

# Search for neutrinoless double beta decay with the NEXt experiment

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ICHEP 2024  
PRAGUE

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[ic hep2024.org](http://ic hep2024.org)

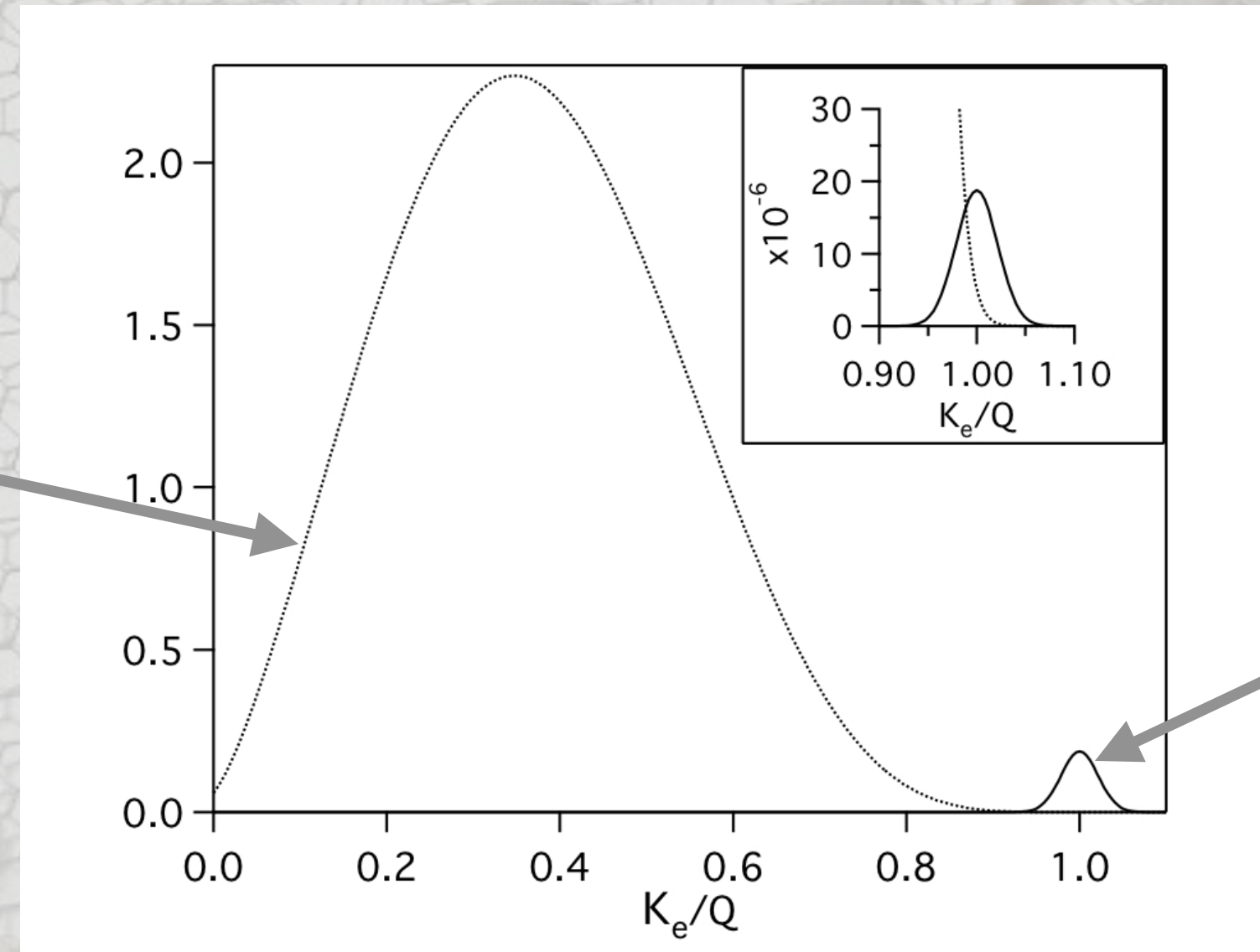
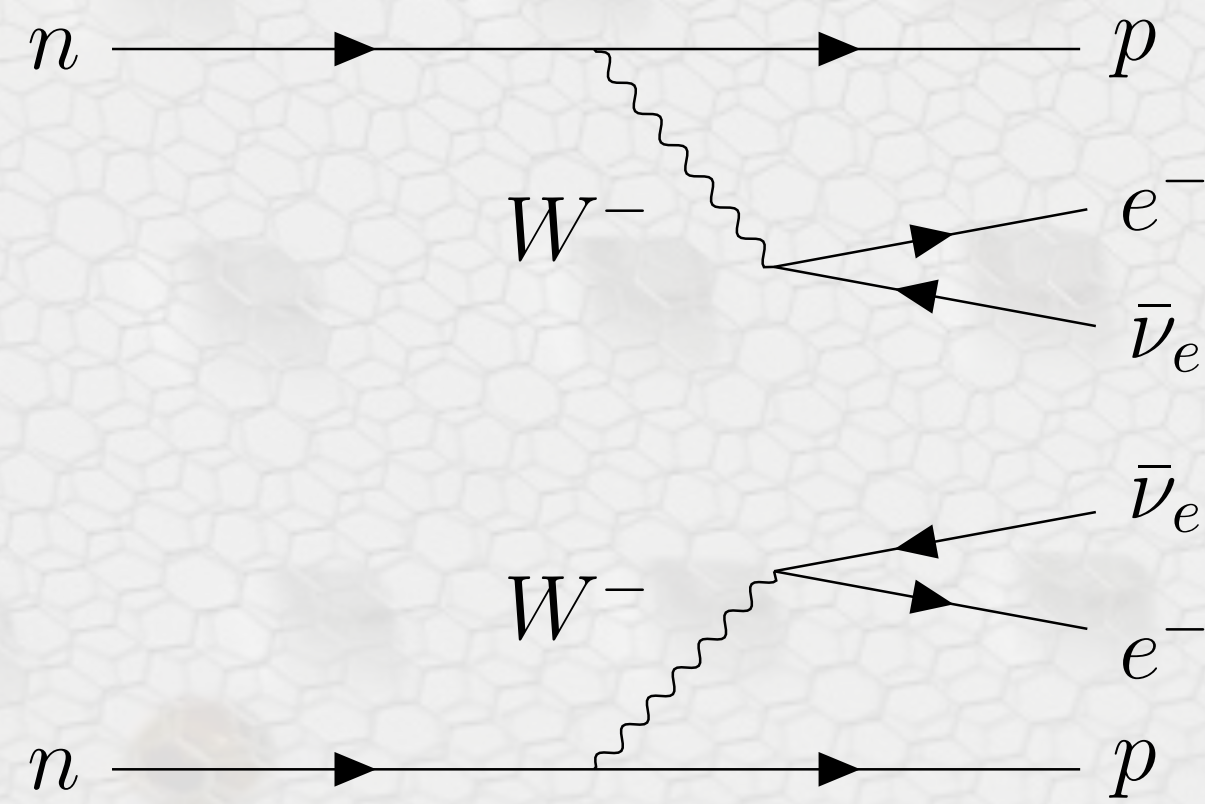


MANCHESTER  
1824

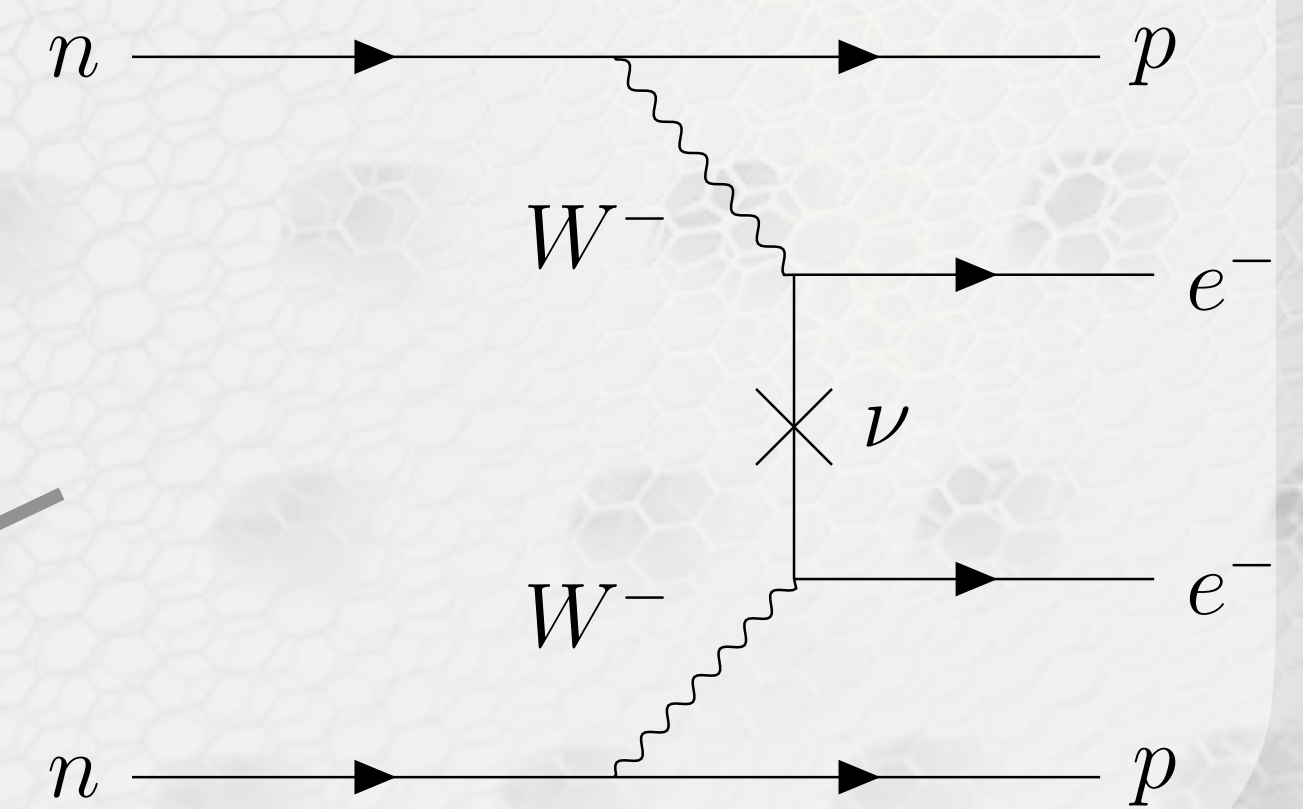
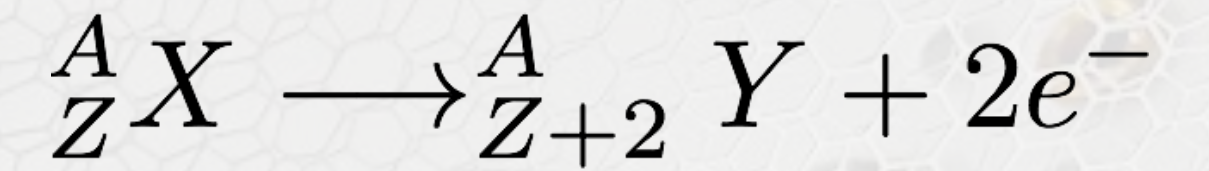
The University of Manchester

# Double beta decay

## $\beta\beta 2\nu$



## $\beta\beta 0\nu$



$$T_{1/2}^{\beta\beta 2\nu}({}^{136}\text{Xe}) = 2.165 \pm 0,016 \pm 0,059 \cdot 10^{21} \text{ y}$$

[Universe 6 (2020) 10, 159]

Continuous spectrum

Discrete spectrum @  $Q_{\beta\beta}$

# Sensitivity to $\beta\beta 0\nu$

$$S(m_{\beta\beta}) = K_2 \epsilon^{-1/2} \sqrt[4]{\frac{c \cdot \Delta E}{M_{\beta\beta} t}} \propto T_{1/2}^{-1/2}$$

# Sensitivity to $\beta\beta 0\nu$

Detection efficiency

Background rate

Energy window  
(Resolution)

$$S(m_{\beta\beta}) = K_2 \epsilon^{-1/2} \sqrt[4]{\frac{c \cdot \Delta E}{M_{\beta\beta} t}} \propto T_{1/2}^{-1/2}$$

$$K_2 = \sqrt{k} K_1 = \sqrt{k \frac{W_{\beta\beta}}{\log 2 N_A} \frac{m_e^2}{G^{0\nu} |M^{0\nu}|^2}}$$

(isotope)

Exposure

# The @next collaboration

\**Neutrino Experiment with Xenon TPC*

**Isotope:**  $^{136}\text{Xe}$

**Detection method:** High Pressure gas Xe TPC

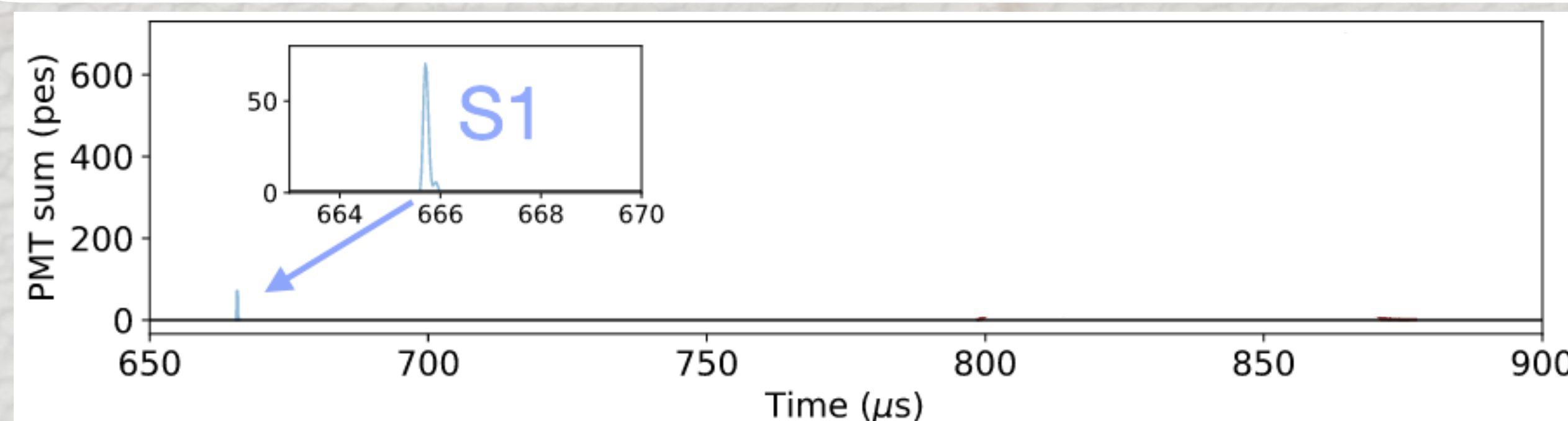
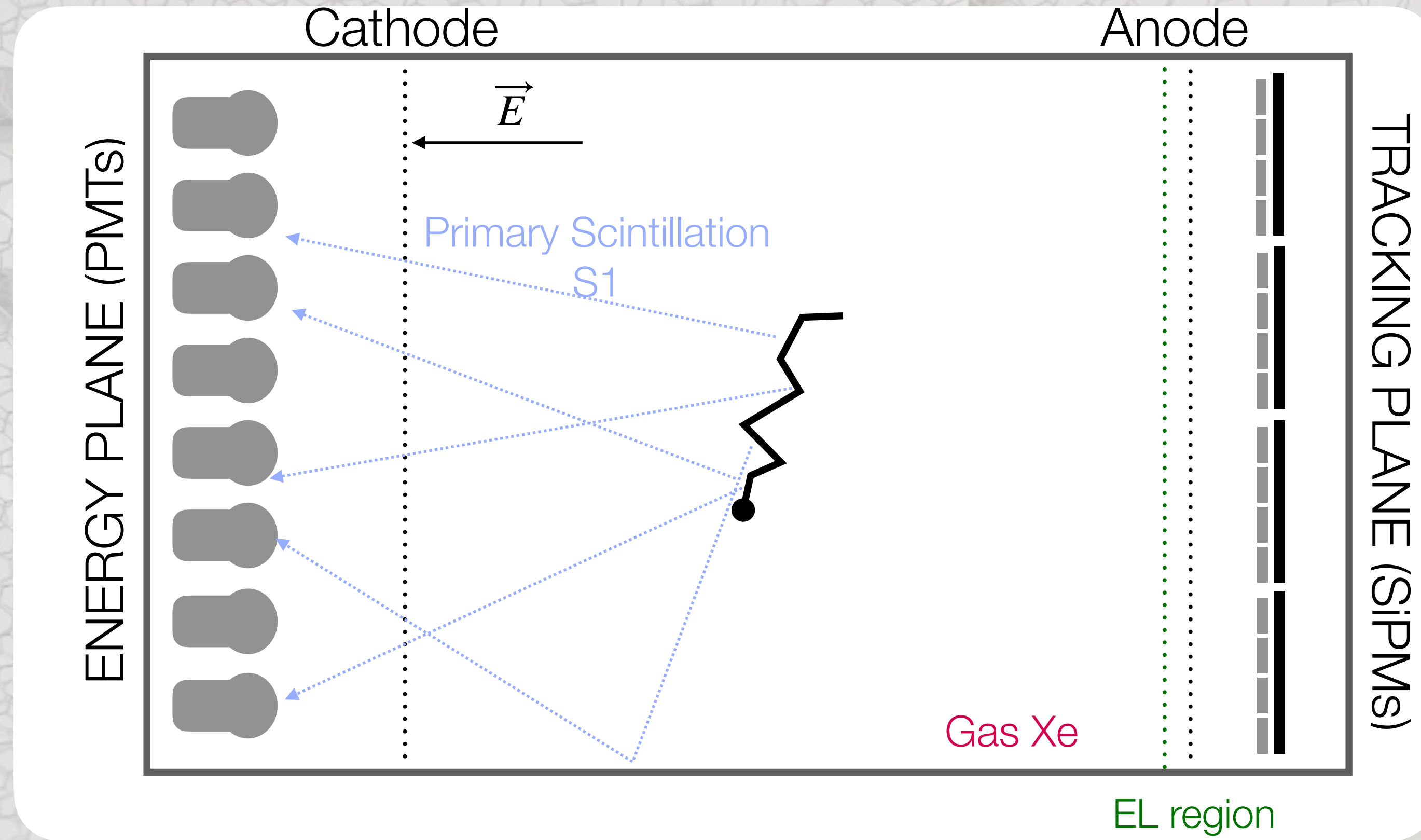
**Q-value:** 2.458 MeV

**Advantages:**

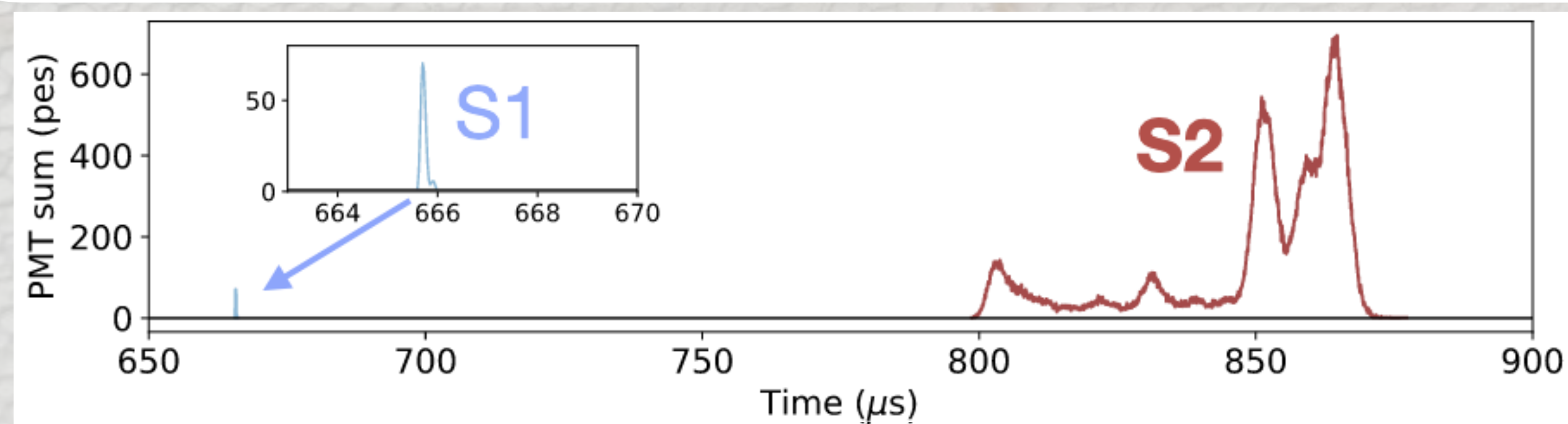
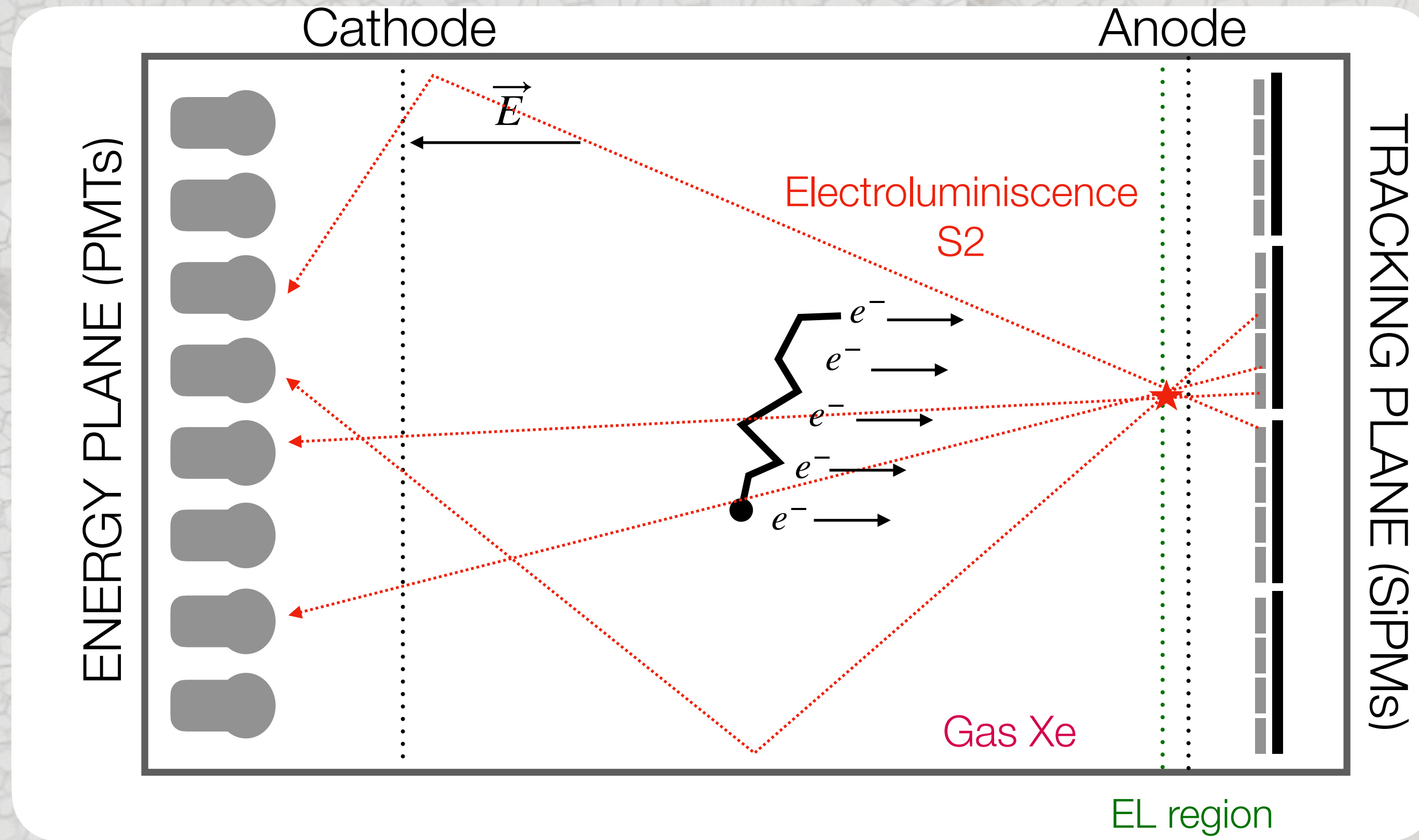
- Best resolution for Xe experiments ( $<1\% \text{FWHM}@Q_{\beta\beta}$ )
- Tracking information (Full tracks)
- Low background



# Principle of operation



# Principle of operation



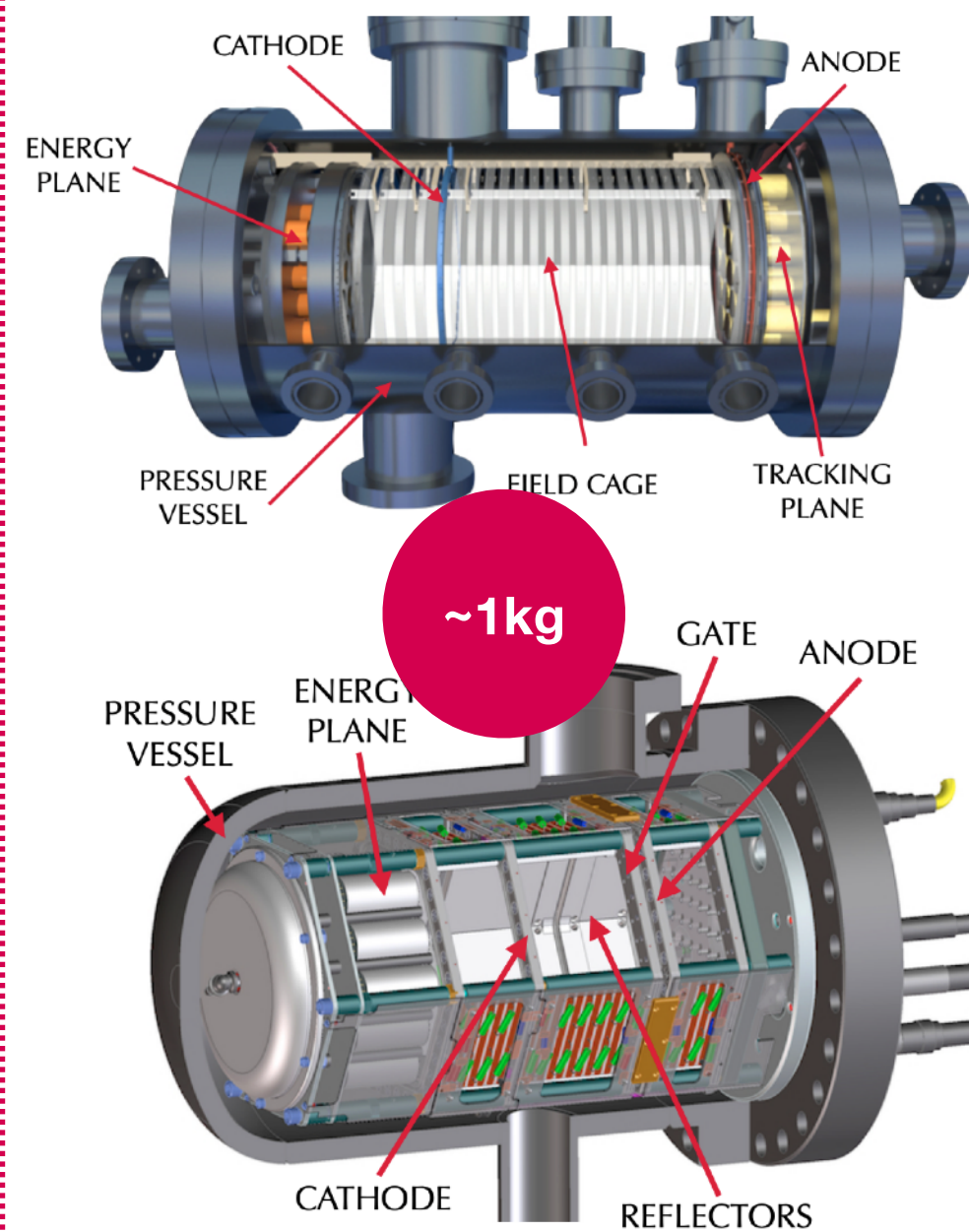
# The @next programme



## PROTOTYPES

2009/2014

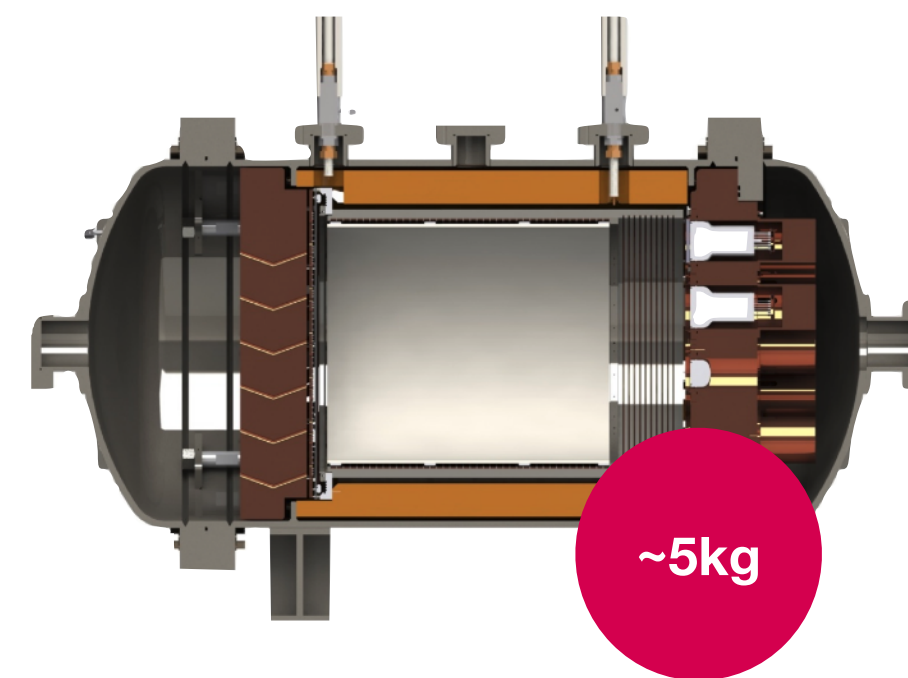
Demonstration of the detector concept



## NEXT-WHITE (NEW)

2015/2021

Background model assessment  
 $2\nu\beta\beta$  measurement for  $^{136}\text{Xe}$



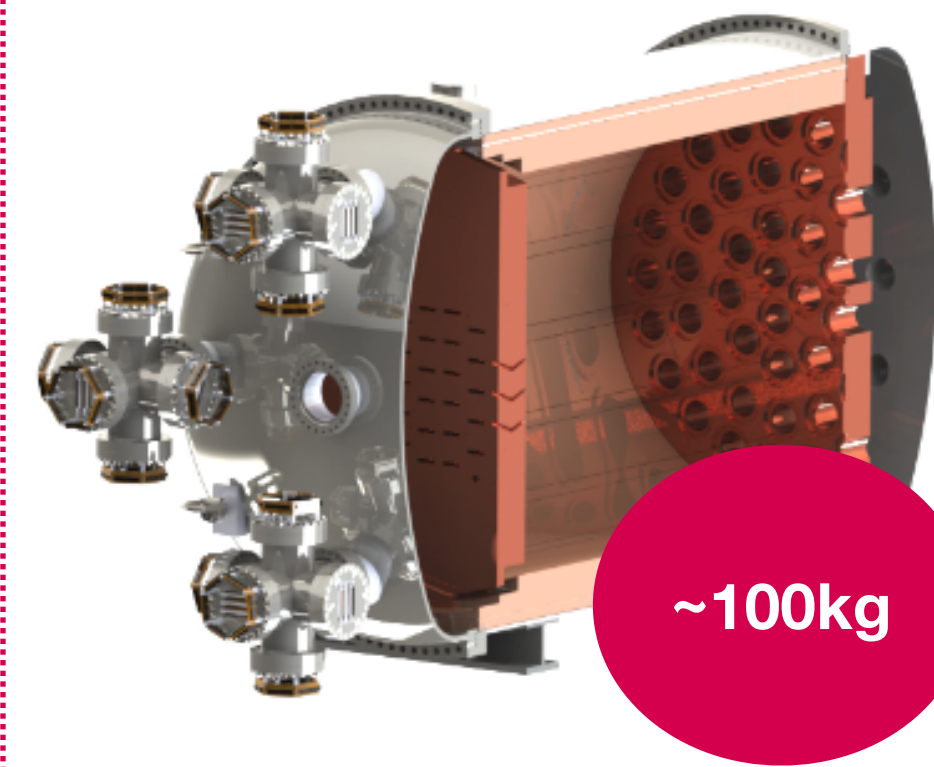
@  Laboratorio Subterráneo Canfranc

## NEXT-100

2024/2027

Scalability

Background improvement  
Neutrinoless double beta decay search in  $^{136}\text{Xe}$



@  Laboratorio Subterráneo Canfranc

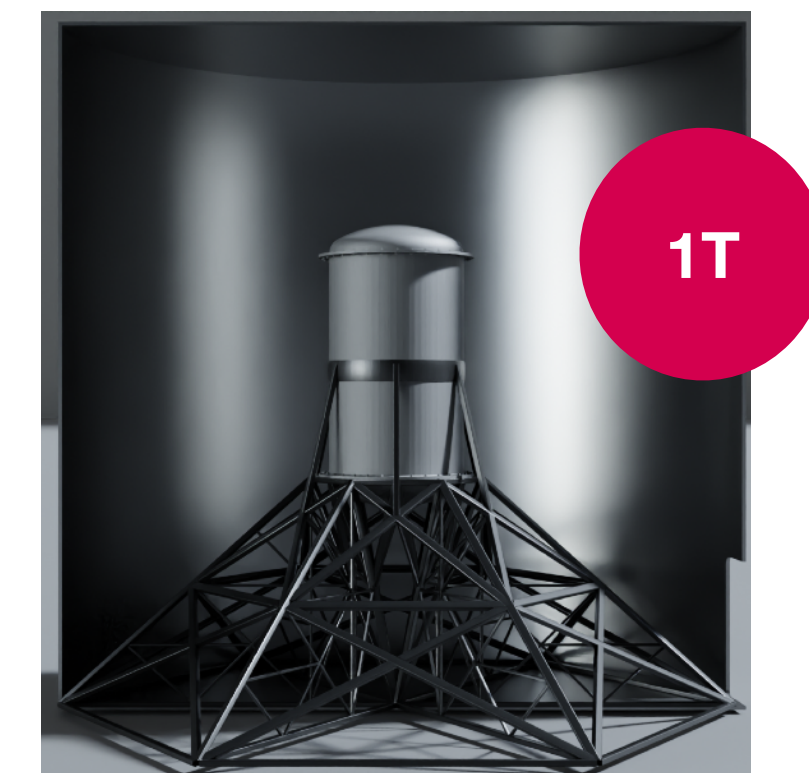
## NEXT-HD

2027?

Neutrinoless double beta decay search through inverted neutrino mass ordering

## NEXT-BOLD

Barium tagging for background-free experiment  
inverted neutrino mass ordering





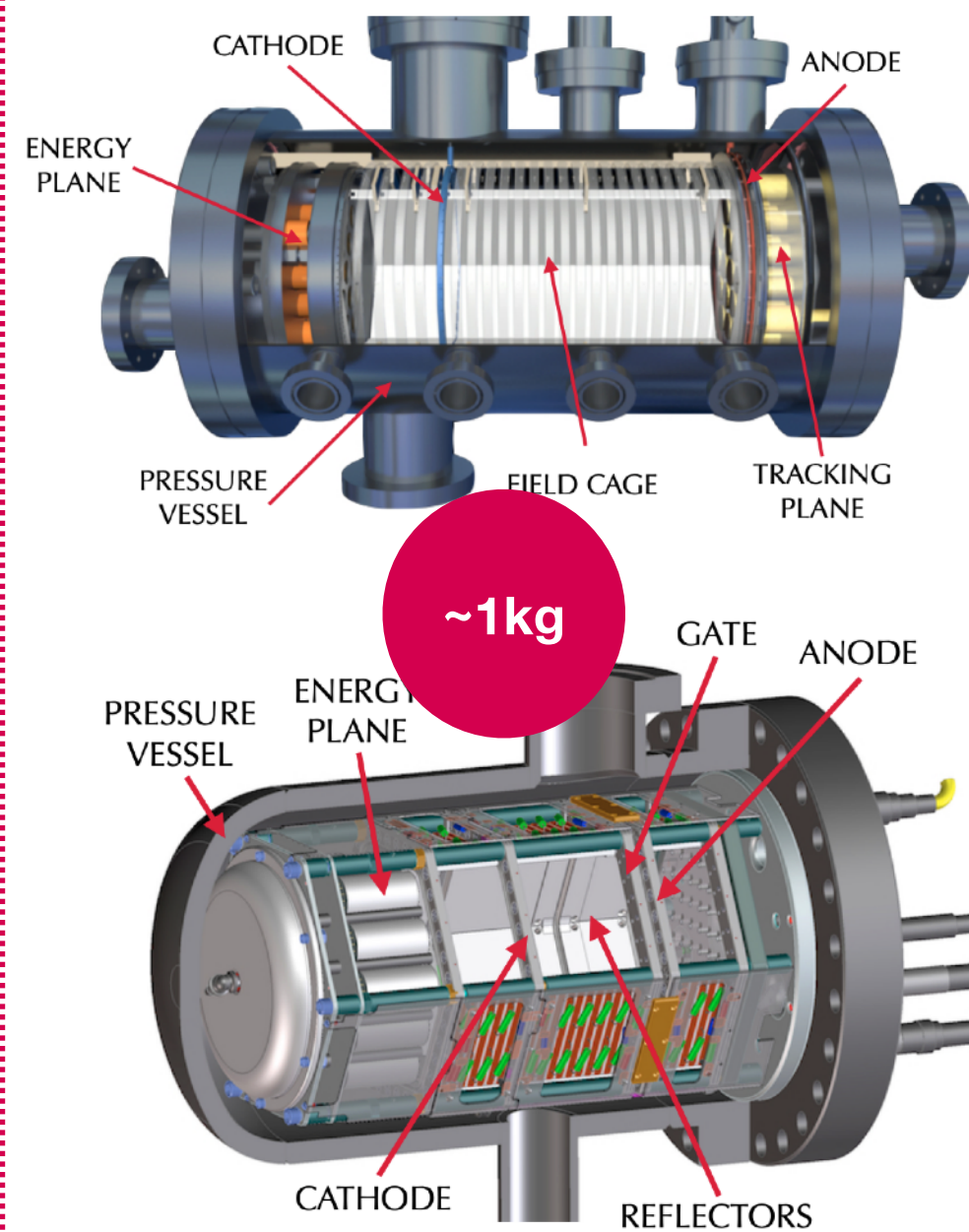
# The @next programme



## PROTOTYPES

2009/2014

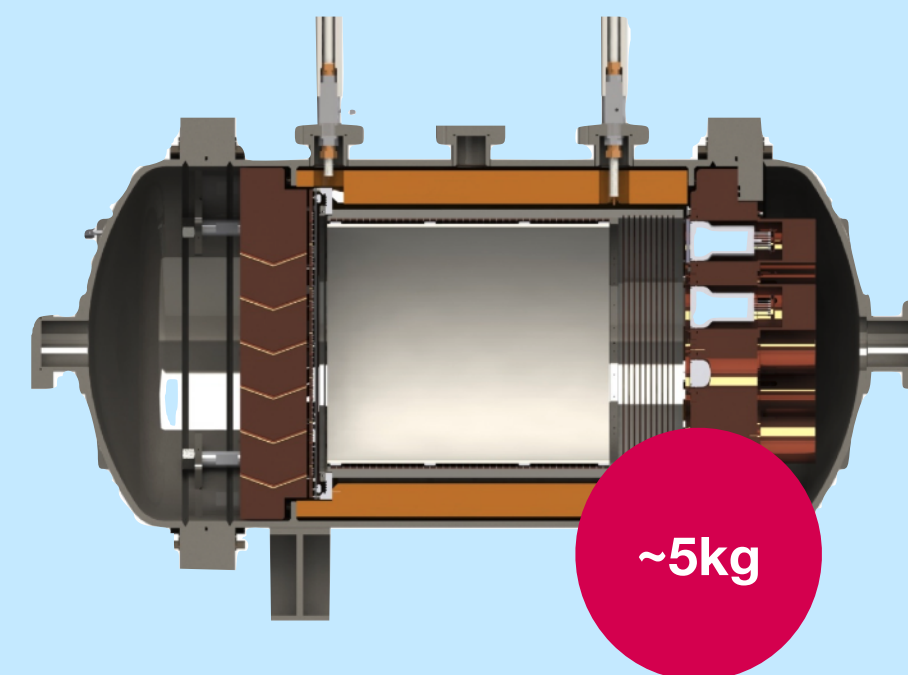
Demonstration of the detector concept



## NEXT-WHITE (NEW)

2015/2021

Background model assessment  
 $2\nu\beta\beta$  measurement for  $^{136}\text{Xe}$



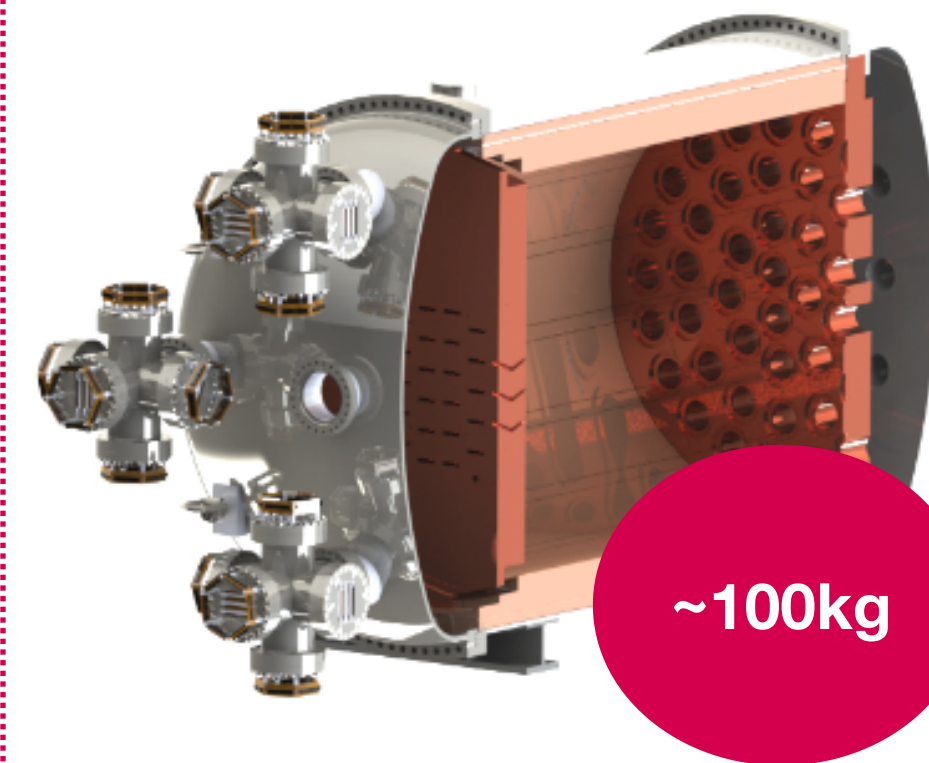
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## NEXT-100

2024/2027

Scalability

Background improvement  
Neutrinoless double beta decay search in  $^{136}\text{Xe}$



@  Laboratorio Subterráneo Canfranc

## NEXT-HD

2027?

Neutrinoless double beta decay search through inverted neutrino mass ordering

## NEXT-BOLD

Barium tagging for background-free experiment  
inverted neutrino mass ordering



# NEXT-White

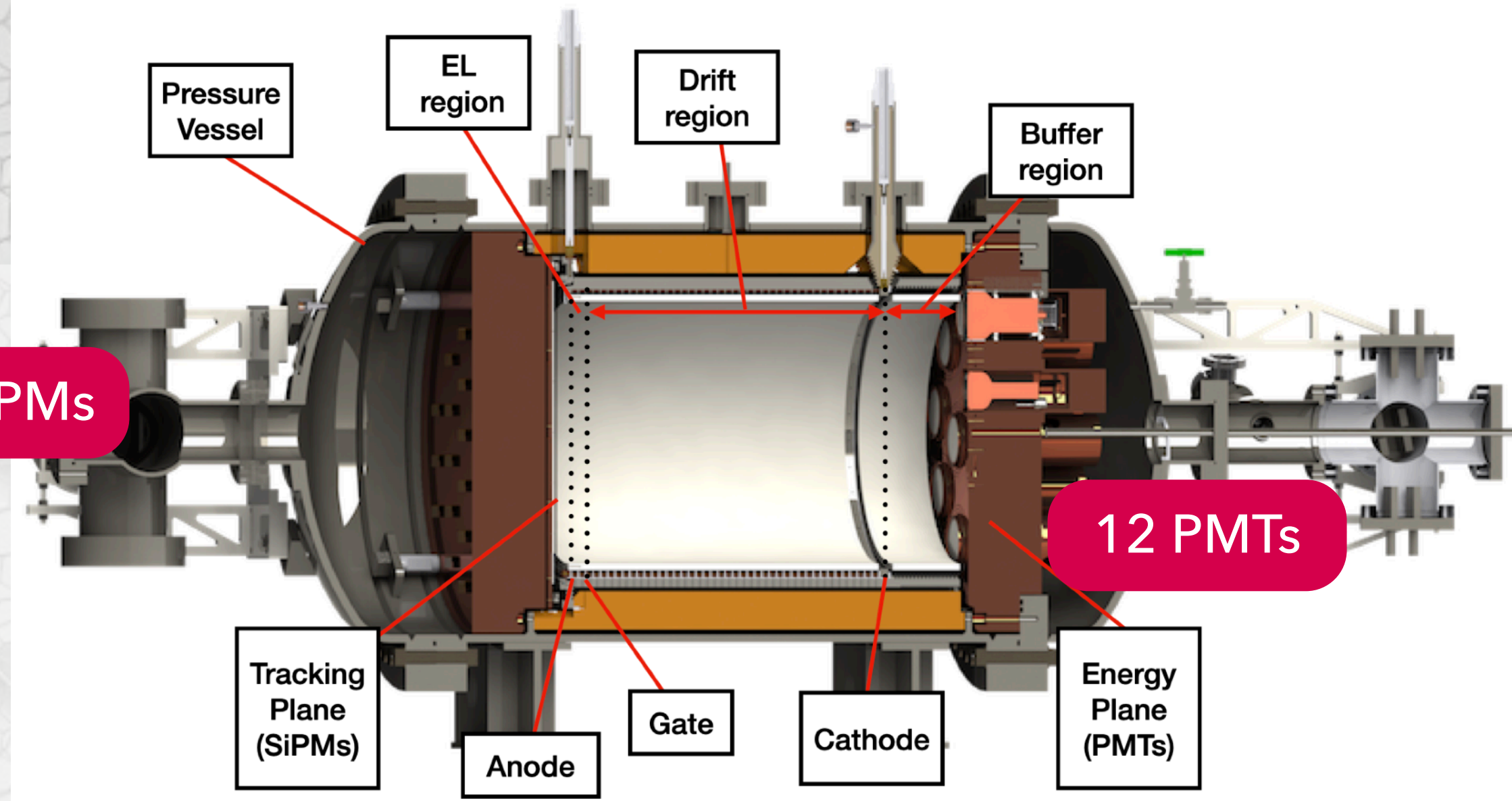
**Operation:** 2016-2021

**Mass:** ~5 kg

**Objectives:**

- Design and refine the calibration techniques
- Validation of the background model
- Measurement of the  $2\nu\beta\beta$  and half-life limit for  $0\nu\beta\beta$
- Energy resolution close to the  $Q_{\beta\beta}$ -value
- Track characterization and background rejection

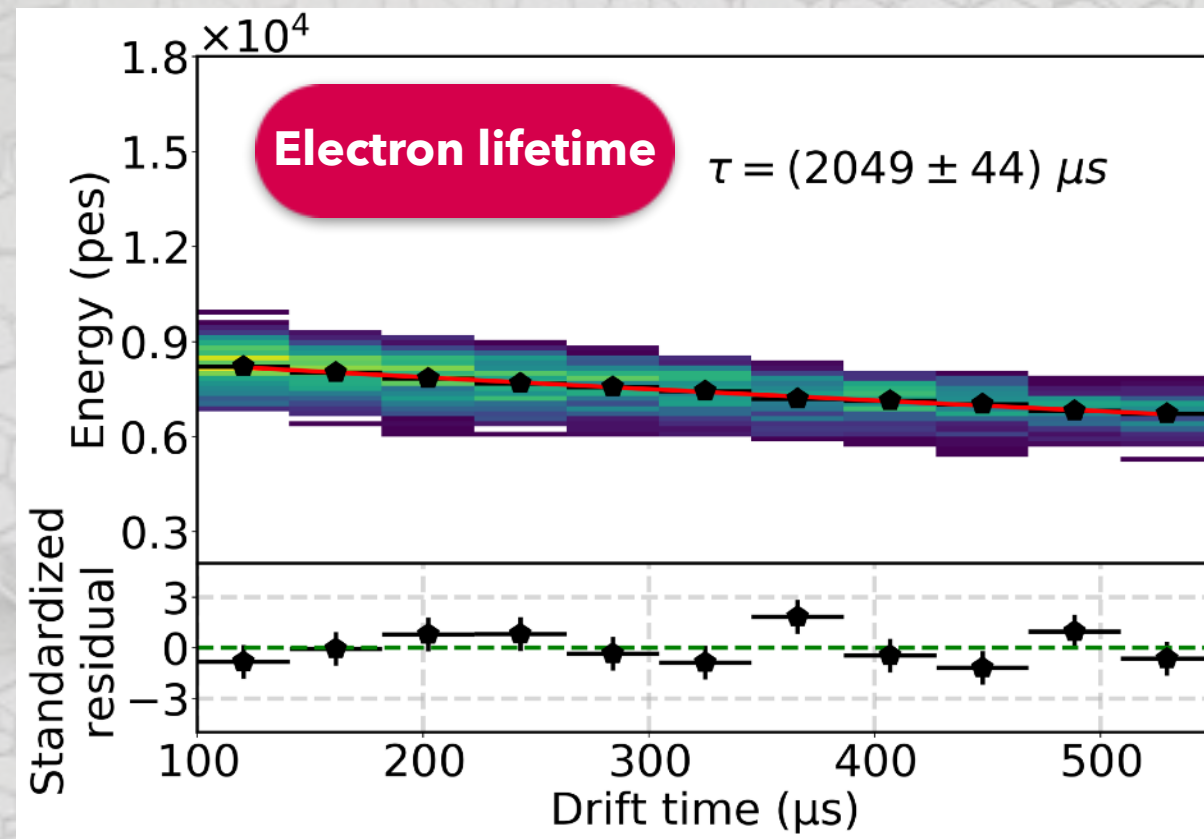
1792 SiPMs



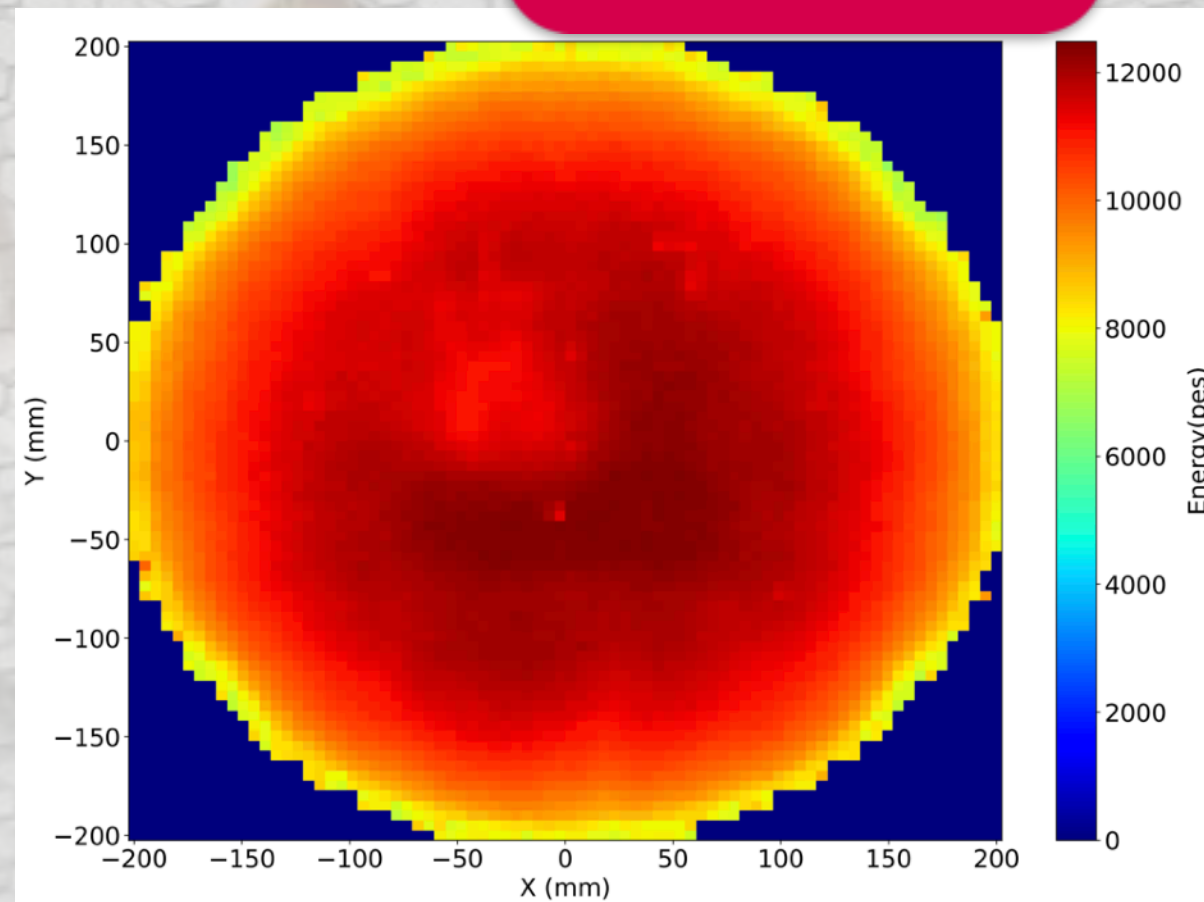
530.3 mm of drift length

# NEXT-White: Energy Calibration

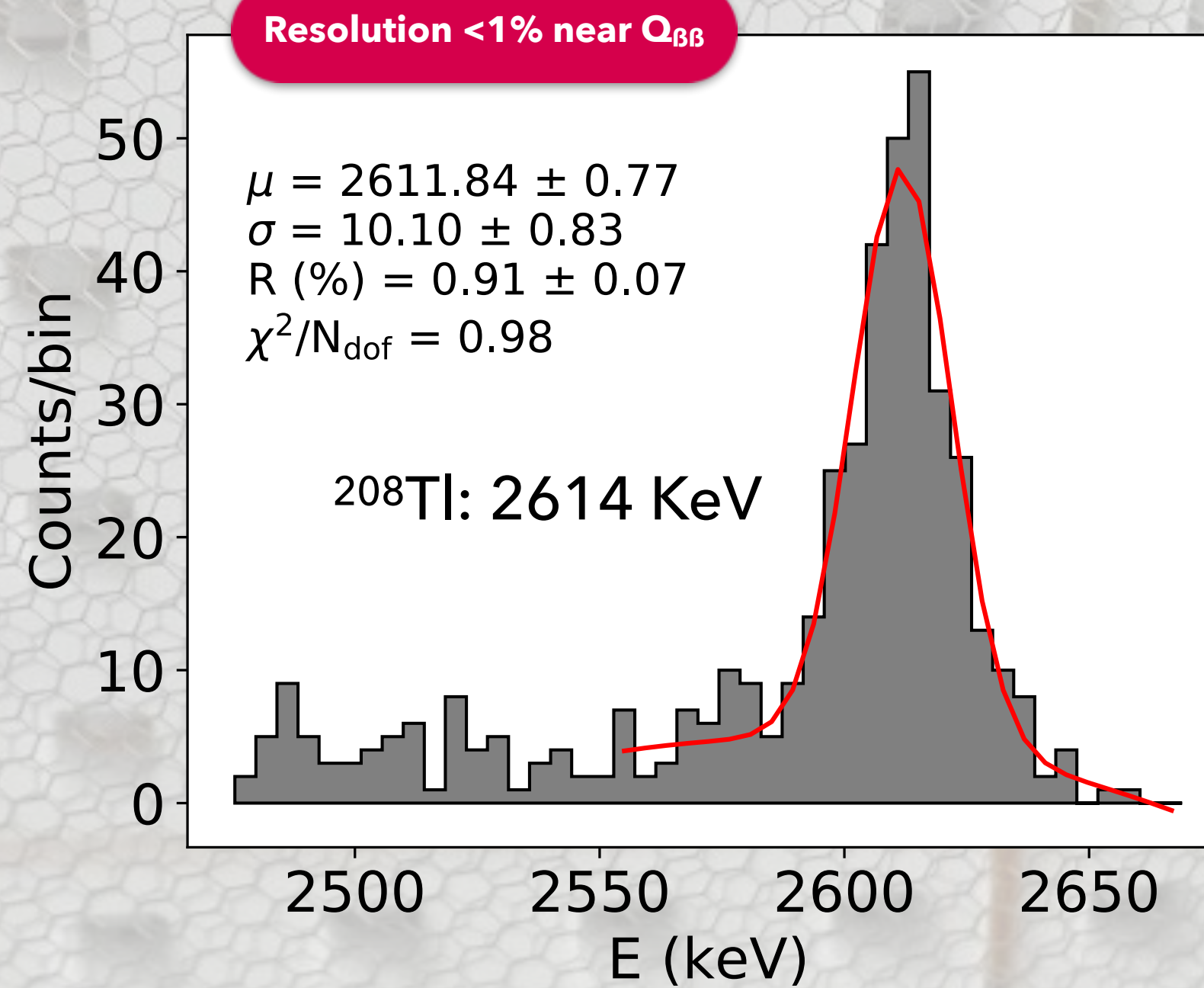
## Low energy calibration ( $^{83m}\text{Kr}$ )



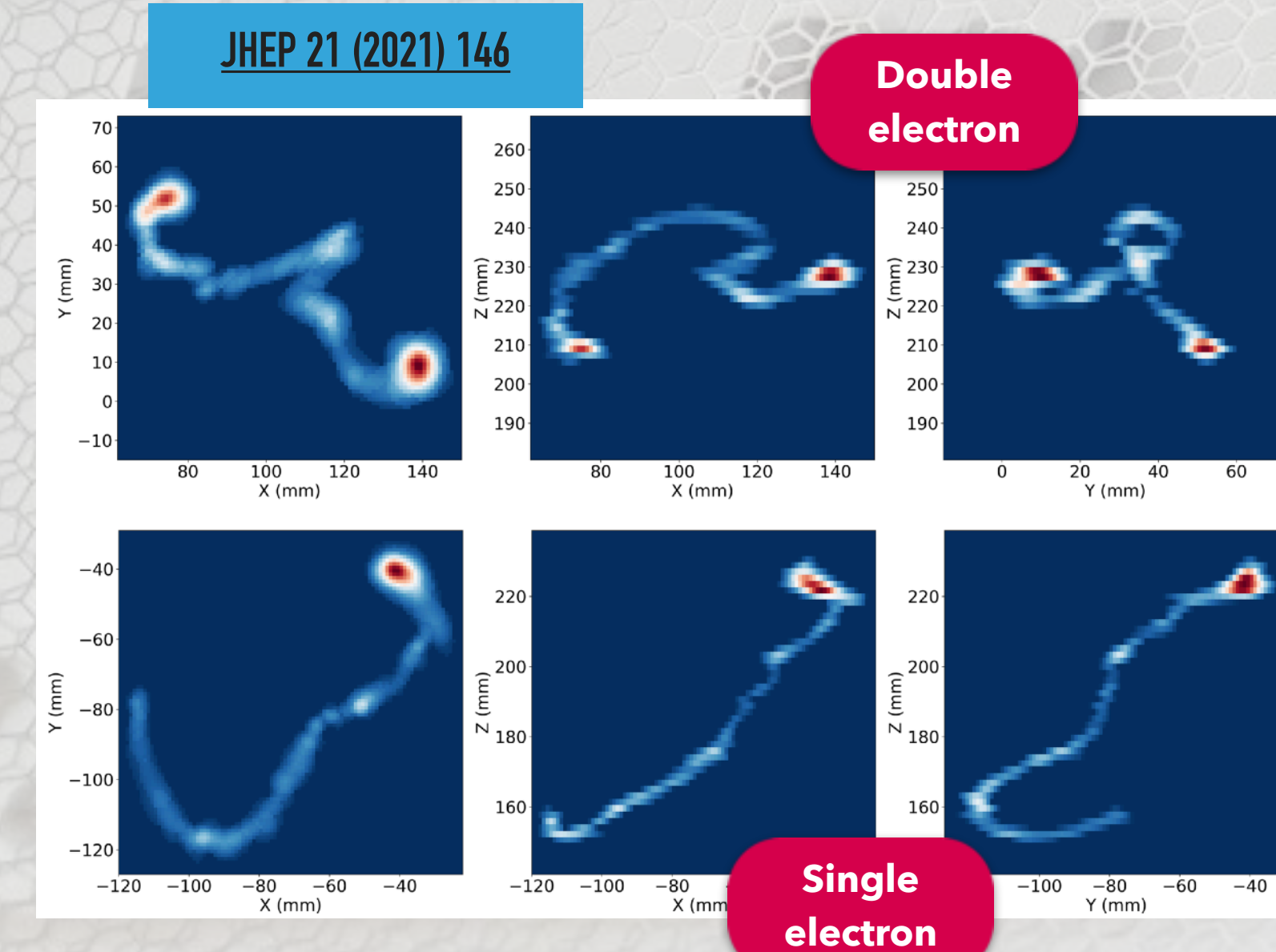
## Geometrical corrections



## High energy calibration ( $^{137}\text{Cs}$ & $^{208}\text{Tl}$ )



## Tracking and signal identification



JINST 12 (2017) NO.01, T01004

JHEP 10 (2019) 052

JHEP 01 (2021) 189

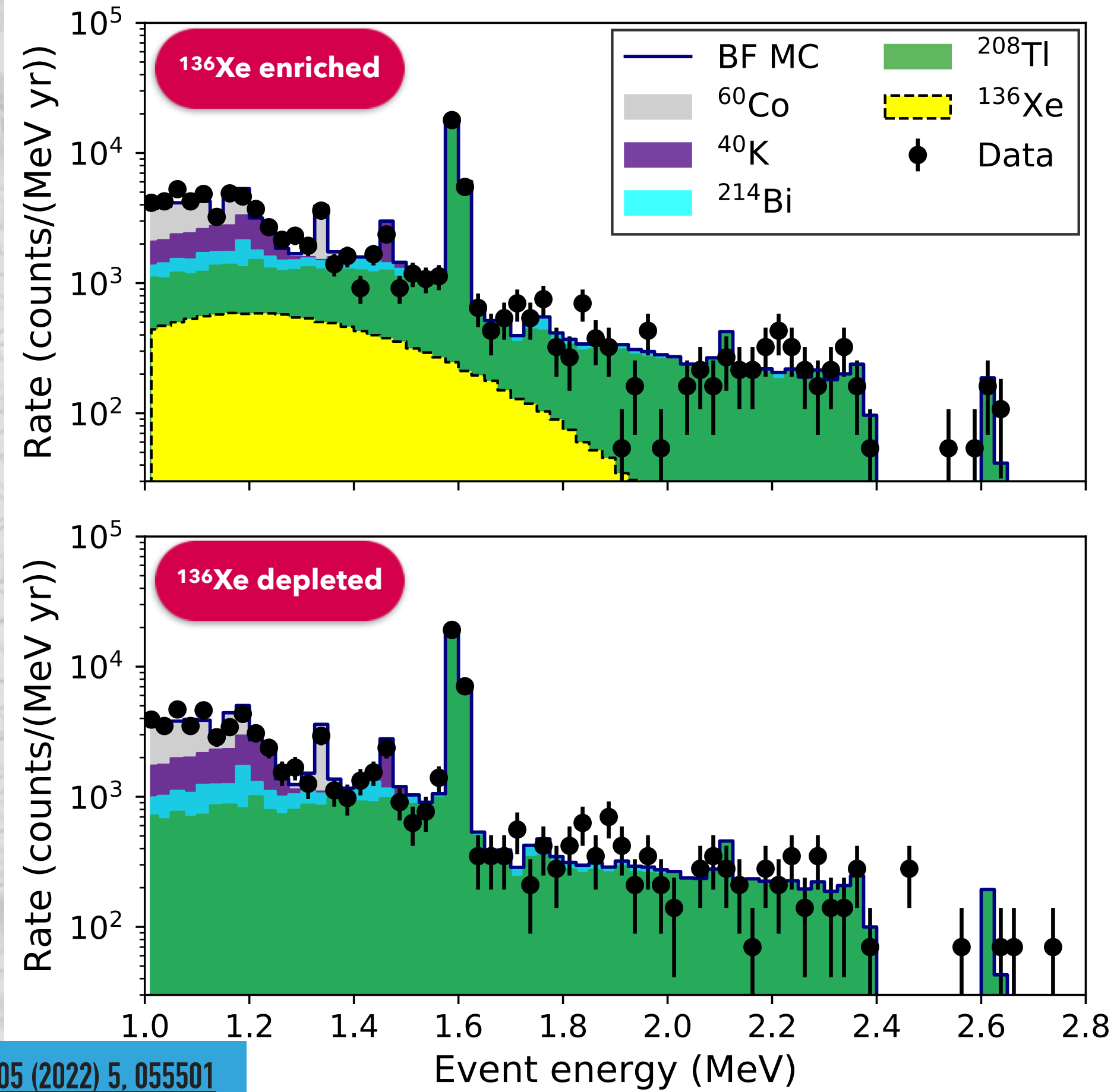
JHEP 10 (2019) 230

JINST 13 (2018) NO.10, P10020

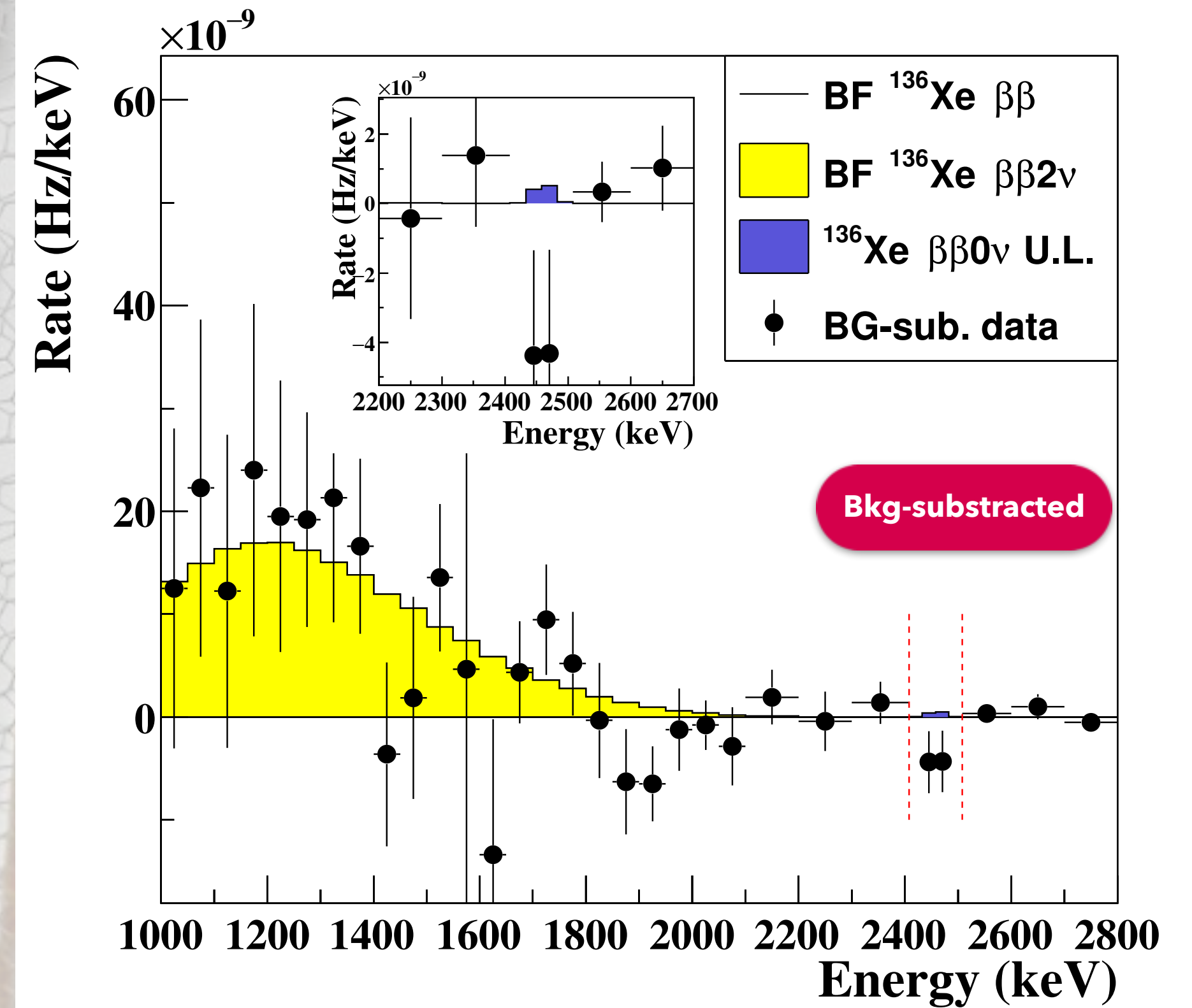
JINST 13 (2018) NO.10, P10014

# NEXT-White: $\beta\beta$ studies

First ever almost background-model independent double beta analysis!



PHYS.REV.C 105 (2022) 5, 055501



JHEP 09 (2023)190

$$2.34^{+0.80}_{-0.46} \text{ (stat)} \ ^{+0.30}_{-0.17} \text{ (sys)} \cdot 10^{21} \text{ yr}$$

$$> 1.3 \cdot 10^{24} \text{ yr (90\% CL)}$$

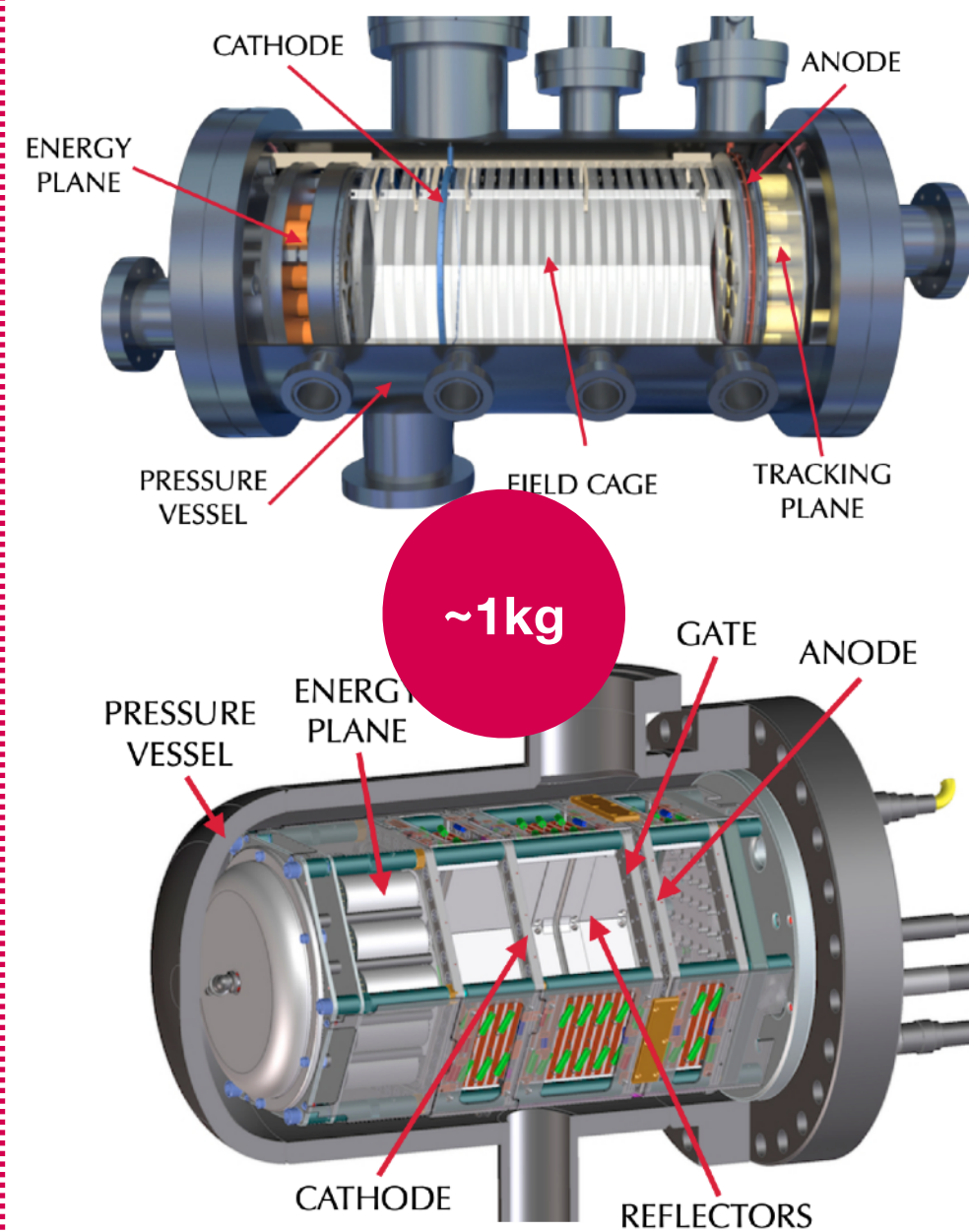
# The @next programme



## PROTOTYPES

2009/2014

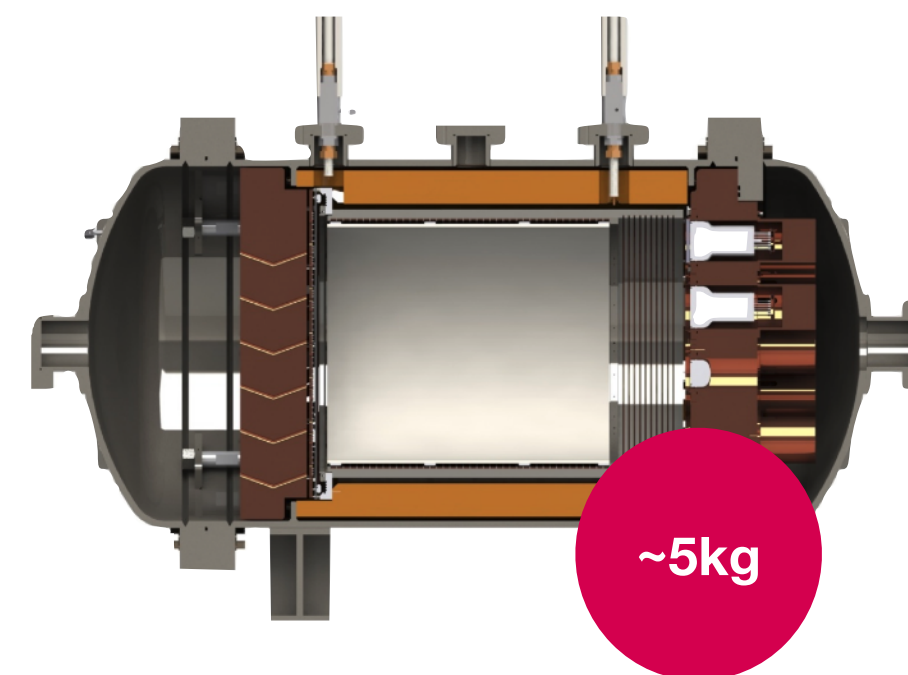
Demonstration of the detector concept



## NEXT-WHITE (NEW)

2015/2021

Background model assessment  
 $2\nu\beta\beta$  measurement  
for  $^{136}\text{Xe}$

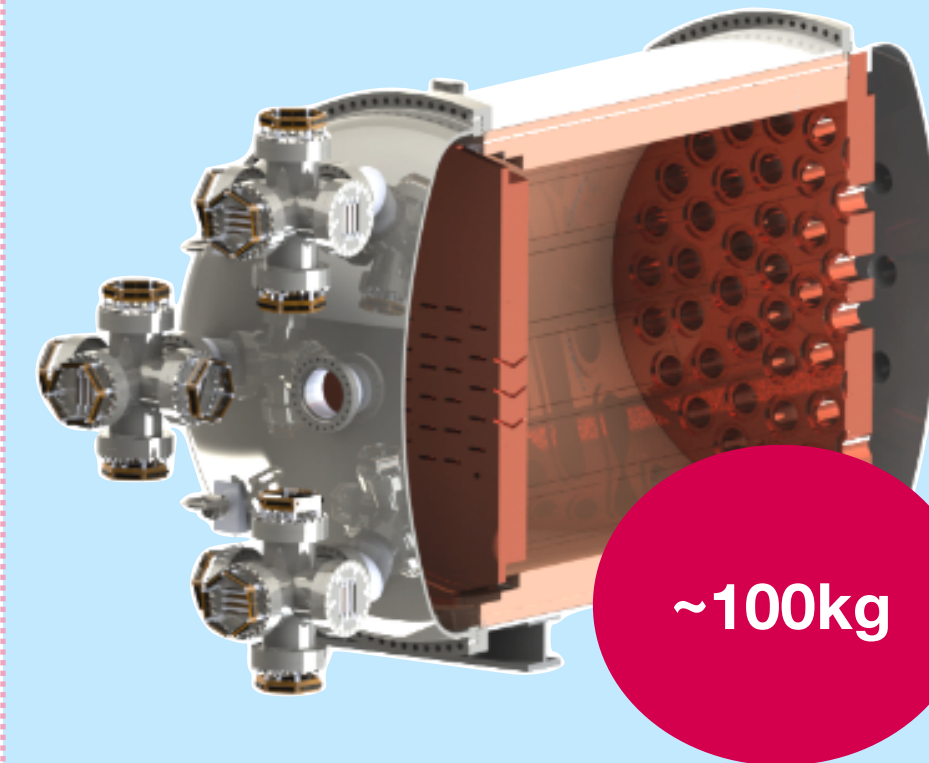


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## NEXT-100

2024/2027

Scalability  
Background improvement  
Neutrinoless double beta decay search in  $^{136}\text{Xe}$



@  Laboratorio Subterráneo Canfranc

## NEXT-HD

2027?

Neutrinoless double beta decay search through inverted neutrino mass ordering

## NEXT-BOLD

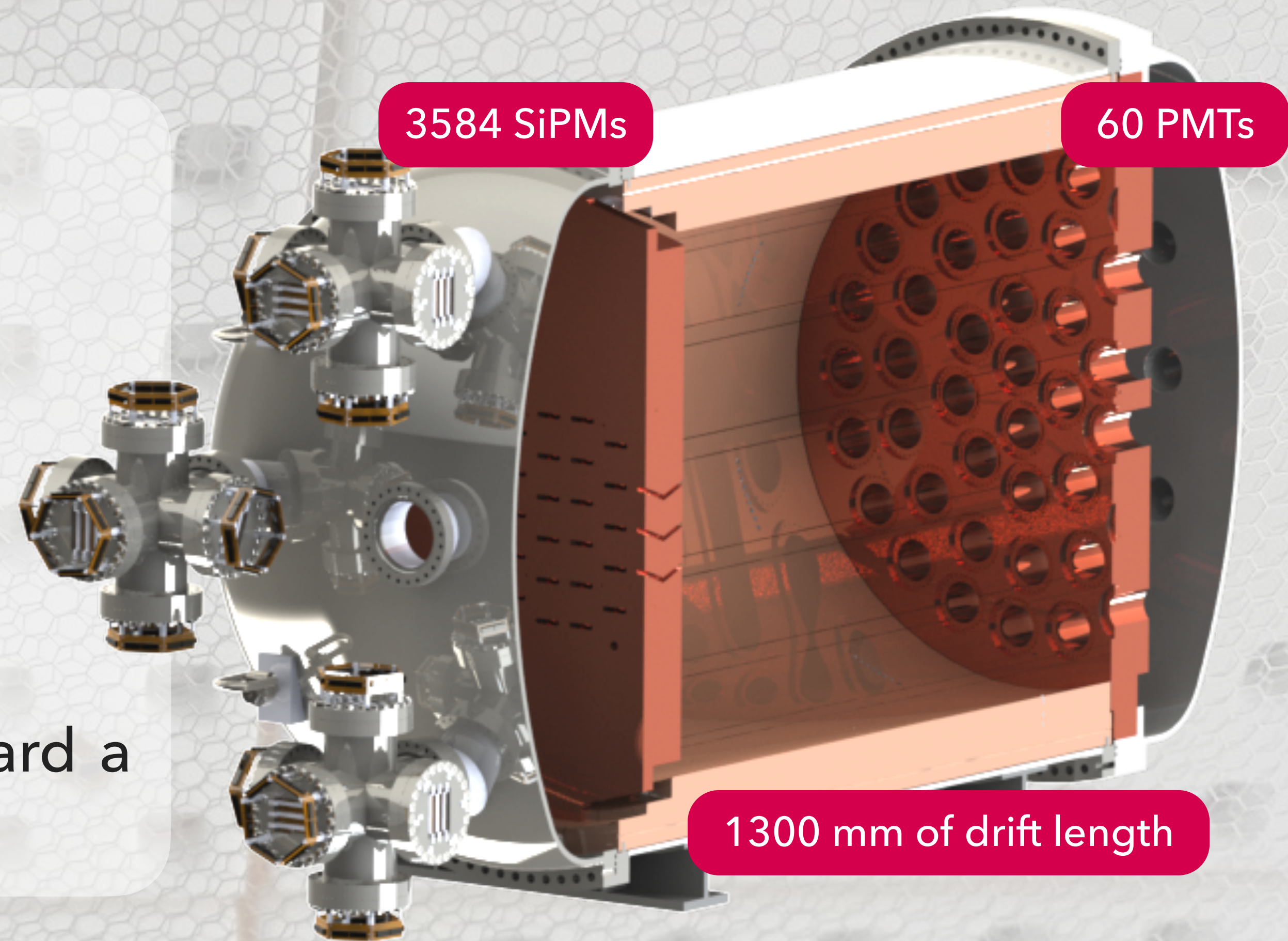
Barium tagging for background-free experiment  
inverted neutrino mass ordering



# NEXT-100

## Objectives:

- Demonstrate scalability
- Energy resolution close to the  $Q_{\beta\beta}$ -value
- Improve radioactive budget
- Competitive search of the  $\beta\beta 0\nu$
- Test-bench for technology upgrades toward a tonne-scale detector



**Mass:** ~100 kg (at 15 bar)

JHEP 05 (2016)

**Sensitivity:**  $6.0 \times 10^{25}$  y after three years

**Background:**  $< 10^{-3}$  counts/(keV · kg · y)

[See poster 189](#)

# NEXT-100

## Objectives:

- Demonstrate scalability
- Energy resolution close to
- Improve radioactivity
- Competitive search
- Test-bench for techn
- tonne-scale detector



1300 mm of drift length

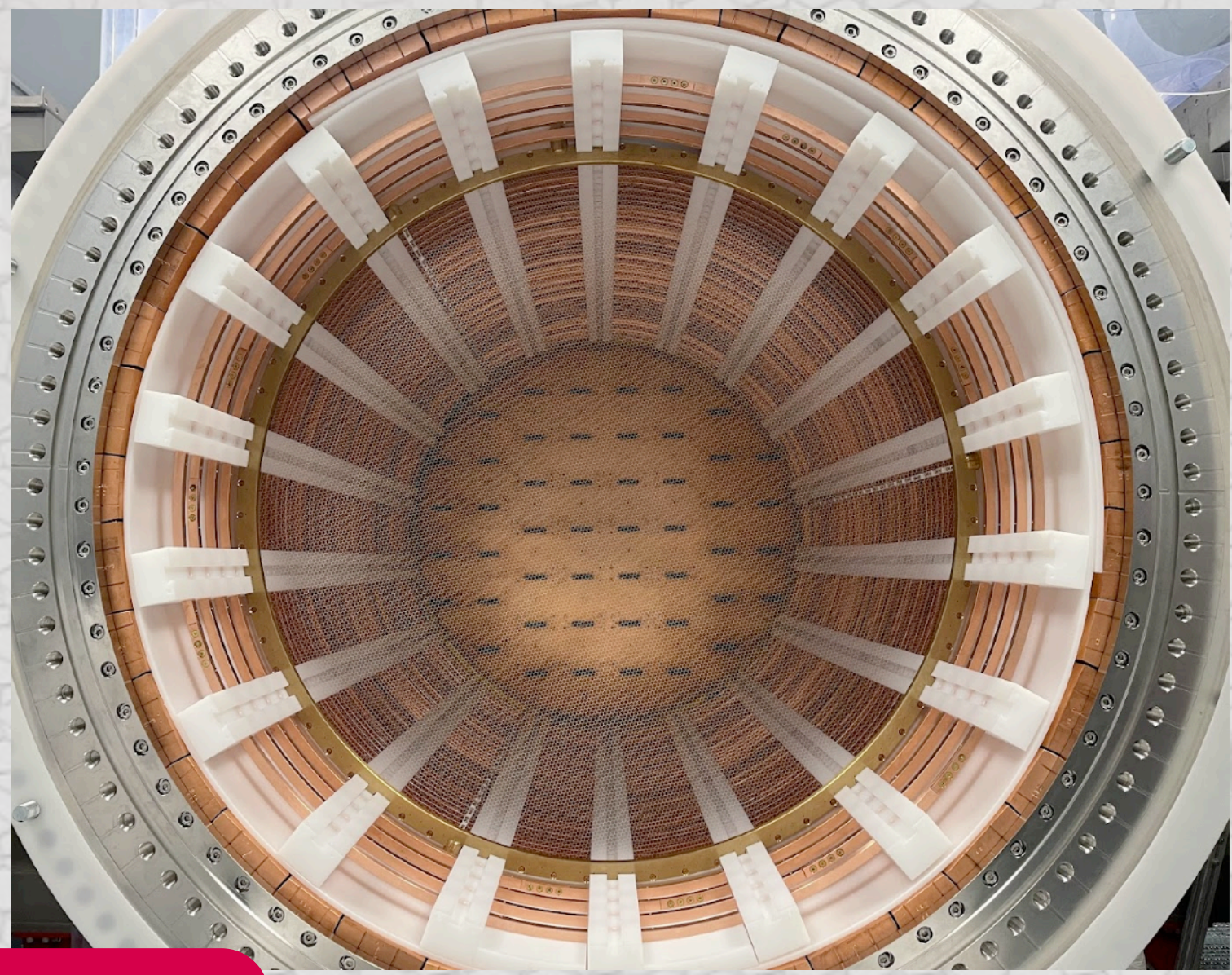
**Mass:** ~100 kg (at 15 bar) JHEP 05 (2016)

**Sensitivity:**  $6.0 \times 10^{25}$  y after three years

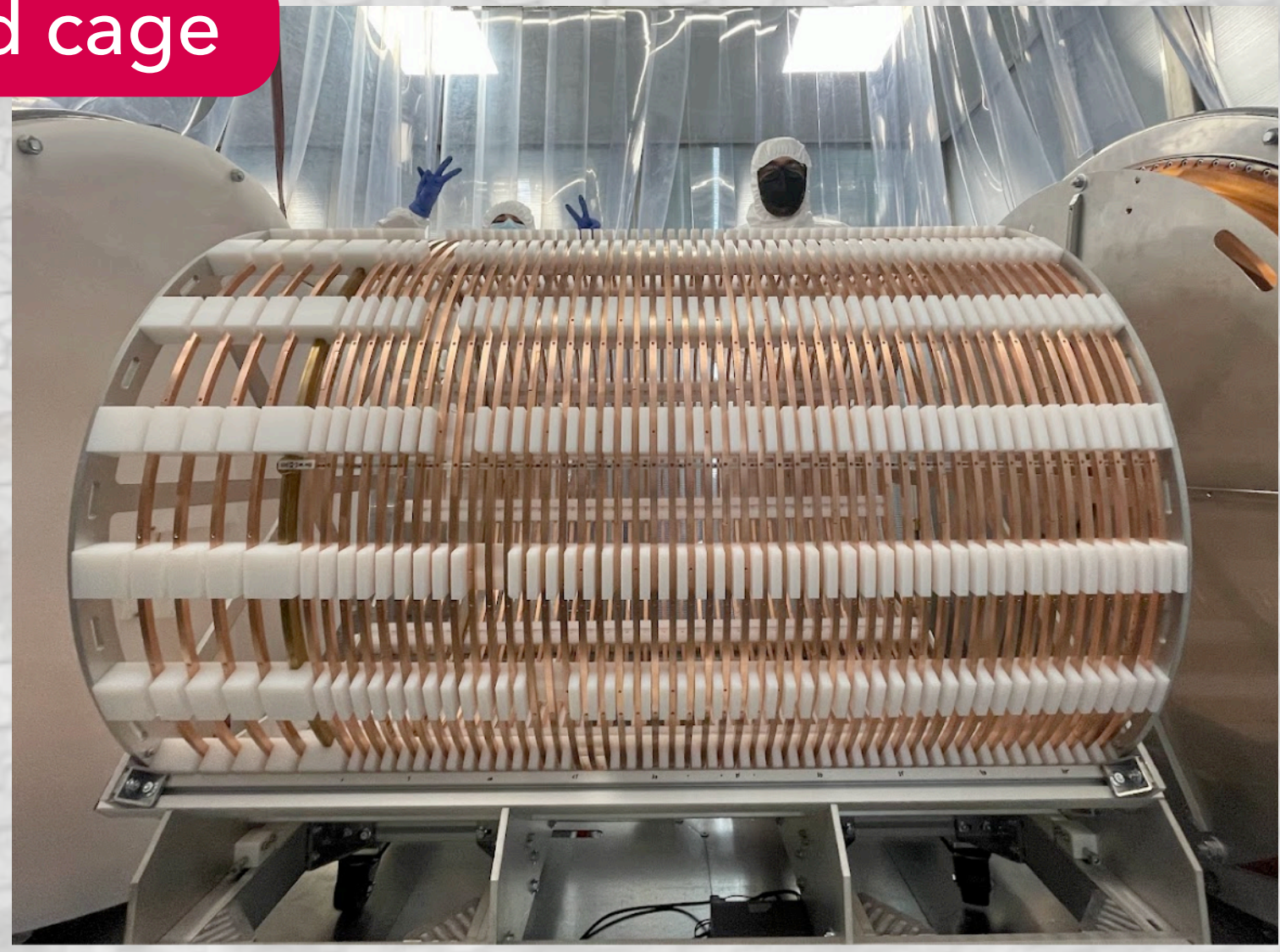
**Background:**  $< 10^{-3}$  counts/(keV · kg · y)

[See poster 189](#)

# NEXT-100: Assembly

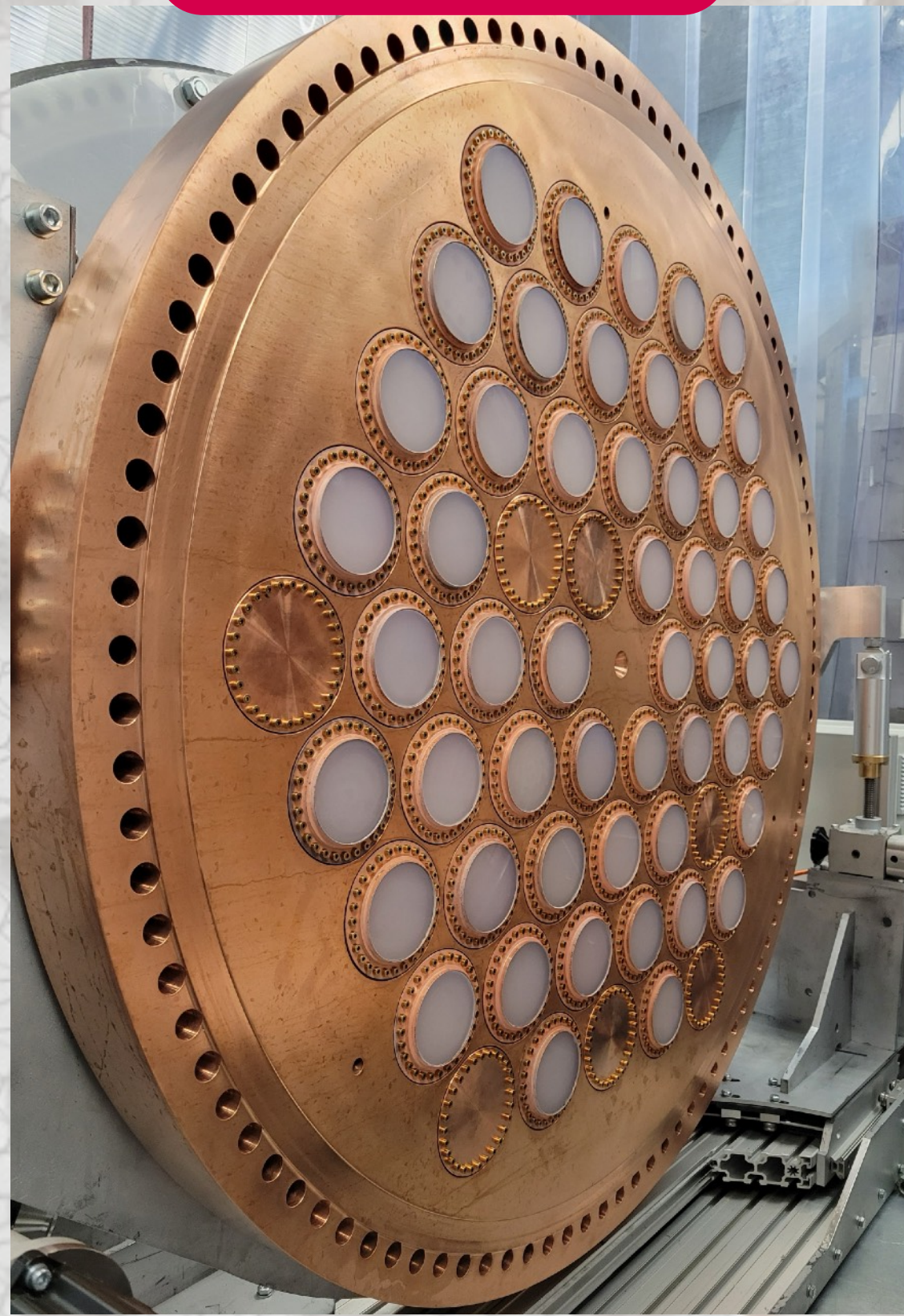


Field cage

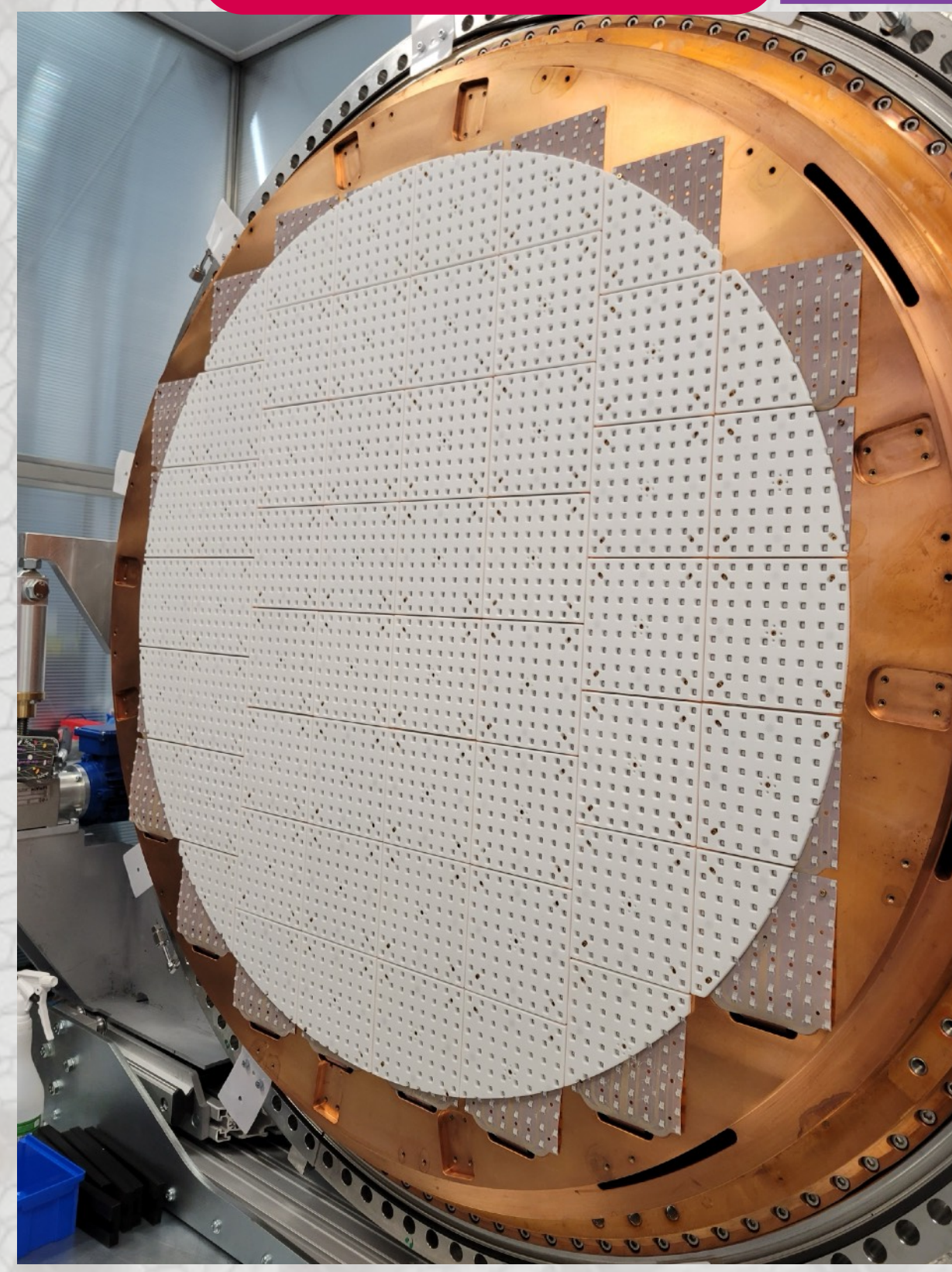


See poster 189

Energy plane

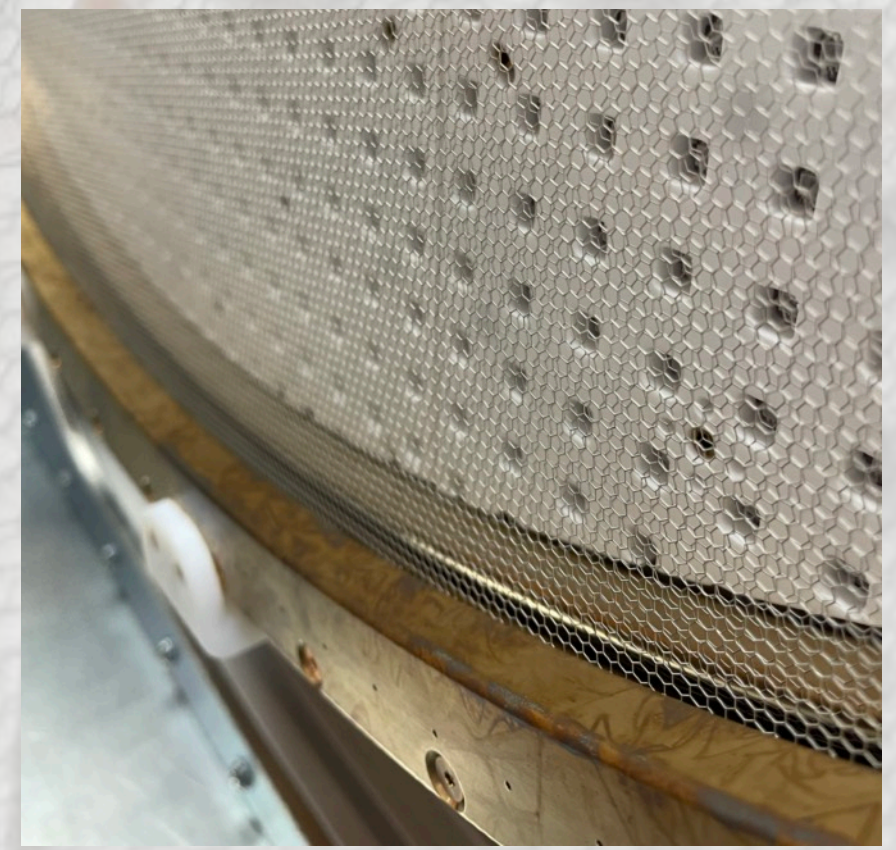


Tracking plane



EL meshes

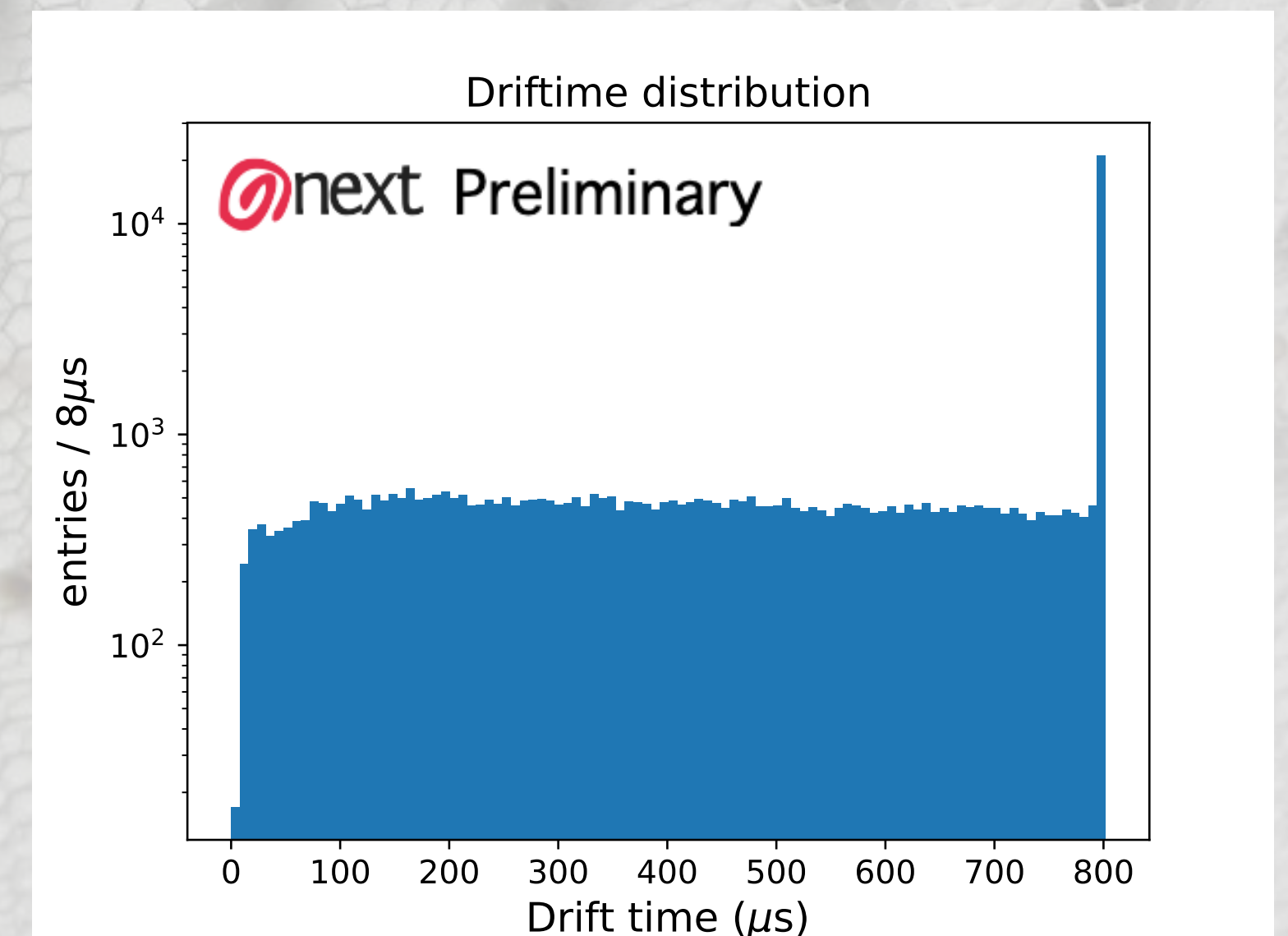
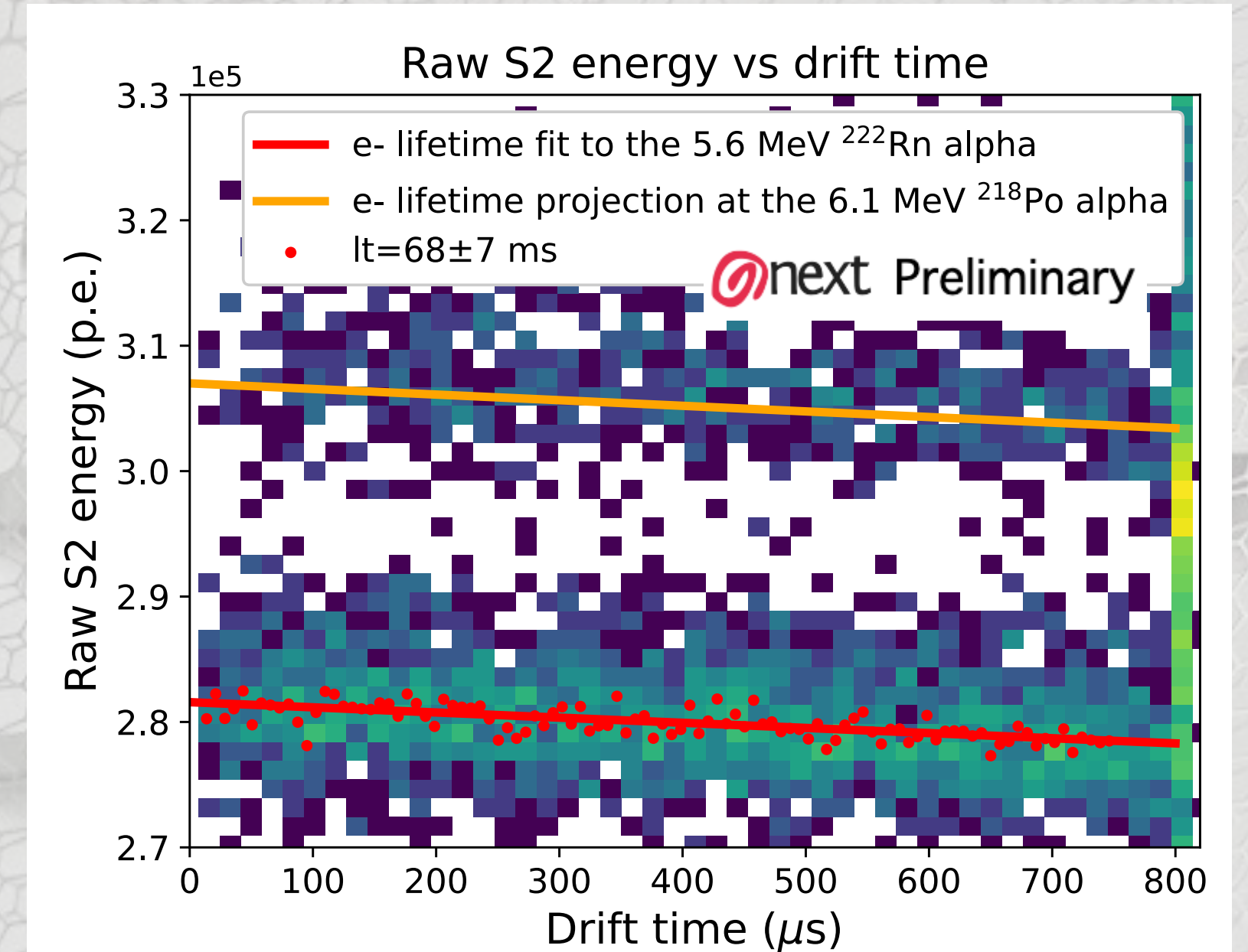
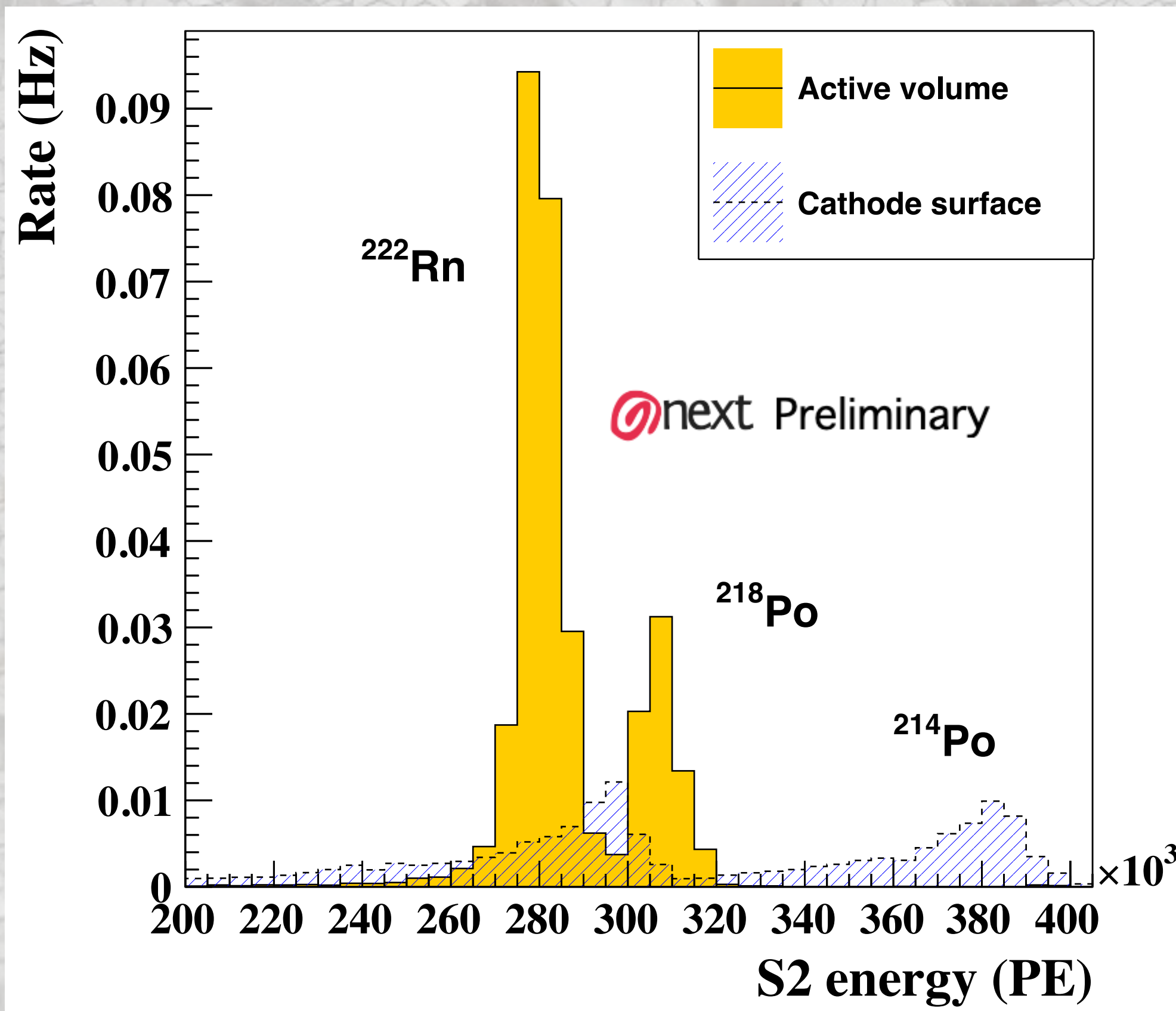
JINST 19 (2024) 02, P02007





# NEXT-100: Comisioning

Ready for operations in May 2024. Currently in commissioning phase, filled with argon and being characterized with  $^{222}\text{Rn}$  decay chain data.



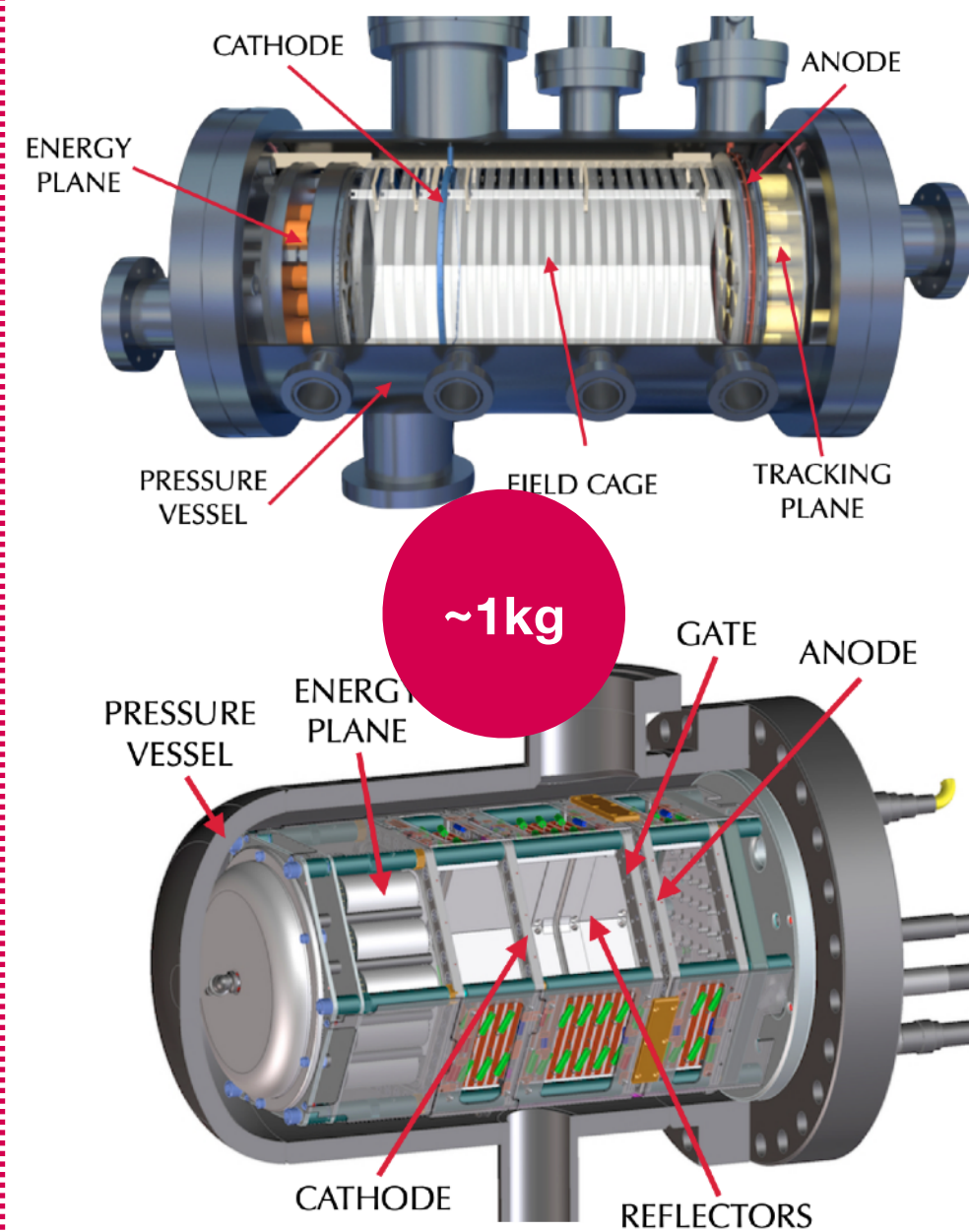
# The @next programme



## PROTOTYPES

2009/2014

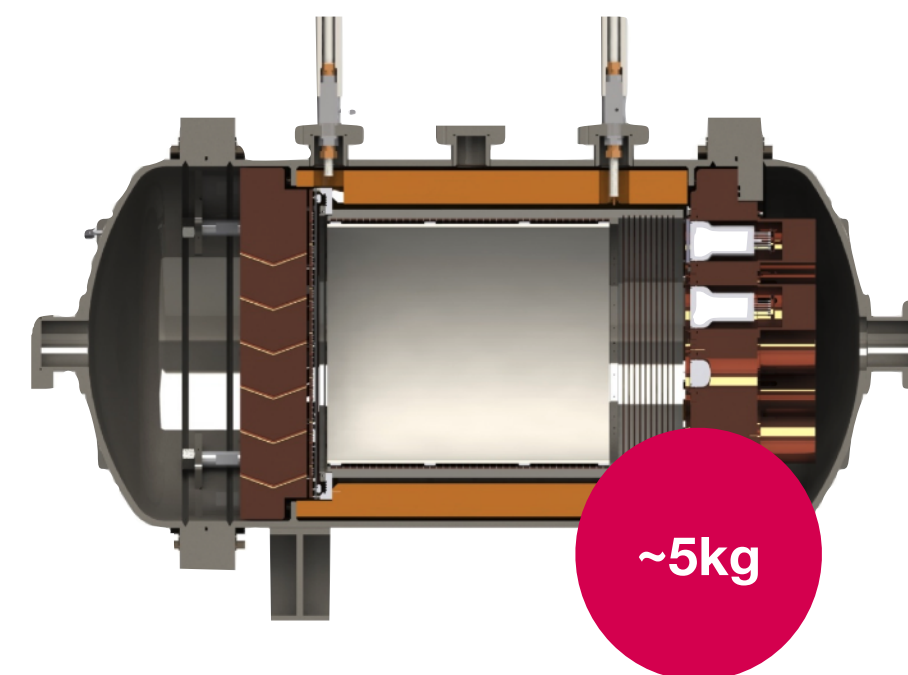
Demonstration of the detector concept



## NEXT-WHITE (NEW)

2015/2021

Background model assessment  
 $2\nu\beta\beta$  measurement for  $^{136}\text{Xe}$



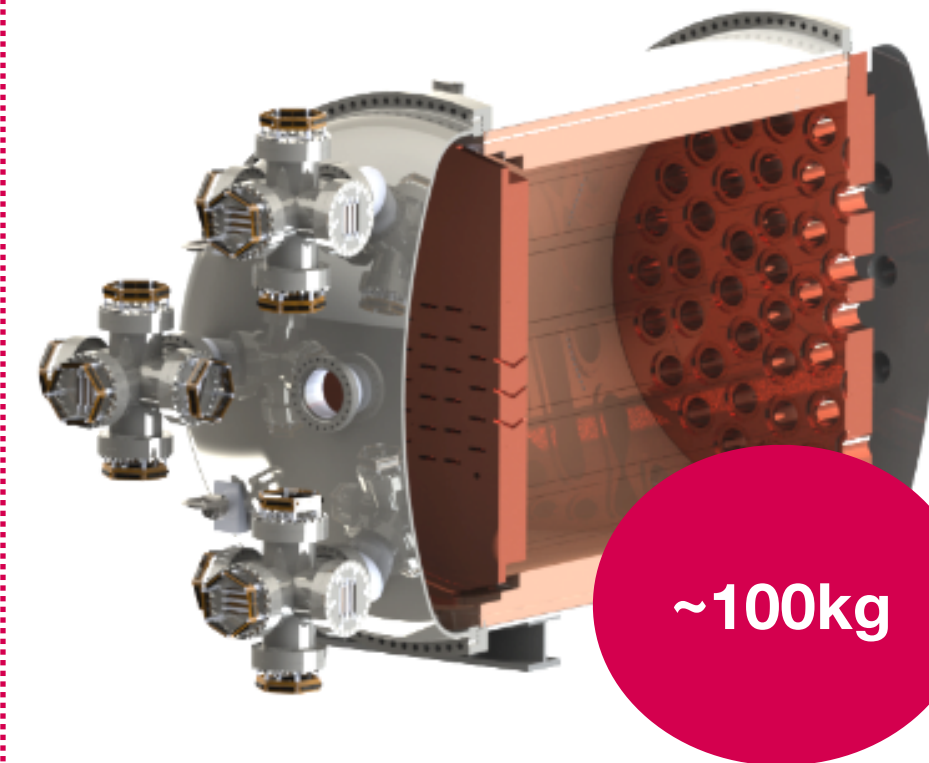
@  Laboratorio Subterráneo Canfranc

## NEXT-100

2024/2027

Scalability

Background improvement  
Neutrinoless double beta decay search in  $^{136}\text{Xe}$



@  Laboratorio Subterráneo Canfranc

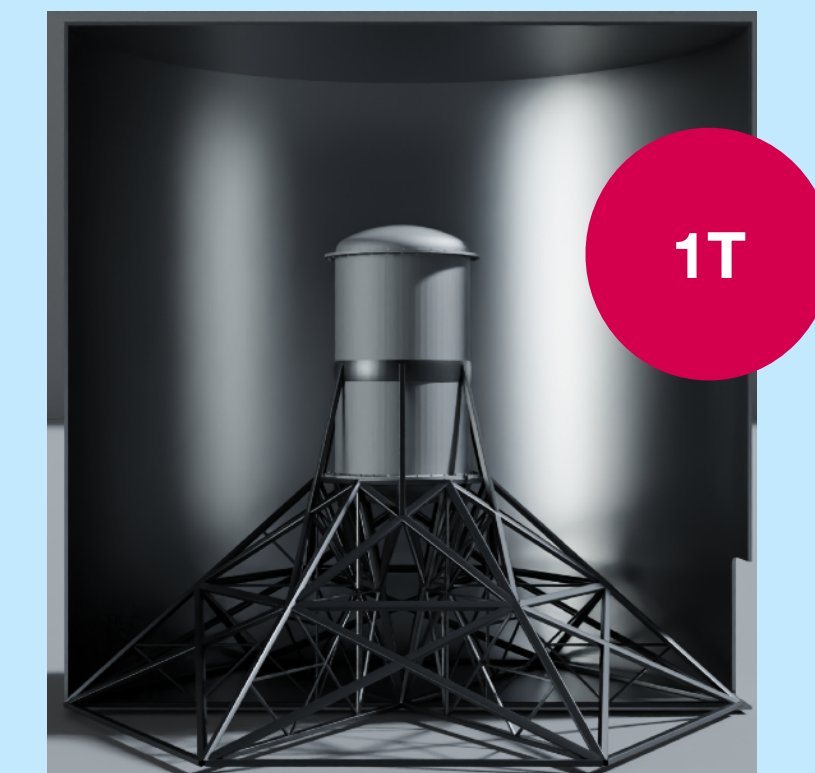
## NEXT-HD

2027?

Neutrinoless double beta decay search through inverted neutrino mass ordering

## NEXT-BOLD

Barium tagging for background-free experiment  
inverted neutrino mass ordering



# NEXT-HD

See poster 221

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1824

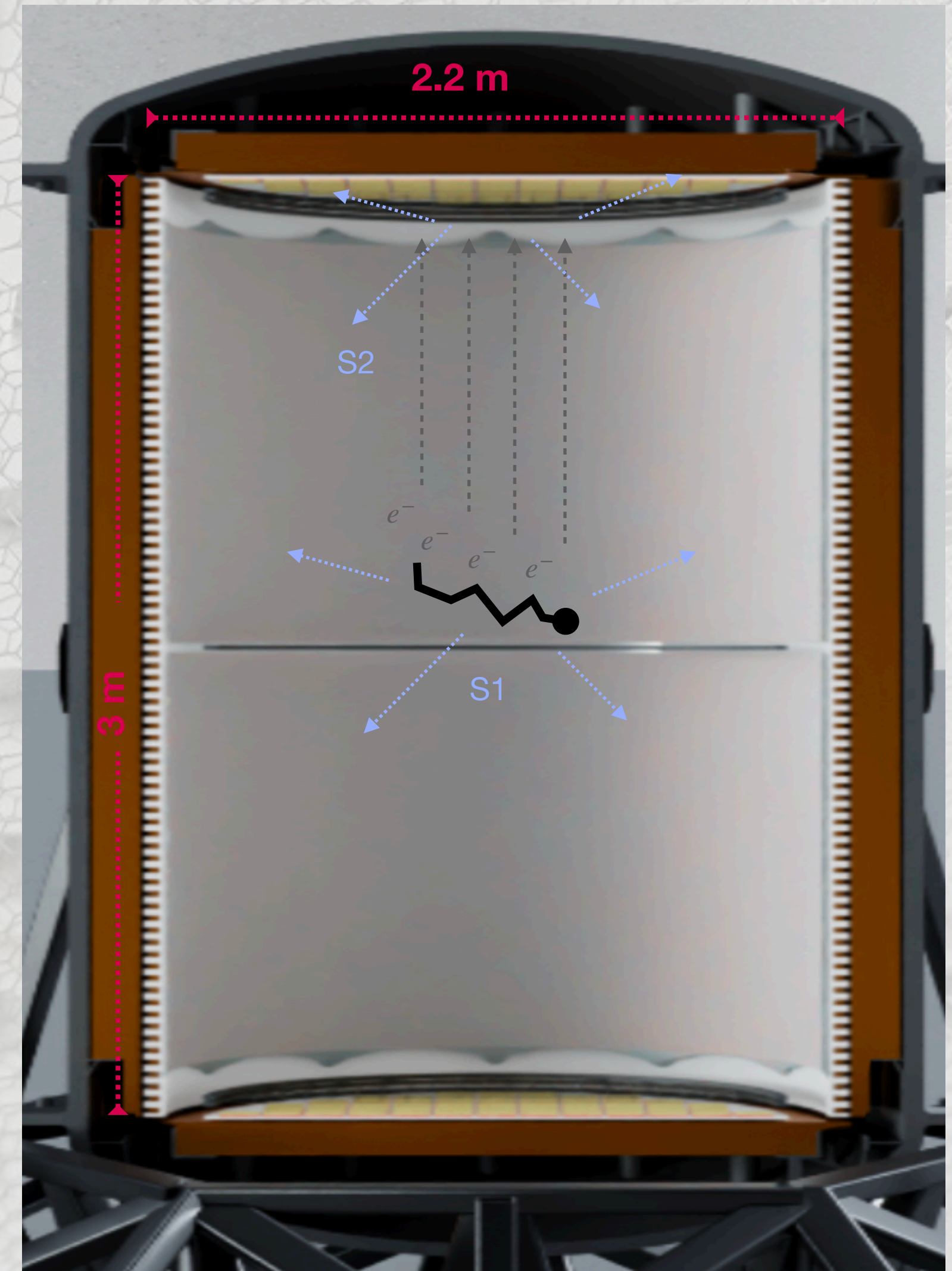
- Symmetric design with central cathode
- Xe/He to reduce transverse diffusion
- Barrel instrumented with fiber optics for energy and S1 measurements
- External water tank shielding

## Projected for 2027

**Mass:** ~1000 kg (at 15 bar)

**Sensitivity:**  $1.2 \times 10^{27}$  y after 5 years

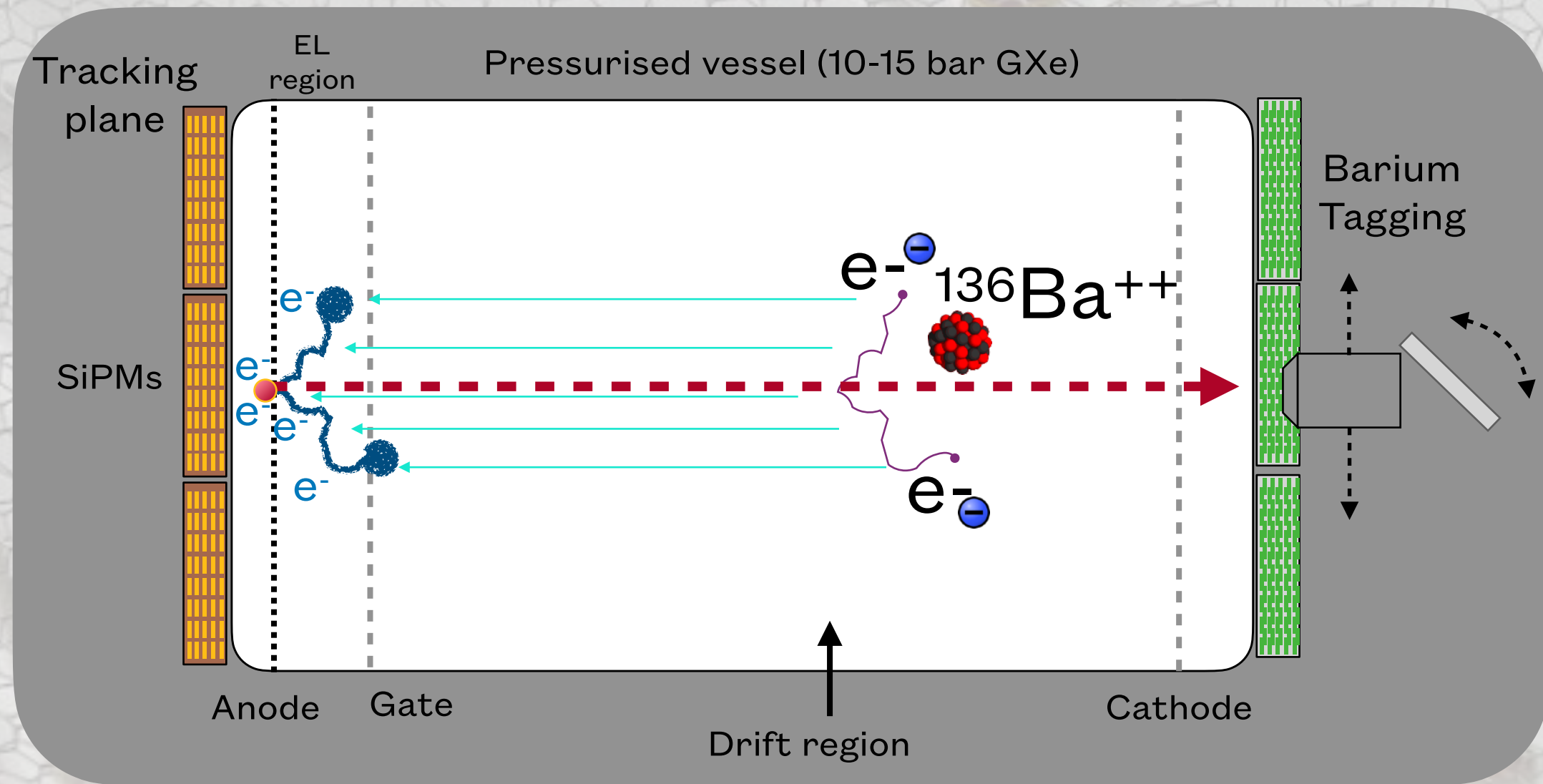
**Background:** 0.01 counts/(keV · ton · yr)



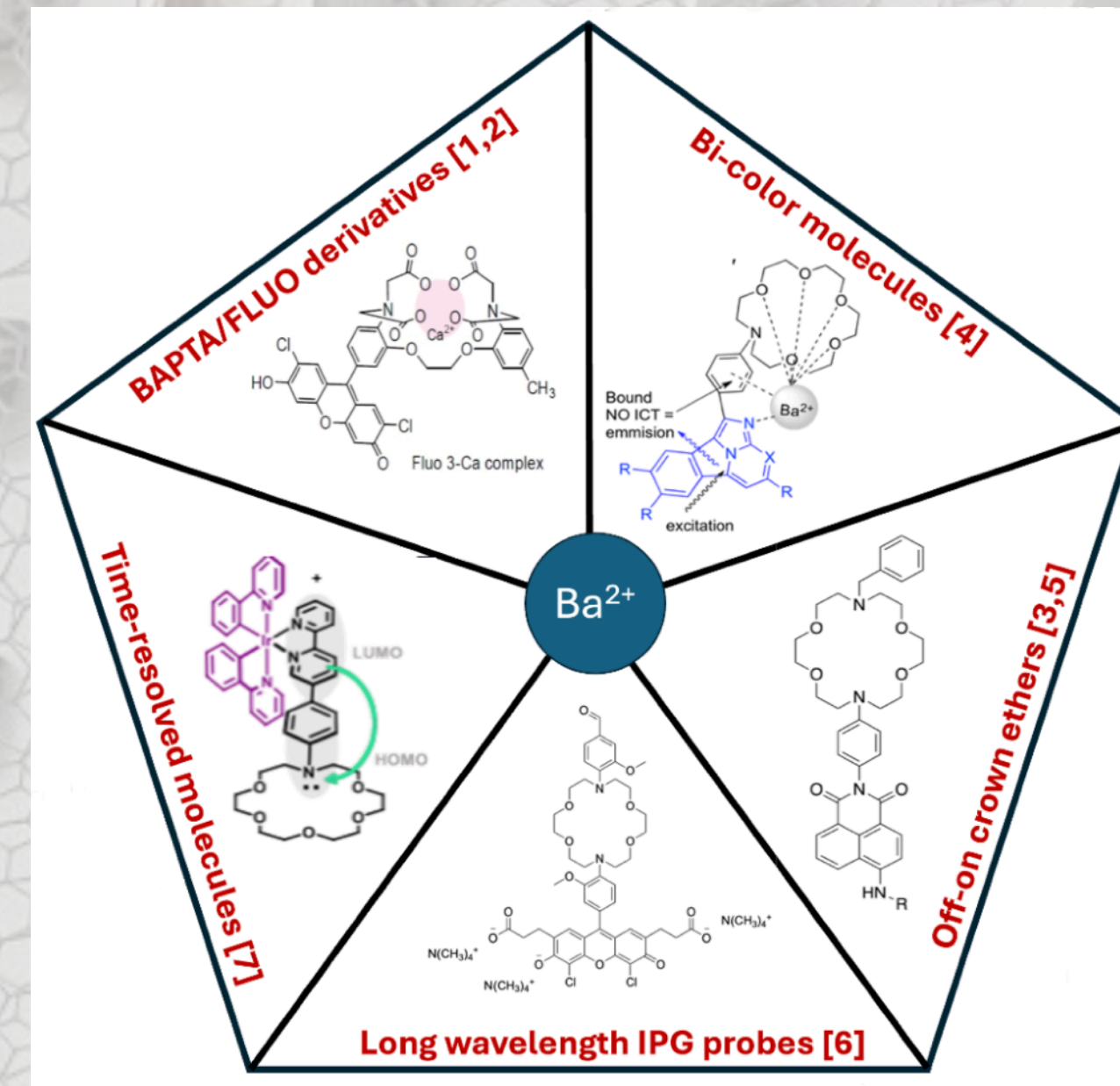
JHEP 2021 (2021) 08

# NEXT-BOLD

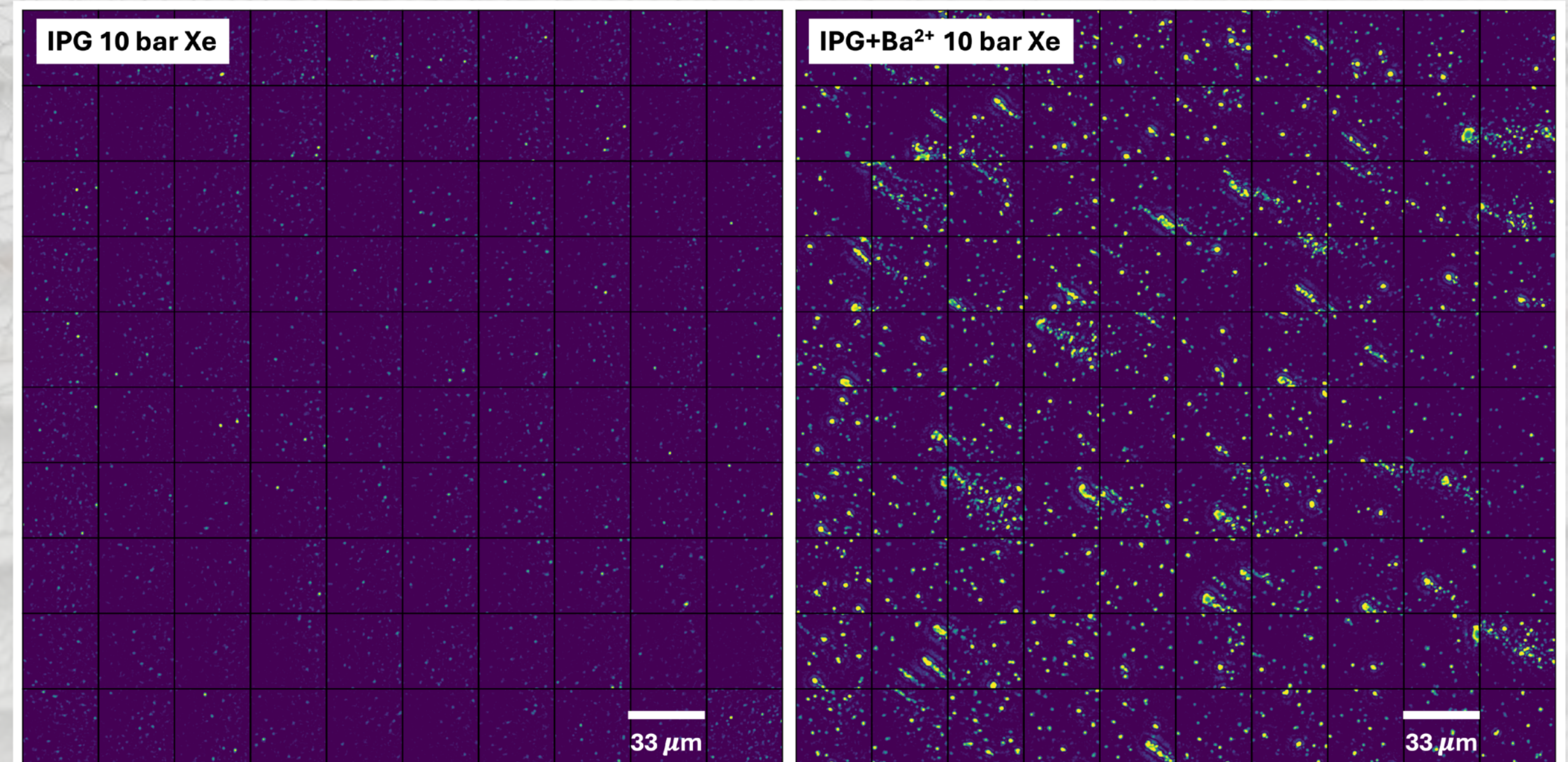
Designed to accommodate Ba tagging



The viability of microscopy systems capable of imaging individual barium ions in high-pressure xenon gas is demonstrated



- [1]. JINST 11 P12011 (2016)
- [2]. Phys. Rev. Lett. 120, 132504 (2018)
- [3]. Sci Rep 9: 15097 (2019)
- [4]. Nature 583, 48 (2020)
- [5]. ACS Sensors 6, 1, 192-20 (2021)
- [6]. [10.26434/chemrxiv-2023-wxpbh](https://doi.org/10.26434/chemrxiv-2023-wxpbh) (2023)
- [7]. Publication in Preparation (2024)



# NEXT in Short

- All the results from NEXT-White demonstrate the performance of the detector technology and sufficiently low background levels for the program
- NEXT100 is running and in commissioning and will be able to provide a competitive measurement of the  $\beta\beta_{0\nu}$  half-life
- The success of the program is being transferred to the design of the upcoming tonne scale
- Barium tagging is knocking at the door!



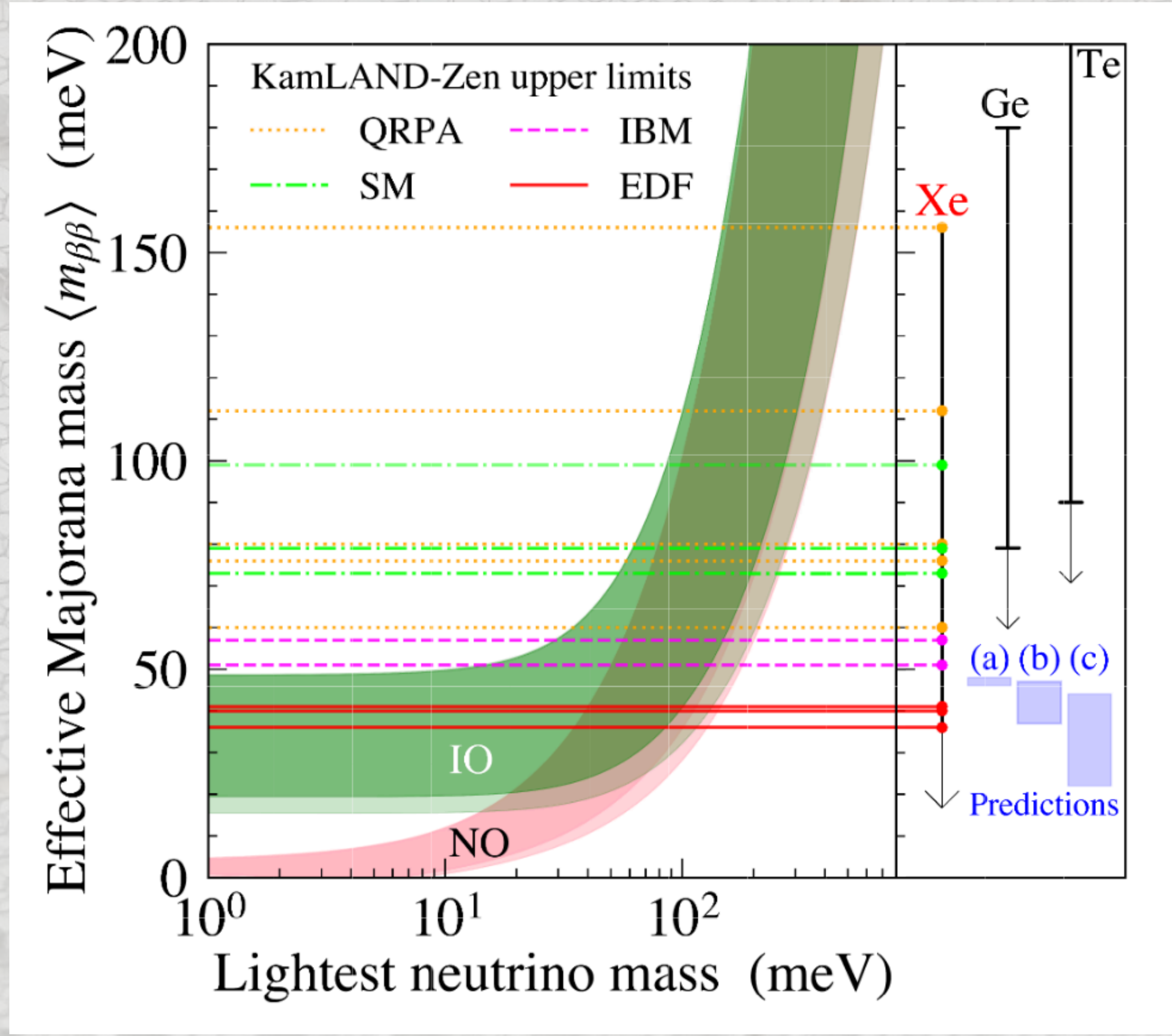
@next

Thanks!

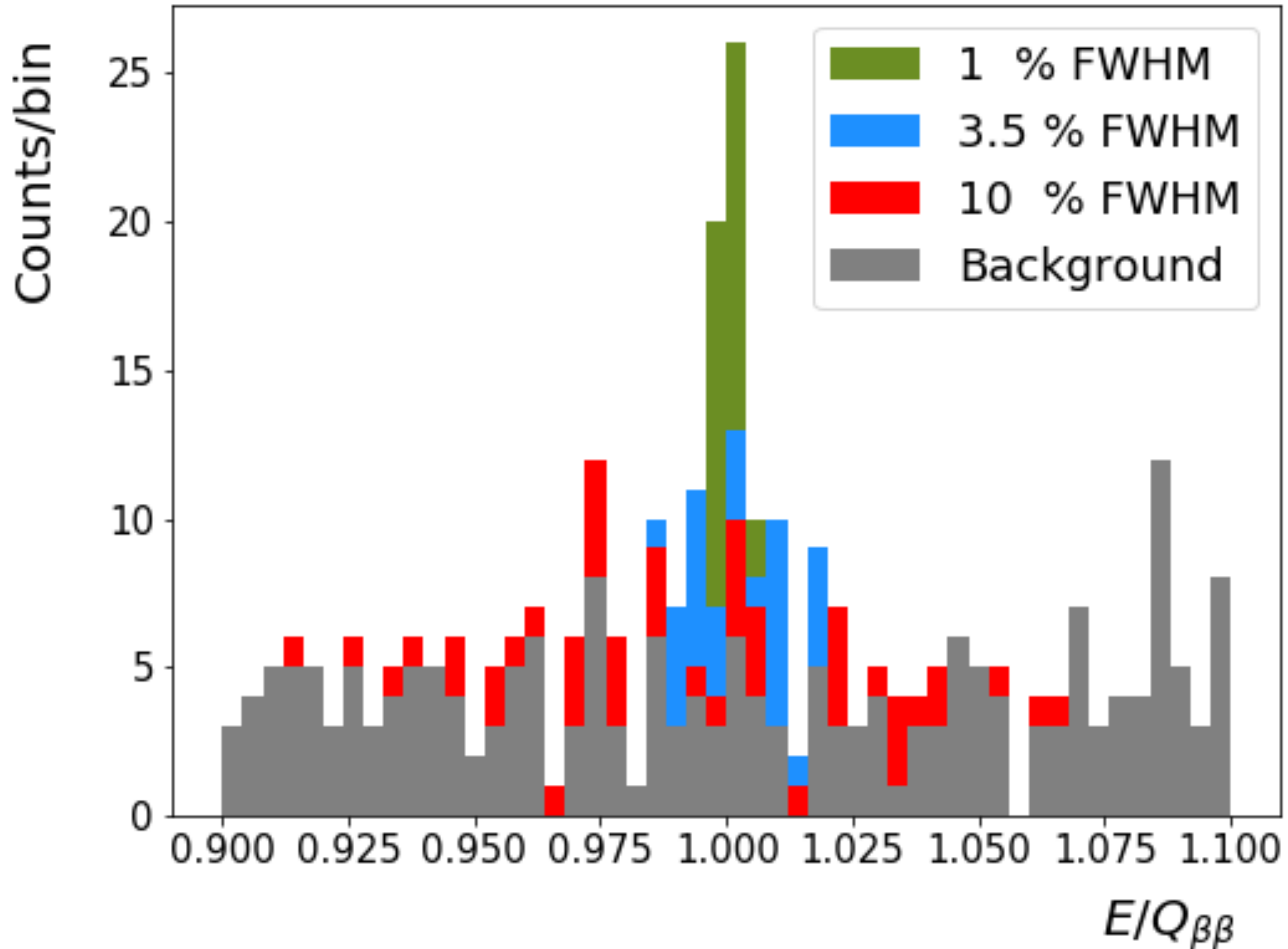


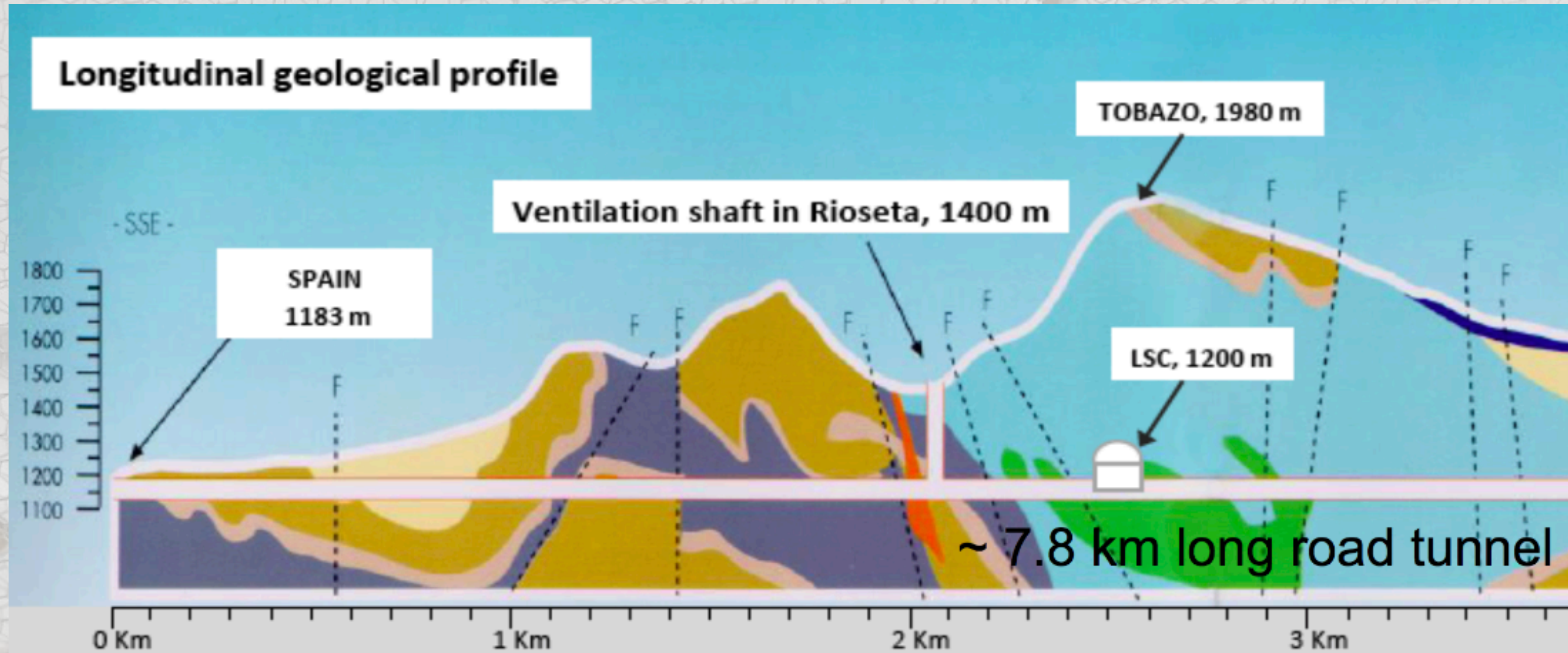
**Back up**

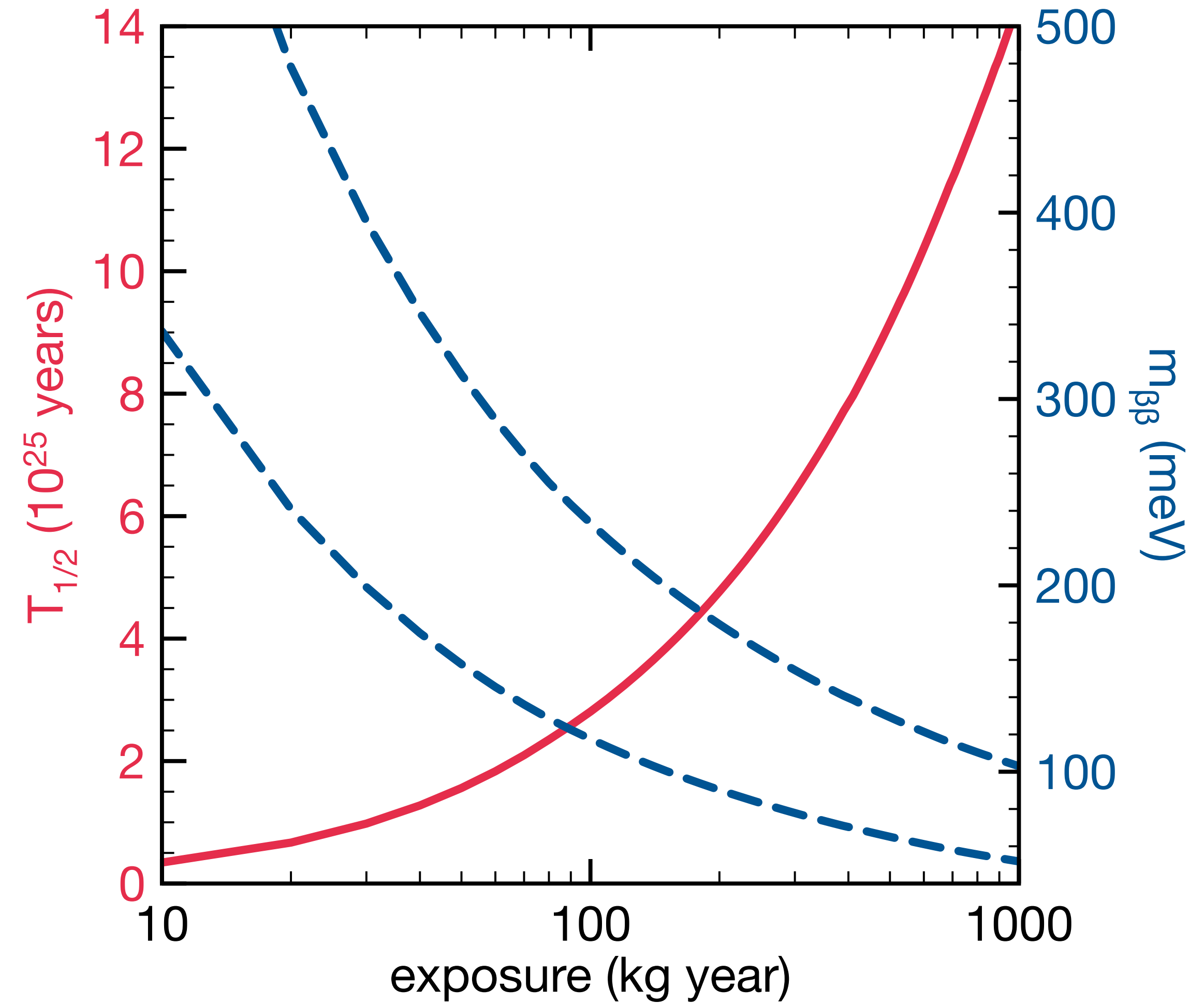
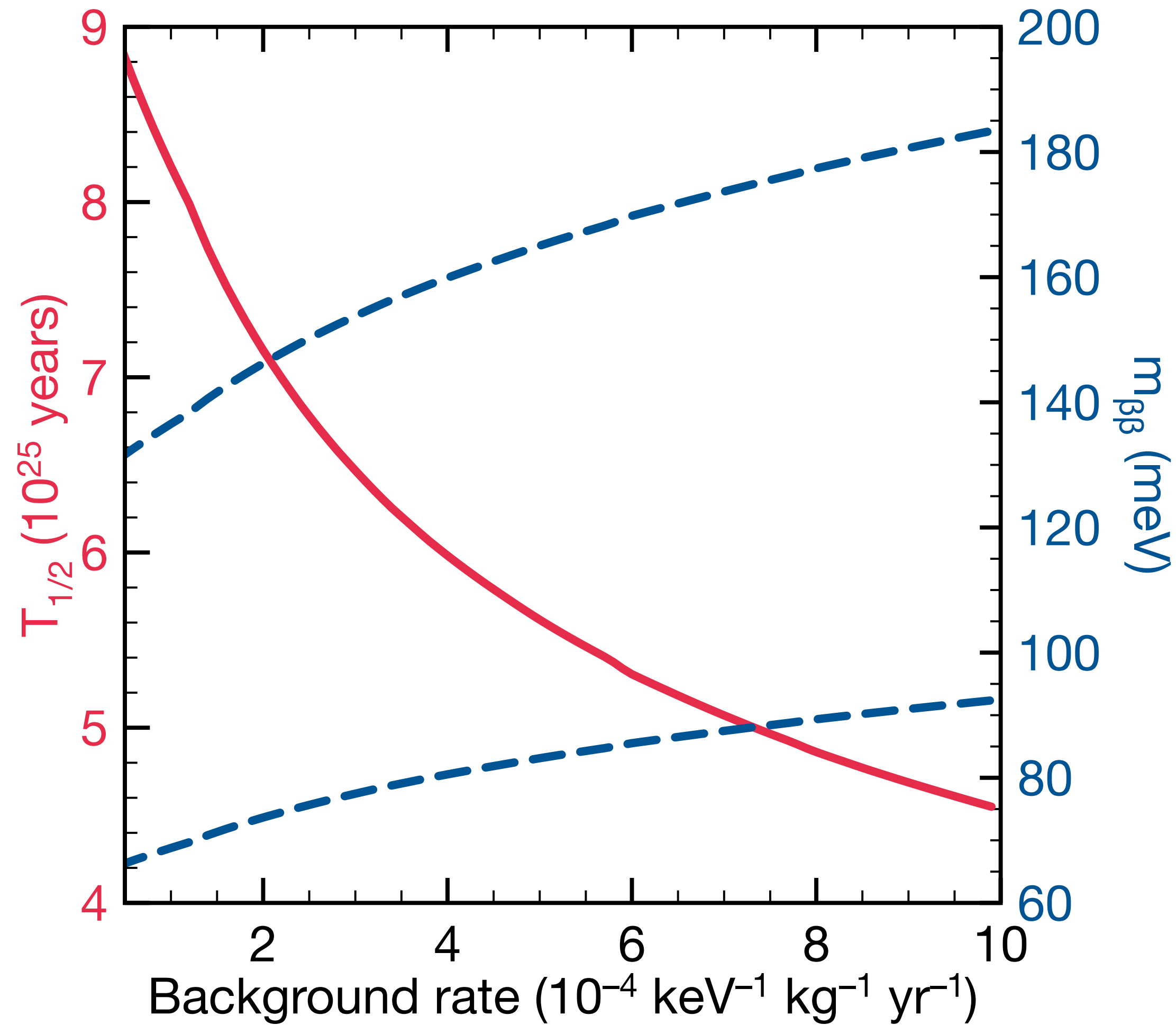








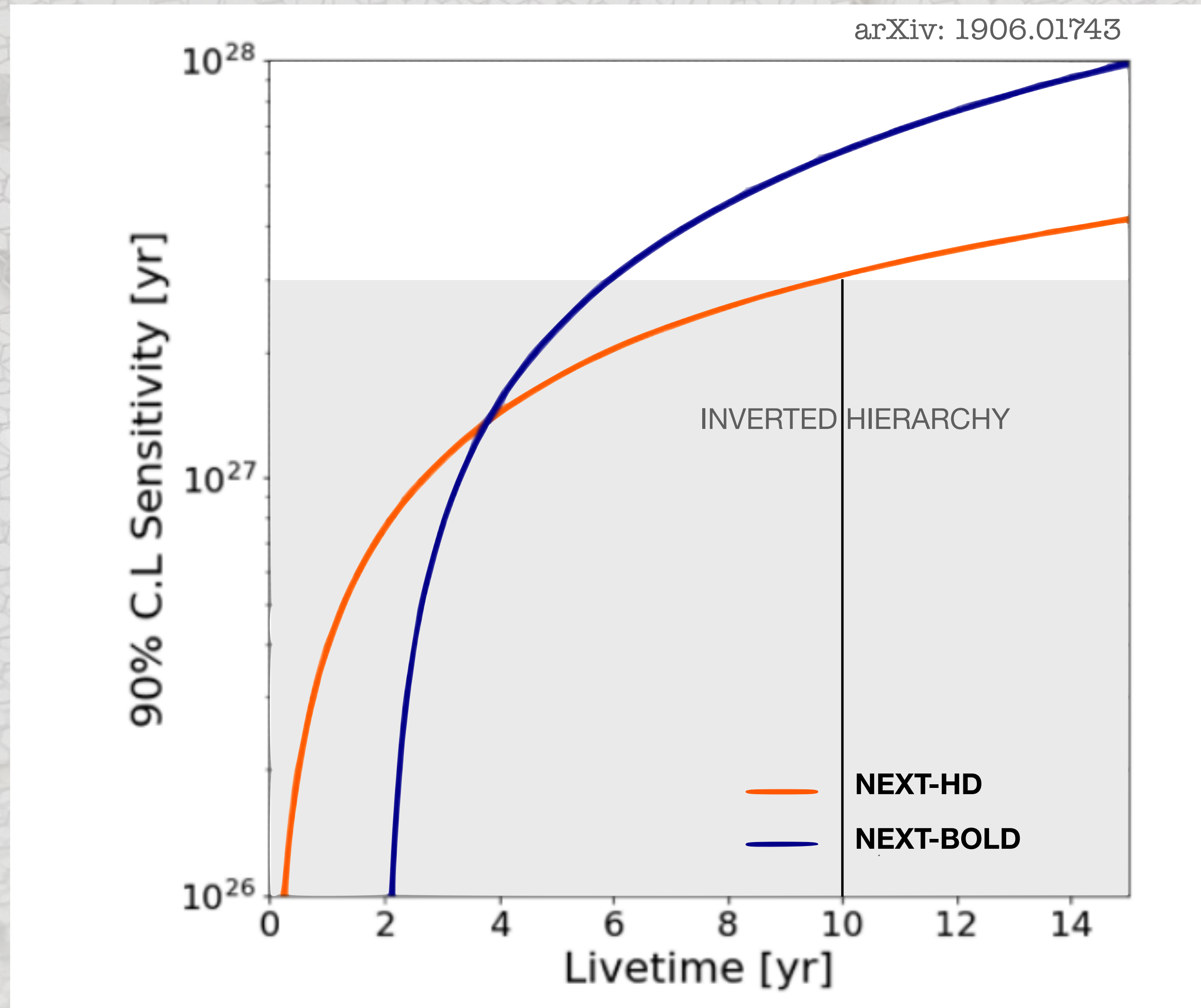


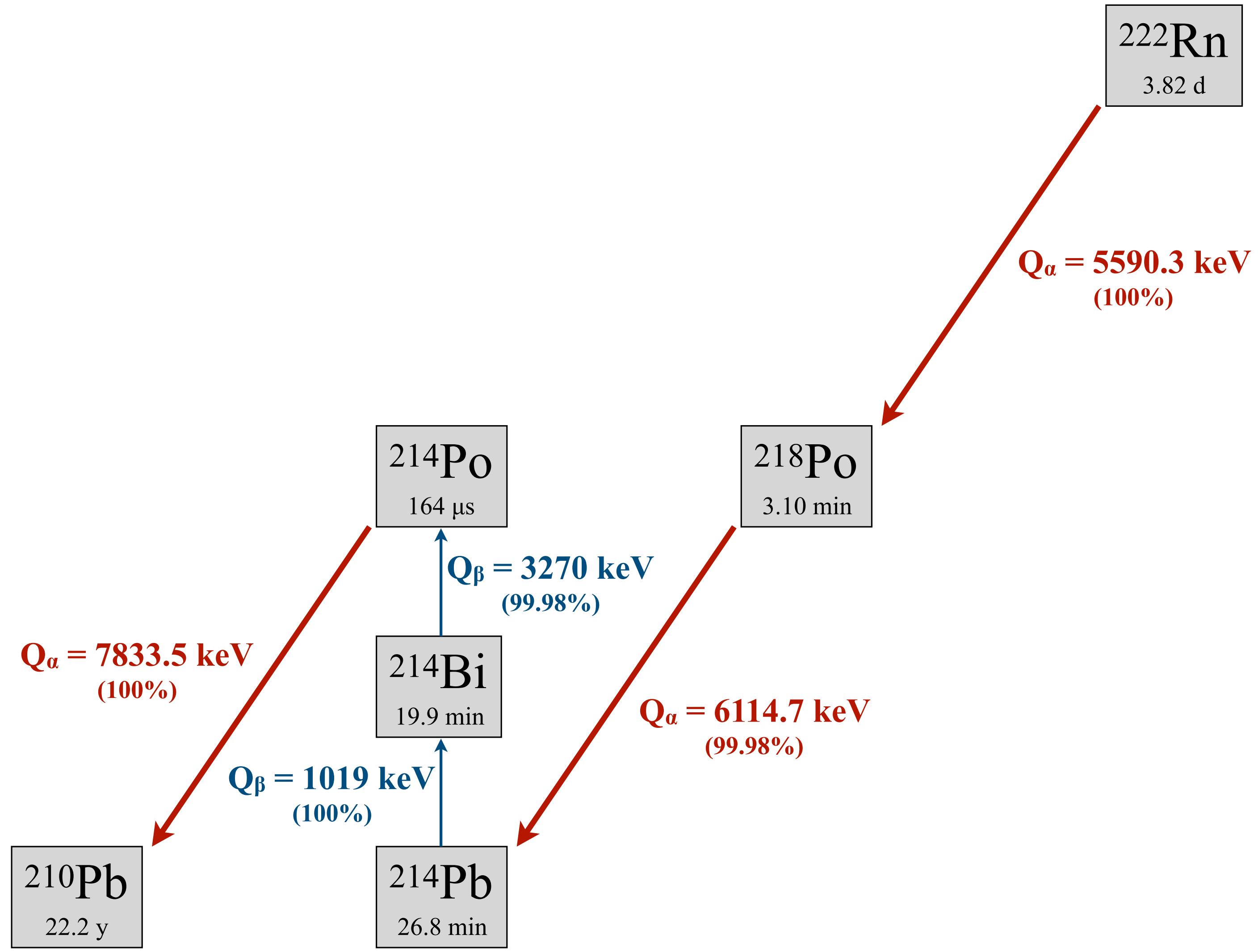


Expected background rate:  $4 \times 10^{-4} \text{ counts}/(\text{keV} \cdot \text{kg} \cdot \text{y})$   
 Expected background: 1 event per year in ROI

Expected sensitivity:  $6 \cdot 10^{25} \text{ yr}$  after 3 years

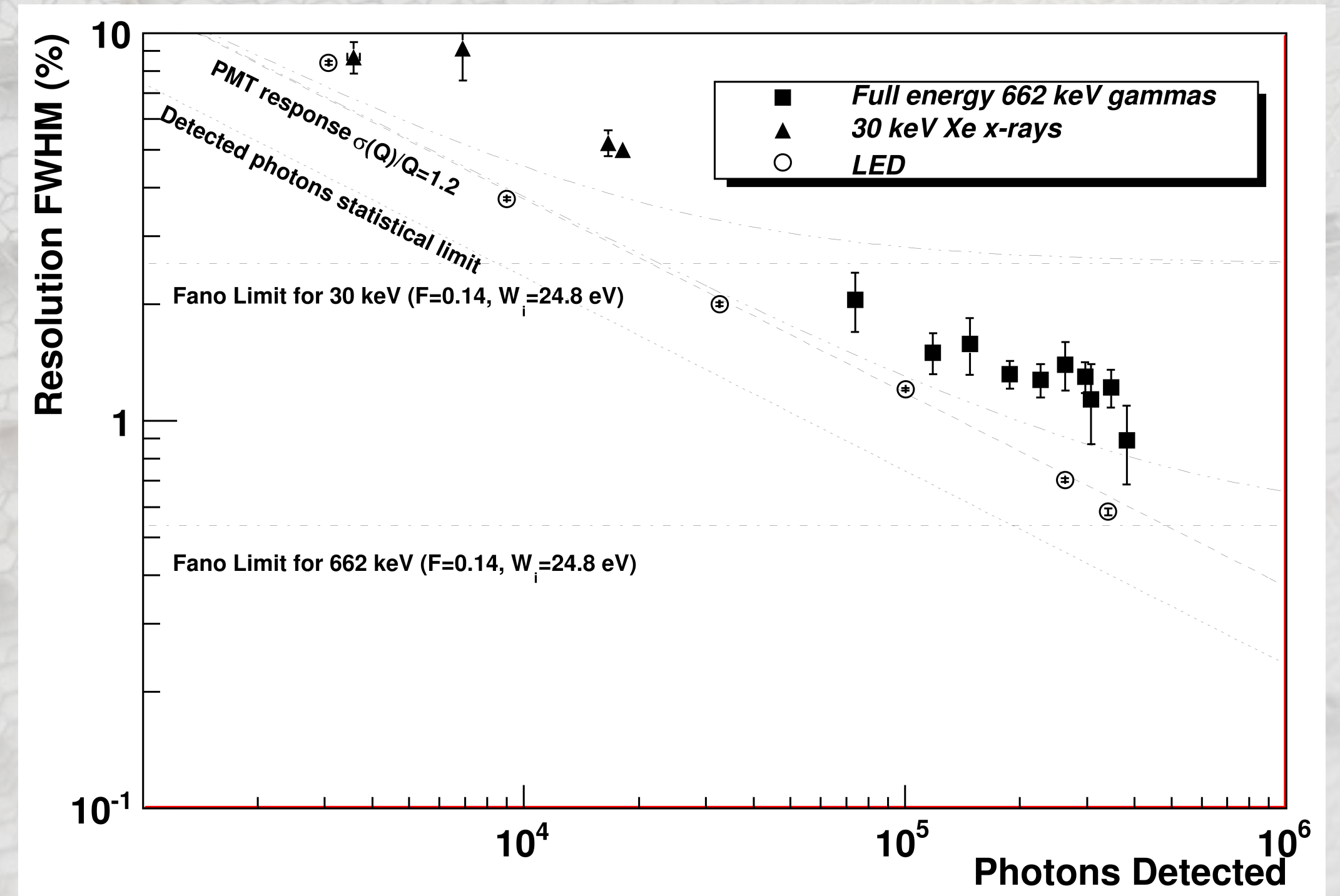
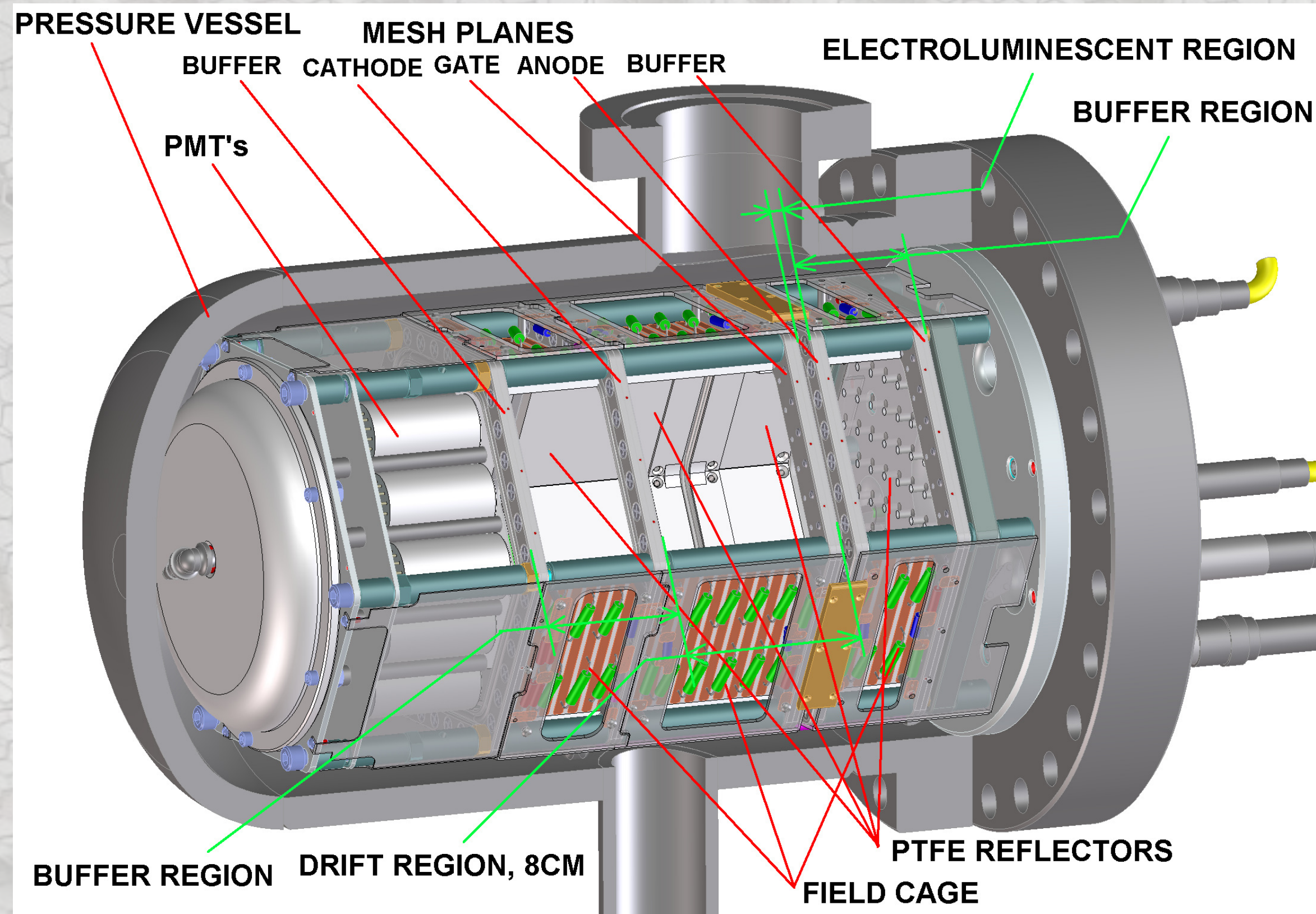






# NEXT-DBDM

**Location:** LBNL (USA)  
**Operation:** 2009-2014  
**Mass:** ~1 kg  
**Resolution:** 0.5%FWHM @  $Q_{\beta\beta}$   
**Objective:** demonstrate the near-intrinsic resolution in high-pressure gas with an EL scheme



# NEXT-DEMO

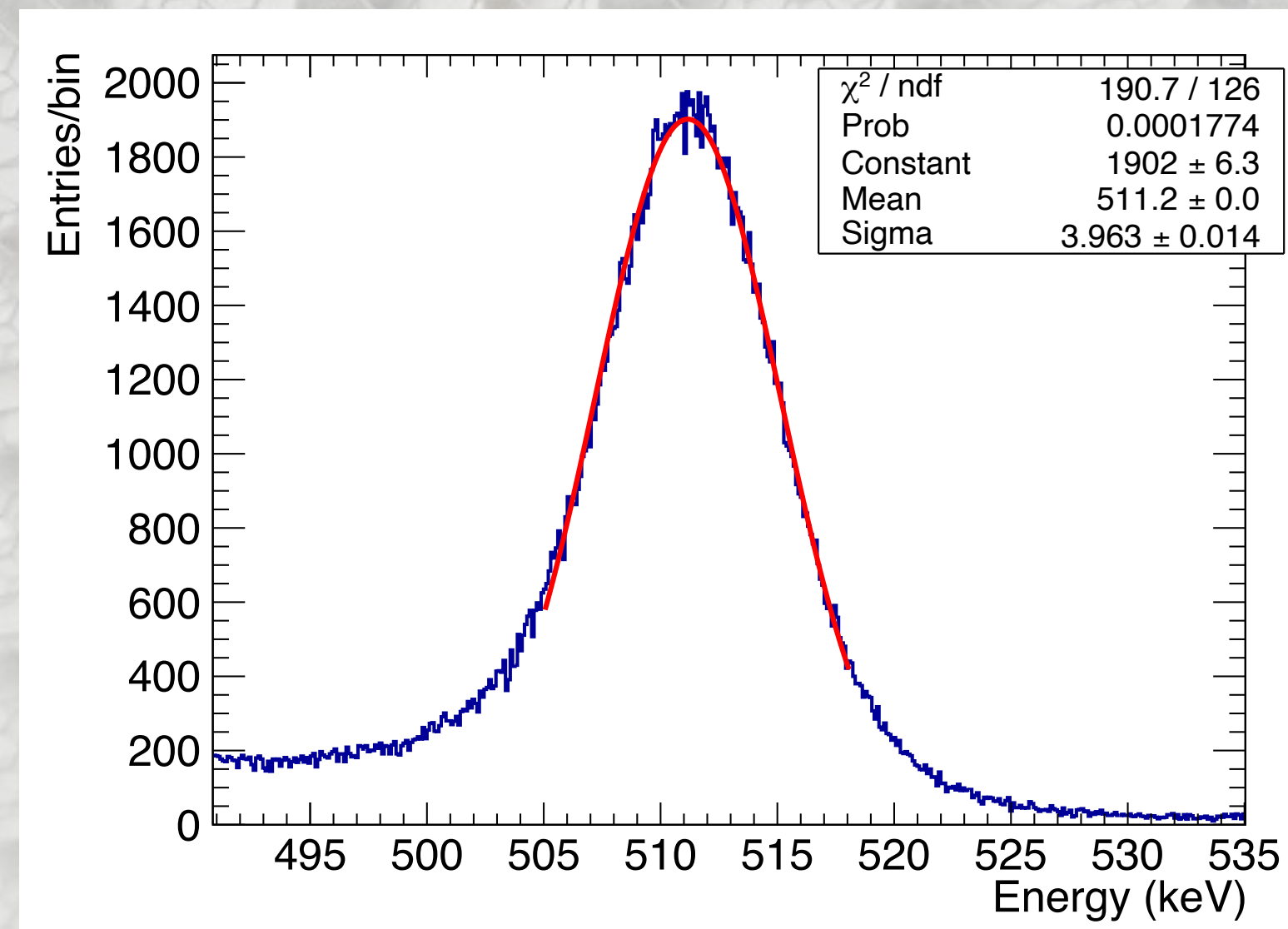
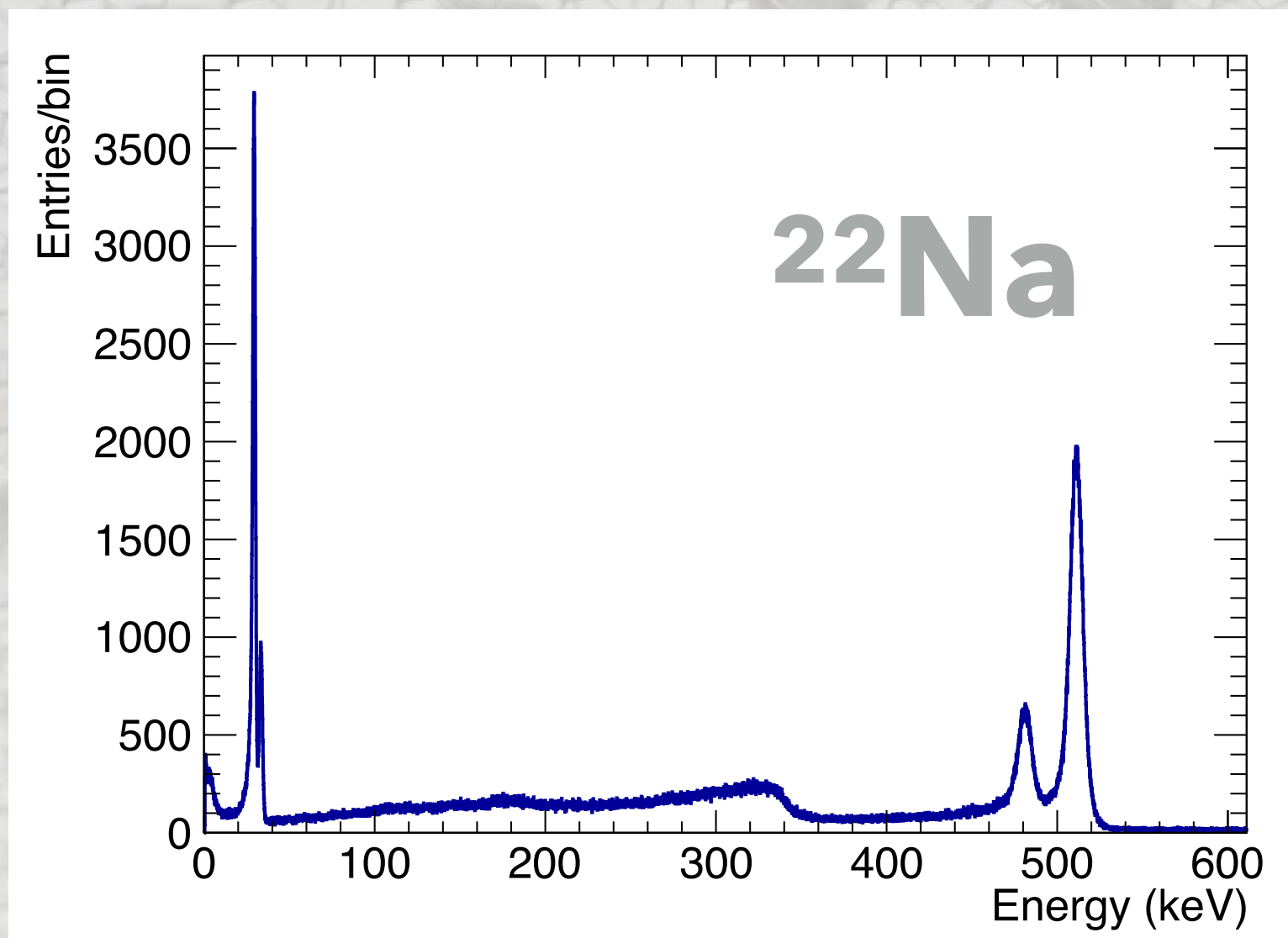
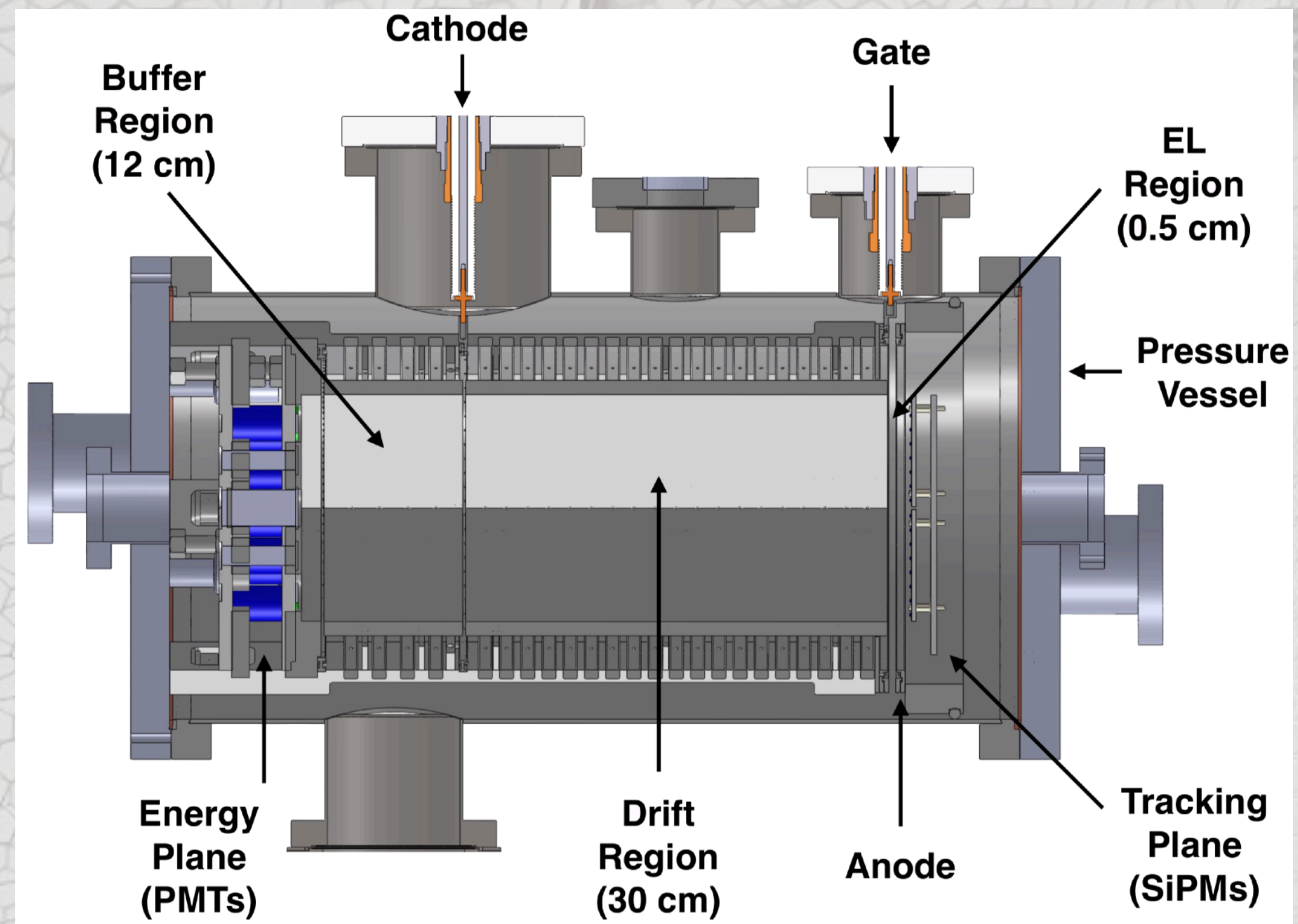
**Location:** IFIC (Spain)

**Operation:** 2009-2014

**Mass:** ~1.5 kg

**Resolution:** 0.74%FWHM @  $Q_{\beta\beta}$  (best)

**Objective:** proof-of-concept of the SOFT proposal



# NEXT-DEMO

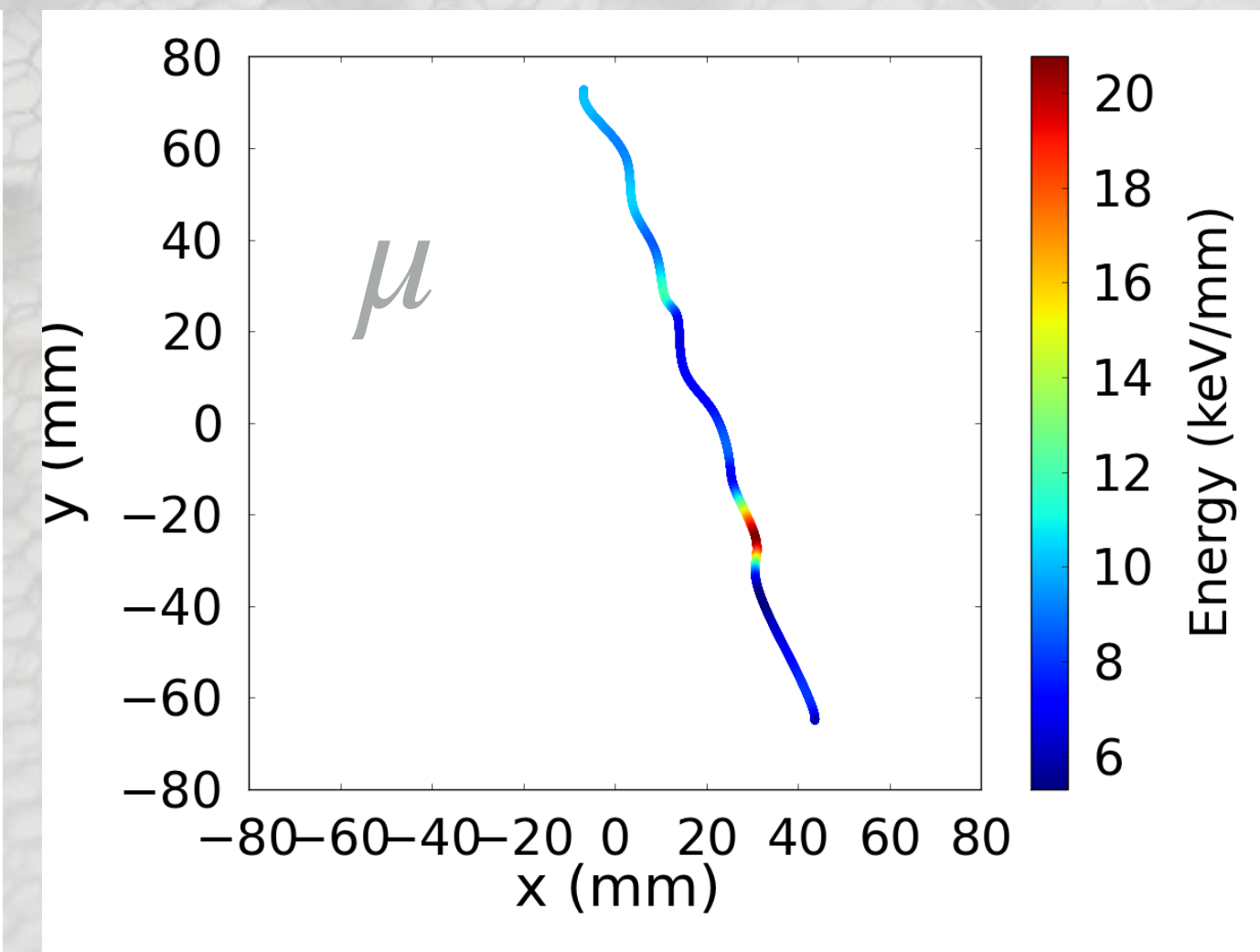
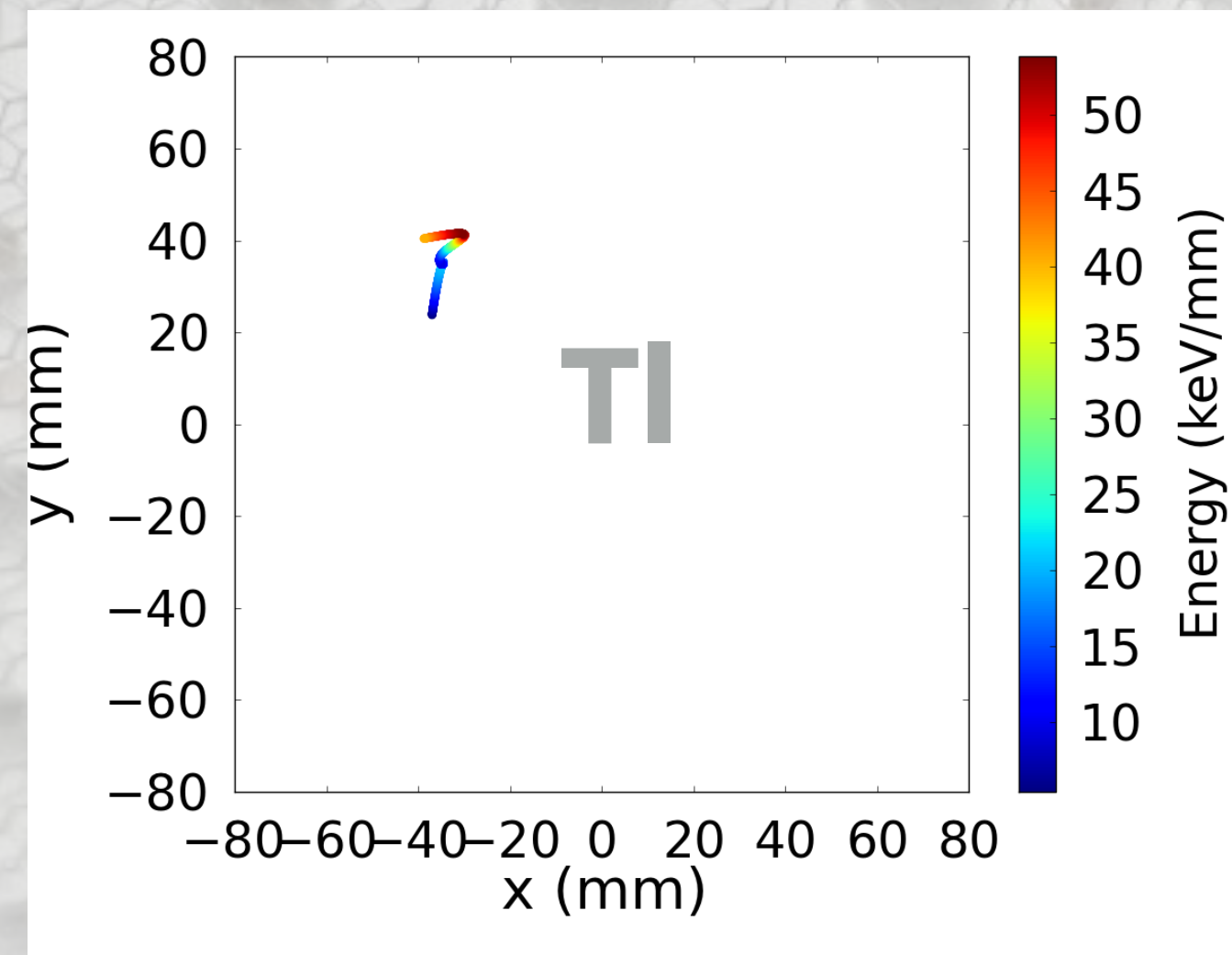
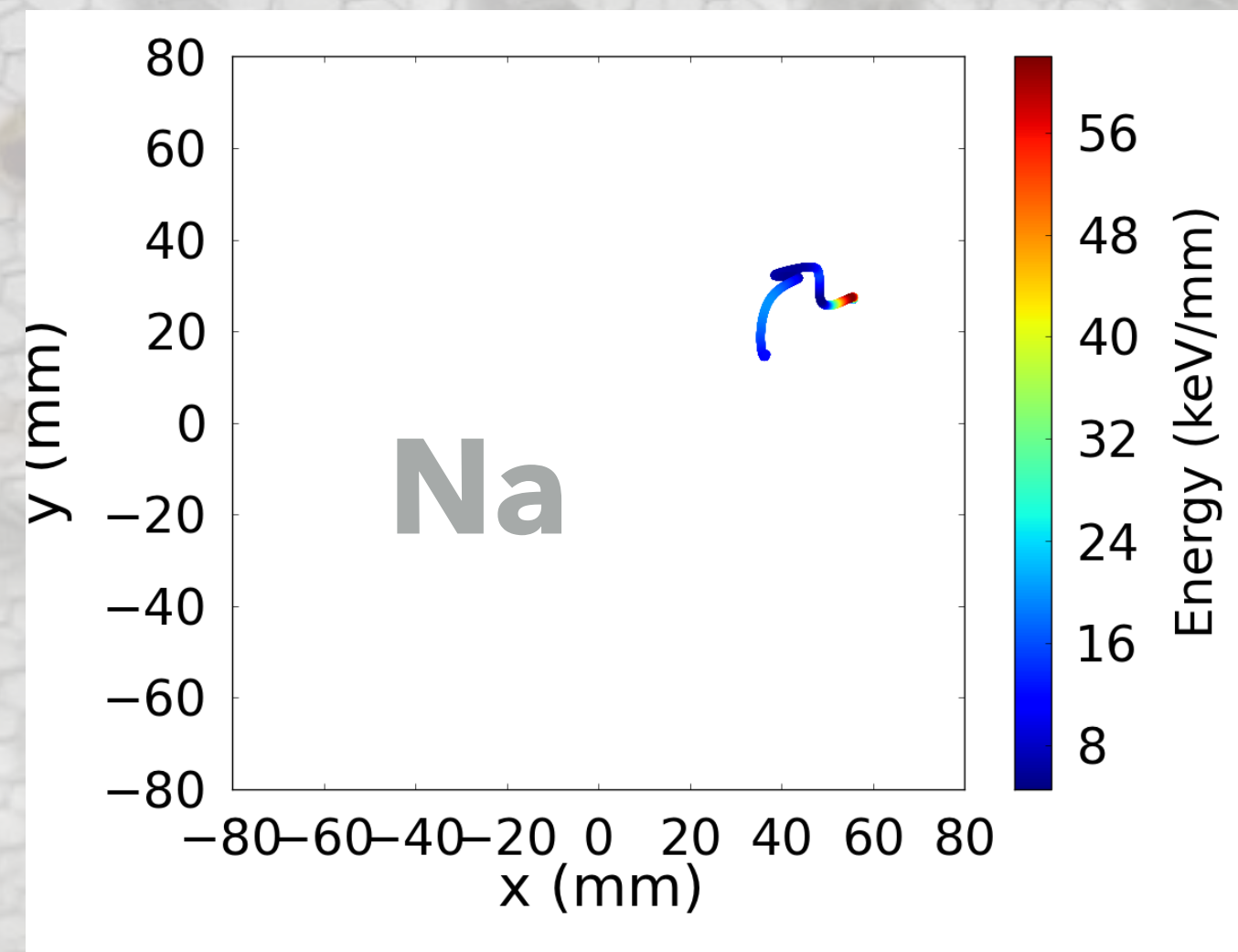
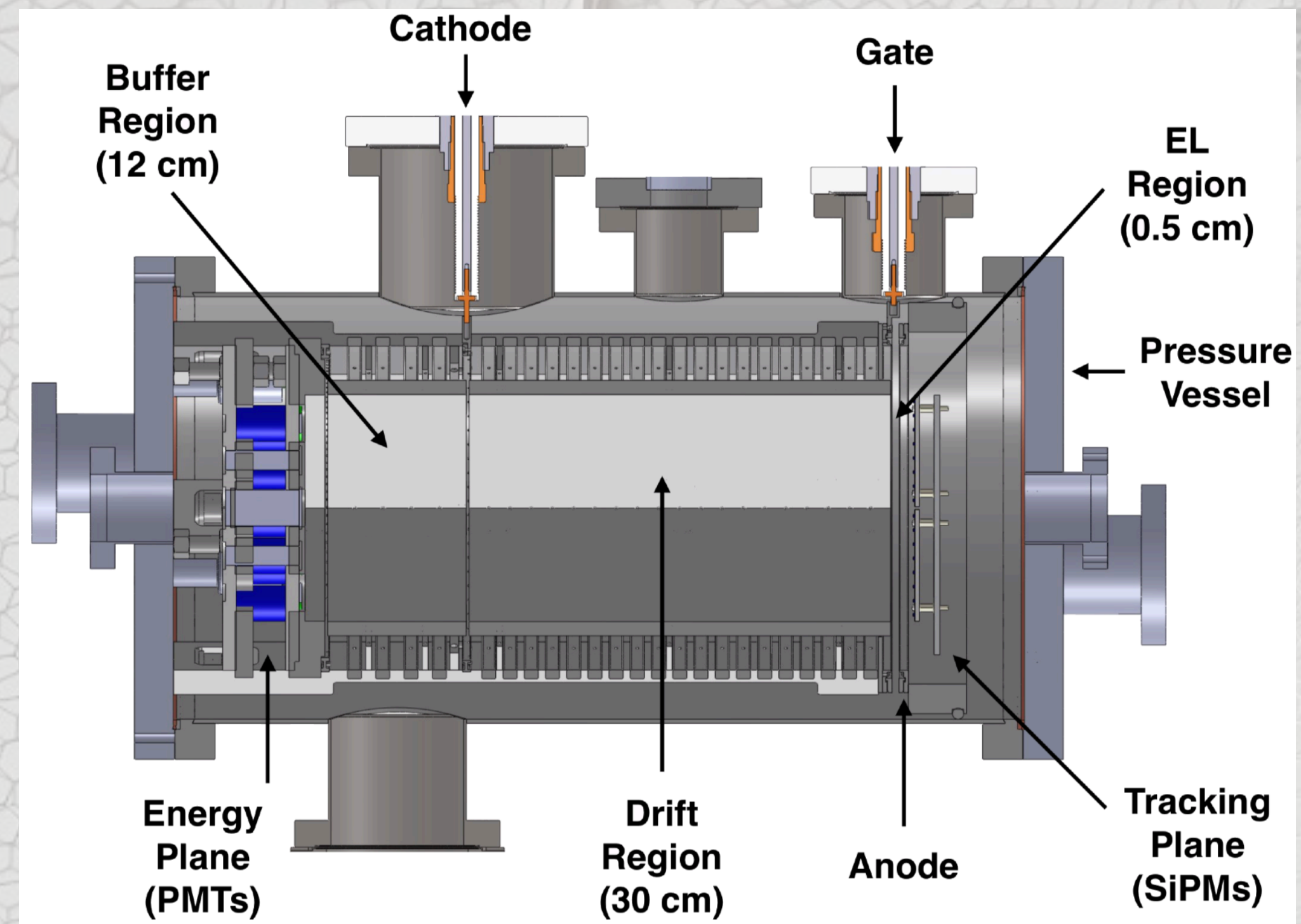
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**Mass:** ~1.5 kg

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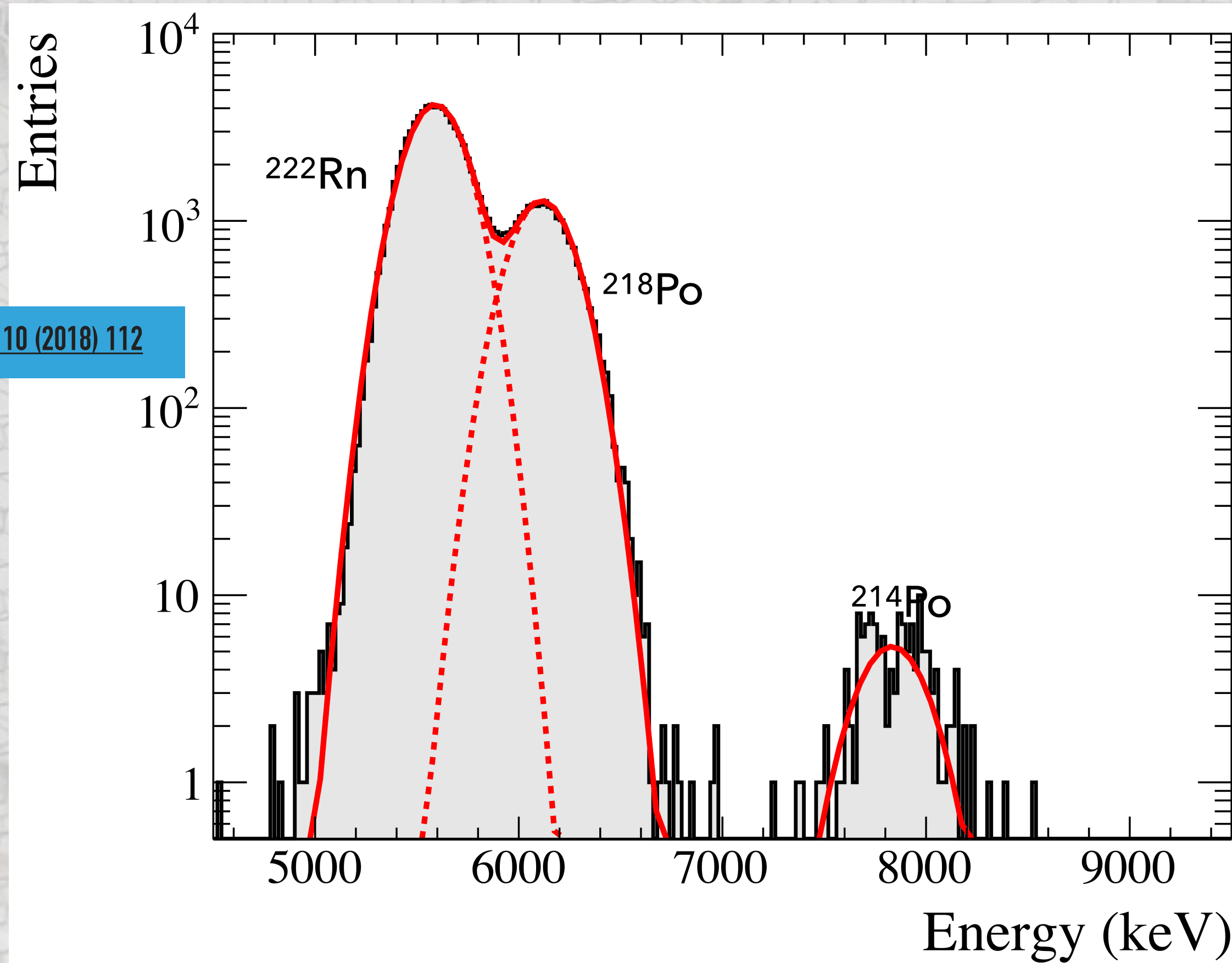
**Objective:** proof-of-concept of the SOFT proposal





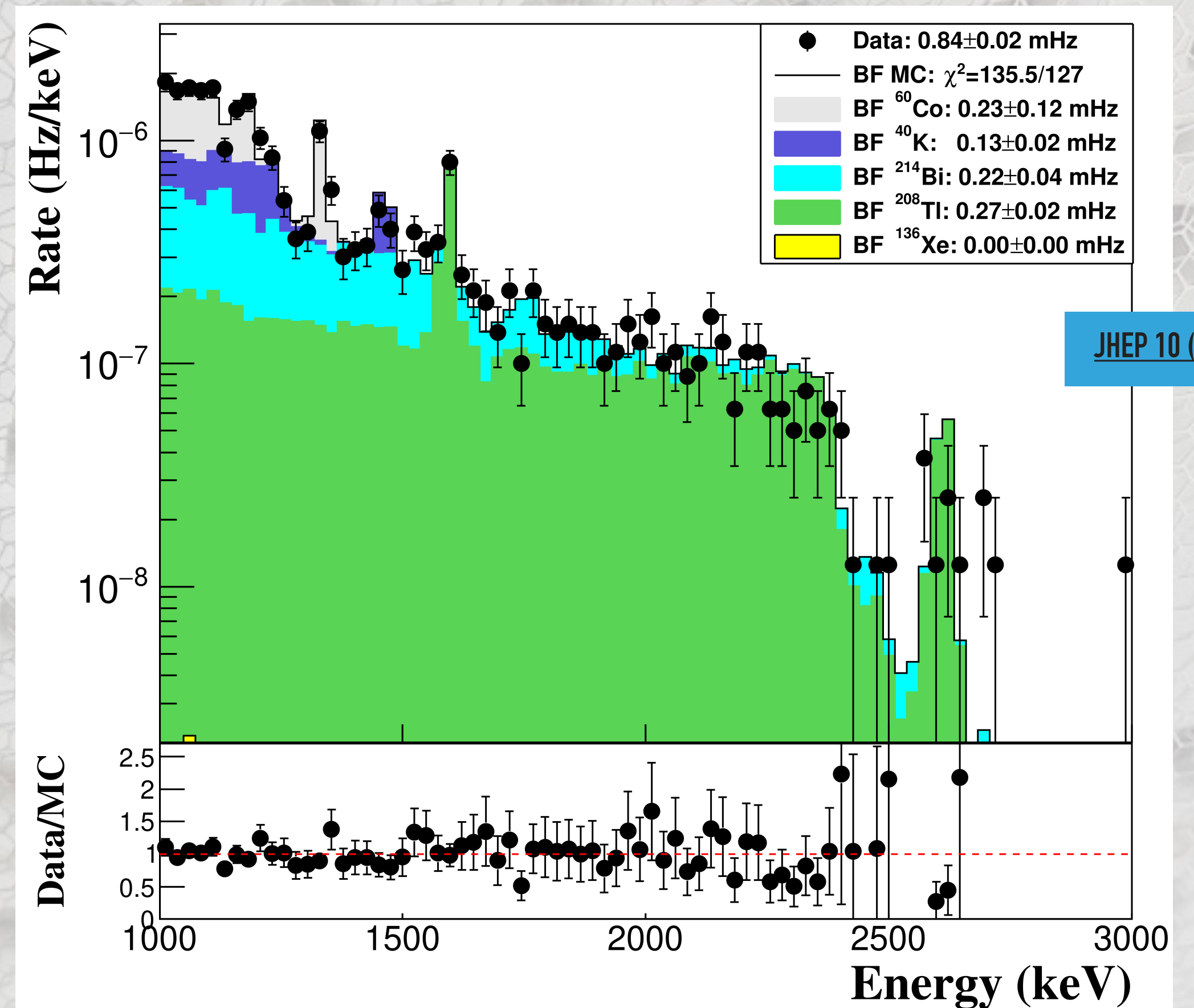
# NEXT-White: Background studies

## Radon-induced backgrounds



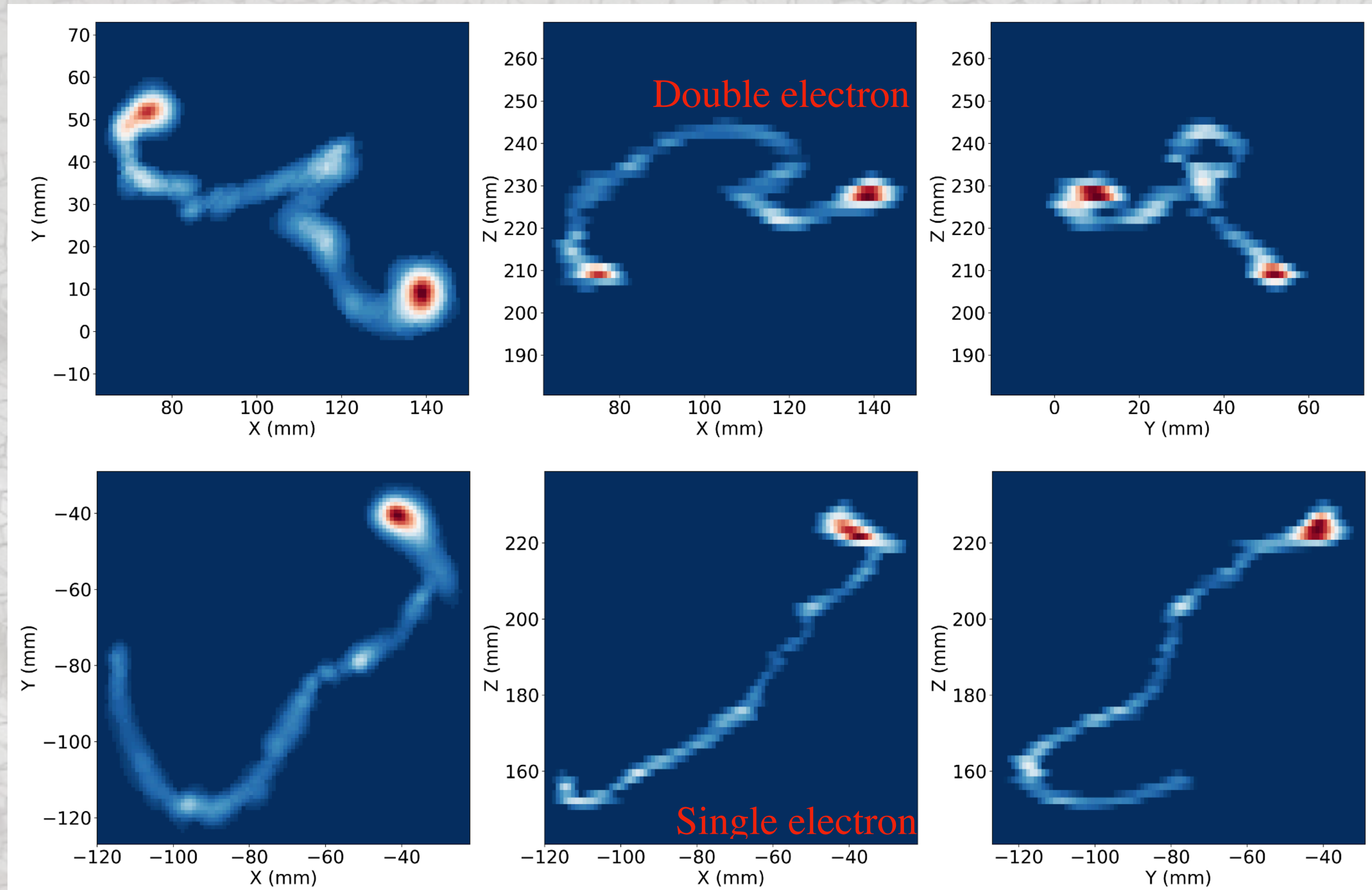
Internal radon has been characterized and measured. It is shown to be negligible for NEXT-100

## Radiogenic backgrounds

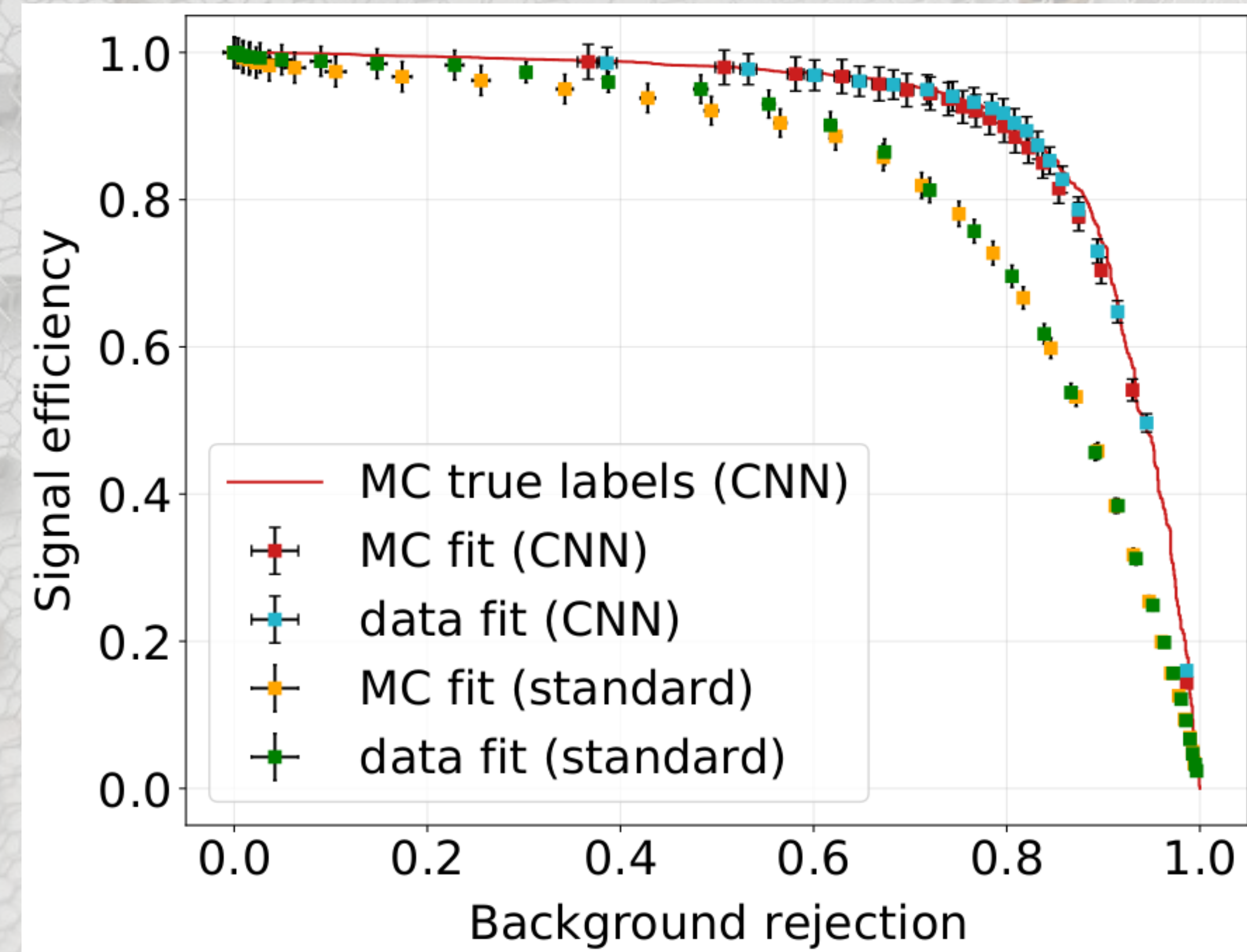


Background model has been validated!

# NEXT-White: Event identification and background rejection



Performed both with a classical analysis (blob search) and a DNN approach.



Successful implementation of the Richardson-Lucy deconvolution algorithm.

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[JHEP 10 \(2019\) 052](#)

[JHEP 01 \(2021\) 189](#)

