The ICARUS Project

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XXIst International Conference on Neutrino Physics and Astrophysics

NEUTRINO 2004

The ICARUS Collaboration

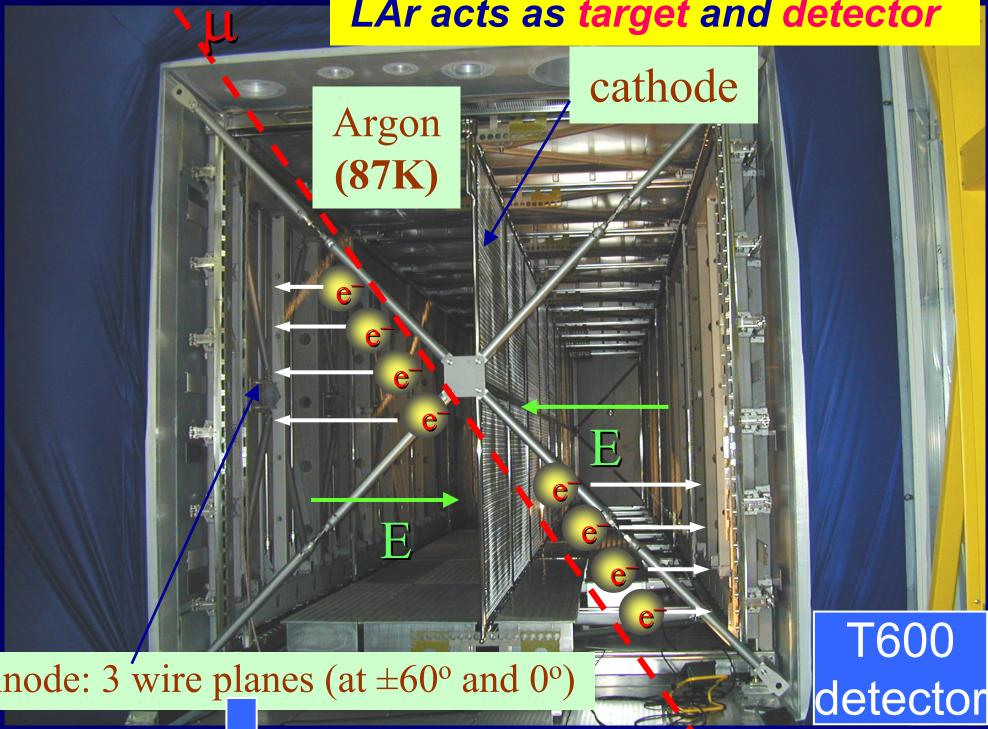
- Research project jointly approved by INFN and CERN
  - **CERN/SPSC 2002-027 (SPSC-P-323) LNGS-EXP 13/89**

– CNGS Physics Program: ICARUS is an official CERN experiment known as CNGS2 (April 2003)

Liquid Argon Detector : Why?

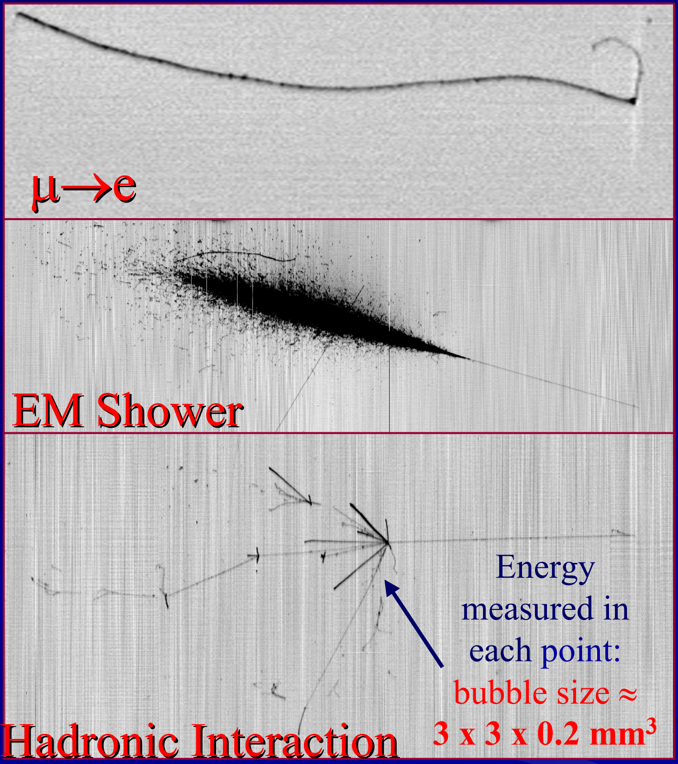
- Easy to obtain with very high purity by specialized industries
  - Concentration on atmosphere ~ 0.9%
  - Cheap: 1 liter cost below 1 €
- Homogeneous medium simultaneously acting as target and detector
- Interesting physical properties for a tracking device:
  - Boiling point = 87.3 K at 1 bar; not flammable
  - Density = 1.4 g/cm^3
  - Radiation length = 14 cm; interaction length = 80 cm
  - Electron mobility = 500 cm^2/Vs
  - dE/dx = 2.1 MeV/cm
- Propagation of charged particles induce…
  - Ionization
    - **Minimum ionizing track: 88000 electron-ion pairs per cm**
    - **After recombination @ 500 V/cm:** ***55000 pairs/cm***
  - Scintillation
    - UV Spectrum λ=128 nm
  - Čerenkov light (given that β > 1/n)

Electronic Bubble Chamber



3-dimensional images

Real Events



After many years of R&D at lab scale…

The road for construction of <u>very massive</u> LAr TPC detectors is now open!

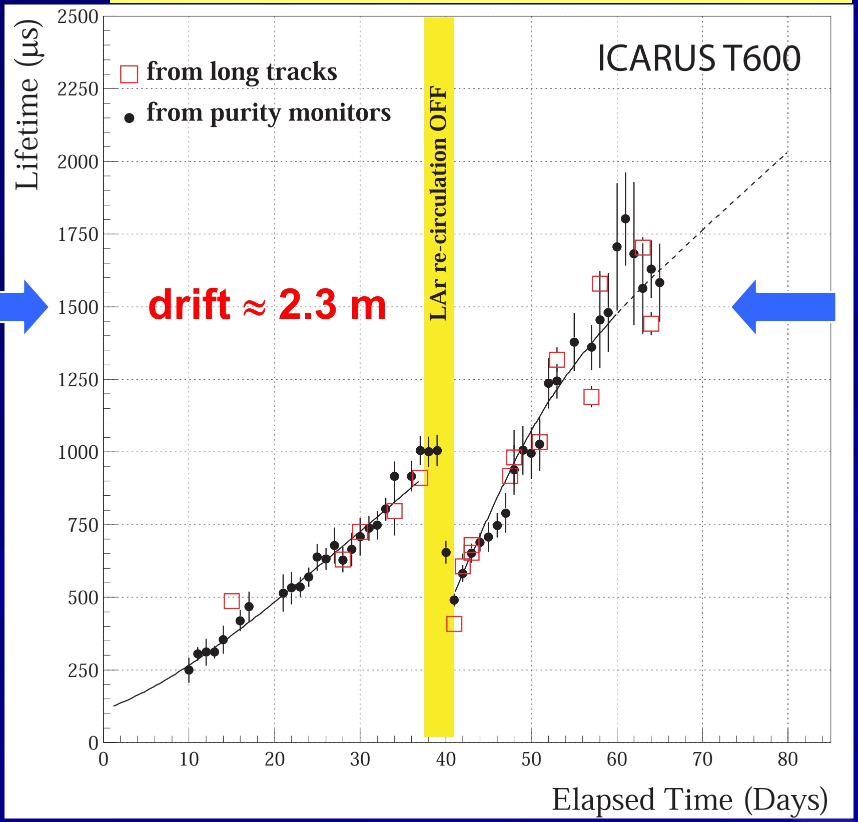
T600 Detector: Cosmic Ray Data

- More than 27000 triggers collected during technical run on surface (summer 2001)
  - **Detector performed according to expectations**
  - Testing 3D reconstruction, particle ID capabilities, …
- Publications so far…
  - *Design, construction and tests of the ICARUS T600 detector,* accepted for publication by NIM A on 31/12/03.
  - *Measurement of the muon decay spectrum with the ICARUS T600 liquid Argon TPC,* Eur. Phys. Journal C33 (2004) 233-241.
  - *Study of electron recombination in liquid Argon with the ICARUS TPC,* Nucl. Inst. Meth. A523 (2004) 275-283.
  - *Analysis of 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.

Liquid Argon Purity

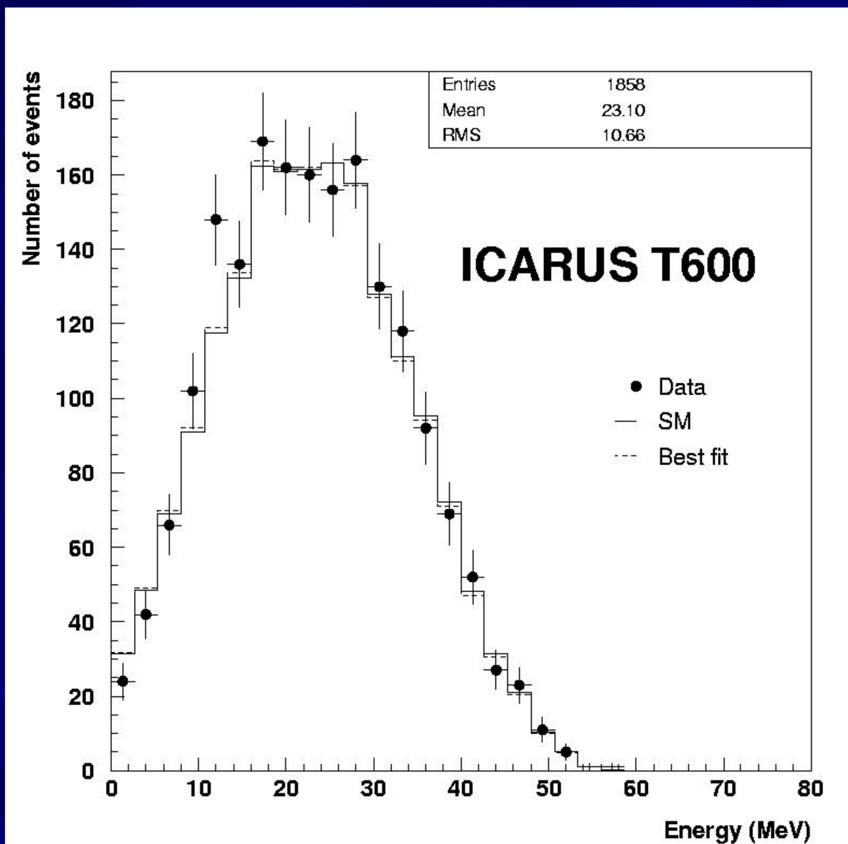
- Long drift distances demand ultra pure Argon
  - Impurities: 0.1 ppb Oxygen-equivalent
- Two independent and complementary methods to measure the LAr purity:
  - **Purity Monitors** : *on-line* information on a fixed position of the chamber (*punctual* measurement).
  - **Muon tracks**: *off-line* analysis measuring the collected charge attenuation from crossing muon tracks (*average* measurement).
- For future modules, the present technology would allow to expand drift distances up to 3m

V_{drift} = 1.56 mm / μs @ 0.5 kV/cm



Liquid Argon TPC is a mature detection technique

Michel Electron Spectrum



- Study of stopping muon sample
  - 3000 events analyzed and fully reconstructed in 3D
- ρ parameter measurement

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

  - Standard Model ρ = 0.75
- Energy resolution for electrons below ~50 MeV

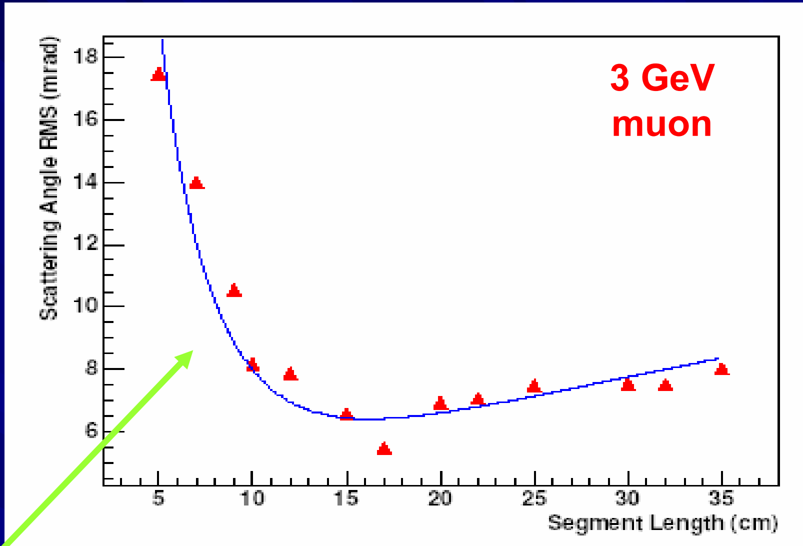
$$\frac{\sigma(E)}{E} = \frac{11\,\%}{\sqrt{E}} \oplus 2\%$$

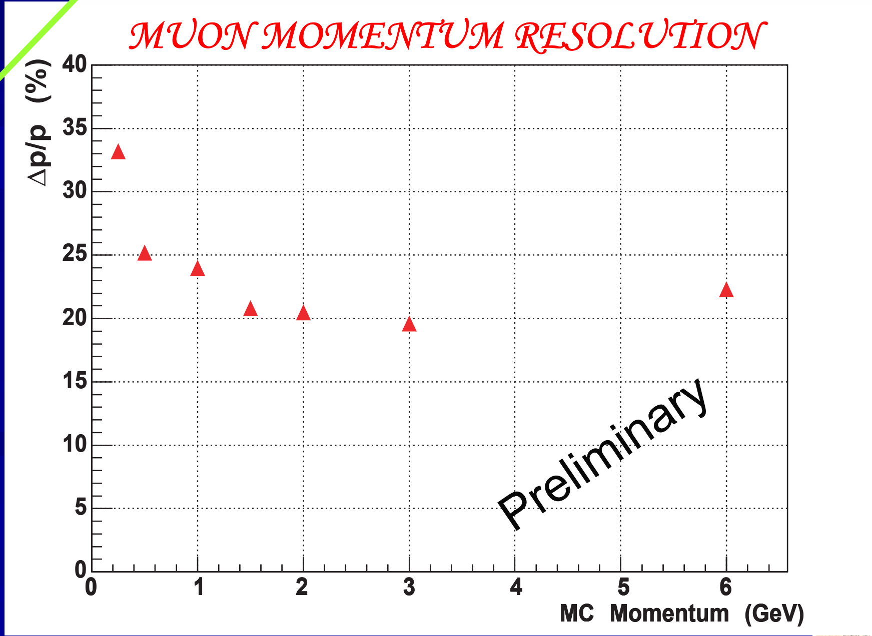
Momentum measurement: Multiple Scattering

- Essential to measure kinematics properties of non-contained events
  - Interest focused on atmospheric events
- Full simulation of muon events for a broad momentum range
  - Include all detector effects
- Split track into segments. Measured angles have two contributions:

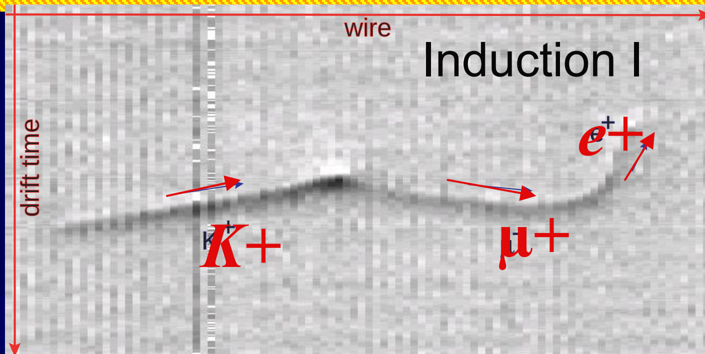
$$\left(\vartheta_{meas}^{RMS}\right)^2 = \left(\vartheta_0^{RMS}\right)^2 + \left(\vartheta_{noise}^{RMS}\right)^2; \quad \vartheta_0^{RMS} \propto \sqrt{L_{seg}} / p; \quad \vartheta_{noise}^{RMS} \propto L_{seg}^{-3/2}$$

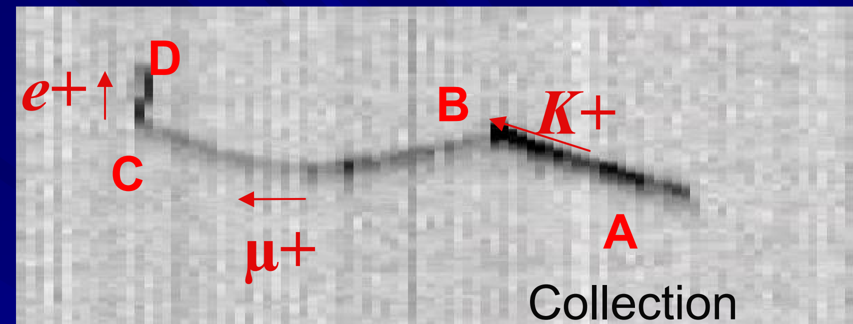
- Momentum extracted from fit over a sample of different segment lengths
- Resolutions ≈20-25%
- Future analysis…
  - Resolution improvement with alternative methods (e.g. Kalman Filter)?
  - Validate conclusions with real data: large sample of stopping muons



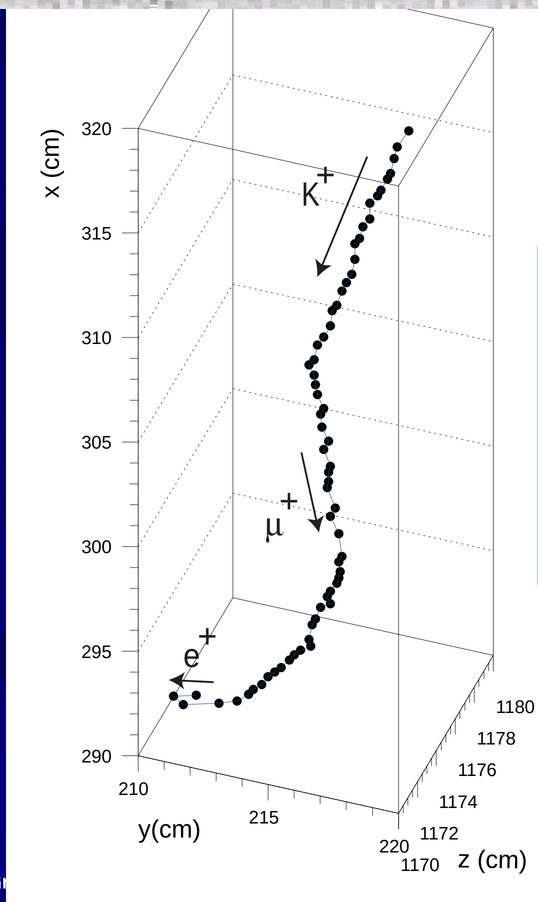


Particle Identification

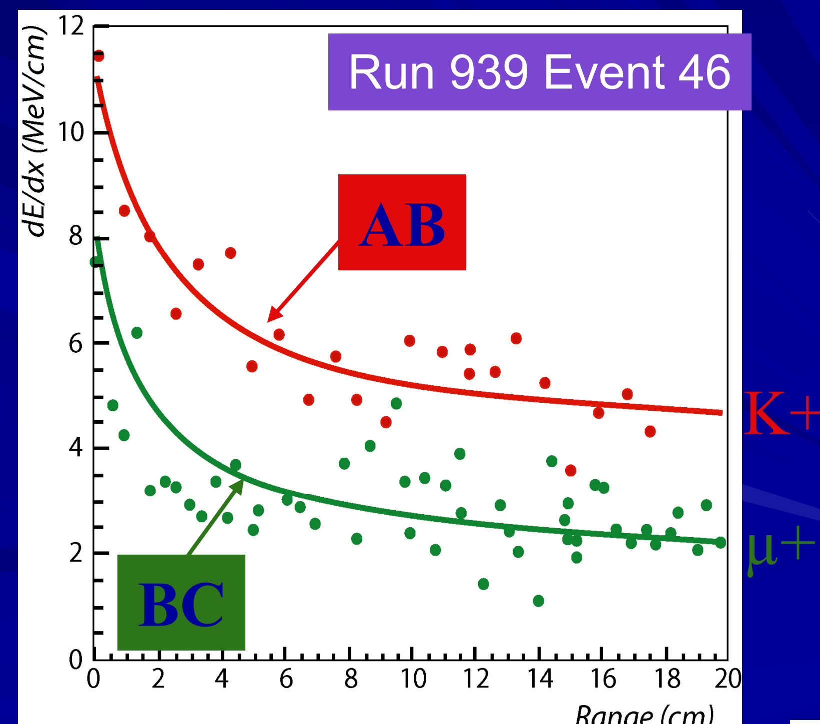




$K^{+}[AB] \rightarrow \mu^{+}[BC] \rightarrow e^{+}[CD]$

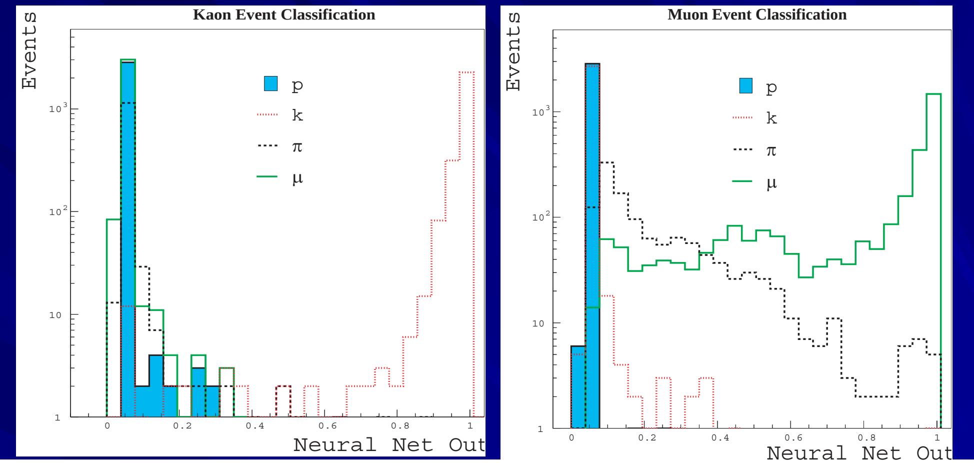


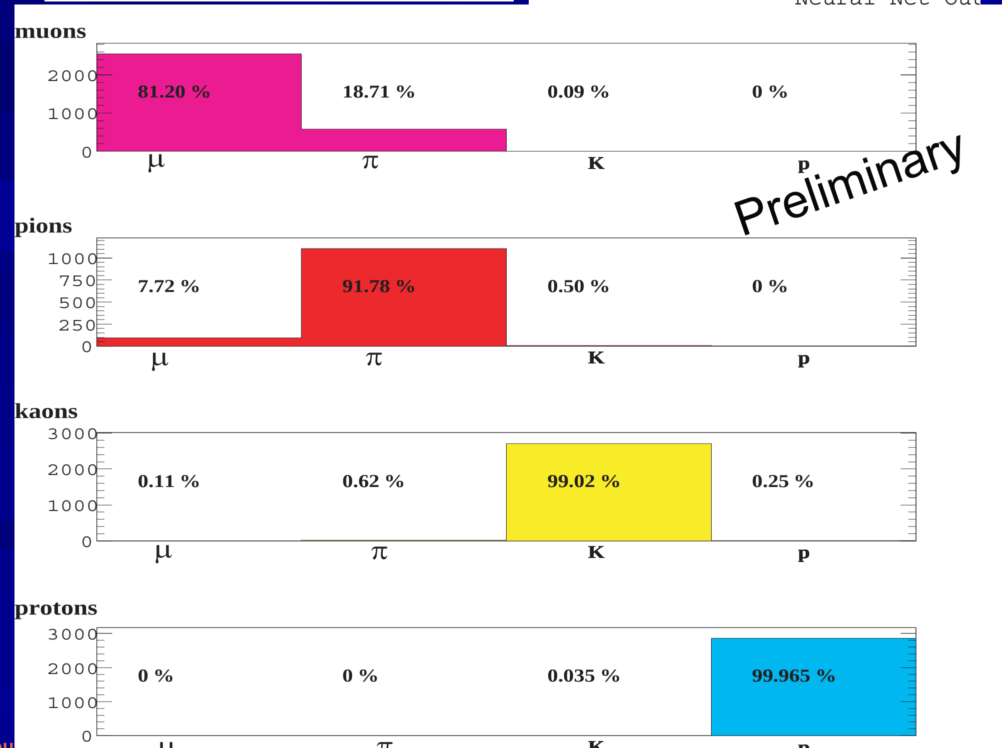
3D reconstruction allows to compute **dE/dx** and **range**



Particle Identification: Neural Network

- Full generation and 3D reconstruction of muons, pions, protons and kaons
- Analysis based on neural network. Discrimination given by:
  - Different stopping power for each particle type
  - Difference on secondary particle production after decay/interaction of parent track
  - Key issues:
    - Accurate energy measurement
    - Good spatial resolution for precise tracking reconstruction
- Very high identification efficiencies (>90%) while low contamination levels (few %) are expected





T600 at LNGS

- Following LNGS Director's mandate, a working group of experts was set up to review:
  - ICARUS T600 (cryogenics, safety, installation, commissioning, operation)
  - Risk Analysis: simulation of possible major failures
  - Technical infrastructure and human resources at LNGS to cope with ICARUS needs

Working Group Conclusions (Nov 2003)

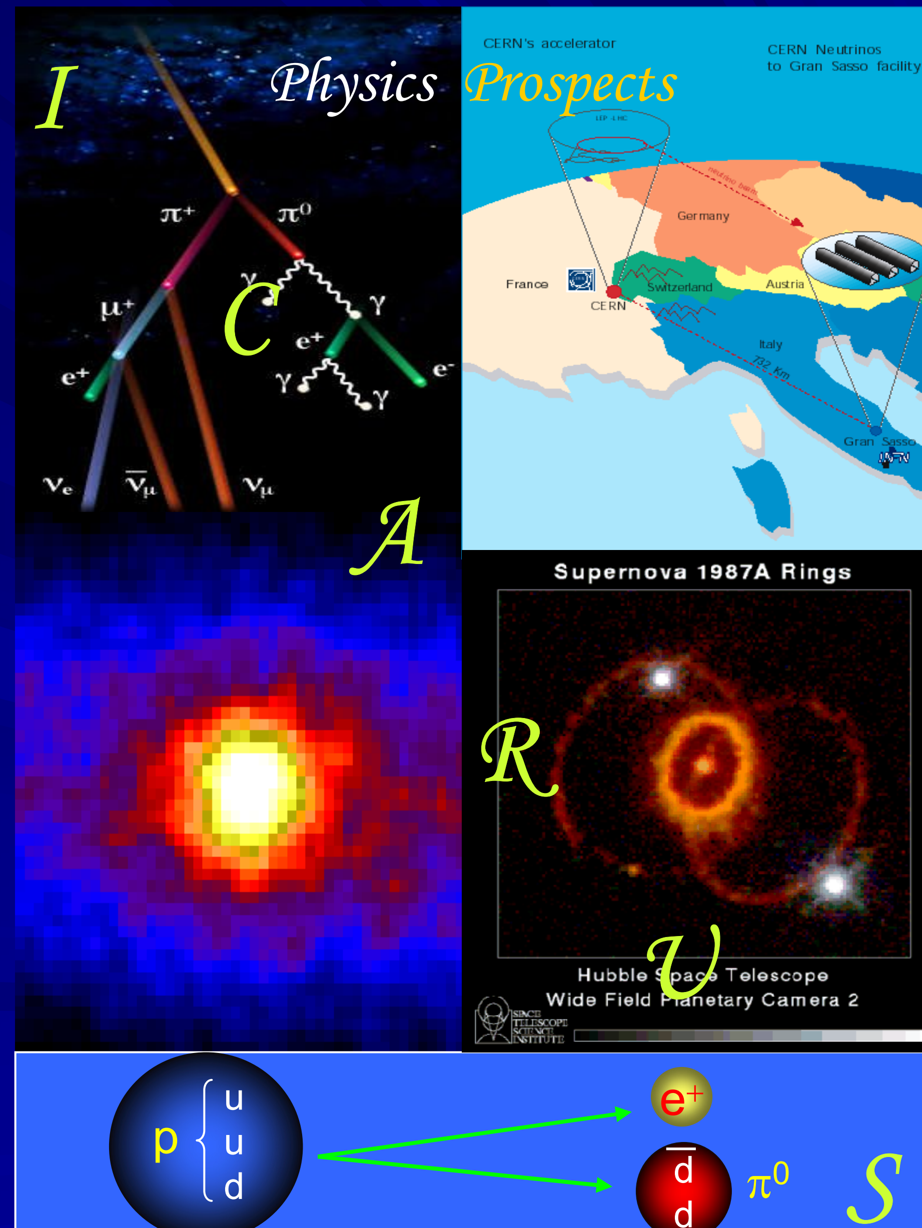
- The ICARUS project is sound and innovative
- Recommended improvements concerning the cryogenic system will be implemented by our collaboration
  - Overall risk linked to LNGS activities is not increased when T600 becomes operational
- A significant amount of work should be carried out at LNGS to upgrade Hall B infrastructure and technical utilities
- T600 can be installed right now underground: allowed to enter hall B (summer 2004)

The T600 Installation Roadmap

Milestones	Estimated start/end dates
LNGS Director's permission to place cryostat underground	End of May
Works on Hall B pavement refurbishing	1-06-04/10-09-04
T600 Transportation to LNGS *"parking lot" position* (adjudicated contract)	July-04/
Control Room Building and Set-up (contract adjudication 30/6/04)	6-10-04/13-09-05
Supporting structure for N2 Utilities & Purification System (adjudicated contract)	14-10-04/30-08-05
Thermal Insulation & Mechanics Installation (adjudicated contract)	30-08-04/13-07-05
Piping Works Installation & Control System (INFN approval needed)	14-07-05/13-09-05
DRY TEST	14-09-05/4-10-05
Upgrade human resources & ventilation, cooling, power distribution systems (LNGS responsibility)	Deadline: 3-10-05
Control System & Liquid Nitrogen Re-Liquifier	Deadline: 30-09-05
LAr Supply, Filling & Commissioning	October 2005

A Rich Physics Programme

- Atmospheric, Solar and Supernova neutrinos
- Long Baseline Neutrino Experiment:
  - Explicit search for $\nu_\mu \rightarrow \nu_\tau$ and $\nu_\mu \rightarrow \nu_e$
- Background-free proton decay searches



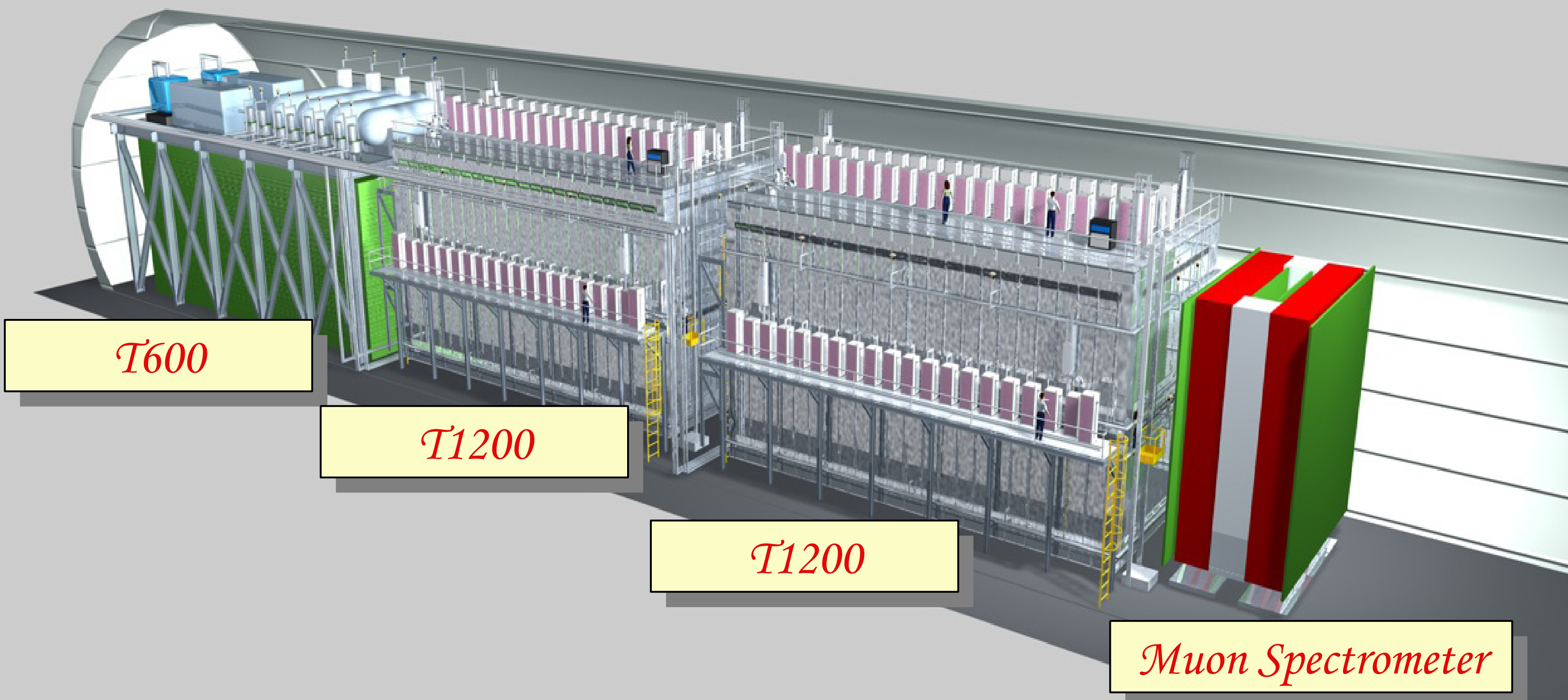
CONCLUSIONS

- The Liquid Argon detection technique is now mature
  - Matches the requirements imposed, to second generation detectors, by neutrino physics and proton decay searches
  - Ability to build very massive detectors
  - It has been demonstrated that drift distances amounting up to several meters are feasible
- The T600 is being moved to LNGS
  - Physics run will start in Autumn, 2005
- The collaboration plans to clone the T600 module in order to reach a final mass of 3 Kton
  - Address fundamental questions related to the Physics Beyond the Standard Model

BACK-UP

ICARUS T3000 + Muon Spectrometer

A Second-Generation Proton Decay Experiment and Neutrino Observatory at Gran Sasso Laboratory



LNGS-EXP 13/89 Add. 3/03

CERN/SPSC 2003-030

SPSC-P-323-Add. 1

Construction strategy:
"Cloning" the successfully operated T600 module

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

- Main reaction $\nu_\tau + Ar \rightarrow \tau + jet;$ $\tau \rightarrow \begin{cases} e\nu\nu & 18\% \\ \mu\nu\nu & 18\% \\ h^- n h^0 \nu & 50\% \\ h^- h^+ h^- n h^0 \nu & 14\% \end{cases}$
  - Search based on kinematical criteria
  - Natural ν_τ contamination below 10^{-7} w.r.t. ν_μ component
  - 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
$\tau \to e$	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**

  - 5 years of CNGS operation (4.5×10^{19} p.o.t.)
  - T3000 detector (2.35 kton active LAr, 1.5 kton fiducial)

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

- Main reaction

  $\nu_e + Ar \rightarrow e^- + jet;$

- Natural ν_e contamination 1%
- Limited by CNGS statistics

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

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

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

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