

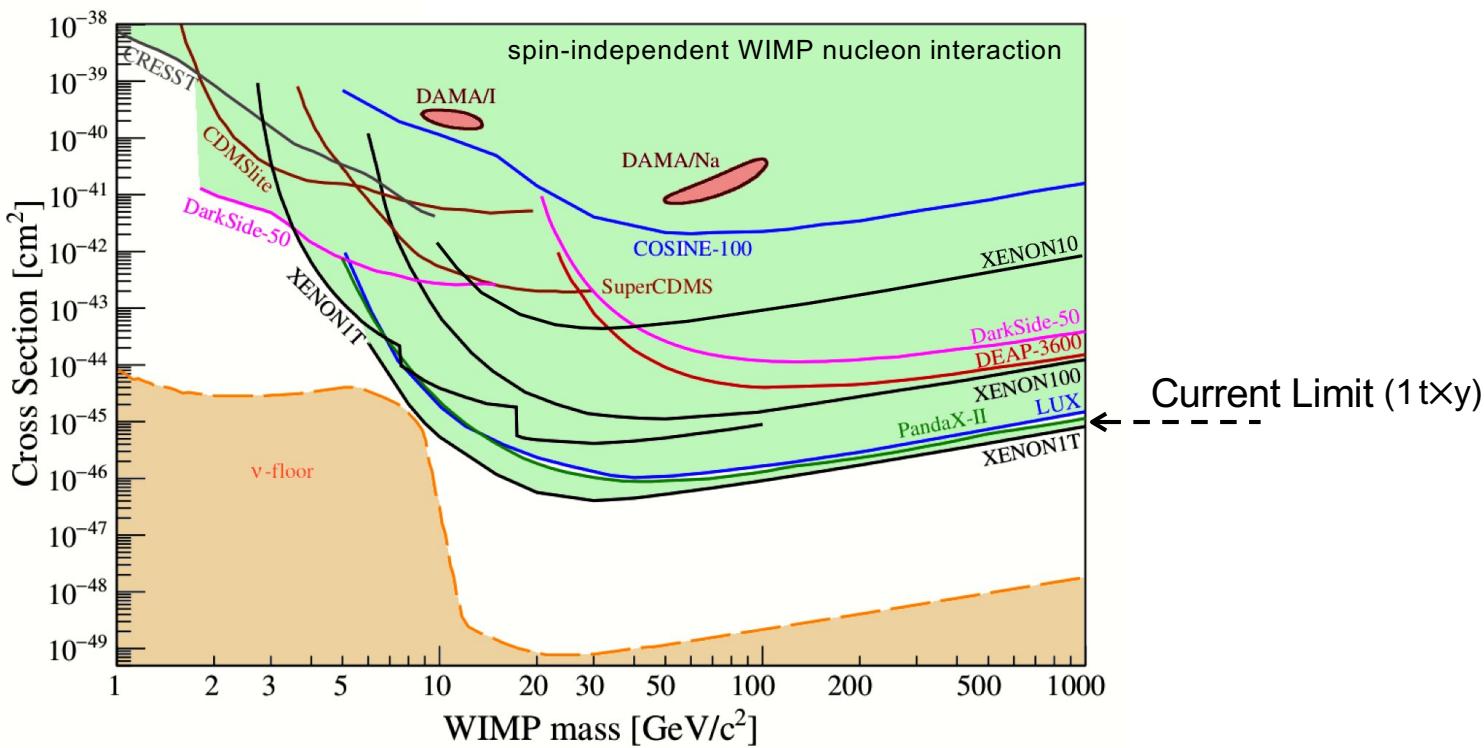
# Future Experiments of Neutrinoless Double Beta Decay Search with $^{136}\text{Xe}$

DARWIN & nEXO

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Subatech – Université de Nantes

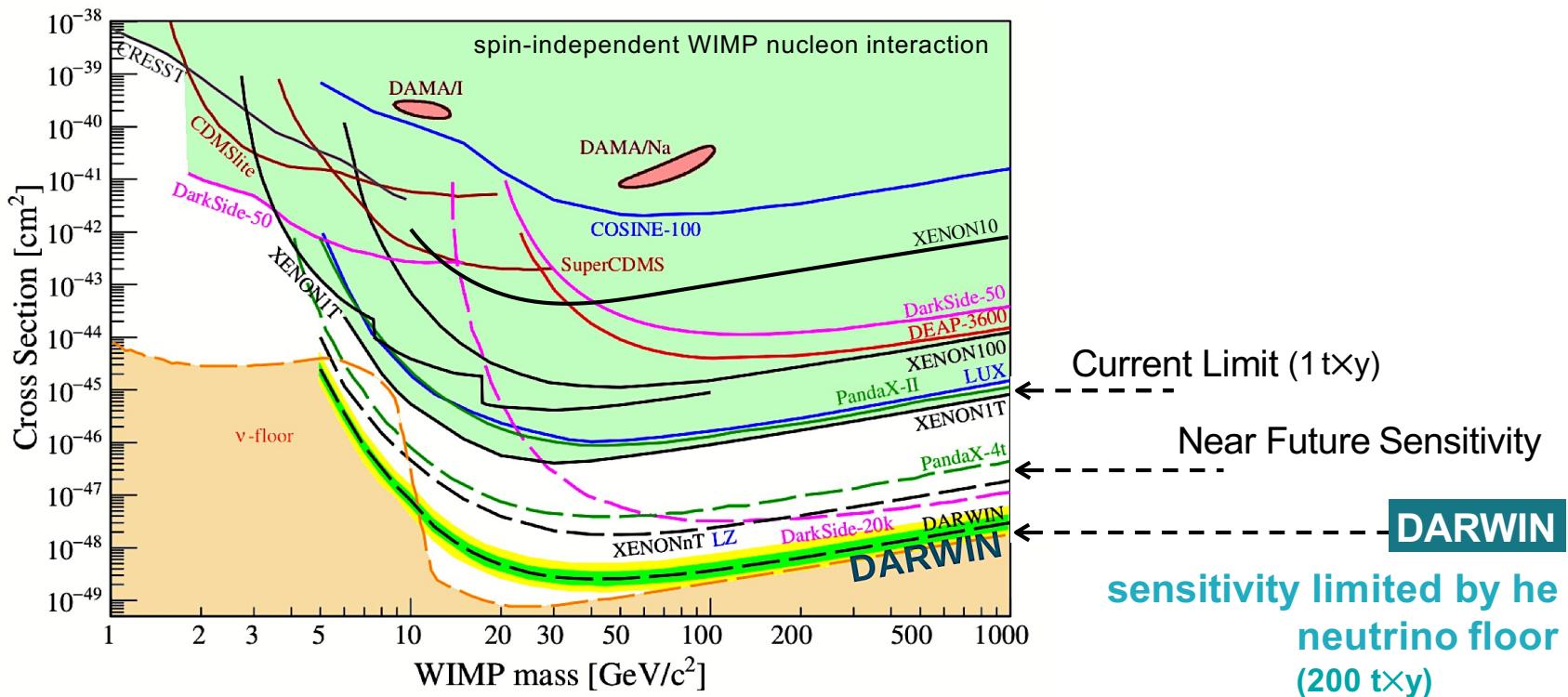
# *WIMP Detection landscape today*

- The highest sensitivity above 2 GeV/c<sup>2</sup> comes from experiments using liquid noble gases as target (Xe, Ar). (heavy target and easy scalability)
- **DARWIN**, the ultimate LXe WIMP detector, with **50t of total mass**, plans to increase 100-fold the current sensitivity.

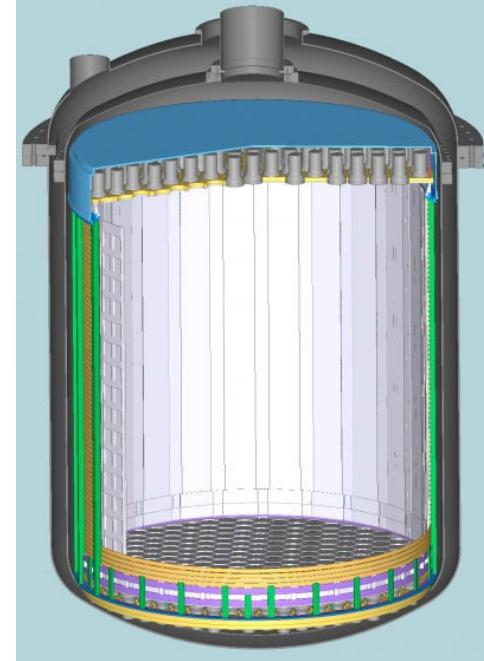


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# Phases of the XENON Program



## XENON10

2005 – 2007

15 cm drift TPC

Total: 25 kg

Target: **14** kg

Fiducial: 5.4 kg

Achieved (2007)

$$\sigma_{\text{SI}} = 8.8 \cdot 10^{-44} \text{ cm}^2$$

@ 100 GeV/c<sup>2</sup>

## XENON100

2008 – 2016

30 cm drift TPC

Total: 161 kg

Target: **62** kg

Fiducial: 34/48 kg

Achieved (2016)

$$\sigma_{\text{SI}} = 1.1 \cdot 10^{-45} \text{ cm}^2$$

@ 55 GeV/c<sup>2</sup>

## XENON1T

2011 – 2018

100 cm drift TPC

Total: 3 200 kg

Target: **2 000** kg

Fiducial: 1 300 kg

Achieved (2018)

$$\sigma_{\text{SI}} = 4.1 \cdot 10^{-47} \text{ cm}^2$$

@ 30 GeV/c<sup>2</sup>

## XENONnT

2019 – 2025

150 cm drift TPC

Total: 8 400 kg

Target: **5 900** kg

Fiducial: ~ 4 000 kg

Projected

$$\sigma_{\text{SI}} = 1.6 \times 10^{-48} \text{ cm}^2$$

@ 50 GeV/c<sup>2</sup>

# *Evolution of LXe TPC as WIMP detectors*

Fiducial mass [kg]

XENON10

5

XENON100

34

LUX

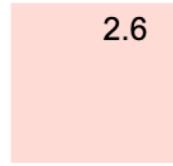
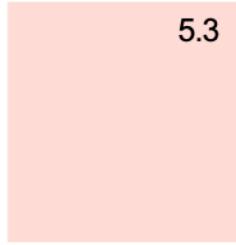
118

PandaX

306

XENON1T

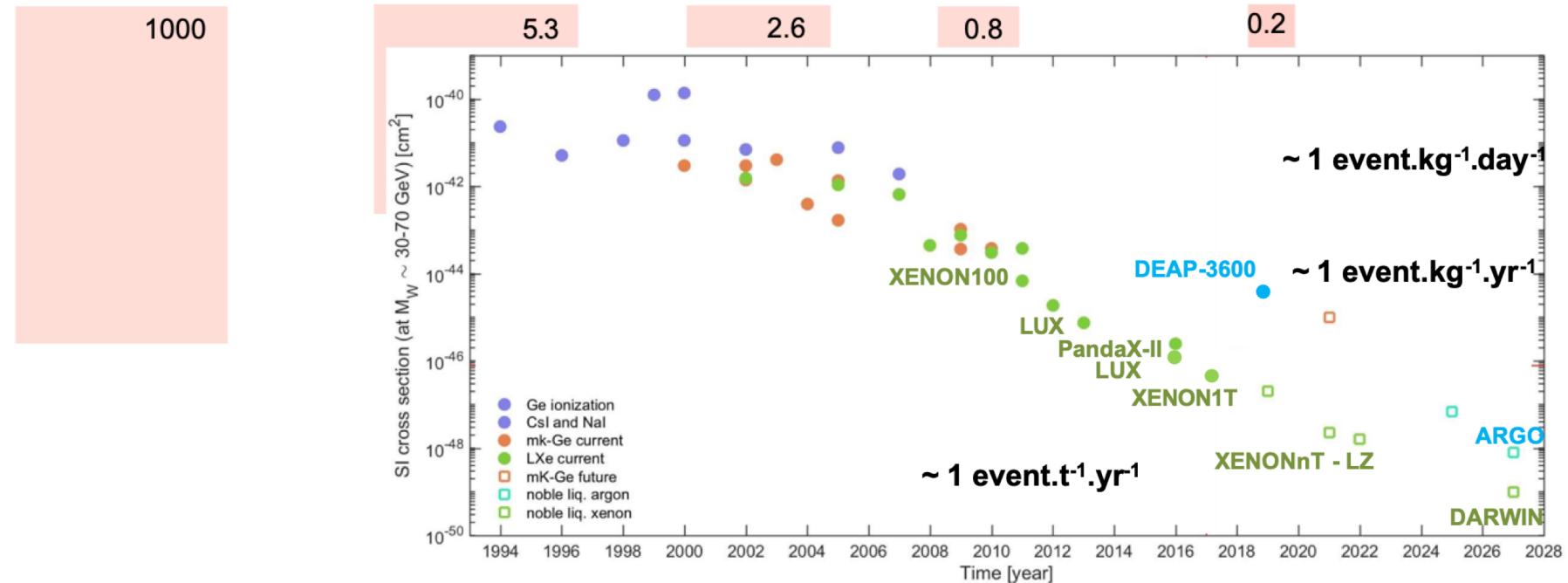
1300



Low-energy ER background  
[events / (tonne keV day)]

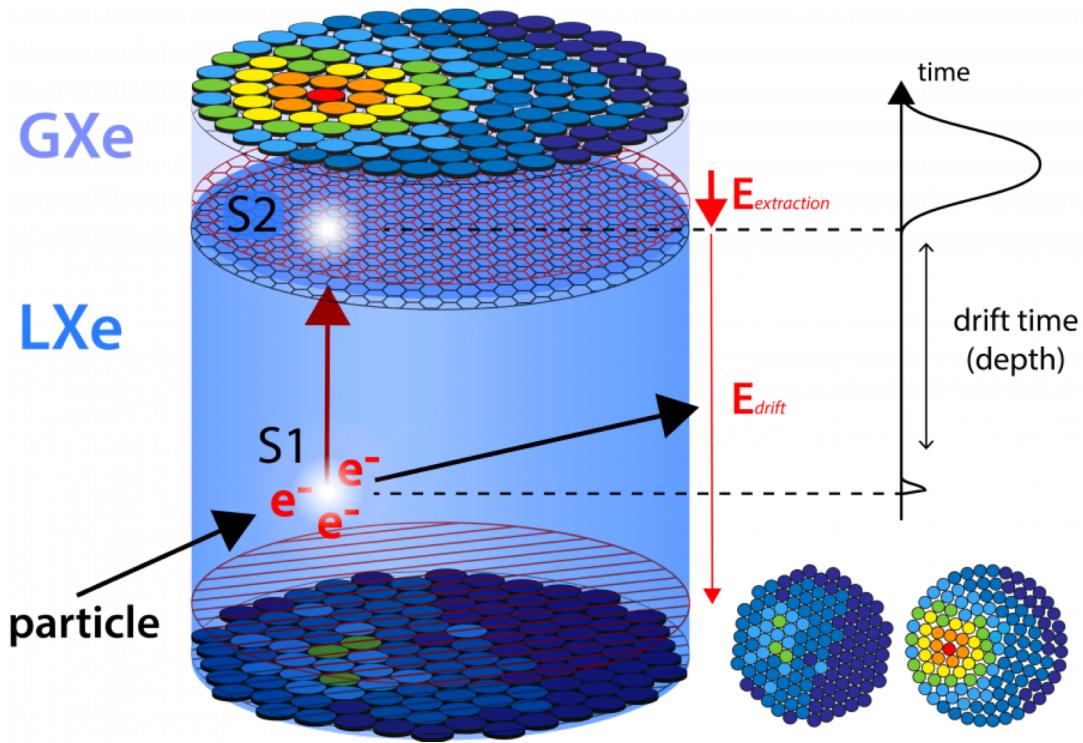
# *Evolution of LXe TPC as WIMP detectors*

Fiducial mass [kg]



# Dual phase TPC: principle

TPC = Time Projection Chamber



S1:

→ Photon ( $\lambda = 178$  nm)  
from Scintillation process

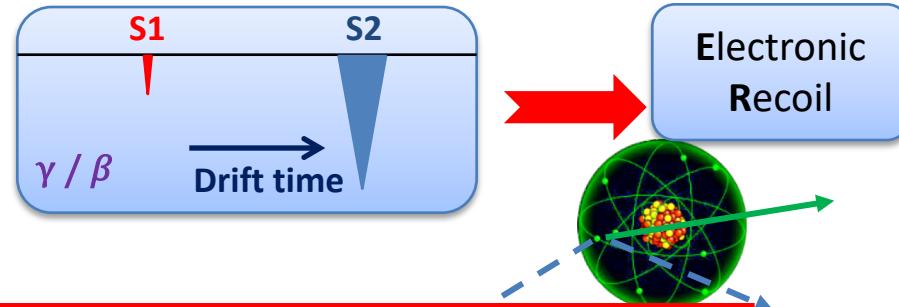
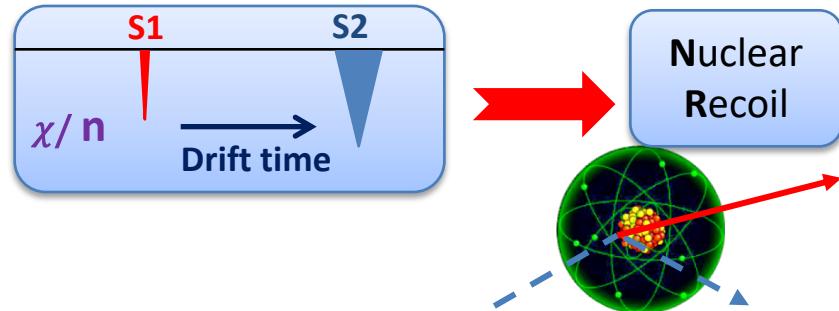
S2:

→ Electrons drift  
→ Extraction in gaseous phase  
→ Proportional scintillation light

3D reconstruction :

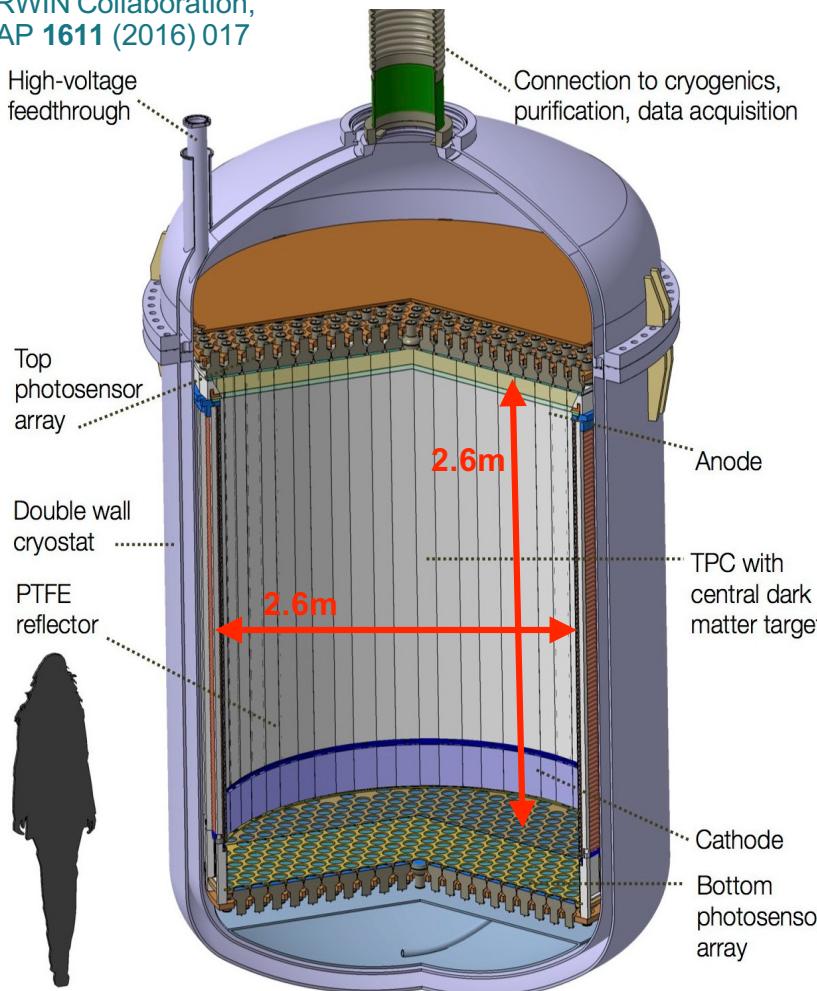
→ X,Y from top array  
→ Z from Drift time

$$(S2/S1)_{WIMP,n} < (S2/S1)_{\gamma,\beta}$$



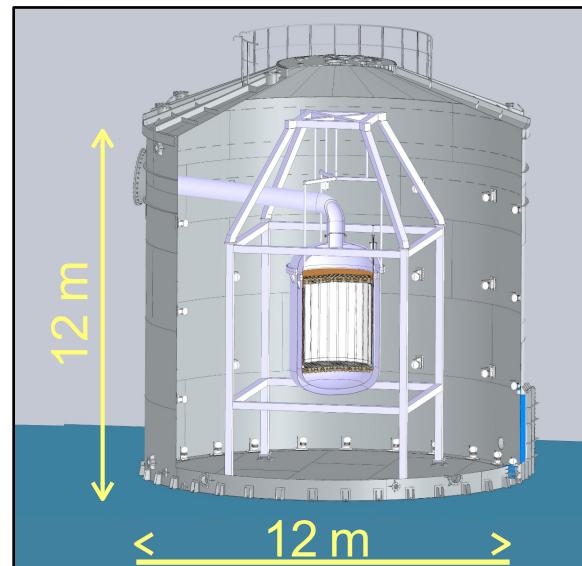
# DARWIN Baseline design

DARWIN Collaboration,  
JCAP 1611 (2016) 017



**baseline design with PMTs but several alternatives under consideration**

- Dual-phase Time Projection Chamber (TPC).
- 50t total (**40t active**) of liquid xenon (LXe).
- Dimensions: **2.6 m diameter and 2.6 m height**.
- Two arrays of photosensors (top and bottom).
- 1910 PMTs of 3" diameter.
- Low-background double-wall cryostat.
- PTFE reflector panels & copper shaping rings.
- Outer shield filled with water (12 m diameter).



Possible realization of DARWIN inside the water tank

# *WIMP Detection landscape today*

Ultra-low Background —— Large Target (40t) —— Low Energy Threshold

DIRECT DETECTION  
OF DARK MATTER

SOLAR AXIONS

GALACTIC AXION-LIKE  
PARTICLES

BOSONIC SUPERWIMPs

DARWIN

much more than a dark  
matter detector

CNNs

NEUTRINOLESS  
DOUBLE-BETA DECAY  
 $^{136}\text{Xe}$

LOW-ENERGY SOLAR  
NEUTRINOS

GALACTIC SUPERNOVA  
NEUTRINOS

■  **$^{136}\text{Xe}$  excellent candidate:**

- Abundance of **8.9% in natural Xe.**
- Q-value = 2.458 MeV (above the ROI of WIMPs)

■ DARWIN will have more than **3.5 t** of active  $^{136}\text{Xe}$ .

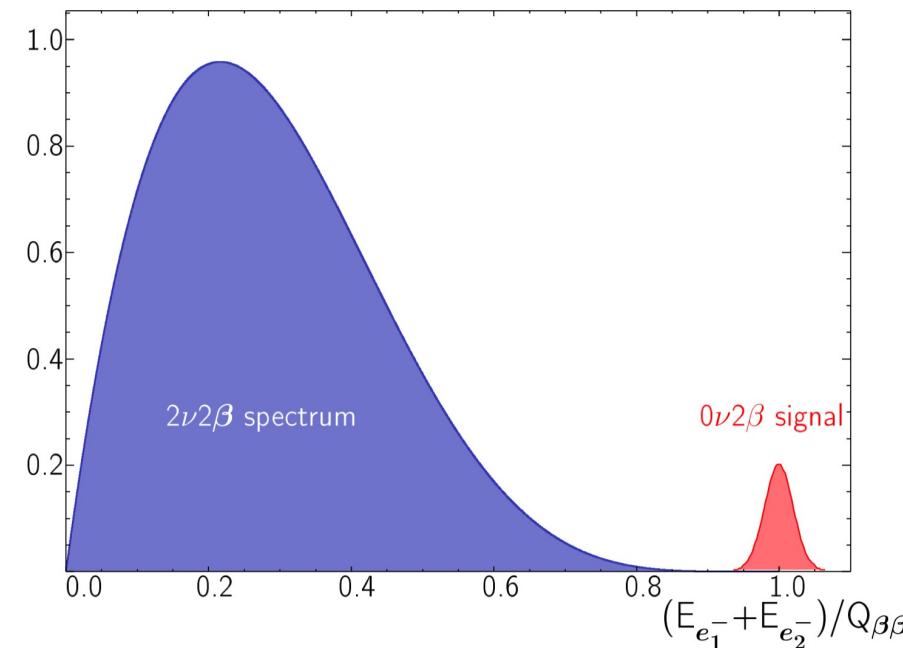
■ Expected energy resolution < 1% at 2.5 MeV

- Already demonstrated by XENON1T (~0.8%)

■ Ultra-low background environment dominated by intrinsic backgrounds:

- $^{222}\text{Rn}$ ,  $2\nu\beta\beta$  decays of  $^{136}\text{Xe}$
- solar  $^8\text{B}$  neutrinos
- $^{137}\text{Xe}$  from cosmogenic activation underground

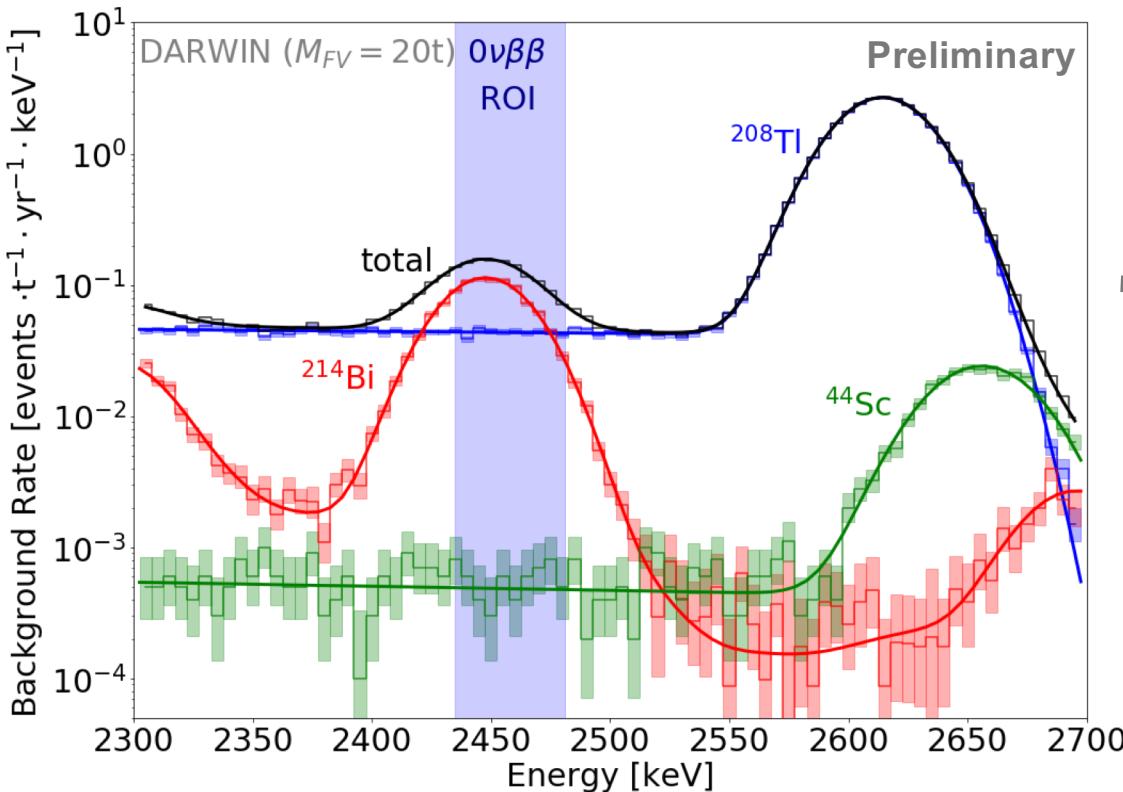
Best lower limit from KamLAND-Zen:  
 $T_{1/2} > 1.07 \times 10^{26} \text{ yr}$  @ 90% CL



Eur. Phys. J. C 80, 808 (2020)

# Material background

Example for 20t (same behaviour for smaller FV)



The main external background in the ROI:

- $^{214}\text{Bi}$  absorption peak (2.45 MeV)
- Compton scattered photons from  $^{208}\text{Tl}$

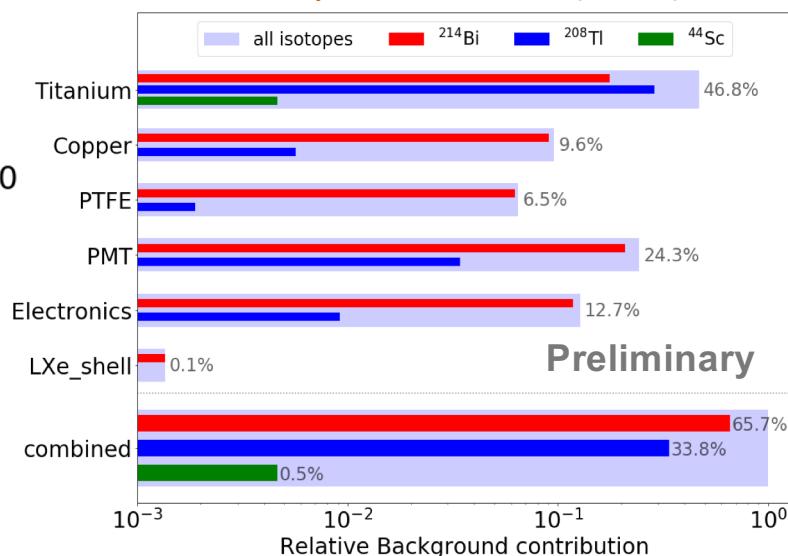
DARWIN ROI for  $0\nu\beta\beta$ :

$\text{Q-value} \pm \text{FWHM}/2$

(2435 - 2481 keV)

Mainly from the cryostat  
and the PMTs

Eur. Phys. J. C 80, 808 (2020)



# Intrinsic background

## ■ $^{222}\text{Rn}$ in the LXe:

- Assumption:  $0.1 \mu\text{Bq}/\text{kg}$
- 10 times lower than XENONnT
- 99.8 % BiPo tagging efficiency

## ■ Irreducible $^8\text{B}$ solar neutrinos ( $\nu\text{-e} \rightarrow \nu\text{-e}$ ):

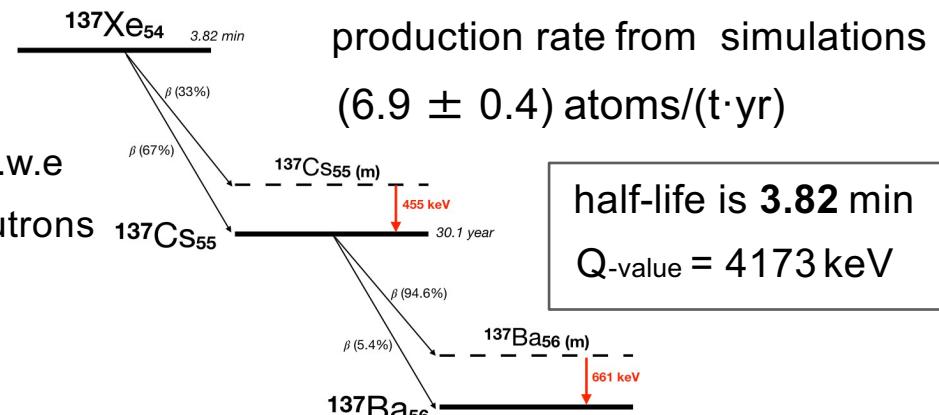
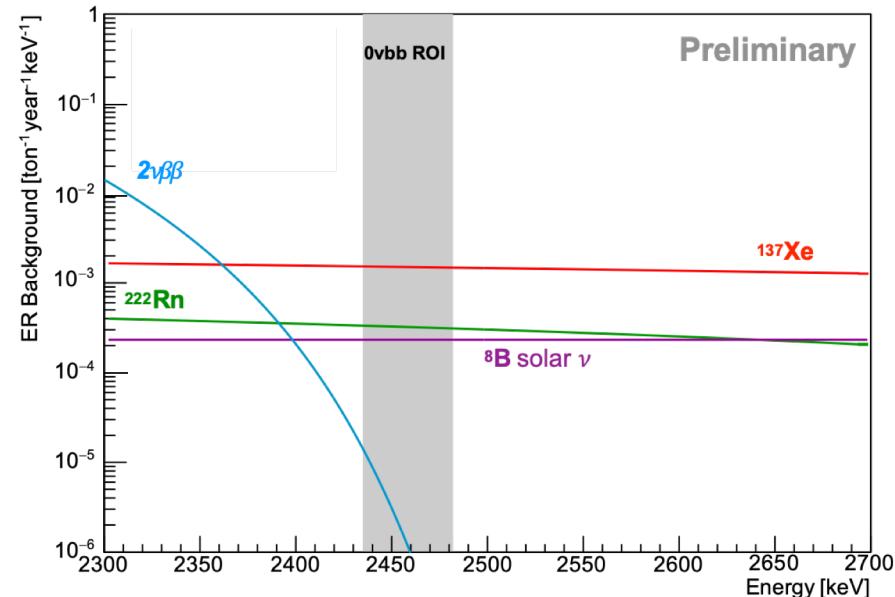
- $\phi_{\nu\text{e}} = 5.46 \times 10^6 \text{ cm}^{-2} \text{ s}^{-1}$

## ■ $2\nu\text{bb}$ decay of $^{136}\text{Xe}$ .

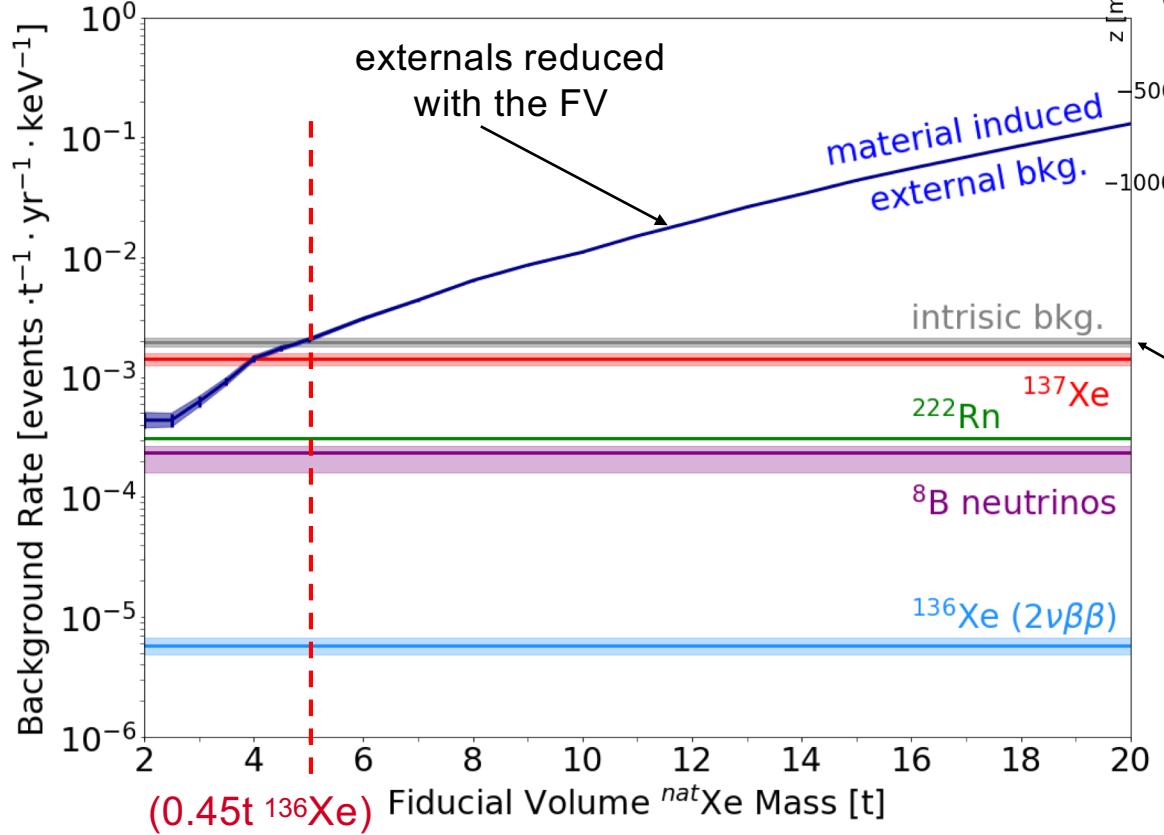
- Subdominant due to the energy resolution

## ■ $^{137}\text{Xe}$ from cosmogenic activation underground:

- Potential background for a depth of 3500 m.w.e
- Dedicated simulations of muon-induced neutrons

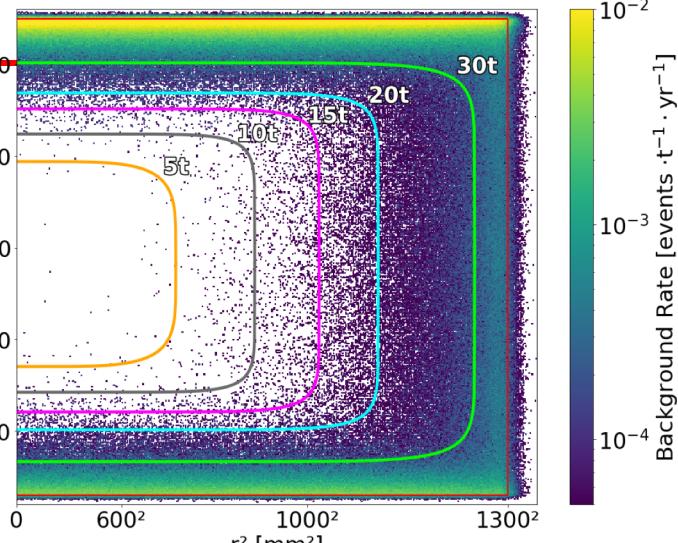


# Total background & Fiducial Volume



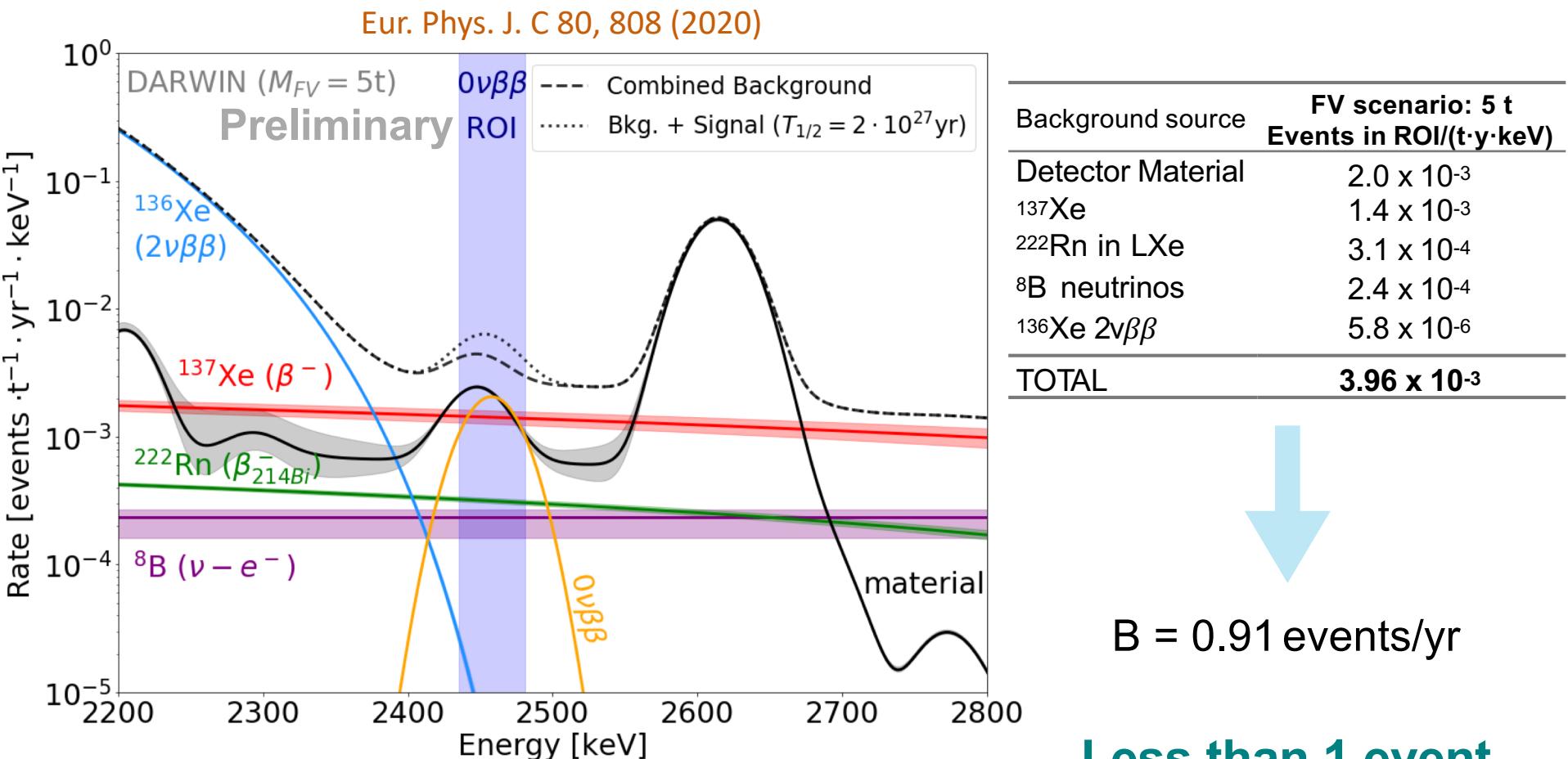
Optimal Value  
5 tonnes

Eur. Phys. J. C 80, 808 (2020)



intrinsics do not change with the fiducialization

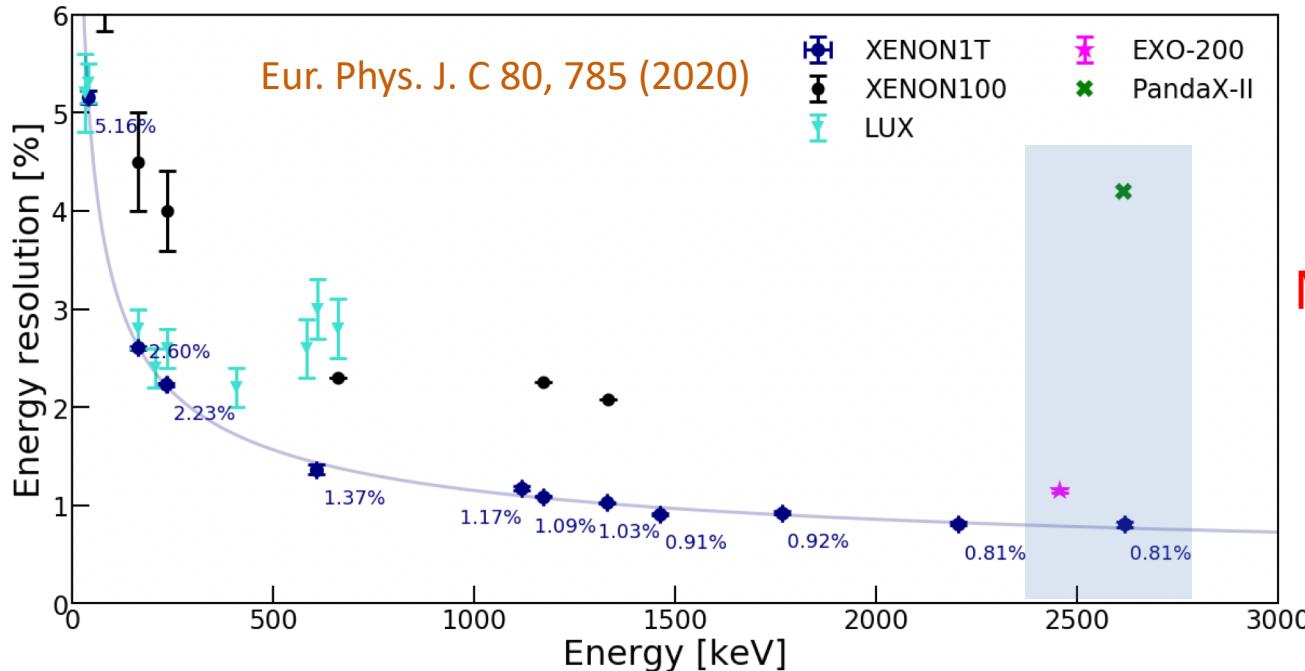
# Total background for 5t Fiducial



The hypothetical  $0\nu\beta\beta$  signal in the plot has a strength of  $0.5 \text{ events/y}$  ( $T_{1/2} \approx 2 \times 10^{27} \text{ years}$ )

**Less than 1 event per year in the ROI !!**

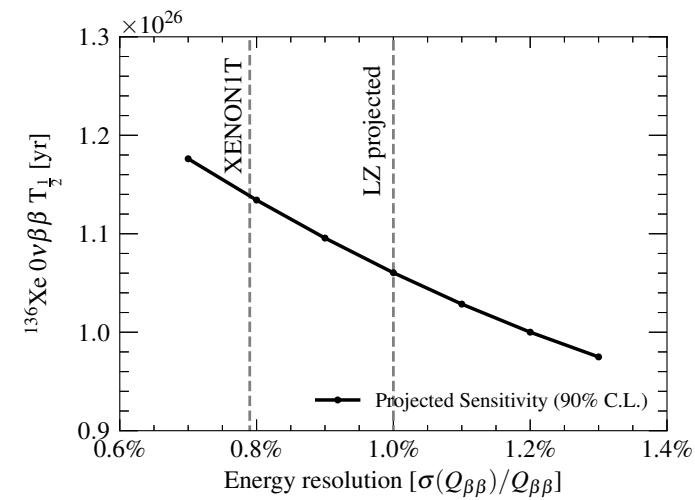
# Last improvements



Talk by  
Maxime Pierre  
(XENON1T)

$$S^{0\nu} = \frac{\ln(2)}{90\% \text{ CL}} \cdot \frac{\alpha}{\epsilon} \cdot \frac{A}{\Delta E} \cdot \frac{\sqrt{M \cdot t}}{b} \cdot \frac{\text{FV mass}}{\text{Resolution @ } Q_{\beta\beta}}$$

Isotopic abundance, FV mass, Livetime, Background rate, Resolution @  $Q_{\beta\beta}$ , Atomic mass, Detection efficiency.

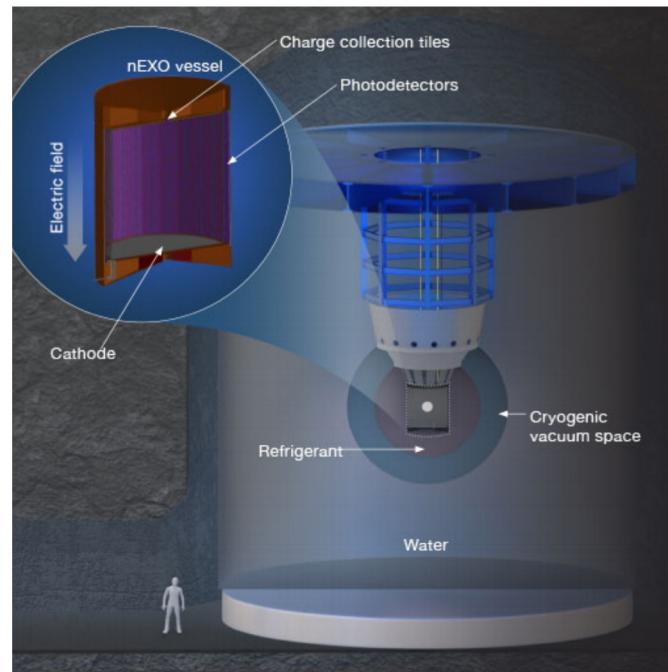


# Future Ovbb LXe experiments

DARWIN – Dual phase (Liquid/gas)



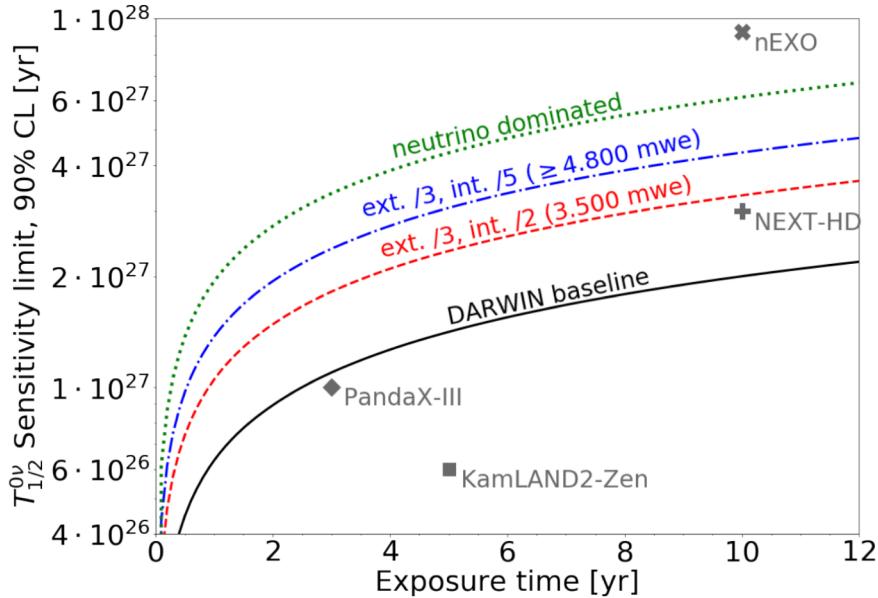
nEXO – Single phase (liquid)



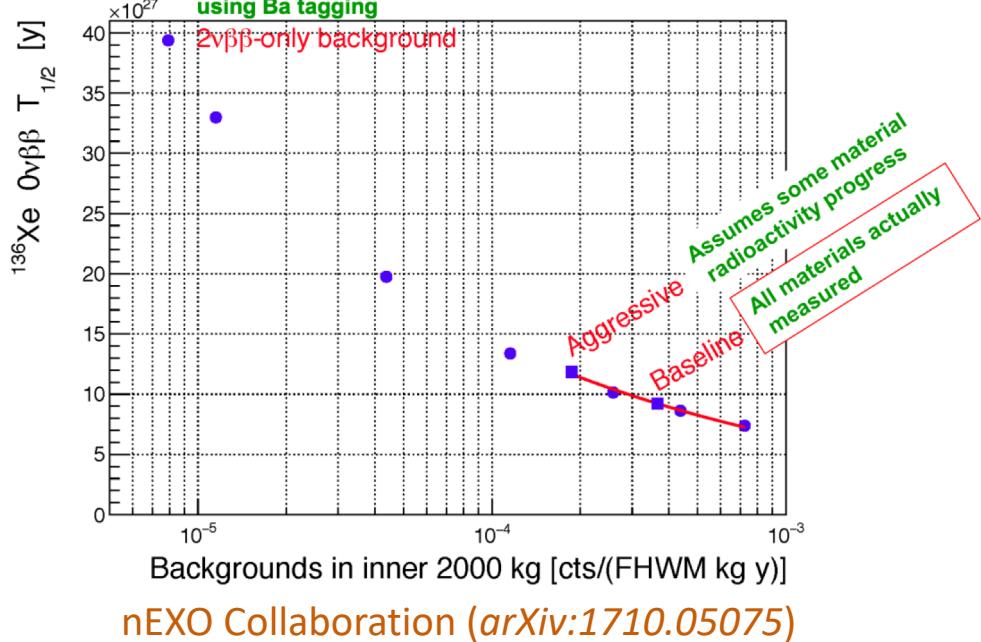
	DARWIN	nEXO
Total LXe	50 t	5 t
Fiducial Mass (0vbb)	5 t	4 t
$^{136}\text{Xe}$ Abundance	8,9 % (natural)	90 % (enriched)
TPC size (approx.)	2,6m H x 2,6 m $\varnothing$	1,3 m H x 1,3 m $\varnothing$

# Ovbb $^{136}\text{Xe}$ perspectives

DARWIN Collaboration ([arXiv:2003.13407](https://arxiv.org/abs/2003.13407))



Asymptotic sensitivity  
for a potential upgrade  
using Ba tagging



Compared to presents results :

(KamLAND-Zen:  $T_{1/2} > 1.07 \times 10^{26}$  yr)

- Darwin : x 10 (baseline) – 20 (enhanced)
- nEXO : x 100 (baseline) – 400 (aggressive)

Great time ahead