Final results of the NEXT-White demonstrator

Adam Redwine
on behalf of
the NEXT Collaboration

אוניברסיטת בן-גוריון בנגב
Ben-Gurion University of the Negev

The NEXT Collaboration

Pursuing $\beta\beta0\nu$ in ^{136}Xe

- An international collaboration since circa 2008
  - Led by J.J. Gómez Cadenez and Dave Nygren with important early contributions by the late James White
  - Operated at and working closely with the Underground Laboratory of Canfranc, Spain
- Collaboration is developing and operating a series of high-pressure xenon time projection chambers
  - Have demonstrated technology to achieve excellent energy resolution, leverage track topology, and minimize background

USA

Spain

Portugal, Israel, Colombia

Spokesperson: J.J. Gomez-Cadenas

LSC

Laboratorio Subterráneo de Canfranc

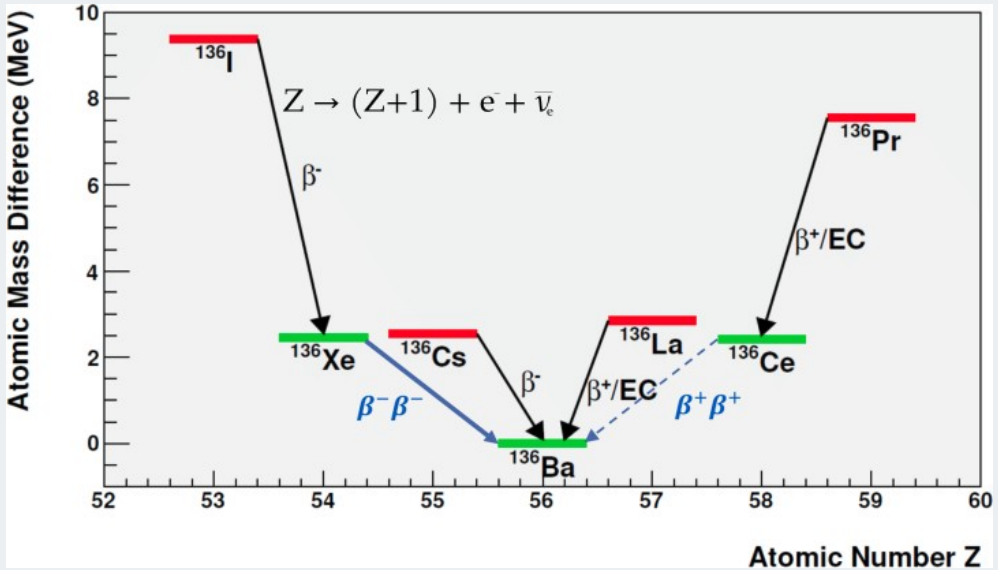
NEXT Collaboration

2022 Collaboration Meeting

Not all collaboration members shown

Neutrinoless Double Beta Decay

- Direct probe of potential Majorana nature of neutrino
  - Would demonstrate violation of total lepton number,
  - Provide supporting evidence for the seesaw mechanism and leptogenesis
  - Give a handle on absolute neutrino mass
- Detectable only when single-beta decay is energetically forbidden
  - Occurs in about a dozen viable isotopes
- Half-life in ^{136}Xe > 2.3 x 10^{26} yr arXiv:2203.02139



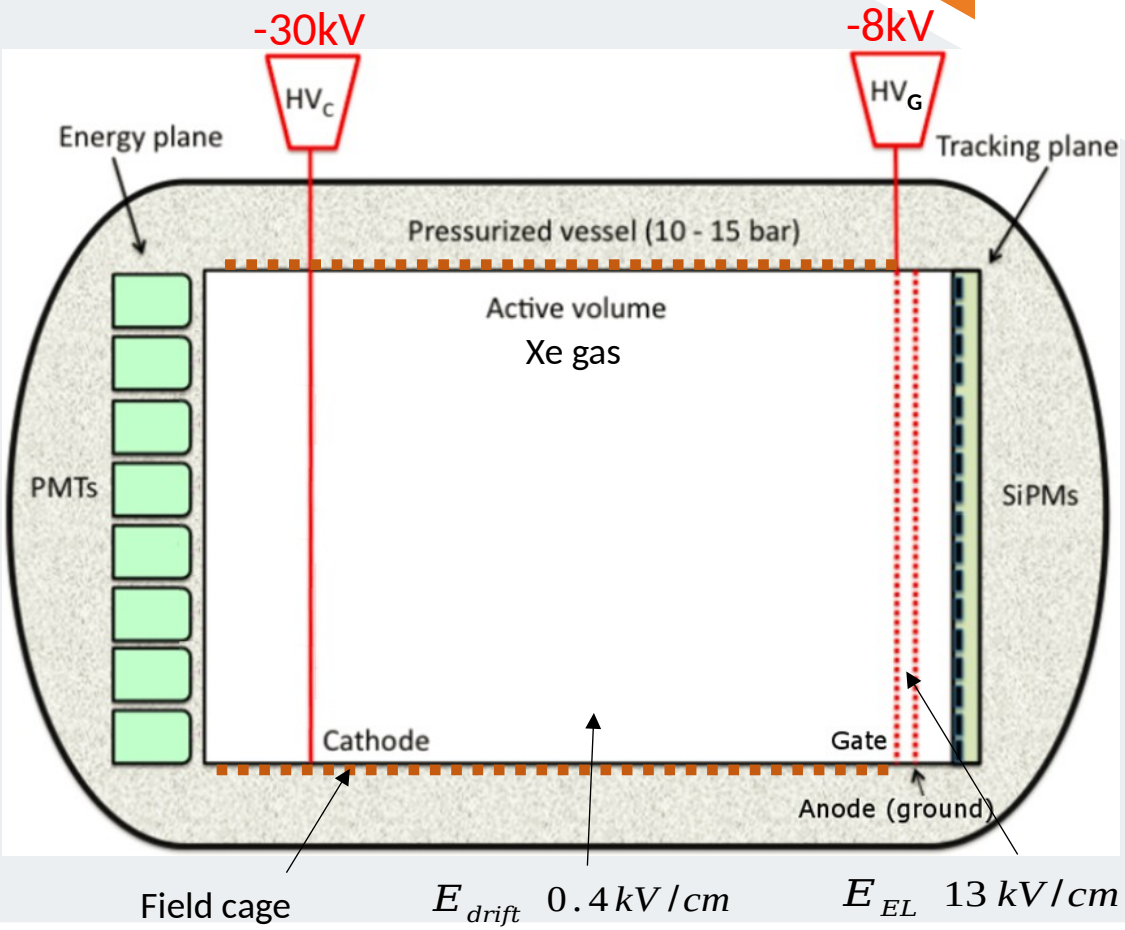
NEXT: Neutrino Experiment with a Xenon TPC

- Searching for ββ0ν in ^{136}Xe in a high-pressure xenon gas TPC
- Working in gas rather than liquid allows:
  - Excellent energy resolution with electroluminescence (EL)
    - demonstrated 1% FWHM at $Q_{\beta\beta}$=2.458 MeV, aiming at 0.5% JHEP 10 (2019) 230
  - Track topology allowing signal/background discrimination based on track shape
    - events span ~10 cm vs. point-like in liquid
- High pressure required to assemble enough mass in a reasonable volume
- Recently concluded operation of NEXT-White detector
- NEXT-100 (97 kg enriched Xe at 15 bar in active volume) is under construction
- Future stages: tonne-scale detector (NEXT-HD), barium tagging

NEXT Time Projection Chambers

NEXT DEMO, NEXT DBDM, NEXT-White, NEXT 100

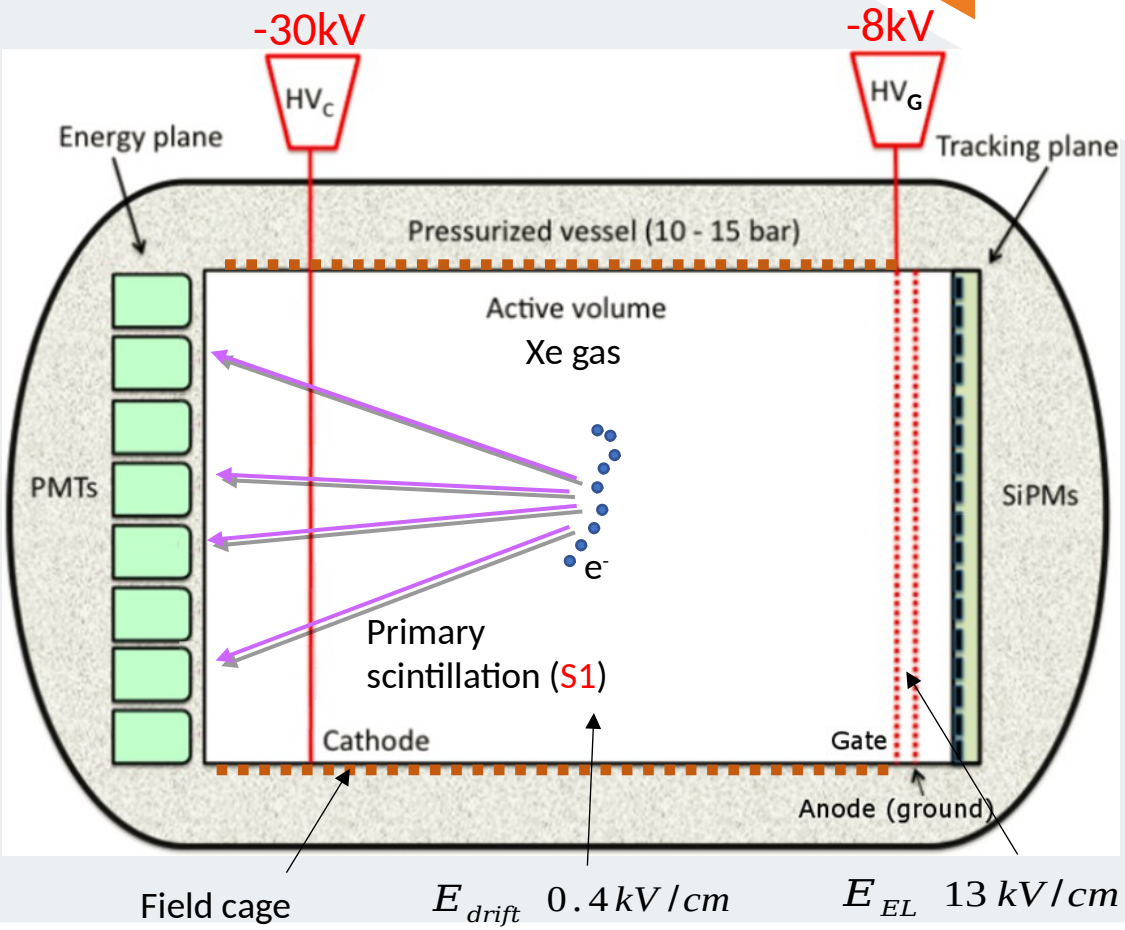
- Event ionizes and excites atoms within fiducial volume



NEXT Time Projection Chambers

NEXT DEMO, NEXT DBDM, NEXT-White, NEXT 100

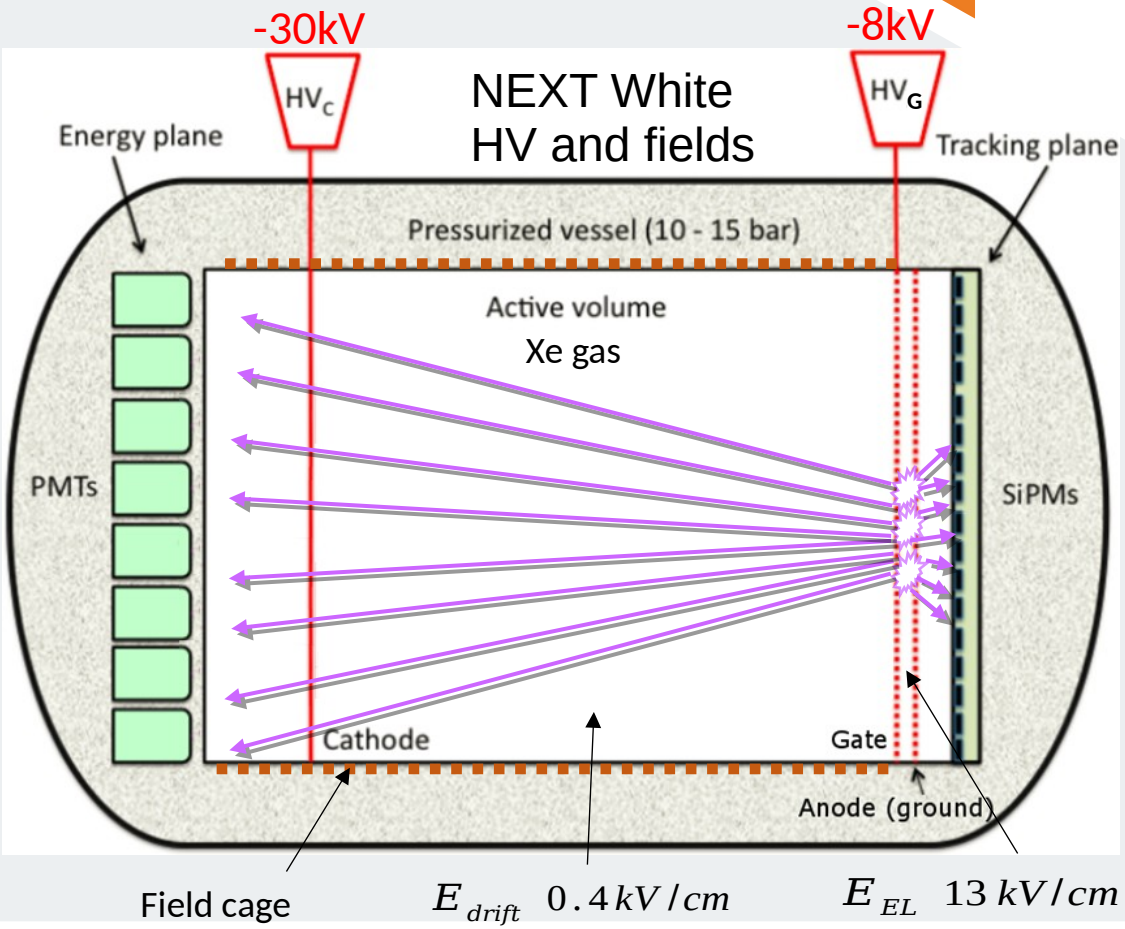
- Event ionizes and excites atoms within fiducial volume
- Energy plane detects de-excitation (S1) for timing



NEXT Time Projection Chambers

NEXT DEMO, NEXT DBDM, NEXT-White, NEXT 100

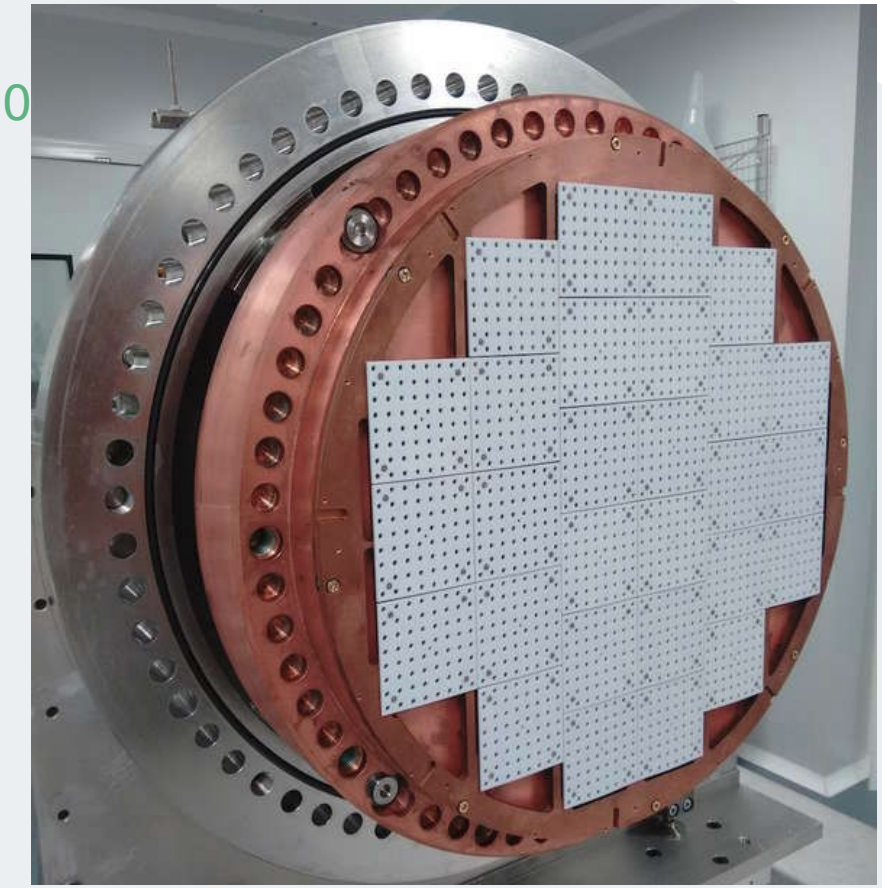
- Event ionizes and excites atoms within fiducial volume
- Energy plane detects de-excitation (S1) for timing
- Electrons drift toward and through high electric field gap, inducing EL proportional to their number
- EL light (S2) integrated by PMTs to measure the event energy
- Event topology reconstructed using xy time-slices recorded by SiPMs



NEXT-White

Radiopure large-scale demonstrator

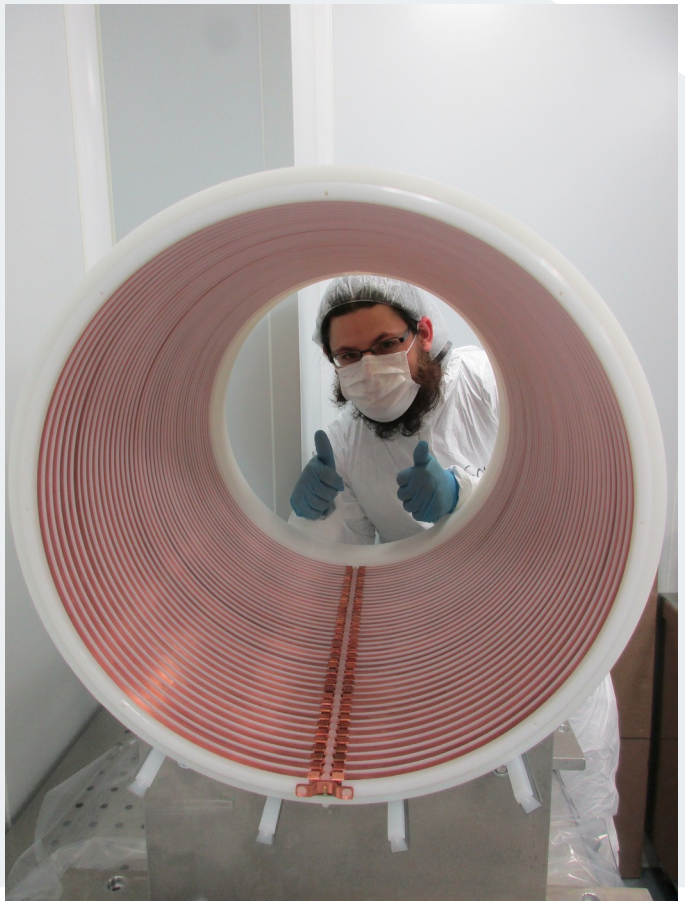
- Operated from 2016 through 2021 JINST 13 (2018) P12010
- Located in Laboratorio Subterranio Canfranc
- Drift length: 530 mm
- Radius: 208 mm
- Mass of xenon: ≈ 5 kg @ 10 bar
- Tracking plane: 1,792, 1 mm^2 silicon photomultipliers
- Energy plane: 12, 3” Hamamatsu PMTs



NEXT-White

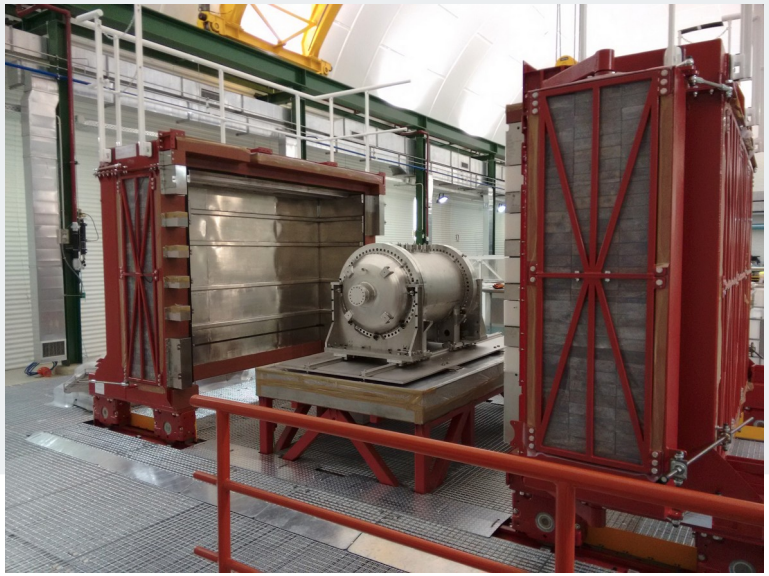
Radiopure large-scale demonstrator

- NEXT-White was the largest high pressure gas TPC using EL to date
  - NEXT-100 (under construction) is more than twice this size
- NEXT-White has demonstrated
  - 1% FWHM resolution at $Q_{\beta\beta}$ and
  - Use of track topology for effective signal discrimination
  - Low background operation and unique background subtraction technique for measuring ββ2ν



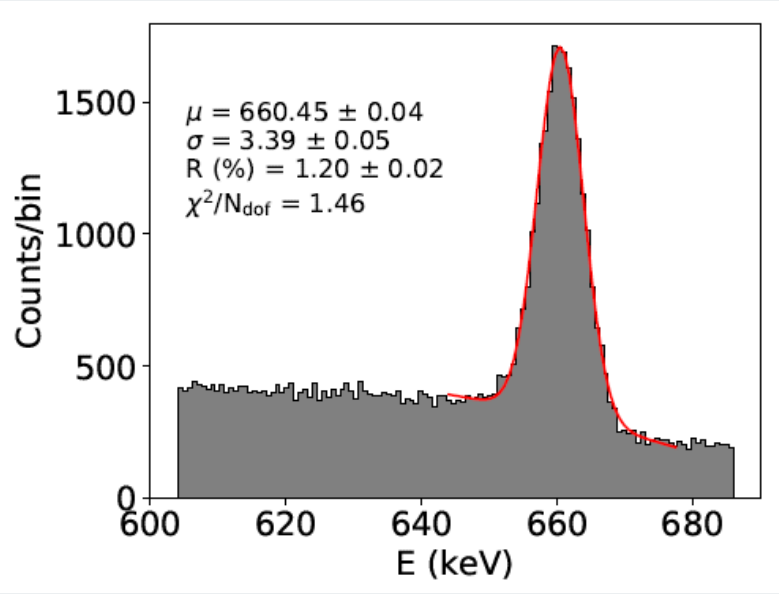
NEXT-White Detector

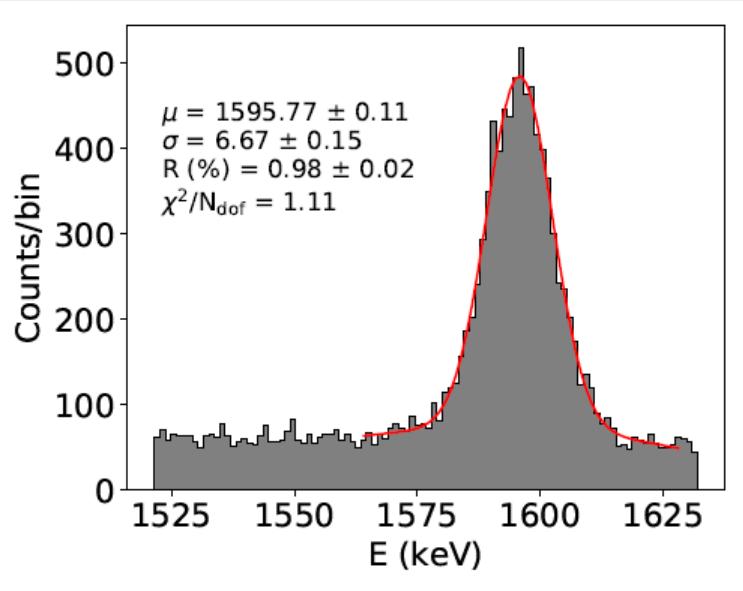
On-Site at Canfranc

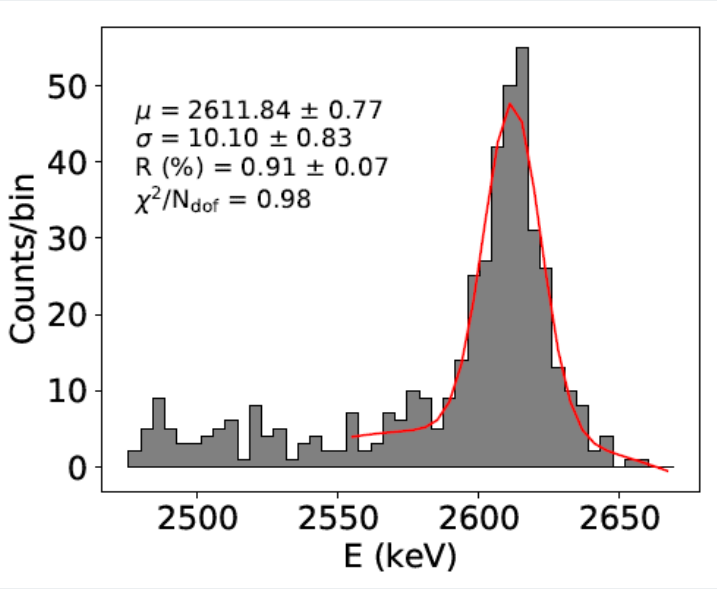


NEXT-White Energy Resolution

- Energy resolution determined using
  - ^{137}Cs 662 keV photopeak
  - ^{208}Tl 1593 keV double escape peak and 2615 keV full absorption peak
- Double escape peak also allows testing of topological analysis



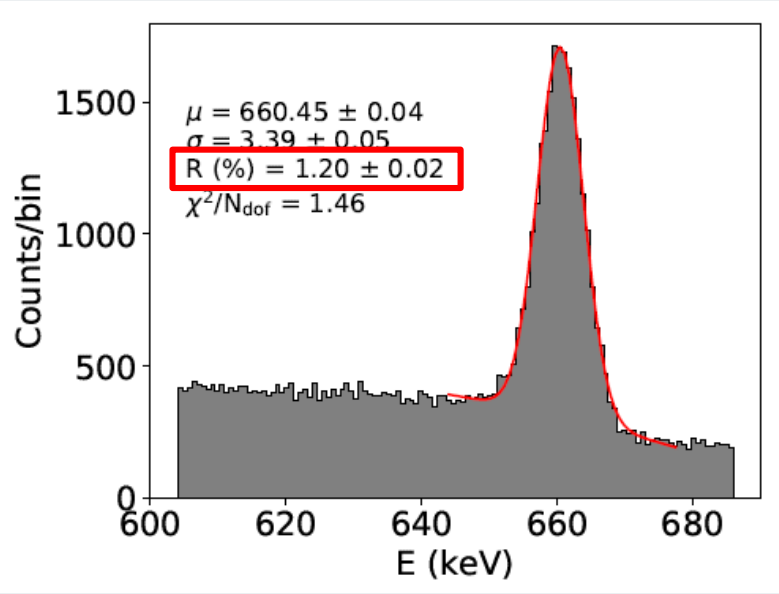


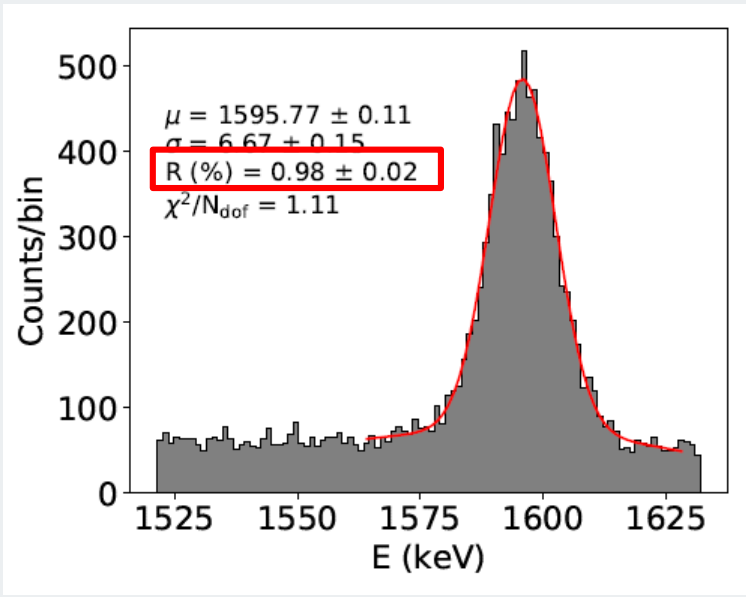


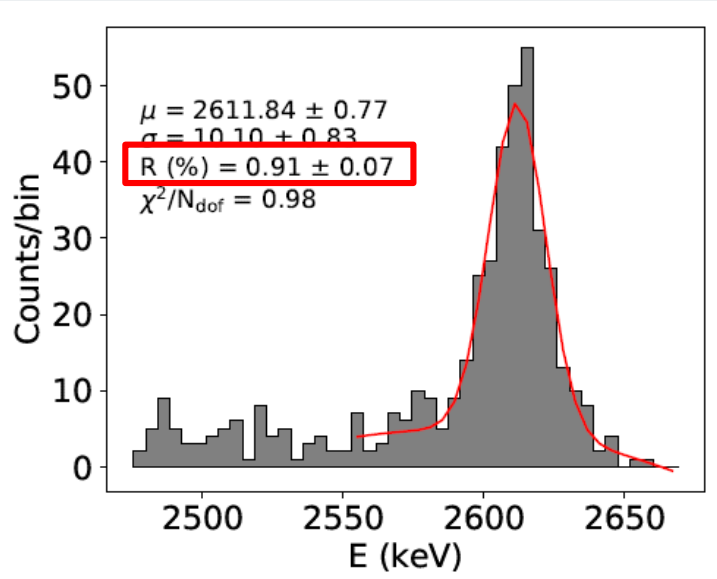
JHEP 10 (2019) 230

NEXT-White Energy Resolution

- Energy resolution determined using
  - ^{137}Cs 662 keV photopeak
  - ^{208}Tl 1593 keV double escape peak and 2615 keV full absorption peak
- Double escape peak also allows testing of topological analysis





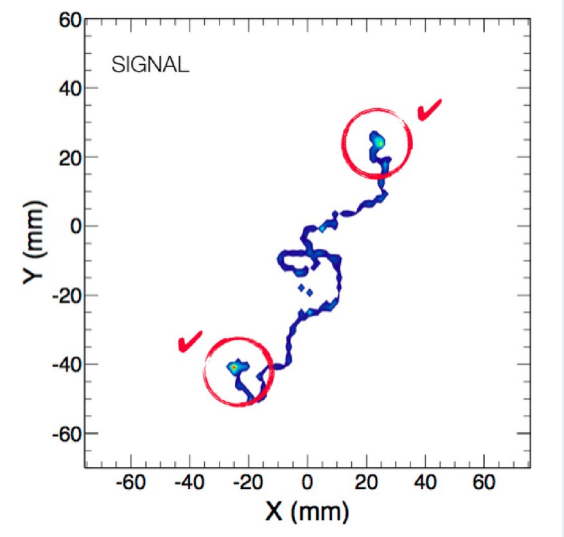


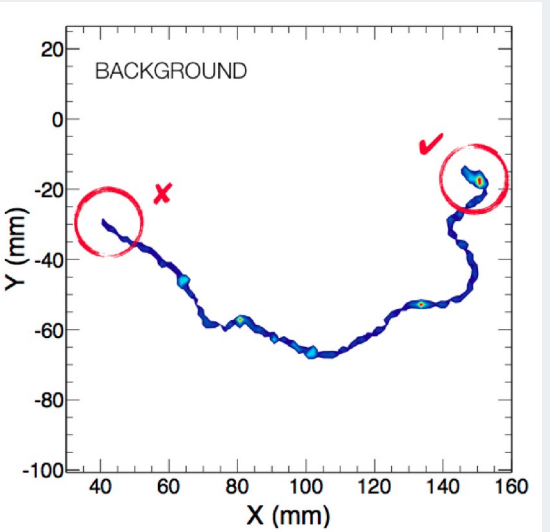
JHEP 10 (2019) 230

Background-Signal Discrimination

Topological Analysis

- Slowing of fast electrons increases energy deposition (blob) at the Bragg peak
- Signal events consist of two fast electrons with coincident start and different ends (two blobs)
- Single-electron background events have only one blob
- Multiple-track events are discarded as background

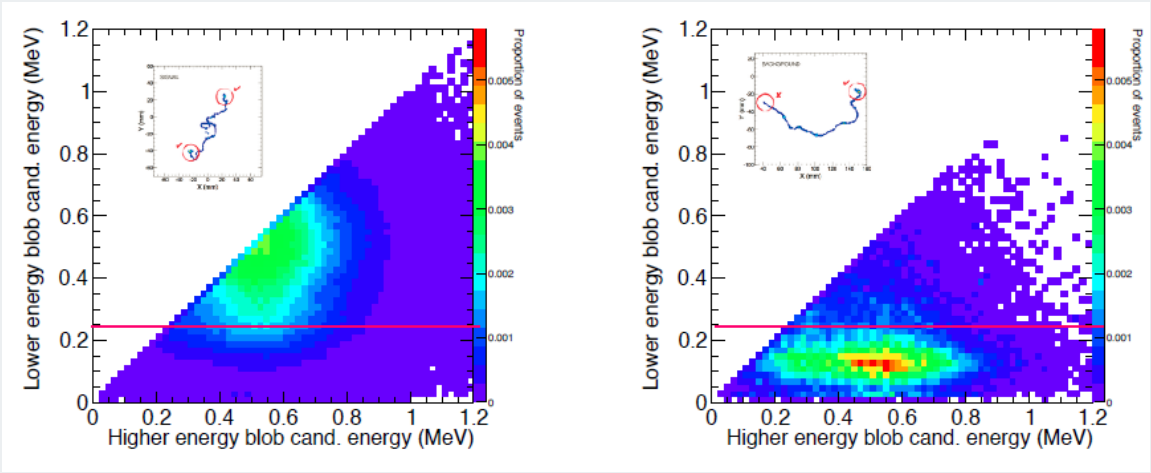




Background-Signal Discrimination

Topological Analysis

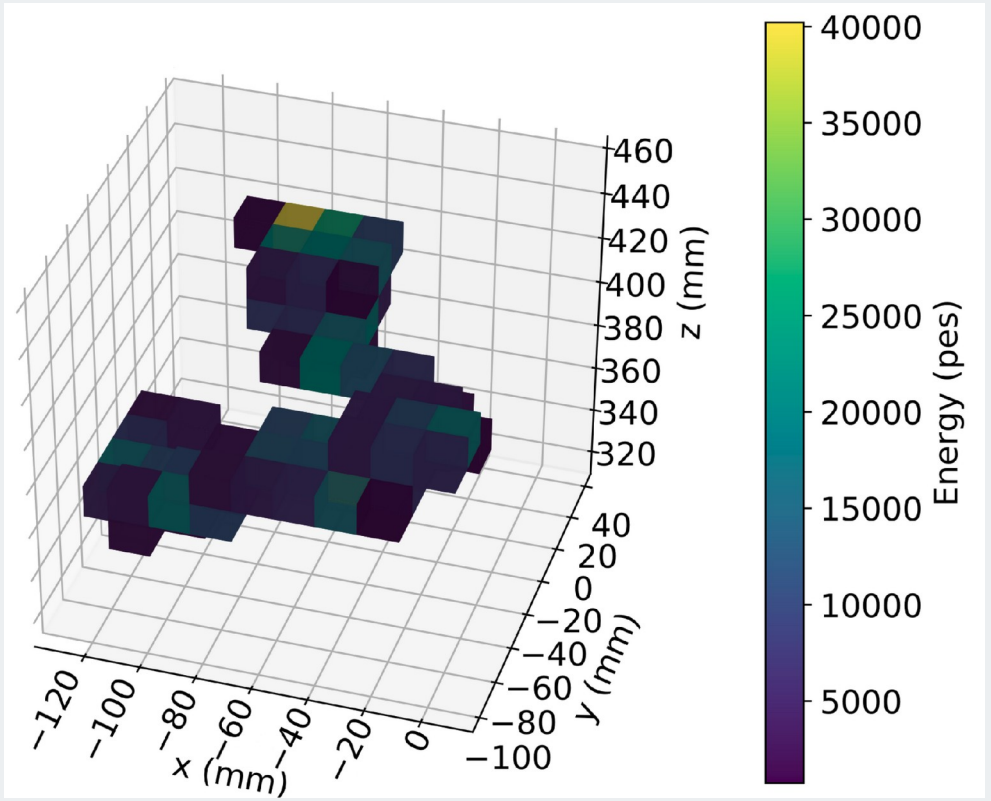
- Slowing of fast electrons increases energy deposition (blob) at the Bragg peak
- Signal events consist of two fast electrons with coincident start and different ends (two blobs)
- Single-electron background events have only one blob
- Multiple-track events are discarded as background



JHEP 1605 (2016) 159

Richardson-Lucy Deconvolution

- Prior topological analysis applied at scale of SiPM hardware resolution (10 mm pitch)
- Topological analysis is impaired by low resolution
  - Ionization electrons diffuse during drift
  - Electroluminescent gap induces light spread
  - Tracking plane has only 1% coverage
- Richardson-Lucy (RL) deconvolution is an iterative process to reverse blurring using known point spread function
- Applied to 1.6 MeV ^{208}Tl pair production ROI data

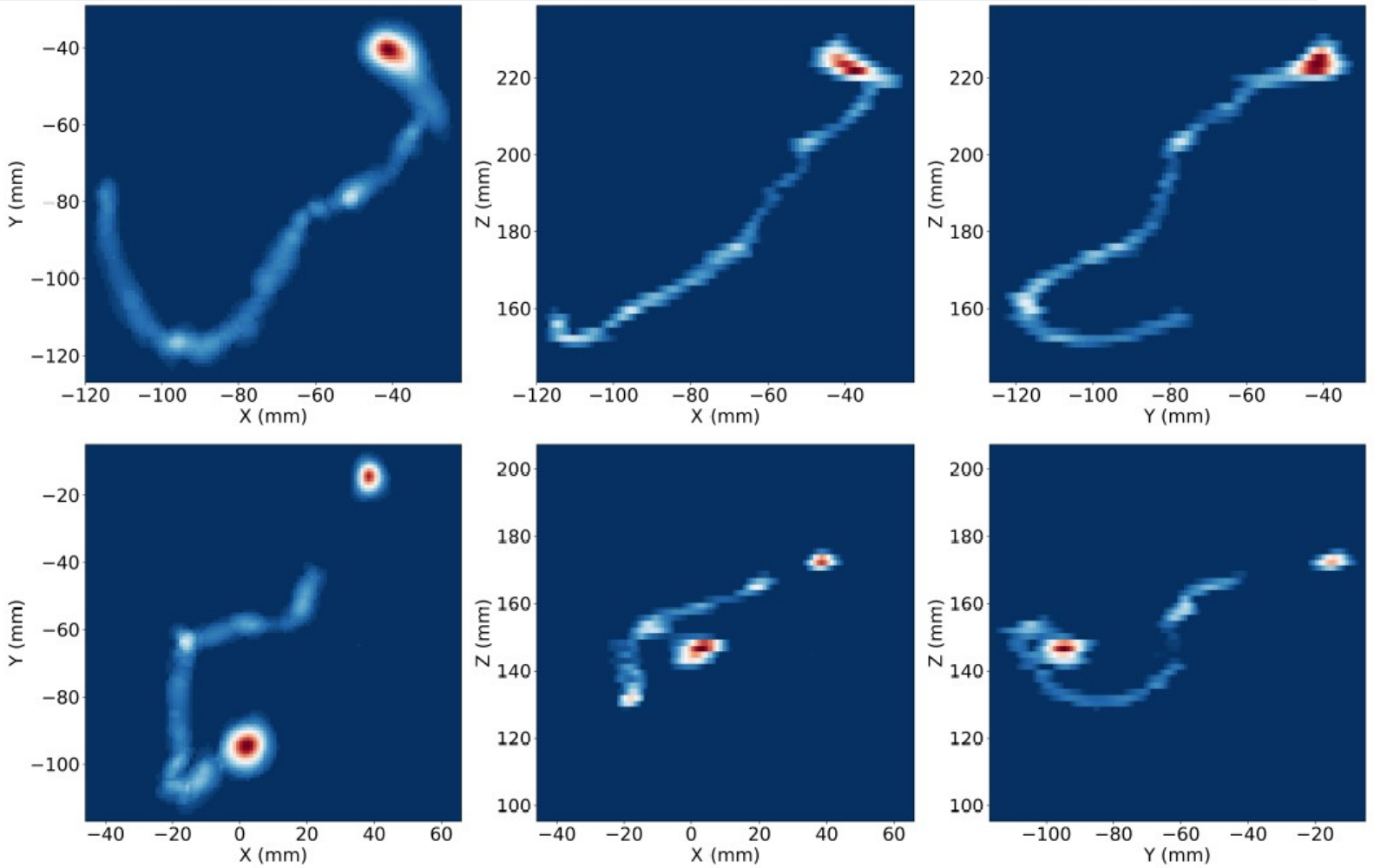


Events Observed in NEXT-White

^{208}Tl double escape peak ROI

- Event energy ~1.6 MeV
- **Real data** recorded by NEXT-White and processed through RL deconvolution
- Compton electron events classified as background

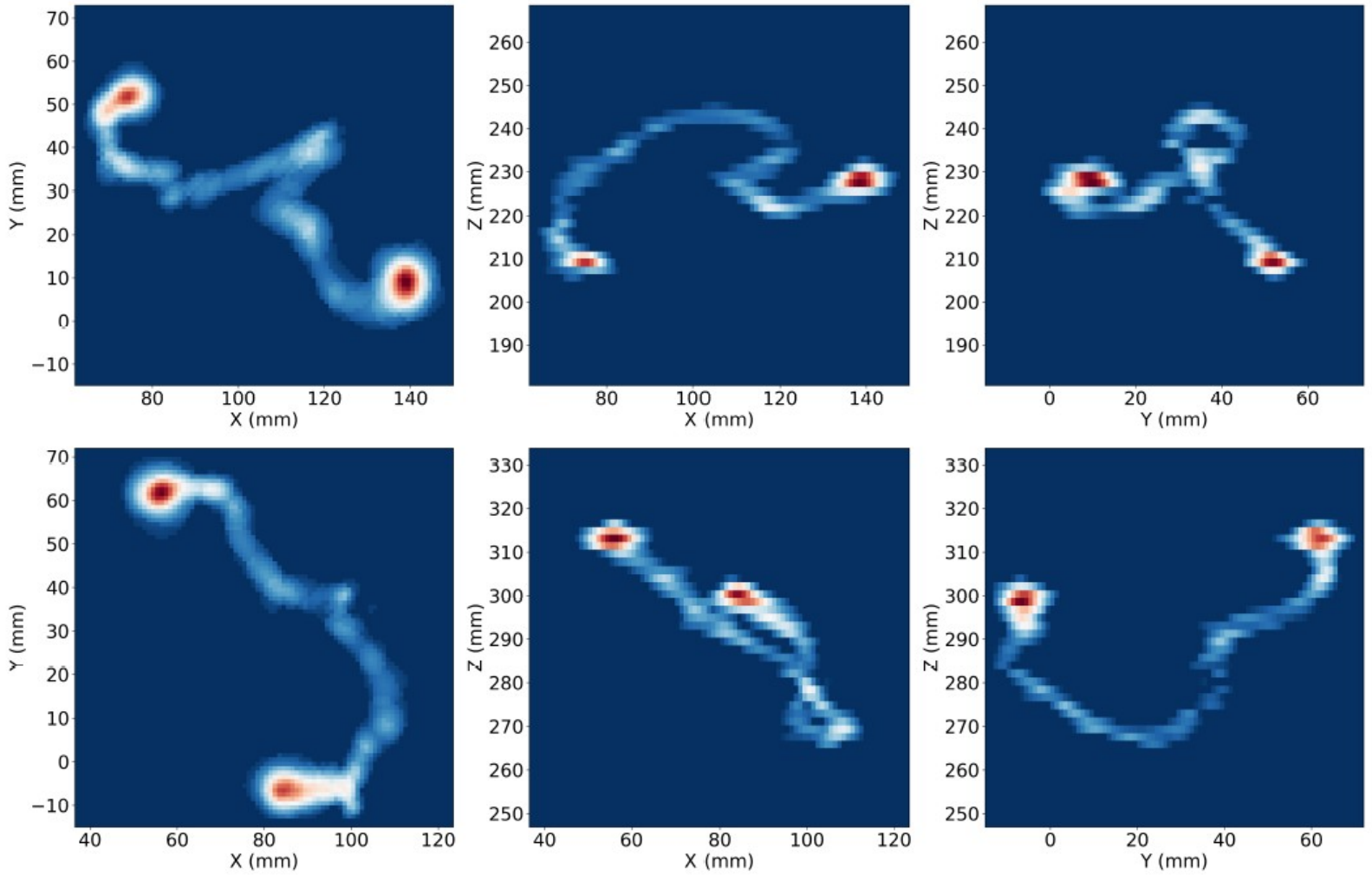
JHEP 21 (2021) 146



Events Observed in NEXT-White

^{208}Tl double escape peak ROI

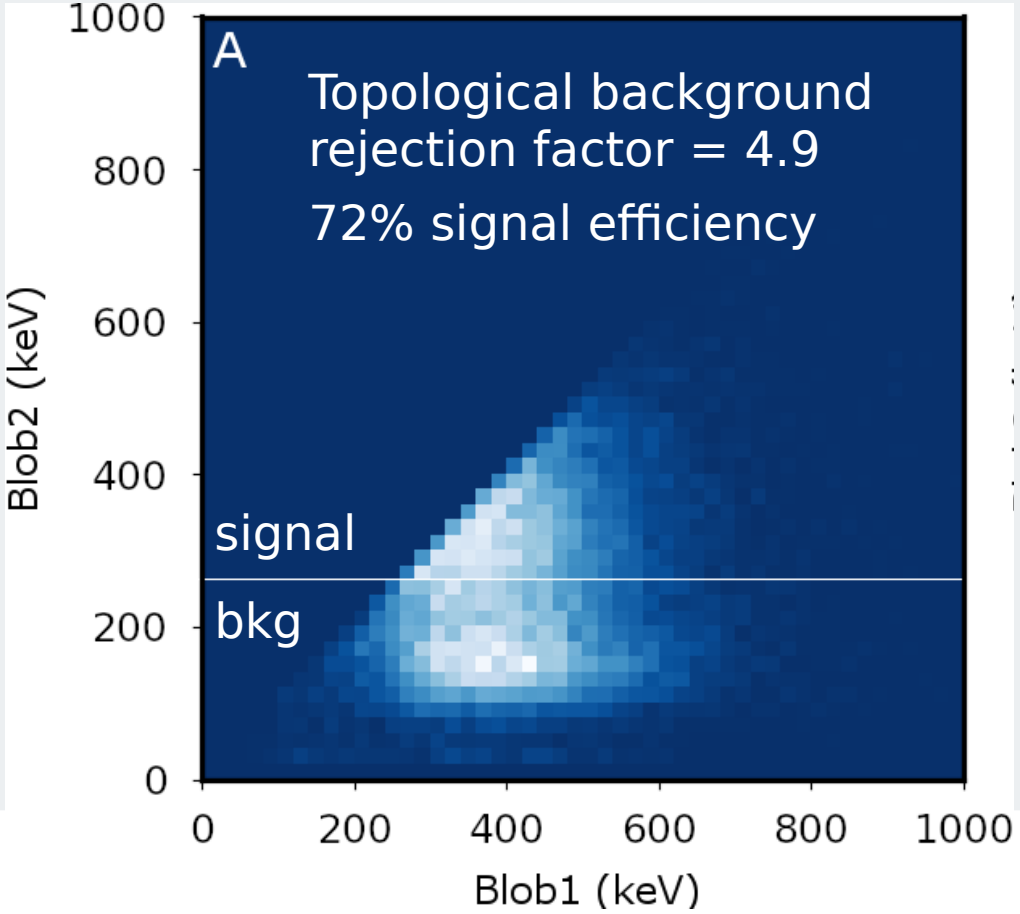
- Event energy ~1.6 MeV
- **Real data** recorded by NEXT-White and processed through RL deconvolution
- Electron-positron pair production events
  - Considered signal-like for topological analysis



Background-Signal Discrimination

Topological Analysis

Prior to RL Deconvolution

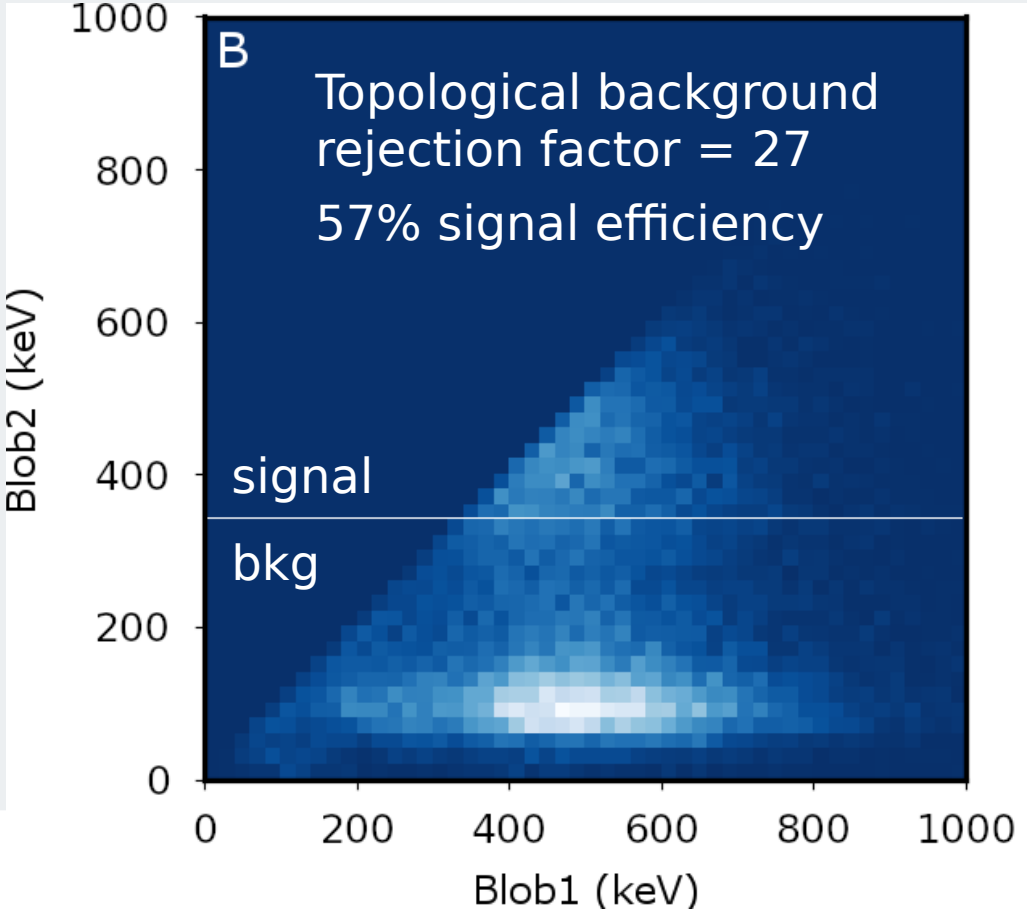


JHEP 10 (2019) 230

Background-Signal Discrimination

Topological Analysis

With RL Deconvolution

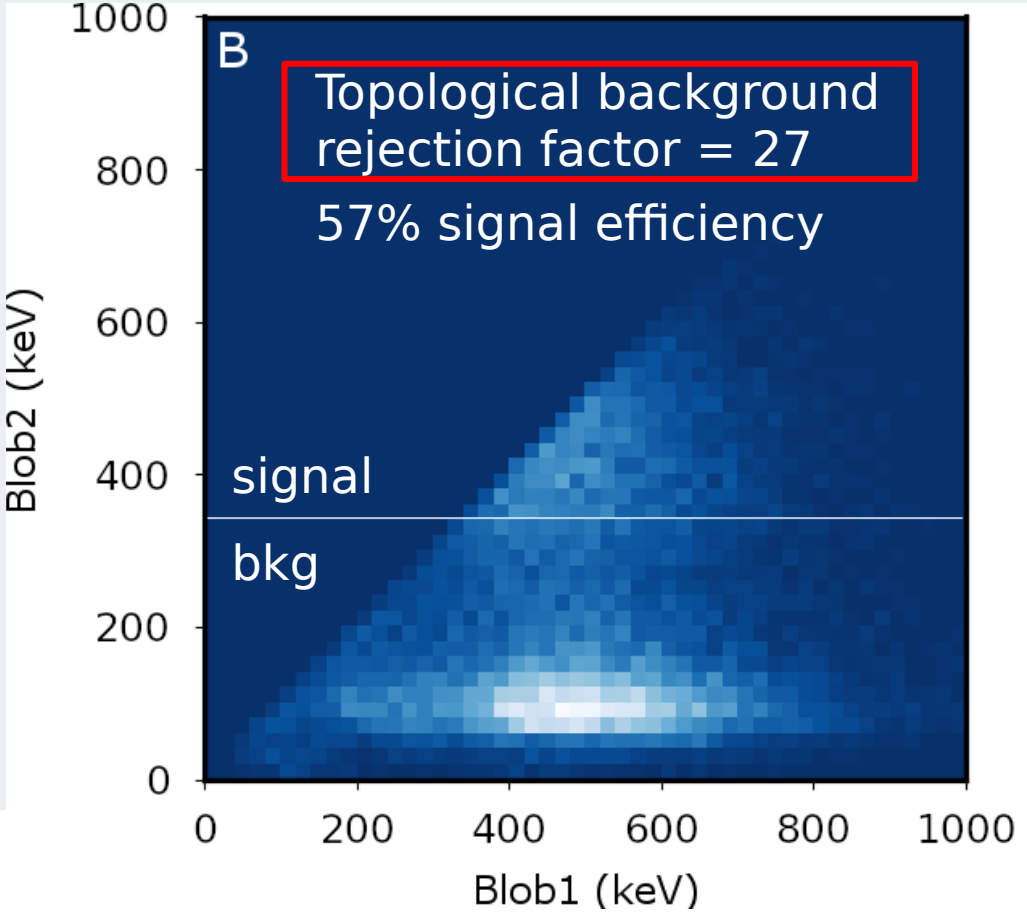


JHEP 10 (2019) 230

Background-Signal Discrimination

Topological Analysis

With RL Deconvolution

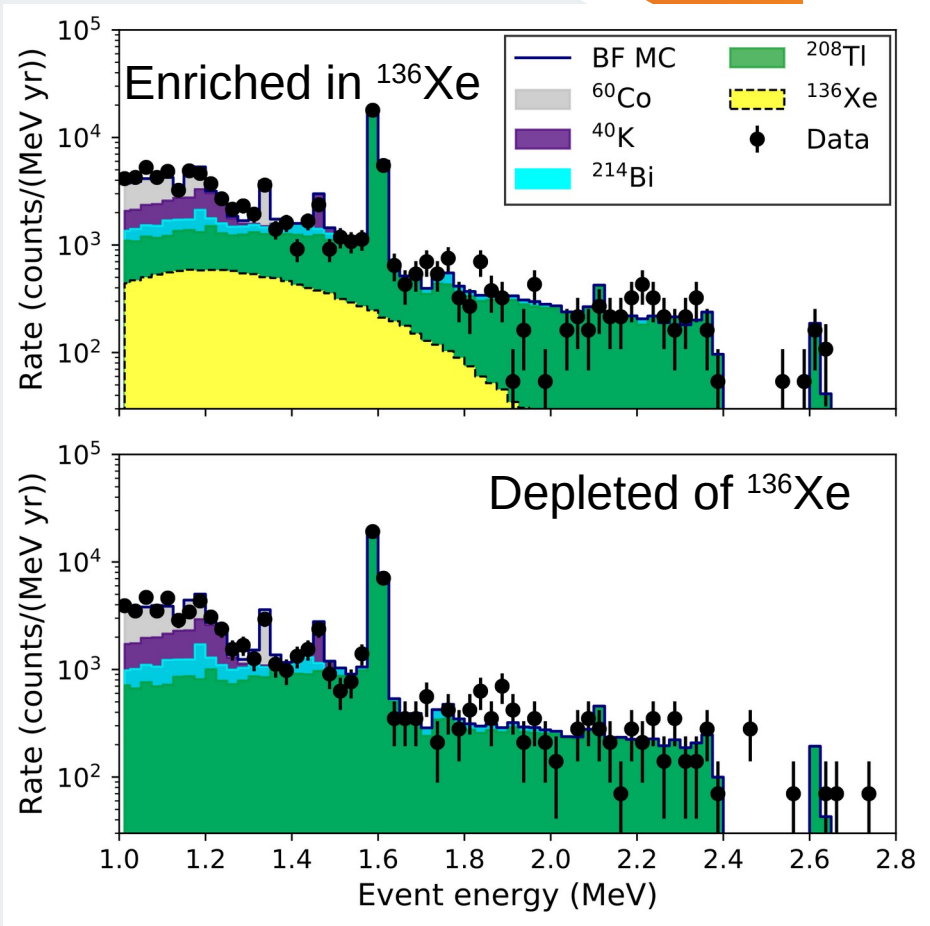


JHEP 10 (2019) 230

ββ2ν $T_{1/2}$ Determination

Background Analysis

- NEXT-White allowed for unique ββ2ν measurement based on two runs with same background rate
  - 208.9 days accumulated runtime with gas depleted to 2.6 ± 0.2 ^{136}Xe
  - 271.6 days accumulated runtime with gas enriched to $90.9 \pm 0.4\%$ ^{136}Xe
- Event rate spectrum of depleted run subtracted from spectrum of enriched run and remaining data fit to ββ2ν spectrum



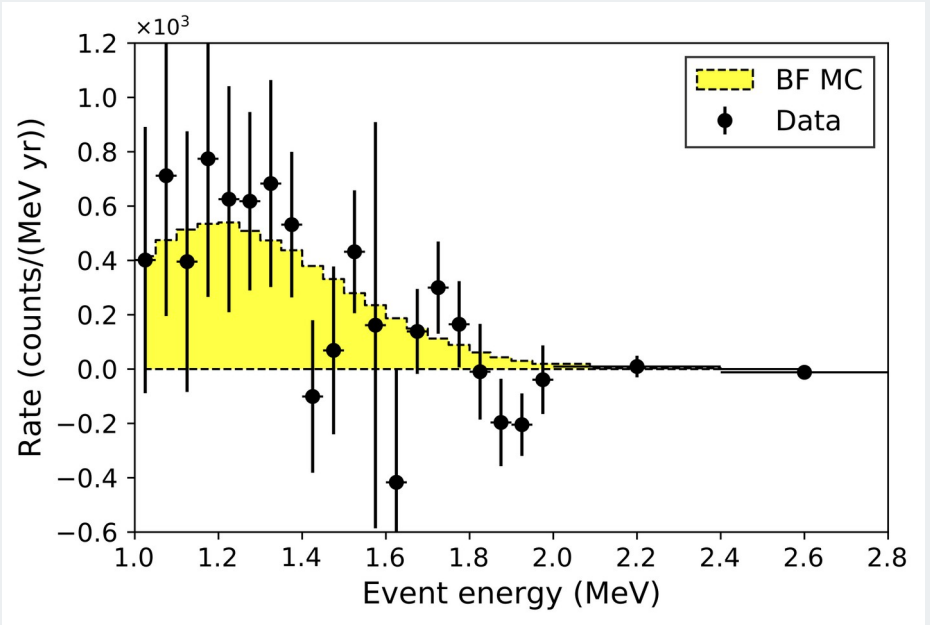
ββ2ν $T_{1/2}$ Determination

Halflife measurement

- Fiducial mass of 3.5 kg PRC 105 (2022) 055501
- Measured half-life is

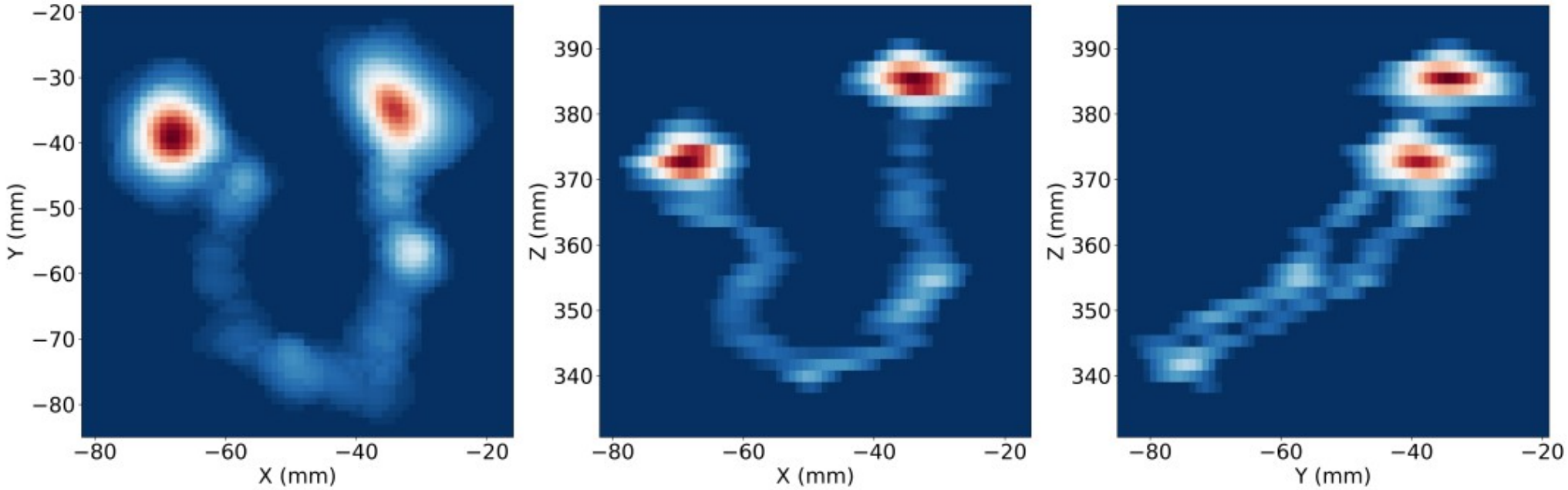
  $T^{2\nu}_{1/2}$: $2.34^{+0.80}_{-0.46}$ (stat) $^{+0.30}_{-0.17}$(sys) $\times 10^{21}$yr

- Consistent with the value reported by others
  - KamLAND-Zen: 2.167±0.016 (stat)±0.059(sys) $\times 10^{21}$yr PRL 122 (2019) 192501
  - EXO-200: 2.11±0.04(stat)±0.21(sys) $\times 10^{21}$ yr PRL 107 (2011) 212501
- Monte Carlo modeling comparison to data shows a stable, well-quantified background to support subtraction method



Candidate ββ2ν Event

Real Data Detected by NEXT-White



NEXT steps

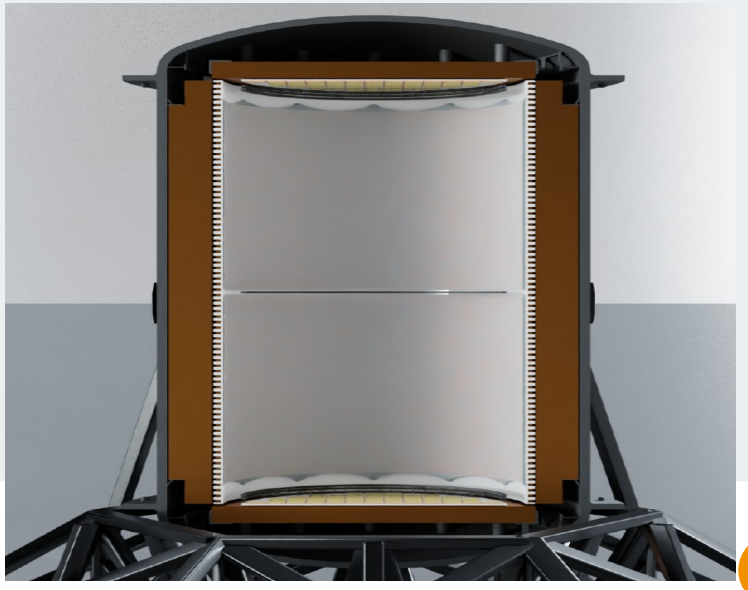
Future detectors from the NEXT Collaboration

- NEXT-100
  - Demonstrate NEXT TPC technology at 100 kg scale
  - Currently under construction at Canfranc

NEXT steps

Future detectors from the NEXT Collaboration

- NEXT-100
  - Demonstrate NEXT TPC technology at 100 kg scale
  - Currently under construction at Canfranc
- NEXT-HD
  - Tonne scale detector planned for 2026 start
  - Bi-directional, symmetric TPC with central cathode
  - Energy and tracking by dense SiPM planes on either end
  - Additional energy information from fibers along sides of the barrel



Conclusions and Summary

- Detection of neutrinoless double-beta decay would provide strong hints at the nature of physics beyond the Standard Model
- NEXT Collaboration has designed and operated a series of gaseous TPCs
  - NEXT-White, world's largest EL-TPC, operated 2016-2021
  - NEXT-White has demonstrated key technologies including
    - Excellent energy resolution,
    - Use of topological analysis for background discrimination, and
    - Low background and model independent ability to measure ββ2ν half-life

Thank You.

אוניברסיטת בן-גוריון בנגב
Ben-Gurion University of the Negev