The Research Activities within CERN Neutrino Platform

Umut KOSE

CERN EP-NU, INFN Bologna

Vulcano Workshop 2018 - Frontier Objects in Astrophysics and Particle Physics

CERN & Neutrinos

Long tradition and rich history of research in neutrino physics

Neutrino beamlines:

	PS (CERN)				SPS (CERN)			
Date	1963	1969	1972	1983	1977	1977	1995	2006
Proton Kinetic Energy (GeV)	20.6	20.6	26	19	350	350 WANF	450	400 CNGS
$\langle E_\nu \rangle$ (GeV)	1.5	1.5	1.5	1	50,150†	20	24.3	17
Experiments	HLBC, Spark Ch.	HLBC, Spark Ch.	GGM, Aachen-Padova	CDHS, CHARM	CDHS, CHARM, BEBC	GGM,CDHS, CHARM, BEBC	NOMAD, CHORUS	OPERA, INCARUS

PDG 2012

Neutrino experiments:

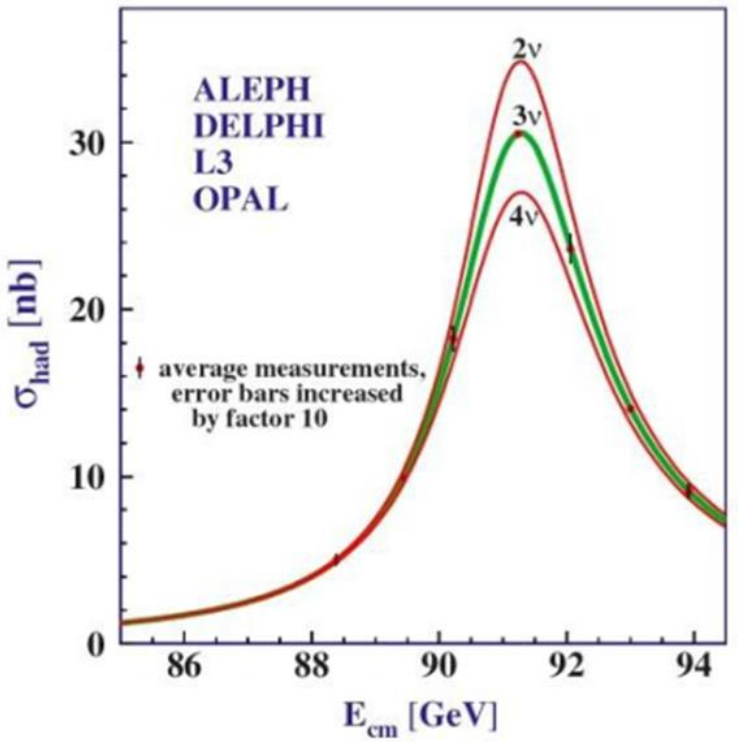
Gargamelle, 1970 – 1979 — **Discovery of neutral current interactions**

BEBC, 1973 – 1984,
CDHS, 1976 – 1984 ,
CHARM I & II, 1979 -1989 — **Deep inelastic neutrino interactions**

CHORUS, 1994 – 1997
NOMAD, 1995 – 1998 — **Short Baseline $\nu_\mu \rightarrow \nu_\tau$ oscillations**

ICARUS, 2009 – 2012
OPERA, 2008 – 2012 — **Long Baseline $\nu_\mu \rightarrow \nu_\tau$ oscillations**

From the width of Z boson



Indirect measurement of N_ν in LEP,1989

$N_\nu = 2.9840 \pm 0.0082$

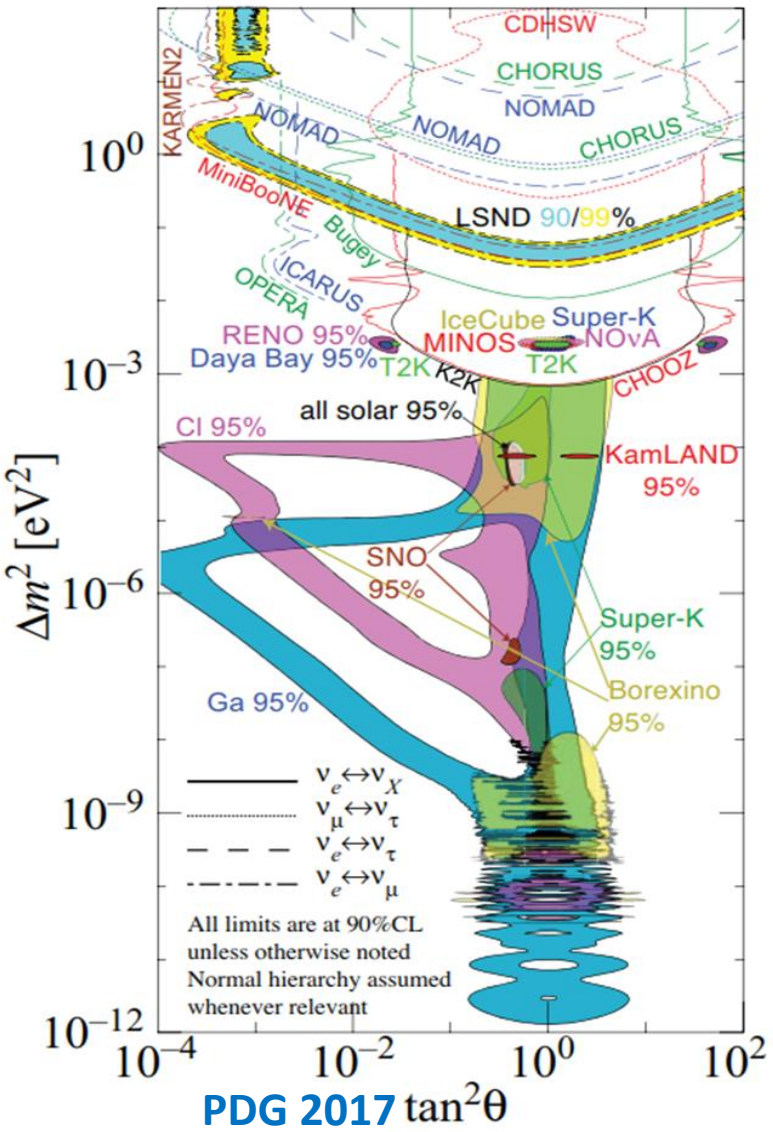
Neutrino Oscillations

Massive neutrinos: $\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix} = U_{PMNS}\begin{pmatrix}\nu_1\\ \nu_2\\ \nu_3\end{pmatrix}$

$$U_{PMNS} = \begin{pmatrix}1 & 0 & 0\\ 0 & cos\theta_{23} & sin\theta_{23}\\ 0 & -sin\theta_{23} & cos\theta_{23}\end{pmatrix}\begin{pmatrix}cos\theta_{13} & 0 & e^{-\delta_{CP}}sin\theta_{13}\\ 0 & 1 & 0\\ -e^{\delta_{CP}}sin\theta_{13} & 0 & cos\theta_{13}\end{pmatrix}\begin{pmatrix}cos\theta_{12} & sin\theta_{12} & 0\\ -sin\theta_{12} & cos\theta_{12} & 0\\ 0 & 0 & 1\end{pmatrix}$$

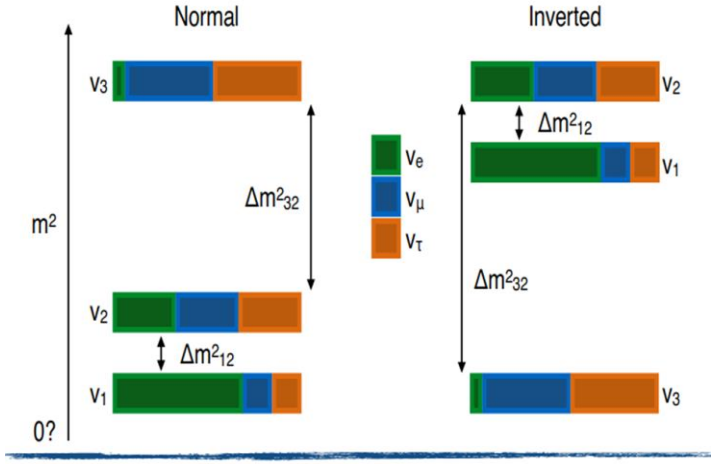
Oscillation parameters

- 3 mixing angles: θ_{12}, θ_{23}, θ_{13}
- 1 CPV Dirac Phase: δ_{CP}
- 2 independent $\Delta m^2_{kj} \equiv m^2_k - m^2_j$, Δm^2_{21}, Δm^2_{31}



PDG 2017

Parameter	best-fit	3σ
Δm^2_{21} [10^{-5} eV^2]	7.37	6.93 – 7.96
$\Delta m^2_{31(23)}$ [10^{-3} eV^2]	2.56 (2.54)	2.45 – 2.69 (2.42 – 2.66)
$\sin^2\theta_{12}$	0.297	0.250 – 0.354
$\sin^2\theta_{23}$, $\Delta m^2_{31(32)} > 0$	0.425	0.381 – 0.615
$\sin^2\theta_{23}$, $\Delta m^2_{32(31)} < 0$	0.589	0.384 – 0.636
$\sin^2\theta_{13}$, $\Delta m^2_{31(32)} > 0$	0.0215	0.0190 – 0.0240
$\sin^2\theta_{13}$, $\Delta m^2_{32(31)} < 0$	0.0216	0.0190 – 0.0242
δ/π	1.38 (1.31)	2σ: (1.0 - 1.9) (2σ: (0.92-1.88))



Worldwide experimental effort to measure the unknowns:

The value of δ_{CP}?
Mass hierarchy?

Absolute neutrino masses?
Dirac or Majorana?

Sterile neutrino states?

Long baseline ν-oscillation

Short baseline ν-oscillation

What is “CERN Neutrino Platform”?

European Strategy in Particle Physics, 2013: Long baseline neutrino program as one of the four scientific objectives

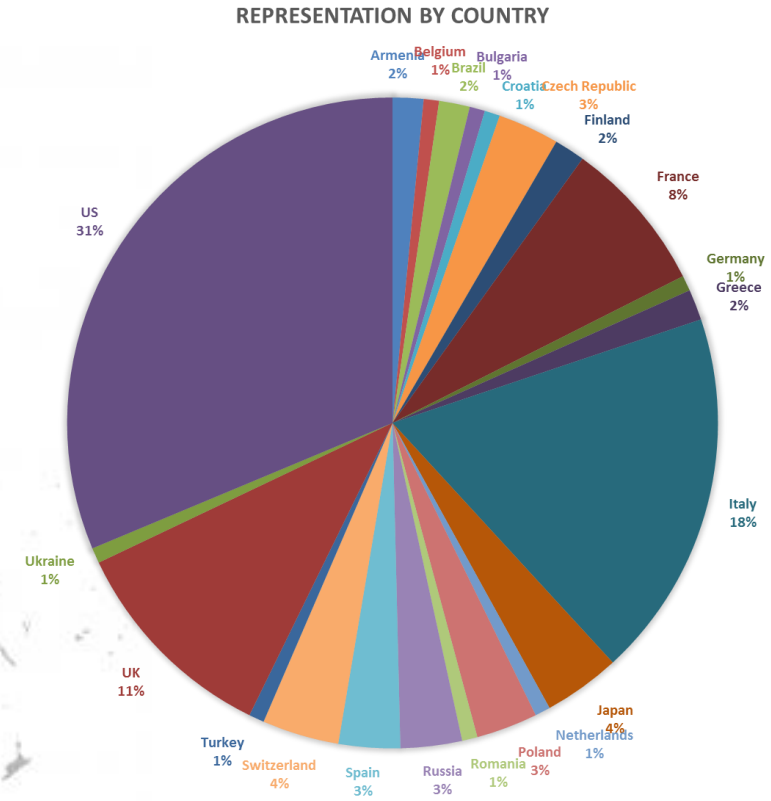
“Rapid progress in neutrino oscillation physics, with significant European involvement, has established a strong scientific case for a long-baseline neutrino programme exploring CP violation and the mass hierarchy in the neutrino sector. CERN should develop a neutrino programme to pave the way for a 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.”

- ***CERN announced in APPEC Paris meeting in 2014 that it will freeze all types of neutrino beam at CERN in favour of world wide activities (US/Japan)***
- ***CERN support European activities towards future short and long baseline experiments in US and Japan***
- ***CERN’s role in all of this:***
    - ***As a support structure for all these activities, where CERN expertise can be a VALUE***
    - ***As a support Laboratory for all European Groups interested in a collaborative effort***
    - ***As a unique R&D and test facility of detectors and components (hardware and software)***
    - ***As a research group active at these facilities and later on physics experiments***

The establishment of the CERN Neutrino Platform part of CERN Middle term plan since 2015.

CERN ν Platform: today

- **Platform organized via an Memorandum of Understanding (MoU) system**
- **CERN Neutrino Platform reacts an input from the community**
- **131 institutes from 22 countries signed the MoU CERN SPS Committee (SPSC) as an entry point for providing a framework for developing a Neutrino Program at CERN.**



CENF: http://cenf.web.cern.ch

MoU: PLAFOND https://edms.cern.ch/document/1353815

In close collaboration with:

✓ CERN Neutrino Platform theory group (CENF-TH)

- https://th-dep.web.cern.ch/neutrino-platform-theory
- **contributes to this activity by supporting an associated activity in theoretical neutrino physics.**
- **strengthening the connections between CERN and the worldwide community in neutrino physics,**
- **promoting research in theoretical neutrino physics at CERN**

✓ CERN EP Neutrino group (CERN EP-NU) (established October 1 2016)

- https://ep-dep.web.cern.ch/organisation/nu
- **focal point for the activities for the neutrino community in Europe**
- **Participate in accelerator-based neutrino projects in Japan and in the US,**
- **Contribute to the analyses of test-beam data from detector prototypes tested at the Neutrino Platform**
  - **Data analysis, computing, simulation, reconstruction, beamline optimization, physics analysis, ….**
- **Organize workshops to bring the community together,**

✓ EP–NU group & the neutrino experiments

ProtoDUNEs (CERN), FNAL LBN Program (DUNE), FNAL SBN Program (ICARUS),
T2K upgrade and NA61

The projects at CERN neutrino Platform:

Neutrino PLATFORM

Approved by the SPSC:

NP01 (WA104): ICARUS as far detector for the SBN
NP02 (WA105/ProtoDUNE-DP): demonstrator and engineering prototype for a double-phase LAr TPC
NP03 (Plafond): Generic R&D framework
NP04 (ProtoDUNE-SP): demonstrator and engineering prototype on for a single-phase LAr TPC
NP05 (BabyMIND): Magnetised muon spectrometer for the WAGASCI experiment at T2K

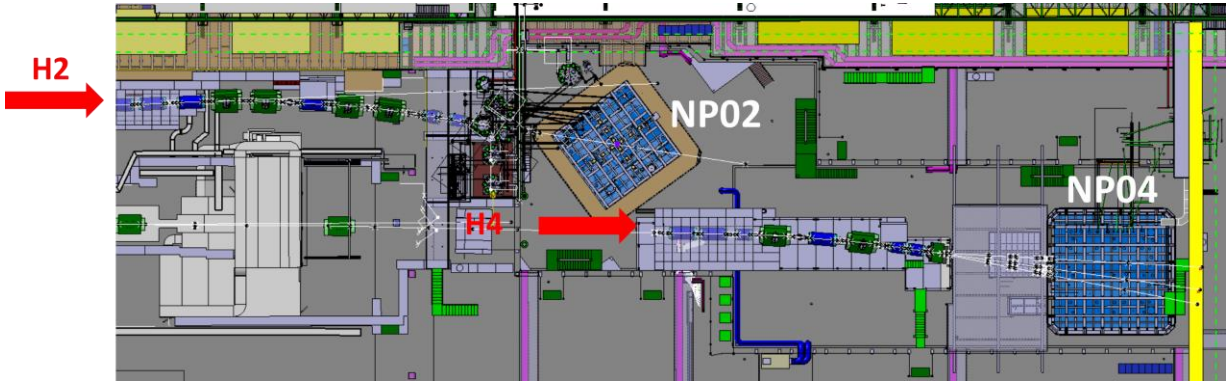
LoI-243 ArgonCube: a modular LAr-TPC R&D
EoI-015 Near Detectors based on gas TPCs for neutrino long baseline experiments

In addition:

- **Near detector studies for T2K and DUNE**
- **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**
- **Dark Matter (LArTPC technology)**
- **More projects in the pipeline**

New experimental area

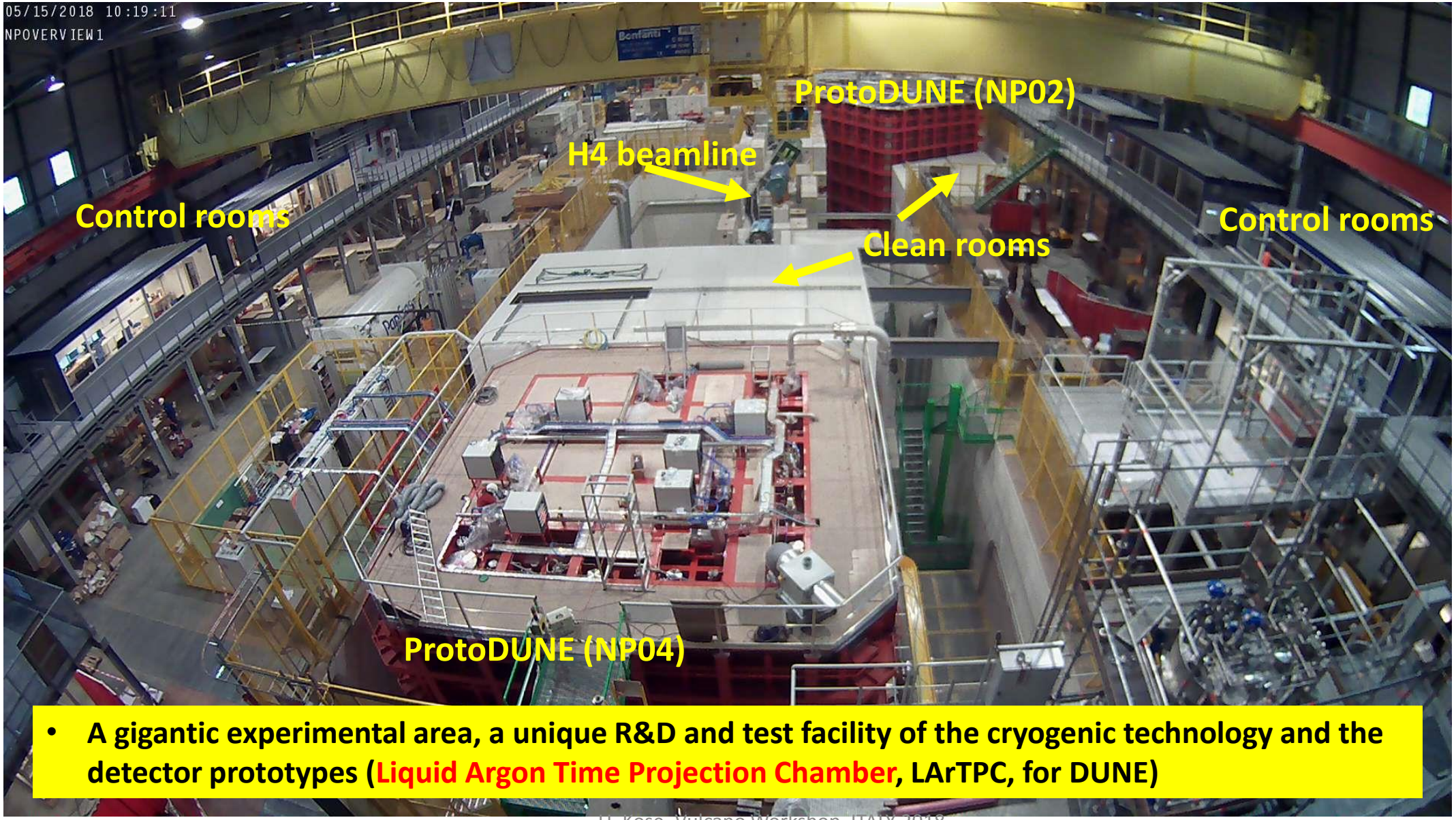
- **Dedicated to Neutrino Platform (Nord Area extension : EHN1) with charged test beams capabilities.**
- **Designed and contracted in 2014,**
- **Civil engineering construction started in January 2015,**
- **Completed on September 2016**



Beam lines H2/H4-VLE (Very Low Energy Extension) for the NP02/NP04 experiments

*** Charged particle beams (pions, kaons, protons, muons, electrons), positive and negative sign,**
*** Particle momentum in the range of sub-GeV to several GeV/c, H2/H4-VLE: 0.5-10 GeV/c**

As of today : http://cenf-ehn1-np.web.cern.ch



- A gigantic experimental area, a unique R&D and test facility of the cryogenic technology and the detector prototypes (Liquid Argon Time Projection Chamber, LArTPC, for DUNE)

Liquid Argon technology

***LAr TPC** is the leading technology for future short/long-baseline accelerator **neutrino oscillation experiments** and an excellent candidate for the next generation of **dark matter search experiments**.*

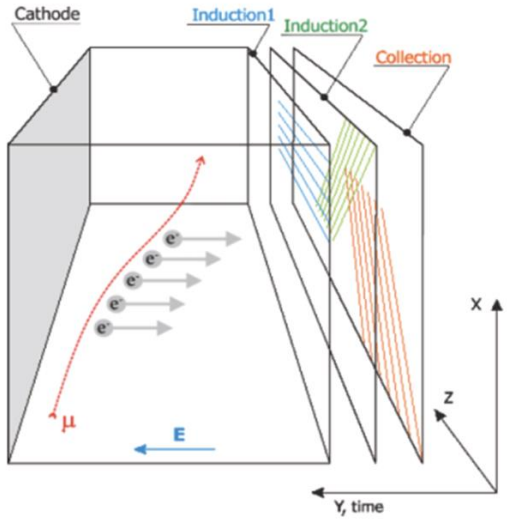
The LAr TPC technology provides:

- excellent 3D imaging capabilities
- excellent energy measurement capability
- totally active calorimeter
- particle ID by dE/dx, range, event topology, …
- scalability to large detectors
- high signal efficiency and background discrimination

Requirements:

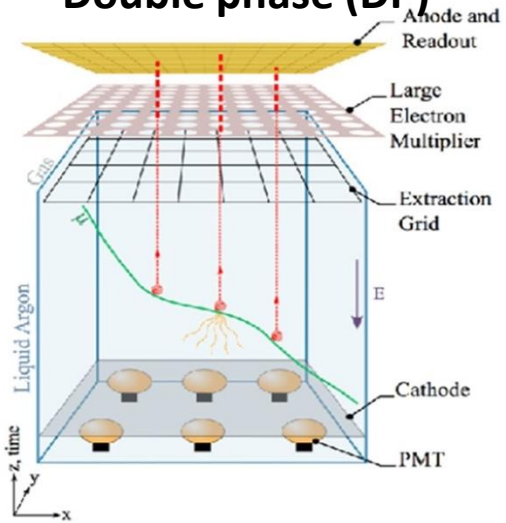
- Large cryogenic vessels (~ktons)
- Liquid purification (at ppt level)
- High voltage system (500V/cm)
- Electronic and DAQ
- Scintillation light detection system

Single phase (SP)



The collection and induction wire planes are in the liquid

Double phase (DP)

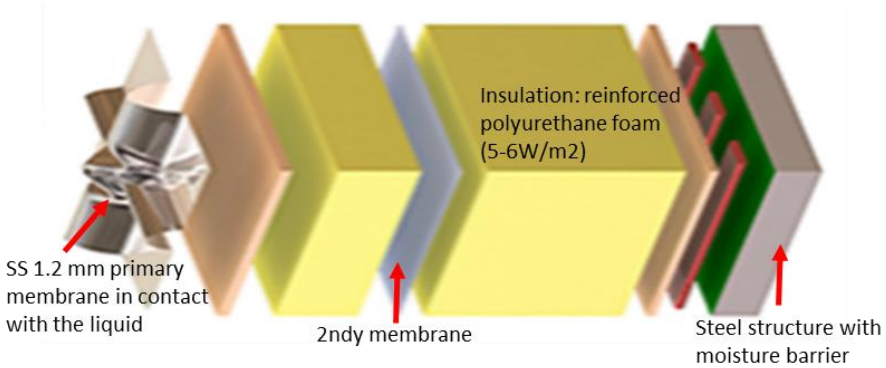


The charge collection anode planes are positioned above the liquid in the Argon gas volume

Cryostats:

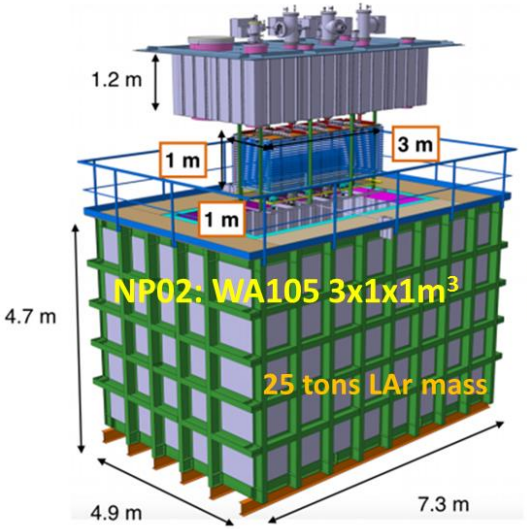
- capable of hosting a new generation of neutrino detectors and a fiducial active detector mass at the level of ktons of LAr.
- thermally and electrically neutral to the external environment
- capable of handling all need services, cryogenics and detector signal penetrations from the outside to the inside of the cold volume
- Scalability to large volumes

Membrane technology: GTT France, LNG industry technology

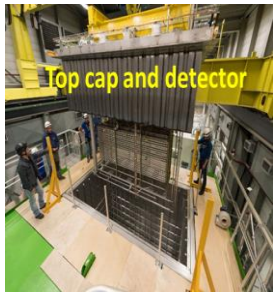


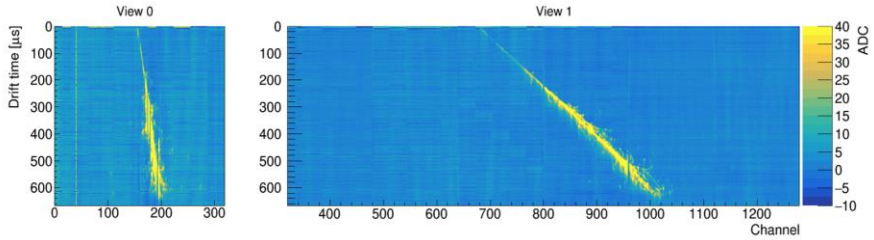
- LNG carriers (>200000 m3 in 5 sub-tanks)
- Floating storages and re-gasification vessels
- Land storage tanks
- Fuel tank for vessels

The same technology is used for ProtoDUNEs as well as SBND, and future DUNE cryostats



NP02 3x1x1 m³



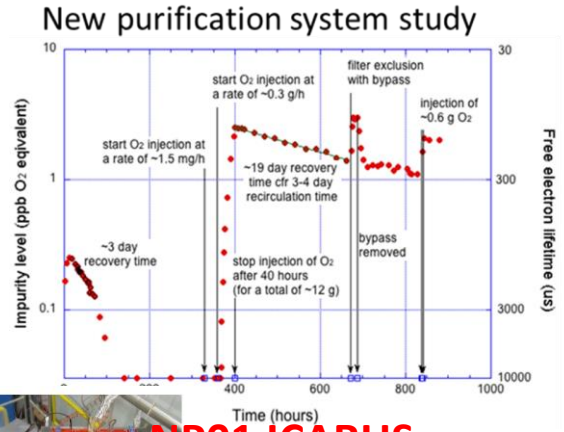


- First prototype of the membrane cryostat, DP tech.
- Detector feasibility and principles
- Engineering design and construction together with cryogenic system,
- Validation for ultrahigh purity environment

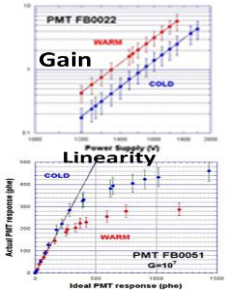
- Excellent performance of liquid argon pump.
- Liquid argon level stable at sub-mm scale
- 350k cosmic events collected
- Stable 500 V/cm drift field over one meter
- First time ever, extraction over 3m² area and LEM amplification demonstrated on the 50x50 cm2, which is the final design for DUNE

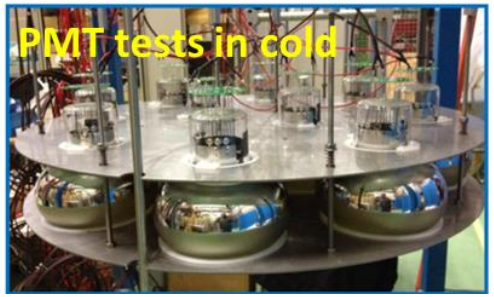
Some activities in LAr

50 liters and 1.5 m^3 LAr chambers is used for testing cold/warm electronics, FEBs, HV feedthroughs, PMT, SiPM performances and study new purification systems.

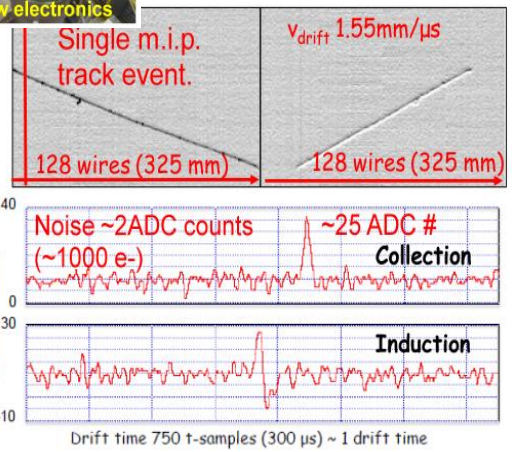


Dedicated DarkRoom in ideasquare

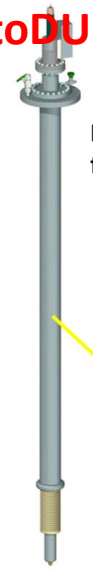




NP01 ICARUS



NP02&NP04 ProtoDUNEs



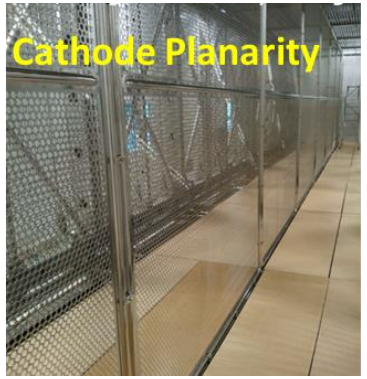
HV feedthrough

- HV steps of ~25 kV,
- Tested up to 293 kV for several hours,
- no sparks in stable LAr conditions
- Tests ongoing.

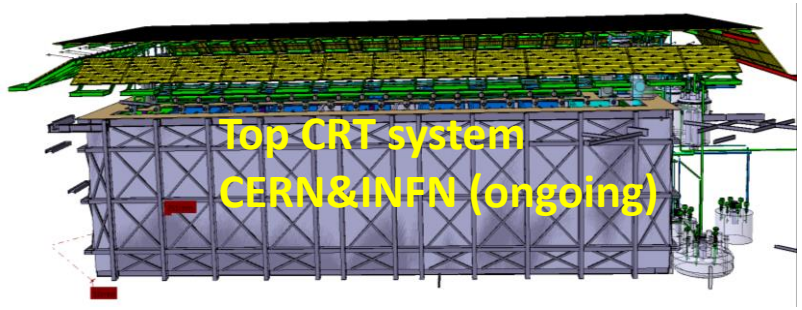
News from project NP01 (WA104):

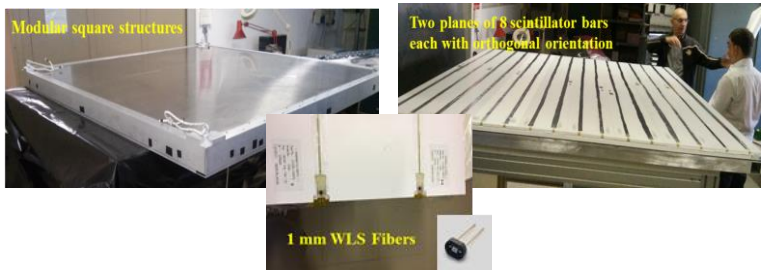
The ICARUS T600 detector, a LAr TPC technology demonstrator, built in 2000 and successfully operated at LNGS on CNGS neutrino beam from 2009 to 2013.

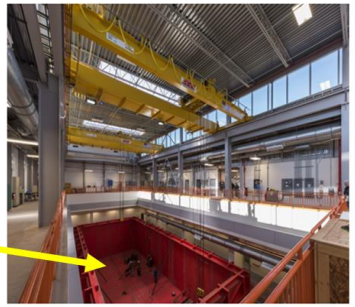
Overhauling of the detector at CERN before shipping to Fermilab as far detector for the SBN program.

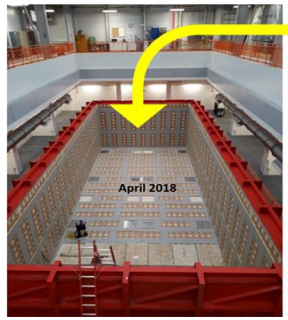


90 PMTs for each wire chamber: 360 in total



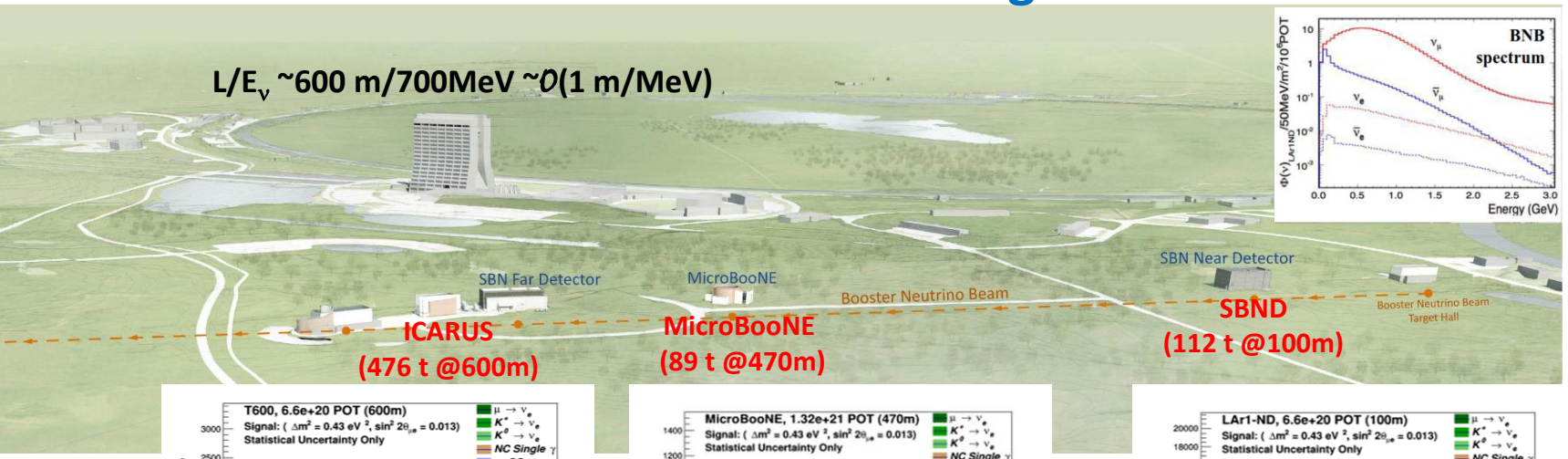


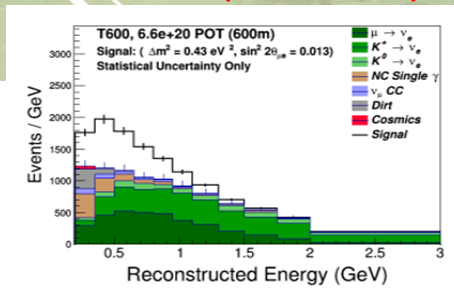


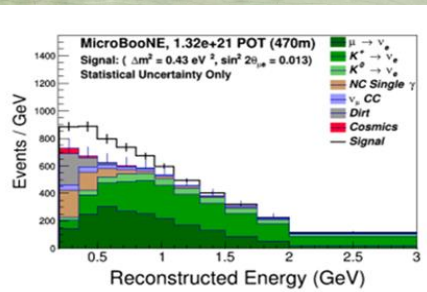


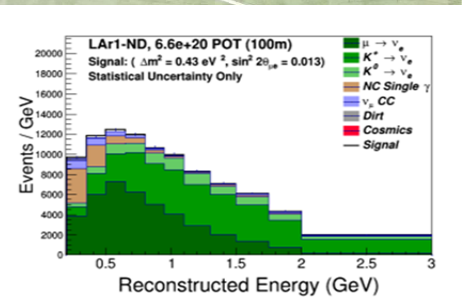
- Warm vessel is constructed at Fermilab by CERN
- Insertion of the two cold cryostat in June 2018
- Construction of the cryogenics by CERN contractors
- Filling with liquid argon in May 2019
- Commissioning the detector in November 2019
- Ready to physics runs

ICARUS at Short Baseline Neutrino Program in Fermilab







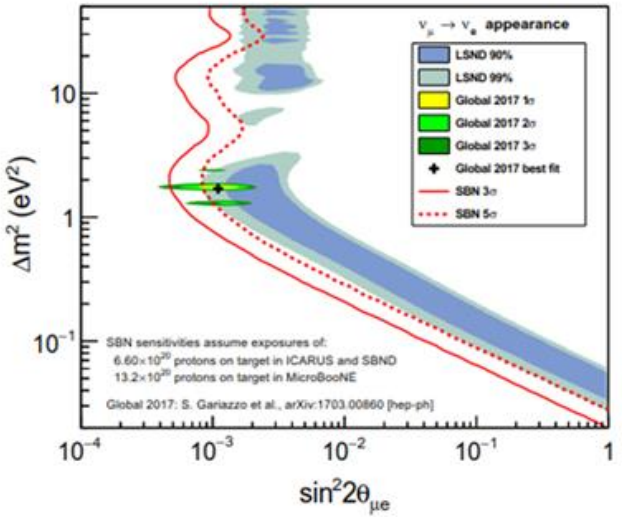


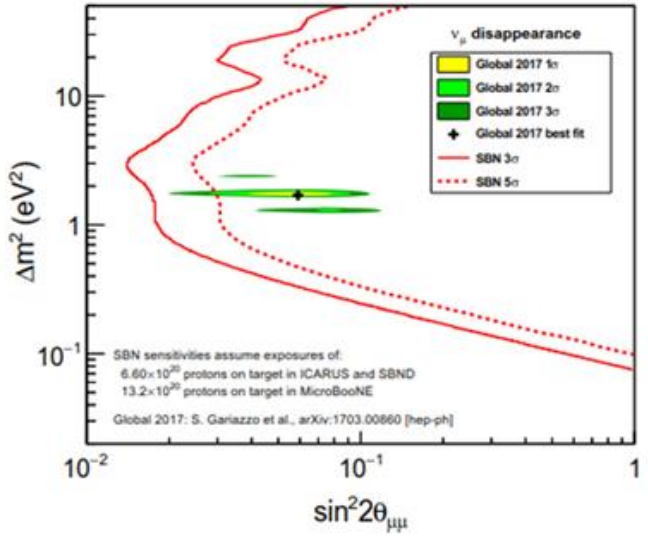
Main physics aims:

- Solving the issue on sterile neutrinos (eV range)
- Neutrino-argon interactions
- Further develop LArTPC technology

- SBN detectors enable 5σ coverage the 99% C.L. allowed region of the LSND signal and global best fit values
- SBN can extend the search for muon neutrino disappearance an order of magnitude beyond the combined analysis of SciBooNE and MiniBooNE

Appearances and disappearances
6.6 10^{20} pot in 3 years

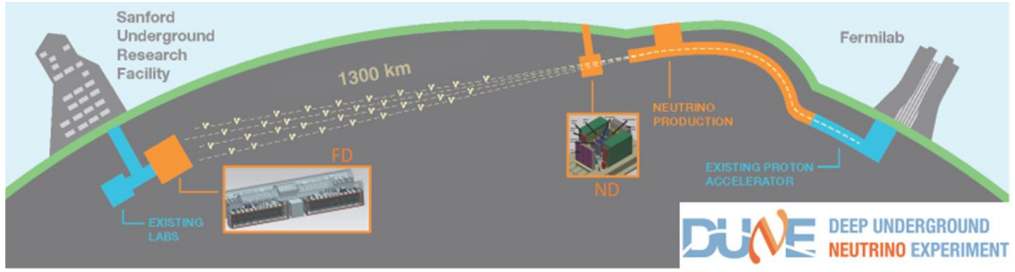




NP02 and NP04: ProtoDUNEs

"large prototypes as demonstrators"

Two prototypes for DUNE far detector with different LArTPC technology: Double Phase (NP02) and Single Phase (NP04)



Detector Engineering:

- Prototype design and engineering for DUNE Far Detector
- full scale detector components: manufacturing methods, installation procedures, operation and performance
  - Field cage, cathode, HV feedthrough, cold electronics
- DAQ strategies, algorithms and data handling

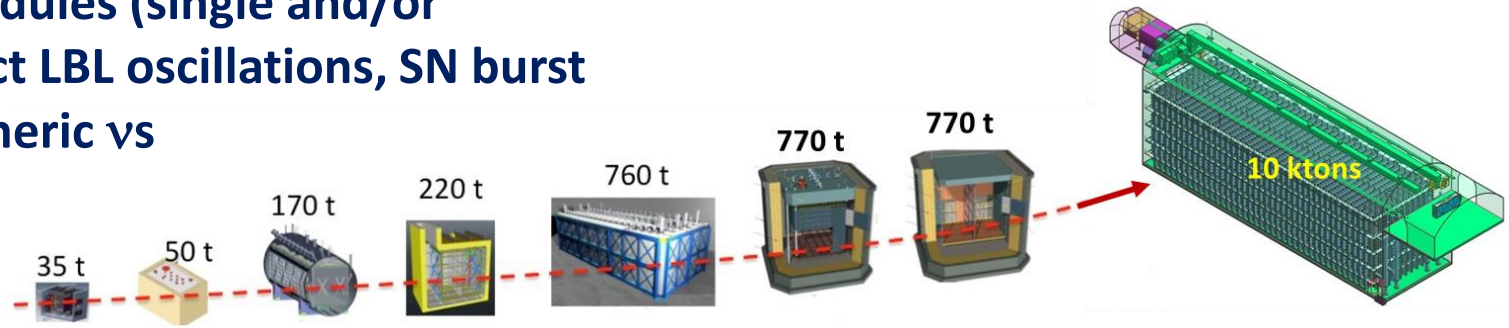
Infrastructure:

- Validation of cryostats solutions and cryogenics systems
- Comparison of single and double phase LAr technologies

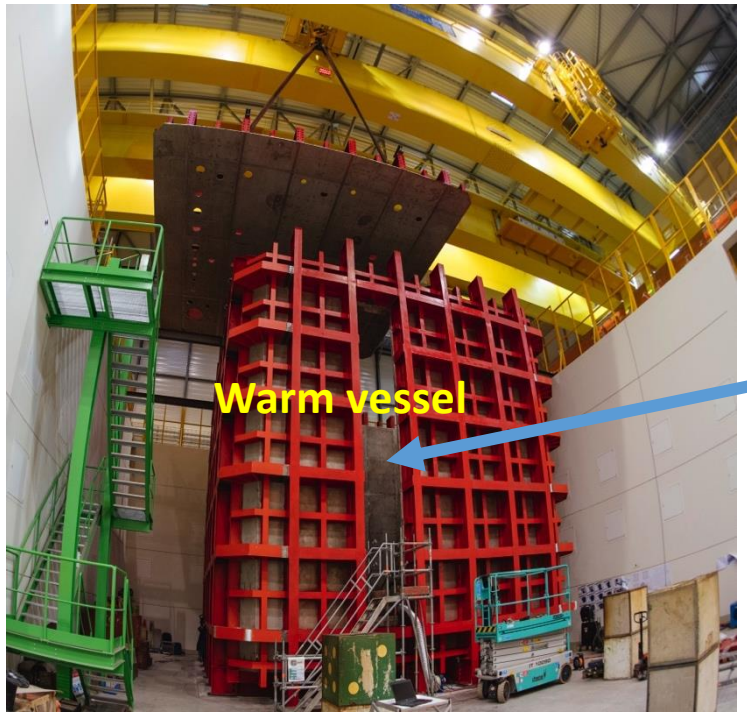
Physics Measurements & detector calibration:

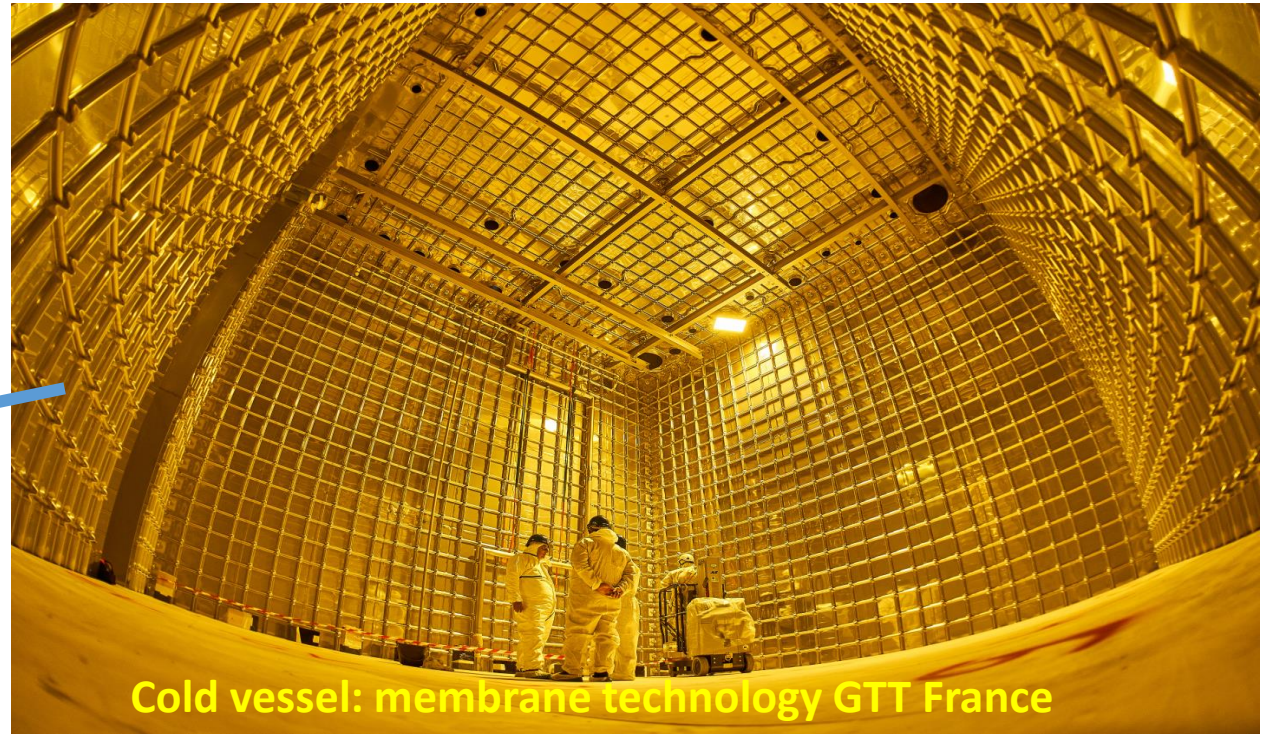
- Exposure to charged particle beam to cover energy range and particle types as expected for DUNE ν interactions
  - 0.5-10 GeV/c mixed hadrons and electrons
- Systematic uncertainties
- Validation/tuning of MC simulations
- Reconstruction tools and particle id tests
- Study particle interactions: pion, muon, kaon
- Muon capture, anti-proton annihilation,…

Final aim: 4 x 10 kton (fiducial) modules (single and/or double phase) with ability to detect LBL oscillations, SN burst neutrinos, nucleon decay, atmospheric νs



ProtoDUNE Cryostats:



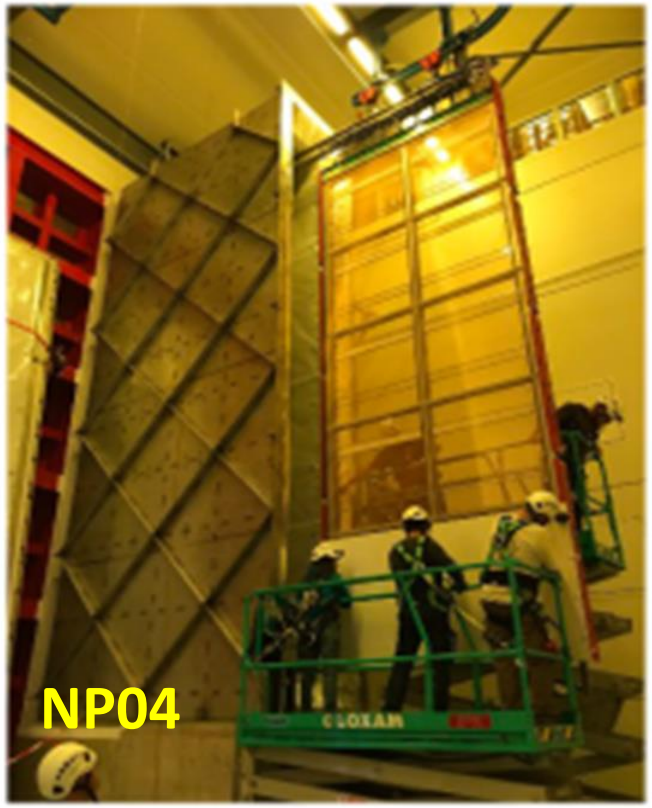


- Two nearly identical membrane cryostats
- 770 t total in LAr mass
- Internal: 7.9 x 8.5 x 8.1 m3
- External: 10.8 x 11.4 x 11.0 m3
- Active volume: 6x6x6 m3
- Engineered and constructed by CERN
- Design scalable to DUNE FD dimensions

10 ktons fiducial volume of DUNE cryostats having dimensions of 15.1 (W) x 14.0 (H) x 62 (L) m^3

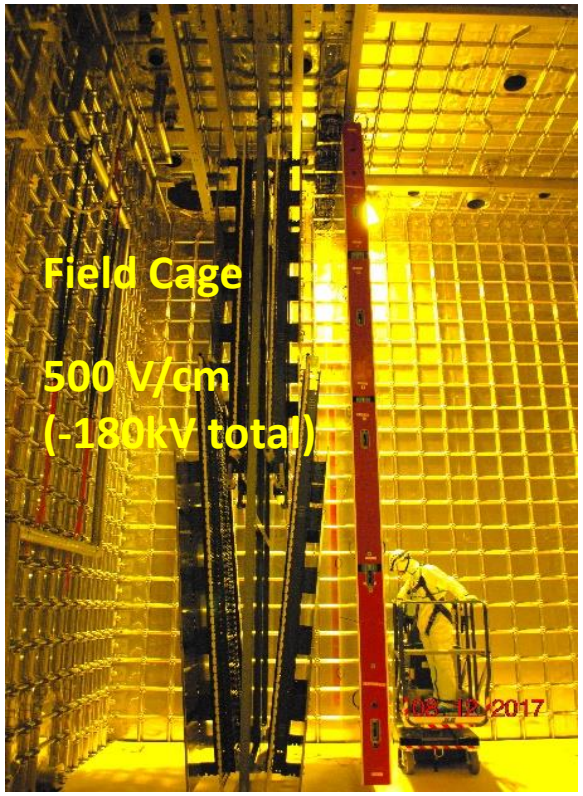
ProtoDUNEs cold boxes:

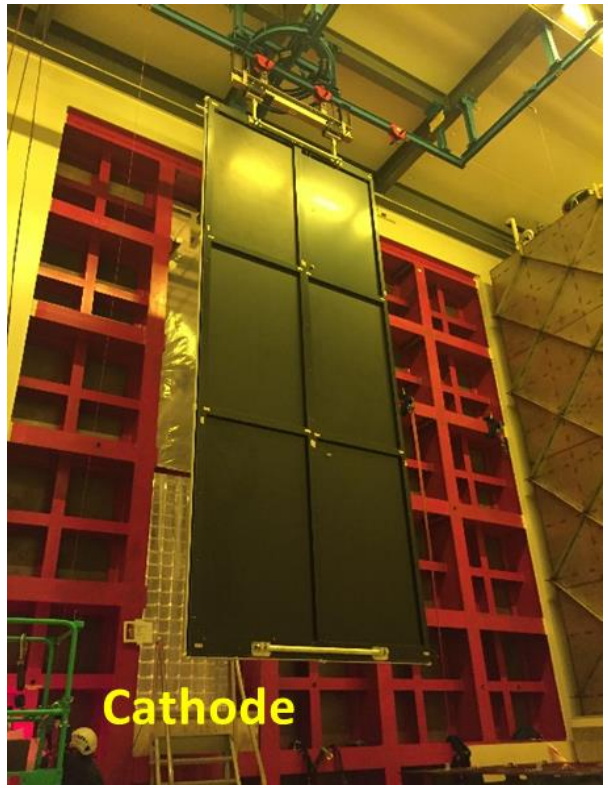
for the detector assembly and final module qualification prior to insertion

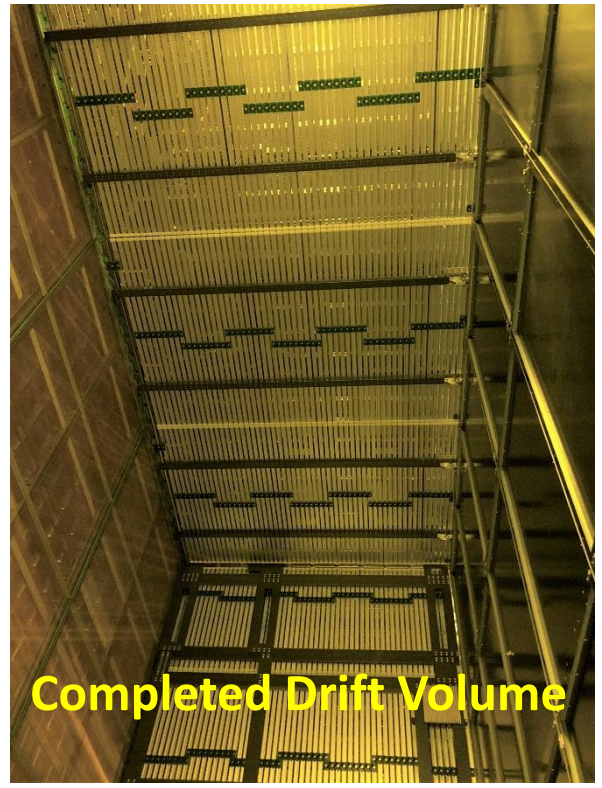


Perform electrical and mechanical tests of Charge Readout Plane units (CRP) for NP02 and Anode Plane Assembly (APA) for NP04 in nominal thermodynamic conditions

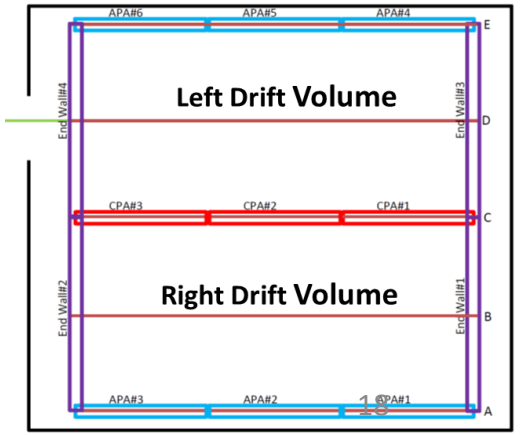
NP04 (ProtoDUNE SP)



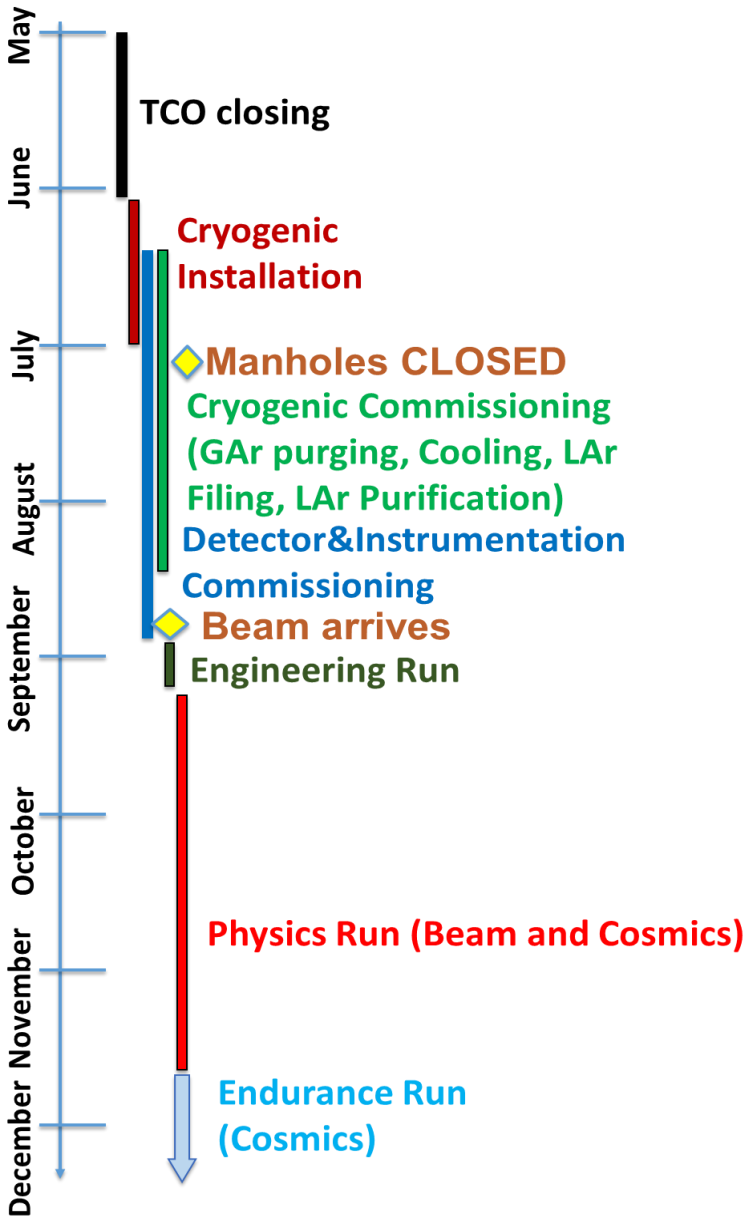




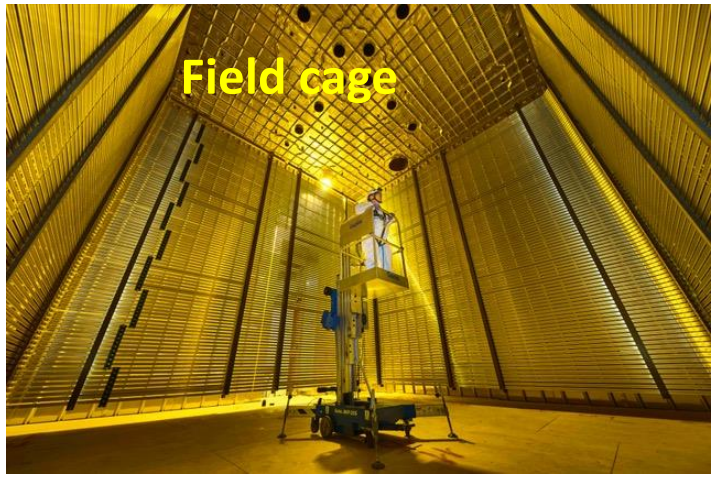
- **ProtoDUNE SP, two drift volumes defined by a central cathode plane flanked by two anode planes, at a distance of 3.6 m, and a field cage surrounding entire active volume.**
- **The first drift volume completely assembled & connected, ready for operation.**
- **All the component of the second drift volume are installed and cabled.**



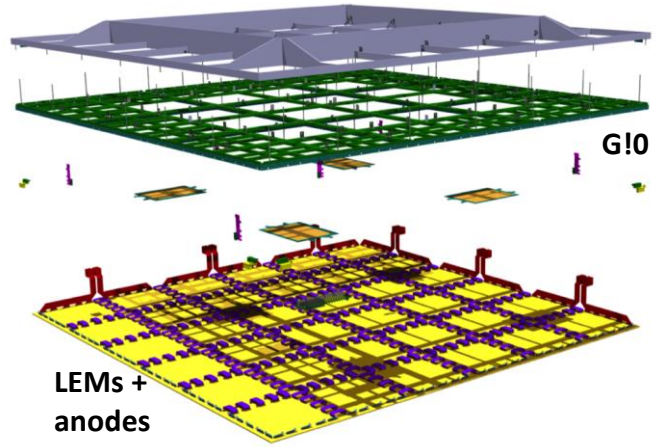
NP04 (protoDUNE-SP): Commissioning and Run



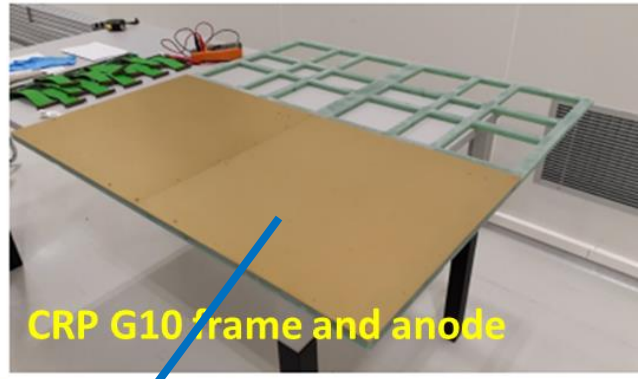
NP02 (ProtoDUNE DP)

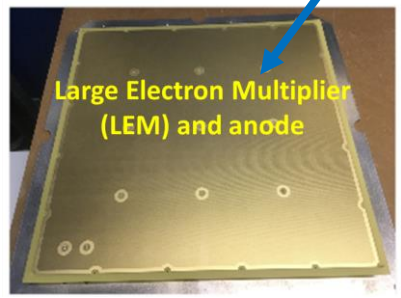


CRP readout system

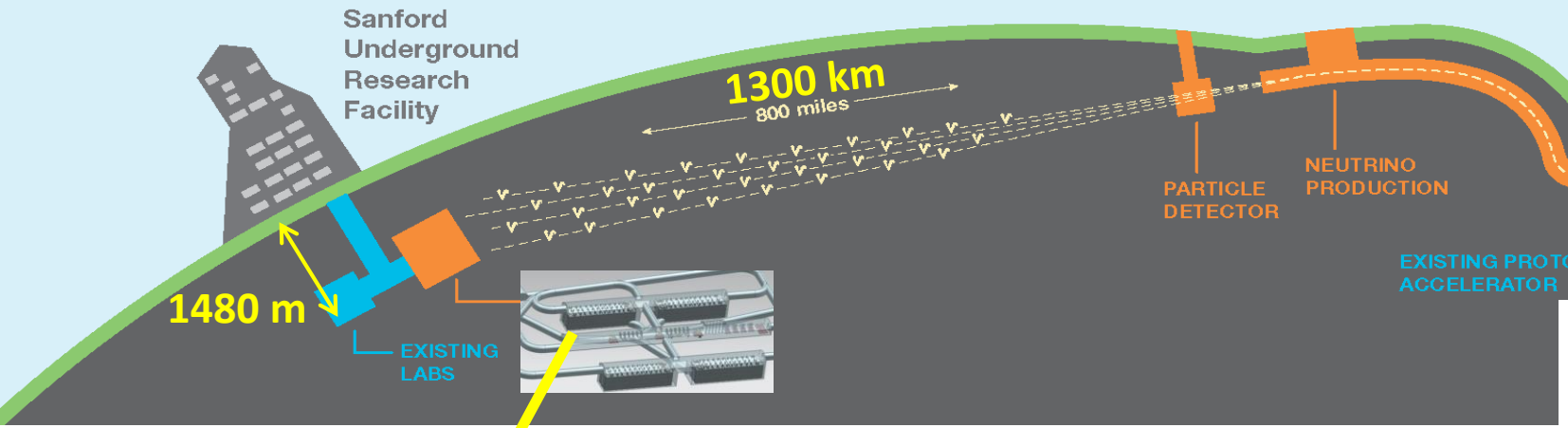


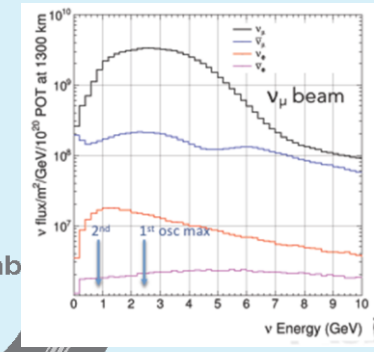
- **CRP productions:**
  - **CRP #1**
    - May 2018: end of assembly
    - June 2018: cold test
    - July 2018: installation in the cryostat
  - **CRP #2**
    - Beginning of July 2018: end of assembly
    - July 2018: in cold test
    - August 2018: installation in the cryostat
  - **CRP 3&4 without instrumenting with LEMs and anode: assembly July 2018**
- **Liquid Argon filling November 2018**
- **Cosmic runs**

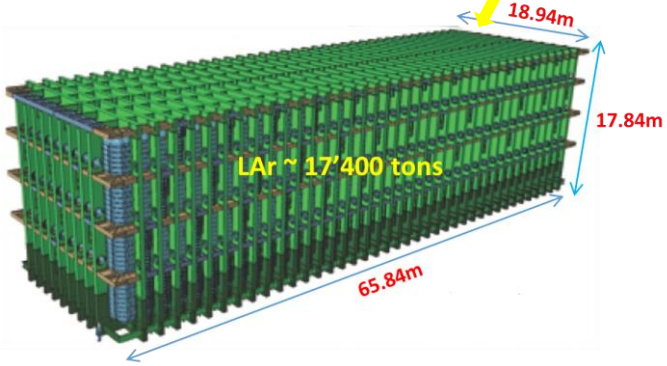




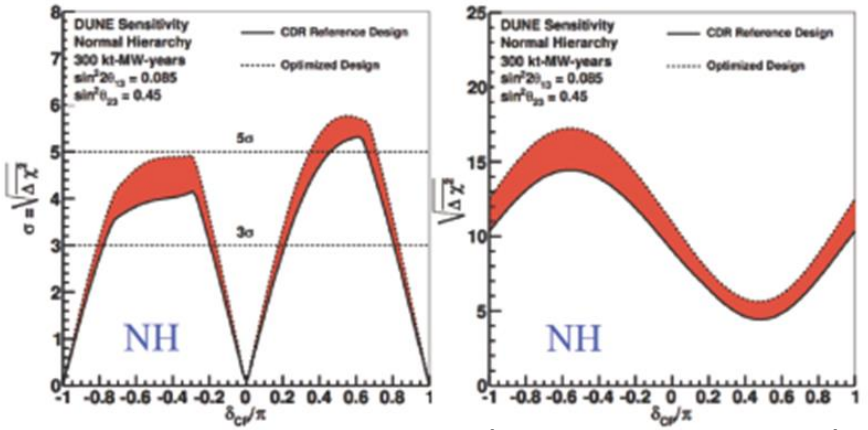
Deep Underground Neutrino Experiment





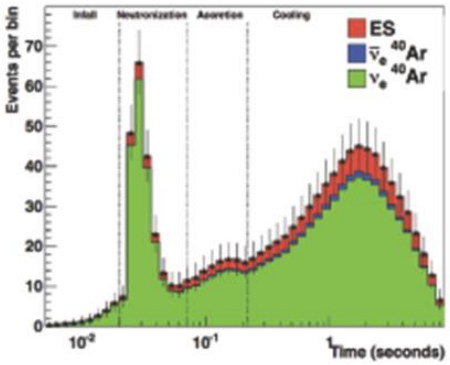


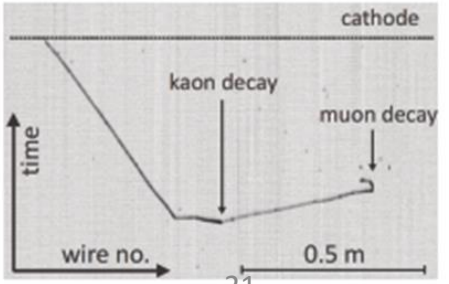
- 4 x 10 kton LArTPC (SP and/or DP)
- Warm structure design
- Cold vessel final design
- Detailed installation procedure
- Structural and thermal analysis



Exposure of 300 kt x MW x year (7 years of data with 40 kt)

- neutrino mass hierarchy, CP violation and precision oscillation physics with neutrino and antineutrino beams
- atmospheric neutrino oscillations
- supernova neutrino bursts
- nucleon decay (particularly sensitive to kaon decay modes)

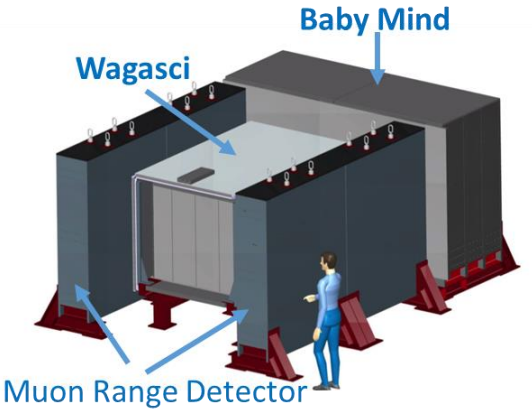


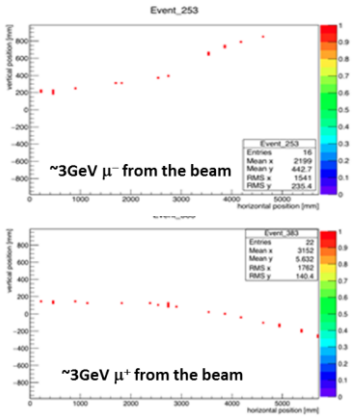


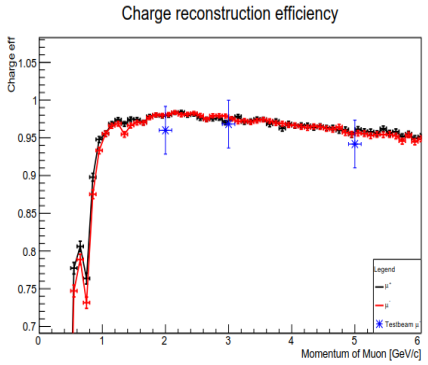
NP05: Baby Mind

Its goal is to precisely identify and track positively or negatively charged muons interacting with matter in the WAGASCI neutrino detector, in Japan. WAGASCI (approved experiment at JPARC) will contribute to constrain systematics for the T2K oscillation analyses.

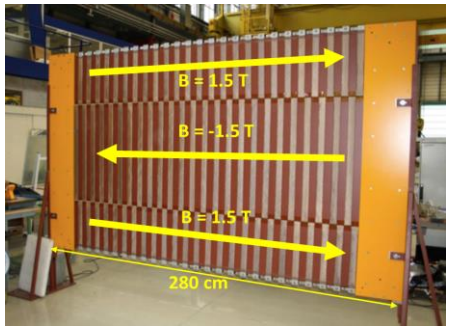
- **75-tonne neutrino detector prototype for a Magnetised Iron Neutrino Detector (MIND).**
- **Interleaving of magnets (33) and scintillator (18) modules**
- **CERN contributed magnet modules, engineering, test beam support.**
- **Transported to Japan on October 2017.**
- **Installed at JPARC on February 2018 and Magnet switched ON on March 2018.**



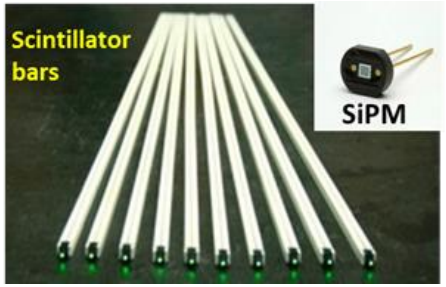




Magnet Module



Scintillator Module



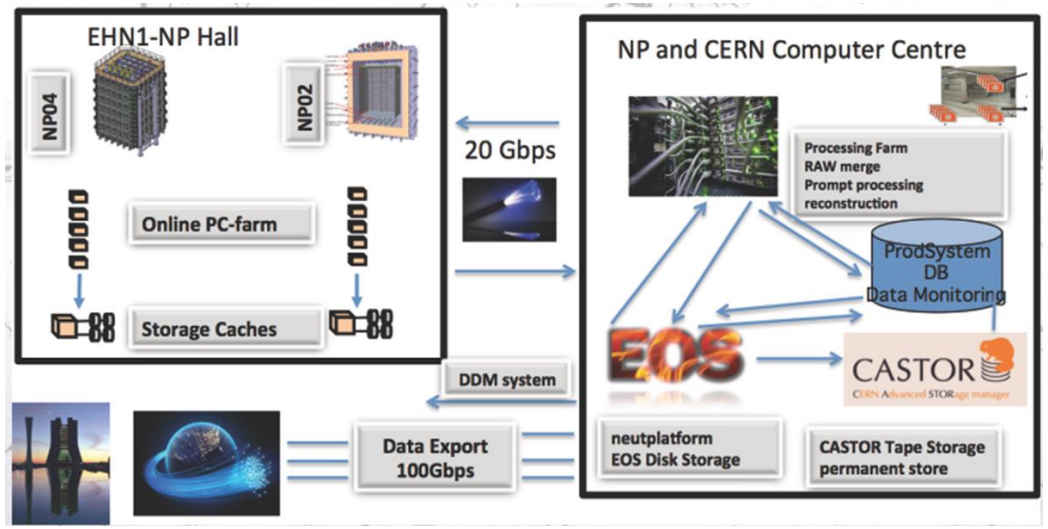
Test results: https://indico.uu.se/event/324/session/6/contribution/72/material/slides/0.pdf

Other activities:

Computing

CERN resources for preparation of the data collection by the protoDUNE prototypes

- **Storage and data distribution**

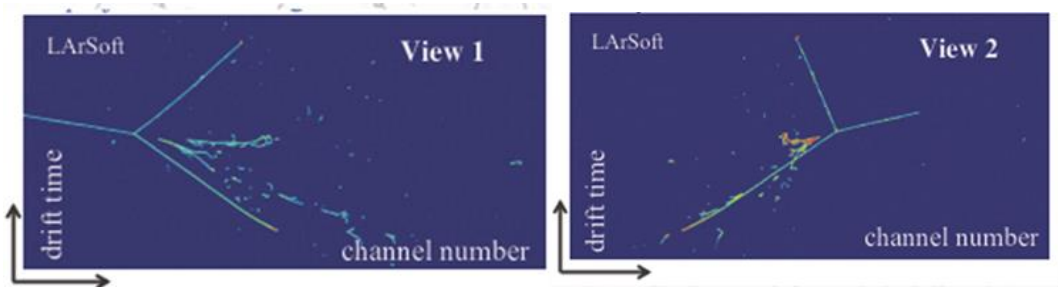


- **exploring the possibility to develop with LHC a new DAQ system based on the ATLAS FELIX concept, to be used in ProtoDUNEs beam test**

  FELIX : https://indico.cern.ch/event/530990/

Simulation, Reconstruction, analyses

- **simulations, event reconstruction and preparation of the analyses for the protoDUNE and SBND detectors**
- **Software developments in the context of the DUNE collaboration**



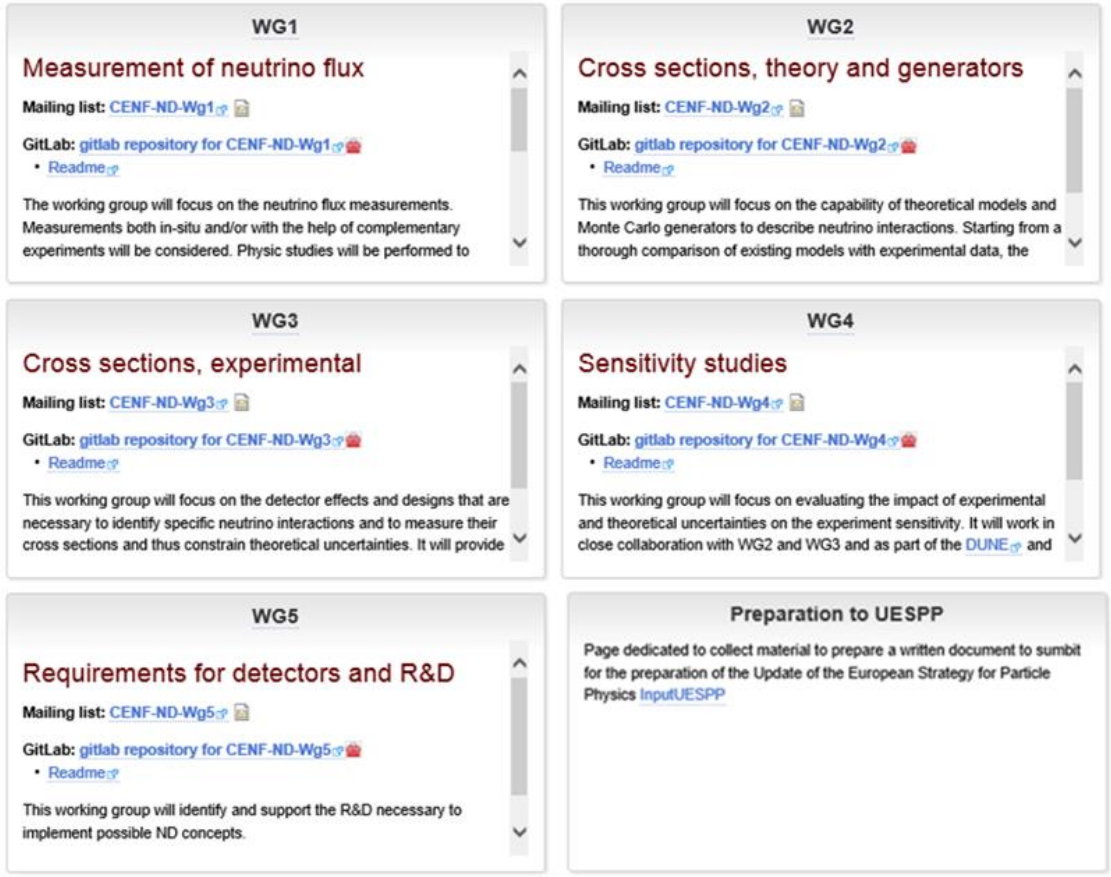
- **Analysis of protoDUNE data**
  - **Inclusive and exclusive pion-Argon cross sections**
  - **…proton-Argon cross sections**
  - **…electron-Argon cross sections**

Momentum Bins (GeV/c)	# of Spills per Bin	# e^+ per Bin	Beam Time per Bin (days)
0.5, 06, 0.7, 0.8, 0.9, 1, 2, 3, 4, 5, 6, 7	5000	300K	1.4

P (GeV/c)	# of Spills	# of e^+	# of K^+	# of μ^+	# of p	# of π^+	Total # of Events	Beam Time (days)
1	70K	84K	≈ 0	70K	689K	625K	1.5M	19.4 days
2	16K	19K	9K	36K	336K	572K	1.0M	4.4 days
3	13K	16K	26K	17K	181K	540K	780K	3.6 days
4	11K	13K	19K	16K	107K	510K	660K	3.1 days
5	11K	13K	29K	13K	96K	510K	660K	3.1 days
6	11K	13K	36K	12K	94K	510K	660K	3.1 days
7	11K	13K	42K	8K	87K	510K	660K	3.1 days
Total	143K	171K	161K	172K	1.6M	3.8M	5.9M	39.7 days

Near Detector related work within CENF

A collaborative effort toward the design of a Near Detector for the new generation of accelerator long-baseline neutrino oscillation experiments



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.

An Update of the European Strategy for Particle Physics is foreseen by May 2020. A call to all members of the particle physics community has opened to submit scientific inputs to the strategy update.

CENF-ND is regrouping institutes not only from EU but also from Japan and US, bringing together many experts in the community. Discussions within the CENF-ND forum is started to propose an input to the UESPP.

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

CERN Neutrino Platform will continue to support the community

CERN-SPSC-2018-012
SPSC-G-034

18 April 2017

Call for proposals for projects at the CERN Neutrino Platform after LS2

The CERN Neutrino Platform was created to assist collaborations of European scientists working on neutrino physics in developing equipment and techniques for use at long-baseline experiments in Japan and the USA. The Neutrino Platform supports generic detector R&D and large detector prototypes or demonstrators. It gives technical, financial and logistical support to approved projects.

The Neutrino Platform has supported users in the development of detectors for experiments at FNAL and at Tokai, and along with use of multiple test beam lines at CERN also comprises the dedicated beamlines in EHN1. Projects in the Neutrino Platform have also involved the participation of CERN experts in detectors and cryogenics.

Following the Long Shutdown scheduled for the end of the accelerator complex running in 2018 (LS2), there may be opportunities for new or upgraded projects to be considered for approval as Neutrino Platform projects.

The SPSC is issuing a call for proposals for projects at the Neutrino Platform following LS2.

Proposals should be submitted to the SPSC by October 2018 and should address the physics or technology case behind the proposal, what are the expected use of CERN resources requested by the proposal, what are the relationships with Neutrino experiments outside of Europe, and what are the expected contributions of participating European collaborators.

The SPSC expects to prepare recommendations to the Research Board for approval of experiments by April 2019.

Any current proposals for Neutrino Platform projects will be considered as part of this evaluation.

This is the first of what is expected to be periodic calls for users at the Neutrino Platform. Potential applicants are invited to address questions about the process to the scientific secretary of the SPSC.

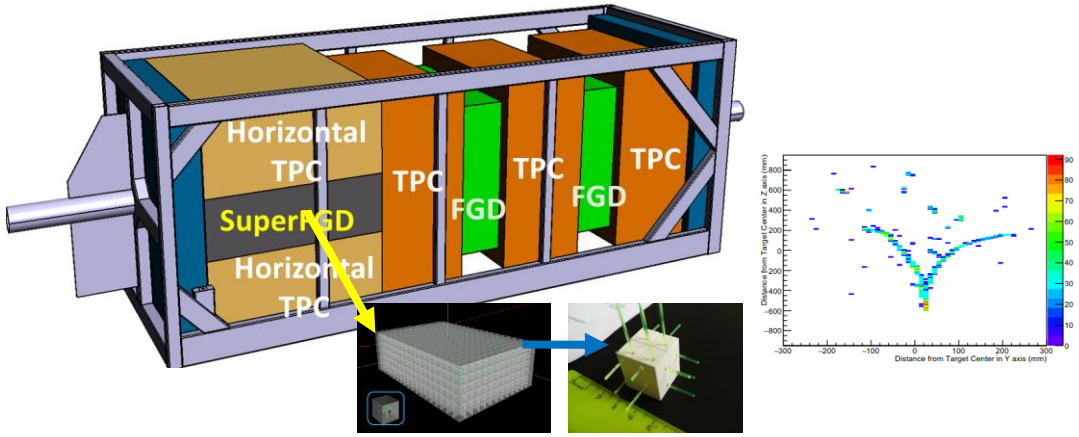
Jordan Nash
Chairperson, SPSC

Eckhard Elsen
CERN Director for Research

The SPS-Committee handles the scientific activities of the neutrino-platform w.r.t. CERN Scientific Policy Committee.

Two proposals already submitted:

- **The T2K-ND280 upgrade proposal** (CERN-SPSC-2018-001 / SPSC-P-357) **improving the angular acceptance and reducing particle momentum threshold**



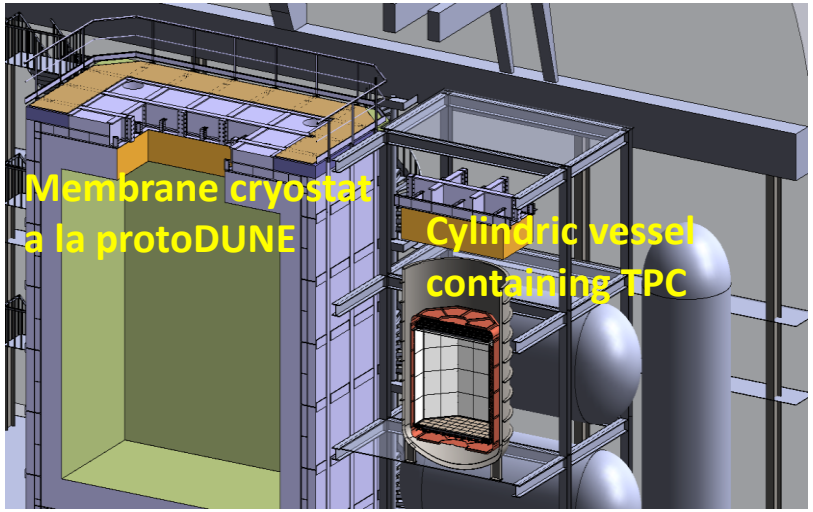
- **Study of Hadron-Nucleus and Nucleus-Nucleus Collisions at the CERN SPS: Early Post-LS2 Measurements and Future Plans.** By the NA61/SHINE Collaboration and the CERN team (CERN-SPSC-2018-008 ; SPSC-P-330-ADD-10)

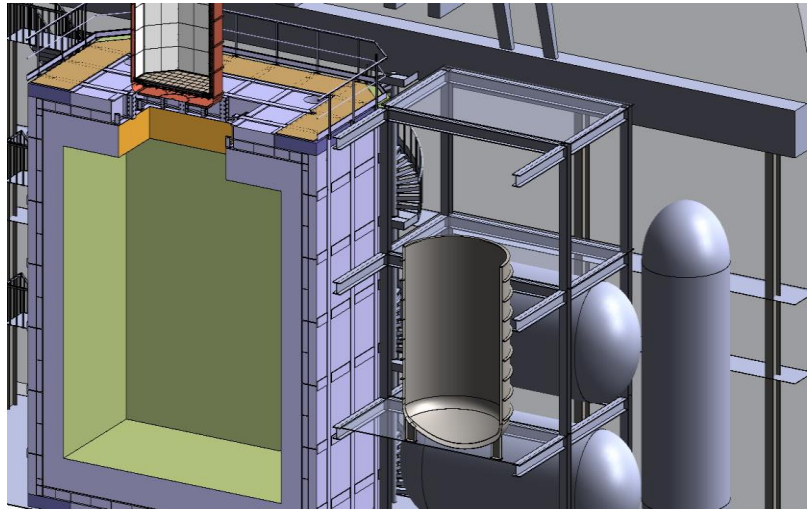
Darkside:

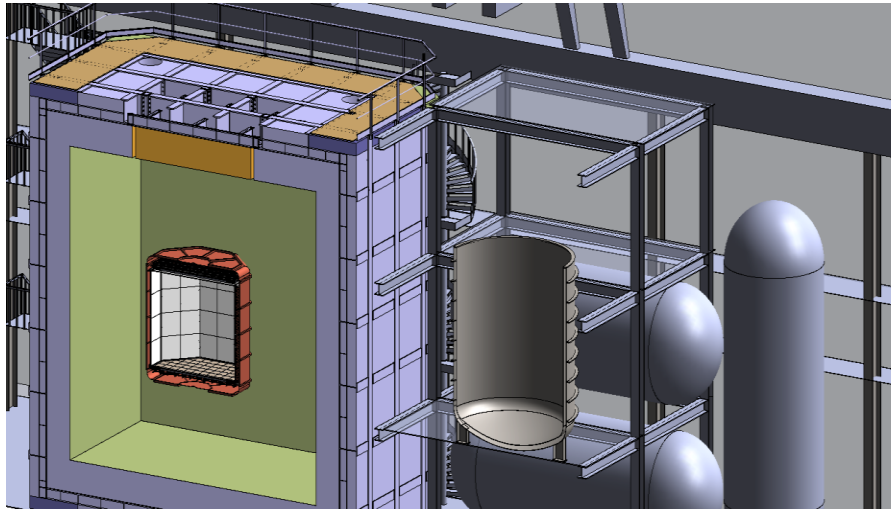
A double phase LArTPC search for direct evidence of dark matter

- **It is a part of the CERN neutrino platform, profiting from protoDUNE experiences**.
  - Membrane Cryostat, engineering integration of full detector components, cryogenic system
  - Simulations, new photon detector technologies

- A LAr^{40} TPC (~30tons) in a protoDUNE type of LAr bath.
- It will be installed in Gran Sasso (Italy)
- Concept to be extended at 300 tons at SNO Lab







Conclusions:

- ✓ **The CERN Neutrino Platform is a unique R&D framework for the international neutrino community.**
- ✓ **Platform offers to the neutrino community support on detector R&D, tests and constructions both on US and Japanese activities.**
- ✓ **Design and construction of large cryostats of a new generation (~1000 tons LAr)**
- ✓ **Large size detector engineering integration: ProtoDUNEs**
- ✓ **Major contribution to the infrastructure of Long Baseline Neutrino Facility**
- ✓ **CERN is also strongly committed to the Short Baseline Program in US**
- ✓ **More activities to assist DUNE and T2K/HK in the definition of their future near detectors**
- ✓ **The CERN neutrino platform is also busy with a variety of other detectors, also profiting from protoDUNEs and ICARUS experience**