Status of the GERDA Experiment

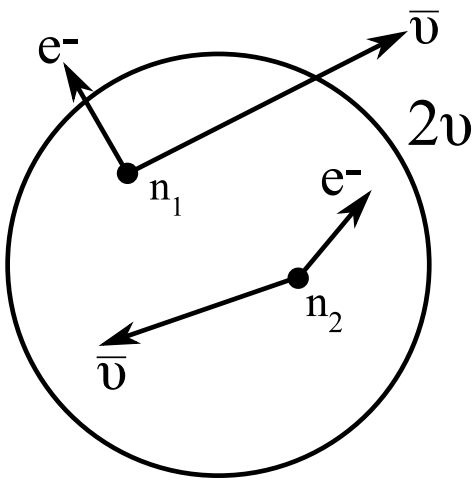
Oliver Schulz

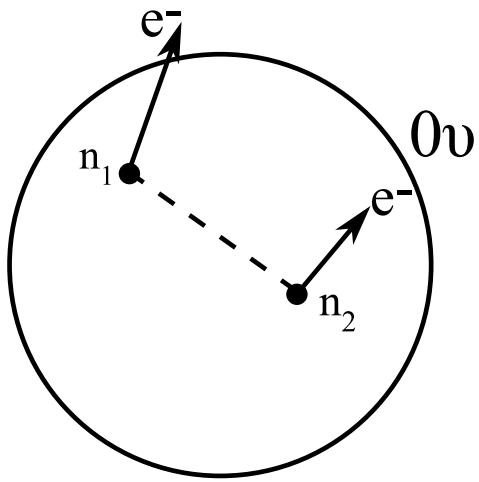
oschulz@mpp.mpg.de

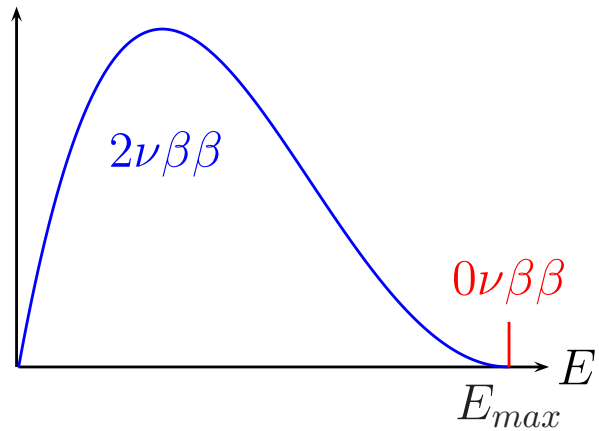
MPP Project Review, December 14, 2015

$0\nu\beta\beta$-Decay

- Single β-decay not allowed for some isotopes, only double β-decay
- If $0\nu\beta\beta$-decay exists, ν must be a Majorana Particle ($\nu = \bar{\nu}$)







$$\left(T_{1/2}^{0\nu}\right)^{-1} = G(Q,Z)\,\left|M_{\text{nucl}}\right|^2\,\langle m_{ee}\rangle^2$$

- Discovery of $0\nu\beta\beta$-decay would
  - Imply lepton-number violation
  - Determine nature of ν (Majorana or Dirac).
  - Give information about absolute Neutrino mass / hierarchy?

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The GERDA Experiment

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- Search for $0\nu\beta\beta$-Decay in $^{76}\mathrm{Ge}$ at $Q_{\beta\beta} = 2039 keV$
- Array of isotopically enriched HPGe detectors, suspended in liquid Argon
- Ultra-low background setup, located underground at LNGS
- Phase-I completed very successfully, world-best limit for $^{76}\mathrm{Ge}$ $0\nu\beta\beta$-Decay
- Phase-II will go beyond: Increased total detector mass, even lower background
- Main activity 2015: Phase-II preparation and commissioning

Organization

- Member institutes:
  INFN LNGS, Jageillonian Univ. Cracow, IKTP TU Dresden, JINR Dubna, IRMM Geel, MPIK Heidelberg, Univ. and INFN Milano and Milano Bicocca, INR Moscow, ITEP Moscow, NRC-KI Moscow, MPP München, TU München, Univ. and INFN Padova, Univ. Tübingen, Univ. Zürich

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- GERDA at MPP:
  - Director: Allen Caldwell
  - Group leader: Bela Majorovits
  - Staff: Oliver Schulz
  - Engineers / Technicians: Christopher Gooch, Hans Seitz
  - PostDocs: Dimitris Palioselitis, Neslihan Becerici-Schmidt (until March)
  - PhD Students: Raphael Kneissl, Heng-Ye Liao, Laura Vanhöfer

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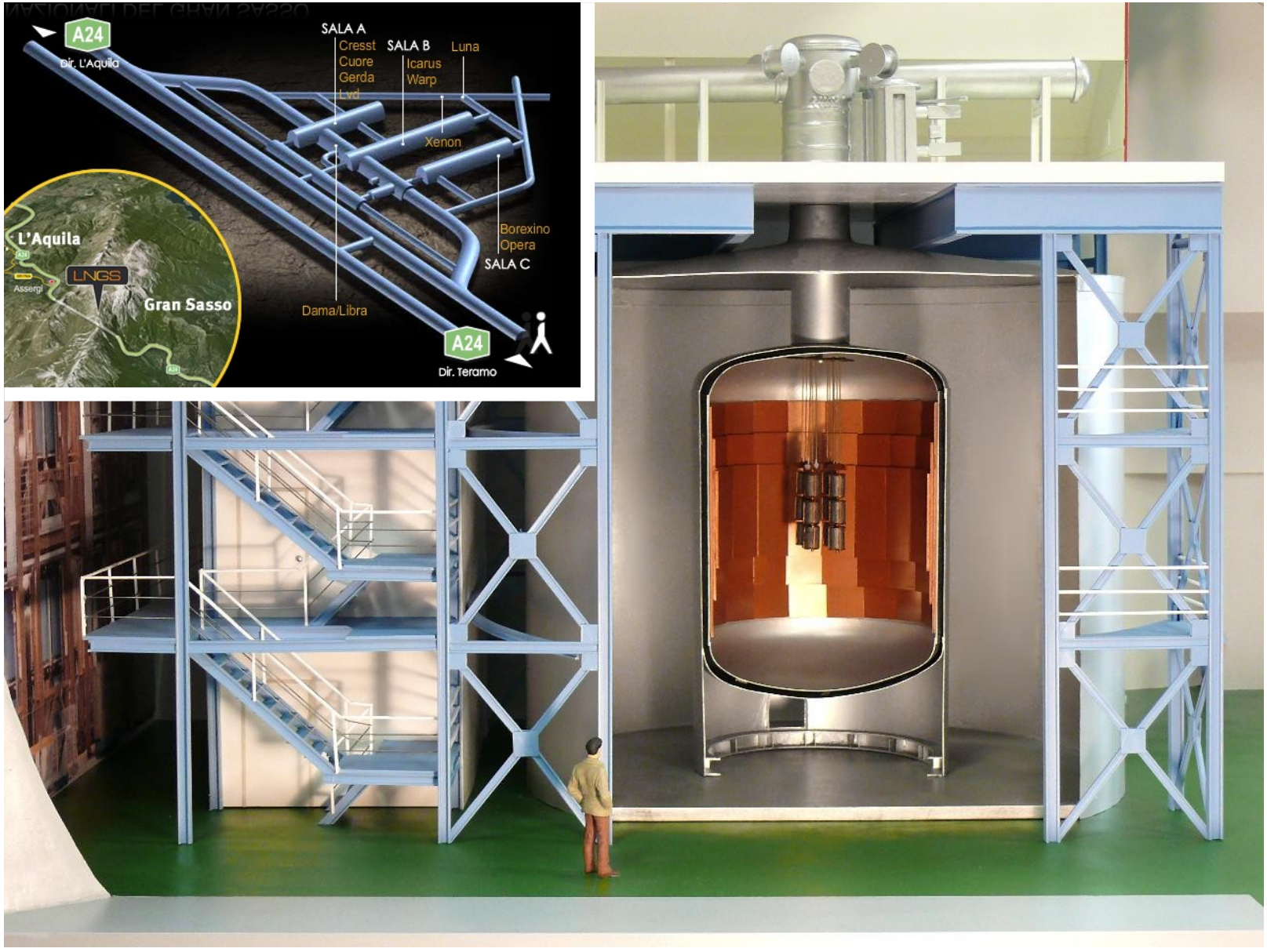

[Eur. Phys. J. C 73 (2013) 2330]

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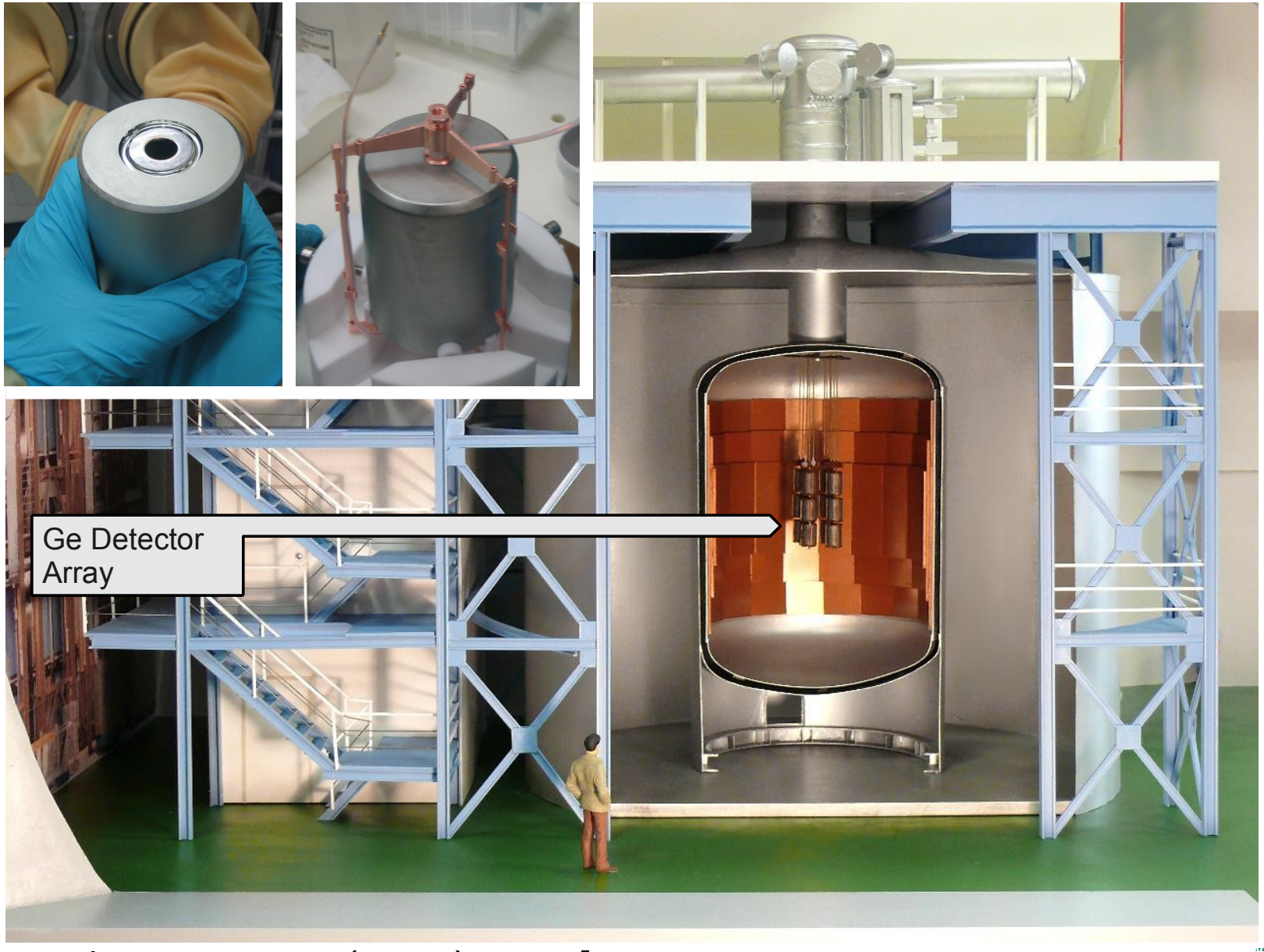

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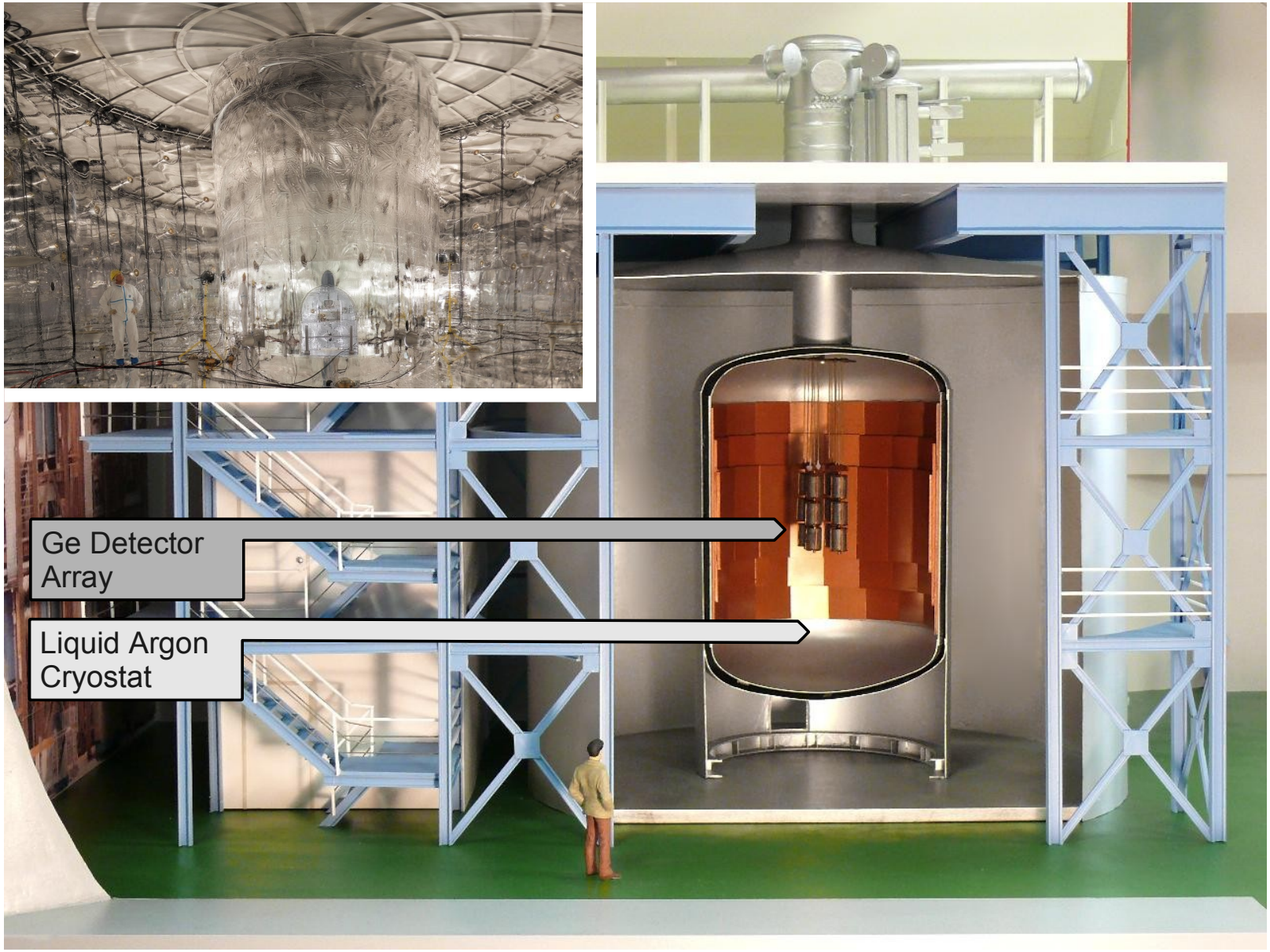

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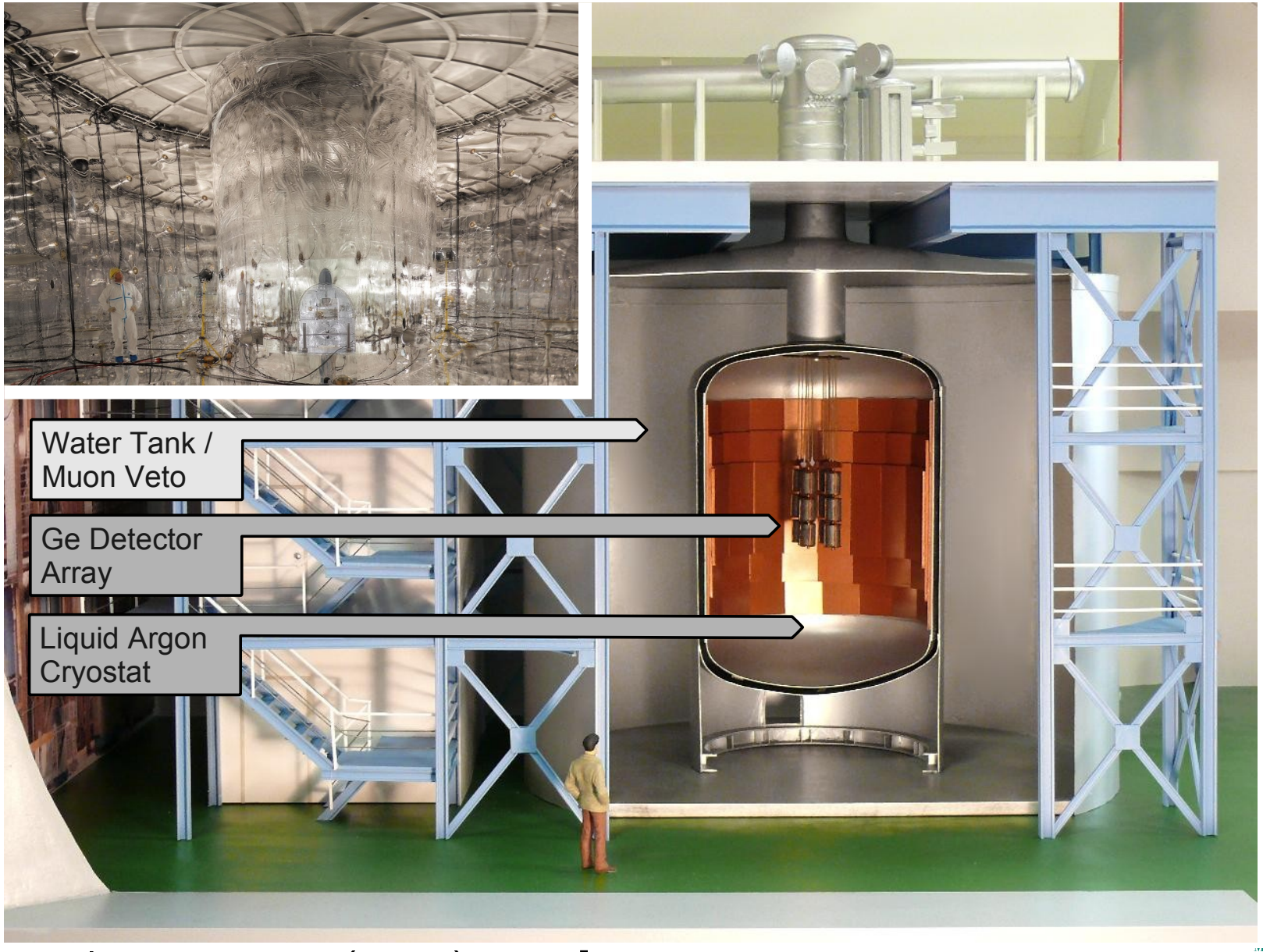

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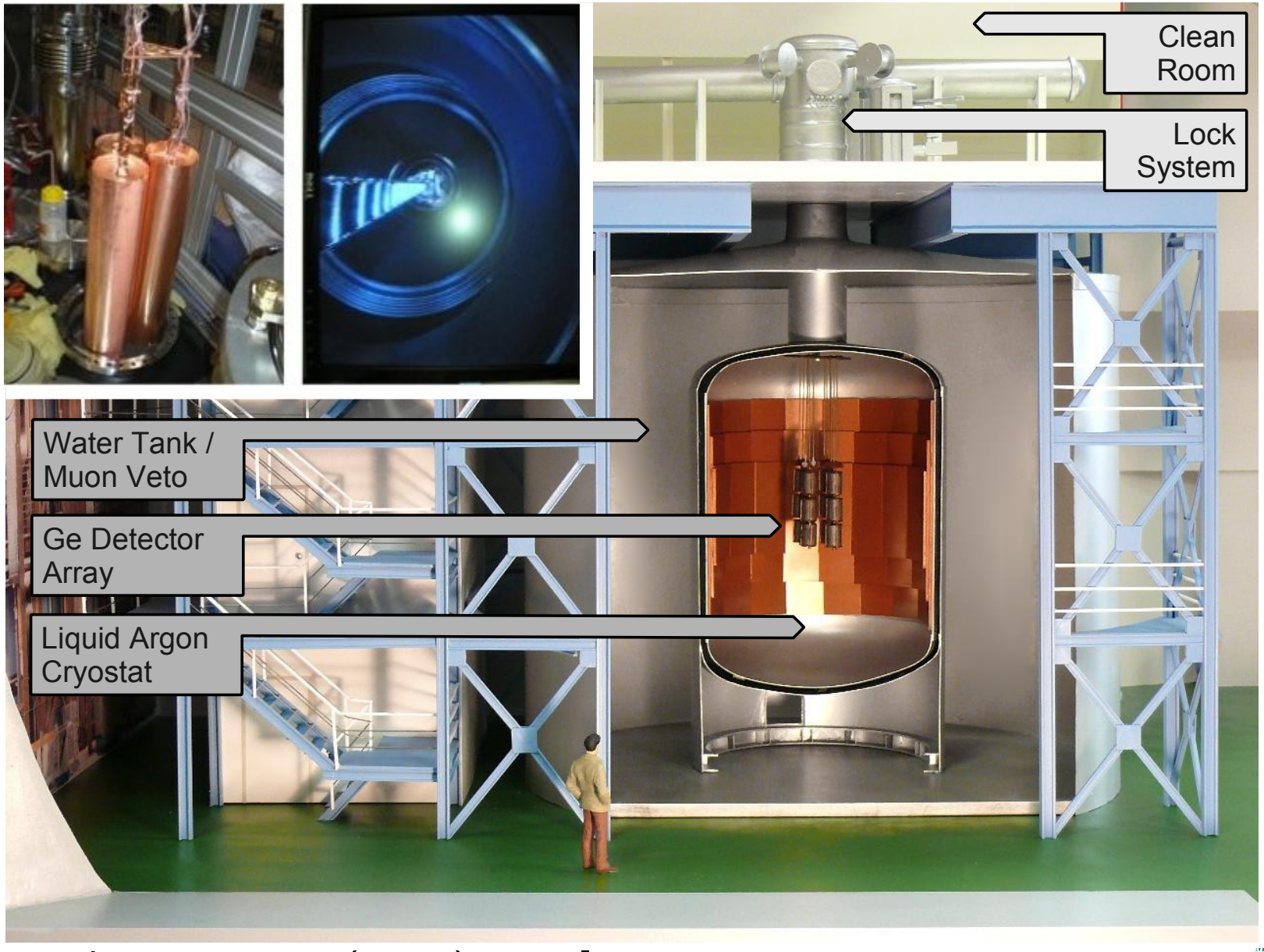
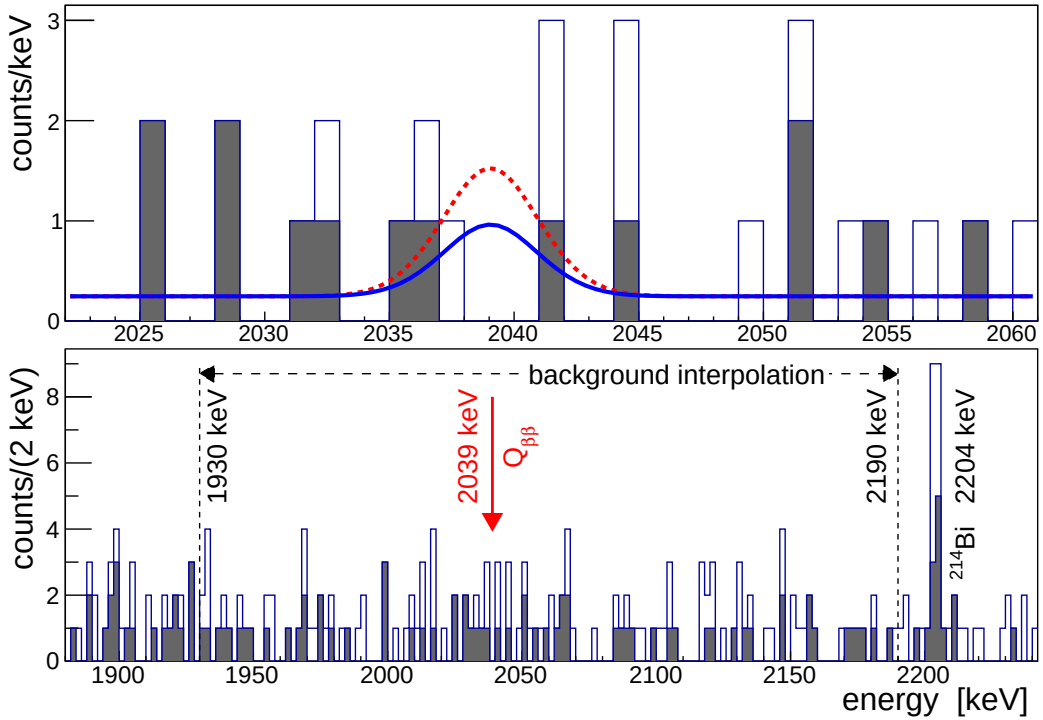


[Eur. Phys. J. C 73 (2013) 2330]

Phase-I ^{76}Ge $0\nu\beta\beta$-Decay Result



- Region of interest unblinded in June 2013:
  7 events in blinded region, 3 remain after PSD
- Phase-I Result: $T^{0\nu}_{1/2} > 2.1 \times 10^{25}$ yr (90% C.L.),
  $T^{0\nu}_{1/2} > 3.0 \times 10^{25}$ yr in combination HDM and IGEX results
  [Phys. Rev. Lett. 111 (2013) 122503]

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GERDA Phase-II Overview

- GERDA Phase-I completed successfully.
  Time for the next step: GERDA Phase-II
- Design goals:
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  - Phase-I coaxial detectors (18 kg) will be re-used in Phase-II
- Lower background: $1 \times 10^{-2} \rightarrow 1 \times 10^{-3}$ cts/(keV·kg·yr)
  - New detector technology: BEGe detectors
    (already tested a few in Phase-I)
  - Active veto around detectors: LAr instrumentation
  - Cleaner/less material: detector holders, electronics, cables

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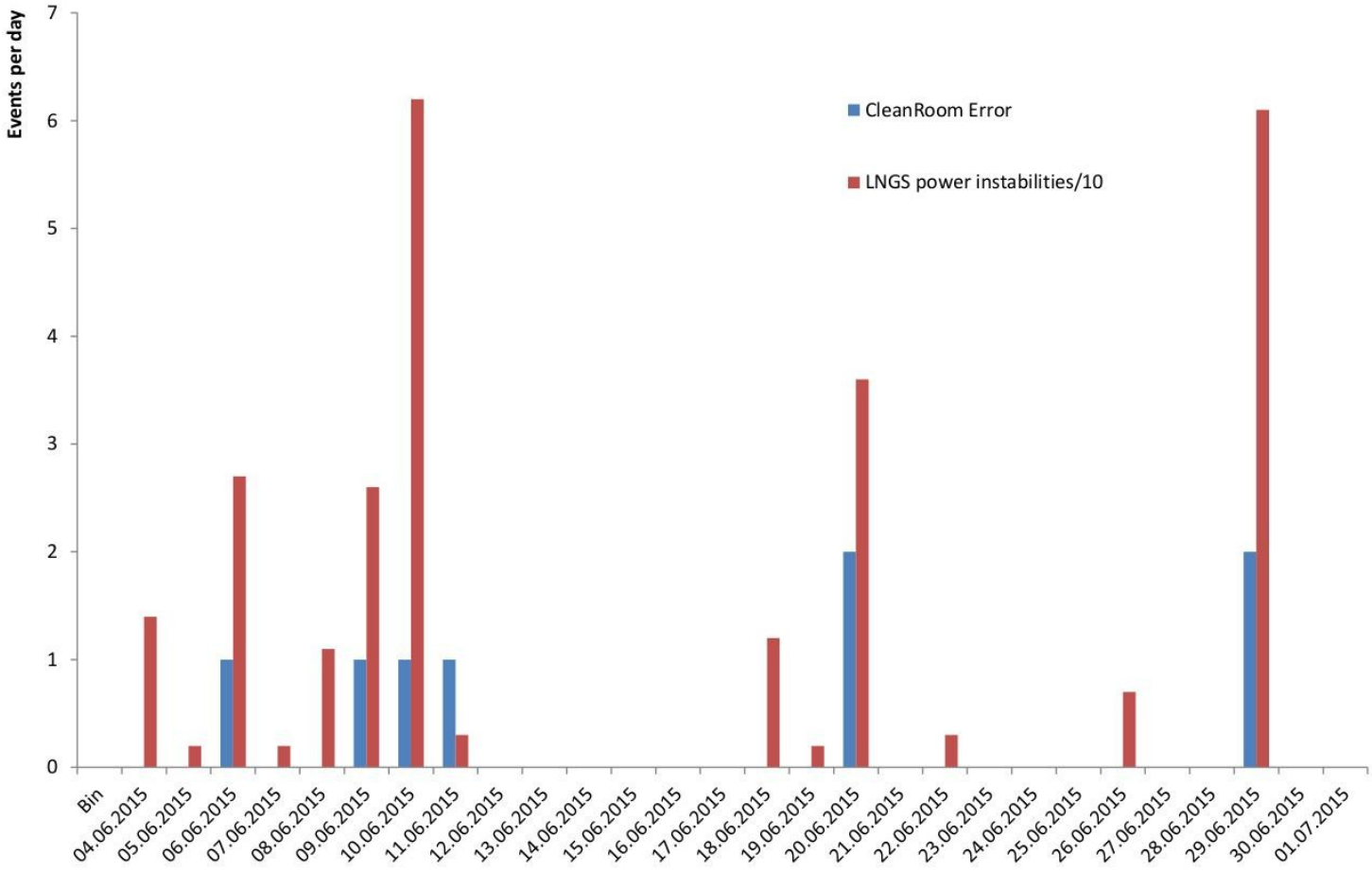

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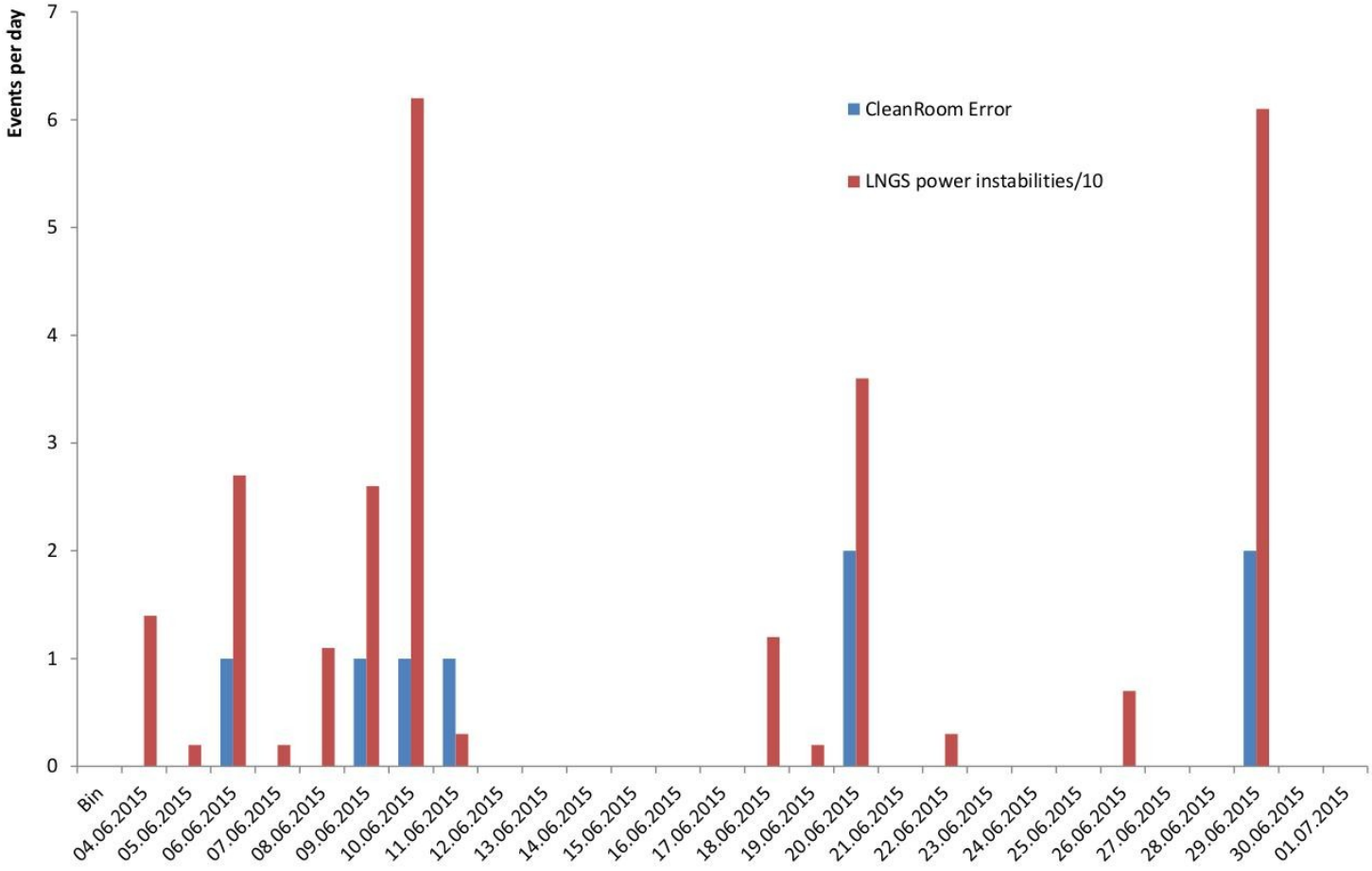

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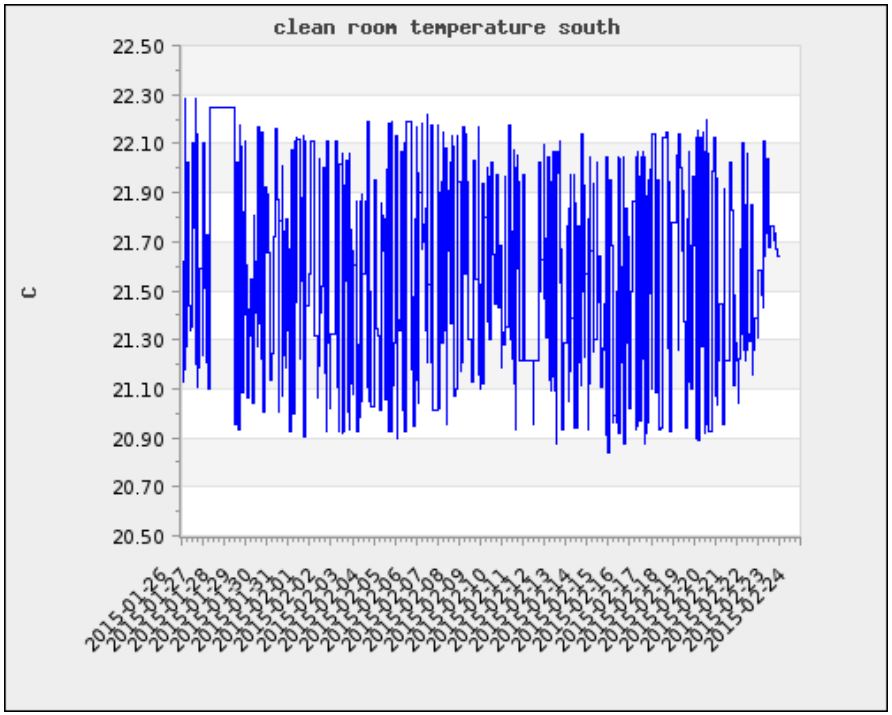

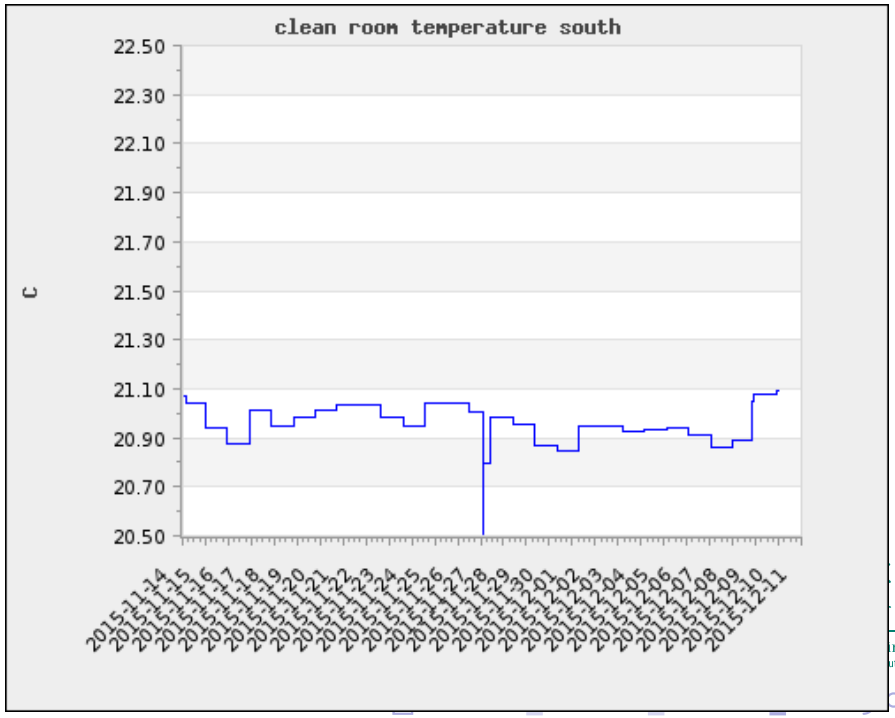

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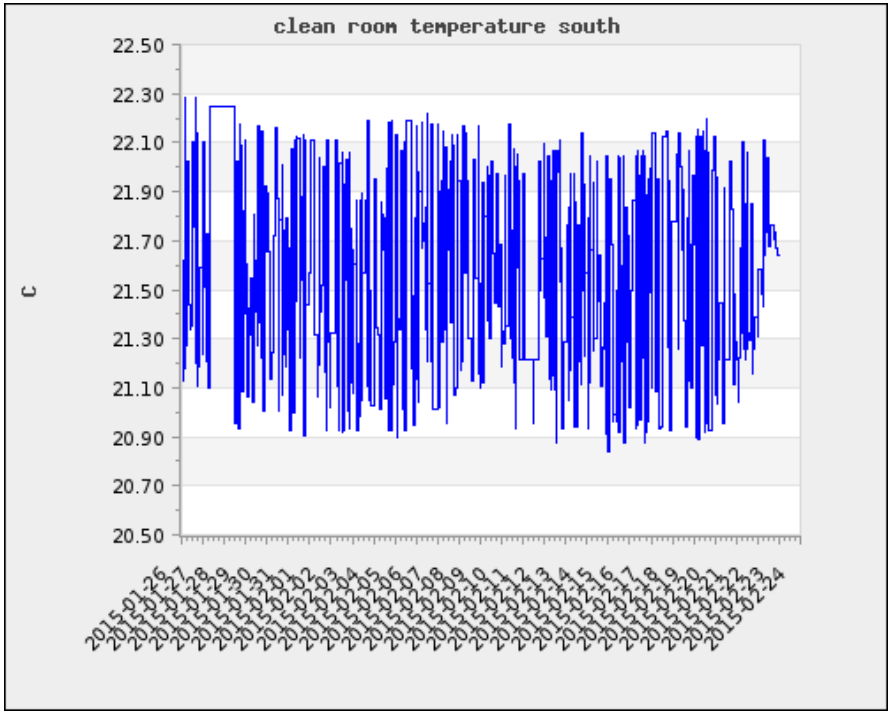
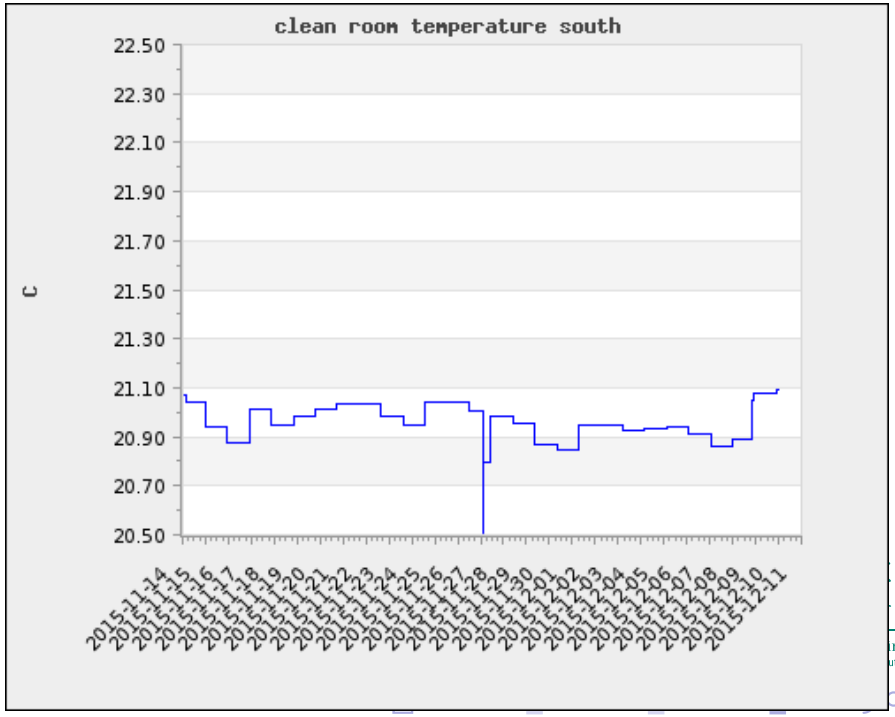
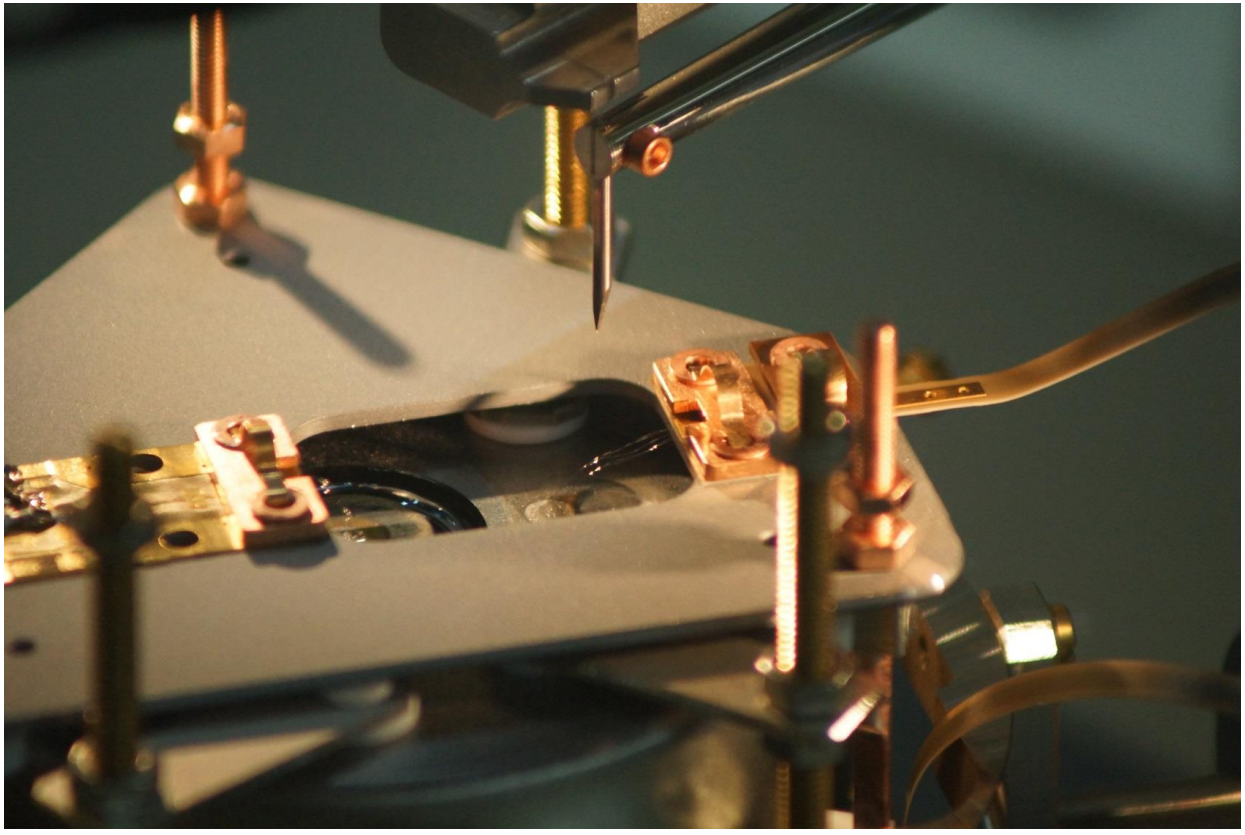
- Maintenance contract with Italian company (Rome)



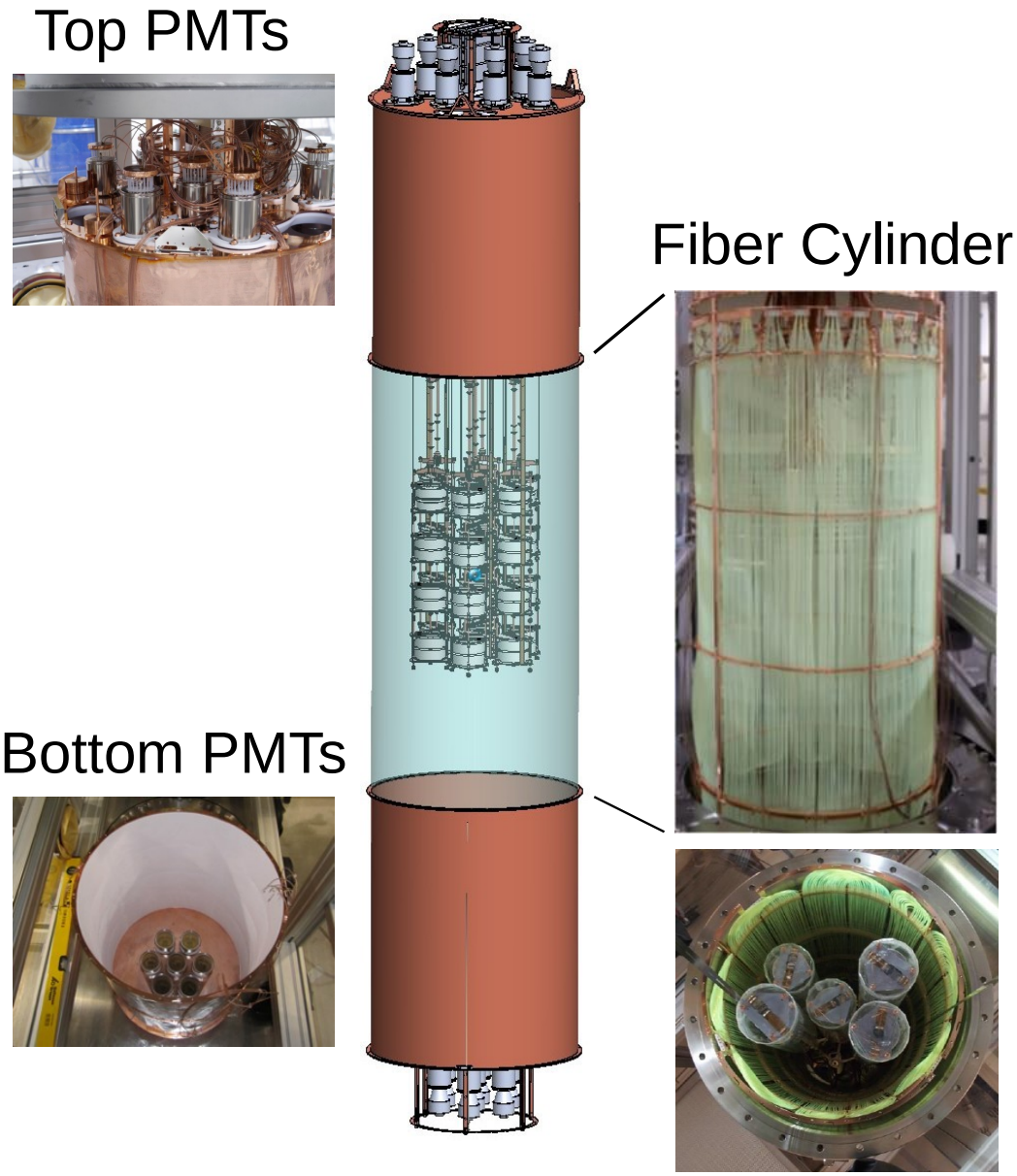


Phase-II Detector Holders, Improved



- Materials: Semiconductor-grade silicon and e-copper
- Wire-bonded detectors (GERDA Al-metalization process)
- New version: Even less material
- New BEGe orientation to reduce leakage current issues

LAr Instrumentation



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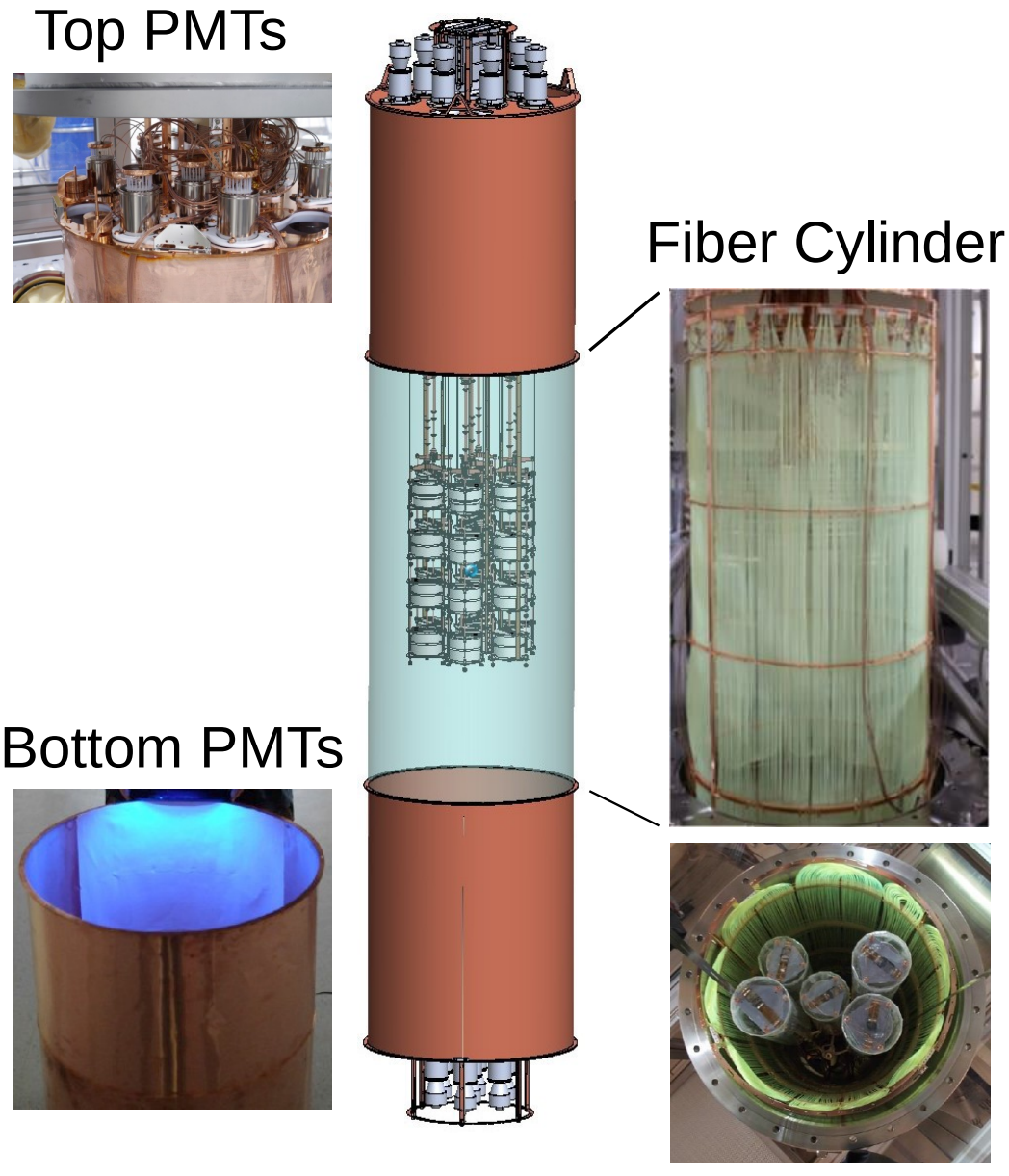

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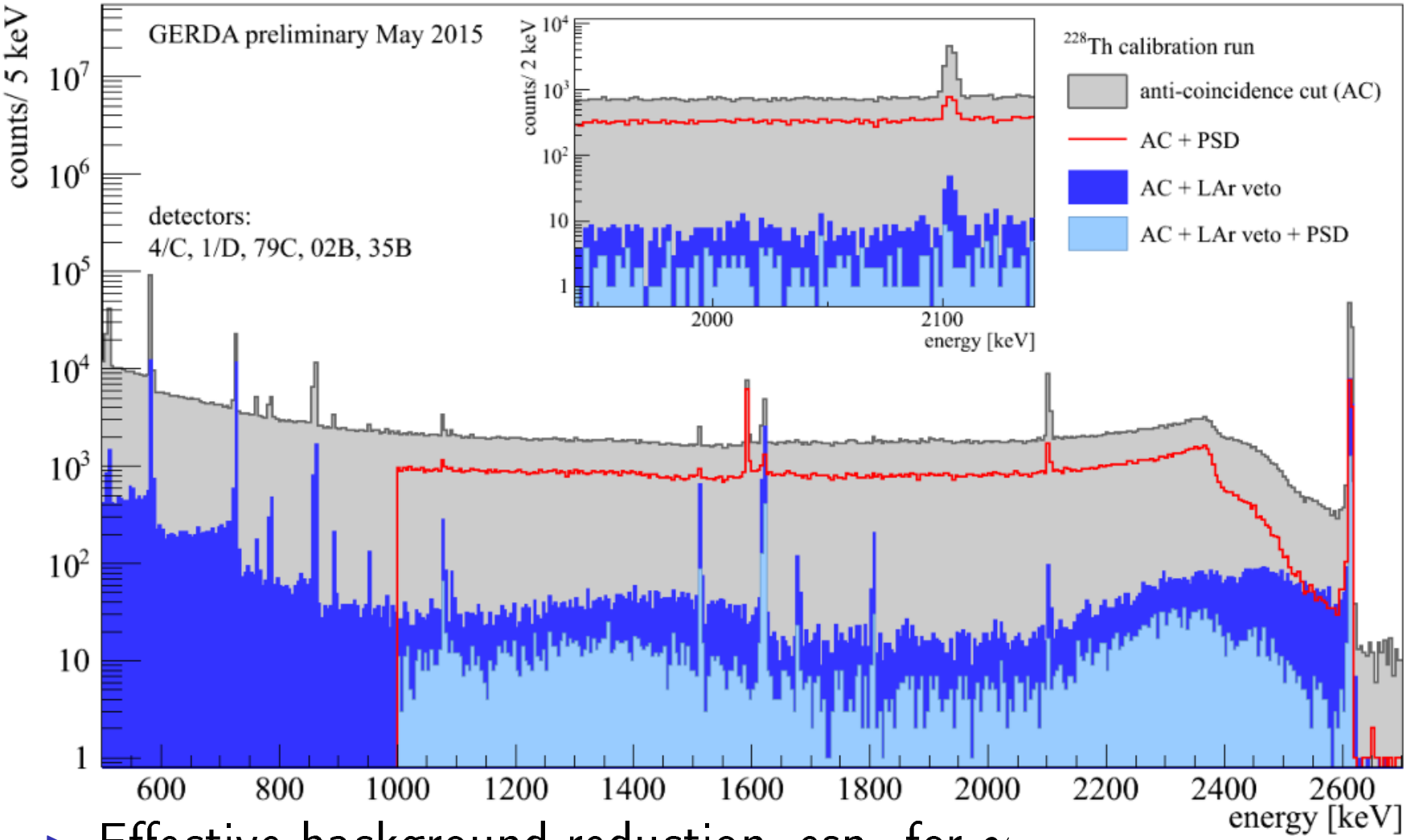
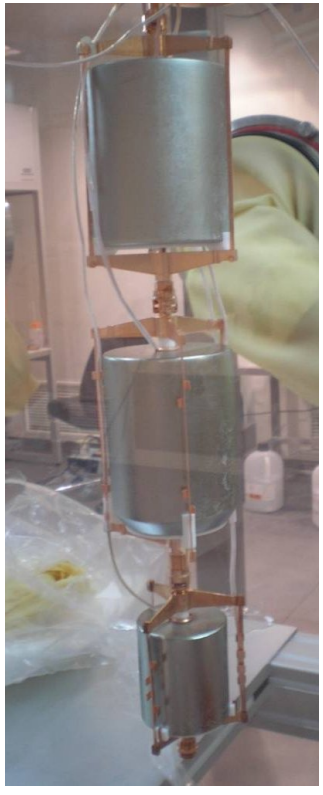
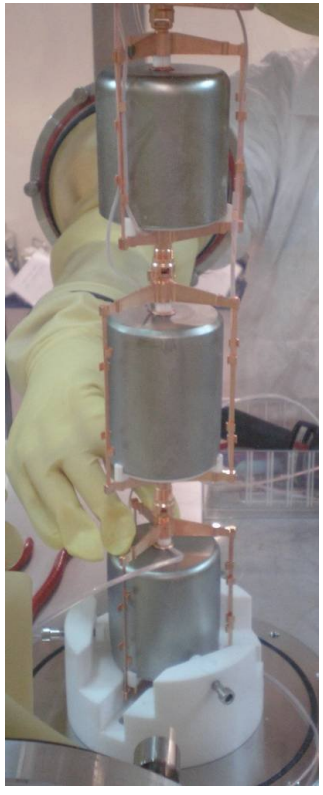
LAr Veto Background Reduction



- Effective background reduction, esp. for γ

Gerda Phase-I Detector Strings

- 8 enriched coaxial detectors from HDM and IGEX (17.7 kg, Nov. 2011 - June 2013)
- 1 non-enriched coaxial detector (3.0 kg)
- May 2012 to June 2013: 5 enriched Phase-II BEGe detectors (3.6 kg)

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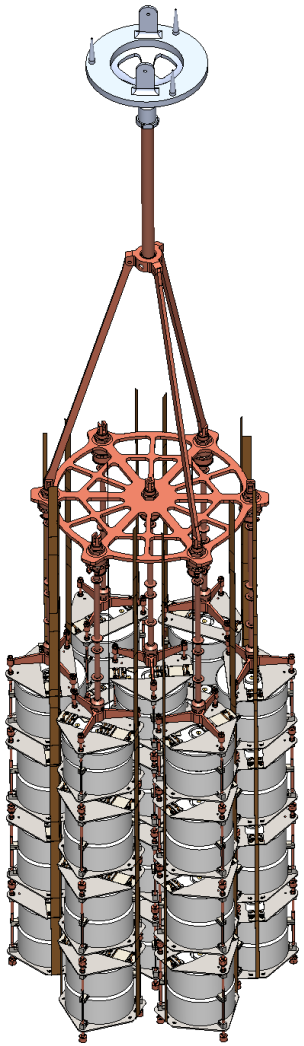
Phase-II Detector Array



- Phase-II array is very different:
  - Single array with 7 strings → large diameter
  - Increased weight
  - Additional weight of LAr instrumentation
  - A lot more channels → a lot more cables
- Needed new lock and new cable chain (developed at MPP, installed 2014)

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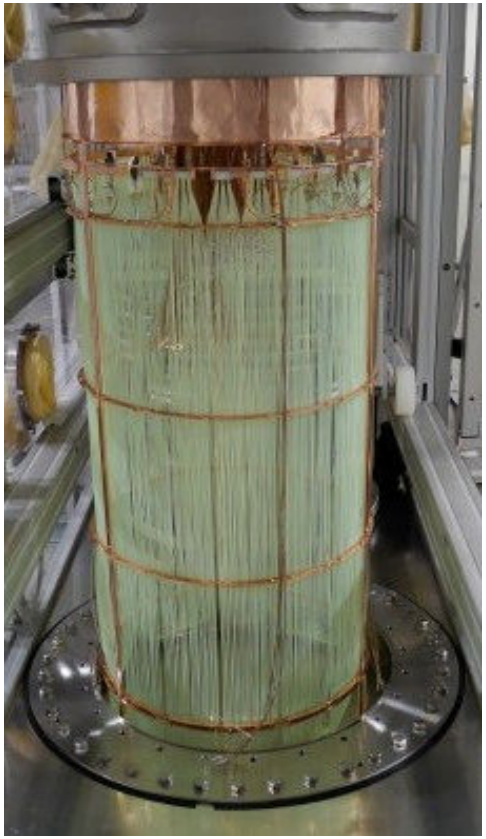

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- It's a tight fit!

Phase-II Integration

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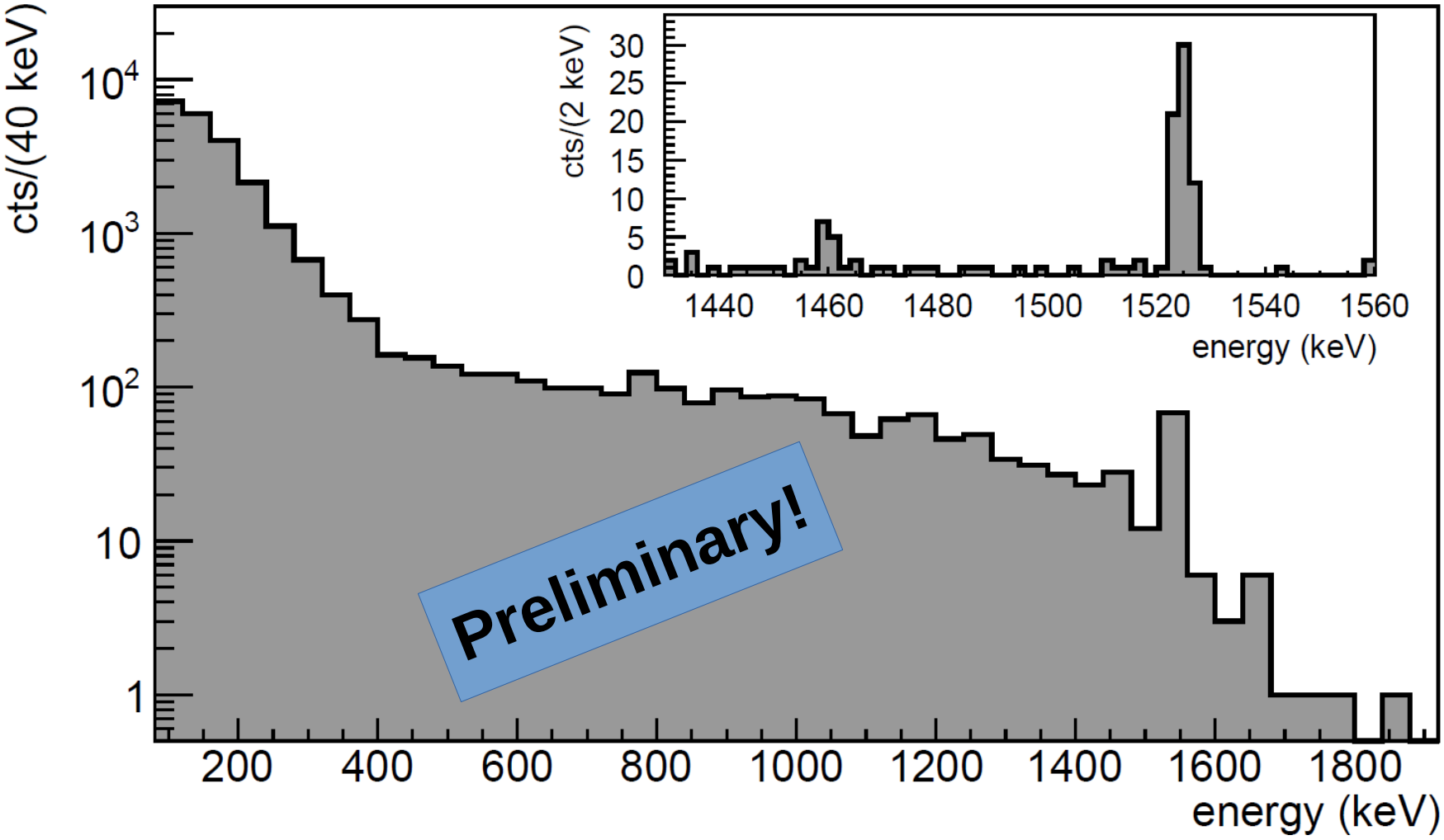
- This week: Installation of last 10 detectors

Phase-2 Commissioning $2\nu\beta\beta$-Spectrum



- Commissioning, stage 2 (5 string assembly), approx. 1 kg y

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GERDA Software Challenges

- Gerda data processing stages:
  - tier-0: Raw data
  - ...
  - tier-4: Format for end-user physics analysis
- Processing involves lots of tools (GERDA software) parameters, calibration functions, etc.
- Phase-I: Lot's of shell scripts, hard-coded parameters, manual steps, software installation non-trivial
- Phase-II: Several sub-detector systems, more channels, more complexity $\rightarrow$ need integrated solution

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  - Python-based workflow management package (by Spotify)
  - Optional server component ("luigid") for orchestration and web-GUI for monitoring
  - Supports atomic file creation, remote file access, etc.

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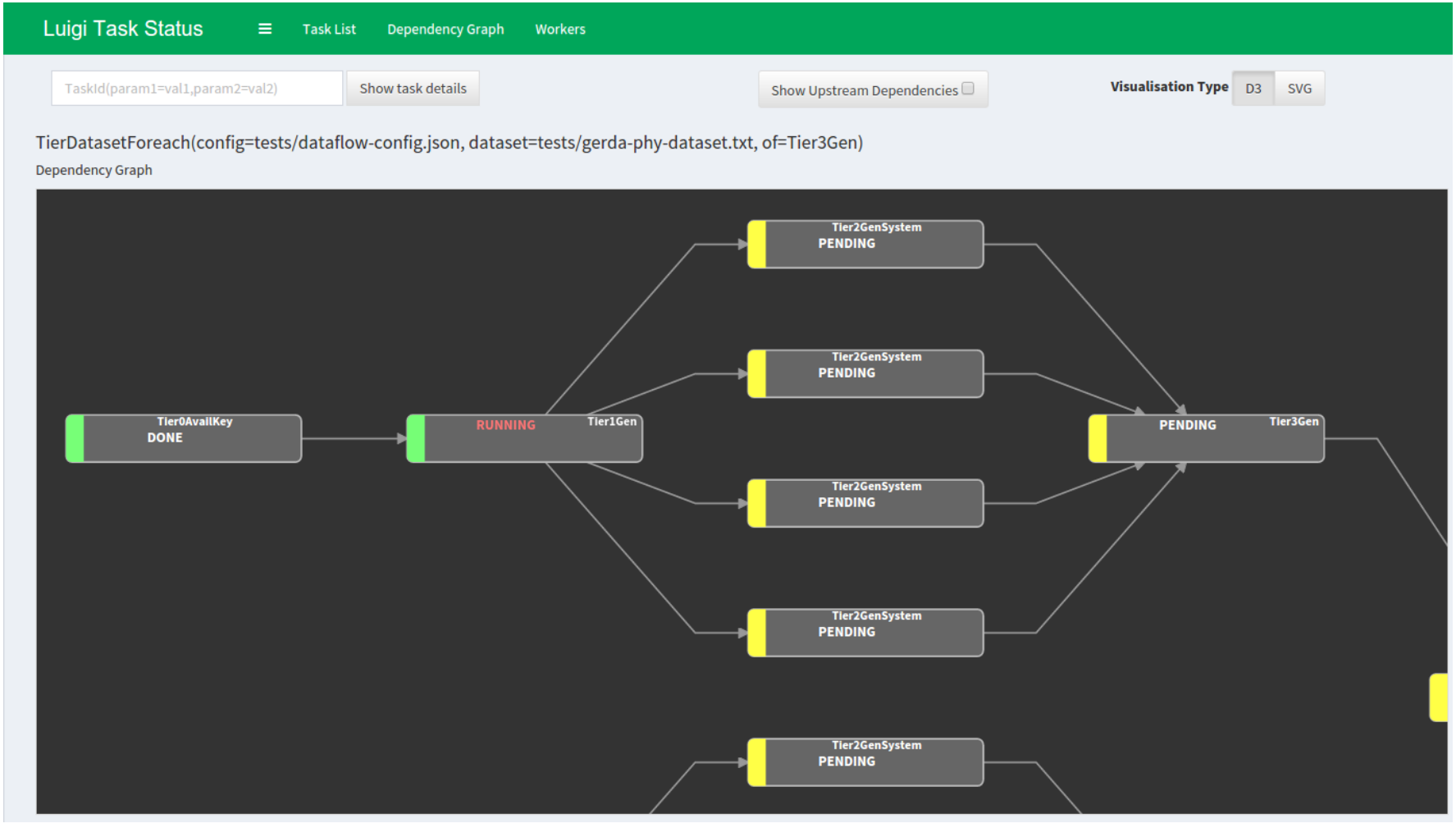
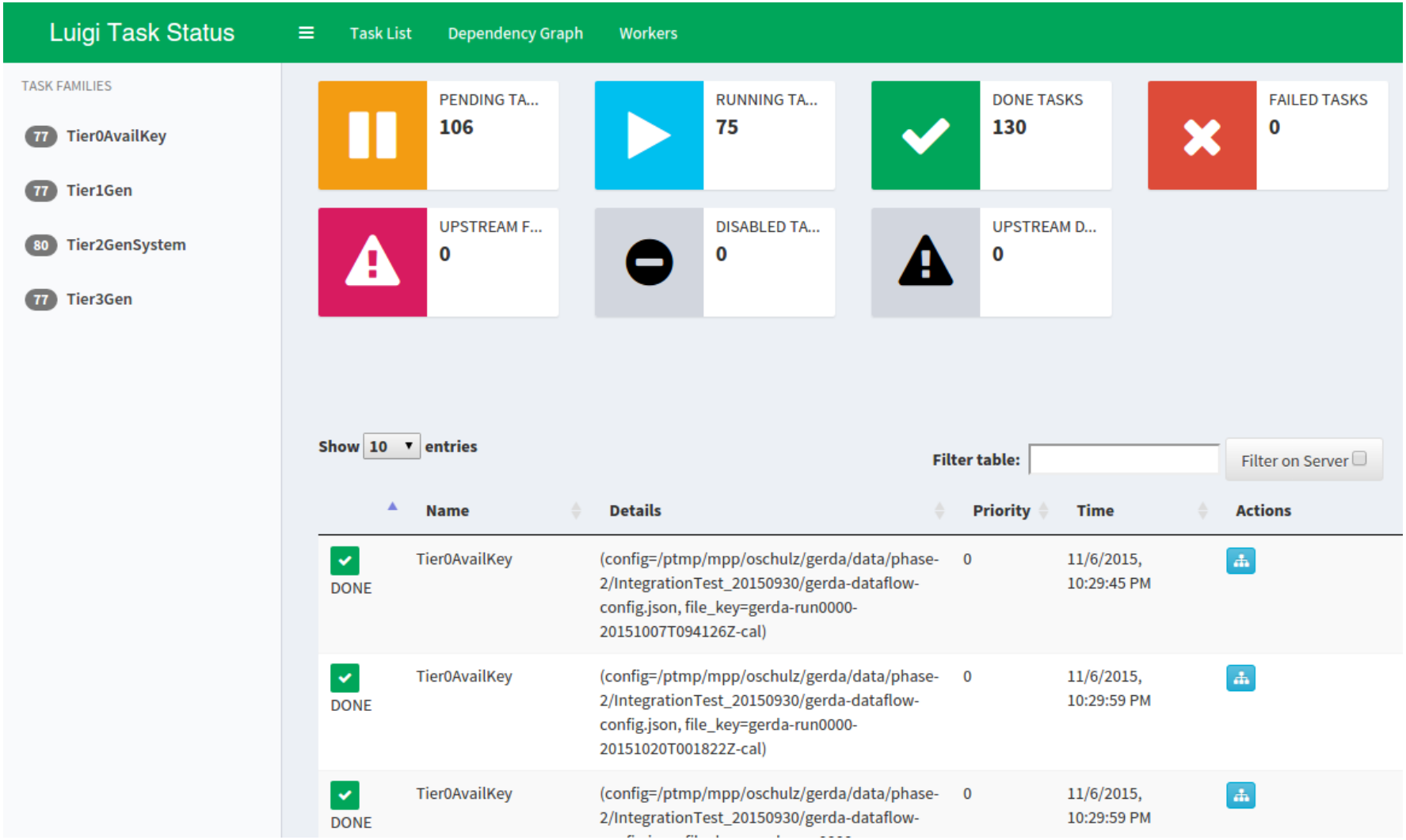
- GERDA Tier-4 generation (and more) coming soon

Luigi GUI Task Visualization



Batch-cluster execution monitoring



Batch jobs at MPCDF, tracked by luigid

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Publications in 2015

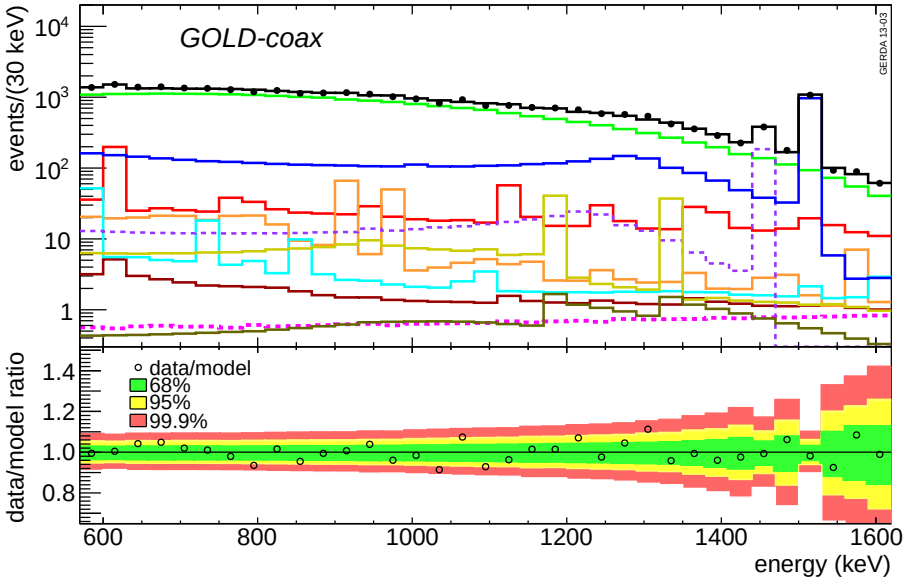
- GERDA Collaboration Papers
  - Production, characterization and operation of 76Ge enriched BEGe detectors in GERDA; EPJC 75 (2015) 39
  - Improvement of the energy resolution via an optimized digital signal processing in GERDA Phase-I; Eur. J. Phys. C 75 (2015) 255
  - Results on $\beta\beta$-decay with emission of two neutrinos or Majorons in 76Ge from GERDA Phase-I; Eur. Phys. J. C 75 (2015) 416
  - $0\nu\beta\beta$-decay of 76Ge into excited states with GERDA Phase-I; J. Phys. G: Nucl. Part. Phys. 42 (2015) 115201
- MPP GERDA Group
  - MPP-2015-33, Systematic uncertainties of artificial neural-network pulse-shape discrimination for $0\nu\beta\beta$-decay searches using true-coaxial HPGe detectors, accepted

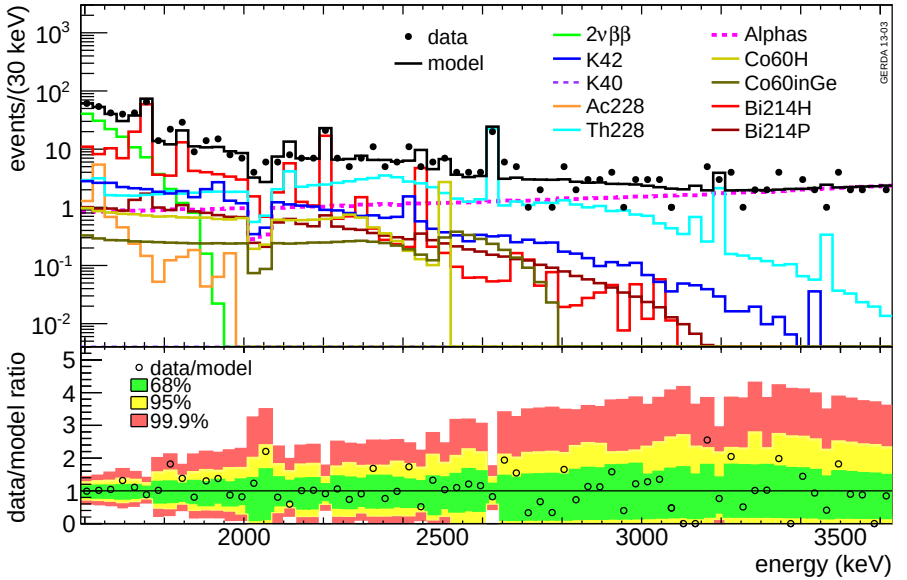
Summary

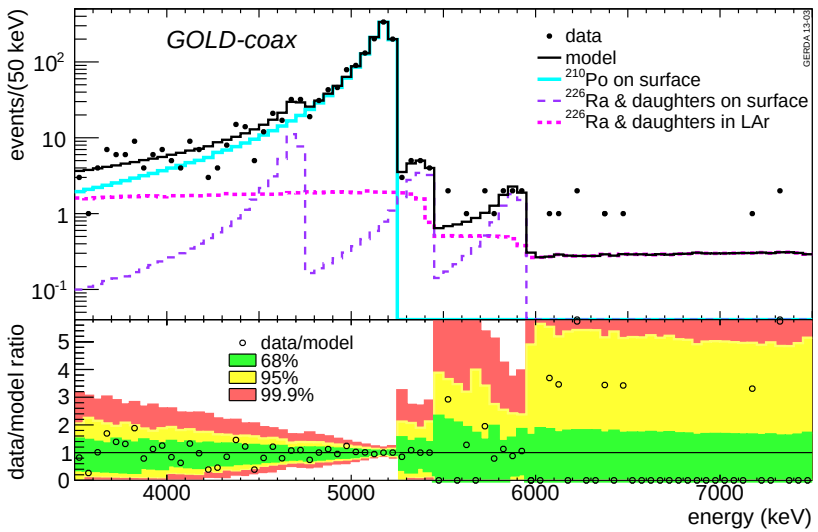
- Gerda Phase-II integration/commissioning began in July
- LAr instrumentation now fully operational
- New software from MPP for automatic data flow
- Phase-II Array integration almost complete
- Background looks promising
- First physics run is in sight

Appendix

Phase-I Background Decomposition







Background index:
2×10^{-2} cts/(keV·kg·yr)
[arXiv:1306.5084, acc. by Eur. Phys. J. C],
1×10^{-2} cts/(keV·kg·yr) after PSD [EPJC 73 (2013) 2583]

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Phase-II Background Expectations

background [10^{-3} cts/(keV·kg·yr)]	without cuts	after PSD cuts	after PSD & veto († opaque MS)
^{228}Th (near)	≤ 5 *	≤ 2.3	≤ 0.01
^{228}Th (1 m away)	< 3	< 1.3	< 0.01
^{228}Th (distant)	< 3 ?	< 1.2 ?	< 0.1 ?
^{214}Bi (holder/MS)	≤ 5 *	≤ 1.7	≤ 0.13 († 0.5)
^{214}Bi (near p+)	< 6	< 0.13	< 0.03 († 0.07)
^{214}Bi (n+)	< 7 ?	< 0.7 ?	< 0.15 († 0.4)
^{214}Bi (1 m away)	< 3	< 1	< 0.08 († 0.2)
^{60}Co (near)	1	0.02	0.001
^{60}Co (in Ge)	≤ 0.3	≤ 0.006	≤ 0.0004
^{68}Ga (in Ge)	≤ 2.3	≤ 0.21	≤ 0.04
^{226}Ra (α near p+)	1.5	< 0.03	< 0.03
^{42}K (β on n+)	~ 20	< 1	< 0.86
unknown (n?)	?	?	?

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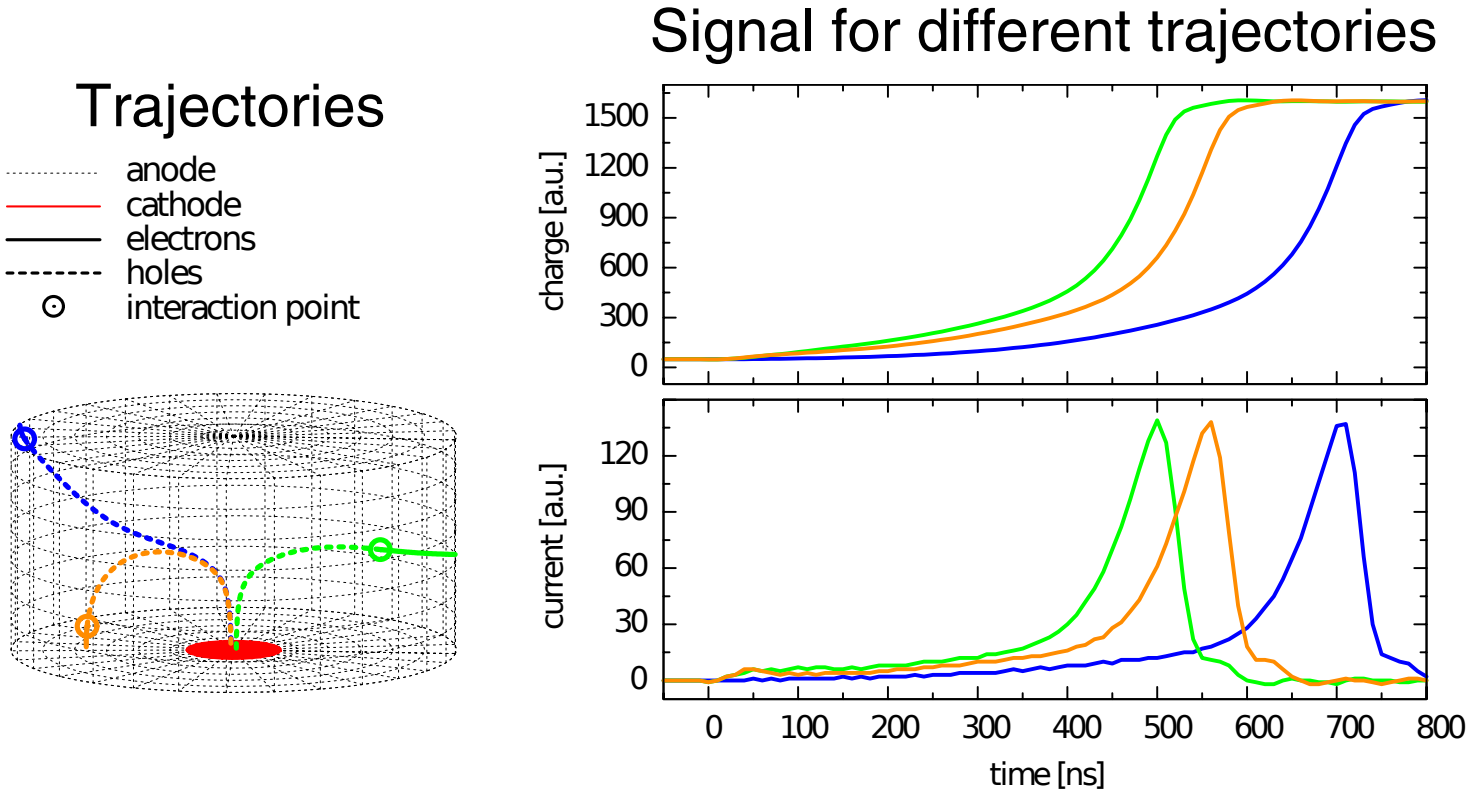
Phase-I and Phase-II Comparison

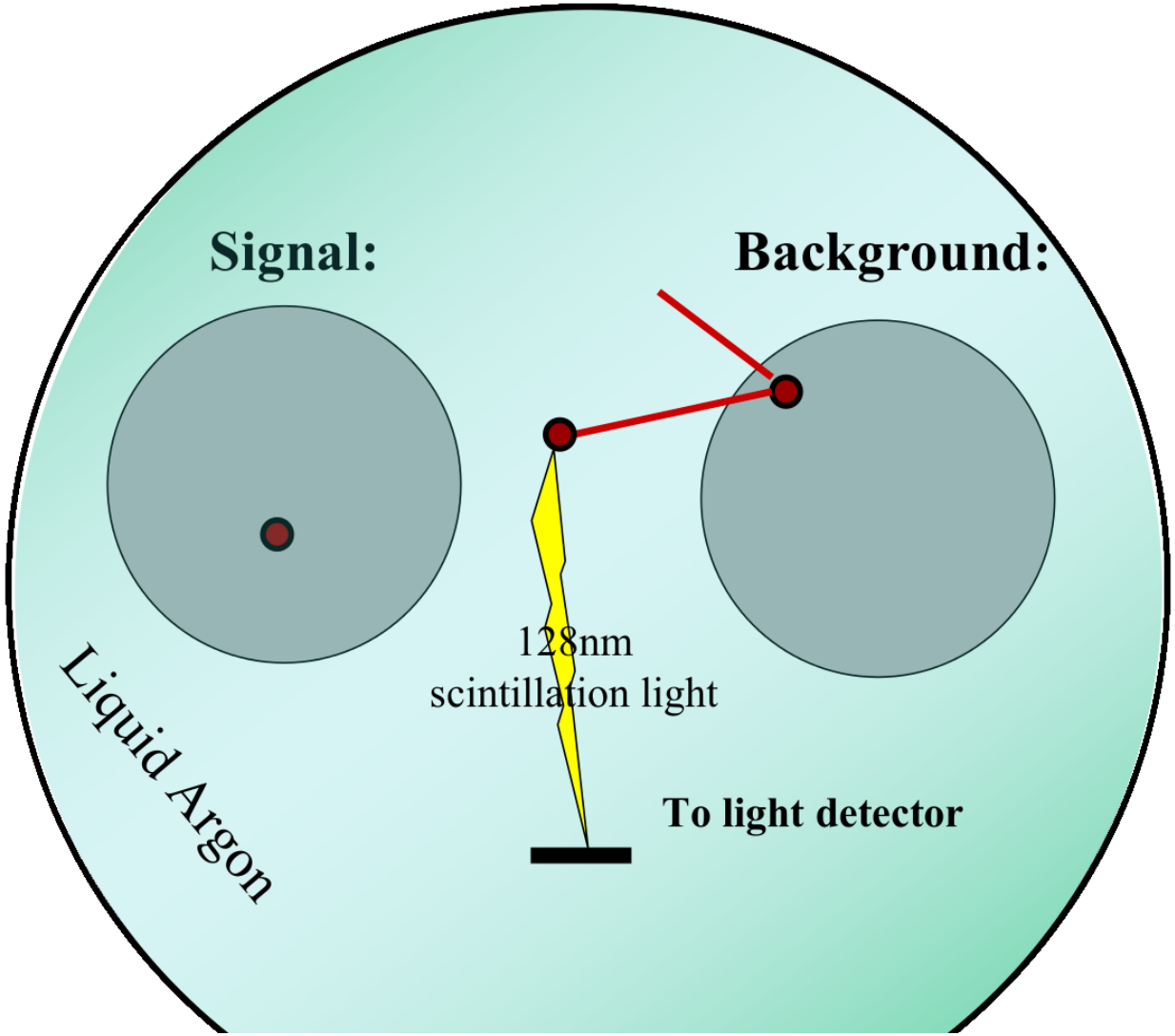
Phase-I	Phase-II
Water-Tank	maintenance
Cherenkov-Veto	maintenance and repairs
LAr-Cryostat	unchanged
2 String Lock	1 String Lock
N/A	LAr-Instrumentation
18 kg Detectors	38 kg Detectors
Cu Detector Holders	Cu + Si Detector Holders
Pin-Contacts	Direct Bonding
CC-2 Amplifier	CC-3 or GeFRO Amplifier
Cu Mini-Shrouds	Optical Mini-Shrouds

BEGe Detectors for Phase-II

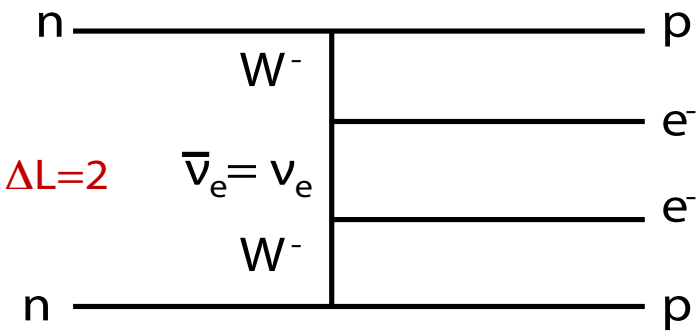


- BEGe: Broad-Energy Germanium Detector (Canberra)
- Increased energy resolution, strong weighting field
- Charges from different points $\rightarrow$ signals at different times
- Can separate single-site events (e.g. $0\nu\beta\beta$-decay) from multi-site event (Compton-scattering + X)

LAr Scintillation as Background Veto



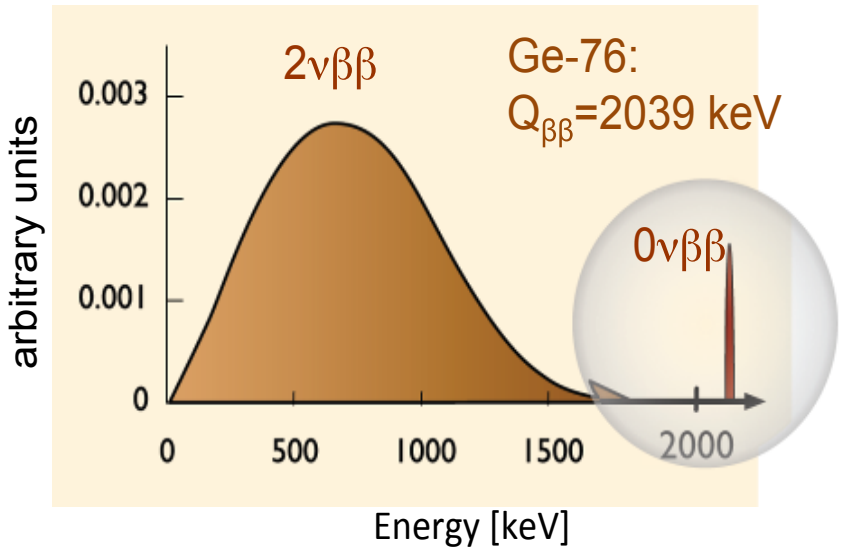
GERDA physics goals

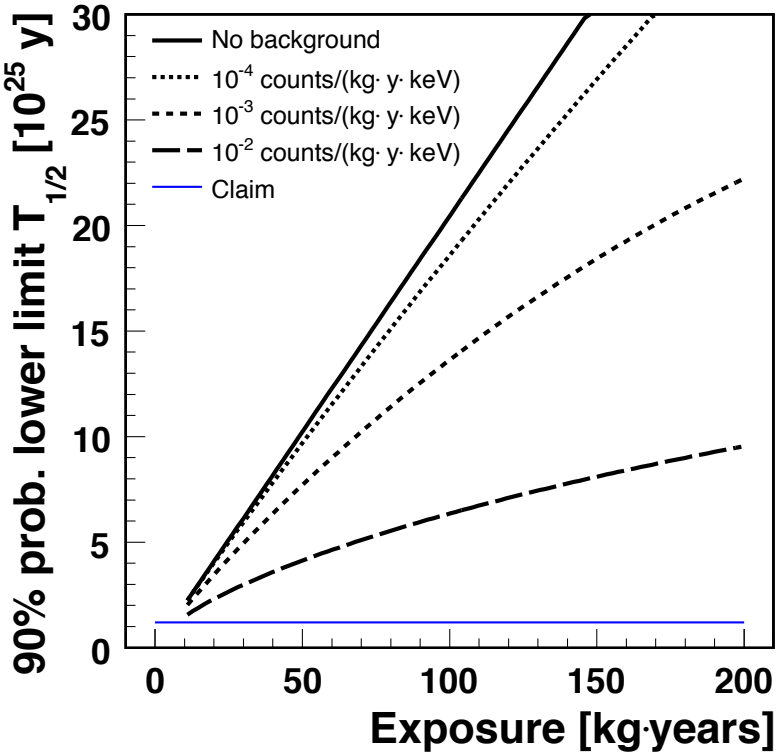


0νββ driven by exchange of light Majorana neutrinos

Phase	I	II
Exposure [kg ·yr]	15	100
Bg [counts/(keV·kg·yr)]	10^{-2}	10^{-3}
Upper limit $m_{\beta\beta}$ [eV]	0.23-0.39	0.09-0.15

A. Smolnikov, P. Grabmayr PRC 81 028502(2010)





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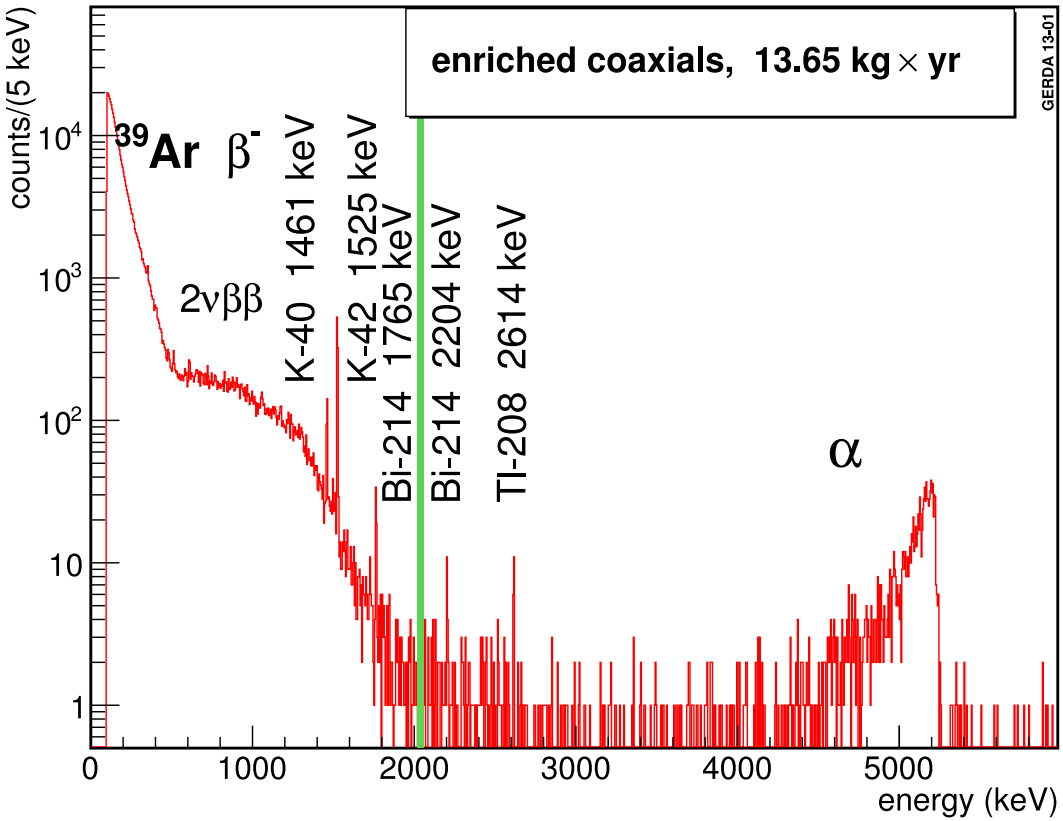
Phase-I Background



No contribution at $Q_{\beta\beta}$:
^{39}**Ar** (Q_β = 565 keV), ^{40}**K**, ^{228}**Ac**

Contribution at $Q_{\beta\beta}$:

- ^{42}**K** (^{42}Ar) → Q_β = 3.5 MeV, E_γ = 2.4 MeV
- ^{214}**Bi** (^{238}U) → Q_β = 3.3 MeV, E_γ = 2.1, 2.2, 2.4 MeV
- ^{208}**Tl** (^{232}Th) → E_γ = 2.6 MeV
- ^{60}**Co** → Q_β = 2.8 MeV
- **α-induced events** (from isotopes in ^{238}U chain)

- Blinded window: 40 keV around $Q_{\beta\beta}$ = 2039 keV
- Achieved background index: 0.02 cts/(keV kg yr) in ROI: 10 × better than HdM and IGEX

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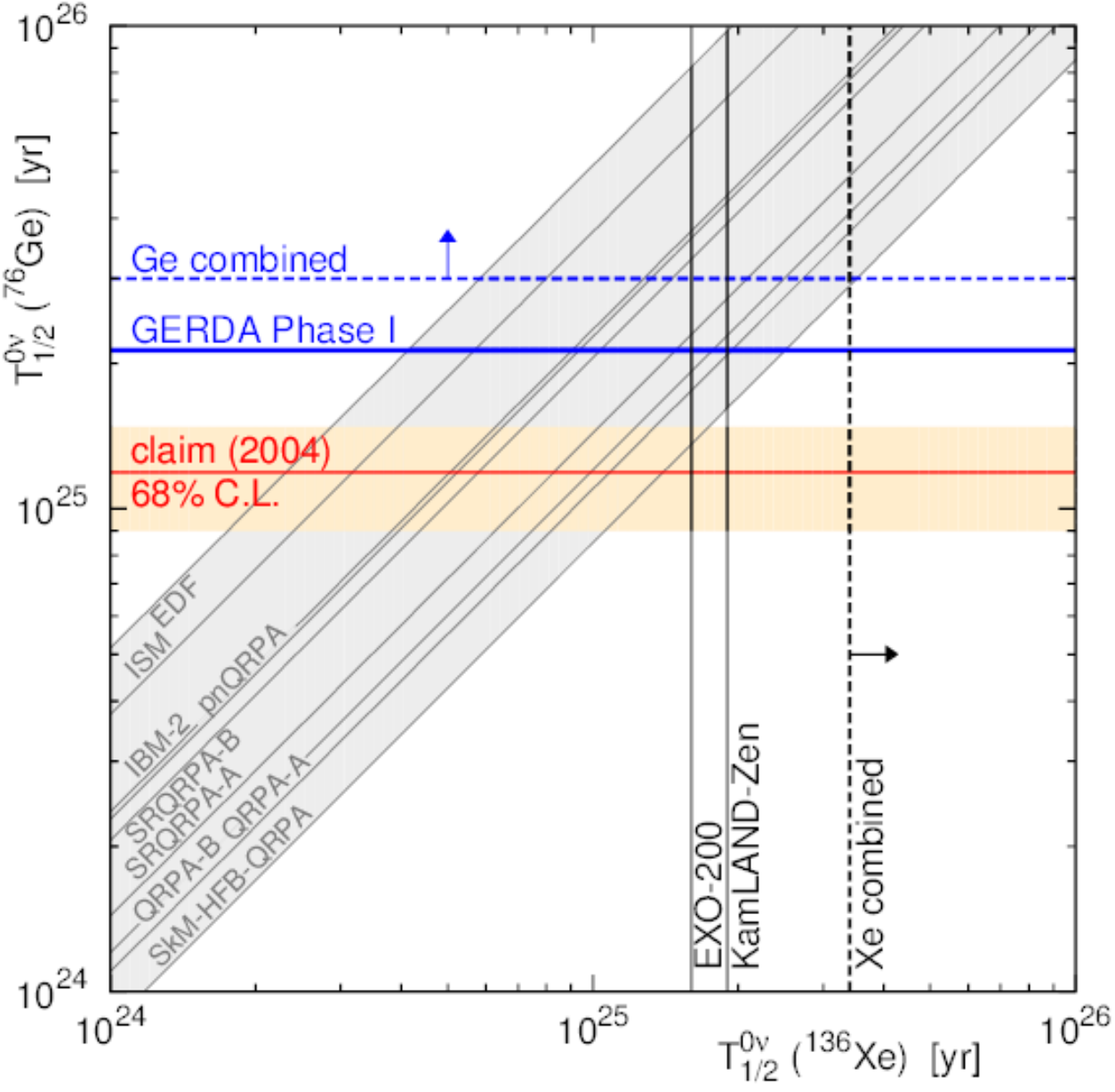
GERDA Phase-I Result Comparison



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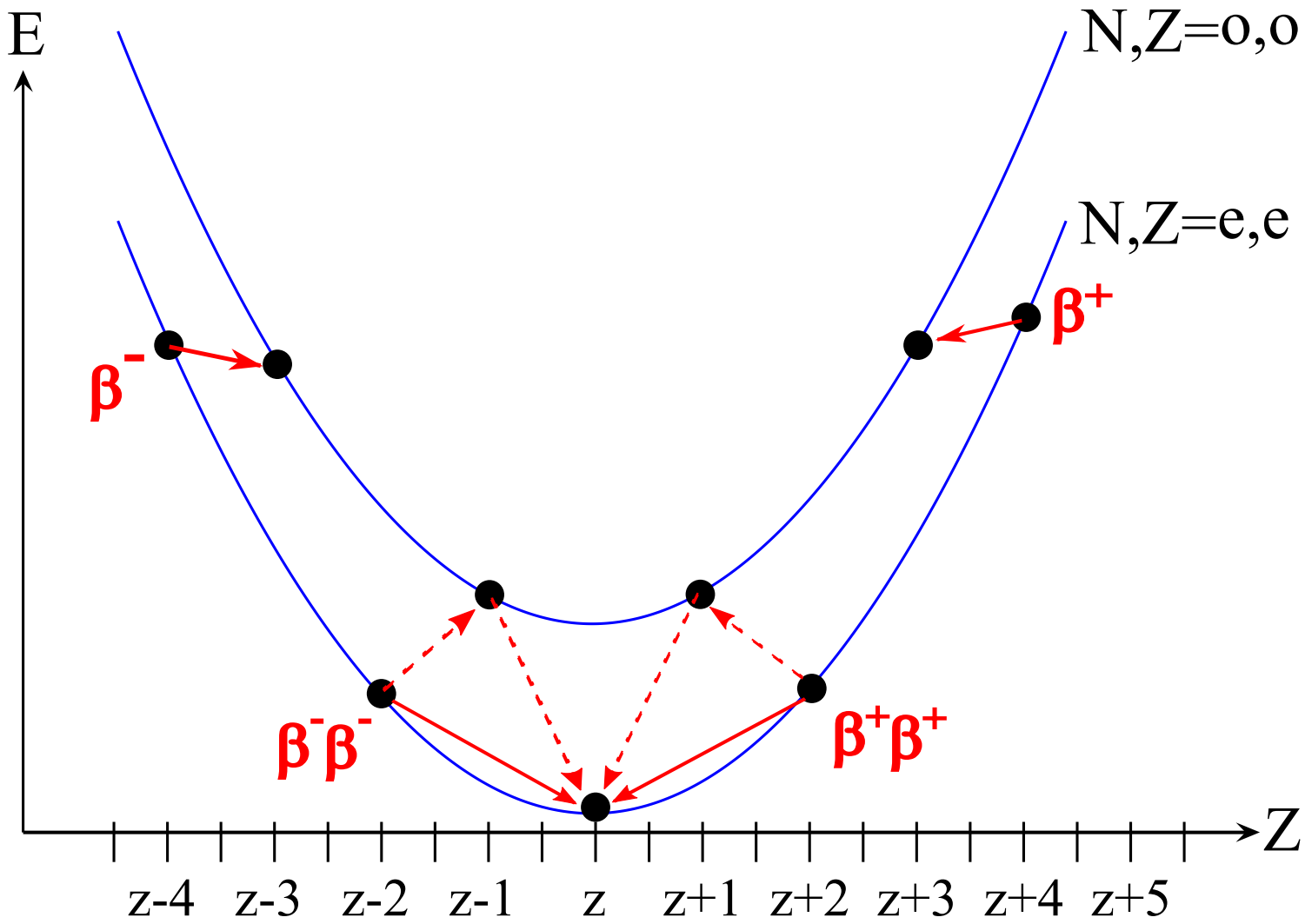
Single and Double Beta Decay



Neutrino Mass Hierarchies

in the 3-neutrino picture