Lightmap reconstruction in nEXO with an internal $^{127}$Xe source

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on behalf of the nEXO collaboration
Light Detection In Noble Elements (LIDINE)
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Background: the nEXO Experiment

- Single phase time projection chamber (TPC) to search for neutrinoless double beta decay
- 5 tonnes liquid xenon enriched to 90% in $^{136}\text{Xe}$
- Half-life sensitivity $> 10^{28}$ years

[arXiv:2106.16243]
Charge & Light Reconstruction

- Long drift length
  ⇒ **electron lifetime** correction

- Variation in photon transport efficiency
  ⇒ **lightmap** correction

- External gamma sources
  - Easy to deploy
  - Calibration over full energy range of interest
  - No risk of introducing backgrounds
  - Strong attenuation in skin xenon
  - Sacrifices livetime

- Internal alpha sources
  - Excellent resolution (~1%)
  - Illumination of entire detector volume
  - Sacrifices livetime

1.2m drift length
Internal Calibration Sources: $^{127}$Xe

- Electron capture to excited states of $^{127}$I
- 36 day half-life, Q = 662 keV
- Mixes uniformly throughout TPC
- Aim for ~1 Bq activity during calibration period
- No sacrifice of livetime required

![Geant4-simulated energy spectrum](image)
$^{127}$Xe Charge & Light Production

- Intrinsic peak width of ~10% due to recombination fluctuations
- Low energy peak near nEXO threshold of ~200 keV
- High energy peak well above threshold
- Well below 0vBB ROI

Substructure smeared into two peaks
Activation & Counting

- $^{127}\text{Xe}$ produced by neutron capture on $^{126}\text{Xe}$
- Sample cylinder containing 70g $^{\text{nat}}\text{Xe}$ gas ($\sim0.1\%^{126}\text{Xe}$) irradiated at MNRC nuclear reactor facility
- Radioassay at MNRC & Stanford, HPGe counting at U. of Alabama to determine activity

Dominant activity after $\sim100$ days is from $^{127}\text{Xe}$
Preliminary Results from Stanford TPC

- Injected $^{127}$Xe during recirculation
- Delayed increase in trigger rate as $^{127}$Xe mixes into TPC volume
- Events from both peaks clearly visible
- Full electron lifetime calibration results to be published soon

**Maximum drift time**

**Minimum drift time**

$^{127}$Xe lines @ 200 & 400 keV

$e$-lifetime $\approx 55$us
Lightmap Reconstruction from Calibration Data

1. Compute efficiency for each event
2. Feed \((x, y, z, \text{eff})\) into a function that fits efficiency throughout entire volume
3. Produce continuous map of light collection efficiency
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![Diagram showing the process of reconstructing a lightmap from calibration data.](image)
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Histogram
Spline fit
Neural net

Layers: [512,256,128,64,32]
Batch size: 64
Learning rate: 4e-4
Epochs: 10
Simulating $^{127}$Xe Data in nEXO

- Simulations using Geant4-based \texttt{nexo-offline} simulation package
- Detailed geometry and NEST software to model charge and light production in TPC
- “Truth” lightmap produced using Chroma, GPU-based ray tracing software
- \textbf{Binomial sampling} of detected photons for each simulated event
- \textbf{Poisson fluctuations} added, representing correlated avalanches

![True Lightmap](image)
Cuts & Peak Selection

- 20 mm standoff cut
- Diagonal peak selection cut in raw detected photons & detected electrons
- Scale efficiency by the expected number of scintillation photons from NEST
- Adding lower energy peak doubles the number of calibration events

Uncorrected light signal smeared by position dependent photon transport efficiency
Results - Reconstructed Lightmap

- Systematic errors that depend on the true lightmap
  - With few training events, NN tends toward uniformity
  - Regions of greater deviation have larger systematic reconstruction errors
  - Errors recede with more calibration events, and are outside inner 2 tonnes
Results - Uncertainty in Reconstructed Lightmap

- 0.5% error in inner 2 tonnes with 1M events (~2 weeks at 1 Bq)
- Improvement slows with larger datasets as calibration data is limited by source width
- Systematic errors visible in smaller datasets disappear with more events
- Significantly better performance toward TPC center where penetration of external gammas is limited
Conclusions

- nEXO requires position-dependent calibrations of the light response to optimize energy resolution
- An internal $^{127}$Xe source avoids some of the drawbacks of other sources
- Activation and implementation of an internal $^{127}$Xe source has been studied at Stanford
- Simulations of $^{127}$Xe decays in nEXO have been used to project the reconstructed lightmap accuracy for various dataset sizes
- At 1 Bq, 0.5% lightmap error in inner 2 tonnes achievable in ~2 weeks
The nEXO Collaboration
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