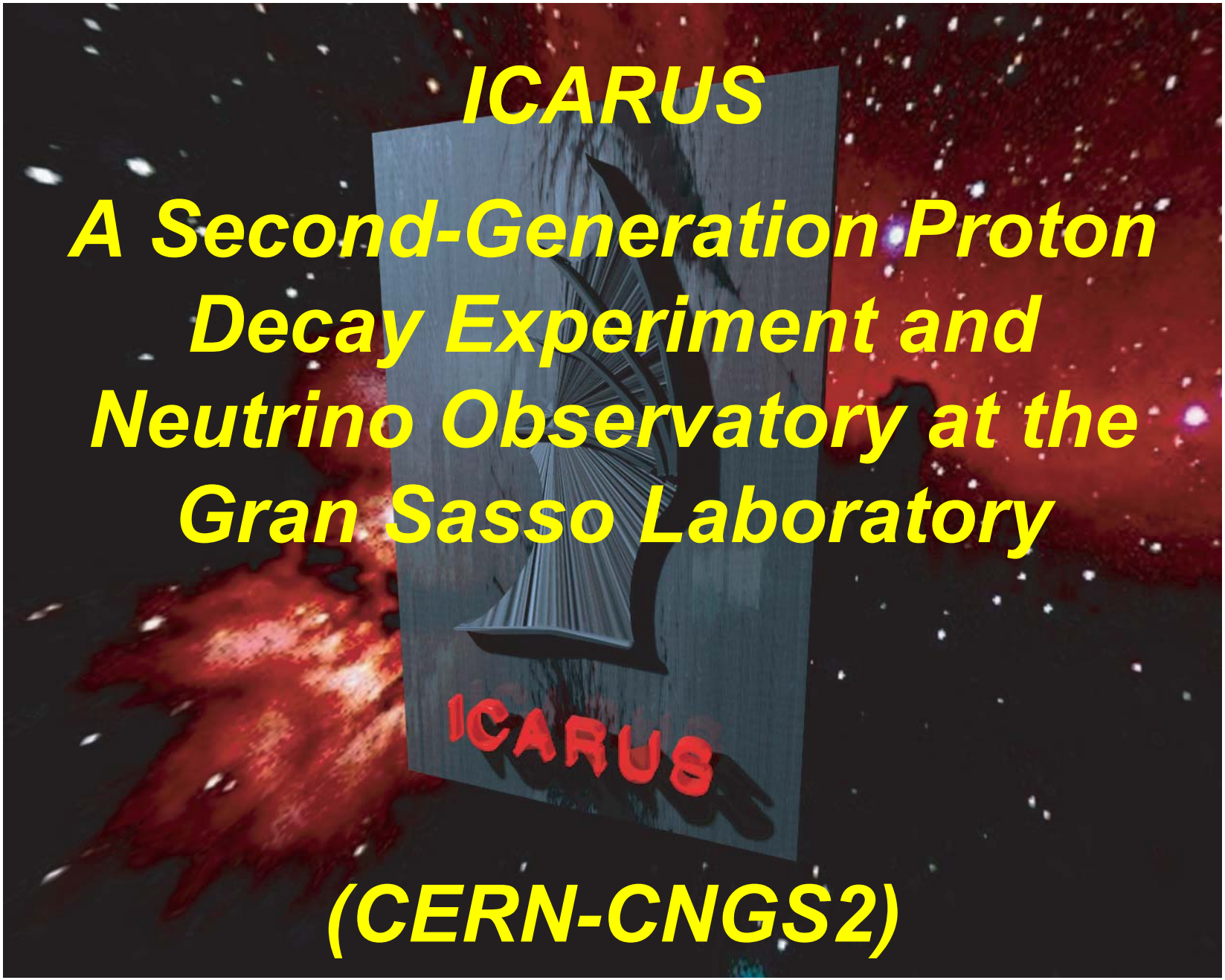
ICARUS
A Second-Generation Proton
Decay Experiment and
Neutrino Observatory at the
Gran Sasso Laboratory
ICARUS
(CERN-CNGS2)

The ICARUS Collaboration (25 institutes, 145 physicists)

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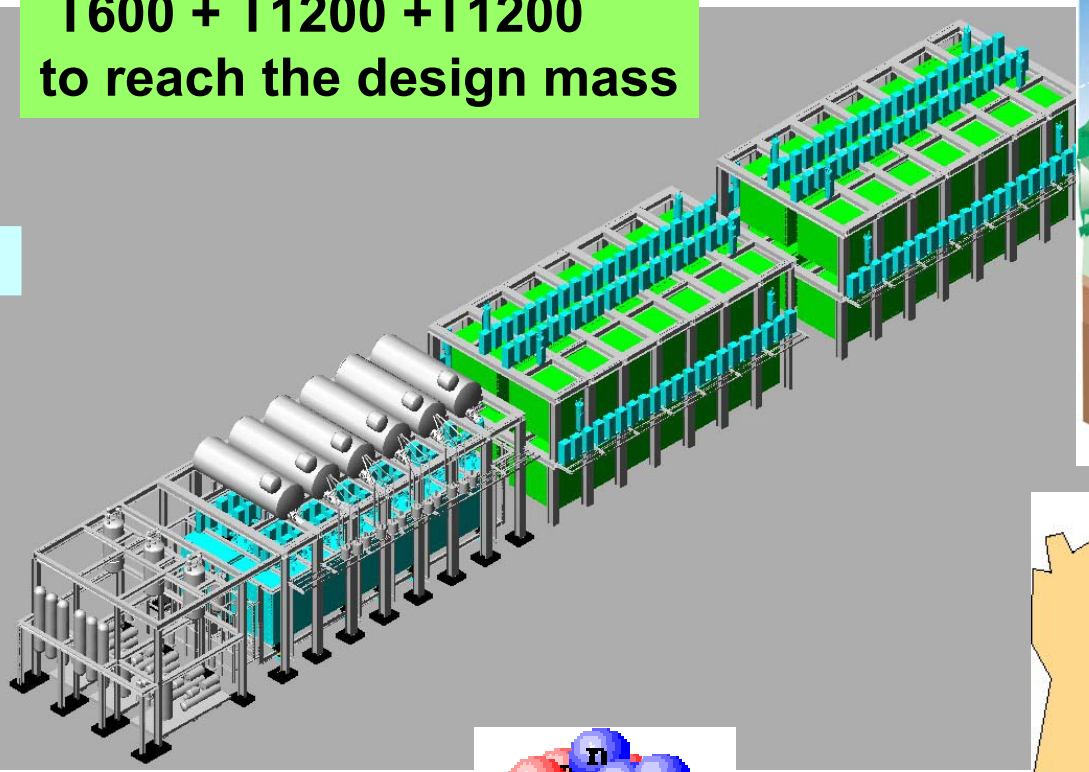
ITALY: L'Aquila, LNF, LNGS, Milano, Napoli, Padova, Pavia, Pisa, CNR Torino, Politec. Milano.
SWITZERLAND: ETH/Zürich.
CHINA: Academia Sinica Beijing.
POLAND: Univ. of Silesia Katowice, Univ. of Mining and Metallurgy Krakow, Inst. of Nucl. Phys. Krakow, Jagellonian Univ. Krakow, Univ. of Technology Krakow, A.Soltan Inst. for Nucl. Studies Warszawa, Warsaw Univ., Wroclaw Univ.
USA: UCLA Los Angeles.
SPAIN: CIEMAT, Univ. of Granada.
RUSSIA:Dubna, INR (Moscow)

A high precision detection technique (LAr TPC)

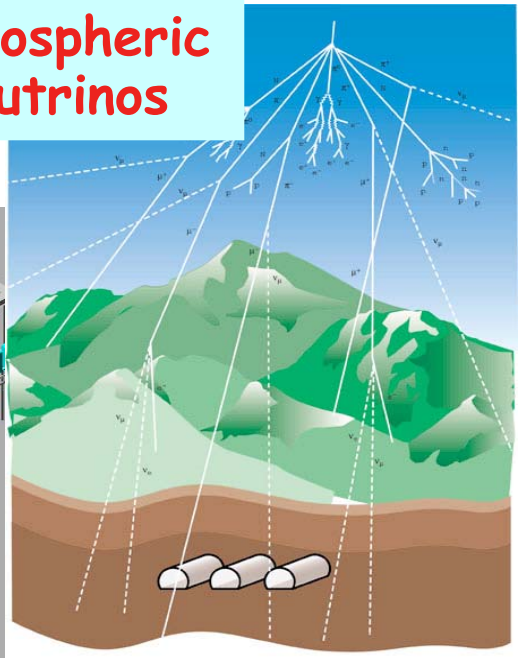
A vast physics program

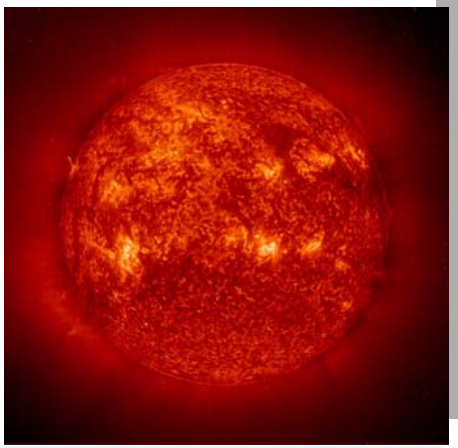
Supernova neutrinos

A modular approach :
T600 + T1200 +T1200
to reach the design mass



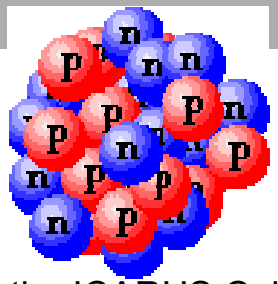
Atmospheric neutrinos



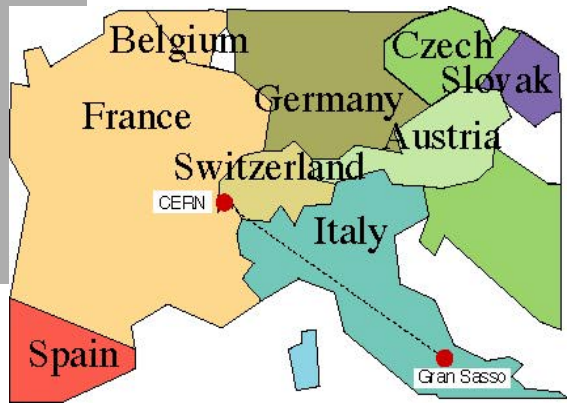


Solar neutrinos

Nucleon stability



$p \longrightarrow e^{+}+\pi^{0}$



Long Baseline neutrinos

Summary

- The first module(T600) of the ICARUS detector has been completed and successfully operated in Pavia in Summer 2001. Since then, the collaboration has been waiting for the installation of the T600 underground in the LNGS laboratory.
- The well known 2002 accident involving a loss of liquid scintillator in Borexino has also introduced very serious delays in the authorizing procedure for a massive amount of LAr. The situation has recently improved for ICARUS and the T600 will now soon be moved to the LNGS.
- The critical path of the detector installation inside hall B is now depending on the large cryogenic infrastructures required.
- Because of the lengthy, forced delay, the collaboration has profited from the Pavia data to perfect offline tools and to check detector performance, now ready to take and analyze data.
- The WANF information has been extrapolated in order to evaluate systematic errors on ν-beam contamination.

General considerations

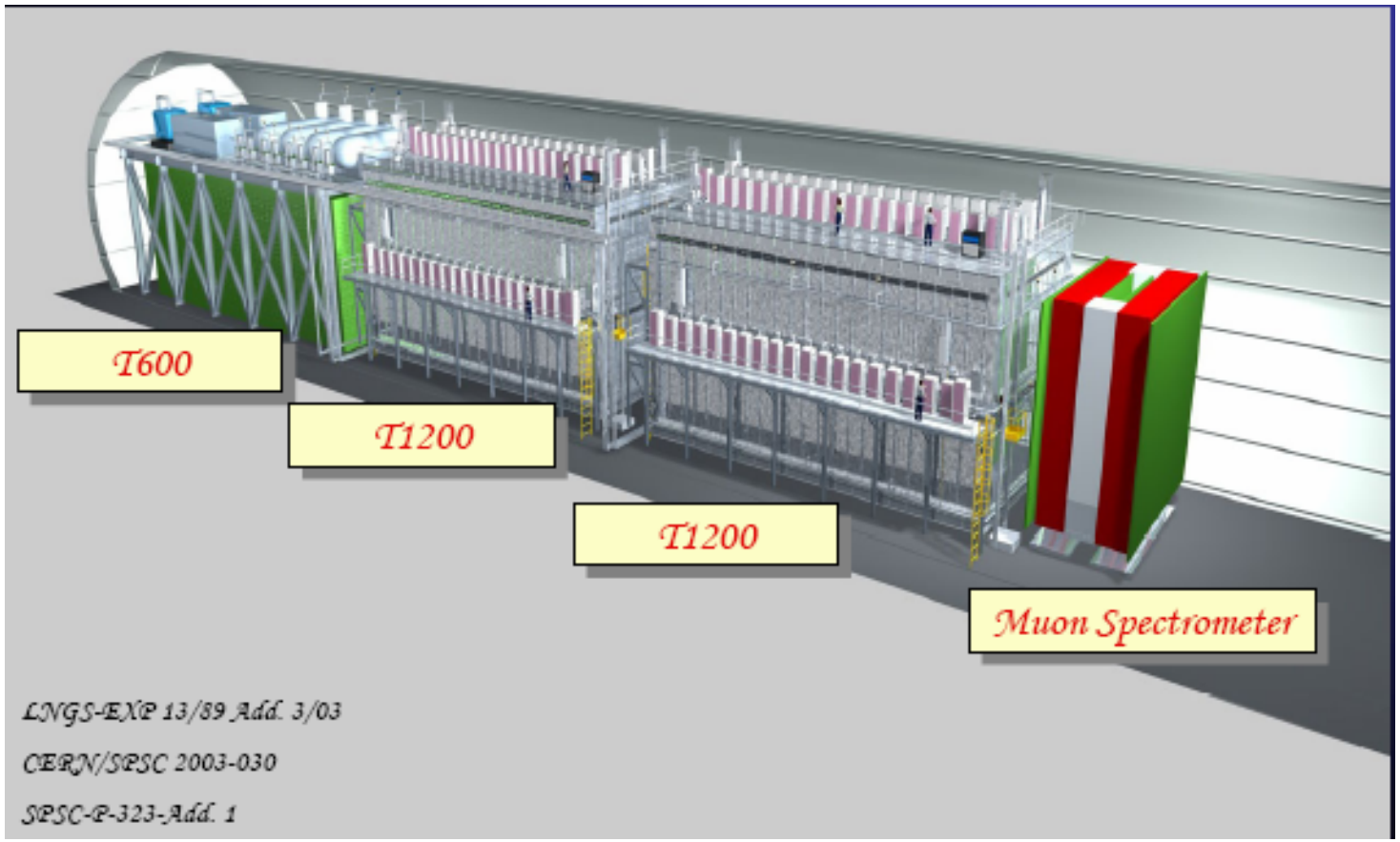
•Modular design: the so-called T600 module and two T1200 modules, for a total liquid Argon mass of about 3000 ton.
•The detector is to be complemented eventually by an iron muon spectrometer to be used for the experiments in the CNGS neutrino beam.
• Cryogenics plants and control rooms complete the detector layout inside the underground hall.

Main subdivision of responsibilities:

T600+T1200+T1200 : INFN+Poland+UCLA

Muon spectrometer:

ETHZ+Spain+Russia



First module : T600

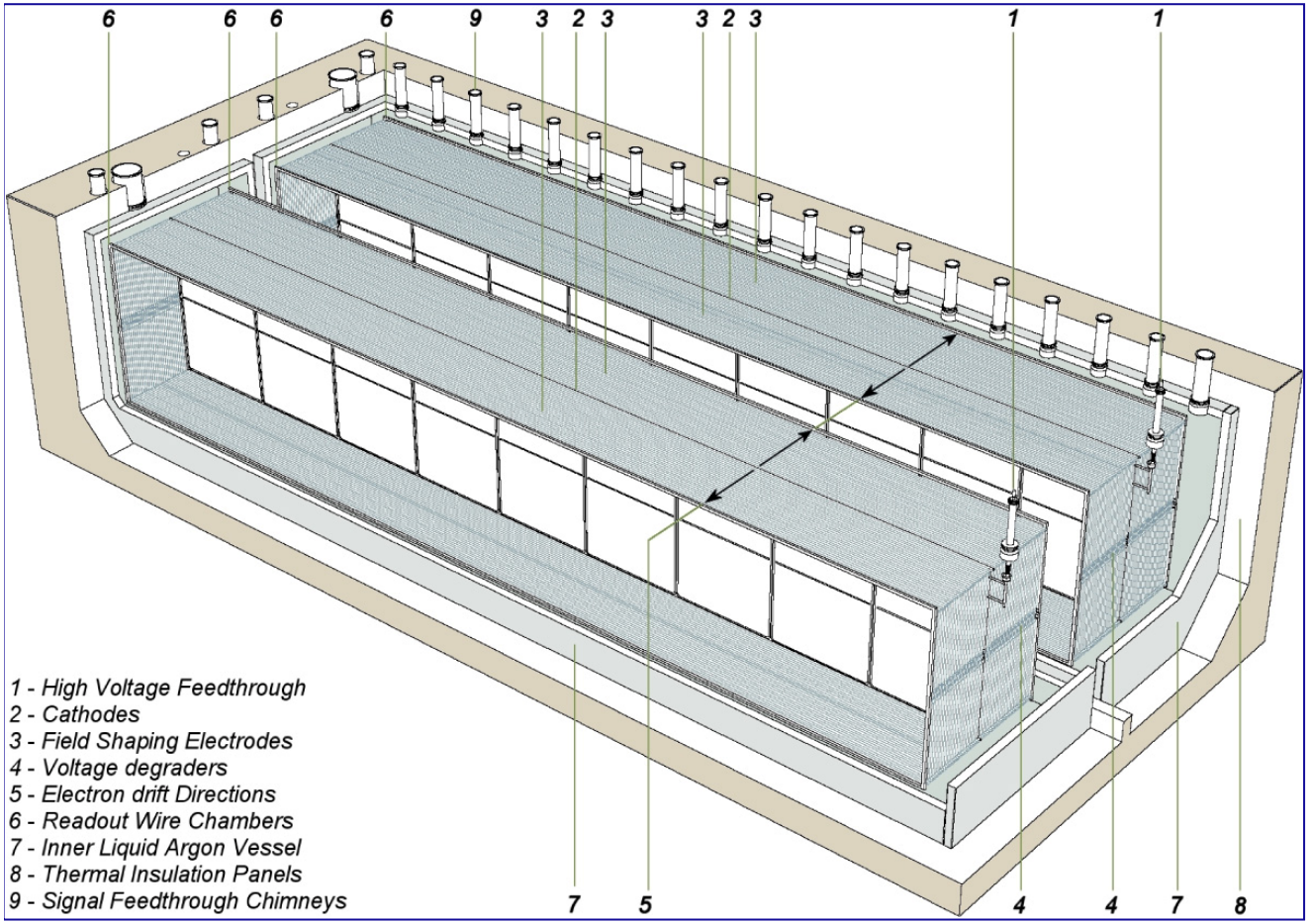
- The detector has been completely constructed and successfully tested with cosmic-ray events in 2001. All features of the expected performance of the large mass LAr detector have been demonstrated experimentally.

- The development of the LAr technology, from the small detector sizes to the "industrial" T600 detector has been funded by INFN, with modest contributions from ETHZ (slow control), IHEP Beijing (wiring) and UCLA (high-voltage system).

- The transportation from Pavia to the GranSasso Laboratory of the two half modules, each of about 300 ton, is now firmly scheduled for December 2004.

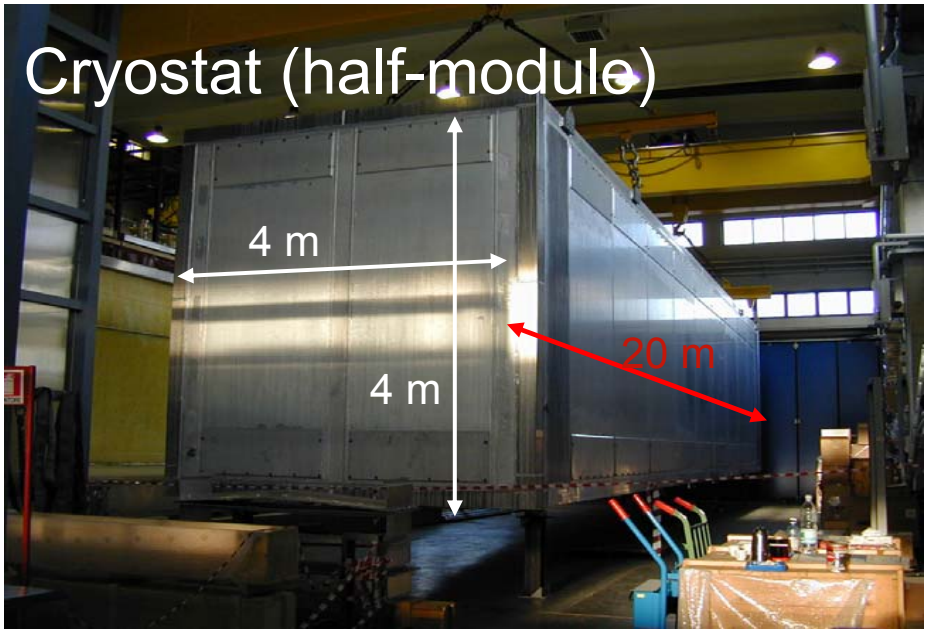
- A large cryogenic facility, dimensioned for the operation of the full liquid Argon mass of 3000 ton (T600 + T1200 + T1200), is now under construction in the Hall B of the LNGS, entirely funded by INFN.

T600



- Two separate containers
  - inner volume/cont. = 3.6 x 3.9 x 19.6 m^3
- Fully imaged mass = 476 ton
- 4 wire chambers with 3 readout planes at 0°, ±60° (two chambers / container)
  - ≈ 54000 wires
- Maximum drift = 1.5 m
- HV = -75 kV @ 0.5 kV/cm
- Scintillation light trigger with 8" VUV sensitive PMTs

The T600 Module :



- Test run of half-unit during first half 2001
  - Three months duration
  - Completely successful
  - Data taking with cosmic rays

T600 analysis 1: Liquid Argon Purity

Long drift distances require a ultra pure Argon

Impurities ≤ 0.1 ppb O_2-equivalent

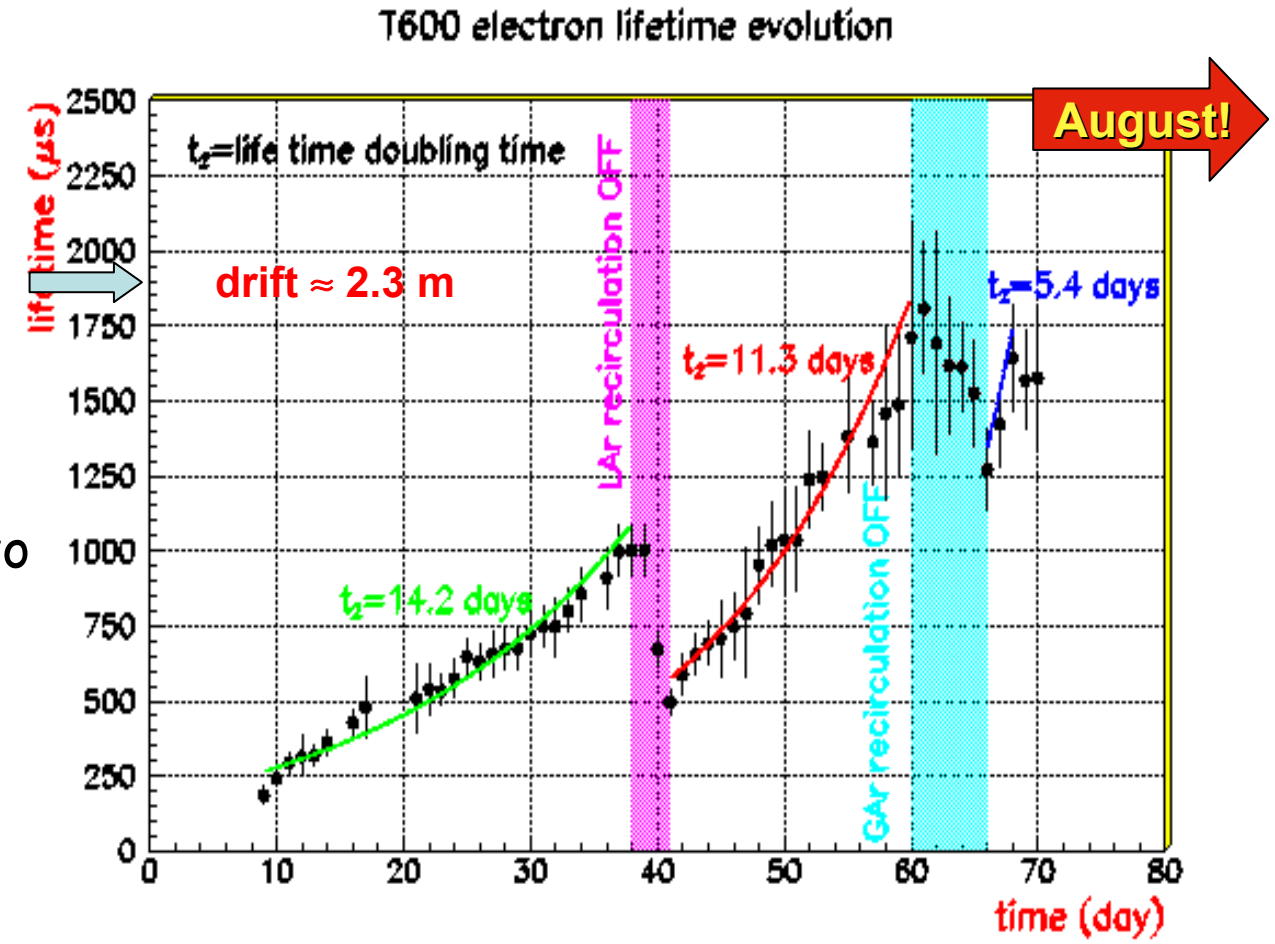
Two independent, complementary methods to measure LAr purity:

Purity Monitors

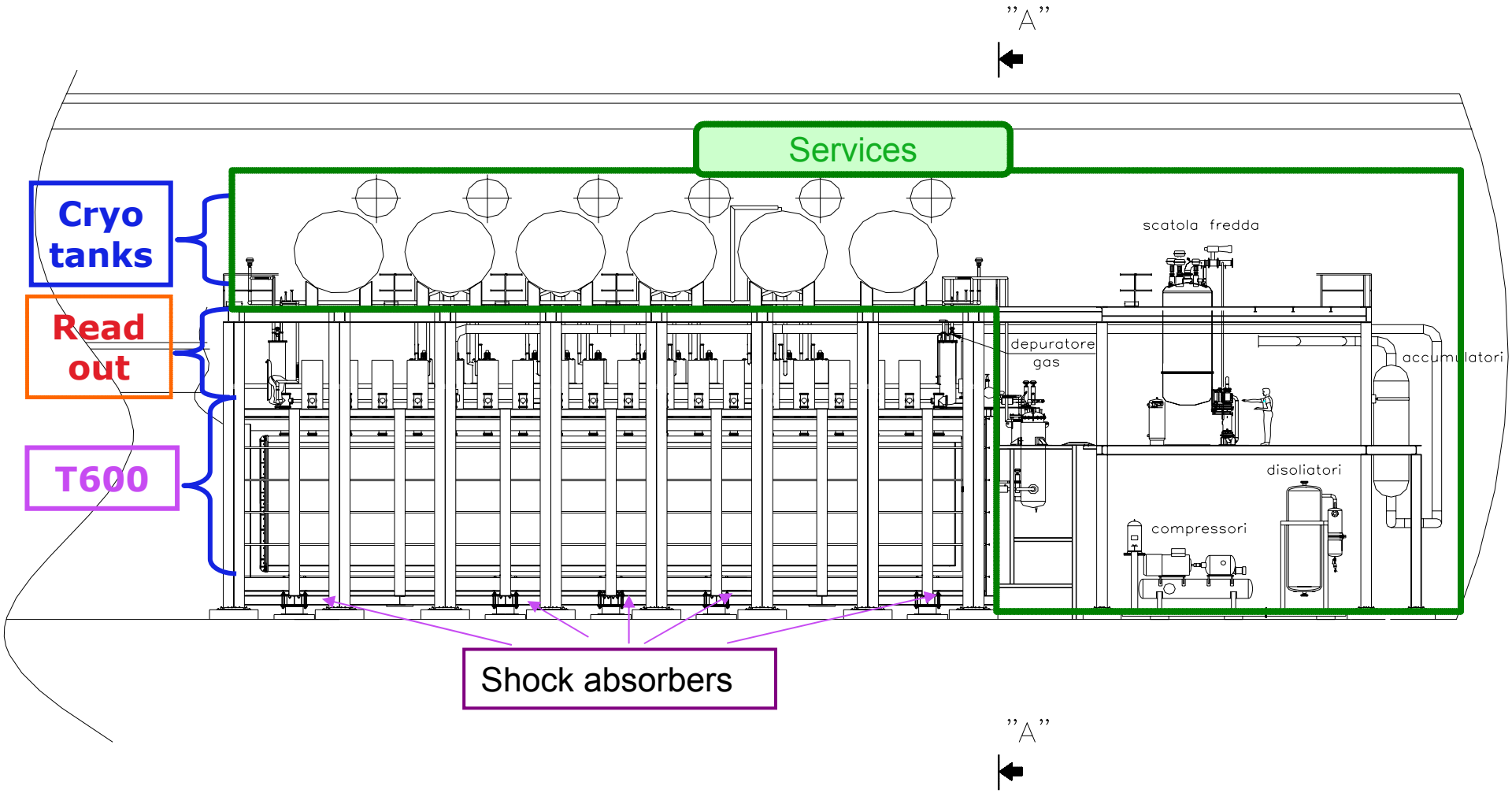
Muon tracks

For future T1200 modules, present technology will allow to increase the maximum drift distance up to 3m

V_{drift}= 1.56 mm / μs @ 0.5 kV/cm



T600 in Hall B

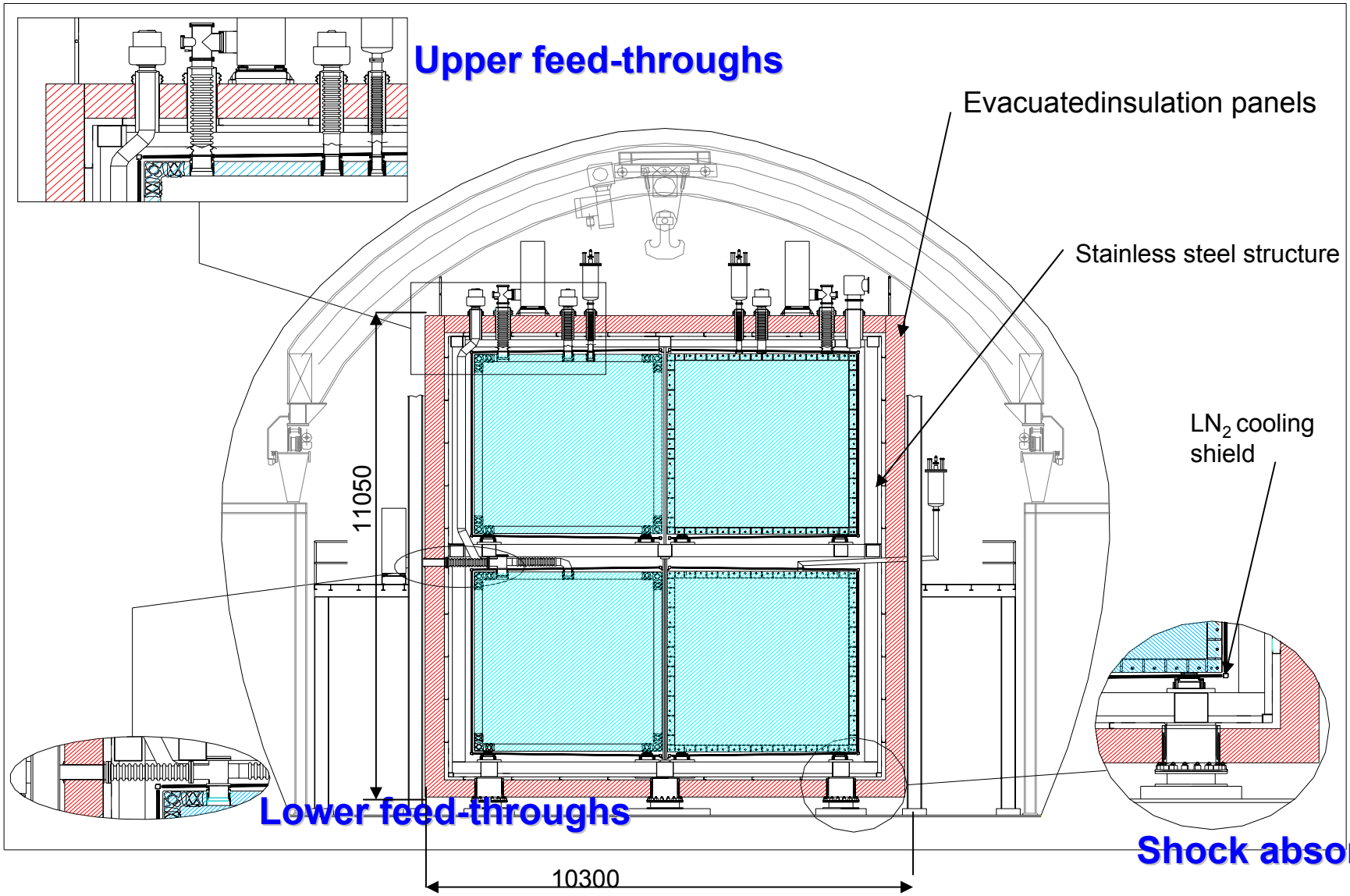


Progress of ICARUS underground

- The authorization for constructing industrial items for ICARUS had been stopped by INFN Management, awaiting for the decisions of:
  1) The "Commissioner", appointed by the Italian government (July 2003), with the task of ensuring that the LNGS infrastructures were made compliant with safety and environmental rules.
  2) The "Scaramelli" working group, appointed by INFN, with the task of recommending all safety and infrastructure requirements for the installation underground of (a) the T600 and (b) the realization of the T1200 modules.
- For the T600:
  - Final green light on 12 September 2004
  - Installation work in Hall B started on Sept. 15, 2004
  - 1st Transport is scheduled for December 3rd

- The "Definitive Project" for T3000 has also been approved by the "Scaramelli" Committee, with a few significant modifications, among which a comprehensive liquid N_2 system, emergency interventions, sealed floor in Hall B, ventilation, heat exchangers, new electric power, auxiliary services,continuity groups, etc.
- The first of the T1200 modules has now received authorization for construction. It is an upgraded "clone" of the T600 with a doubled drift time to 3 m. The total cost of the module is about 22 MEuro.
- INFN funding amounting to 20 MEuro has been granted. The remaining 10% of the contributions (≈ 2 MEuro) should be subdivided amongst the non Italian Institutions. In the eventuality that these would not come forward with adequate funding, the Italian contribution will be sufficient to equip one wire out of two with electronics (one wire every 6 mm).
- The remaining main components of the detector (second T1200 module [22 MEuro] and eventually the Iron spectrometer[4 MEuro]) will be the subject of an Addendum of the MOU, once the collaborating institutions will have defined an appropriate funding scheme.

The T1200 unit

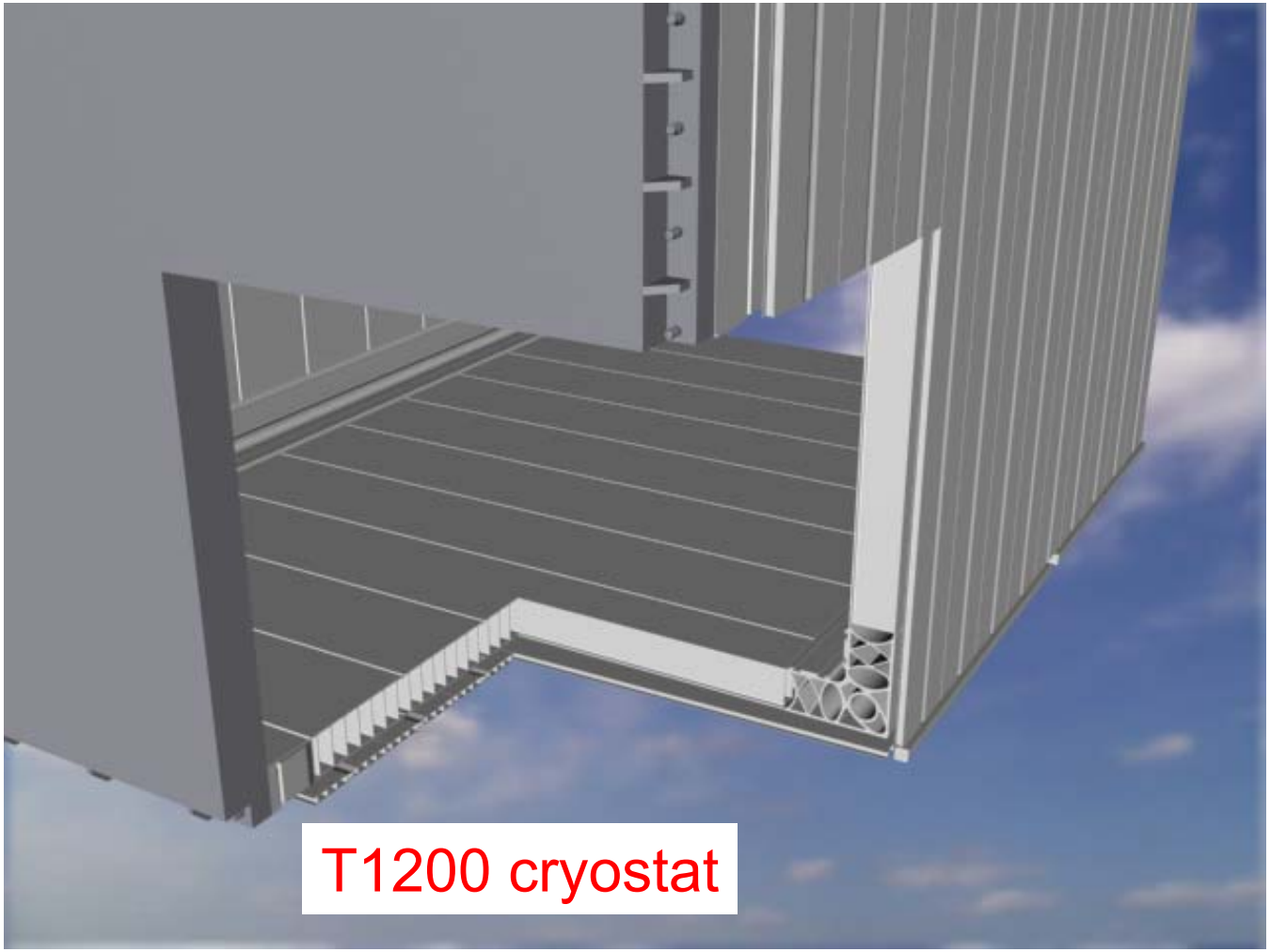


T1200 = 2 x T600 with differences:

New cryostat → enhanced intrinsic safety, easier mounting of chambers

Double drift distance → less channels but higher voltage

- All the detailed design work has been completed
- Procedure for call for tenders has been approved by INFN
- From the technical point of view of the Collaboration, the Final project is ready



Anode wires for T1200 - production in Poland

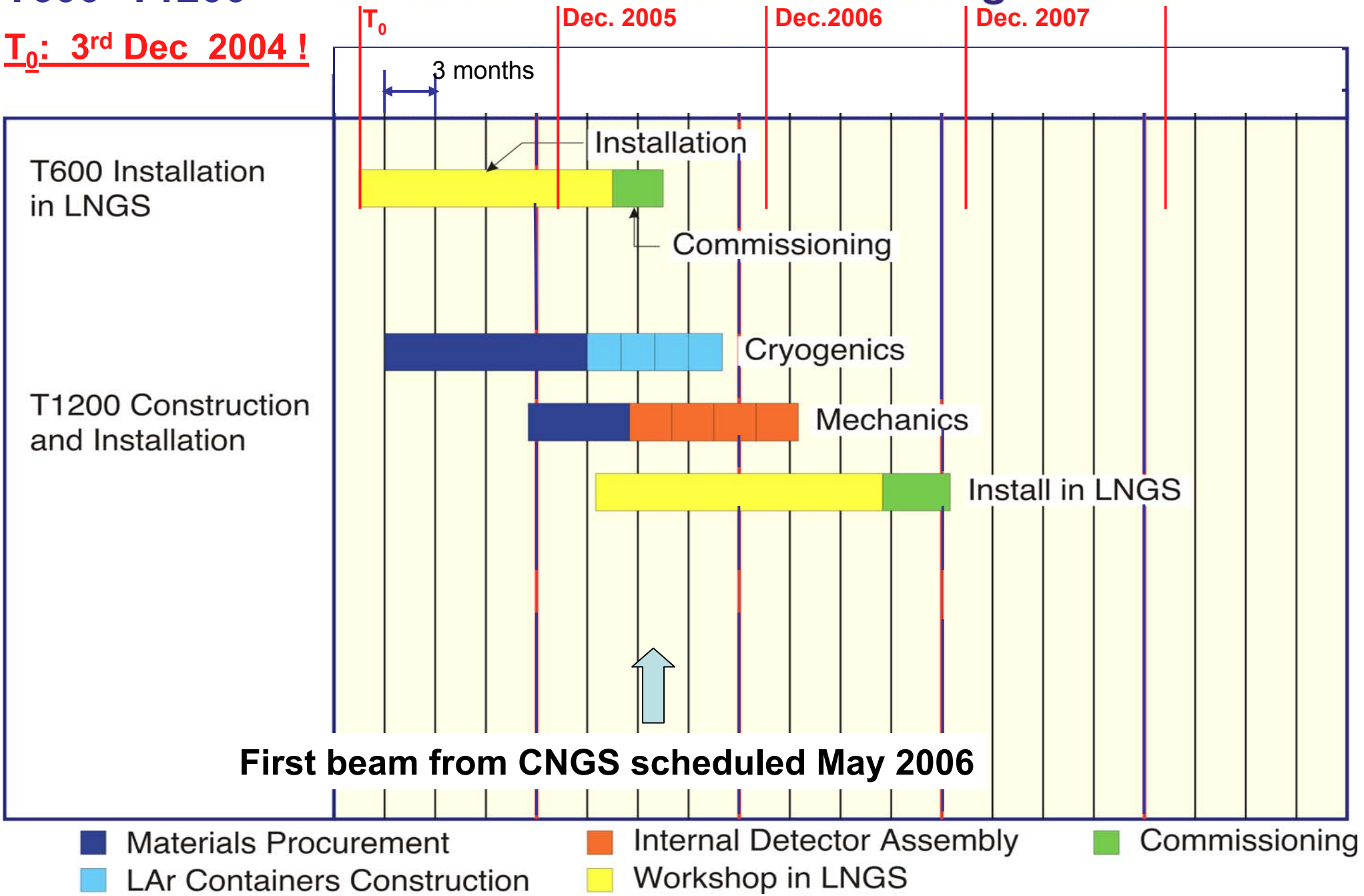
Present status:

- All the equipment has been constructed, purchased or borrowed from Pavia with many improvements as compared to the original Pavia setup for the wire production of T600.
- Common work of the experimental groups from Warsaw, Katowice and Cracow, in close collaboration with the Pavia group.
- Laboratory in Cracow (12x5.5 m^2) prepared in order to start production.

T600+T1200

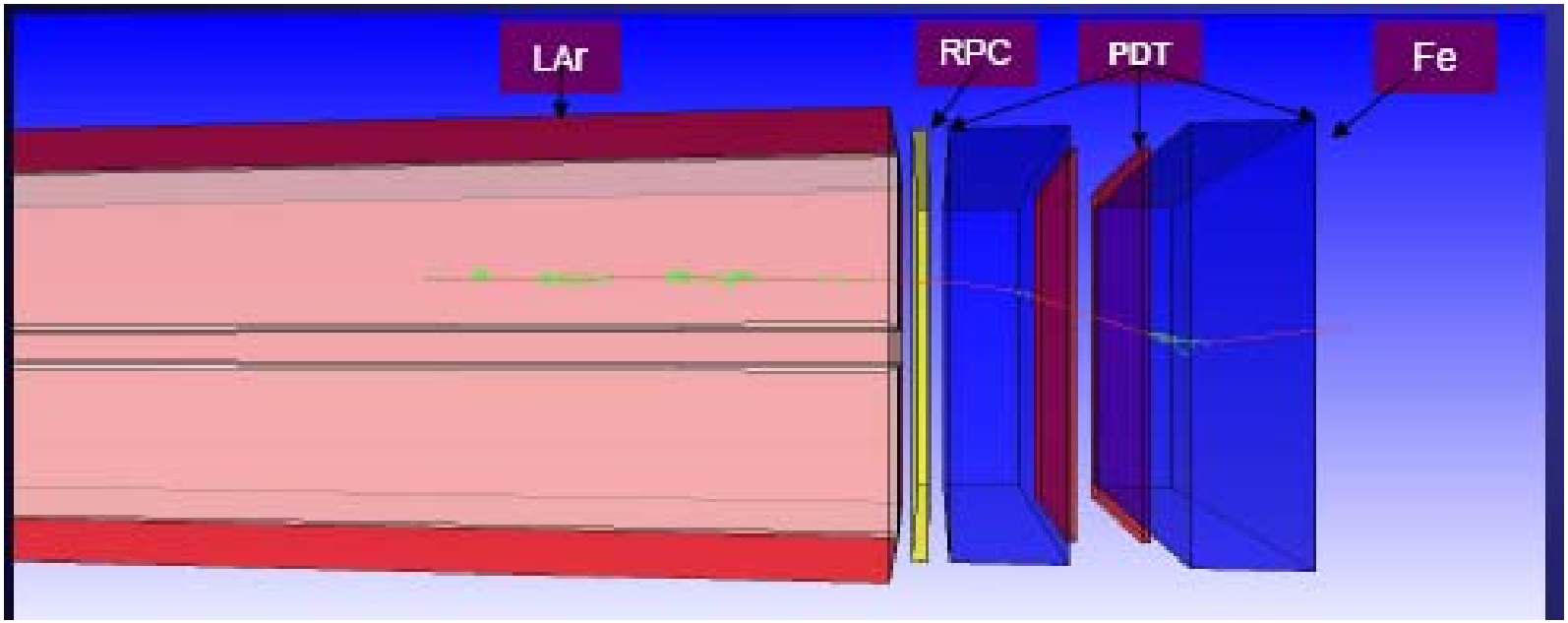
Construction and Commissioning in LNGS

T_0: 3rd Dec 2004 !



Muon Spectrometer

Subject to availability of financial resources (4 MEuro)



- **Passive Material: Magnetized Iron**
  B= 1.8T ; Cross section 8.5x8.5 m^2 ; two bending Sections, each 1.5m long
- **Sensitive part: planes of proportional drift tubes**
- **RPC plane for trigger**

Following the T600 technical run and awaiting for permission to continue installation in LNGS: considerable progress in data reconstruction, analysis, validation of detector performances

"Design, construction and tests of the ICARUS T600 detector", Nucl. Inst. Meth., A527 (2004) 329-410

"Study of electron recombination in liquid Argon with the ICARUS TPC",Nucl. Inst. Meth., A523 (2004) 275-286

"Measurement of the muon decay spectrum with the ICARUS T600 liquid Argon TPC", The European Physical Journal C, Eur. Phys. J. C *33*, 233-241 (2004)

"Detection of Cerenkov light emission in liquid Argon", Nucl. Inst. Meth., A516 (2004) 348-363

"Analysis of the liquid Argon purity in the ICARUS T600 TPC", Nucl. Inst. Meth., A516 (2004) 68-79

"Observation of long ionizing tracks with the ICARUS T600 first half-module", Nucl. Inst. Meth., A508 (2003) 287-294

"Performance of the 10 m3 ICARUS liquid argon prototype", Nucl. Inst. Meth., A498 (2003) 292-311

T600 analysis 2: Michel parameter

Stopping μ sample : 3000 events analyzed

→ Test of automatic 3D reconstruction

Measurement of Michel ρ parameter

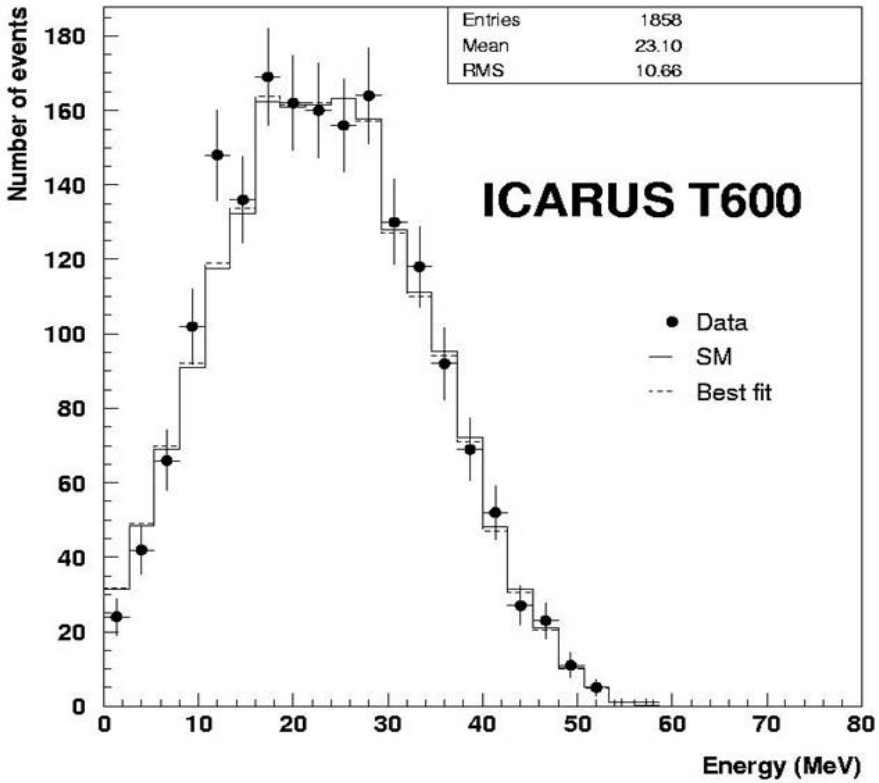
$$\rho = 0.72 \pm 0.06(stat) \pm 0.08(sys)$$

Standard model ρ=0.75

Resolution for low E electrons

$$\frac{\sigma(E)}{E} = \frac{11\,\%}{\sqrt{E}} \oplus 2\,\%$$

(E in MeV, bremsstrahlung not reconstructed)

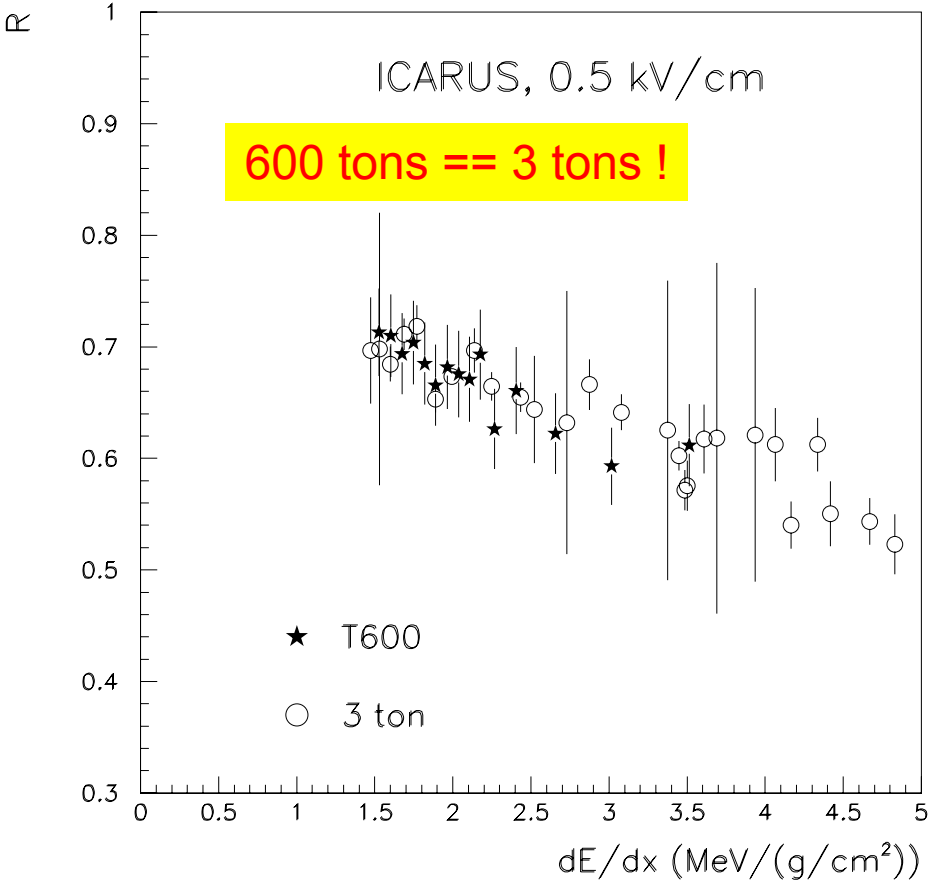


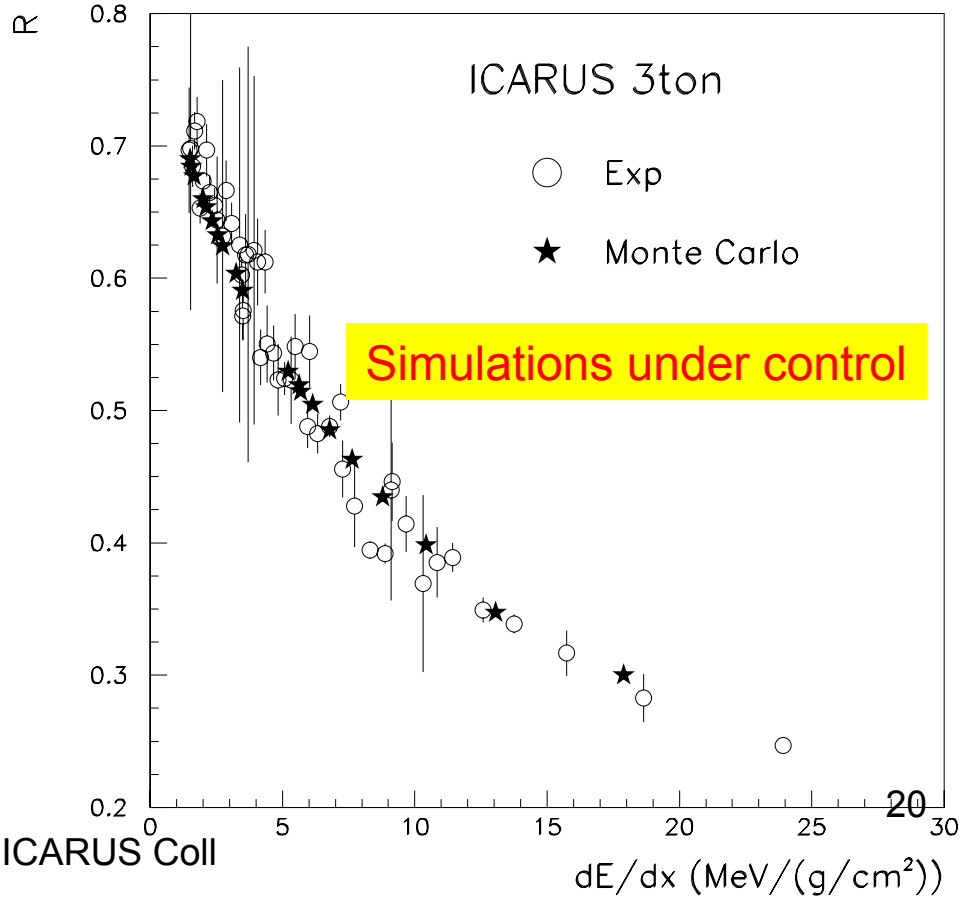
T600 analysis 3:Electron Recombination

$$Q = RQ_0, R = R(dE/dx, \mathsf{E}_{drift})$$

From track segment in stopping μ and p events

Agreement : T600, 3ton prototype, literature data, MC simulations

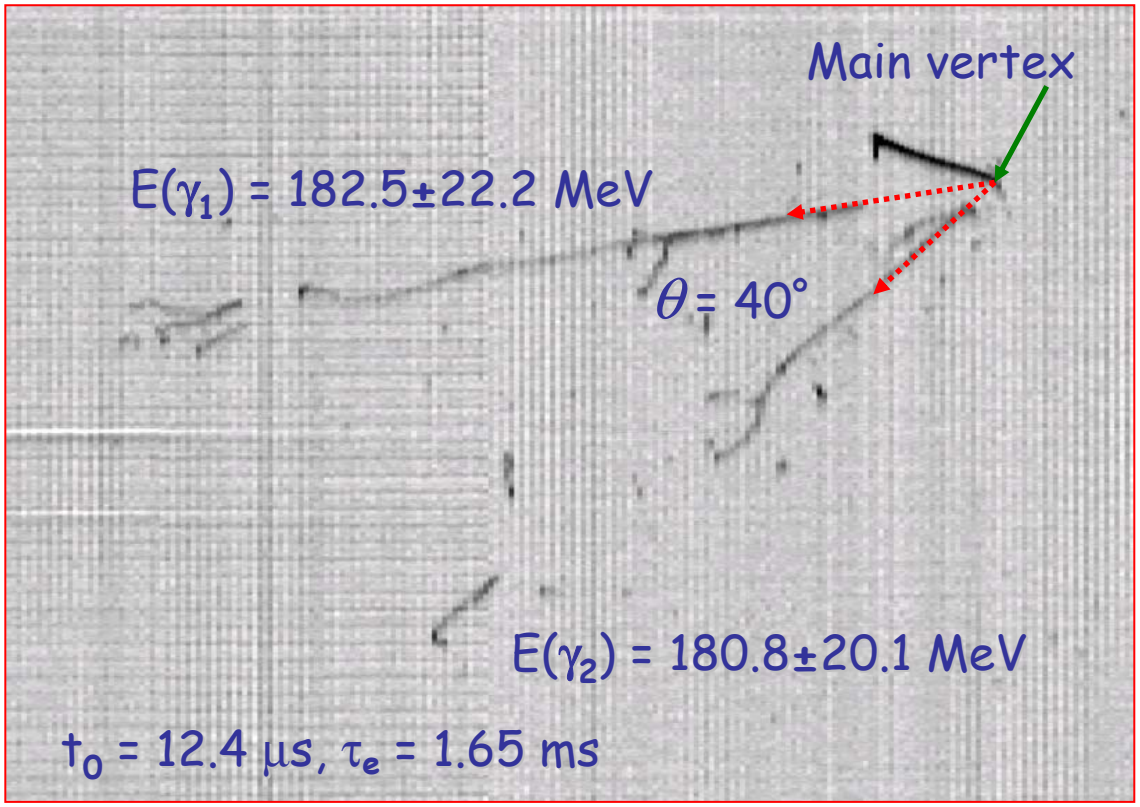




r the ICARUS Coll

T600 analysis 4: π^0 mass reconstruction

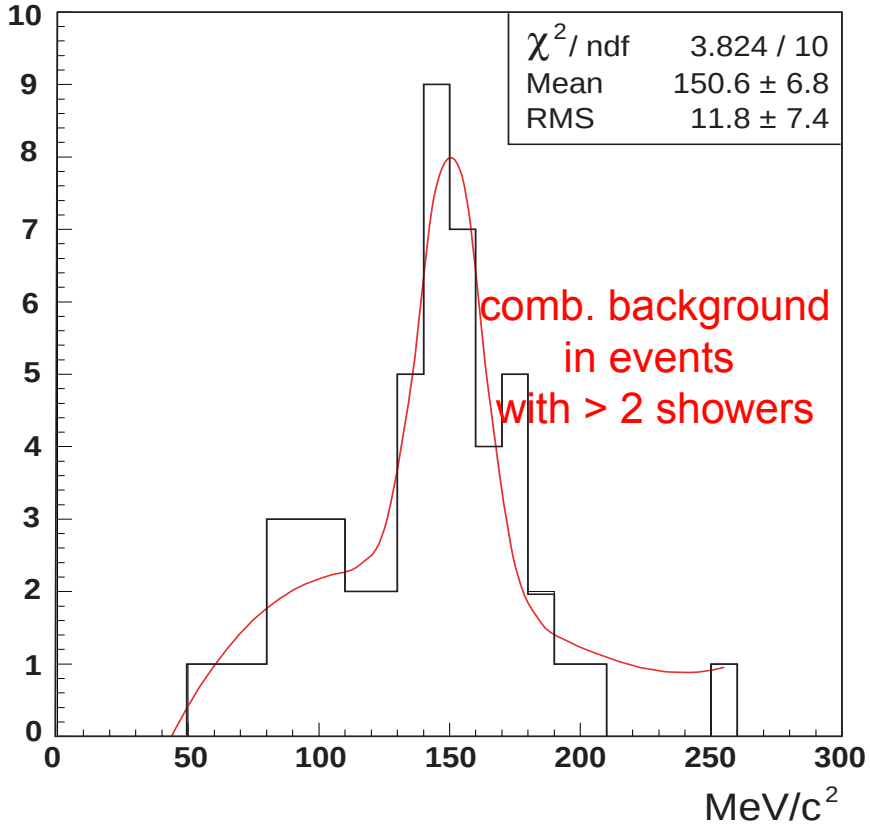
Run 712 Evt 7 (Left Collection View)



Poland+ Pavia analysis TM 14-2004

Preliminary

51 $\pi^0 \longrightarrow \gamma\gamma$ candidate events



$M_{\gamma\gamma} = 150.6 \pm 11.8$ MeV/c²

in agreement with expected e.m. resolution!

MC simulations for ICARUS

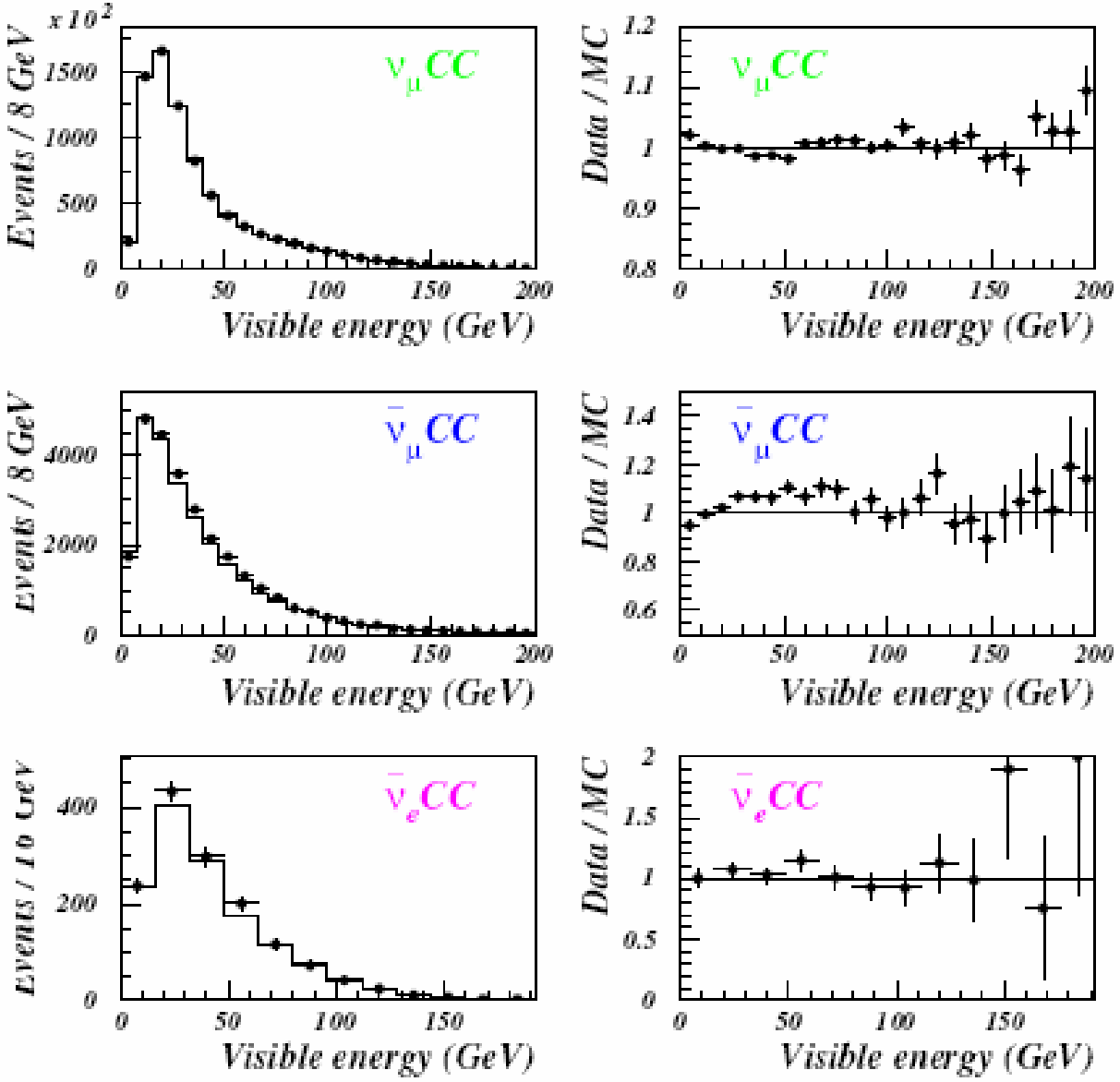
Complete simulation environment based on FLUKA (www.fluka.org)

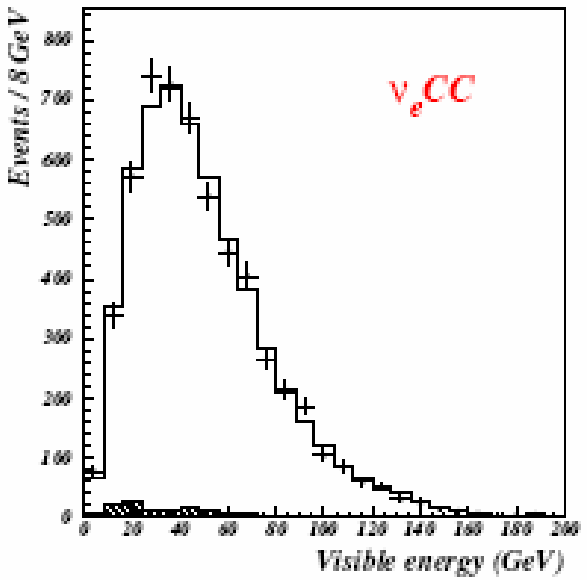
FLUKA authors in the collaboration → full control, dedicated improvements

- Cosmic ray showers
- CNGS beam
  - Leading role since proposal
  - ***Ongoing: implementation of latest design in collaboration with CERN AB***
    - ➡ ***Beam composition, control of systematic errors***
- Future beams for θ_{13} (JHEP 0209, 004/2002, NJP 4,88 (2002))
- Neutrino events with nuclear effects NUX-FLUKA (nuint02)
  - ***Ongoing: improvements of ν int. in the resonance region***
- Background events
- Full detector simulation with
  - Well tested, high accuracy interaction and transport models
  - Electron recombination (quenching) according to data
  - Scintillation and Cerenkov light
  - Mapping into views
  - Noise, electron diffusion, signal shaping

Test of ν production in MC : WANF data

Comparison Data-MC
in NOMAD
(A.Guglielmi, NOW2004)





very good agreement !

MC ν_μ normalized to data

CNGS: $\nu_\mu \rightarrow \nu_\tau$ Oscillations

- Search based on kinematical criteria
- Natural ν_τ contamination below 10^{-7} w.r.t. ν_μ
- Several decay modes investigated (electron decay is the "golden" channel)

Super-Kamiokande: $1.6 < \Delta m^2 < 3.0$ at 90% C.L.

τ decay mode	Signal $\Delta m^2 = 1.6 \times 10^{-3}$ eV^2	Signal $\Delta m^2 = 2.5 \times 10^{-3}$ eV^2	Signal $\Delta m^2 = 3.0 \times 10^{-3}$ eV^2	Signal $\Delta m^2 = 4.0 \times 10^{-3}$ eV^2	BG
$\tau \rightarrow e$	3.7	9	13	23	0.7
$\tau \rightarrow \rho$ DIS	0.6	1.5	2.2	3.9	< 0.1
$\tau \rightarrow \rho$ QE	0.6	1.4	2.0	3.6	< 0.1
Total	**4.9**	**11.9**	**17.2**	**30.5**	**0.7**

5 years of CNGS operation (4.5 **x 10^{19}** p.o.t) Shared Mode
T3000 detector , Muon spectrometer not included
(2.35 kton active LAr, 1.5 kton fiducial → 34 **x 10^{19} p.o.t. x kton**)

Systematic uncertainty on ν_μ flux: ≈ 5%

CNGS: $\nu_\mu \rightarrow \nu_e$ Oscillations

NEW : Systematics evaluation from WANF experience :

ν_e / ν_μ : 3.1 % normalization error

For $\Delta m^2_{23} = 2.5 \times 10^{-3}$ eV^2

$$(\sin^2 2\theta_{13})_{CNGS,\tau} < 0.04 \quad or \quad \theta_{13} < 6^o$$

Chooz : $\sin^2 2\theta_{13} < 0.14$, or $\theta_{13} < 11^o$

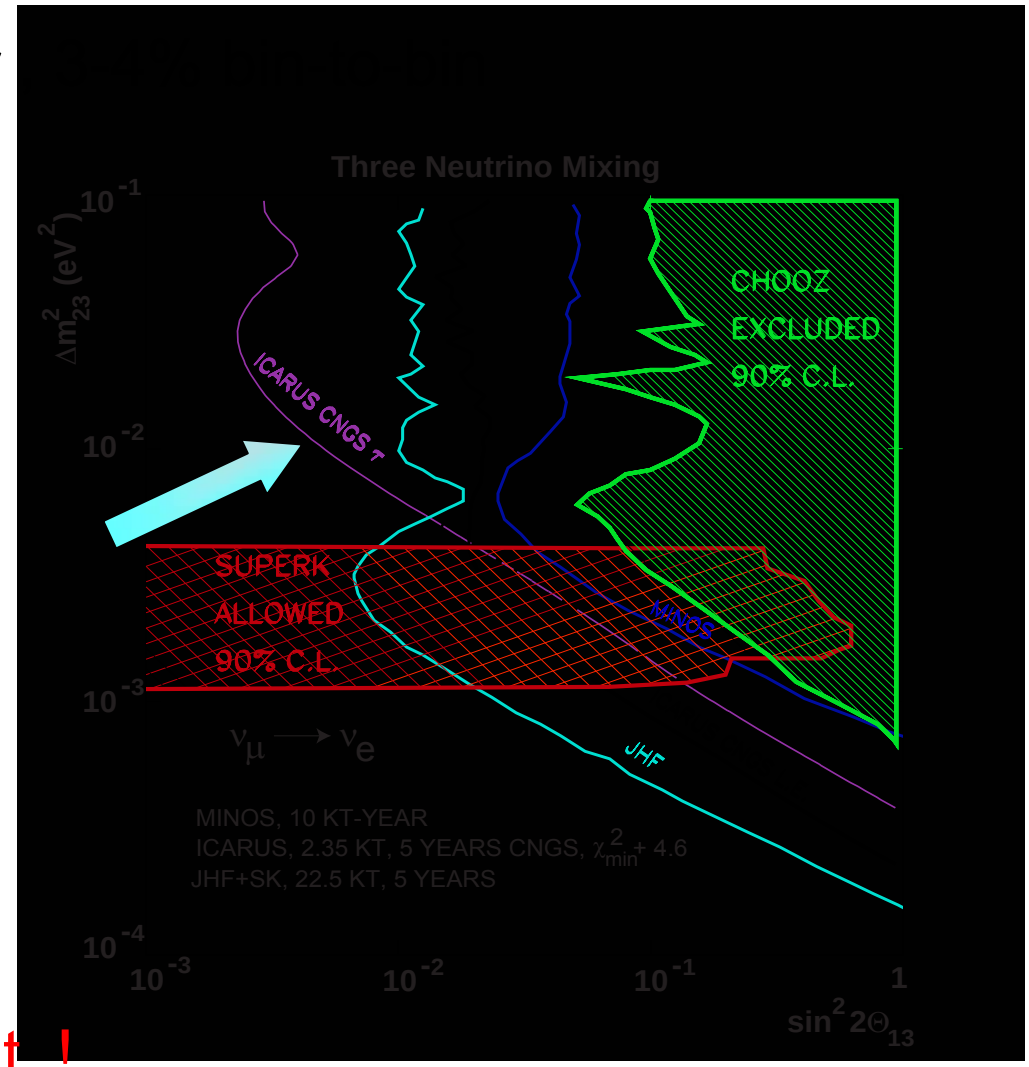
STATISTICS (at $\theta_{13}=6^0$):

14 $\nu_\mu \rightarrow \nu_e$CC events

OVER :

76 ν_e CC from beam and ν_τ

(34 10^{19} kton x pot , similar for OPERA, A. Guglielmi NOW2004)



CNGS intensity: INCREASE p.o.t. !

John Dainton
Villars 2004
October 7th 2004
CERN seminar

From High Intensity Protons Working group:

- ***start 2004/5:***
  - ***PS: multi-turn ejection***
  - ***increase SPS intensity (impacts all machines)***
  - ***0.9s PSB repetition***
- ***Linac 4 design***
  - ***→ construction decision @ end 2006***

(i) PSB repetition period of 0.9 s
(ii) 7×10^{13} ppp in SPS
(iii) Linac4 injecting into PSB

In parenthesis: keeping nominal CNGS

	Standard (i)	CNGS x2 batch (i)+(ii)	Linac 4 (i)+(ii)+(iii)	Basic user's request
CNGS flux [$\times 10^{19}$ pot/year]	**4.7 (4.5)**	**7.0 (4.5)**	**7.5 (4.5)**	**4.5**
FT spills [$\times 10^{5}$ /year]	**3.2 (3.4)**	**3.0 (5.1)**	**3.2 (5.6)**	**7.2**

Intensity upgrade is possible and recommended

Conclusions

- The ICARUS technology has been shown to be feasible on a large mass scale (kton).
- While waiting — the collaboration has been working to perfect the analysis and improve the software tools → ready to process underground data as soon as they may become available.
- The T600 transport to LNGS will start in December.
- The construction of the first T1200 module is now allowed to start in parallel with the installation of the T600 detector.
- The procedure for the realisation of the second T1200 detector may start only when the collaborating institutions will have been able to agree on the funding scheme. This decision is urgent.
- The addition of a muon spectrometer is also dependent on the availability of a full coverage of the financial resources (≈ 4 MEuro).
- In order to exploit as much as possible the physics potentials of the CNGS beam at Gran Sasso, all efforts in order to achieve substantial improvements of the beam intensity should be pursued.