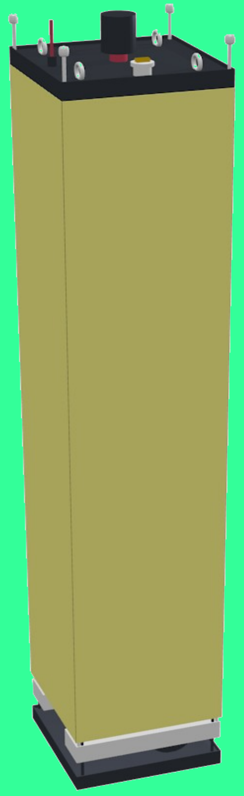
ArgonCube: scalable modular approach for large LArTPCs



15th Topical Seminar on Innovative Particle and Radiation Detectors (IPRD19) 14-17 October 2019   Siena, Italy

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LABORATORIUM FÜR HOCHENERGIEPHYSIK LHEP UNIVERSITÄT BERN

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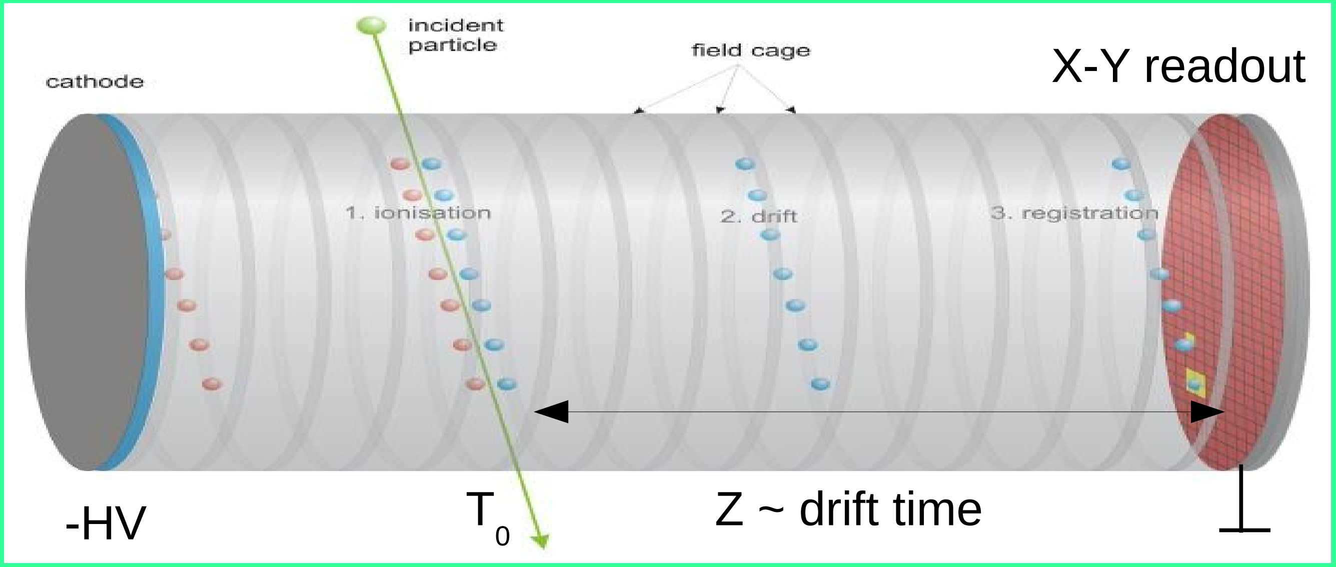
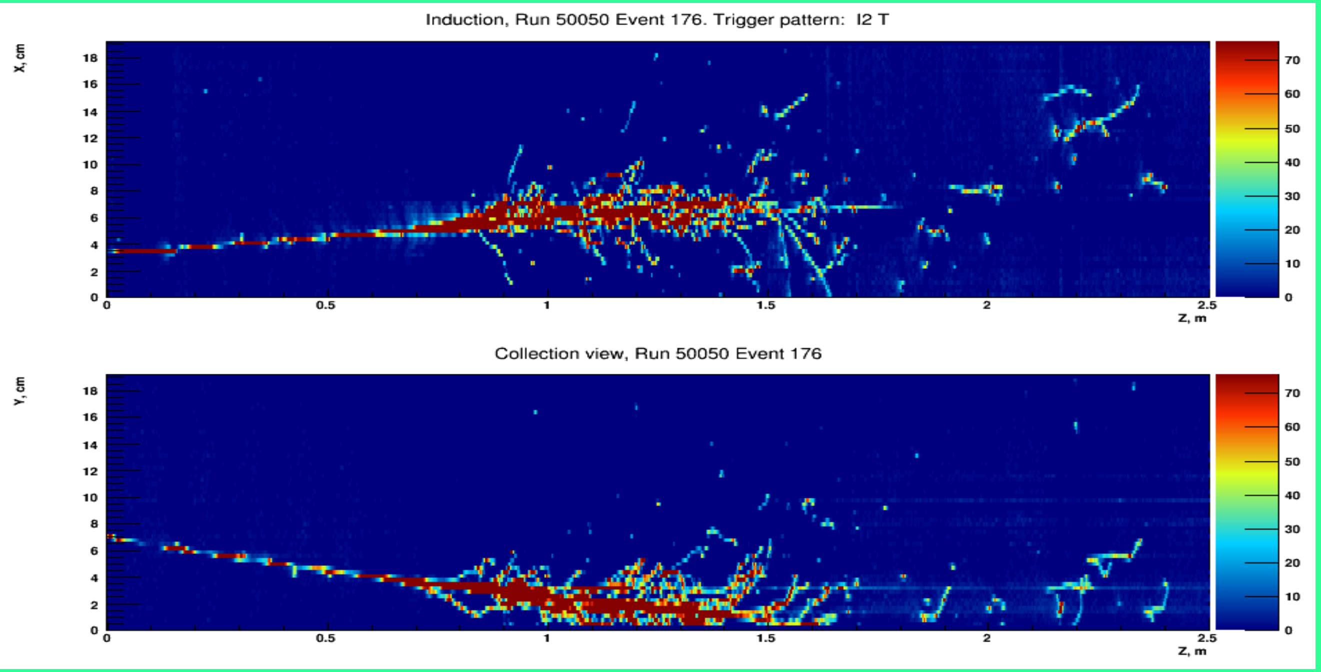
Liquid Argon Time Projection Chamber



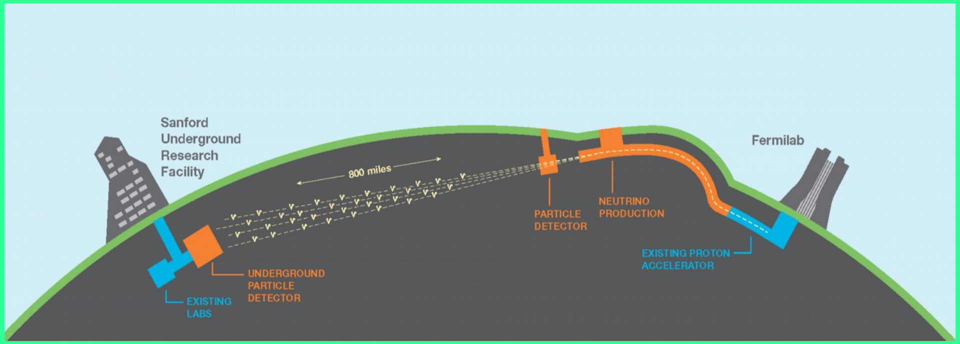
Charge yield (MIP)
~ **9000 e/mm** (1.5 fC/mm)
T_0 by scintillation

Classic charge readout:
X: Induction (non-destructive)
Y: Collection



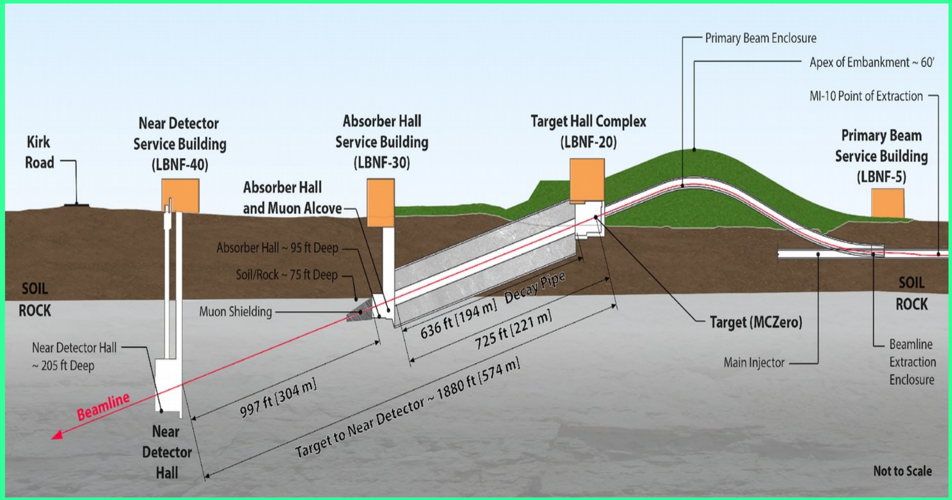
ArgonCube: design inspired by LBNO→ LBNE→ LBNX→ DUNE requirements

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).



mND ~ 150 ton ->
Neutrino events pile up!

The Solution – ArgonCube

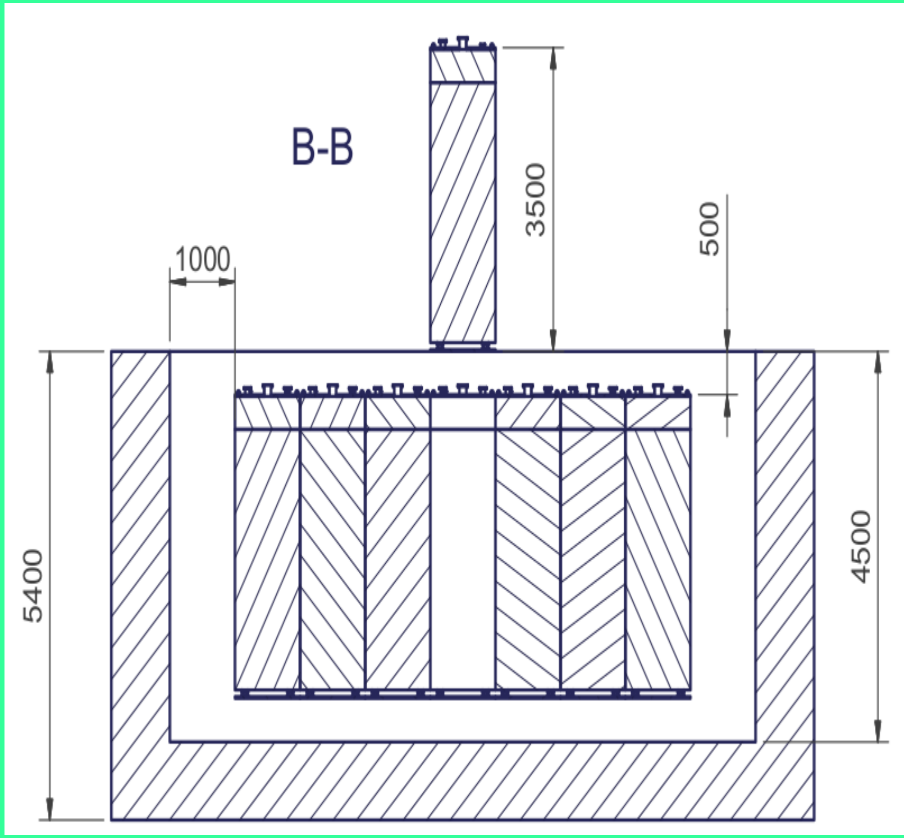
Instead of a monolithic detector volume, divide the detector into a number of self-contained TPC modules sharing a common cryostat - I. Kreslo & M. Weber, 2014

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%)

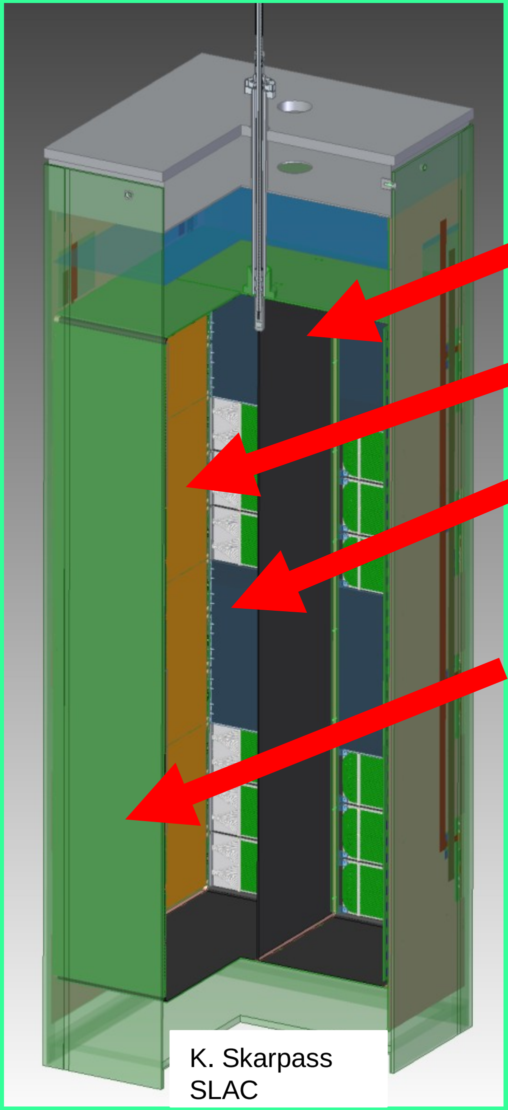
Also

Unambiguous charge readout

All of which is good for reducing pileup



ARGONCUBE
Module design features



Central cathode
2 TPC volumes

Pixelated anode plane

Dielectric light readout within TPCs

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

Thin walls

Min. material budget

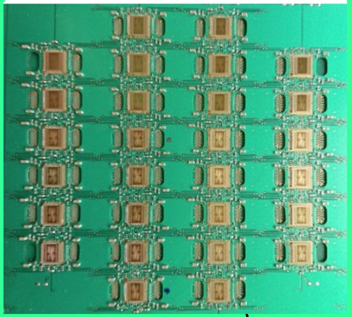
Resistive shell

Limited LAr convection

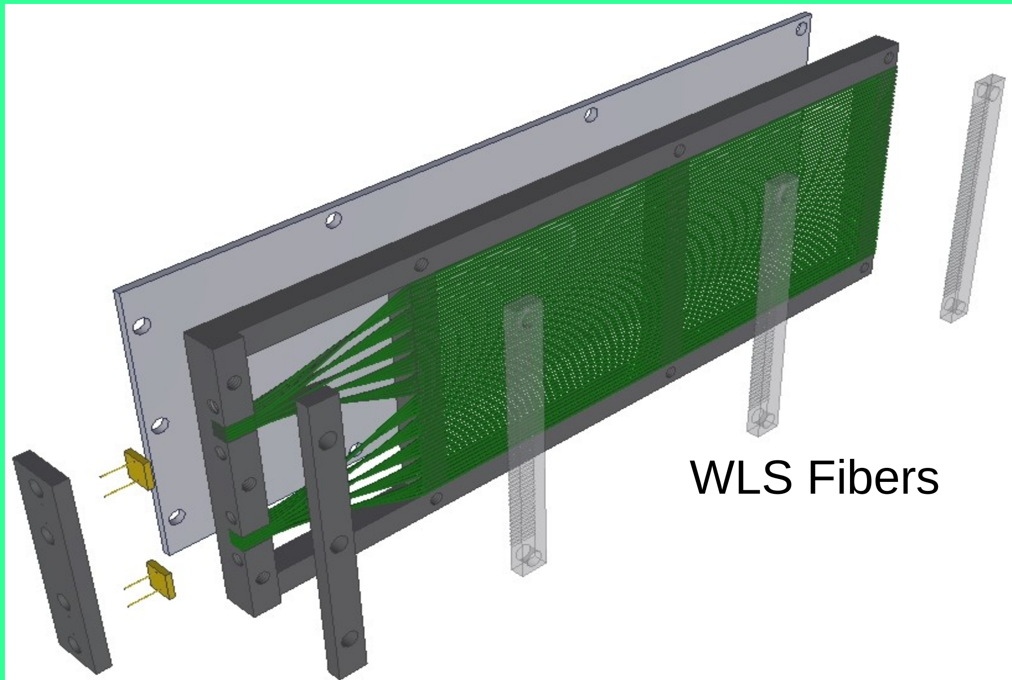
Heat management

< 100 W/module overall

LArPix ASIC



Scintillation Light Readout, option 1:
Light Collection Module (collaboration with JINR, Russia)



VUV scintillation light is double-shifted to green

LAr scintillation light
128 nm

TPB: 128 nm → 420 nm

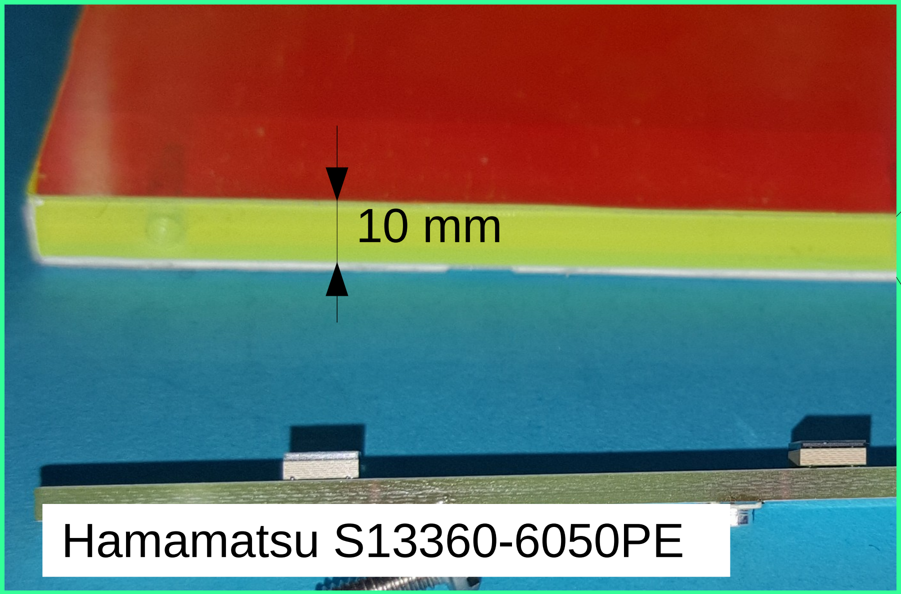
WLS fiber
420 nm → 500 nm

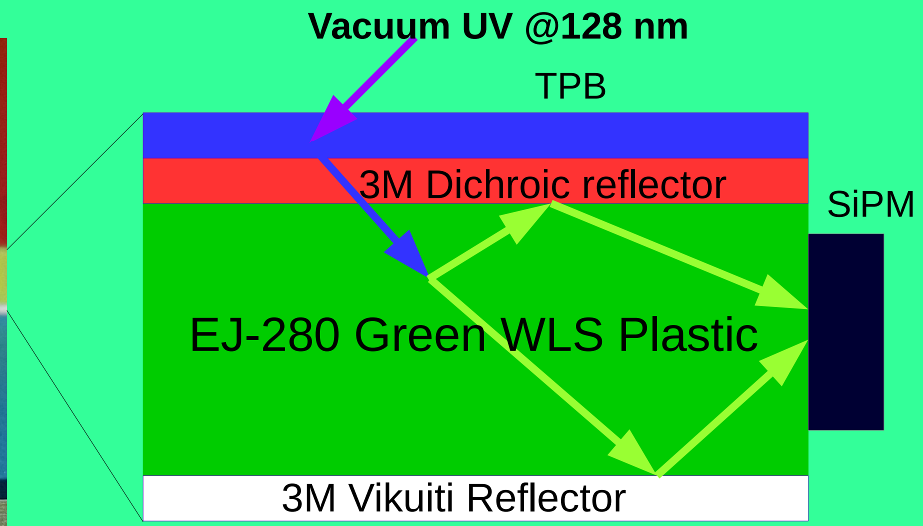
SiPM

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.

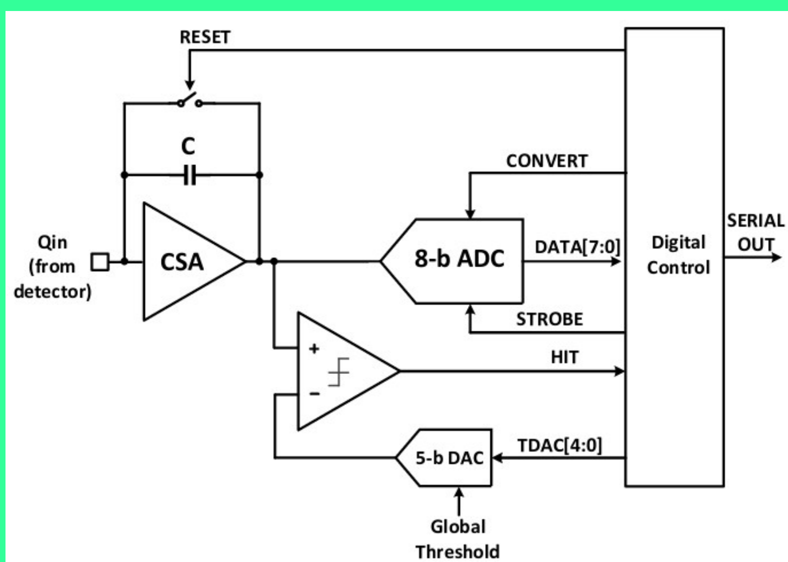
This was enabled by the LArPix ASIC, developed at Dan Dwyer at LBNL.

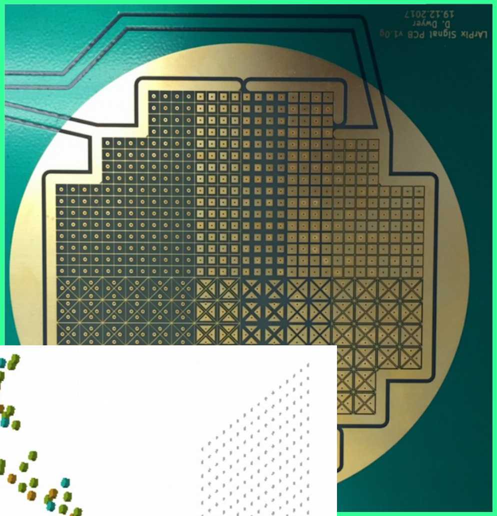
Power consumption per pixel: 62 μW (37 μW digital).

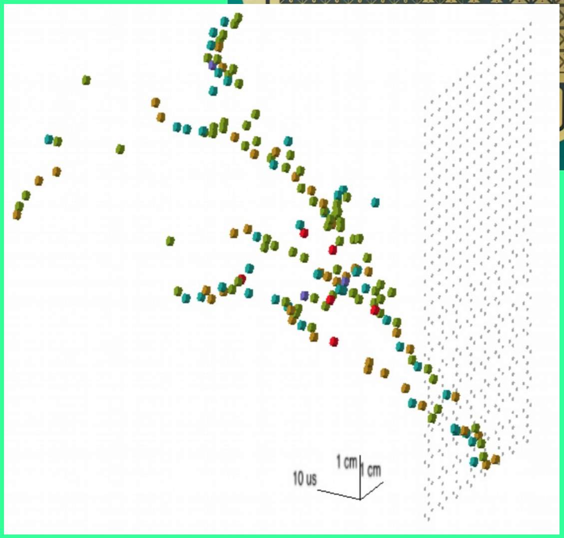
Data rate: O (0.1) MB/s/m^2

LArPix V2: **64 channels / ASIC**

Pixel **4x4 mm, 0.5 us time stamp**





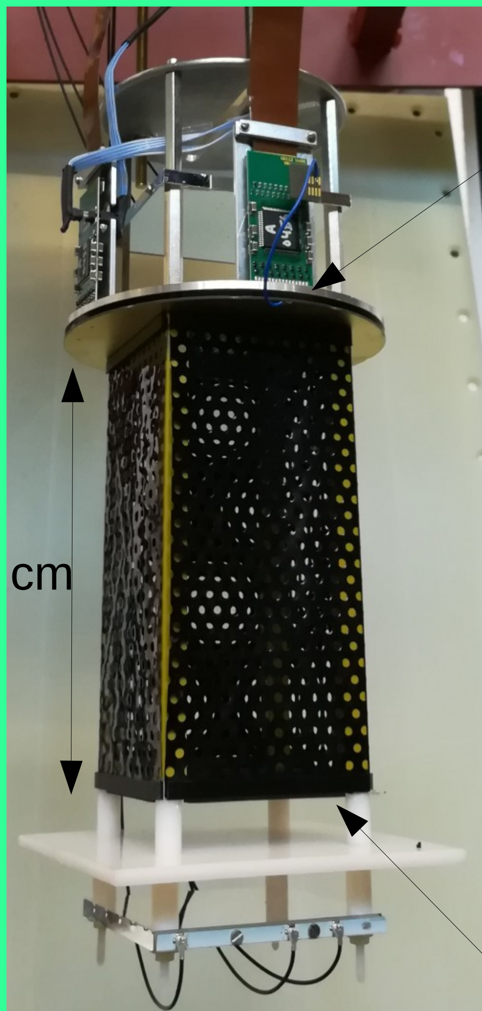


Unfiltered 3D information from cosmic muon.
JINST 13 (2018) no.10, P10007

Field uniformity test is conducted, data analysis in progress.

First Resistive Shell LArTPC (RSTPC)

No more field shaping rings and resistors!



Anode at GND

15 cm

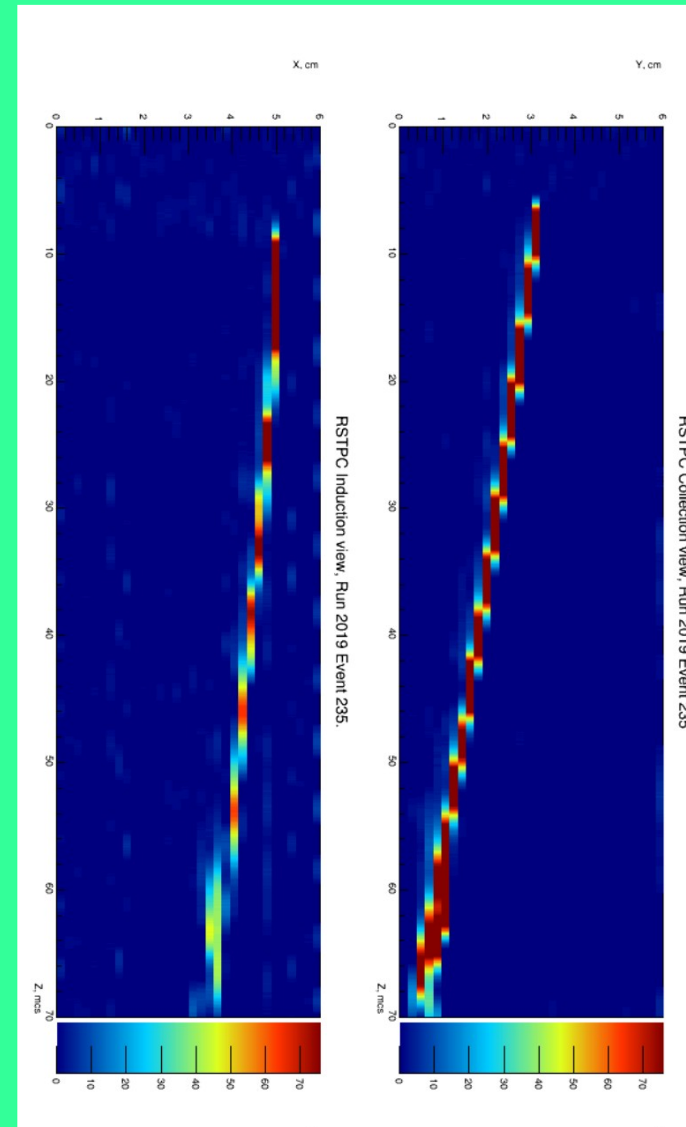
Cathode at -HV(up to 25 kV)

Resistive foil:
DuPont DR8

16 Gohm/sq in cold

Field uniformity by muon tracks:

Better than 1%



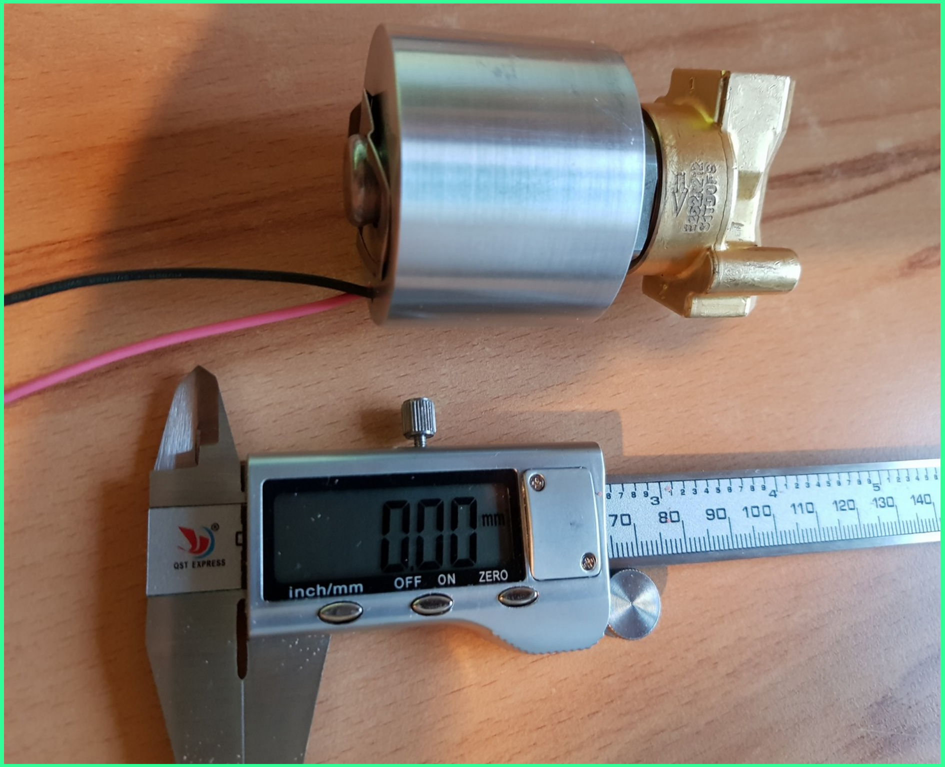
Novel cryogenic liquid valve developed

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

Operates fully immersed in liquid argon

PLC-friendly controller

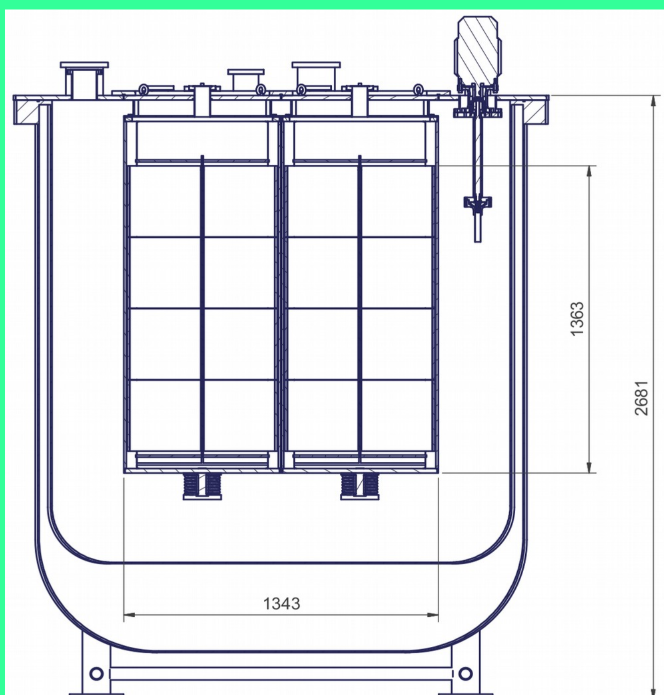
Patent pending..

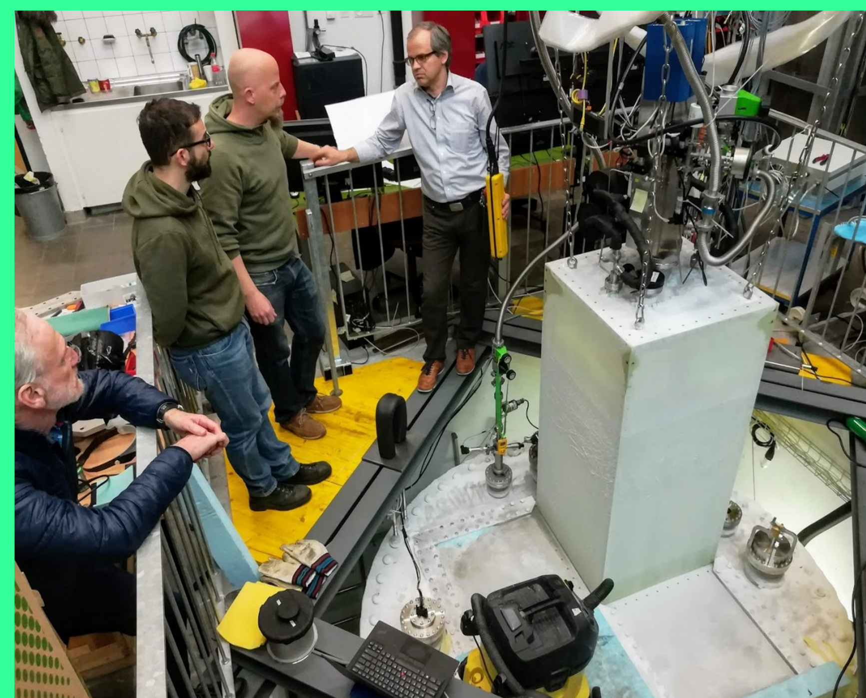


The DUNE Proto-ND *(ArgonCube 2x2 Demonstrator, ~1/50 scale ND)*
2020 goes to Fermilab to on-axis NuMi beam

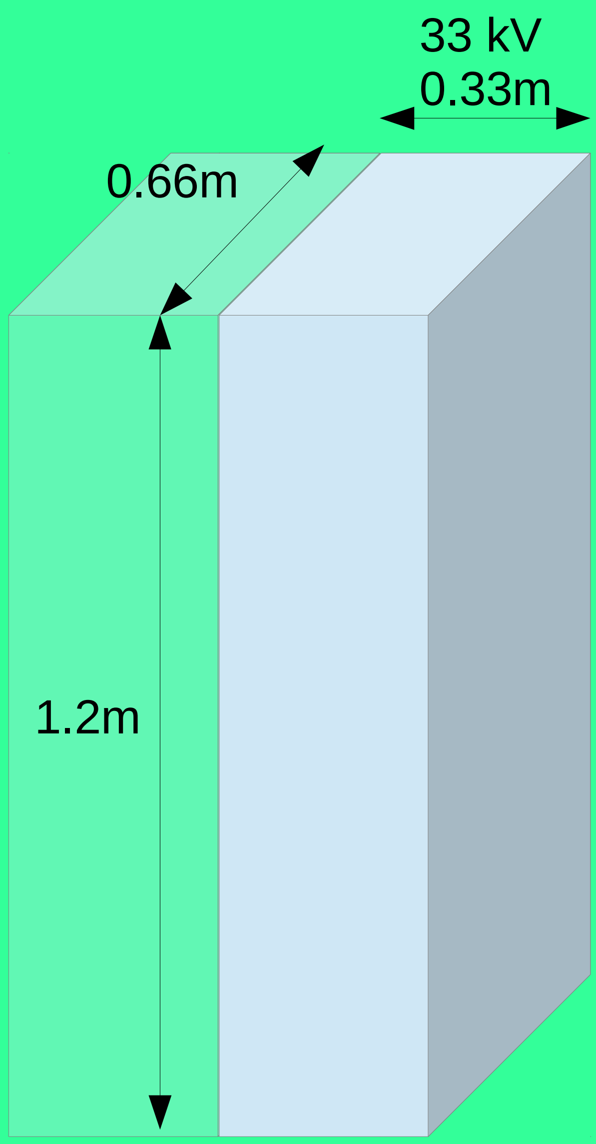
Vacuum insulated LN2-cooled cryostat, housing 4 modules, 2.4t active LAr
Top flange sealed with Indium wire

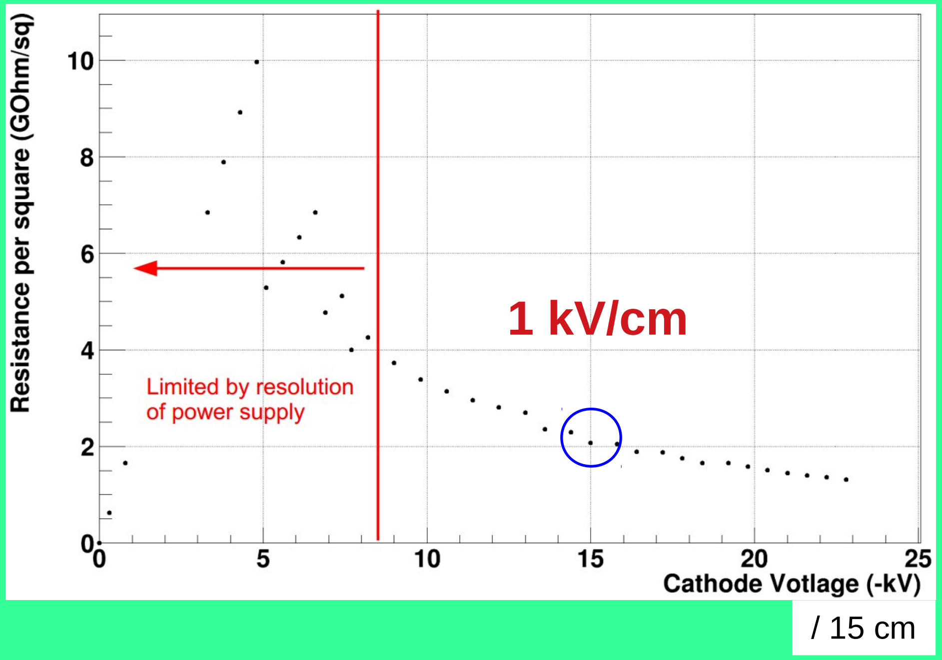
130 uS drift time at 1kV/cm
Pixelated charge readout: **400k Pixels (13M Pix for DUNE ND)**
4 x 4 x 1.5mm voxel
192 SiPMs for scintillation R/O





DUNE Proto-ND module with RS





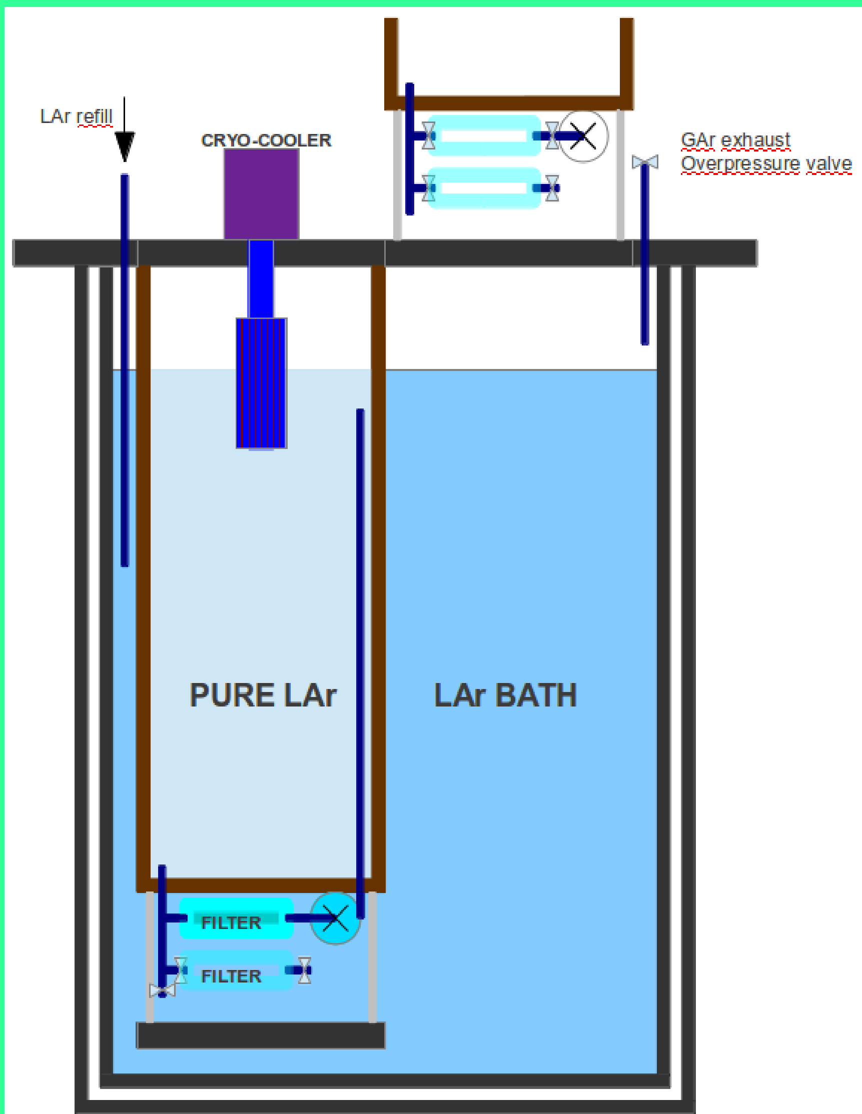
2 G/sq @ 1kV/cm,   U=**33kV**

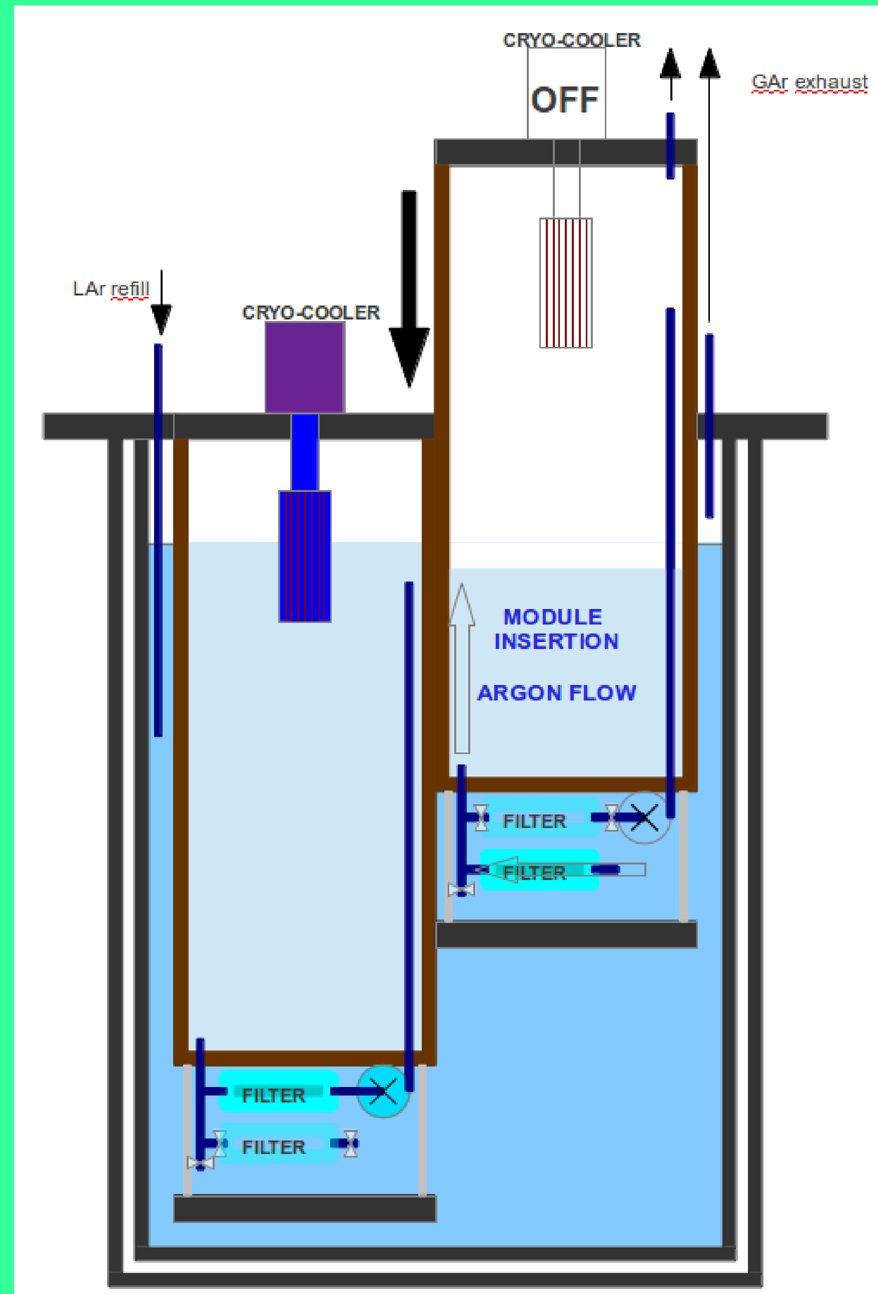
P= 4.5 W/m^2

~10 W/module — acceptable.

Cryogenics:

Module *cold* extraction / re - insertion





DUNE Proto-ND module tests

2 measuring campains (one in progress), goal:

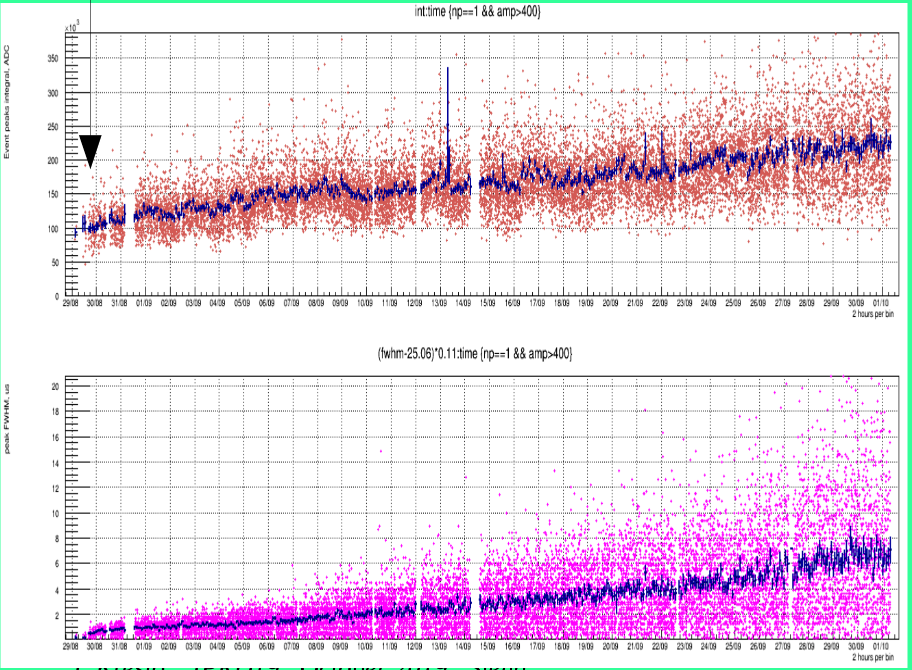
demonstrate cryogenics & purification
demonstrate module cold extraction / insertion

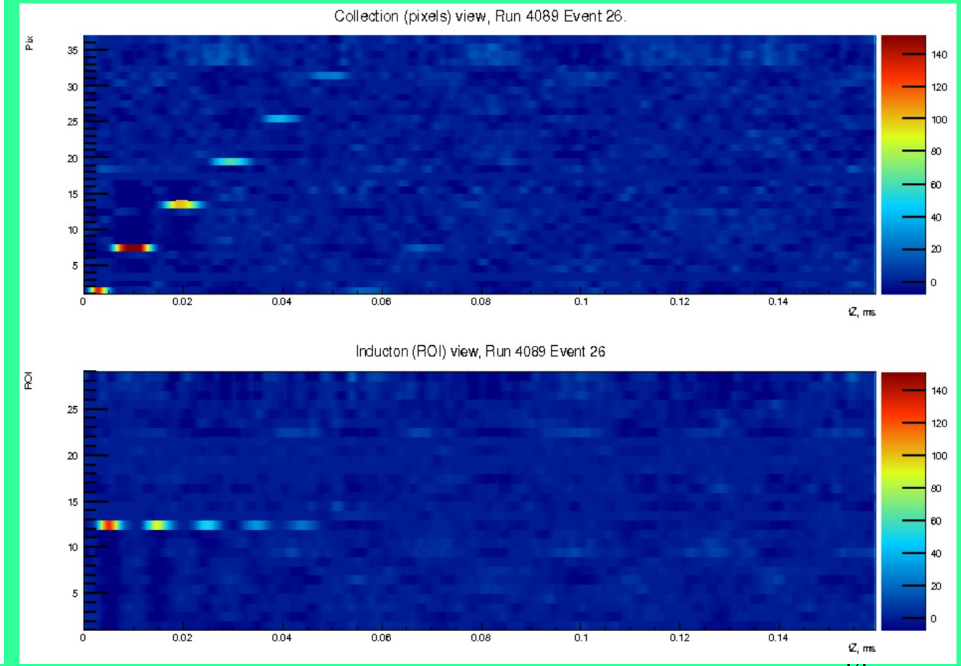
Before extraction: steady purification rate, stopped at ~30 us life time (>10 cm long muon tracks observed)

Extraction / Reinsertion performed successfully

Re-Purification : back to starting point after 1 week

Note: filter material used is 100 times less efficient that the state of art!





Dune Proto-ND current status

All novel aspects of ArgonCube have been demonstrated:

Charge R/O – arXiv:1801.08884, JINST 13 (2018) no.10, P10007

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

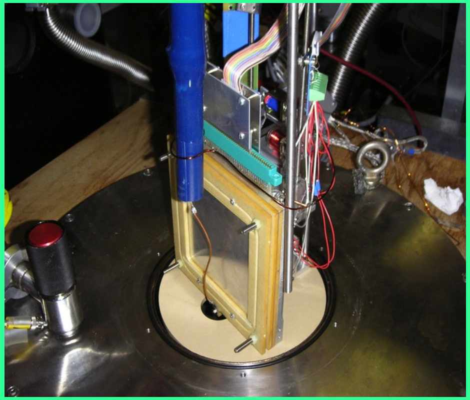
ARGONCUBE is accepted as the technology for DUNE Near Detector.
DUNE ND CDR 2019, TDR 2020, Installation 2025.
Option for DUNE Far Detector «module of opportunity»

Thank you!


Fermilab
Yale University
CERN
BROOKHAVEN
NATIONAL LABORATORY
JINR
LHEP
UNIVERSITÄT BERN

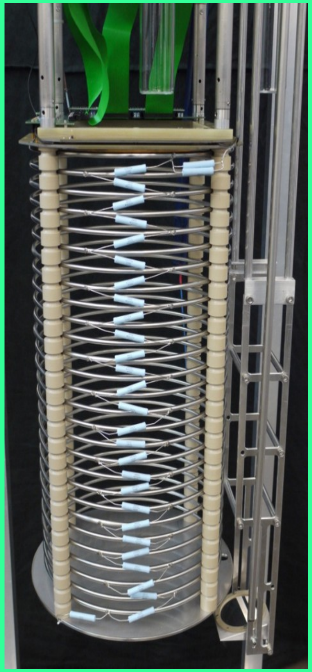
Backup slides

Evolution of LAr TPCs at Bern



L=0.5 cm

L=25 cm



L=57 cm

ARGONTUBE
L=500 cm

JINST 4, P07011 (2009)

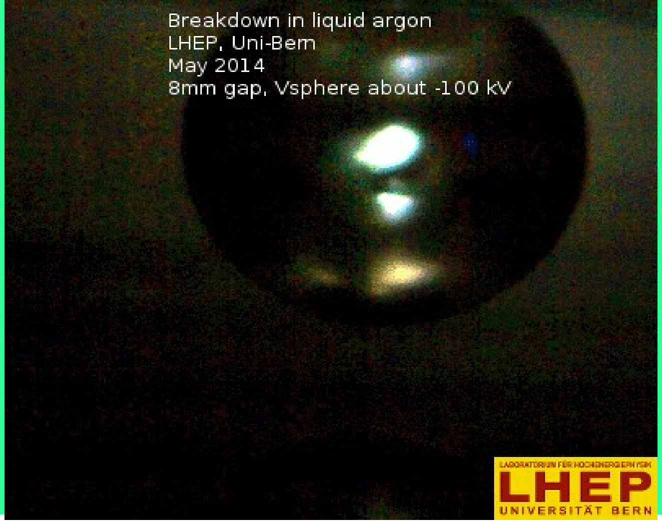
New J. Phys. 12, 113024 (2010)

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

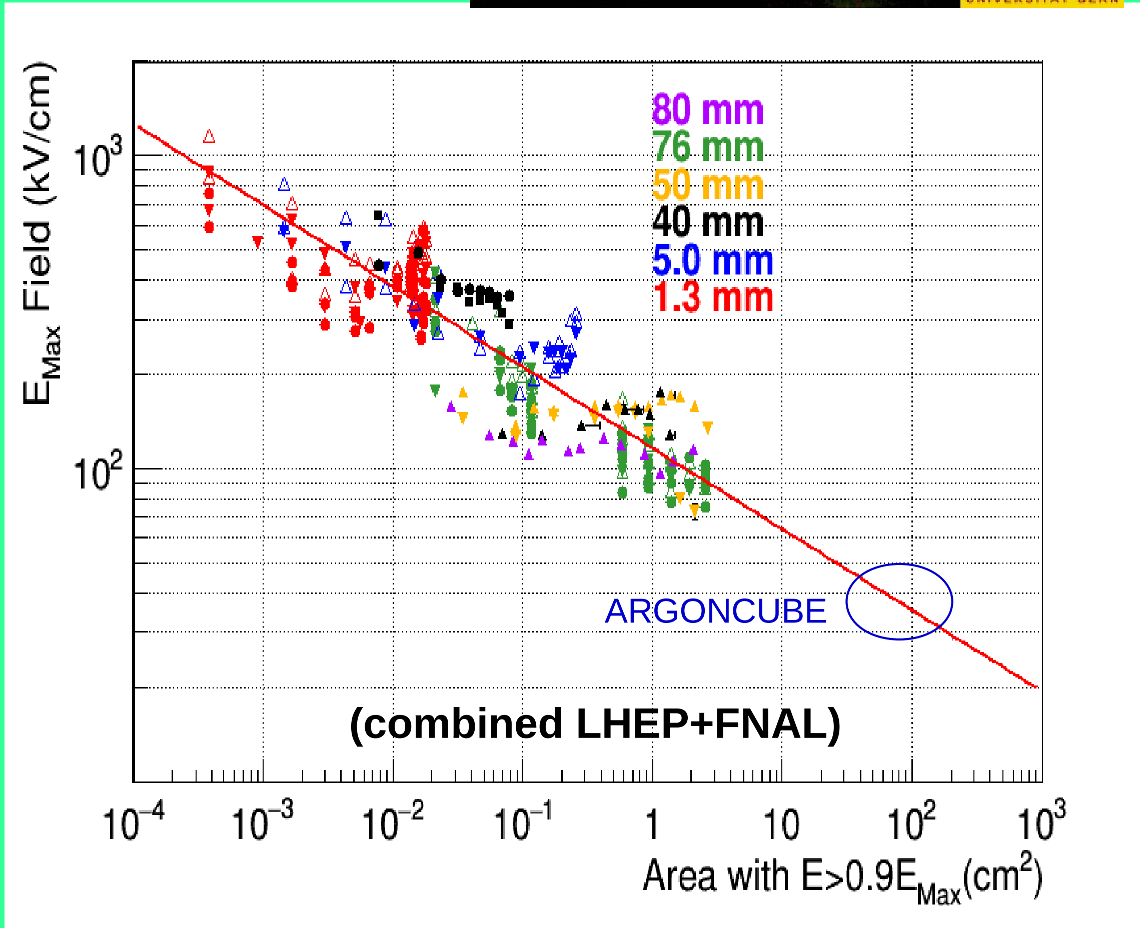
2. Studied V/A characteristics

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.

Why liquid argon at DUNE ND?

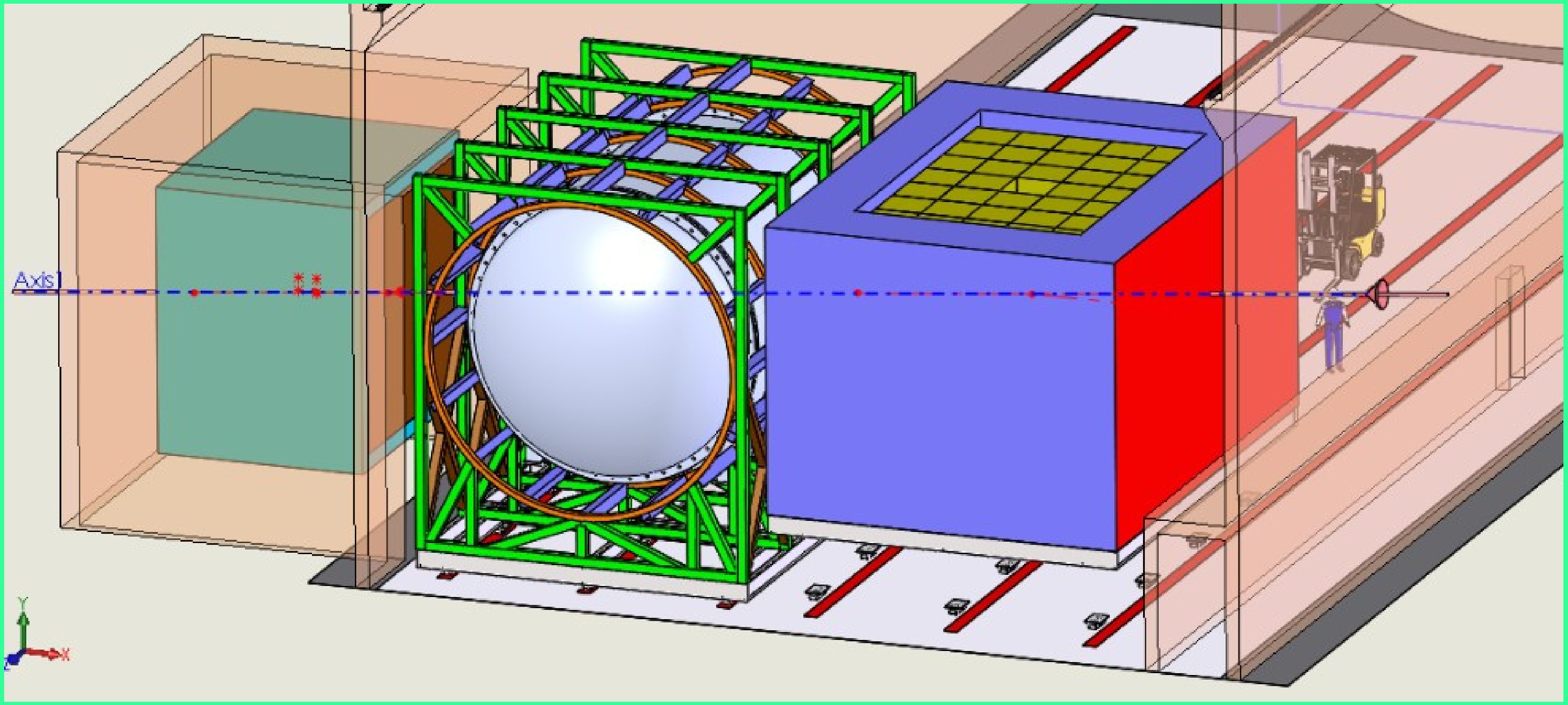
Sample the unoscillated beam usingthe same target material as the FD.
Essential in order to constrain uncertainties on neutrino cross sections.

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.

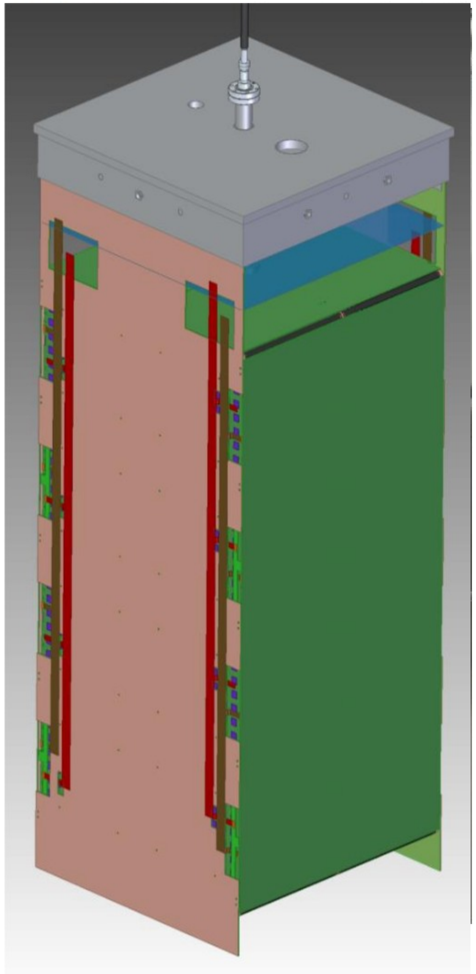
The energy and angular resolution and mass is sufficient to extract a high-statistics sample of neutrino-electron elastic scattering events, which have a known cross section.
Can be used to constrain the flux to better than 2%.
(MINERvA arXiv:1906.00111)

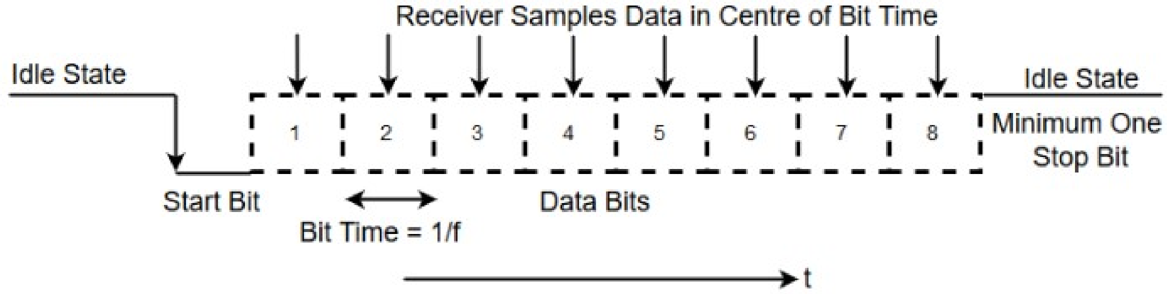
Constrain electron neutrino contamination.
Use e/γ separation to reduce NC background.

Dune ND with ArgonCube



Pixel readout features





UART-like communication with a 54 bit data word

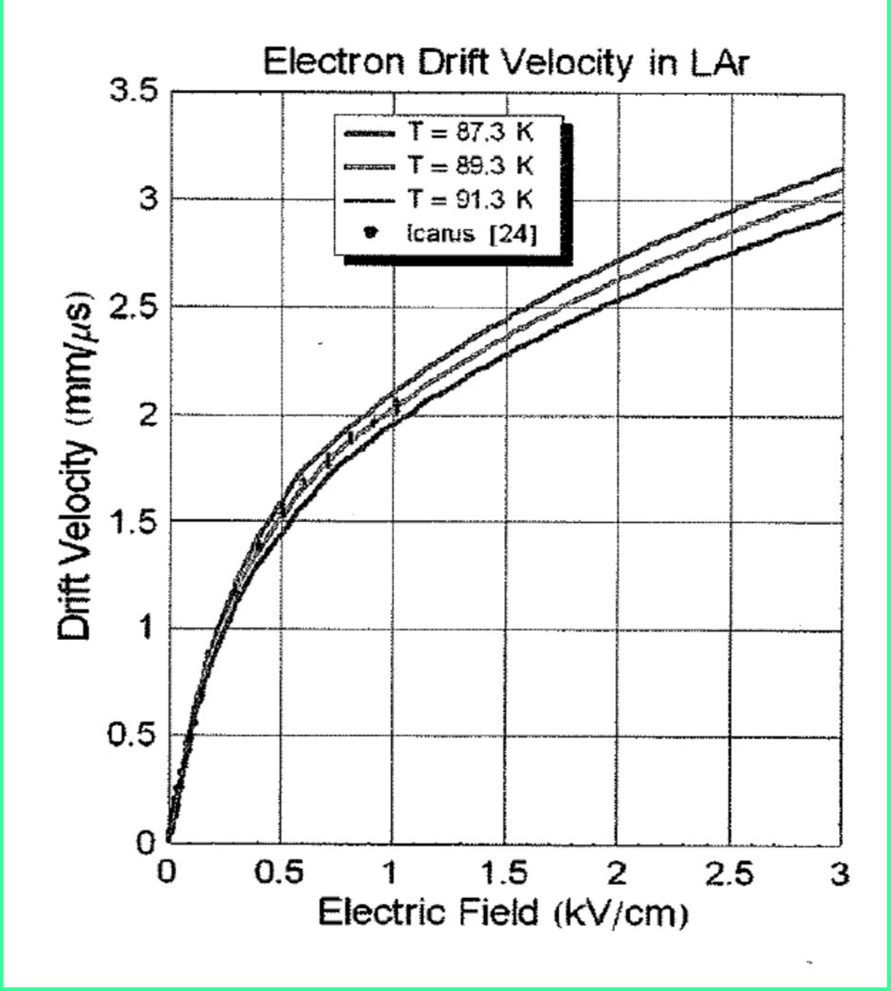
300Hz	54 bit, 16 chips, 60cm drift
~10Hz	54 bit, 1 chips, 30cm drift

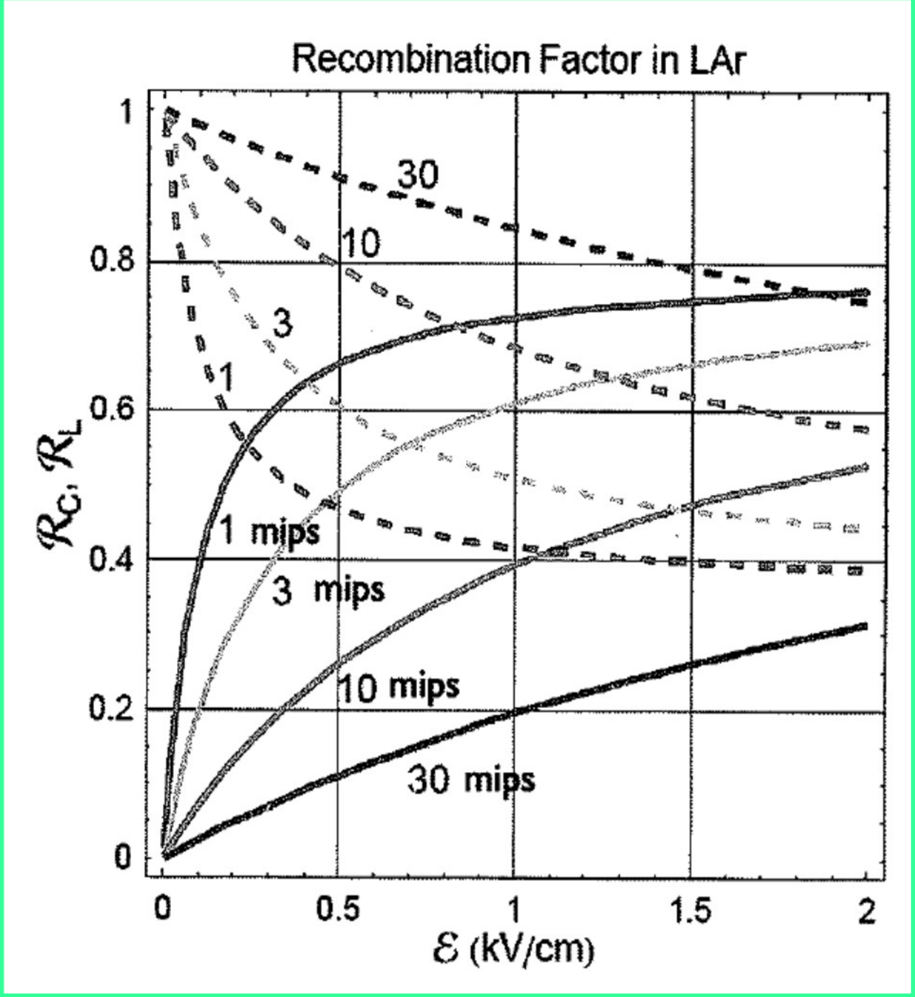
1 chip	540 bit/s
5000 chip	2,7 Mbit/s

Liquid argon properties
http://atlas.web.cern.ch/Atlas

Atomic number	18
Atomic weight (u)	39.94
Radiation length (cm)	14.2
Absorption length (cm)	83.6
Molière radius (cm)	10.1
Critical energy (MeV)	30.5
< DEmip (1 cm) > (MeV)	2.1
W-value (1 MeV electrons) (eV/ion-pair)	23.3
Fano factor	0.107
Electron mobility at bp (m2 V-1 s-1)	0.048
Ion mobility at bp (x105) (m2 V-1 s-1)	0.016
Dielectric constant	1.6
Heat capacity (Cp) (cal mol-1 K-1)	10.05
Thermal conductivity (x103) (cal s-1 cm-1 K-1)	30
Critical point temperature (K)	150.85
Normal boiling point (bp) (K)	87.27
Liquid density at bp (g cm-3)	1.40
Heat of vaporization at bp (cal mol-1)	1557.5
Gas/liquid ratio	784.0

Temperature (K)	Pressure (bars)
87.15	1.0
89.3	1.25
91.8	1.6


Electron Drift Velocity in LAr
T = 87.3 K
T = 89.3 K
T = 91.3 K
Icarus [24]
Drift Velocity (mm/μs)
Electric Field (kV/cm)
0
0.5
1
1.5
2
2.5
3
3.5


Recombination Factor in LAr
$\mathcal{R}_C$, $\mathcal{R}_L$
$\mathcal{E}$ (kV/cm)
30
10
3
1
1 mips
3 mips
10 mips
30 mips
0
0.2
0.4
0.6
0.8
1
0.5
1.5
2