

NEXT

Searching for the $\beta\beta 0\nu$ decay with
High-Pressure ^{136}Xe TPCs

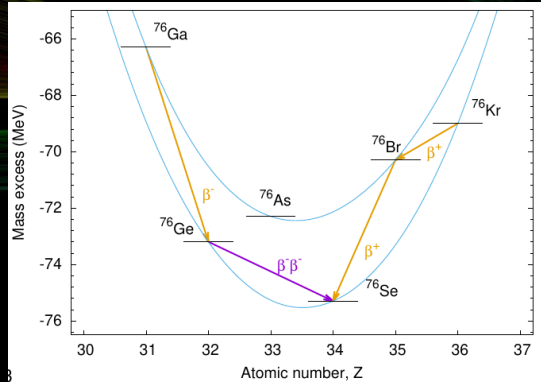
LIDINE 2025, Hong Kong

Pau Novella, IFIC (CSIC & U.V.)

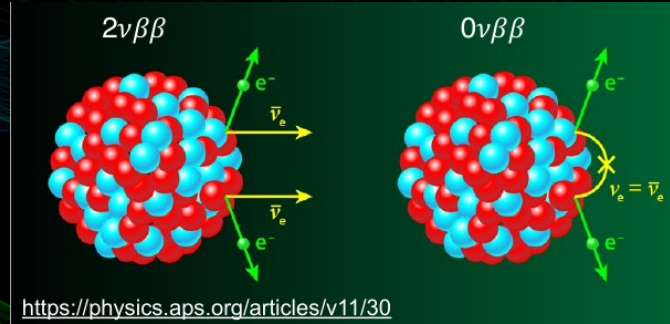
On behalf of the NEXT Collaboration

Neutrinoless Double Beta Decay

- Currently, the only viable experimental approach to probe the nature of neutrino masses



$^{48}\text{Ca} \rightarrow ^{48}\text{Ti}$
 $^{76}\text{Ge} \rightarrow ^{76}\text{Se}$
 $^{82}\text{Se} \rightarrow ^{82}\text{Kr}$
 $^{96}\text{Zr} \rightarrow ^{96}\text{Mo}$
 $^{100}\text{Mo} \rightarrow ^{100}\text{Ru}$
 $^{110}\text{Pd} \rightarrow ^{110}\text{Cd}$
 $^{116}\text{Cd} \rightarrow ^{116}\text{Sn}$
 $^{124}\text{Sn} \rightarrow ^{124}\text{Te}$
 $^{130}\text{Te} \rightarrow ^{130}\text{Xe}$
 $^{136}\text{Xe} \rightarrow ^{136}\text{Ba}$
 $^{150}\text{Nd} \rightarrow ^{150}\text{Sm}$

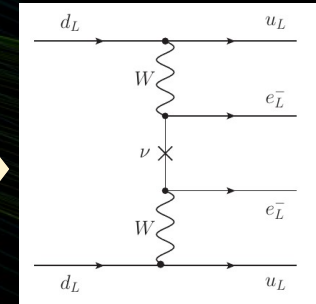


<https://physics.aps.org/articles/v11/30>

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

$$0\nu\beta\beta: (A, Z) \rightarrow (A, Z+2) + 2e^-$$

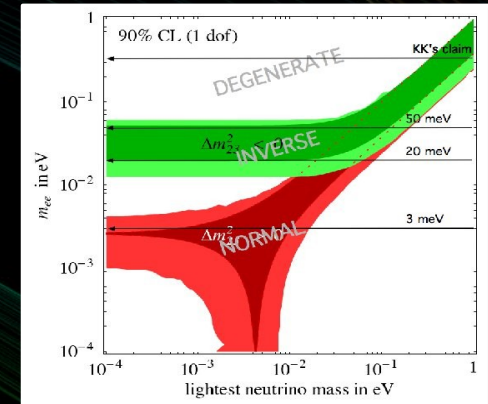
Mass mechanism



$\beta\beta 0\nu$

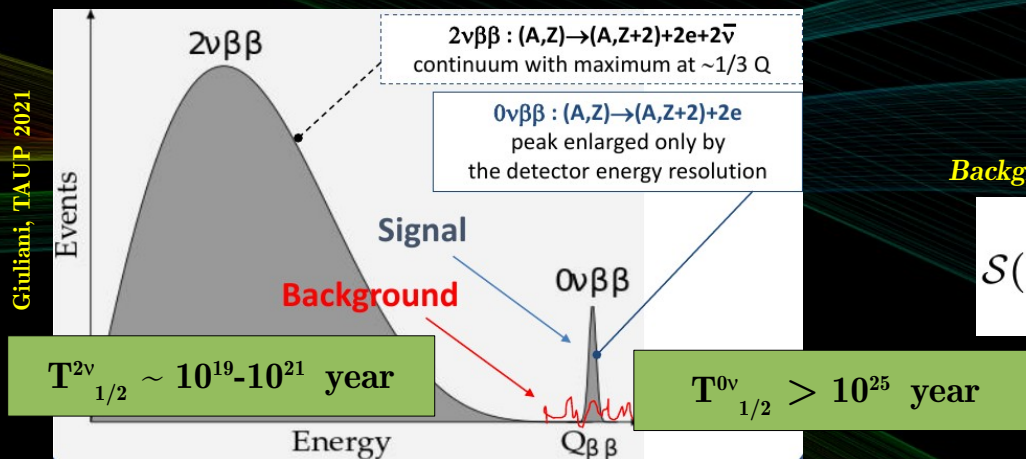
Observation

- neutrinos are Majorana fermions [PRD 25 (1982) 2951]
- LNV (+2): matter created w/o antimatter
- Constraints to the absolute mass (m_{ee})



Searching for the $\beta\beta 0\nu$ decay

- Looking for an extremely rare process...



$$\frac{1}{T_{1/2}^{0\nu}} = G^{0\nu}(Q, Z) |M^{0\nu}|^2 \langle m_\nu \rangle^2$$

Background-free experiment

$$\mathcal{S}(m_{\beta\beta}) \propto \sqrt{\frac{1}{\varepsilon M t}}$$

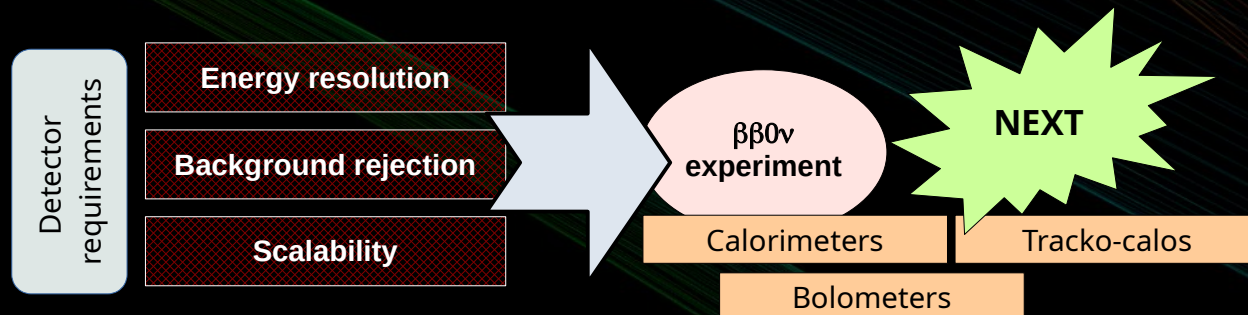
Background-limited experiment

$$\mathcal{S}(m_{\beta\beta}) \propto \sqrt{1/\varepsilon} \left(\frac{b \Delta E}{M t} \right)^{1/4}$$

- No only a matter of size, backgrounds are the key!

How to reduce the backgrounds:

- $\beta\beta 2\nu$: energy resolution (ΔE)
- Radiogenics: radiopurity + ΔE + ?
- Cosmogenics: muon vetoes + ΔE + ?



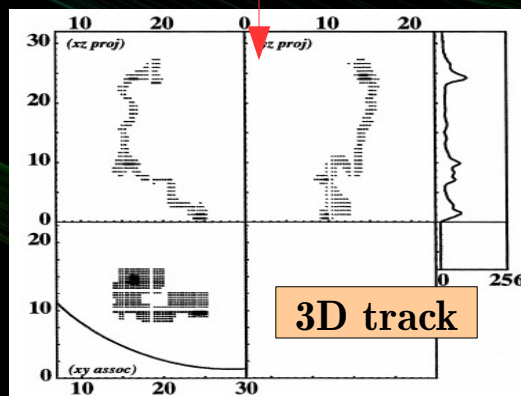
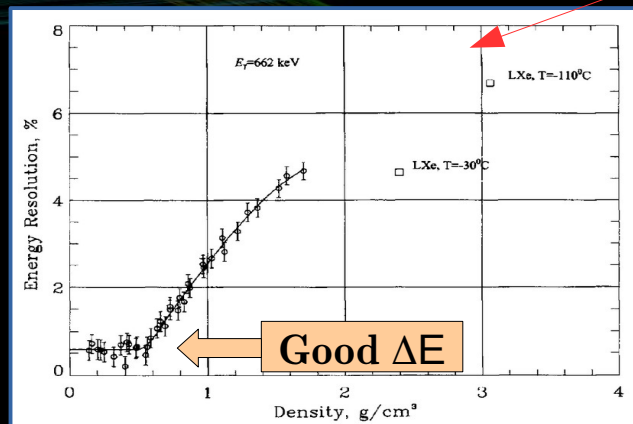
NEXT: HP Gas-Xe TPC Detectors

- Sensitivity to the $\beta\beta 0\nu$ decay:

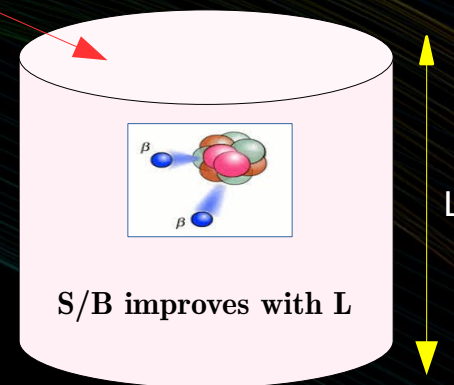
$$T_{1/2}^{-1} \propto a \cdot \epsilon \cdot \sqrt{\frac{Mt}{\Delta E \cdot B}}$$



- $Q_{\beta\beta} = 2.46$ MeV
- Scint/Ionization
- Cheap/Easy to enrich
- Long $\beta\beta 2\nu$ mode



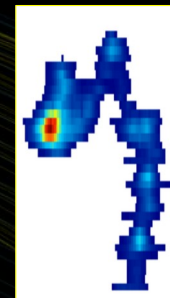
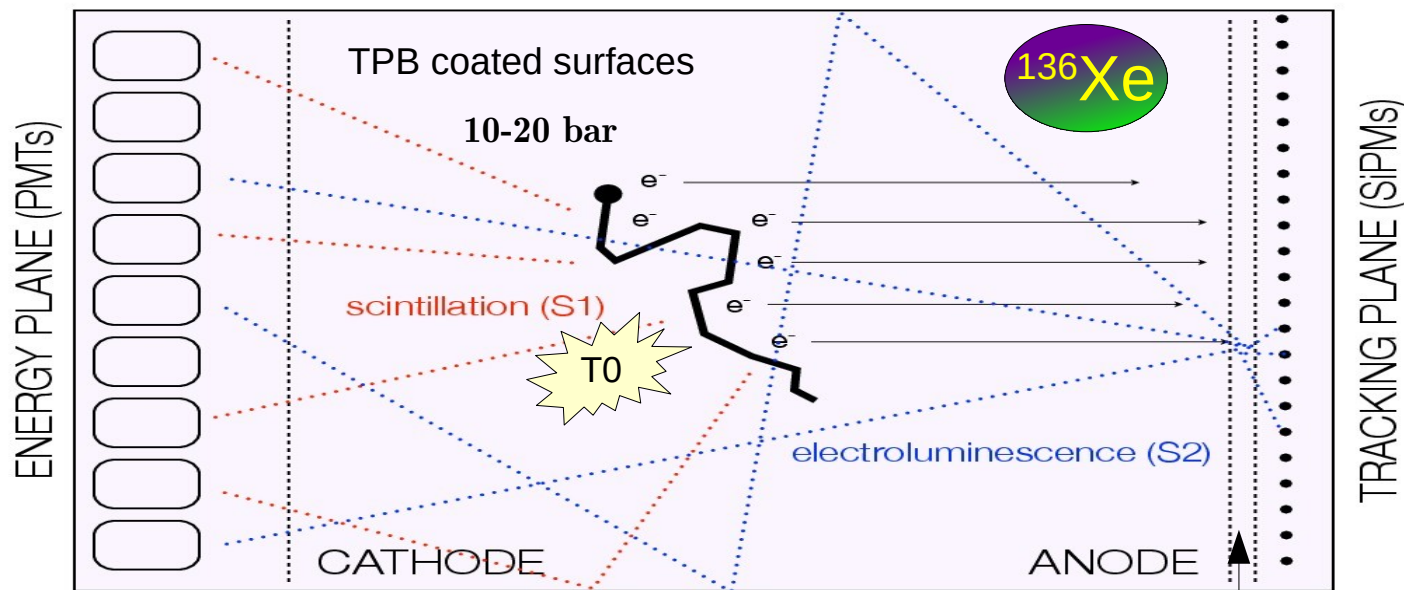
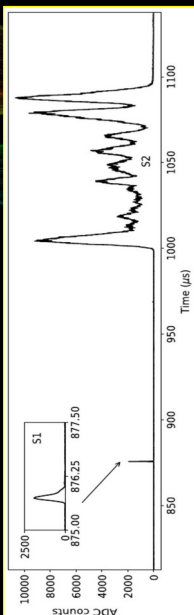
R. Luescher et al, PLB 434 (1998)



Source=Detector

The NEXT TPC Concept

Gas TPC with 2 dedicated readout planes

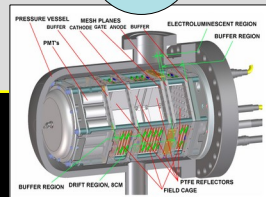
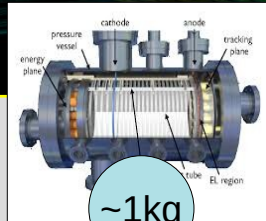


EL: linear gain, no avalanche fluctuations: optimize ΔE

The NEXT Project

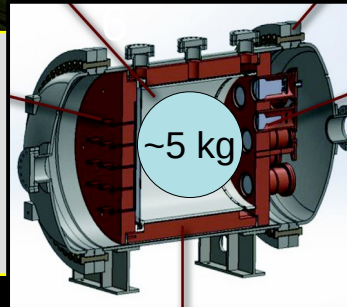
- Search for the $\beta\beta 0\nu$ decay with a HPXe-TPC

R&D
Proof of Concept



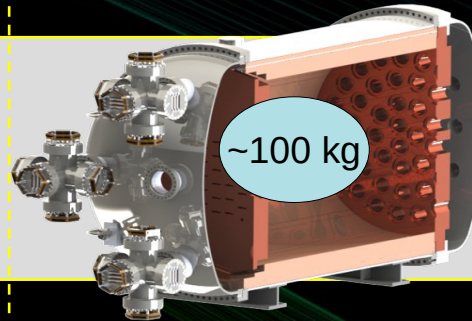
2009-2014

NEXT-White
Background+ $\beta\beta 2\nu$



2015-2021

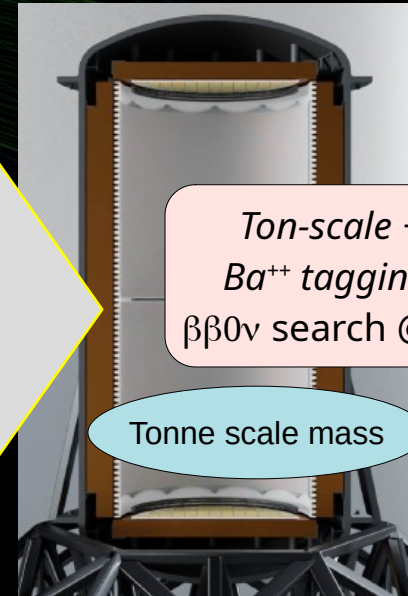
NEXT-100 (+upgrades)
 $\beta\beta 0\nu$ search



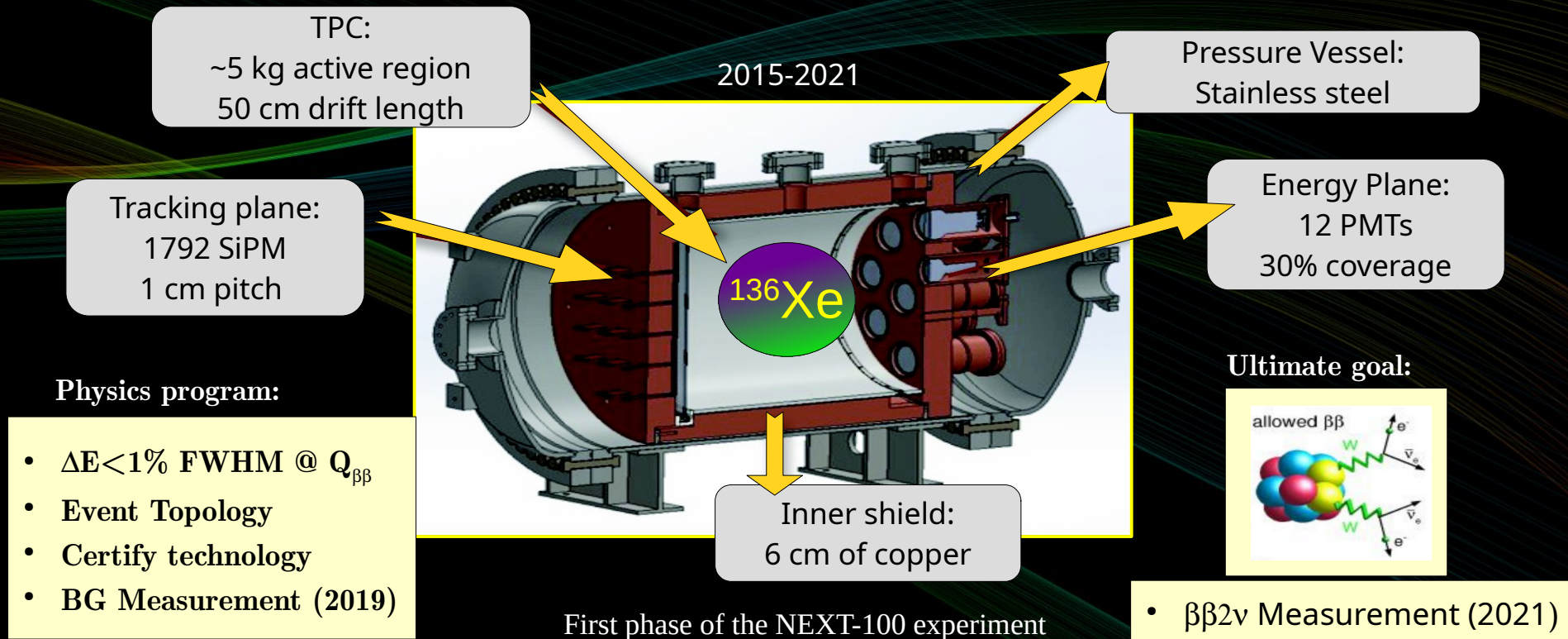
2023-2030

Ton-scale +
 Ba^{++} tagging:
 $\beta\beta 0\nu$ search @ IH

Tonne scale mass

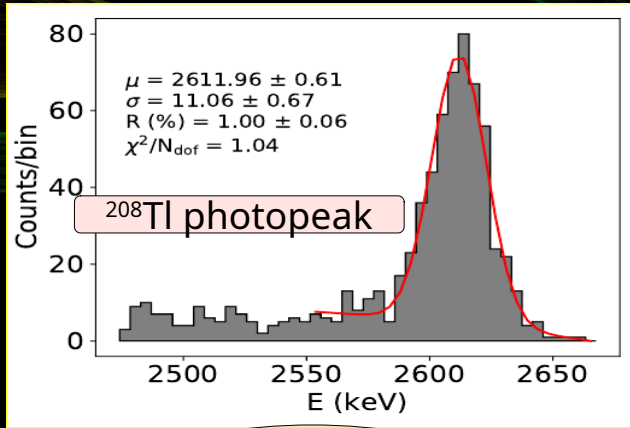


NEXT-White: Physics @ LSC



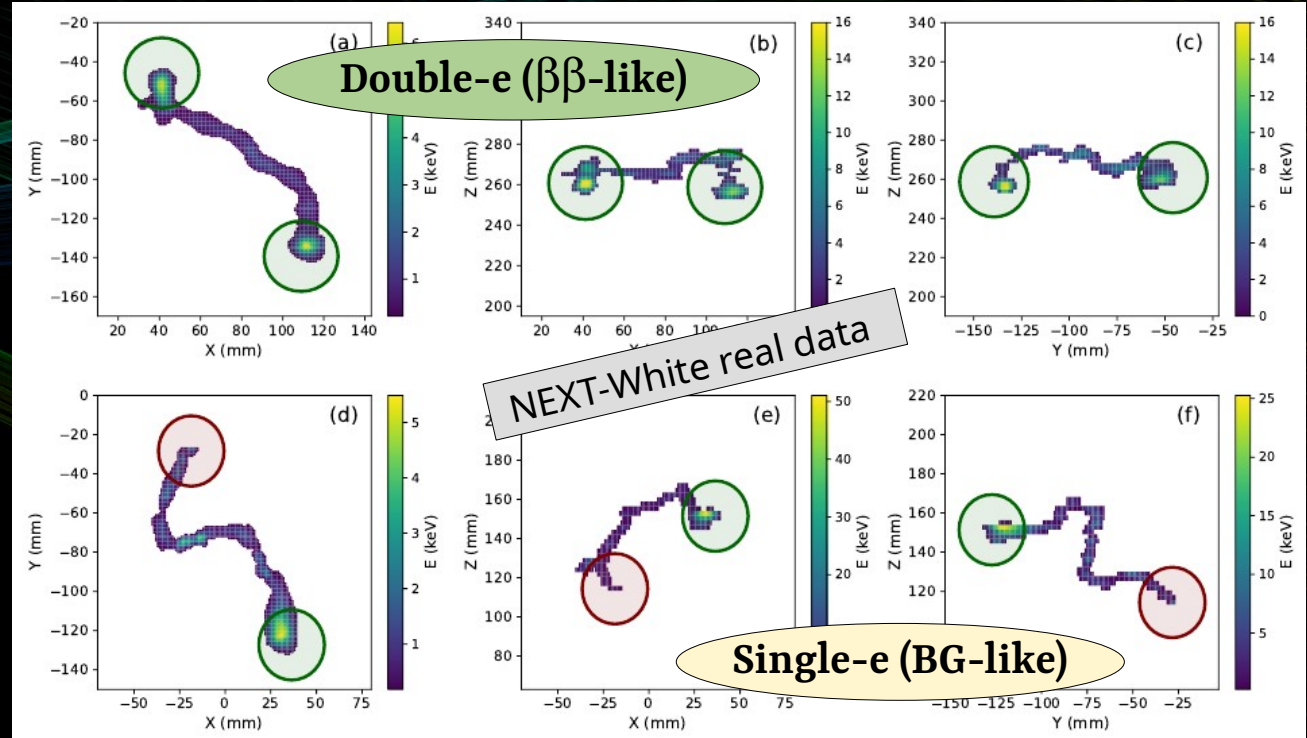
NEXT-White: Performance

JHEP 10 (2019) 230



$\Delta E = 1\%$

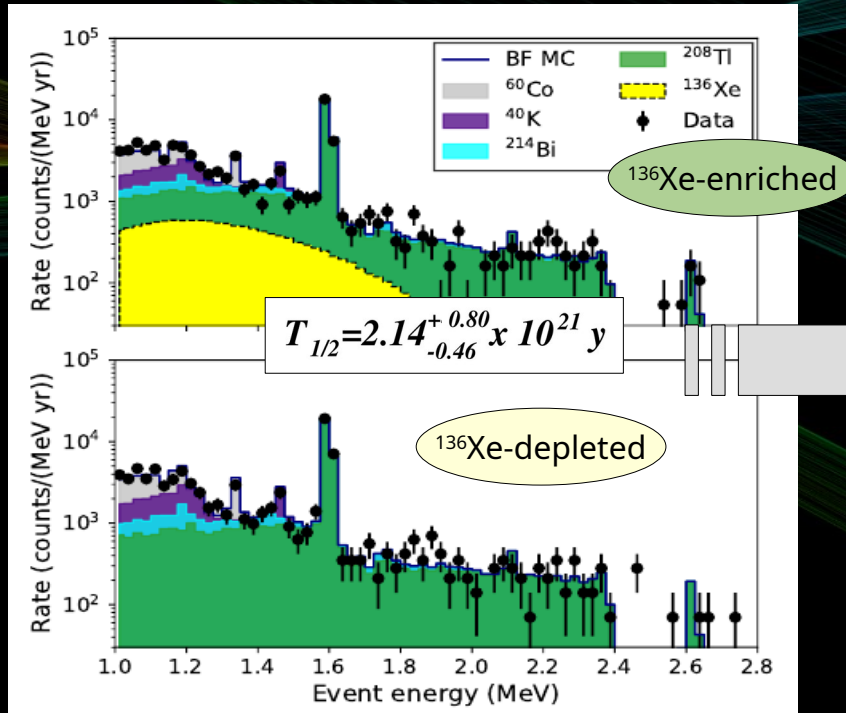
FHWM @ $\sim Q_{\beta\beta}$



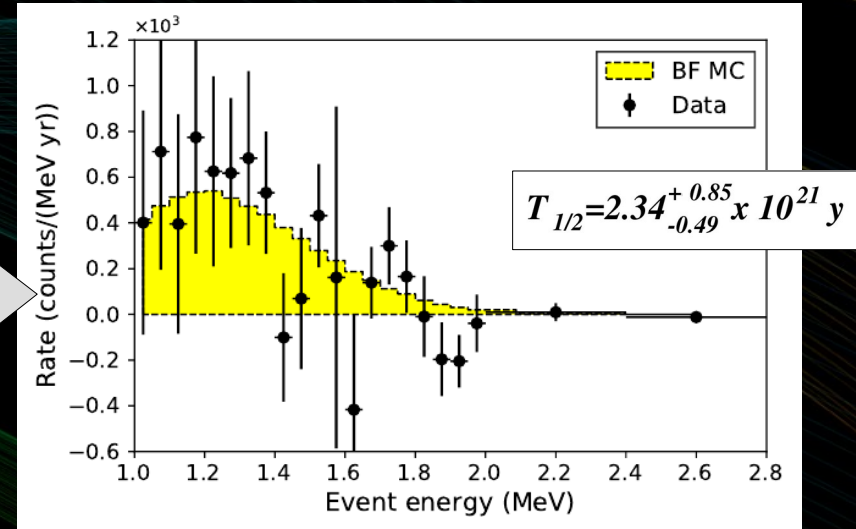
- $\beta\beta 0\nu$ candidate: events fully contained + one track with 2 blobs at the extremes + E within ROI

NEXT-White: $\beta\beta 2\nu$ Measurement

- Background-model-dependent method:



- Background-subtraction method, with little dependence on background model:



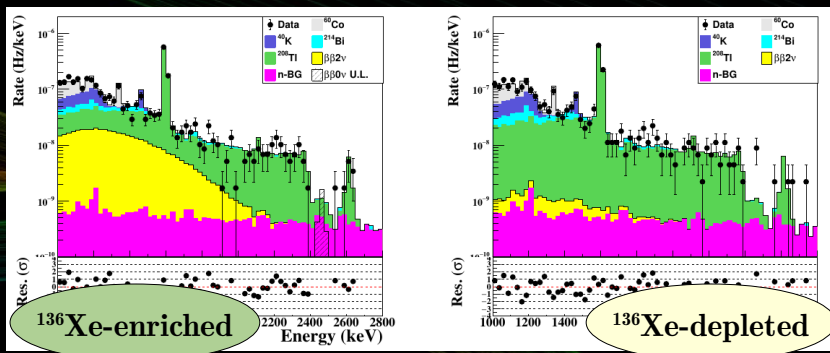
- Novel (so far unique in the field) technique possible due to the Xenon-based NEXT technology

Phys.Rev.C 105 (2022) 5, 055501

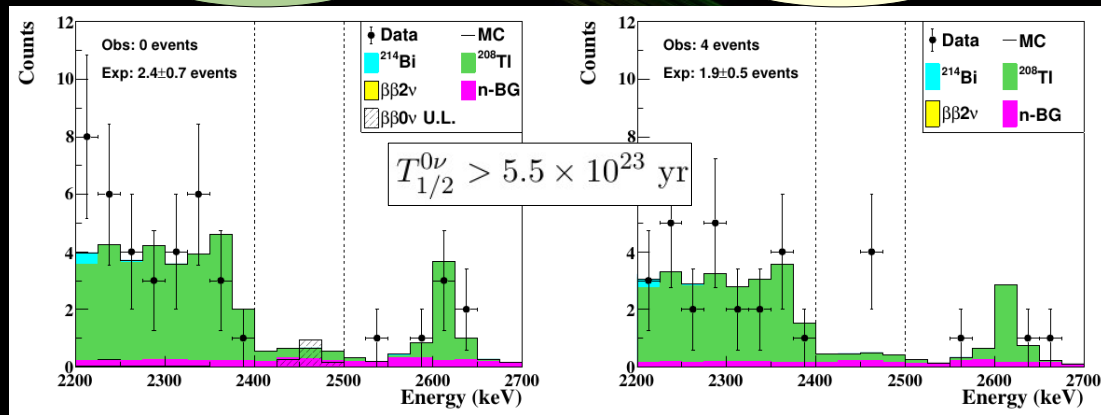
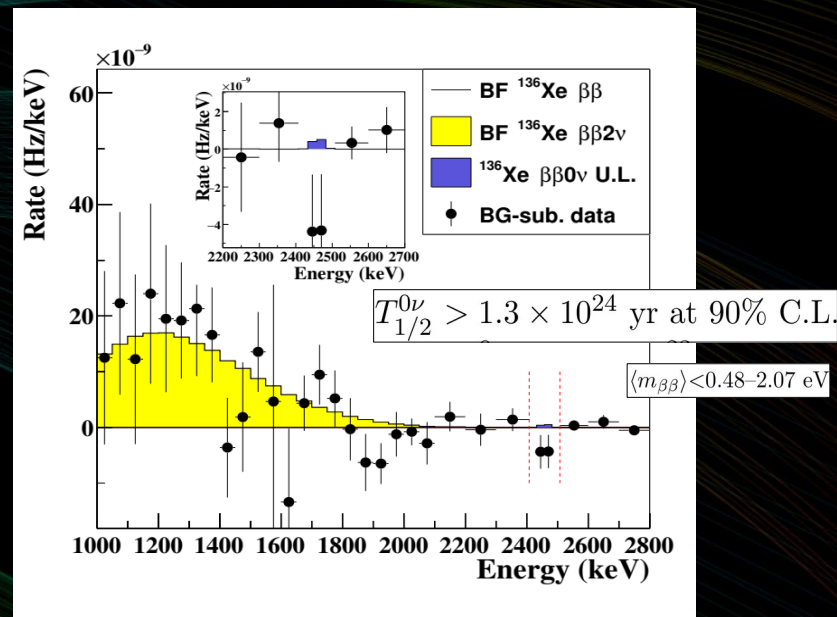
Precision limited by exposure (3.5 kg of Xe)!

NEXT-White: Demonstration of $\beta\beta 0\nu$ searches

- Background-model-dependent:



- Background-subtraction (novel in the field):

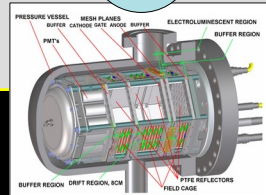
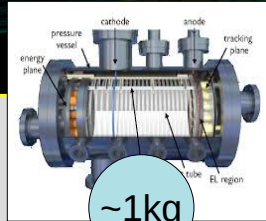


- $\beta\beta$ analyses demonstrate the capabilities of the NEXT technology with only 3.5 kg of Xe!

The NEXT Project

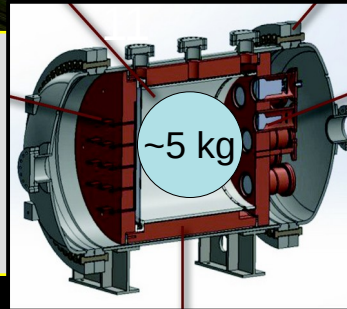
- Search for the $\beta\beta 0\nu$ decay with a HPXe-TPC

R&D
Proof of Concept



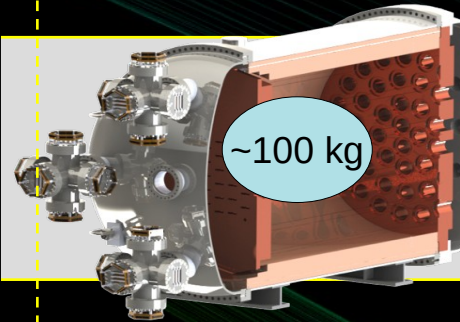
2009-2014

NEXT-White
Background+ $\beta\beta 2\nu$



2015-2021

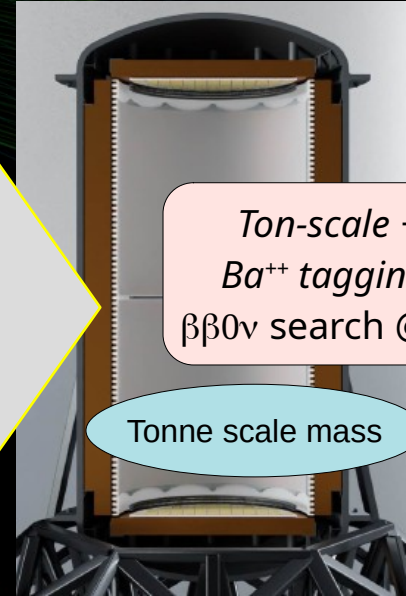
NEXT-100 (+upgrades)
 $\beta\beta 0\nu$ search



2023-2030

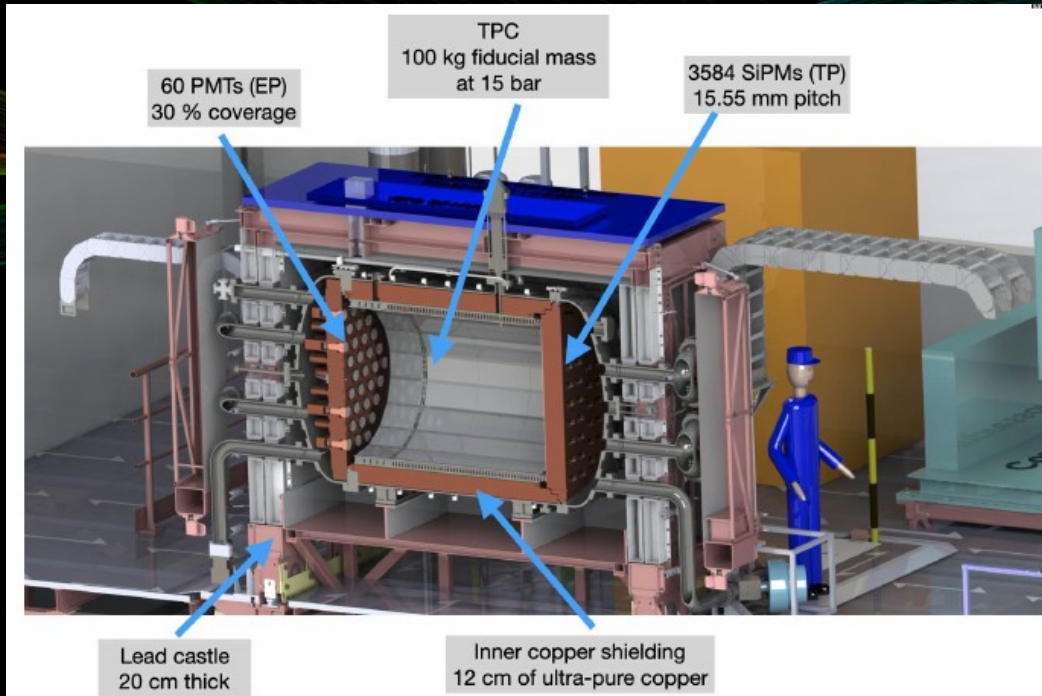
Ton-scale +
 Ba^{++} tagging:
 $\beta\beta 0\nu$ search @ IH

Tonne scale mass

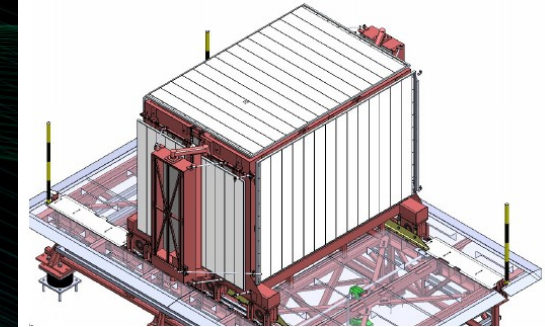


The NEXT-100 Detector

- Scales up the NEXT-White technology (~ 100 kg) to perform competitive $\beta\beta 0\nu$ searches



Muon veto covering the lead castle:



Goals of NEXT-100:

- Energy resolution $< 1\%$ FWHM
- Improve radioactive budget
- Competitive Search of $\beta\beta 0\nu$
- Prepare the ton-scale...

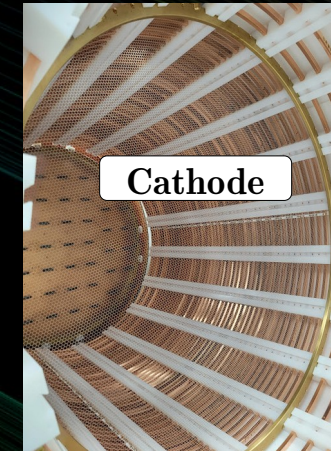
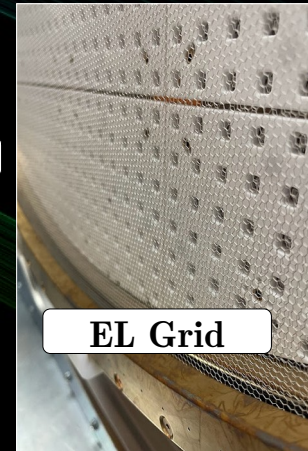
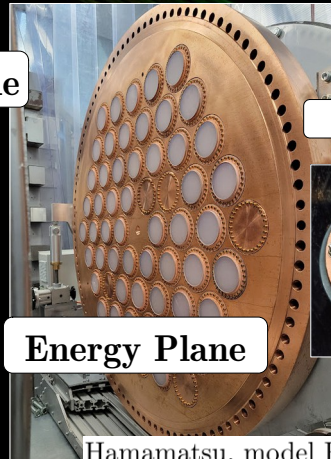
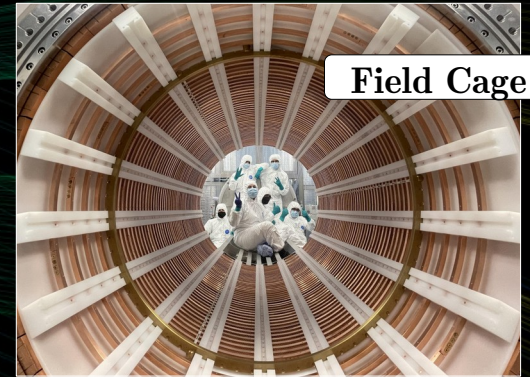
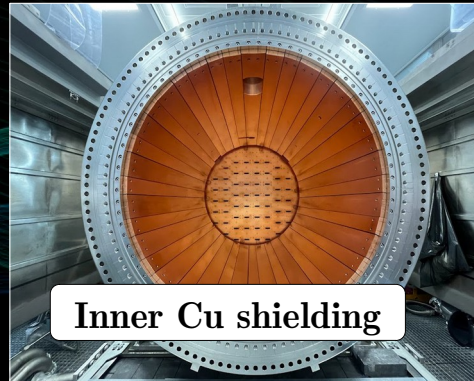
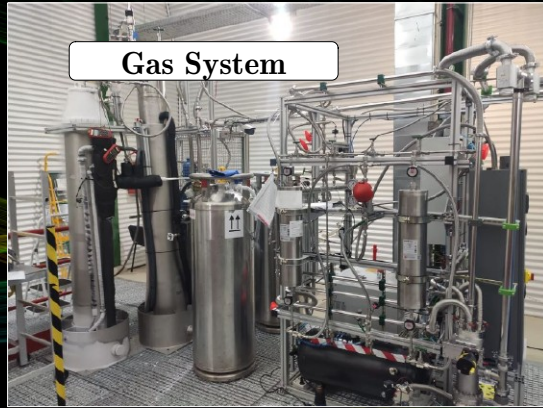
- Detector operating at the LSC since 2024

ArXiv:2505.17848 (accepted in EPJC)

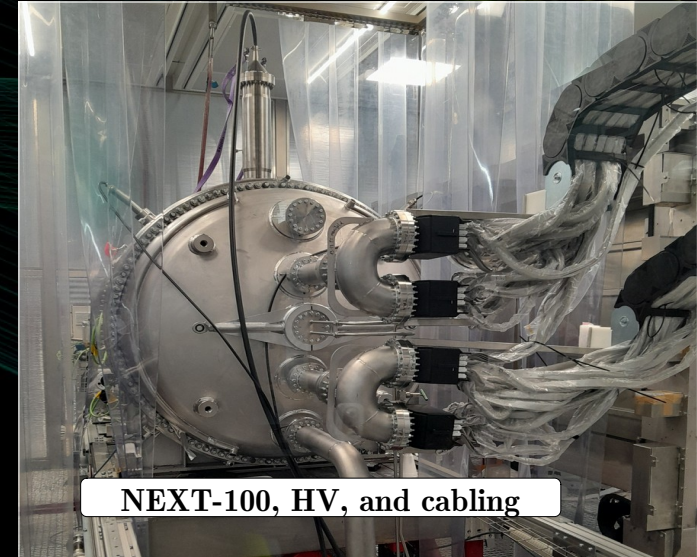
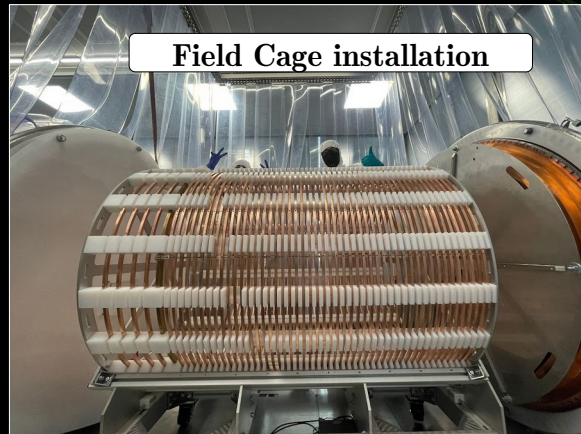
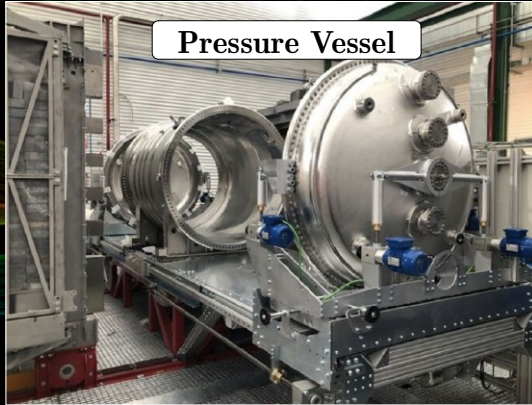
JINST 7 (2012) T06001

JHEP 1605 (2016) 159

NEXT-100 Building Blocks



NEXT-100 Installation @ LSC



- NEXT ready since mid 2024

- 2024-2025: commissioning
- 2025: calibration/background @ 4 bar
- 2026-2030: $\beta\beta 0\nu$ search @ 10 bar

Drift field: 120 V/cm

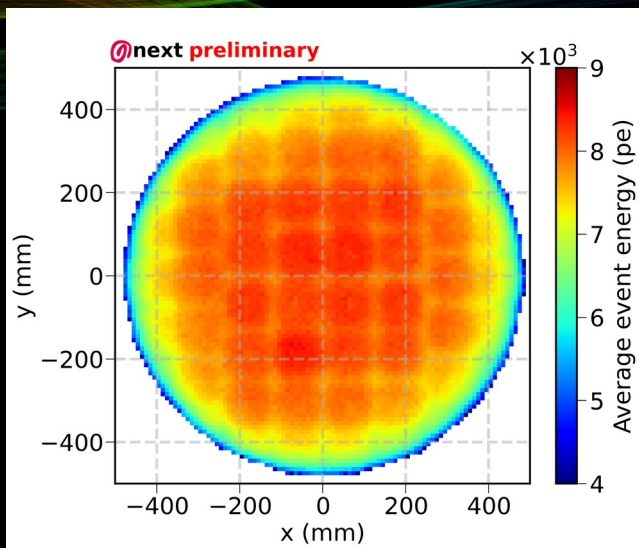
EL field: 0.9 kV/cm

P = 4 bar

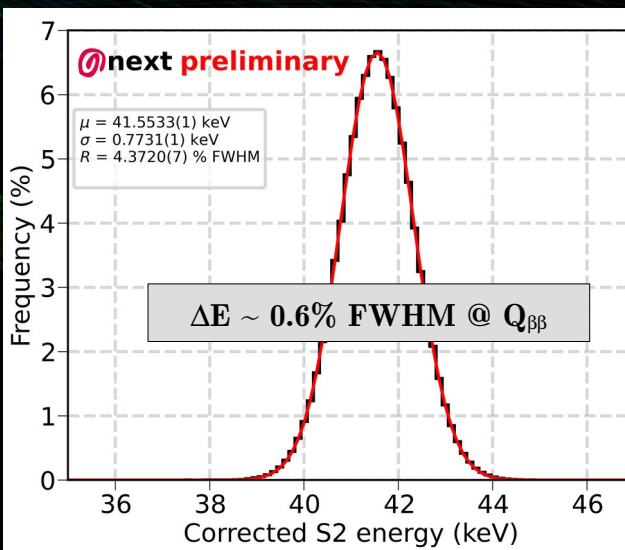
NEXT-100: Kr-83m Calibration

- Introduced through the gas system: 41.5 keV decays in the active volume

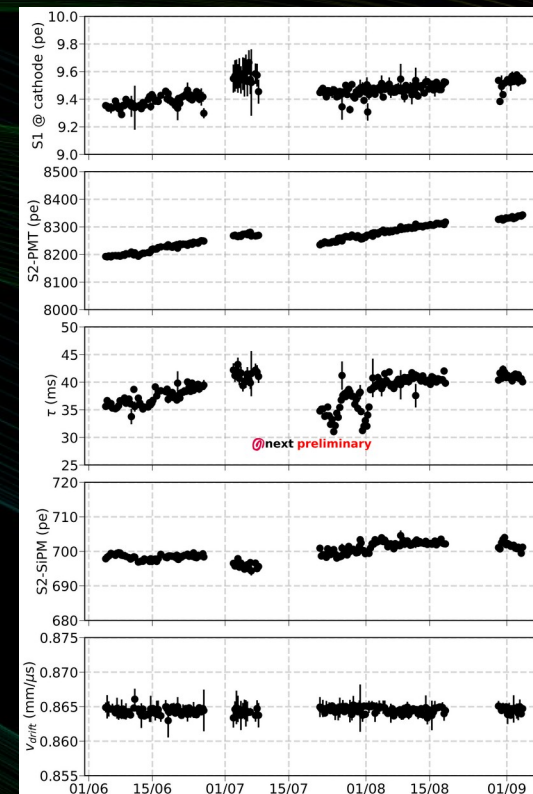
Geometrical
and lifetime corrections



Energy Resolution



Monitoring



- Continuous calibration and monitoring of the detector

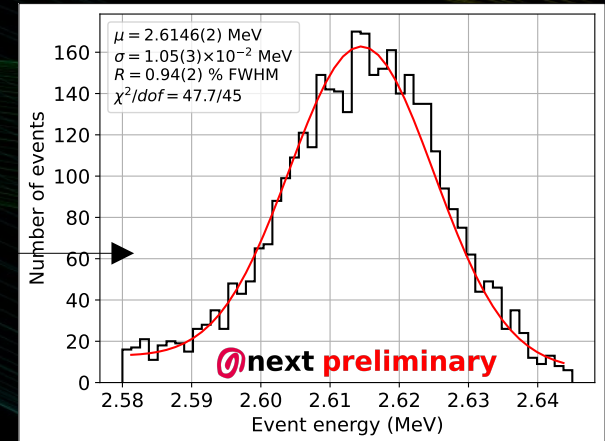
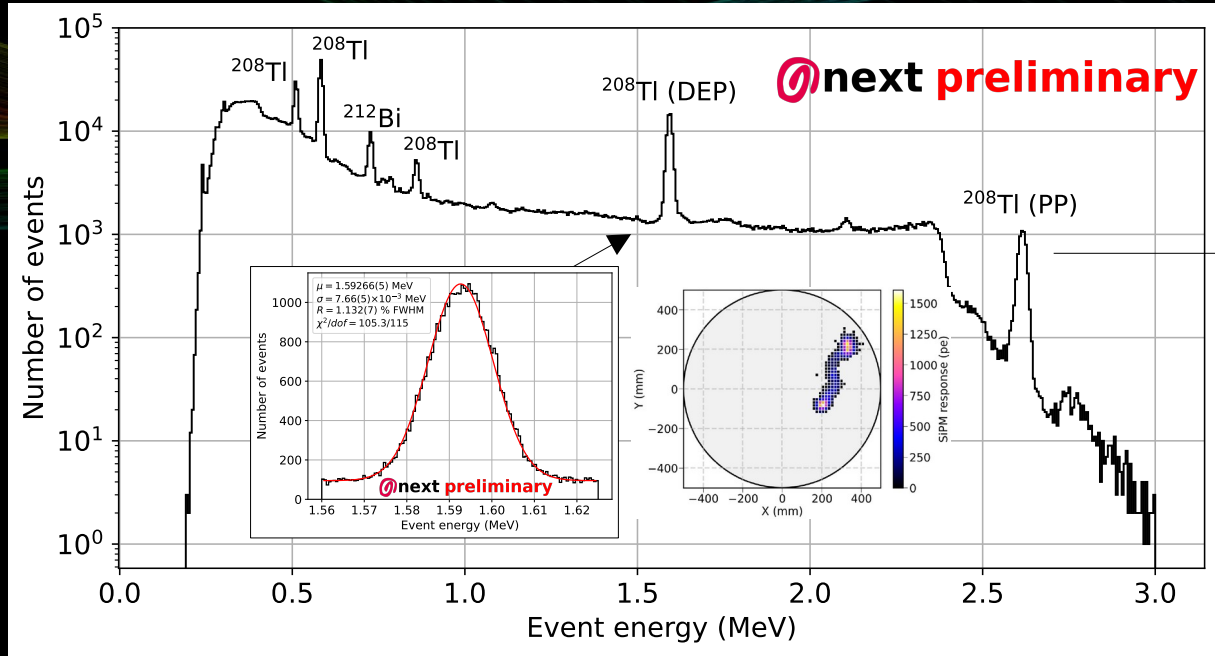
Drift field: 120 V/cm

EL field: 0.9 kV/cm

P = 4 bar

NEXT-100: Th-228 Calibration

- Th-228 calibration source deployed in dedicated port on the pressure vessel:



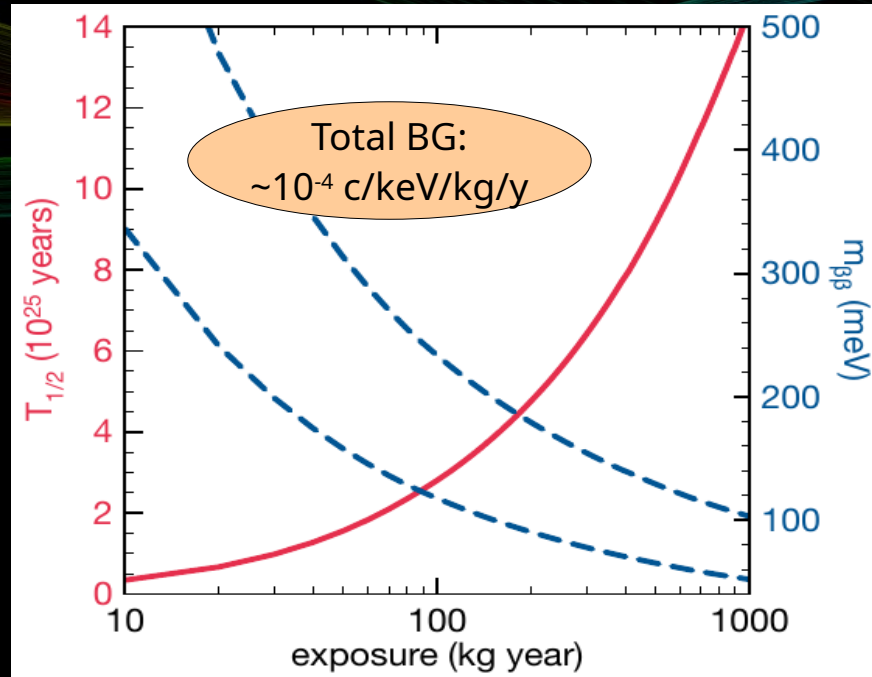
$\Delta E < 1\%$

FWHM @ $\sim Q_{\beta\beta}$

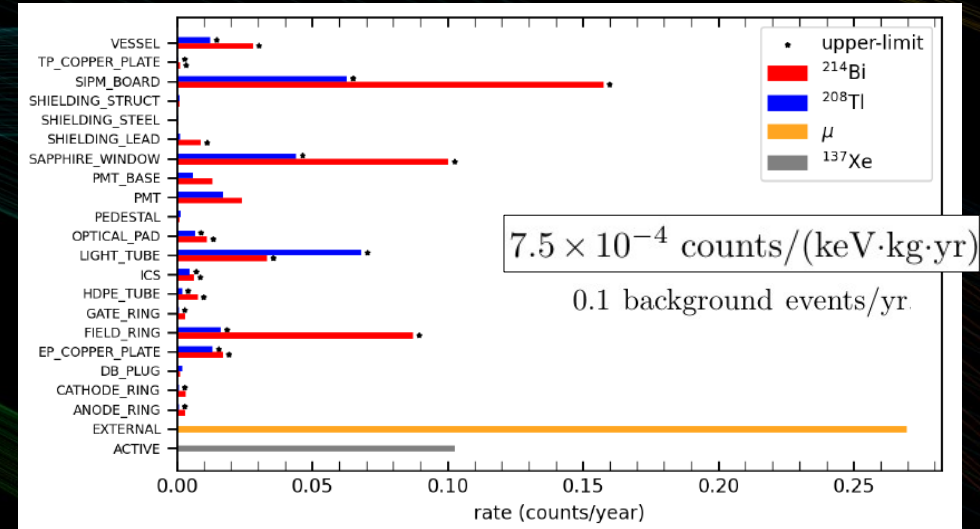
- Analysis of the energy scale and energy resolution versus energy

NEXT-100 Physics Case

- Sensitivity study @ 2016:



- New BG budget estimation: radiopurity screening + MC

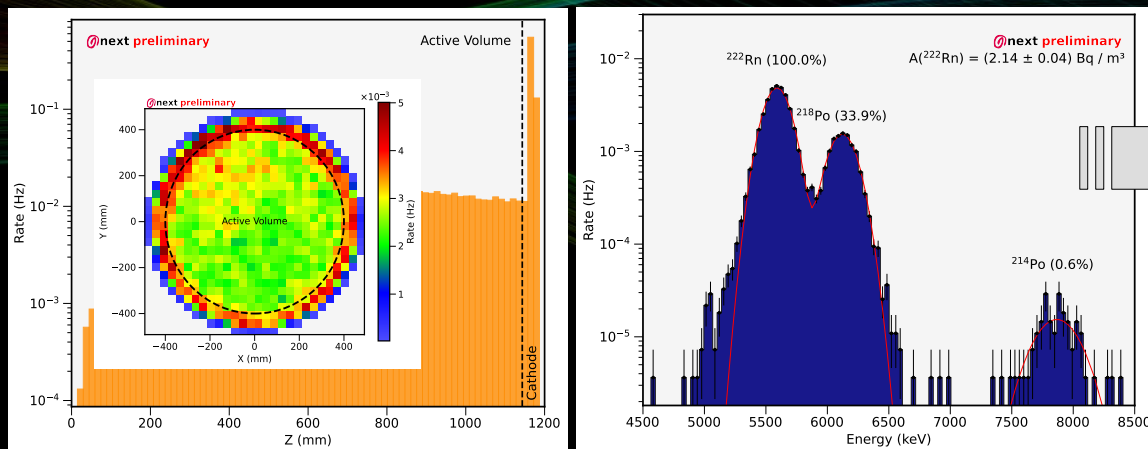
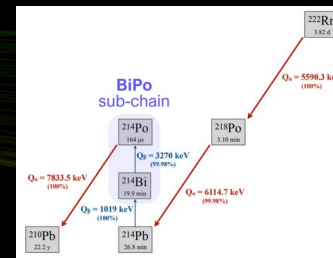


- Sensitivity: 4.1×10^{25} yr at 90% CL (3 years)
- Now measuring directly the BGs in NEXT-100...

NEXT-100: Rn Background (I)

- Measurement of internal Rn-induced background: Bi-214 @ Cathode surface
- Alpha decays from Rn-222 decay chain:

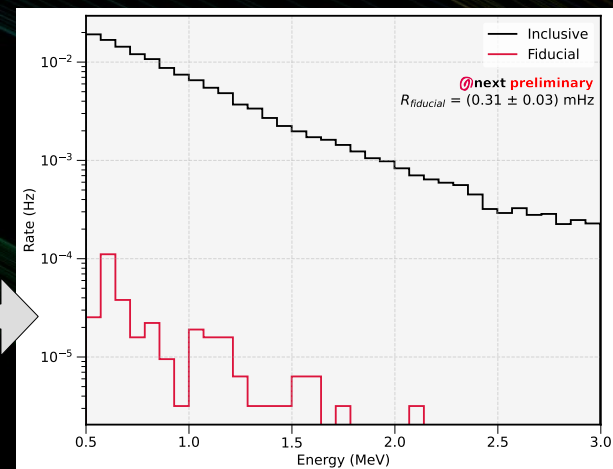
Rn from outgassing @ 4 bar



Activity of Bi-214 @ Cathode

$$A(\text{Bi-214}) = 1.17 \text{ Hz}$$

- $\beta\beta$ Rn-induced background highly suppressed by “fiducialization”
 - Rn-induced fiducial background: $R = 0.31 \text{ mHz}$
 - Not dominant background (less outgassing @ 10 bar!)

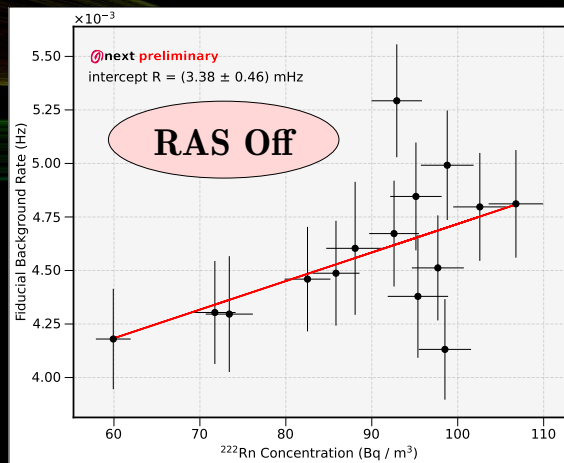


NEXT-100: Rn Background (II)

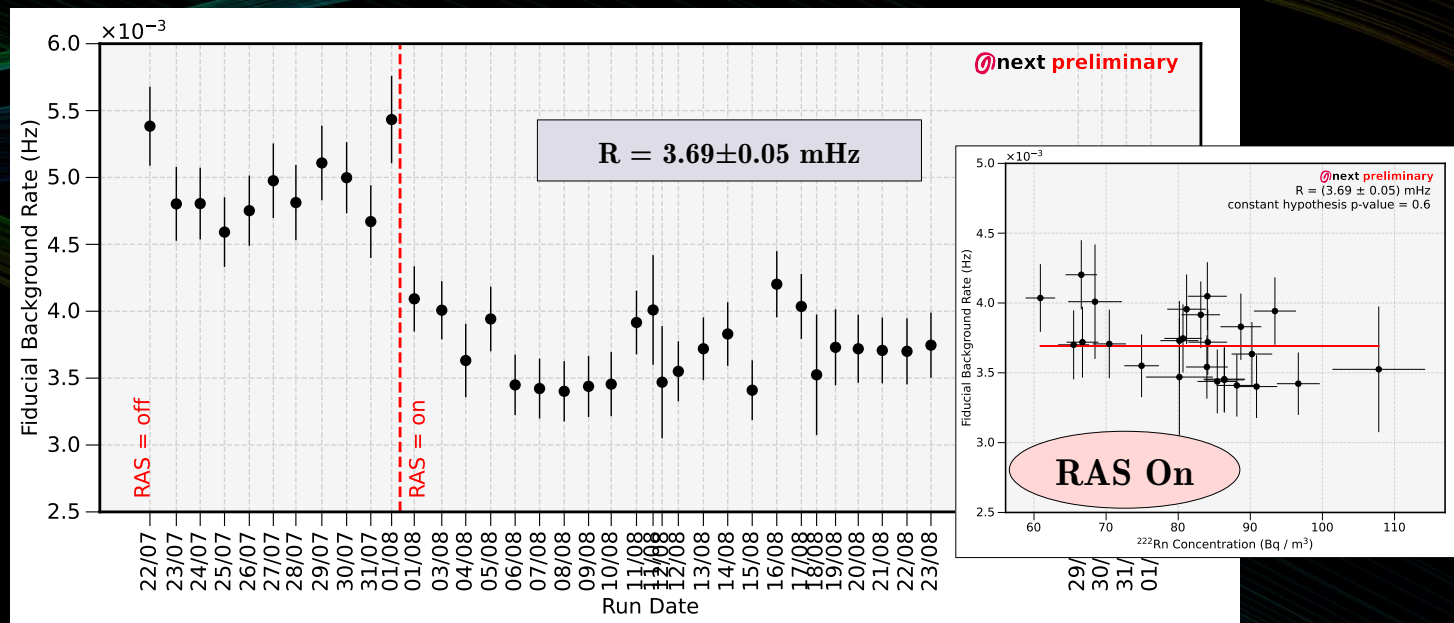
- Radon abatement system (RAS) delivering air within NEXT-100 lead castle

Universe 8 (2022) 2, 112

Airborne Rn @ LSC air



$$R(\text{No-Rn}) = 3.4 \pm 0.5 \text{ mHz}$$

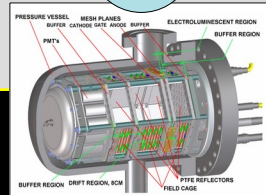
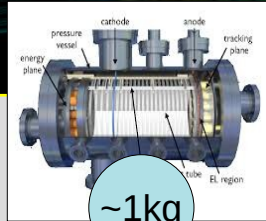


- NEXT-100 operates in a virtually Rn-free environment thanks to RAS @ LSC

The NEXT Project

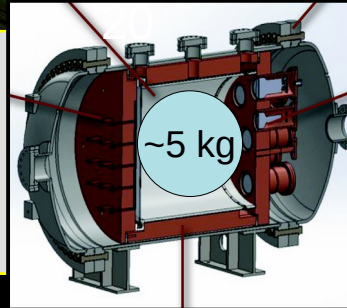
- Search for the $\beta\beta 0\nu$ decay with a HPXe-TPC

R&D
Proof of Concept



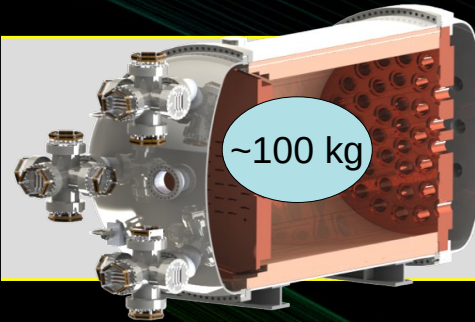
2009-2014

NEXT-White
Background+ $\beta\beta 2\nu$



2015-2021

NEXT-100 (+upgrades)
 $\beta\beta 0\nu$ search



2023-2030

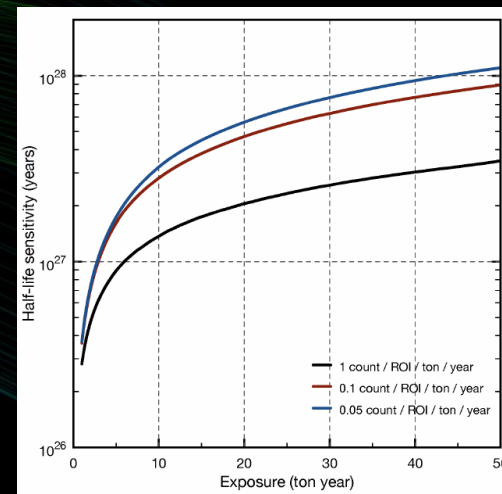
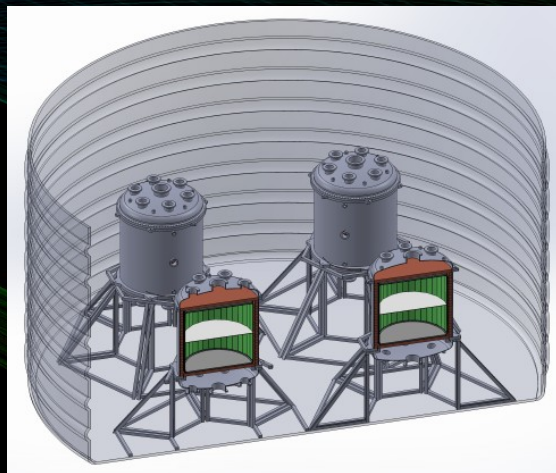
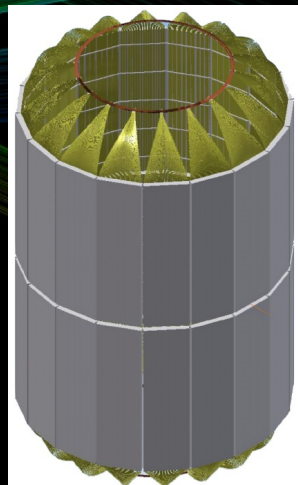
Ton-scale +
 Ba^{++} tagging:
 $\beta\beta 0\nu$ search @ IH

Tonne scale mass

NEXT at the Ton-scale: NEXT-HD

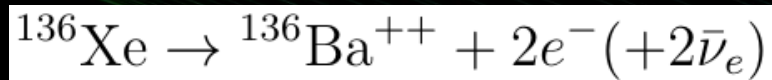
- Next generation of $\beta\beta$ experiments: exposures $>10^3$ kg and BG index < 1 count/ton/yr: $T_{1/2} \sim 10^{27}-10^{28}$ year
- Conceptual design of a NEXT tonne-scale detector: symmetric TPC, dense SiPM array, Barrel fiber detector (S1+S2)

JHEP 2021 (2021) 08, 164

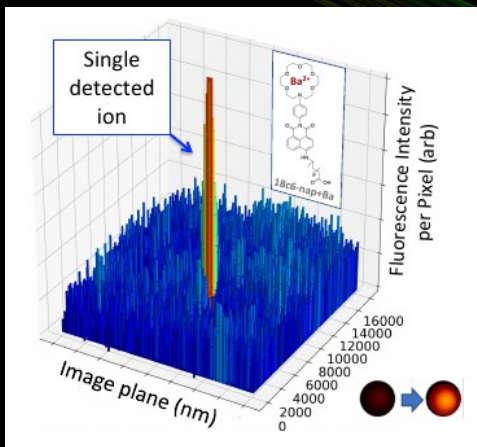


- Gas mixtures: low diffusion (Xe+He4) to improve resolution and H3 (if possible) to mitigate cosmogenic BGs
- First module to be installed at LSC (~ 2030) $\rightarrow$ multi-modular approach: ~ 5 ton

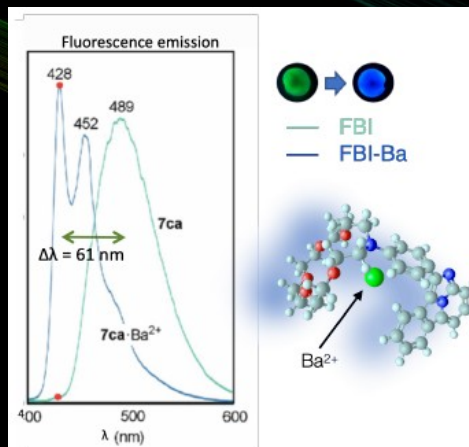
NEXT with Ba-tagging: BOLD



- Efficient ID of $\text{Ba}^{2+} \rightarrow$ BG-free experiment
- R&D on Single Molecule Fluorescent Imaging:

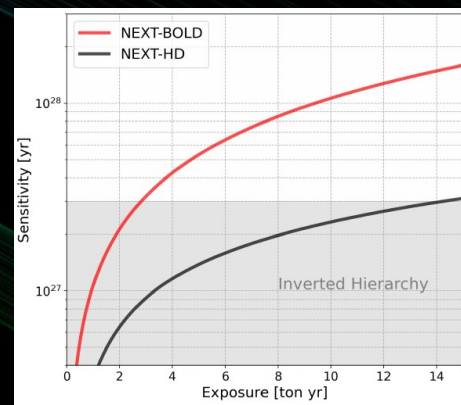
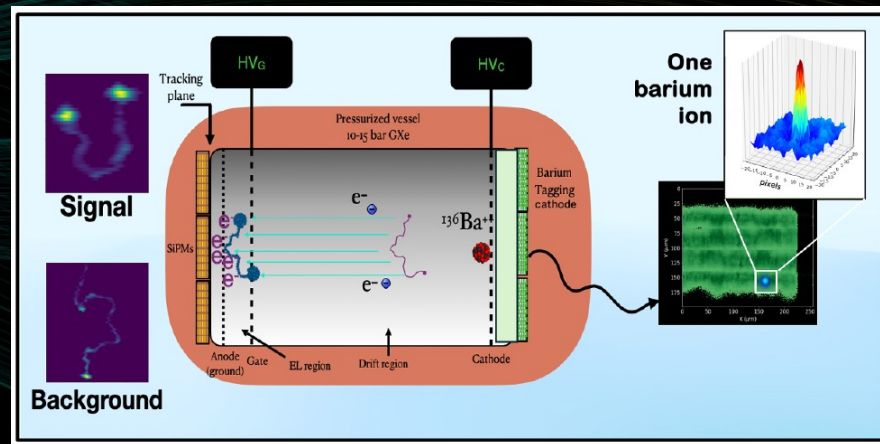


PRL 120 (2018) 132504



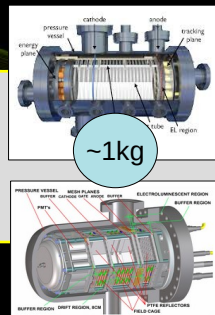
Nature 583 (2020) 7814

Nature Commun. 13 (2022) 1, 7741



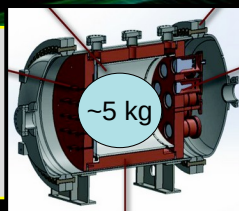
Summary

R&D
Proof of Concept



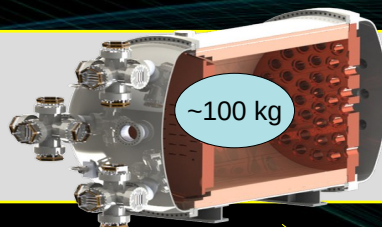
2009-2014

NEXT-White
Background+ $\beta\beta 2\nu$



2015-2021

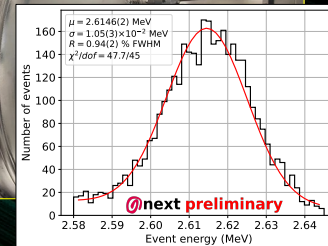
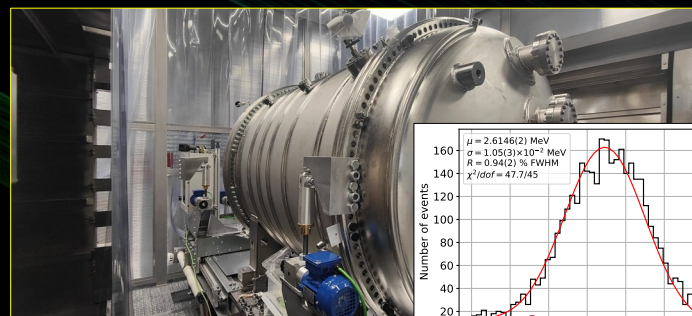
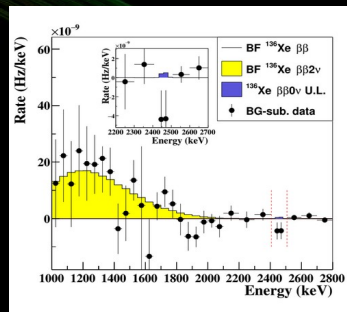
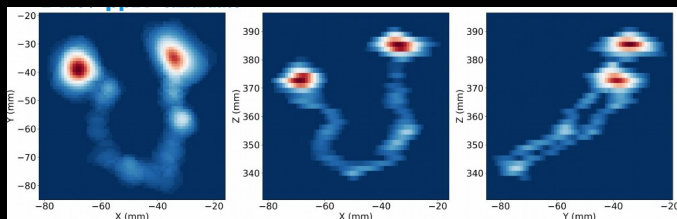
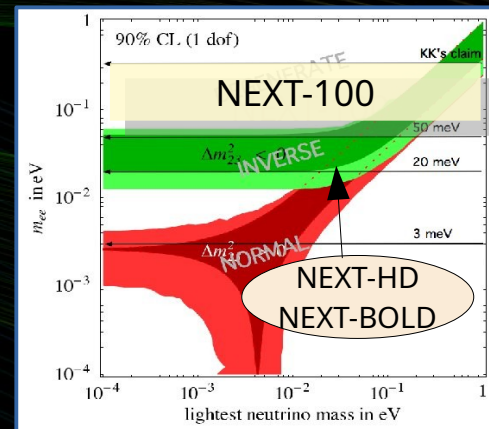
NEXT-100 (+upgrades)
 $\beta\beta 0\nu$ search



2023-2030

Ton-scale +
 Ba^{++} tagging:
 $\beta\beta 0\nu$ search @ IH

Tonne scale mass



NEXT-100 $\beta\beta 0\nu$ search to start in 2026!

[illegible]