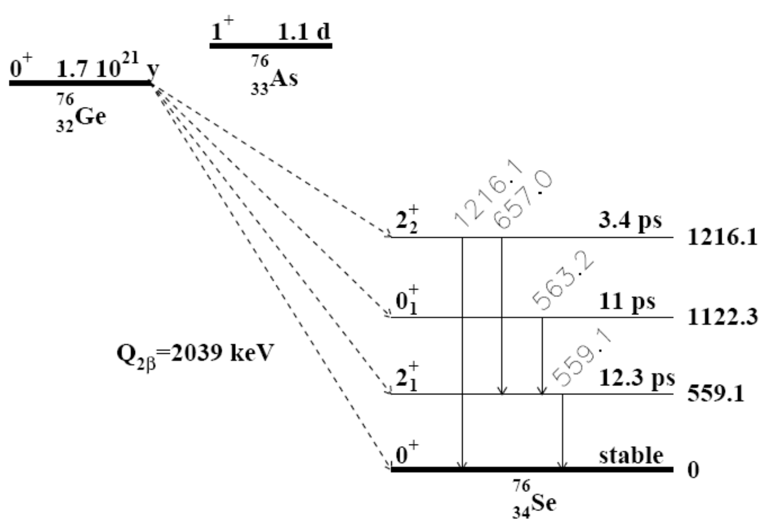
Characterization of BEGe detectors in GERDA

C.M. Cattadori- INFN-Milano Bicocca

for the BEGe GERDA WG

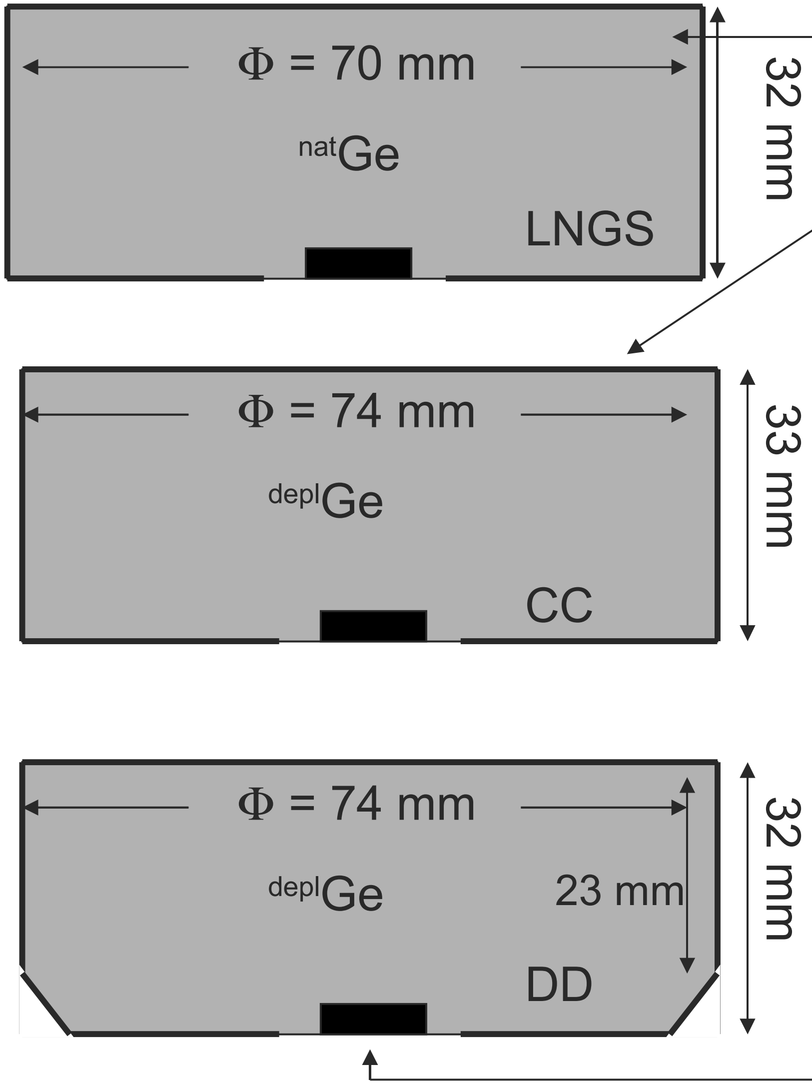
M. Agostini, E. Bellotti ,L. Baudis, D. Budjas, A. Caldwell, C.M.Cattadori, A. Di Vacri, V. Kornoukhov, A. Garfagnini, P. Grabmayer, M. Hult, J.Jochum, M.Laubenstein, L. Pandola, G. Pivato, S. Schoenert, M. Tarka, C. Ur, K. Zuber



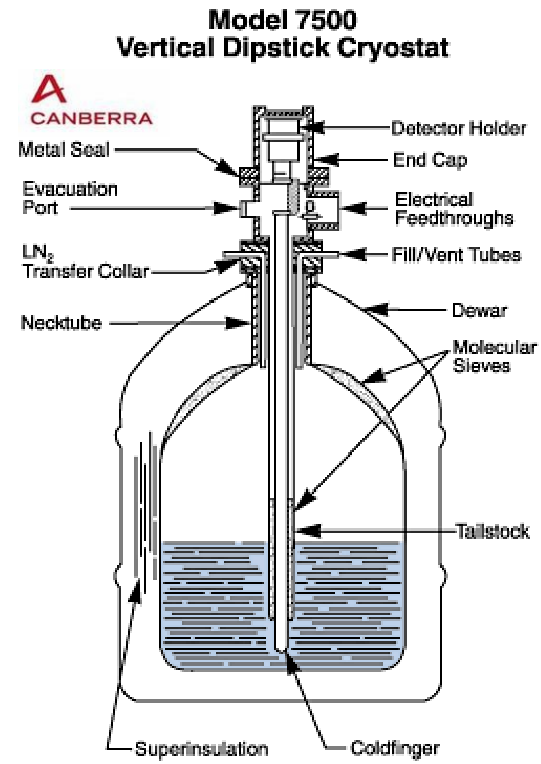
Outline

- Characterization of 3 Canberra BEGe detectors
  - The detectors
  - The ^{depl}BEGe detectors
  - Energy Resolution & Linearity
  - Count rate vs HV
  - The dead layer determination
  - Average pulses and RT distributions
  - Single Site Events/ Multi Site Events Pulse Shape Discrimination
- Comparison and discussion of the results of the 6 BEGe detectors tested so far in GERDA.

The detectors

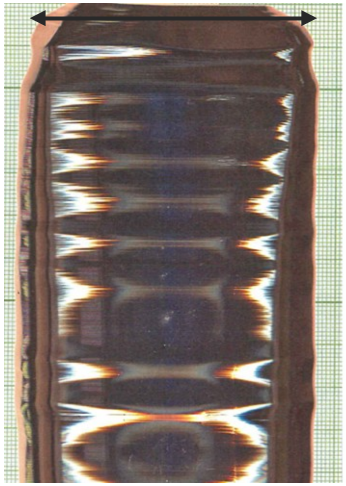


- P-type HPGe
- Li-drifted, n+, wrap around contact for HV+.
- p+ B implanted at bottom center for Readout electrode.



^{depl}BEGe

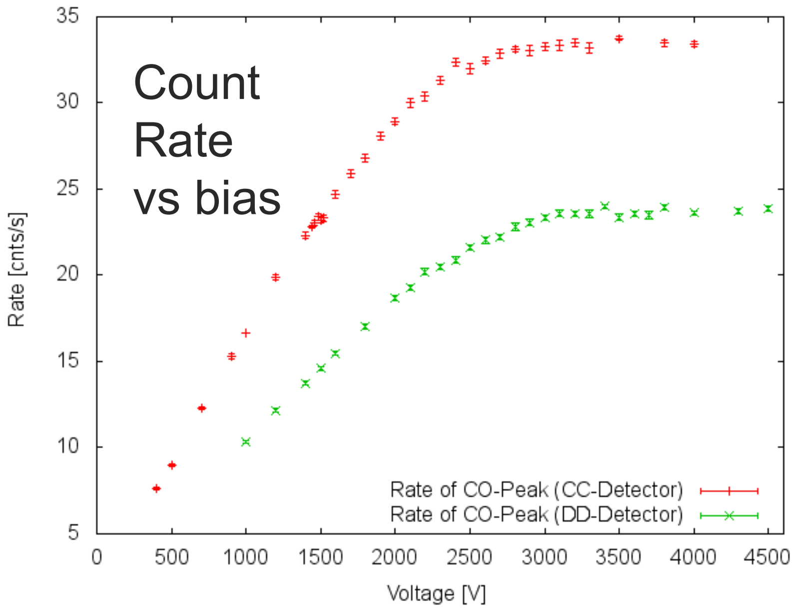
- Since 2009 GERDA is pursuing with Canberra an R&D for the production and characterization of BEGe detectors from ^{depl}Ge from ECP plant then refined & reduced to metal @ PPM (21.5 kg) → same origin and chemical purification "history" of 37.5 kg ^{enr}Ge.
  - Canberra Oak Ridge for x-tal pulling. Industrial process discussed and modified to minimize the Ge wastes
  - Canberra Olen for detector production
- 4 p-type x-tal ingots pulled in 2009.
- 2 ^{depl}BEGe made out from the x-tals and then characterized by GERDA collaboration so far (in hands since april 2010)
- 2 -3 more detectors will be produced & tested

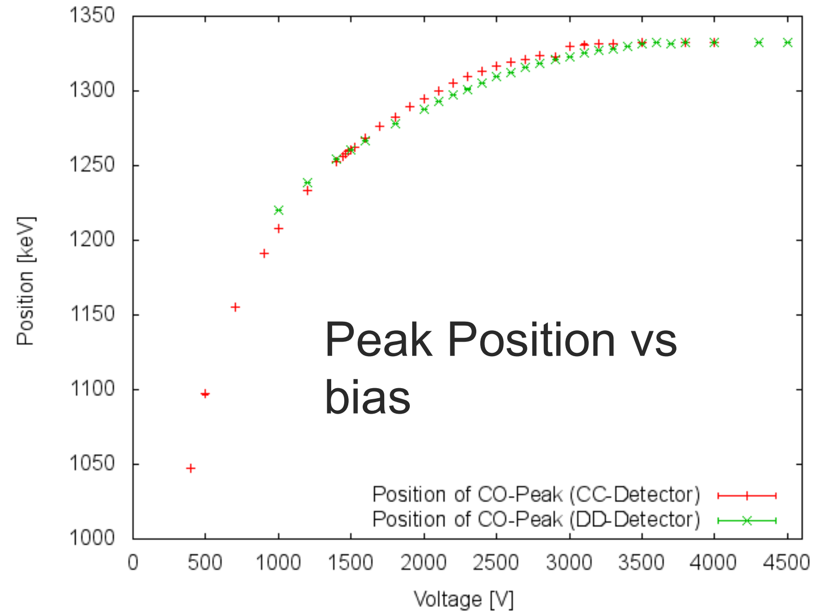


Purpose of the R&D:

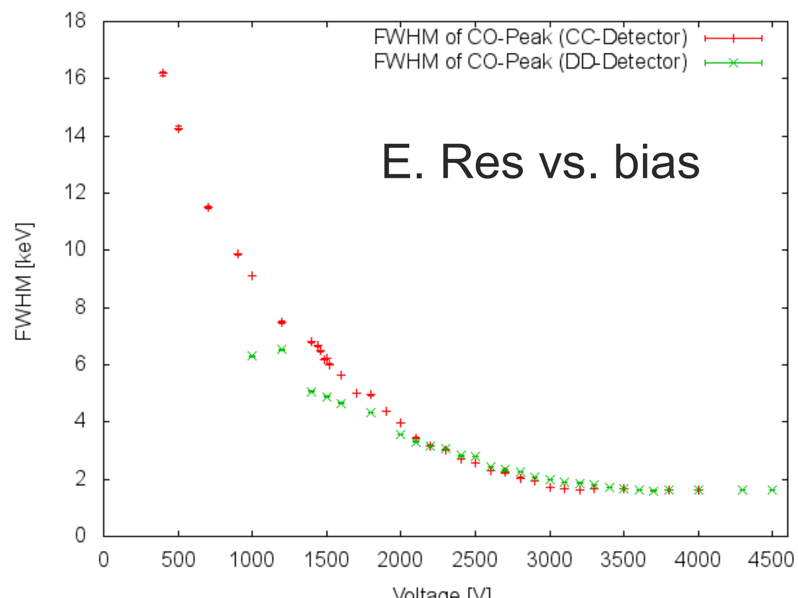
- Demonstrate that the ECP/PPM material is good for Ge HP
- Qualify the industrial procedure, modified to maximize

HV scanning of the two ^{depl}BEGe by ^{60}Co source

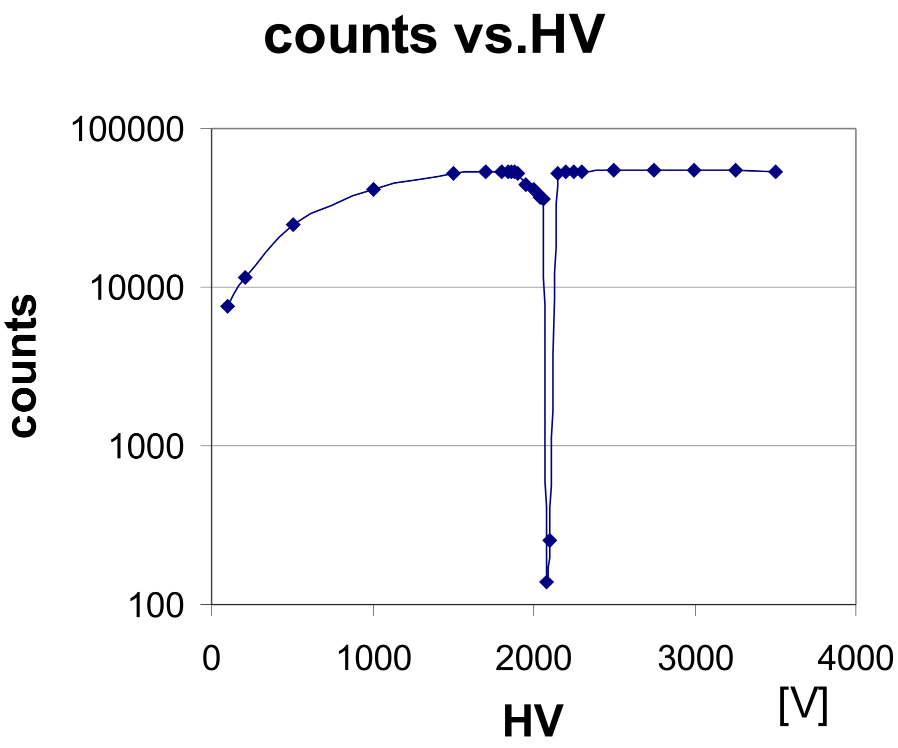


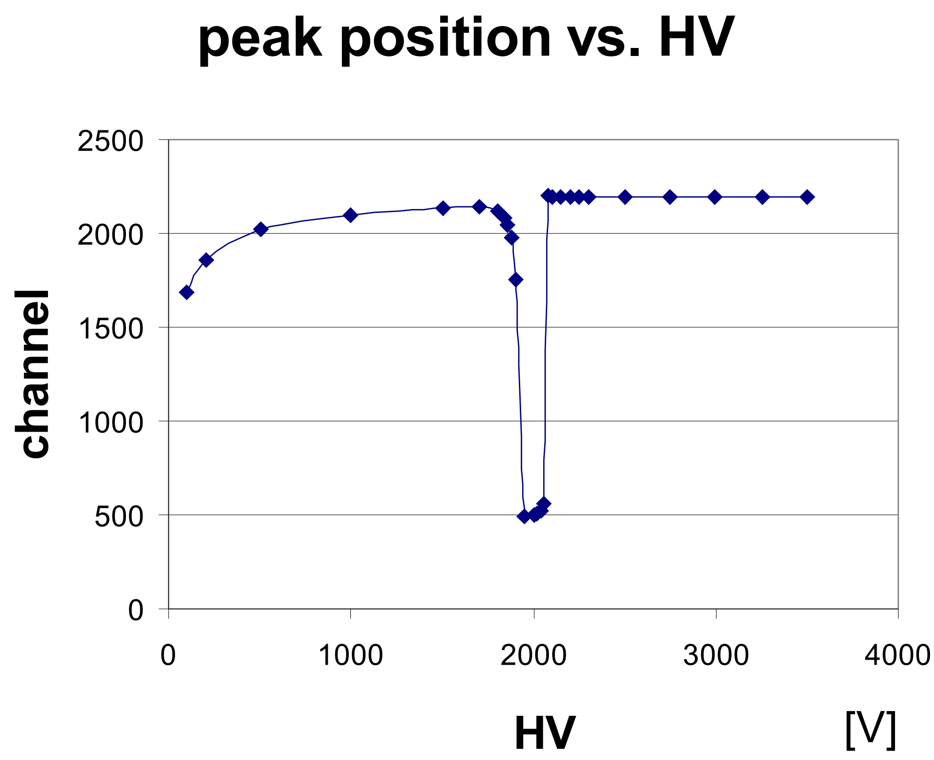


→ Standard behaviour



HV scanning of the $^{nat}BEGe_{LNGS}$ by ^{137}Cs source

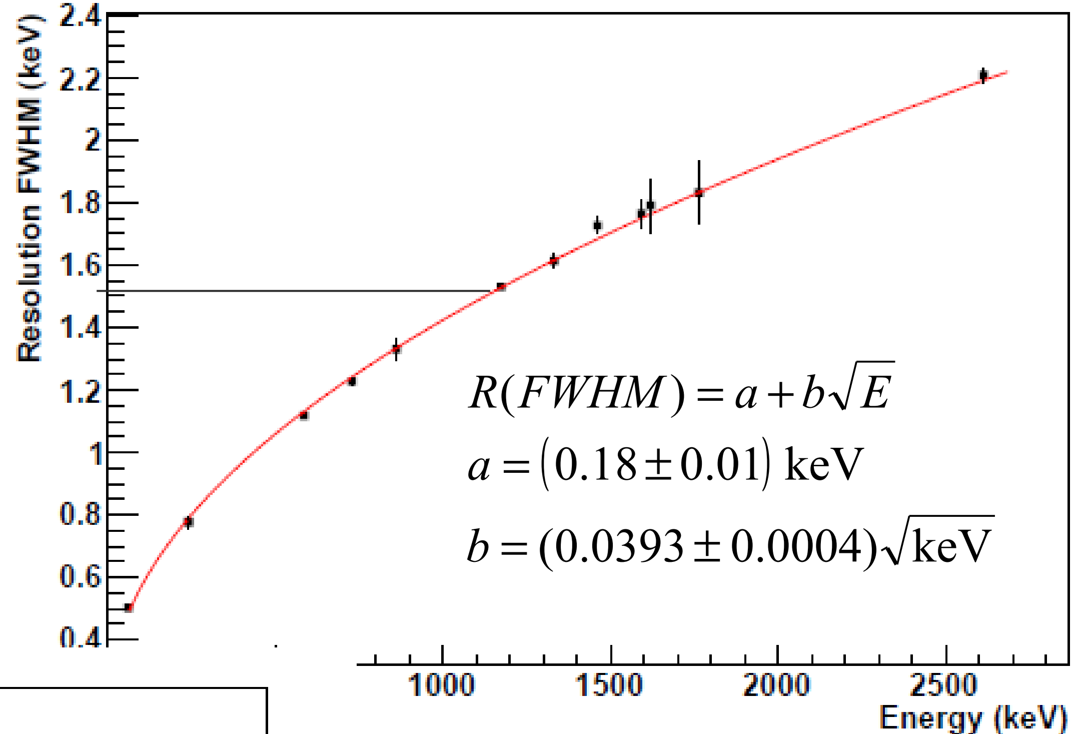


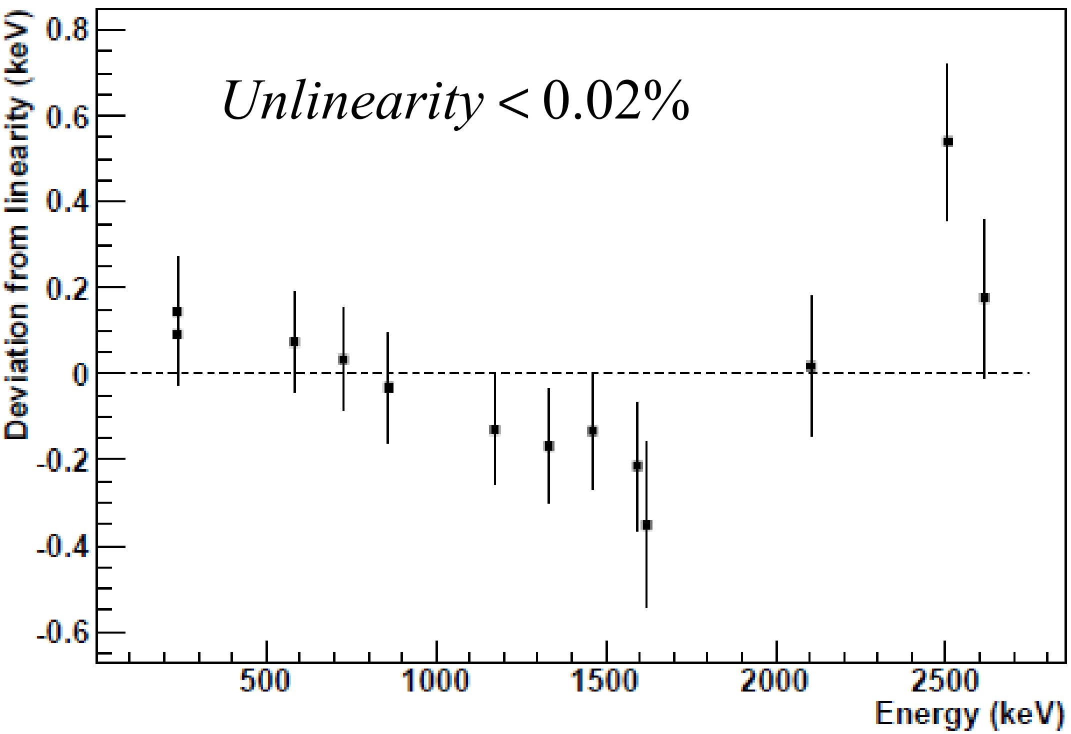


- Peculiarity shows up @ ~ 2000 V, in CR curves.
- Not an artefact
- Studied carefully (explanation in extra slides, please ask question!)

Resolution & Linearity of the ${}^{nat}BEGe_{LNGS}$ detector

At the bias operational V (3500 V) Resolution and Linearity have been carefully studied irradiating with ${}^{241}Am$, ${}^{137}Cs$, ${}^{60}Co$, ${}^{228}Th$ sources.





R= 500 eV @ 60 keV

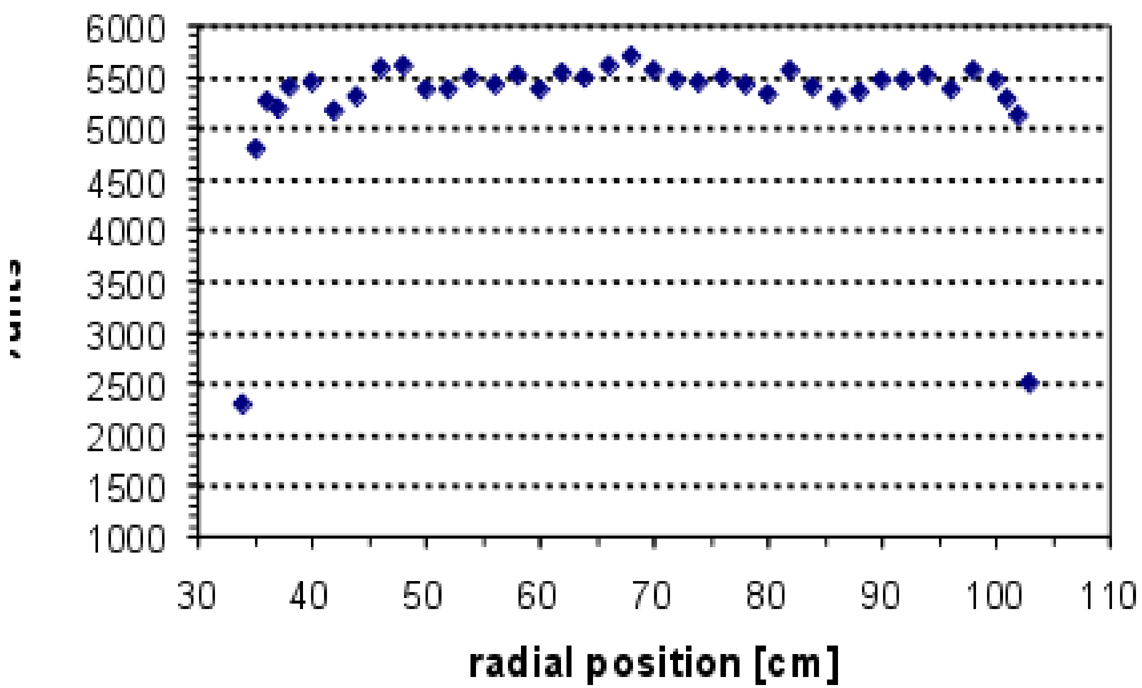
R=1.56 keV @ 1.332 MeV (6 µs shaping time)

R (pulser)=

Standard, excellent behaviour

Determination of the active volume of the $^{nat}BEGe_{LNGS}$ (70 x 32 mm)

- By top radial and lateral axial scanning with ^{241}Am source (425 kBq)
- The estimated
  - diameter of the active volume is ~ 69 mm.
  - height of the active volume is ~ 29 mm.



Dead Layer (DL) thickness determination for the $BEGe_{LNGS}$

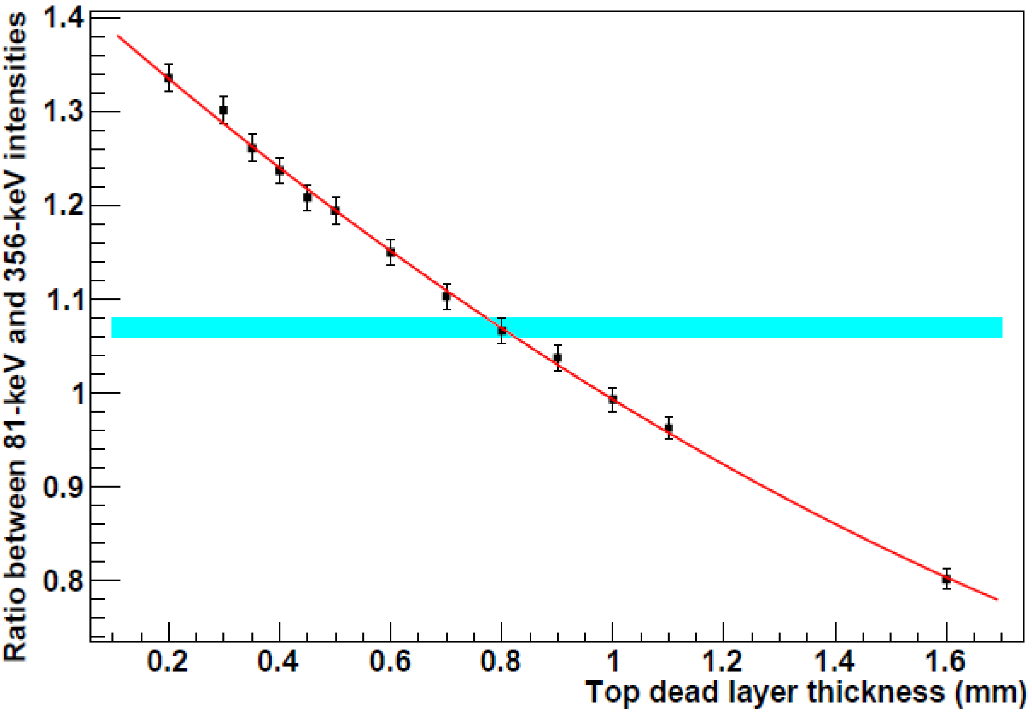
- The average thickness of the DL is derived by the ratio of the intensities of the 81 keV and 356 keV γ-lines of a ^{133}Ba 125 kBq source

- The DL thickness on the top of the detector, which is necessary to reproduce the experimental ratio

R = 1.07±0.01

is

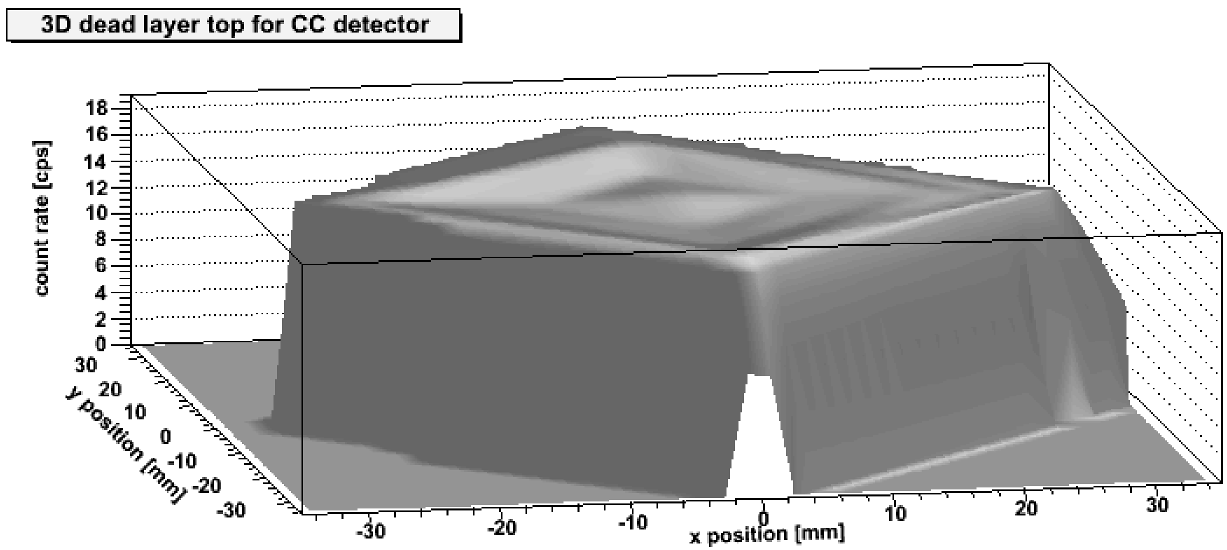
(0.79 ±0.03 stat ± 0.9 syst) mm

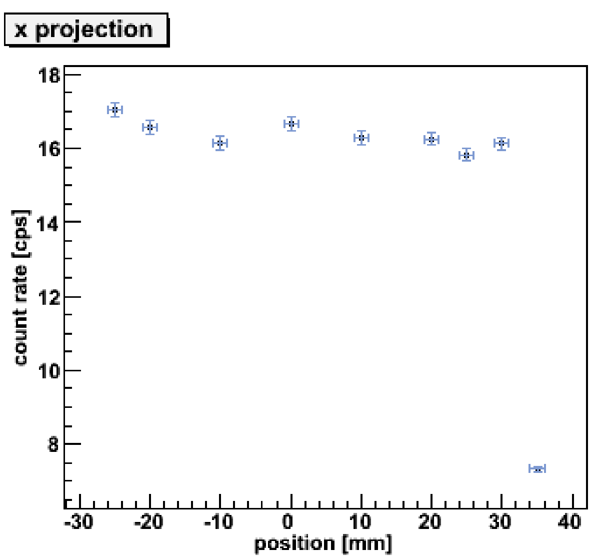


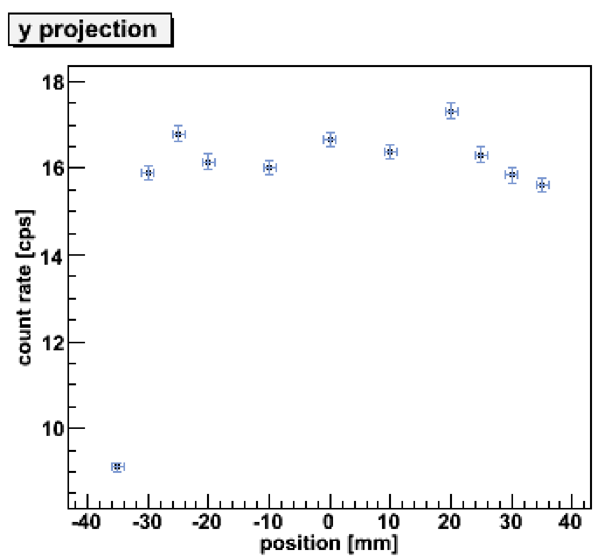
- The DL thickness on the side

is 0.7 mm.

Active volume determination of $^{depl}BEGe_{CC}$





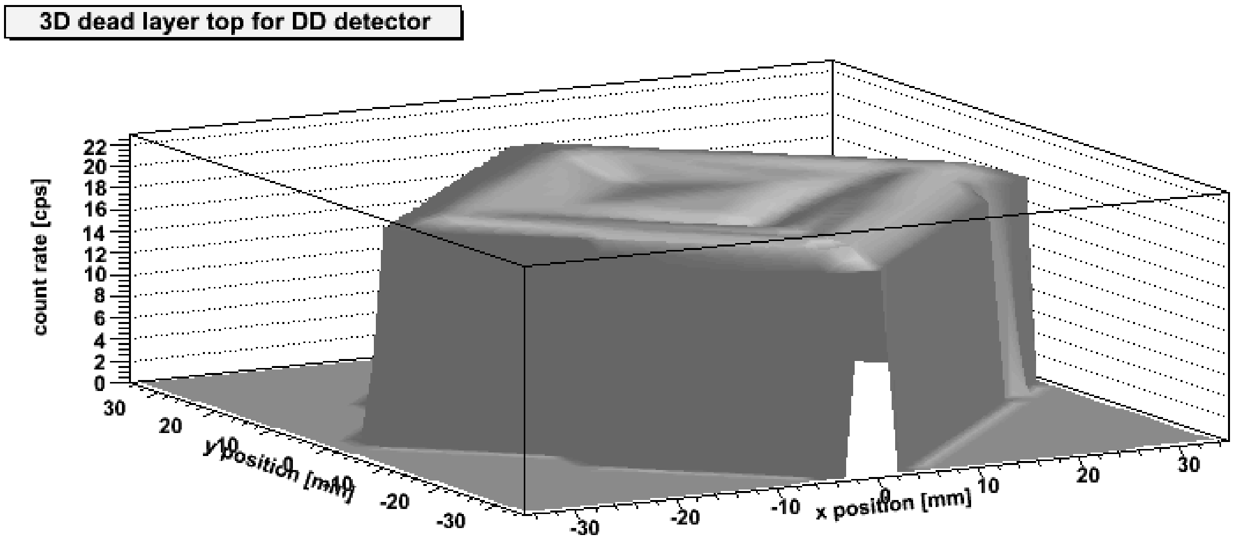


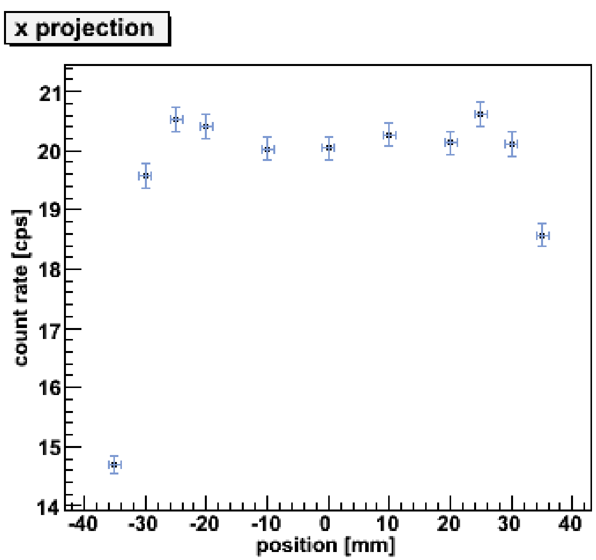
Radial & axial scanning by ^{241}Am source

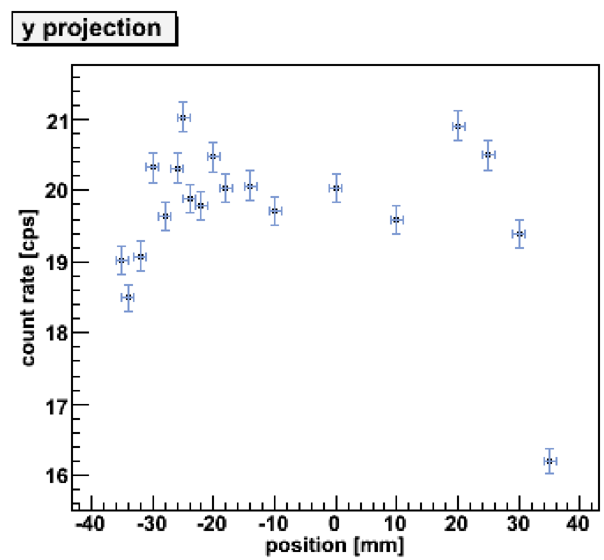
For DL determination need to go through MC

DL values not yet available

Active volume determination of $^{depl}BEGe_{DD}$







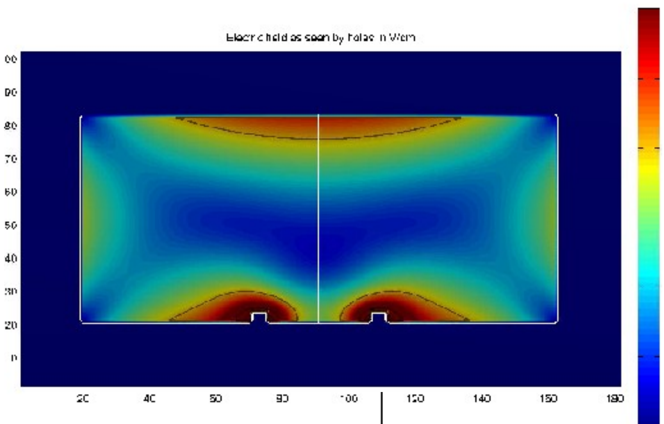
Radial & axial scanning by ^{241}Am source

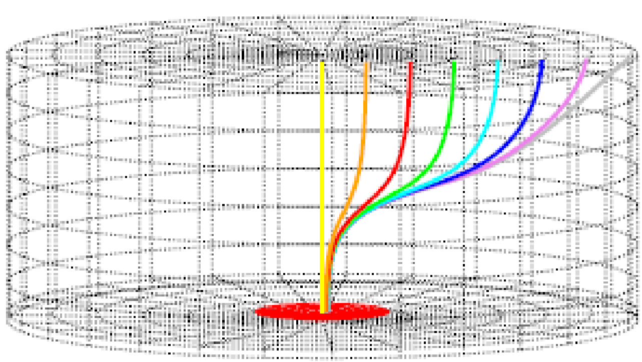
For DL determination need to go through MC

DL values not yet available

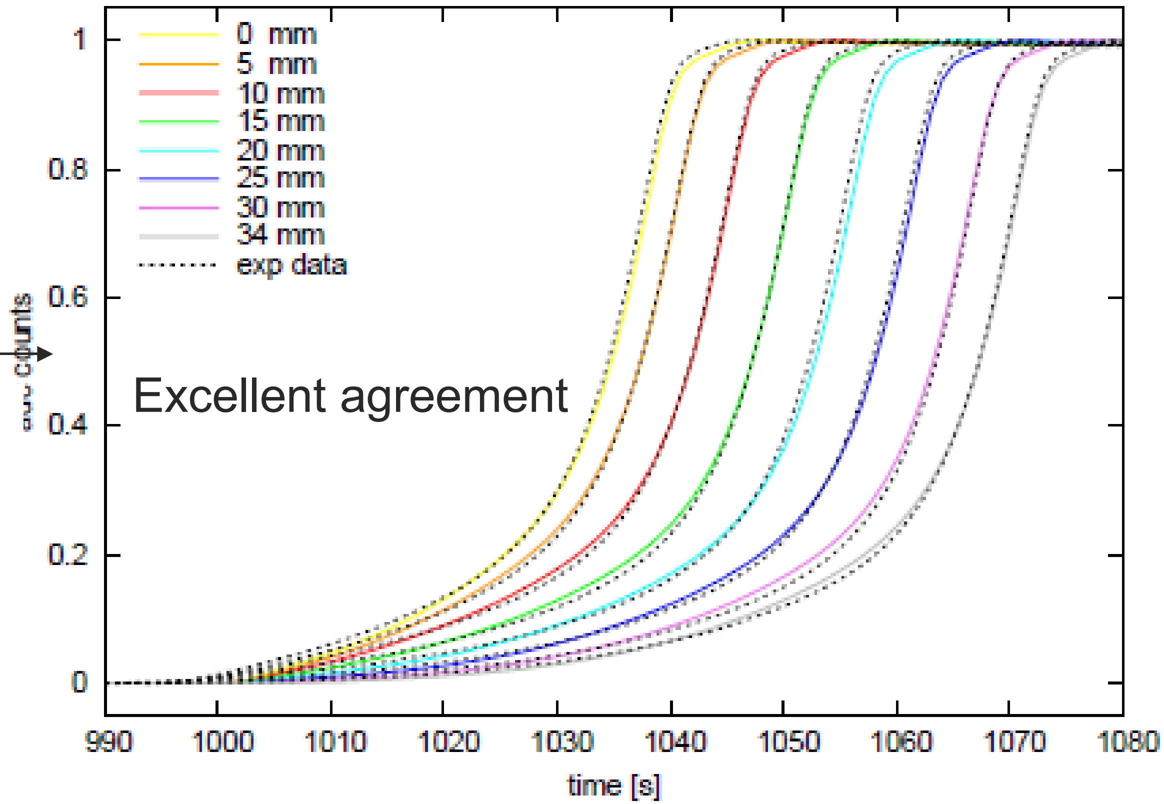
Comparison of exp data with the detector modeling

- Model ingredients: actual geometry, impurity density profile, E field
- Output: V_{depl} & pulse simulation



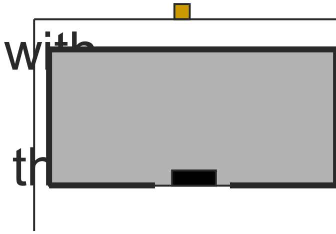


Comparison of exp vs simulated pulses for the LNGS BEGe scanning the top surface with ^{241}Am

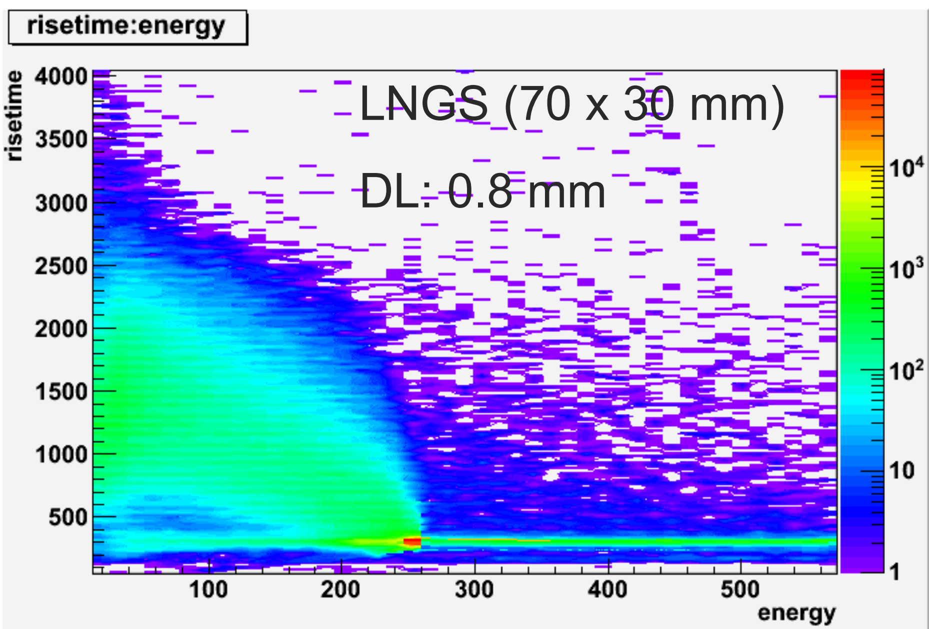


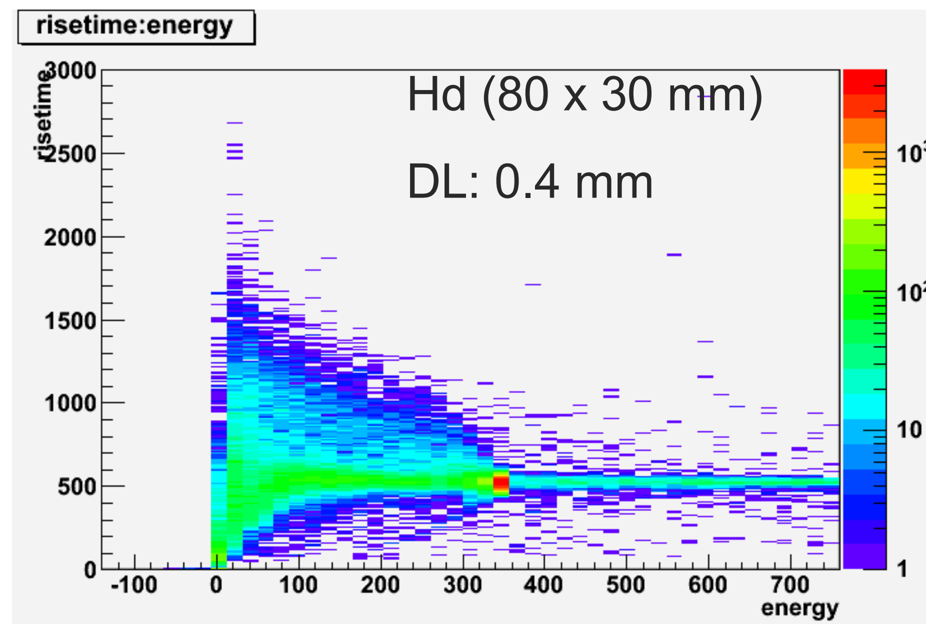
Preliminary presented at NSS09

Preliminary: Pulse RT & search of Slow pulses



- To study the "slow pulses" we have irradiated the detectors with uncollimated ^{241}Am source placed on the top surface
- Questions: Are the the slow pulses (RT > 500 ns) related to the detector DL thickness?
  - Observation: SP number increases at decreasing of energy→ slow pulses from γs interaction at the border of Active Volume and the DL. (μ_{60keV}= 1 mm)
  - Is the SP number related to the thickness of the DL?

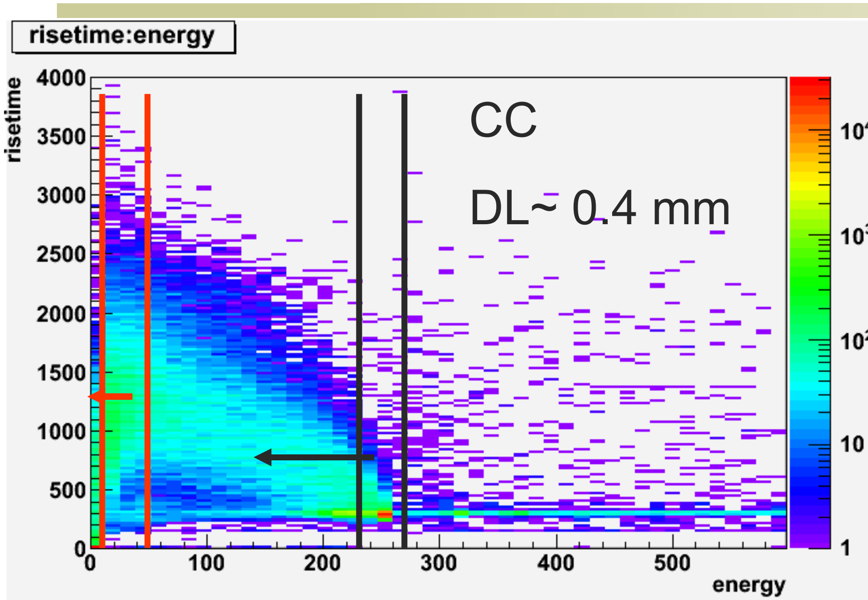


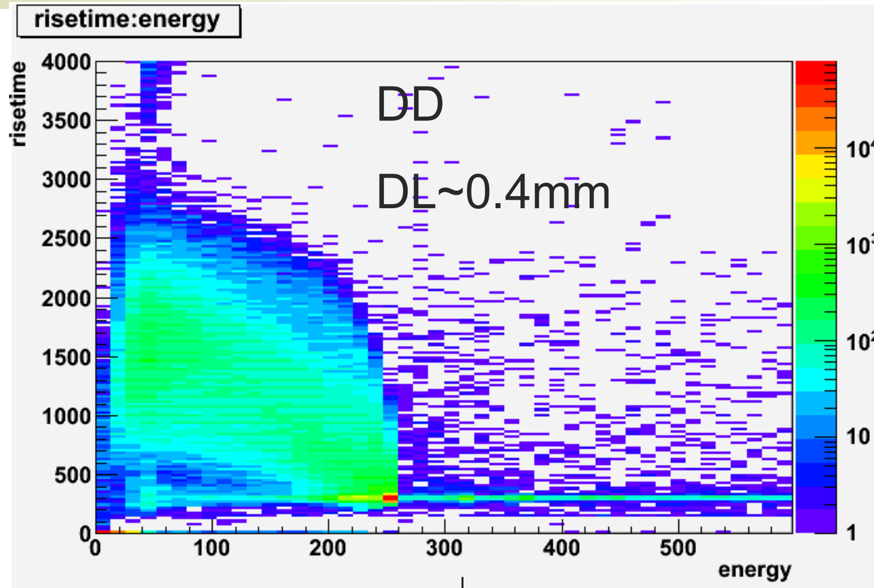


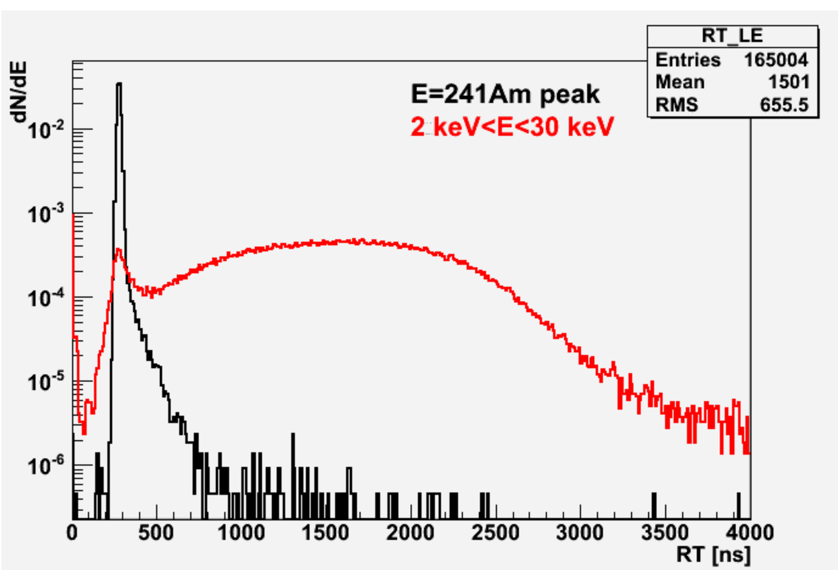
Msmnt performed in over ground lab

Msmnt performed in shallow lab

Pulse RT & search of Slow pulses in $^{depl}BEGe_{DD}$ & $^{depl}BEGe_{CC}$







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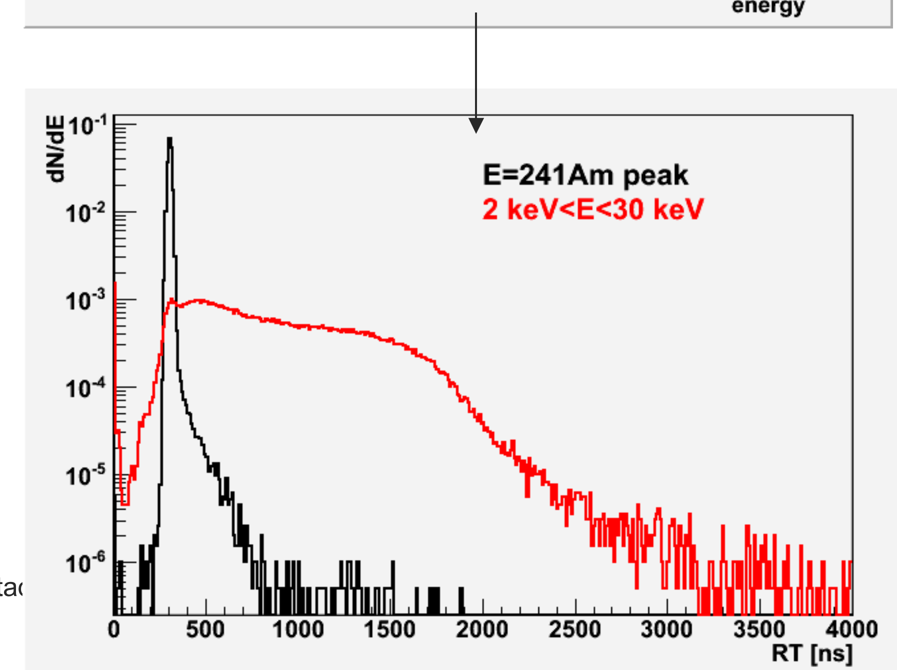
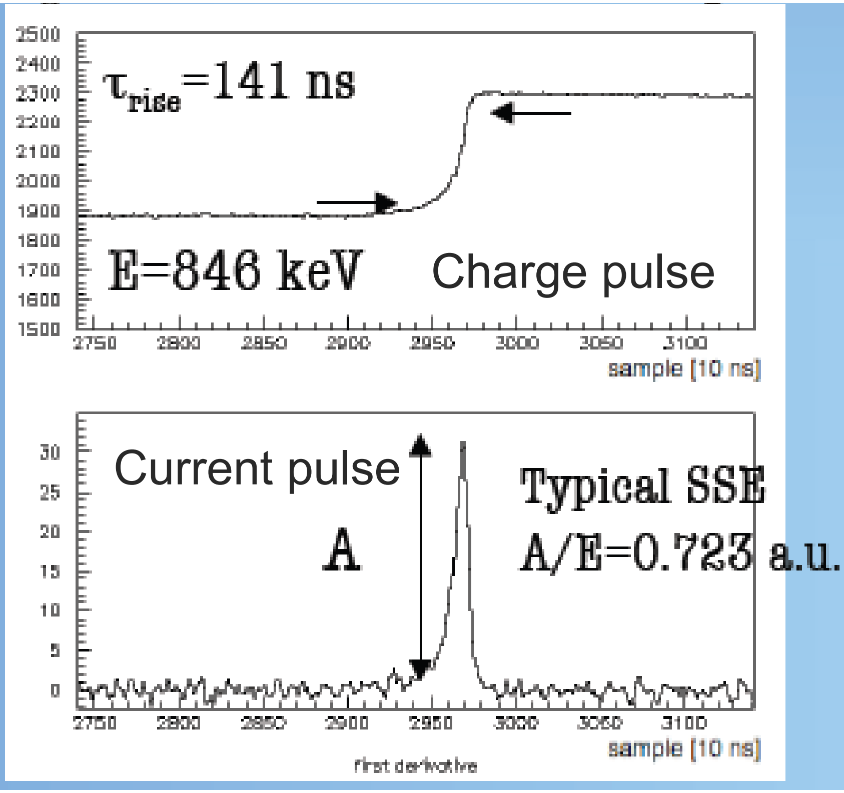
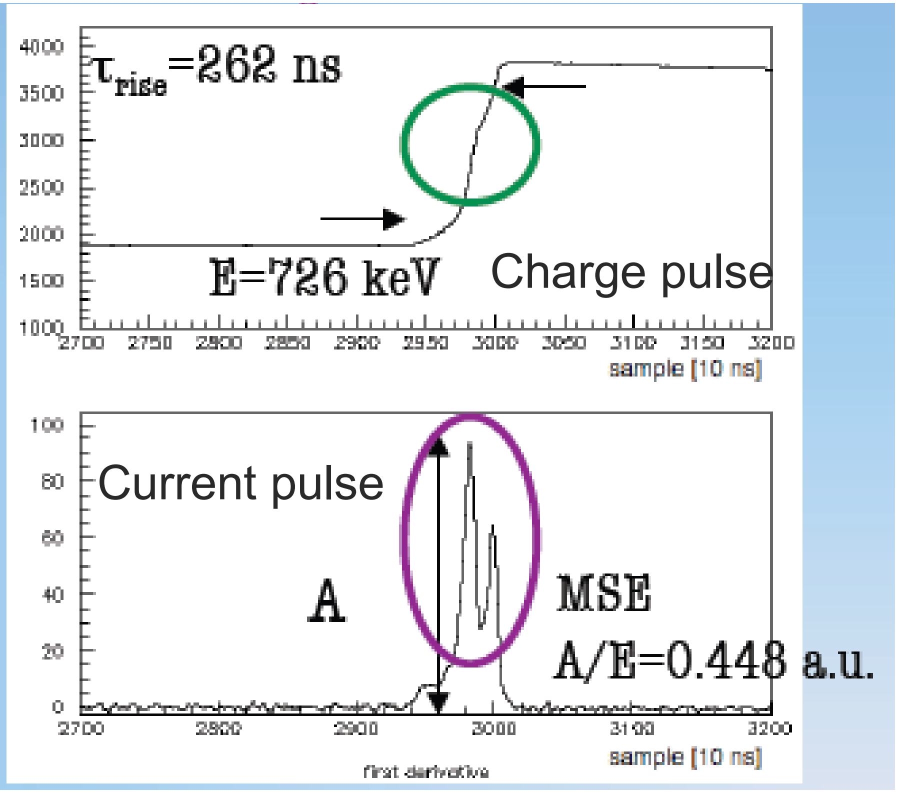


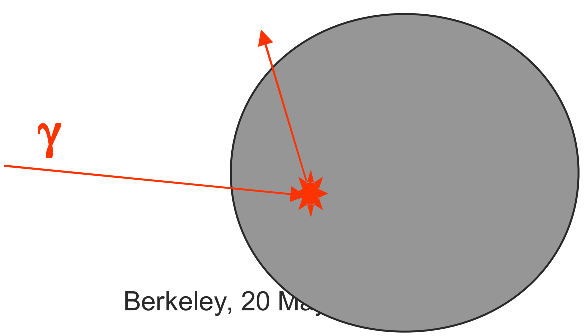
Slow Pulses (cont'd)

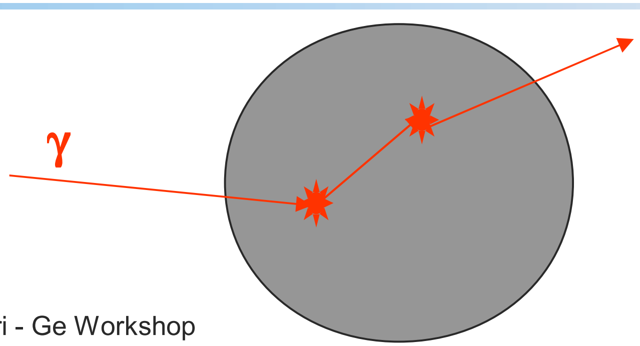
- Work in progress as DL not yet derived from data for CC and DD ^{depl}BEGe
- Investigate SP in data collected irradiating with sources of different energies (if Slow Pulses related to DL should be less increasing the energy of γ)

The PSD to identify SSE & MSE



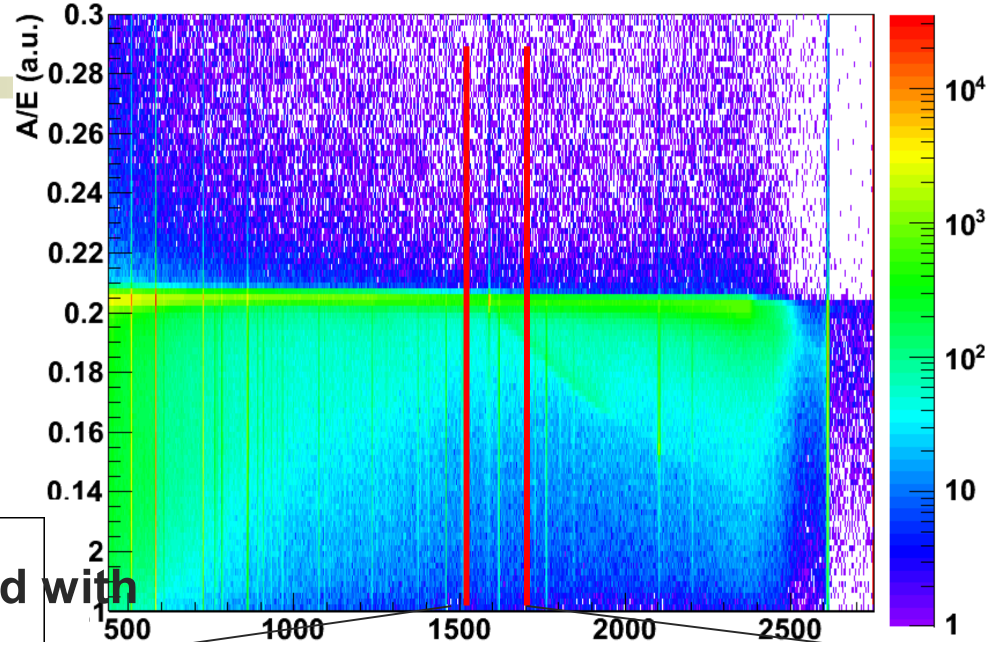


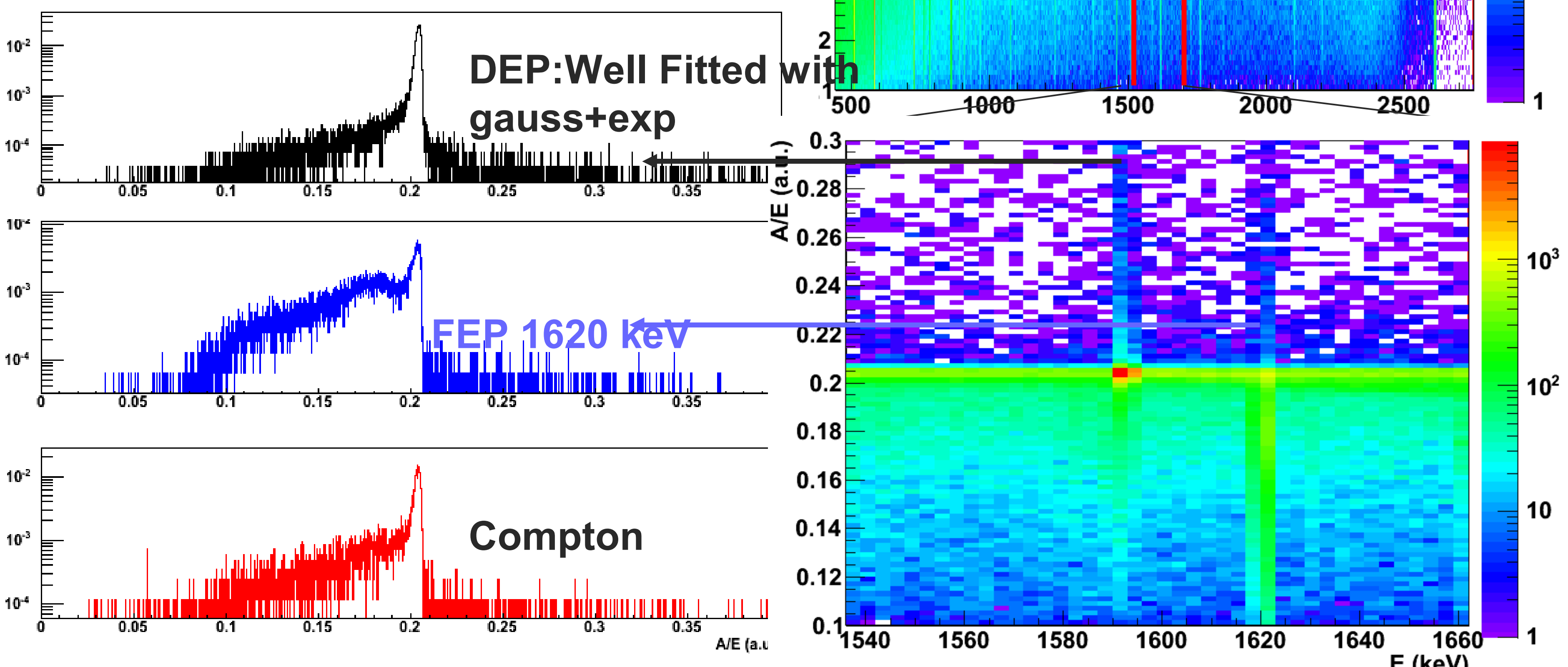




Example: Definition of the PSD cuts on the ^{228}Th data for the $BEGe_{LNGS}$

- The detector is irradiated with 95 kBq ^{228}Th source
- Events are plotted in A/E vs E
- Select ΔE (DEP,FEP,CC)→ projected on A/E axis

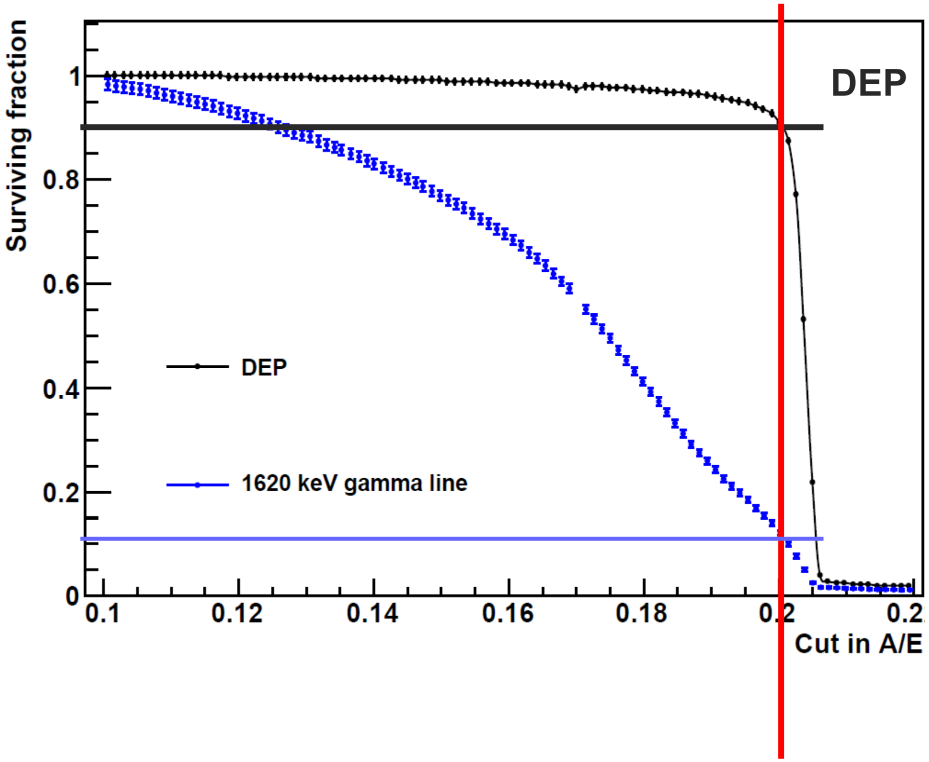


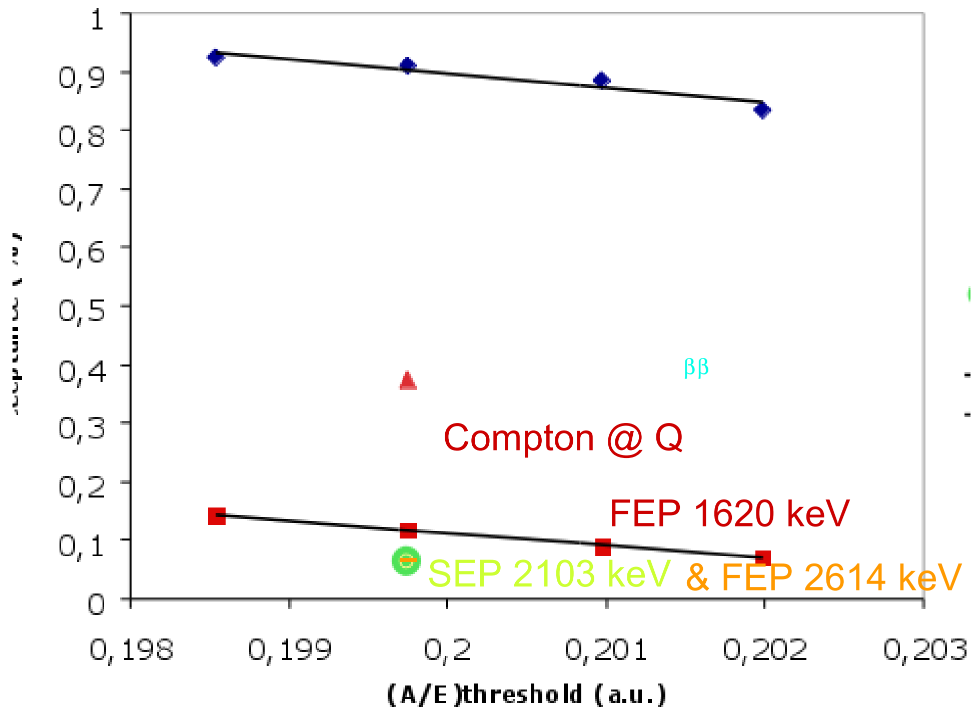


Acceptance as a function of A/E cut

Define cut requiring an acceptance of 90% of the DEP peak →

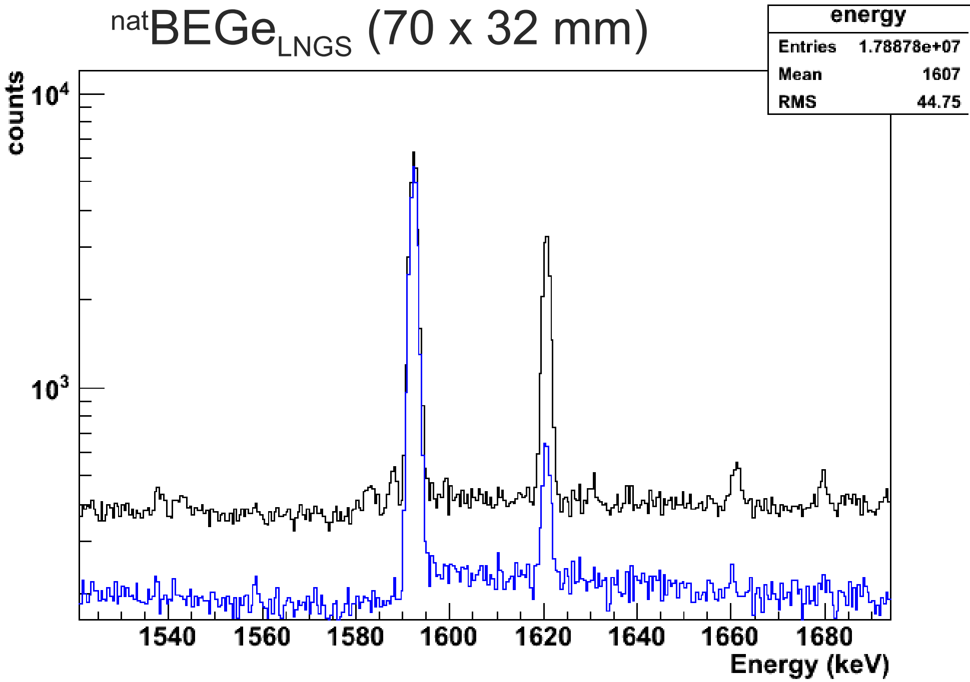
~10% acceptance of the 1620 keV FEP



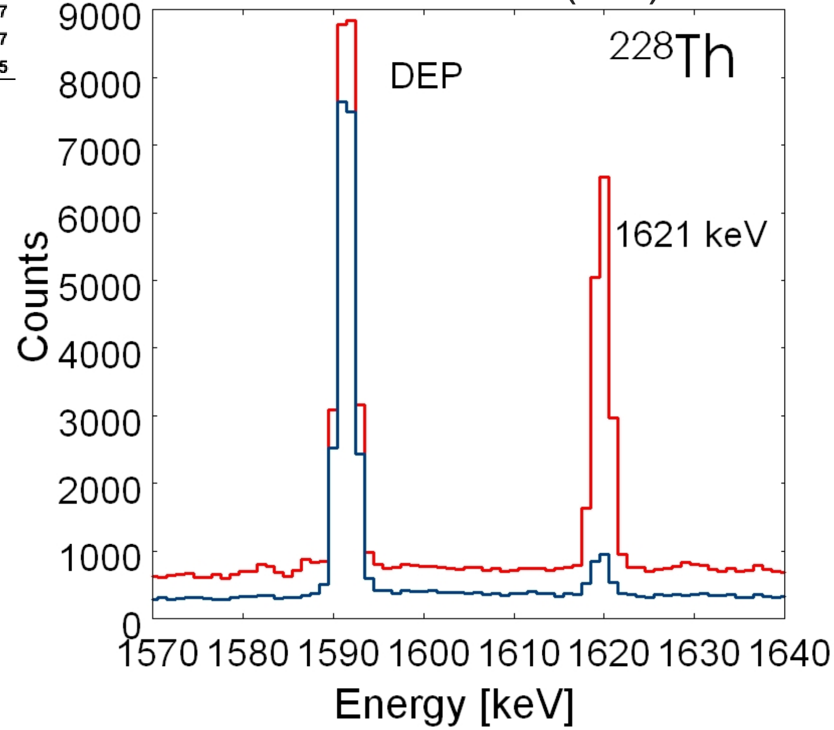


Energy spectra when applying the PSD cut

${}^{nat}BEGe_{LNGS}$ (70 x 32 mm)



${}^{depl}BEGe$ (DD)



- When applying the PSD cut
  - the DEP peek (SSE) survive at 90% while the FEP @ 1620 keV (^{212}Bi line) is reduced at ~10%
  - The Compton Continuum is reduced of a factor ~ 2

PSD: comparison of results from all the BEGe tested in GERDA

				PSD Acceptance [%]				
Dim.sns	Contact dim [mm]	Mass [g]	V_{depl} [V]	Compton @Qbb	DEP 1592 keV	FEP 1621 keV	SEP 2103 keV	FEP 2614 keV
81 x 32 Hd	15	868	4000 3700	39 ± 2	90±1.6	9.5±1.5	5.8 ± 0.6	7.7 ± 0.7
70 x 32 LNGS	15	632	3000 2600	37.5±0.5	90±0.6	11.5±0.1	6.2±0.4	6.4±0.1
60 x 26 Geel	15	390	3000	45 ± 2	90 ± 3	18 ± 3	6.8 ±1.7	14 ± 3
80 x 30 Geel	15	825	3500	49 ± 2	90 ± 3	29 ± 2	23 ± 2	Not avlbl
74 x 33 Depl CC	9	752	3500	38.3 ± 0.3	90 ±1.1	10 ± 0.6	5.4 ±0.3	8.3 ± 0.1
74 x 32 Depl DD	22	~750	3500	39.8±0.3	90±1.1	11.3±0.6	5.8±0.4	8.8±0.1

Conclusions

- In the GERDA collaboration 6 BEGe (3 commercial, two from ^{depl}Ge GERDA-custom Canberra production run) detectors have been tested until now.
- All of them show superior En Res and no charge collection inefficiencies, extra dead-layers etc.
- The PSD applying the A/E cuts originally developed in GERDA collaboration (D. Budjas et al., JINST 4 (2009) P10007), acts as follows in all detectors
  - When Single Site Events $\beta\beta$-like (i.e. DEP @ 1.593 keV) are accepted with 90% efficiency
  - ~ 6-8% of the MSE from γs interactions are accepted at the ^{208}Tl SEP (2.103 MeV) and ^{208}Tl (2.614 MeV) lines
  - The acceptance of events at Compton Continuum is <=40% as expected from physics of Compton interactions (SSE)
- Two detectors show some deviations on PSD of γ-like events: further investigation.

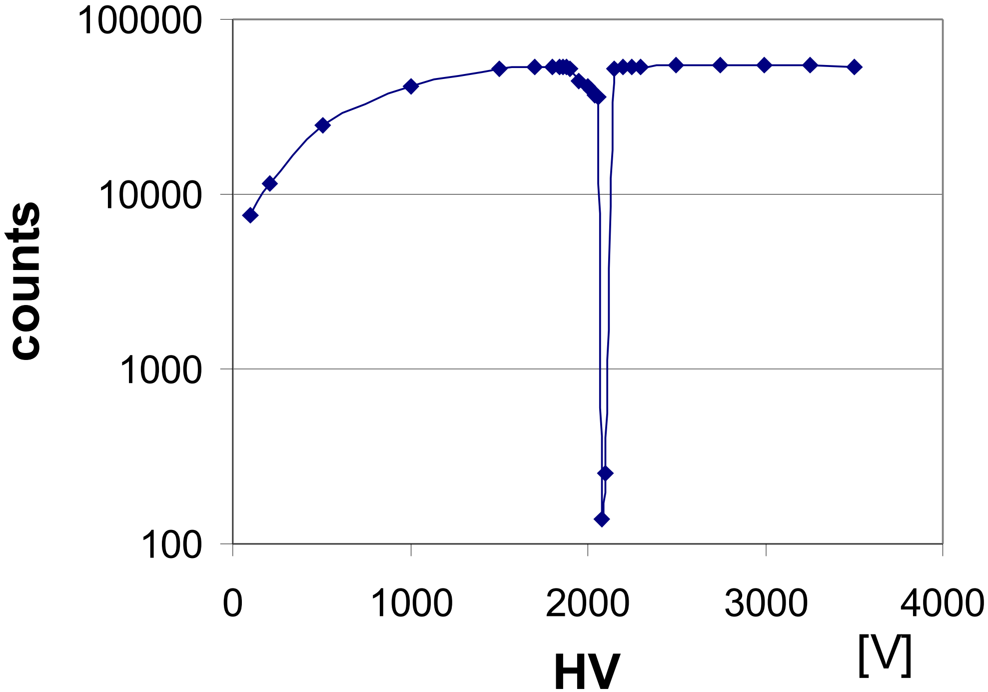
Conclusions

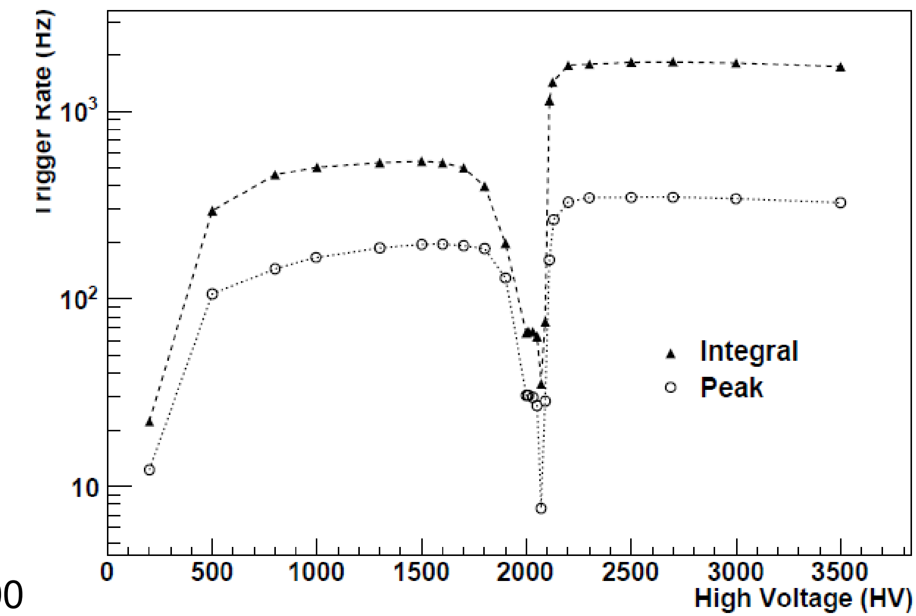
- The exp.data together with the detector modeling show that:
  - Bckgrd from ^{68}Ge (β^+ Q_β=1.8 MeV + 2γ 511) keV, will be rejected as ^{208}Tl SEP γ-like events at ~ 94% level
  - Bckgrd from external ^{60}Co (γs 1.17 MeV keV & 1.332 MeV) i.e. γ-like, will be rejected at ~1% (0.10 x 0.10) level
  - Bckgrd from internal ^{60}Co (β^- Q_β=2.8 MeV + γs 1.17 MeV keV & 1.332 MeV) will be also rejected at 99%

- Slow Pulses: work in progress.
  - Some indications from (70 x 30 mm) that pulses with RT > 700 ns related to DL thickness, but not fully consistent with all the detectors tested so far → repeat msrmnts/analysis
  - Possible correlation with readout contact/insulating groove dimensions
  - Need further study
- The detector modeling (E field and pulse shapes in the full detector volume) is very advanced and is a powerful tool!

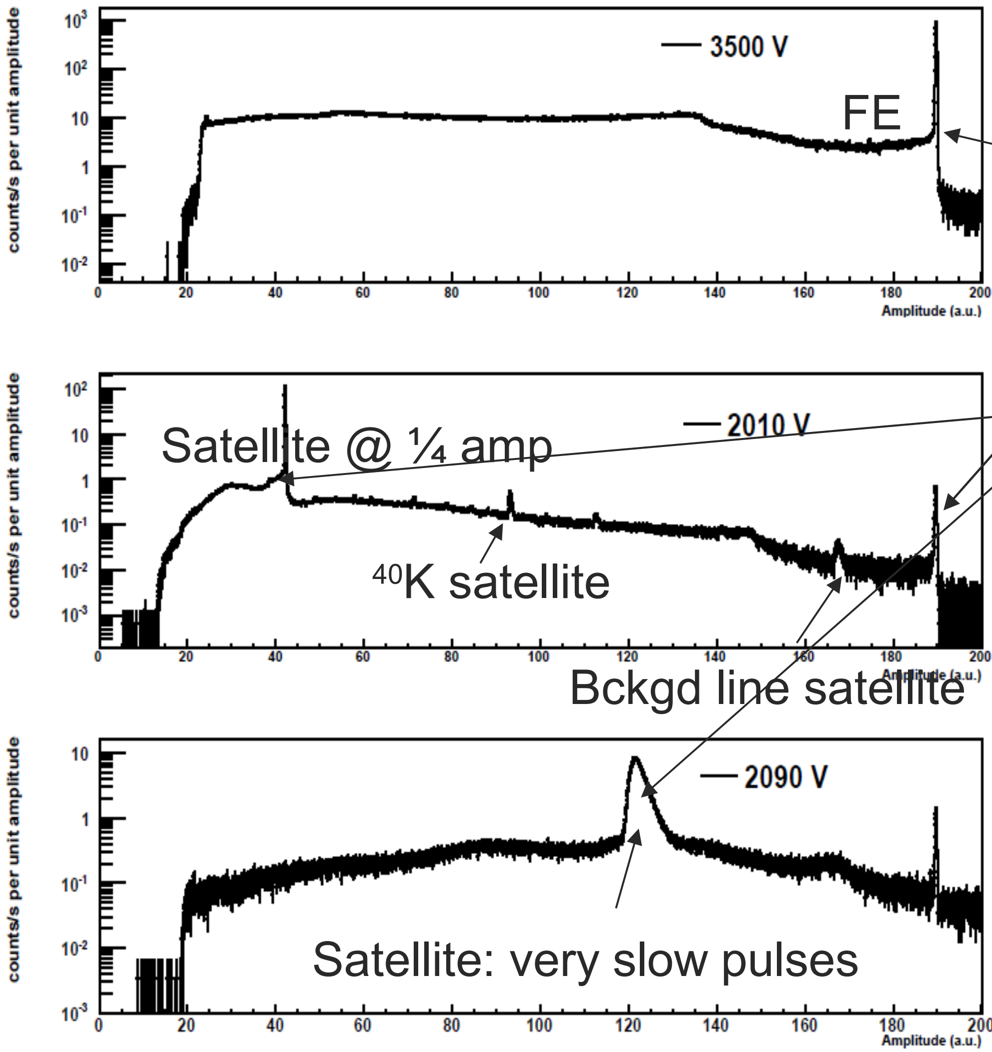
EXTRA SLIDES

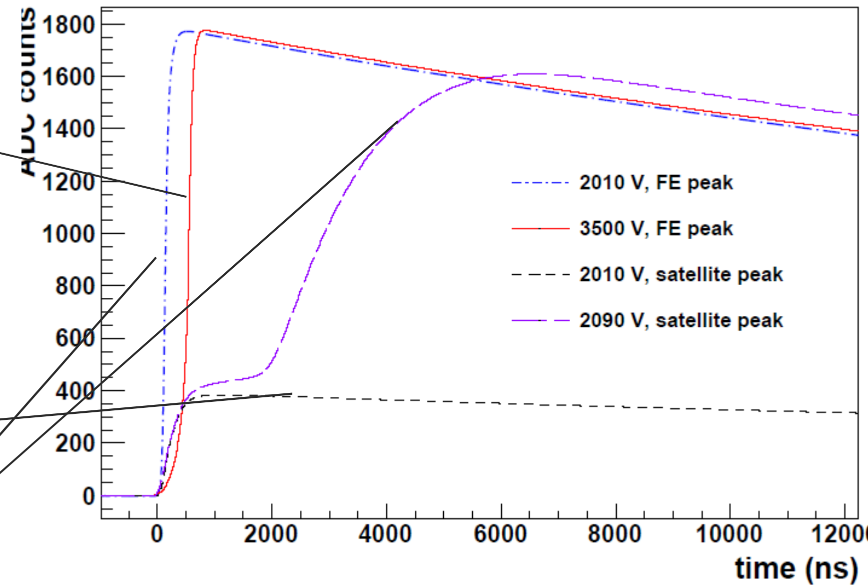
counts vs.HV


100000
10000
1000
100
counts
0
1000
2000
3000
4000
HV
[V]


Trigger Rate (Hz)
10^3
10^2
10
Integral
Peak
0
500
1000
1500
2000
2500
3000
3500
High Voltage (HV)

Satellite peaks in ^{137}Cs spectra





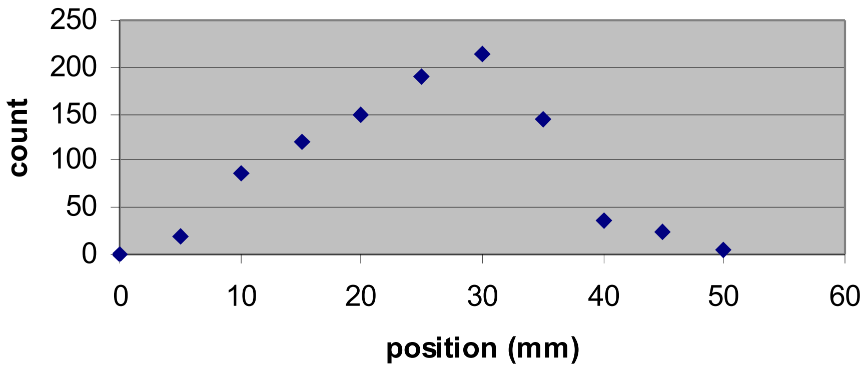
Effects related to

- Readout Electrode dimension
- Impurity profile impact Efield

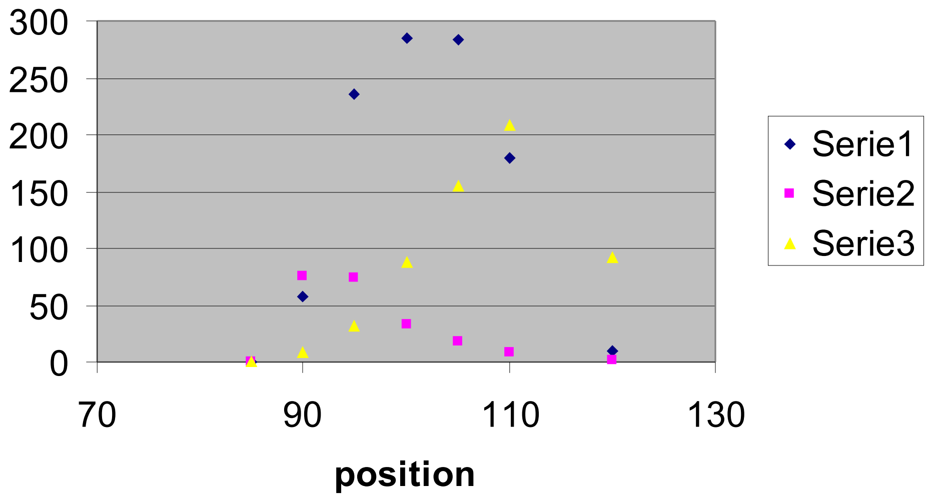
The bubble-locking interpretation and experimental evidences

with ^{137}Cs @ V_{bias}= 2010 V

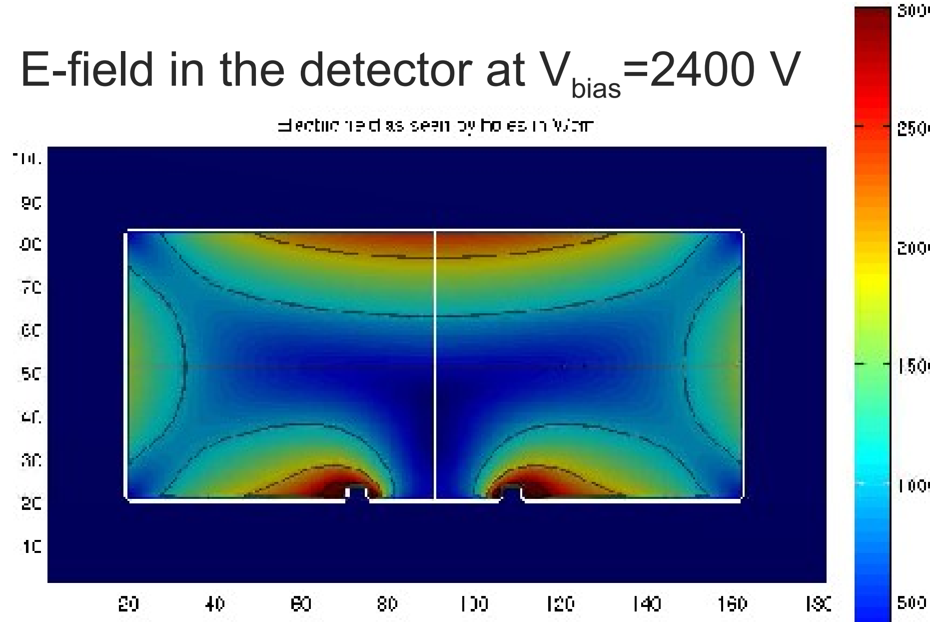
radial scanning from the top

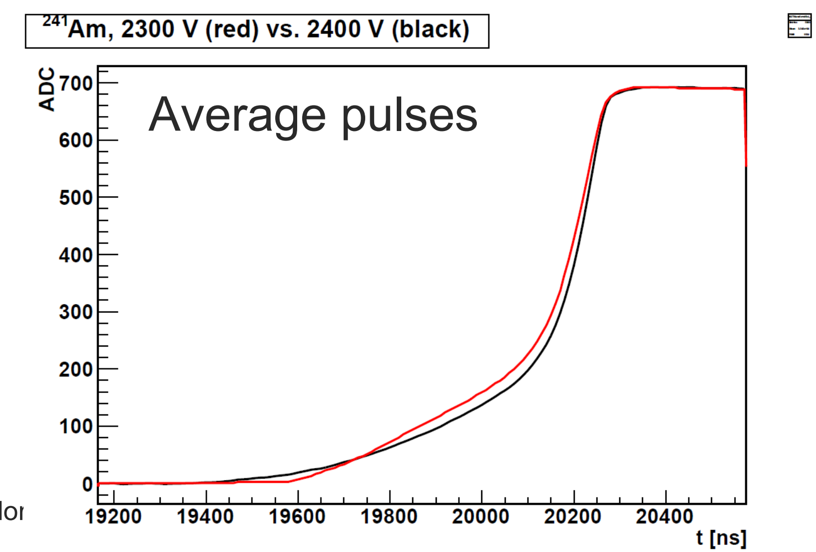


vertical scanning



E-field in the detector at V_{bias}=2400 V

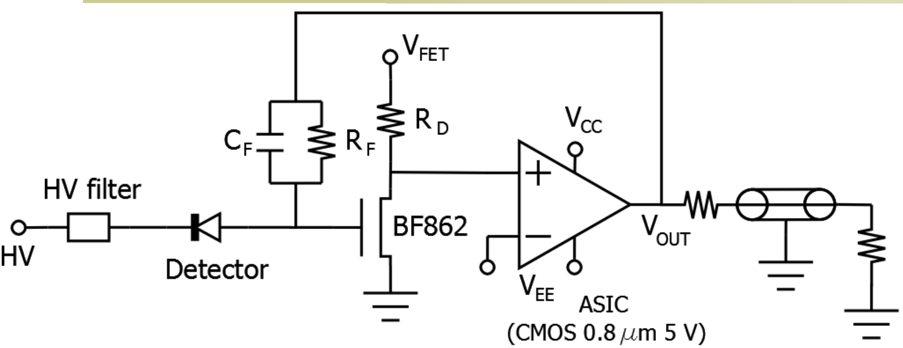


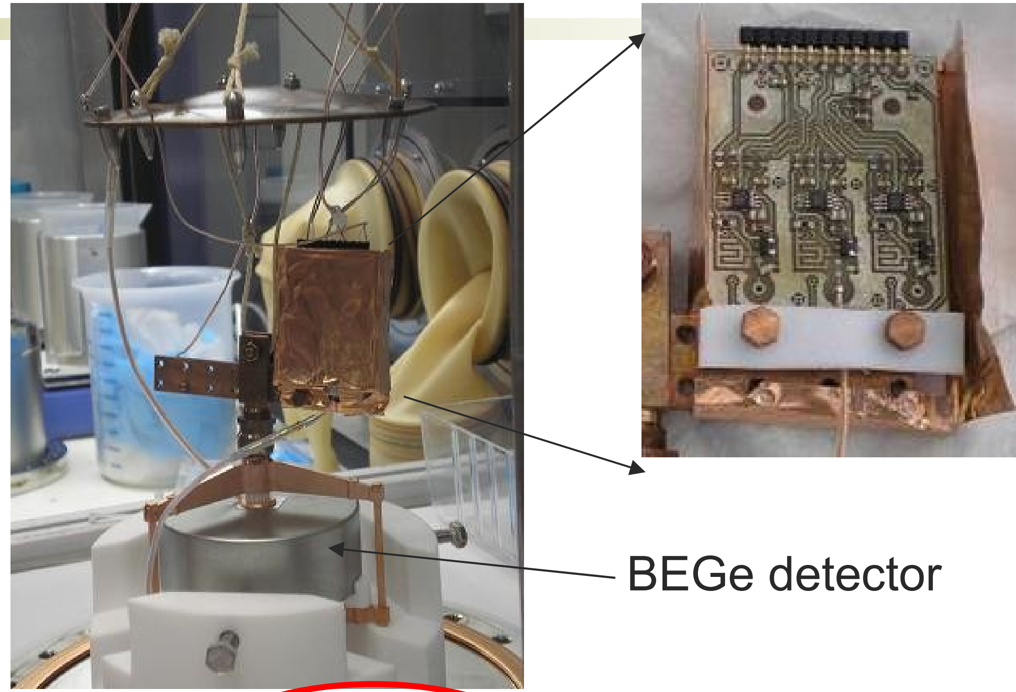


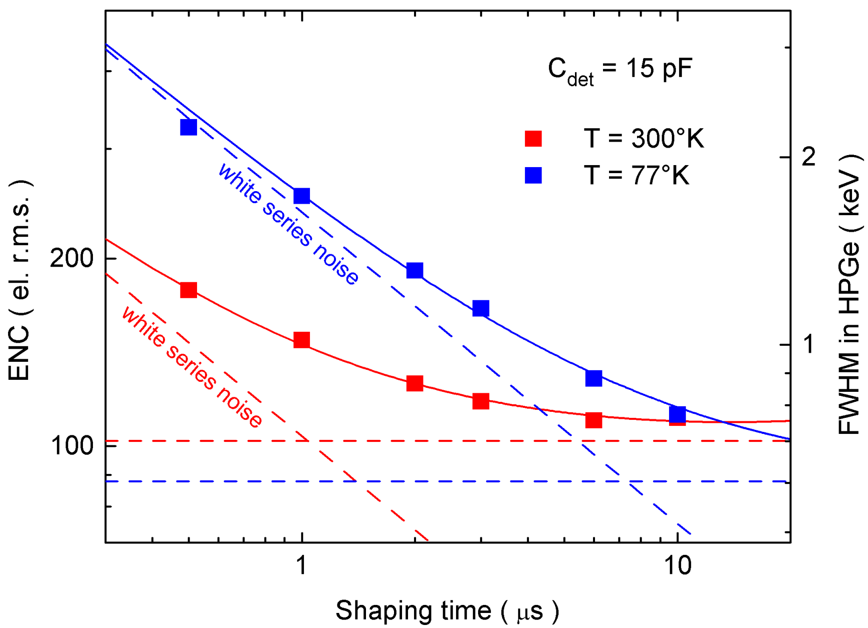
Specifications for GERDA Phase I FE electronic:

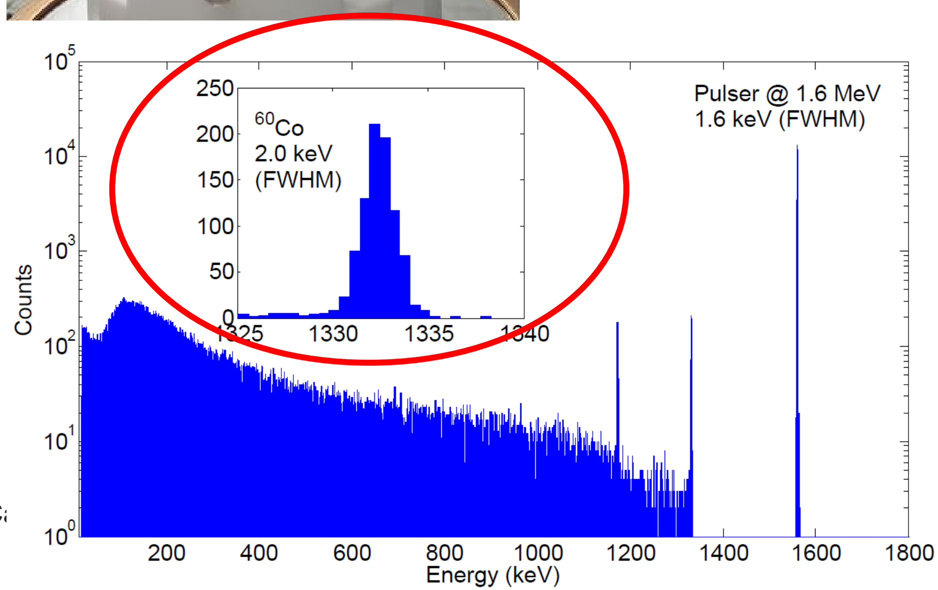
- Charge Sensitive Amplifier
  - Sensitivity: ~ 150 mV / MeV
  - Range Dynamic: > 5-6 MeV (now 8-9 MeV)
  - Working @ Criogenic T
  - Large Open loop gain (~ 10^5) to guarantee stability (but cryogenics helps)
  - Noise: <1 keV in Ge (< 150 e^- r.m.s) @ 1 MeV, τ = 8 -10 μs, at T= 77°K
  - Rise time: < 30 ns to allow PSD of ionization events in Ge detectors
  - Compact / integrated as possible
  - Drive 50 Ω load through 6 m (later 10 m and then 20 m) long cables
  - Power dissipation: < 50 mW /ch (as low as possible)
  - Output stage: Better differential (later single ended)
- PCB requirements
  - 3ch modularity to serve 1 string
  - Radiopurity: as low as possible later set limit < 500 μBq ^{232}Th and 2.5 mBq ^{238}U for distance
  - Interconnection with input detector and output/LV cables by pins
  - Cryogenic (stable vs deformations for thermal cycles etc.)

The recentest results with bare BEGe (80 x 40 mm) & cold FE in LARGE setup (@GDL):

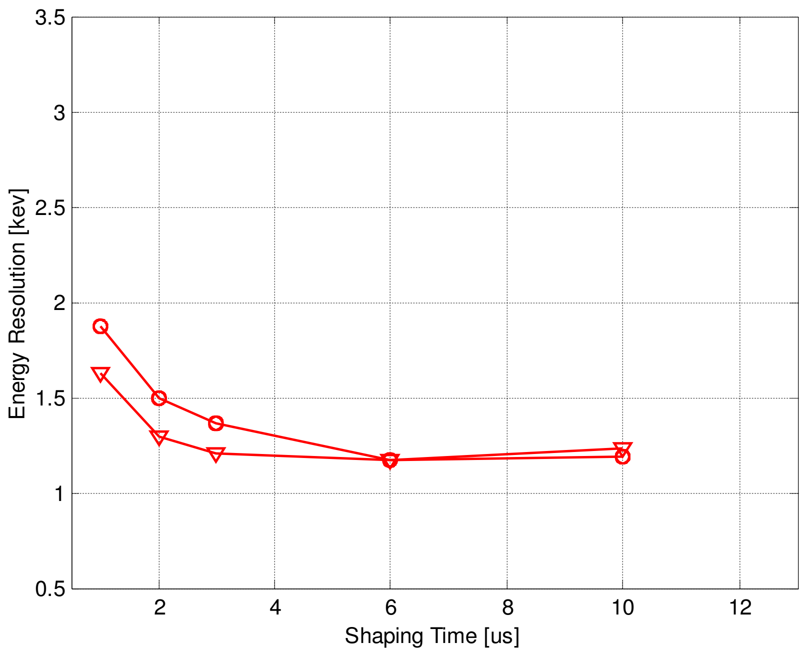




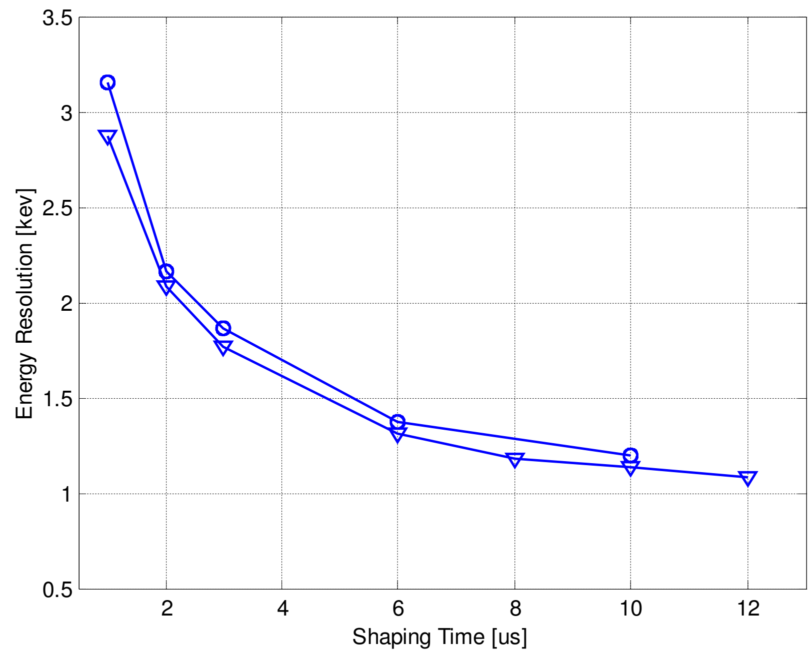




CSA Intrinsic Energy Resolution: Cdet = 33 pF



Room Temperature



LN Temperature

Circle : 6 V JFET Power Supply Triangle : 12 V JFET Power Supply

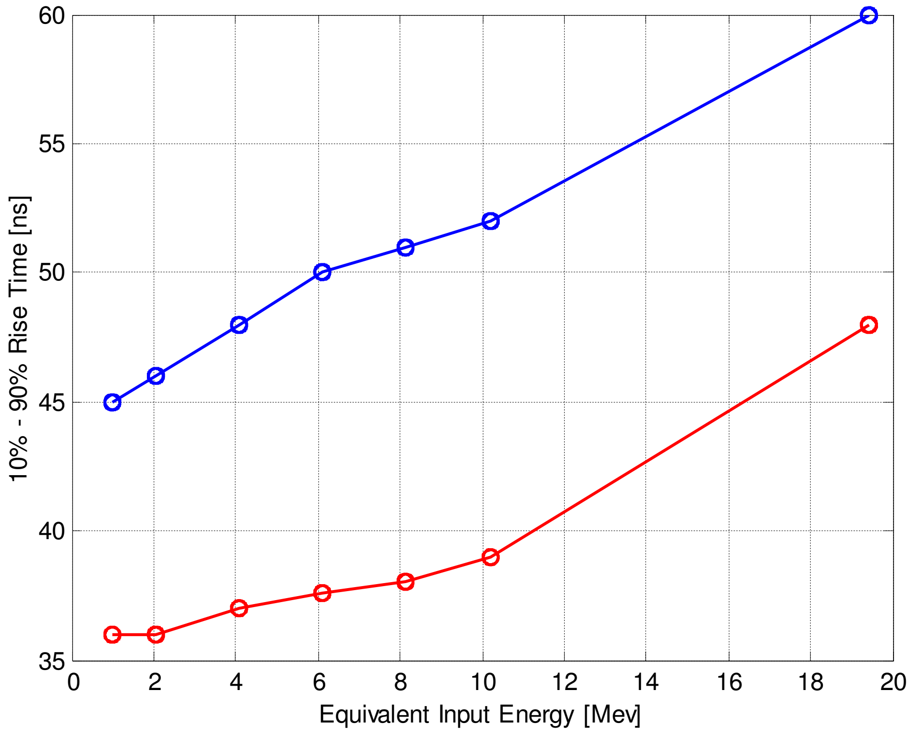
CSA Rise Time

- Blue line:
  CSA + 10 m long output cables
  (50 Ohm terminated)

- Red line:
  CSA + 1 m long output cables
  (50 Ohm terminated)

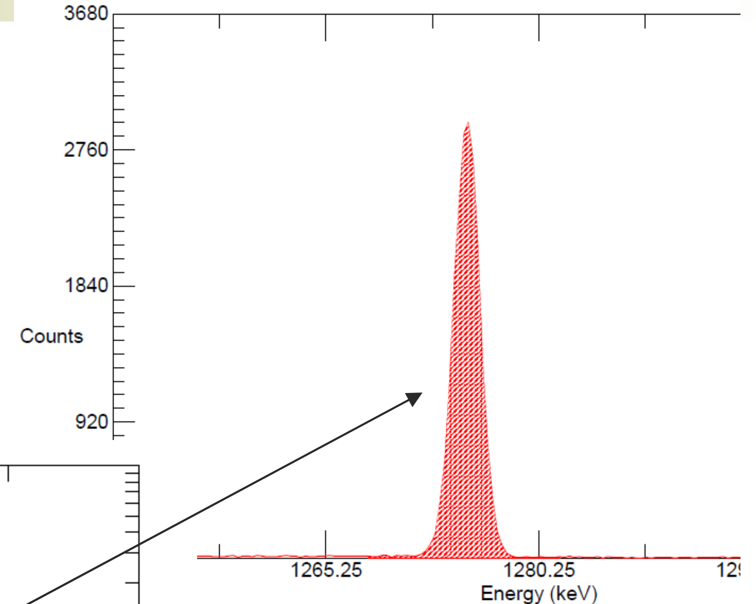
- Pulser signal 5 ns rise time

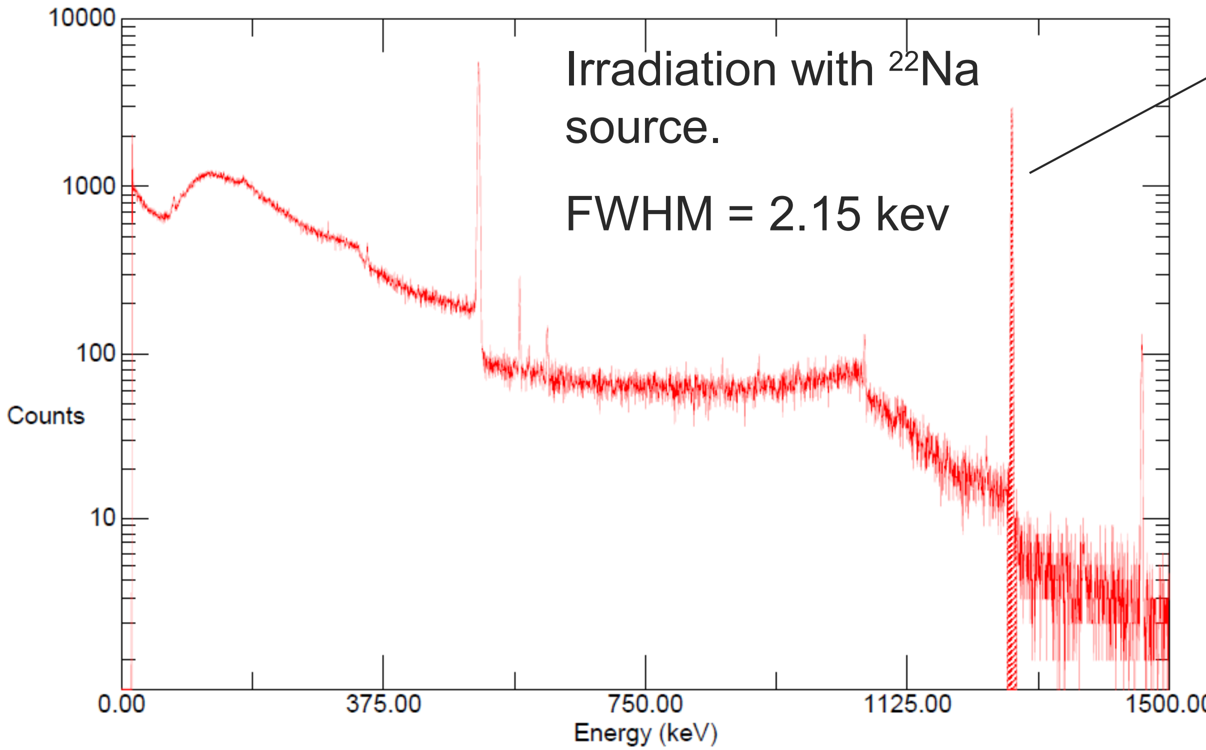
- Rise time defined as
  time interval between 10% and 90% of CSA output signal



Spectroscopy with CC2 CSA + encapsulated detector

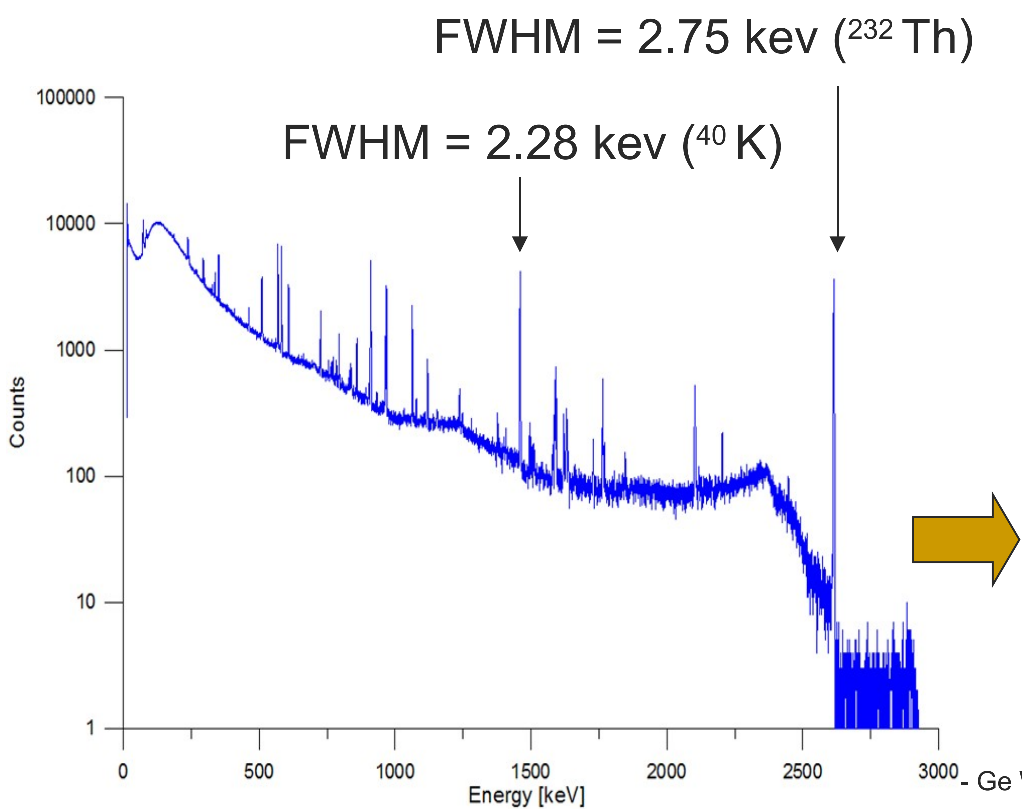
- Analog Amplifier (10 us Shaping Time)
- MCA
- Reproducible Energy Resolution
  (σ = 0.03 kev over 20 short measurements)
- Rate 2 kHz

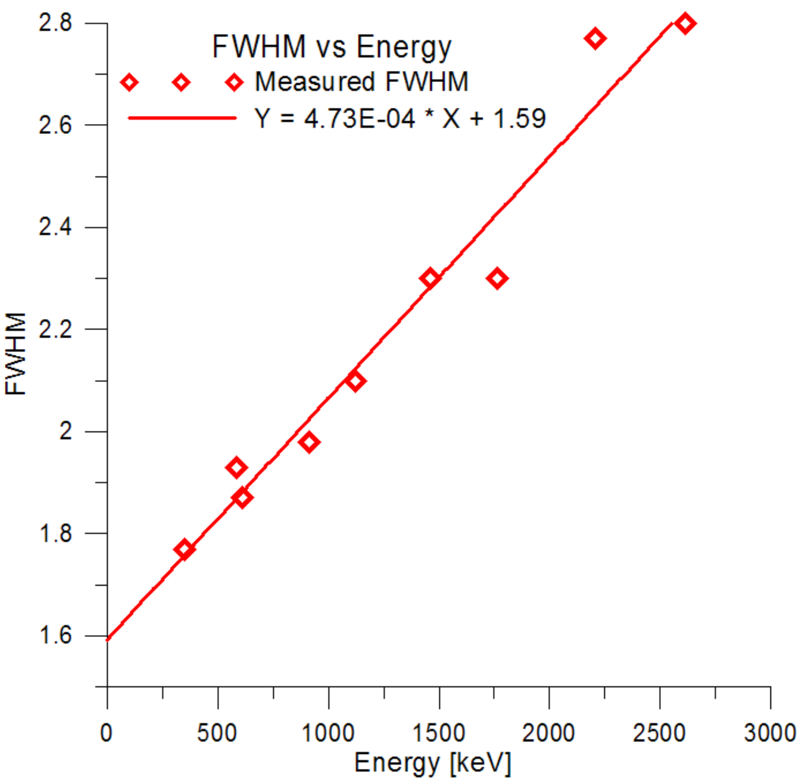




Spectroscopy with CC2 CSA + encapsulated detector

- Analog Amplifier (10 us Shaping Time)
- MCA
- Background long acquisition (over the night)

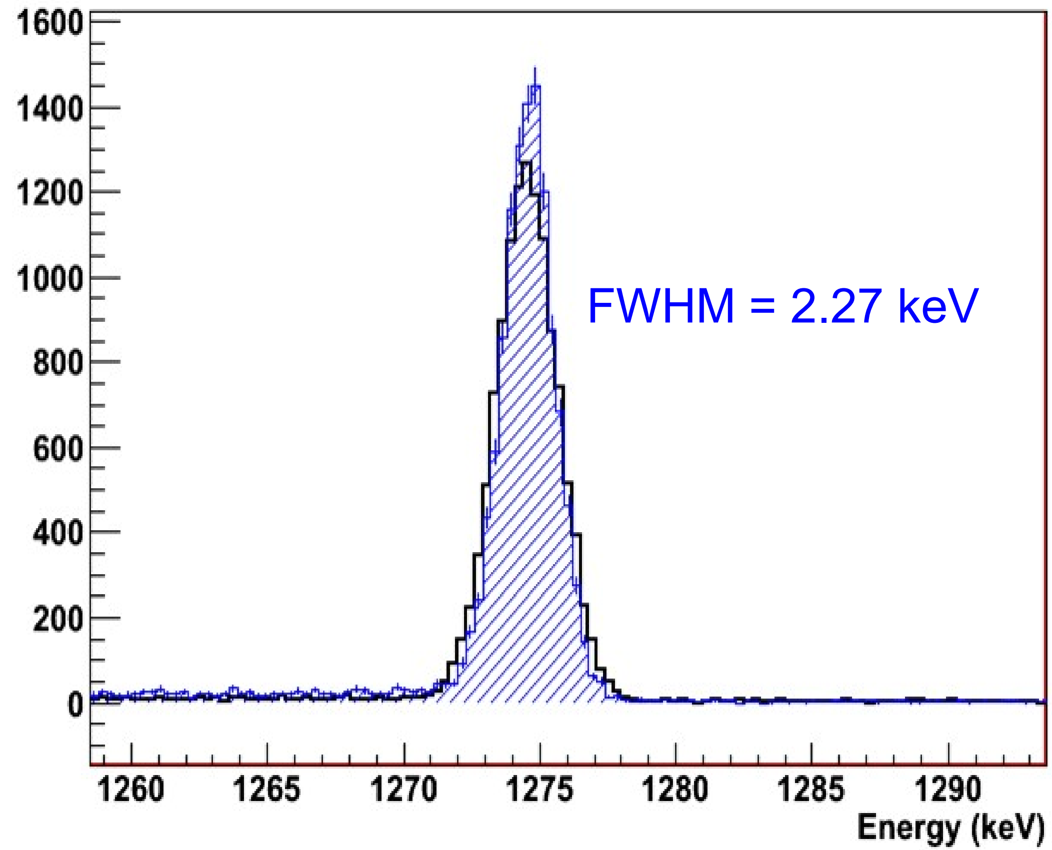




Digital Spectroscopy with CC2 CSA

- CAEN FADC
- Off-line processing
- Digital FIR filtering with symmetric weighting function for baseline
- CSA output signals with 700 us decaying time

  (from 10% to 90%)
- Good agreement with single-pole exponentially decaying pulse model



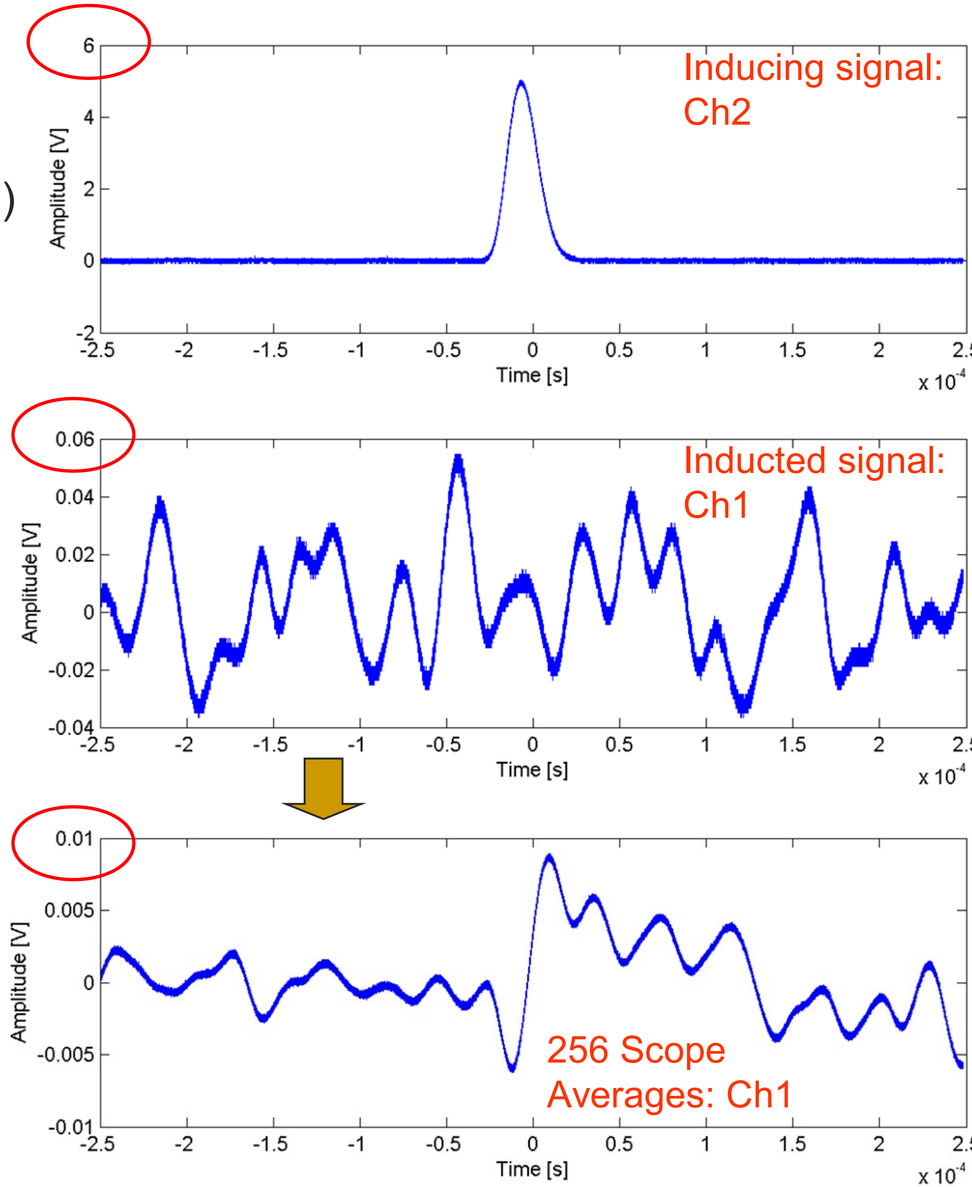
Crosstalk between Channels

- Between Ch2 (detector) and Ch1
- Same procedure as for PZ0:
  Ch1 and Ch2 through analog shaper (10us)
  Gain amplification for Ch2 = 200
  Gain amplification for Ch1 = 1000
- Experimental Result:

  $\Delta Ch1 / \Delta Ch2 = (15\ mV / 5\ V) / 5 = 0.06\ \%$

- Very similar results for cross-talk measurement between Ch2 and Ch3
- Because cross-talk is low, it is also difficult to estimate because of the electronic noise
- As a conservative assumption :

  Cross-talk < 0.1%



Summary of CC2 measured characteristics

- Best energy resolution @ LNT : 0.7 keV FWHM (0 pF Cdet)
  1.1 keV FWHM (33 pF Cdet)
  (with 1 Mev pulser signal, τ =12 μs)

- Best energy resolution @ LNT : 1.96 kev FWHM for ^{22} Na
  ($\tau =$ 12 us shaping time, 5k counts acquisition)

- 15 MeV guaranteed energy dynamic range

- 50 Ω drive capability with 10 m long cables

- Power consumption < 140 mW (down to 100 mW for 10 Mev dyn. range)

- Rise time : less then 55 ns with 50 Ohm terminated, long cables and energy up to 15 Mev

- Cross-talk : < 0.1%

- Power Supply Rejection Ratio : OK

- Expected CSA radio-activity <= 150 μBq for 3ch PCB for both ^{232}Th & ^{238}U

Stability in an underground thermostatized lab