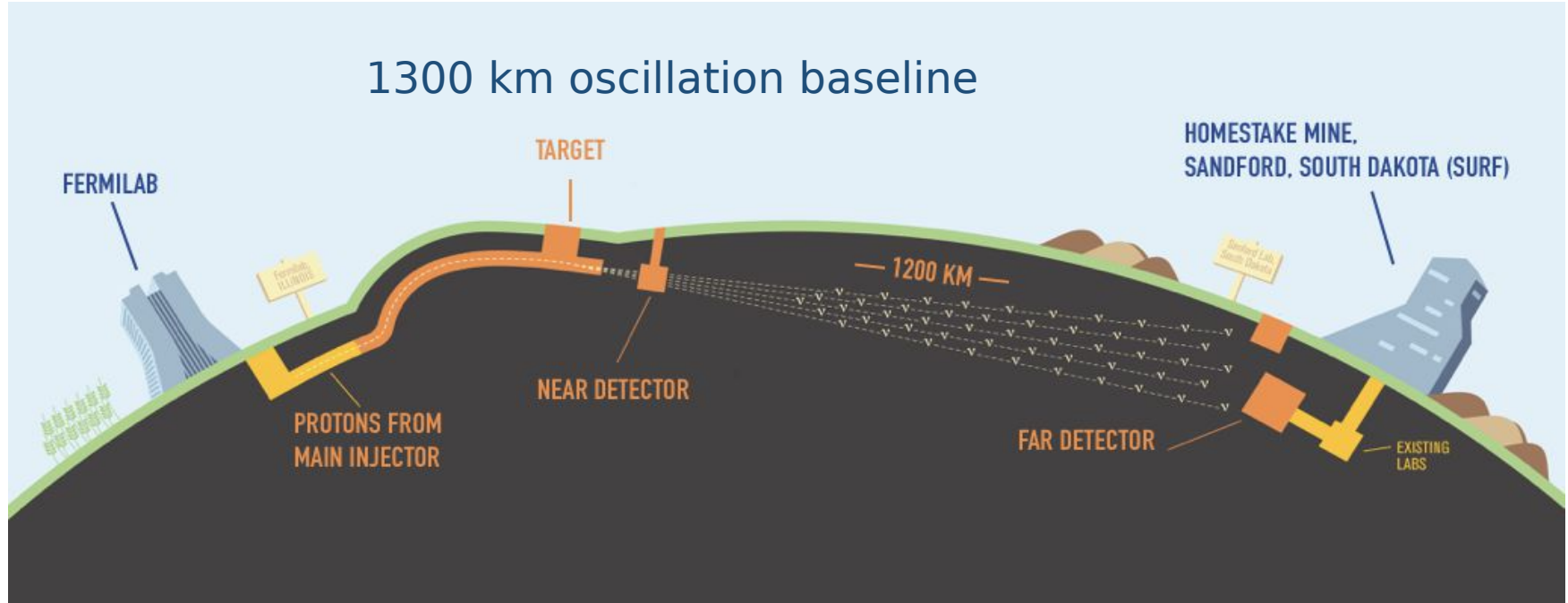


# Status of protoDUNE Dual Phase

Jaime Dawson on behalf of the DUNE collaboration

# DUNE Physics



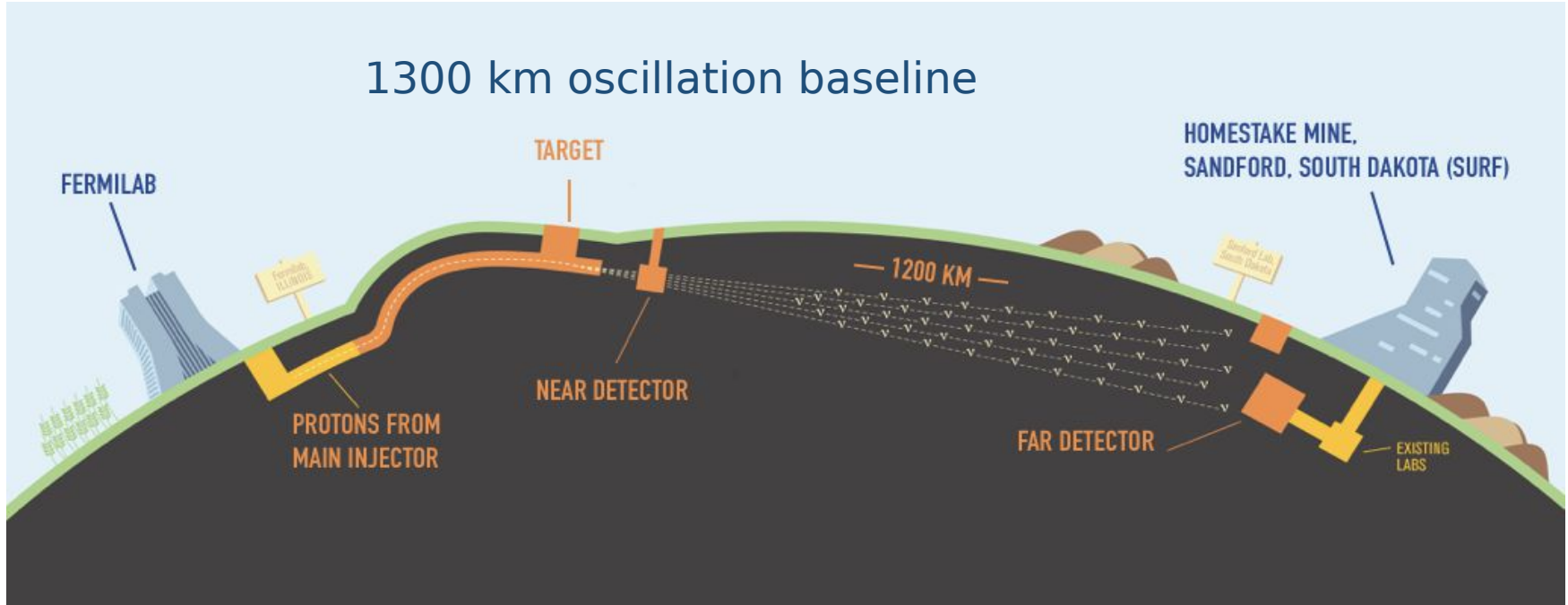
## DUNE is a next-generation neutrino oscillation experiment

### Physics goals :

- Neutrino oscillations : measure  $\nu_\mu$  disappearance +  $\nu_e$  and  $\nu_\tau$  appearance (both neutrino and anti-neutrino modes)
- **Mass Ordering, leptonic CP Violation discovery,  $\theta_{23}$  octant and more in a single experiment + physics beyond the Standard Model**
- Large underground detectors : **Nucleon Decay searches, SuperNovae core collapse etc**

# DUNE Physics

1300 km oscillation baseline



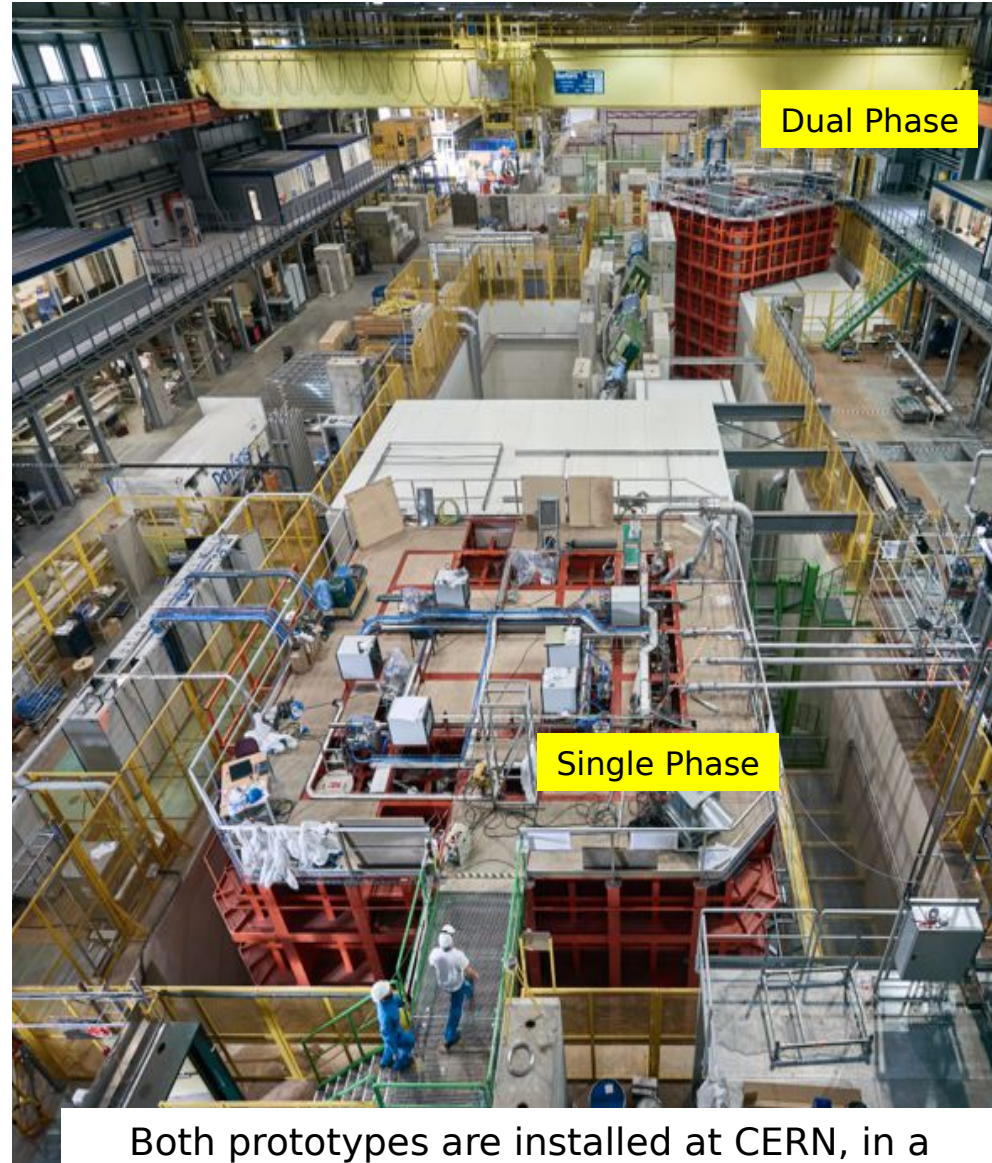
1.2 MW wide-band beam from Fermilab (upgradable to 2.4 MW)

Near Detector to measure initial composition

Far detectors at SURF :  
4 x 10kt (fid) Liquid Argon TPCs  
1.5 km underground  
Two modules to be ready by 2024

# protoDUNE

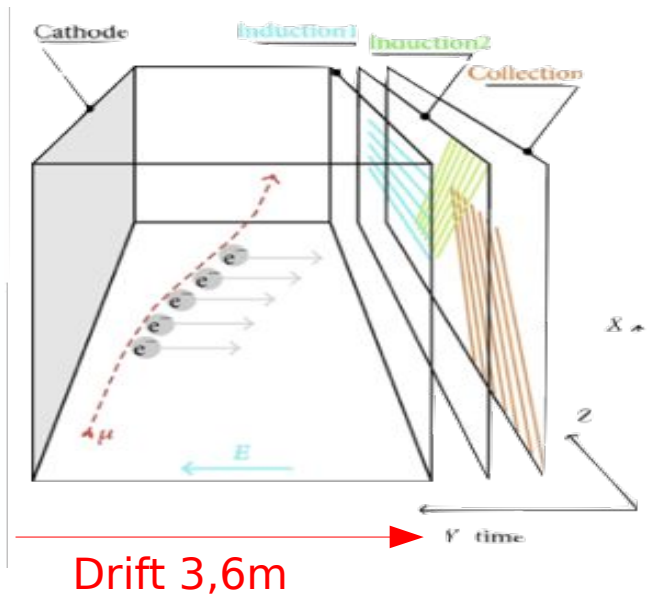
- Giant Liquid Argon TPCs (LArTPC) – one Single-Phase, one Dual-Phase
- hosted at the CERN neutrino platform
- Necessary R&D step towards the DUNE Far Detectors
  - Tests of all engineering solutions and installation procedures
  - Use full-size components identical to those planned for DUNE FD
- 300t fiducial mass of LAr
  - Technology demonstrators
  - Demonstrate long term performance and stability
- Charged particle test beams to characterise detector response over the energy range of interest for DUNE ( $\sim 0.5$  GeV to 8 GeV)



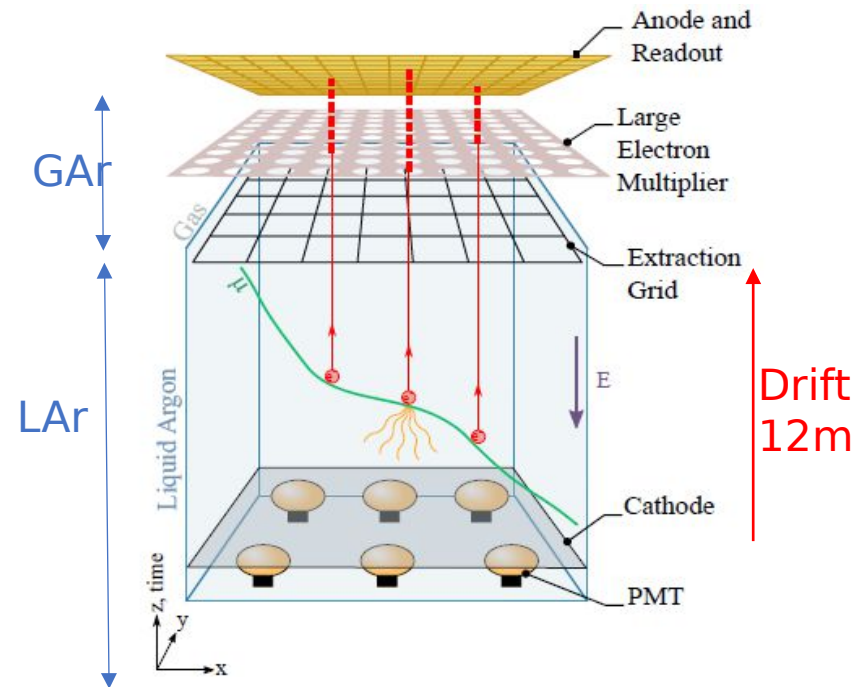
Both prototypes are installed at CERN, in a dedicated extension of the North Area

# Single Phase - Dual Phase

- Horizontal drift, distance 3.6 m
- Anode wires immersed in LAr
- Vertical Anode and Cathode Plane Assemblies (APA, CPA)
- 1 collection, 2 induction wires at  $37.7^\circ$  wire pitch 5 mm
- Photon detectors: light guides + SiPM, embedded in APAs



- Vertical drift, distance 12 m
- Ionization electrons extracted from LAr to gaseous volume
- Signal amplified in GAR by Large Electron Multiplier (LEM)
- Charge collected on 2 orthogonal views, 3 mm pitch
- Photon detectors: PMTs below the cathode



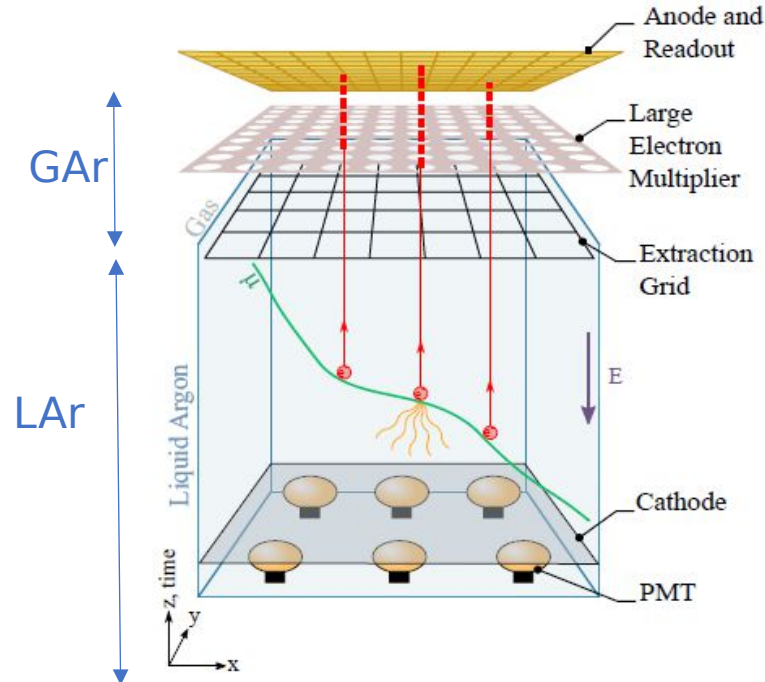
# Single Phase - Dual Phase

In Liquid

**Ionization:** ~8k electrons/mm from a mip

**Recombination:** electrons captured by their parent ions

**Lifetime:** electrons captured by impurities during drift



In Gas

**Extraction:** probability of extraction > 90%

**Amplification:** Townsend avalanches of electrons

Nominal Eamp is 33 kV/cm and ENC is 1500 electrons

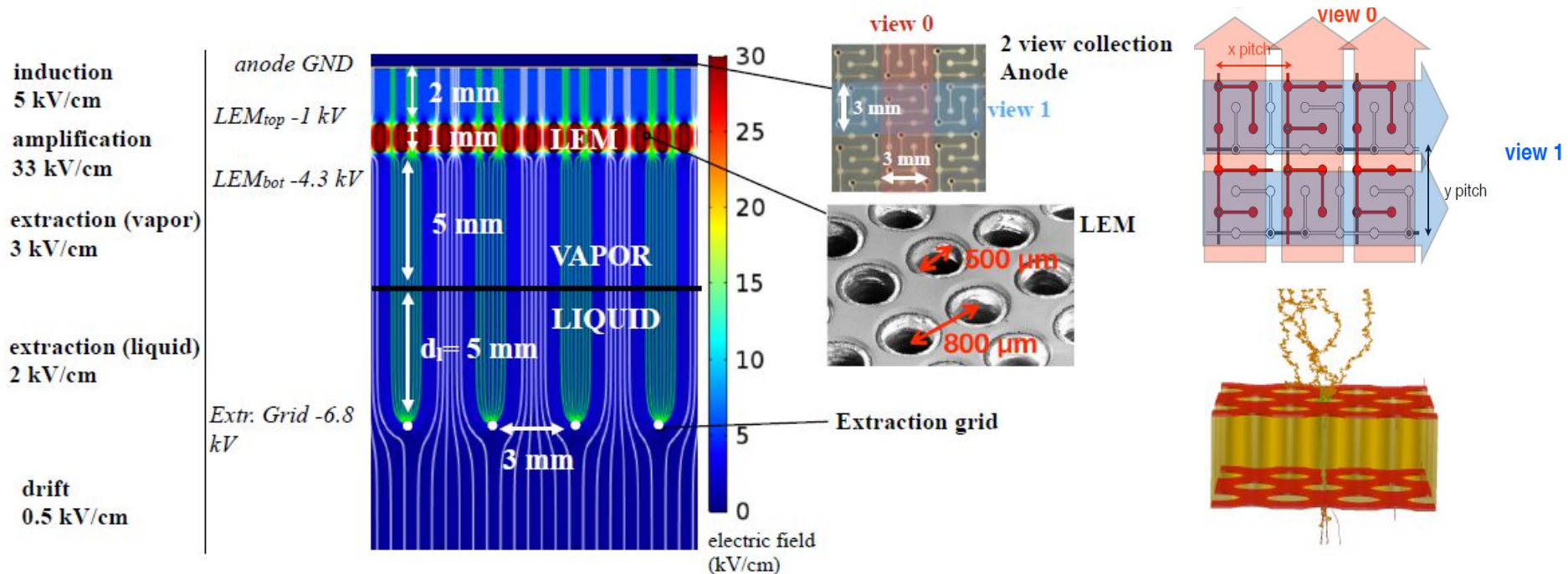
**S/N > 10 for a mip on both views**

Single Phase measures 6ms lifetime!

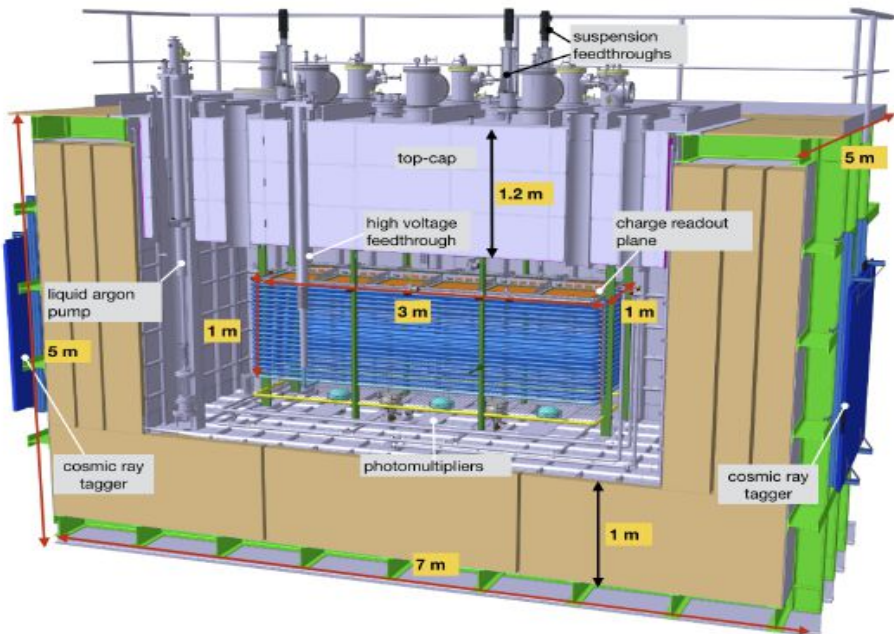
# Charge Read Out Planes

Each CRP is 3m x 3m and contains:

- 1 x Extraction Grid
- 36 x Large Electron Multipliers (0.5m x 0.5m)
- 36 x Anodes



# Dual-Phase 4t demonstrator



3x1x1 m<sup>3</sup> (4t) fiducial volume,  
installed at CERN  
500k cosmic events in summer-fall  
2017

First results on

- charge amplification
- light detection
- LAr purity

**arXiv:1806.03317 [ins-det]**

**B. Aimard et al, 2018, JINST 13, P11003**



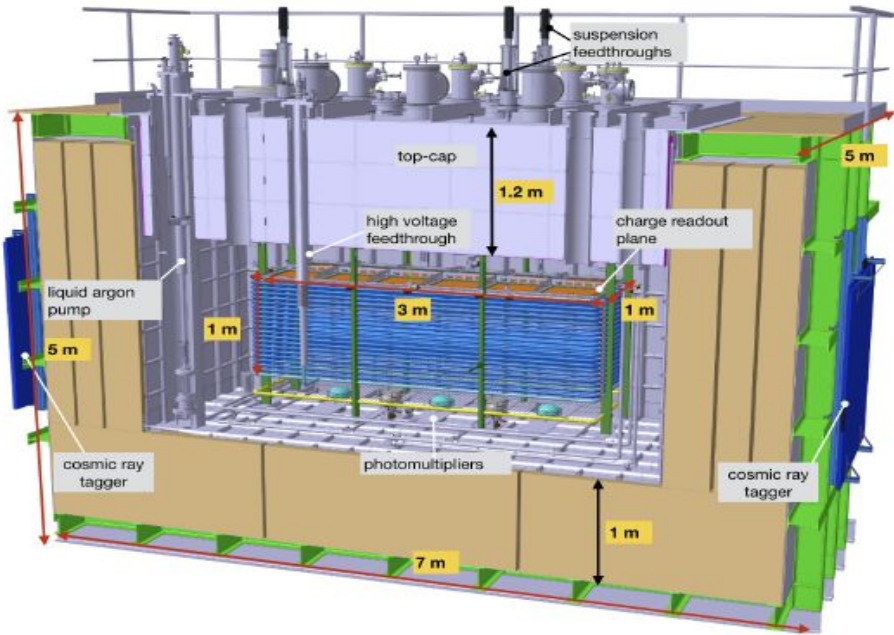
Technical problems encountered with

- Extraction Grid
- LEM HV

Gain needed for DUNE could not be  
demonstrated

Issues addressed for protoDUNE

# Dual-Phase 4t demonstrator

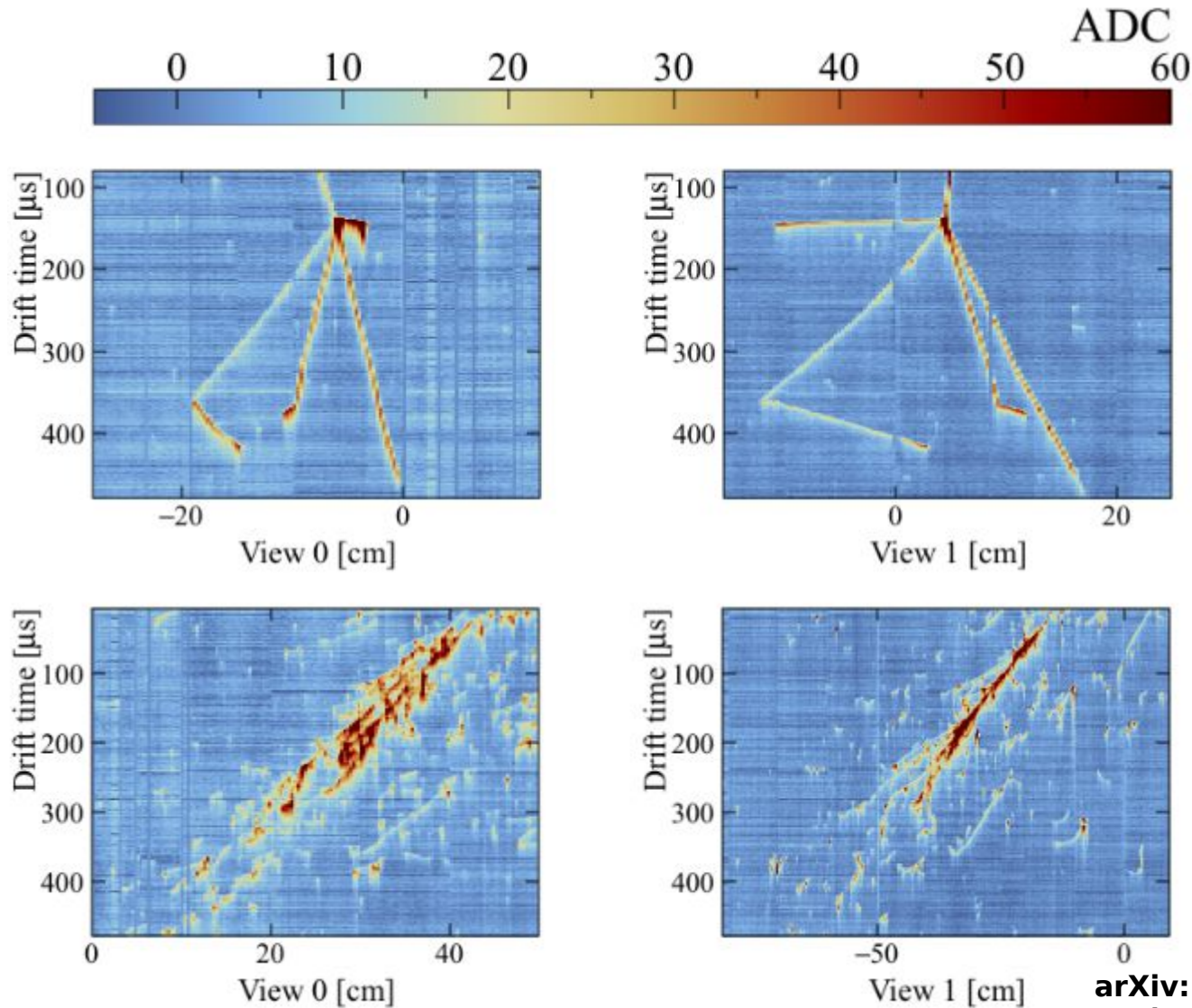


Several milestones achieved

- LAr level stability over time
- Stable drift field for entire operation
- Equal charge splitting at the anode
- Purity compatible with a 4ms electron lifetime



# Dual-Phase 4t demonstrator

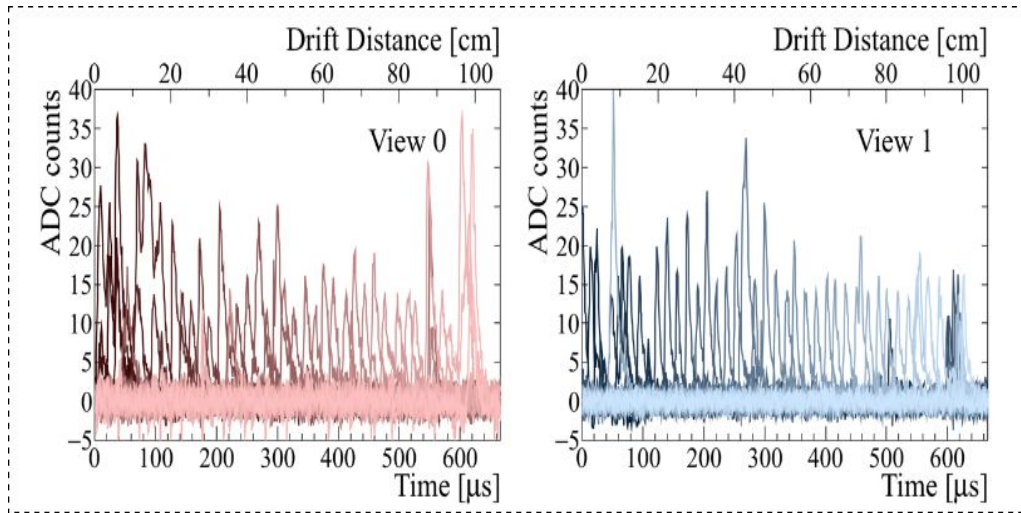
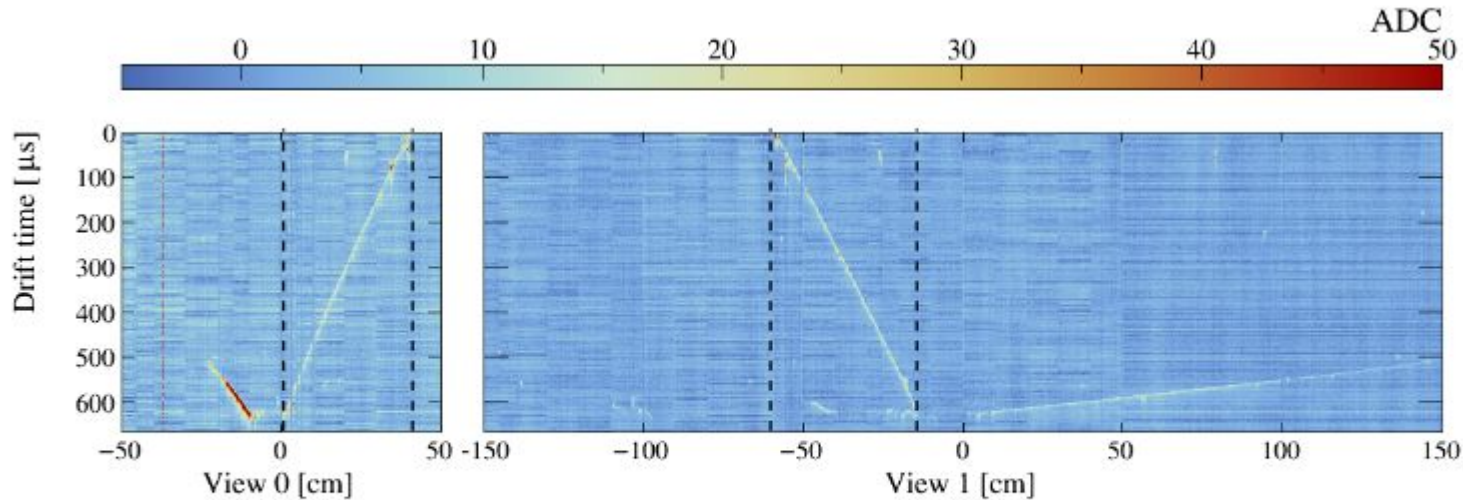


Hadronic shower

Electronic shower

arXiv:1806.03317 [ins-det]  
B. Aimard et al, 2018, JINST 13, P11003

# Dual-Phase 4t demonstrator



Through-going muon

arXiv:1806.03317 [ins-det]  
B. Aimard et al, 2018, JINST 13, P11003

# Dual-Phase 4t demonstrator

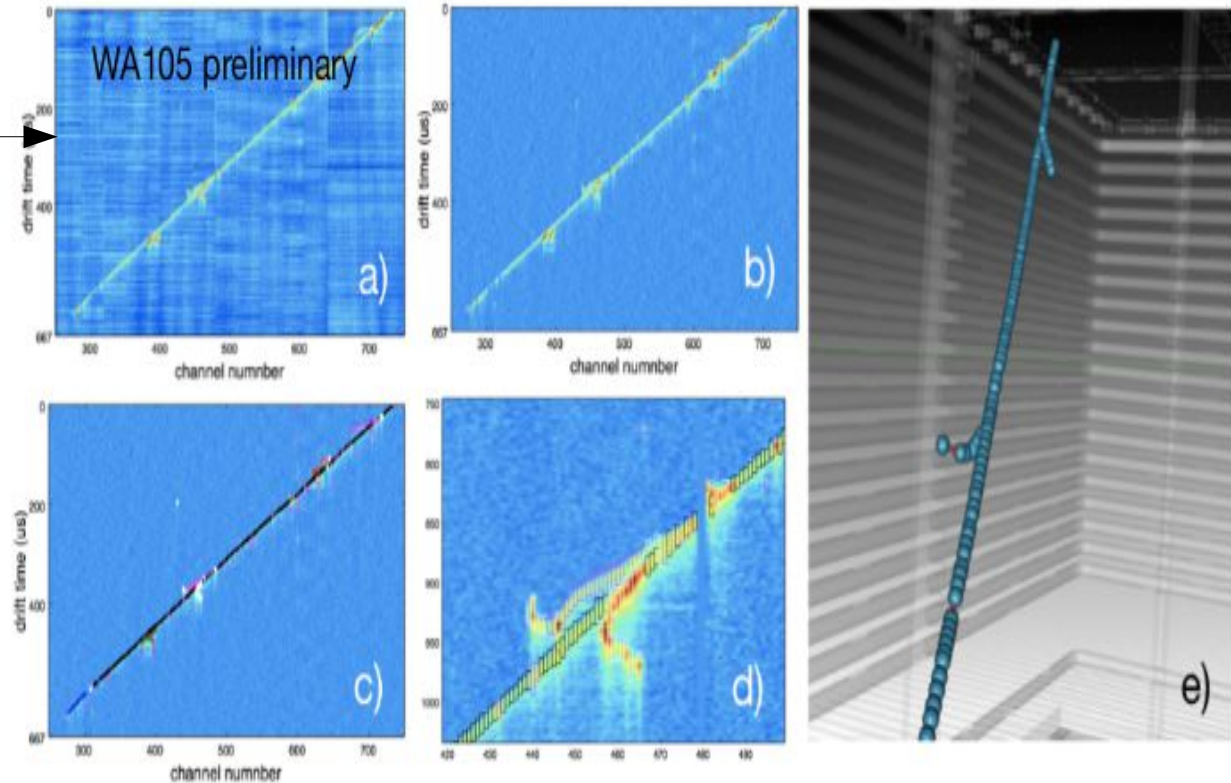
Analysis is ongoing includes:

Noise filtering  
3D reconstruction  
Track selection

Study of the LEM  
amplification and S/N ratio

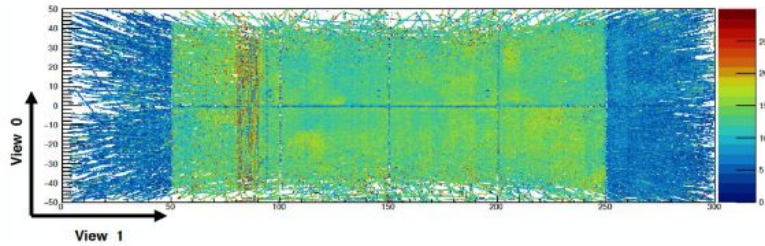
Electric field uniformity and  
Space charge effects

Studies on Light Signal

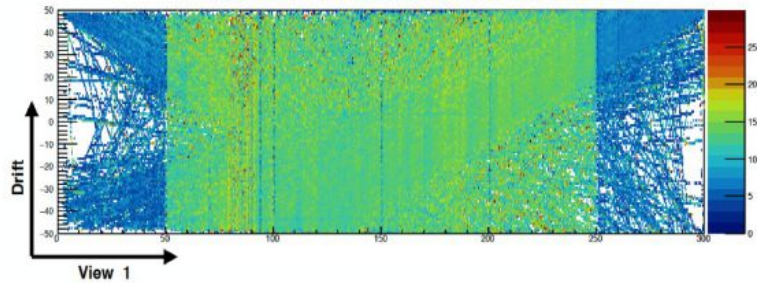


# Dual-Phase 4t demonstrator

$\langle dQ/dS \rangle$  uniformity across the CRP



$\langle dQ/dS \rangle$  uniformity along the drift



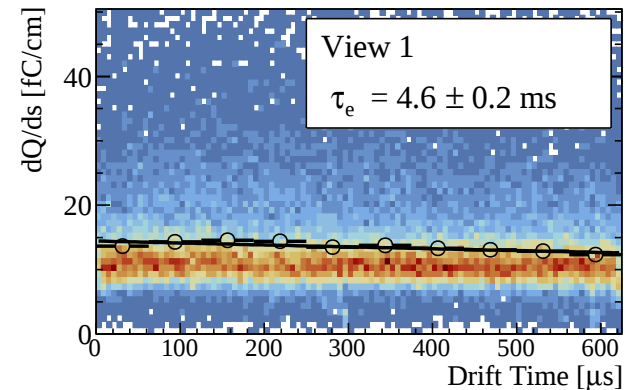
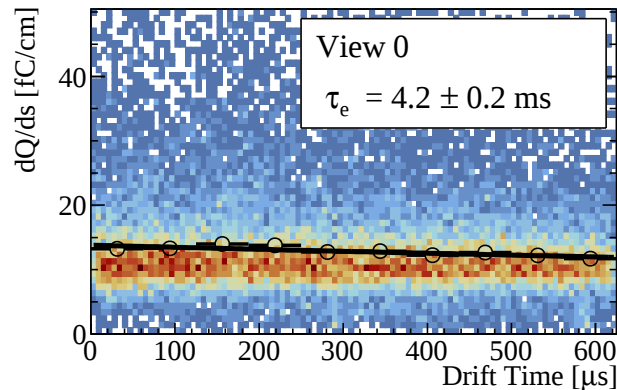
500k cosmic events in summer-fall 2017  
example crossing muons

Using through-going muon tracks (top to bottom)

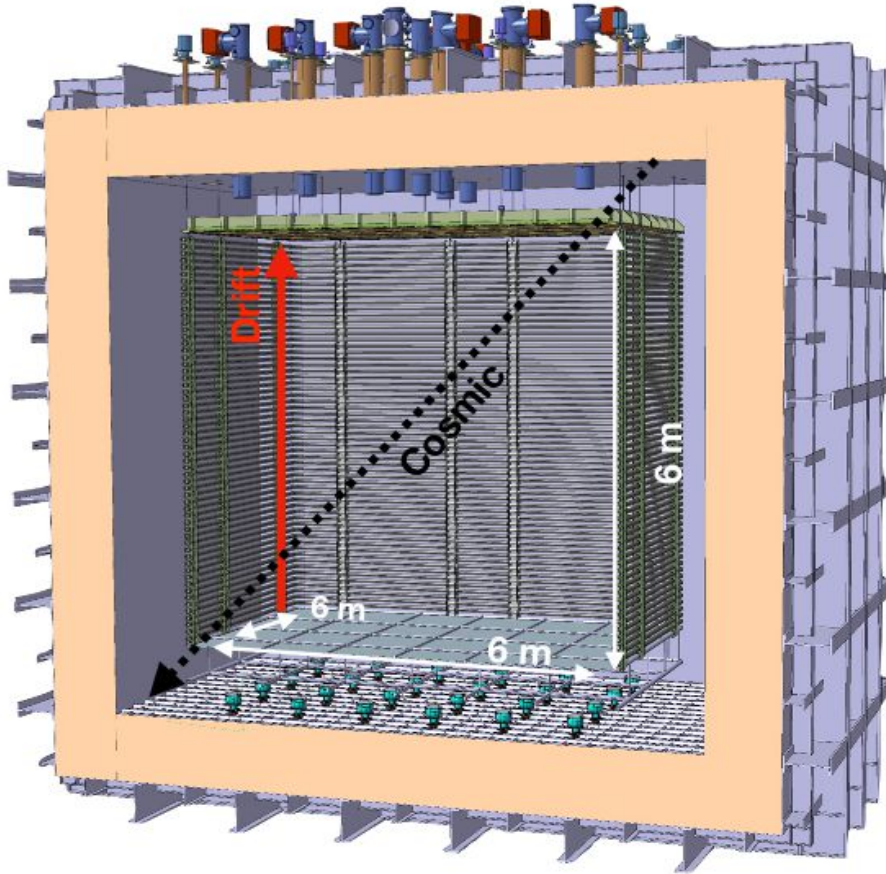
And 3D reconstruction

Calculate  $dQ/dS$  for each hit of track

**Indicates electron lifetime**



# ProtoDUNE Dual Phase



Fiducial mass is 300t

Half the drift length of DUNE FD  
Drift field 0.5 kV/cm  $\rightarrow$  -300 kV  
on cathode

Expected S/N > 20

36 photomultipliers

DUNE Interim Design Report  
Dual Phase - arXiv:1807.10340

# Drift Field



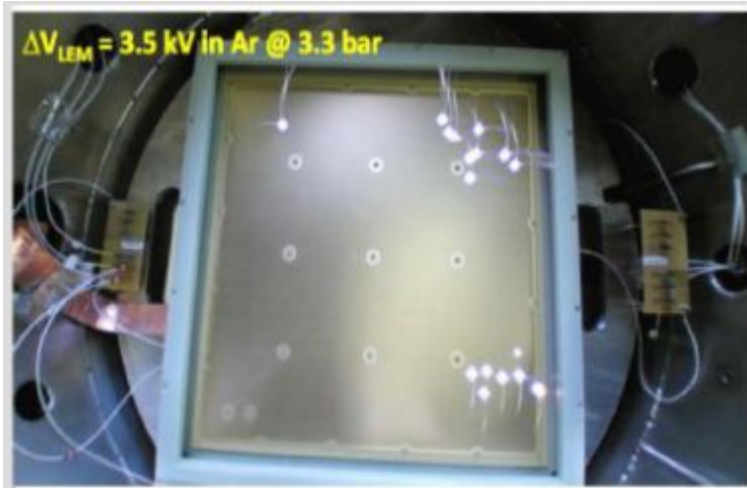
Drift field objective is 0.5 kV/cm  
-300 kV on Dual-Phase cathode  
Cathode design is modular (3m x 3m)  
60% optical transparency  
Maximum local field requirement  
<30kV/cm

High Voltage feedthrough based on  
ICARUS design same from Single/Dual-  
phase

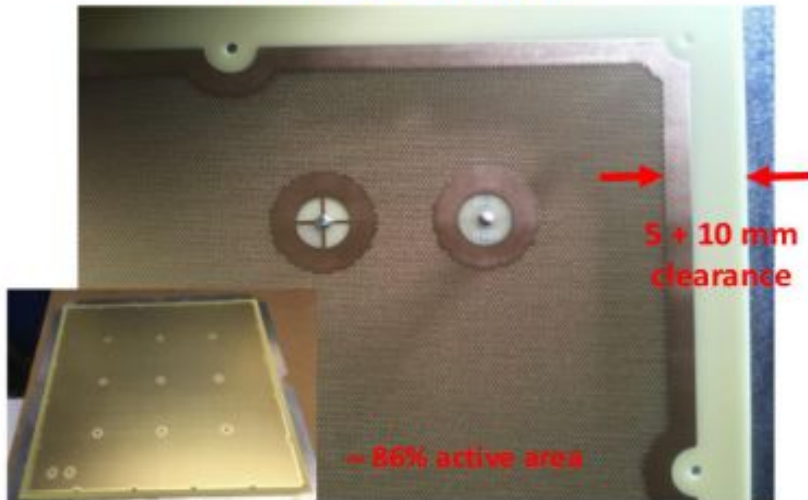
HV extender-degrader delivers HV to field  
rings and cathode

- April 2018 : field cage completed, stable operation at 150 kV in middle of cathode, ground on top and bottom
- Demonstrated OK for 0.5 kV/cm

# Large Electron Multiplier



**CFR-35 – NP02**



LEM s are tested in gaseous argon  
3 types have been tested (CFR-34, 35, 36)

Arrived at a LEM design:  
No trips > 64h  
No sparks  
Effective gain > 20

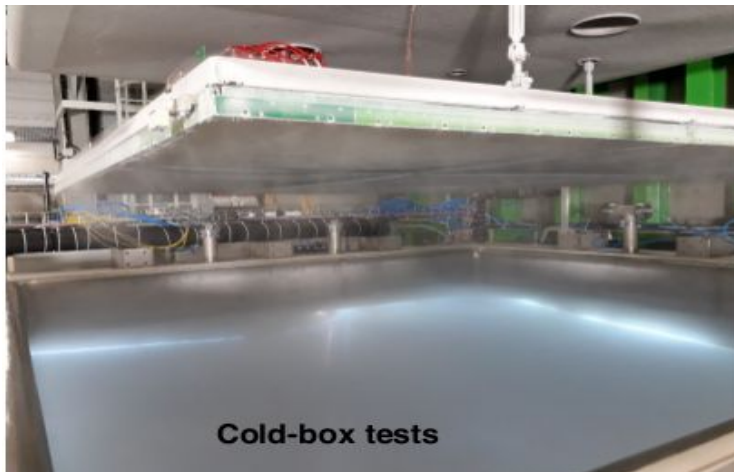
Further optimisation of active area possible

# Charge Read-Out Planes:



CRP assembly in clean room

- June 2018 : first Charge Readout Plane (CRP) assembly completed
- August 2018 : first CRP cold-box test completed



Cold-box tests



CRP testing in cold box

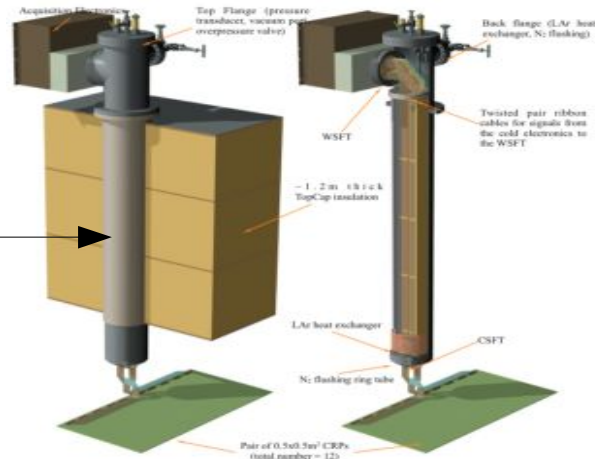
# Accessible Cold Electronics

Specially developed signal chimneys

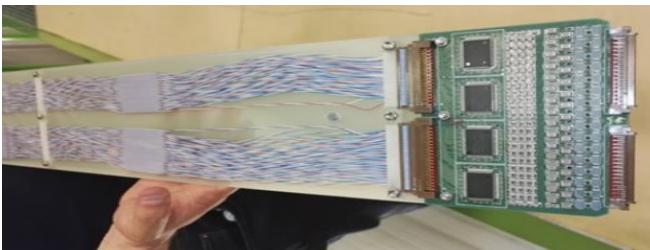
- 16-channel Cryogenic ASIC amplifiers close to the anodes but are also externally accessible!

On the tank deck (warm):  
digital electronics

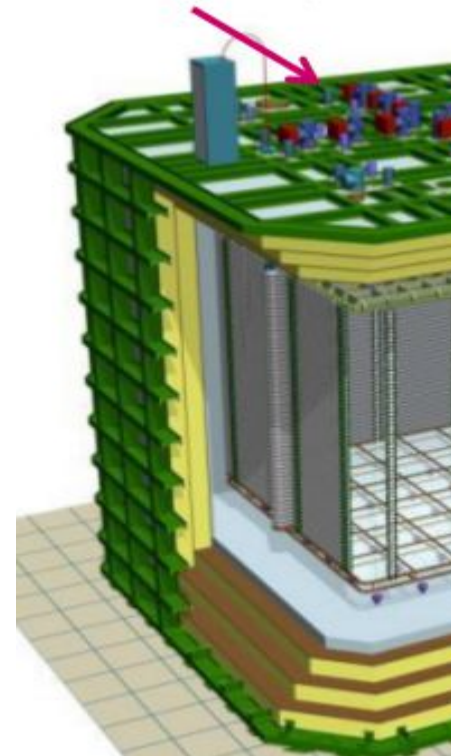
- Based on uTCA standard
- 1 uTCA crate/ signal chimney
- AMC card – 64 channels, 12 bit ADC, 2.5 MHz
- 10 AMC cards (64 channels/card)
- Total of 12 uTCA crates (7,680 channels)



Front End cards mounted on insertion blades



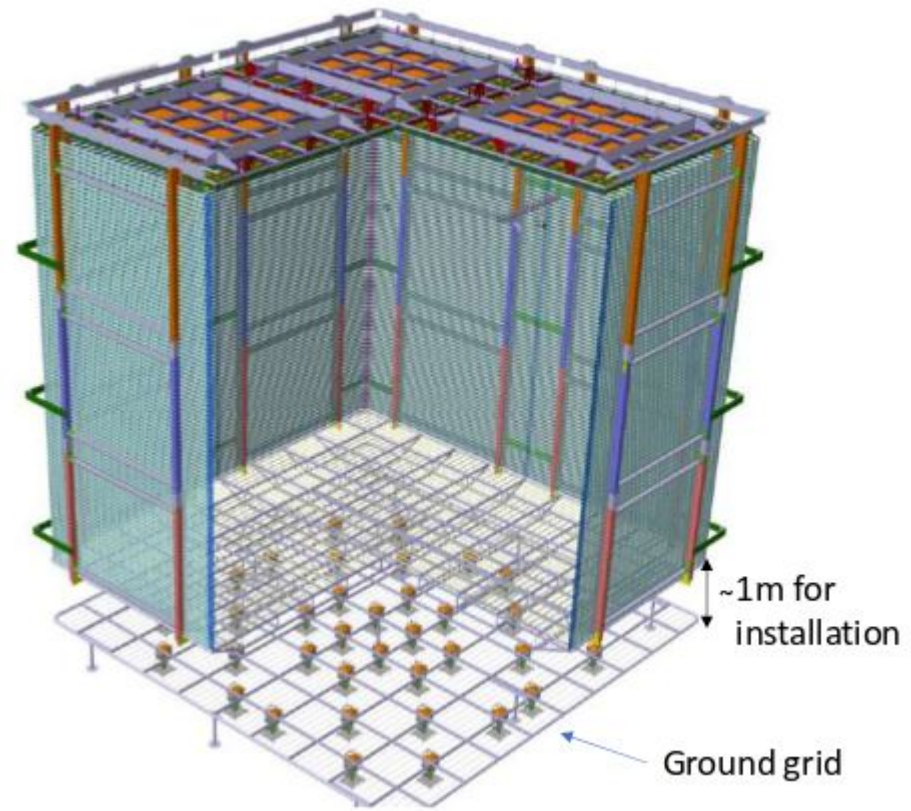
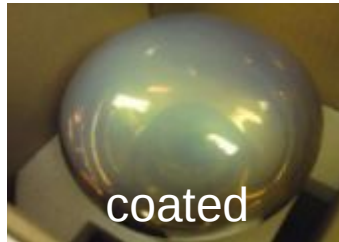
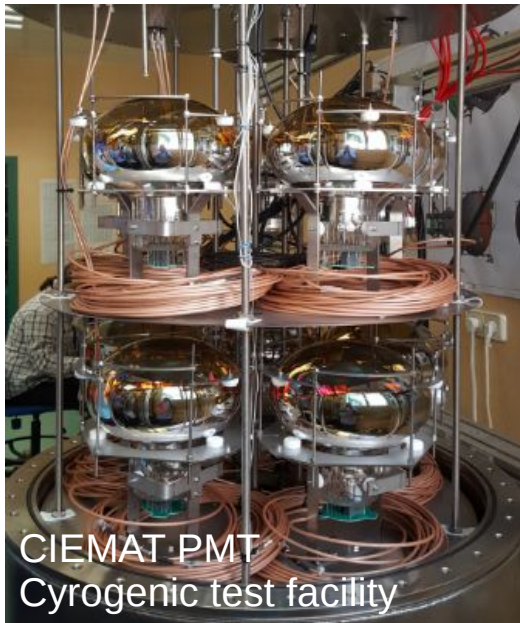
Successfully tested on the  
4t demonstrator



# Light Read Out

Light signal gives the  $t_0$  of an event  
→ determines the  $z$  co-ordinate

36 PMTs (Hamamatsu R5912-02  
MOD 8 inch) coated with TPB – as  
used in 4t demonstrator



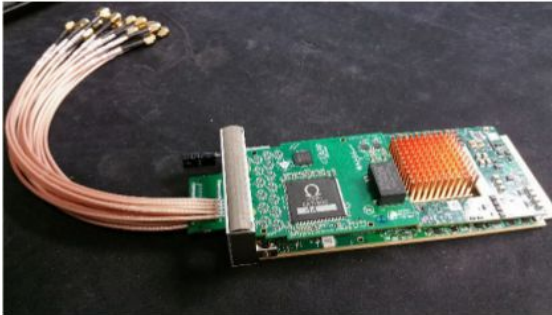
PMTs are at CERN

Calibration system using fibres

PMTs to be tested before installation

# Light Read-Out

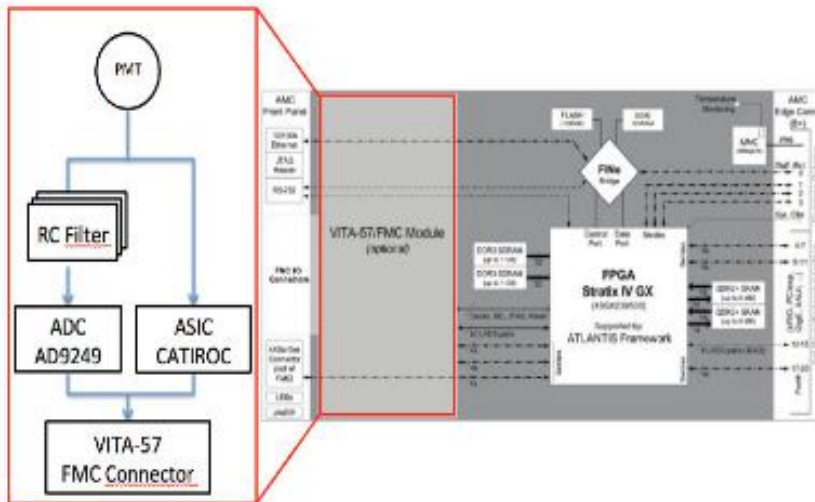
1uTCA crate for Light Read-Out electronics  
Designed to integrate into Global DAQ



Under-development  
16 channels  
Anti-aliasing low pass filter

**ADC:** AD9249 65 MHz, 14 bits provides waveform with a window of  $\pm 4$ ms around beam trigger down-sampled to 400 ns

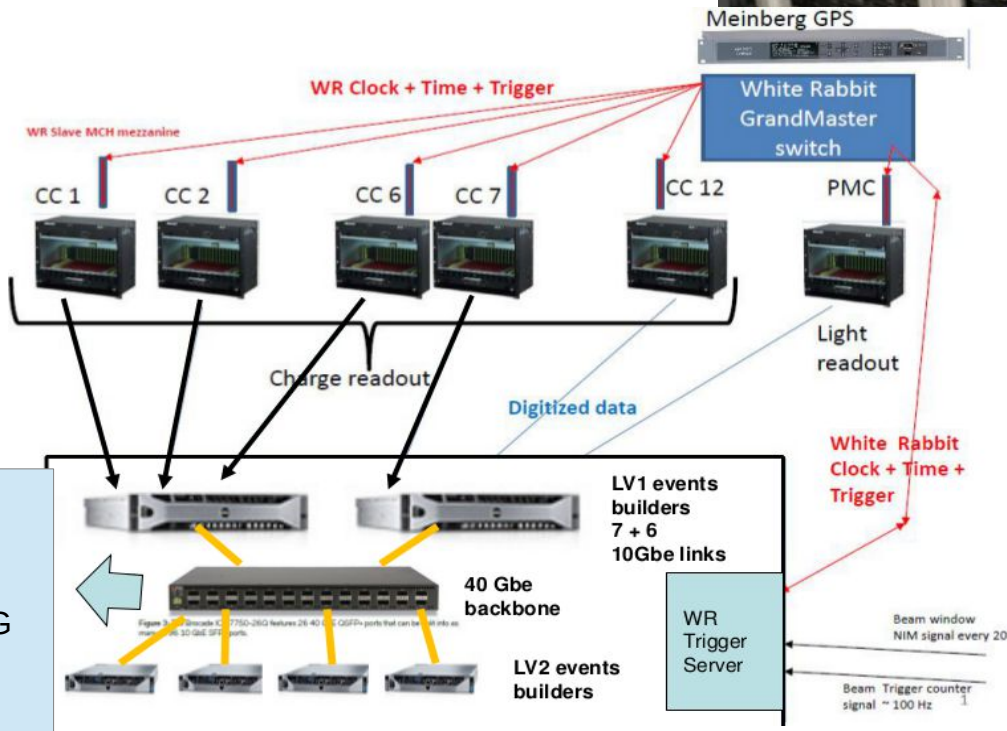
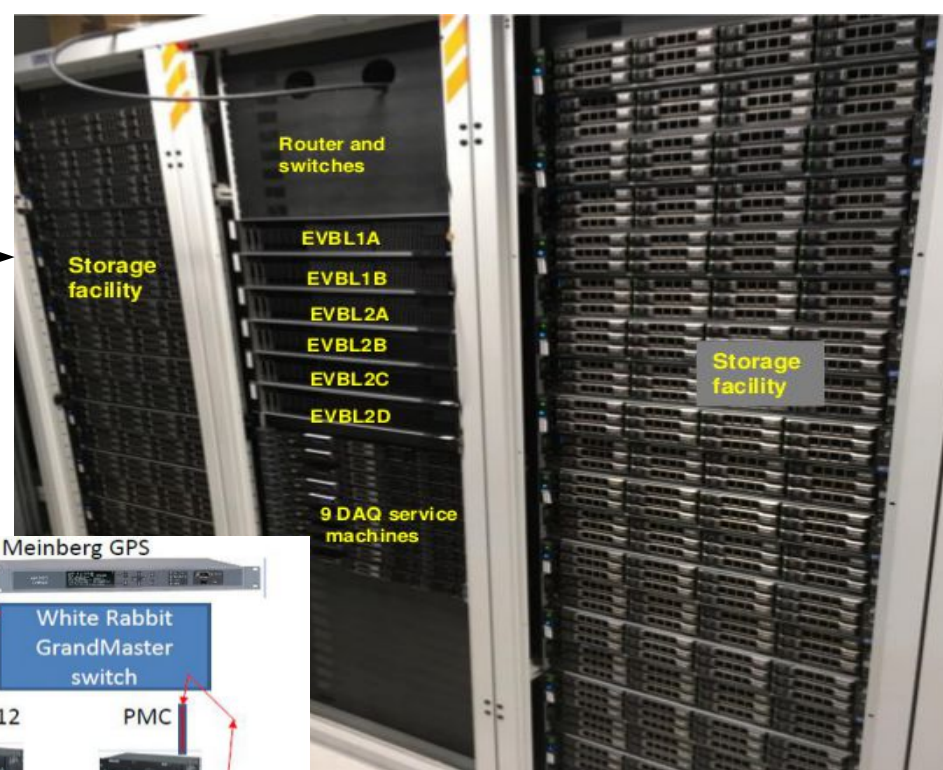
**ASIC:** CATIROC  
Provides auto-triggered channel-wise Q, t and generates light trigger



# Global DAQ

Inside the NP-02 DAQ room

All electronics/DAQ for protoDUNE  
Dual-Phase CRPs in-hand



# Conclusion

- Construction of ProtoDUNE Dual-Phase is nearing completion
  - Main detector components to be installed by end of February 2019
  - Cryostat closure by end of March 2019
- Will allow
  - Realistic testing of all parts proposed for DUNE FD
  - Including installation procedures
  - Detector response determined with cosmic ray muons
  - Performance characterisation and comparison with Single-Phase

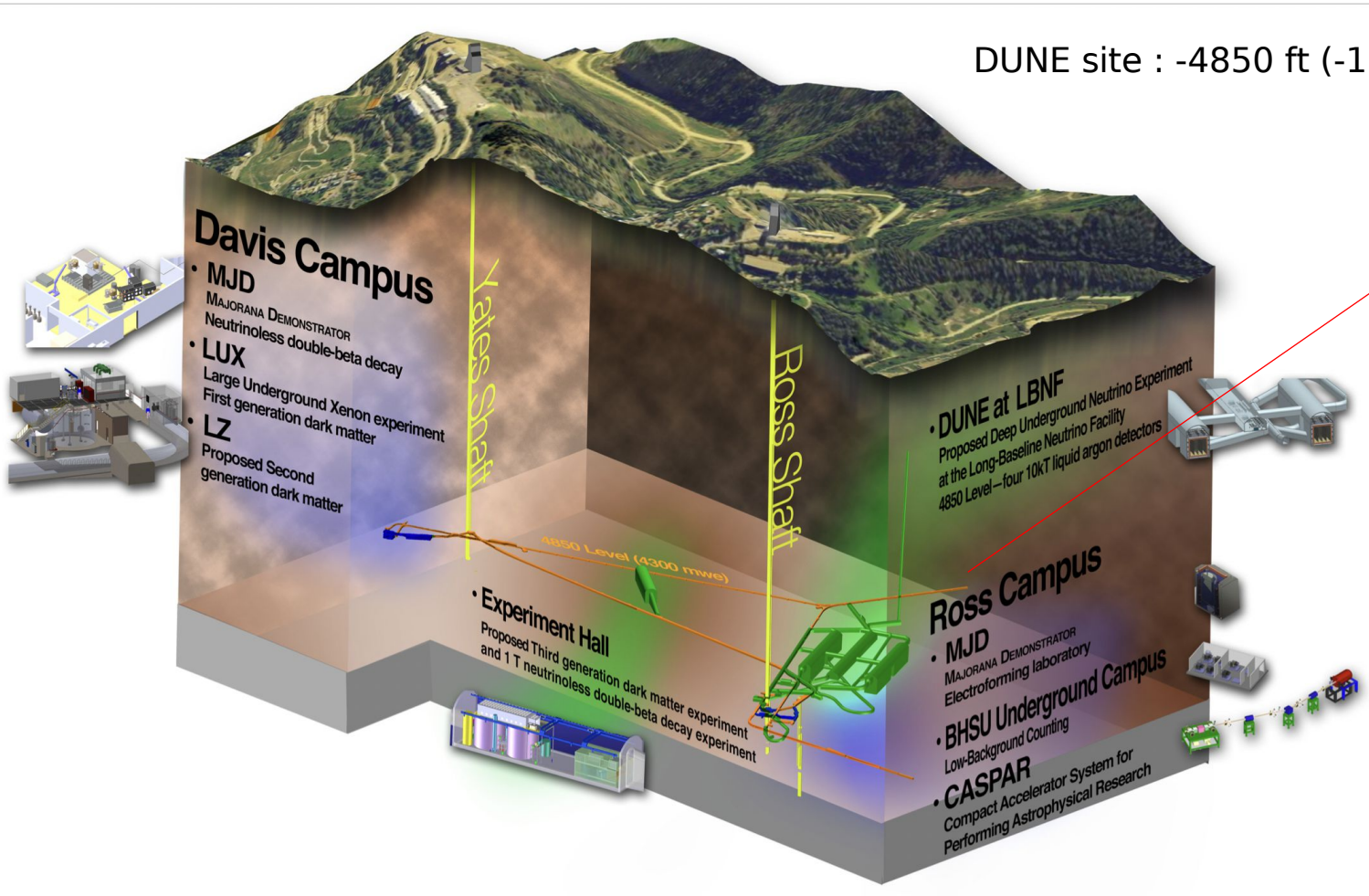
# backup

# Far Detector location - SURF

## Sanford Underground Research Facility (Lead, South Dakota)

Located at Homestake goldmine

DUNE site : -4850 ft (-1500 m) level

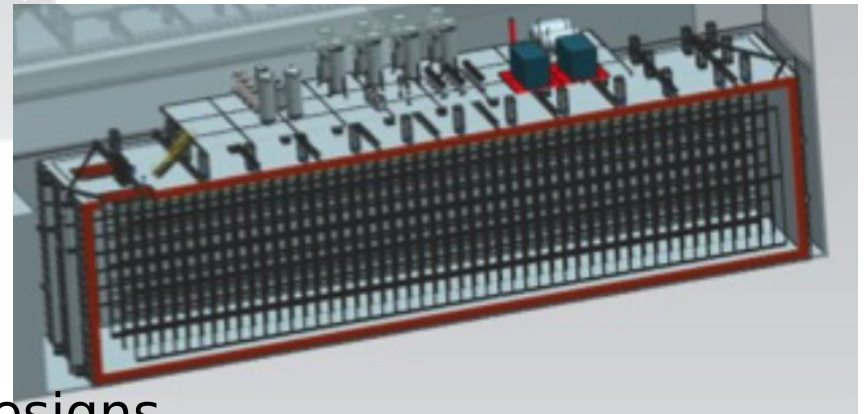
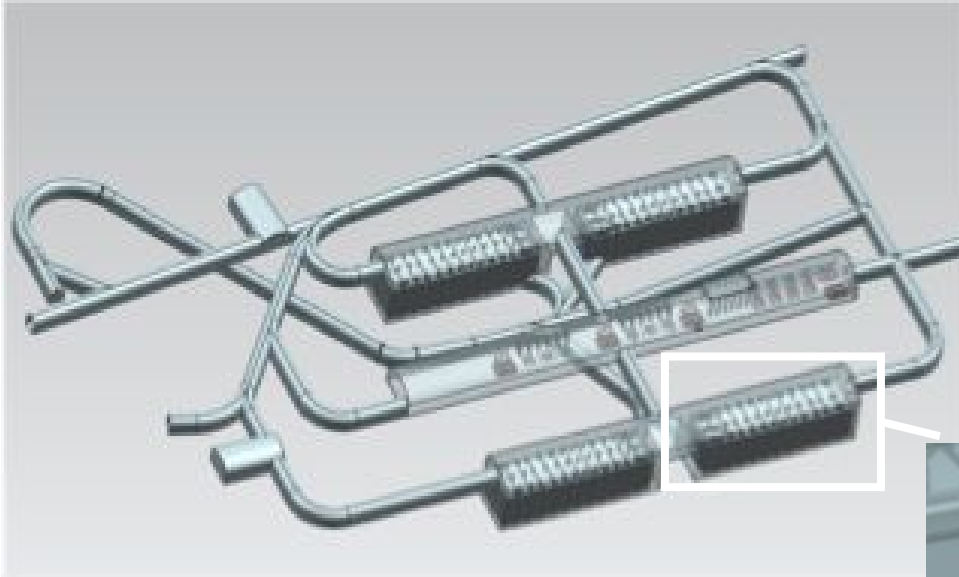


# DUNE Far Detectors

Liquid Argon (LAr) as both target and detection medium

Fiducial mass 4x10 kt

**DUNE Far Detector Interim Design Reports are available**  
(arXiv:1807.10334, 1807.10327, 1807.10340)

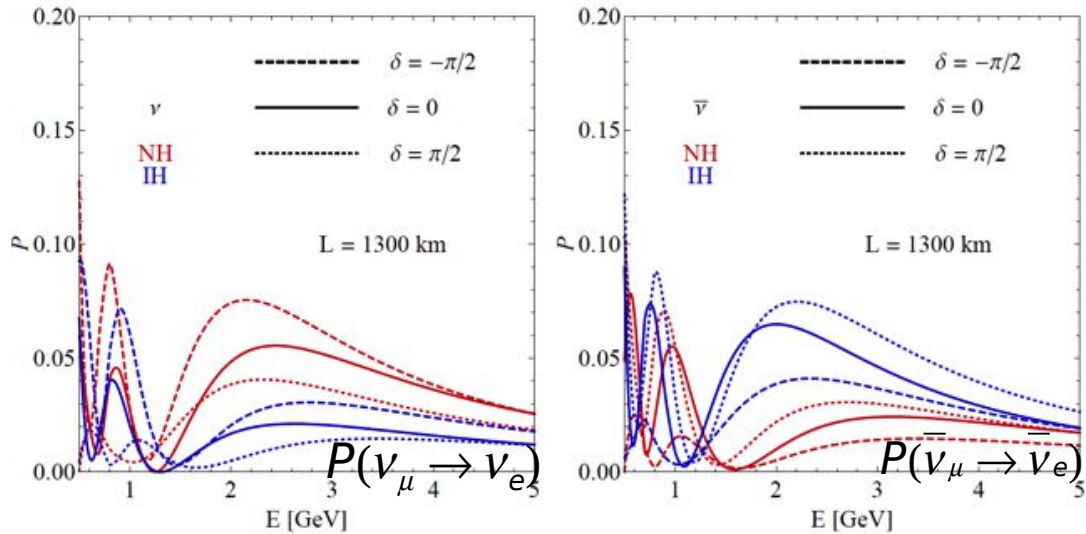


Detector modules : LAr TPCs  
Single- and Dual-Phase detector designs

Staged construction, 1st module ready by 2024

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# DUNE physics

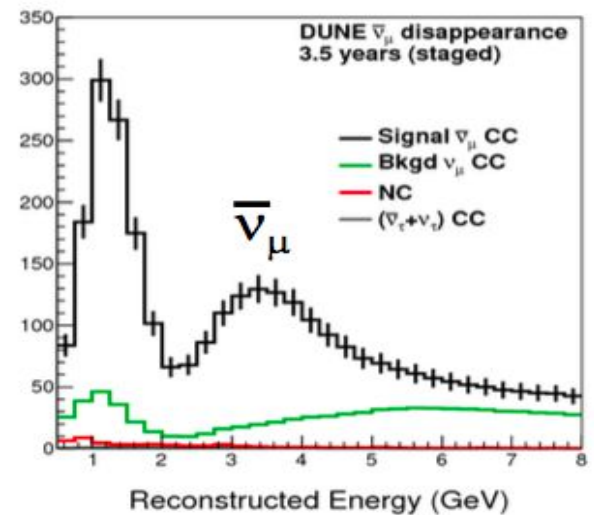
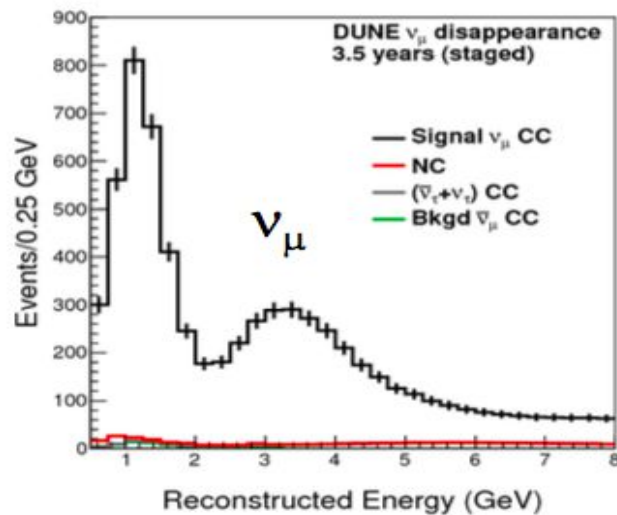
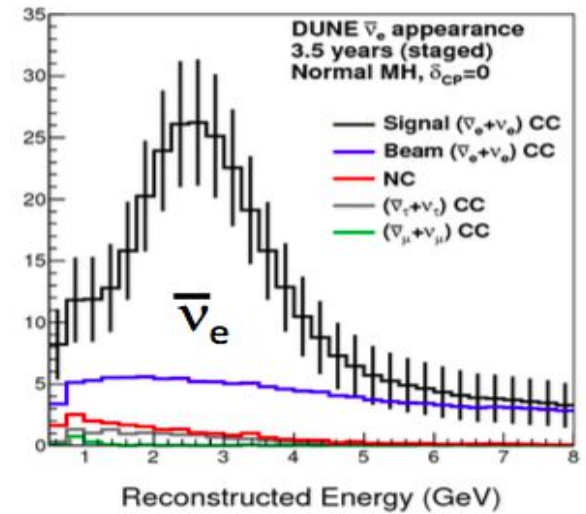
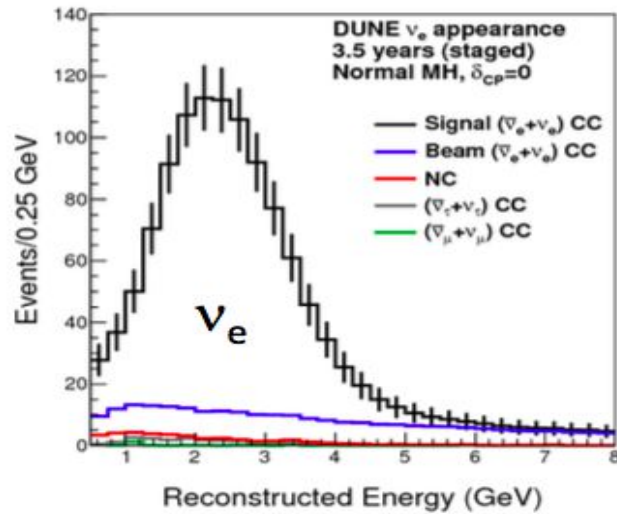


## Measure

- both appearance and disappearance
- for both neutrinos and anti-neutrinos

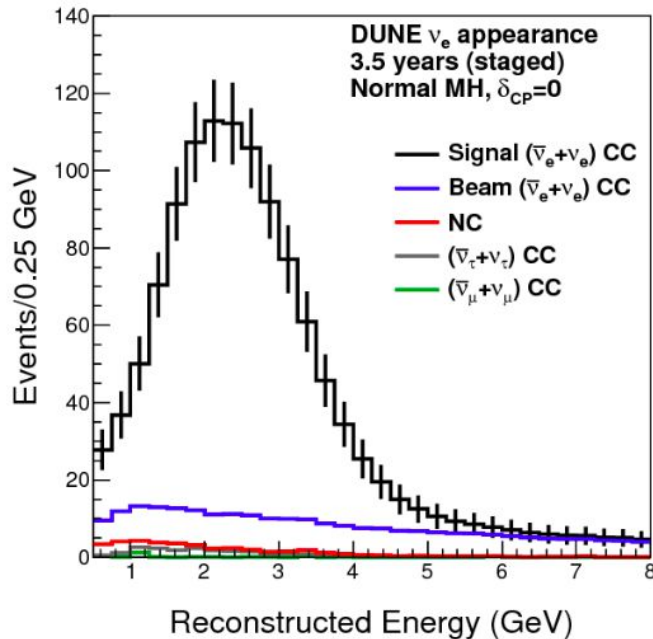
MH and CP effects can be disentangled at 1300 km baseline

# DUNE Physics



# DUNE physics

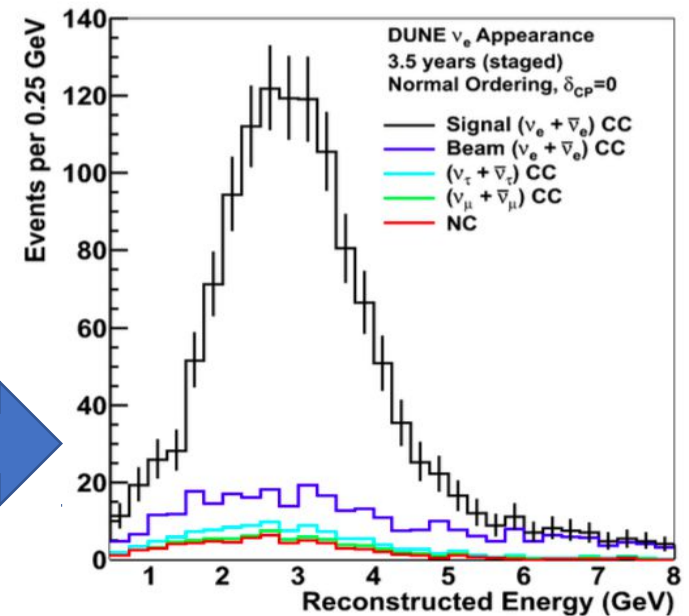
## $\nu_e$ appearance in CDR



- full simulation
- automated energy reconstruction
- deep-learning based event selection (Convolutional Visual Network, CVN)



## New MC studies

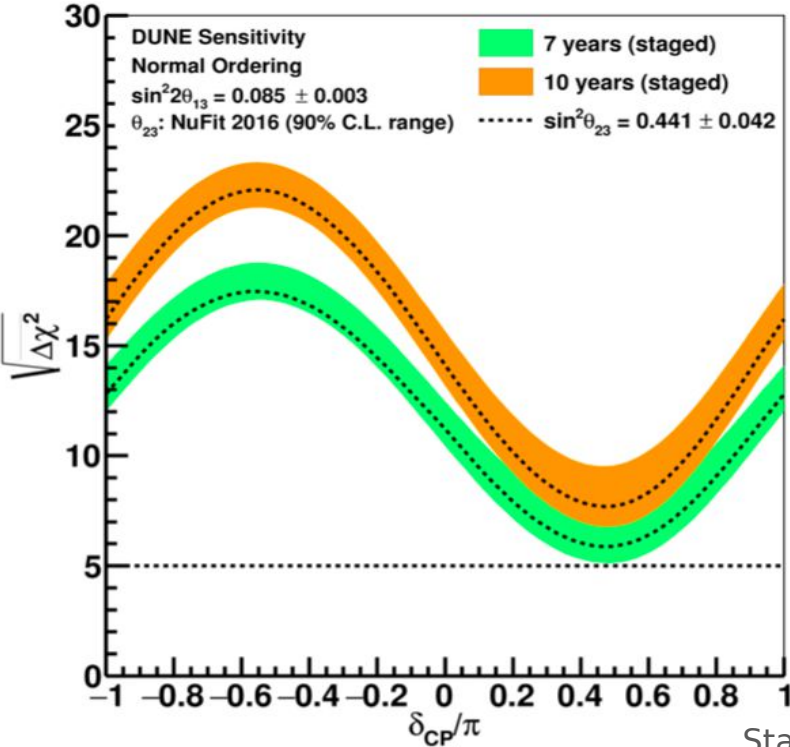


Improved sensitivity to oscillation parameters

Full update planned for TDR in 2019

# DUNE physics: Neutrino Mass Ordering and CP-violation

## MH sensitivity, Normal Ordering

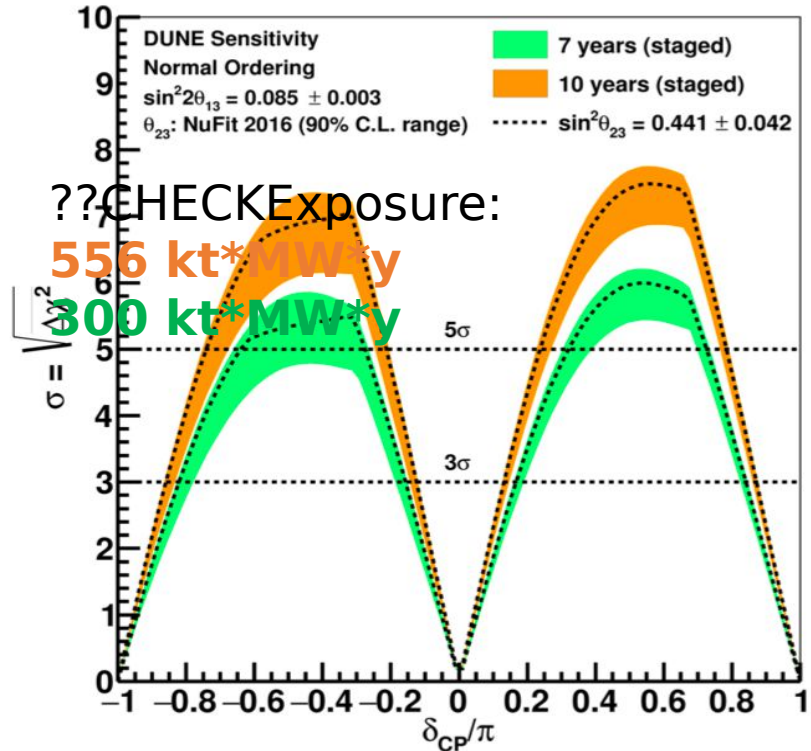


>5 $\sigma$  sensitivity for both orderings and the full range of  $\delta_{CP}$

Staging :

- 2026: 20kt far detector with 1.2 MW beam
- 2027: 30kt far detector
- 2029: 40kt far detector
- 2032: Upgrade to 2.4MW beam

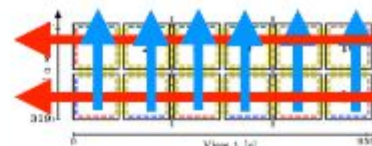
## CPV sensitivity, Normal Ordering



3 $\sigma$  sensitivity to 50% of values in 10 years

# Gain

Deposited charge measured on **view 0** (3m strips) and **view 1** (1 m strips)

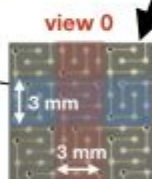


$$\text{Effective Gain} = \langle dQ/ds \rangle_{\text{view0}} + \langle dQ/ds \rangle_{\text{view1}} / \langle dQ/ds_{\text{expected}} \rangle$$

$$dQ/ds_{\text{view}}$$

$$= f_{\text{share}} \times (\epsilon_{\text{extr}} \times G_{\text{LEM}} \times E_{\text{coll}}) \times dQ/ds_{\text{expected}}$$

50%



**Extraction efficiency**  
fraction of electrons which are extracted from the liquid

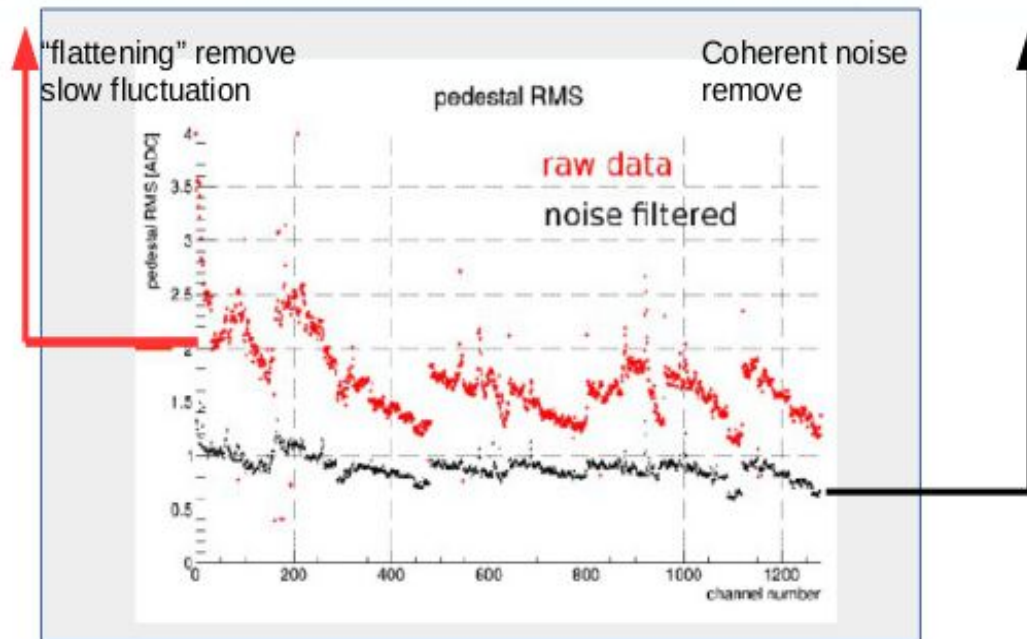
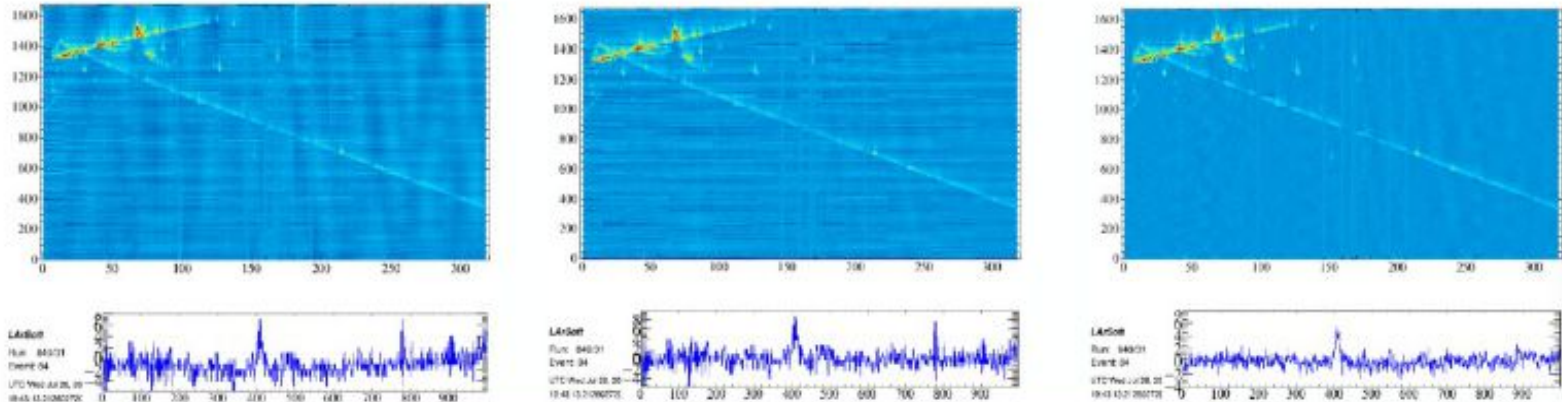
**LEM Amplification**  
multiplication factor of the electrons  
x transparency of its bottom electrode

**Collection Efficiency**  
fraction of electrons transferred from LEM to anode



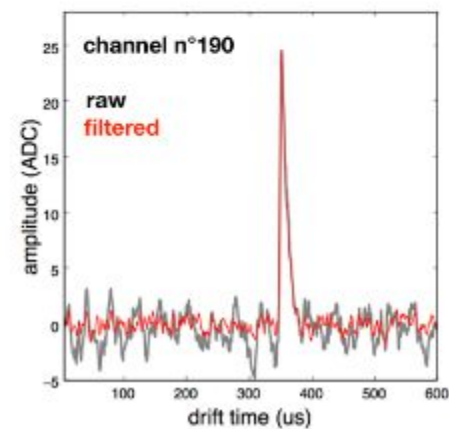
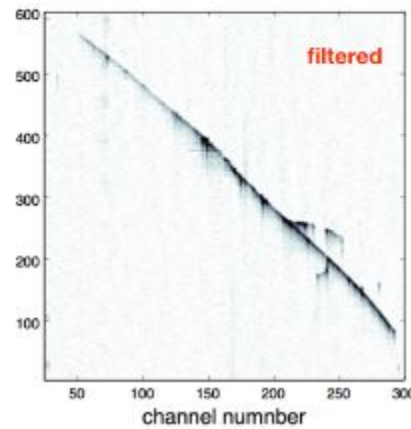
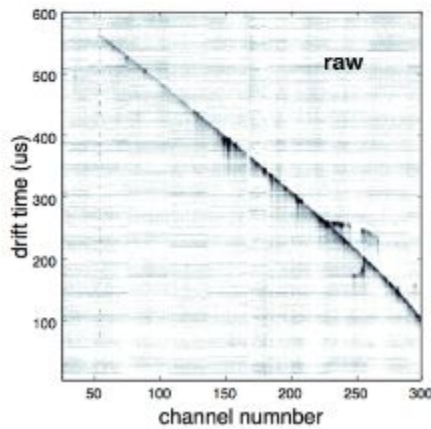
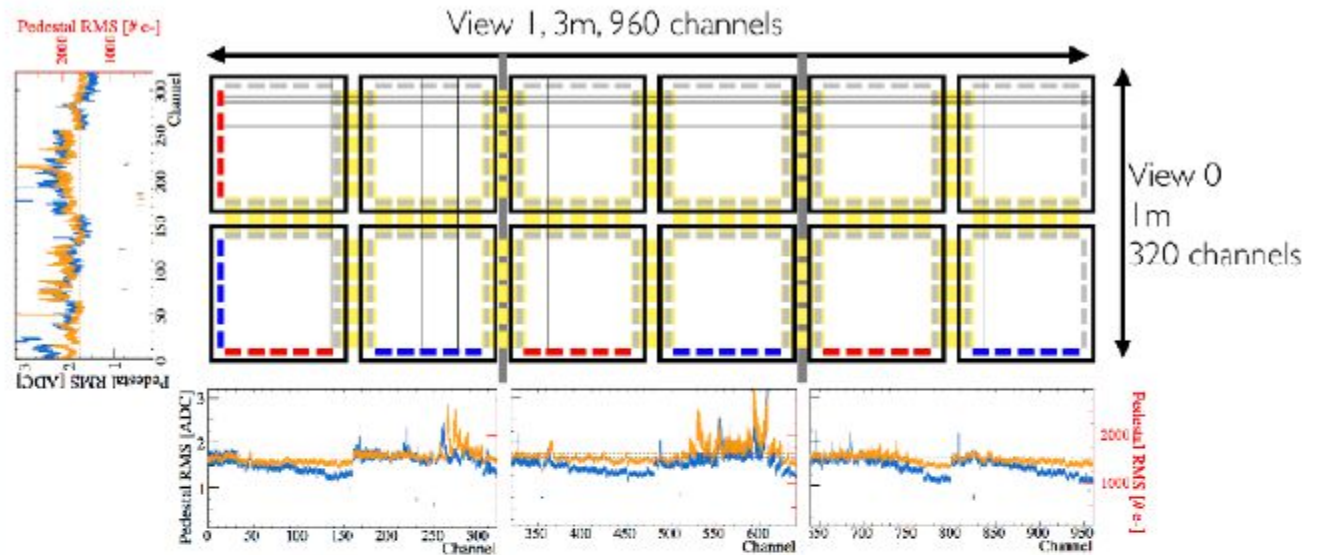
**G<sub>eff</sub>, effective gain → goal 20**

# Dual-Phase 4t demonstrator



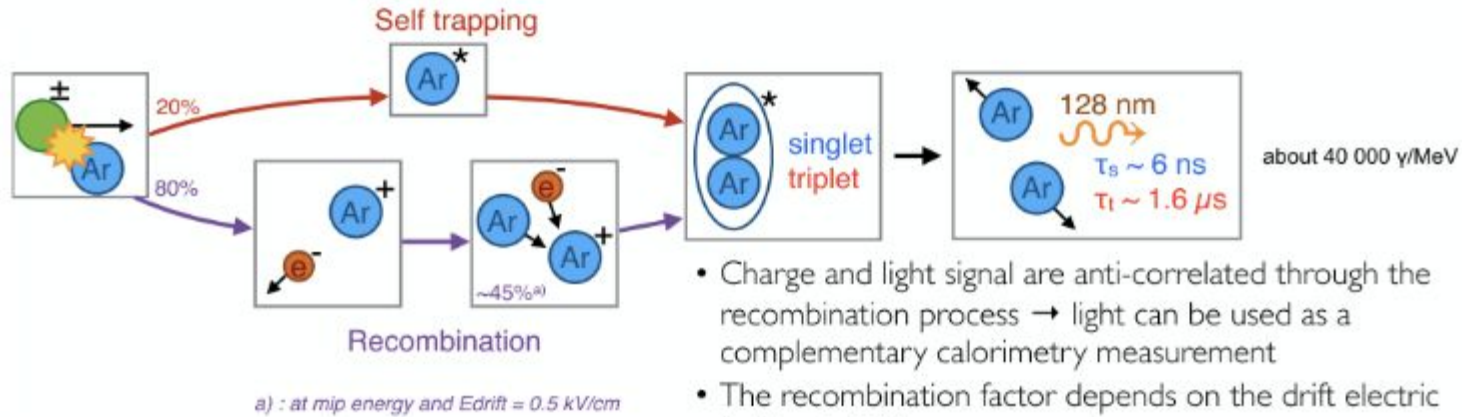
# 3x1x1 Noise level

Noise stable  
at cryogenic  
temperature  
at around  
1550 e<sup>-</sup>

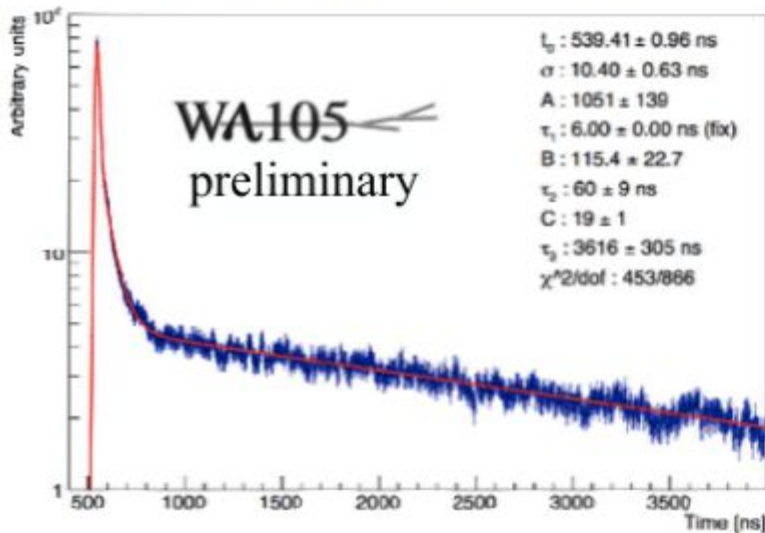


A. Scarpelli, NOW 2018

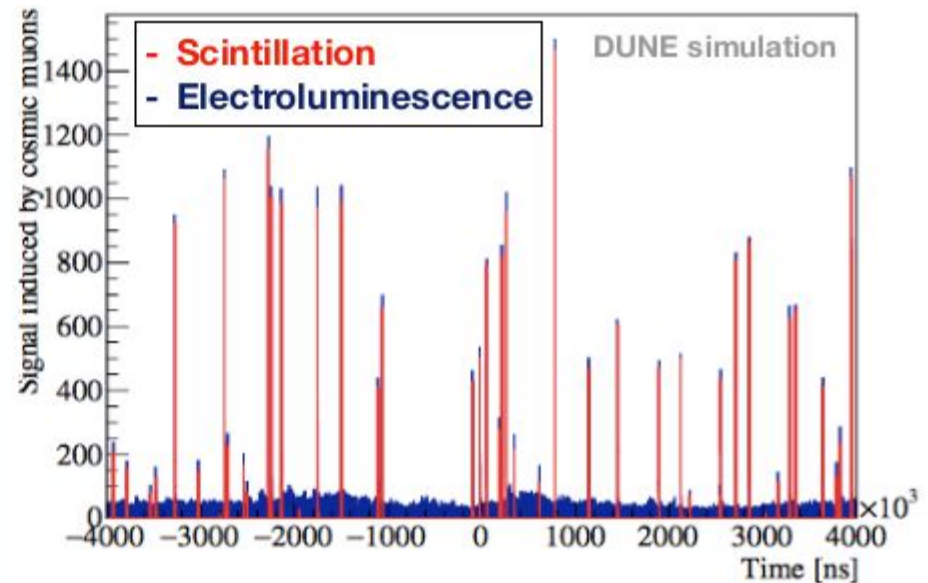
# Light Signal 3x1x1



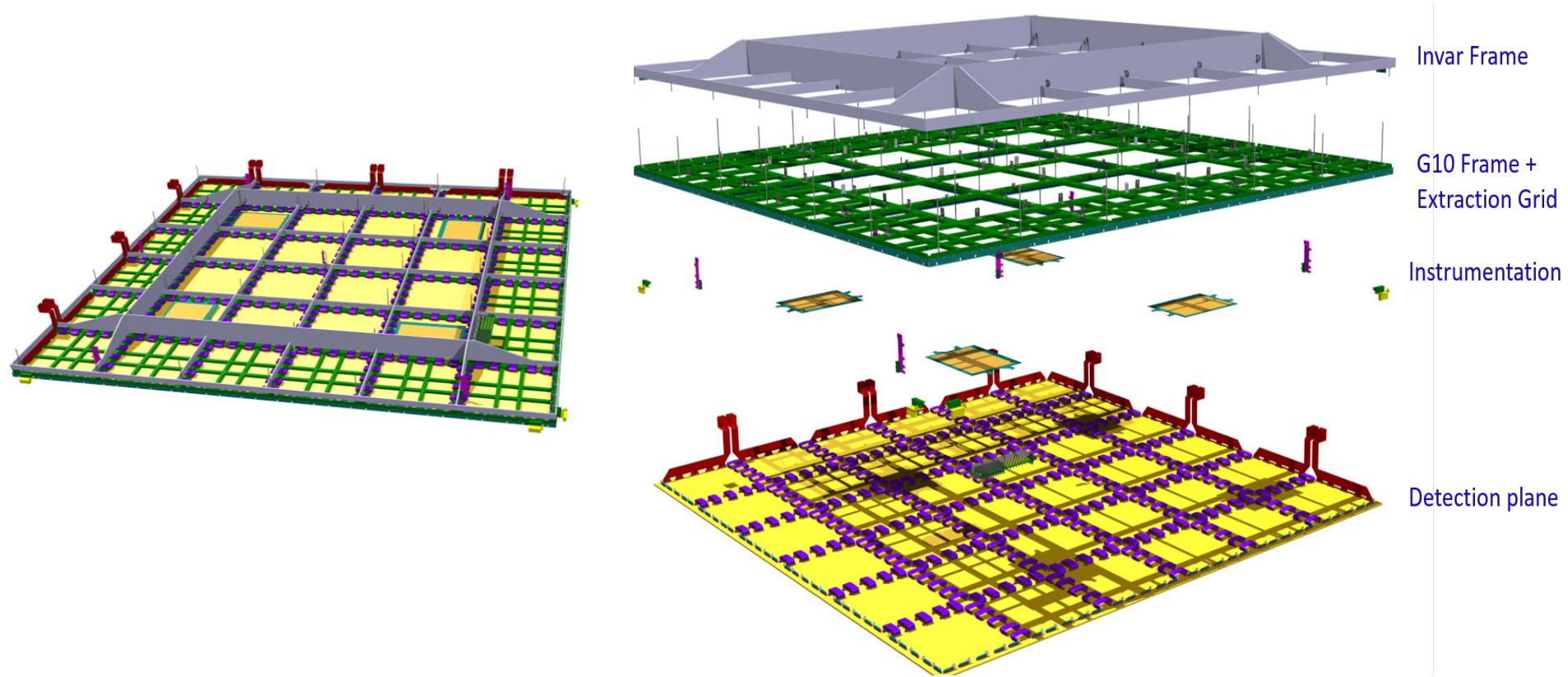
Scintillation time in GAr (1000 mBar, 215 K)



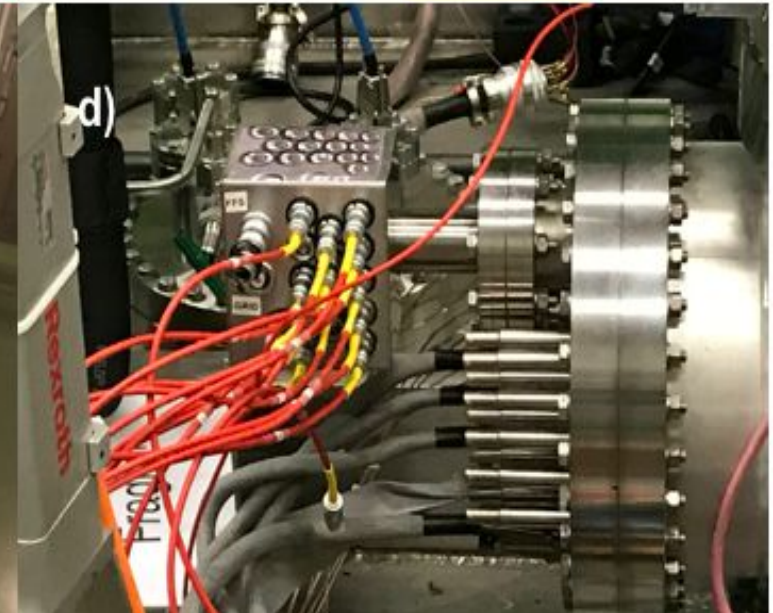
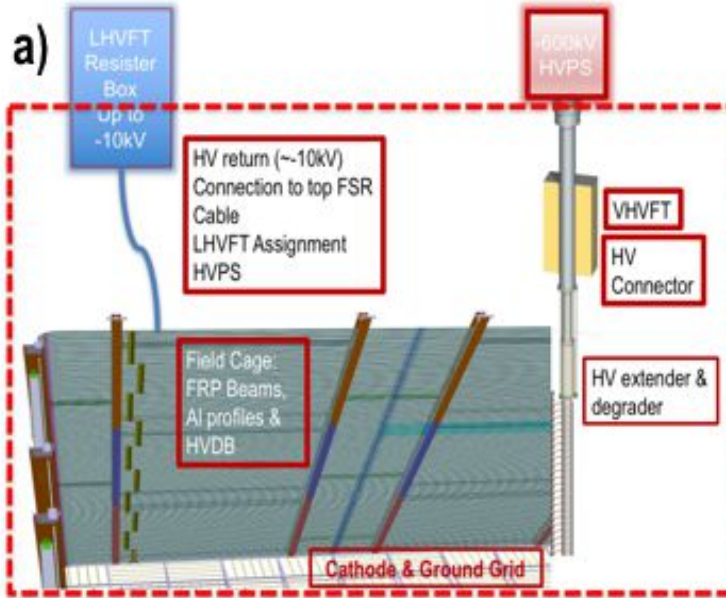
Measurement in the 3x1x1 during detector cool down  
A. Scarpelli, NOW 2018



# CRP



# 3x1x1 HV



### Details of ProtoDUNE dual-phase back-end architecture

