# The CERN Neutrino Platform

Filippo Resnati (CERN EP-NU)

# 2013 European Strategy

High-priority large-scale scientific activities

"Rapid progress in neutrino oscillation physics, with significant European involvement, has established a strong scientific case for a long-baseline neutrino programme exploring CP violation and the mass hierarchy in the neutrino sector. ***CERN*** *should develop a* ***neutrino programme to pave the way*** *for a* ***substantial European role*** *in future* ***long-baseline experiments****. Europe should explore the possibility of major participation in leading long-baseline neutrino projects* ***in the US and Japan****."*

This led to the establishment of the CERN Neutrino Platform part of the CERN Medium Term Plan since 2015

# NP mandate

- **Assist** the various groups in their R&D phase in the short and medium term and give **coherence** to a fragmented European Neutrino Community

- Provide a charged particle test beam **infrastructure** for tests and R&D

- Bring R&D programs to the level of **technology demonstrators** in view of major construction activities

- Continue R&D on **neutrino beam**, as possible basis for further collaborations

- Support the **short baseline** activities (infrastructure & detectors)

- Support the **long baselines** activities (infrastructure & detectors)

- Be a partner in the **physics exploitation**

# MoU framework

**Memorandum of Understanding** for providing a framework for developing a Neutrino Program at CERN https://edms.cern.ch/document/1353815

NP reacts on **input from the community**

As of today, **106** institutes signed the MOU

CERN SPS Committee (SPSC) as an entry point

# NP participations

Acad. of Sciences, Czech Republic; AGH University of Science and Technology, Krakow, Poland; Alikhanian National Science Laboratory (YerPhi), Armenia; Argonne National Laboratory, United States; Boston University Study Abroad Program Geneva, Switzerland; Brookhaven National Laboratory, United States; Campinas University, Brazil; CEA/IRFU,Centre d'études de Saclay Gif-sur-Yvette – IRFU, France; Centre d'études nucléaires de Bordeaux-Gradignan, France; Centre National de la Recherche Scientifique - LAPP-Laboratoire d'Annecy-le-Vieux; France; Centro de Investigaciones Energéti cas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain; Colorado State University, United States; Czech Technical University, Czech Republic; Dipartimento de Fisica e Astronomia, Universita di Roma, Italy; Dipartimento di Fisica E. Pancini, Università di Napoli Federico II, Italy; Dipartimento di Fisica, Universita di Bari, Italy; Dipartimento di Fisica, Universita di Bologna, Italy; Dipartimento di Matematica e Fisica, Universita del Salento, Lecce, Italy; Dipartimento di Matematica e Fisica, Universita Roma Tre, Italy; Duke University, United States; ETH Zurich Institute for Particle Physics, Switzerland; European Organization for Nuclear Res. (CERN), Federal University of ABC, Brazil, Fermi National Accelerator Lab., United States; High Energy Accelerator Research Organization, Tsukuba, Japan, Indiana University, Bloomington, United States; INFN e Laboratori Nazionali di Frascati, Italy; INFN, LNGS, Assergi, Italy; INFN, Rome, Italy; INFN, Sezione de Bari, Italy; INFN, Sezione di Lecce, Italy; INFN, Sezione di Pavia, Italy; Institut de Fisica d'Altes Energies (IFAE), Bellaterra, Barcelona, Spain; Institute of Theoritical Physics and Modeling, Armenia; Joint Institute for Nuclear Research (JINR), Dubna, Russia; Justus-Liebig-Universität Gießen, Germany; Kansas University, United States; Laboratoire de physique nucléaire et de hautes énergies Paris (LPNHE), France; Laboratori Nazionali del Gran Sasso, Italy; Lancaster University, United Kingdom; Lawrence Berkeley National Lab., Berkeley, United States; Lebedev Physical Institute of Russian Academy of Science, Moscow, Russia, Lomonosov Moscow State University, Russia; Los Alamos National Laboratory, United States; Louisiana State University, United States; Michigan State University, United States; Middle East Technical University (METU), Ankara, Turkey, National Centre for Nuclear Research, Otwock, Poland, National Taras Schevchenko University of Kyiv, Ukraine, National Technical University of Athens, NTUA, Greece; OMEGA Ecole Polytechnique IN2P3 / CNRS, France; Princeton University, United States; Roma 2, Italy; Ruder Boskovic Institute, Zagreb, Croatia, Russian Academy of Sciences - Institute for Nuclear Research, Russia; SLAC National Accelerator Laboratory, United States; South Dakota School of Mines and Technology, Rapid City, United States; Southern Methodist University, Dallas, United States; State University of New York (Stonybrook), United States; STFC - Rutherford Appleton Lab. - Rutherford Appleton Laboratory, United Kingdom; Theoretical Nuclear Physics Research Group, Department of Physics and Astronomy, Ghent University, Belgium; Univ. of Valencia and CSIC - Instituto de Fisica Corpuscular (IFIC), Spain; Universita & INFN, Milano-Bicocca, Italy; Università degli Studi e INFN Milano - Sezione di Milano, Italy; Universita e INFN, Bologna - Sezione di Bologna (INFN) , Italy; Universita e INFN, Catania - Sezione di Catania, Italy; Universita e INFN, Napoli - Sezione di Napoli (INFN) , Italy; Universita e INFN, Padova, Italy; Universitaet Bern - Laboratorium fuer Hochenergiephysik, Switzerland; Universite Claude Bernard-Lyon I - Institut de Physique Nucleaire de Lyon, France; Universite de Geneve - Dept. de Phys. Nucl. et Corpuscul., Switzerland; Universite de Paris VII - Laboratoire APC - Astroparticules et Cosmologie, France; Université Paris Diderot, France; Université Pierre et Marie Curie (UPMC) et Paris Diderot, France; Université Savoie Mont Blanc, France; University of Bristol, United States; University of California Davis, United States; University of California Los Angeles, United States; University of California, Berkeley, United States; University of California, Irvine, United States; University of Cambridge, United Kingdom; University of Glasgow, United Kingdom; University of Hawaii, Honolulu, United States; University of Houston, United States; University of Jyvaskyla - Department of Physics, Finland, University of Liverpool, United Kingdom; University of London - University College London, United Kingdom; University of Manchester, United Kingdom; University of Minnesota, United States; University of Minnesota, Duluth, United States; University of Oulu, Finland, University of Oxford - Particle Physics, United Kingdom; University of Pennsylvania, Philadelphia, United States; University of Pittsburgh, United States; University of Seville, Spain; University of Sheffield, United Kingdom; University of Sofia, Department of Physics, Bulgaria, University of Sussex, United Kingdom; University of Texas, Arlington, United States; University of Warwick, United Kingdom; University of Wisconsin, Madison, United States; Virginia Tech, United States; Warsaw University of Technology, Poland, William & Mary College, United States; Yale University, United States;

# NP activities

Project already *approved* by the SPSC:

**NP01** (WA104): ICARUS detector as far detector for the SBN program in the US

**NP02** (WA105/ProtoDUNE-DP): R&D program, large size demonstrator and prototype on a charge particle beam of the double-phase LAr TPC technology

**NP04** (ProtoDUNE-SP): Large size engineering demonstrator and prototype on a charge particle beam of the single-phase LAr TPC

**NP05** (BabyMIND): Magnetised muon spectrometer for the WAGASCI experiment in Japan

**NP03** (Plafond): Generic R&D framework

In addition:

- Near detector studies for T2K and DUNE, developments on HP gas TPC as near detectors
- Performance study and requirement assessment of neutrino near detectors
- Participation in the design and construction of the DUNE cryostats
- Active participation in FNAL-SBN program
- Active participation in the DUNE program

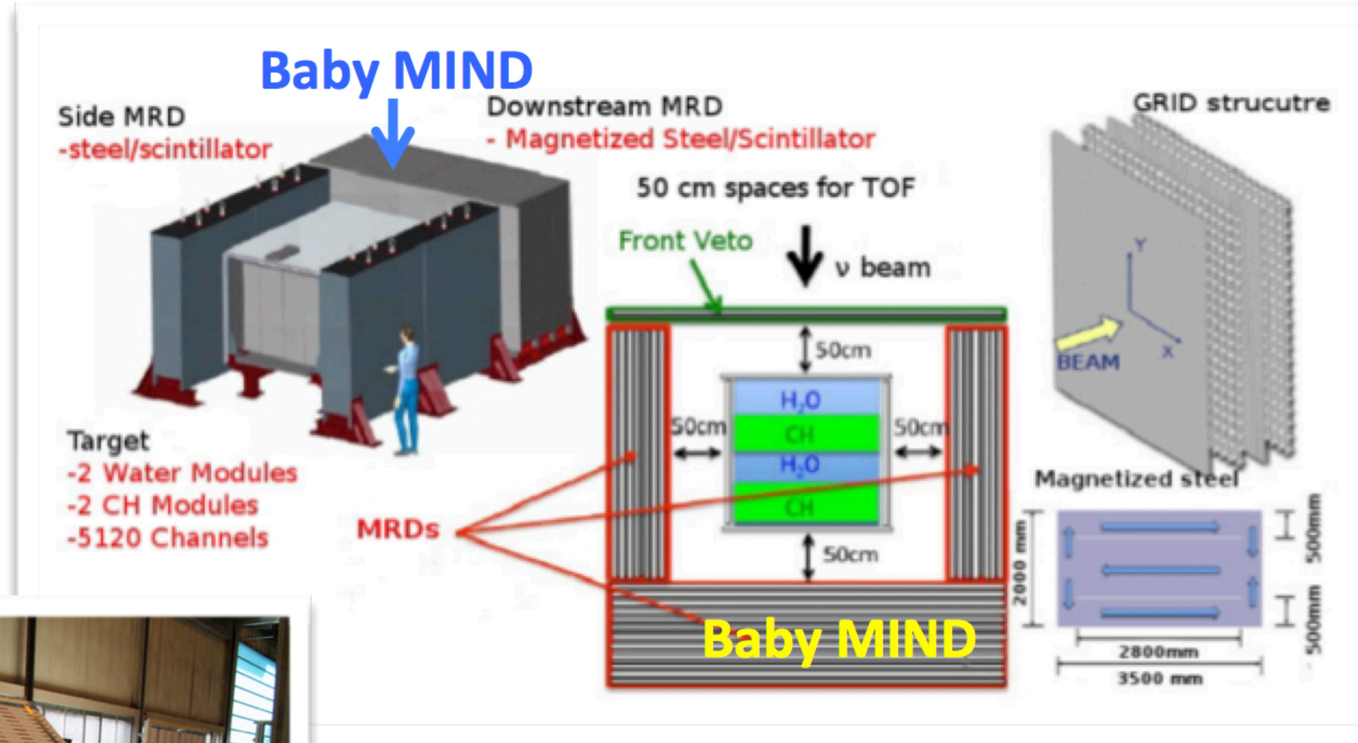
# NP05 / BabyMIND

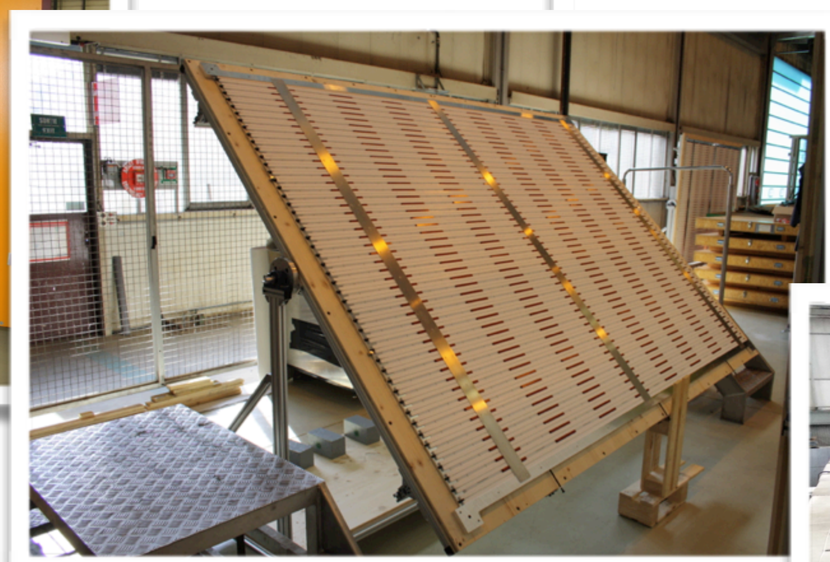
NP05 / BabyMIND Collaboration:
Instituto de Fisica Corpuscular (IFIC), Spain - Institute for Nuclear Research (INR), Russia - University of Geneva, Switzerland - University of Glasgow, United Kingdom - University of Sofia, Bulgaria - European Organisation for Nuclear Research (CERN), Switzerland

# NP05 / BabyMIND

Magnetised muon spectrometer for the WAGASCI experiment (T2K beam line)
Interleaving of magnets (33) and scintillator (18) modules

Main systems:
- Magnet modules (CERN)
- Scintillator modules (JINR and UniGe)
- Readout electronics (UniGe and Sofia)
- Support mechanics (UniGe)

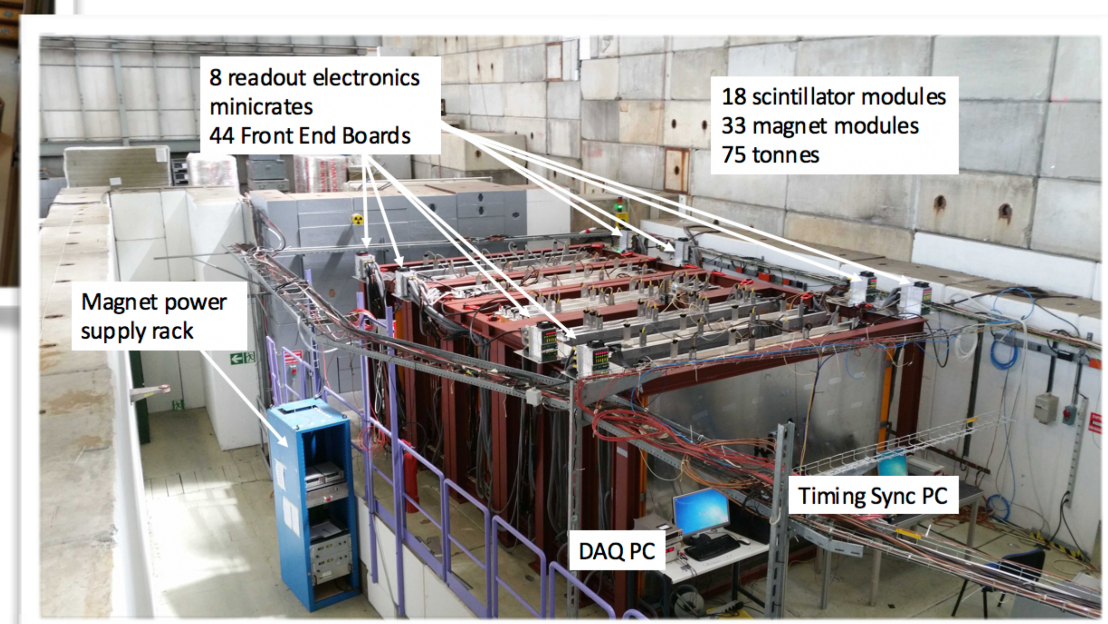


Baby MIND beam tests at PS in July 2017

Results recently presented at NuFact2017:
https://indico.uu.se/event/324/session/6/contribution/72/material/slides/0.pdf

On its way to Japan



# NP01 / WA104

NP01 / WA104 Collaboration:
Argonne National Laboratory (ANL), USA - Brookhaven National Laboratory (BNL), USA - European Organisation for Nuclear Research (CERN), Switzerland - Colorado State University, USA - Fermi National Laboratory (FNAL), USA - INFN Catania and University Catania, Italy - INFN GSSI, Italy - INFN LNGS, Italy - INFN Milano and Milano Bicocca, Italy - INFN Napoli, Italy - INFN Padova and University, Italy - INFN Pavia and University, Italy - Los Alamos National Laboratory (LANL), USA - Pittsburgh University, USA - SLAC, USA - Texas University, USA

# NP01 / WA104

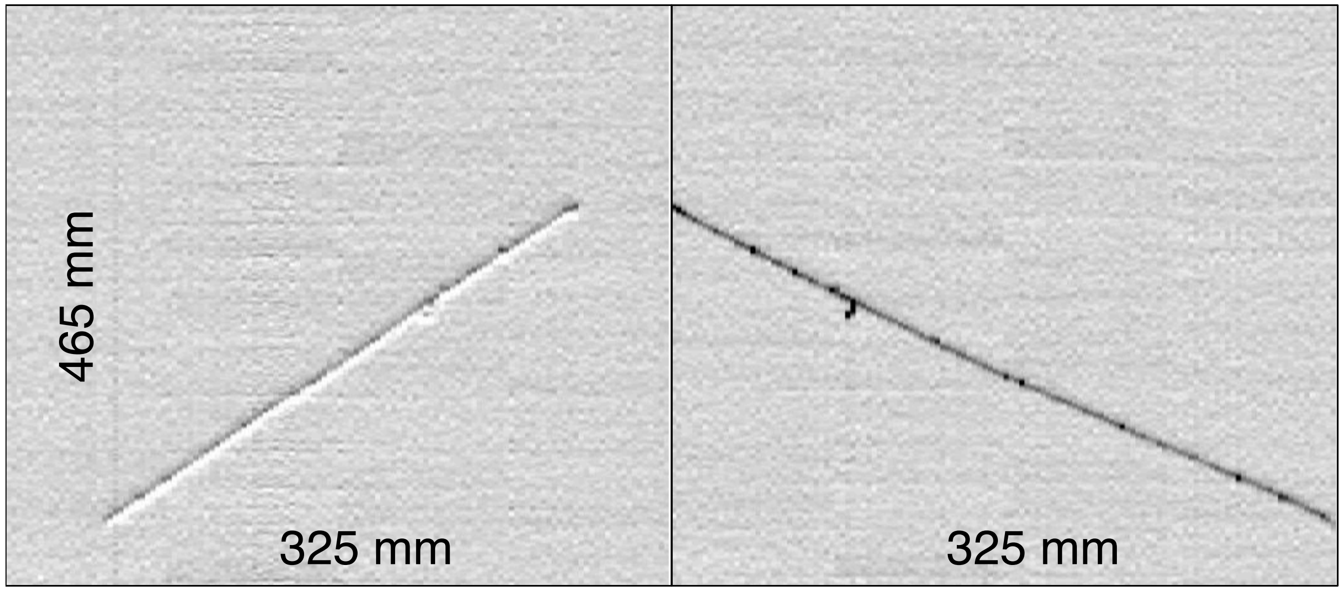
ICARUS T600 LAr TPCs successfully operated underground at LNGS on CNGS neutrino beam from 2009 to 2013.

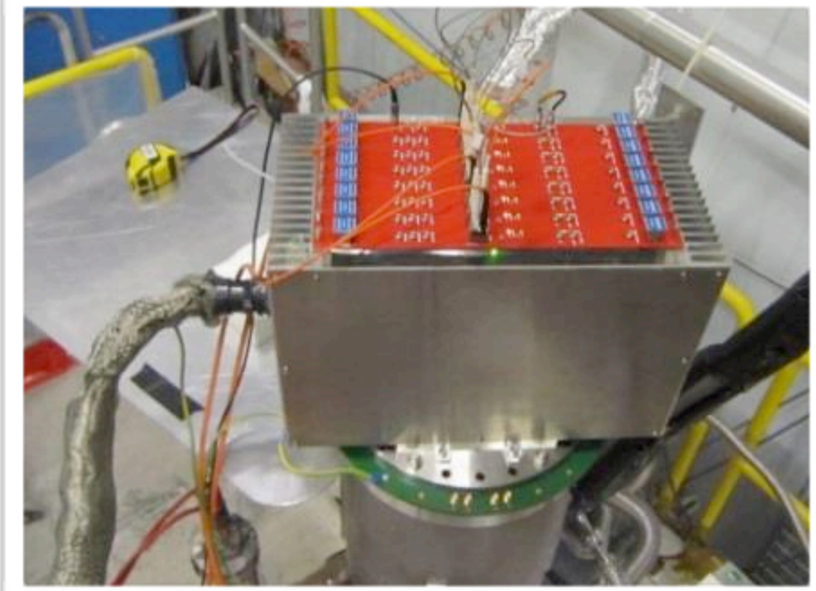
Refurbish and ICARUS T600 as far detector for the SBN program on the US (on surface at Fermilab):
- New cold (extruded aluminium) and warm (passive isolation) vessels
- Upgrade of light detection system (more sensitive, more coverage, new calibration system)
- Cabling and connectivity re-done (light and charge signals)
- Faster and higher performance electronics (FE, digitisation, DAQ systems)
- Refurbishing of the central cathode
- Design and construction (ongoing) of the top Cosmic Ray Tagger
- Proximity cryogenics re-design and presently in production.

These activities were conducted at CERN from December 2014 until June 2017
Transport of the ICARUS modules to Fermilab from 12 June to 26 July 2017

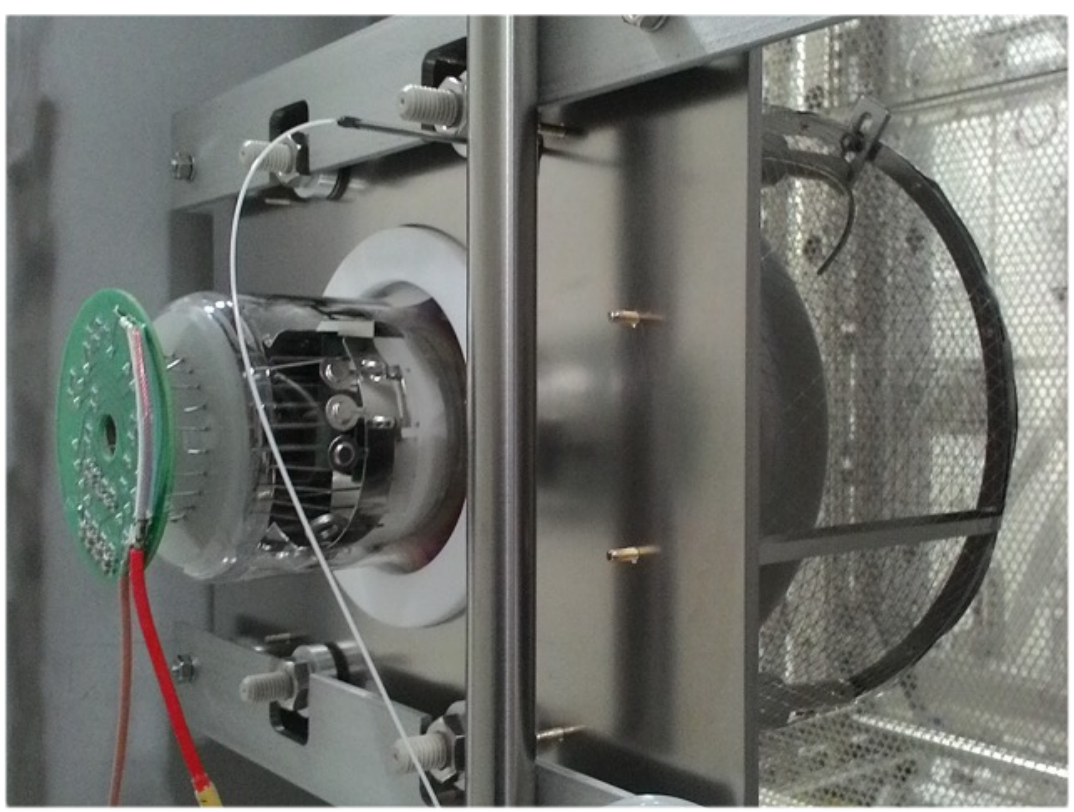
# NP01 / WA104

Heavily tested collecting with cosmic rays in the 50l ICARUS chamber at CERN



Dedicated clean room to host the two ICARUS modules

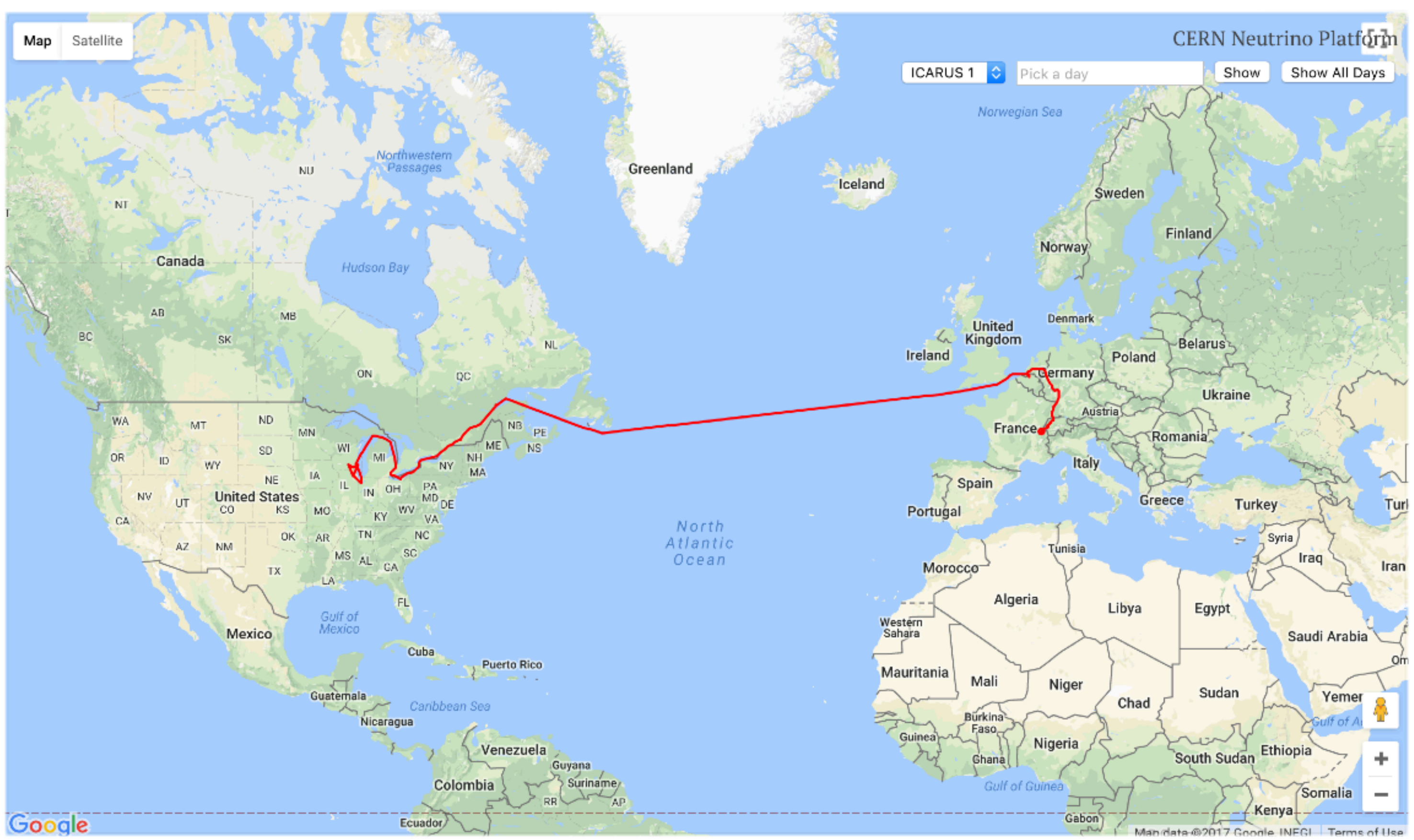


# ICARUS trip

| | |
|---|---|
| Dep. CERN | 12 June 2017 |
| ↓ truck | |
| Arr. Basel (CH) | 16 June 2017 |
| Dep. Basel (CH) | 16 June 2017 |
| ↓ barge | |
| Arr. Antwerp (BE) | 20 June 2017 |
| Dep. Antwerp (BE) | 22 June 2017 |
| ↓ ship | |
| Arr. Burns Harbor (USA, IN) | 10 July 2017 |
| Dep. Burns Harbor (USA, IN) | 24 July 2017 |
| ↓ truck | |
| Arrival at FERMILAB | 26 July 2017 |

Photos from the transportation

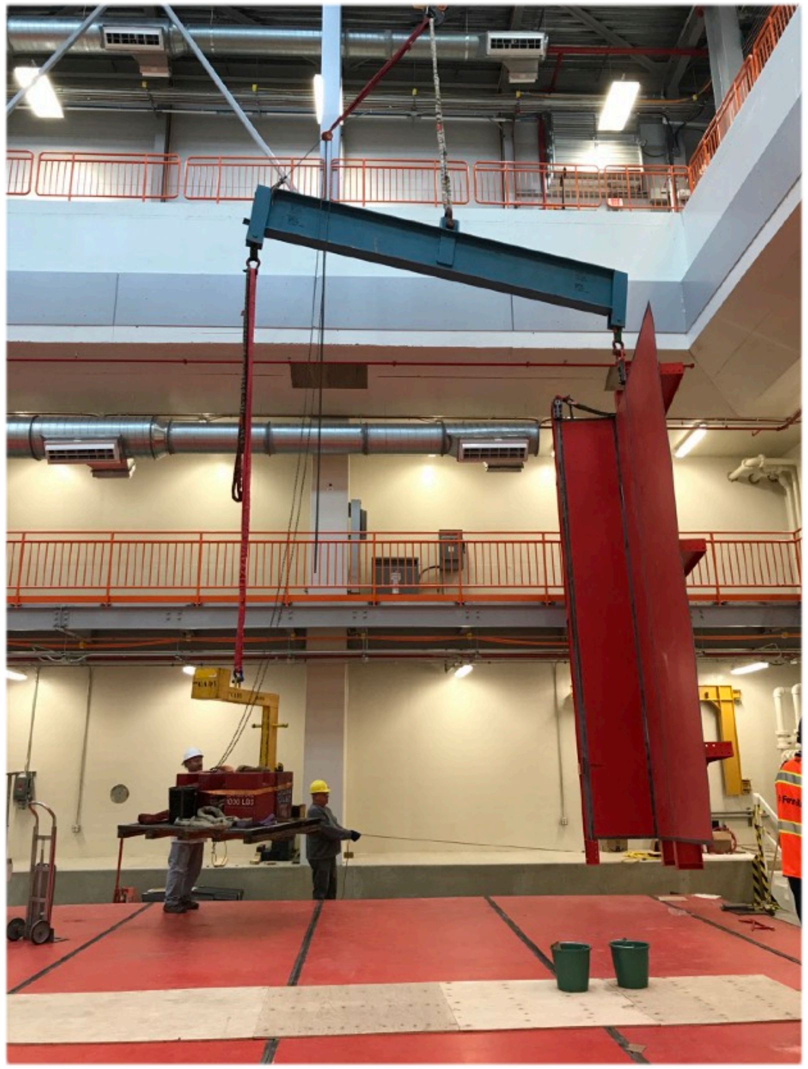






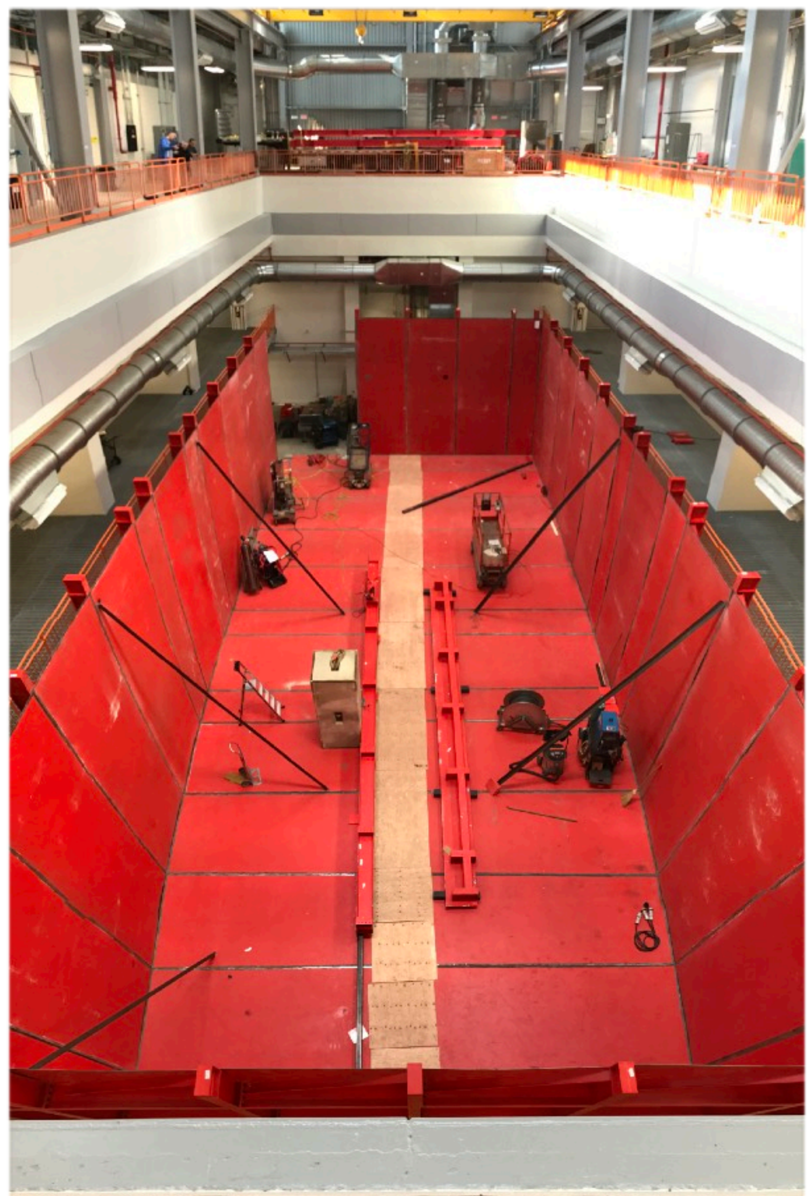
http://icarustrip.web.cern.ch

# NP01 / WA104



Warm vessel construction at Fermilab by CERN
Ready to host ICARUS. Next steps:

- Insertion of the two cold cryostats in the warm vessel
- Construction of the cryogenics by CERN contractors

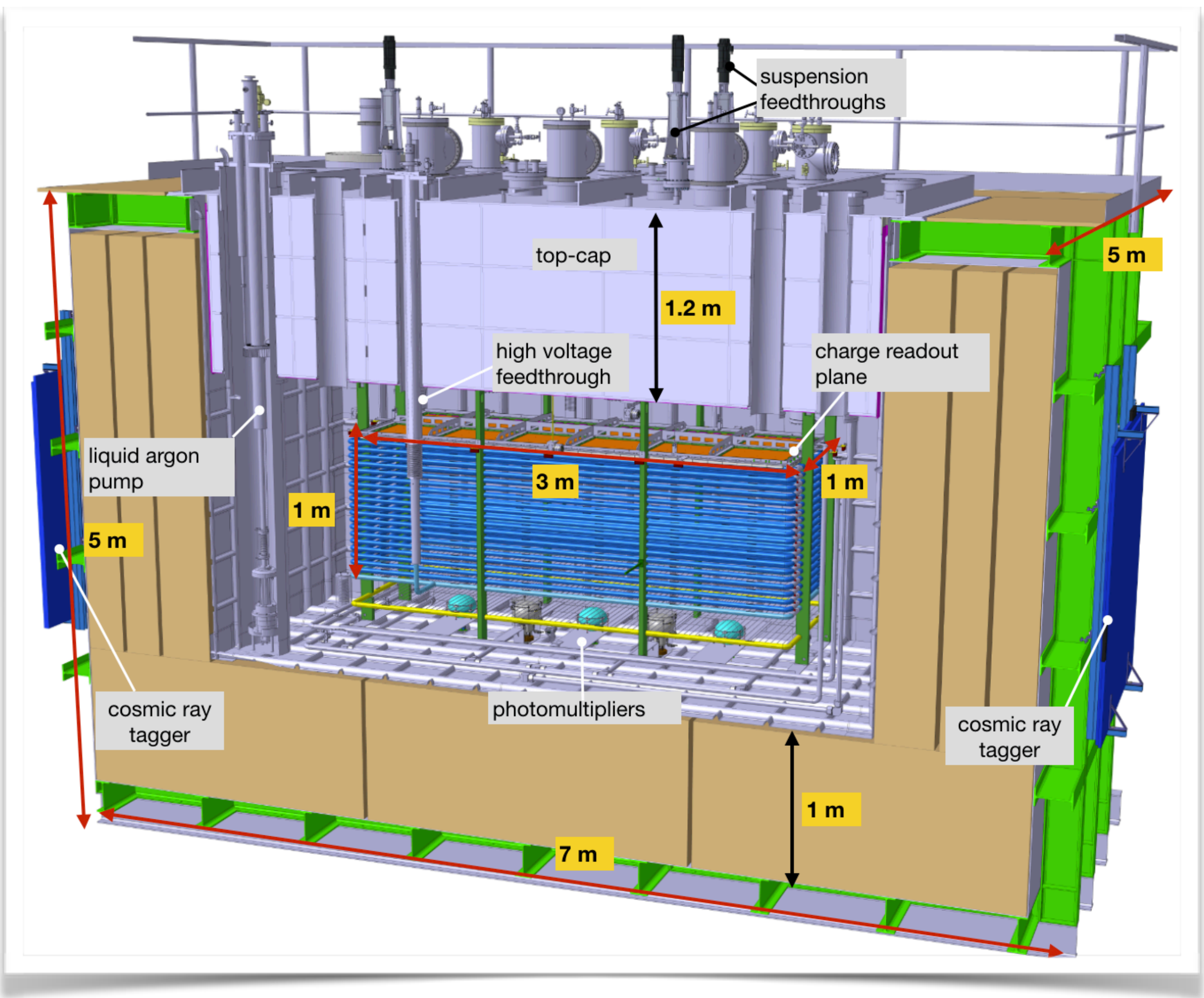


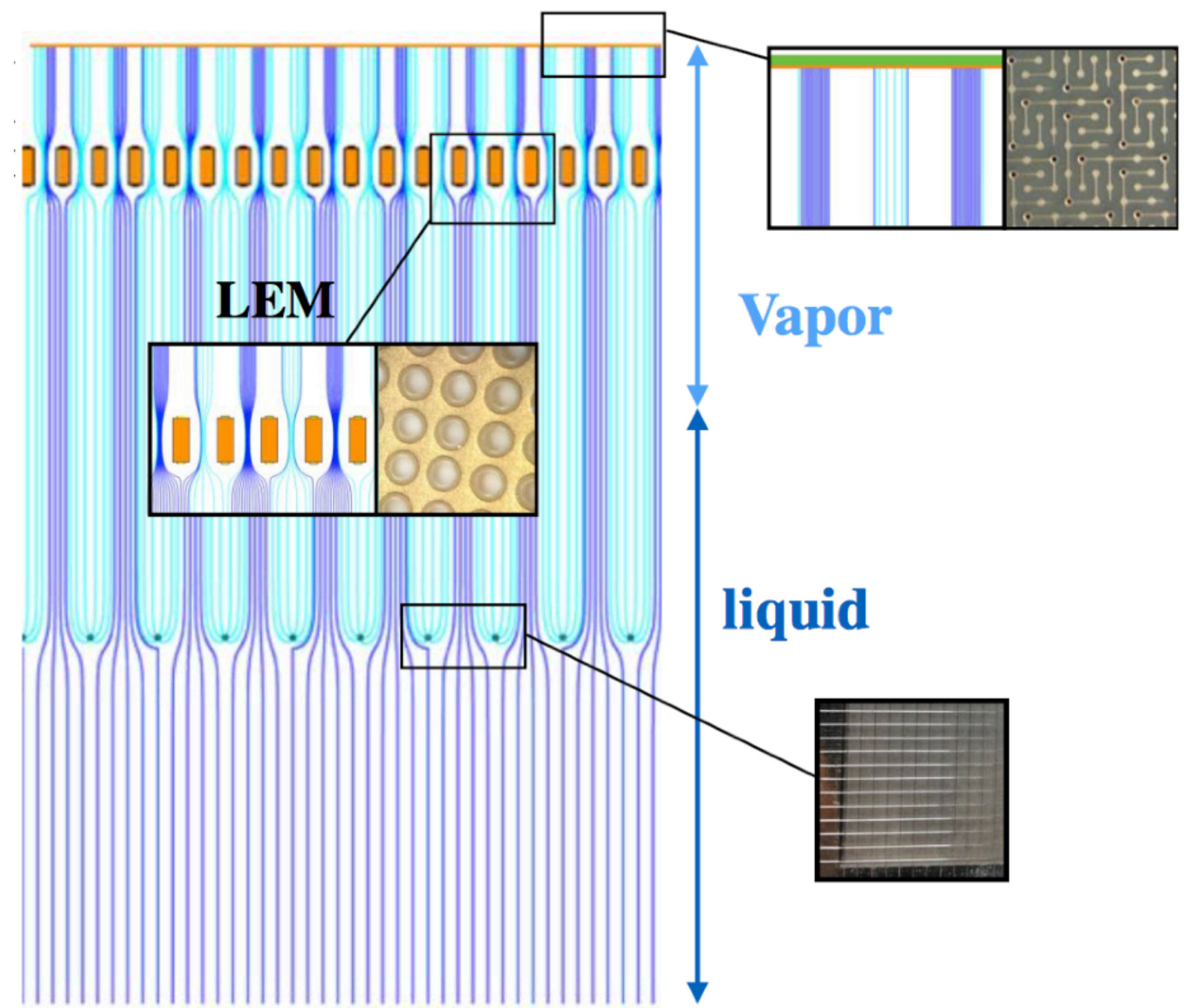
# NP02 & NP04: ProtoDUNEs

NP02 and NP04 ProtoDUNEs Collaborations:
very large subset of the LBNF-DUNE Collaboration

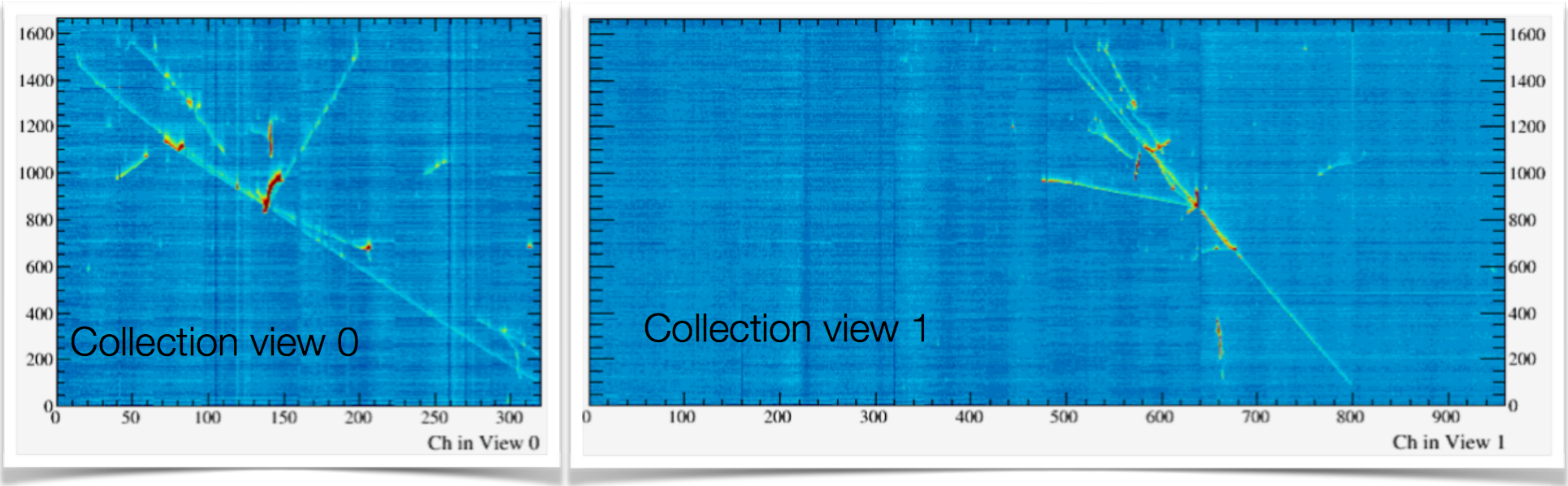
# Double phase argon TPC

3x1x1: 3 m³ active volume prototype and scalability demonstrator
In operation at CERN since spring 2017



# 3x1x1 double phase TPC




High quality data illustrates the state of the art imaging of the dual phase technology:

- About 350 k cosmic events collected.
- Stable 500 V/cm drift field over one meter.
- Excellent performance of liquid argon pump.
- Liquid argon purity compatible with 10-20 ms free electron lifetime.
- First time achieved at CERN with a membrane cryostat.
- Liquid argon level stable at sub-mm scale.
- First time ever electron extraction over 3 $m^2$
- LEM amplification demonstrated on the 50x50 $cm^2$ (final design for DUNE)
- Good S/N ratio on two collection views (3 meter and 1 meter strips)
- Some stability problems still under investigation and clarification

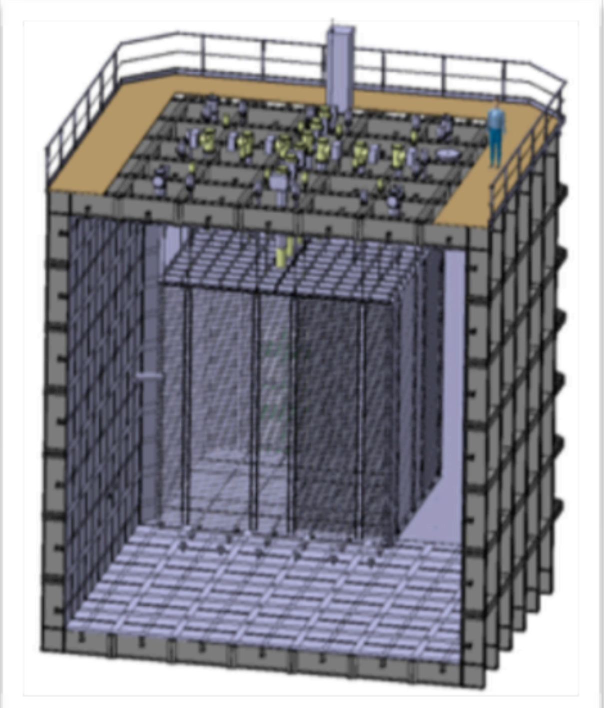
# EHN1 extension

Extension of the EHN1 building in the CERN North Area to host ProtoDUNEs.
Two almost identical cryostats, two 700 ton liquid argon TPCs, two very different technologies:
- double phase (NP02) and single phase (NP04) LAr TPC prototypes (full size components)
- on charge particle beam before LS2 (end 2018)

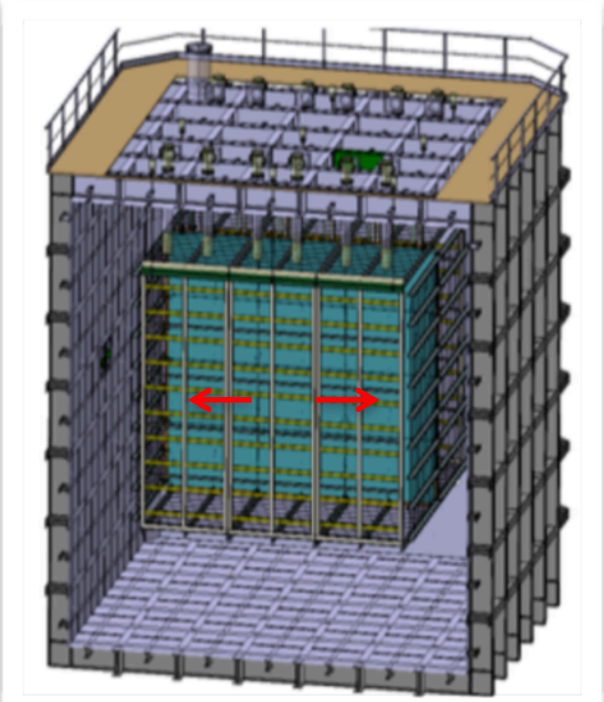

Approximate external dimensions 11x11x11m$^3$
Approximate internal dimensions 8x8x8 m$^3$

# ProtoDUNEs

Engineering and functional prototyping and detector performance studies
The critical components are fully representative of what will be in DUNE
For instance the new technology for large volume cryostats.

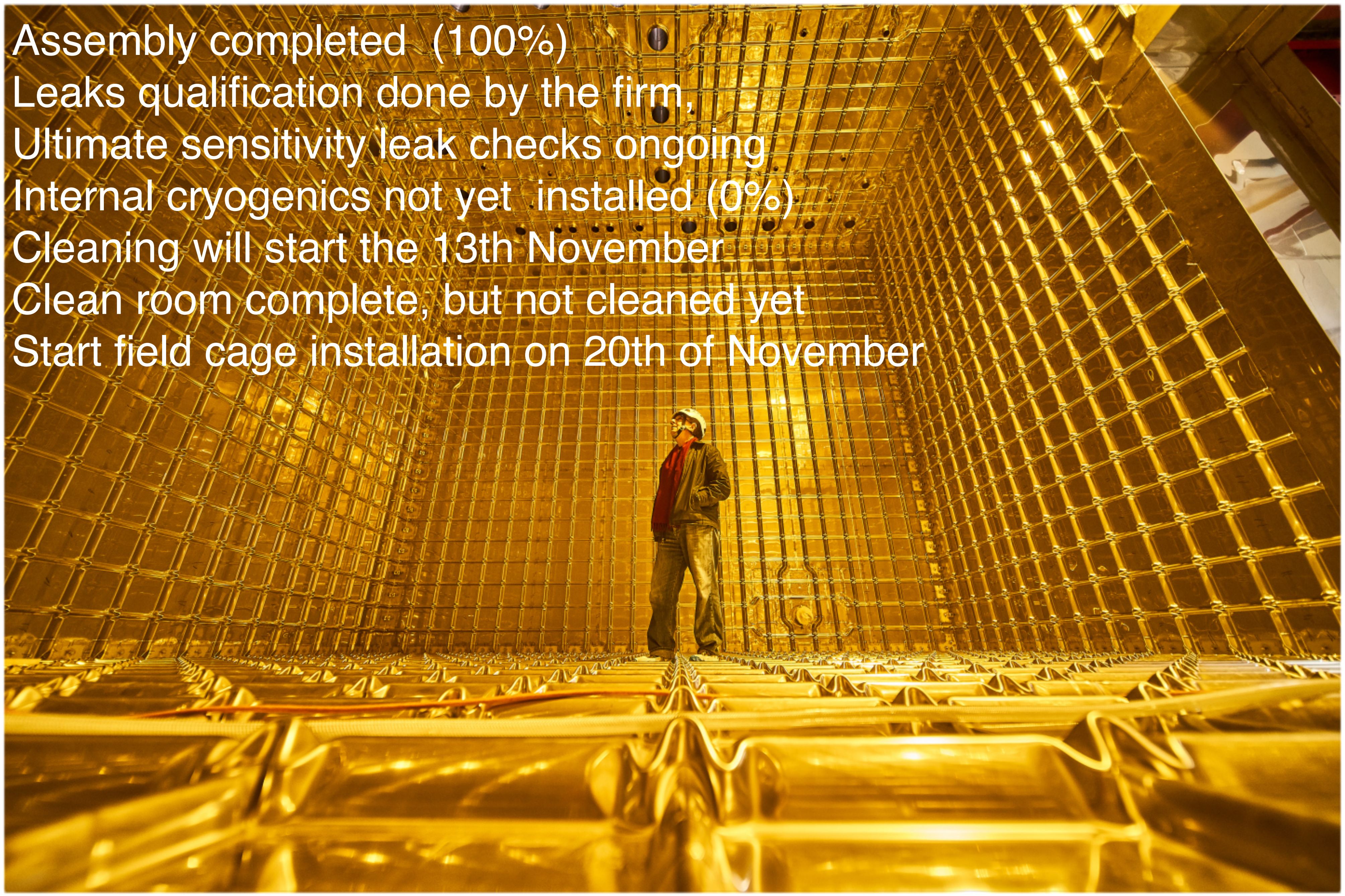


Double phase LAr TPC (NP02)
The 3x1x1 is the prototype
Active volume 6x6x6 $m^3$
Electrons drift vertically (6 m -> 300 kV at the cathode)
Electrons are extracted in the vapour phase
Electrons undergo charge amplification in the LEM holes
Charge is equally shared between two orthogonal sets of strips on an anode
Electronics is cold but extractable (special chimneys developed)

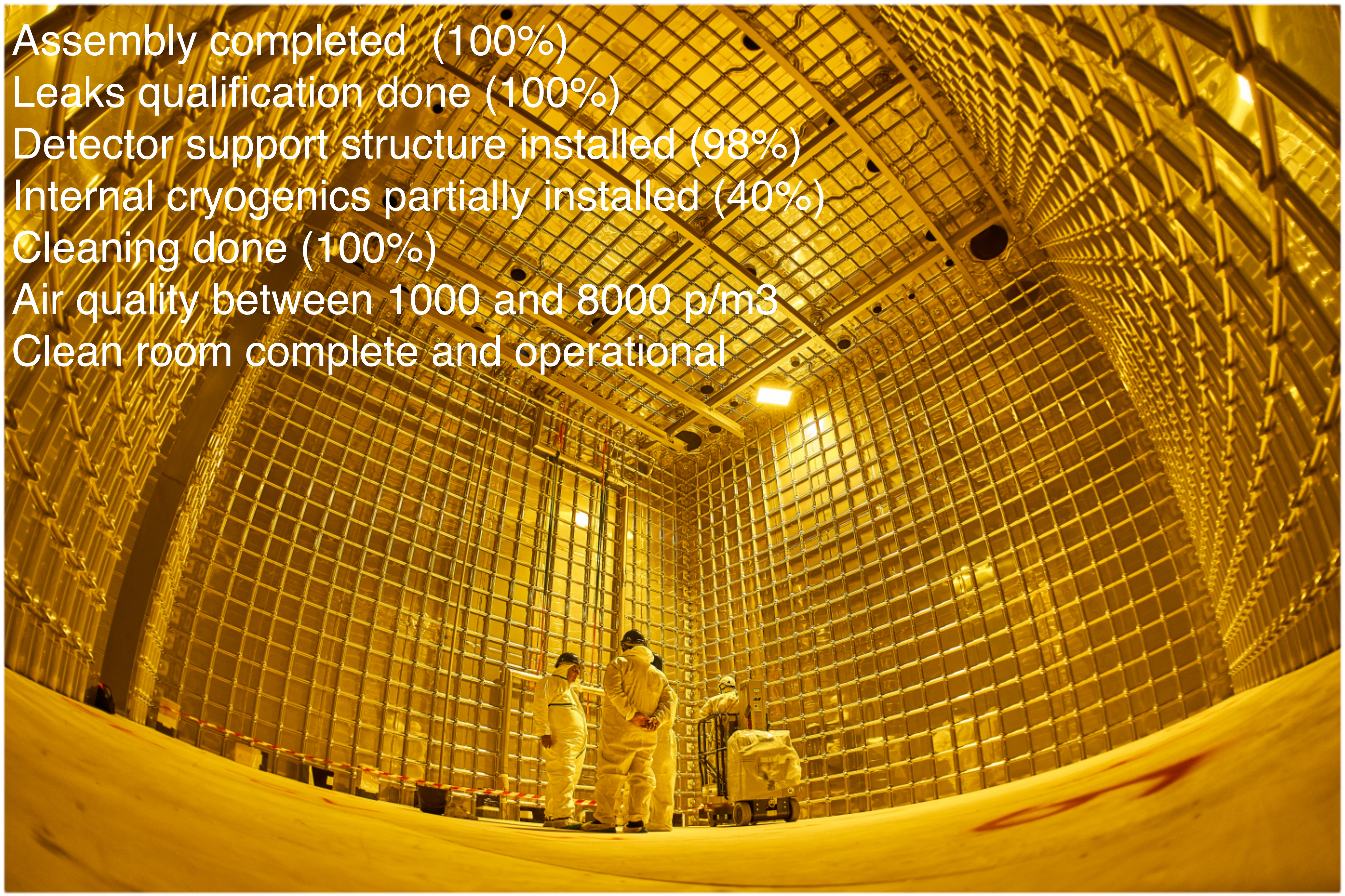


Single phase LAr TPC (NP04)
Active volume 6x6x7 $m^3$
Electrons drift horizontally orthogonal to the particle beam
3.6 m drift -> 180 kV at the cathode
Electrons drift in liquid and induce signals on wires
Wires wrapped around APAs (full DUNE size) to gain modularity
Electronics installed in liquid argon -> improve S/N ratio

# NP02 double phase

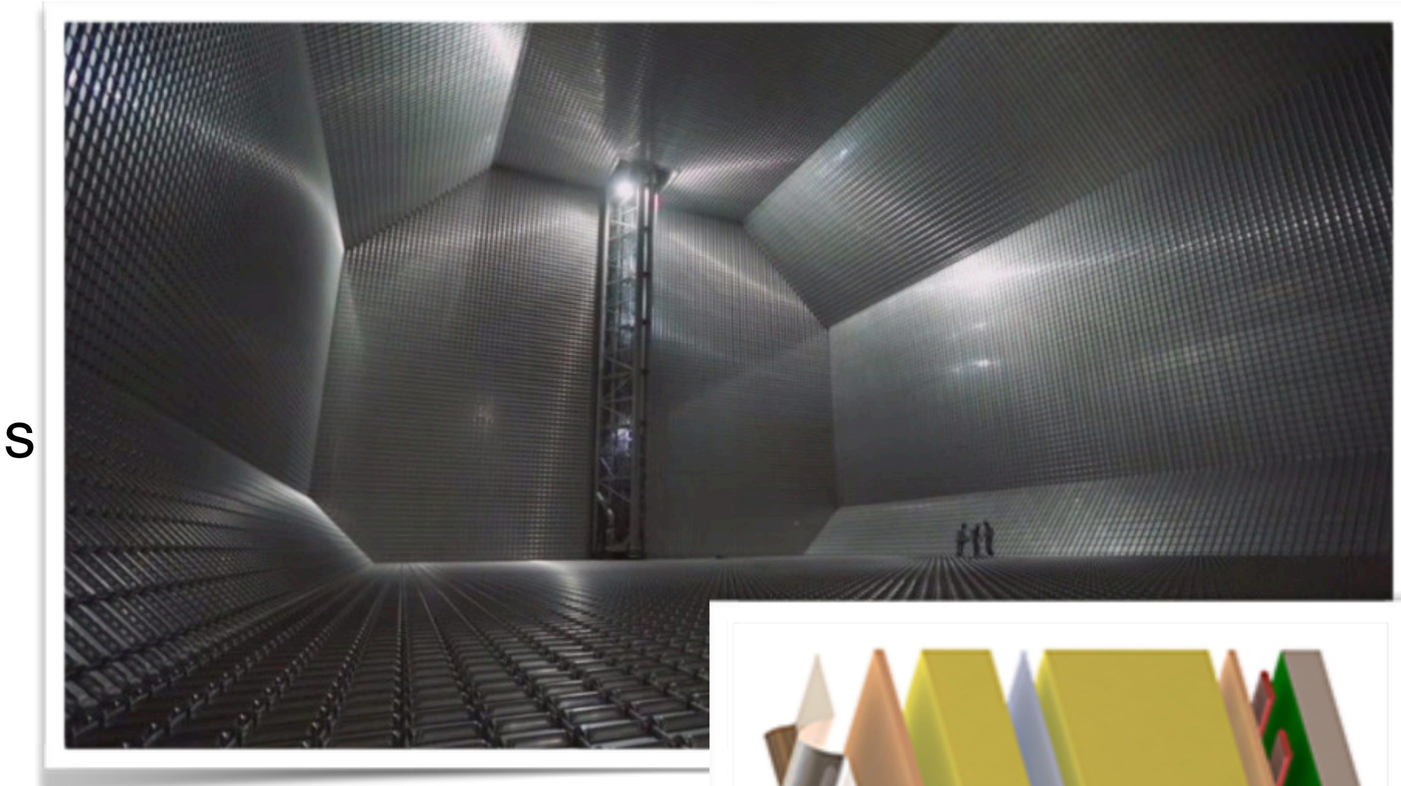


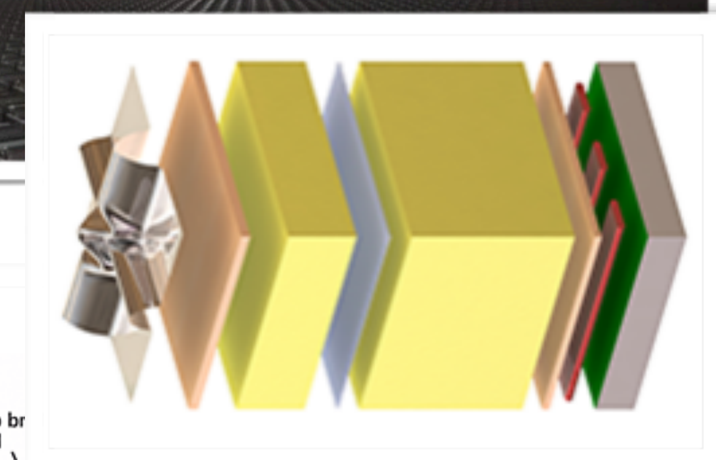
# NP04 single phase



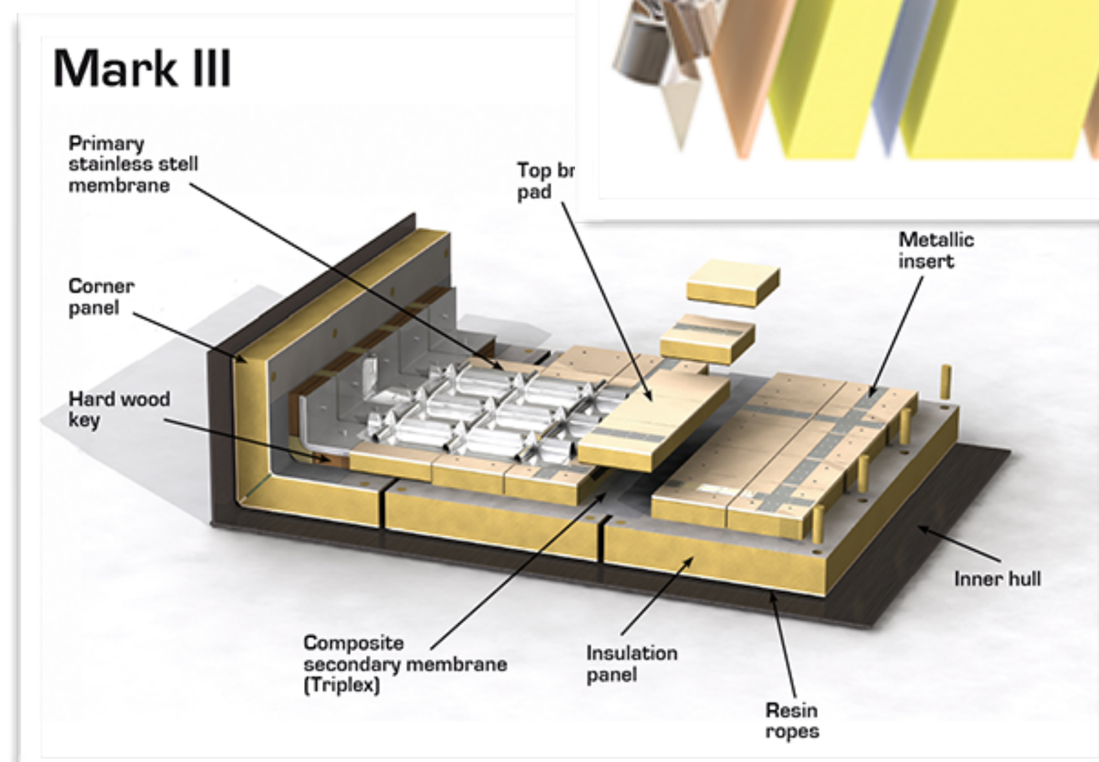
# The technology

Royalties owner: GTT (France)
Licensee: Gabadi (Spain) among several
Applications:
- LNG carriers (>200000 m$^3$ in 5 sub-tanks)
- Floating storages and re-gasification vessels
- Land storage tanks
- Fuel tank for vessels
- Cryostats for LAr TPCs





- Primary membrane: in contact with the liquified gas. Flexible and elastic to accomodate wave impacts, vessel deformation, thermal expansion and contraction. Not self supporting.
- Thermal insulation: passive, in between and directly connected to the primary membrane and the hull.
- Hull: the warm structure, sustains and support the entire system.



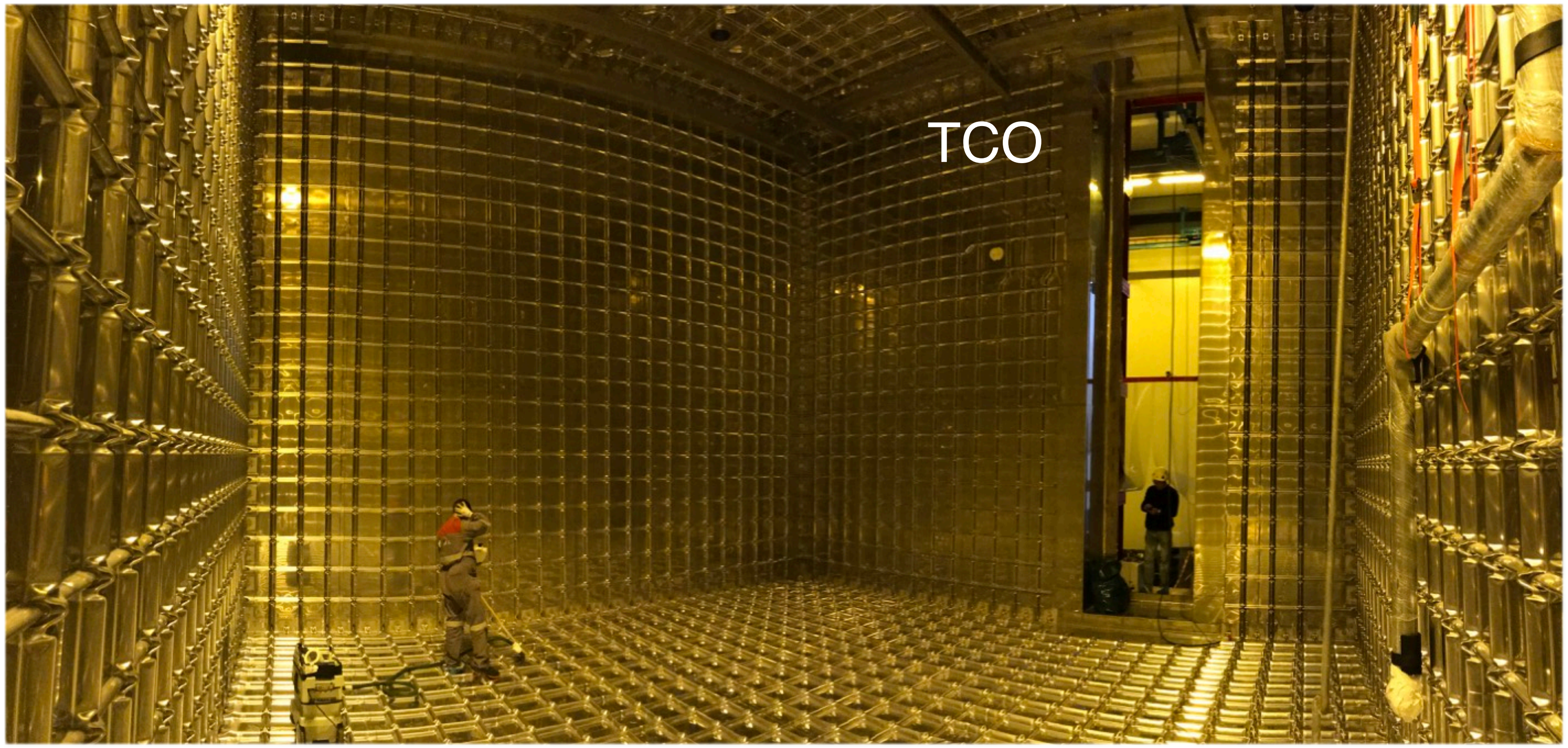

www.gtt.fr

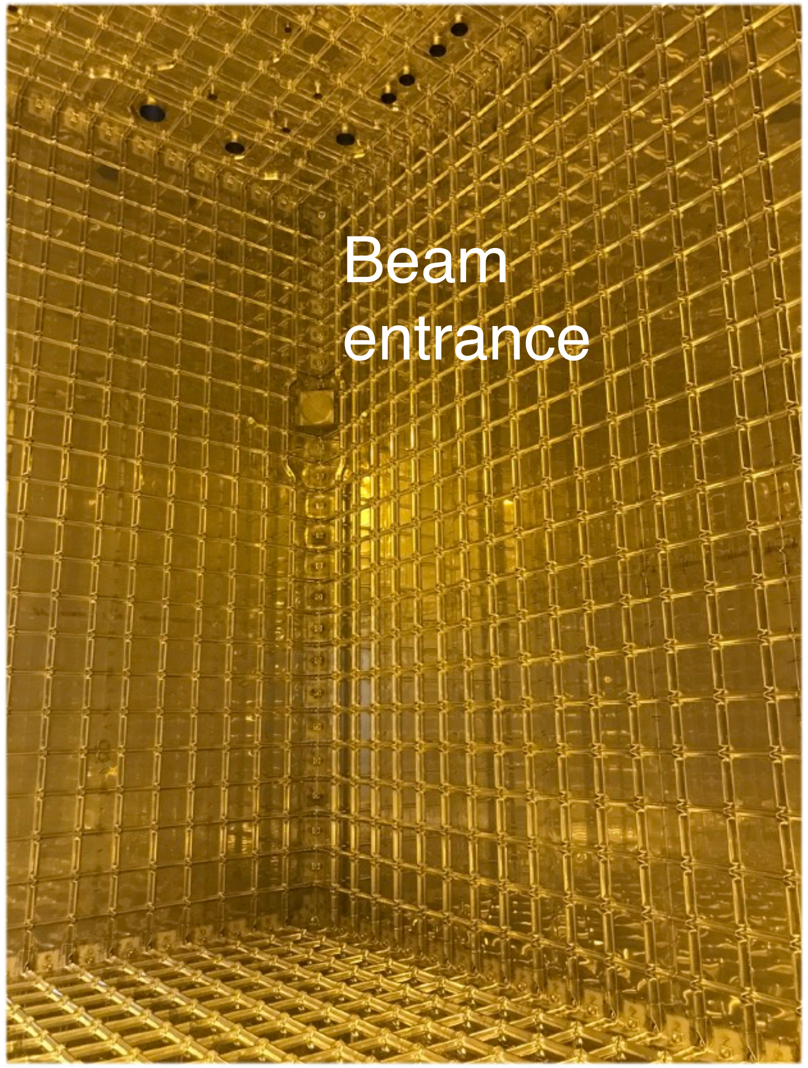
# ProtoDUNE cryostats

Differences with LNG tanks:

- LAr instead of LNG (LAr is denser)
- Smaller (~8x8x8 $m^3$ compared to ~30x30x40 $m^3$)
- No sloshing issues except in case of earthquake (anyway minor waves)
- Several openings - typically on the roof - for feedthroughs, detector support, cryogenic lines, …
- Beam entrance (missing insulation to minimise beam perturbations)
- More stringent requirement on heat input (5-7 $W/m^2$) -> 79 cm thick insulation
- Installation of the detector: activities going on inside the cryostat for months after the cryostat is 'completed'
- Temporary Cryostat Opening (TCO) that is closed at the very end

# ProtoDUNE features




Roof openings (from inside)

Roof openings (from outside)

# Warm structure

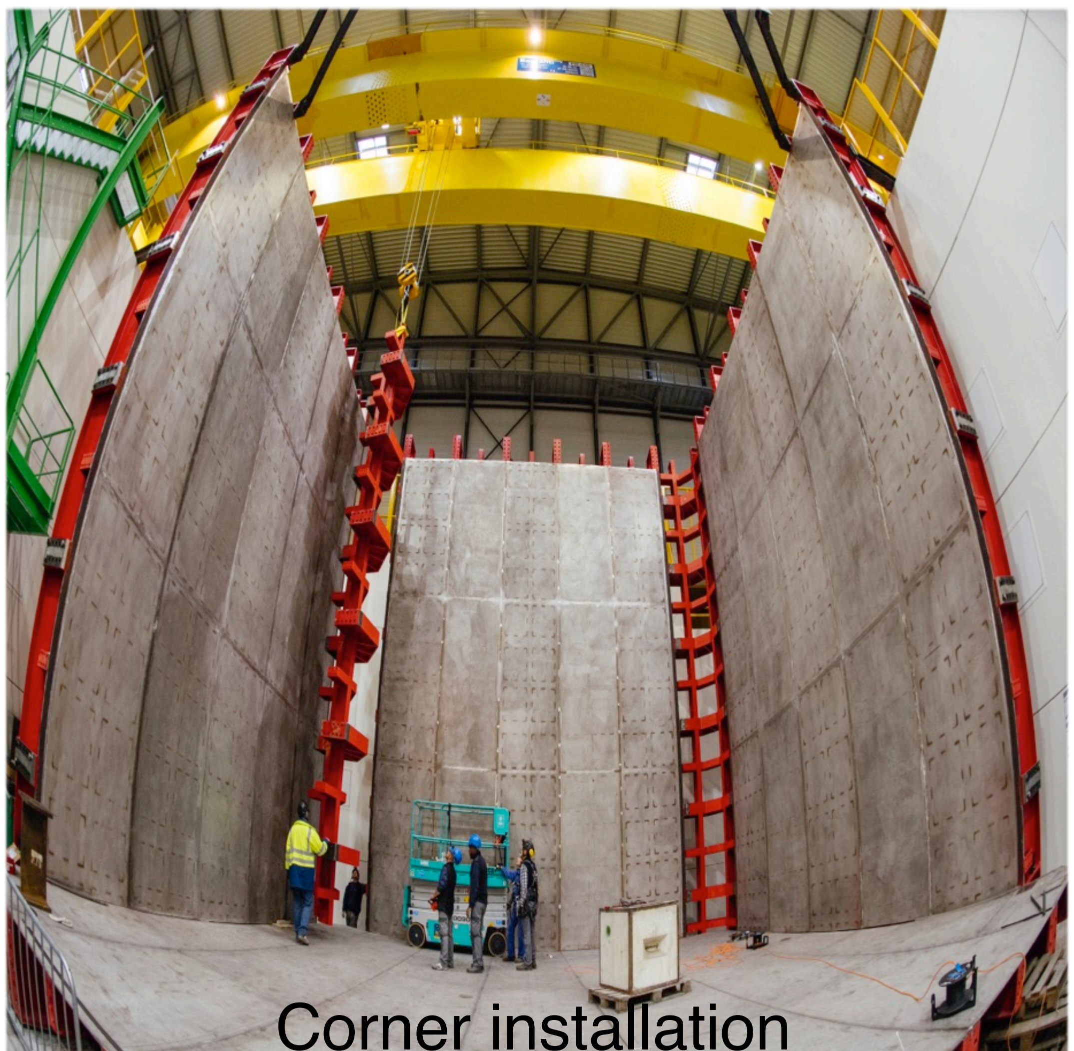
About 250 ton of steel in total
Support structure: carbon steel IPE600 1.6 m pitch interleaved with IPE240
Warm skin: 10 mm think stainless steel 304L (gas tight welded)
Rated for: weight of the detector + weight of LAr + 350 mbar overpressure

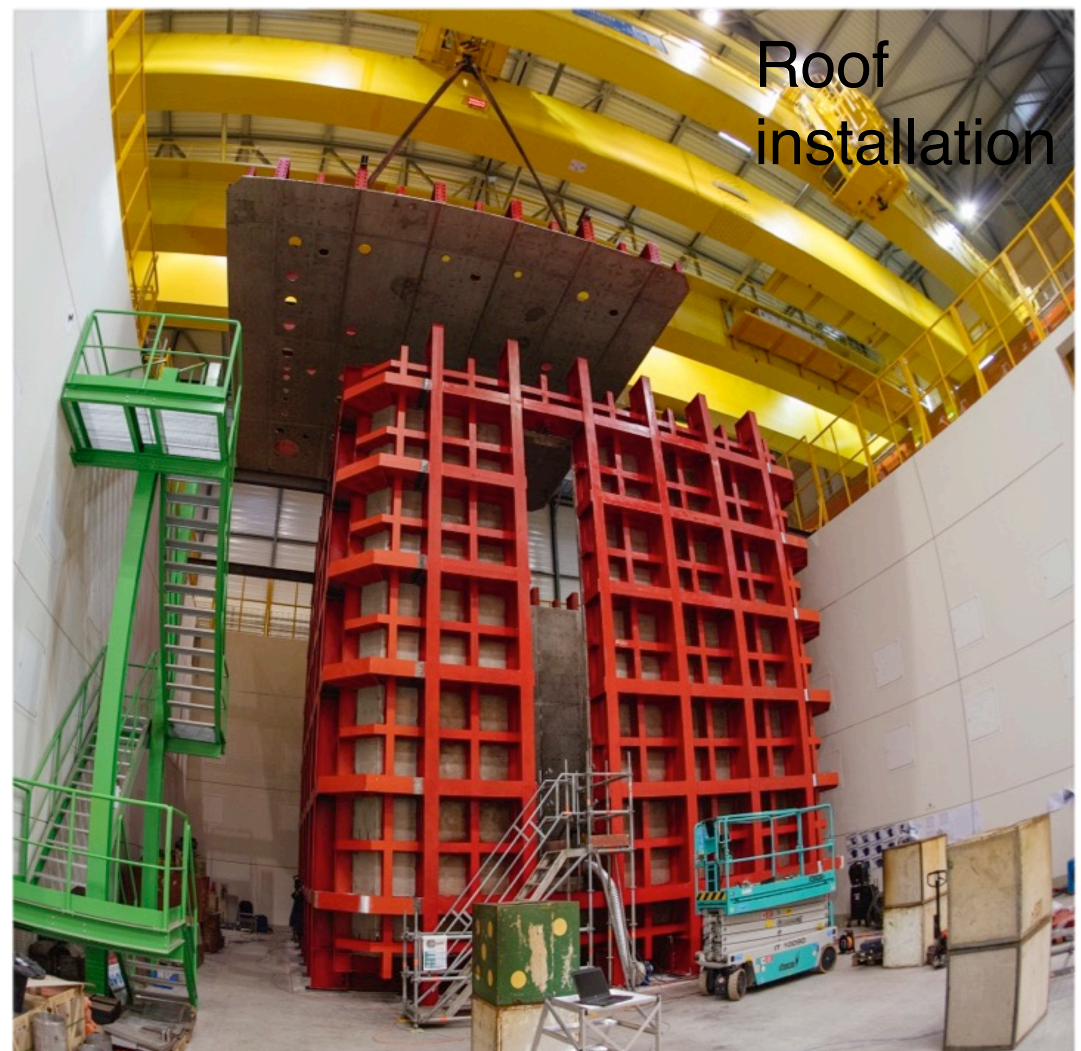
NP04: started 15 August 2016 finished 7 January 2017 -> 21 weeks
NP02: started 7 January 2017 finished 13 March 2017 -> 9 weeks
Manpower: 10 Technicians, 9 welders and 4 crane drivers


Components
welding


Floor preparation


Wall
handling


Corner installation


Roof
installation

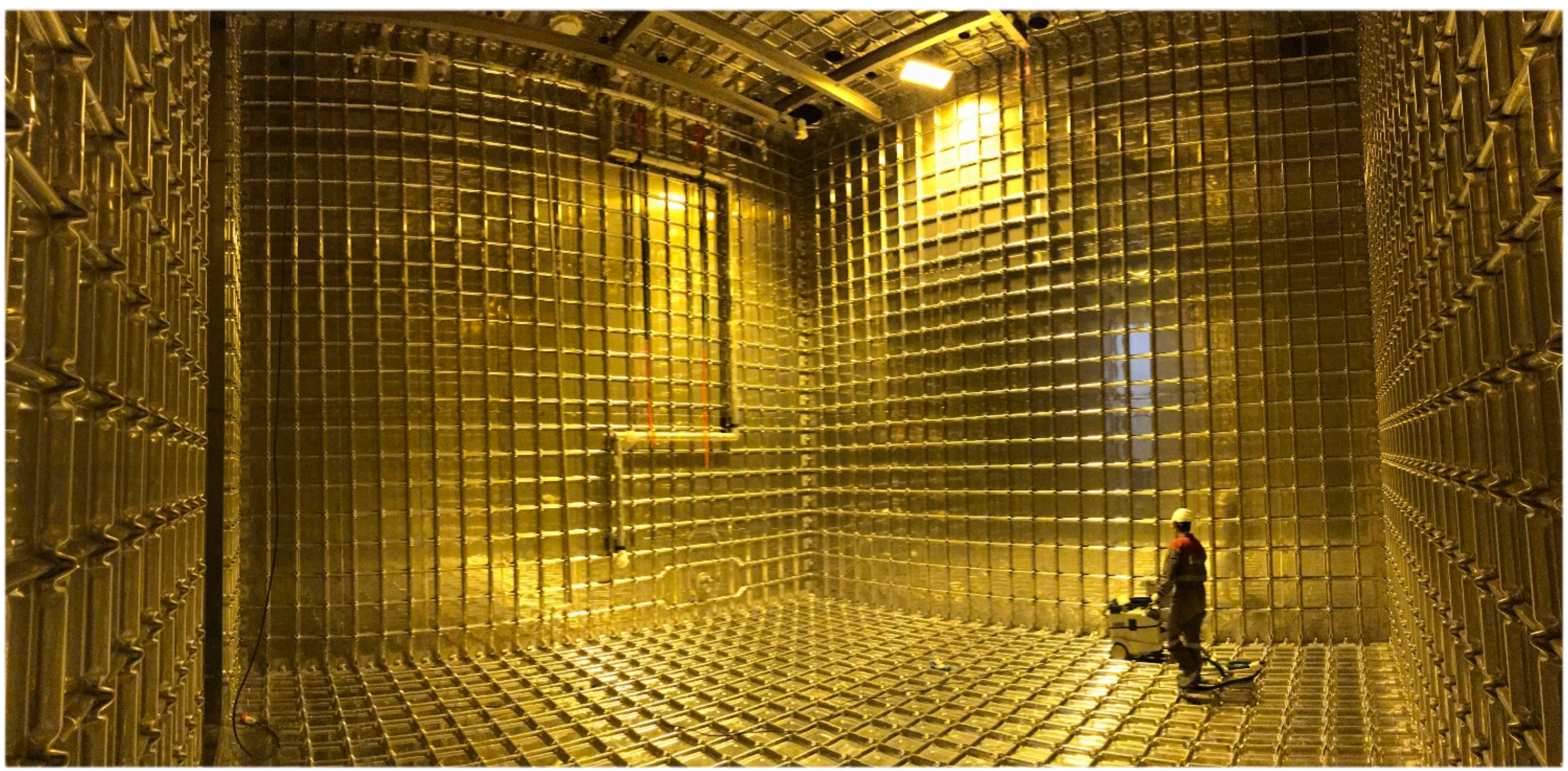

Final welding

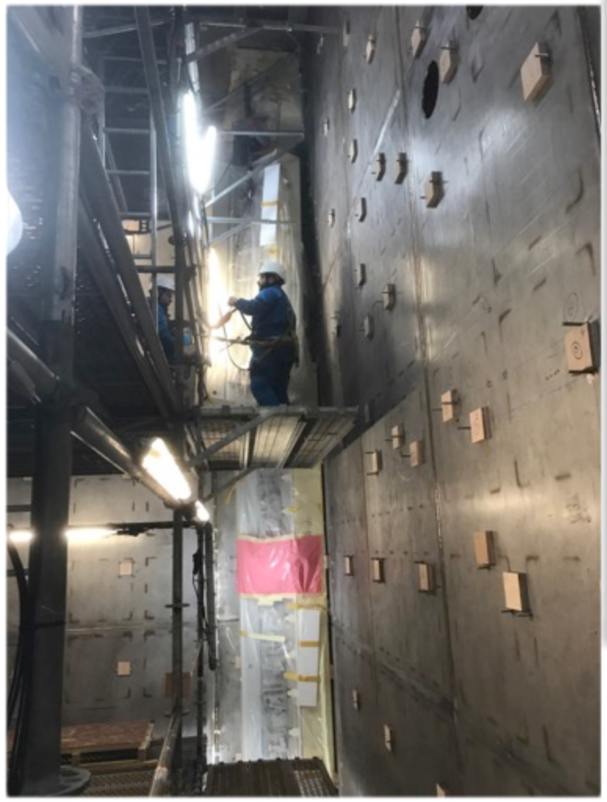
# Insulation and membrane

Up to about 60 workers (engineers, carpenters, welders, foreman, technicians, scaffolders):
- Gabadi for construction work, welding, and management
- GTT for quality control and supervision

NP04 (handover on 7th January)
start date 9th of January
last welding 1 September (34 weeks)
Scaffolding removal 11 October

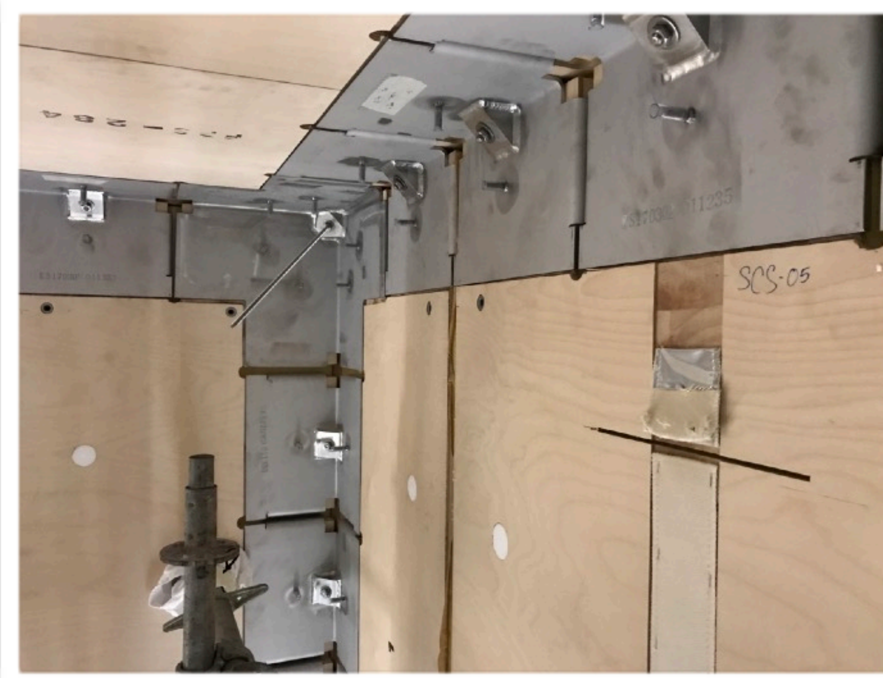
NP02 (handover on 13th March)
start date 13th of March
last welding 22 September (28 weeks)
Scaffolding removal 10 October











SCS-05

# Cryogenics

Internal cryogenics:
- Installation ongoing for NP04
- Imminent completion of NP04 and beginning of NP02

External cryogenics:
- Installation of the mechanical supports completed
- Installation of the cry control electronics ongoing
- Cryo hardware in production (external companies)
- Installation from February 2018

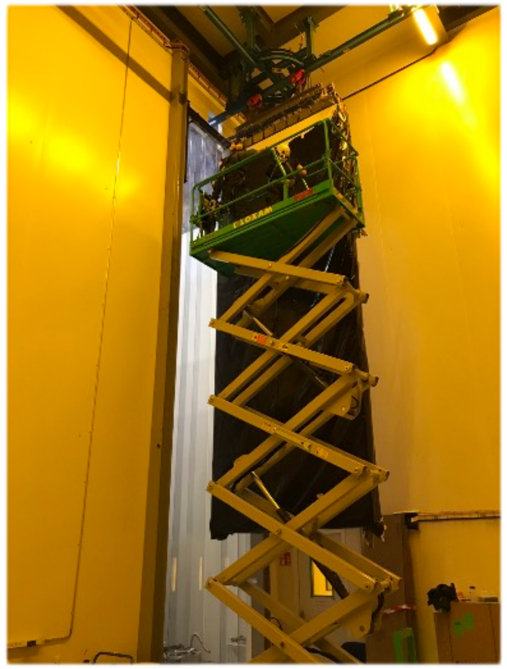
# Cold test box

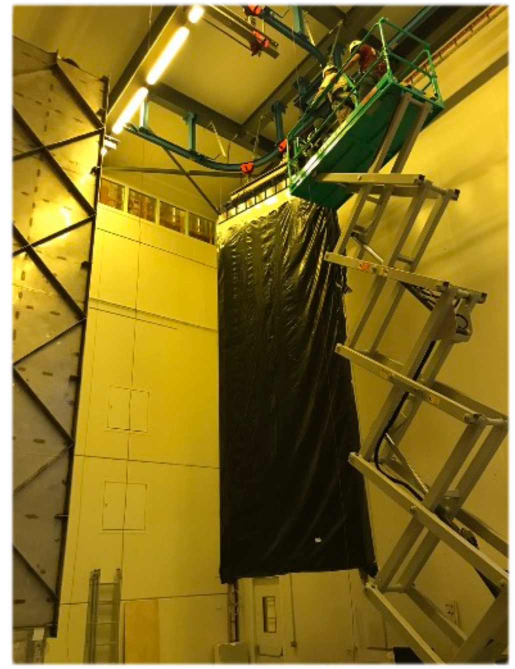
Cryogenic plant next to the NP04 clean room

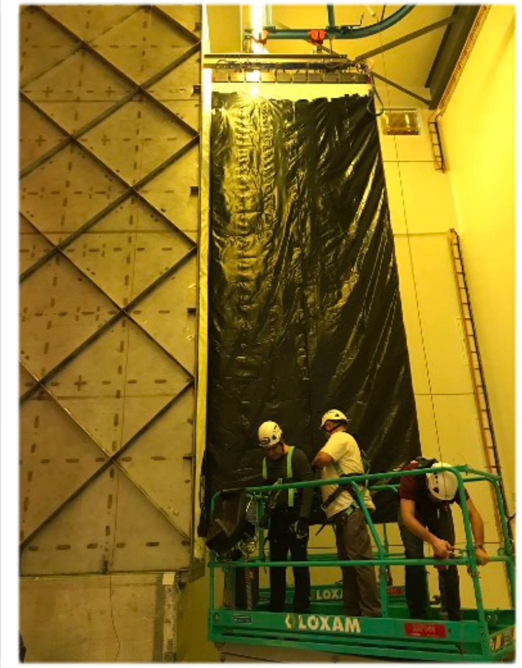
- SS structure with passive thermal insulation
- Installed in the NP04 clean room
- DSS beam to hold the APA
- 7 m tall door gives access to the APA
- Cooled (~150K) flushing cold $GN_2$
- 17 $m^3$ $LN_2$ dewar provides the cold gas
- Cryo-control integrated in the DCS


Cold box open inside the NP04 clean room

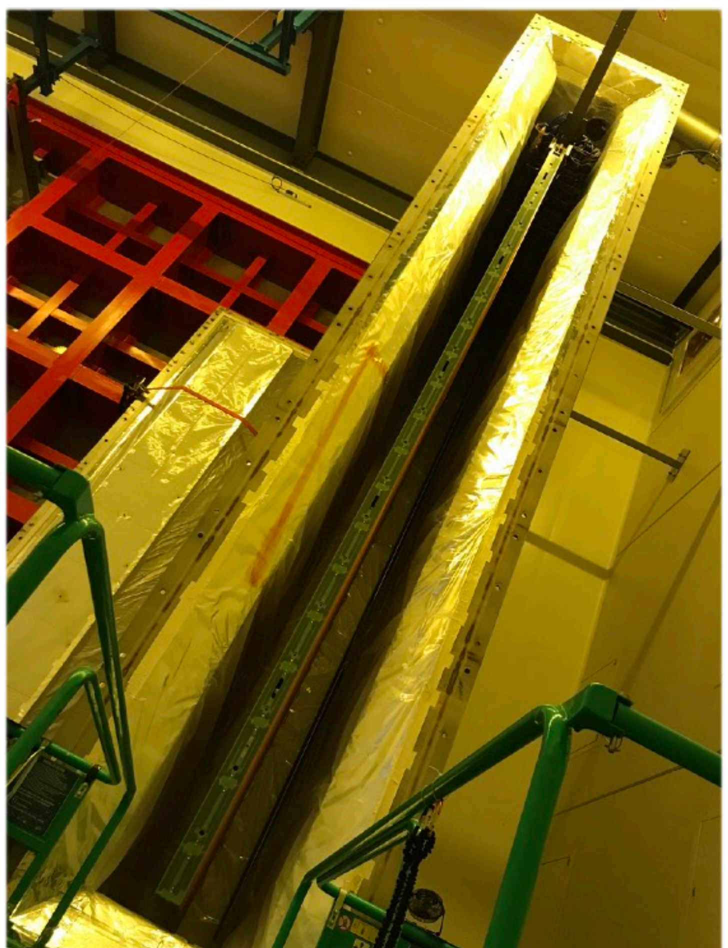
# APA in cold box

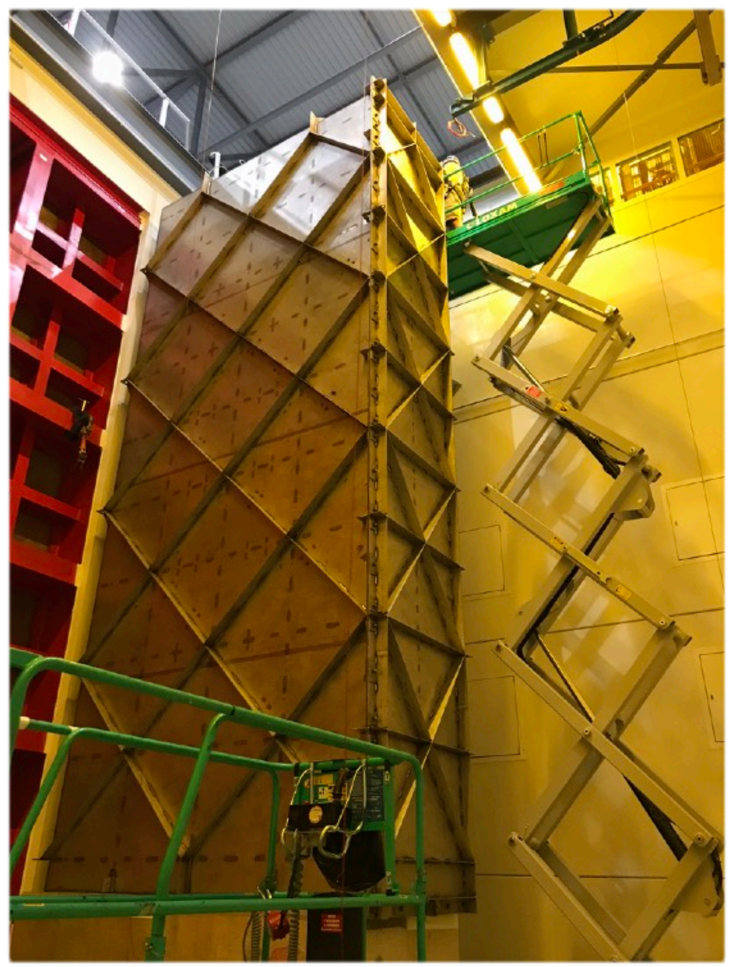












CE/PD electronics connected, setting up the DAQ.

Noise test ongoing at room temperature.

First cool-down of the APA imminent

# Additional activities

Combine **DCS and DAQ**, exporting the Front-End-Link-EXchange (FELIX) technology (à la ATLAS) from collider experiments to neutrino experiments

Online **computing farm**
(more than 1000 cores)
Data storage based on EOS
Tier0 for protoDUNE data

Production of the **field cages** for both NP04 and NP02
**HV systems** (aluminium field shaping rings, resistive cathode, HV feedthrough, …)
Production of the single phase **cathode** system
**Technical infrastructure** (cooling, ventilation, electricity, building, safety, cranes, access, …)
Two new **beam lines** (extension of H2 and H4 beam lines)
Activities in event **reconstruction**, **simulations**, **data analysis** with CERN EP-NU

# CENF-ND Forum

Next generation LBN experiments in preparation, collaboration are defining the design of ND: better control of the systematics -> better sensitivity -> shorter exposure time for physics

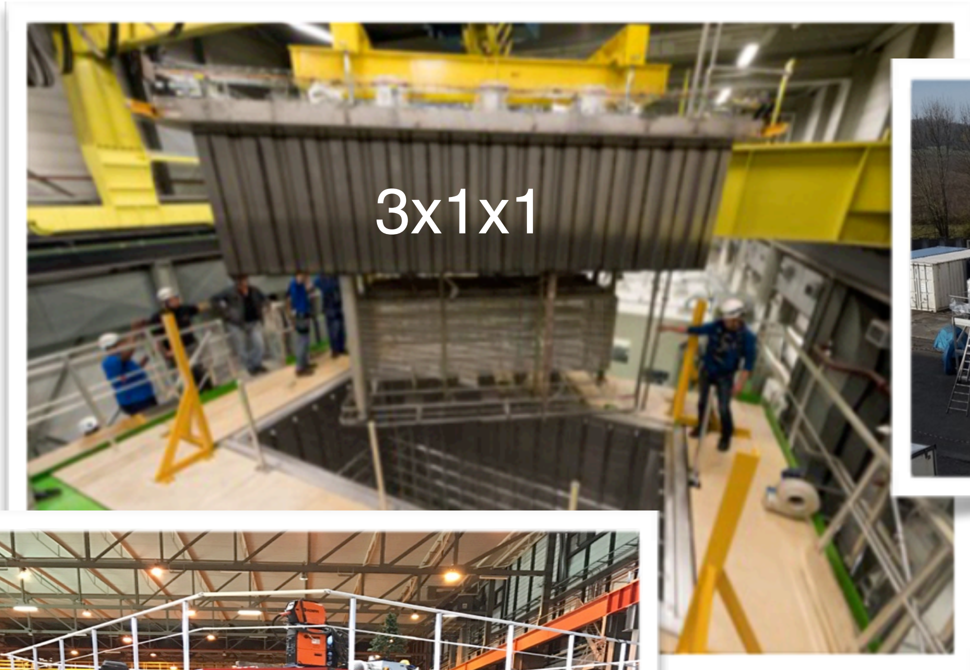
The CENF-ND forum is set to provide **support** to the ongoing efforts of the **DUNE** and **HK** collaborations, strength the European support, attract new institutes, endorse participation from Japanese and American Institutes.

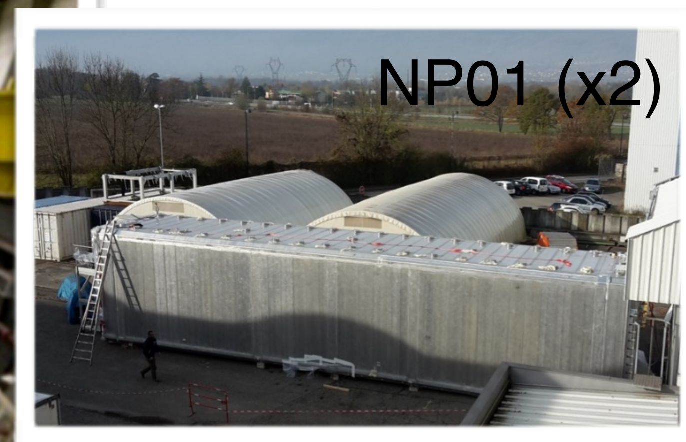
The effort started in July and growing up. 1 steering group and 5 Working Groups
**Steering group**: P. Sala (CERN/INFN-Mi), S. Bordoni (CERN), A. Weber (U. Oxford/RAL), M. Zito (CEA, Paris)
**WG1** - Flux: M. Diwan (BNL), B. Popov (LPNHE, Paris)
**WG2** - Cross-section (TH): M. Martini (CEA,Paris), F. Sanchez (IFAE, Barcelona)
**WG3** - Cross-section (Exp): S. Bolognesi (CEA,Paris), TBD (expected from LAr community)
**WG4** - Sensitivity studies: L. H. Whitehead (CERN), D. Meloni (Roma 3)
**WG5** - R&D: E. Radicioni (INFN-Ba), T. Lux (IFAE, Barcelona)

Convenors from both T2K and DUNE and in connection with NA61/SHINE and NuSTEC
Each WG should:
- determine a **priority list** of topics of general interest for the LBN community
- **ideas** on possible R&D of broad applications (gas systems, cosmic veto, …) -> link to NP
- deliverables set of both short term scale (1 year) and longer term (activities supporting all-life long LBN experiment)
- Vidyo meetings, visiting and Workshop at CERN are being organised

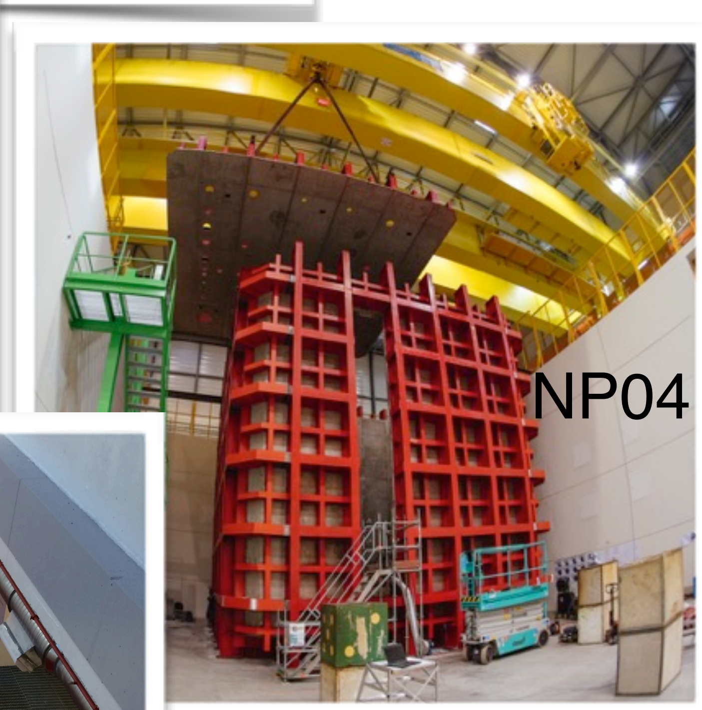
https://twiki.cern.ch/twiki/bin/view/CENF/NearDetector

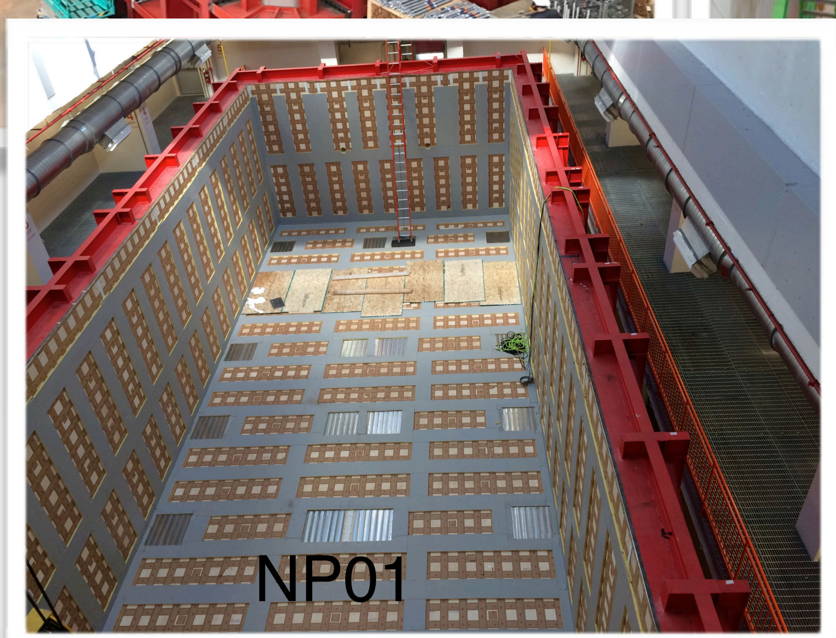
# Recap on cryostats



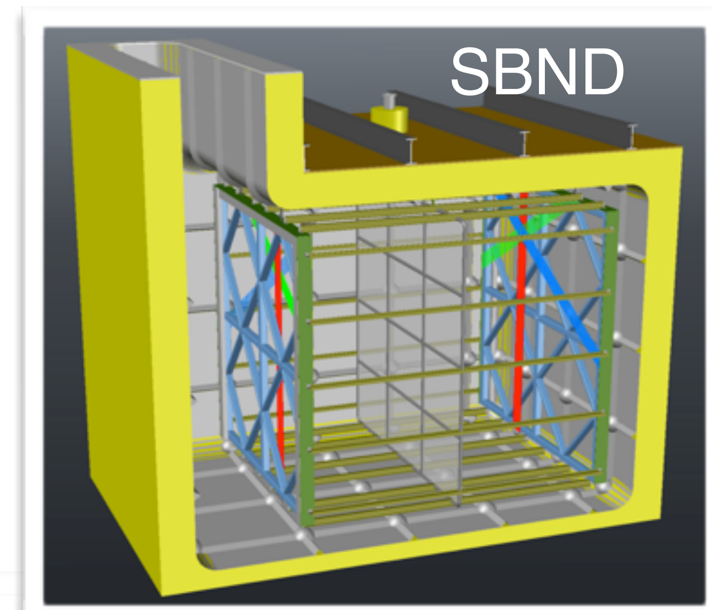



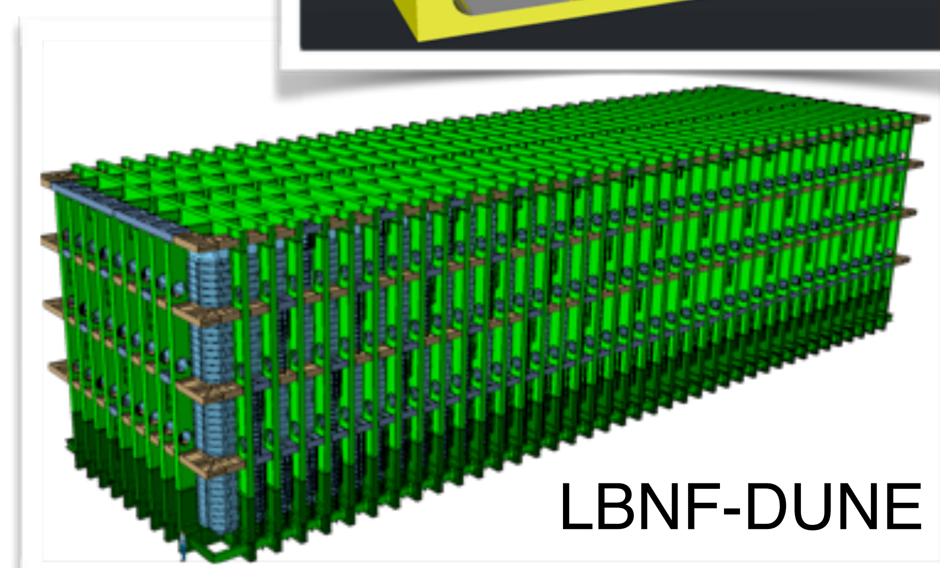





Design phase



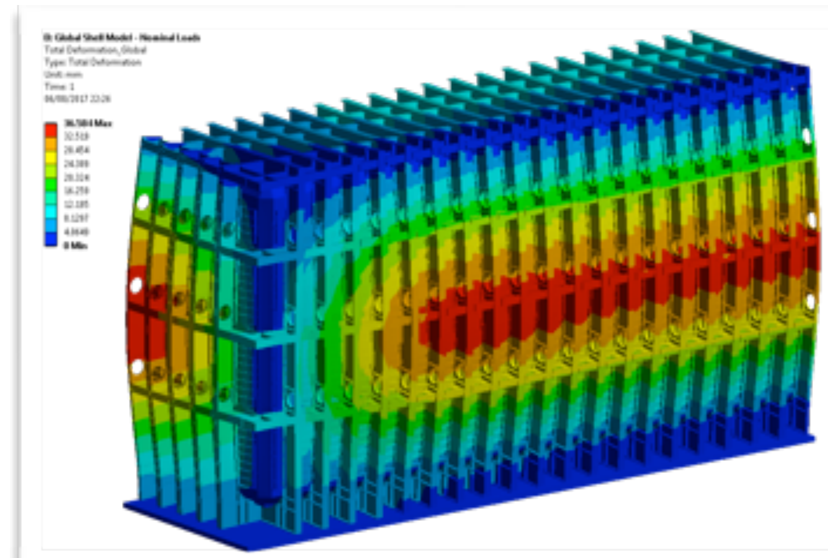



# LBNF-DUNE

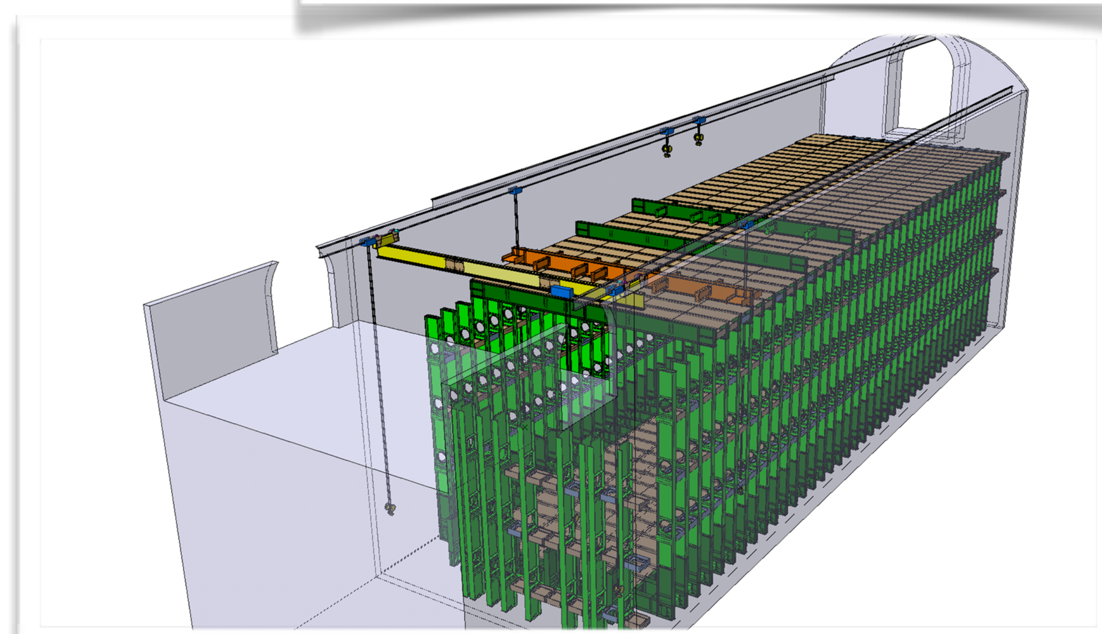
Warm structure final review done and ok:
- Final warm structure design
- Drawings and models repository
- Detailed structural analysis
- Plans for destructive tests and QA
- Analysis of installations scenarios
- Requirements on tools and infrastructure
- Requirements on host lab responsibilities
- Access, safety and construction codes aspects

Warm structure Final Design review at SURF on 21-22 August 2017

https://web.fnal.gov/project/LBNF/ReviewsAndAssessments/LBNF%20Cryostat%201%20Steel%20Structure%20(Warm%20Structure)%20Final%20Design%20Review/SitePages/Home.aspx



CERN approved to issue a Design Contract with GTT
Contract should be ready before end of 2017.
Design work in 2018 with following deliverables:
- Cold vessel final design
- Table of materials to be ordered
- Detailed installation procedure
- Structural and thermal analysis
- QA plans
- List of firms to be contracted for the execution
- Overall schedule compatible with start of installation at SURF in 2021



# Conclusions

The CERN Neutrino Platform is very active on several fronts.

NP offers to the neutrino community support for detector R&D, tests and construction for both US and Japanese activities.

At EHN1 extension two LAr TPC prototypes for LBNF-DUNE will be operated on a charge particle test beam starting from next year.

NP is involved in installation and commissioning of LAr detectors in Europe and in US.

NP has major responsibility towards cryostats. The first LBNF cryostat should be ready for installation by end of 2020.

CERN is also strongly committed to the FNAL short baseline program.

More activities to assist DUNE and T2K/HK in the definition of their future near detector are being planned.