Liquid Argon TPC for LBNE

- LArTPC technique, sensitivity, and challenges
- Integrated plan to get to LBNE scale detectors
- Progress on designs for LBNE detectors
LArTPC technique

Passing charged particles ionize Argon – 55k ionization electrons/cm

Electric field drifts electrons meters to wire chamber planes

Induction/Collection planes image charge, record dE/dx

ArgoNeuT induction and collection planes
Unique Detectors
precision measurements in neutrino physics appear scalable to large volumes

- Neutrino oscillation physics: ~6 times more sensitive than WC technology translates into smaller volumes for same physics reach
- Proton decay searches
  - sensitive to p k
  - Extend sensitivity beyond SK limits with detectors larger than 5kton
- Supernova and solar neutrinos
Neutrino Oscillation Physics: 80-90% efficient for $\nu_e$ detection, nearly eliminate backgrounds → from neutral current pion production

Graphs showing data from 300kT H$_2$O Cerenkov and 50kT liquid argon detectors.

Translates into $x6$ reach in electron neutrino appearance searches and therefore CP Violation

(M. Dierckxsens, 2008)
p → K^+\nu

LArTPCs most sensitive to this decay mode
Supernova neutrino reactions in WC and LAr are sizable and complementary in reaction type and signal shape.

### Interaction Rates ($x10^4$)

<table>
<thead>
<tr>
<th>Interaction</th>
<th>Rates ($x10^4$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\bar{\nu}_e + p \rightarrow n + e^+$</td>
<td>2.3</td>
</tr>
<tr>
<td>$\nu_e + e^- \rightarrow \nu_e + e^-$</td>
<td>0.1</td>
</tr>
<tr>
<td>$\nu_x +^{16}O \rightarrow^{16}O + \nu_x$</td>
<td>0.05</td>
</tr>
<tr>
<td>$\nu_x +^{16}O \rightarrow^{16}F + e^-$</td>
<td>0.2</td>
</tr>
</tbody>
</table>

### Supernova Relic Searches

SuperNoVA relic searches also possible...

### LAr

<table>
<thead>
<tr>
<th>Interaction</th>
<th>Rates ($x10^4$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\nu_e + ^{40}Ar \rightarrow ^{40}K^* + e^-$</td>
<td></td>
</tr>
<tr>
<td>$\bar{\nu}_e + ^{40}Ar \rightarrow ^{40}Cl^* + e^+$</td>
<td></td>
</tr>
<tr>
<td>$\nu_\alpha + ^{40}Ar \rightarrow ^{40}Ar^* + \nu_\alpha$</td>
<td>$\rightarrow ^{40}Ar + \gamma_1 + \ldots \gamma_n$</td>
</tr>
<tr>
<td>$\nu_e + e^- \rightarrow \nu_e + e^-$</td>
<td></td>
</tr>
<tr>
<td>$\bar{\nu}_e + e^- \rightarrow \bar{\nu}_e + e^-$</td>
<td></td>
</tr>
<tr>
<td>$\nu_x + e^- \rightarrow \nu_x + e^-$</td>
<td></td>
</tr>
</tbody>
</table>

A. Bueno NP2008, via K.Scholberg
Main challenges for massive LArTPCs

- **Purification Issues: large, industrial vessels**
  - Test stand measurements
  - Purification techniques for non-evacuatable vessels
  - Purity in full scale experiment
- **Cold, Low Noise Electronics and signal multiplexing**
  - Test stand measurements
  - Plan for R&D towards cold electronics
- **Vessels: design, materials, insulation**
  - Learn as we go in designing MicroBooNE
- **Vessel siting underground: safety, installation ...**
- **Understanding costs of these detectors**
History of LarTPC development

Early work by Chen, Radeka, Willis, and others in the US in the late 70s.

Early and continuing work by Rubbia and others within the ICARUS collaboration

Over the last 30+ years → first cosmic ray tracks in a large volume

T300 – 300 ton ICARUS surface test in Pavia in 2001
Current programs

ICARUS readying for beam in Gran Sasso, considering next-generation efforts: DoubleLAr, Modular...

GLACIER effort in the LAGUNA collaboration in Europe:
GLACIER: Combination of charge and light collection, single large drift area

KEK-ETHZ collaboration to develop larger detectors for T2KK

While there are big challenges to scaling these detectors to Large sizes – worldwide interest in doing so.
Liquid-Argon Time Projection Chambers
Status of R&D Program in the US

TPCs in the United States:

Yale TPC
Location: Yale University
Active volume: 0.00002 kton
Year of first tracks: 2007

Bo
Location: Fermilab
Active volume: 0.00002 kton
Year of first tracks: 2008

ArgoNeuT
Location: Fermilab
Active volume: 0.00003 kton
First neutrinos: June 2009
Start of construction: 2010

MicroBooNE
Location: Fermilab
Active volume: 0.1 kton

Test stands to improve liquid-argon technology:

Luke
Location: Fermilab
Purpose: materials test station
Operational: since 2008

LAPD
Location: Fermilab
Purpose: LAr purity demo
Operational: 2010
Luke: Materials Test Stand at FNAL
Test materials in Argon and purification techniques for clean LAr

BNL 4-ch Amp  ArgoNeuT Bias Board  Cables/Cable-Tie Bundle
Luke: Materials Test Stand at FNAL
Test materials in Argon and purification techniques for clean LAr

<table>
<thead>
<tr>
<th>Material</th>
<th>Sample Surface Area (cm²)</th>
<th>94 K liquid</th>
<th>≈120 K vapor</th>
<th>≈225 K Vapor</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red-X Corona Dope⁷</td>
<td>100</td>
<td>None</td>
<td>None</td>
<td>LT Reduced from 8 to 1 ms; recovery observed.</td>
<td>H₂O concentration not monitored.</td>
</tr>
<tr>
<td>Deactivated Rosin Flux⁵</td>
<td>200</td>
<td>None</td>
<td>Not Tested</td>
<td>LT reduced from 8 to 1.5 ms; recovery observed</td>
<td>H₂O concentration not monitored.</td>
</tr>
<tr>
<td>FR4</td>
<td>1000</td>
<td>None</td>
<td>Not Tested</td>
<td>LT reduced from 8 to &lt;1 ms</td>
<td>Outgassed enough H₂O at 225 K to saturate sintered metal return.</td>
</tr>
<tr>
<td>Taconic⁴</td>
<td>600</td>
<td>None</td>
<td>Not Tested</td>
<td>LT reduced.</td>
<td>Sample outgases water at 225 K.</td>
</tr>
<tr>
<td>Hitachi BE 67G³</td>
<td>300</td>
<td>None</td>
<td>Not Tested</td>
<td>LT reduced; recovery observed</td>
<td>Sample outgases water at 225 K; outgassing reduced over time.</td>
</tr>
<tr>
<td>TacFreg⁶</td>
<td>200</td>
<td>None</td>
<td>None</td>
<td>LT reduced; recovery observed</td>
<td>Sample outgases water at 225 K; outgassing reduced over time.</td>
</tr>
<tr>
<td>FR4, y-plane wire endpoint for uBooNE</td>
<td>225</td>
<td>None</td>
<td>None</td>
<td>LT reduced from 8 to 3 ms</td>
<td>Sample outgases water at 225 K.</td>
</tr>
<tr>
<td>FR4, y-plane wire cover for uBooNE</td>
<td>225</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>Sample was evacuated in airlock prior to testing</td>
</tr>
<tr>
<td>Devcon 5-min epoxy</td>
<td>100</td>
<td>None</td>
<td>None</td>
<td>LT reduced from 10 to 6 ms; some recovery observed</td>
<td>Sample outgases water at 225 K.</td>
</tr>
</tbody>
</table>
Achieve purity in an un-evacuable vessel

- Small test stands at FNAL
- 20 ton purity demonstrator: LAPD (underway)
- MicroBooNE R&D program

- Flush tank with clean Argon gas
- Monitor level of $O_2$ in tank as it is flushed
- 2.6 volume changes to reach 100ppm $O_2$
0.3 ton TPC using MINOS to catch muons

Installation and Commissioning Underground

Data run began mid-September – expect ~20k neutrino and anti-neutrino events by March
MicroBooNE R&D
- Cold electronics
  - Implementation of cold electronics in Gar
  - Development and testing of cold electronics in Lar
- Purity: Test of Gar purge in large, fully instrumented vessel
- TPC design and wire stringing
- Data!
- Measure physics xsecs and sensitivities
- Test ease of surface running
- Develop tools for Analysis

Measure low energy neutrino Interactions:
- MiniBooNE low energy excess
- Suite of low energy cross section mmnts.

Fermilab Stage 1 approval in 2008
CD-0 from DOE this week
Partial funding through NSF MRI and proposals (1.5M total)
# Liquid-Argon Time Projection Chambers

**Outlook of R&D Program in the US**

<table>
<thead>
<tr>
<th>Chamber</th>
<th>Active Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Yale TPC &amp; Bo</strong></td>
<td>0.00002 kton</td>
</tr>
<tr>
<td>Yale TPC: Dismantled</td>
<td></td>
</tr>
<tr>
<td>Bo: Operational</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15x</td>
</tr>
<tr>
<td><strong>ArgoNeuT</strong></td>
<td>0.0003 kton</td>
</tr>
<tr>
<td>Operational</td>
<td></td>
</tr>
<tr>
<td>Physics: Measure neutrino-argon cross sections</td>
<td></td>
</tr>
<tr>
<td></td>
<td>330x</td>
</tr>
<tr>
<td><strong>MicroBooNE</strong></td>
<td>0.1 kton</td>
</tr>
<tr>
<td>Construction begins 2010</td>
<td></td>
</tr>
<tr>
<td>Physics: Investigate low-energy neutrino interactions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4 x 50x</td>
</tr>
<tr>
<td><strong>LAr TPC for LBNE</strong></td>
<td>20 kton</td>
</tr>
<tr>
<td>R&amp;D in progress</td>
<td></td>
</tr>
<tr>
<td>Physics: Measure neutrino oscillations at 1,000+ km</td>
<td></td>
</tr>
<tr>
<td><strong>Final goal</strong></td>
<td>N x 20 kton</td>
</tr>
<tr>
<td>Replicate proven technology</td>
<td></td>
</tr>
<tr>
<td>Physics: Search for CP violation in neutrino sector</td>
<td></td>
</tr>
</tbody>
</table>
For DUSEL, developing conceptual designs for 3-6 x 20Kton modules

LANNDD 20kton concept

- 20m x 20m x 40m “box-car”
- Free standing
- Evacuatable vessel
- Vacuum insulated
Membrane Cryostat:
- Externally supported by cavern walls
- Un-evauable
- Passive insulation

Pilot underground cavern
For LNG storage: Daejeon, Korea

Geostock Prototype for LNG storage
Also developing membrane prototype separated into smaller volumes

ie: 4 x 5kton bays
Cavern requirements

- Standard lab module 100m long houses detector
- 10m pit for secondary containment (standard)
- Environmental req. similar to FNAL lab space
- Assuming equivalence with FNAL design standards (ODH)
Lar20 in Standard Lab module aligned with beam from FNAL
Signal cable lengths increasing to >10-20 meters for detector fiducial volume > 1kton resulting in high capacitance and high noise.

Electronics: Cold front end multiplexed inside the cryostat

Cold electronics decouples the electrode and cryostat design from the readout design: *noise independent of the fiducial volume.*

Conceptual Design assumes cold electronics
MicroBooNE

Cross section of TPC at DUSEL

TPC design parameters: The same for both conceptual designs for cryostats

- 2.5m drift
- 2-3 wire planes
- 3-5mm drift
- TPC design
- Wire stringing methods

Wire chambers

2.5m drift

Build off MicroBooNE design
A Modular Wire Frame Design to Accommodate Cold Electronics

Wire Length:
- Y: 10m
- U: 4.6m
- V: 4.6m

Number of Wires @3mm pitch
- Y: 1333
- U: 3552
- V: 3552
Total:
8437 each side
Status of developing conceptual design for CD-1

• Detector design parameters
  - 2.5m drift distance
  - Fiducial mass = 1/6 of 100kt Water Cherenkov \( \text{16.7kt (LAr20)} \)
  - 2 - 3 wire planes, wire spacing = 3 - 5 mm
  - Cold electronics

• Engineering firms will provide conceptual designs for:
  - Cavern excavation
  - Modular & membrane style cryostats
  - Installation for both depth options: 300 ft and 4850 ft
  - Cryogenics plant above/below ground
  - Underground cryogen safety mitigation
  - Contract negotiations underway

Issues related to argon purity, TPC design, neutrino interactions: Answered along the way with program scaling from small to large
Brief Summary
Lots of progress towards conceptual design for Final goal: LAr20 and beyond

Final goal: Detectors at DUSEL for broad physics program
Neutrino oscillations, Nucleon decay, Astrophysics
Continuing progress on test stands and experiments needed to develop LAr technology to get there

Poster given to Governor Rounds on his recent trip to Fermilab

Particle Signatures
Fermilab 2009
Backup Slides
Impressive physics reach for CP Violation search
Concept for supply of cryogenics underground: implementation that minimizes cost, safety risk, technical risks (ie: purity)