Studies of GERDA phase II detector signals

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GERDA

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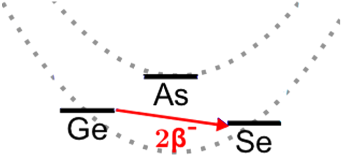
TUM

Outline

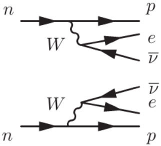
1. Introduction
   - Neutrino-less Double Beta Decay
   - The GERDA experiment
   - ^{42}K background
   - BEGe Pulse Shape Analysis
2. Efficiency for detectors in vacuum cryostats
   - ^{90}Sr measurements
   - ^{106}Ru measurements
3. Monte Carlo analysis
   - Surface events identification and validation with ^{90}Sr data
   - Potential impact on GERDA

Double Beta Decay



$\beta\beta(2\nu)$

$$(A,Z) \longrightarrow (A,Z{+}2){+}2e^{-}{+}2\overline{\nu}_e$$



$\beta\beta(0\nu)$

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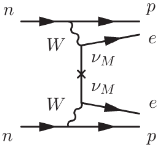
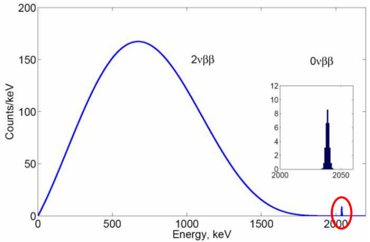


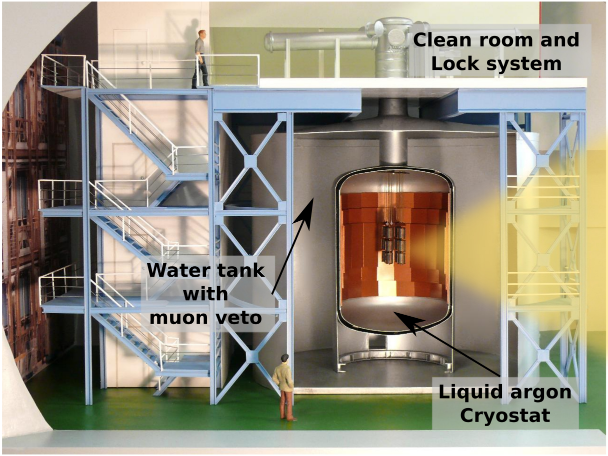


[Oleg Chkvorets, PhD thesis, July 2008]

Double beta decay of ^{76}Ge:

- $T_{1/2}^{\beta\beta(2\nu)} \sim 1.4 \cdot 10^{21}$y
- enrichment: 7% $\rightarrow\sim$ 86%
- source and detector (FWHM$\sim$ 0.15%)
- $Q_{\beta\beta}$= 2039 keV

Germanium Detector Array (GERDA)



GERDA phases

Phase I — Coaxial

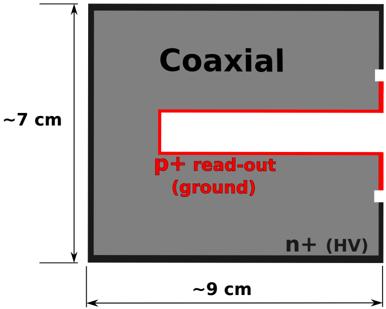
- 17.6 kg HPGe (86% ^{76}Ge)
- Goal: $T_{1/2}^{\beta\beta(0\nu)}\,(^{76}Ge) \gtrsim 10^{25}$ y
- Measured Background Index (B.I.) before PSD

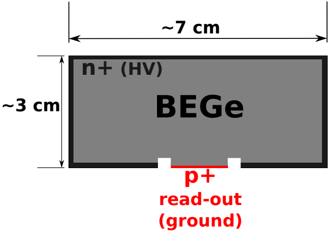
  $1.7^{+0.9}_{-0.5} \cdot 10^{-2} cts/(keV \cdot kg \cdot yr)$

  1950keV - 2150keV (Nov11-Feb12)

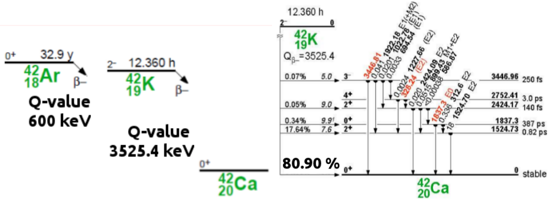
Phase II — Coaxial+*BEGe*

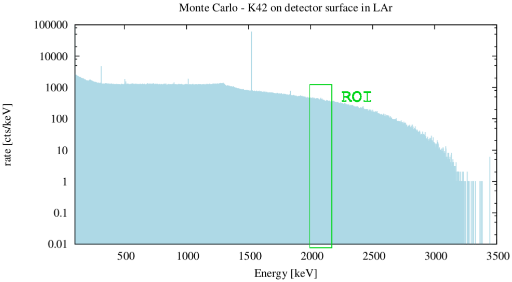
- + 20 kg *BEGe* (87% ^{76}Ge)
- Enhanced Pulse Shape Analysis
- LAr instrumentation
- Goal:
  - B. I. $\lesssim 1.0 \cdot 10^{-3} cts/(keV \cdot kg \cdot yr)$
  - $T_{1/2}^{\beta\beta(0\nu)}\,(^{76}Ge) \gtrsim 1.5 \cdot 10^{26}$ yr





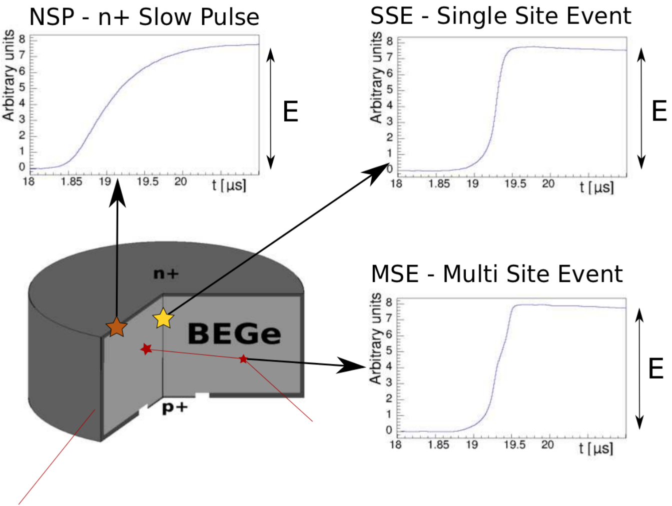
^{42}K in GERDA





Phase I solution

The A/E method



[JINST, 4 2009, P10007]

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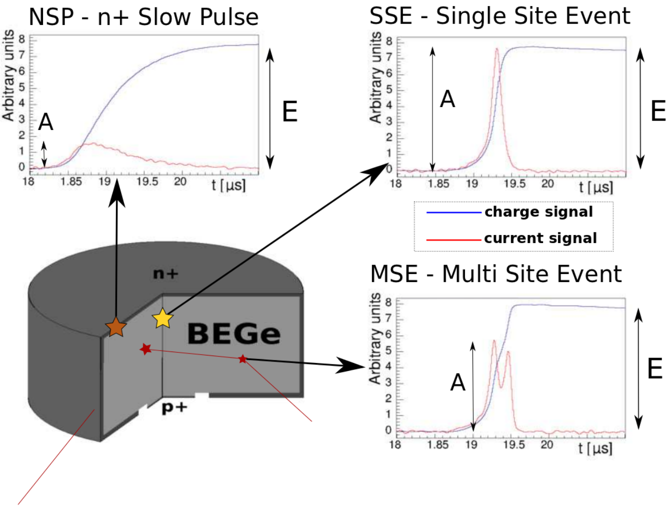

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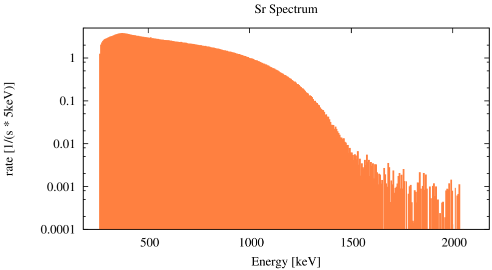
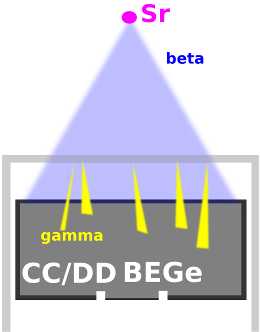
^{90}Sr measurements

To test the rejection of n+ surface events we measured β-emitters with *BEGe* in vacuum cryostats.

$$^{90}Sr \rightarrow ^{90} Y \rightarrow ^{90} Zr$$
$$Q_\beta = 2280 \mathrm{keV}$$

^{90}Sr stability tests: detector, cryostat and HV dependence.





Detector	⌀[mm]	Thickness [mm]	Mass [kg]	Dead Layer [mm]	Cryostat
DD	74	32	0.700	0.45	Al 1.5 mm
CC	74.5	33	0.760	0.70	Al 1.5 mm
LD	71.5	50.5	1.018	0.60	C fibre 0.6 mm
BBS	75.1	30.7	0.734	0.50	Al 1.5 mm

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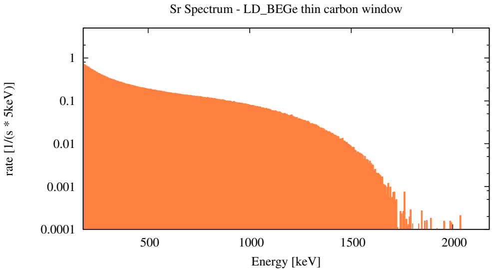

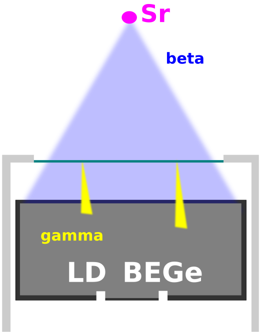

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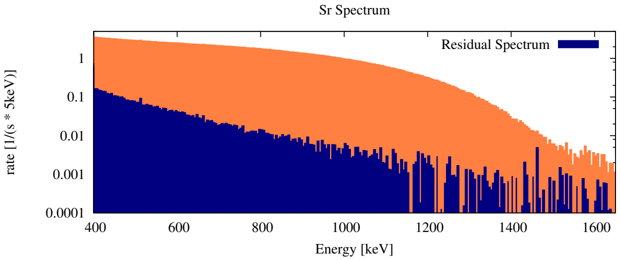
Acceptance of ^{90}Sr

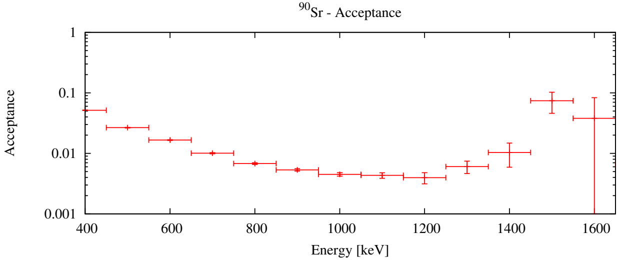


^{90}Sr Spectrum

before the analysis

and

after the cut

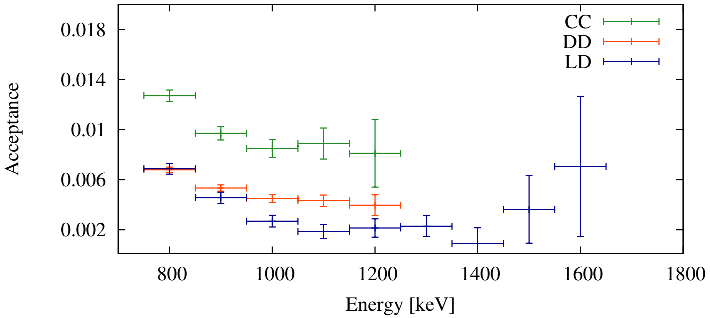


Acceptance for 100 keV bins

~90% of SSE survive

^{90}Sr results

	DL [mm]	E[MeV]	Acceptance	Comments
DD Sr	0.45	0.8 - 1.2	$6.08 \pm 0.07\ 10^{-3}$	Al end cap bremsstrahlung
CC Sr	0.70	0.8 - 1.2	$12.7 \pm 0.1\ 10^{-3}$	Al end cap and 0.7 mm DL
LD Sr	0.60	0.8 - 1.6	$3.5 \pm 0.2\ 10^{-3}$	non standard *BEGe*



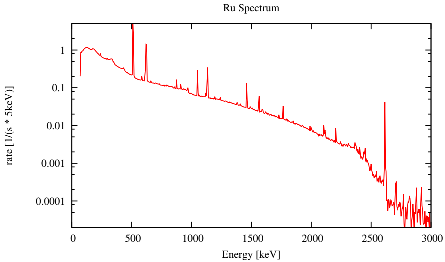
^{106}Ru measurement

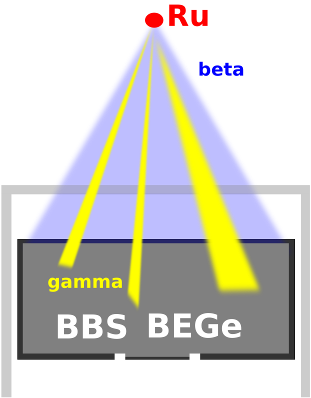
$Q_{\beta\beta}$= 2039 keV

Direct γ spectrum

$^{106}Ru \rightarrow ^{106} Rh \rightarrow ^{106} Pd$

$Q_\beta = 3541\mathrm{keV}$





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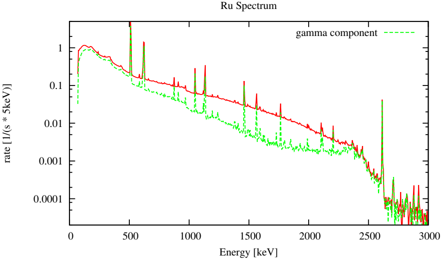
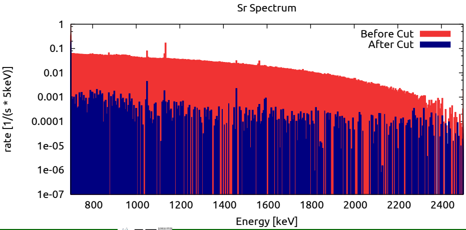
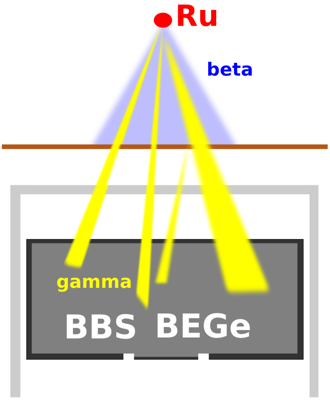
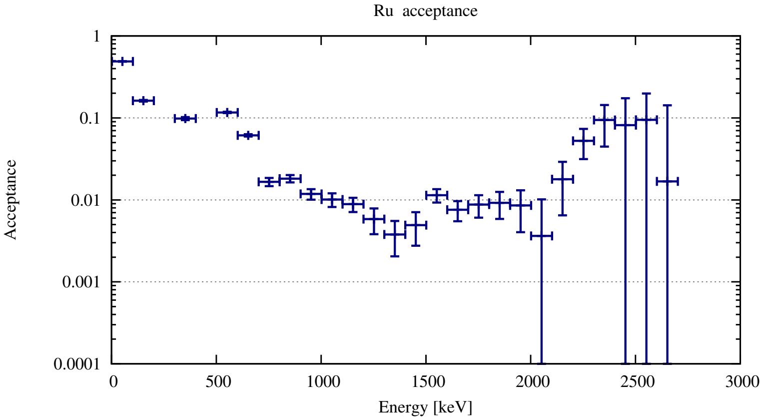






Rejection between 1 and 2 MeV



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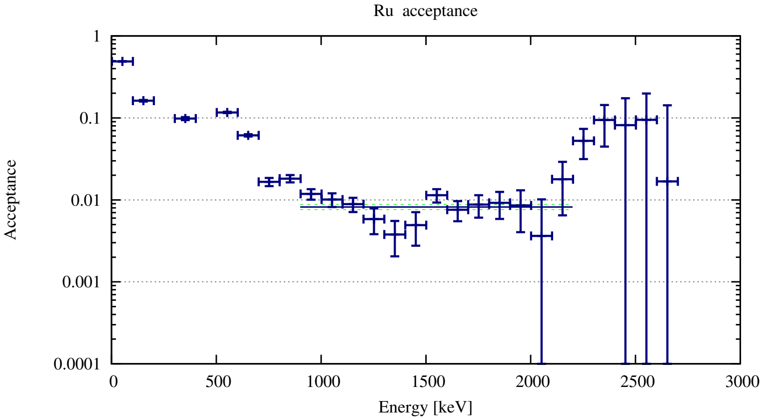

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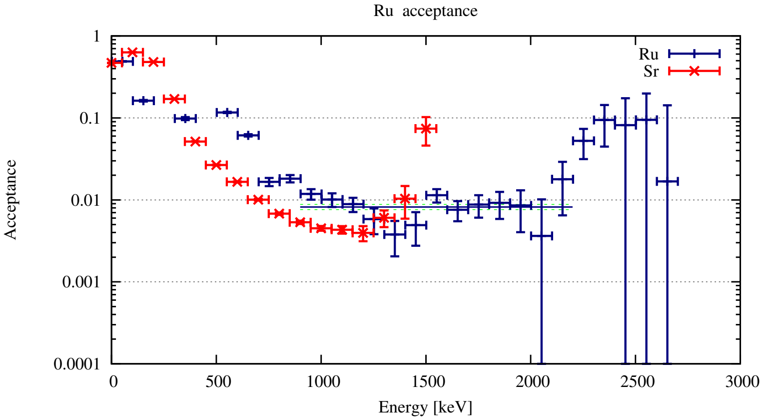
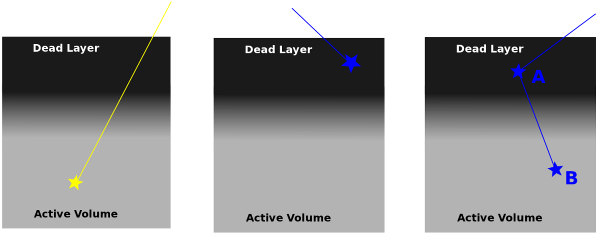


The cut performance seems to be stable between 1 and 2 MeV, we will suppose that the upper limit got with the ^{90}Sr at 1 MeV is still valid at 2 MeV.

At least 99% of NSP are rejected.

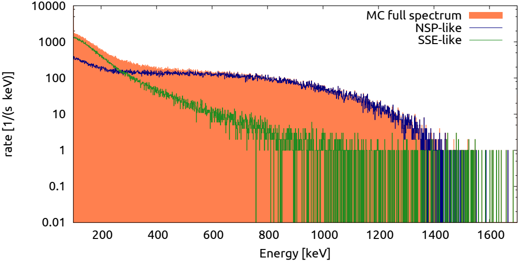
NSP interpretation and MC approach



Laboratory			
Charge collection:	fast (SSE)	slow (NSP)	slow (NSP)
Read energy:	100%	?	100% B + ?% A

Monte Carlo:			
Energy:	100%	Zero	100% B
Flag:	gamma-like		NSP-like

Monte Carlo Analysis & ^{90}Sr validation



^{90}Sr Spectrum;

gamma-like spectrum;
NSP-like spectrum;

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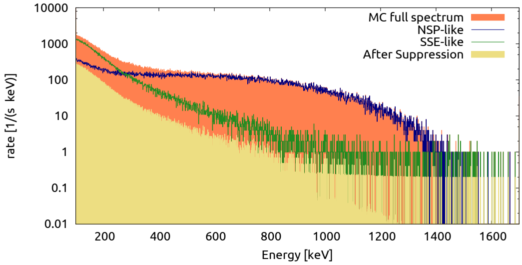

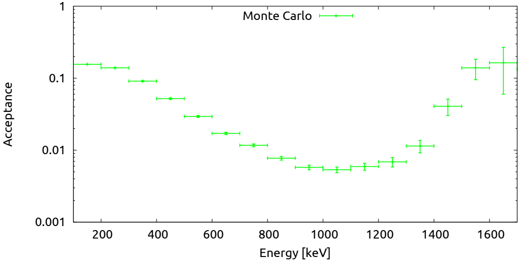

^{90}Sr Spectrum;

gamma-like spectrum;
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Cut efficiency hypothesis:

80% of gamma-like

99.9% NSP-like rejection

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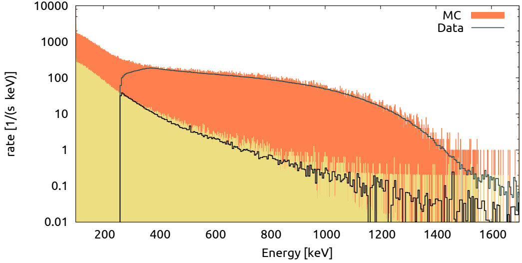

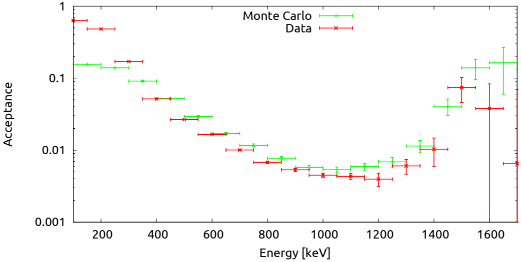

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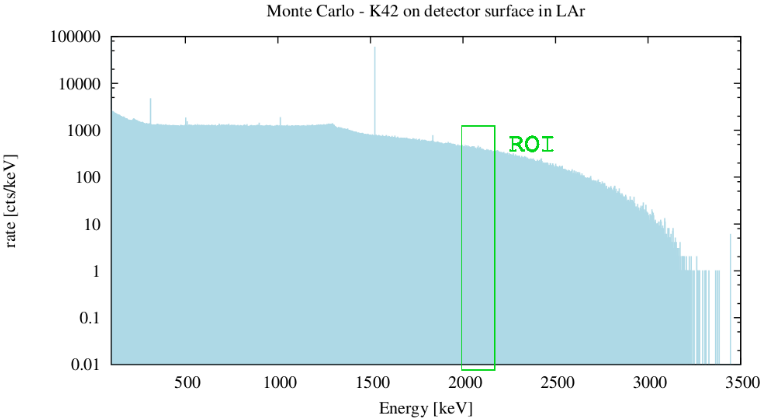
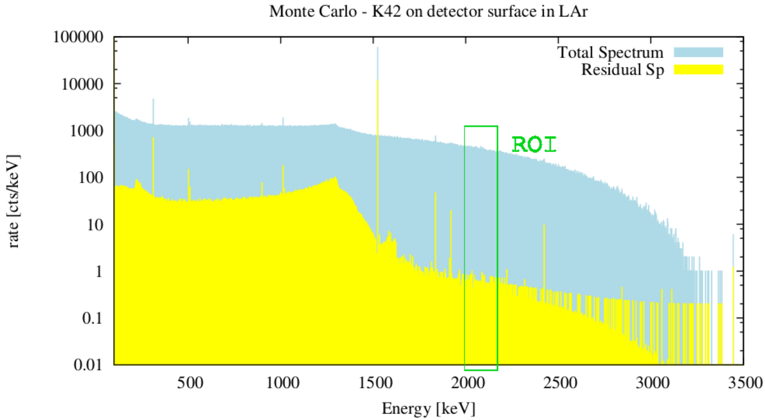
^{42}K in LAr simulation



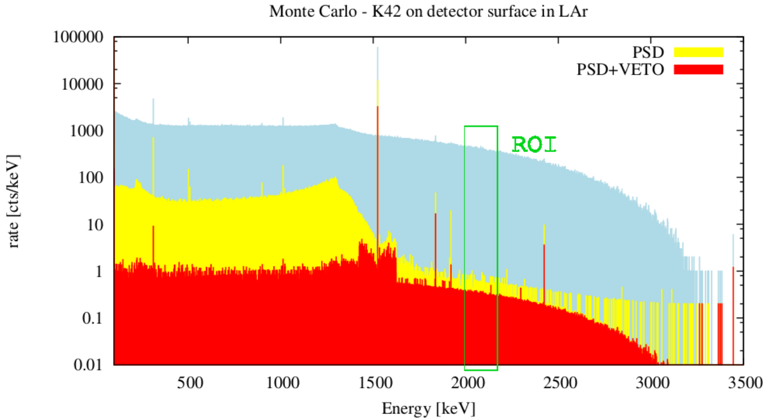
Method	survival fraction	suppression factor

^{42}K in LAr simulation



Method	survival fraction	suppression factor	
PSD	0.12%	830	99.9% for β & 80% for α

^{42}K in LAr simulation



Method	survival fraction	suppression factor	
PSD	0.12%	830	99.9% for β & 80% for α
PSD + LAr Veto	0.08%	1250	Threshold: 100 keV

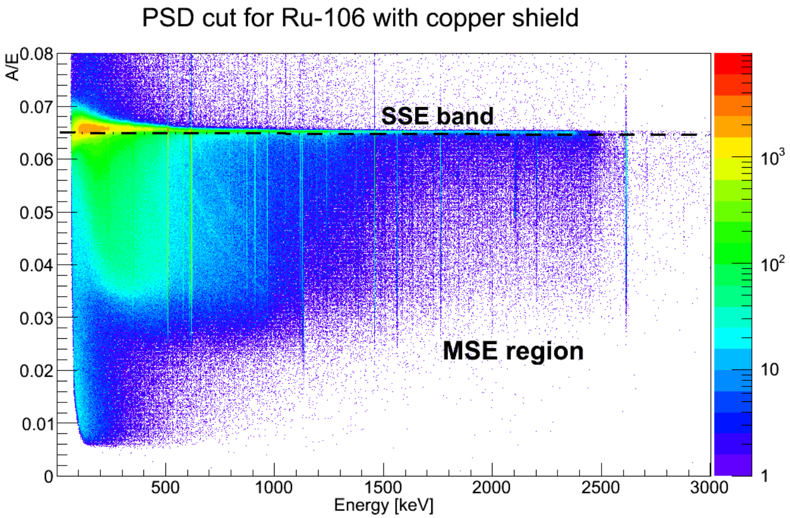
Summary

- Study of BEGe detector response to surface interactions on the n^+ contact.
- Measure of external β-source spectrum suppression in vacuum cryostats ($> 99\%$).
  Analysis of HV, cryostat and dead layer thickness dependences.
- Develop of Monte Carlo analysis criteria to identify the candidate NSP events.
- Estimation of β-particle discrimination efficiency ($> 99.9\%$).
- Prediction for the potential reduction of ^{42}K background in GERDA Phase II down to a level compatible with the specifications $\left[\mathcal{O}(10^{-4})\text{ cts/(keV}\cdot\text{kg}\cdot\text{yr)}\right]$.

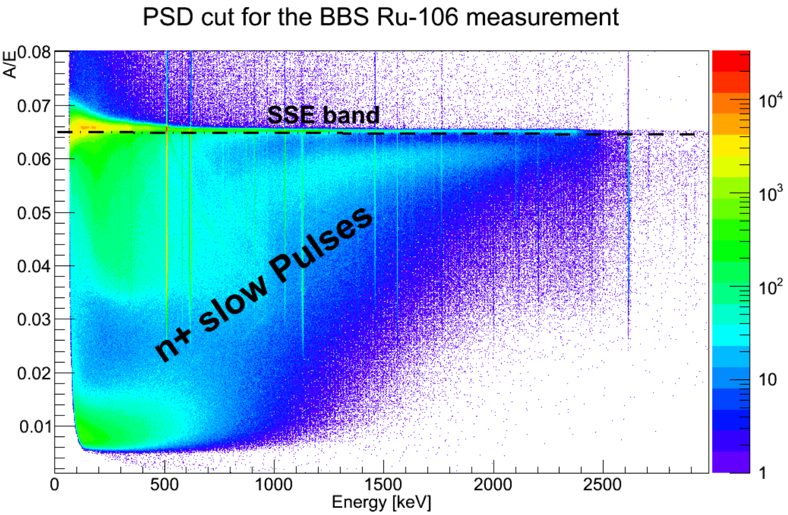
Outlook

- Test with bare *BEGe* in liquid argon spiked in ^{42}Ar (LArGe) are on going at LNGS. The efficiency predicted seems to be achievable after some improvements of the electronic noise.
- Due to the sensitivity to electronic conditions, GERDA Phase II set-up (pre-amp, etc.) have to be tested and tuned to reach a sufficient pulse shape analysis performances.
- A better understanding of the charge collection from the nominal dead layer is needed to provide improve the Monte Carlo simulations of surface events. The MAJORANA collaboration is also working on it.
- Up to now the cut is optimized for the high energy part of the spectrum, it will be interesting to extend this study to the lower energies.

The A/E cut


PSD cut for Ru-106 with copper shield
A/E
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
500
1000
1500
2000
2500
3000
Energy [keV]
SSE band
MSE region
10^3
10^2
10
1

The A/E cut



PSD cut for the BBS Ru-106 measurement
A/E
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
500
1000
1500
2000
2500
Energy [keV]
SSE band
n+ slow Pulses
10^4
10^3
10^2
10
1