ArgonCube
novel approach to large mass tracking detectors for neutrino physics

International Session-Conference of the Section of Nuclear Physics of the Physical Sciences Department of the Russian Academy of Sciences "Physics of fundamental interactions" dedicated to 50th anniversary of Baksan Neutrino Observatory
Nalchik, June 2017

Igor Kreslo
AEC/LHEP University of Bern

LABORATORIUM FÜR HOCHENERGIEPHYSIK LHEP UNIVERSITÄT BERN

UNIVERSITÄT BERN

AEC
ALBERT EINSTEIN CENTER
FOR FUNDAMENTAL PHYSICS

Towards multi-kt high granularity detectors

High-precision measurements era
for neutrino physics

	Normal Ordering ($\Delta\chi^2 = 0.97$)		Inverted Ordering (best fit)		Any Ordering
	bfp $\pm 1\sigma$	3σ range	bfp $\pm 1\sigma$	3σ range	3σ range
$\sin^2\theta_{12}$	$0.304^{+0.013}_{-0.012}$	$0.270 \to 0.344$	$0.304^{+0.013}_{-0.012}$	$0.270 \to 0.344$	$0.270 \to 0.344$
$\theta_{12}/^\circ$	$33.48^{+0.78}_{-0.75}$	$31.29 \to 35.91$	$33.48^{+0.78}_{-0.75}$	$31.29 \to 35.91$	$31.29 \to 35.91$
$\sin^2\theta_{23}$	$0.452^{+0.052}_{-0.028}$	$0.382 \to 0.643$	$0.579^{+0.025}_{-0.037}$	$0.389 \to 0.644$	$0.385 \to 0.644$
$\theta_{23}/^\circ$	$42.3^{+3.0}_{-1.6}$	$38.2 \to 53.3$	$49.5^{+1.5}_{-2.2}$	$38.6 \to 53.3$	$38.3 \to 53.3$
$\sin^2\theta_{13}$	$0.0218^{+0.0010}_{-0.0010}$	$0.0186 \to 0.0250$	$0.0219^{+0.0011}_{-0.0010}$	$0.0188 \to 0.0251$	$0.0188 \to 0.0251$
$\theta_{13}/^\circ$	$8.50^{+0.20}_{-0.21}$	$7.85 \to 9.10$	$8.51^{+0.20}_{-0.21}$	$7.87 \to 9.11$	$7.87 \to 9.11$
$\delta_{CP}/^\circ$	306^{+39}_{-70}	$0 \to 360$	254^{+63}_{-62}	$0 \to 360$	$0 \to 360$
$\frac{\Delta m^2_{21}}{10^{-5}\ \mathrm{eV}^2}$	$7.50^{+0.19}_{-0.17}$	$7.02 \to 8.09$	$7.50^{+0.19}_{-0.17}$	$7.02 \to 8.09$	$7.02 \to 8.09$
$\frac{\Delta m^2_{3\ell}}{10^{-3}\ \mathrm{eV}^2}$	$+2.457^{+0.047}_{-0.047}$	$+2.317 \to +2.607$	$-2.449^{+0.048}_{-0.047}$	$-2.590 \to -2.307$	$\begin{bmatrix} +2.325 \to +2.599 \\ -2.590 \to -2.307 \end{bmatrix}$

Table 2. Three-flavor oscillation parameters from our fit to global data after the NOW 2014 conference [27]. The results are presented

M.C.Gonzalez-Garcia et al., Nuc.Phys. B00(2015)1-16

CP-violation in lepton sector (δ phase)
Neutrino mass hierarchy
Ultra-low cross-section physics
(e.g. Proton decay)

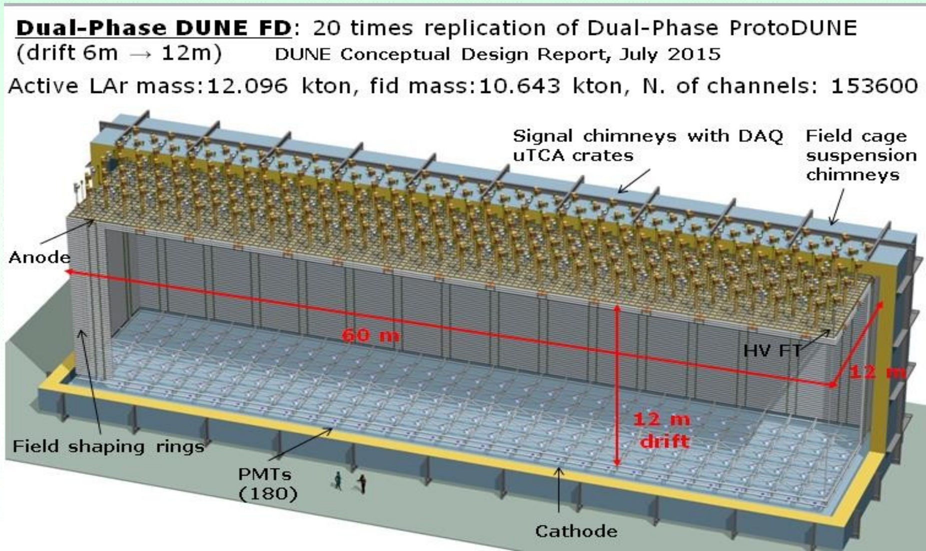
Present state-of-art:
Water Cerenkov (Super-K)
Bulk scintillators (Daya Bay, (D)-Choos)
Liquid Argon TPC (ICARUS, uBooNE, SBND)

Need:
- Larger detectors
- Higher resolution
- Higher granularity

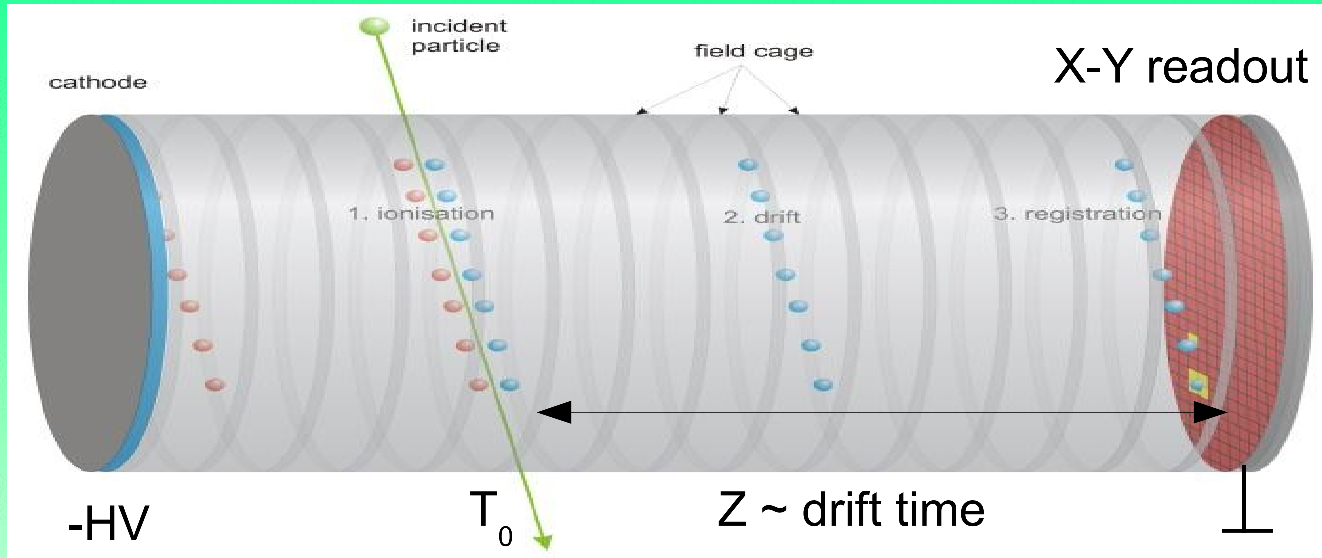
Liquid Argon Time Projection Chambers

Example: DUNE far detector

- Active mass 12 kton
- Drift distance 12 meters
- Drift times of the order of 10 ms
- Ultra-high argon purity required (<0.1ppb oxygen equivalent impurities)
- High voltage of the order of MV !

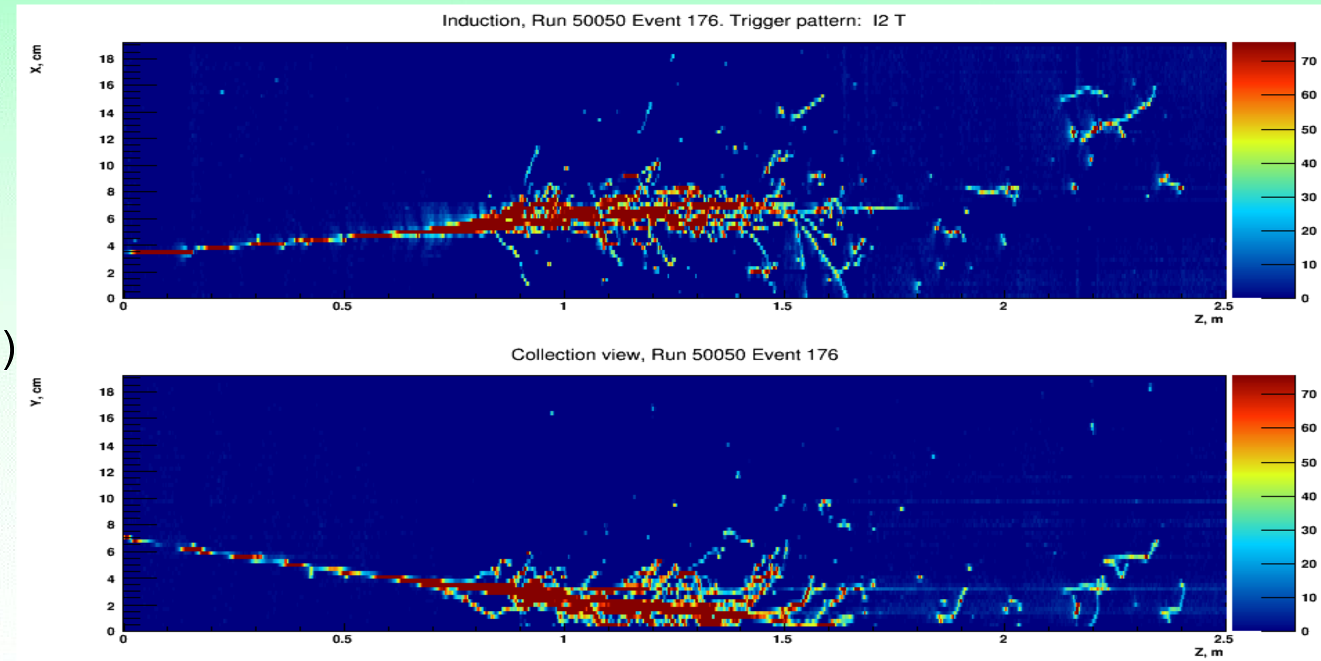


Liquid Argon Time Projection Chamber



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

Charge readout:
X: Induction (non-destructive)
Y: Collection



ARGONCUBE concept

Challenges:

- Keeping high purity in enormous volume
- Ultra-high voltage (~MV) -> large size & stored energy
- Wire readout -> pileup -> Reconstruction ambiguity

ArgonCube:

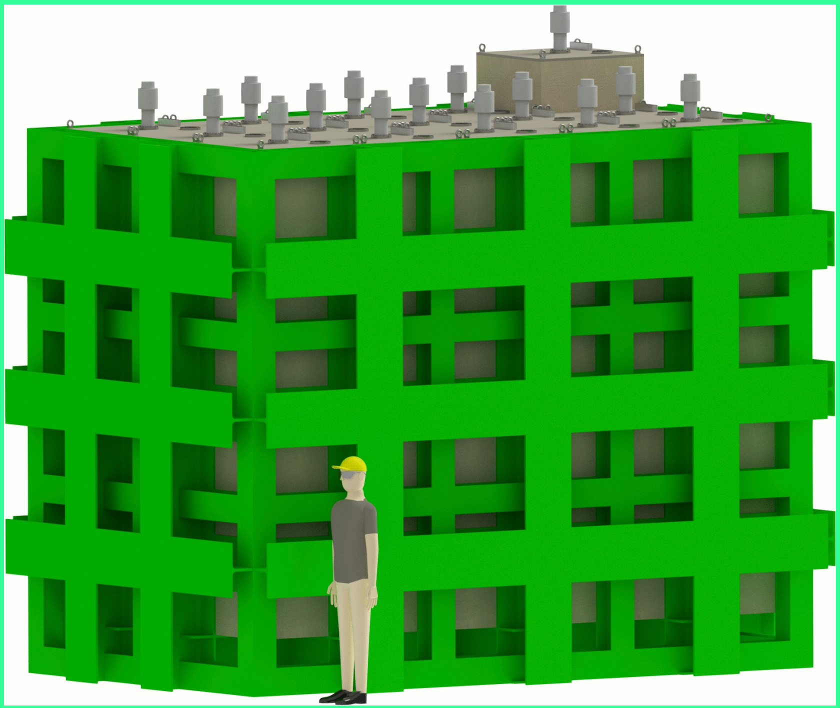
- Volume split to modules in common cryostat
- Low voltage -> low risk associated with breakdown
- Pixel readout -> simple reconstruction

LAr anomalous dielectric strength studied in detail by our group:

JINST 11 (2016) no.03, P03017.
JINST 9 (2014) P07023.
JINST 9 (2014) P04006.

Simple solutions for severe challenges

Modular TPC — performance



- **ArgonCube modular structure**

- Total argon volume split by ~1-10 ton modules

- High active mass-ratio (95%)

- Transportable modules

- Unified modules → high redundancy

- Step-by-step commissioning

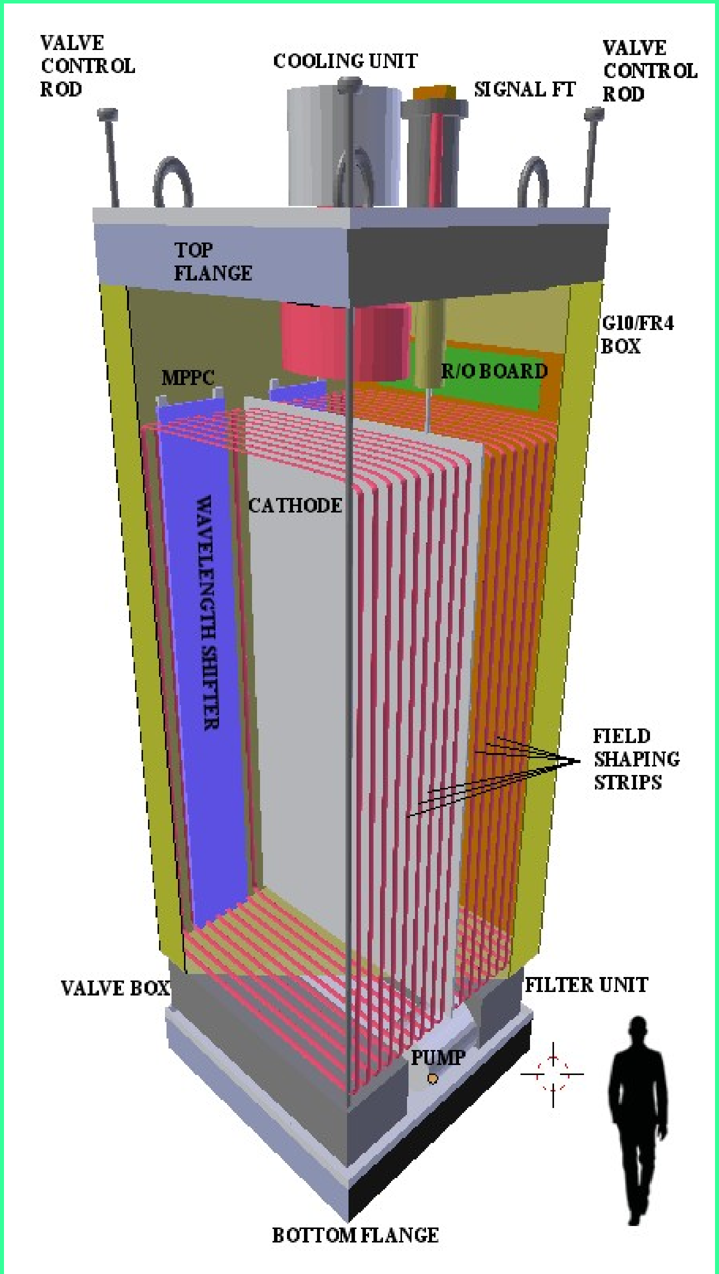
- Extract module → repair → re-insert

- Scalable and extendable (same tech. for ND and FD)

- Iterative upgrade with new technologies

Allows efficient detector start-up
Drastically reduced cost of failures

ARGONCUBE module (collaboration with CERN)



Module: an independent TPC

- Individual thermal/purity management

- Cathode bias (-100 kV) supplied via HV feed-through
- Relatively low voltage => breakdown-free setup
- Electrically transparent container => low dead volume

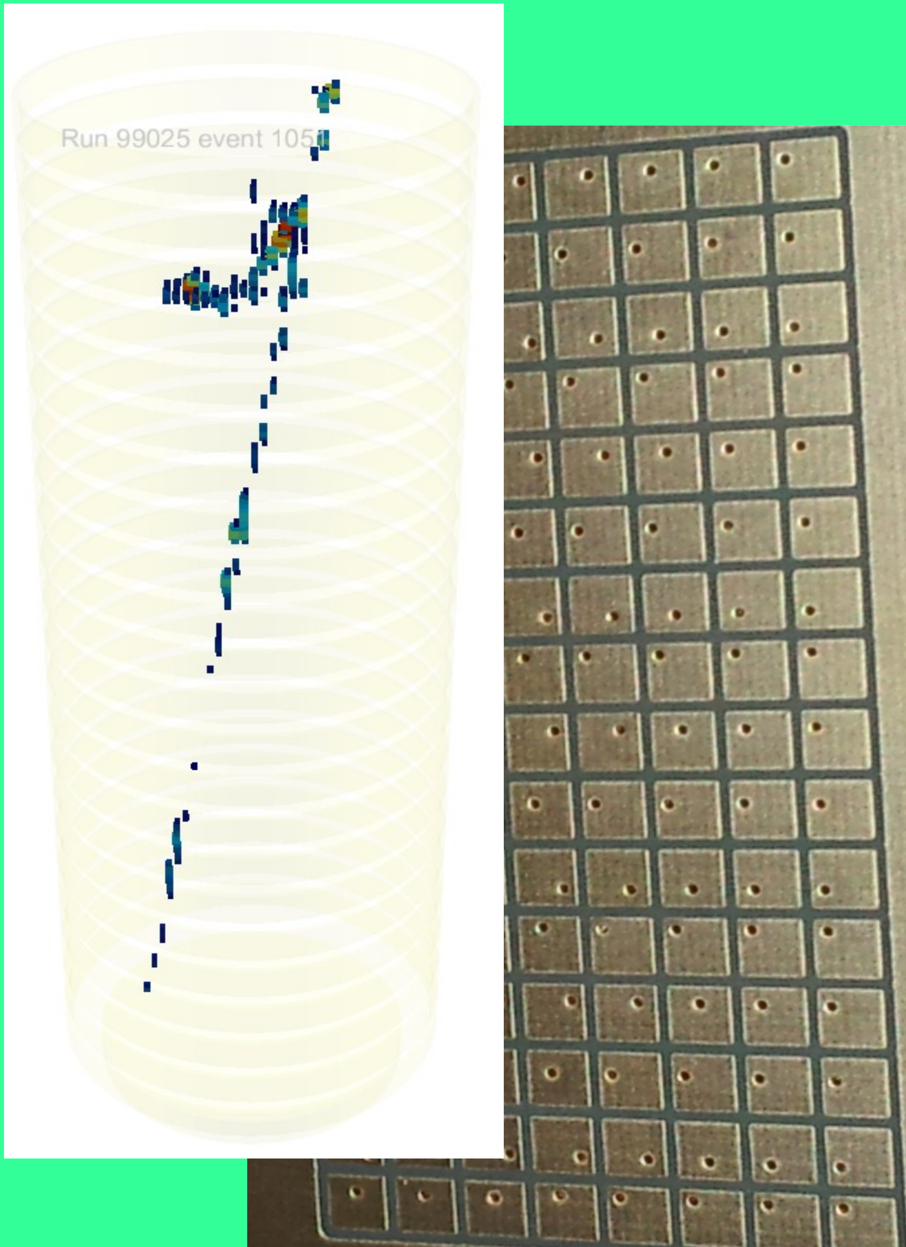
- Drift time ~ 0.5 ms => reduced purity requirements

- Mechanically robust production technology
- Low failure cost

- Charge readout: pad arrays, *e.g.* 4x4 mm^2 pads
- Light readout via WLS light guides & SiPMs

Reliable/repairable self-contained unit

Pixelized TPC readout (collaboration with BNL, LBNL, USA)

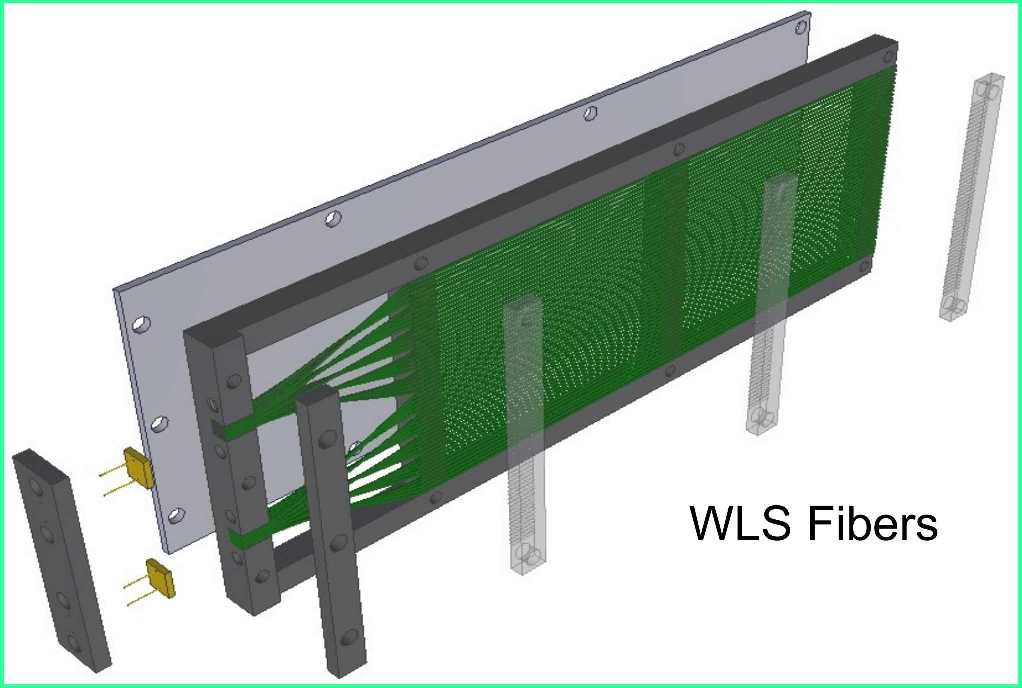


Pixels (pads) charge readout

- PCB-technology for R/O plane manufacturing
- 8x8 pads ROIs served by cold ASICs
- Unambiguous event reconstruction
- High track reconstruction efficiency
- High accuracy of kinematics reconstruction
- High overall detection efficiency
- Challenge for data compression (~ 1M ch/module)

Improves reconstructed physics accuracy

Scintillating light detection (collaboration with JINR, Russia)



VUV scintillation light is double-shifted to green

LAr scintillation light
128 nm

TPB: 128 nm → 420 nm

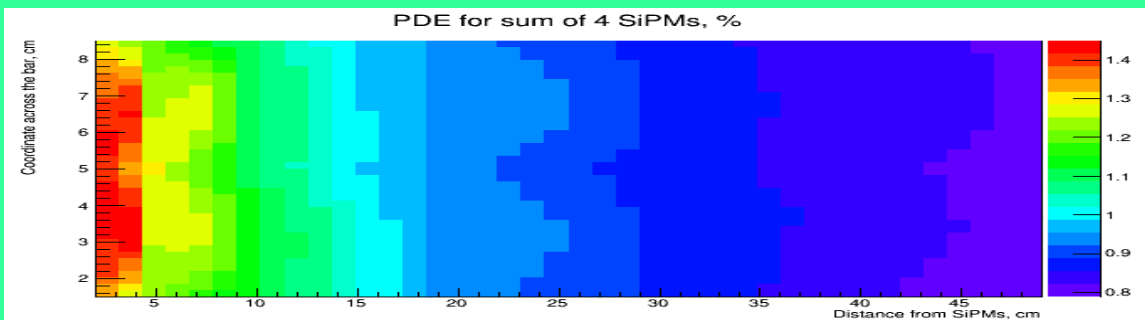
WLS fiber or bar
420 nm → 500 nm

SiPM

- Tetraphenil-butadiene (TPB) as primary WLS
- Kuraray green fibers as secondary WLS
- SiPMs as photon detectors
- SiPM dark current at 87K is O(Hz) at 1 p.e.
- Estimated efficiency — 1%

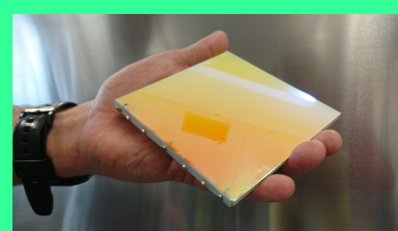
Efficient light collection from large area

Scintillating light detection (collaboration with JINR, Russia)

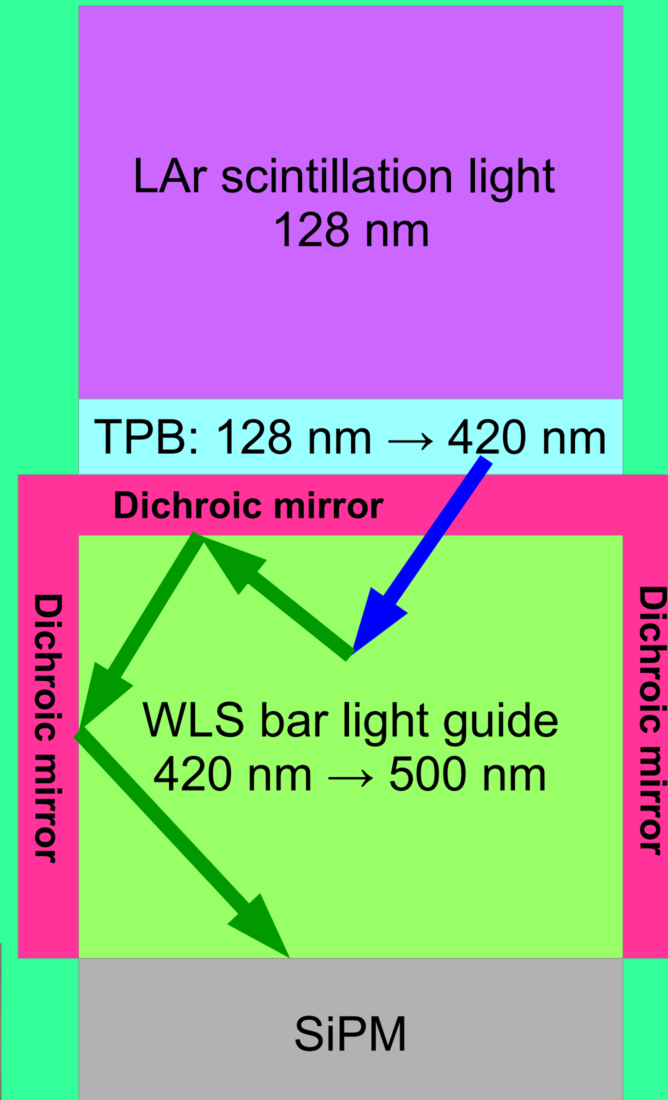


- Tetraphenil-butadiene (TPB) as primary WLS
- Bar light guide as secondary WLS
- Dichroic mirror to keep 500 nm photons inside
- SiPMs as photon detectors
- SiPM dark current at 87K is O(Hz) at 1 p.e.
- Measured efficiency — 1%

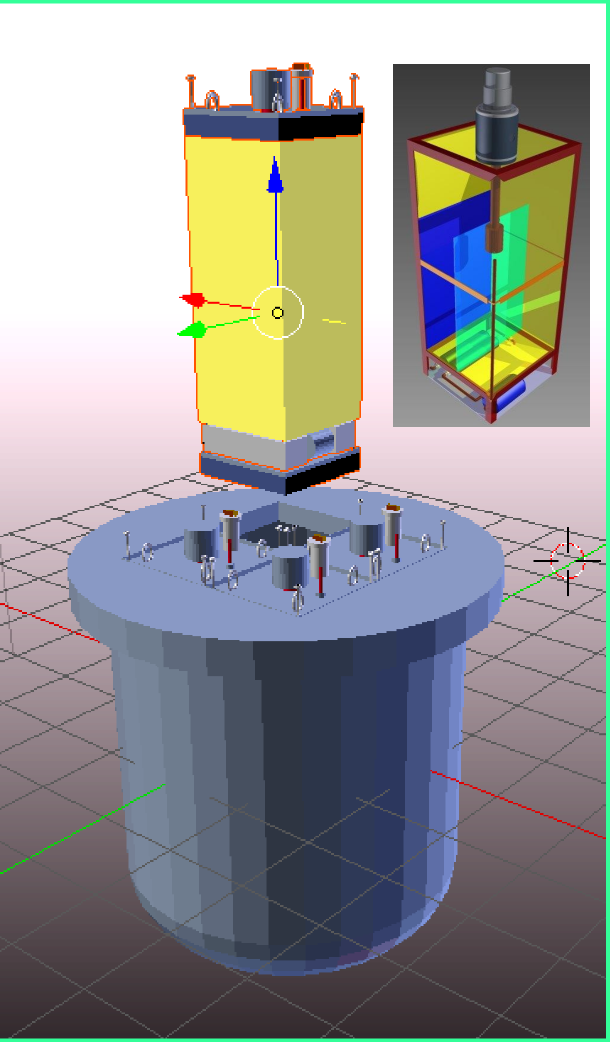
Mechanically very robust



ArCLight 10x10 cm



At LHEP, Bern - 4 tons prototype



Vacuum insulated cryostat

4 modules in G10/FR4 containers

67x67 cm^2, 1.8m high

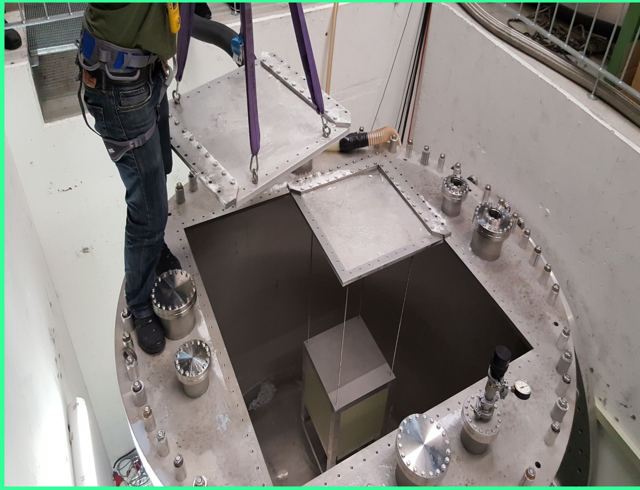
Argon volume ~ 0.6 m^3 per module

Argon mass ~ 820 kg per module

Active mass ~ 750 kg per module

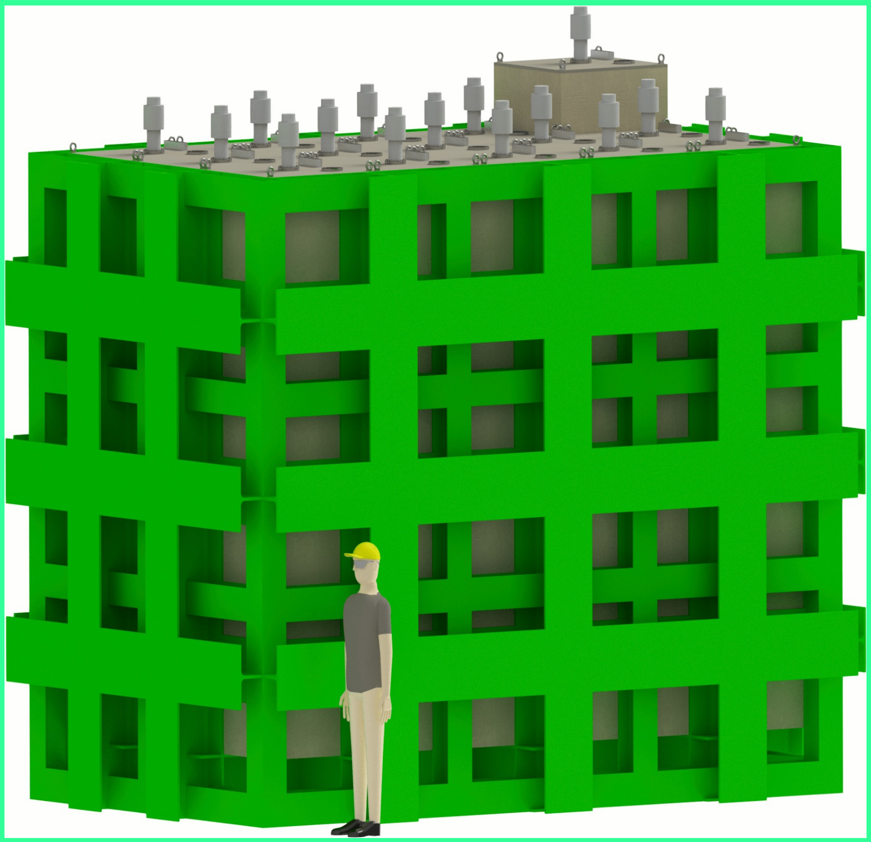
Drift length 33 cm

Cathode bias 33 kV



**Test all involved novel solutions at a reduced scale, verify mechanical and thermal simulations.
Obtain reconstructed tracks of cosmic ray events.**

DUNE Near Detector



Foam insulated cryostat

Cryostat dimensions 5 x 7 x 4 m^3

15 modules

1 x 1 m^2, 2 m high

Argon volume ~ 2 m^3
Argon mass ~ 2.8 t per module
Active mass ~ 2.6 t per module
Total Active mass — 39 t

Drift length 0.5m, cathode bias 50 kV

High performance, low operational risks
Potentially scalable to FD scale (future upgrades)

Summary

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

Fully modular structure

- High active mass ratio (95%)
- 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

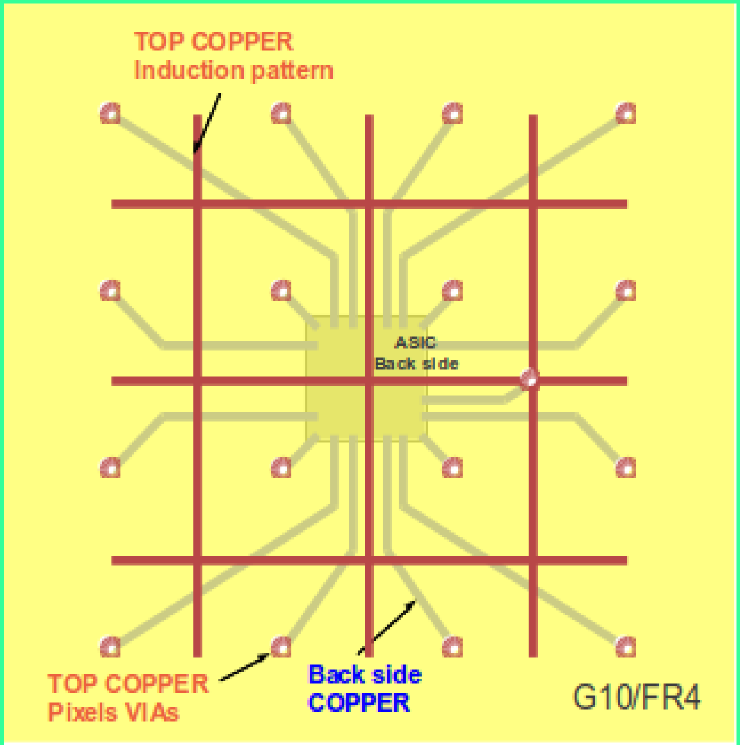
ARGONCUBE is accepted as the technology for DUNE Near Detector.

Thank you!

Fermilab
Yale University
CERN
BROOKHAVEN
NATIONAL LABORATORY
JINR
LHEP
UNIVERSITÄT BERN

Backup slides

Charge readout baseline (final goal) option

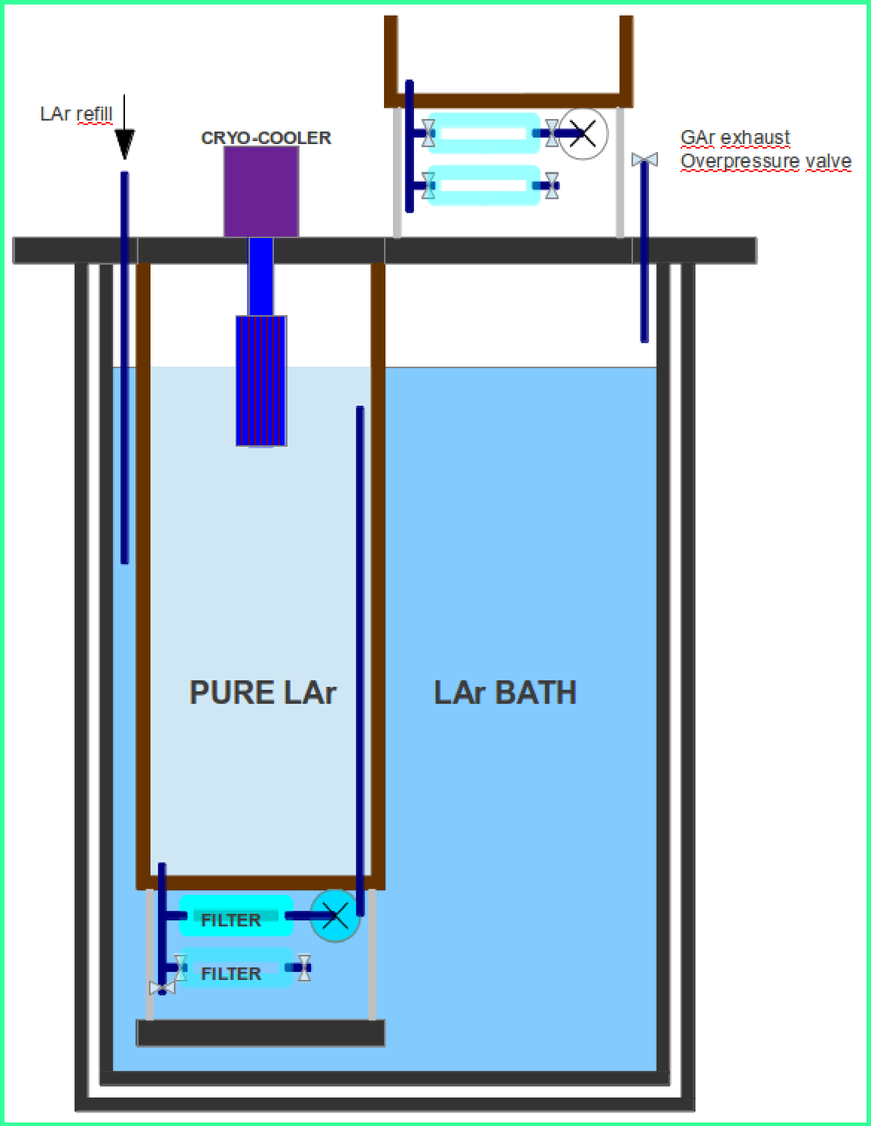


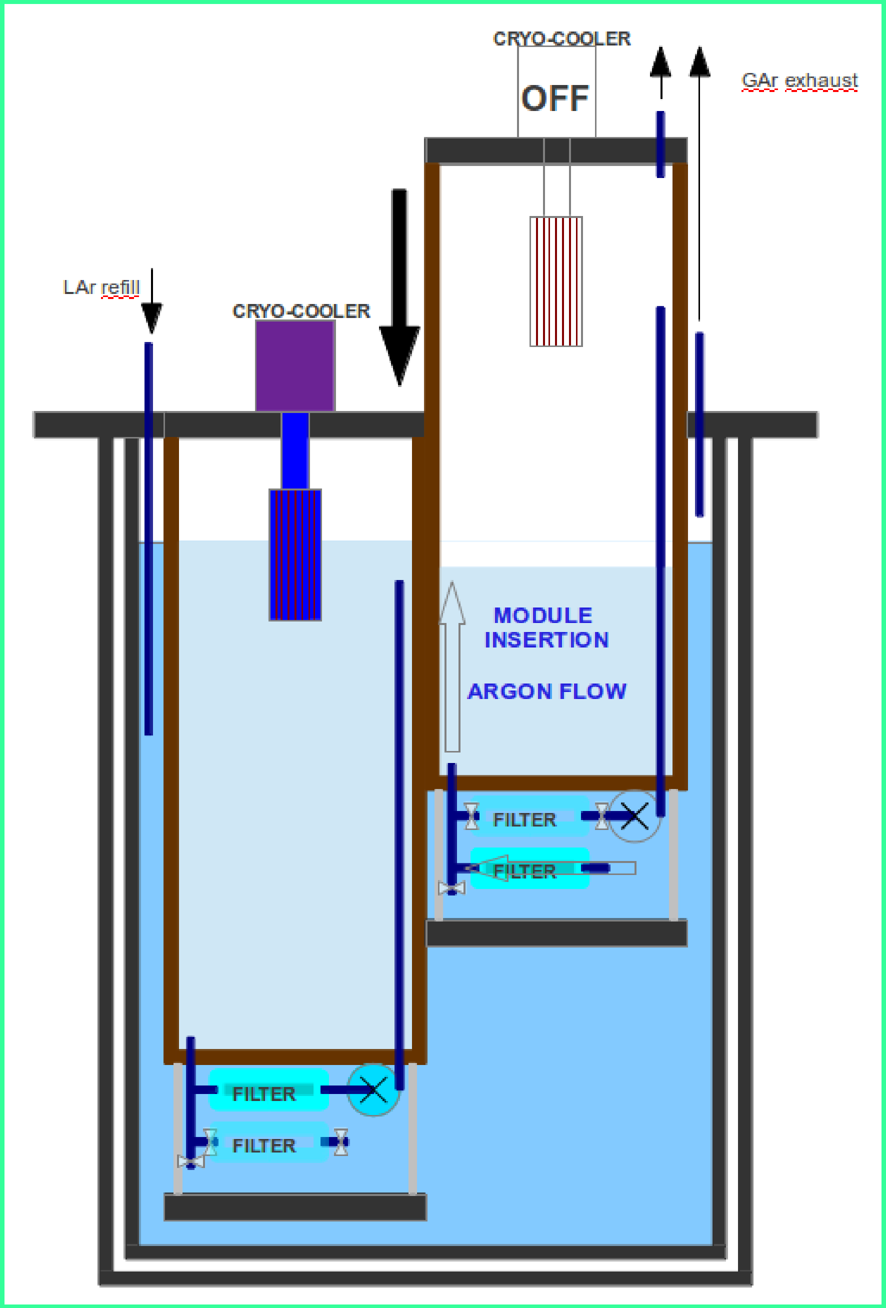
Pad array divided into Regions Of Interest (ROI)

- ROI is a 8x8 pad area
- Pad size to be optimized, baseline is 4x4 mm^2
- One ROI – one readout ASIC
- Charge amplifier, ADC, zero suppression logic, data MUX
- Wake-up channel sensing early induction signal
- Low power in wait-state (2 to 5 W/ton)
- Low pad capacitance (~5 pF)
- ENC ~ 500 e-
- Detection threshold 165 keV for LET (1 MIP), S/N=10

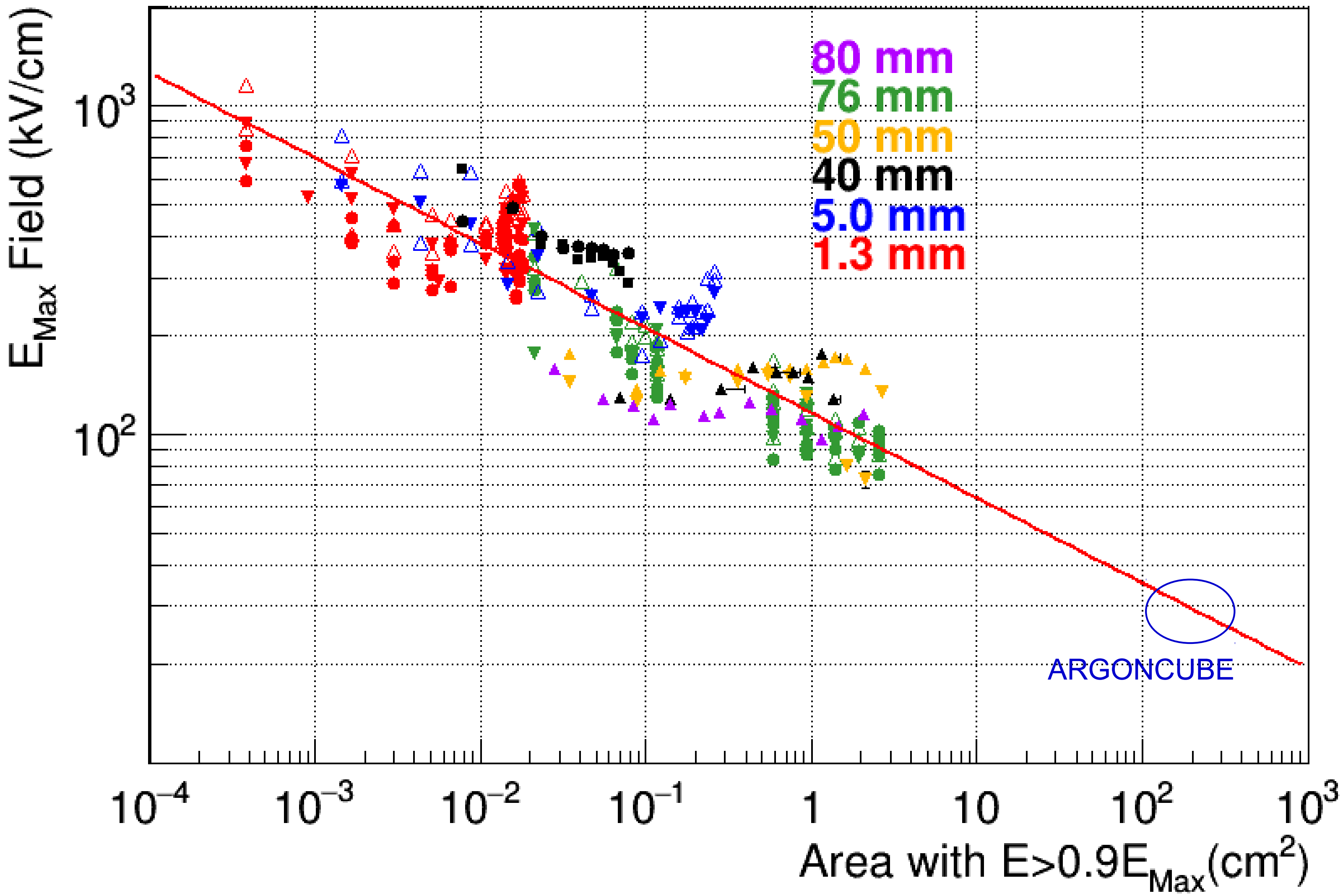
Top tracking performance for a kton-scale TPC

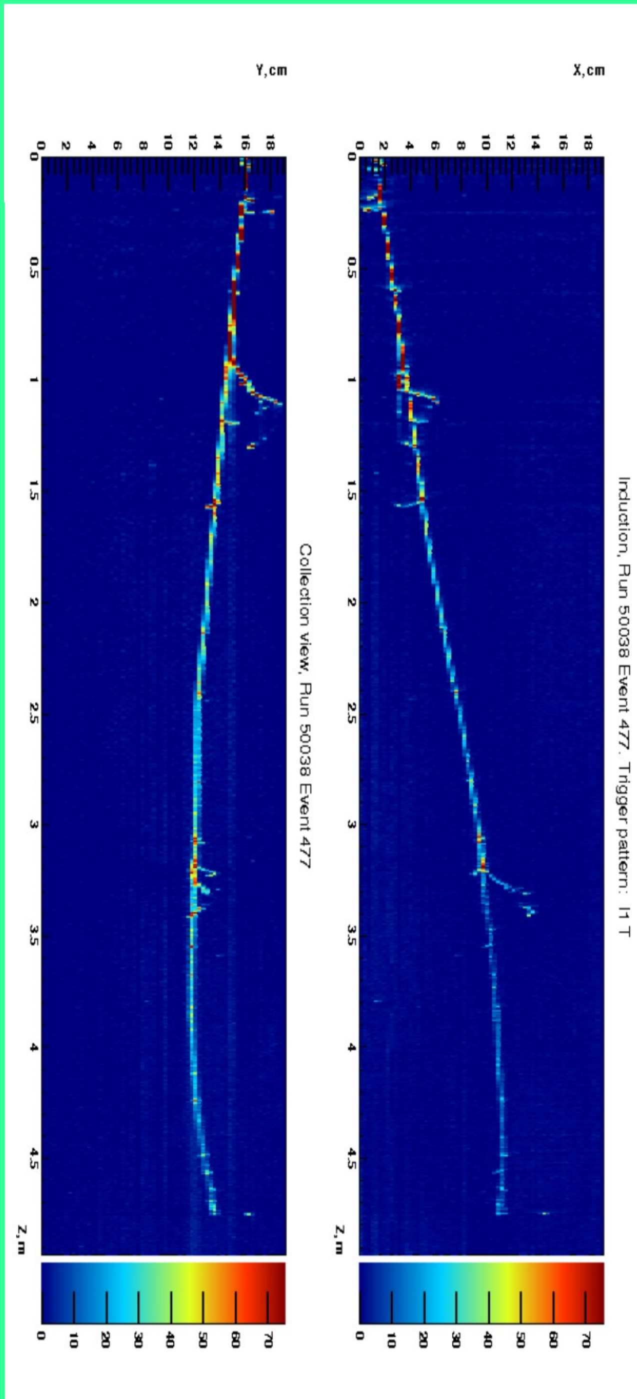
Module insertion

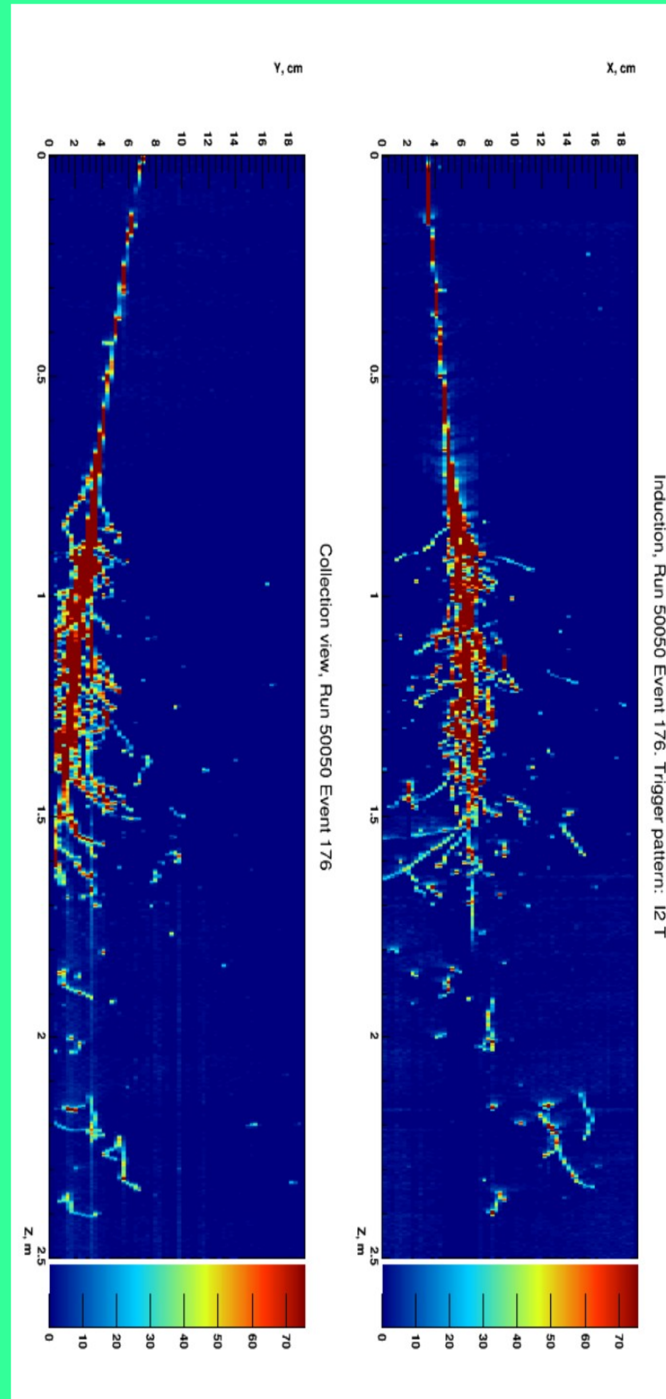




Breakdown in liquid Argon: detailed study (combined LHEP+FNAL)







ARGONTUBE

Cosmic ray events

Free electron life time >2ms

S/N ratio MIP near R/O ~30

Drift time ~4 ms
@ ~400 V/cm

Voltage reached: >400 kV

Experience gained,
problems learned,
conclusion made:

More than 100 kV in LAr is
not easy!

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

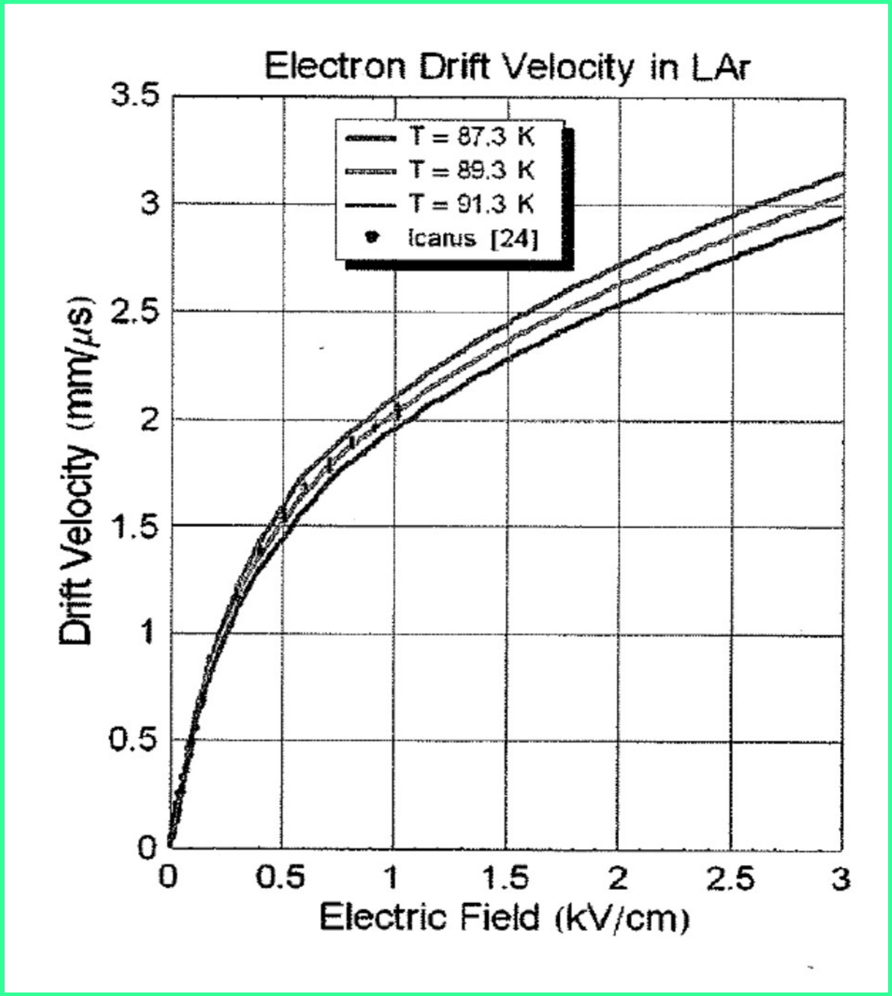
Liquid density at bp (g cm-3) 1.40

Heat of vaporization at bp (cal mol-1) 1557.5

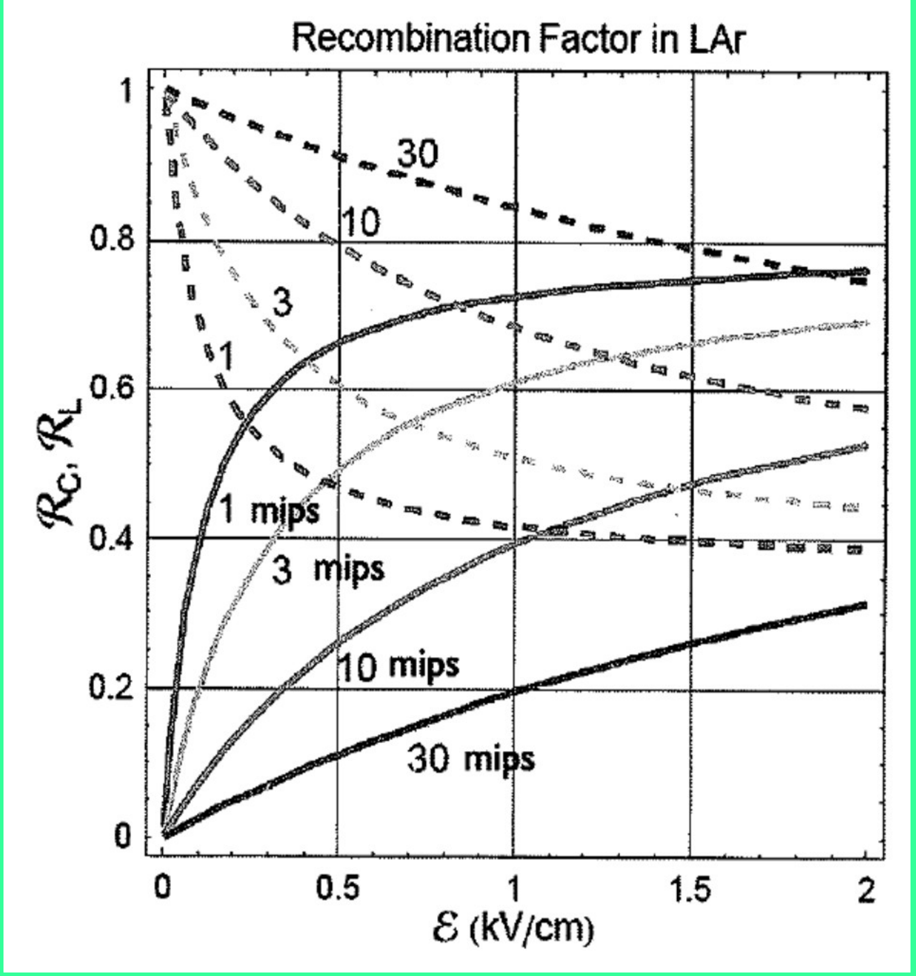
Gas/liquid ratio 784.0

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)



Recombination Factor in LAr
30
10
3
1
1 mips
3 mips
10 mips
30 mips
$\mathcal{R}_C$, $\mathcal{R}_L$
$\mathcal{E}$ (kV/cm)