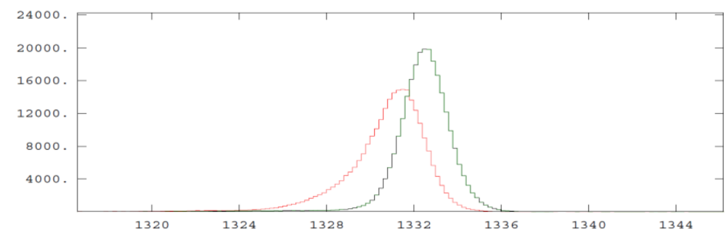
FWHM 1.3MeV	FWTM / FWHM
1.80	1.85
1.87	1.85
1.93	1.86
1.98	1.83
2.12	1.81
2.25	1.83

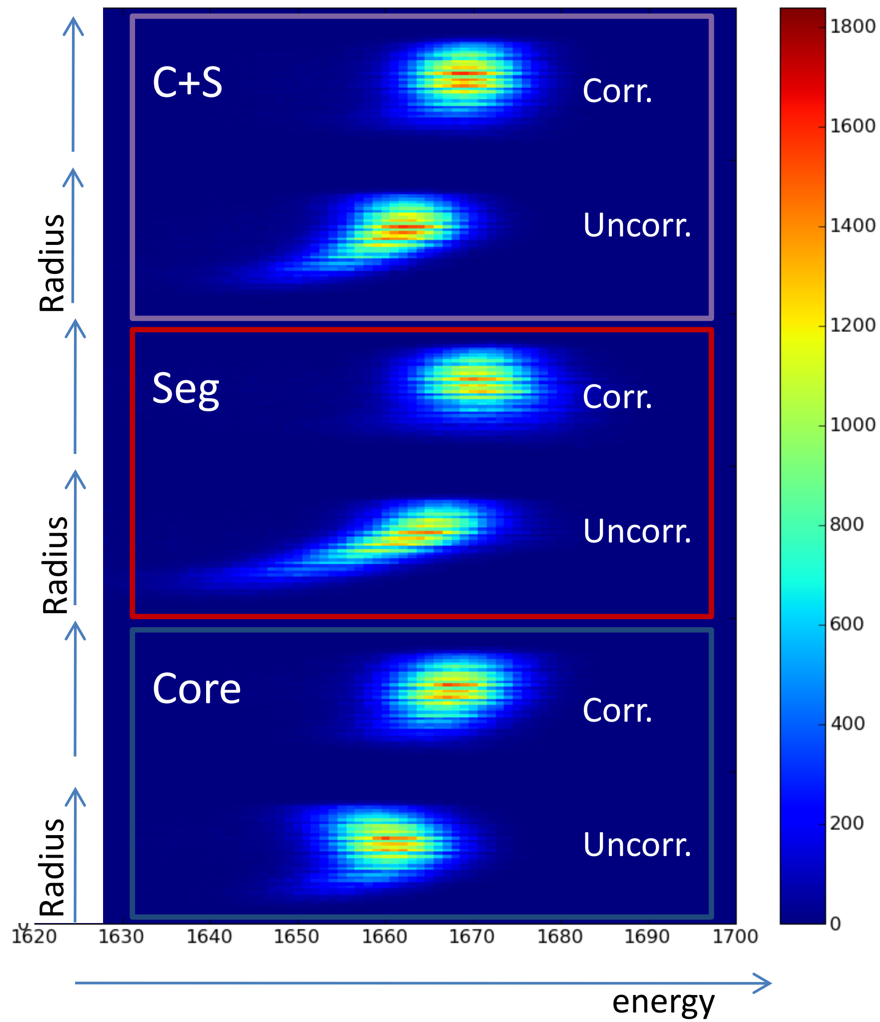
Correction of neutron damage









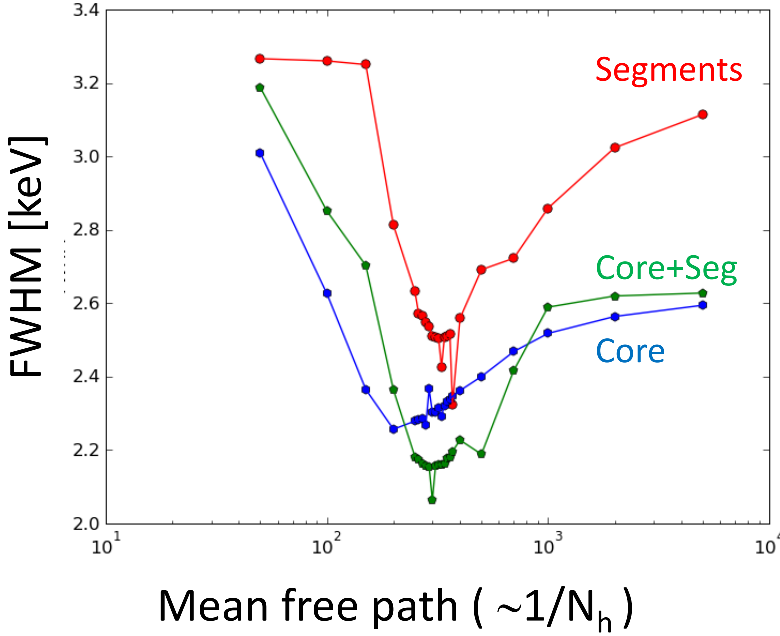


FWHM 1.3MeV	FWTM / FWHM
2.06	1.91
2.44	1.83
2.51	1.83
2.88	2.34
2.30	1.83
2.34	1.83

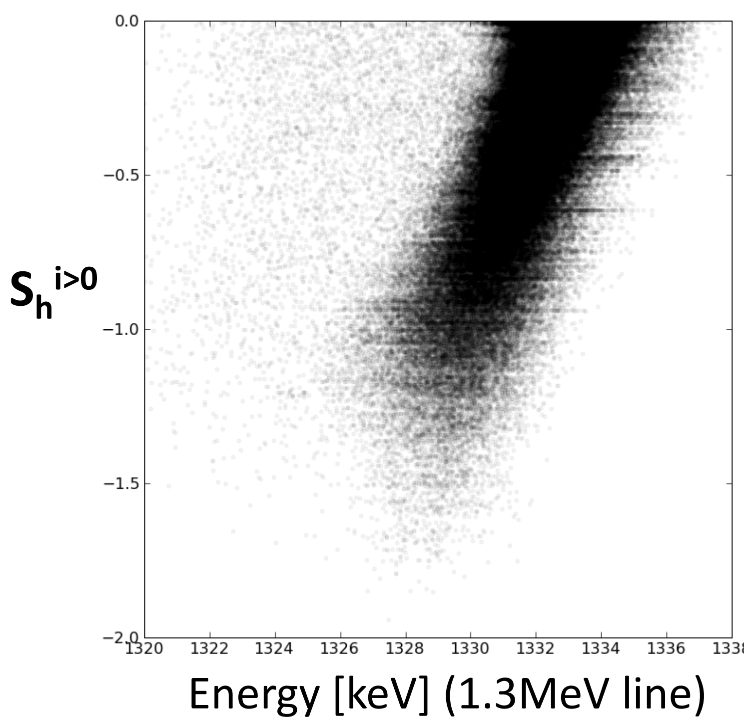
Correction of neutron damage

$$\eta^i_{tot}(\vec{x}_0) = 1 + \left[N_e s^i_e(\vec{x}_0) + N_h s^i_h(\vec{x}_0)\right]$$

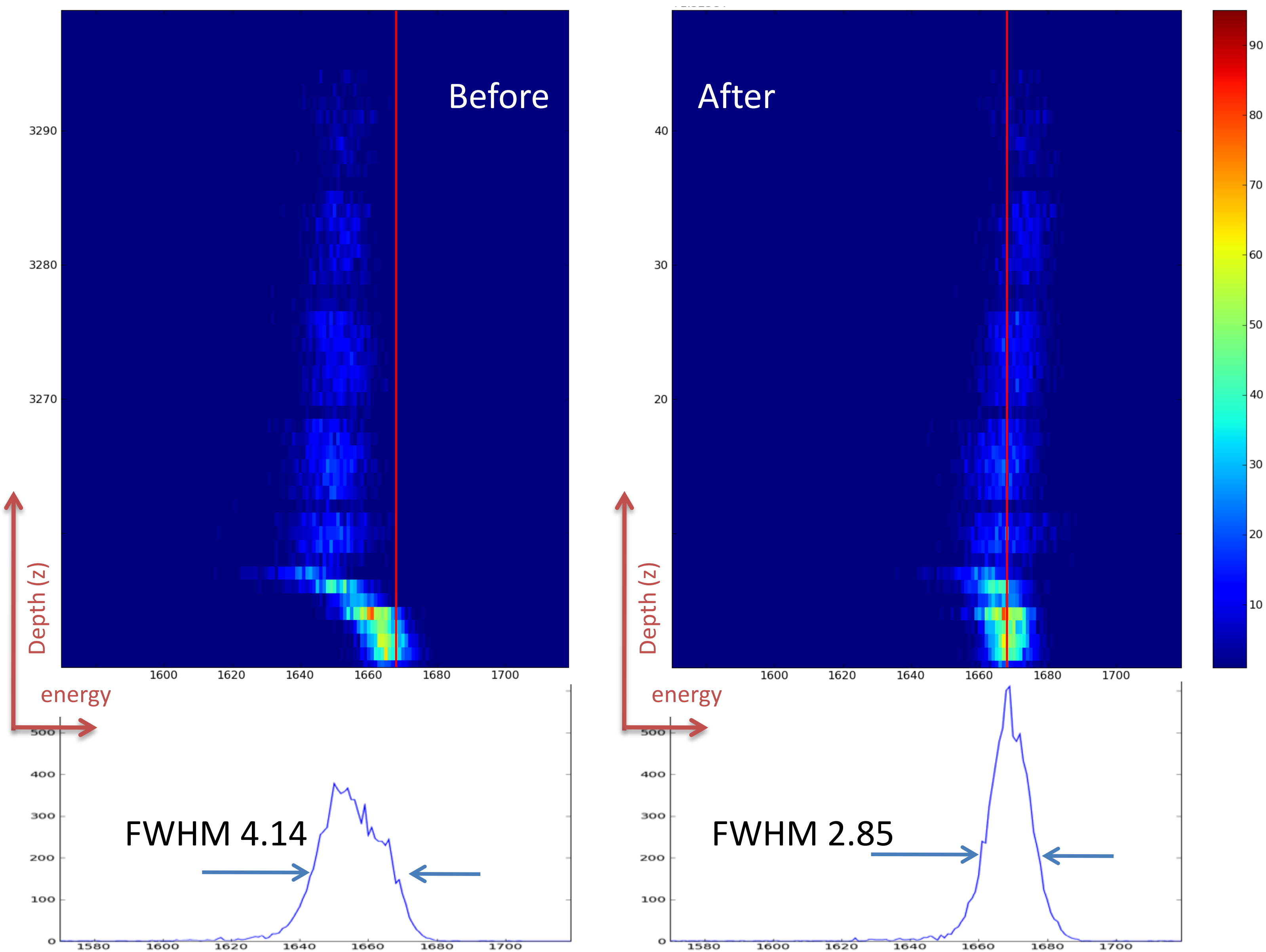
• N_e fixed, Scan for N_h :



Segment $S_h^i(x)$ vs energy:



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



Conclusion & ideas for the future

•AGATA : best data ever to investigate trapping!

•Neutron damage confirms PSA principle
(and PSA works also in neutron damaged detectors)

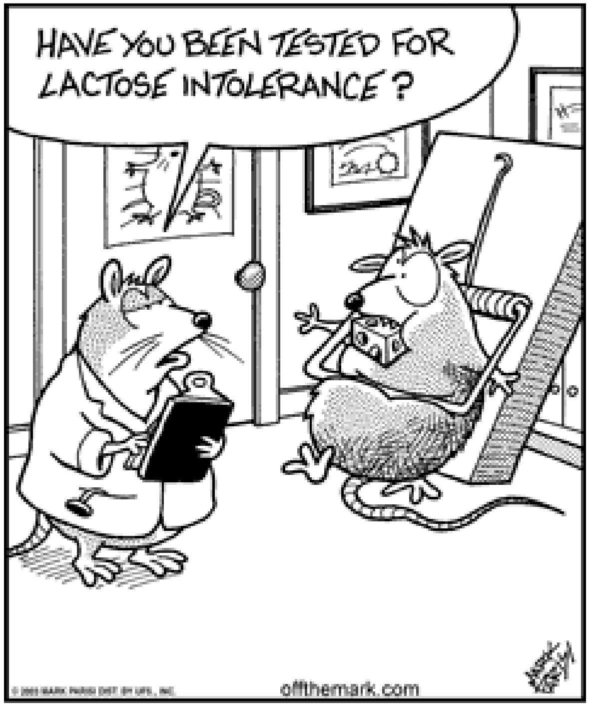
•First results promising with simple assumptions
→simple 2 parameter fit

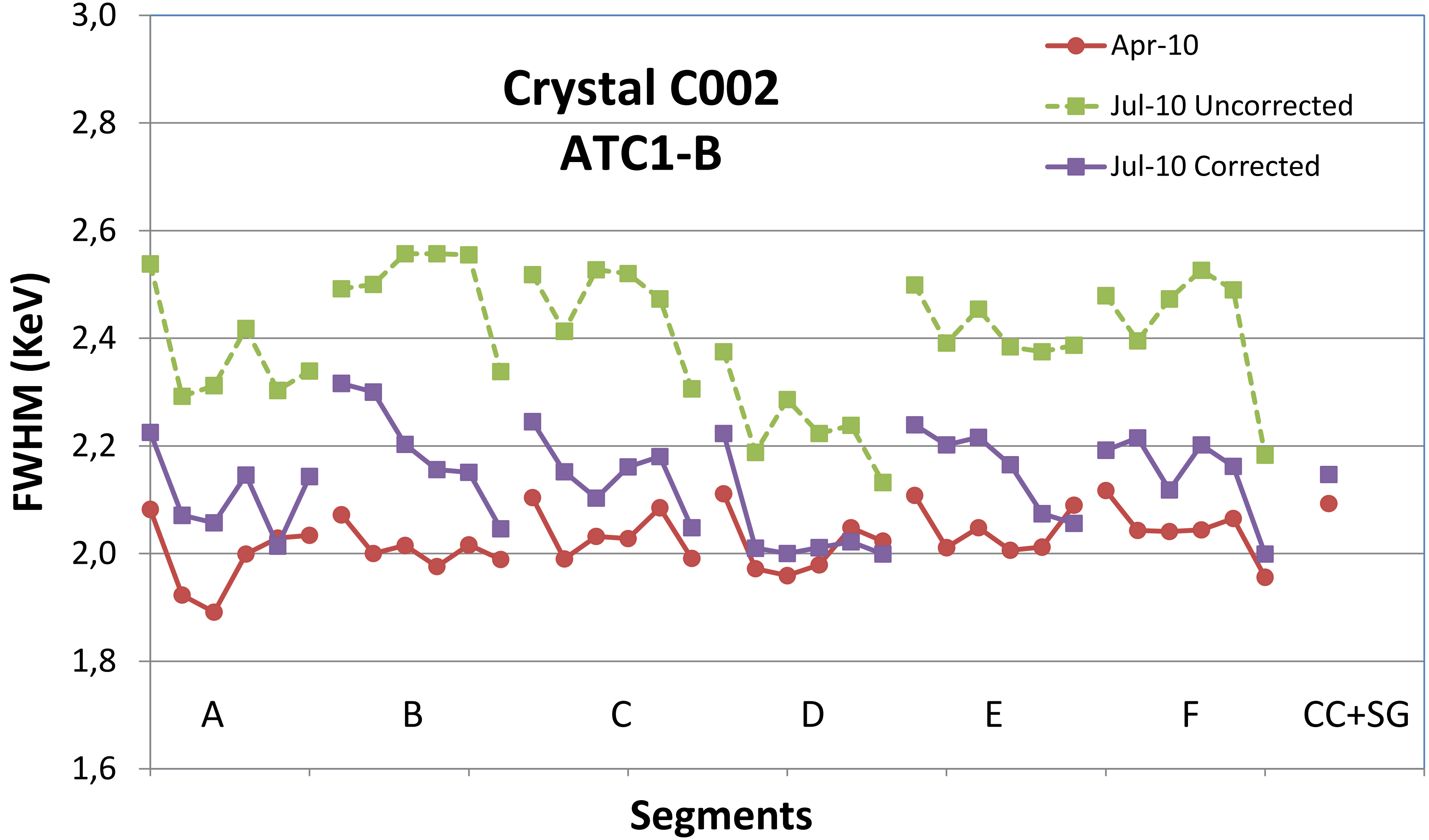
•N_t assumed homogeneous in detector
→CV measurement for determination of trap distributions?

•"grilling" less effective near core?
→Equilibrium charge states of traps vs position?

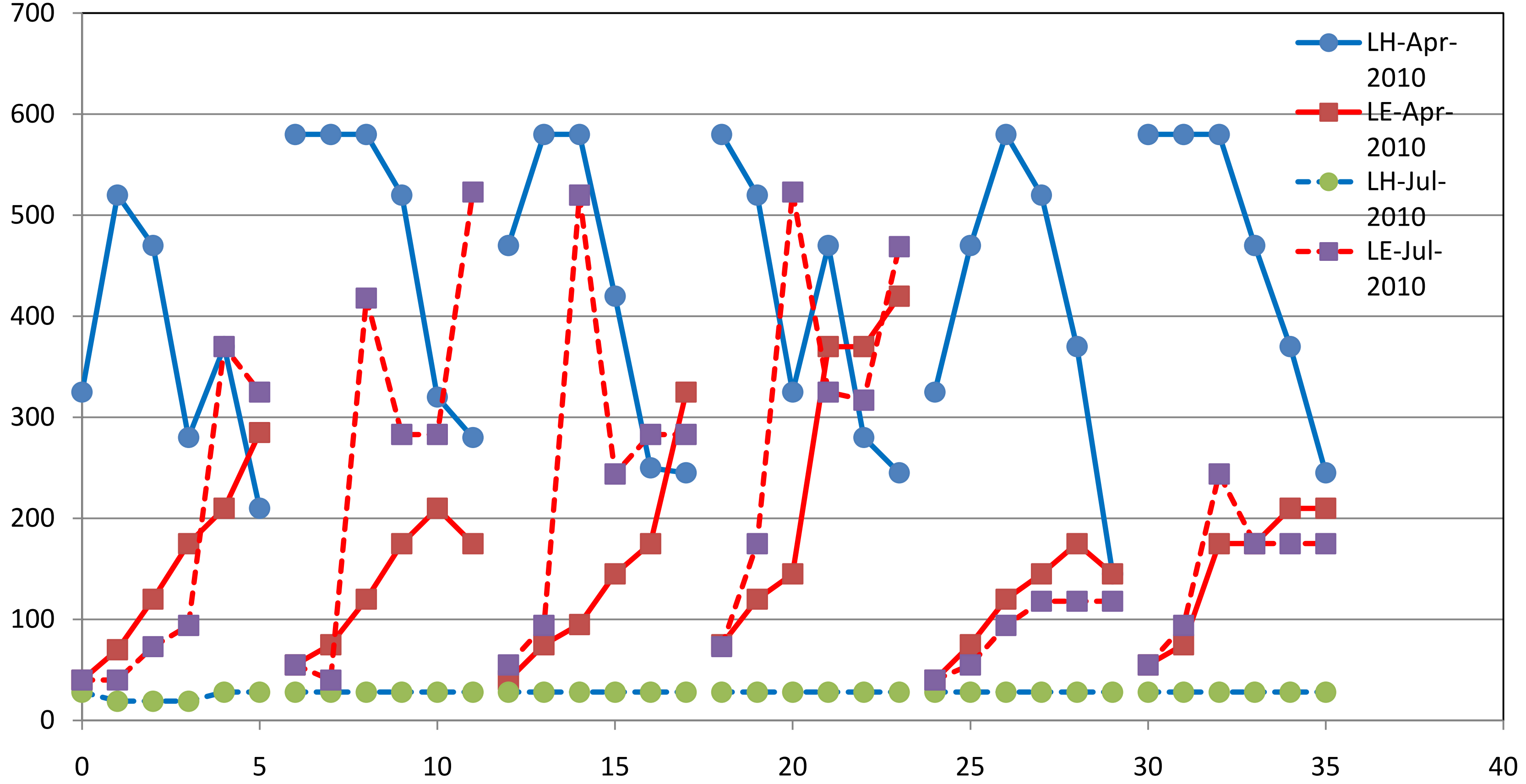
•Better descriptions $< \sigma\, v > \propto E^x < v^y >$?

•Field dependence investigation
→ Investigations as function of bias voltage?





Crystal C002
ATC1-B
Apr-10
Jul-10 Uncorrected
Jul-10 Corrected
FWHM (KeV)
3,0
2,8
2,6
2,4
2,2
2,0
1,8
1,6
A
B
C
D
E
F
CC+SG
Segments


LH-Apr-2010
LE-Apr-2010
LH-Jul-2010
LE-Jul-2010
700
600
500
400
300
200
100
0
0
5
10
15
20
25
30
35
40