ArgonCube: A Modular Approach for Large Liquid Argon Time Projection Chambers

Roman Berner | LHEP | University of Bern

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ArgonCube Idea

ArgonCube [1] provides a novel solution for large Liquid Argon Time Projection Chambers (LArTPCs)

Segmenting a big volume by identical but separate modules:

→ contained TPCs share a common LAr bath

→ scalability to very large active volume with minimal amount of inactive material

→ easy to repair, maintain and upgrade single modules

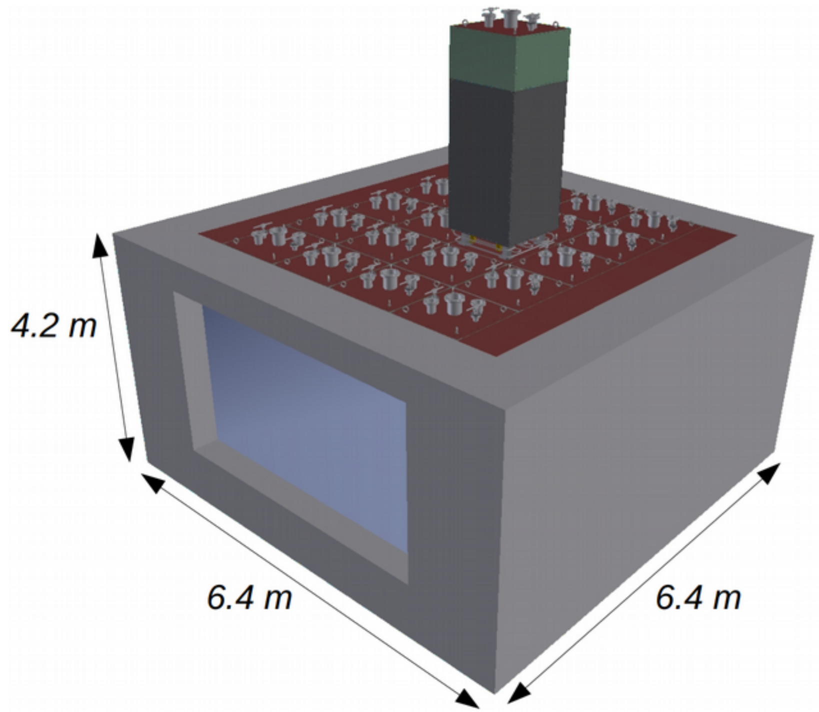
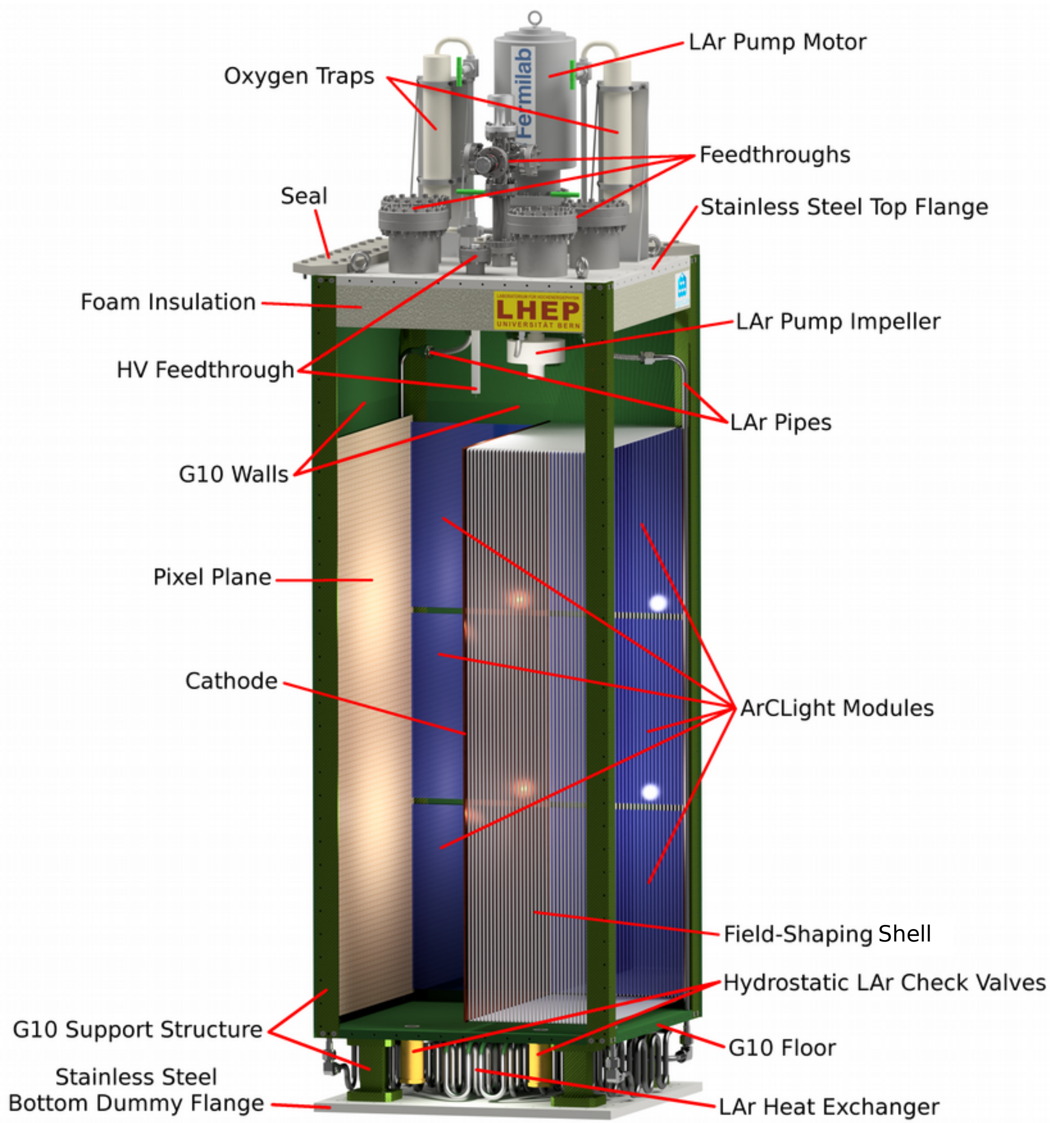


Illustration of the DUNE LAr near-detector, possibly being upgraded to 5 x 7 modules.

ArgonCube Module

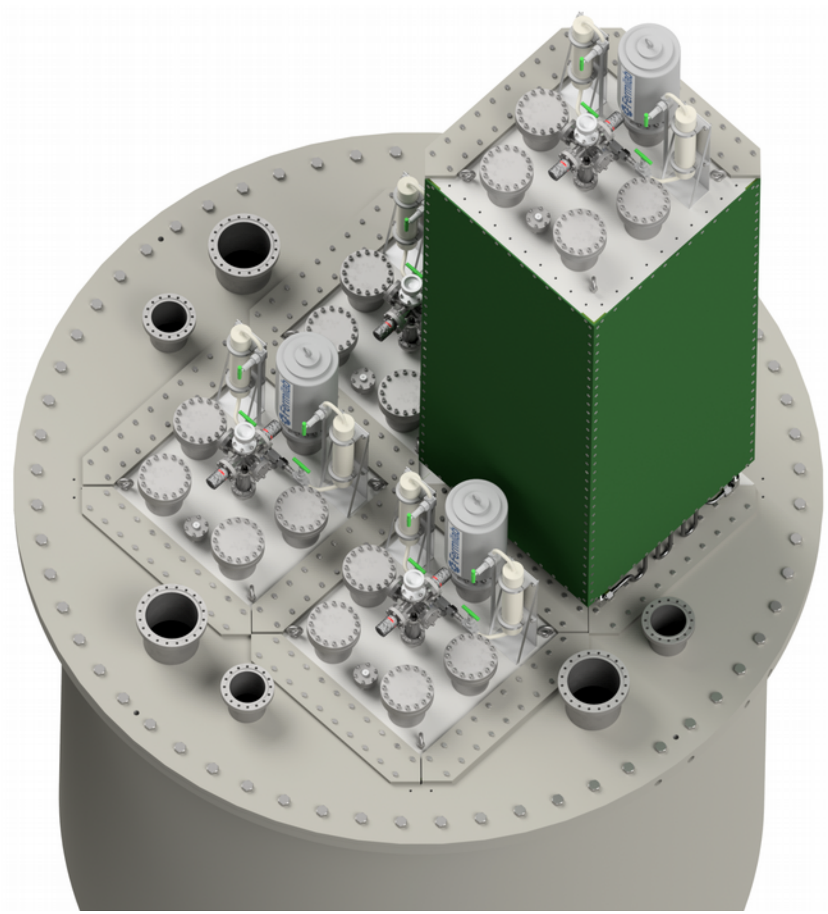


Cut-away illustration of a instrumented (small) prototype module (footprint: 67 cm x 67 cm)

- Module is split by cathode plane into two independent TPCs
- Contained scintillation light within each TPC
- Thin module walls (~1cm G10*) with interaction lengths comparable to LAr
  → 'transparent' to passing particles
- Short drift length with E_{drift} = 1kV/cm and t_{drift} ~ 150 μs
  → safe cathode voltage [2,3]
  → less stringent req. on LAr purity
  → negl. track smearing due to e^- diffusion
- Pixelated charge readout
  → true and unambiguous 3D tracking [4]
- ArCLight modules
  → large area photon detection [5]

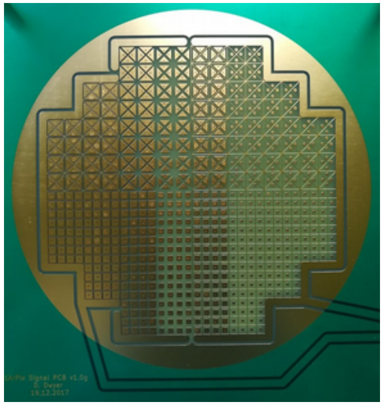
*high-pressure fibreglass

R&D Projects for Module Instrumentation

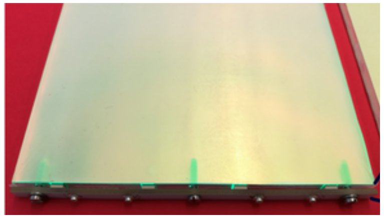


Cryostat for 2x2 prototype modules at Bern

LArPix
→ charge readout

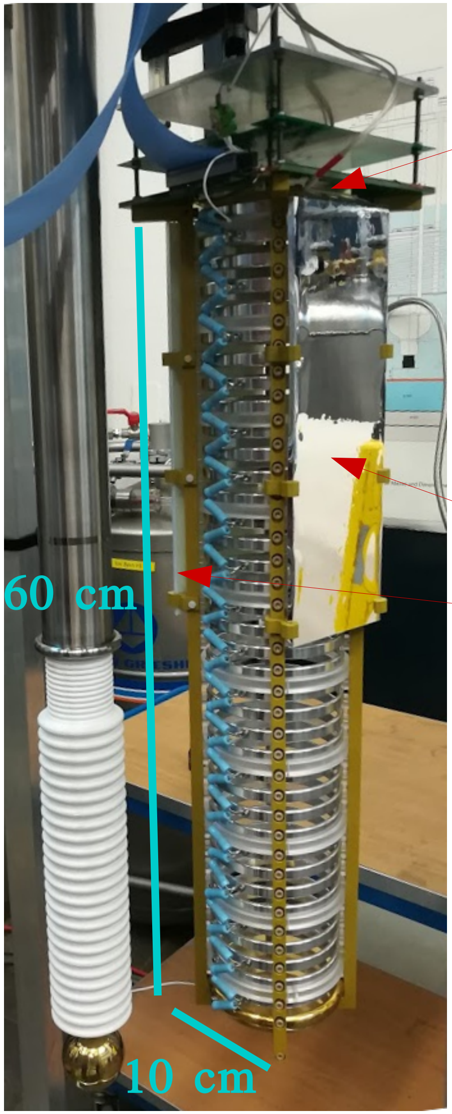


ArCLight
→ light readout



Resistive Shell TPC
→ field shaping

Pixel Demonstrator TPC

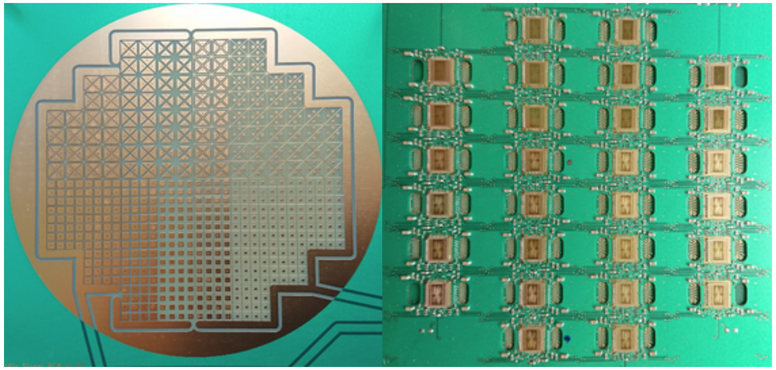


V_{cath} = 60 kV

E_{drift} = 1 kV/cm

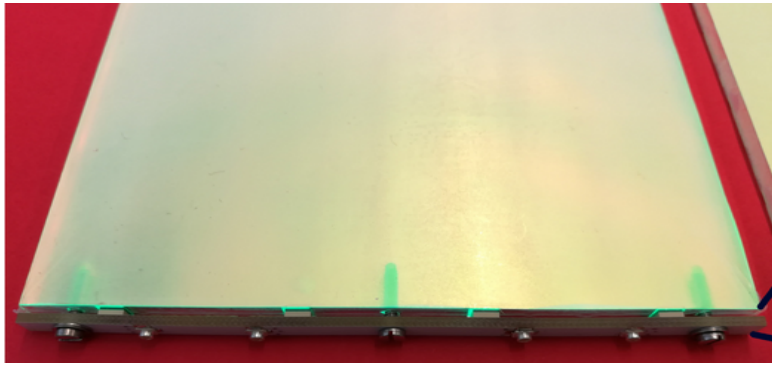
Pixelated Charge Readout [4]

- 28 chips with 832 pixels

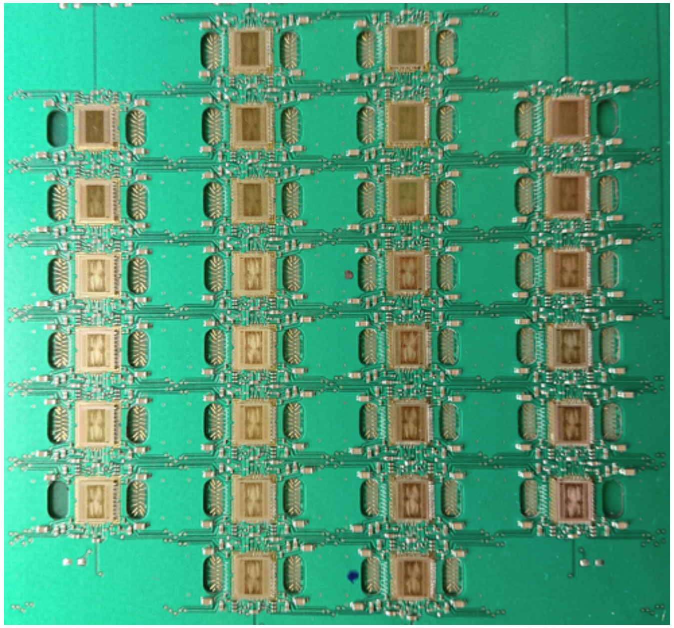


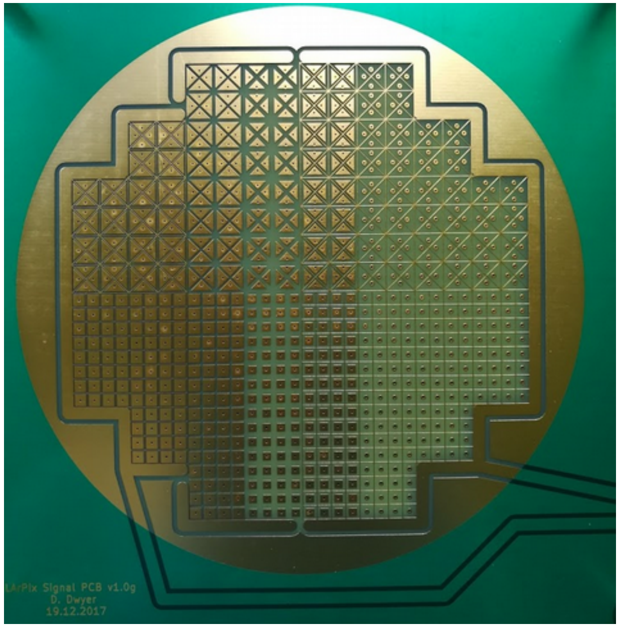
ArgonCube Light Readout: ArCLight [5]

- Large area photon detector



Pixelated Charge Readout: LArPix





https://arxiv.org/abs/1808.02969

LArPix (developed at LBNL):

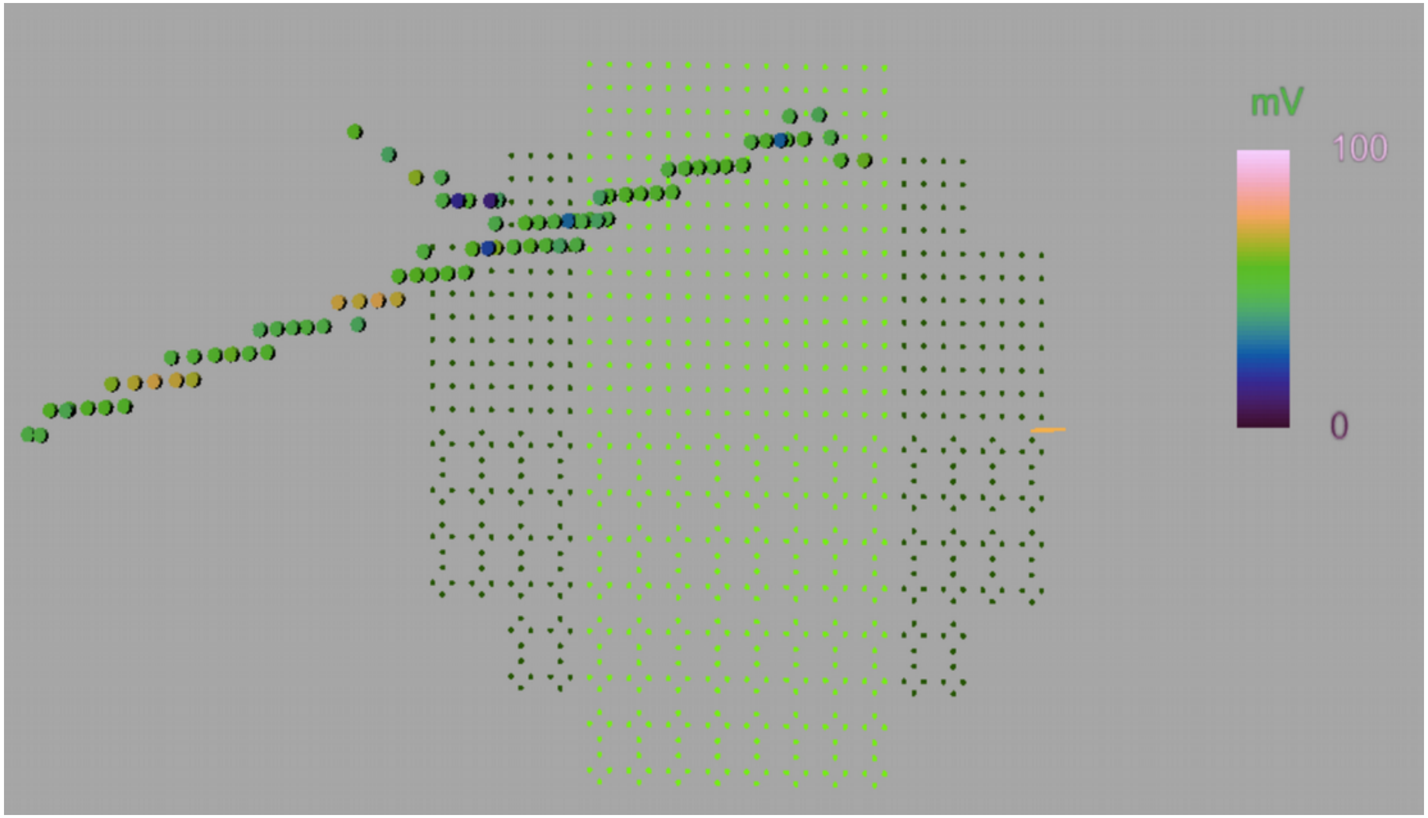
- ASIC for cryogenic amplification and digitization (32 pixels/ASIC)
- Low power consumption (~60 μW/channel)

Pixel plane with LArPix:

- 28 chips with 832 pixels, different pixel geometries
- Half of the board: Focusing grid
- Each pixel has an independent front-end channel (no analog multiplexing)
- Expected data rate: 0.1 $Mb/m^2/s$

Pixelated Charge Readout: LArPix

- Native 3D tracking by direct access to 3D space points
  → simplifies high multiplicity event reconstruction
- Flat response as a function of angle

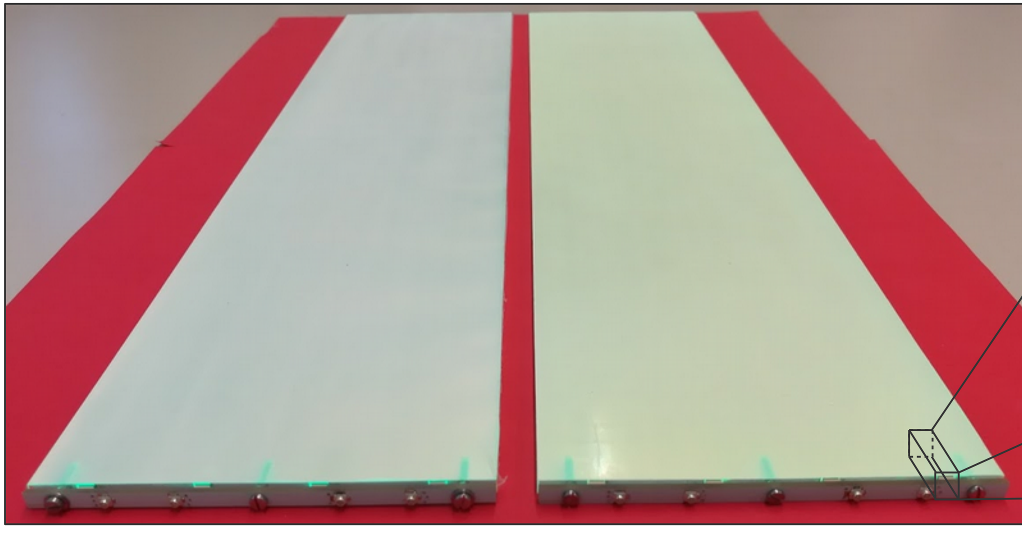


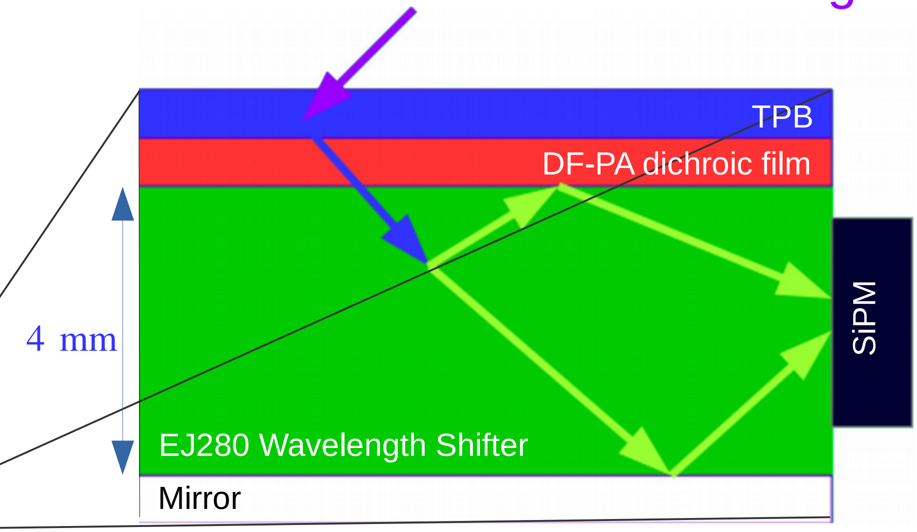
Candidate of a cosmic muon with a delta electron. Uncalibrated data.
Credits to: S. Kohn (LBNL)

Interactive event display:
https://goo.gl/swpFR8
https://goo.gl/93Giuj
https://goo.gl/wMTXzq

ArgonCube Light Readout: ArCLight

Working principle explained on slide 17





TPB: 1,1,4,4-Tetraphenyl-1,3-Butadiene

- Compact combination of SiPMs with a dielectric light trap
  → Resilient to electric fields (can be put inside field shaping structure)
  → Suited for a modular TPC design

- Photon Detection Efficiency of ~1%
- Sub-ns timing resolution is possible (with proper TDC*)

*Time to Digital Converter

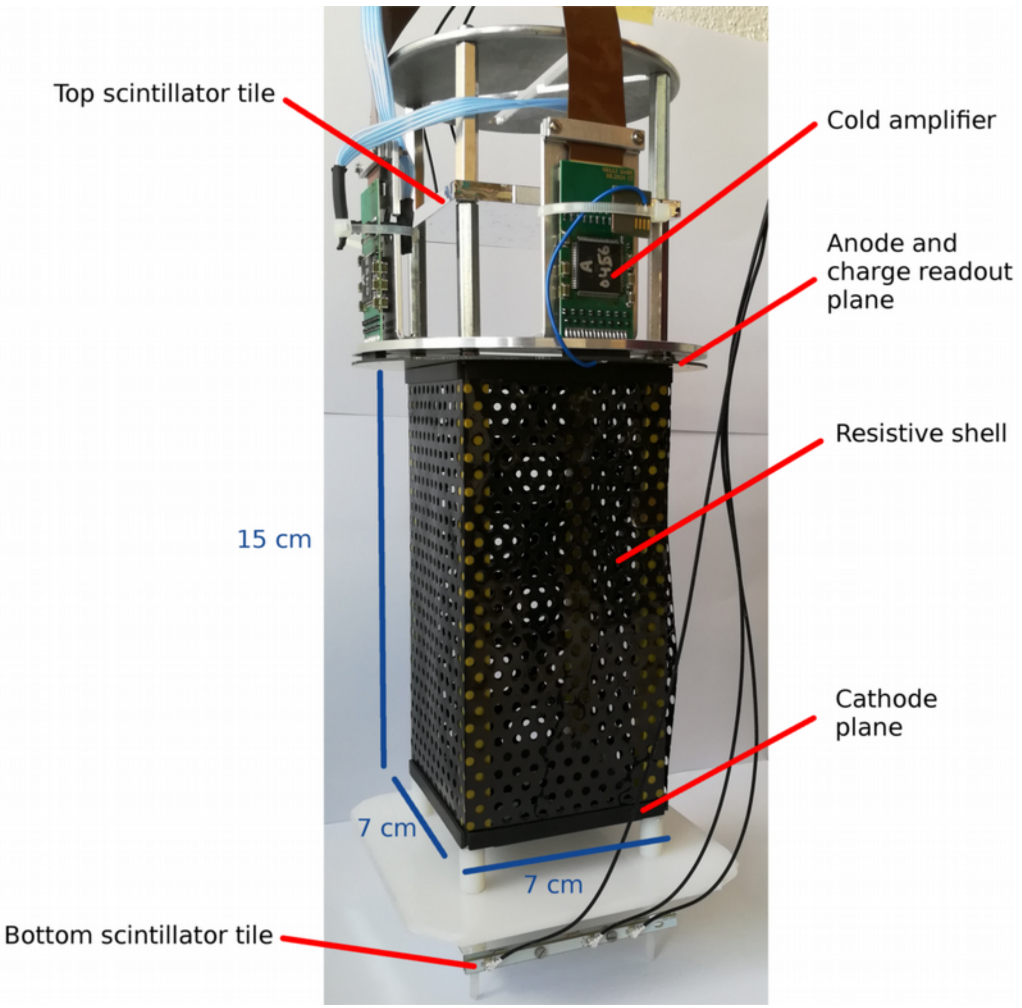
https://arxiv.org/abs/1711.11409

Resistive Shell TPC: Field Shaping

Replace traditional field cage with highly resistive polyimide foil

(~10^9 Ω/square, 50 μm thickness)

- Minimise dense material near active volume and maximise fiducial volume
- Slowdown possible discharge effects and minimise power release
- Uniform field with continuous field shaping
  → no field based optimization
- Power dissipation spread over whole foil
  → no hot components, less boiling
- Reduced number of components
  → less possible failure points



Resistive shell provided by T. Miao (FNAL)

MDPI

Article

First Operation of a Resistive Field-Shell Liquid Argon Time Projection Chamber - A New Approach for Field Shaping

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Abstract: We present a new technology using a carbon-loaded polyimide foil for the shaping of the electric field in Time Projection Chambers (TPCs). This technology allows for the minimization of inactive material near the active volume of the TPC and thus is well suited to reduce background events originated by radioactive decays or scattering on the material itself. Furthermore, the high and continuous electric resistance of the foil limits the power dissipation and minimizes the risks in case of a electric field breakdown. Replacing the traditional field cage with a resistive shell decreases the number of components within the TPC and therefore reduces the potential points of failure when operating the TPC. A prototype TPC with such a resistive shell and with a cathode made from the same material has been tested in liquid Argon (LAr) for several days and with electric fields up to about 1.5 kV/cm. The experiment showed that it is feasible to produce and shape the electric field in liquefied noble gas detectors with this new technology.

Paper draft.
Will be published soon!

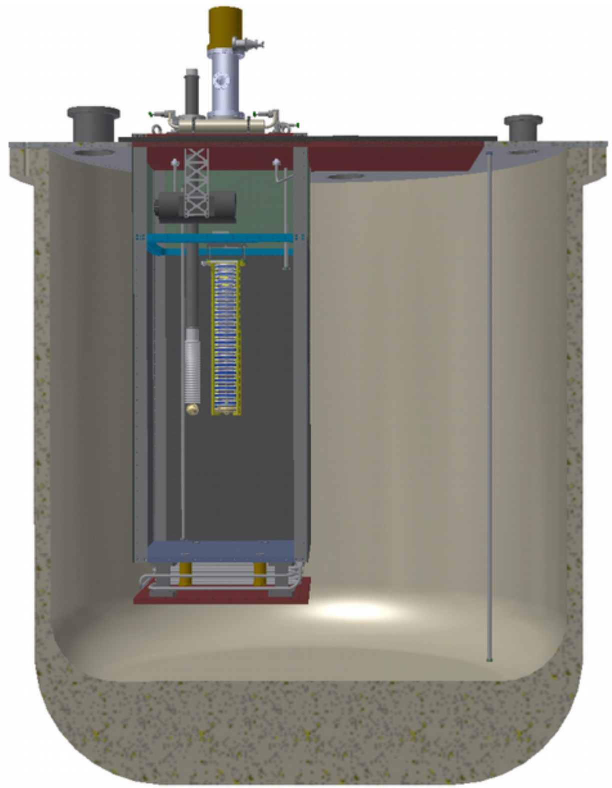
Keywords: Time Projection Chamber (TPC), liquefied noble gas detectors, noble liquid detectors, field shaping, field cage, resistive shell TPC

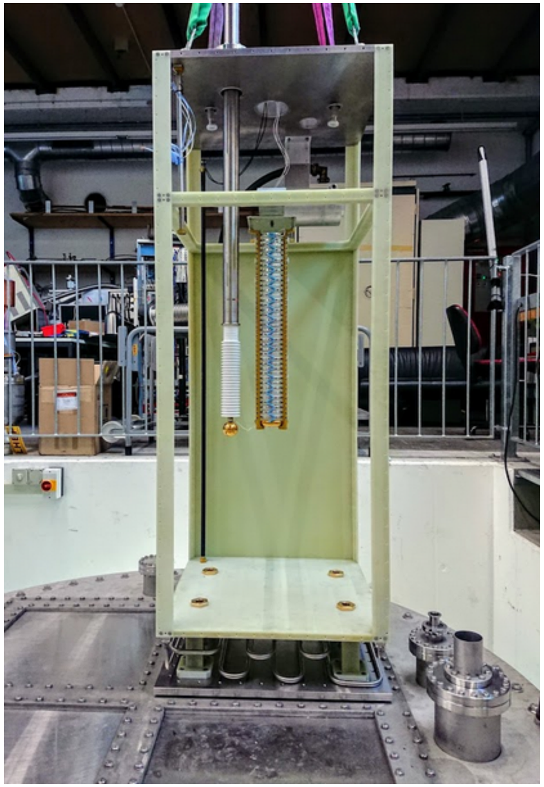
Upcoming studies

Pixel demonstrator TPC in (an early version of) the ArgonCube module:

→ Test LAr filtration & recirculation as well as construction techniques

→ Test if required LAr purity can be maintained upon extraction and insertion of the module

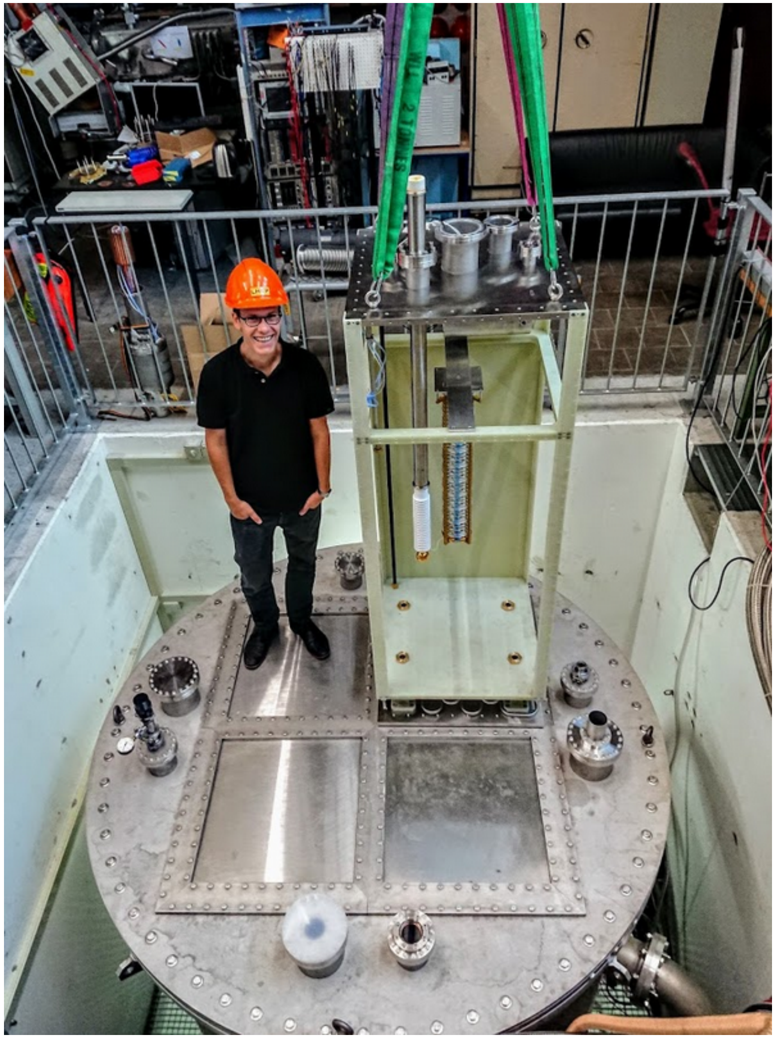




Furthermore: Test Scalability of Resistive Shell to larger drift volumes

Summary

- ArgonCube provides a novel solution for very large Liquid Argon TPCs
- The design simplifies replacing, maintaining and upgrading single modules without significant detector downtime
- New technologies (LArPix, ArCLight and the Resistive Shell) have shown to be feasible for the instrumentation of the ArgonCube modules



References

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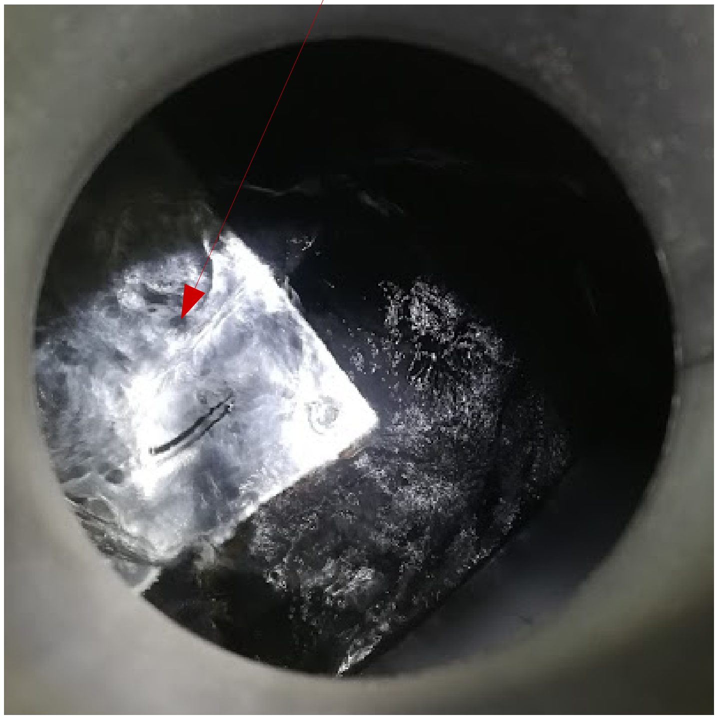
Backup

Liquid Argon as Detector Material

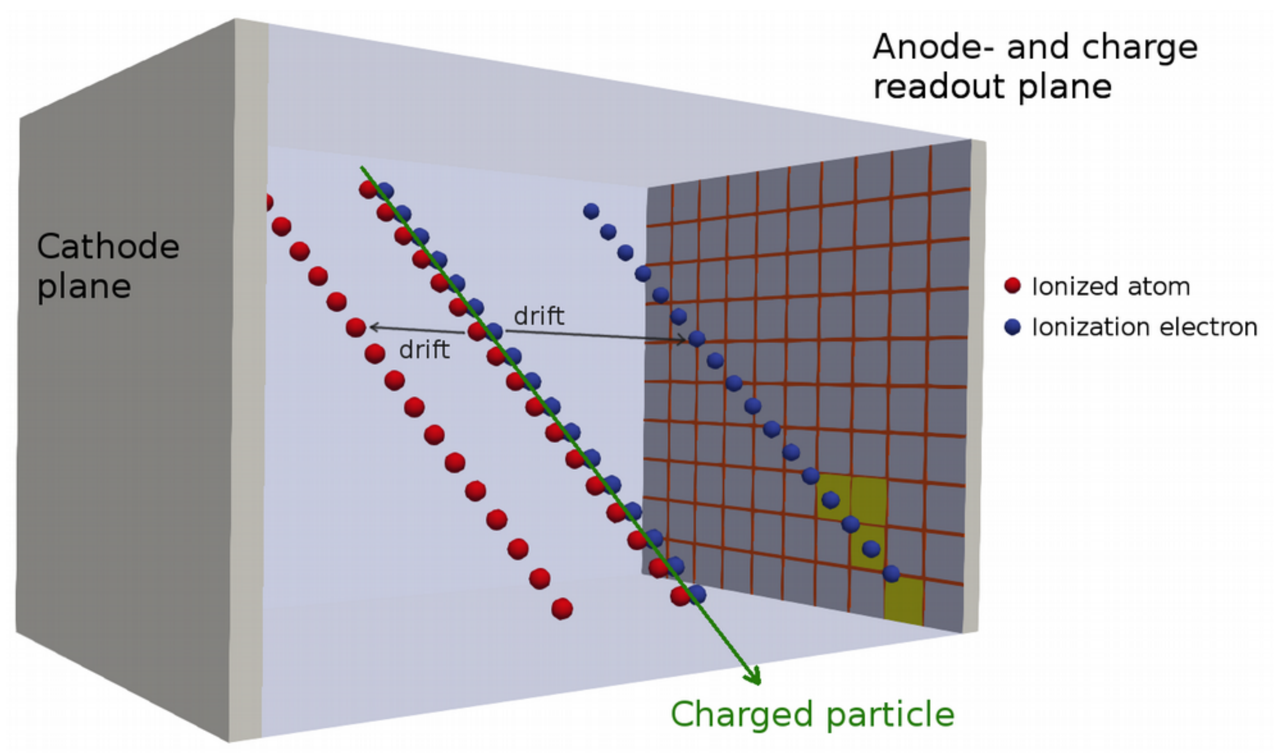
- High density ($1.4 \cdot 10^3$ kg m^{-3})
  → high event rate
- Abundant (~1% by volume of Earth's atmosphere)
  → affordable to buy
- High ionisation yield (9800 e/mm for MIP, no recomb.)
  → tracking and calorimetry
- Prompt scintillation light (<6.2 ns) [6]
  → absolute spatial reference
- ~ 40k photons per deposited MeV (at zero field)
- High attenuation length for own scintillation light (>2m)
  → transparency
- Liquid at 87 K
  → cooling with LN_2
- High electron mobility
  → ~230 $cm^2 V^{-1} s^{-1}$ (at 1kV/cm)

TPC immersed in LAr



Working principle of a Time Projection Chamber

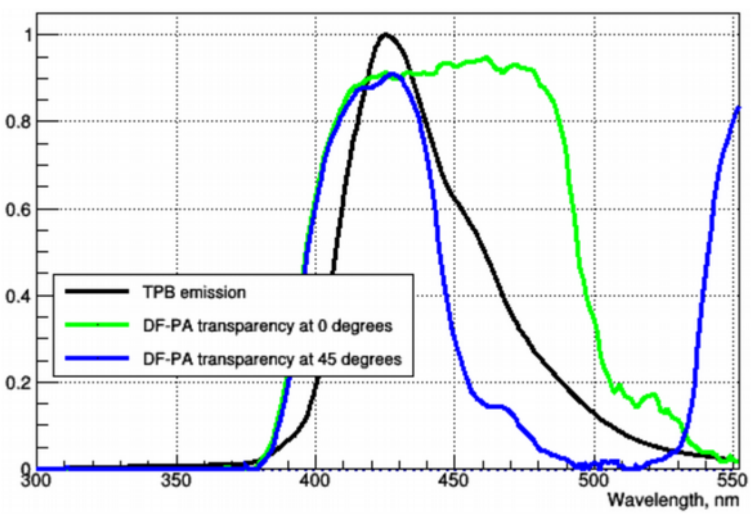
- Charged particles ionize and excite Argon atoms
- $\sim$ 40k photons per MeV energy deposited (in LAr, at zero field)
- Scintillation light → reconstruct time of interaction
- Ionization electrons drift towards 2D charge readout plane
- Time and charge signal allows for 3D event reconstruction

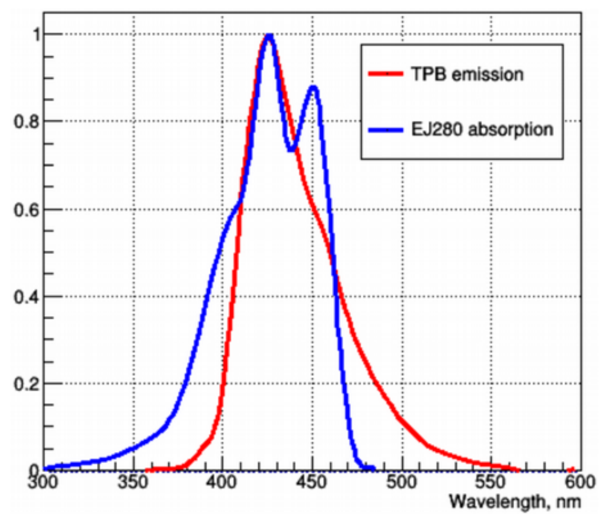


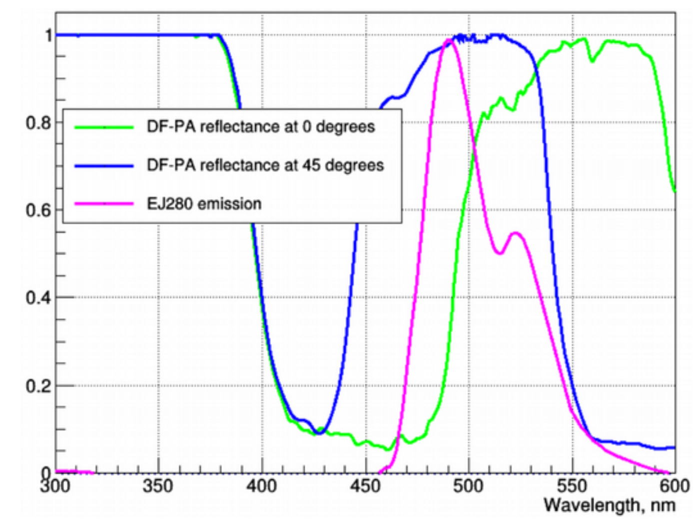
TPCs provide excellent tracking and calorimetry of charged particles

Working Principle of ArCLight

- LAr scintillation light (λ≃128 nm) is shifted by TPB* to blue (λ≃430 nm)
- Dichroic film is transparent for blue and reflective for other wavelengths
- Plastic wavelength shifter: Shifting blue light to green
- Silicon Photomultipliers (SiPMs) can be operated in cold and within magnetic fields







Long attenuation length of wavelength shifter, O(m) → scalability: up to several m^2

Photon detection efficiency (depends on #SiPMs): 0.1% – 1% (measured)

https://arxiv.org/pdf/1711.11409.pdf

* TPB: 1,1,4,4-Tetraphenyl-1,3-Butadiene