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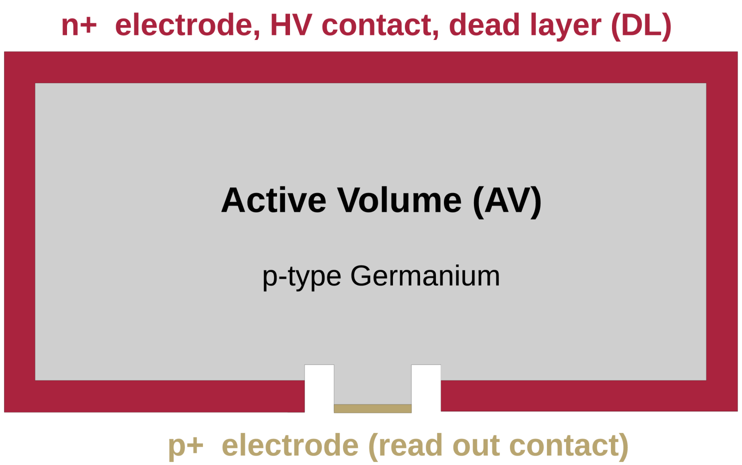
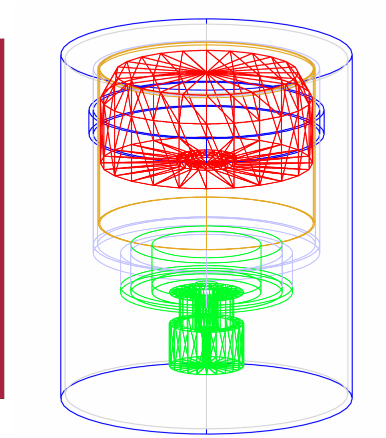
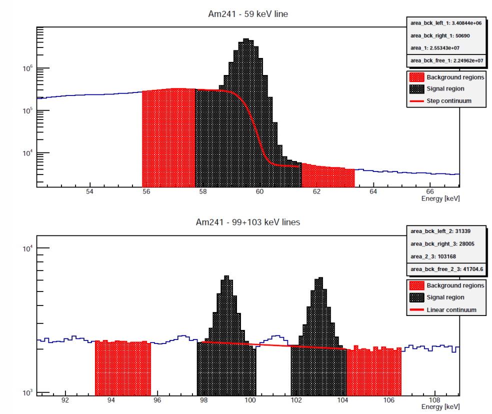
Physikalisches Institut
Kepler Center for Astro and Particle Physics

GERDA







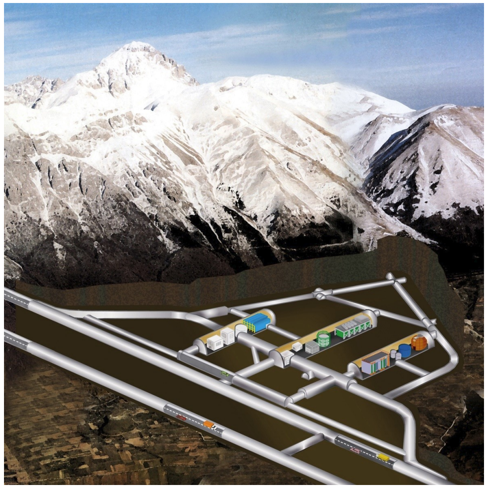
Dead layer and active volume determination of enriched BEGe detectors for the GERDA experiment

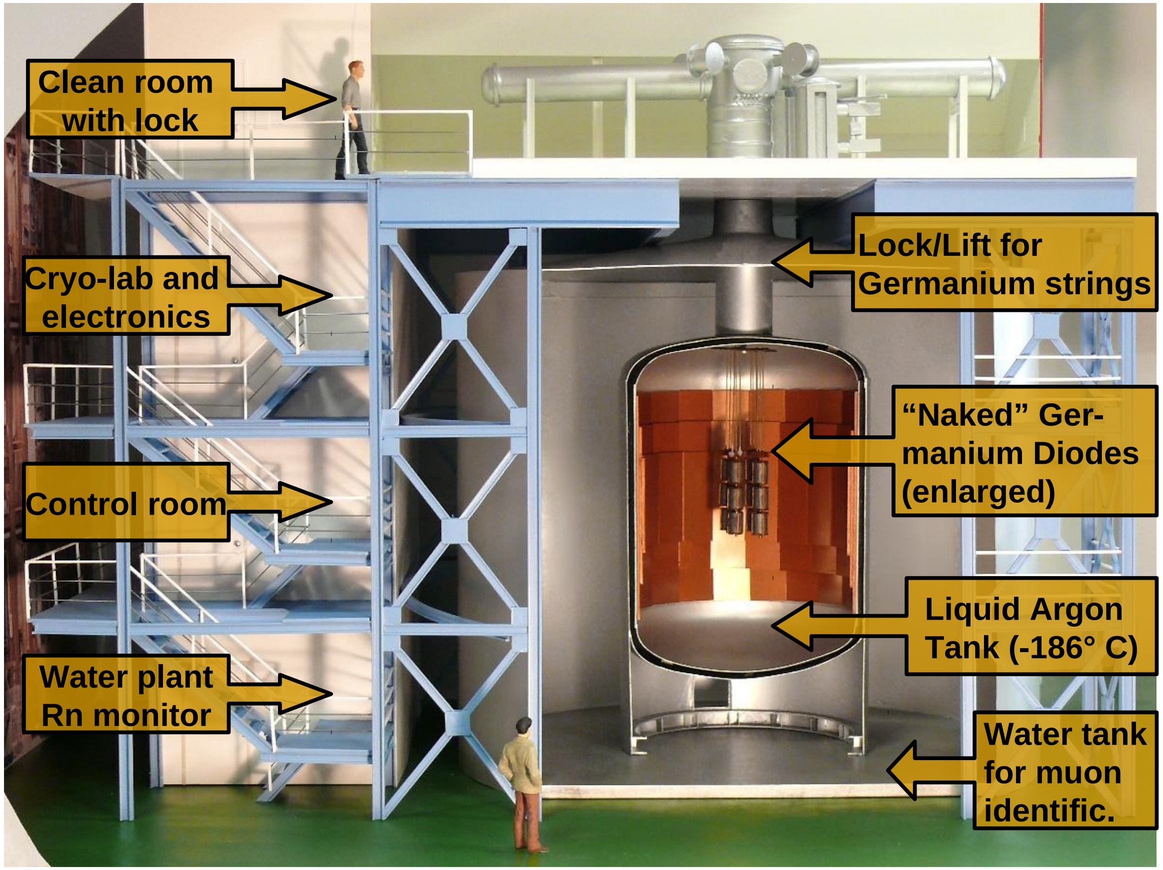
Raphael Falkenstein
for the GERDA collaboration

27.03.2014
DPG-Frühjahrstagung, Mainz

GERDA
Germanium Detector Array

- Experiment designed to investigate the **$0\nu\beta\beta$ decay in ^{76}Ge**
- Located at the Laboratori Nationali del Gran Sasso **(LNGS)**, Italy, with a natural shielding from cosmic radiation of ~ **3800 m** water equivalent.
- Uses **Ge diodes** enriched in ^{76}Ge as **source and detector**

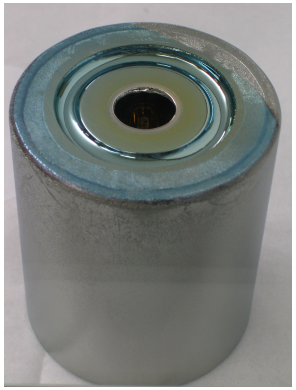




- **Liquid Argon (LAr)** is used as γ-shield and cooling medium
- The Germanium detectors are operated “naked” in LAr

Phase I

- Between 11/2011 and 05/13 with ~ 18 kg of ^{enr}**Ge** diodes (mostly coax type)

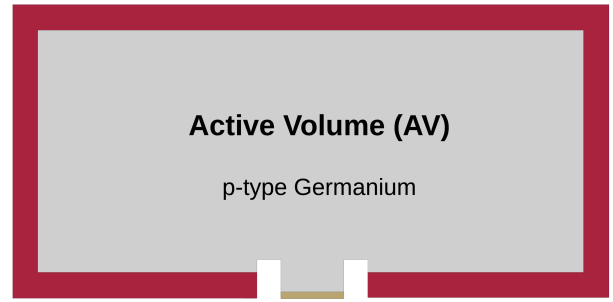


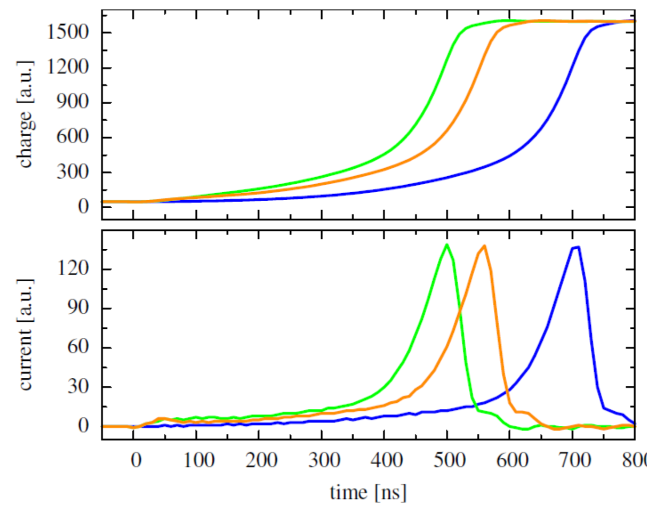
Phase II

- ~ 20 kg of **BEGe** detectors enriched in ^{76}Ge at 86 % level will be additionally deployed
- 5 BEGe's with a total mass of ~ 3 kg already deployed in GERDA since July 2012
- **Physics goal of Phase II** is to increase our sensitivity and especially the reduction of the background index in the ROI ($Q_{\beta\beta}$ = 2039 keV) to a level of **10^{-3} cts/(keV · kg · yr)**

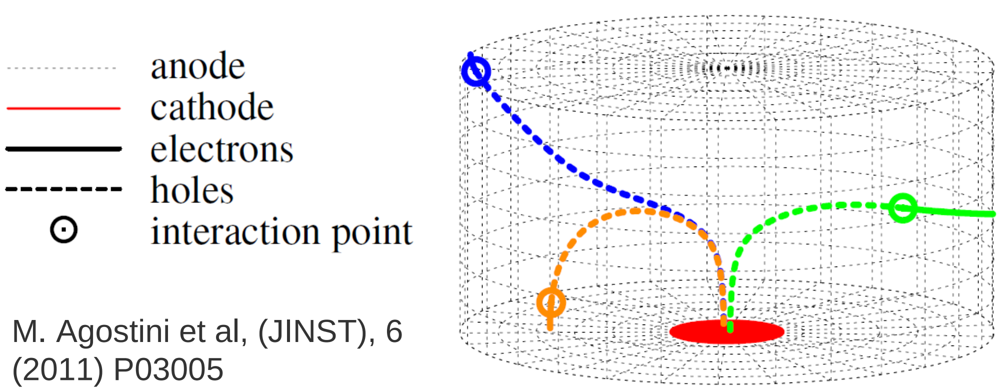
Broad Energy Germanium detector (BEGe)

- **Smaller size** compared to the Phase I coax. detectors
- Smaller size of **read-out-electrode**
  - Lower capacitance
  - Lower noise
  - Better **energy resolution** (~ 1.75 keV @ 1.33 MeV)
- Enhanced **pulse shape discrimination** performance due to peculiar electric field created by the small contact
  → Allows in particular to discriminate **single-site events** (0νββ-decay-like) from **multi-site events** (gamma-ray background events)





(b) Charge and current pulses



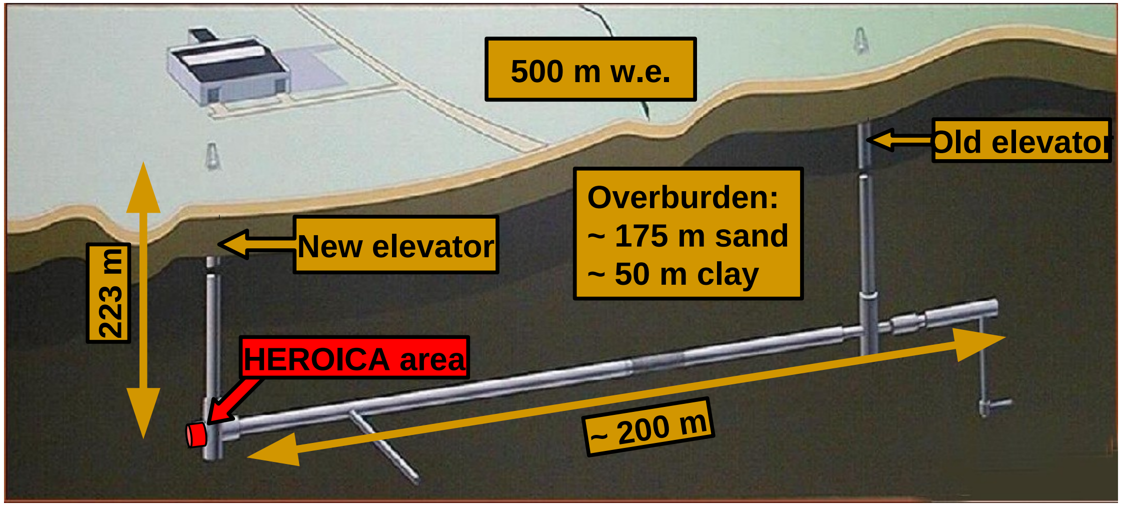
M. Agostini et al, (JINST), 6 (2011) P03005

Acceptance tests of enriched BEGe detectors

- Determine all the important **detector parameters** of our 30 BEGe detectors, like depletion voltage, **detector active volume**, dead layer uniformity over the surface, charge collection uniformity and test the performance of the diodes in terms of energy resolution and quality of pulse shape discrimination
- Do the detectors fulfill our requirements and the specs of the manufacturer?
- **Complete characterization** of the detector properties prior to their installation in the GERDA experiment

HADES - High Activity Disposal Experimental Site

- Location for **acceptance testing** and **storage** of the diodes
- Located in at the Belgian Nuclear Research Center SCK•CEN, Mol, Belgium



Importance of Active Volume determination for GERDA

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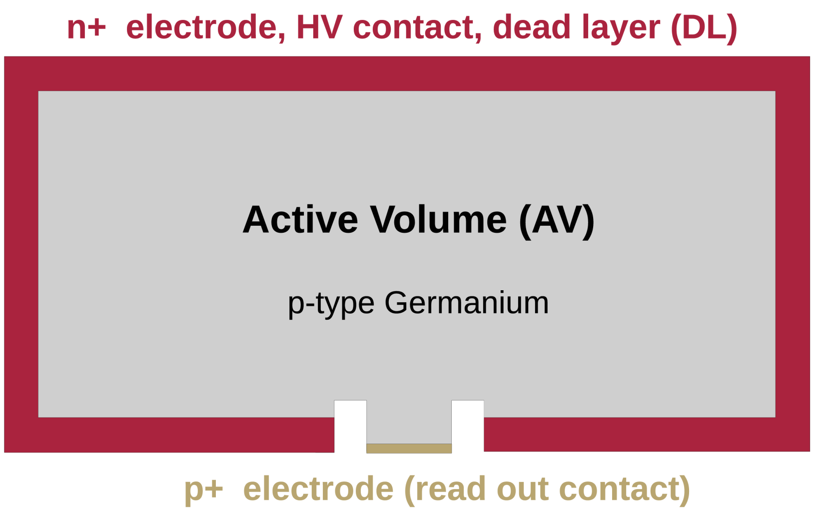
- The goals of GERDA
  - Determination of the **0νbb half life** or improved lower limit with high precision
  - Measure the half life of **2νbb** with high precision
- The **Active Volumes** of the detectors and therefore the Active Masses affect the value for the half life and the **uncertainties** contribute to the **systematic errors**



Active volume fraction

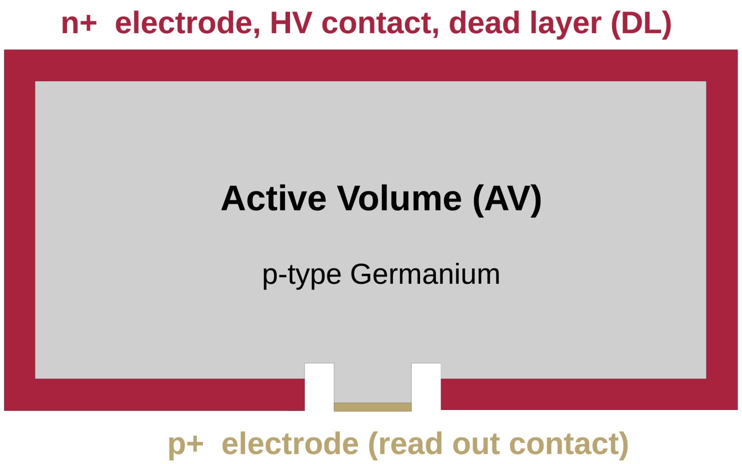
$$T^{0\nu}_{1/2} \propto a\,\epsilon\,\eta\sqrt{\frac{Mt}{B\,\Delta E}}$$

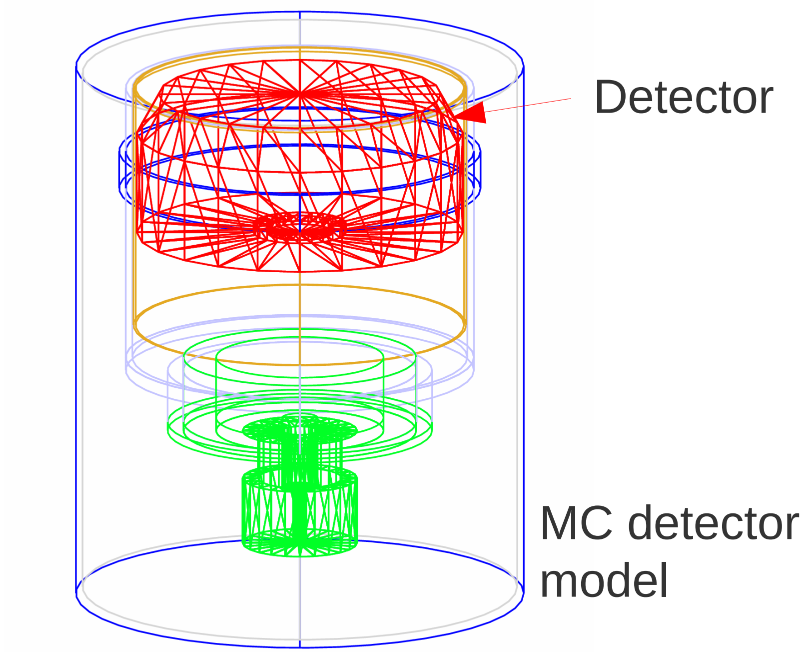
- a = istotopic abundance
- ϵ = detection efficiency
- η = active volume fraction
- Mt = exposure
- B = background index
- ΔE= energy resolution

Precise knowledge of Active Volumes is very important for the GERDA physics analysis

How to measure the Active Volume?

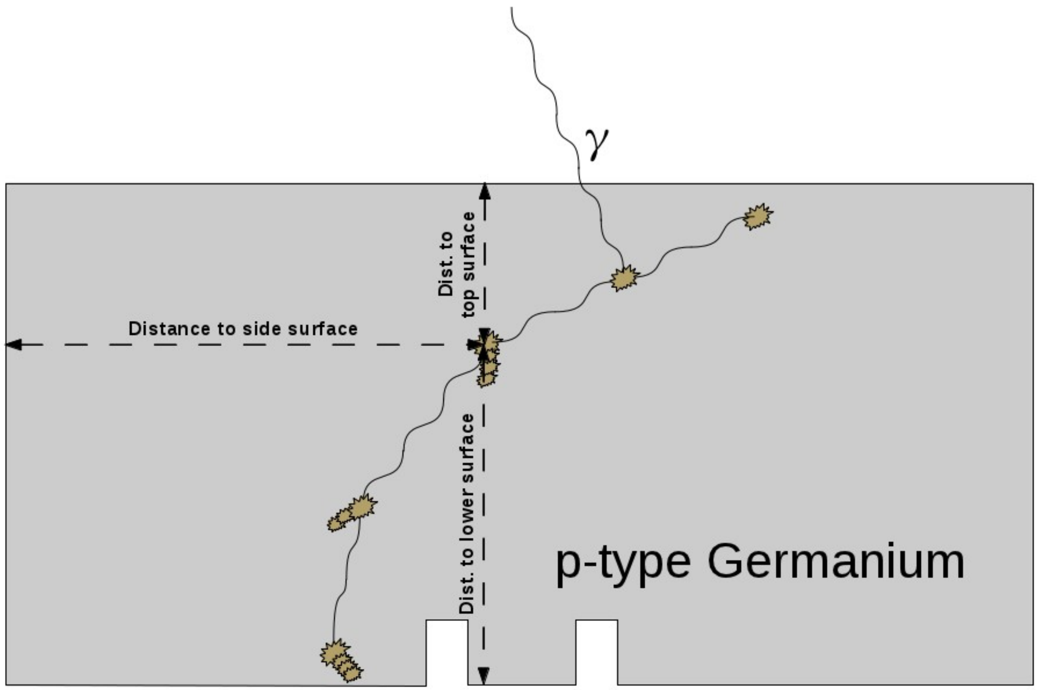
- Li-diffused n+ contact.
- No depletion in this outer layer.
  → Dead layer in the range of 0.5 – 1.0 mm
- The Boron implanted contact is negligible, ~ 0.6 µm
- Dead layer defines AV of the detector
- **How can the DL thickness be measured?**
  - DL cannot be measured from the Li diffusion process.
  - **The Idea:** Compare experimental γ-spectrum with MC spectra obtained with different DL thicknesses
  - MC spectrum which fits best to the experimental spectrum defines the DL
  - **Possible observables:** peak counts, ratios of peak counts, the full spectrum, ...



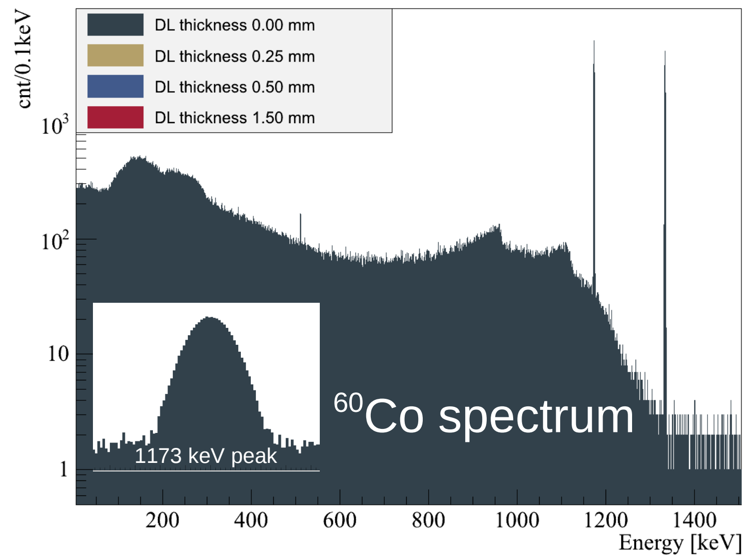


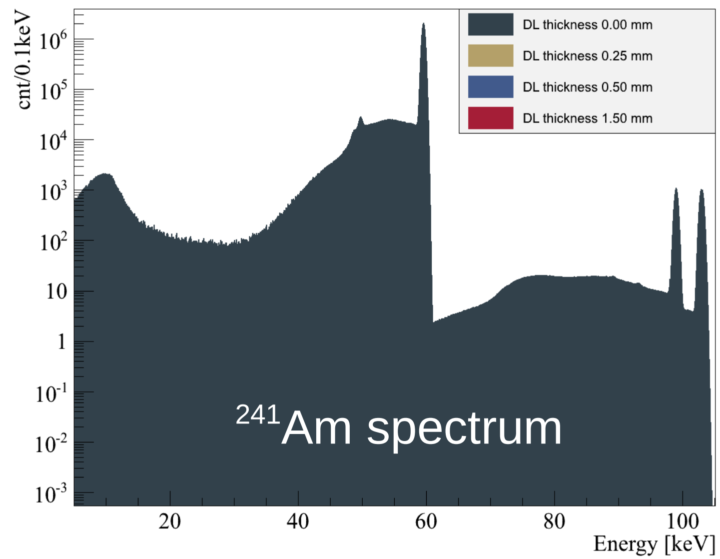
Dead layer postprocessing (DLPP)

- **One** MC simulation **without dead layer** for every detector, instead of many simulations with different DL's
- Save **hit positions** and **energies** for every event



Spectra corresponding to different DL thicknesses





Dead layer postprocessing (DLPP)

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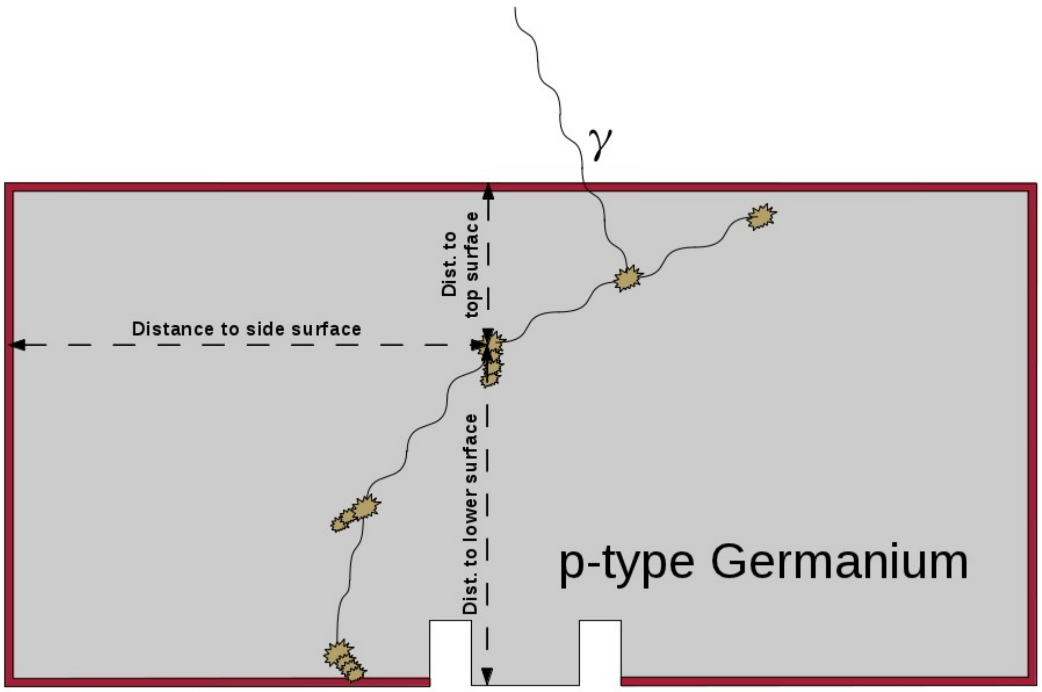
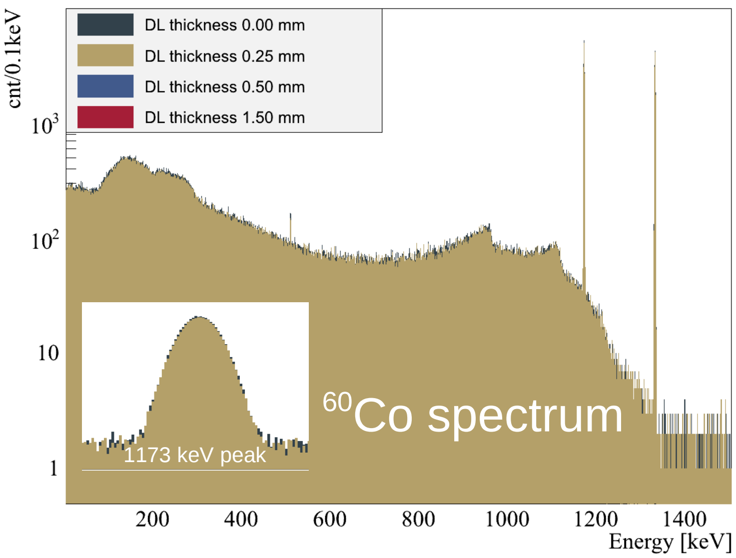
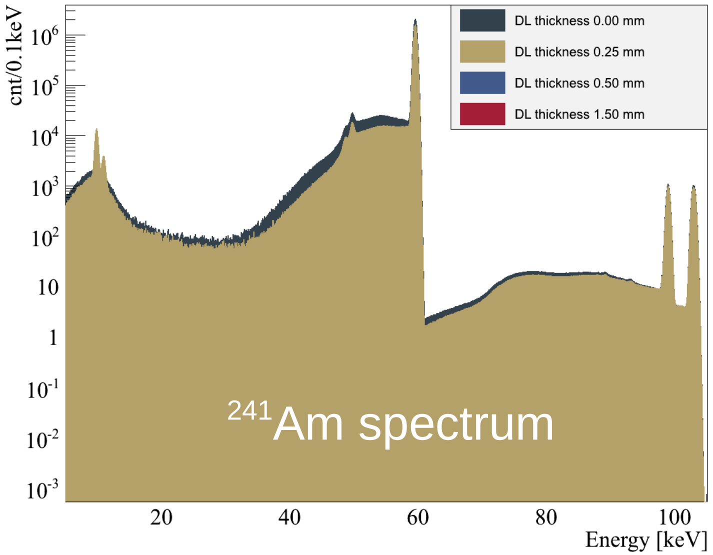
- **One** MC simulation **without dead layer** for every detector, instead of many simulations with different DL's
- Save **hit positions** and **energies** for every event
- Reconstruct the energy and generate the MC spectra for different DL thicknesses by **volume cuts** in the postprocessing step



Spectra corresponding to different DL thicknesses





Dead layer postprocessing (DLPP)

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- **One** MC simulation **without dead layer** for every detector, instead of many simulations with different DL's
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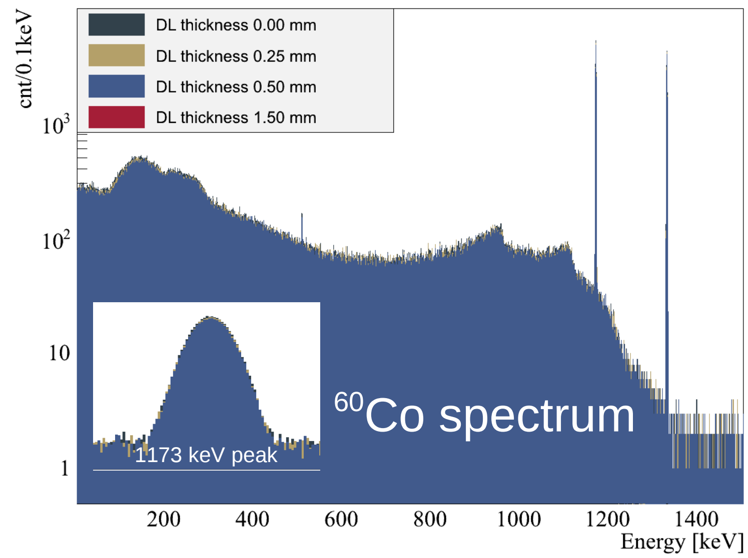
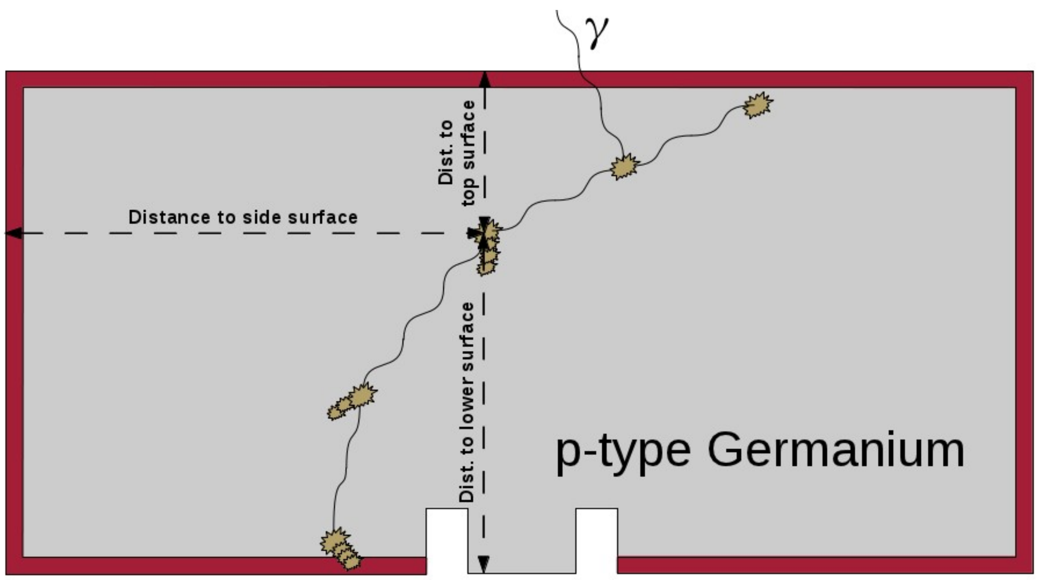
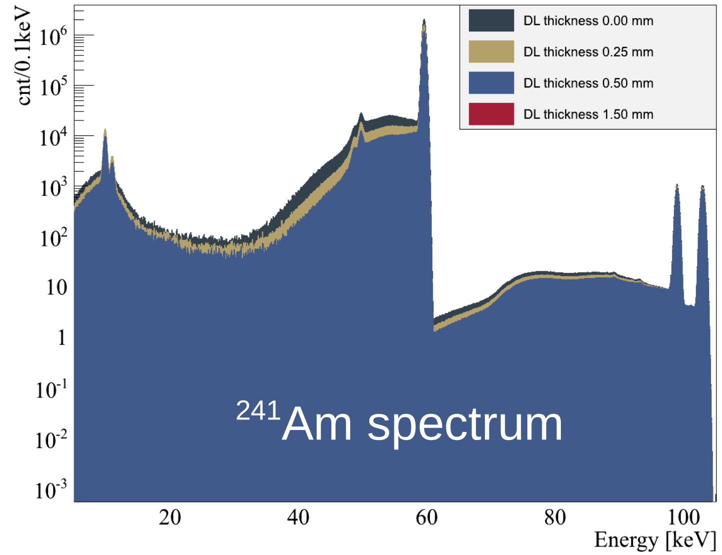
  → Cut hits in the DL

Spectra corresponding to different DL thicknesses



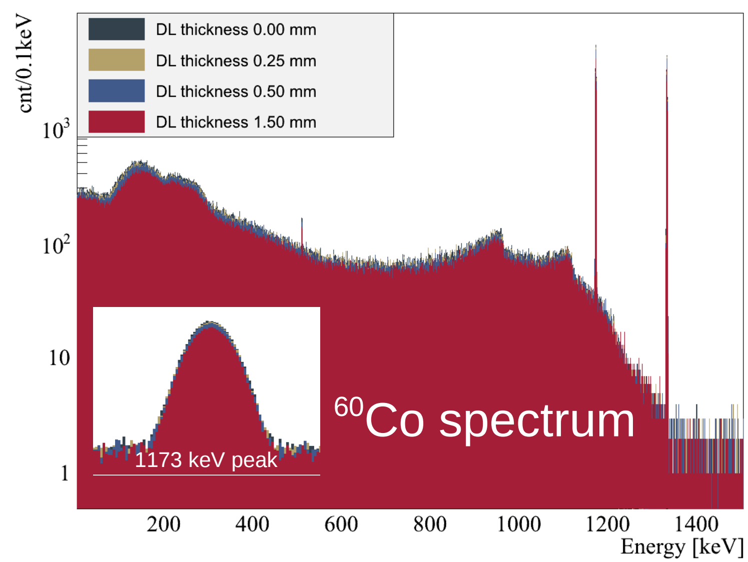


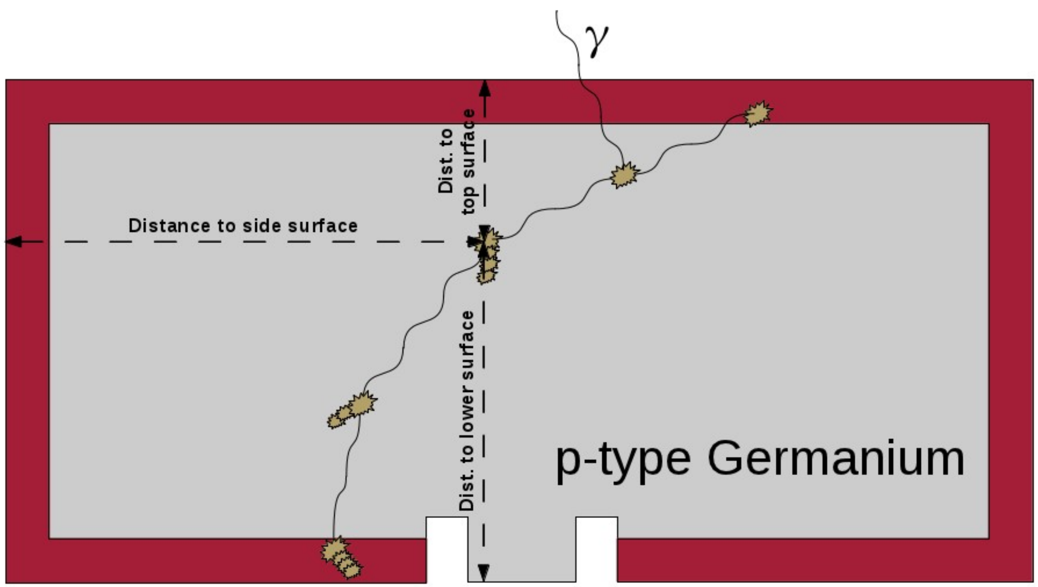


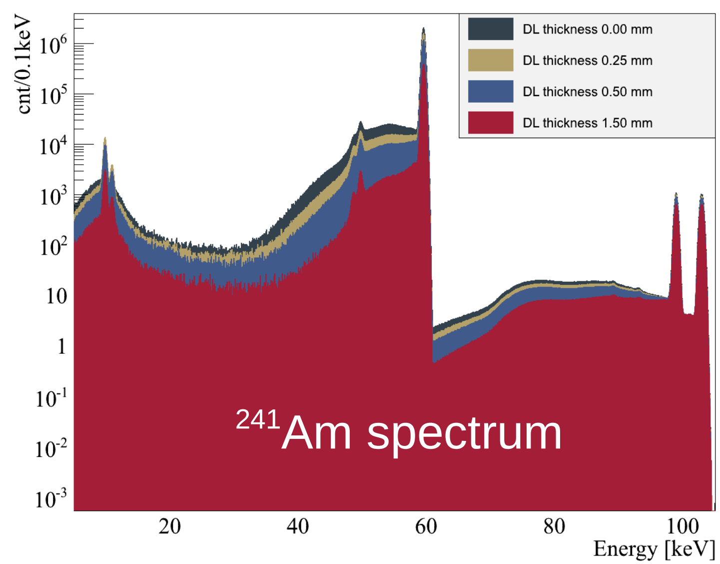
Dead layer postprocessing (DLPP)

- **One** MC simulation **without dead layer** for every detector, instead of many simulations with different DL's
- Save **hit positions** and **energies** for every event
- Reconstruct the energy and generate the MC spectra for different DL thicknesses by **volume cuts** in the postprocessing step
  → Cut hits in the DL
- 150 DL variations from 0 – 1.5 mm

Spectra corresponding to different DL thicknesses

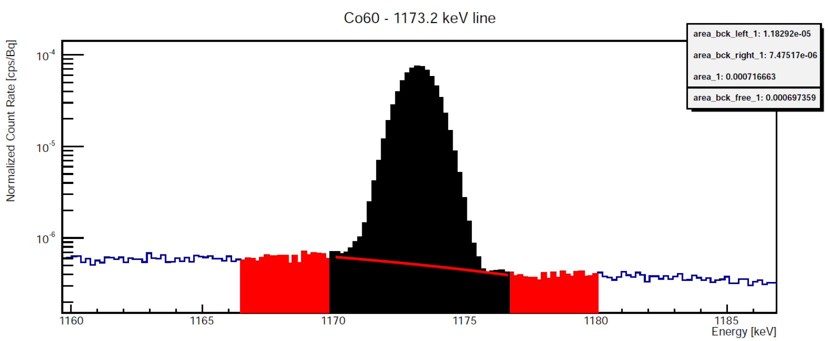


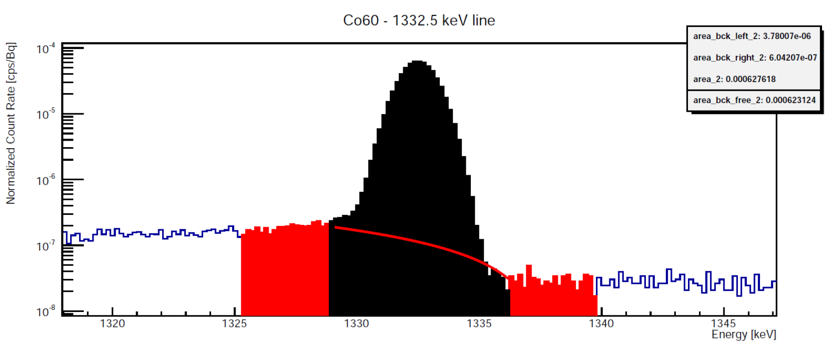


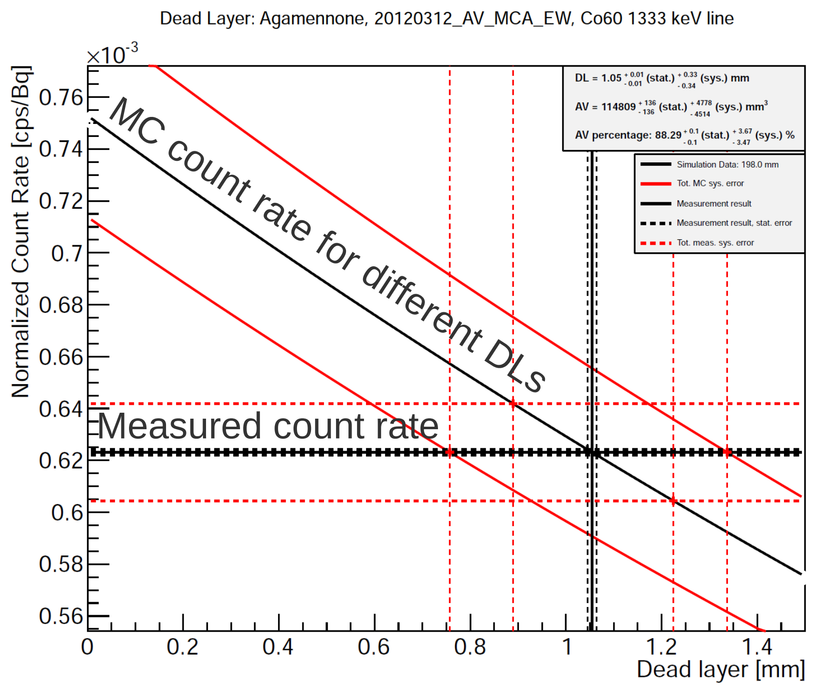


Active Volume determination using ^{60}Co

- Use the two energetic γ-lines of ^{60}Co (1173 keV and 1333 keV)
- DL determined by comparing the experimental peak count rate with the MC simulation
- The intersection between MC rate as function of the DL and the measured rate defines the DL of the detector
- Calculate AV by geometrical function, assuming a homogeneous DL





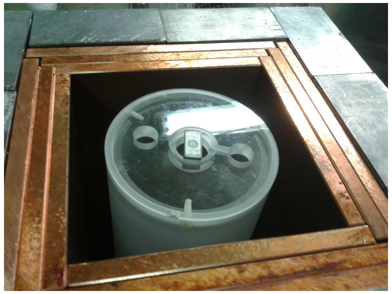


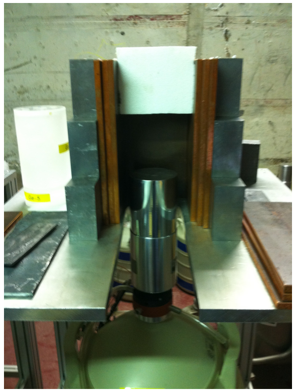
Avg. upper surface dead layer determination using ^{241}Am

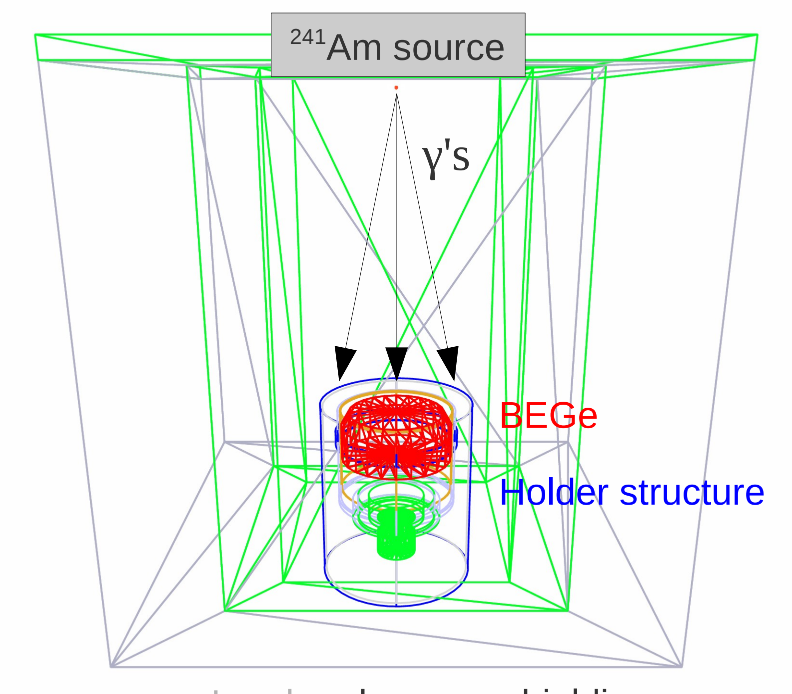
- Simulate three γ-lines of ^{241}Am
- Calculate the Ratio:

$$\frac{Counts(59.5\,keV)}{Counts(99\,keV)+Counts(103\,keV)}$$

- DL determined by comparing the experimental ratio of the γ-lines with the corresponding MC ratio
- The intersection between MC ratio as a function of the DL and the experimental ratio defines the average upper surface DL of the detector
  → Calculate AV by geometrical function, assuming a homogeneous DL thickness







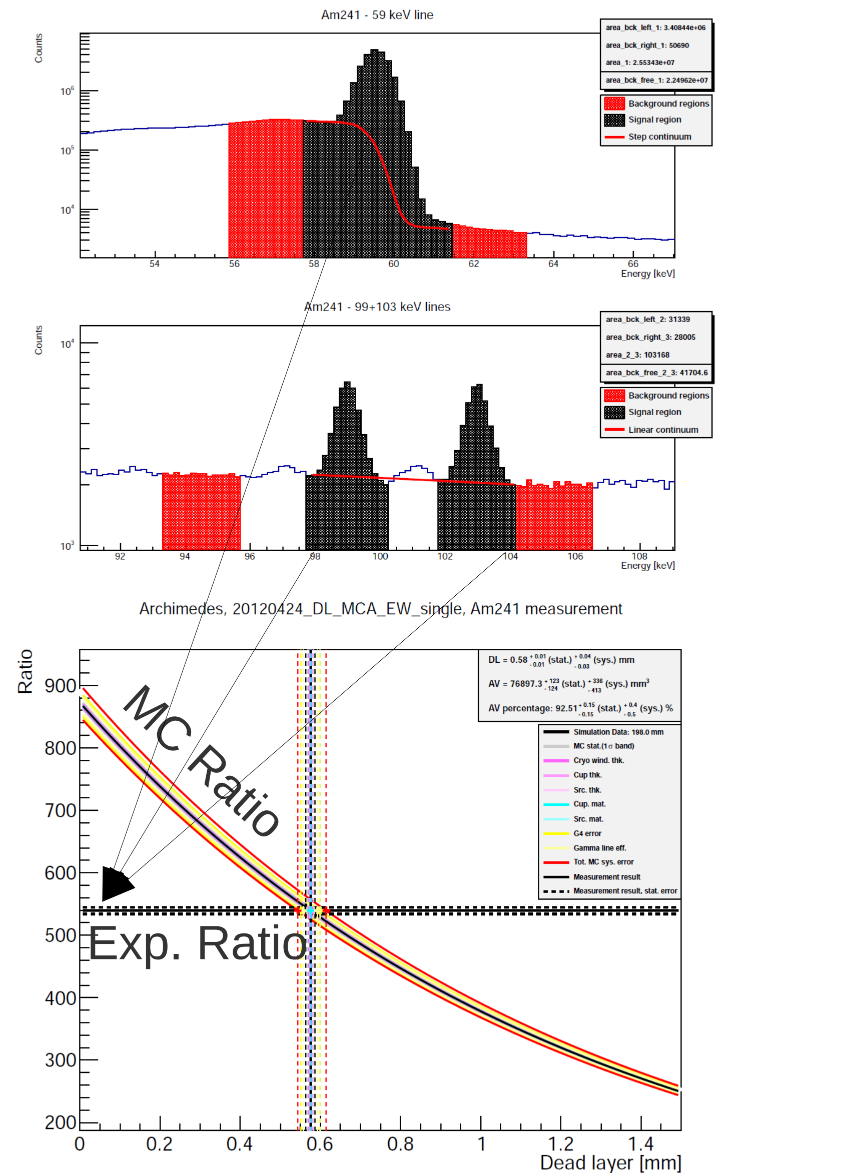
Lead and copper shielding

Avg. upper surface dead layer determination using ^{241}Am

- Simulate three γ-lines of ^{241}Am
- Calculate the Ratio:

$$\frac{Counts(59.5\,keV)}{Counts(99\,keV)+Counts(103\,keV)}$$

- DL determined by comparing the experimental ratio of the γ-lines with the corresponding MC ratio
- The intersection between MC ratio as a function of the DL and the experimental ratio defines the average upper surface DL of the detector
  → Calculate AV by geometrical function, assuming a homogeneous DL thickness



Comparison of peak-counts (bulk) and ratio method (upper surface)

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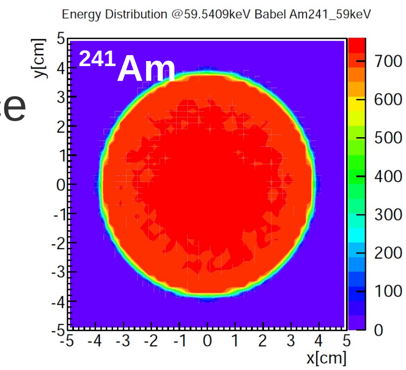
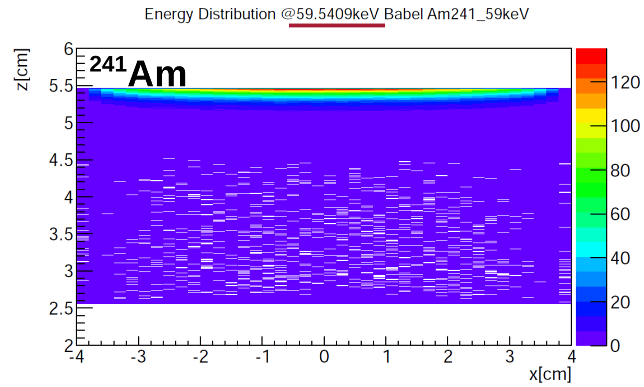
Top view **Lateral view**

Ratio method with ^{241}Am

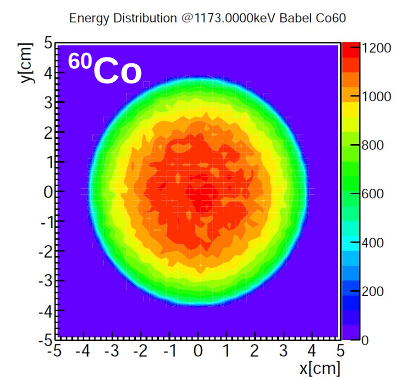
- ^{241}Am γ's only penetrate upper surface
  → Only upper surface (top DL) is probed
  → Gives upper surface DL

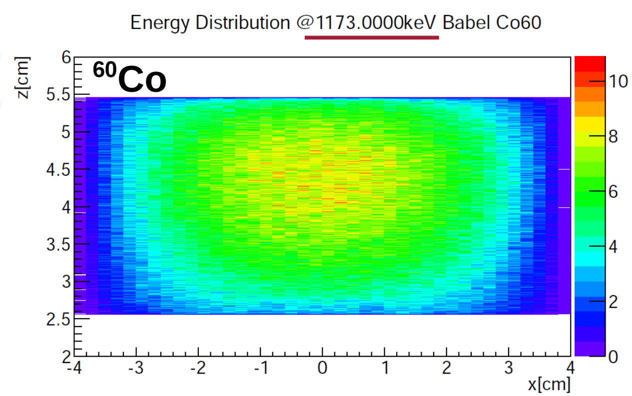




Peak-Counts method with ^{60}Co

- ^{60}Co is sensitive to the whole detector volume
  → γ's also penetrate into bulk
  → Probes also side and bottom DL





DL/AV values are only correct if the assumption of a homogeneous DL thickness is correct

Comparison of peak-counts (bulk) and ratio method (upper surface)

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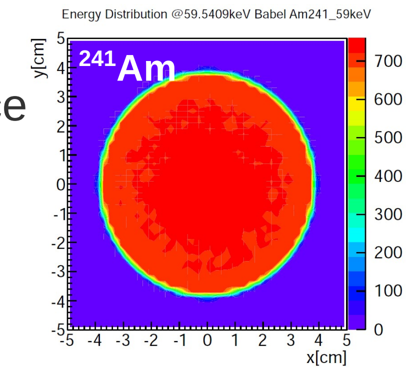

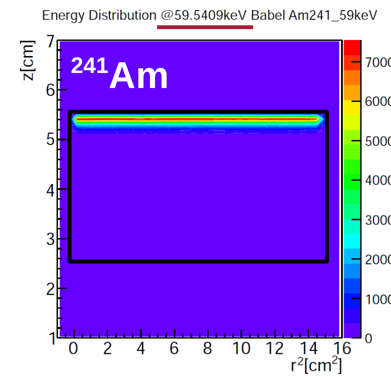

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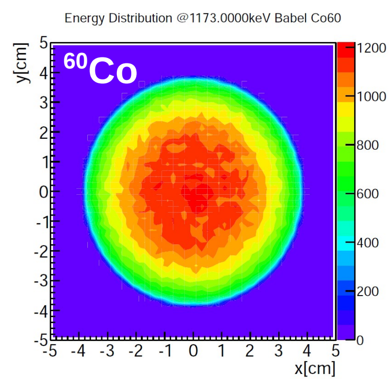

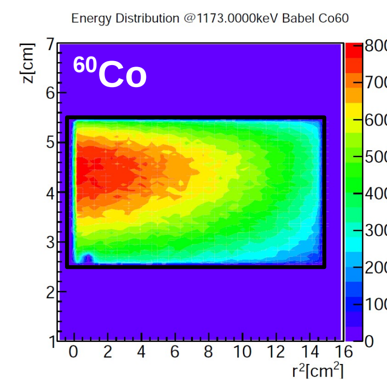

DL/AV values are only correct if the assumption of a homogeneous DL thickness is correct

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Systematics for ^{60}Co

	Systematic uncertainty	^{60}Co Peak counts
MC	MC statistics	~ 0.1 %
	Geant4 physics processes	4.00 %
	Gamma line probabilities	0.03 % (0.0006 %)
Source	Source geometry (thickness)	0.02 %
	Source material	0.01 %
	Source distance	1.20 %
	Source activity	1.00 %
Detector	Diode dimensions	2.50 %
Cryostat	Diode distance to endcap	1.00 %
	Cryostat endcap thickness	0.15 %
	Cryostat detector cup thickness	0.06 %
	Cryostat detector cup mat	0.03 %
DAQ	Shaping time	0.2 %
	DAQ dead time	5/10 % on deadtime
Statistics	**Stat. uncert.** from measurement	Typically ~ 0.5-1.0 %

Systematics for ^{60}Co

MC

Source

Detector

Cryostat

DAQ

Statistics

Systematic uncertainty	^{60}Co Peak counts
MC statistics	~ 0.1 %
Geant4 physics processes	4.00 %
Gamma line probabilities	0.03 % (0.0006 %)
Source geometry (thickness)	0.02 %
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Diode dimensions	2.50 %
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Cryostat endcap thickness	0.15 %
Cryostat detector cup thickness	0.06 %
Cryostat detector cup mat	0.03 %
Shaping time	0.2 %
DAQ dead time	5/10 % on deadtime
Stat. uncert. from measurement	Typically ~ 0.5-1.0 %

Total **syst.** uncertainty propagated to **DL**:
~ 30 %

Propagated to **AV**:
~ 3.5%

Systematics for ^{241}Am

	Systematic uncertainty	^{241}Am Peak ratio
MC	MC statistics	~ 1 %
	Geant4 physics processes	2.00 %
	Gamma line probabilities	~ 1.5 %
Source	Source geometry (thickness)	~ 0.02 %
	Source material	0.014 %
Cryostat	Cryostat endcap thickness	0.31 %
	Cryostat detector cup thickness	0.03 %
	Cryostat detector cup mat	0.01 %
Statistics	**Stat. uncert.** from measurement	Typically 0.8-4.0 %

Systematics for ^{241}Am

	Systematic uncertainty	^{241}Am Peak ratio
MC	MC statistics	~ 1 %
	Geant4 physics processes	2.00 %
	Gamma line probabilities	~ 1.5 %
Source	Source geometry (thickness)	~ 0.02 %
	Source material	0.014 %
Cryostat	Cryostat endcap thickness	0.31 %
	Cryostat detector cup thickness	0.03 %
	Cryostat detector cup mat	0.01 %
Statistics	**Stat. uncert.** from measurement	Typically 0.8-4.0 %

Total **syst.** uncertainty propagated to **DL**:
~ 6%

Propagated to **AV**:
~ 0.5%

Summary

- Active volumes of the BEGe detectors are an important parameter for the GERDA Phase II physics analysis
- AV is determined via the DL with different methods (^{60}Co, ^{241}Am) by comparing experimental and MC spectra.
- Systematic uncertainties on the AV fraction are around ± 0.5 % for the ^{241}Am method and around ± 3.5 % for the ^{60}Co method
- Typical DL's of our detectors are between 0.5 and 1.0 mm
  → Around 89-94 % AV fractions
- Discrepancies between surface and bulk methods for many detectors observed
  → AV values obtained with ^{60}Co-method are systematically lower by (1-3 %) compared to the ^{241}Am surface probe result