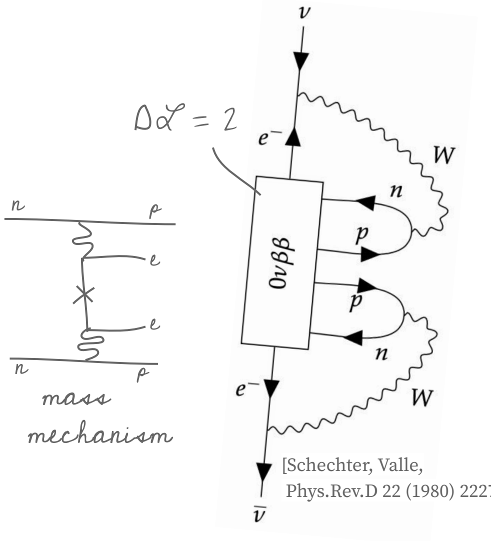
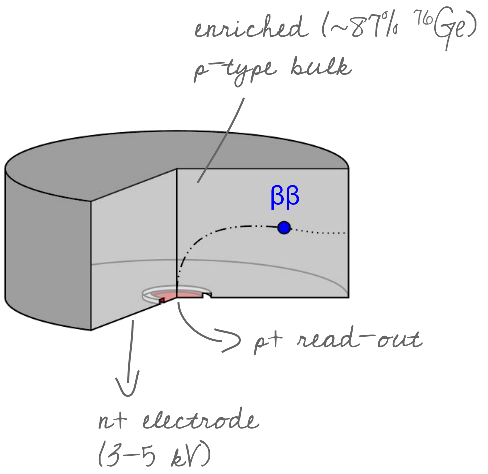
The final result of GERDA

Christoph Wiesinger (TUM,) for the GERDA collaboration, 19th October 2021

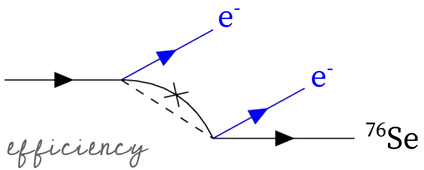


[Schechter, Valle, Phys.Rev.D 22 (1980) 2227]

Experimental approach

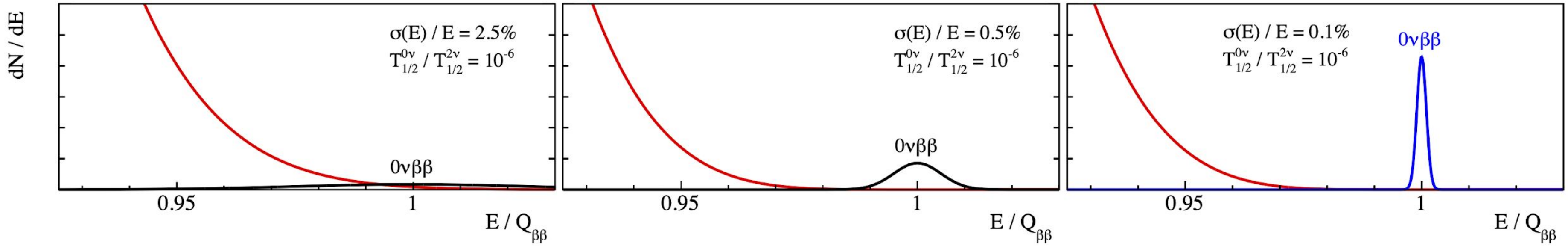


HPGe detectors enriched in ^{76}Ge

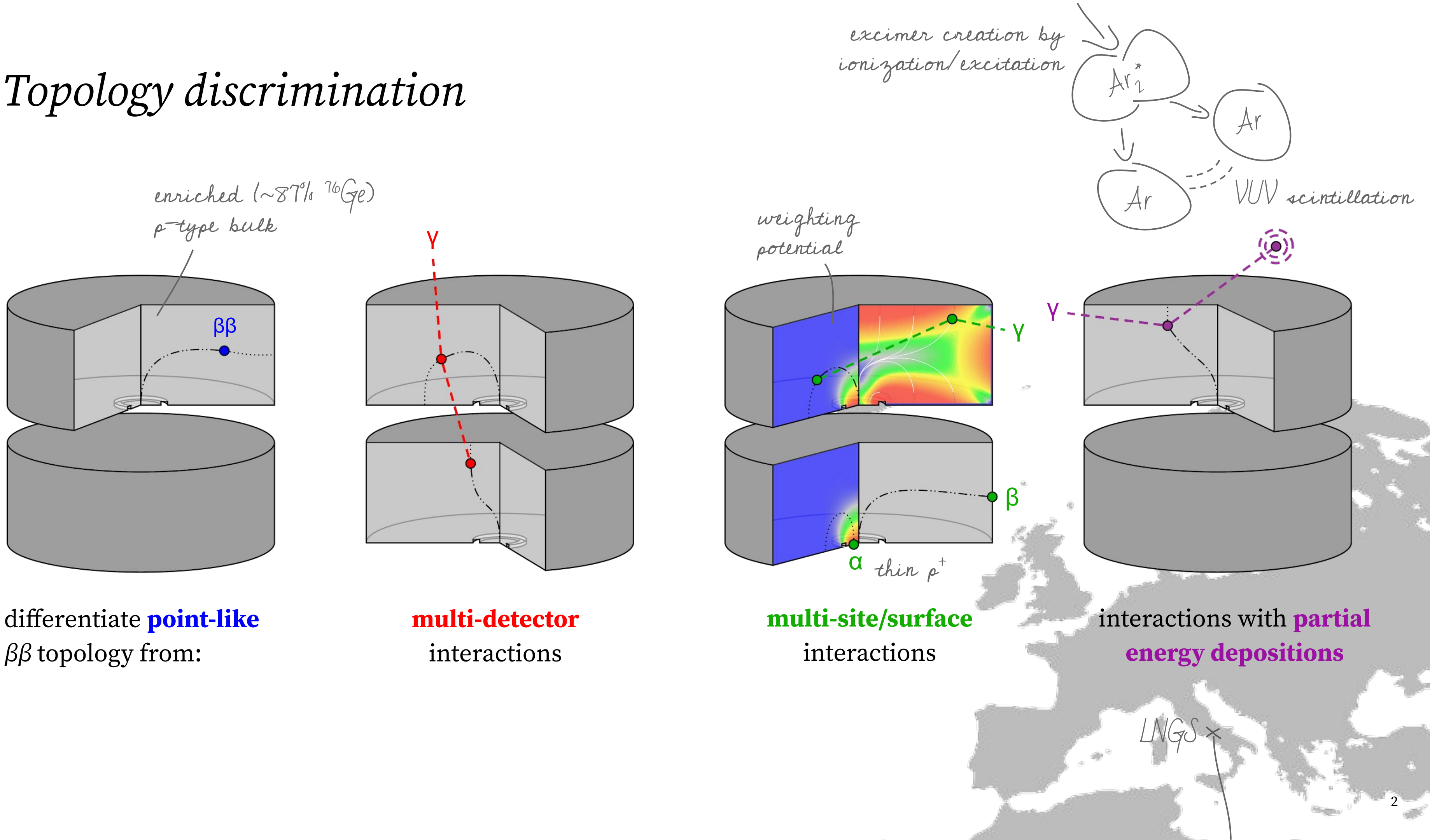


- source = detector –> *high efficiency*
- energy resolution ***σ(E) / E* < 0.1%** at **$Q_{\beta\beta}$ = 2039 keV**
- **high-purity** material –> *no intrinsic background*
  [Astropart.Phys. 91 (2017) 15-21]
- high stopping power –> *topology information*

HPGe detectors



Topology discrimination



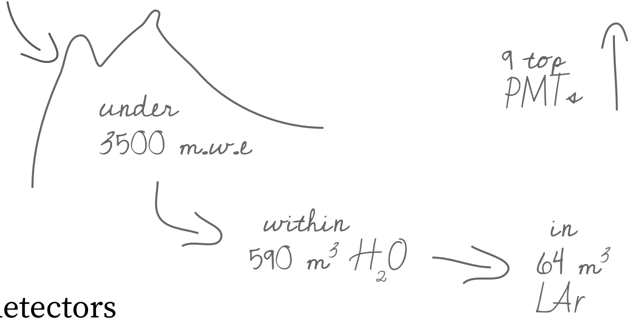
differentiate **point-like** $\beta\beta$ topology from:

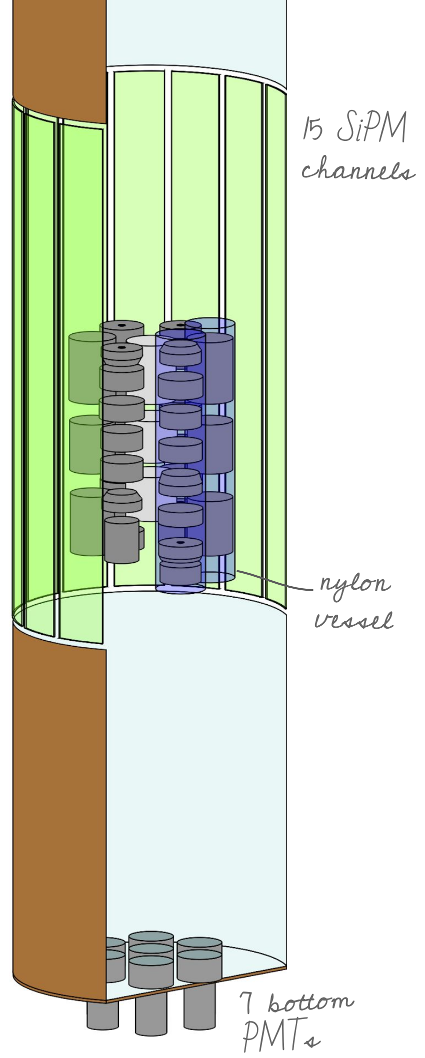
multi-detector interactions

multi-site/surface interactions

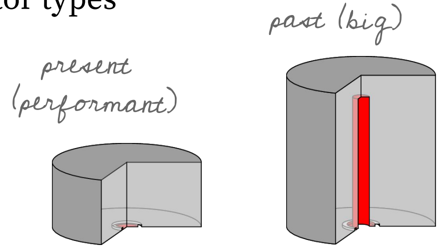
interactions with **partial energy depositions**

GERDA Phase II





- **35.6 kg** (later **44.2 kg**) of **enriched HPGe** detectors in ultra-low background **LAr** environment
  [Eur.Phys.J. C78 (2018) no.5, 388]
- two (later three) detector types

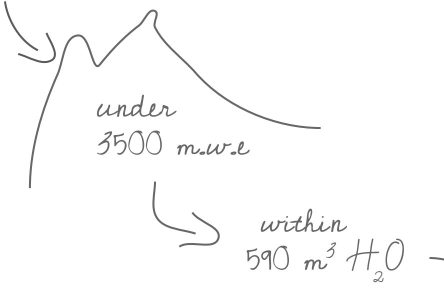


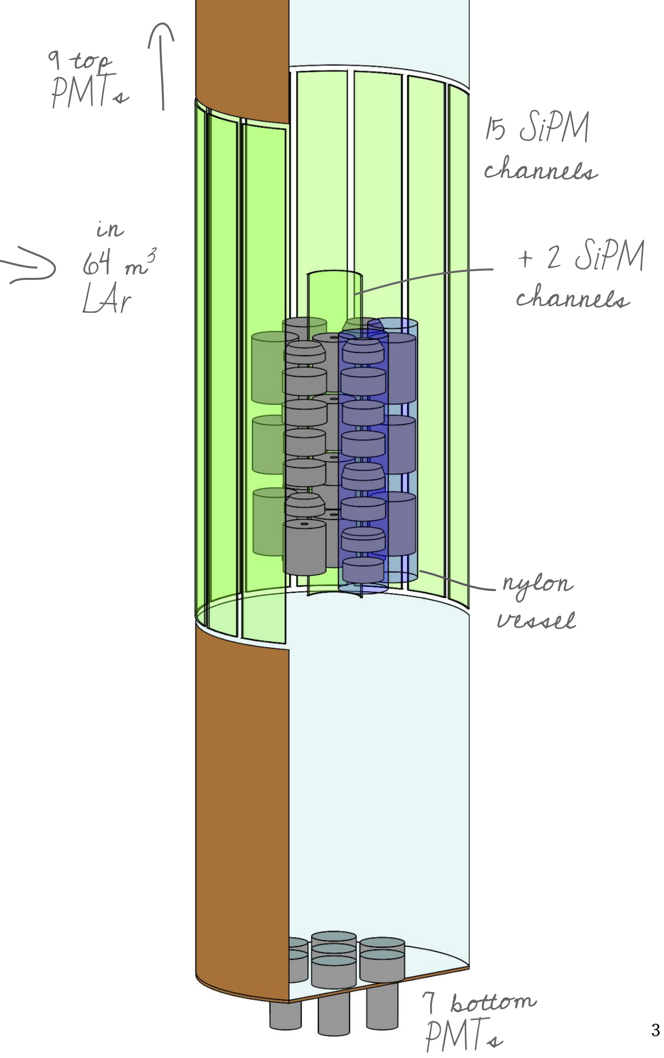
BEGe (semi-)**coaxial**

[Budjas et al., JINST 4 (2009) P10007]

- hybrid **scintillation** light read-out with **PMTs** and WLS fibers/**SiPMs**
- **low activity** materials and little passive mass

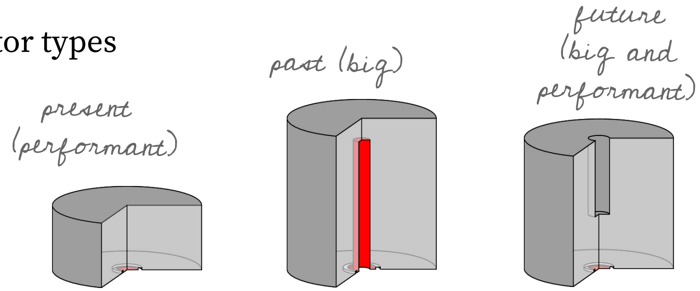
GERDA Phase II





- **35.6 kg** (later **44.2 kg**) of **enriched HPGe** detectors in ultra-low background **LAr** environment
  [Eur.Phys.J. C78 (2018) no.5, 388]

- two (later three) detector types



BEGe
[Budjas et al., JINST 4 (2009) P10007]

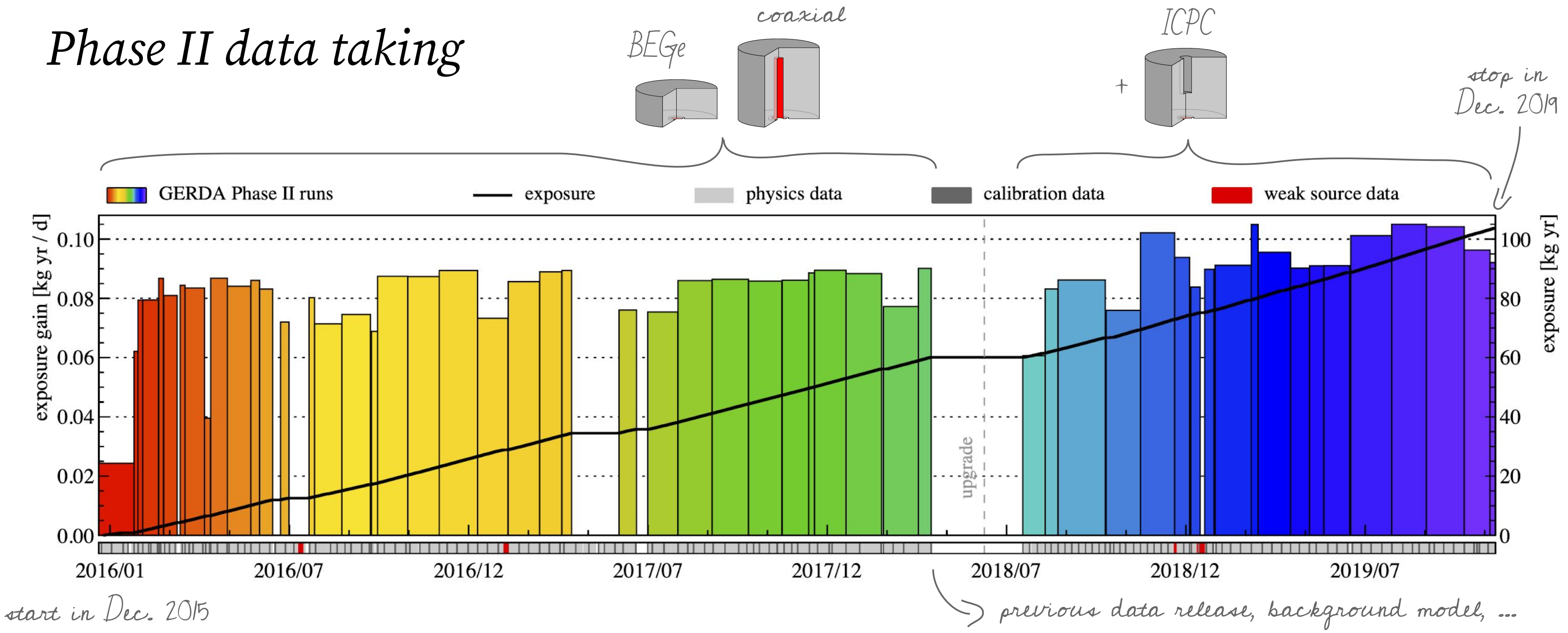
(semi-)**coaxial**

ICPC
[Cooper et al., Nucl.Instrum.Meth. A665, 25 (2011) 25-32]

- hybrid **scintillation** light read-out with **PMTs** and WLS fibers/**SiPMs**

- **low activity** materials and little passive mass

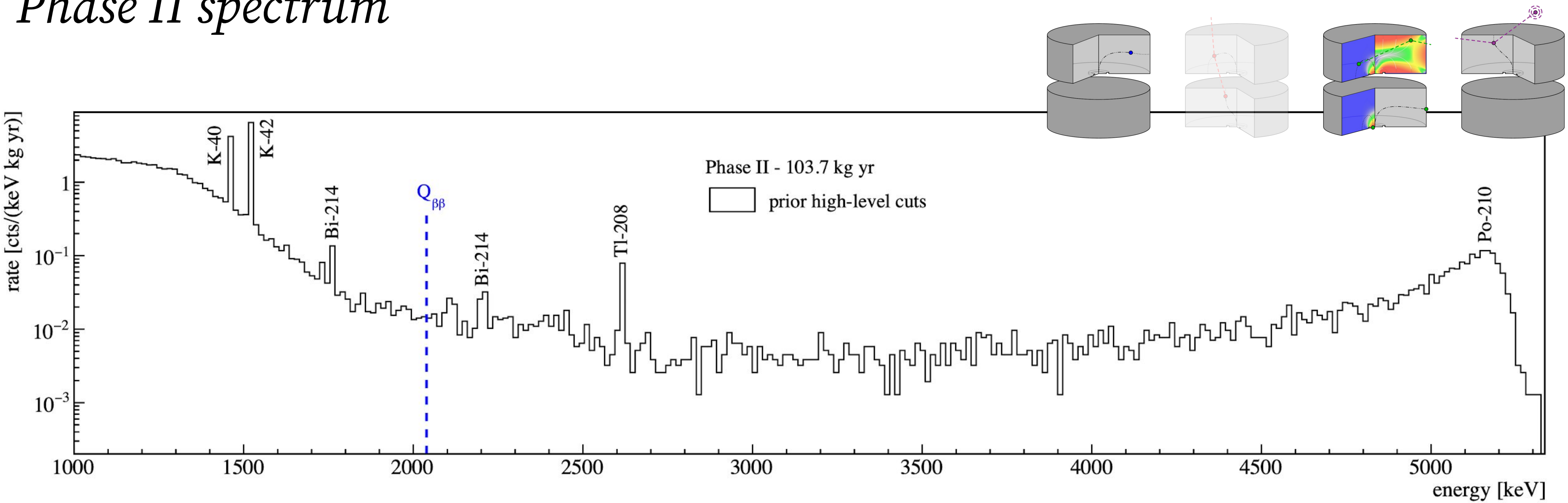
Phase II data taking



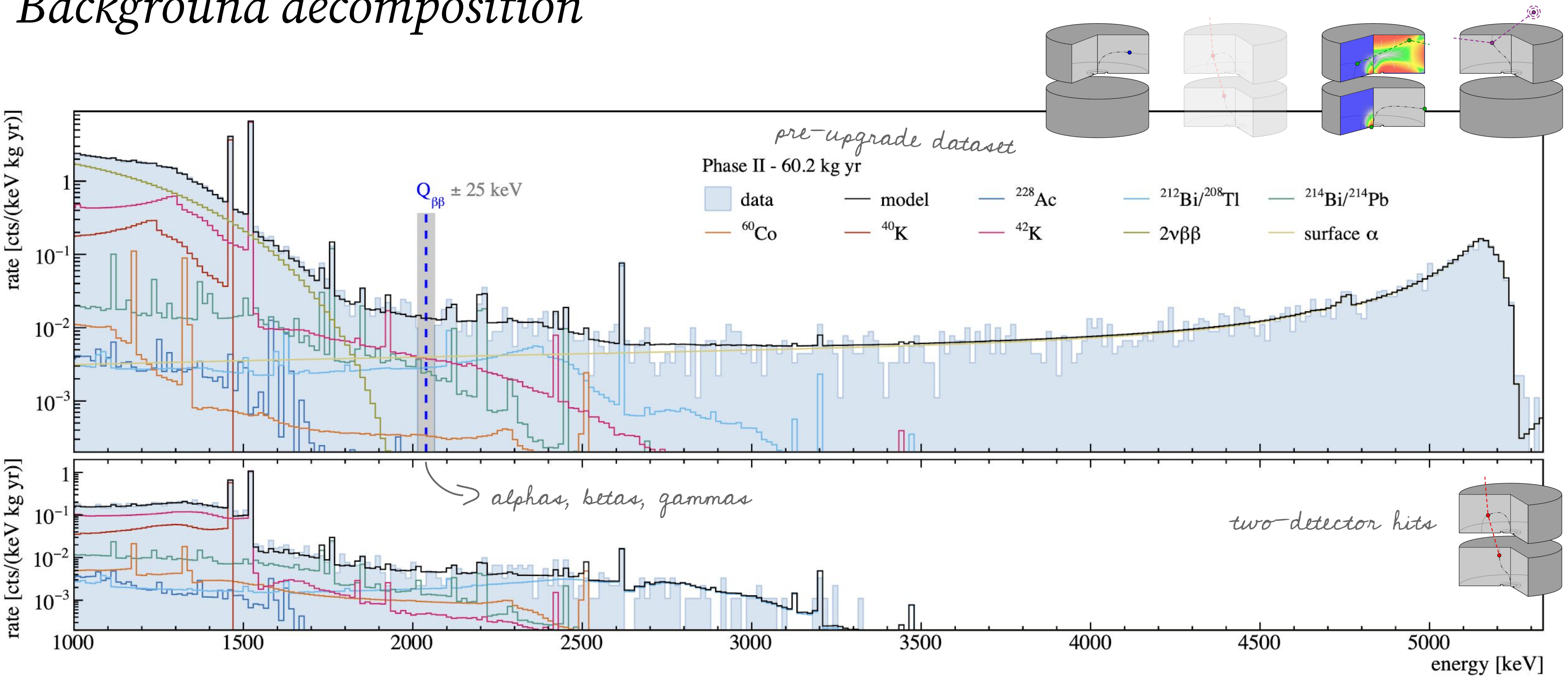
- **4 yr** operation, with about **90%** duty cycle (incl. upgrade works)
- **103.7 kg yr** of data selected for analysis

largest ^{76}Ge exposure ever taken

Phase II spectrum



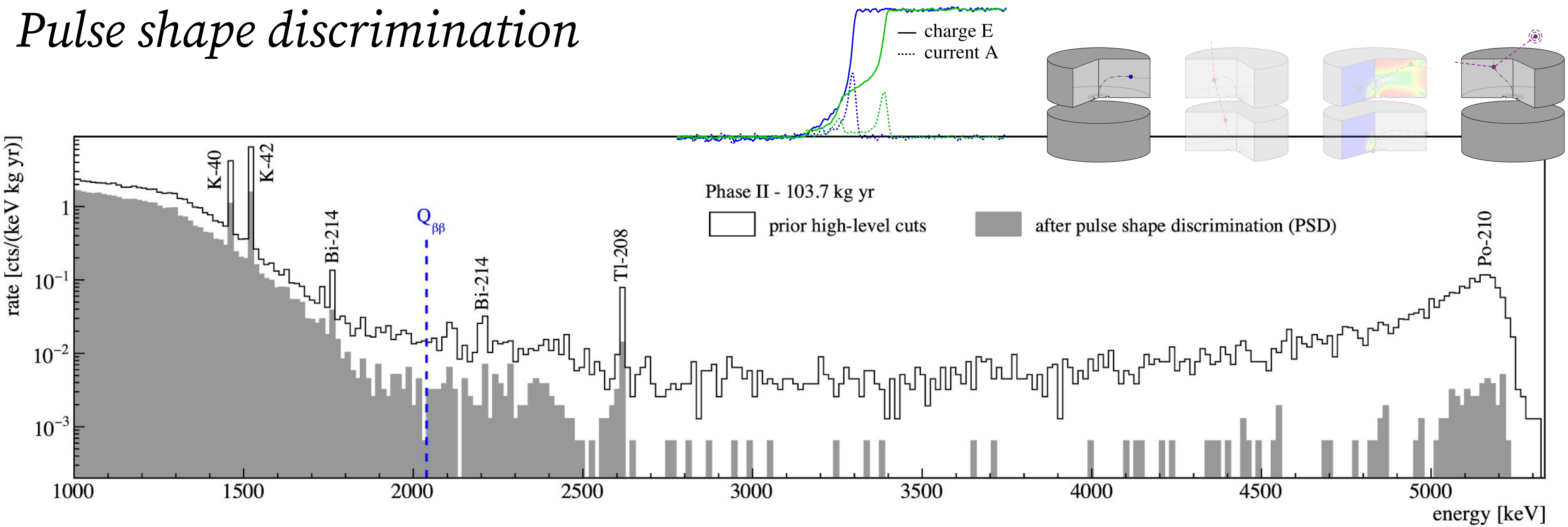
Background decomposition



- combined Bayesian fit to multiple datasets with Monte Carlo *pdf*s for **nearby components**
  [JHEP 03 (2020) 139]

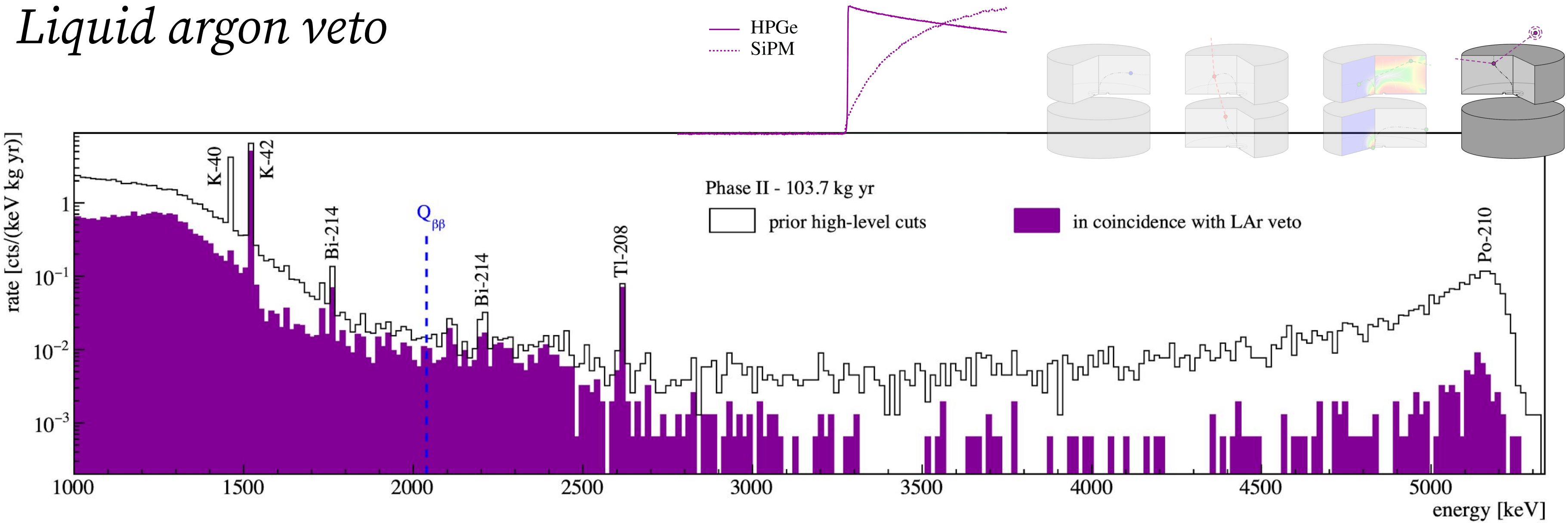
screening measurements as priors

Pulse shape discrimination



- two-sided **mono-parametric** A/E cut for **BEGe / ICPC** detectors
  [Budjas et al., JINST 4 (2009) P10007]
- artificial neural network analysis plus consecutive risetime cut for coaxial detectors
  [Eur. Phys. J. C73 (2013) 2583]
- cut definition / training with ^{228}Th **calibration data** –> ^{208}Tl DEP is signal proxy
- $0\nu\beta\beta$ signal efficiency **~90%** (~70% for coaxials)

Liquid argon veto



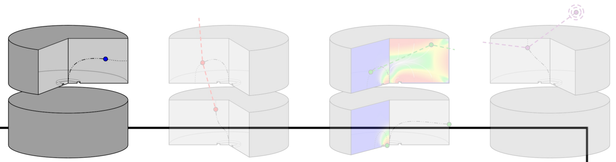
- channel-wise **(anti-)coincidence condition** (PMTs/SiPMs)
- **sub-PE threshold** over characteristic scintillation **emission time**

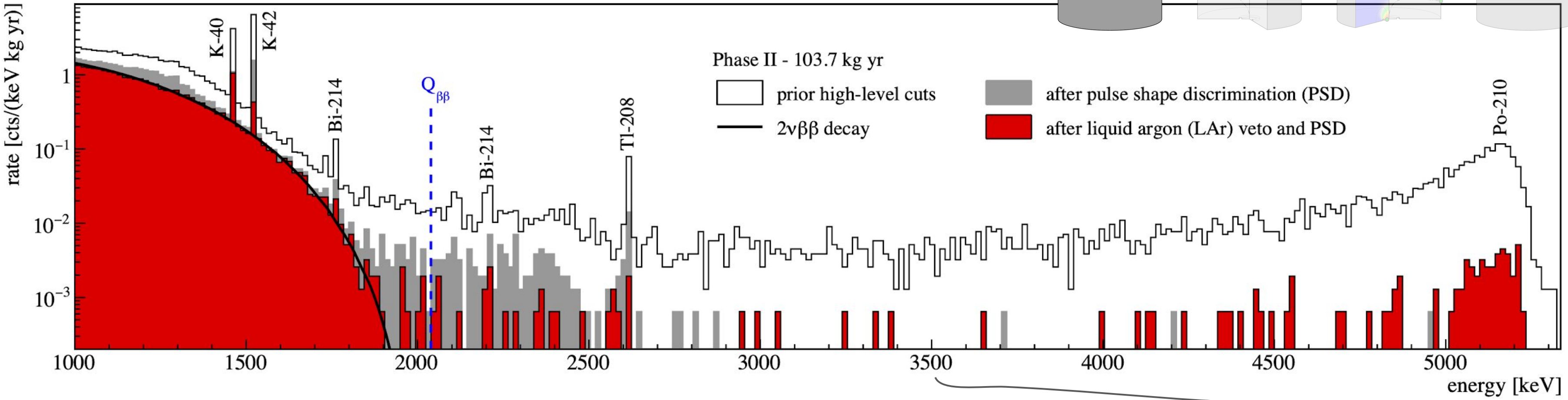
triplet lifetime ~1 μs

- 0νββ signal efficiency (1 - random coincidence rate) **> 97%**

^{39}Ar, dark rate

Final Phase II spectrum



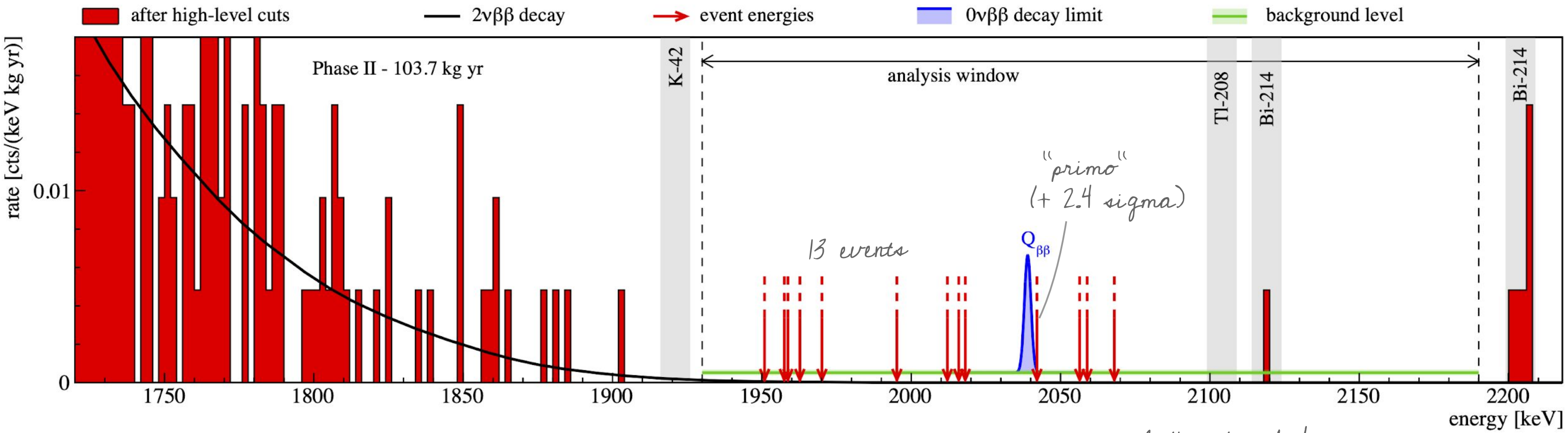


no surviving alphas in BEGe / ICPC

- "pure" **2νββ continuum** -> 2nbb precision studies, Majorons, Lorentz violation, ...
- sparse **single counts** at > $Q_{\beta\beta}$

Final GERDA result

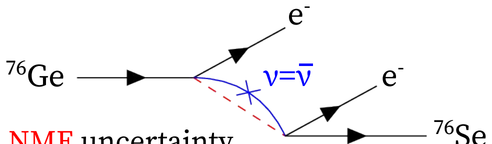
< 1 cts in 100 kg yr and 5 keV



resolution tracked

- background index $\mathbf{5.2^{+1.6}_{-1.3} \cdot 10^{-4}}$ **cts/(keV kg yr)**, energy resolution **~3 keV** (FWHM) per detector/period
- combined (data partitions, Phase I) **unbinned maximum likelihood fit** Gaussian signal on flat background
  [Nature 544 (2017) 47]
- **Frequentist**: $N^{0\nu} = 0$ best fit, $\boldsymbol{T_{1/2} > 1.8 \cdot 10^{26}}$ **yr** (median sensitivity -"-) at 90% C.L.,
  Bayesian: flat prior on rate, $T_{1/2} > 1.4 \cdot 10^{26}$ yr at 90% C.I. $> 2.3 \cdot 10^{26}$ yr for flat prior on m_{bb}

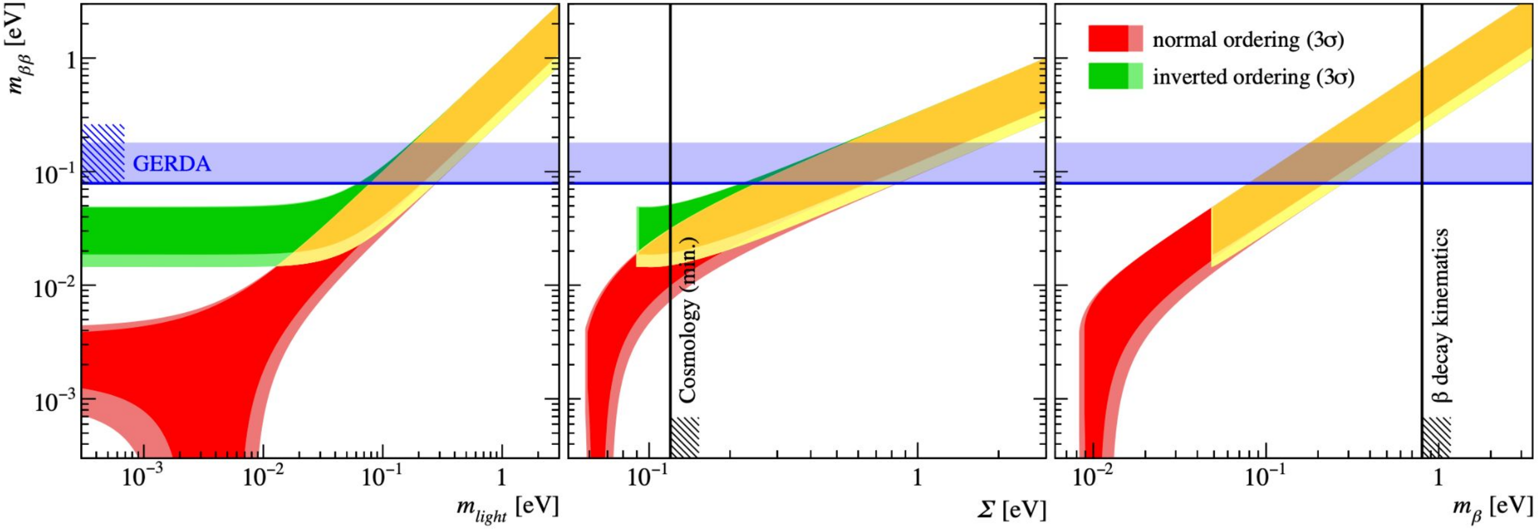
Mass constraints



NME uncertainty

[Engel, Menéndez, Rept.Prog.Phys. 80 (2017) no.4, 046301]

three flavour oscillation parameters from [Esteban et al., JHEP 09 (2020) 178]



$m_{\beta\beta}$ **< [0.08,0.18] eV**

-> Planck+BAO: Σ **< 0.12 eV**

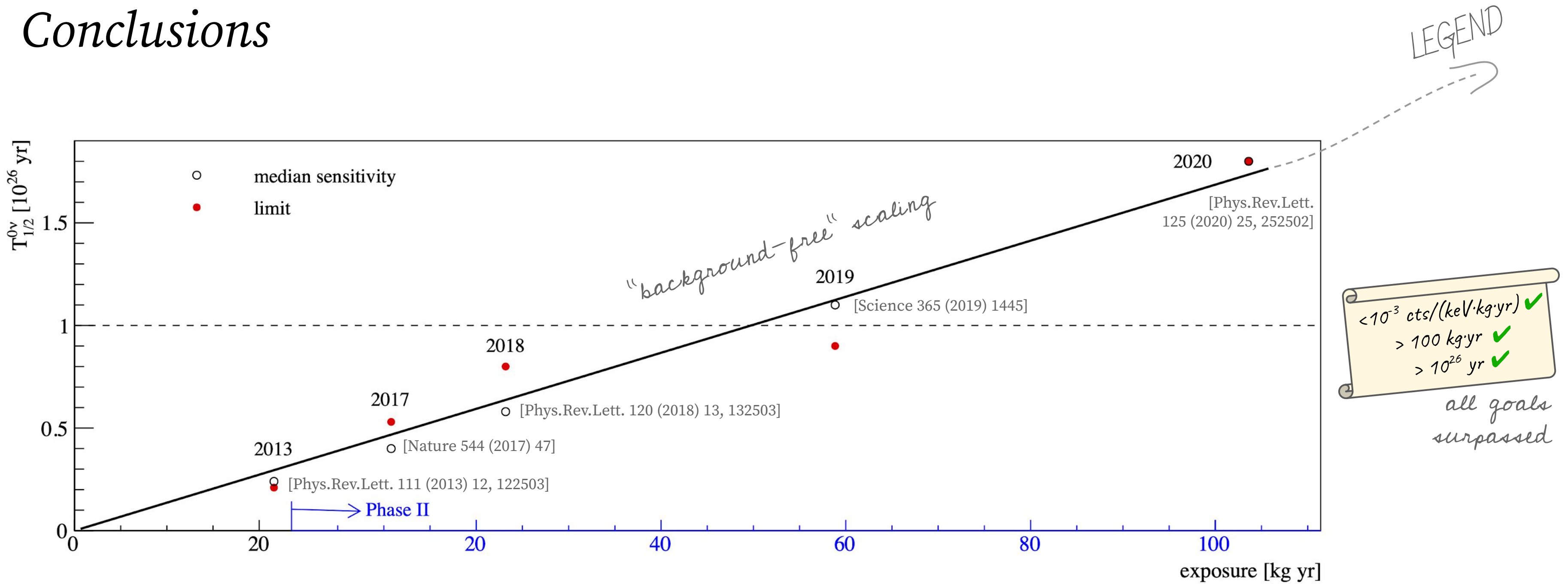
[Aghanim et al., Astron.Astrophys. 641 (2020) A6]

-> KATRIN: m_β **< 0.8 eV**

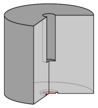
[Aker et al., arXiv:2105.08533]

- given "standard" assumptions 0νββ decay searches constrain **neutrino mass**
- **interplay** with cosmology / direct mass measurements -> m_{light} < [0.1,0.5] eV, sum < [0.2,1.5] eV, m_β < [0.1,0.5] eV
  [Science 365 (2019) 1445]

Conclusions



- GERDA has finished successfully, **no signal found** → *first experiment with sensitivity beyond 10^{26} yr*
- first deployment of **enriched ICPC detectors** [Eur.Phys.J.C 81 (2021) 505]
- further results (2νββ decay, exotics) to come



GERmanium Detector Array - GERDA

Heidelberg 2004

Zurich 2019

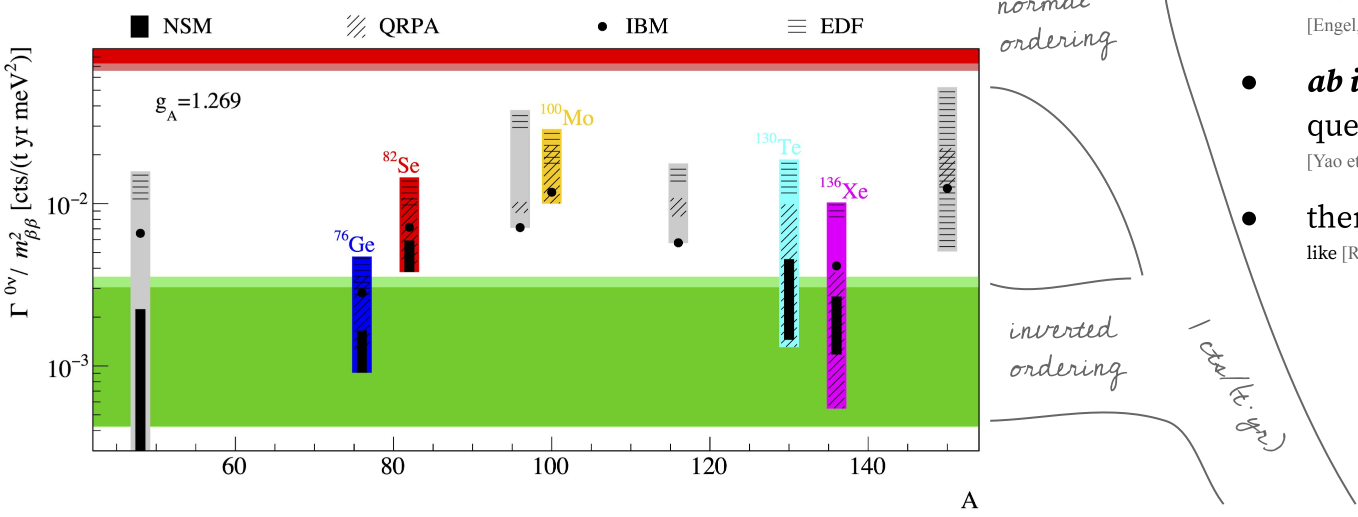
Backup

Nuclear physics aspects

- SM-allowed **2νββ decay** observed in **11** out of 35 naturally abundant **even-even nuclei**
  [Tretyak, Zdesenko, Atom.Data Nucl.Data Tabl. 80 (2002) 83-116]
- **0νββ decay** rate defined by interplay of **BSM physics** and **nuclear structure** details

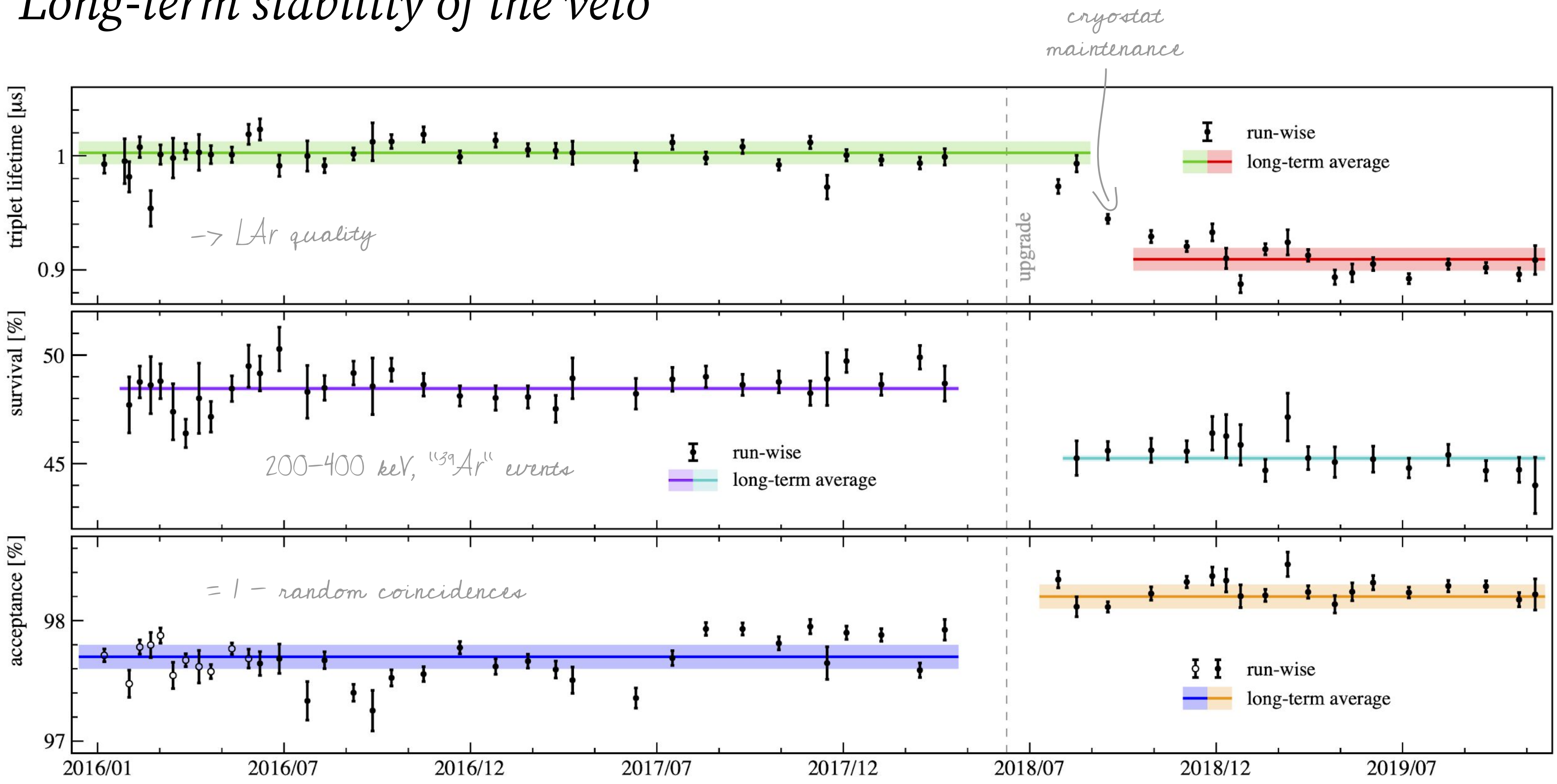
$$\Gamma^{0\nu} = \frac{N_A}{M(^A\mathrm{X})} \cdot ln(2) \cdot G^{0\nu} \cdot |g_A^2\, \mathcal{M}^{0\nu}|^2 \cdot \left(\frac{m_{\beta\beta}}{m_e}\right)^2$$

~10^{28} t^{-1} ~10^{-14} yr^{-1} ~10 ~10^{-14} (for m_{bb} < 100 meV)



- nuclear model dependence, **matrix element** uncertainty
  [Engel, Menéndez, Rept.Prog.Phys. 80 (2017) 4, 046301]
- ***ab initio*** calculations may solve quenching issue
  [Yao et al. Phys.Rev.Lett. 124 (2020) 23, 232501]
- there is no **super-isotope**
  like [Robertson, Mod.Phys.Lett.A 28 (2013) 1350021]

Long-term stability of the veto



GERDA result comparison