Investigations and development of the suppression methods of the background in the LArGe low-background test facility for the GERDA experiment

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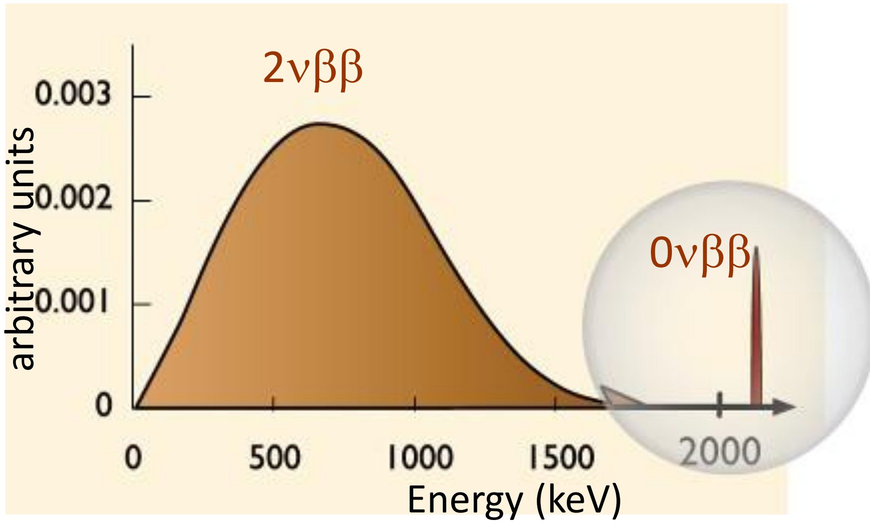
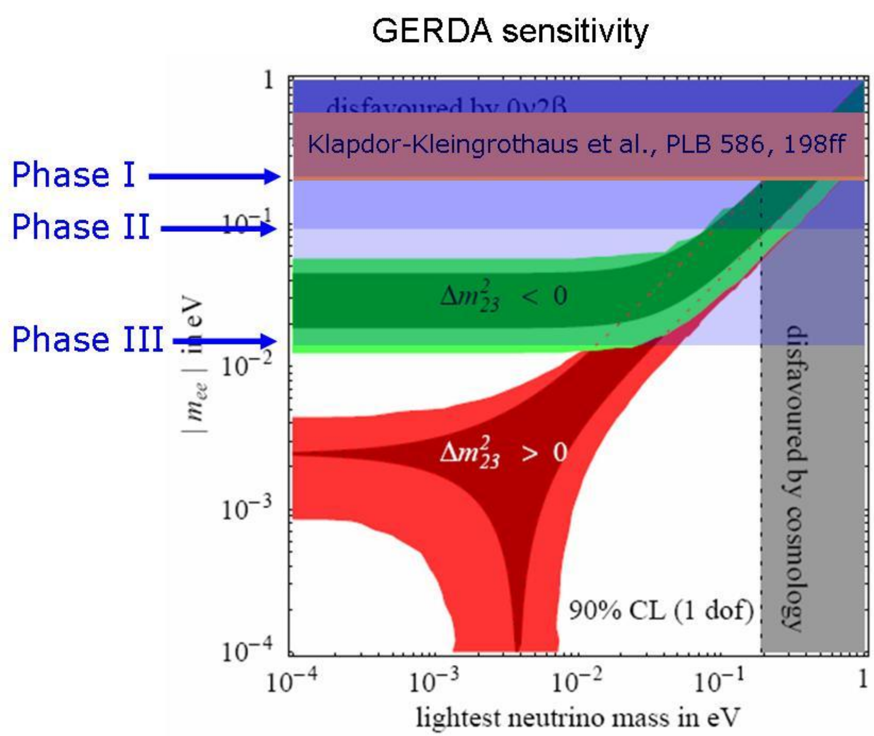
Motivation



The main goal of the GERDA experiment is the search for neutrinoless double beta decay of ^{76}Ge. Background level is one of the most important factors for the successful experiment.

Phase1: expected BI ~ 0.01 counts / (kg · y · keV)

Phase2: expected BI ~ 1 counts / (ton · y ·keV)



$$T^{0\nu}_{1/2} \propto \langle m_{\beta\beta} \rangle^{-2} \propto const \sqrt{\frac{M \times t}{\Delta E \times B}}$$

M Mass

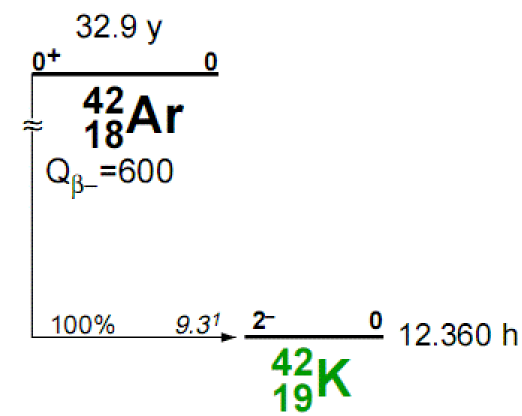
t Time

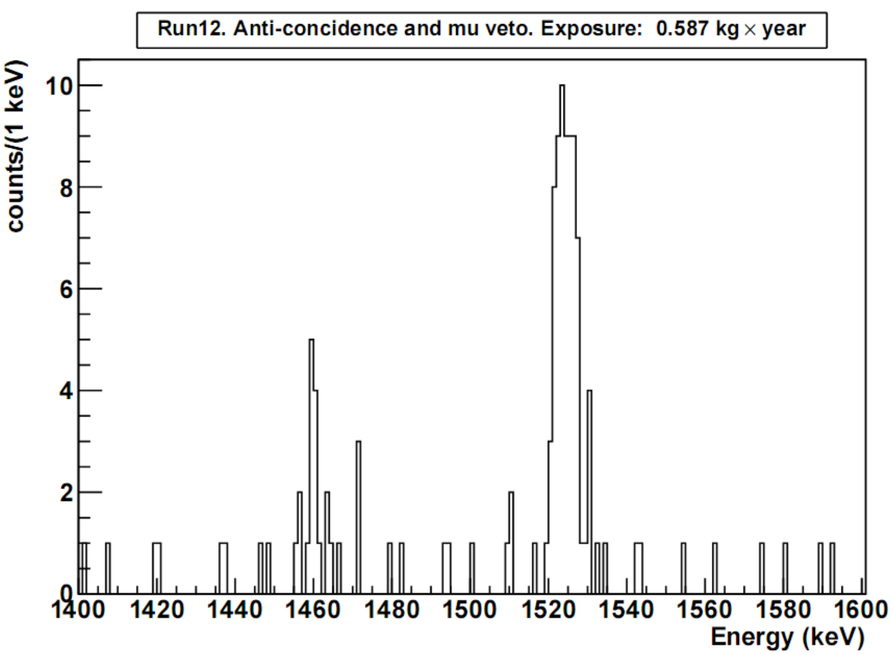
B Background rate

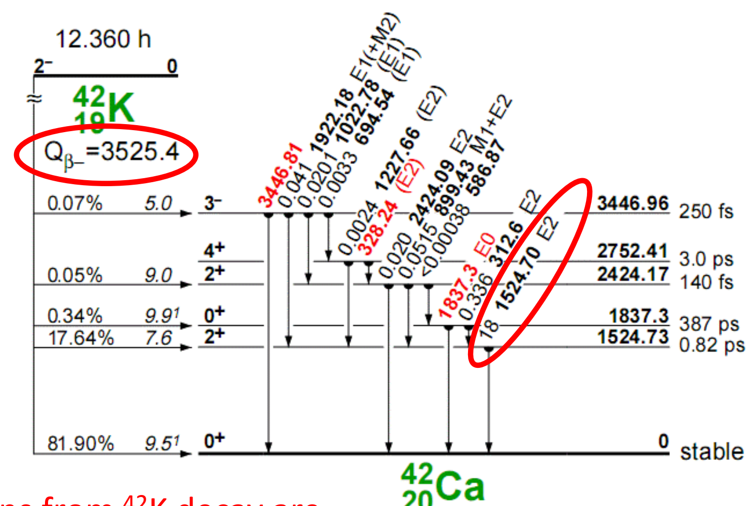
ΔE Energy resolution

Unexpected ^{42}Ar background

For the estimate of the ^{42}Ar concentration in liquid Ar in GERDA cryostat, as performed in the **proposal** of GERDA for estimation of the **limit of ^{42}Ar/^{nat}Ar < $3{\cdot}10^{-21}$** [Barabash et al., 2002] has been taken into account. In the later paper it was **<4.3 10^{-21}** [V.D. Ashitkov et al., 2003].
Already during first **commissioning** runs with non-enriched detectors it was found that the intensity of 1525 keV peak from ^{42}K (daughter of ^{42}Ar) **at least is 10 times higher** than expected from the limit [Bar02] assuming homogeneous distribution of ^{42}Ar. (It will be shown later that it was additionally increased by electric field)
Possible explanation: ^{42}K ion collection on the surface by E-field.



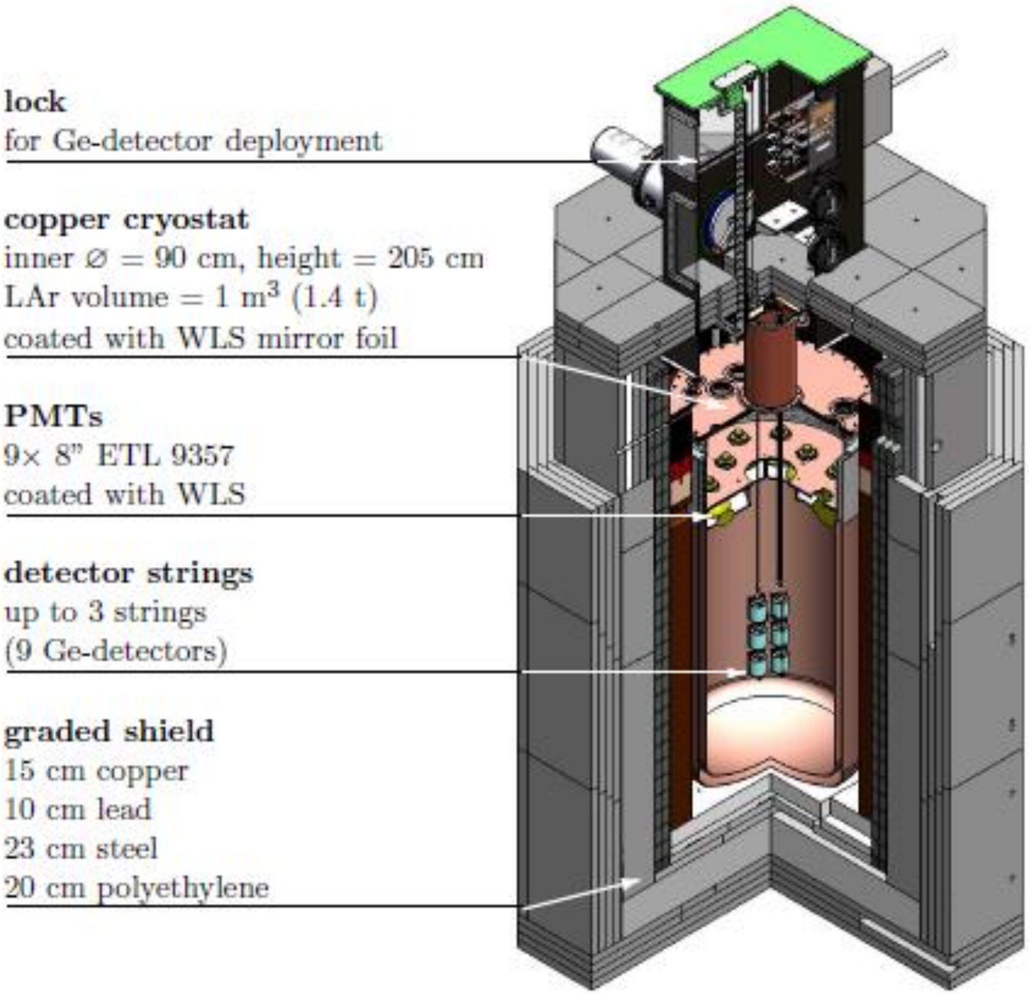




Electrons from ^{42}K decay are dangerous background for $0\nu\beta\beta$ search

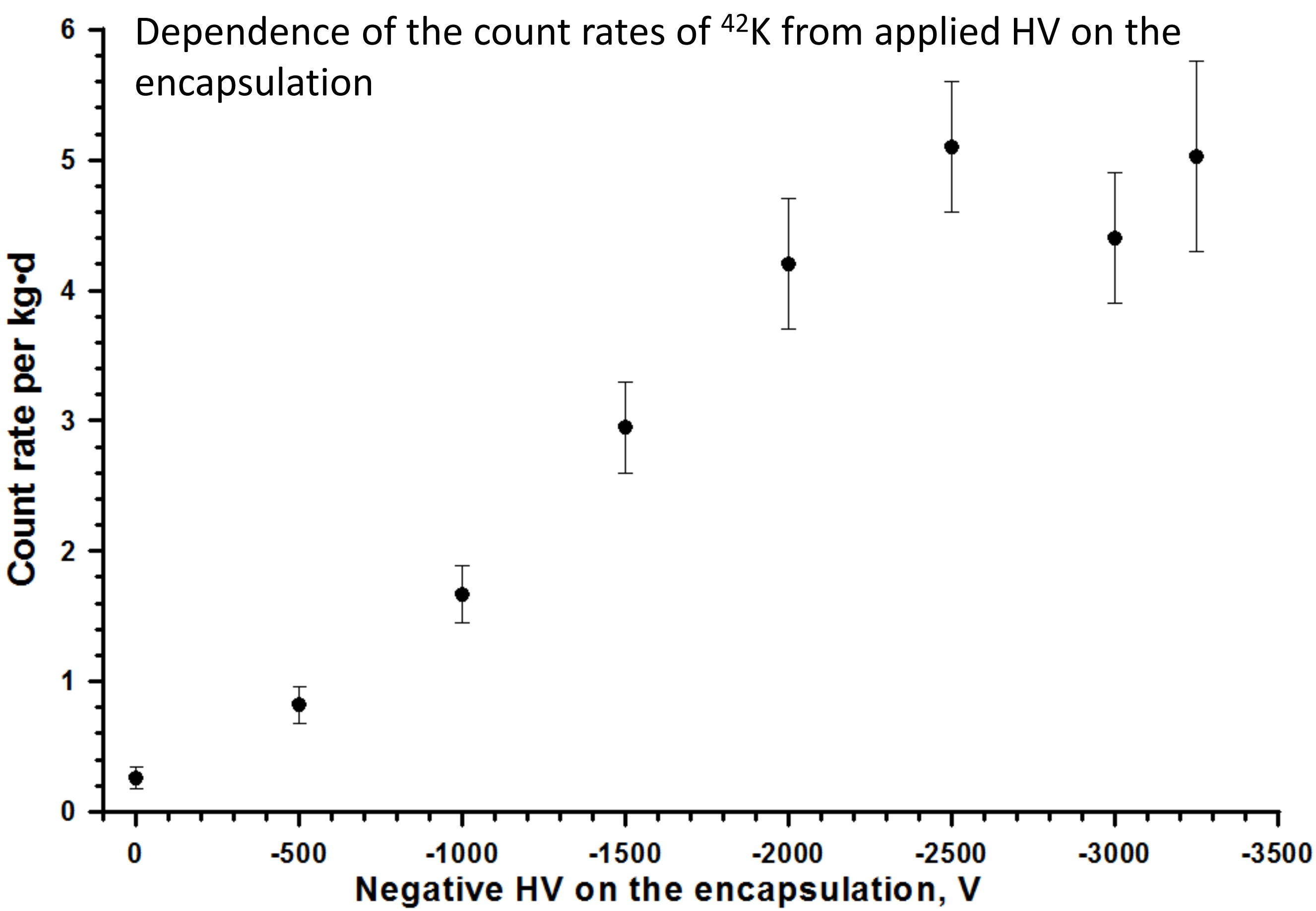
LArGe test facility

LArGe is a low background test facility, which has been created in order to investigate the possibility to suppress background by using anticoincidence with liquid Ar scintillation signal detected by PMTs.

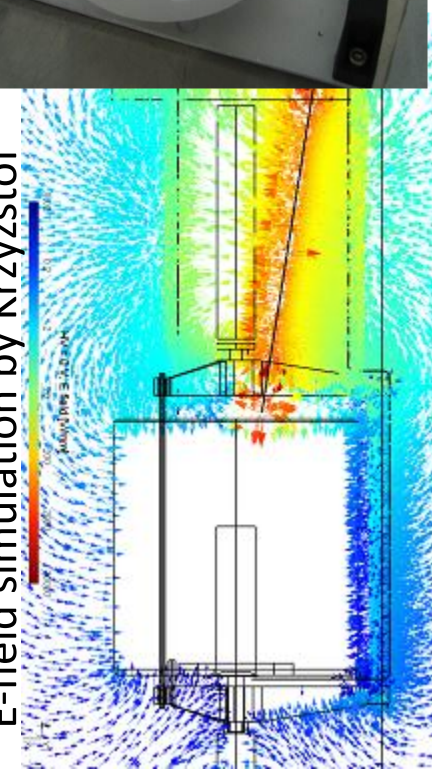


^{42}K collection by encapsulated detector

Measurements with a germanium detector have been performed in LArGe (in a “no-source” mode) for investigation of the collection processes of ^{42}K. The detector was fully **encapsulated** by a PTFE/Cu/PTFE sandwich.



Dependence of the count rates of ^{42}K from applied HV on the encapsulation

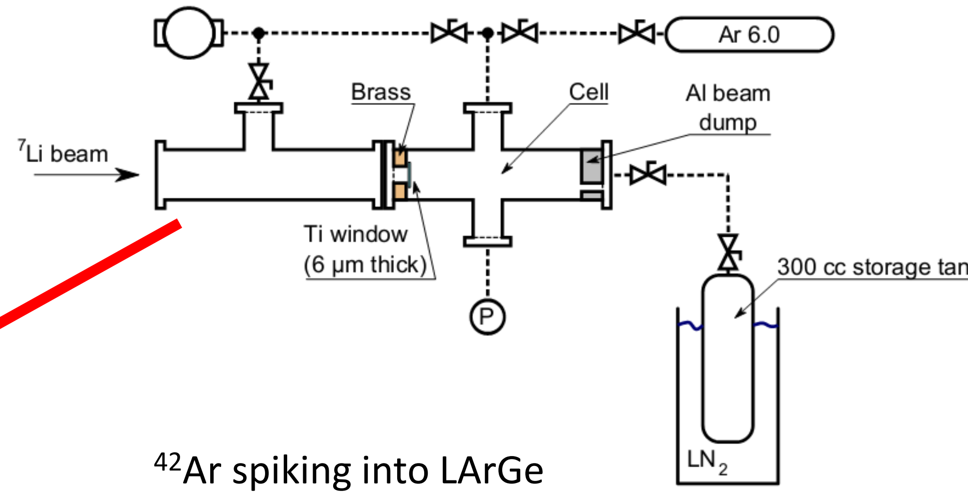


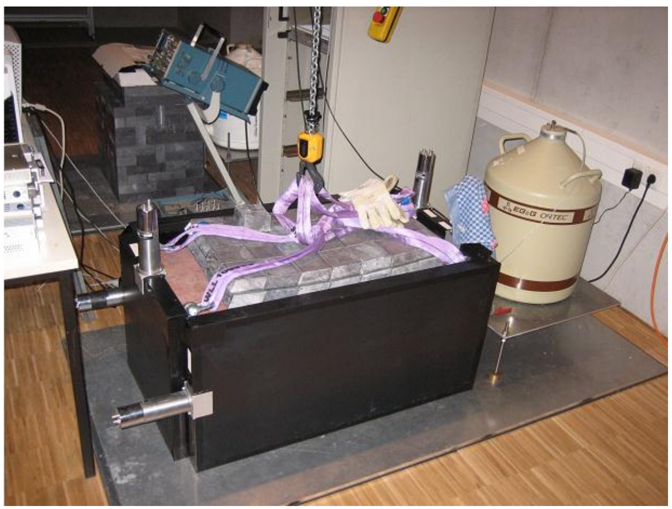
E-field simulation by Krzyzstof

^{42}Ar source production & spiking

For further detailed investigation of the collection processes of ^{42}K and for direct estimation of the activity of ^{42}Ar well-known amount of the activity of ^{42}Ar has been introduced into the LArGe volume.

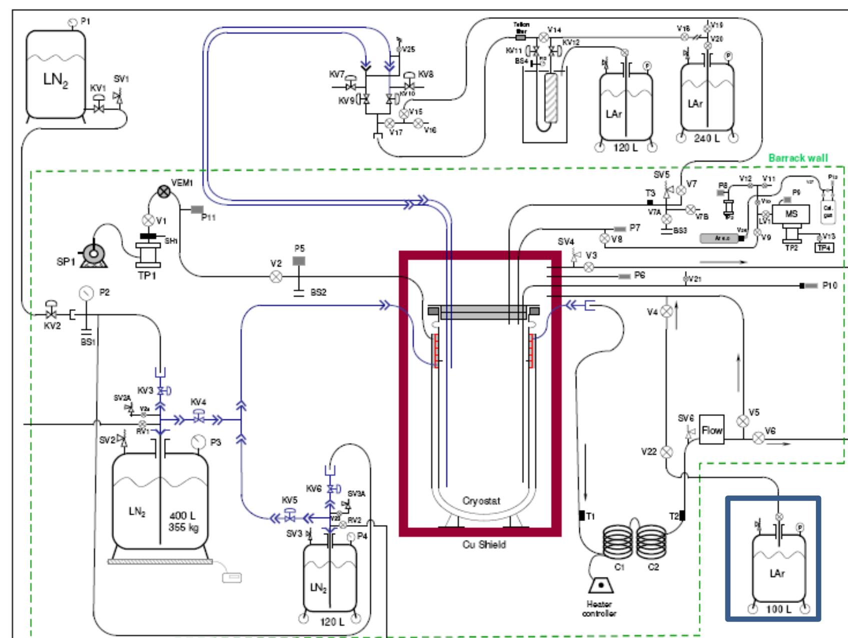
^{42}Ar production at MLL Garching by TUM from ^{40}Ar via (^{7}Li, α p)





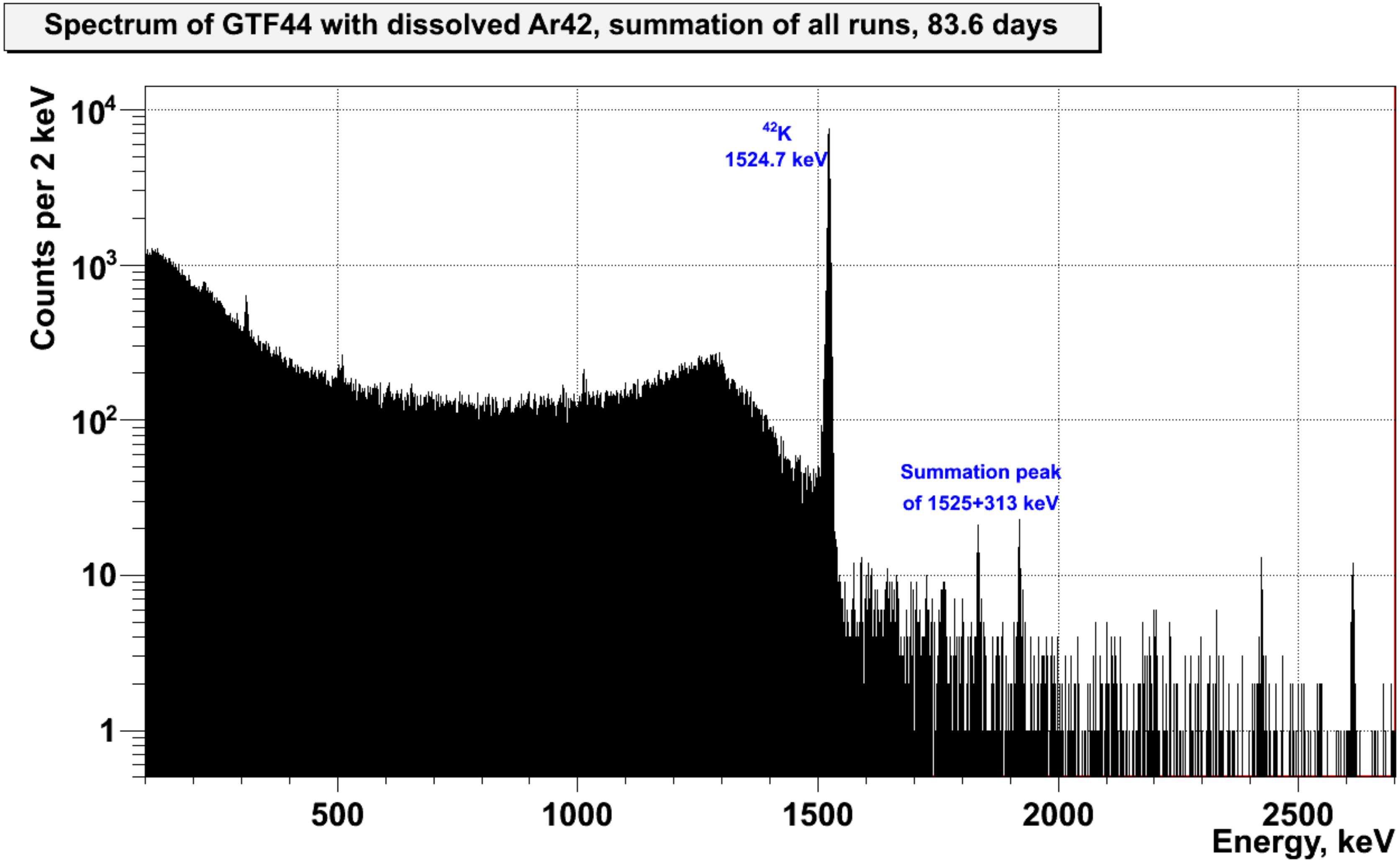
Screening at Garching and LNGS. Estimated activity of ^{42}Ar is **5.18±0.91 Bq**

^{42}Ar spiking into LArGe



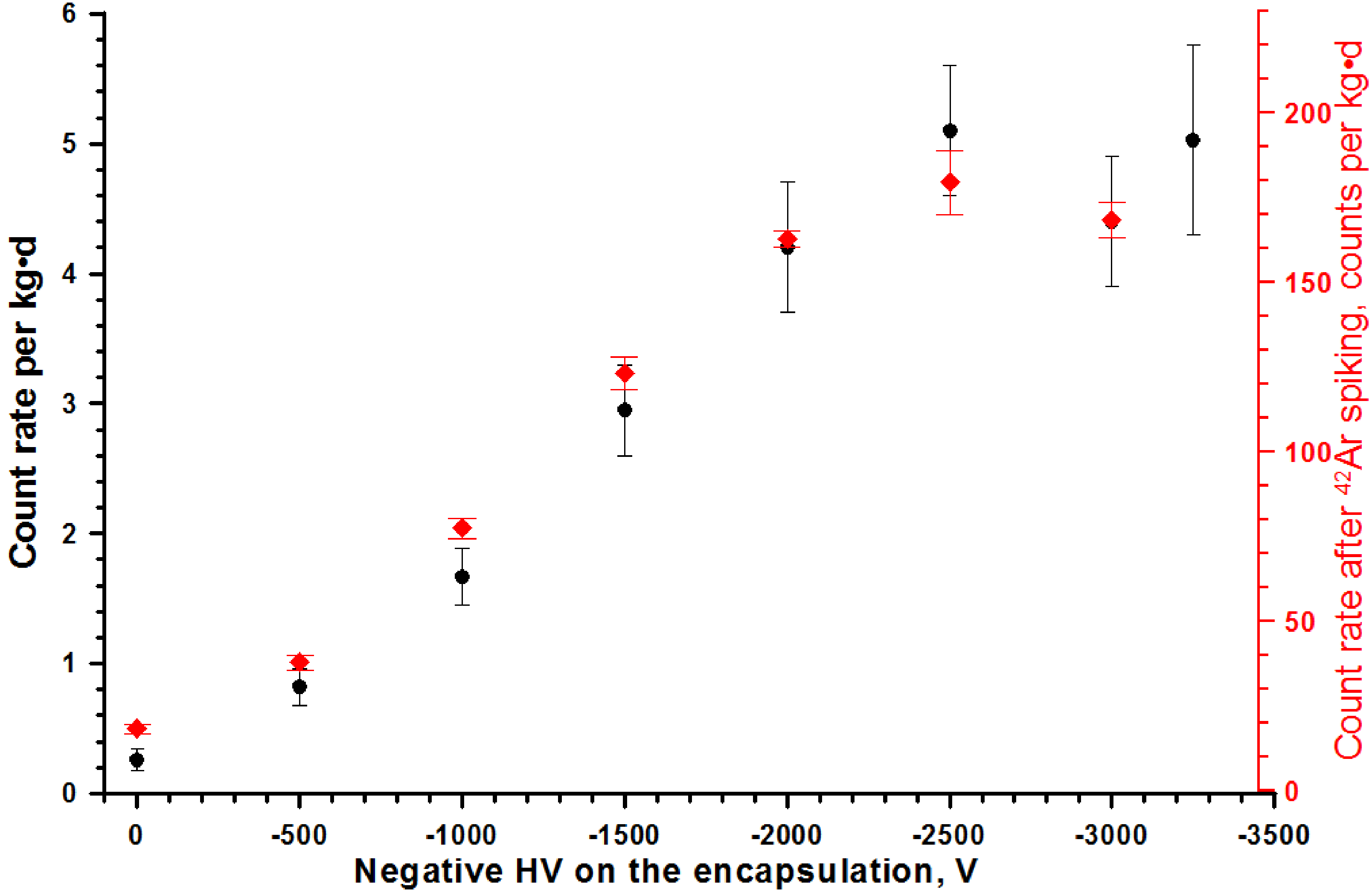
^{42}K spectrum

After dissolving of ^{42}Ar into LArGe count rates under the peak increased by about factor of 40 with respect to the measurements with natural Ar.

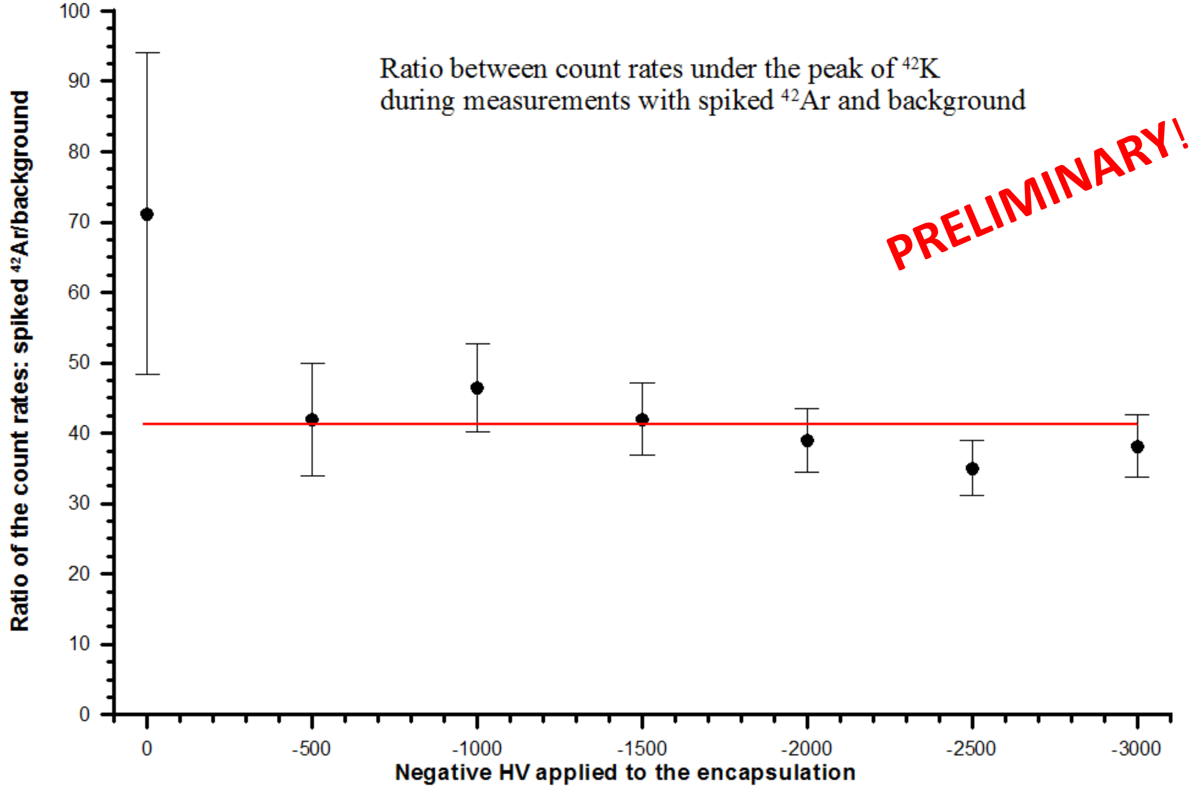


Dependence of ^{42}K count rate

Intensity of ^{42}K line shows similar behavior depending on the applied negative HV both for the natural and spiked Ar cases.



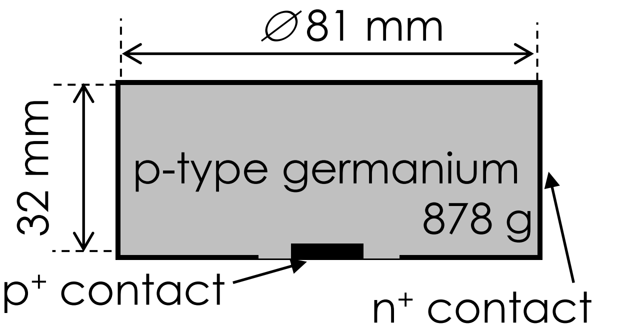
Estimations of the activity of ^{42}Ar

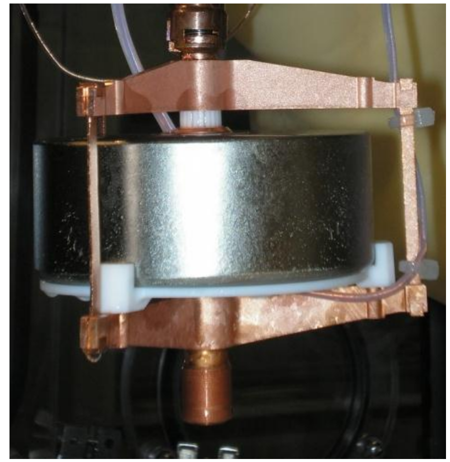


With well-known activity at different HV biasing of the encapsulation it is possible estimate to directly the abundance of ^{42}Ar in natural LAr using ratio of the count rates. Assuming that there is no significant influence of the collection properties of ^{42}K in LAr after dissolving it inside LArGe, we can estimate concentration of ^{42}Ar. Average value of the activity is **86.2±4.5(stat)±17.6(system) μBq/kg.** This corresponds to ^{42}Ar concentration: $^{42}Ar/^{nat}Ar = 8.5 \cdot 10^{-21}$.

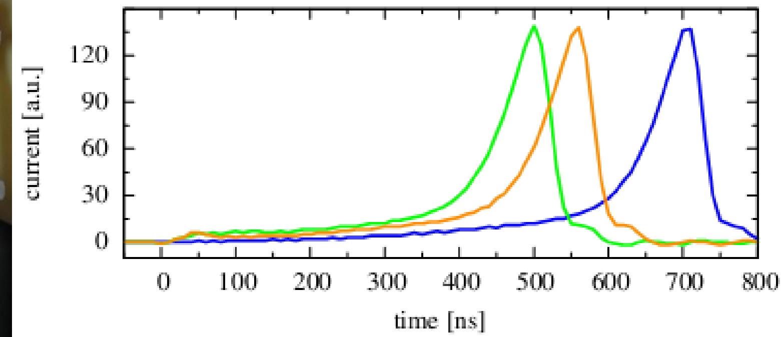
Independent estimations from GERDA background measurements in field-free configuration gives: **(92.8±5.2±4.5) μBq/kg**.

GERDA phase II detectors: BEGe

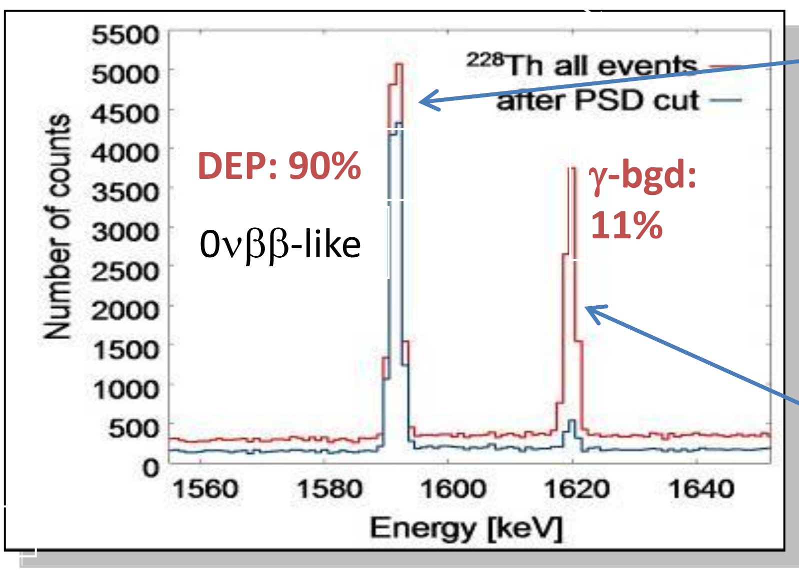


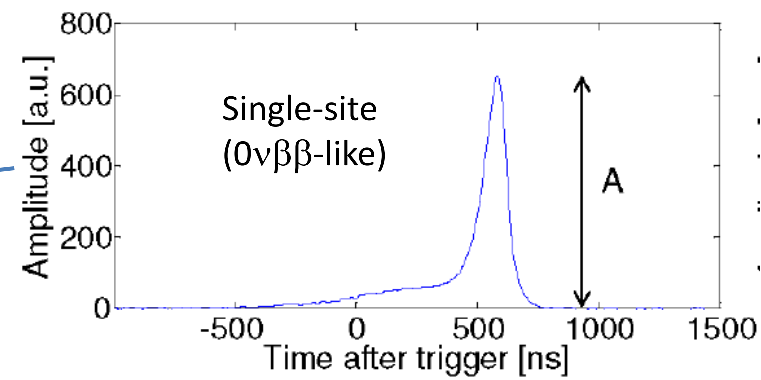


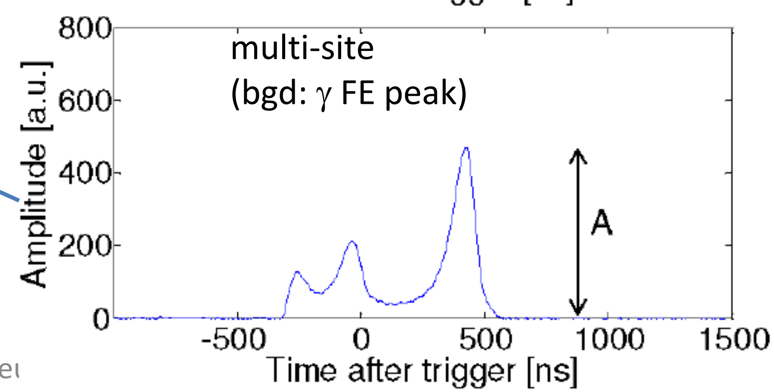
M. Agostini et al, (JINST), 6 (2011) P03005



FWHM @ 59.5 keV	**0.49 keV**
FWHM @ 1.33 MeV	**1.59 keV**

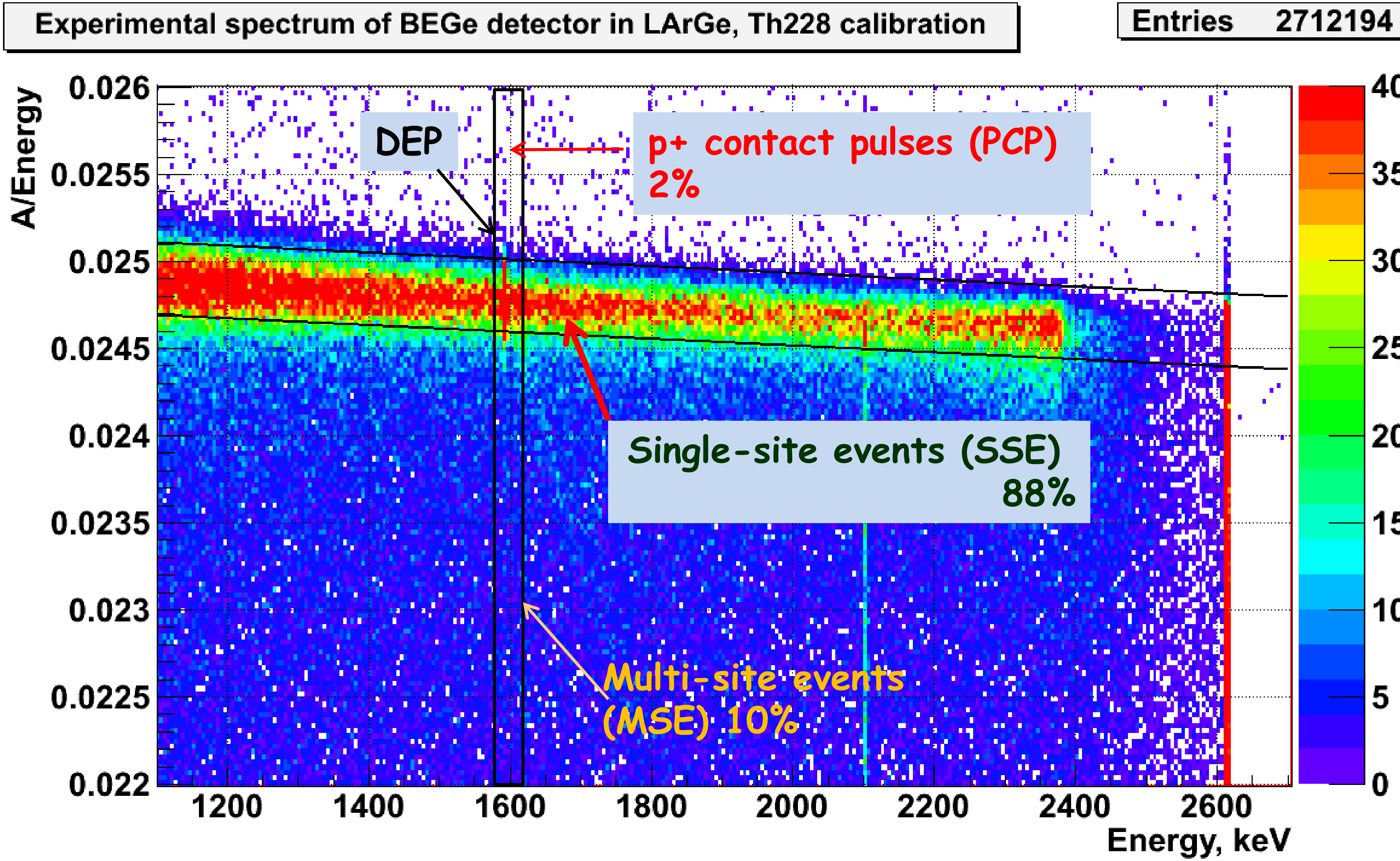






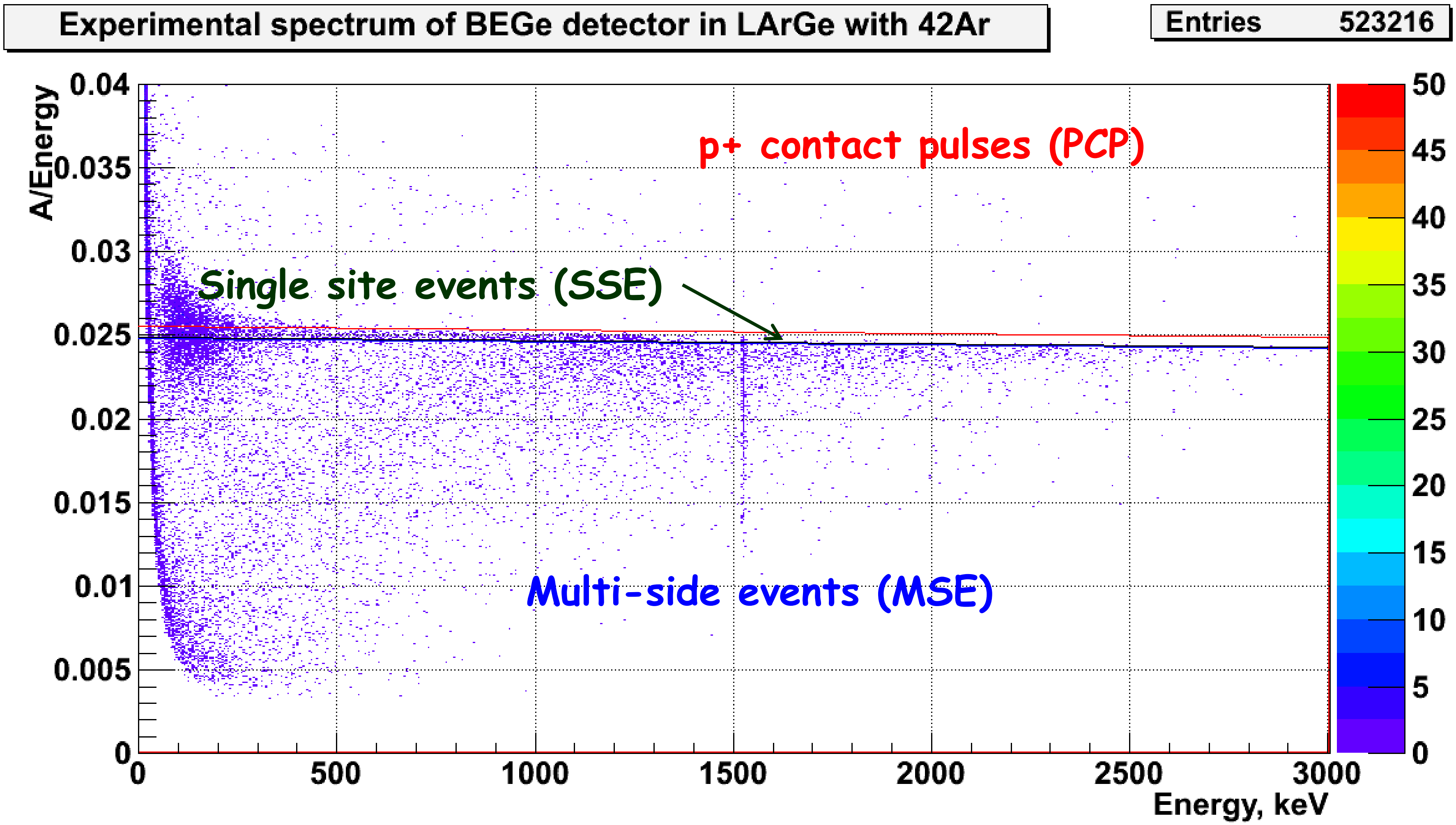
PSD cut determination

Criteria of the Pulse Shape Discrimination (PSD) cut was obtained using ^{228}Th calibration.

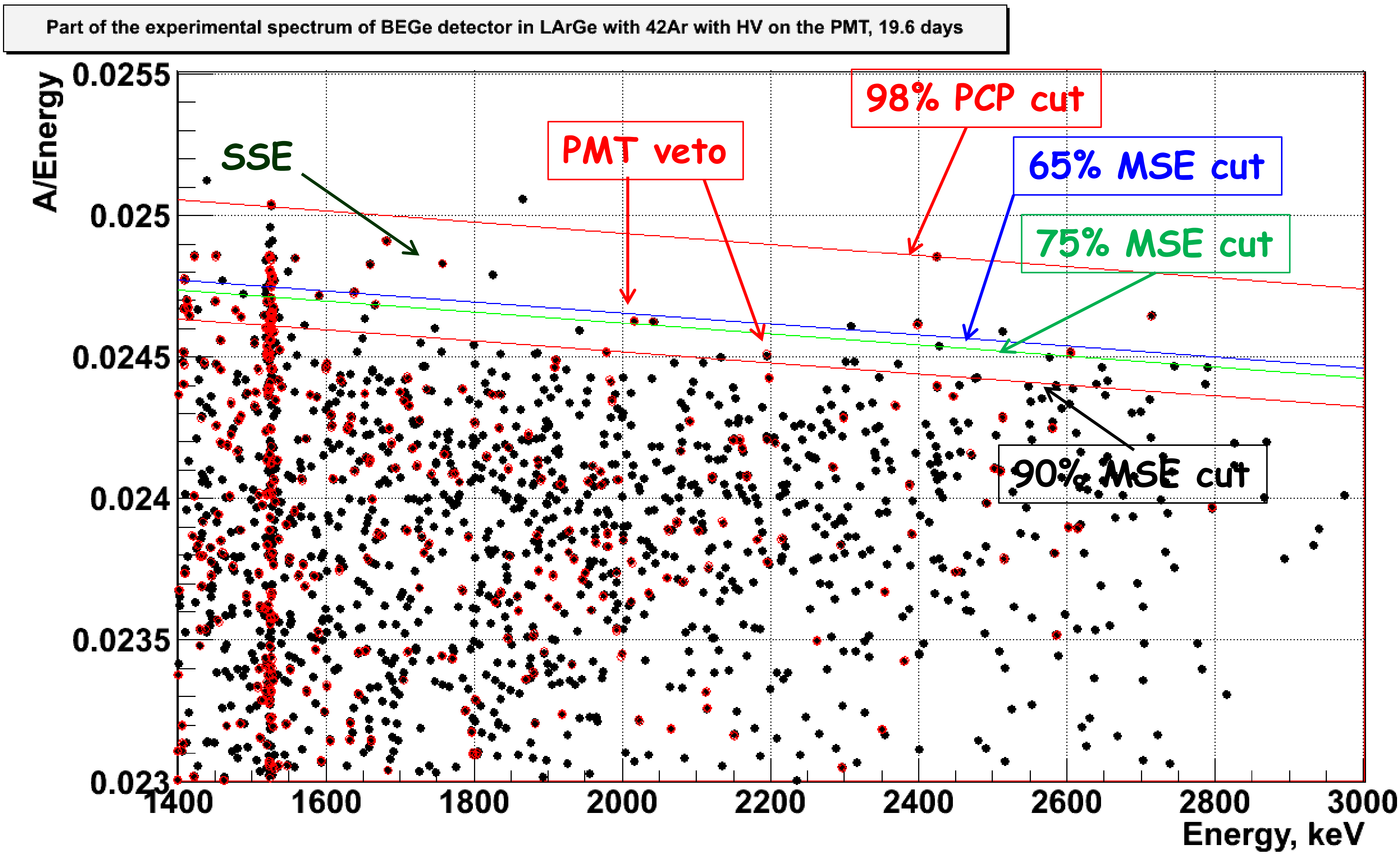


Suppression of ^{42}Ar by PSD

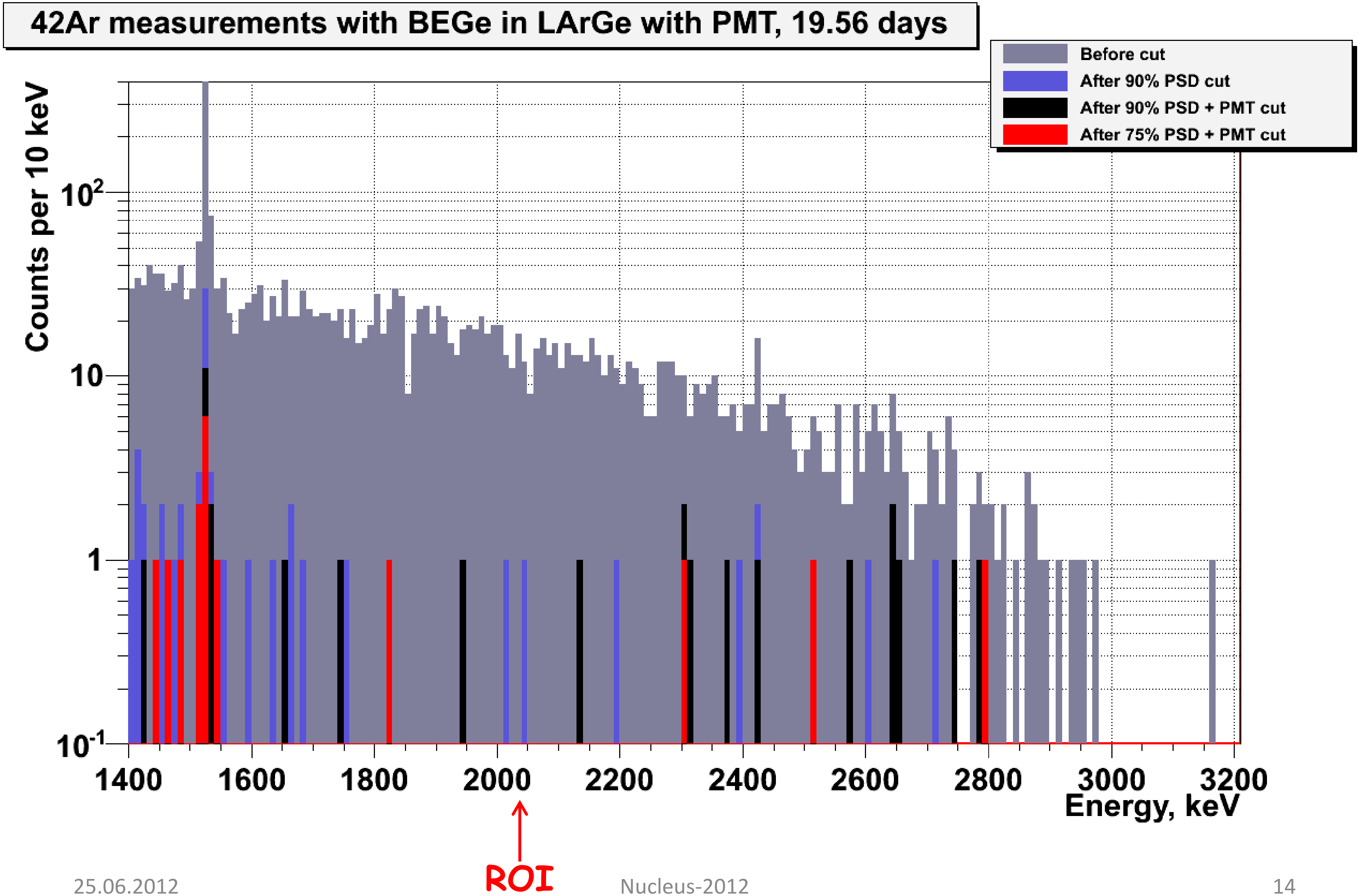
We can dramatically suppress background beta events of ^{42}K applying PSD cut obtained from ^{228}Th calibration .



Suppression of ^{42}Ar by PSD+PMT



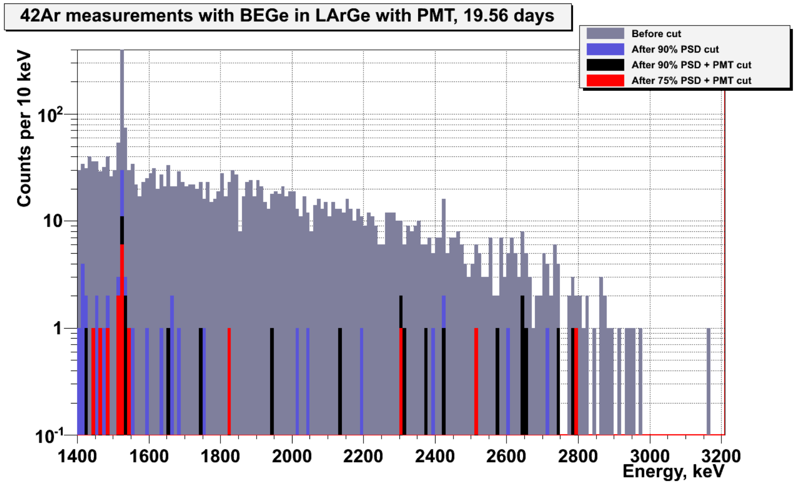
Suppression of ^{42}Ar by PSD+PMT



Suppression of ^{42}Ar by PSD+PMT

Energy region, keV	Before cut	PMT veto only	98% PCP cut +PMT	PCP+ 90% MSE +PMT	PCP+ 75% MSE +PMT	PCP+ 65% MSE +PMT
1520-1529	405	151 (39%)	150 (38%)	9 (2.3%)	5 (1.2%)	5 (1.2%)
1989-2089	143	113 (82%)	107 (77%)	0	0	0
1839-2239	**610**	**470 (80%)**	**454 (77%)**	**2 (0.3%)**	**0**	**0**
1540-3000	1640	1265 (80%)	1223 (77%)	19 (1.2%)	5 (0.3%)	4 (0.3%)

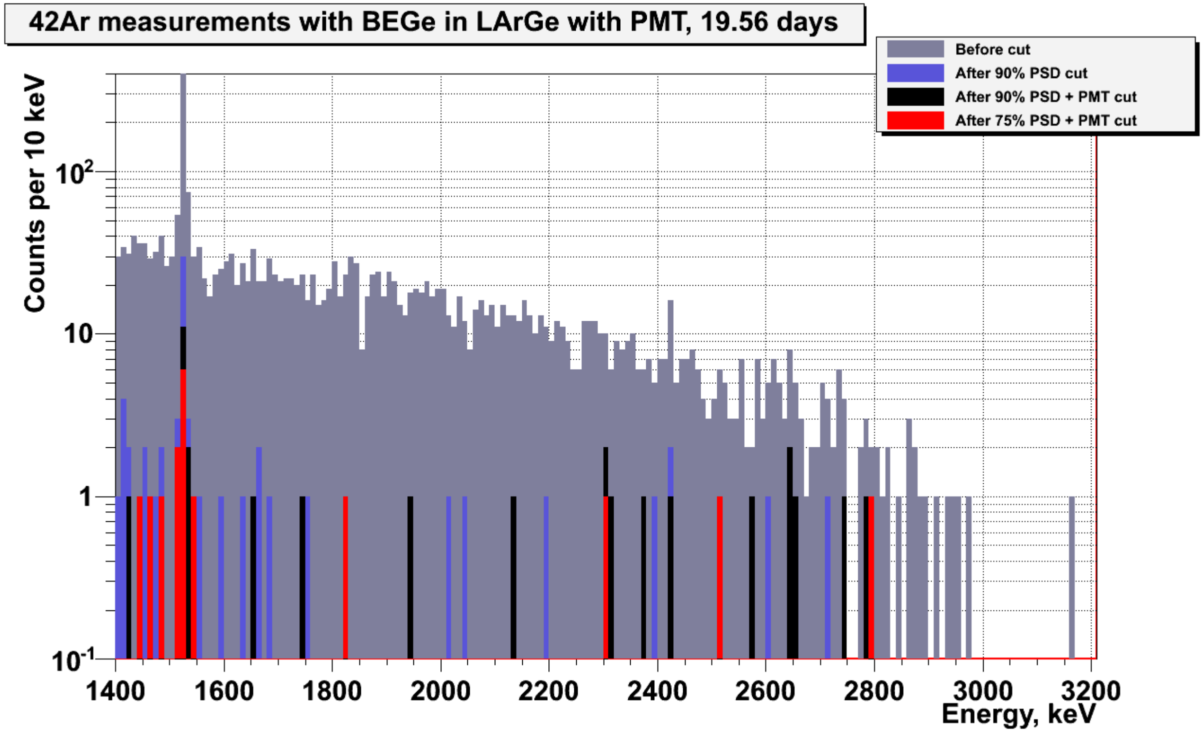
Upper limit on the 90% PSD + PMT acceptance in 400 keV is **<0.97 %** [90% c.l.]
MC predictions:
PMT veto survivals are **68 %** (using 100 keV threshold).
PSD veto survivals are **0.12%.**



Acceptances in the table corrected on the PMT veto acceptance 96.6%.

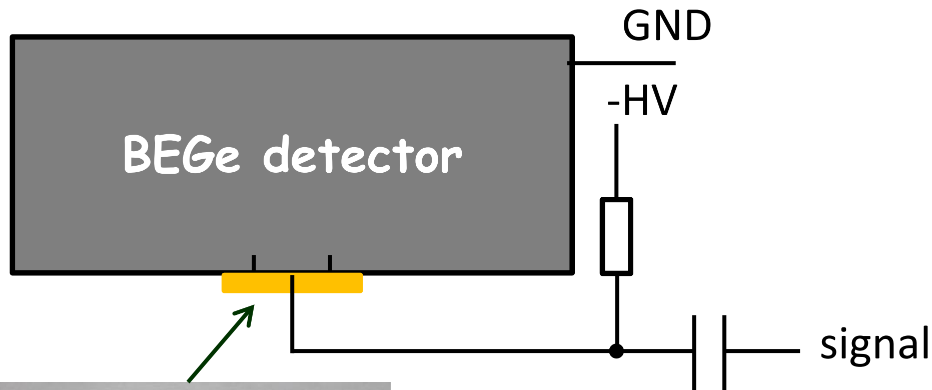
^{42}Ar background studies

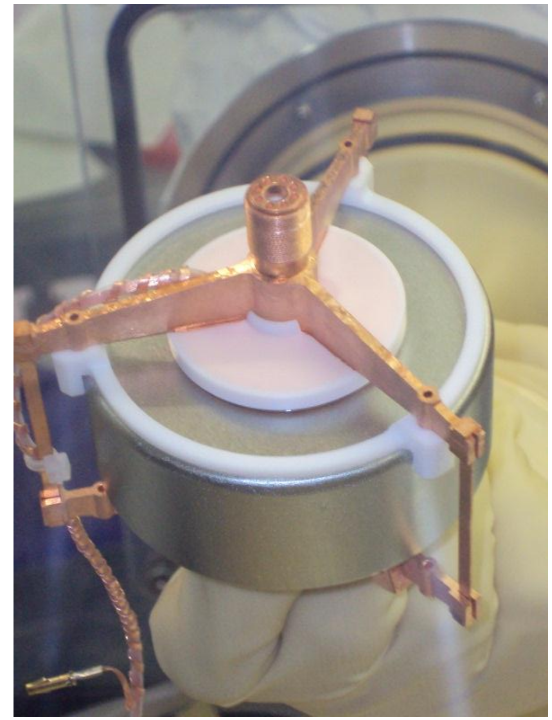
Estimation of the background count rate from ^{42}K in GERDA with bare BEGe without cut:
0.29-0.45 cts/(kg year keV). (standard biasing scheme & w/o MS)
Limit from the current measurements after 90% PSD + PMT cut:
<(2.8-4.3) · 10^{-3} cts/(kg year keV).
MC predictions:
(2.4-3.7) · 10^{-4} cts/(kg year keV).
Suppression required for GERDA Phase II (10^{-3} cts/(kg year keV)) can be achieved **even in a non-free-field configuration**.



BEGe detector in AC mode

Measurements with BEGe detector in AC mode allow to ground the surface and to greatly suppress collection of the ions by electric field.





PRELIMINARY!

	Normal mode, 17.8 days		AC mode, 10.9 days	
Energy range, keV	Counts	Cts /(kg d)	Counts	Cts /(kg d)
1510-1540	559	**36.1(15)**	72	**7.6(9)**
1540-3000	1571	**101.6(26)**	124	**13.0(11)**
1989-2089	130	**8.4(7)**	13	**1.4(4)**

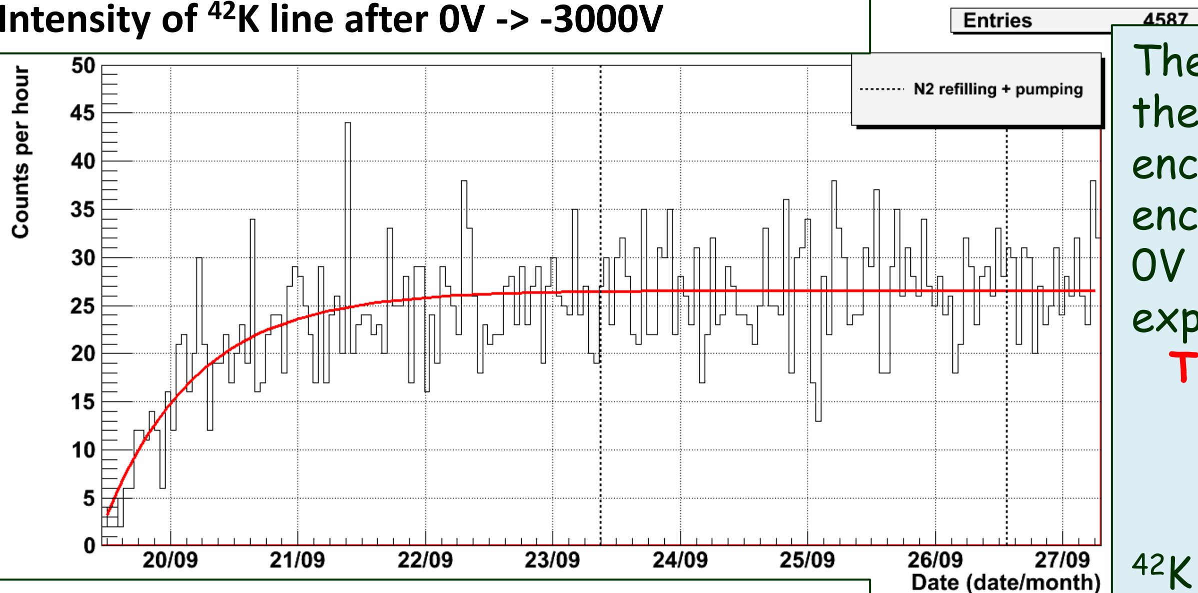
Conclusion

- Investigations of the background caused by ^{42}Ar has been performed in the low-background test facility LArGe.
- Comparison between count rates for the natural and spiked Ar gives an ^{42}Ar concentration in natural LAr. Preliminary estimation of the activity is 86.2±4.5(stat)±17.6(system) μBq/kg.
- It was proven that PSD is an effective method to suppress background from ^{42}K for GERDA Phase2. The limit on the suppression factor in ROI of $0\nu\beta\beta$ obtained for the BEGe detector together with PMT veto is higher than 100 times.
- Field-free configuration allows to suppress background from ^{42}K. Measurements with detector in AC mode shows 5-8 times reduction.
- Results from current measurements indicates that required suppression for ^{42}K background can be achieved in GERDA Phase II experiment.

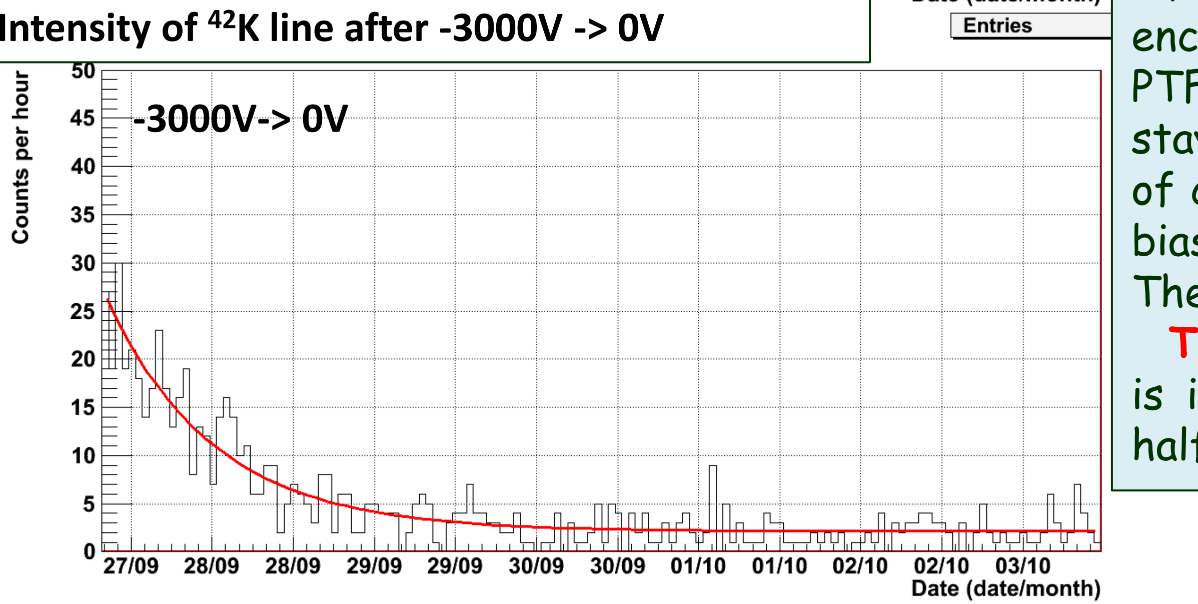
Back up slides

^{42}K collection

Intensity of ^{42}K line after 0V -> -3000V



Intensity of ^{42}K line after -3000V -> 0V



The measured time constant for the ^{42}K accumulation towards the encapsulation after switching the encapsulation bias voltage from 0V to -3000V follows an exponential transient with

$T_{1/2}$= 11.4(13) hours.

^{42}K ions attracted by the encapsulation are sticking to the PTFE surface (or alternatively stay close by in case of absence of convection) after switching the bias voltage from -3000 V to 0 V. The measured half-life of

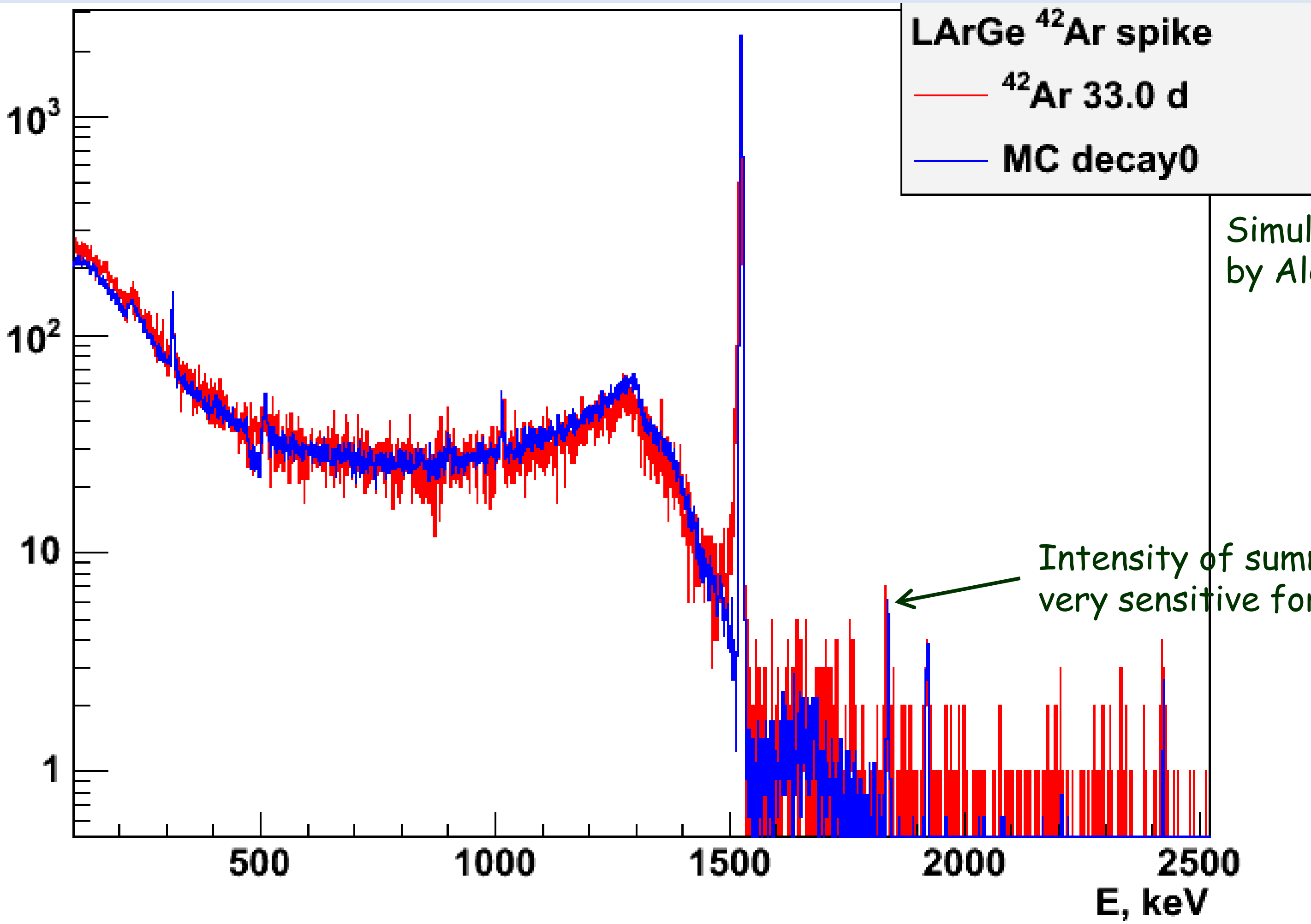
$T_{1/2}$ = 11.1(10) hours

is in agreement with the nuclear half-life of ^{42}K (12.36 hours)

^{42}K location

Comparison between simulation and experiment gives an important information about ^{42}K location. At least a big fraction of ^{42}K ions should be located near detector to explain experimental data.

Experiment data and simulation (uniformly distributed on the surface)

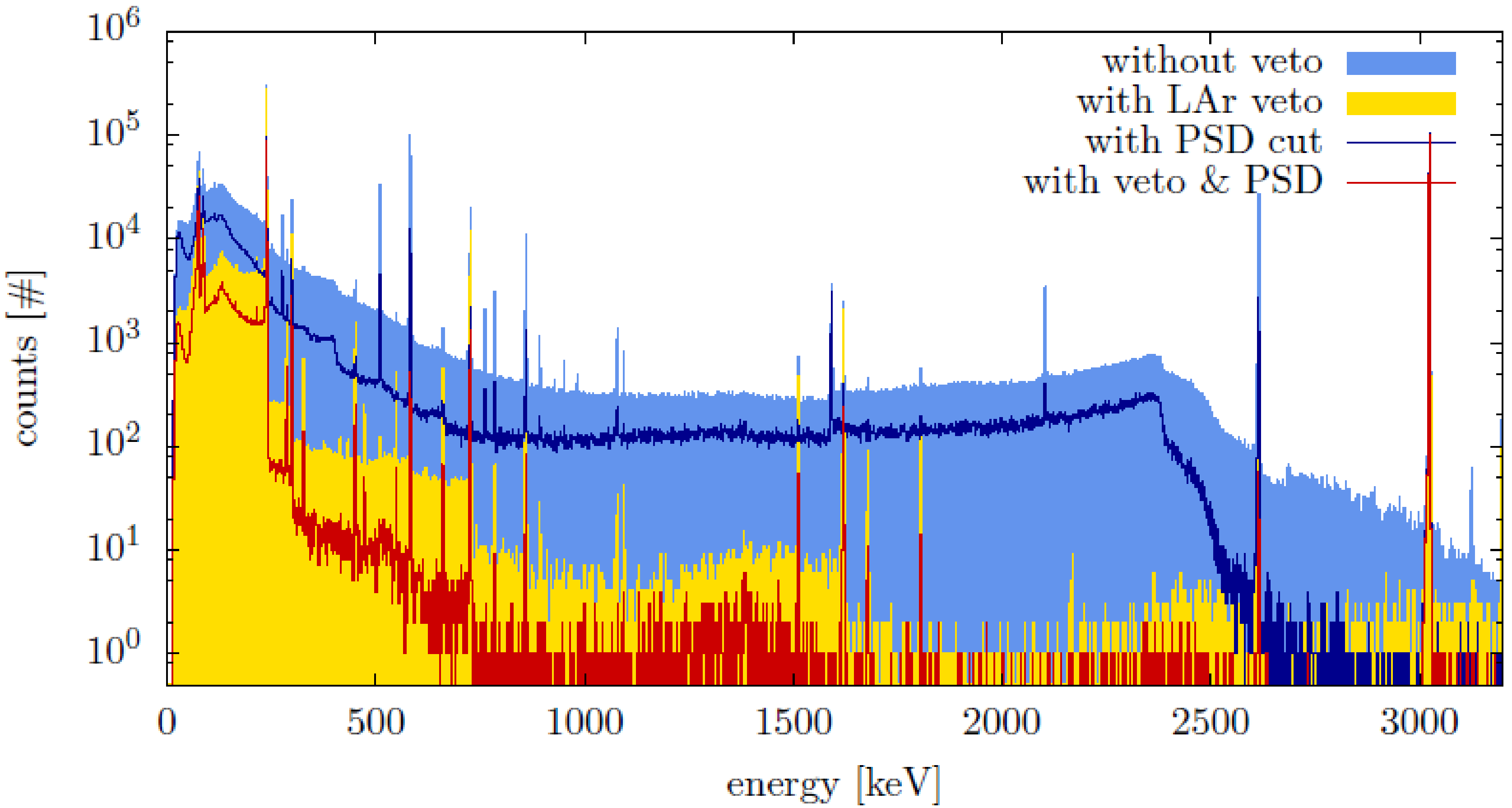


Simulation performed by Alexander Klimenko

Intensity of summation peak is very sensitive for source location

LArGe test facility

Measurements with LArGe shows very good suppression of the background. For internal ^{228}Th calibration suppression factor 5000 in ROI has been obtained.



Phase II background summary: $Q_{\beta\beta}$

Background goal: < 10^{-3} cts/(keV·kg·yr) **PRELIMINARY**

background	without cuts [cts/(keV·kg·yr)]	PSD survival	LAr veto survival	after cuts [cts/(keV·kg·yr)]	
^{208}Tl	≤ 0.01	0.4	$4\cdot10^{-3}$	≤ $1.6\cdot10^{-5}$	a
^{214}Bi	≤ 0.01	0.25	0.3	≤ $7.5\cdot10^{-4}$	a
^{60}Co	≤ $4\cdot10^{-4}$	0.01	0.02	≤ $8\cdot10^{-8}$	a
^{60}Co (in Ge)	≤ $4\cdot10^{-4}$	0.01	0.02	≤ $8\cdot10^{-8}$	a,b
^{68}Ga (in Ge)	≤ 0.015	0.05	0.2	≤ $3\cdot10^{-5}$	b,c
^{210}Po (α on p+)	≤ $4\cdot10^{-3}$	< 0.08	–	< $3.2\cdot10^{-4}$	
^{42}K (β on n+)	0.29 – 0.45	$1.2\cdot10^{-3}$	0.68	(2.4 – 3.7) $\cdot10^{-4}$	b,d

PSD and veto combined acceptance of $0\nu\beta\beta$-decay events is ~86% (with good read-out electronics performance; in case of increased noise, signal acceptance or background suppression will be reduced)

Comments:

[a] observed anti-correlation of PSD and veto not taken into account

[b] detector anti-coincidence not taken into account

[c] includes additional suppression by factor 5 via ^{68}Ge 10 keV X-ray delayed anti-coincidence

[d] reducing ^{42}K ion attraction to detector surfaces can strongly reduce background rate

2νββ

exposure : 6.1 kg yr