Status of Liquid Argon TPC R&D

28/Nov./2016 Neutrino frontier workshop 2016

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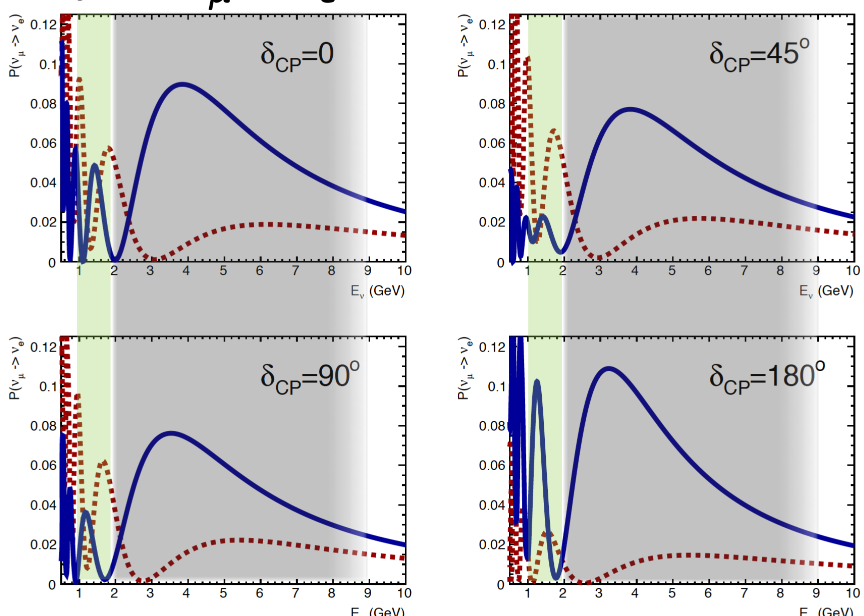
R&D collaboration with KEK,

and Kure National College of Technology

Introduction

- LAr TPC
  - 3D imaging(TPC)
  - Precision energy resolution in several GeV wide range
  - Possibility of large detector for future neutrino oscillation and nucleon decay experiments

Probability of $\nu_\mu \rightarrow \nu_e$ @<u>2300 km</u>(CERN-Pyhäsalmi),NH, $\sin^2 2\theta_{13} = 0.09$



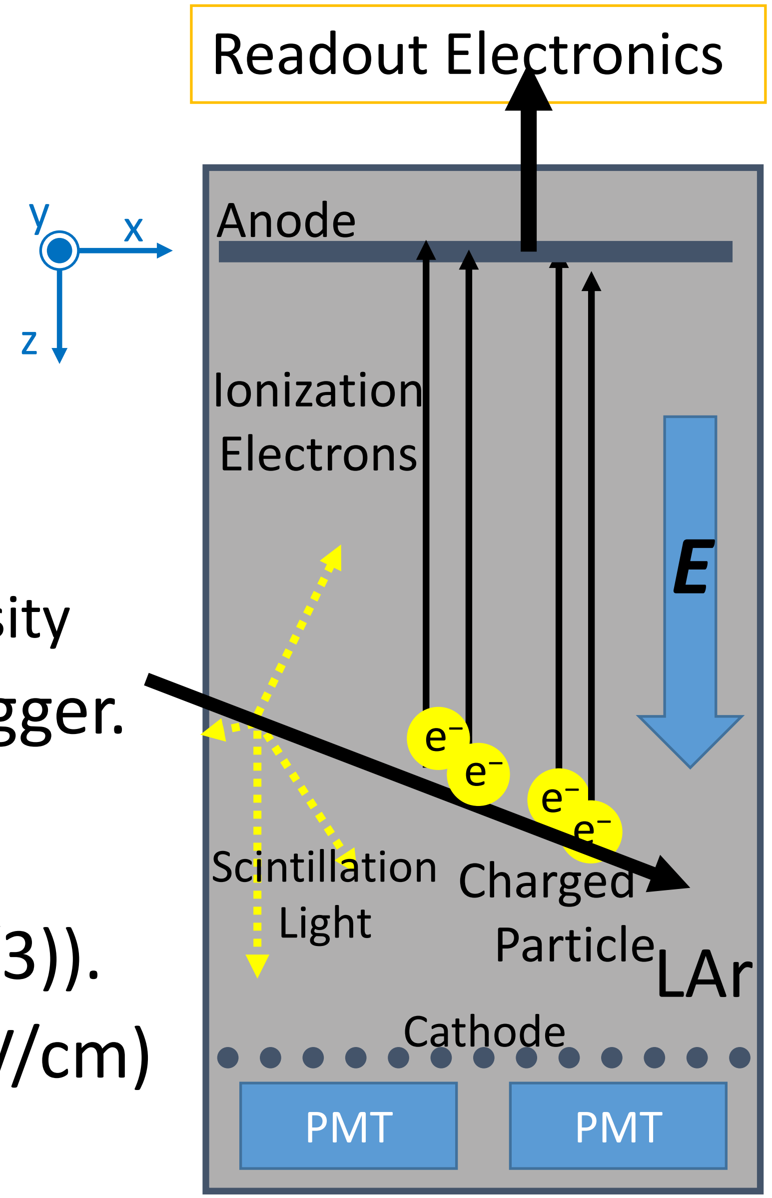
For measurement *CP* phase and mass hierarchy, it is necessary to distinguish a few GeV neutrino.

Future plan for large(> 10 kt) LAr TPC

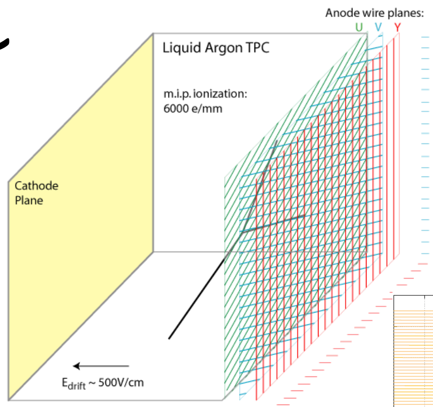
LAr TPC principal

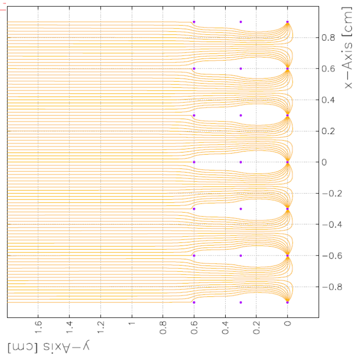
- Drifted ionization electron
  - 2D(x,y) information from anode (readout plane) with 3-4 mm pitch
  - z information from timing

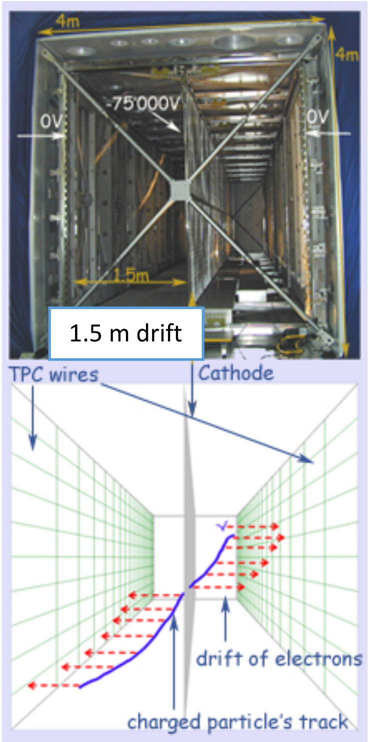
  → 3D tracking
  - dE/dx information from electron density
- LAr scintillation (128 nm) makes trigger.
- Expected number of electron ~ 1 fC/mm (after recombination (2/3)).
- Drift velocity ~1.6 mm/μs (@ 500 V/cm)
- Diffusion ~ 1-2 mm @ 5m drift



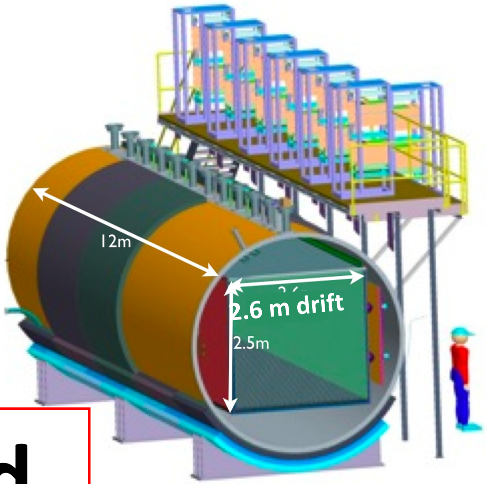
Large LAr TPC







- ICARUS
  - 300 t × 2
  - 1.5 m drift
  - 3 direction wire readout
  - (4 m × 20 m anode) × 2, ~27000 ch
- MicroBooNE
  - 170 t
  - 2.6 m drift
  - 3 direction wire readout
  - 2.5 m × 12 m anode, 8256 ch



Larger detector are planed.

Toward > 10 kt LAr TPC

Larger TPC leads longer drift length.

Long drift → reduce channel number

- Long drift (> 5 m) requires those technology
  - ➢ LAr purity
    - Purity < 0.1 ppb for long term
  - ➢ High voltage
    - > 250 kV (500 V/cm)
  - ➢ Readout system
    - Low noise high signal gain
    - Wide dynamic range
    - Cold operation
    - Economical
    - …

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    - …
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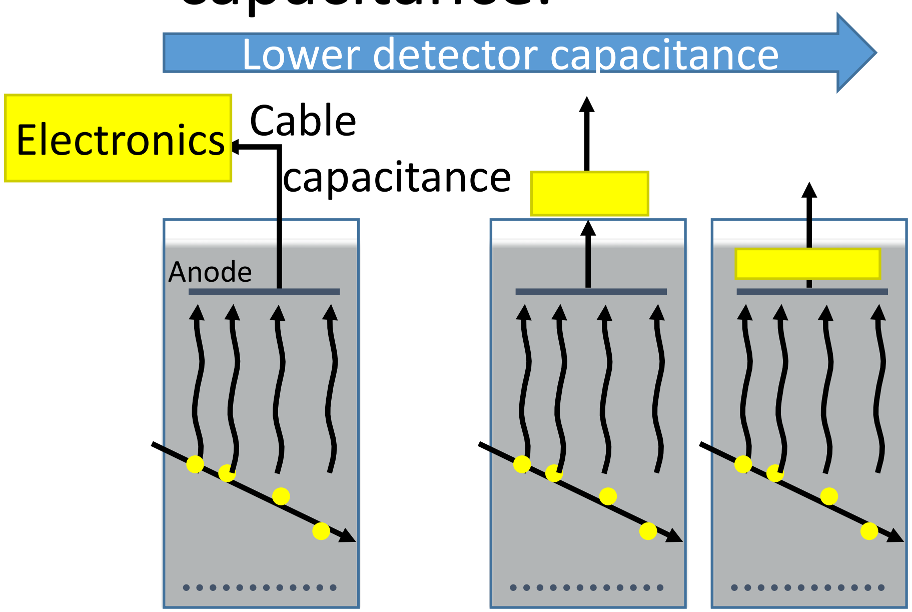
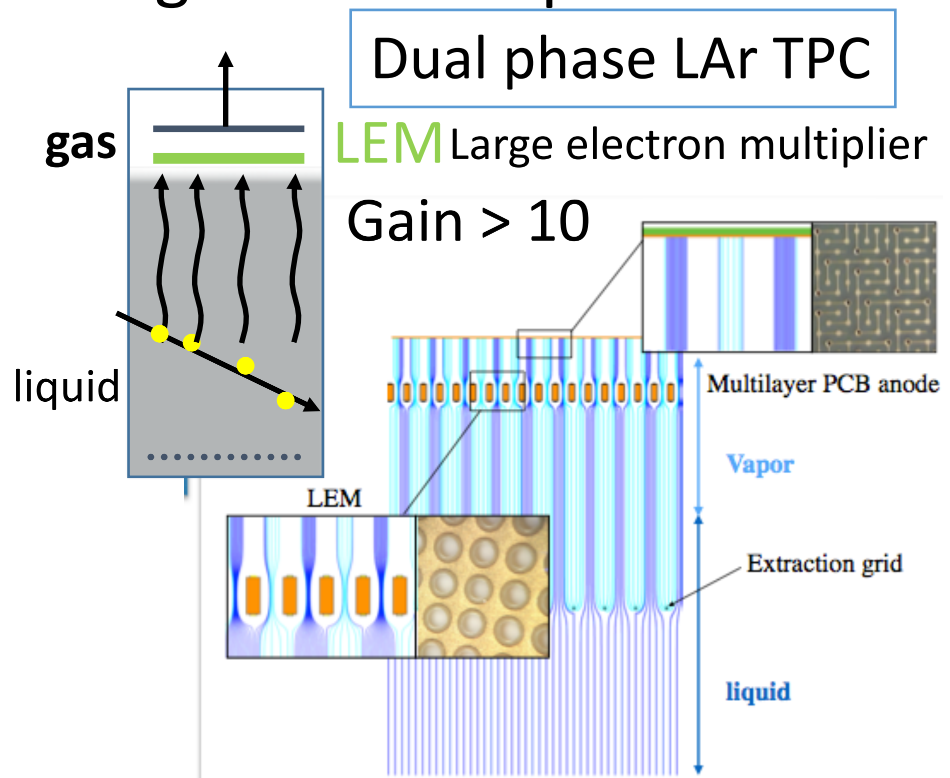
Requirement for electronics

- Configuration of electronics is as close as possible to anode to reduce detector capacitance.



Low temperature operation

- Target of electronics development is for single and dual phase.

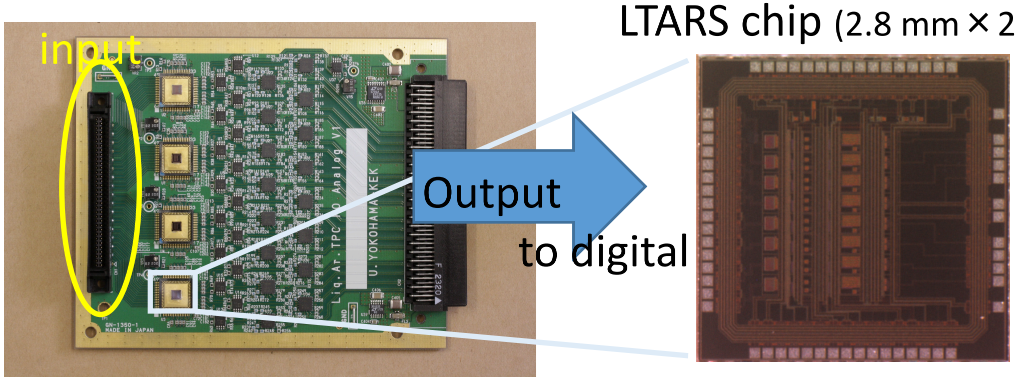


Wide dynamic range

Analog chip and board (32 ch) for small bench

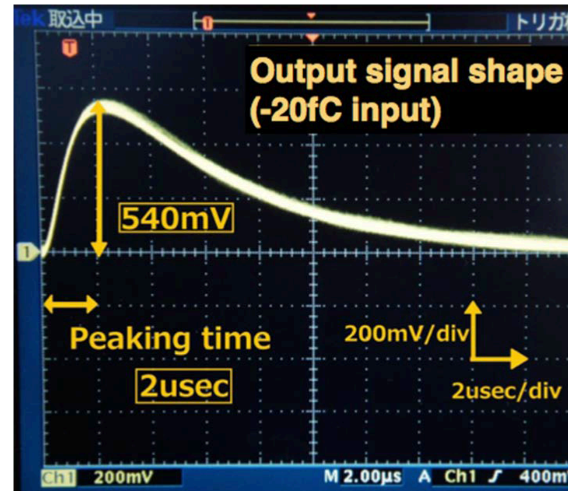
LTARS ASIC chip (8 ch in 1 chip) was developed for 10 l LAr TPC.

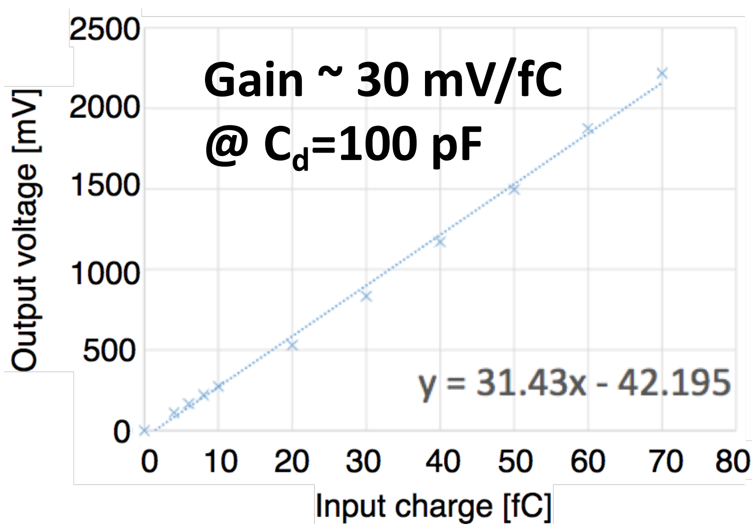
LTARS chip (2.8 mm × 2.8 mm)

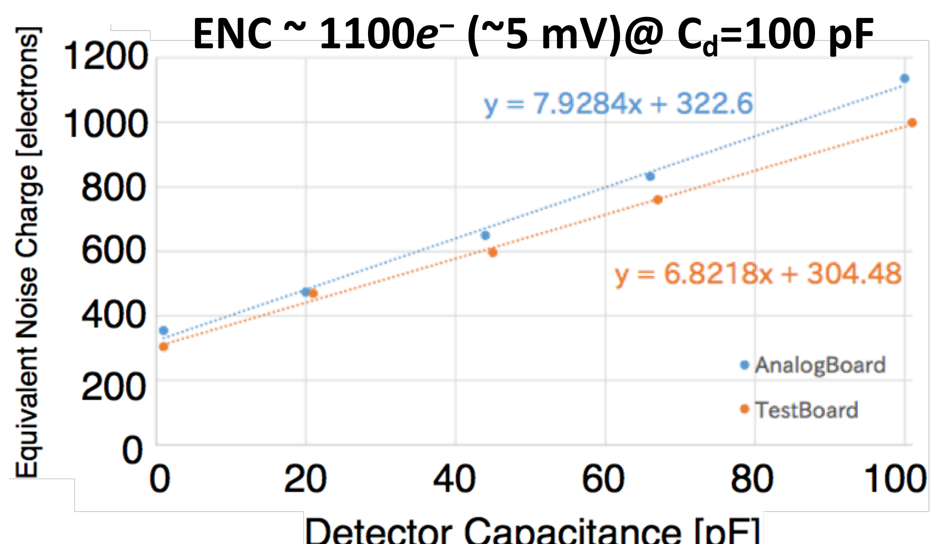


4 LTARS, 32 ch
Analog board

8 ch





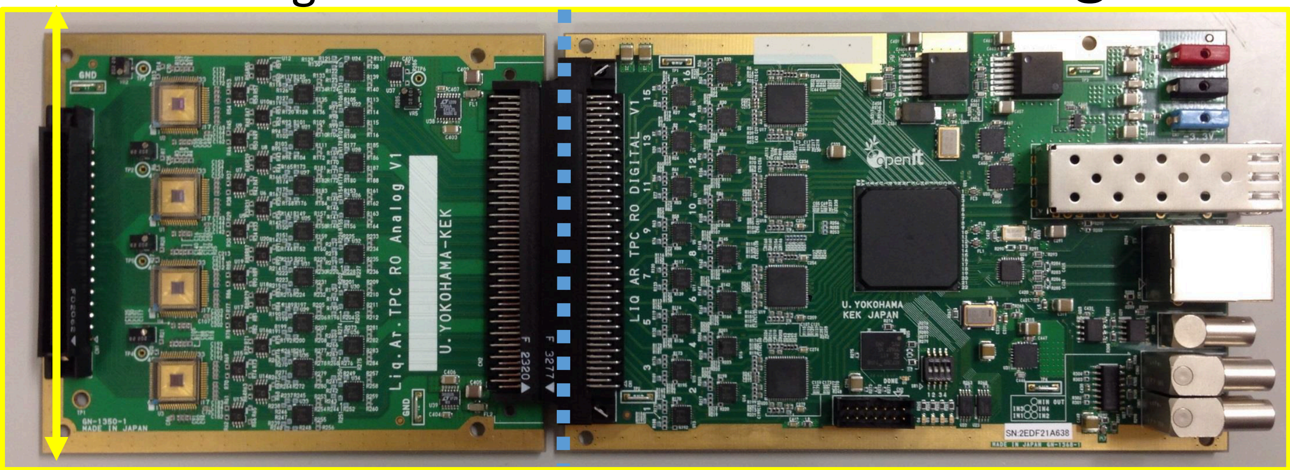


Readout system for small LAr TPC bench

- Test of 10 l LAr TPC real equipment readout
- Compact readout system

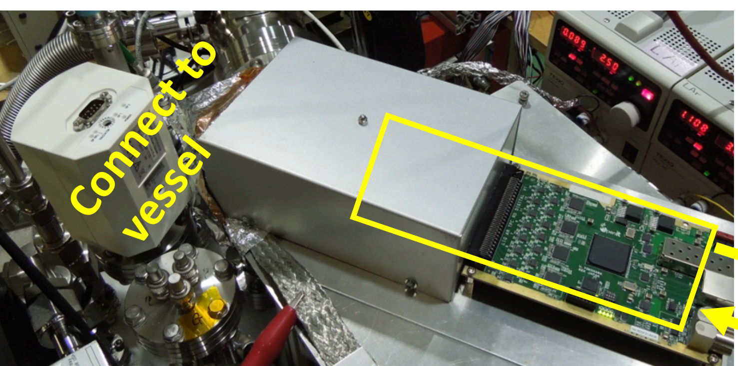
9 cm Analog board

Digital board



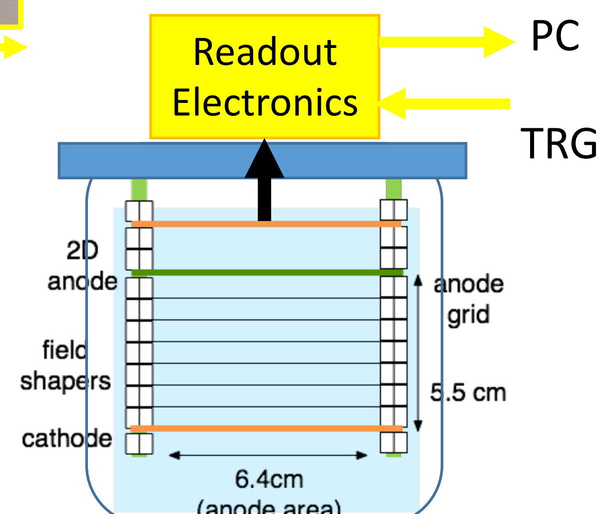
14.5 cm

- 32 ch differential input
- 12 bits FADC
- Sampling rate 40M
- Airtix-7 FPGA
- Ethernet output



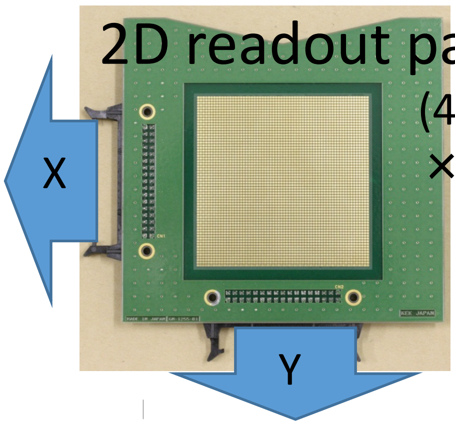
Ethernet for DAQ (SiTCP)

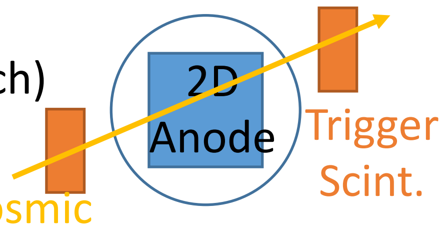
External trigger input



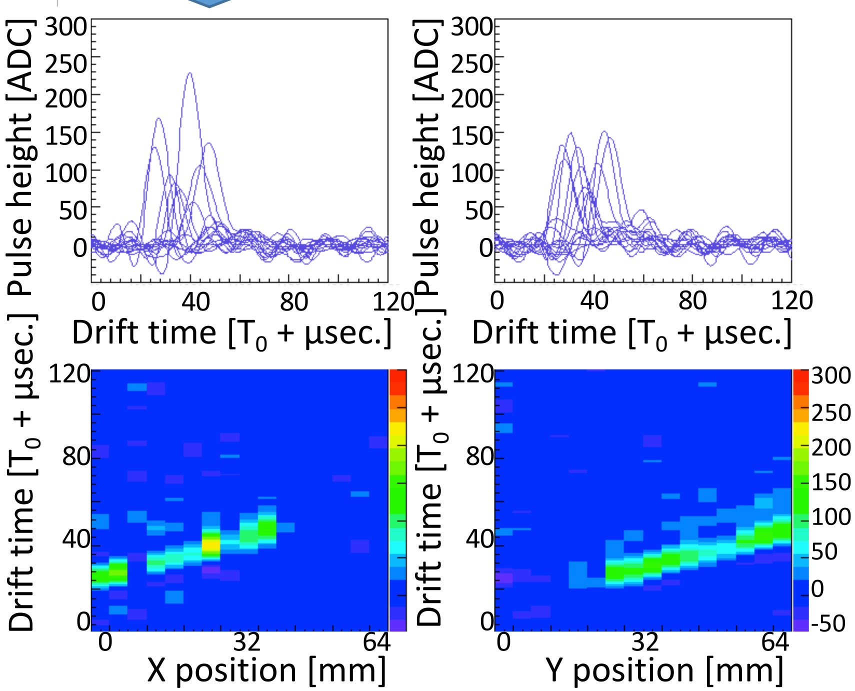
Cosmic test with small test bench

Anode
2D readout pad
(4mm × 16ch)
× (4mm × 16ch)

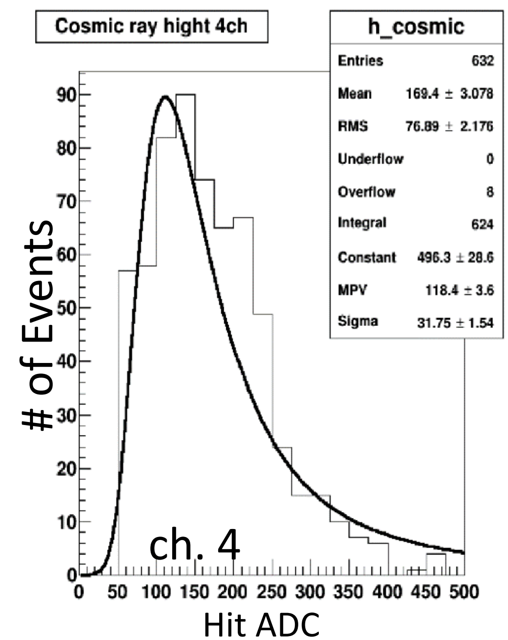




With external trigger.



Signal size are evaluated from ~600 cosmic muon tracks.

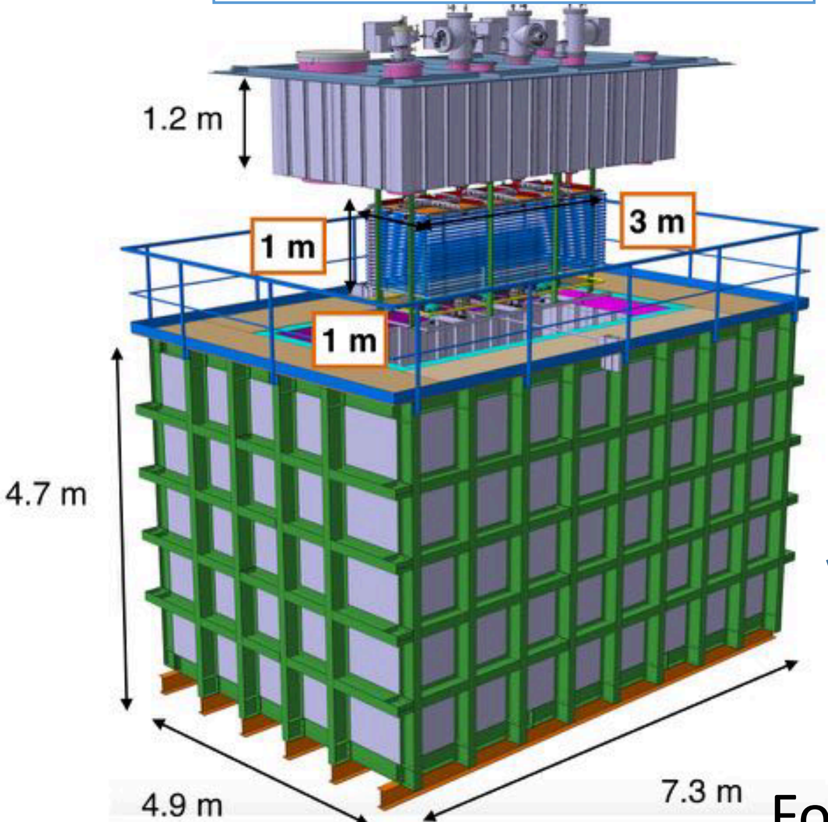


MIP signal ~120 ADC in ch4
(noise ~11 ADC in RMS)
These value are as expected

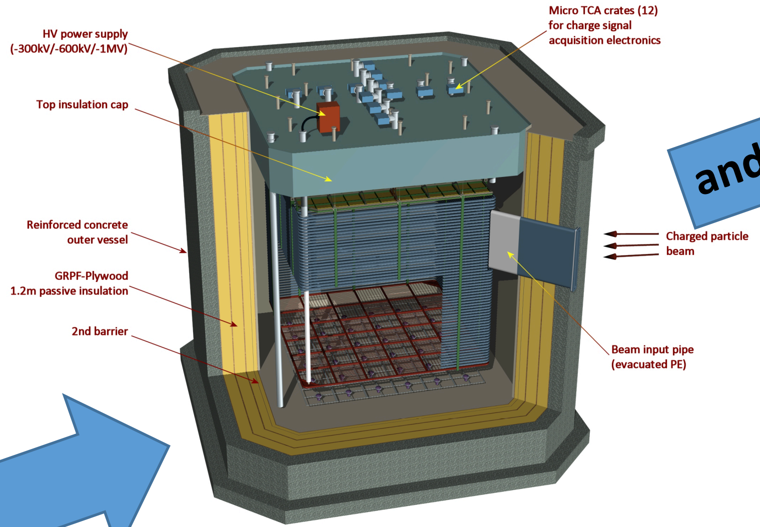
→ **S/N > 10**

Steps for larger detector

3 m × 1 m × 1 m
WA105 pilot detector



6 m × 6 m × 6 m
WA105 (dual-phase DUNE) detector



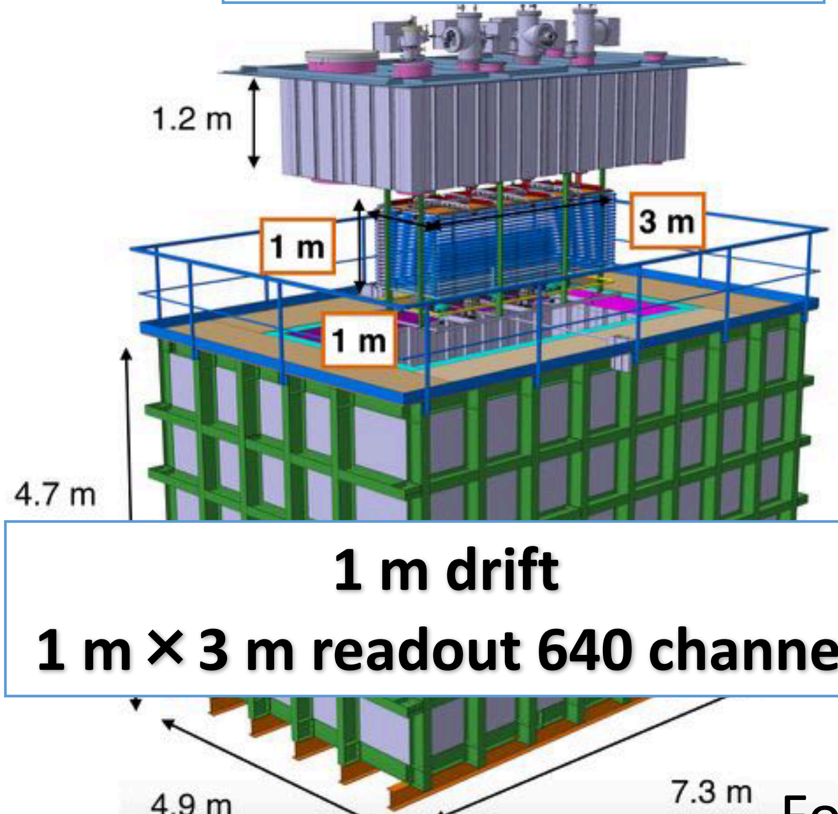
and more …

Components of technology development are closely linked.

For implementation to large detector, our readout system is has been developing.

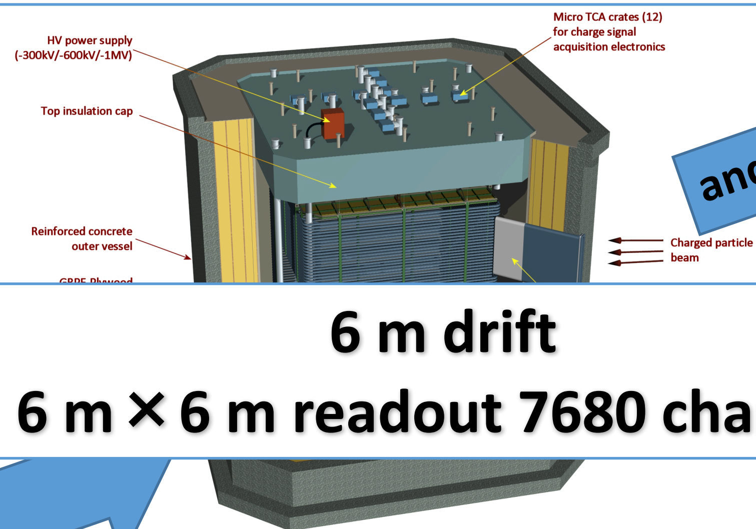
Steps for larger detector

3 m × 1 m × 1 m
WA105 pilot detector



1 m drift
1 m × 3 m readout 640 channel

6 m × 6 m × 6 m
WA105 (dual-phase DUNE) detector



6 m drift
6 m × 6 m readout 7680 channel

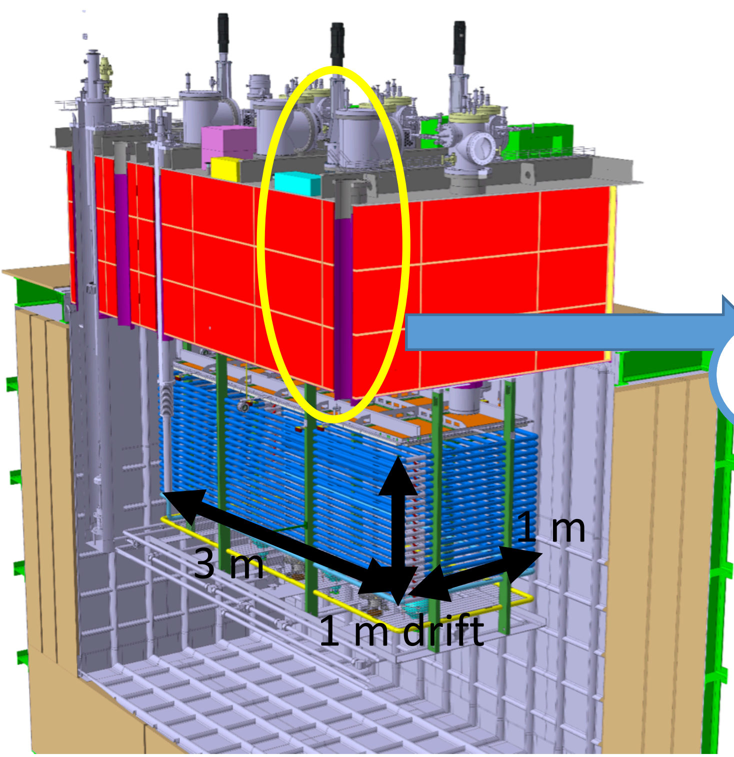
and more …

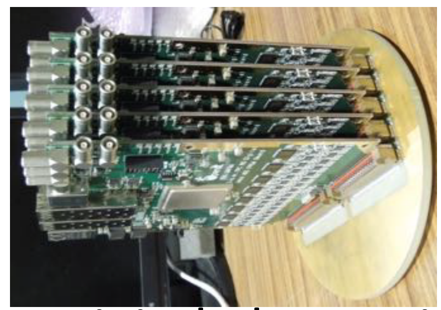
Components of technology development are closely linked.

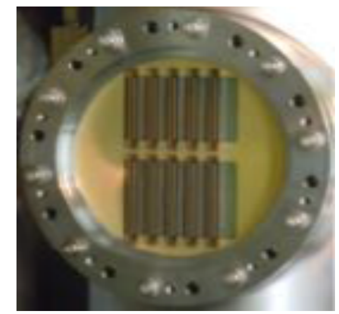
For implementation to large detector, our readout system is has been developing.

3 × 1 × 1 readout configuration

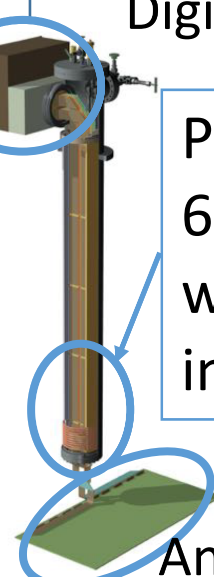
- Readout test @ 3 × 1 × 1 detector







Digital electronics



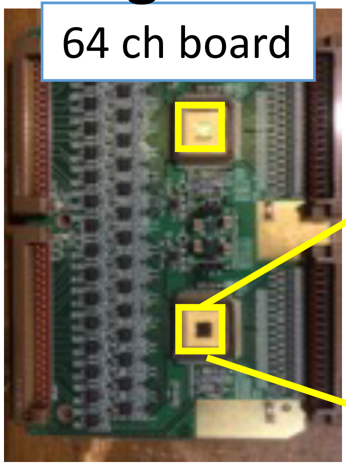
Pre-amplifier is configured
640 ch (10 boards)
which are connected to vessel
in chimney in cold at ~ -160 C˚.

Anode pad

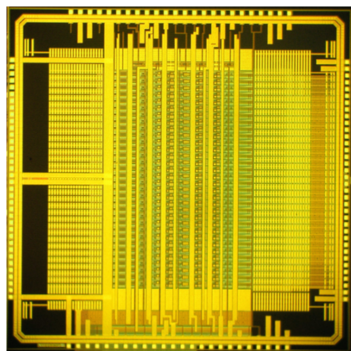
Analog boards required cold operation.

Development new analog board

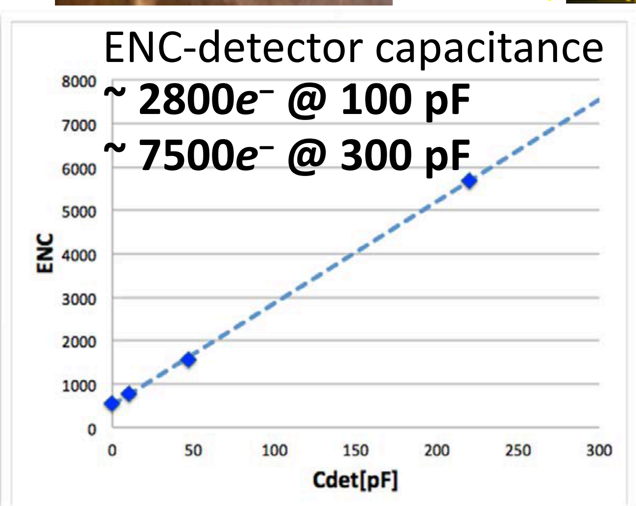
Assuming 3 × 1 × 1 configuration,
analog board must be highly integrated and low consumption.

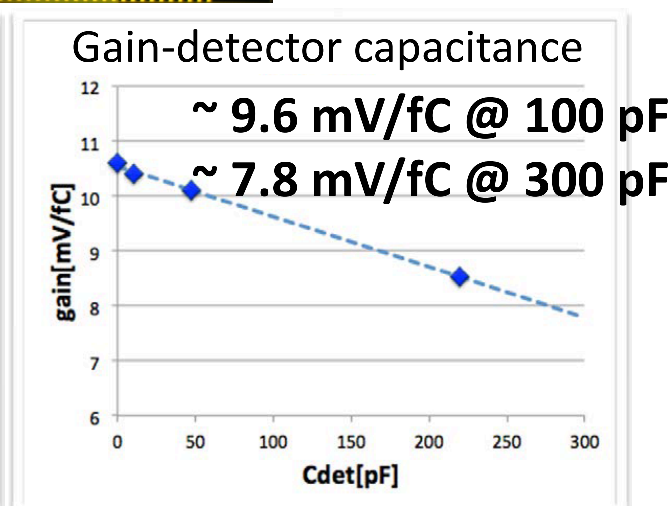


LTARS2014



32 ch readout
Size 5 mm × 5 mm
Operation voltage ± 0.9 V
Consumption < 50 mW in 1 chip
for single and dual-phase detector

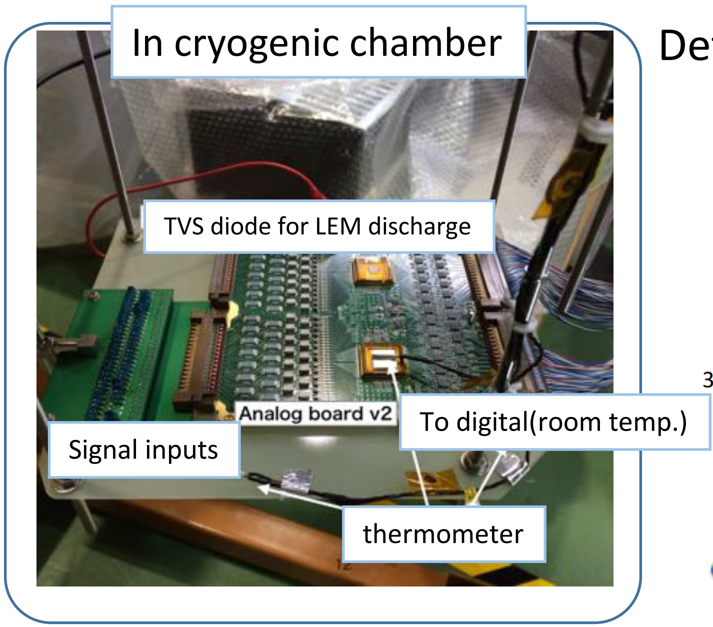


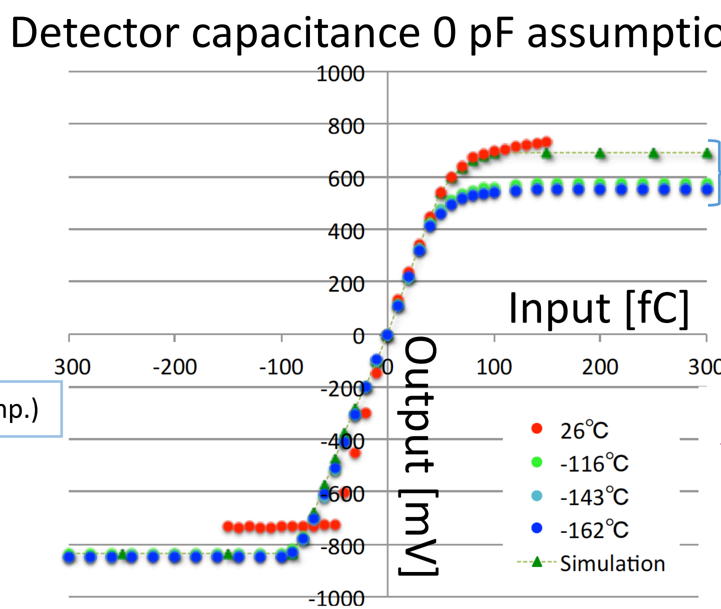


LTARS2014 performance is checked @room temperature

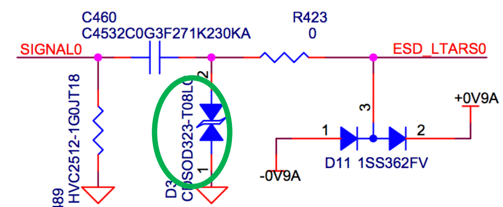
Analog electronics cold test

Assuming 3 × 1 × 1 configuration,
analog board must be cold environment at − 160 ˚C.



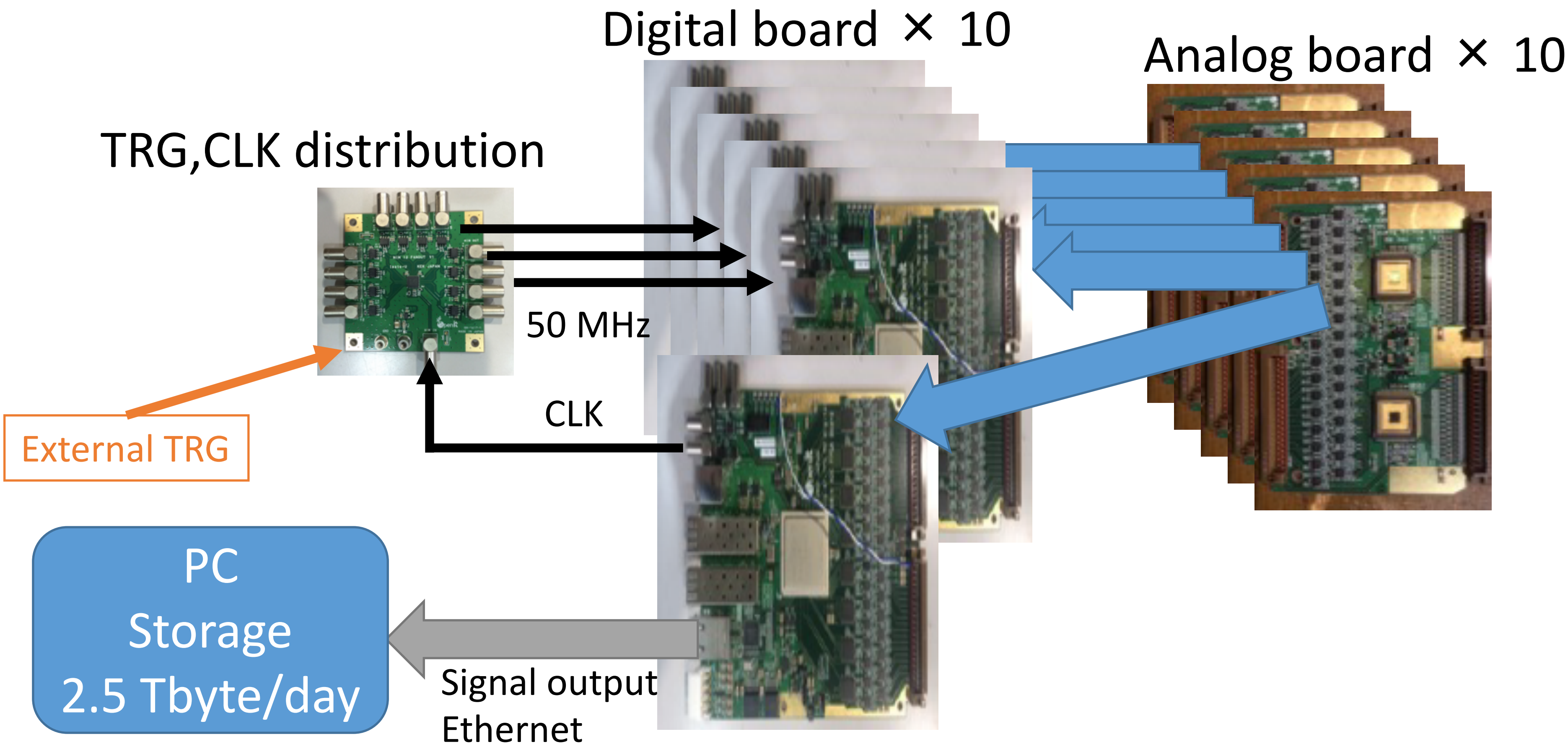


Disagreement between simulation and cold performance due to TVS leak current



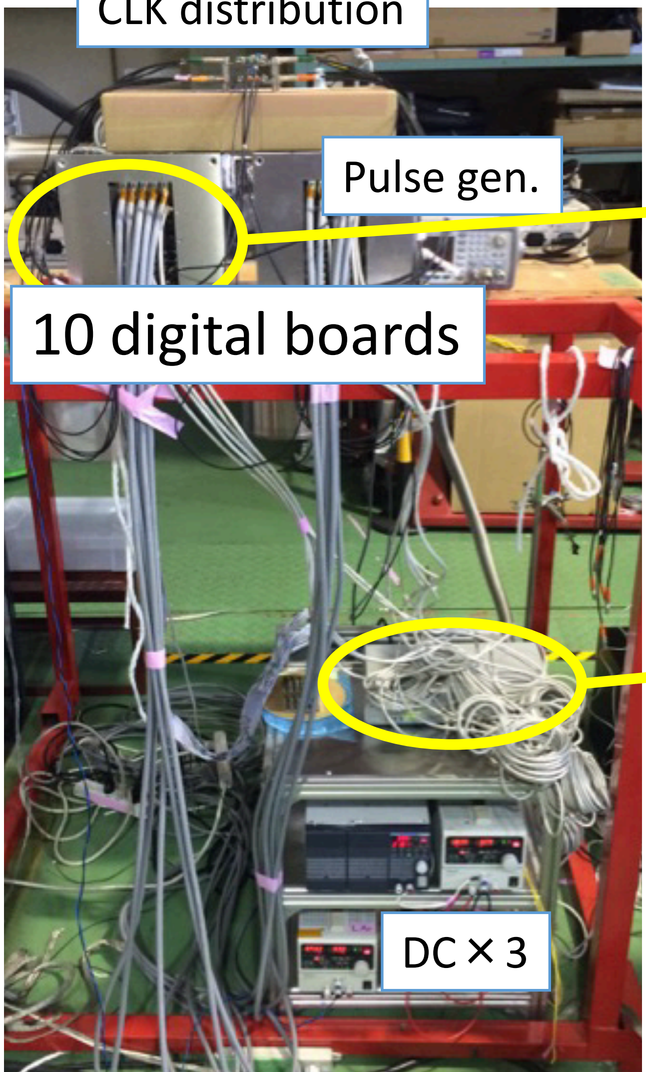
In −160 ˚C, analog board is worked.
To check LATRS2014 self and evaluate components
We have plan of cold test again.

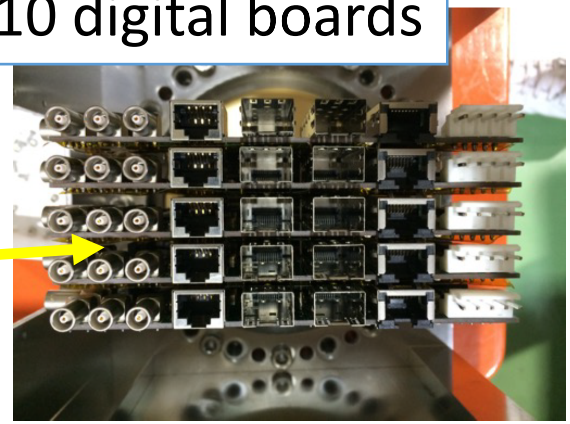
Digital boards readout



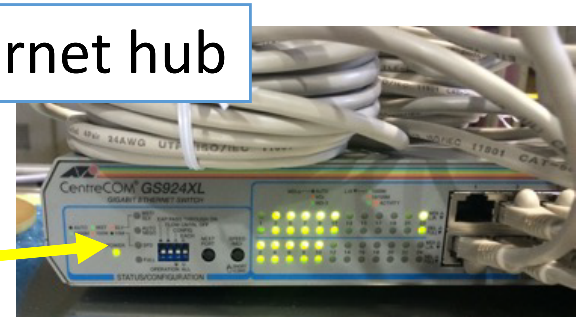
- Developed readout system is checked with equivalent configuration of 3 × 1 × 1 detector.

Readout test





Configuration is considered for 3 × 1 × 1 detector



To check further,
now 10 boards readout test
is in progress.

Summary

- For realization of a large LAr TPC,
  fundamental technologies R&D are in progress.

- LTARS performance is checked using small TPC.
- LTARS2014 is developed for large detector.
- LTARS2014 cold test
  - Temperature characteristics are measured.
    and test is planed to check further.
- Readout test equivalent 3 m × 1 m × 1 m detector 640 ch
  - 10 boards readout is in progress.

Backup

Liquid argon medium

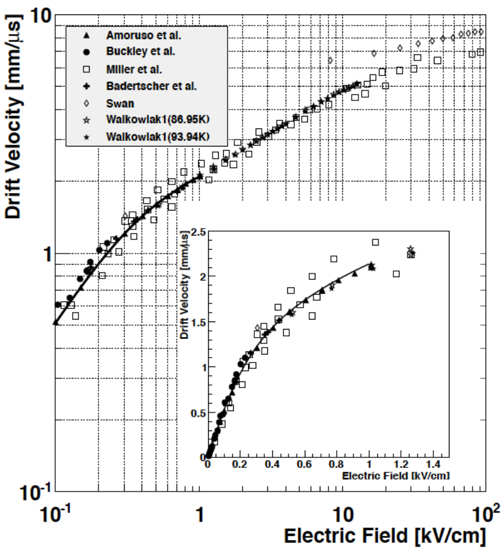


FIG. 19: Drift velocity in liquid argon for fields up to 100 kV/cm. The general plot (data collected from [47, 49–53]) is in log-scale to give a good overview, while the zoom-in, in the interesting region of the electric field for ArDM, is in linear scale. The solid line is a 5^{th} order polynomial proposed by [49]. It is fitted between 0 and 2 kV/cm and includes all the presented data. All data are corrected according to Equation (3.3) to a common temperature of 87 K.

Drift fields E=0.5,0.75,1,1.25,1.5 kV/cm

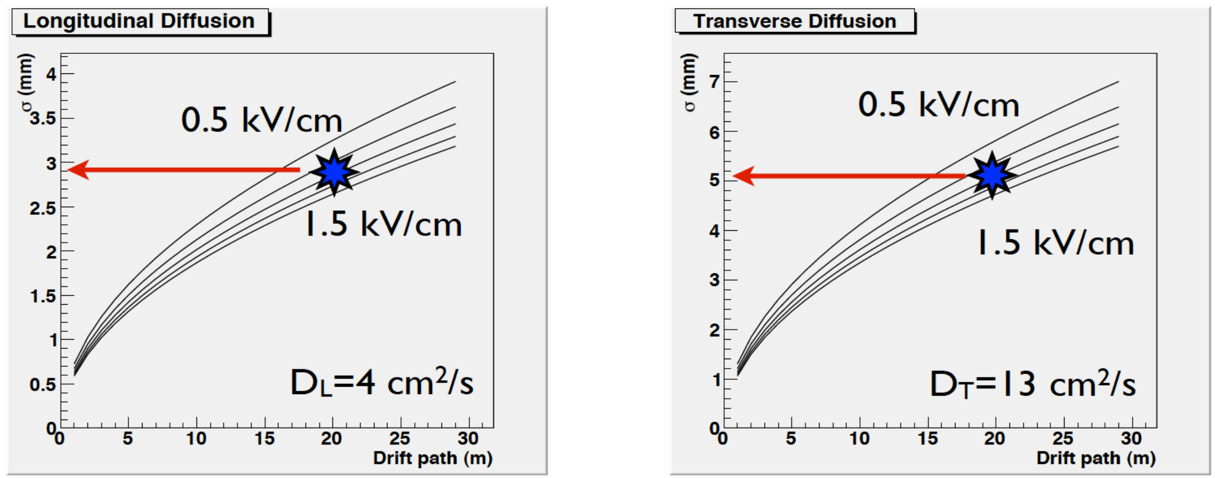
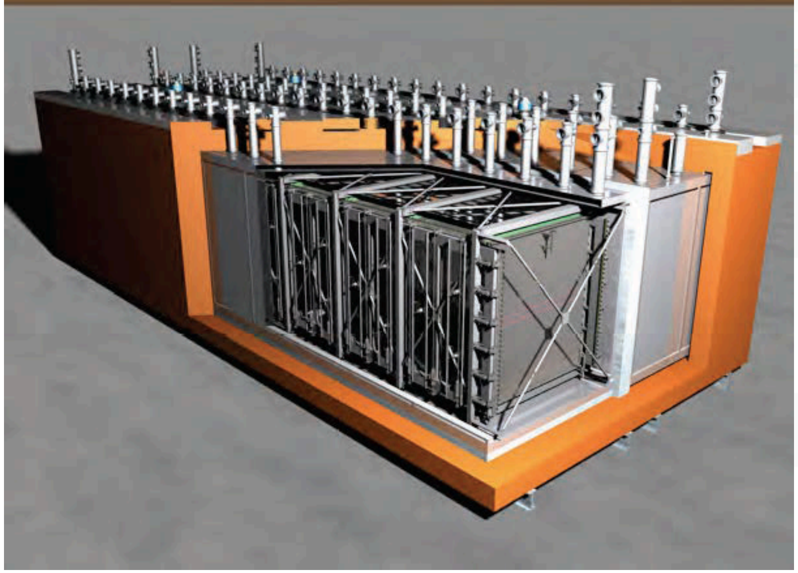
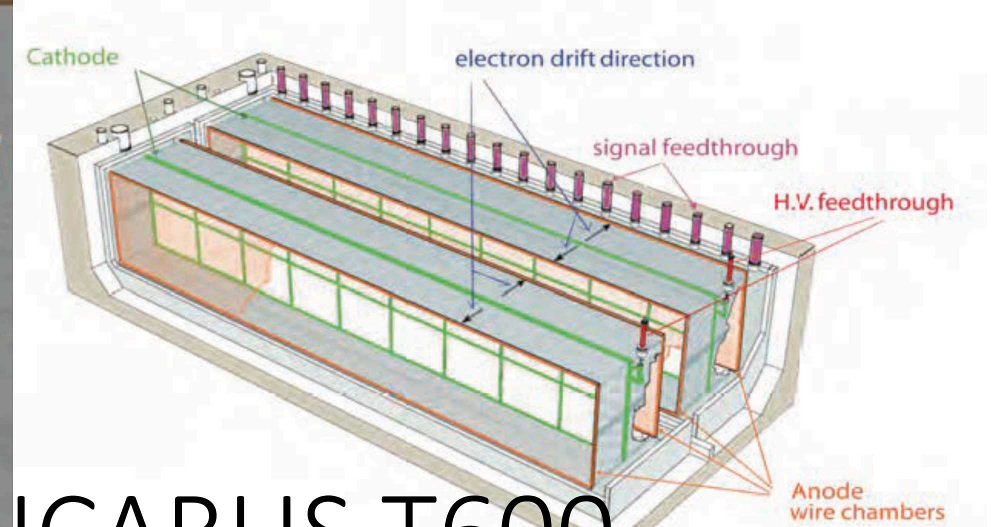


FIG. 21: Expected longitudinal and transversal diffusion in liquid argon as a function of the drift distance, for various drift fields.

	Water	He	Ne	Ar	Kr	Xe
Boiling Point [K] @ 1atm	373	4.2	27.1	87.3	120.0	165.0
Density [g/cm³]	1	0.125	1.2	1.4	2.4	3.0
Radiation Length [cm]	36.1	755.2	24.0	14.0	4.9	2.8
Scintillation [γ /MeV]	-	19,000	30,000	40,000	25,000	42,000
dE/dx [MeV/cm]	1.9		1.4	2.1	3.0	3.8
Scintillation λ [nm]		80	78	128	150	175





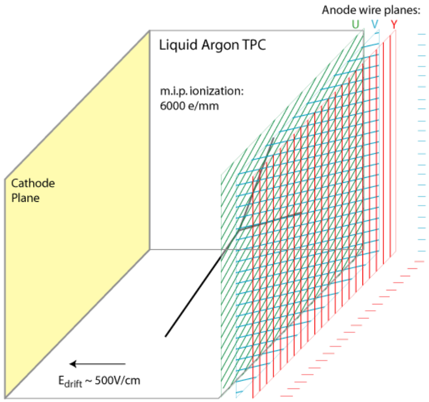
ICARUS T600

The ICARUS T600 detector is made of a large cryostat split into two identical, adjacent modules with internal dimensions $3.6 \times 3.9 \times 19.6$ m^3 filled with about 760 t of ultra-pure liquid Argon. Such units may be operated together as a unique detector.

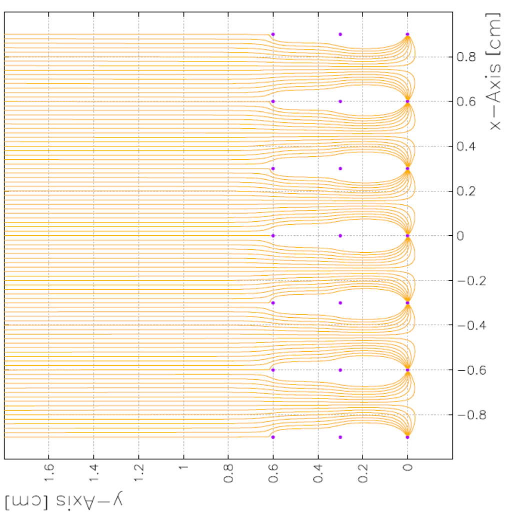
Each module houses two TPCs separated by a common central cathode. A uniform electric field (500 V/cm) is applied to the drift volume. Each TPC is made of three parallel wire planes, 3 mm apart, with 3 mm pitch, facing the drift path (1.5 m). Globally, 53248 wires with length up to 9 m are installed in the detector. By appropriate voltage biasing, the first two signal sensing planes (Induction-1, and -2) provide induced signals in a non-destructive way, whereas the last Collection plane finally collects the ionization charge. The reliable operation of the high-voltage system has been extensively tested up in the ICARUST600 up to about twice the operating voltage (150 kV, corresponding to 1 kV/cm).

On each chamber, the wire planes are oriented at 0˚, ±60˚ angles with respect to the horizontal direction. Therefore a three-dimensional image of the ionizing event is reconstructed combining the wire coordinate on each plane at a given drift time. A remarkable resolution of about 1 mm3 is uniformly achieved over the whole active volume (~340 m^3 corresponding to 476 t).

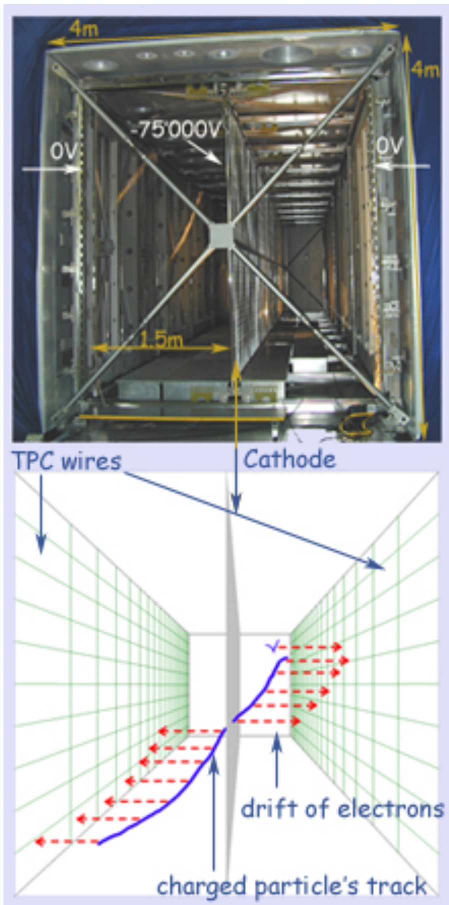
ICARUS



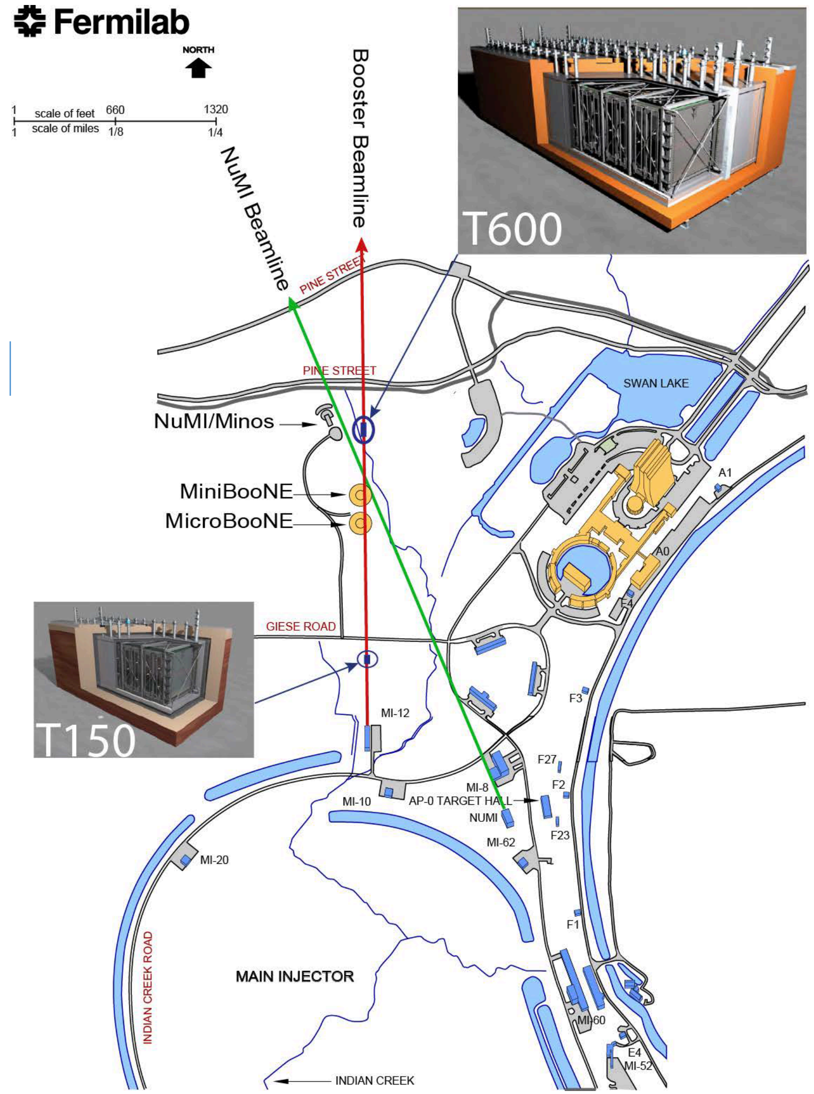
Anode wire planes:
U V Y
Liquid Argon TPC
m.i.p. ionization:
6000 e/mm
Cathode
Plane
E drift ~ 500V/cm



x−Axis [cm]
y−Axis [cm]

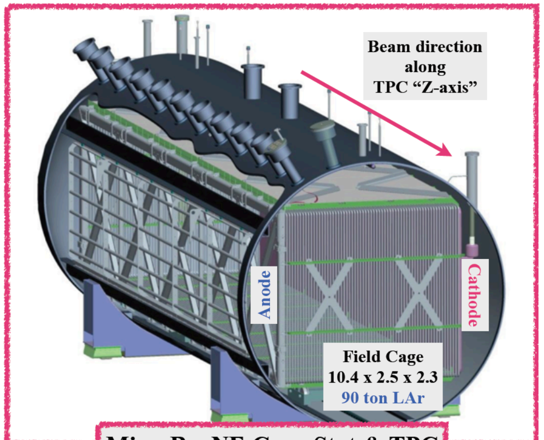


4m
4m
-75000V
0V
0V
1.5m
TPC wires
Cathode
drift of electrons
charged particle's track

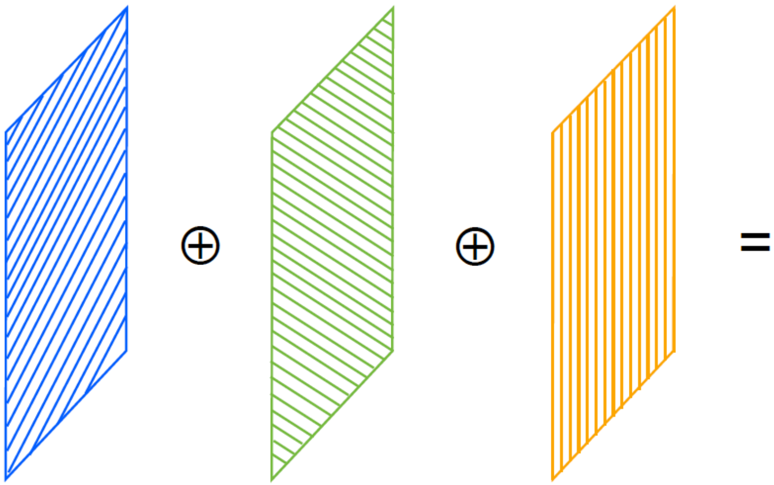


Fermilab
NORTH
scale of feet 660 1320
scale of miles 1/8 1/4
NuMI Beamline
Booster Beamline
T600
T150
PINE STREET
PINE STREET
SWAN LAKE
NuMI/Minos
MiniBooNE
MicroBooNE
GIESE ROAD
MI-12
MI-10
AP-0 TARGET HALL
NUMI
MI-62
MI-20
MAIN INJECTOR
INDIAN CREEK ROAD
INDIAN CREEK

MicroBooNE



MicroBooNE Cryo-Stat & TPC

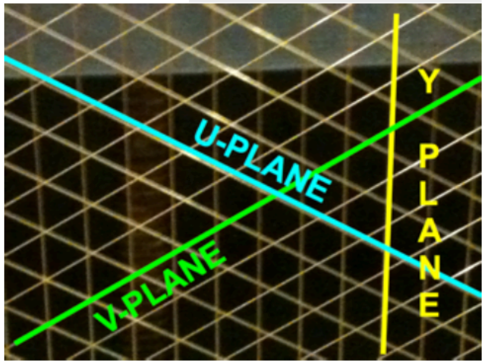


U plane
(induction)

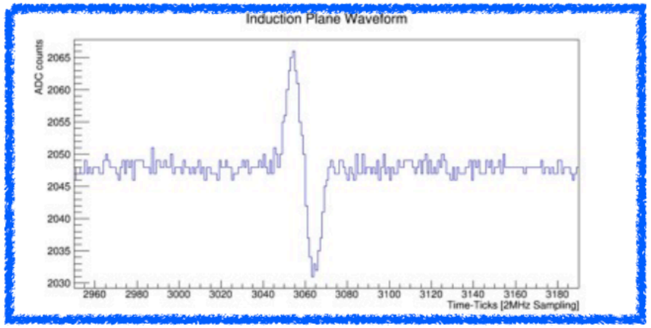
V plane
(induction)

Y plane
(collection)

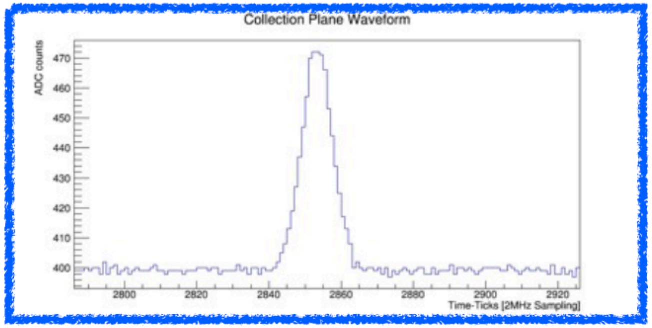
Picture courtesy of J. Asaadi



8256 wires w/ pitch = 3mm
(Y, Z) = coincidence on wire



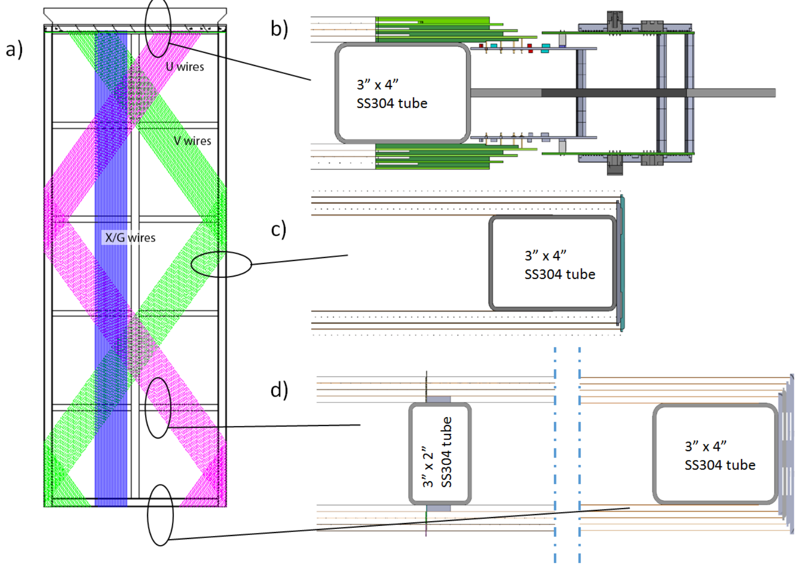
Induction Plane MC Waveform
(Bi-polar pulse as e⁻ pass through)

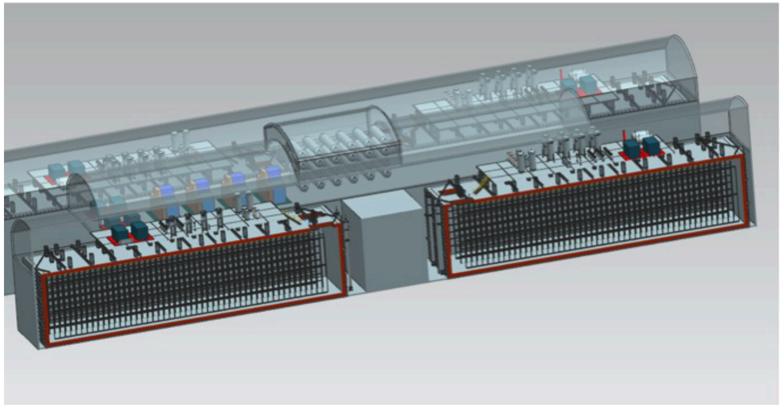


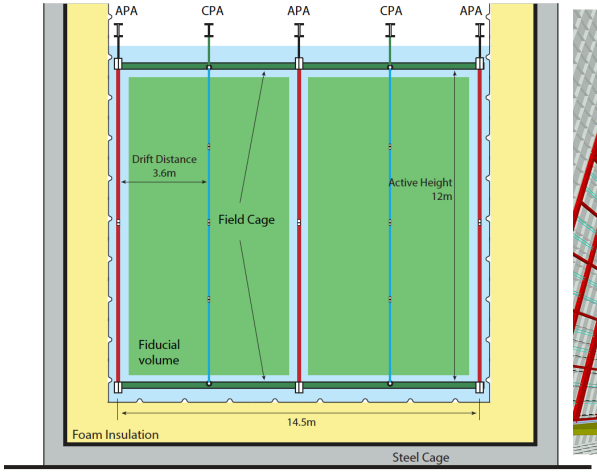
Collection Plane MC Waveform
(Uni-polar pulse as e⁻ pass through)

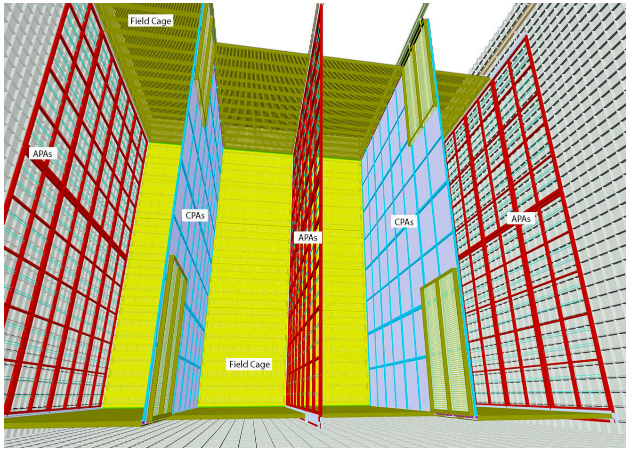
10 kt DUNE far detector

Deep Underground Neutrino Experiment

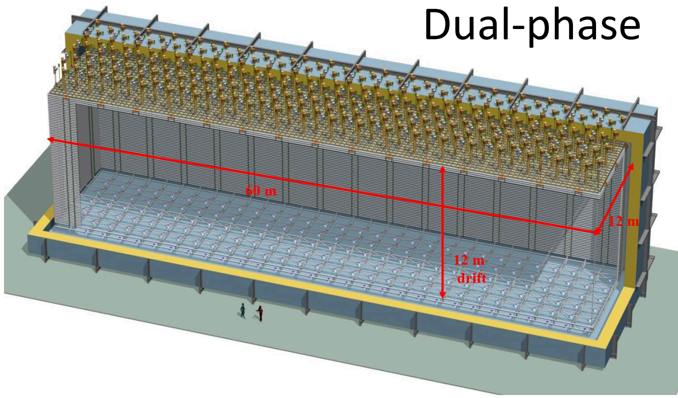








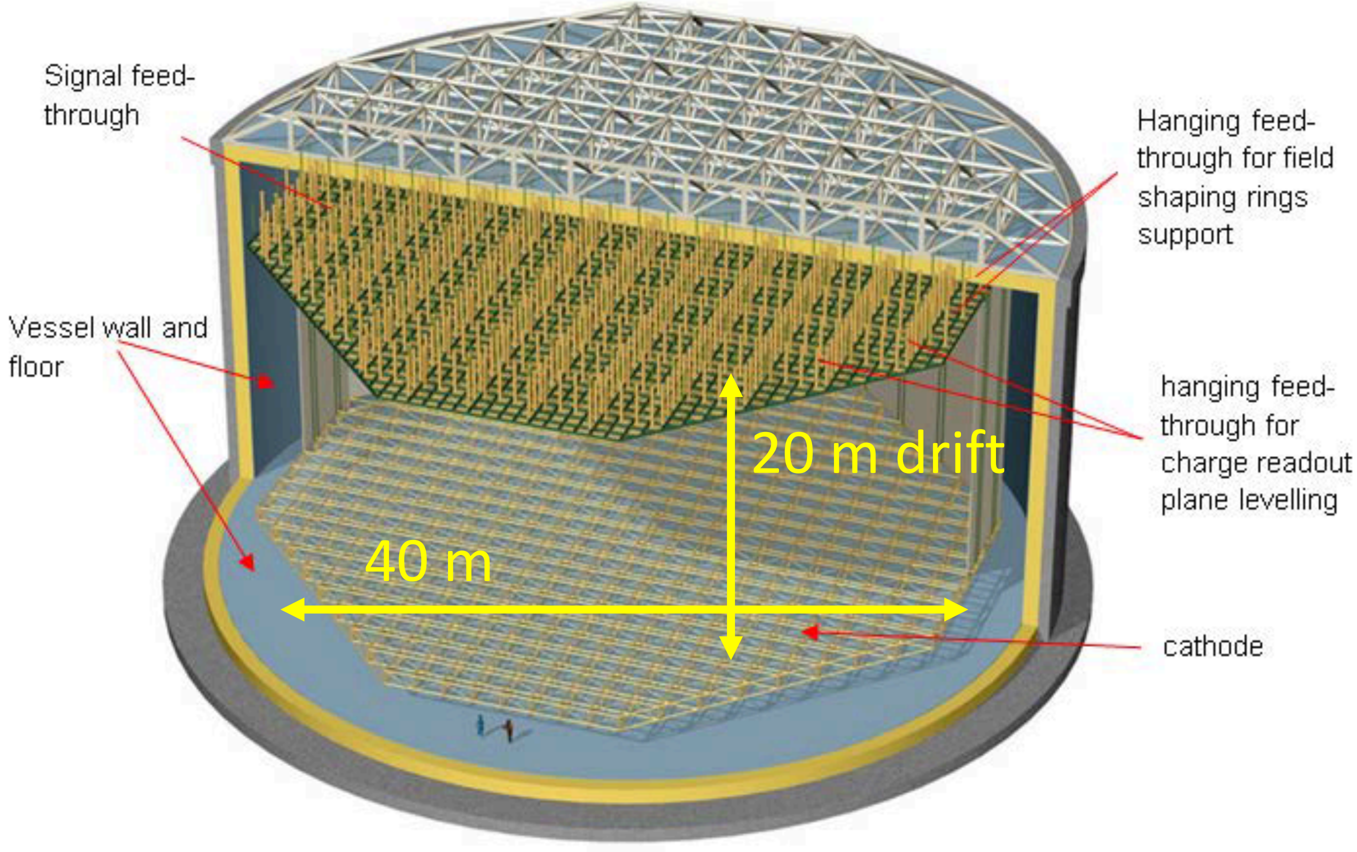
Dual-phase



Design is being developed to accommodate both single-and dual-phase detectors

LAGUNA-LBNO 50 kt detector

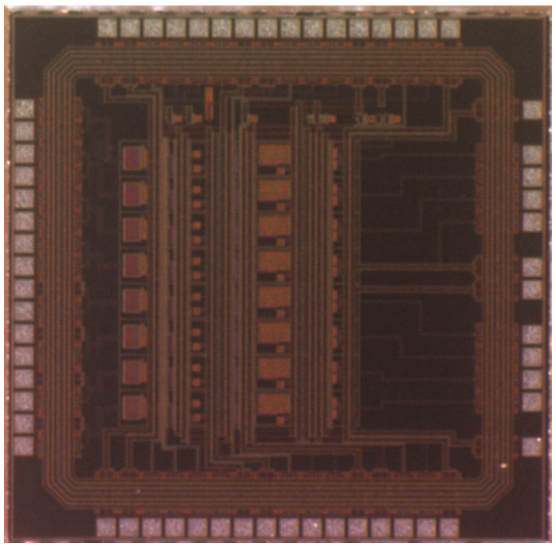
Large Apparatus studying Grand Unification and Neutrino Astrophysics for Long Baseline Neutrino Oscillation



LTARS vs LTARS2014

Low Temperature Analog Readout

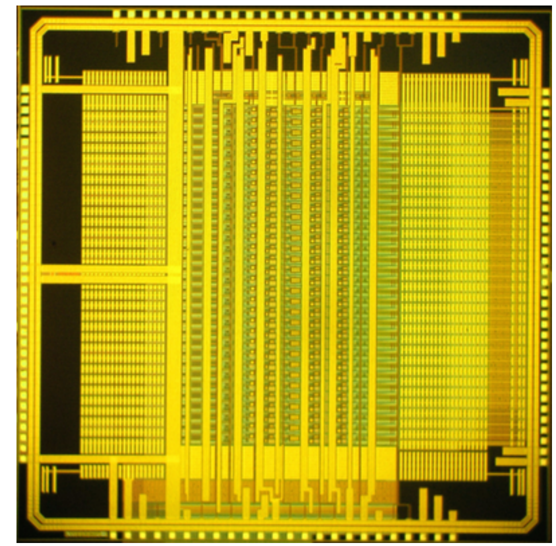
LTARS



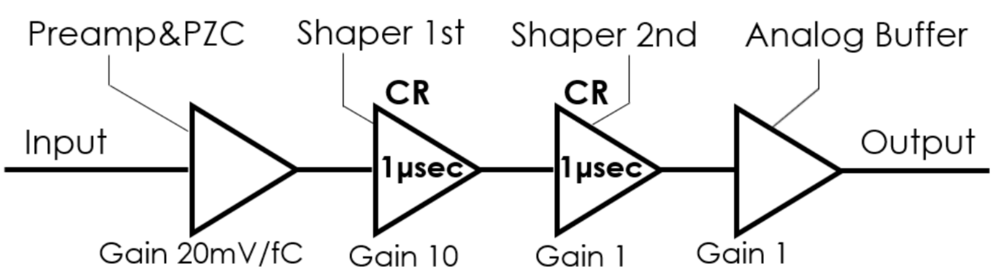
2.8 × 2.8 mm^2

LTARS		LTARS2014
8ch	# of channel	32 ch
~100 pF	acceptable $C_{det.}$	~300 pF
±2.5 V	operation voltage	±0.9 V

LTARS2014



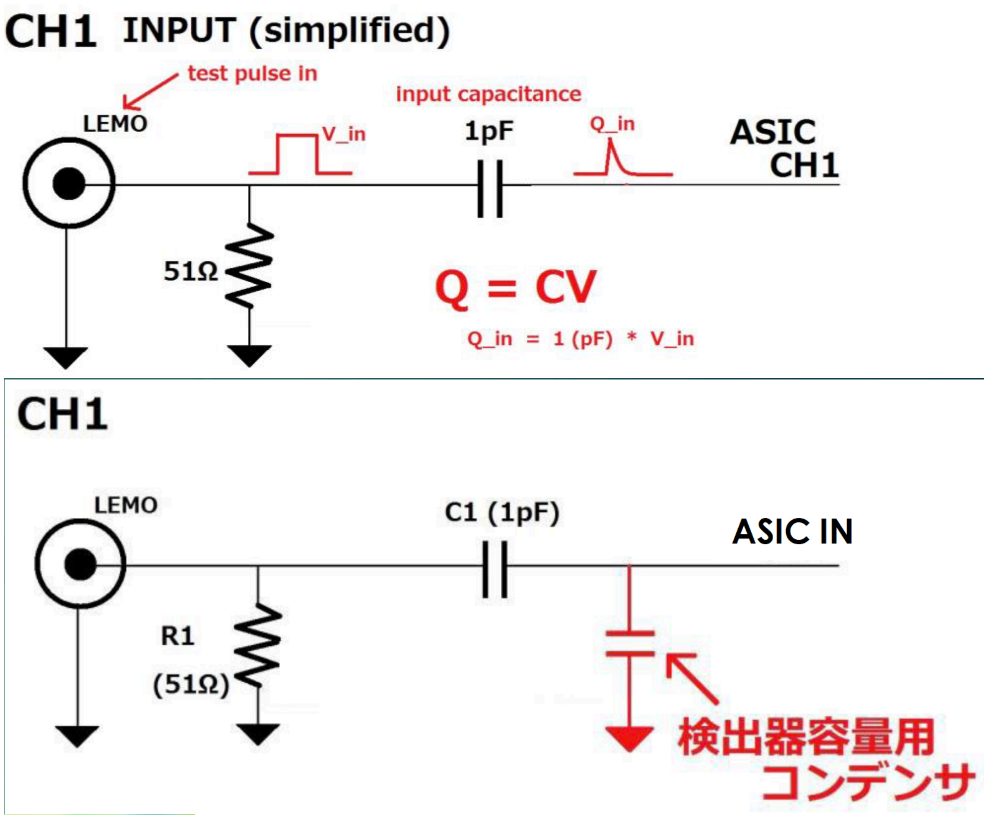
5 × 5 mm^2

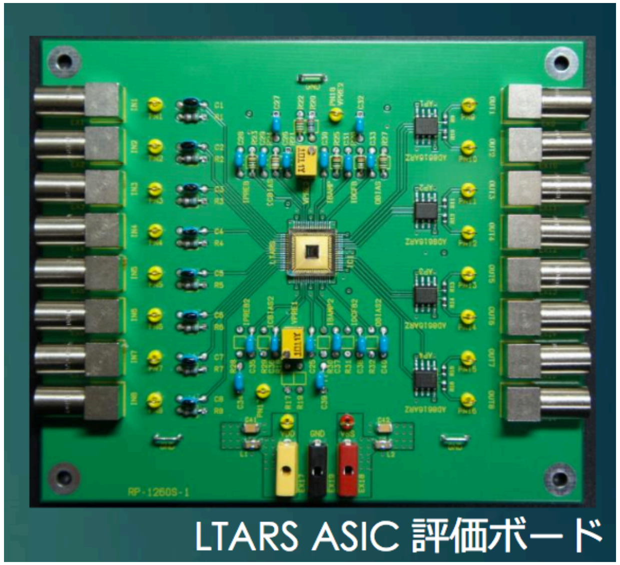


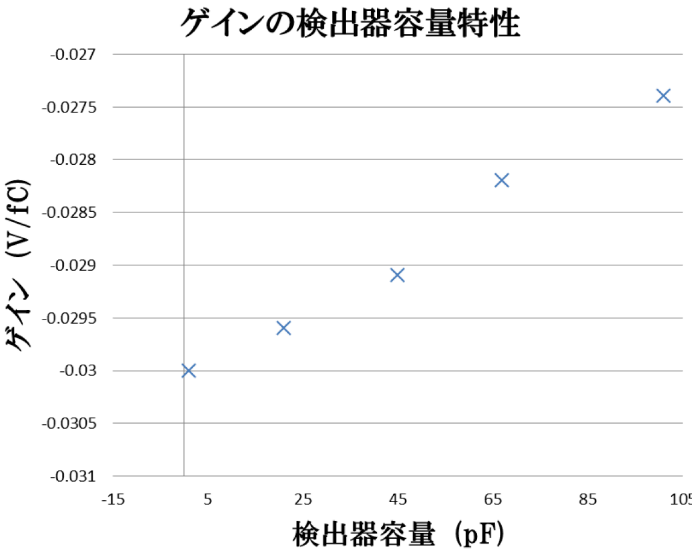
Low consumption < 50 mW/32 ch

For single and dual phase

Gain-detector capacitance

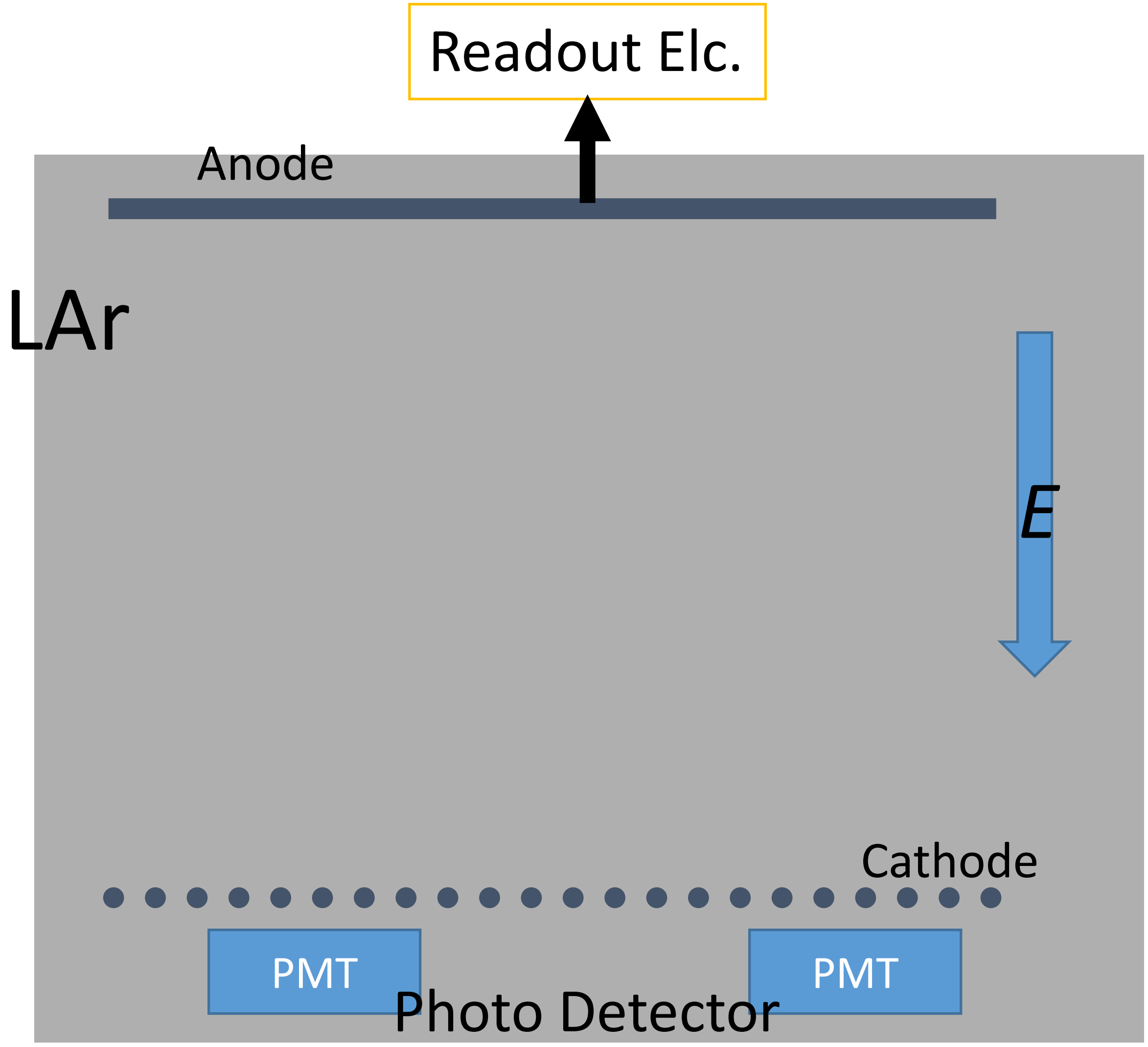




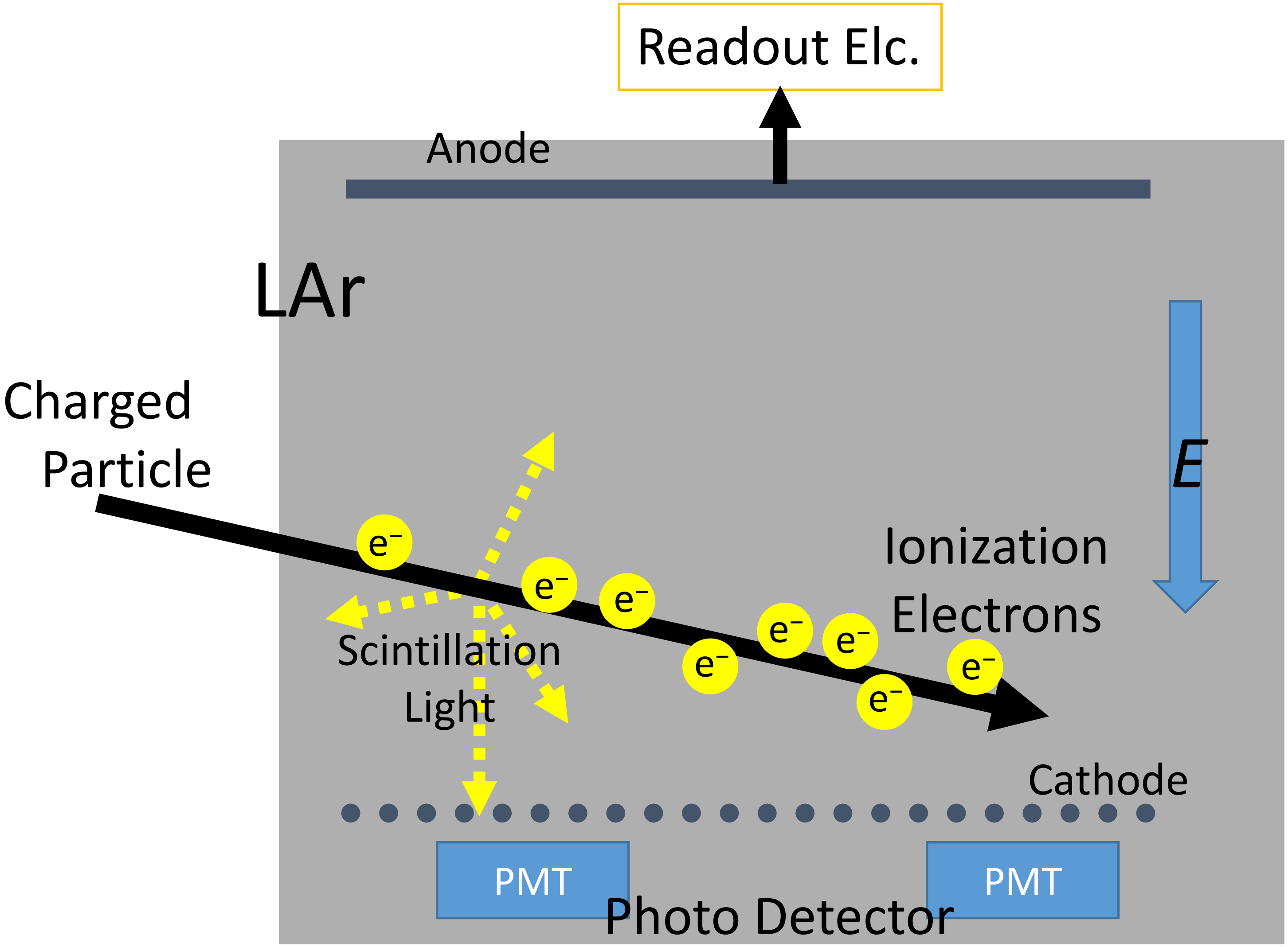


ASIC設計段階で初段トランジスタの
ドレイン電流を絞っているため、
大きな負荷容量に対しゲインが落ちる。

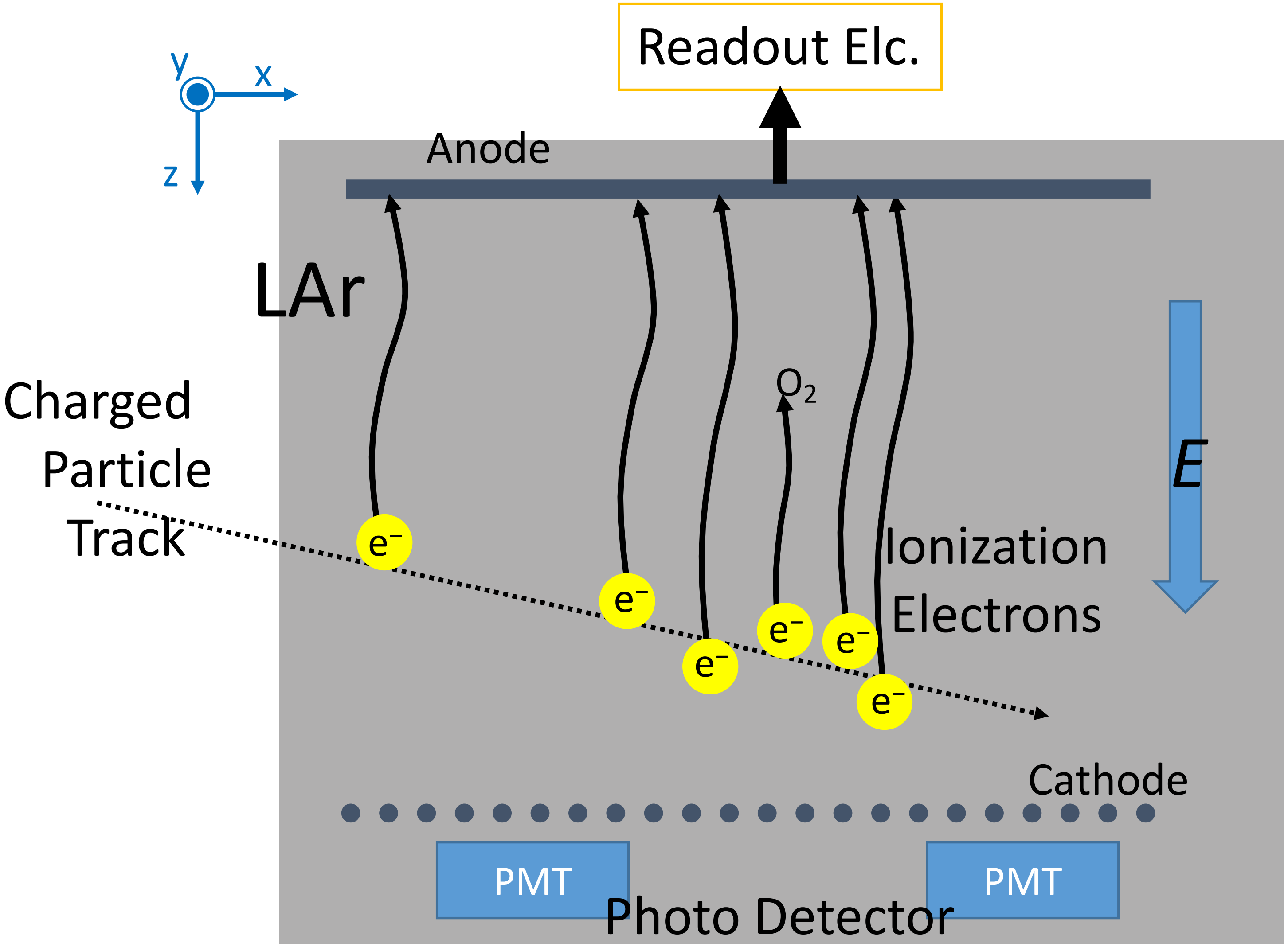
LAr TPC working principal (1)



LAr TPC working principal (2)



LAr TPC working principal (3)



Plan for large LAr TPC

$3 \times 1 \times 1$ m^3, WA105 pilot detector

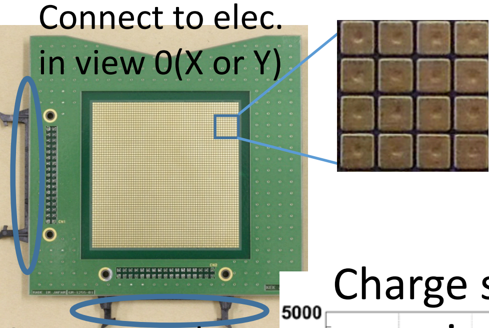
- Cosmic run until Spring 2017.

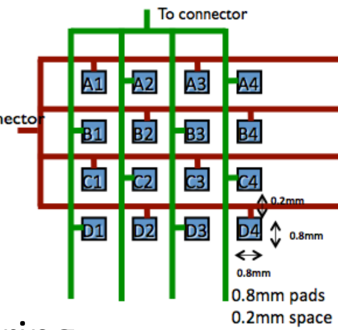
$6 \times 6 \times 6$ m^3, WA105 detector

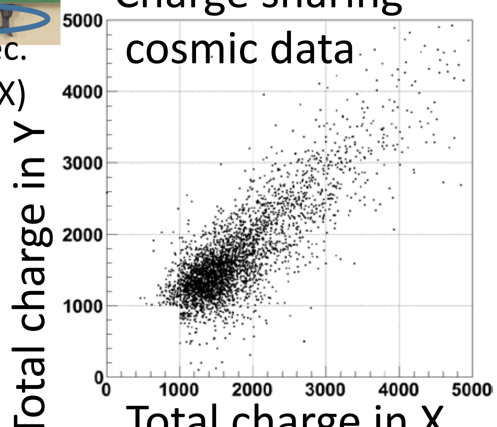
- Cryostat is been constructing.
- Spring 2017: detector installation
- Winter 2017: TCO & cryostat sealing
- Winter 2018: start cryostat operation
- Spring 2018: ready to collect beam data

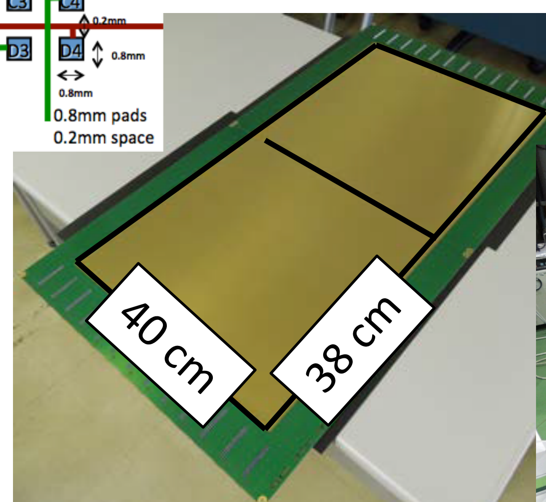
2D readout pad anode

- 4 mm pitch readout
  (small pads are connected along X or Y direction independently)
- Charge is collected by pads and shared equally in X and Y channel.
- Large readout anode pad is developed (40 cm × 38 cm), based on largest multilayer PCB in commercially product.

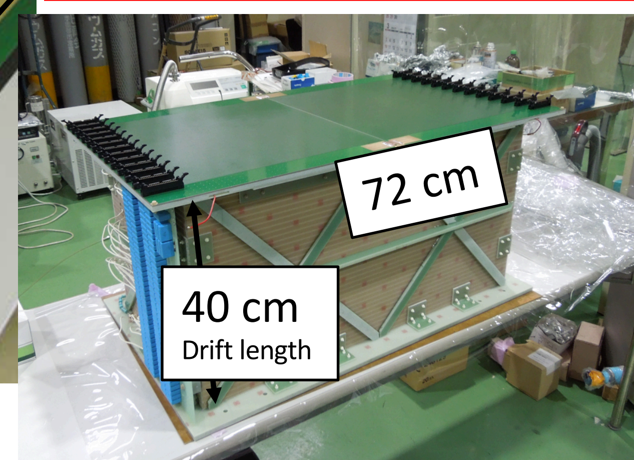






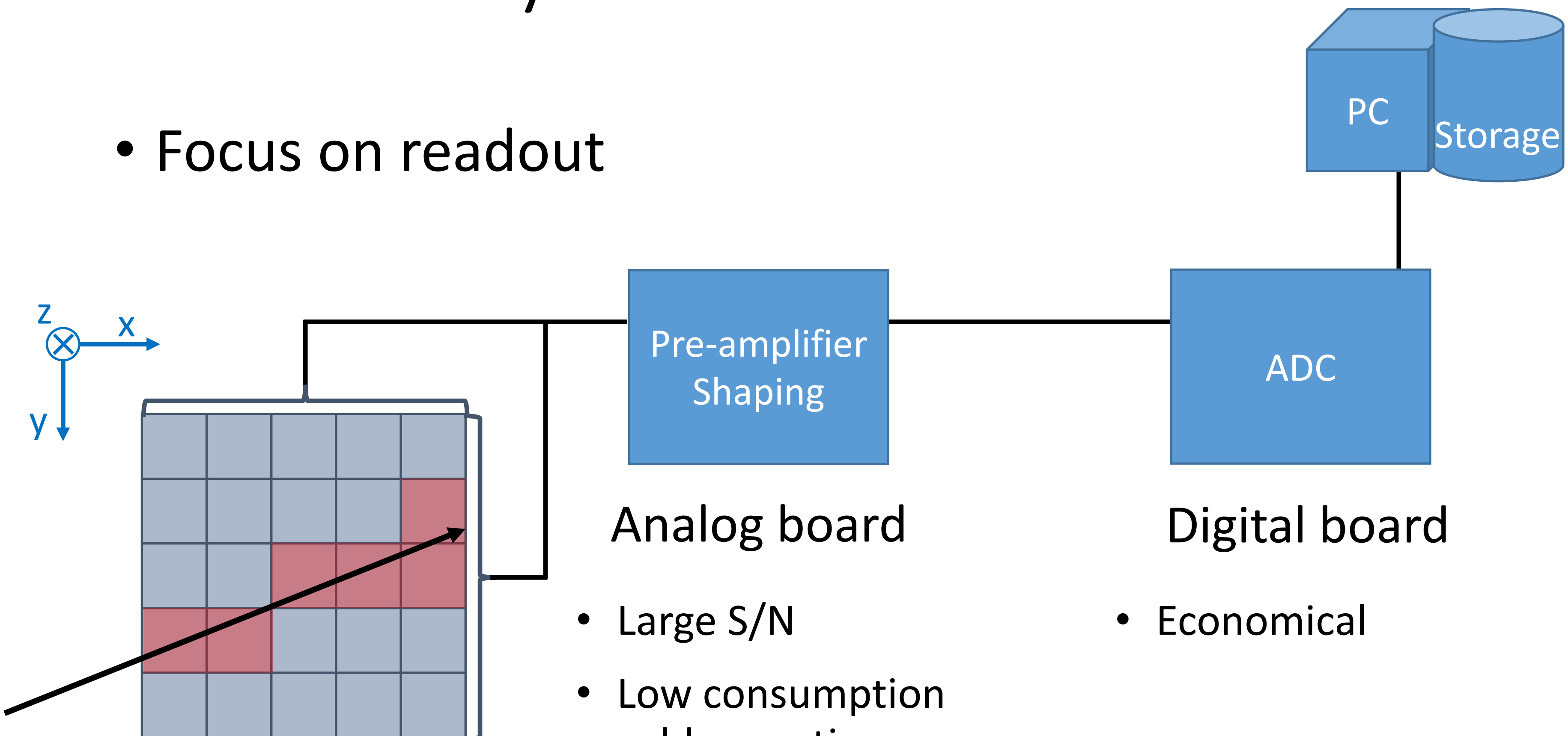


Realize large area by connecting several boards.



Readout system

- Focus on readout



Analog board

- Large S/N
- Low consumption cold operation
- Wide dynamic range
- Multi-channel economical

Digital board

- Economical

2D detector

- Large area