Status report on ICARUS T600 (CNGS-2)

F. Pietropaolo
(ICARUS Collaboration)

SPSC, 26-06-2007

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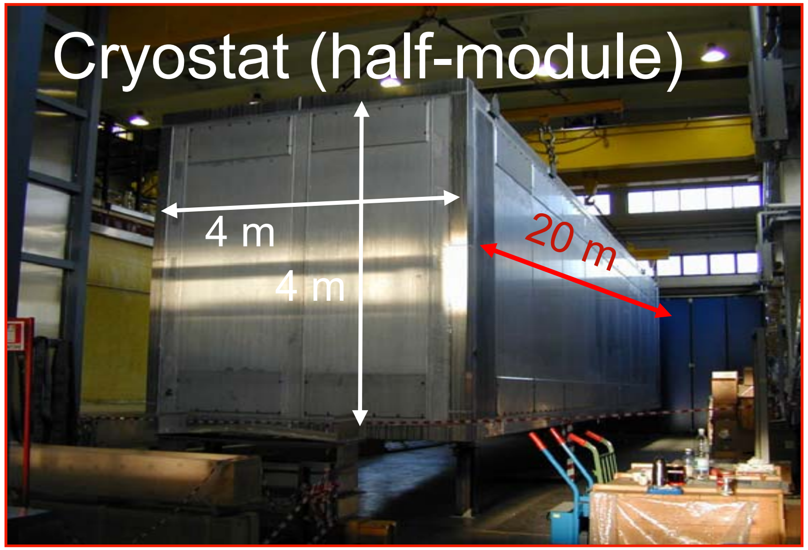
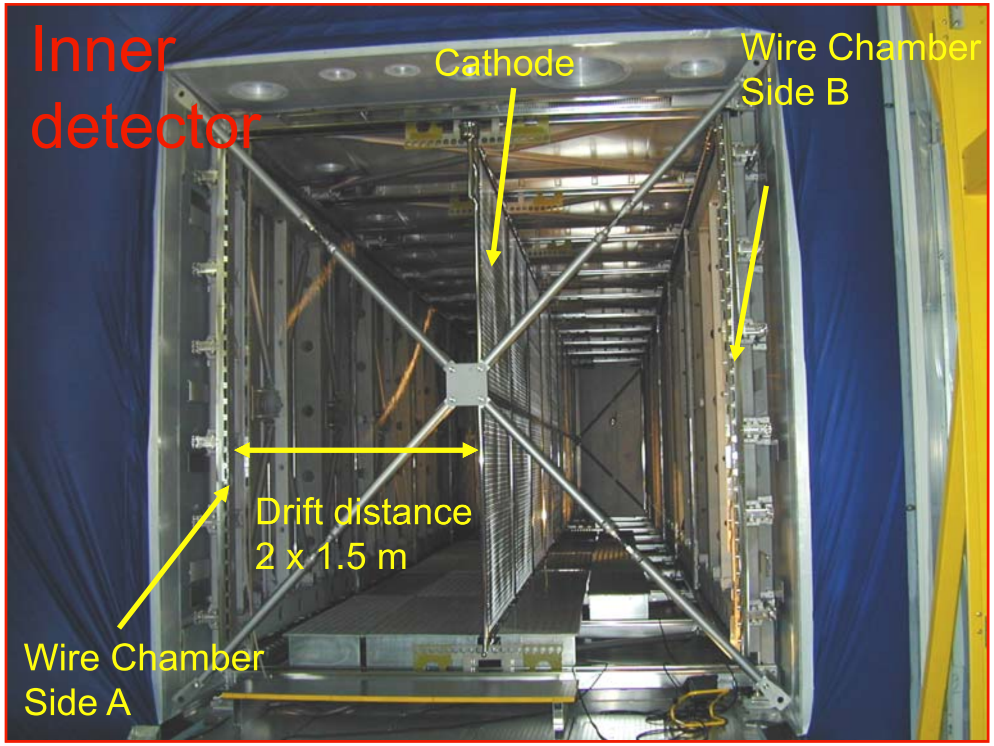
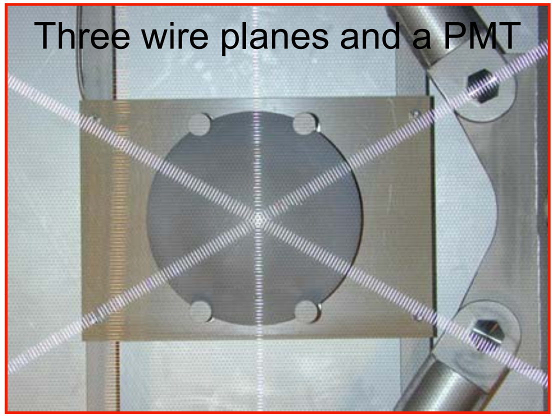
The ICARUS T600 LAr-TPC

- Approved and funded by INFN in 1996.
- Built between years 1997 and 2002 (including prototyping, industrialization and testing).
- Completely assembled in the INFN assembly hall in Pavia
- Full scale demonstration on surface during 2001:
  - Three months duration with cosmic rays
  - Study of detector performance
  - Full scale analyses
  - Completely successful
- T600 second half-module terminated in 2002.
- Access to LNGS postponed because of Borexino accident until early 2005
- Argon activities suspended also on surface (Pavia)
- Now (2007) under final installation at LNGS.

The T600 module: 2001 in Pavia







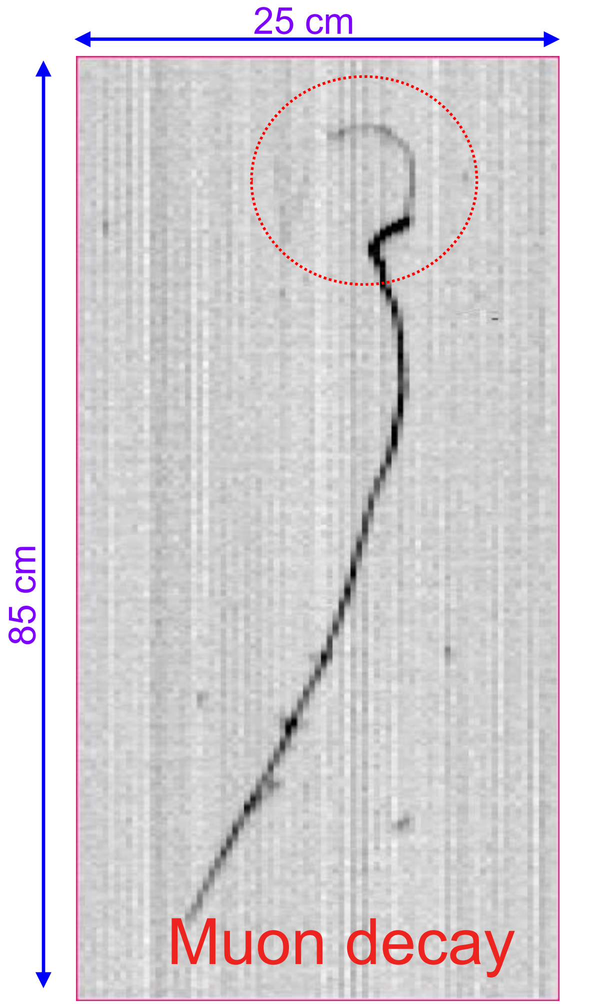
Test run in Pavia

Walking on the detector…

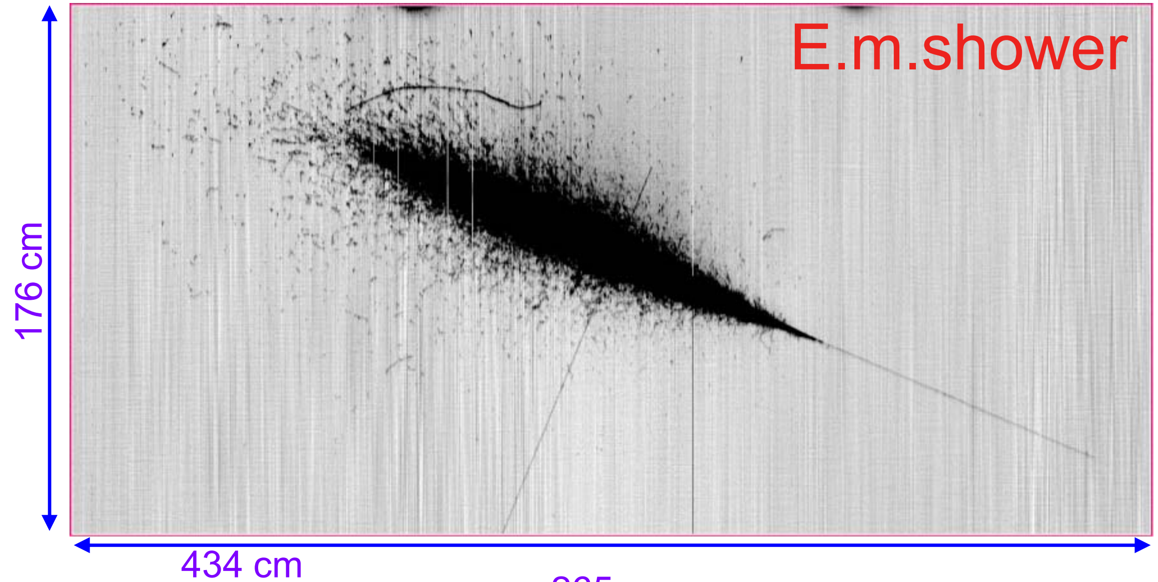
August 2001

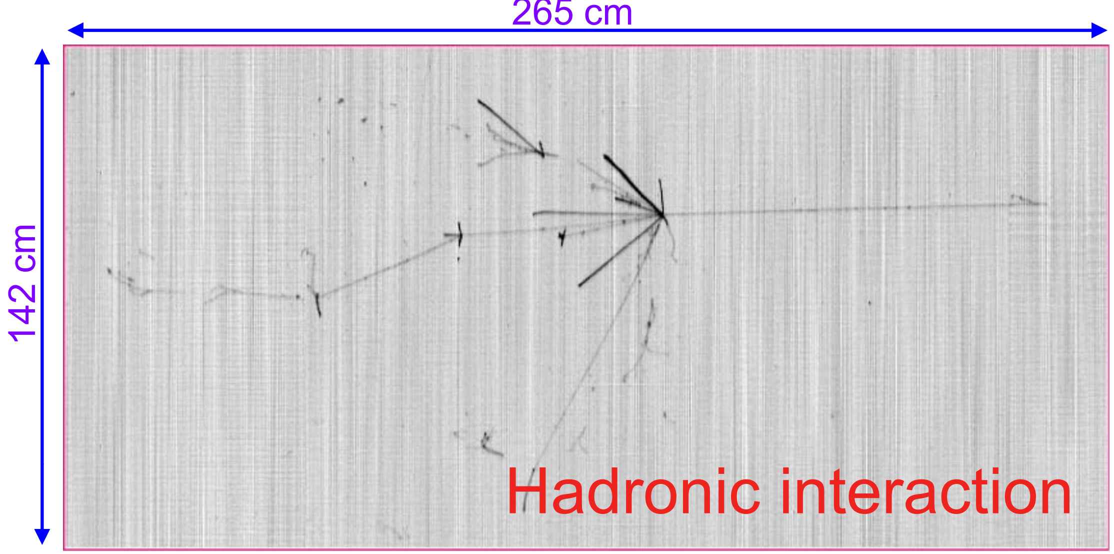
…and observing cosmic events

Electronic “Bubble Chamber”



Run 960, Event 4 Collection Left





Run 308, Event 160 Collection Left

Publications

The T300 technical run in Pavia has been reported by numerous articles illustrating the successful development of this new technology

1. F. Arneodo *et al.*, *"Observation of long ionizing tracks with the ICARUS T600 first half-module"*, NIM-**A508** (2003) 287-294.
2. S. Amoruso *et al.*, *"Analysis of the liquid argon purity in the ICARUS T600 TPC"*, NIM-**A516** (2004) 68-79.
3. M. Antonello *et al.*, *"Detection of Cherenkov light emission in liquid argon"*, NIM-**A516** (2004) 348-363.
4. S. Amoruso *et al.*, *"Study of electron recombination in liquid argon with the ICARUS TPC"*, NIM-**A523** (2004) 275-286.
5. S. Amoruso *et al.*, *"Measurement of the μ decay spectrum with the ICARUS liquid Argon TPC"*, EPJ-**C33** (2004) 233-241.
6. S. Amerio *et al.*, *"Design, construction and test of the ICARUS T600 detector"*, NIM-**A527** (2004) 329-410
7. A. Ankowski *et al.*, *"Characterization of ETL 9357FLA Photomultiplier Tubes for Cryogenic Temperature Applications"*, NIM-**A556** (2006) 146-157
8. A. Ankowski *et al.*, *"Measurement of through-going particle momentum by means of multiple scattering with the ICARUS T600 TPC"*, EPJ-**C48** (2006) 667-676
9. F.Arneodo *et al.*, *"Performance of a liquid Argon time projection chamber exposed to the CERN West Area Neutrino Facility neutrino beam"*, Phys.Rev.-**D74** (2006) 1-12
10. ICARUS collaboration, *"Analysis of Liquid Argon Scintillation Light Signals with the ICARUS T600 Detector"*, *in preparation (2007)*
11. ICARUS collaboration, *"Pi-zero reconstruction in ICARUS T600"*, *in preparation (2007)*

The path to underground operation(1)

- In December 2003 a *generalized risk analysis for large mass cryogenic liquid detectors to be operated underground* was completed by the LNGS staff under the mandate of a specially nominated Government's "*Extraordinary Commissioner*".
- In particular the detailed consequences for the operation of ICARUS were specified and new procedures were agreed.
- Hall B was chosen as the location for T600.
- In December 2004 the ICARUS collaboration received the "green light" to initiate the transfer of the two T300 modules from PAVIA to LNGS, however only to a "parking position" in Hall B.
- Incidentally the final position was finally reached only in June 2007.
- In view of the simultaneous installation of other experiments and in particular of the extensive use of space in Hall B for the construction of OPERA, a very difficult and conflicting situation has further slowed down the timetable of the installation of ICARUS.

Moving to LNGS

end 2004

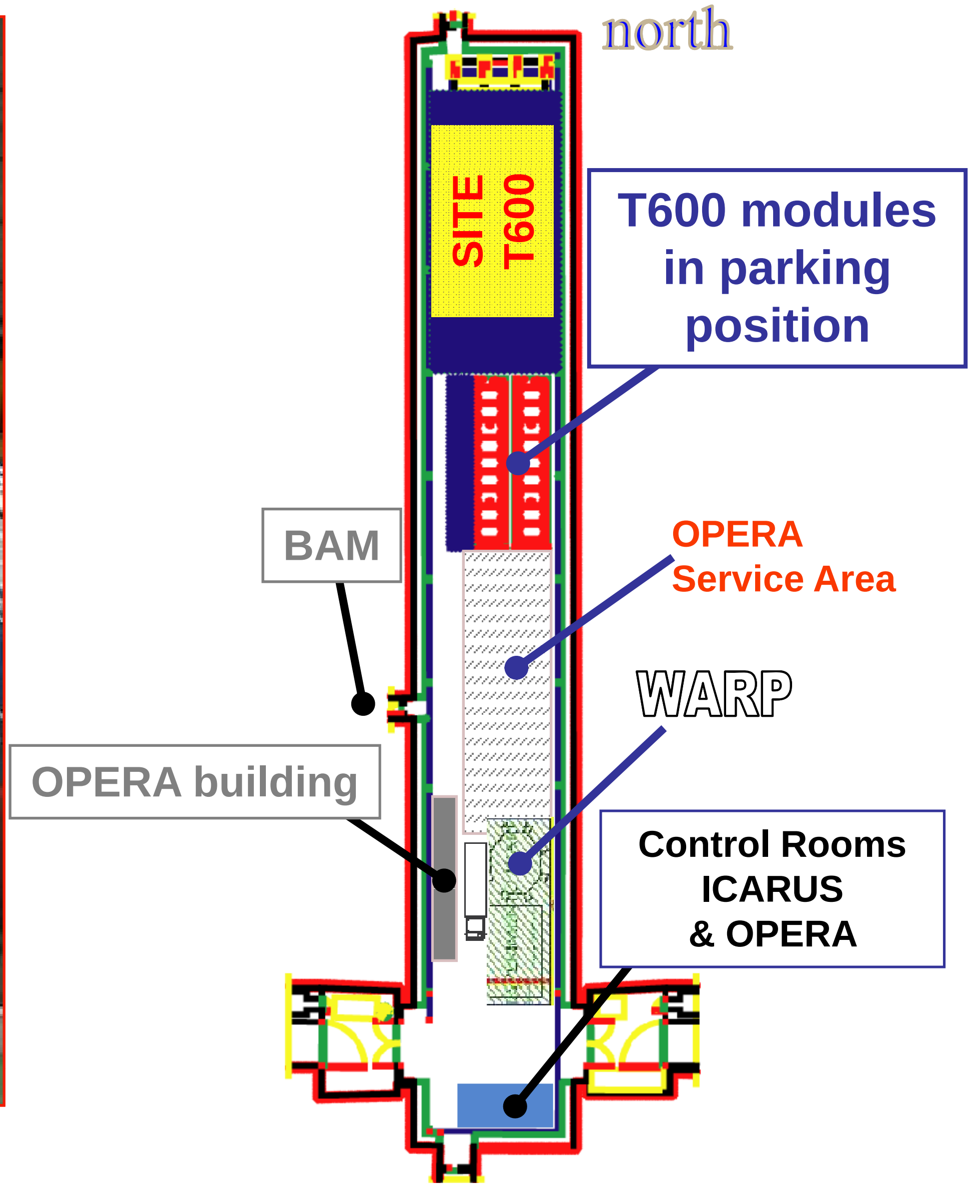
On the road

Entering into LNGS Hall B

end 2004

to the parking lot

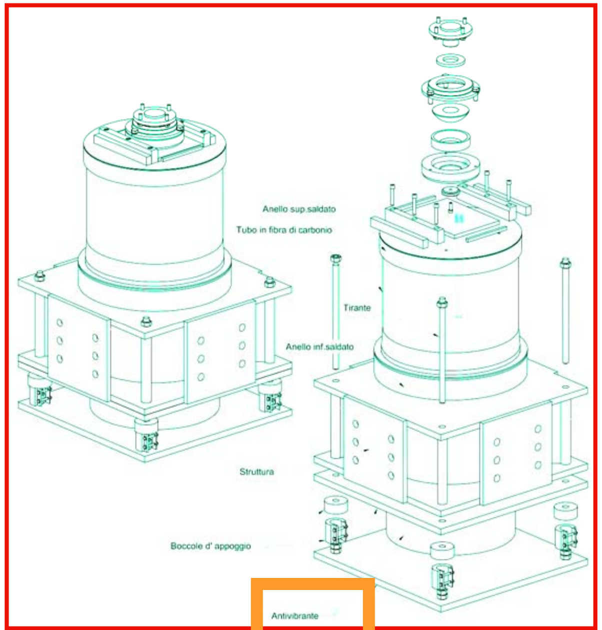
The busy situation in Hall B

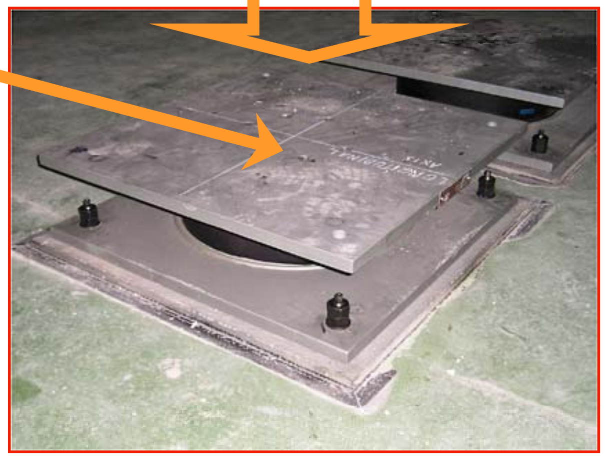


The path to underground operation(2)

- The stainless steel structure of the underground supporting cage was completed in March 2005.
- In the following months, the bottom insulation panels and the side-walls were installed. By March 2006 they were vacuum tested at the required insulation level < 7 W/m^2.
- At the same time the supporting feet, mounted on the anti-seismic shock absorbers, were welded and tested.
- All the insulation panels were mounted in their final location, except the downstream end-cap. The cold shields were all tested and installed by April 2007.
- Finally, the positioning of the two T300 cryostats inside the holding structure has been completed on June 19, 2007.

Frames, shock absorbers and feet.

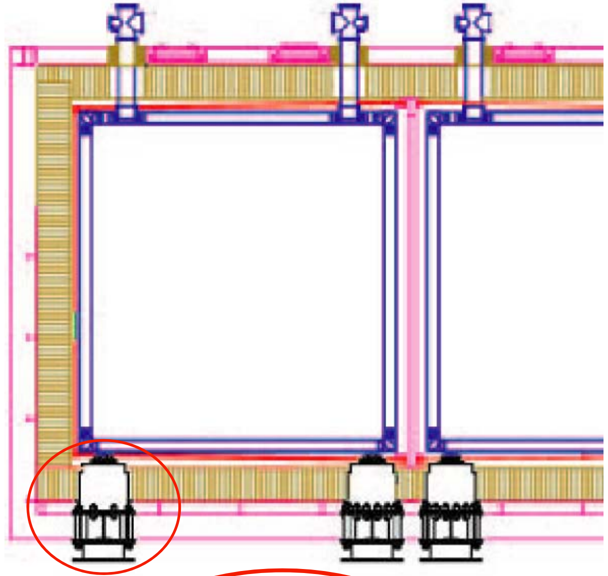


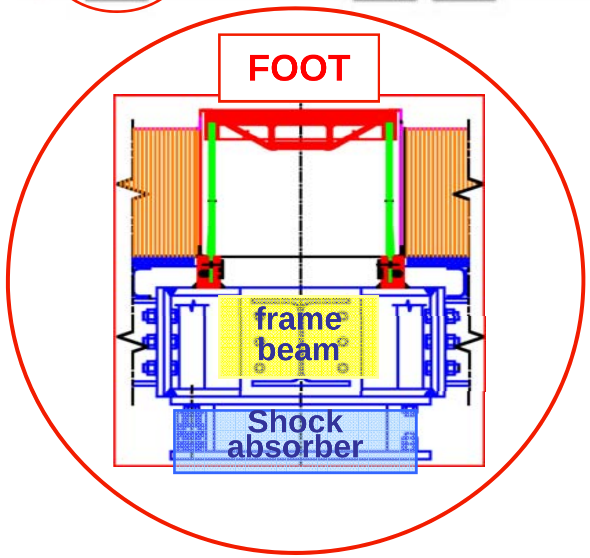


The **20** support feet, stainless steel made, are fastened to the shock absorbers and welded to the bottom panel (He-tested).

The bottom frame

- A tight container (a **metallic cage**) is suspended on the shock absorbers.
- The cage is used for both pressure and seismic **force containment**.

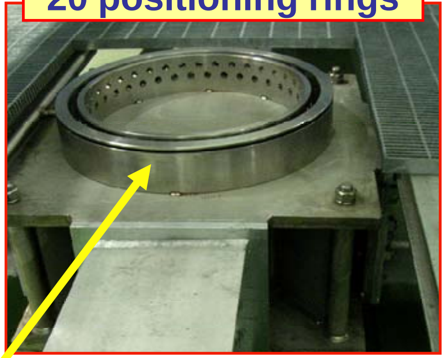


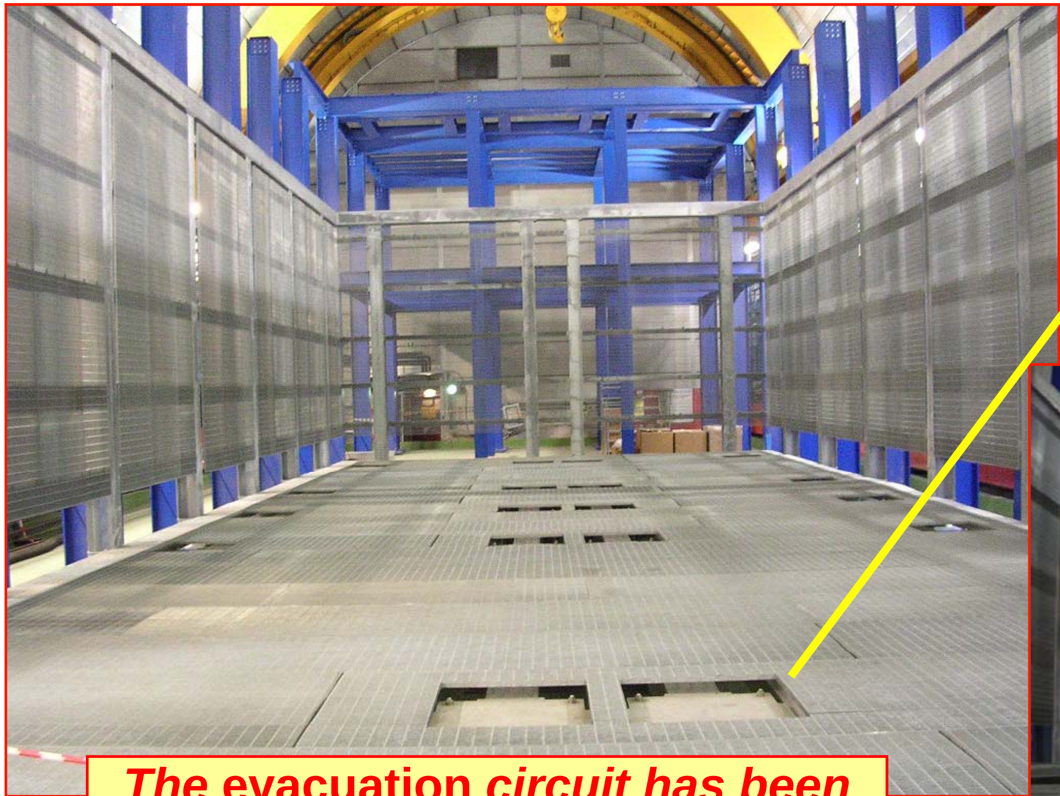


safety…

- **Insulation acts as a containment box in case of cryogenic liquid spillages and stands 100 mbar overpressure.**

20 positioning rings





The evacuation circuit has been vacuum tested : < 10^{-8} mbar l s^{-1})

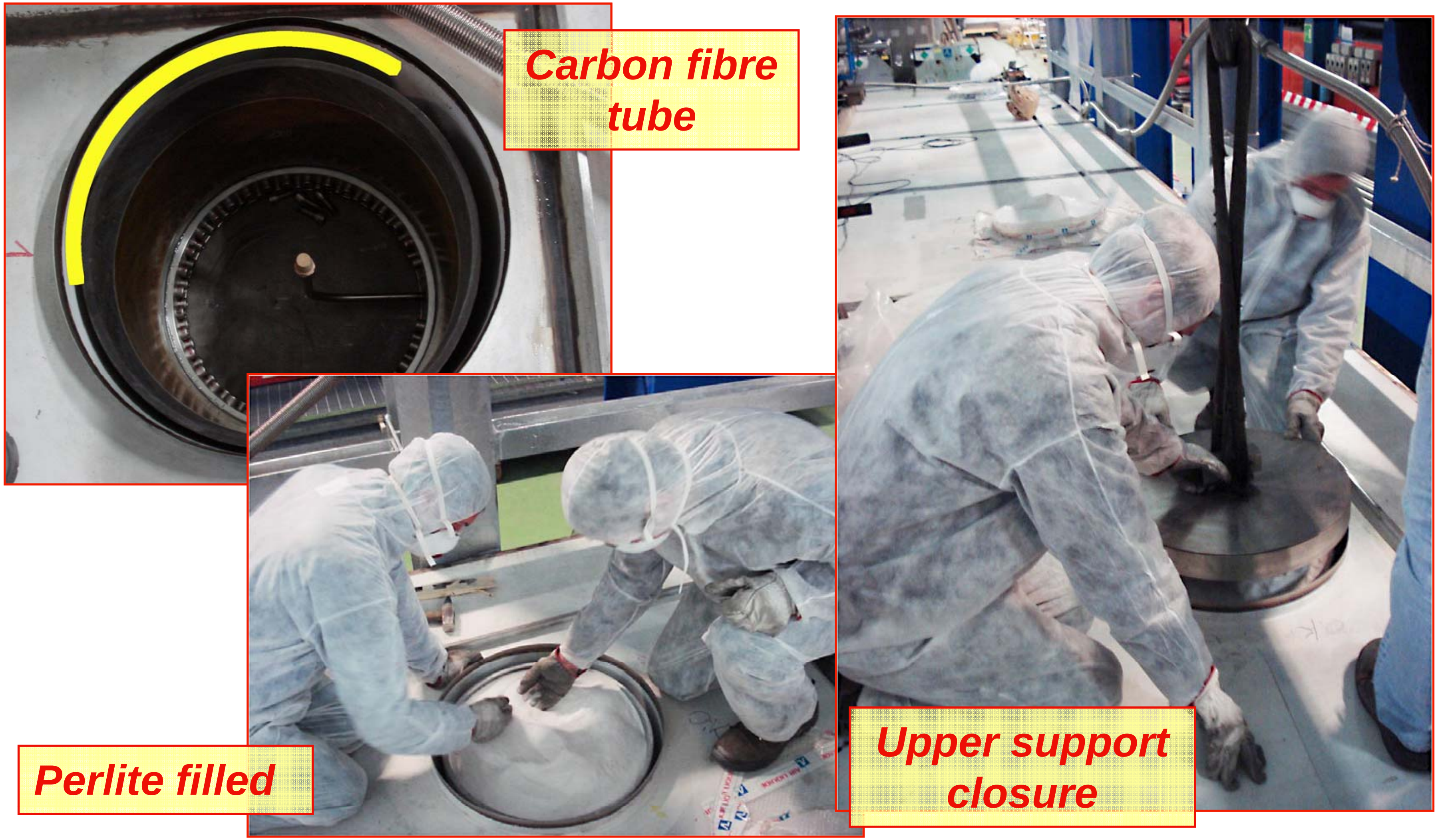
March 2005

The insulation panels

end 2006

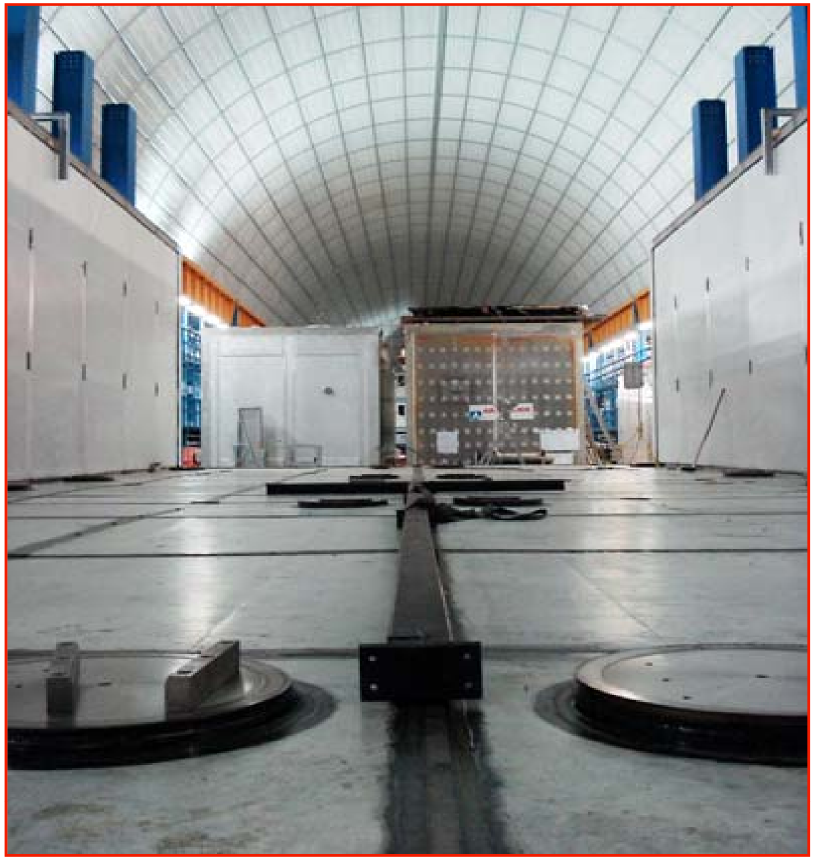
- **The insulation panels, ready at factory at the end of 2005, were transferred to LNGS late in 2006.**

The “feet”



Bottom and lateral insulation

April 2007



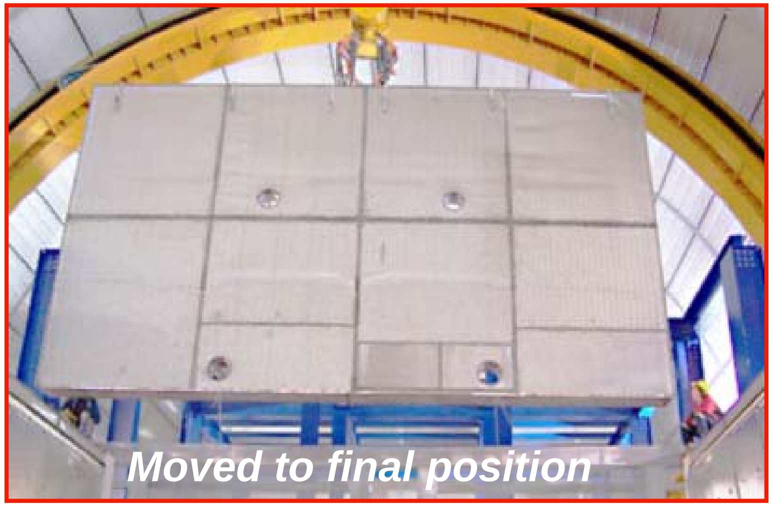
Place ready to host the cryostats.

- **The *bottom and lateral insulations (vacuum tested up to 10^{-4} mbar)* are in place and welded.**
- **The *support feet* of the cryostats are ready and vacuum tested.**
- **The *LN cold shields (vacuum tested)* are ready to be installed.**

Upstream closure

June 8th 2007

The panel has been transported in two parts



Moved to final position

Then, re-welded

Ready in place

Moving the cryostats…

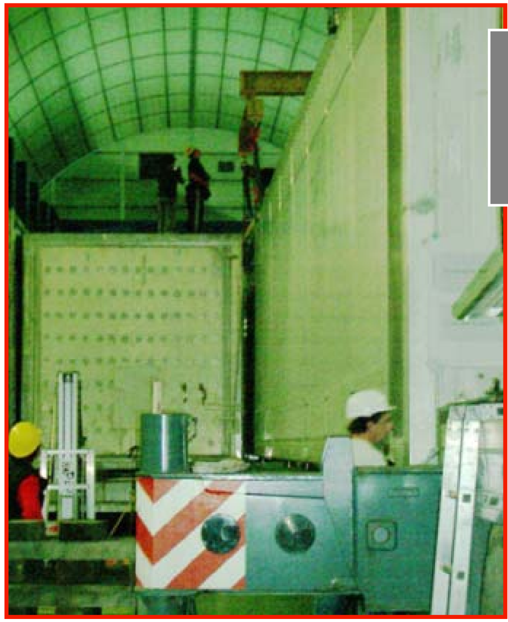
June 15th **2007**

First semi-module on the way

First semi-module in place

Place of second semi-module

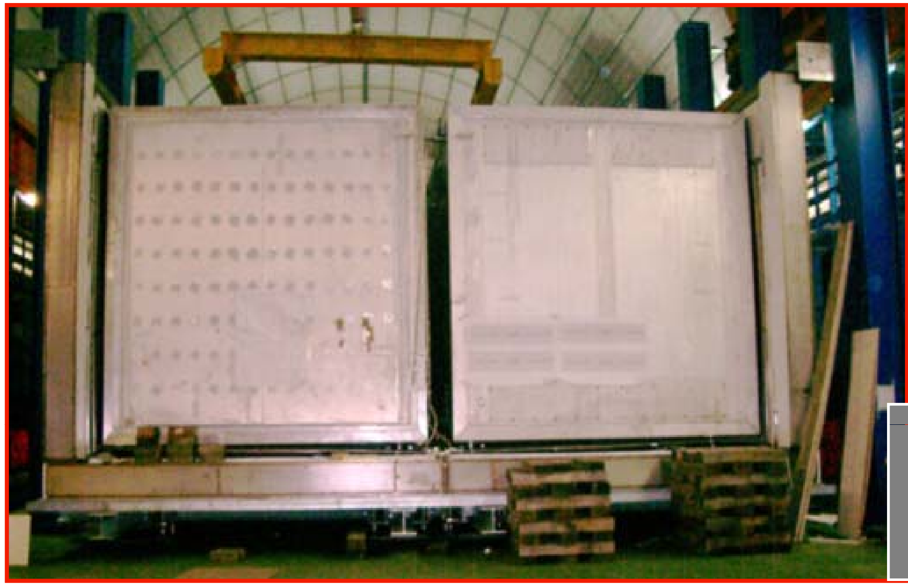
… in their final location



Moving the second semi-module

June 19th *2007*

Almost in place

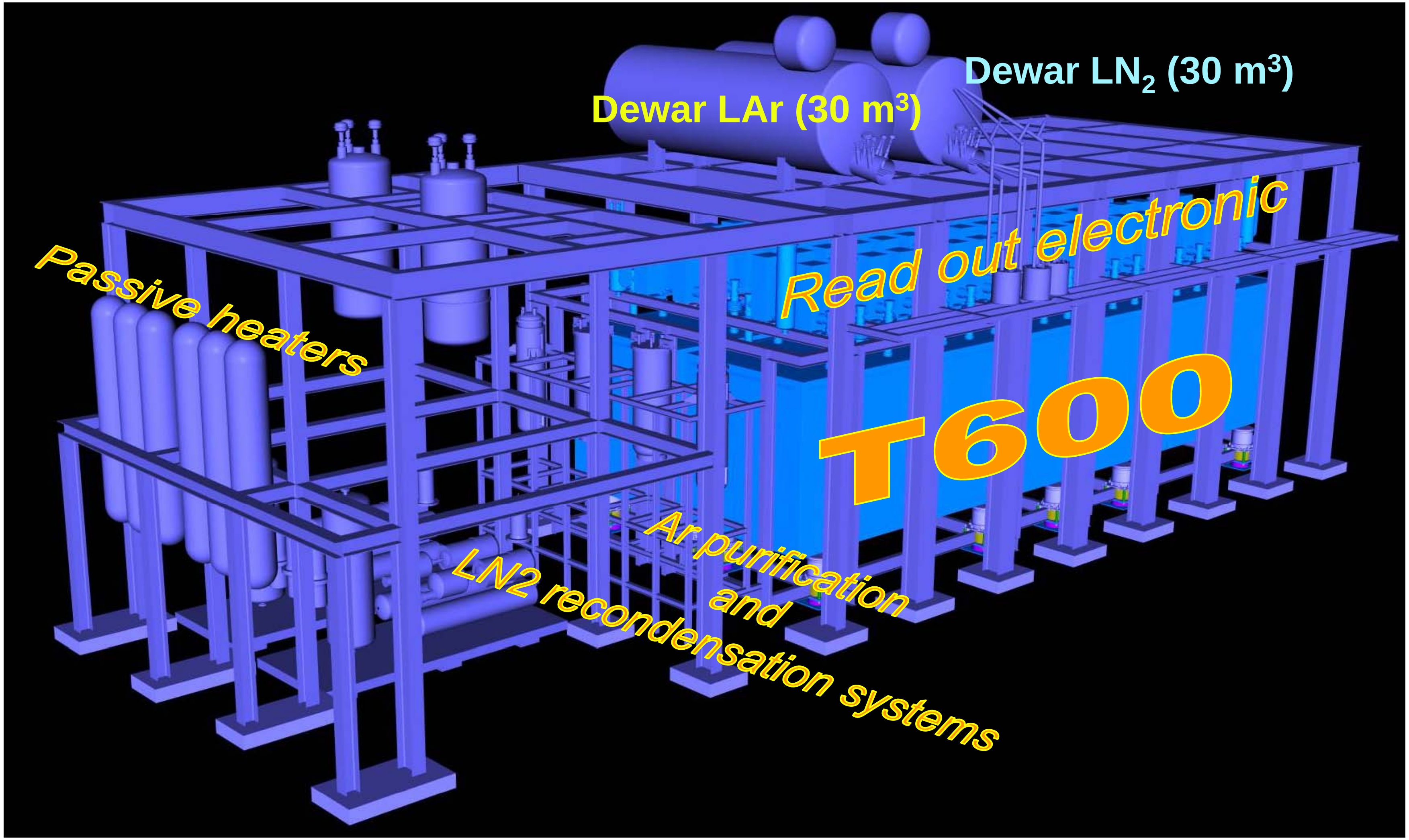


The positioning of the two cryostats inside the holding structure has been completed on June 19, 2007

Summarizing the progress achieved:

• T600 modules moved to LNGS:	December 2004
• Anti seismic frame (partially) installed:	Feb-Mar 2005
• Test of the insulation (< 7 W/m^2):	Oct-Dec 2005
• Cryogenic components (@ factory):	Jan-March 2006
• Insulation panels @ LNGS:	December 2006
• Cryostats in their final position:	June 19th, 2007

T600 general layout



Future actions...

With the cryostats in place:

Accurate inspection of the wire chamber mechanics, of the PM's and of the inner slow control instrumentation (*18 days*)…

…Installation of the signals *chimneys* (*15 days*)…

When the upper floor is accessible:

- Installation of the electronics racks (*36 man-days*):
  - On board power supply cabling
  - T600 cabling (*25 man-days*)
- Test of the racks (*36 man-days*).
- Trigger system installation and test.

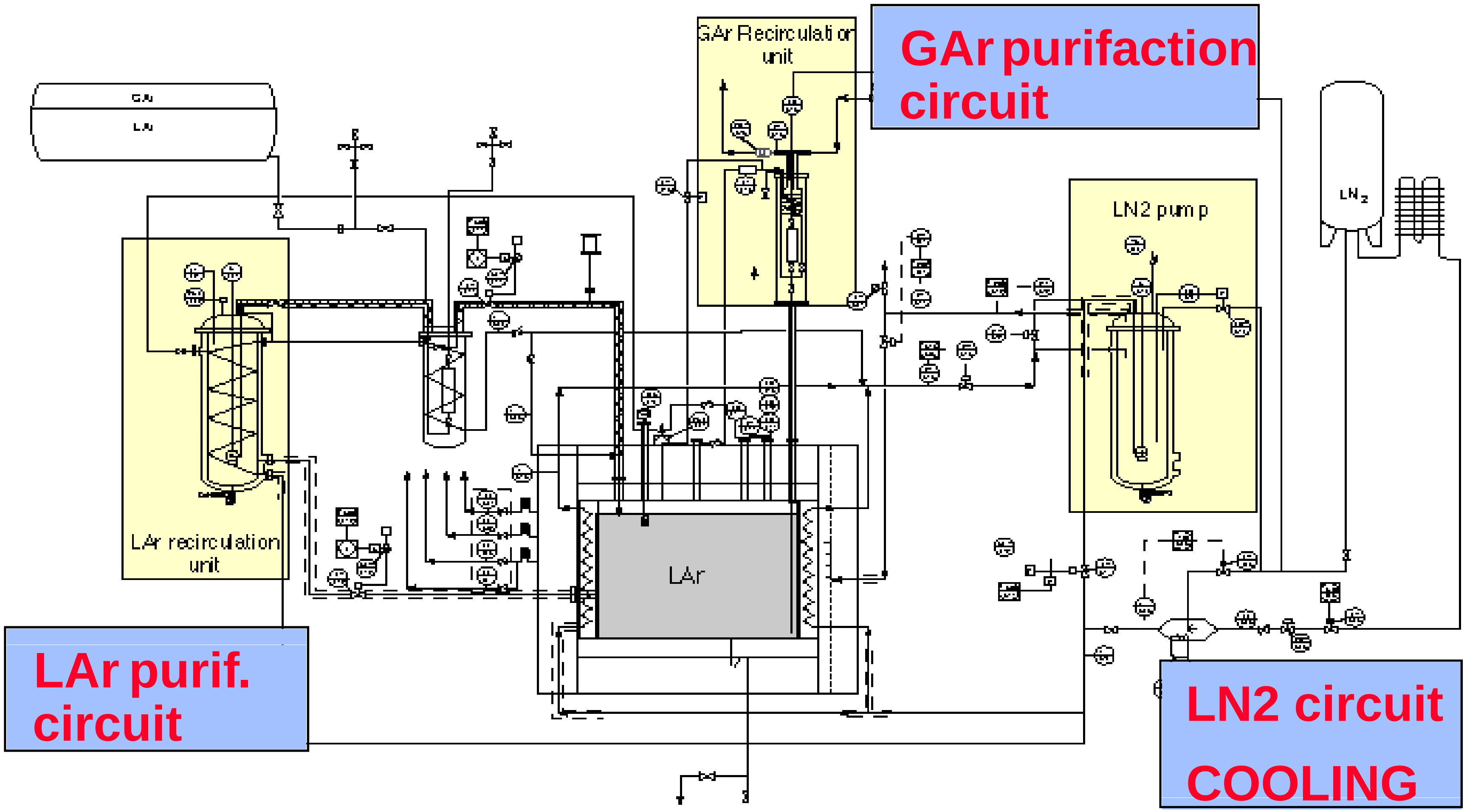
General Infrastructures

The development of these activities, their cost and the schedule are under the responsibility of LNGS

- ✓ MAINS supply (from the main cabinet to Hall B).
- ✓ Continuity power supply (UPS).
- ✓ Water cooling circuit.
- ✓ Cold pipeline for the cryo-liquids filling.
- ✓ ETHERNET cabling.
- ✓ Sensor-nets for the safety controls, in Hall B.
- ✓ Software for the Central Labs controls room.
- ✓ Production of cryogenic liquids for T600

All these activities are scheduled to be completed by the end of 2007

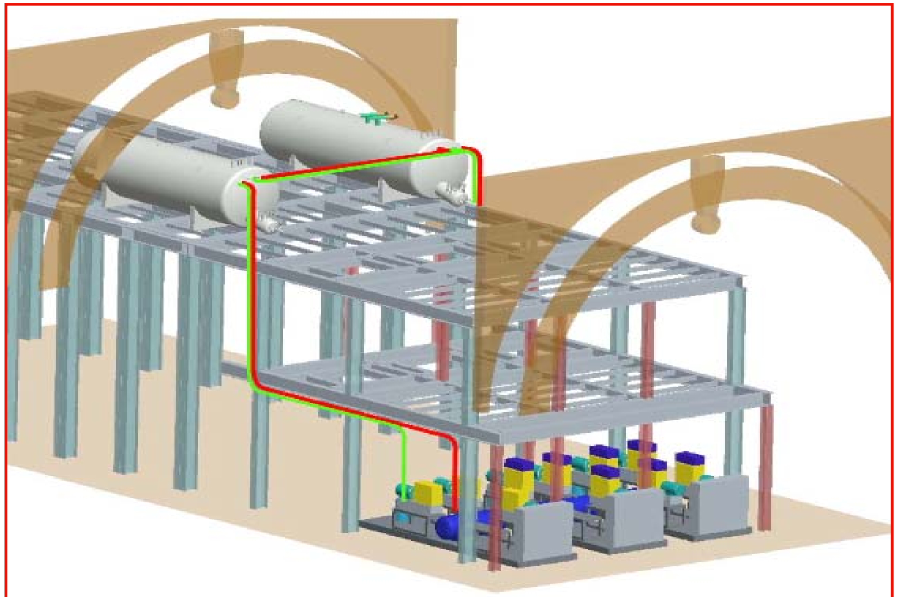
Layout of cryogenic structure



LN2 re-condensation

The liquefier system is under construction at Stirling site under their responsibility.

- All geometrical constraints and matching interfaces with Air Liquide have been *negotiated and solved*.
- The commissioning is foreseen for December 2007.



- It will be then possible to operate ICARUS T600 in a closed circuit, without Nitrogen outflow, with a factor 2 of safety in installed power

Schedule toward completion

Cryostats in final position (DONE)	June 19th, 07
Completing the cold shielding and top floor	July 20th, 07
Detector inspection and cabling of feed-throughs	August 07
Instrumentation of the cryogenic plant	August 07
Readout electronics & cabling in place	October 07

⇨**T600 main detector completed by October 2007.**

N_2 and Ar cryogenic circuits assembly	December 07

⇨**General Infrastructures completed by December 2007.**

⇨**Evacuate the cryostats**
⇨**Cooling down**
⇨**Filling with N2 and LAr**
⇨***First cosmic events***

~ *Early* 2008

Conclusion

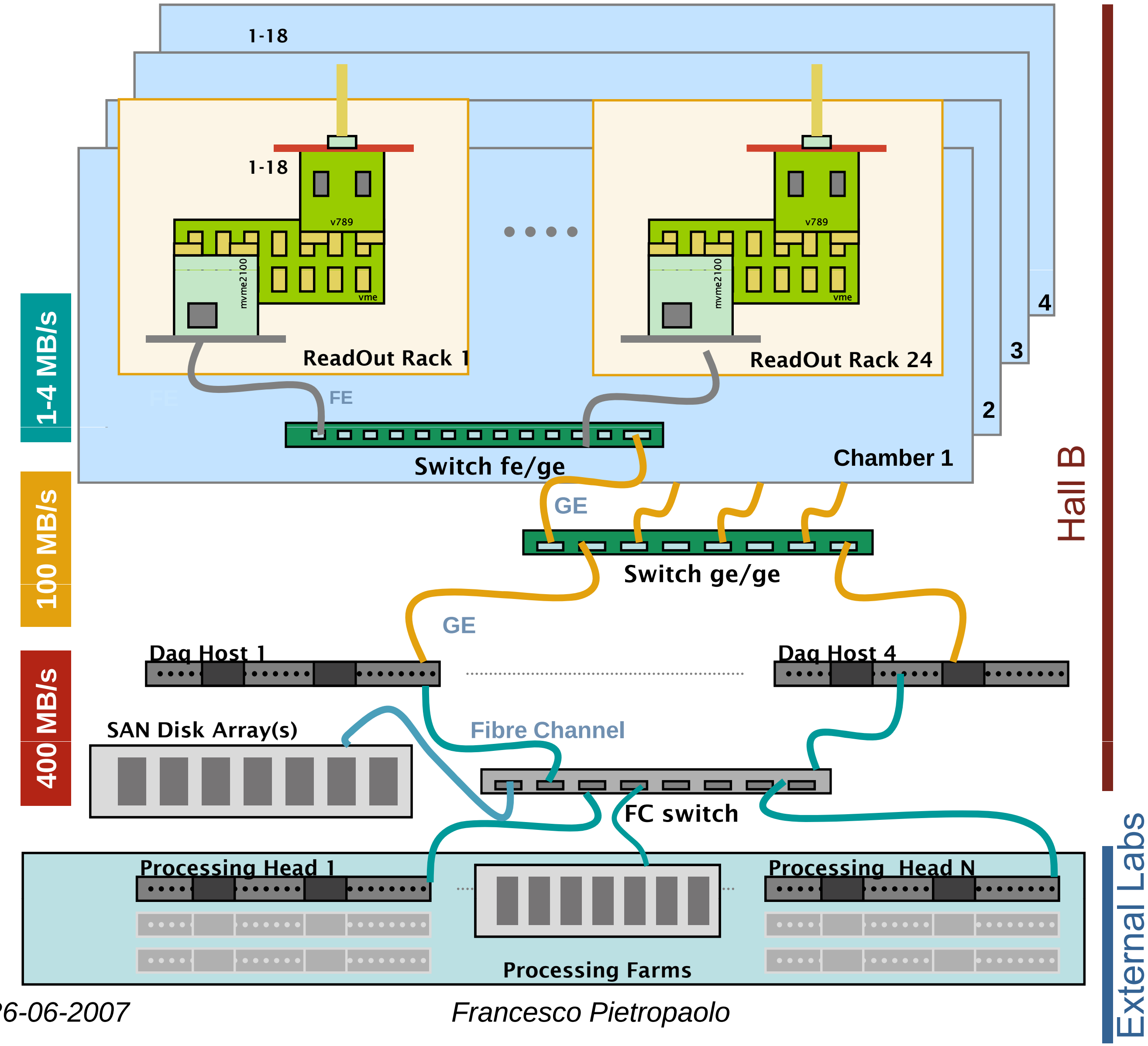
- The delicate installation of T600 underground is proceeding smoothly and nearing its completion
- There is excellent expectation that both detector and LNGS infrastructures will be fully operational early in 2008…
- …on time for the first CNGS physics run scheduled for Spring 2008

- Additional slides

DAQ event builder

- The Event Builder architecture foresees: 4 DAQ hosts, 2 hosts as Virtual Filesystem controllers and 4 Disk Arrays (at least 30 TBytes) as short term storage.
- Moreover Switches and long haul Tranceivers for the dedicated GigaEthernet and FiberChannel networks are needed to transfer data from the Hall B to the external laboratories (7km away) at a rate of 2Gbit/s.
- At present funding allows for: the complete networking infrastructure, 1 DAQ host + 1 processing node, 7 TBytes of storage (only in hall B) equivalent to ~100K full drift events.
- These limited resources are nevertheless enough for a first run: all the components are procured and/or installed at LNGS.

DAQ architecture



Event rates and storage needs

- **High energy cosmic rays:**
  - ~150 through-going muons/hour,
  - ~0.3/day atmospheric neutrinos
  - ~200 GBytes/day
- **CNGS events:**
  - ~10 ν interactions inside the T600 per day +
  - ~20 μ/day from interactions in surrounding rock
  - ~1.5 GBytes/day + up to ~2TBytes per day initially (for trigger rates and efficiency tests)
- **Calibration:**
  - ~100 GBytes live storage
  - (~500 GBytes during commissioning)
- **Low energy events (including solar + supernovae ν):**
  - ~1-2 ev/day from solar ν
  - ~2 Hz (5 MeV thresh.): mainly natural radioactivity and PM dark current
  - up to 2.0 TBytes/day: data reduction mandatory!

Computing resources

LIVE storage:

- ~10 TBytes (underground) + 10 TBytes (outside).
- ~5 TBytes for low energy event buffer.
- ~5 TBytes intermediate storage for first processing

Long term storage:

- ~100 TBytes/yr (real events)
- ~10 TBytes (MC events)

Raw data processing:

~10 8-core machines.

MonteCarlo:

~1 CPU unit (event generation) + 7 CPU unit for analysis

Trigger system

- The trigger system will be capable of generating a signal for both global and localized detector regions according to the event type and size, exploiting light and ionization signals in LAr.
  - The front-end electronics provide analogue signals corresponding to the sum of 32 adjacent wires, i.e. about 10 cm slice of LAr.
  - A custom developed board (LTCU) able to discriminate these signals and to provide suitable input for the trigger logics is being tested on small LAr-TPC prototypes at LNL laboratory and CERN.
  - The signals from PMT and from the LTCU will be elaborated by powerful FPGA's mounted on a dedicated crate to compose coincidence patterns between light and wire planes.
  - The use of FPGA's allows large flexibility in programming the pattern topologies and multiple trigger conditions.
  - In this way several trigger pattern like isolated cosmic muons, atmospheric and solar neutrinos, proton decay and neutrinos from the CNGS beam will coexist.
- The CNGS beam trigger will also profit from the early warning signal delivered from CERN-SPS to produce a gate corresponding to the beam extraction and arrival at LNGS. This activity is under way in collaboration with CERN and LNGS
  - Based on similar developments undertaken by OPERA, CERN and LNGS.

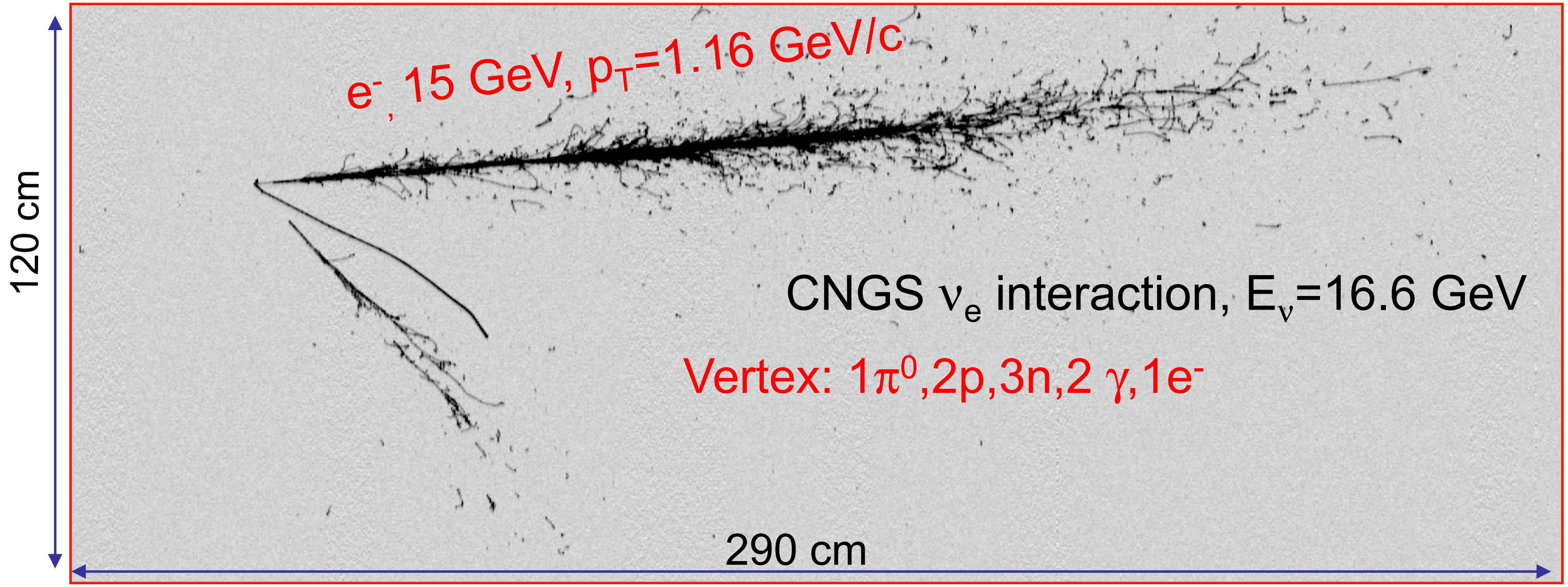
Physics issues

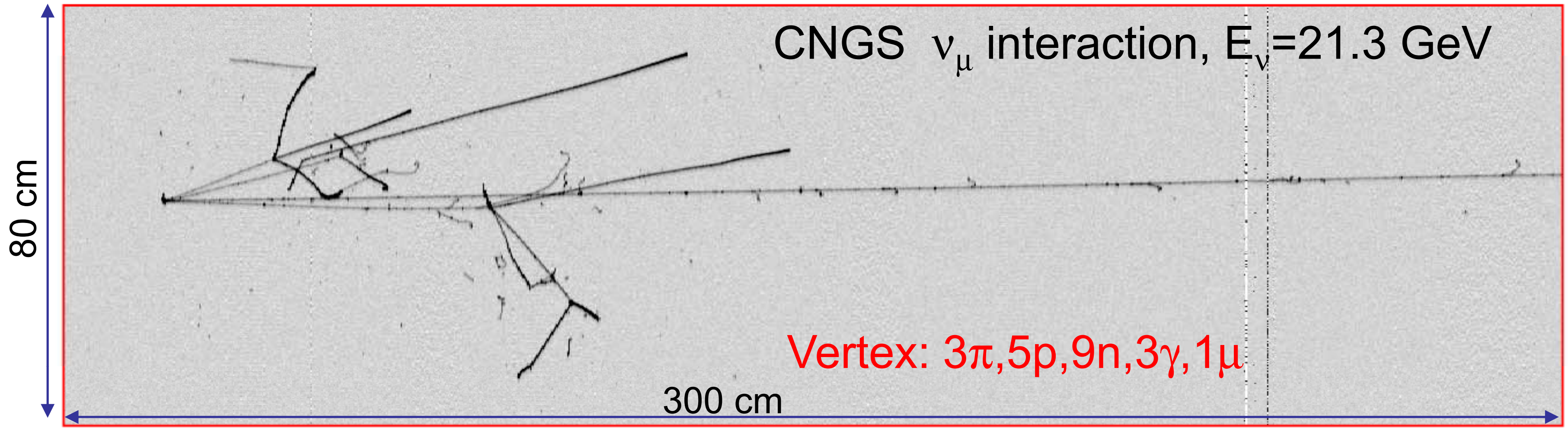
- The ICARUS T600 detector is a necessary intermediate technical step towards a much more massive LAr detector (multikton Lar-TPC are now being actively studied in Europe and US), but it offers also some interesting physics in itself.
- The T600 will collect simultaneously "self triggered" events of different nature. This in particular represents:
  - ≈ 100 ev/year of individually recorded atmospheric CC cosmic rays.
  - Solar neutrino electron rates >5 MeV.
  - Supernovae neutrinos.
  - A zero background proton decay with 3 x 10^{32} nucleons for "exotic" channels.
  - CNGS beam related neutrino events (for the study of ν_τ appearance):
    - The T600 raw fiducial volume ≈ 480 t is equivalent nominally 1200 ν_μ CC ev/y for 5 years and 7-8 ν_e CC ev/year.
- A complete review of the T600 potentialities was recently presented to the SPSC (Oct. 2006 meeting). In particular, the possibility to check the LSND effect with e-like deep inelastic CC events, complementary to MiniBooNE, was put forward.
  - A detailed study of sterile neutrino search with the T600 detector has been performed, confirming the potentiality anticipated in October 2006.

Search for sterile neutrinos @ CNGS

- The possibility of one or more additional, “sterile” kinds of neutrino - namely of neutrinos which do not participate in the weak interactions - has been put forward by an interpretation of the Los Alamos LSND.
- Very recently, the Mini-BooNE experiment has disclosed its results, which are not consistent with the LSND observations.
  - Both LSND and MiniBoone experiments are characterised by:
    - << 1 GeV quasi-elastic events requiring elaborate selection criteria
    - a relatively short oscillation path from the source to the detector
    - the addition of substantial competing backgrounds due to misinterpreted events.
    - therefore the signal should appear as an event excess peaking at low values of the visible ν energy.
- The ICARUS technology allows for a completely independent check, with the great advantage of the total rejection of neutral current backgrounds.
  - The CNGS beam and the ICARUS “bubble chamber” identification is based on:
    - Deep inelastic ν_e CC events recorded in the minimum bias mode.
    - Extremely good background discrimination, limited only to the intrinsic beam ν_e contamination: ≤0.8% in the chosen E_ν interval of 10 $\div$ 30 GeV.
    - Excellent electron discrimination against converted γ's because of the differences in ionization losses in the earliest part of the track (negligible NC backgrounds).
    - Very long path-length which ensures several oscillations periods from source to detector in the foreseen LSND window (with L/E values similar to those of LSND and MiniBooNE)

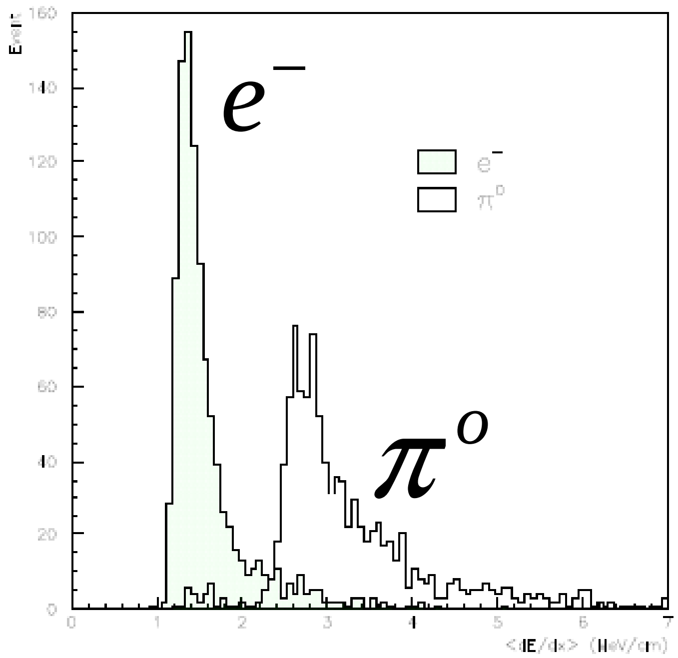
Reconstructed CC events in T600



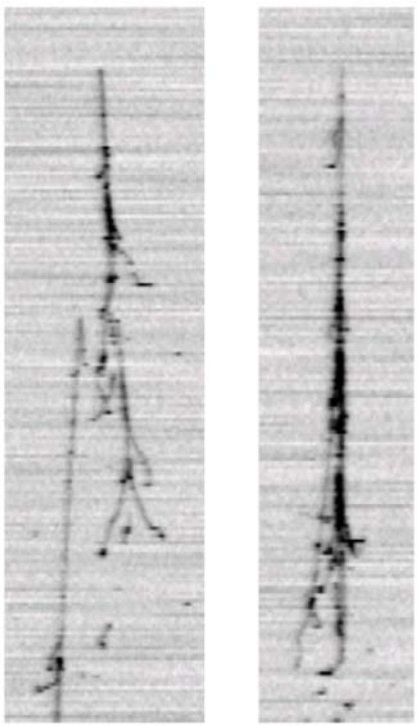


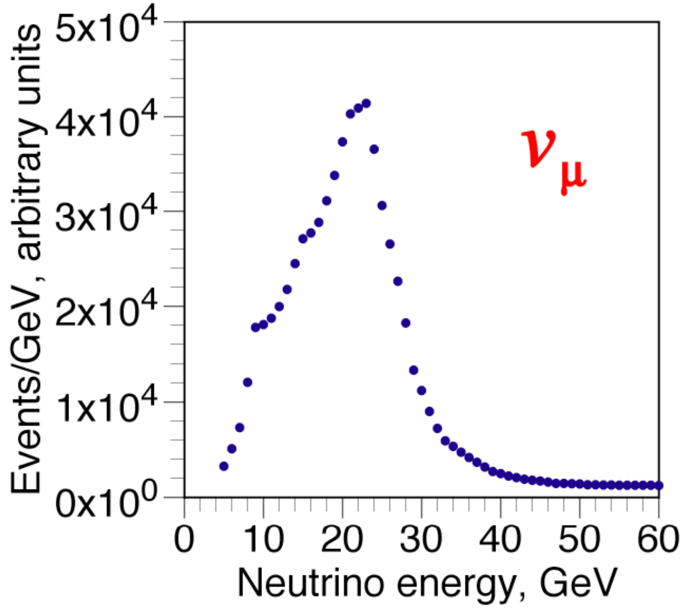
Events with leading electron signature

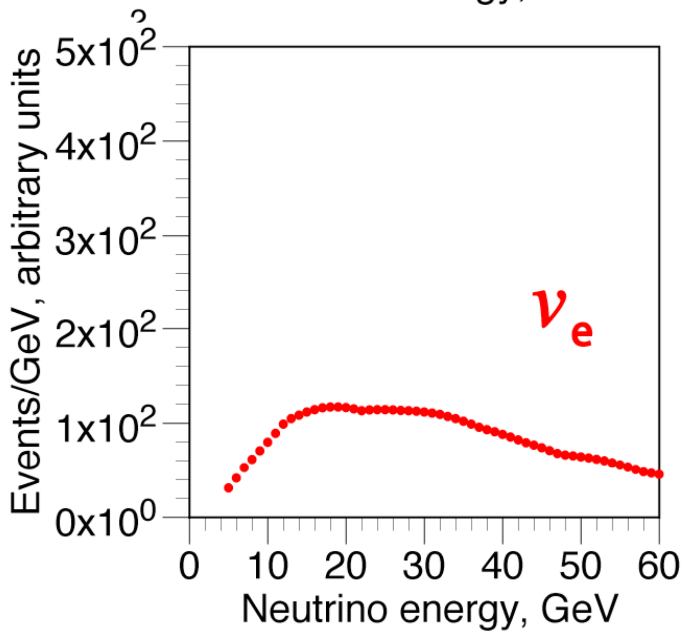
- The CNGS ν_μ spectrum has a most probable energy of about 25 GeV.
- The calculated ν_e spectrum is expected to be accurate within 5%.
- Electron shower events are extremely well identified experimentally, because of the ionization behaviour in the first cells after the vertex.



electron (right) and π^0 (left) in T600

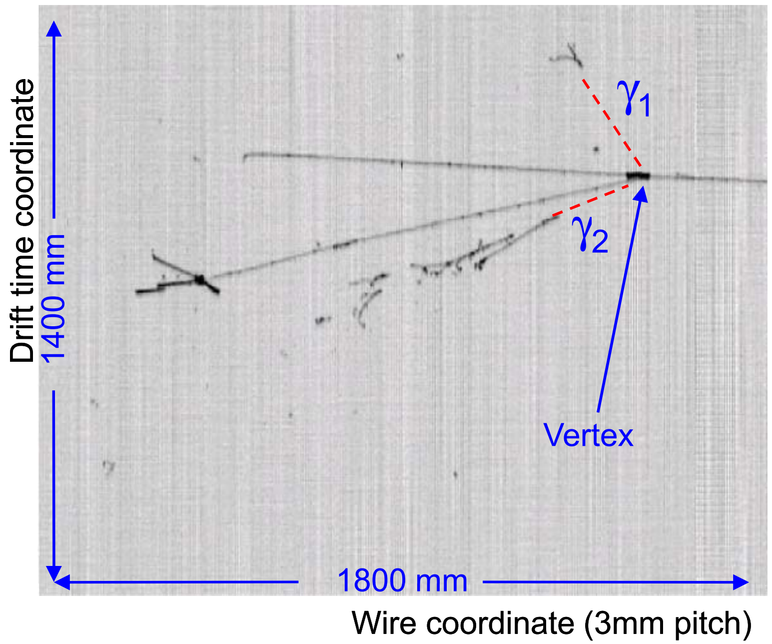


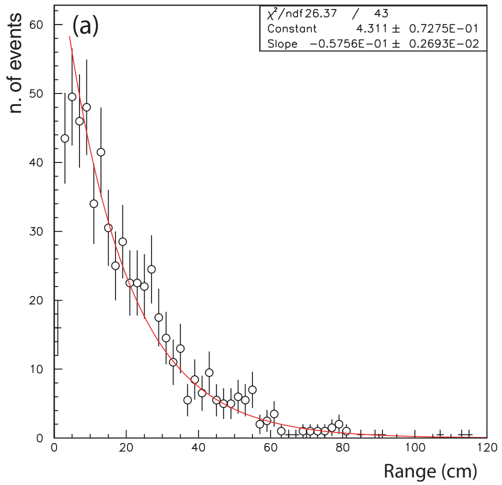




π^0 reconstruction (on-going analysis)

230 hadronic interactions with $\pi^0 \rightarrow \gamma\gamma$ candidates have been selected from ICARUS T300 Pavia run





The measured photon radiation length is

$$X_{\gamma,meas} = (17.4 \pm 0.8)\text{cm}$$

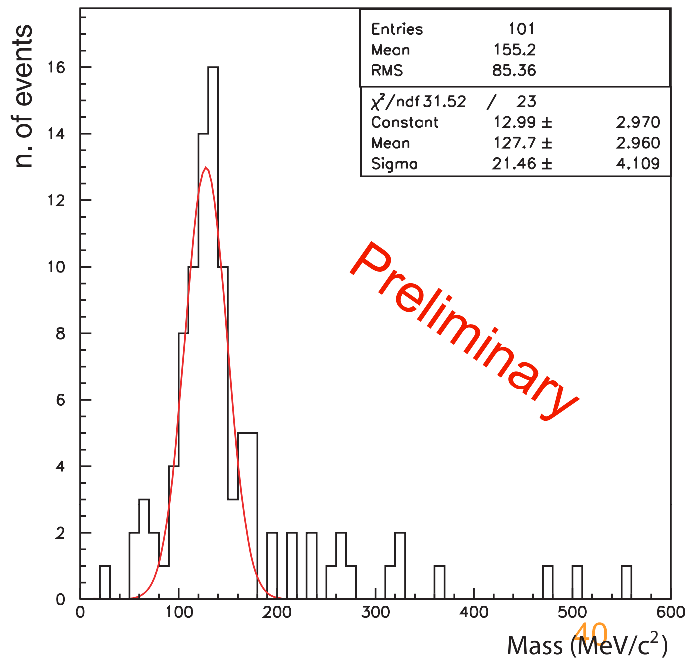
in agreement with expectation:

$$X_{\gamma,\exp} = \frac{9}{7} \cdot 14\text{cm} = 18\text{cm}$$

The average (γ,γ) invariant mass is in agreement with the π^0 mass hypothesis (m_{π^0} = 135 MeV/c^2);

$$m_{\gamma\gamma} = 127.7 \pm 3.0(stat) \pm 4.0(sys)\text{MeV/c}^2$$

The systematic error is mostly due to the calibration



NC background rejection

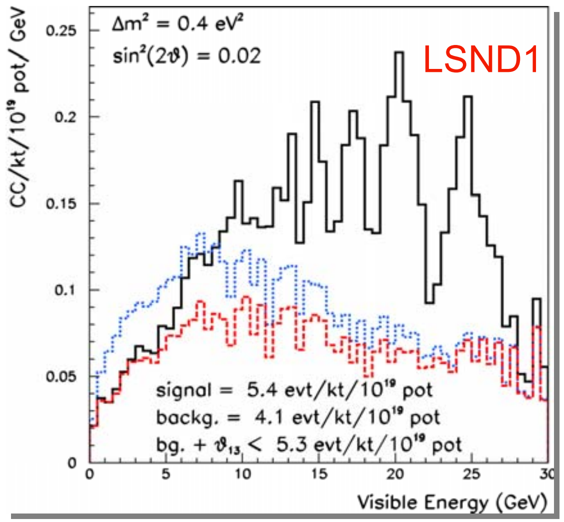
- A full simulation of oscillated and background events in the T600 module has been carried out for different possible combinations of the oscillation parameters in the LSND allowed region
- The latest calculations of the CNGS neutrino spectra and the nominal intensity (4.5 10^{19} pot/y) have been assumed.
- All background sources have been considered:
  - Intrinsic beam ν_e contamination
  - Intrinsic beam anti- ν_e contamination
  - Neutral current events misidentified as ν_e events

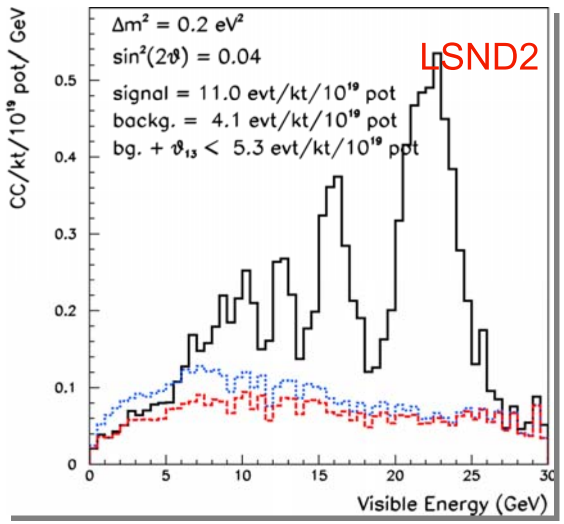
    ν_μ oscillations into ν_τ followed by ν_τ CC events and τ decay in e +X
- The background due to neutral current events has been rejected thanks to:
  - vertex reconstruction;
  - pion mass reconstruction;
  - dE/dx analysis of the electron/photon tracks.
- Residual misidentification < 0.1%
- Electron identification efficiency = 90%

>> NC background negligible with respect to intrinsic ν_e <<

The case of large exposure

- The visible energy spectra in the ideal situation of very large exposure (1700 kt 10^{19} pot) have been reconstructed.
  - The hypothetical spectrum from a θ_{13} driven oscillation in the Chooz limit for $\Delta m_{23} = 2.5\ 10^{-3}\ eV^2$ is also included.
  - The energy resolution of the LAr-TPC allows peak separation for most of the explored oscillation parameters.
- Both background and the θ_{13} events have a lower energy than the LSND-like oscillations.
  - True for most of the LSND allowed region, where the mass difference is much larger than the atmospheric one.
  - In this region, the number of LSND-oscillated events is independent on the value of the mass difference, since the oscillation appears as a modulation of the original muon neutrino flux.



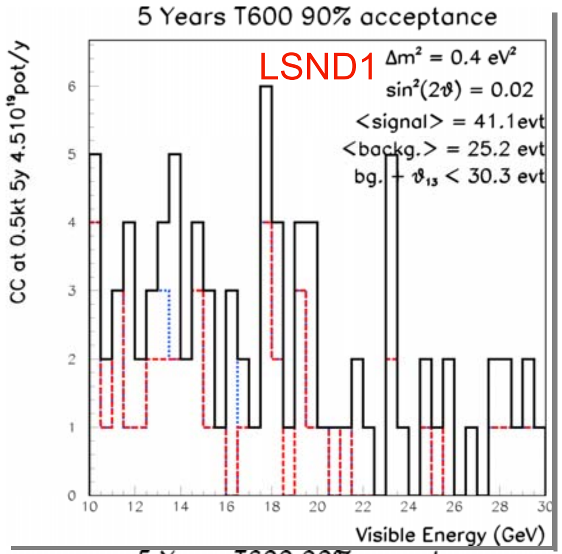


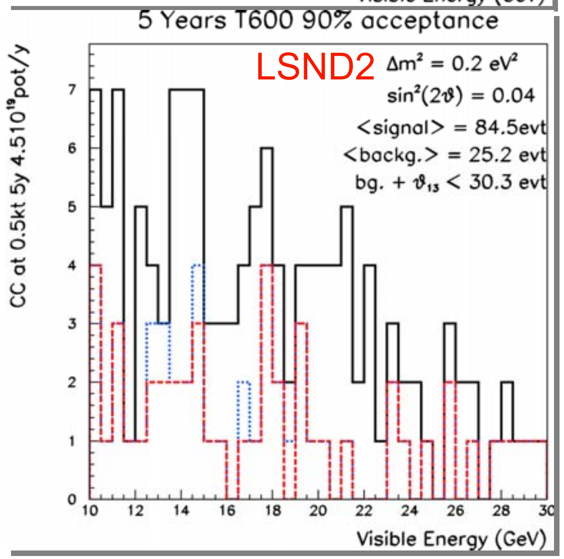
T600 performance

- Due to the limited exposure (11 kt 10^{19} pot in 5 years), a poor reconstruction of the oscillation pattern will be available with the T600
- However the oscillated event rate can be significantly larger than the expected backgrounds.
- A 10 GeV threshold on the visible energy has been applied to enhance the signal to background ratio

	Background					$\nu_\mu \leftrightarrow \nu_e$ θ_{13}	$\nu_\mu \leftrightarrow \nu_e$ signal	
	ν_e	ν_τ	NC	$\bar{\nu}_e$	TOTAL	CHOOZ lim.	LSND1	LSND2
$0<E_{vis}<30$GeV	27	5	1	1.5	35	10	50	101
$10<E_{vis}<30$GeV	22	2	0.3	1	25	5	41	85

- Spectra and rates have been obtained assuming a minimal fiducial volume cut on the vertex position, corresponding to 90% acceptance.





Physics reach

- The $\sin^2(2\theta)$-Δm^2 explored region covers most of LNSD allowed areas and extends to lower value of Δm^2
- Two indicated points are reference values of MiniBooNE proposal and of previous slides
- One year of data taking will be enough to exclude $\sin^2(2\theta)$ values larger than 10^{-2} at 90% CL.