INFN Istituto Nazionale di Fisica Nucleare
Roma 1

DEEP UNDERGROUND NEUTRINO EXPERIMENT

SEMINARI di
Fisica Sperimentale delle Particelle Elementari

New technologies for new discoveries: ProtoDUNE at CERN for the international DUNE mega-science project

May 8, 2020 Flavio Cavanna | Fermilab Yale University

Outline

The LArTPC technology: from the original concept to protoDUNE - the ultimate step of detector development.

Motivations to the LArTPC technology choice for DUNE: *new technologies for new discoveries*

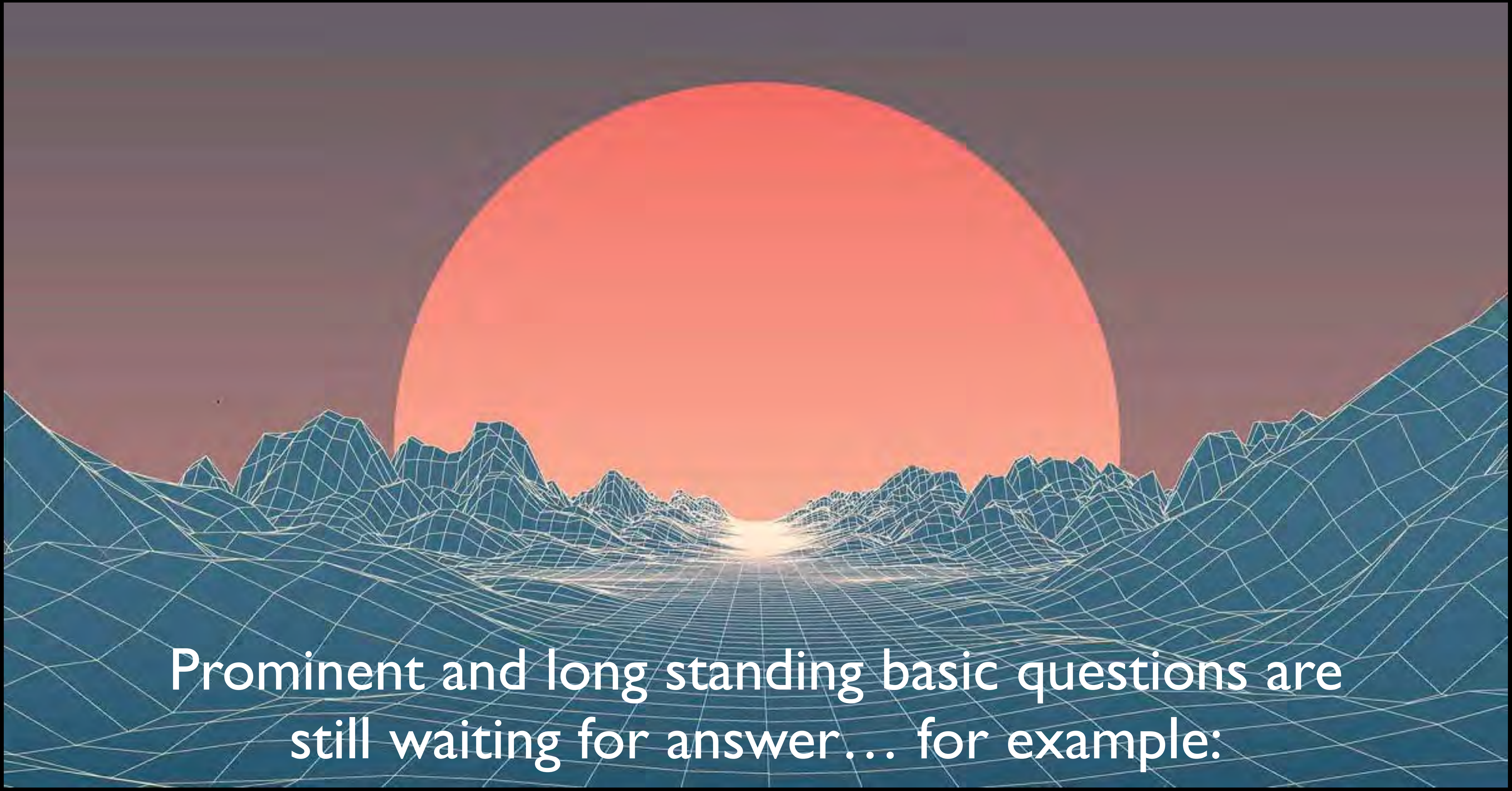
LArTPC technology in two "flavors"

ProtoDUNE at the CERN Neutrino Platform:

500+ days of continuing operation

Preview of first results on LArTPC performance

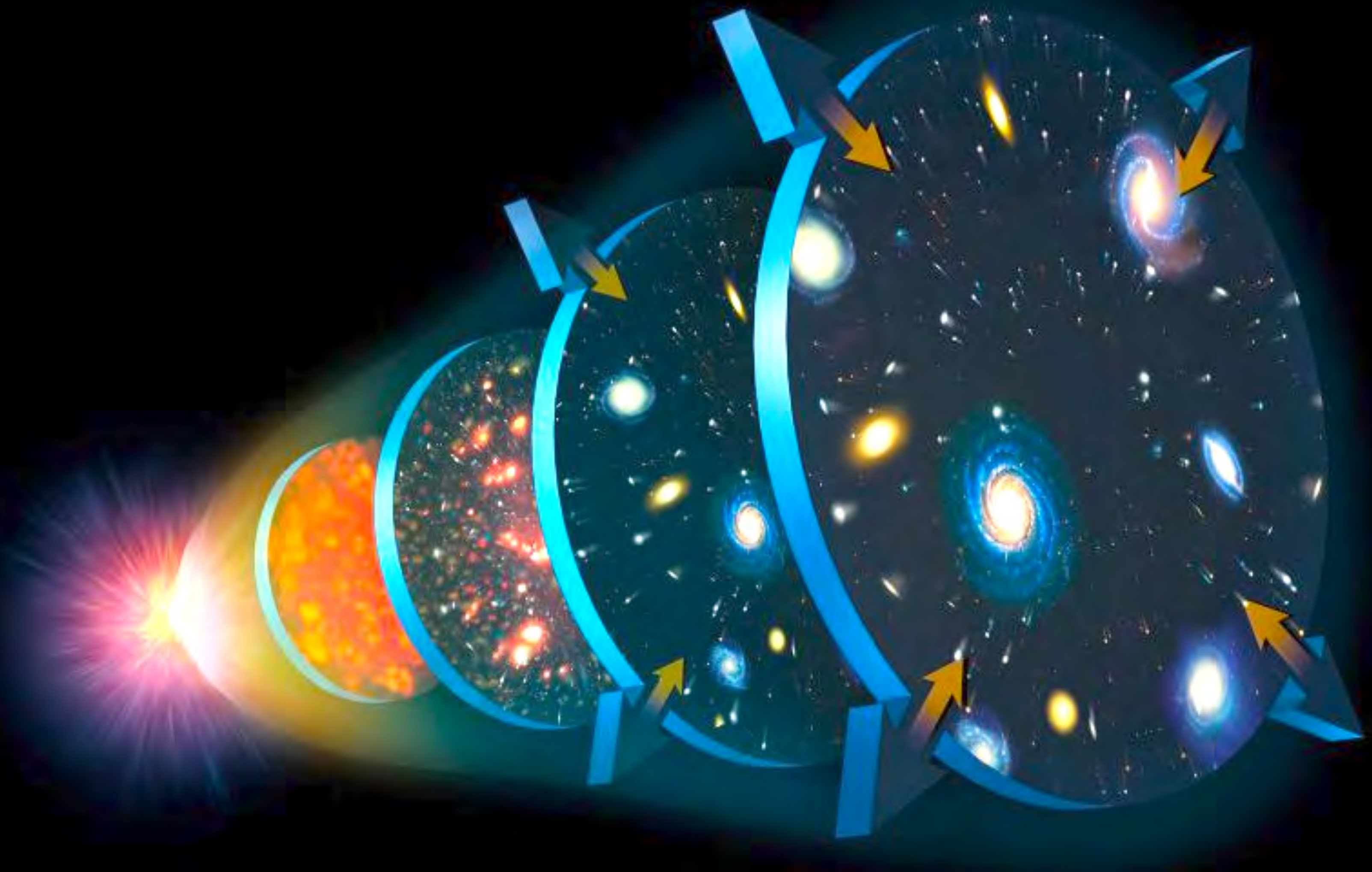
Motivations to the LArTPC technology choice for DUNE



Prominent and long standing basic questions are still waiting for answer… for example:

© istock.com/Magnilion

According to current
understanding of the
Big Bang,
matter and antimatter were
formed in equal
amounts when the universe
began.



But if that were the case, all matter should have annihilated with antimatter by now, releasing lots of energy and filling the universe with light and radiation and no matter at all.

So, the question is “why is the world made of matter and not antimatter or nothing at all”?

The answer may hide in the way we distinguish between matter and antimatter:
the CP transformations

In the Standard Model a tiny amount of violation of the CP symmetry exists in the baryon sector…

.. but this CP violation is not enough to account for the observed matter-antimatter unbalance. Therefore, other CP violation sources must contribute

CP violation in the **neutrino** sector **is the prime candidate**

If this is true, we should find signs of CP violation in the oscillation of today's neutrinos….

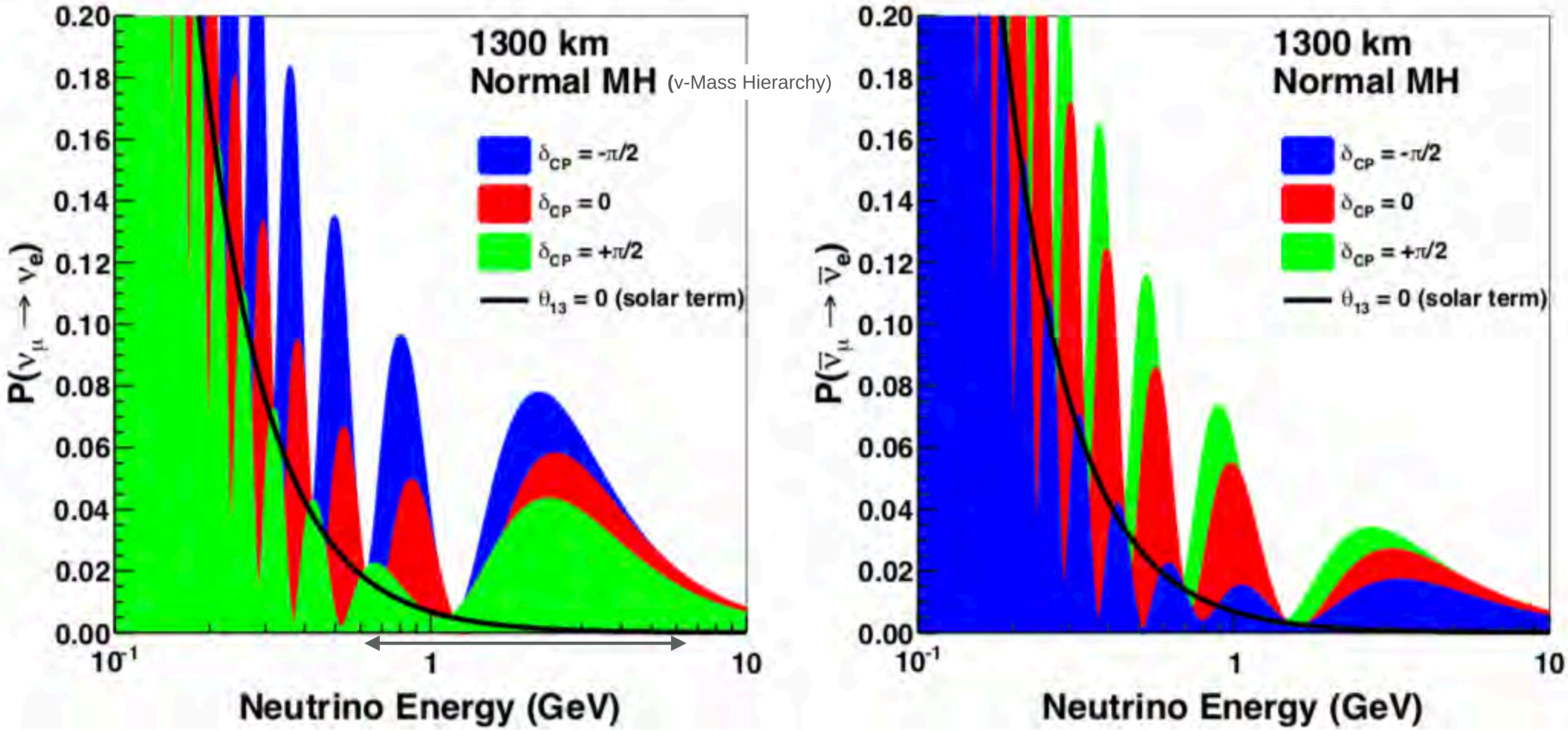
DUNE/LBNF: the Long Baseline Neutrino program

Far Detector

Near Detector

The **DUNE**/**LBNF** project in the US is the first **neutrino** international mega-science **project** [based on the ATLAS-CMS/LHC model at CERN in Europe and similar in size to LIGO]

the oscillation patterns of ν_μ and $\bar{\nu}_\mu$ beams over a 1300 km long baseline



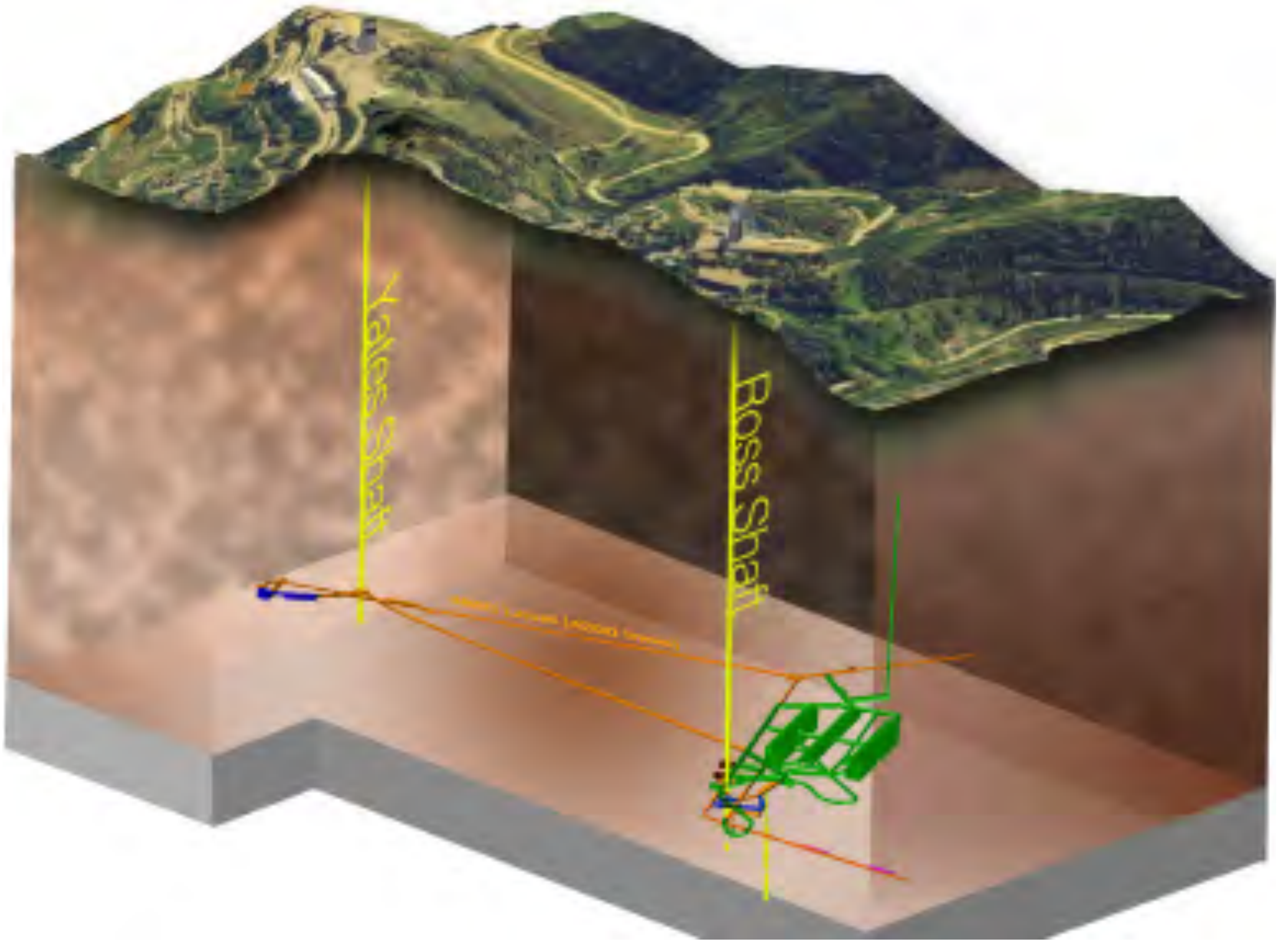
The CP Asymmetry

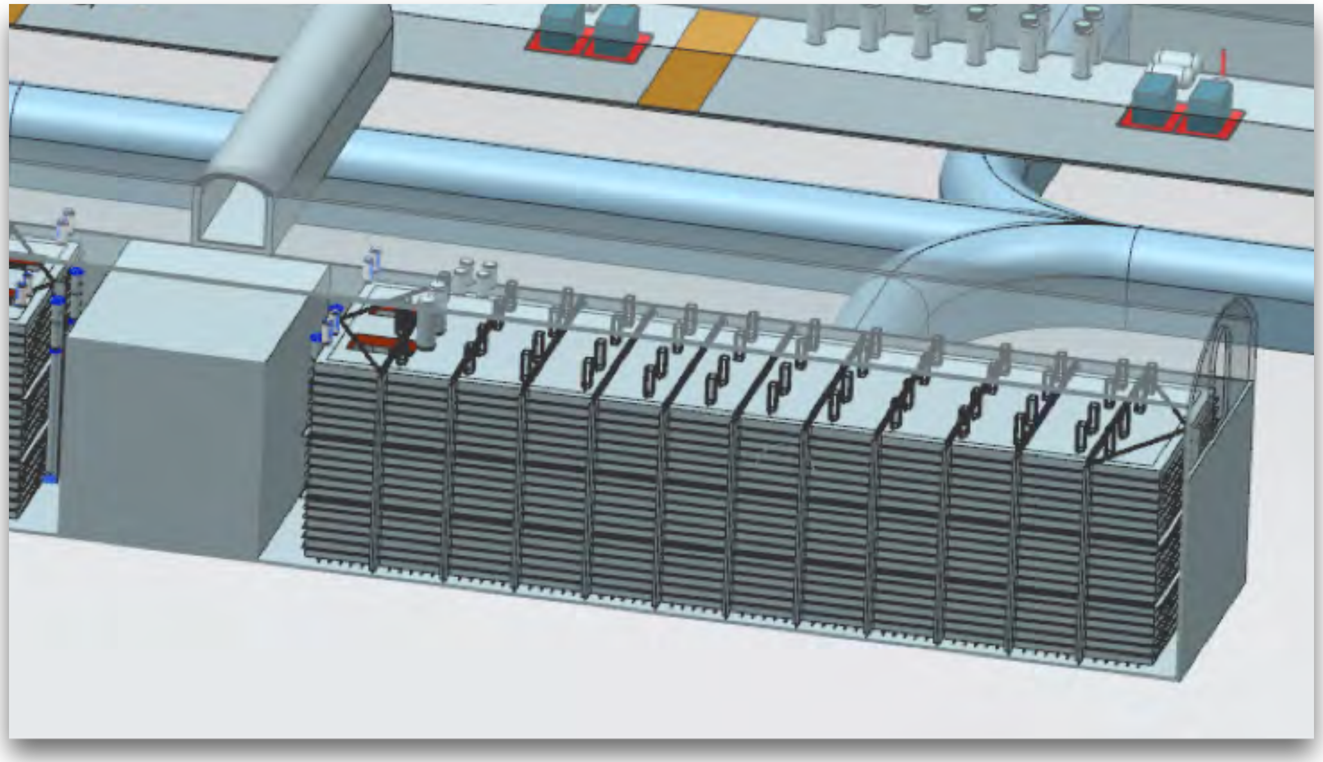
$$\mathcal{A}_{CP} = \frac{P(\nu_\mu \rightarrow \nu_e) - P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)}{P(\nu_\mu \rightarrow \nu_e) + P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)}$$

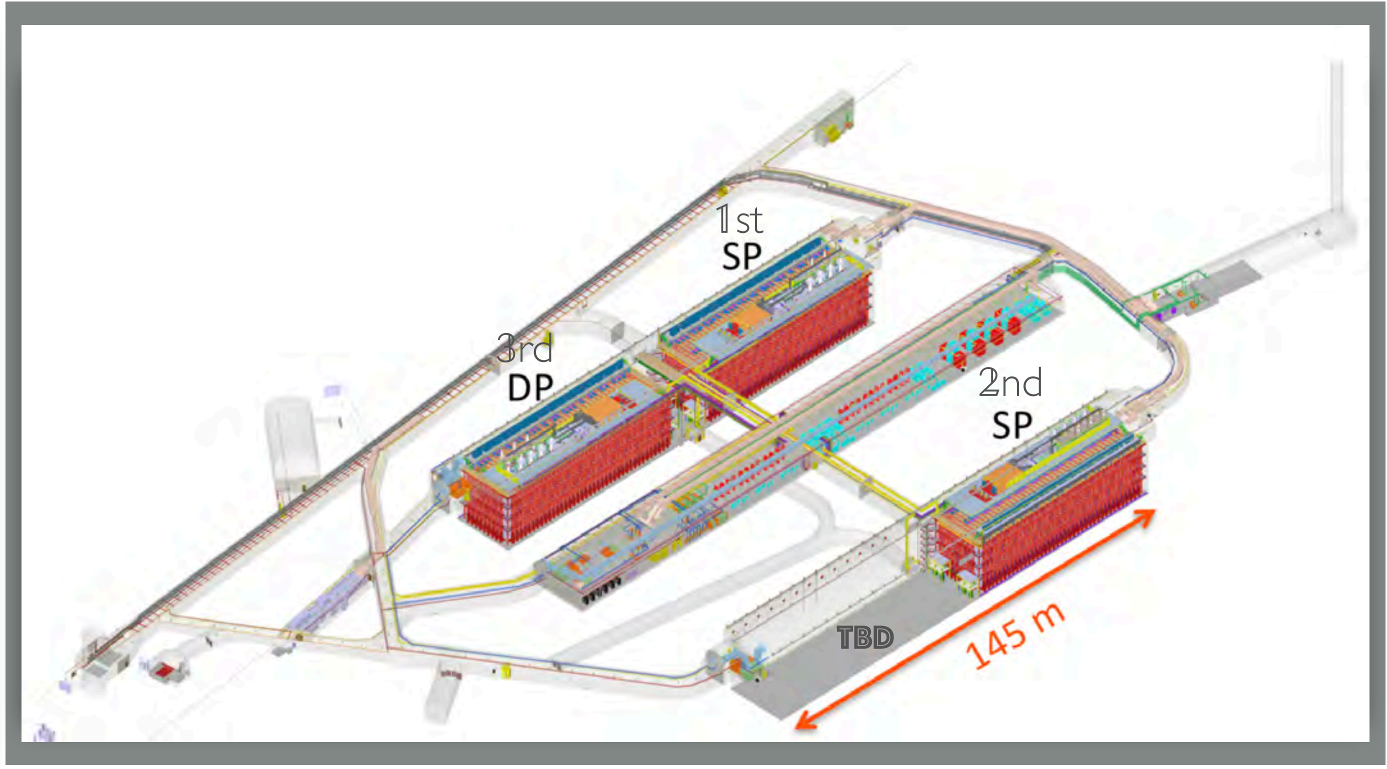
The signal for ν_e $(\bar{\nu}_e)$ appearance is an excess of charged current (CC) ν_e and $\bar{\nu}_e$ events over the expected background
(in the ~[0.5-5] GeV Energy range)

“Far Site”: SURF 4850 Level

- Major underground excavation removing ~800,000 tons of rock
- Two large caverns housing **four** cryostats and a central utility space
- $4 \times 17{,}000$ **tons of LAr to fill the cryostats:** ***the target for neutrino interactions***

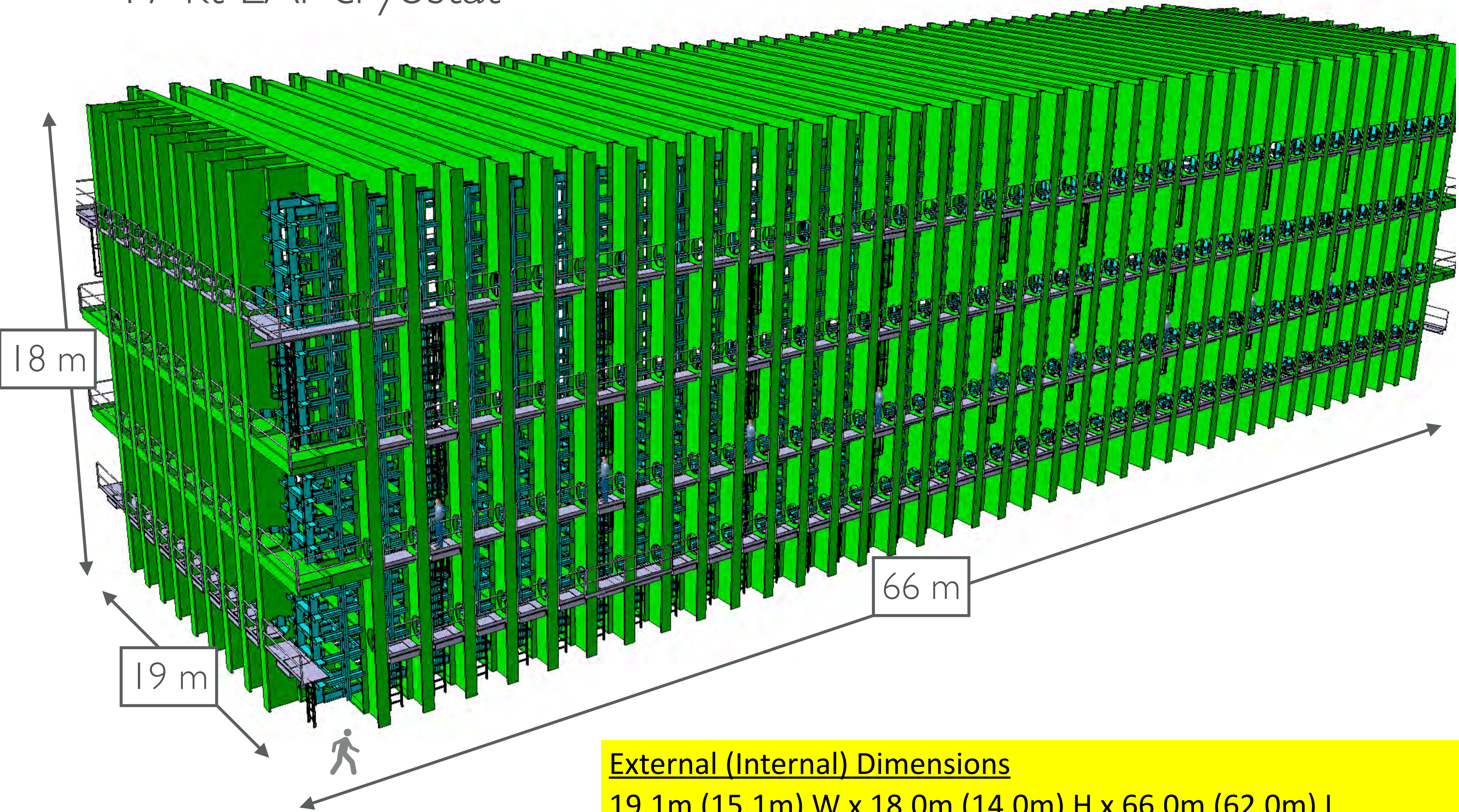






The first FD Module:

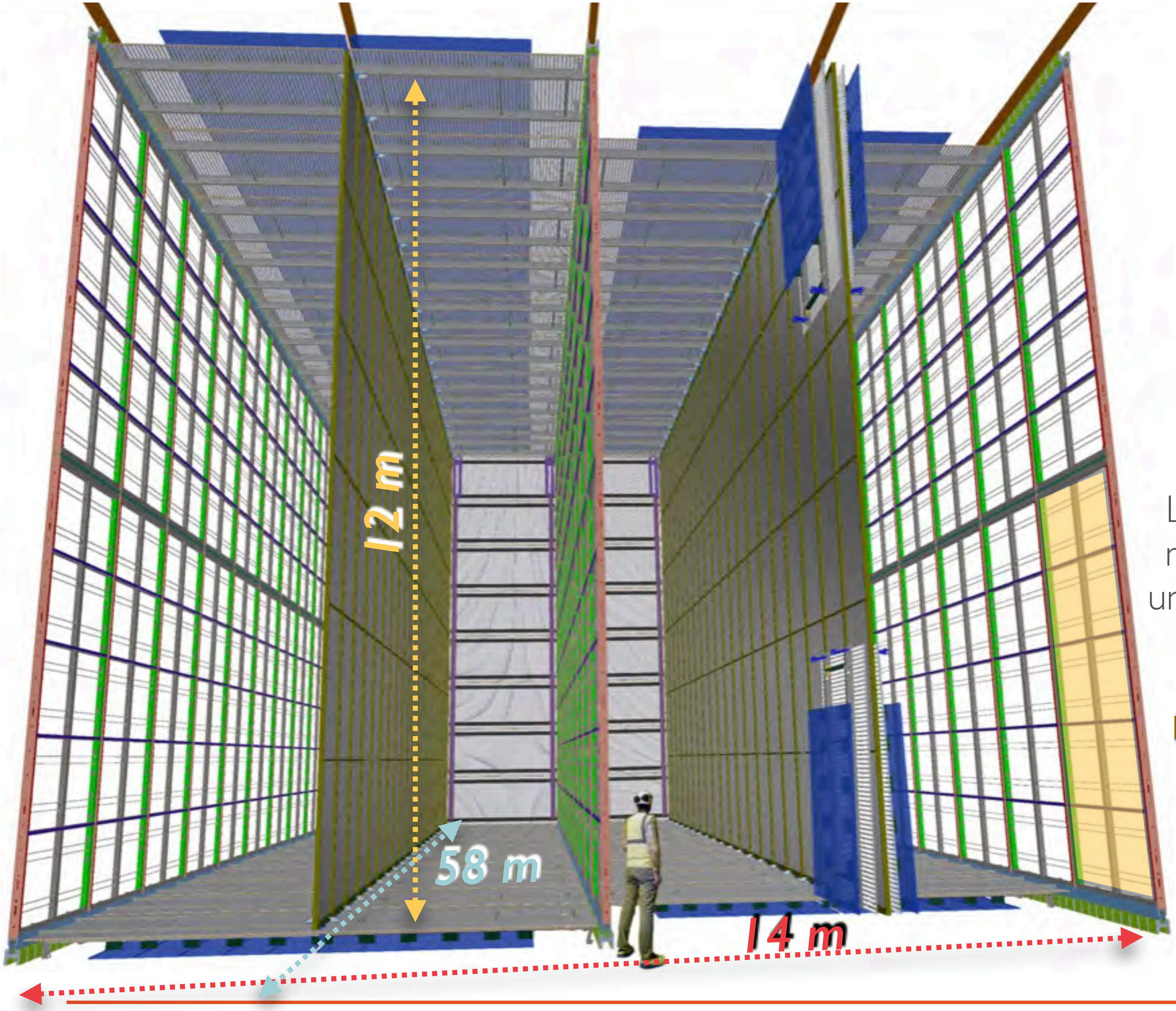
17 kt LAr cryostat



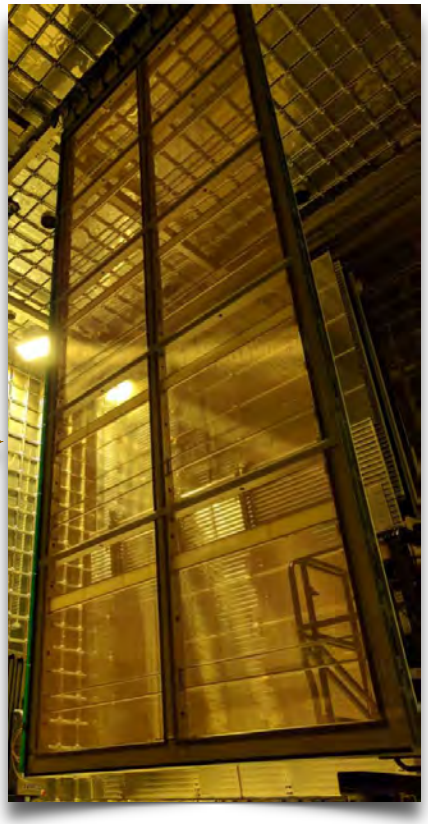
External (Internal) Dimensions

19.1m (15.1m) W x 18.0m (14.0m) H x 66.0m (62.0m) L

and the **LArTPC** instrumented inside the cryostat



LArTPC modular unit (APA) in real



New technologies for new discoveries

Liquid Argon Time Projection Chamber - LAr TPC is the **Technology Choice** for the International Neutrino Program in the US

Q:

Why **Liquid Argon Time Projection Chamber**?

A:

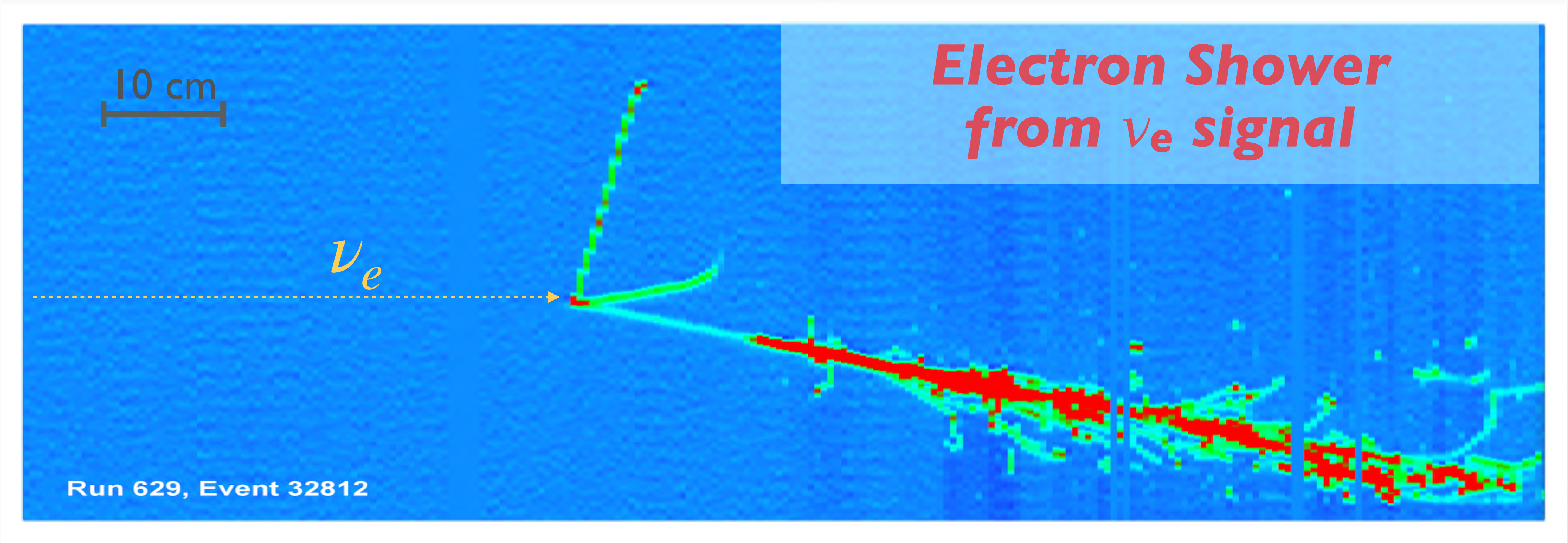
LAr TPC is a modern technology with Automated 3D Imaging, Particle ID (e.g. e/γ separation) with added full Calorimetry and Self-Triggering Capability

Combine Target and Detector in one

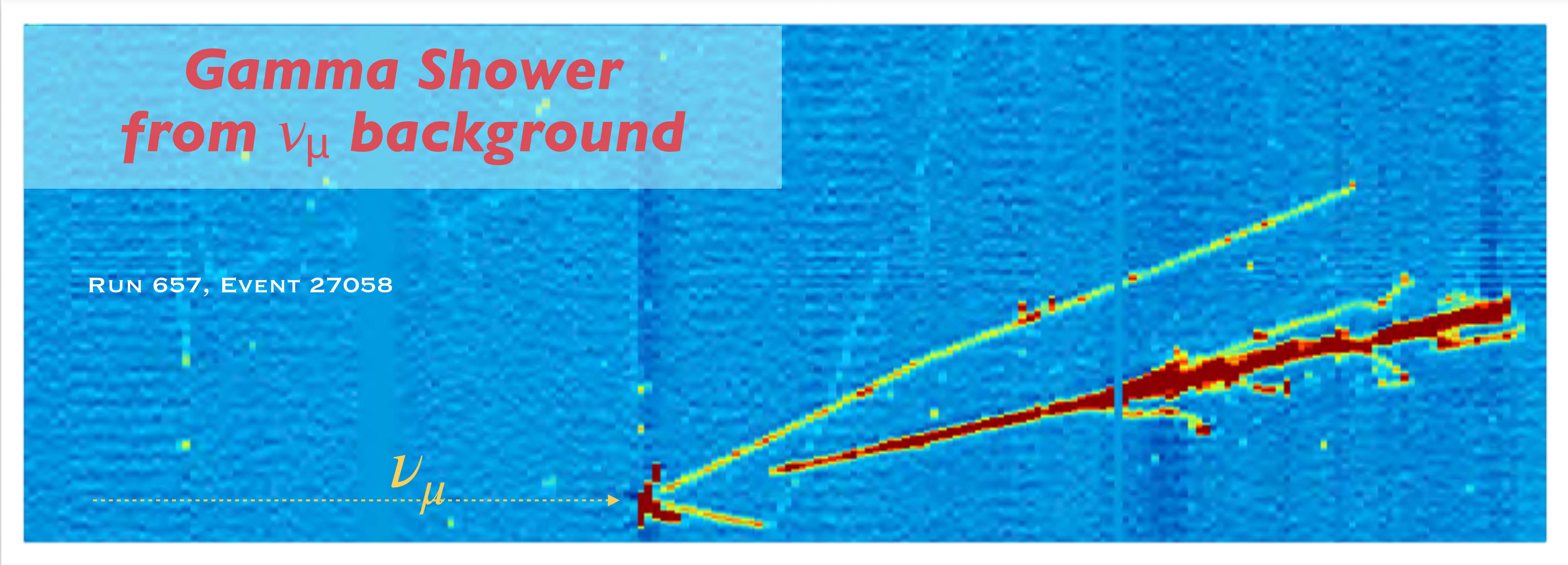
Scalable to very large mass

e/γ separation

ArgoNeuT
FNAL
2009-10



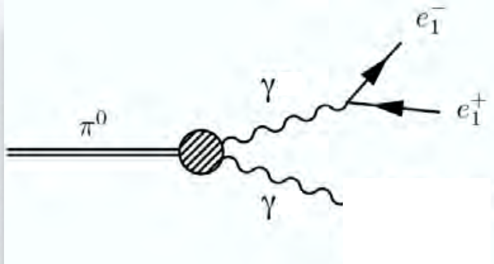
Electron Shower from ν_e signal



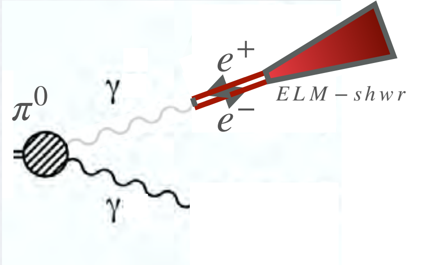
Gamma Shower from ν_μ background

ν_e appearance and background rejection

($\nu_e \rightarrow$) electron / γ ($\leftarrow \pi^0$) discrimination

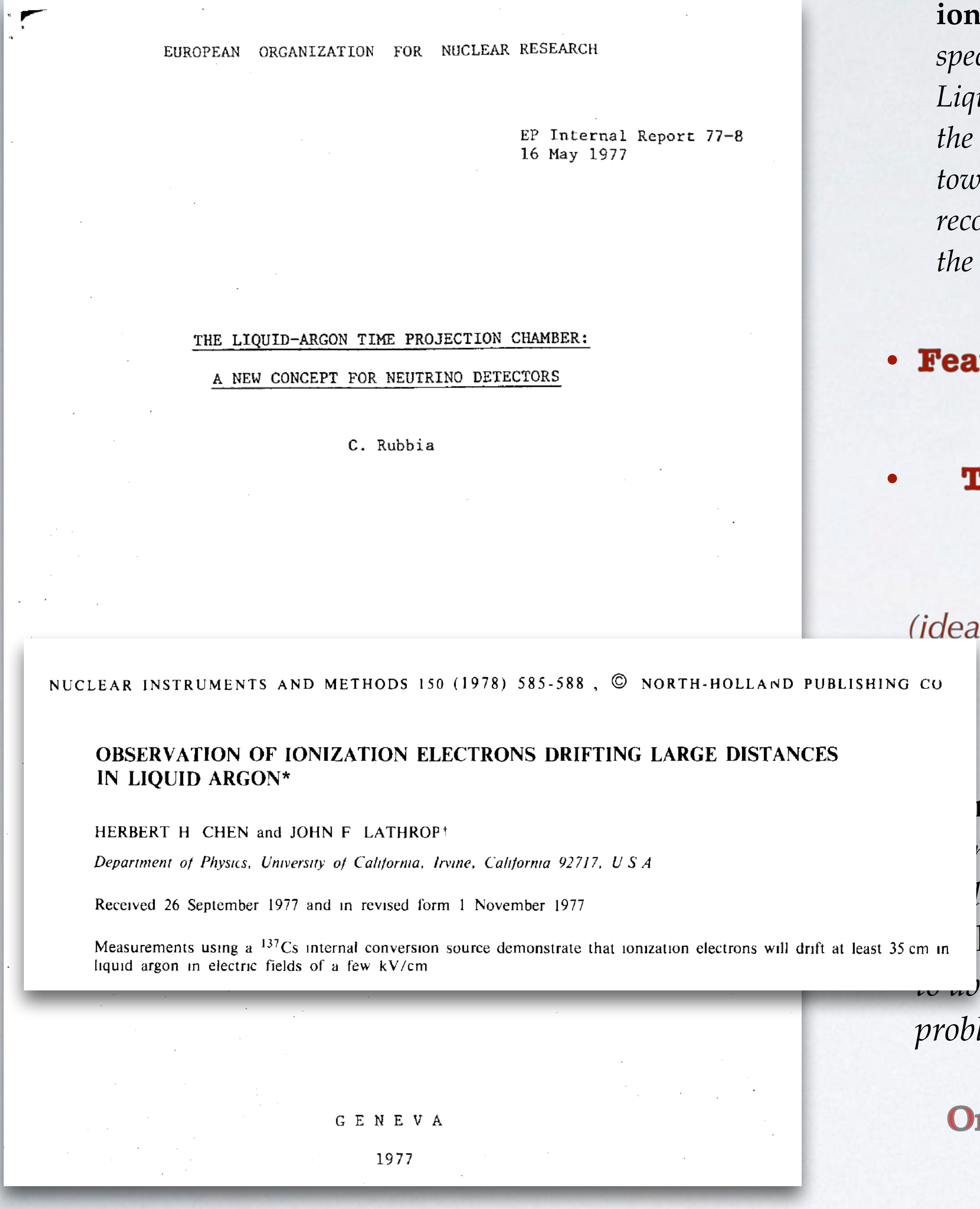


In theory



In the detector

1977 - the LArTPC Concept



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

EP Internal Report 77-8
16 May 1977

THE LIQUID-ARGON TIME PROJECTION CHAMBER:
A NEW CONCEPT FOR NEUTRINO DETECTORS

C. Rubbia

GENEVA
1977

NUCLEAR INSTRUMENTS AND METHODS 150 (1978) 585-588, © NORTH-HOLLAND PUBLISHING CO

OBSERVATION OF IONIZATION ELECTRONS DRIFTING LARGE DISTANCES IN LIQUID ARGON*

HERBERT H CHEN and JOHN F LATHROP†

Department of Physics, University of California, Irvine, California 92717, U S A

Received 26 September 1977 and in revised form 1 November 1977

Measurements using a ^{137}Cs internal conversion source demonstrate that ionization electrons will drift at least 35 cm in liquid argon in electric fields of a few kV/cm

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Quoting this document, "*the original idea of Nygren (1974)*" for a so-called *"Time Projection Chamber (TPC)"* with a noble gas as **ionization** medium "*is extended to a liquefied noble gas - more specifically, liquid Argon - leading to what is"* thereafter *"called a Liquid-Argon TPC* (**LAr-TPC**). *Briefly, the idea consists of drifting the whole electron image of an event occurring in the noble liquid towards a collecting multi-electrode array which is capable of reconstructing the three-dimensional image (x,y,z) of the event from the (x,y) information and the drift time (t)"*.

- **Features of different experimental technologies are combined in a single device**
- **The liquid Argon is at the same time the active medium of the detector and the target of the experiment**

(ideal for detection and full reconstruction of rare events like neutrino interactions and nucleon decays).

main limitation of the proposed technique was also
rly defined: "*the purity of the Argon is the main*
nological problem. … electron lifetimes corresponding to
ual Oxygen impurity content of about 4 x 10^{-2} ppm" are
hable. However, this limits "*the electron mean free path*
about 30 cm. Clearly, Oxygen-free Argon is the central problem for the LAr TPC".

Only after several years an effective, fast purification method became available.

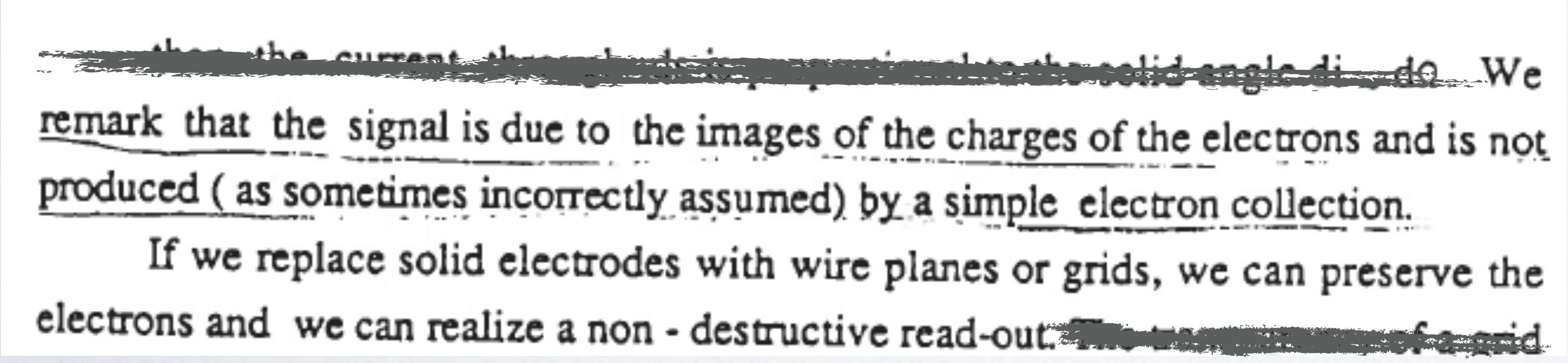
1986 - proposal for a massive LArTPC ICARUS

“Principle of Operation (from ICARUS Proposal)**:**

*The imaging of the **ionising** events inside the cryogenic volume of the detector is made possible because of*
(1) the long lifetime of the drifting electrons in excess of one millisecond (i.e. very high LAr purity) *and*
(2) the sensitivity of modern (low noise) *charge sensitive amplifiers that are capable of sensing an electron signal produced by a few millimetres of minimum ionising tracks”.*

… “***main features***” …

Non-destructive read-out *with determination of the **t=0** signal* …(for the measurement of) *the drift time and hence of the drift distance*



[redacted] We remark that the signal is due to the images of the charges of the electrons and is not produced (as sometimes incorrectly assumed) by a simple electron collection.

If we replace solid electrodes with wire planes or grids, we can preserve the electrons and we can realize a non - destructive read-out. [redacted]

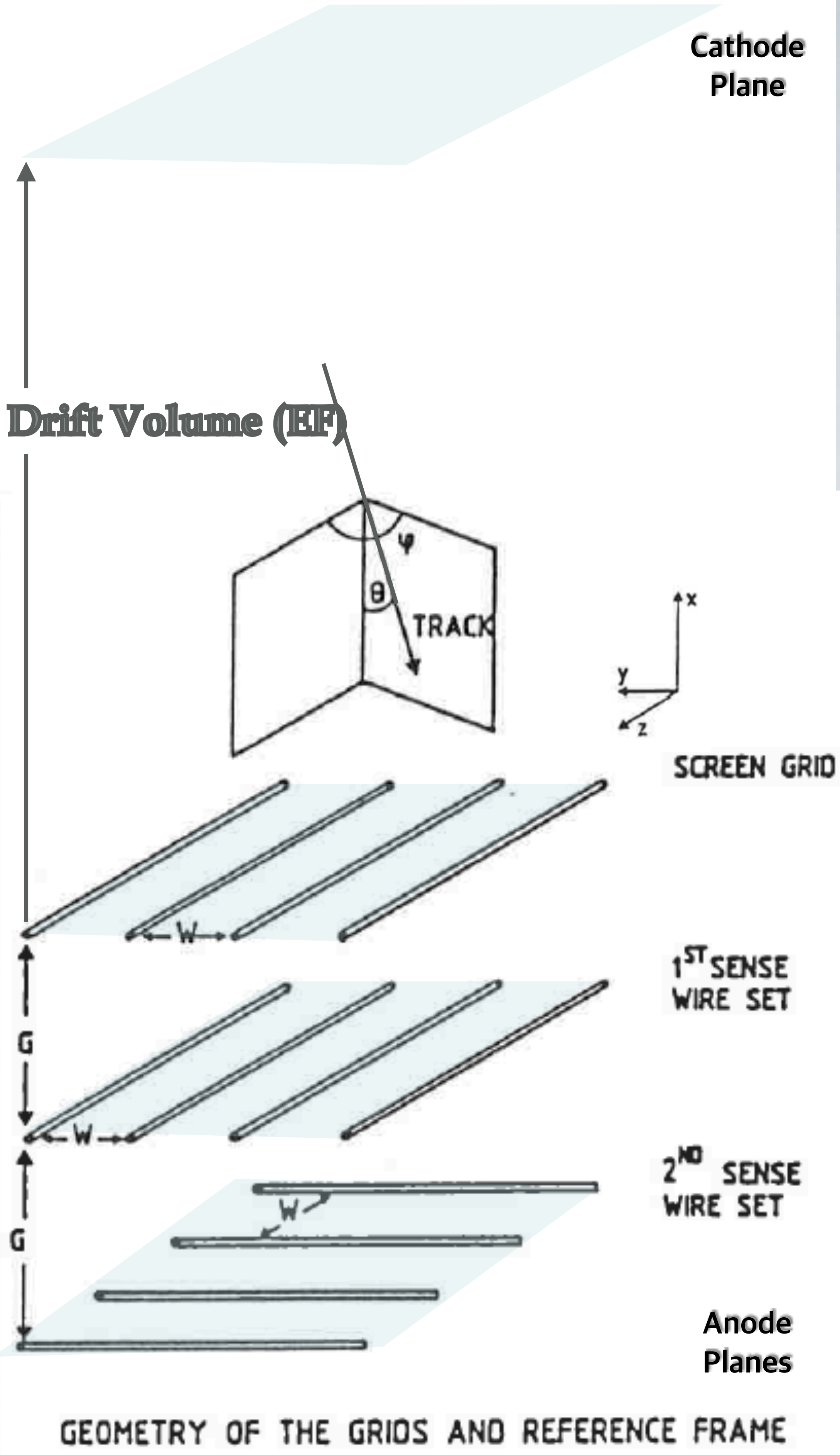
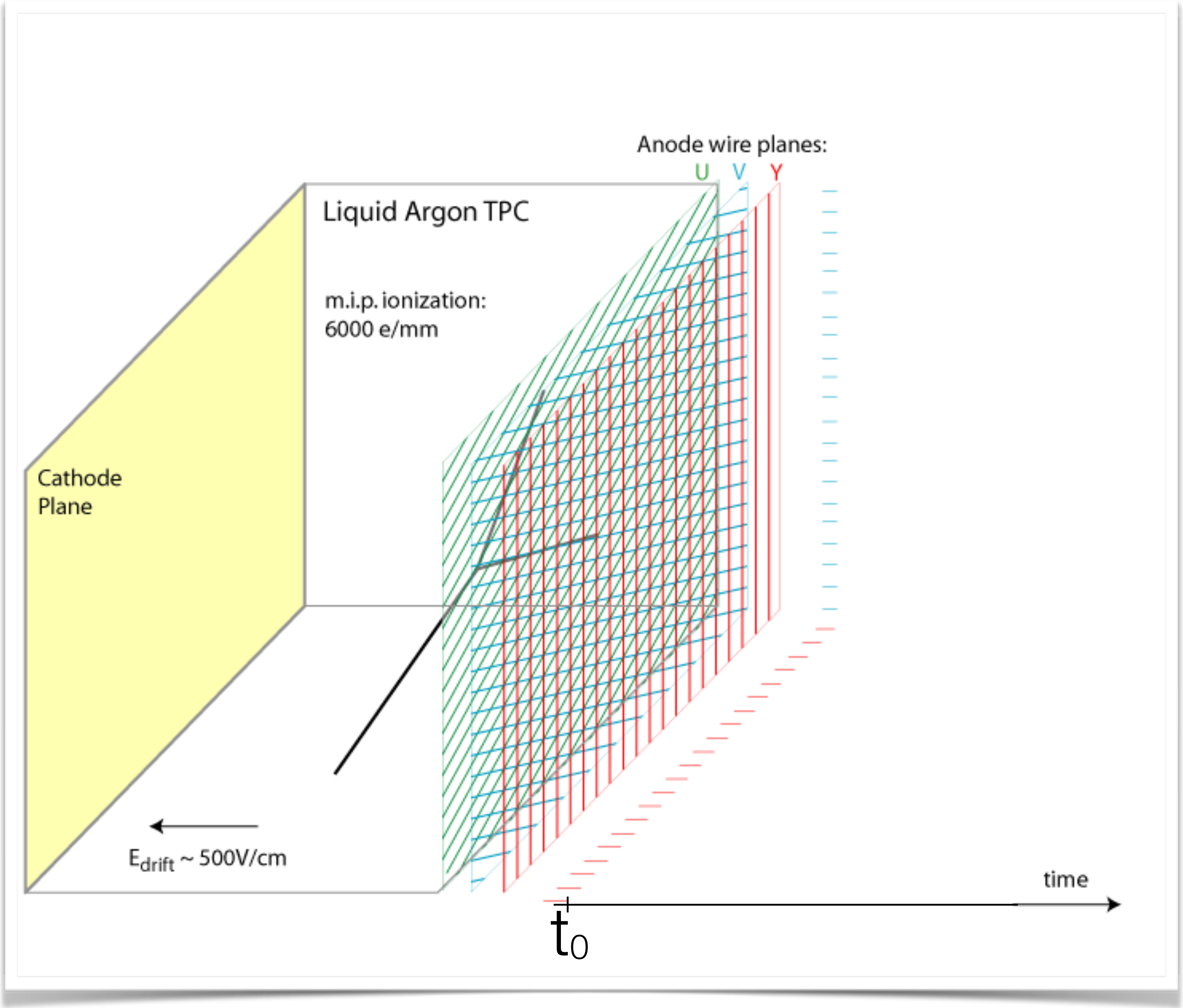
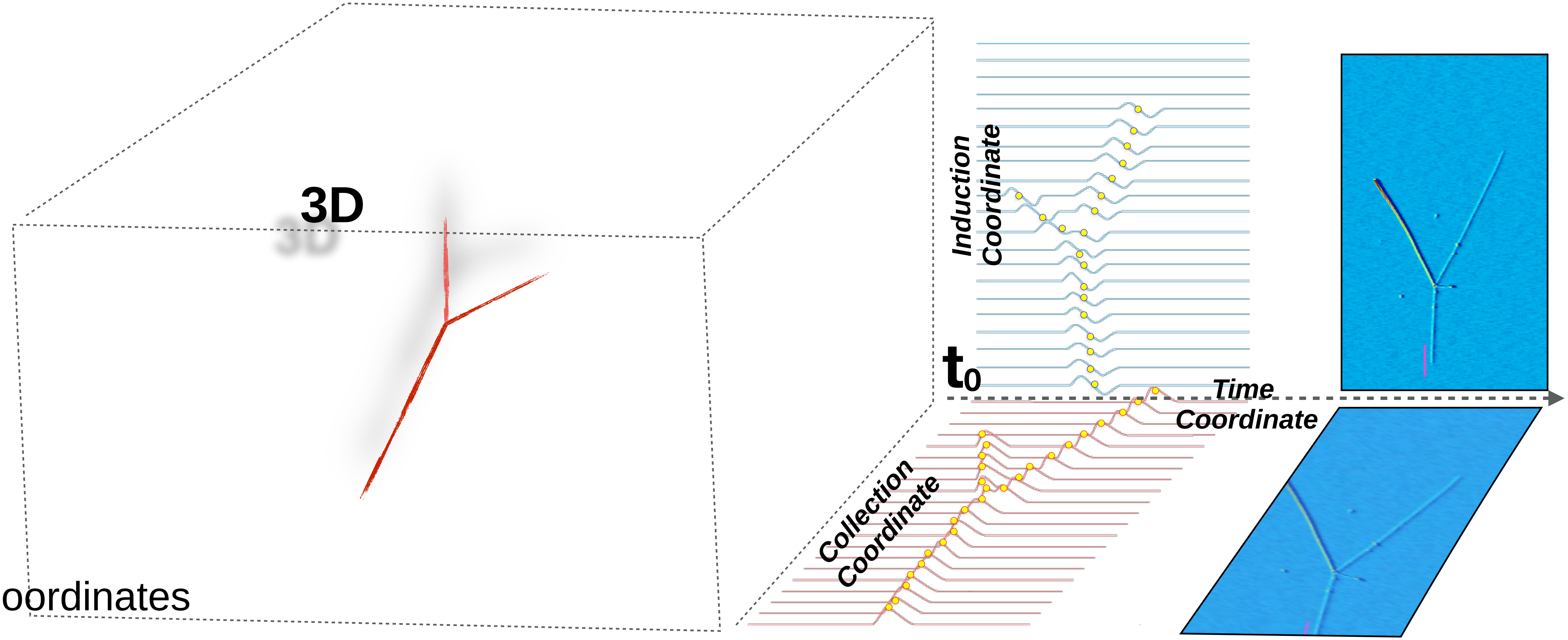


Figure 40. Geometry of the grids and reference frame

LArTPC at work: Imaging and Energy Reconstruction



LArTPC at work: Imaging and Energy Reconstruction



2D Image(s)
(graphic rendering)

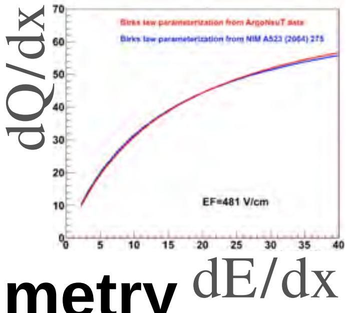
1. Hit coordinates

   (wire# and t_{hit} ⇒ 2 x 2D ⇒ **3D image**

2. Hit Amplitude ⇒ **dQ** Ionization Charge Deposited

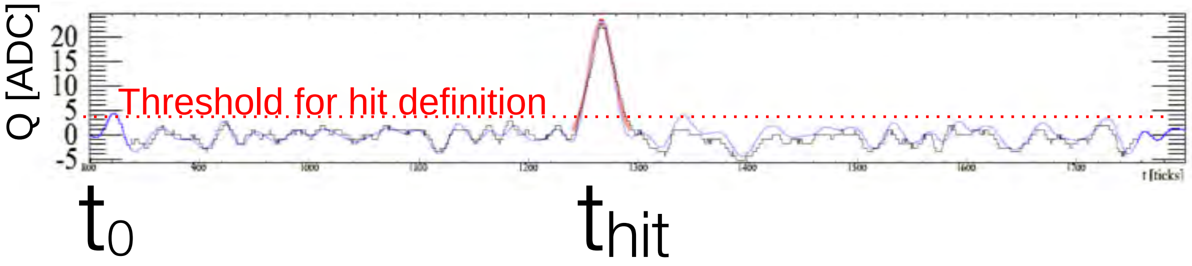
3. Distance in space between hits ⇒ **dx** (track pitch)

4. dQ/dx ⇒ dE/dx ⇒ **Ptcl Id**



5. $$\int_l \frac{dE}{dx}\,dx = E_{Tot}$$ ⇒ **Calorimetry**

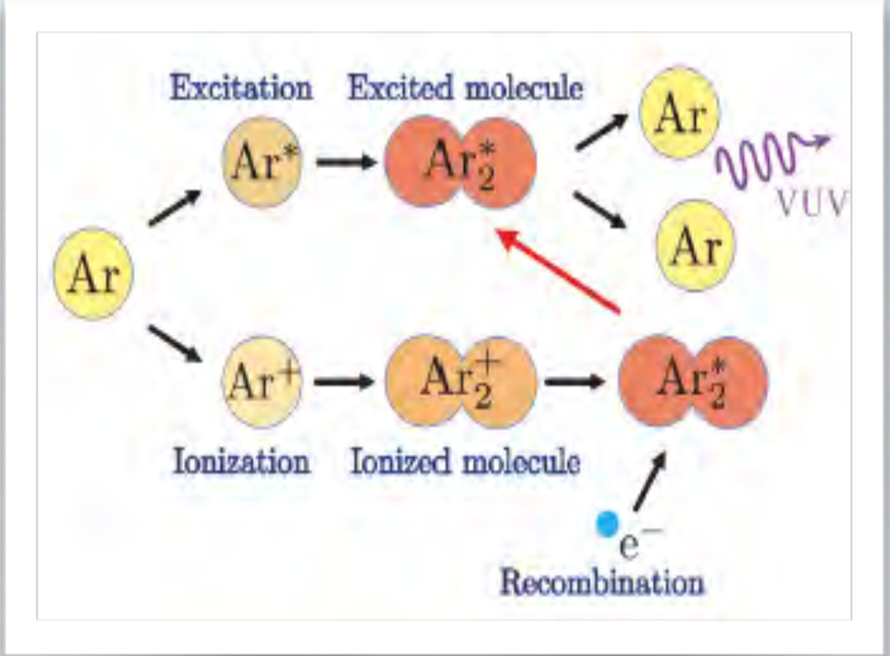
TPC wire Signal: find **Hit**



(real) TPC wire Signal

t0 time

Need a fast signal
to identify the time of the interaction (t0)



Prompt scintillation light produced in LAr as part of the ionization process ideal for t0 (and a lot more):

Need a ***Photo-Detector*** *embedded in the TPC structure*

Ar Scintillation light is very abundant (40 k photons/MeV) but photon wavelength is in the VUV (128 nm)

Need wavelength-shifter (easiest solution)

in the modern LArTPC technology - Light Detector (PDS) is becoming an important complement to the Charge Detector (TPC)

LArTPC at work: LAr purity - the issue, the solution

Ionization electrons must drift over distance of $\mathcal{O}$(m), ie drift times $\mathcal{O}$(ms), without substantial capture by electronegative impurities ⇒ limit on level of contamination [O_2-equiv] ≤ 100 ppt (part per trillion)

"The starting material is Argon gas which has a (typical) *impurity concentration of ≈ 0.1 ppm of Oxygen. The gas is passed through the* (filter) *cartridge to remove the Oxygen present … at a typical rate of 0.35 l of gas per second. The gas is then liquefied …"*
[J. Bahcall, M. Baldo-Ceolin, D.B. Cline and C.Rubbia, **Phys.Lett B178**, (1986)]

The issue:

At this rate it would take ~1000 yr to purify&fill one DUNE Module

The solution:

"Argon purification in the liquid phase" **[NIM A333 (1993), 567]**

"we have shown that ultrapure liquid Argon can be obtained by direct purification of the liquid. The final purity corresponds to an electro-negative impurity concentrations below 0.1 ppb O_2 equivalent, equal to that obtained with similar procedures (OXY reactant + molecular sieves) *purifying the gas phase. … The flows are almost three orders of magnitude (the ratio of the densities) higher. As a consequence, the problem of filling a large scale detector is much simplified (… few weeks for a kiloton sized detector)".*

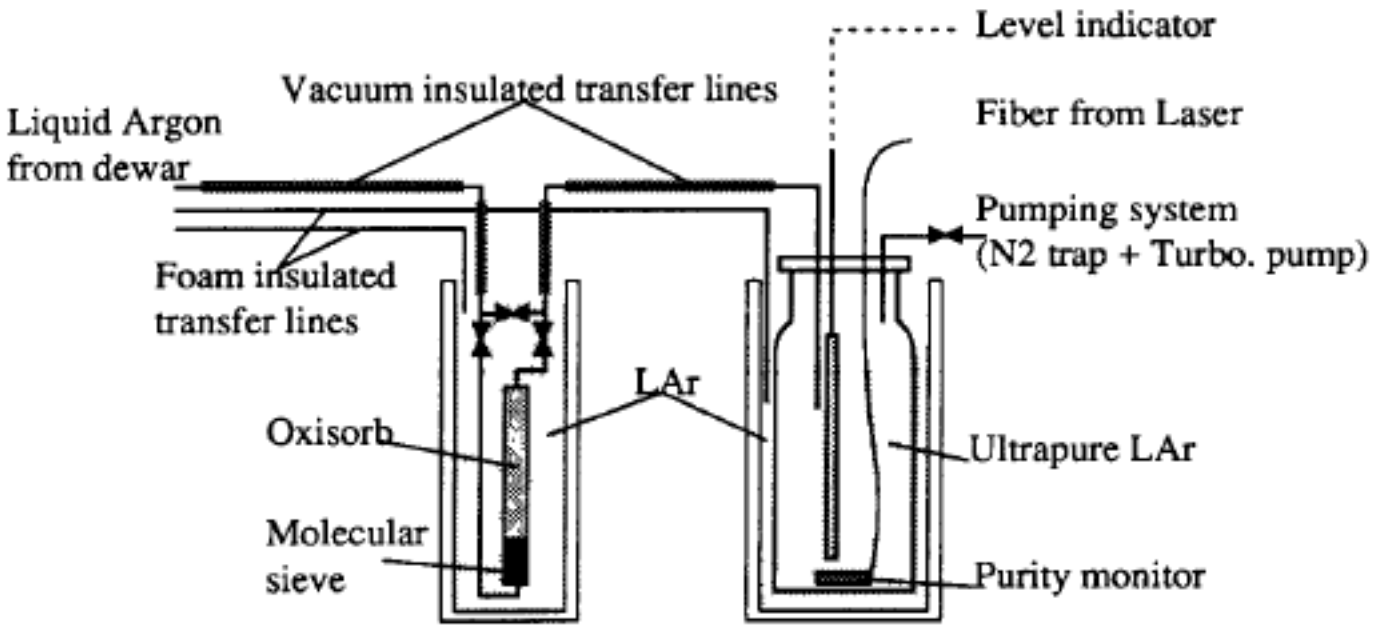


Fig. 1. Schematic view of the liquid phase argon purification system.

LArTPC technology in two “flavors”

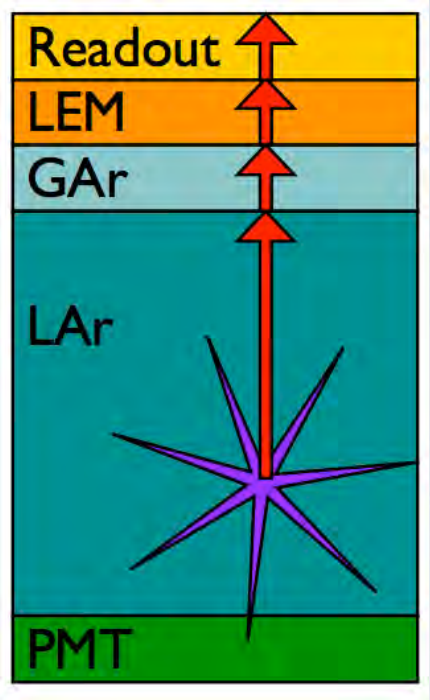
While the first LArTPC detectors for Neutrino Physics were built/operated..

a new concept in the technology *(derived from LArTPC detectors for Dark Matter Search)* was proposed and developed:

Dual Phase LAr+GAr TPC

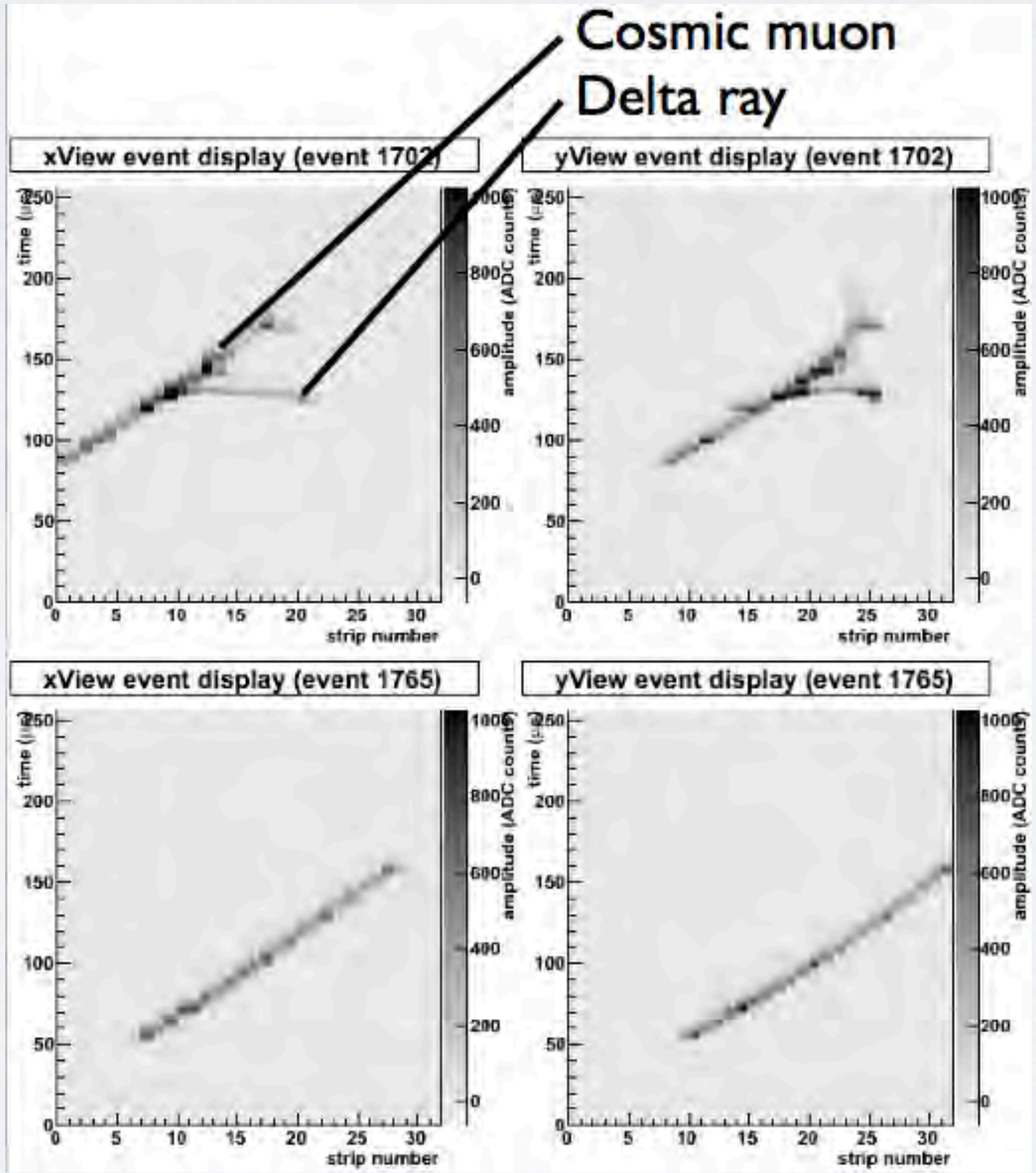
where the read/out system is in the gas
(above the liquid)

Dual Phase Ar TPC Concept (~2005)



a 3D-imaging and calorimetric device capable of adjustable charge amplification
based on LEM -
Large Electron Multiplier


Electron avalanche in LEM hole

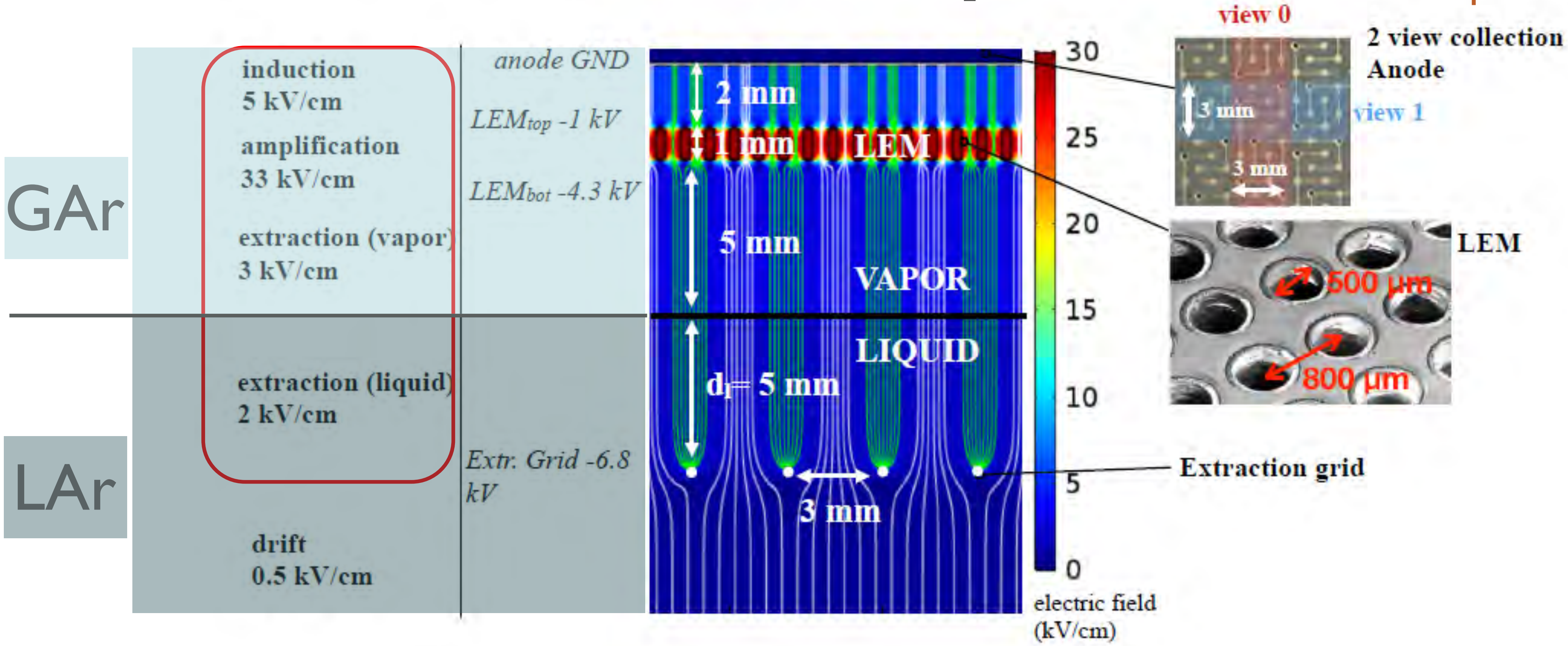


Proof of Principle

LAr LEM-TPC
@ CERN (by **ETH**)

LArTPC Dual Phase concept

Dual-phase readout



Charge Readout Plane integrating LEM-anode sandwiches

Features of dual-phase design:

- Gain in the gas phase → robust and tunable S/N, lower detection threshold, compensation for charge attenuation due to long drift paths
- Finer readout pitch (3.125 mm), implemented in two identical collection views (X,Y) on 3m long strips
- Long drift projective geometry: reduced number of readout channels, absence of dead materials in the drift volume
- Fewer construction modules, costs, installation

- Full accessibility and replaceability of cryogenic front-end (FE) electronics during detector operation

LARTPC (SINGLE PHASE) READY FOR PHYSICS ON NEUTRINO BEAMS

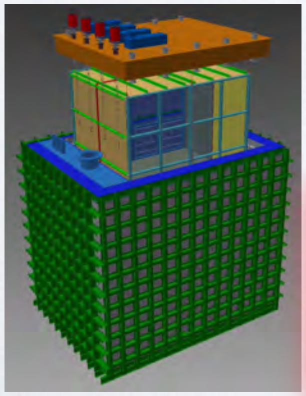
Icarus 50 lt - CERN WANF (1997)

ArgoNeuT 0.5 t - FNAL NuMI (2008-9)

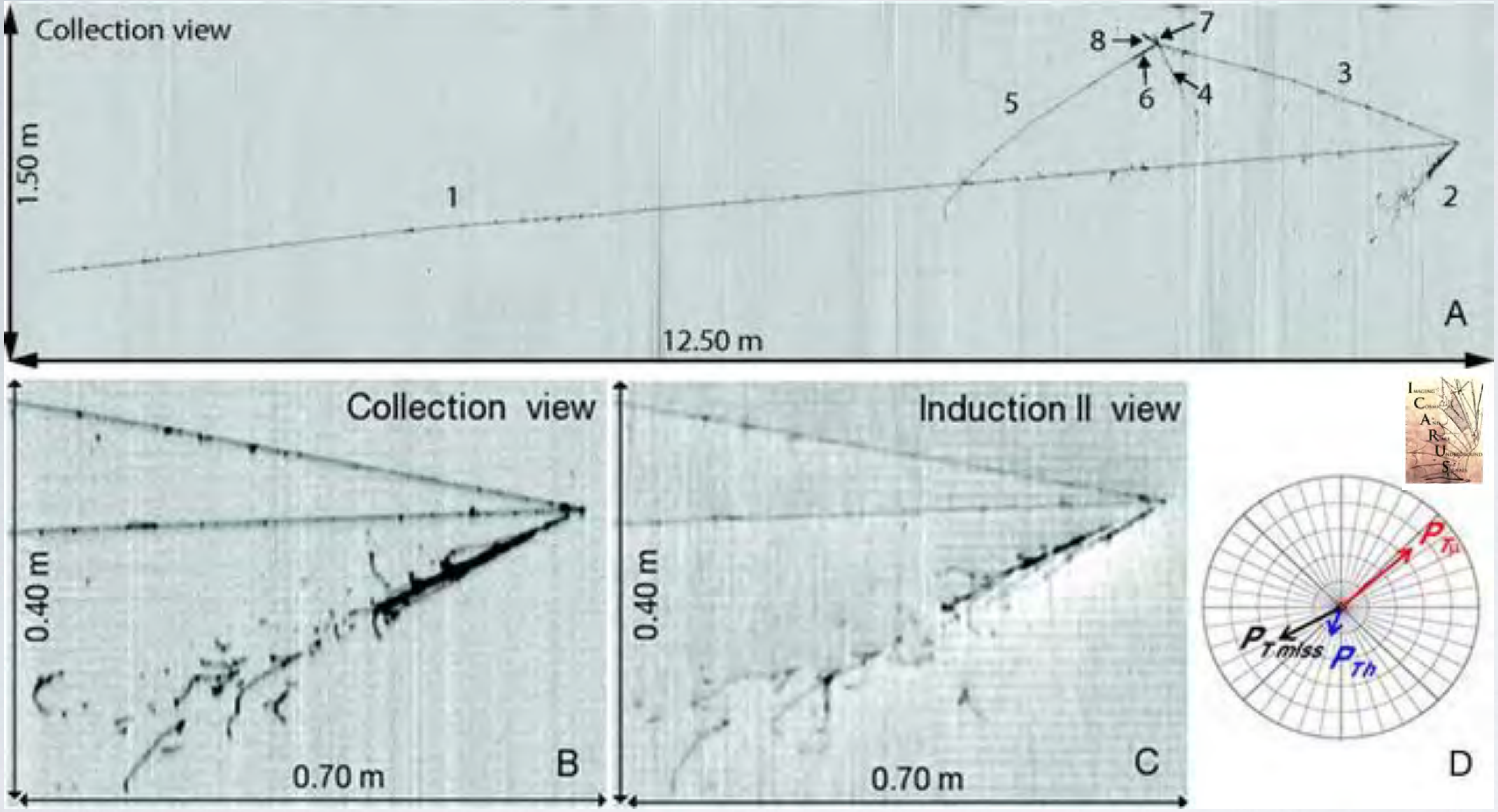
MicroBooNE 100 t - FNAL Booster (2015-present)

ICARUS 300 t x 2

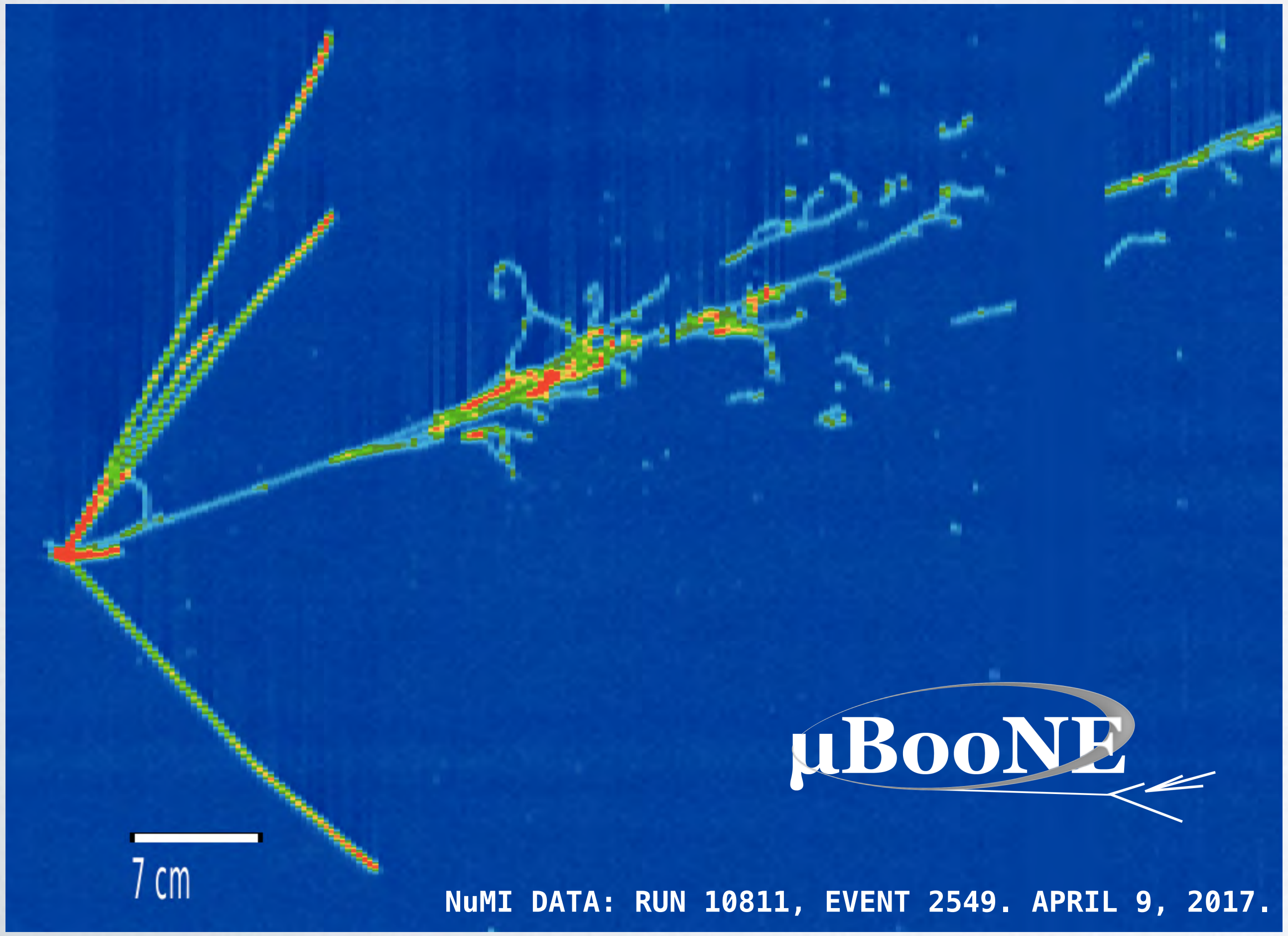
- CERN CNGS (2010-13)
- FNAL Booster (today LAr filling completed !)



SBND 200 t - FNAL Booster (under construction)



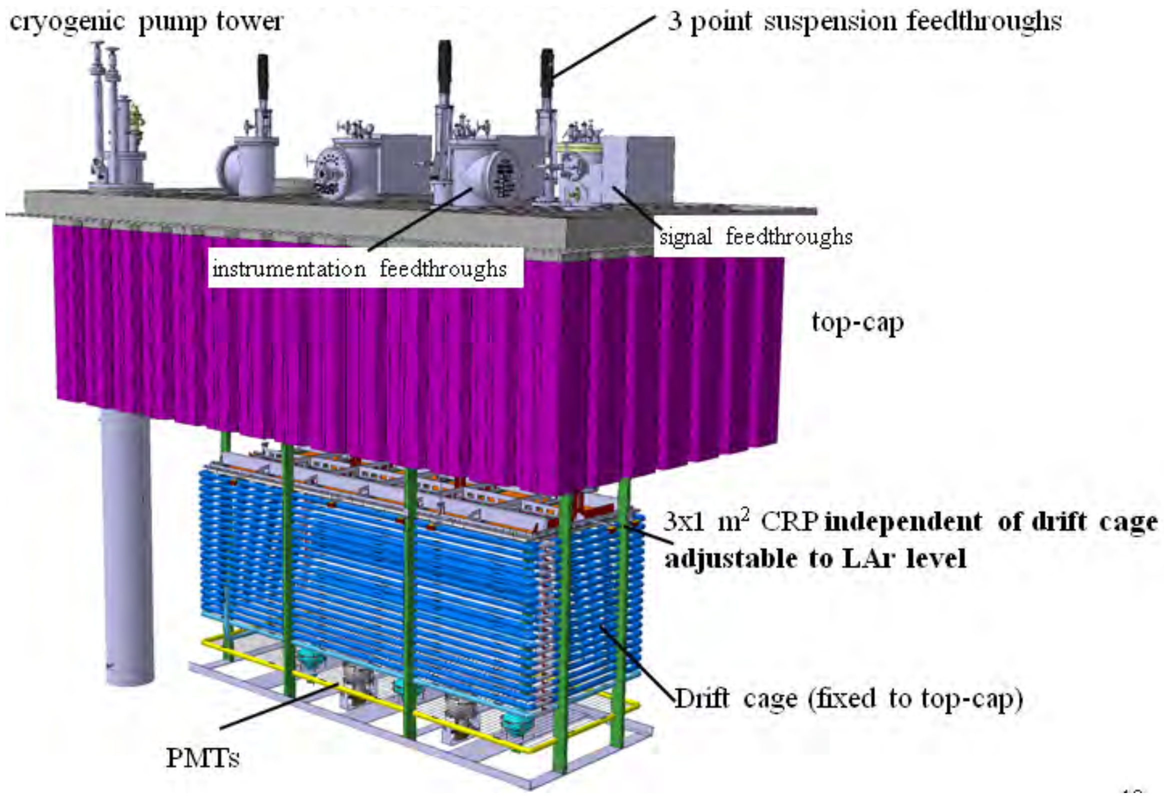
ICARUS at GranSasso Lab operated on the CNGS beam from 2010 to 20013 producing physics results



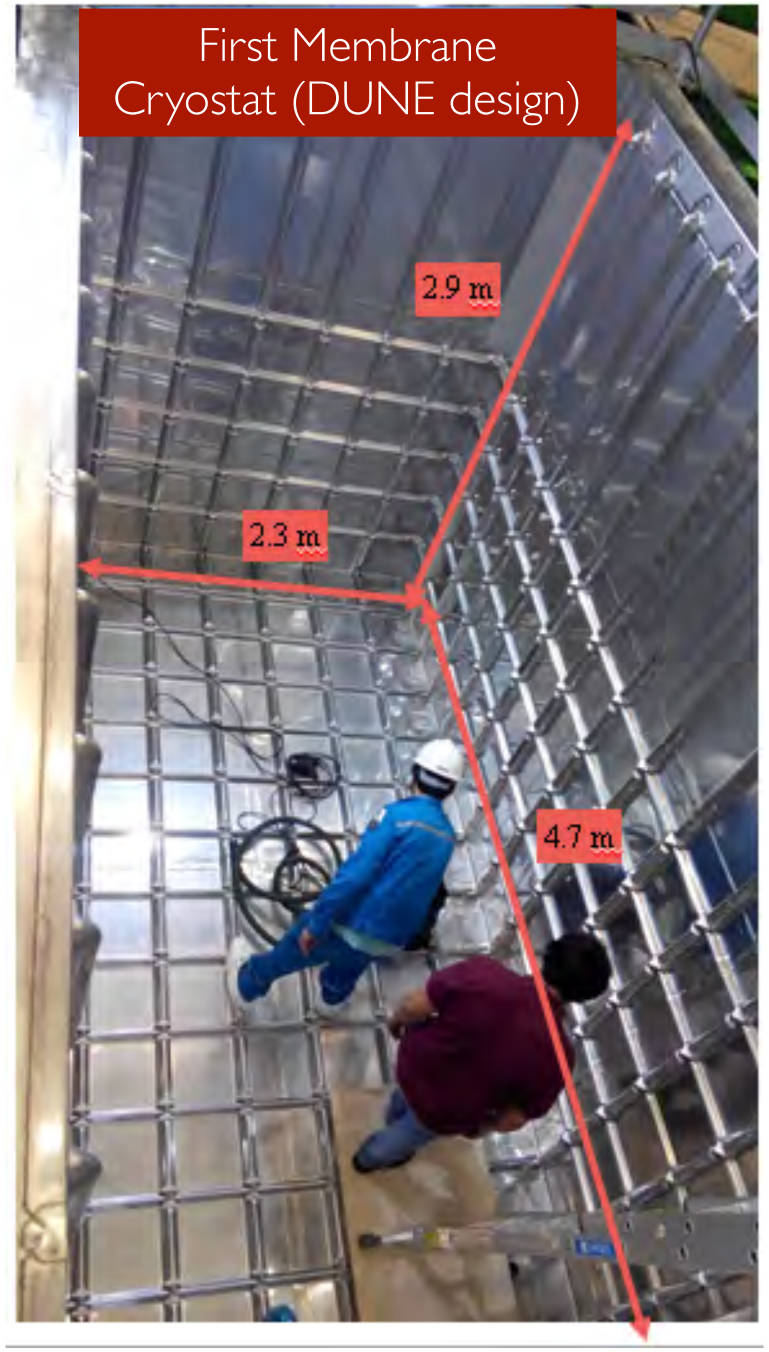
MicroBooNE at FNAL takes neutrino data since 2015 and is producing physics results

(a main one expected in summer)

Pilot Dual Phase Detector:
$3 \times 1 \times 1\ m^3$ at CERN



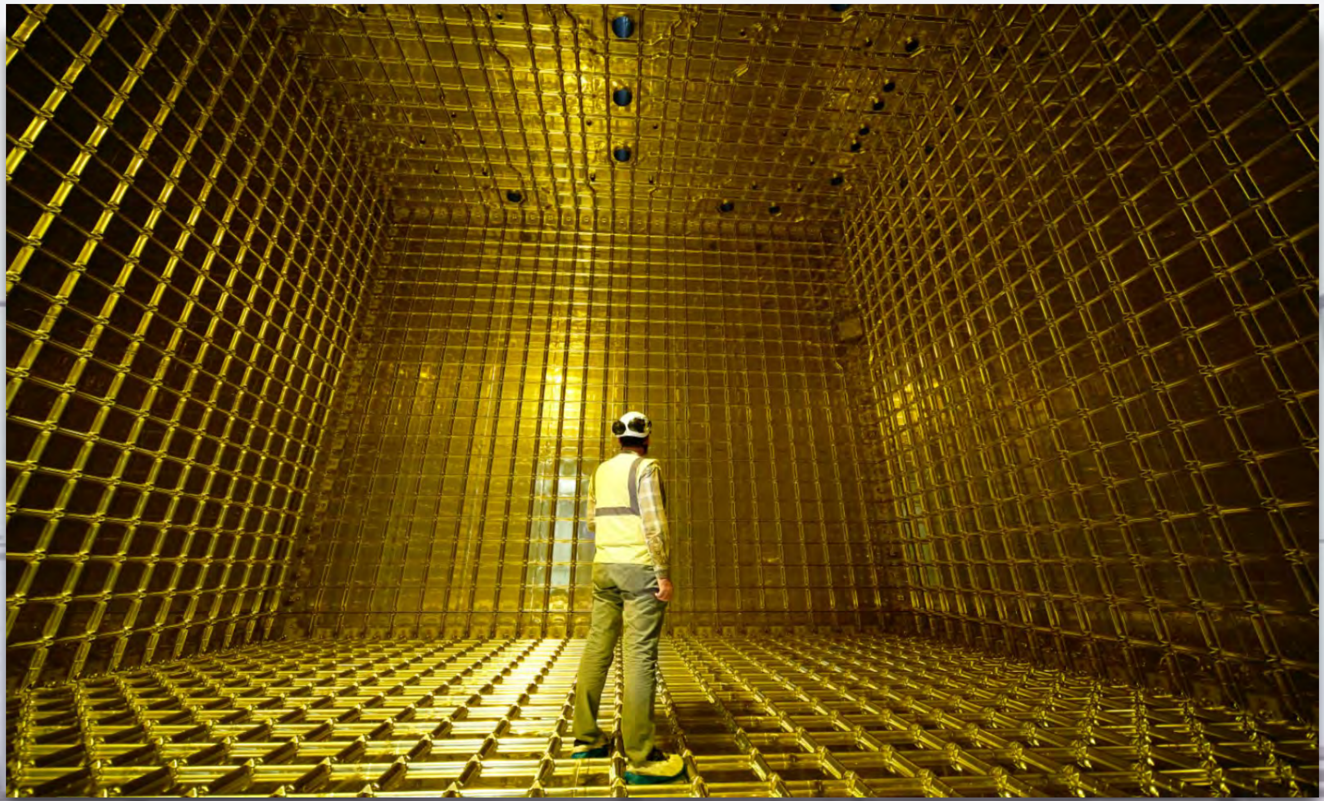
Detector installation completed in fall 2016


First Membrane Cryostat (DUNE design)

DUNE First Module

17,000 t LArTPC Single Phase

one giant leap for the technology



protoDUNE-SP
1kt LAr

ICARUS

MICROBOONE

SBND

DUNE 2nd or 3rd Module

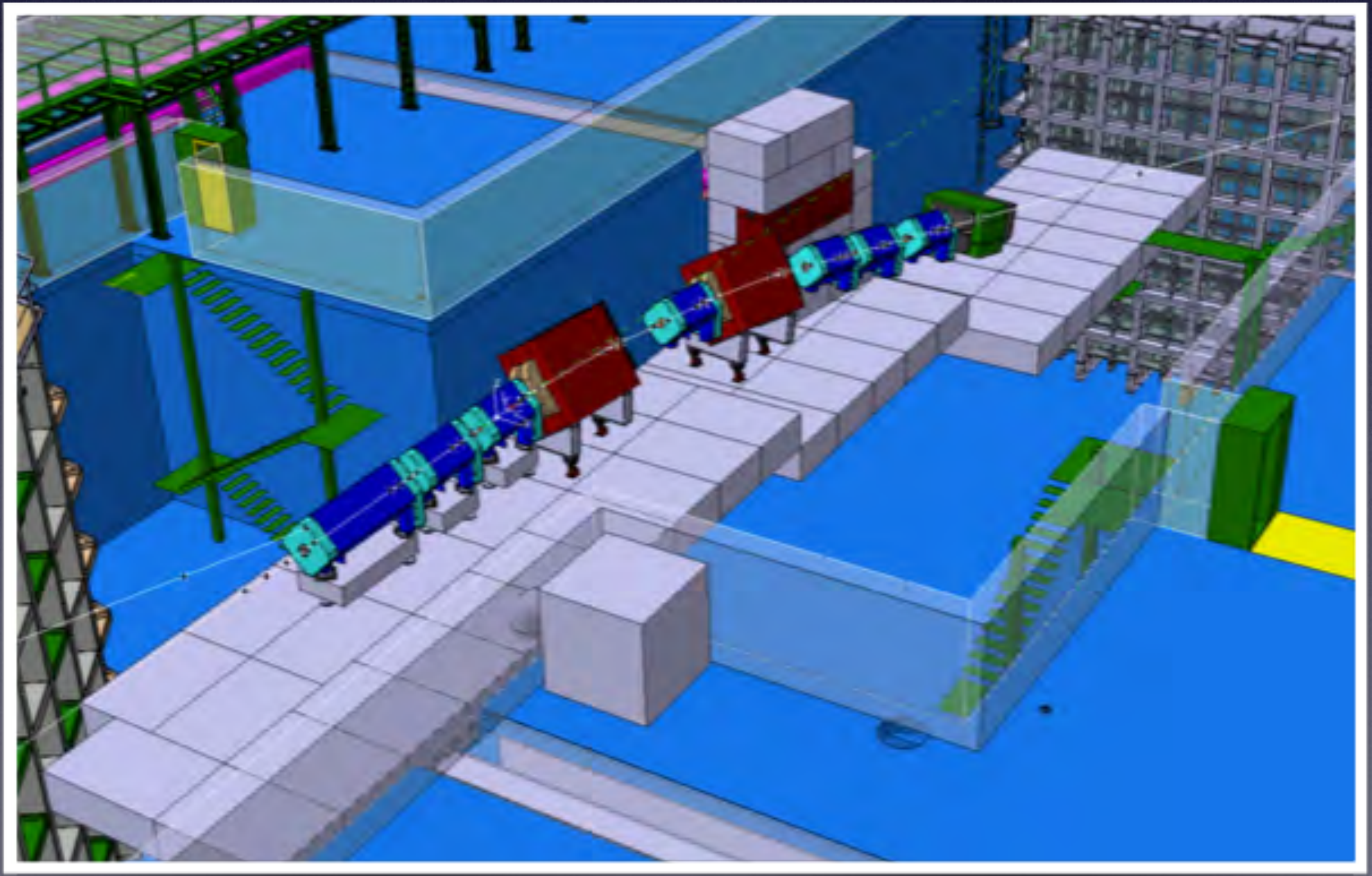
17,000 t LArTPC Dual Phase

protoDUNE-DP

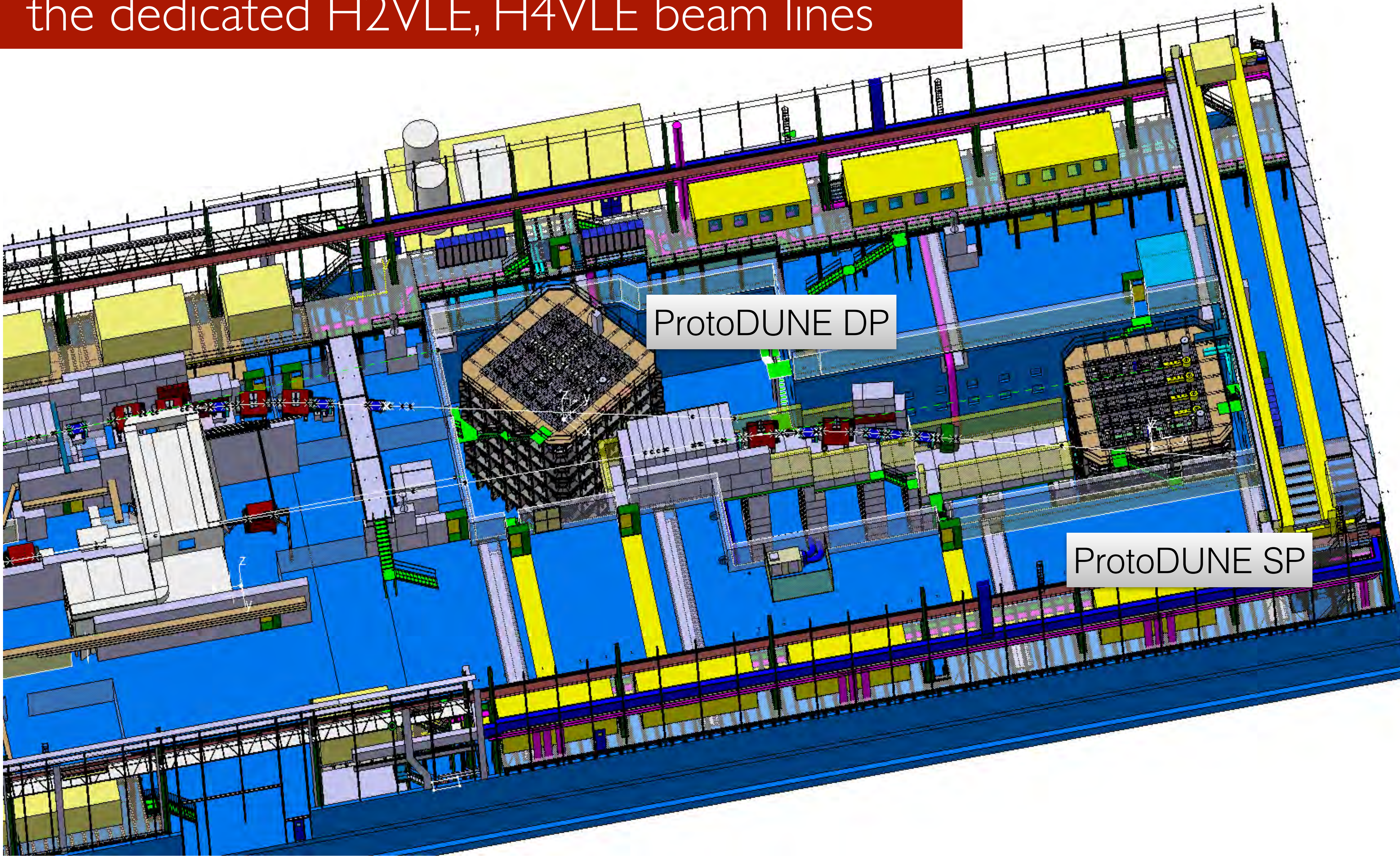
1kt LAr

$3 \times 1 \times 1\ m^3$

ProtoDUNE at CERN



The Neutrino Platform and the dedicated H2VLE, H4VLE beam lines


ProtoDUNE DP

ProtoDUNE SP

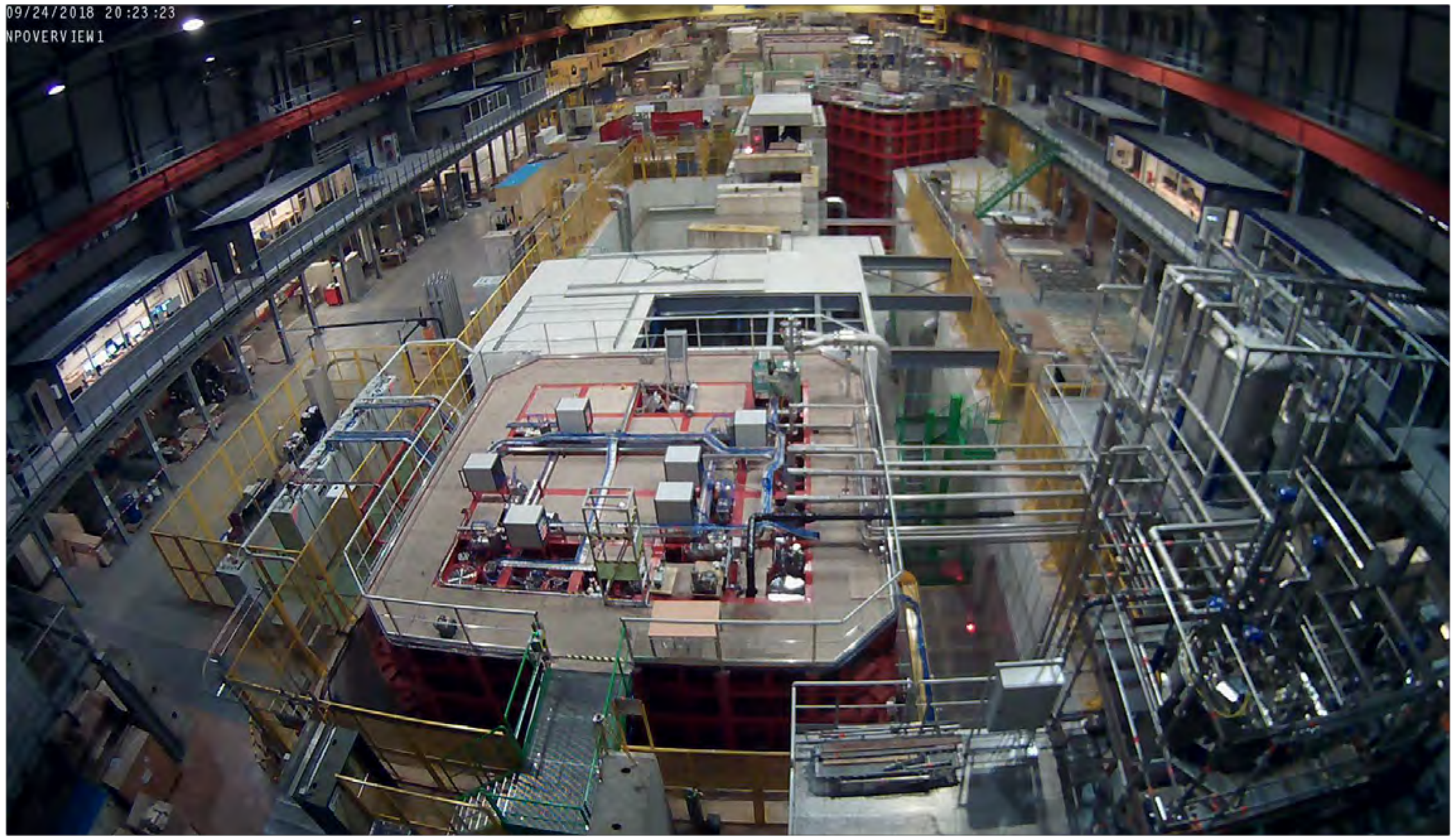
extension of the EHN1 experimental area at CERN's Prévessin site

the CERN Neutrino Platform:
a new dedicated experimental facility for

PROTO DUNE

- **Dec. 12, 2015**

Sept. 21, 2018



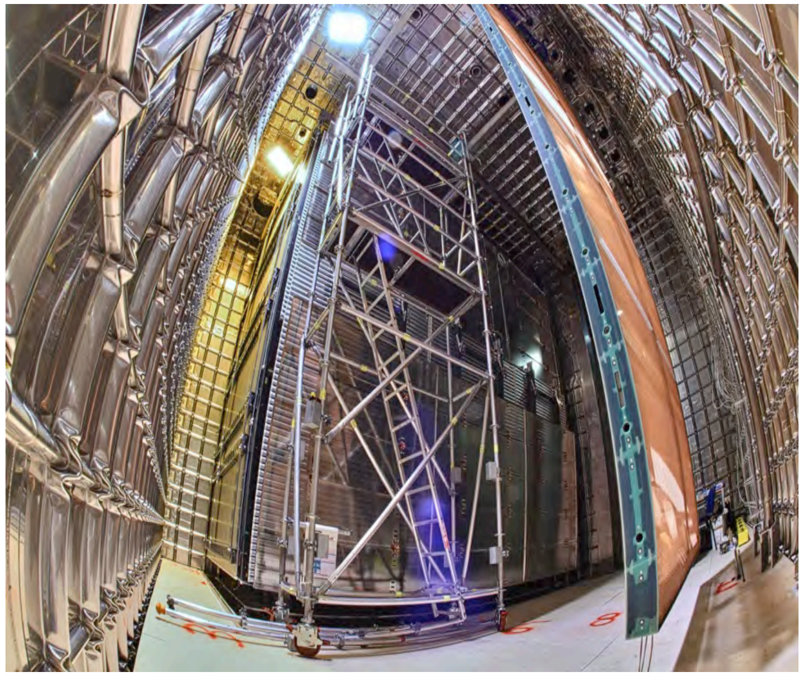
Neutrino PLATFORM

PROTO DUNE SP in few snapshots

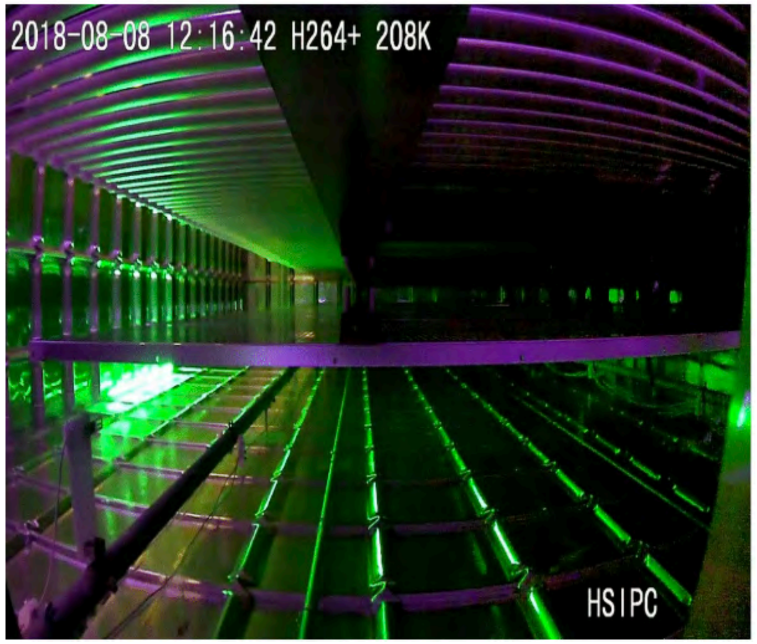
March 2016, construction of EHN1 extension

November 2016, cryostat structure assembly

September 2017, cryostat completion

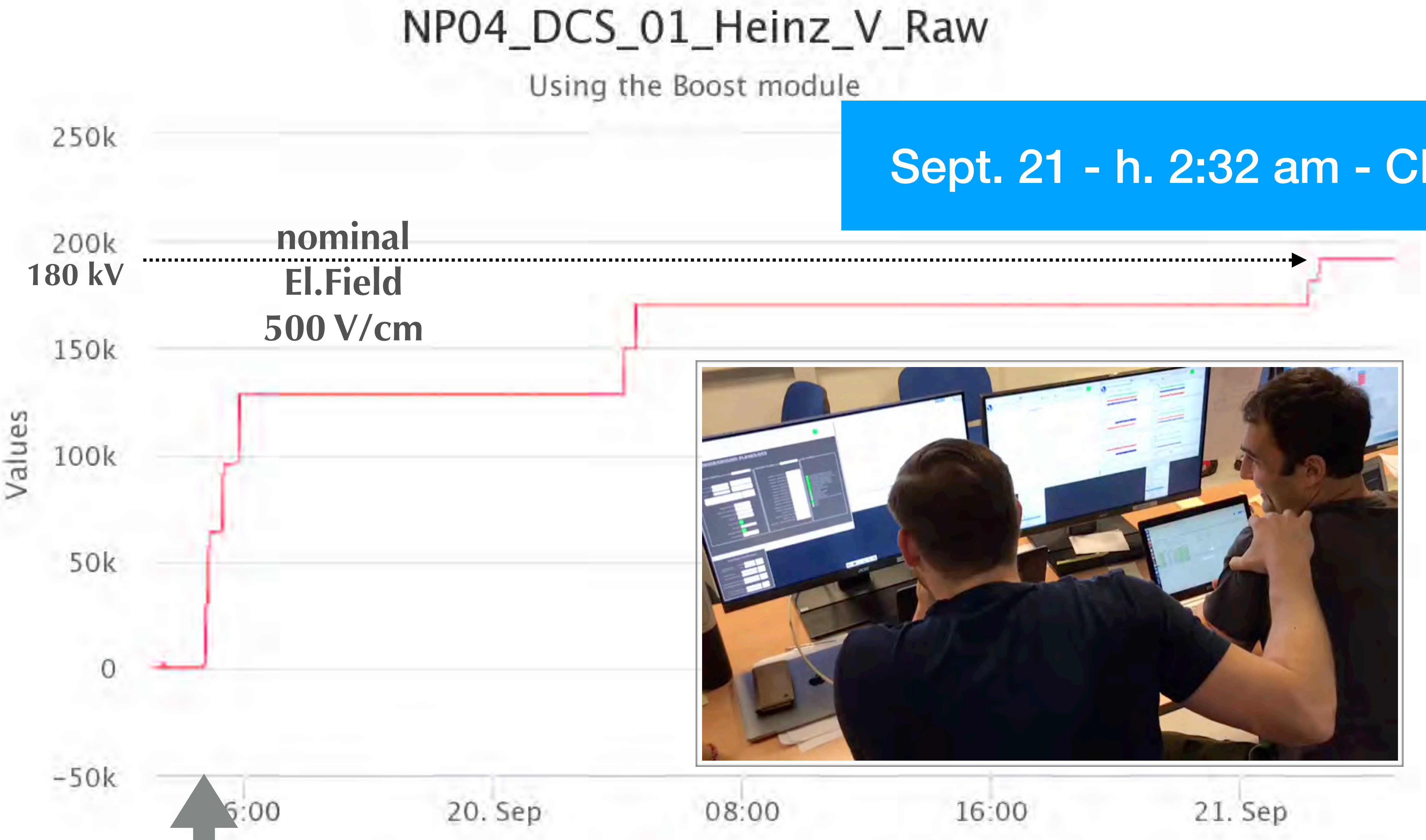


February 2018, detector assembly



August 2018, LAr filling

September 19, 2018 - ready for beam!



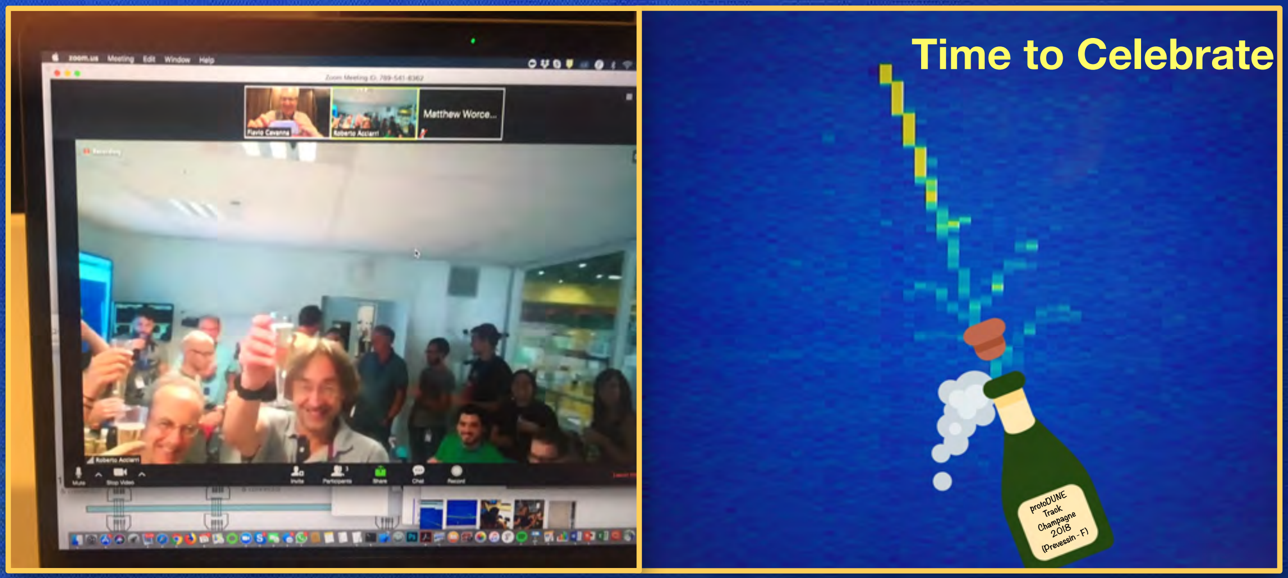
Sept. 21 - h. 2:32 am - CDT

180 kV

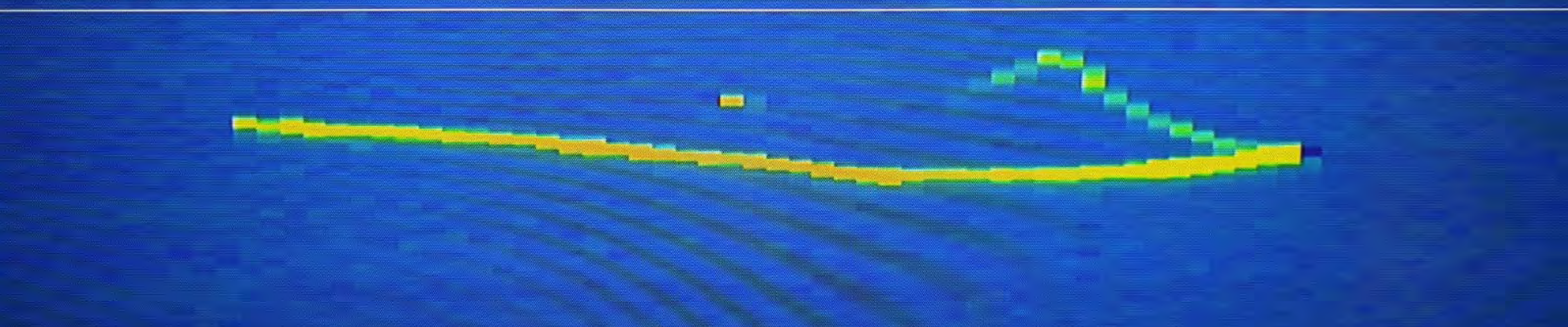
nominal
El.Field
500 V/cm

Sept.19

HV Ramp from 0 to 180 kV (Nominal)

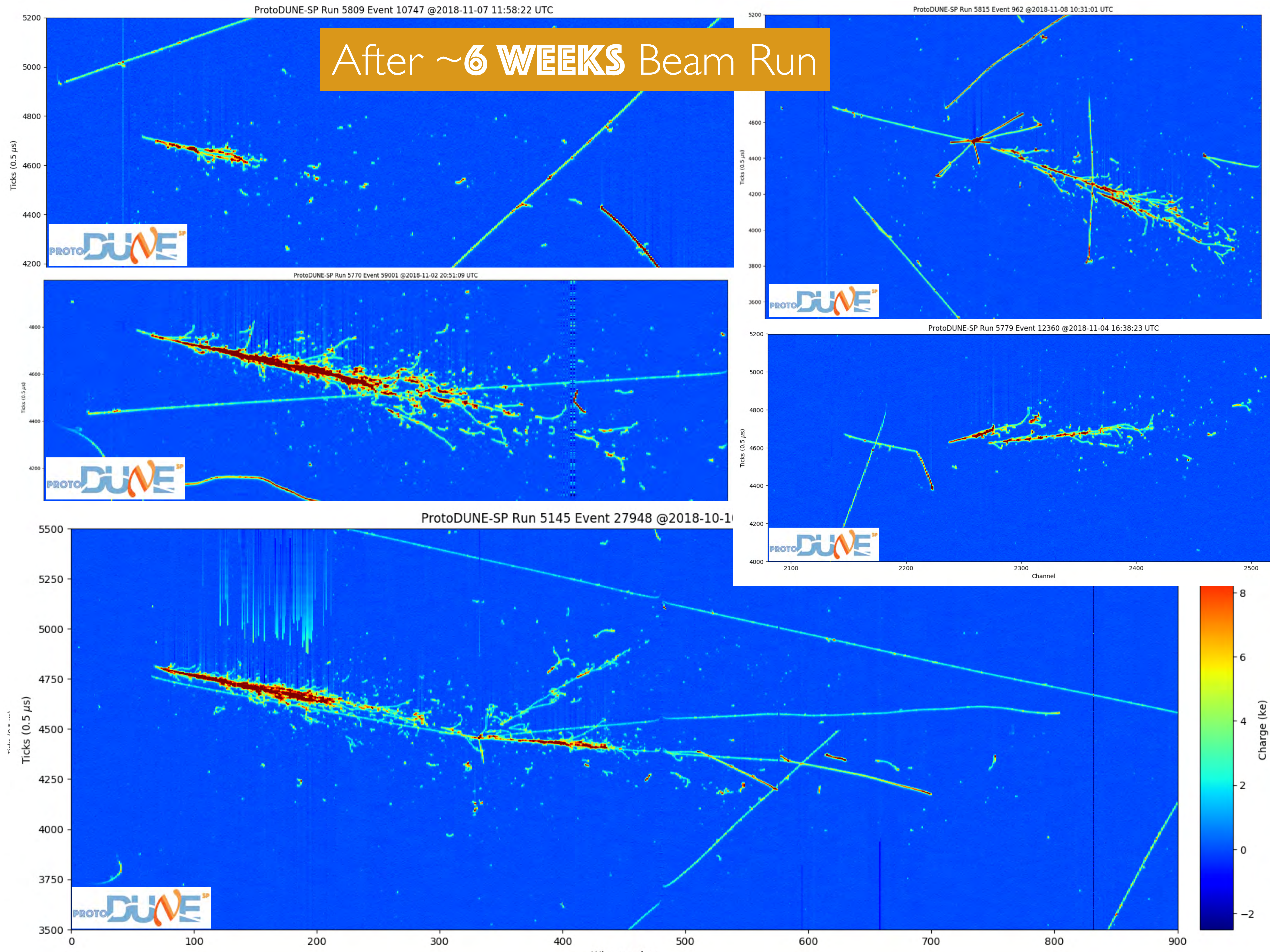


few seconds after, from the On-Line Monitor



First track recorded at Nominal El.Field

After ~6 WEEKS Beam Run

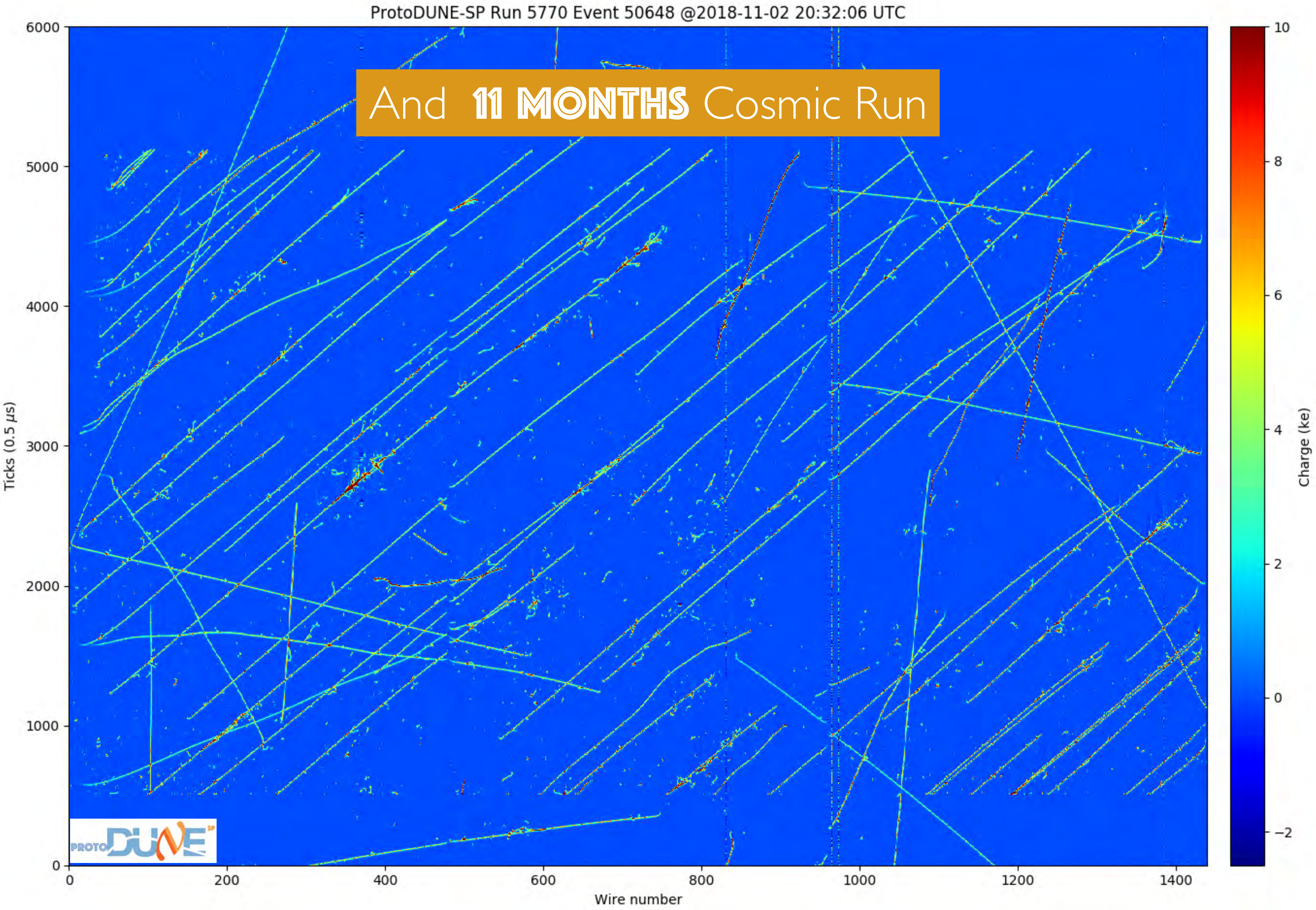


real beam event in 3D

click here for a

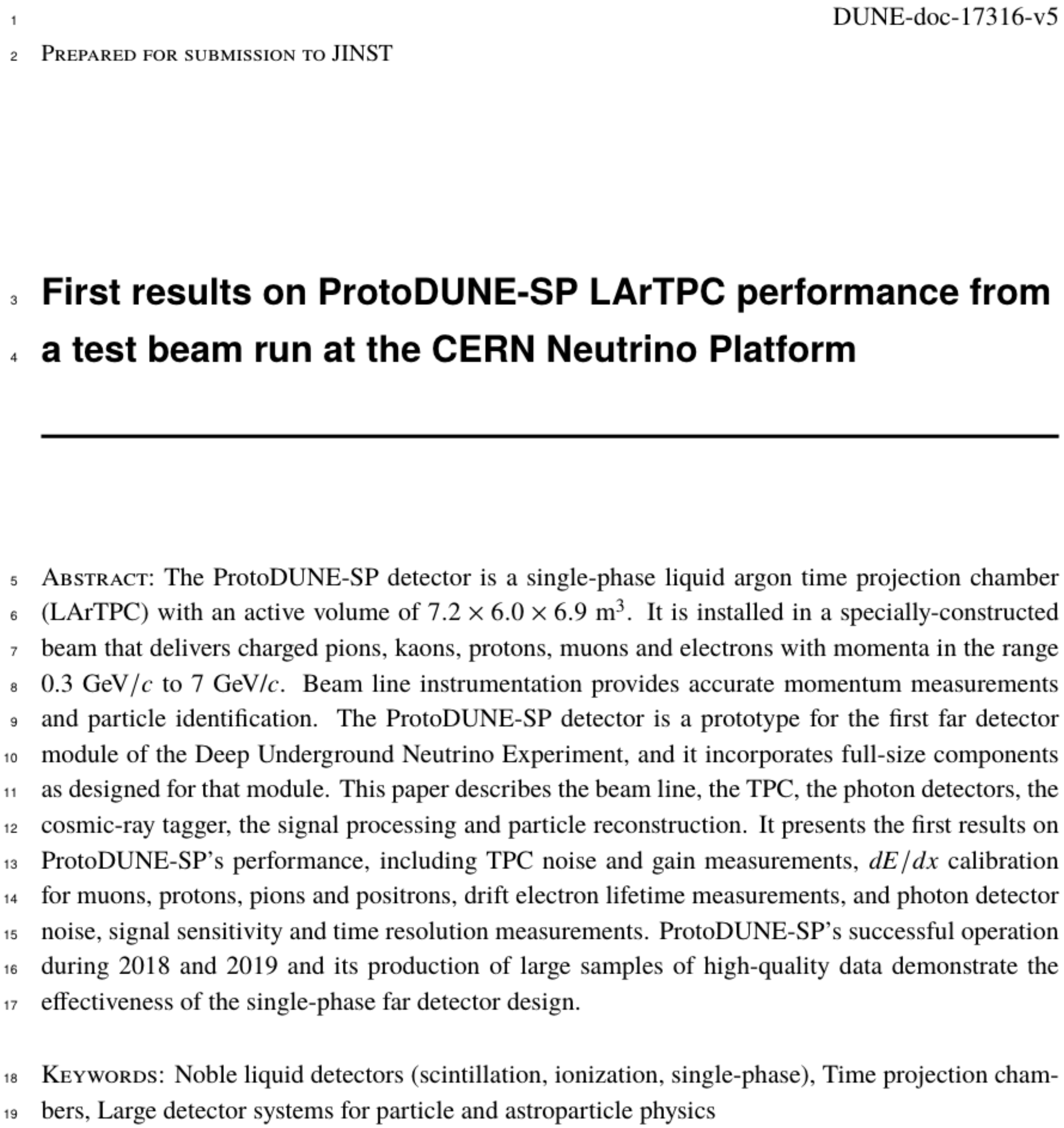
gallery of ProtoDUNE events

And 11 MONTHS Cosmic Run



1ST PAPER COMPLETED ON DEC. 15, 2019

Currently under DUNE internal review
expect to submit for publication buy end of April



DUNE-doc-17316-v5

PREPARED FOR SUBMISSION TO JINST

First results on ProtoDUNE-SP LArTPC performance from a test beam run at the CERN Neutrino Platform

ABSTRACT: The ProtoDUNE-SP detector is a single-phase liquid argon time projection chamber (LArTPC) with an active volume of $7.2 \times 6.0 \times 6.9$ m^3. It is installed in a specially-constructed beam that delivers charged pions, kaons, protons, muons and electrons with momenta in the range 0.3 GeV$/c$ to 7 GeV$/c$. Beam line instrumentation provides accurate momentum measurements and particle identification. The ProtoDUNE-SP detector is a prototype for the first far detector module of the Deep Underground Neutrino Experiment, and it incorporates full-size components as designed for that module. This paper describes the beam line, the TPC, the photon detectors, the cosmic-ray tagger, the signal processing and particle reconstruction. It presents the first results on ProtoDUNE-SP's performance, including TPC noise and gain measurements, dE/dx calibration for muons, protons, pions and positrons, drift electron lifetime measurements, and photon detector noise, signal sensitivity and time resolution measurements. ProtoDUNE-SP's successful operation during 2018 and 2019 and its production of large samples of high-quality data demonstrate the effectiveness of the single-phase far detector design.

KEYWORDS: Noble liquid detectors (scintillation, ionization, single-phase), Time projection chambers, Large detector systems for particle and astroparticle physics

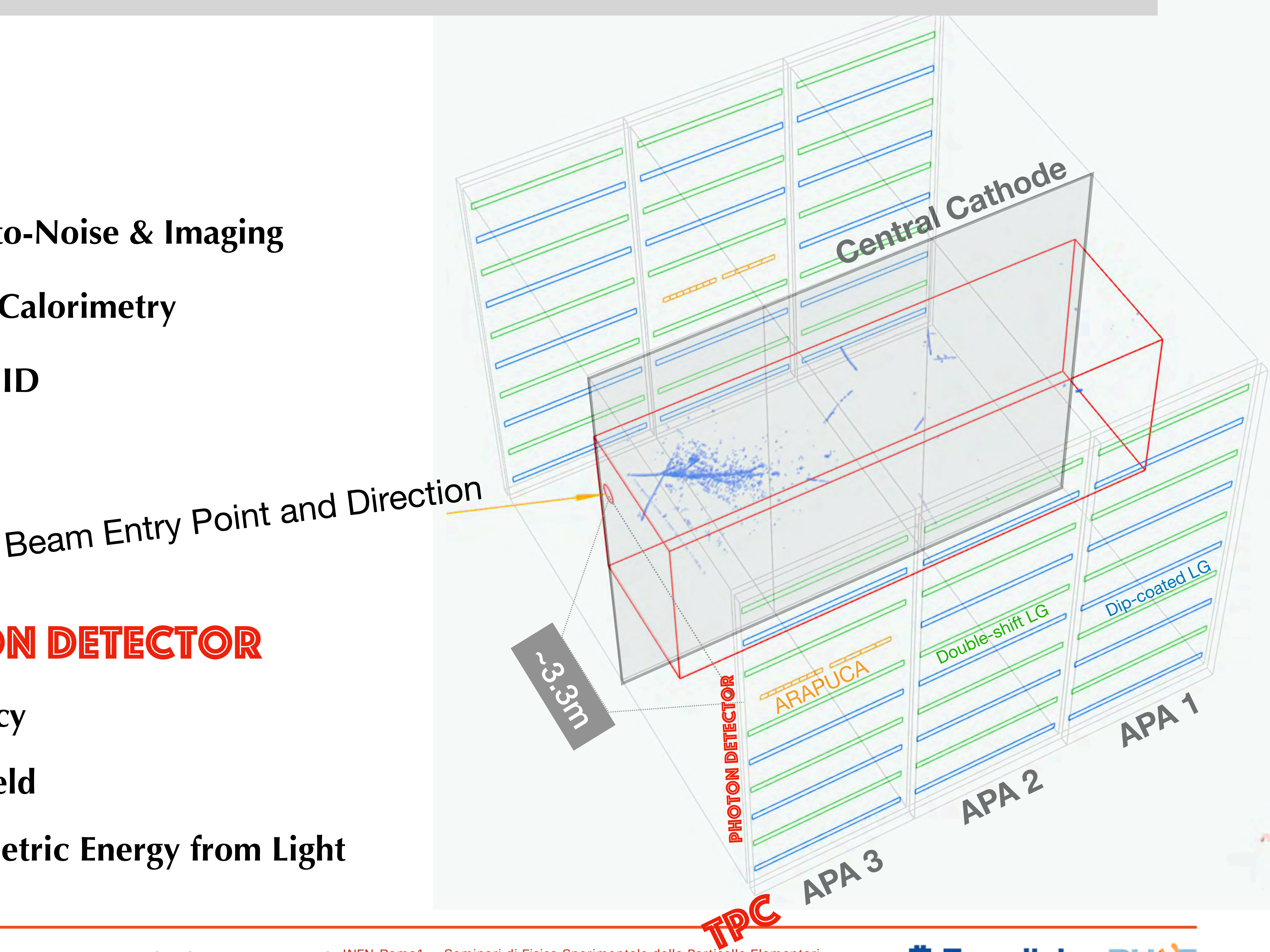
DETECTOR RESPONSE (BEAM DATA)

TPC

- Signal-to-Noise & Imaging
- dE/dx - Calorimetry
- Particle ID

PHOTON DETECTOR

- Efficiency
- Light Yield
- Calorimetric Energy from Light

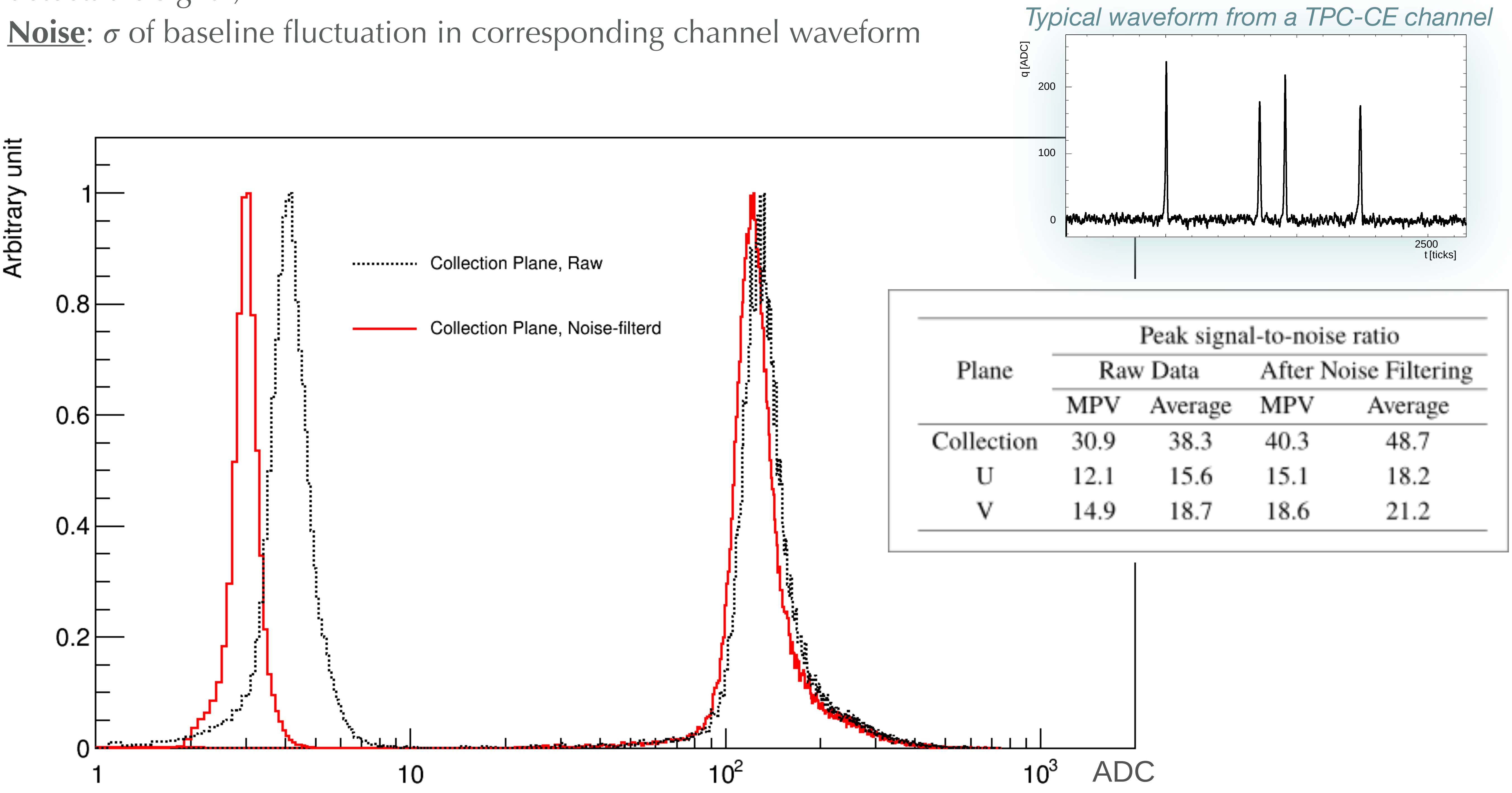


TPC + CE PERFORMANCE : Signal to Noise Ratio

Signal: detected Charge (*hit Peak-amplitude)* in individual channel waveform from mip tracks (the minimal detectable signal)

Noise: σ of baseline fluctuation in corresponding channel waveform

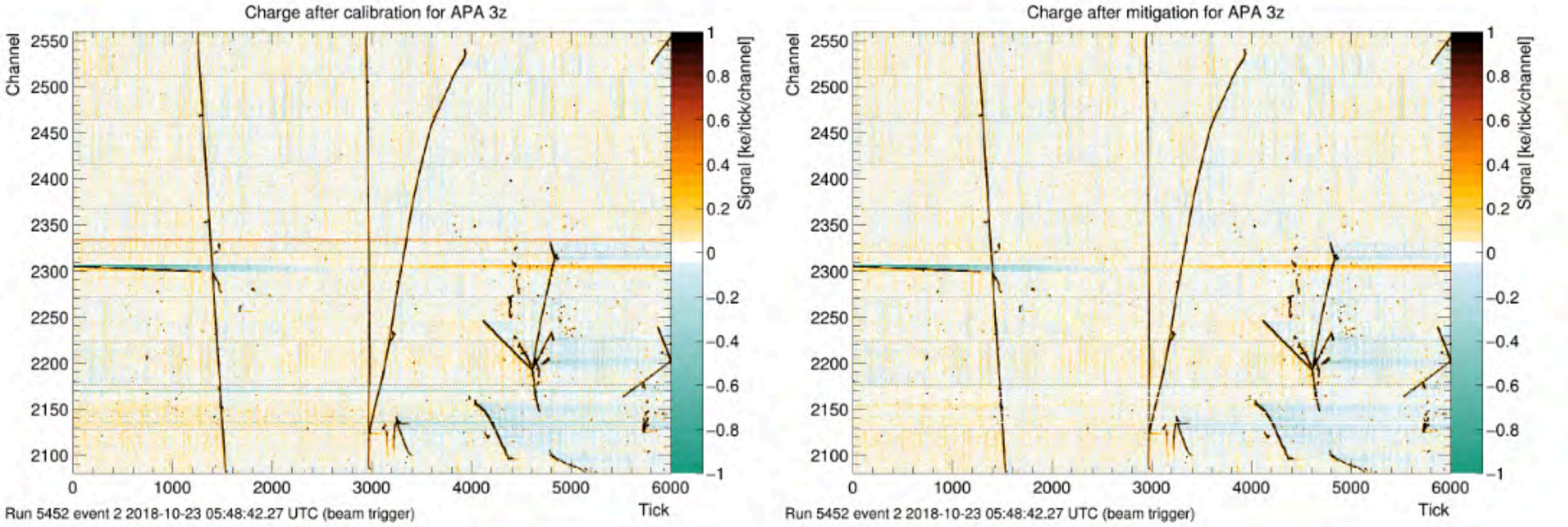
Typical waveform from a TPC-CE channel



Plane	Peak signal-to-noise ratio			
	Raw Data		After Noise Filtering	
	MPV	Average	MPV	Average
Collection	30.9	38.3	40.3	48.7
U	12.1	15.6	15.1	18.2
V	14.9	18.7	18.6	21.2

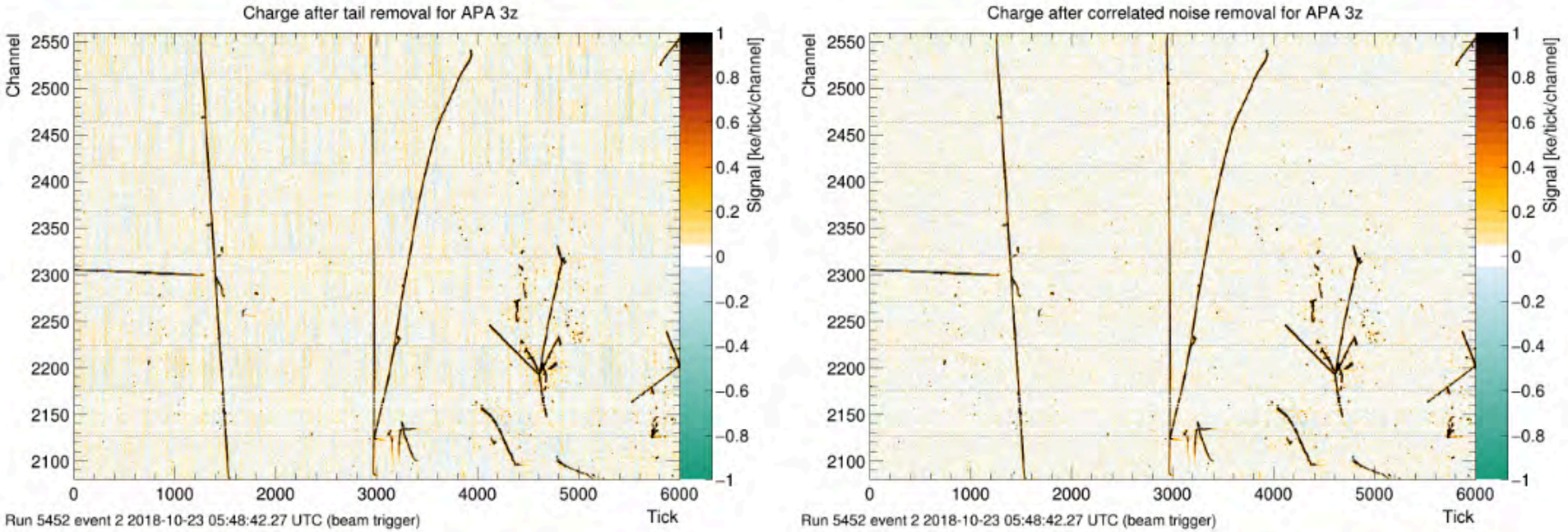
138 e/ADC

TPC + CE PERFORMANCE : Imaging



(a) After pedestal subtraction and calibration.

(b) After mitigation (Sticky code)

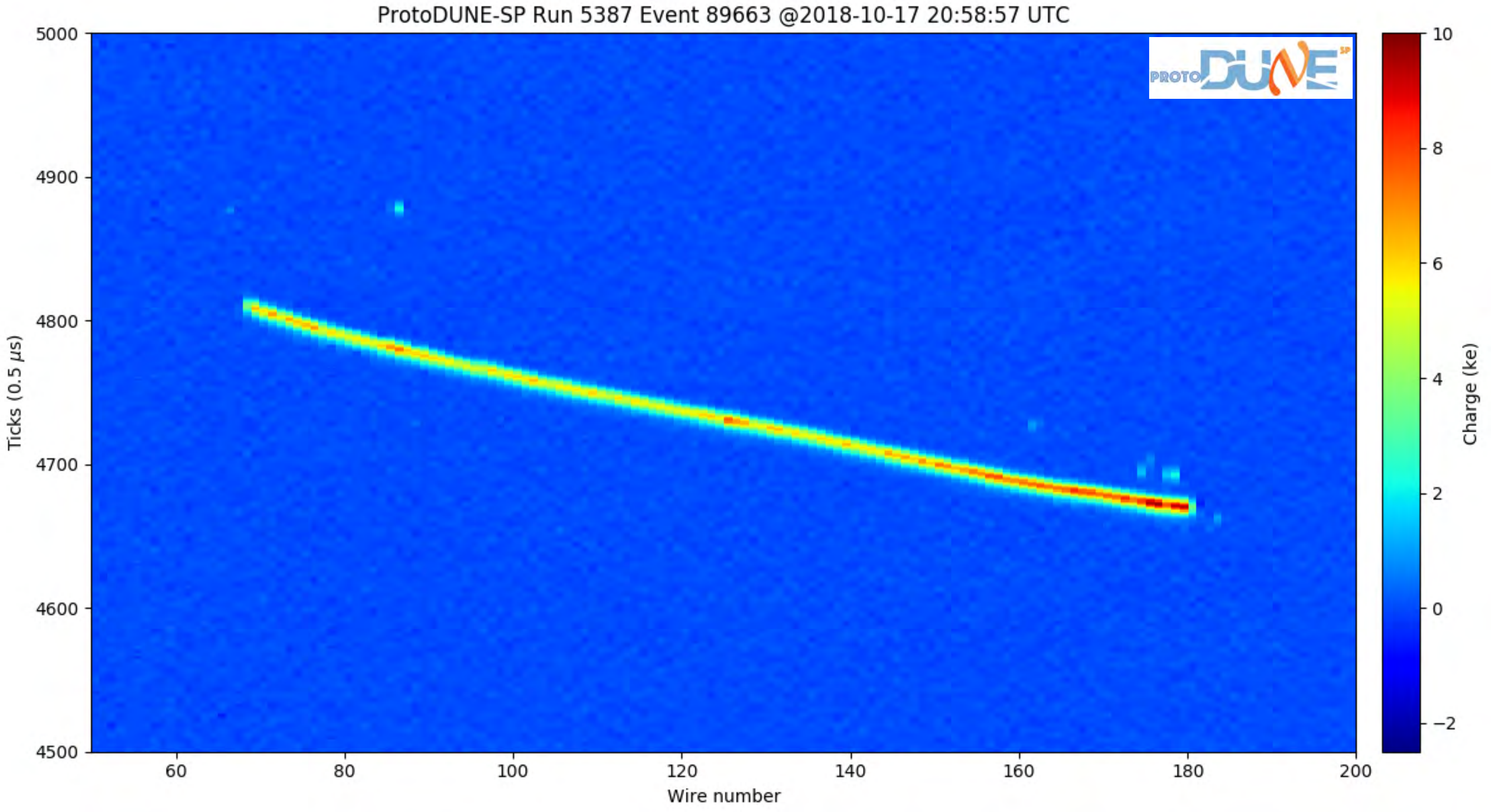


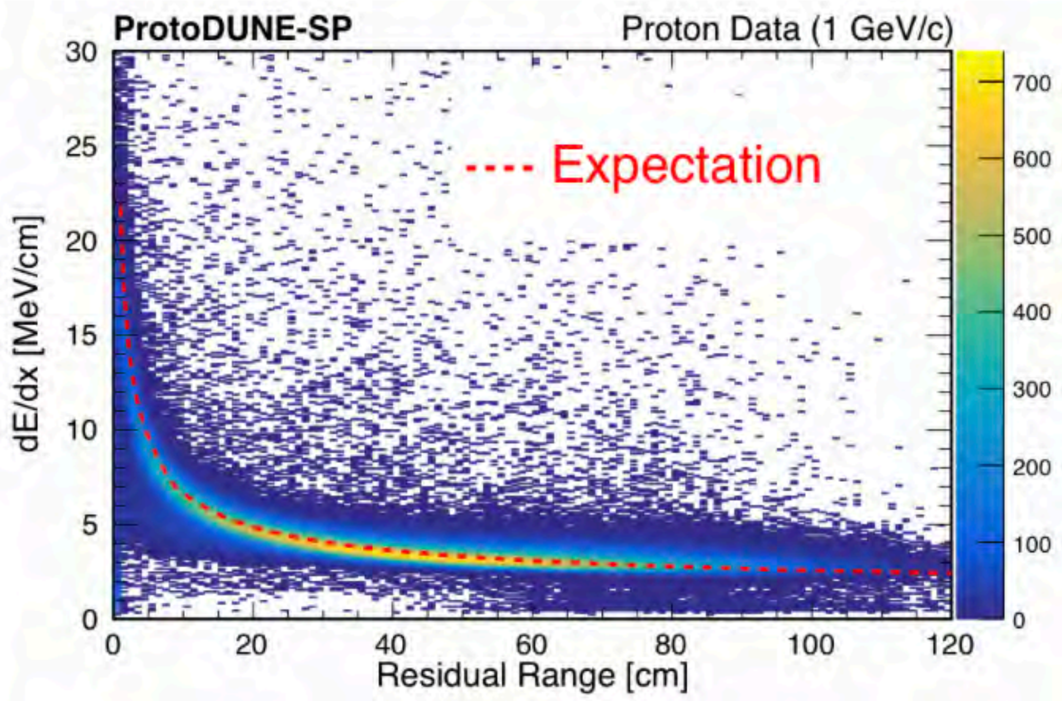
(c) After tail removal.

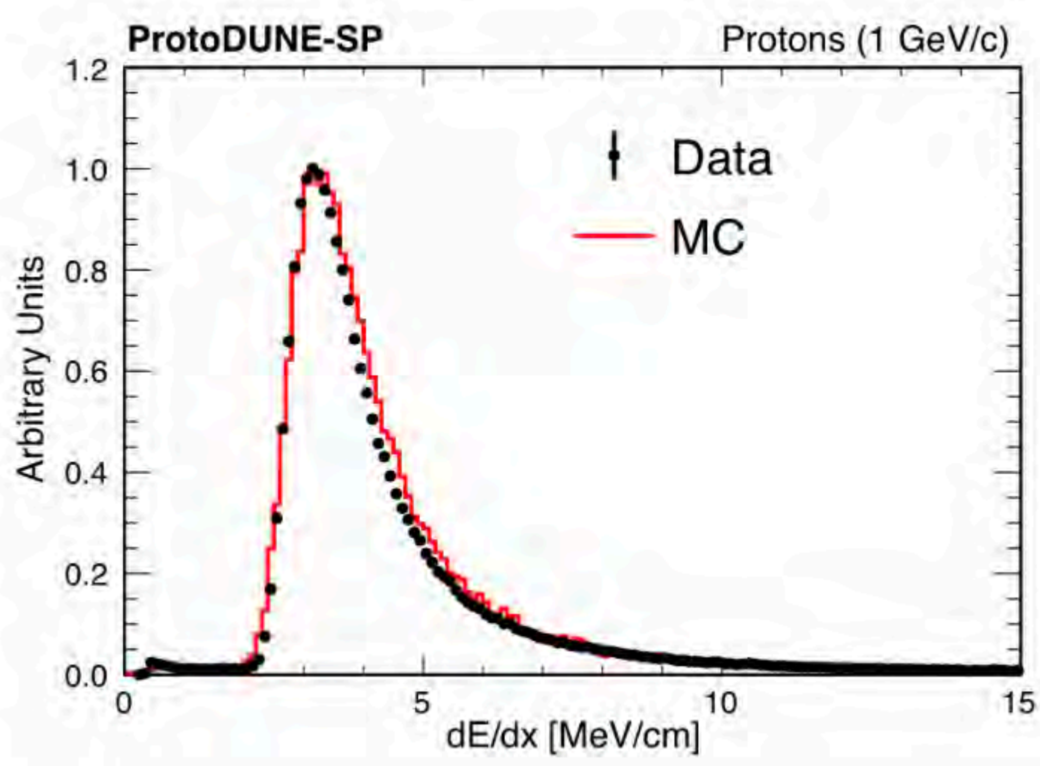
(d) After correlated noise removal.

TPC + CE PERFORMANCE : dE/dx - Calorimetry

1 GEV PROTONS

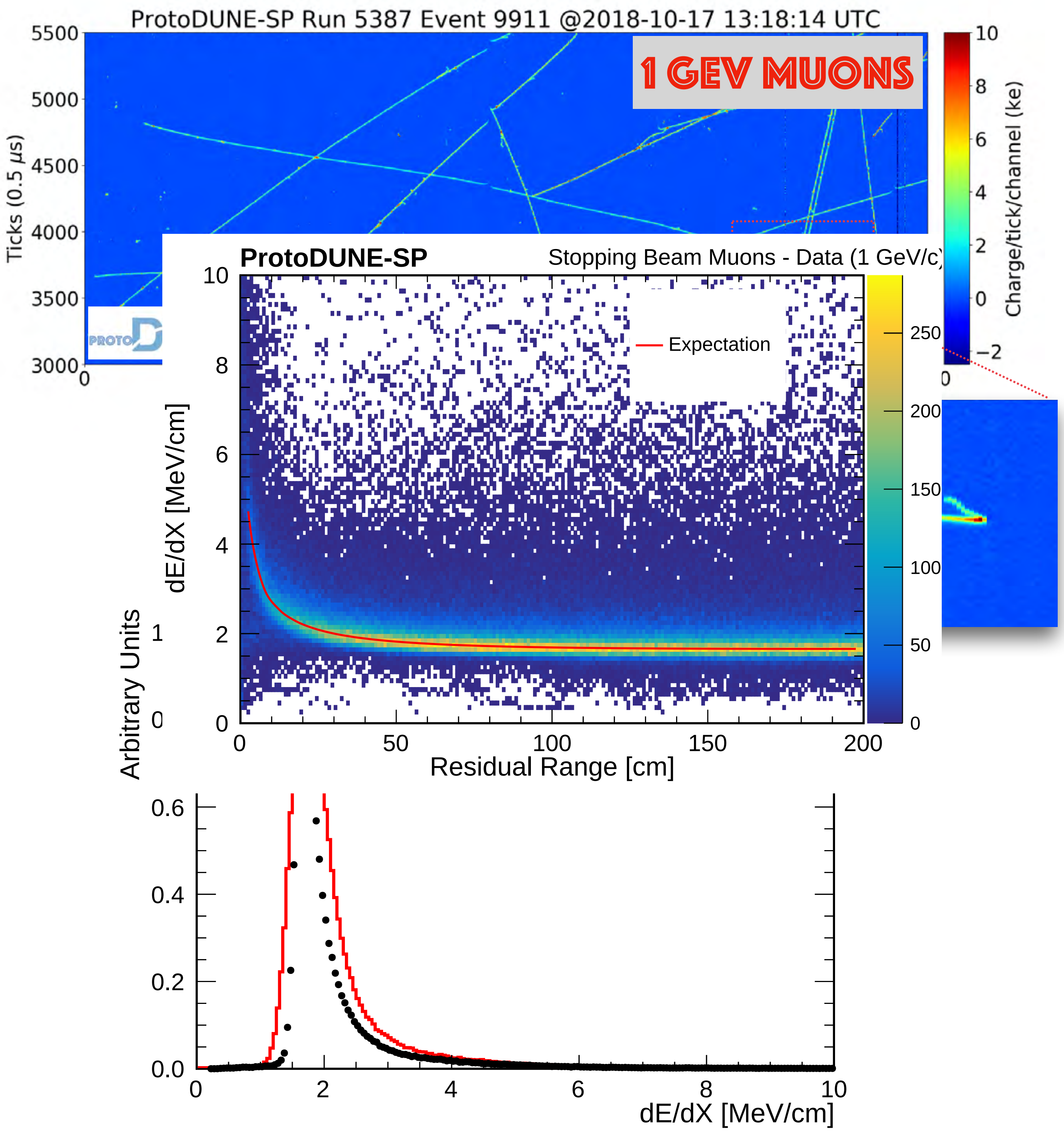


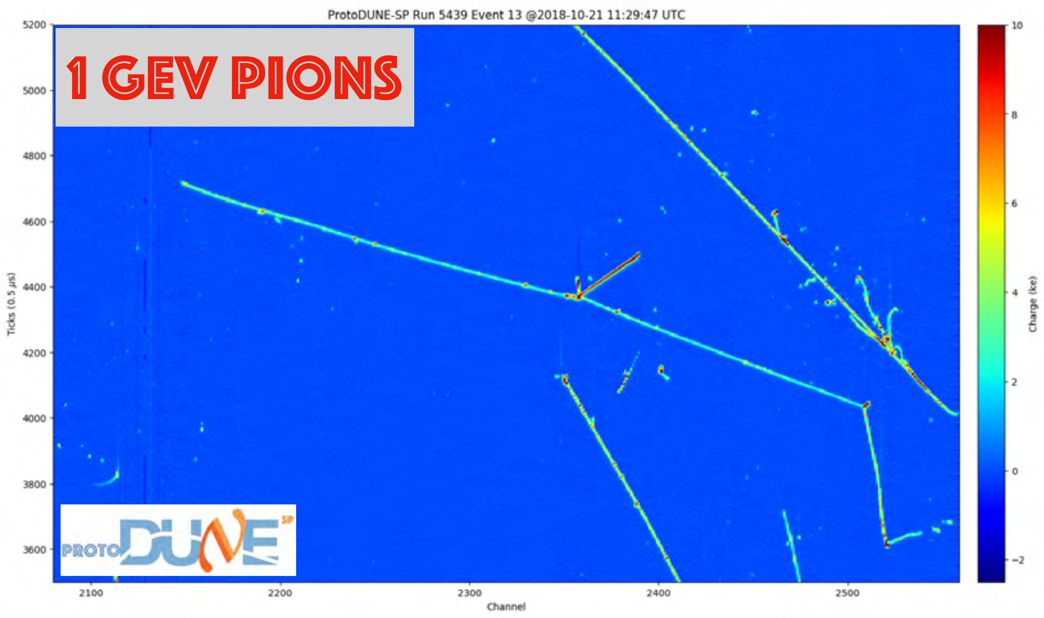


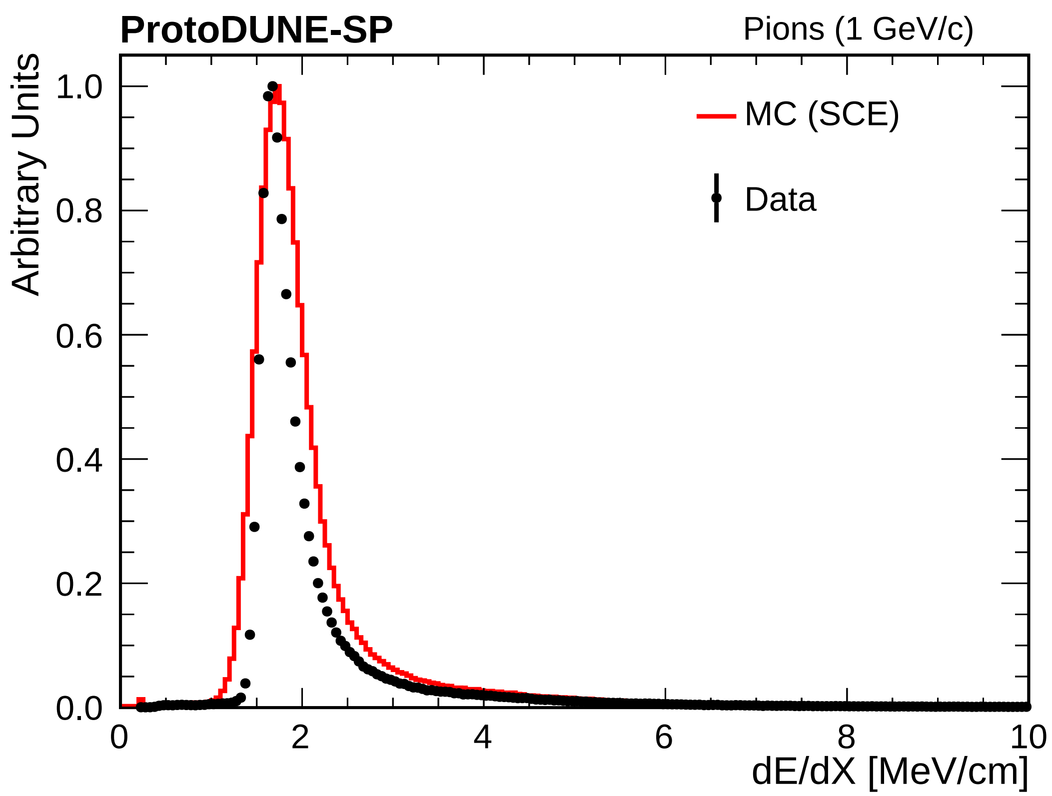


Resolution appears better in DATA than in MonteCarlo !

TPC + CE PERFORMANCE : dE/dx - Calorimetry







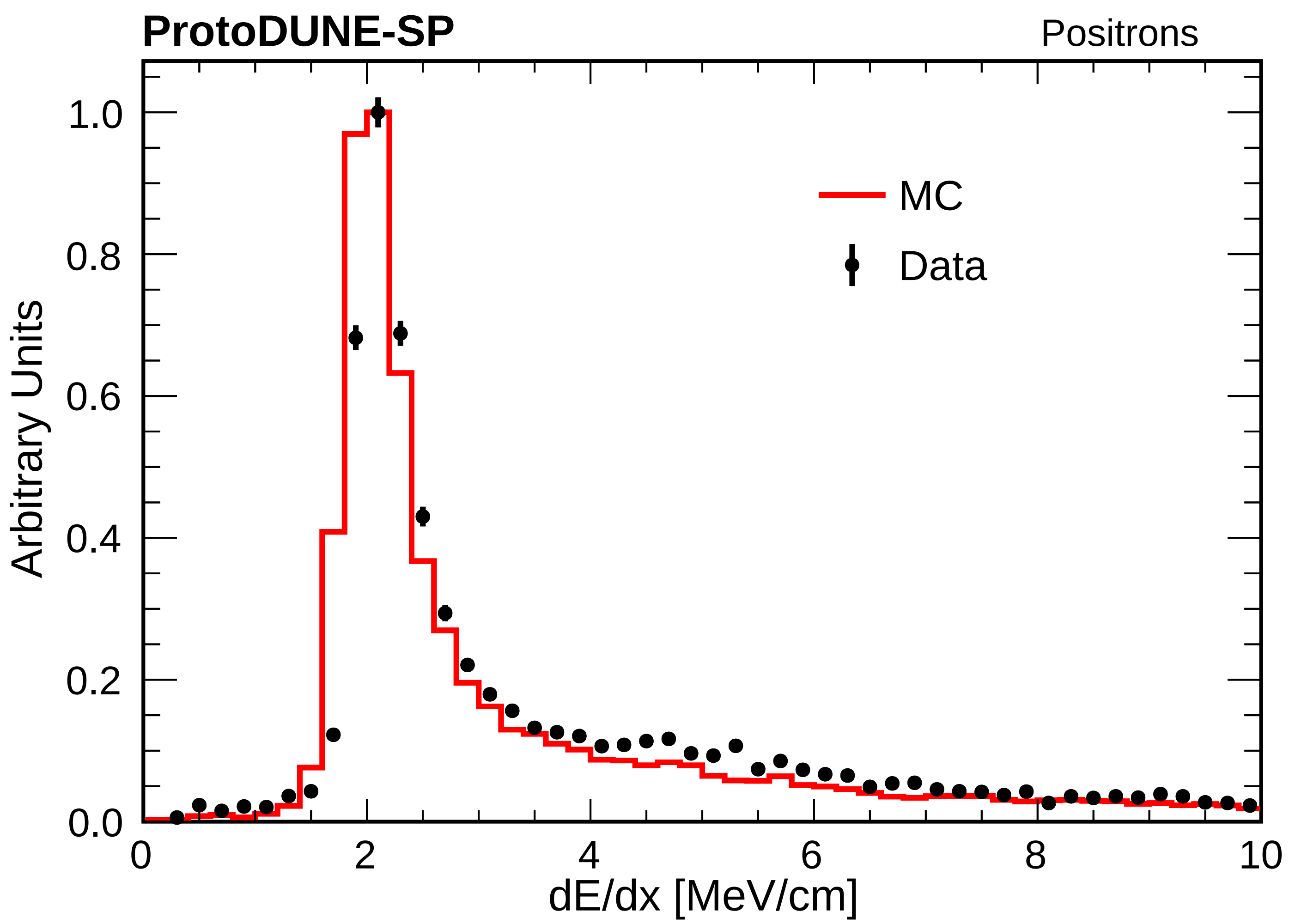
Resolution appears better in DATA than in MonteCarlo !

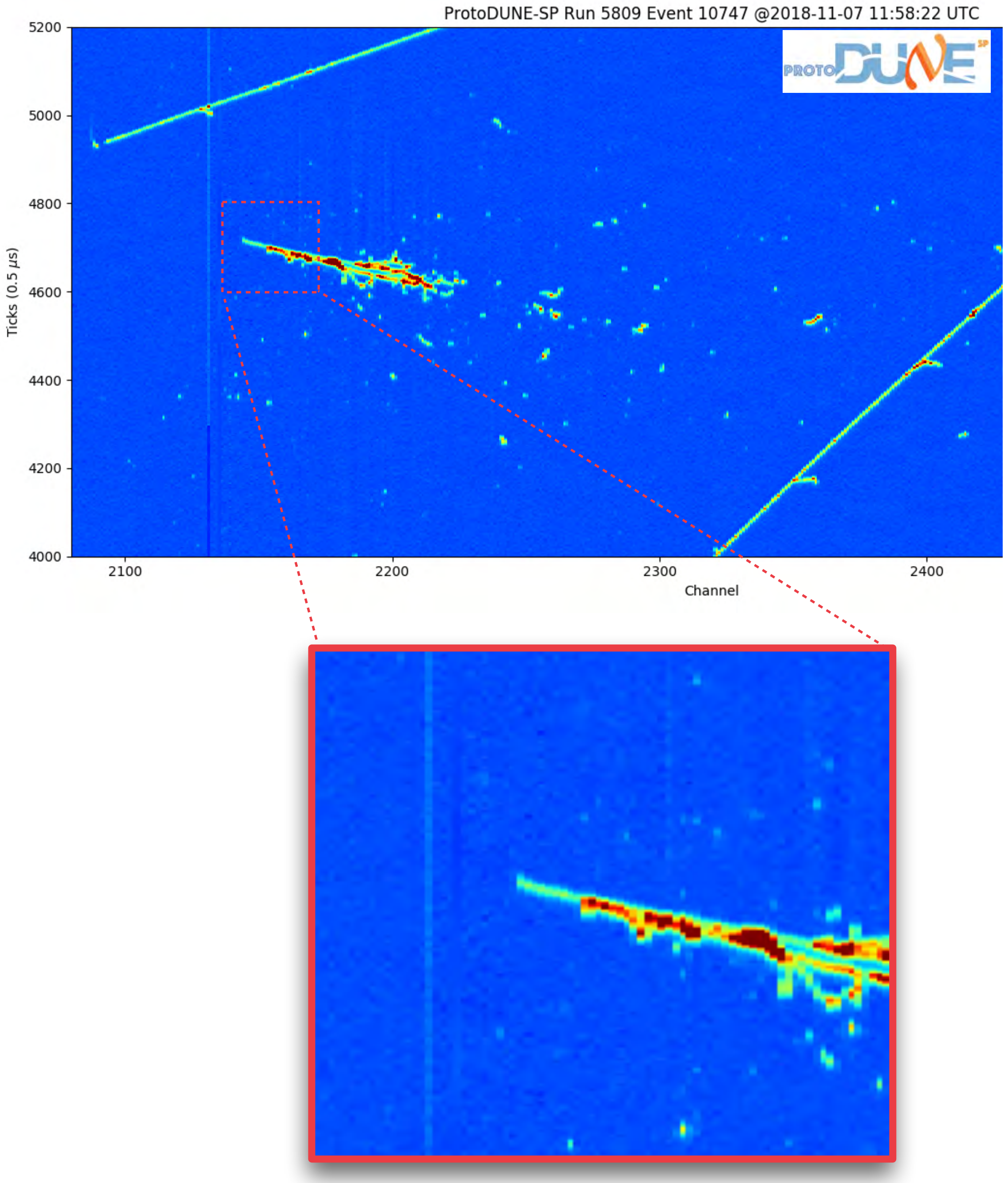
dE/dx width is found to depend on diffusion constant and field response

TPC + CE PERFORMANCE : dE/dx - Calorimetry

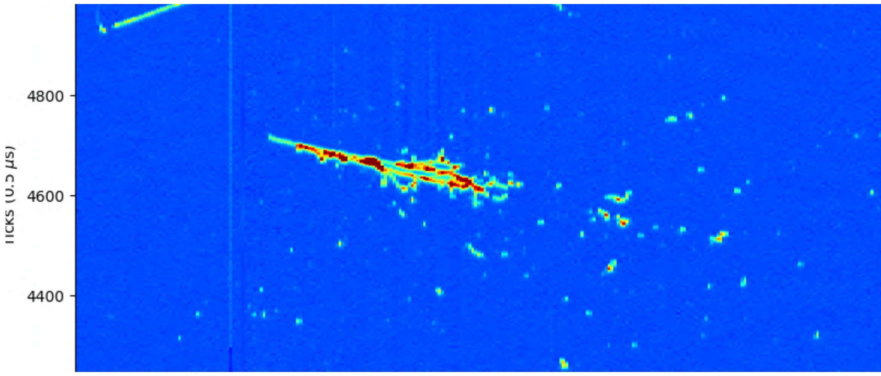
(after Space Charge Calibration)

1 GEV ELECTRONS

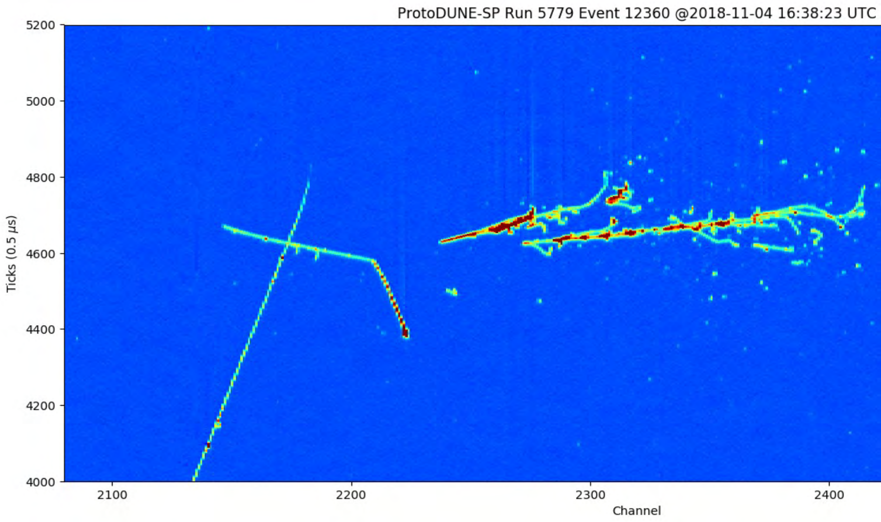




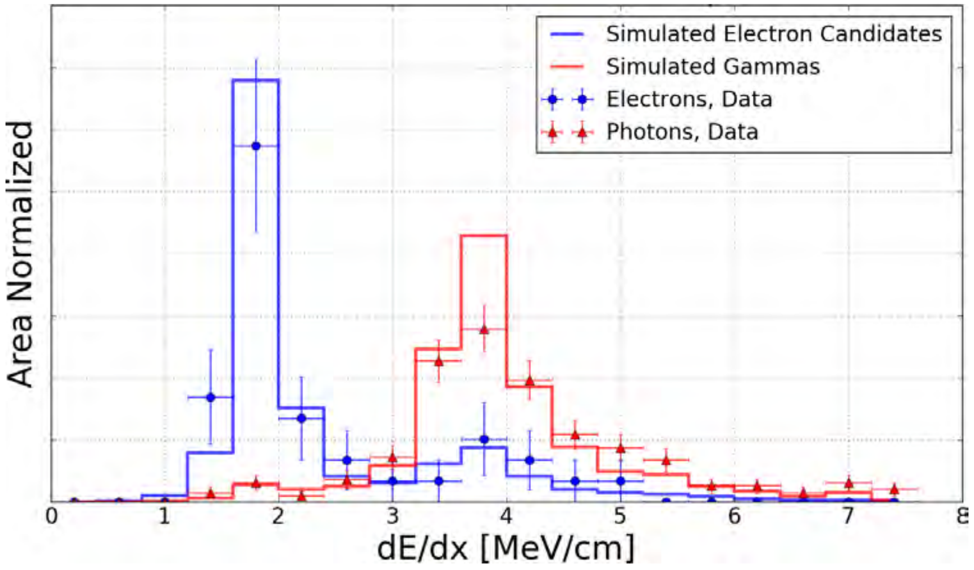
Electron/photon dE/dx



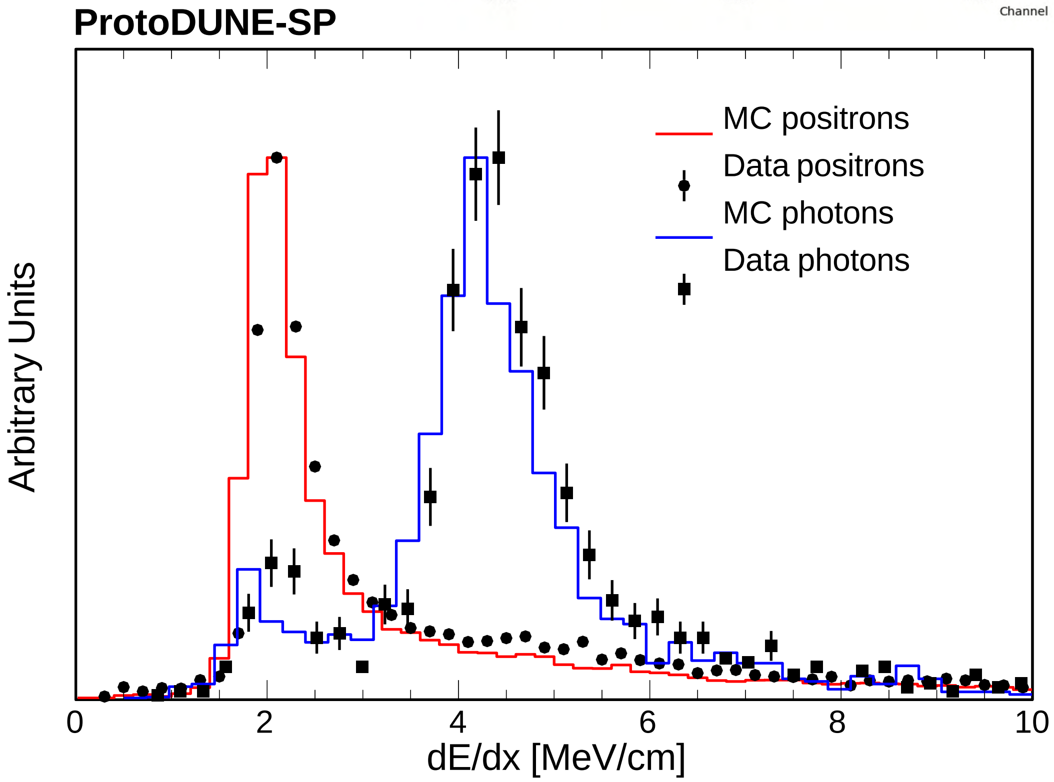
- Measure dE/dx at the beginning of electron or photon.
- 1 GeV beam electrons.
- Photons from 6 GeV pion interactions.
- Clear e/γ separation in dE/dx distributions.



ArgoNeuT, PRD 95, 072005 (2017)



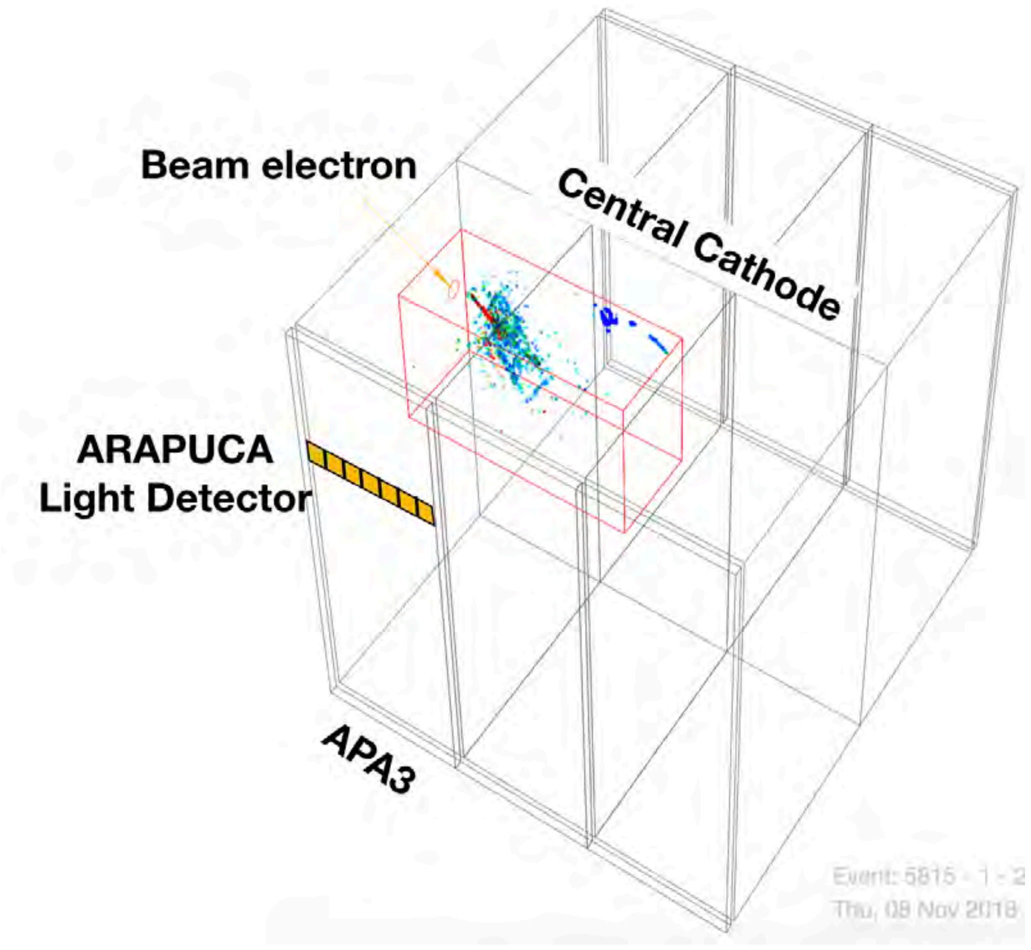
Hand picked events, limited statistics



Fully automated reconstruction and event selection, large statistics.

PHOTO-DETECTOR PERFORMANCE :

calorimetric response to EM showers from *LIGHT Signal*



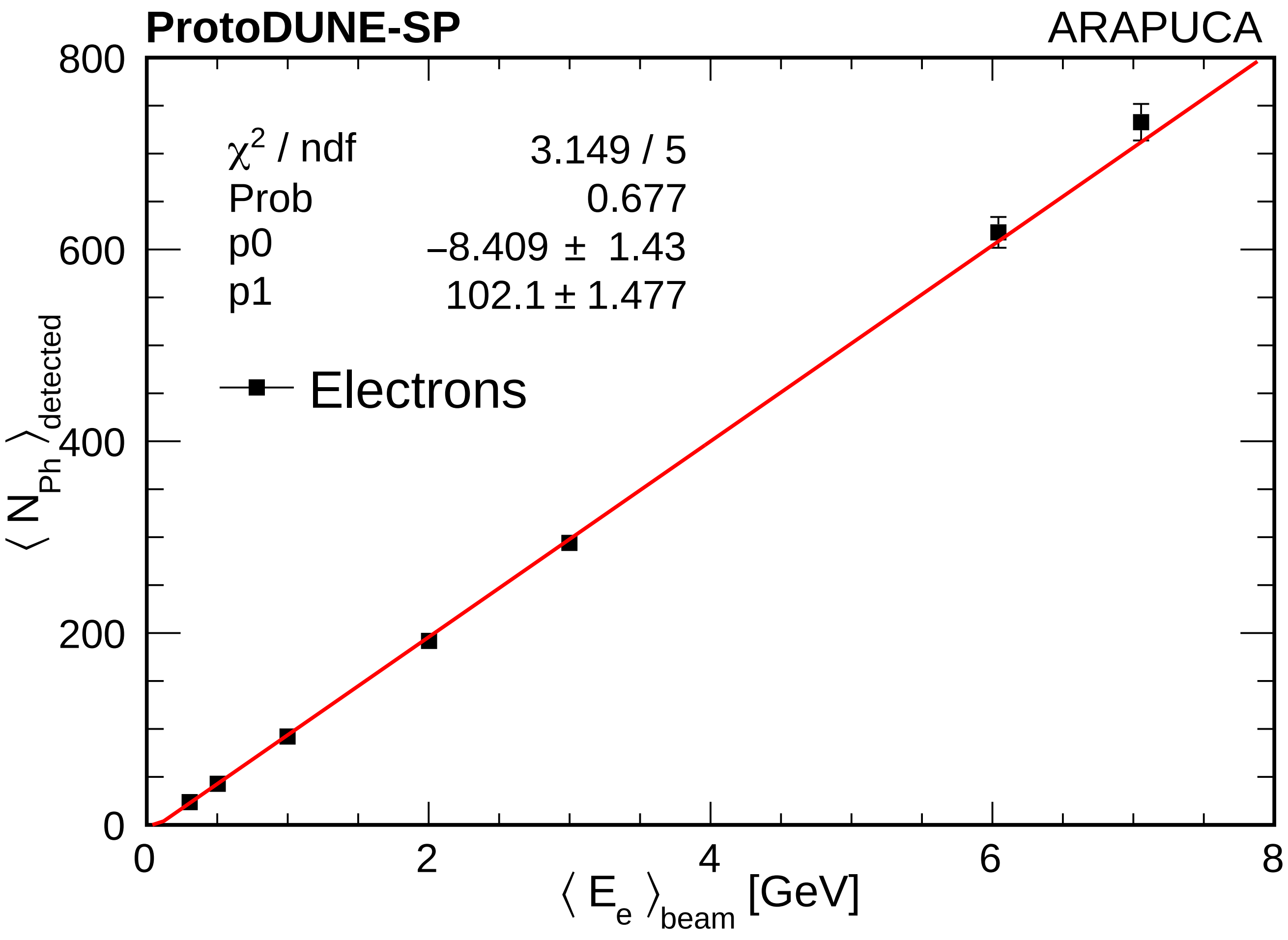
LINEARITY

Observed (first approx) linear response over the entire range of energies.

The slope gives the light yield

$$LY = 102\ Ph/GeV$$

from (only) one ARAPUCA PhDet module, relative to a diffused light source (EM shower) at a distance of about 3 m



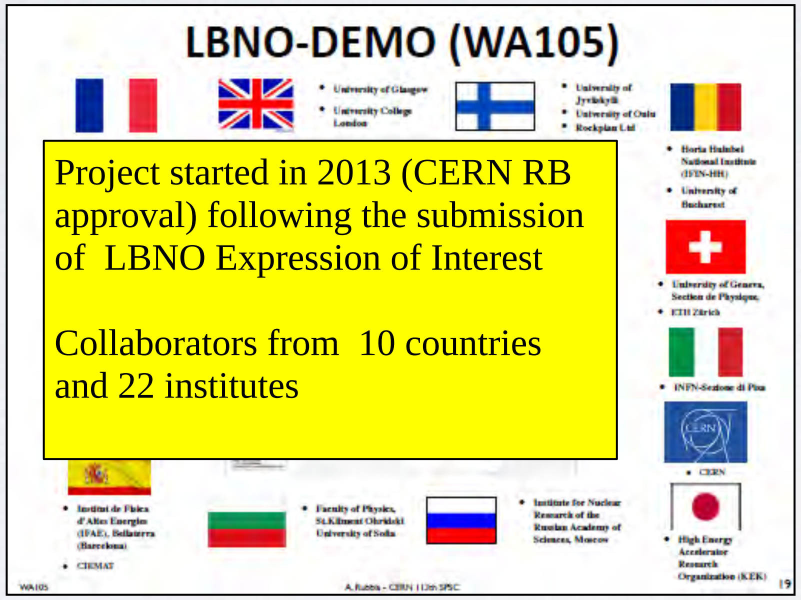
single ARAPUCA module
(~0.5‰ photo-sensitive area coverage)

PROTO DUNE SP (Phase 1) MISSION

- ☑ Prototyping production and installation procedures for DUNE Far Detector Design
- ☑ Validating design from perspective of basic detector performance → inform TDR
- ☑ **Accumulating test-beam data to understand/calibrate response of detector to different particle species** **~ 3M BEAM TRIGGERS ACCUMULATED AND ANALYZED**
- ☑ **Demonstrating long term operational stability of the detector** **500+ DAYS OF OPERATION**

protoDUNE DUAL Phase

History of Dual-Phase ProtoDUNE / WA105



LBNO-DEMO (WA105)

- University of Glasgow
- University College London

- University of Jyväskylä
- University of Oulu
- Rockplan Ltd

- Horia Hulubei National Institute (IFIN-HH)
- University of Bucharest

- University of Geneva, Section de Physique,
- ETH Zürich

- INFN-Sezione di Pisa

- CERN

- Institut de Fisica d'Altes Energies (IFAE), Bellaterra (Barcelona)
- CIEMAT

- Faculty of Physics, St.Kliment Ohridski University of Sofia

- Institute for Nuclear Research of the Russian Academy of Sciences, Moscow

- High Energy Accelerator Research Organization (KEK)

WA105 A.Rubbia - CERN 113th SPSC 19

Project started in 2013 (CERN RB approval) following the submission of LBNO Expression of Interest

Collaborators from 10 countries and 22 institutes

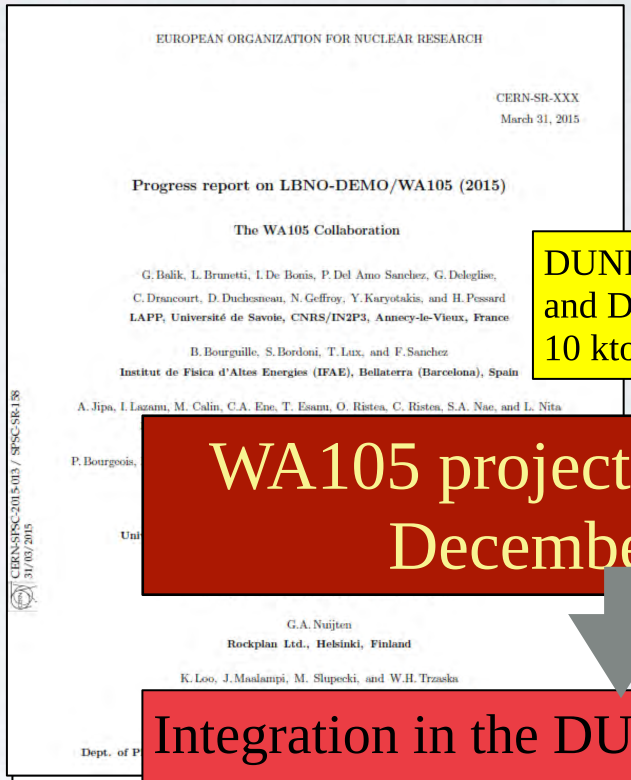
EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

March 31st, 2014
CERN-SPSC-2014-013
SPSC-TDR-004

Technical Design Report
for large-scale neutrino detectors prototyping
and phased performance assessment
in view of a long-baseline oscillation experiment

) Collaboration

TDR:
submitted on 31st March 2014
CERN-SPSC-2014-013
SPSC-TDR-004(2014)



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-SR-XXX
March 31, 2015

CERN-SPSC-2015-013 / SPSC-SR-158
31/03/2015

Progress report on LBNO-DEMO/WA105 (2015)

The WA105 Collaboration

G. Balik, L. Brunetti, I. De Bonis, P. Del Amo Sanchez, G. Deleglise,
C. Drancourt, D. Duchesneau, N. Geffroy, Y. Karyotakis, and H. Pessard
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A. Jipa, I. Lazanu, M. Calin, C.A. Ene, T. Esanu, O. Ristea, C. Ristea, S.A. Nae, and L. Nita

P. Bourgeois,

Uni

G.A. Nuijten
Rockplan Ltd., Helsinki, Finland

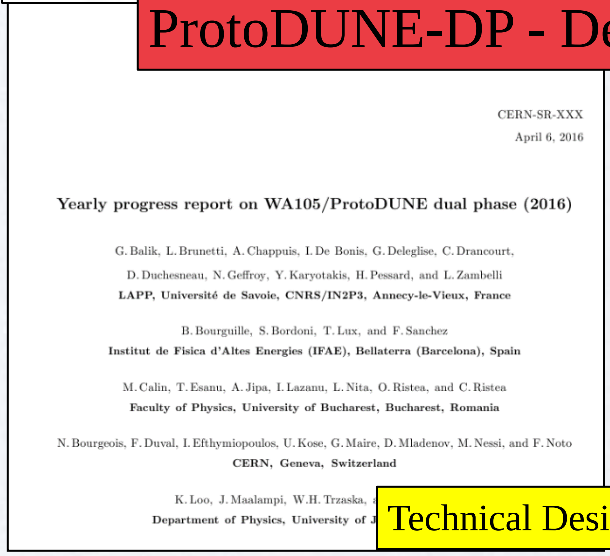
K. Loo, J. Maalampi, M. Slupecki, and W.H. Trzaska

Dept. of P

DUNE CDR, July 2015: WA105 and Dual-phase
10 kton design

WA105 project MOU signed
December 2015

Integration in the DUNE project as
ProtoDUNE-DP - December 2015



CERN-SR-XXX
April 6, 2016

Yearly progress report on WA105/ProtoDUNE dual phase (2016)

G. Balik, L. Brunetti, A. Chappuis, I. De Bonis, G. Deleglise, C. Drancourt,
D. Duchesneau, N. Geffroy, Y. Karyotakis, H. Pessard, and L. Zambelli
LAPP, Université de Savoie, CNRS/IN2P3, Annecy-le-Vieux, France

B. Bourguille, S. Bordoni, T. Lux, and F. Sanchez
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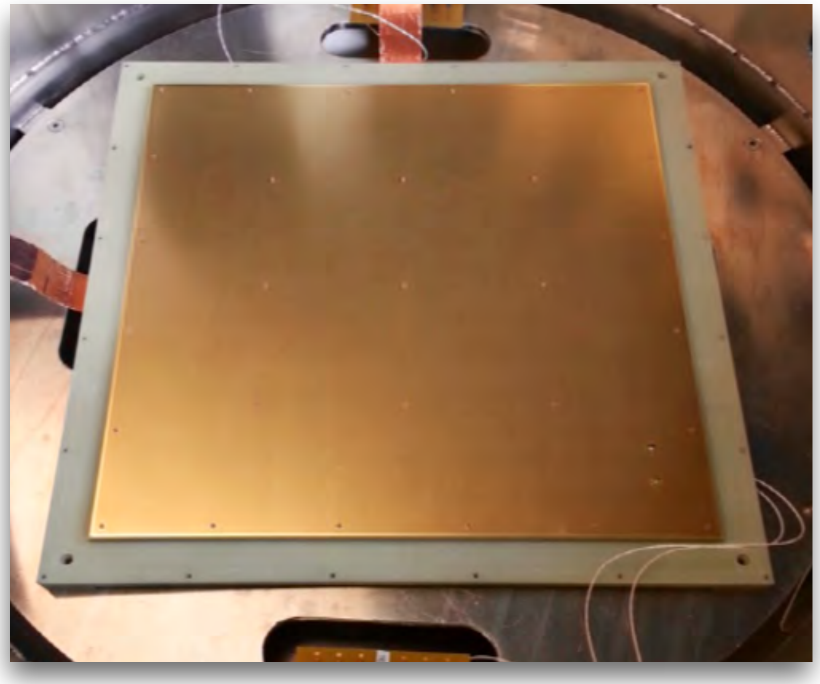
Faculty of Physics, University of Bucharest, Bucharest, Romania

N. Bourgeois, F. Duval, I. Efthymiopoulos, U. Kose, G. Maire, D. Mladenov, M. Nessi, and F. Noto
CERN, Geneva, Switzerland

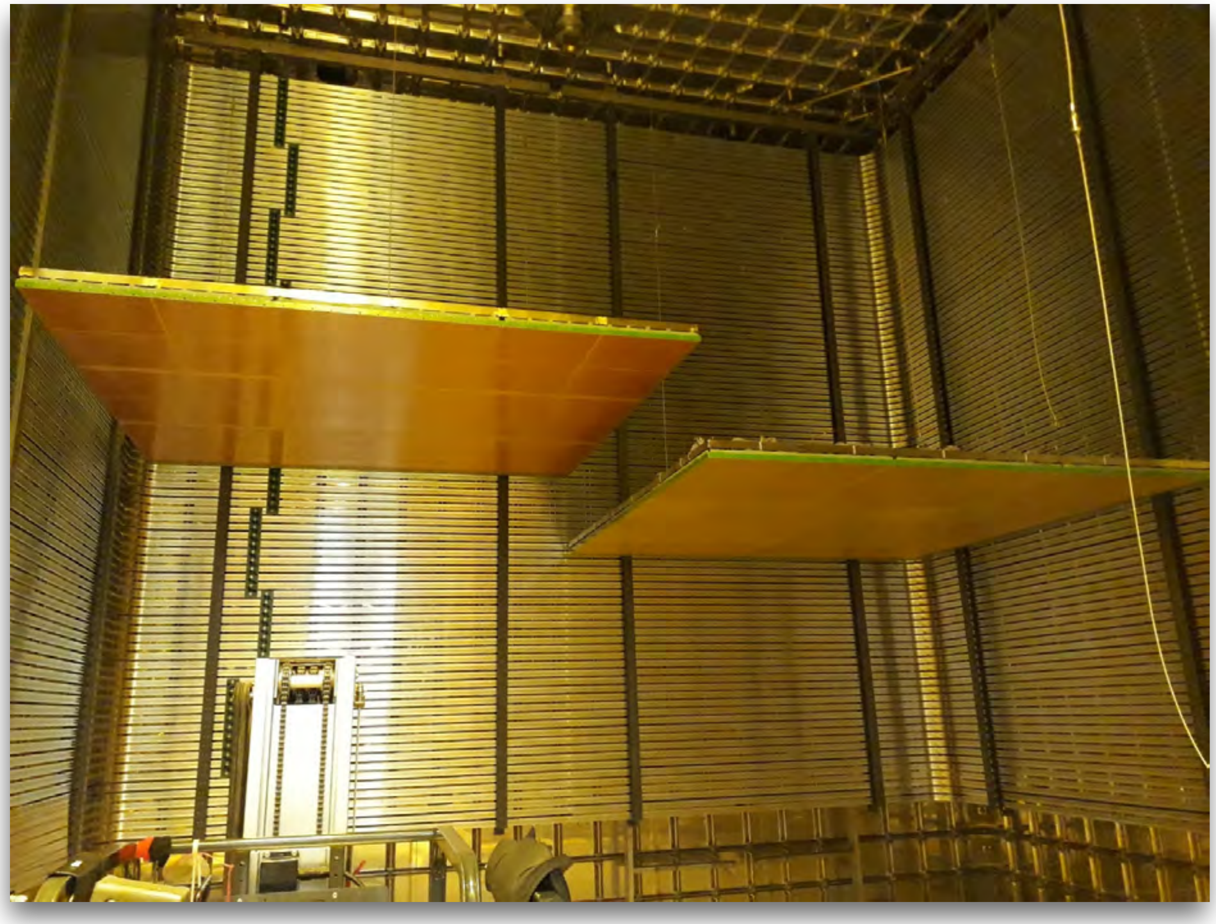
K. Loo, J. Maalampi, W.H. Trzaska,
Department of Physics, University of J

Technical Design Review April 2017

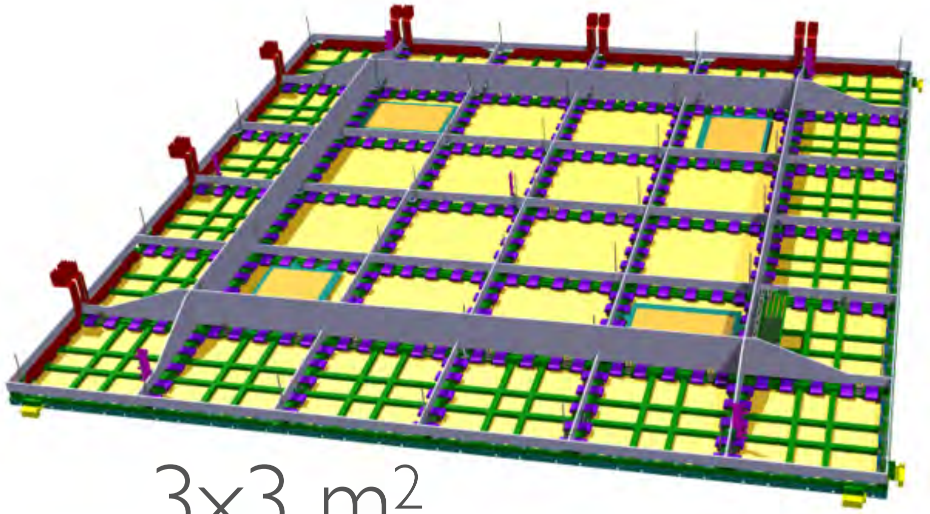
During detector installation inside protoDUNE-DP cryostat (spring 2019)



LEM-anode sandwich (50x50 cm^2)



Charge Readout Plane (CRP) integrating 36 LEM Anode sandwiches

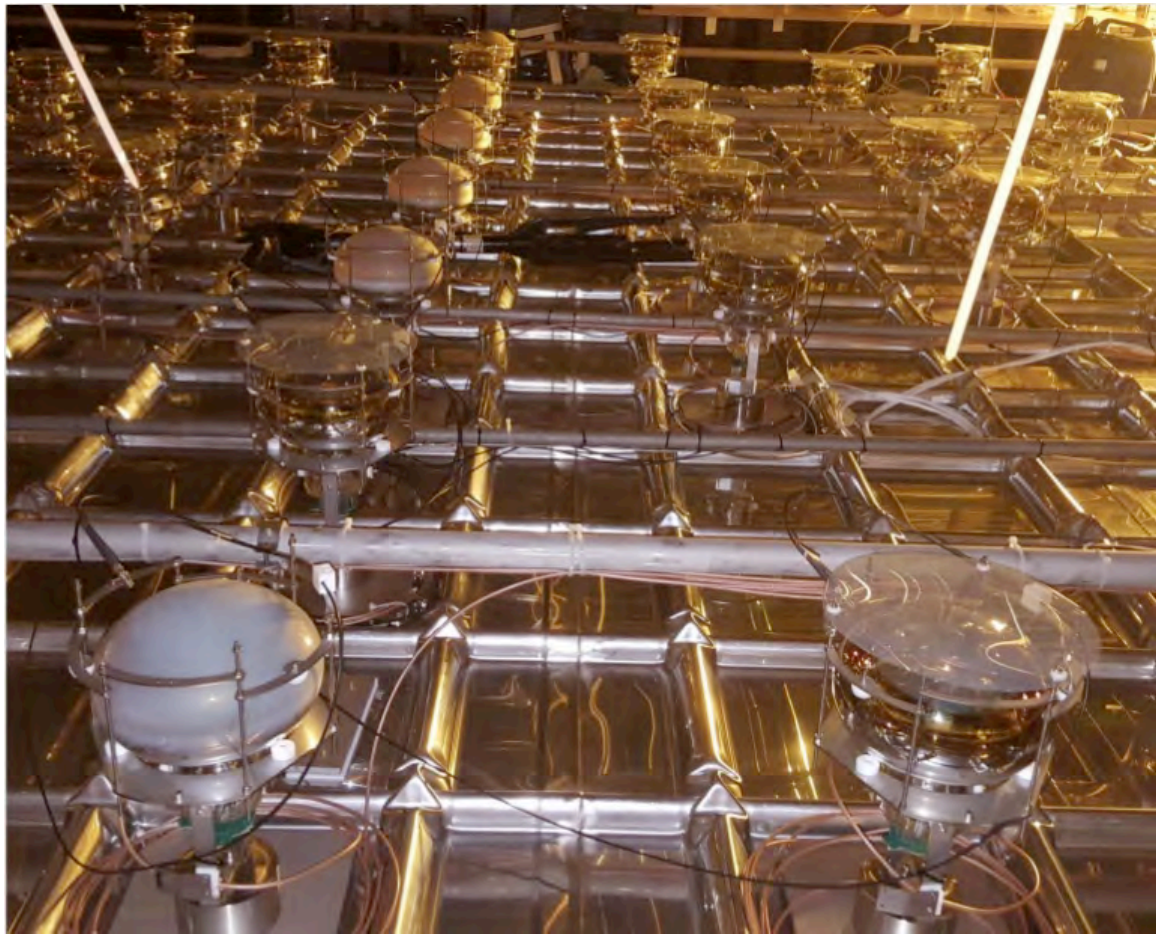


3x3 m^2

$< 50\ \mu\mathrm{m}$ accuracy in positioning wrt to LAr surface level

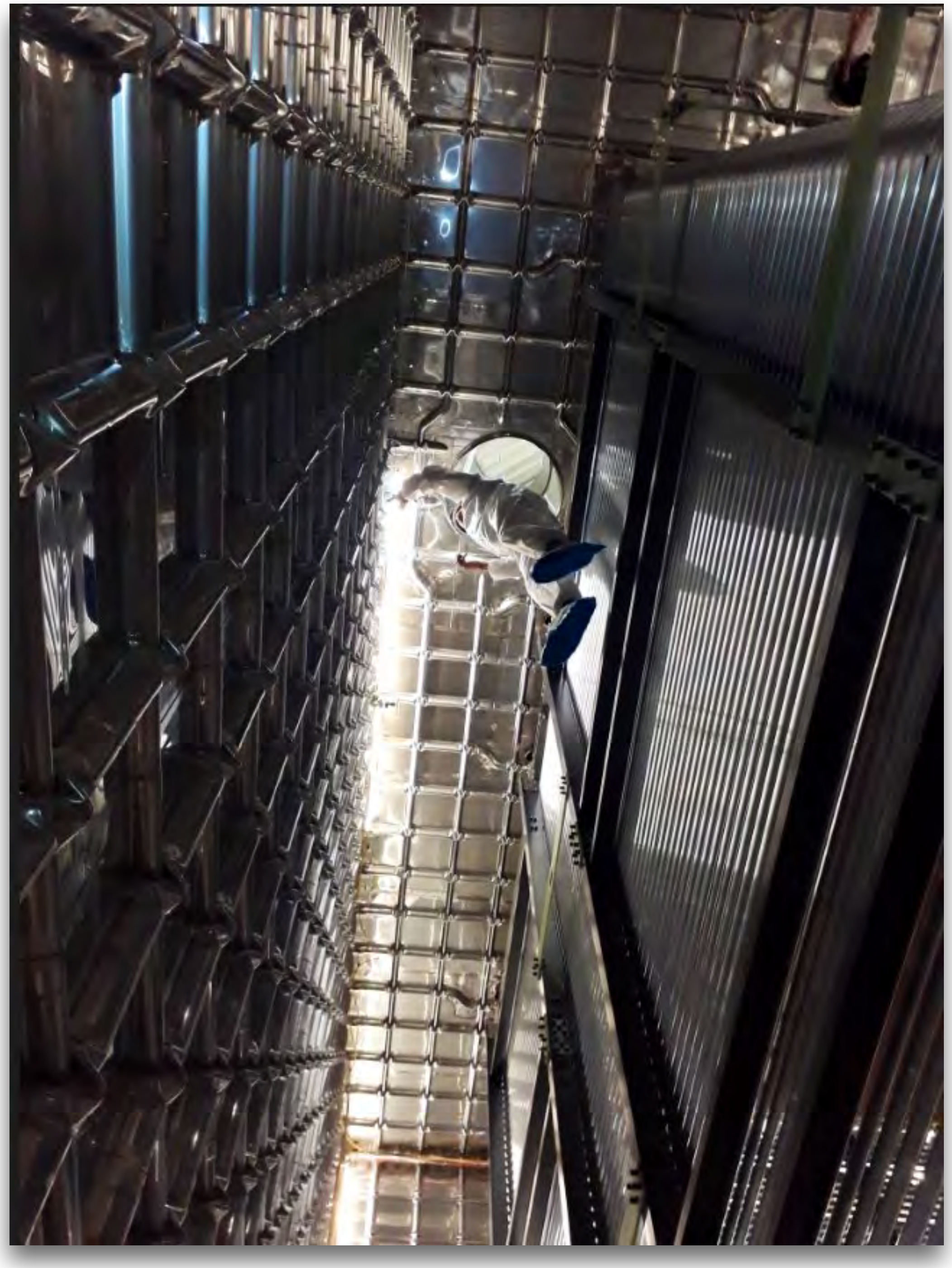
Photon Detector: PMT Array with wavelength-shifter

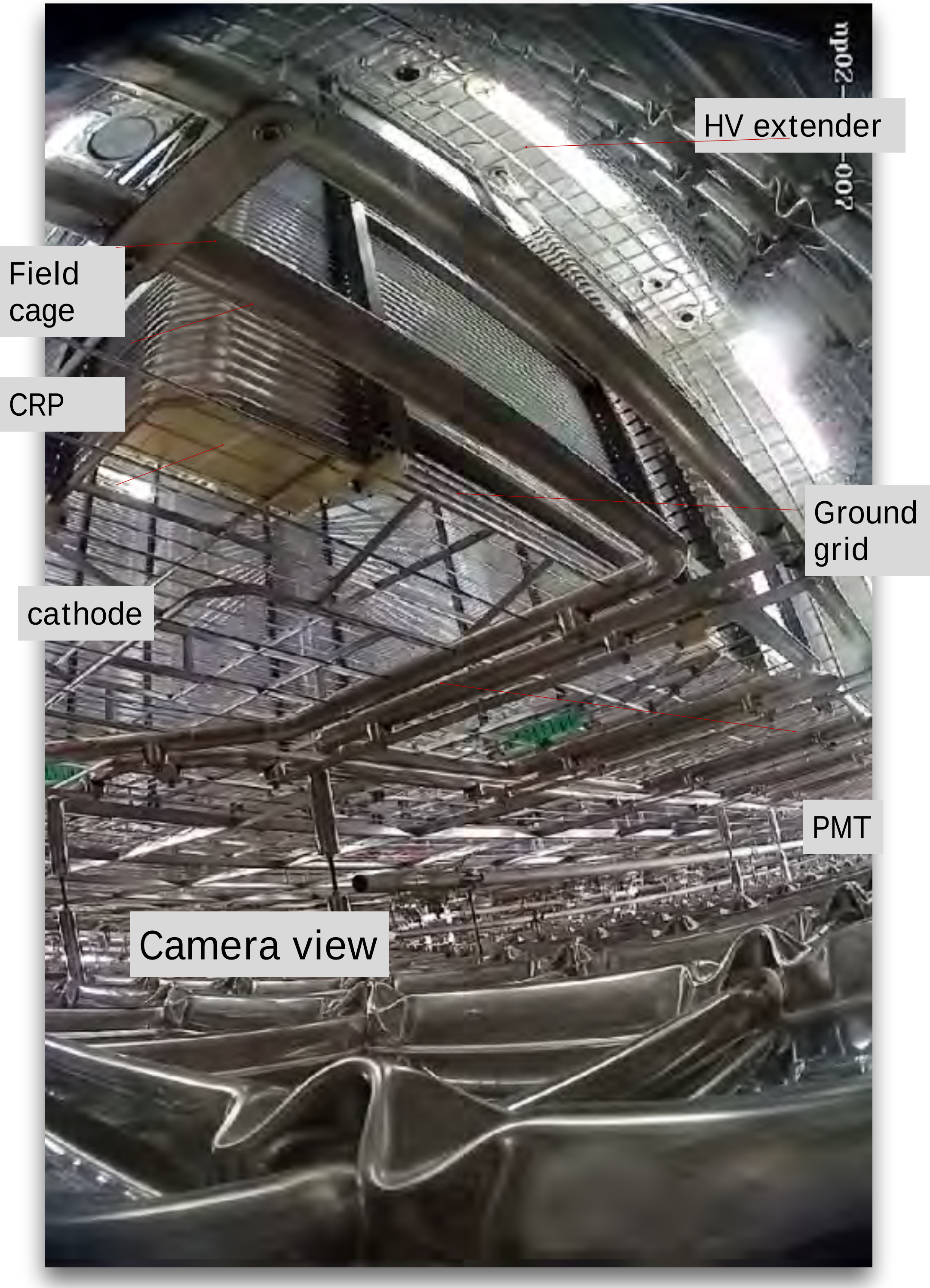
- 30 PMTs with PEN sheets and 6 PMTs with TPB coating



Last day with cryostat open

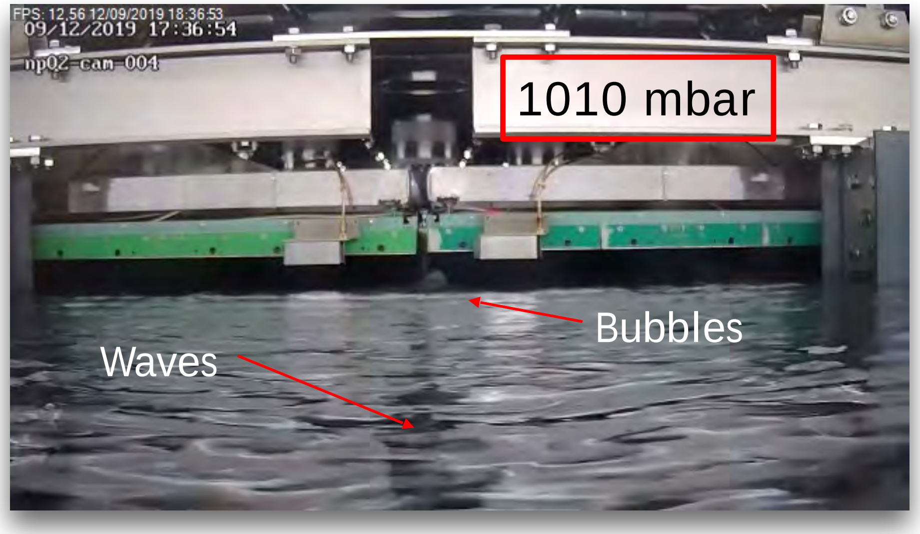
June 13th 2019

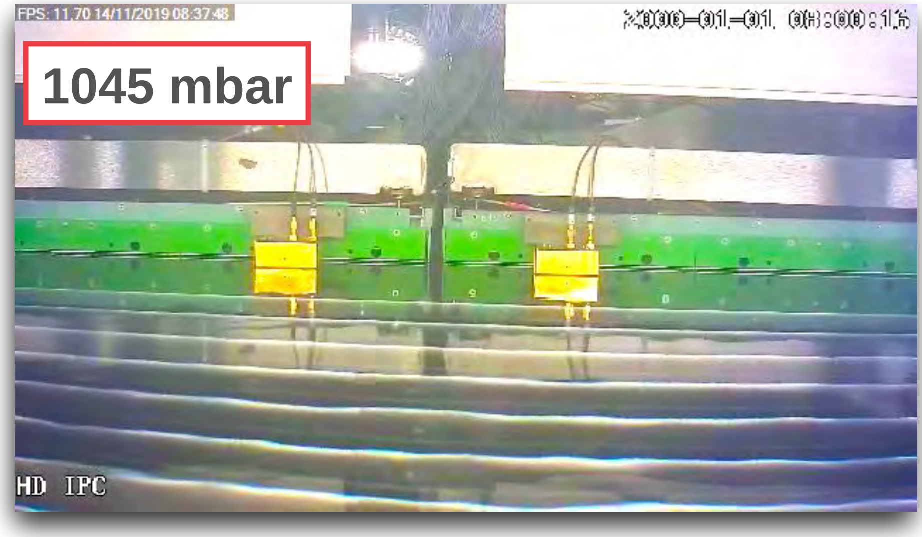




- June 2019: cryostat purge with Ar gas and cool-down procedure with a mist of LAr droplets to about 150k
- July 2019: filling with LAr ~40 tons/day
- August 2019 detector filled, start of operation

CRPs commissioning





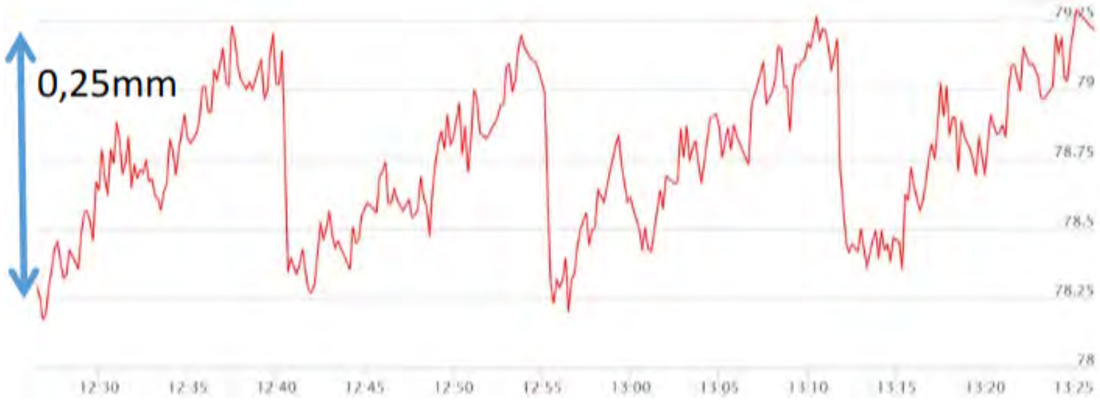
- ✓ Bubbles forming along internal surface of first field cage ring. *Phenomenon not yet completely characterized related to heath flow and cryogenics*

- ✓ CRP operation at higher cryostat gas pressure (1045 mbar) to dump formation of bubbles and LAr surface perturbations.

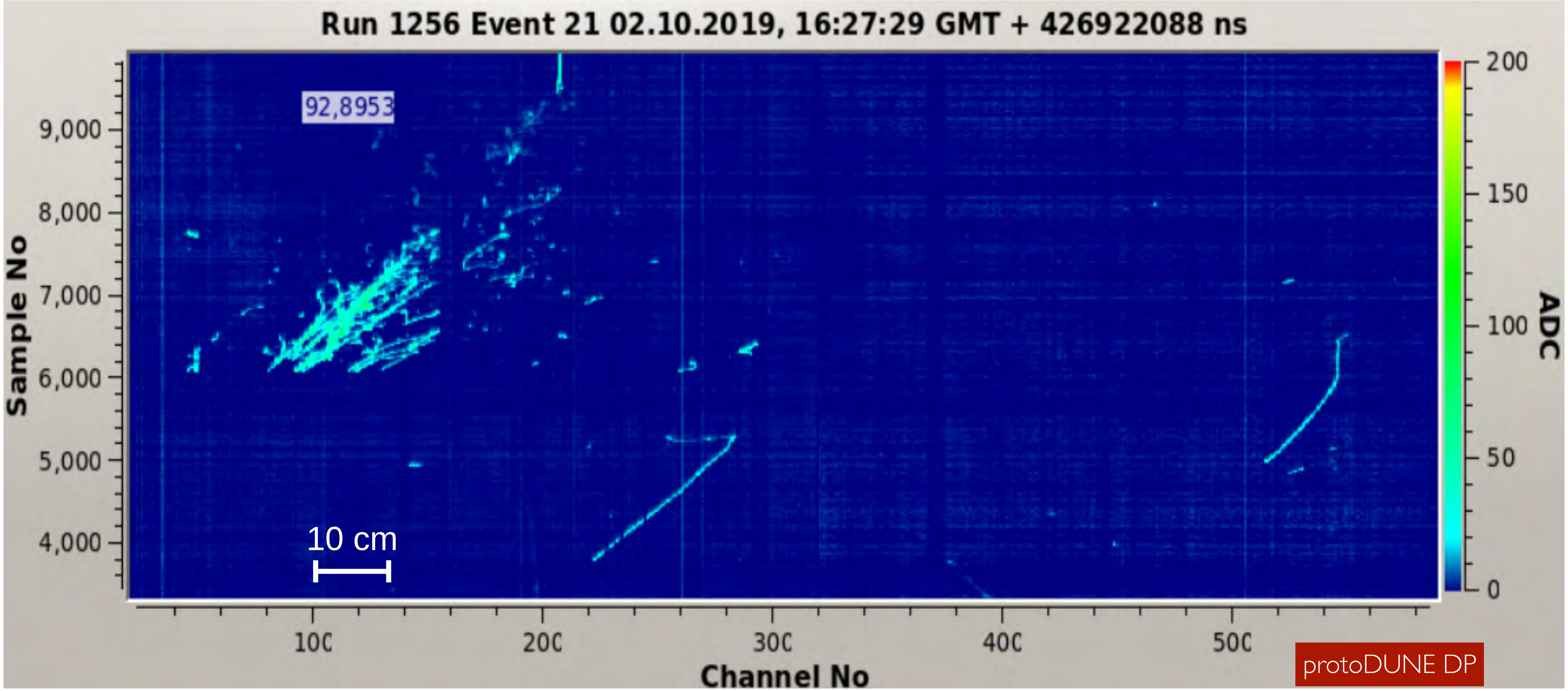
→ Stability HV tests of grids + LEMs
→ Grids of all 4 CRPs tested up to 7.5kV extraction voltage (exceeding goal)

CRP LAr level tracking (adjustments of 250 um every 15 minutes). LAr level increasing by ~1mm/hour

- ✓ Implemented automatic tracking of LAr level based on level meters reading

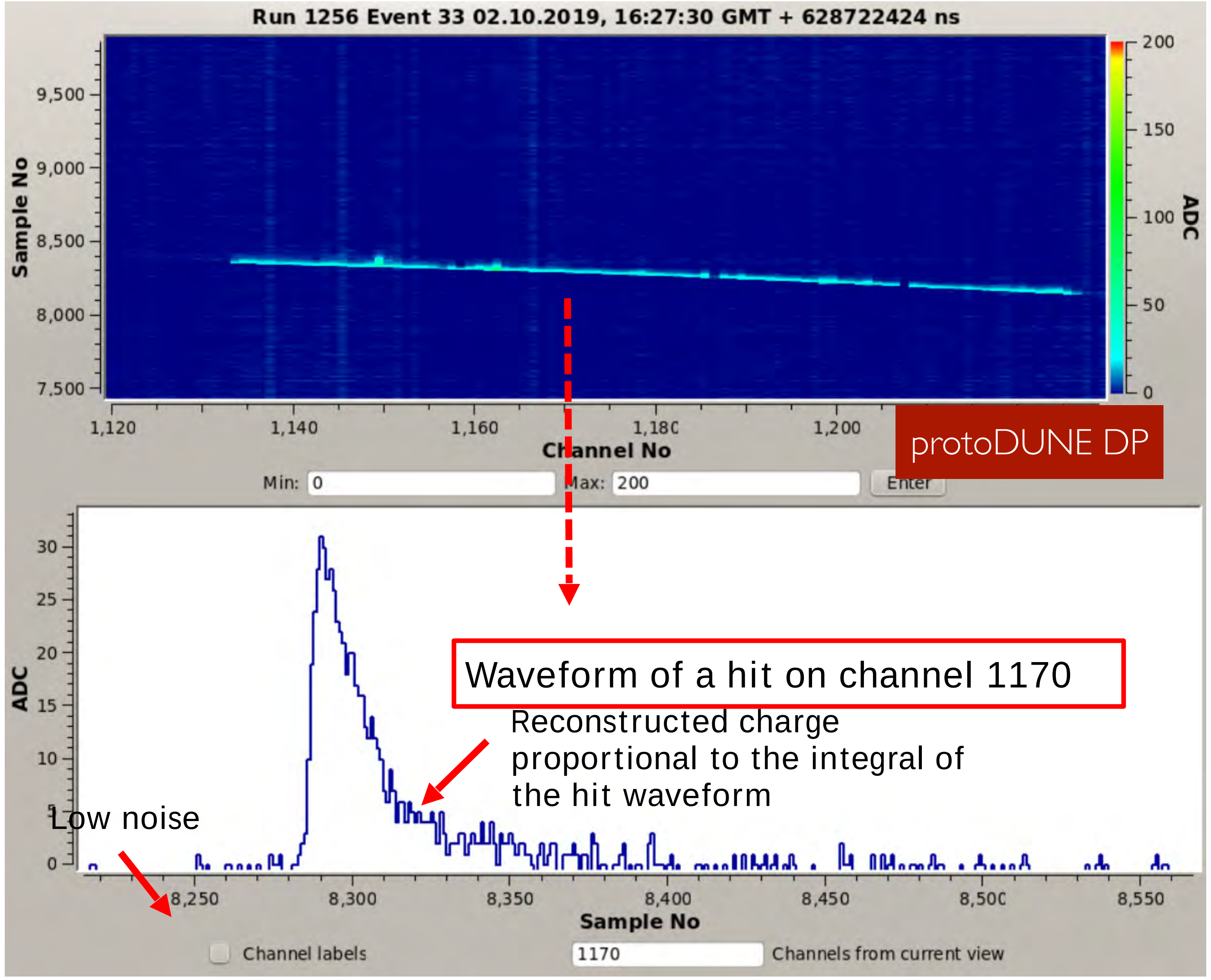


Event with electromagnetic showers and two muon decays
- LEM ΔV= 3.1 kV



Horizontal muon track
- LEM ΔV= 3.1 kV

Multiple hadronic interactions in a shower - LEM ΔV= 3.2 kV



Min: 0 Max: 200

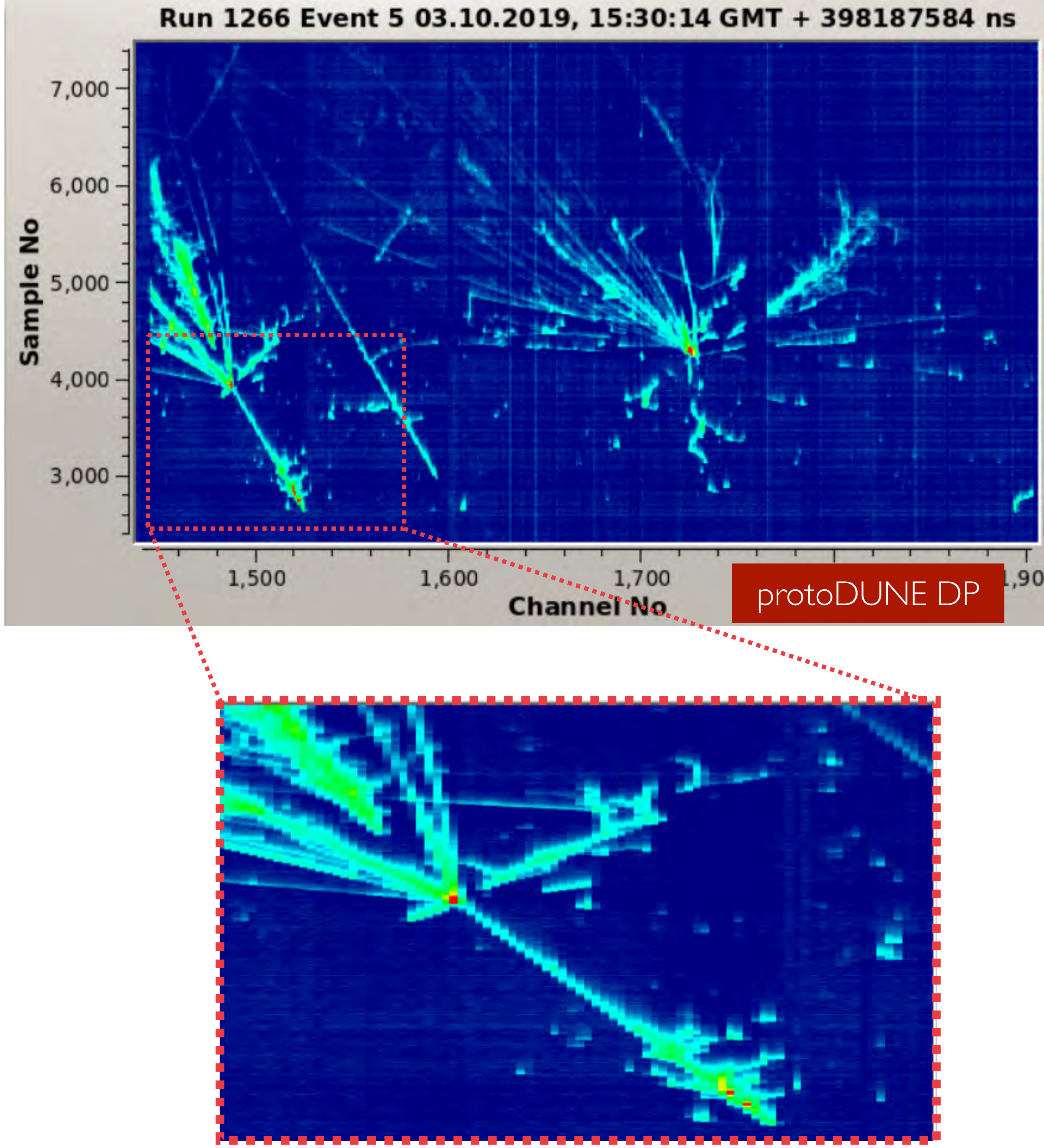
1170

protoDUNE DP

Waveform of a hit on channel 1170

Reconstructed charge proportional to the integral of the hit waveform

Low noise



protoDUNE DP

Outlook:

Compelling questions in Physics await being addressed

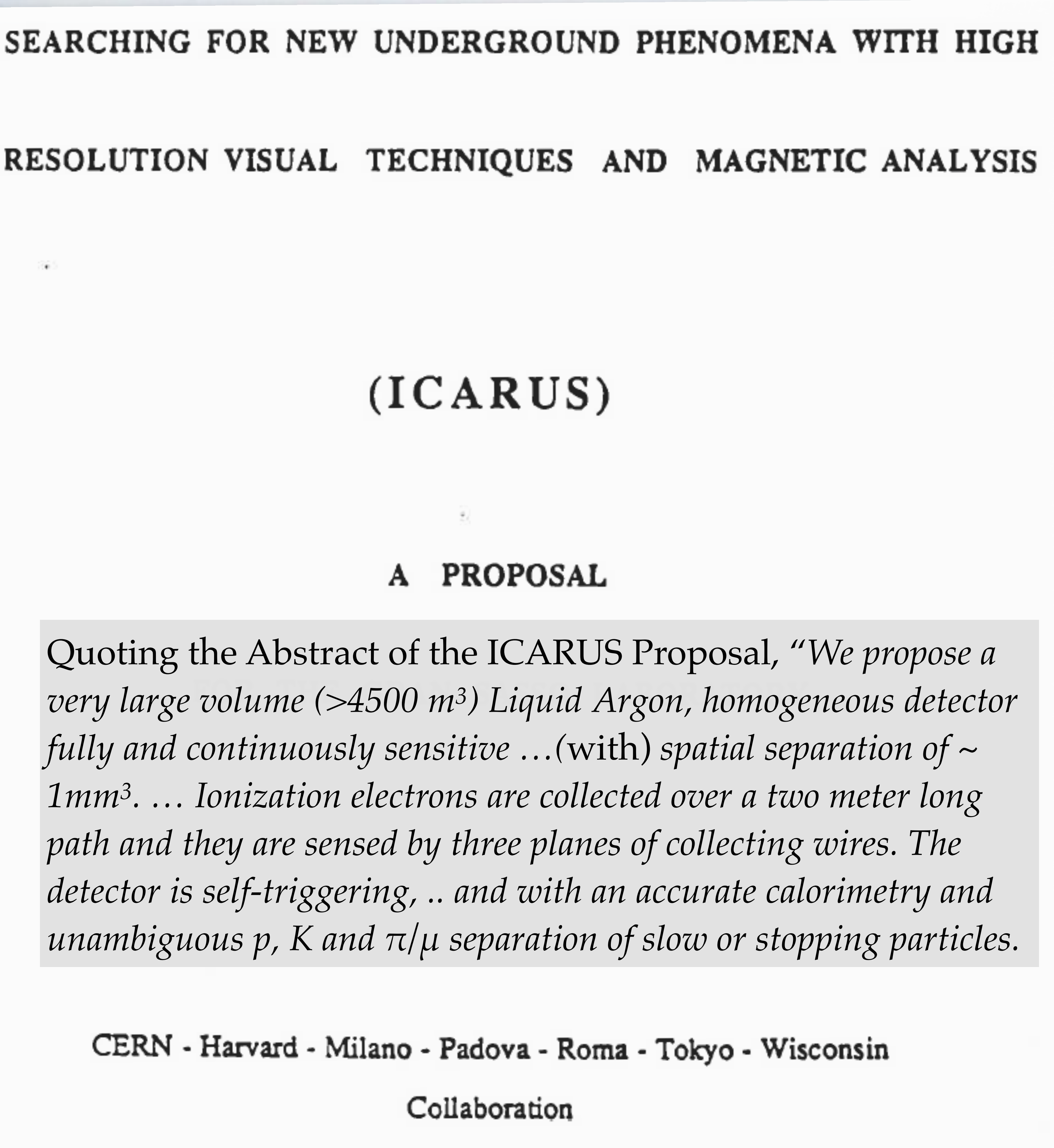
The liquid Ar TPC is the new experimental technology adopted for the worldwide Neutrino Program in the U.S.

The realization of the DUNE/LBNF will represent one of the most challenging and endeavoring effort in HEP.

The path toward DUNE is now open by the success of ProtoDUNE at CERN

BACKUP SLIDES

1986 - proposal for a massive LArTPC



SEARCHING FOR NEW UNDERGROUND PHENOMENA WITH HIGH RESOLUTION VISUAL TECHNIQUES AND MAGNETIC ANALYSIS

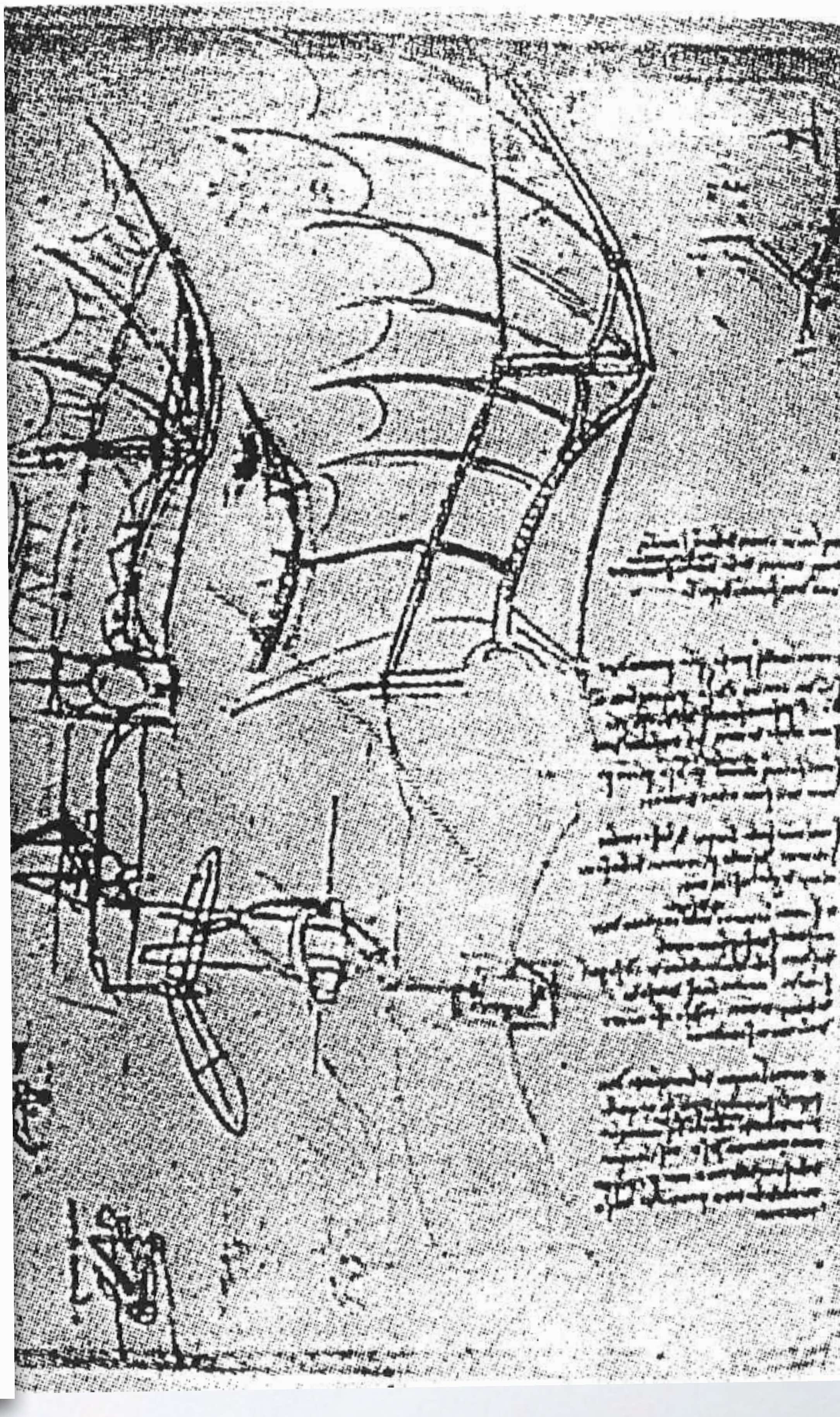
(ICARUS)

A PROPOSAL

CERN - Harvard - Milano - Padova - Roma - Tokyo - Wisconsin

Collaboration

Quoting the Abstract of the ICARUS Proposal, *"We propose a very large volume (>4500 m^3) Liquid Argon, homogeneous detector fully and continuously sensitive …*(with) *spatial separation of ~ $1mm^3$. … Ionization electrons are collected over a two meter long path and they are sensed by three planes of collecting wires. The detector is self-triggering, .. and with an accurate calorimetry and unambiguous p, K and π/μ separation of slow or stopping particles.*

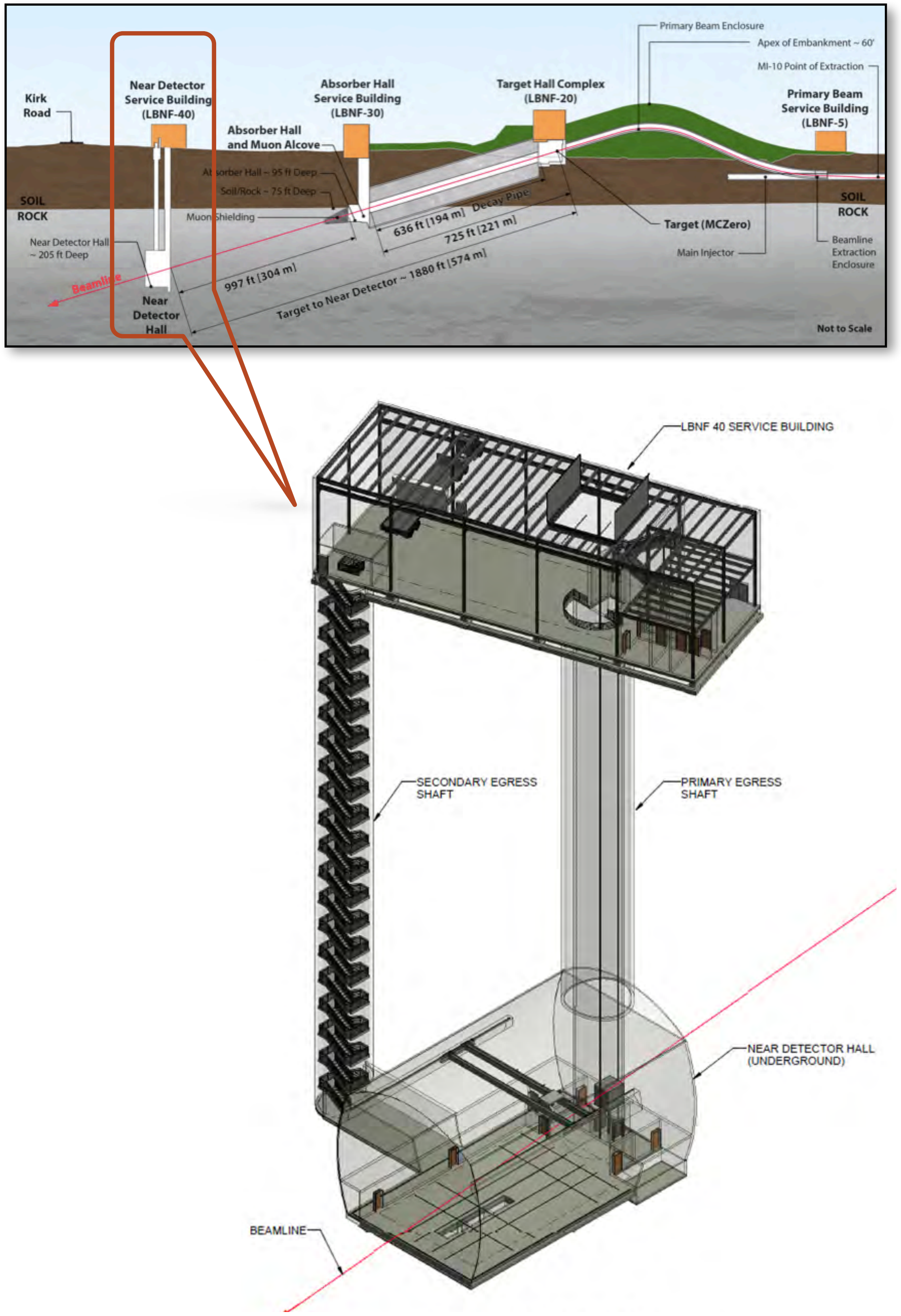


ICARUS Logo from the Flying Machine with Beating Wings by Leonardo da Vinci

“Near Site” - DUNE: ND at Fermilab

DUNE Near Detector

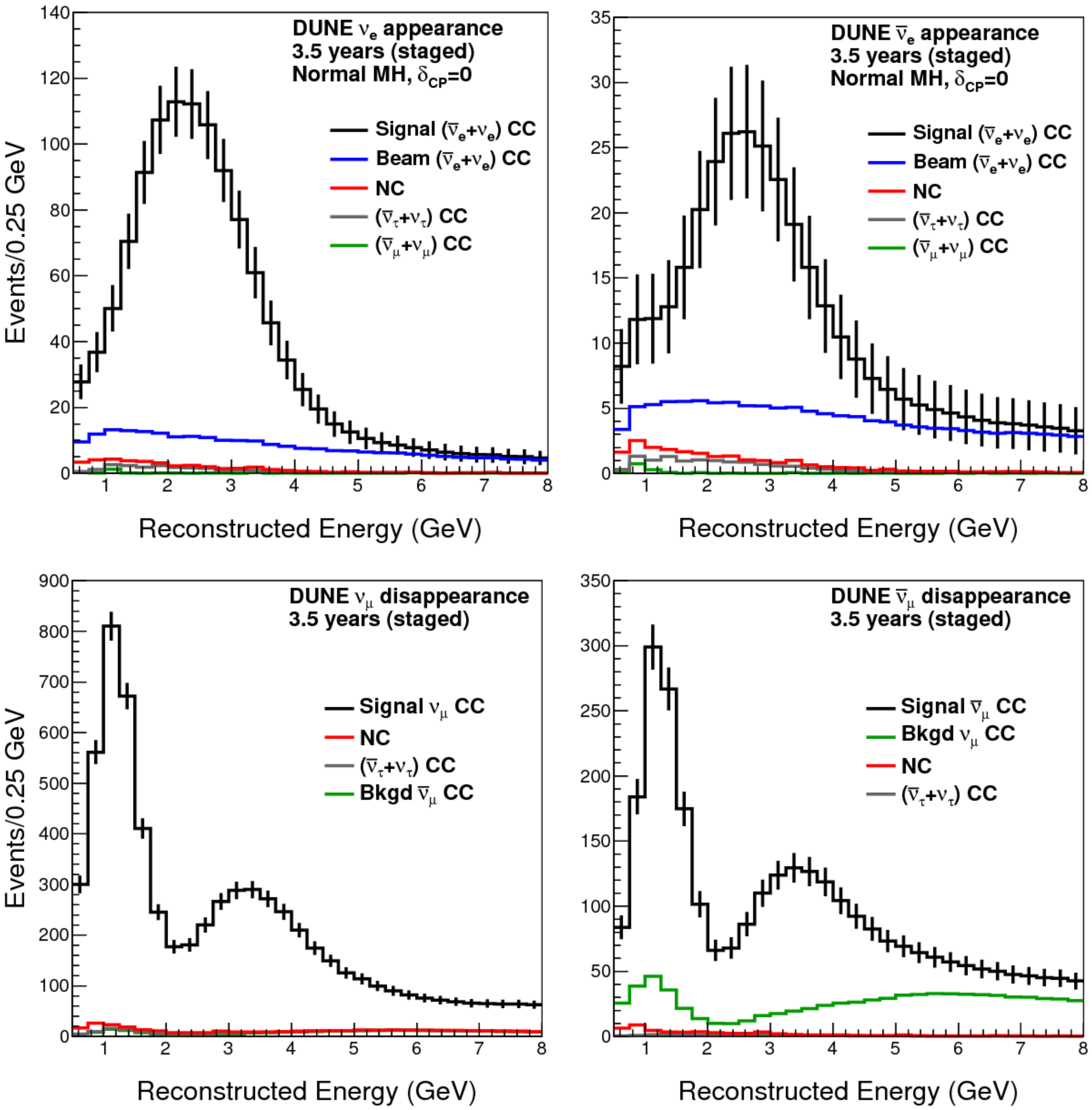
- DUNE ND design concept is an integrated system composed of multiple detectors:
  - HPGArTPC
  - Highly segmented LArTPC
  - Magnetized multi-purpose tracker
  - Electromagnetic calorimeter
  - Muon chambers
- Primary purpose is to **constrain systematic uncertainty** for long-baseline oscillation analysis
  - Constrain flux, cross-section, and detector uncertainties



Oscillation Sensitivity Calculations

DUNE Conceptual Design Report (CDR)
arXiv:1512.06148

Beam: ν-mode Beam: $\bar{\nu}$-mode

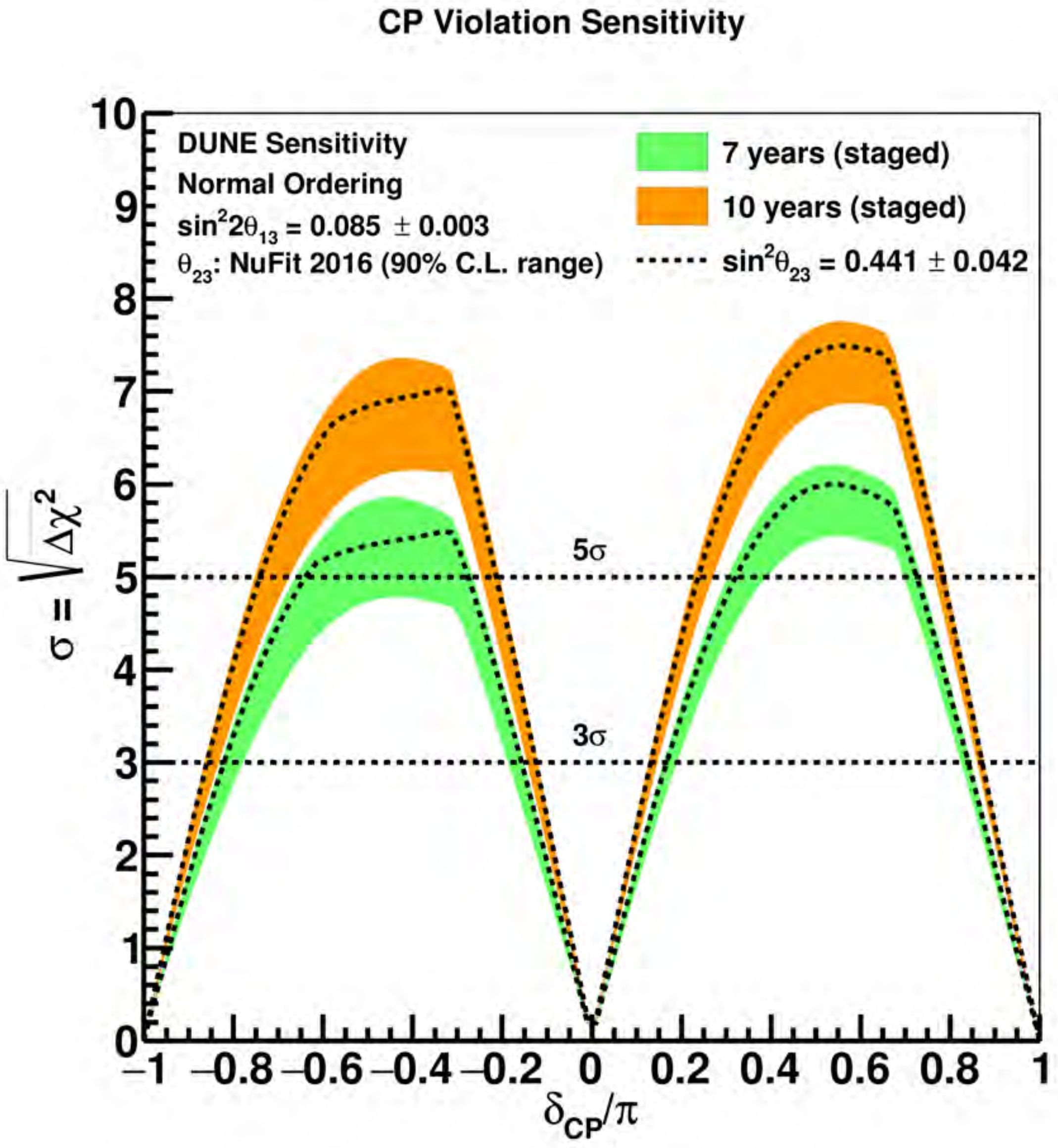


- Order 1000 ν_e appearance events in ~7 years of equal running in neutrino and antineutrino mode
- Simultaneous fit to four spectra to extract oscillation parameters
- Systematics approximated using normalization uncertainties

- Reconstructed spectra based on GEANT4 beam simulation, GENIE event generator, and Fast MC using detector response parameterized at the single particle level
  - Efficiency tuned using hand scan results
- GLoBES configurations arXiv: 1606.09550

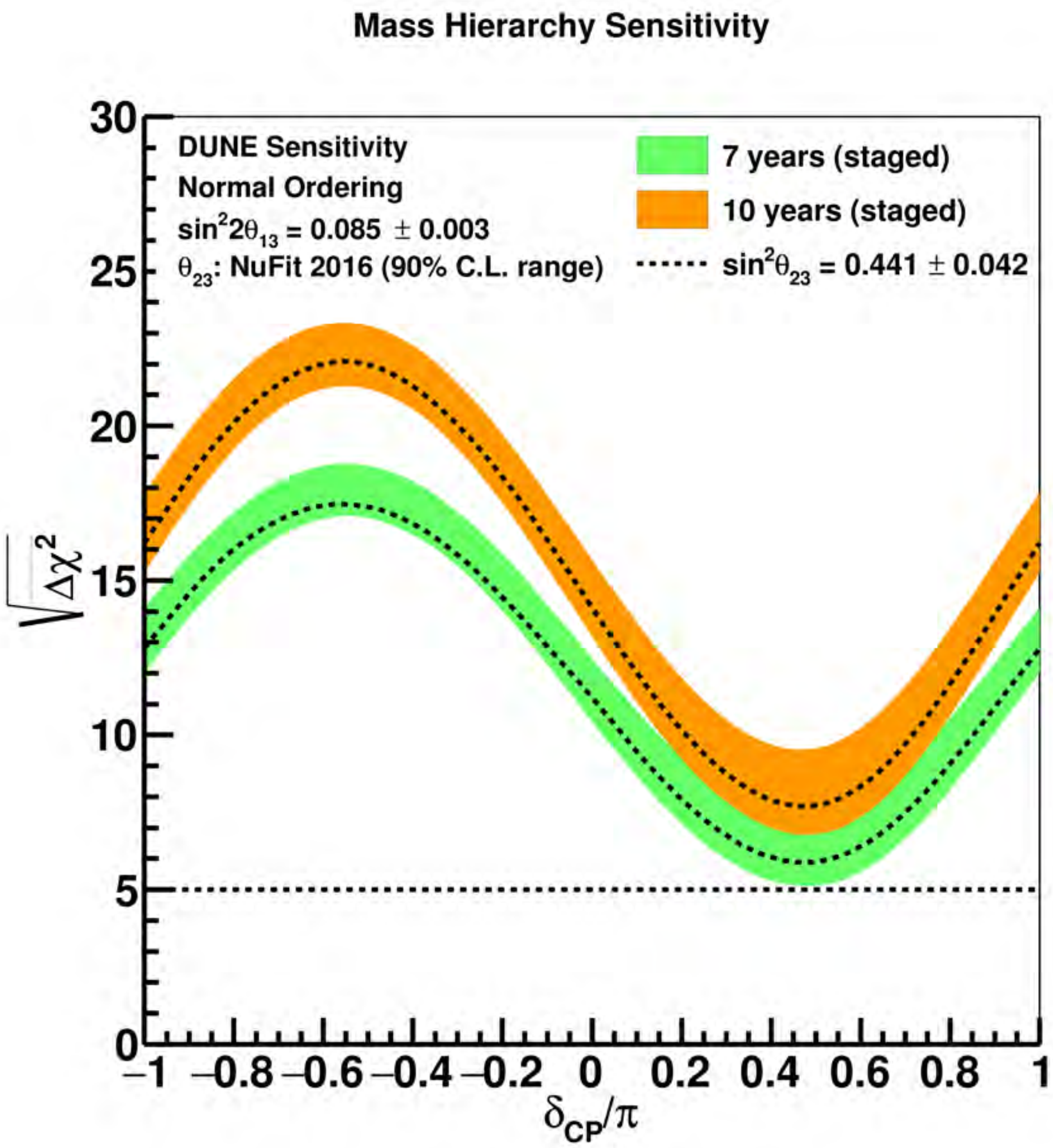
CP Violation Sensitivity

CP Violation



Width of band indicates variation in possible central values of θ_{23}

Mass Ordering



Width of band indicates variation in possible central values of θ_{23}

DUNE Far Detector Challenges

Scale up in size

- Cryostat for 10-kt fiducial: 15.1 (W) x 14.0 (H) x 62 (L) m^3

  a big step up from ICARUS & MicroBooNE [from $\mathcal{O}$(100 t) to $\mathcal{O}$(10 kt)]

underground location&expected duration of the experiment

- Assembly in underground and no access (no maintenance/repair for ~20 yrs) - somehow similar constraints as for HEP experiments in space

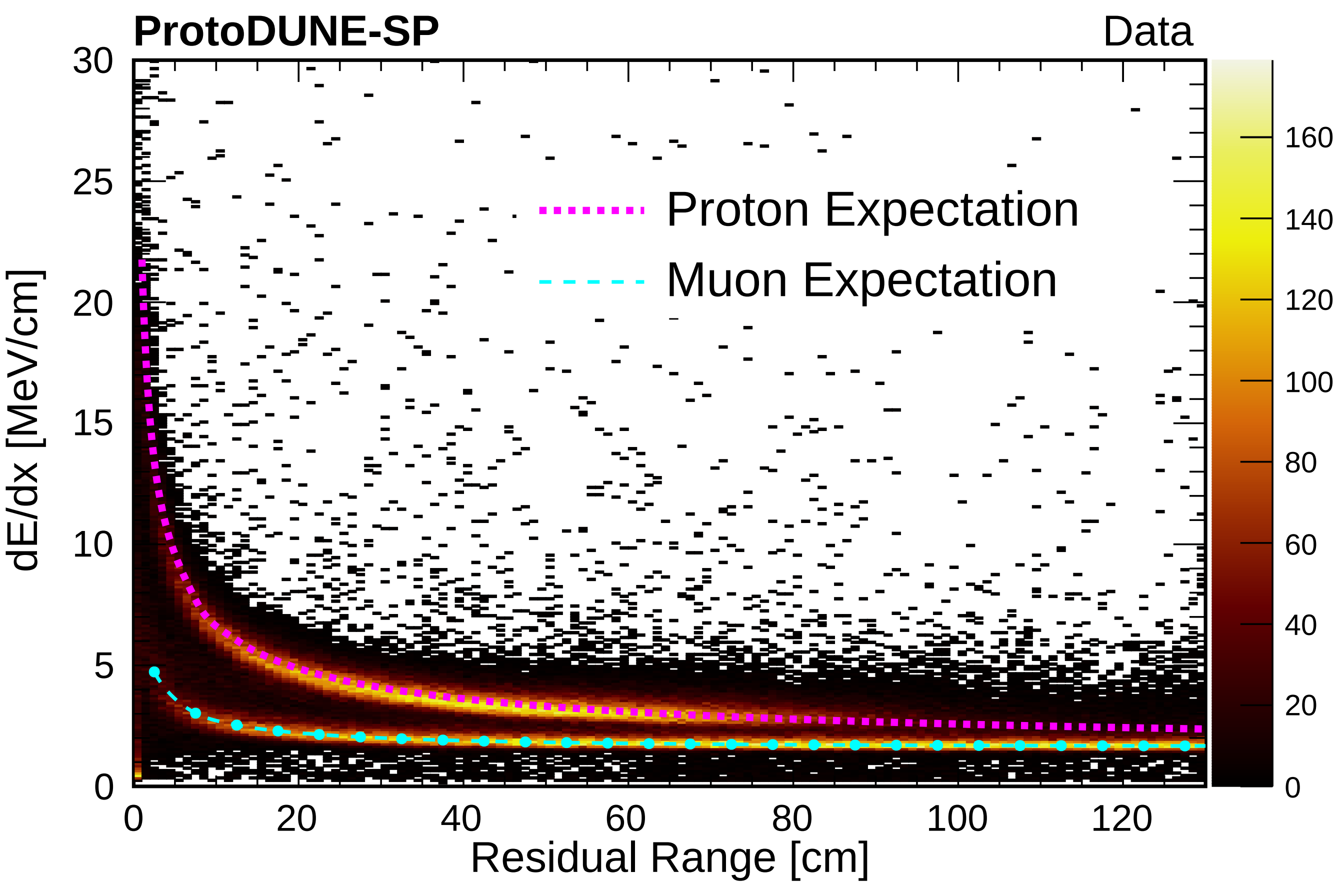
Technical challenges

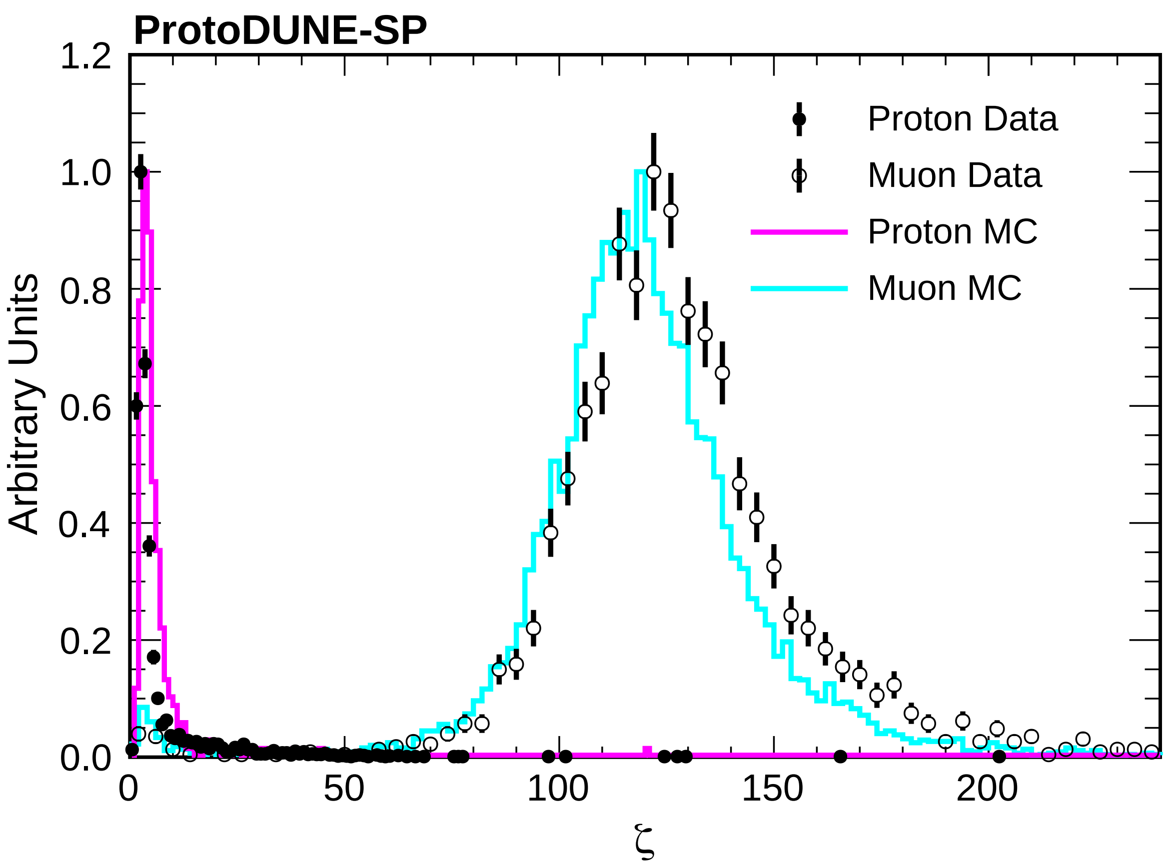
- Longer Drift and related more stringent requirement:
  - *on HV system*
  - *on LAr Purity*
- Detector Stability over time: Cold electronics/TPC, PhotoSensor/PDS
- Overall Mechanical engineering + QA/QC
- …

Solution to proof FD design:

- **build a** large-scale 1kt prototype

TPC + CE PERFORMANCE : dE/dx - Ptcl Id

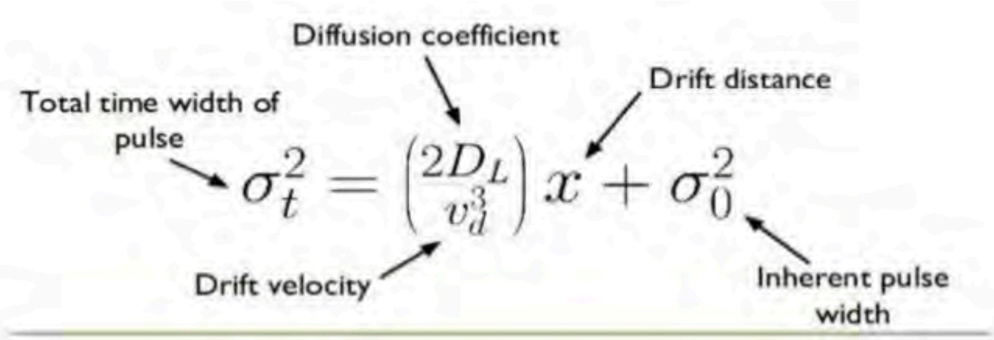




- Very well understood detector response to particles of different species.
- Excellent separation of muons and protons using calorimetric information.

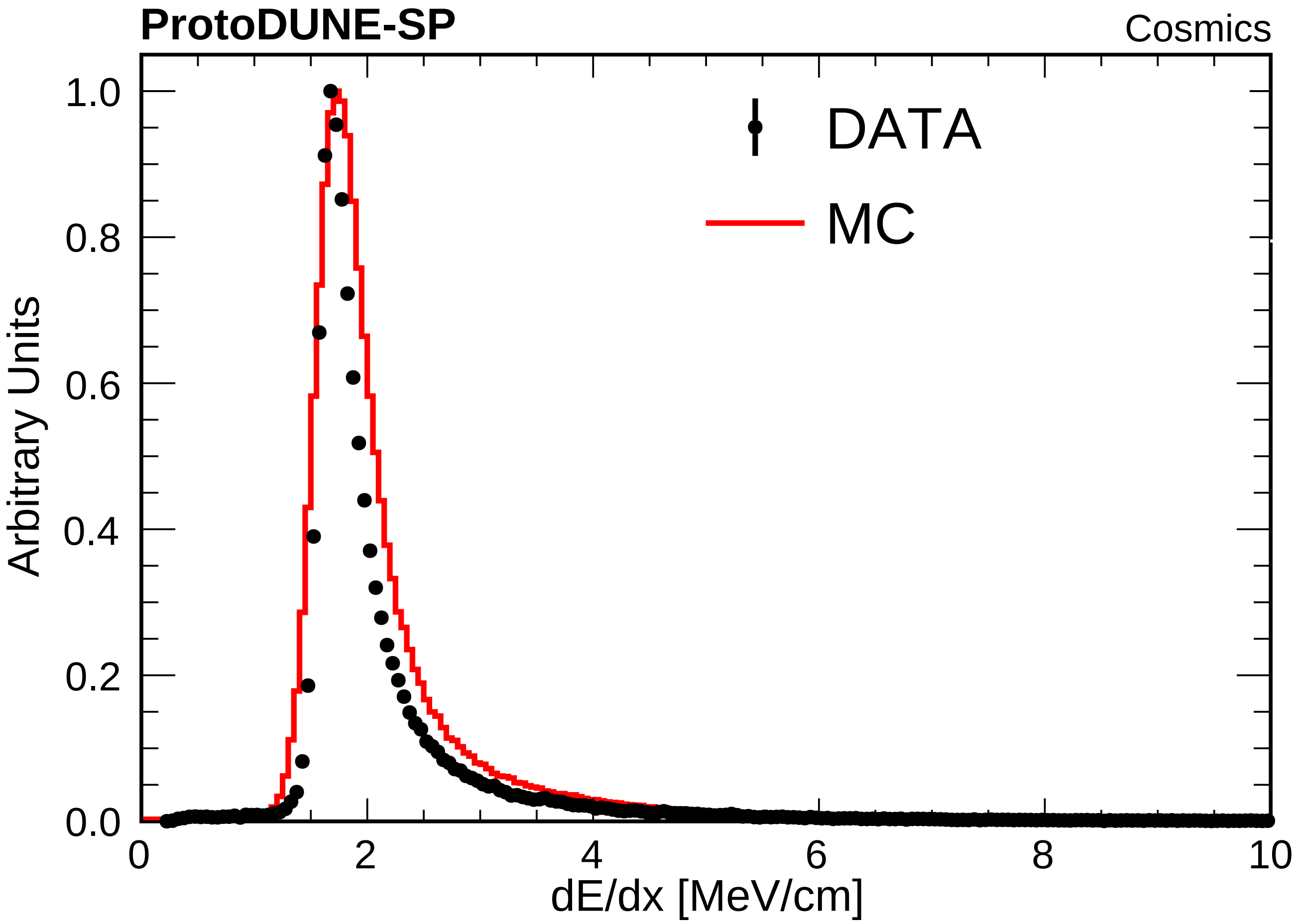
Stopping muon dE/dx distributions for the ProtoDUNE-SP cosmic data and MC.

Diffusion in data appears to be less than in simulation

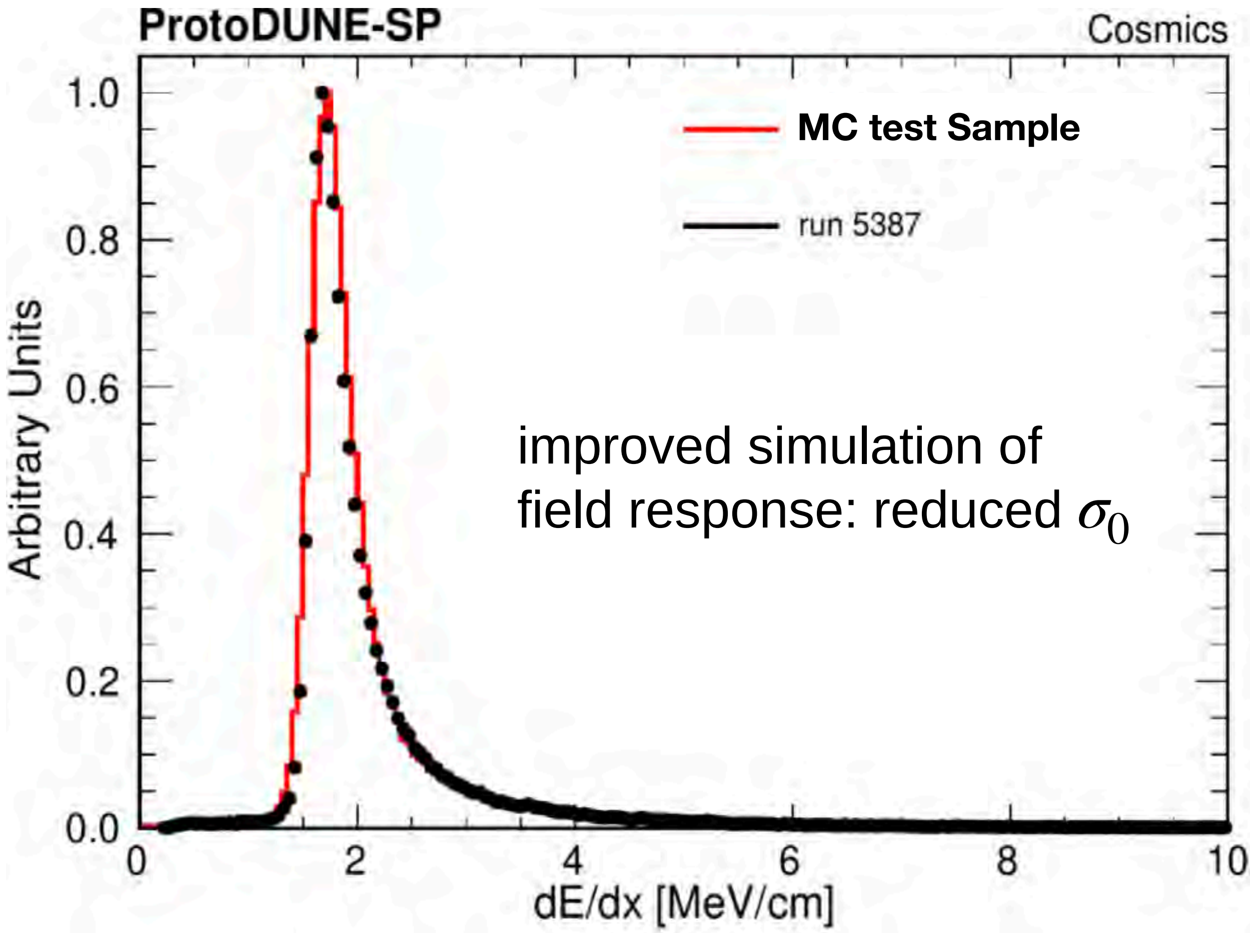


$$\sigma_t^2 = \left(\frac{2D_L}{v_d^3}\right) x + \sigma_0^2$$

Width of dE/dx for Data and MC doesn't agree



MC Tuning of longitudinal diffusion in progress



improved simulation of field response: reduced σ_0