The ICARUS Project

FRONTIERS IN CONTEMPORARY PHYSICS II

Vanderbilt University, March 5-10, 2001

Sergio Navas (ETH Zürich)

✔ Detection Principle
✔ The T600 Module
✔ Physics Programme:
  • Atmospheric neutrinos
  • Solar and Supernova neutrinos
  • Long Baseline neutrinos
  • Proton decay searches
The performance of a neutrino detector is proportional to its total mass and also to its geometrical granularity with which the events can be reconstructed.
Neutrino and rare process physics with ICARUS

- Supernova neutrinos
- Solar neutrinos
- Atmospheric neutrinos
- Nucleon stability
- Long Baseline neutrinos
**Event imaging in liquid Argon**

The LAr TPC technique is based on the fact that ionization electrons can drift over large distances (meters) in a volume of purified liquid Argon under a strong electric field. If a proper readout system is realized (i.e. a set of fine pitch wire grids) it is possible to realize a massive "electronic bubble chamber", with superb 3-D imaging.

\[ E = 500 \text{ V/cm} \]

\[ I_0 = \frac{e(v^+ + v^-)}{d} \]

Electron-ion pairs are produced. Electrons give the main contribution to the induced current due to the much larger mobility.

A set of wires at the end of the drift give a sampling of the track. No charge multiplication occurs near the wires. Electrons can be used to induce signals on subsequent wires planes with different orientations \(\Rightarrow 3D \text{ imaging} \).
ICARUS: a graded strategy

✔ After several years of R&D and prototyping, the ICARUS collaboration is now realizing the first 600 ton module, which will be installed at Gran Sasso in the year 2001.

Lab activities:

Small-scale prototypes
(3 tons, 50 l)

→ "15 ton"

→ T600
  (2x300 ton)

Cooperation with specialized industries:

→ Air Liquide for Cryostat and Argon purification
→ BREME Tecnica for internal detector mechanics
→ CAEN for readout electronics

We are here!
ICARUS 15 ton (10m³) prototype (1999-2000)

A major step of the R&D program has been the construction and operation of a 10m³ prototype

1. Test of the cryostat technology
2. Test of the “variable-geometry” wire chamber
3. Test of the liquid phase purification system
4. Test of trigger via scintillation light
5. Large scale test of final readout electronics

→ First operation of a 15 ton LAr mass as an actual “detector”
Tracks in 15 ton prototype

10m³ Module at LNGS

Cosmic Ray tracks recorded during the 10 m³ operation
The ICARUS T600 module

Number of independent containers = 2
Single container Internal Dimensions: Length = 19.6 m, Width = 3.9 m, Height = 4.2 m
Total (cold) Internal Volume = 534 m³
Sensitive LAr mass = 476 ton

Number of wires chambers = 4
Readout planes / chamber = 3 at 0°, ±60° from horizontal
Maximum drift = 1.5 m
Operating field = 500 V / cm
Maximum drift time ≈ 1 ms
Wires pitch = 3 mm
Total number of channels = 58368

HV feedthroughs

Signal feedthroughs

External insulation layer (400 mm)

LN2 cooling circuit

2 independent aluminum containers each one transportable inside the GS Laboratory
First half-module delivery in Pavia (Feb 29, 2000)
Assembly of the T600 internal detector (Mar-Jul 2000)
Wire installation in T600 internal detector (Jul-Oct 2000)
T600 - Completed Internal Detector view

Wire Chamber Side A

Drift distance 1.5 m

Wire Chamber Side B
Slow control sensor (behind wire planes)

- Wires before tensioning
- Purity Monitors
- Position meter
- PMT
The three wire planes at $0^\circ, \pm 60^\circ$ (wire pitch = 3mm)

and one PMT
Readout electronic installation on top of dewar (Dec 2000-now)
Status of the T600 (first half module)

✔ Assembly of the internal detector mechanics finished.
✔ Wires positioning (3 planes) completed.
✔ Central cathode, auxiliary instrumentation, photomultipliers, sensors and signal cables installed and tested.
✔ Thermal insulation and cryogenic system proceeded in parallel.
✔ Electronics and DAQ system delivered.

Planning

Next steps:

1. Vacuum (~3 weeks)
2. Cooling (~3 weeks) + filling
3. LAr purification

obtain big track (~20 m long)

The ICARUS T600 detector has a physics program of its own, immediately relevant for neutrino oscillation physics: solar+SN neutrinos, atmospheric neutrinos

It should be installed in LNGS tunnel next year.
The ICARUS T600 detector

- has a **physics program** of its own, immediately relevant for neutrino oscillation physics: **solar+SN neutrinos, atmospheric neutrinos**

- Though with limited statistics, due its relatively small mass, compared to the standard for underground detectors set by the operating SuperKamiokande.

However, the T600 should also be considered as one more step towards larger detector masses.

- solving technical issues associated with actual operation of a large mass LAr device in an underground site (LNGS Tunnel).

- fully establish the imaging, PID, calorimetric energy reconstruction capabilities of REAL events, during steady detector operations

- In situ proof of actual physics performance of this novel detector technique, in particular measurement of backgrounds, extrapolable to larger mass detectors

Physics issues for both present and future LAr detectors:

- Atmospheric $\nu$
- Solar+SN $\nu$
- CNGS+Nufactory $\nu$
- $p$ decay
Two reactions can be measured independently:

\[ \nu_x + e^- \rightarrow \nu_x + e^- \]

- Elastic scattering on atomic electron
- \(\nu\) absorption on Argon nuclei

**Signature:**
- Primary electron track
- Absorption: surrounded by low energy secondary tracks (\(^{40}K^*\) de-excitation).

Prototype setup: electron track visible down to kinetic \(T = 150\) KeV

Electron track **threshold** = \(5\) MeV (needed to reduce background contribution and to establish the \(e^-\) direction in elastic scattering).

Sensitive to \(^8\)B component of the solar spectrum.
Elastic scattering $\nu$ event

$E_e = 5.6$ MeV

Electron track
Signal selection

- **Elastic events**: Angular distribution of the electron peaked in the solar ν direction.

- **Absorption events**: Electron track directions can be considered isotropically distributed.

For a 600 Ton detector
All cuts imposed

<table>
<thead>
<tr>
<th></th>
<th>Events/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elastic channel</td>
<td>212</td>
</tr>
<tr>
<td>Background</td>
<td>6</td>
</tr>
<tr>
<td>Absorption channels</td>
<td>759</td>
</tr>
<tr>
<td>Background</td>
<td>26</td>
</tr>
</tbody>
</table>

The off-line selection can be done in terms of the energy of the main electron and the correlation between multiplicity and energy of the associated tracks.
Absorption $\nu$ event

Typical Montecarlo Gamow -Teller digitised event

$E_{\text{main electron}} = 6700$ keV

Associated compton energy = 2140 keV

Multiplicity = 3
Solar neutrinos sensitivity

\[ R \equiv \frac{N^{ES}}{N^{ABS}} \frac{N^{ES}}{N^{ABS}} \]

ES = elastic scattering

\[ \nu_x + e^- \rightarrow \nu_x + e^- \]

ABS = absorption events

\[ \nu_e + ^{40}Ar \rightarrow ^{40}K^+ + e^- \]

Independent of the $^8B$ total $\nu$ flux predicted by solar models.

\[ \Delta R / R \approx 7\%(1\text{kt} \times \text{yr}), \ 5\%(2\text{kt} \times \text{yr}), \ 4\%(4\text{kt} \times \text{yr}) \]

Sergio Navas, ETH/Zürich, ICARUS Collaboration, 7/3/2001
ICARUS can detect neutrinos coming from stellar collapses in our Galaxy via the same two processes!

Supernova neutrino rates in 5 KTON ICARUS

<table>
<thead>
<tr>
<th>Process</th>
<th>600 ton</th>
<th>5 kton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elastic scattering</td>
<td>7</td>
<td>64</td>
</tr>
<tr>
<td>Absorption events</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fermi</td>
<td>14</td>
<td>120</td>
</tr>
<tr>
<td>GT</td>
<td>28</td>
<td>240</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>49</strong></td>
<td><strong>424</strong></td>
</tr>
</tbody>
</table>
The accumulated statistics will be modest. For a 2 kton x year exposure they will be comparable to first generation water Cerenkov detectors: Kamiokande, IMB

\[ 270 \nu_\mu + \bar{\nu}_\mu \text{ CC} \quad 150 \nu_e + \nu_e \text{ CC} \quad 190 \nu \text{ NC} \quad \Rightarrow 610 \text{ events in total} \]

Complicated final events with multi-pion products will be completely analyzed and reconstructed \( \Rightarrow \) \textbf{Zenith angle reconstruction significantly improved!}

Events can be fully reconstructed up to kinematics production threshold (50% of the total predicted rate has \( P_{\text{lepton}} < 400 \text{ MeV} \)) \( \Rightarrow \) \textbf{Fundamental contribution to the understanding of the low energy part of the atmospheric neutrino spectrum}
For a 2 kton x year exposure, we will measure a significant deficit of upward-going muon-like events.

<table>
<thead>
<tr>
<th></th>
<th>No osci</th>
<th>$5 \times 10^{-4}$</th>
<th>$1 \times 10^{-3}$</th>
<th>$3.5 \times 10^{-3}$</th>
<th>$5 \times 10^{-3}$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Muon-like</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Downward</td>
<td>102 ± 10</td>
<td>102 ± 10</td>
<td>102 ± 10</td>
<td>98 ± 10</td>
<td>95 ± 10</td>
</tr>
<tr>
<td>Upward</td>
<td>94 ± 10</td>
<td>46 ± 7</td>
<td>46 ± 7</td>
<td>47 ± 7</td>
<td>49 ± 7</td>
</tr>
<tr>
<td><strong>Electron-like</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Downward</td>
<td>56 ± 7</td>
<td>56 ± 7</td>
<td>56 ± 7</td>
<td>56 ± 7</td>
<td>56 ± 7</td>
</tr>
<tr>
<td>Upward</td>
<td>48 ± 7</td>
<td>48 ± 7</td>
<td>48 ± 7</td>
<td>48 ± 7</td>
<td>48 ± 7</td>
</tr>
</tbody>
</table>

$\nu_\mu \rightarrow \nu_\tau$ or $\nu_\mu \rightarrow \nu_s$ oscillations? The clean NC sample measured allows “indirect” $\nu_\tau$ appearance search.

\[
R_{NC/e} = \frac{NC^{data}}{MC^{NC}} \frac{\nu_e CC^{data}}{\nu_e CC^{MC}}
\]

Expected error on $R_{NC/e}$: **15% (22%)** for a **2 (1)** kton x year

**Uncertainty similar to the one obtained by Super-Kamiokande** (we are not dominated by systematic uncertainty on poorly known cross sections, e.g. single $\pi^0$ production)

Sergio Navas, ETHZürich, ICARUS Collaboration, 7/3/2001
Atmospheric CC events

(simulated $\nu_\mu$ event)

$\nu_\mu$ Q-el. interaction

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

(simulated $\nu_e$ event)

$\nu_e$ quasielastic interaction

$E_\nu = 450$ MeV
$P_e = 200$ MeV
$T_p = 240$ MeV
Two possible options:
A) $\approx 8 \times T600$
B) $4 \times T1400$ (better for physics)
### Atmospheric neutrinos

**Simulation based on FLUKA interaction and transport code, 3D representation of Earth and atmosphere, Geomagnetic effects included, All relevant physics taken into account: energy losses, polarized decays**

<table>
<thead>
<tr>
<th></th>
<th>(5 \text{kton} \times \text{year})</th>
<th>(\Delta m^2_{23} ) (eV(^2))</th>
<th>No osci</th>
<th>(5 \times 10^{-4})</th>
<th>(1 \times 10^{-3})</th>
<th>(3.5 \times 10^{-3})</th>
<th>(5 \times 10^{-3})</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Muon-like</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contained</td>
<td>418 ± 20</td>
<td>319 ± 18</td>
<td>307 ± 18</td>
<td>291 ± 17</td>
<td>282 ± 17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Partially-Contained</td>
<td>257 ± 16</td>
<td>196 ± 14</td>
<td>188 ± 14</td>
<td>179 ± 13</td>
<td>173 ± 13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No proton</td>
<td>260 ± 16</td>
<td>190 ± 14</td>
<td>185 ± 14</td>
<td>170 ± 13</td>
<td>165 ± 13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>One proton</td>
<td>205 ± 14</td>
<td>160 ± 13</td>
<td>150 ± 12</td>
<td>145 ± 12</td>
<td>140 ± 12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multi-prong</td>
<td>210 ± 14</td>
<td>165 ± 13</td>
<td>160 ± 13</td>
<td>155 ± 12</td>
<td>150 ± 12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(P_{\text{lepton}} &lt; 400 \text{ MeV})</td>
<td>285 ± 17</td>
<td>205 ± 14</td>
<td>200 ± 14</td>
<td>185 ± 14</td>
<td>175 ± 13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(P_{\text{lepton}} \geq 400 \text{ MeV})</td>
<td>390 ± 20</td>
<td>310 ± 18</td>
<td>295 ± 17</td>
<td>285 ± 17</td>
<td>280 ± 17</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Electron-like</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No proton</td>
<td>160 ± 13</td>
<td>160 ± 13</td>
<td>160 ± 13</td>
<td>160 ± 13</td>
<td>160 ± 13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>One proton</td>
<td>120 ± 11</td>
<td>120 ± 11</td>
<td>120 ± 11</td>
<td>120 ± 11</td>
<td>120 ± 11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multi-prong</td>
<td>100 ± 10</td>
<td>100 ± 10</td>
<td>100 ± 10</td>
<td>100 ± 10</td>
<td>100 ± 10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(P_{\text{lepton}} &lt; 400 \text{ MeV})</td>
<td>185 ± 14</td>
<td>185 ± 14</td>
<td>185 ± 14</td>
<td>185 ± 14</td>
<td>185 ± 14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(P_{\text{lepton}} \geq 400 \text{ MeV})</td>
<td>195 ± 14</td>
<td>195 ± 14</td>
<td>195 ± 14</td>
<td>195 ± 14</td>
<td>195 ± 14</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>NC</strong></td>
<td>480 ± 22</td>
<td>480 ± 22</td>
<td>480 ± 22</td>
<td>480 ± 22</td>
<td>480 ± 22</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1535 Events/year</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
$\nu_\mu$ disappearance: L/E distribution

$$P(\nu_\alpha \rightarrow \nu_\beta) = \sin^2 2\theta \sin^2 \left(1.27 \Delta m^2 \frac{L}{E}\right)$$

\[\Delta (L/E)_{RMS} \approx 30\%\]

Oscillation parameters:
- $\Delta m^2_{32} = 3.5 \times 10^{-3} \text{ eV}^2$
- $\sin^2 \Theta_{23} = 0.5$
- $\sin^2 2\Theta_{13} = 0.1$

Electron sample can be used as a reference for no oscillation case

- For $25 \text{ kt year}$
The expected \( \nu_e \) and \( \nu_\tau \) contamination of the CNGS beam are of the order of \( 10^{-2} \) and \( 10^{-7} \) respect to the dominant \( \nu_\mu \).

Primary protons: \( 400 \text{ GeV} \),
Pots per year: \( 4.5 \times 10^{19} \) pots

Planned beam commissioning: May 2005
CNGS events in 5 kton, 4 years running

\[ \theta_{23} = 45^\circ, \theta_{13} = 7^\circ \]

<table>
<thead>
<tr>
<th>( \nu_\mu ) CC</th>
<th>( \bar{\nu}_\mu ) CC</th>
<th>( \nu_e ) CC</th>
<th>( \bar{\nu}_e ) CC</th>
<th>( \nu ) NC</th>
<th>( \bar{\nu} ) NC</th>
</tr>
</thead>
<tbody>
<tr>
<td>54300</td>
<td>1090</td>
<td>437</td>
<td>29</td>
<td>17550</td>
<td>410</td>
</tr>
<tr>
<td>53820</td>
<td>1088</td>
<td>437</td>
<td>29</td>
<td></td>
<td></td>
</tr>
<tr>
<td>49330</td>
<td>1070</td>
<td>437</td>
<td>29</td>
<td></td>
<td></td>
</tr>
<tr>
<td>44910</td>
<td>1057</td>
<td>436</td>
<td>29</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \Delta m^2_{23} ) (eV^2)</td>
<td>( 1 \times 10^{-3} )</td>
<td>( 3.5 \times 10^{-3} )</td>
<td>( 5 \times 10^{-3} )</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Analysis of the electron sample
  - Exploit the small intrinsic \( \nu_e \) contamination of the beam (0.8% of \( \nu_\mu \) CC)
  - Exploit the good \( e/\pi^0 \) separation

Statistical excess visible before cuts \( \Rightarrow \) this is the main reason for performing this experiment at long baseline!
\( \nu_\mu \rightarrow \nu_\tau \) oscillations

\[ \nu_\tau + N \rightarrow \tau + \text{jet} \; ; \; \tau \rightarrow e + \nu \nu \nu 
\]

Charged current (CC)

(\( Br \approx 18\% \))

Background:

\[ \nu_e + N \rightarrow e + \text{jet} \]

Charged current (CC)

Reconstructed visible energy spectrum of electron events clearly evidences excess from oscillations into tau neutrino

\( \Delta m^2 = 3.5 \times 10^{-3} \text{ eV}^2 \)

ICARUS 4 years (after cuts)

<table>
<thead>
<tr>
<th>( \Delta m^2 (\text{eV}^2) )</th>
<th>( \nu_\tau ) CC</th>
<th>( \nu_e, \bar{\nu}_e ) CC</th>
<th>( \nu_\mu, \bar{\nu}_\mu ) CC</th>
<th>( \nu_\mu ) NC</th>
</tr>
</thead>
<tbody>
<tr>
<td>( 1 \times 10^{-3} )</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( 2 \times 10^{-3} )</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( 3 \times 10^{-3} )</td>
<td>26</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( 3.5 \times 10^{-3} )</td>
<td>35</td>
<td>4.1</td>
<td>1.0</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>( 5 \times 10^{-3} )</td>
<td>71</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( 7 \times 10^{-3} )</td>
<td>121</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( 1 \times 10^{-2} )</td>
<td>248</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

110 evts

470 \( \nu_e \) evts

\( \nu_e \) CC

Reconstructed energy

Sergio Navas, ETH/Zürich, ICARUS Collaboration, 7/3/2001

32
**ν_µ → ν_e oscillations : Search for θ_{13} ≠ 0**

\[ Δm^2_{32} = 3.5 \times 10^{-3} \text{ eV}^2; \sin^2 2θ_{23} = 1 \]

**ICARUS 4 years**

Cuts: Fiducial, \( E_e > 1 \text{ GeV}, E_{vis} < 20 \text{ GeV} \)

\[ Δm^2_{23} = 3.5 \times 10^{-3} \text{ eV}^2, \theta_{23} = 45° \]

<table>
<thead>
<tr>
<th>( θ_{13} ) (degrees)</th>
<th>( \sin^2 2θ_{13} )</th>
<th>( ν_e \text{ CC} )</th>
<th>( ν_µ \rightarrow ν_τ )</th>
<th>( τ \rightarrow e )</th>
<th>( ν_µ \rightarrow ν_e )</th>
<th>Total</th>
<th>Statistical significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>0.095</td>
<td>79</td>
<td>74</td>
<td>84</td>
<td>237</td>
<td>6.8σ</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0.076</td>
<td>79</td>
<td>75</td>
<td>67</td>
<td>221</td>
<td>5.4σ</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0.058</td>
<td>79</td>
<td>76</td>
<td>51</td>
<td>206</td>
<td>4.1σ</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.030</td>
<td>79</td>
<td>77</td>
<td>26</td>
<td>182</td>
<td>2.1σ</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.011</td>
<td>79</td>
<td>77</td>
<td>10</td>
<td>166</td>
<td>0.8σ</td>
<td></td>
</tr>
</tbody>
</table>

\[
P(ν_µ \rightarrow ν_τ) = \cos^4 θ_{13} \sin^2 2θ_{23} Δ^2_{32}\]

\[
P(ν_µ \rightarrow ν_e) = \sin^2 2θ_{13} \sin^2 θ_{23} Δ^2_{32}\]

Sergio Navas, ETH Zürich, ICARUS Collaboration, 7/3/2001
Sensitivity to $\theta_{13}$ in three family-mixing

- Sensitivity to $\nu_\mu \rightarrow \nu_e$ oscillations in presence of $\nu_\mu \rightarrow \nu_\tau$ (three family mixing)

- Factor 5 improvement on $\sin^2 2\theta_{13}$ at $\Delta m^2 = 3 \times 10^{-3}$ eV$^2$

- Almost two-orders of magnitude improvement over existing limit at high $\Delta m^2$
Nucleon decay search

\[ 5 \text{kTons detector} \rightarrow 3 \times 10^{33} \text{nucleons} \Rightarrow \tau_p (10^{32} \text{years}) > 6 \times T(\text{yr}) \times \varepsilon \quad @ \ 90 \text{ C.L.} \]

Thanks to excellent tracking and particle id capabilities

LAr unique tool

Extremely efficient background rejection
High detection efficiency
Bias-free, fully exclusive channel searches!

\[ p \rightarrow \bar{\nu} K^+ \text{ decay} \]

\[ n \rightarrow \nu K^0 \text{ decay} \]

\[ p \rightarrow e^+ \pi^0 \text{ decay} \]
\[ p \rightarrow e^+ \pi^0 \quad \text{and} \quad p \rightarrow K^+ \nabla \] decay kinematics

Exposure: 1000 kton x year

Nuclear effects: pion absorption and rescattering included (FLUKA)

<table>
<thead>
<tr>
<th>Exclusive Channel Cuts</th>
<th>( p \rightarrow e^+ \pi^0 )</th>
<th>( \nu_e ) CC</th>
<th>( \bar{\nu}_e ) CC</th>
<th>( \nu_\mu ) CC</th>
<th>( \bar{\nu}_\mu ) CC</th>
<th>( \nu_{NC} )</th>
<th>( \bar{\nu}_{NC} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>One ( \pi^0 )</td>
<td>54.00%</td>
<td>6610</td>
<td>2137</td>
<td>15264</td>
<td>5808</td>
<td>8089</td>
<td>3100</td>
</tr>
<tr>
<td>One electron</td>
<td>54.00%</td>
<td>6577</td>
<td>2127</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>No ( \pi^\pm ), No protons</td>
<td>51.50%</td>
<td>1234</td>
<td>668</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total Momentum &lt; 0.4 GeV</td>
<td>46.85%</td>
<td>461</td>
<td>128</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.93 GeV &lt; Total E &lt; 0.97 GeV</td>
<td>45.65%</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cuts</th>
<th>( p \rightarrow K^+ \bar{\nu} )</th>
<th>( \nu_e ) CC</th>
<th>( \bar{\nu}_e ) CC</th>
<th>( \nu_\mu ) CC</th>
<th>( \bar{\nu}_\mu ) CC</th>
<th>( \nu_{NC} )</th>
<th>( \bar{\nu}_{NC} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>One Kaon</td>
<td>97.30%</td>
<td>310</td>
<td>59</td>
<td>921</td>
<td>214</td>
<td>370</td>
<td>104</td>
</tr>
<tr>
<td>No ( \pi^0 )</td>
<td>97.15%</td>
<td>161</td>
<td>30</td>
<td>462</td>
<td>107</td>
<td>197</td>
<td>51</td>
</tr>
<tr>
<td>No electrons</td>
<td>97.15%</td>
<td>0</td>
<td>0</td>
<td>455</td>
<td>107</td>
<td>197</td>
<td>51</td>
</tr>
<tr>
<td>No muons</td>
<td>97.15%</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>197</td>
<td>51</td>
</tr>
<tr>
<td>No charged pions</td>
<td>97.15%</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>109</td>
<td>22</td>
</tr>
<tr>
<td>Total Energy &lt; 0.8 GeV</td>
<td>97.15%</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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</tr>
</tbody>
</table>

\[ \approx 45\% \pi^0 \text{ absorbed in Ar nucleus} \]

\[ \tau_p (p \rightarrow e^+ \pi^0) > 2.5 \times 10^{32} \text{ yrs} \]
\[ \tau_p (p \rightarrow K^+ \nabla) > 5 \times 10^{32} \text{ yrs} \]
Conclusions

★ The ICARUS T600, based on a novel technique, is now almost ready
★ Given the past record with previous prototypes, we are confident that also the T600 will come into operation smoothly…
  → We hope to present the first 20 m long tracks with 3 mm granularity soon!
  → It will demonstrate that the technique, even on such large scales, is now mature.
★ Operation inside the Gran Sasso tunnel in the course of next year (2002) should allow an appropriate scaling up for the increase of the mass
★ The technology, once it is scaled to the “right” size, will become a powerful tool in order to explore
  ✔ neutrino oscillations from both, accelerator and non-accelerator beams
  ✔ Solar and Supernova neutrinos
  ✔ and nucleon decay searches.