ArgonCube: A Modular LArTPC with Pixelated Charge Readout

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DUNE
DEEP UNDERGROUND
NEUTRINO EXPERIMENT

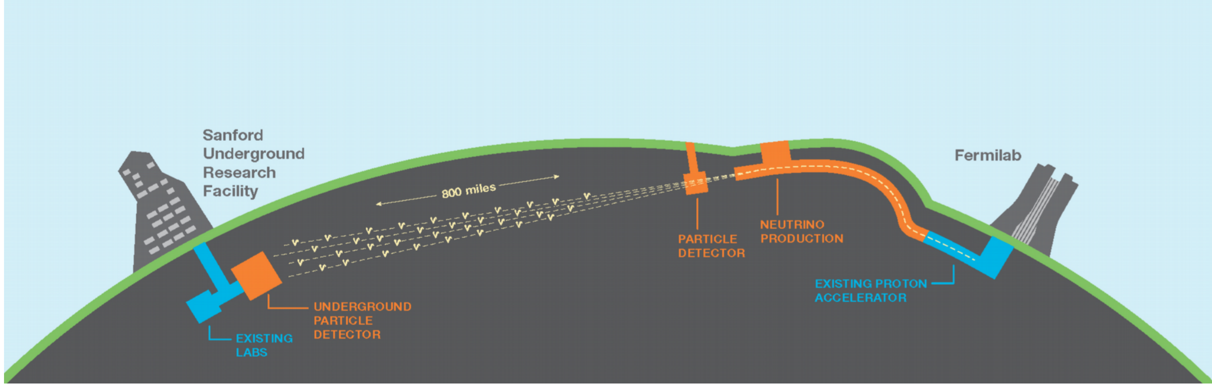
ArgonCube

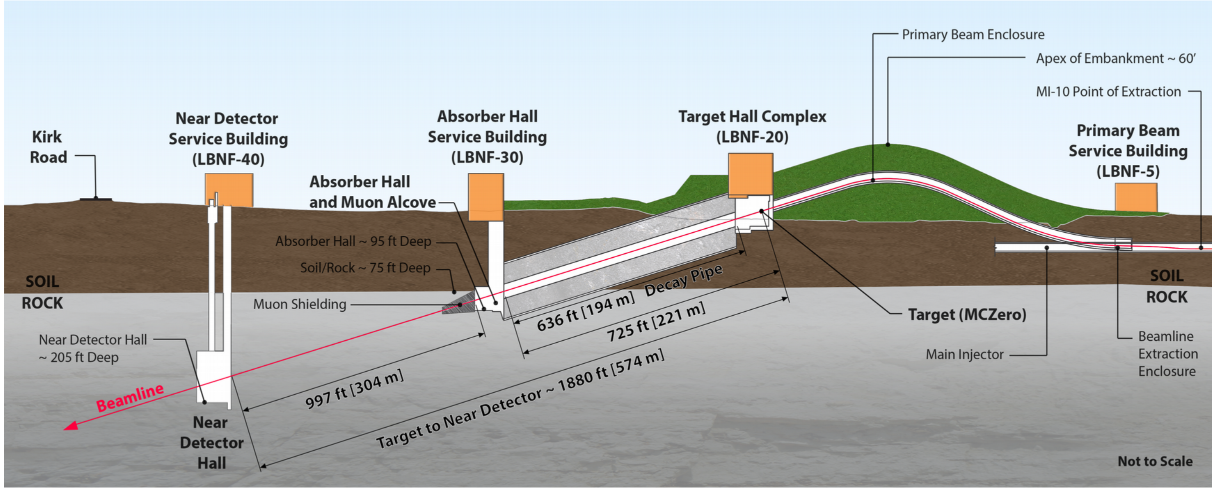
Liquid Argon in DUNE

MW ν beam from Fermilab across 1’280 km to the 4 x 10 kt **LAr** DUNE FD at SURF, **~3.4 ν events per hour**.

LAr is desirable in the ND to constrain **uncertainties** and **flux**.

At the ND, 574 m from the target, **~0.16 ν events per tonne of LAr and per beam spill** (10 μs).





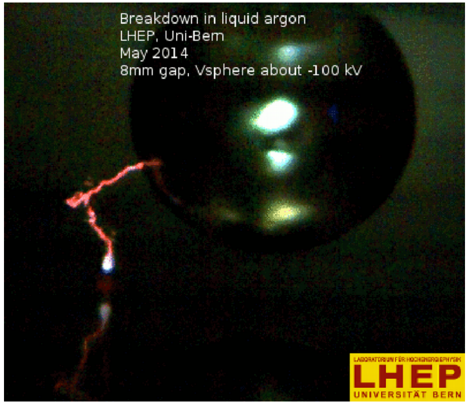
Argon***Tube*** (2013)

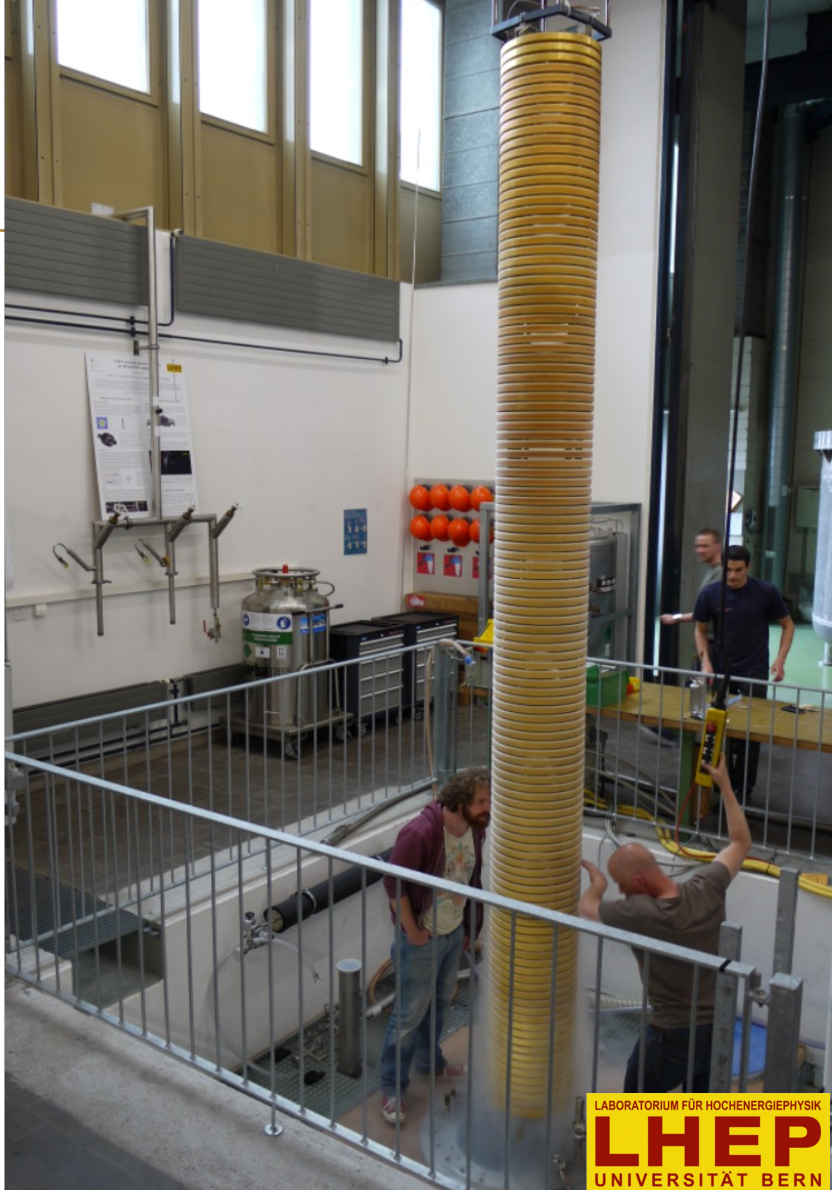
ArgonTube was built to investigate **long drift distances** in LArTPC's. (JINST 8 (2013), P07002)

It succeeded in demonstrating aspects of modern LArTPC's:

- Cold amplifiers (BNL's LARASIC4*)
- UV laser E-field calibration

But it also showed the dielectric strength of LAr to be much lower than expected:





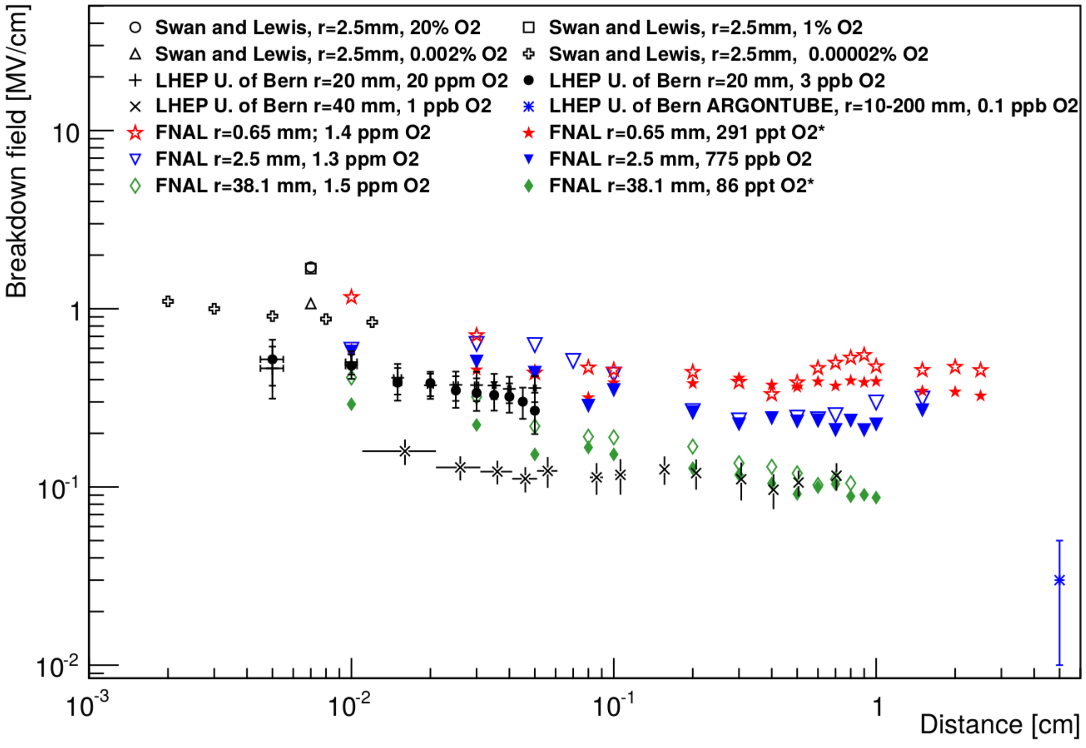
Dielectric Strength of Liquid Argon

Breakdowns were found to occur at field strengths of ~**40 kV/cm**.

Breakdowns are bad:

- Can damage R/O electronics
- (Partially) discharges TPC
- Distorts E-field uniformity
- Triggers Light R/O
- High power consumption

Results from Bern reproduced by Fermilab



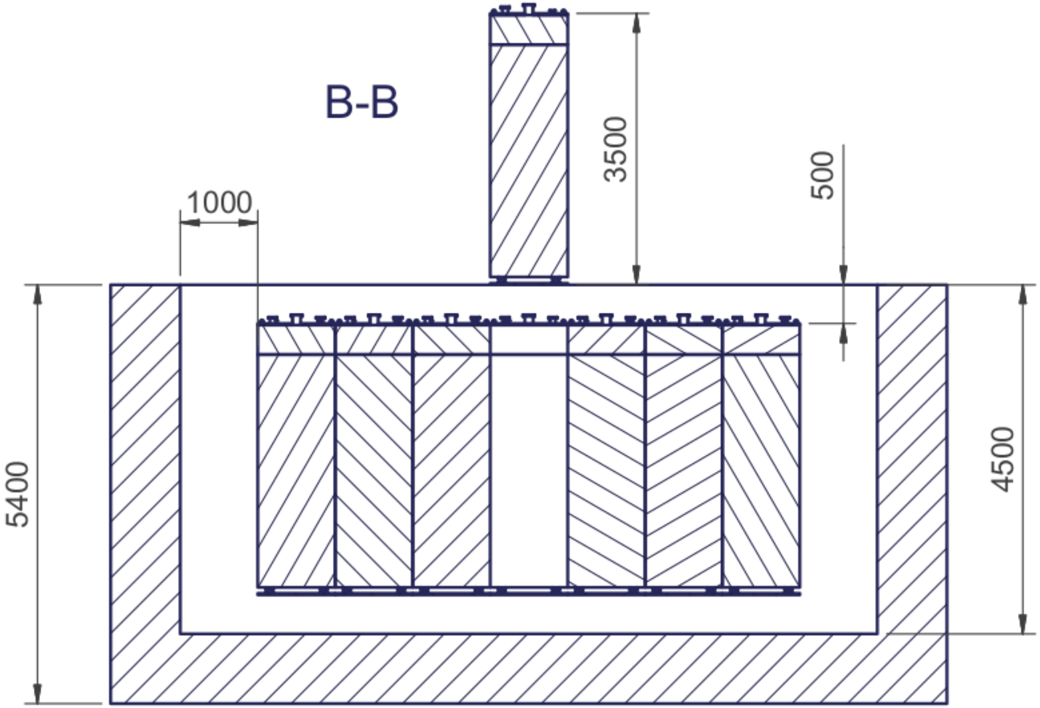
JINST 9 (2014) no.11, P11001

The Solution – ArgonCube

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

- Short drift distances
- Low cathode voltage
- Reduced stored energy
- Reduced purity requirements
- Contained scintillation light
- Upgradeable/repairable w/o downtime
- Unambiguous charge R/O

→ **Reduced pileup**



Resistive Shell TPC

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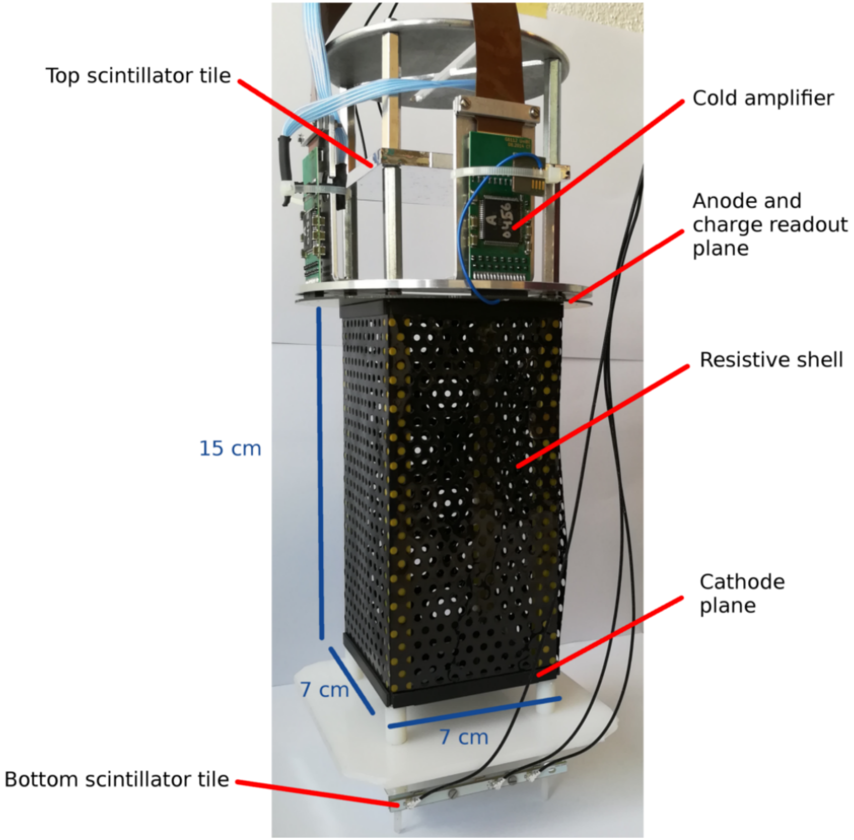
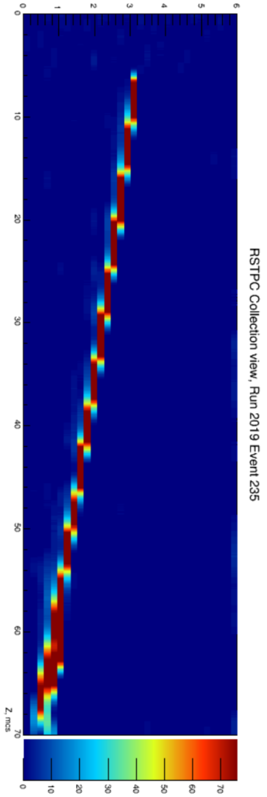
Highly **resistive Kapton foil** is laminated to G10 planes forming the field shell and cathode of the TPC.

- **Minimise dead material**
- **Maximise active volume**
- Continuous field shaping
- Reduce component count and potential points of failure
- Limit power dissipation in the case of a HV breakdown



Resistive shell TPC. Instruments 3 (2019), no.2, 28.

Resistive Shell TPC



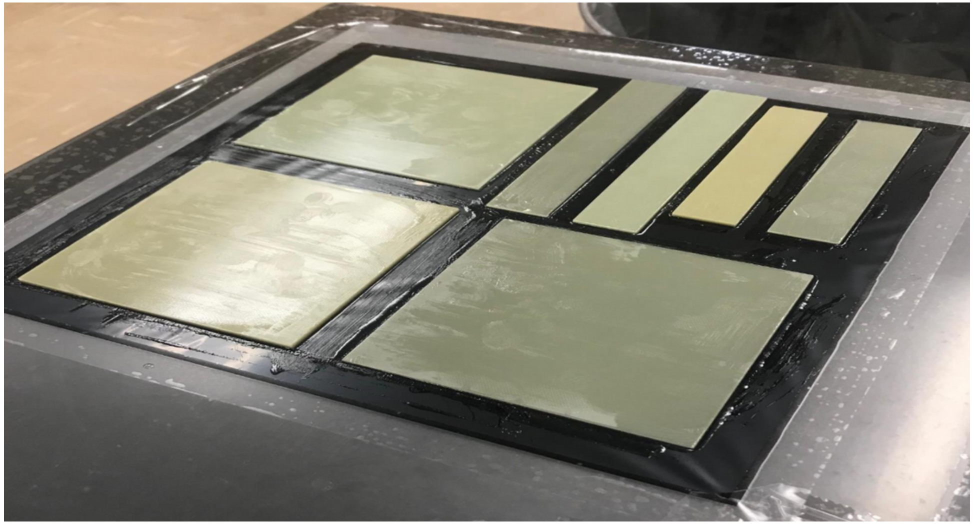
Prototype resistive shell TPC, Bern 2018

- 50 µm carbon-loaded Kapton
- E-field range: 0.0 to 1.5 kV/cm
- O (1) GΩ/sq
  - maintain field-strength
  - keep power consumption low
- Tested with crossing muons

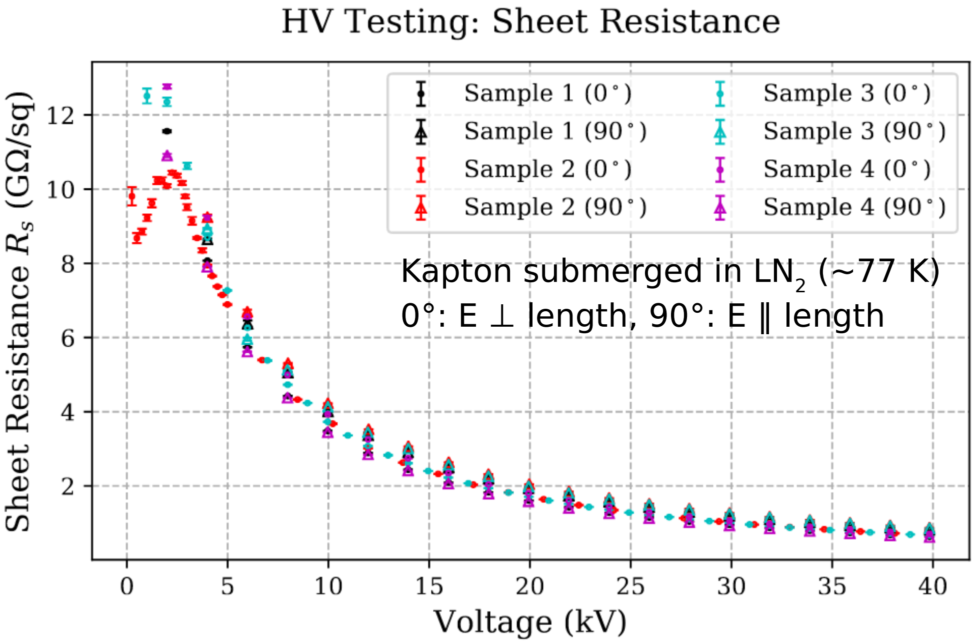
Cosmic muon crossing resistive shell TPC at 1.0kV/cm, July 2018.

Resistive Shell TPC Results

SLAC has taken on the responsibility of developing the resistive shell TPC.



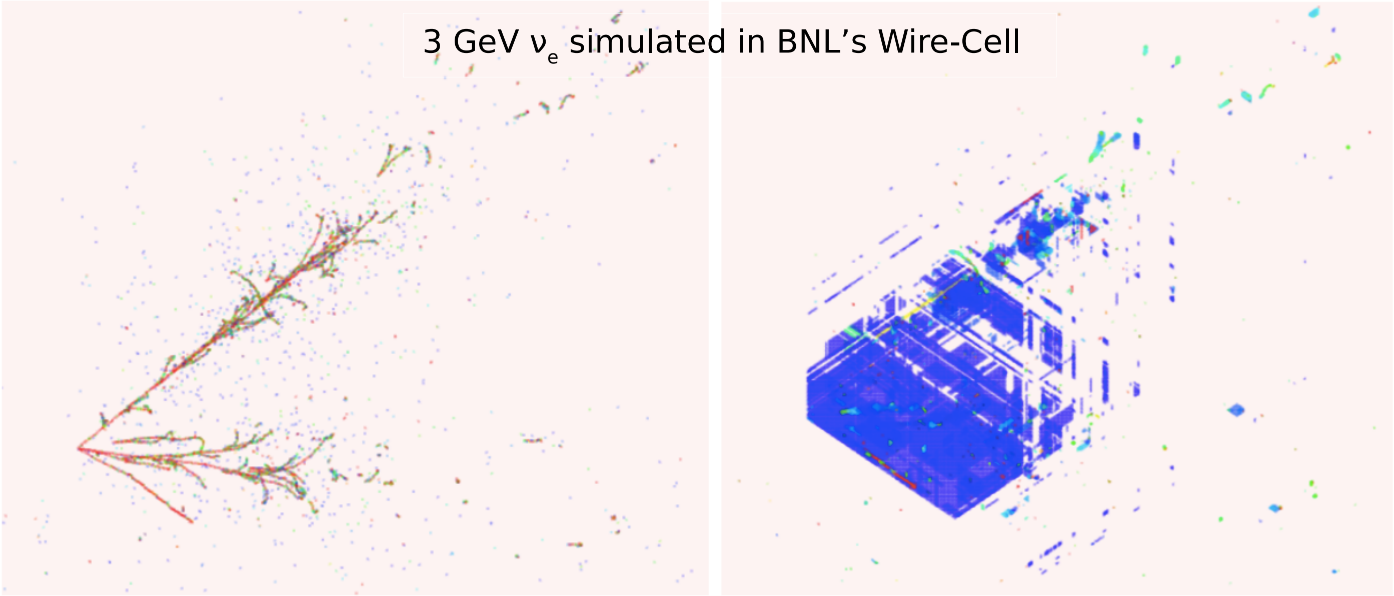
SLAC test setup: lamination techniques, electric connectivity, metallisation between anode and cathode, uniform resistivity O (1) GΩ/sq.



F. Drielsma (SLAC)

Addressing a high-rate environment

Traditional projective wire readouts do **not** have a **flat response** as a function of angle, and the need for full waveforms also lead to **very large data rates**. An alternative was needed.

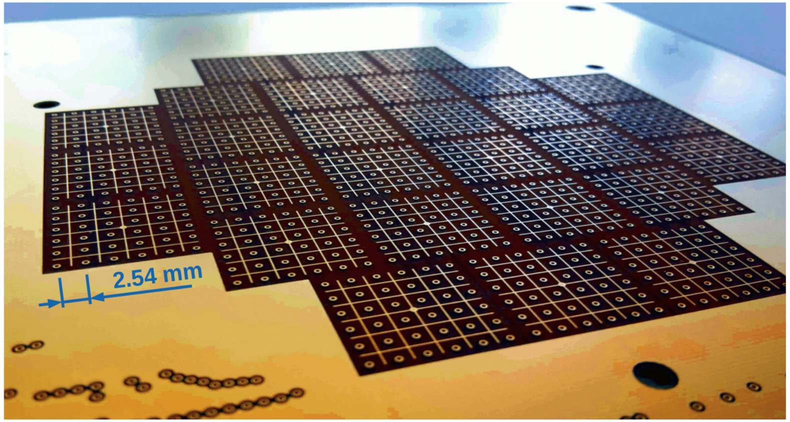


Luckily, Bern had an EXO group, which was working on an pixel readout for gaseous Xe. This formed the basis of our first **pixel readout**.

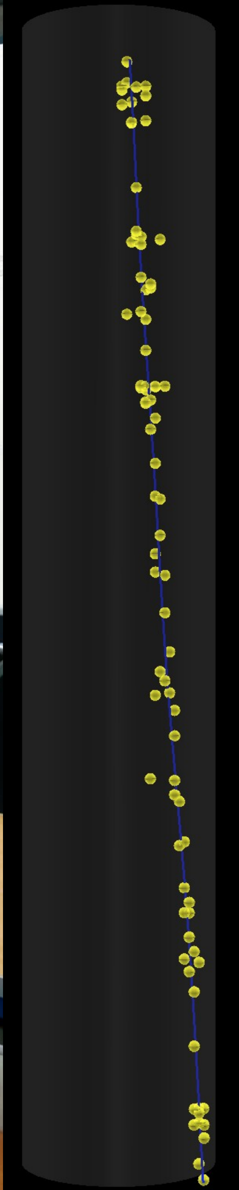
Pixelated Anode Plane

2016 Pixel demonstration TPC in Bern (arXiv:1801.08884)

- 1008 pixels
- 64 channels
- 60 cm drift
- LARASIC4*



Unfortunately, LARASIC4* is designed for wire planes, providing only cold amplification. Signals had to be **multiplexed** then digitised in warm.

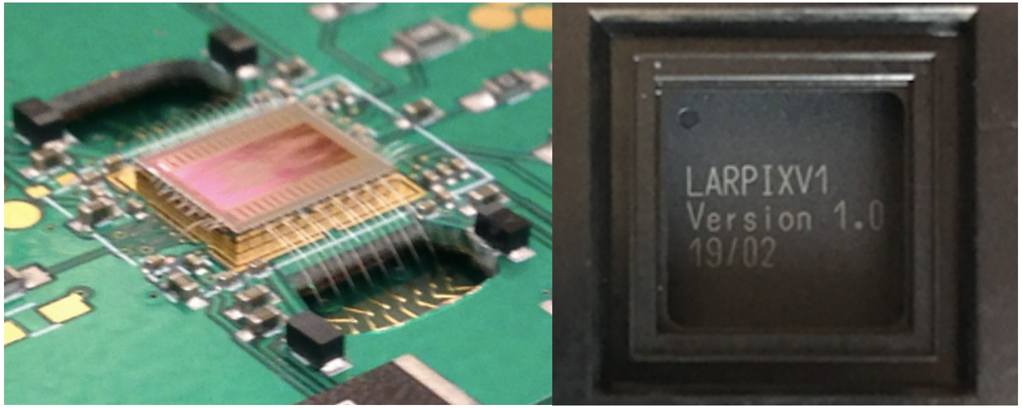


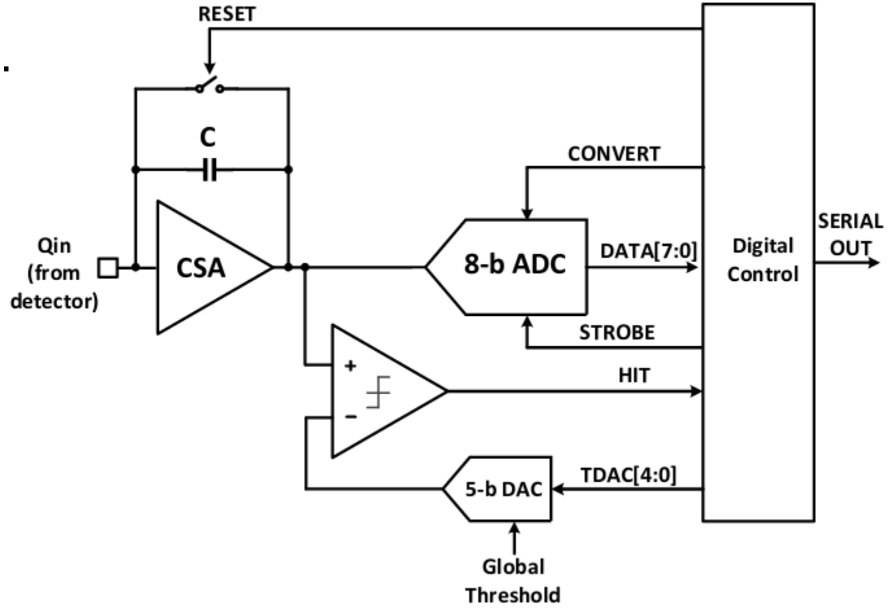
True Unambiguous Charge Readout

Low-power cold amplification and digitisation of every pixel is required for **true 3D readout**.

This was enabled by the **LArPix ASIC**, developed by Dan Dwyer at LBNL.
Power consumption per pixel: 62 µW (37 µW digital).

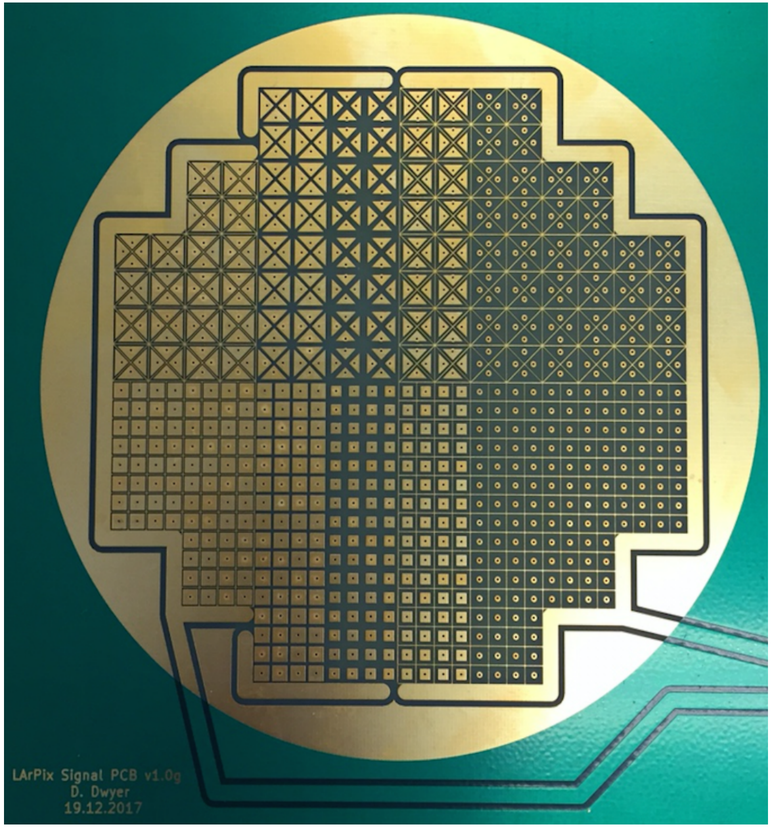
O (0.5) MB/s/m^2 for 1 m drift in surface cosmic flux.

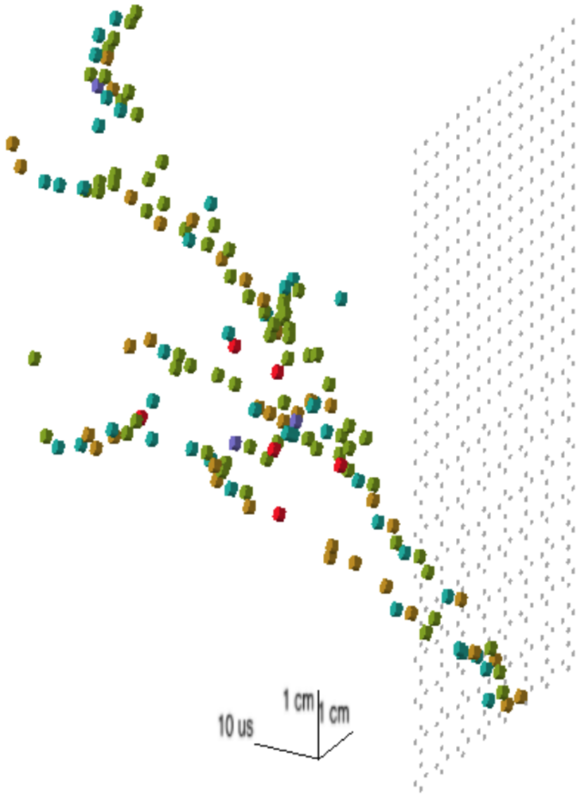




LArPix ASIC block diagram. JINST 13 (2018) no.10, P10007.

True Unambiguous Charge Readout





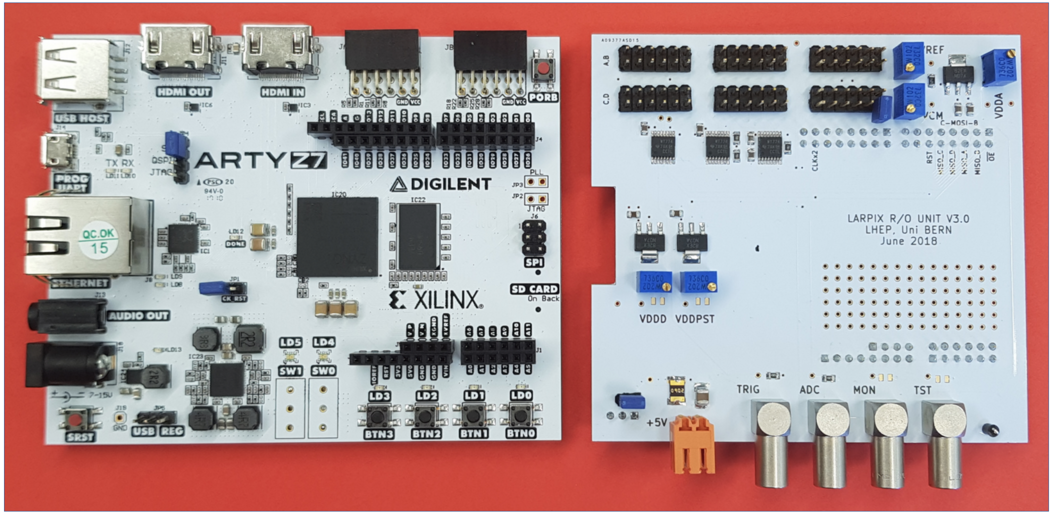
60 cm drift test TPC, prototype pixel anode, and unfiltered 3D information from a cosmic muon. JINST 13 (2018) no.10, P10007.

Pixels Front-End Electronics (Prototype)

Digilent **Arty-Z7 FPGA** evaluation module and a custom-designed mezzanine.

- 4 LArPix daisy-chains per unit
- 256 LArPix per daisy-chain
- 64 pixels per LArPix
- 66k pixels (1 m^2 @ 4 mm pitch)

Signals from severals units into single **Gigabit optical link**.



Digilent Arty-Z7 FPGA & mezzanine board.

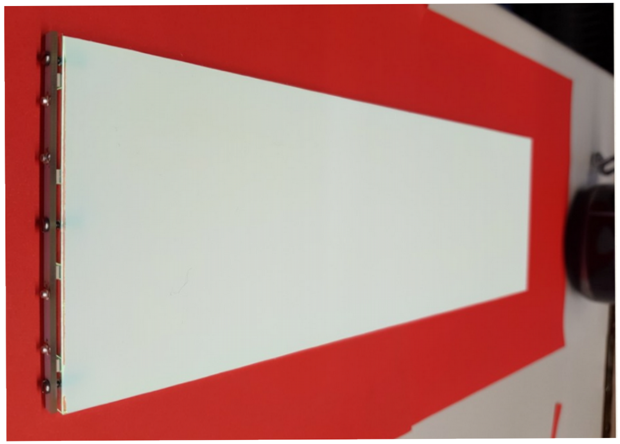
10 kHz rate limit at each daisy-chain (80 kB/s).

Maximum per unit 320 kB/s << on-board Gigabit Ethernet controller limit.

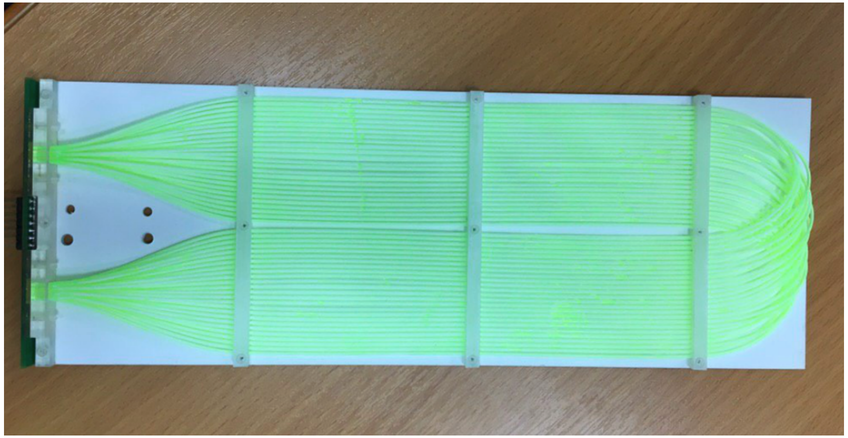
Light Readout

Two complementary **dielectric light readout systems** have been developed:

- Bern’s **ArCLight** and JINR’s **Light Collection Module** (LCM).
- Both use **SiPMs** and **TPB** to convert from 128 nm to 425 nm.
- ArCLight uses sheets of WLS plastic an dichroic mirrors. LCM uses WLS fibres.
- ArCLight has better position resolution, while LCM has higher efficiency.



Prototype ArCLight tile.



JINR’s Prototype LCM.

ArCLight

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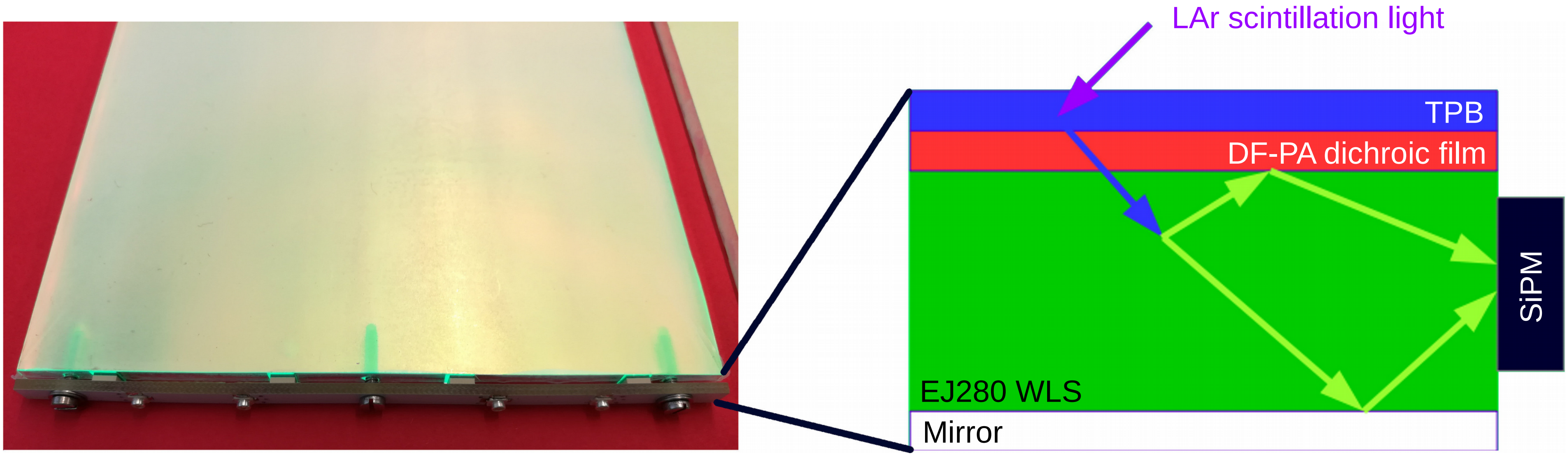
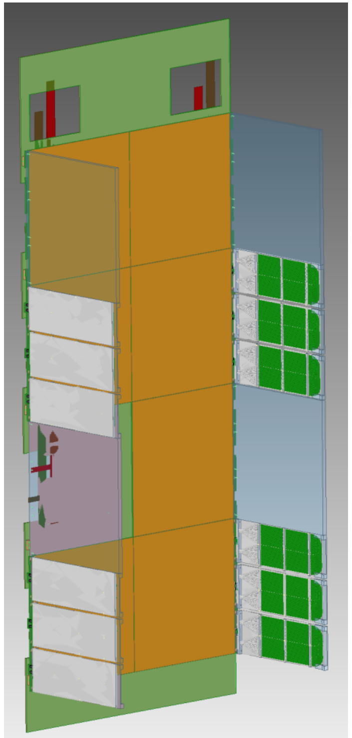
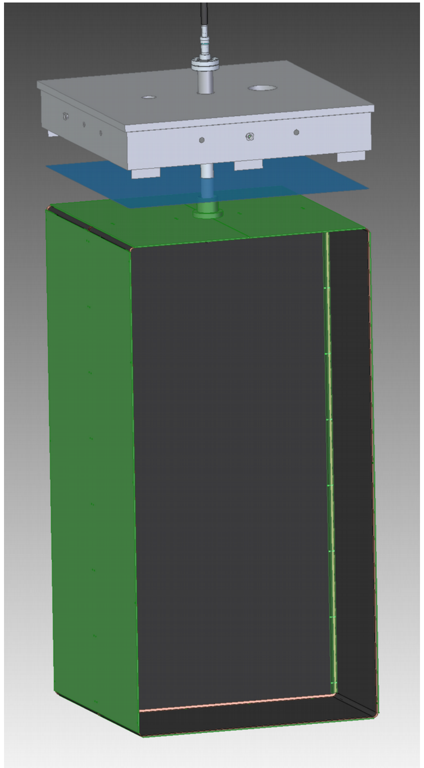


Cross section of an ArCLight prototype. Instruments 2 (2018), no.1, 3.

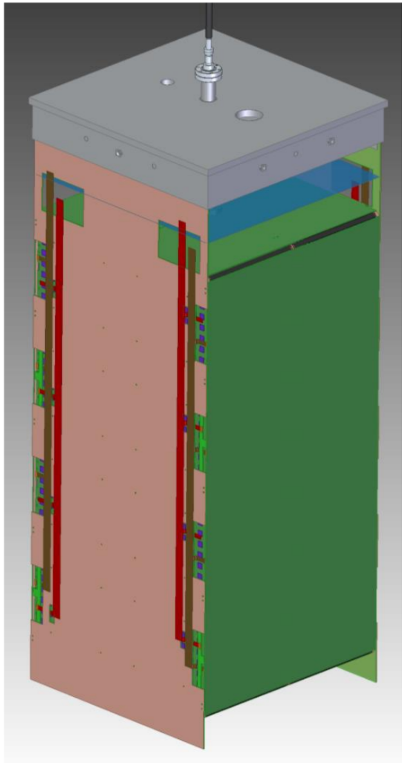
ArgonCube Module Construction



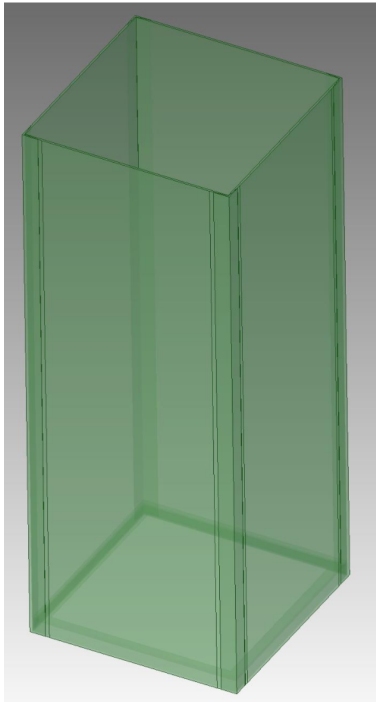
Light & Charge R/O,
half detector



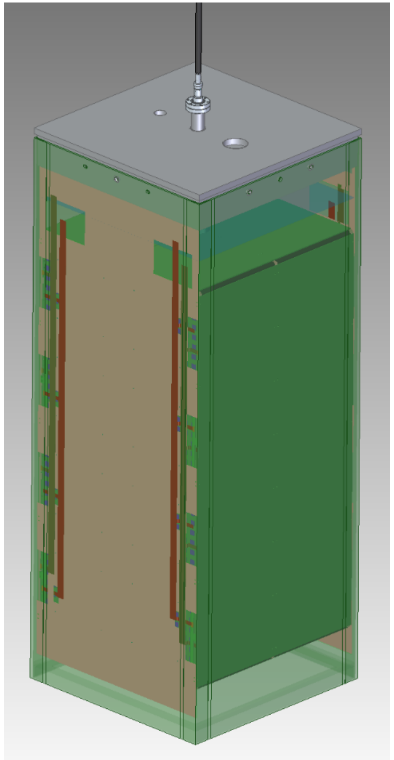
Resistive shell



Naked detector



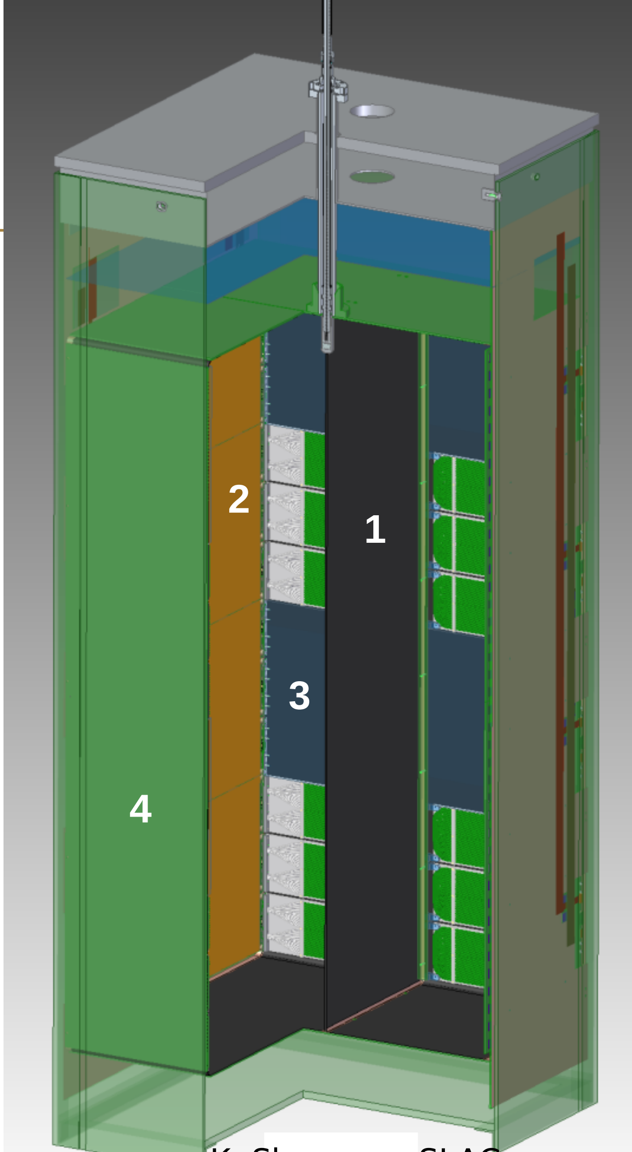
Module bucket



Module

The ArgonCube Module

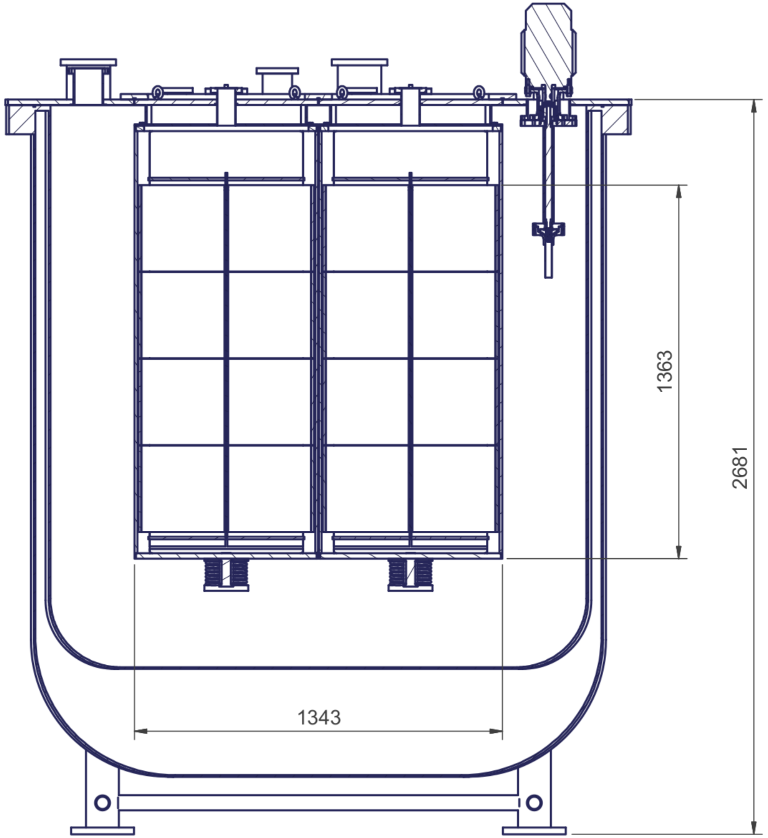
1. **Central cathode**: splits module into 2 TPCs
2. **Pixelated anode plane**
3. **Dielectric light readout** within TPCs
4. **G10 structure**:
    - good dielectric **shielding**
    - comparable **radiation length** to LAr
    - comparable **hadronic interaction length** to LAr
    - **opaque** to scintillation light



K. Skarpaas, SLAC

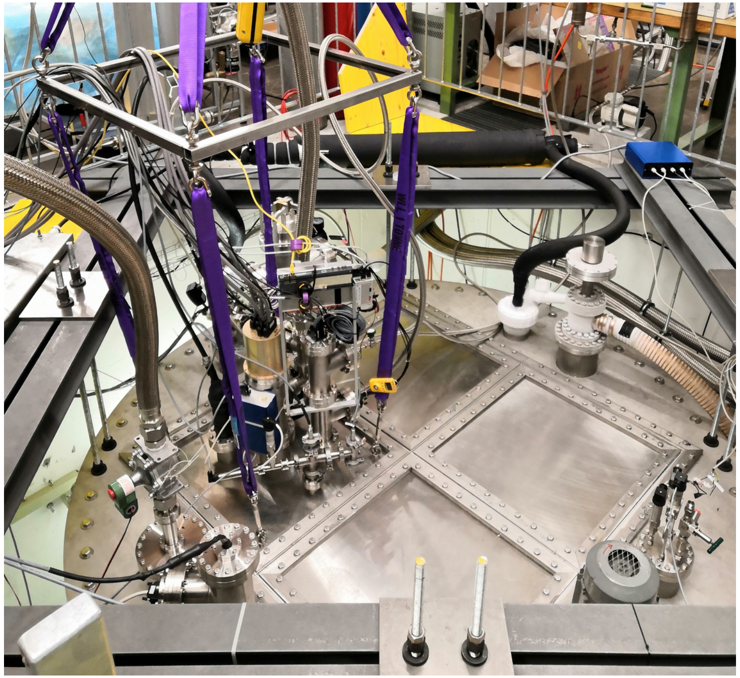
ArgonCube 2x2 Demonstrator

- Vacuum insulated LN_2-cooled cryostat
- **Configuration**: 2x2 modules
- **Module dimension**: 67 cm x 67 cm x 140 cm (LWH)
- **Total active LAr volume**: ~2.4 t
- **Applied E-field**: 0.5 – 1.0 kV/cm



ArgonCube 2x2 in DUNE

In spring of 2020, the 2x2 will be moved into the MINOS-ND hall at Fermilab (**ProtoDUNE-ND**).

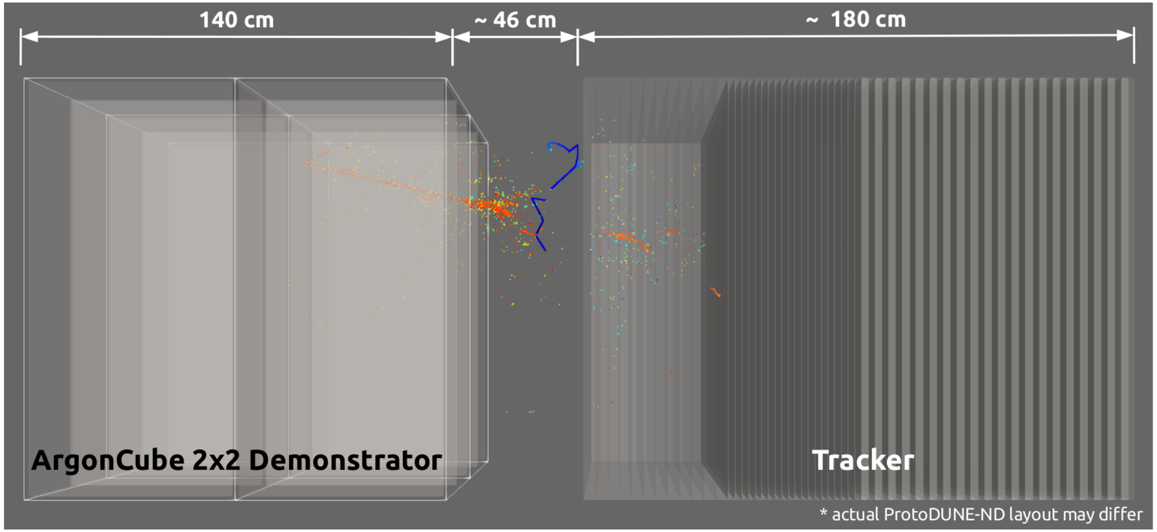


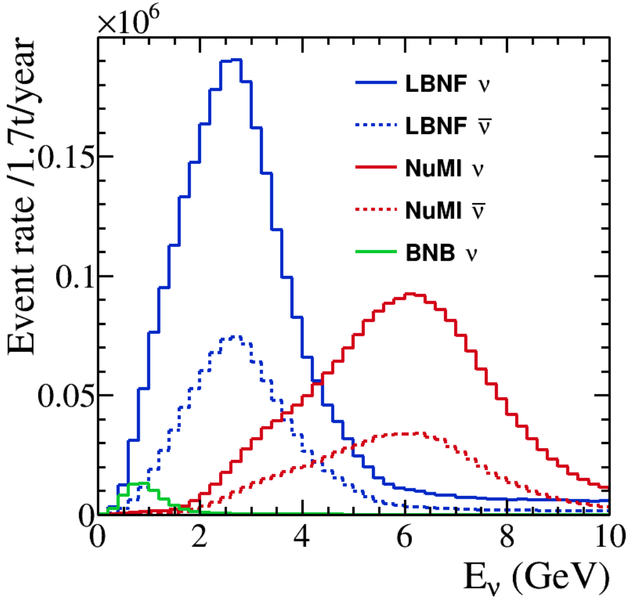
ArgonCube 2x2 cryostat being operated with a single module at the University of Bern, August 2019.

MINOS-ND hall at Fermilab.

Detector Physics Goals of 2x2 in ProtoDUNE-ND

- Combining light and charge signals
- Combining fast and slow detector responses
- Reconstruction in a modular environment
- Electric field calibration using through-going muons





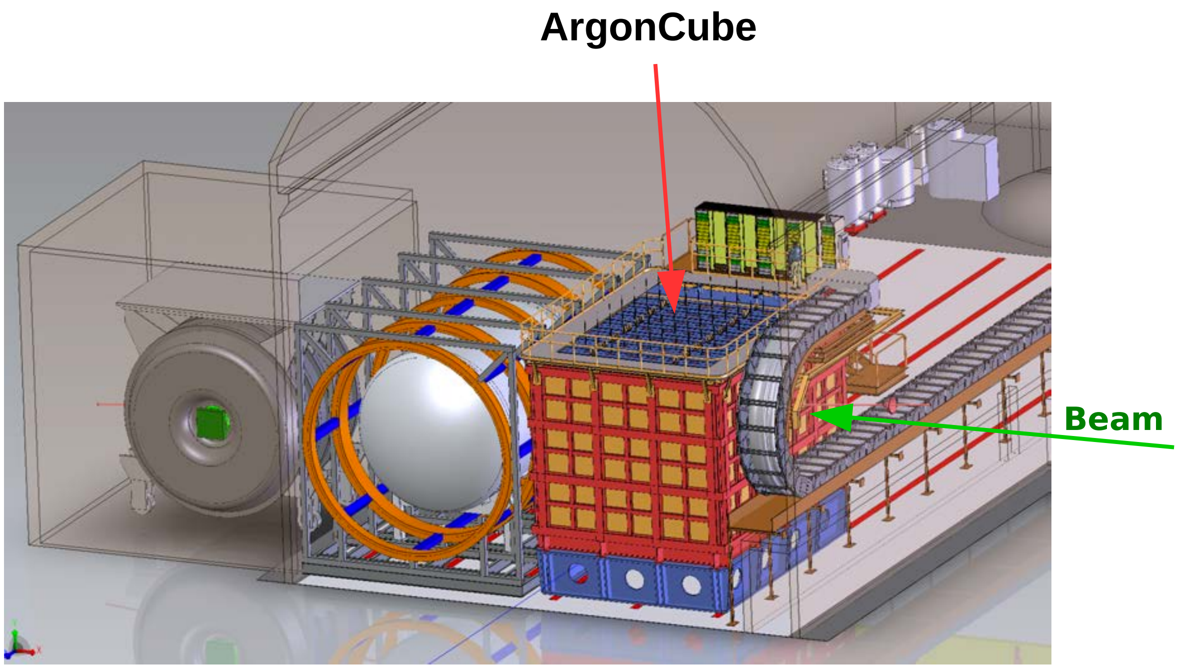
O (1E6) events/t/year

(NuMI on-axis ν)

An Application of ArgonCube in DUNE

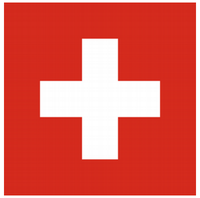
In June 2019 the LBNC recommended **ArgonCube** as the core component of the near detector.

- 35 modules, 70 TPCs
- 3 m tall, 7 m wide, 5 m in beam
- Optimised for:
  - hadronic shower containment
  - side-going muons
  - momentum from spectrometer
- 67 t FV → 11 ν/s



DUNE ND complex by R. Flight, University of Rochester.

The ArgonCube Collaboration



Backup

What Motivates LAr at the Near Site?

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- 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 to far.
  → *Hight multiplicity at near site necessitates differences in design.*

- The energy and angular resolution and the target mass is sufficient to extract 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.*

What is a Liquid Argon Time Projection Chamber?

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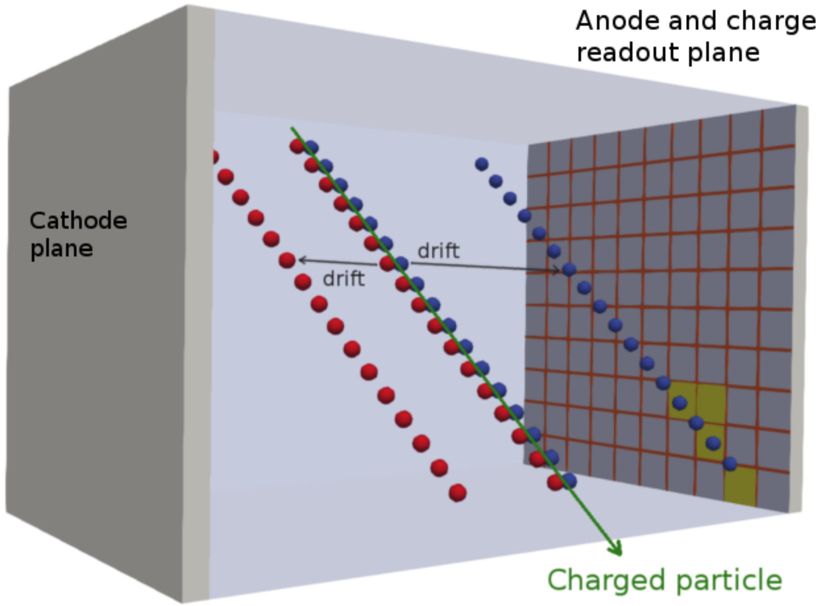
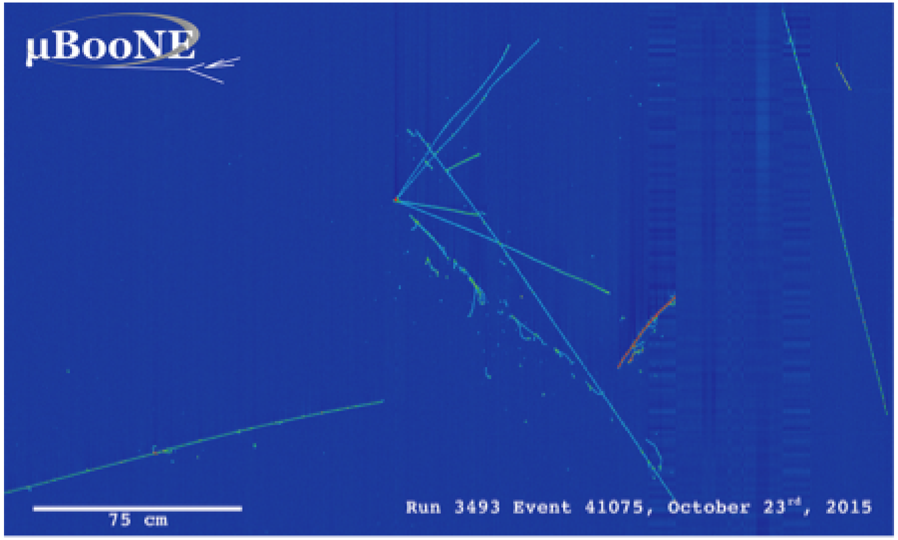
A detector that provides both **precise tracking and calorimetry**, with a high target density.





LAr is transparent to its own scintillation light, which is used to fix the 3rd spatial component.

Module of Opportunity