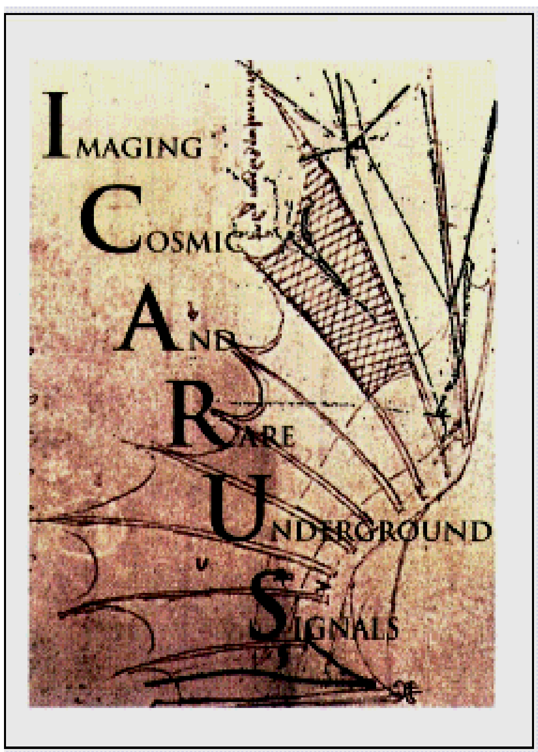
The ICARUS Experiment in the Gran Sasso Underground Laboratory

Agnieszka Zalewska, INP PAN Cracow

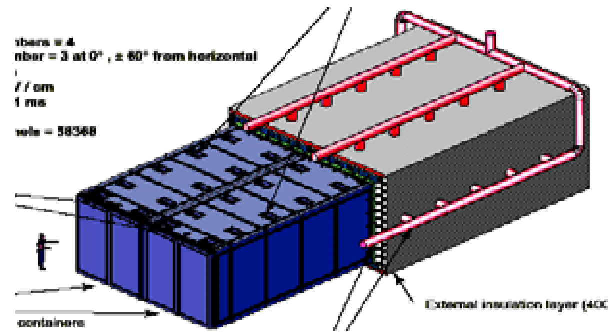
Modular detector built up with 300t LAr TPC's



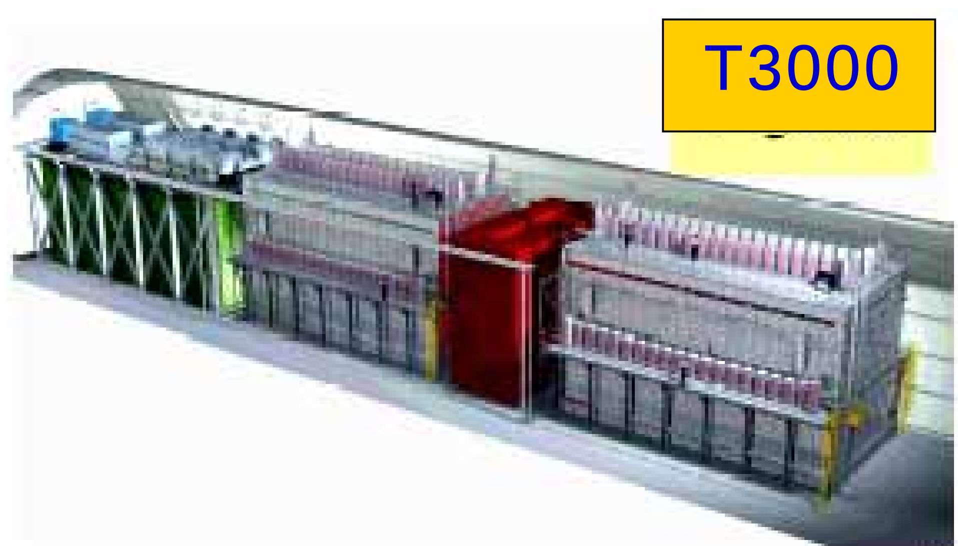
A.Zalewska, Epiphany 2004, 9.01.2004

Two phases:

T600



T3000



The ICARUS collaboration

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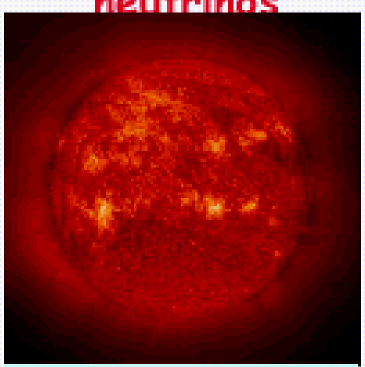
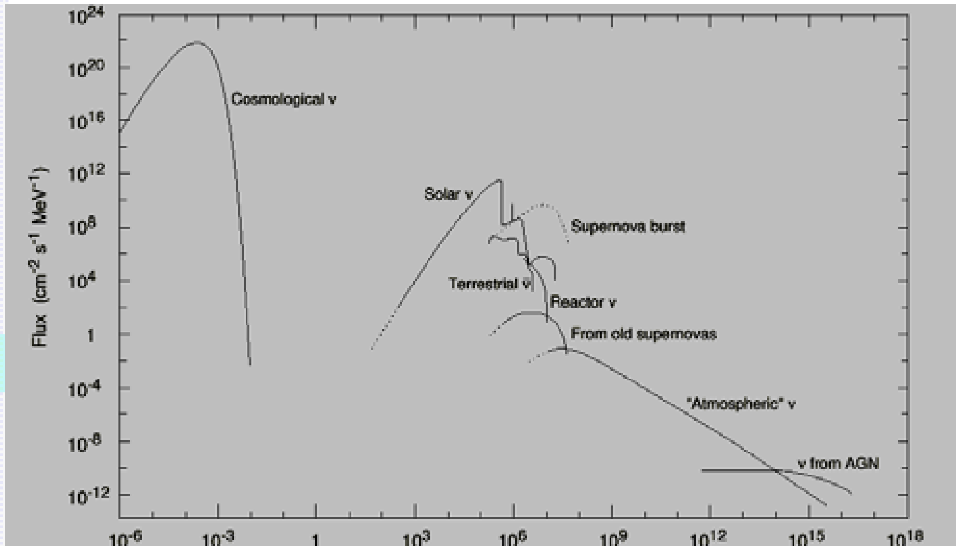
Italy: University and INFN of l'Aquila, LNF, LNGS, Milano, Napoli, Padova, Pavia, CNR Torino, Politecnico di Milano
Switzerland: ETH Zurich
Poland: Univ. of Silesia, UST Krakow, Inst. of Nucl. Phys. PAN Krakow, Univ. of Technology Krakow, Inst. for Nucl. Studies Warsaw, Warsaw Univ., Univ. of Technology Warsaw, Wroclaw Univ.
China: Academia Sinica Benjing
USA: UCLA Los Angeles
Spain: Univ. of Granada, CIEMAT Madrid
Russia: Moscow

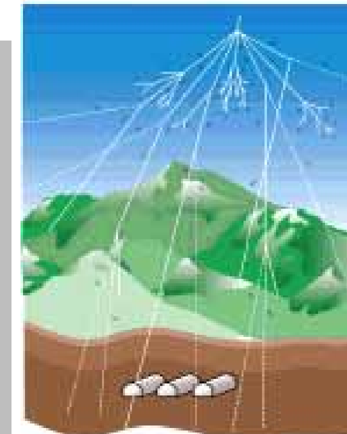
A vast physics programme

Supernova neutrinos



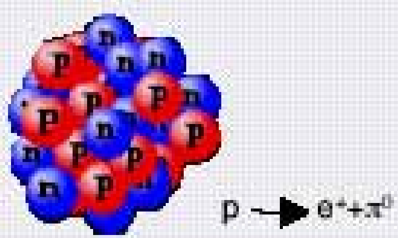
Solar neutrinos





Atmospheric neutrinos

Long Baseline neutrinos



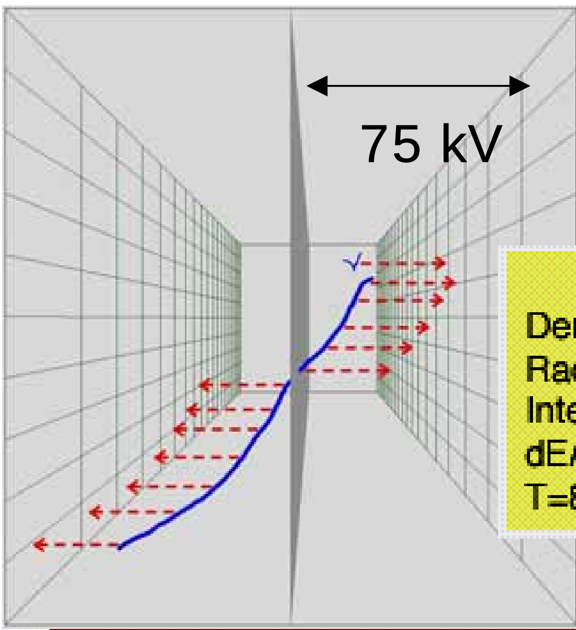
Nucleon stability

Localisation: Hall B of the Gran Sasso laboratory

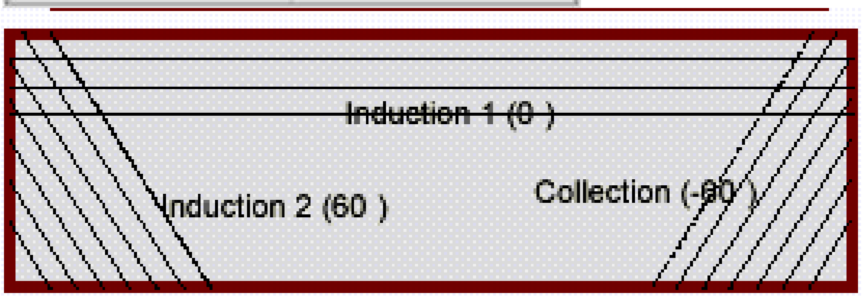
In the Roma-Teramo highway tunnel, under 1400 m of rock

LAr TPC - principle of operation

Ionization electrons drift (msec) over large distances (meters) in a volume of highly purified liquid Argon (0.1 ppb of O_2) under the action of an E field. With a set of wire grids (traversed by the electrons in ~ 2-3 μs) one can realize a massive, continuously sensitive electronic “bubble chamber”.



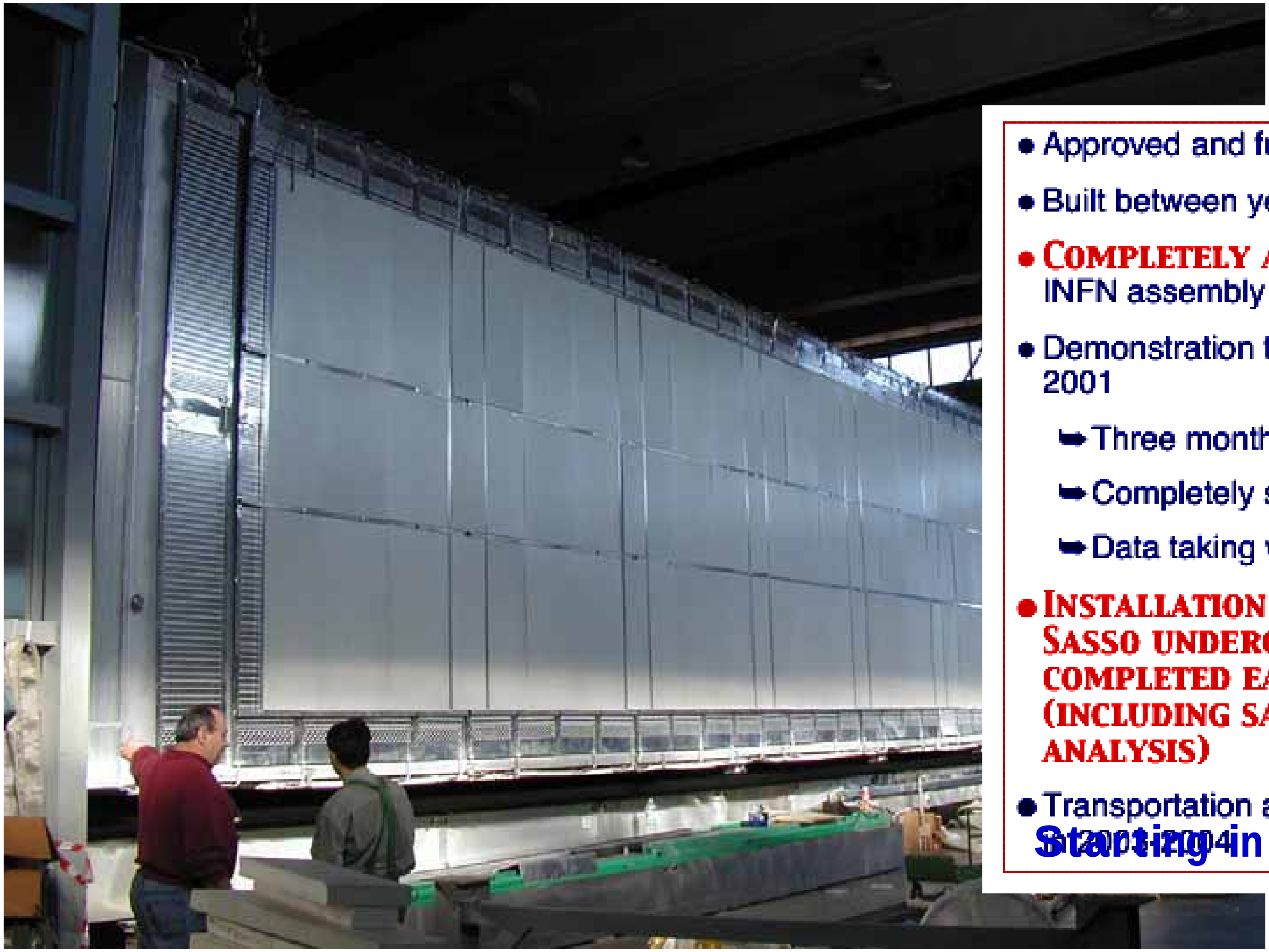
LAr
Density 1.4 g/cm^3
Radiation length 14 cm
Interaction length 80 cm
dE/dx(mip) = 2.1 MeV/cm
T=88K @ 1 bar



Side wall

Single ”bubble” 3x3x0.6 mm^3
no signal multiplication, about
8000 e^--ion pairs per mm

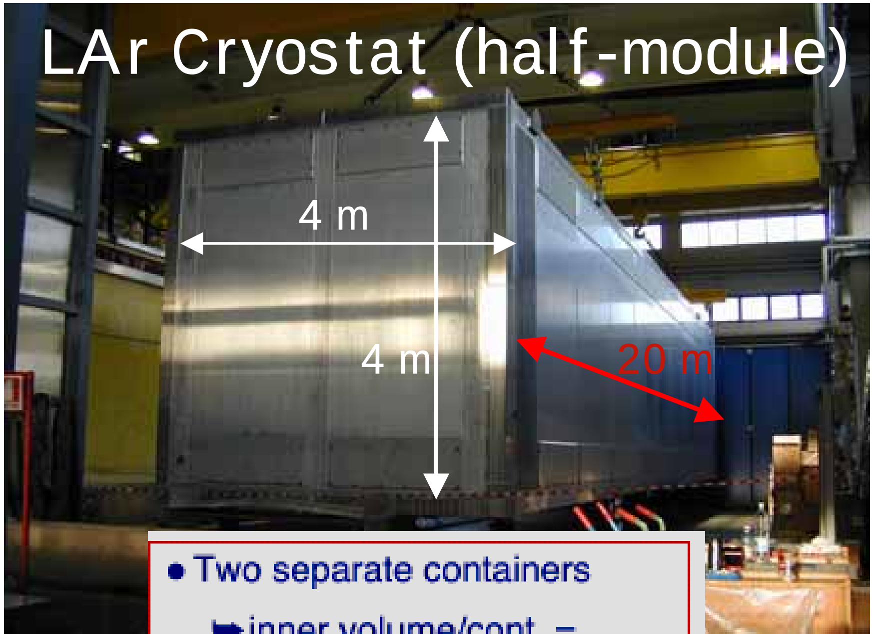
T600 detector



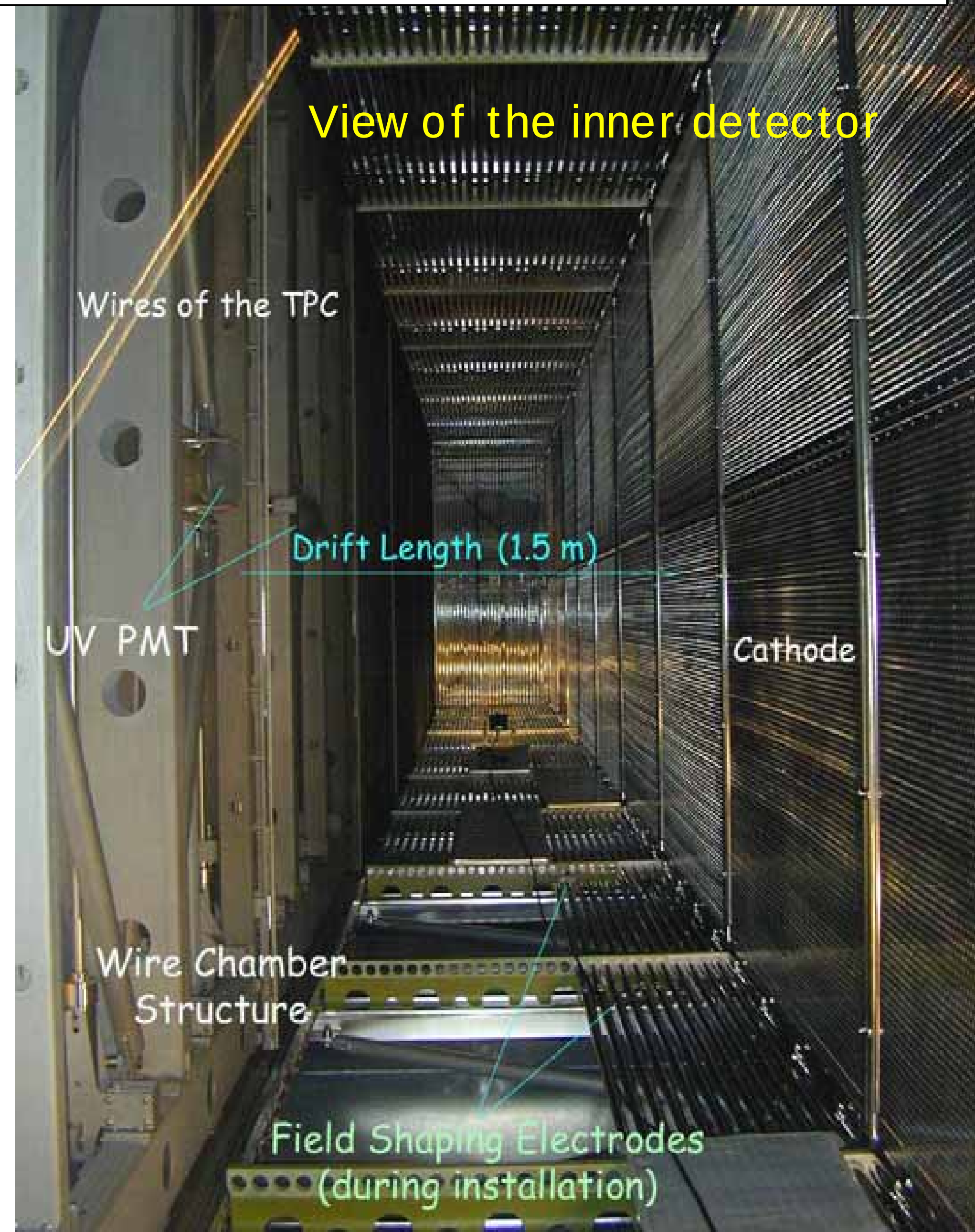
- Approved and funded in 1996
- Built between years 1997 and 2001
- **COMPLETELY ASSEMBLED** in the INFN assembly hall in Pavia
- Demonstration test run during first half 2001
  - Three months duration
  - Completely successful
  - Data taking with cosmic rays
- **INSTALLATION PLAN IN THE GRAN SASSO UNDERGROUND LAB COMPLETED EARLY 2003 (INCLUDING SAFETY RISK ANALYSIS)**
- Transportation and installation in LNGS in 2003-2004

Starting in April 2004

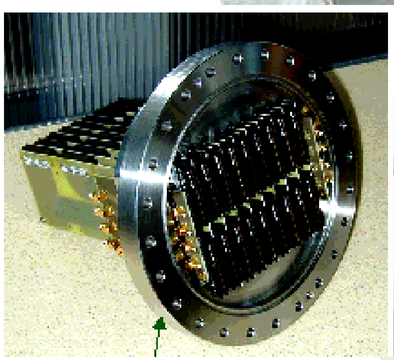
T600 detector - during the construction phase

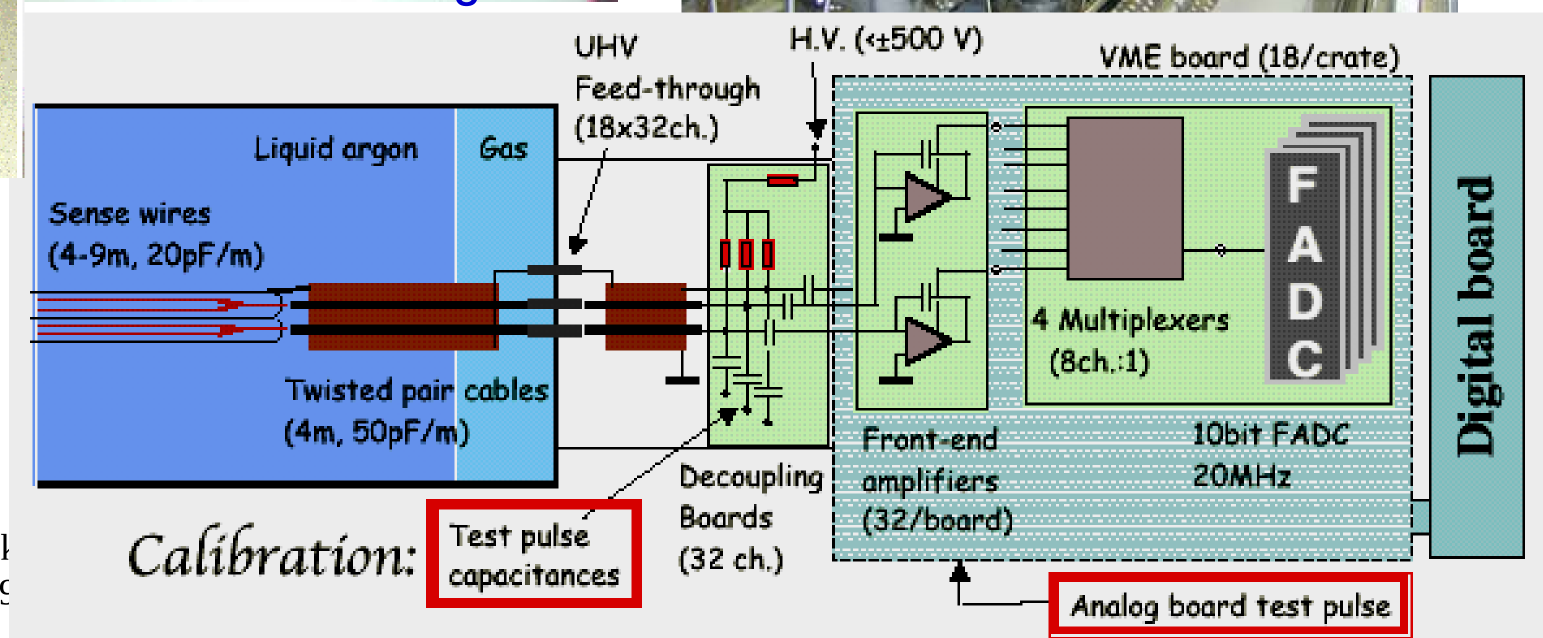


- Two separate containers
  - ➥ inner volume/cont. = **3.6 x 3.9 x 19.6 m³**
- **SENSITIVE MASS = 476 TON**
- 4 wire chambers with 3 readout planes at 0°, ±60° (two chambers / container)
  - ➥ **≈ 54000 WIRES**
    None broke during test
- Maximum drift = 1.5 m
  - ➥ HV = -75 kV @ 0.5 kV/cm
- **SCINTILLATION LIGHT READOUT** with 8" VUV sensitive PMTs

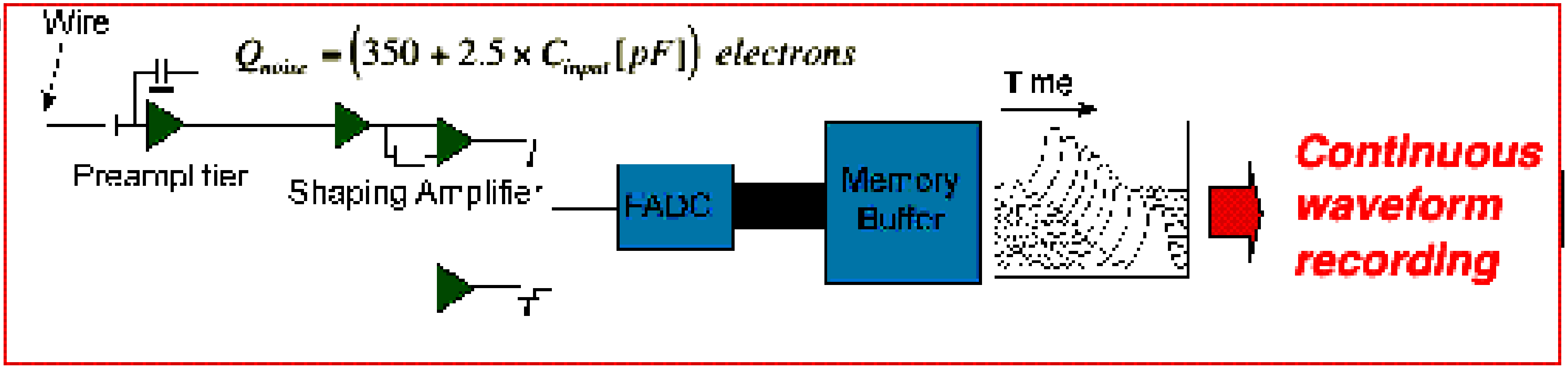


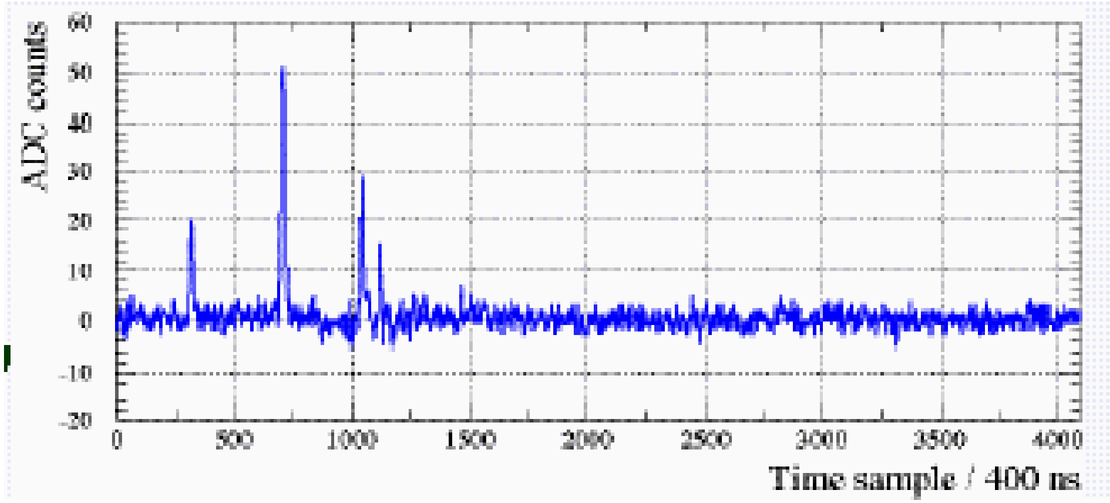
T600 detector readout electronics

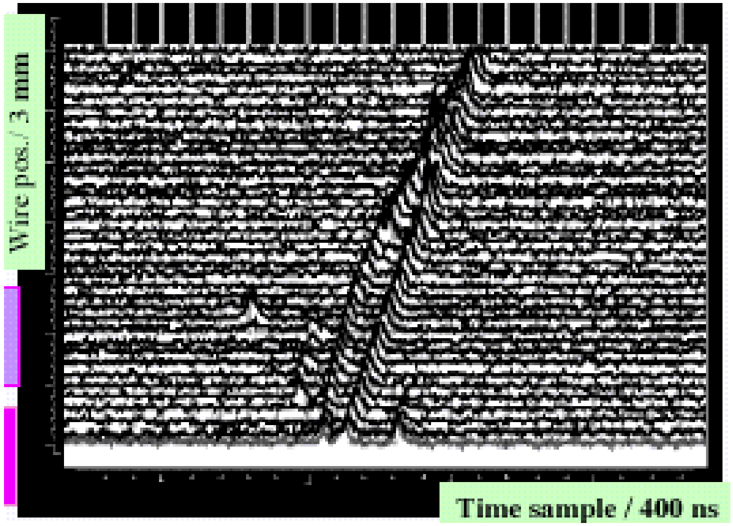




Data taking







$(S/N)_{mip}$ = 8-10

T600 - surface tests in Pavia in 2001

Technical run held in Pavia in Summer 2001: ascertain the maturity of large scale liquid Argon imaging TPC. Main phases:

clean-up (vacuum) 10 days, cool-down 15 days, LAr filling 15 days, debug and data-taking 68 days

Technol

succes

- **Cryogenics**
- **Wire chamber mechanics (no broken wire)**
- **Argon purification (drift electron lifetime > 1.8 ms)**
- **High voltage for the drift (75 kV nominal, 150 kV reached)**
- **Collection of scintillation light**
- **Slow control**
- **Readout and DAQ**
- **Event 3D reconstruction**
- **Calibration**

In addition to the 18 m long track requested by the Scientific Committees, a large number of cosmic-ray events was collected:

about 28000 triggers with different topologies

4.5 TB of data, 200 MB/event.

Valuable data to check performance of a such large scale detector.

Results of the same quantitative quality as those obtained with small prototypes (e.g. 3 ton, 50 liter, …) are achieved with a 300 ton device.

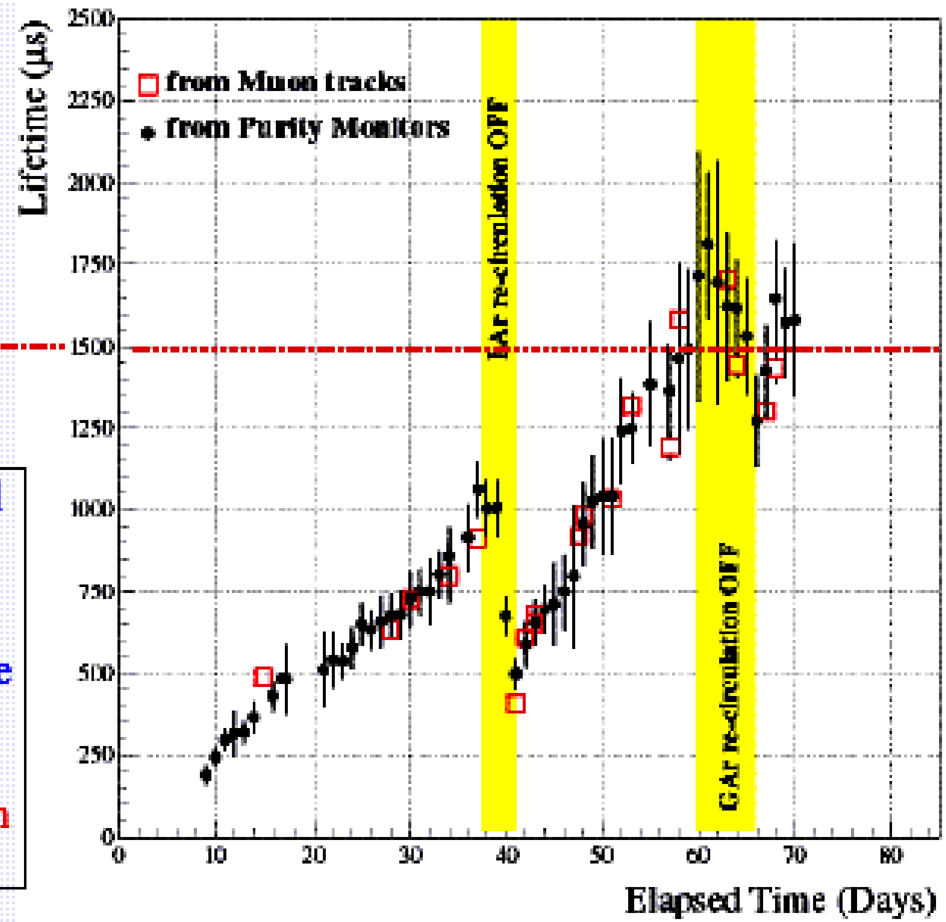
T600 - Argon purity: drift electron lifetime

Drifting electrons can attach to Impurities in LAr ➡ loss of signal

Electronegative Impurities must be kept below 0.1 ppb O_2 equivalent

Purity is measured
on-line by Purity Monitors ,
off-line by Muon tracks

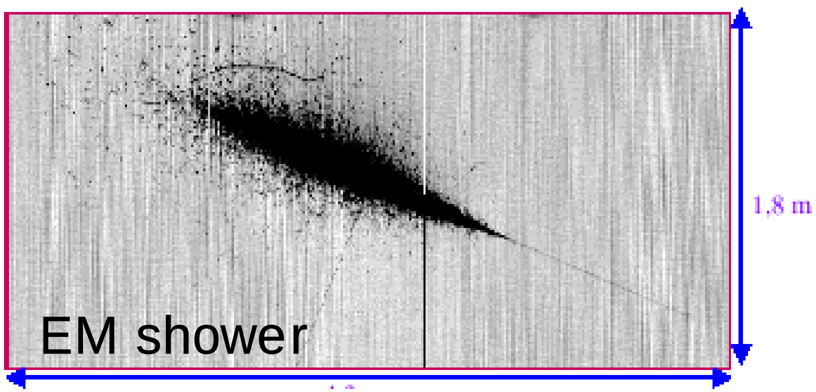
1500 µs ≈ 2.4 m

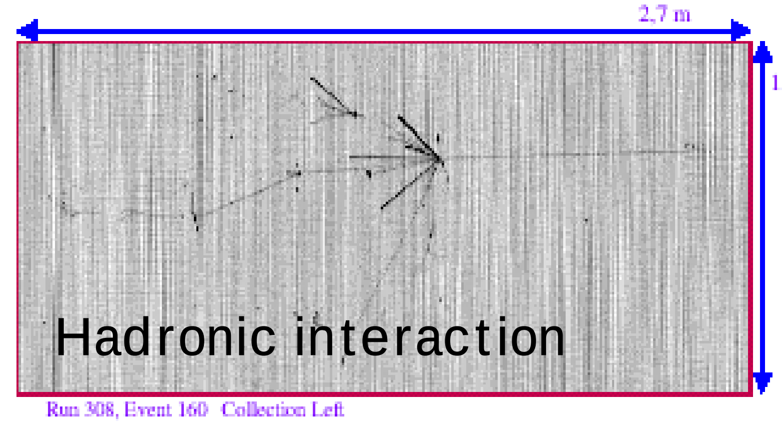


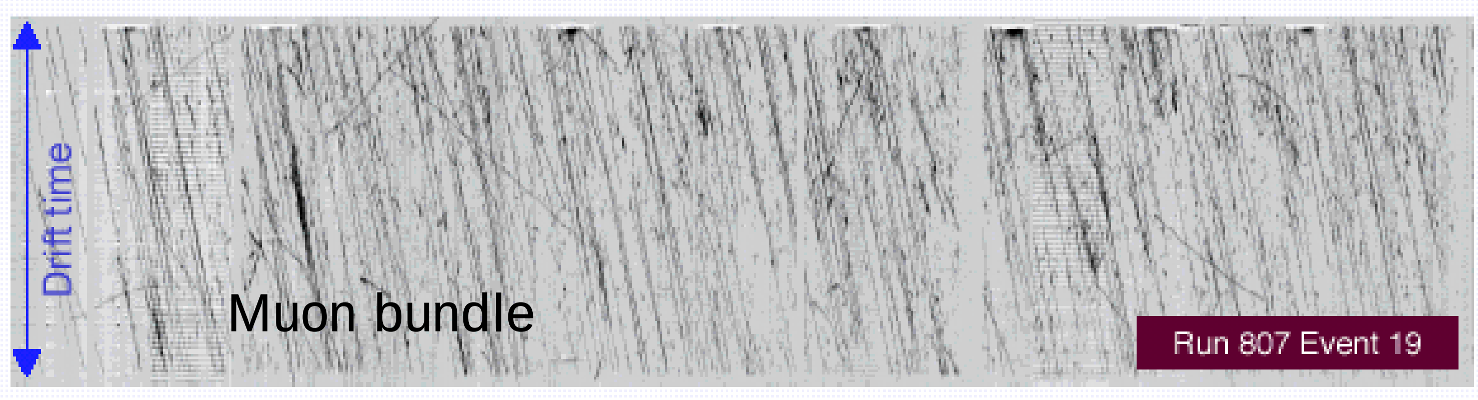
- Max. Lifetime reached ≈ 1.8 ms and growing
- The purity is uniform over the whole volume
- There is no evidence of τ_e saturation (≈100 days to reach 3ms)

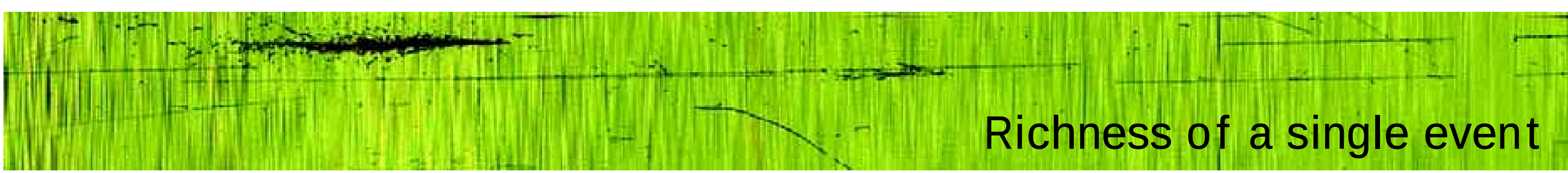
P. Sala, ICRC2003, Aug. 2003

T600 - data quality





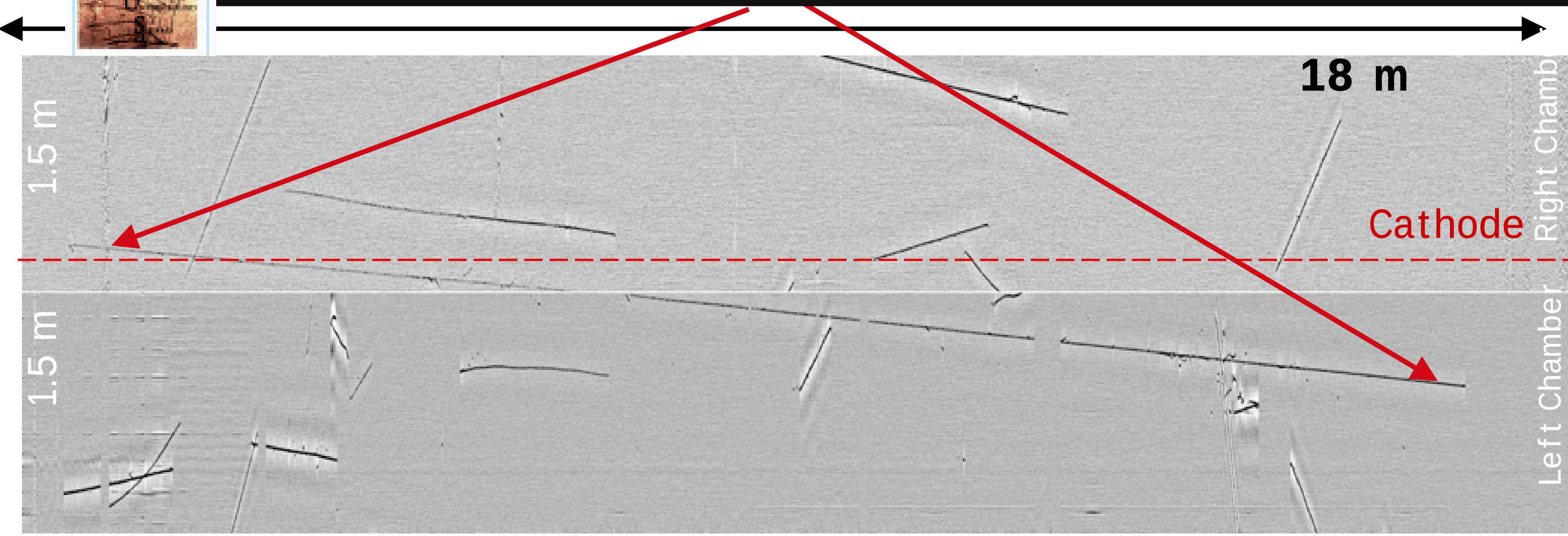


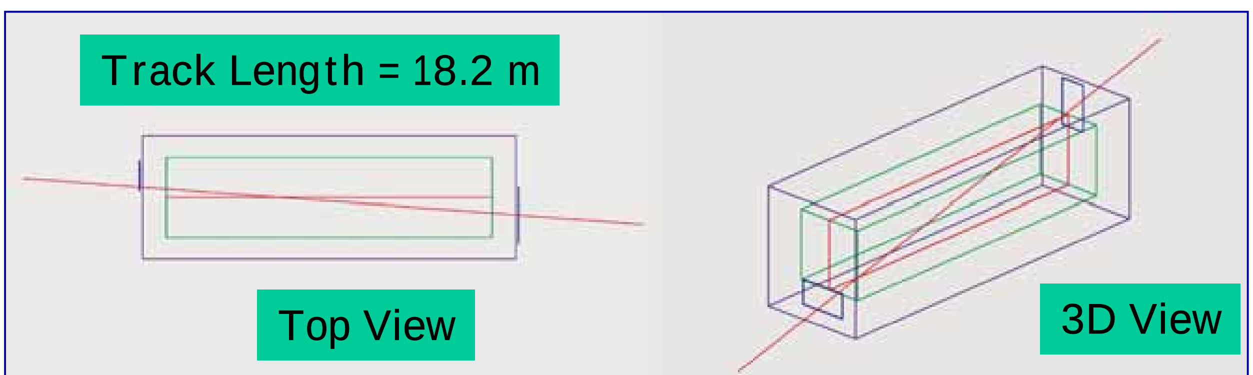


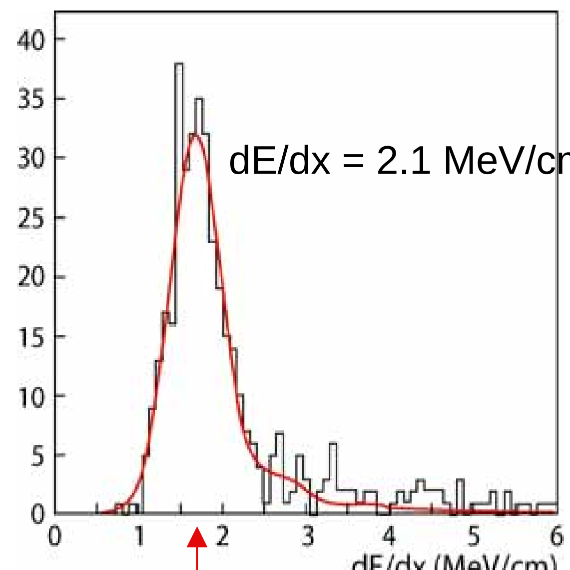
T600 - data analyses

- Progress on reconstruction, analysis and detector performance understanding
  - Big effort on detector response modeling
    - Full detailed simulation, digitization and noise
  - Big effort on automatic reconstruction
    - Hit, clustering, tracking in 2D and 3D, calorimetric reconstruction
- Publications
  - ✓ *Performance of the 10 m^3 ICARUS liquid argon prototype*, NIM A498 (2002) 292-311
  - ✓ *Observation of long ionizing tracks with the ICARUS T600 first half-module* , NIM in press
  - IN PHASE OF SUBMISSION:
    1. Detection of Cerenkov light emission in Liquid Argon
    2. Design, construction and tests of the ICARUS T600 detector (100 pages)
    3. Analysis of the liquid argon purity in the very large ICARUS T600 TPC
    4. Momentum estimation via multiple scattering in the ICARUS T600 TPC
    5. Analysis of of the stopping muon sample in the ICARUS T600 TPC
    6. Study of electron recombination (quenching)
    7. Observation of multi-muon events

T600 - long muon track crossing cathode



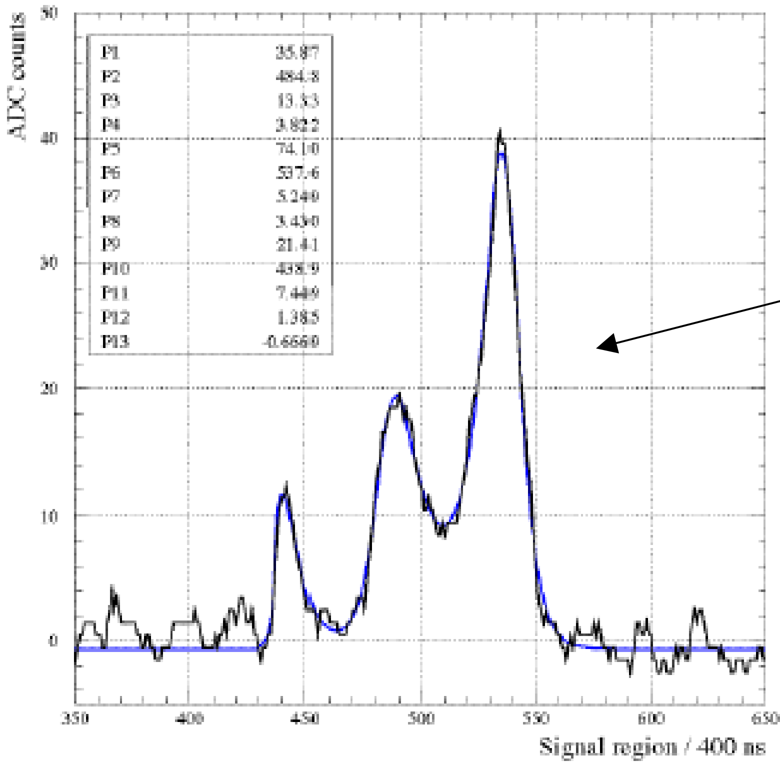




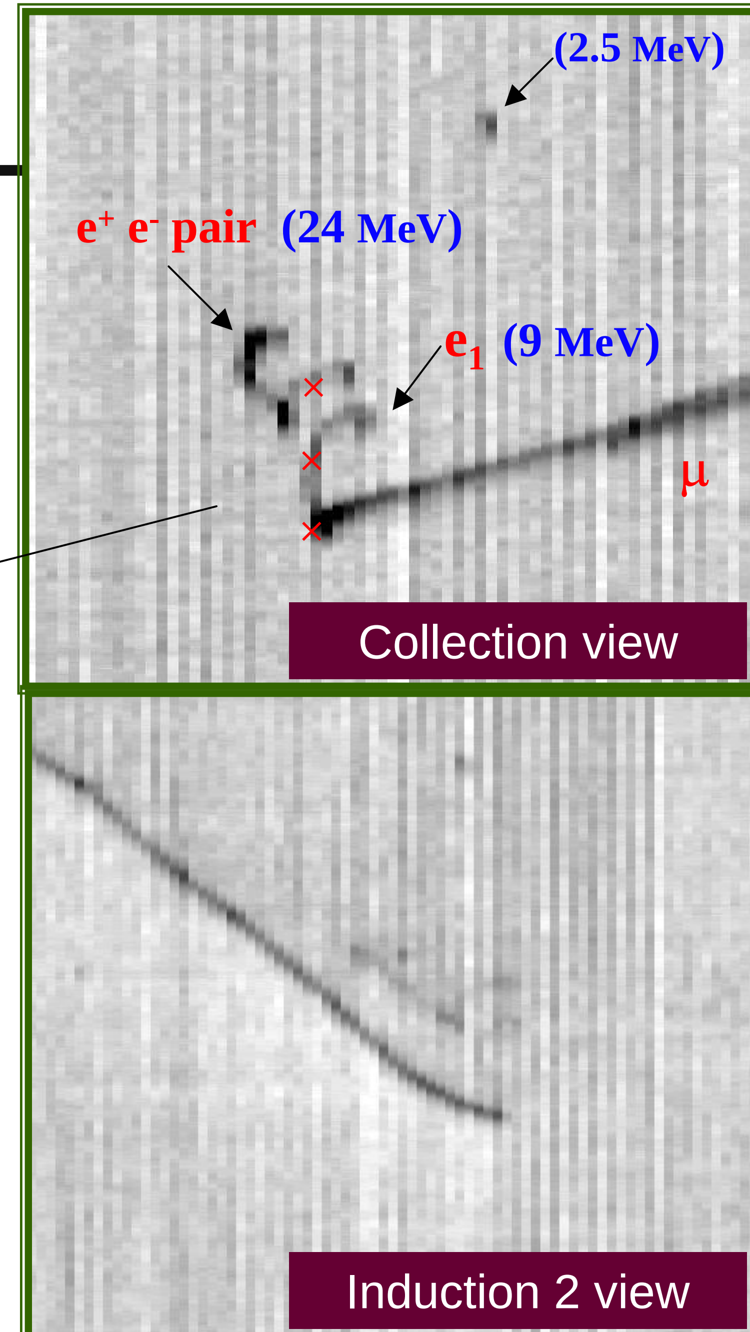
A.Zalewska, Epiphany 2004, 9.01.2004

T600 Bremsstrahlung + pair production

Run 975, Event 163



Fitted signal shapes on single wire



A.Zalewska, Epiphany 2004, 9.01.2004

T600 - π^0 candidate

158 MeV

$\theta = 141^o$

$M_{inv} = 650$ MeV

752 MeV

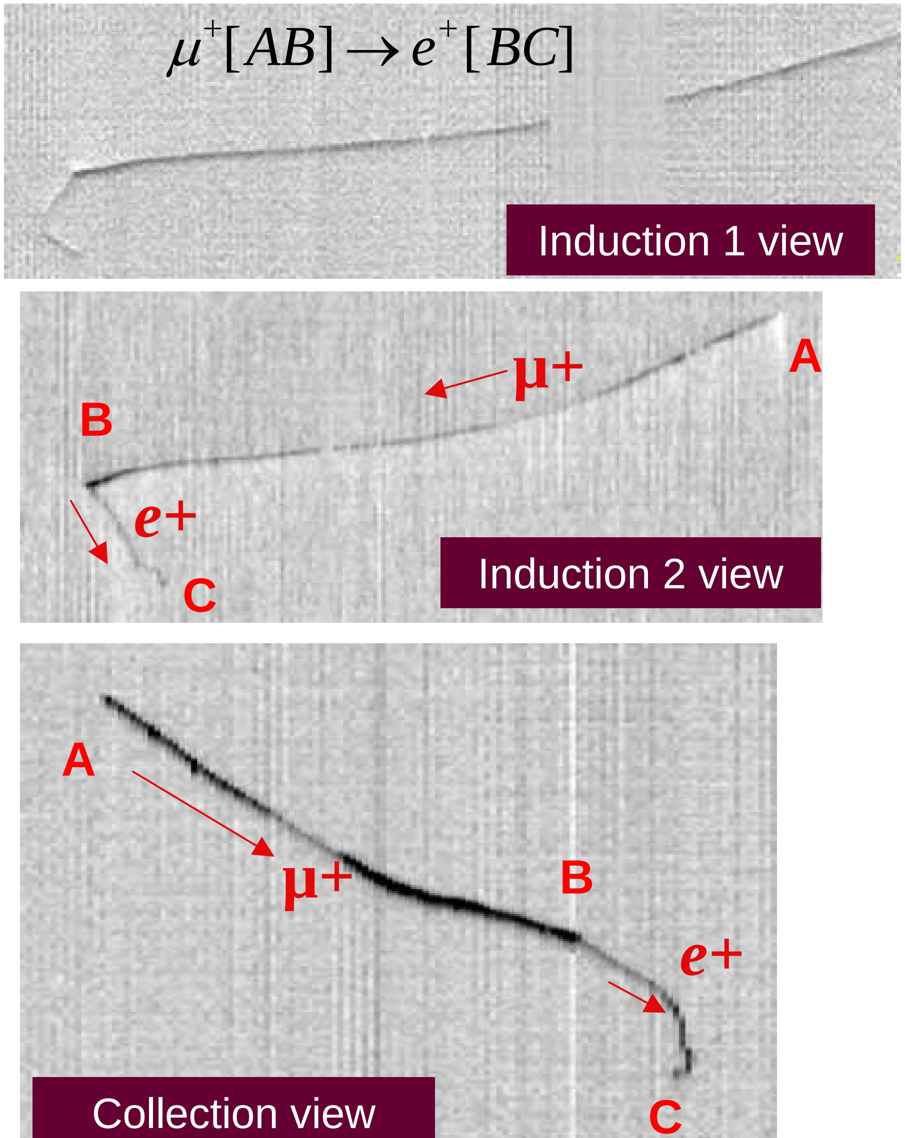
$\theta = 25^o$

$M_{inv} = 140$ MeV

140 MeV

Run 975, Event 151

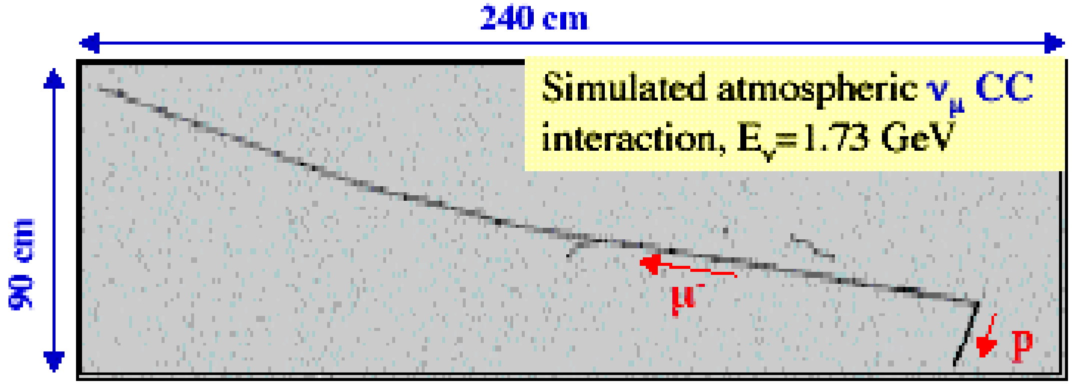
T600 - reconstruction of stopping muon

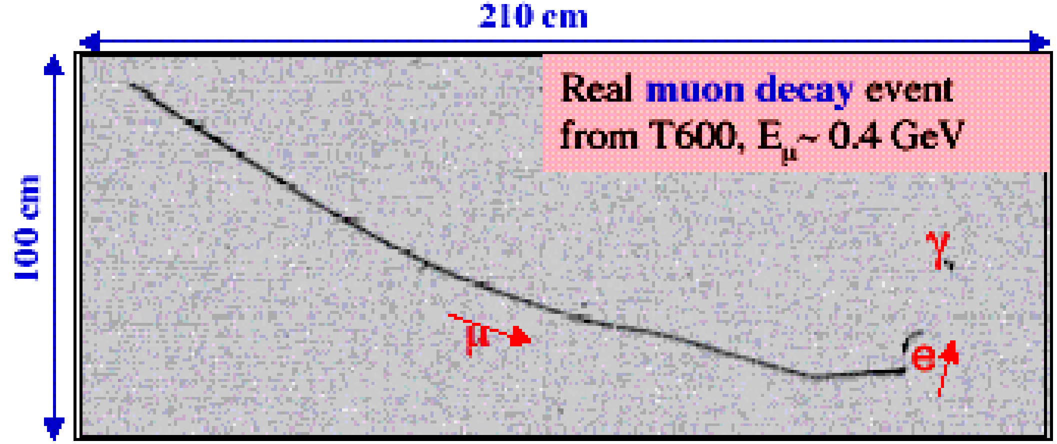


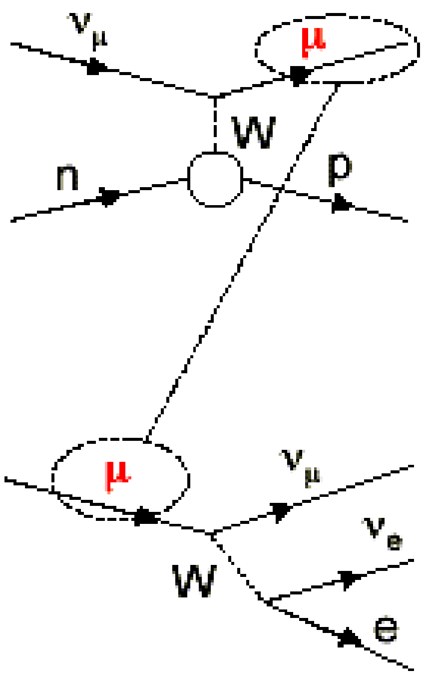
Run 939 Event 95 Right chamber

T_e=36.2 MeV
Range=15.4 cm

The stopping muon sample







Developed tools:

- **Spatial** reconstruction
- **Calorimetric** reconstruction

→ **First physics measurement**: Michel ρ parameter

Javier Rico, ETH-Zurich

ICHEP July 17th-23rd 2003, Aachen, Germany

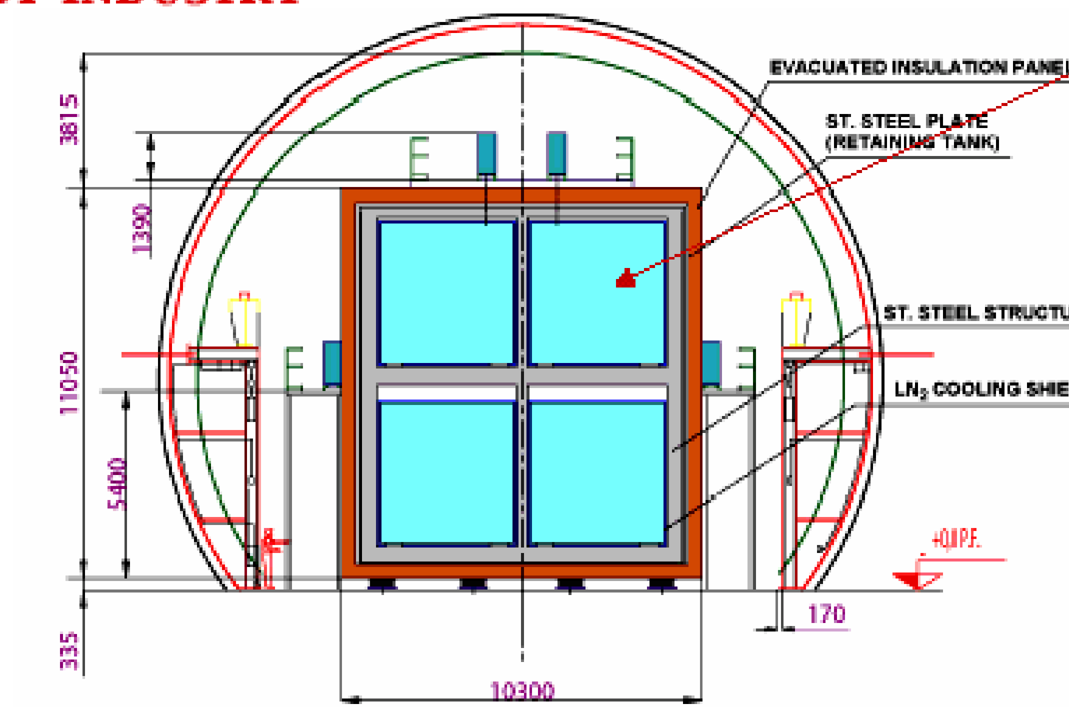
$\rho = 0.72 \pm 0.06(\textbf{stat}) \pm 0.08(\textbf{syst})$

T3000 detector

- The ICARUS collaboration has proposed an underground modular T3000 detector for LNGS based on the cloning of the T600
  - ➡ T3000 = T600 + T1200 + T1200
  - ➡ **DESIGN FULLY PROVEN BY T600 TECHNICAL RUN**
  - ➡ **READY TO BE BUILT BY INDUSTRY**

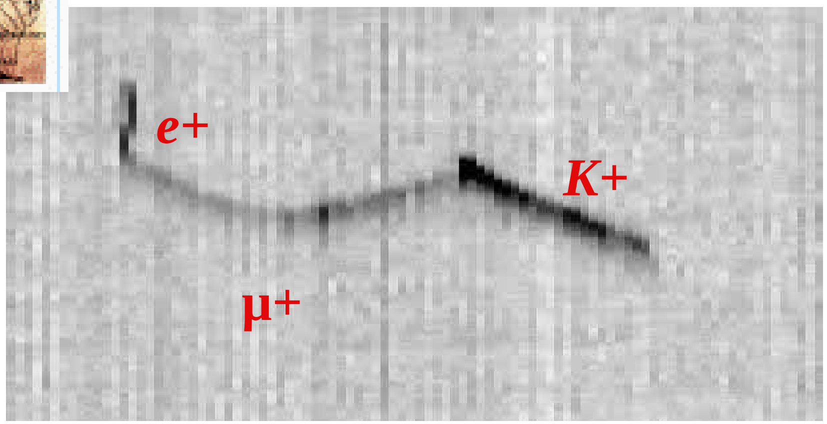
Cloning of the T600 modules to reach the design sensitive mass - LNGS-EXP 13/89 add. 2/01, CERN/SPSC 2002-027 (SPSC-P-323)

A magnetised muon spectrometer for ICARUS T3000 at the LNGS/CNGS - LNGS-EXP 13/89 add.3/01, CERN/SPSC 2003-030

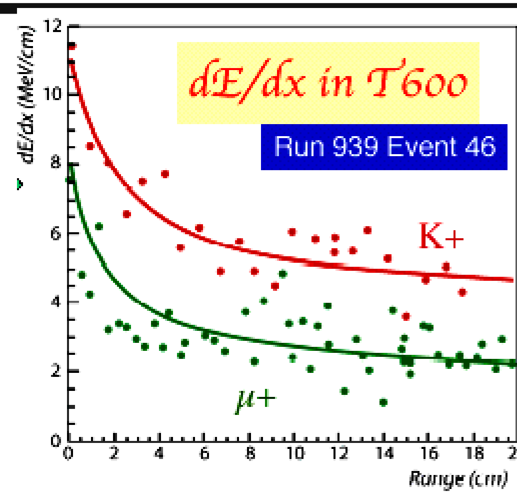


Goal: CNGS start up in 2006

ICARUS physics - proton decay

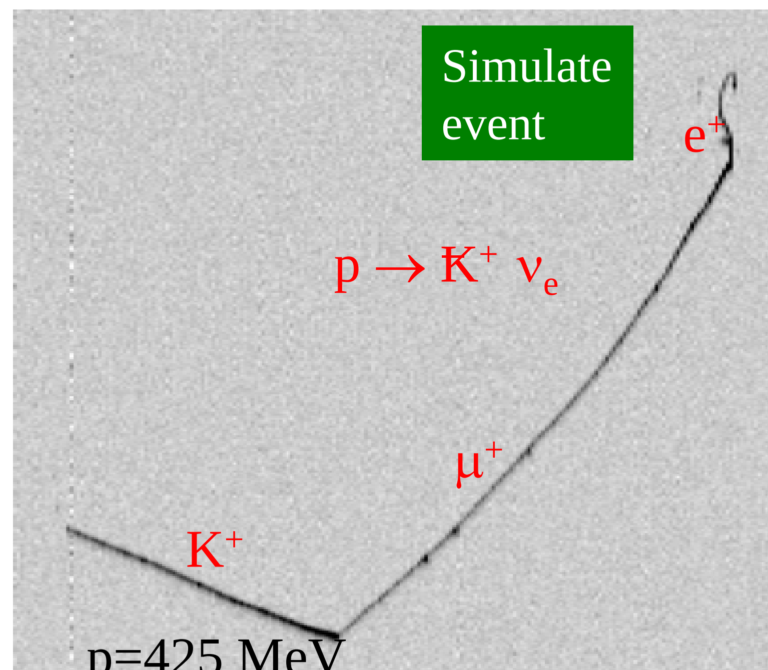


T600: Run 939 Event 46



65 cm

53 cm



A.Zalewska, Epiphany 2004, 9.01.2004

ICARUS physics - proton decay

Channel		Eff. (%)	Observed (evts.)	Bkg. (evts.)	Exposure (kTon×yr)	τ/B limit (10^{32} yr)	Needed Exp. to reach SK (kTon×yr)
$p \to e^+ \pi^0$	SuperK	43	0	0.2	79	50 → 30 [1 evt]	
	ICARUS	45	–	0.005	5	2.7	94
$p \to K^+ \bar{\nu}$	SuperK				79	19 → 13 [1 evt]	
prompt $\gamma\ \mu^+$	SuperK	8.7	0	0.3		10 → 7	
$K^+ \to \pi^+ \pi^0$	SuperK	6.5	0	0.8		7.5 → 5	
	ICARUS	97	–	0.005	5	5.7	17
$p \to \mu^+ \pi^0$	SuperK	32	0	0.4	79	37 → 24 [1 evt]	
	ICARUS	45	–	0.04	5	2.6	102

SuperK results compiled by M. Goodman for NNN02, January 2002

- Water Cerenkov are notoriously good at back-to-back three-rings events hence in $e\pi^0$ and $\mu\pi^0$ channels channels SuperK gains on the mass, even though backgrounds are round the corner
- In the favoured $p \to \nu K$ channel, the efficiency is LAr is ≈10 times better than the channels investigated
  - ICARUS T3000 fiducial is equivalent to 23.5 kton H_2O to be compared to SuperK 22.5 kton

ICARUS physics - atmospheric, solar, SN ν's

The ICARUS analysis of atmospheric neutrinos is characterized by

- Unbiased, systematic-free observation.
- Good energy and angular reconstruction
- Improvements expected in:
  - Low energy events
  - Clean electron sample
  - All final states
  - Neutral current events

1 year T600, $\Delta m^2=2.5\mathrm{x}10^{-3}\ \mathrm{eV}^2$		
	All	$P_{lepton} < 400$ MeV
ν_μ CC	46	16
ν_e CC	35	18
NC	45	

The ICARUS analysis of solar and SN neutrinos is characterised by

- Two types of measured processes: elastic scattering and absorption

$\nu_x + e^- \rightarrow \nu_x + e^-$ $\quad$ $\nu_e + {}^{40}Ar \rightarrow {}^{40}K^* + e^-$ $\quad$ $\bar{\nu}_x + e^- \rightarrow \bar{\nu}_x + e^-$ $\quad$ $\bar{\nu}_e + {}^{40}Ar \rightarrow {}^{40}Cl^* + e^+$

- For solar neutrinos it is limited to energies above 8MeV
- Big signal in a short time for SN ν's and anty-ν's allows for a lower threshold

ICARUS physics - CNGS beam

ICARUS will measure:

- ν_μ CC: online study of beam profile, steering and normalization
- ν_e CC: search for $\nu_\mu \rightarrow \nu_e$ oscillations: best sensitivity until the JHF-SK
- ν_τ CC: search for $\nu_\mu \rightarrow \nu_\tau$ oscillations with sensitivity similar to OPERA
- NC events: search for $\nu_\mu \rightarrow \nu_s$ oscillations or exotic models.

- Detector configuration
  - T3000
  - Active LAr: 2.35 ktons
- 5 years of CNGS running
  - Shared mode
  - 4.5×10^{19} p.o.t./year

Process	Expected Rates
ν_μ CC	32600
$\overline{\nu_\mu}$ CC	652
ν_e CC	262
$\overline{\nu_e}$ CC	17
ν NC	10600
ν NC	243
ν_τ CC, Δm^2 (eV^2)	
1×10^{-3}	31
2×10^{-3}	125
3×10^{-3}	280
5×10^{-3}	750

ICARUS physics - CNGS beam

T600+2 x T1200 modules

(2.35 kton active LAr, 1.5 kton fiducial)

5 year CNGS shared running

(2.25×10^{20} p.o.t.)

Super-Kamiokande:
$1.6 < \Delta m^2 < 4.0$ at 90% C.L.

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

- Several decay channels exploited (golden channel = electron)
- (low) backgrounds measured in situ (control samples)
- High sensitivity to signal; oscillation parameters determination

Conclusions

After many years of R&D program the LAr TPC technology is mature for building the ktons scale detectors

Big progress has been achieved in the full simulation and reconstruction software and in the data analysis

T600 transportation and installation process in the Gran Sasso laboratory should start in April 2004

T3000 detector for the CNGS beam is now the main goal (and challenge from the financial and organizational point of view)

Long term thinking: LAr offers the best sensitivity/kton for the θ_{13} mixing angle - giant LAr detector?

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

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

$$(\sin^2 2\theta_{13})_{CHOOZ} < 0.14 \quad \text{or} \quad \theta_{13} < 11^\circ$$

$$(\sin^2 2\theta_{13})_{MINOS} < 0.06 \quad \text{or} \quad \theta_{13} < 7^\circ$$