Underground Neutrino Experiment

Qian Yue
Tsinghua University
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Outline

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- Neutrino Science
- 0νββ decay
- 0νββ experimental technologies
- World-wide 0νββ experiments
- Summary

Neutrino Science

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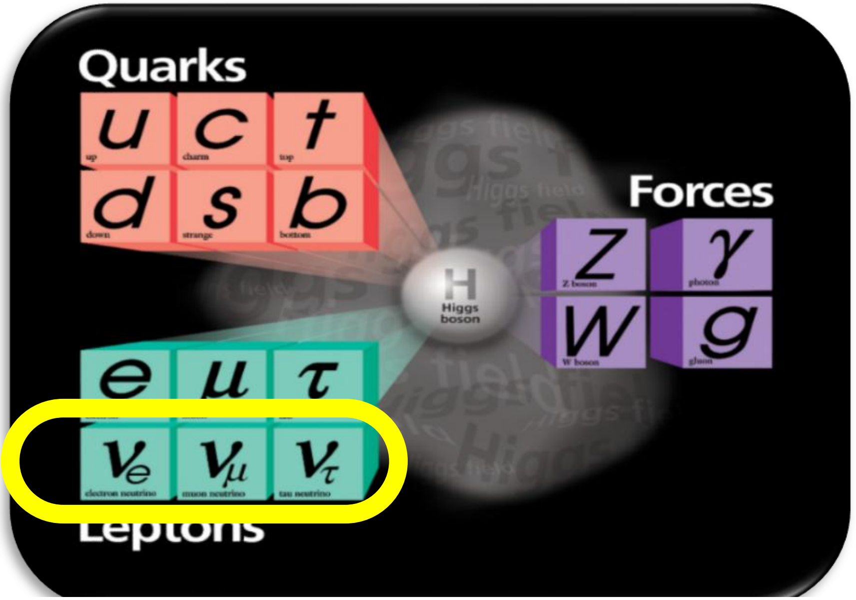
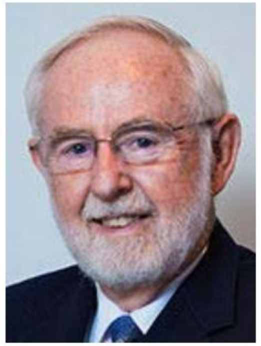


2015



Takaaki Kajita

Arthur B. McDonald

"For the discovery of neutrino oscillations, which shows that neutrinos have mass"

- The discovery of neutrino oscillation in 1998 is a strong indication of new physics beyond SM.
- Studies of neutrino properties: the forefront in particle physics, and intensely pursued by the major research groups.
- One of the fundamental nature of neutrinos is: They are **Majorana or Dirac particles?**

0νββ experiment

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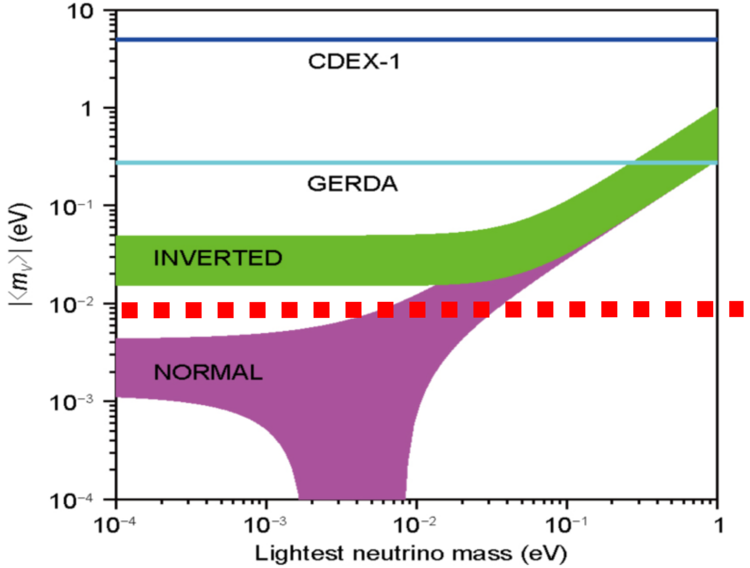
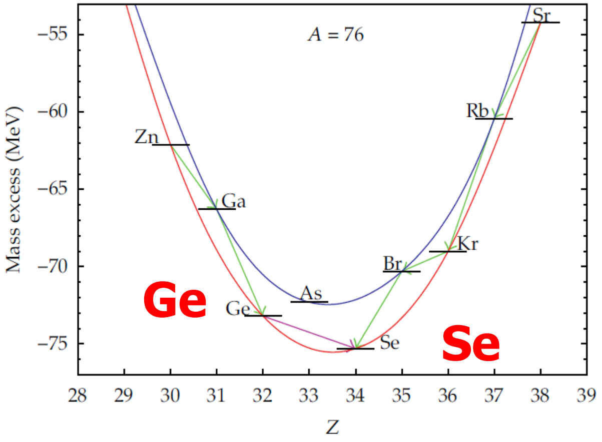
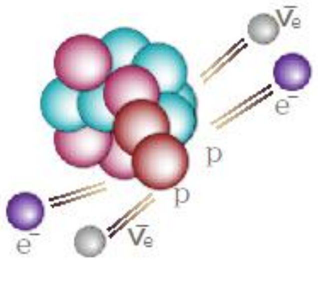
- 0νββ experiment: the most sensitive way to probe the Majorana-Dirac nature of the neutrinos.
- ν mass ordering measured by 0νββ experiment if the sensitivity of $m_{\beta\beta}$ reaches ~10meV.
- If there is a positive signature of 0νββ event, it will be a lepton number violation process. A scientific discovery of historical importance if it is true.

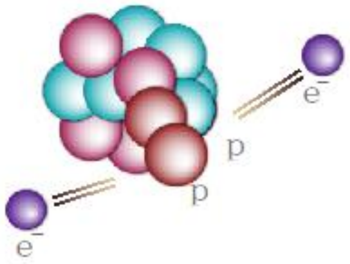




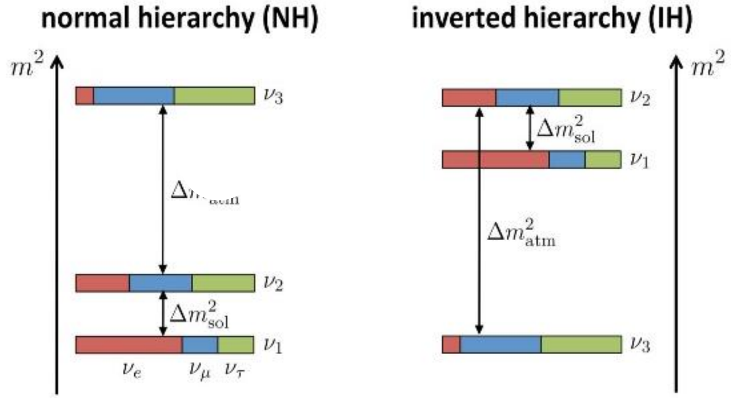
$\nu = \bar{\nu}$ ΔL=2



2νββ



0νββ



0νββ experiment

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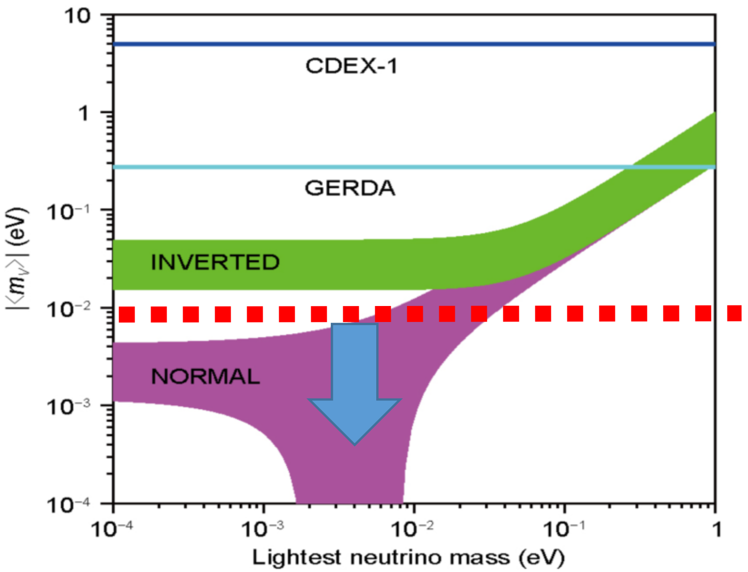
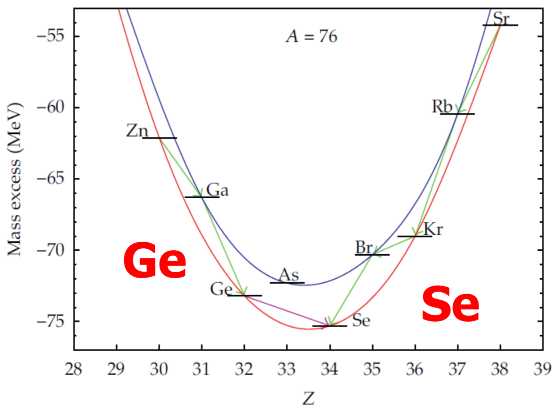
- **0νββ experiment**: the most sensitive way to probe the Majorana-Dirac nature of the neutrinos.
- ~~ν mass ordering measured by 0νββ experiment if the sensitivity of $m_{\beta\beta}$ reaches ~10meV.~~ (If achieved)
- If there is a positive signature of 0νββ event, it will be a lepton number violation process. A scientific discovery of historical importance if it is true.

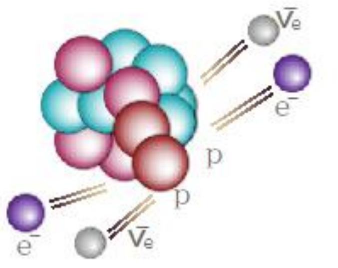


$$(Z,A) \rightarrow (Z+2,A) + 2e^- + 2\bar{\nu}_e.$$

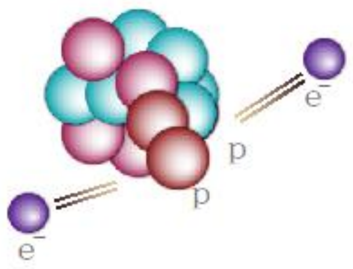


Michael Moe **in 1987 first observed in Se-82**

$\nu = \bar{\nu}$ ΔL=2



2νββ



0νββ

- 0νββ exp need to focus on the far future to scan the whole NO region and find 0νββ events, NOT just the near target to reach the ~10meV sensitivity.

0νββ experiment

- 0νββ experiment: the most sensitive way to probe the Majorana-Dirac nature of the neutrinos.
- ~~ν mass ordering measured by 0νββ experiment if the sensitivity of $m_{\beta\beta}$ reaches ~10meV.~~ (If achieved)
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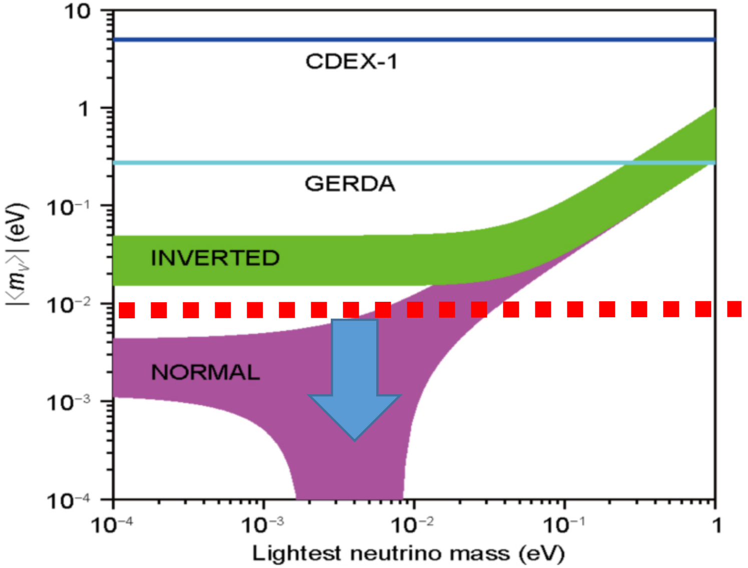

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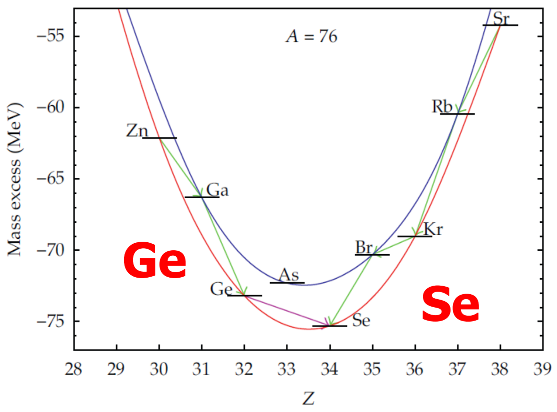

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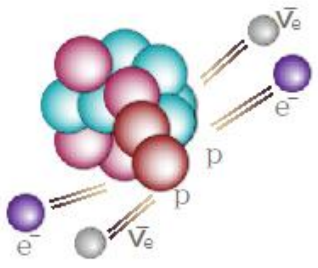
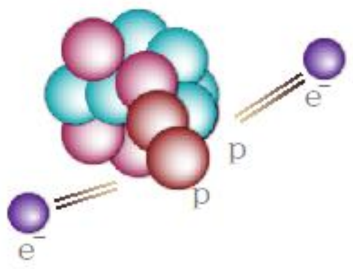
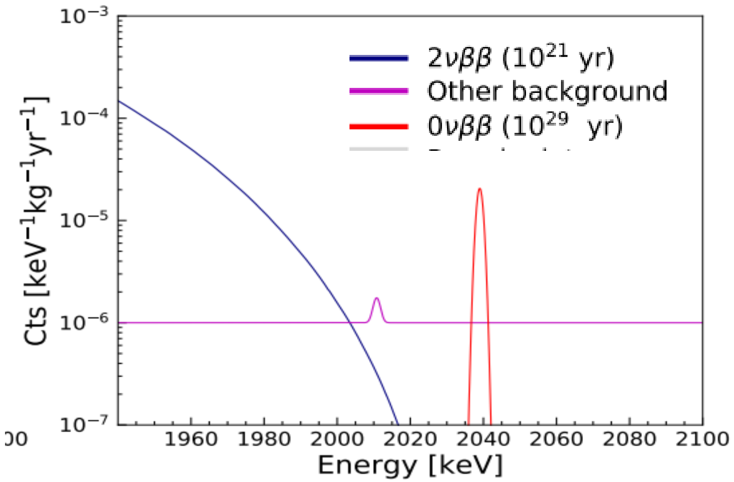


2νββ



0νββ



0νββ experiment principle

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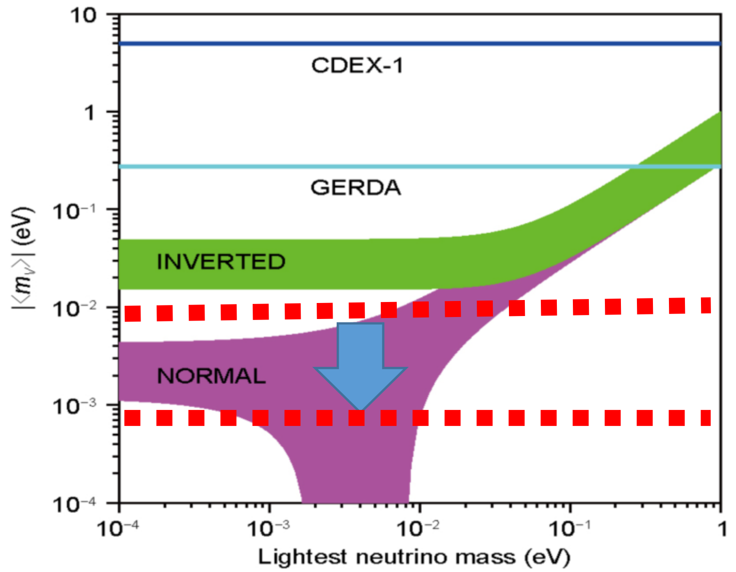
- In order to get $m_{\beta\beta}$, need to experimentally measure $T_{1/2}^{0\nu}$.
- The recent sensitivities: $m_{\beta\beta}$ <100meV.
- Next sensitivity target: $m_{\beta\beta}$ ~10meV.
- Scan almost the whole NO region: $m_{\beta\beta}$ <1meV.
- 0νββ Half-life $T_{1/2}^{0\nu}$ should be measured to >10^{30}yr.



$$T_{1/2}^{0\nu} = \left(G\,|\mathcal{M}|^2 \langle m_{\beta\beta}\rangle^2\right)^{-1} \simeq 10^{27-28} \left(\frac{0.01\ \mathrm{eV}}{\langle m_{\beta\beta}\rangle}\right)^2 \mathrm{year}$$

0νββ experiment principle

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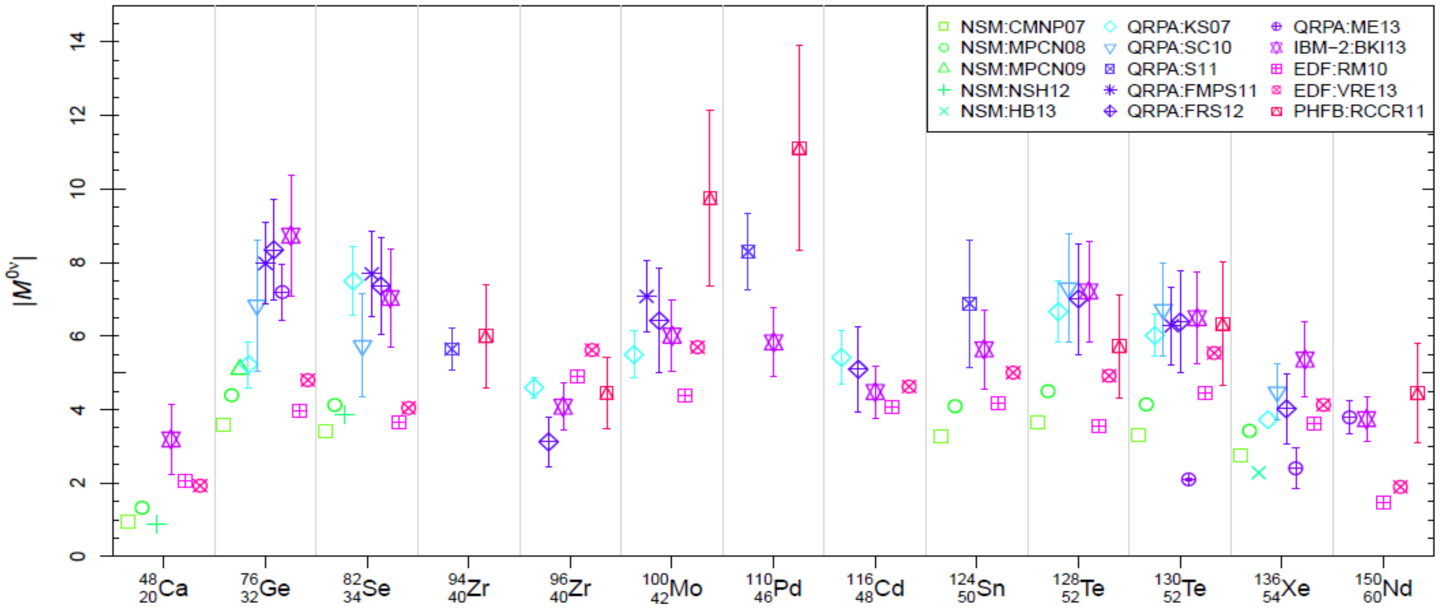
- Nuclear matrix elements can be calculated based on some models which describe many-body interactions of nucleons in nuclei.
- Since different models focus on different aspects of nuclear physics, large uncertainties (a factor of 2 or 3) are unavoidable.



$$T^{0\nu}_{1/2} = \left(G\,|\mathcal{M}|^2\,\langle m_{\beta\beta}\rangle^2\right)^{-1} \simeq 10^{27-28}\left(\frac{0.01\ \mathrm{eV}}{\langle m_{\beta\beta}\rangle}\right)^2\ \mathrm{year}$$

0νββ experiment principle

CDEX

- In order to get $m_{\beta\beta}$, need to experimentally measure $T_{1/2}^{0\nu}$.
- The recent sensitivities: $m_{\beta\beta}$ <100meV.
- **BI, ΔE, M, t, A, ε** are important parameters for 0νββ experiments.
- Signature: Energy peak at known Q value.

$$T_{1/2}^{0\nu} = \left(G\,|\mathcal{M}|^2 \langle m_{\beta\beta}\rangle^2\right)^{-1} \simeq 10^{27-28} \left(\frac{0.01\ \mathrm{eV}}{\langle m_{\beta\beta}\rangle}\right)^2 \mathrm{year}$$

Phase space factor   NME

$$T_{1/2}^{0\nu} \propto \varepsilon \cdot A \cdot \sqrt{\frac{M \cdot T}{BI \cdot \Delta E}}$$

Target mass   Time

Detection Efficiency   Isotope abundance   Background   Energy resolution

0νββ experiment Principle

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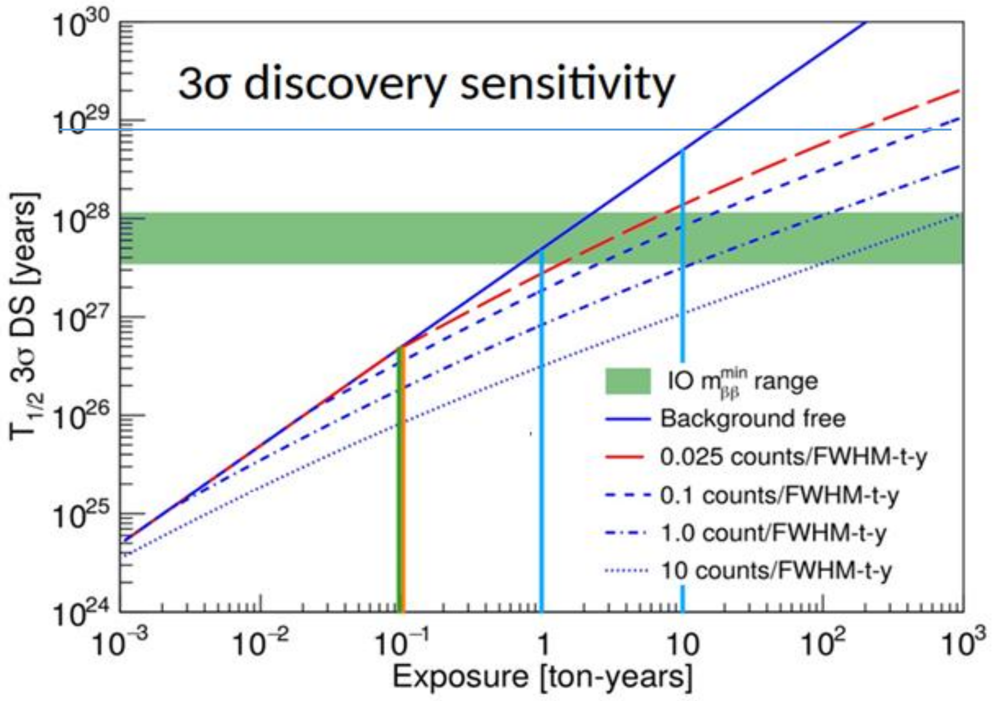
- Non-Zero Background：

$$T_{1/2}^{0\nu} \propto \varepsilon \cdot A \cdot \sqrt{\frac{M \cdot T}{BI \cdot \Delta E}}$$

- Zero Background： $\Delta E \cdot BI \cdot M \cdot T < 1$

$$T_{1/2}^{0\nu} \propto \varepsilon \cdot A \cdot M \cdot T$$



- Zero Background situation: $T_{1/2}^{0\nu}$ changes with $M \cdot T$ linearly.

- Under any circumstances, controlling the background and maintaining a high energy resolution are of utmost importance, the challenge to keep the zero-background condition is much difficult for large-scale experiments.

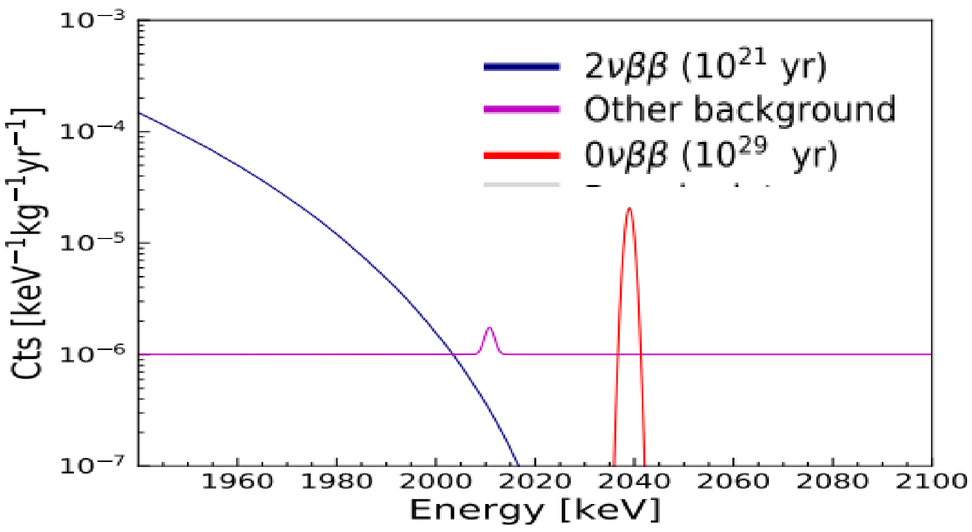
0νββ experiment Principle

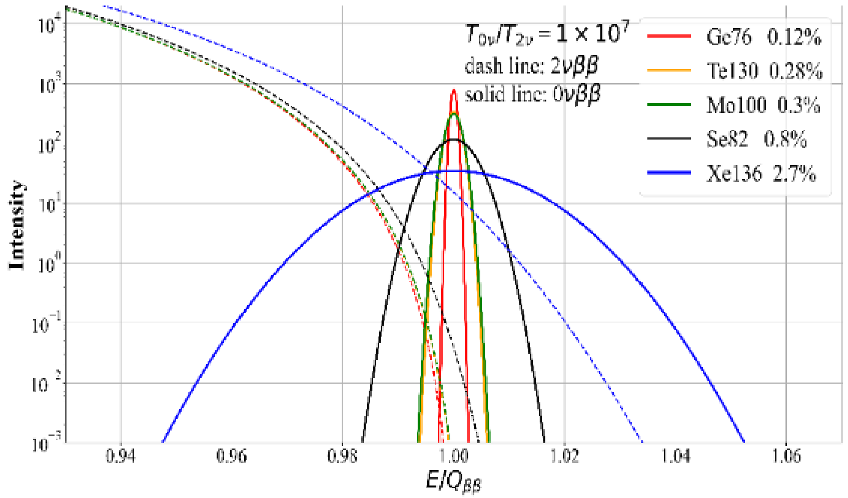
CDEX

- Zero Background： $\Delta E \cdot BI \cdot M \cdot T < 1$

$$T_{1/2}^{0\nu} \propto \varepsilon \cdot A \cdot M \cdot T$$

- Excellent E_R with high $Q_{\beta\beta}$ value:
  - ✓ Precisely measured Energy peak at known $Q_{\beta\beta}$ value： smoking-gun signature;
  - ✓ no irreducible 2νββ background contamination;
  - ✓ suppress ambient background within narrow ROI energy window.



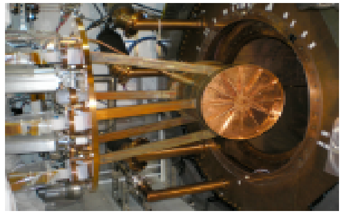


Ref: MJD: PRL 120 132502 (2018) CUORE: PRL 124 122501 (2020) CUPID-Mo: EPJC 80 44 (2020) CUPID-0: EPJC 78 734 (2018) EXO-200: PRL 123 161802 (2019)

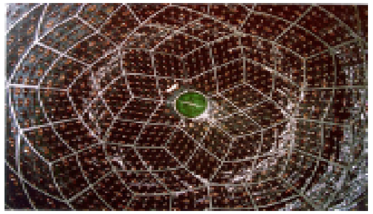
0νββ experiments

CUORE

EXO200



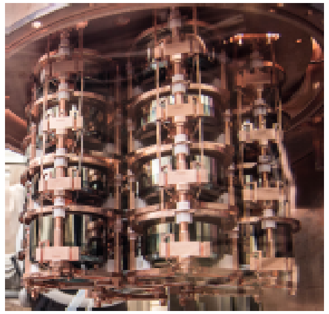
KamLAND Zen



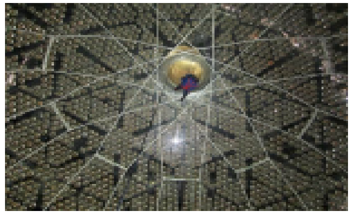
Collaboration	Isotope	Technique	mass (0νββ isotope)	Status
CANDLES	Ca-48	305 kg CaF_2 crystals - liq. scint	0.3 kg	Construction
CARVEL	Ca-48	$^{48}CaWO_4$ crystal scint.	~ ton	R&D
GERDA I	Ge-76	Ge diodes in LAr	15 kg	Complete
GERDA II	Ge-76	Point contact Ge in LAr	31	Operating
MAJORANA DEMONSTRATOR	Ge-76	Point contact Ge	25 kg	Operating
LEGEND	Ge-76	Point contact with active veto	~ ton	R&D
NEMO3	Mo-100 Se-82	Foils with tracking	6.9 kg 0.9 kg	Complete
SuperNEMO Demonstrator	Se-82	Foils with tracking	7 kg	Construction
SuperNEMO	Se-82	Foils with tracking	100 kg	R&D
LUCIFER (CUPID)	Se-82	ZnSe scint. bolometer	18 kg	R&D
AMoRE	Mo-100	$CaMoO_4$ scint. bolometer	1.5 - 200 kg	R&D
LUMINEU (CUPID)	Mo-100	$ZnMoO_4$ / Li_2MoO_4 scint. bolometer	1.5 - 5 kg	R&D
COBRA	Cd-114,116	CdZnTe detectors	10 kg	R&D
CUORICINO, CUORE-0	Te-130	TeO_2 Bolometer	10 kg, 11 kg	Complete
CUORE	Te-130	TeO_2 Bolometer	**206 kg**	Operating
CUPID	Te-130	TeO_2 Bolometer & scint.	~ ton	R&D
SNO+	Te-130	0.3% ^{nat}Te suspended in Scint	**160 kg**	Construction
EXO200	Xe-136	Xe liquid TPC	79 kg	Operating
nEXO	Xe-136	Xe liquid TPC	~ ton	R&D
KamLAND-Zen (I, II)	Xe-136	2.7% in liquid scint.	**380 kg**	Complete
KamLAND2-Zen	Xe-136	2.7% in liquid scint.	**750 kg**	Upgrade
NEXT-NEW	Xe-136	High pressure Xe TPC	5 kg	Operating
NEXT-100	Xe-136	High pressure Xe TPC	100 kg - ton	R&D
PandaX - III	Xe-136	High pressure Xe TPC	~ ton	R&D
DCBA	Nd-150	Nd foils & tracking chambers	20 kg	R&D

GERDA

MAJORANA



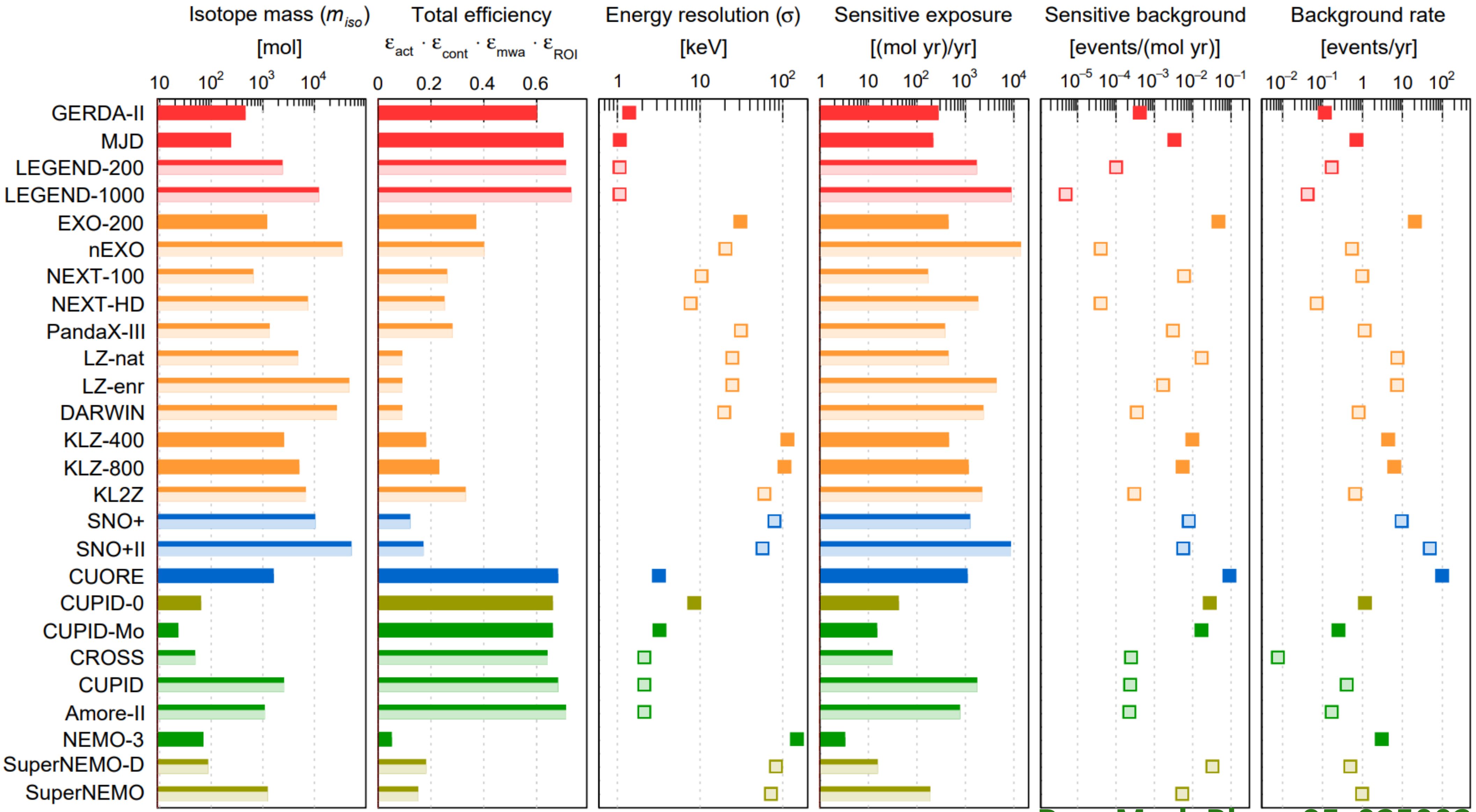
SNO+



0νββ experiments

Experiment		Isotope	$\varepsilon\ [\frac{mol\ yr}{yr}]$	Livetime[yr]	$B\ [\frac{events}{mol\ yr}]$	Status	eff_{act}	σ[keV]	eff_{ROI}
HPGe	GERDA-II	^{76}Ge	722		4.20E-04	completed	88	1.4	95
	MJD	^{76}Ge	527		2.30E-03	completed	90	1.1	95
	LEGEND-200	^{76}Ge	1684	10	1.00E-04	construction	91	1.1	95
	LEGEND-1000	^{76}Ge	8763	10	4.90E-06	proposed	92	1.1	95
	CDEX-1	^{76}Ge	0.75		1.09	completed	84	1.2	95
	CDEX-300n	^{76}Ge	1906	5	5.00E-05	proposed	91	1.1	95
	CDEX-1T	^{76}Ge	8763	5	2.50E-06	proposed	92	1.1	95
	CDEX-10T	^{76}Ge	87630	10	5.00E-07	proposed	92	1.1	95
Xe TPC	EXO-200	^{136}Xe	1324		4.70E-02	completed	46	31	95
	nEXO	^{136}Xe	13700	10	4.00E-05	proposed	64	20	95
	NEXT-100	^{136}Xe	167	10	5.90E-03	construction	88	10	80
	NEXT-HD	^{136}Xe	1809	10	4.00E-05	proposed	95	7.7	65
	PandaX-III-200	^{136}Xe	374	10	3.00E-03	construction	77	31	76
	LZ-nat	^{136}Xe	440	10	1.70E-02	construction	14	25	84
	LZ-enr	^{136}Xe	4302	10	1.70E-03	proposed	14	25	84
	Darwin	^{136}Xe	2312	10	3.50E-04	proposed	13	20	76
Liquid Scintillators	KLZ-400	^{136}Xe	657		9.90E-03	completed	44	114	42
	KLZ-800	^{136}Xe	1173	10	1.40E-03	taking data	58	114	42
	KL2Z	^{136}Xe	2176	10	3.00E-04	proposed	80	60	42
	JUNO-50T	^{136}Xe	235290	5	3.00E-04	proposed	80	48	76
	SNO+I	^{130}Te	1232	10	7.80E-03	construction	20	80	62
	SNO+II	^{130}Te	8521	10	5.70E-03	proposed	27	57	62
Cryogenic calorimeters	CUORE	^{130}Te	1088	10	9.10E-02	taking data	100	3.2	84
	CUPID-0	^{82}Se	410		2.80E-02	completed	100	8.5	95
	CUPID-Mo	^{100}Mo	150		1.70E-02	completed	100	3.2	95
	CROSS	^{100}Mo	31	10	2.50E-02	construction	100	2.1	95
	CUPID	^{100}Mo	1717	10	2.30E-04	proposed	100	2.1	95
	AMORE	^{100}Mo	760	10	2.20E-04	proposed	100	2.1	95
Tracking calorimeters	NEMO-3	^{100}Mo	3	10	9.30E-01	completed	100	148	42
	SuperNEMO-D	^{82}Se	15	10	2.10E-02	construction	100	83	64
	SuperNEMO	^{82}Se	185	10	5.40E-03	proposed	100	72	54

0νββ experiments



Rev. Mod. Phys. 95, 025002 (2023)

Results from International 0νββ experiments

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核素	实验	探测器技术	$T_{1/2}^{0\nu}$ [yr]	$m_{\beta\beta}$ [meV]	文献
^{48}Ca	ELEGANT-VI	CaF_2(Eu) 闪烁体	$> 5.8\times10^{22}$	< 3.5~22 eV	PHYSICAL REVIEW C 78, 058501 (2008)
^{76}Ge	GERDA	高纯锗探测器	$> 1.8\times10^{26}$	< 79~180	PHYSICAL REVIEW LETTERS 125, 252502 (2020)
^{76}Ge	LEGEND	高纯锗探测器	$> 1.9\times10^{26}$	< 75~170	(预印本) arXiv:2501.10046, (2025)
^{82}Se	CUPID-0	ZnSe 闪烁体量热器	$> 4.6\times10^{24}$	< 263~545	PHYSICAL REVIEW LETTERS 129, 111801 (2022)
^{96}Zr	NEMO-3	径迹量能器	$> 9.2\times10^{21}$	< 7.2~19.5 eV	NUCLEAR PHYSICS A 847, 168–179 (2010)
^{100}Mo	CUPID-Mo	Li_2MoO_4 闪烁体量热器	$> 1.8\times10^{24}$	< 280~490	EUROPEAN PHYSICAL JOURNAL C, 82:1033, (2022)
^{116}Cd	AURORA	$^{116}CdWO_4$ 闪烁体	$> 2.2\times10^{23}$	< 1~1.7 eV	PHYSICAL REVIEW D 98, 092007 (2018)
^{130}Te	CUORE	TeO_2 量热器	$> 2.2\times10^{25}$	< 90~305	NATURE 604, 7 (2022)
^{136}Xe	KamLAND-Zen	掺 Xe 液体闪烁体	$> 2.3\times10^{26}$	< 36~160	PHYSICAL REVIEW LETTERS 130, 051801 (2023)
^{136}Xe	KamLAND-Zen	掺 Xe 液体闪烁体	$> 3.8\times10^{26}$	< 28~122	(预印本) arXiv:2406.11438, (2024)
^{150}Nd	NEMO-3	径迹量能器	$> 2.0\times10^{22}$	< 1.6~5.3 eV	PHYSICAL REVIEW D 94, 072003 (2016)

Results from International 0νββ experiments

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实验组	核素	丰度	靶质量	$Q_{\beta\beta}$处 能量分辨率σ	本底水平 [c/ROI•ton•yr]	曝光量 (kg·y)	半衰期 (10^{25}y)	有效中微子质量 (meV)
GERDA	^{76}Ge	87%	44.2 kg	0.05%	2.1	127.2	> 18	< 79-180
Majorana	^{76}Ge	88%	40.4 kg	0.05%	28.2	64.5	> 8.3	< 113-269
Legend-200	^{76}Ge	90%	143 kg	0.05%	2.04	48.3	> 19	< 75-170
KamLAND-Zen	^{136}Xe	90%	745 kg	4.64%	23.8	2097	> 38	< 28-122
EXO-200	^{136}Xe	80.6%	74.7 kg	1.15%	192.0	234.1	> 3.5	< 93-286
CUORE	^{130}Te	34.2%	206 kg	0.31%	470.0	372.5	> 3.2	< 90-305

International 0νββ experiments

CDEX

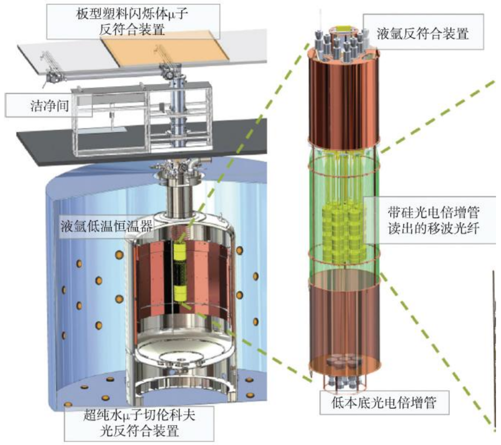
- 目前多种实验技术方案参与“无双”实验的国际竞争；
- 主要核素：锗-76、硒-82、钼-100、碲-130、氙-136、钕-150等。

富集锗阵列
核素：锗-76
欧美联合LEGEND
中国CDEX@CJPL

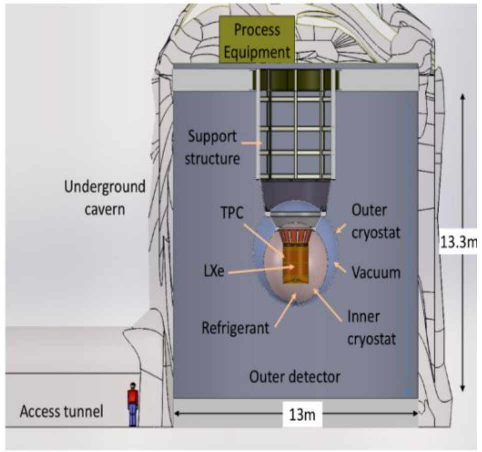
富集氙或自然氙液体TPC实验
核素：氙-136
富集氙：美国nEXO（高能所参加）
天然氙：欧美XLZD、中国PandaX@CJPL

液闪添加氙-136实验
核素：氙-136
日本Kamland-Zen
中国JUNO-0vbb

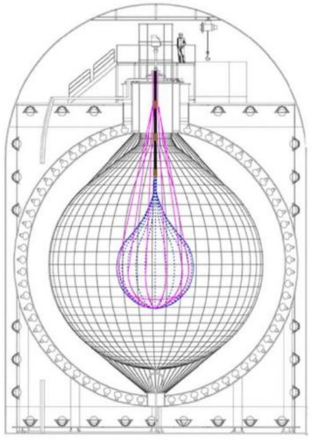
液闪添加碲-130实验
核素：碲-130
加拿大SNO+
中国JUNO-0vbb



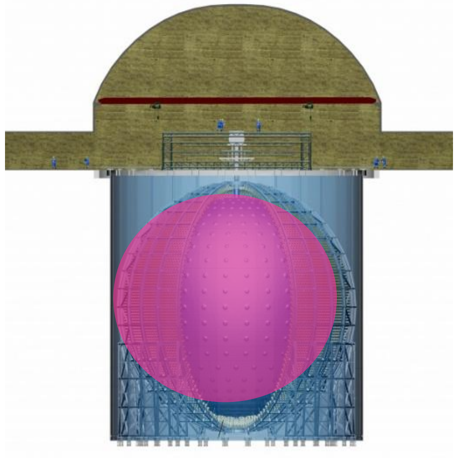
LEGEND



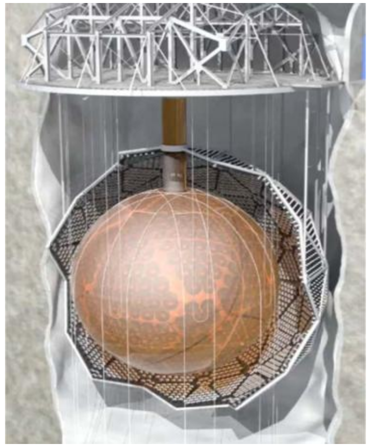
nEXO



KamLAND-Zen



JUNO-$0\nu\beta\beta$



SNO+

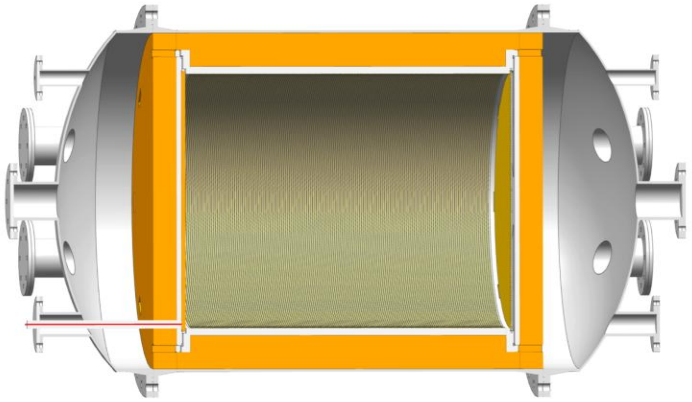
International 0vββ experiments

- 目前多种实验技术方案参与“无双”实验的国际竞争；
- 主要核素：锗-76、硒-82、钼-100、碲-130、氙-136、钕-150等。

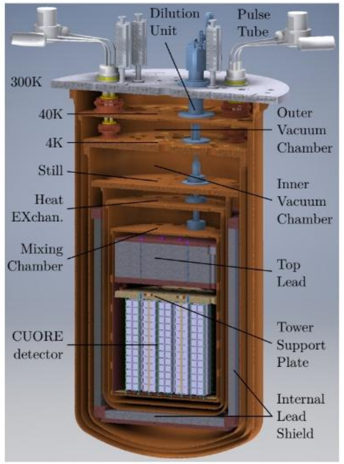
高气压TPC
核素：硒-82、氙-136
欧洲NEXT
中国NvDEx、PandaX-III

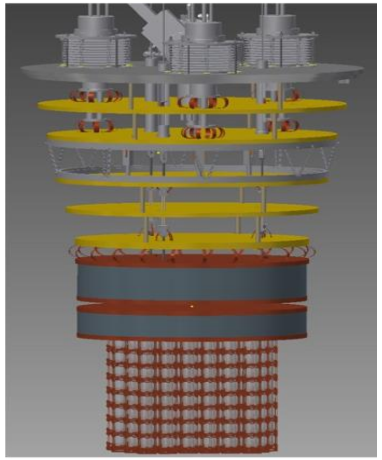
超低温晶体量热器
核素：钼-100
欧洲CUPID、韩国AMoRE
中国CUPID-CJPL

液闪掺杂实验
核素：钕Nd-150…
……
中国JNE

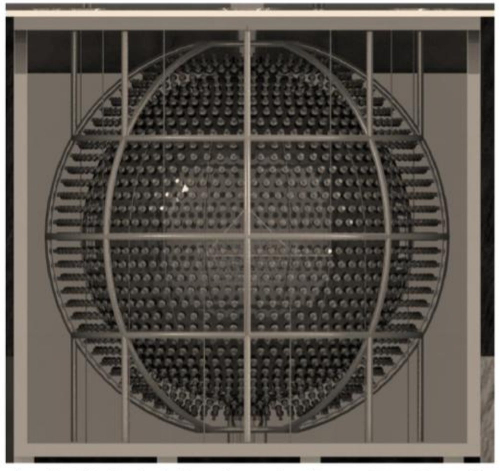


NvDEx PandaX-III



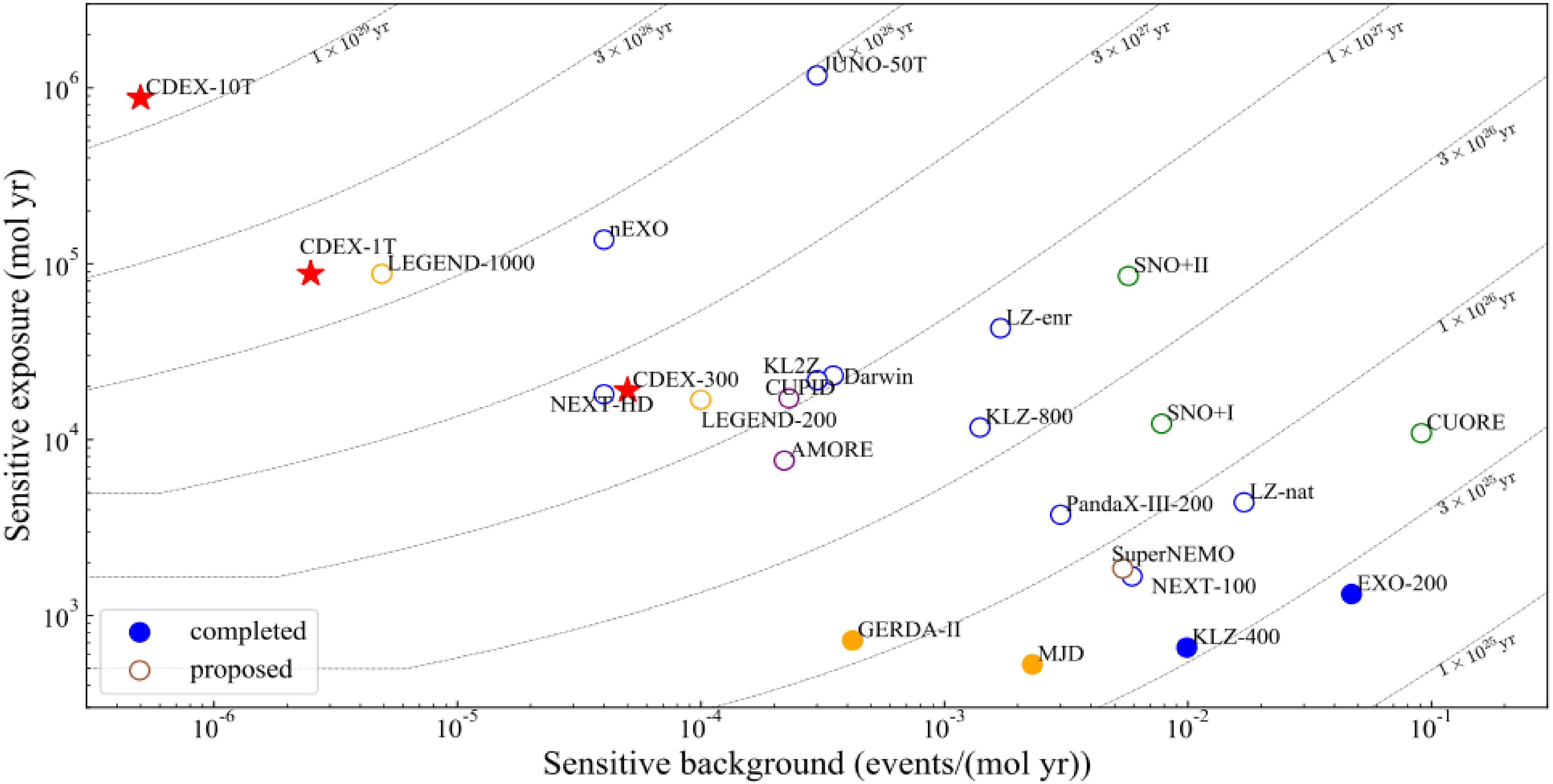


CUPID AMoRE



JNE

Sensitivities of international 0νββ experiments



^{76}Ge 0νββ experiments

CDEX

- LAr AC + Enriched Germanium array;
- Prototype：

  ---BEGe（CDEX）、ICPC（LEGEND）、PPC（GERDA）；

- PreAMP：

  ---ASIC（CDEX, L-1000）、JFET（G、M、L-200）.

^{76}Ge 0νββ experiments

CDEX

GERDA	
mass	45 kg
exposure	127 kg yr
bkg idx	$5.2 \cdot 10^{-4}$ cts/(keV kg yr)
resolution	2.6 keV

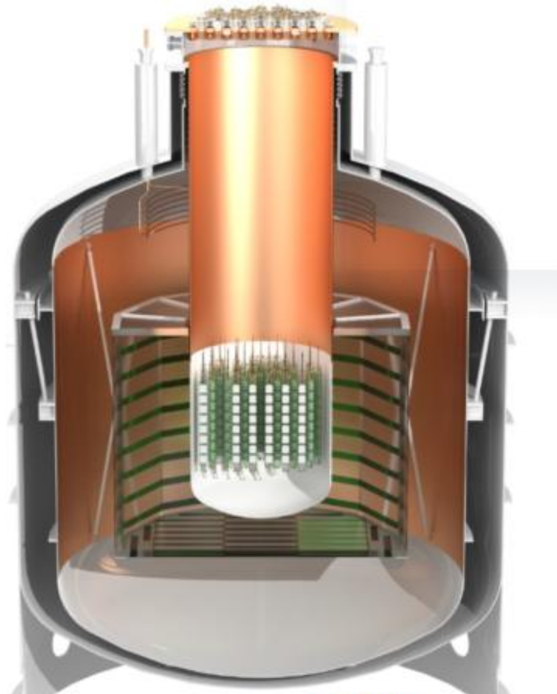
MAJORANA Demonstrator	
mass	30 kg
exposure	65 kg yr
bkg idx	$6.6 \cdot 10^{-3}$ cts/(keV kg yr)
resolution	2.52 keV

LEGEND-200 goal	
mass	**200 kg**
exposure	**1000 kg yr** x10 ↑
bkg idx	$2 \cdot 10^{-4}$ cts/(keV kg yr) x2.5 ↓
resolution	2.5 keV

LEGEND-1000 goal	
mass	**1000 kg**
exposure	**10 000 kg yr** x100 ↑
bkg idx	10^{-5} cts/(keV kg yr) x50 ↓
resolution	2.5 keV

lowest bkg

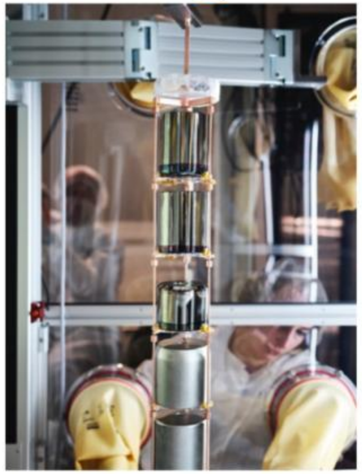
best E reso

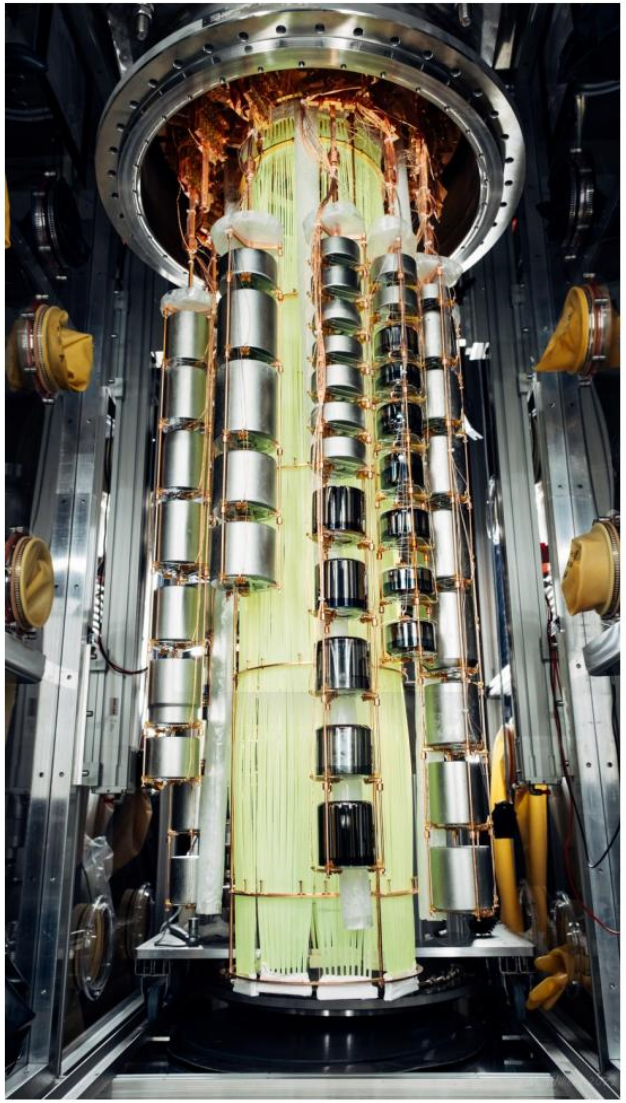


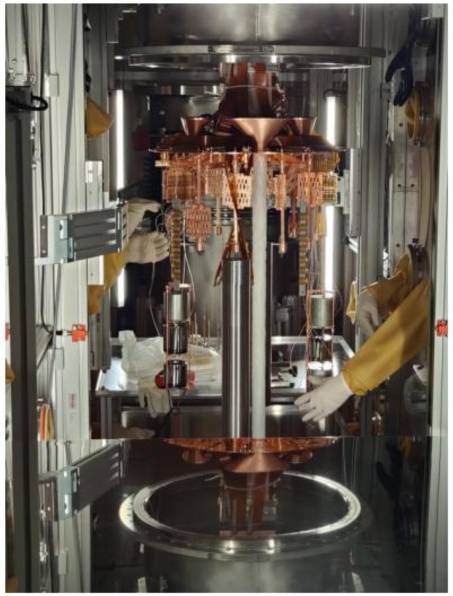
credit to Patrick Krause

^{76}Ge 0νββ experiments

CDEX

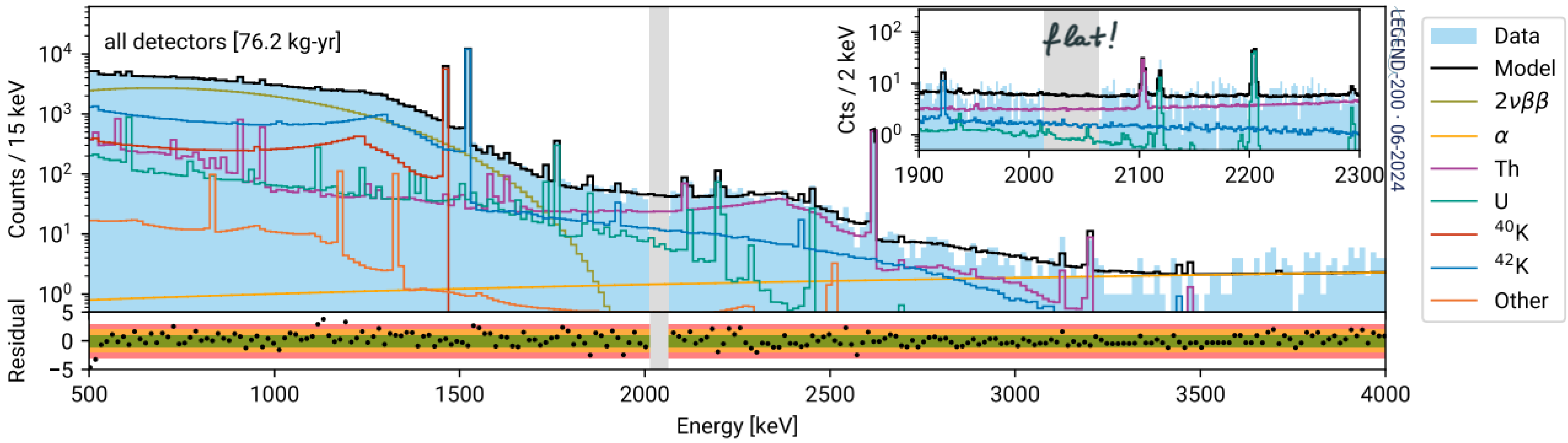


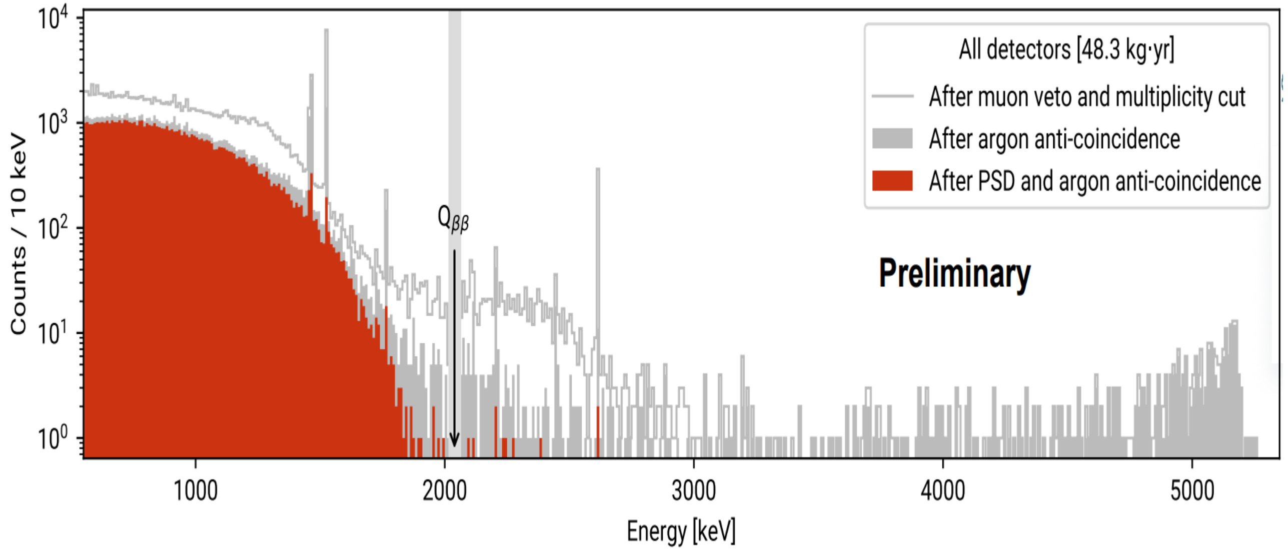


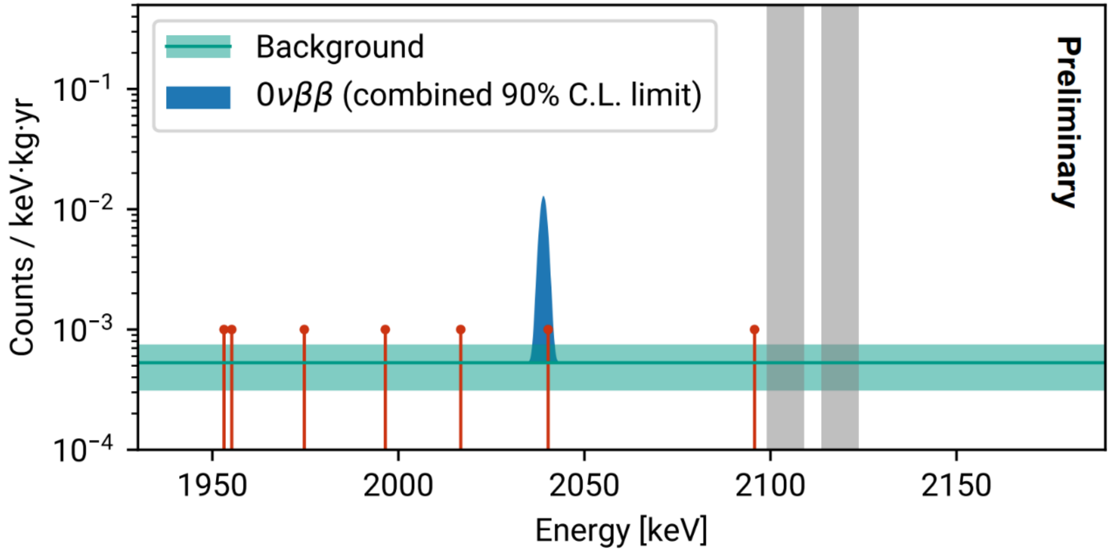


LEGEND-200 new results

CDEX

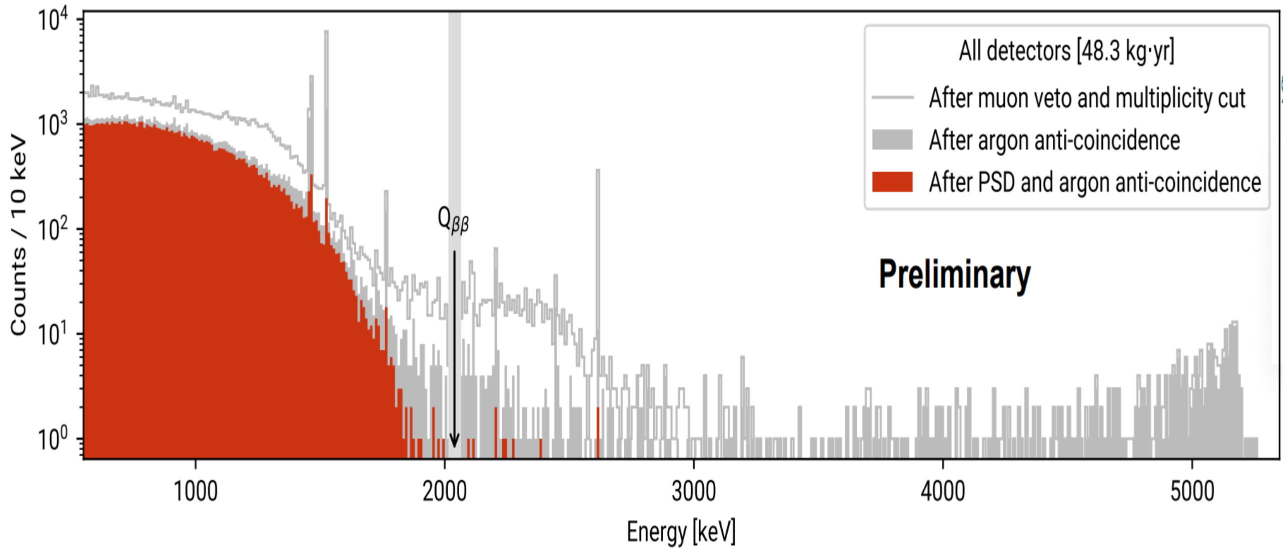


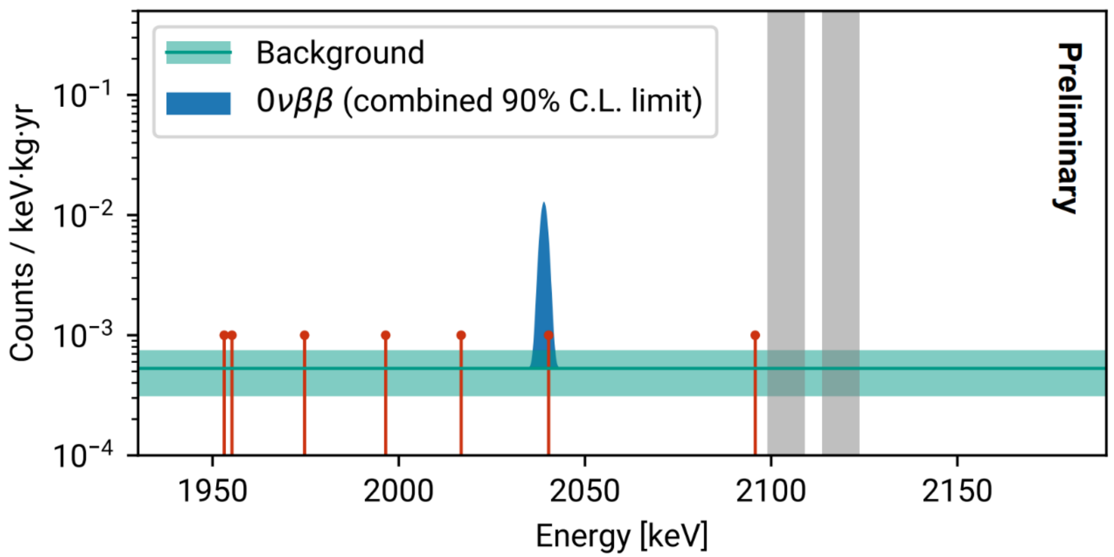




LEGEND-200 new results

- BI=5.3±2.2×10^{-4} cpkky（数据量少，误差较大，高于预期）
- PPC/ICPC FWHM ΔE=2.50±0.01 keV @2.039MeV（σ=0.05%）
- BEGe FWHM ΔE=2.06±0.01 keV @2.039MeV （好于预期）
- $T_{1/2}^{0\nu} > 1.9\times10^{26}$ yr





LEGEND Collaboration

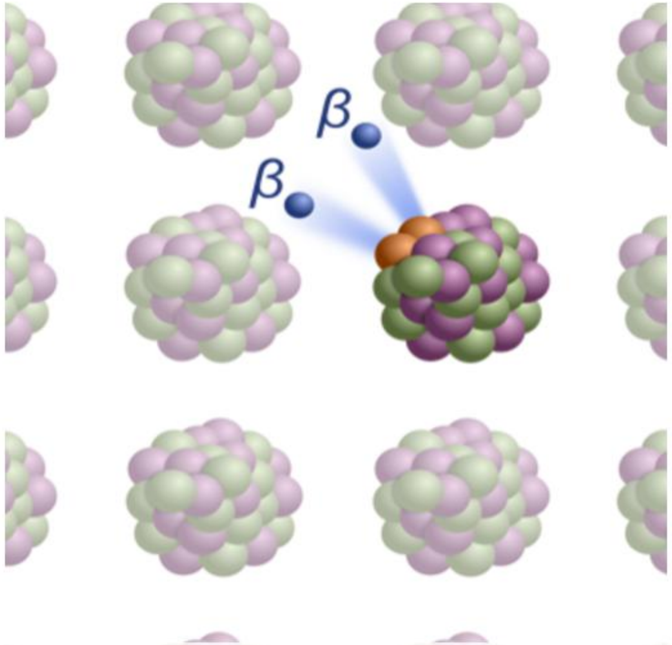
2016年10月，美国亚特兰大，LEGEND成立

2018年7月，西昌会议，并访问锦屏地下实验室

2018年11月,美国诺克斯维尔会议

LEGEND

The LEGEND collaboration is comprised of over 250 researchers from about 50 institutions from around the world, working together to develop the largest ^{76}Ge neutrinoless double-beta decay experiment in history. By combining the technological expertise and experience from the GERDA experiment and MAJORANA DEMONSTRATOR, LEGEND is expected to reach a design sensitivity two orders of magnitude greater than its predecessors.



The physics case

Majorana neutrinos

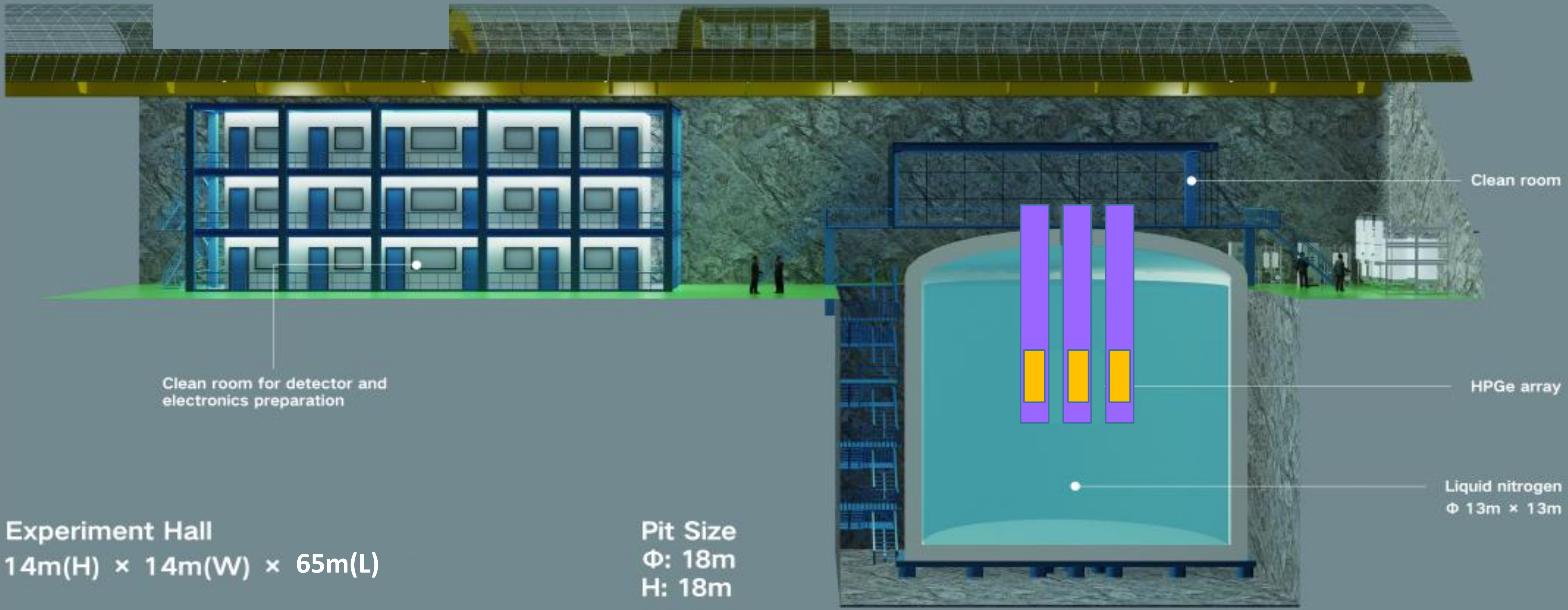
Find Us

Conferences, Workshops &

Join LEGEND

Jobs & Projects Available

CDEX-1T
Conceptual Layout



^{136}Xe 0νββ experiment

CDEX

- **Detector：** En-LXeTPC, N-LXeTPC, LS-Xe, HPGas-Xe…
- **0νββ Experiments:**

  ---nEXO, Kamland-Zen，JUNO-0νββ，PandaX-III，NEXT， …
- **DM+0νββ Experiments:** XLZD，PandaX-xT

nEXO

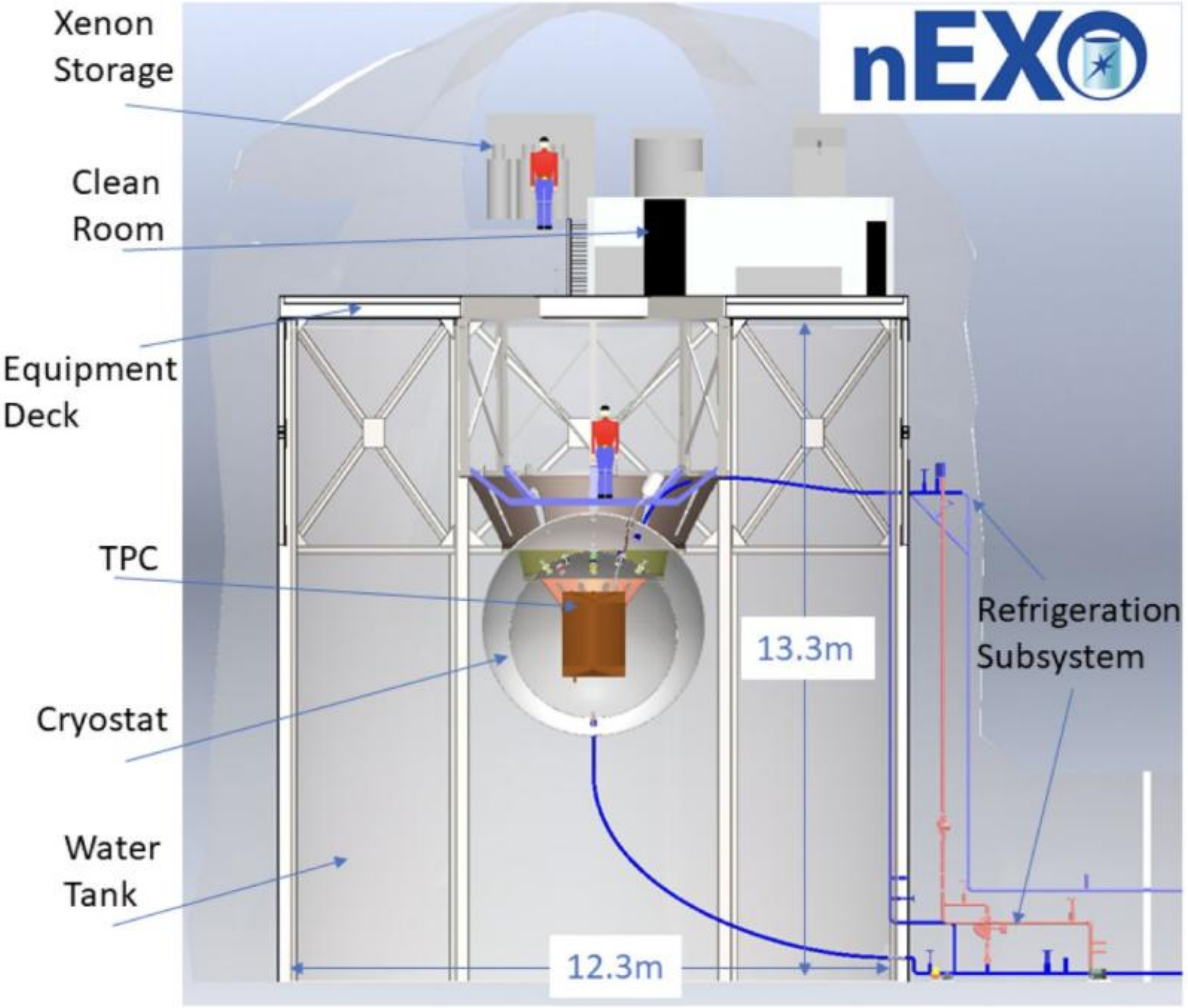
CDEX

nEXO

nEXO

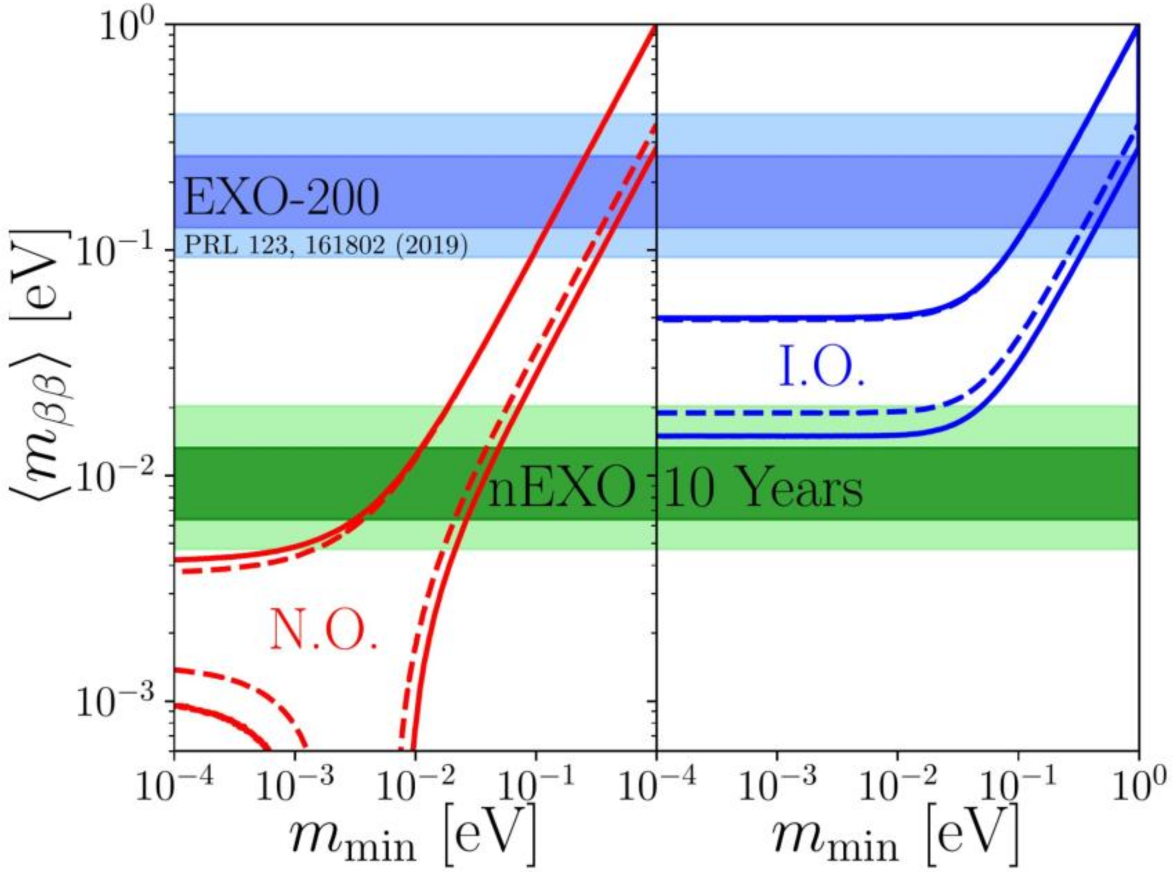
nEXO is a proposed $0\nu\beta\beta$ experiment

- 5-tonne single-phase liquid Xe TPC
- 90% enriched in the target isotope, ^{136}Xe
- Extensive radio-assay program (ultra low backgrounds validated by EXO-200 data)

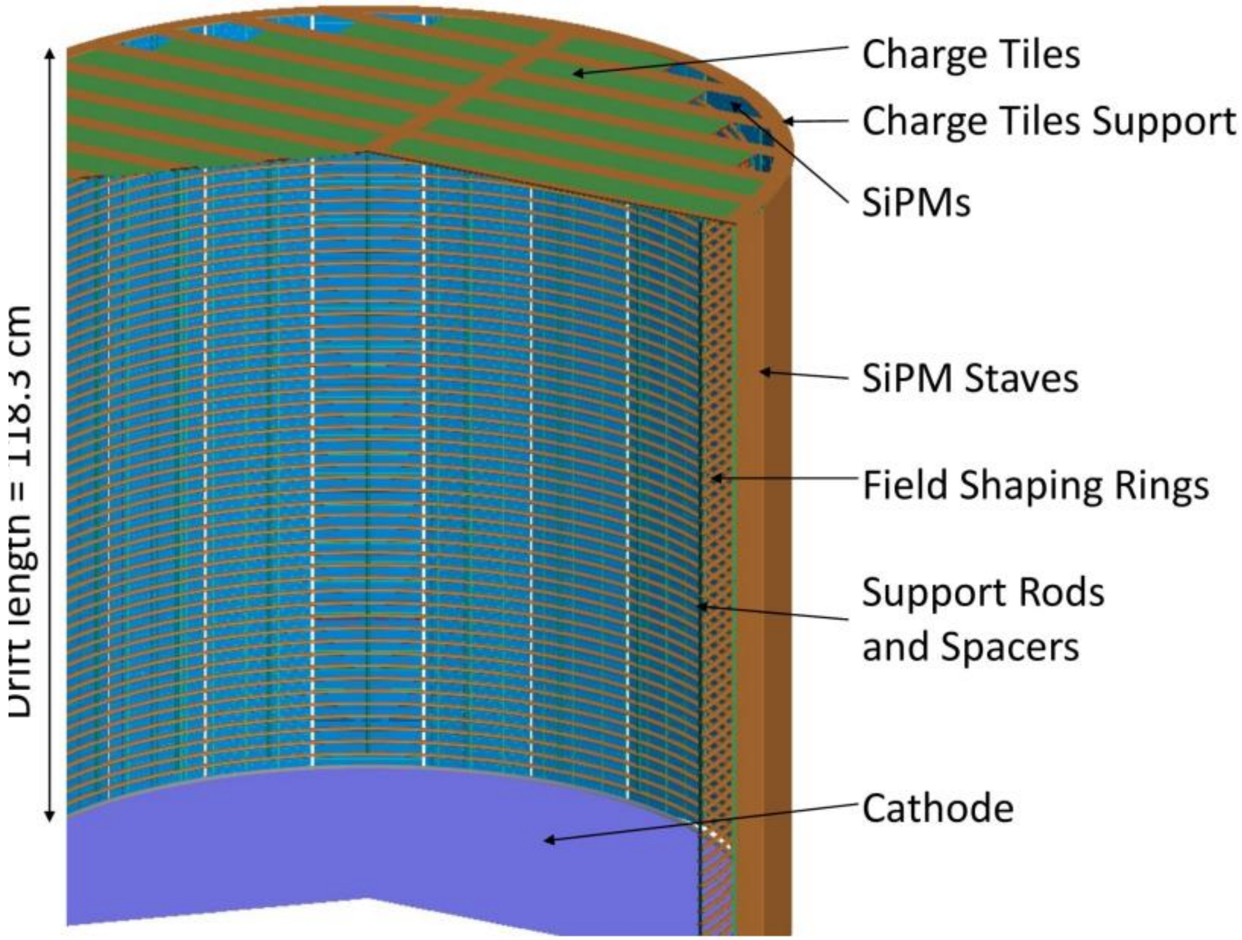


nEXO

CDEX



EXO-200
PRL 123, 161802 (2019)
I.O.
nEXO 10 Years
N.O.
$\langle m_{\beta\beta} \rangle$ [eV]
$m_{\min}$ [eV]
$m_{\min}$ [eV]



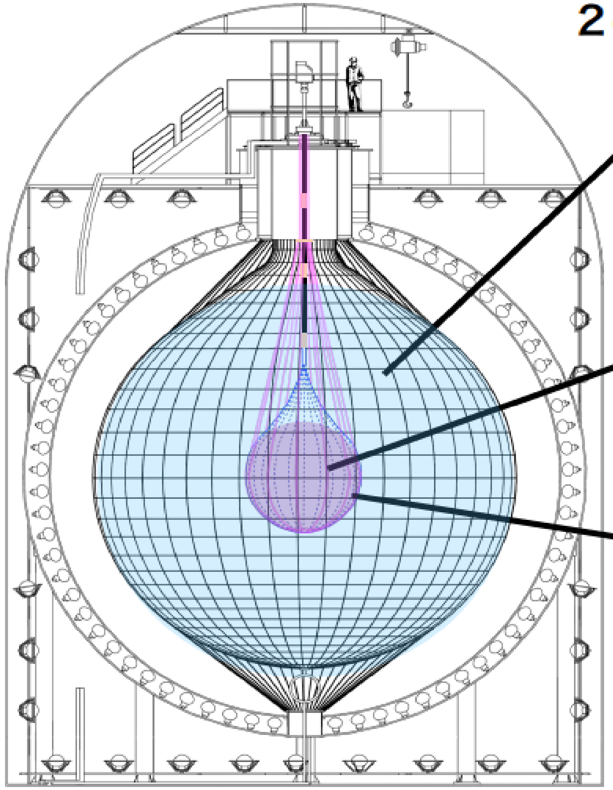
Charge Tiles
Charge Tiles Support
SiPMs
SiPM Staves
Field Shaping Rings
Support Rods
and Spacers
Cathode
Drift length = 118.3 cm

KLZ

CDEX

Zero Neutrino Double Beta

KamLAND detector



2-type of liquid scintillator

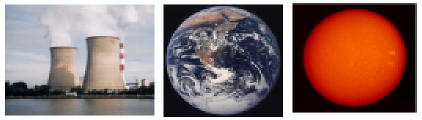
1000-ton pure liquid scintillator

U, Th < 10^{-17} g/g

745 kg Xe-loaded liquid scintillator (91% enrichment)

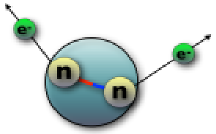
inner balloon (IB)

2002– KamLAND



reactor, geo, solar neutrino observation

2011– KamLAND-Zen



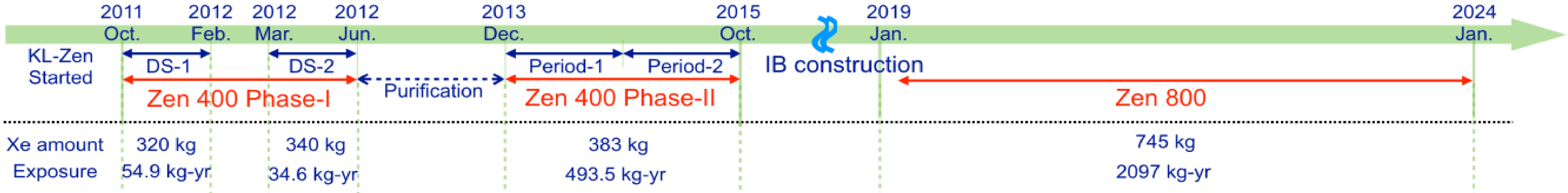
double beta decay measurement ($0\nu\beta\beta$ search)

2019– Xe increase, cleaner balloon

big and pure : no background from external gamma-rays
purification of LS, replacement of mini-balloon are possible

→ **high scalability**

Xe **320 kg** **340 kg** **383 kg** **745 kg** **largest ^{136}Xe !!**



KLZ

0νββ search : Feb. 5, 2019 – Jan. 12, 2024
with the complete KamLAND-Zen 800 data-set

CDEX

KLZ

- $T_{1/2}^{0\nu}$ > 3.8×10^26 yr (Combined KLZ400 and KLZ800)

$0\nu\beta\beta$ candidate

(sensitive to $0\nu\beta\beta$ signal)

1131 days livetime

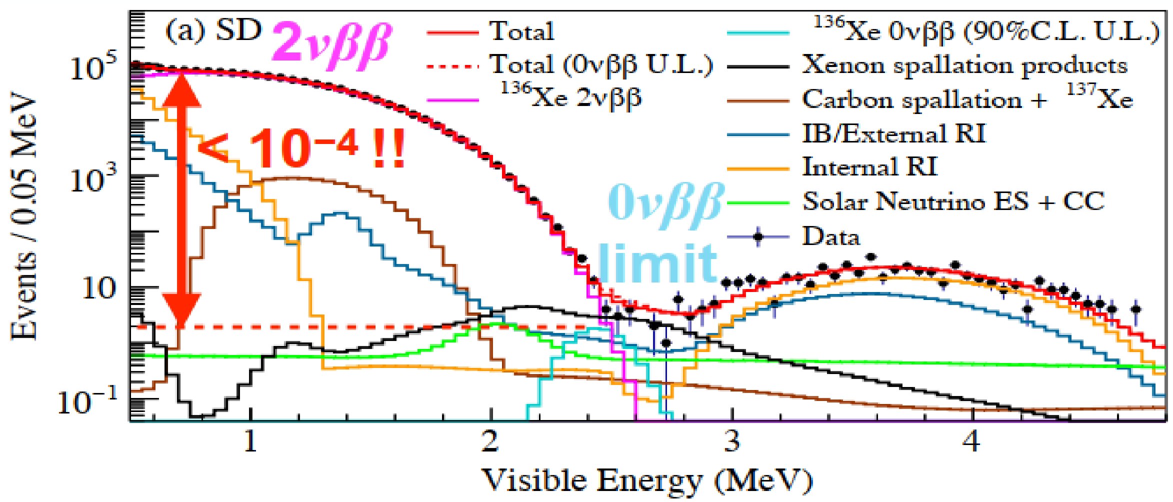
R < 1.57 m

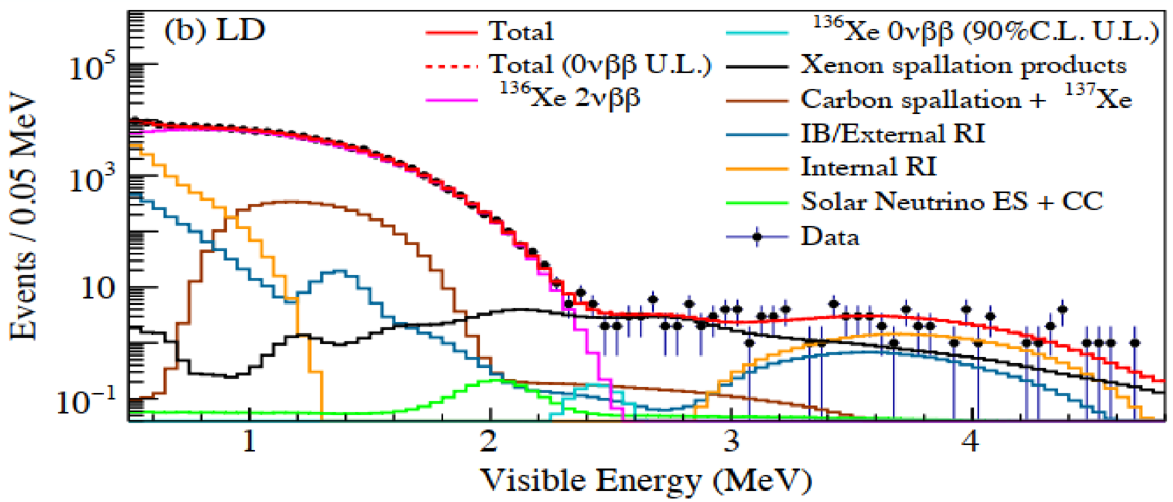
long-lived candidate

(Long-lived BG constraint)

111 days livetime

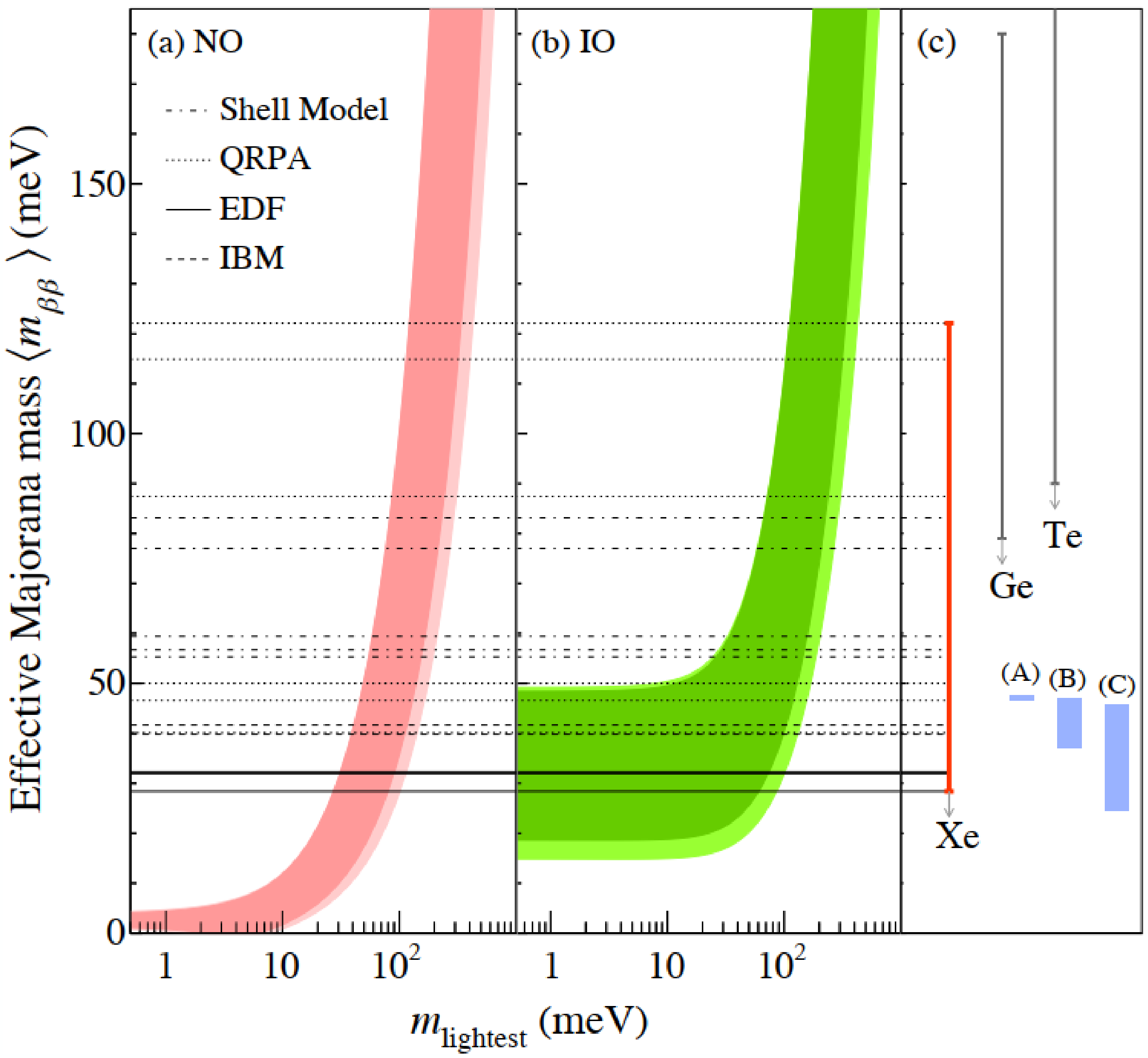
R < 1.57 m





KLZ

CDEX



NME for ^{136}Xe : 1.11−4.77

NME calculations assuming g_A ~ 1.27

Shell Model

[1] J. Menéndez, J. of Phys. G **45**, 014003 (2018).
[2] M. Horoi and A. Neacsu, Phys. Rev. C **93**, 024308 (2016).
[3] L. Coraggio, A. Gargano, N. Itaco, R. Mancino, and F. Nowacki, Phys. Rev. C **101**, 044315 (2020).
[4] L. Coraggio *et al.*, Phys. Rev. C **105**, 034312 (2022).

QRPA

[5] M. T. Mustonen and J. Engel, Phys. Rev. C **87**, 064302 (2013).
[6] J. Hyvärinen and J. Suhonen, Phys. Rev. C **91**, 024613 (2015).
[7] F. Šimkovic, A. Smetana, and P. Vogel, Phys. Rev. C **98**, 064325 (2018).
[8] D.-L. Fang, A. Faessler, and F. Šimkovic, Phys. Rev. C **97**, 045503 (2018).
[9] J. Terasaki, Phys. Rev. C **102**, 044303 (2020).

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[10] T. R. Rodríguez and G. Martínez-Pinedo, Phys. Re Lett. **105**, 252503 (2010).
[11] N. L. Vaquero, T. R. Rodríguez, and J. L. Egido, Phy Rev. Lett. **111**, 142501 (2013).
[12] L. S. Song, J. M. Yao, P. Ring, and J. Meng, Phys. Re C **95**, 024305 (2017).

IBM

[13] J. Barea, J. Kotila, and F. Iachello, Phys. Rev. C 9 034304 (2015).
[14] F. F. Deppisch, L. Graf, F. Iachello, and J. Kotila, Phy Rev. D **102**, 095016 (2020).

Theoretical model

(A) K. Harigaya, M. Ibe, and T. T. Yanagida, Phys. Rev. D **86**, 013002 (2012).
(B) T. Asaka, Y. Heo, and T. Yoshida, Phys. Lett. B **811**, 135956 (2020).
(C) K. Asai, The European Physical Journal C **80**, 76 (2020).

KamLAND-Zen (^{136}Xe)

⟨$m_{\beta\beta}$⟩ < 28−122 meV

$m_{lightest}$ < 84−353 meV

Most stringent tests of the neutrino mass in the IO region

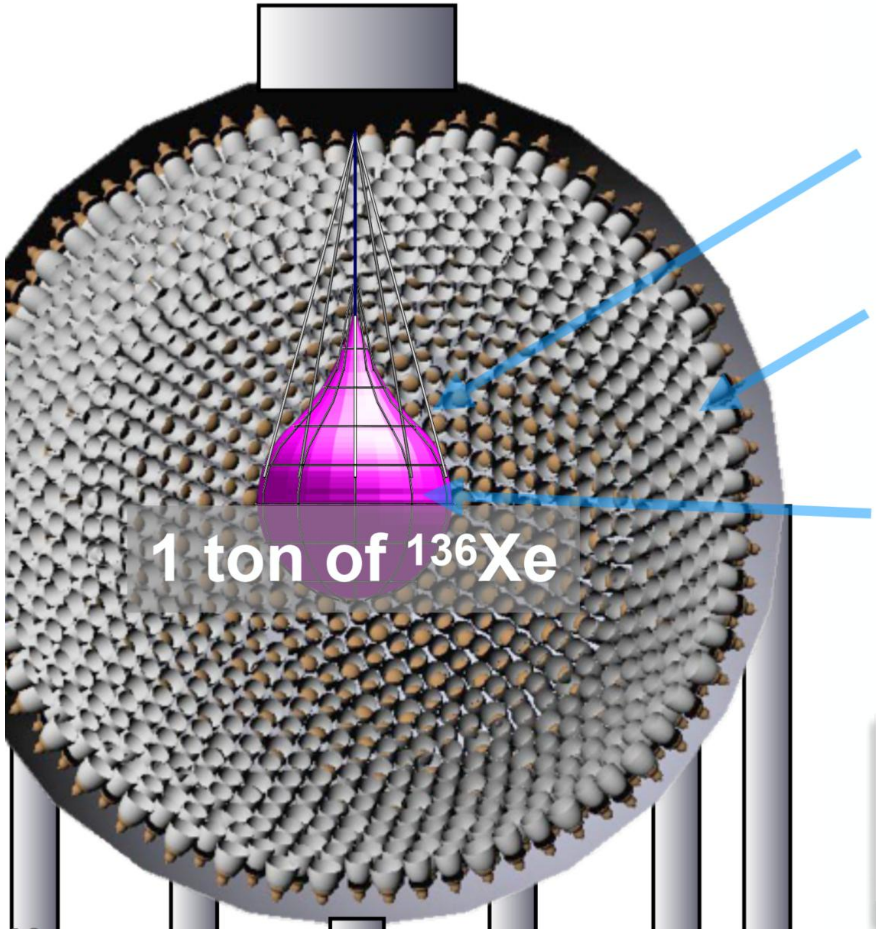
KLZ

CDEX

Future: KamLAND2-Zen

KamLAND → KamLAND2

Enlarge opening
General use: accommodate various devices such as $CdWO_4$, NaI, CaF_2 detectors



New electronics
To improve background suppression.
Tagging long lived isotope from cosmic ray spallation.

Scintillation inner balloon
BG reduction from Xe-LS container

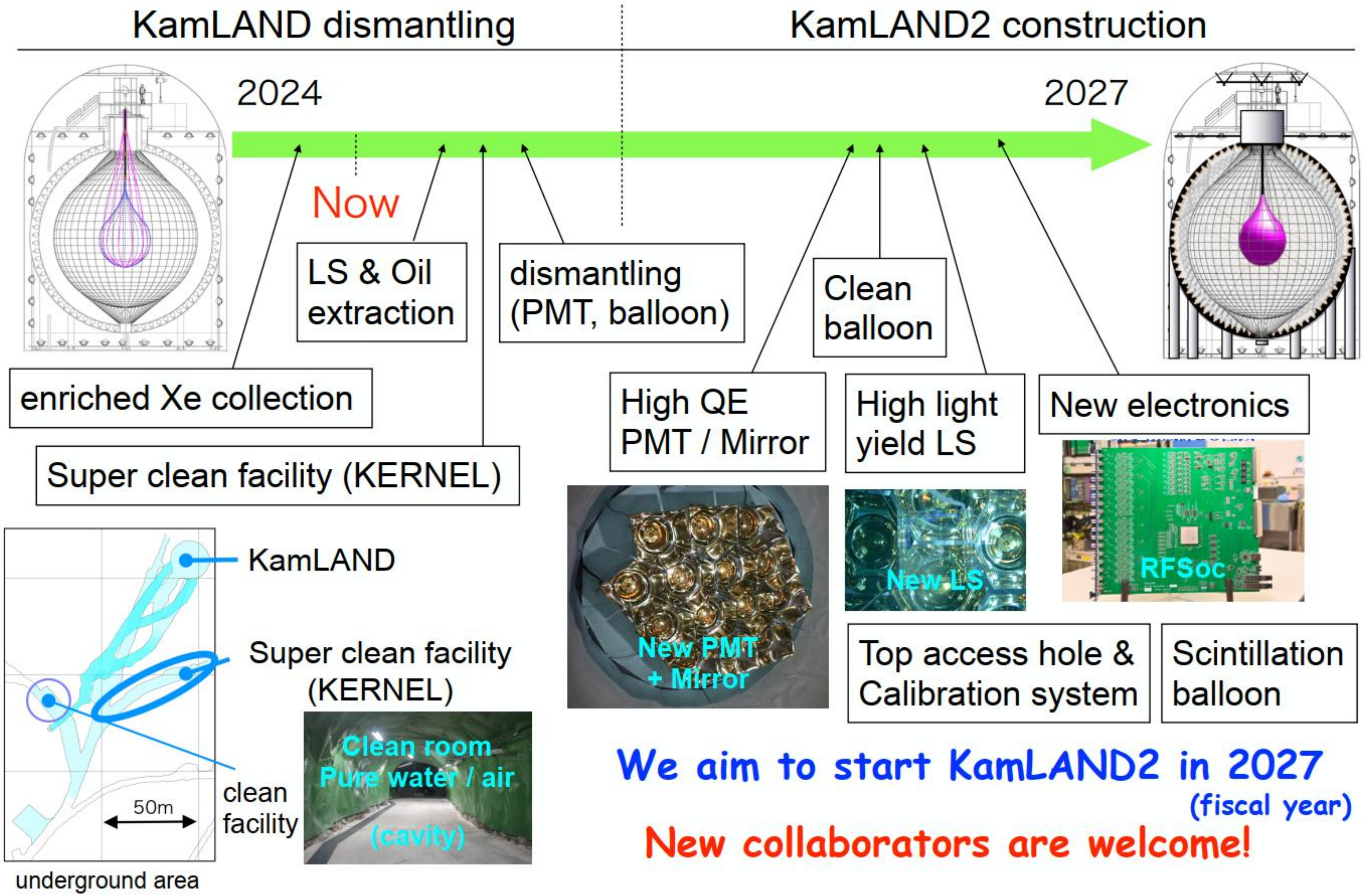
Winstone cone & High QE PMT
Improve light collection efficiency and photo coverage

Brighter LS
Current LS ~8,000 photon/MeV
LAB based new LS ~12,000 photon/MeV

$\sigma(2.6\text{MeV}) = 4\% \rightarrow \sim 2\%$
Target $\langle m_{\beta\beta} \rangle$ ~20 meV in 5 yrs

KLZ

CDEX



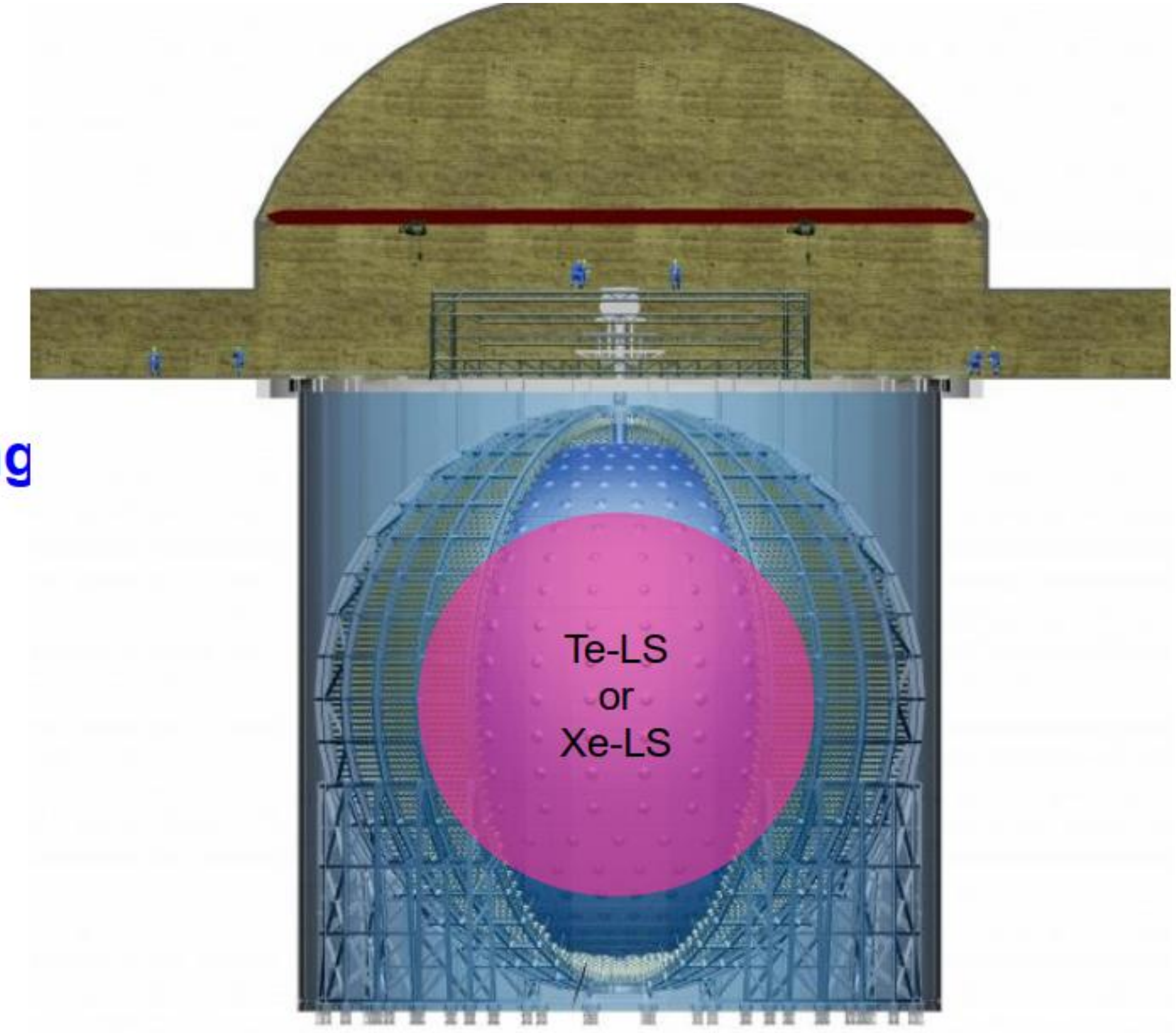
We aim to start KamLAND2 in 2027
(fiscal year)

New collaborators are welcome!

JUNO-0νββ

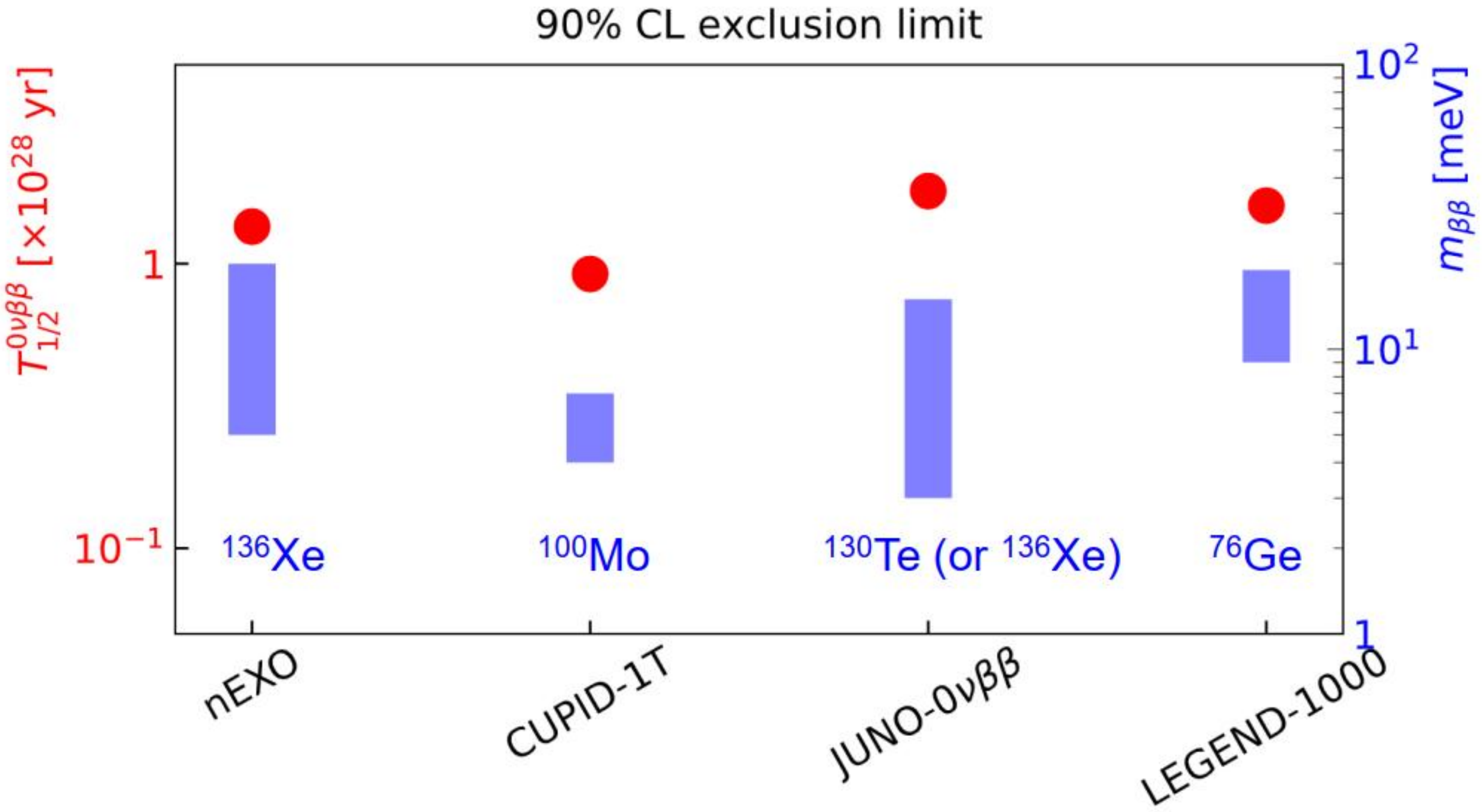
CDEX

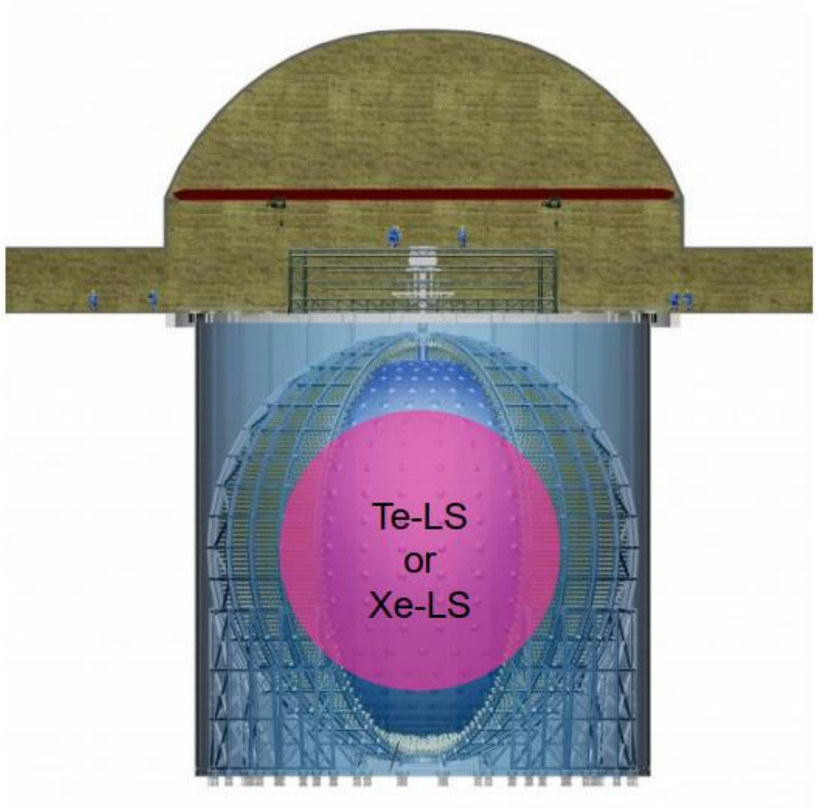
- JUNO offers an unique opportunity to search for 0νββ
  - 20 kton LS → **100-ton scale isotope loading** (e.g., Tellurium, Xenon)
  - Low background
  - Energy resolution < 3% @ 1 MeV → **2.4x better than KamLAND-Zen**



JUNO-0νββ

CDEX

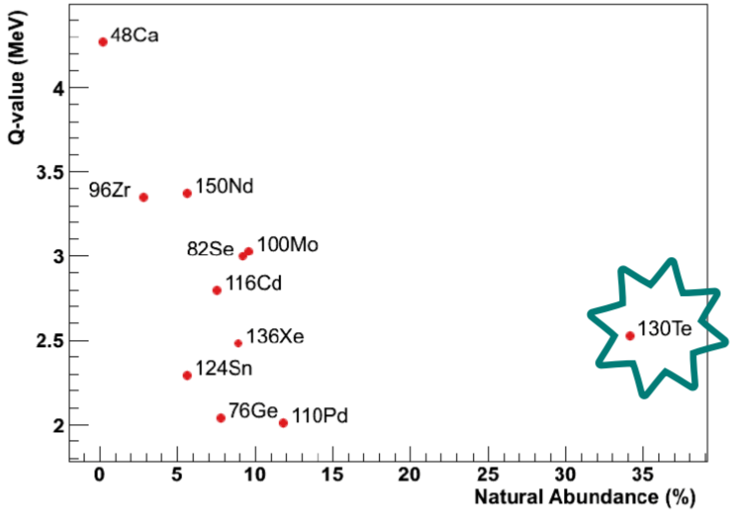


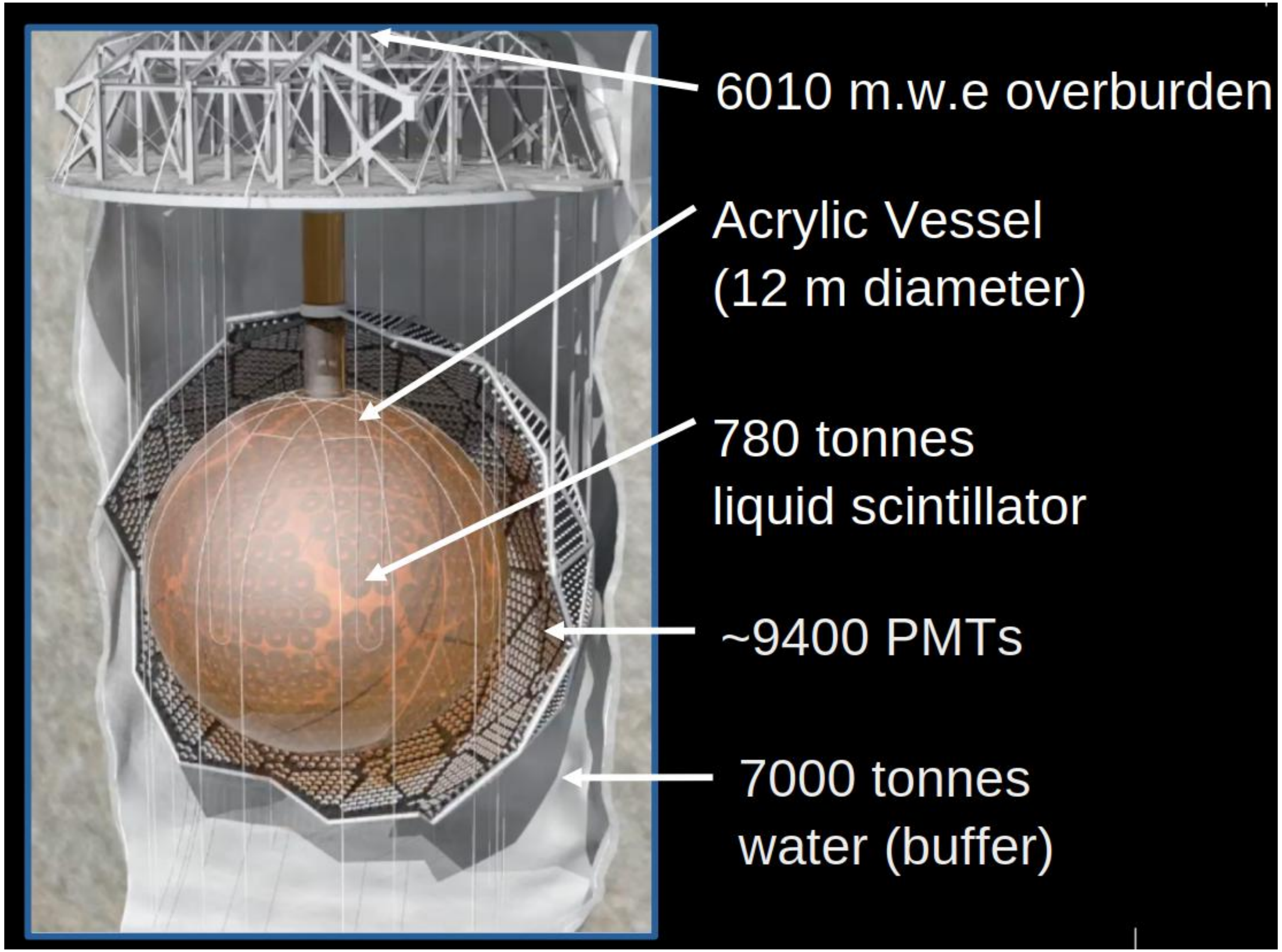


Concept of the experiment

SNO+

- Three target's materials:
  - 905 t of *ultra-pure water* (2017-2019);
  - ~780 t of *high purity liquid scintillator* + 2.2 g/L PPO +bisMSB (2022-2024);
  - 3.9 t ^{nat}*Te-loaded scintillator* (2024 -).





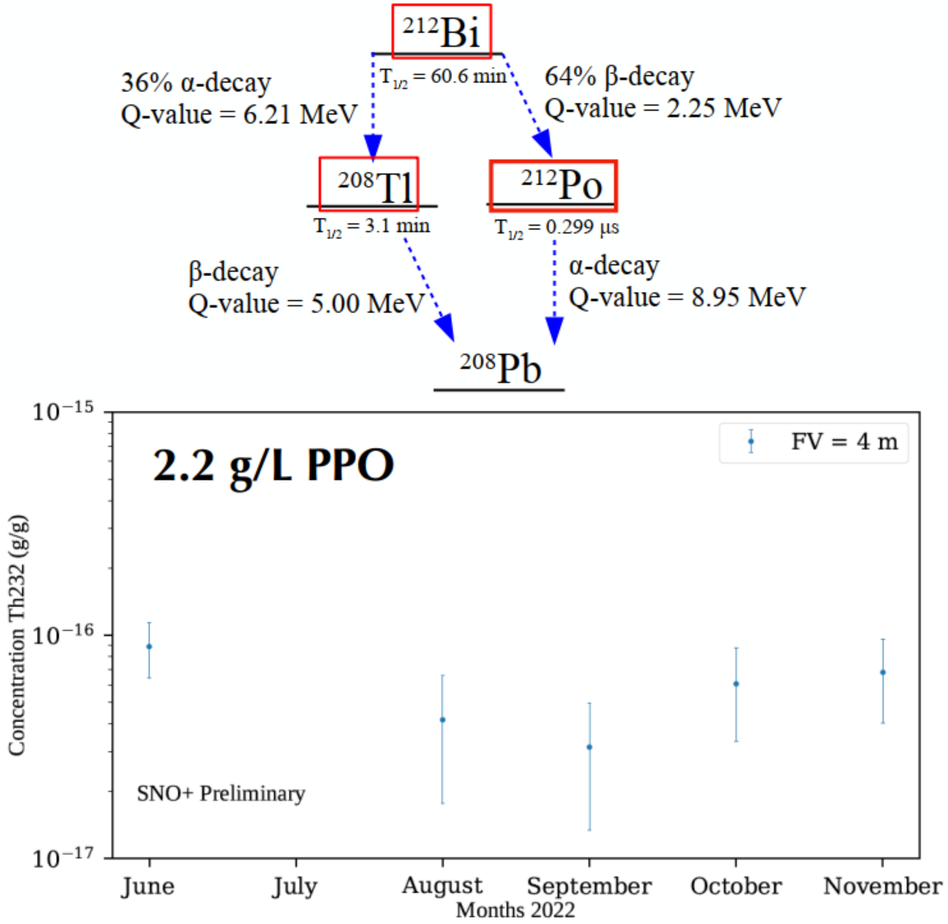
CDEX

SNO+

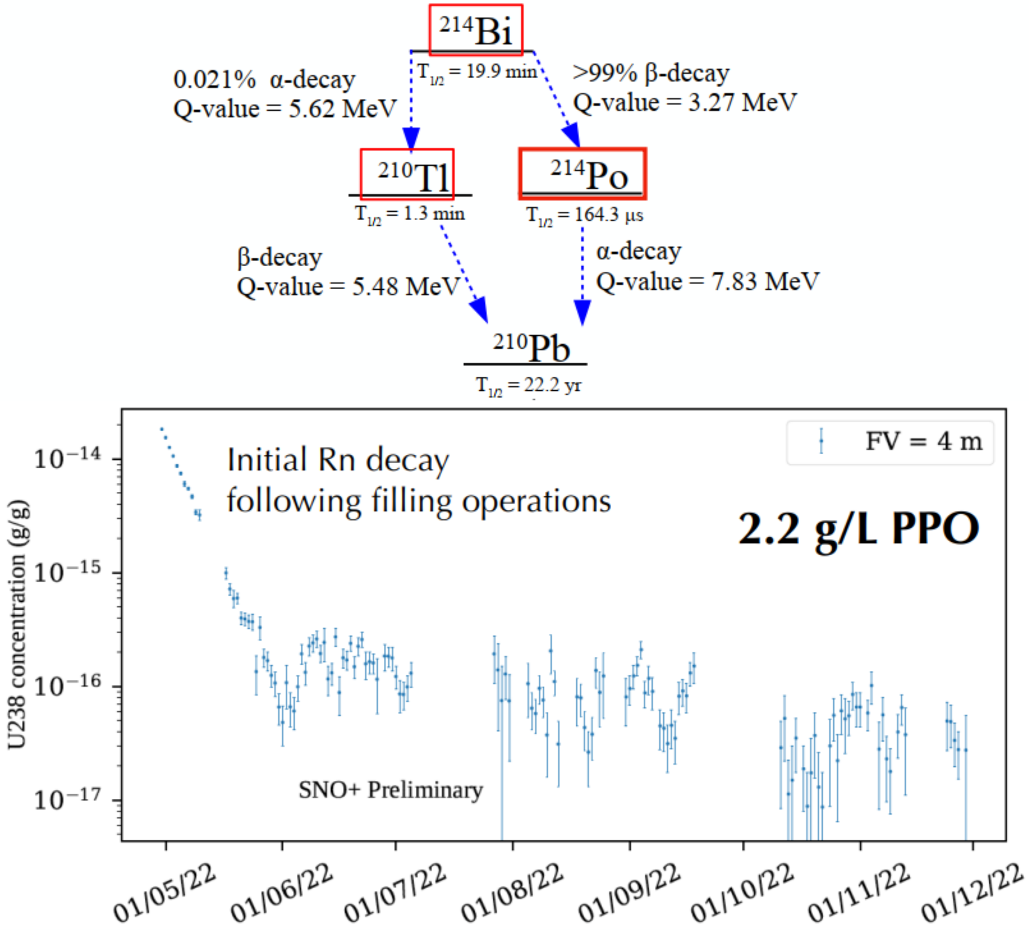
CDEX

- Preparation for the double-beta decay phase: background and target-out measurement

^{232}Th via ^{212}BiPo



^{238}U via ^{214}BiPo

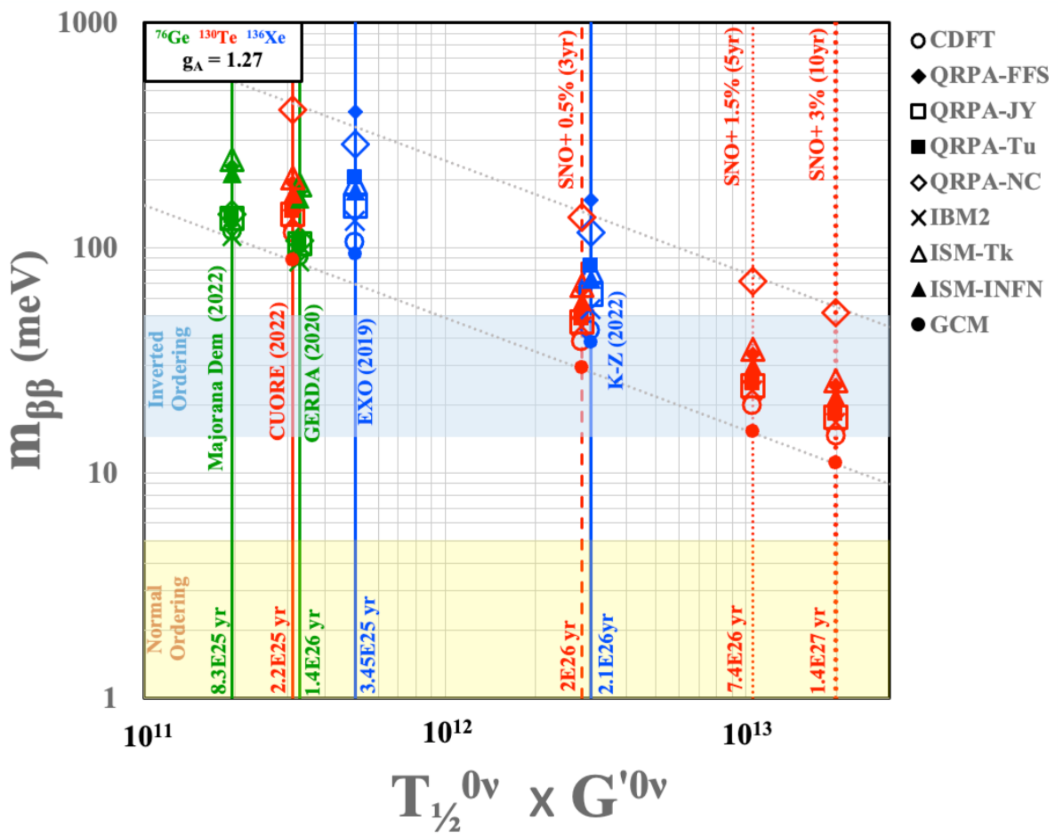


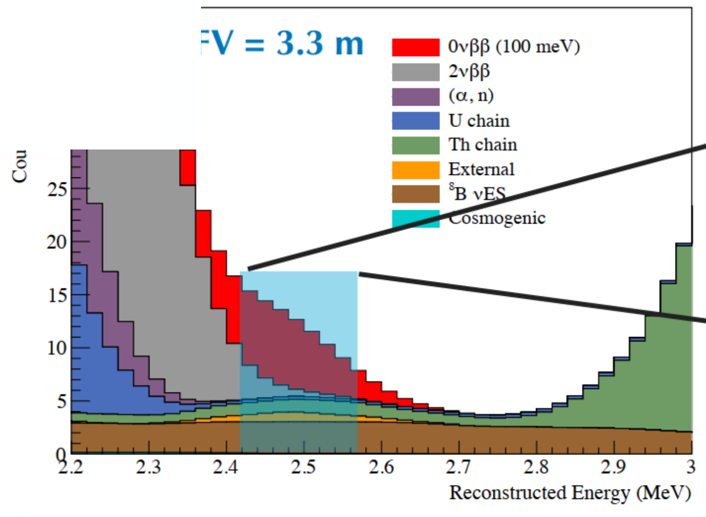
^{232}Th = $(5.7\pm0.3)10^{-17}$ g/g

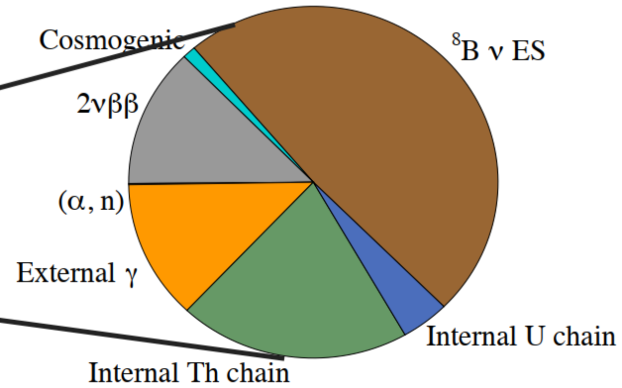
^{238}U = $(5.3\pm0.1)10^{-17}$ g/g

Below DBD-phase requirements!

SNO+







Events in the Region Of Interest

^{100}Mo 0νββ experiments

CDEX

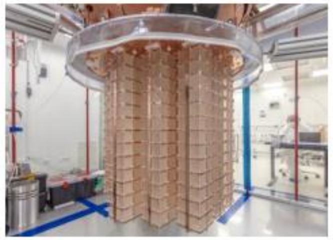
LMO crystal

CUORE (^{130}Te)

- $988\ ^{nat}TeO_2$ crystals
- 742kg of TeO_2 and 206kg ^{130}Te
- Data-taking since 2019
- $\Delta E_{FWHM}@Q_{\beta\beta}$~7 keV ($\frac{\sigma_E}{E}$~0.1%)

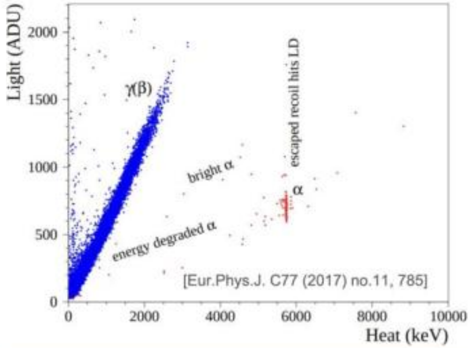
CUPID (^{100}Mo)

- Builds on the predecessor CUORE (currently operating), reusing existing infrastructure
- Upgrade detector array with Li_2MoO_4 scintillation bolometers
  - Particle identification gives x100 bkg reduction compared with CUORE
  - Higher Q-value of ^{100}Mo helps to suppress γ backgrounds from U/Th chains

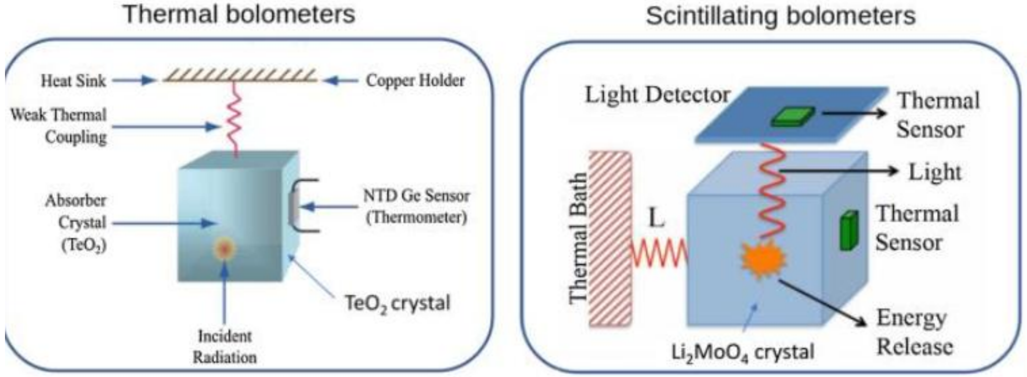


- Few features pushed the choice towards $Li_2{}^{100}MoO_4$:

- Higher energy resolution (7.4 vs 20 keV)
- Excellent radiopurity (ZnSe crystals have much higher U\Th contamination, ~30 times)
- Easier crystal growth



CUPID



Baseline

$T_{1/2}^{0\nu} > 1.1 \times 10^{27}$ yr

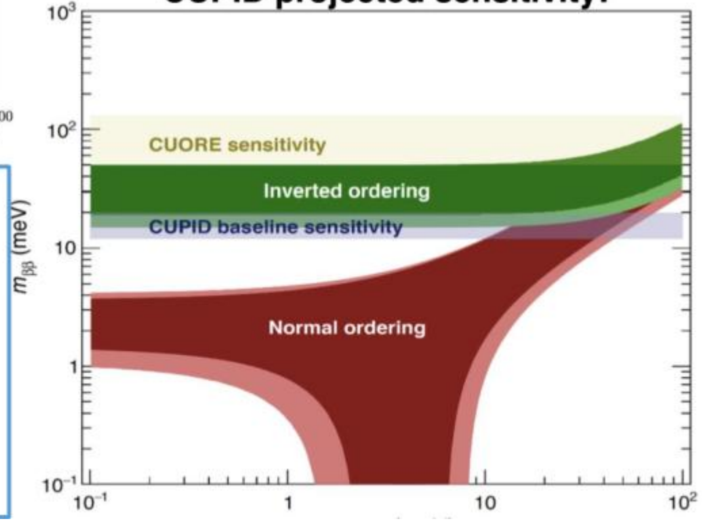
$\langle m_{\beta\beta} \rangle = 12 - 20$meV

Reach

$T_{1/2}^{0\nu} > 2 \times 10^{27}$ yr

$\langle m_{\beta\beta} \rangle = 9 - 15$meV

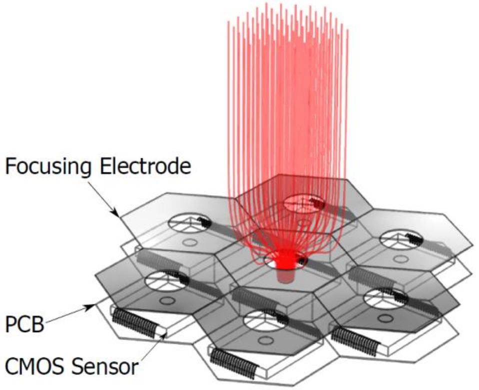
CUPID projected sensitivity:

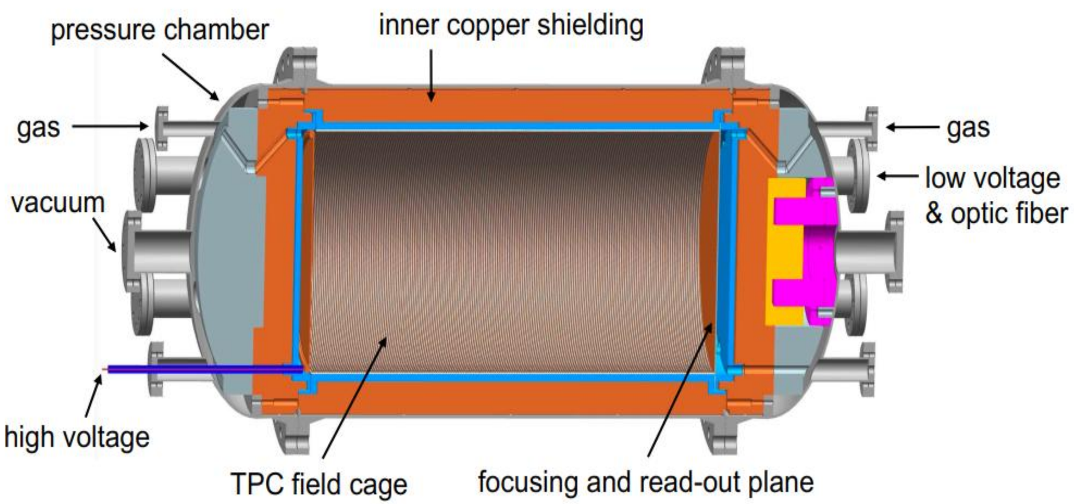


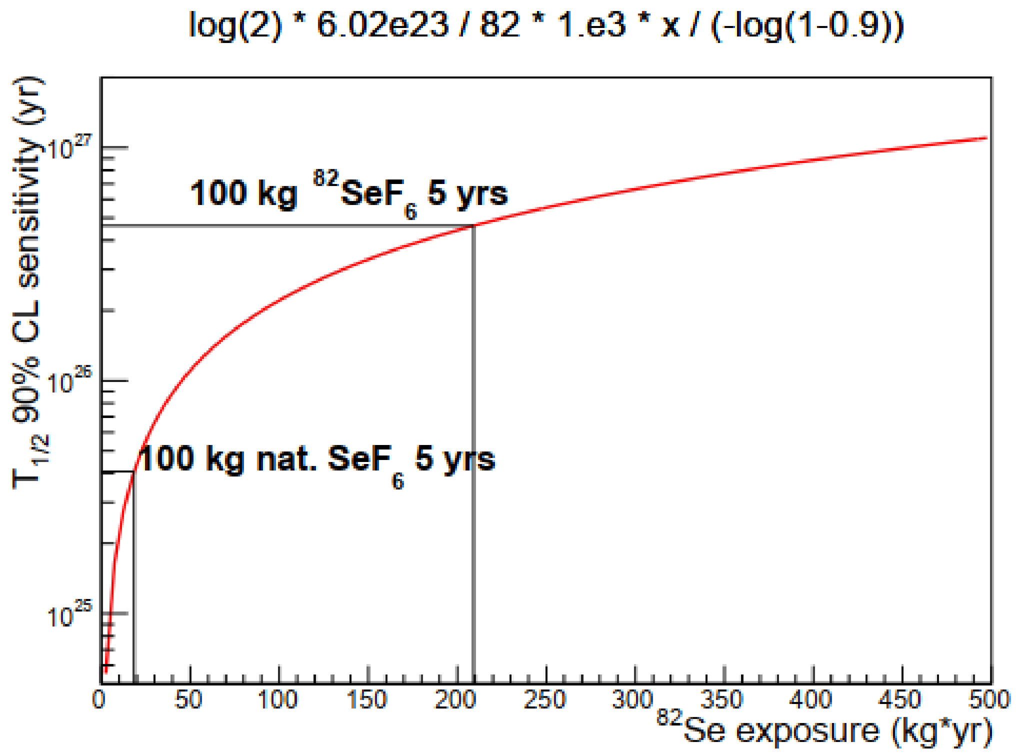
^{82}Se 0νββ experiments

CDEX

◻ HP-Gas TPC (SeF$_6$+Topmetal)

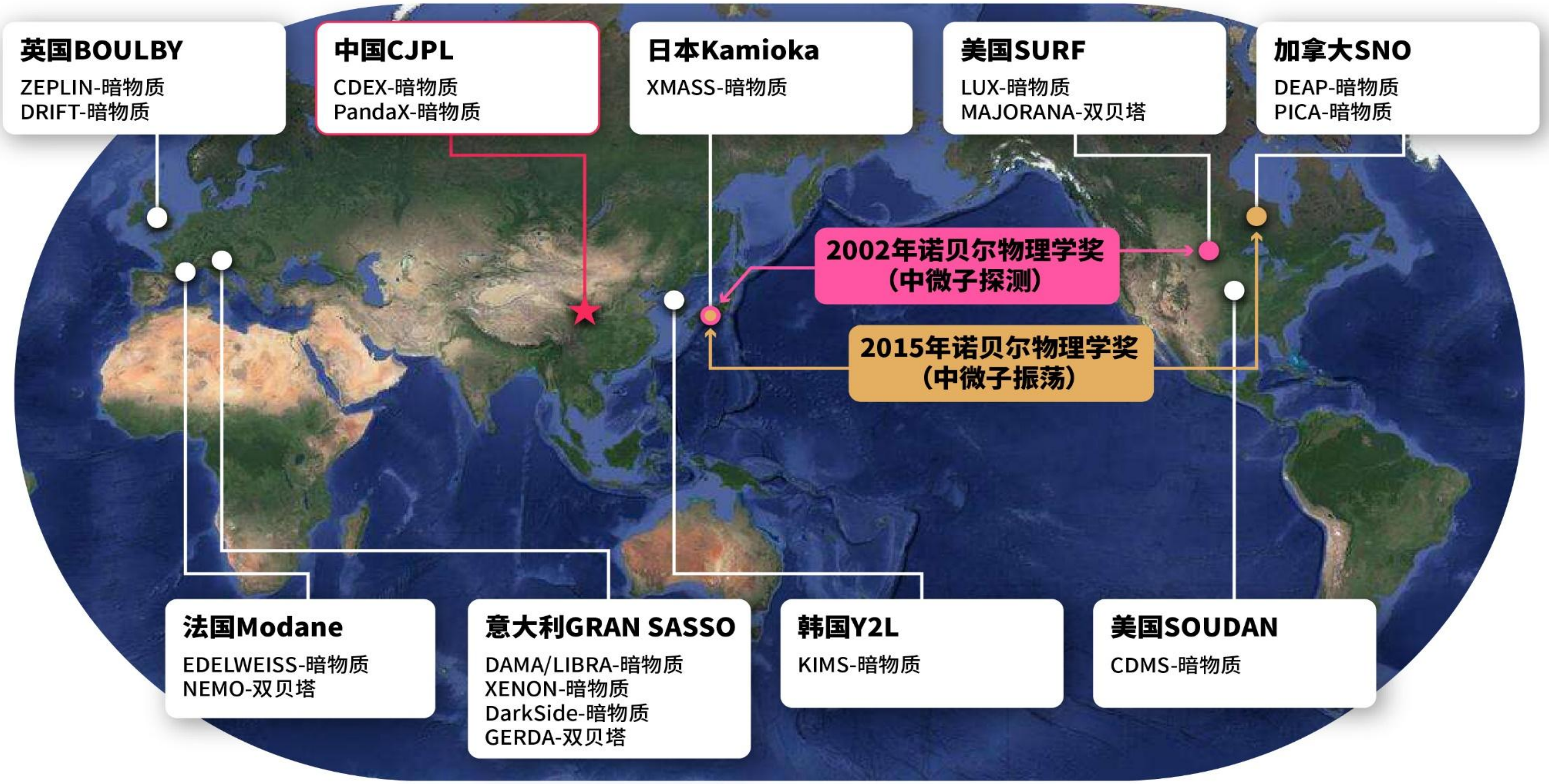




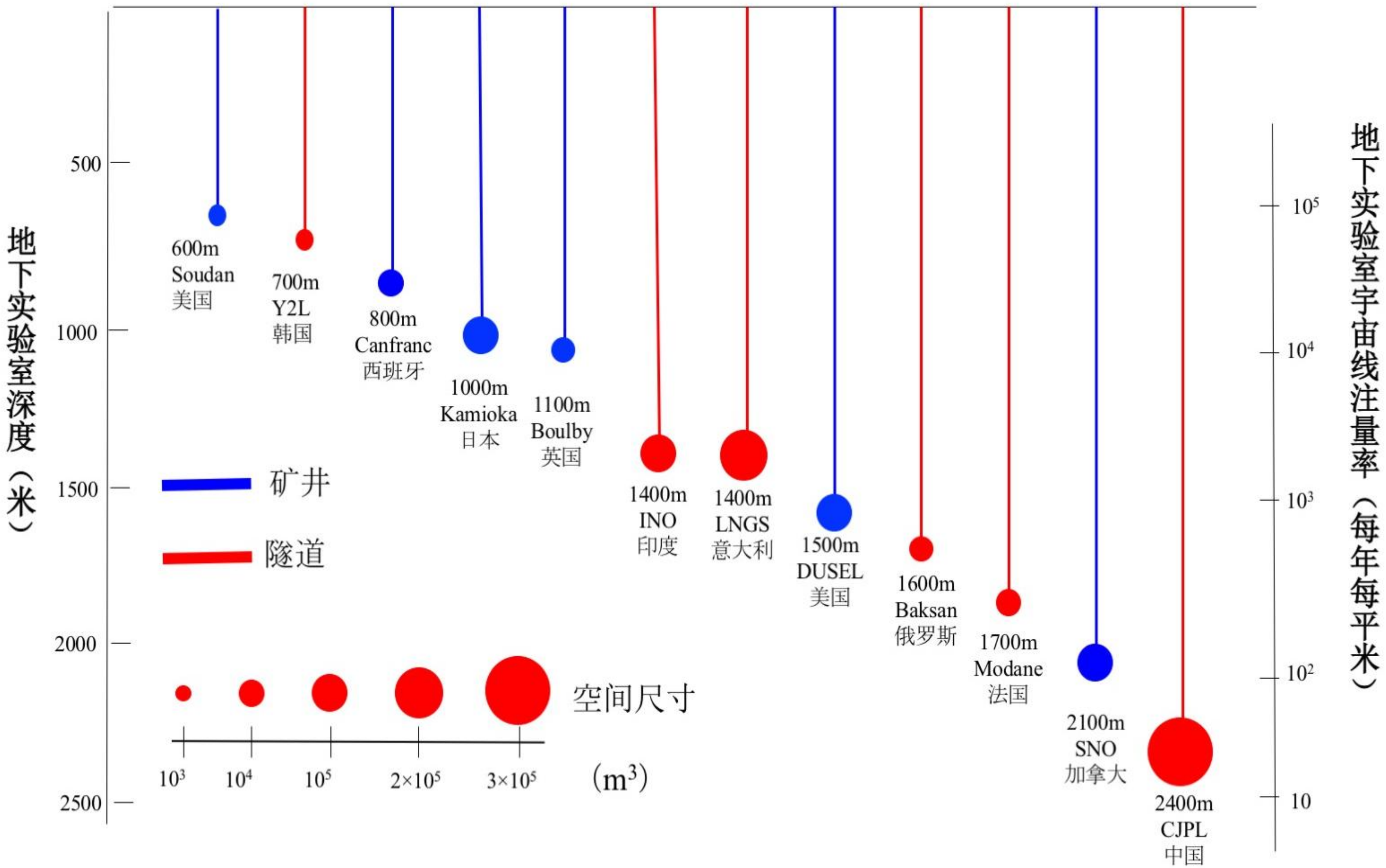


Main world-wide UL

CDEX



CJPL—The deepest underground laboratory



CDEX

CJPL

国家重大科技基础设施
极深地下极低辐射本底前沿物理实验设施
垂直岩石覆盖厚度2400米
距离西出口9km
距离东出口9km
排水隧道
Draining Tunnel
1号门
No.1 Gateway
2号门
No.2 Gateway
2号辅助隧道
No.2 Auxiliary Tunnel
1号辅助隧道
No.1 Auxiliary Tunnel
交通隧道B
Traffic Tunnel B
交通隧道A
Traffic Tunnel A
辅助隧道 Auxiliary Tunnel
交通隧道 Traffic Tunnel
排水隧道 Draining Tunnel
核天体物理实验
中微子实验
无中微子双贝塔衰变实验
低本底中心
暗物质实验（常温水屏蔽）
暗物质实验（低温液氮屏蔽）
中微子实验
无中微子双贝塔衰变实验
A1
A2
B1
B2
C1
C2
D1
D2
实验厅A
Hall A
实验厅B
Hall B
实验厅C
Hall C
实验厅D
Hall D
国际上宇宙射线通量最少、岩石覆盖厚度最深、可用空间最大、综合条件最好的极深地下实验设施，能提供极低辐射本底实验条件，满足暗物质、中微子、无中微子双贝塔衰变、核天体物理等实验极端辐射本底实验需求。

New Milestone——2023.12.7

Summary

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- Neutrino is the only particle beyond the Standard Model of particle physics..
- 0νββ is almost the only way to experimentally confirm: Neutrino is its own anti-particle. So 0νββ experiment is a long-term activity, not just 10-20 yr.
- CJPL has provided a world-level underground platform to push forward 0νββ experiments in China. JUNO is also a world-level low-background platform for next generation 0νββ experiments.
- CDEX、CUPID-China、JUNO-0vbb、NvDEx、PandaX and so on, have shown a very important start and good progresses comparing with our international colleagues. It’s realy a long-term job. Work hard and keep aggressive!

CDEX

Thank you for your attention!

Welcome to CJPL!