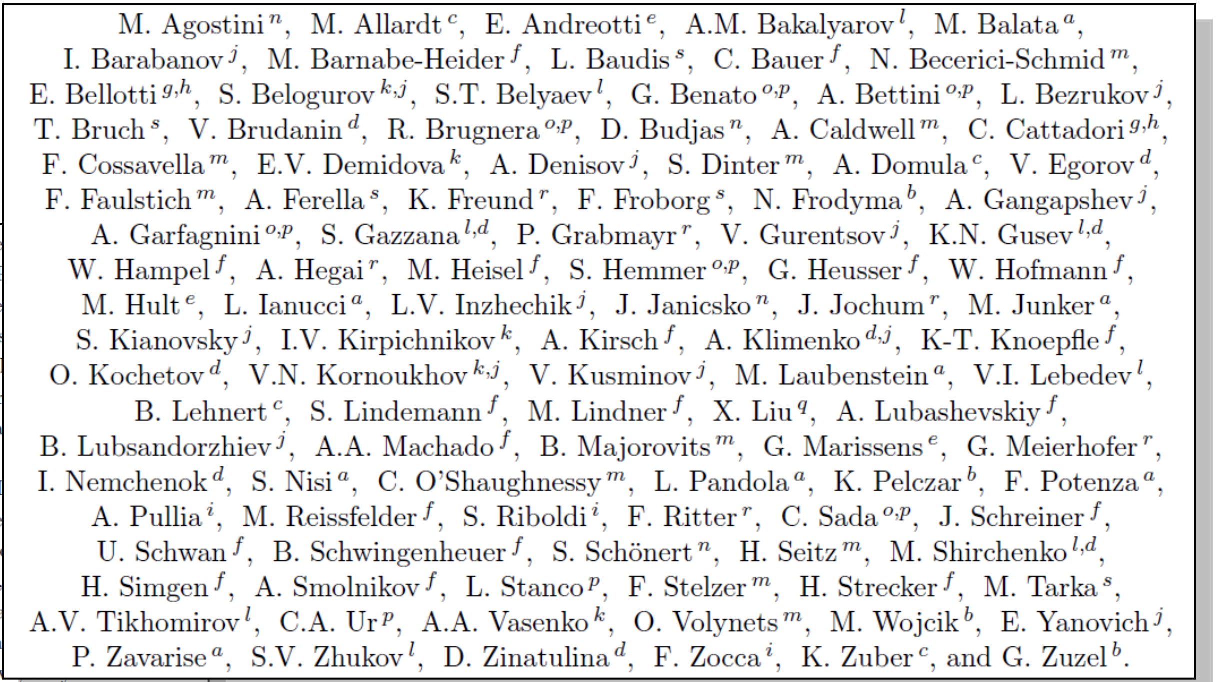
Status of the GERDA experiment at LNGS and results from the ongoing commissioning phase

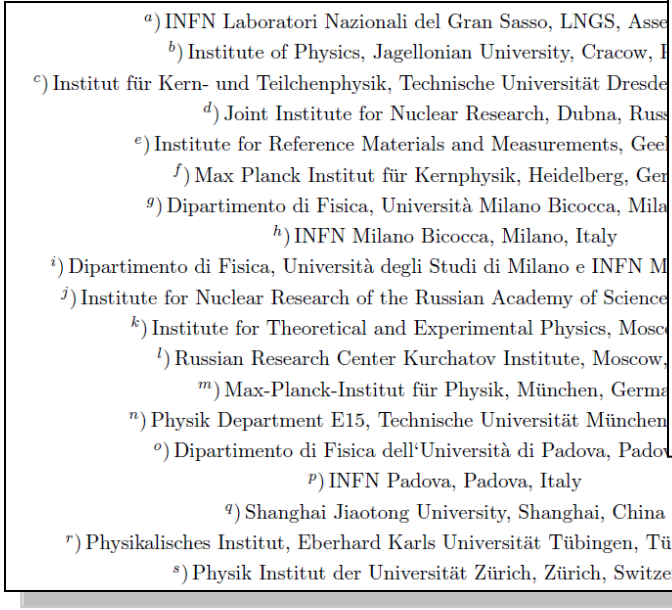
Neutrino Telescope
15.-18.3.2011

Stefan Schönert (TUM)
on behalf of the GERDA collaboration
GERDA publications: http://www.mpi-hd.mpg.de/GERDA

~ 100 members
19 institutions
6 countries



M. Agostini[n], M. Allardt[c], E. Andreotti[e], A.M. Bakalyarov[l], M. Balata[a], I. Barabanov[j], M. Barnabe-Heider[f], L. Baudis[s], C. Bauer[f], N. Becerici-Schmid[m], E. Bellotti[g,h], S. Belogurov[k,j], S.T. Belyaev[l], G. Benato[o,p], A. Bettini[o,p], L. Bezrukov[j], T. Bruch[s], V. Brudanin[d], R. Brugnera[o,p], D. Budjas[n], A. Caldwell[m], C. Cattadori[g,h], F. Cossavella[m], E.V. Demidova[k], A. Denisov[j], S. Dinter[m], A. Domula[c], V. Egorov[d], F. Faulstich[m], A. Ferella[s], K. Freund[r], F. Froborg[s], N. Frodyma[b], A. Gangapshev[j], A. Garfagnini[o,p], S. Gazzana[l,d], P. Grabmayr[r], V. Gurentsov[j], K.N. Gusev[l,d], W. Hampel[f], A. Hegai[r], M. Heisel[f], S. Hemmer[o,p], G. Heusser[f], W. Hofmann[f], M. Hult[e], L. Ianucci[a], L.V. Inzhechik[j], J. Janicsko[n], J. Jochum[r], M. Junker[a], S. Kianovsky[j], I.V. Kirpichnikov[k], A. Kirsch[f], A. Klimenko[d,j], K-T. Knoepfle[f], O. Kochetov[d], V.N. Kornoukhov[k,j], V. Kusminov[j], M. Laubenstein[a], V.I. Lebedev[l], B. Lehnert[c], S. Lindemann[f], M. Lindner[f], X. Liu[q], A. Lubashevskiy[f], B. Lubsandorzhiev[j], A.A. Machado[f], B. Majorovits[m], G. Marissens[e], G. Meierhofer[r], I. Nemchenok[d], S. Nisi[a], C. O'Shaughnessy[m], L. Pandola[a], K. Pelczar[b], F. Potenza[a], A. Pullia[i], M. Reissfelder[f], S. Riboldi[i], F. Ritter[r], C. Sada[o,p], J. Schreiner[f], U. Schwan[f], B. Schwingenheuer[f], S. Schönert[n], H. Seitz[m], M. Shirchenko[l,d], H. Simgen[f], A. Smolnikov[f], L. Stanco[p], F. Stelzer[m], H. Strecker[f], M. Tarka[s], A.V. Tikhomirov[l], C.A. Ur[p], A.A. Vasenko[k], O. Volynets[m], M. Wojcik[b], E. Yanovich[j], P. Zavarise[a], S.V. Zhukov[l], D. Zinatulina[d], F. Zocca[i], K. Zuber[c], and G. Zuzel[b].



a) INFN Laboratori Nazionali del Gran Sasso, LNGS, Asse
b) Institute of Physics, Jagellonian University, Cracow, I
c) Institut für Kern- und Teilchenphysik, Technische Universität Dresde
d) Joint Institute for Nuclear Research, Dubna, Russ
e) Institute for Reference Materials and Measurements, Geel
f) Max Planck Institut für Kernphysik, Heidelberg, Ger
g) Dipartimento di Fisica, Università Milano Bicocca, Mila
h) INFN Milano Bicocca, Milano, Italy
i) Dipartimento di Fisica, Università degli Studi di Milano e INFN M
j) Institute for Nuclear Research of the Russian Academy of Science
k) Institute for Theoretical and Experimental Physics, Mosc
l) Russian Research Center Kurchatov Institute, Moscow,
m) Max-Planck-Institut für Physik, München, Germa
n) Physik Department E15, Technische Universität München
o) Dipartimento di Fisica dell'Università di Padova, Padov
p) INFN Padova, Padova, Italy
q) Shanghai Jiaotong University, Shanghai, China
r) Physikalisches Institut, Eberhard Karls Universität Tübingen, Tübingen, Germany
s) Physik Institut der Universität Zürich, Zürich, Switzerland

Characteristics of ^{76}Ge for $0\nu\beta\beta$ search

- **Favorable nuclear matrix** element $|M^{0\nu}|=3 - 9$
- **Reasonable slow $2\nu\beta\beta$ rate** ($T_{1/2} = 1.4 \times 10^{21}$ y) and **high $Q_{\beta\beta}$ value (2039 keV)**
- Ge as **source and detector**
- **Elemental Ge** maximizes the source-to-total mass ratio
- **Industrial techniques** and facilities available to enrich from 7% to ~86%
- **Intrinsic high-purity** Ge diodes & HP-Ge detector technologies well established
- **Excellent energy resolution**: FWHM ~3 keV at 2039 keV (0.16%)
- Powerful signal identification & background rejection possible with **novel detector** concepts:
  - time structure of charge signal (PSA) using **BEGe detectors**
  - granularity
  - **liquid argon** scintillation as **active veto system**
- **Best limits** on $0\nu\beta\beta$ - decay used Ge (IGEX & Heidelberg-Moscow) $T_{1/2} > 1.9 \times 10^{25}$ y (90%CL) **[& claim for evidence]**

Phases and physics reach

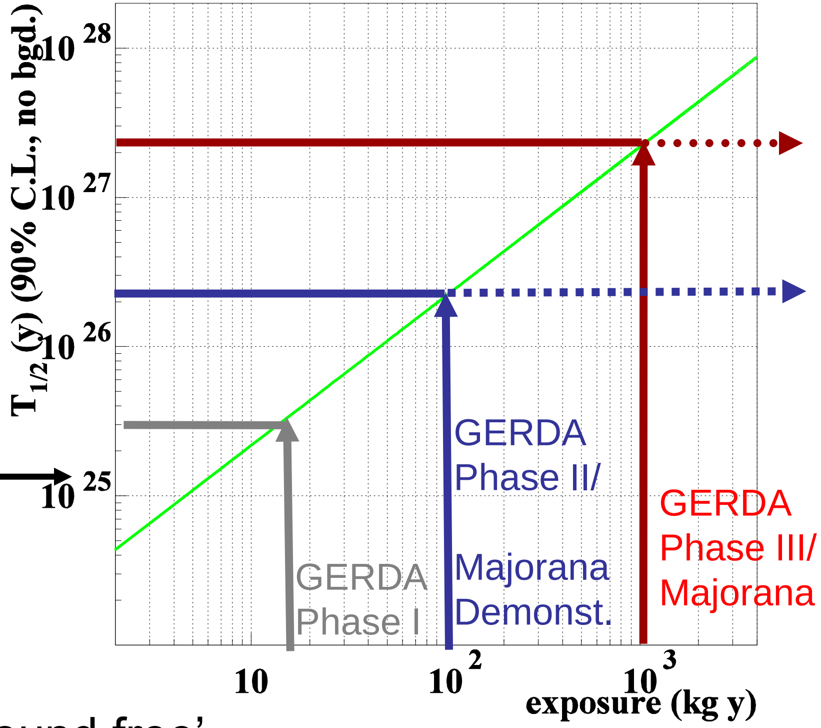
$2\cdot10^{27}$ (90 % CL) *

$2\cdot10^{26}$ (90 % CL) *

$3\cdot10^{25}$ (90 % CL)*

KK →

***: no event in ROI**



<24 - 41 meV

<75 - 129 meV

assuming
$|M^{0\nu}|$=2.99-8.99
[Smol&Grab PRC'10]
and 86% enrichment

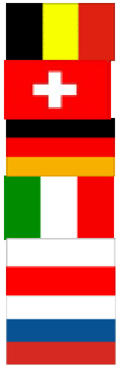
required for 'background free'
exp. with ΔE~3.3 keV (FWHM): **$O(10^{-3})$** **$O(10^{-4})$** counts/(kg·y·keV)

Background requirement for GERDA/Majorana:

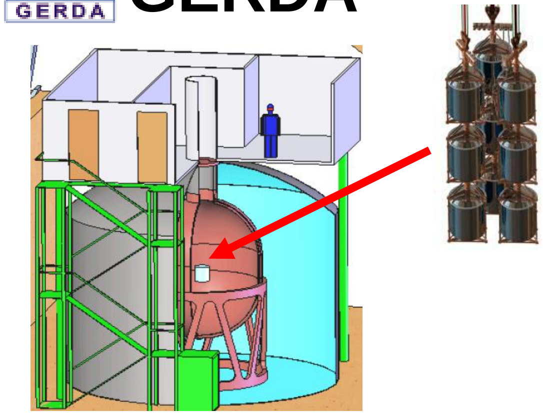
⇒Background reduction by factor **10^2 - 10^3** required w.r.t. to precursor exps.

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

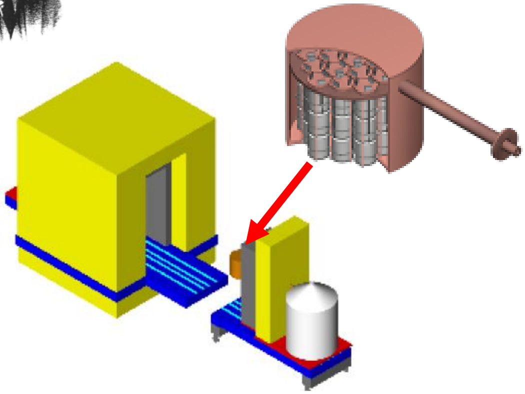
Two new ^{76}Ge Projects:

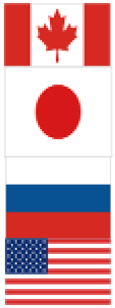


GERDA



Majorana





•'Bare' ^{enr}Ge array in liquid argon
•Shield: high-purity liquid Argon / H_2O
•Phase I: 18 kg (HdM/IGEX) / 15 kg nat.
•Phase II: add ~20 kg new enr. Detectors; total ~40 kg

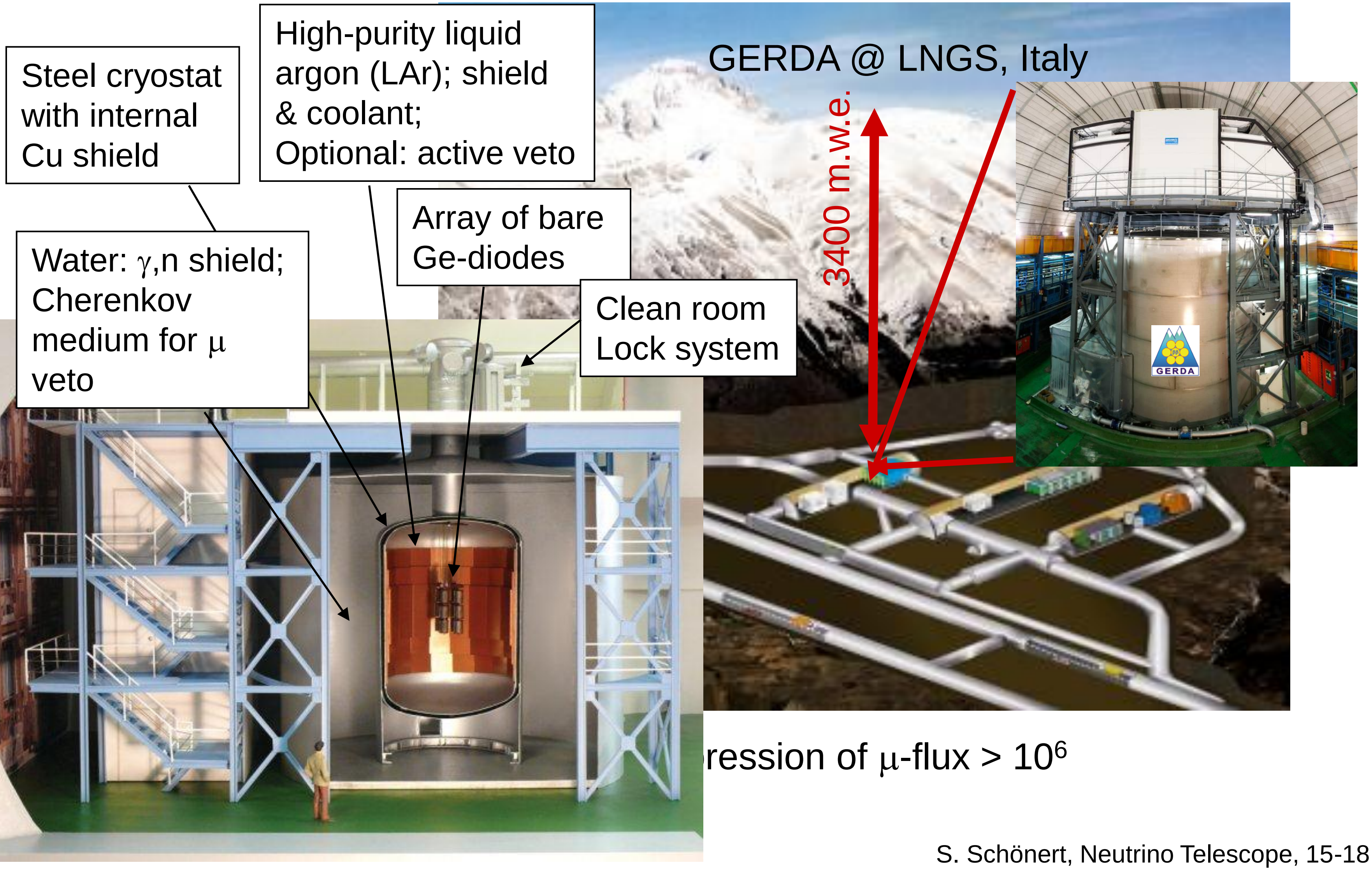
•Array(s) of ^{enr}Ge housed in high-purity electroformed copper cryostat
•Shield: electroformed copper / lead
•Initial phase: R&D demonstrator module: Total ~60 kg (30 kg enr.)

Physics goals: degenerate mass range
Technology: study of bgds. and exp. techniques

LoI
- open exchange of knowledge & technologies (e.g. MaGe MC)
- intention to merge for O(1 ton) exp. (inv. Hierarchy) selecting the best technologies tested in GERDA and Majorana

Background reduction:

Deep underground site for suppression of cosmic ray muons &
graded shielding against ambient radiation &
rigorous material selection &
signal analysis



Steel cryostat with internal Cu shield

High-purity liquid argon (LAr); shield & coolant;
Optional: active veto

Array of bare Ge-diodes

Clean room
Lock system

Water: γ,n shield; Cherenkov medium for μ veto

ression of μ-flux > 10^6

Unloading of vacuum cryostat

(6 March 08)

Produced from selected
low-background austenitic steel

Construction of water tank

19 May 08

∅ 10 m

H = 9.5 m

V = 650 m^3

Designed for external γ,n,μ background ~10^{-4} cts/(keV kg y)

construction of clean room

27 feb 09

clean room, active cooling device getting prepared for installation

Water tank and cryostat prior muon veto installations

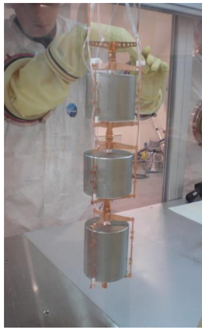
WT and cryostat with muon veto installed

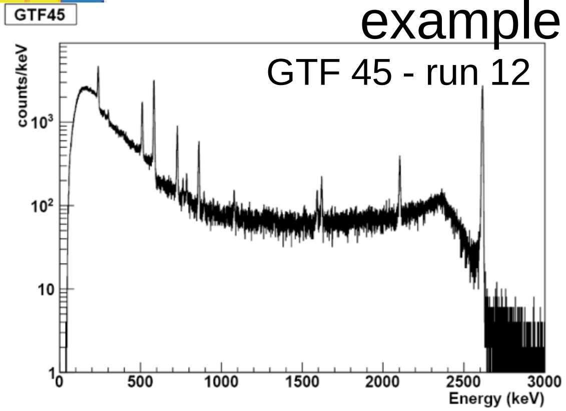
“Pill box”

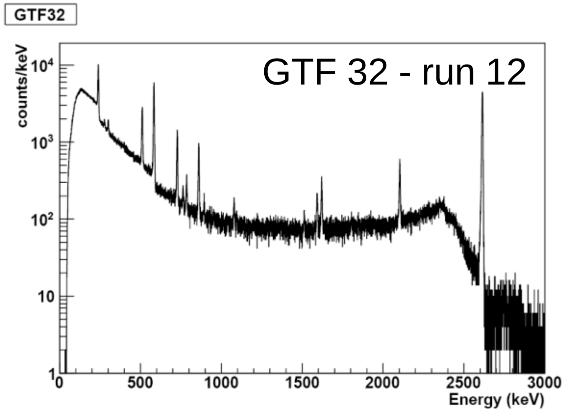
Glove-box for Ge-detector handling and mounting into commissioning lock under N_2 atmosphere installed in clean room

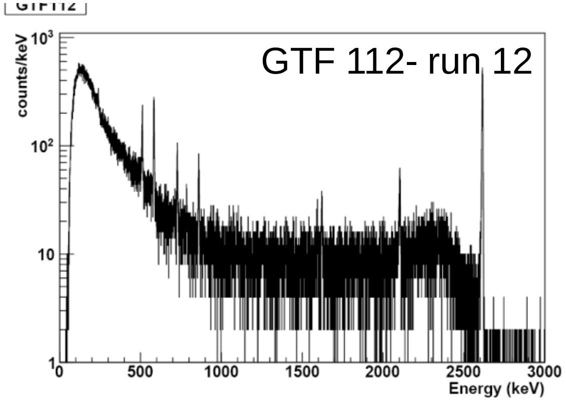
- **Nov/Dec.’09**: Liquid argon fill
- **Jan ’10:** Commissioning of cryogenic system
- **Apr/Mai ’10:** emergency drainage tests of water tank
- **Apr/Mai ’10:** Installation c-lock
- **May ’10:** 1st deployment of FE&detector mock-up (27 pF) - pulser resolution 1.4 keV (FWHM); first deployment of non-enriched detector
- **June ‘10:** Start of commissioning run with ^{nat}Ge detector string
- **Soon**: start of Phase I physics data taking

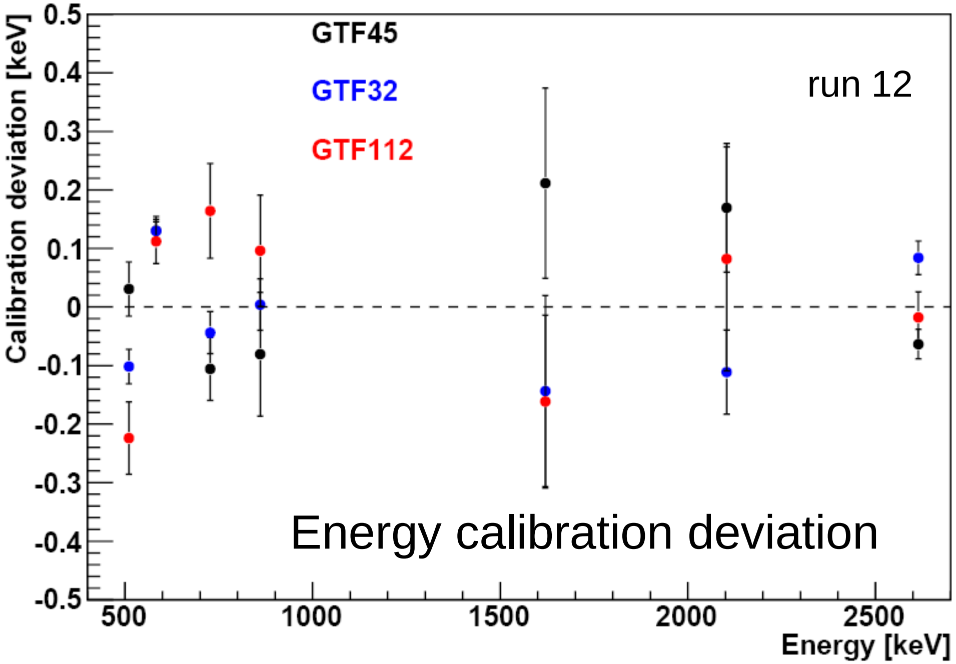
Commissioning runs with non-enriched low-background detectors to study performance and backgrounds example: Energy calibration with ^{228}Th γ-source









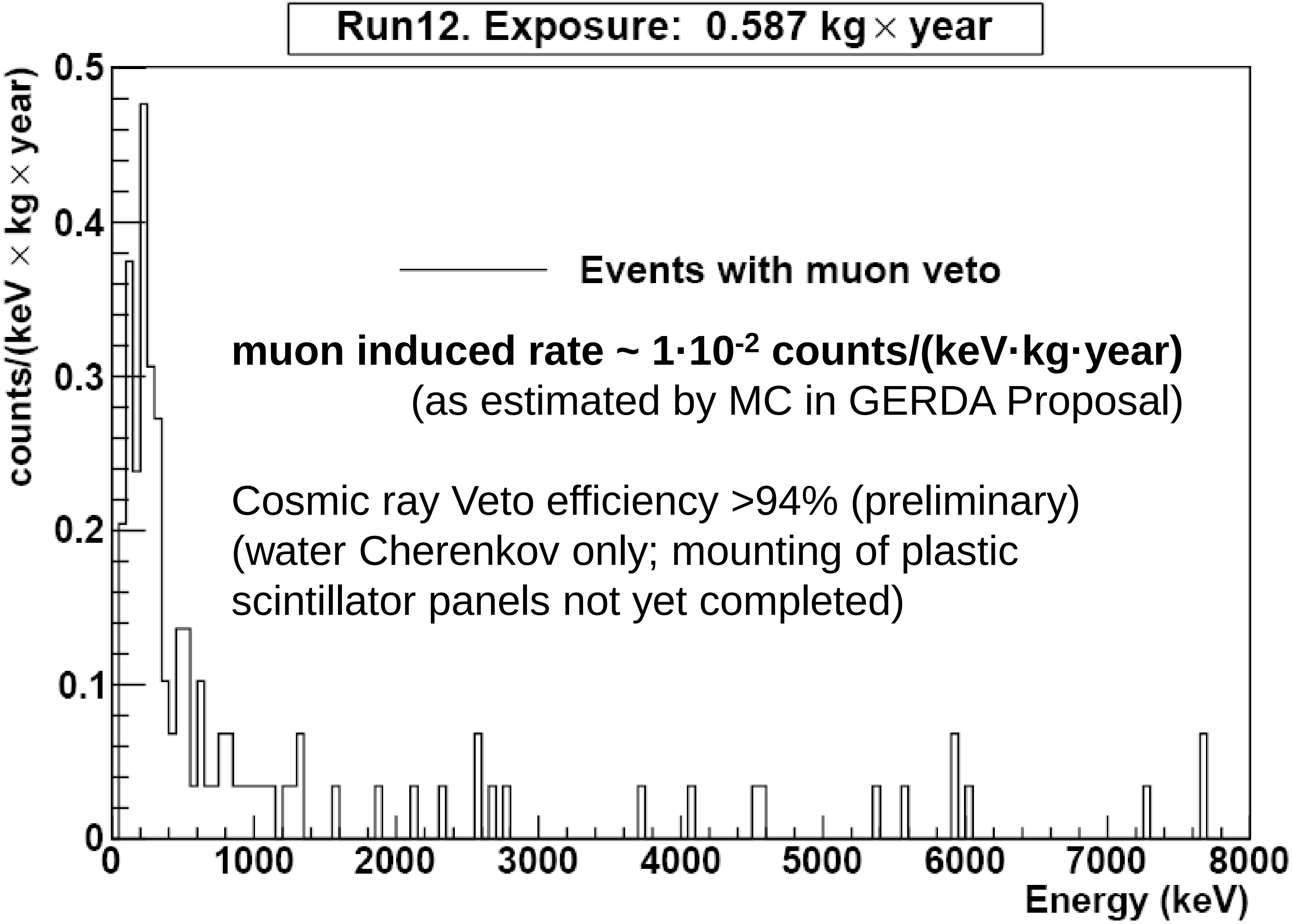


Measured energy resolution in GERDA during commissioning phase: dependent on chosen detector configuration (e.g.: p+ or n+ read-out, mini-shroud,..):

- Coaxial detectors (Phase I): from 3.6 keV to ~6 keV (FWHM) at 2.6 MeV
- BEGe (Phase II): 2.8 keV (FWHM) at 2.6 MeV

Results from commissioning run 12:

Muon induced events in Ge detectors



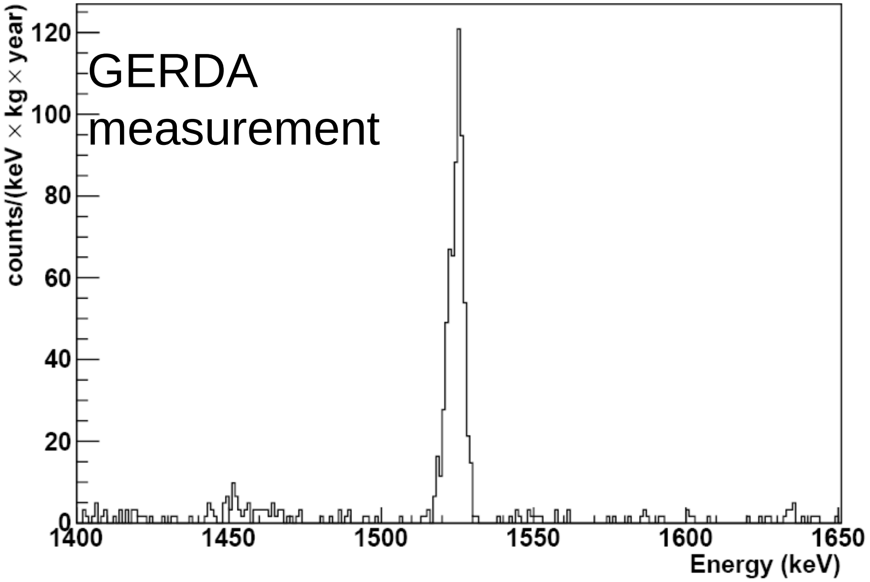
muon induced rate ~ $1 \cdot 10^{-2}$ counts/(keV·kg·year)
(as estimated by MC in GERDA Proposal)

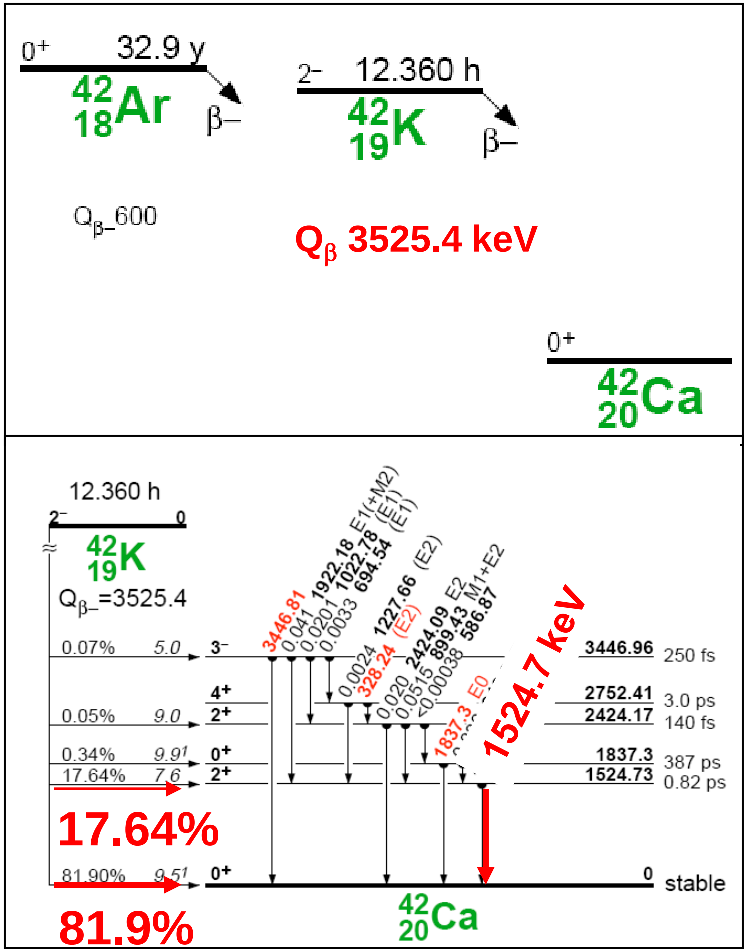
Cosmic ray Veto efficiency >94% (preliminary)
(water Cherenkov only; mounting of plastic
scintillator panels not yet completed)

The unexpected ^{42}Ar (^{42}K) Signal

<u>GERDA proposal:</u> ^{42}Ar/^{nat}Ar <3·10^{-21}

[Barabash et al. 2002]

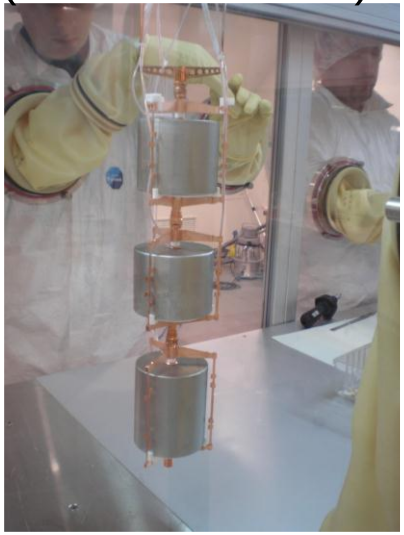


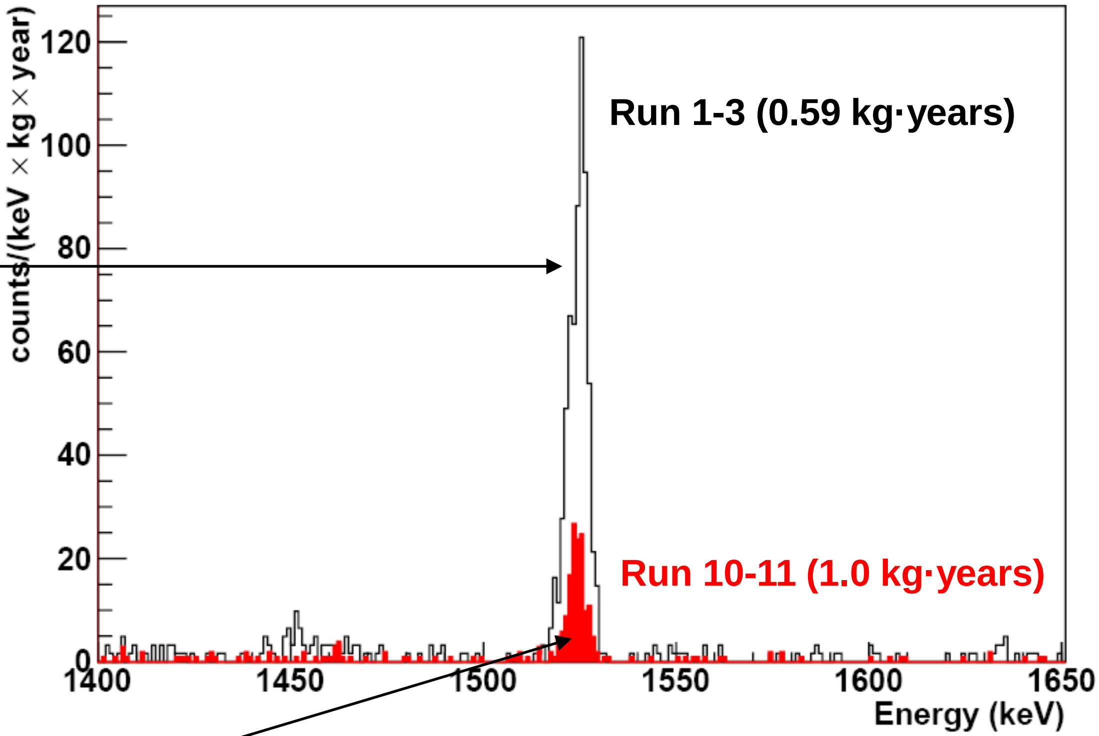


- True value could be x10 higher than limit;
- Additional enhancement of count rate due to collection of ^{42}K ions by E-field of diodes
- If ^{42}K decay on detector surface ⇒ bgd to 0νββ

Enhancement of ^{42}K(^{42}Ar) count rate by E-field of detectors: 1525 keV peak

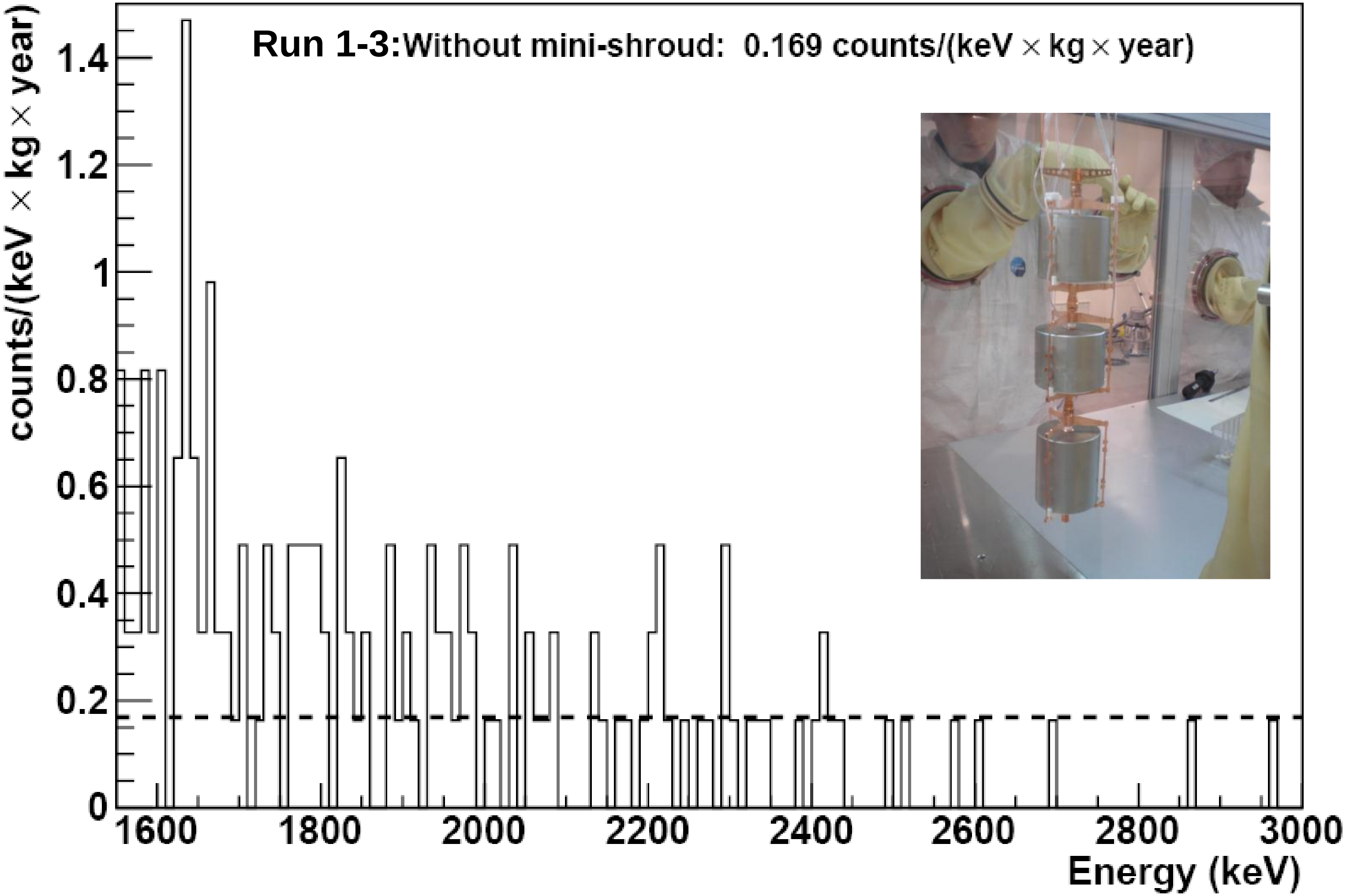
+HV on n+ contact
(w/o mini-shroud)



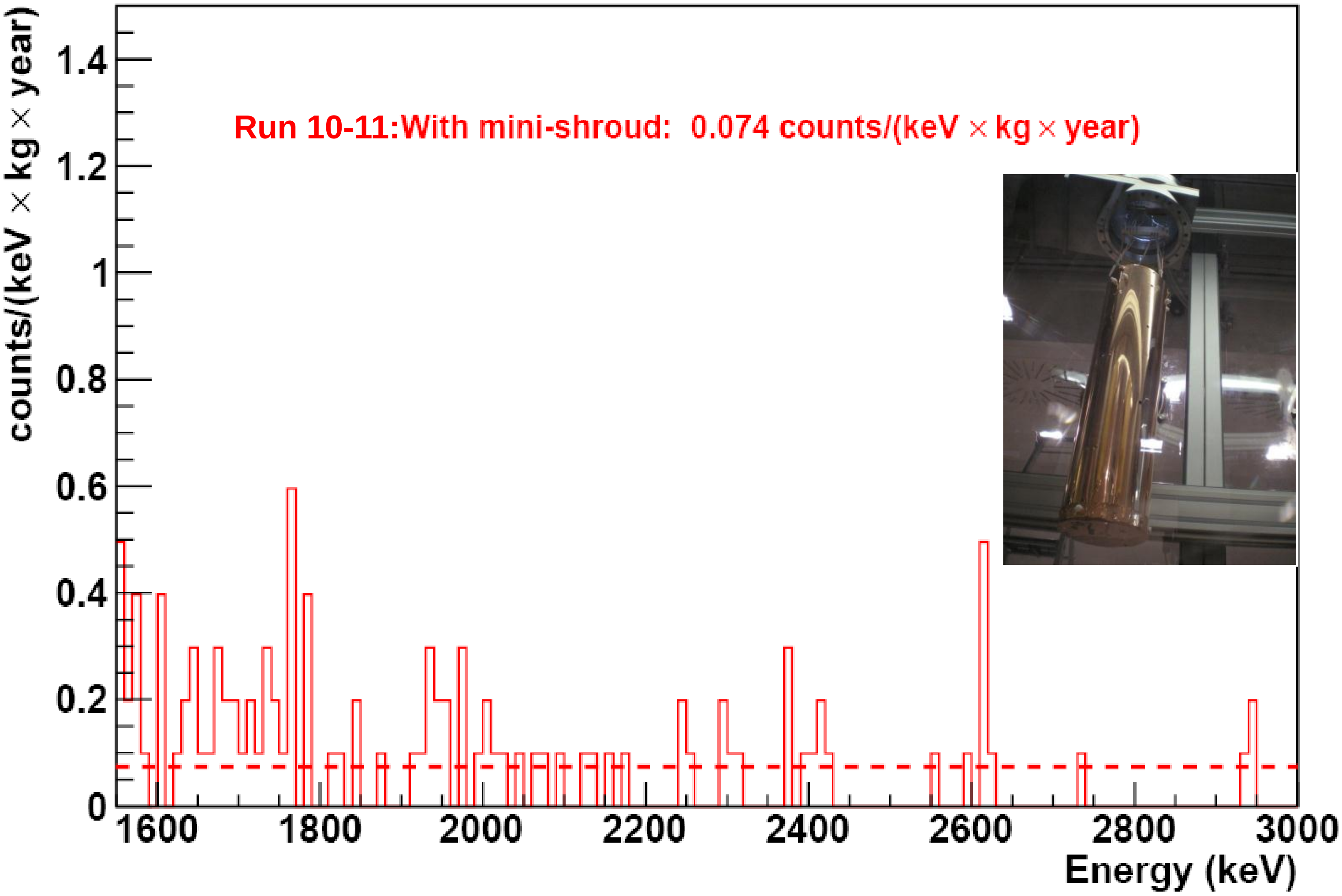


mini-shroud
shields
E-field &
possible
convections

Enhancement of ^{42}K(^{42}Ar) count rate by E-field of detectors: high-energy region

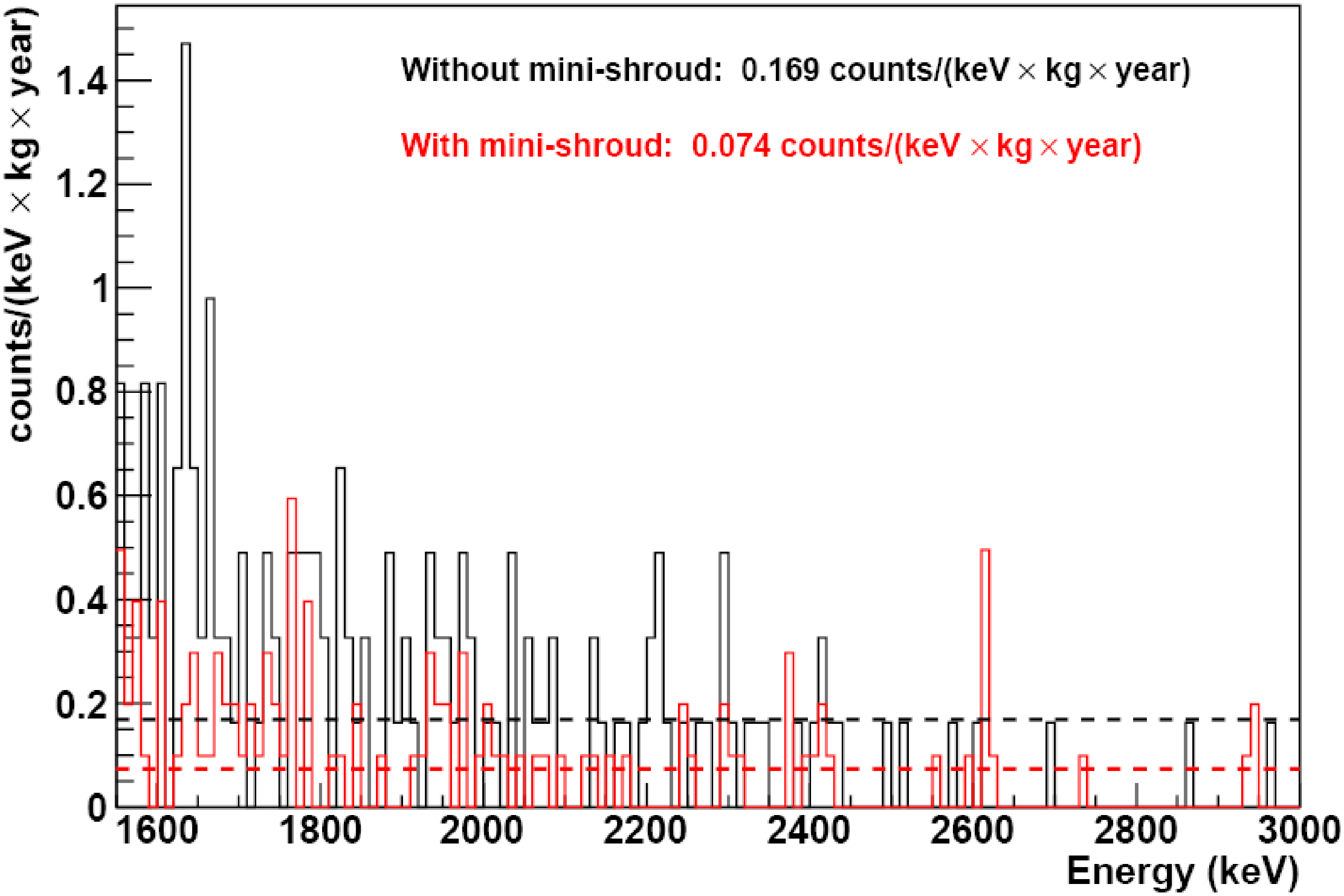


Enhancement of ^{42}K(^{42}Ar) count rate by E-field of detectors: high-energy region



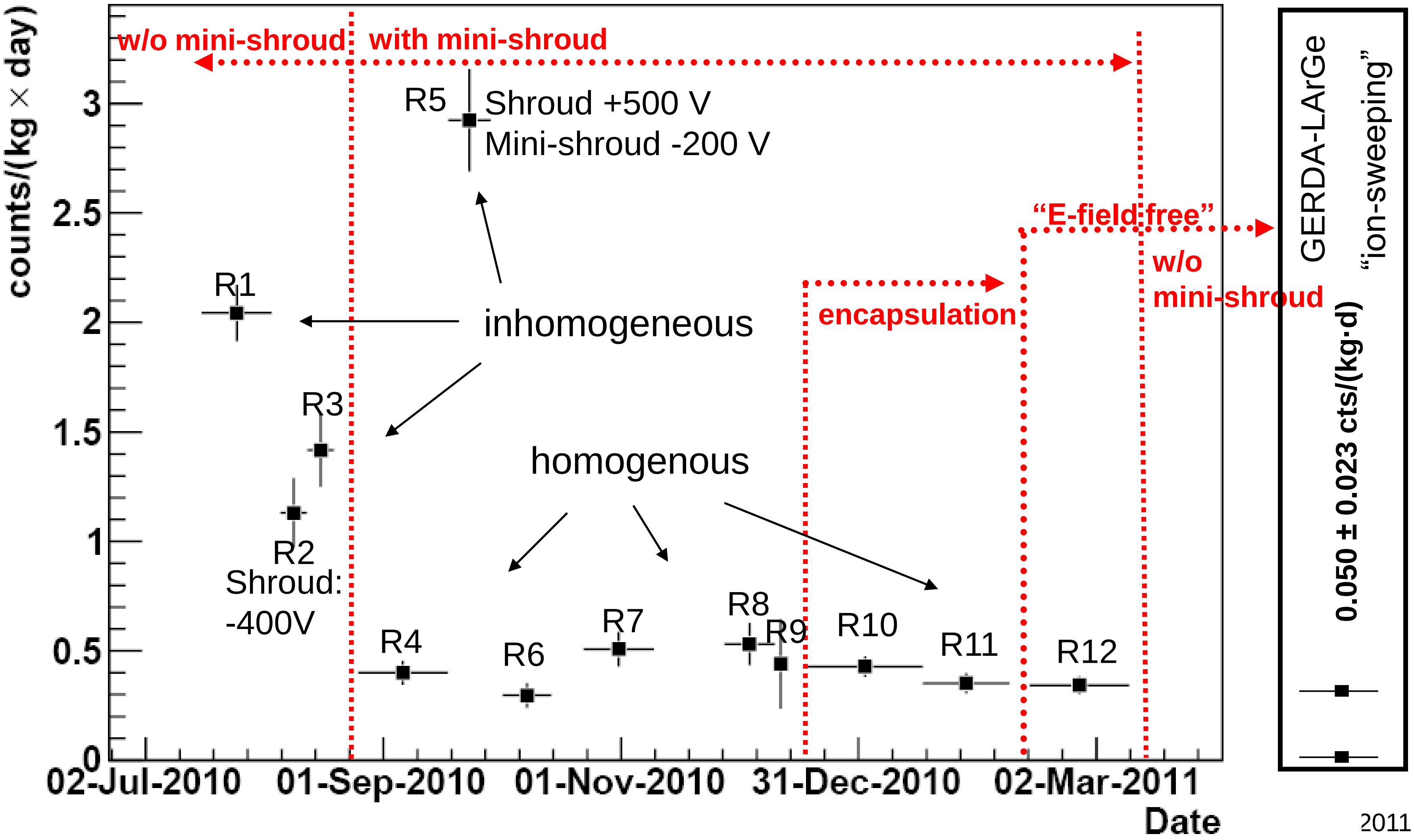
S. Schönert, Neutrino Telescope, 15-18.3.2011

Enhancement of ^{42}K(^{42}Ar) count rate by E-field of detectors: high-energy region



Summary of commissioning runs with **non-enriched** detectors

Counting rate of the 1525 keV ^{42}K (^{42}Ar) line

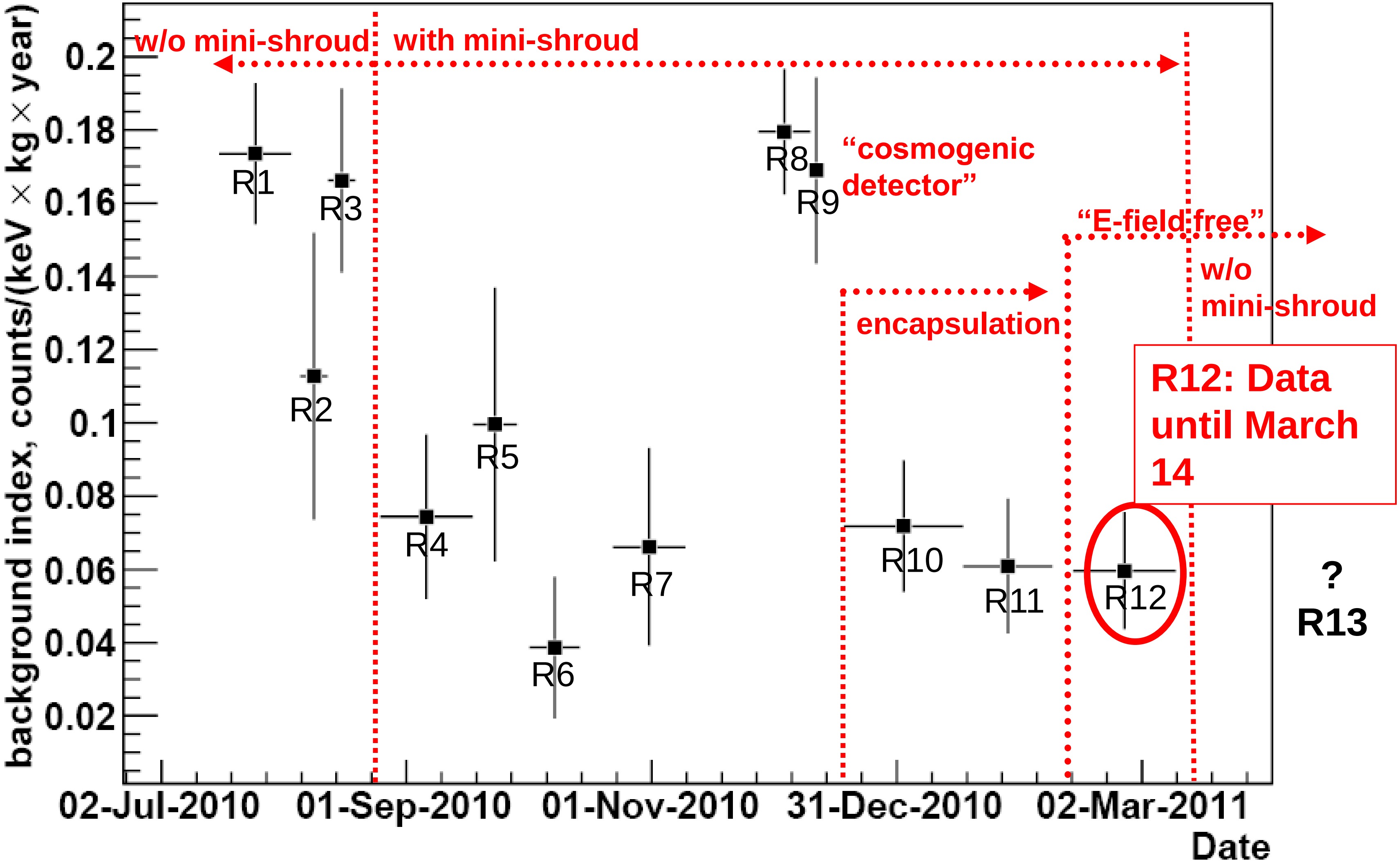


2011

Summary of commissioning runs with **non-enriched** detectors: background indices

(derived in $Q_{\beta\beta}$±200 keV)

Run History



w/o mini-shroud

with mini-shroud

"cosmogenic detector"

"E-field free"

encapsulation

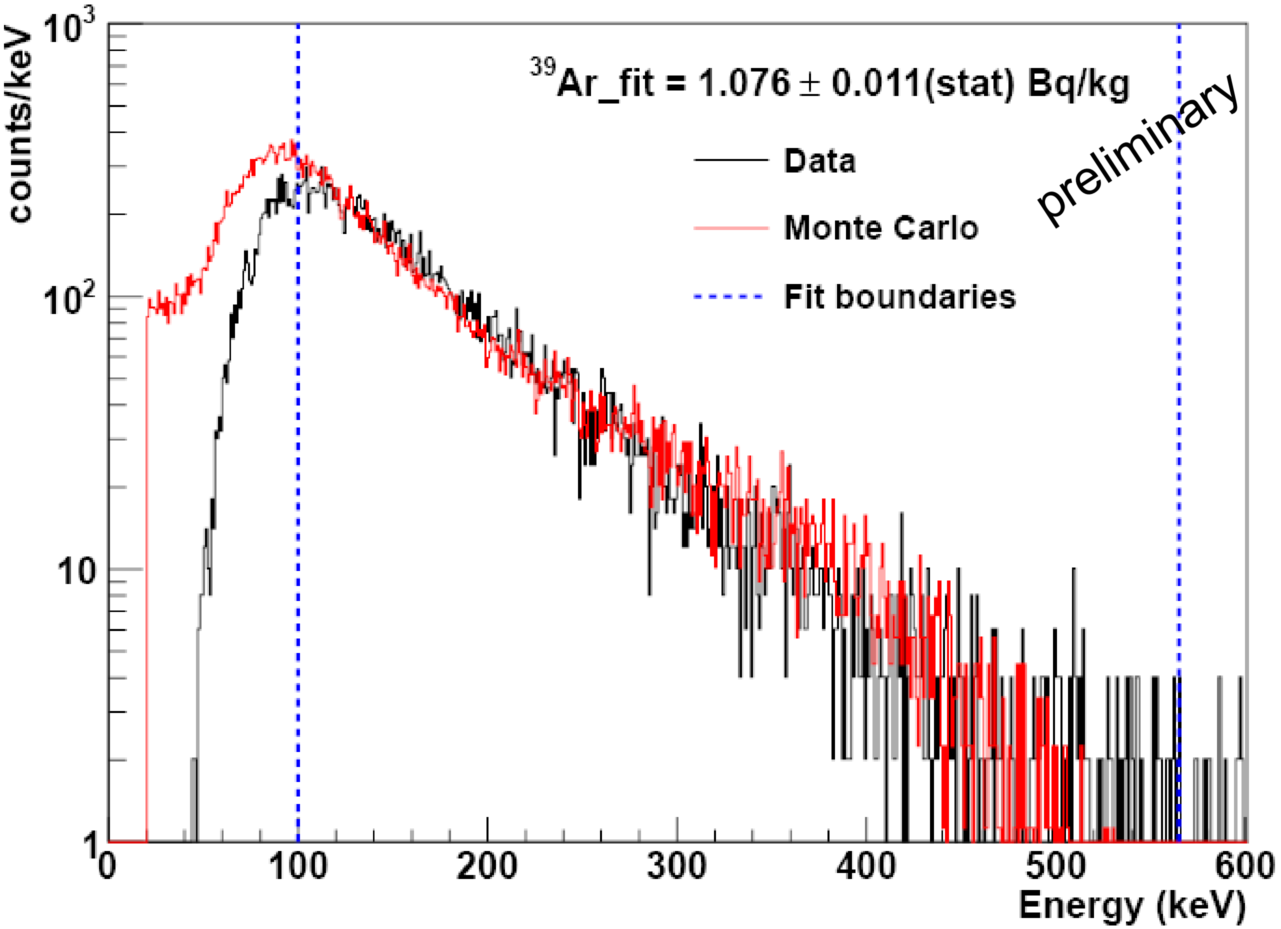
w/o mini-shroud

R12: Data until March 14

?
R13

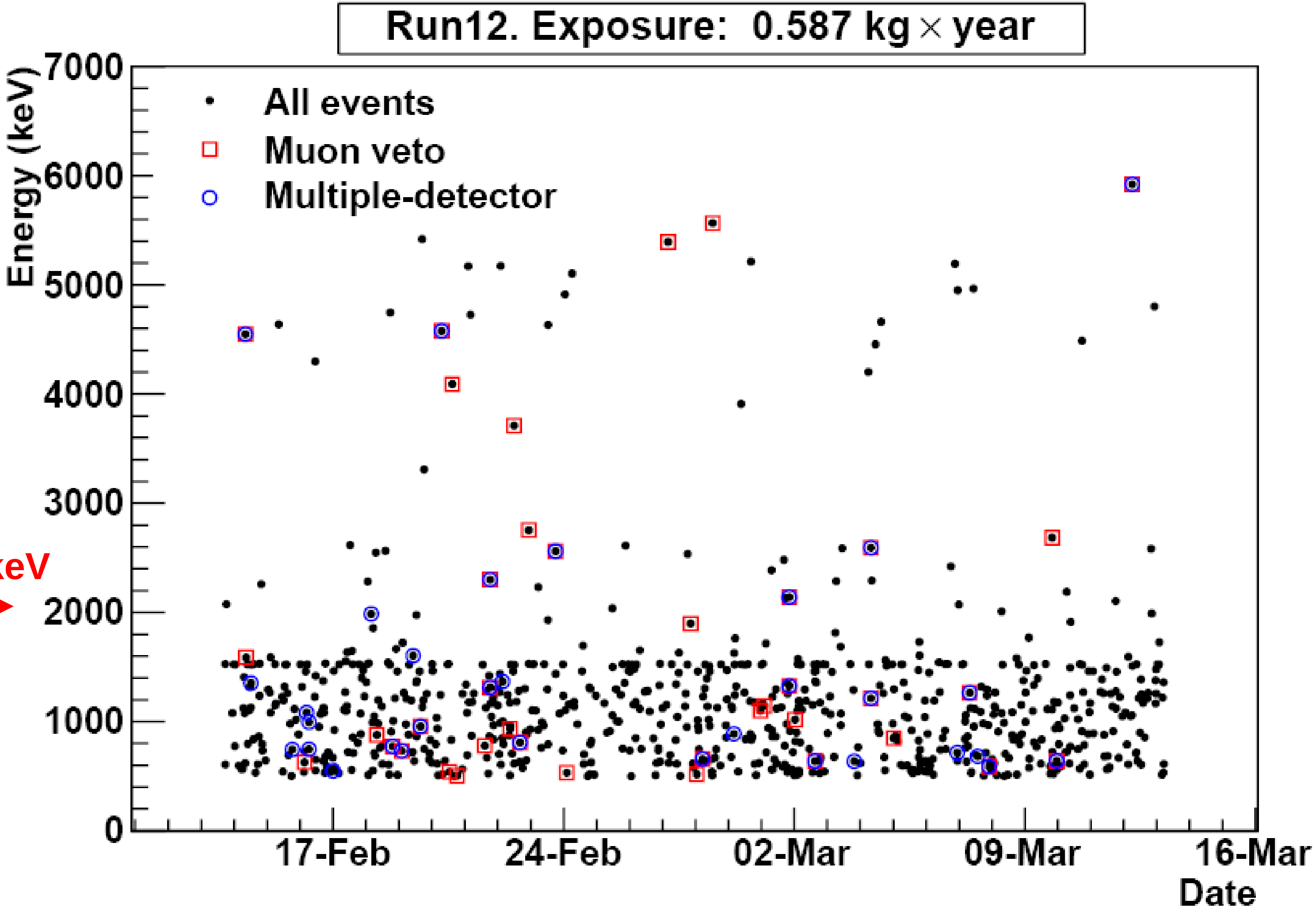
Results from commissioning run 12:

The low-energy spectrum: ^{39}Ar



Results from commissioning run 12:

Event distribution: energy vs. time



$Q_{\beta\beta}$=2039 keV →

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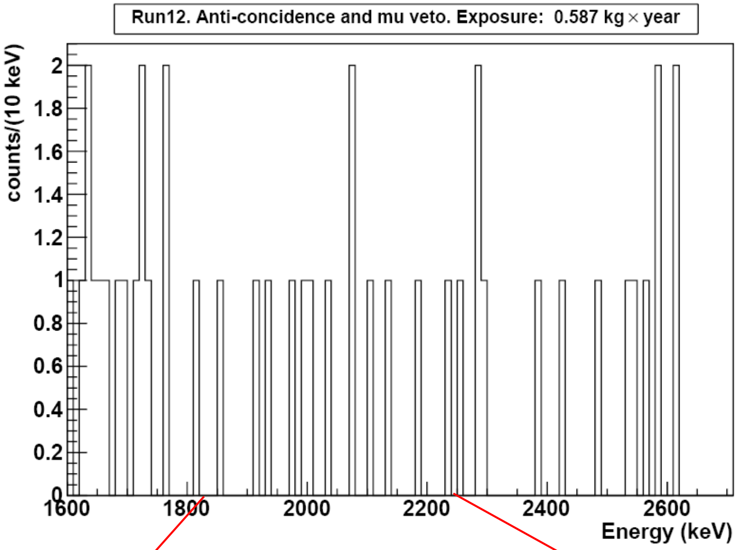
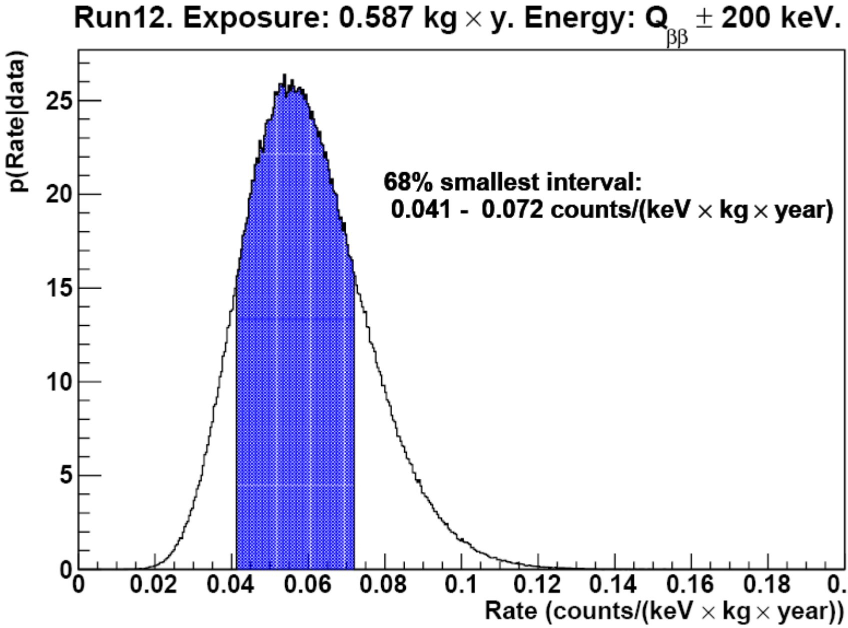
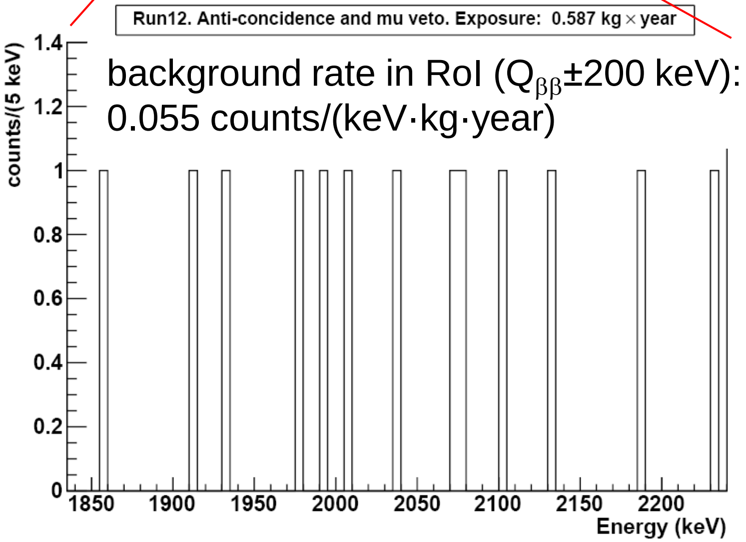
Results from commissioning run 12:

Count rate in Region of Interest



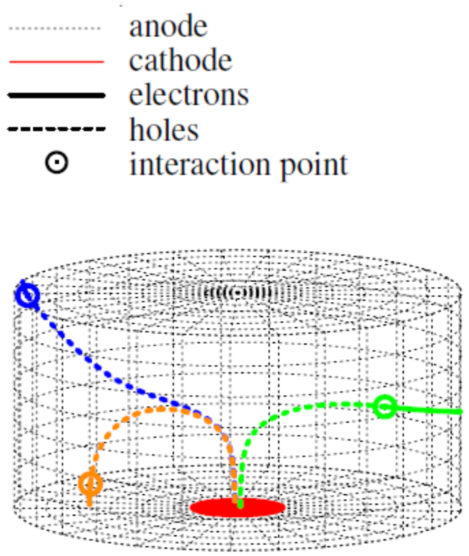


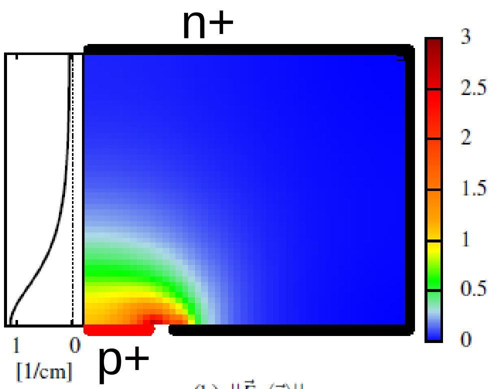


background rate in RoI ($Q_{\beta\beta}$±200 keV): 0.055 counts/(keV·kg·year)

- Bgd rate significantly lower than previous experiments (HdM, IGEX), but still higher than Phase I bgd-goal (ie. 0.01 cnts/(keV·kg·year))
- likely: cosmogenic bgd contribution because of exposure historly of crystals
- Run13: “field-free” (ie. n+ contact @ 0V) & removal of mini-shroud
- Deployment of 3 enriched detectors known (low) activation history

Phase II detectors

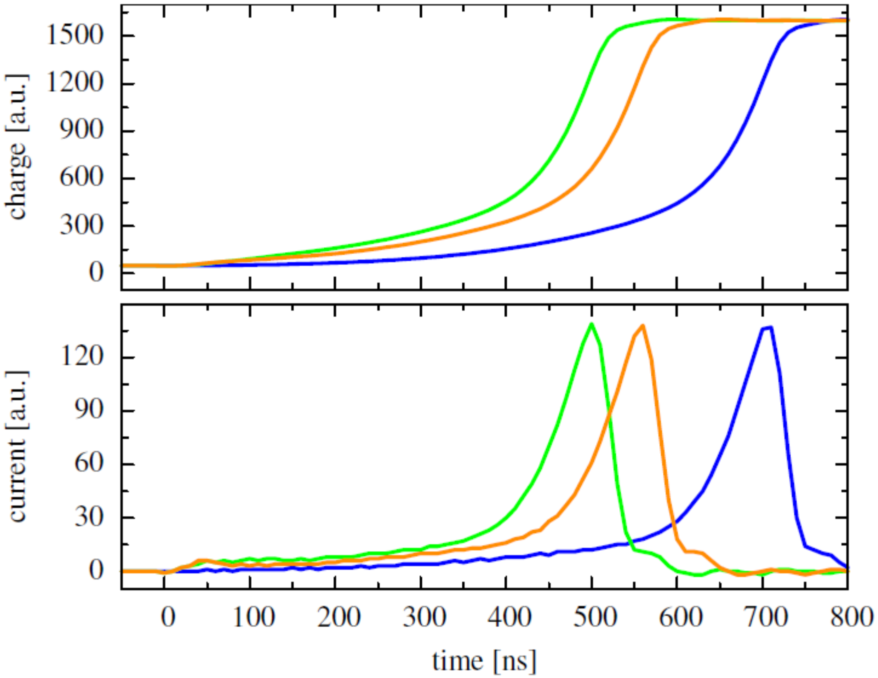


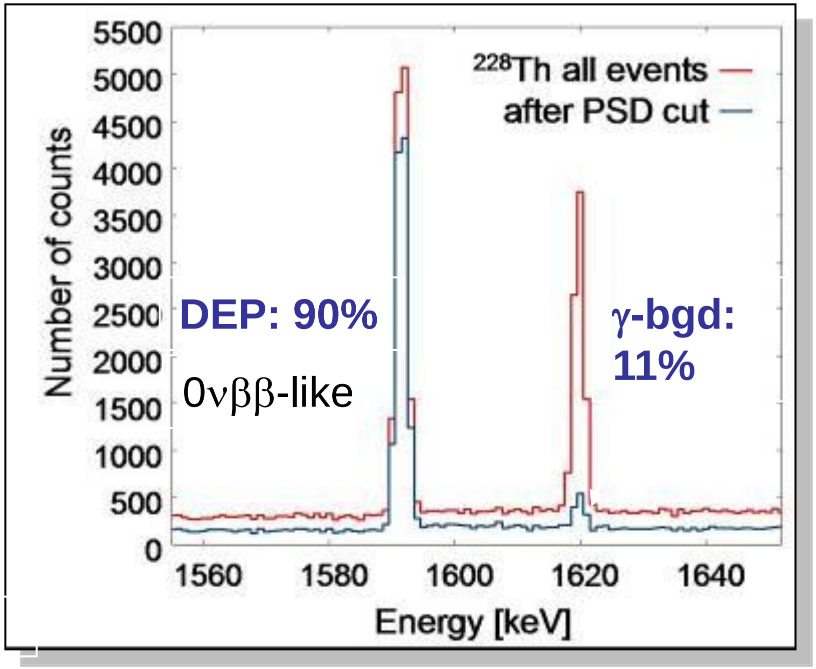


(b) $\|\vec{E}_w(\vec{r})\|$

Signal shape provides clear topology for event-by-event signal ID / bgd discrimination:

- SSE/MSE discrimination
- Surface events:
  - n+ slow pulses
  - p+: ‘amplified’ current pulses



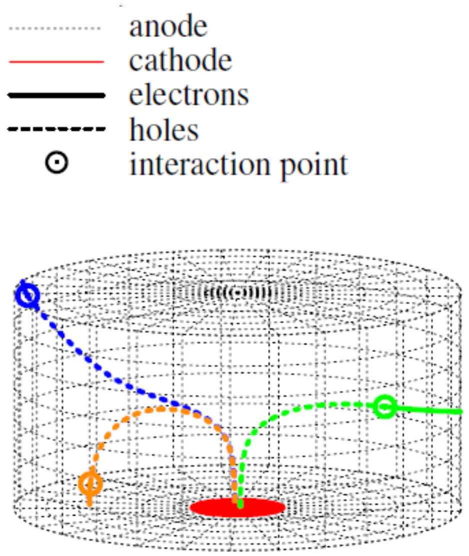


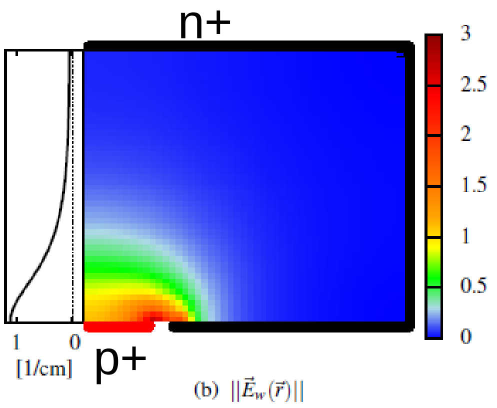
DEP: 90%

0νββ-like

γ-bgd: 11%

Phase II detectors





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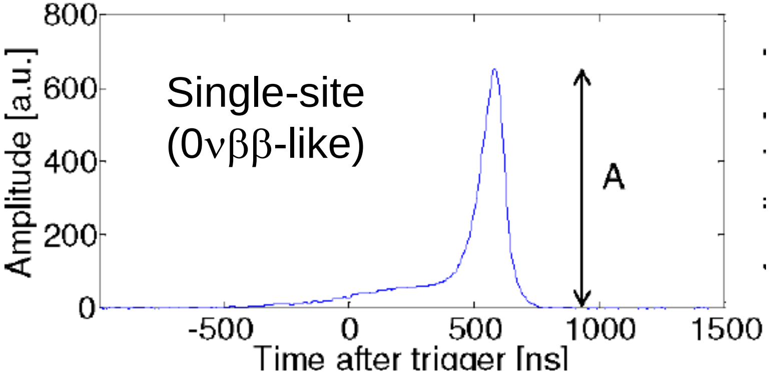
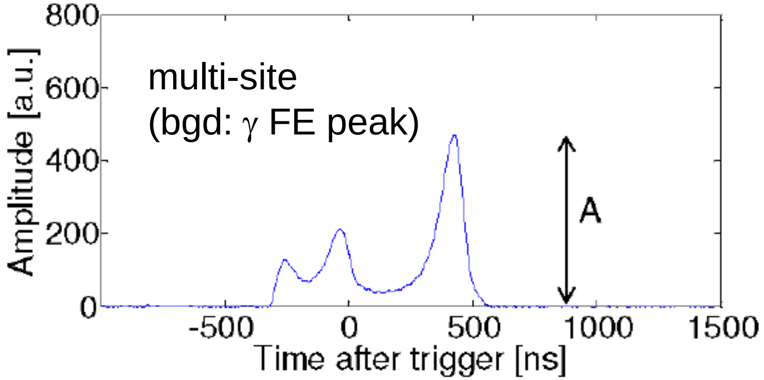
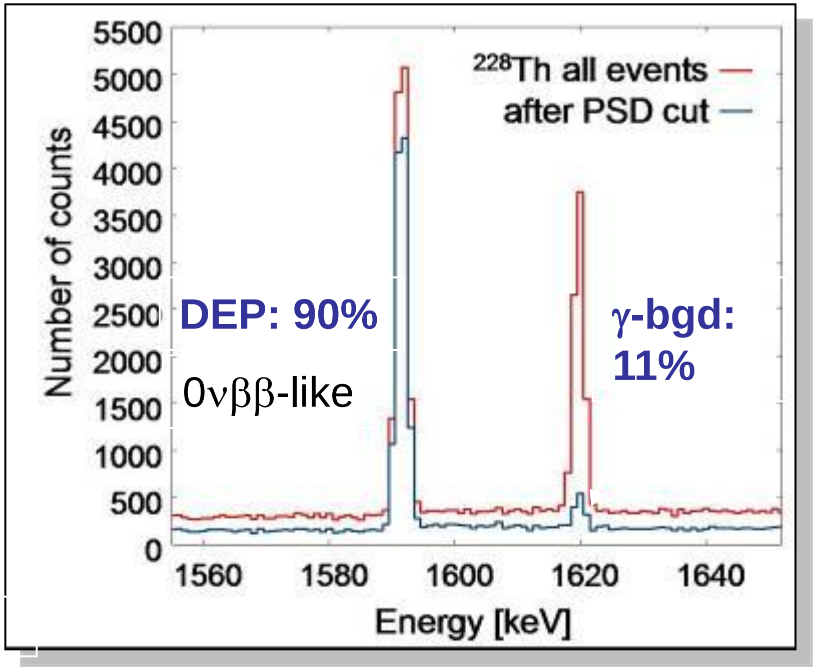

Single-site (0νββ-like)


multi-site (bgd: γ FE peak)


DEP: 90%

0νββ-like

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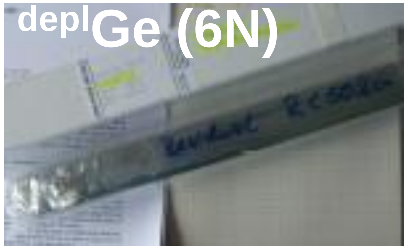
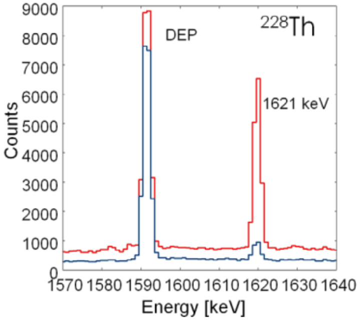
Production of BEGe detectors from ^{enr}Ge for GERDA Phase II


$^{depl}GeO_2$:


^{depl}Ge (6N)

Crystal pulling

crystal slice

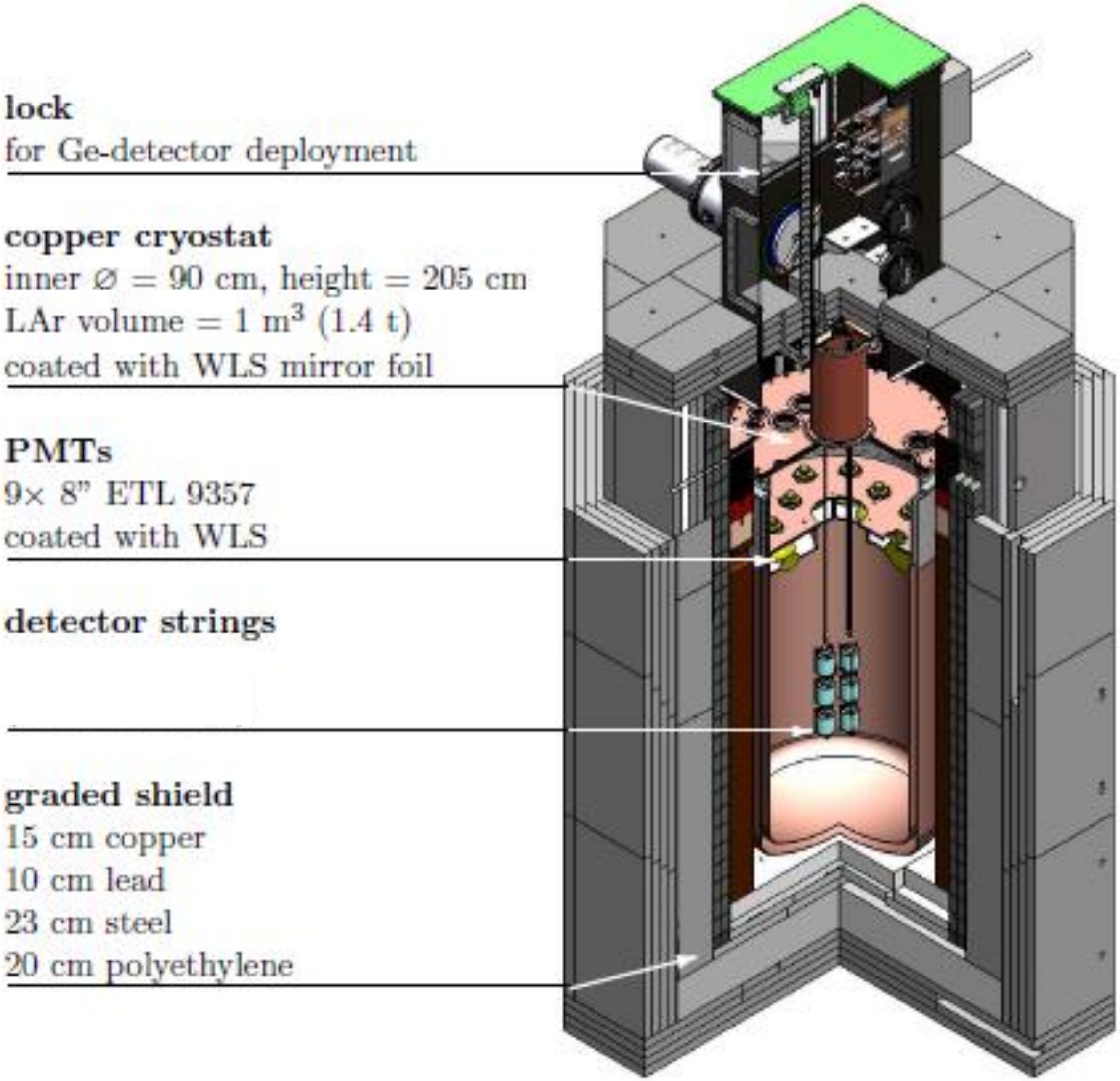


Full production chain tested with isotopic depleted germanium

After successful test of production production chain with ^{depl}Ge:

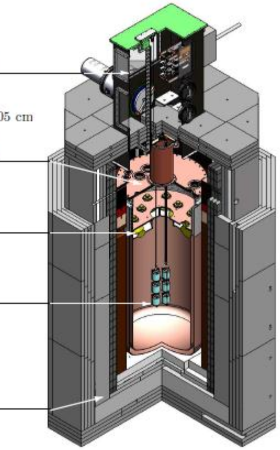
- **37.5 kg of 86% ^{enr}Ge** (in form of GeO2) purified to **35.4 kg (94%) of 6N** (+ 1.1 kg tail = 97%);
- crystal pulling and detector fabrication under preparation

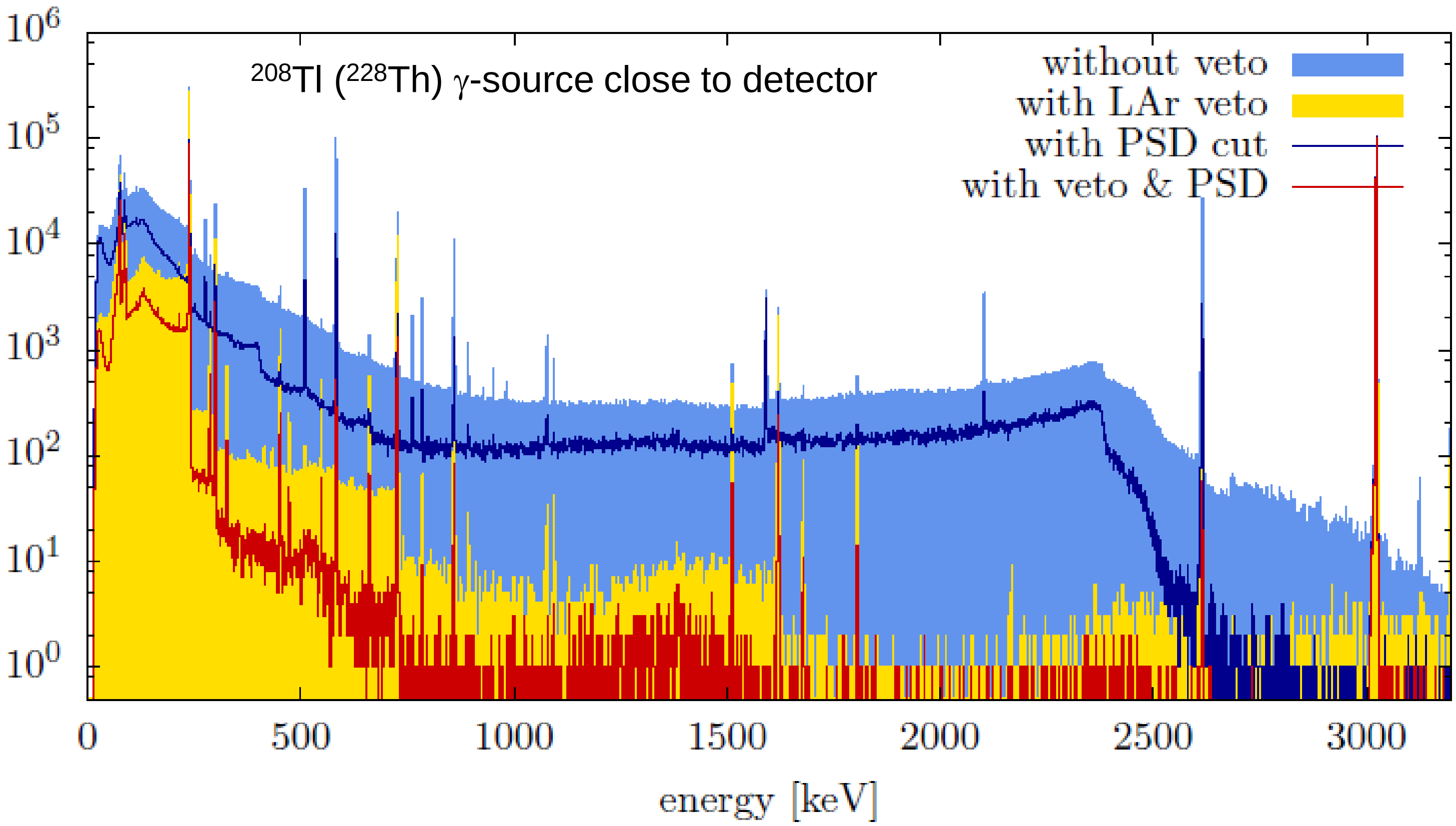
R&D liquid argon instrumentation



Low background **GERDA-LArGe test facility @ LNGS**: Detection of coincident liquid argon scintillation light to discriminate background

R&D liquid argon instrumentation





Operation of Phase II detector prototype in LArGe:

Measured suppression factor at $Q_{\beta\beta}$: **~0.5·10^4** for a ^{228}Th calibration source

Also: successful read out scintillation light with fibers coupled to SiPMs

Conclusions & Outlook

- GERDA experimental **installations completed** successfully; cryogenic and auxiliary systems operate very stable
- Detector **commissioning** with **non-enriched detectors** started summer 2010 and is still ongoing
- **Initial count rate** (run 1-3,5) **dominated by ^{42}K** (^{42}Ar progenitor) due to concentration of ^{42}K close to the detectors by E-field of diodes ⇒ **field-free configuration**
- **12 commissioning runs** with different detectors, read-out schemes, E-field configurations completed successfully
- Background with **non-enriched detectors currently at 0.05 cts/(keV kg year).** Goal for Phase I: 0.01 cts/(keV kg year).
- Deployment of first string(s) with **enriched detectors Phase I** soon to study background with enriched detectors ⇒ start of Phase I physics run

Conclusions & Outlook (cont.)

- Thick-window **p-type BEGe** detectors for **Phase II**
- Powerful **particle ID** and **background discrimination** by pulse shape analysis: MSE/SSE, p+ contact (α) and n+ (β) surface events
- Full **production chain tested** for BEGe Phase II detectors
- 37.5 kg of 86% **^{enr}Ge** (in form of GeO2) successfully transformed to **35.4 kg** (94%) of 6N
- Crystal **pulling** and **detector production** under preparation
- **Liquid argon instrumentation** shown in **GERDA-LArGe** test stand to be a powerful method to discriminate backgrounds: **implementation in GERDA if needed**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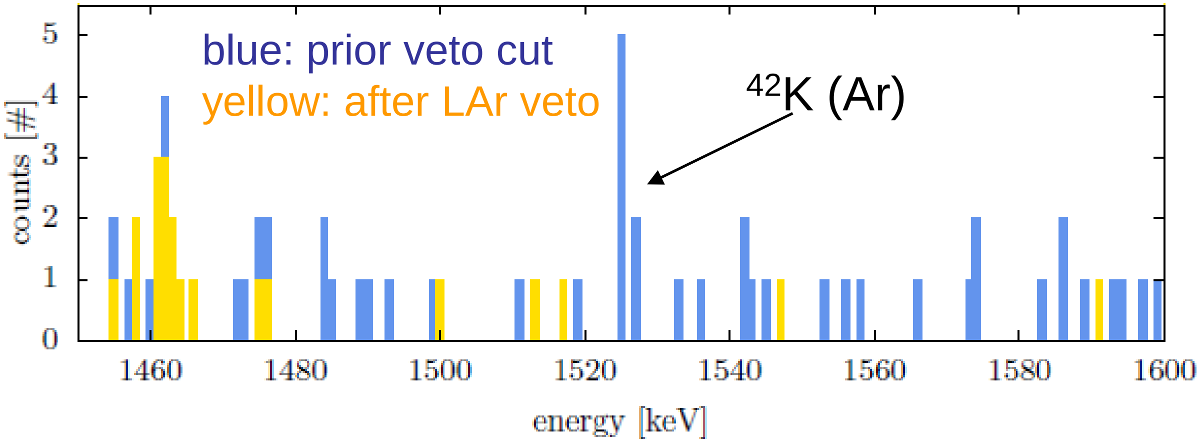
Extra slides

GERDA-LArGe low backgroud run with GTF44

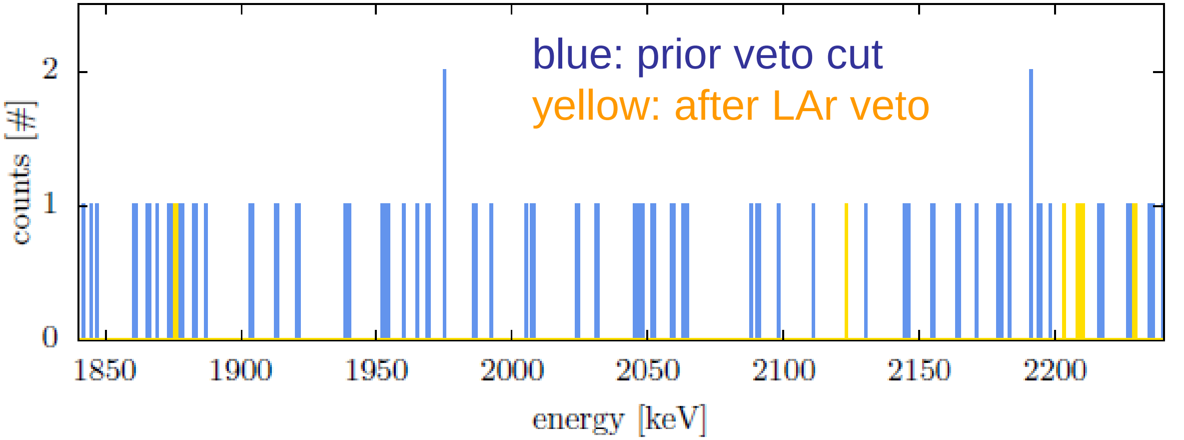


(0.050 ± 0.023)

$\mathrm{cts}/(\mathrm{kg}\cdot\mathrm{d})$

Reduced rate most likely to "ion sweeping" (work in progress)

Figure 5.6: Close-up of the energy region around the 1525 keV ^{42}K-peak. None of the 7 counts in the peak (1523-1527 keV) survives the LAr veto cut. The peak at 1460 keV is from ^{40}K.



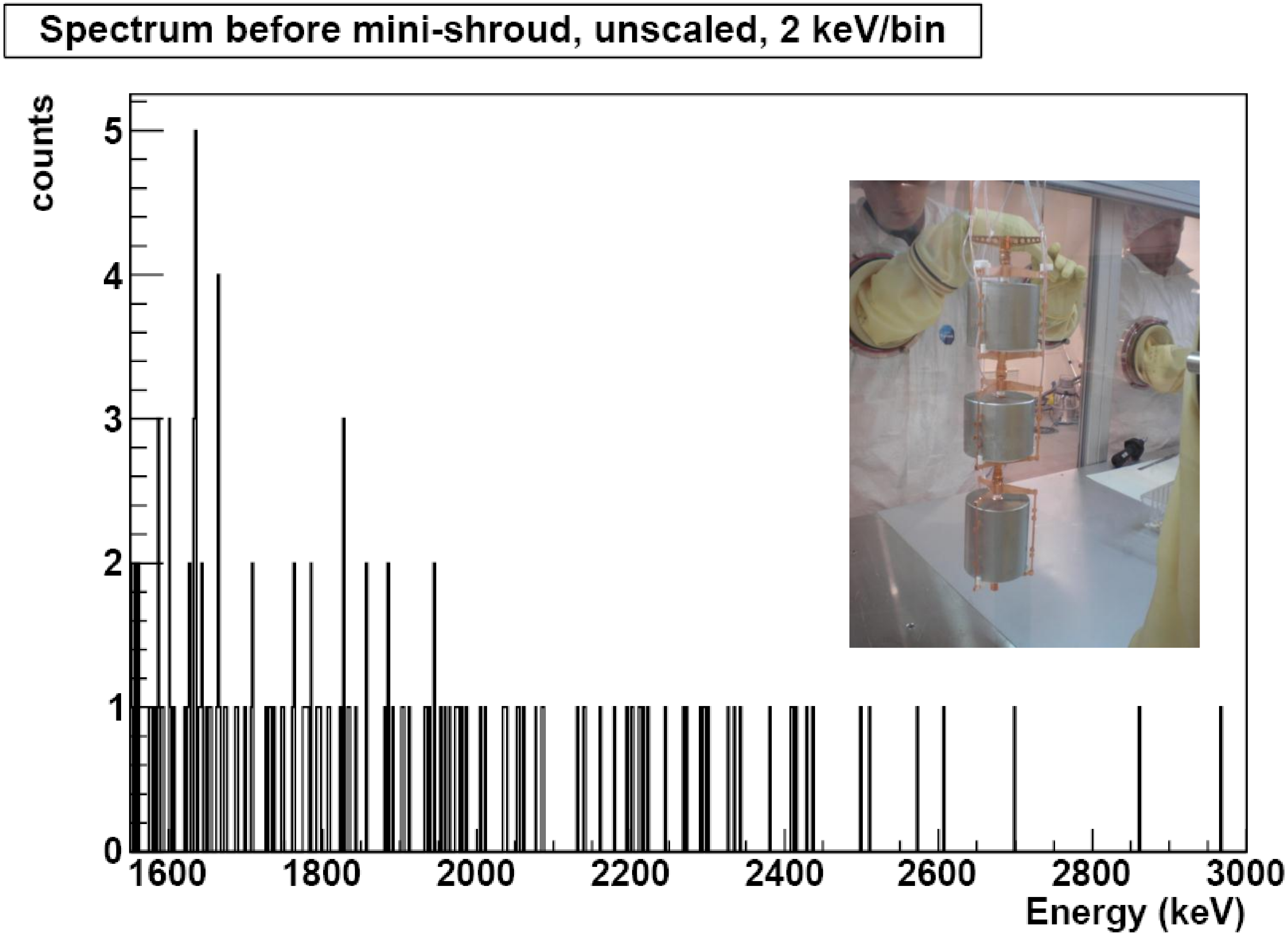
bg index $[\mathrm{cts}/(\mathrm{keV}\cdot\mathrm{kg}\cdot\mathrm{y})]$

$0.12 - 4.6 \cdot 10^{-2}$

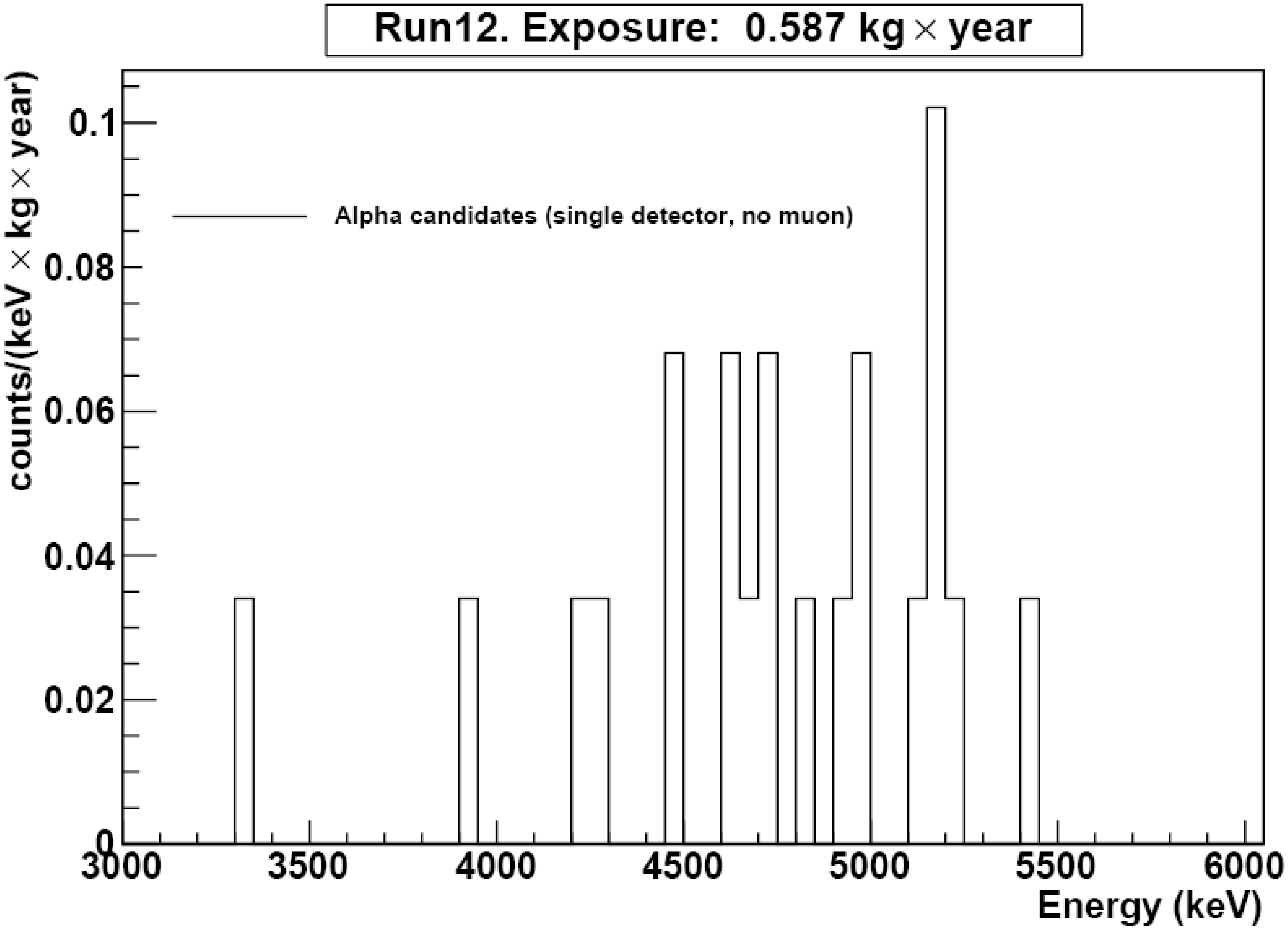
90% confidence interval

Figure 5.7: The LArGe background in the ROI of the $0\nu\beta\beta$-decay. In the vetoed spectrum (yellow) only one count is present in a 300 keV interval around $Q_{\beta\beta} = 2039$ keV, and no count in a 100 keV interval. A ^{214}Bi peak appears at 2204 keV. The exposure is 116 kg·d (47.05 days).

Run 1-3 with 2 keV bins

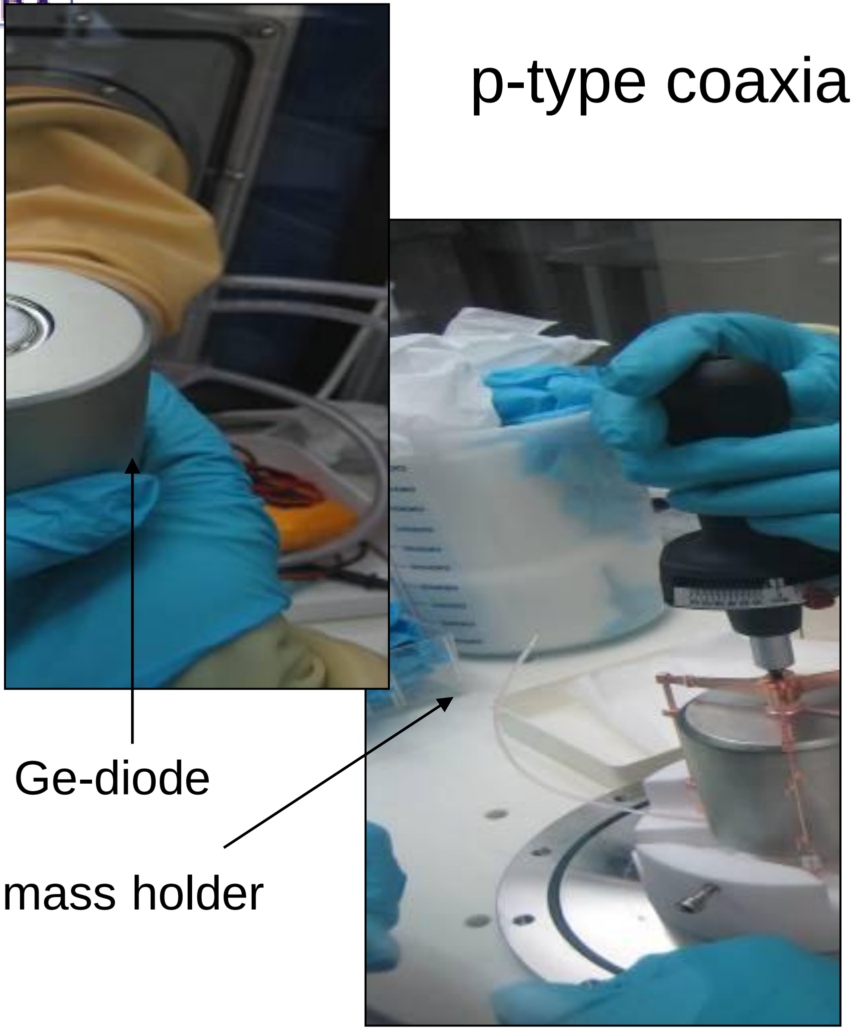

Spectrum before mini-shroud, unscaled, 2 keV/bin

Results from run 12:
Alpha candidate events



Phase I detectors

p-type coaxial detectors



Detector handling under N_2 atmosphere

<u>8 diodes (from HdM, IGEX):</u>

- Enriched 86% in ^{76}Ge
- All diodes refurbished with new contacts optimized for LAr
- Energy resolution in LAr: ~2.5 keV (FWHM) @1.3 MeV
- Well tested procedure for detector handling
- Total mass 17.66 kg (after refurbishing)

<u>6 diodes from Genius-TF ^{nat}Ge:</u>

- Same refurbishing & testing as enriched diodes
- Total mass: 15.60 kg

Background in Heidelberg-Moscow Experiment

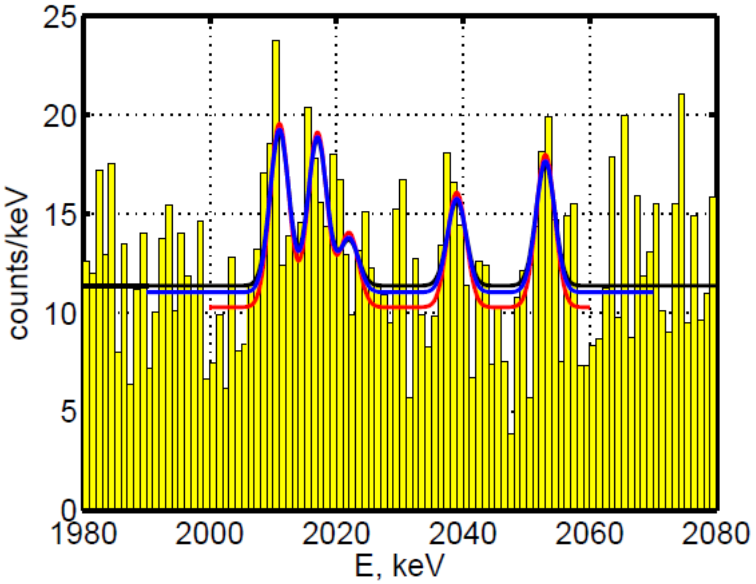
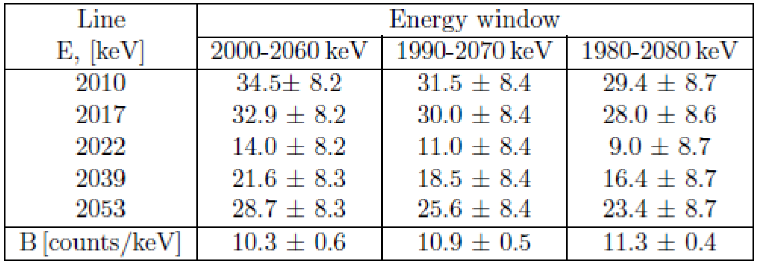


Figure 3.14: Fits of the HdM spectrum for three energy windows: 2000-2060 keV, 1990-2070 keV and 1980-2080 keV. The spectrum is fitted with fixed peak positions [28] and fixed peak widths (3.48 keV FWHM) defined by the energy calibration. The fitted background depends on the energy interval.



Line E, [keV]	Energy window 2000-2060 keV	 1990-2070 keV	 1980-2080 keV
2010	34.5± 8.2	31.5 ± 8.4	29.4 ± 8.7
2017	32.9 ± 8.2	30.0 ± 8.4	28.0 ± 8.6
2022	14.0 ± 8.2	11.0 ± 8.4	9.0 ± 8.7
2039	21.6 ± 8.3	18.5 ± 8.4	16.4 ± 8.7
2053	28.7 ± 8.3	25.6 ± 8.4	23.4 ± 8.7
B [counts/keV]	10.3 ± 0.6	10.9 ± 0.5	11.3 ± 0.4

Table 3.8: Intensities of the peaks in the region of interest around $Q_{\beta\beta}$ obtained from fit using different energy windows.

Background:
0.16 counts/(keV kg year)

O. Chkvorets, Diss. Univ. Heidelberg, 2008