NEXT

NEXT-White Results and Roadmap towards a ton-scale detector

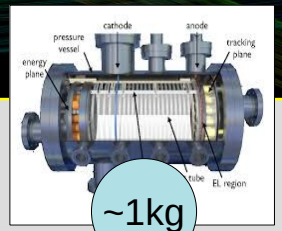
10th Symposium on Large TPCs for low-energy rare event detection

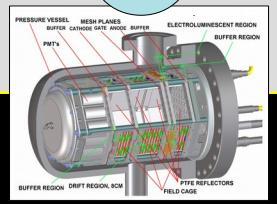
Pau Novella, IFIC (CSIC & U.V.)
On behalf of the NEXT Collaboration

Overview: The NEXT Project

Search for the ββ0ν decay with a HPXe-TPC

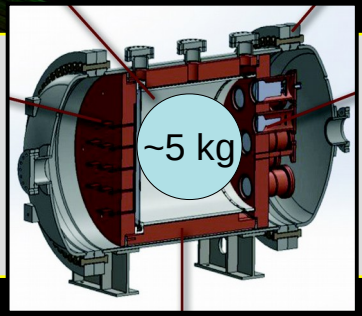
R&D
Proof of Concept





2009-2014

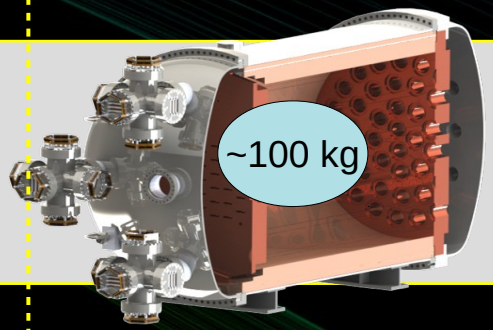
NEXT-White
Background+ββ2ν



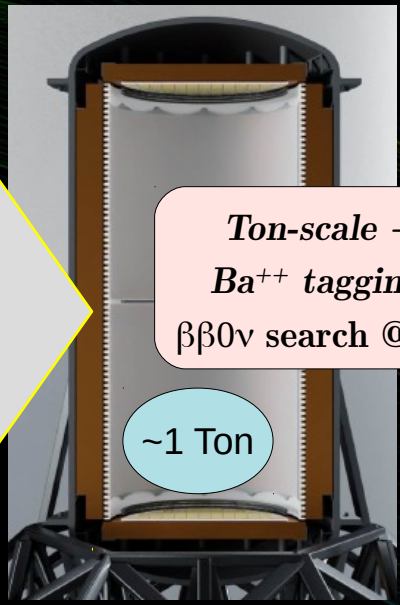
2015-2021

This talk

NEXT-100 (+upgrades)
ββ0ν search



2022-2025



Ton-scale +
Ba^{++} tagging:
ββ0ν search @ IH

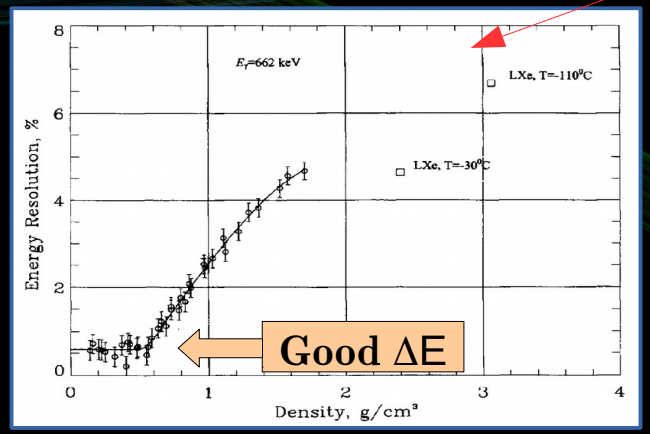
~1 Ton

NEXT: HP Gas-Xe TPC

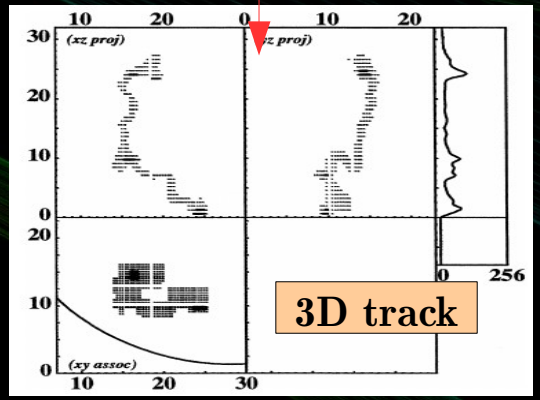
- **Sensitivity to the ββ0ν decay:**

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

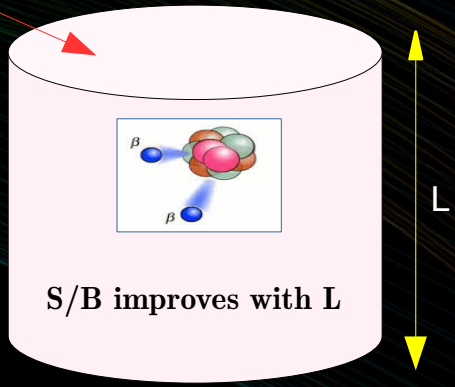
- $Q_{\beta\beta}$=2.48 MeV
- Scint/Ionization
- Cheap/Easy to enrich
- Long ββ2ν mode



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



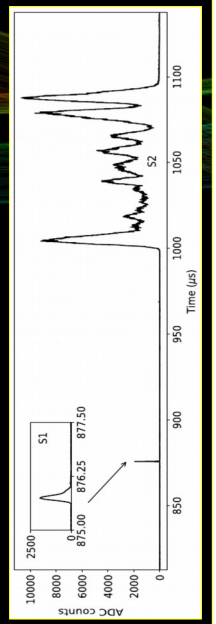
R. Luescher et al, PLB 434 (1998)

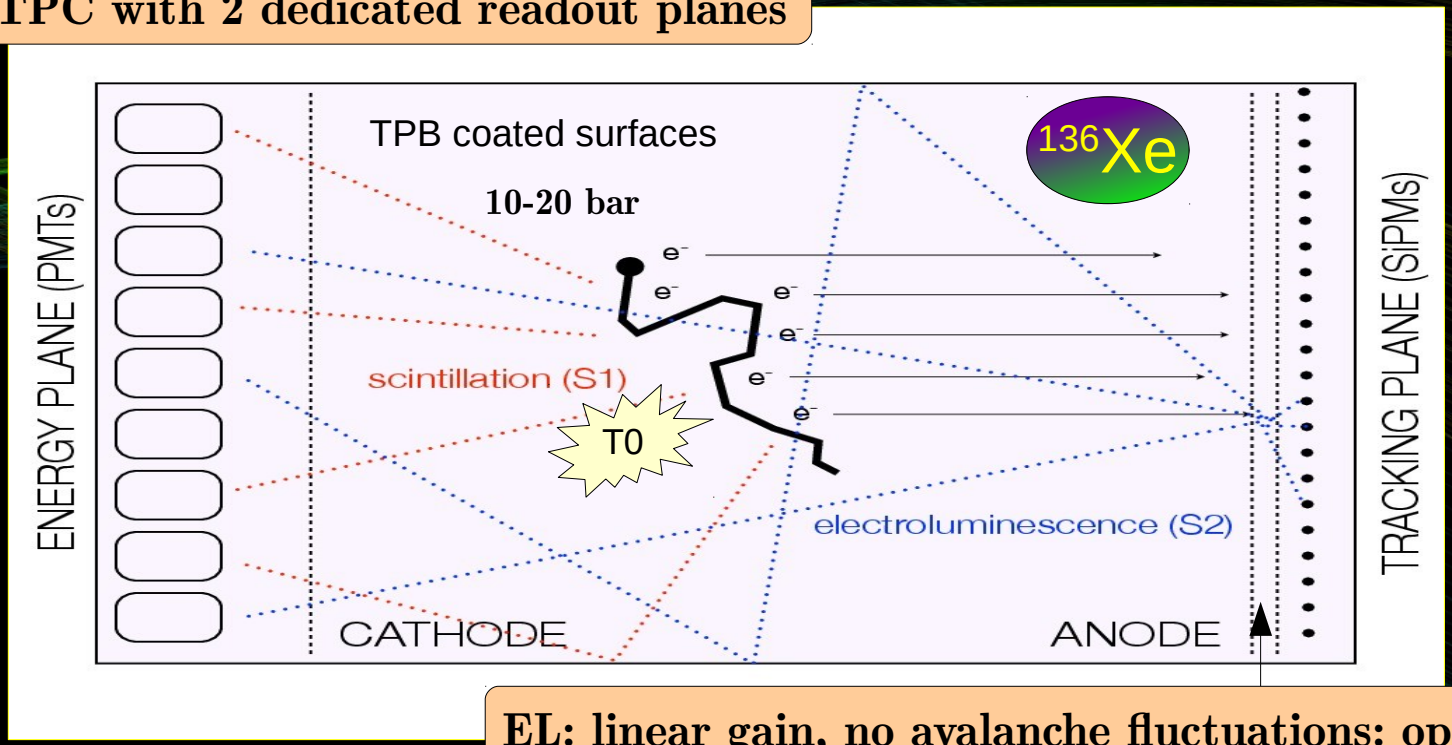


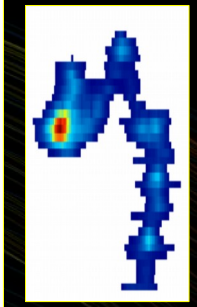
Source=Detector

The NEXT TPC Concept

Gas TPC with 2 dedicated readout planes







EL: linear gain, no avalanche fluctuations: optimize ΔE

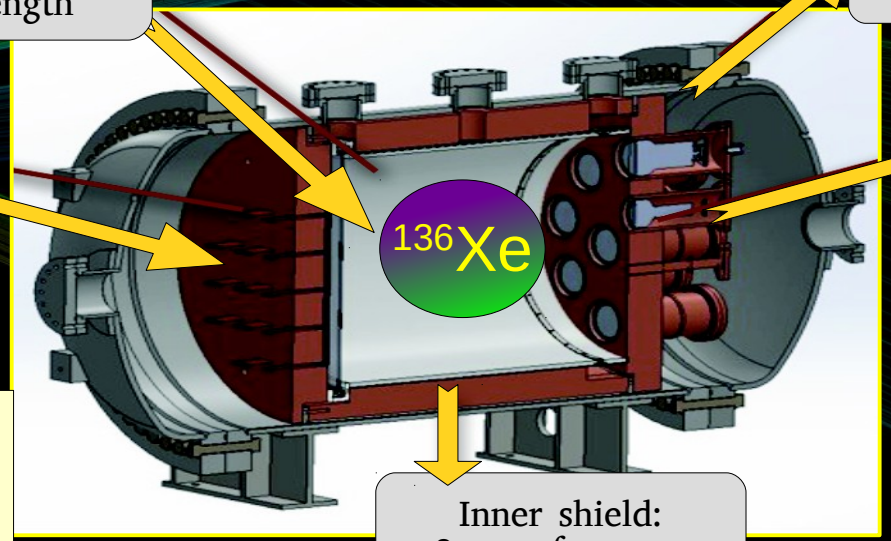
NEXT-White: Physics @ LSC

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

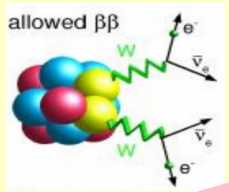
Physics program:

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

Achieved!

First phase of the NEXT-100 experiment

Ultimate goal:

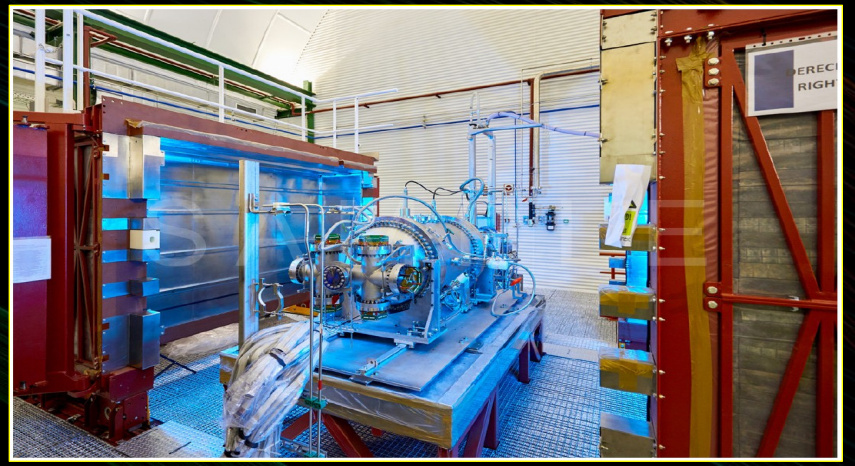


This talk!

The NEXT-White @ LSC

JINST 13 (2018) no.12, P12010

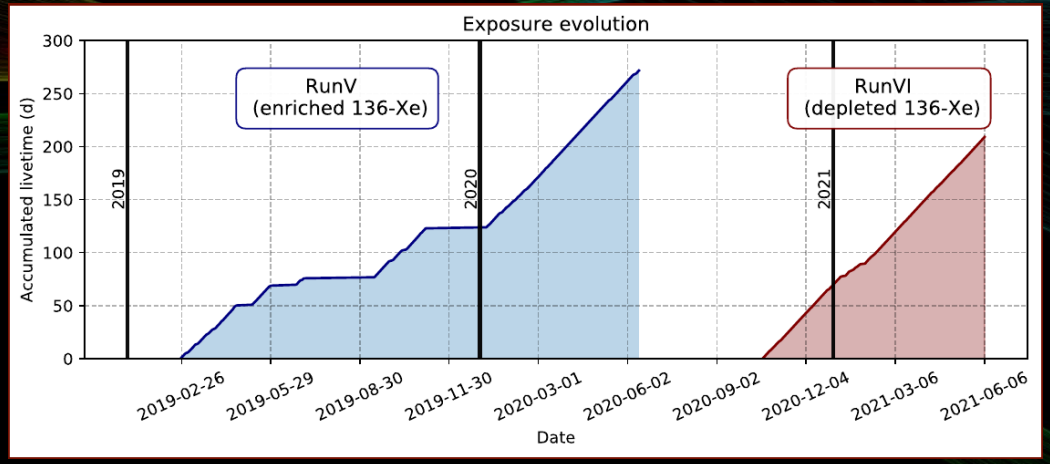
- Infrastructures: seismic platform, lead castle, Rn abatement system
- Available xenon: 100 kg of ^{136}Xe and 100 kg of Xe depleted in ^{136}Xe (~5 kg used)
- Installation/commissioning in 2015, stable operation since October 2016 to Summer 2021



NEXT-White Operation

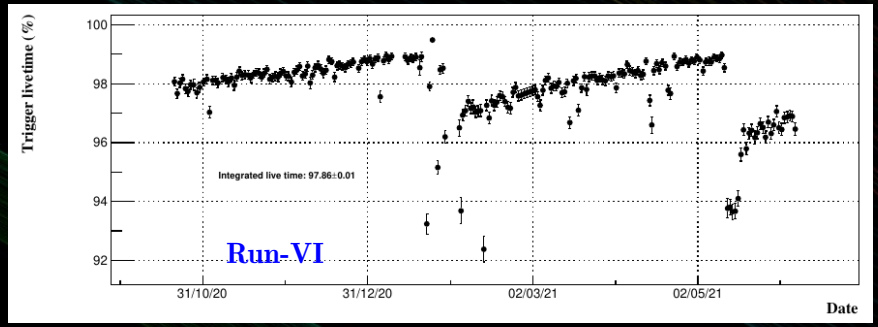
10.2 bar
Drift: 0.4 kV/cm
EL: 1.3 kV/(cm · bar)

- 2016-2018: Calibration campaigns with ^{83}Kr, ^{137}Cs, ^{228}Th @ 7/10 bar (Run-I – Run-III)
- 2018-2019: Background measurement with ^{136}Xe-depeleted xenon (Run-IV)
- 2019-2021: $\beta\beta2\nu$ combining ^{136}Xe-enriched (Run-V) and ^{136}Xe-depleted (Run-VI) data:



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

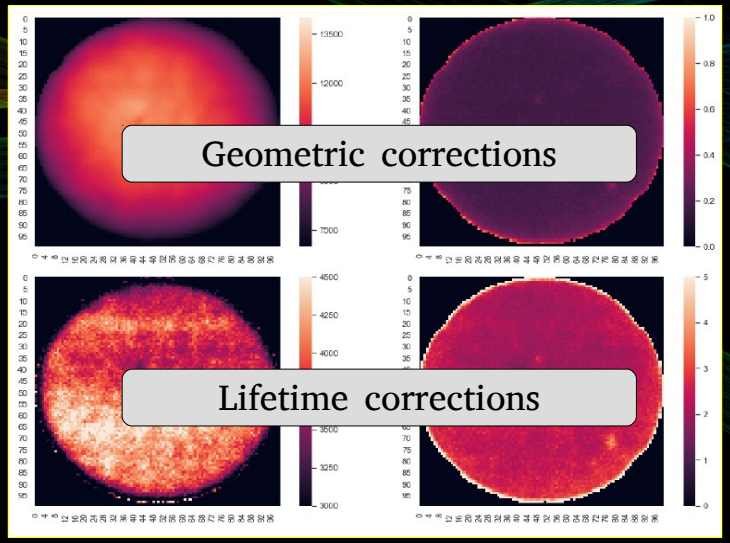
- Total run-times: 271.6 day (Run-V) and 208.9 day (Run-VI)
- DAQ dead time: ~3% @ Run-V and ~2% @ Run-VI
- Summer 2021: detector decommissioning



Kr-based monitoring: e- lifetime ~ 13 ms, v_d ~ 0.9mm/μs, ~300 p.e/keV

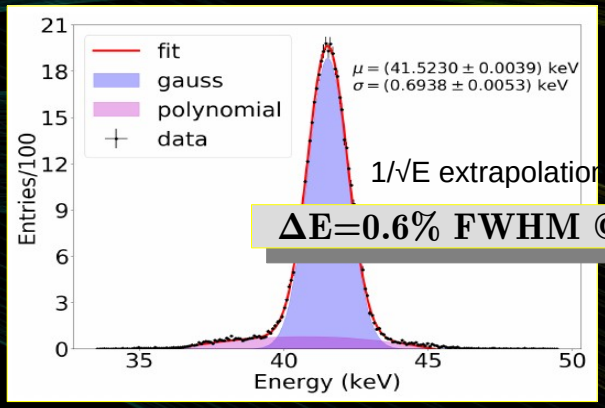
NEXT-White Calibration: ^{83m}Kr

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

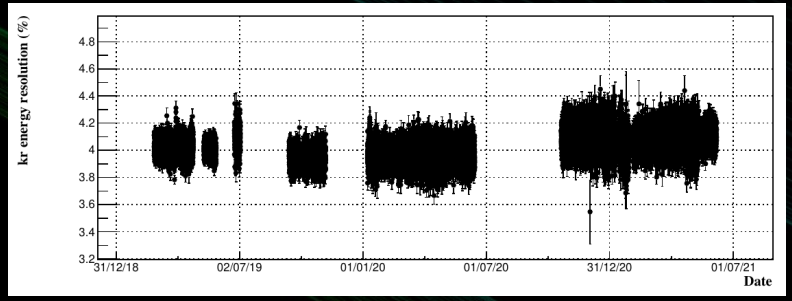


- Detector *continuously* monitored and calibrated:
  - e- attachment and light yield
- **JINST 13 (2018) no.10, P10014 (7bar)**

- **Energy resolution:**

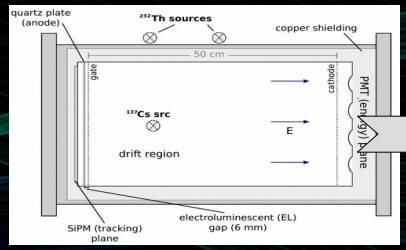


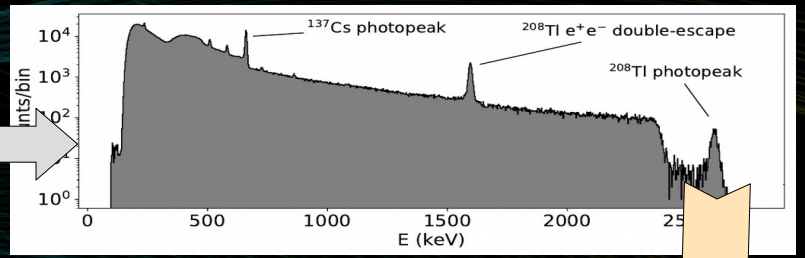
- **Monitoring of energy resolution evolution in time:**



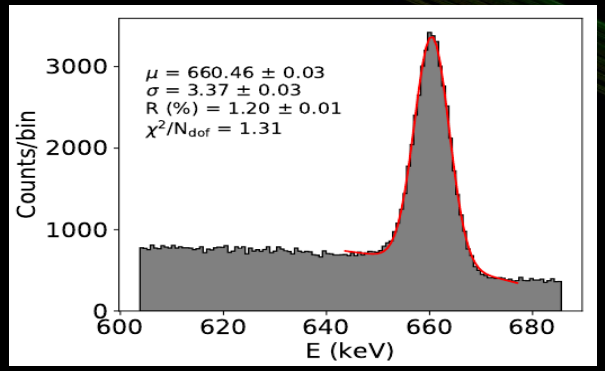
NEXT-White Calibration: $^{208}Tl/^{137}Cs$

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

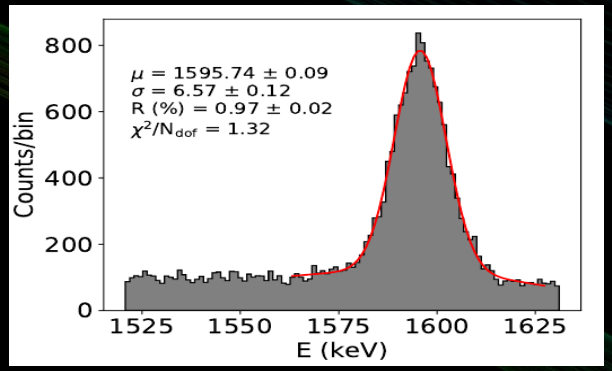


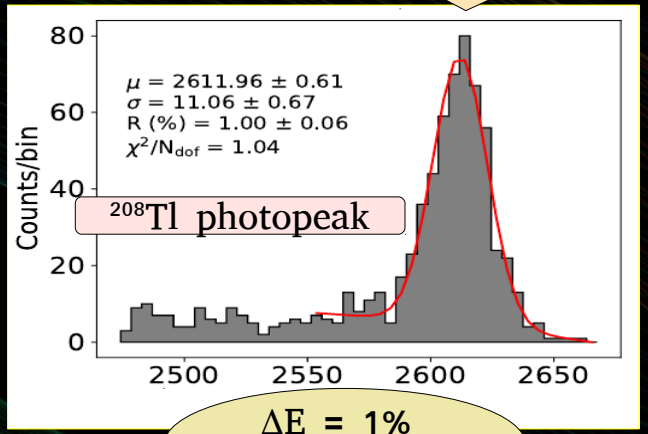


^{137}Cs photopeak



^{208}Tl double-escape





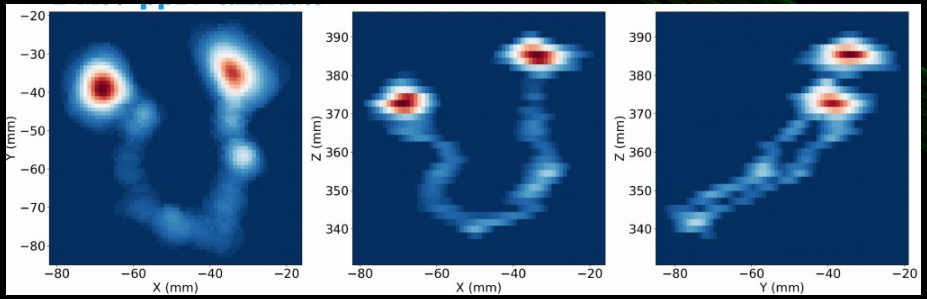
ΔE = 1% FHWM @~$Q_{\beta\beta}$

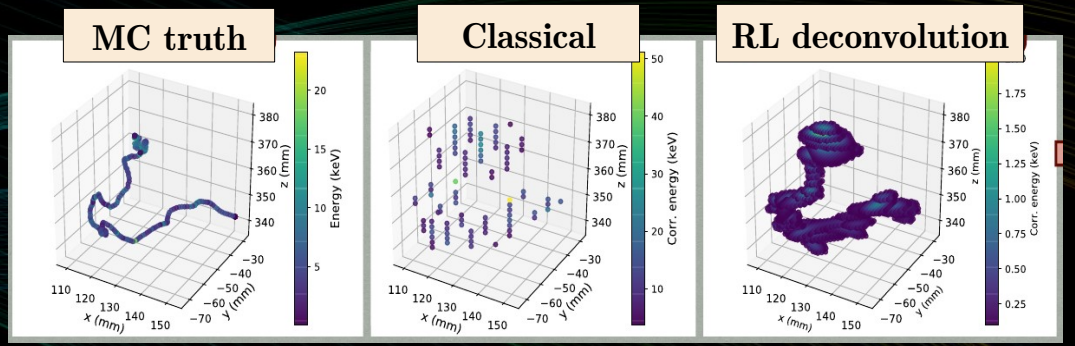
- JHEP 10 (2019) 230
- JINST 13 (2018) no.10, P10020

Best energy resolution in Xe!

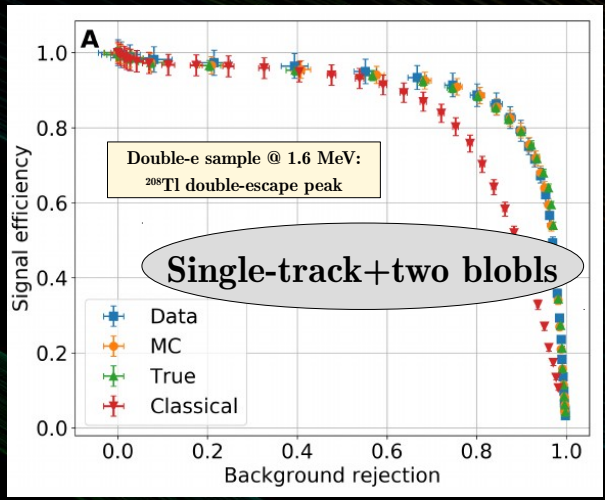
NEXT-White Topological Signature

- Track reconstruction:
  - *Classical* analysis: corrected hits
  - RL-deconv. over corrected hits
    - Reduction in image *smearing* (diffusion, light spread, ...)
  - Track reconstruction
    - ββ event candidate @ 2.0 MeV:





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

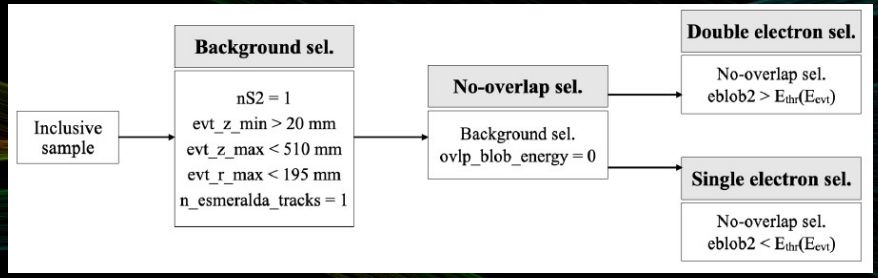


JHEP 21 (2020) 146

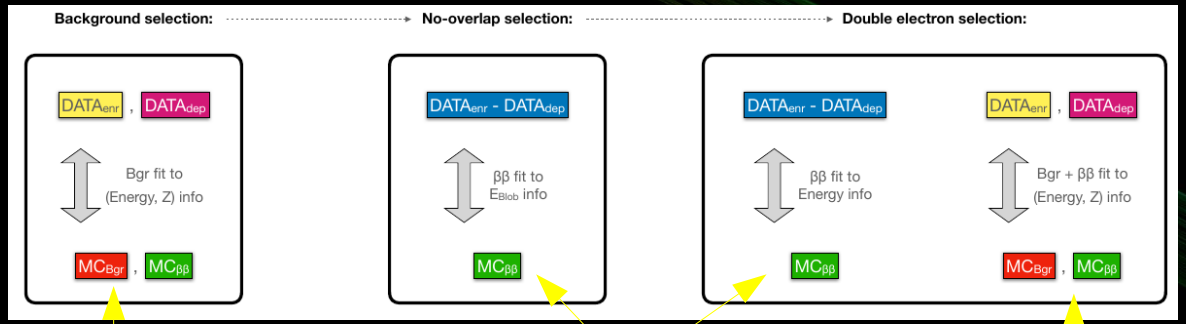
DNNs: JINST 12 (2017) no.01, T01004
CNNs: JHEP 01 (2021) 189
SiPM: JHEP 10 (2019) 052

ββ2ν: Event Selection & Analysis Approaches

- Selections applied for different approaches and checks:

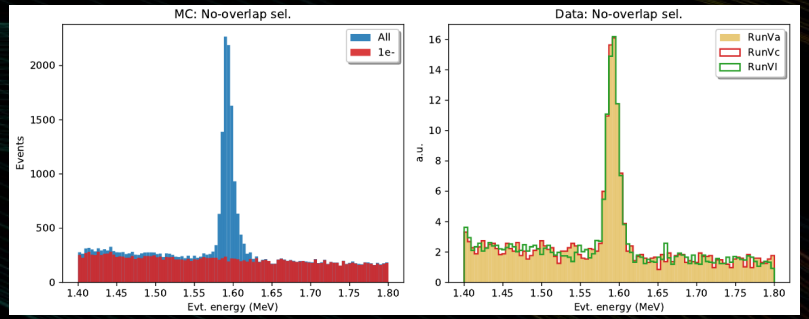


- Background and ββ2ν fit approaches:



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:**

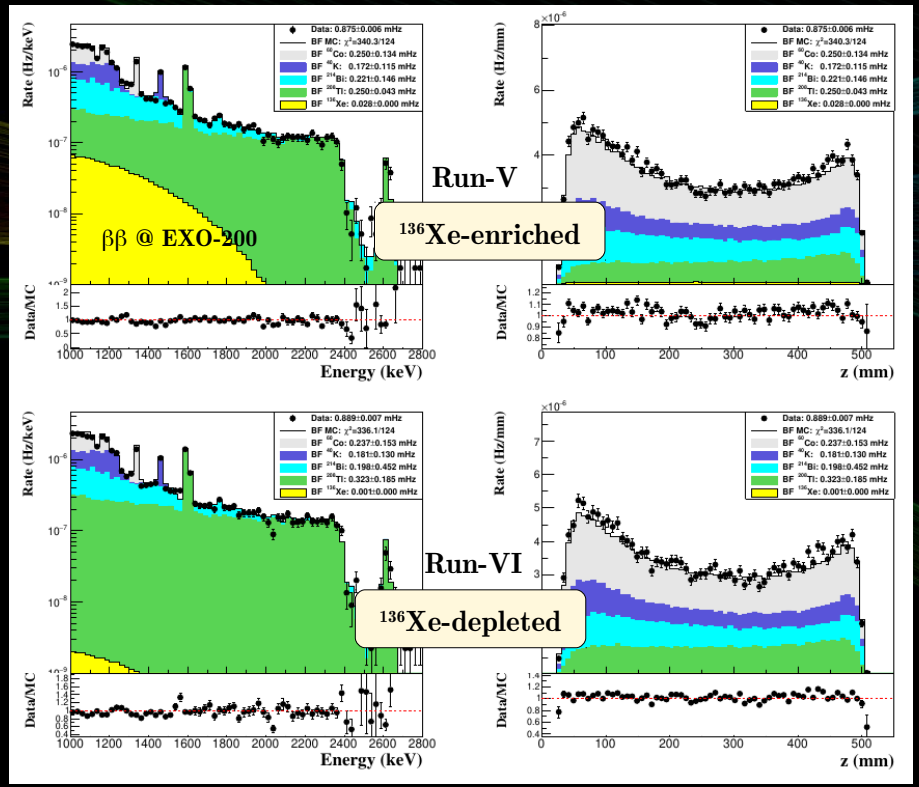


- **Unique capabilities of NEXT:**
  - **Topology-based BG rejection**
  - **Background subtraction**
    - ~BG-model-independent result

Systematic Uncertainties

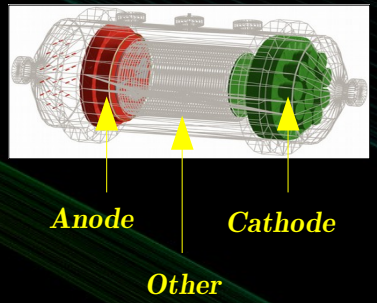
Type	Source	Run-V	Run-VI	Correlated?
Norm.	DAQ livetime	0.01%	0.01%	No
	Trigger efficiency	0.2%	0.2%	Yes
	Gas density	-	0.6%	No
	$\beta\beta$ selection (1e/2e)	2.1/2.8%	2.1/3.0%	No
	^{136}Xe fraction	0.4%	0.2%	No
	Xe atoms	0.2%	0.2%	Yes
Energy	Energy scale	0.25%	0.25%	Yes

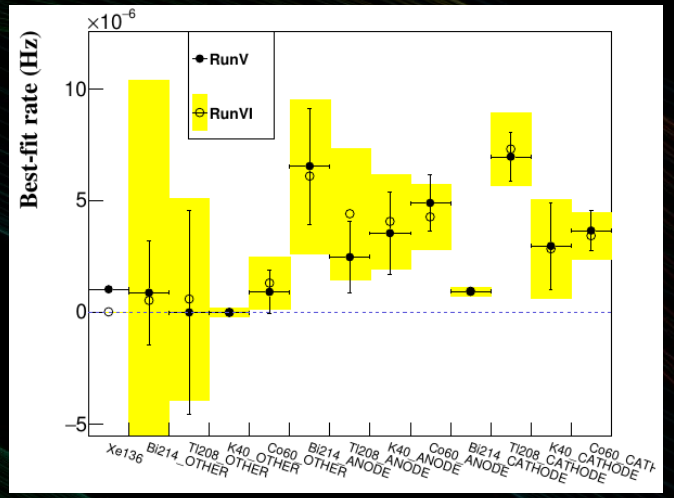
ββ2ν: Radiogenic Background



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



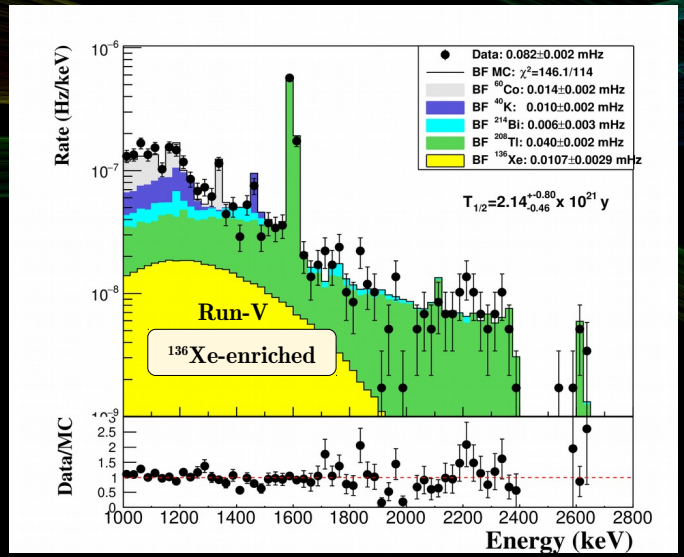


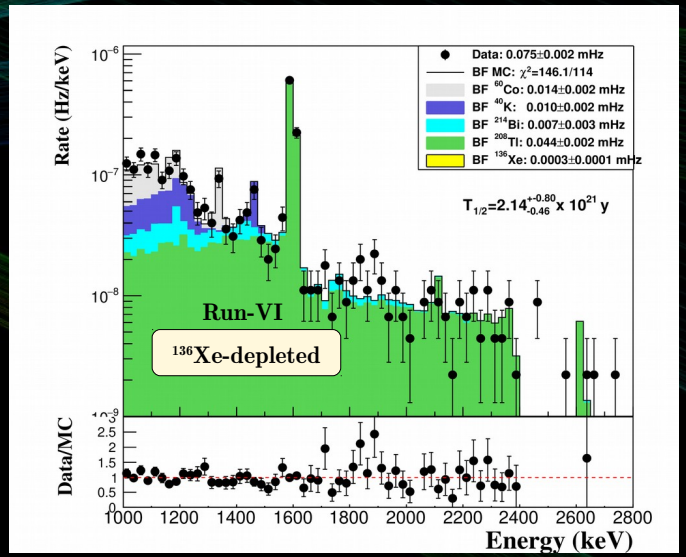
- 12 BG sources measured to be stable in time

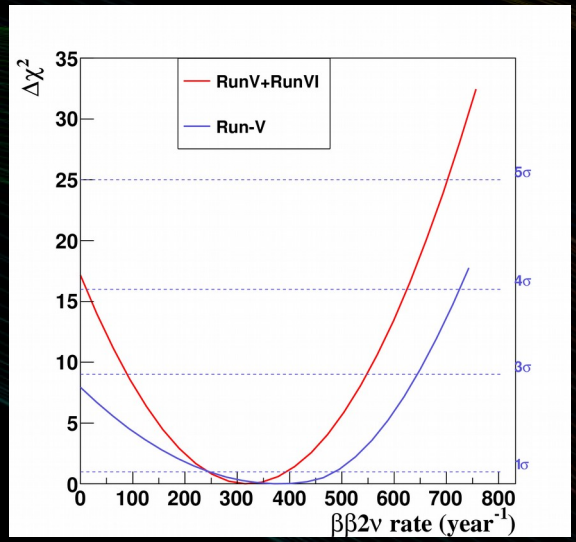
arXiv:2111.11091

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





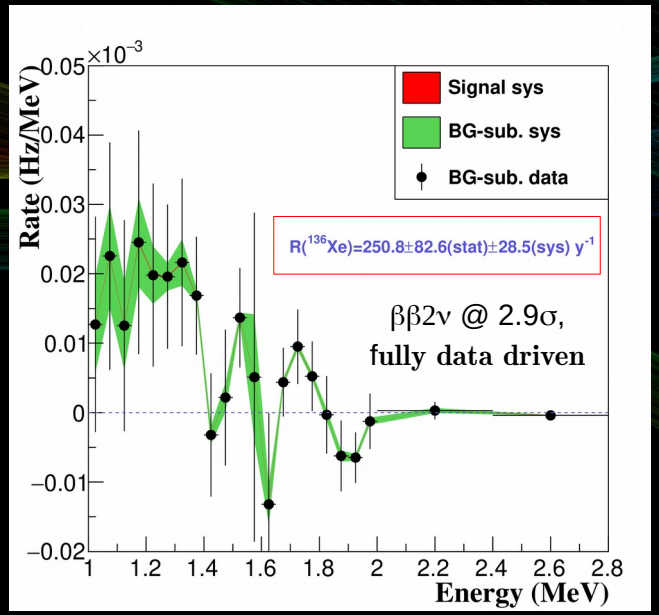


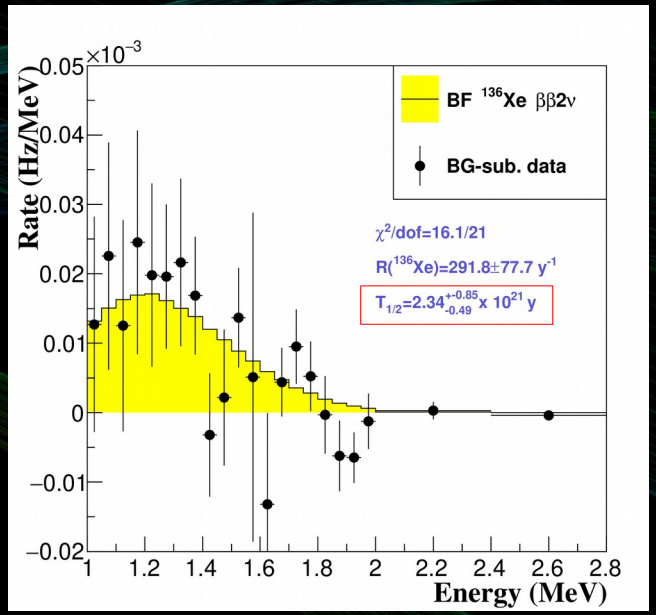
- The ^{136}Xe-depleted sample improves the precision by constraining the backgrounds
- 4.1σ measurement (4σ expected), but poor goodness of fit: $\chi^2/\mathrm{dof} = 146.1/114$, p-value = 2.3%

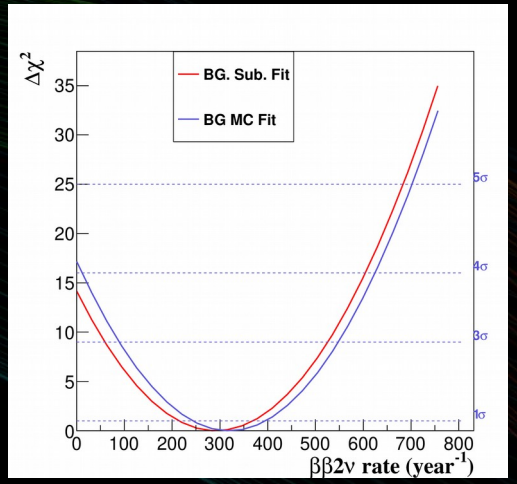
ββ2ν: BG-Subtraction Fit

arXiv:2111.11091

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



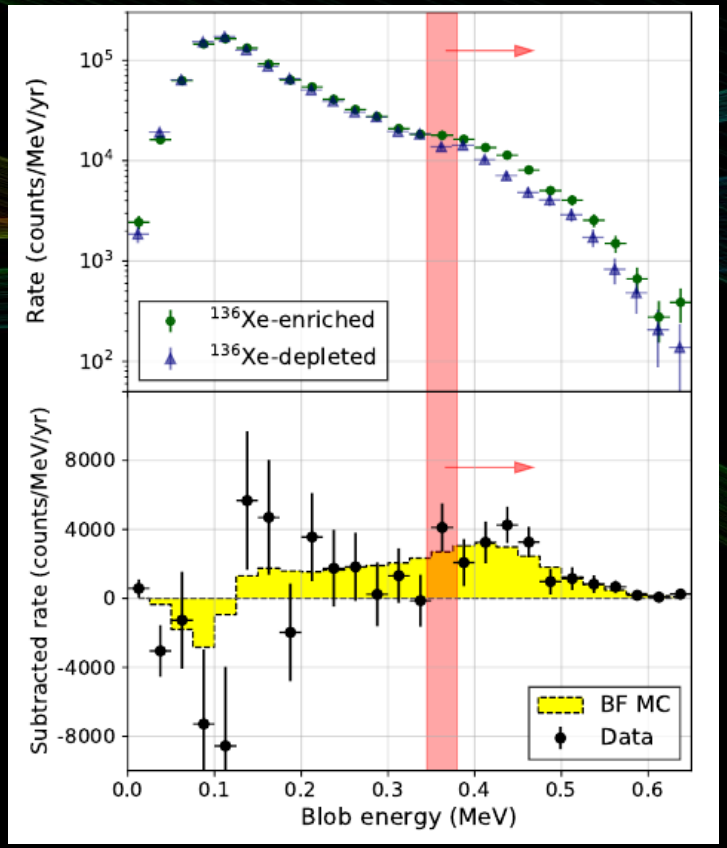




- Fit to the ββ2ν expectation (BG-model independent!): $T_{1/2}$ measured @ 3.8 sigma (4.1σ expected)
- Fully consistent with BG-model-dependent fit, but excellent goodness of fit: χ^2/dof=16.1/21

arXiv:2111.11091

ββ2ν: BG-Subtraction Fit (II)



- Alternative analysis considering the energy distribution of the less energetic blob instead of track energy, and without applying topological selection (cut on blob energy)

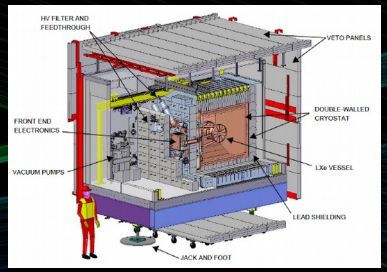
$$T^{2\nu}_{1/2} = 1.66^{+0.29}_{-0.21}(\text{stat})^{+0.25}_{-0.15}(\text{sys}) \times 10^{21}\ \text{year}.$$

$\chi^2/\text{dof} = 24.8/25$, p-value = 47%

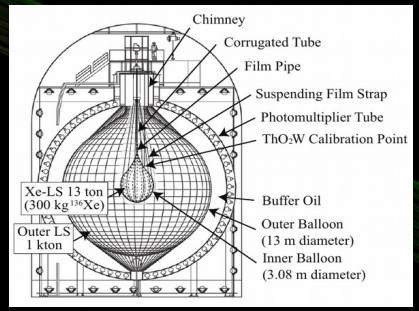
arXiv:2111.11091

^{136}Xe ββ2ν Measurements

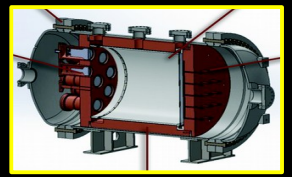
EXO-200
^{136}Xe ~142 kg

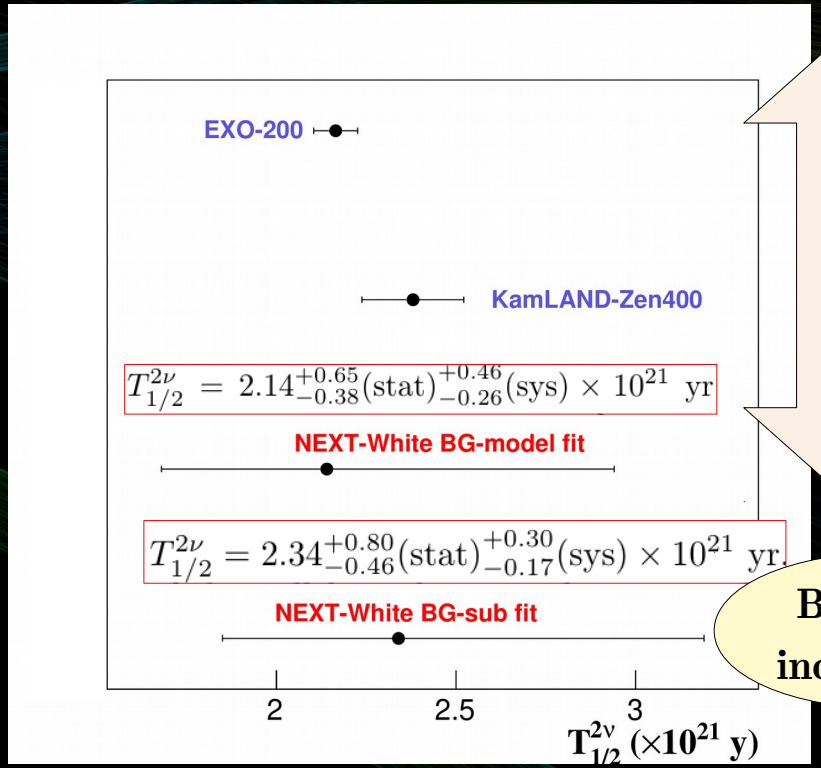


KamLAND-Zen400
^{136}Xe ~129 kg



NEXT-White
^{136}Xe ~4.3 kg



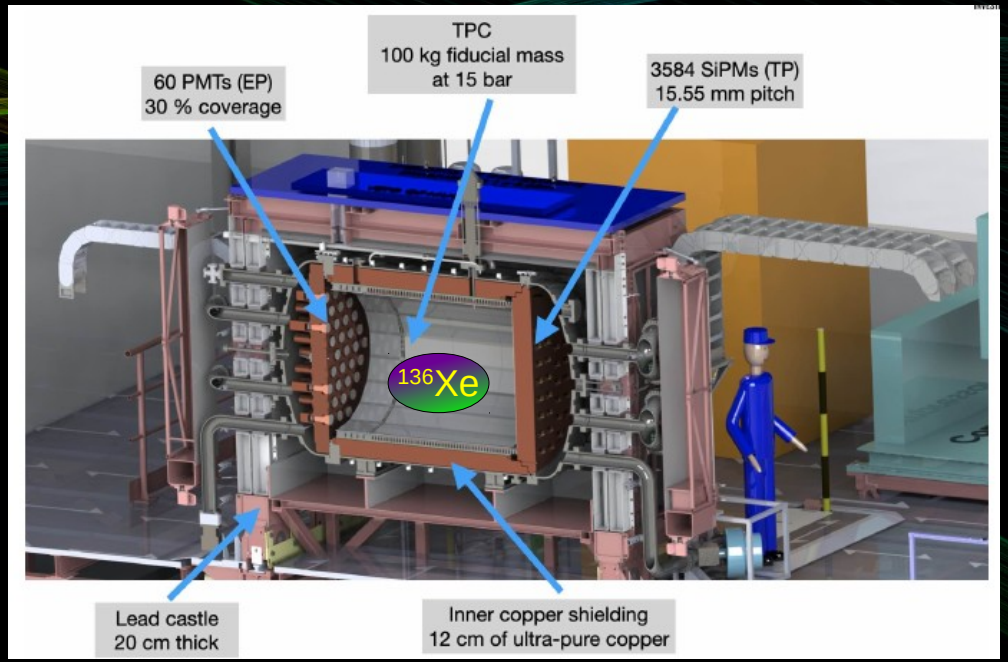


The NEXT-100 Detector

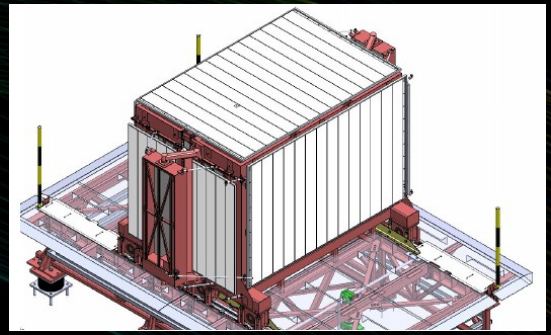
JINST 7 (2012) T06001
JHEP 1605 (2016) 159

- Infrastructures in place, installed at the LSC during first half of 2022.

NEXT-100 @ HALL A of LSC



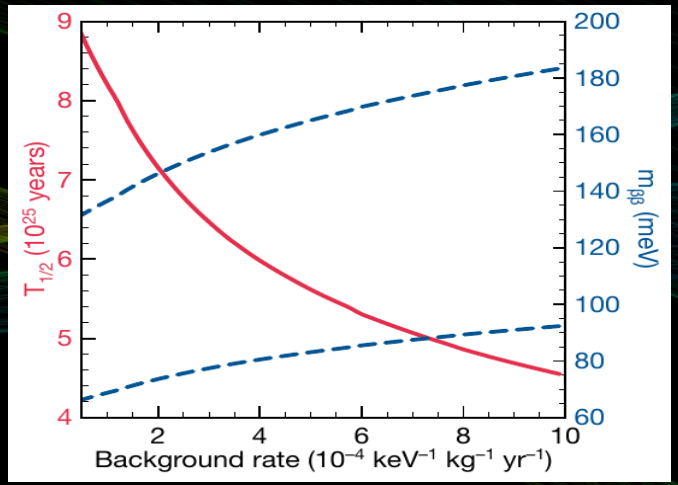
Muon veto covering the lead castle:

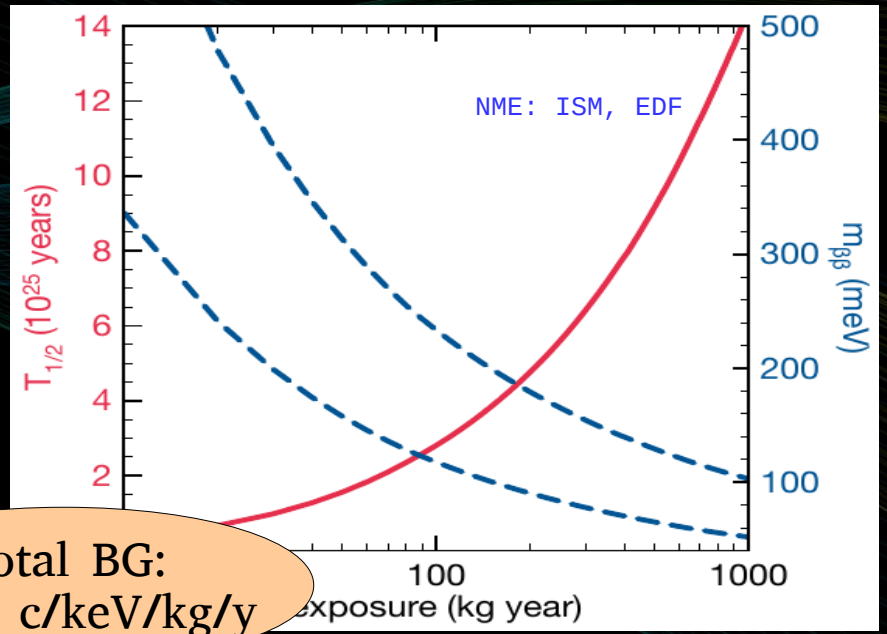


Goals of NEXT-100:

- 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

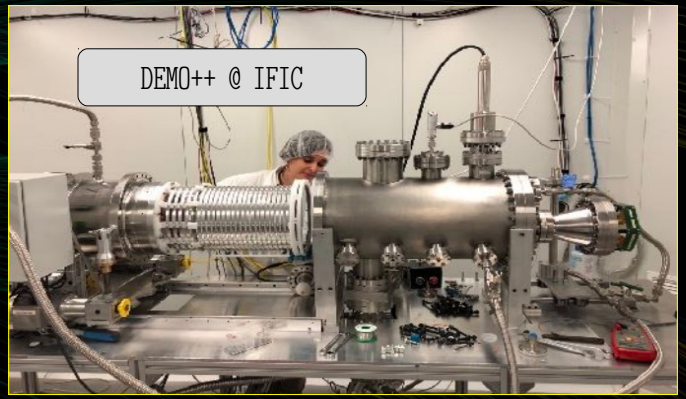
~validated with NEXT-White!

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

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

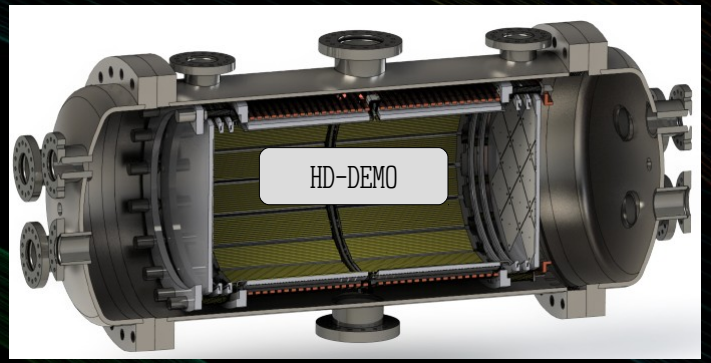
NEXT @ Ton-Scale: R&D

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



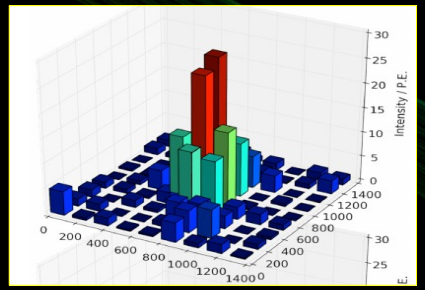
NEXT-HD

- 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++, AXOLOTEL, HD-DEMO
- arXiv:1906.01743, JHEP 2021 (2021) 08, 164



NEXT-BOLD

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

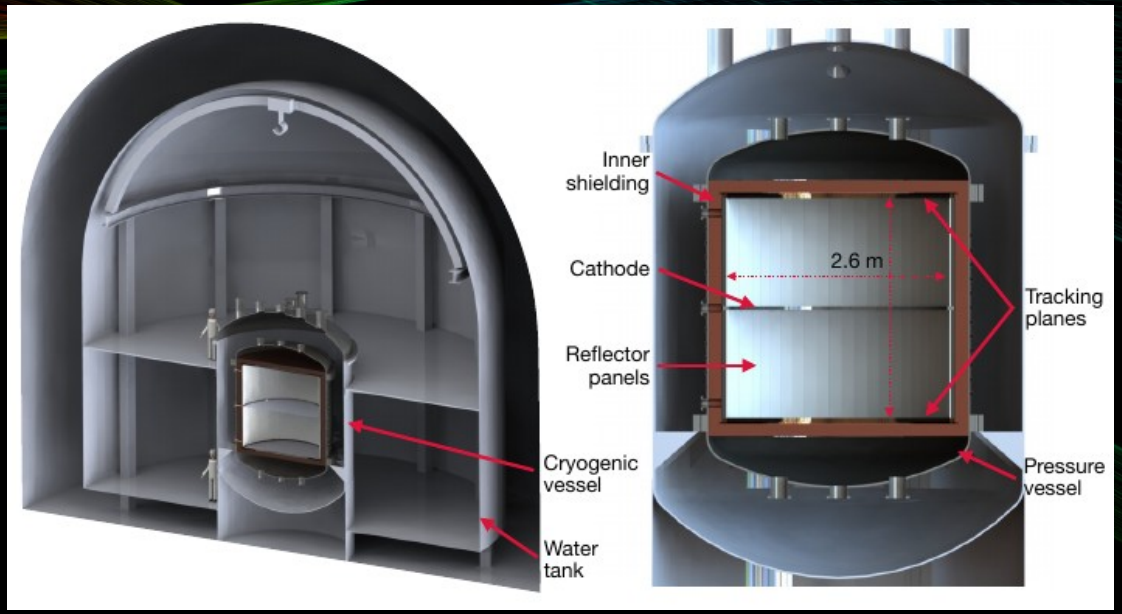


JHEP 2021 (2021) 08, 164

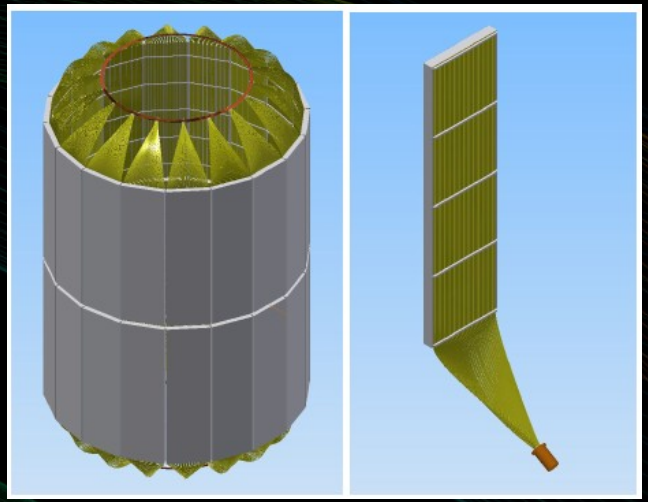
NEXT-HD

- Symmetric TPC holding ~1 ton of Xe at 15 bar, inside instrumented water tank
- Possible multi-module approach: first module to be deployed at LSC

NEXT-HD detector:



Barrel Fiber Detector (S1 & S2):



- Energy resolution $< 0.7\%$ FWHM (more light collection and less geo. effects)

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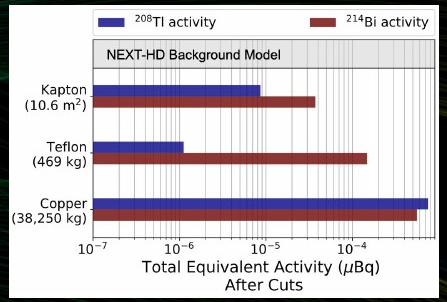
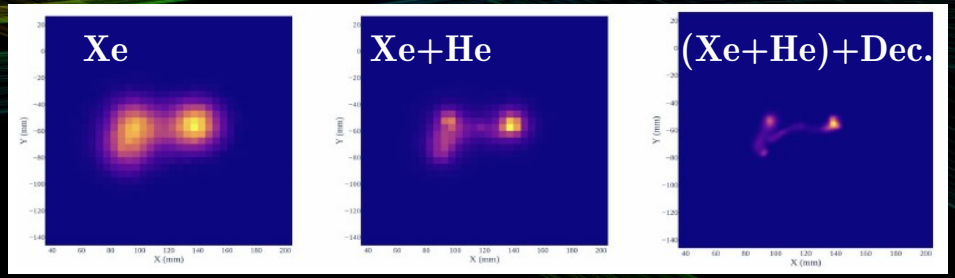
NEXT-HD Physics Case

- Improved energy resolution (<0.7% FWHM)
- Reduced background budget (no PMTs)
- Improved background rejection power

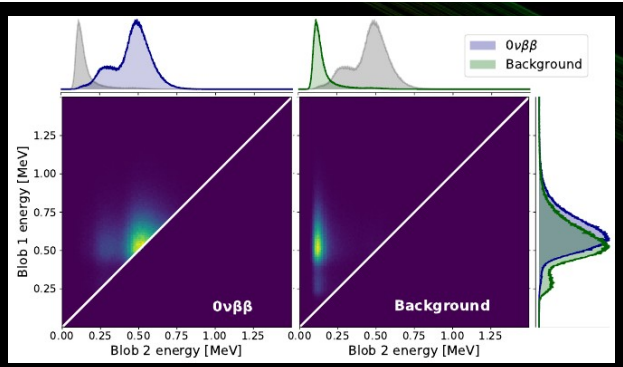


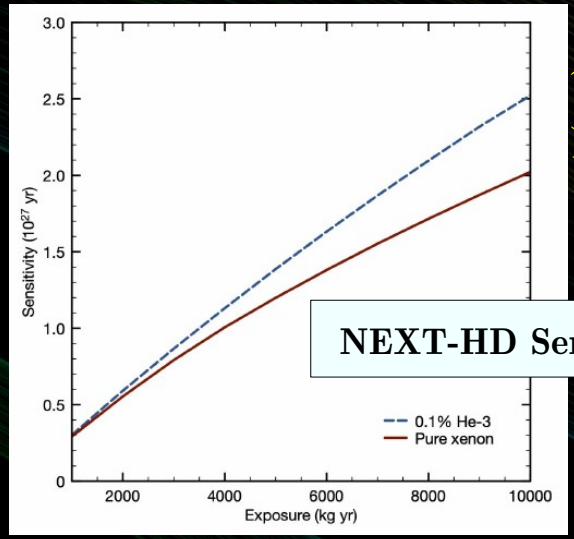
Dominant BG Contributions

Tracking performance



Signal vs BG discrimination

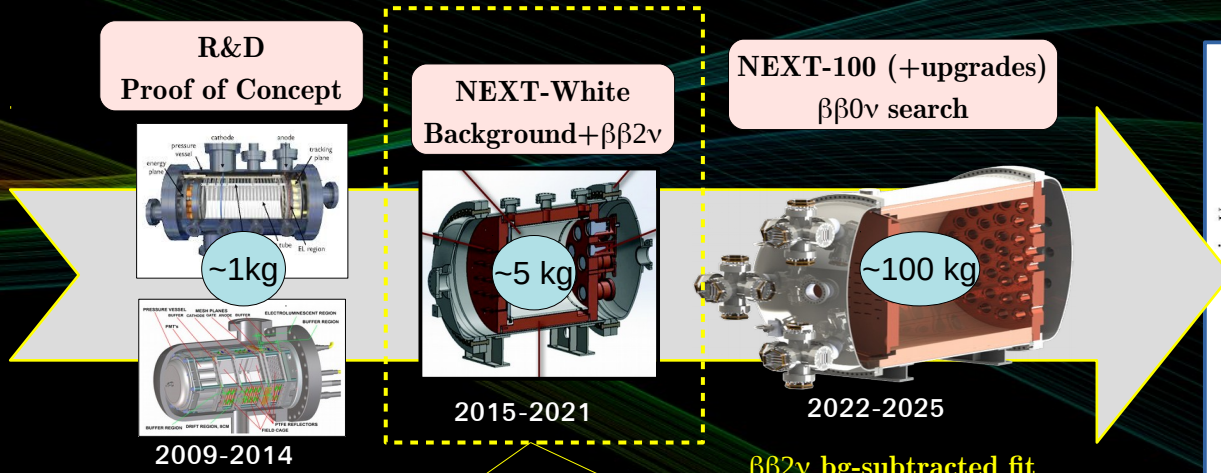


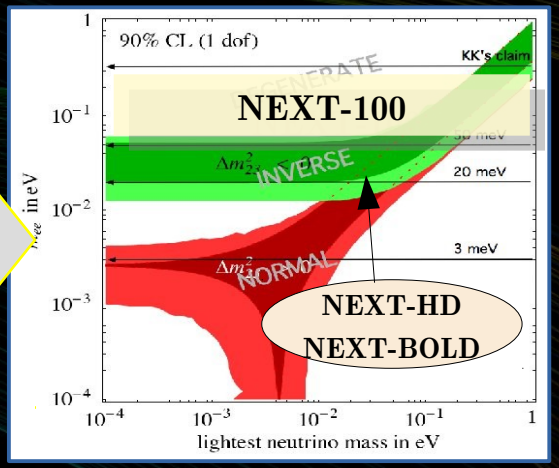


J.Phys.G 47 (2020) 7, 075001

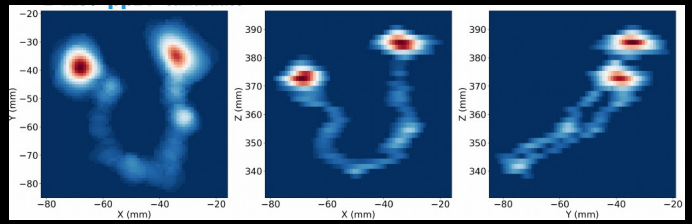
Summary

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

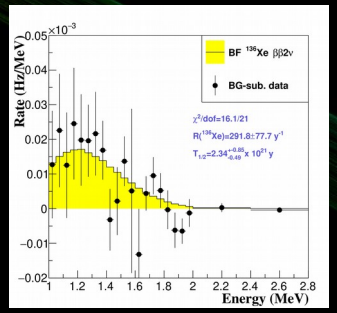




ββ event candidate



ββ2ν bg-subtracted fit



- Energy resolution < 1% FWHM
- Topology-based BG rejection
- BG-model-independent ββ searches

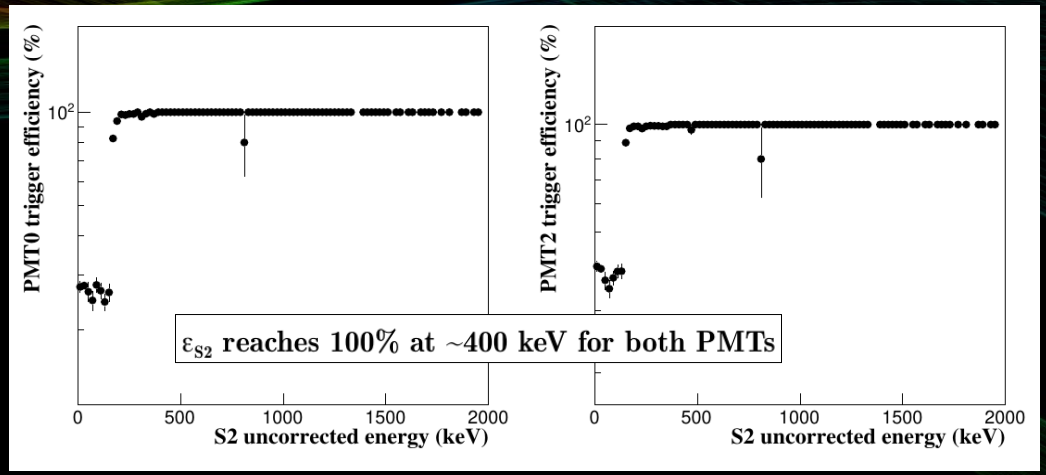
The NEXT Collaboration

Back Up

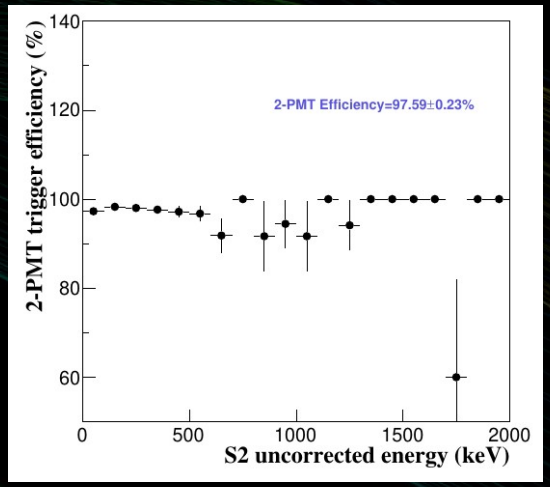
NEXT-White Trigger Efficiency

- Evaluated by processing *random* S2 signals with a trigger simulation
- Trigger configuration: 2 central PMT with valid S2 signals in time coincidence

Valid S2: $S2q > 10^5$ ADCs | $S2h > 4095$ ADCs | $2\mu s < S2t < 600\mu s$



2-PMT coincidence: 1.2 μs

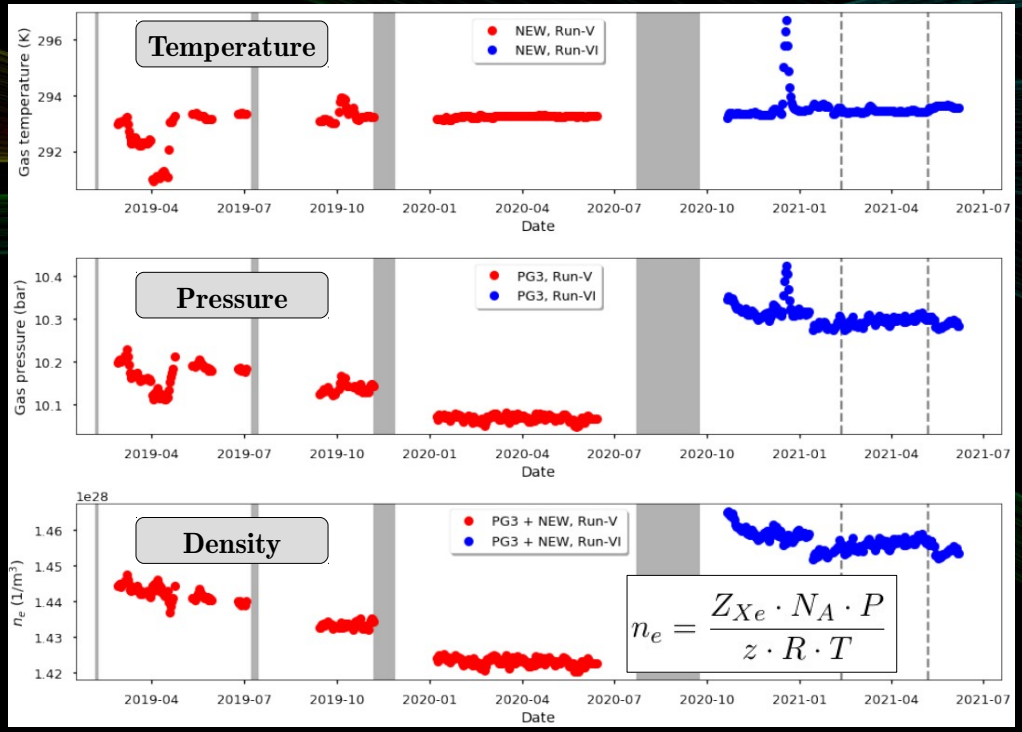


- Trigger-related correction to exposure: ~5%
  - for events above 400 keV

Run period	DAQ livetime (%)	ϵ_{S2} (%)	ϵ_{2PMT} (%)
Run-V	97.04±0.01	100	97.6±0.2
Run-VI	98.10±0.01	100	97.6±0.2

Gas Density

- Density variations → variations in BG absorption length → Run-V vs Run-VI correction



Run period	n_e $(10^{28})/\mathrm{m}^3$	n_e/n_e(Run-V)	R/R(Run-V)
Run-Va	1.4422	1.0085	1.0109
Run-Vb	1.4333	1.0022	1.0028
Run-Vc	1.4230	0.9950	0.9936
Run-V	1.4301	1	1
Run-VI	1.4568	1.0187	1.0241

$$<n_e(\text{Run-VI/V})> = (1.0187 \pm 0.002)\ <n_e(\text{Run-V})>$$

- Rate dependence on gas density:

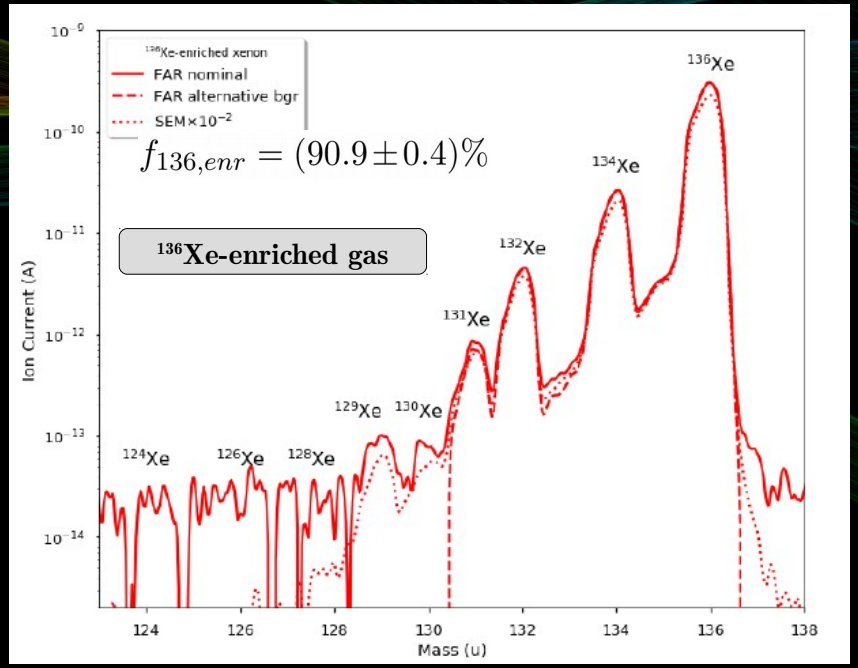
$$\frac{\Delta R}{R} \Big/ \frac{\Delta n_e}{n_e} = 1.288 \pm 0.288$$

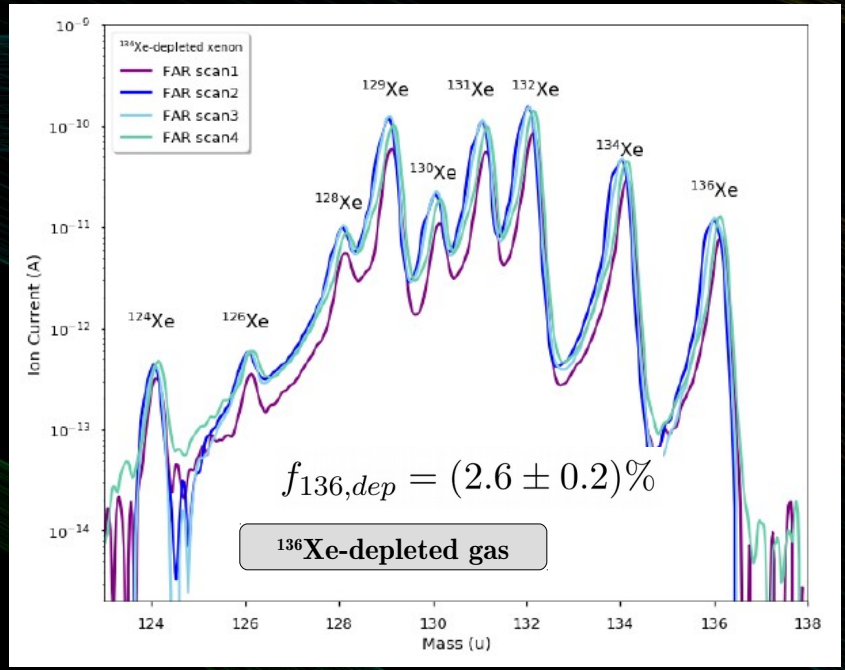
- Run-VI correction:

$$\frac{\Delta R}{R} = (2.41 \pm 0.60)\%$$

Isotopic Composition of the Xe Gas

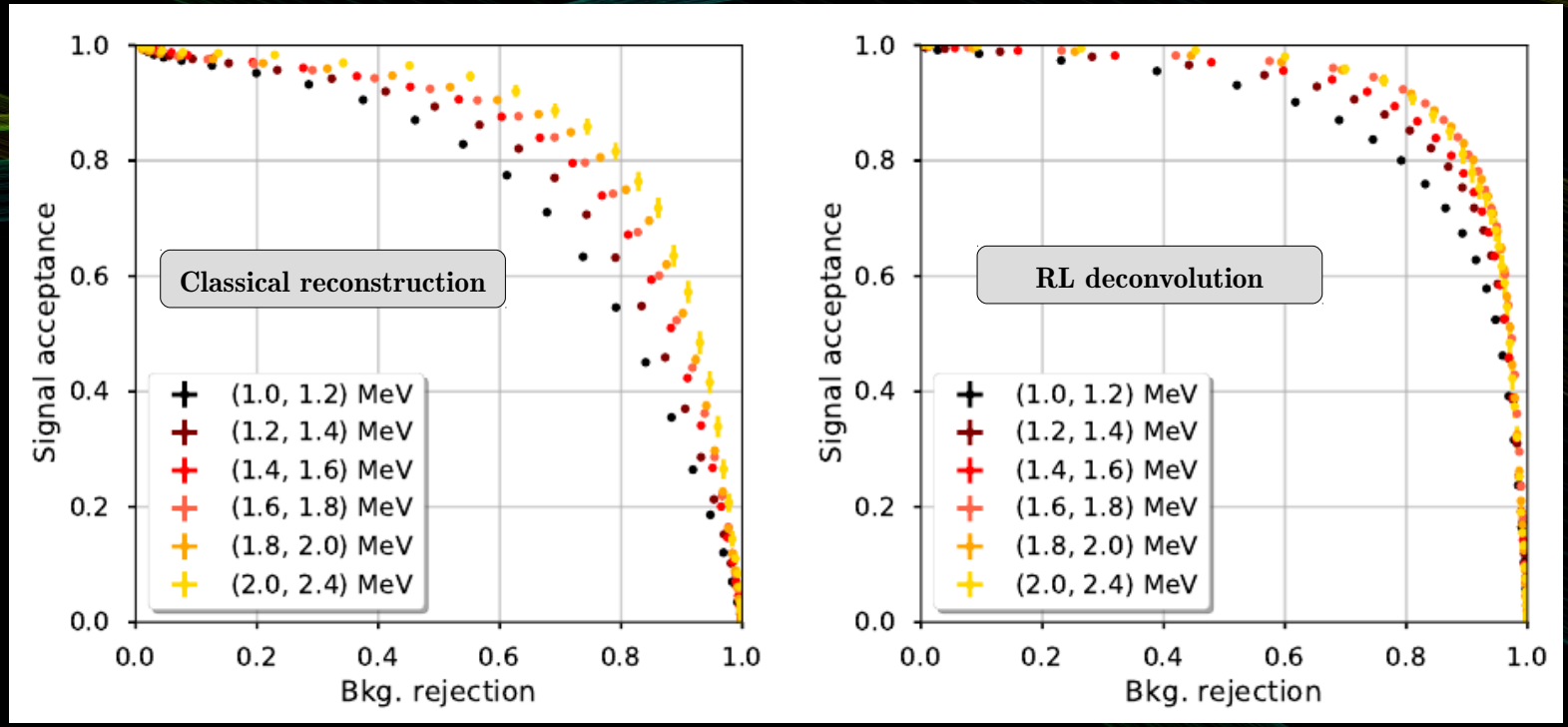
- **Fraction of ^{136}Xe in gas measured with RGA scans:**





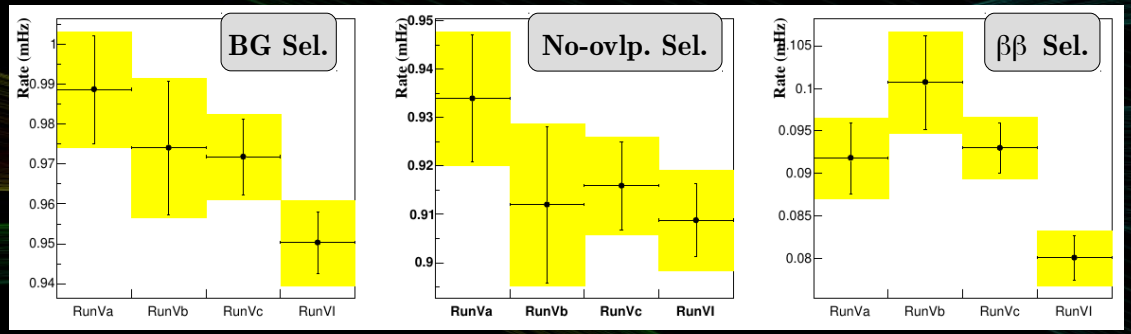
Selection Eficiency vs Energy

- Although optimized for 1.6 MeV, RL @ JHEP performs well in ROI for ββ2ν analysis

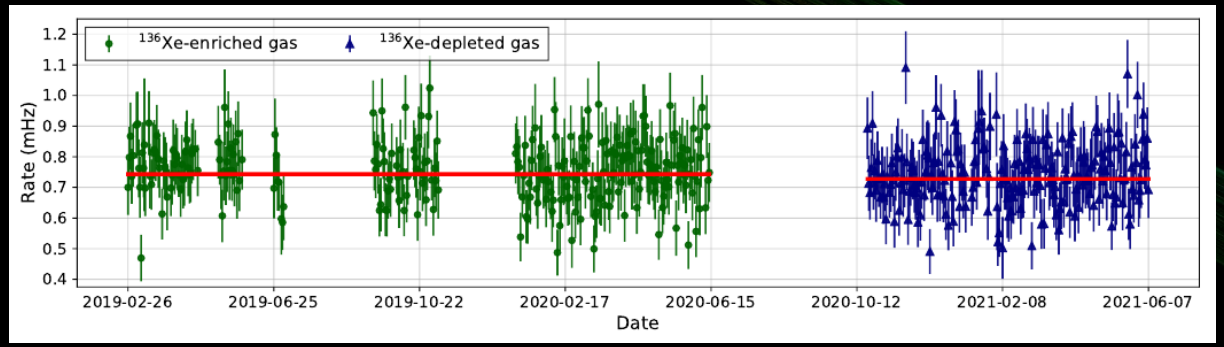


Background Stability Checks

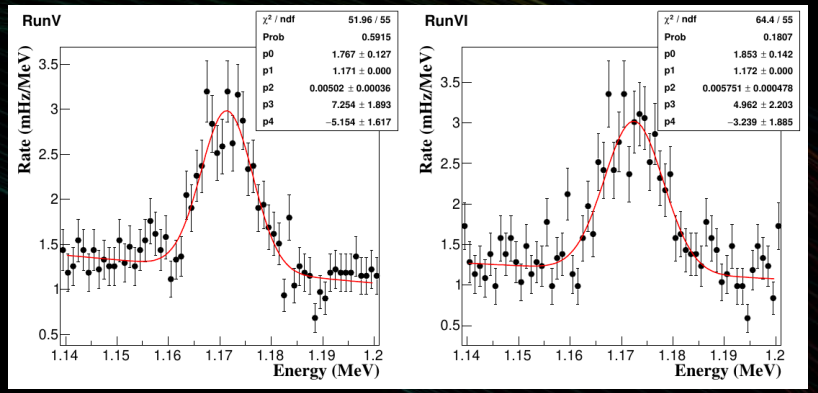
- Corrected rates for each data taking period



- Fiducial rates on a daily-basis:



- Intensity of ^{60}Co line



Background Model