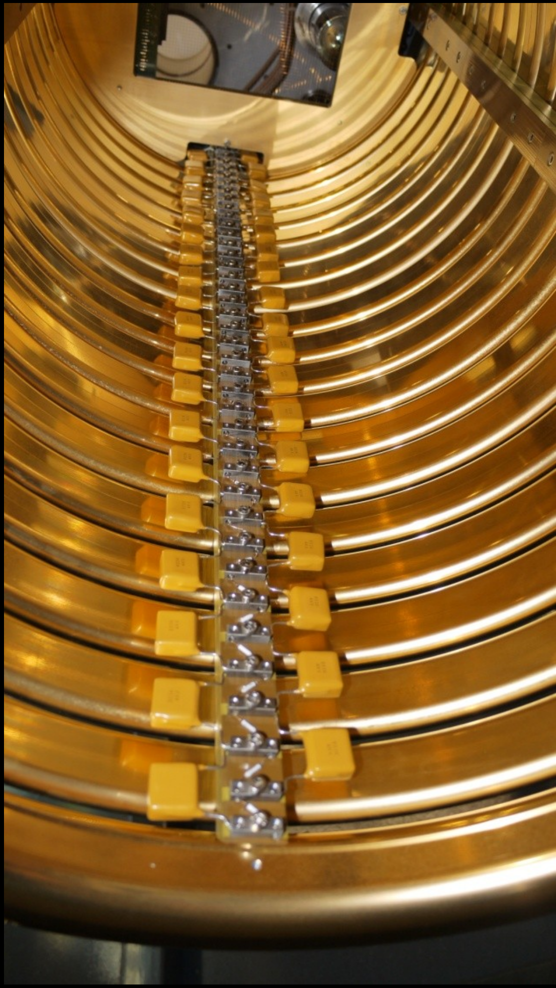
ArgonCube *a novel, fully-modular approach for the realization of large-mass liquid argon TPC neutrino detectors*

CERN SPSC LoI 243, 2015



Antonio Ereditato and Igor Kreslo
University of Bern

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Letter of Intent

ArgonCube: a novel, fully-modular approach for the realization of large-mass liquid argon TPC neutrino detectors

C. Amsler, M. Auger, A. Ereditato[a], D. Göldi, R. Hänni, I. Kreslo, M. Lüthi, P. Lutz,
Ch. Rudolph Von Rohr, Th. Strauss, M. Weber
Albert Einstein Center for Fundamental Physics (AEC) - Laboratory for High Energy Physics (LHEP), University of Bern, Bern, Switzerland

M. Bishai, H. Chen, G. De Geronimo, F. Lanni, D. Lissauer, V. Radeka, B. Yu
Brookhaven National Laboratory (BNL), Upton, NY 11973-5000, USA

J. Bremer, U. Kose, D. Mladenov, M. Nessi, F. Noto, D. Smargianaki
European Organization for Particle Physics (CERN), Geneva, Switzerland

Y. Arbelo, F. Barbato, D. Bleiner, A. Borgschulte, F. La Mattina
Swiss Federal Laboratories for Materials and Technology (EMPA), CH-8600 Dübendorf, Switzerland

A. Marchionni, O. Palamara, J. L. Raaf, G. P. Zeller
Fermi National Accelerator Laboratory (FNAL), Batavia, IL 60510 USA

M. Zeyrek
Middle East Technical University (METU), TR-06800, Ankara, Turkey

T. Gamble, N. McConkey, N. J. C. Spooner, M. Thiesse
University of Sheffield, Sheffield, UK

J. Asaadi, M. Soderberg
Syracuse University University, Syracuse, NY 13244 USA

F. Bay, E. Cavus
The Scientific and Technological Research Council of Turkey (TUBITAK), Ankara, Turkey

B. Fleming
Yale University, New Haven, CT 06520 USA

Motivations of the LoI

- R&D on a fully-modular LAr TPC design for neutrino physics. Aims:
    - Simple, cheap, robust, affordable, performing, scalable, “democratic”

- Envisioned mid-long term applications:
    - SBN upgrade
    - DUNE far detector
    - DUNE near detector

- R&D proceeding through 3 phases:

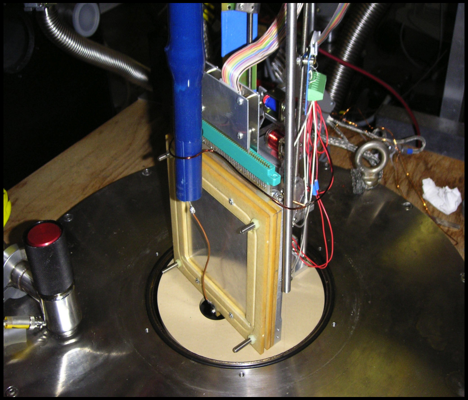
Phase-0	basically accomplished in Bern and USA
Phase-1	to be executed in Bern
Phase-2	“large-size” detector at CERN

- Mix of robust/reliable options and challenging new features

- Committed and skilled international collaboration

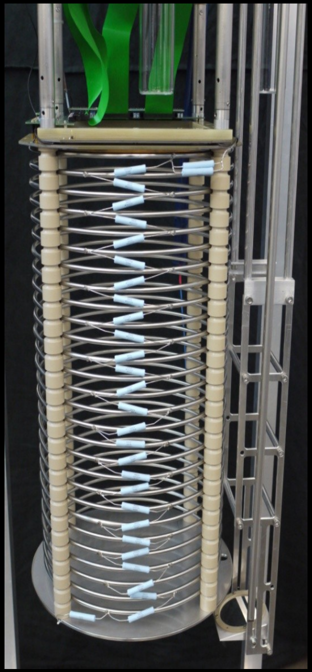
Phase - 0

Evolution of LAr TPCs at LHEP Bern



L=0.5 cm

L=25 cm



L=57 cm

ARGONTUBE
L=500 cm

JINST 4, P07011 (2009)

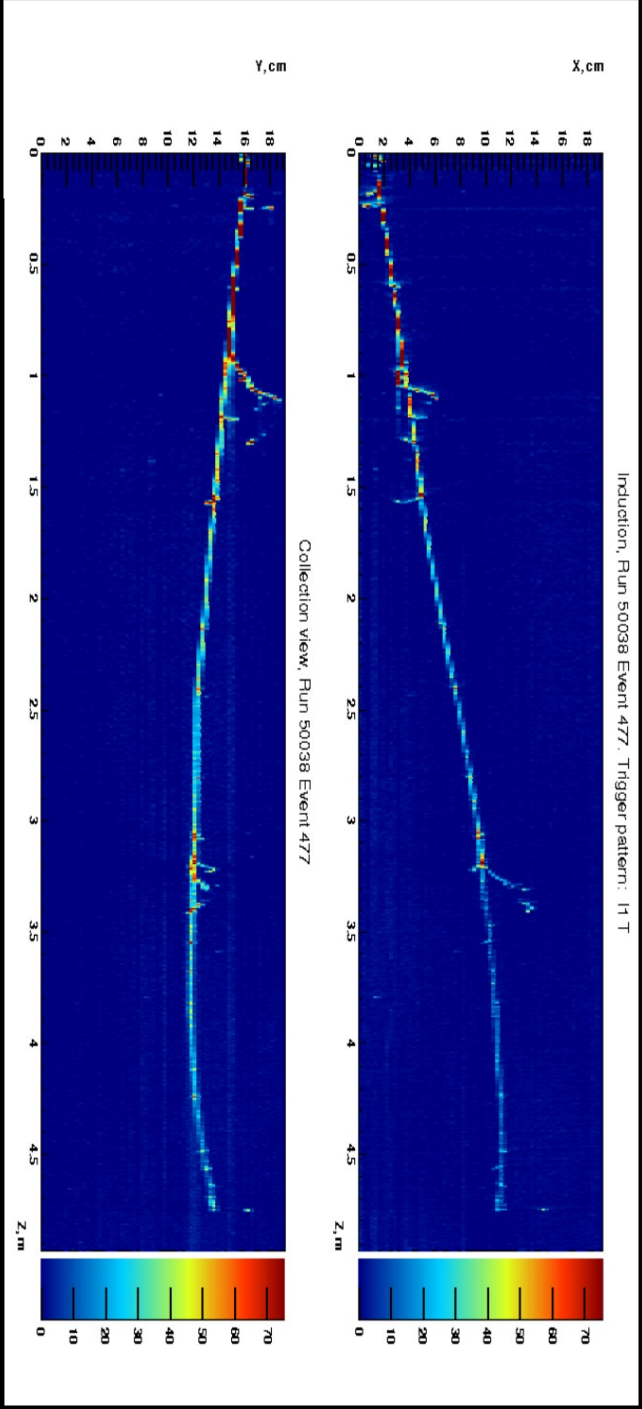
New J. Phys. 12, 113024 (2010)

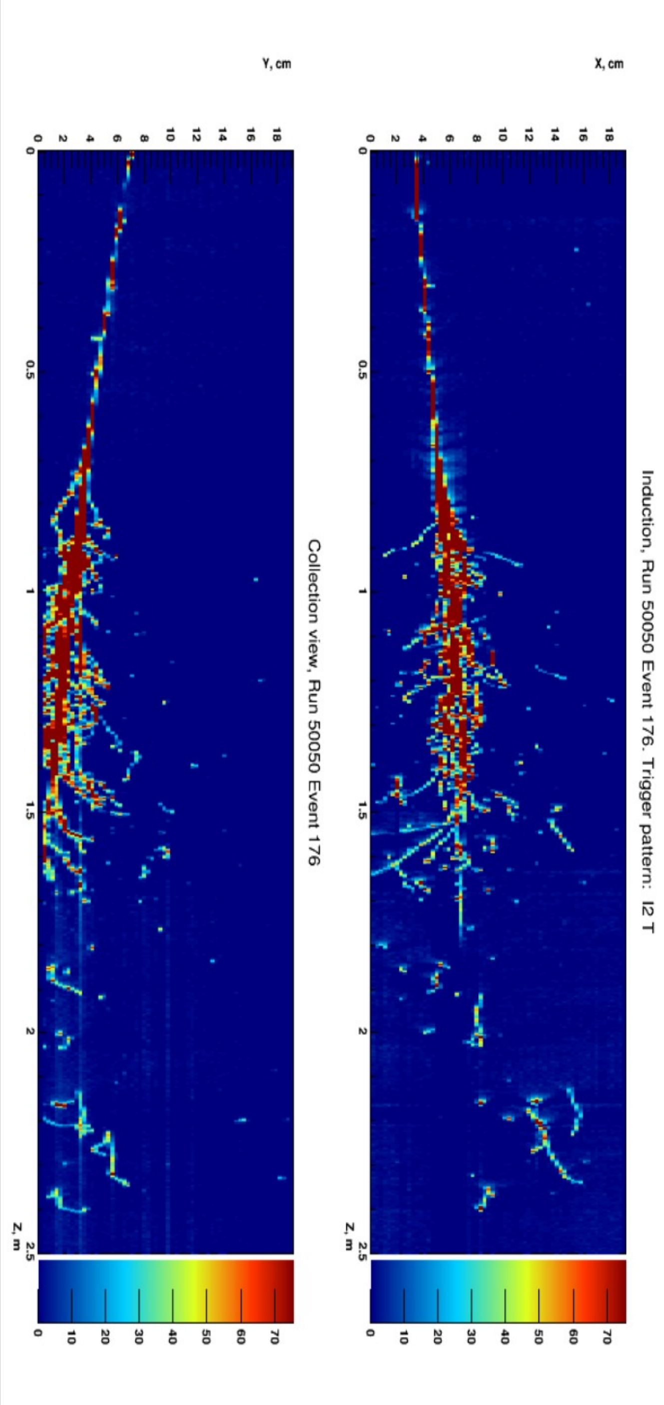
JINST 5, P10009 (2010)

JINST 7 (2012) C02011

JINST 1307 (2013) P07002

ARGONTUBE
Cosmic ray events



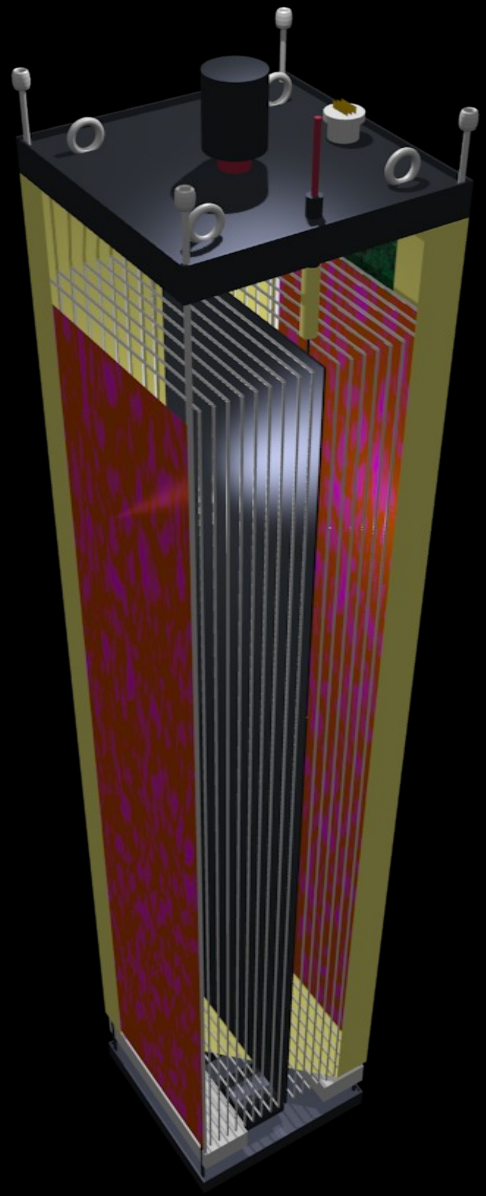


Free electron life time >2ms

S/N ratio MIP near R/O ~30

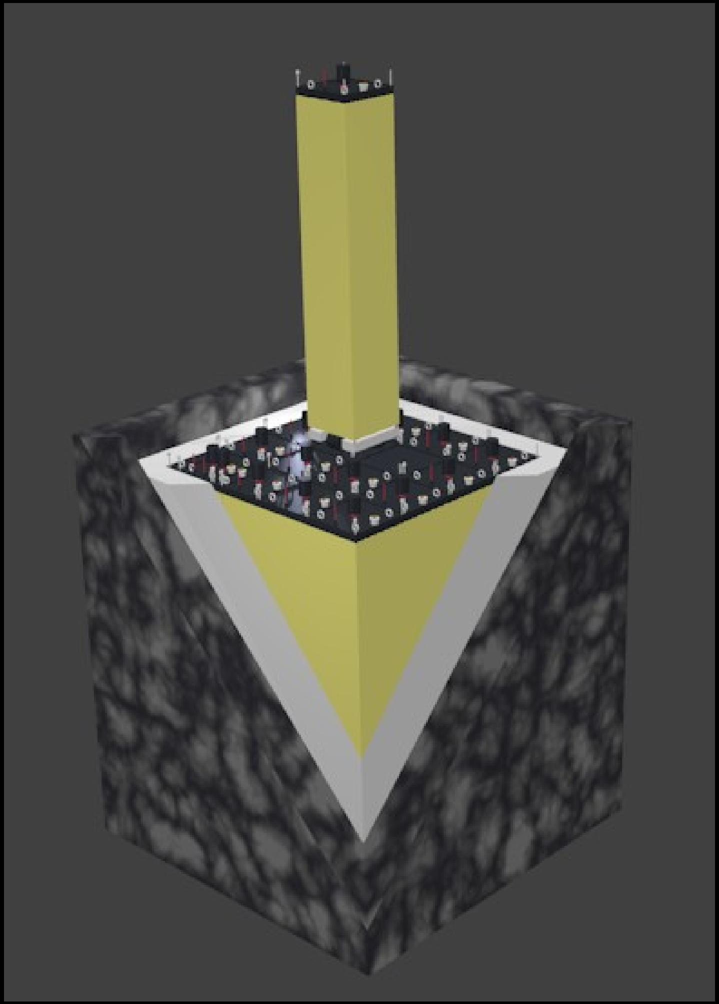
Drift time ~4 ms
@ ~400 V/cm

ArgonCube modularity



- Shared construction
- Replaceable units
- Incremental & upgrade
- Easier requirements

Modular TPC — performance



ArgonCube modular structure

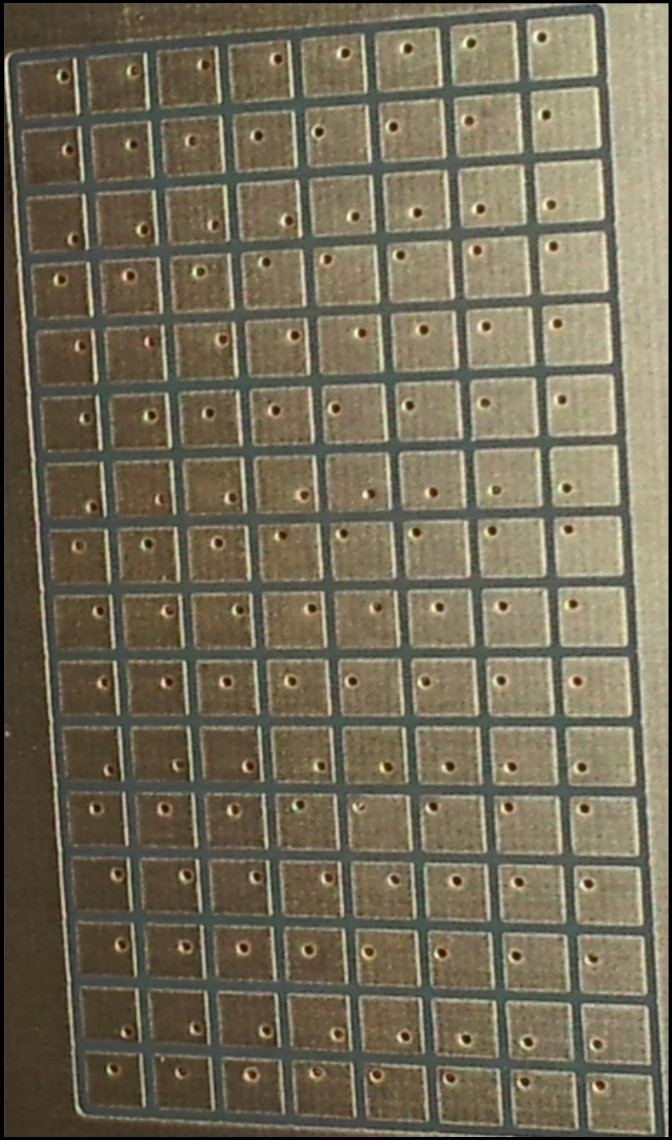
- Total argon volume split by ~50 ton modules
- High active mass-ratio (97%)
- Transportable modules
- Unified modules → high redundancy
- Step-by-step commissioning
- Extract module → repair → re-insert
- Scalable and extendable (same tech. for ND and FD)
- Iterative upgrade with new technologies

ArgonCube short drift-length modules

- Horizontal electron drift L = 1 m
- Low field distortion due to ion space charge (< 3%)
- Cathode potential ~100 kV => no issues with HV
- Low stored E-field energy ~ 10 J per module
- Drift time ~ 0.5 ms => reduced purity requirements

Allows efficient detector start-up
Drastically reduced cost of failures

Pixelized TPC readout



Pixels (pads) charge readout

- Unambiguous event reconstruction

- High track reconstruction efficiency

- High accuracy of kinematics reconstruction

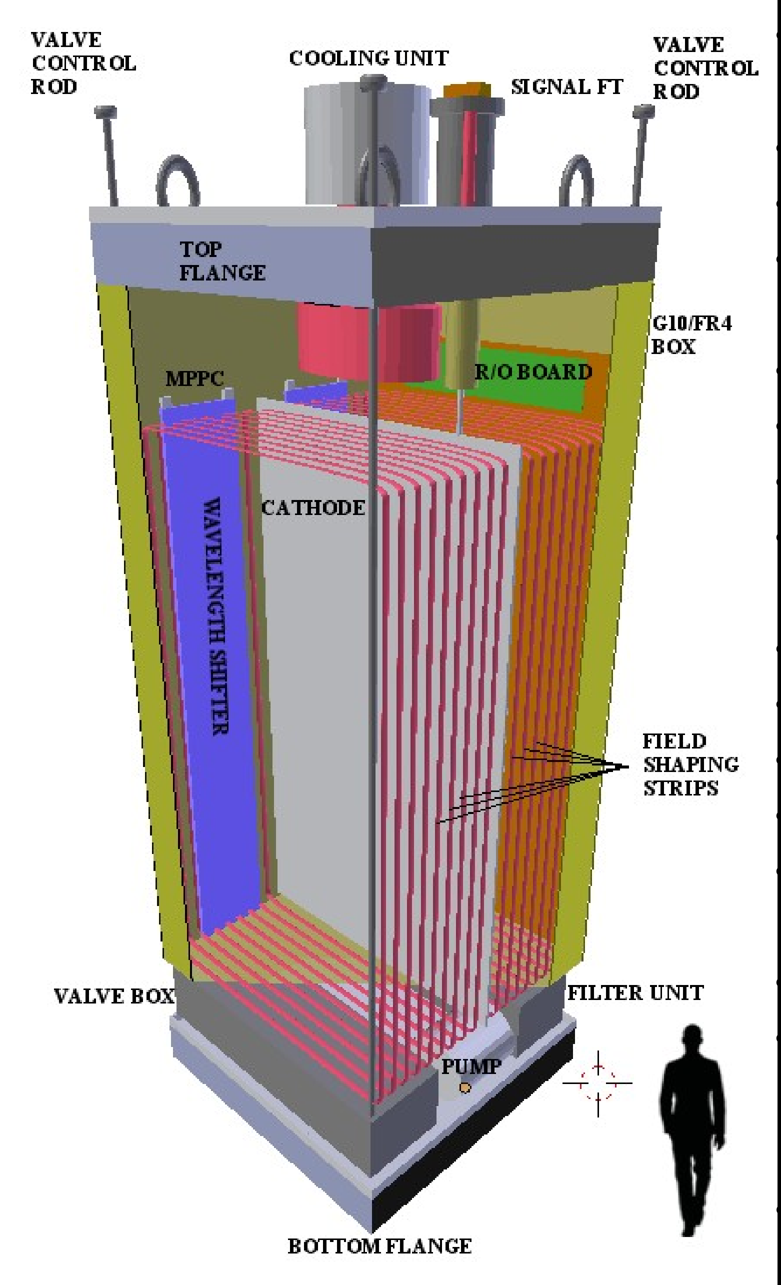
- High overall detection efficiency

- Wire modules as a reference

- Challenge for data compression (~ 2M ch/module)

Improves reconstructed physics accuracy

ARGONCUBE module



Module: an independent TPC

- LAr purification: recirculation through Oxygen-traps
- Temperature: individual cryo-cooler unit
(removes heat input from electronics and heat leaks)

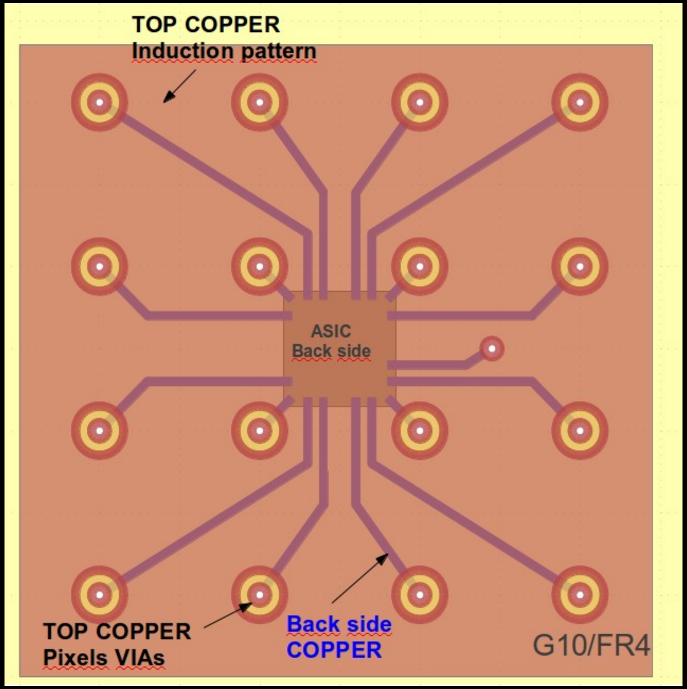
- Cathode bias (-100 kV) supplied via HV feed-through
- Resistive divider for field shaper
- Relatively low voltage => breakdown-free setup
- Electrically transparent container => low dead volume

- PCB-technology for R/O plane manufacturing
- Pad arrays for charge readout, *e.g.* 4x4 mm^2 pads
- 8x8 pads ROI served by one R/O ASIC at the PCB back
- Mechanically robust production technology
- Low failure cost

- Light collection via WLS light guides
- Light readout with SiPMs in coincidence

Reliable/repairable self-contained unit

Charge readout baseline option

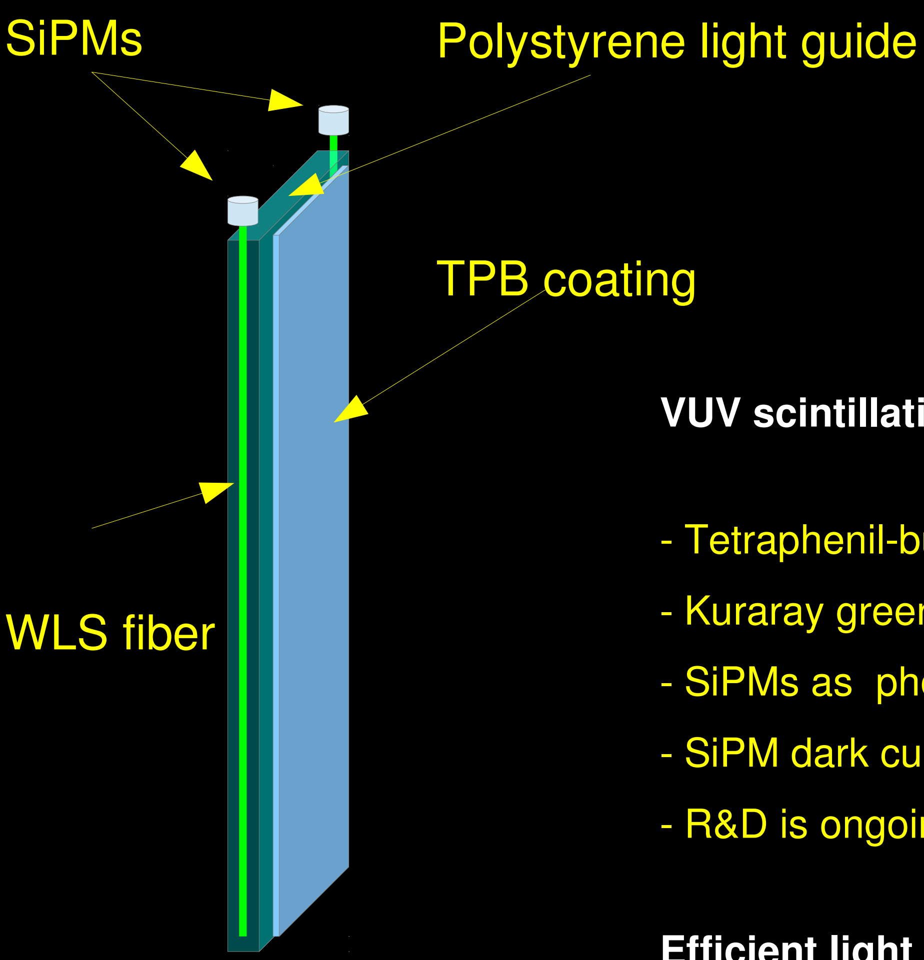


Pad array divided into Regions Of Interest (ROI)

- 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

Scintillating light detection

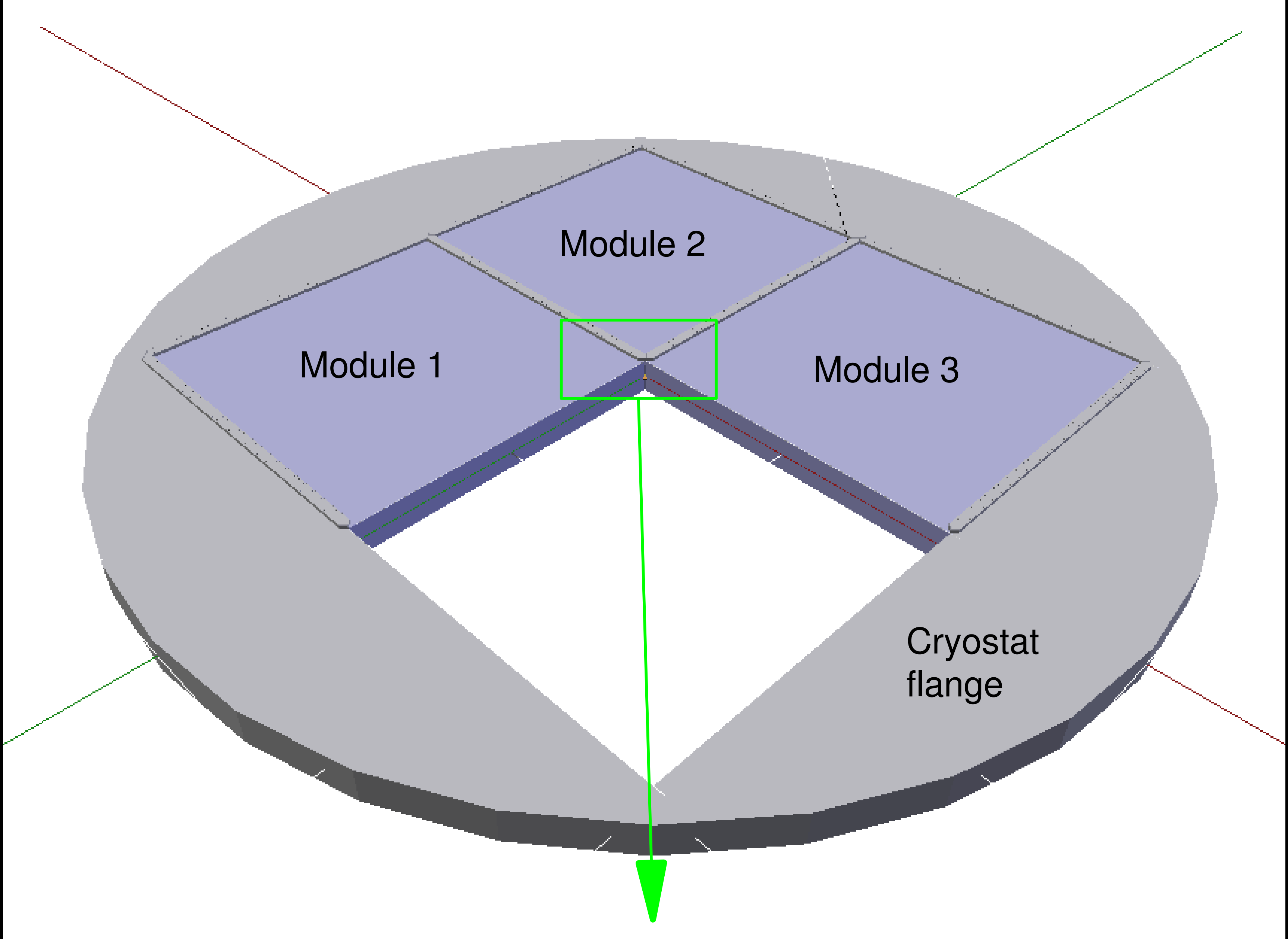


VUV scintillation light is double-shifted to green

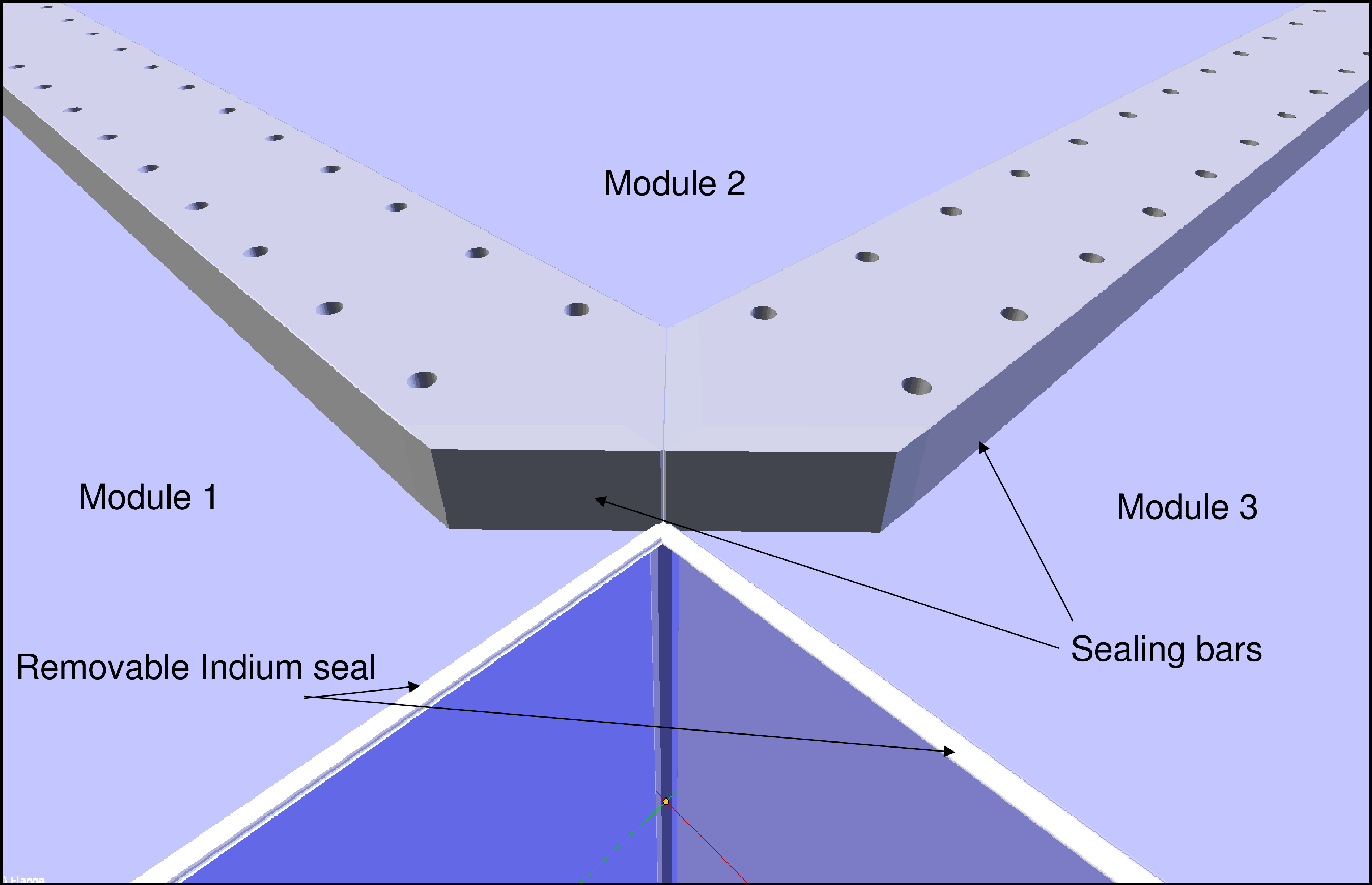
- Tetraphenil-butadiene (TPB) as primary WLS
- Kuraray green fibers as secondary WLS
- SiPMs as photon detectors
- SiPM dark current at 87K is O(Hz) at 1 p.e.
- R&D is ongoing e.*g.* within SBND — promising results!

Efficient light collection from large area

ArgonCube top flange



ArgonCube top flange : removable seal



Module 2

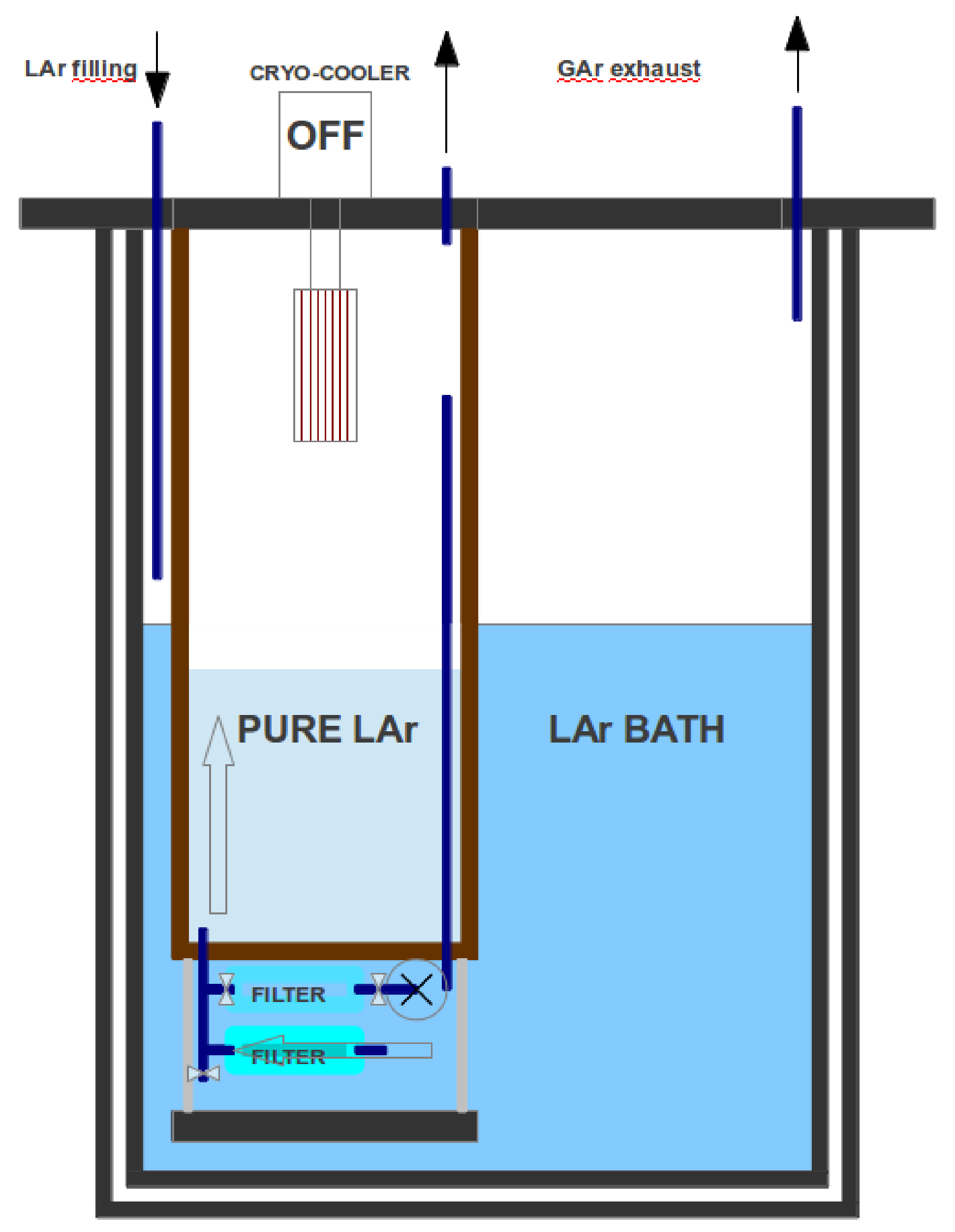
Module 1

Module 3

Sealing bars

Removable Indium seal

ArgonCube : startup



Initial filling sequence

- One module is in its place

- Rest of the cryostat top flange closed with dummy flanges

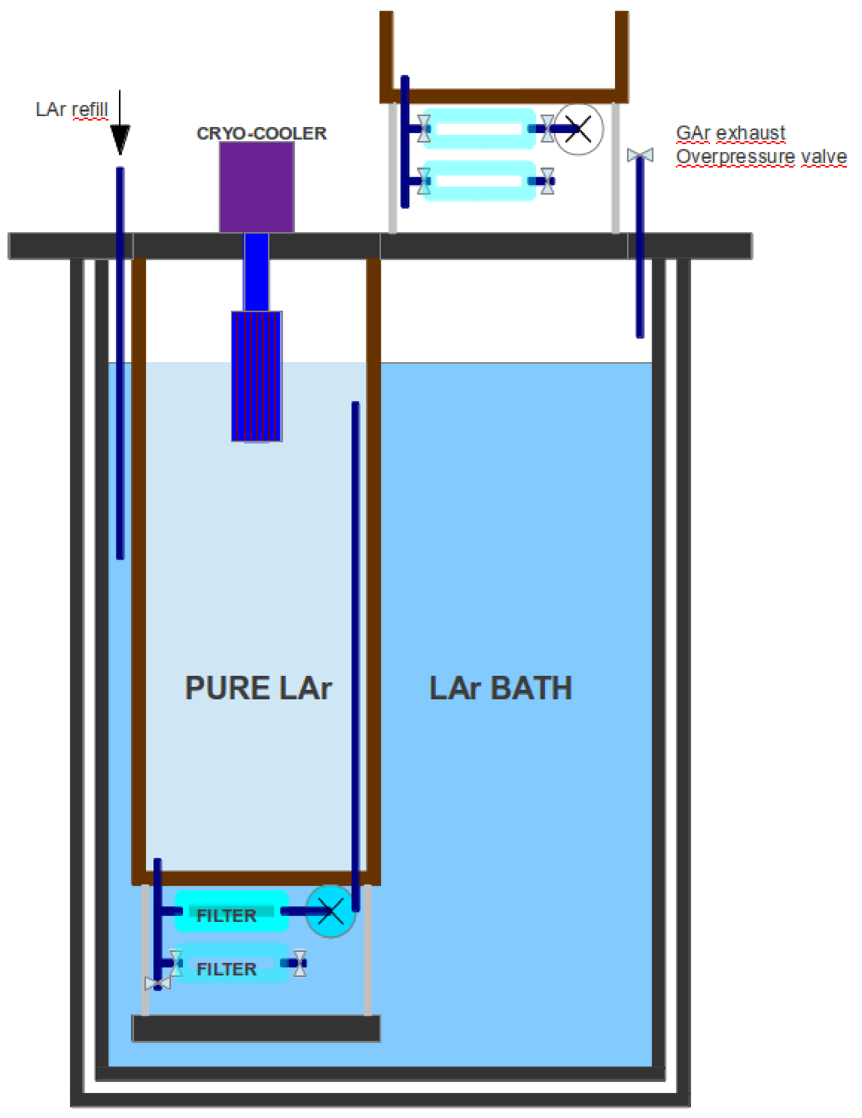
- Liquid argon arrives to the outer volume

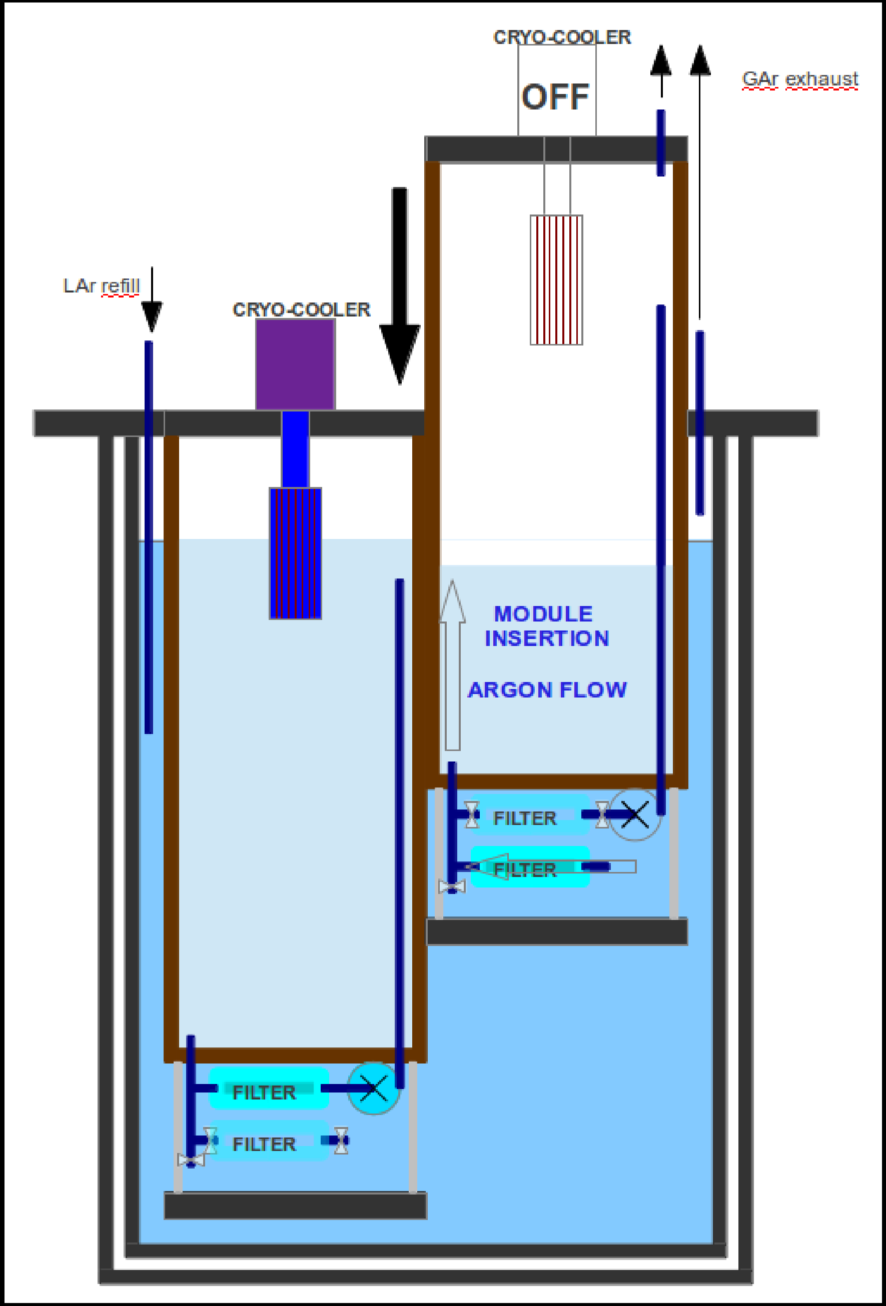
- Liquid argon from outer volume reaches the inner module volume via Oxygen-trap

- Evaporated argon exhausted via both inner outer unidirectional valves

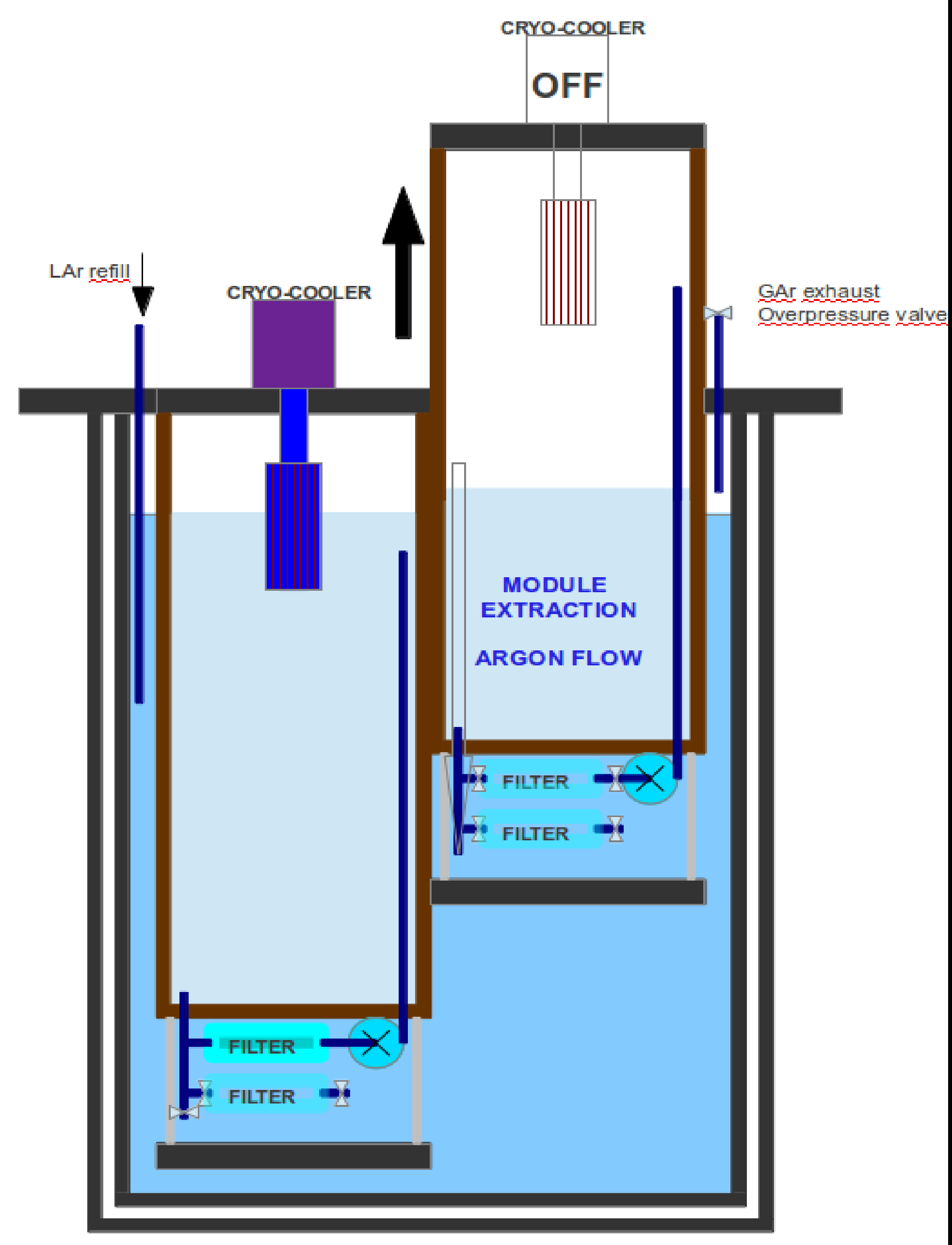
Once filled — ready for data taking

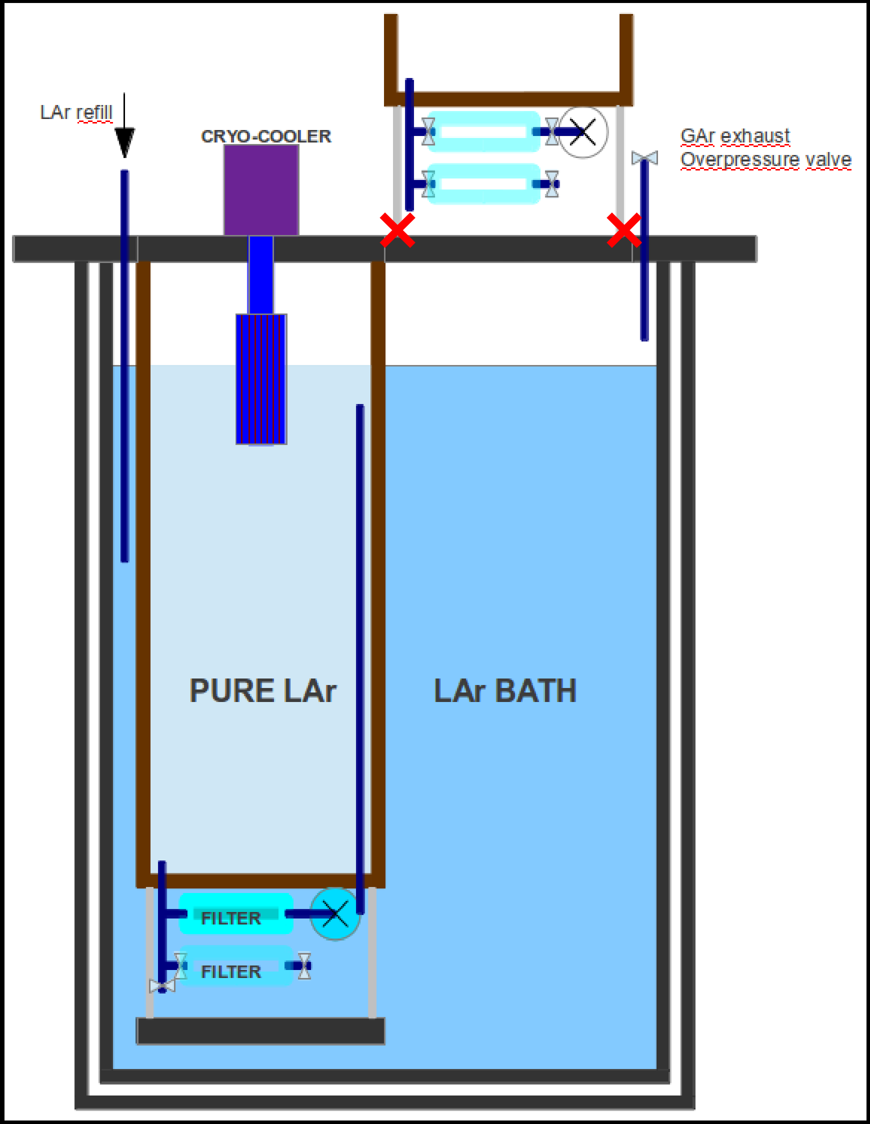
Module insertion



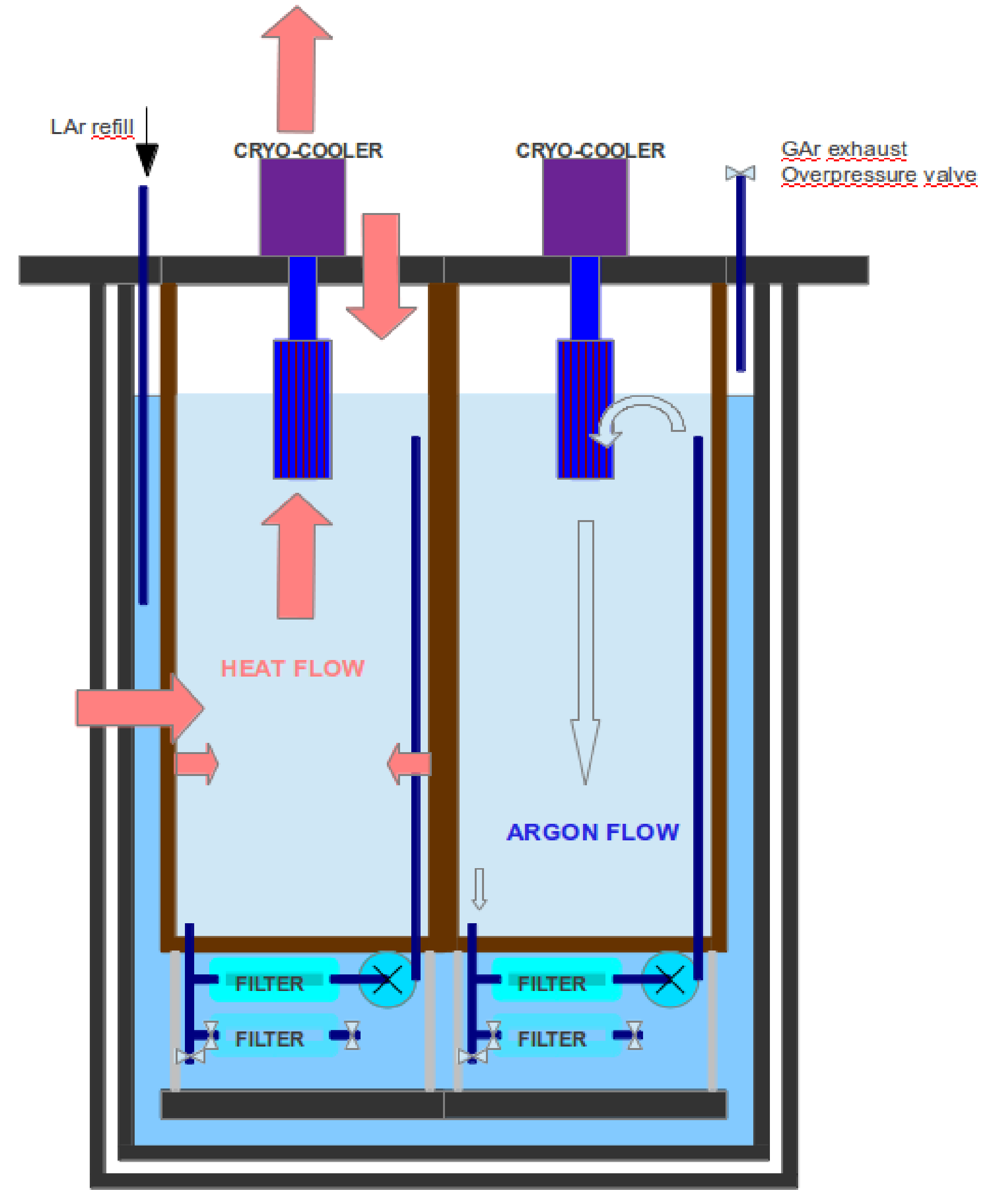


Module extraction





Heat management



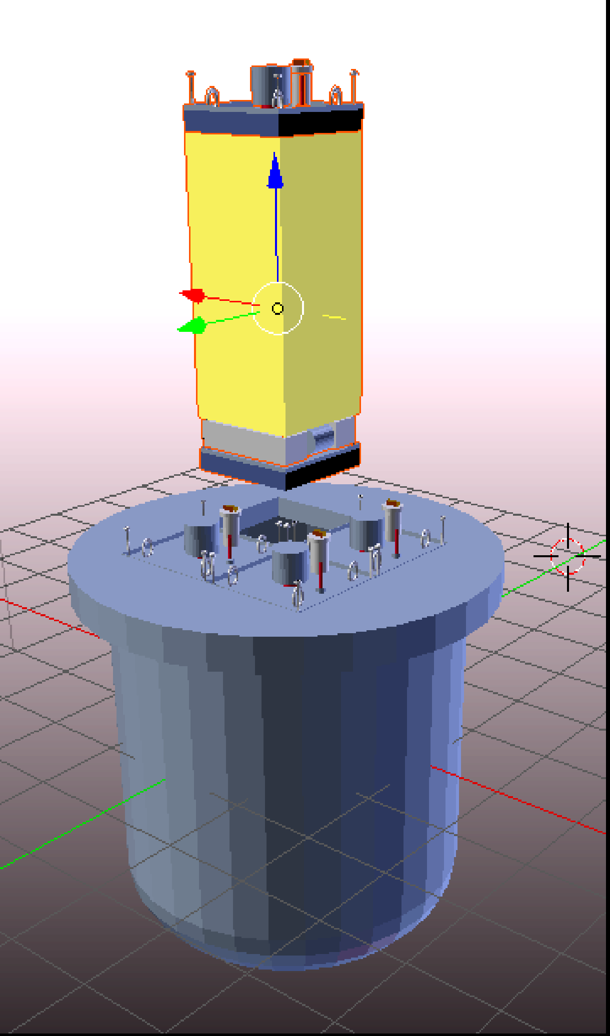
Heat removal by Cryo-cooler

- Heat input from walls and electronics is taken away by circulating liquid

- Near the surface this heat is intercepted by cryocooler cold head
(up to 200 W cooling power)

Distributed and redundant cooling

R&D Phase - 1



Activities in Bern

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

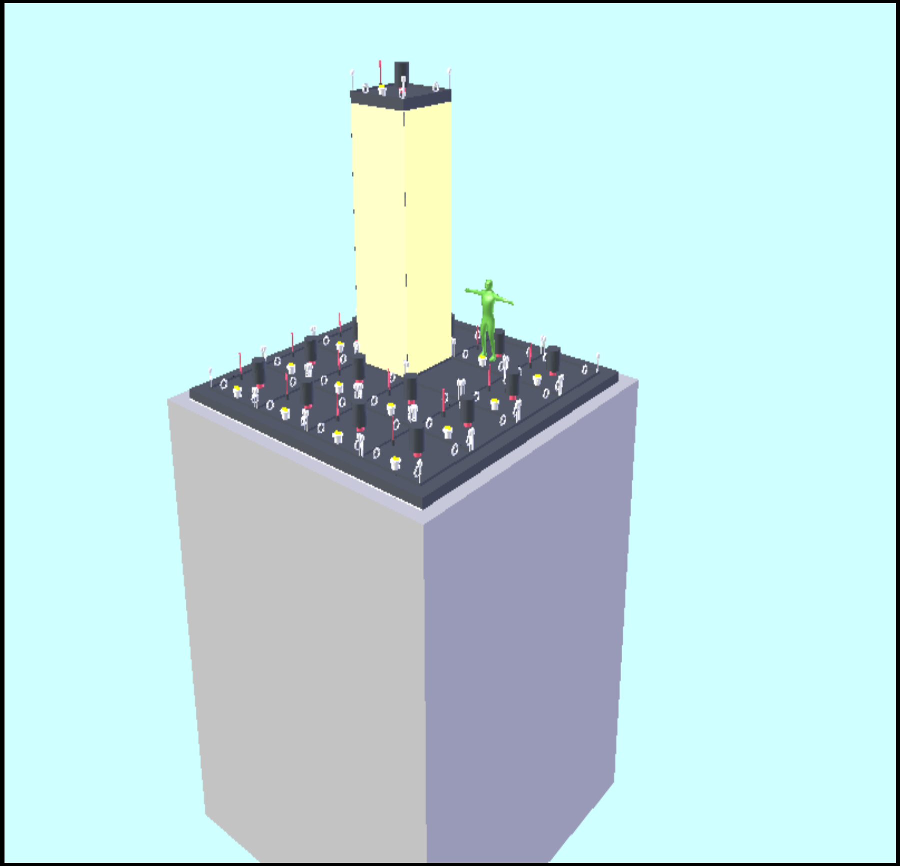
Active mass ~ 750 kg per module

Drift length 33 cm

Cathode bias 30-100 kV

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

R&D Phase - 2



Foam insulated cryostat (2 examples)

Cryostat dimensions 4.8 x 2.4 x 2.9 m^3
4 modules
2 x 1 m^2, 2.9 m high
Argon volume ~ 4.8 m^3 per module
Argon mass ~ 6.7 t per module
Active mass ~ 6.5 t per module

Cryostat dimensions 9.5 x 7.3 x 9.3 m^3
12 modules
2 x 2 m^2, 9 m high
Argon volume ~ 34 m^3
Argon mass ~ 47.6 t per module
Active mass ~ 46.2 t per module

Drift length 1m, cathode bias 50-100 kV

Goals: test real-scale arrangement, optimize cryogenic parameters and R/O geometry, obtain reconstructed beam events in the 0.5-20 GeV range : leptons, hadrons. Quantify accuracy of reconstructed physics parameters.

CONCLUSIONS

- The ArgonCube Collaboration is proposing and R&D activity at CERN for a cost effective, reliable and preforming design of large-scale LAr TPCs

- Fully modular structure

- High active mass ratio (97%)
- 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

Thank you!


Fermilab
Yale University
CERN
BROOKHAVEN NATIONAL LABORATORY
LABORATORIUM FÜR HOCHENERGIEPHYSIK
LHEP
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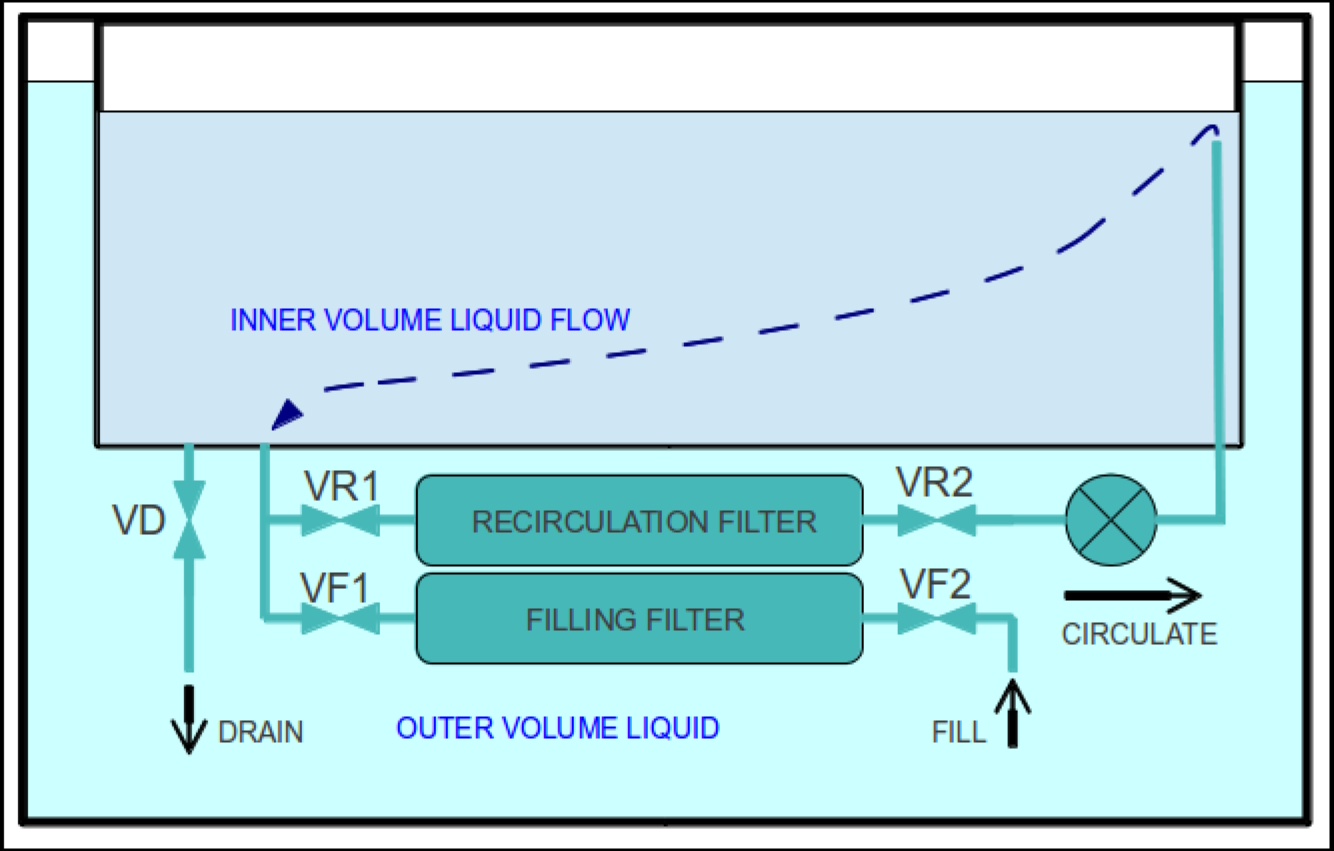
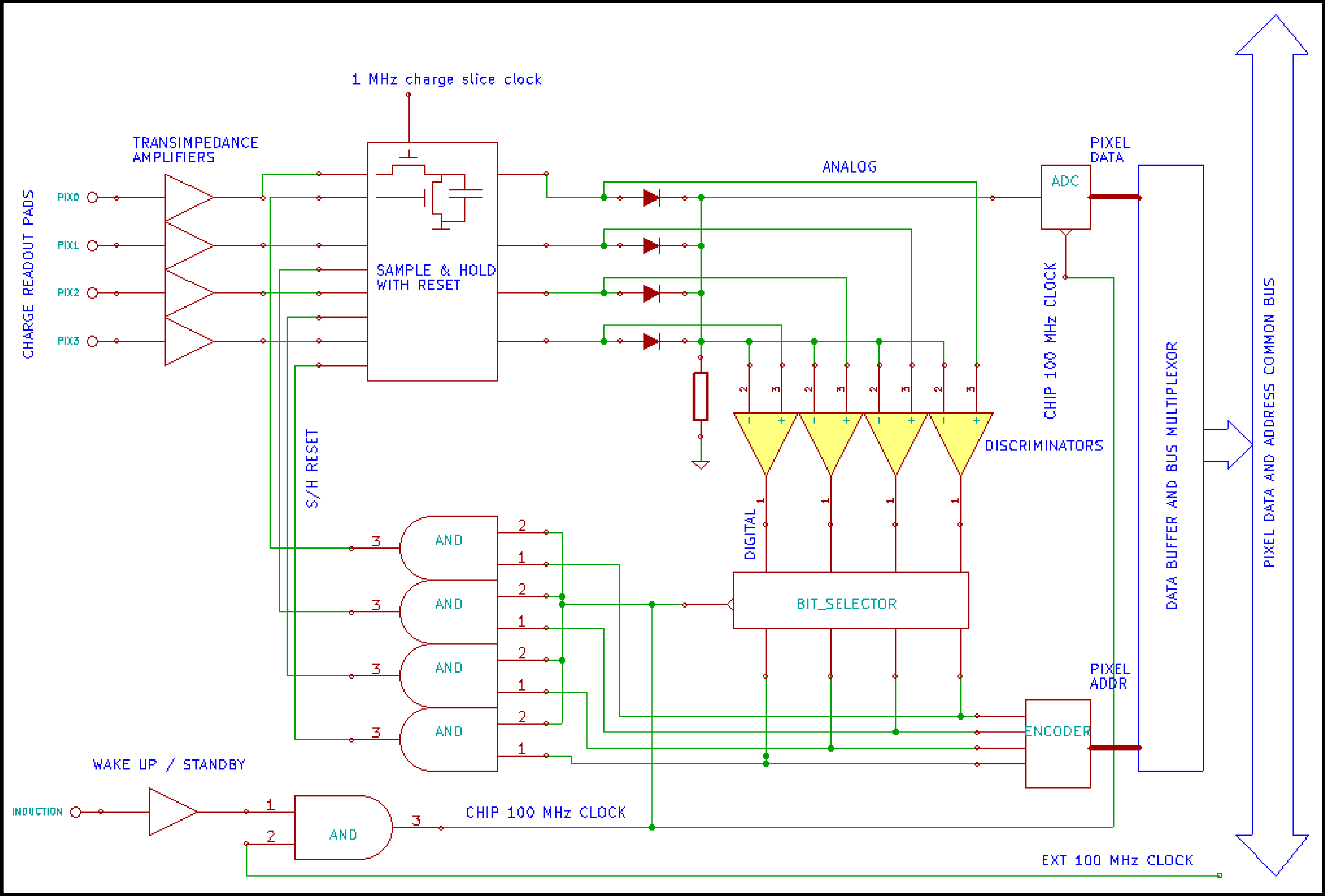
Backup slide



Backup slide



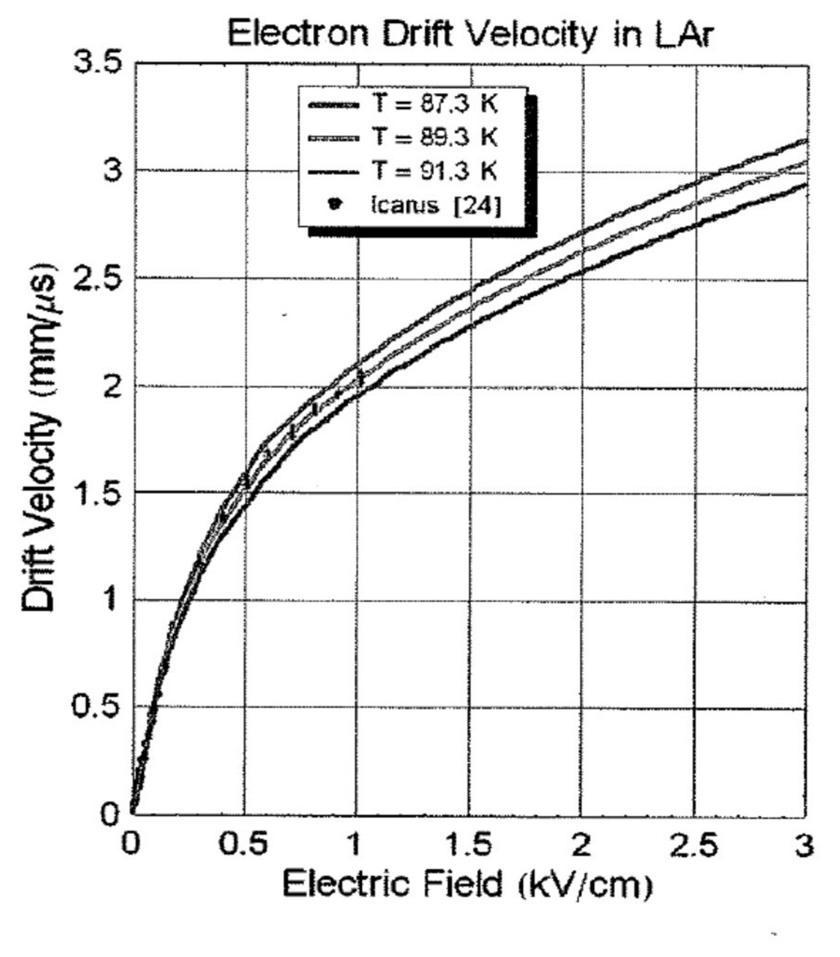
Backup slide

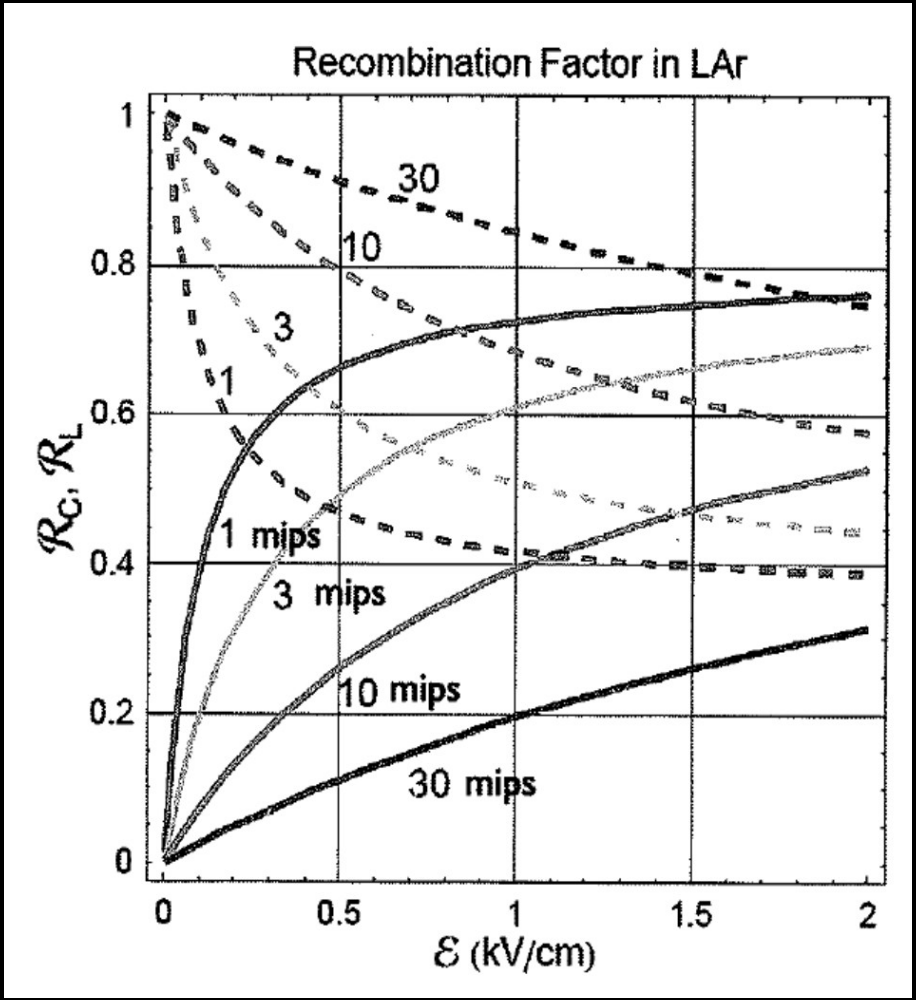
A Liquid argon properties
http://atlas.web.cern.ch/Atlas

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

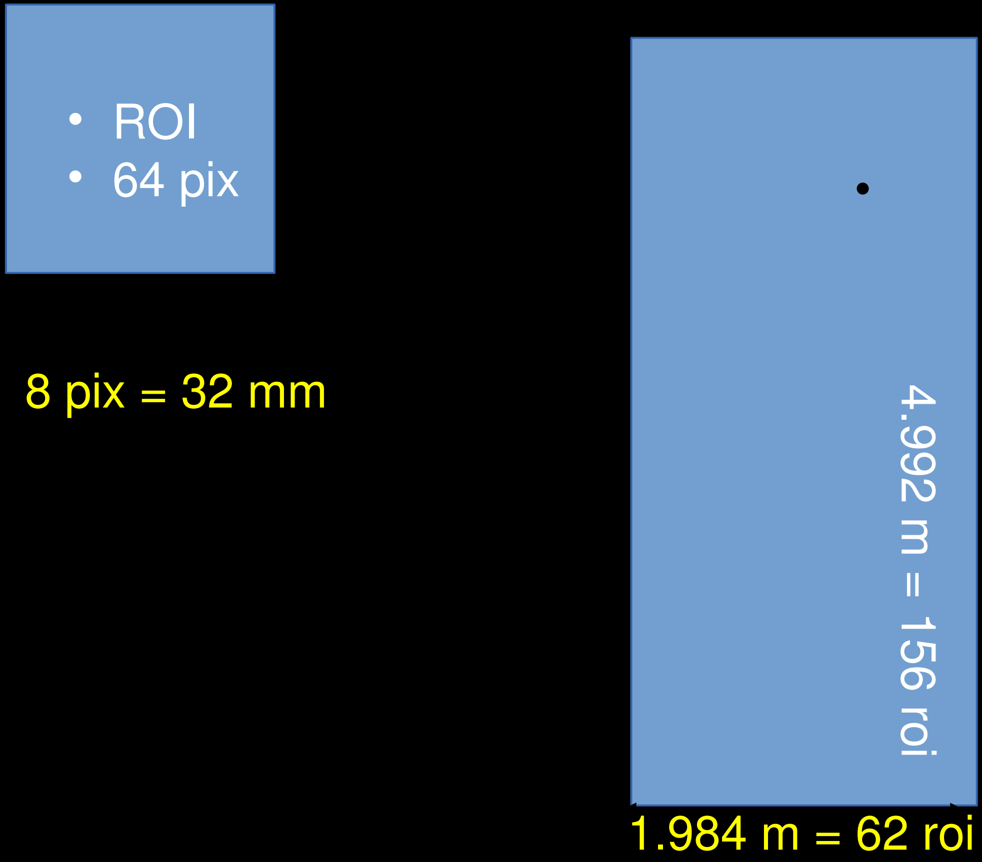
Backup slide





Backup slide

- 4x4 mm pixels



- ROI
- 64 pix

8 pix = 32 mm

4.992 m = 156 roi

1.984 m = 62 roi

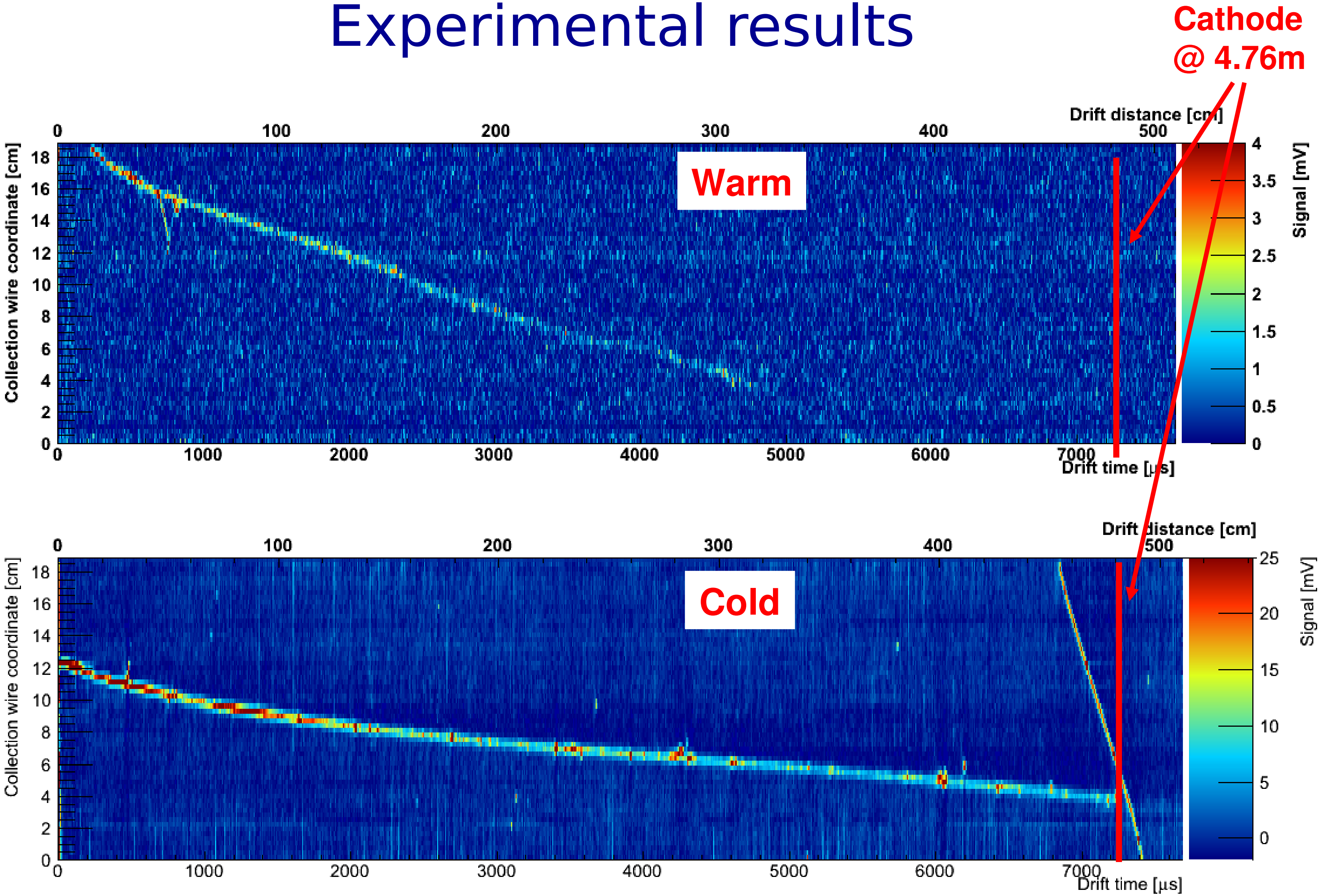
619008 ch
9672 roi

m(LAr)=14 ton

<Pch>=0.1mW/ch →
<Ptot>=0.6 kW

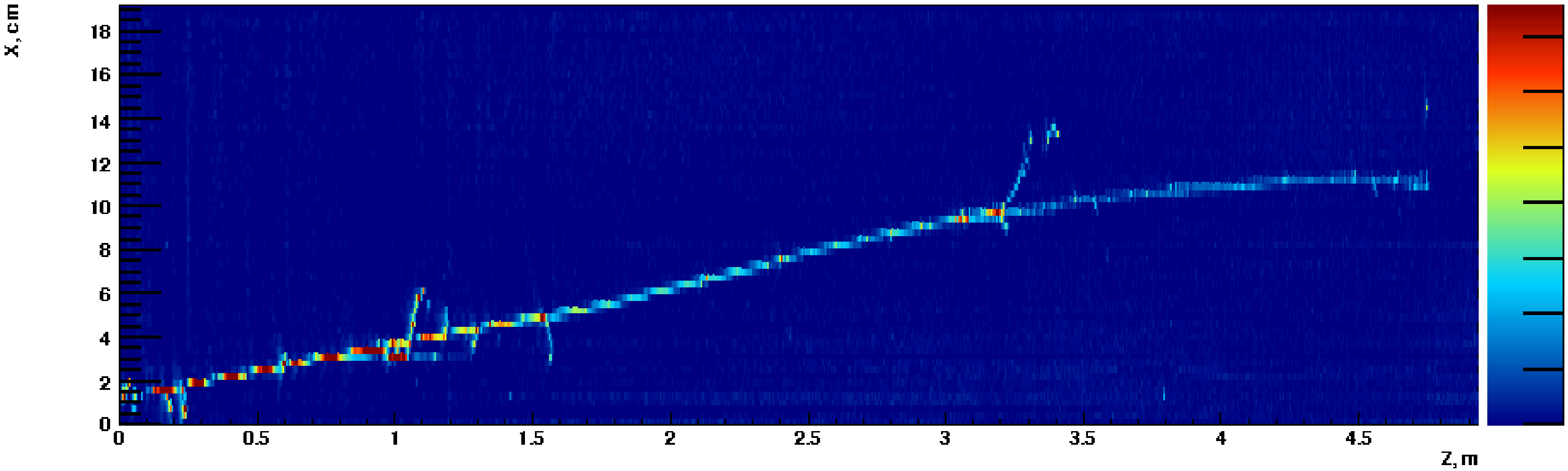
4.4 W/ton of LAr

Experimental results

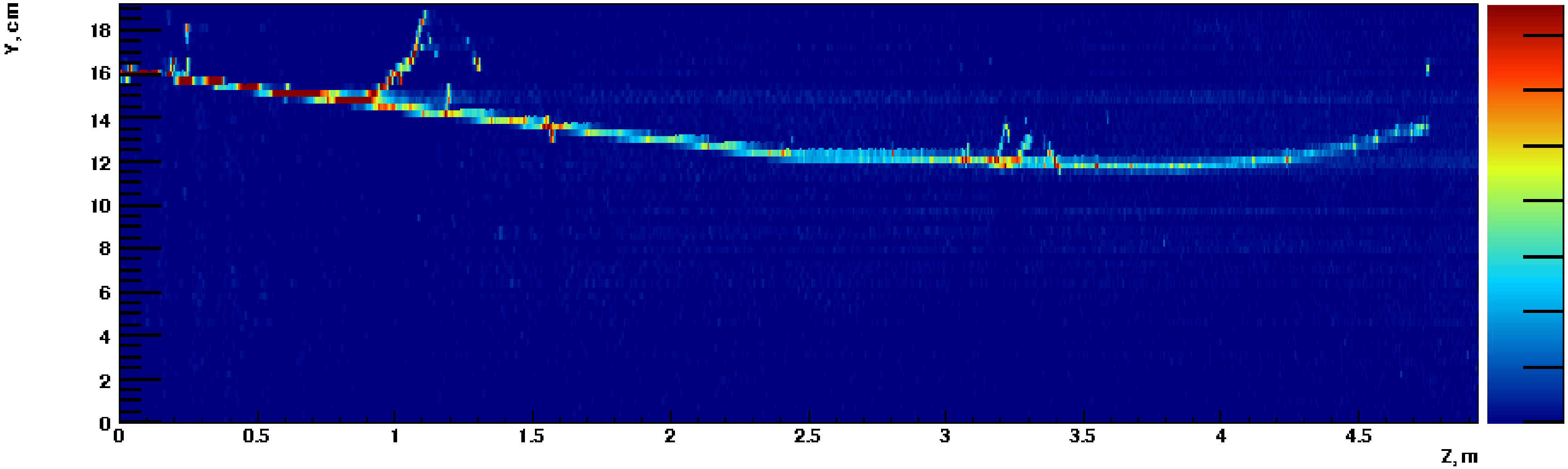


S/N (mip) = 15.7 ± 3.8 (~ 200 V/cm)

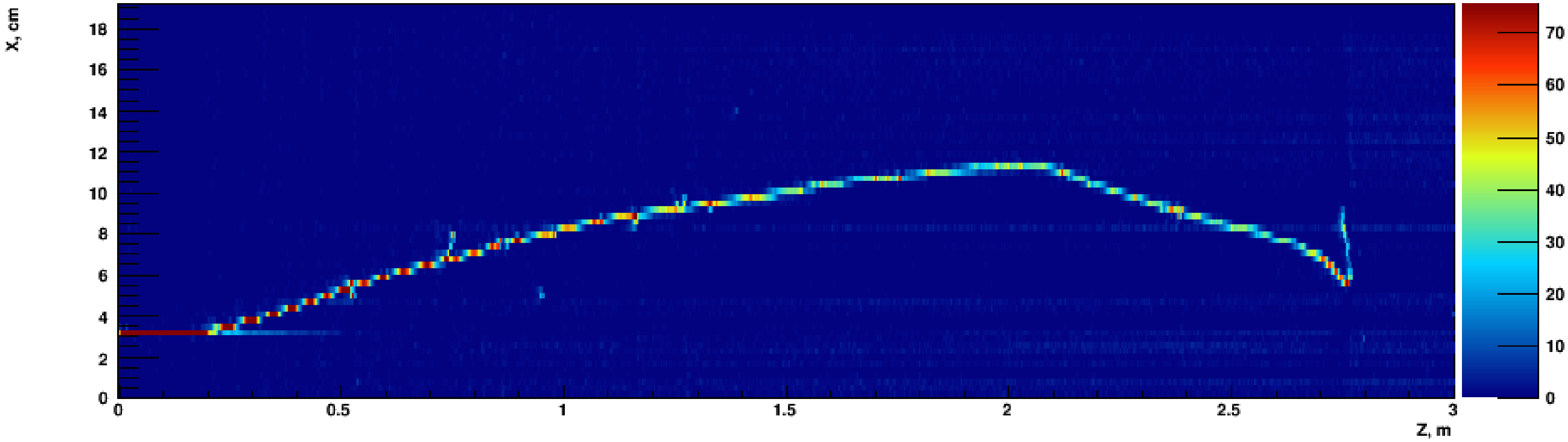
Induction, Run 50038 Event 477. Trigger pattern: I1 T



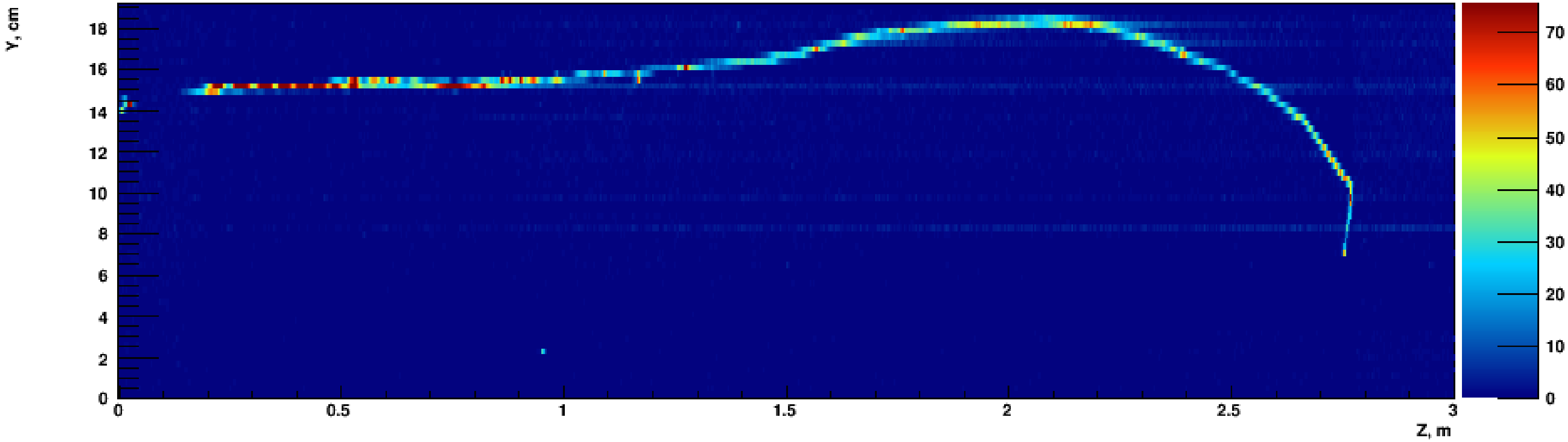
Collection view, Run 50038 Event 477



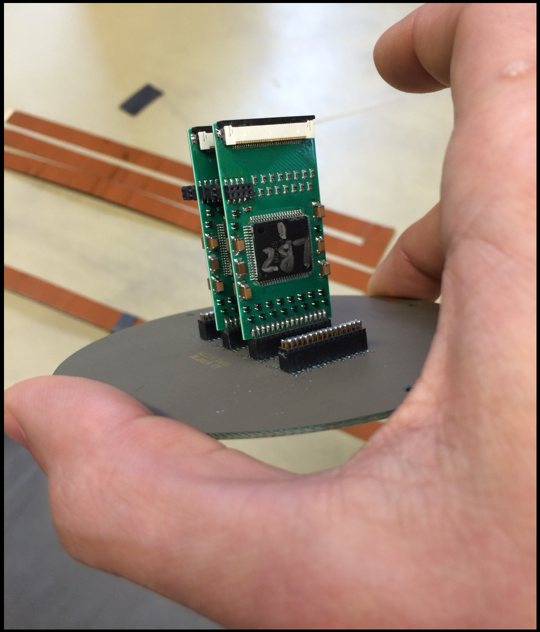
Induction, Run 50050 Event 141. Trigger pattern: I1 T

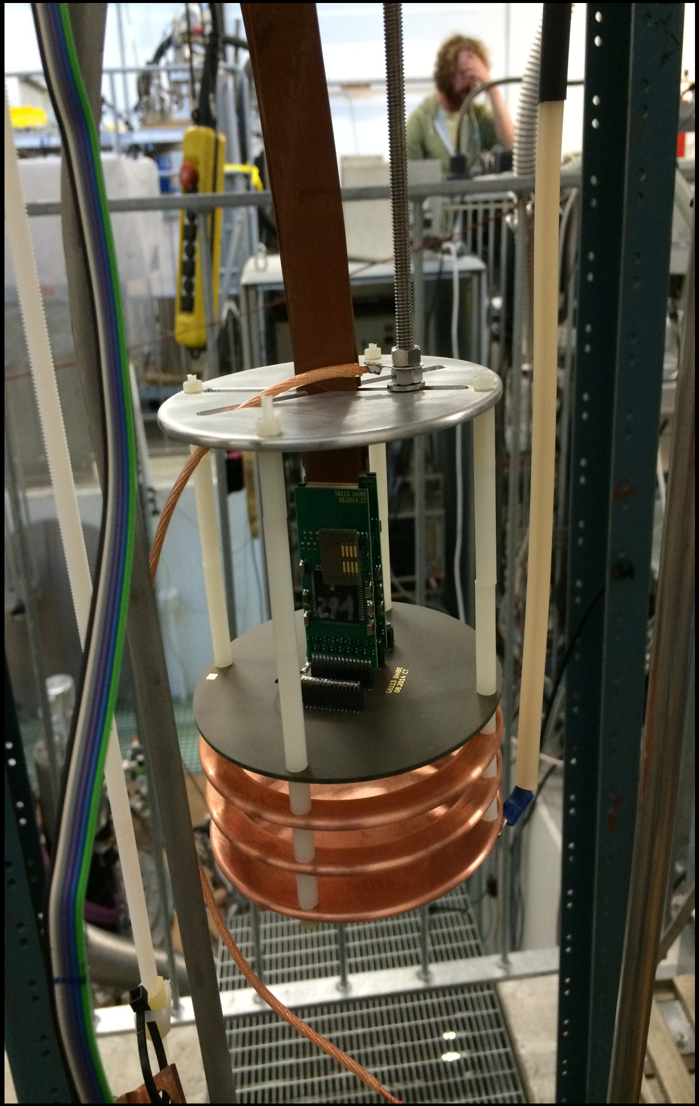


Collection view, Run 50050 Event 141



Example of R&D in progress: pixel readout





Average power and data flow

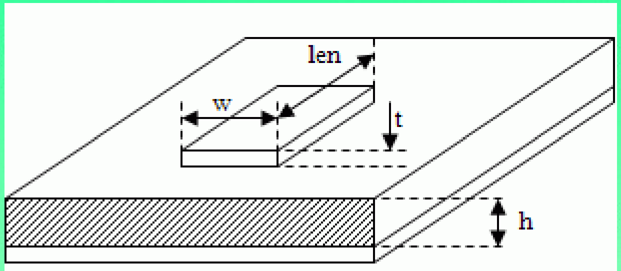
power per ind channel, mW	6	6	6	6
power per full channel,mW	200	200	200	200
APA height, m	5	5	5	5
APA width, m	2	2	2	2
Drift time, ms	1	1	1	1
Time slice, us	1	1	1	1
Drift length, m	1	1	1	1
Argon mass, t	14	14	14	14
pixel size, mm		3	4	5
pixels/roi side	8			
pixels/roi	64	64	64	64
roi side, mm		24	32	40
Nroi/width		83	62	50
Nroi/height		208	156	125
Nroi/plane		17264	9672	6250
Max active roi (diag. Track)		223	167	134
Wakeup time, in time slices	5	5	5	5
<P> per plane, W		117	68	46
<P> per ton of LAr W/ton		8.36	4.86	3.29
Npix per plane		1104896	619008	400000
ADC bits	16	16	16	16
pixel in roi address, bits	6	6	6	6
Time slice number, bits	10	10	10	10
Data, KB per drift (1 track)		446	334	268
Data flow MB/s (1tr/frame)		435	326	261

$$(\underbrace{C2*C16*C6/C5/1000*C11}_{\text{pixels}}+\underbrace{C1*C15}_{\text{ind.}})$$

R/O capacitance

Rectangular Pad Capacitance Calculator:
(includes core and fringing capacitance)

$$C = 8.8542\,\varepsilon_r \cdot \frac{(w-h)\cdot(l-h)}{h} + 26.40\cdot(\varepsilon_r + 1.41)\cdot\frac{(w+l)}{\ln\left(\frac{5.98h}{(0.8h+t)}\right)}$$



Copper thickness, mm	0.05	0.05	0.05	0.05
Wire width, mm	0.3	0.3	0.3	0.3
Inter-layer thickness, mm	0.2	0.2	0.2	0.2
Pixel size, mm		3	4	5
pixels per roi side	8	8	8	8
Dielectric constant	4.2	4.2	4.2	4.2
Induction pattern length, mm		48	64	80
Induction pattern capacitance, pf		5.00	6.66	8.32
Pixel capacitance, pf		1.97	3.37	5.14