Gordon Research Conference, 2017 Hong Kong

# Neutrino-less double beta decay experiments


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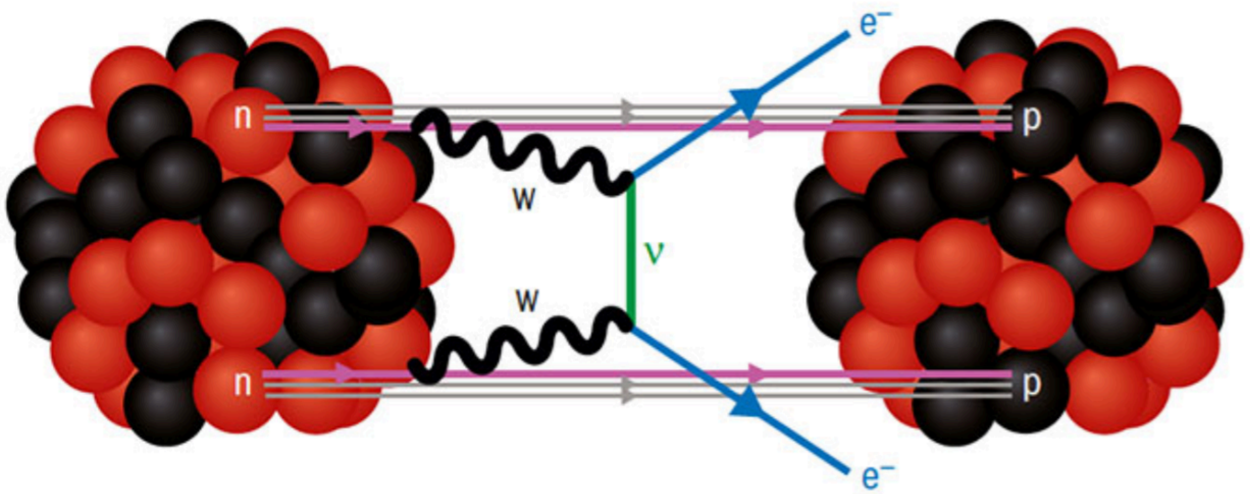
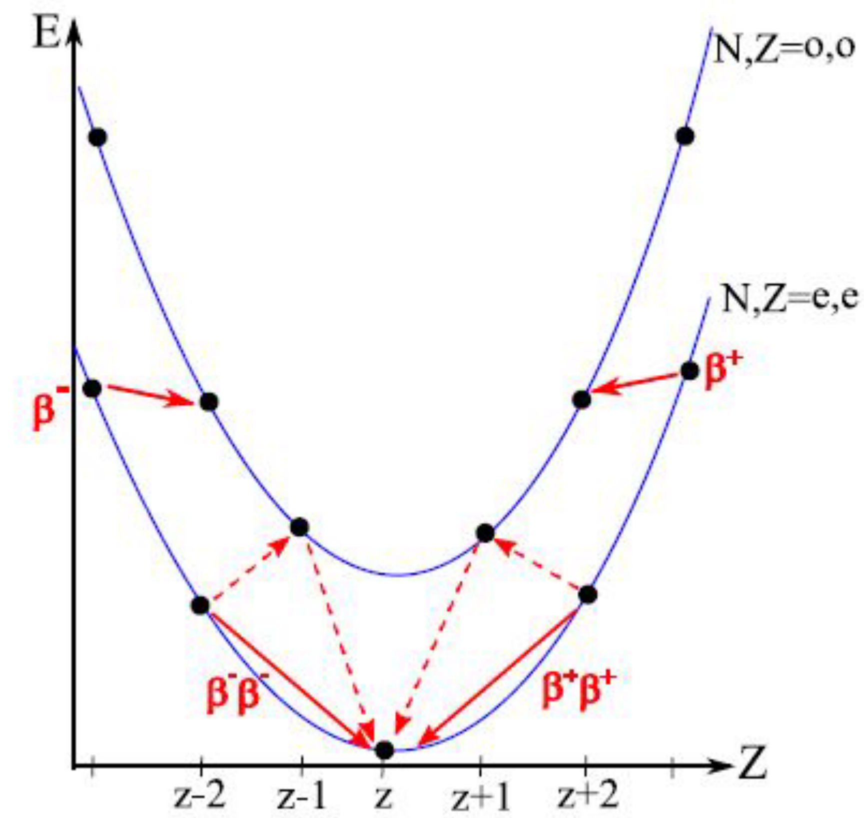
on behalf of the NEXT collaboration

# Neutrinoless double beta decay



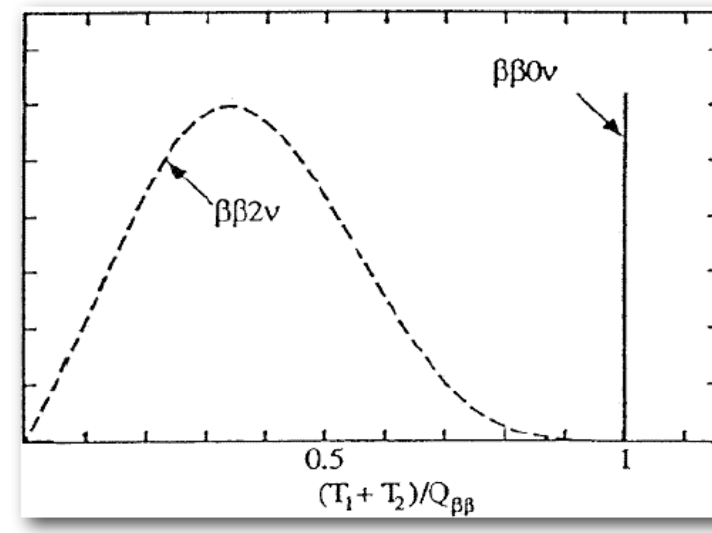

$$[T^{0\nu}_{1/2}]^{-1} = G^{0\nu}(Q,Z)\ |M^{0\nu}|^2\ m^2_{\beta\beta}$$

$$m_{\beta\beta} = \left|\sum_i m_i\ U^2_{ei}\right|$$

- Exploring **$m_{\beta\beta}$ one order** of magnitude further down requires **periods two orders** of magnitude longer

# 0νββ experiments

- Experiments measure the kinetic energies of the two emitted electrons (monochromatic line at the Q-value)




- For background-limited experiments the 0νββ sensitivity:

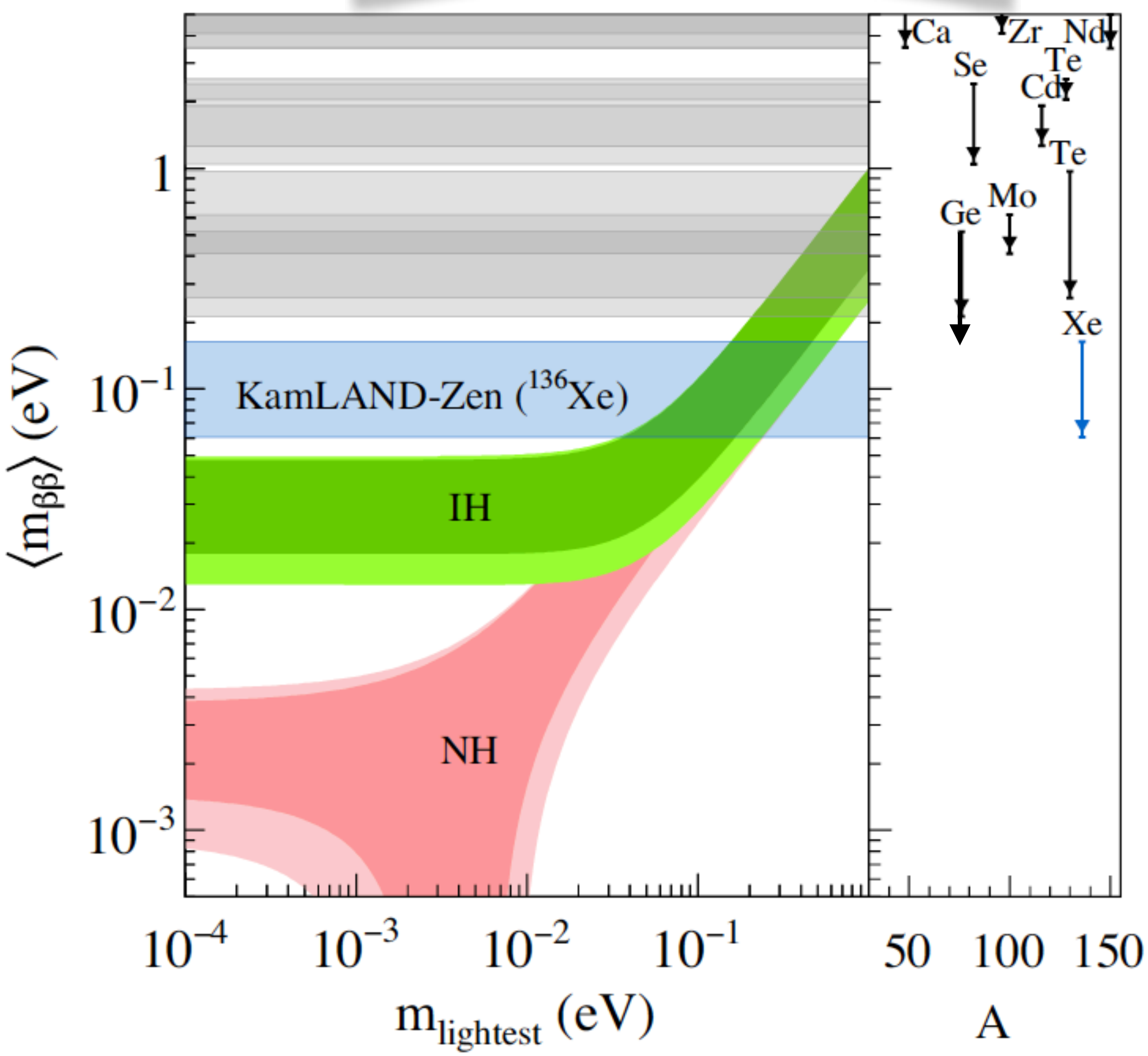
$$S(T^{0\nu}_{1/2}) = K\,\epsilon\,\sqrt{\frac{Mt}{c\,\Delta E}}$$

- For an experiment with background ($c$): an improvement of a factor **10 in $m_{\beta\beta}$** requires a factor of **10000 in isotope mass** ($M$) for the same running time ($t$). For a background-free experiment: ***$S(T^{0\nu}_{1/2}) \propto M$***

- Things to take into consideration:
  - Underground operation, energy resolution, Q value, scale up, extra handles to reduce background (tagging of daughter isotope, pattern of energy deposition, ...)

# State of the art

Current limits on $m_{\beta\beta}$:



# State of the art

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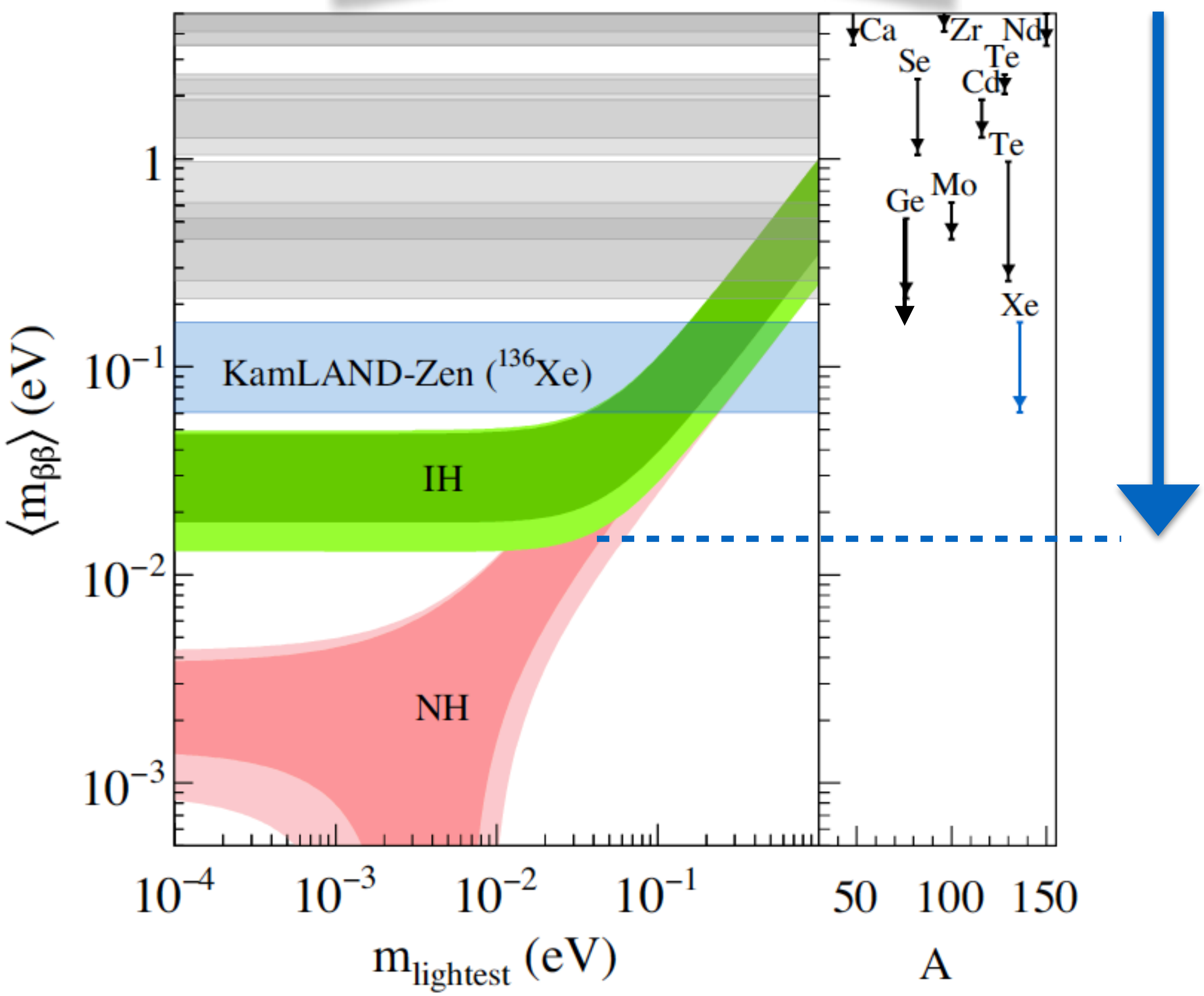
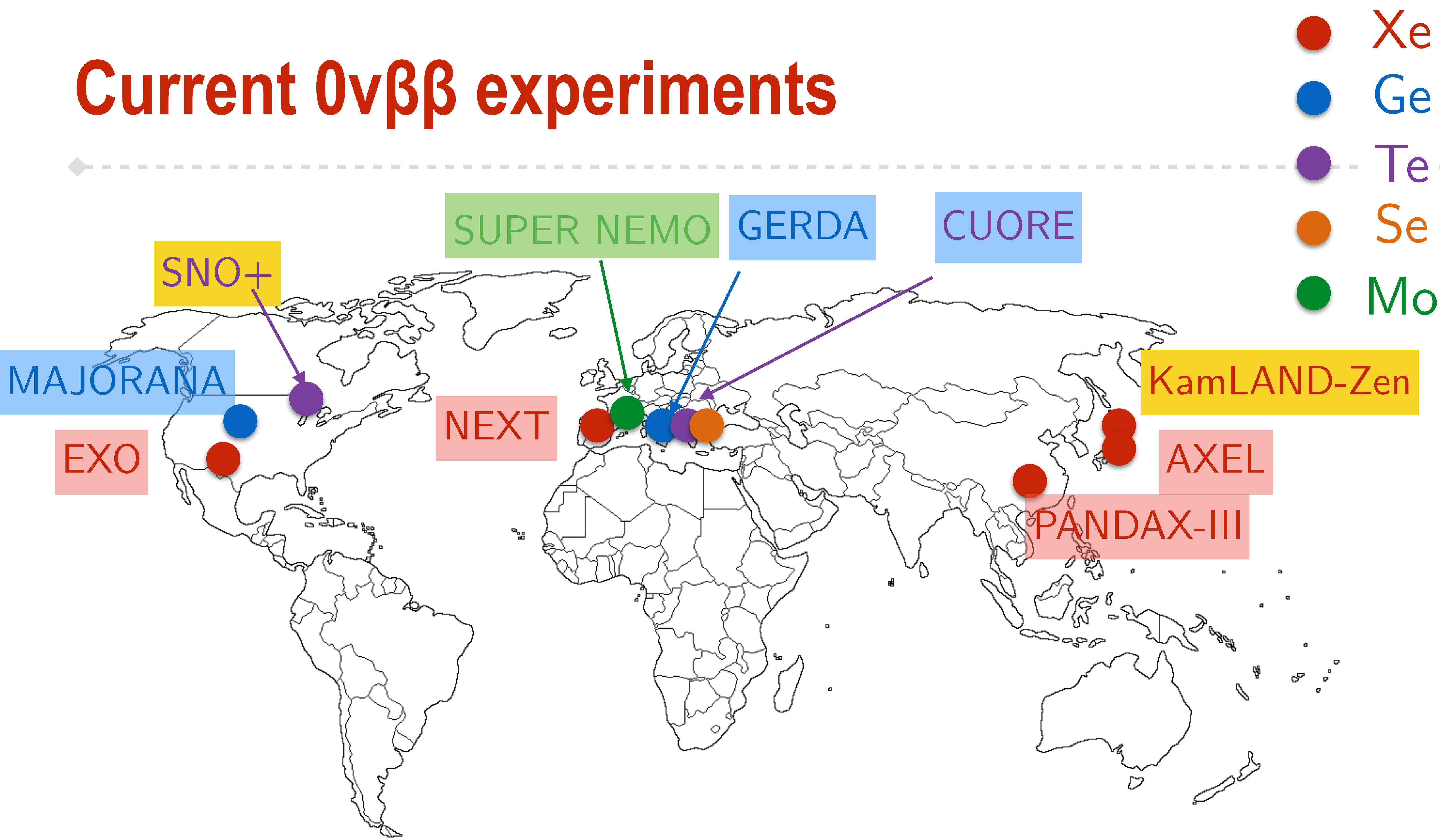



**Future** experiments to explore the **IH require ($m_{\beta\beta}$~10meV)**:

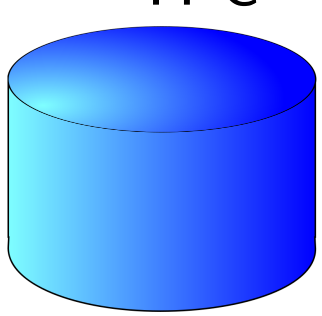
1) Large masses (**tonne** scale) : technology must be scalable and cheap

2) Background in the range of **1 event/tonne** (to cover the IH in a reasonable time): large background reduction needed wrt to current state of the art

# Current 0νββ experiments




= TPC



source=detector

= Calorimeter-Loaded scintillator

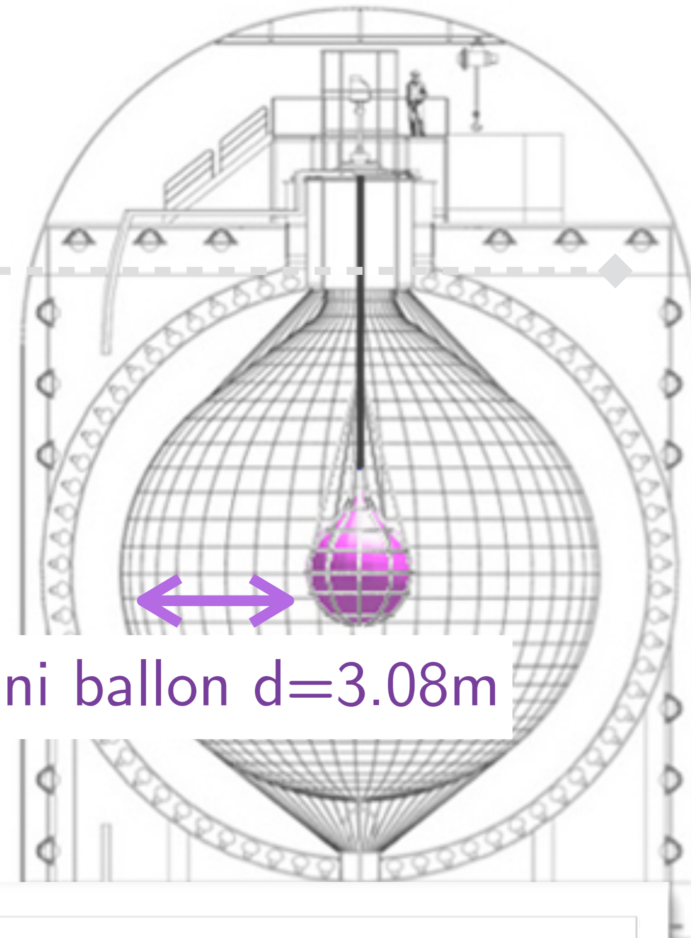
= Calorimeter: Semi-conductor, bolometer

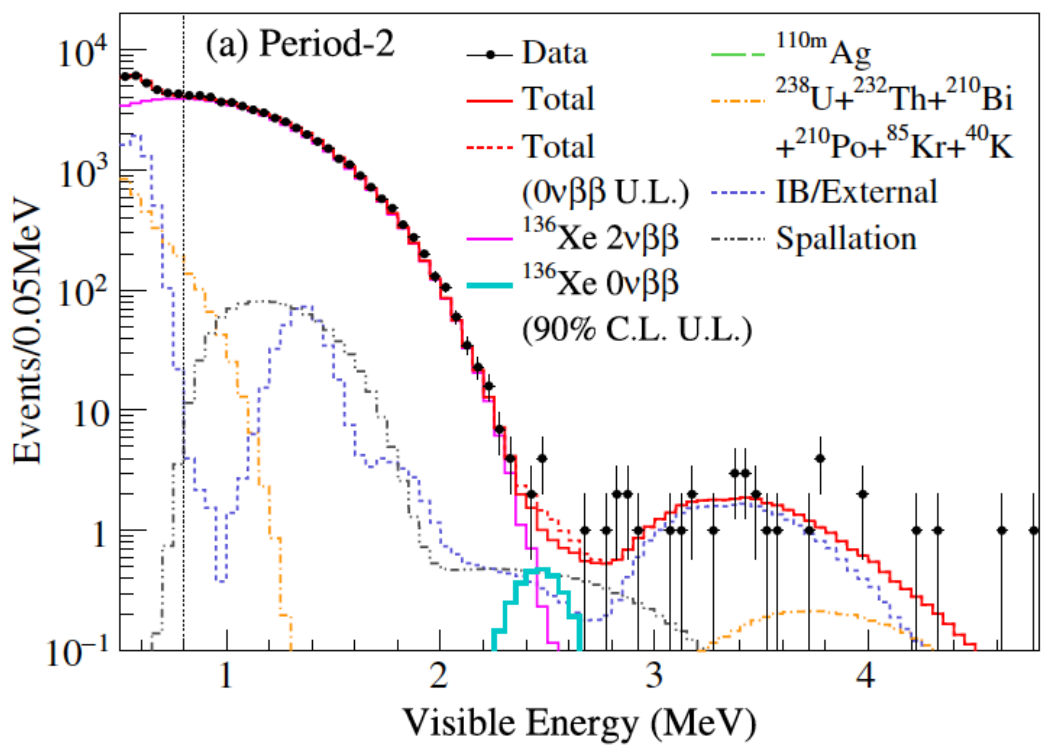
= Tracko-calo

**source ≠ detector**

# KamLAND-Zero neutrino ββ decay

- Isotope: 383kg of $^{136}$**Xe** dissolved in liquid scintillator,
- **Poor energy resolution:** 11% FWHM at the Q-value
- **Shielding:** low background rate 1.6e$^{-4}$ c/(kev/kg/yr)
- **Easy to scale up**




Combining phaseI and phaseII:
**(best limit!)**
$T_{1/2} > 1.07 \times 10^{26}$ yr at 90% C.L
(sensitivity: $5.6 \times 10^{25}$) **($m_{\beta\beta}$~61-165meV)**

**Phys. Rev. Lett. 117, 082503**

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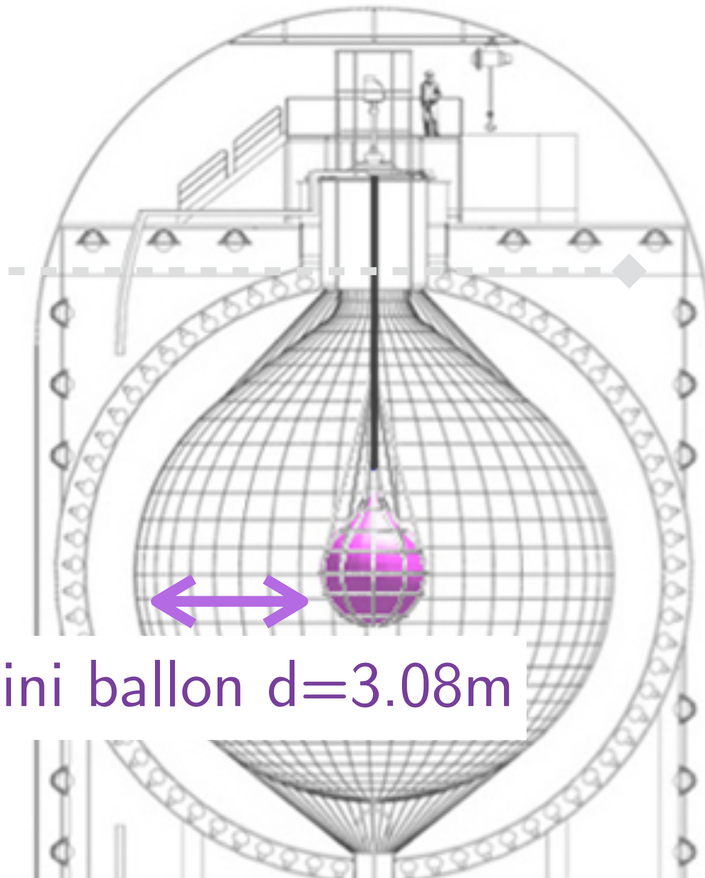


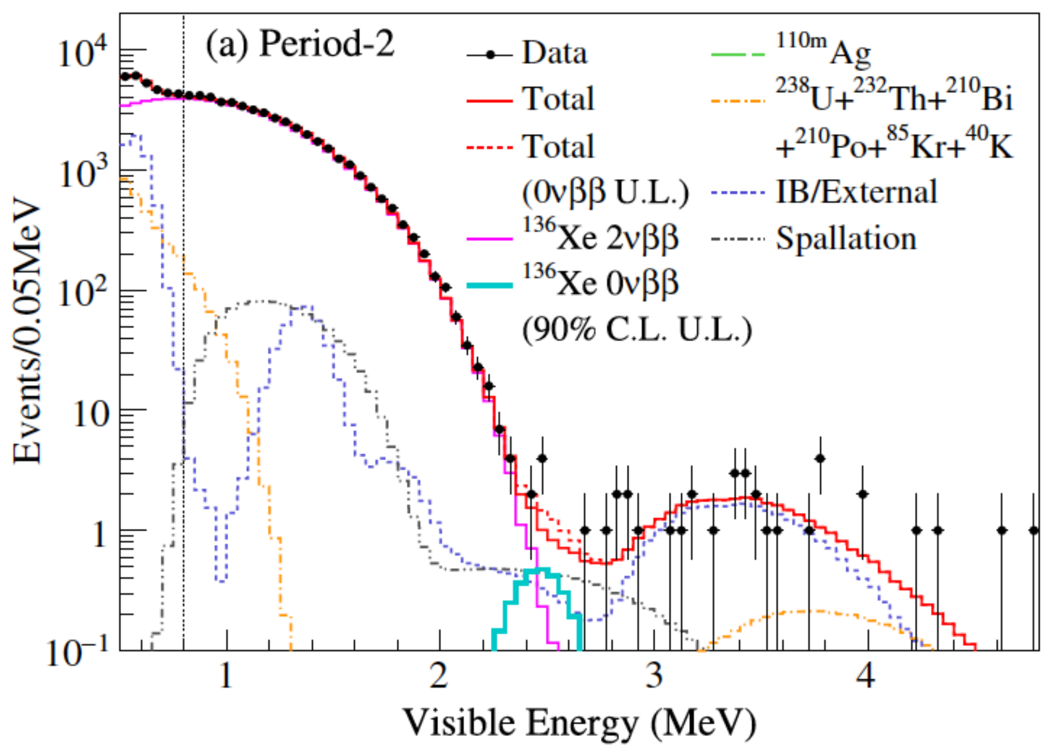


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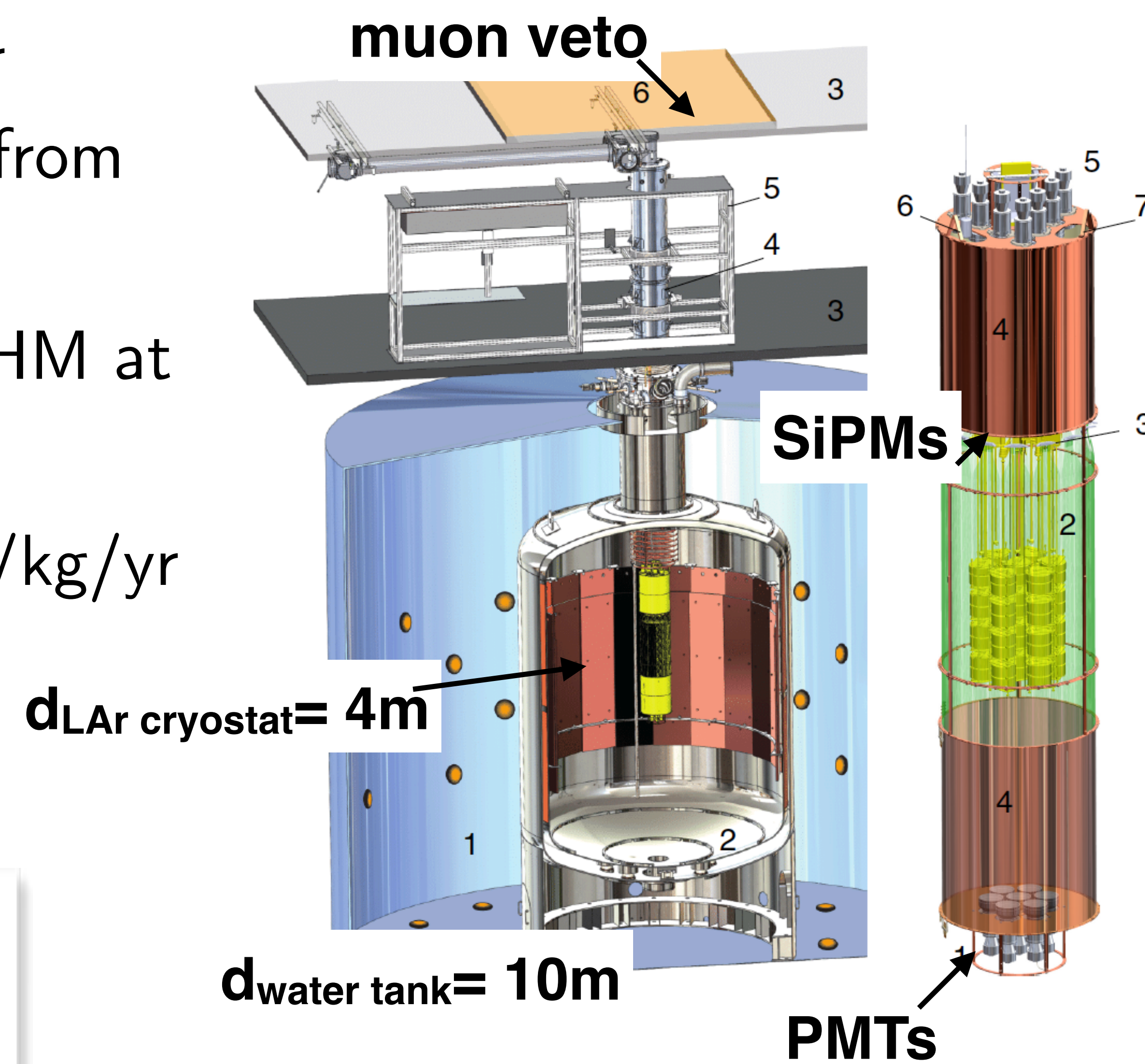
- **Future plan: 1)** install a bigger MB of 800kg of $^{136}$Xe (2018) to explore down to **$m_{\beta\beta}$ =40meV**; **2)** install (2020?) the 1tonne MB covering most of the IH region!

# GERDA: The GERmanium Detector Array

- **Germanium diodes Ge-76** immersed in LAr (SiPMs and PMTs to detect Ar scintillation from bkg events), 35kg in phaseII.
- **Excellent energy resolution**: 0.1-0.2% FWHM at Q-value (bkg free)
- **Low background rate:** 0.7-3.5 x $10^{-3}$ c/keV/kg/yr (background free)
- **Scalability expensive**

$T^{0\nu}_{1/2} > 5.3 \times 10^{25}$ yr at 90% C.L (sensitivity: $4\times10^{25}$) **($m_{\beta\beta}$~150-330meV)**

*Nature* 544, 47–52 (06 April 2017)



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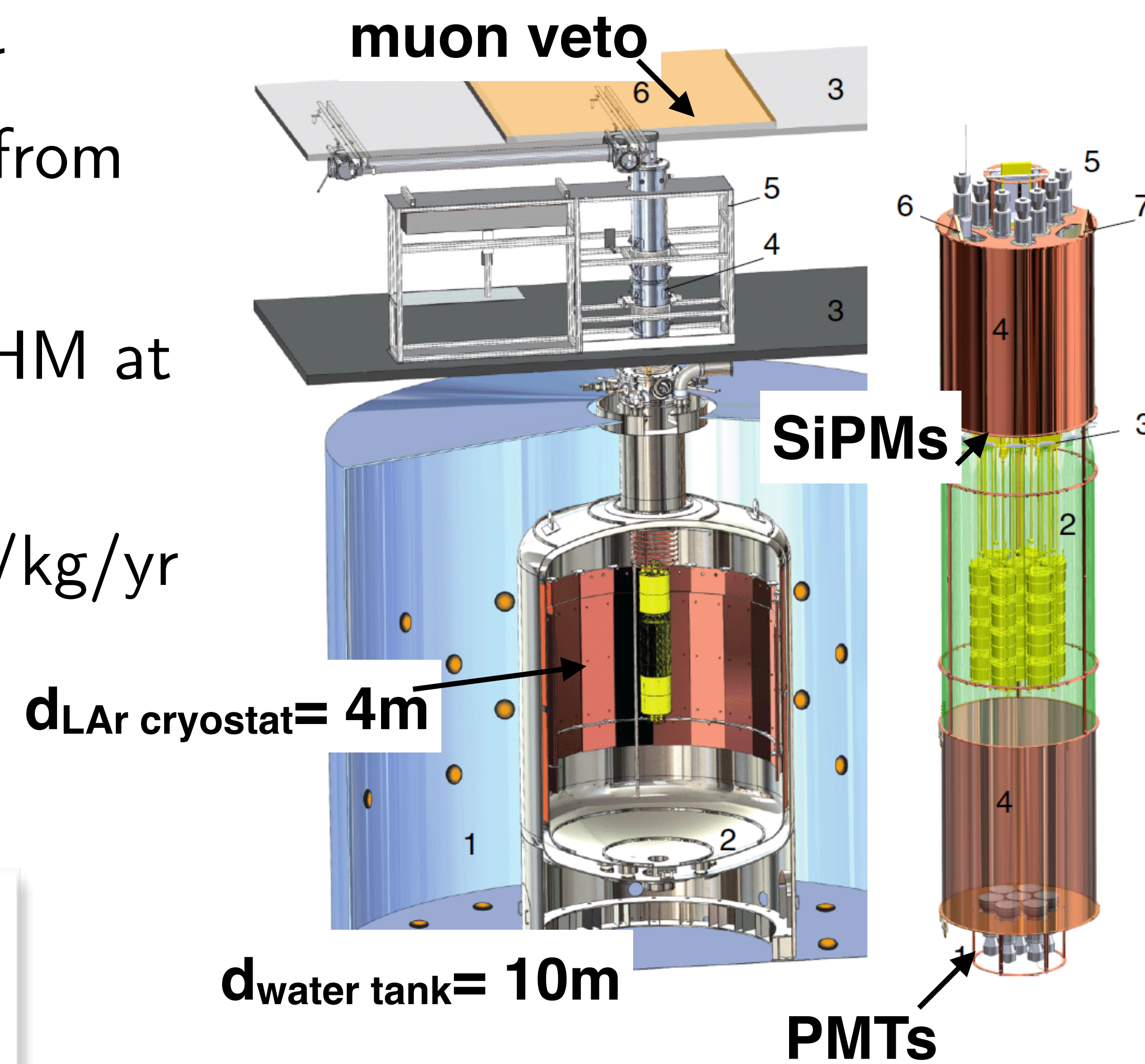


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(sensitivity: $4\times10^{25}$) **($m_{\beta\beta}\sim$150-330meV)**

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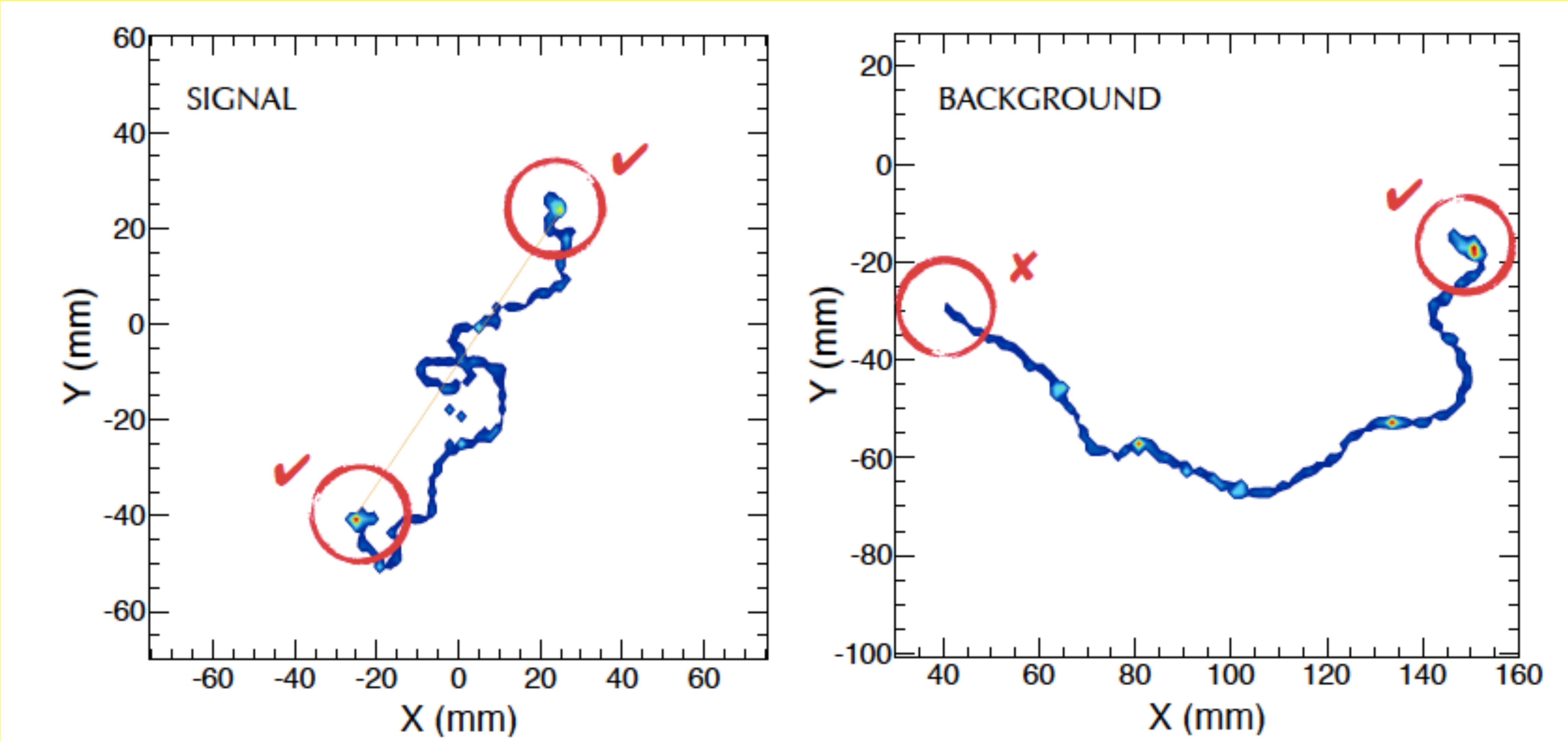
- **Future plan with** Majorana+GERDA = Legend Collaboration (http://legend-exp.org) sensitivity goals: **1)** $10^{27}$ with 200kg, **2)** $10^{28}$ with 1 tonne (10-20meV)

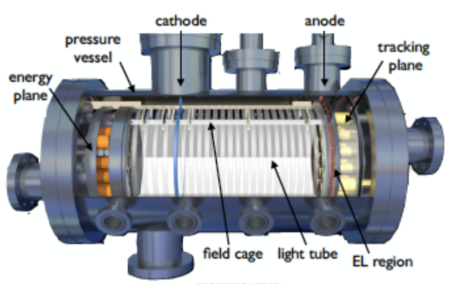
# next: Neutrino Experiment with a Xenon TPC

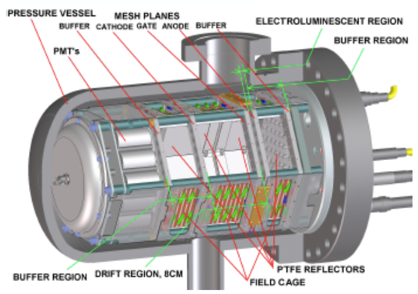
LSC
Laboratorio Subterráneo de Canfranc

- **High pressure Xenon gas, electroluminescent TPC with readouts for calorimetry and tracking.**
  - Isotope: $^{136}$**Xe** (easy to enrich and to purify)
  - Electroluminescence used to amplify the ionization signal (linear process, huge gain)
  - **Excellent energy resolution:** **<1%** FWHM at the Q-value (the resolution due to Fano factor fluctuations of Xe Gas at Q-value is 0.3% FWHM)
  - **Easy to scale up**
  - Low background rate: 4x $10^{-4}$ c/keV/kg/yr
  - **Tracking:** electrons travel 15cm each (15bar) on average


SIGNAL
Y (mm)
X (mm)
60
40
20
0
-20
-40
-60
BACKGROUND
20
80
100
120
140
160
-80
-100

# NEXT phases: 2009 - 2020's



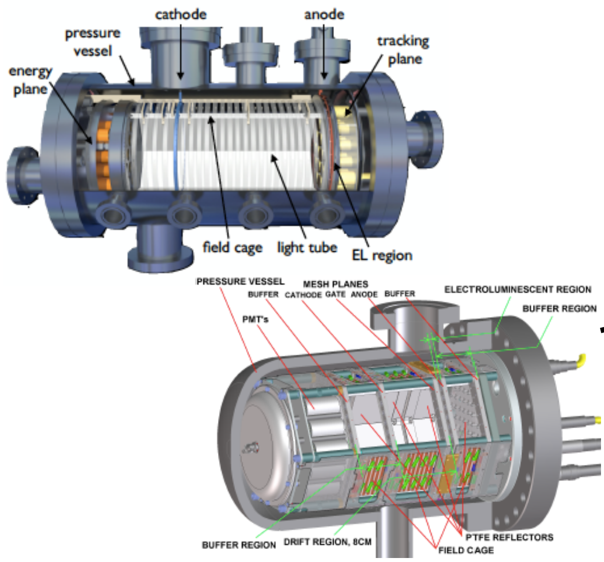




**Prototypes (~1 kg)**

[2009 - 2014]

**Demonstration of detector concept [<1% FWHM, tracking]**

# NEXT phases: 2009 - 2020’s

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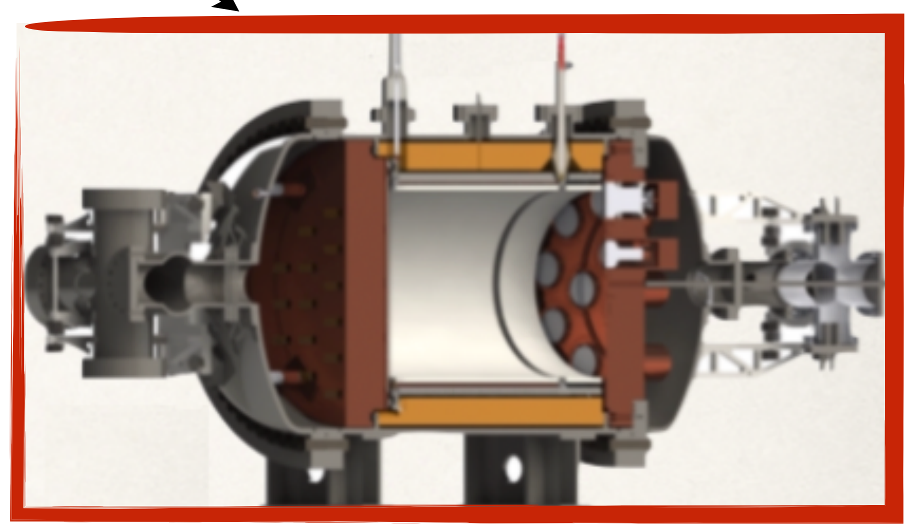
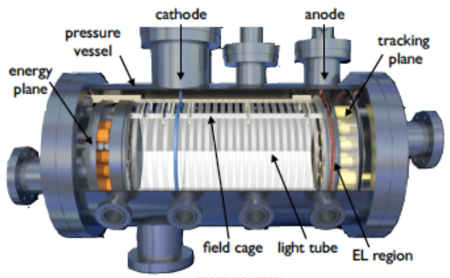
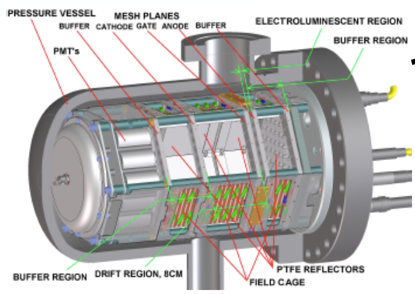


**NEXT-NEW (~5 kg)**
[2015 - 2018]

Underground and radio-pure operations, background, $2\nu\beta\beta$

# NEXT phases: 2009 - 2020's

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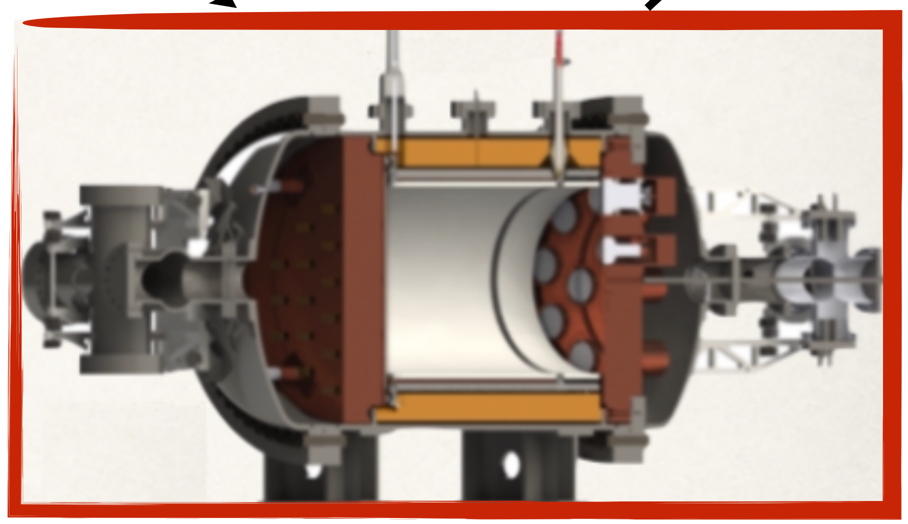

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[2015 - 2018]

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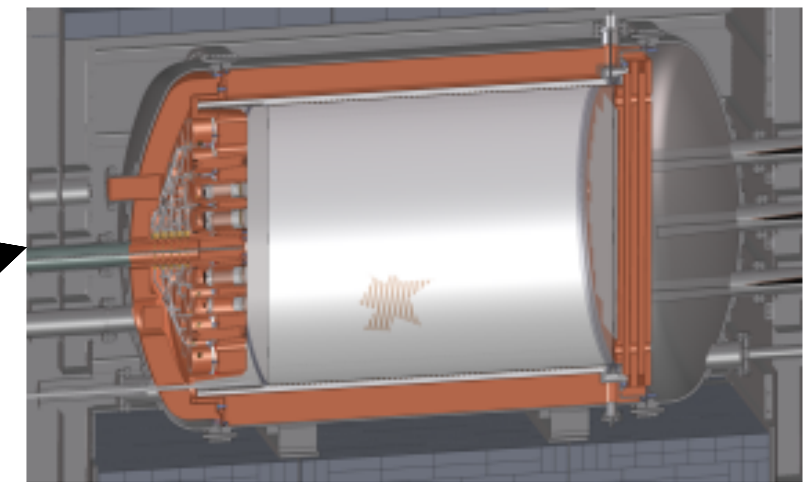
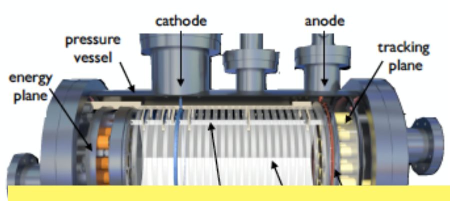
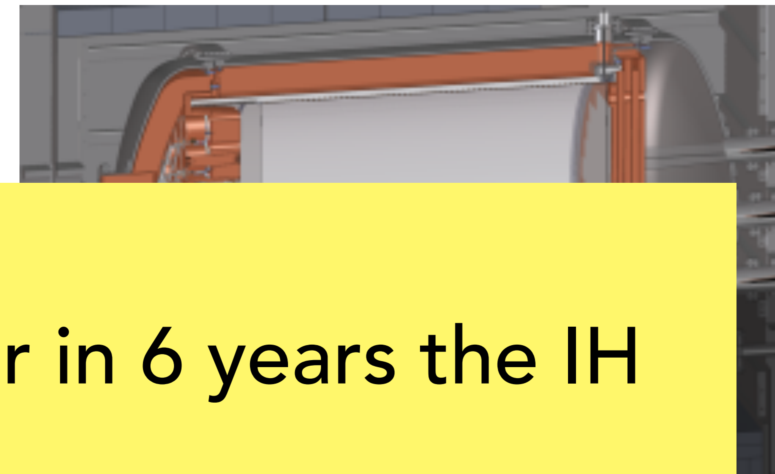


**NEXT-100 (~100 kg)**
**sensitivity: $6\times10^{25}$ yr**
[2018 - 2020's]

Neutrinoless double beta decay searches

# NEXT phases: 2009 - 2020's



Multi-tonne future generation:
NEXT-tonne with ~1c/tonne/year will cover in 6 years the IH

* **ongoing** R&D on Single Molecule Fluorescent imaging for **Barium tagging**.

* **ongoing** R&D with gaseous mixtures can provide low diffusion, **improving rejection** by a factor x4.

[2015 - 2018]

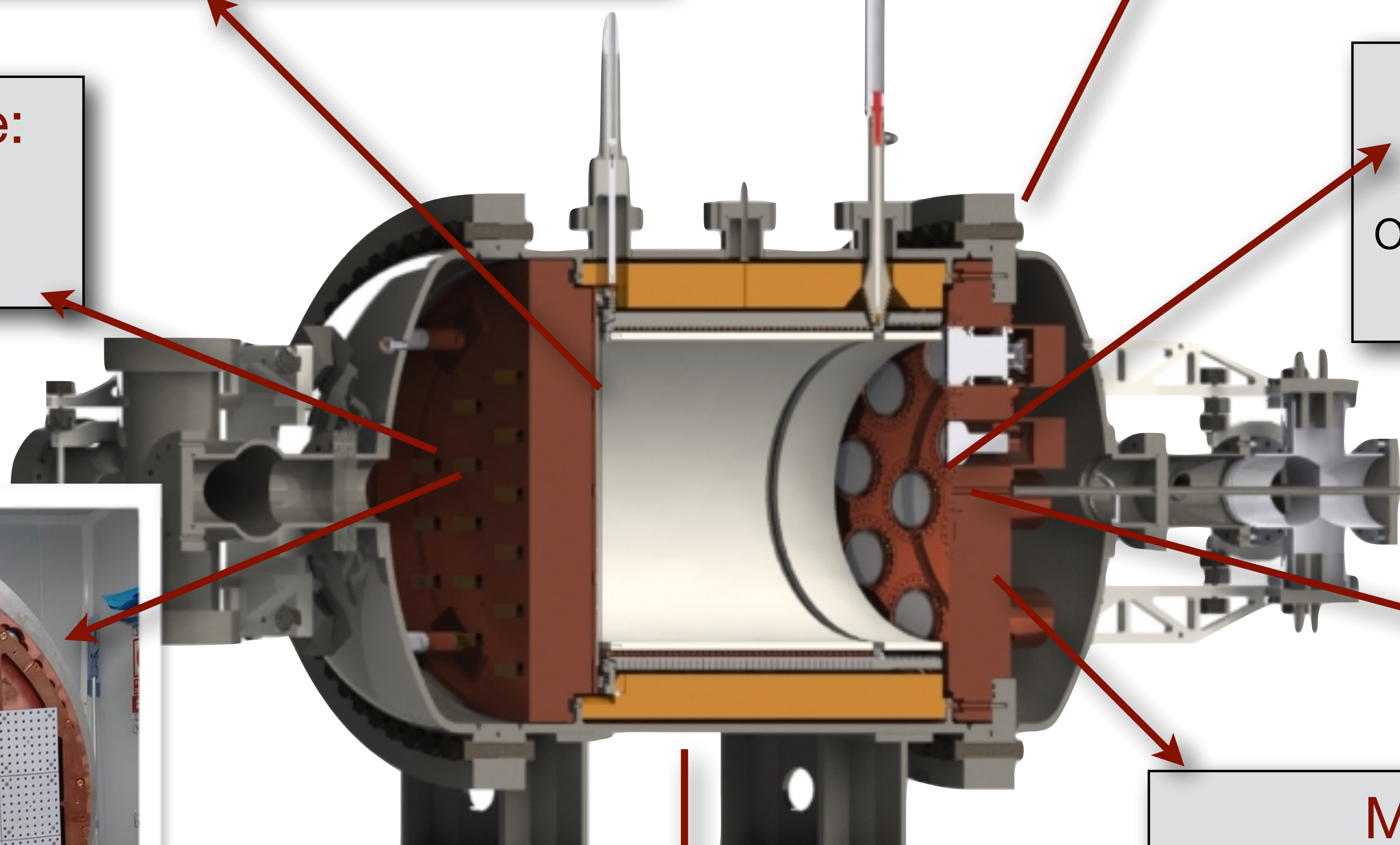
**Underground and radio-pure operations, background, 2νββ**

# NEXT detector

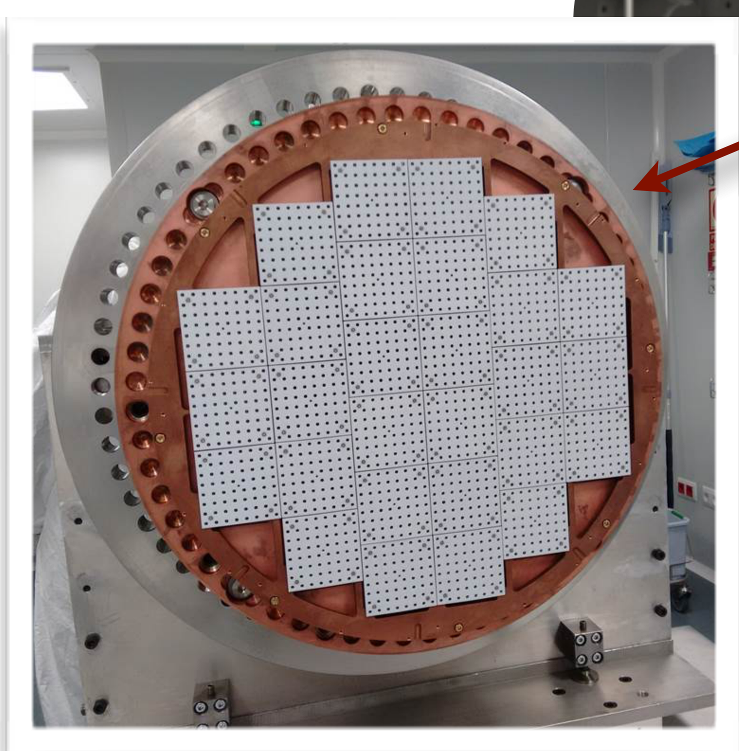
Time Projection Chamber:
5 kg active region(@15bar), 50 cm drift length

Pressure vessel:
316-Ti steel, 30 bar max pressure

Tracking plane:
1,800 SiPMs,
1 cm pitch



Energy plane:
12 PMTs,
operating at vacuum.
30% coverage



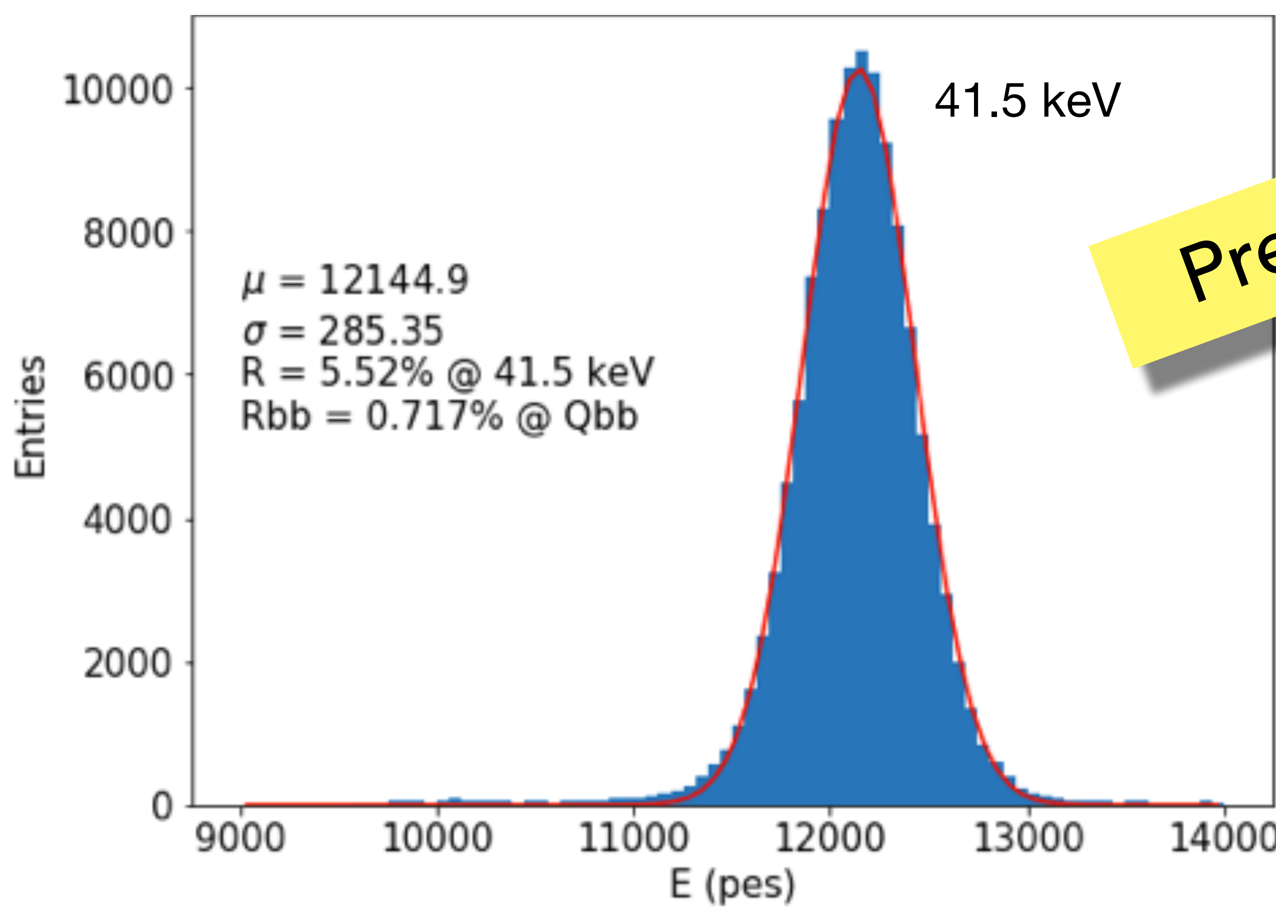
Mother can:
12 cm copper plate that separates pressure from vacuum and ads shielding.

Inner shield:
copper, 6 cm thick

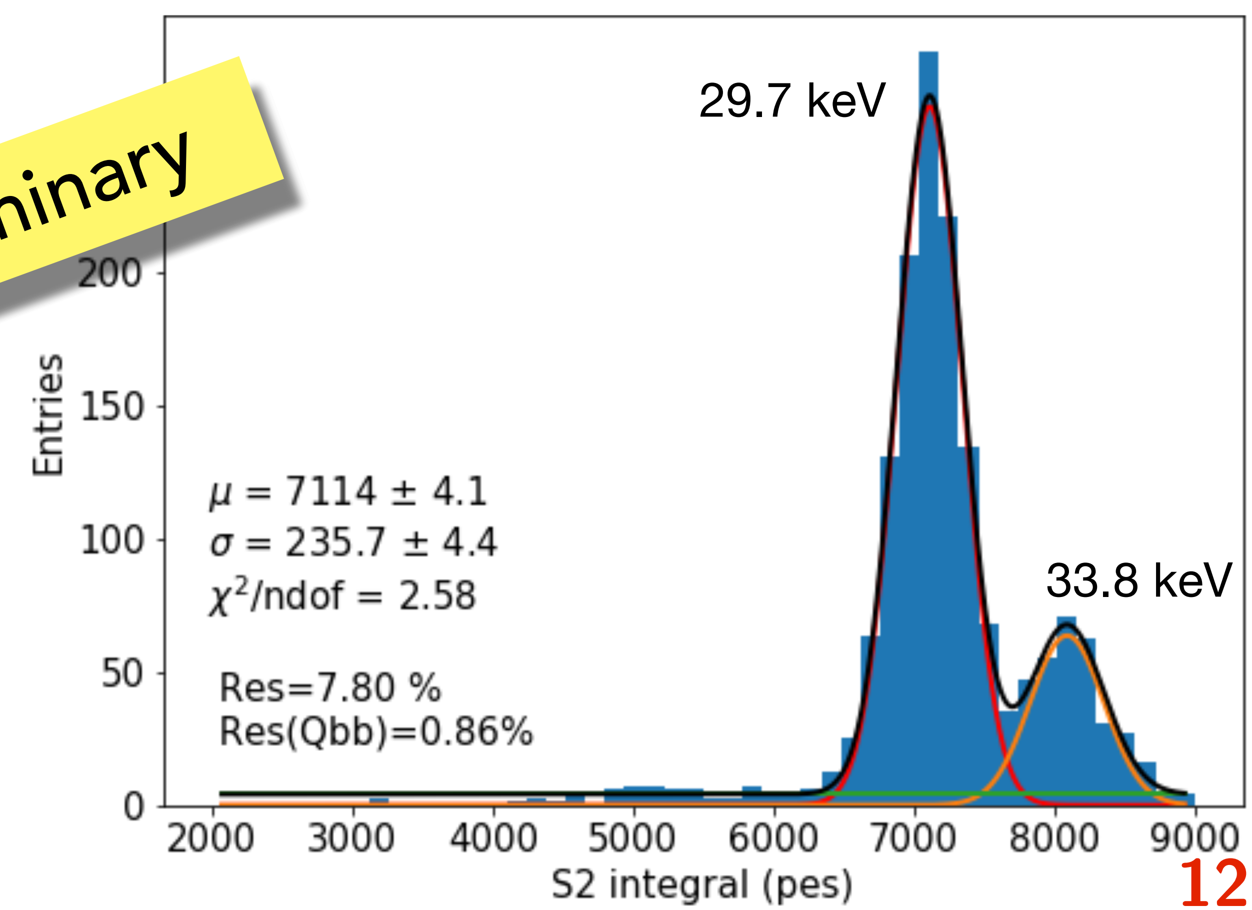
# NEXT energy resolution performance:
## low energies

- 5.5% FWHM energy resolution measured with Kr-83 conversion electrons at 41.5 keV → $1/\sqrt{E}$ extrapolation yields **0.7% FWHM** resolution at Q-value
- Sufficient to separate 29.7 and 33.8 keV xenon x-rays

**Kr-83 conversion electrons**




**Xenon x-rays**

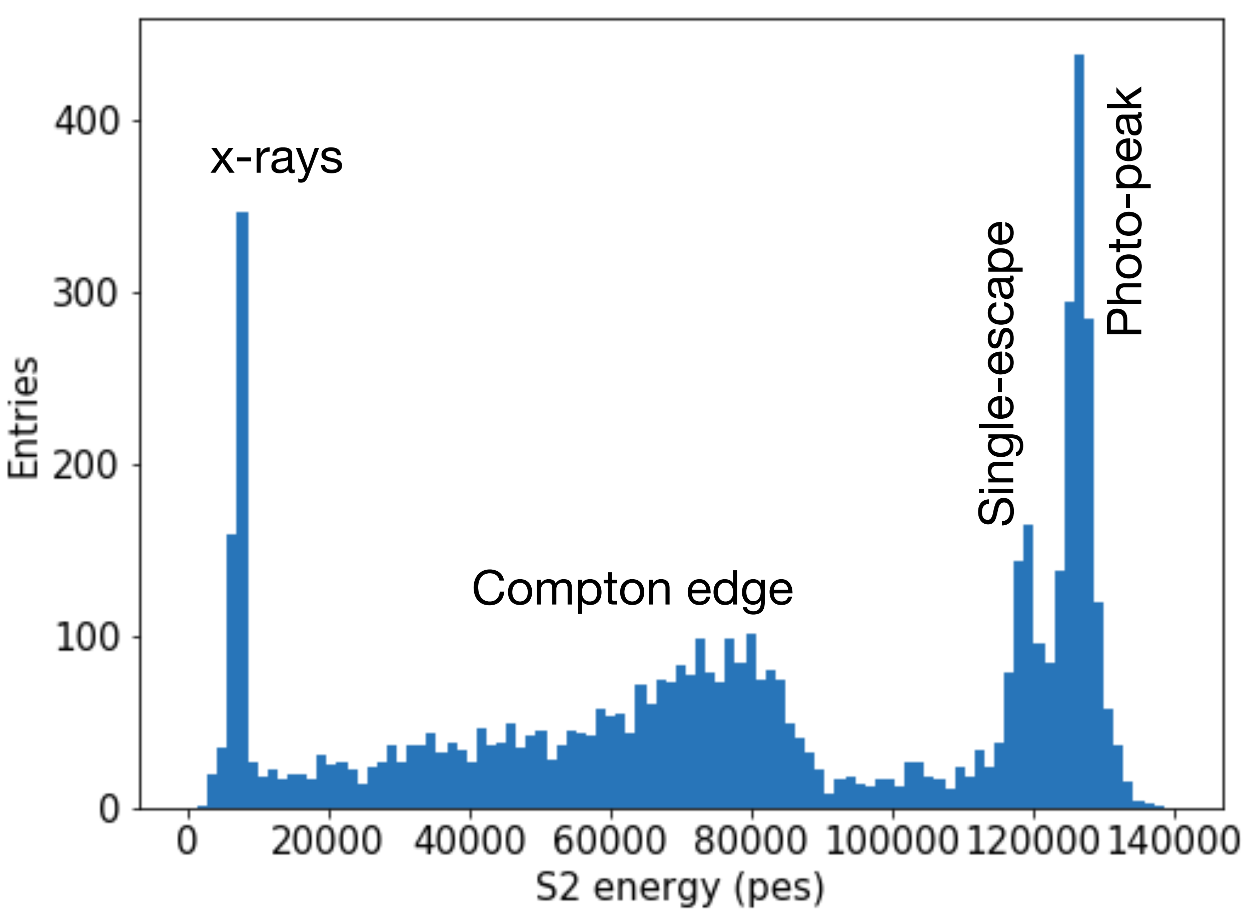


# NEXT energy reconstruction:
## higher energies

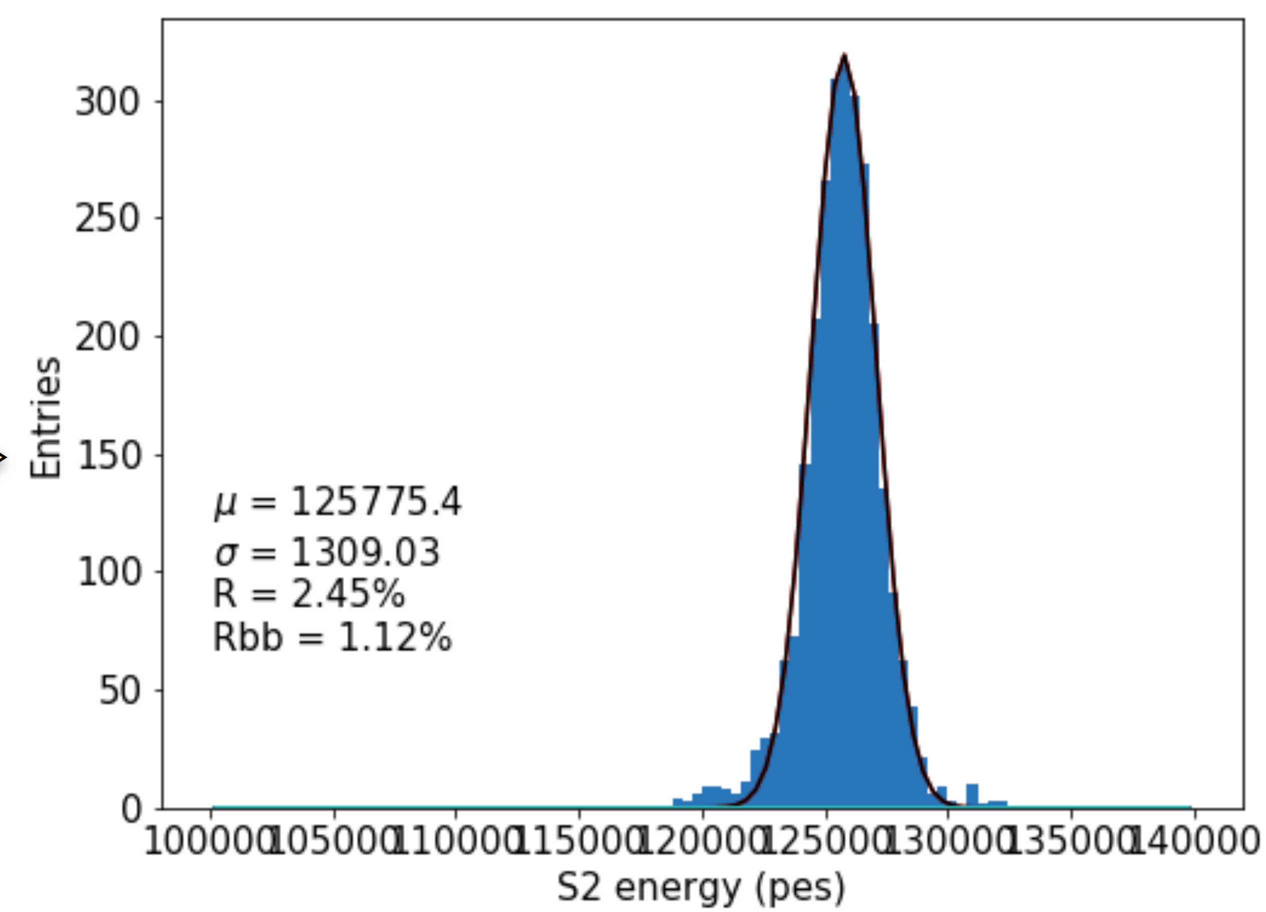
- Good energy resolution maintained at higher energies (511 keV from $^{22}Na$)

Preliminary

**Full spectrum**

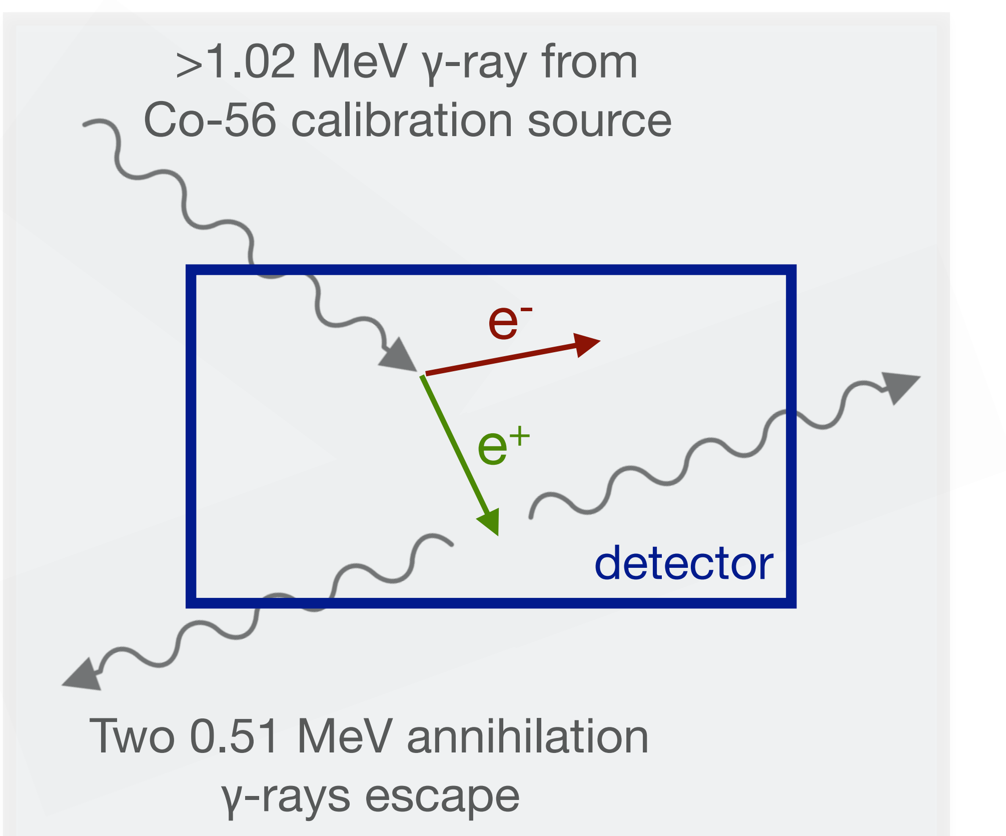


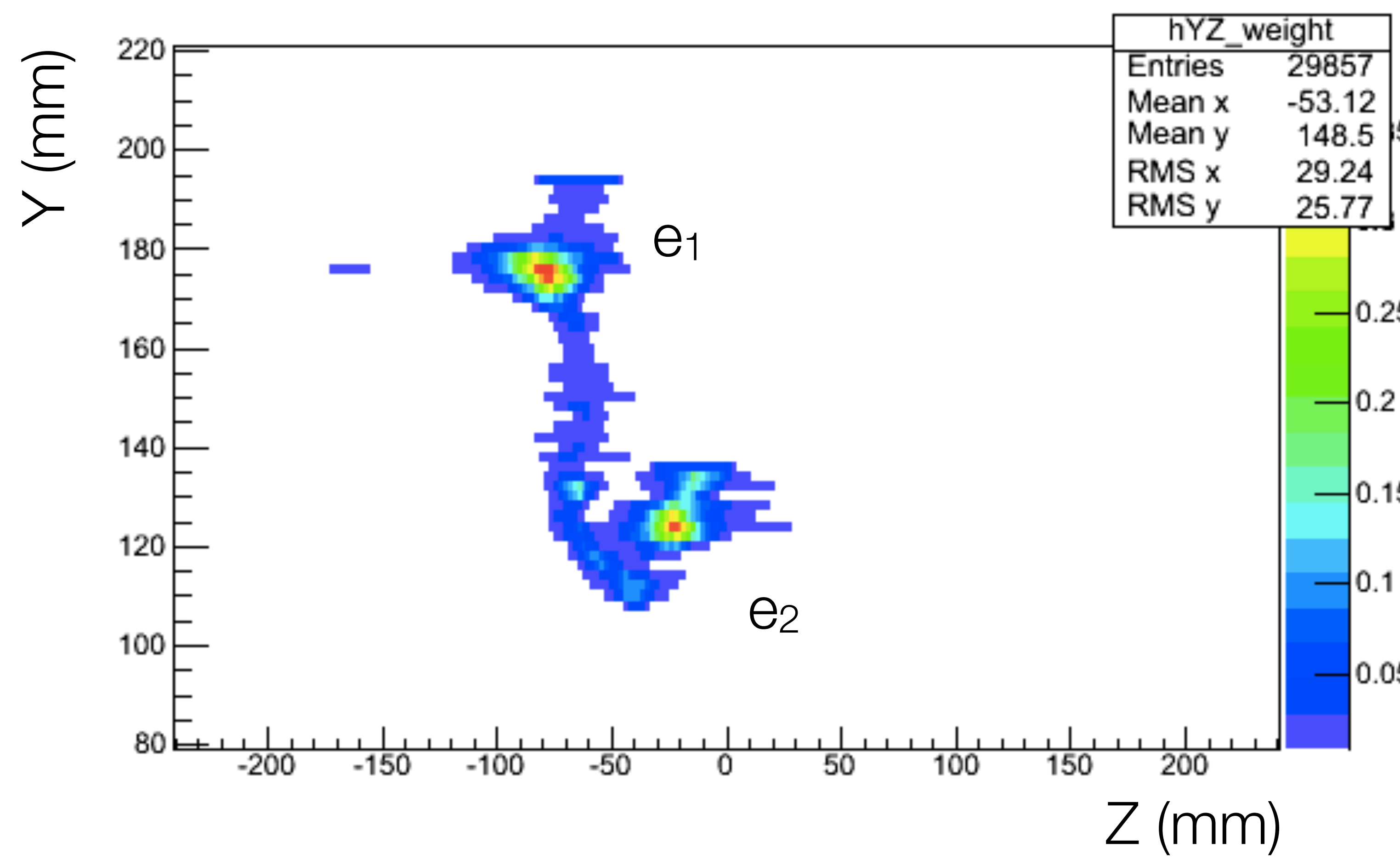

**Select $^{22}Na$ photo-peak events**



# NEXT-NEW tracking reconstruction

- Observe the two stopping electron tracks emitted from common vertex, characteristic of double beta decays
- Powerful handle for single-electron background suppression



# Outlook

- **Several technologies** studying a **variety of isotopes**: Ge Diodes, (scintillating) bolometers, liquid scintillator calorimeters and Xe (LXe, HPXe) TPCs, with the potential to study Ge, Te, Mo, Se and Xe.
- Exploring the **IH** appears feasible (**tonne scale** experiments with **negligible backgrounds**) but will require an intense experimental effort ($\sim$10 years) and a serious investment.
- Observation of **0νββ** will establish that the **neutrino is a Majorana fermion** (its own anti-particle), implying the existence of a new form of matter which has not been observed so far.
  - This discovery would have profound implications for cosmology, as Majorana neutrinos violate lepton number and could **explain** why there is **more matter than antimatter in the Universe**.
- ***The field, now more than three-quarter of a century old, remains one of the most exciting of fundamental physics today.***

# Thanks for you attention!

IFIC Valencia • Zaragoza • Politécnica Valencia • Santiago de Compostela • Girona

• Texas A.M • Texas Arlington, • Fermilab • Argonne • Iowa state

Coimbra • Aveiro

JINR

A. Nariño

**Co-spokepersons: D. Nygren (UTA) & J.J. Gómez-Cadenas (IFIC)**

## The NEXT Collaboration

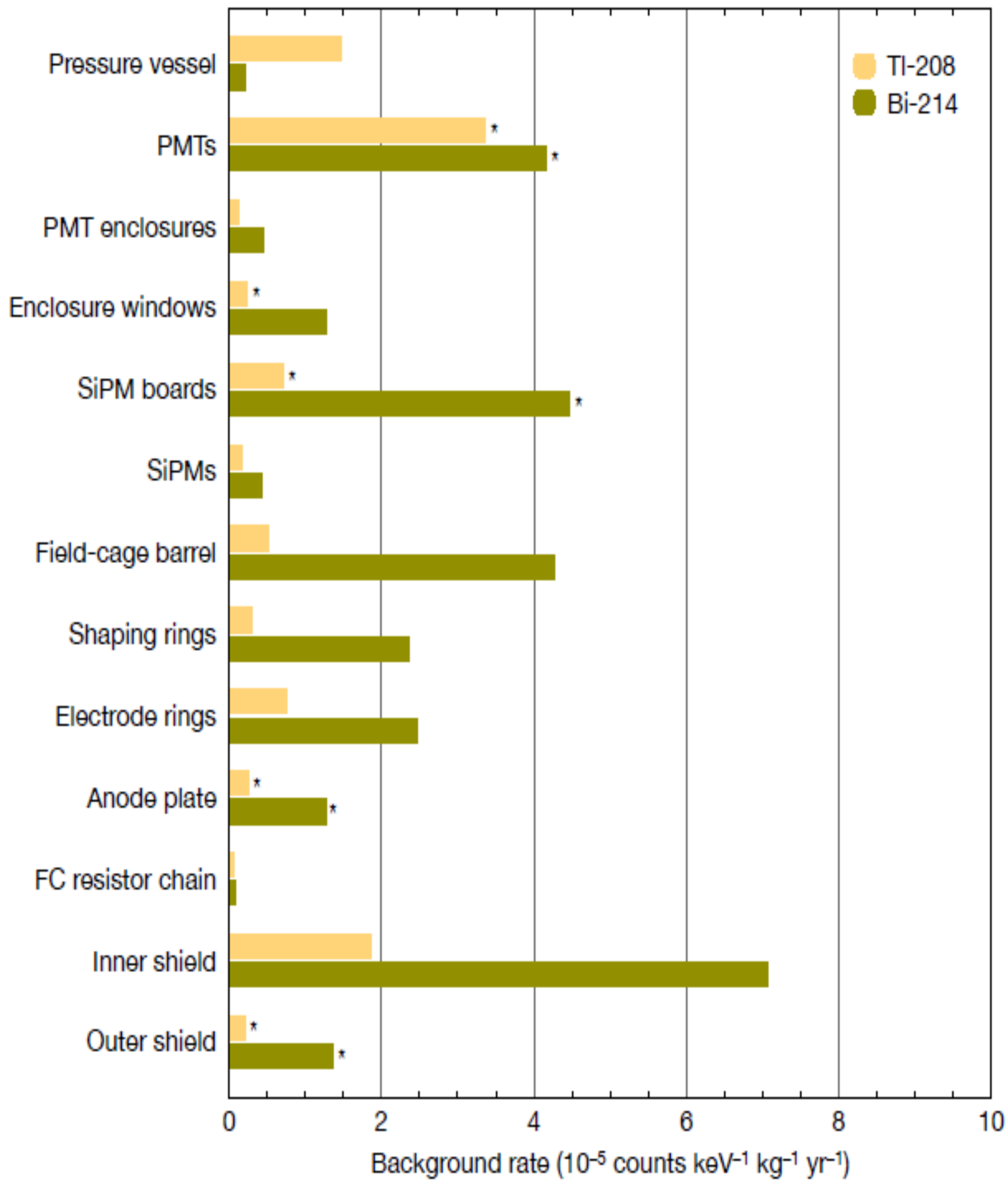
next

*Backup...*

# *NEXT100 scalability to tonne scale*

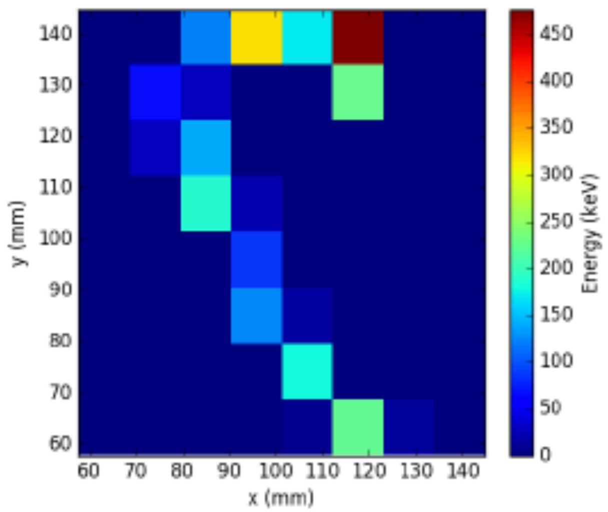
- NEXT-100 MC calculations (energy resolution 0.7% FWHM, high diffusion) yield 8 events/tonne/year in the ROI.
- We need to reduce the background rate by an order of magnitude:
  - **Improve energy resolution** from 0.7% to 0.5% FWHM will reduce the dominant background (Bi214) by a factor 2.
  - Gaseous mixtures can provide low diffusion, **improving rejection** by a factor ~4
- Therefore NEXT-100 can demonstrate ~ 1 event/tonne/year

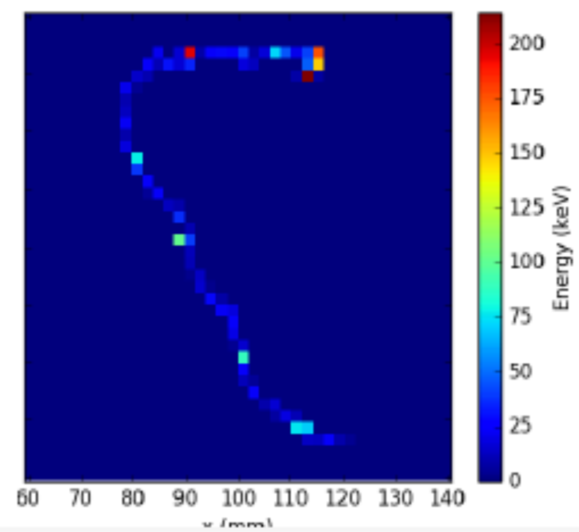
# NEXT bkg



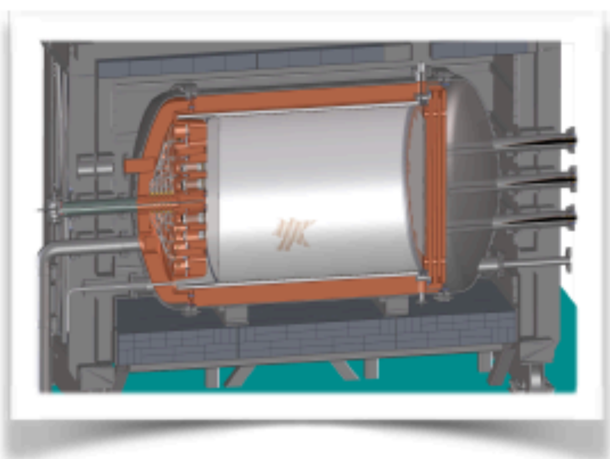
Pressure vessel
PMTs
PMT enclosures
Enclosure windows
SiPM boards
SiPMs
Field-cage barrel
Shaping rings
Electrode rings
Anode plate
FC resistor chain
Inner shield
Outer shield
Tl-208
Bi-214
0
2
4
6
8
10
Background rate ($10^{-5}$ counts keV$^{-1}$ kg$^{-1}$ yr$^{-1}$)

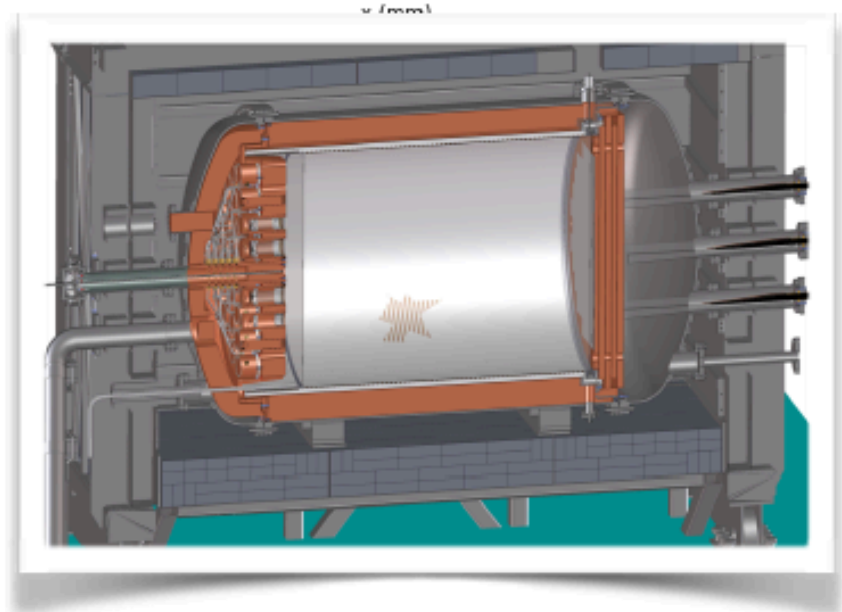
# NEXT: ton scale



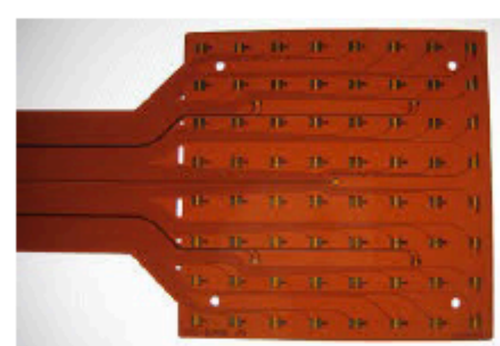




Low diffusion: f ~(1/5)





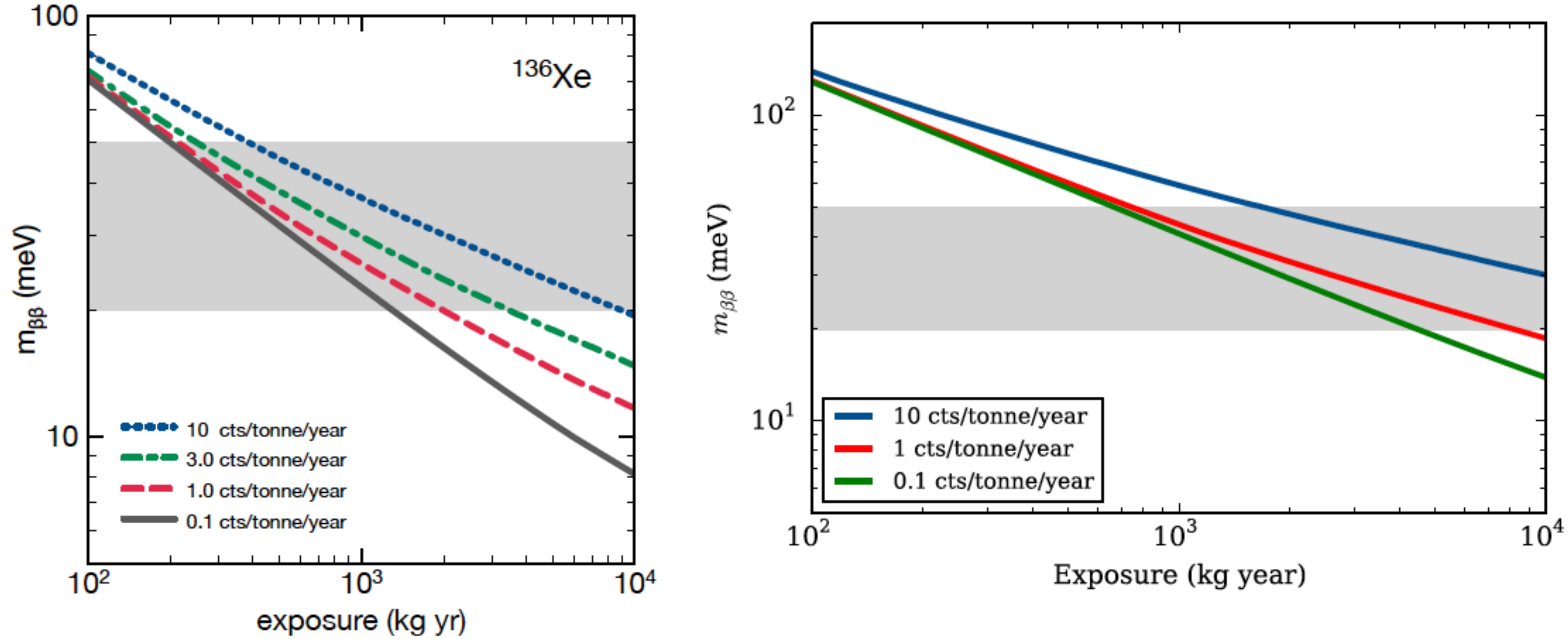
Scale: f ~(1/2)



Radiopurity: f ~(1/2)

- **Reaching 1 event ton/year in the ROI appears possible.**

# “Effective” background free




- Plot shows the sensitivity of a 100% (30 %) efficient Xenon experiment (with a reasonable NME set).
- With a background ~10 cts/tonne/year and a mass of 1 ton, 10 years of run are required (e.g, 30 years for an efficiency of 30 %).
- With a background count of ~1 cts/tonne/year, “only” 2 years are required (6 years for an efficiency of 30%).

**GERDA**: 3.5 keV x 0.7 (3.5) x $10^{-3}$ ckky: ~3 - 12 events/ton

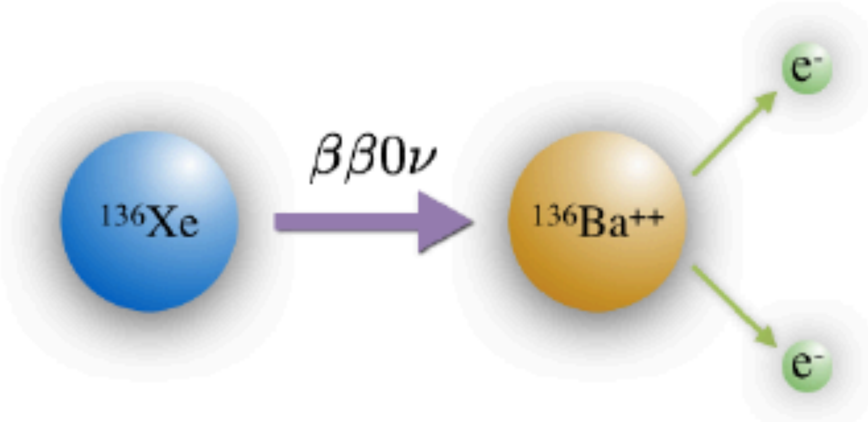
**EXO**: 75 keV x 1 x $10^{-3}$ ckky: ~127 events/ton

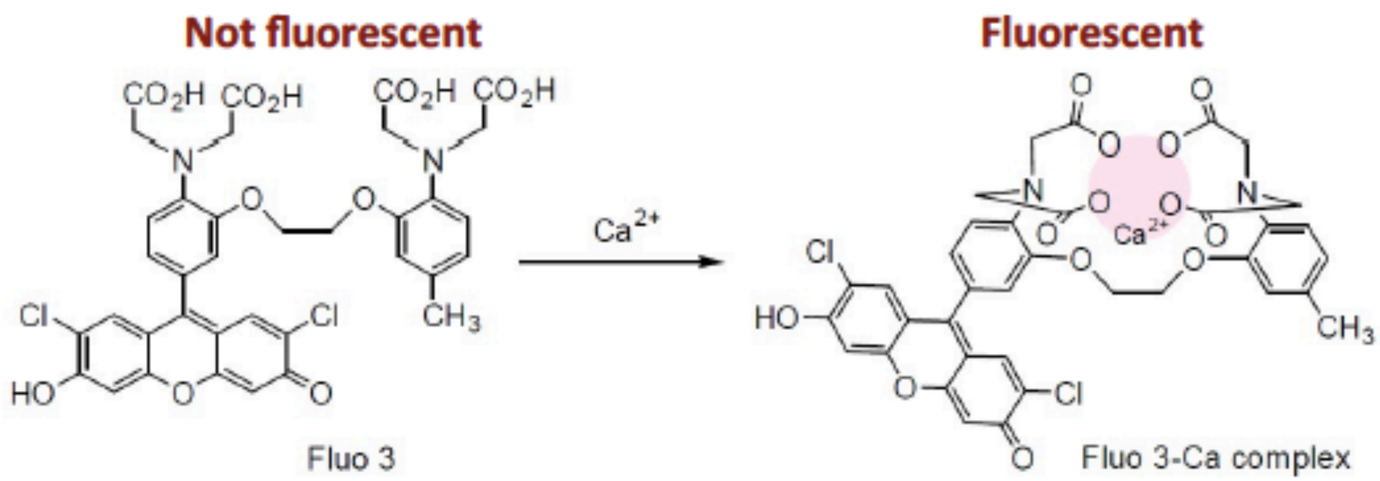
**KamLAND-Zen**: 250 keV x 1.6 x $10^{-4}$ 40 events/ton: (~20 from bb0nu)

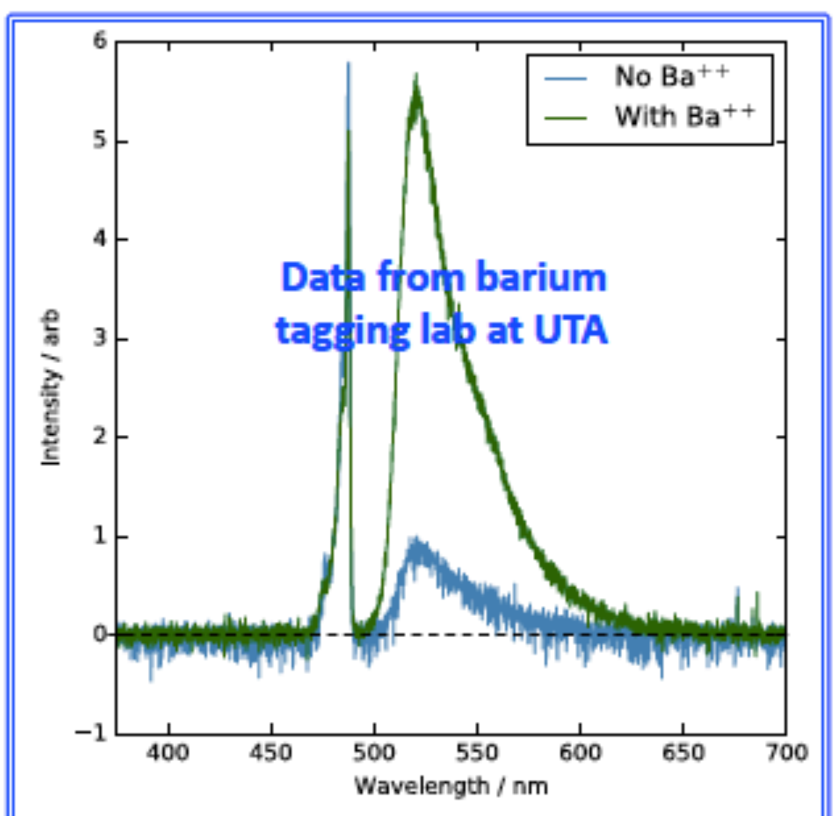
**CUORE**: 5 keV x 6 x $10^{-2}$ ckky: ~300 events/ton

**NEXT**: 17.5 keV x 4 x $10^{-4}$ ckky: ~5-10 events/ton

# BA-TAGGING



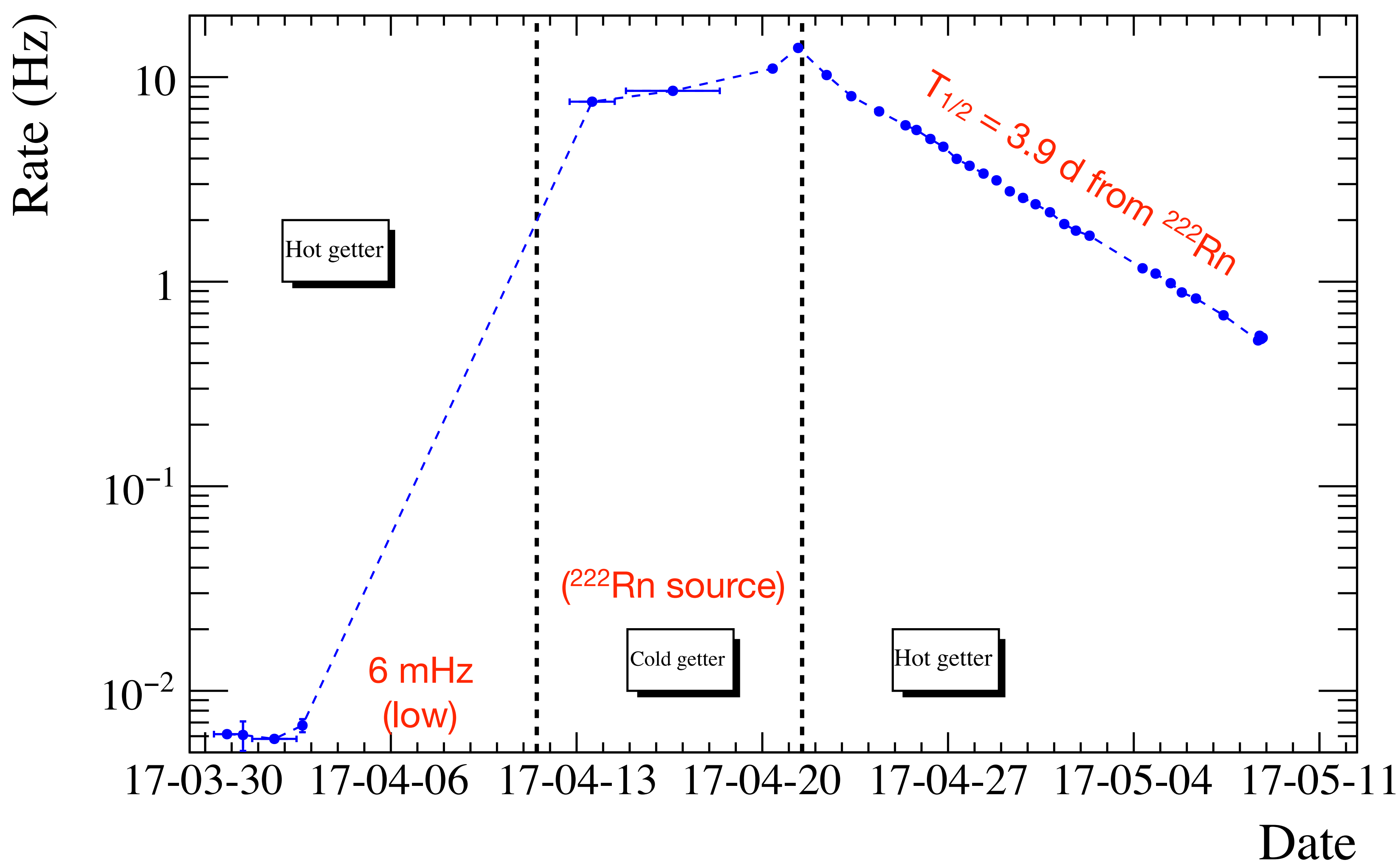




- Xe-136 decays produce Ba++
- Ba++ will drift towards cathode (hopefully without recombining)
- Coat cathode with PSMA molecule, which will capture BA++
- PSMA + BA++ will fluoresce when illuminated with 342 nm light (broad band, 360-430… can design a system to detect blue light. Interrogation rate at ~100 kHz.
- This idea is a new form of Ba-tagging in gas which does not involve extracting the Ba++ ion to vacuum.
- **Potentially: background free experiment.**

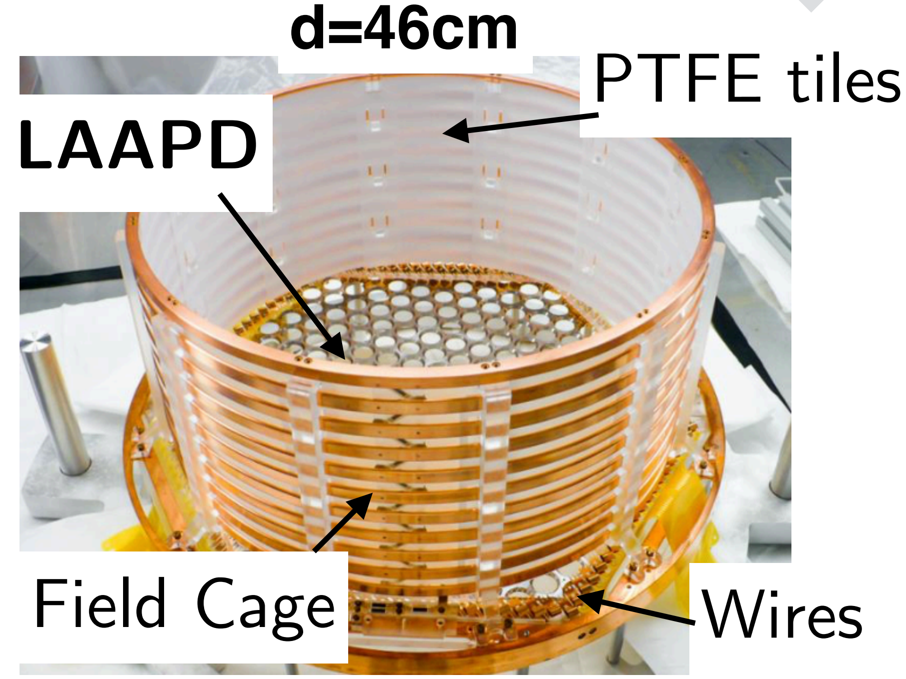
# NEXT radon-induced backgrounds

- Alpha production rate measured in NEW during normal (hot getter) operations point to very low $^{222}$Rn-induced backgrounds for NEXT-100
  - *< $10^{-4}$ counts / (keV·kg·yr)*



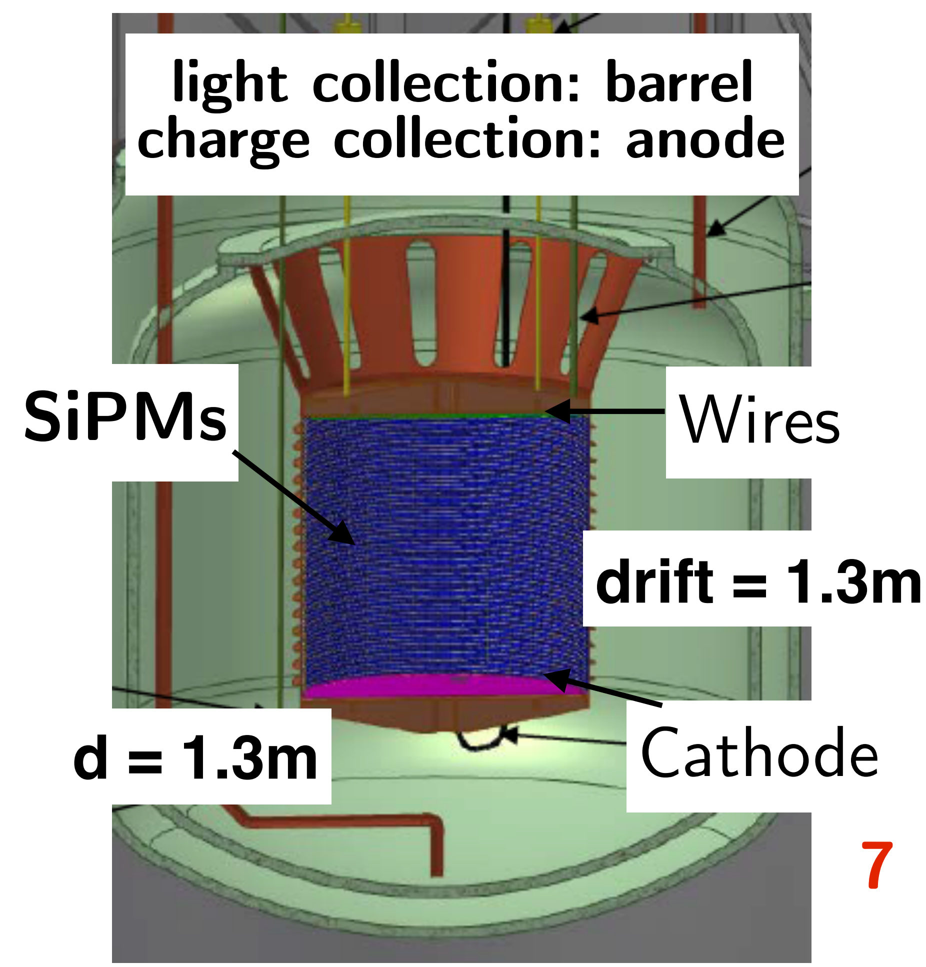
# EXO: Enriched Xenon Observatory

- **Liquid** xenon (enriched at 80.6% in $^{136}$Xe) TPC (measures both scintillation and ionization)
- **Medium energy resolution**: 3% FWHM at Q-value (high fluctuations in ion/electron creation)
- **Low background rate:** 1.7x10$^{-3}$ c/keV/kg/yr
- **Easy to scale up:** compactness




$T^{0\nu}_{1/2} > 1.1 \times 10^{25}$ yr at 90% C.L
(sensitivity: 1.9x10$^{25}$) **($m_{\beta\beta}$~190-450meV)**

*Nature* 510, 229–234 (12 June 2014)




- **Future plan: 1) nEXO** ("next EXO") a 5 tonne experiment: R&D undergoing, sensitivity goal: 7x10$^{27}$ yrs (90% CL); **2)** Ba tagging