Dead Layer and Active Volume Determination for GERDA Phase II

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DPG Spring Meeting
05/02/2013 Dresden

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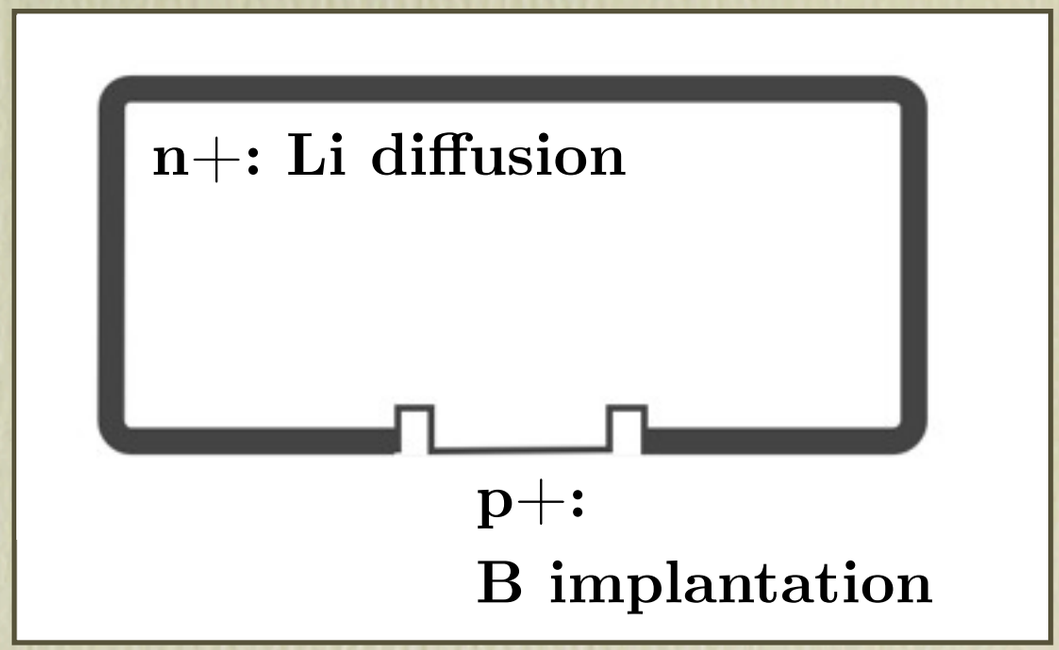
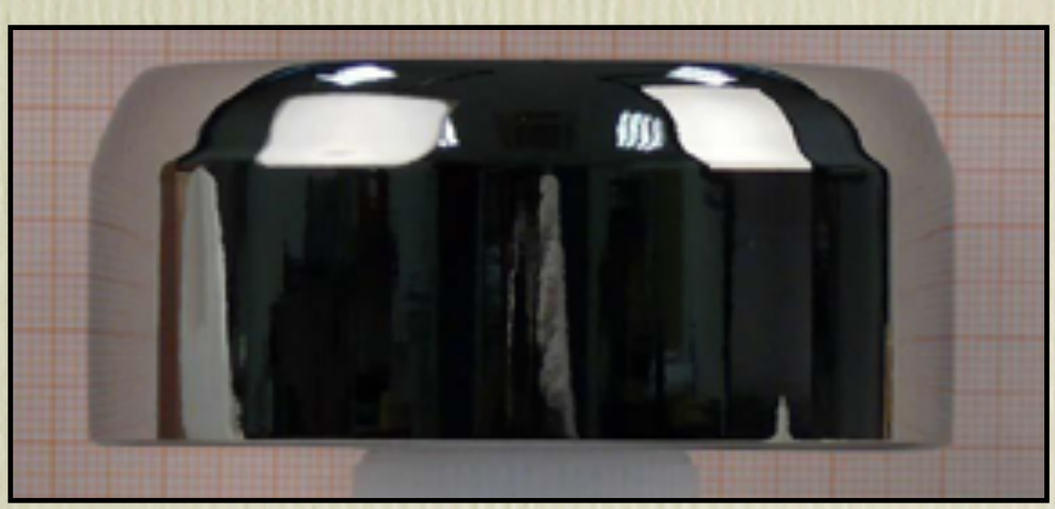
Dead Layer (DL) of BEGe Detectors

- Creating the contacts is the last production step
- n+ contact: Li is diffused in a bath. Then annealed in furnace: 0.5 - 1.0 mm DL
- p+ contact: B implantation with 75 keV ion beam: 0.6 microns DL





- **Thick n+ DL determines active detector volume**
- **Cannot be determined from production process**

Active Volume (AV) of BEGe Detectors

DL = Dead Layer
AV = Active Volume

- The AV is essential for all GERDA physics analysis
- We measure the DL but we need to know the AV
- The AV uncertainty for Phase I coaxial detectors is the dominating systematic uncertainty (5%) arXiv:1212.3210 [nucl-ex]
- Measure 30 detectors in a short time

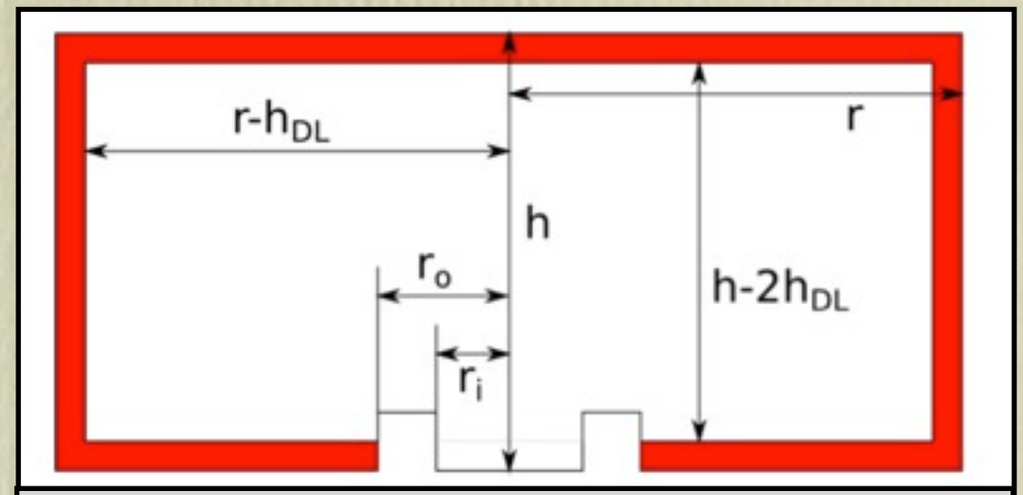
Outline

Part I: Methods

Part II: Systematic uncertainties

How to Measure the DL Thickness?

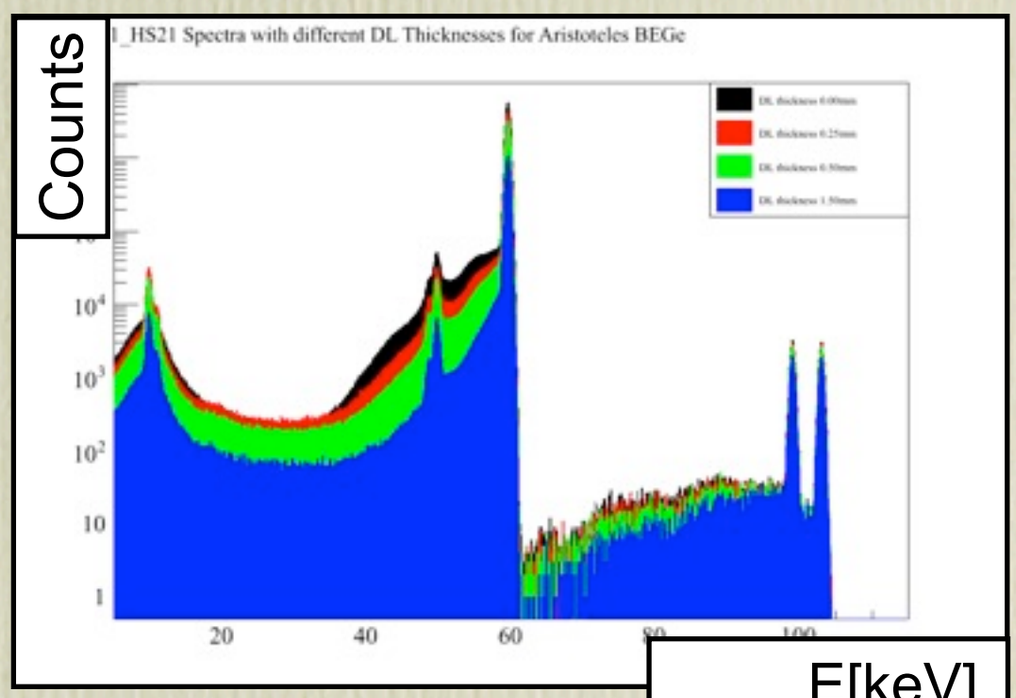
- Compare exp. spectrum with MC spectra with various DL thicknesses
- Choose MC spectrum that fits best the exp. spectrum.
- In spectrum: Choose good observable e.g. peak counts or ratio of peak counts



Assumption in MC: homogeneous n+ DL with various thickness

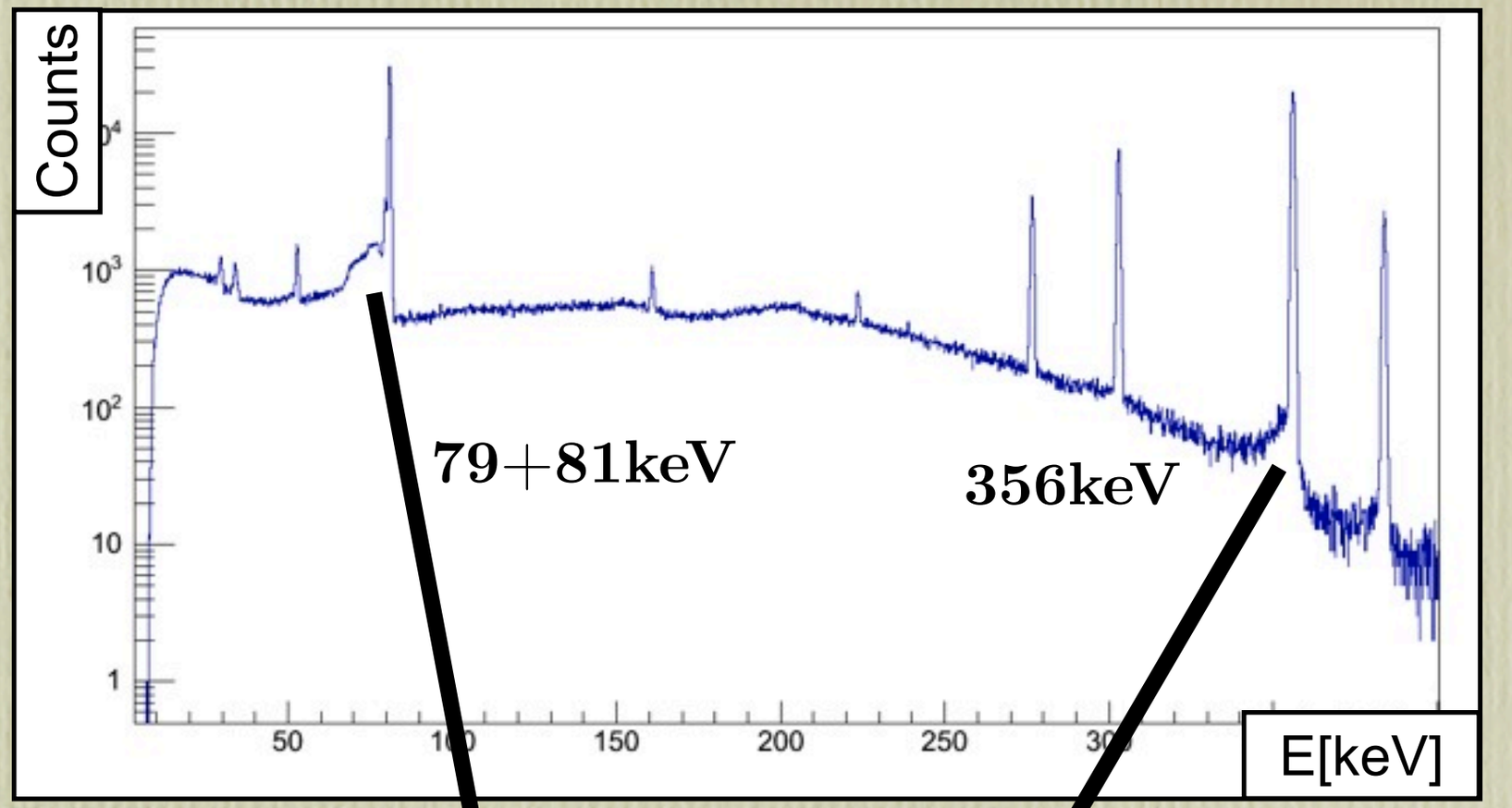
Monte Carlo & Dead Layer Post Processing

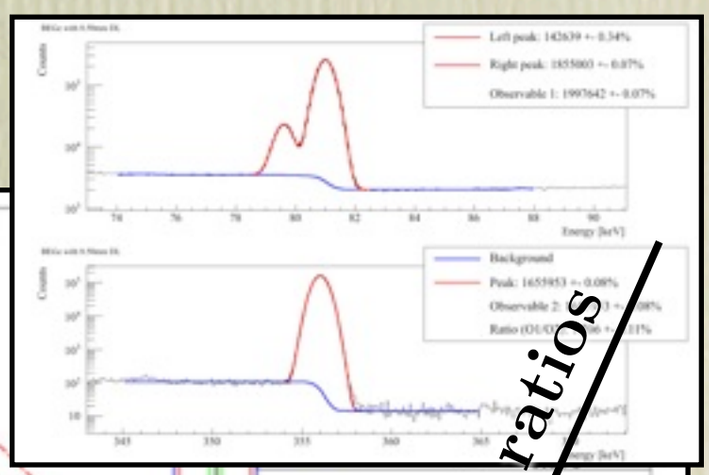
- One MC simulation with full hit information
  - Particle tracking down to 0.001mm / 250eV
- Posterior volume cuts for different DL thicknesses yields the respective MC spectra
  - 150 DL variations from 0 to 1.5mm

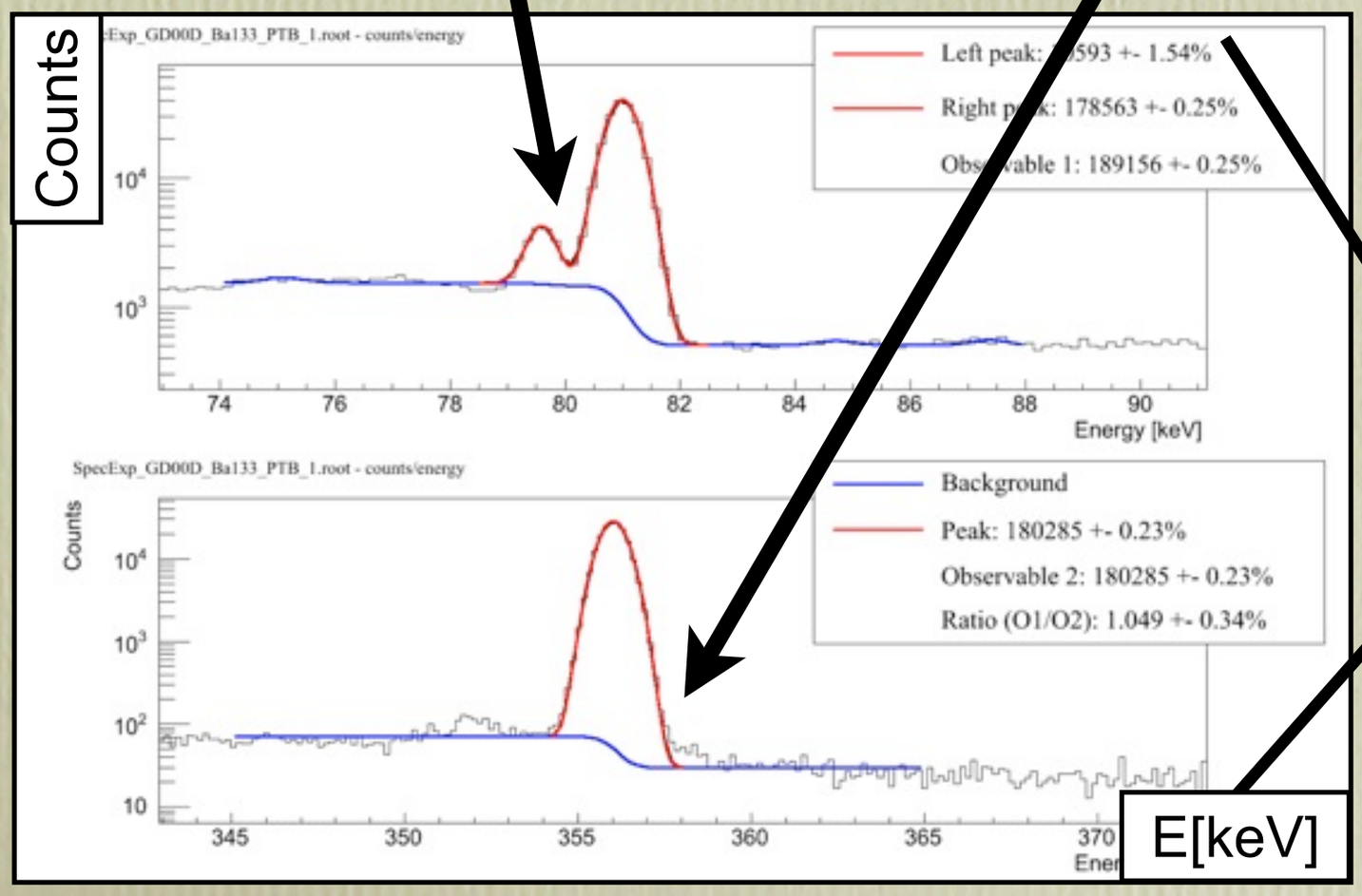


133Ba Source

- Ratio between peak counts in 79+81 keV and 356 keV
- First ROI has double peak structure
- Outdated gamma line efficiency in Geant4 is corrected

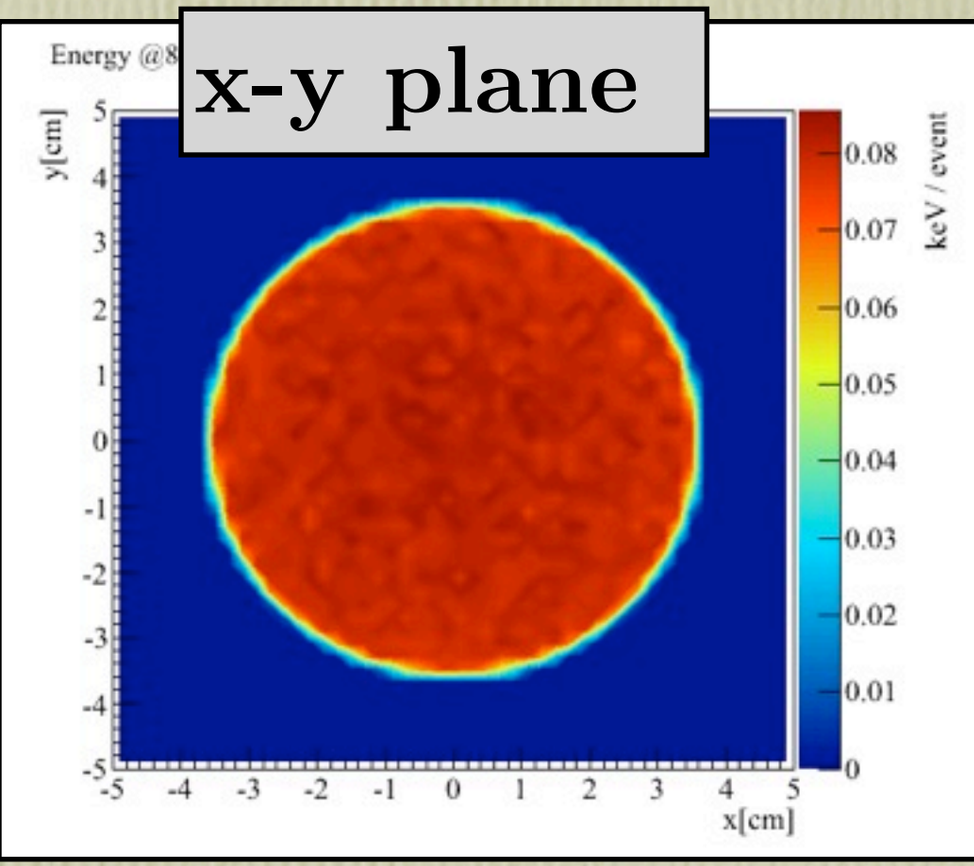




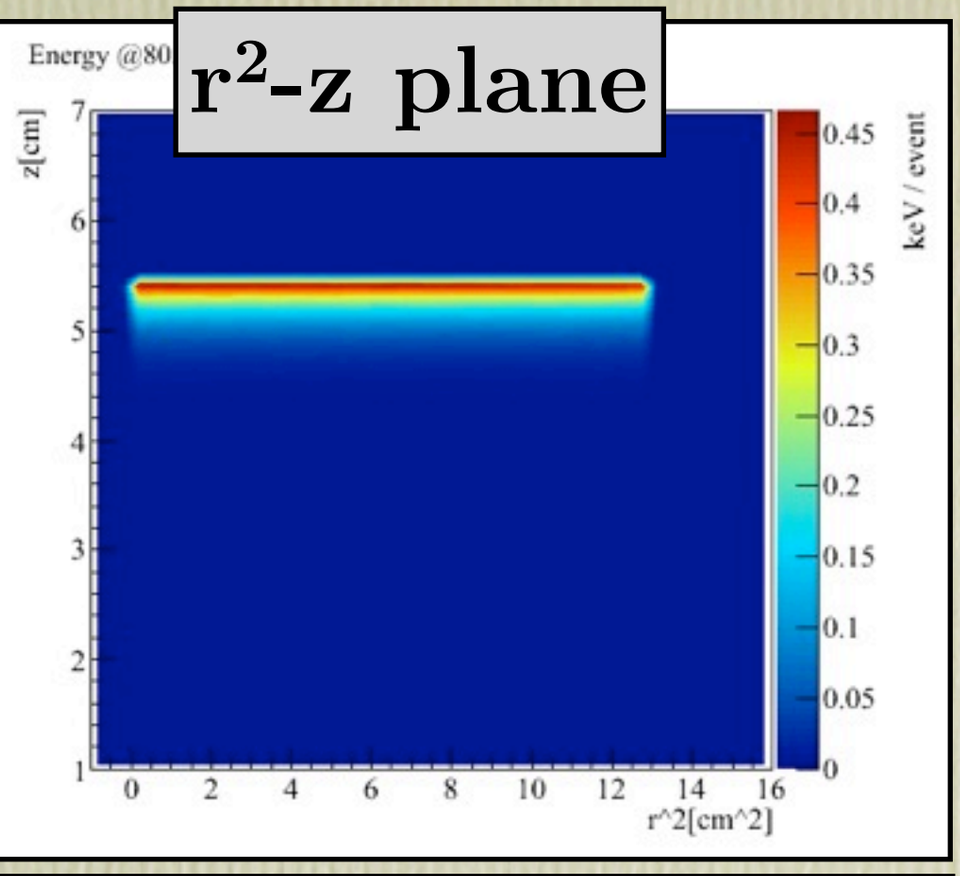


Energy Distribution inside a BEGe (133Ba)

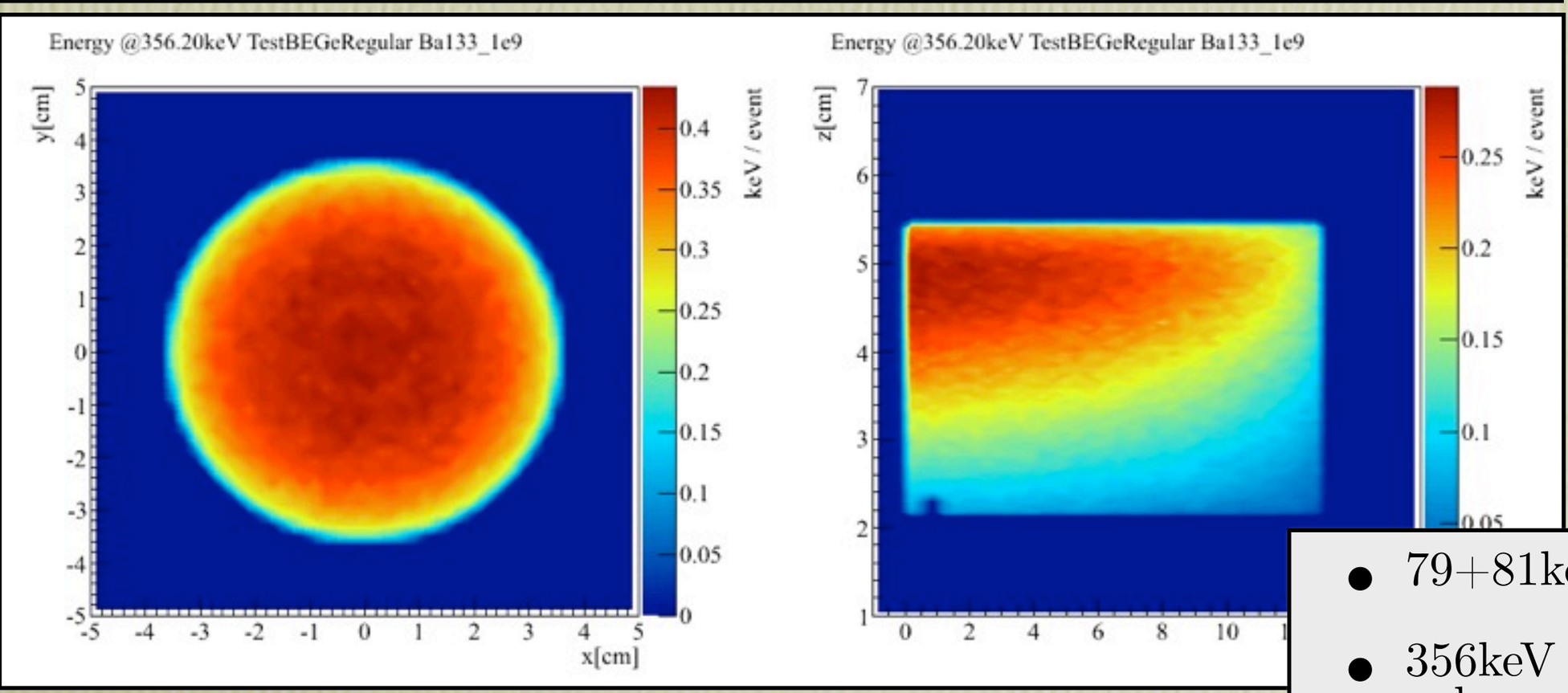
x-y plane



r^2-z plane



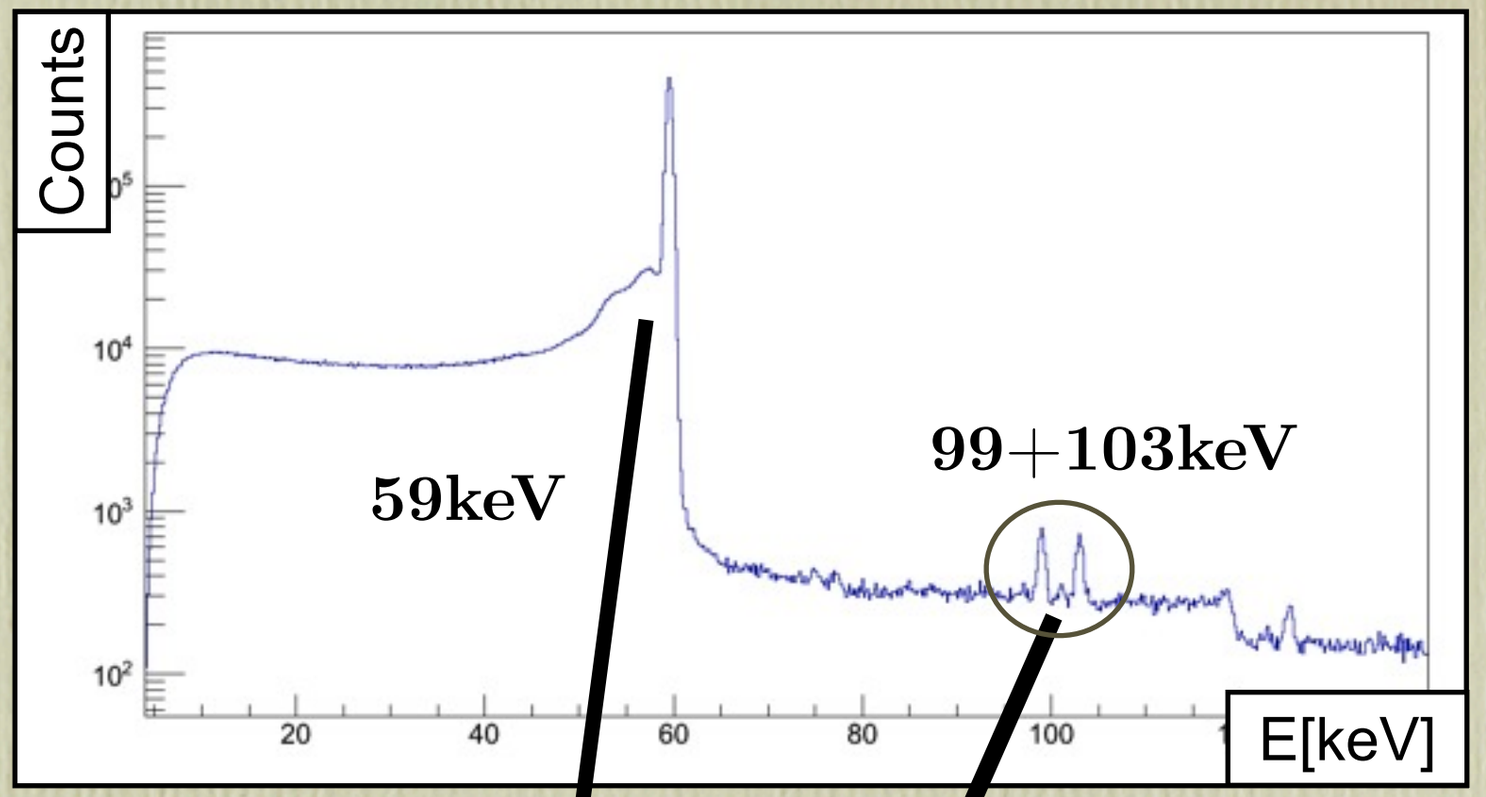
79+81 keV peak



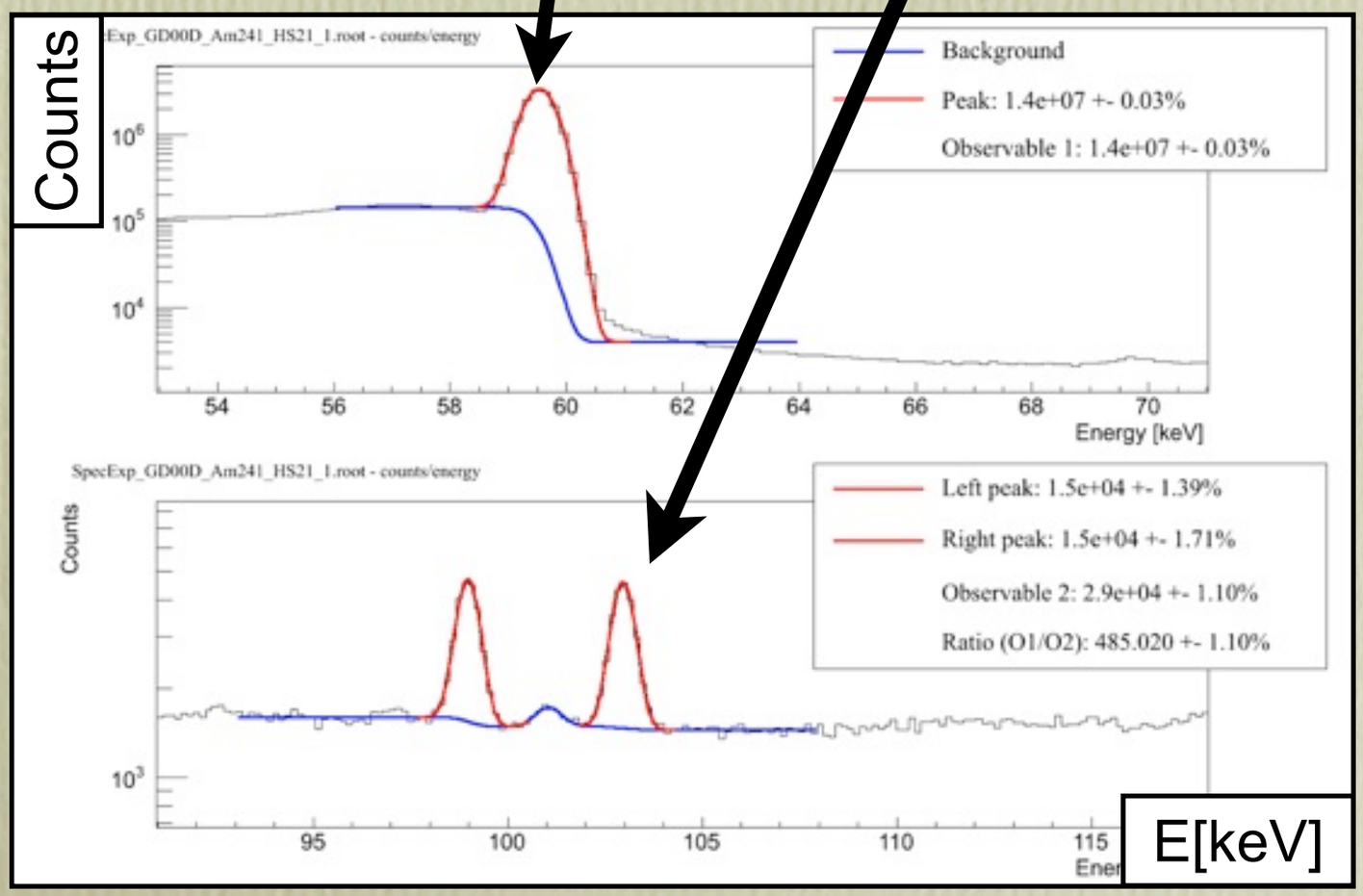
356 keV peak

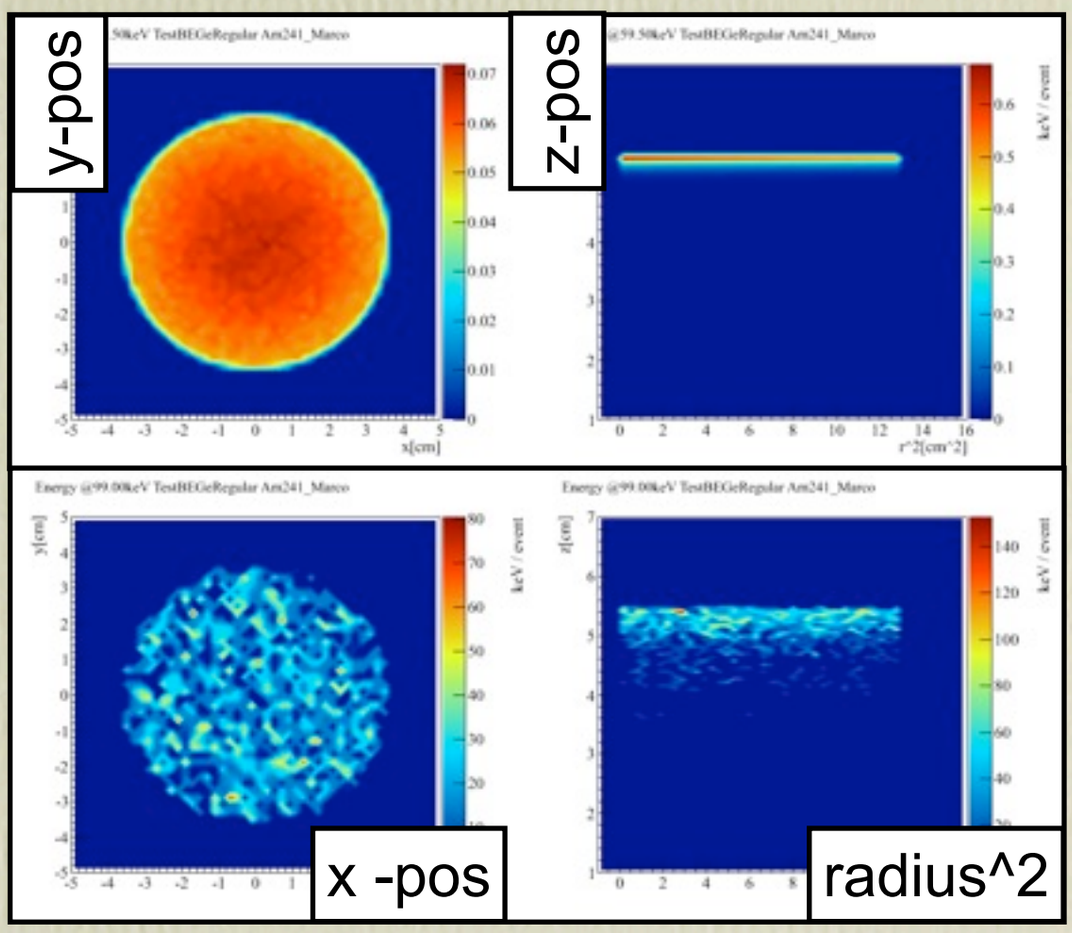
- 79+81keV probe the surface
- 356keV probes a part of the volume

241Am Source

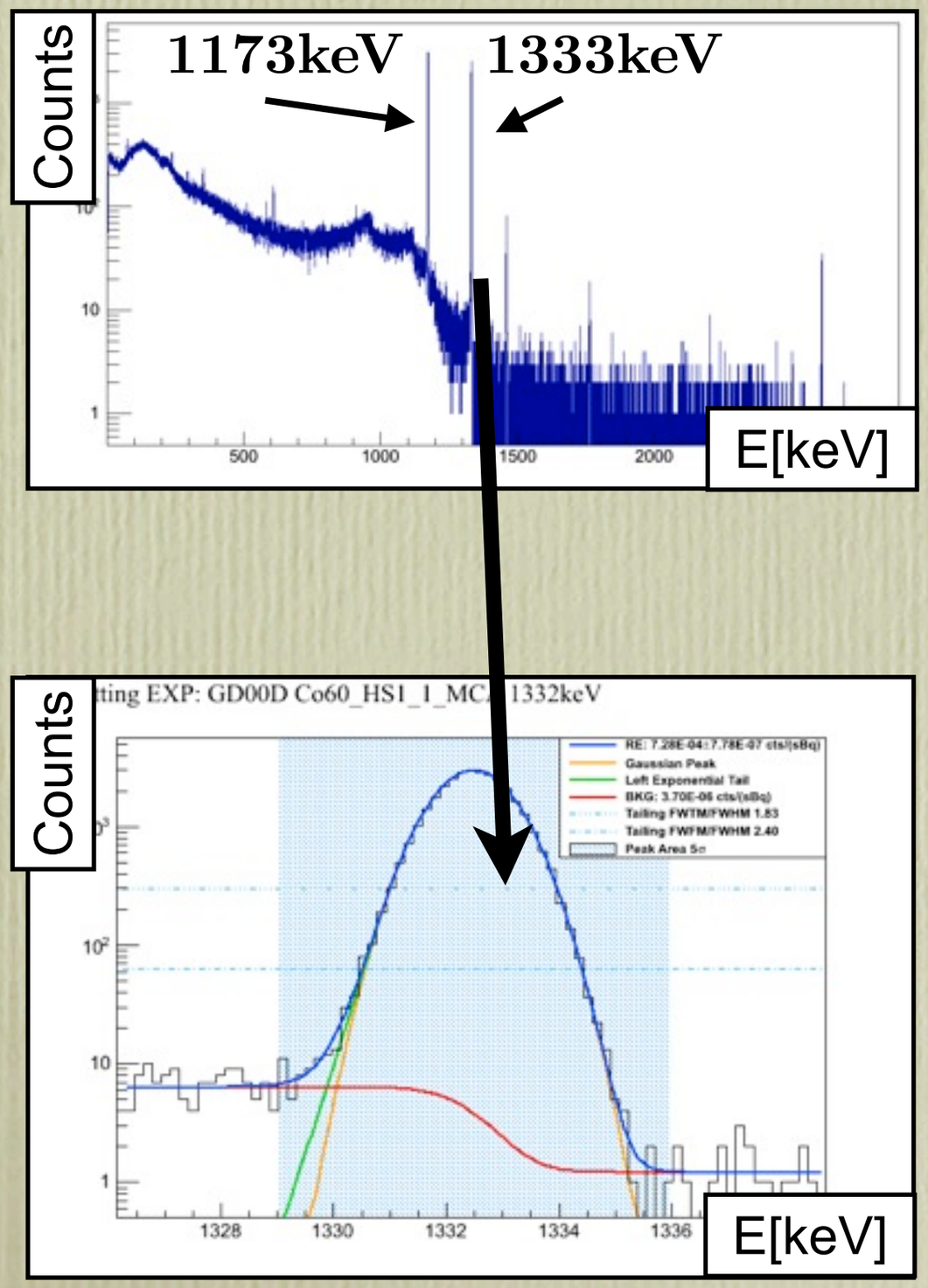


- Ratio between 59 keV and 99+103 keV peak
- Both peaks test only the upper DL surface
- Second double peak low probability (0.02%) and dominates statistical uncertainty

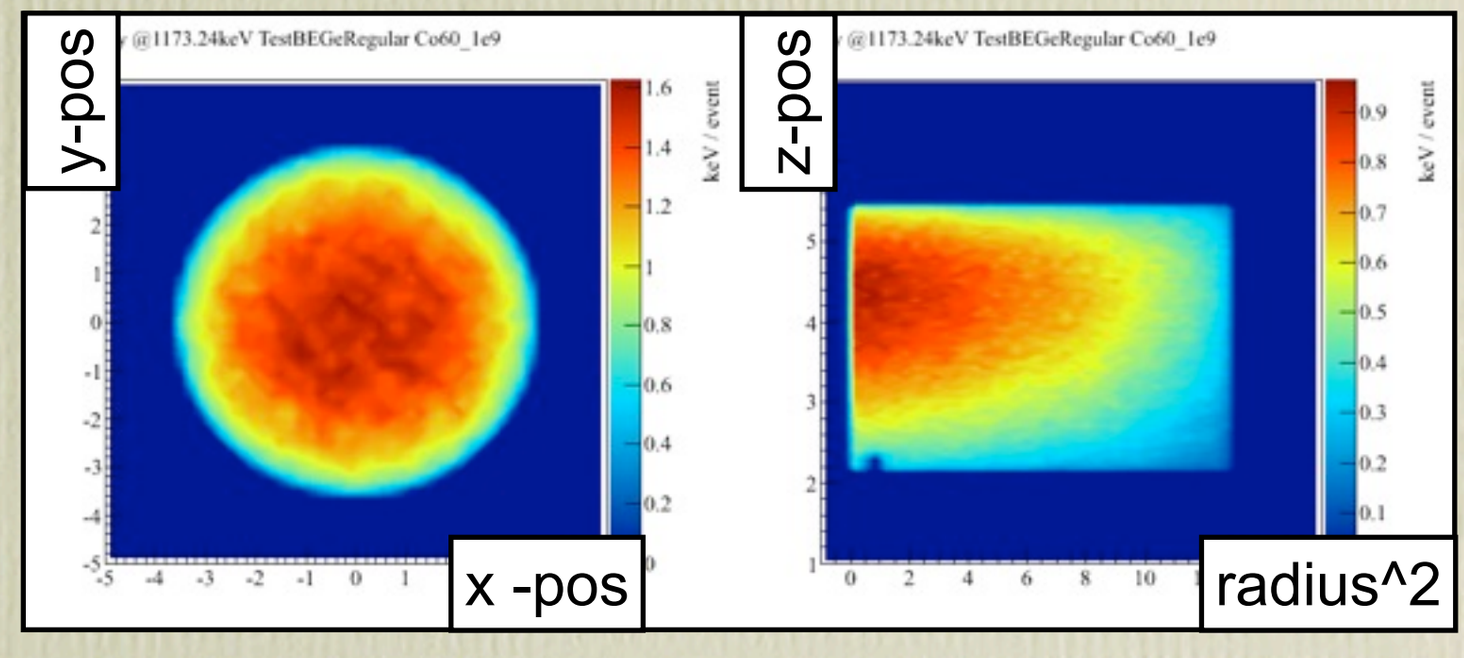




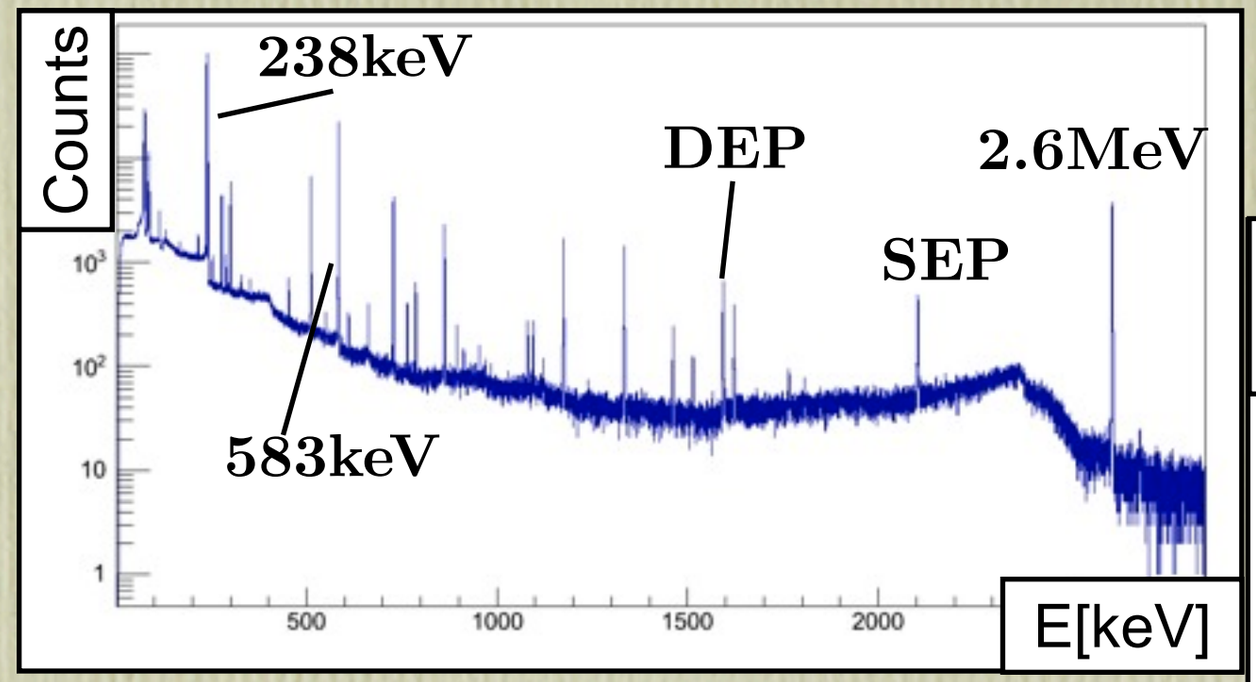
60Co Spectrum



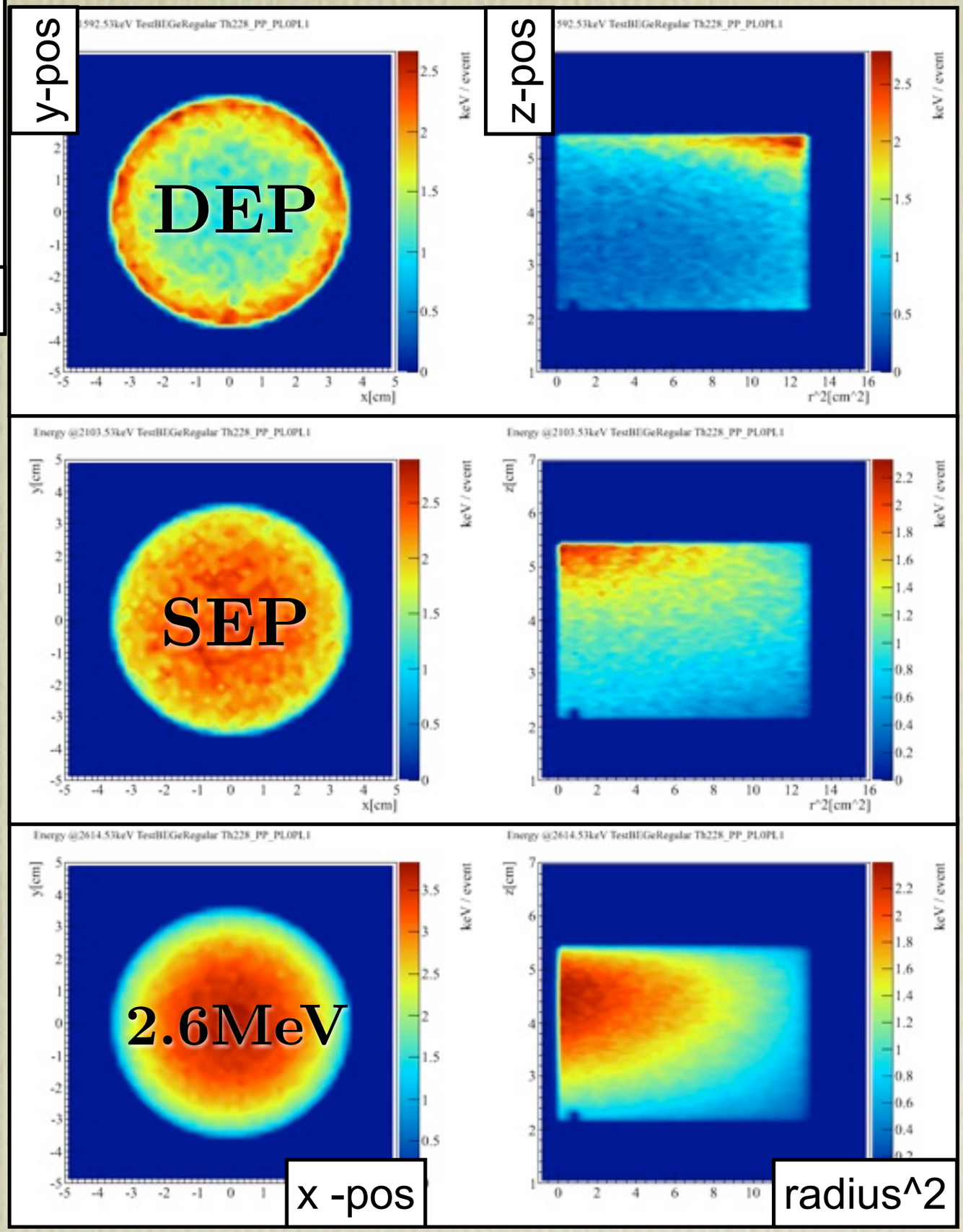
- Compare directly peak counts in MC and experimental spectrum
  - Large and many systematic uncertainties
- Both peaks 1173 keV and 1333 keV probe the volume but we infer a DL thickness
- DL/AV value is only correct if assumption of homogeneous DL thickness is correct



228Th Spectrum

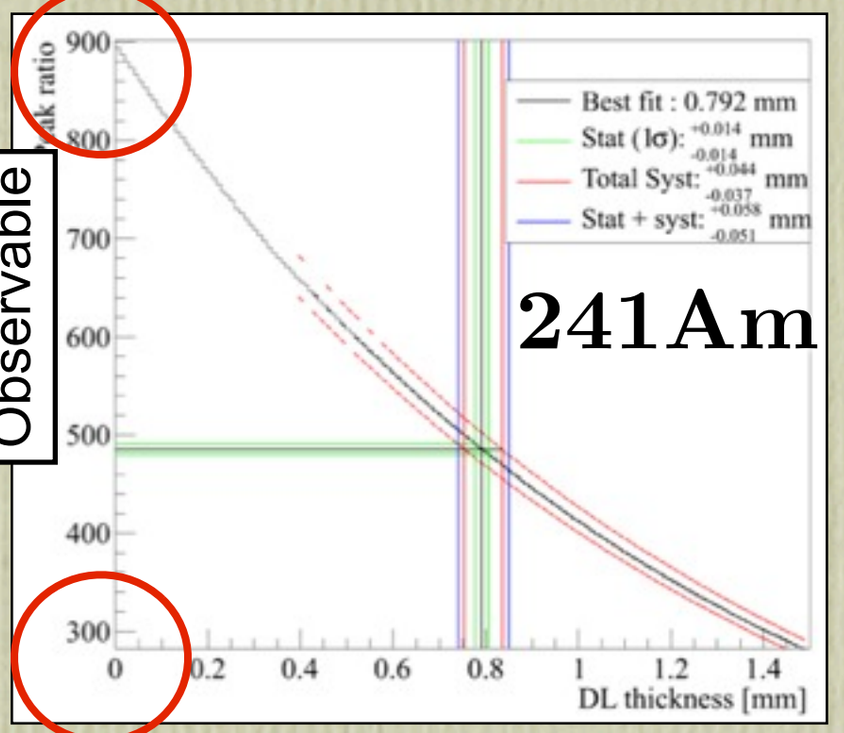


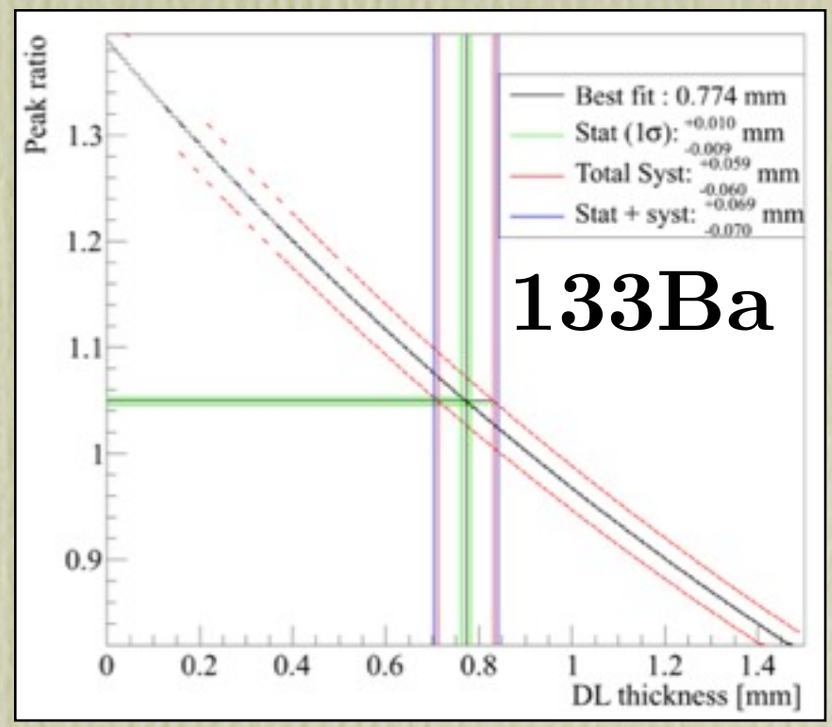
- Interesting probes possible:
  - DEP: probes mainly the corners of the detector
  - SEP: probes mainly the top volume of the detector
  - 2.6MeV probes the center volume
- No systematic uncertainties from the source and outside geometry

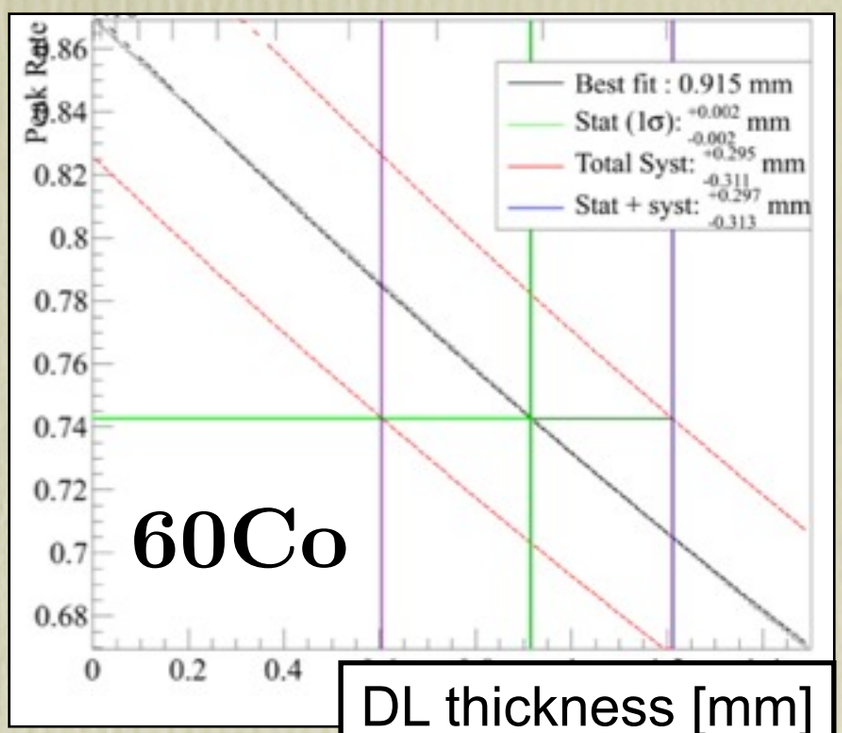


Propagation of Uncertainties

Relative change of observable between 0.0 and 1.5mm DL







Method	"Sensitivity"	What is probed
241Am 59keV / 100keV	67%	Surface only
133Ba 89keV / 356keV	39%	Surface vs top volume
60Co 1173keV or 1333keV	24%	Center volume
228Th 2.6MeV/DEP	13%	Center volume vs corner
228Th SEP/DEP	12%	Top volume vs corner

- **Systematics propagated from observable to DL to AV**

Different Systematics (example of one detector)

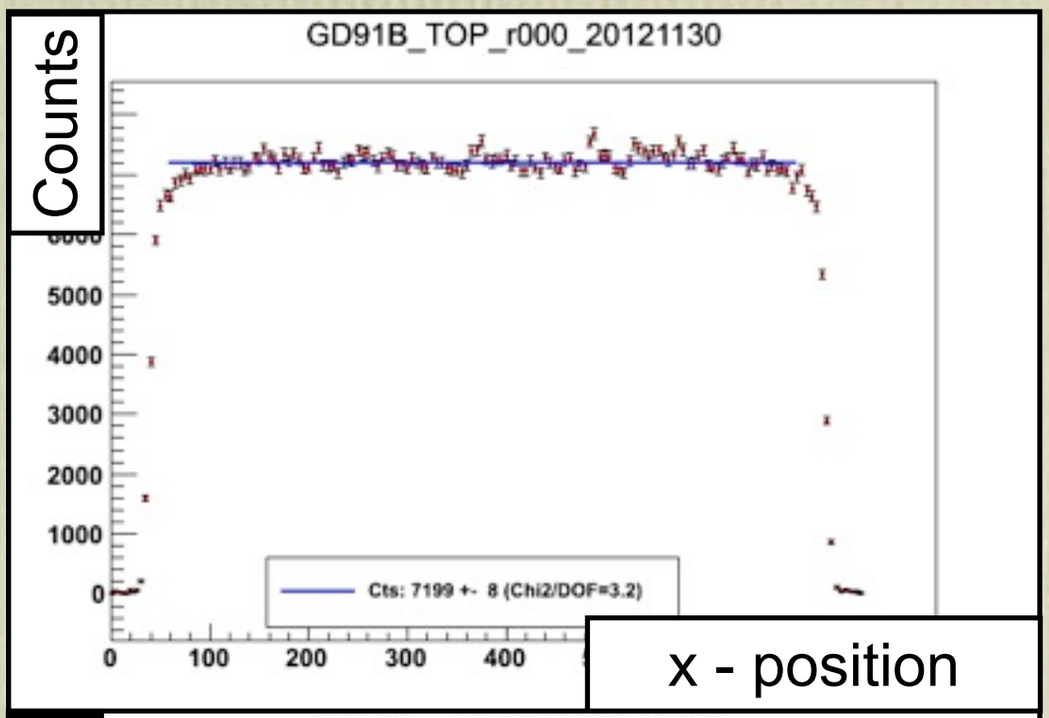
	Systematic +-DL[%]	133Ba	241Am	60Co
Monte Carlo	MC statistics	0.4	1.4	0.1
	Geant4 physics processes	**7.2**	**3.2**	**24.9**
	Gamma line probabilities	**2.5**	**2.9**	0.2
Source	Source geometry	0.1	<0.1	0.1
	Source material	<0.1	**1.9**	0.1
	Source distance	---	---	3.7
	Source activity	---	---	**18.6**
Detector	Detector dimensions	---	---	**18.6**
	Detector distance to endcap	---	---	1.9
Cryostat	Cryostat endcap thickness	1.0	0.5	0.9
	Cryostat detector cub	0.3	<0.1	0.4
DAQ	DAQ dead time	---	---	0.2
	Statistical Errors	1.3	**1.8**	0.1
	Summation in quadrature	**7.8**	**5.3**	**36.5**
	DL systematics are propagated into the AV fraction [%]	**91.4 ±0.7**	**91.2 ±0.5**	**89.9 ±3.8**

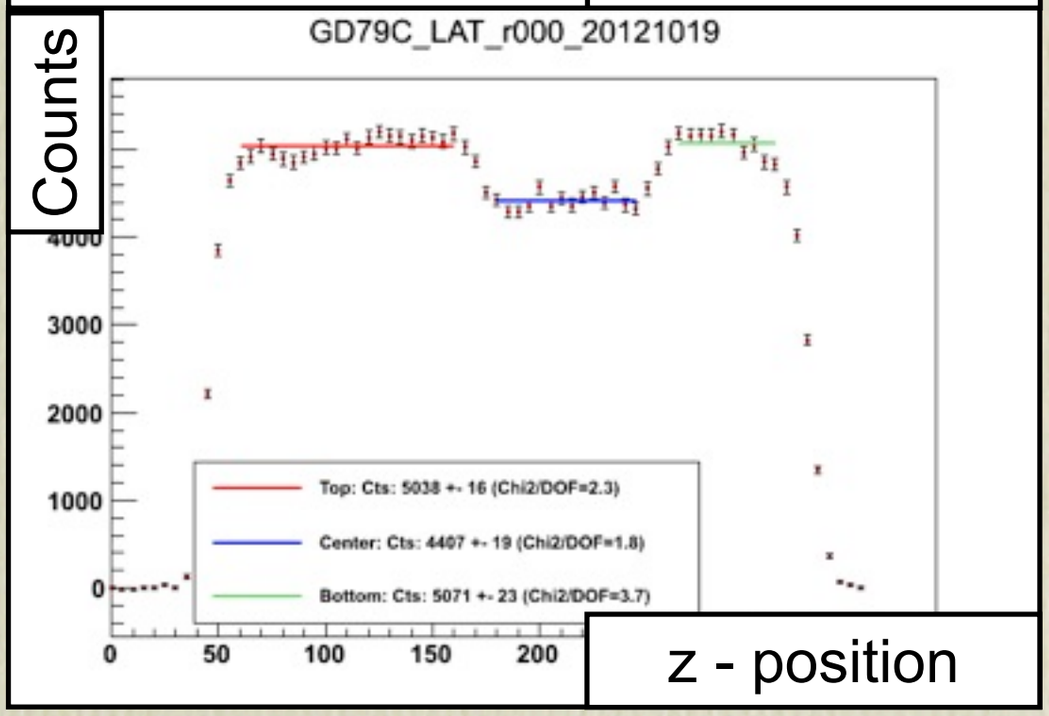
Results, Limitations and Outlook

We observe a discrepancy between surface and volume probes for many detectors

DL is what we measure but the AV is what we need

- Is the assumption of a homogenous DL thickness correct?





- Surface raster scans (pictures)
- AV dependance on HV
- AV dependance on DAQ settings
- Investigation of transition layer

Conclusion

- BEGe active volumes are an essential part of all GERDA physics analysis in Phase II
- The active volume is determined via the dead layer with different methods (241Am, 133Ba, 60Co, 228Th)
- Each method probes different parts of the detector (surface, bulk, corners)
- Systematics depending on method ±1% AV fraction (241Am / 133Ba) and ±4% (60Co)
- Ongoing investigation of discrepancy of methods

Acknowledgement:
We kindly thank the ZIH @ TU Dresden for the supply and support of the CPU farms DEIMOS and ATLAS for the Monte Carlo simulations.