Liquid Argon R&D in the US
• LArTPC technique, sensitivity, and challenges
• Integrated plan to get to massive 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

Signal on a single wire for multi-track event
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 $p \rightarrow \nu k$
  - Extend sensitivity beyond SK limits with detectors as “small” as 5kton
- Supernova (relic and burst) and solar neutrinos
Neutrino Oscillation Physics: 80-90% efficient for electron neutrino detection. Nearly eliminate backgrounds from neutral current pion production. Translates into x6 reach in electron neutrino appearance searches.
p \rightarrow K^+\nu

Sensitive beyond anticipated limits even with 5kton LArTPC
Supernova neutrino reaction in LAr are sizable and complementary in reaction type and signal shape to WC.

**100 kt of LAr, SN @ 10 kpc**

<table>
<thead>
<tr>
<th>Interaction</th>
<th>Rates (×10^4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\nu_e) CC ((^{40}\text{Ar}, , ^{40}\text{K}^*))</td>
<td>2.5</td>
</tr>
<tr>
<td>(\nu_x) NC ((^{40}\text{Ar}^*))</td>
<td>3.0</td>
</tr>
<tr>
<td>(\nu_x) ES</td>
<td>0.1</td>
</tr>
<tr>
<td>anti–(\nu_e) CC ((^{40}\text{Ar}, , ^{40}\text{Cl}^*))</td>
<td>0.054</td>
</tr>
</tbody>
</table>

\[
\begin{align*}
\nu_e + ^{40}\text{Ar} & \rightarrow ^{40}\text{K}^* + e^- \\
\bar{\nu}_e + ^{40}\text{Ar} & \rightarrow ^{40}\text{Cl}^* + e^+ \\
\nu_\alpha + ^{40}\text{Ar} & \rightarrow ^{40}\text{Ar}^* + \nu_\alpha \\
& \quad \rightarrow ^{40}\text{Ar} + \gamma_1 + \ldots \gamma_n \\
\nu_e + e^- & \rightarrow \nu_e + e^- \\
\bar{\nu}_e + e^- & \rightarrow \bar{\nu}_e + e^- \\
\nu_x + e^- & \rightarrow \nu_x + e^- 
\end{align*}
\]

A. Bueno NP2008, via K. Scholberg

SuperNoVA relic searches: expect at least 6 events in 10ktons... (Talk yesterday by C. Lunardini)
Liquid Argon R&D in the US

- LArTPC technique, sensitivity, and challenges
- Integrated plan to get to massive detectors
- Progress on designs for LBNE detectors
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**
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: 0.0003 kton
- Year of first tracks: 2008
- First neutrinos: June 2009

**MicroBooNE**
- Location: Fermilab
- Active volume: 0.1 kton
- Start of construction: 2010

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

终生 & Imps vs Time for Different Samples

Lifetime & Imps vs Time for Different Samples

filter
condenser

Lifeime  Imps (=k/lifetime)

zero test  BNL Pre-Amp in Cryostat (120K)  T962 Board in Cryostat (220K)  T962 Board in Ar-lock (290K)  Cables in Ar-lock (290K)

sample Cage  Purity Monitor  Scrubber Filter
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>Effect of Material on Electron Drift Lifetime (LT)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red-X Corona Dope</td>
<td>100</td>
<td>None None LT Reduced from 8 to 1 ms; recovery observed.</td>
<td>H₂O concentration not monitored.</td>
</tr>
<tr>
<td>Deactivated Rosin Flux</td>
<td>200</td>
<td>None Not Tested 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 Not Tested LT reduced from 8 to &lt;1 ms</td>
<td>Outgassed enough H₂O at 255 K to saturate sintered metal return.</td>
</tr>
<tr>
<td>Taconic</td>
<td>600</td>
<td>None Not Tested LT reduced.</td>
<td>Sample outgases water at 255 K.</td>
</tr>
<tr>
<td>Hitachi BE 67G</td>
<td>300</td>
<td>None Not Tested LT reduced; recovery observed</td>
<td>Sample outgases water at 255 K; outgassing reduced over time.</td>
</tr>
<tr>
<td>TacFreg</td>
<td>200</td>
<td>None None LT reduced; recovery observed</td>
<td>Sample outgases water at 255 K; outgassing reduced over time.</td>
</tr>
<tr>
<td>FR4, y-plane wire endpoint for uBooNE</td>
<td>225</td>
<td>None None LT reduced from 8 to 3 ms</td>
<td>Sample outgases water at 255 K.</td>
</tr>
<tr>
<td>FR4, y-plane wire cover for uBooNE</td>
<td>225</td>
<td>None None 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 None LT reduced from 10 to 6 ms; some recovery observed</td>
<td>Sample outgases water at 255 K.</td>
</tr>
</tbody>
</table>
Achieve purity in an un-evacuable vessel
- Small test stands at FNAL
- 20 ton purity demonstrator: LAPD
- MicroBooNE R&D program

Flush tank with clean Argon gas
- Monitor level of O₂ in tank as it is flushed
- 2.6 volume changes to reach 100ppm O₂
## Schedule

<table>
<thead>
<tr>
<th></th>
<th>Construction</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oct. 09</td>
<td>Skid design complete</td>
<td>Piping and materials for</td>
</tr>
<tr>
<td></td>
<td></td>
<td>skids ordered</td>
</tr>
<tr>
<td>Nov. 09</td>
<td>ODH analysis begins</td>
<td>Heat exchanger designed</td>
</tr>
<tr>
<td>Dec. 09</td>
<td>Pump vessel completed</td>
<td>Install skids</td>
</tr>
<tr>
<td>Jan. 10</td>
<td>Install insulation</td>
<td>ODH safety review</td>
</tr>
<tr>
<td>Feb. 10</td>
<td>Initial purges with gas</td>
<td>Initial fill with LAr</td>
</tr>
<tr>
<td>Mar. 10</td>
<td>Achieve required e-lifetime</td>
<td>Run at required lifetime</td>
</tr>
<tr>
<td></td>
<td></td>
<td>for 4 weeks</td>
</tr>
<tr>
<td>Apr. 10</td>
<td>Begin NIM paper</td>
<td>Start phase II</td>
</tr>
</tbody>
</table>
Cryostat Design: “Warm” vs “Cold” Electronics

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.*

Signal cable lengths increasing to >10-20 meters for detector fiducial volume > 1kton resulting in high capacitance and high noise.
Cold (87K) Electronics Concept

- Cosmic Ray Test Stand CMOS tests
  - Edwards (Michigan State)
- ASIC Development & testing
  - Radeka, Rescia (BNL)
  - Yarema (FNAL)
- Integration, grounding
  - Marvin Johnson (FNAL)
0.3 ton TPC using MINOS to catch muons

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
• Data!
• Measure physics xsecs and sensitivities (PD, SN)
• 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.

MicroBooNE Physics

Fermilab Stage 1 approval in 2008
CD-0 (Mission need) from DOE last 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>
<th>Physics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yale TPC &amp; Bo</td>
<td>0.00002 kton</td>
<td>Dismantled</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Operational</td>
</tr>
<tr>
<td>ArgoNeuT</td>
<td>0.0003 kton</td>
<td>Operational</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Measure neutrino-argon cross sections</td>
</tr>
<tr>
<td>MicroBooNE</td>
<td>0.1 kton</td>
<td>Construction begins 2010</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Investigate low-energy neutrino interactions</td>
</tr>
<tr>
<td>LAr TPC for LBNE</td>
<td>20 kton</td>
<td>R&amp;D in progress</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Measure neutrino oscillations at 1,000+ km</td>
</tr>
<tr>
<td>Final goal</td>
<td>N x 20 kton</td>
<td>Replicate proven technology</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Search for CP violation in neutrino sector</td>
</tr>
</tbody>
</table>
LBNE program:

- Intense neutrino and anti-neutrino beams from Fermilab
  - Start with 700 kW beam
  - Upgrade with high intensity proton machine (Project X) to 2MW
- Baseline of > 1000 km
- Very massive detectors in Homestake/DUSEL

L = 1300 km
(more matter effect in the oscillations)

Broad band beam can cover 1st and 2nd maximum
LAr20 in Standard Lab module (20 x 20 x 100m) aligned with beam from FNAL

Also developing concepts for 300 ft location...
Standard Caverns can house LArTPC modules

- Standard lab module 20 x 20 x 100m long houses detector
- 10m pit for secondary containment (standard)
- Environmental req. similar to FNAL lab space
- Equivalence with FNAL design standards (ODH)
Developing conceptual designs for 3-6 x 20Kton modules

Membrane Cryostat:
- Externally supported by cavern walls
- Un-evauable
- Passive insulation

Pilot underground cavern
For LNG storage: Daejeon, Korea

Geostock Prototype for
LNG storage
Membrane cryostat conceptual design separated into smaller volumes ie: 4 x 5kton bays
TPC design parameters: The same for both conceptual designs for cryostats

- 2.5m drift
- 2-3 wire planes
- 3-5mm wire pitch

Wire chambers

Cross section of TPC at DUSEL for Membrane cryostat

Build off MicroBooNE design

MicroBooNE
Membrane Cryostat - Continuous Hanging Construction (Bo Yu – BNL)

- No dead space along beam direction, no dead space across wire planes, minimal dead space in one horizontal plane.
- All wires are 8m long, U & V planes have insulating joints. Eliminate most of the short corner wires in framed modules.
- Requires additional weights or tensioners to keep the wires stretched. A MicroBooNE style wire arrangement will require 1ton/m load at the bottom of each wire “curtain”.

Cathode plane
Cold electronics
Sensing wires
A Modular Wire Frame “Ladder” Design

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
LANNDD 20kton concept

- 20m x 20m x 40m “box-car”
- Free standing
- Evacuable vessel
- Vacuum insulated
Front End Electronics
Status of developing conceptual design for CD-1  
Project office for LAr at DUSEL through FNAL

- Detector design parameters
  - 2.5m drift distance
  - Fiducial mass = 1/6 of 100kt Water Cherenkov   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
  - 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 South Dakota's Governor Rounds on his recent trip to Fermilab
Backup Slides
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.
History of LarTPC development in US

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

R&D tapered off in US until recently

Current US Program.....