CERN Contribution to the Future ν Programs

CERN, March 3, 2015

Sergio Bertolucci

From the European Strategy Document

f) 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.

From the P5 Report

Recommendation 12 : In collaboration with international partners, develop a coherent short- and long-baseline neutrino program hosted at Fermilab.

The minimum requirements to proceed are the identified capability to reach an exposure of at least **120 kt*MW*yr by the 2035 timeframe**, the far detector situated **underground** with cavern space for expansion **to at least 40 kt LAr fiducial** volume, and **1.2 MW beam power upgradable to multi megawatt** power. The experiment should have the demonstrated capability to search for **supernova (SN) bursts** and for **proton decay**, providing a significant improvement in discovery sensitivity over current searches for the proton lifetime.

Japan Roadmap

Association of Japanese High Energy Physicists (community organisation) regards that ILC and Hyper-K are the two priority projects in Japan.

- Hyper-K, through international cooperation
- ILC: hosting ILC as a global project

In summer 2014 some more events

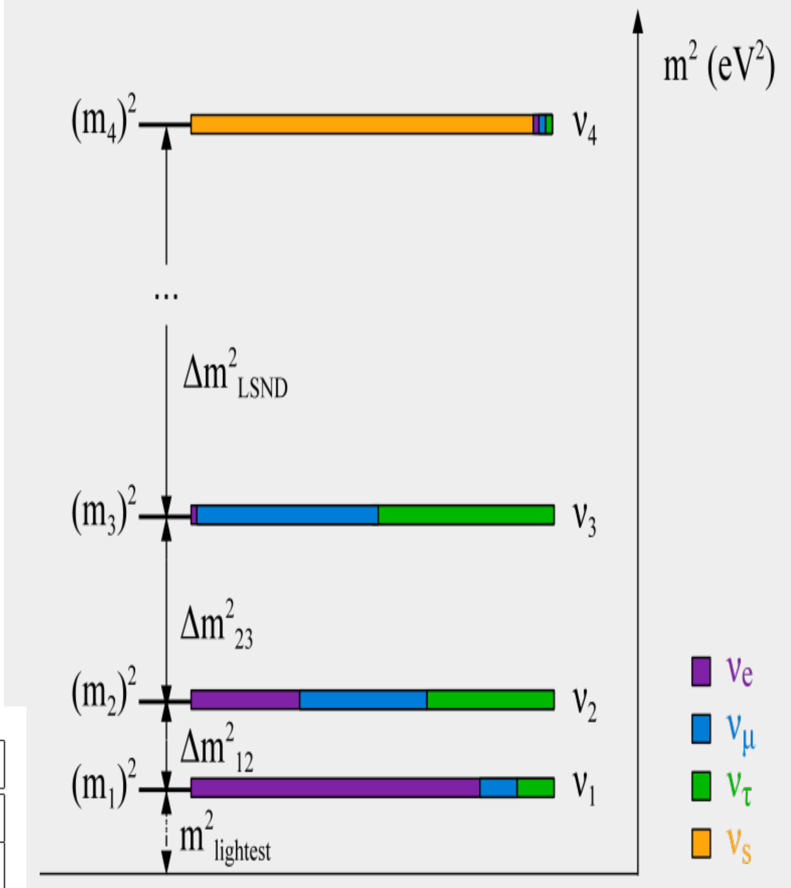
- *In June the APPEC Paris meeting dedicated to Large Neutrino Infrastructures, where most FAs and leaders in the field where present, started drafting a possible future strategy*
  - ***CERN broke symmetry and announced that it will freeze for the moment all types of Neutrino beams at CERN (Short and Long Baseline) in favor of common activities in US and Japan***
- In July FNAL management called for a meeting/discussion on how to plan the future of the the LBNF facility in the US with the goal of creating a new real international project
  - ***An interim steering group(iIEB) which aimed to bring together a new international Collaboration. A new Collaboration (ELBNF) was created in winter 2014 with the goal of leading the detector and physics effort (~145 institutions involved)***
  - ***A white paper which defines the rules for a US based international High Intensity Facility (LHC model) was presented***

…then in January 2015

- Presentation of a CDR on a Short Baseline Program at the FNAL Booster
- Presentation of a LOI for a new international collaboration on a Long Baseline Program at the FNAL Main Injector
- Constitution meeting of the new ELBNF collaboration

SBN Physics Program : The Three Neutrino Paradigm

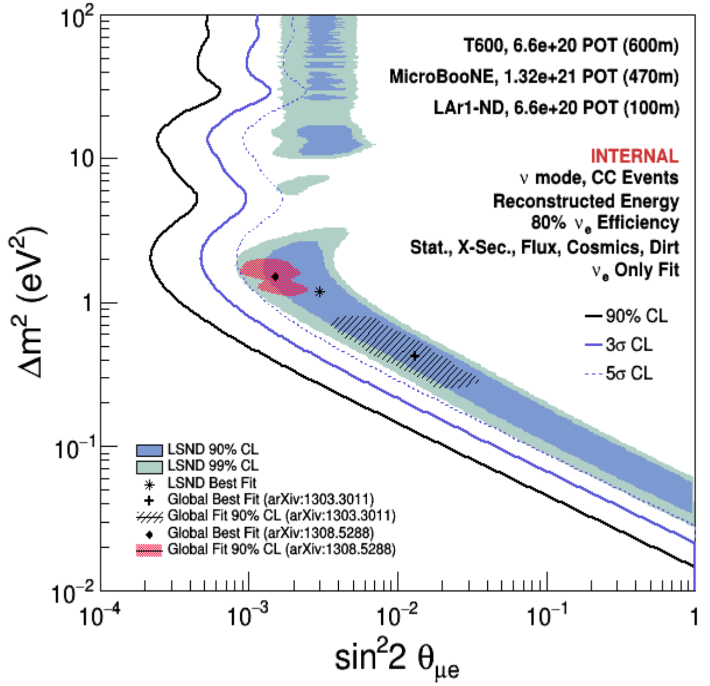
- A Multi-detector program will address the unexplained anomalies which together could be hinting at new physics (steriles?)
  - *MicroBooNE will address MiniBooNE low energy excess but is not designed to explore the complete sterile neutrino oscillation parameter space on its own*
  - *Plans to have all 3 detectors in operation in 2018 (Approved experiment by FNAL PAC in Feb 2015)*



Experiment	Type	Channel	Significance
LSND	DAR	$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ CC	3.8σ
MiniBooNE	SBL accelerator	$\nu_\mu \rightarrow \nu_e$ CC	3.4σ
MiniBooNE	SBL accelerator	$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ CC	2.8σ
GALLEX/SAGE	Source - e capture	ν_e disappearance	2.8σ
Reactors	Beta-decay	$\bar{\nu}_e$ disappearance	3.0σ

SBN Physics Program : The Three Neutrino Paradigm

- Results from multiple experiments have hinted at a possible additional oscillation
- While each of the measurements alone lack the significance to claim a discovery, together they could be hinting at important new physics



One thing is certain…

The discovery of a light sterile neutrino would be monumental for particle physics and cosmology!

ELBNF

A merger of all previous efforts and any other interested parties to build, operate, exploit

- a (staged) 40 Kt LAr detector, at the SURF site, 1300 Km from FNAL
- An high granularity/high precision near detector

exposed to a 1.2 MW, tunable ν beam produced by the PIP-II upgrade at FNAL by 2024, evolving to a power of 2.3 MW by ~ 2030.

A 25+ years Physics Program

On the beam:

- Perform a comprehensive investigation of neutrino oscillations to:
  - test CP violation in the lepton sector
  - determine the ordering of the neutrino masses
  - test the three-neutrino paradigm
- Perform a broad set of neutrino scattering measurements with the near detector

Exploit the large, high-resolution, underground far detector for non-accelerator physics topics:

- atmospheric neutrino measurements
- searches for nucleon decay
- measurement of astrophysical neutrinos (especially those from a core-collapse supernova).

Governance and Relations with the Host Lab

- ELBNF will follow a model derived from the CERN LHC, which clearly separates the ownership of the experiment (International Collaboration) from the ownership of the facility (Host Lab)
- Collaboration and Host Lab rights and obligation are regulated by MoU's
- A strong Experiment - Facility Interface Group (EFIG) is key.

Signatures on the LOI for ELBNF

- As of 11 Jan 2005 nominal deadline there were 503 signatures
- They will form the basis of the new ELBNF collaboration
- Signers represent:
  - 142 Institutions*
    - 69 US Institutions
    - 73 non-US Institutions
  - 23 Countries
- Signing the LOI remains open for additional members at least through the 22-23 Jan meeting

*includes Indian & Czech groups which intend to join

Countries represented":

Armenia, Belgium, Brazil, Bulgaria, Canada, Columbia, Czech Republic, France, Germany, India, Iran, Italy, Japan, Mexico, Netherlands, Pakistan, Poland, Russia, Spain, Switzerland, Turkey, UK, USA

" Color coded by continent

Constraining the PMNS Matrix

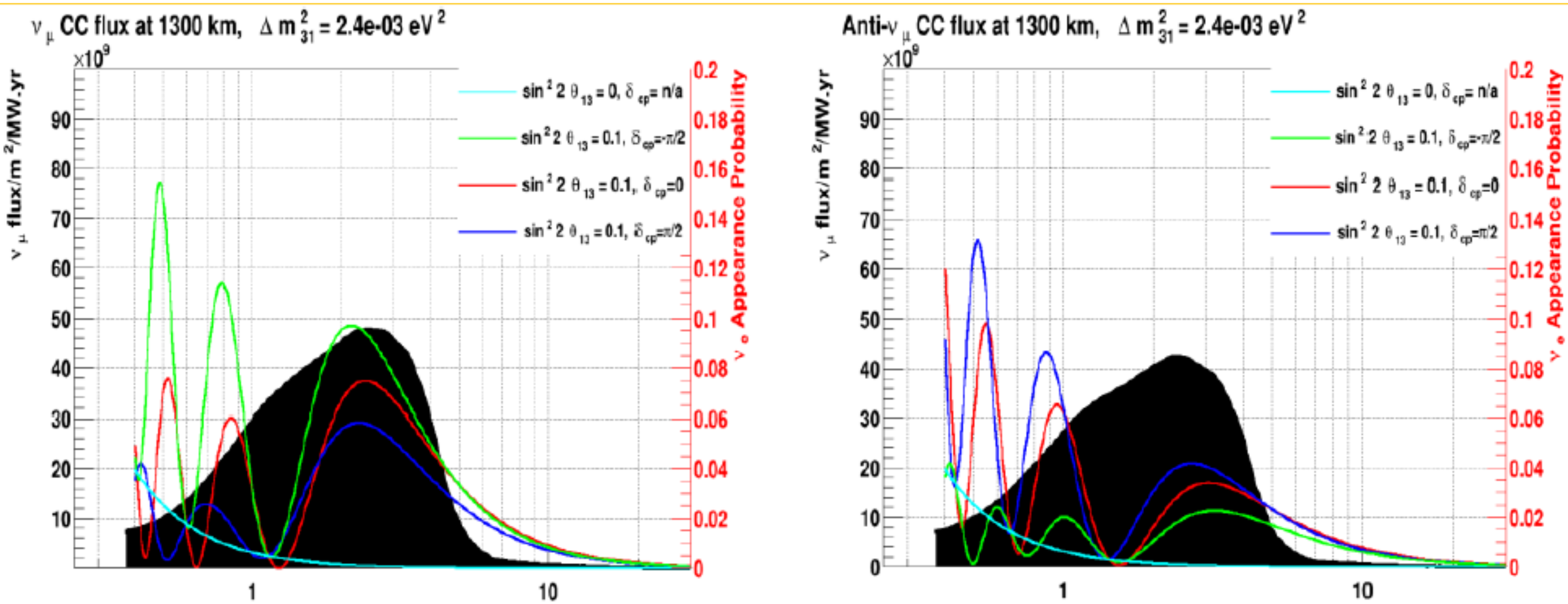
$$P(\nu_\mu \to \nu_e) \approx \sin^2 \theta_{23} \sin^2 2\theta_{13} \frac{\sin^2(\Delta_{31} - aL)}{(\Delta_{31} - aL)^2} \Delta_{31}^2$$

$$+ \sin 2\theta_{23} \sin 2\theta_{13} \sin 2\theta_{12} \frac{\sin(\Delta_{31} - aL)}{(\Delta_{31} - aL)} \Delta_{31} \frac{\sin(aL)}{aL} \Delta_{21} \cos(\Delta_{31} + \delta_{CP})$$

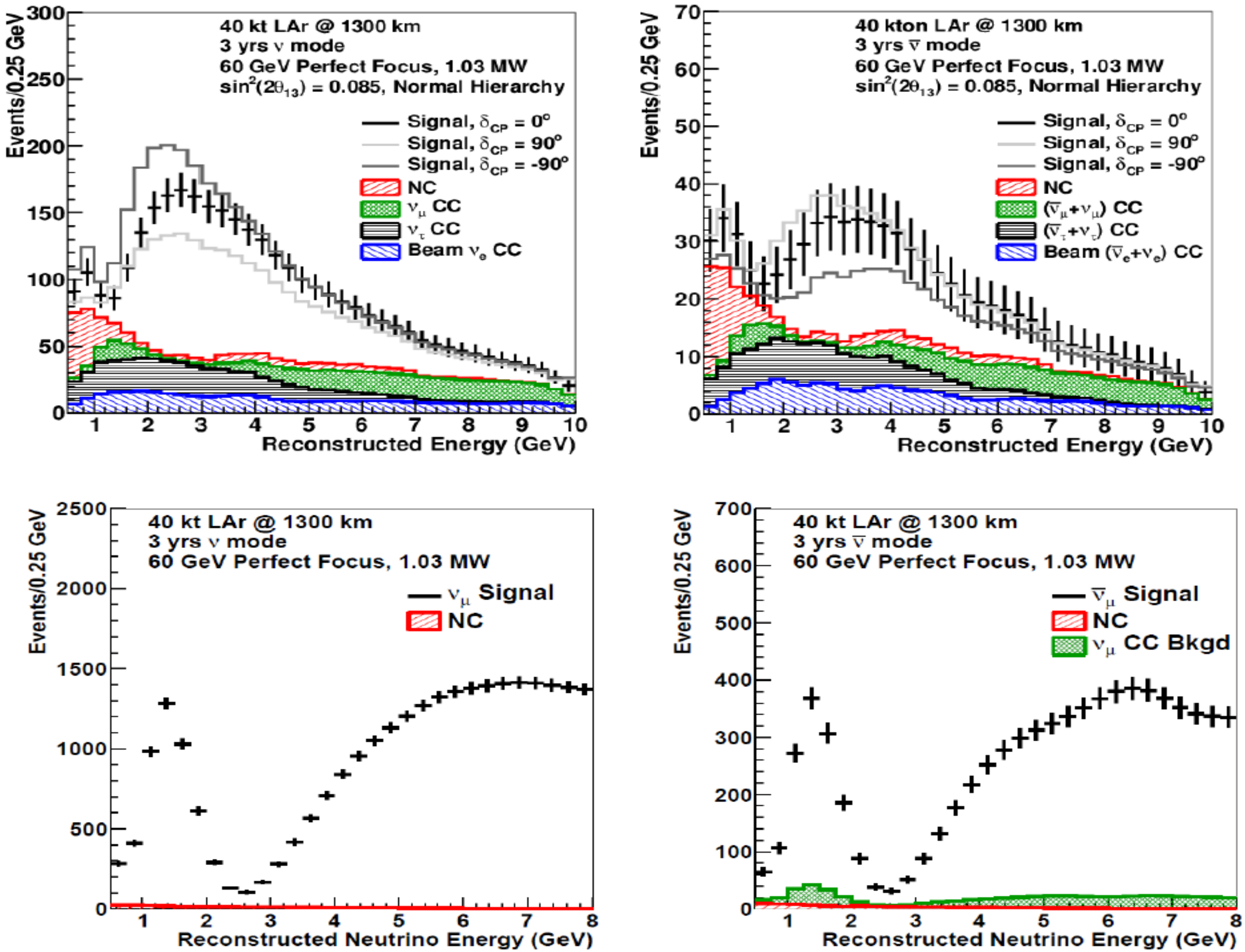
$$+ \cos^2 \theta_{23} \sin^2 2\theta_{12} \frac{\sin^2(aL)}{(aL)^2} \Delta_{21}^2$$

with $\Delta_{ij} = \Delta m_{ij}^2 L/4E$, and $a = G_F N_e/\sqrt{2}$.

Oscillation Probabilities vs E



ν_e(antiν_e) appear, ν_μ(antiν_μ) disapp



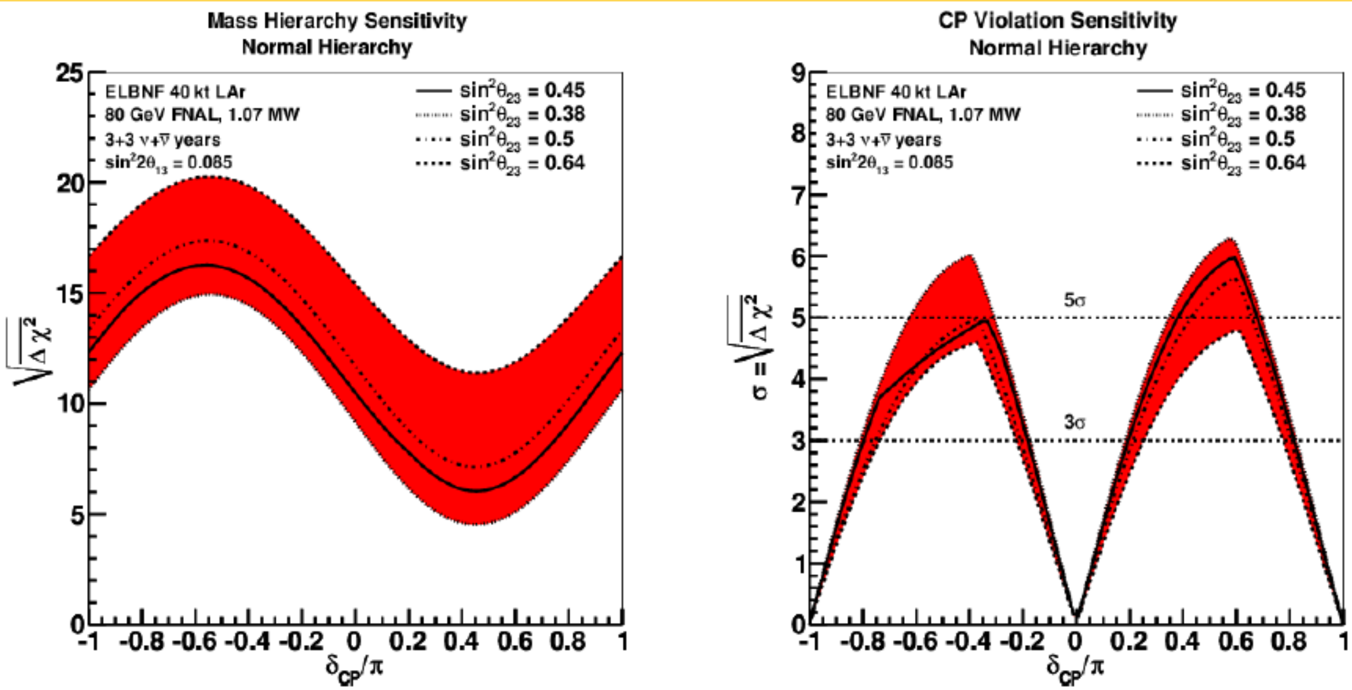


FIGURE 3: *Expected sensitivity of ELBNF to determination of the neutrino mass hierarchy (left) and discovery of CP violation, i.e. $\delta_{CP} \neq 0$ or π, (right) for a 40-kt fiducial mass LAr TPC and an 80-GeV, 1.07-MW beam from FNAL to SURF with three years of running in neutrino and three years in antineutrino mode. The Nu-Fit central value for θ_{23} (solid line) is shown in comparison with other values of θ_{23} The width of the band corresponds to the 3σ range allowed by Nu-Fit. Note that the sensitivity to MH increases for increasing values of θ_{23} while the corresponding sensitivity to CP violation decreases. Sensitivities are for true normal hierarchy; neutrino mass hierarchy is assumed to be unknown in the CPV fits.*

Parameter	Value Used for the ELBNF Sensitivities
	For ν_e CC appearance studies:
ν_e CC efficiency	80%
ν_μ NC mis-identification rate	1%
ν_μ CC mis-identification rate	1%
	For ν_μ CC disappearance studies:
ν_μ CC efficiency	85%
ν_μ NC mis-identification rate	1%
Other background	0%
	Neutrino energy resolutions:
ν_e CC energy resolution	$15\%/\sqrt{E(GeV)}$
ν_μ CC energy resolution	$15\%/\sqrt{E(GeV)}$

How does CERN fit in all this?

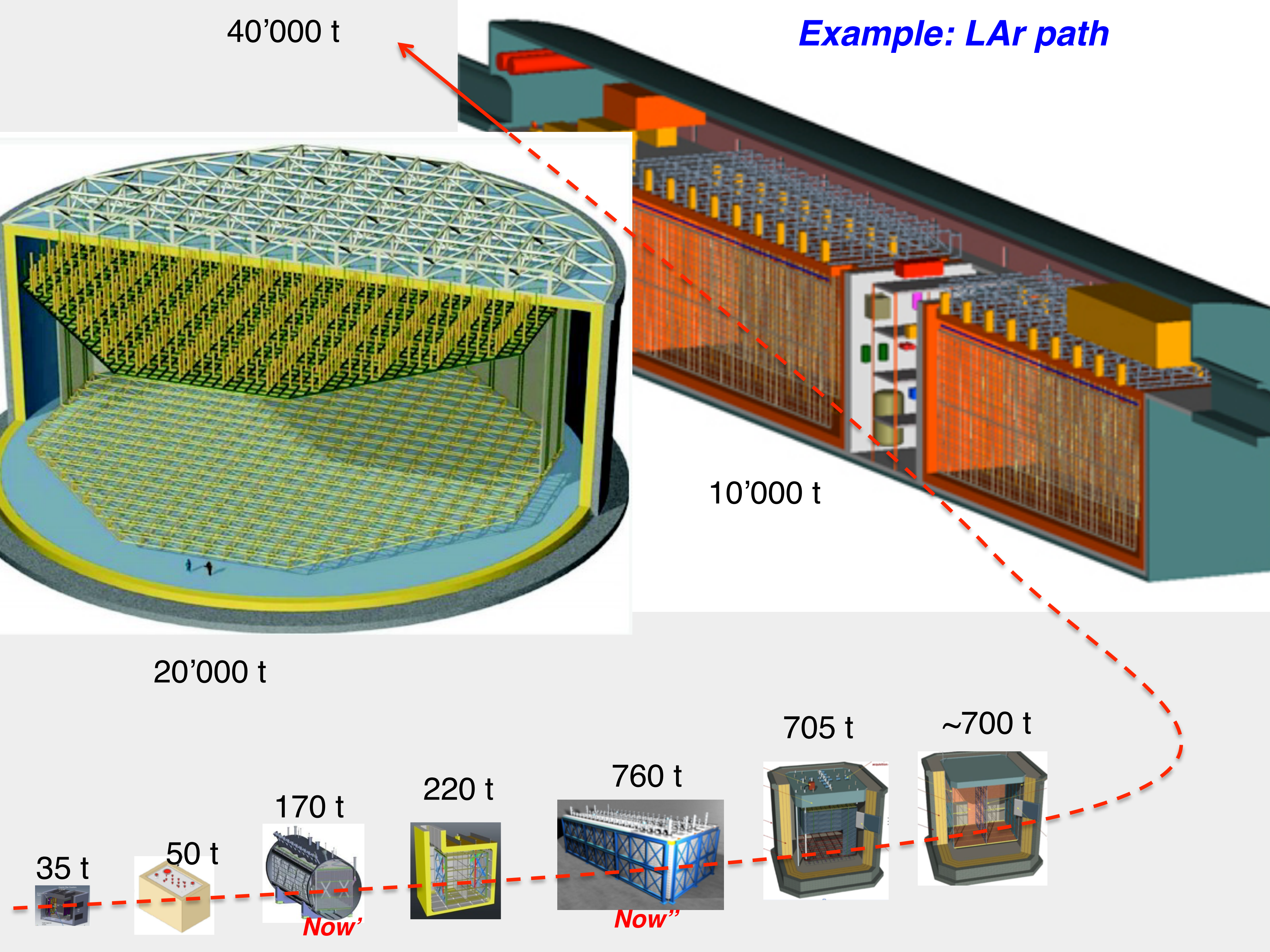
- ✓ As a support structure for all these activities, where CERN expertise can be a VALUE
- ✓ As the support Laboratory for all European Groups interested in a collaborative effort
- ✓ As a unique R&D and tests facility of detectors and components (hardware and software)
- ✓ As a research group active at these

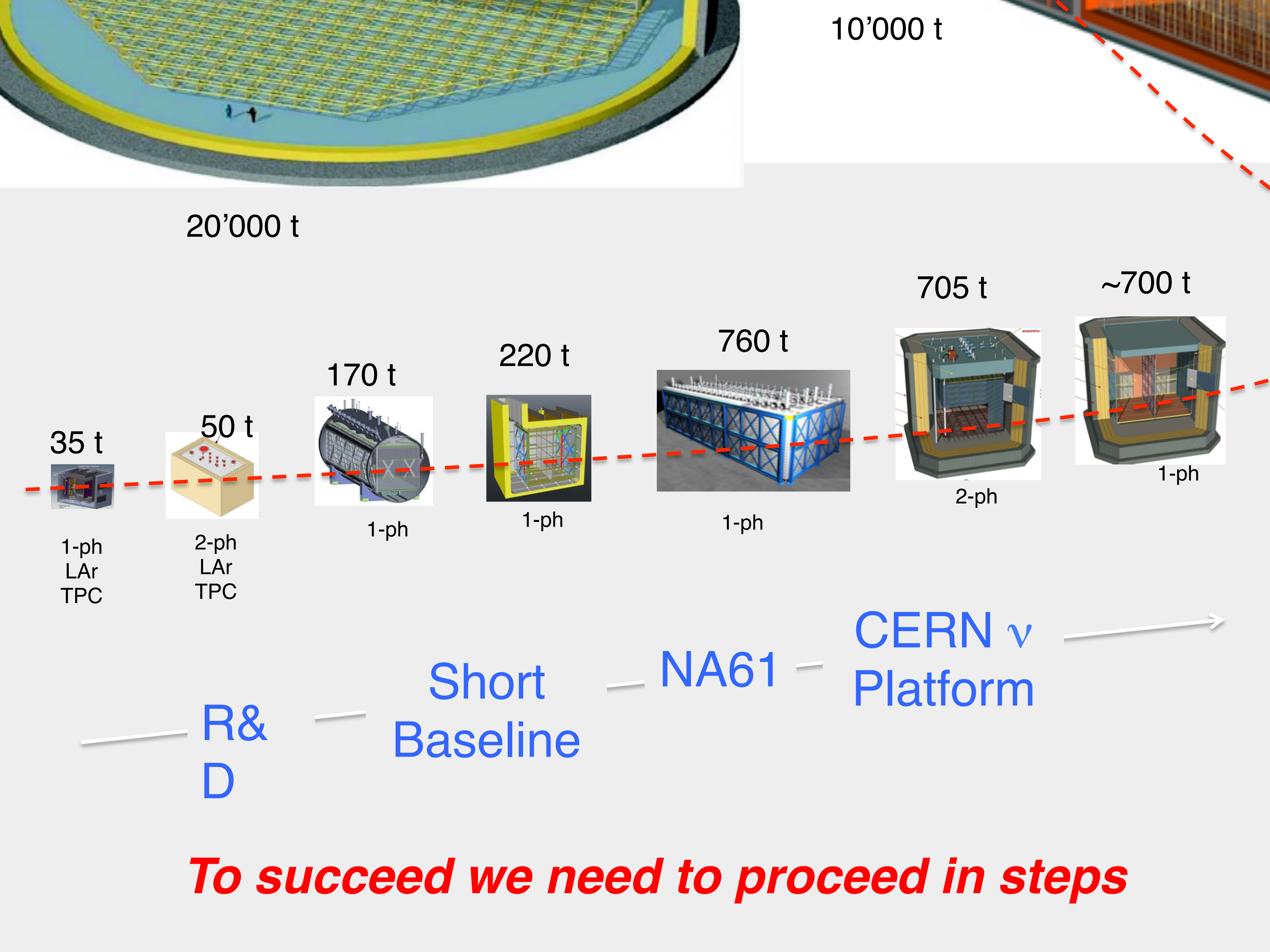
→ NEUTRINO PLATFORM

CERN ν Platform Initial Mandate (Coord. M.Nessi)

- Assist the various groups in their R&D phase (detectors and components) in the short and medium term and give coherence to a fragmented European Neutrino Community
- Provide to the ν community a test beam infrastructure (charged particles)
- Bring R&D at the level of technology demonstrators in view of major technical decisions
- Continue R&D on ν beam, as a possible base for further collaborations
- Support the short baseline activities (infrastructure & detectors)
- Support the long baseline activities (infrastructure & detectors)

- LAr TPC technology has been adopted in both Short and Long baselines (in the US facilities)
- The time scale for the 2 US projects is very aggressive :
  - 2017 for the Short baseline
  - 2021 for starting the installation of the Long baseline far detector(s)
- Large jump from ~1Kt now to 40 Kt tomorrow


Example: LAr path
40’000 t
10’000 t
20’000 t
35 t
50 t
170 t
220 t
760 t
705 t
~700 t
Now’
Now”


10'000 t
20'000 t
35 t
1-ph
LAr
TPC
50 t
2-ph
LAr
TPC
170 t
1-ph
220 t
1-ph
760 t
1-ph
705 t
2-ph
~700 t
1-ph
R&
D
Short
Baseline
NA61
CERN ν
Platform
To succeed we need to proceed in steps

In steps for the next 3-4 years

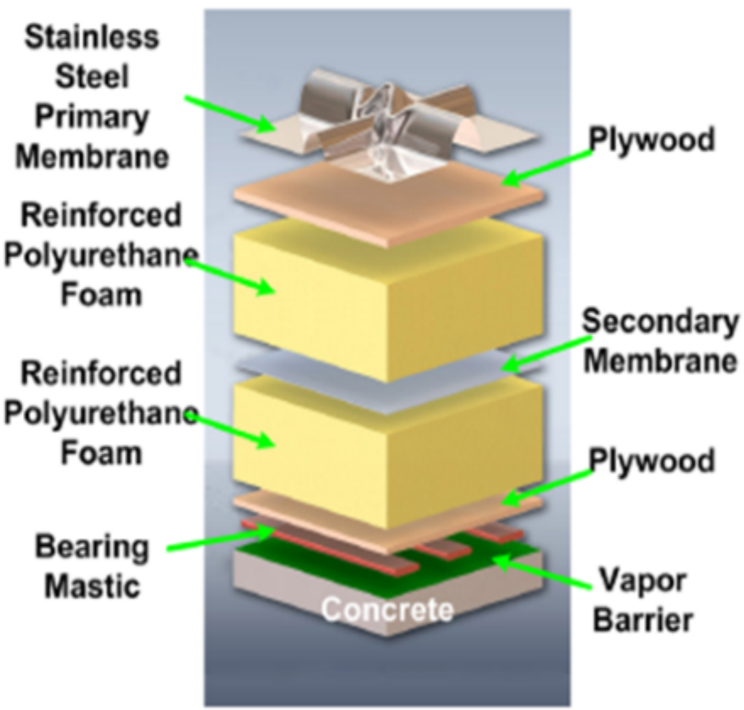
- To optimize the TPC single phase technology, beyond what was done by ICARUS, MICROBONE and LArIAT
- *To prove the potential of a 2 phases LAr TPC*
- To gain experience on new techniques for light detection in LAr
- *To calibrate the response to hadrons and leptons*
- To learn how to deal with all possible nu-e topologies (large samples of data)
- *To optimize the detector modularity and integration process*
- To gain experience on membrane cryostats construction
- *To learn the cryo-techniques necessary at the multi-kt scale*
- To exercise and learn about automatic data reconstruction and large data set handling (PBytes)
- ….

In practice the activity consists on :

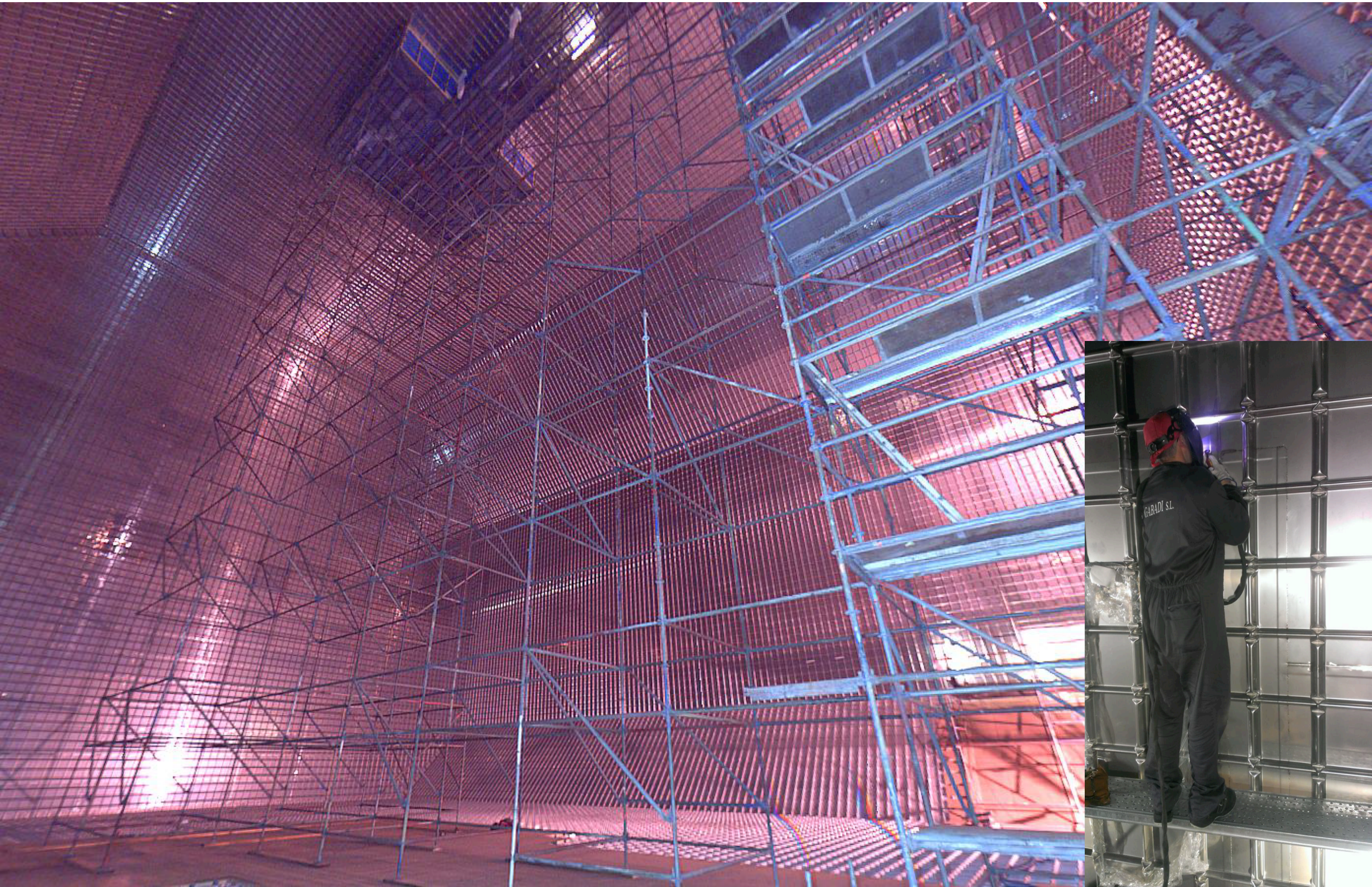
- experimenting new technologies of large volume cryostats
- creating a strong cryogenics group at CERN working in strong cooperation with the FNAL one
- preparing a new test beam facilities for large cryogenic detectors
- helping the Short baseline detectors (ICARUS and LAr1-ND) to be ready in situ for 2017
- supporting new R&D on single and double phases LAr detector for the Long baseline (large demonstrators)
- supporting the R&D of new ν detectors in general
- basic R&D on ν beam components

Cryostats & Cryogenics activities

- We are re-creating a LAr cryogenics group at CERN which should serve the needs of the community at large (in cooperation with FNAL)
- Existing Cryolab @ CERN, augmented by 5 FTEs
- 5 large cryostats and related cryogenics under scrutiny and construction !

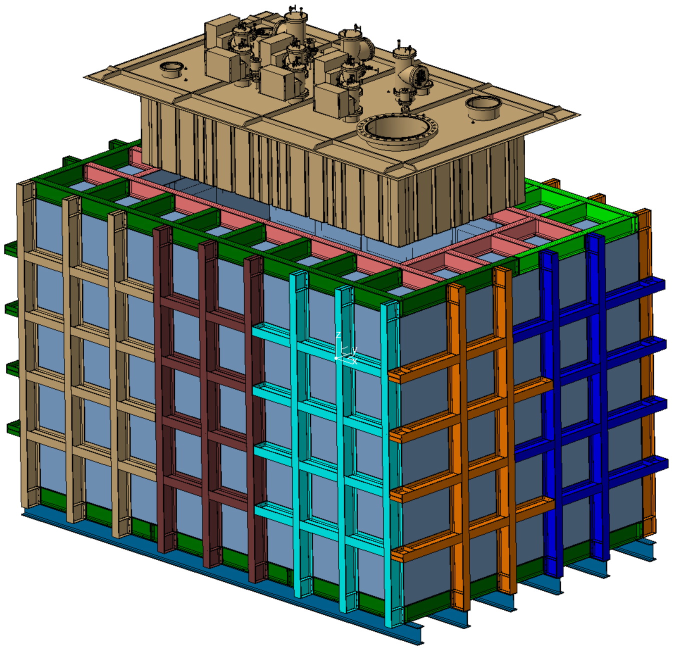


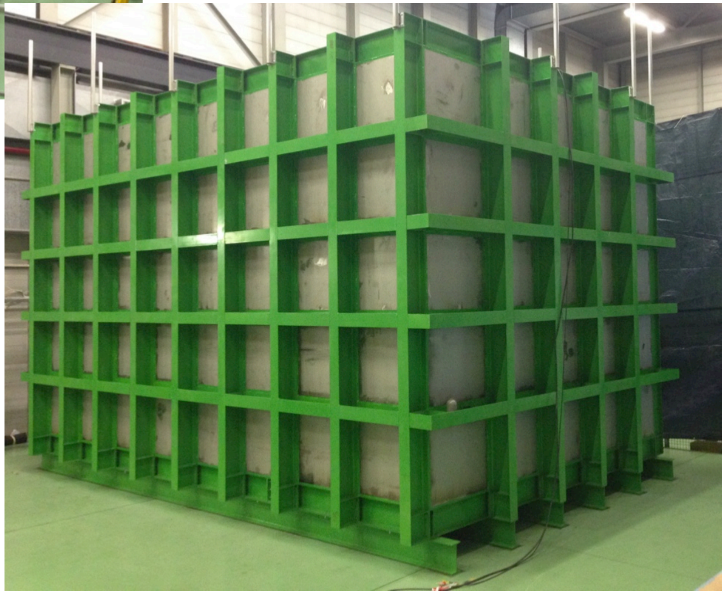
Membrane cryostats (GTT licence)



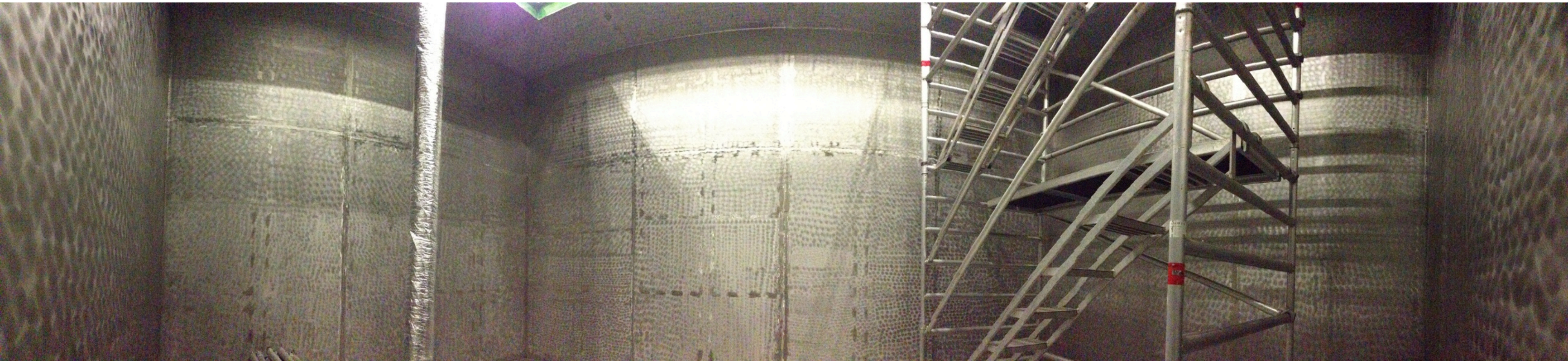
The outer structure

First 50 t memebrane cryostat under construction at CERN





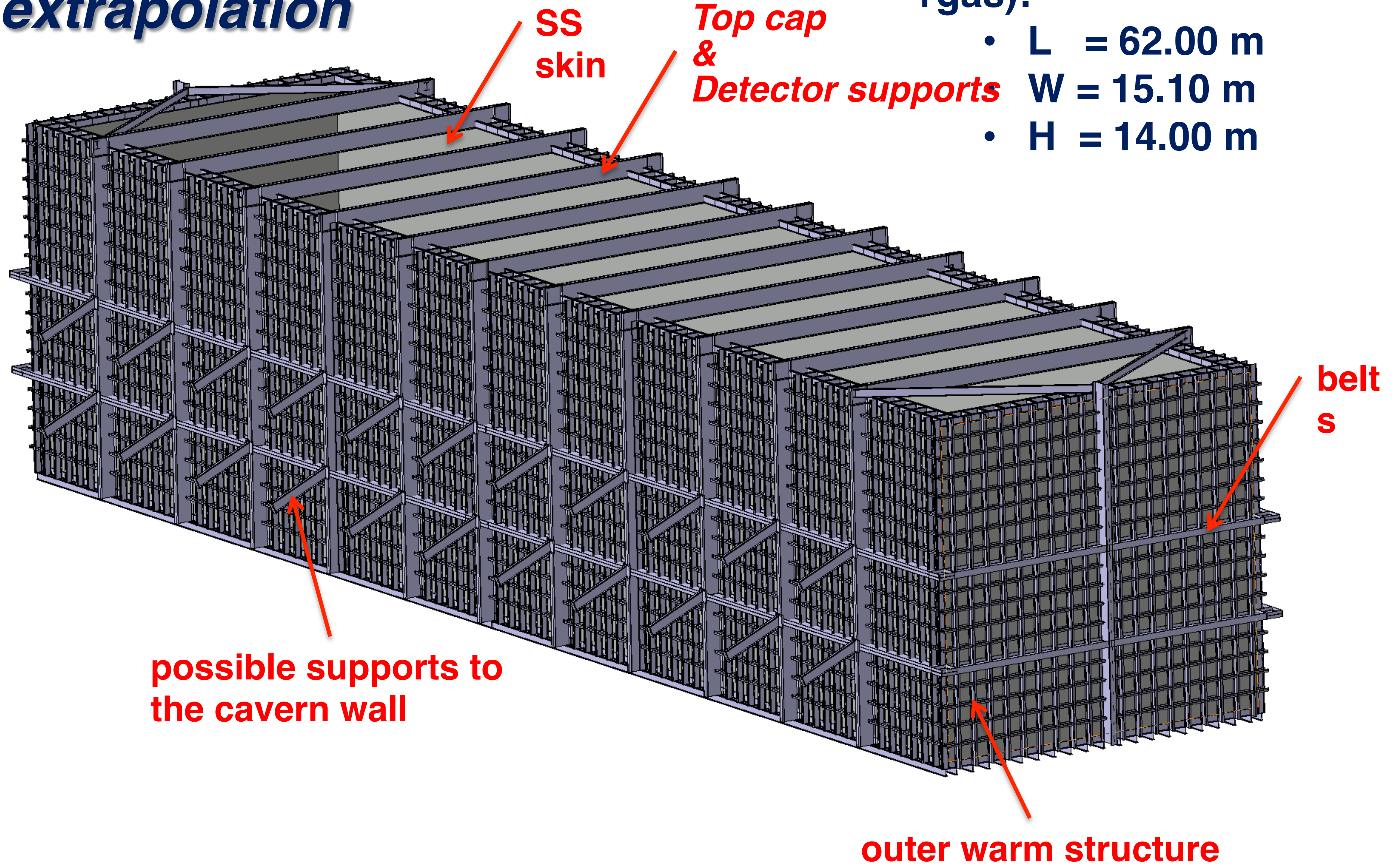
The stainless steel plates (form inside)



4 LBNF Cryostats extrapolation

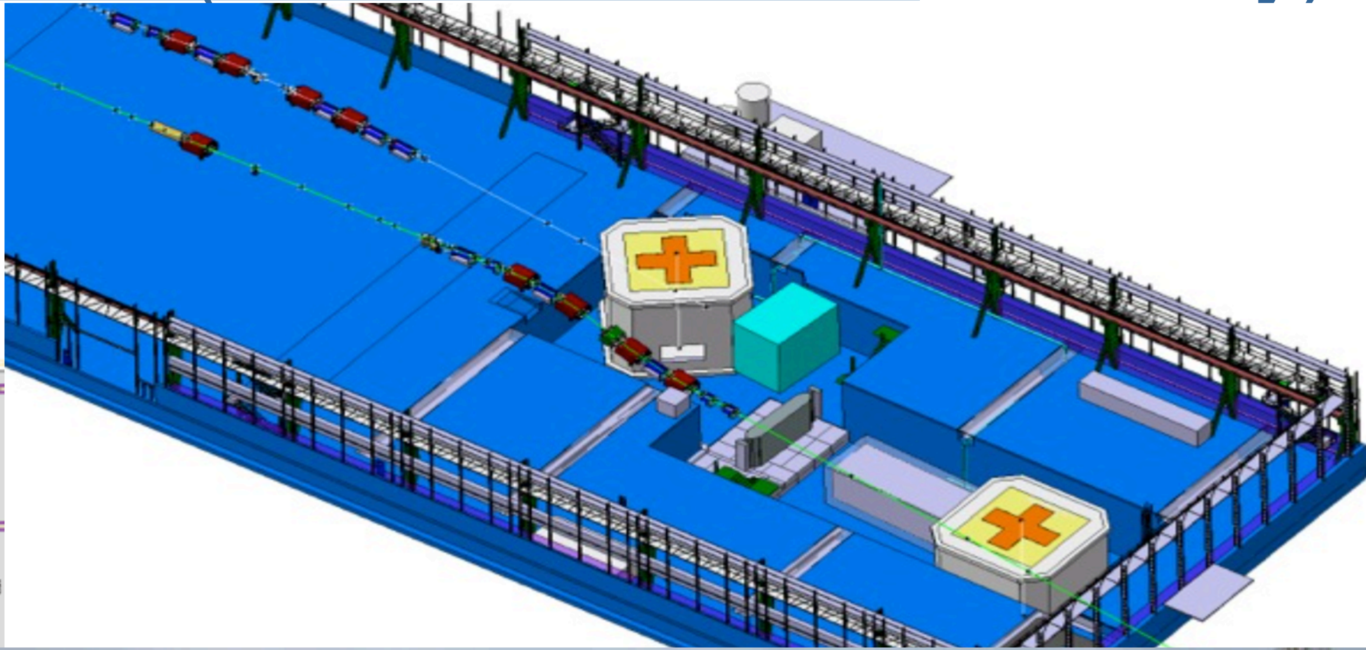
Inner dimension (liquid +gas):

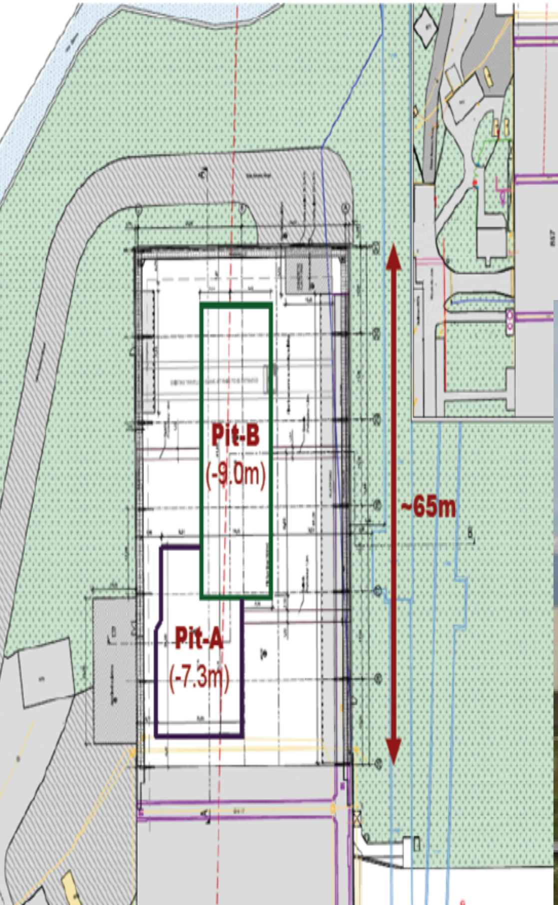
- L = 62.00 m
- W = 15.10 m
- H = 14.00 m



LAr = 17’432 tons (95% liquid)

EHN1 extension (test beam and test facility)

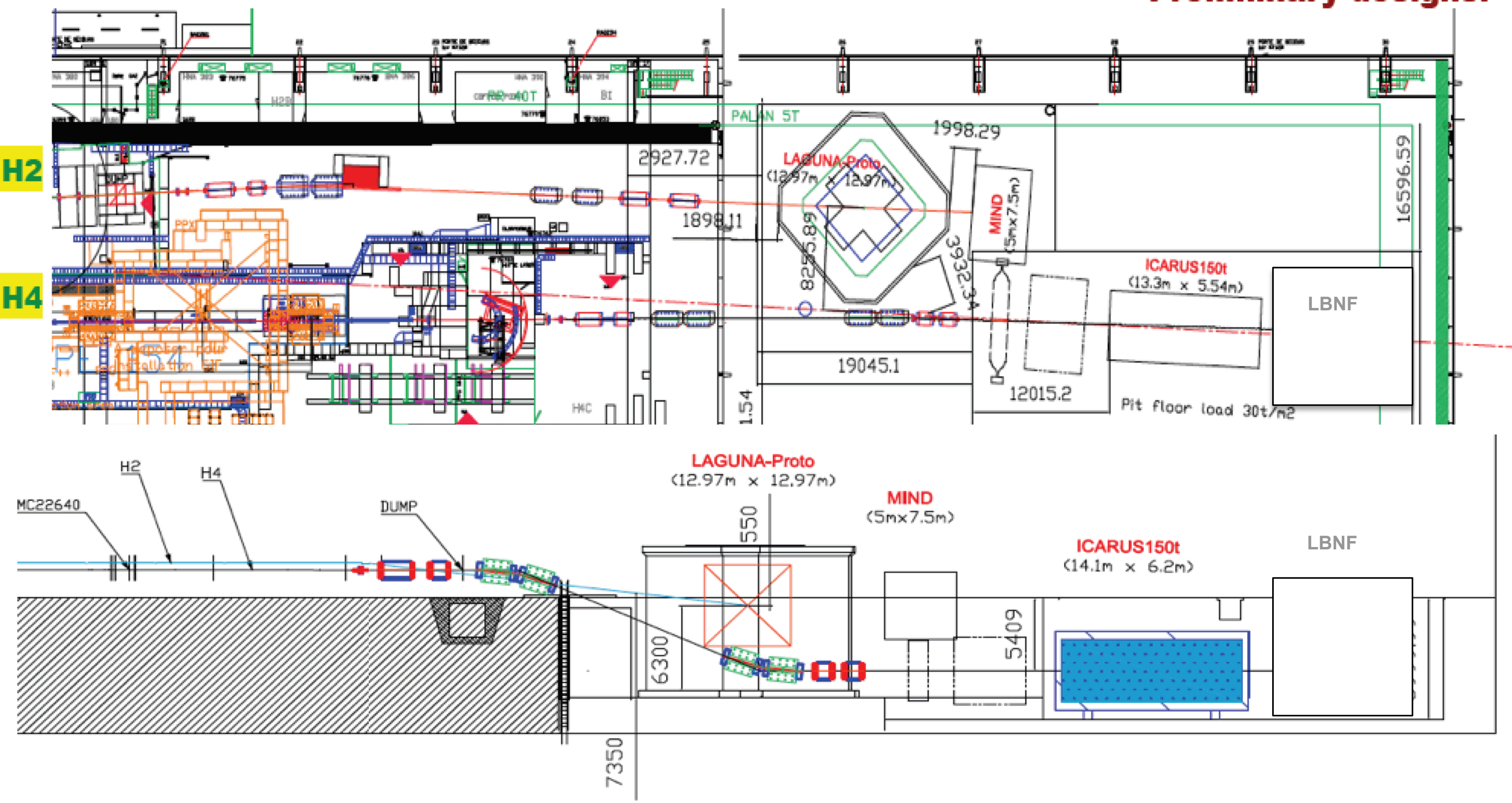




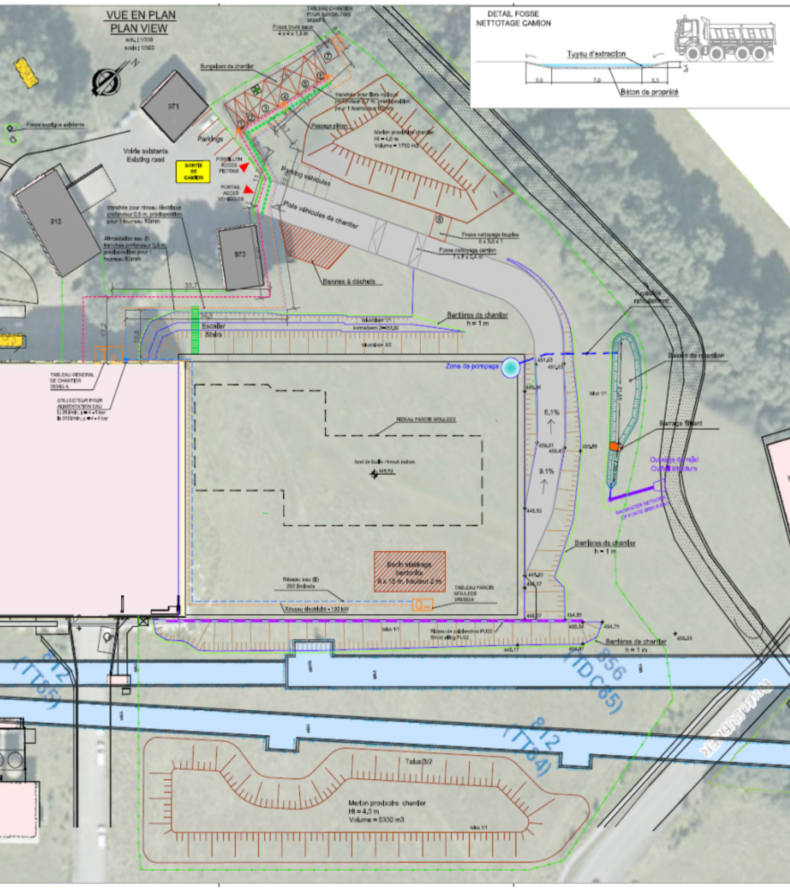
Charged tertiary beams

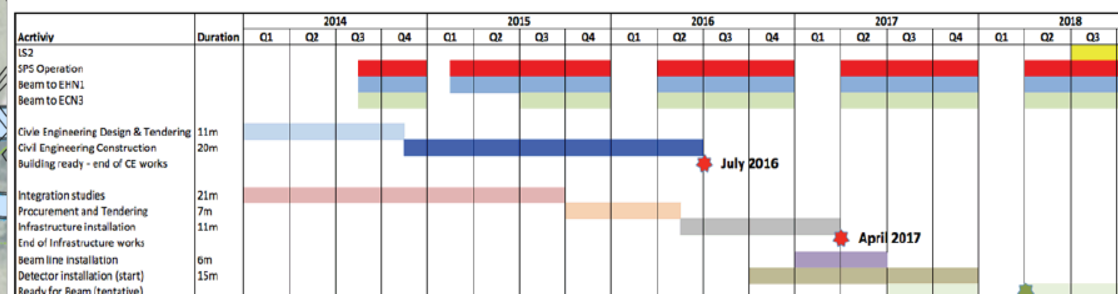
- H2 extension: **1-20 GeV/c**, hadrons ($\pi^{\pm}$, $\mu^{\pm}$, p - mixed beam), electrons($e^{\pm}$)
- H4 extension: **1-5(7) GeV/c**, hadrons ($\pi^{\pm}$, $\mu^{\pm}$, p - mixed beam), electrons($e^{\pm}$)
    - interest to go lower, down to 0.2 GeV beams for LBN TPC test

Preliminary designs!



EHN1 project status

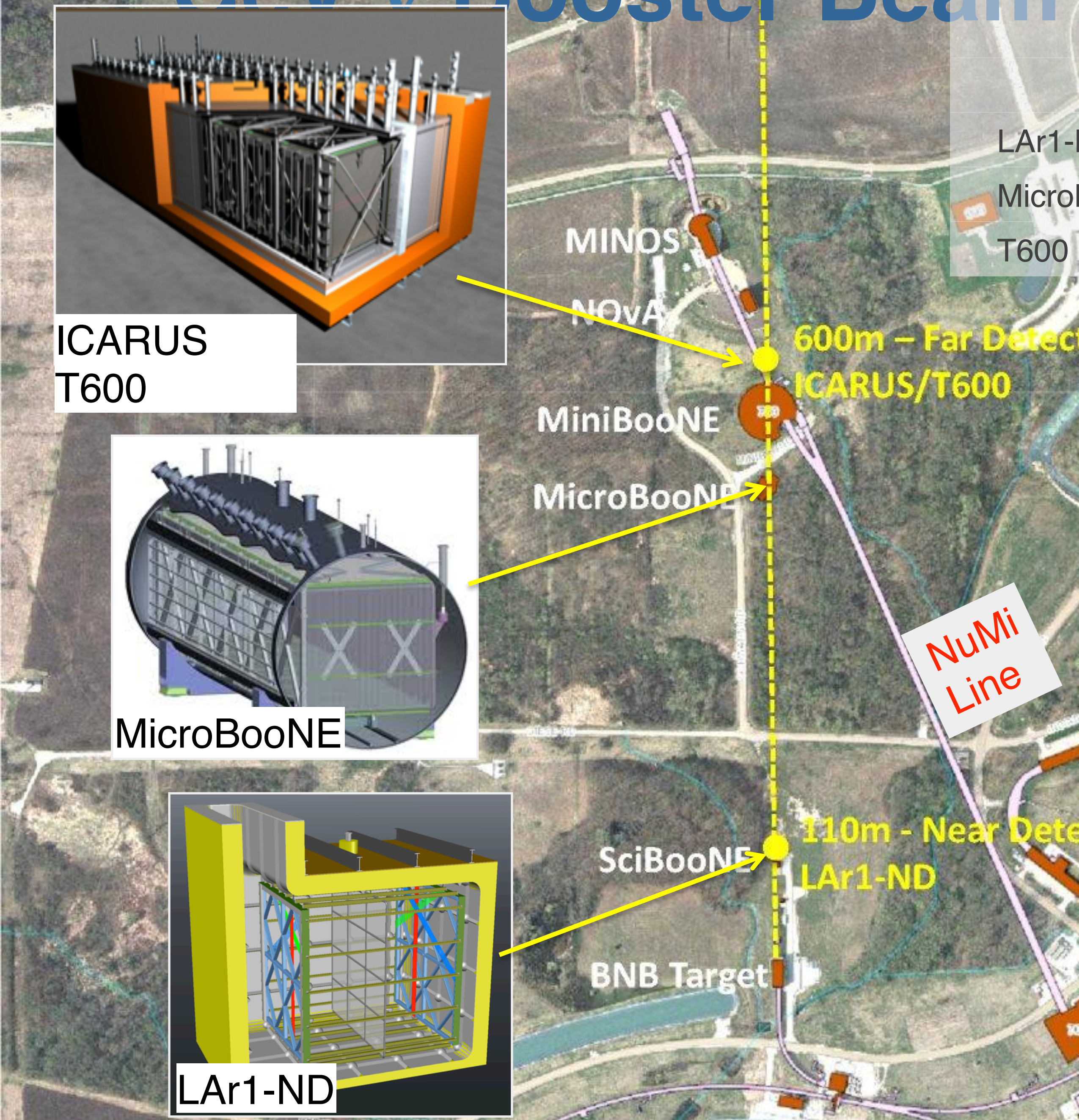




- Activities beyond CE construction are still tentati

- **Target dates:**
  - CE works completed : **July 2016**
  - Infrastructure completed : **April 2017**
  - Experiments ready for beam for **2017/2018 SPS run**

GeV ν Booster Beam



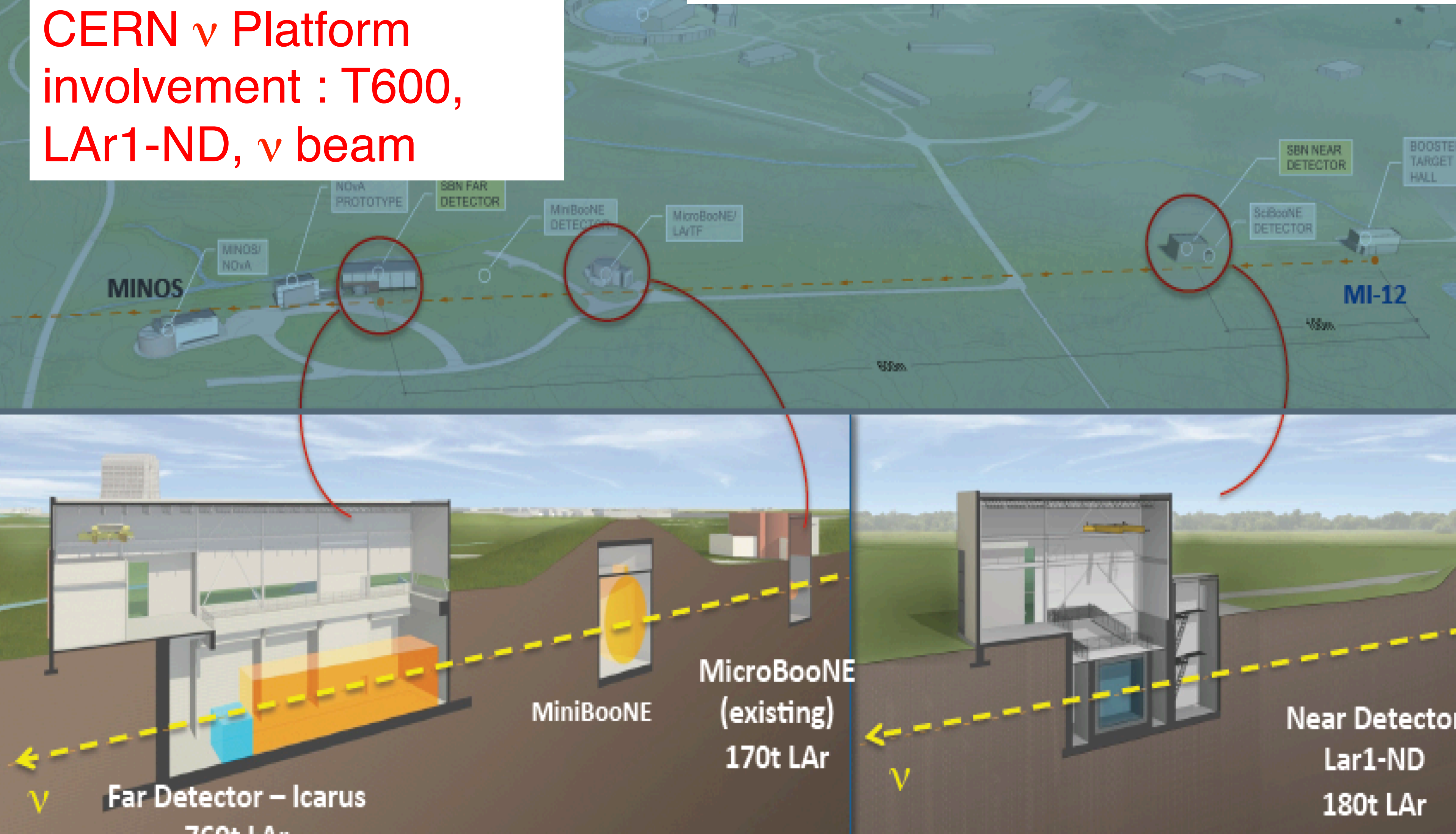
	LAr	Mass
	Total	Active
LAr1-ND	220t	112t
MicroBooNE	170t	89t
T600	760t	476t

– 8 GeV proton beam
– ν flux peaks ~700 MeV !
– Robust target and horn system!
– Neutrino fluxes well understood 10+ years of study by MiniBooNE and SciBooNE!
– Beam near surface (~10m) => modest civil construction cost!

The Committee *"recommends Stage 1 approval for the SBN program, which incorporates LAr1ND and ICARUS with MicroBooNE towards a coherent SBN program. We recommend that the laboratory provide the necessary engineering and technical resources to allow the program to move forward expeditiously, and to understand the scope of the Booster Neutrino Beamline modifications and improvements."*

FNAL PAC recommendation, 5 February 2015

CERN ν Platform involvement : T600, LAr1-ND, ν beam



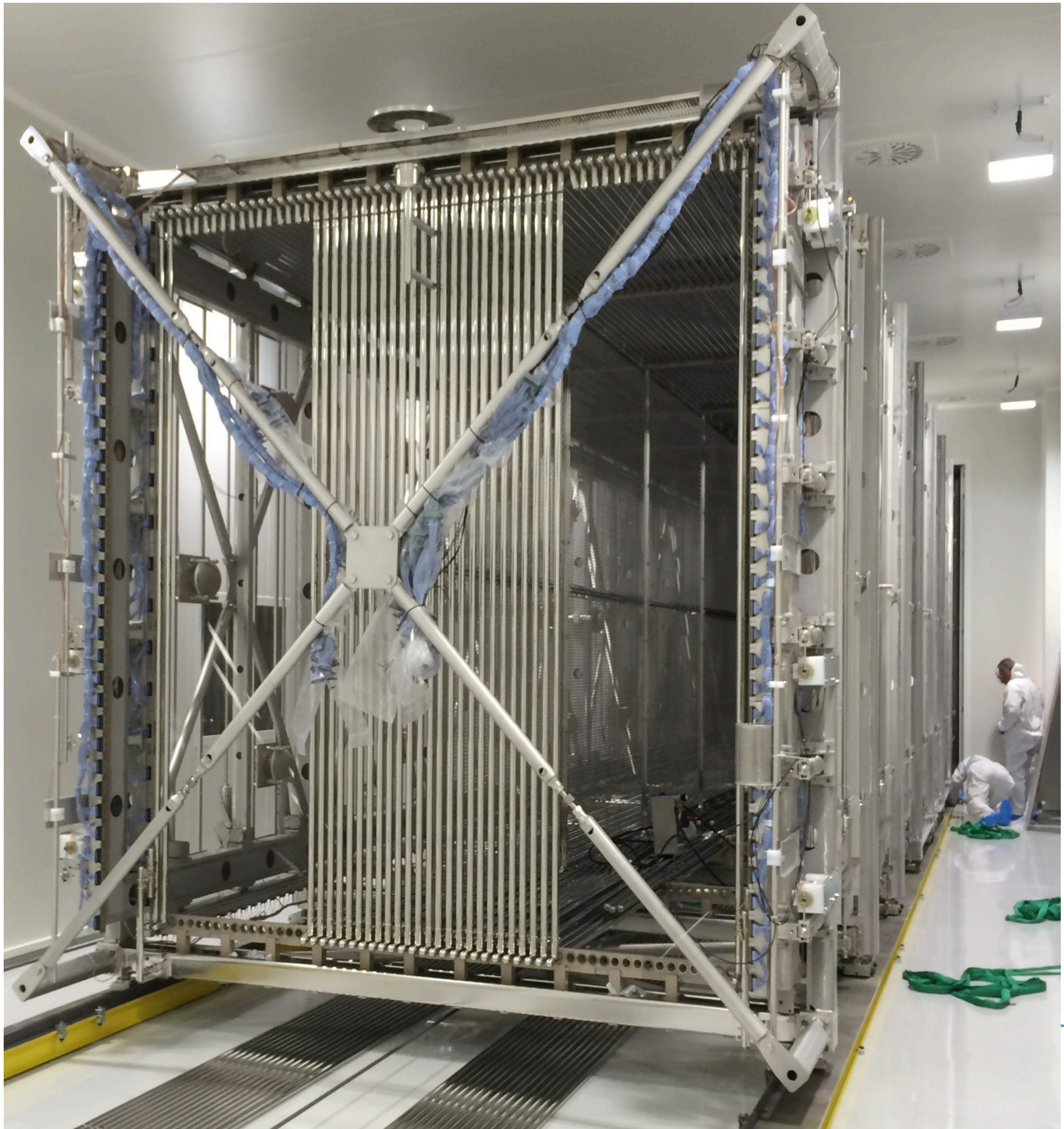
WA104 : ICARUS detector overhauling

- *Detector moved (2014) from the GS Laboratory to CERN*
- *Prepare at CERN all the necessary infrastructure (clean rooms, cryogenics, …)*
- *Reshape the detector with new components (more PMTs, fix cathode, new inner cabling, new electronics ?, ..)*
- *Construct a new generation of cold cryostats*
- *Reshape, maintain and modernize the cryogenics plant*
- *Reassemble the 2 T300 detectors inside their cryostats*
- *Construct a new outer vessel*
- *Make it ready for shipment to FNAL*

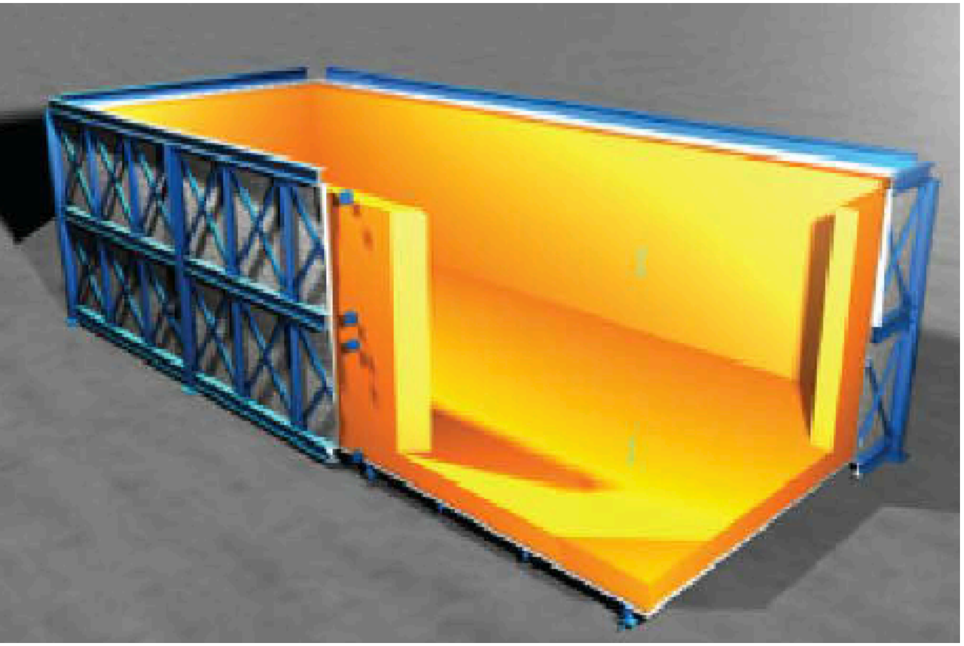
ICARUS Detector dismantling at LNGS

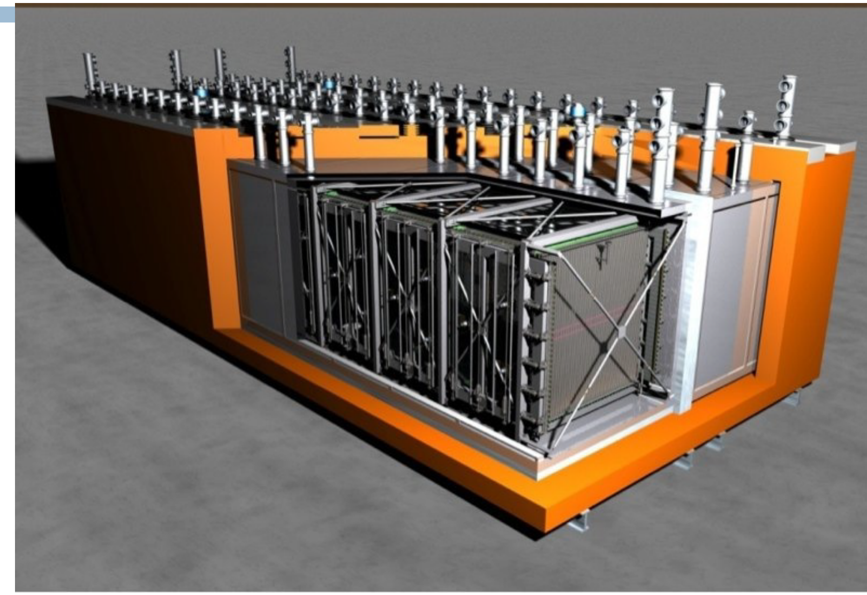
and moving to CERN (10 days trip)

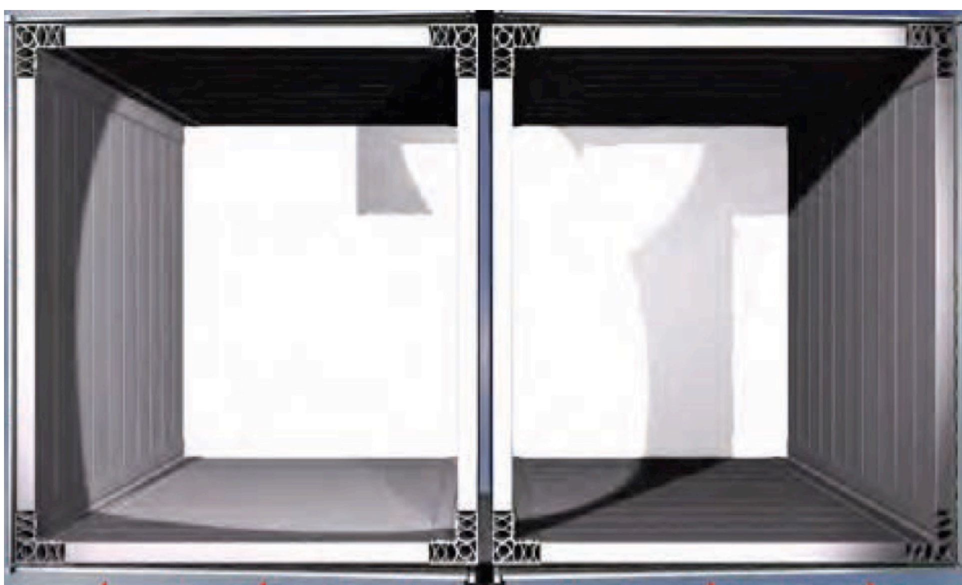
...now in the CERN dedicated clean room

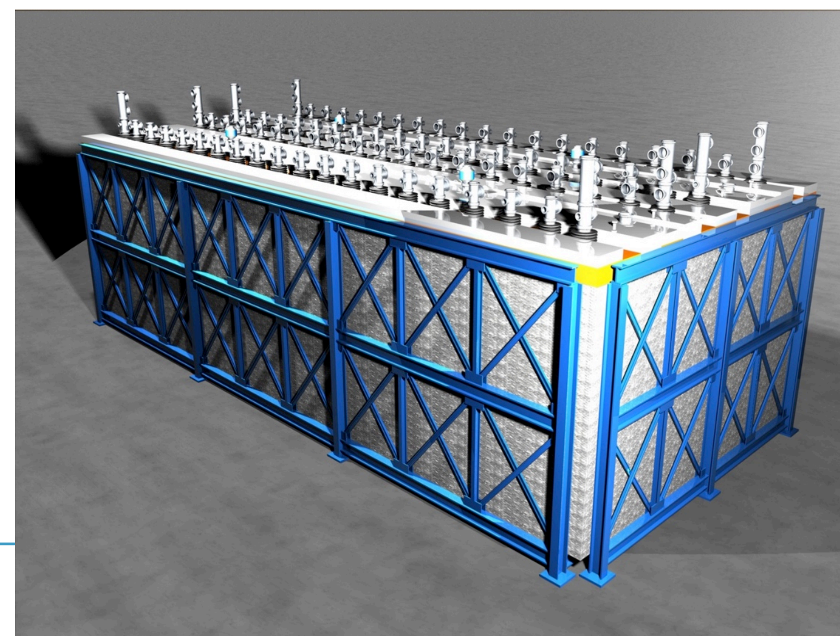


ICARUS Cryostat





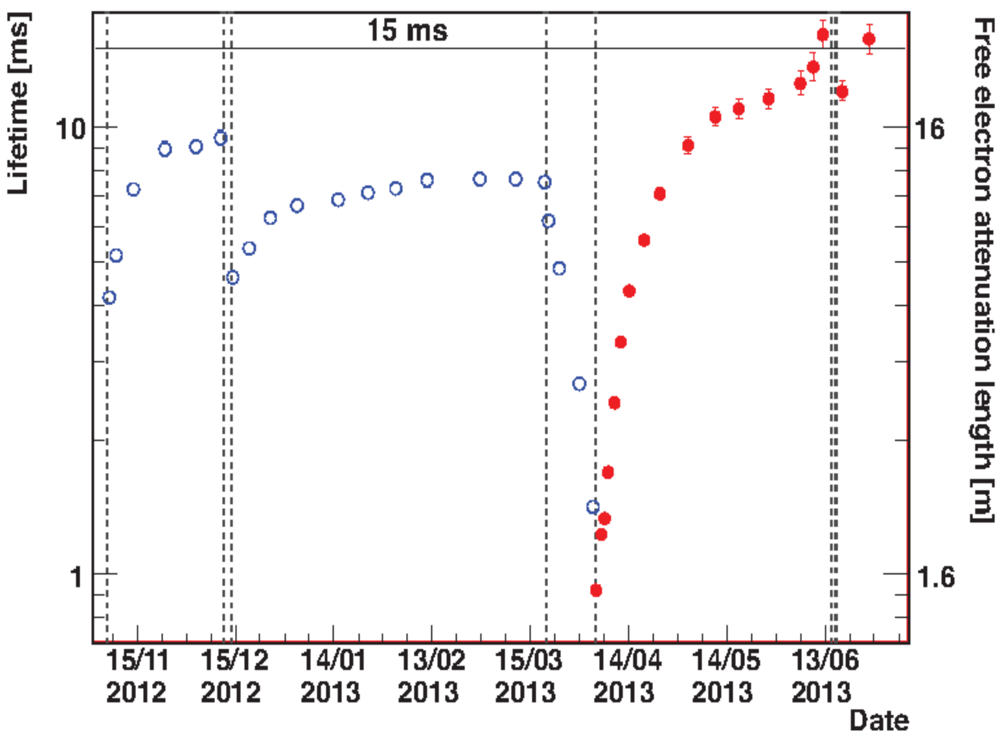


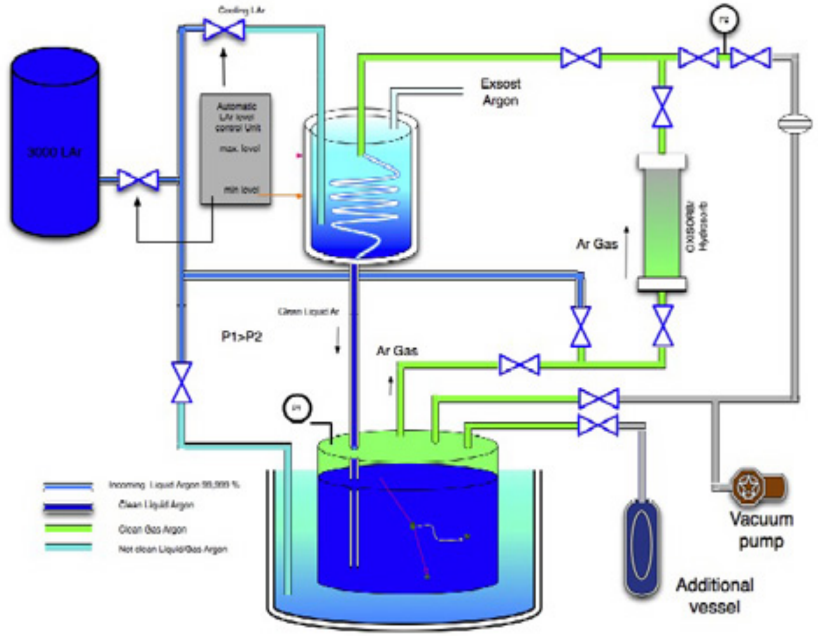


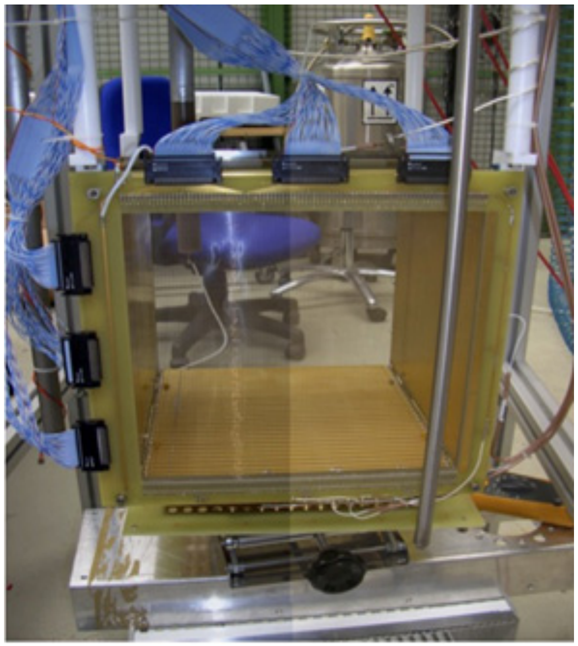
New purity achievements

- LBNF requires: τ_{ele}>12 ms and E_{drift} = 0.5kV/cm for 15% attenuation at 3.0 m,
- The result in Icarino is τ_{ele} ≈21 ms corresponding to ≈15 ppt, namely a ≈10^{-11} molecular Oxygen eq. impurity.

T600







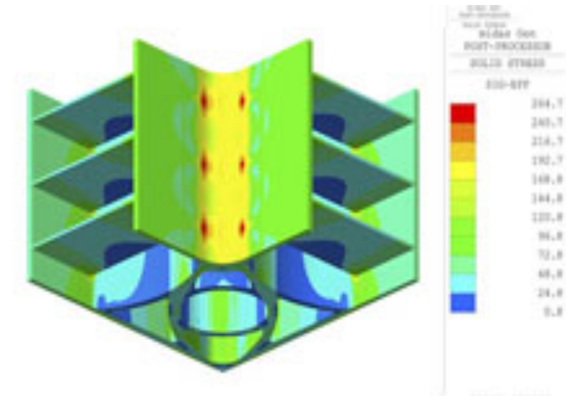
R&D-4: New cold bodies design

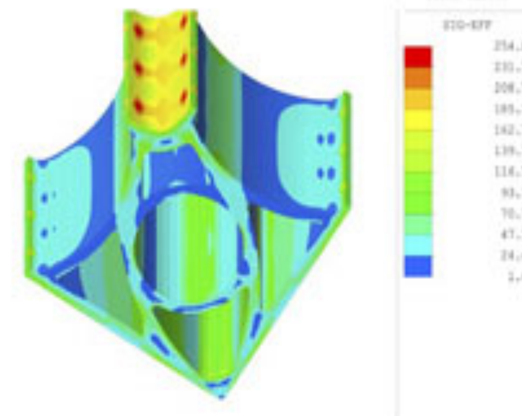
The new cold bodies design, to the Milano Politecnico (Finzi e Associati).

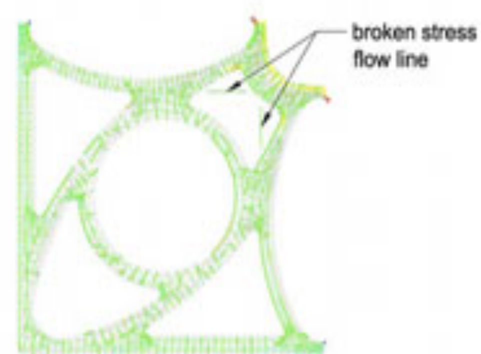
Work is progressing:

- Detailed modeling of the aluminum profiles (complete).
- Compute behavior under the several loading conditions (complete)
- Optimization of the aluminum profiles (done)
- Define assembly and welding procedures (in progress)
- Verify time scale and construction cost (in progress)

This solution could represent a valid alternative to membrane (as originally foreseen for MODULAr) for LAr containment.

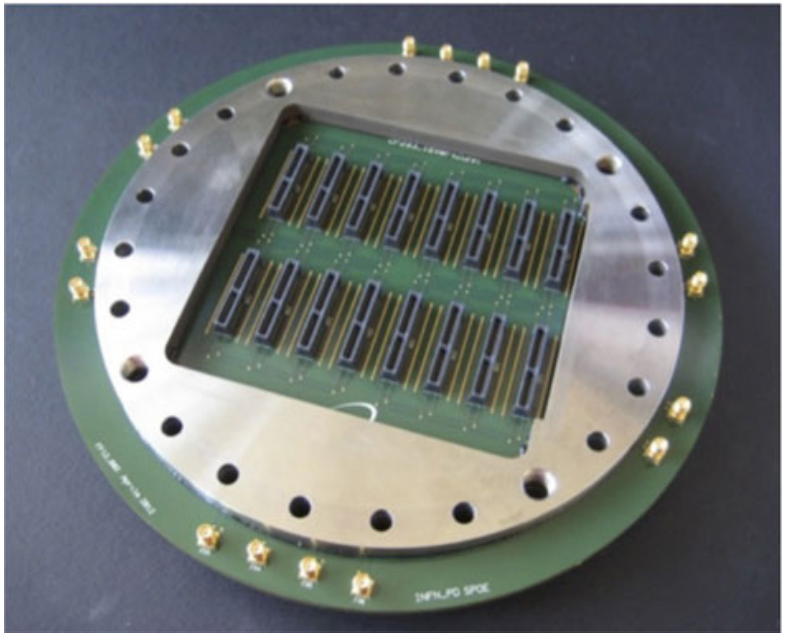




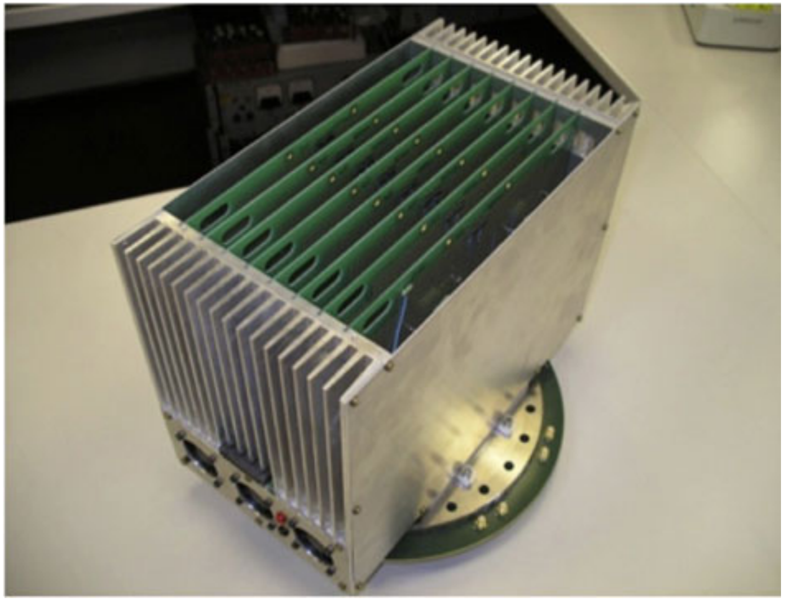


The flange as electronics backplane

- Multiplicity has been reduced to 16 cables (512 channels) to allow for more space among connector rows and permitting the use of the external side of the flange as electronic cards backplane in a special crate.

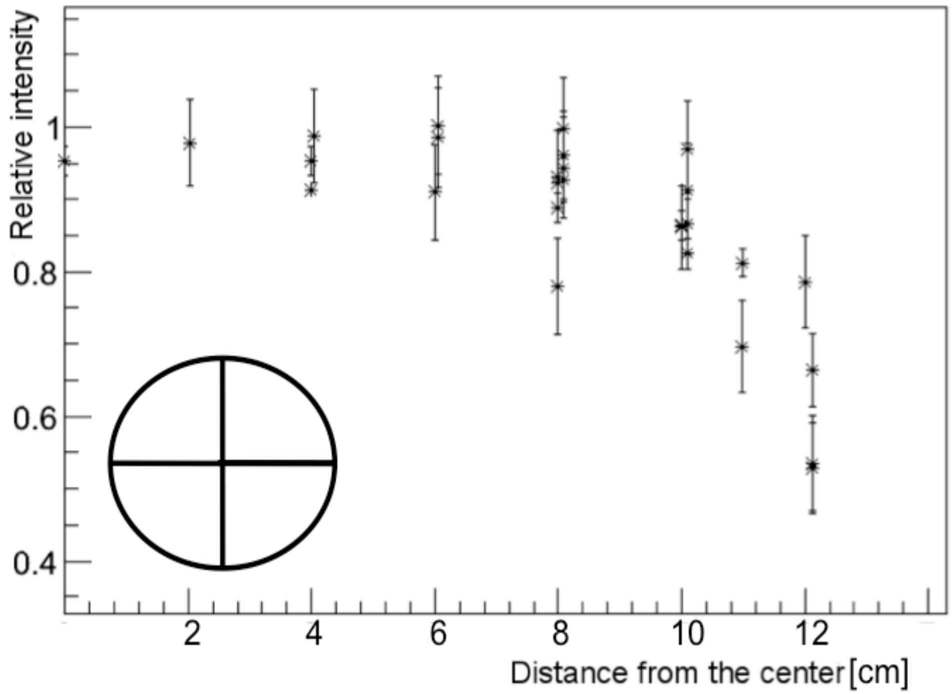


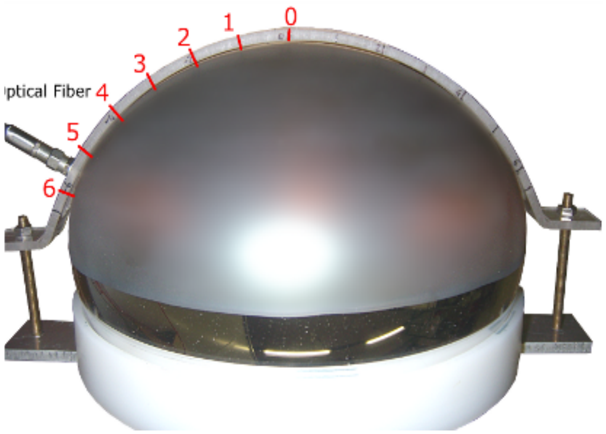
- The connectors on the external side allow for direct insertion of electronics boards where both analogue and digital electronics, with a compact design, are housed.



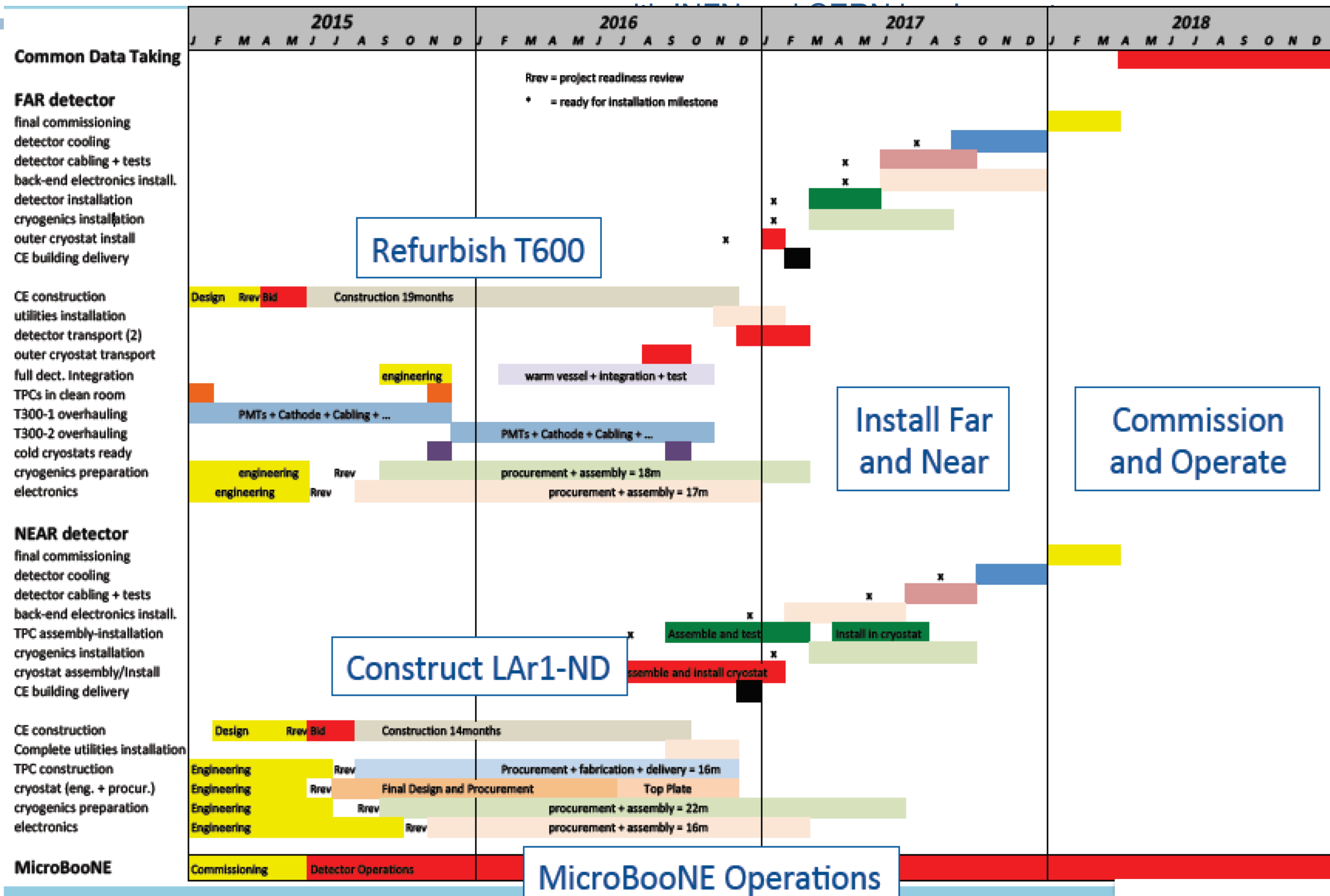
Response uniformity

- Example of response uniformity of HAMAMATSU R5912 series.



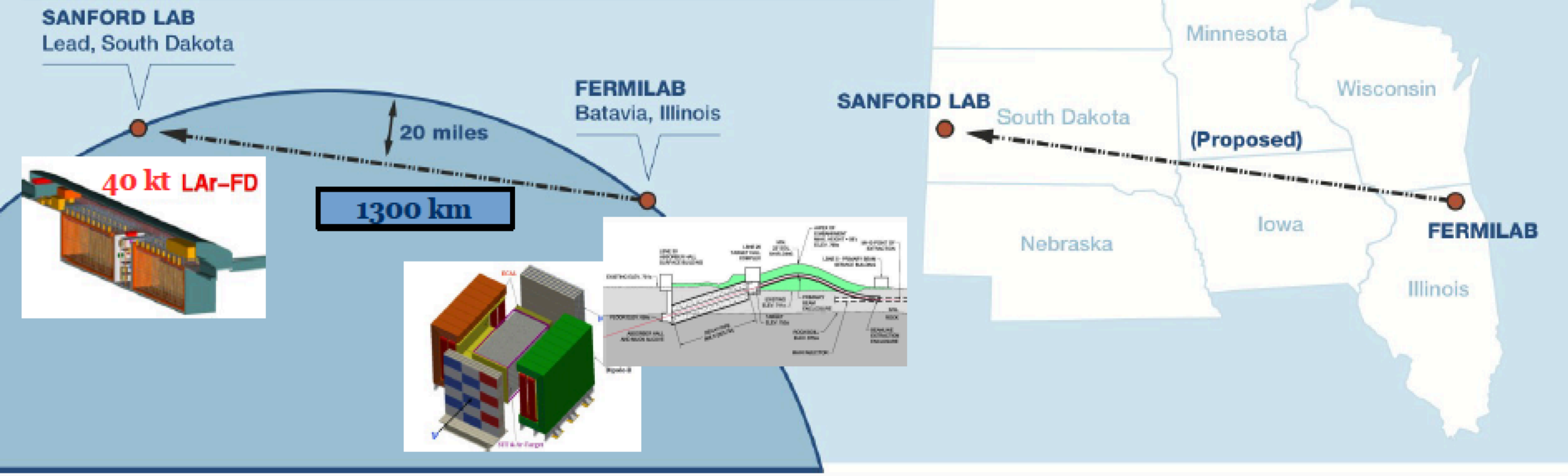


- Measurements are carried on by illuminating the PMT windows in different positions, with an optical fiber. Data in figure are normalized to the response in the central position.



2015
2016
2017
2018
J F M A M J J A S O N D
Rrev = project readiness review
* = ready for installation milestone
Common Data Taking
FAR detector
final commissioning
detector cooling
detector cabling + tests
back-end electronics install.
detector installation
cryogenics installation
outer cryostat install
CE building delivery
Refurbish T600
CE construction
Design
Rrev
Bid
Construction 19months
utilities installation
detector transport (2)
outer cryostat transport
full dect. Integration
engineering
warm vessel + integration + test
TPCs in clean room
T300-1 overhauling
PMTs + Cathode + Cabling + ...
T300-2 overhauling
PMTs + Cathode + Cabling + ...
cold cryostats ready
cryogenics preparation
engineering
Rrev
procurement + assembly = 18m
electronics
engineering
Rrev
procurement + assembly = 17m
Install Far and Near
Commission and Operate
NEAR detector
final commissioning
detector cooling
detector cabling + tests
back-end electronics install.
TPC assembly-installation
Assemble and test
Install in cryostat
cryogenics installation
cryostat assembly/Install
ssemble and Install cryostat
CE building delivery
Construct LAr1-ND
CE construction
Design
Rrev
Bid
Construction 14months
Complete utilities installation
TPC construction
Engineering
Rrev
Procurement + fabrication + delivery = 16m
cryostat (eng. + procur.)
Engineering
Rrev
Final Design and Procurement
Top Plate
cryogenics preparation
Engineering
Rrev
procurement + assembly = 22m
electronics
Engineering
Rrev
procurement + assembly = 16m
MicroBooNE
Commissioning
Detector Operations
MicroBooNE Operations

Experiment at the Long-Baseline Neutrino Facility



- Protons from Main Injector, new νμ beam line
- Precision near detector (ND)
- Massive underground far detector (FD)
  - – LAr TPC, integrated optical photon detection system, 40Kt
  - – 1300 km baseline
  - – first beam in 2024-25, 1.2 MW, then >2 MW

sensitive to several oscillation parameters:

→ Mass Hierarchy (MH), δ_{CP} (CPV), θ_{23} octant, θ_{13}

Also sensitive to atmospheric neutrinos, super Nova events and to proton decay.

Our (Platform) spectrum of activities (medium term)

Large scale demonstrators

- Single Phase LAr TPC
- *Double Phase LAr TPC*

Infrastructure

- *cryostats*
- *cryogenics*

Beam component R&D

- *Secondary ν beam components*
- *Primary proton beam accelerator components*

Generic ν detector R&D

- *New TPCs*
- *Magnetic near detector (TPC)*
- *Various components (H2O, Sci, LAr)*
- *Muon spectrometers*

Two phases LAr TPC

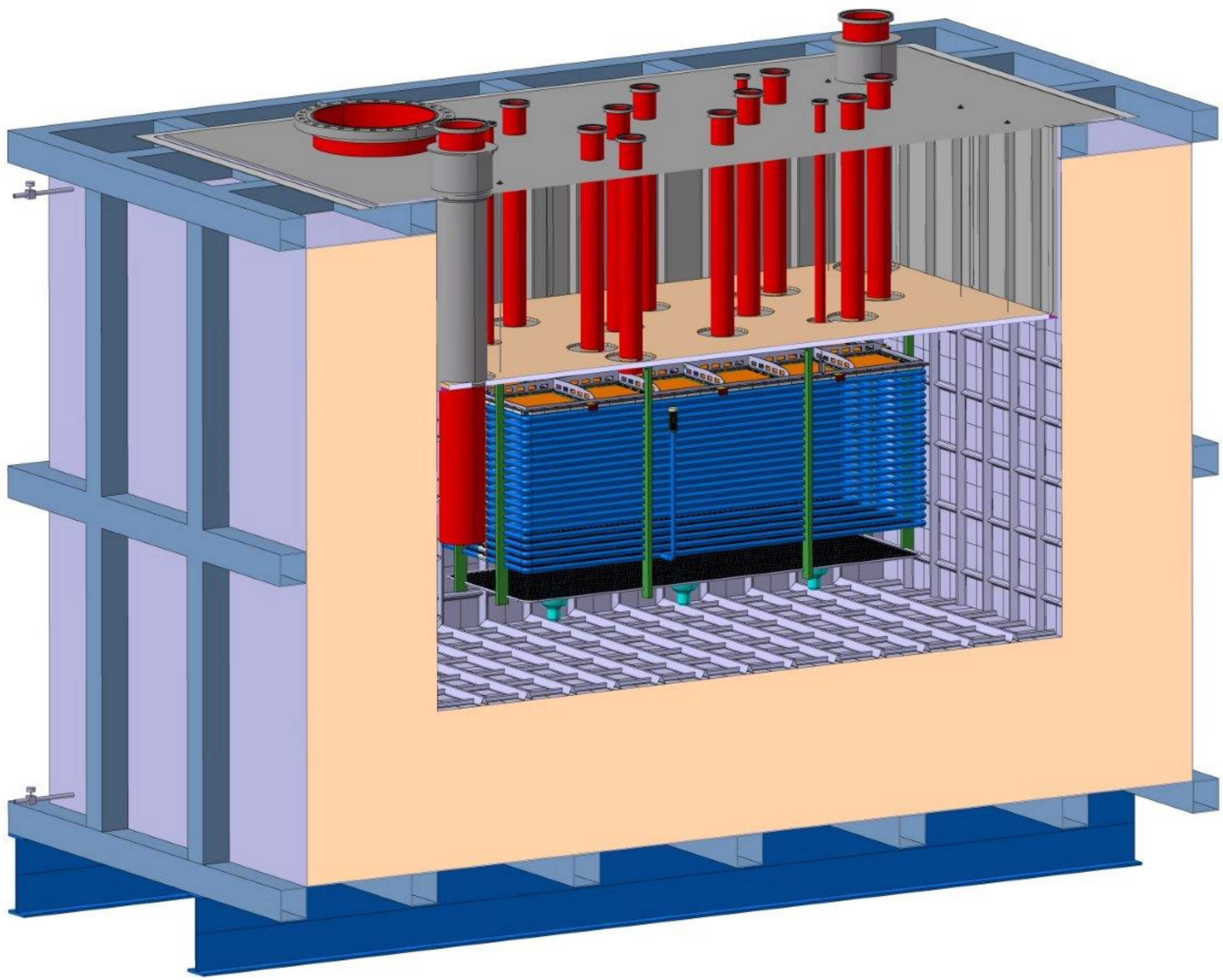
- WA105 (previous LAGUNA) Collaboration
- Long drifts possible because signal amplification in the gas phase (LEM technique)
- Optimal use of the LAr mass (effective mass)

→ Need large demonstrators before implementation in LBNF

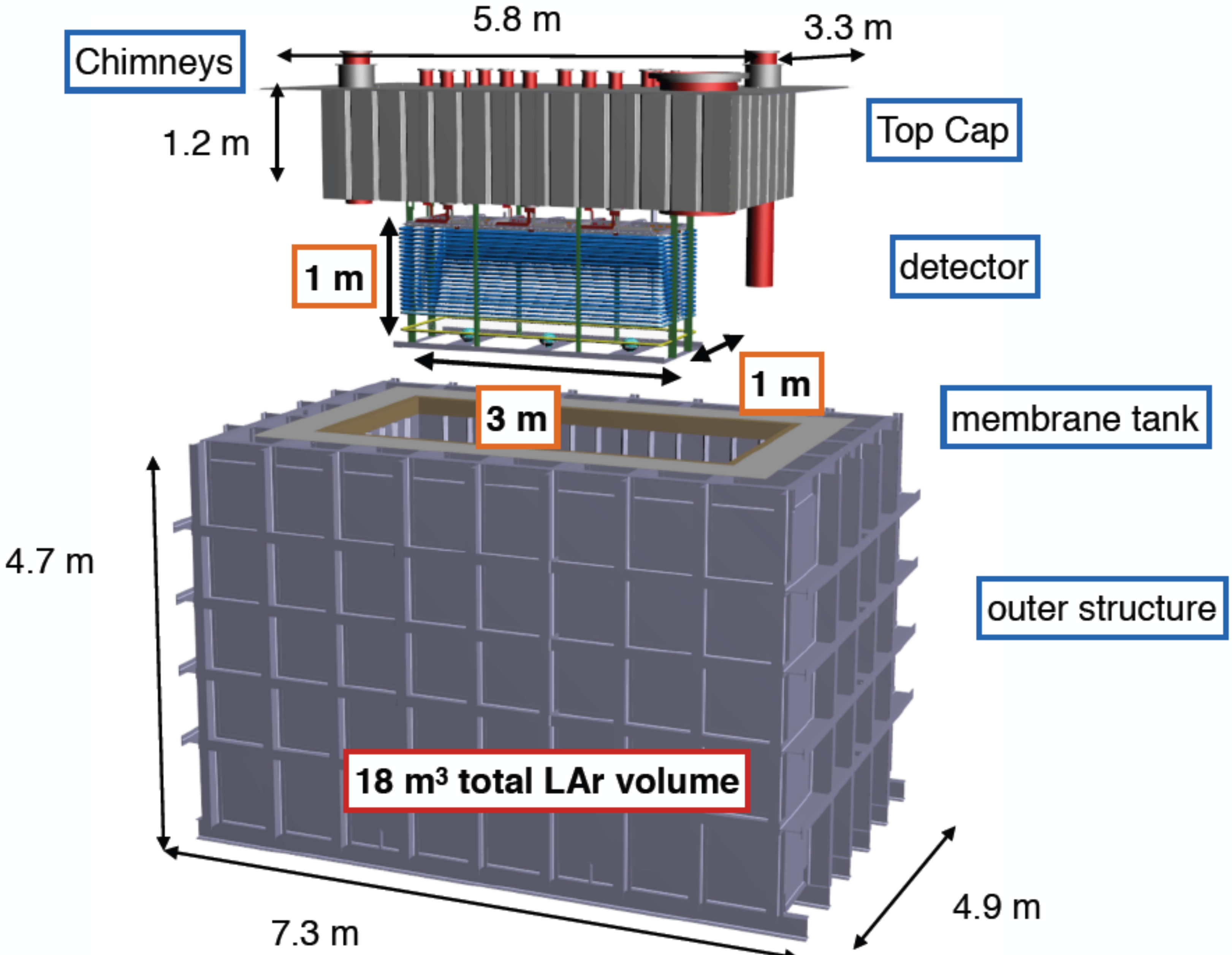
Two phases LAr TPC

- *Prepare at CERN all the necessary infrastructure*
- Construct a new generation of cryostats based on membrane technology
- *Provide all the necessary cryogenics*
- Construct and test 2 prototypes of a 2-phases LAr TPC
  - 3 x1 x 1 m^3
  - 6 x 6 x 6 m^3
- *Charged beam tests at the SPS with full readout capabilities*

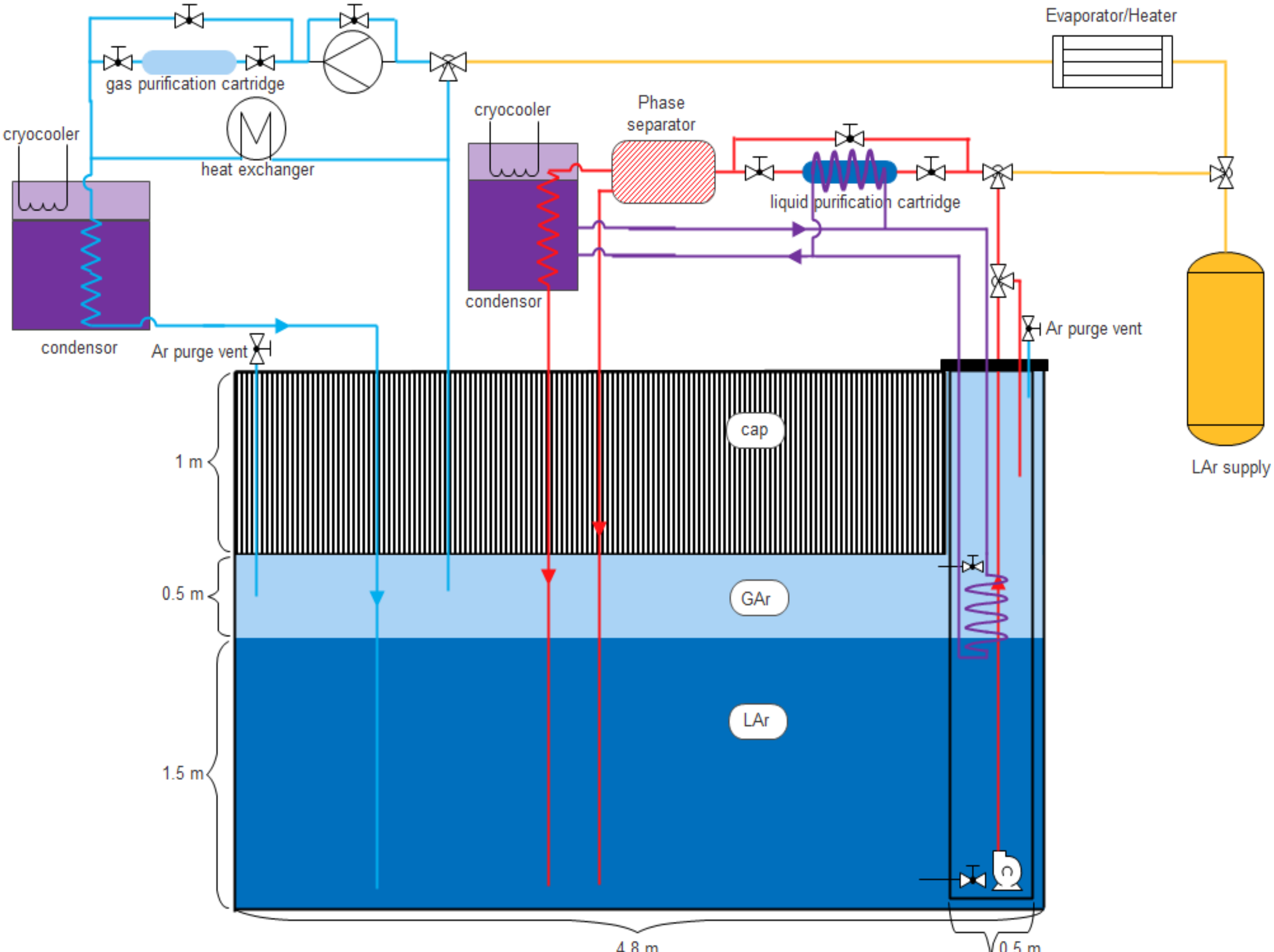
First 2 phases prototype under construction ready in Fall 2015, 17 m^3 LAr)



WA105 $3x1x1m^3$

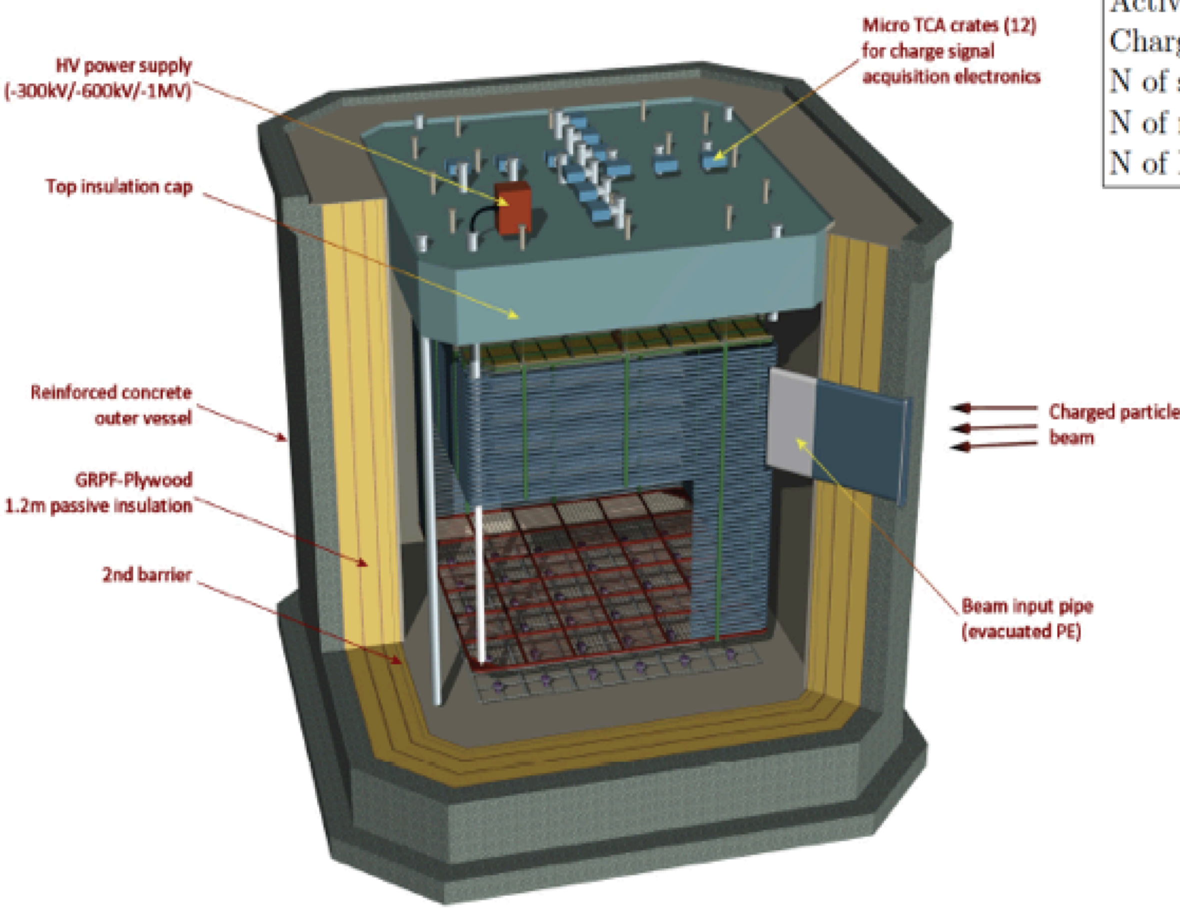


First 2 phases prototype ready in Fall 2015

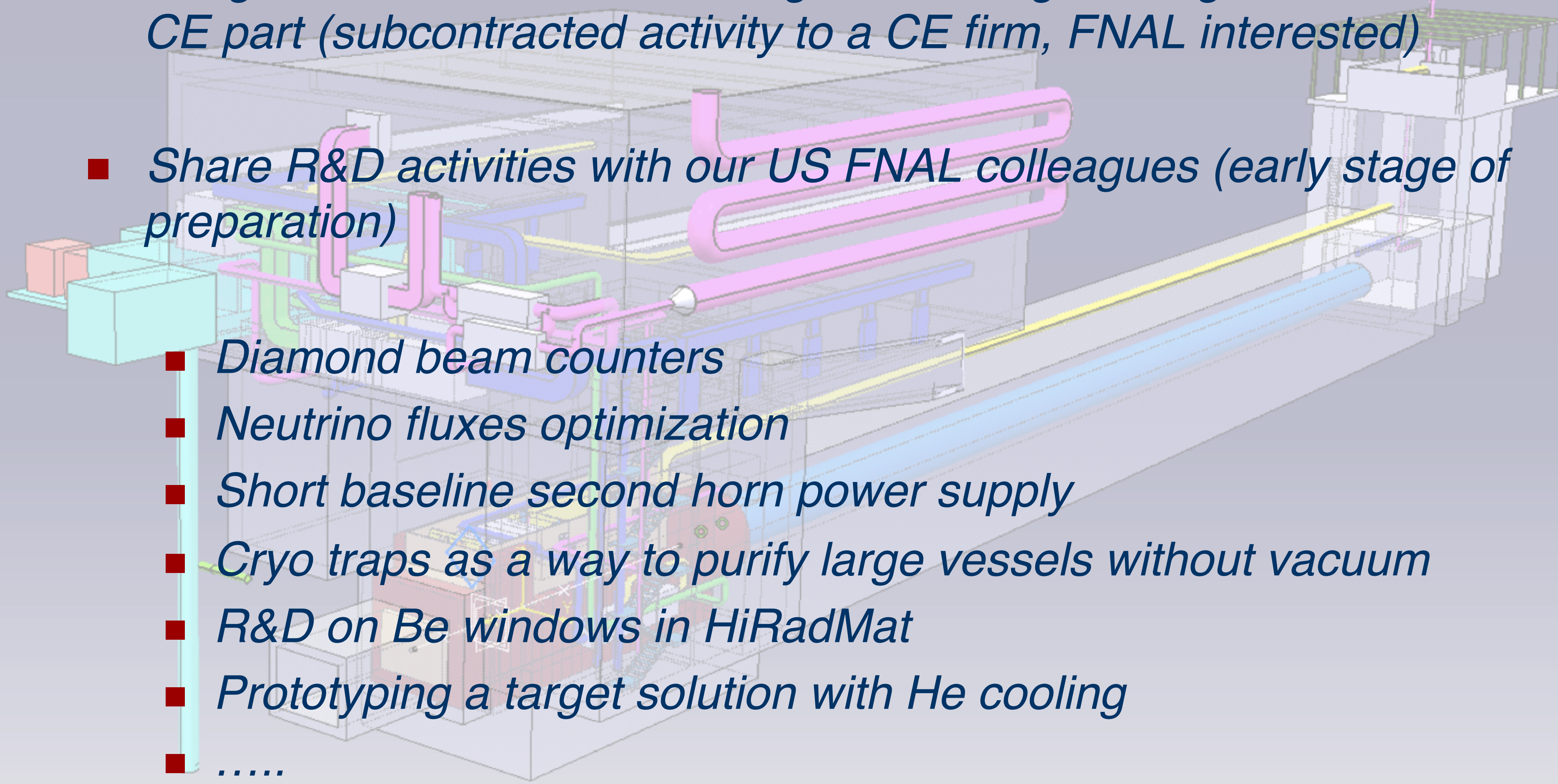


WA105 large demonstrator (2 phases LAr TPC)

Liquid argon density	T/m^3	1.38
Liquid argon volume height	m	7.6
Active liquid argon height	m	5.99
Hydrostatic pressure at the bottom	bar	1.03
Inner vessel size (WxLxH)	m^3	$8.3 \times 8.3 \times 8.1$
Inner vessel base surface	m^2	67.6
Total liquid argon volume	m^3	509.6
Total liquid argon mass	t	705
Active LAr area	m^2	36
Charge readout module (0.5 x0.5 m^2)		36
N of signal feedthrough		12
N of readout channels		7680
N of PMT		36



Neutrino Beam lines activities



- *Bring the CENF functional design at the engineering level for the CE part (subcontracted activity to a CE firm, FNAL interested)*

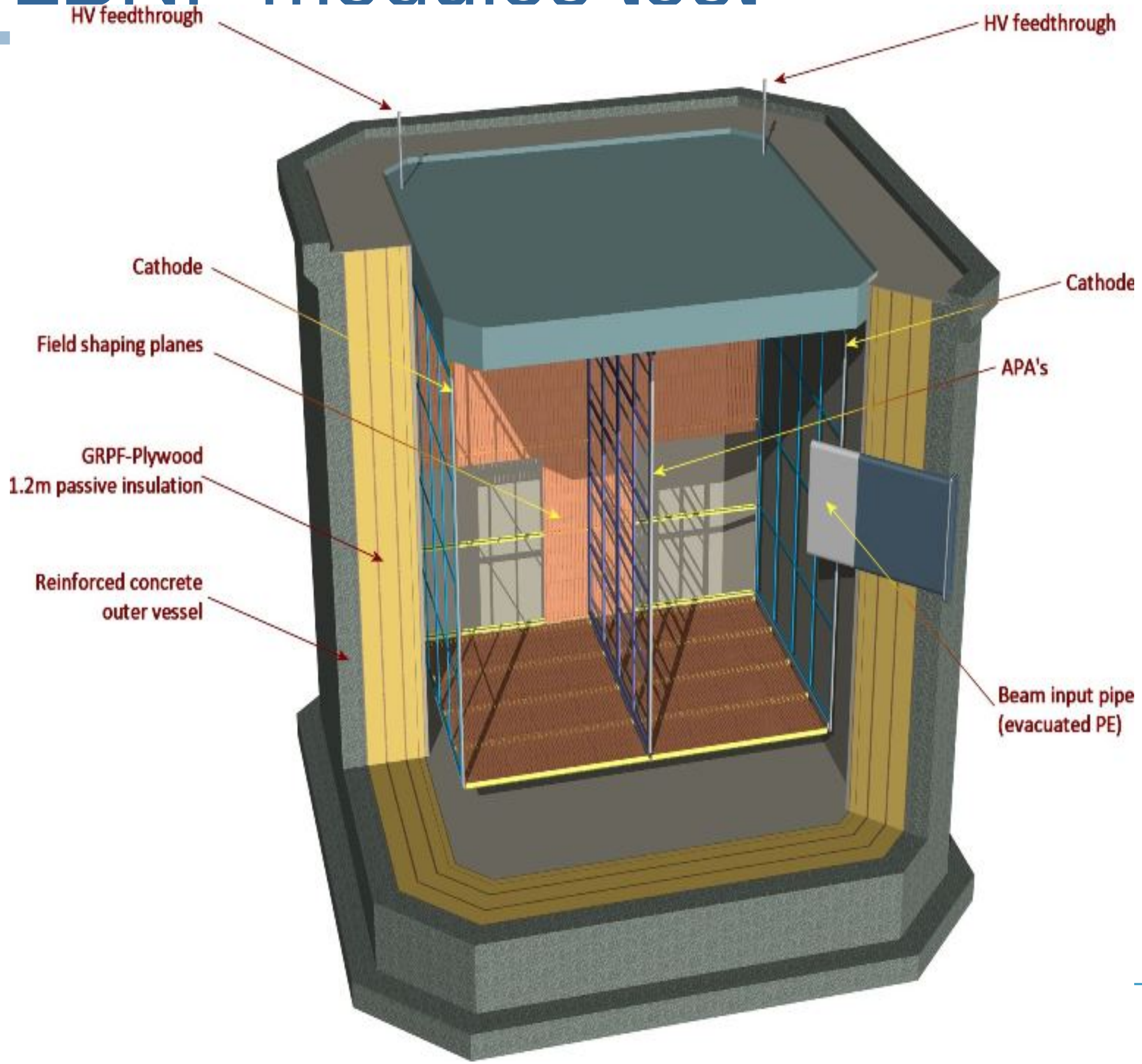
- *Share R&D activities with our US FNAL colleagues (early stage of preparation)*
  - *Diamond beam counters*
  - *Neutrino fluxes optimization*
  - *Short baseline second horn power supply*
  - *Cryo traps as a way to purify large vessels without vacuum*
  - *R&D on Be windows in HiRadMat*
  - *Prototyping a target solution with He cooling*
  - *…..*

Detector Projects presently under consideration

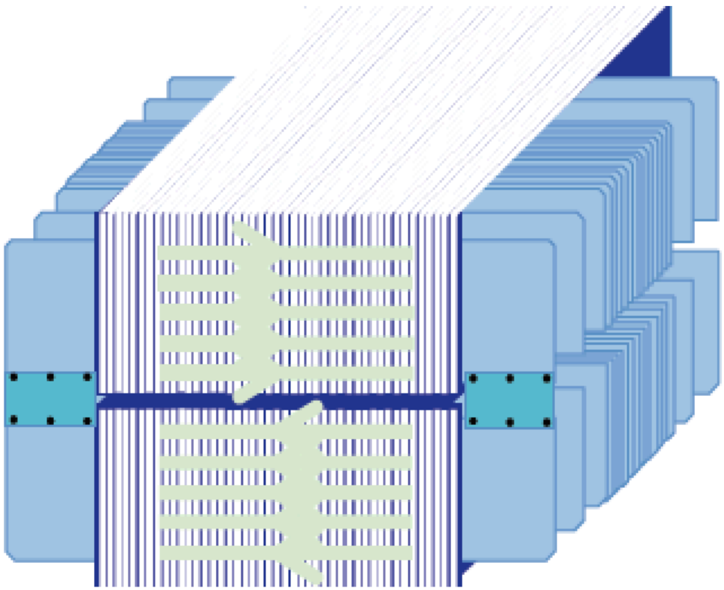
SPSC

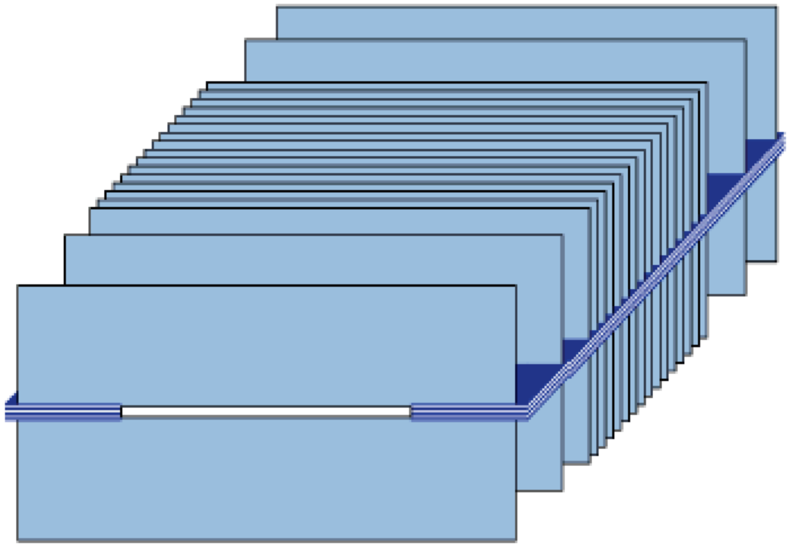
- *WA104 NESSiE R&D and test of a new generation of muon spectrometers*
- *Baby MIND : demonstrator and test of a new muon tracking detector (T2K, ND-HKK?)*
- ***LBNF test of a TPC module***
- *ArgonCube : prototypes of a new generation of highly modular TPCs*
- *HKK : R&D and test of detector components (EU)*
- *Construction and test of a new magnetized TPC (future ND ?)*
- *Participation in the design and construction of LAR1-ND cryostat and cryo plant*

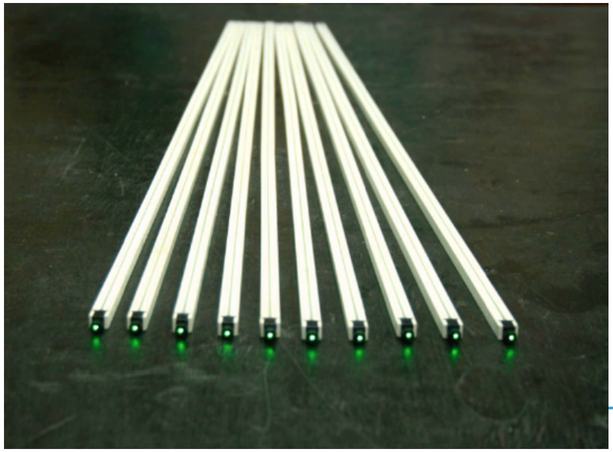
LBNF modules test

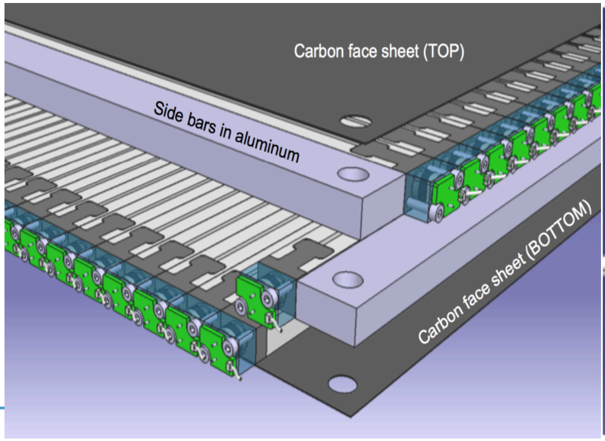


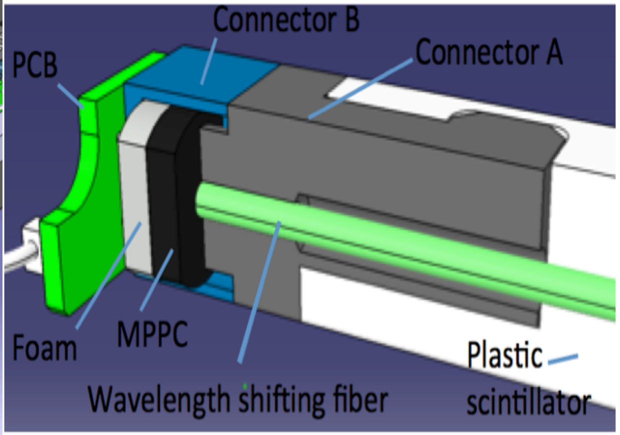
Baby MIND detector/spectrometer



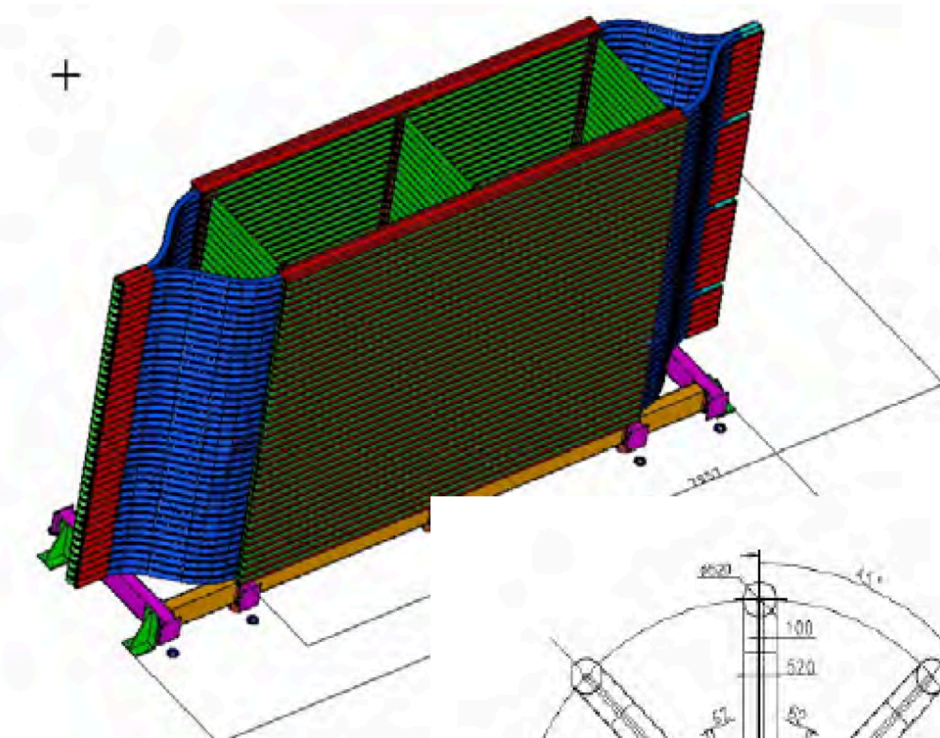


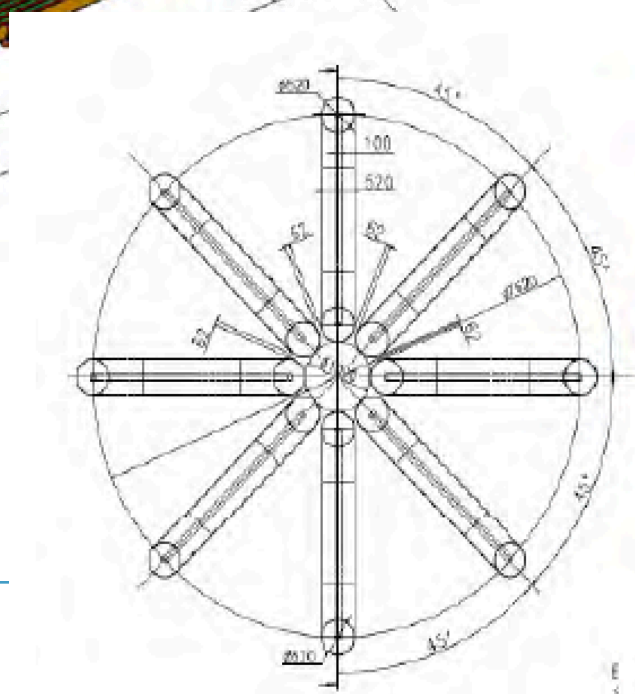


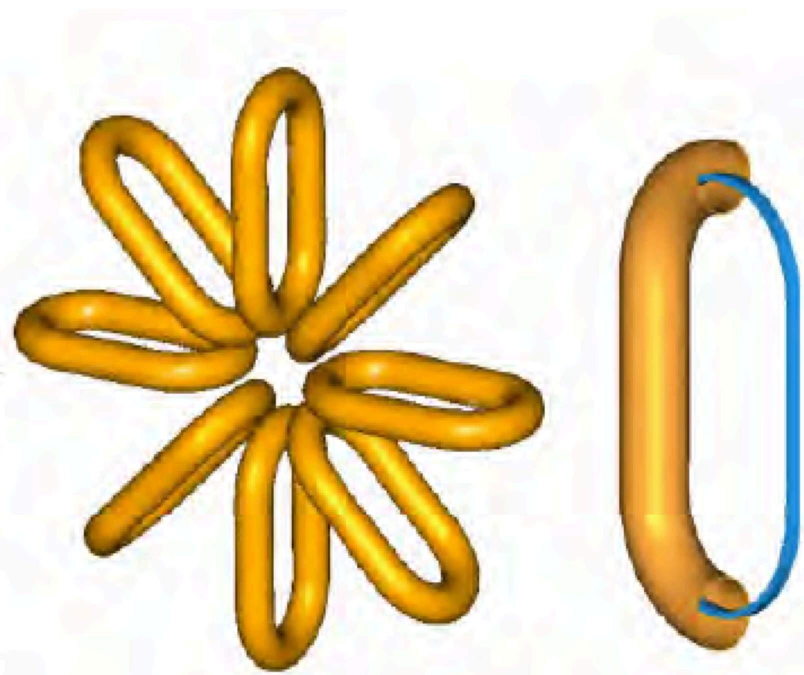




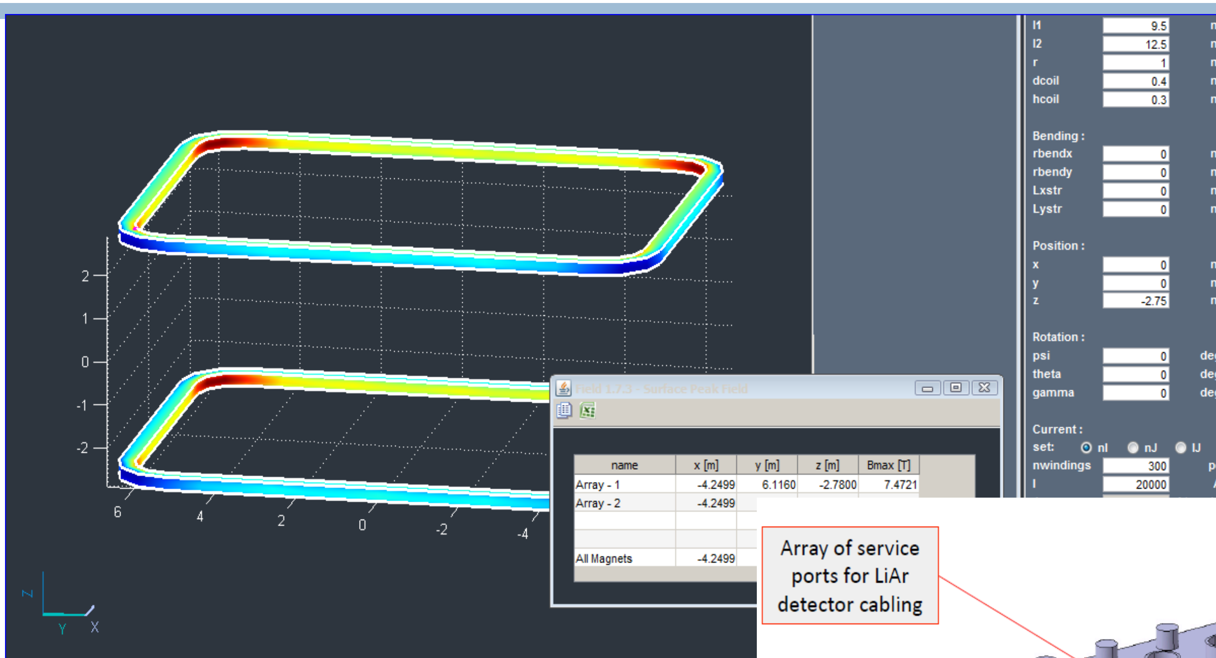
Air core magnets R&D (NESSIE)

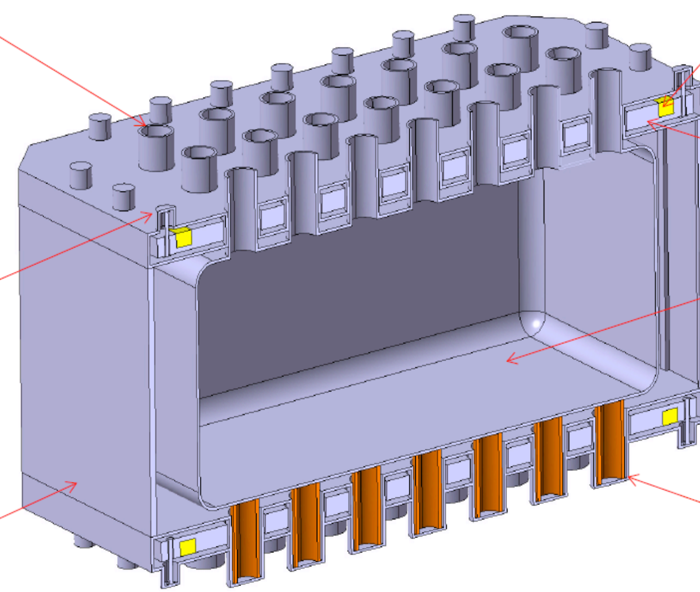




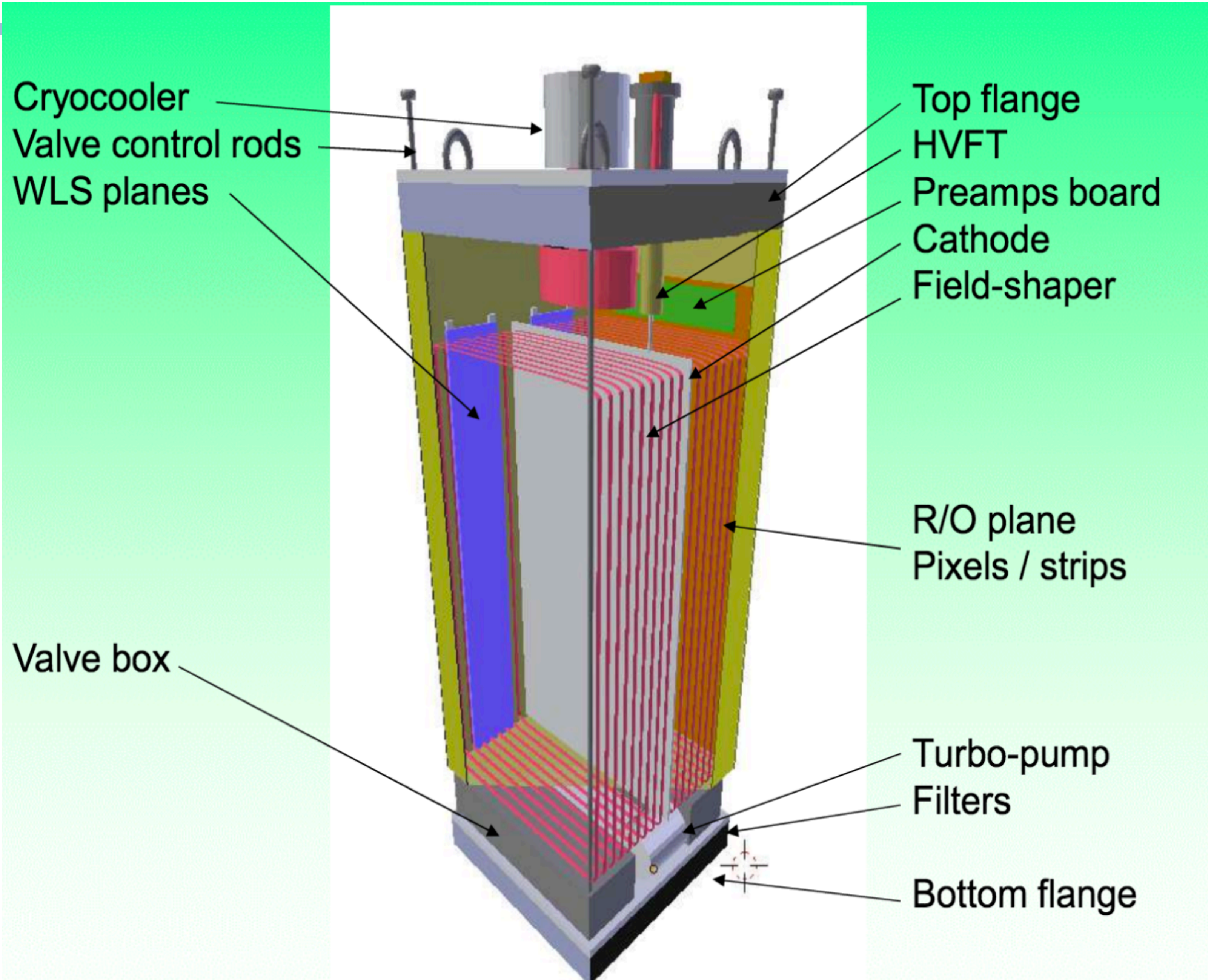


A fully magnetized TPC ?





A very modular TPC ? (ArgonCube)



In summary

- ✓ CERN offers a platform for Neutrino detectors R&D. This platform is now part of the CERN MTP. We will support this platform in an active way and will help WA104, WA105 and all others proposals approved by the SPSC.
- ✓ CERN is building a large “neutrino” test area (EHN1 extension) with charged beams capabilities, available in 2017. No neutrino beam in planning so far.
- ✓ CERN will collaborate with FNAL on the LBNF infrastructure
- ✓ CERN will assist the EU neutrino community in their long term common plans.
- ✓ In the short term, CERN is helping in getting a Short Baseline operational at FNAL with an agreed physics program … and later a Long Baseline

THANK YOU