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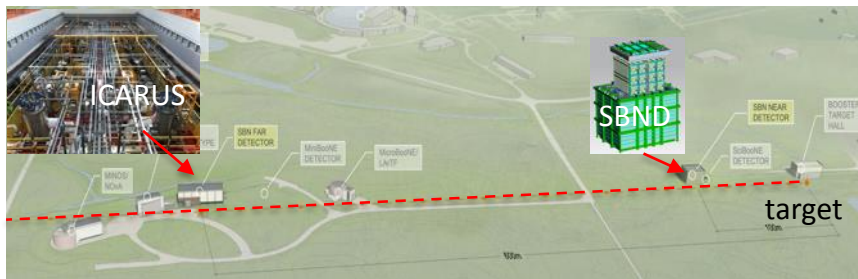
# Neutrino detectors : future short and long baseline technologies R&D requirements

Marzio Nesi, CERN

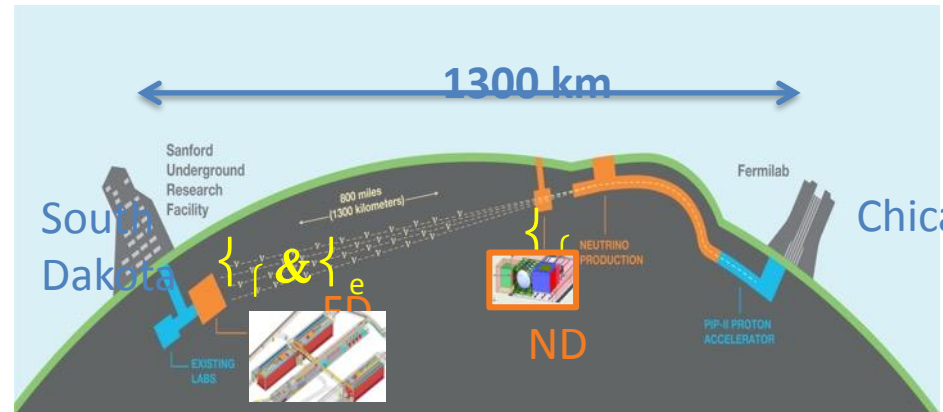
22 February 2021

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# Today's scenario ..... as far as it is known

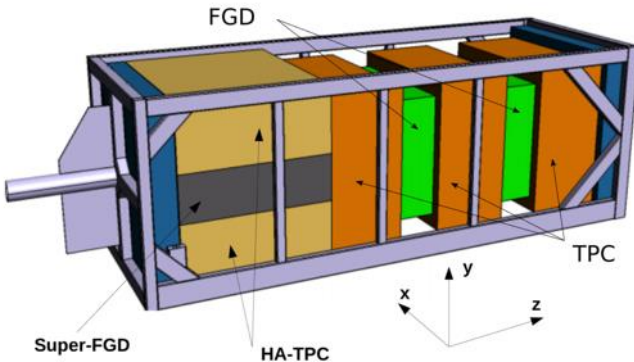


✓ US short baseline (SBN) : ICARUS, SBND



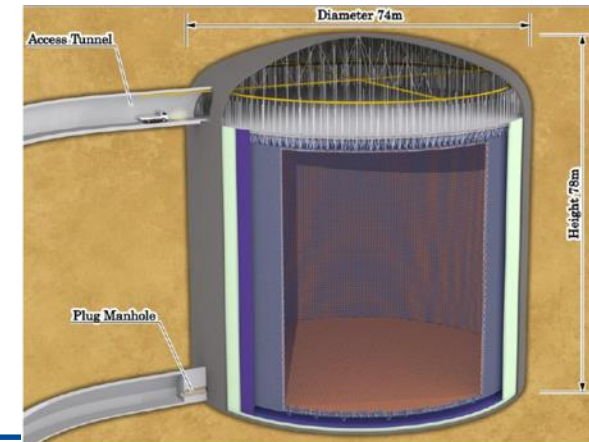
✓ US long baseline (LBNF) : DUNE

ND280

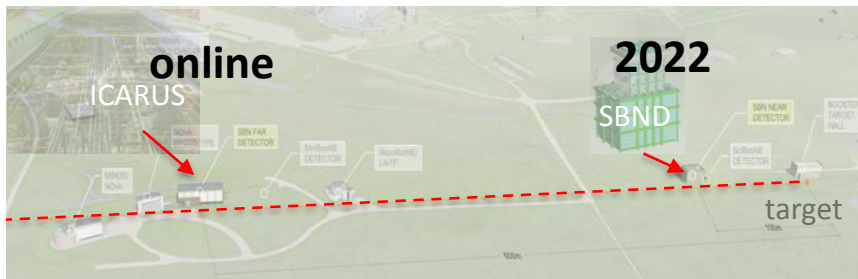


✓ Japanese long baseline (T2K) : ND280, Super-Kamiokande

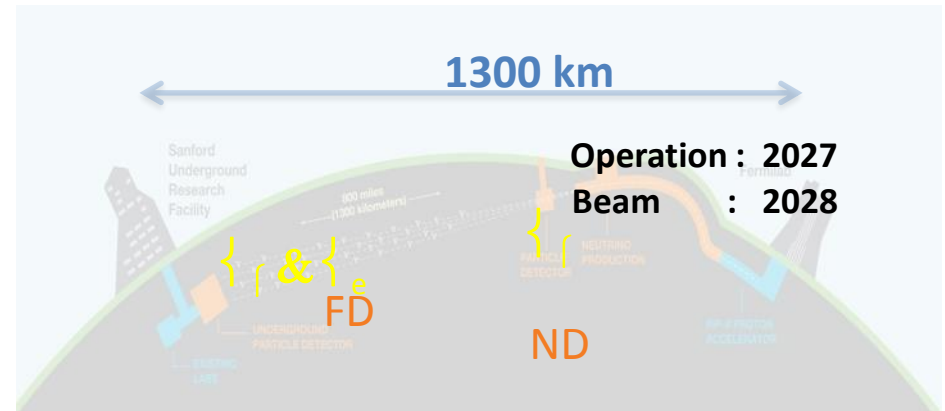
✓ Japanese long baseline: Hyper-Kamiokande



# Today's scenario ..... as far as it is known

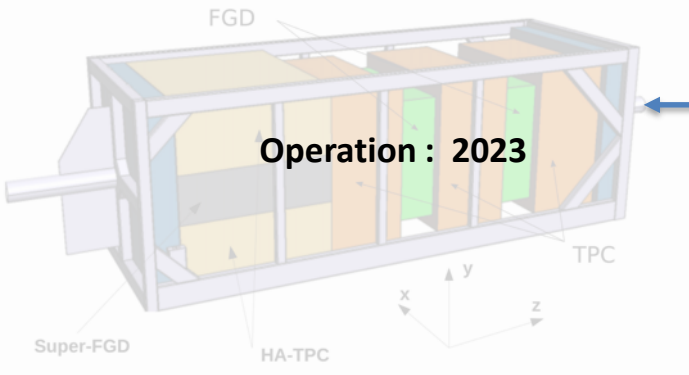


✓ US short baseline (SBN) : ICARUS, SBND



✓ US long baseline (LBNF) : DUNE

ND280



✓ Japanese long baseline (T2K) : ND280, Super-Kamiokande

✓ Japanese long baseline: Hyper-Kamiokande



# Two types of $\nu$ targets, two types of detector technologies

US  $\nu$  program

**LAr**

Japanese  $\nu$  program

**H<sub>2</sub>O**

## *Far Detectors :*

- *Oscillation physics*
- *Proton decay*
- *Astro-particle*

**Statistics**

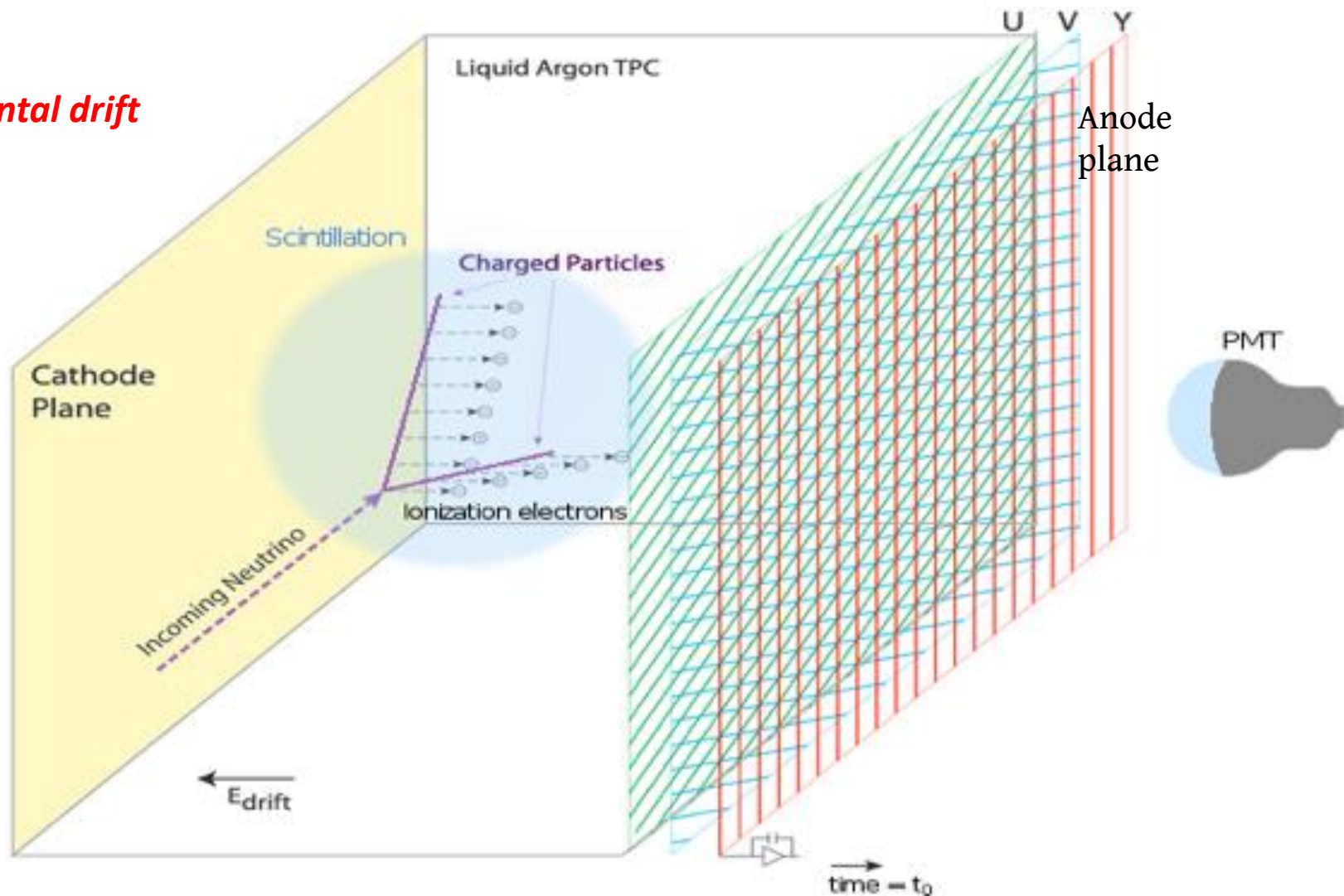
## *Near Detectors :*

- *Beam properties*  
(E, Content, ..)
- *$\nu$  cross sections*

**Systematics**

# US program based on LAr TPC technology

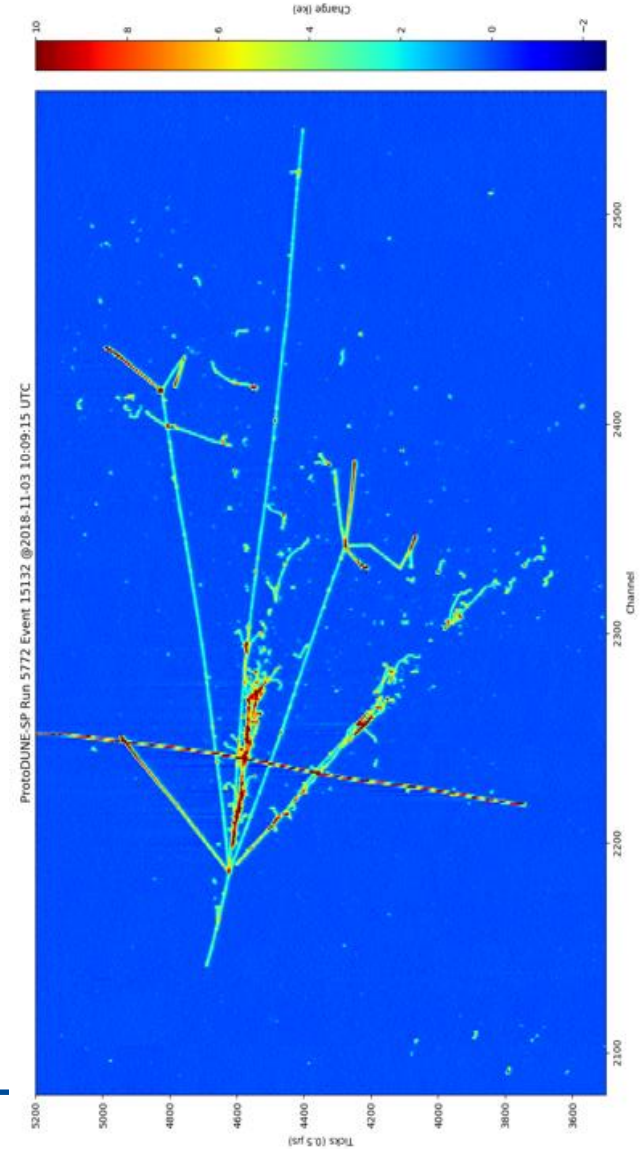
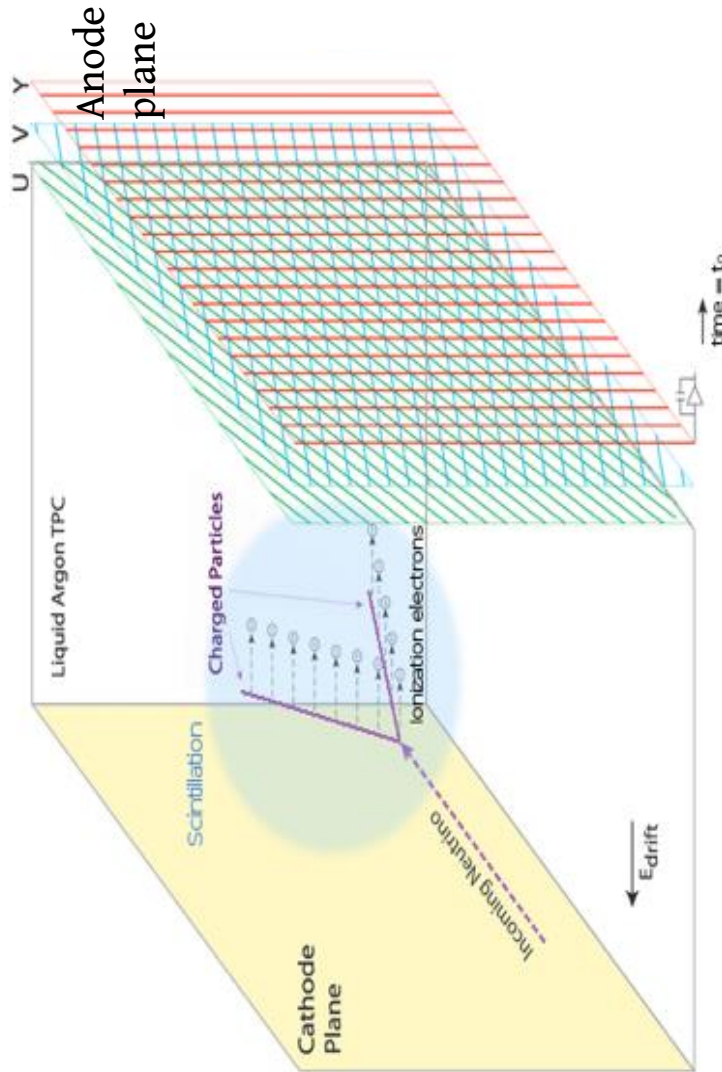
*Horizontal drift*





# US program based on LAr TPC technology

*or vertical*



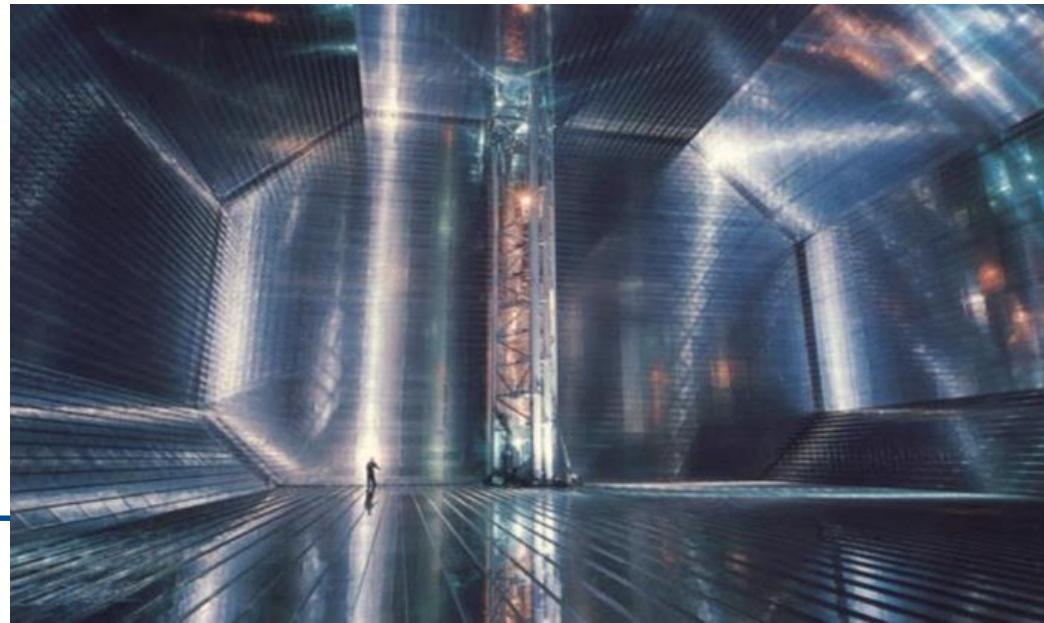
# Challenges:

- ✓ Very large volumes (up to 20ktons of cryogenic liquid / TPC)
  - ✓ Very pure LAr ( $O_2$ ,  $H_2O$  at tens of ppt level,  $e^-$  drift time > 10 ms)
  - ✓ Long living and stable cryogenics environment (1K, 15-20 y)
  - ✓ Deep underground (up to 1.5 km) locations
  - ✓ Radiopurity for low energies
- 
- ✓ *High voltage operation up to 350-600 kV ( $\sim 500V/cm$ )*
  - ✓ *Very uniform electric fields over very large volumes ( $10^{-4}$ )*
  - ✓ *Charged particle precision tracking in very large volumes (mm)*
  - ✓ *ns tracking tagging with photon detectors*
  - ✓ *Charged particles and photon calorimetry*
  - ✓ *High-efficiency particle ID capability*
  - ✓ *Measurement precision systematics at few % level*
  - ✓ *Complex 3D pattern recognition*
  - ✓ *5-10 MeV energy thresholds trigger capability*
  - ✓ *.....*

# LAr TPC : large cryostat vessels

- ✓ Cold cryostat volume  $\sim 13'000 \text{ m}^3$ , an industrial type of building
- ✓ Liquid argon  $\sim 18 \text{ ktons}$  / cryostat
- ✓ Passive insulation to minimize long-term operation risks (no vacuum insulation)
- ✓ Location : deep underground with limited elevator access : very modular assembly, minimal welding, ...

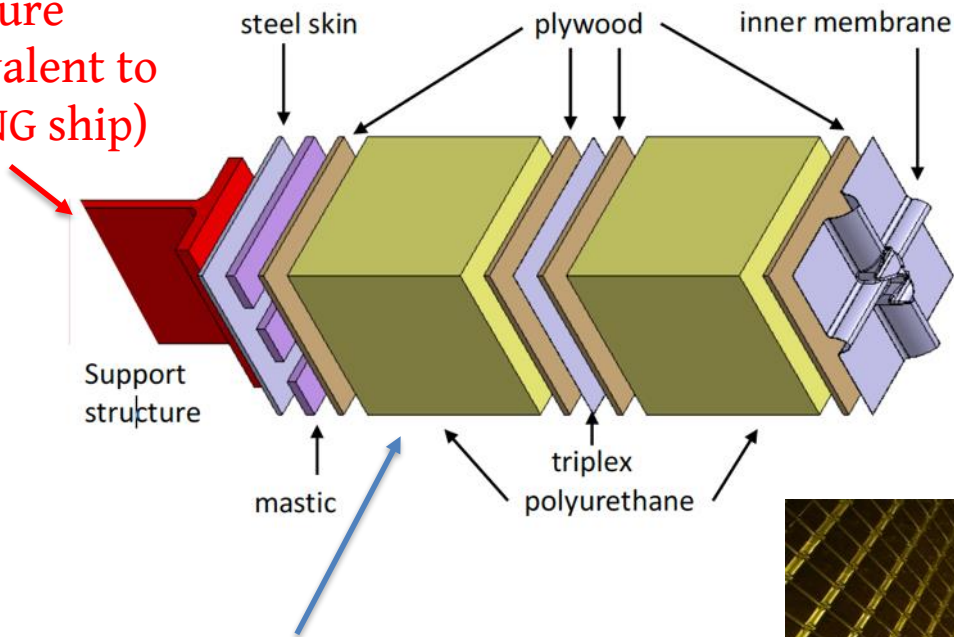
***LNG technology adopted***





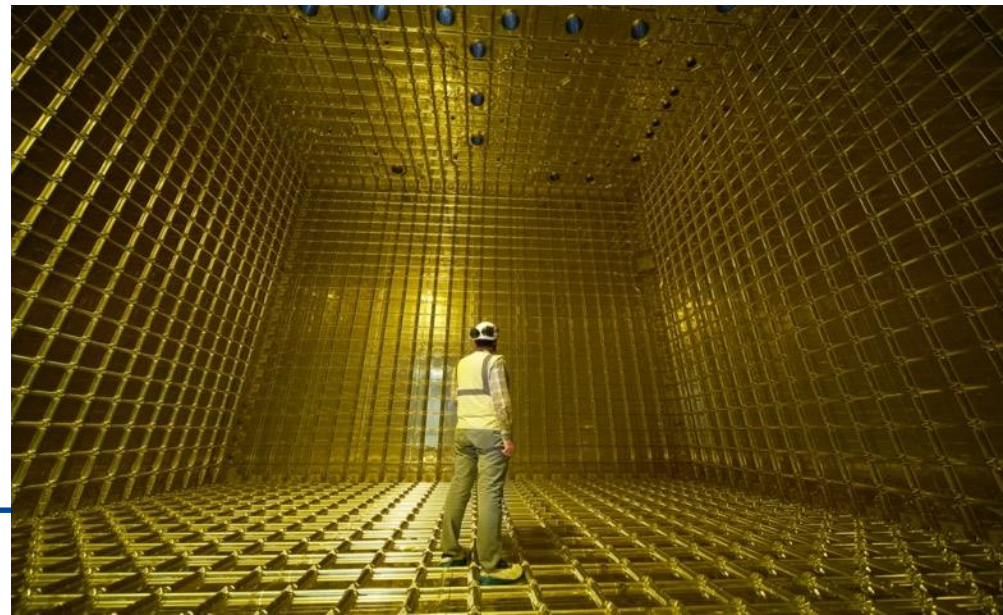
# LAr TPC : large membrane cryostats

Warm steel  
structure  
(equivalent to  
the LNG ship)



Cold structure (protected by industrial IP)

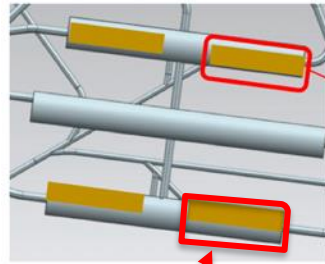
- ✓ 80 cm PU reinforces foam
- ✓ corrugated primary membrane
- ✓ additional secondary membrane
- ✓ + many details



# LAr TPC : LBNF membrane cryostats

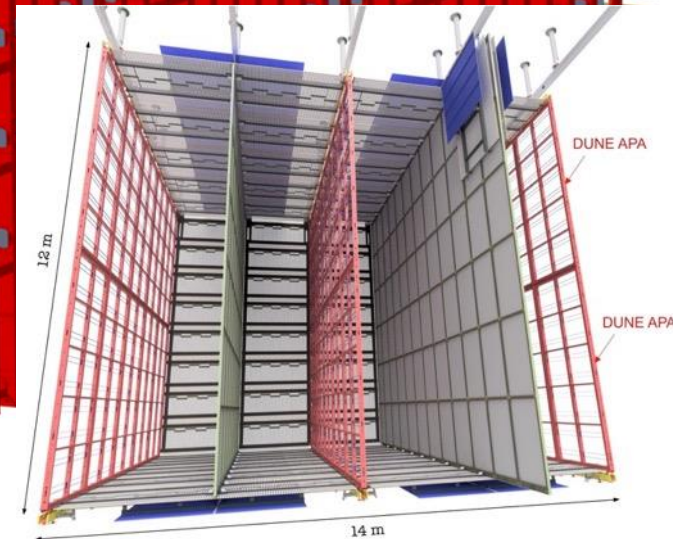
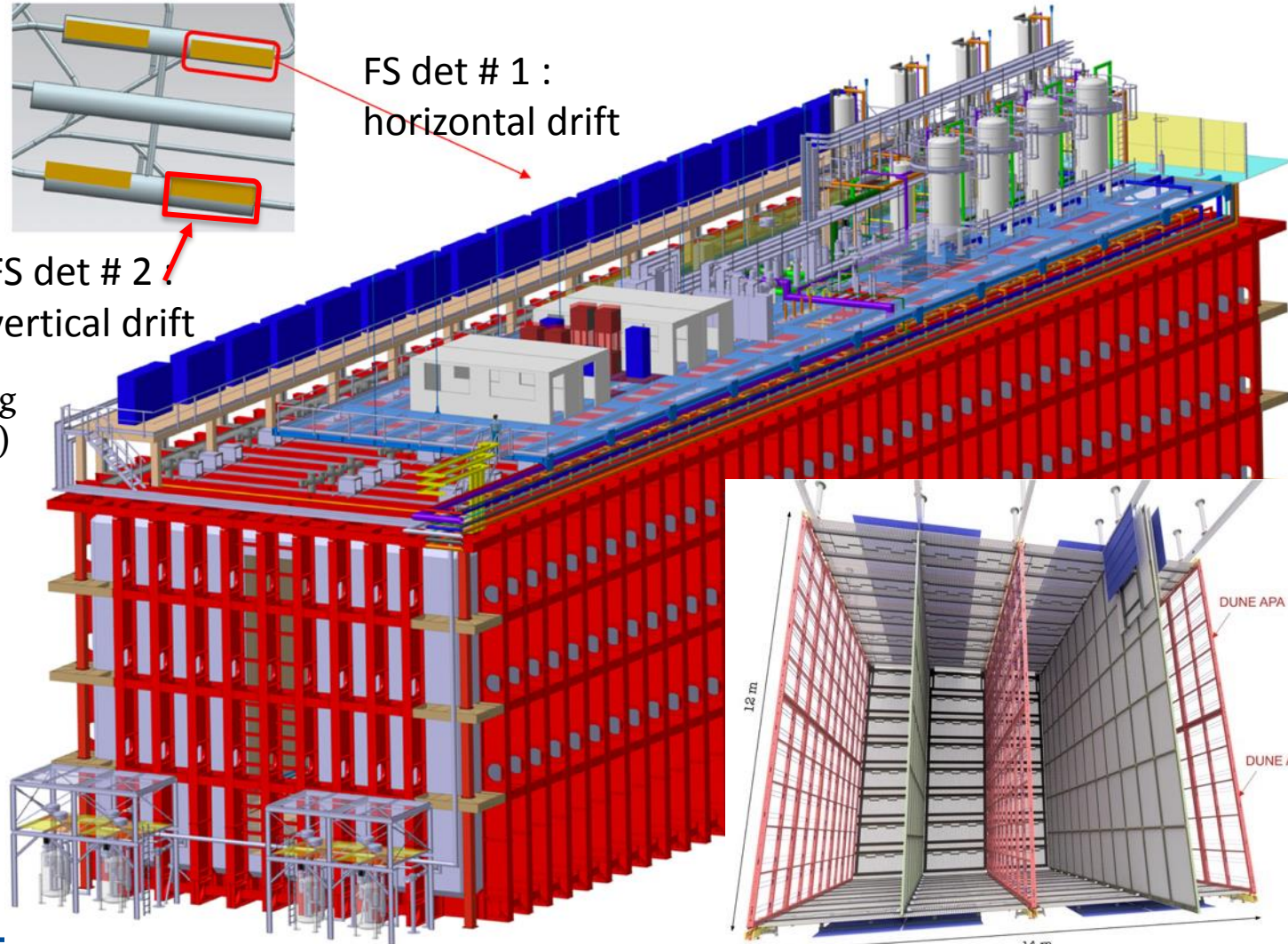
*65'840 mm x 18'940 mm x 17'840 mm (L x W x H)*

## Far Detectors



FS det # 2 :  
vertical drift

FS det # 1 :  
horizontal drift



Horizontal drift TPC

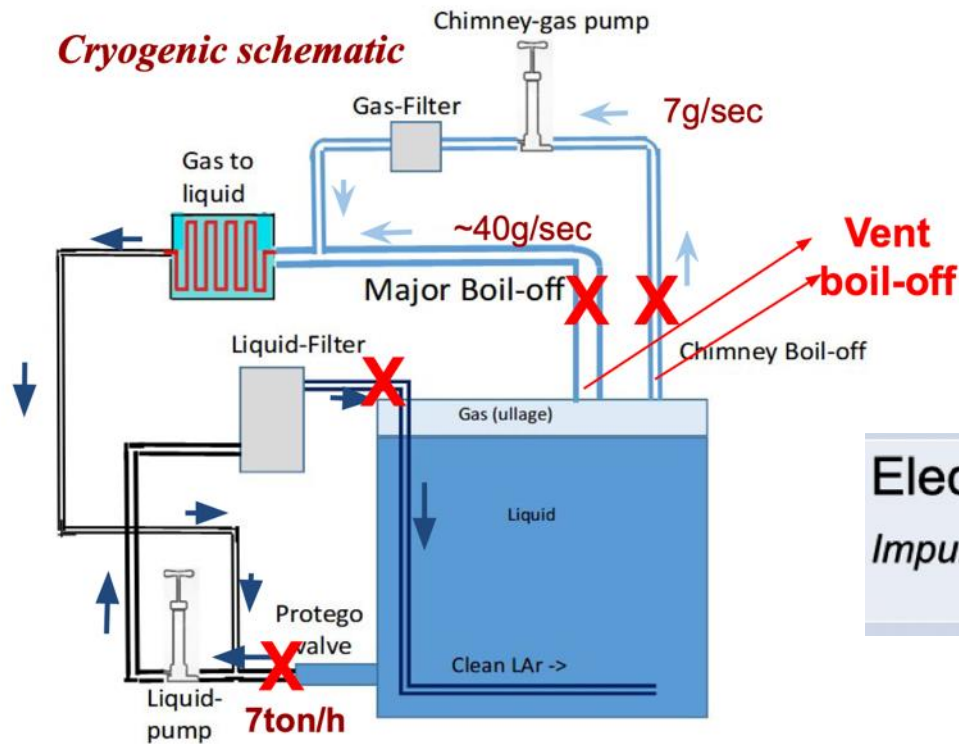
- High precision tracking  
(TPC charge collection)
- High precision  
calorimetry  
(charge and  
scintillation light)
- 17.5 ktons of LAr/det
- >10 ktons active/det

# LAr TPC : Cryogenic system

- ✓ High purity LAr ( $O_2$ ,  $H_2O$ , ..) from ppm at delivery to 10-30 ppt
  - Drift Time > 10 ms for large drifts (4-10 m)
- ✓ Cooling power ~ 10 kW/1000 tons of LAr (scaling with the cryostat surface area, Residual Heat Input (RHI): 5-6 W/m<sup>2</sup>)
- ✓ Temperature uniformity at the 1K level, with precision measurement at 10 mK
- ✓ High level of operation reliability and safety
  - *Liquid volume recirculation every 4-5 days*
  - *Liquid and gas filter systems (active copper-coated catalytic media ( $O_2$ ) and molecular sieve ( $H_2O$ ))*



# LAr TPC : Cryogenic system



## ProtoDUNE performance

Electron Lifetime	> ~30 ms in TPC **
Impurity Concentration	< 10 ppt

- *Liquid volume recirculation every 4-5 days*
- *Liquid and gas filter systems (active copper-coated catalytic media ( $O_2$ ) and molecular sieve ( $H_2O$ ))*

# LAr TPC : E field and HV system

In the TPC, each pair of facing cathode and anode planes form an electron-drift region. A field cage (FC) must completely surround the four open sides of this region to provide the necessary boundary conditions to ensure a uniform electric field within, unaffected by the presence of the cryostat walls.

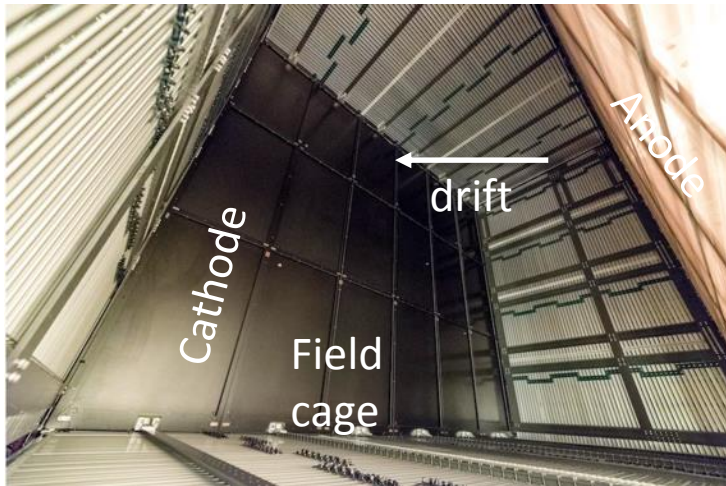
FC and Cathode geometry depend on the drift direction!

*The FC is required to:*

- 1. provide the nominal drift field (typically of 500 V/cm) with  $10^{-4}$  precision*
- 2. withstand 180-600 kV near the cathode*
- 3. define the drift distance between the anode and cathode to few mm*
- 4. limit the electric field in the LAr volume to under 30 kV/cm*
- 5. minimize the peak energy transfer in case of a HV discharge anywhere on the field cage or cathode*
- 6. provide redundancy in the resistor divider chain*

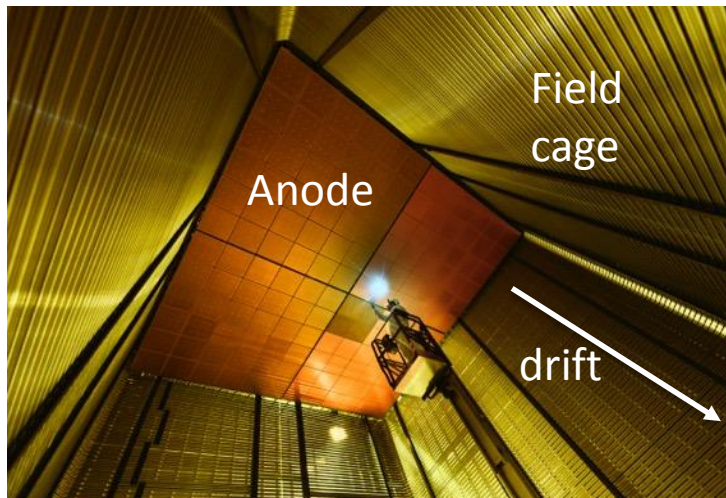


# LAr TPC : E field and HV system

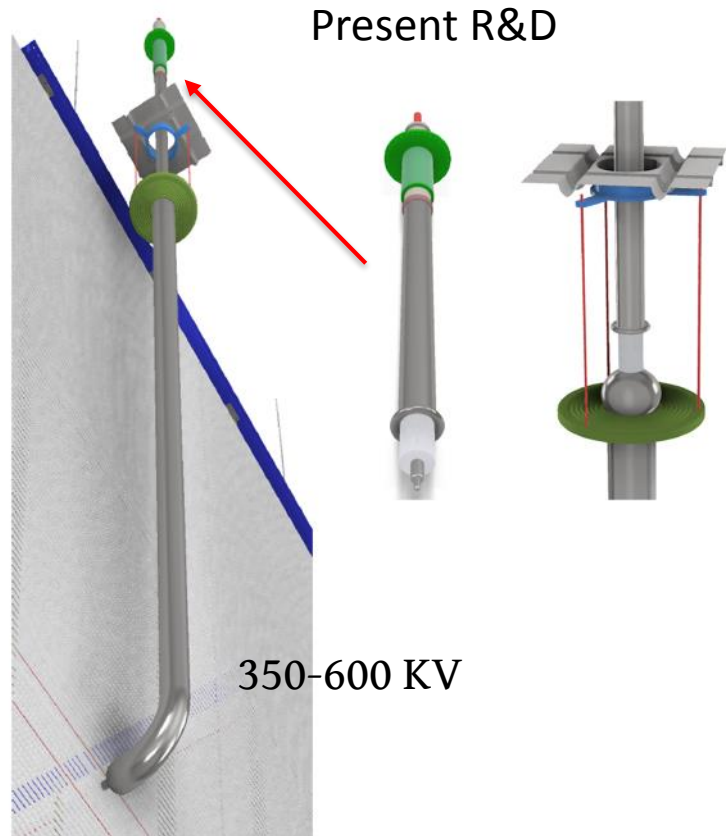


## Critical technology

- ✓ Low noise Power Suppliers up to 350-600 KV
- ✓ HV filter
- ✓ 350-600 KV HV cable (PS to feed-through)
- ✓ HV feed-throughs
- ✓ HV feeders in the LAr (extenders)
- ✓ HV connections to the Cathode
- ✓ Electronics and cryostat protection from HV breakdowns



# LAr TPC : E field and HV system



## Critical technology

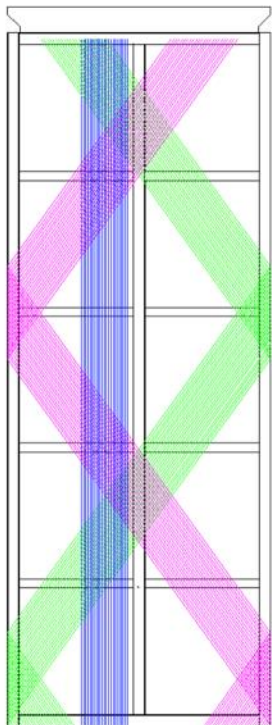
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- ✓ HV feed-throughs
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- ✓ HV connections to the Cathode
- ✓ Electronics and cryostat protection from HV breakdowns

# Anodes technologies: Wire chamber (APA)

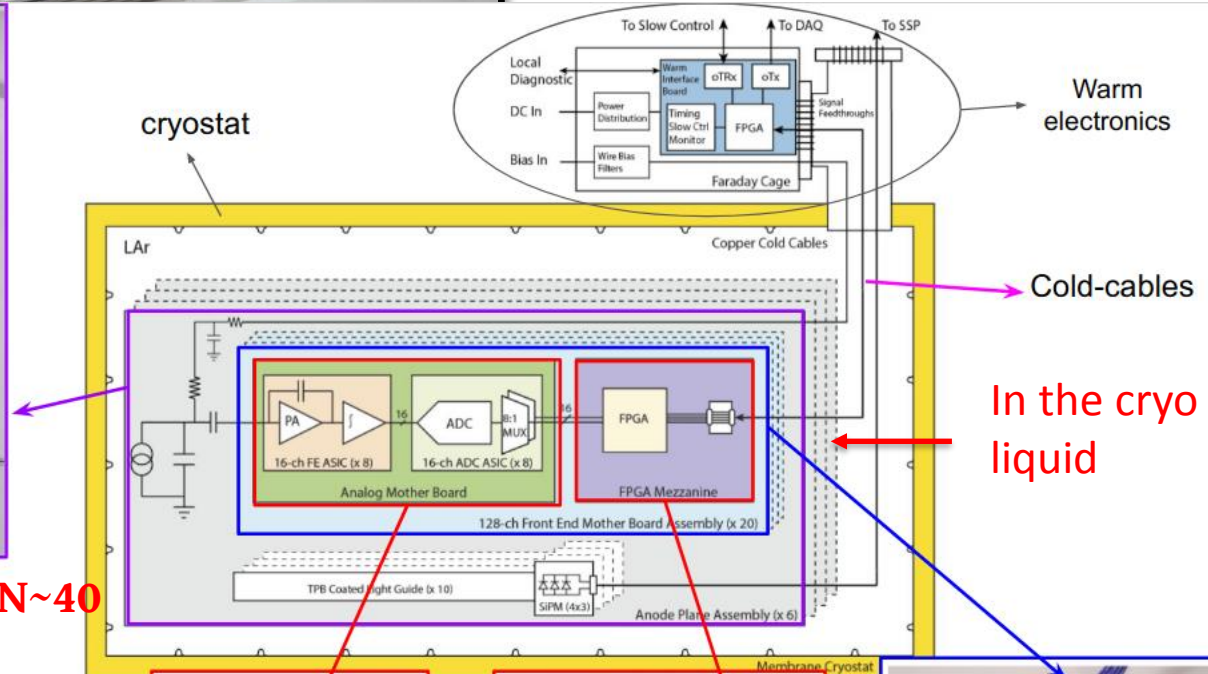
$X=0^\circ$ ,  $U=+30^\circ$ ,  $V=-30^\circ$   
3d wires,  $150\mu\text{m}$  BeCu



Solution adopted for  
the DUNE single  
phase first far  
detector



protoDUNE S/N~40



**Analog Motherboard:** 8 front end ASICs with CMOS technology for amplification and pulse shaping. 8 analog to digital conversion with ADC ASICs

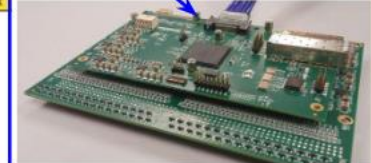
**FPGA Mezzanine:** Multiplexing and readout of digitized signals



+



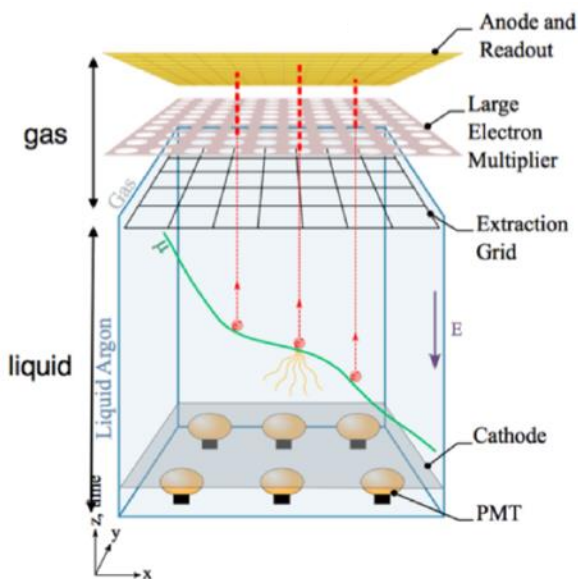
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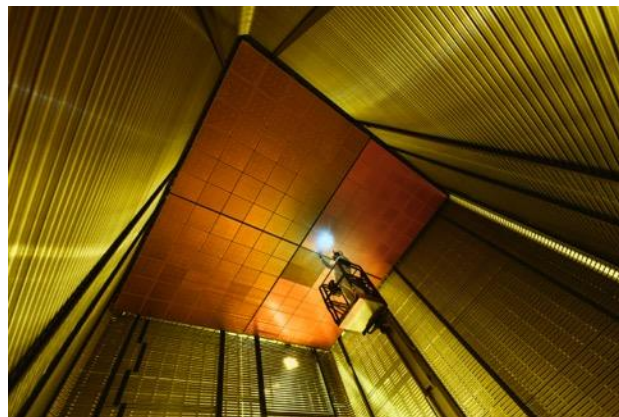
Front End Motherboard (20 per APA)



# Anodes technologies: DP (double phase)

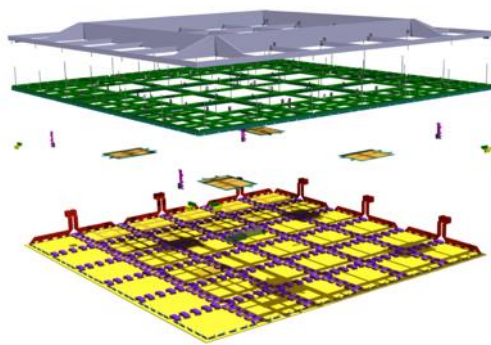
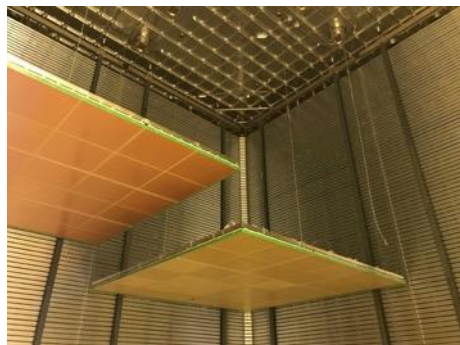


LEM S/N > 50 expectation

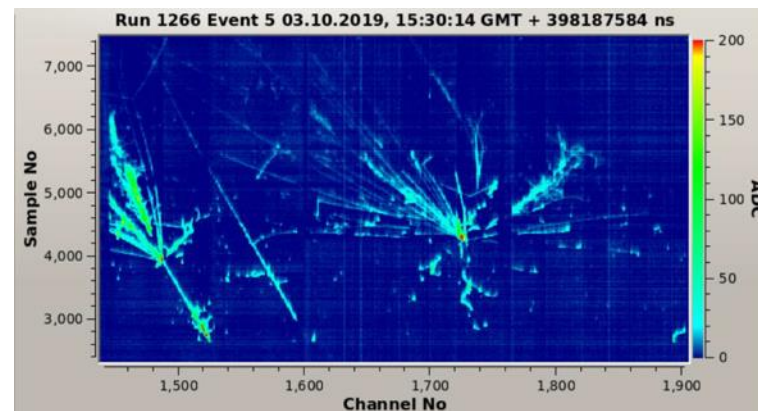


Solution tested in  
ProtoDUNE @ CERN  
Needs more R&D to  
solve stability problems

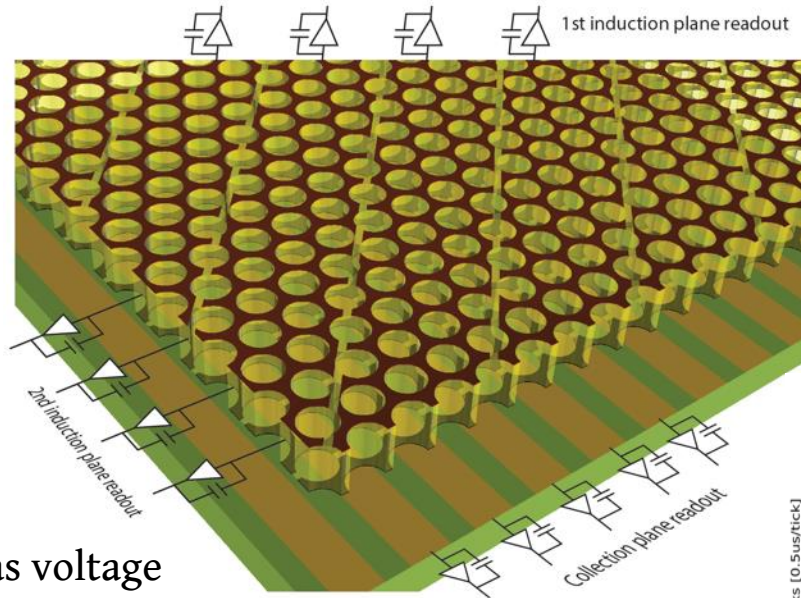
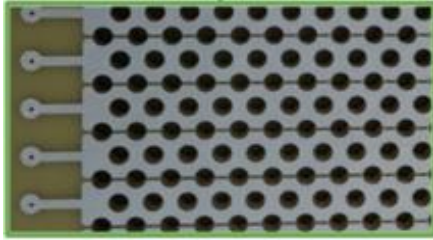
Amplification in the gas  
difficult to stabilize !!



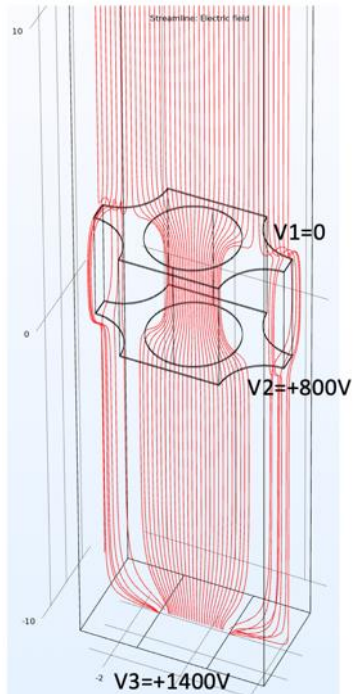
LEM : thick GEM technology



# Anodes technologies: Perforated PCB strips



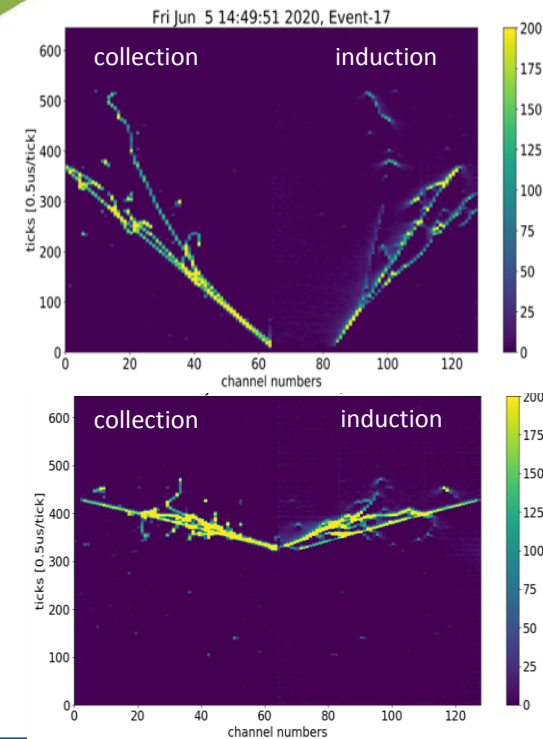
Solution adopted for the DUNE single phase Vertical Drift second far detector



The bias voltage needed across the two sides of the perforated anode PCB to pull electrons through the holes strongly depends on the optical transparency and the thickness of the PCB.

PCB strips ~ 5mm

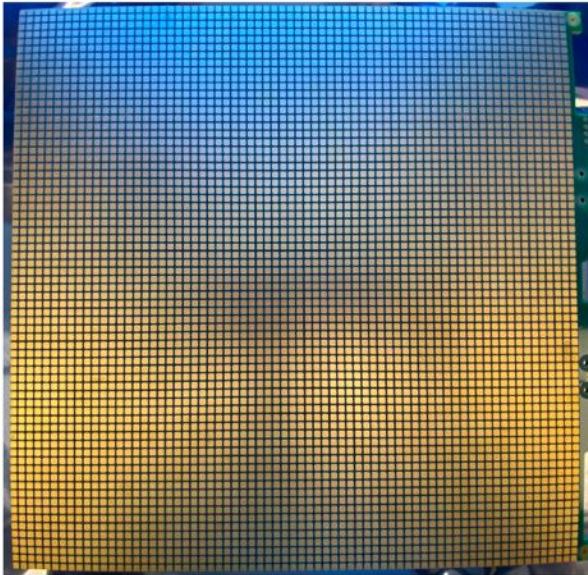
Holes diameter 2mm



Electron paths from a line charge in a 3-view configuration



# Anodes technologies: Pixel anode readout



- ✓ 1000 cm<sup>2</sup> anode tile prototype
- ✓ 100 ASICs with 4 IO entry-points
- ✓ 6'400 channels
- ✓ ~ 4x 4 mm<sup>2</sup> pixels

Adopted for the LAr DUNE Near Detector, could be an interesting solution for the DUNE far detector #3

LArPix v1 ASIC:

low noise ( $\sim 300e^-$ )  
low power ( $\sim 60\mu W/ch$ )  
3D readout, 64 ch

LArPix-v2 bare die

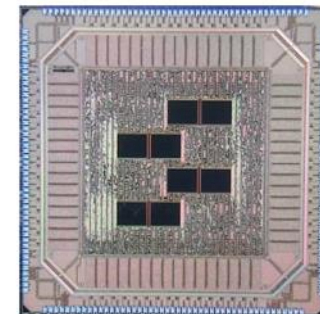
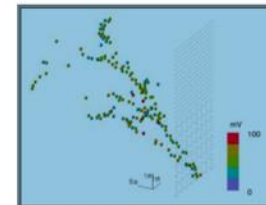
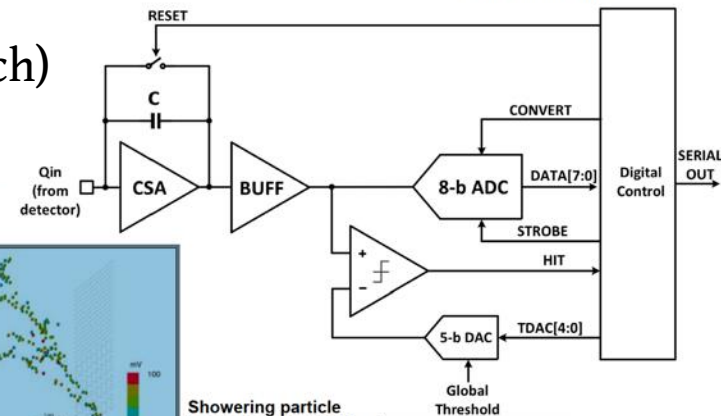


Diagram LArPix front-end and readout chain

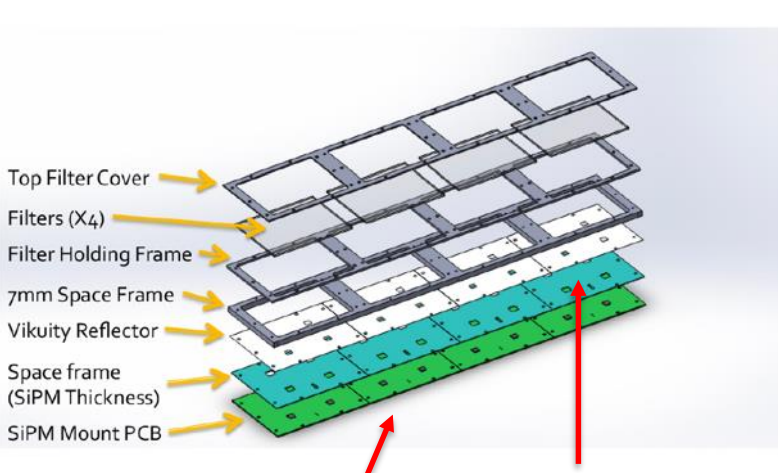


Showering particle imaged using LArPix v1

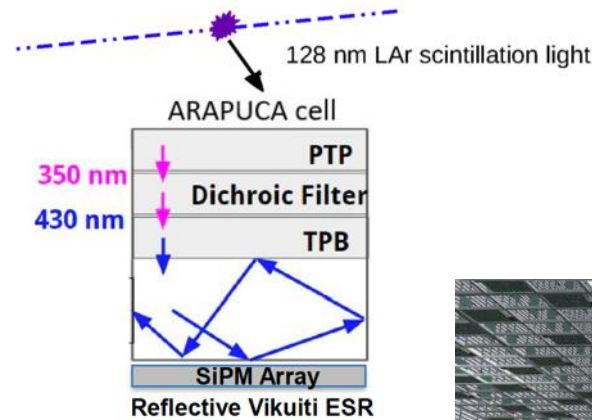
# Photons technologies: Arapuca

- ✓ SiPM technology covering 1000-2000 m<sup>2</sup>
- ✓ Some Arapuca operating at 300 KV (Vertical DRIFT)

Solution adopted for the DUNE single phase Horizontal and Vertical Drift far detectors



Arapuca super cell, cell  $\sim 100 \text{ cm}^2$

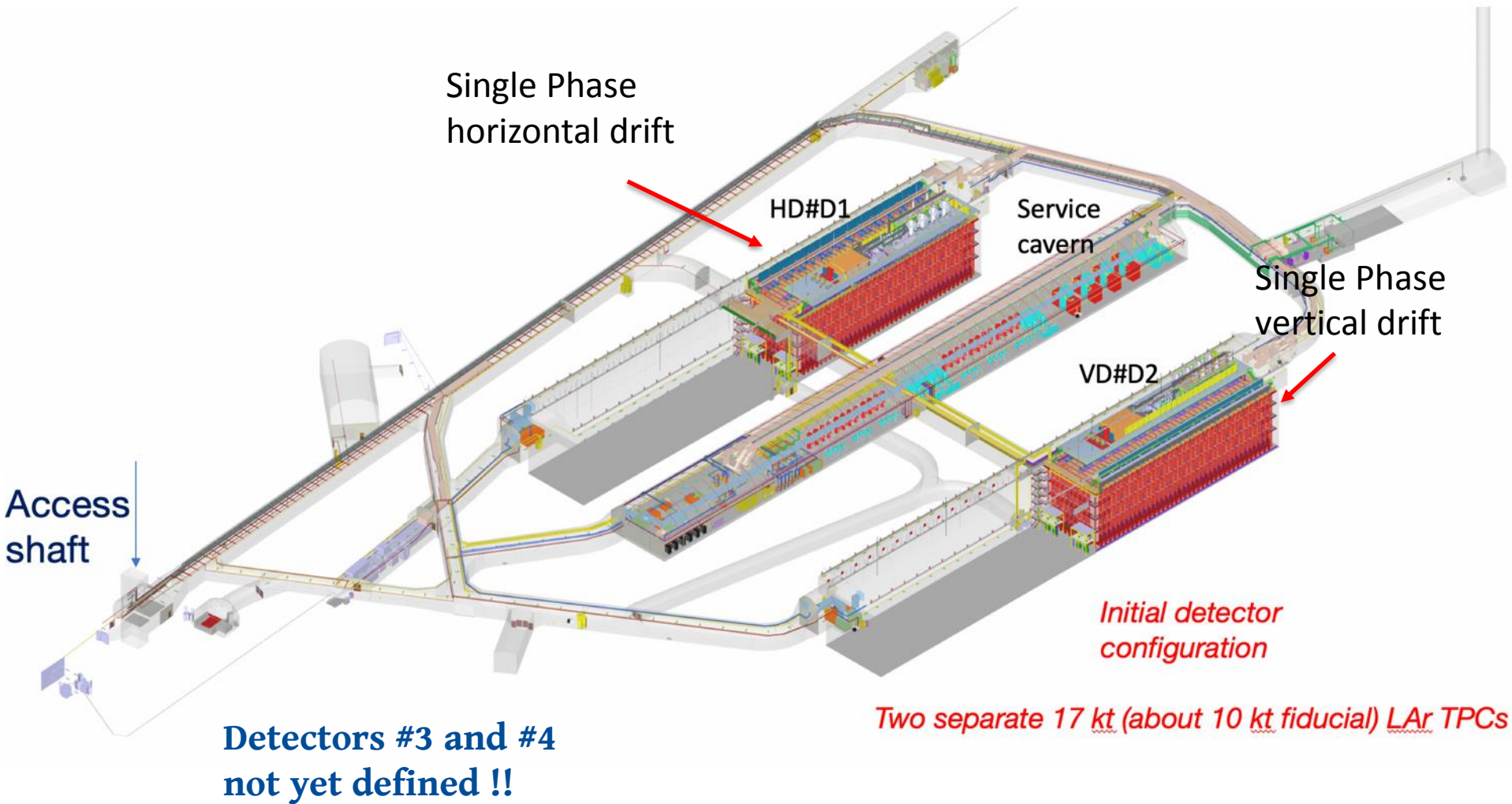


$\sim 90$  SiPMs/cell, total detection efficiency at 128nm  $\sim 4\%$

*Adding 10-15 ppm of Xenon (light 175 nm) this will improve a lot !! (protoDUNE)*

Scintillation light is first wavelength shifted to 350 nm to pass through a dichroic filter, then again to 430 nm after the filter, at which point it can no longer return through the acceptance window. It internally reflects until absorbed by the photosensor array with good acceptance.

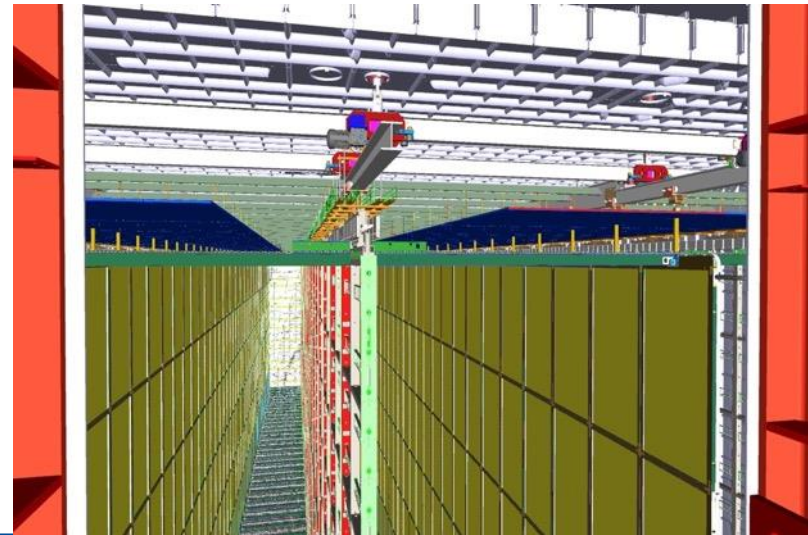
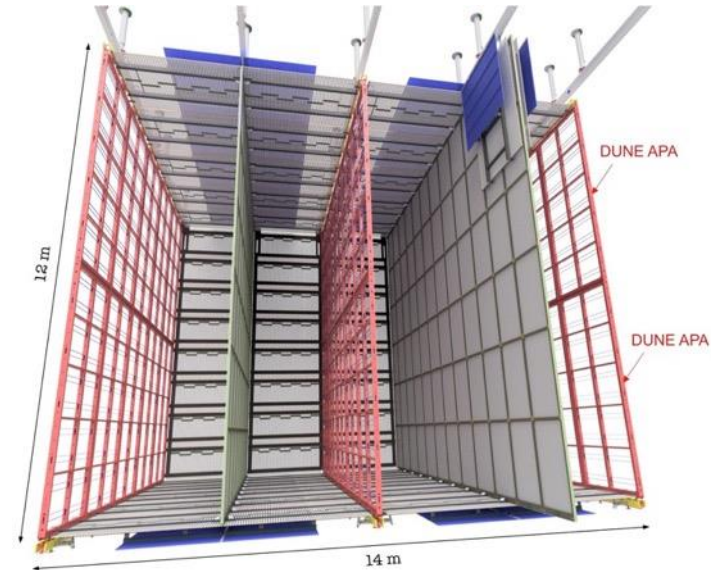
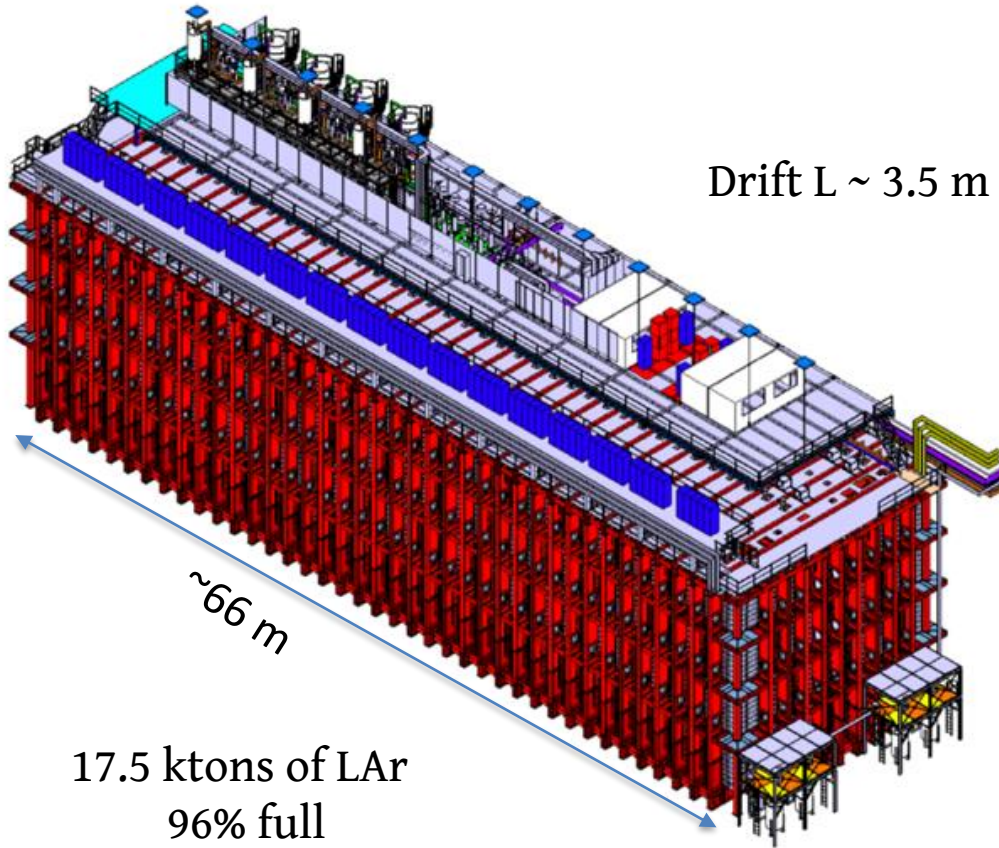
# DUNE Far detectors





# DUNE Far detector#1 SP-HD

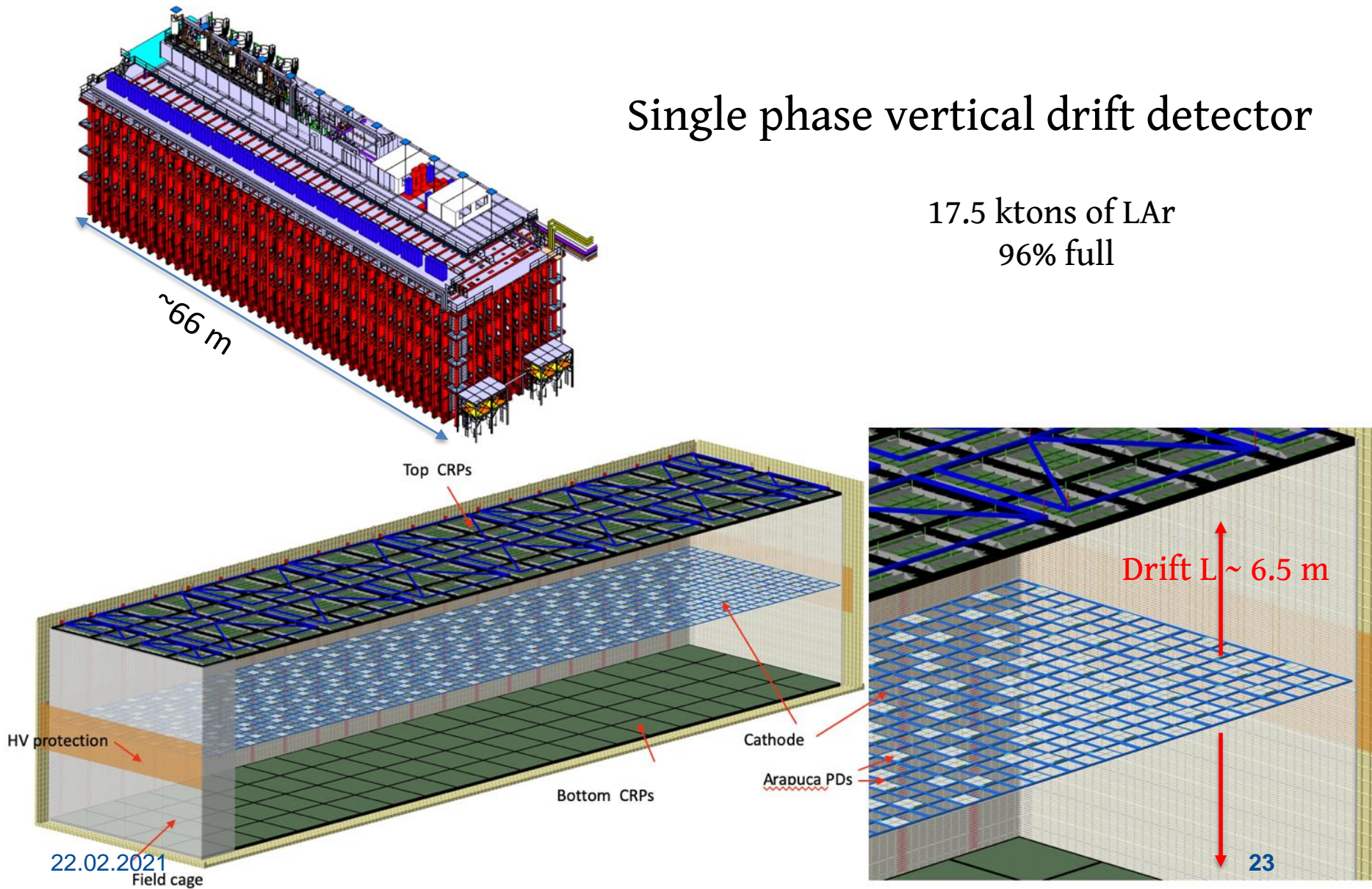
Single phase horizontal drift detector



# DUNE Far detector#1 SP-VD

Single phase vertical drift detector

17.5 ktons of LAr  
96% full



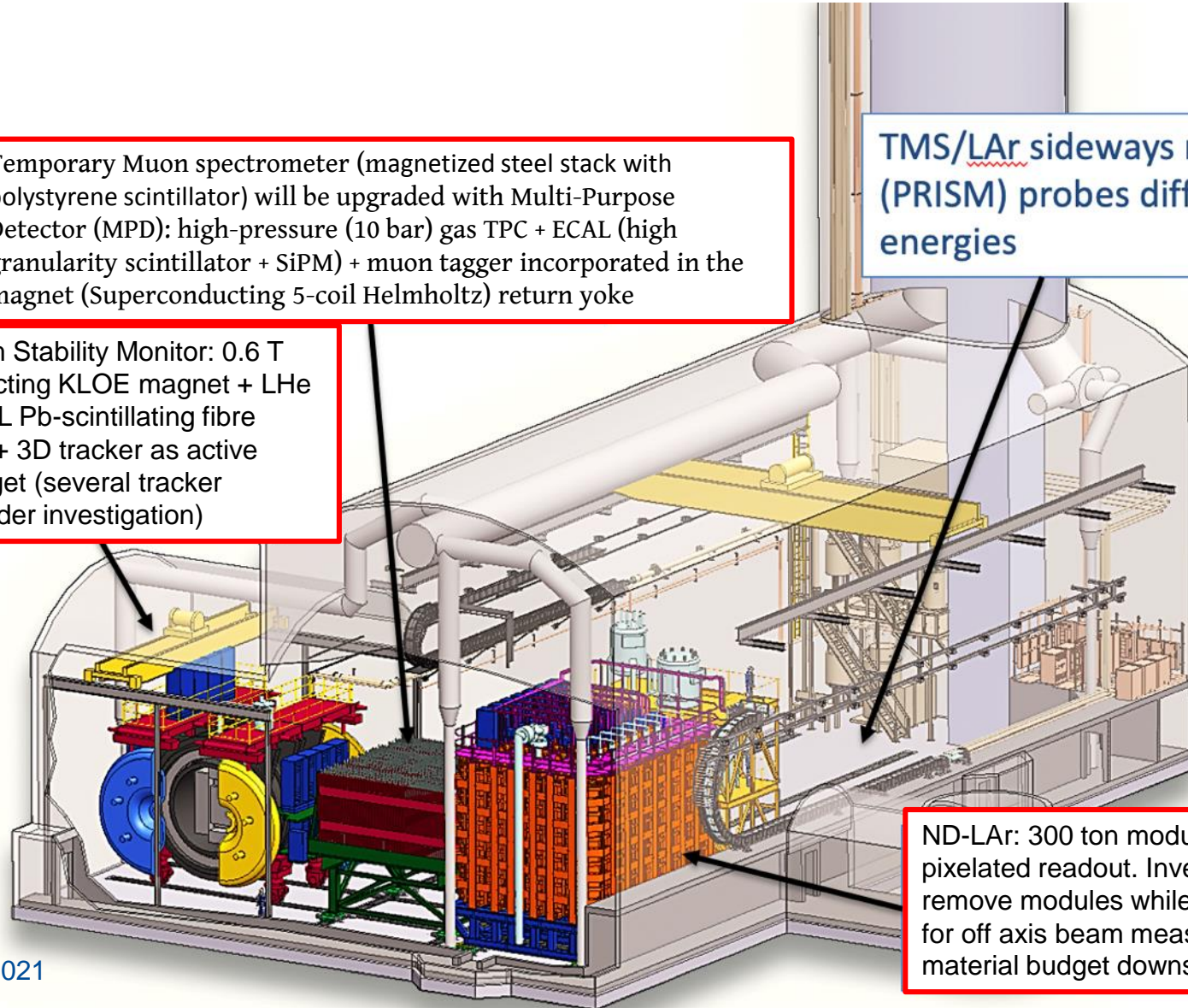


# DUNE Near Detector complex

Temporary Muon spectrometer (magnetized steel stack with polystyrene scintillator) will be upgraded with Multi-Purpose Detector (MPD): high-pressure (10 bar) gas TPC + ECAL (high granularity scintillator + SiPM) + muon tagger incorporated in the magnet (Superconducting 5-coil Helmholtz) return yoke

TMS/LAr sideways movement (PRISM) probes different neutrino energies

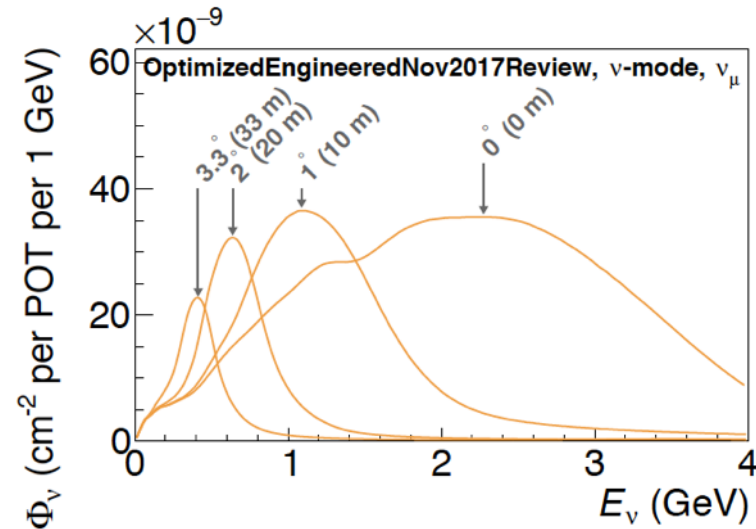
SAND Beam Stability Monitor: 0.6 T superconducting KLOE magnet + LHe plant + ECAL Pb-scintillating fibre calorimeter + 3D tracker as active neutrino target (several tracker solutions under investigation)



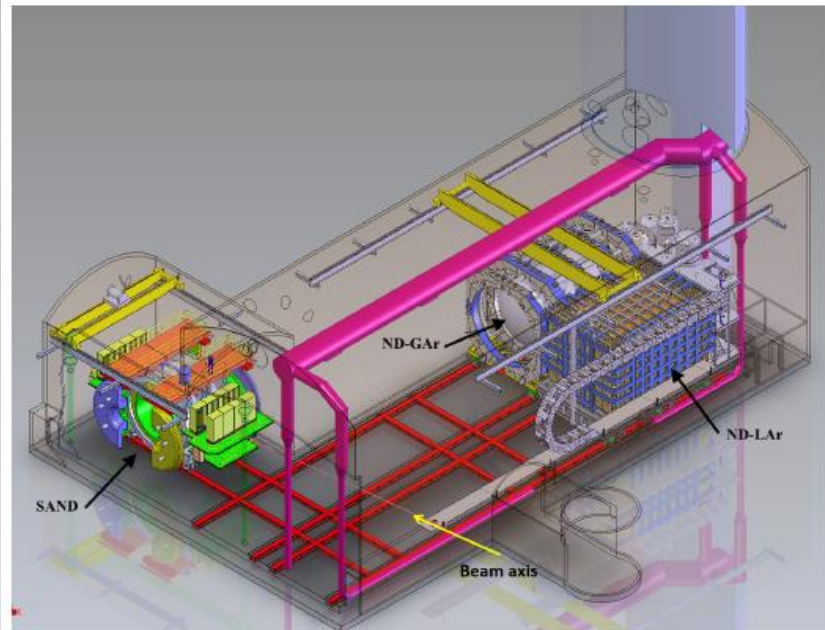
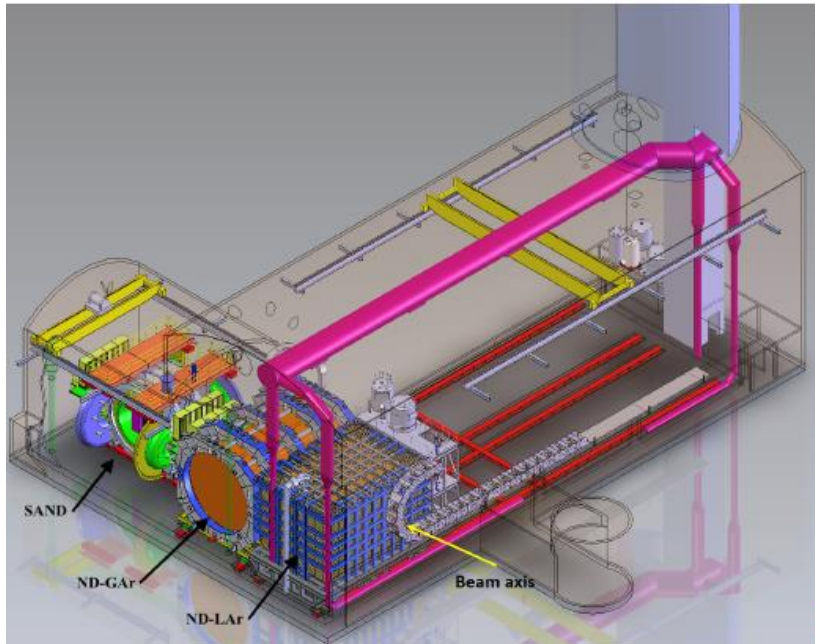
ND-LAr: 300 ton modular LAr TPC with pixelated readout. Investigation of possibly remove modules while operation. Movable for off axis beam measurement. Low material budget downstream cryostat wall

# DUNE Near detector complex

$\nu$  interaction  
topologies at  
different  
energies



PRISM  
concept



# LBNF/DUNE Challenges:

- ✓ Major underground excavation and civil engineering (2024 readiness)
- ✓ Extended cryogenics system, all underground
- ✓ Complexity of LAr large quantity delivery (filling  $\sim 1$  y/detector)
- ✓ 5 years of components manufacturing across  $\sim 30$  nations
- ✓ Very complex detector integration and installation (large clean rooms, assemblies tested in cold before insertion into the cryostat, complex warm to cold penetrations, special grounding layout, ...)
- ✓ Very diversified Near Detector complex, with various technologies
- ✓ Complete new  $\nu$  beam :1.2MW to 2.4MW (PIP-II new p accelerator,  $\nu$  beamline components, radiation protection issues, ...)

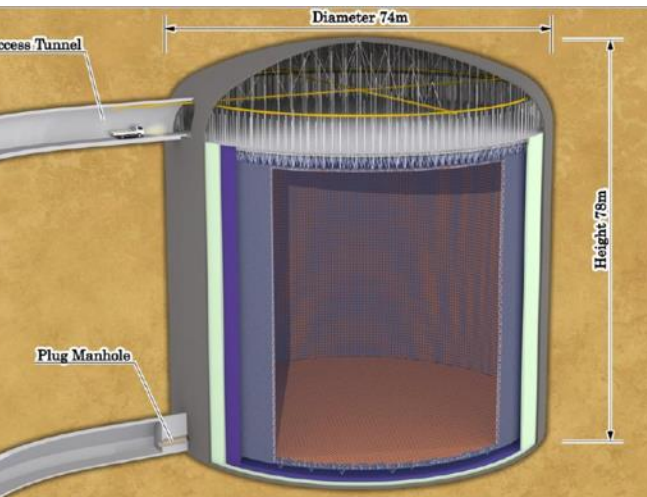
# LBNF/DUNE R&D requirements:

- ✓ Bring the cryostat technology to a final implementation stage
- ✓ Continue to test cryogenics, filtering system and operation stability
- ✓ Continue in the next 2-3 years to finalize the start of the components mass production through a Module-0 test in the protoDUNE facilities (for Horizontal and Vertical drift solution and LAr Near detector). Photon detectors (Arapucas) and PCB anode technologies are key R&D elements. Need PDs operating at 300KV and optimized for Xenon light.
- ✓ Demonstrate stable and safe technology in LAr at least at 350kV for all components. Low noise HV filter system, 350KV HV cable!
- ✓ tools to inspect the detector during operation (Curious Cryo Fish, cameras, ...). Calibration tools (lasers, movable sources, BI207 sources)
- ✓ Continue the development of automatic event reconstruction using neural networks
- ✓ Complete the integration and preparation work for the large installation activities underground



# HK : Hyper-Kamiokande

Water Cherenkov detector with **187 kton fiducial mass**  
(8x larger than Super- Kamiokande)



**1.3 MW beam**

**J-PARC Main Ring**  
(KEK-JAEA, Tokai)



**New near/intermediate detectors to control systematic uncertainties !!**



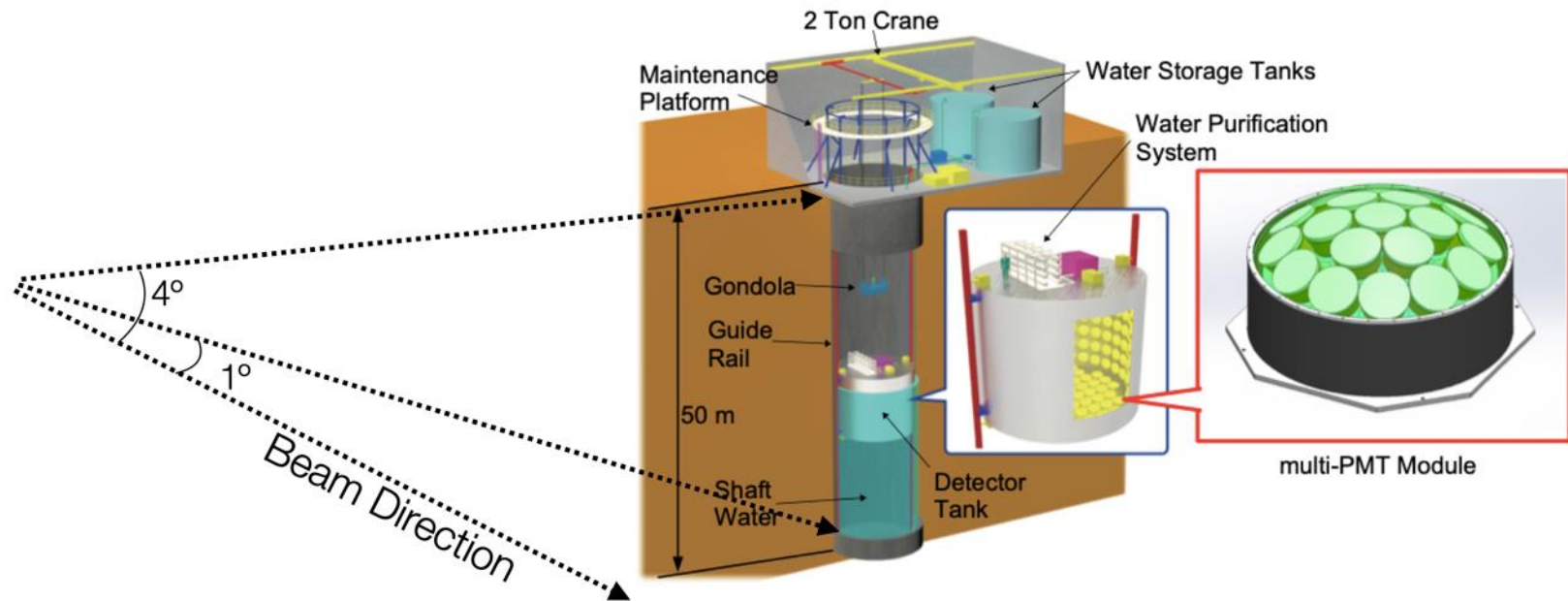
# HK near/intermediate detectors

Controlling systematic uncertainties on modeling of neutrino flux and interactions is critical

Hyper-K plans a set of near/intermediate detectors:

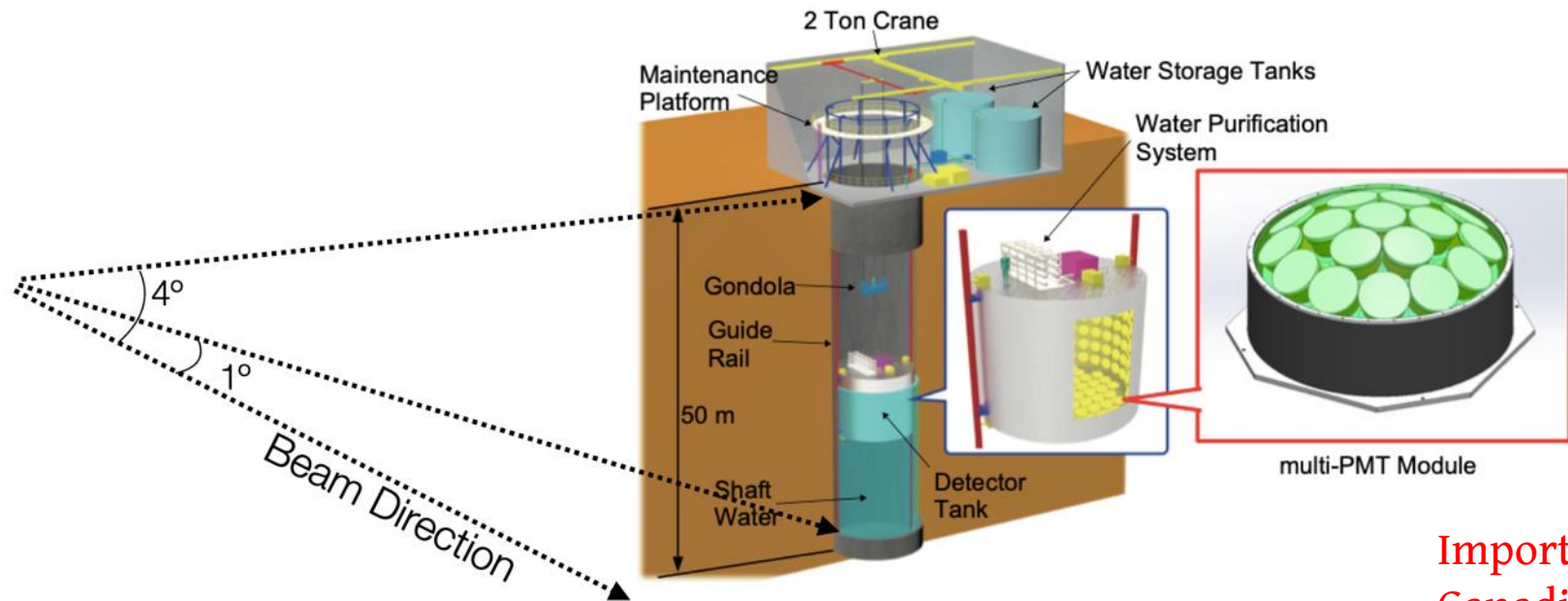
- ✓ **INGRID** - beam direction measurement and beam monitoring (on axis)
- ✓ **Upgraded T2K ND280** - charge selection for wrong-sign, study of hadronic recoil system (off axis), measurement of un-oscillated flux
- ✓ **IWCD** - Water target with measurements at varying off-axis angles and measurements of electron (anti)neutrino cross sections (at 1-2 km from  $\nu$  target)

# HK intermediate detector (IWCD) @ 1-2 km



- ✓ 1 kton scale water Cherenkov detector located ~1-2 km from the neutrino target
- ✓ Position of detector can be moved vertically to perform measurements at different off-axis angles to exploit correlations between neutrino energy and final state lepton kinematics
- ✓ Can be loaded with Gd to measure neutron multiplicities in neutrino interactions
- ✓ Use multi-PMT photosensors with excellent spatial (80 mm) and timing (1.6 ns FWHM) resolution

# HK intermediate detector (IWCD) @ 750m



Important  
Canadian-  
European  
R&D effort

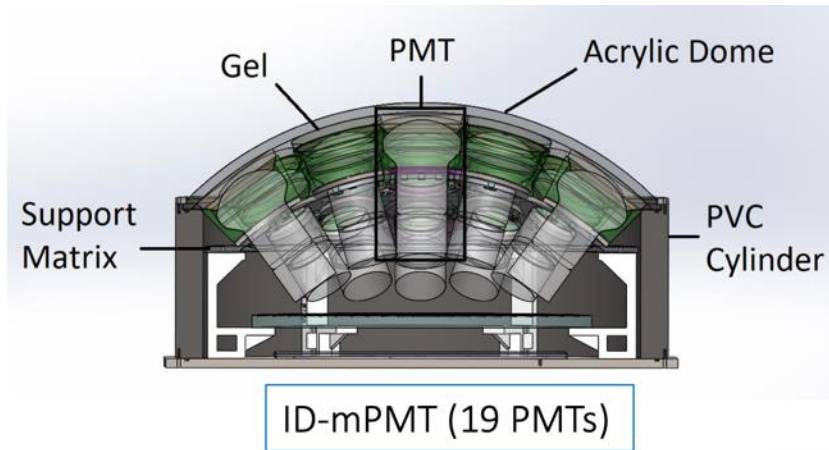
Complexity :

- ✓ Vertical movement system with important integration issues
- ✓ Water purification system
- ✓ New R&D on multi-PMT (also as a possible option for the HK outer detector)



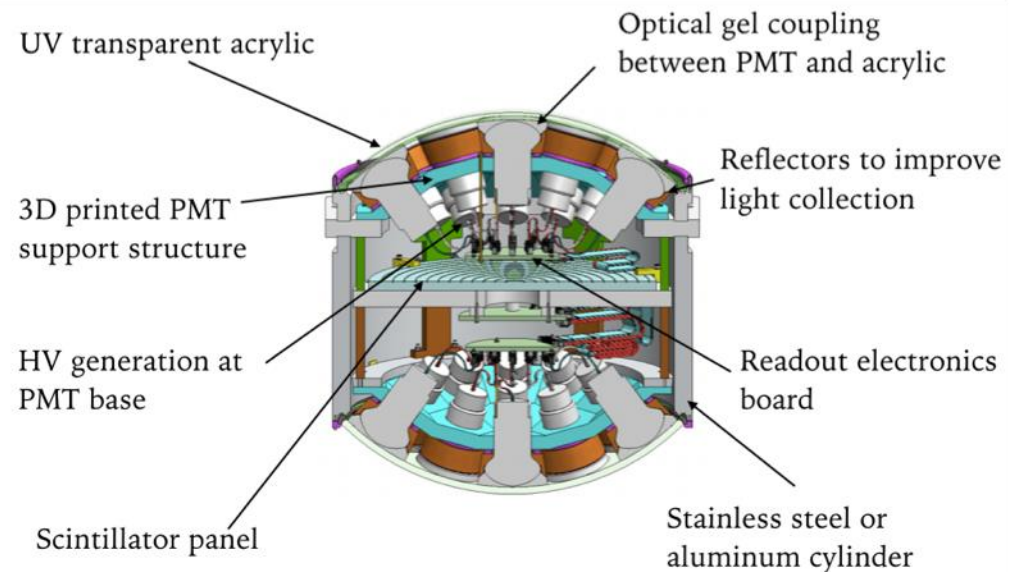
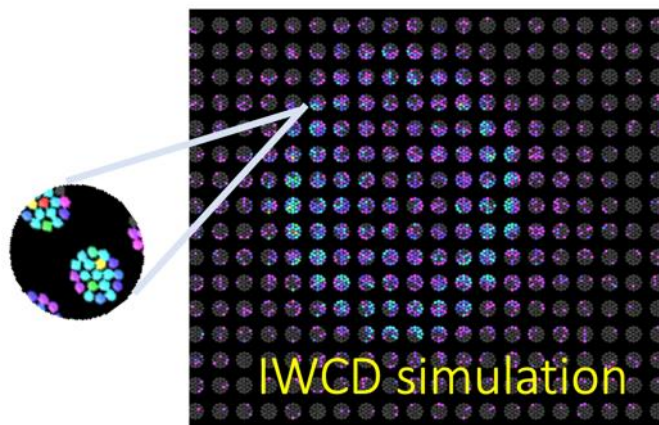
# IWCD multi PMT (3") project

Photodetectors and electronics arranged inside a pressure resistant vessel → Increased granularity

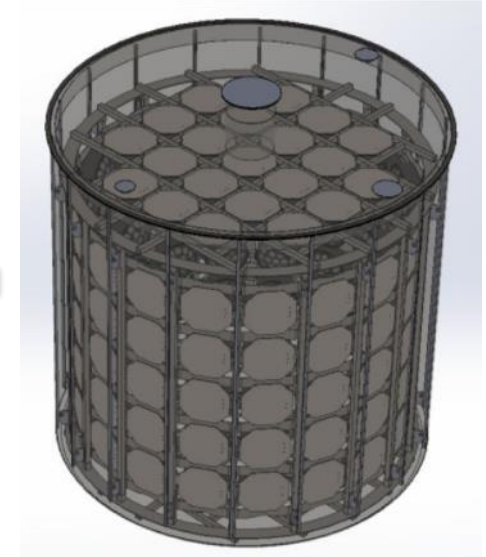
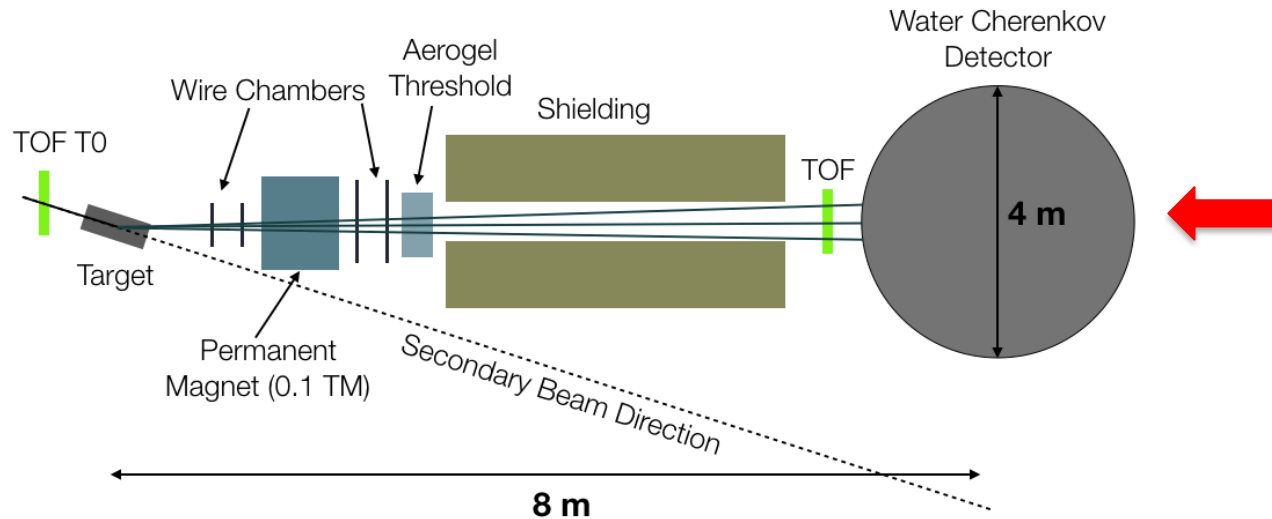


## Advantages:

- Superior photon counting
- Improved angular acceptance & vertex resolution
- Extension of dynamic range
- Intrinsic directional sensitivity (80 mm spatial)
- Local coincidences
- Improved timing resolution (1.6 ns FWHM)



# HK intermediate detector (IWCD)

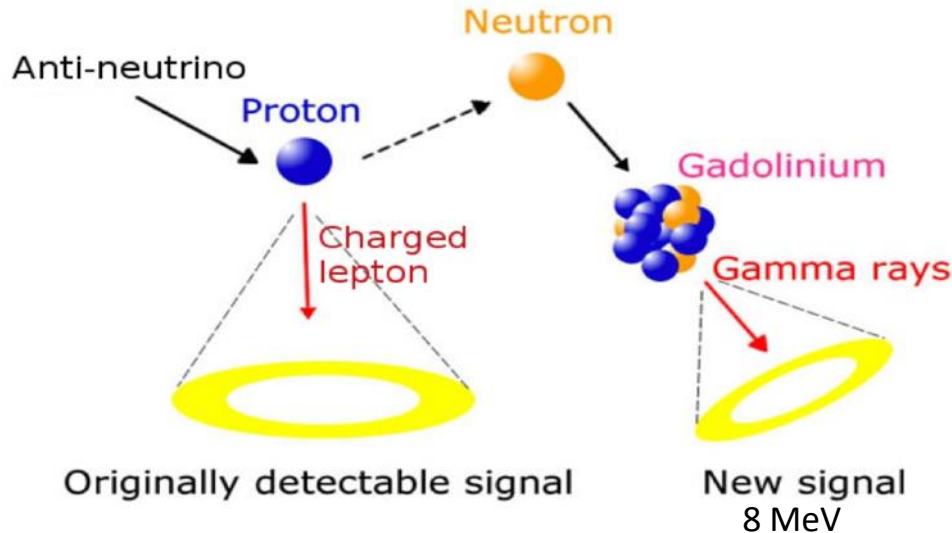


- ✓ Plan test experiment in tertiary beam to evaluate detector response and calibration procedure (1% goal)
- ✓ Operation with  $p$ ,  $e$ ,  $\pi^\pm$ ,  $\mu^\pm$ ,  $n$  with momentum range 140 MeV/c - 1200 MeV/c

Proposal: CERN-SPSC-2020-005, CERN east area

# Gadolinium doping or scintillator added

Plans to load Gd in the water



- Statistical **neutrino/anti-neutrino separation** would be possible
- Large uncertainty in number and energies of neutrons produced
- Super-K has been doped with an initial 0.01% of Gd. First results very positive!  
→ goal for 2021 0.1%

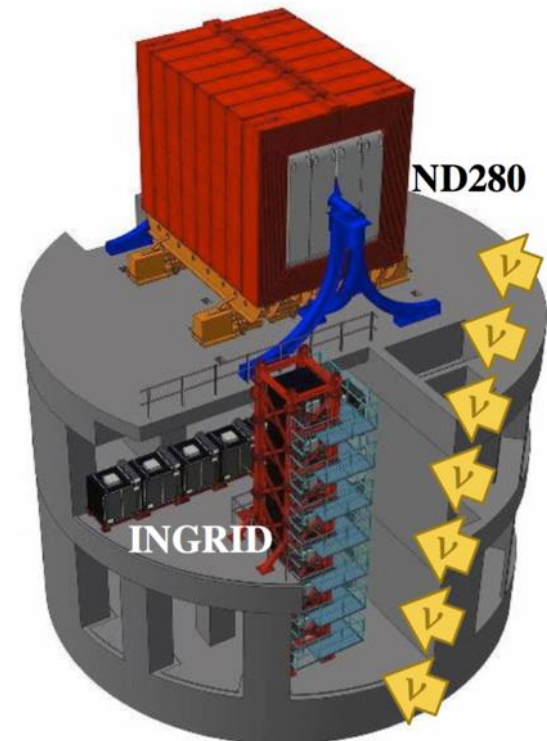
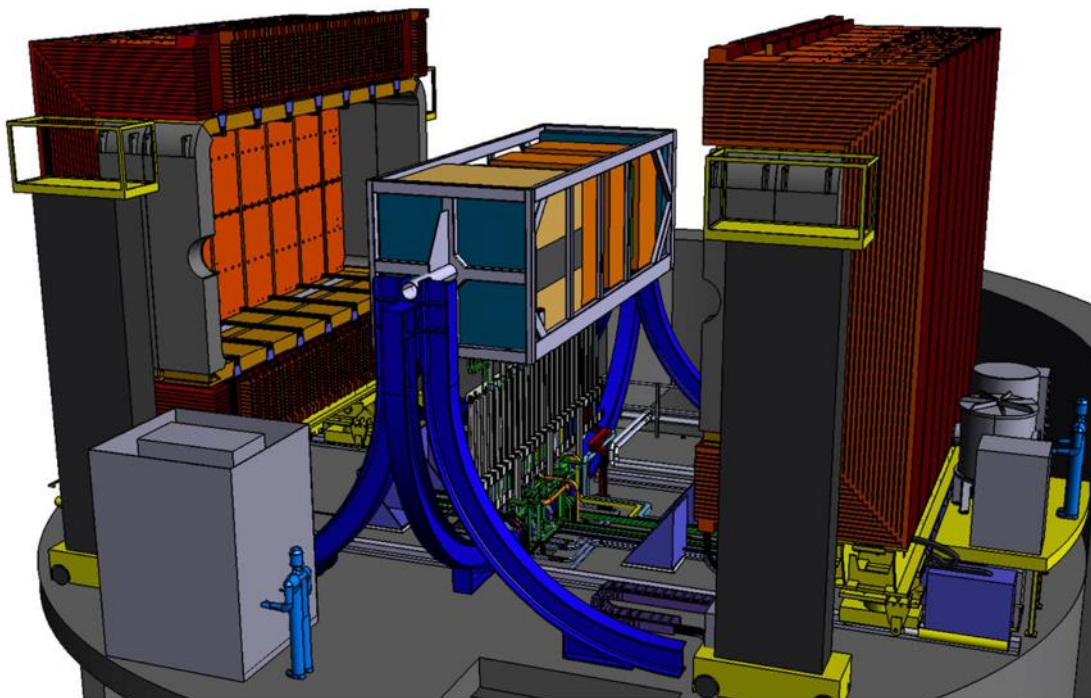
A limitation of water Cherenkov detectors is the inability to detect particles with velocity below the threshold for Cherenkov radiation production. If scintillator can be added to the water, the scintillation light can be used to detect particles below the Cherenkov threshold, leading to potential improvements in the energy reconstruction and classification of neutrino interaction events.



# HK near detectors (upgraded ND280) @ 280m

- ✓ T2K is in the process of upgrading the magnetized ND280 detector. Planned installation in 2022 and operation in 2023. It will be further upgraded for HK!
- ✓ New Super-FGD tracker, horizontal TPCs and TOF counter

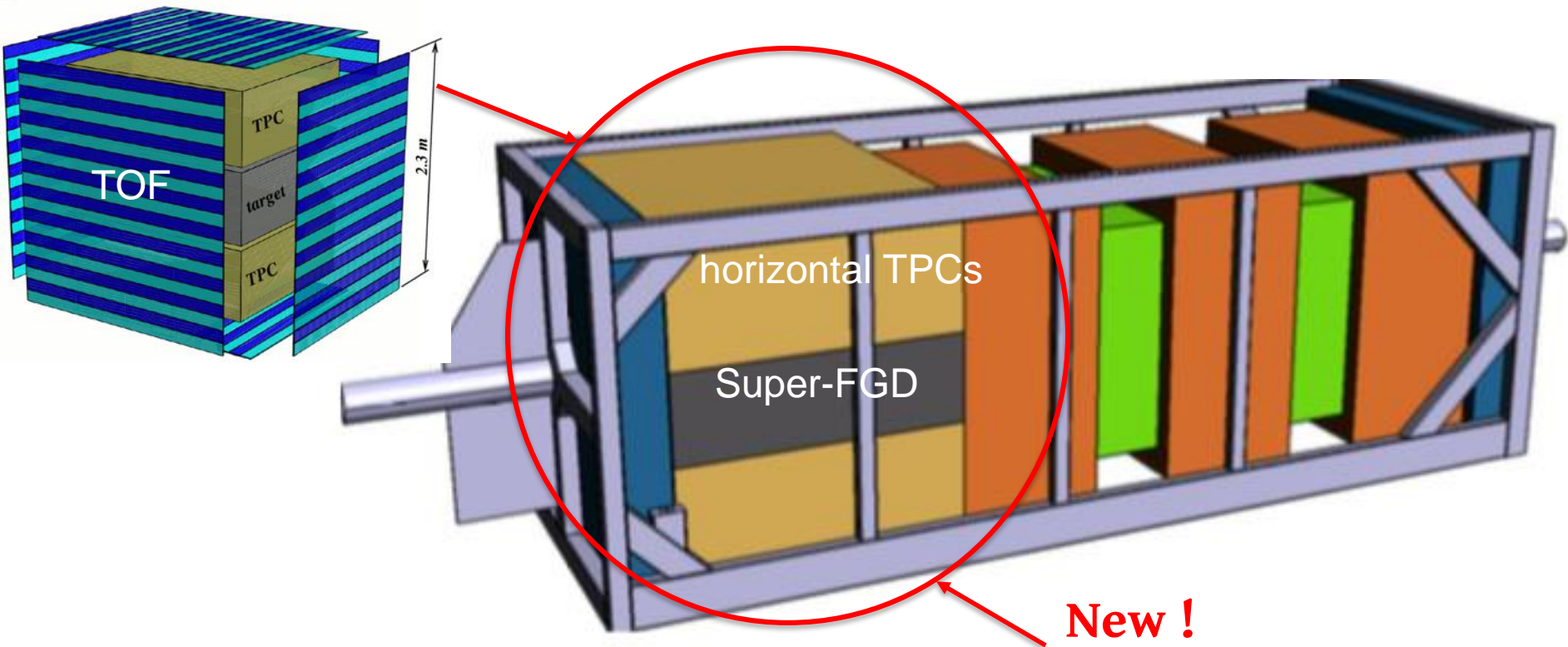
**ND280 upgrade TDR: CERN-SPSC-2019-001 (arXiv:1901.03750)**



# HK near detectors (upgraded ND280) @ 280m

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**ND280 upgrade TDR: CERN-SPSC-2019-001 (arXiv:1901.03750)**



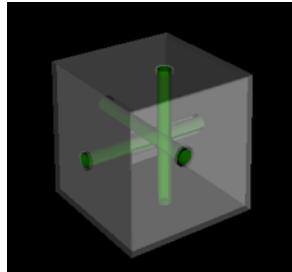
# HK near detectors (upgraded ND280) @ 280m

- ✓ Full polar angle acceptance for muons produced in Charged Current neutrino interactions with similar performance in terms of momentum resolution,  $dE/dx$ , charge measurement as the current ND280
- ✓ Fiducial mass doubled (each of the two present ND280 targets has a fiducial mass of approximately one ton)
- ✓ Improved tracking efficiency for low energy pions and protons contained inside the active target detector, in order to determine the event topology, with proton-pion identification (lowering the detection threshold).
- ✓ Highly efficient Time-Of-Flight detector, to reconstruct the direction (backward versus forward or inward versus outward) of all the tracks crossing the TPCs. If possible, the TOF detector should also contribute to the particle identification



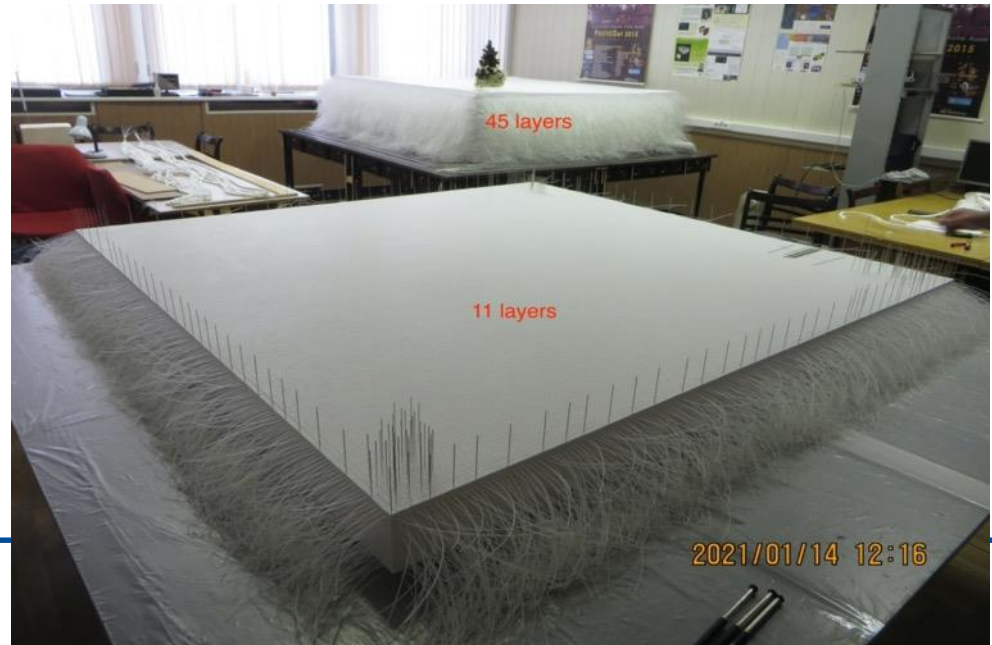
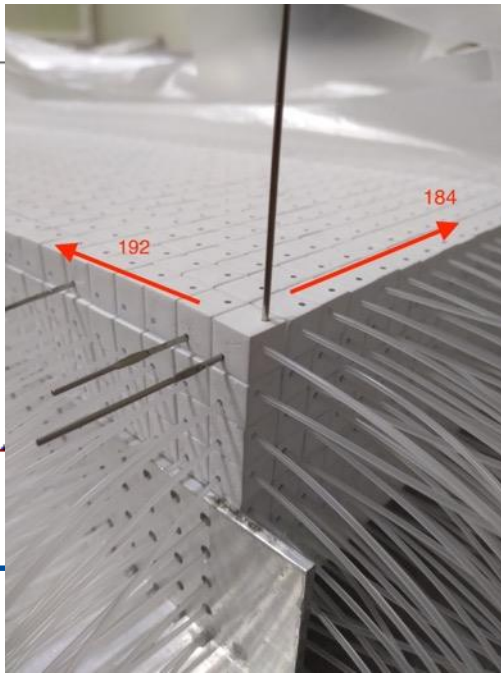
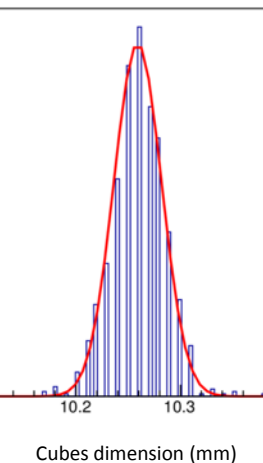
# Super Fine-Grained Detectors (FGDs)

active part  $192 \times 192 \times 56$  cubes,  
with the size of each cube  
being  $1 \times 1 \times 1$  cm<sup>3</sup>. The total  
numbers of cubes and readout  
channels will be ~2.1M cubes  
and ~58,000 channels



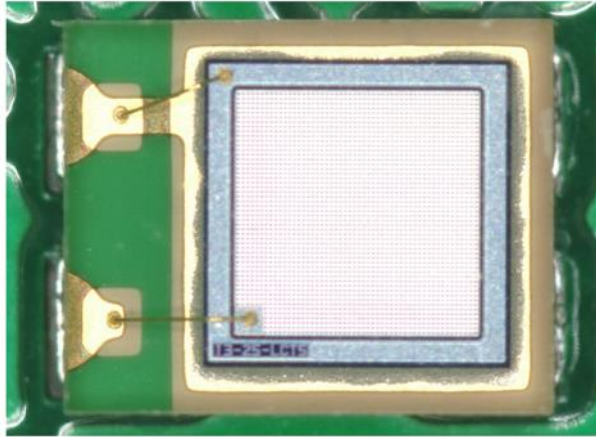
by injection  
molding

Polystyrene 1.5% PTP and 0.01% POPOP.  
reflecting layer by etching the scintillator  
surface with a chemical agent (50–80  $\mu$ m) Three  
orthogonal through-holes of 1.5 mm diameter  
to accommodate WLS fibers



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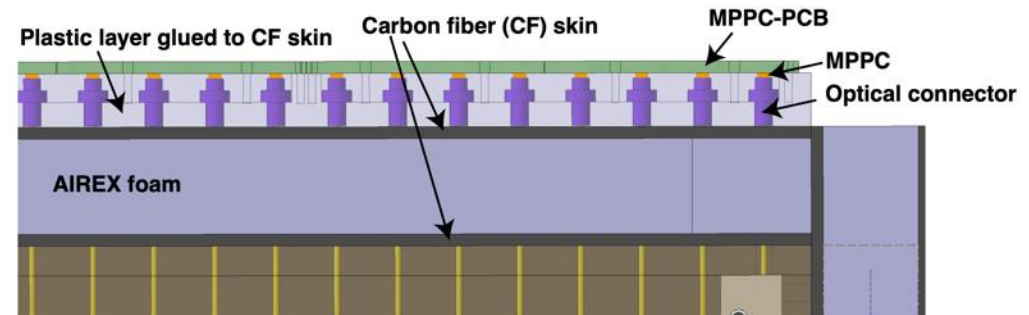
# Super Fine-Grained Detectors (FGDs)



Photosensor : MPPC S13360-1325PE

Sensitive area : 1.3 mm × 1.3 mm

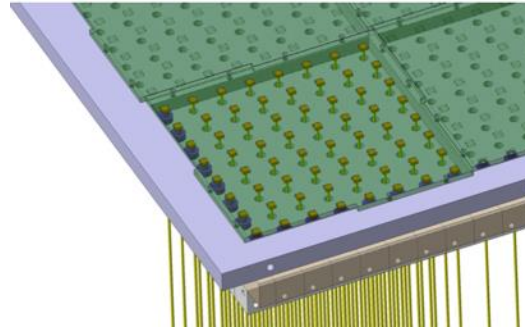
~ 70 photoelectrons per MIP for a channel



Item	Specification
Effective photosensitive area	1.3 mm x 1.3 mm
Pixel pitch	25 $\mu$ m
Number of pixels	2668 pixels
Fill factor	47%
Package type	Surface mount
Breakdown voltage ( $V_{BR}$ )	53 $\pm$ 5 V
Peak sensitivity wavelength	450 nm
Photo detection efficiency	25%
Gain	7.0 x 10 <sup>5</sup>
Dark count	70 kcps (typ.)
Crosstalk probability	1%

Box panel of AIREX foam sandwiched by carbon fiber (CF) skins. WLS fibers are brought outside the box through the holes in the panel and glued to the optical connectors. The optical connectors are inserted in holes of the plastic layer glued to the CF skin for the mechanical alignment to the MPPCs soldered on the MPPC-PCBs

# Super Fine-Grained Detectors (FGDs)



CITIROC as  
frontend  
ASICs

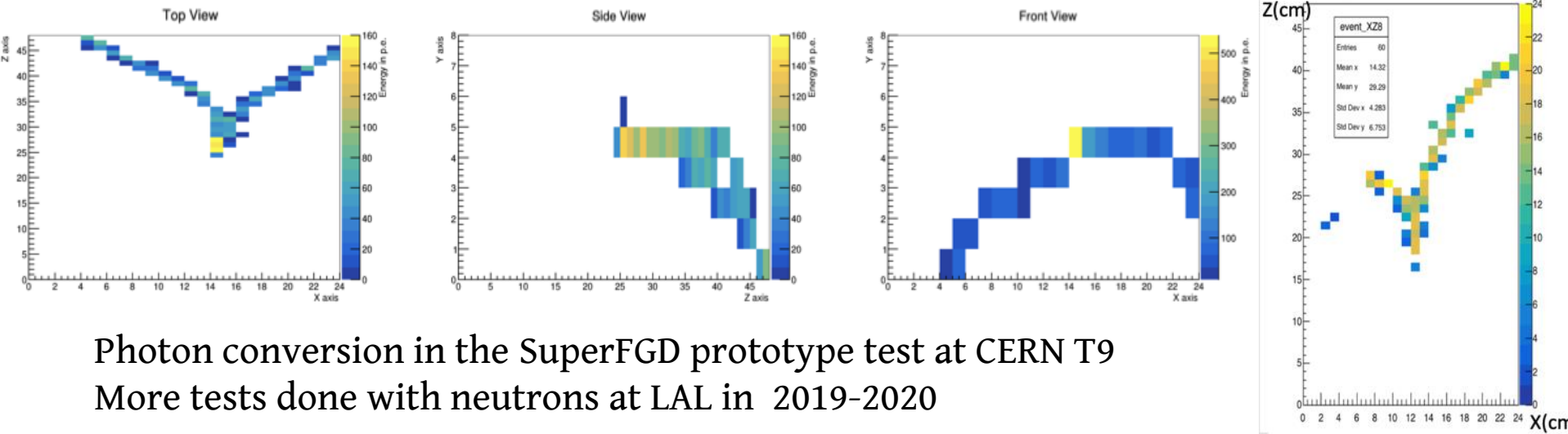
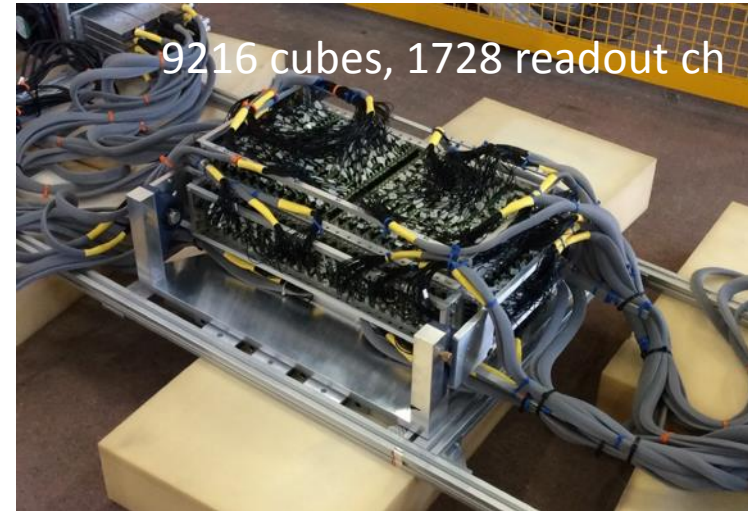
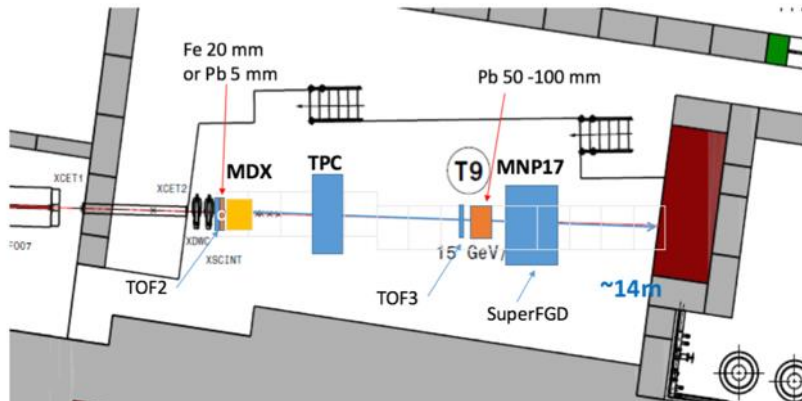


Two preamps with different gain (high and low gain) per input channel, slow shapers for charge readout, and a fast shaper together with a discriminator for timing information.

Item	Unit	Nominal
<i>System</i>		
Number of channels	[]	58368
Life term: experiment phase	[yr]	20
Life term: test/QC phase	[yr]	0.2
Expected operation fraction	[hr/year]	4000
Power requirements	[W]	<2000
<i>Beam parameters</i>		
Bunches per spill	[]	8
Bunch width (separation)	[ns]	80 (581)
Spill duration	[us]	5
Spill rate 2018 (for design)	[Hz]	0.4 (1.0)
Beam power 2018 (for design)	[kW]	500 (1300)
<i>Readout chip</i>		
Readout window beam/calibration/cosmics	[ms/spill]	0.020/100/300
Deadtime (within beam readout)	[μs/spill]	0
Deadtime (outside beam readout)	[ms/spill]	0to500
Hit amplitude dynamic range	[pe]	1500
Hit amplitude resolution 1 MIP (10 MIPs)	[pe]	2 (100)
Hit detection threshold	[pe]	0.5
Hit time resolution (1 cube)	[ns]	1
Hits per channel per spill (beam window)	[/ch/spill]	0.01
Hits per channel per spill (noise, b.w.)	[/ch/spill]	1
Hits per ROC per spill (b.w.)	[/ROC/spill]	50
<i>Material budget</i>		
FEE (if direct mount)	[% x/X <sub>0</sub> ]	2
MPPC PCB, cables, connectors	[% x/X <sub>0</sub> ]	3
<i>Environmental conditions</i>		
Operating temperature (storage)	[C]	20 (0-40)
Operating humidity (storage)	[% RH]	10
Magnetic field	[T]	0.2



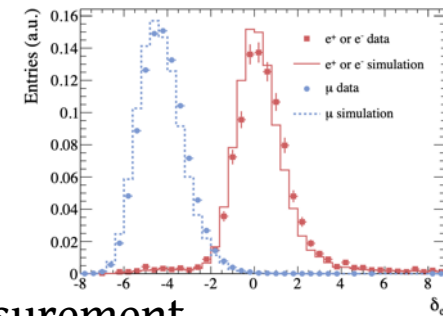
# Super Fine-Grained Detectors (FGDs)



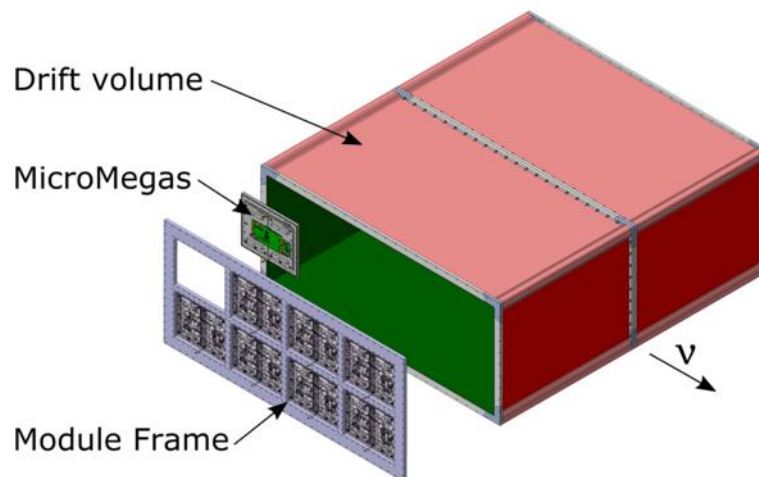
Photon conversion in the SuperFGD prototype test at CERN T9  
More tests done with neutrons at LAL in 2019-2020

# High-Angle Time Projection Chambers : HA-TPC

- ✓ Track reconstruction in 3D. Space point resolution around  $800\ \mu\text{m}$
- ✓ Charge measurement
- ✓ Momentum measurement ( $<10\%$  at  $1\ \text{GeV}/c$ )
- ✓ Particle identification by combining  $dE/dx$  with momentum measurement



**Low momentum of a few hundred MeV/c in the high angle and back**

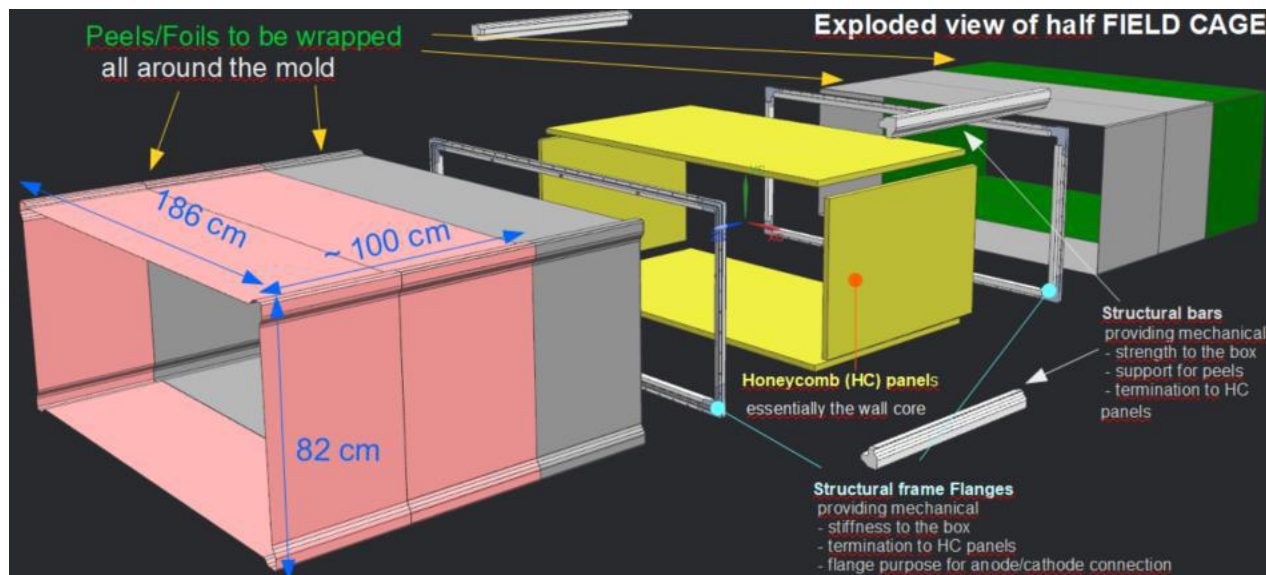


Parameter	Value
Overall $x \times y \times z$ (m)	$2.0 \times 0.8 \times 1.8$
Drift distance (cm)	90
Magnetic Field (T)	0.2
Electric field (V/cm)	275
Gas $\text{Ar-CF}_4\text{-iC}_4\text{H}_{10}$ (%)	95 - 3 - 2
Drift Velocity $\text{cm}/\mu\text{s}$	7.8
Transverse diffusion ( $\mu\text{m}/\sqrt{\text{cm}}$ )	265
Micromegas gain	1000
Micromegas dim. $z \times y$ (mm)	$340 \times 410$
Pad $z \times y$ (mm)	$10 \times 11$
N pads	36864
el. noise (ENC)	800
S/N	100
Sampling frequency (MHz)	25
N time samples	511

# High-Angle Time Projection Chambers : HA-TPC

## Field Cages :

- ✓ Dielectric, low-Z materials
- ✓ Composite materials techniques
- ✓ Thin walls laminated on a mold
- ✓  $\sim 4\%$   $X_0$  material budget



275 V/cm

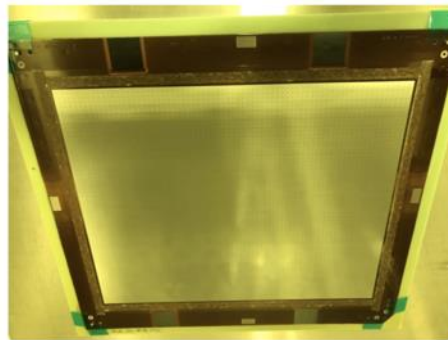
27 KV

TPC operated at atmospheric pressure

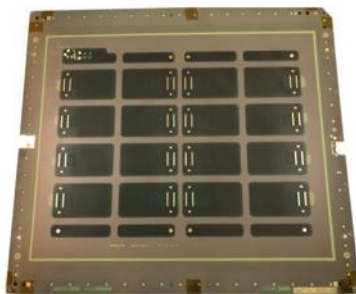
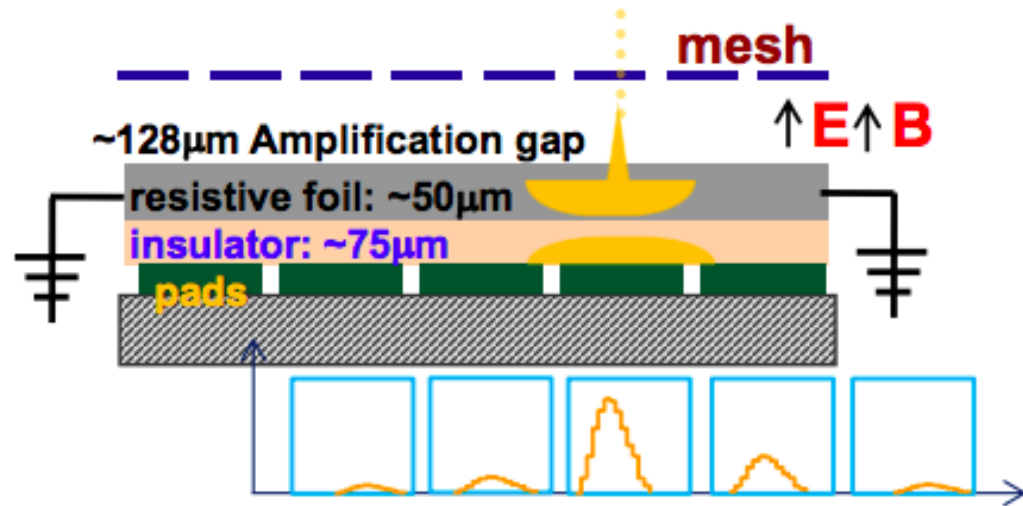


# High-Angle Time Projection Chambers : HA-TPC

- 8 resistive MMs per volume

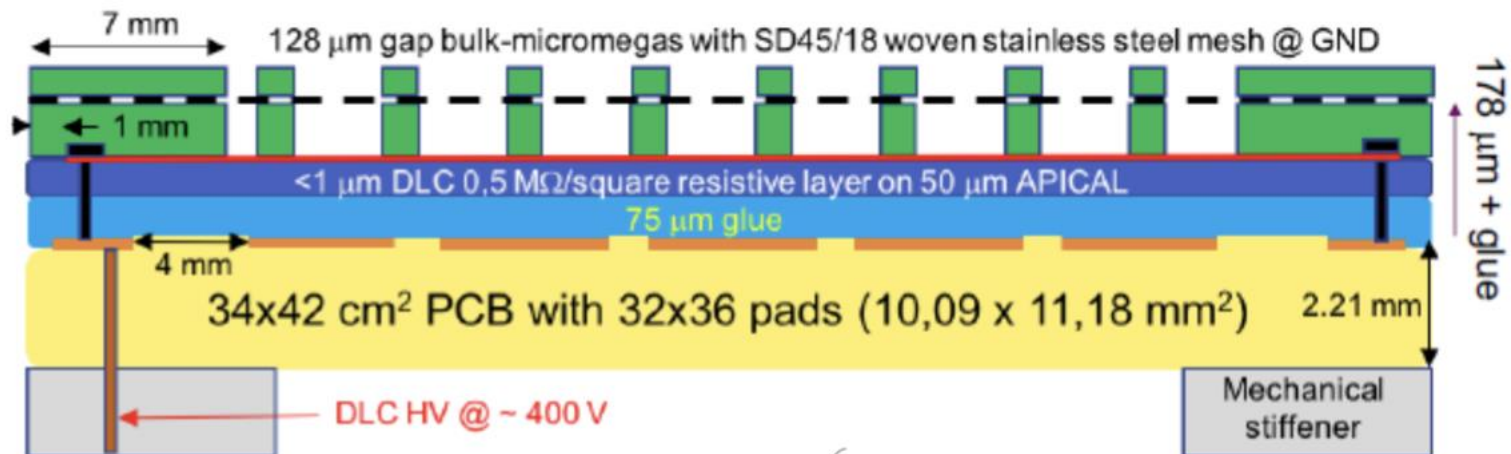


Bulk-micromegas side



Connector side

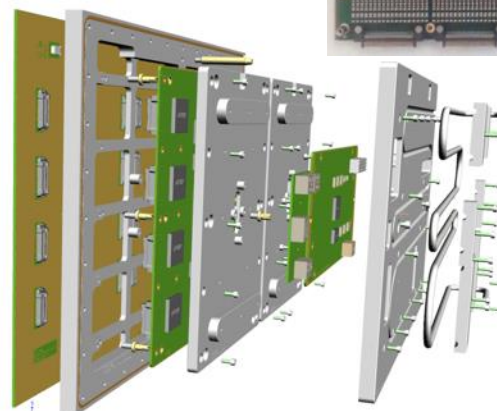
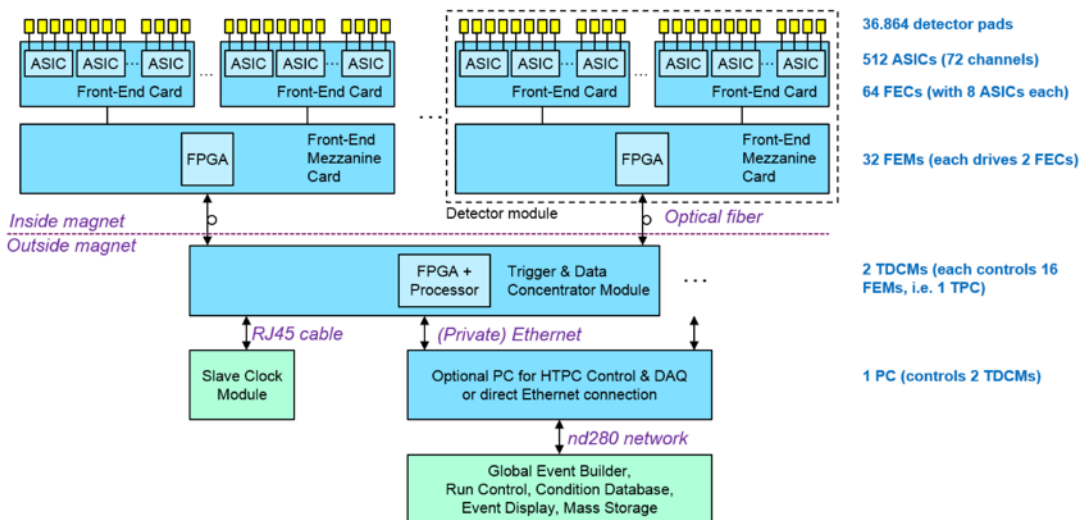
Resistive Micromegas technology chosen as baseline



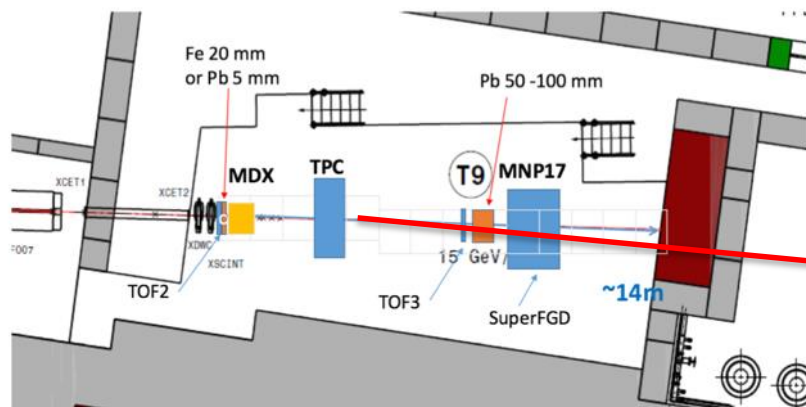
# High-Angle Time Projection Chambers : HA-TPC

32 Micromegas detector modules, each detector module holds 3 types of boards:

- Two Front-End Cards(FECs), with 576-channel each. These capture the analog signals of the 1152 pads of the detector module and convert the acquired samples in digital format using an octal-channel analog to digital converter (ADC).
- A Front-End Mezzanine card(FEM). This controls the 2 FECs and performs elementary data processing as baseline offset correction, zero-suppression and temporary data storage.
- A Power Distribution Card (PDC). This performs local conversion of the supplied voltage (e.g. 24 V) to 4-5V used by the FECs and the FEM.

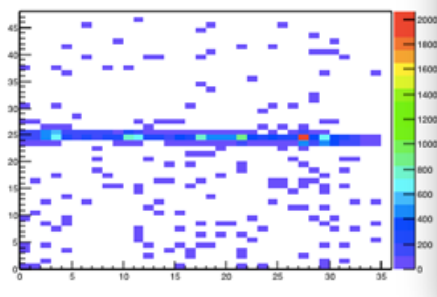


# High-Angle Time Projection Chambers : HA-TPC

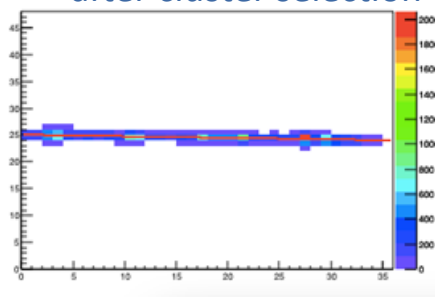


Muon track

before cluster selection

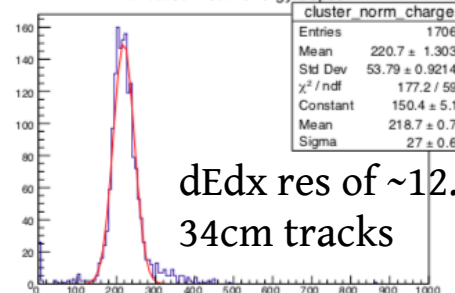


after cluster selection



Muons dEdx

Truncated mean energy deposit



dEdx res of ~12.3% for  
34cm tracks

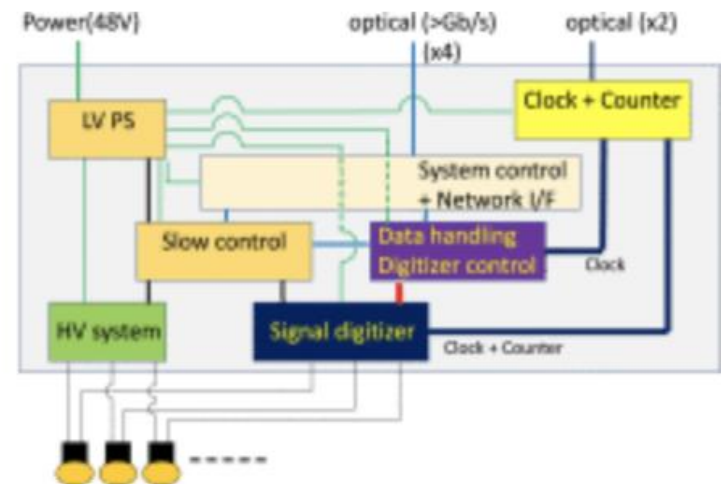
Test at the CERN T9 beam. Micromegas MM0 mounted on the HARP field cage

Test at Desy : Spatial resolution ~150 $\mu$ m , dE/dx resolution 7%

## HK Large area PMT optimization

The inner detector will be instrumented with 40'000 large area photo-detectors (50 cm diameter).

- 3 20" device candidates under investigation
- Optimize sensors cover (SS or Polyphenylen-sulfide or carbon fibers)
- Plan to put all front-end electronics in a water-tight case, submerged in water. The digitizing electronics will be close to the photo-sensors, so that cable lengths will be reduced





# HK and T2K Challenges:

- ✓ Major underground excavation and civil engineering for HK
- ✓ Important extension and upgrade of the T2K and HK near detectors
- ✓ Very short time scale for the ND280 near detector for the next T2K running period.
- ✓ Completely new approach to an intermediate Water Cherenkov detector, with new optimized photon detector concepts and new water doping possibilities
- ✓ Some of the learning from the IWCD might extend to HK components
- ✓ Very diversified Near Detector complex, with various technologies
- ✓ Important effort on new types of materials, new front end electronics components and PMTs applications. All R&Ds are followed by test beams qualification.

# Summary

- ✓ A new research period and new facilities are opening in oscillation neutrino accelerator physics with very large construction plans over almost 1 decade
- ✓ In both programs the complexity of the detectors is increasing by an order of magnitude. Much bigger far detectors, more diversified near detectors. More dependences from industrial projects / initiatives
- ✓ Many new steps on a variety of activities (large vessels, extreme cryogenic conditions, many aspects of target material purity, new type of materials, novel front end electronics components, new generation of event reconstruction techniques, ...
- ✓ Proper engineering approaches, both structural and electrical, are becoming more important in the community, in particular for all what concerns integration and installation underground

# Summary

- ✓ Schedules are aggressive, but possible!
- ✓ The community has adopted the concept of test beams to test and qualify the performance of what has been built (ProtoDUNE as an example for DUNE, CERN NP in several T2K/HK cases)
- ✓ The community is growing and it will compete in size with the LHC community. Most FAs will be involved in both programs (LHC/Neutrino)
- ✓ Costs are increasing and resources will become a competition between the Neutrino community and the rest of the IHEP community. All this requires a proper regulation to avoid surprises. R&D efforts are already playing an important part of it!
- ✓ Photon detectors and PCBs type of readout technology (Micromegas, pixels, perforated strips,...) and related front end micro electronics represent the core of the R&D activity