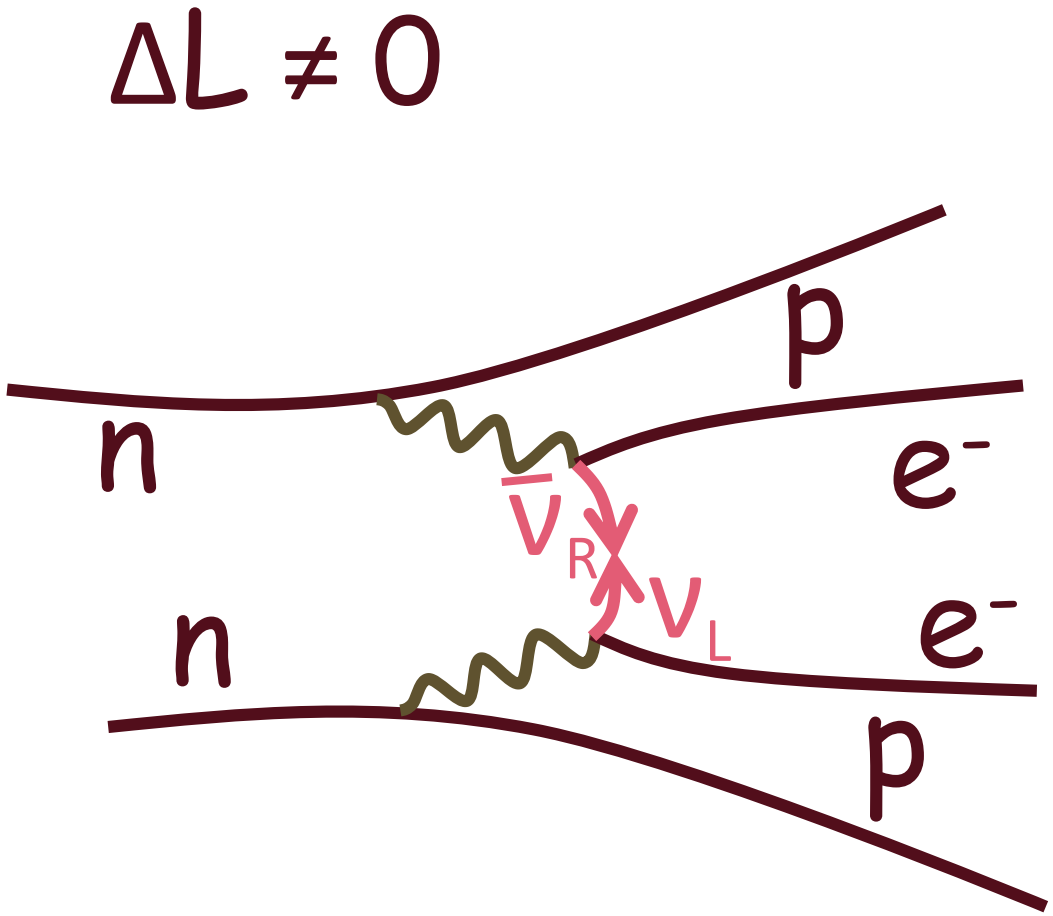
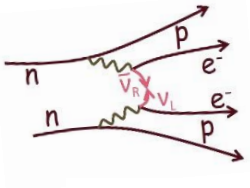
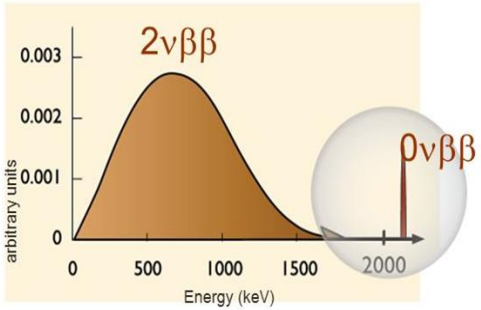
Double Beta Decay and Lepton Number Violation





Double Beta Decay and Lepton Number Violation

$\Delta L \neq 0$



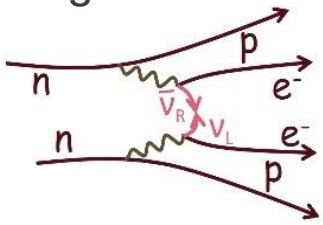
easiest but not easy way to see

if ν are Majorana-type

sensitivity on $T^{0\nu}_{1/2}$

mid term: a few 10^{26} yrs ($m_{\beta\beta}$ ~ 40-100 meV)
long term: a few 10^{27} yrs ($m_{\beta\beta}$ ~ 10- 20 meV)

via ν exchange

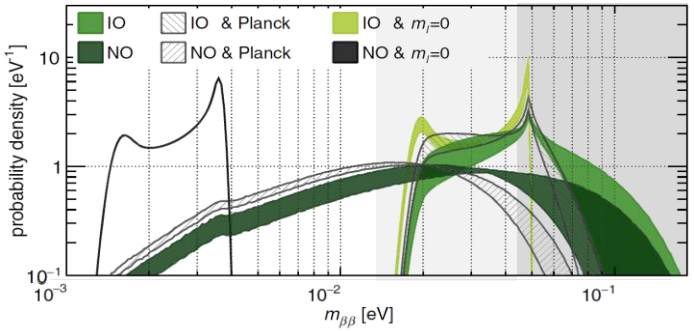


effective neutrino mass

$$1 / T^{0\nu}_{1/2} = G \cdot NME^2 \cdot m^2_{\beta\beta}$$

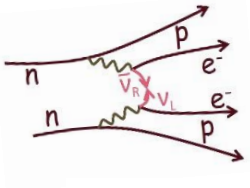
phase space nuclear matrix element

(Agostini, Benato, Detwiler, PRD 96 (2017) 053001
also A. Caldwell et al., PRD 96 (2017) 073001)

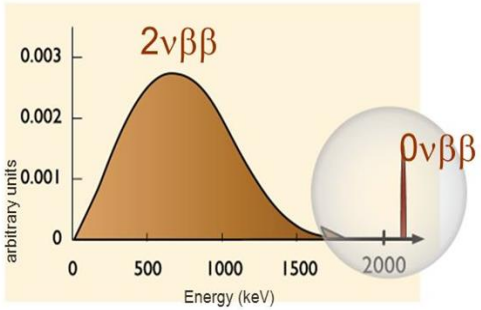


high discovery potential for IH and NH

- not hierarchy, but m_ν is important -



Double Beta Decay and Lepton Number Violation $\Delta L \neq 0$



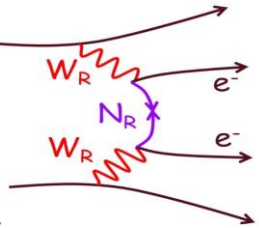
easiest but not easy way to see

if ν are Majorana-type

sensitivity on $T^{0\nu}_{1/2}$

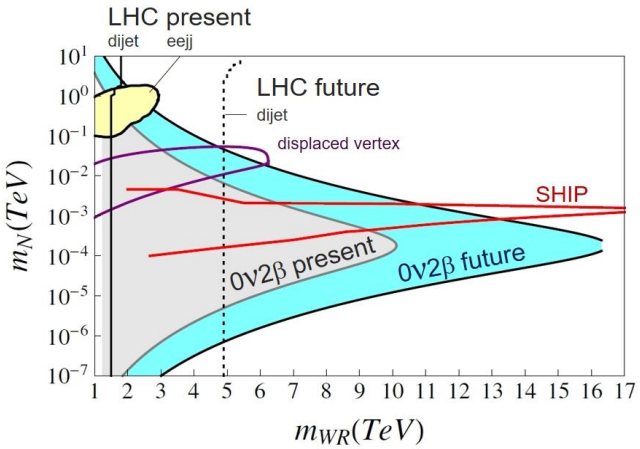
mid term: a few 10^{26} yrs ($m_{\beta\beta}$ ~ 40-100 meV)
long term: a few 10^{27} yrs ($m_{\beta\beta}$ ~ 10- 20 meV)

other $\Delta L \neq 0$ processes



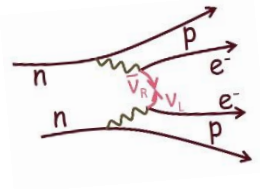
LR symmetry

heavy W_R and N_R exchange



arXiv 1509.00423v1

$0\nu\beta\beta$ searches complementary and competetive
- $\Delta L \neq 0$ is the key, not so much $m_{\beta\beta}$ -

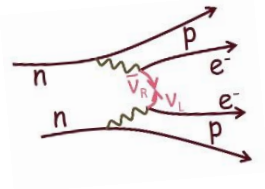


Search for Neutrino-less Double Beta Decay

$\Delta L \neq 0$

Ge detectors	GERDA	very good ΔE lowest background
	Majorana	
	LEGEND	
liquid noble gas **Xe**	EXO	large detector masses
	nEXO	
loaded liquid scintillator **Xe, Te**	KamLAND-Zen	
	KamLAND2-Zen	
	SNO+	
gaseous detectors **Xe, Se,Nd,Ca**	SuperNEMO	tracking
	NEXT	
	PANDA - X	
CdZnTe detectors	COBRA	larger variety of isotopes new techniques
cryo bolometers Te	CUORE	
cryo + light Te, Mo	Cupid, AMoRe	

competetive limits | running | in preparation | R&D and future projects



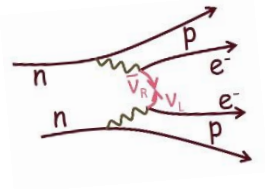
Search for Neutrino-less Double Beta Decay

$\Delta L \neq 0$

D largest contributor (BMBF, MPG)

Ge detectors	GERDA	3 MPI (Caldwell, Hofmann, Lindner), 3 Uni (Jochum, Schönert, Zuber)
	Majorana	1 MPI/Uni (Mertens)
	LEGEND	3 MPI (Caldwell, Hofmann/Hinton, Lindner), 5 Uni (Jochum, Kröninger, Mertens, Schönert, Zuber) Institut für Kristallzüchtung Berin
liquid noble gas Xe	EXO	1 -2 Uni (Anton, Fierlinger)
	nEXO	
loaded liquid scintillator Xe, Te	KamLAND-Zen	
	KamLAND2-Zen	
	SNO+	1 Uni (Zuber)
gaseous detectors Xe, Se,Nd,Ca	SuperNEMO	
	NEXT	
	PANDA - X	
CdZnTe detectors	COBRA	3 Uni (Gößling, Hagner, Kröninger, Zuber)
cryo bolometers Te	CUORE	
cryo + light Te, Mo	Cupid, AMoRe	1 Uni (Enss, Gastaldo), KIT (Blümer)

competetive limits | running | in preparation | R&D and future projects



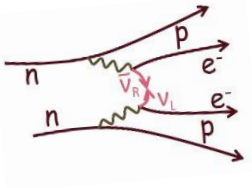
Search for Neutrino-less Double Beta Decay

$\Delta L \neq 0$

butor

Ge detectors	GERDA	3 MPI 3 Uni	biggest involvement
	Majorana	1 MPI	
	LEGEND	3 MPI 4 Uni	largest discovery potential
liquid noble gas Xe	EXO	1 -2 Uni (Anton, Fierlinger)	
	nEXO		
loaded liquid scintillator Xe, Te	KamLAND-Zen		
	KamLAND2-Zen		
	SNO+	1 Uni (Zuber)	
gaseous detectors Xe, Se,Nd,Ca	SuperNEMO		
	NEXT		
	PANDA - X		
CdZnTe detectors	COBRA	3 Uni (Gößling, Hagner, Kröninger, Zuber)	
cryo bolometers Te	CUORE		
cryo + light Te, Mo	Cupid, AMoRe	1 Uni (Enss, Gastaldo), KIT (Blümer)	

competetive limits | running | in preparation | R&D and future projects



EXO 200 / nEXO

$\Delta L \neq 0$

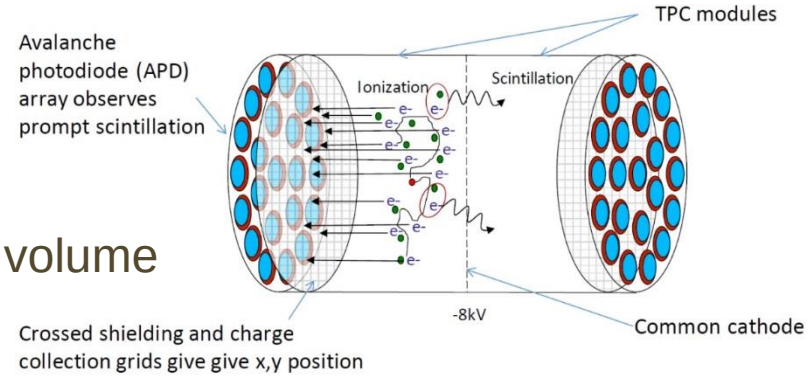
liquid Xenon TPC enriched in ^{136}Xe (80.6 %), charge and light detection

WIPP New Mexico USA

ΔE ~ 88 keV FWHM

self shielding, multi site recognition

EXO 200: 170 $kg_{isotope}$ total / 80 $kg_{isotope}$ active volume



results:

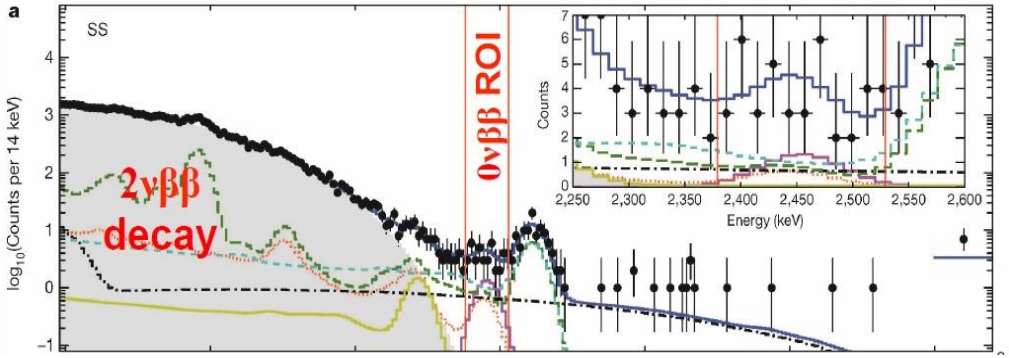
180 kg·yr exposure published

sensitivity $3.8 \cdot 10^{25}$ yr

$T_{1/2}^{0\nu\beta\beta} > 1.8 \cdot 10^{25}$ yr

background in ROI

150 / FWHM·$t_{isotope}$·yr



PRL 120 072701 (2018)

plan: nEXO

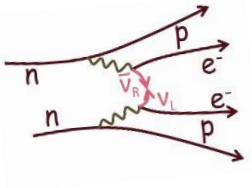
5000 kg

R&D on Ba tagging

goal $T_{1/2}^{0\nu\beta\beta} > 4.1 \cdot 10^{27}$ yr

background in ROI ~ 0.6 / FWHM·$t_{isotope}$·yr

arXiv 1710.05075



nEXO

$\Delta L \neq 0$

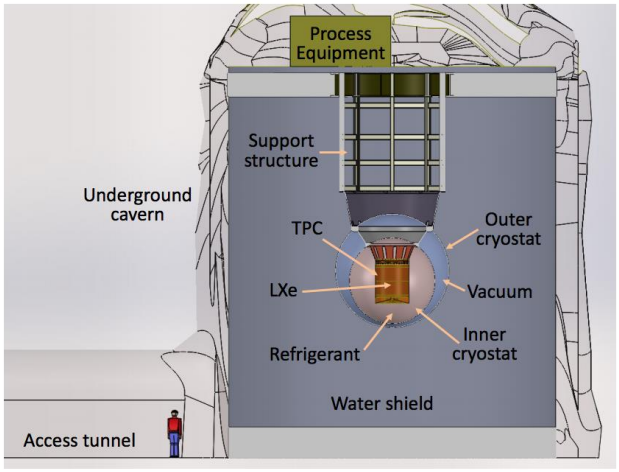
liquid Xenon single TPC

5000 kg enriched lXe

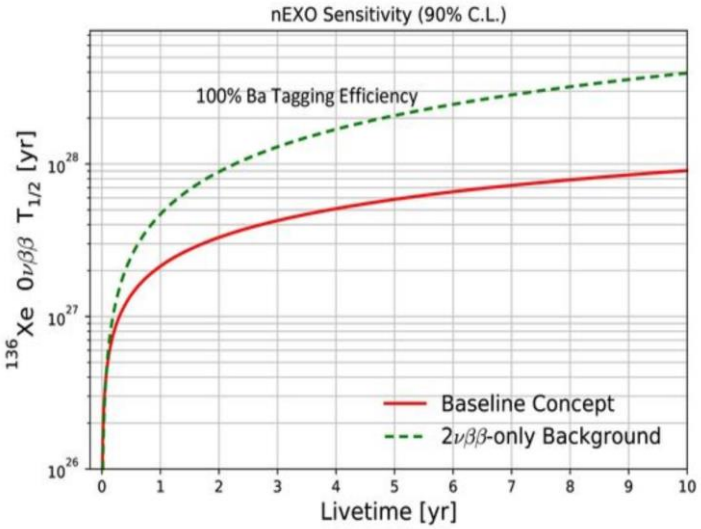
expected to be at SNOLAB

improved performance:

energy and position resolution ….



R&D on Ba-tagging



<u>plan:</u> nEXO

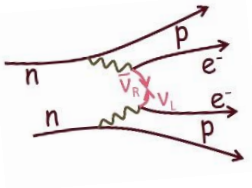
5000 kg

R&D on Ba tagging

goal $T_{1/2}^{0\nu\beta\beta} > 4.1 \cdot 10^{27}$ yr

background in ROI ~ 0.6 / FWHM·$t_{isotope}$·yr

arXiv 1710.05075



KamLAND-Zen

$\Delta L \neq 0$

3 m diam. ballon: liquid scintillator loaded with enriched Xenon inserted into KamLAND

ΔE ~ 250 keV FWHM

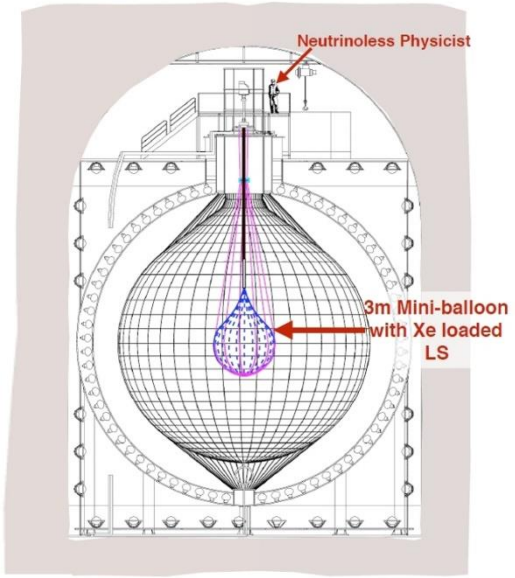
results: 383 kg Xe / 110 $kg_{isotope}$ in FV

~ 600 kg·yr

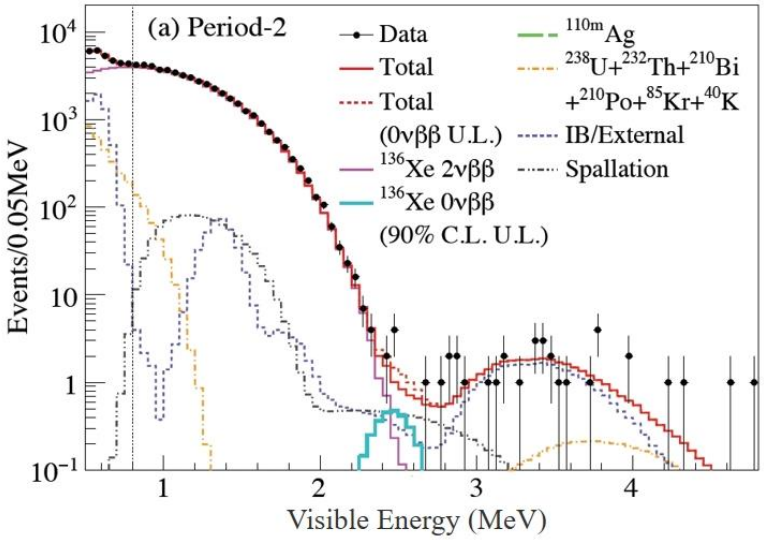
$T_{1/2}^{0\nu\beta\beta} > 10.7 \cdot 10^{25}$ yr

sensitivity $5.6 \cdot 10^{25}$ yr

background in ROI ~ 100 / FWHM·$t_{isotope}$·yr



PRL 117 082503 (2016)



starting: KamLAND Zen 800

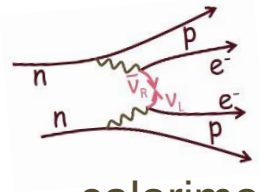
750kg Xe

goal sensitivity

$T_{1/2}^{0\nu\beta\beta} > 4.6 \cdot 10^{26}$ yr

background ~ 10 / FWHM·$t_{isotope}$·yr

plan: **KamLAND2**: 1000 kg

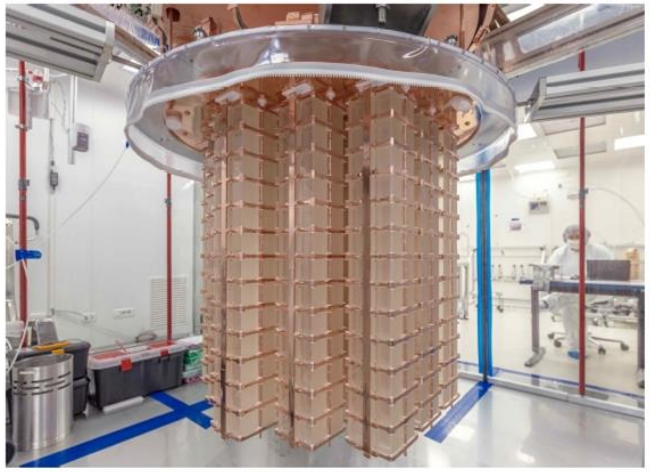


Cuore @ LNGS

$\Delta L \neq 0$

calorimetry at mK temperature
in natural TeO_2 crystals ^{130}Te (30%)

CUORE 750 kg TeO_2 (206 kg ^{130}Te)
988 crystals



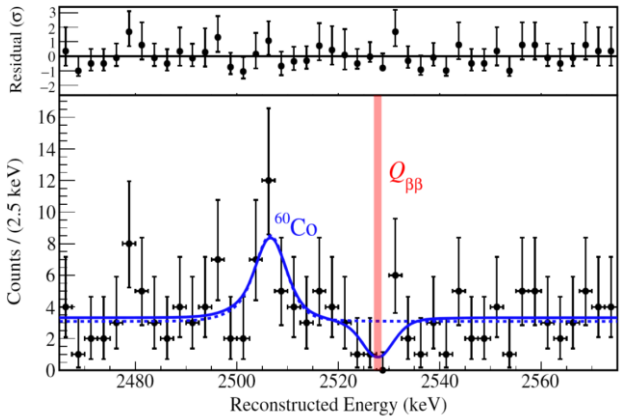
results:

86.3 kg·yr (24 kg·yr ^{130}Te)

ΔE ~ 7.7 keV FWHM

$$T_{1/2}^{0\nu\beta\beta} > 1.5 \cdot 10^{25} \text{ yr}$$

background in ROI
~ 360 / FWHM·$t_{isotope}$·yr



Phys.Rev.Lett 120, 132501 (2018)

goals:

goal sensitivity

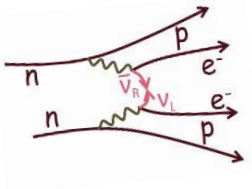
$$T_{1/2}^{0\nu\beta\beta} > 9.5 \cdot 10^{25} \text{ yr}$$

background
~ 180 / FWHM·$t_{isotope}$·yr

potential upgrade with calorimetry + light

CUORE => CUPID (might interest german groups)

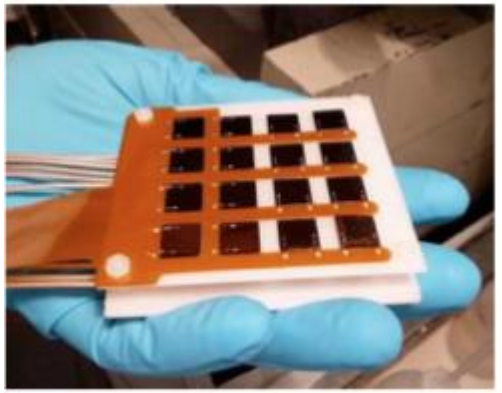
AMORE (Korea) large funding, sensors from D



COBRA @ LNGS

$\Delta L \neq 0$

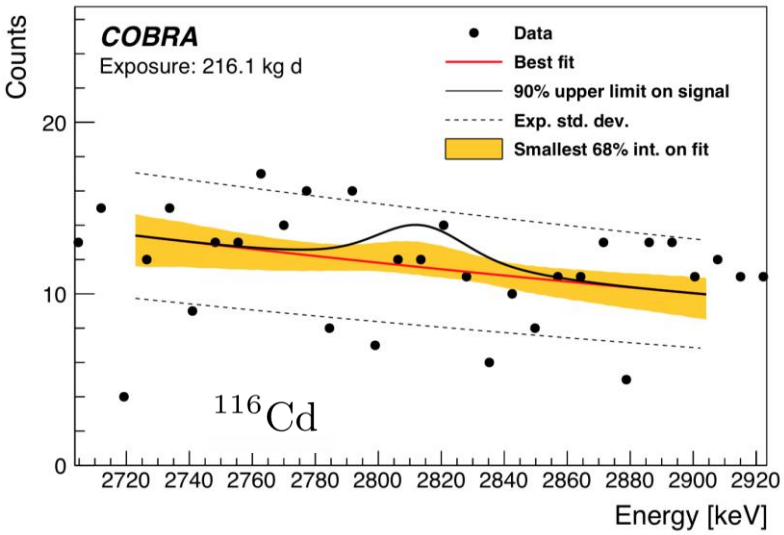
room temperature CdZnTe detector with coplanar-grid



several isotopes

results: 234.7 kg·d

Isotope	$N/10^{23}$ [$\frac{\text{atoms}}{\text{kg}}$]	b [$\frac{\text{counts}}{\text{keV kg yr}}$]	$T_{1/2}$ 90% C.L. [10^{21}yr]	K
^{114}Cd	6.59	$213.9^{+1}_{-1.7}$	1.6	0.07
^{128}Te	8.08	$65.5^{+0.5}_{-1.6}$	1.9	0.17
^{70}Zn	0.015	$45.1^{+0.6}_{-1}$	6.8×10^{-3}	0.06
^{130}Te	8.62	$3.6^{+0.1}_{-0.3}$	6.1	0.14
^{116}Cd	1.73	$2.7^{+0.1}_{-0.2}$	1.1	0.27

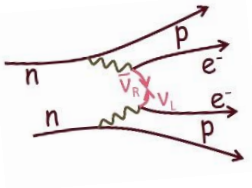


plan:

finish detector characterization and upgrade to COBRA XDEM in 2018

with larger detectors

arXiv:1509.04113



Ge detectors: GERDA & Majorana Demonstrator

$\Delta L \neq 0$

Majorana Demonstrator

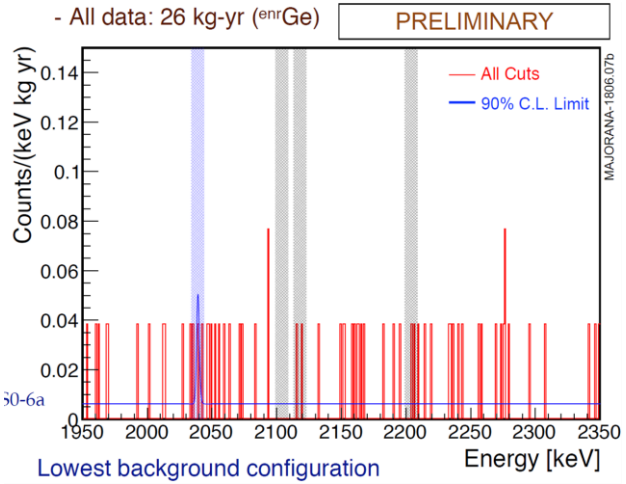
26 kg·yr

background in ROI
15 / FWHM·$t_{isotope}$·yr

Neutrino 2018 conference

sensitivity 4.8 ·10^{25} yr

$T_{1/2}^{0\nu\beta\beta}$ > 2.7·10^{25} yr



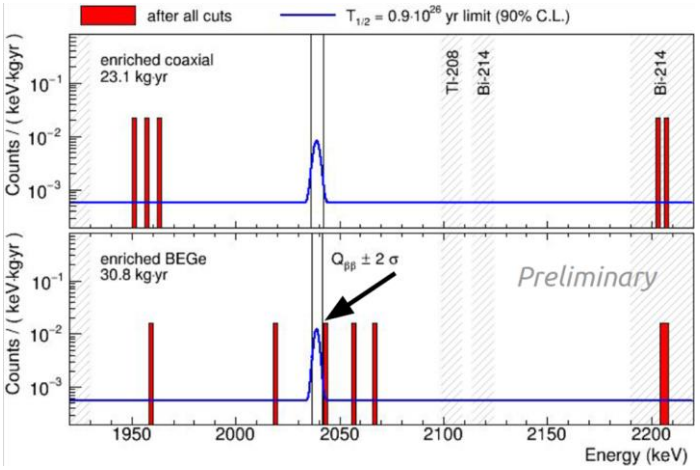
GERDA:

82.4 kg·yr total exposure

background in ROI
2 / FWHM·$t_{isotope}$·yr

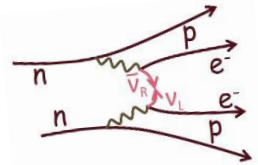
sensitivity 11·10^{25} yr

$T_{1/2}^{0\nu\beta\beta}$ > 9·10^{25} yr



first background free 0νββ experiment
→ potential for discovery (up to ~ 10^{26} yr)

makes sense to grow larger (background goal for LEGEND 200 alm ostreached)

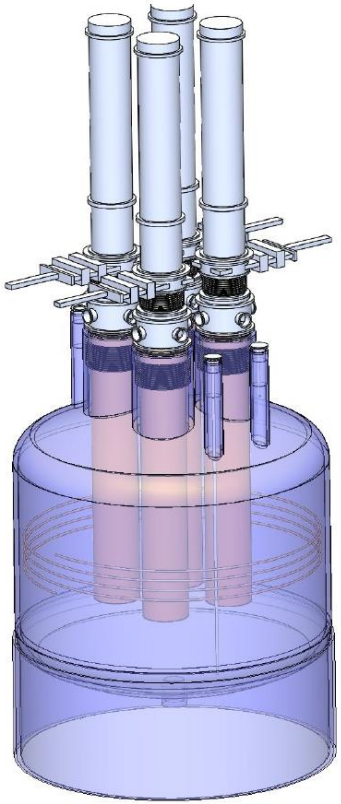


Search for Neutrinoless Double Beta Decay

$\Delta L \neq 0$

new collaboration formed LEGEND
Majorana + GERDA members + others

⇒ one worldwide collaboration on ^{76}Ge



use GERDA concept and
staged approach to 1000kg

LEGEND 200: first 200kg in GERDA setup @ Gran Sasso

- starting 2021
- ^{76}Ge available for 150kg of detectors
- funded by NSF, INFN, MPI, BMBF

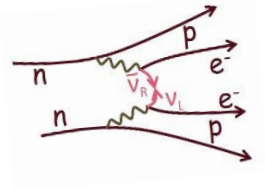
sensitivity $> 10^{27}$ yr

⇒ Still needs some ^{76}Ge, but 90% fundend for ~ 190 kg…

background level amost reached (needs x3 improvement cmp. GERDA)

sensitivity $> 10^{28}$ yr

LEGEND 1000: 1000kg phase depends on US down selection process
same for nEXO

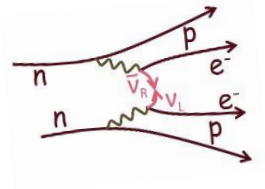


Search for Neutrinoless Double Beta Decay

$\Delta L \neq 0$

			isotope mass [kg] in FV	FWHM [keV]	background [(FWHM $t_{isotope}$ yr)$^{-1}$]	3σ discovery sensitivity taken from PRD 96(2017) 053001 $T_{1/2}$ [10^{26} yr]	$m_{\beta\beta}$ [meV]
Ge detectors	GERDA	Ge	37	3	2		
	Majorana	Ge	26	3	15		
	LEGEND 200 kg	Ge	155	3	0,6	8.4	40-73
	LEGEND 1000 kg	Ge	780	3	0.1	45	17-31
liquid noble gas	EXO	Xe	80	88	150		
	nEXO	Xe	4300	58	0.6	41	9-22
loaded liquid scintillator	KamLAND 400 kg	Xe	110	250	100		
	KamLAND 800/1000 kg	Xe	~180	250	~40/2	1.6 /8	47-108 /21-49
	SNO+	Te	260	190	60	4.8	22-54
cryo bolometers	CUORE	Te	206	5	180/ 360	0.5	66-164

background numbers from PRD 96(2017) 053001 for future experiments
and most recent publications or talks (mostly Neutrino 2018) for running experiments

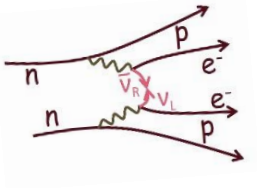


Search for Neutrinoless Double Beta Decay

$\Delta L \neq 0$

			isotope mass [kg] in FV	FWHM [keV]	background [(FWHM $t_{isotope}$ yr)$^{-1}$]	3σ discovery sensitivity taken from PRD 96(2017) 053001 $T_{1/2}$ [10^{26} yr]	$m_{\beta\beta}$ [meV]
Ge detectors	GERDA	Ge	37	3	2		
	Majorana	Ge	26	3	15		
	LEGEND 200 kg	Ge	155	3	0,6	8.4	40-73
	LEGEND 1000 kg	Ge	780	3	0.1	45	17-31
liquid noble gas	EXO	Xe	80	88	150		
	nEXO	Xe	4300	58	0.6	41	9-22
loaded liquid scintillator	KamLAND 400 kg	Xe	110	250	100		
	KamLAND 800/1000 kg	Xe	~180	250	40 / 2	1.6 /8	47-108 /21-49
	SNO+	Te	260	190	60	4.8	22-54
cryo bolometers	CUORE	Te	206	5	180/ 360	0.5	66-164

low background essential for discovery potential



Search for Neutrinoless Double Beta Decay

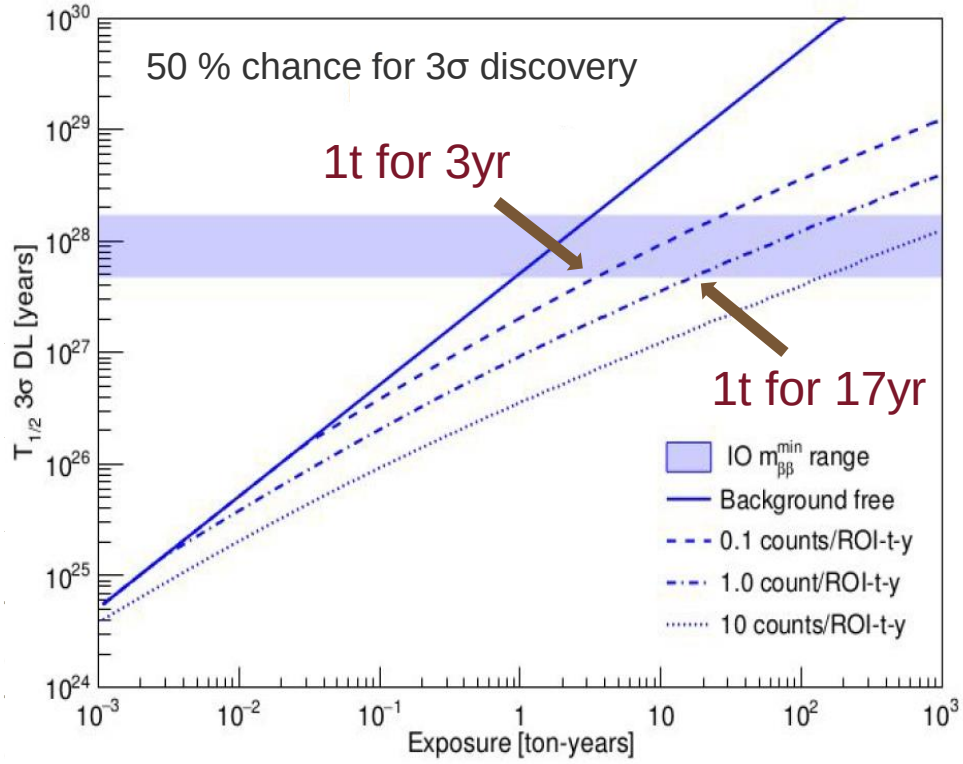
$\Delta L \neq 0$

Ge detectors
- GERDA
- Majorana
- LEGEND: 200 kg → 1000 kg

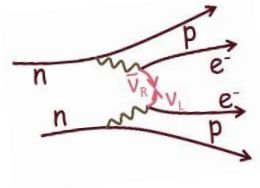
liquid noble gas
- EXO
- nEXO

loaded liquid scintillator
- KamLAND: 400 kg → 800 kg
- SNO+

cryo bolometers
- CUORE



low background essential for discovery potential



Summary

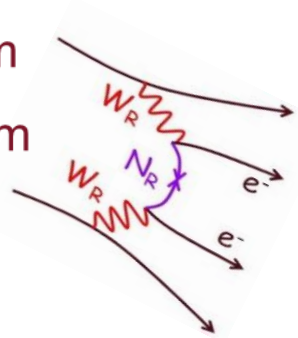
$\Delta L \neq 0$

- search for double beta decay highly motivated:

  $\Delta L \neq 0$, Majorana ν , lightness of ν-mass, Leptogenesis

- next experiments explore range up to $T_{1/2} < 10^{27}$yr mid term

  $\Rightarrow$ chance for discovey of $\Delta L \neq 0$ $T_{1/2} < 10^{28}$yr long term



- field is very active and competitive,
  variety of approaches and technologies

Germany

- strong focus on ^{76}G, LEGEND among the most sensitive

  GERDA achieved: lowest background, best energy resolution, highest discovery potential

- activities on ^{136}Xe, nEXO among the most sensitive

- activities on other technologies: SNO+, COBRA, bolometer + light

END