Presentation to the Fermilab PAC, Fall 2007
MicroBooNE: Liquid Argon Time Projection Chamber

- Address the MiniBooNE low energy excess
- Perform precision neutrino cross section measurements
- Take the next necessary step in LArTPC R&D towards long baseline CP violation physics

Exposed to on axis BNB and off-axis NuMI beam

70 ton fiducial volume LArTPC

Booster beam
Strong Collaboration brings together people with expertise in LAr, LArTPCs, and neutrino physics

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28 scientists from 2 national labs 5 universities

*Spokesperson
†Deputy Spokesperson
- Liquid Argon Time Projection Chambers
- Physics motivation for the experiment
  - MiniBooNE low energy excess
  - Measuring low E neutrino cross sections
- Baseline design of the detector
- Cost and Schedule
- MicroBooNE in the broader program
Liquid Argon TPCs:

- Drift ionization electrons over meters of pure liquid argon to collection planes to image track
- Passing charged particles ionize Argon: 55,000 electrons/cm
- Extensive experience from ICARUS effort
Particles in LArTPCs

T300 data from Pavia test run 2001

Hadronic shower from Yale TPC run, April 2007

Use topology to differentiate event classes
LArTPCs image events and collect charge do e/γ separation via dE/dx

No other low energy neutrino experiment has been able to differentiate electrons from photons!
LArTPCs image events and collect charge do $e/\gamma$ separation via $dE/dx$

For 80% electron efficiency neutral pion inefficiency is <5%

MicroBooNE Monte Carlo simulation: GEANT4
LArTPCs image events and collect charge

$\rightarrow$ do $e/\gamma$ separation via dE/dx

Other studies are consistent with these results...

$\pi^0$ inefficiency vs energy:

at 250 MeV, inefficiency is $\sim 6\%$

Conservatively assume $6\% \pm 10\%$
Need fine-grained detectors and e/γ separation to understand this rich energy regime!

Running and future beams

Key for future ν experiments!
• Liquid Argon Time Projection Chambers
• Physics motivation for the experiment
  • MiniBooNE low energy excess
  • Measuring low E neutrino cross sections
• Baseline design of the detector
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• MicroBooNE in the broader program
What are these events?

- **Basic checks show no unusual features (ring-like, distributed evenly in space/time)**
- **In a region of high, but well-constrained backgrounds**
- **Persist at lower energies**
- **xxxxxx in off-axis NuMI beam**

What do they suggest?
Interpretations as electron neutrinos

3+2 models include CP fits MiniBooNE and LSND very well

tension when disappearance expts are included

Sterile neutrinos that can travel in Extra Dimesions responsible for anomaly:

Pre-diction that we would see a low energy excess!

and others......
Interpretation as photons

Standard Model process not yet calculated?

will affect neutron-star cooling.....

compare to MiniBooNE visible energy
Problem with MiniBooNE detector: cannot differentiate electrons from photons

- cannot reduce photon background at low $E_\nu$
- cannot interpret the excess as electron neutrino like or photon like

*Need LArTPC technology to address this!*
Key improvements in MicroBooNE are:

- e/γ separation capability which removes $\nu_\mu$ misID
- electron neutrino efficiency (~x2 better than MiniBooNE)
- sensitivity at low energies (down to tens of MeV compared to 200 MeV on MiniBooNE)

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**Bknds vs. E**

Background fractions at lowest energies

(inside)
Fold dE/dx tag into predictions from MiniBooNE to determine MicroBooNE sensitivity

<table>
<thead>
<tr>
<th>Process</th>
<th>200-300 MeV (mB)</th>
<th>300-475 MeV (mB)</th>
<th>total events (mB)</th>
<th>Scaling factor</th>
<th>total events (µB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;signal&quot;</td>
<td>91</td>
<td>96</td>
<td>187</td>
<td>0.29</td>
<td>54</td>
</tr>
</tbody>
</table>

**Backgrounds from Intrinsic νe φs**

<table>
<thead>
<tr>
<th>Process</th>
<th>200-300 MeV (mB)</th>
<th>300-475 MeV (mB)</th>
<th>total events (mB)</th>
<th>Scaling factor</th>
<th>total events (µB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>νe - μ</td>
<td>19.2</td>
<td>48</td>
<td>67.2</td>
<td>0.29</td>
<td>19.2</td>
</tr>
<tr>
<td>νe - k↑</td>
<td>7</td>
<td>14</td>
<td>21</td>
<td>0.29</td>
<td>6.0</td>
</tr>
<tr>
<td>νe - k↓</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>0.29</td>
<td>1.7</td>
</tr>
<tr>
<td>νe - π</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0.29</td>
<td>0.3</td>
</tr>
</tbody>
</table>

**Backgrounds from νµ misIDs**

<table>
<thead>
<tr>
<th>Process</th>
<th>200-300 MeV (mB)</th>
<th>300-475 MeV (mB)</th>
<th>total events (mB)</th>
<th>Scaling factor</th>
<th>total events (µB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NCνπ0</td>
<td>115</td>
<td>76</td>
<td>191</td>
<td>0.0034</td>
<td>1.6</td>
</tr>
<tr>
<td>Dirt</td>
<td>99</td>
<td>50</td>
<td>149</td>
<td>0.0034</td>
<td>1.3</td>
</tr>
<tr>
<td>Δ → Nγ</td>
<td>20</td>
<td>51</td>
<td>71</td>
<td>0.0034</td>
<td>0.6</td>
</tr>
<tr>
<td>Other</td>
<td>24</td>
<td>30</td>
<td>54</td>
<td>0.0034</td>
<td>0.5</td>
</tr>
<tr>
<td>Total</td>
<td>286</td>
<td>274</td>
<td>560</td>
<td>1.6</td>
<td>31.2</td>
</tr>
</tbody>
</table>

Detector size based on sensitivity, and beam request

This does not include improved background rejection due to topology or understanding of the beam
If the excess is photons:

- efficiency $\sim x2$ better than MiniBooNE for gammas
- $dE/dx$ tag reduces $\nu_e$ intrinsic backgrounds

<table>
<thead>
<tr>
<th>Process</th>
<th>total events ($\mu$B)</th>
<th>Uncertainties from mB</th>
<th>dE/dx unc.</th>
<th>Total unc.</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>“signal”</td>
<td>54</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\nu_e - \mu$</td>
<td>0.6</td>
<td>0.07</td>
<td>0.1</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td>$\nu_e - k^+$</td>
<td>0.2</td>
<td>0.16</td>
<td>0.1</td>
<td>0.18</td>
<td></td>
</tr>
<tr>
<td>$\nu_e - k^0$</td>
<td>0.05</td>
<td>0.3</td>
<td>0.1</td>
<td>0.32</td>
<td></td>
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<tr>
<td>$\nu_e - \pi$</td>
<td>0.01</td>
<td>0.33</td>
<td>0.1</td>
<td>0.35</td>
<td></td>
</tr>
<tr>
<td>NC$\pi^0$</td>
<td>55</td>
<td>0.13</td>
<td>0</td>
<td>0.13</td>
<td></td>
</tr>
<tr>
<td>Dirt</td>
<td>43</td>
<td>0.18</td>
<td>0</td>
<td>0.18</td>
<td></td>
</tr>
<tr>
<td>$\Delta \rightarrow N\gamma$</td>
<td>20</td>
<td>0.18</td>
<td>0</td>
<td>0.18</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>15</td>
<td>0.18</td>
<td>0</td>
<td>0.18</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>133.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

“signal” 187.1

Excess 53.4

Statistical Error 11.6

Systematic Error 10.7

Total Error 15.7

Significance 3.4
Results from NuMI on low energy excess embargoed for now
Liquid Argon Time Projection Chambers
Physics motivation for the experiment
  - MiniBooNE low energy excess
  - Measuring low E neutrino cross sections
Baseline design of the detector
Cost and Schedule
MicroBooNE in the broader program

Important for next generation neutrino oscillation experiments
Interesting in their own right
Rich energy regime in region of many existing and future neutrino experiments

- CCFRR
- BNL 7-feet
- ANL 12-feet
- ANL 12-feet

Running and future beams

- MiniBooNE
- T2K
- K2K
- NuMI off-axis
- NuMI on-axis
- CNGS
- T600

LAr neutrino experiment

higher energy low statistics
BNB and NuMI beams span this region well.

Unlike most neutrino experiments in this region, MicroBooNE can perform precision cross section measurements with fine-grained detector and $dE/dx \Rightarrow e/\gamma$ separation.
Existing data on fine-grained detectors is minimal!

Interesting channel: Recent measurements of $M_A$

- K2K $1.20 \pm 0.12$ GeV
- MiniBooNE $1.25 \pm 0.12$ GeV

inconsistent with world average $1.03 \pm 0.02$ GeV

MINERvA will measure $M_A$ above 1-2 GeV
MicroBooNE at 1 GeV and below.....
Sizable event rates!

For 6E20 pot
~100k total
~40,000 $\nu_\mu$ CCQE
~8000 NC$\pi^0$

For 8E20 pot
~60k total
~20,000 $\nu_\mu$ CCQE
~xxxx NC$\pi^0$
Collect samples of signal $\nu_e$s and background NC$\pi^0$s in energy region of interest for NOvA

Note: For running in LE mode. In ME mode, rate and shape worsen considerably.

Window in which to collect data before the NOvA ME beam run!
- Liquid Argon Time Projection Chambers
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The MicroBooNE Detector

- Outer vessel: 4.7 m in diameter, 13.5 m long
- Contains 170 tons liquid Argon
  - 100 tons Active Volume (2.5m x 2.5 m x 12 m TPC)
  - 73 tons Fiducial volume (25cm buffer on all sides)
- Catwalk supports Cryogenic and Electronic system components
Vacuum feedthroughs penetrate warm and cold vessels and carry signal/calibration/monitoring channels.

Based on ATLAS experience with 180k channels installed and operated for >1 year.

HV feedthrough (200 kV) -- ICARUS solution (warm feedthrough) still under study.

Cryogenics:

Inner cold vessel:
- 3.8m OD, 13.2m long

Outer warm vessel:
- 4.7m OD, 13.5m long

Temperature controlled via LN$_2$ cooling loops to within 1K
- boil off argon
- control operating temperature and pressure
Purification

Liquid Argon is continuously purified to 0.1 ppb O2 impurities

Flow rate: 10 gallons/minute
- 2 days for complete volume exchange

50,000 gallon storage dewar:
- Filtration prior to main vessel fill
- LAr storage in case of access

Filter system: based on ICARUS design but....
- non proprietary
- filters can be regenerated in situ

System designed at FNAL
Demonstrated at FNAL and Yale

ICARUS style purity monitors will measure purity in situ
Inner Detector: Field Cage

Design considerations:
- electron mobility
- temperature gradients
- Diffusion and recombination
- electron lifetime
- electronics Signal/Noise

- 2.6 m drift (2.6m x 2.6m x 12m)
- slightly offset for HV clearance
- 130kV HV for $v_{drift}=1.6\text{mm}/\mu\text{s}$
- Field cage: SS tubes step voltage in 2kV

Simulated by Maxwell 2D v.9
Inner Detector: Wire Planes

Signal electrodes
- 2 induction planes at ± 60°
- 1 vertical collection plane
- electrodes: 150 mm gold plated SS

3mm wire pitch
Planes biased at: -204V, 0V, 400V

Total of ~12k channels

Ionization electron drift lines for a uniform track (Garfield-9)

Wire holder guides wires to pre-amp and crimps in place
Inner Detector: Mechanical Support

Mechanical support of wires and wire frames
figs 4.23 and 4.27

could include this....
Inner Detector: Readout electronics

Design Considerations
- **dynamic range:**
  - MIP readout (2.1 MeV/cm) for e/\(\gamma\)
  - ionization from recoil protons and EM showers up to 3 GeV
- **Wire proximity:** minimize coherent noise
- **Sampling Rate for shaper:** 2 MHz
- **Data taking modes:** beam, calib, nhit,...
- minimize power consumption

Overall: Maximize Signal/Noise
minimize inteconnection lengths

*Cryogenic pre-amplifiers*

Need to achieve 1 MIP resolution
1 MIP = 2.1 MeV/cm
or 0.6 MeV/3mm = 15k electrons

attenuated to ~3k es over 2.6m drift
Noise of ~1700es on warm pre-amps is too much!
Inner Detector: Readout electronics

Cold electronics:
S/N ~20-30
primarily from reduced capacitance
- warm: 400 pF
- cold: 150pF
- length of electrodes
- readout connections
- cable lengths from WC to feedthrough

Pros:
- Avoids transmission of low level signals
- May allow for fewer signal feedthroughs
- Reliability

Cons
- Bubbling
- Cryogenic load
- Argon purity

Many years experience designing and operating cold electronics in HEP experiments!
Inner Detector : PhotoMultiplier Tubes

Neutrino interaction rate:
⇒ 1 spill in 200

Cosmic interaction rate:
⇒ 6 per ~3ms drift readout

PMTs tag spills with neutrino interactions by looking for prompt light signal in coincidence with 1.6 ms spill from the BNB

Prompt light: 128 nm scintillation light ($10^4$ photons/MeV)

PMTs used in ICARUS T600 operable at cryogenic temps.

128nm light shifted to the visible via WLS painted on PMT face

60 PMTs are located in "lune" behind the TPC WC planes
Readout Architecture

Processing and temporary storage of readout from 12,000 channels

12 readout crates for 12 feedthroughs
- signals are shaped
- continuously sampled at 20msps
- digitized in ADCs
- FPGA for data processing and signal reduction
Data Acquisition

- Multi-port Gigabit-Ethernet Switch
- 12 Readout Partitions
  - 1:1 Fragment Builder PCs real-time: networked storage
  - 2 PCs: Event Builder/Manager (not necessarily real-time)

LAr Cryostat
• Liquid Argon Time Projection Chambers
• Physics motivation for the experiment
  • MiniBooNE low energy excess
  • Measuring low E neutrino cross sections
• Baseline design of the detector
• Cost and Schedule
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## Cost: Total Materials = 6.1M

<table>
<thead>
<tr>
<th>Resource Items</th>
<th>Cost</th>
<th>Materials Cost Estimate</th>
<th>Labor Cost Estimate</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Micro BooNE Project</strong> Conceptual Design &amp; Cost Estimate</td>
<td>$9,358,000.00</td>
<td>$6,048,000.00</td>
<td>$3,310,000.00</td>
<td></td>
</tr>
<tr>
<td><strong>Facility &amp; Infrastructure</strong></td>
<td>$425,000.00</td>
<td></td>
<td></td>
<td>FESS estimate of Shield-Block building on newly constructed concrete pad. Pad area includes space for storage vessels. Total floor load of 600 tons, 500 psf. Includes utility conduit to MB enclosure. Includes labor and contingency</td>
</tr>
<tr>
<td><strong>Cryostat</strong></td>
<td>$1,720,000.00</td>
<td>$1,420,000.00</td>
<td>$300,000.00</td>
<td>Cryostat Vessel, including feed-throughs for cryo and vacuum systems. 50+ tons fiducial volume. 175 tons LAr total. Inner cryostat 3.2m OD, 13.2m long. Sits inside vacuum vessel 4.7m OD, 13.5m long. About 100 tons empty. About 300 tons full.</td>
</tr>
<tr>
<td><strong>Cryogenics</strong></td>
<td>$2,130,000.00</td>
<td>$1,730,000.00</td>
<td>$400,000.00</td>
<td>Cryogenics system. Includes 5000 gal N2 dewar for feed-through cooling bop. 2 23,000-gal argon dewars for storage. About 300 tons total weight with liquid gases</td>
</tr>
<tr>
<td><strong>TPC</strong></td>
<td>$1,266,000.00</td>
<td>$566,000.00</td>
<td>$700,000.00</td>
<td>3 planes, Y, U&amp;V @ 60 deg 3 mm pitch HV cage 500 V/cm 1 HV feed-through multiple signal feed-through along length</td>
</tr>
<tr>
<td><strong>Electronics &amp; Readout</strong></td>
<td>$2,507,000.00</td>
<td>$1,707,000.00</td>
<td>$800,000.00</td>
<td>10,000 channels @ $152/Ch, single phase. 12 or 14 bit ADC, 200-400 ns digitization, frequency charge injection at wire for calibration</td>
</tr>
<tr>
<td><strong>DAQ &amp; Monitoring</strong></td>
<td>$319,000.00</td>
<td>$200,000.00</td>
<td>$110,000.00</td>
<td>DAQ Hardware &amp; labor, Detector Monitoring Hardware &amp; Labor</td>
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<tr>
<td><strong>Installation &amp; Integration</strong></td>
<td>$1,000,000.00</td>
<td>$0.00</td>
<td>$1,000,000.00</td>
<td>Installation Labor</td>
</tr>
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</table>
Technically driven schedule -> Ready for beam in late 2010

<table>
<thead>
<tr>
<th>Task Name</th>
<th>Duration</th>
<th>Start</th>
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</thead>
<tbody>
<tr>
<td>Vico Boone</td>
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<tr>
<td>Pre Conceptual Design</td>
<td>25 days</td>
<td>Mon 3/27/07</td>
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<tr>
<td>PAC Proposal Submission</td>
<td>0 days</td>
<td>Fri 5/29/07</td>
</tr>
<tr>
<td>Reviews</td>
<td>260 days</td>
<td>Fri 3/20/08</td>
</tr>
<tr>
<td>First Director's Review &amp; GOO</td>
<td>0 days</td>
<td>Fri 3/28/08</td>
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<tr>
<td>CD-1 Review &amp; Approval (release of funds)</td>
<td>0 days</td>
<td>Fri 3/19/08</td>
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<tr>
<td>CD-2 Procurement Reviews</td>
<td>0 days</td>
<td>Fri 3/20/08</td>
</tr>
<tr>
<td>Design Phase of Project</td>
<td></td>
<td></td>
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<tr>
<td>Conceptual Design</td>
<td>110 days</td>
<td>Mon 10/1/07</td>
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<tr>
<td>Technical Design Report</td>
<td>30 days</td>
<td>Mon 12/13/07</td>
</tr>
<tr>
<td>Cryostat &amp; Cryogenics System Design</td>
<td>12 mons</td>
<td>Mon 9/11/07</td>
</tr>
<tr>
<td>TPC, Electronics &amp; Feedthrough Design</td>
<td>10 mons</td>
<td>Mon 3/3/00</td>
</tr>
<tr>
<td>Procurement &amp; Fabrication Phase of Project</td>
<td>260 days</td>
<td>Mon 2/1/09</td>
</tr>
<tr>
<td>Procurement of Cryostat</td>
<td>12 mons</td>
<td>Mon 3/2/08</td>
</tr>
<tr>
<td>Cryostat System, Equipment &amp; Fabrication</td>
<td>10 mons</td>
<td>Mon 3/2/08</td>
</tr>
<tr>
<td>TPC &amp; Feedthrough Fabrication</td>
<td>6 mons</td>
<td>Mon 3/2/08</td>
</tr>
<tr>
<td>Electronics Fabrication</td>
<td>12 mons</td>
<td>Mon 3/2/08</td>
</tr>
<tr>
<td>Construction of Experiment Area</td>
<td>30 days</td>
<td>Mon 3/2/08</td>
</tr>
<tr>
<td>End-Beam Phase (Early)</td>
<td>30 days</td>
<td>Mon 3/2/08</td>
</tr>
<tr>
<td>Preparation of the Experiment Area</td>
<td>2 mons</td>
<td>Mon 4/27/08</td>
</tr>
<tr>
<td>Cryostat, Assembly, TPC installation</td>
<td>6 mons</td>
<td>Mon 2/1/09</td>
</tr>
<tr>
<td>Outfit Vessel Assembly &amp; Cryostat Installation</td>
<td>40 days</td>
<td>Mon 7/13/10</td>
</tr>
<tr>
<td>Cryogenics Assembly &amp; Installation</td>
<td>6 mons</td>
<td>Mon 12/27/09</td>
</tr>
<tr>
<td>Electronics Installation</td>
<td>6 mons</td>
<td>Mon 2/1/09</td>
</tr>
<tr>
<td>Commissioning</td>
<td>60 days</td>
<td>Mon 3/13/10</td>
</tr>
<tr>
<td>Electronics &amp; Readout Check-out</td>
<td>30 days</td>
<td>Mon 1/18/10</td>
</tr>
<tr>
<td>Filling and Initial Purification</td>
<td>20 days</td>
<td>Mon 3/13/10</td>
</tr>
<tr>
<td>Control Tracks, Upgrade</td>
<td>10 days</td>
<td>Mon 11/14/10</td>
</tr>
<tr>
<td>Ready for Beam</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

highlight schedule drivers
slide needs some work

schedule cropped needs fix

Ready for beam in late 2010
• Liquid Argon Time Projection Chambers
• Physics motivation for the experiment
  • MiniBooNE low energy excess
  • Measuring low E neutrino cross sections
• Baseline design of the detector
• Cost and Schedule
• MicroBooNE in the broader program
Test stands:
ArgoNeuT
Materials Test

start doing physics here!

2007 2008 2010 2013-15 201?

50-100 ktons: Search for CP Violation in neutrino sector

5 kton: sensitivity to mass hierarchy, increase sensitivity to $\theta_{13}$

20 ton purity demonstration

MicroBooNE 170 ton
One of the four top level recommendations from the NuSAG report, 2007:

“A phased program with milestones and using technology suitable for a 50-100kton detector is recommended for the liquid argon detector option. Upon completion of the existing R&D project to achieve purity sufficient for long drift times, to design low noise electronics, and to qualify materials, construction of a test module that could be exposed to a neutrino beam is recommended”

Quote from Fermilab Steering Committee on the importance of pursuing LArTPC R&D for the future
MicroBooNE is a perfect fit in this phased program. Gain experience:

- Achieving and maintaining purity (FNAL design)
- Implementing cold, low noise, electronics
- Designing, constructing, and installing field cage, wire chambers, PMTs, etc.

- Collect large sample of 1 GeV neutrino interactions
  - Developing simulation and reconstruction techniques
  - Removing cosmic background from surface detector
  - Measuring neutrino interactions on Liquid Argon

This R&D program makes the next necessary advances towards massive LArTPC with a design that ensures MicroBooNE will meet its physics goals.

Timeline is important: Must proceed with R&D so as to be ready for technology decision for next step in long baseline program.
Achieving and Maintaining purity

Filter development at FNAL:

- Designed, built, and tested new filters for LAr
  - Materials test stand
  - ArgoNeuT
  - 20 ton purity demonstration

MicroBooNE ⇒ use these in a running physics experiment

Using FNAL filters at Yale
- achieved good purity
- regenerated filters in the lab

First tracks in US seen April '07!
Cold electronics:

- ~x4 reduction in noise compared to ICARUS
- allows for MIP resolution (2.1 MeV/cm) -> important for e/gamma separation.
- will be crucial for very large detectors with very long wires

Expertise is with BNL team:
Design based on experience with 40,000 channels running for 15 years

- first employed in Helios-NA34 experiment (late 1980s)
- further R&D for the GEM detector and for the ATLAS LAr calorimeter
- Major installation: NA48 experiment and ATLAS.
MicroBooNE

- address the MiniBooNE low energy excess
- precisely measure low energy neutrino cross sections
- make the next necessary step in LArTPC R&D

We ask the PAC to endorse the physics and technological program for MicroBooNE towards Stage 1 approval.

Presentation to the Fermilab PAC, Fall 2007
Backup Slides

todos:
Readout Architecture and Cold Electronics slide

gamma table

Is Physics R&D and Hardware R&D borne out well enough?