NEXT

Measurement of the ^{136}Xe $\beta\beta2\nu$ half-life in NEXT-White

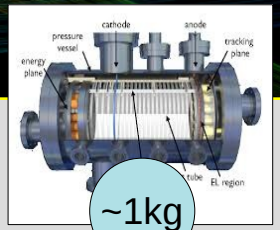
EPS-HEP Conference 2021

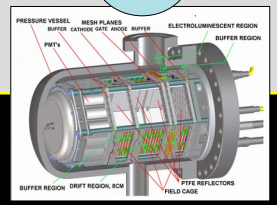
Pau Novella, IFIC (CSIC & U.V.)
On behalf of the NEXT Collaboration

Overview: The NEXT Project

Search for the ββ0ν decay with a HPXe-TPC

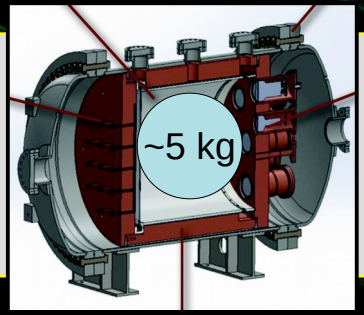
R&D
Proof of Concept





2009-2014

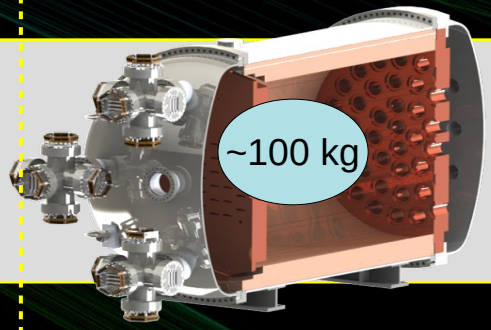
NEXT-White
Background+ββ2ν



2015-2021

This talk

NEXT-100 (+upgrades)
ββ0ν search



2021-2025

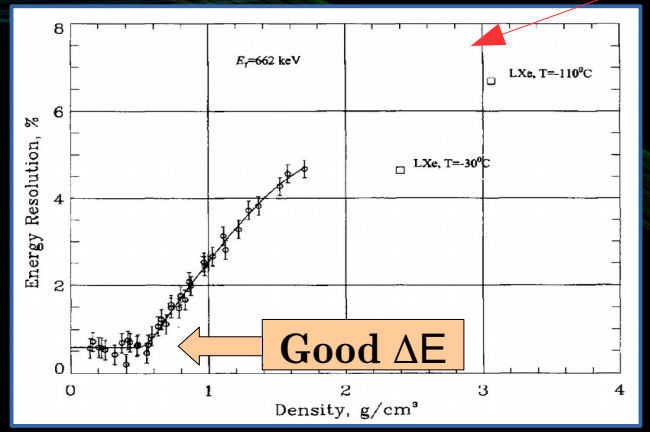
Ton-scale +
Ba^{++} tagging:
ββ0ν search
in the IH land

NEXT: HP Gas-Xe TPC

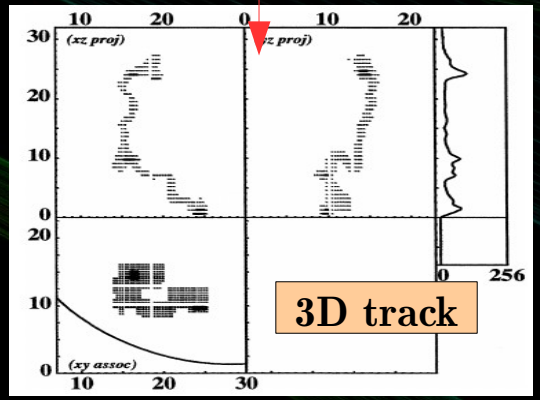
- **Sensitivity to the ββ0ν decay:**

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

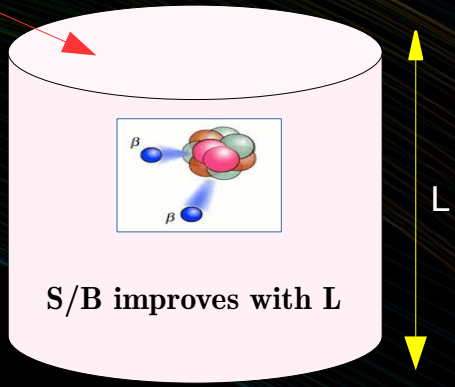
- $Q_{\beta\beta}$=2.48 MeV
- Scint/Ionization
- Cheap/Easy to enrich
- Long ββ2ν mode



Bolotnikov et Al. Nucl. Ins. Meth A 396 (1997)



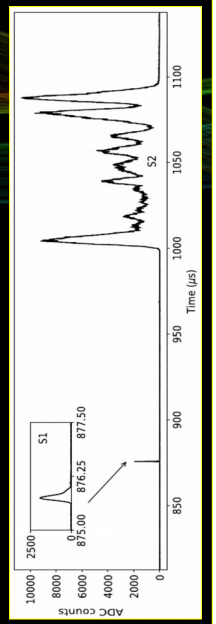
R. Luescher et al, PLB 434 (1998)

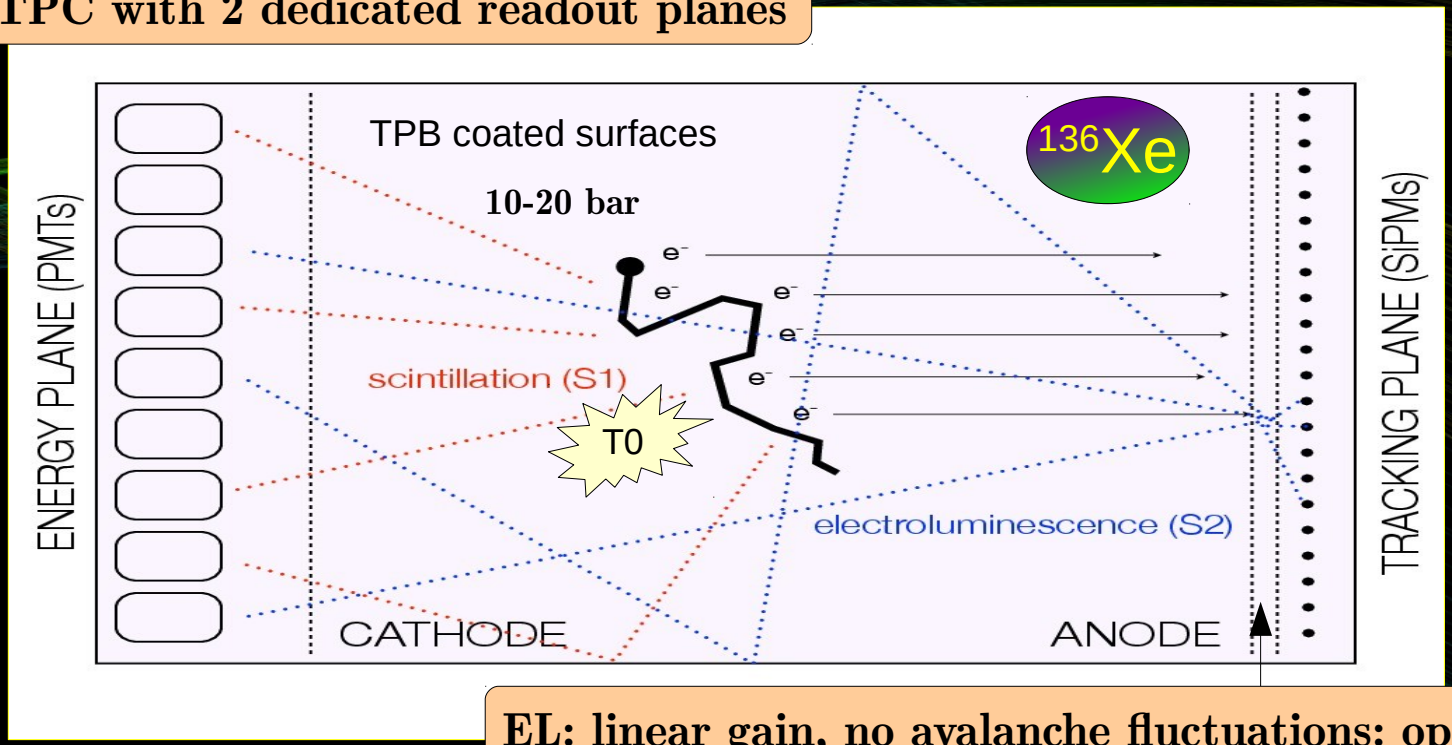


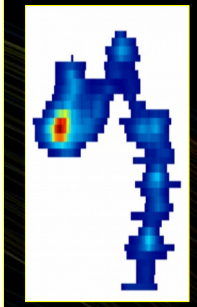
Source=Detector

The NEXT TPC Concept

Gas TPC with 2 dedicated readout planes







EL: linear gain, no avalanche fluctuations: optimize ΔE

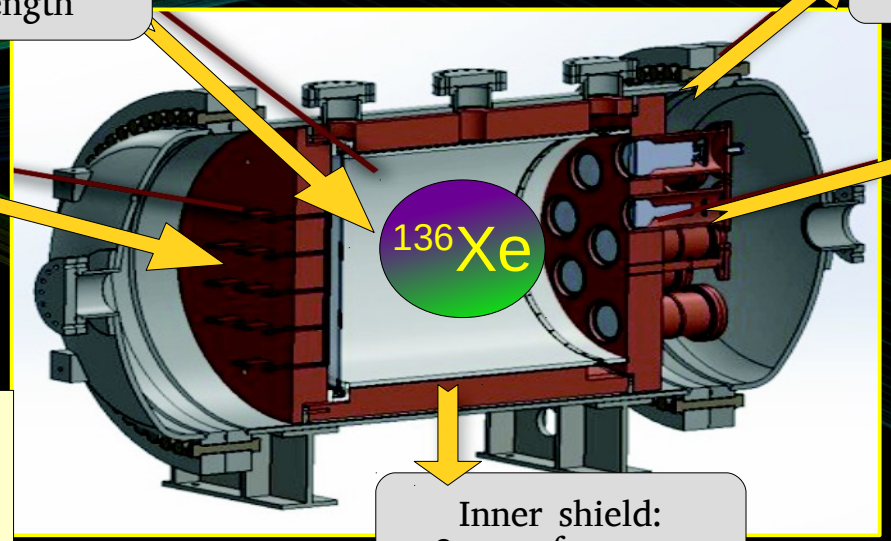
NEXT-White: Physics @ LSC

TPC:
~5 kg active region
50 cm drift length

2015-2019

Pressure Vessel:
Steel, up to 30 bar

Tracking plane:
1792 SiPM
1 cm pitch



Energy Plane:
12 PMTs
30% coverage

Inner shield:
6 cm of copper

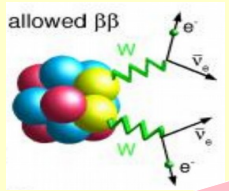
Physics program:

- $\Delta E<1\%$ FWHM @ $Q_{\beta\beta}$
- **Event Topology**
- **Certify technology**
- **BG Measurement (2019)**

Achieved!

First phase of the NEXT-100 experiment

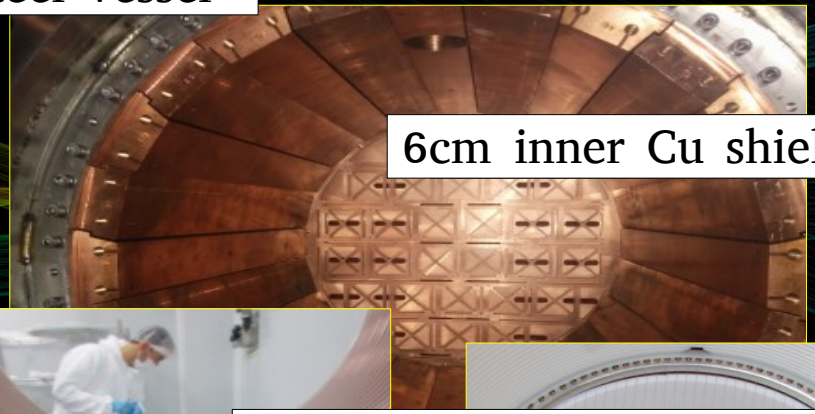
Ultimate goal:



This talk!

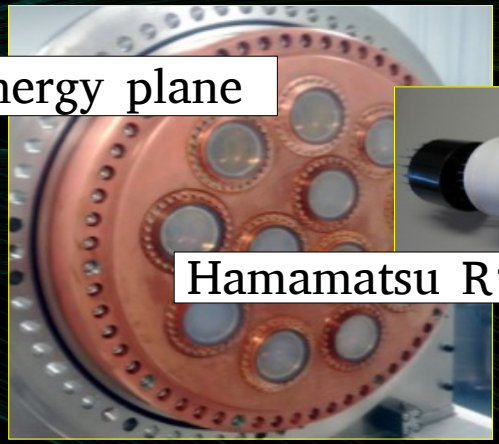
The NEXT-Withe Detector

Steel vessel

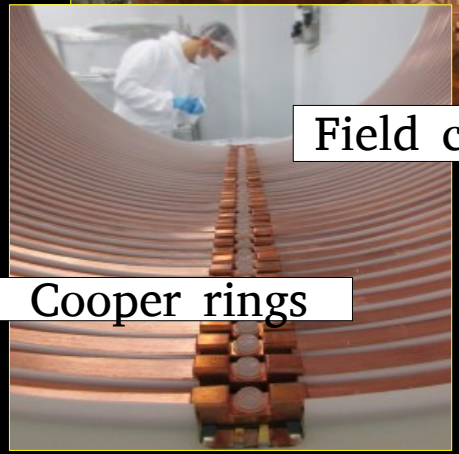


6cm inner Cu shield

Energy plane

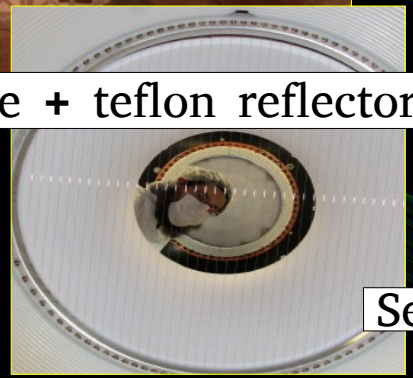


Hamamatsu R11410-10



Cooper rings

Field cage + teflon reflector

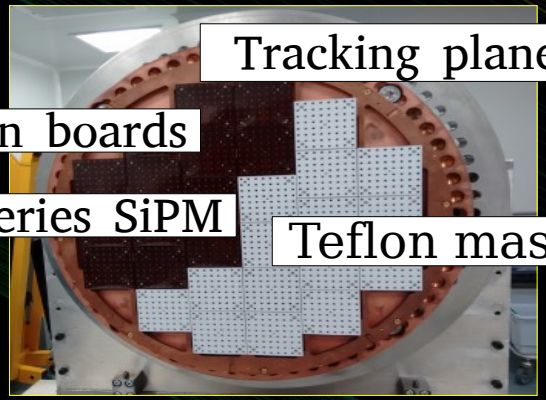


Tracking plane

Kapton boards

SensL C-series SiPM

Teflon masks



JINST 13 (2018) no.12, P12010

NEXT-White @ LSC

- Infrastructures: seismic platform, lead castle, Rn abatement system
- Available xenon: 100 kg of ^{136}Xe and 100 kg of Xe depleted in ^{136}Xe (~5 kg used)
- Installation/commissioning in 2015, stable operation since October 2016

NEW-White Operation

- 2016-2018: Calibration campaigns
  - @ 7/10 bar with ^{136}Xe-depleted gas
  - ^{83}Kr, ^{137}Cs, ^{228}Th (^{22}Na, ^{56}Co)
- 2018-2019: background measurement EPS2019
  - @10 bar with ^{136}Xe-depleted gas (Run-IV)

- 2019-2021: $\beta\beta2\nu$ measurement → ^{136}Xe-enriched (Run-V) + ^{136}Xe-depleted (Run-VI) EPS2021

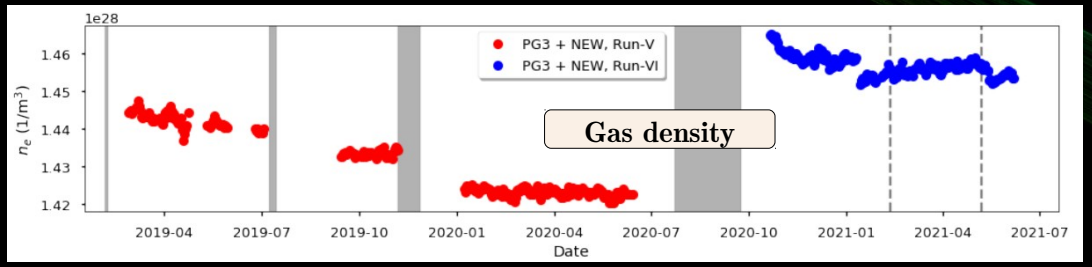
^{136}Xe @ 90.9±0.4% ^{136}Xe @ 2.6±0.2%

NEXT-White Data Taking

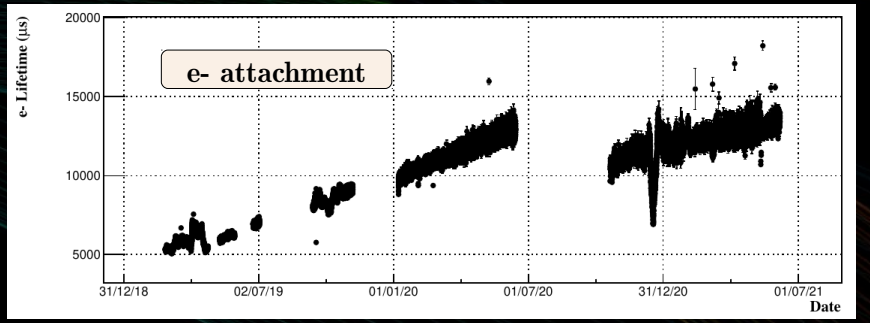
- **Total run-times for $\beta\beta2\nu$ analysis: 271.6 day (Run-V) and 208.9 day (Run-VI)**

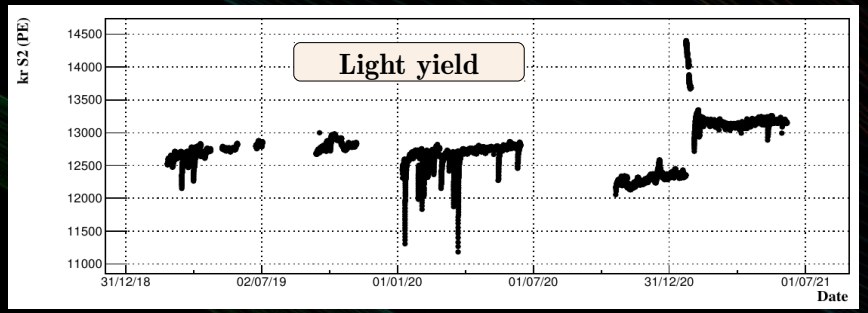
Run period	Start Date	Run time (day)	Triggers
Run-Va	25-02-2019	75.8	617,896
Run-Vb	13-09-2019	47.1	412,902
Run-Vc	08-01-2020	148.7	1,117,101
Run-V	25-02-2019	271.6	2,147,899
Run-VI	20-10-2020	208.9	1,646,501

- **Slow-controls used to monitor detector stability:**



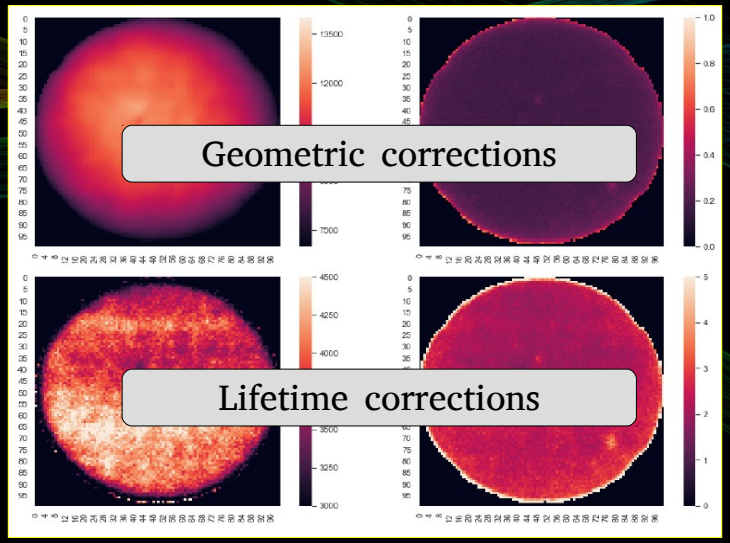
- **^{83m}Kr used to monitor detector performance:**





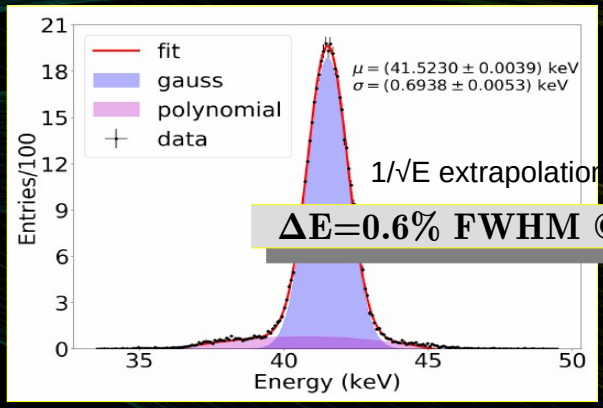
NEXT-White Calibration: ^{83m}Kr

- Point like source (41.5 keV) uniformly distributed in active volume (gas)
- **Calibration XY maps:**

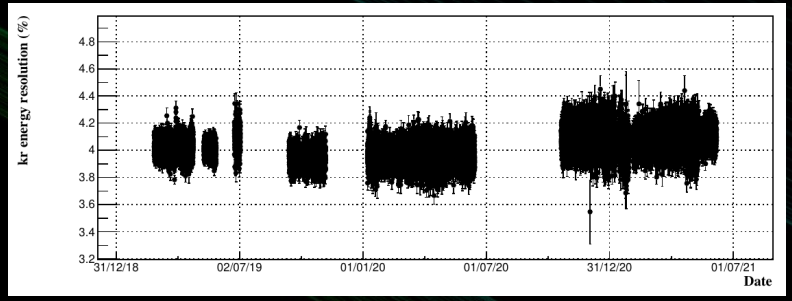


- Detector *continuously* monitored and calibrated:
  - e- attachment and light yield
- **JINST 13 (2018) no.10, P10014 (7bar)**

- **Energy resolution:**

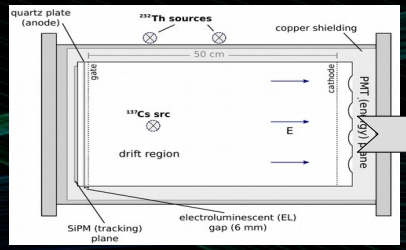


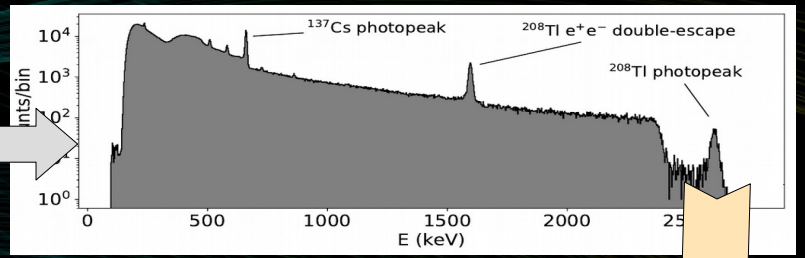
- **Monitoring of energy resolution evolution in time:**



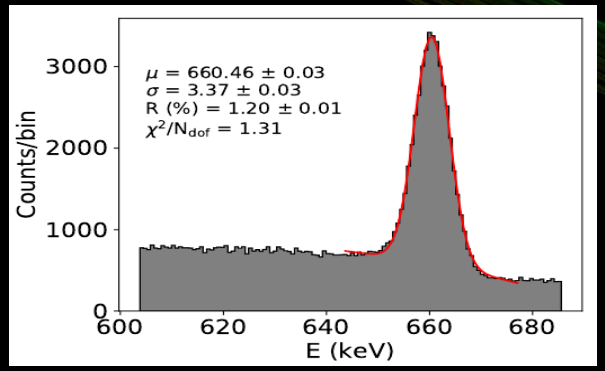
NEXT-White Calibration: $^{208}Tl/^{137}Cs$

- $^{232}Th/^{137}Cs$ gamma-ray interactions from external sources
  - Energy scale
  - Energy resolution vs E
  - Energy resolution @ $Q_{\beta\beta}$

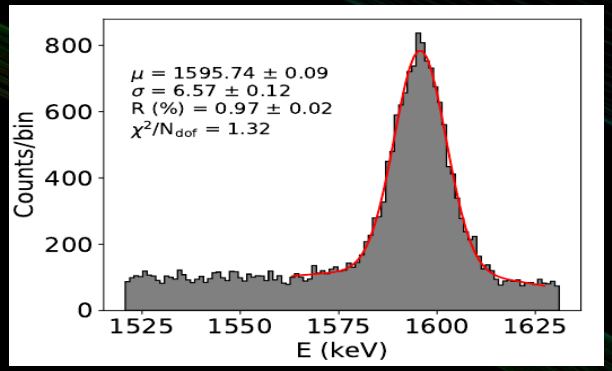


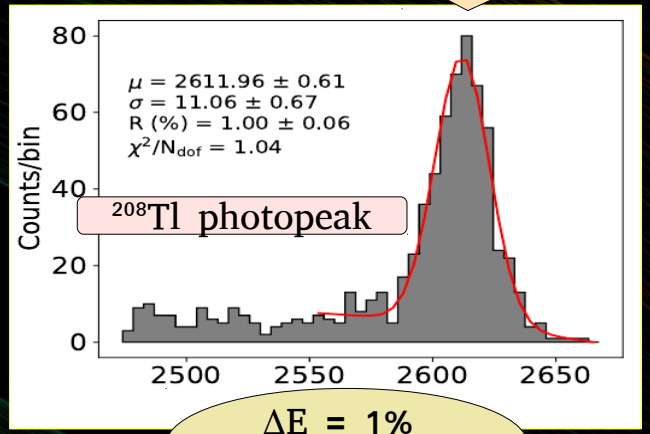


^{137}Cs photopeak



^{208}Tl double-escape





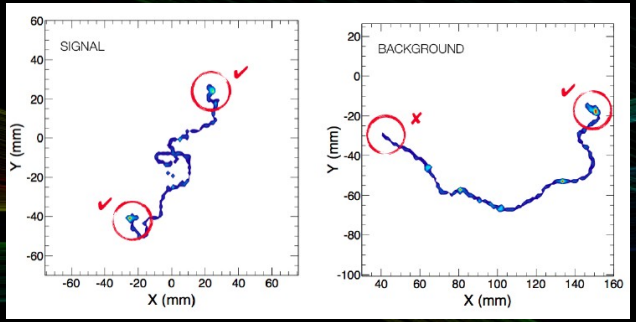
ΔE = 1% FHWM @~$Q_{\beta\beta}$

- JHEP 10 (2019) 230
- JINST 13 (2018) no.10, P10020

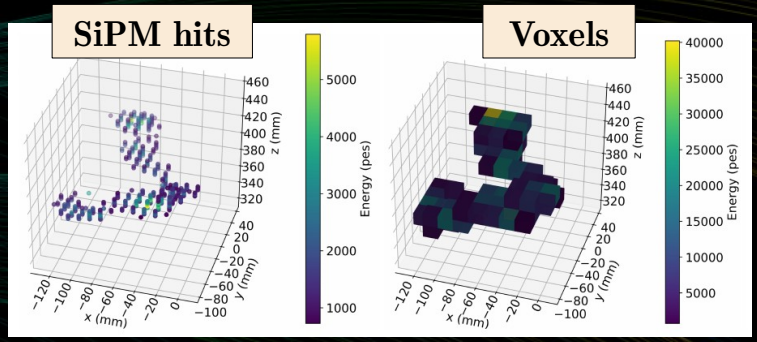
Best energy resolution in Xe!

NEXT-White Topological Signature

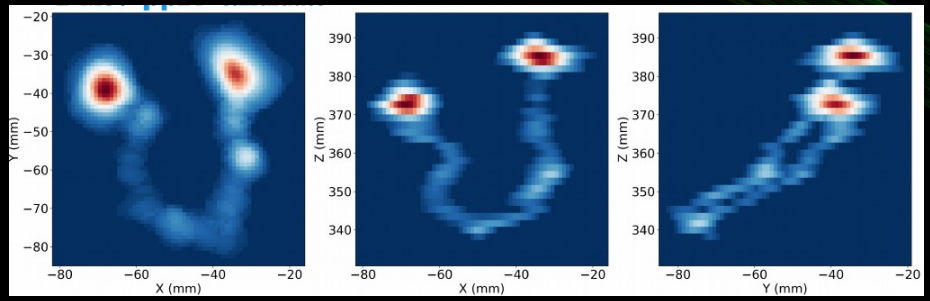
- Signal vs Background rejection:



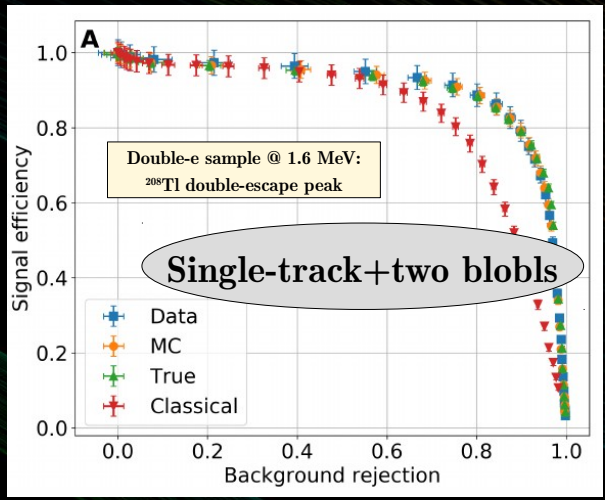
- Simple track reconstruction:
  - Coarse image: SiPM pitch, diffusion, light spread, ...



- Richardson-Lucy deconvolution: reduce image smearing
  - ββ event candidate @ 2.0 MeV:



- Selection efficiency:
  - Sig. eff: 56.6%
    BG accept: 3.7%

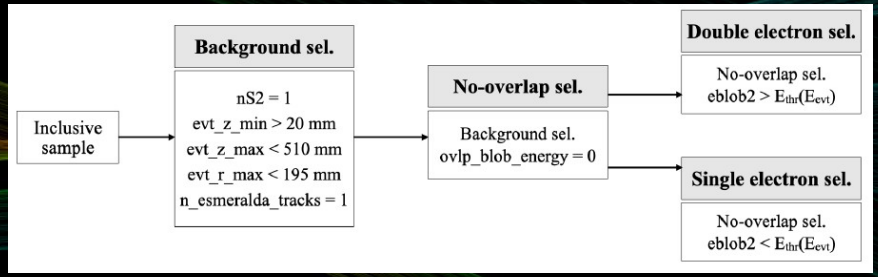


arXiv:2102.11931

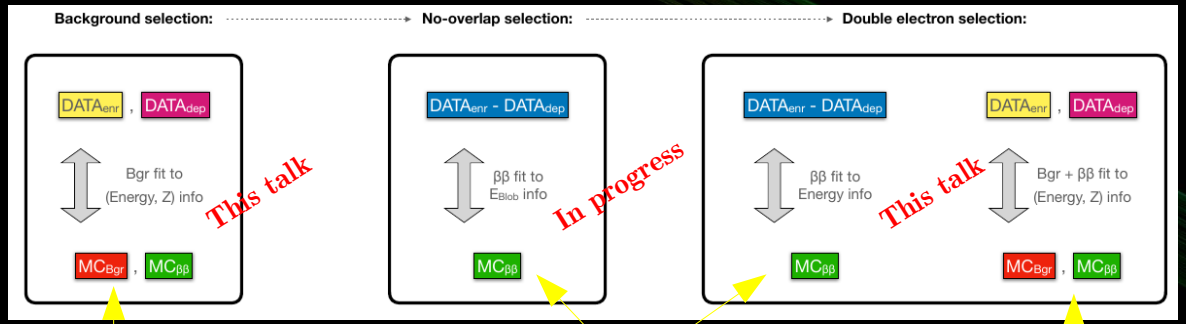
DNNs: JINST 12 (2017) no.01, T01004
CNNs: JHEP 01 (2021) 189
SiPM: JHEP 10 (2019) 052

ββ2ν: Event Selection & Analysis Approaches

- Selections applied for different approaches and checks:



- Background and ββ2ν fit approaches:

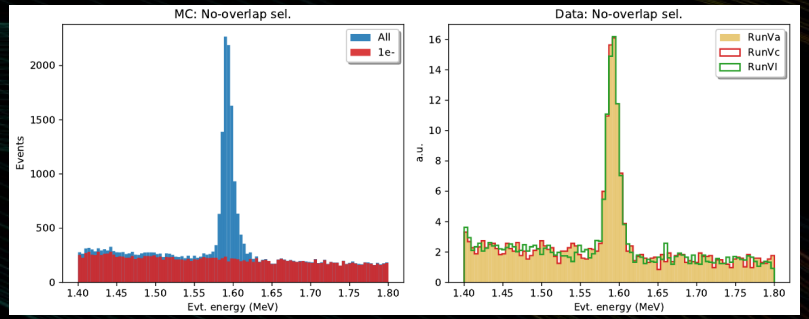


BG stability

BG-model-independent ββ fits

BG-model-dependent ββ fit

- Efficiencies from Tl-208 calibration data
- double-e vs single-e efficiencies from events @ 1.6 MeV:



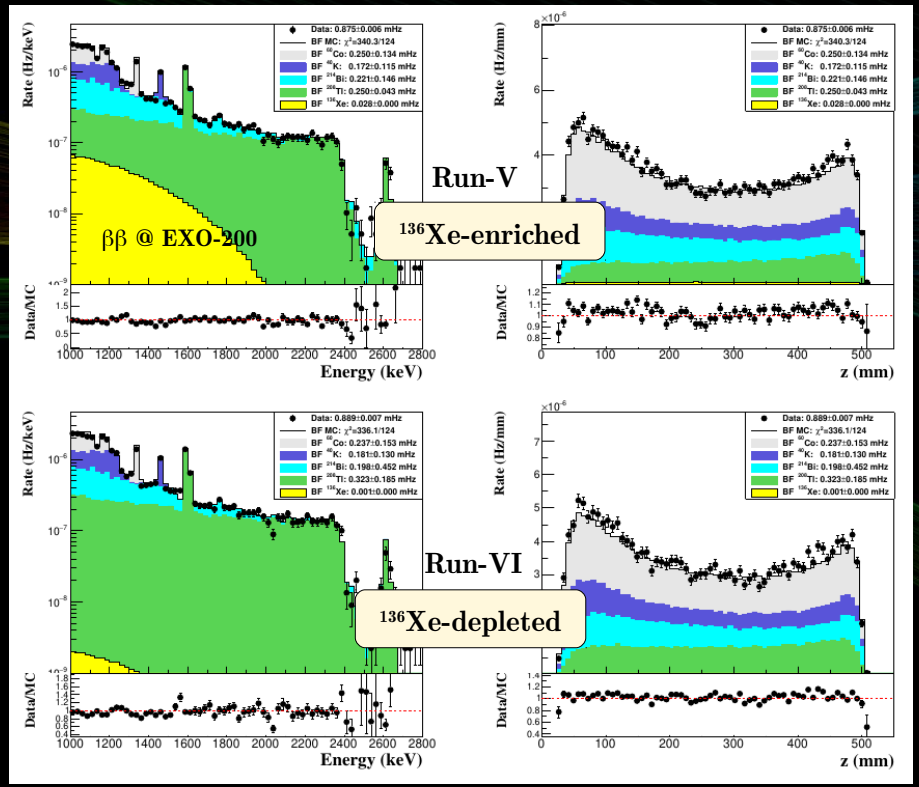
- Unique capabilities of NEXT:
  - Topology-based BG rejection
  - Background subtraction
    - ~BG-model-independent result

Systematic Uncertainties

NEXT-White preliminary

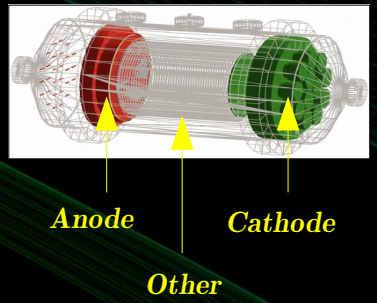
Type	Source	Run-V	Run-VI	Correlated?
Norm.	DAQ livetime	0.01%	0.01%	No
	Trigger efficiency	0.2%	0.2%	Yes
	Gas density	-	0.6%	No
	ββ selection	2.6/7.3%	2.8/7.3%	No
	^{136}Xe fraction	0.4%	0.2%	No
	Xe atoms	0.2%	0.2%	Yes
Energy	Energy scale	0.25%	0.25%	Yes

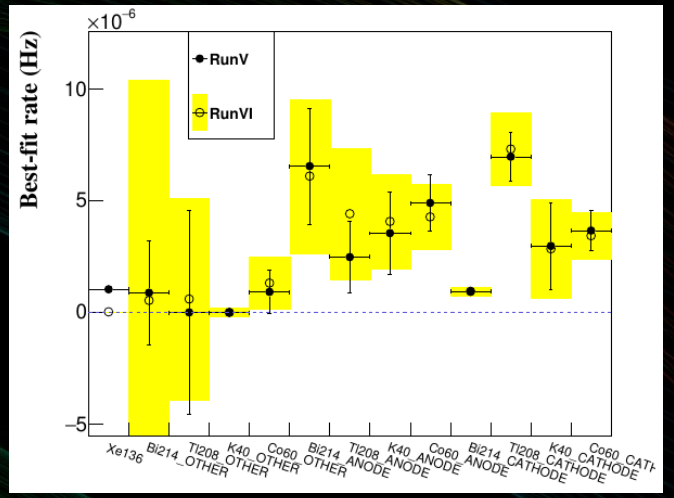
ββ2ν: Radiogenic Background



Update w.r.t. JHEP 10 (2019) 051

- BG model based on extensive radio-purity campaign
  - JINST 8 (2013) T01002, JINST 10 (2015) 05, P05006)
  - Four isotopes (^{214}Bi, ^{208}Tl, ^{60}Co, ^{40}K) and 84 sources
- Fiducial radiogenic background fit:
  - R+S(E+Z), 4 isotopes from 3 effective volumes

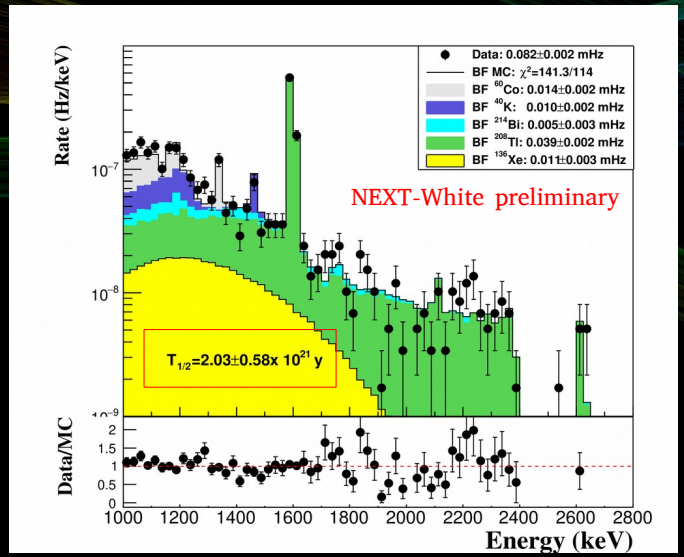


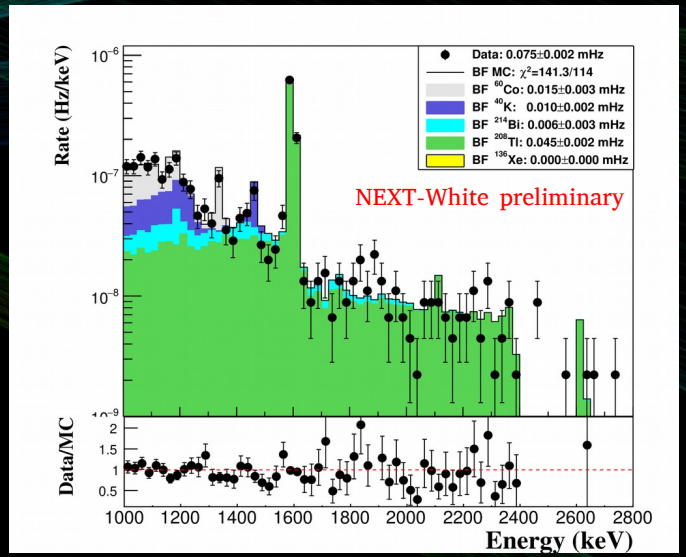


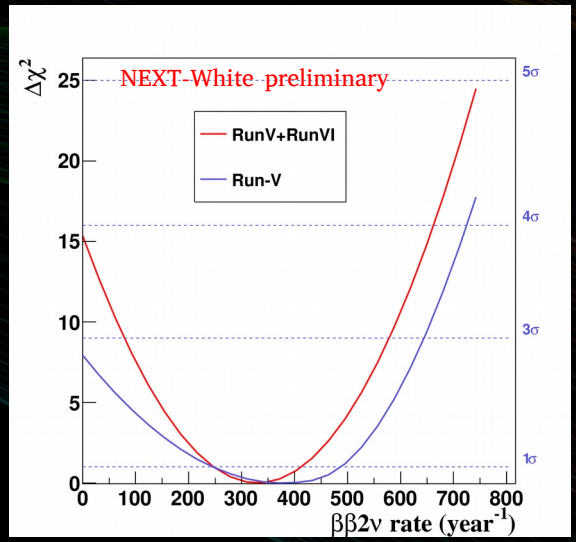
- 12 BG sources measured to be stable in time

ββ2ν: BG-model-dependent Fit

- Joint fit of the ^{136}Xe-enriched and the ^{136}Xe-depleted samples
- Rate of ββ events extracted along with total radiogenic background rates



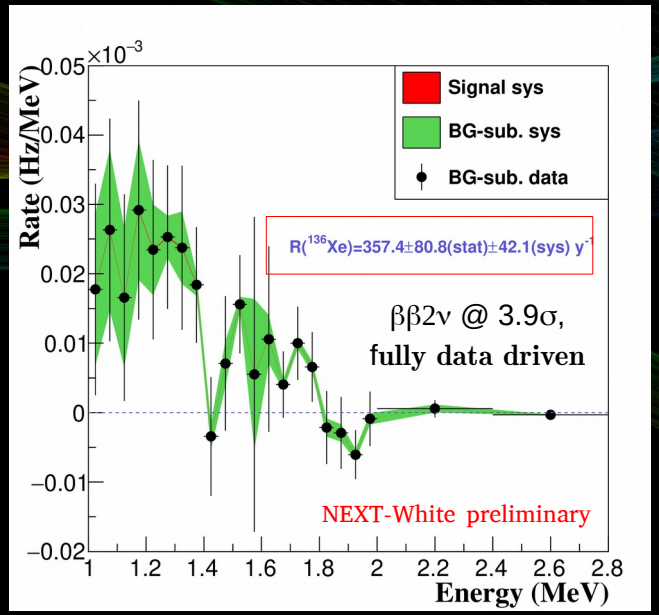


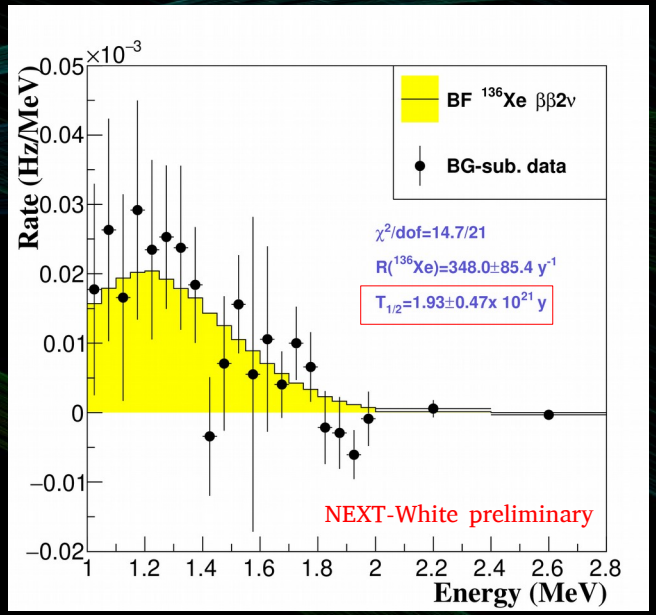


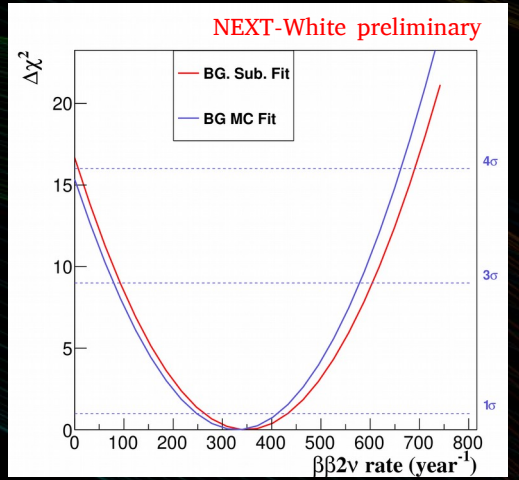
- The ^{136}Xe-depleted sample improves the precision by constraining the backgrounds
- 3.9σ measurement (4σ expected), but poor goodness of fit: $\chi^2/\text{dof} = 142/114$, p-value = 4.2%

ββ2ν: BG-Subtraction Fit

- Backround-subtracted ββ spectra: ^{136}Xe-enriched - ^{136}Xe-depleted (unique in NEXT!):







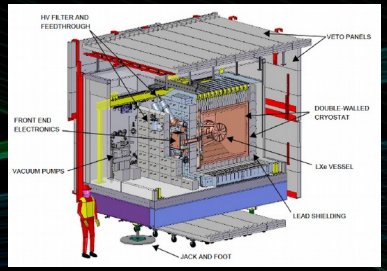
- Fit to the ββ2ν expectation (BG-model independent!): $T_{1/2}$ measured @ 4.1 sigma (3.8σ expected)
- Fully consistent with BG-model-dependent fit, but excellent goodness of fit: χ^2/dof=14.6/21

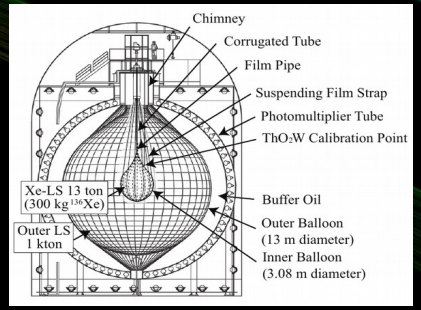
^{136}Xe ββ2ν Measurements

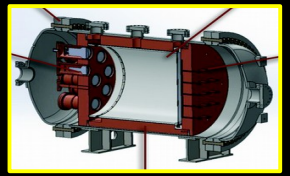
EXO-200
^{136}Xe ~142 kg

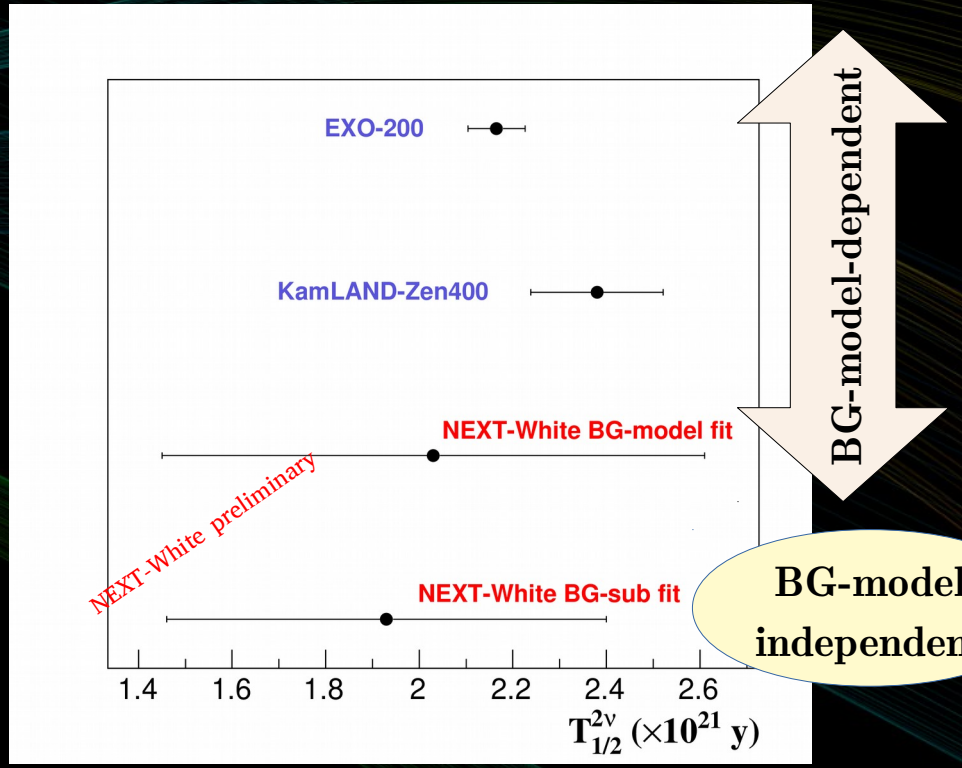
KamLAND-Zen400
^{136}Xe ~129 kg

NEXT-White
^{136}Xe ~3.9 kg







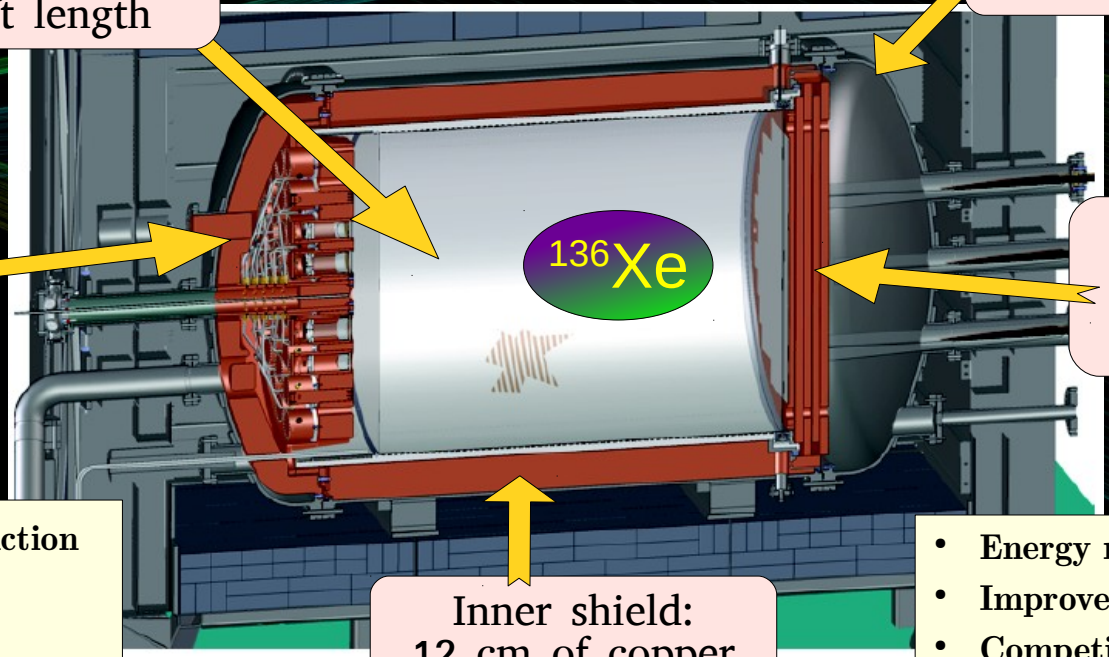


The NEXT-100 Detector

JINST 7 (2012) T06001

TPC:
100 kg active region
130 cm drift length

Pressure Vessel:
Steel, up to 15 bar



Energy Plane:
60 PMTs
30% coverage

Tracking plane:
4000-7000 SiPM
1.0-1.5 cm pitch

Inner shield:
12 cm of copper

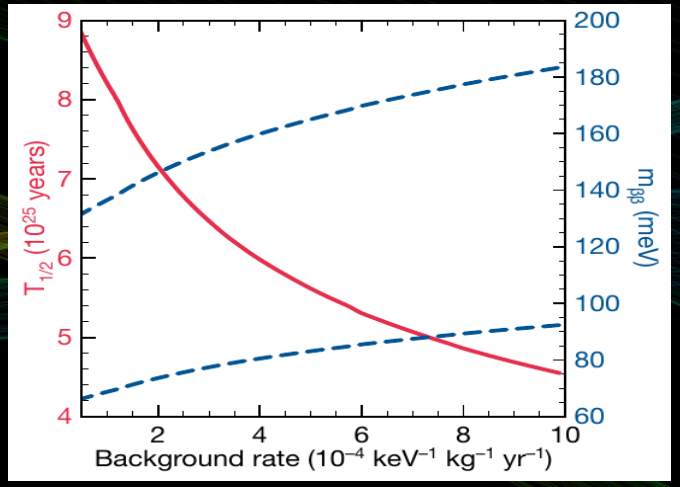
Timeline:

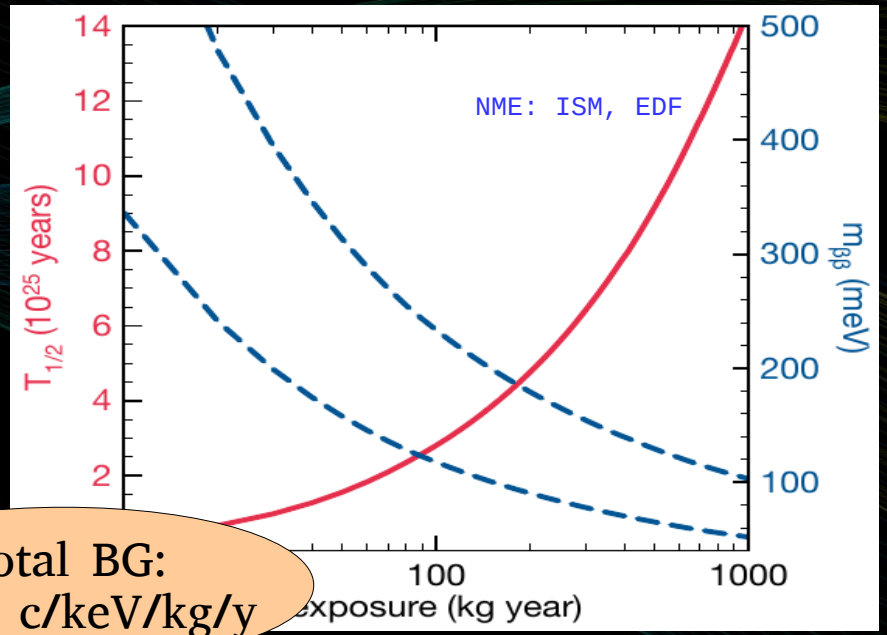
- 2021-2022: construction
- 2022-2025: Physics
- >2025: upgrades

Goals:

- Energy resolution <1% FWHM
- Improve radioactive budget
- Competitive Search of $\beta\beta0\nu$
- Prepare the ton-scale...

Physics Case of NEXT-100





Sensitivity: JHEP 1605 (2016) 159

Background model

Background rejection

Total BG: 5×10^{-4} c/keV/kg/y

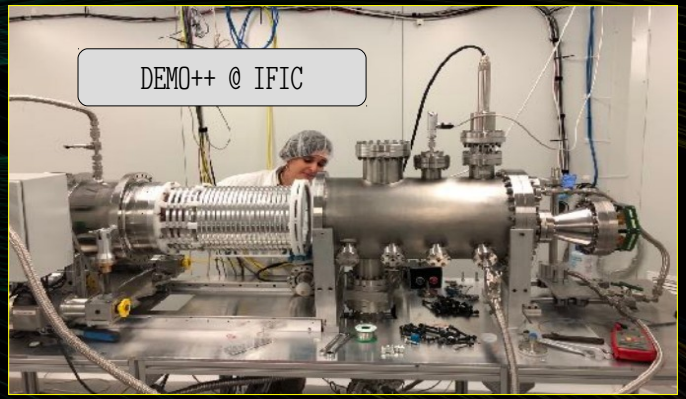
~validated with NEXT-White!

$m_{\beta\beta}$ < 70-130 meV @ 90% CL (5 years of data)

- **Prove technology for ton-scale (+ gas additives, Ba tagging...)**

NEXT @ Ton-Scale: R&D

- Goal: explore the IH region with a HPXe-TPC
- *Incremental approach* towards a ton-scale detector

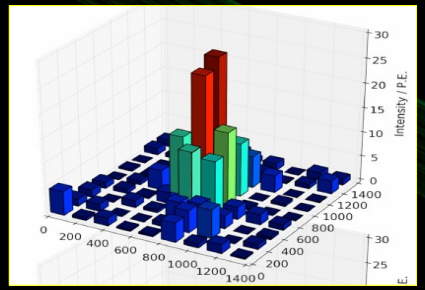


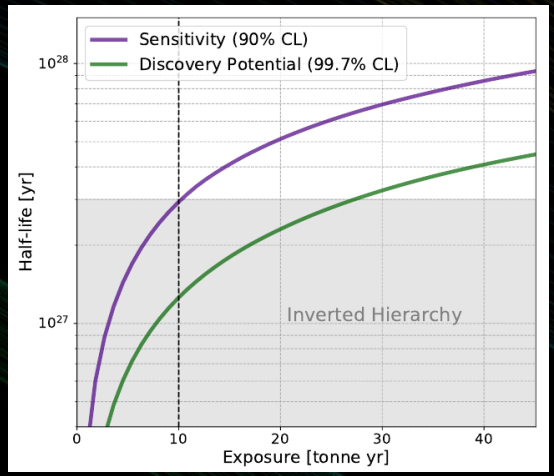
NEXT-HD

- SiPM instead of PMTs (main background source)
- Operation at low temperatures (reduce dark noise)
- Low diffusion gas mixtures (topological signature)
- WLS fibers for S1+S2 measurement
- R&D: DEMO++ and AXOLOTEL
- arXiv:1906.01743, arXiv:2005.06467

NEXT-BOLD

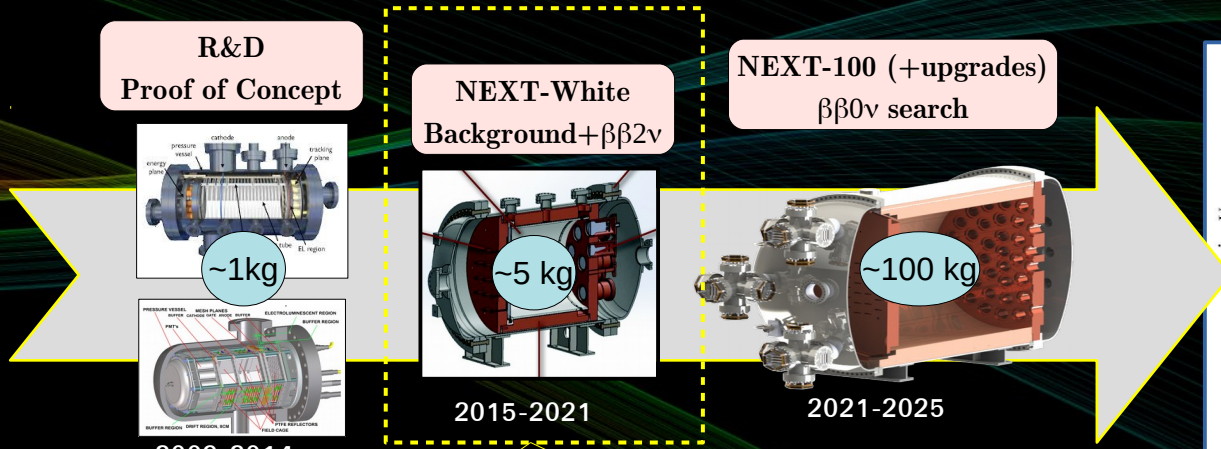
- Ba++ tagging using SMFI
- PRL 120 (2018) 132504
- Nature 583, 48-54 (2020)

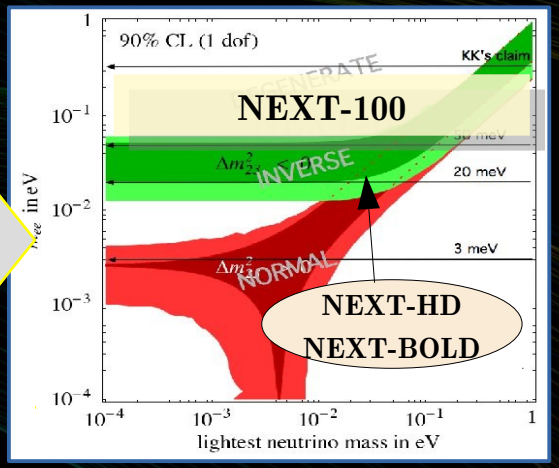




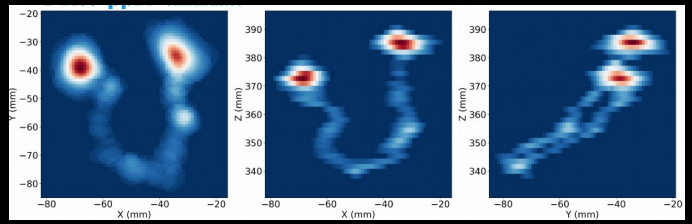
Summary

- NEW-White physics program concluded: **unique** capabilities of the HP-Xe TPC technology in the ββ0ν search

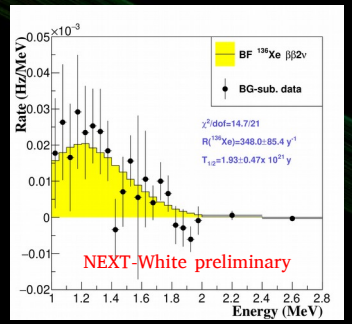




ββ event candidate



ββ2ν bg-subtracted fit



- Energy resolution < 1% FWHM
- Topology-based BG rejection
- BG-model-independent ββ searches:
  - ββ2ν $T_{1/2} = (1.93 \pm 047) \times 10^{21}$ y

The NEXT Collaboration

LSC
Laboratorio Subterráneo de Canfranc

Ikerbasque · DIPC · Girona · UAM · IFIC · Santiago · UPV · Zaragoza

Iowa State · ANL · UTA · FNAL · LBNL · Harvard · Texas A&M · PNNL

Aveiro · Coimbra LIBPhys · Coimbra LIP · A. Nariño · BGU

Spokespersons: J.J. Gomez-Cadenas (Spain), D. Nygren (USA)

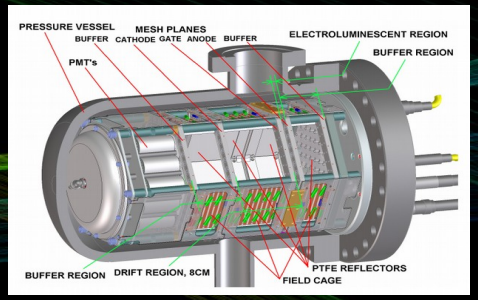
Funded by: erc · MARIE CURIE ACTIONS · GOBIERNO DE ESPAÑA · MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD · GENERALITAT VALENCIANA · FCT Fundação para a Ciência e a Tecnologia · U.S. DEPARTMENT OF ENERGY · UNIVERSITY OF TEXAS ARLINGTON

Back Up

R&D: Proving the technology

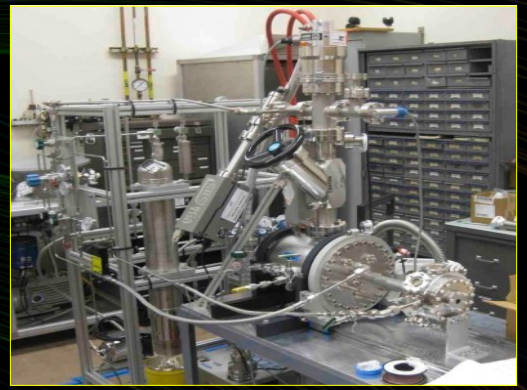
2012-2014

- **The NEXT-DBDM @ LBL (1 kg Xe):**



Gas Xe EL-TPC:
Energy resolution (only PMTs)

"*Intrinsic*" ΔE: 0.5% @ Q_{bb}



- **The NEXT-DEMO @ IFIC (1.5 kg Xe):**

Nucl.Ins.Meth. A708 (2013)

JINST 8 (2013) P0400

JINST 8 (2013) P09011

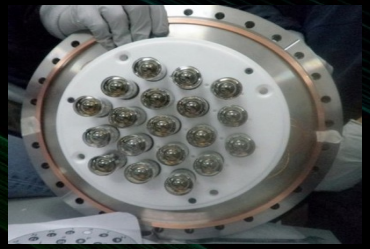
JINST 9 (2014) 10, P10007

JINST 8 (2013) P05025

JINST 10 (2015) 03, P0302

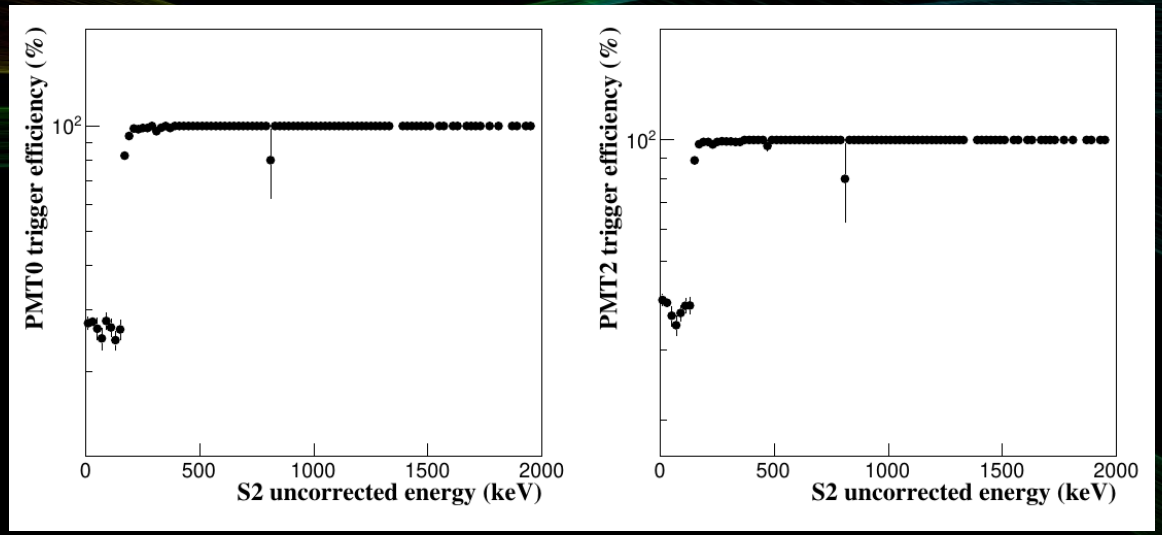
JHEP 1601 (2016) 1045

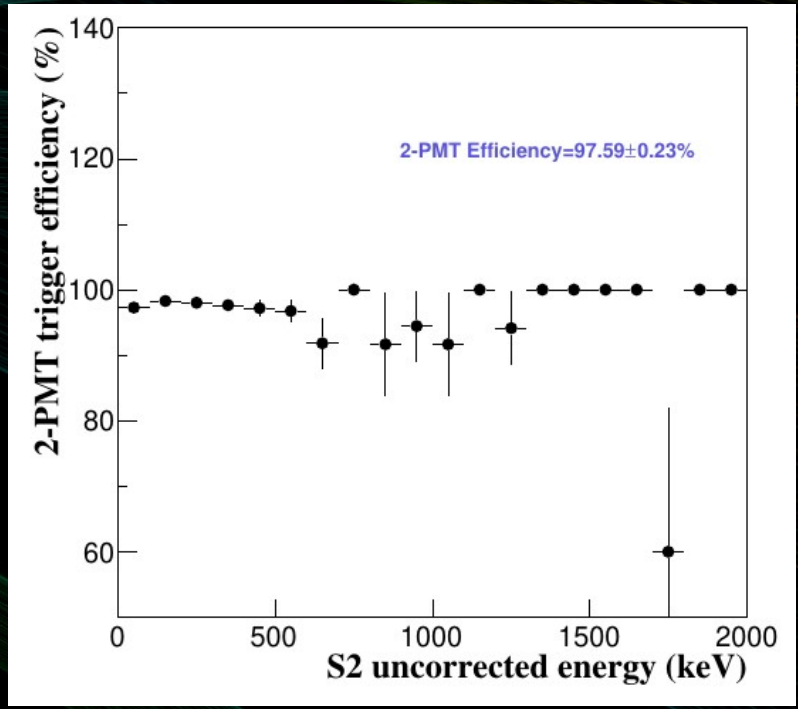
***Complete* prototype: PMT+SiPM**



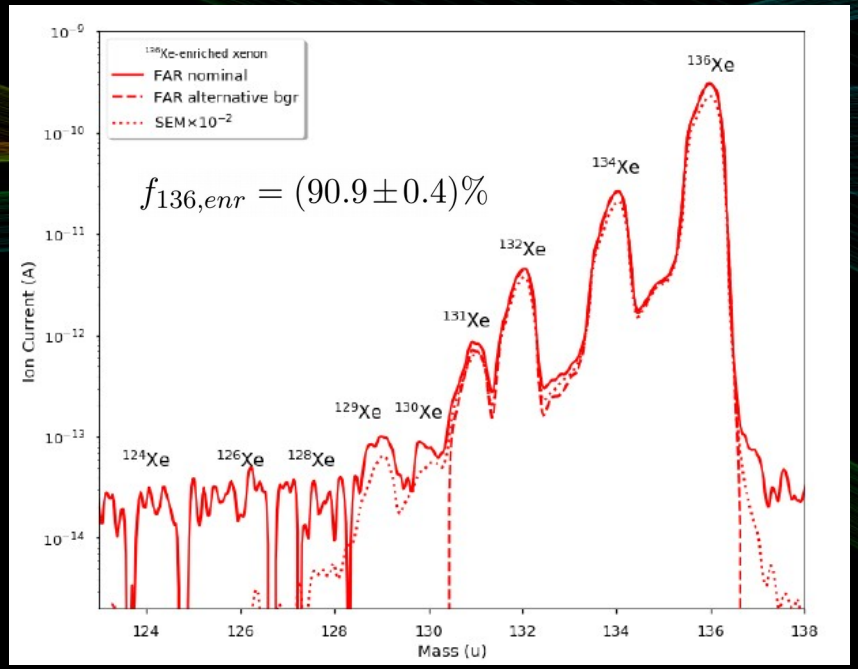
ΔE in large volume: <<1% @ $Q_{\beta\beta}$
Proof of topological signature

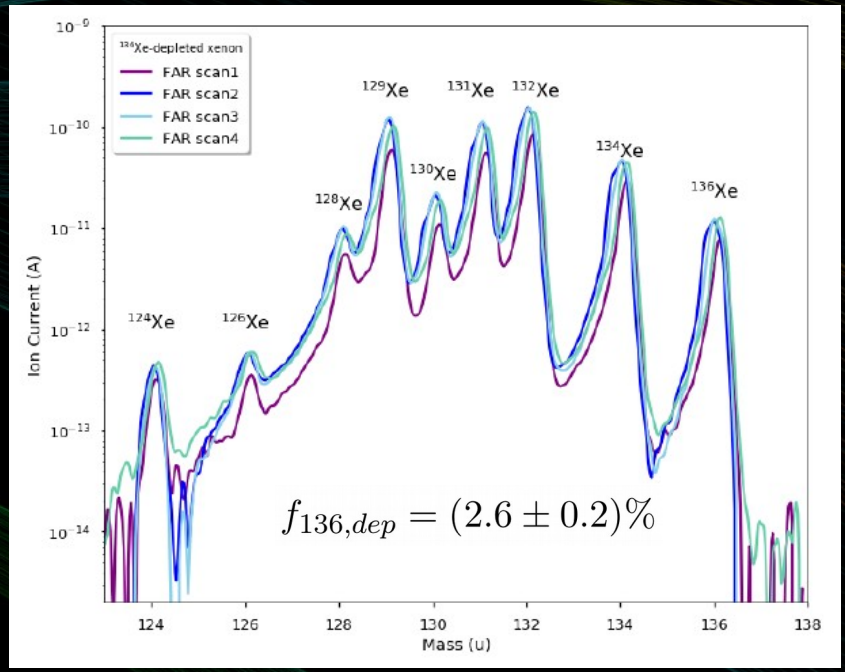
NETX-White Trigger Efficiency



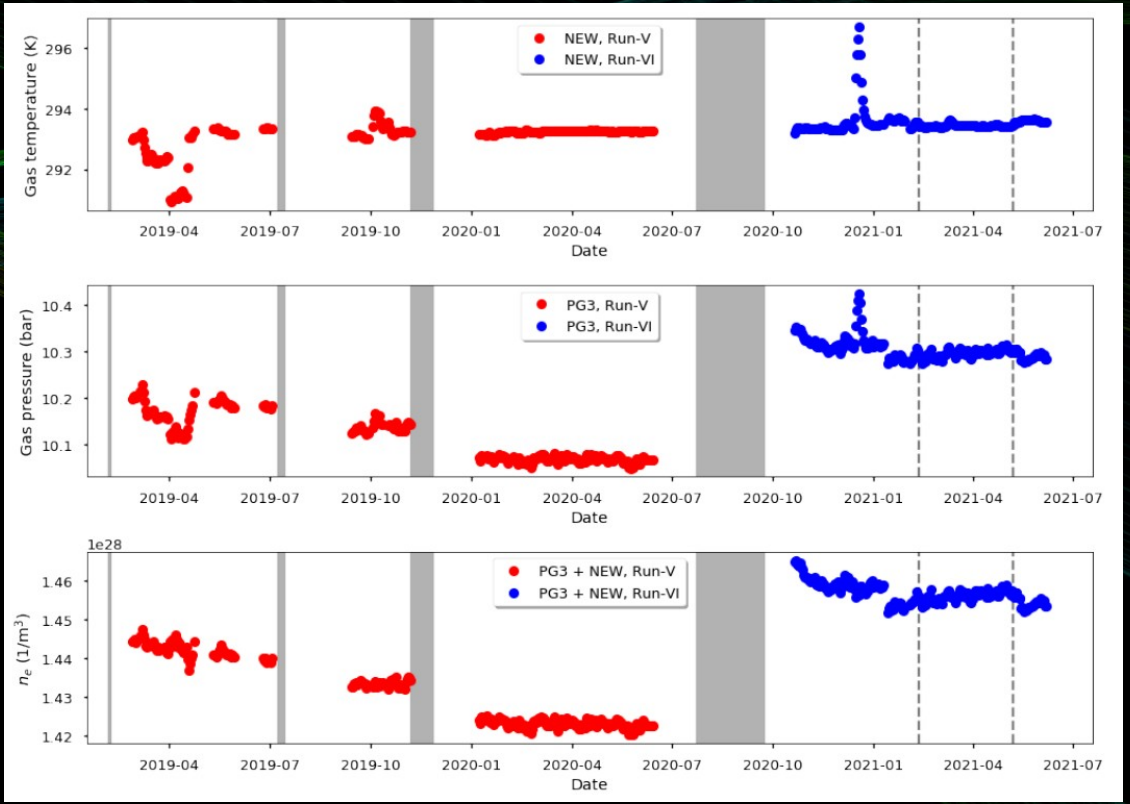


Isotopic Composition of the Xe Gas

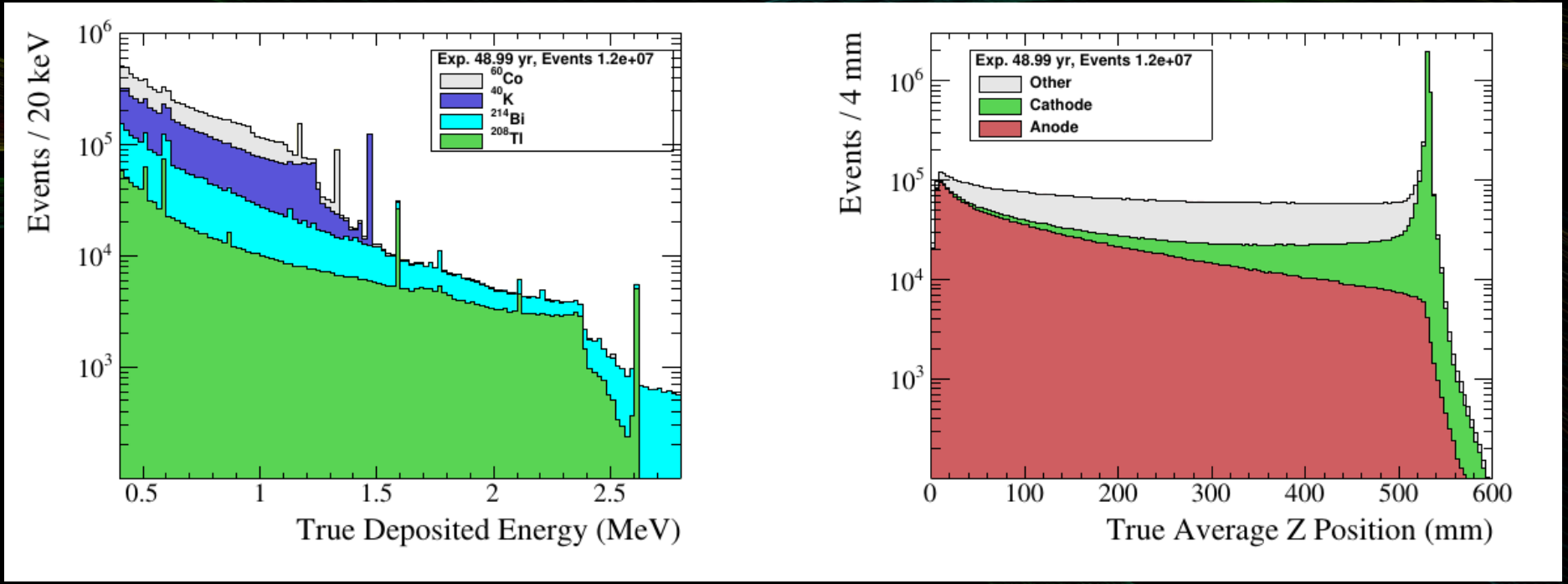




Gas Density Variation



Background Model



Energy Scale