The Atmospheric and Solar Neutrino Experiment with the ICARUS T600 Detector @ Gran Sasso Laboratory

TAUP 2001

O. Palamara
Sept. 10th, 2001
OUTLINE:

• **ICARUS T600: status of the detector**
  - 1997-2000: Realization completed (Pavia-INFN Exp. Hall)
  - April-Aug. 2001: Full Test in experimental conditions (Pavia)
  - 2002: Transportation to LNGS (Underground Site) re-mounting and start physics run

• **The atmospheric neutrino experiment:**
  - Event Rate Evaluation
  - Reconstruction capability with ICARUS

• **The solar neutrino experiment:**
  - Signal and Background event Rate Evaluation
    - Signal: Based on BP98 Solar $\nu$ Flux
    - Bckgd: based on neutron flux direct measurement performed by ICARUS Collaboration at LNGS (Hall C)
  - Signal to Background Discrimination: from full MC simulation
The ICARUS Collaboration

- INFN-Laboratori Nazionali del GranSasso, Italy
- Inst. of Exp. Physics, Warsaw University, Warsaw-Poland
- Inst. for Particle Physics, ETH, Zurich-Switzerland
- Dip.to di Fisica e INFN, Padova-Italy
- Dip.to di Fisica e INFN, Milano-Italy
- Dip.to di Fisica e INFN, Pavia-Italy
- Dip.to di Fisica e INFN, L’Aquila-Italy
- CERN, Geneva-Switzerland
- Dip.to Ing. Nucleare, Univ. di Milano, Milano-Italy
- IHPE-Academia Sinica, Beijing-China
- Dep.t of Physics, UCLA, Los Angeles-California, USA
- H.Niewodniczanski Inst. of Nucl. Phys., Krakow-Poland
- Inst. of Physics, Wroclaw Univ., Wroclaw-Poland
- Inst. of Physics, Silesia Univ., Katowice-Poland
- A. Soltan Inst. Of Nucl. Studies, Warsaw-Poland
- Fac. of Phys. And Nucl. Tech., Krakow-Poland
- ICFG-CNR and Dip.to di Fisica, Torino-Italy
- INFN-Laboratori Nazionali di Frascati, Roma-Italy
- Inst. of Physics, Jagellonian Univ., Krakow-Poland
- INFN-Pisa, Italy
The ICARUS technology

• **Working principle:**
  • Ionization chamber filled with LAr, equipped with sophisticated electronic read-out system (TPC) for 3D imaging reconstruction, calorimetric measurement, particle ID.
  • Absolute timing definition and internal trigger from LAr scintillation light detection

• **T600 detector:**
  • Cryostat: 2 identical, adjacent half modules (3.6x3.9x19.9 m³)
  • Internal detector:
    - 2 TPC per half module (3 wire planes @ 60°: induction I, induction II, collection)
    - field shaping system (cathode, race track, HV feed-through)
    - array of PMT’s for scintillation light detection
    - monitors and probes
  • Electronics: analogue board + digital board
View of the inner detector

The T600 Detector during construction

LAr Cryostat (half-module)

4 m

Wire of the TPC

Drift Length (1.5 m)

UV PMT

Wires of the TPC

Field Shaping Electrodes (during installation)

Wire Chamber Structure

Signal Flanges and feed-throughs

Electronic Racks
Run @ P_{v}: full test in final experimental configuration (May-Aug 2001)

Collection of large statistics of cosmic ray data with various trigger configurations: from long $\mu$ tracks (up to 18 m length), to high multiplicity $\mu$ bundles, to large el.m. and hadronic showers
Full 2D View from the Collection Wire Plane

Drift coord. (m)

Wire coord. (m)

1. El.m. shower

2. Zoom views
   - μ stop and decay in e

3. El.m. shower
   - Detail of a long (14 m) μ track with δ-ray spots

T600 test @ Pv: Run 201 - Evt 12
A spectacular event showing a dense Air Shower formed by hundreds of parallel tracks (muons and pions) and low energy $\gamma$'s converting into electrons. Also visible in the zoom views a hadr. shower, an el.m. shower and a muon bundle.

T600 test @ P6: Run 308 - Evt 4 (July 2nd, 2001)
Full 2D view from the Collection Wire Plane

Drift Coord. (m)

Wire coord. (m)

3.9 m

1.3 m

Zoom View

T600 test @ Pv: Run 308 - Evt 7

Large e.m. shower

Sept. 10th 2001 O. Palamara - LNGS 9
• Observation of atmospheric neutrino interactions with unique experimental features
• Capability to observe electron and muon neutrino CC events and NC events without detector biases and down to the kinematical threshold

• Improvements with respect to previous observations:
  - complicated final states with multi-pion production will be completely analyzed and reconstructed
  - better reconstruction of the incoming neutrino variables (i.e. incidence angle, energy) by using the information coming from all particles produced in the final state
Difference between real and reconstructed neutrino angle for events with $E_{\nu} > 1$ GeV

- $E_{\nu} < 500$ MeV: the resolution is dominated by the smearing introduced by the Fermi motion of the initial state nucleon and re-interaction of hadrons inside the nucleus
- $E_{\nu} > 500$ MeV: the improvement in resolution when all particles are detected is significant

Zenith angle resolution as a function of the incoming neutrino energy
Expected atmospheric neutrino rates for an exposure of 2 Kton year (in case of no oscill. and $\nu_\mu \rightarrow \tau$ oscill. with maximal mixing)

Given the clean event reconstruction, the ratio $R$ of “muon like” to “electron like” events can be determined free of large experimental errors

- About 60% of CC events contain a proton with kinetic energy >50 MeV in final state
- Detection of single recoil proton or multi-prong final state will provide a precise determination of the incoming $\nu$ energy and direction

Almost 50% of the atm. events lies below the Super-Kamiokande thr. ($p_{\text{lepton}}=400$ MeV)

ICARUS can really contribute to the understanding of the low energy part of the atm. $\nu$ spectrum

Statistics comparable to those obtained with the first generation of water Cerenkov detectors (Kamiokande and IMB)

<table>
<thead>
<tr>
<th>$\Delta m^2_{21}$ (eV$^2$)</th>
<th>2 kton$\times$year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No osci 5 x 10$^{-4}$</td>
</tr>
<tr>
<td>Muon-like</td>
<td></td>
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<tr>
<td>Contained</td>
<td>104 ± 10</td>
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<tr>
<td>Partially-Contained</td>
<td>82 ± 9</td>
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<tr>
<td>No proton</td>
<td>52 ± 7</td>
</tr>
<tr>
<td>One proton</td>
<td>52 ± 7</td>
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<tr>
<td>Multi-prong</td>
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<tr>
<td>$p_{\text{lepton}} &lt; 400$ MeV</td>
<td>74 ± 9</td>
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<tr>
<td>$p_{\text{lepton}} &gt; 400$ MeV</td>
<td>78 ± 9</td>
</tr>
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</table>

TOTAL: 614 ± 25
Difference in the rates of upward and downward going atm. neutrino events for a 2 Kton year exposure

<table>
<thead>
<tr>
<th></th>
<th>2 kton x year</th>
<th>$\Delta m^2_{23}$ (eV$^2$)</th>
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<tbody>
<tr>
<td></td>
<td>No osci</td>
<td>$5 \times 10^{-4}$</td>
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<tr>
<td><strong>Muon-like</strong></td>
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<tr>
<td>Downward</td>
<td>102 ± 10</td>
<td>102 ± 10</td>
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<tr>
<td>Upward</td>
<td>94 ± 10</td>
<td>46 ± 7</td>
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<tr>
<td><strong>Electron-like</strong></td>
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<tr>
<td>Downward</td>
<td>56 ± 7</td>
<td>56 ± 7</td>
</tr>
<tr>
<td>Upward</td>
<td>48 ± 7</td>
<td>48 ± 7</td>
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</table>

Table 1: Predicted downward ($\cos \theta_{\text{zenith}} > 0.2$) and upward ($\cos \theta_{\text{zenith}} < -0.2$) atmospheric neutrino rates in case no oscillations occur and assuming $\nu_\mu \rightarrow \nu_\tau$ oscillations take place with maximal mixing. Four different $\Delta m^2$ values have been considered. Only statistical errors are quoted. As a reference, we also show the total expected rates for both muon and electron-like events.

Quite evident deficit of upward going “muon like” events, for the range of osc. parameters allowed by SK measurements.
Atmospheric $\nu$ events

$\nu_\mu$ quasi-elastic interaction

$E_\nu = 370$ MeV
$P_\mu = 250$ MeV
$T_\mu = 90$ MeV

$\nu_e$ quasi-elastic interaction

$E_\nu = 450$ MeV
$P_e = 200$ MeV
$T_e = 240$ MeV

(simulated $\nu_\mu$ event)

(simulated $\nu_e$ event)
Cosmic ray event containing a hadronic interaction vertex providing an “Atmospheric neutrino”-like topology

Preliminary analysis

- Trk. 1 - m.i.p.
  - $E_{\text{dep}} = 31 \text{ MeV}$
  - $L_{\text{trk}} \sim 18 \text{ cm}$

- Trk. 2 - heavily i.p.
  - $E_{\text{dep}} = 191 \text{ MeV}$
  - $L_{\text{trk}} \sim 53 \text{ cm}$

- Trk. 3 - m.i.p.
  - $E_{\text{dep}} = 105 \text{ MeV}$
  - $L_{\text{trk}} \sim 60 \text{ cm}$

- Trk. 4 - heavily i.p.
  - $E_{\text{dep}} = 42 \text{ MeV}$
  - $L_{\text{trk}} \sim 16 \text{ cm}$

- Trk. 5 - m.i.p.
  - $E_{\text{dep}} = 111 \text{ MeV}$
  - $L_{\text{trk}} \sim 60 \text{ cm}$

10 m$^3$ test @ LNGS: Run 641 - Evt 14 (Apr. 14th, 2000)
3D reconstruction

10 m³ test @ LNGS: Run 641 - Evt 14 (Apr. 14th, 2000)

10 m³ active volume
Solar neutrino Physics with ICARUS T600

- Sensitive to $^8B$ component of the Solar $\nu$ Spectrum
- Two reactions can be exploited for Solar model independent studies

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Nuclear $K^*$ level Diagram

- Sensitive to $^8B$ component of the Solar $\nu$ Spectrum
- Two reactions can be exploited for Solar model independent studies

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Solar $\nu$ interaction on Argon:

$$\nu + \text{Ar} \rightarrow K^* + e$$

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$\nu$ Elastic Scattering on Atomic Electrons:

$$\nu_x + e \rightarrow \nu_x + e$$

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One primary e-track (above threshold) + M secondary e-tracks from Compton conversion of $K^*$ de-excitation gamma's

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One isolated e-track (above threshold) with high angular correlation to the Sun direction
(Relatively) High Statistics available and reduced background, depending on the actual energy threshold:

\[ T_{thr}(e) = 5 \text{ MeV} \]

(limited by background)

Event rates for an exposure of 1 Kton year

**Inputs:**
- BP98 ν Flux (\(^8\text{B}\))
- Ar nuclear shell model calculation and measures on mirror nucleus
- n meas. @ LNGS
- \(\gamma\) meas. @ LNGS

Sept. 10th 2001

<table>
<thead>
<tr>
<th>(T_{th}) (MeV)</th>
<th>Elastic</th>
<th>Fermi</th>
<th>Gamow-Teller</th>
<th>Photons (10^8)</th>
<th>Neutrons</th>
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Table 1: Calculated solar neutrino reactions for an exposure of 1 kton × year, as a function of the primary electron kinetic energy threshold \(T_{th}\). No oscillation hypothesis
Full MC simulation for determination of:

- Signal (ES, F and GT reactions) detection efficiency
- Background rejection power
- Sample contamination

<table>
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<tr>
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<th>ES Channel</th>
<th>Background</th>
<th>F+GT Contamination</th>
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<th>F+GT Channel</th>
<th>Background</th>
<th>ES Contamination</th>
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<td>1616</td>
<td>55</td>
<td>17</td>
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The off-line selection between elastic and absorption events is based on the energy of the main electron (primary track, above 5 MeV) and on the total associated energy and multiplicity of secondary tracks (Compton).
Real Event recorded with 50lt ICARUS Prototype

Lowpass filter cutoff = 0.00 MHz
Median filter is ON with length = 3

Read events: 4 - Written events: 0
Selection rate = 90 %

Run # 129 - Event # 195
26-Nov-1997 12:17:29
E = 200 V/cm - dt = 400 ns

5.6 MeV e-Track
(Gamma source)

End-point
A Montecarlo event (Absorption reaction)

E primary electron track = 6700 keV
Associated Compton energy = 2140 KeV
Multiplicity of secondary tracks = 3

Compton activity limited to volume of about 50 cm radius around the primary vertex
Assumed threshold for single Compton electron 150 KeV
Cosmic ray event containing a “Solar neutrino”-like signature

“inverse β reaction” type with:

- e-like track
  \(~6.5\text{ MeV}\)

- 2 e-like spots from Compton conversion

End-point

\(~800\text{KeV}\)

\(~800\text{KeV}\)

Preliminary analysis

T600 test @ Pv: Run 785 - Evt 4 (July 22nd, 2001)
Conclusions

• The ICARUS Technology is now fully operational at experimental scale (T600 detector has been tested on surface over 100 days)

• After many years of technological development, it may start acting as a new, high resolution, real-time “player” in the Solar and Atmospheric ν “games” (after installation in the GranSasso underground site)

• Detection of atmospheric ν_µ, ν_e (ν_τ) - CC+NC - interactions down to the production threshold

• Two solar-ν reactions in LAr are available, well separated in signature and available at rather large statistics for SSM model independent study

• Possibility of enlarging the LAr mass at GS are under evaluation

☞ to find more about the physics programme of the T600: LNGS-P28/2001 and LNGS-EXP 13/89 add. 1/01 (March 2001)
☞ to find more about ICARUS: www.aquila.infn.it/icarus or www.cern.ch/icarus