Do we understand the Universe we live in?

Standard Cosmological Model

Standard Model of Particle Physic
Standard Models are incomplete...

• What’s the origin of matter – antimatter asymmetry in today’s Universe?

• What is dark matter or dark energy?

• What is the nature of gravity?

• Can all forces in nature be unified?
In Search of “New” Standard Model

■ LHC: direct search for new particles
  ◆ Discovery of Higgs!
  ◆ Hints of New Physics?

■ Precision measurements:
  ◆ EDMs of $e$, $n$, atoms, etc.
  ◆ Weak mixing angle
  ◆ $0\nu\beta\beta$
  ◆ Muon $g-2$
  ◆ Lepton flavor violation
  ◆ $\pi$, $K$ and $B$ decays
  ◆ Unitarity tests

Mostly Nuclear Physics
Neutrino Oscillation and Neutrino Mass

- **Super-K**: atmospheric $\nu_\mu$ neutrino oscillation
- **SNO**: solar $\nu_e$ flavor transformation
- **K2K**: accelerator $\nu_\mu$ oscillation
- **Kamland**: reactor $\overline{\nu}_e$ disappearance and oscillation

Neutrinos have Mass

The first evidence of physics beyond the Standard Model!
Unknown Properties of Neutrinos

Major Questions in Neutrino Physics

• Majorana particle, (i.e. its own antiparticle)

• Absolute mass scale of neutrinos.

• Mass hierarchy

• Mixing Angle Theta-13 (measured !)

• CP violation phase

• Anomalies (Sterile neutrinos?)
Eight Identical detectors in three underground sites connected by tunnels
Daya Bay Experiment Measured the Last Mixing Angle $\theta_{13}$ (2012)

$\sin^2 2\theta_{13} = 0.090 + 0.008 - 0.009$

Most precise measurement of $\theta_{13}$ (Aug. 2013)

Next step: Improve measurement precision, search for sterile neutrino and Mass Hierarchy

S. Jetter, NuFACT 2013
Double Beta Decay

Observation of $0\nu\beta\beta$:
- Majorana neutrino
- Neutrino mass scale
- Lepton number violation
The EXO-200 Detector

- HV Filter and Feedthrough
- Veto Panels
- Front End Electronics
- Vacuum Pumps

- Double-Walled Cryostat: 25 mm ea
- LXe Vessel: 1.37 mm
- Lead Shielding: > 25 cm
- Veto Panels

High purity Heat transfer fluid HFE7000
> 50 cm
Liquid Xenon Time Projection Chamber

The EXO-200 time projection chamber uses both scintillation and ionization signals to fully reconstruct energy depositions inside liquid xenon.

Event topology is a powerful tool not only for gamma background rejection, but also for signal discovery.
EXO-200 installation site: WIPP

- EXO-200 installed at WIPP (Waste Isolation Pilot Plant), in Carlsbad, NM
- 1600 mwe flat overburden (2150 feet, 650 m)
- U.S. DOE salt mine for low-level radioactive waste storage
- Cleanroom installed on adjustable stands to compensate salt movements.
- Salt “rock” low activity relative to hard-rock mine

\[
\Phi_\mu \sim 1.5 \times 10^5 \text{ yr}^{-1} \text{ m}^{-2} \text{ sr}^{-1} \\
U \sim 0.048 \text{ ppm} \\
Th \sim 0.25 \text{ ppm} \\
K \sim 480 \text{ ppm}
\]

0νββ Search with First Two Years of Data

Energy window for 0νββ search

Background events from the fit

<table>
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<tr>
<th>Source</th>
<th>Value</th>
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<tr>
<td>232Th</td>
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<td>137Xe</td>
<td>7.0</td>
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<tr>
<td>Total</td>
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Background index: \((1.7 \pm 0.2) \cdot 10^{-3} \text{ keV}^{-1} \text{ kg}^{-1} \text{ yr}^{-1}\)
nEXO Detector

- 5 tonne LXe TPC “as similar to EXO-200 as possible”, initially without Ba-tagging.
- 4.7 tonnes of active $^{enr}$Xe (80% or higher), 1.0% ($\sigma$) energy resolution.
- Assuming Observed EXO-200 backgrounds minus the Rn in the shield. $\beta\beta$-scales like the volume, the background like the surface area.
- Provide access ports for a possible later upgrade to Ba tagging
nEXO in the SNOlab Cryopit

6,000 m.w.e. depth sufficient to shield cosmogenic background.
Preliminary Artistic View of nEXO TPC

Baseline concept: (Improved TPC design).
- Single drift volume
- Charge collection on the anode plane
- Light collection on the barrel behind field shaping rings
nEXO Front End Electronics

Charge readout tile concept

UV sensitive SiPM under development

nEXO Cold Electronics Test Apparatus

- Low noise, low background cold front end electronics is necessary to reach the experimental sensitivity.

- Illinois group is leading conceptual design and testing of this R&D effort.
What can Neutrino tell us about the Universe?

• What role did neutrino play in the evolution of the universe? (~ 4% mass of the universe, absolute mass scale? Number of species? … double beta decay experiment, tritium decay experiment, sterile neutrino search…)

• Can neutrino be responsible for the matter and anti-matter asymmetry? (CP violation phase? … long baseline neutrino experiment)

• Neutrino might be the best probe deep into the universe (IceCube…)

• Supernovae neutrinos, relic neutrinos…