Liquid argon shielding for GERDA

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MPIK Heidelberg
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Acknowledgements

- Experimental work presented here have been carried out in the framework of the R&D for the GERDA double beta decay experiment
- Publications under preparation:
  - LAr purification: G. Zuzel, H. Simgen
  - Operations of HP-Ge detectors in with LAr scintillation read out: P. Peiffer, M. Di Marco
  - LAr scintillation studies: P. Peiffer, T. Pollmann, A. Smolnikov, S. Vasieliev
  - Ar-36 0νECEC: O. Chkvorets, M. Bernabe-Heider, K. Gusev
- Work partly supported by ILIAS/IDEA

Outline

- Reminder: baseline design of GERDA
  - Operation of HP Ge in LAr as **passive** shield
- Radiopurity of LAr
  - Radon
- LAr scintillation
  - Active veto system
  - Phtoelectron yield with optimized WLS and reflectors
  - Pulse shape studies (α, γ/β,neutrons) of LAr and with Xe doping
- 1 m_ LAr prototype set up at LNGS in GERDA DetLab
- Outlook and ILIAS-next/JRA2 WPs

Scope of this talk

('spirit of ILIAS-next JRA2')

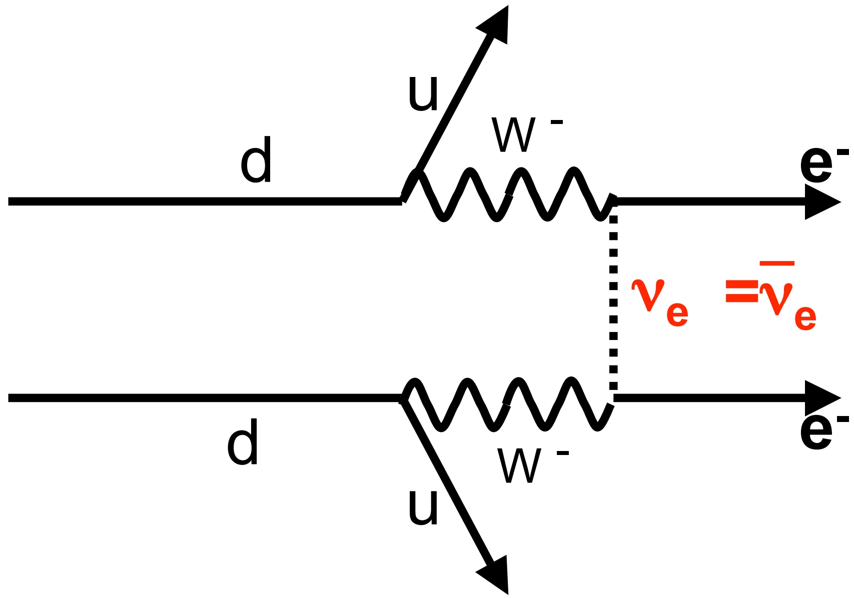
- Discuss LAr shield (not Ge-76 detectors)
- LAr as shield against nuclear radiation:
  - High purity & high density (1.4 g/cm_)
  - Cryogenic cooling for HP-Ge detectors
  - Scintillation light to discriminate backgrounds
  - Pulse shape characteristics for particle id
- R&D relevant not only for GERDA, but also for DM and next generation LAr detectors

GERDA baseline (High purity & high density; Cryogenic cooling)

Option for later phase (Scintillation light; Pulse shape characteristics)

Reminder: 0ν-ββ Decay

$$(A, Z) \rightarrow (A, Z+2) + e_1^- + e_2^-$$



ΔL=2

Assume leading term is exchange of light Majorana neutrinos

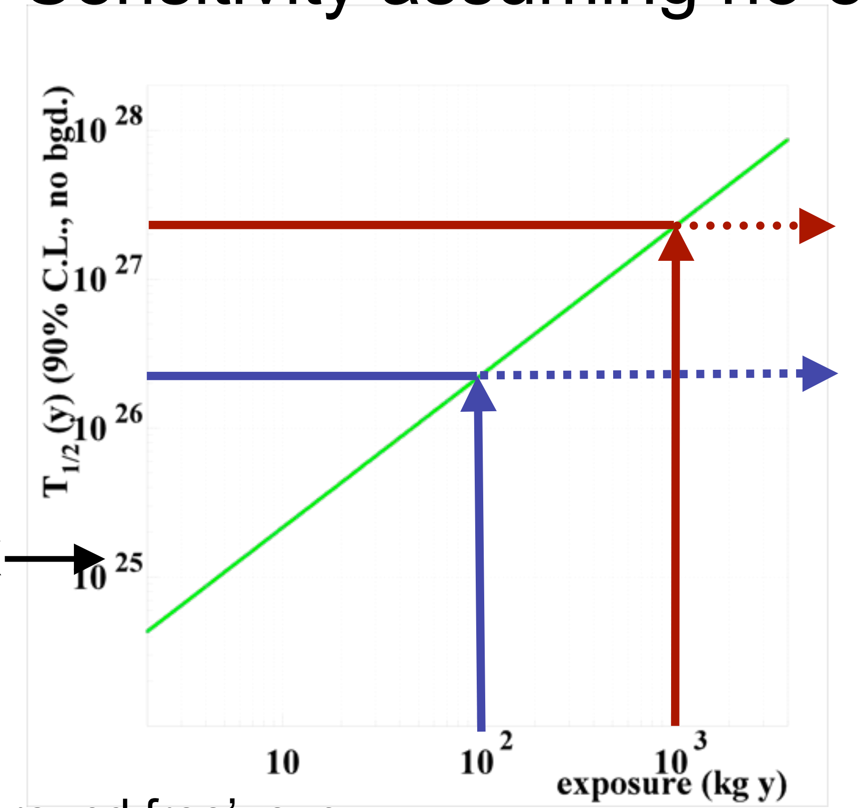
$$T_{1/2}\,(0\nu)^{-}\_ = G\;M\_\;m\_{ee}$$

Effective neutrino mass

Phase space

Nuclear matrix element

^{76}Ge DBD: Sensitivity assuming no events in ROI



KK

<54 meV

<171 meV

assuming
$|M^{0\nu}|=2.5$ [Rod06]
and 89% enrichment

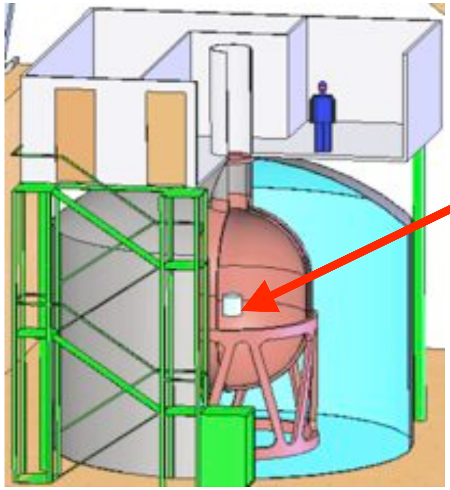
required for 'background free' exp.
with ΔE~3.3 keV (FWHM): **$O(10^{-3})$** **$O(10^{-4})$** counts/(kg·y·keV)

New experiments:

⇒Background reduction by factor **10^2 - 10^3** required w.r. to precursor exps.

⇒Degenerate mass scale **$O(10^2$ kg·y)** ⇒ Inverted mass scale **$O(10^3$ kg·y)**

Reminder: GERDA @ LNGS



•'Bare' ^{enr}Ge array in liquid argon (nitrogen)
•Shield: high-purity liquid **argon** (**N**) / H_2O
•Phase I: ~18 kg (HdM/IGEX diodes)
•Phase II: add ~20 kg new enr. Detectors with **segmented** electrodes; total ~40 kg

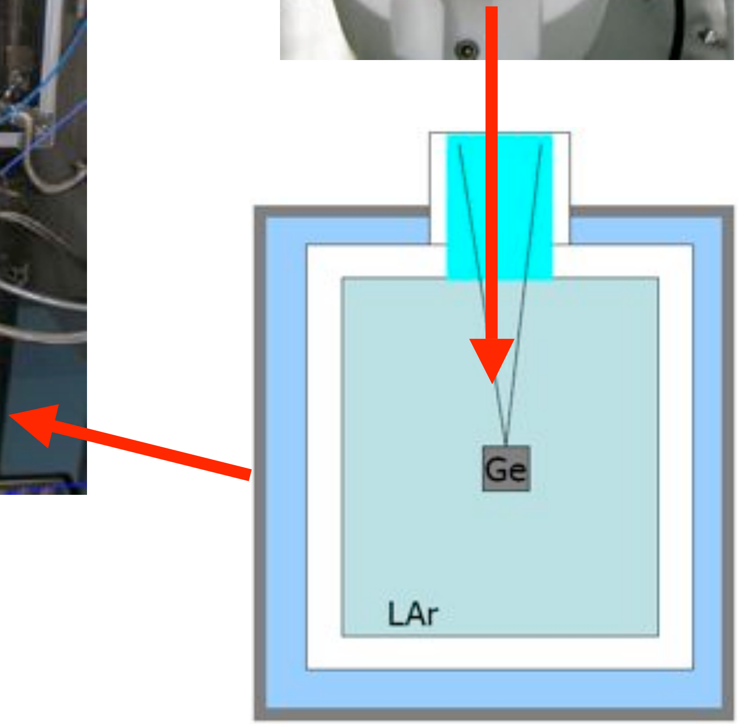
Phase I+II (100 kg years):
Physics goals: degenerate mass range
Technology: study of bgds. and exp. Techniques
Background: 10^{-3} counts/(kg·y·keV)

Depending on physics results of Phase I+II:
Phase III: 1 ton exp. to explore inv. hierarchy mass range ~10 meV
Background: 10^{-4} counts/(kg·y·keV) ⇒ advanced reduction techniques

Operation of HP-Ge in LAr

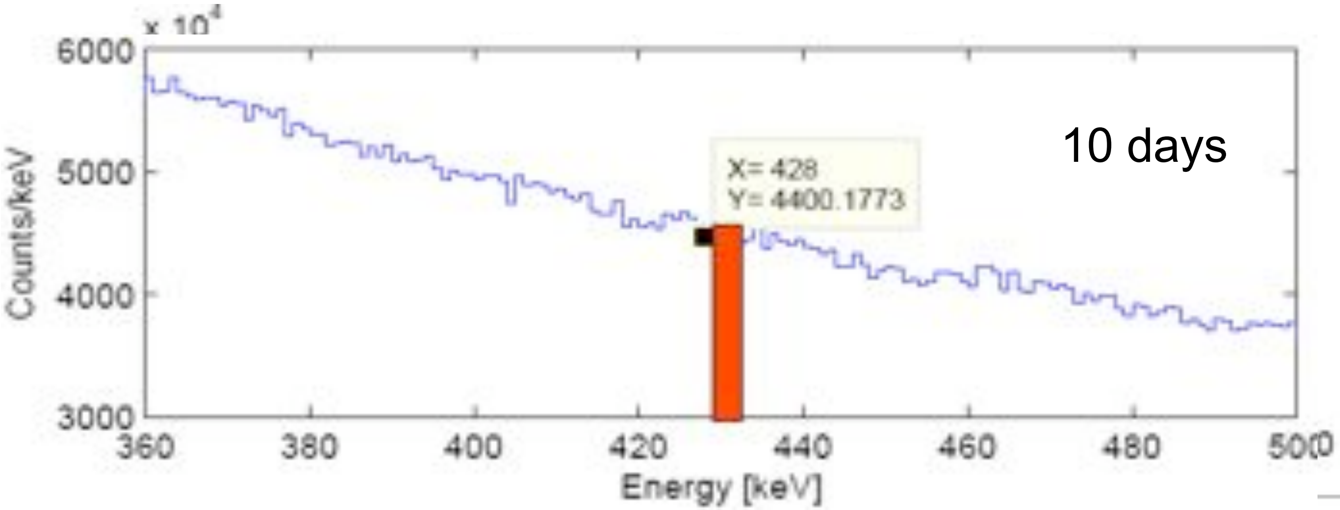
(detector test stand in GERDA DetLab at LNGS)

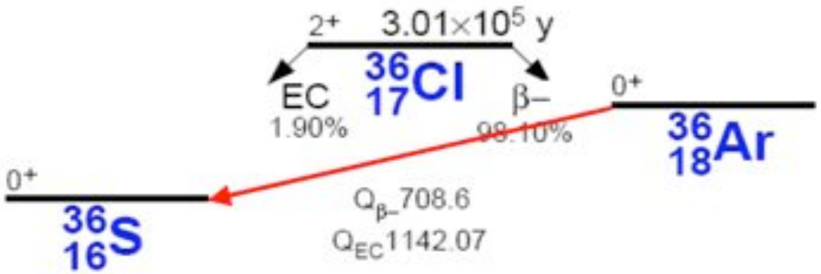
1.6 kg non-enriched
Prototype detector

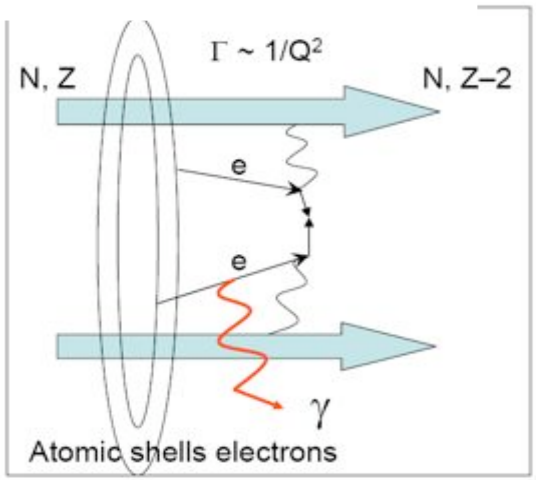


- Steel dewar with 70 liter of argon
- Modest shield:2 cm lead
- Not a low-background steup!!

Measurements with 1.6 kg detector in LAr test setup in GERDA DetLab at LNGS







^{36}Ar: 0.336% natural abundance

$E\gamma = Q - E_K - E_L$ = 430.8 keV

First 0νECEC limit on ^{36}Ar

Isotope	Abundance, %	Mode	$T_{1/2}$, y	Ref.
^{36}Ar	0.336	0νECEC	$1.9 \cdot 10^{18}$ (68%)	this work
^{50}Cr	4.345	(0ν+2ν)ECβ+	$1.3 \cdot 10^{18}$ (95%)	Bikit et al. (2003) [12]
^{64}Zn	48.63	0νECEC	$1.0 \cdot 10^{18}$ (68%)	Danevich et al. (2005) [13]
		0νECβ+	$1.3 \cdot 10^{20}$ (90%)	Kim et al. (2003) [13]
^{74}Se	0.89	0νECEC	$6.4 \cdot 10^{18}$ (90%)	Barabash et al. (2006) [14]
		(0ν+2ν)ECβ+	$1.9 \cdot 10^{18}$ (90%)	-"-
^{106}Cd	1.25	2νECEC	$4.8 \cdot 10^{19}$ (90%)	Stekl et al. (2006) [15]
^{108}Cd	0.89	0νECEC	$2.5 \cdot 10^{17}$ (68%)	Danevich et al. (2003) [16]
^{112}Sn	0.97	(0ν+2ν)ECβ+	$1.5 \cdot 10^{18}$ (68%)	Kim et al. (2003) [17]
^{120}Te	0.09	2νECEC	$9.4 \cdot 10^{15}$ (90%)	Kiel et al. (2003) [18]
^{130}Ba	0.106	0νECβ+	$2.0 \cdot 10^{17}$ (90%)	Cerulli et al. (2004) [19]
^{136}Ce	0.185	2νECEC	$4.5 \cdot 10^{16}$ (68%)	Belli et al. (2003) [20]
^{138}Ce	0.251	2νECEC	$6.1 \cdot 10^{16}$ (68%)	-"-
^{180}W	0.12	0νECEC	$1.3 \cdot 10^{17}$ (68%)	Danevich et al. (2003) [21]

This work:
>1.9 10^{18} years (68% C.L.)
(not bad for detector test!)

Results of recent experiments (2003-2006) searching for ECEC transitions 10^{16} -10^{19} y

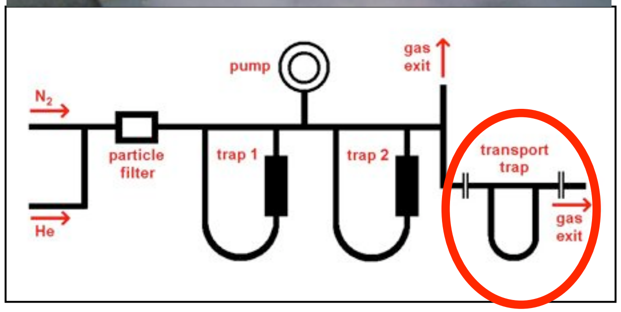
N.B.: Theory: 0νECEC not competitive compared to 0νββ!

LAr radiopurity: Measurement of ^{222}Rn

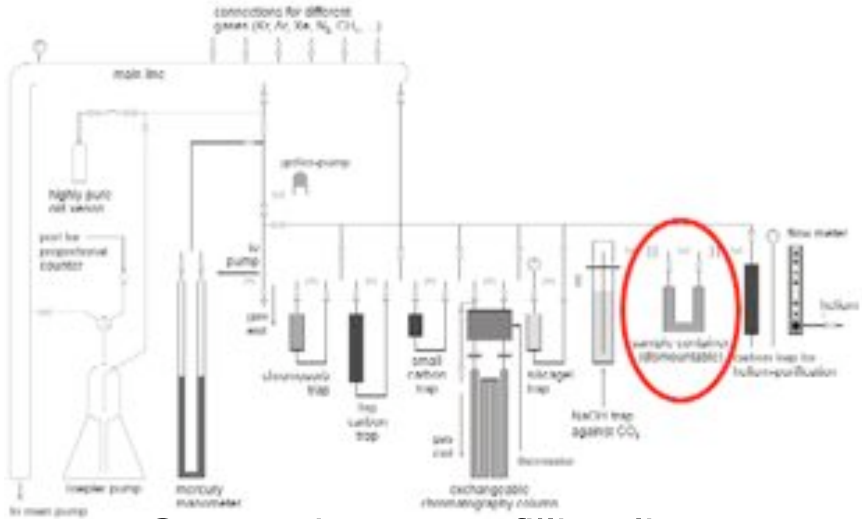
Requirement for GERDA: 0.5 μBq/m_ (STP) or less than 1 ^{222}Rn atom/m^3

$\Rightarrow 10^{-4}$ cts/(kg keV year) at $Q_{\beta\beta}$ in GERDA

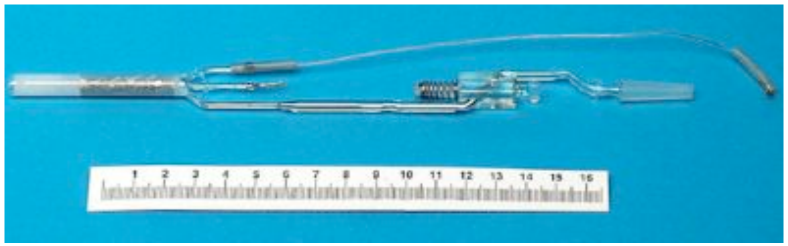
Mobile Radon Extraction Unit (MoREx)



MoREx schematics



Gas and counter filling line



Gallex/GNO counters

LAr radiopurity: ^{222}Rn concentration in LAr

Date	Quality	Sample size	^{222}Rn activity [mBq/m^3] when measured	after production
29.09.04	Ar 4.6	117 m^3	2.9 ± 0.2	> 8
04.11.04	Ar 4.6	141 m^3	0.20 ± 0.02	—
08.06.05	Ar 5.0	200 m^3	6.0 ± 0.1	8.4 ± 0.2
21.11.05	Ar 5.0	85 m^3	0.048 ± 0.004	—
28.11.06	Ar 5.0 (GS)	4 m^3	< 0.020	—
13.06.05	Ar 6.0	104 m^3	0.11 ± 0.01	0.38 ± 0.02

Best: <20 μBq/m_ (WARP, long storage time)

Rn emanation of SOL storage tank 6 μBq/m_ (STP) for BOREXINO LAKN;
best: 1 μBq/m_
worst: ~100 μBq/m_ (STP)

LAr purification (^{222}Rn)

Purification of N_2 in liquid phase adsorption on activated charcoal

$\Rightarrow ^{222}$Rn <0.5 μBq/m^3 (STP) at 100 m_ (STP) / hour production rate for BOREXINO

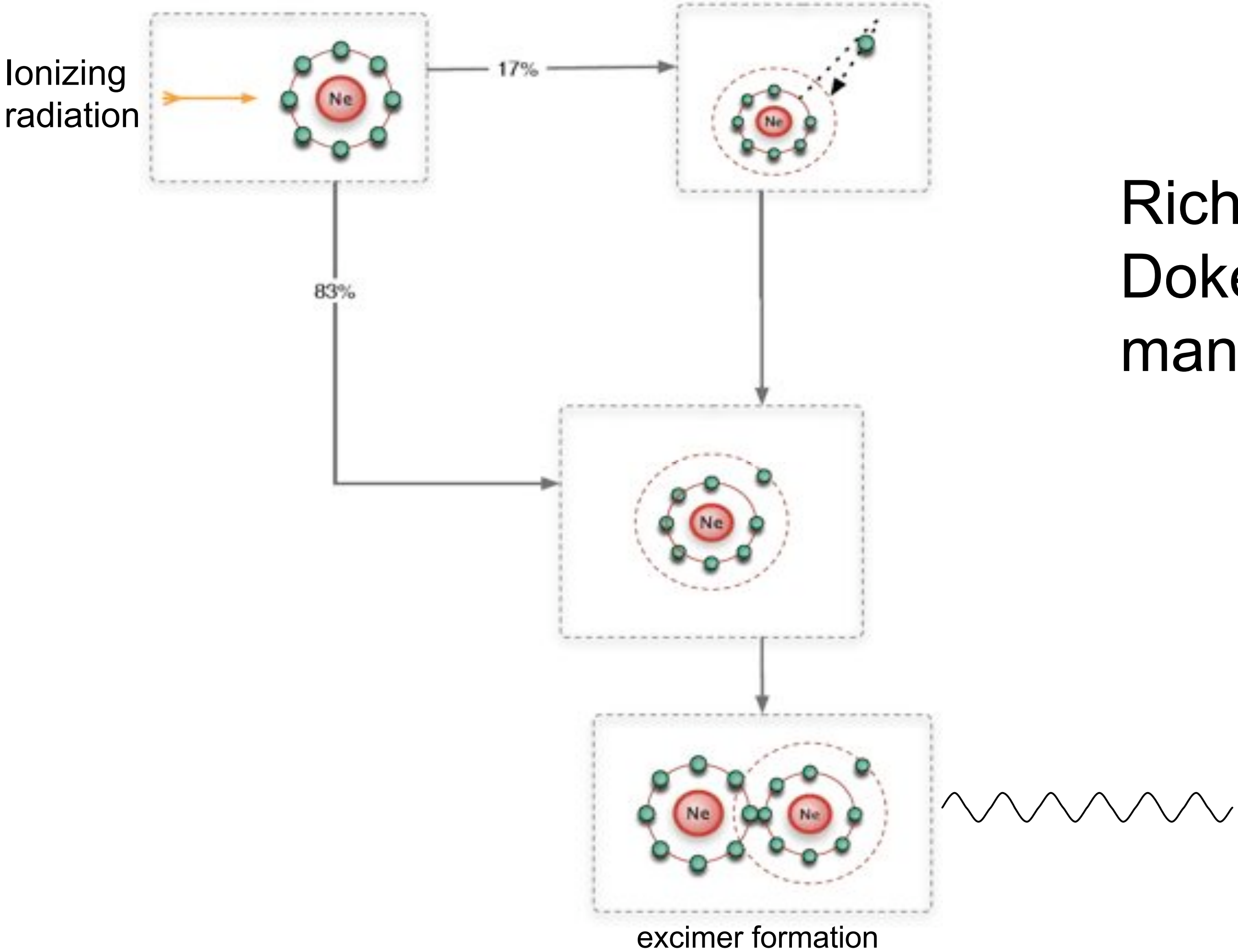
Argon (laboratory measurements):
Reduction factors (work is ongoing):
•>2700 / kg of charcoal adsorber (gas phase, 150 g trap)
•~240 / kg (liquid phase, 60 g trap)

Strategy how to meet purity specs:
•Selection of tanks with low emanation
•Select supplier & define filling procedure
•Wait until initial Rn decays
•Active cooling of experimental cryostat
•Purification unit (for refilling)

$\Rightarrow ^{222}$Rn <1 μBq/m^3 (STP)

N.B. ^{39}Ar/^{41}Ar no issue for DBD;
argon more challenging than nitrogen!

Well known: LAr scintillates!

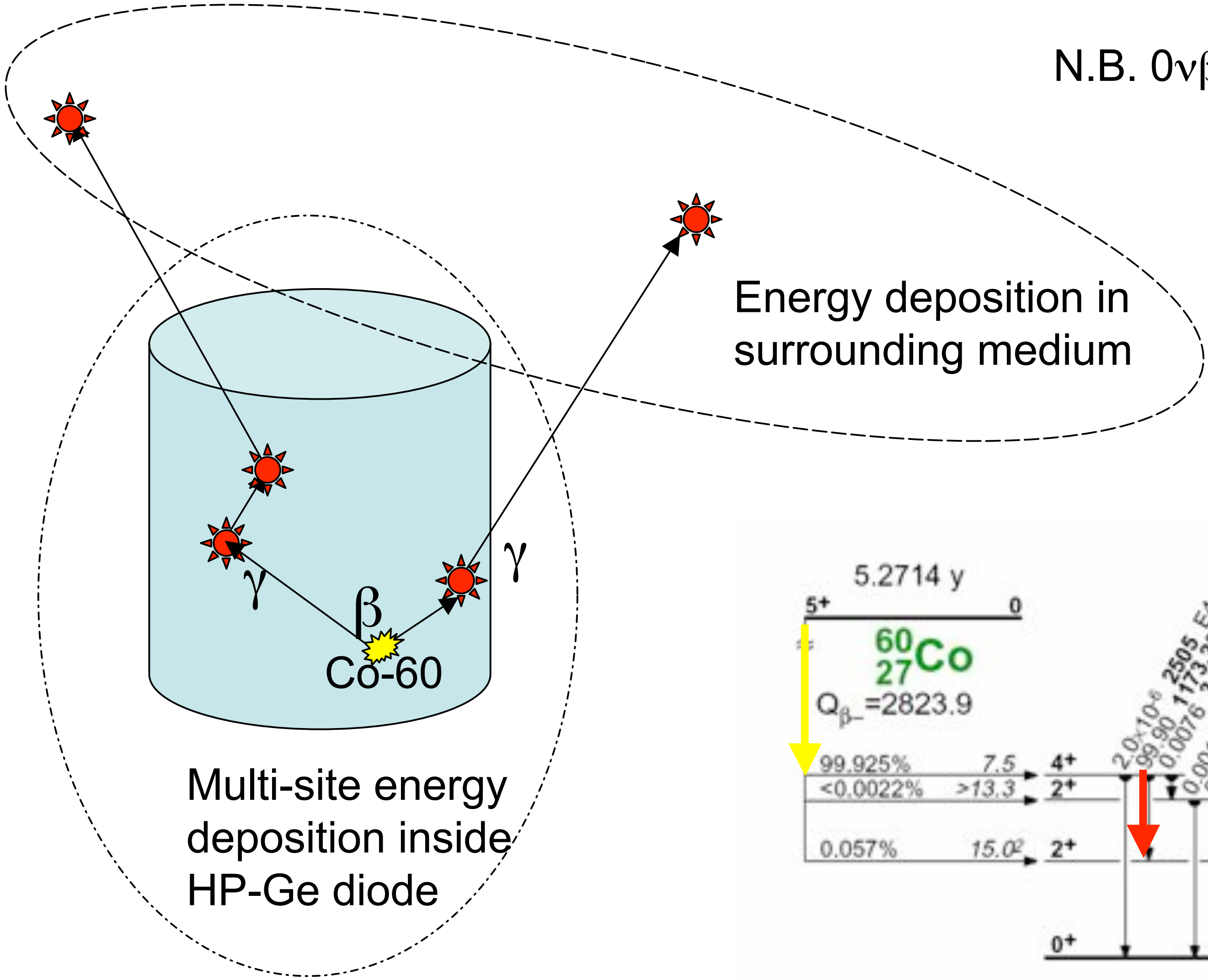


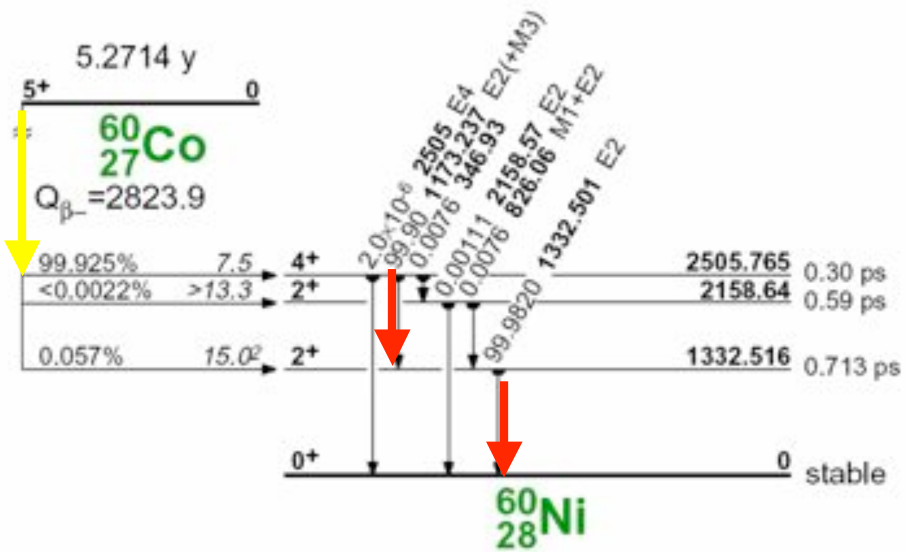
Rich literature:
Doke, Hitachi,…and many more

128 nm
τ_s=6 nsec
τ_t=1.6 μsec
I_s/I_t: 0.3 electrons
1.3 α

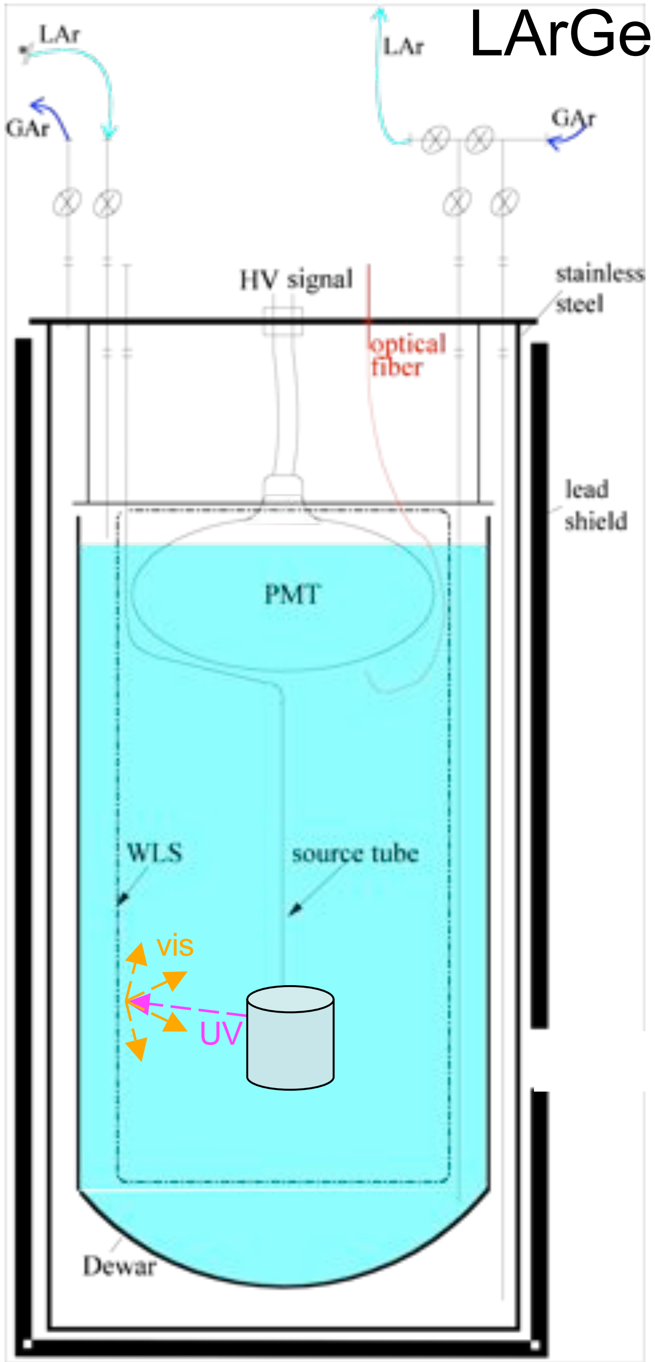
LAr veto: physics principle

N.B. $0\nu\beta\beta$ is single-site





LArGe@MPI-K: Schematic system description



- Dewar _29 cm, h=65 cm (43 L – total volume)
- Light detection: WLS (VM2000 + PST/TPB)
  + PMT(8“, ETL 9357-KFLB)
- Active volume _20 cm, h=43 cm
  ≈ 19 kg **LAr** (13,5 L)
- Shielding: 5 cm lead (+ 10 cm BP for n)
  +15 mwe underground

specular reflectivity (TPB in PST on 3M)

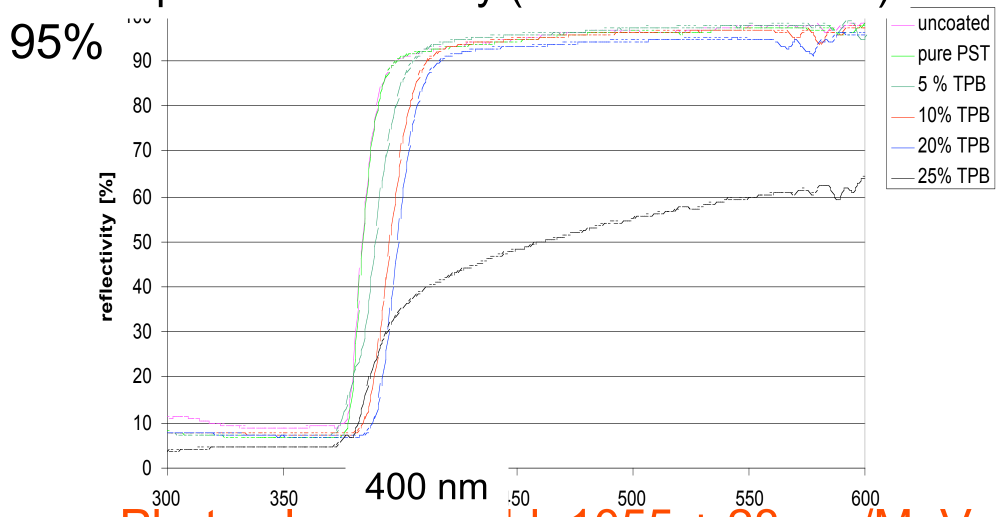
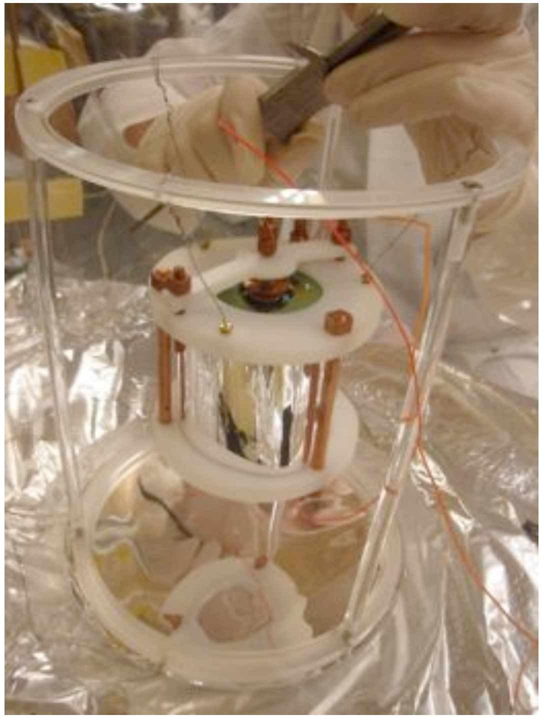


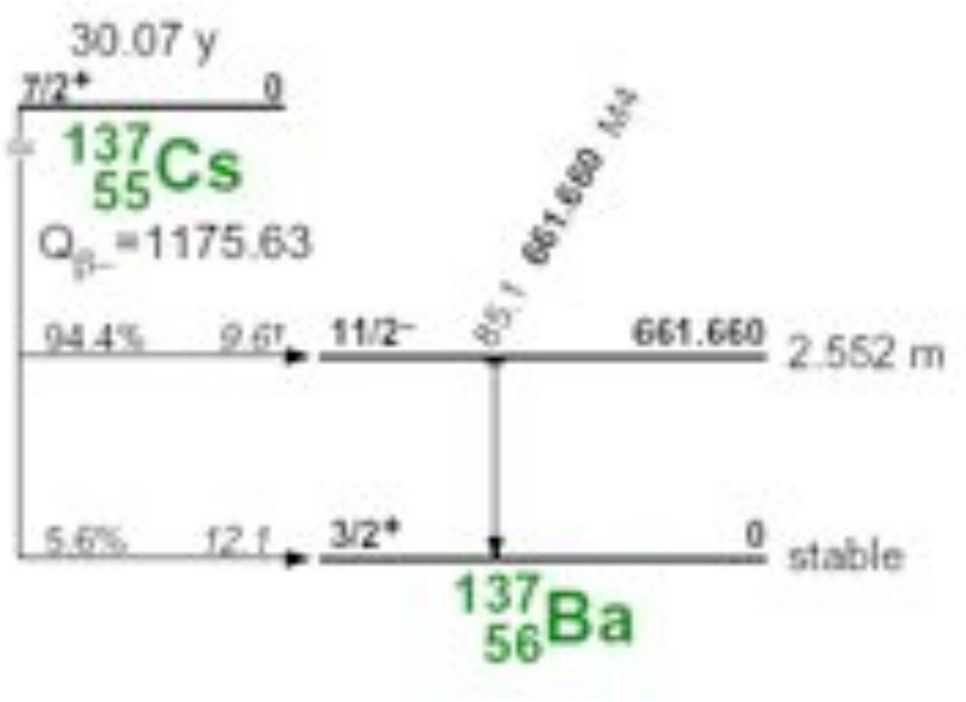
Photo electron yield: 1055 ± 28 pe/MeV

LArGe at MPIK-Heidelberg



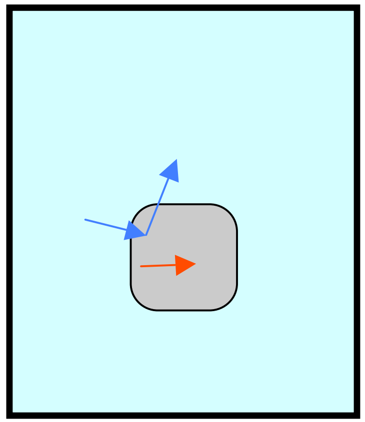
LAr veto: a simple case

^{137}Cs : single γ line at 662 keV



full energy peak : no suppression with LAr veto

Compton continuum: suppressed by LAr veto



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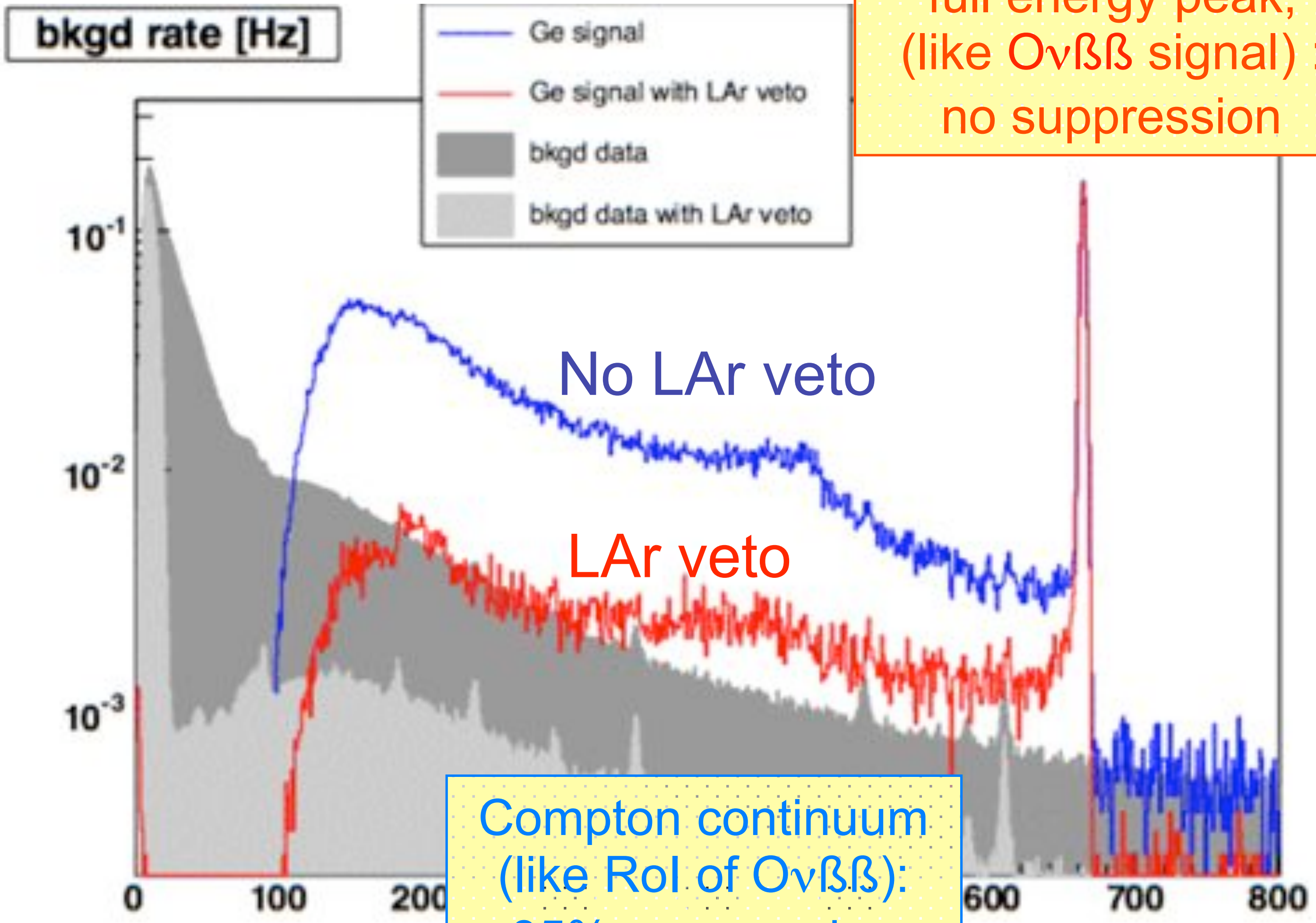
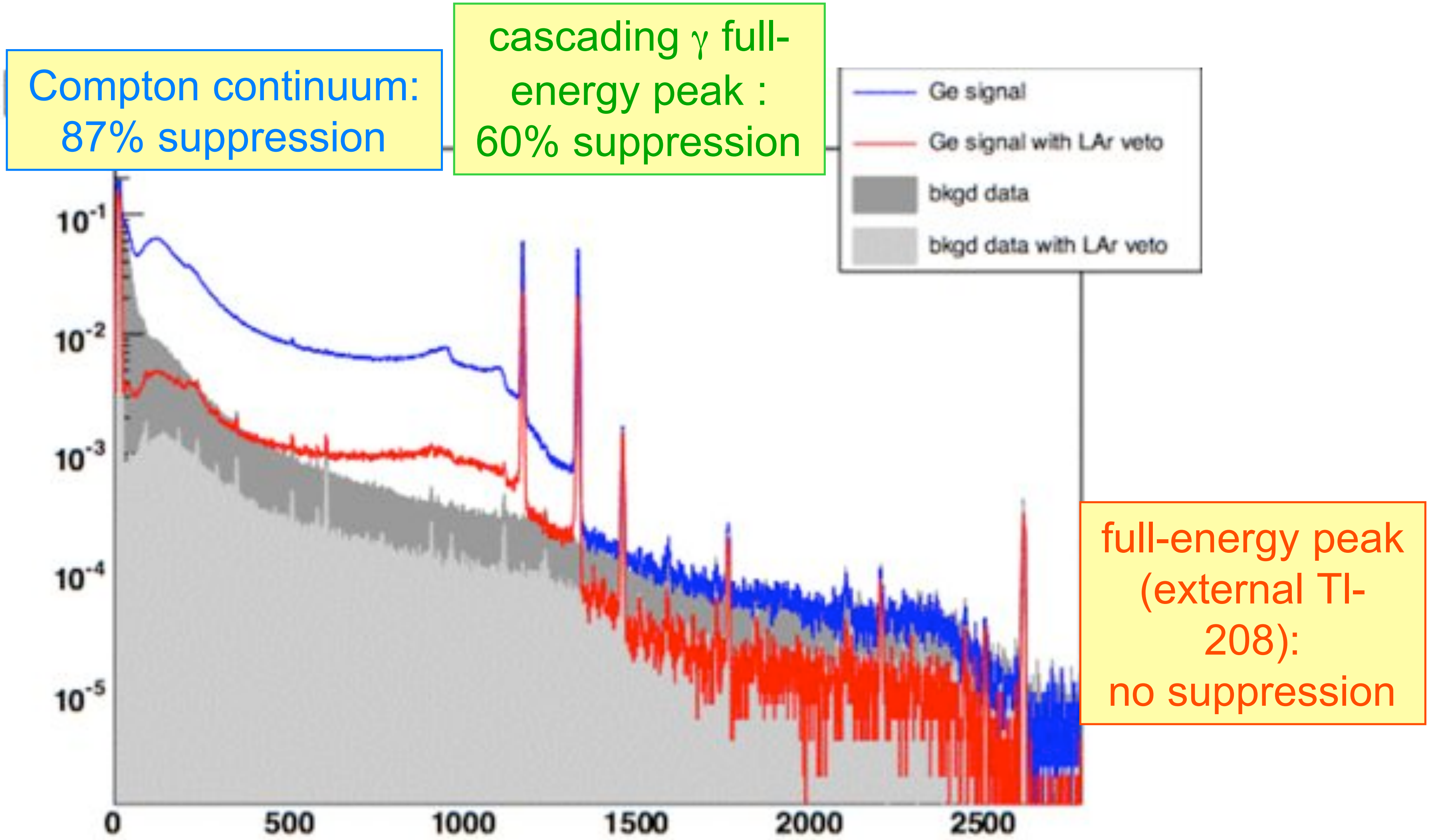


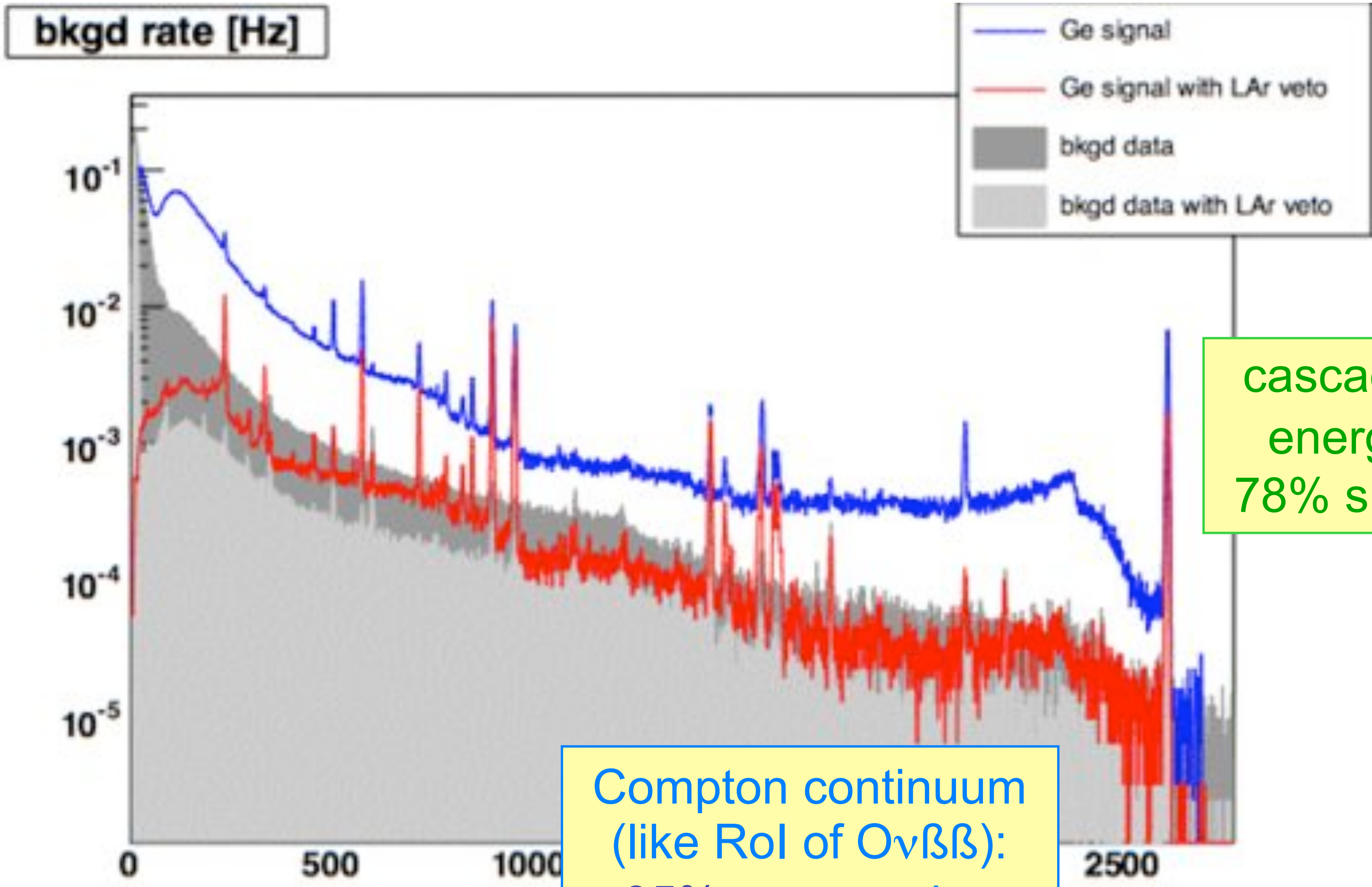
full energy peak,
(like 0νßß signal) :
no suppression

Compton continuum
(like RoI of 0νßß):
85% suppression

LAr veto: ^{60}Co



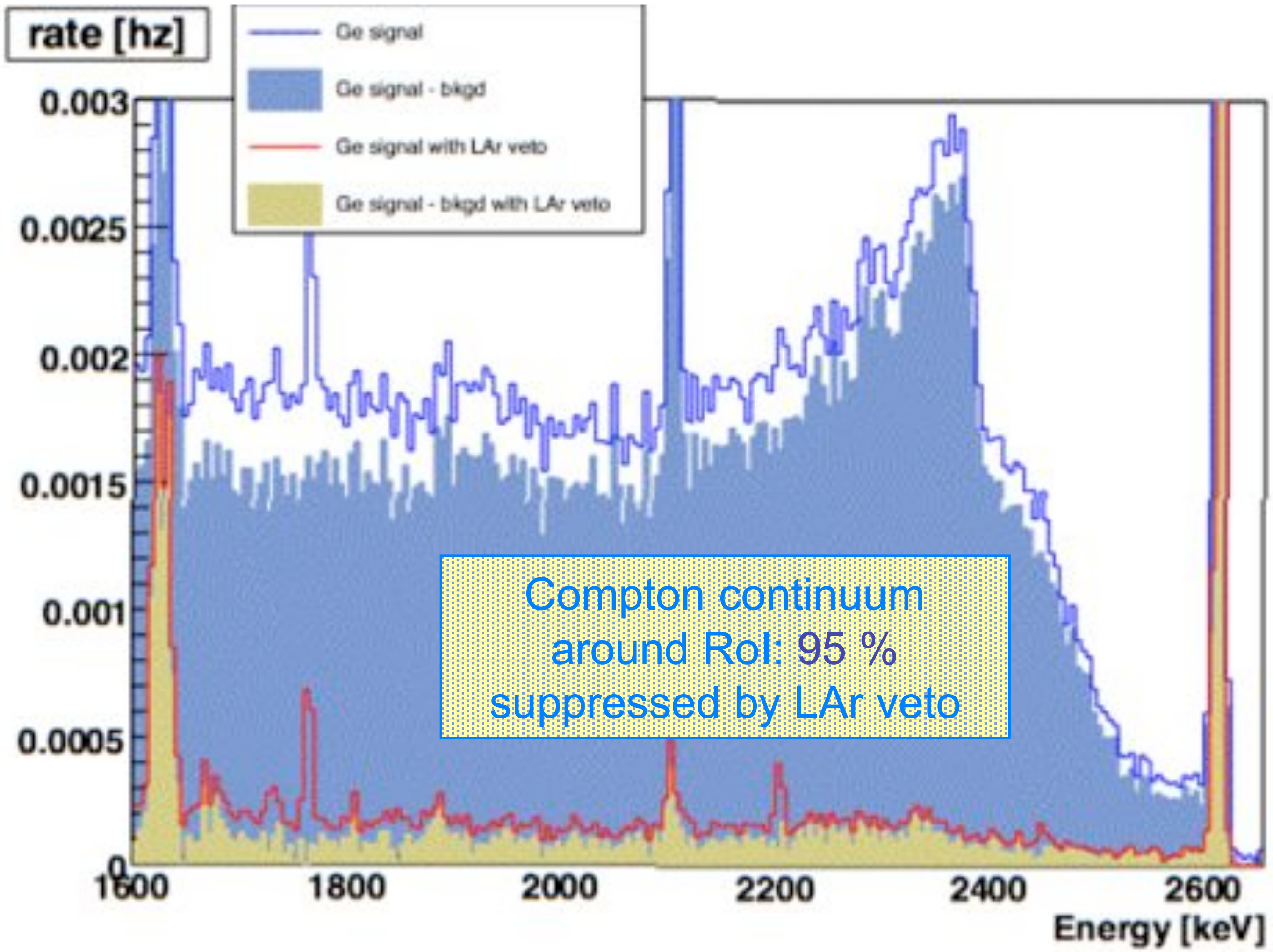
LAr veto: ^{232}Th



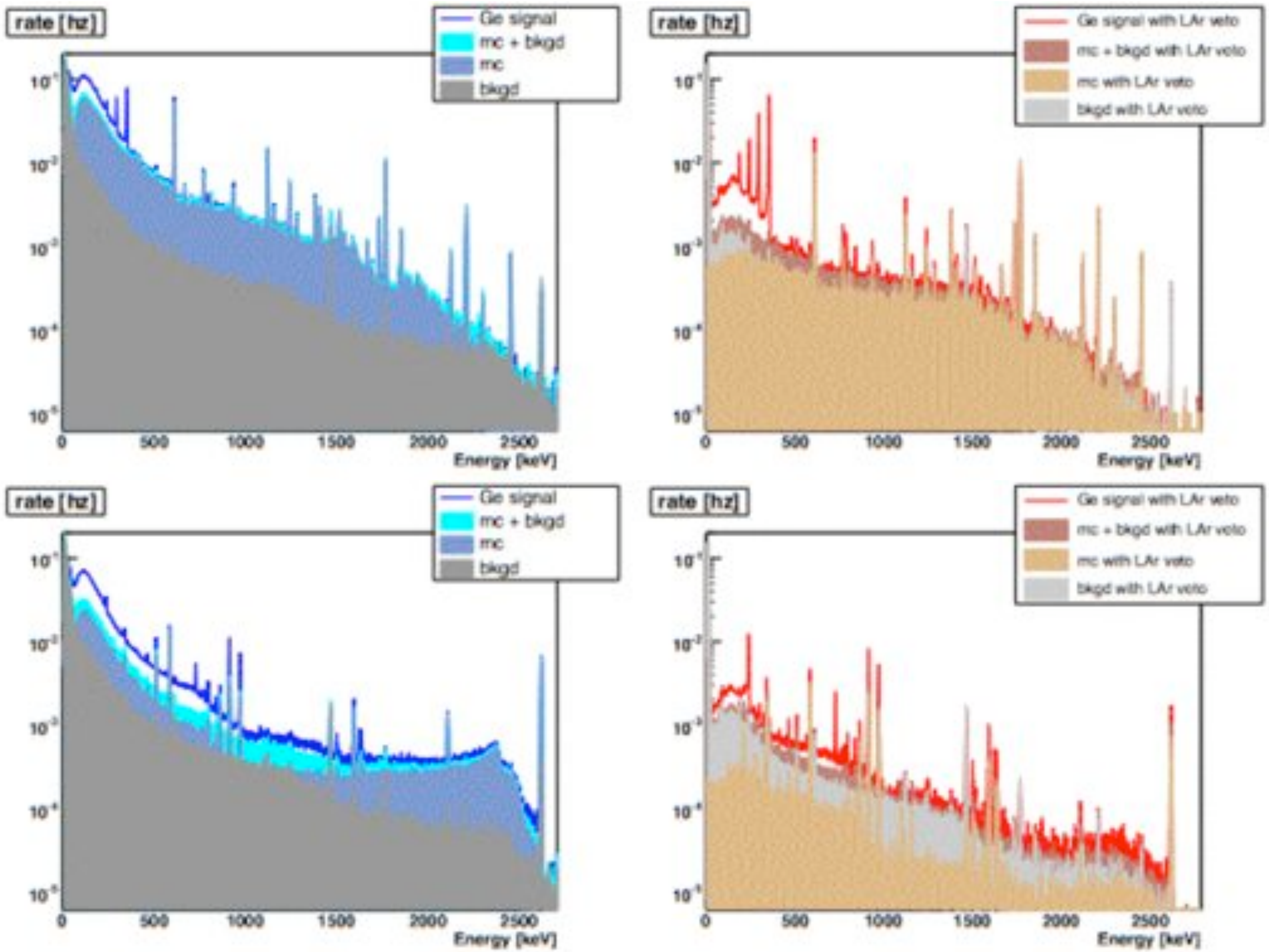
cascading γ full-energy peak : 78% suppressed

Compton continuum (like RoI of 0νßß): 95% suppression

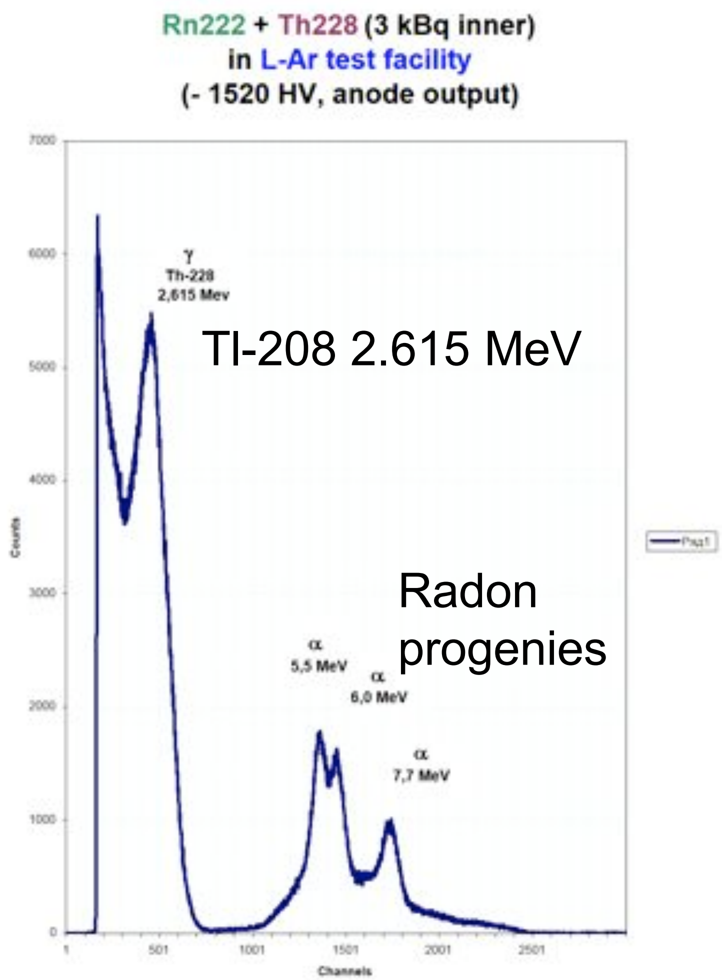
LAr veto: ^{232}Th

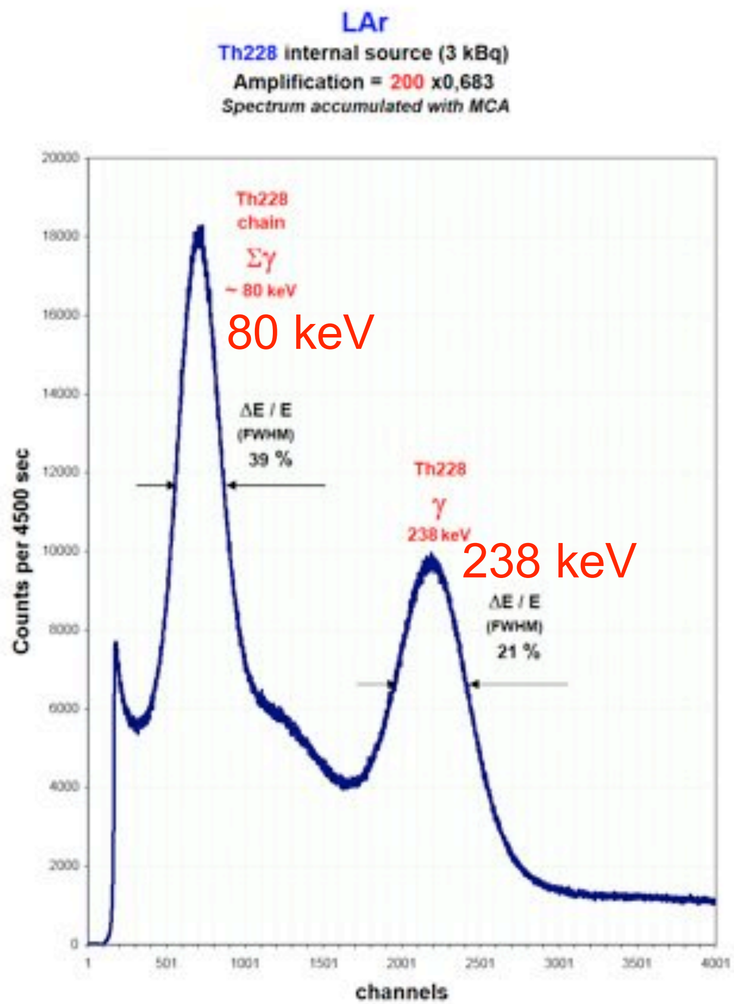


comparison with Monte-Carlo



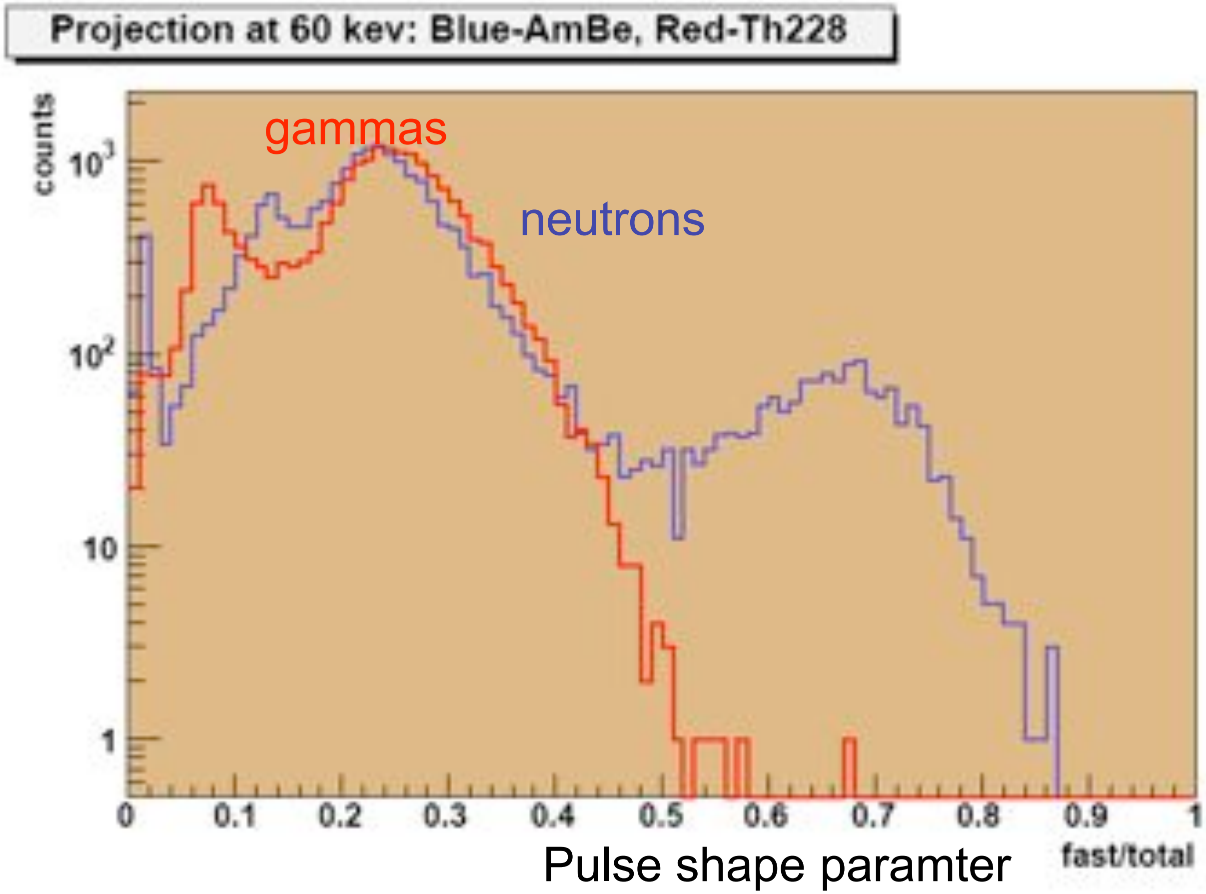
Spectroscopic performance of LAr spectrometer



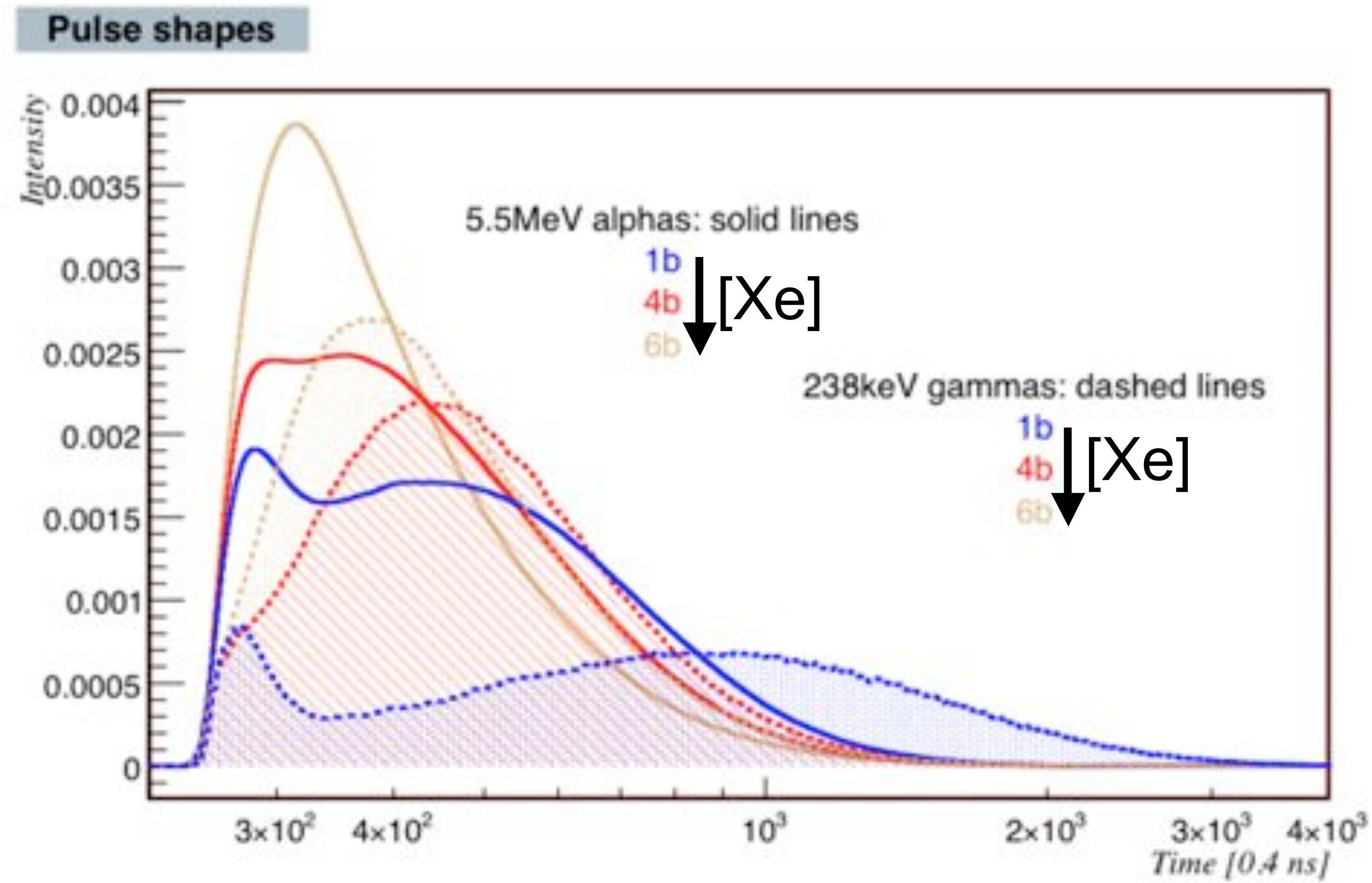


Pulse shapes discrimination

AmBe (neutron+gamma) & **Th228 (gamma)** sources
Projection with threshold 60 keV



Xe admixtures to Ar: pulse shape studies



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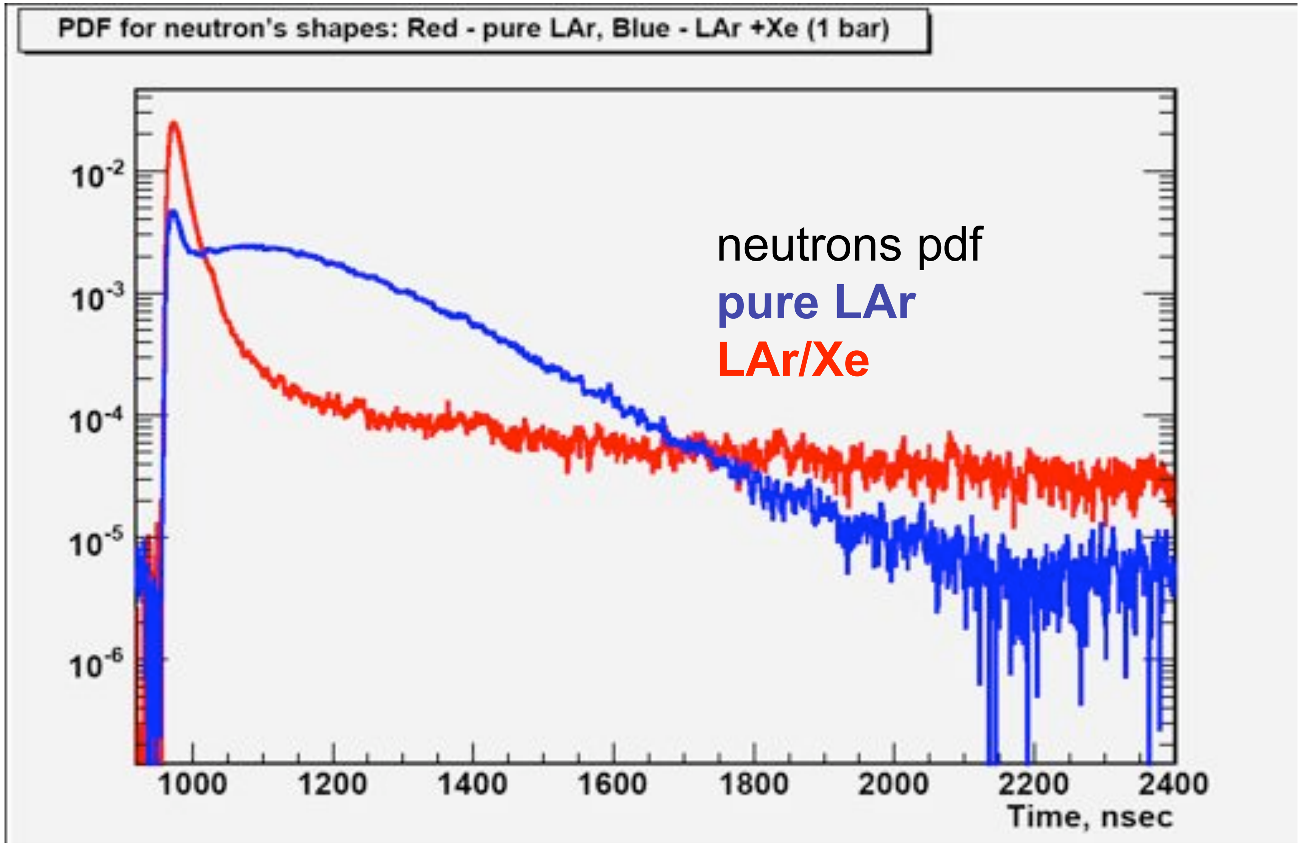
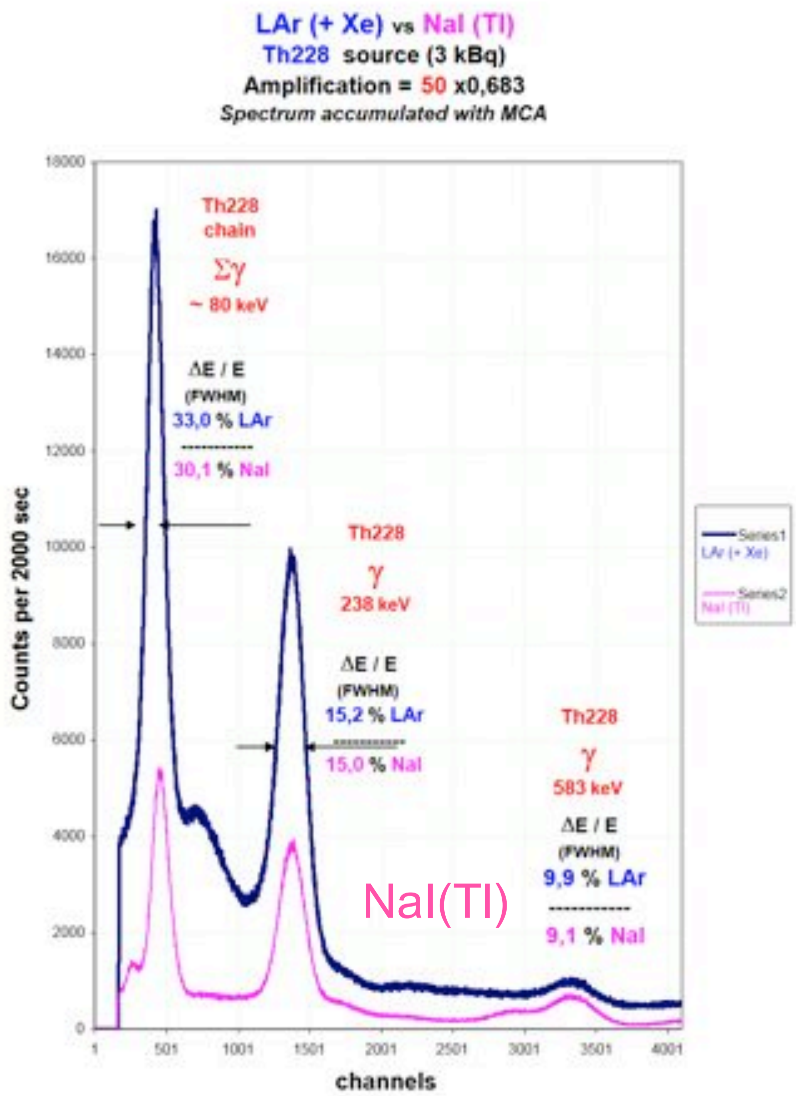


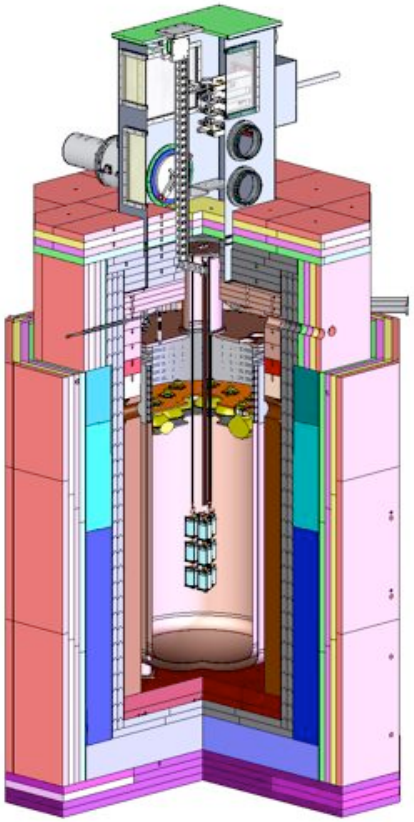
Under study: can small Xe admixtures improve pulse shape discrimination?

Xe admixtures to LAr: spectroscopic performance



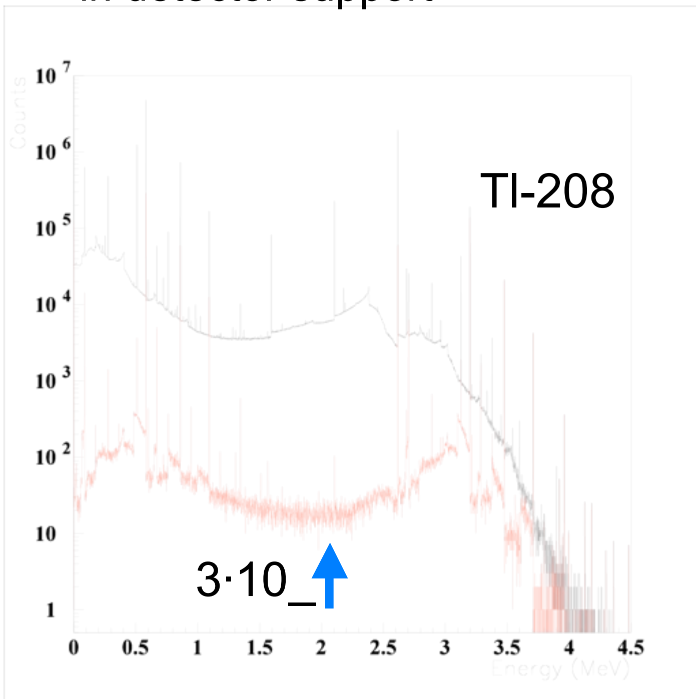
20 kg LAr:
ΔE/E **7,5 % at 1 MeV**
(similar to 3” **NaI(Tl)**)

Next steps



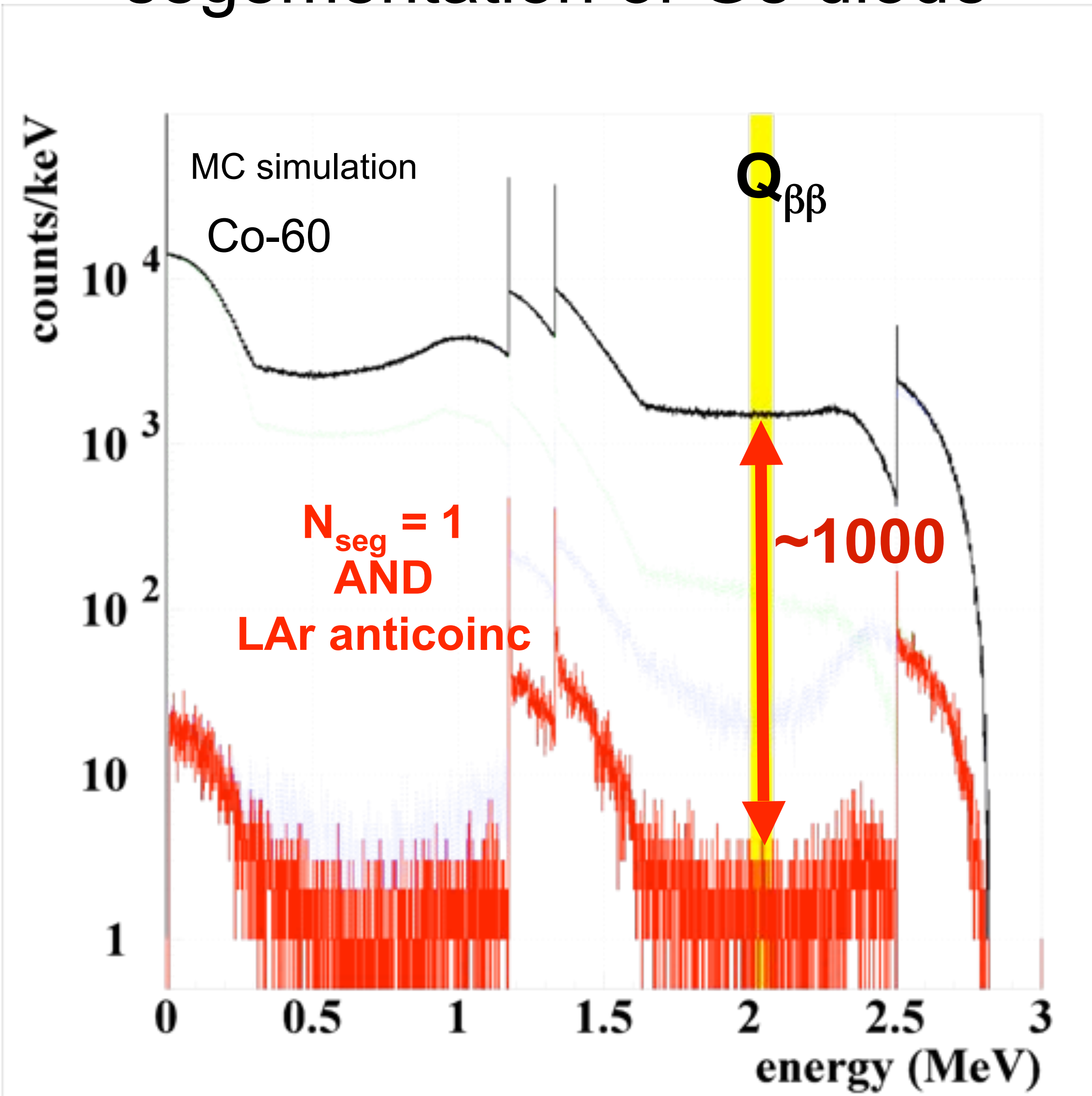
- ✓ ∅ = 90 cm ⇒ no significant escape of LAr scintillation
- ✓ h = 200 cm, volume = 1000 L ~ 1.4 ton of LAr
- ✓ can fit 9 crystals
- ✓ shield: 15 cm Cu/10 cm Pb/23 cm Steel/20 cm PE
- ✓ 9 PMT's 8" (ETL type K9357)

Example:
Background suppression for contaminations located in detector support



- •LAr pulse shape to study bgd sources (beta/gamma, alpha, neutrons)
- •Investigate DM potential!

Combining LAr suppression and electrode segementation of Ge diode



Example:
7-fold
segmentation

Summary/Outlook

- GERDA baseline design: LAr as passive shielding (1.4 g/cm_) under construction
  $\Rightarrow$ bgd index: **<10^{-3}** cts/(keV kg y)

- R&D for a 1 ton Ge experiment ongoing in parallel $\Rightarrow$ bgd index: **<10^{-4}** cts/(keV kg y)

- Close links with
  - LAr / LXe DM search
  - next generation LAr detectors (e.g. Laguna) [idea: doping with Xe-136 $\Rightarrow$ DBD experiment with multi-ton Xe target]

- ILIAS-next plans (JRA2):
  - WP2 - NOBLE LIQUID AND GAS DETECTORS
    - TASK 2.2 ADVANCED METHODS OF LIGHT READOUT
    - TASK 2.3 IONISATION AND SCINTILLATION PROCESSES AT KEV ENERGIES
    - TASK 2.5 ADVANCED STUDY OF PULSE SHAPE PROPERTIES OF LAr SCINTILLATION LIGHT
    - TASK 2.6 PROPAGATION OF XUV PHOTONS IN LIQUID ARGON
  - WP3 - ADVANCED SEMICONDUCTOR DETECTORS WITH ACTIVE AND PASSIVE BACKGROUND CONTROL
    - TASK 3.1 NOVEL LIQUID ARGON ACTIVE VETO SYSTEM FOR GE DETECTORS
    - TASK 3.3 ADVANCED PULSE SHAPE ANALYSIS IN GE AND LARGE HYBRID DETECTORS
    - TASK 3.4 OPTIMIZED ELECTRODES SEGMENTATION SCHEMES FOR Ge AND CdZnTe DETECTORS FOR BACKGROUND SUPPRESSION AND PARTICLE ID

EXTRA SLIDES

Date	Quality	Sample size	^{222}Rn activity [mBq/m^3] when measured	after production
29.09.04	Ar 4.6	117 m^3	2.9 ± 0.2	> 8
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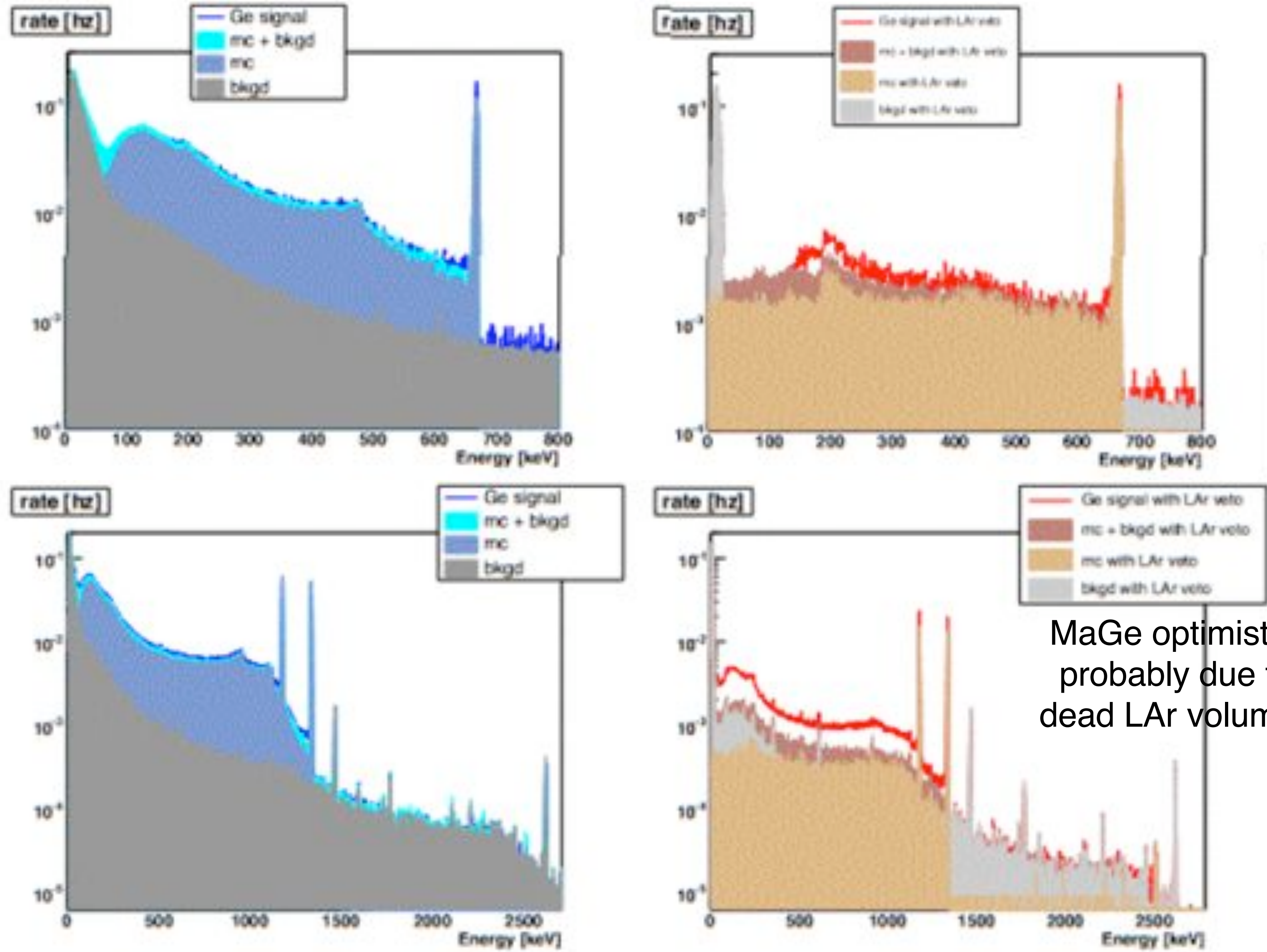
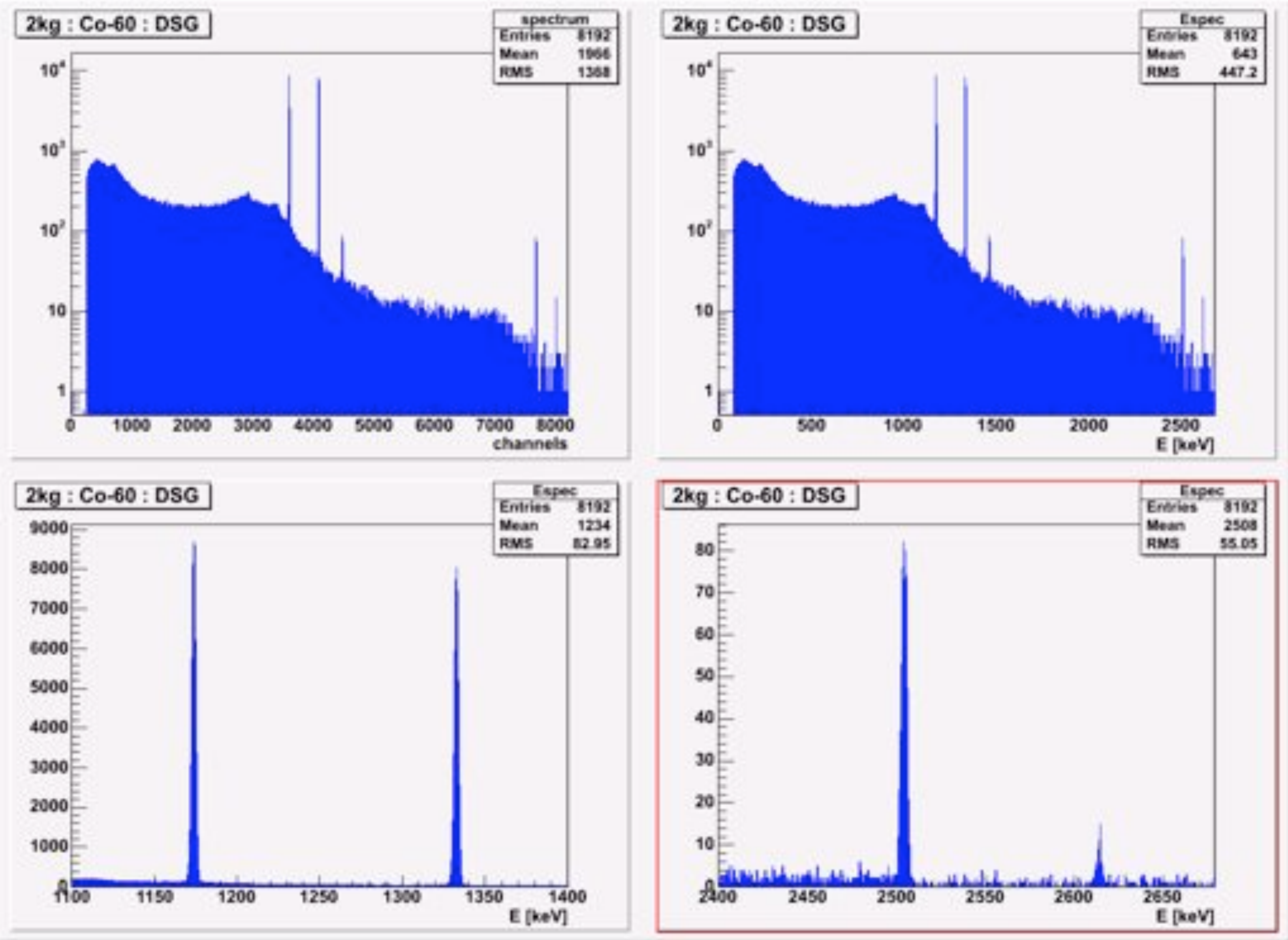
Tank	Volume [m^3]	Emanation rate [mBq]	Spec. emanation rate [mBq/m^3]	Expected conc. [mBq/m^3]
LAr transport tank for 6.0 quality only	0.67	42 ± 2	63	0.08
LAr storage tank for 5.0 quality*	3	177 ± 6	59	0.07
LN_2 storage tank for 7.0 quality only	3	2.7 ± 0.3	0.9	0.001
LN_2 storage tank for 6.0 quality only	16	65 ± 6	4	0.005
LAr storage tank for 4.0 quality	0.3	~ 33	~ 110	~ 0.13
LAr storage tank for 5.0 quality*	3	~ 38	~ 13	~ 0.015
LAr storage tank for 5.0 quality (GS)	5	~ 16	~ 3.2	< 0.02

comparison to Monte-Carlo



MaGe optimistic:
probably due to
dead LAr volumes

Bare HP-Ge detector operated in LAr



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