ArgonCube: scalable modular approach for large LArTPCs

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Liquid Argon Time Projection Chamber

Charge yield (MIP) 
\(~ 9000 \text{ e/mm}~ (1.5 \text{ fC/mm})\)

\(T_0\) by scintillation

**Classic** charge readout:
X: Induction (non-destructive)
Y: Collection
ArgonCube: design inspired by LBNO → LBNE → LBNX → DUNE requirements

Multi MW LBNF beam from FNAL 1280 km to the LAr DUNE far detector (FD) at SURF

LAr is desirable in the near detector (ND), to uncertainties near to far, and constrain the flux.

At the near detector, 574 m from the first focusing horn, a 1.2 MW beam corresponds to \(~0.16\) neutrino events per tonne of argon per spill (10 μs).

\[ m_{\text{ND}} \sim 150 \text{ ton} \rightarrow \text{Neutrino events pile up!} \]
The Solution – ArgonCube

Instead of a monolithic detector volume, divide the detector into a number of self-contained TPC modules sharing a common cryostat - I. Kreslo & M. Weber, 2014

Short drift distances (< 1m)
Low cathode voltage (< 100 kV)
Reduced stored energy
Reduce purity requirements
Contained scintillation light
Upgradeable/repairable sans downtime
High active mass ratio (~85%)

Also

Unambiguous charge readout

All of which is good for reducing pileup
ARGONCUBE
Module design features

Central cathode
2 TPC volumes

Thin walls
Min. material budget

Pixelated anode plane

Dielectric light readout within TPCs

G10 structure:
good dielectric shielding, and comparable radiation & hadronic interaction lengths to Lar

Resistive field shell

Limited LAr convection
Heat management
< 100 W/module overall
Scintillation Light Readout, option 1:
Light Collection Module (collaboration with JINR, Russia)

LAr scintillation light 128 nm
TPB: 128 nm → 420 nm
WLS fiber 420 nm → 500 nm
SiPM

VUV scintillation light is double-shifted to green

PDE ~ 1% (10x30 cm, 2 SiPMs)
Scintillation Light Readout, option 2: ArCLight - ArgonCube light detector
(design inspired by s.c. Arapuca: A.A. Machado and E. Segreto 2016 JINST 11 C02004)

Self-supporting, technologically simple

SiPMs are placed at one edge only
Can be placed in high field region
(parallel to the the drift)

Auger M. et al., Instruments 2 (2018) no.1, 3

- SiPM dark current at 87K is O(Hz) at 1 p.e.
- Photon collection efficiency:

$$\epsilon_{coll} = \frac{f}{1 - \langle R_{490}\rangle (1 - f)}$$

PDE ~ 0.1% (30x30 cm, 6 SiPMs)

Time resolution ~ 6ns

Some coordinate resolution
Pixelated charge readout: bespoke ASIC LArPix (LBNL)

Low-power cold amplification and digitisation of every pixel is required for true 3D readout. This was enabled by the LArPix ASIC, developed at Dan Dwyer at LBNL.

Power consumption per pixel: 62 μW (37 μW digital).

Data rate: O (0.1) MB/s/m²

LArPix V2: 64 channels / ASIC

Pixel 4x4 mm, 0.5 us time stamp

Unfiltered 3D information from cosmic muon. JINST 13 (2018) no.10, P10007
First Resistive Shell LArTPC (RSTPC)
No more field shaping rings and resistors!

Field uniformity test is conducted, data analysis in progress.

Anode at GND

Resistive foil: DuPont DR8

16 Gohm/sq in cold

Field uniformity by muon tracks:

Better than 1%

Cathode at -HV (up to 25 kV)
Novel cryogenic liquid valve developed

Bistable: toggled by a current pulse, no heat dissipation in either state

Operates fully immersed in liquid argon

PLC-friendly controller

Patent pending
The **DUNE Proto-ND** (*ArgonCube 2x2 Demonstrator, ~1/50 scale ND*)

**2020 goes to Fermilab to on-axis NuMi beam**

Vacuum insulated LN2-cooled cryostat, housing 4 modules, 2.4t active LAr

Top flange sealed with Indium wire

130 uS drift time at 1kV/cm

Pixelated charge readout: **400k Pixels (13M Pix for DUNE ND)**

4 x 4 x 1.5mm voxel

**192 SiPMs** for scintillation R/O
DUNE Proto-ND module with RS

33 kV
0.33m

0.66m

1.2m

2 G/sq @ 1kV/cm, \( U=33 \text{kV} \)

\[ P= 4.5 \text{ W/m}^2 \]

\(~10 \text{ W/module} — \text{acceptable.}\)
Cryogenics:
Module *cold* extraction / re-insertion
DUNE Proto-ND module tests

2 measuring campaigns (one in progress), goal:

**demonstrate cryogenics & purification**
**demonstrate module cold extraction / insertion**

Before extraction: steady purification rate, stopped at ~30 us life time
(>10 cm long muon tracks observed)

Extraction / Reinsertion performed successfully

Re-Purification: back to starting point after 1 week

*Note: filter material used is 100 times less efficient than the state of art!*
Dune Proto-ND current status

All novel aspects of ArgonCube have been demonstrated:
  Light R/O – Instruments 2 (2018) no.1, 3
  Field shell – Instruments 3 (2019) no.2, 28

- Bern has secured funding for production of 4 modules.
- FNAL is providing support for facilities to deployment in NuMI.
- JINR is providing the light R/O.
- LBNL has secured funding for the charge R/O (supplemented by Bern).
- Rochester is providing a high level DAQ, beam trigger, and muon tagger.
- SLAC is providing the mechanical module design & production of TPC components.

Will operate on-axis in NuMI in 2020.
Summary

ARGONCUBE concept — an optimal solution for large, scalable tracking detector.

- High active mass ratio (85%)
- Unified modules → high redundancy
- Step-by-step commissioning: «democratic» construction and incremental installation
- Repairing single module without stopping data taking
- Scalable and extendable (same tech. for ND and FD)
- Iterative upgrade with new technologies
- Low cost of module failure

Short-drift length modules

- Relatively low electric potentials — reduced risk for breakdowns
- Reduced purity requirements

Pixel charge readout

- Up to 50% increase in reconstruction efficiency w.r.t. wire readout
- Improved accuracy of kinematical event reconstruction

ARGONCUBE is accepted as the technology for DUNE Near Detector.
Option for DUNE Far Detector «module of opportunity»
Thank you!
Backup slides
Evolution of LAr TPCs at Bern

L=0.5 cm  L=25 cm  L=57 cm

ARGONTUBE  L=500 cm

JINST 4, P07011 (2009)
JINST 5, P10009 (2010)

JINST 7 (2012) C02011
JINST 1307 (2013) P07002
Breakdown in liquid Argon: detailed study at Bern

1. Abnormally low dielectric strength at long distances
2. Studied V/A characteristics
3. Studied time-resolved light emission spectra
4. Discovered slow streamers in LAr discharge
5. Measured 1st Townsend coefficient at fields O(100 kV/cm)
6. Suggested method to improve breakdown field by factor of 10

M. Auger et al., JINST 9, P07023 (2014)
A. Blatter et al., JINST 9, P04006 (2014)
M. Auger et al., JINST 11 (2016) no.03, P03017.
Sample the unoscillated beam using the same target material as the FD. Essential in order to constrain uncertainties on neutrino cross sections.

Major uncertainties (event topology, secondary interactions) are primarily common near-far. High multiplicity at near site necessitates differences in design, differences are likely second-order.

The energy and angular resolution and mass is sufficient to extract a high-statistics sample of neutrino-electron elastic scattering events, which have a known cross section. Can be used to constrain the flux to better than 2%. (MINERvA arXiv:1906.00111)

Constrain electron neutrino contamination. Use e/γ separation to reduce NC background.
Dune ND with ArgonCube
Pixel readout features

UART-like communication with a 54 bit data word

300Hz  54 bit, 16 chips, 60cm drift

~10Hz  54 bit, 1 chips, 30cm drift

1 chip  540 bit/s

5000 chip  2.7 Mbit/s
Liquid argon properties
http://atlas.web.cern.ch/Atlas

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
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<tbody>
<tr>
<td>Atomic number</td>
<td>18</td>
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<tr>
<td>Atomic weight (u)</td>
<td>39.94</td>
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<tr>
<td>Radiation length (cm)</td>
<td>14.2</td>
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<tr>
<td>Absorption length (cm)</td>
<td>83.6</td>
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<tr>
<td>Molière radius (cm)</td>
<td>10.1</td>
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<tr>
<td>Critical energy (MeV)</td>
<td>30.5</td>
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<td>$&lt; \text{DEmip (1 cm)} &gt; \ (\text{MeV})$</td>
<td>2.1</td>
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<tr>
<td>W-value (1 MeV electrons) (eV/ion-pair)</td>
<td>23.3</td>
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<tr>
<td>Fano factor</td>
<td>0.107</td>
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<tr>
<td>Electron mobility at bp (m$^2$ V$^{-1}$ s$^{-1}$)</td>
<td>0.048</td>
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<tr>
<td>Ion mobility at bp (x10$^5$) (m$^2$ V$^{-1}$ s$^{-1}$)</td>
<td>0.016</td>
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<tr>
<td>Dielectric constant</td>
<td>1.6</td>
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<tr>
<td>Heat capacity (Cp) (cal mol$^{-1}$ K$^{-1}$)</td>
<td>10.05</td>
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<tr>
<td>Thermal conductivity (x10$^3$) (cal s$^{-1}$ cm$^{-1}$ K$^{-1}$)</td>
<td>30</td>
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<tr>
<td>Critical point temperature (K)</td>
<td>150.85</td>
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<td>Normal boiling point (bp) (K)</td>
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<td>Liquid density at bp (g cm$^{-3}$)</td>
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<td>Heat of vaporization at bp (cal mol$^{-1}$)</td>
<td>1557.5</td>
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<td>Gas/liquid ratio</td>
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<td>Temperature (K) : Pressure (bars)</td>
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