Electroluminescence R&D Toward Ton-Scale HPGXe Neutrinoless Double Beta Decay Experiments

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Supported by:
Neutrinoless Double-Beta Decay

- If a neutrino is its own antiparticle (Majorana) a double beta decay without emission of antineutrinos is possible.

- This would cause the two beta particles to carry all the energy difference from the initial and final nuclei.

- Seeing this event would tell us that Lepton number is not conserved.
Basic Principles of the Detector

- 10-15 bar of HPGXe136
- Drift Region 300 V/cm
- Electroluminescent Region of 56 kV/cm (5.6 kV/cm/bar at 10 bar, 3.73 kV/cm/bar at 15 bar)
- PMTs and SiPMs for capturing 175nm light that will be wavelength shifted with TPB
Advantages of HPGXe136

Using gaseous Xenon versus liquid allows a clear topological reconstruction and low fluctuation gain using electroluminescense

Measuring ionization only (@662 keV)

**Bolotnikov, & Ramsey NIMA, 396, 360–370.**

\[
e^{-} + \text{Xe} \rightarrow e^{-} + \text{Xe}^{*} \rightarrow e^{-} + \text{Xe} + \gamma
\]
How to Tell if We Have a $0\nu\beta\beta$ Decay

2 Steps

- First, topology: spaghetti with two meatballs
- Second, energy resolution

To do this we need a way to separate single electron tracks from signal using the event topology
Sequence of Detectors for NEXT Program

• NEXT-DBDM  <1kg located in Berkeley National Lab
• NEXT-DEMO  1-2kg located in Valencia
• NEXT-NEW  5-10kg currently collecting second run of data in Laboratorio Subterráneo de Canfranc (LSC)
• NEXT-100  100kg under construction in the tunnels of Canfranc
• NEXT-XXX  1 tonne with location to be determined
NEXT-NEW Components

- Copper rings
- HDPE field cage + teflon reflector
- Tracking plane of 1 cm pitch, Kapton boards, teflon masks
- High Voltage Feedthrough
- Inner copper shield 6 cm thick
- Energy plane, 30% coverage
The most recent run of NEXT-NEW provided an energy resolution that extrapolates to 0.43% FWHM at Qbb assuming no constant term.


J. Renner et al., Initial results on energy resolution of the NEXT-White detector, JINST 13 (2018) , no.10 P10020, [arXiv:1808.01804]
NEXT-NEW Results Using Co-56

Paola Ferrario, The NEXT double beta decay experiment, [arXiv:1710.03022]
Electroluminescence Requirements

- Robust under HV discharges
- >80% photon transparency
- EL response to be smooth and better than 0.5% FWHM after calibration
- < 1% peak-to-peak gain stability over time once charged
- Radio purity better than 20% of tracking plane
- Small photoelectric yield (<10^4) i.e. number of released photoelectrons by the 175 nm VUV photons, per primary electron entering the EL region must be <10^4
Scaling up Electroluminescence

- Large electric fields create electrostatic forces which warp the thin meshes (standard in smaller diameter EL regions)
Scaling up Electroluminescence

- Large electric fields create electrostatic forces which warp the thin meshes which are standard in smaller diameter EL regions.
- Make Anode out of a solid piece of transparent and resistive material so only dealing with the warping on one side.
Anode Requirements

- Robust under HV discharges
- Transparent to visible light
- Resistive
- Minimal deflection under high electrostatic forces
Anode Material Options

Two transparent, resistive anode configurations were considered

Static dissipative acrylic

- Pro: simplicity of manufacture, guaranteed uniformity
- Pro: radio-purity measured to be acceptable

PEDOT coating on acrylic or quartz

- Pro: known radio-pure
- Con: Manufacture at large scale is awkward, maybe non-uniform

PEDOT coated acrylic, spin coated onto large disk at UTA and cut up
Anode Material Resistivity Properties

Resistivity Uniformity of both samples has been quantified:

\[ \text{SDA: } 20.9 \pm 2.4 \text{ M}\Omega/\text{sq.} \]

\[ \text{Pedot: } 3.16 \pm 0.15 \text{ M}\Omega/\text{sq. (but tunable in principle)} \]
Anode Material Optical Properties

Optical transparency of both samples has been quantified.

**Bulk Losses:**
<0.5% light loss for both

**Sheet Losses:**
SDA: 84% transparent
Pedot: 83.3% transparent
Scaling up Electroluminescence Mesh

- The tighter the mesh is tensioned the less it deforms
- A single support post greatly decreases the amount of deflection under the same tension
- The post must be insulating but enough leakage current to avoid surface charge up effects
Effect on EL Due to Support Posts

- Affected region of support post is likely to be slightly larger than the post itself due to local field and optical response distortions.
- Assume events passing within some distance of a support post must be discarded.
- Inefficiency was assessed for various effective support post diameters using NEXT-100 MC neutrinoless double beta decay events.
Break Down Test Set Up

• Spherical electrodes with test insulator pieces held between for breakdown tests.
• One (right) was grounded to vessel and other (left) brought to HV to stress insulator
• Electrodes were ground down slightly to hold a 6.4mm post of material between them
• Voltage was slowly increased until a spark was heard
Preliminary Tests in Air

• Preliminary screening of materials in air to test for particularly weak insulators.

• Resistive UHMW, intended to grade potential, drew large surface current (much higher than DC resistance), sparked and failed destructively.

• Other than resistive UHMW, all other materials passed preliminary testing.
Repeatability

• Before systematic scan of materials in HPG, repeatability was quantified.

• Three HDPE posts of 8.4mm lengths were tested in argon gas to establish repeatability of breakdown strength.

• Error bars on each point correspond to stat error from repeated spark measurements.

• Found to be repeatable within ~10%
PEEK failed destructively at low voltage (~15 kV) in argon gas. Further testing of PEEK suspended on this basis.

All other tested materials could be sparked but recovered their original behavior after breakdown.
• Also compared to empty argon and xenon gap strength.
• HDPE compared favorably to the gap, suggesting its main contribution is to reduce the stressed area of argon / xenon gas.
Good performance from PTFE and UHMW but more stochastic at the highest pressures / E fields.
• POM (acetyl) had low breakdown of less than half that of gas
• Breakdown was still non-destructive
• Suggests acetyl surface somehow facilitates gas breakdowns.
Following suggestion of Lockwitz and Jostlein paper, compared to dielectric permittivity.

• HV strength found to be inversely proportional to dielectric constant

• Materials with high permittivities induce larger electric fields near the interfaces which may initiate breakdowns

SDA Anode with HDPE Support Installed

- Drilling through HDPE so they’re vented to prevent virtual leaks
- Putting blind holes in the SDA and cryofitting the posts into the anode

Anode for DEMO++ with Support Post inserted
Absorption Tests

- Indications (from our collaboration and others) suggested high pressure gasses may absorb into some polymers and cause them to swell mechanically.

- This is a problem for TPC construction, if sufficiently severe.

- We tested mass and volume changes of polymers under gas exposure to explore this effect.
Vacuum Pump
Ion Gauge
Relief Valve
Pressure Vessel I
Pressure Vessel II
Ar/Xe Bottle

Absorption Tests Set Up

Typical 6cm posts that were soaked in Xenon and Argon

Where posts were soaked
Where posts were vacuumed on after soaking
Absorption Test Results

- Minimal swelling was observed in Argon for all materials
- PEEK and POM did not appear to swell
- PTFE, HDPE, and UHMW all increased in both length and mass
HDPE has been selected as the material to be used for insulating HV supports in NEXT.

HPGAr shows similar trend in HV strength to xenon, but at lower voltages.

While significant for xenon, absorption and swelling does not appear to be a large effect in HPGAr.
Photoetching Large Scale Mesh

- Large unsupported mesh is a challenge
- We are exploring photoetching meshes
- Largest piece that can be manufactured 61 cm so we are looking at soldering together six “pie slices”
We tested both Nickel and Stainless Steel mesh.
Able to solder the Stainless Steel mesh together.
Because the mesh is so thin, the manufacturer needed a thicker edge to hold onto on the outside which resulted in a rough edge once removed.
Phase 2 mesh used “breakpoints” rather than an edge all the way along resulting in a uniform thickness.
High Capacity vessel for testing large scale EL regions

- In commissioning now
- 1.5 m diameter HPGAr test vessel for large readout planes
- Pressure rating 10 bar
- Hot and cold getters
- 100kV HV feedthrough in progress
- High capacity system (1067 liters)
- No recapture (so HPGAr only, for now)
Summary

• There are several challenges with scaling up Electroluminescent regions

• Static dissipative acrylic works well for a new method of a transparent and resistive surface

• Support posts within the EL region can be made from HDPE

• Photoetched stainless steel meshes are showing promise
Backup Slides
• Higher pressures increased in mass and length faster for PTFE, HDPE, and UHMW.
• Evacuation restored all materials to original condition.
Xenon Absorption Tests

- Clear correlation between mass and length change ratio for each of the materials
- PTFE appears to display a distinct slope compared to the other two
Micromegas readouts for double beta decay searches

Figure 6. Energy spectra of the $^{241}$Am alpha peak measured in the setup at 2 (top left), 3 (top right), 4 (bottom left) and 5 bar (bottom right). The red line and the value for the energy resolution are the result of the fit to a Gaussian function.