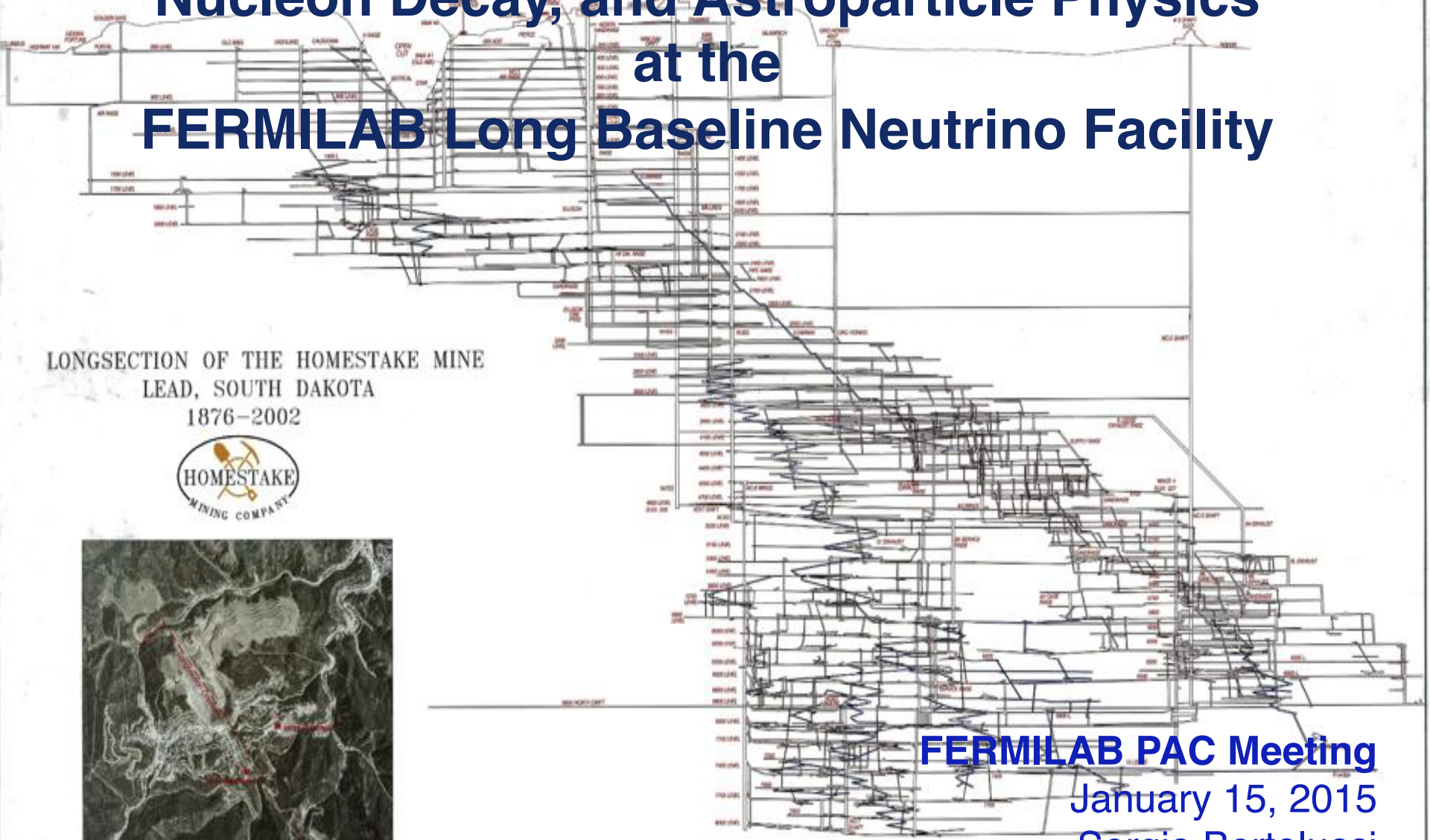
An Experimental Program in Neutrino Physics, Nucleon Decay, and Astroparticle Physics at the FERMILAB Long Baseline Neutrino Facility



FERMILAB PAC Meeting
January 15, 2015
Sergio Bertolucci
CERN

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.

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.

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).

- A large community, with an impressive amount of experience…
- …trying to become a single collaboration

ELBNF LOI Signatures* from 142 Institutions

UFABC
Alabama
Alfenas
Aligarh Muslim
APC - Paris
Argonne
ASCR
Atlantico
Banaras
Bartoszek Engineering
Bern
Bhabha
Boston
Brookhaven
Brown
Budker
California (Berkeley)
California (Davis)
California (Irvine)
California (Los Angeles)
Caltech
Cambridge
Campinas
Catania
CBPF
CERN
Charles University
Chicago
Ciemat
Cincinnati
Cinvestav
Colima
Colorado
Colorado State
Columbia
COMSATS IIT
CTU
Dakota State
Delhi
DESY
Drexel
Duke
ETHZ
Feira de Santana
Fermilab
Goias
Gran Sasso
Guwahati
Hamburg
Harish-Chandra
Hawaii
Houston
Huddersfield
Hyderabad
Idaho State
IFAE
IFC
IIT
Indiana
Institute for Nuclear Search
Iowa State
IPM
IPNL Lyon
IPPP Durham
Jammu
JG Boissevain Design
Kansas State
KEK
Koneru Lakshmaiah
Lancaster
LAPP
Lawrence Berkeley National Lab
Liege
Liverpool
London UCL
Los Alamos National Laboratory
Louisiana State
Lucknow
Manchester
Maryland
Max Planck MPP
MIT
Michigan State
Milano
Milano & INFN Bicocca
Minnesota
Minnesota (Duluth)
Napoli
NCBJ
Nehru
New Mexico
NIKHEF
Northern Illinois
Northwestern
Notre Dame
Observatorio Nacional
Ohio State
Order of Engineers Genoa
Oregon State
Oxford
Ozark Integrated Circuits Co
Padova
Panjab
Pavia
Pennsylvania State
Pisa
Pittsburgh
Princeton
Punjab
Rochester
Saclay
SLAC
STFC Rutherford Appleton
Sheffield
Sofia
South Carolina
South Dakota
SD School of Mines & Technology
SURF
South Dakota State
Southern Methodist
Stanford
Stony Brook
Sussex
Syracuse
Tennessee
Texas (Arlington)
Texas (Austin)
Tubitak
Tufts
VECC
Virginia Tech
Warwick
Warsaw
Washington
Wichita State
William and Mary
Wisconsin
Wroclaw
Yale
Yerevan
York

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

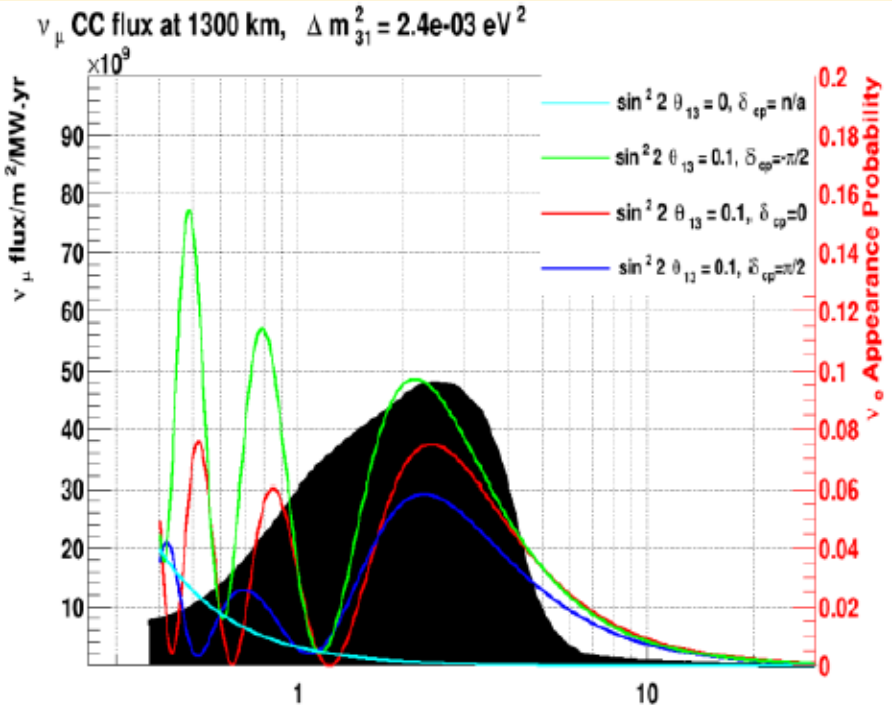
$$P(\nu_\mu \to \nu_e) \approx \sin^2\ \theta_{23} \sin^2 2\theta_{13} \frac{\sin^2(\Delta_{31}-aL)}{(\Delta_{31}-aL)^2}\ \Delta_{31}^2$$

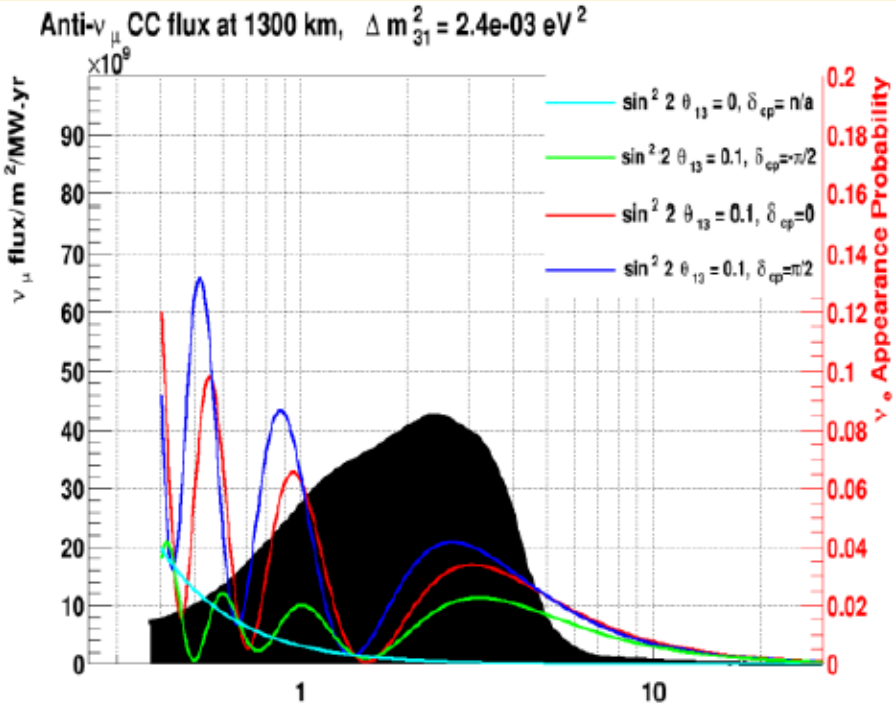
$$+ \sin 2\theta_{23} \sin 2\theta_{13} \sin 2\theta_{12} \frac{\sin(\Delta_{31}-aL)}{(\Delta_{31}-aL)} \Delta_{31} \frac{\sin(aL)}{aL} \Delta_{21} \cos(\Delta_{31} + \delta_{CP})$$

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

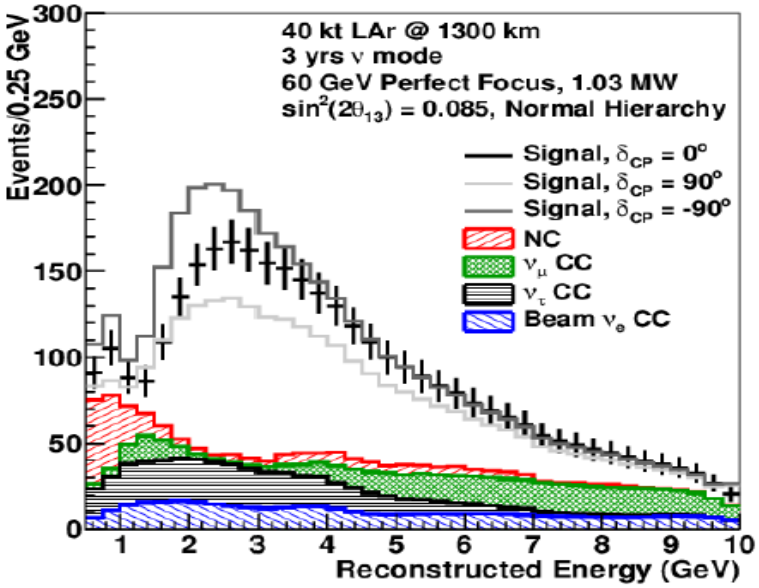
with $\Delta_{ij} = \Delta m_{ij}^2 L/4E$, and $a = G_F N_e/\sqrt{2}$.

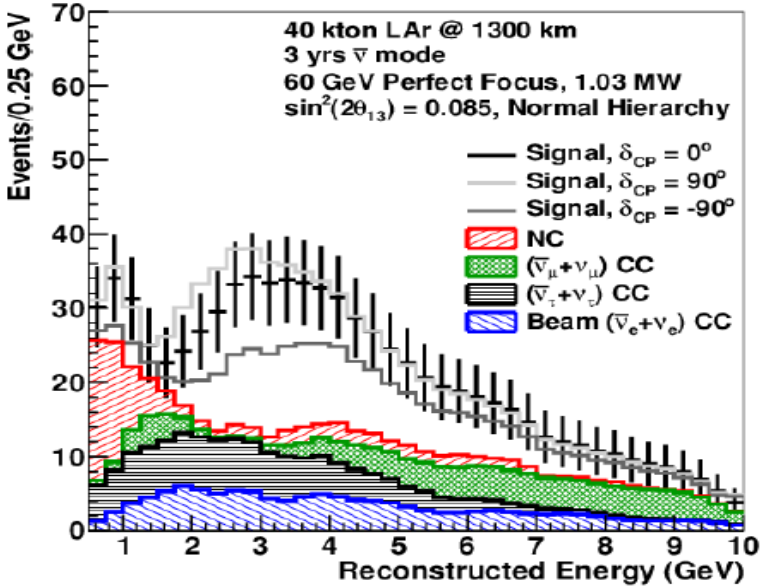
Oscillation Probabilities vs E

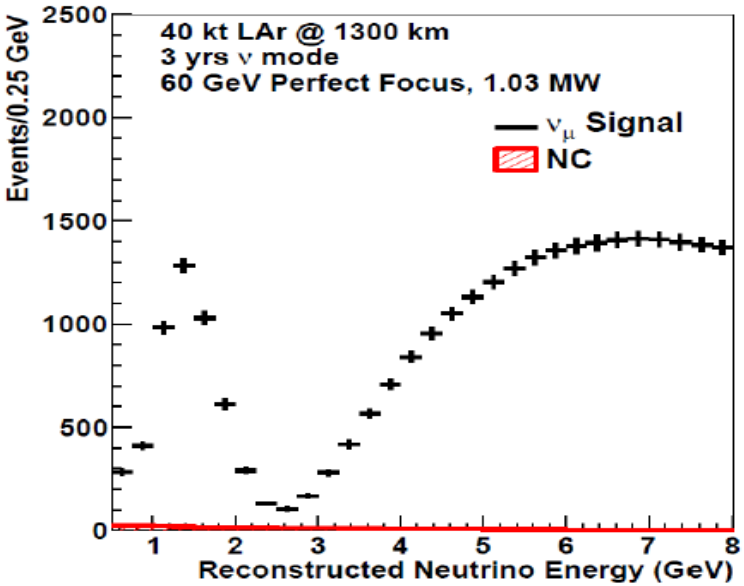


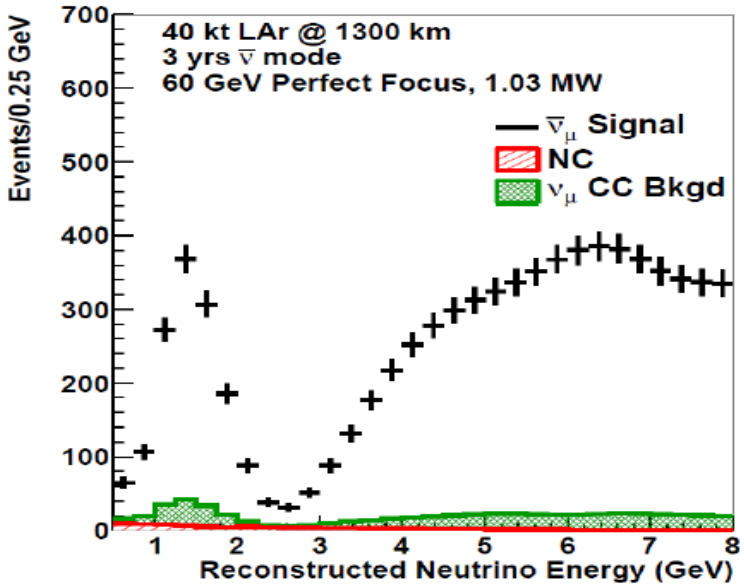


ν_e(antiν_e) appear, ν_μ(antiν_μ) disapp









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	$15\%/\sqrt{E(GeV)}$

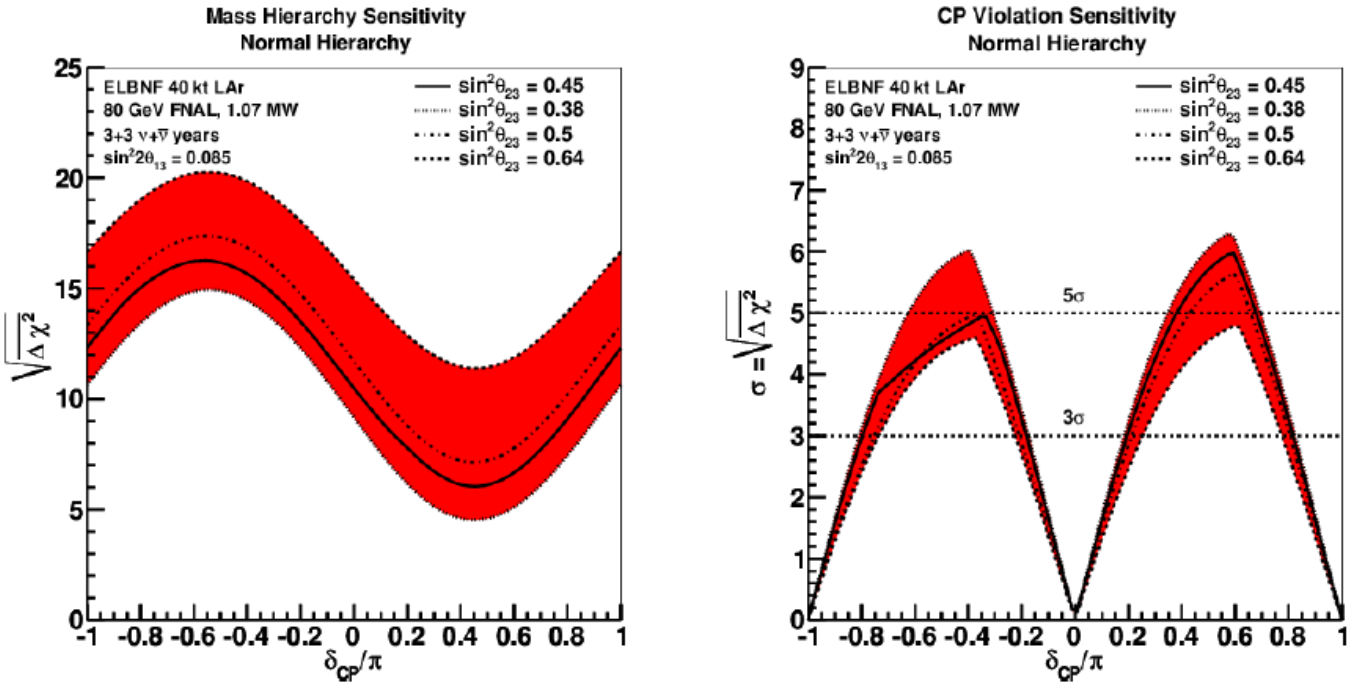
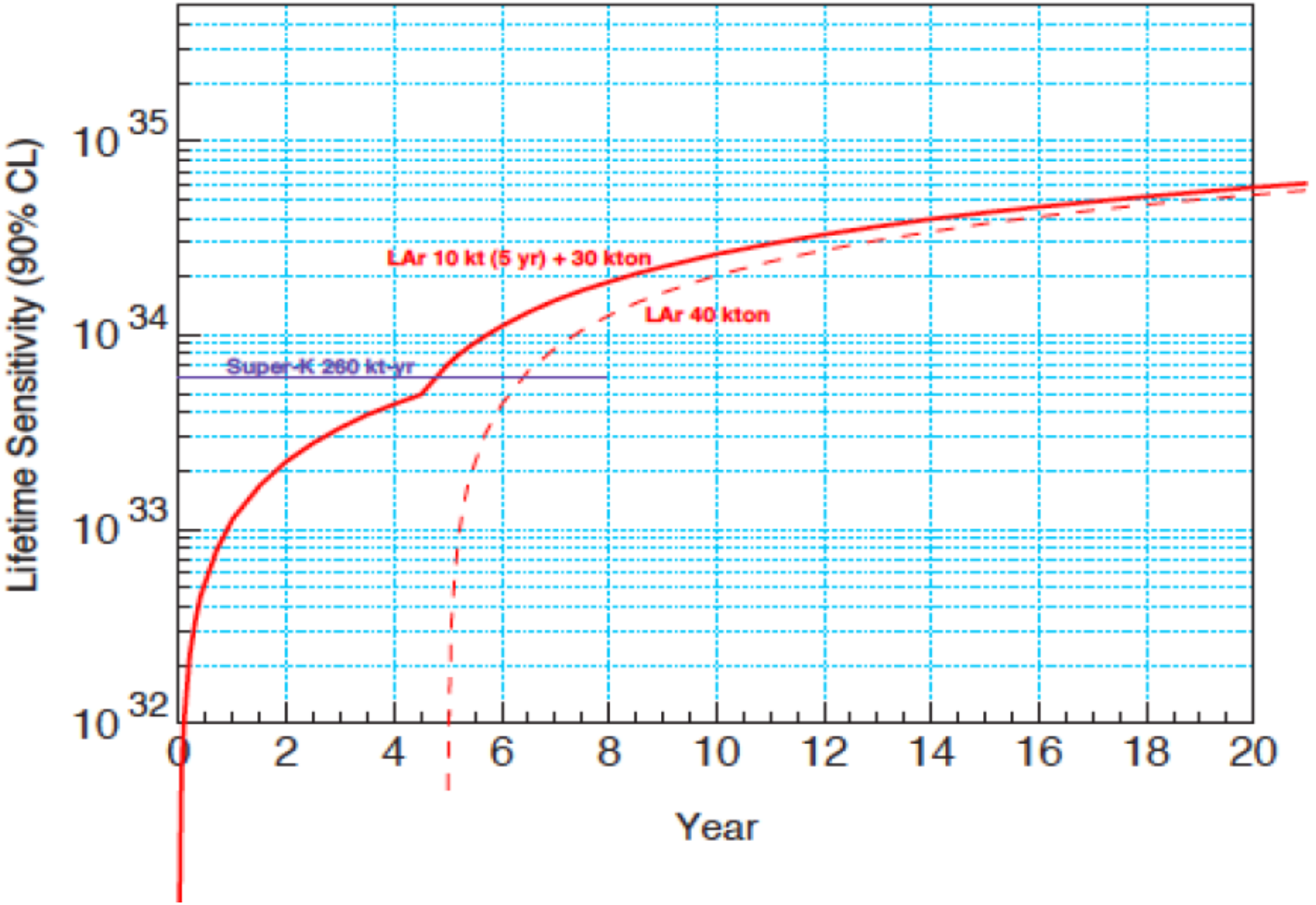
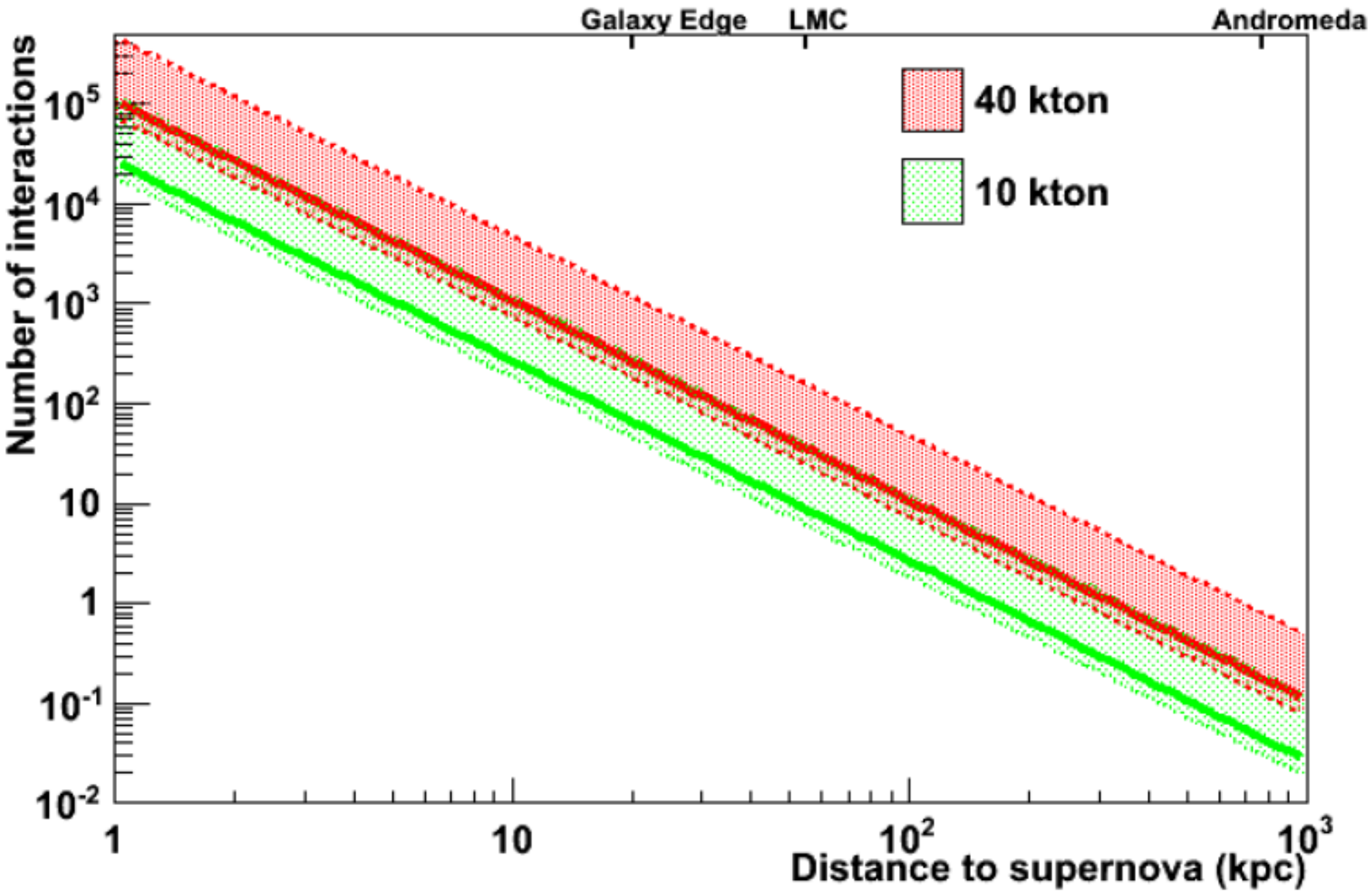


FIGURE 3: *Expected sensitivity of ELBNF to determination of the neutrino mass hierarchy (left) and discovery of CP violation, i.e. $\delta_{CP} \neq 0$ or π, (right) for a 40-kt fiducial mass LAr TPC and an 80-GeV, 1.07-MW beam from FNAL to SURF with three years of running in neutrino and three years 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.*

Proton decay sensitivity



Supernova neutrino.



The IIEB

An Interim International Executive Board was formed to

- steer the process of the formation of ELBNF
- draft a governance model
- to foster the submission of an LOI to the PAC
- etc..

It will dissolve as soon as the Collaboration IB will be set-up

Next steps

Proto-collaboration meeting at FNAL on Jan 22-23 to:

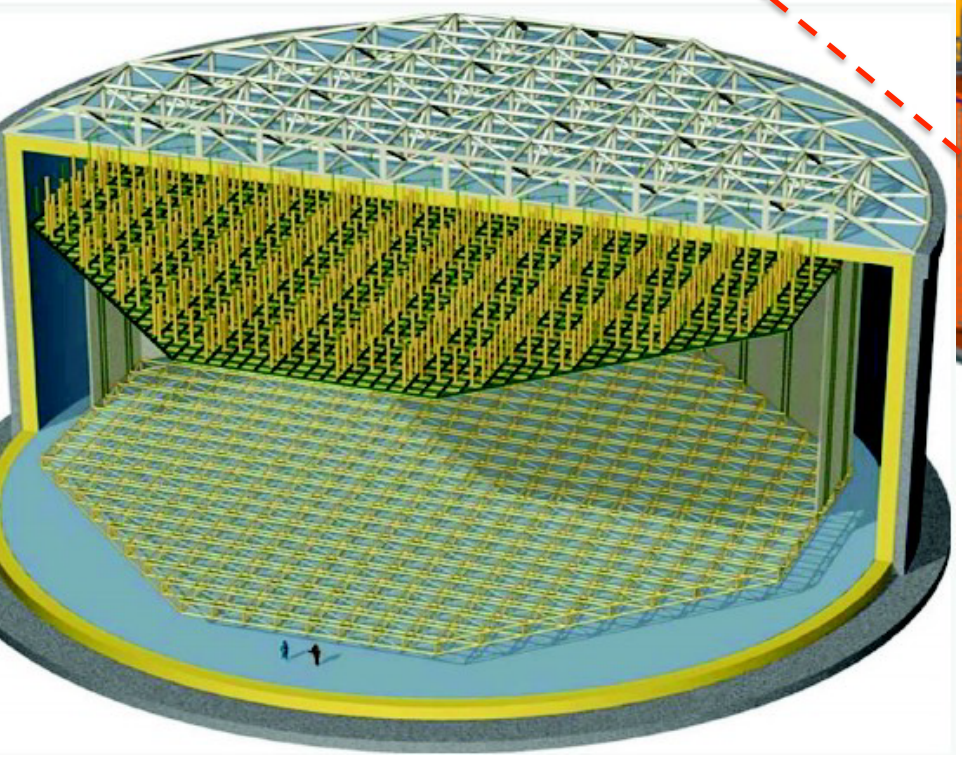
- Agree on a minimal level of organization and governance
- Set a prioritized roadmap to the CDR
- Launch spokesperson selection process
- Form the relevant Working Groups to make progress before the full organization is in place, and to provide a way for individuals/groups to get involved in R&D efforts, CDR writing and other collaboration activities

Governance and Relations with the Host Lab

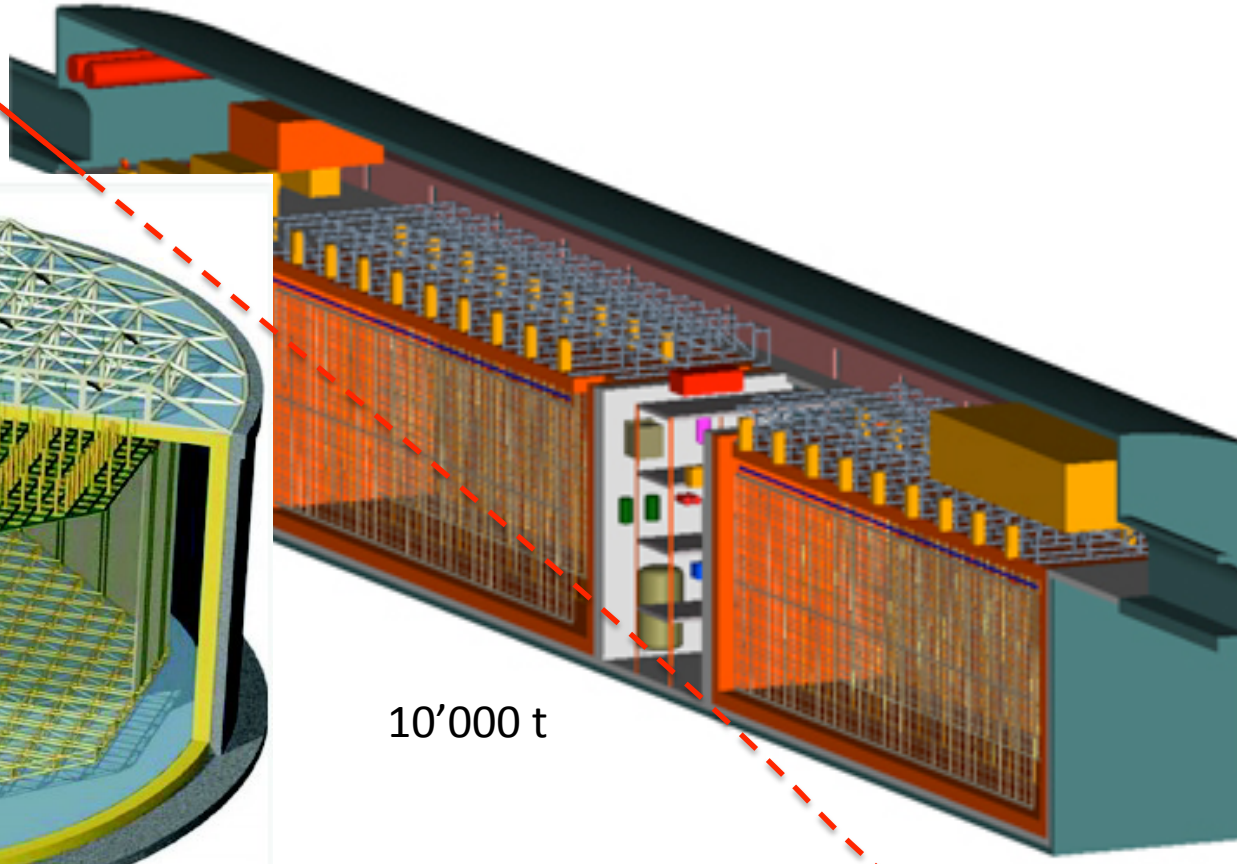
- ELBNF will follow a model derived from the CERN LHC, which clearly separates the ownership of the experiment (International Collaboration) from the ownership of the facility (Host Lab)
- Collaboration and Host Lab rights and obligation are regulated by MoU's
- A strong Experiment - Facility Interface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

A large R&D program

- To optimize the TPC single phase technology, beyond what was done by ICARUS, MICROBONE, LARIAT and LBNE
- To prove the potential of a 2 phases LAr TPC
- To gain experience on new techniques for light detections in LAr
- To calibrate the response to hadrons and leptons
- To learn how to deal with all nu-e possible topologies
- 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 data automatic reconstruction and large data set handling (PBytes)

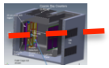


20’000 t



10’000 t

35 t

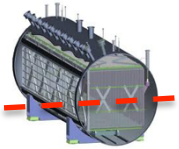


now

50 t

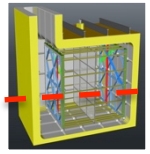
now’

170 t

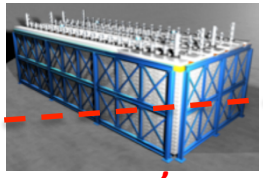


now

220 t

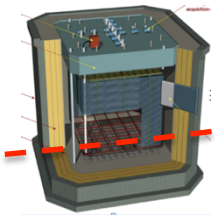


760 t

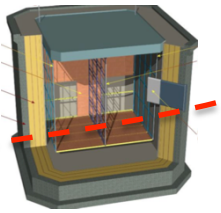


now’

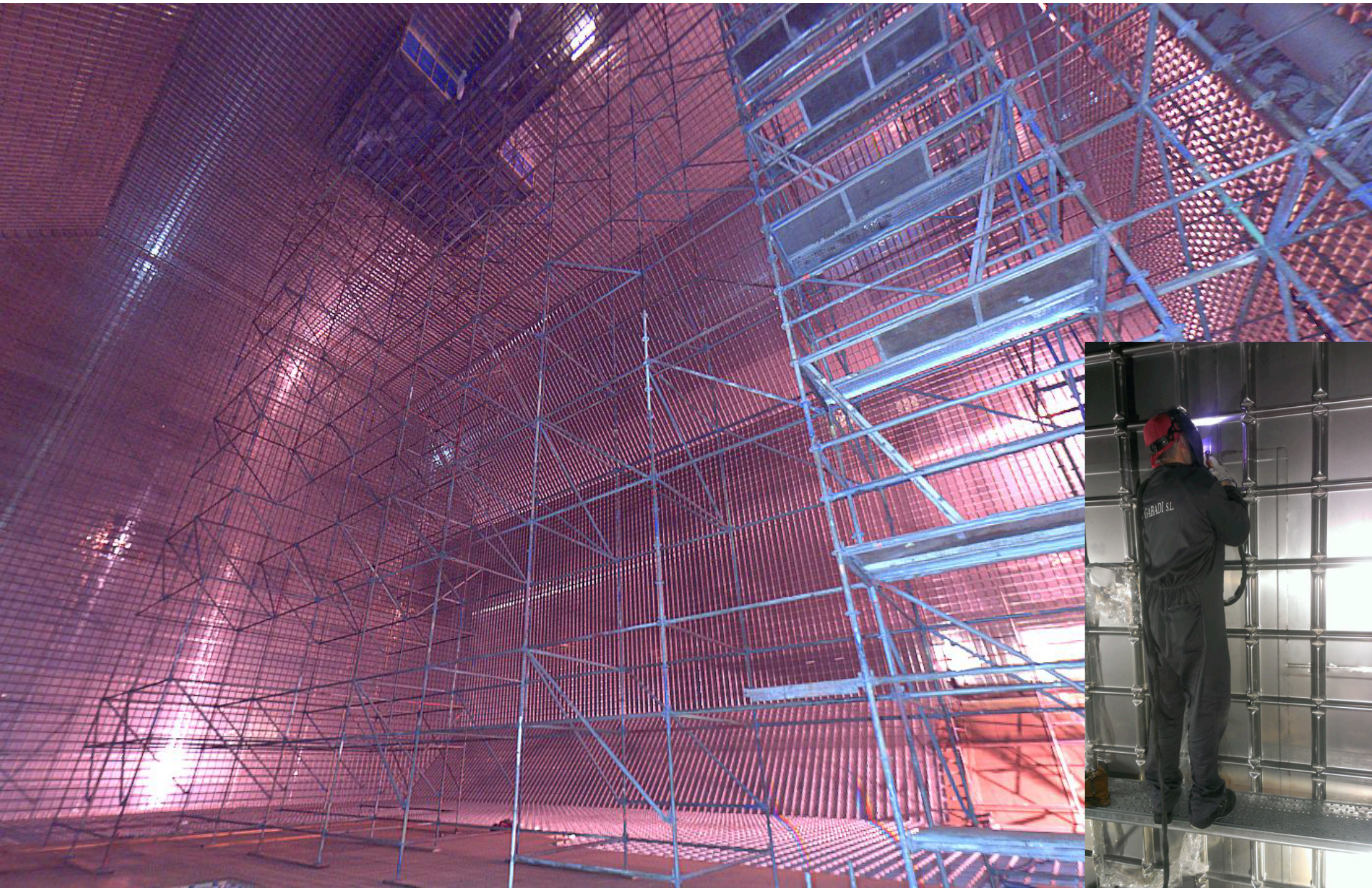
705 t

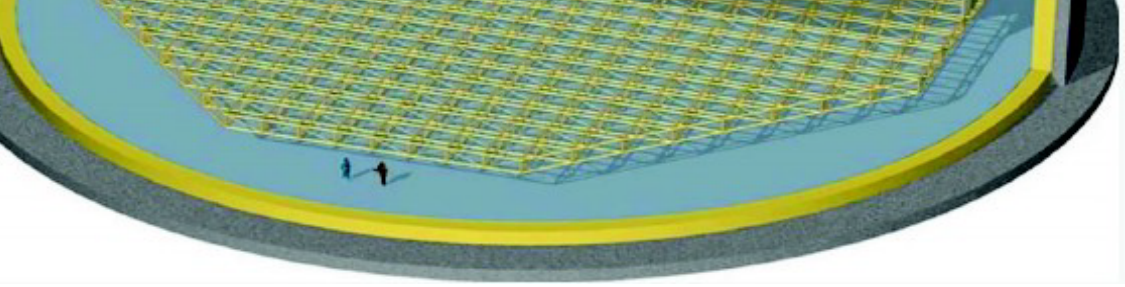


~700 t



Membrane cryostats (GTT license)





10’000 t

20’000 t

705 t

~700 t

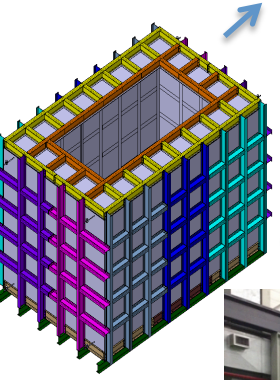
760 t

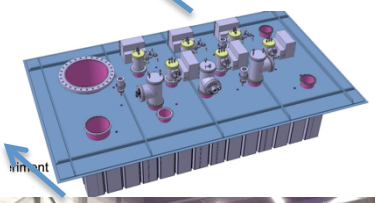
220 t

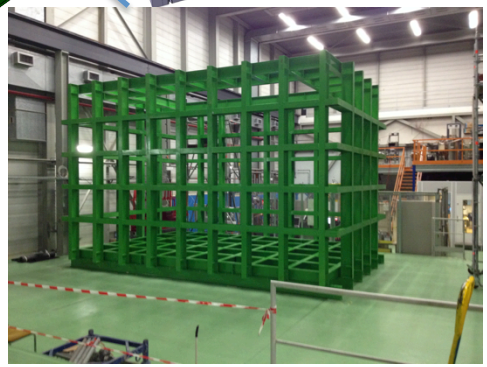
50 t

now’

now’

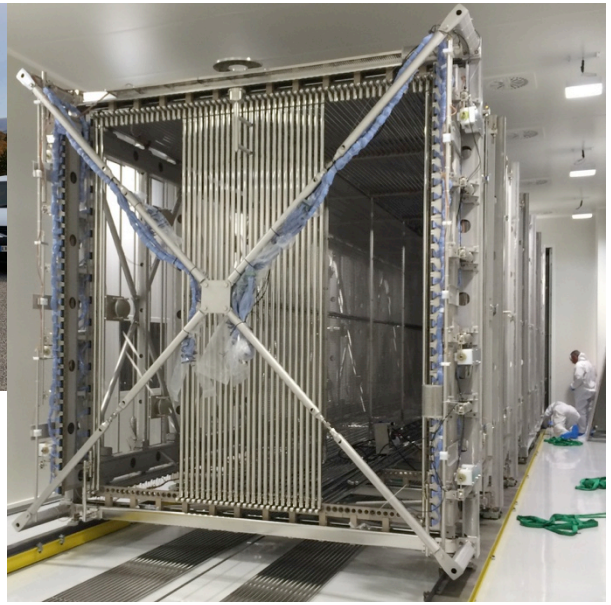


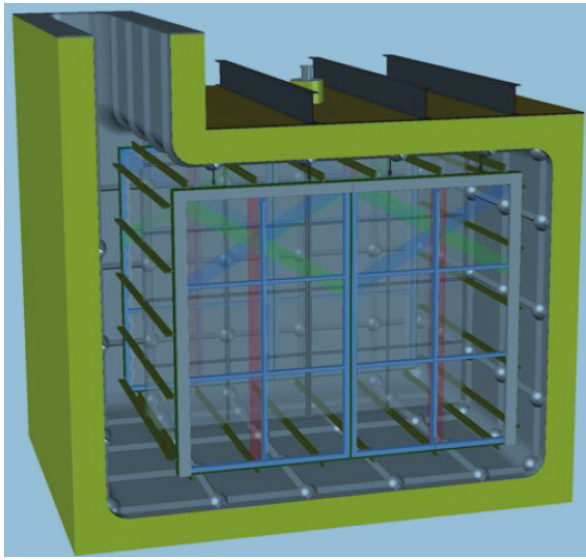


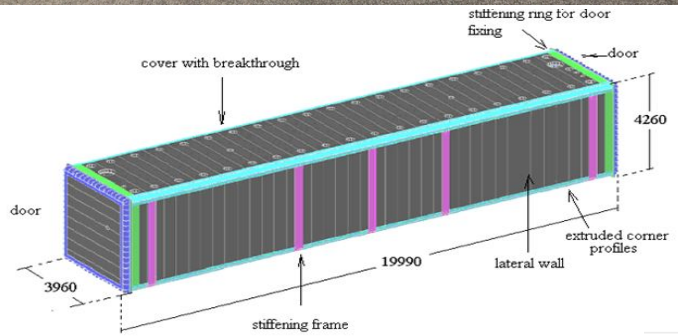


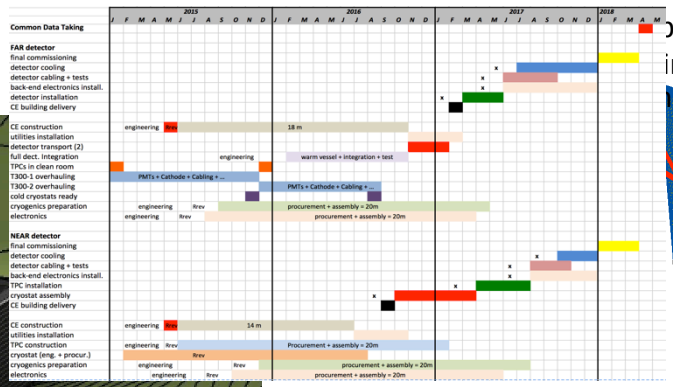
- ✓ *Building the first membrane cryostat at CERN (April)*
- ✓ *Learning the lesson and finding solutions*
- ✓ *Finding and solving all procurements issues*
- ✓ *With a frame conctract with GTT*
- ✓ *Then 4 more cryostats (2015-2017)*
- ✓ *And a cryogenics which follows (new cryo group formed)*

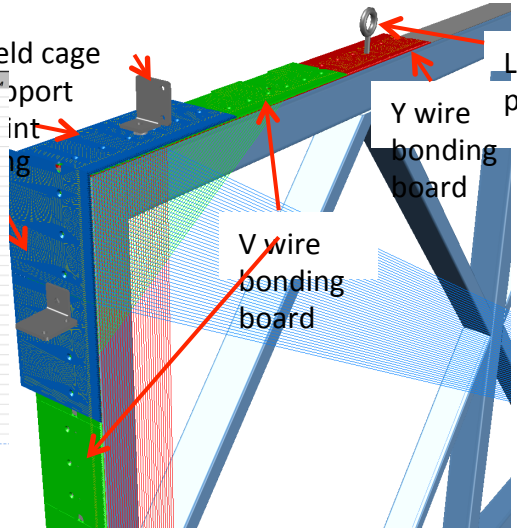
Support to the FNAL short baseline





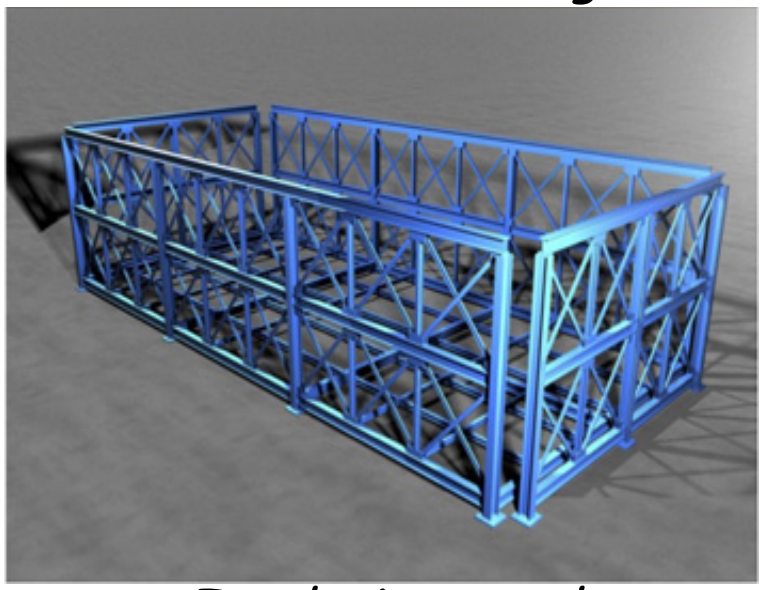




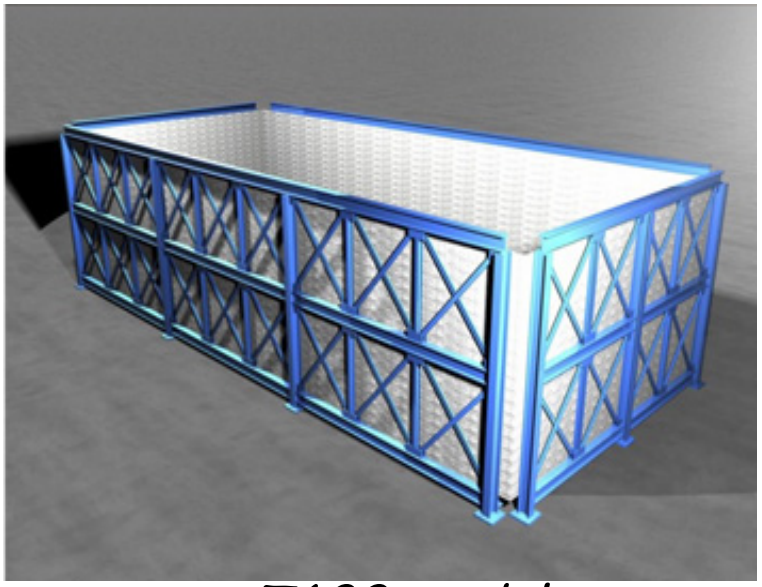


New T600 layout

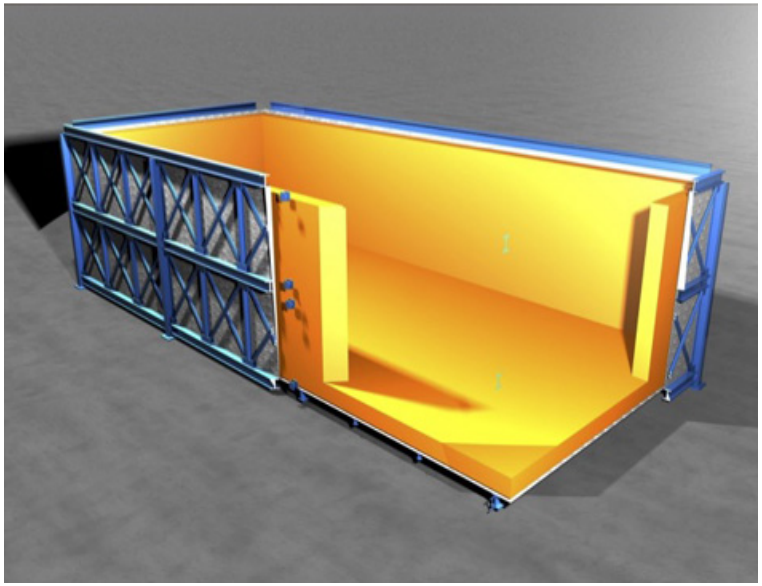
Warm vessel cage



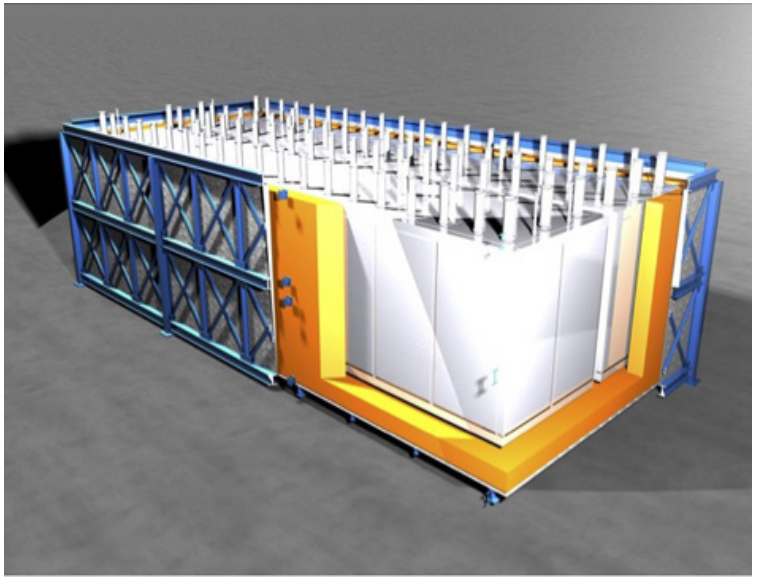
External skin



Insulation panels



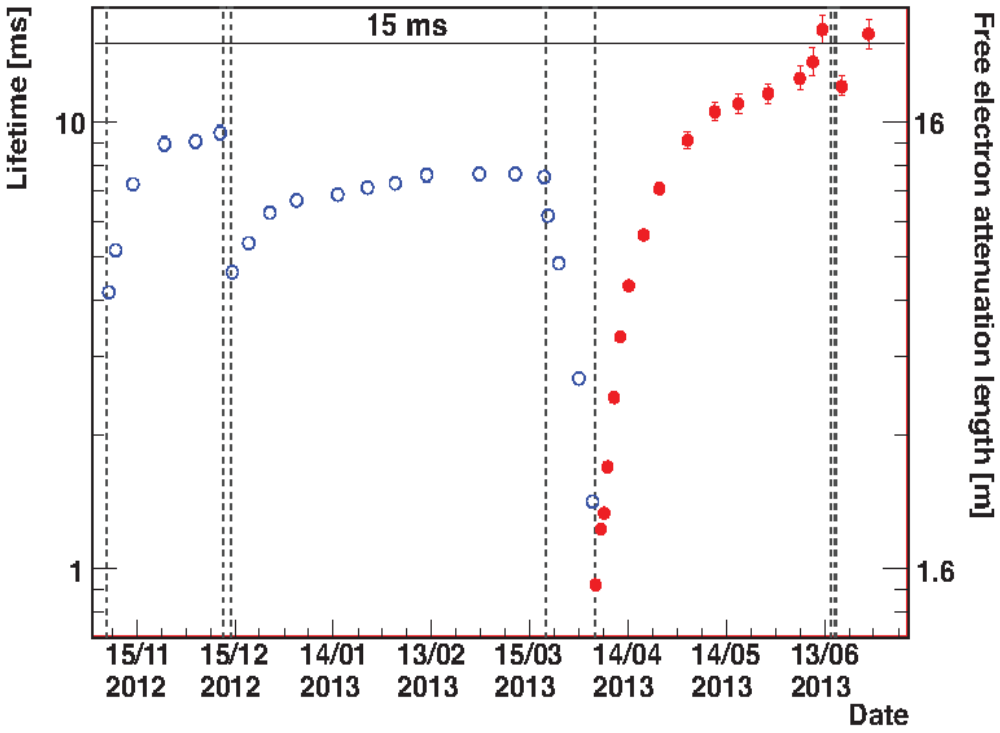
T600 modules

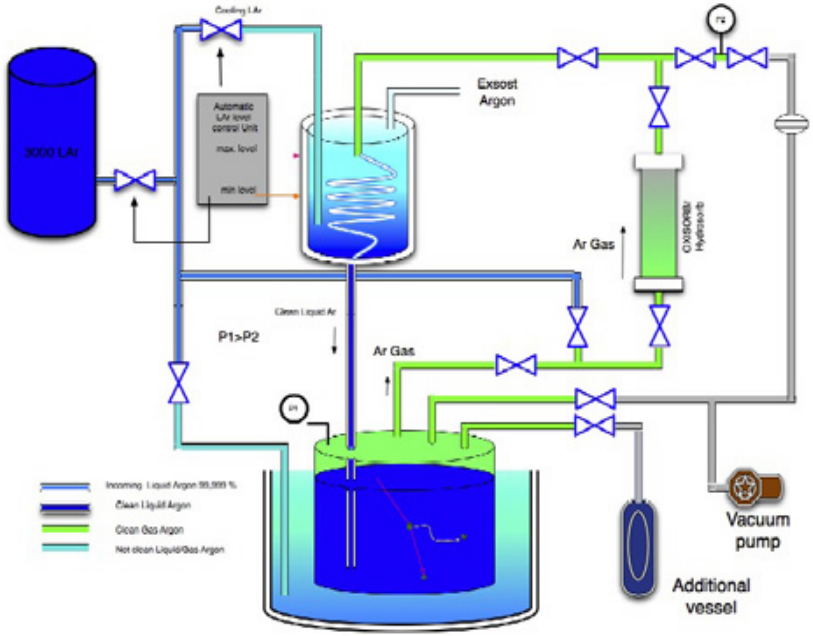


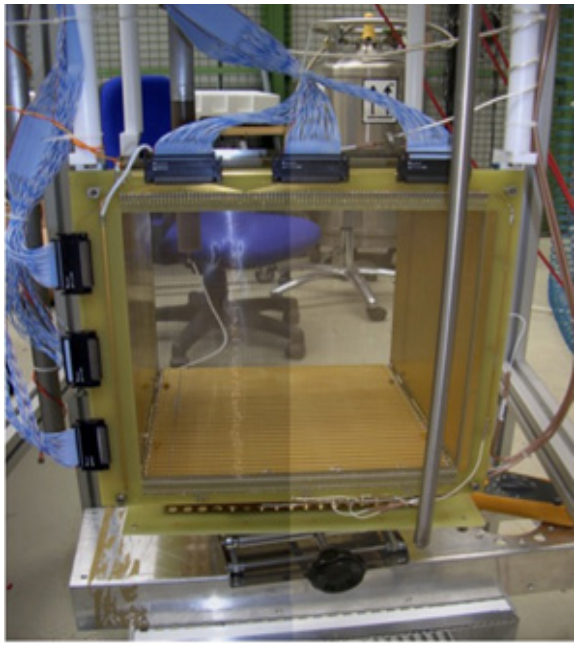
New purity achievements

- 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







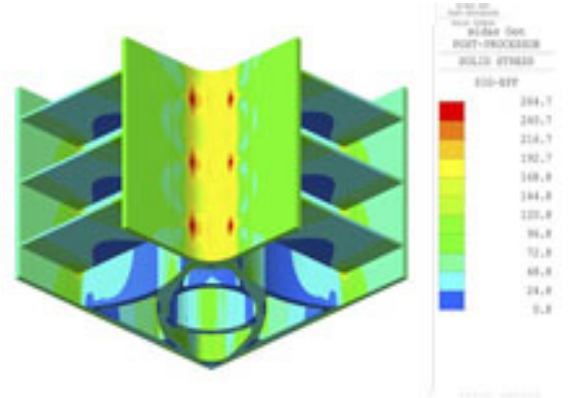
R&D-4: New cold bodies design

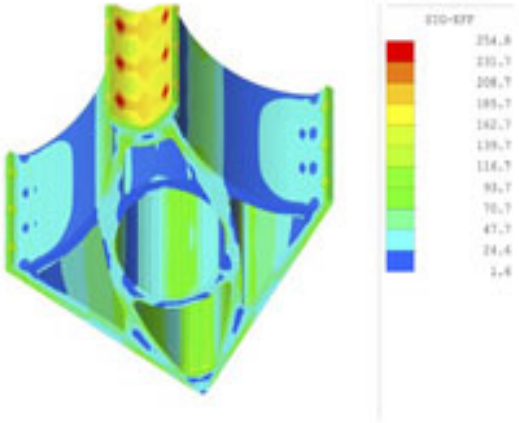
The new cold bodies design, to the Milano Politecnico (Finzi e Associati).

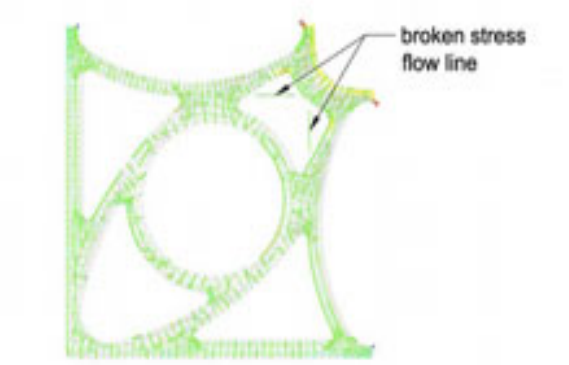
Work is progressing:

- 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.

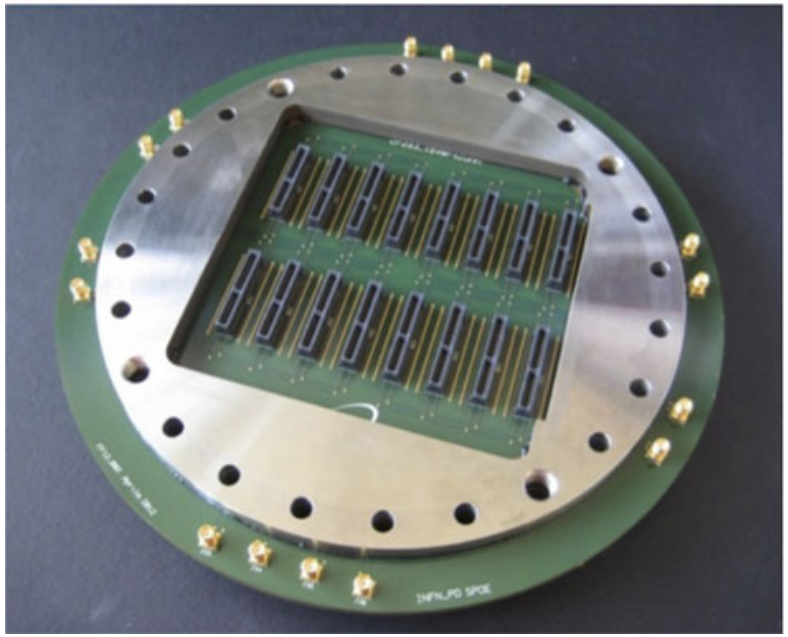




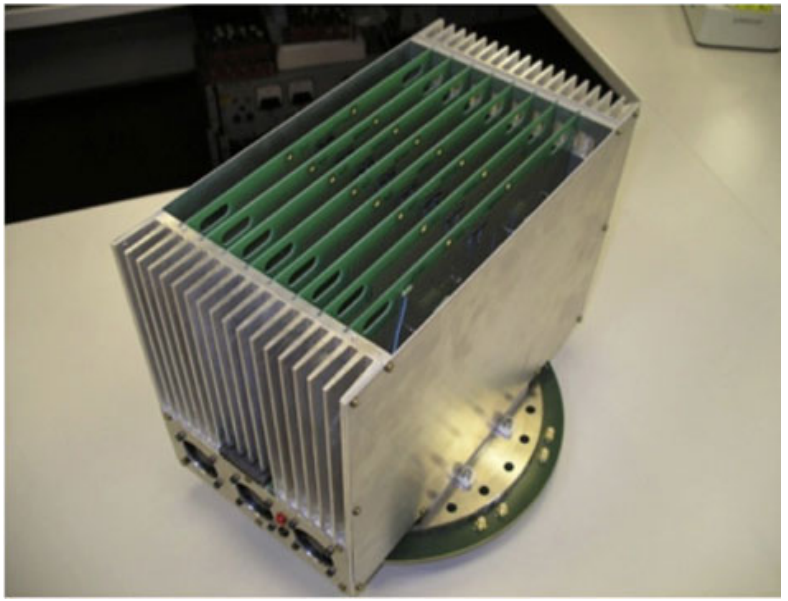


The flange as electronics backplane

- 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.

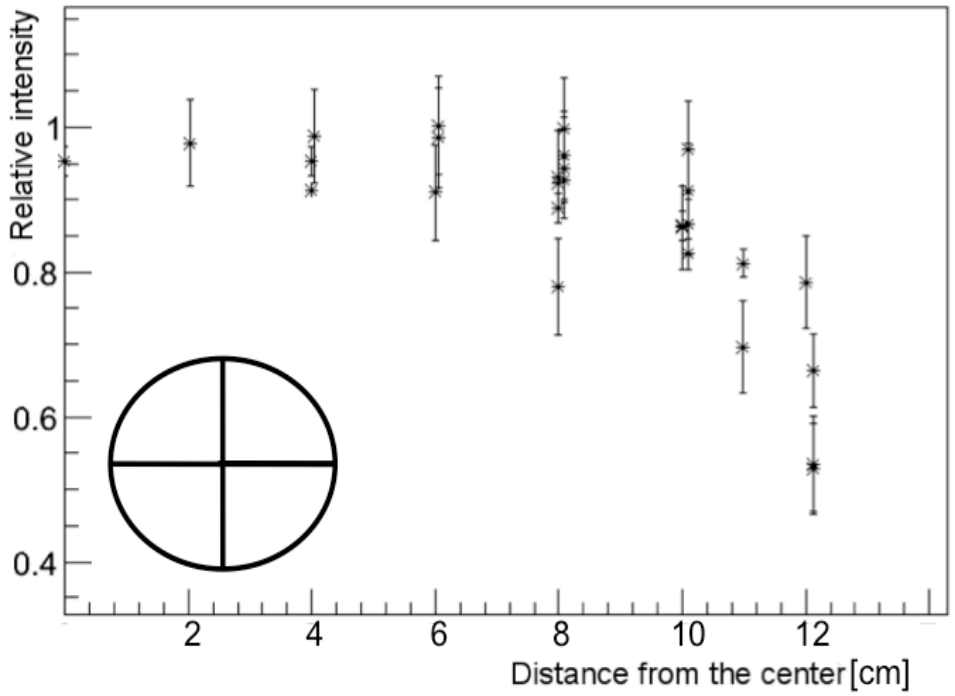


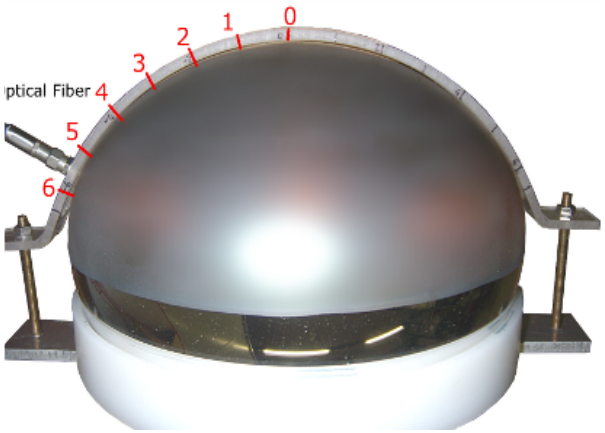
- The connectors on the external side allow for direct insertion of electronics boards where both analogue and digital electronics, with a compact design, are housed.



Response uniformity

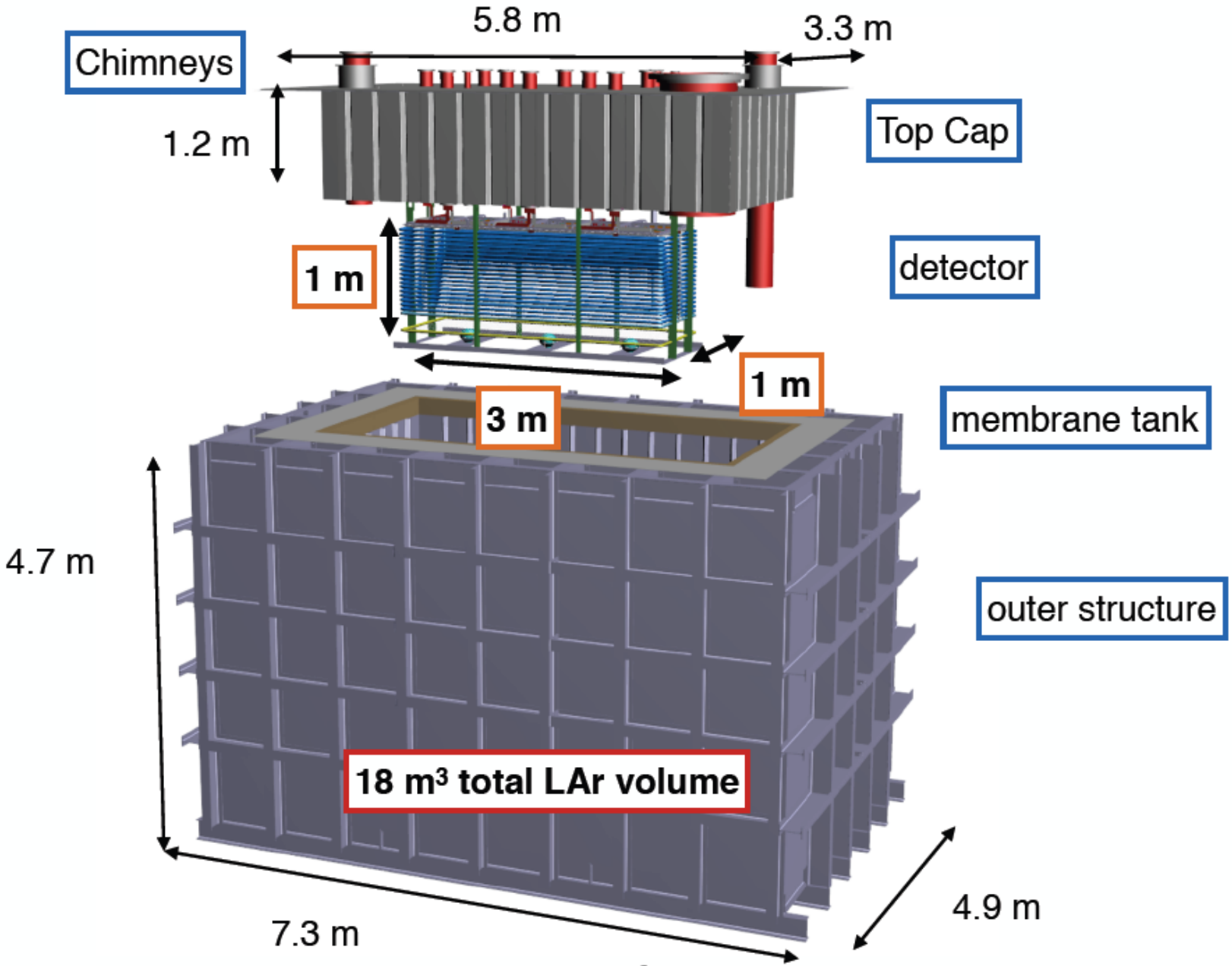
- Example of response uniformity of HAMAMATSU R5912 series.



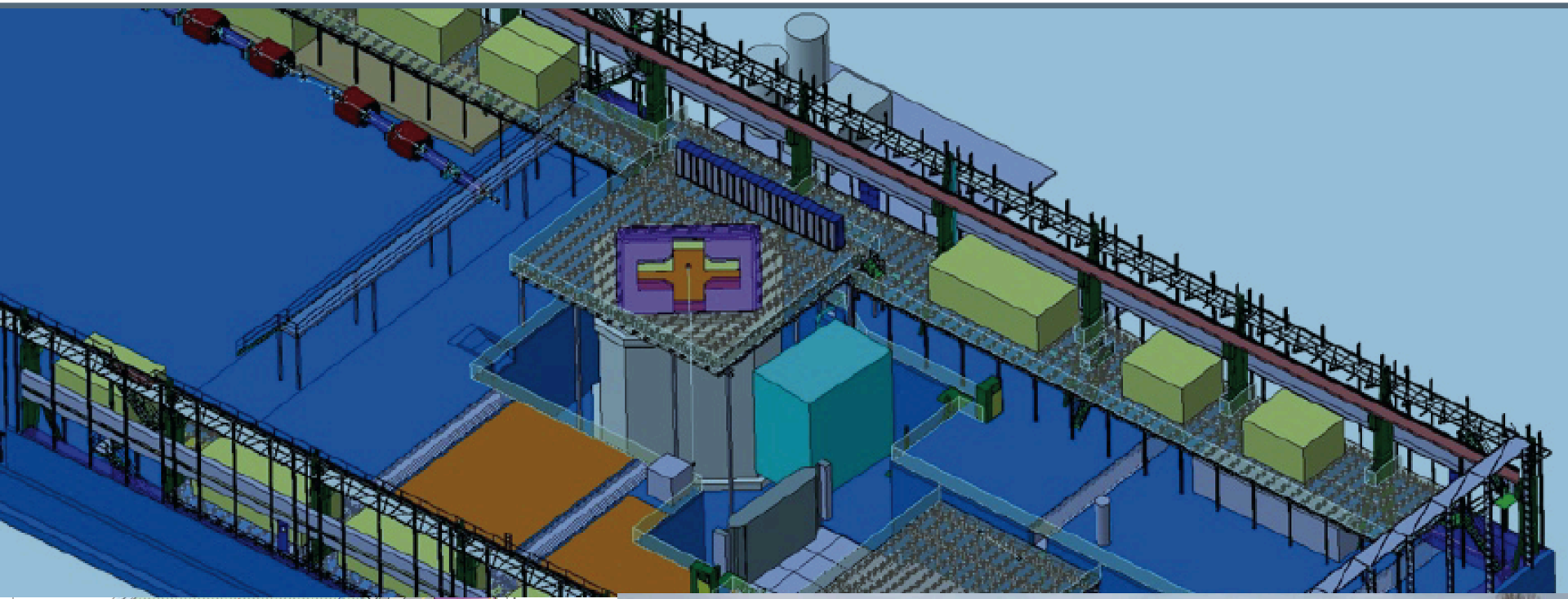


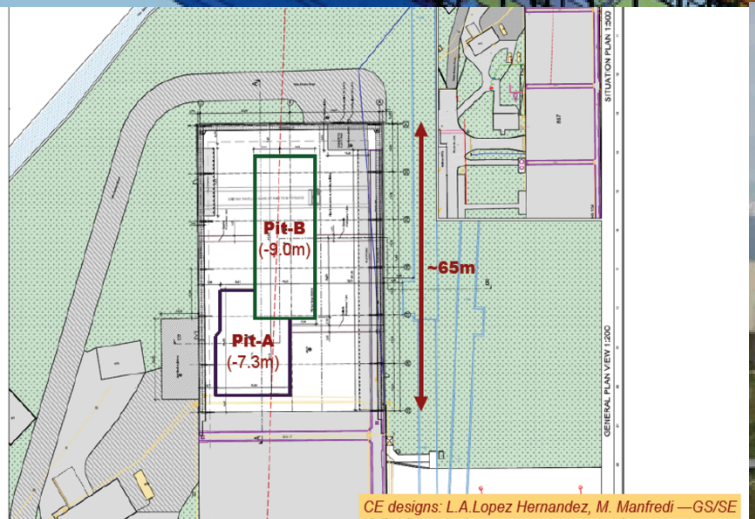
- Measurements are carried on by illuminating the PMT windows in different positions, with an optical fiber. Data in figure are normalized to the response in the central position.

WA105 3x1x1m³



EHN1 extension (test beam and test facility)

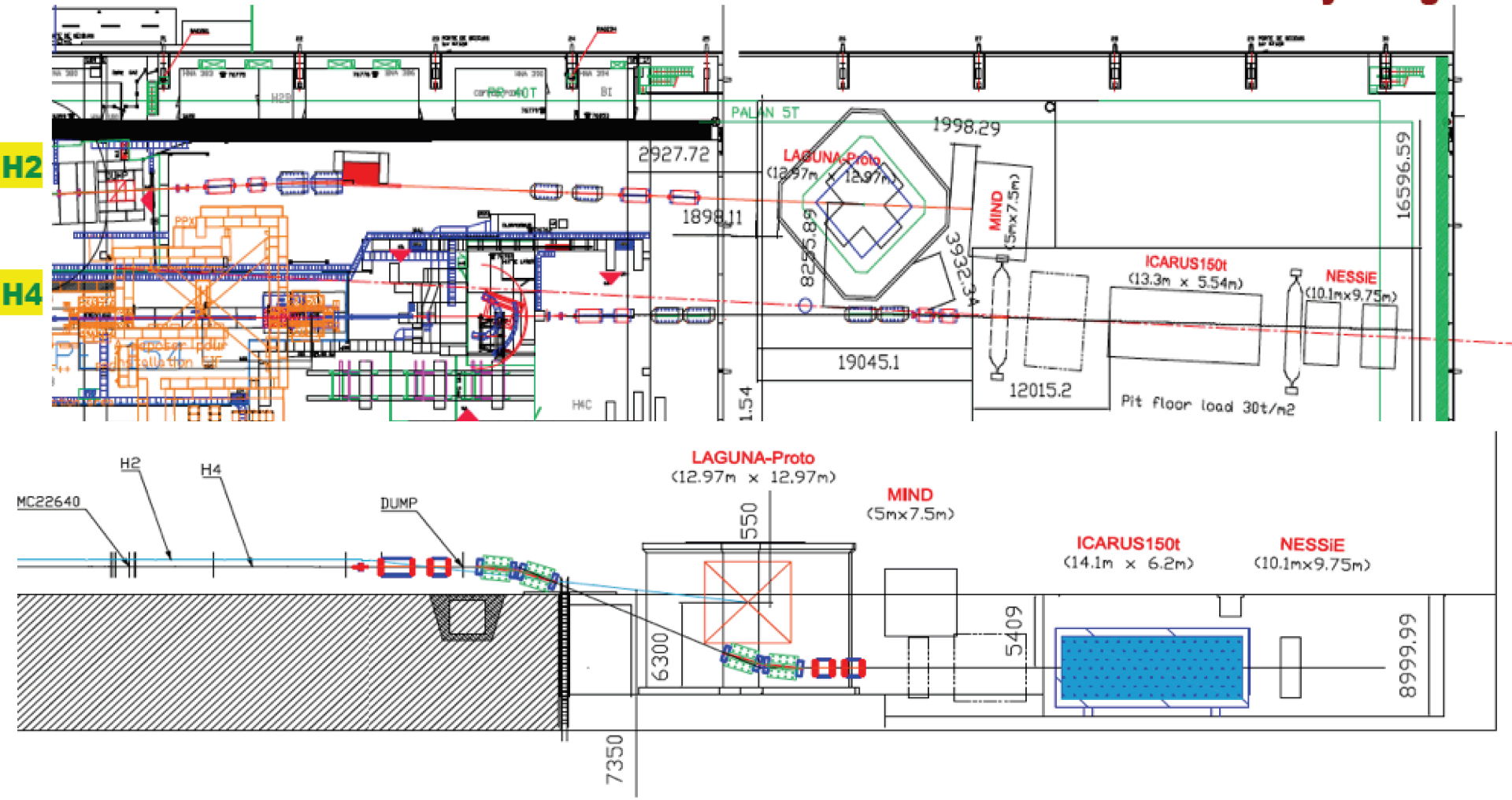




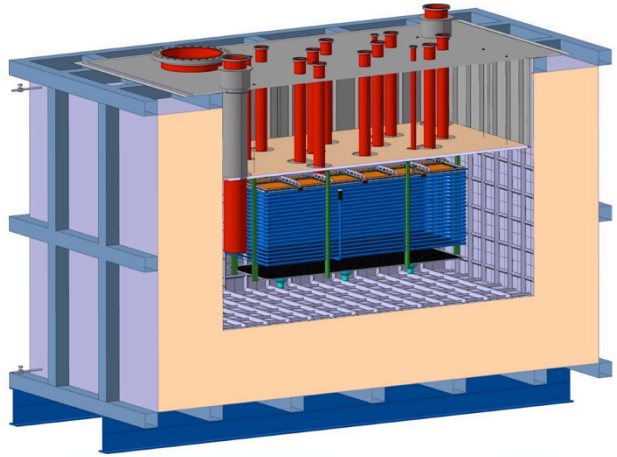
Charged tertiary beams

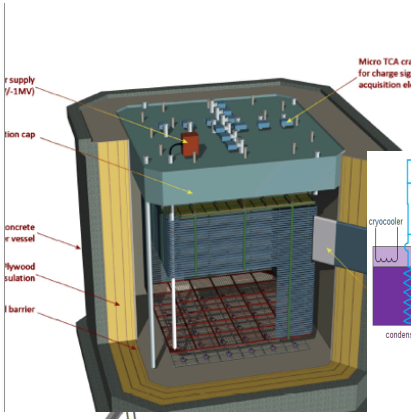
- H2 extension: **1-20 GeV/c**, hadrons ($\pi^{\pm}$, $\mu^{\pm}$, p - mixed beam), electrons($e^{\pm}$)
- H4 extension: **1-5(7) GeV/c**, hadrons ($\pi^{\pm}$, $\mu^{\pm}$, p - mixed beam), electrons($e^{\pm}$)
  - interest to go lower, down to 0.2 GeV beams for LBN TPC test

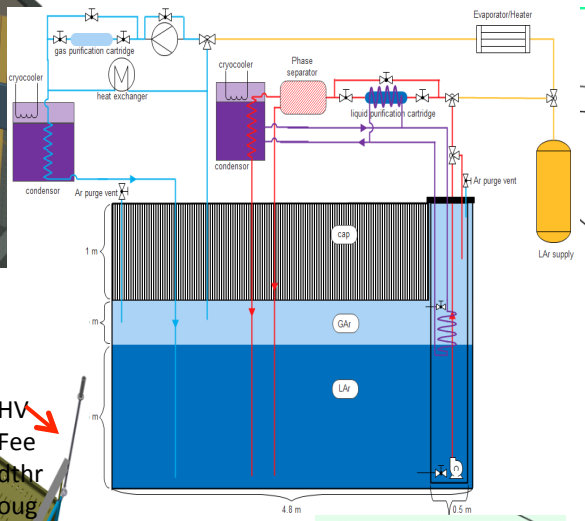
Preliminary designs!

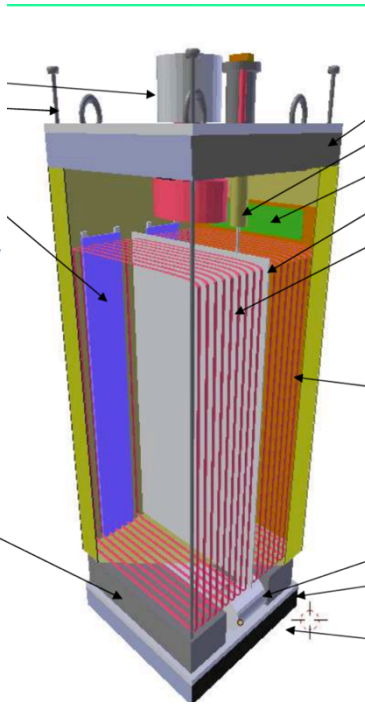


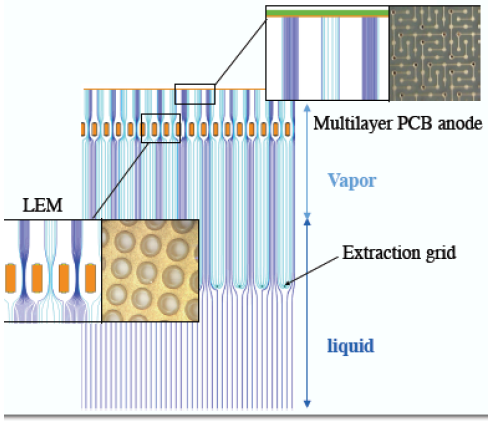
Cern supports new ideas and new detector R&D

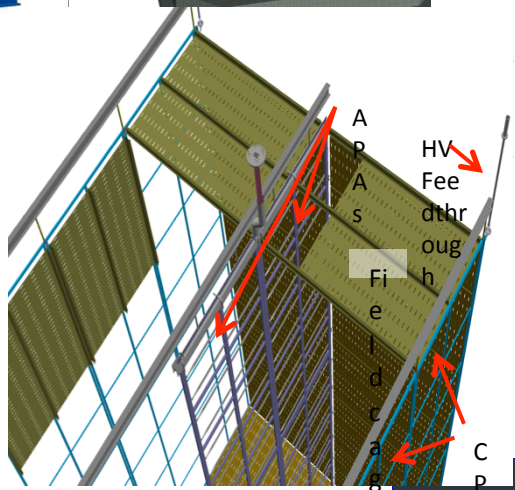


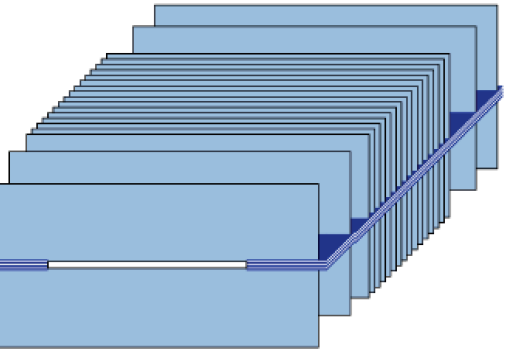


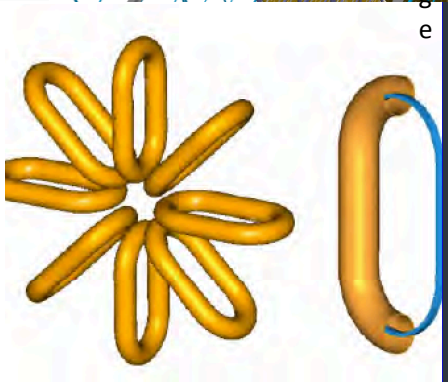


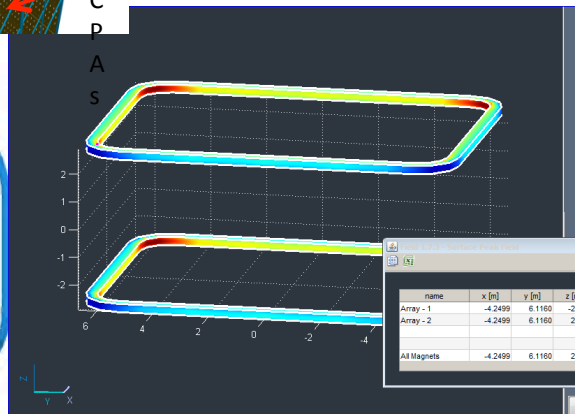


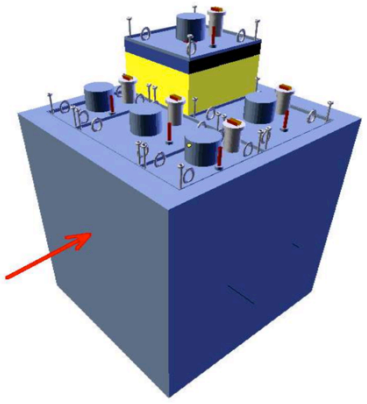








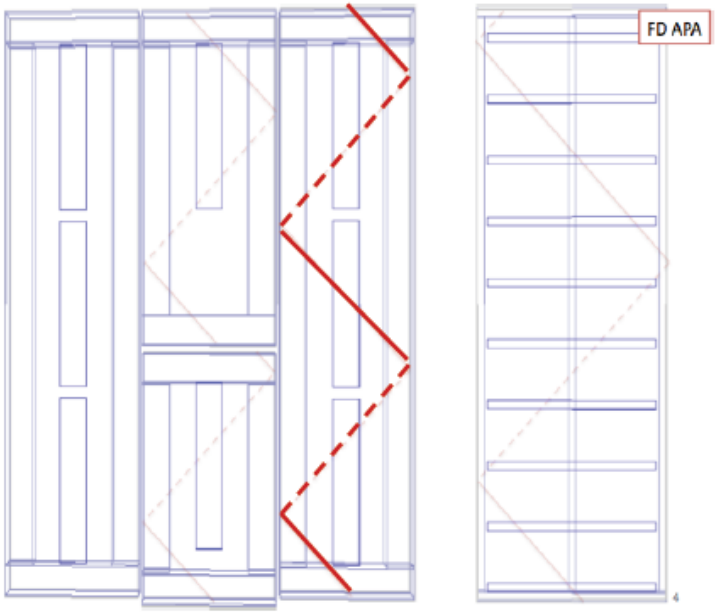


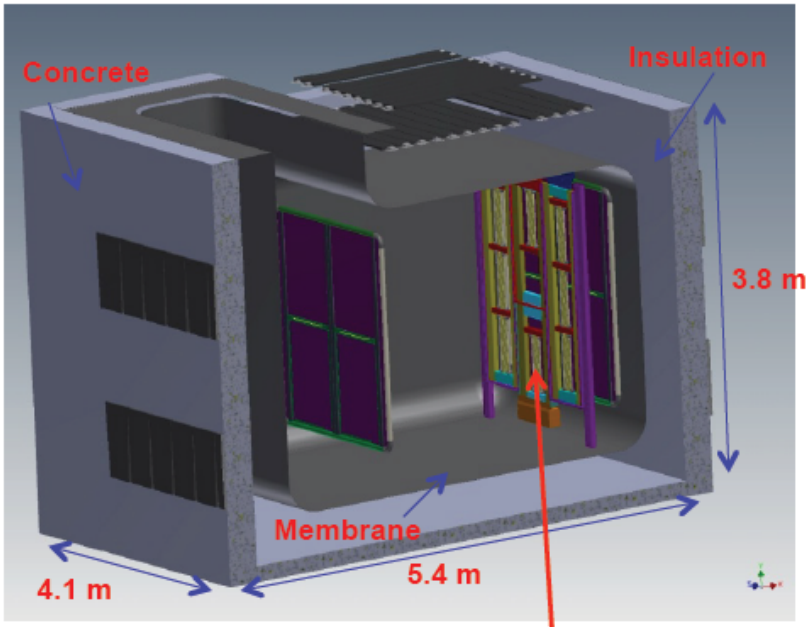


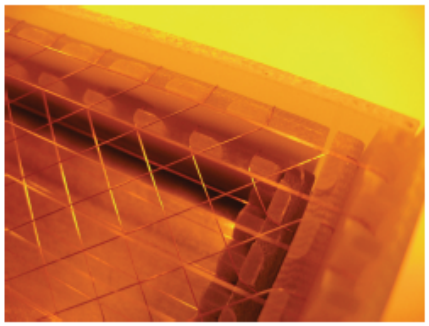
35 ton Prototype

★ 35 ton prototype

- Crucial test of LBNE TPC concept
- Installed at Fermilab
- 2m x 2m x 2m TPC
- Two drift volumes (long/short)
- 4 APA modules



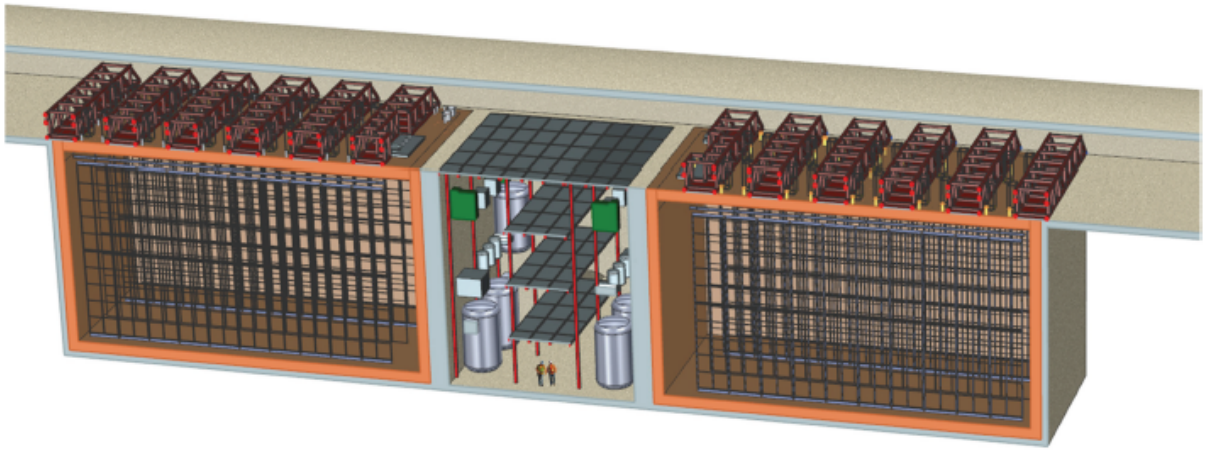


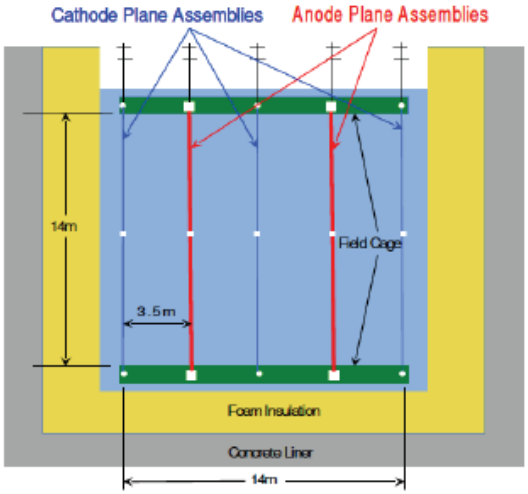


From LBNE → ELBNF

★ The LBNE TPC Design

- Single-Phase ICARUS-inspired design
- Scale up by a factor ~50:
  - Industry "standard" membrane cryostat
  - Modular wire plane readout "Anode Plane Assemblies" APAs
  - Analogue and digital electronics inside cryostat
  - APAs: wrapped – reading out two drift volumes
  - Wire mesh cathode planes **-185kV**
  - FR4 PCB/copper Field Cage





cross section view of the TPC components inside the cryostat

Single Phase Prototype at CERN

★ EoI

- "Expression of Interest for a Full-Scale Detector Engineering Test and Test Beam Calibration of a Single-Phase LAr TPC" submitted to SPSC in October
  - 186 authors, 43 institutes, 6 countries (including Italy, Switzerland, UK)
  - from LBNE, LBNO and ICARUS collaborations
- SPCS invites technical proposal ~spring/summer 2015

★ Status

- Detailed plans/design still evolving
- Submit technical proposal for June 1st
- Beam late 2017/early 2018 - challenging but plausible timeline

Still early days… things are evolving

In summary

- The process of setting up a large international collaboration is in motion and it is proceeding fast.
- On Jan 22-23 first proto-collaboration meeting
- A strong R&D program has started.
- Decisions on the civil engineering at SURF will have to be taken soon and considering the implications, the experiment should be giving it maximum attention.

THANK YOU