First results from LEGEND-200:

searching for 0νββ in ^{76}Ge

Giovanna Saleh[1] on behalf of the LEGEND Collaboration

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EPS HEP2025 Marseille 07-11 July 2025

Summary

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- First results
  - Exposure
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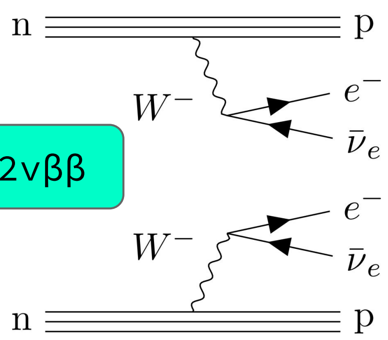
  - Energy spectrum
  - First unblinding: background index and half-life limit
- Conclusions

Introduction

(Neutrinoless) double beta decay



2vββ

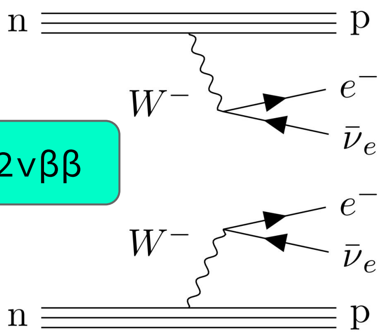
ΔL = 0

Allowed by SM
Observed experimentally

Highly suppressed
(second order weak process)

(Neutrinoless) double beta decay

2νββ



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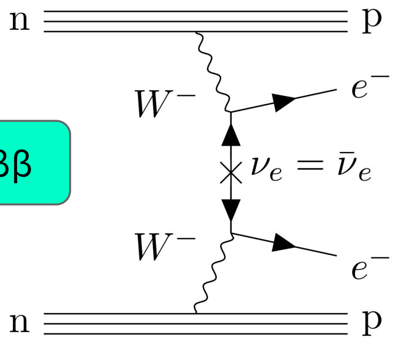


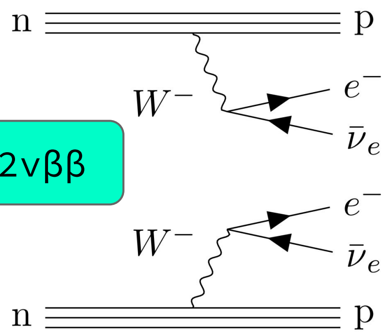
ΔL = 2

Not allowed by SM
Not observed

If observed ⇒ neutrinos
are Majorana fermions

(Neutrinoless) double beta decay

2νββ



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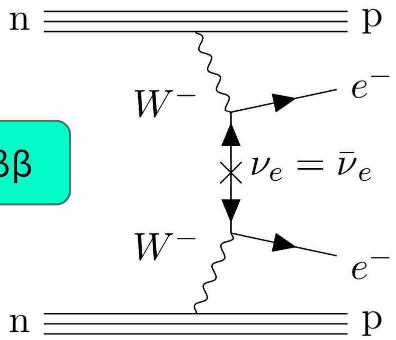

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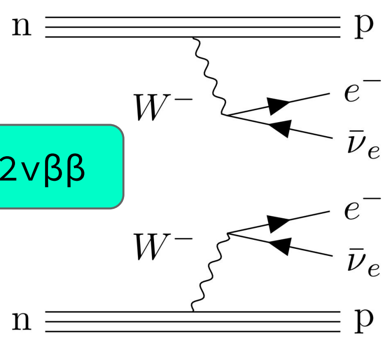
Half life:

$$\left[T_{1/2}^{0\nu}\right]^{-1} = G^{0\nu}(\mathrm{Q}_{\beta\beta}, Z)\ |M^{0\nu}|^2\ \frac{|m_{\beta\beta}|^2}{m_e^2}$$

(Neutrinoless) double beta decay

2νββ



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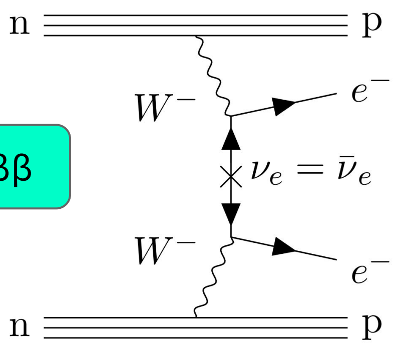

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Half-life:

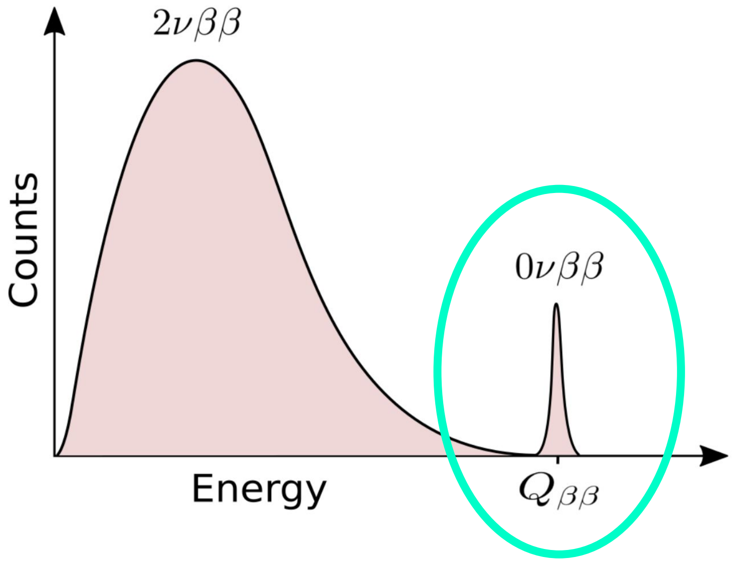
$$[T^{0\nu}_{1/2}]^{-1} = G^{0\nu}(Q_{\beta\beta}, Z)\,|M^{0\nu}|^2\,\frac{|m_{\beta\beta}|^2}{m_e^2}$$

Phase space integral

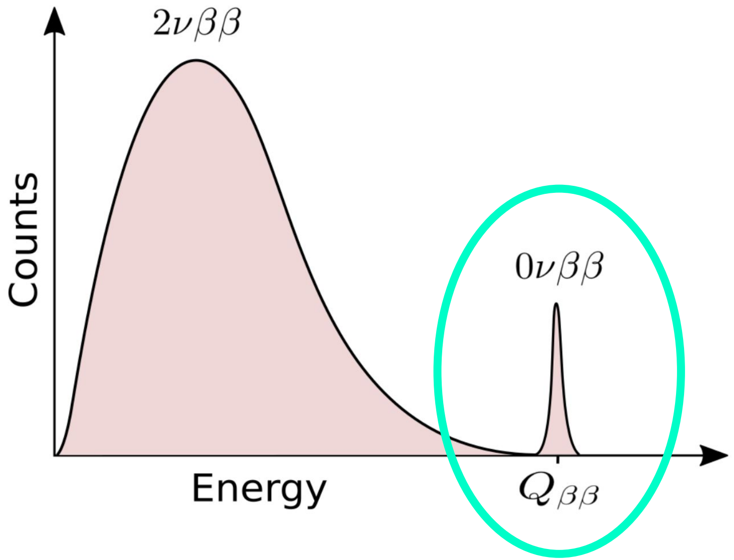
Nuclear matrix element

Effective ν Majorana mass

(Neutrinoless) double beta decay



(Neutrinoless) double beta decay

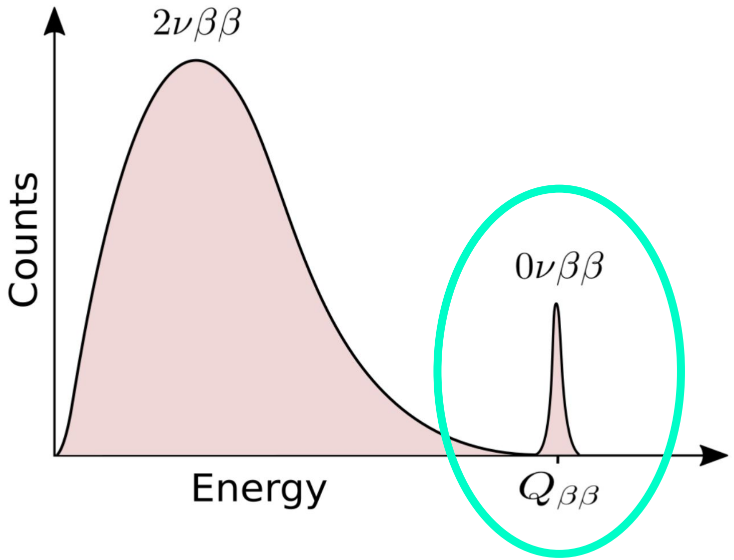


Experimental sensitivity:

$$T^{0\nu}_{1/2} \propto \begin{cases} M \cdot t & \text{-> BACKGROUND FREE} \\ \sqrt{\frac{M \cdot t}{B \cdot \sigma}} & \text{-> WITH BACKGROUND} \end{cases}$$

M = Total mass
t = Acquisition time
B = Background fraction
σ = Energy resolution at Qbb

(Neutrinoless) double beta decay



Experimental sensitivity:

$$T^{0\nu}_{1/2} \propto \begin{cases} M \cdot t \cdot f \cdot \varepsilon & \text{-> BACKGROUND FREE} \\ \sqrt{\frac{M \cdot t}{B \cdot \sigma}} \cdot f \cdot \varepsilon & \text{-> WITH BACKGROUND} \end{cases}$$

M = Total mass
t = Acquisition time
B = Background fraction
σ = Energy resolution at Qbb
f = Fraction of 0vbb decaying isotope
ε = Detection efficiency

Experimental panorama

Experiment	Isotope	Median sensitivity (x 10^{26} yr)	Half-life limit (x 10^{26} yr)	$m_{\beta\beta}$ limit (meV)	Source
KamLAND-Zen	^{136}Xe	2.3	3.8	28-122	arXiv:2406.11438
GERDA	^{76}Ge	1.8	1.8	79-180	PhysRevLett.125.252502
CUORE	^{130}Te	0.44	0.38	70-240	arXiv:2406.11438

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+ First results from **LEGEND**

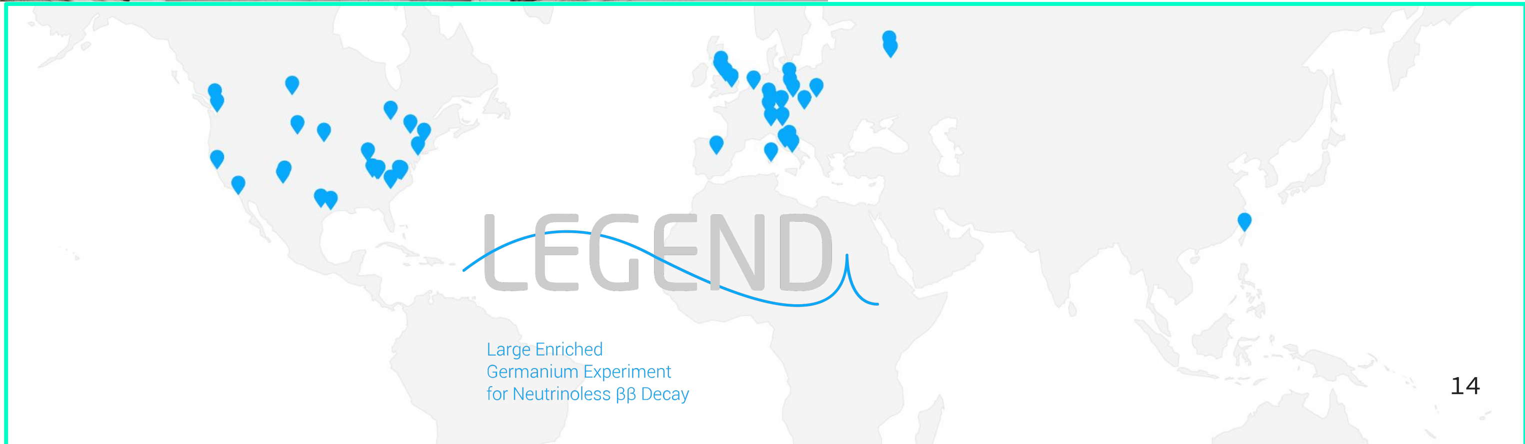
LEGEND(-200)

The collaboration

+ 59 institutions
+ 300 members

GERDA + 

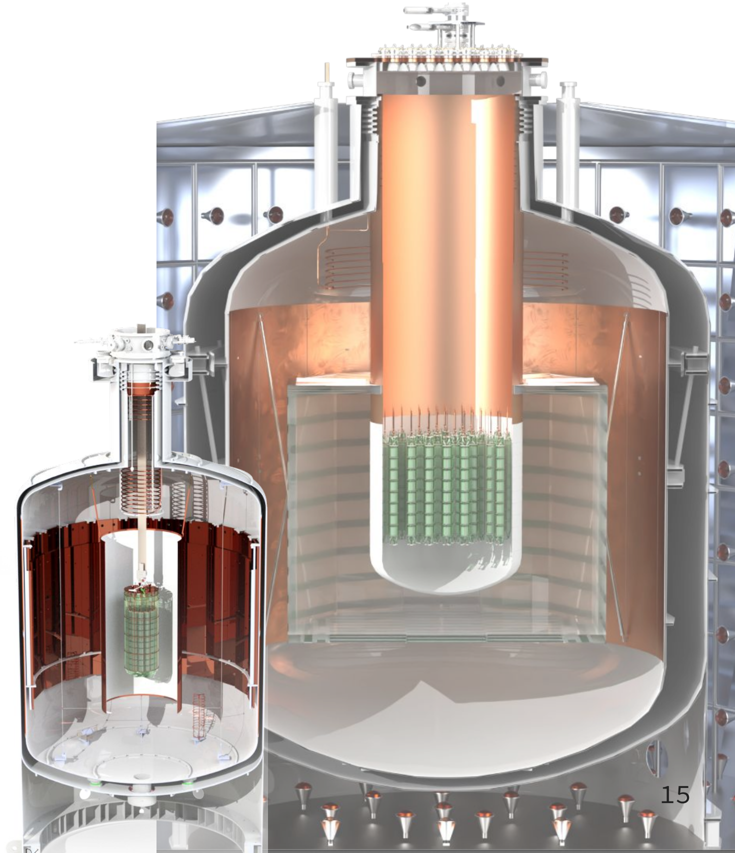
=



The LEGEND project

	LEGEND-200	LEGEND-1000
Mass [kg]	200	1 000
Exposure [kg yr]	1 000	10 000
BI goal [cts/(keV kg yr)]	$2 \cdot 10^{-4}$	10^{-5}
Half-life sensitivity [yr]	10^{27}	10^{28}
$m_{\beta\beta}$ sensitivity [meV]	33 - 89	9 - 24

"The collaboration aims to develop a ***phased, 76Ge-based*** *double-beta decay experimental program with* ***discovery potential*** *at a* ***half-life beyond 10^{28} yr****, using existing resources as appropriate to expedite physics results"*



The LEGEND project

Dedicated talk by Malgorzata Haranczyk on Friday 11 Jul 2025, 08:45

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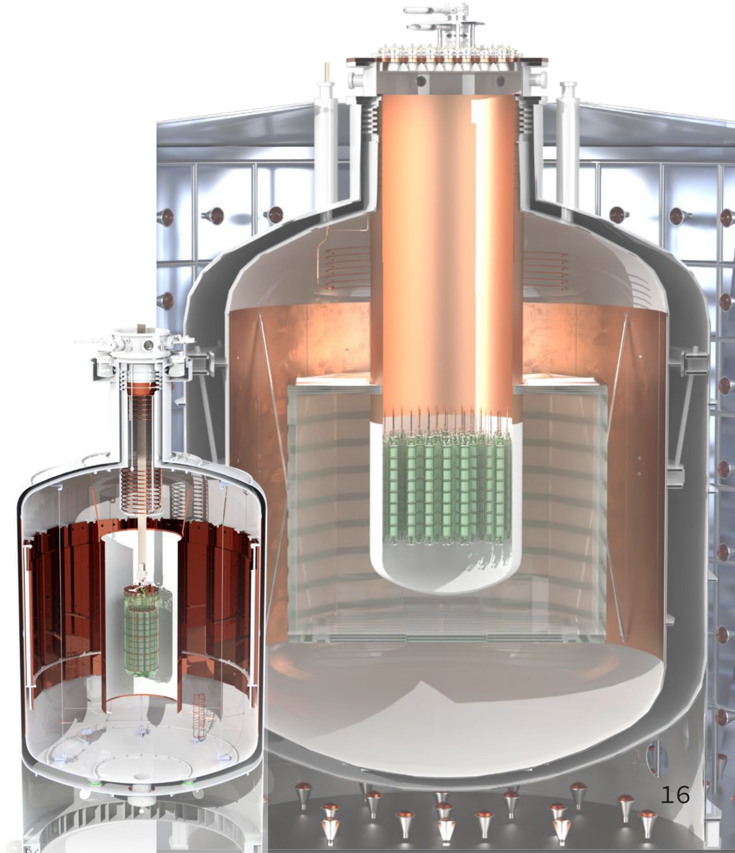
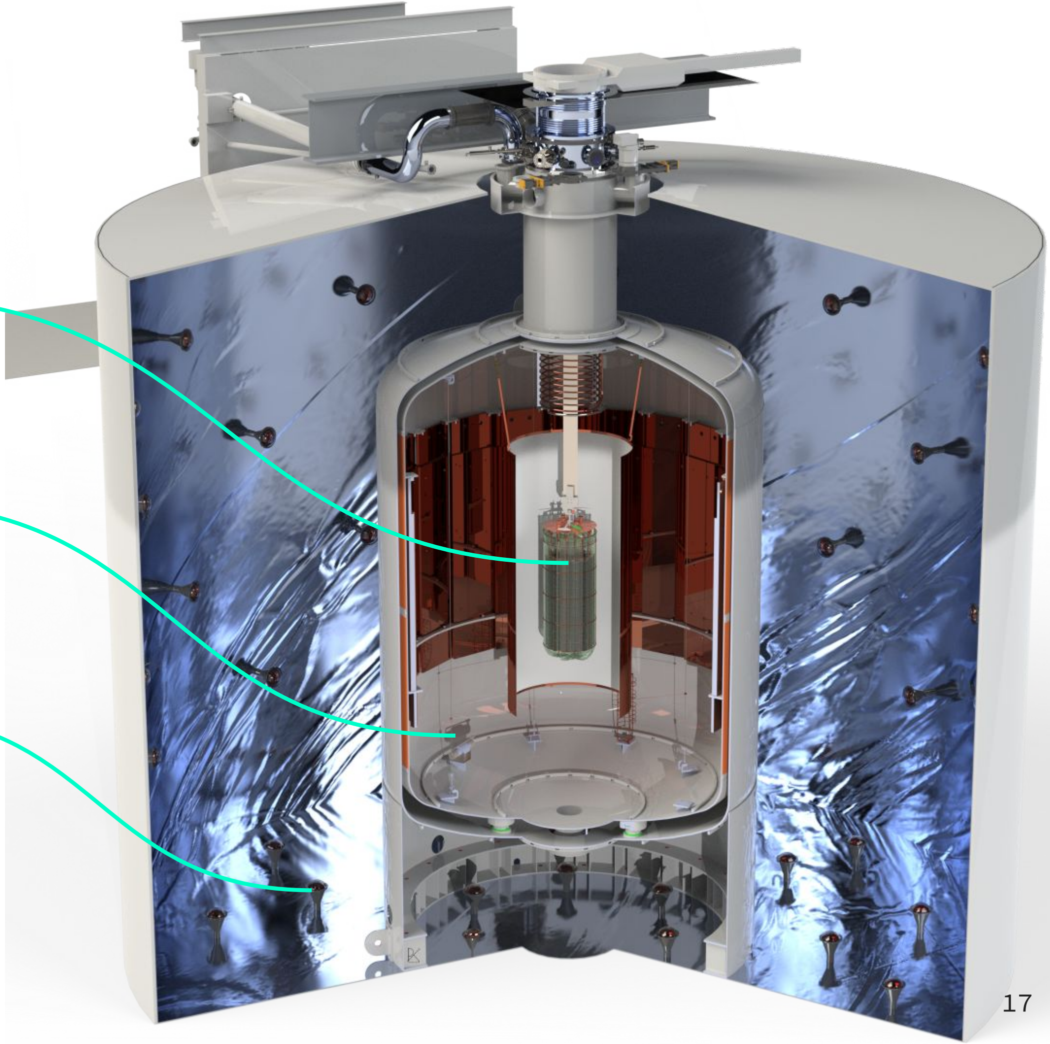


The experiment

HPGe detectors

Liquid Argon (LAr) cryostat
Volume: 64 m^3
Role: Coolant & shield & active veto (fibers+SiPM)

Water tank
Volume: 590 m^3
Role: Shield & active veto (PMTs)



The detectors

Active high purity germanium detectors enriched in ^{76}Ge

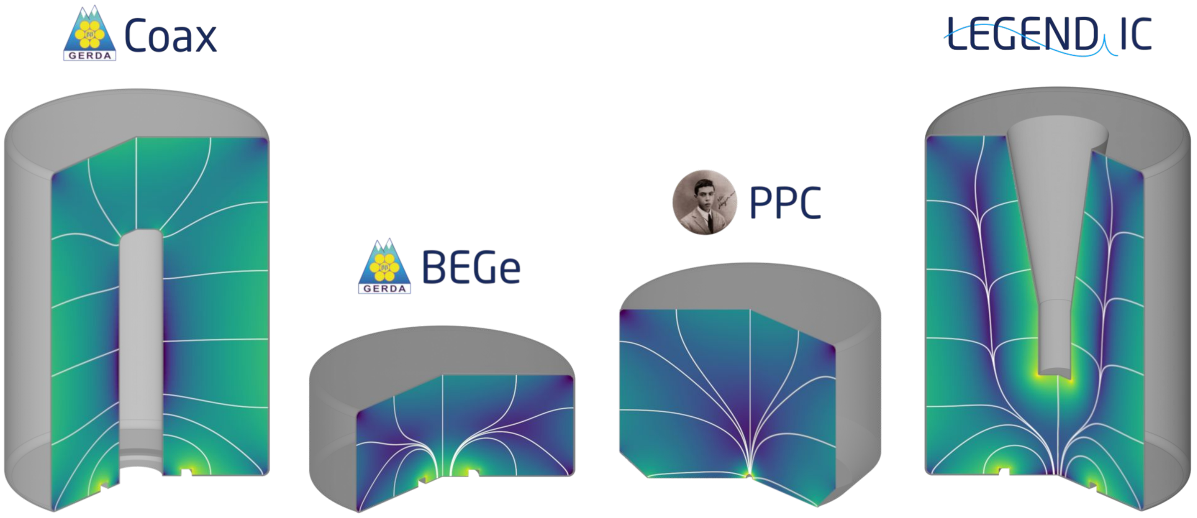
Detector = Source

- Well known technology
- **Excellent energy resolution:**
  FWHM ~ 0.1% @$Q_{\beta\beta}$

- $^{76}Ge \rightarrow {}^{76}Se + 2e$ [+ 2ν]
- *f*(^{76}Ge, *nat*) ~ 8%
  → ***f*(^{76}Ge, *enr*) ~ 92%**
- **$Q_{\beta\beta}(^{76}Ge)$ = 2039.061 ± 0.007 keV** [*]

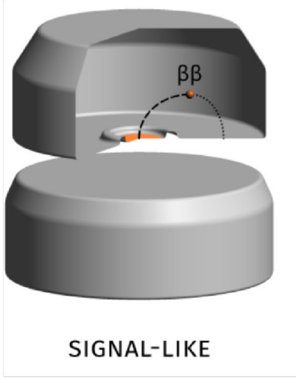
The detectors

Active high purity germanium detectors enriched in ^{76}Ge

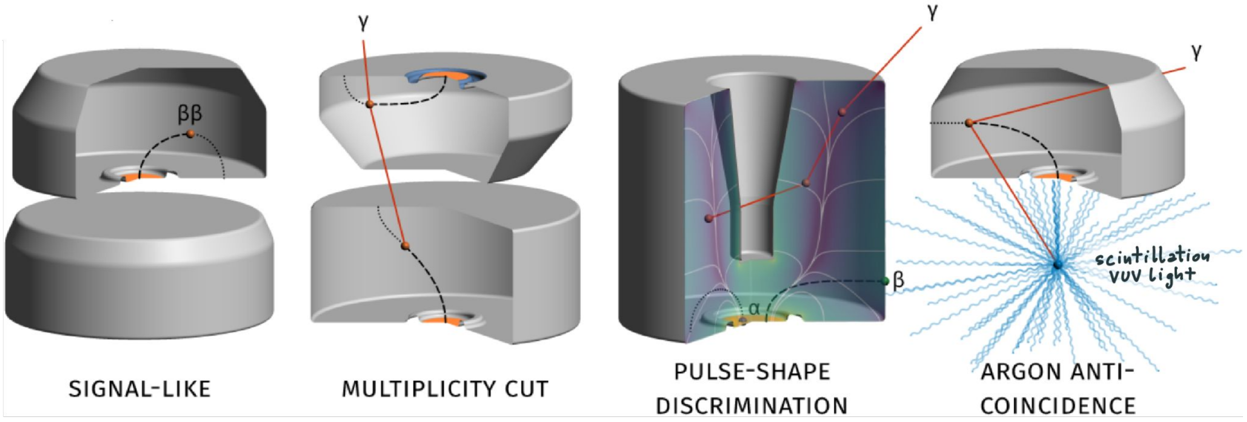


Mass fraction: 10% 13% 16% 61%

Background suppression strategies



Background suppression strategies



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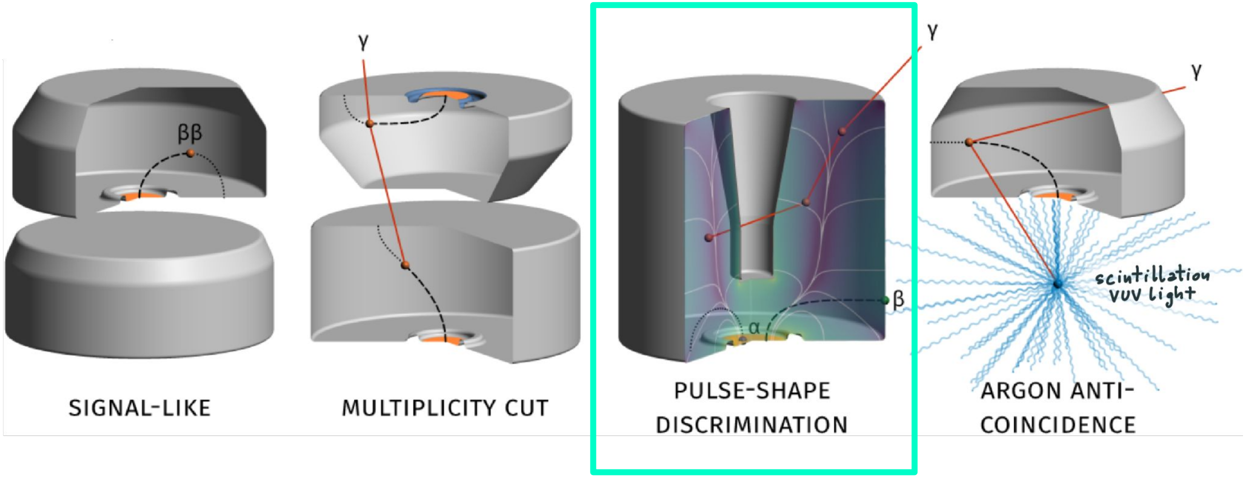
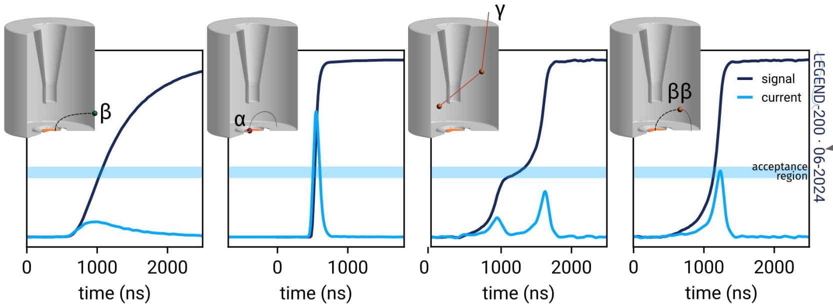
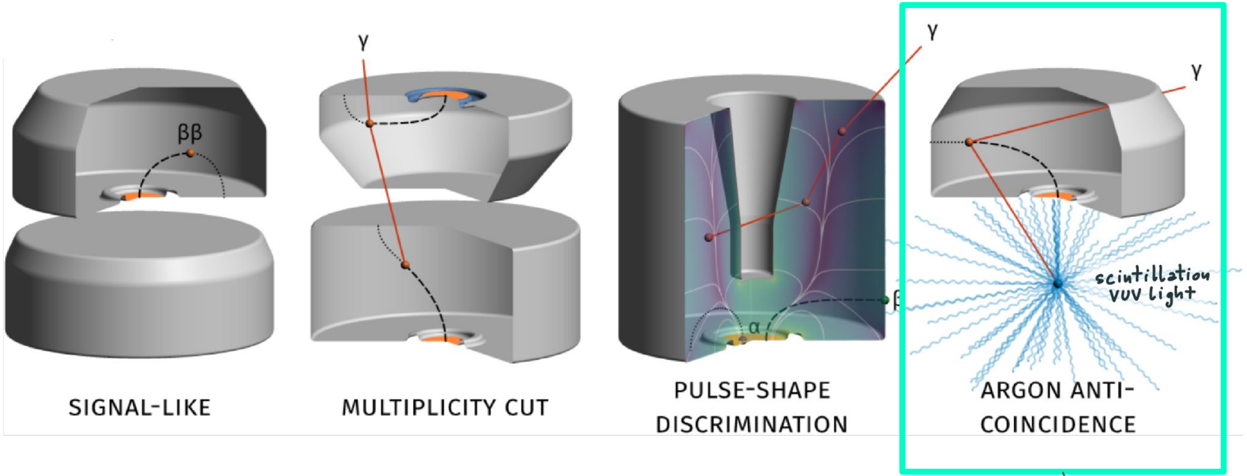


PSD parameters (depending on detector type): **A/E** (ratio between the amplitude of the current pulse and the energy of the event), **LQ** (charge collected in the last part of the rising edge), **ANN** (Artificial Neural Network)

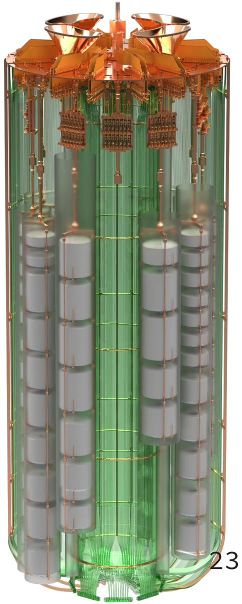


The **shape** of the acquired signal depends on the **topology** of the energy release in the detector, which depends on the event type.

Background suppression strategies

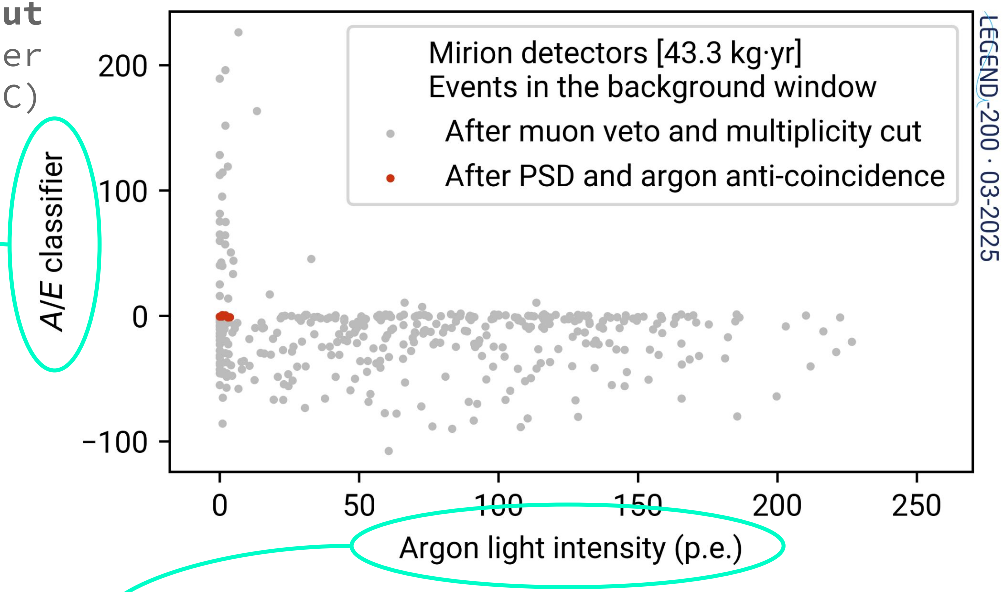


Instrumented **LAr** (fibers, SiPMs) detects **scintillation light** when some energy is released in argon in coincidence with an energy deposition in germanium.



Background suppression strategies

PSD cut
parameter
IC, BEGe, (PPC)



LAr cut
parameter

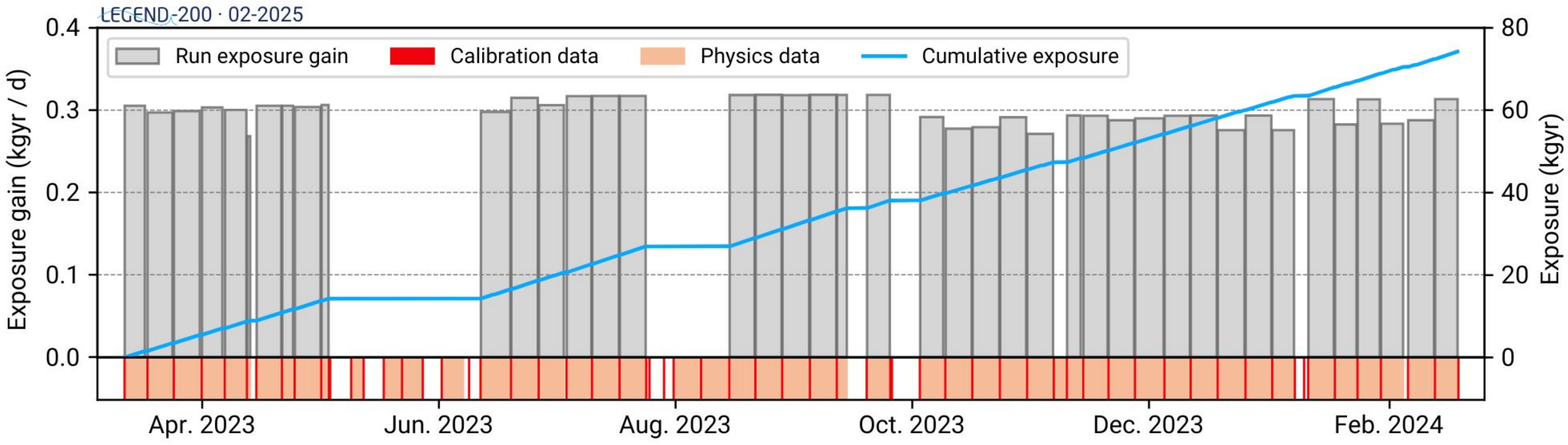
PSD and LAr cut are **strongly anticorrelated**

⇒ The combination is powerful for background suppression

First results

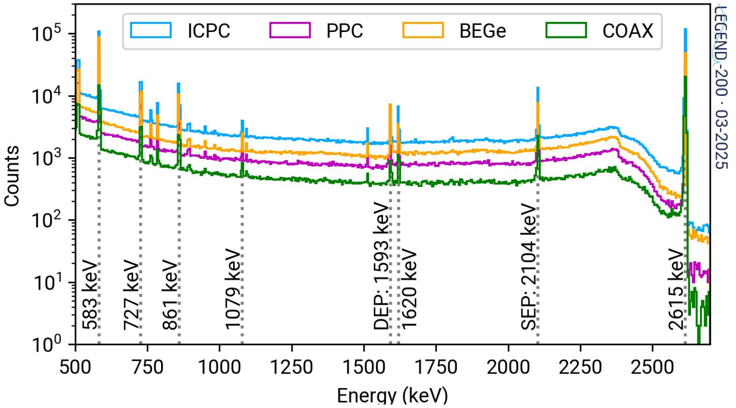
Exposure

142.5 kg of Germanium (101 detectors)
Approximately **one year** of data taking



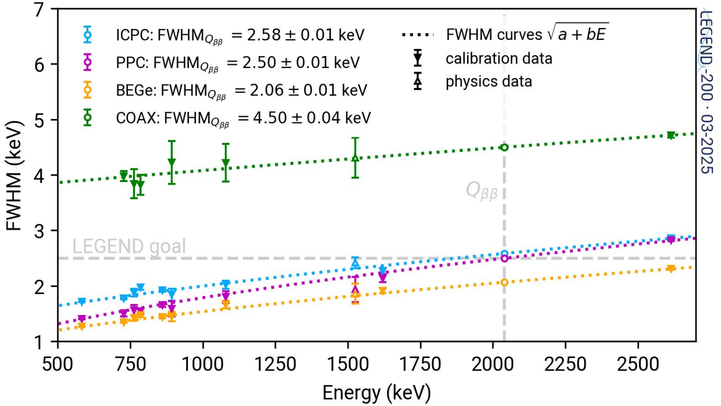
Gaps mostly due to test periods

Performance and stability

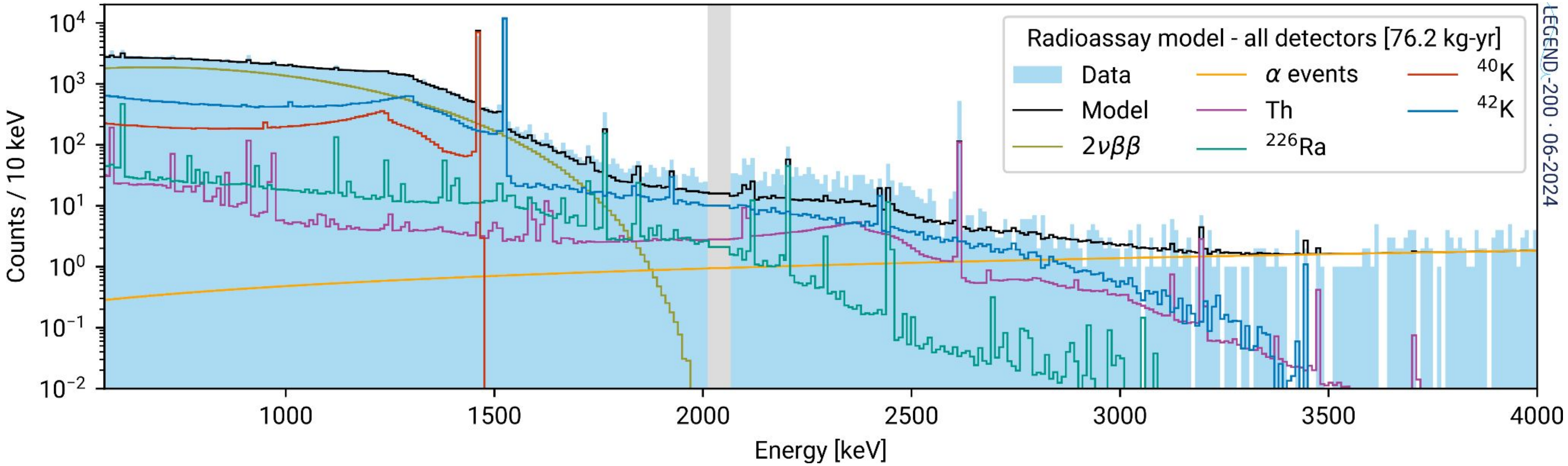


Weekly
^{228}Th calibration

Energy resolution
extrapolated at $Q_{\beta\beta}$



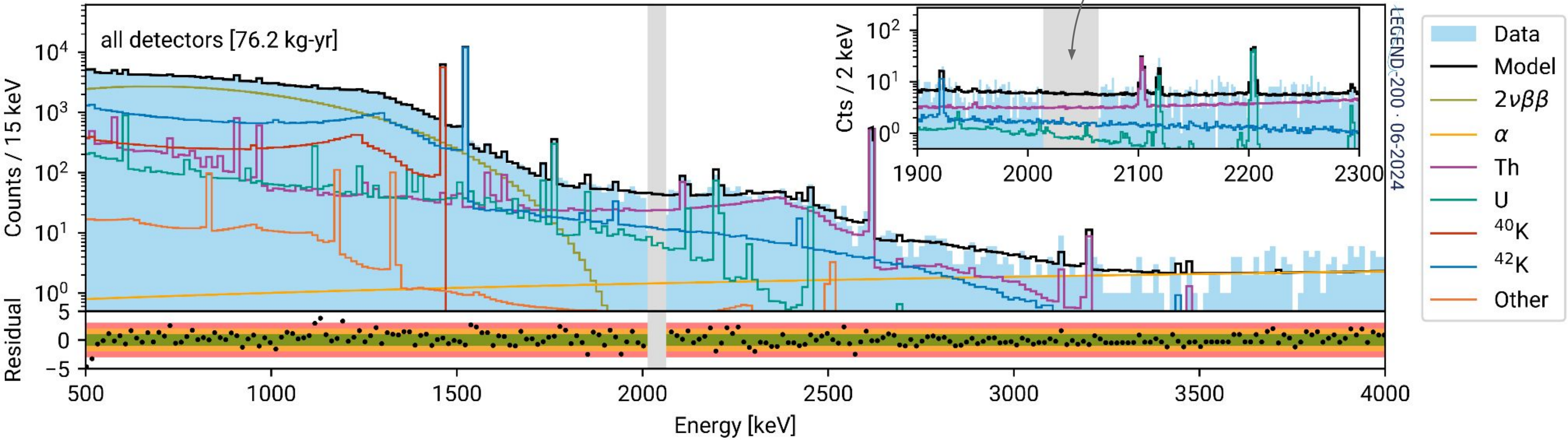
Background Prediction (radioassay)



Background (before analysis cuts) higher than expected from radioassays

Background model

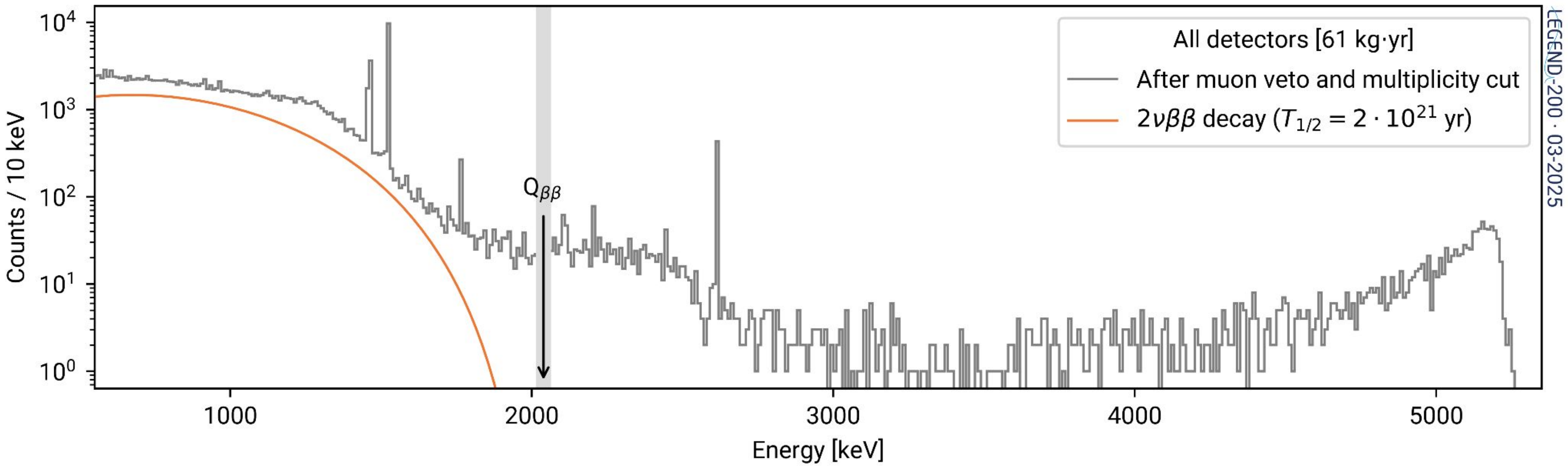
Background ~flat @$Q_{\beta\beta}$



Background model fit suggests the excess to be due to ^{228}Th decay chain
⇸ Screening and cleaning campaign to identify and remove source

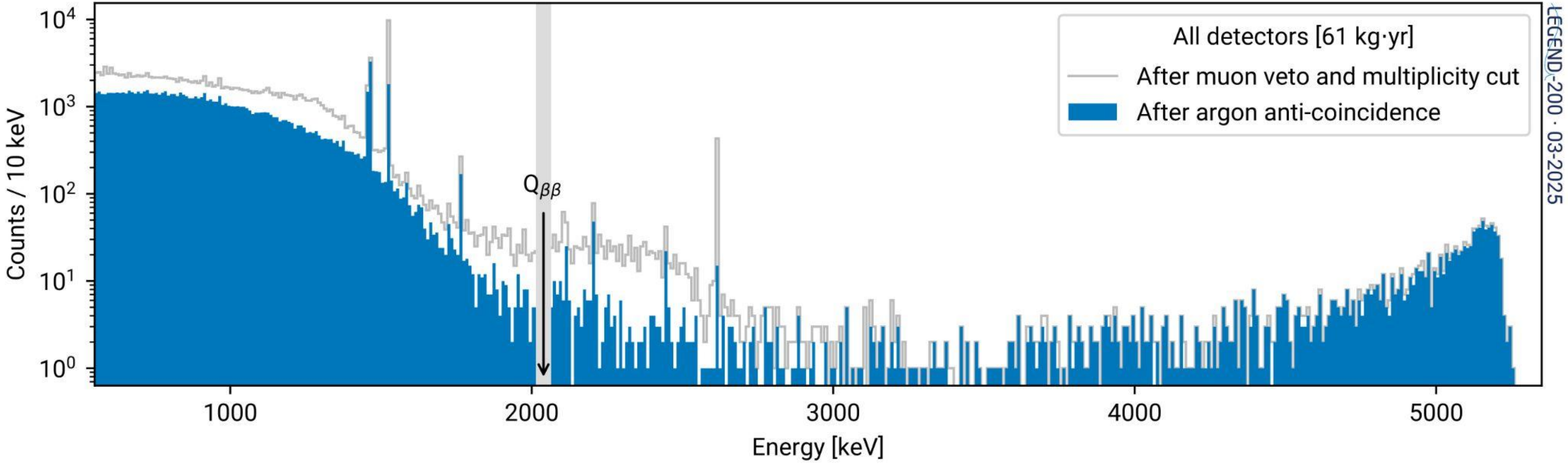
[Results from current data taking will prove effectiveness]

Energy spectrum



Fully **blind** analysis in the region **Qbb ± 25 keV**

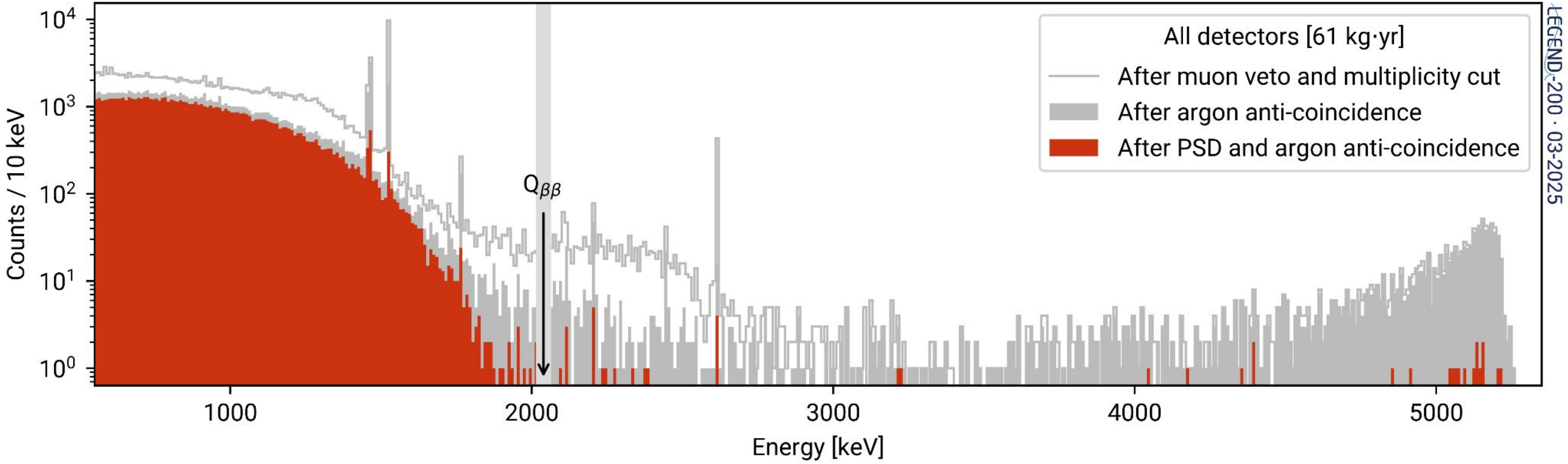
Energy spectrum



Effective suppression of **Compton** events releasing energy in a HPGe and in LAr

Efficiency LAr (0vbb) ~ 93 %

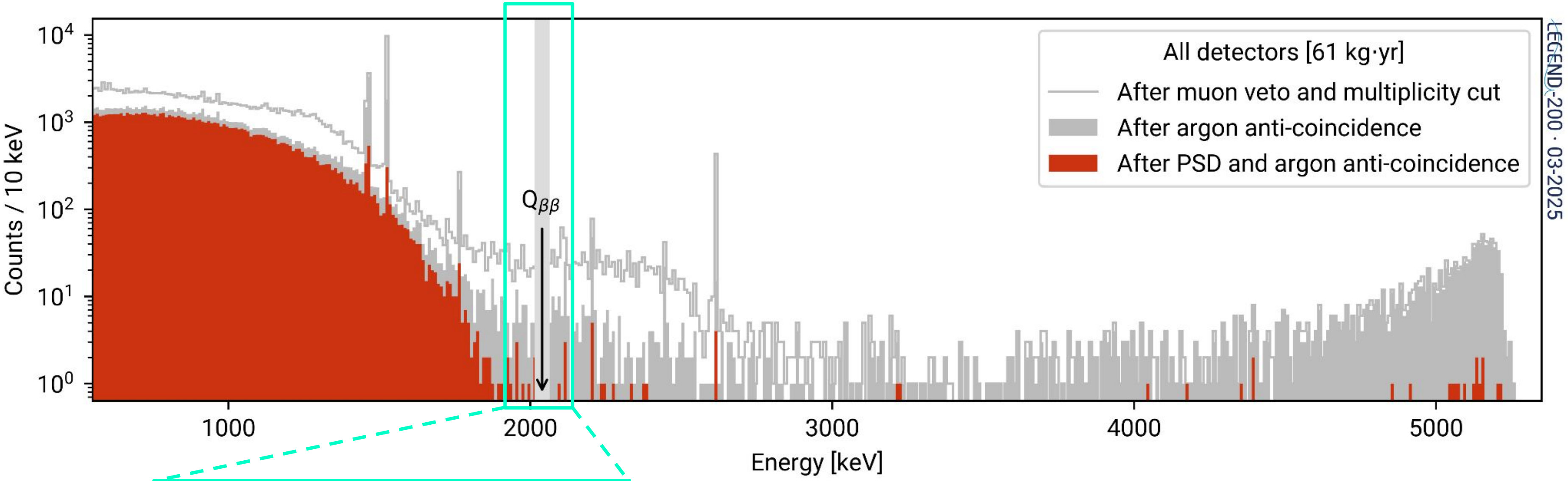
Energy spectrum

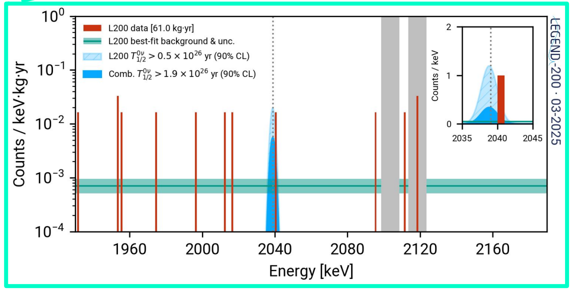


Effective suppression of **Compton** events releasing all the energy within one HPGe (multi-site events) and **α** and **β** (surface events)

PSD efficiency (0vbb) ~ 76-85 %

Unblinding





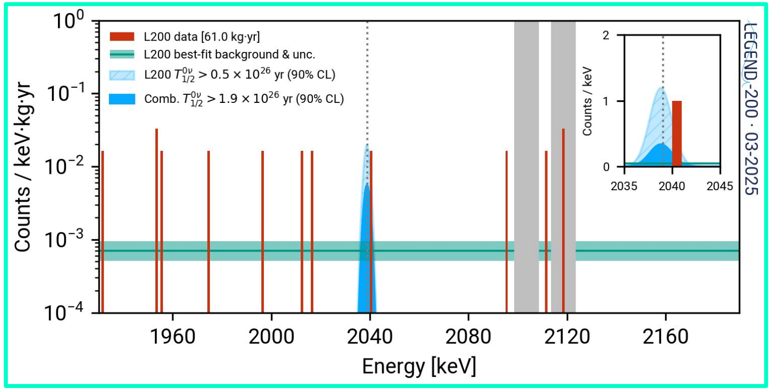
Analysis window: [1930-2190] keV

Known gamma lines (excluded):

- ^{208}Tl -> (2104 ± 5) keV
- ^{214}Bi -> (2119 ± 5) keV

arXiv:2505.10440
(sent to PRL for publication)

Unblinding: bkg index and half-life limit



- Two separate unblindings:
  - **Golden dataset: 48.3 kg yr**
  - **Silver dataset: 12.7 kg yr**
- Total: 61.0 kg yr
- 11 events in the analysis window after cuts

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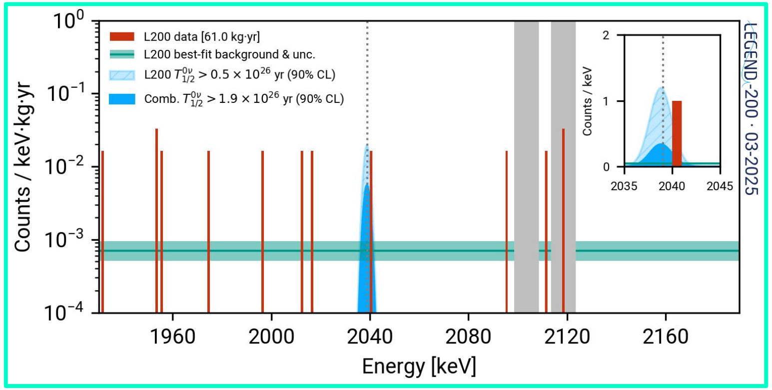

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- Corresponding background index (68% CL, frequentist analysis):
  - **BI(golden) = $5^{+3}_{-2} \times 10^{-4}$ cts/(keV kg yr)**
  - **BI(silver) = $13^{+8}_{-5} \times 10^{-4}$ cts/(keV kg yr)**

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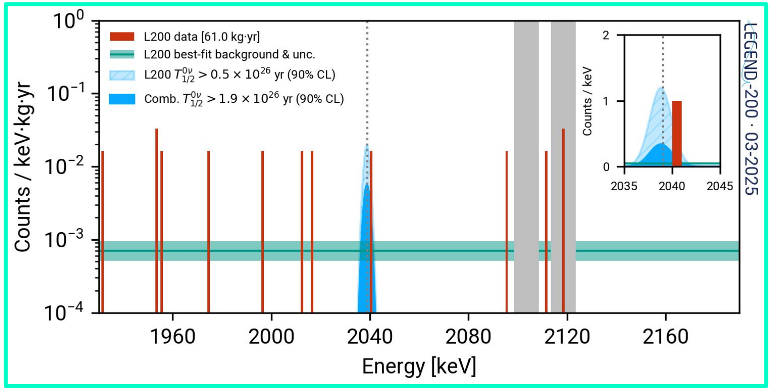

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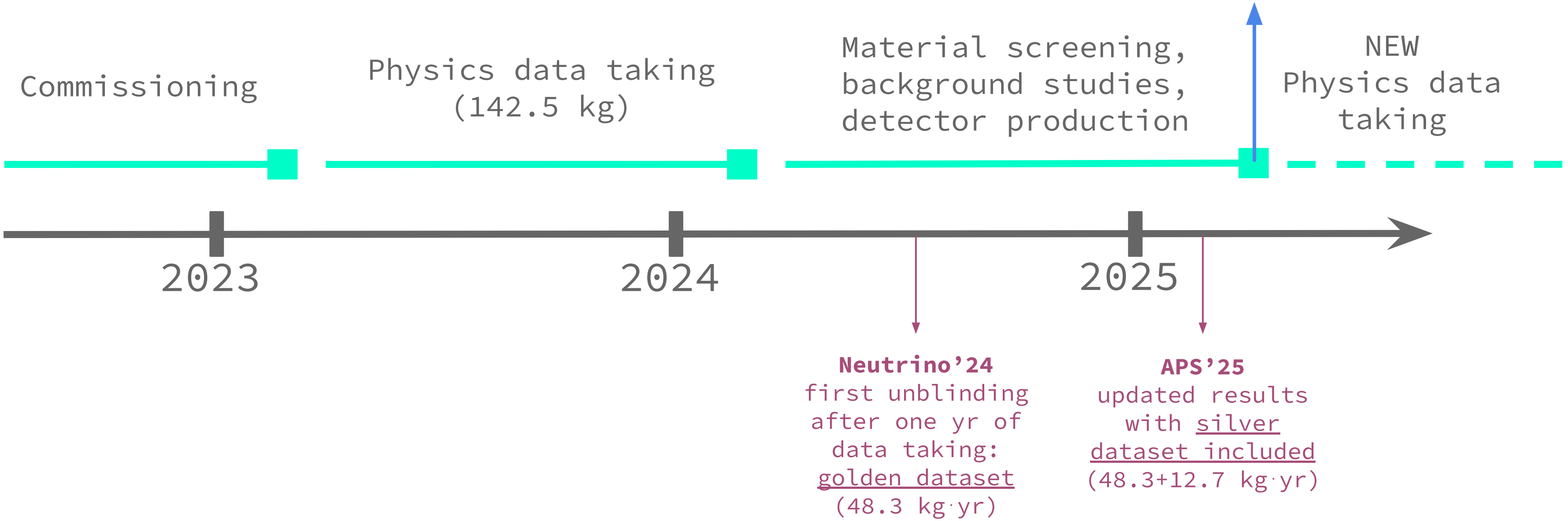
  - **BI(silver) = 13^{+8}_{-5} x 10^{-4} cts/(keV kg yr)**
- Combined fit GERDA+MJD+LEGEND (90% CL, frequentist analysis):
  - Half-life limit: **$T^{0\nu}_{1/2}$ > 1.9 x 10^{26} yr** -> **mbb < 70-200 meV**
  - Median exclusion sensitivity: 2.8 x 10^{26} yr
- Bayesian analysis provides compatible results

Past, present and future

May 2025 - redeployment of the array:

- **35 kg** of **new** Ge mass
- **130 kg** of Ge in **total**
- **Only best performing HPGes** deployed

  ⇒ Higher efficiency and best performance expected



Conclusions

- First year of physics data taking with LEGEND-200 completed
    - **142.5 kg** of Germanium operated
    - 4 HPGe detector geometries

- Performance of the experiment has been studied
    - Energy resolution mostly compatible with goal: 2.5 keV FWHM @Qbb (0.12%)
    - Background (before analysis cuts) higher than expected (radioassay model)
      ⇸ Screening and cleaning campaign to identify and remove source

- First results from LEGEND-200 have been presented (arXiv:2505.10440)
    - 61 kg yr exposure
    - LEGEND-only fit: $\mathbf{T^{0\nu}_{1/2} > 0.5 \times 10^{26}}$ **yr**
    - Combined fit GERDA+MJD+LEGEND (^{76}Ge limit): $\mathbf{T^{0\nu}_{1/2} > 1.95 \times 10^{26}}$ **yr**
    ⇸ Limit < sensitivity due to an event at 1.3σ from Qbb