nEXO: The Next Generation Double-Beta Decay Experiment

Results of nEXO detector development

Thomas Brunner for the nEXO collaboration

TAUP2017– July 25, 2017
Searching for $0\nu\beta\beta$ in $^{136}\text{Xe}$ with EXO

Liquid-Xe Time Projection Chamber
- Liquid Xe at 168K
- Cryogenic electronics in LXe
- Detection of scintillation light and secondary charges
- 2D read out of secondary charges at segmented anode
- Full 3D event reconstruction:
  1. Energy reconstruction
  2. Position reconstruction
  3. Event Multiplicity

See talks by C. Licciardi and R. MacLellan
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Development focuses on:
- High voltage
- Light detection
- Charge detection
- Radioassays
- (Ba-tagging)

$T_{1/2}^{0\nu} > 10^{25}$ years !!
→ Need:
  - high target mass
  - high exposure
  - low background rate
  - good energy resolution

See talks by C. Licciardi and R. MacLellan

See talk by Chris Chambers
Advantages of nEXO

Build on the experience gained and the success of EXO-200 using well established techniques

1. Energy measurement
2. Event multiplicity (γ’s Compton scatter depositing energy in more than one site in large detectors).
3. Depth in the detector (or distance from the walls) is (for large monolithic detectors) a powerful parameter for discriminating between signal and (external) backgrounds.
4. α discrimination (from e⁻ / γ), possible in many detectors.

Phased approach:
1. EXO-200: 200kg liquid-Xe TPC
2. nEXO: 5-ton liquid Xe TPC with Ba tagging option (SNO lab cryopit)

Take full advantage of monolithic detector!

See Friday plenary session by Caio Licciardi
The nEXO TPC

- Long, single drift
  - HV
  - Xe purity (low outgassing)
- Novel charge tiles
  - very low noise
  - modularity
  - self-supporting
- SiPMs on the barrel
  - optically open, reflective field cage
  - no HV required
  - Robust
  - larger gain
  - large scale production
- In-Xe electronics
  - radioactivity

In-xenon cold electronics (charge and SiPMs)

SiPM ‘staves’ coating the barrel

EXO-200 for size comparison

charge strip-pad tiles (anode)

1.3 m electron drift
diameter (1.3 m)

cathode

In-Xe electronics

46 cm

radioactivity
Photon sensors

- Need ~4m² of VUV-sensitive SiPMs
- SiPMs and electronics mounted in LXe
- Increase photon detection efficiency through reflective surfaces
Analog SiPMs - baseline solution for nEXO

• High gain (low noise)
• Large manufacturing capabilities (> 4 m²)
• But efficiency and radioactivity need work

1.3x1.3 mm² T2K Multi-Pixel Photon counter
Pictures courtesy of Kyoto University

Requirements:
• Efficiency at 175nm > 15%
• Correlated avalanche rate < 20%
• Dark noise rate < 50Hz/mm²
• Low radioactivity
SiPM Photodetector

At least one type of 6 x 6 mm$^2$ VUV devices now match our desired properties, with a bias requirement $\sim 30$V (as opposed to the 1500V of EXO-200 APDs)

FBK low field SiPM: $T_h = 0.45\pm/0.12$ ppt, $U = 0.86\pm/-0.05$ ppt 
FBK standard field SiPM: $T_h = 0.44\pm/-0.05$ ppt, $U = 0.99\pm/-0.02$ ppt
SiPM Photodetector

- Hamamatsu produces devices with QE>15% @ 175nm but encapsulation is too radioactive → trying to procure un-encapsulated devices

- First nEXO-specific run at FBK (Italy) provided ~10% QE [I.Ostrovskiy et al. IEEE TNS 62 (2015) 1825.]
- New FBK “RGB” devices reach 15% QE with 7.7 x 7.7mm².

- Working closely with manufacturers to develop SiPMs to reach >15% QE at 175nm
- $^{232}$Th and $^{238}$U content of FBK SiPMs found to be <1 ppt
- Development of integration of 1x1cm² SiPMs into 10x10cm² tiles
- First tests in liquid Xe
3D-integrated dSiPM for nEXO

Advantages over analog SiPM + analog electronics

- All in one chip assembly: photon come in, bits come out
- Power scales with avalanche count not with capacitance
- Allow lower power or better timing resolution and granularity
- After-pulsing can be completely eliminated for a given time scale

Challenges

- Need custom SPAD array
- Large scale scaling
- Significant R&D required

See talk by Serge Charlebois

nEXO radio assay showed sub-ppt Th/U purity
Charge will be collected on arrays of strips fabricated onto low background dielectric wafers (low radioactivity quartz has been identified)

- Self-supporting/no tension
- Built-on electronics (on back)
- Far fewer cables
- Ultimately more reliable, lower noise, lower activity

Max metallization cover with min capacitance

- 10 x 10cm² Prototype Tile
- Metallized strips on fused silica substrate
- 60 orthogonal channels (30 x 30), 3mm strip pitch
- Strip intersections isolated with SiO₂ layer
Charge Readout

Preliminary

- PMT (trigger)
- Charge collection

Event 360 I Sum Ionization Energy: 1049.8 keV

Chart showing data and the Geant IV + Electronics model comparison. The graph illustrates the energy distribution over time with a peak at 1049.8 keV.
High Voltage R&D

Focus of development

• Spark mitigation $\rightarrow$ stable operation up to -100 kV
• Protection of electronics and detector in case of HV breakdown
• High reflectivity at 175 nm
• Low radioactivity

Ideas:

• High-resistivity Si field shaping rings to limit spark current
• Reflective coating of cathode and field-shaping rings
High Voltage R&D test setups

30l LXe Bern HV test setup now at Carleton U. with cryogenic cameras

400 cc LXe HV setup at SLAC

Max 800 kg LXe setup at LLNL to accommodate full or near-full size parts horizontally (under development)

HV tests of ~30cm scale geometries

Test of breakdown voltage in LXe for different small size geometries

HV tests in LXe for different full-nEXO diameter size geometries
Radioactivity studies of materials for nEXO

Techniques applied:
- Ge detector counting
- Neutron-activation analysis
- Inductively-Coupled Plasma Mass Spectrometry (IC PMS)

nEXO background budget by component
- TPC internals dominate (as expected)
- Several radioassay entries with only 90% CL limit

Great effort spent on measuring radioactive backgrounds and identifying suitable materials for nEXO.

See talk by Ryan MacLellan
See poster by John Orrell
nEXO Sensitivity & Discovery Potential

Methodology:
• 90% enrichment
• 1% $\sigma E/E$ resolution
• Realistic background projections based on measurements
• EXO-200-like analysis

- $T_{1/2} = 9.06 \times 10^{27}$ yr

- nEXO is the next generation 0$\nu\beta\beta$ experiment with 5 T enriched LXe
- nEXO expands on the success of EXO-200 and improves performance via R&D efforts
- nEXO baseline R&D is well advanced
Backup
nEXO Sensitivity to Neutrino Mass

- Allowed neutrino mass bands:
  90% CL, Forero et al., PRD 90 (2014)
  Forero et al., private comm.

- Based on 10yr Sensitivity of $9.06 \times 10^{27}$ y

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