ICARUS Status and Plans

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For the ICARUS Collaboration

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The ICARUS Collaboration

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A multi-faceted programme

Our future physics oriented programme is characterized by:

1) Continued analysis of ≈3000 ν events already collected with CNGS2. A main result has been the major clarification of sterile neutrino search, now concentrated on a small possible window in $\Delta m^2_{41}$, compatible also with cosmological predictions for dark matter. More results are also coming.

2) T600 Overhaul + construction of smaller T150 detector “clone” under CERN approved experiment WA104 & recommendations of CTS

3) This new dual detector configuration will definitively clarify the sterile neutrino questions and on the same time ensure the bulk of the preparatory phase of the LNBE Coll., accumulating $> 10^6$ ν events in a short ν baseline for test and analysis purposes as a running premise to LBNE.

4) Possible long term use of T600 as “near detector” of LBNE.
ICARUS @ LNGS: the first LARGE LAr-TPC

- Two identical modules (2 chambers per module)
  - Liquid Ar active mass: \( \approx 476 \text{ t} \)
  - Drift length = 1.5 m (1 ms)
  - \( E_{\text{drift}} = 0.5 \text{ kV/cm}; \quad v_{\text{drift}} = 1.55 \text{ mm/\mu s} \)

- In operation since may 2010
- Decommissioning started on June 27th, cryo empty on July 25th (740 tons of LAr recovered).

- 3 readout wire planes/chamber, @ 0, ± 60°
  - ~54000 wires, 3m m pitch
  - 20+54 PMTs, 8” Ø, for scintillation light:
    - VUV light (128nm) with wave shifter (TPB)

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The ICARUS detector at LNGS Laboratory

- Exposed to CNGS $\nu$ beam up to December 3rd 2012, taking data also with Cosmics to study detector capability for atm.-$\nu$ and proton decay search up to June 2013 reaching a total exposure of 0.73 kt year.

- Total collected CNGS event statistics: $8.6 \times 10^{19}$ pot with remarkable detector live-time > 93 %

- $\tau_{\text{ele}} > 5\text{ms}$ (~60 ppt $[O_2]_{\text{eq}}$): maximum charge attenuation of 17% at 1.5m

- Different operating conditions successfully tested in the last months:
  - Larger drift electric field (1 kV/cm)
  - New pump for LAr purification allowing to exceed $\tau_{\text{ele}} > 7$ms

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T600 run at LNGS: first publications

4. “Precision measurement of the neutrino velocity with the ICARUS detector in the CNGS beam”, JHEP 11 (2012) 049.

- Analysis of the large amount of physics data becoming progressively the main activity of the collaboration
- Technical papers in preparation on cryogenic plant performance, trigger system, μ momentum reconstruction by Multiple Scattering
The situation of the short baseline neutrinos

- The possibility of short-baseline neutrino oscillations due to the existence of one or more sterile neutrinos at the eV scale is a hot topic in current neutrino physics.
- Sterile neutrino existence is not only very important “per se” but also for Astrophysics and Cosmology and its relation to Dark Mass.
- Recent results, including ICARUS, have considerably increased the evidence on the so far preferred 3+1 alternative for $\nu_e$ and $\nu_\mu$ appearance and disappearance in short-baseline experiments, given by the general formula

$$P \rightarrow 4|U_4|^2 \left(|U_4|^2 \sin^2 \left( \frac{m^2_{41} L}{4E} \right) \right)$$

- The ICARUS experiment has shown that the the MiniBooNE low-energy anomaly (for its 3 lowest energy bins) is incompatible with $\nu$ oscillations and probably due to other (instrumental) effects.
A search for LSND effects with ICARUS at CNGS

- The CNGS facility delivered an almost pure $\nu_\mu$ beam in $10$-$30$ GeV $E_\nu$ range (beam associated $\nu_e \sim 1\%$) at a distance $L=732$ km from target.

- There are differences w.r.t. LNSD exp.
  - $L/E_\nu \sim 1$ m/MeV at LSND, but $L/E_\nu \approx 36.5$ m/MeV at CNGS
  - LSND -like short distance oscill. signal averages to $\sin^2(1.27 \Delta m^2_{\text{new}} L / E) \sim 1/2$ and $<P>_{\nu_\mu \rightarrow \nu_e} \sim 1/2 \sin^2(2\theta_{\text{new}})$

- When compared to other long baseline results (MINOS and T2K) ICARUS operates in a $L/E_\nu$ region in which contributions from $\nu$ oscillations are not yet too relevant.

- Unique detection properties of LAr-TPC technique allow to identify unambiguously individual e-events with high efficiency.
**Search for $\nu_e$ events in CNGS beam**

- $\nu_e$ CC event candidates are visually selected with vertex inside fiducial volume (for shower id.): > 5 cm from TPC walls and 50 cm downstream.

- **Energy selection: <30 GeV**
  - 50% reduction on intrinsic beam $\nu_e$
  - only 15% signal events rejected

- $\nu_\mu$ CC events identified by $L > 250$ cm primary track without had. int.

- The “Electron signature” requires:
  - A charged track from primary vertex, m.i.p. on 8 wires, subsequently building up into a shower; very dense sampling: every $0.02 X_0$
  - Isolation (150 mrad) from other ionizing tracks near the vertex in at least one of the TPC views.

- Electron efficiency studied with events from a MC (FLUKA) reproducing in every detail the signals from wire planes: $\eta = 0.74 \pm 0.05$ ($\eta = 0.65 \pm 0.06$ for intrinsic $\nu_e$ beam due to its harder spectrum).
**e/γ separation and π^0 reconstruction in ICARUS**

- **MC**: single electrons (Compton)
- **MC**: \(e^+ e^-\) pairs (γ conversions)
- **data**: EM cascades (from π^0 decays)

\[ \theta = 28.0 \pm 2.5^\circ \]

\[ E_k = 685 \pm 25 \text{ MeV} \]

\[ E_k = 102 \pm 10 \text{ MeV} \]

\[ p_{\pi^0} = 912 \pm 26 \text{ MeV/c} \]

\[ m_{\pi^0} = 127 \pm 19 \text{ MeV/c}^2 \]

**Unique feature of LAr to distinguish e from γ and reconstruct π^0**

\( \Rightarrow \) Estimated bkg. from π^0 in NC and \(\nu_\mu\) CC: negligible (from MC and scanning)
The new ICARUS results

- Enlarged statistics wrt first publication: 1995 \( \nu \) interactions (6.0 \( 10^{19} \) pot over the full recorded sample of 8.6 \( 10^{19} \) pot), EPJ C73:2599
- Re-evaluation of the selection efficiency for beam \( \nu_e \)
- Four events found with a clear electron signature
- In all events the single electron shower is opposite to hadronic component in the transverse plane.
- The evolution of the actual \( \text{d}E/\text{d}x \) from a single track to an e.m. shower for the electron shower is shown along the individual wires.

- The expected number of e- events from intrinsic \( \nu_e \) beam, \( \theta_{13} \sim 90^\circ \) and \( \nu_\mu - \nu_\tau \) oscillations is then 6.4\( \pm 0.9 \) (syst. only).
The ICARUS results exclude the existence of the (otherwise questionable) low energy sterile neutrino peak presented by MiniBooNE both in the neutrino and antineutrino channels. This is also confirmed by OPERA.
ICARUS result strongly limits the window of parameters for a possible LSND anomaly to a very narrow region ($\Delta m^2 \approx 0.5 \text{ eV}^2$ and $\sin^2 2\theta \approx 0.005$) where there is an overall agreement (90% CL) of

- the present ICARUS limit
- the limits of KARMEN
- the positive signals of LSND and MiniBooNE
A new coherence of the global 3+1 fits

Giunti, Laveder et al., arXiv:1308.5288

- Global fits of \( \sin^2 \theta_{\mu e} \) (appearance) and of \( \sin^2 \theta_{\text{ee}} \) & \( \sin^2 \theta_{\mu \mu} \) (disappearance) with the corresponding common range values for \( \Delta m^2_{41} \). ICARUS result is relevant in excluding most of the area: a well defined common region, \( 0.82 < \Delta m^2_{41} < 2.19 \text{ eV}^2 \) within expectations of cosmological results.

- \( \Delta m^2_{41} \approx 6 \text{ eV}^2 \) region not allowed mainly because of old BNL-E776 data and cosmological exclusion. The crucial indication in favor of short-baseline is still given by the old LSND result: MINIBOONE experiment was inconclusive.

- ICARUS-NESSIE P347, now WA104 will be able to give a definitive answer to the sterile neutrino hypothesis.
Muon momentum by multiple scattering

- Excellent benchmark: horizontal $\mu$ from CNGS stopping in the T600
  - Calorimetric measurement is possible
  - The energy range (0.5-4.0 GeV) is perfectly matched to future short and long baseline experiments
  - Momentum measurement using the first 4 meters of $\mu$ track (130 stopping $\mu$s from $\nu_\mu CC$ in the upstream rock)

- Good resolution over the full muon momentum range
- Higher statistics and extension to full CNGS sample ongoing
NEW: Simultaneous 3D polygonal fit → 2D hit-to-hit associations no longer needed

Automation of reconstruction

- CNGS event primary vertex: automatic reconstruction
  - Validation with visually identified CNGS vertices
  - Algorithm efficiency ~ 97%
- Automatic event segmentation algorithm
  - Track identification
  - Shower identification
  - Ready in 2D, to be extended in 3D

**FIRST STAGE**, output from segmentation: clusters and vertices

Candidates for shower: high density of vertices

Just single hits -> neutron, noise

**SECOND STAGE**, Track clusters, after merging clusters from the segmentation stage:

Selected example in green

Deltas are excluded during the clusters merging.
A new experiment, capable to clarify all the ν anomalies at the appropriate > 5 sigma level is therefore highly desirable.

Such an experiment is based on two main, innovative concepts and a low energy ν and anti-ν beam.

- The first new concept is the comparison for spectral differences of two (or more) identical detectors located at two different distances. In the case of absence of “anomalies”, the two distributions will be a precise copy of each other, without any Monte Carlo comparison.

- The second new concept is the novel, now fully operational large mass Liquid LAr-TPC detectors developed by the ICARUS collaboration. The detector is a “bubble chamber like” sampling, homogeneous calorimeter with excellent accuracies and the total energy reconstruction of the event from charge integration.
Alternative 1: ICARUS at CERN

New CERN SPS 2 GeV neutrino facility in North Area

Far position: 1600 m
ICARUS-T600 detector + magnetic spectrometer

Near position: 410 m
150t LAr-TPC detector to be built + magnetic spectrometer
Alternative 2. LAr-TPC alternative at Fermilab

LAr1:1 kton fiducial volume Liquid Argon TPC is Far detector

MicroBooNE (60 t) is the Near detector

Considered a number of different locations to take advantage of Booster Neutrino Beam and NuMI beam
Basic features

- Our proposed experiment, collecting a large amount of data both with neutrino and antineutrino focusing and muon momentum determination may be able to give a likely definitive answer to the 4 following queries:
  - the LSND/+MiniBooNe both antineutrino and neutrino $\nu_\mu \rightarrow \nu_e$ oscillation anomalies;
  - The Gallex + Reactor oscillatory disappearance of the initial $\nu-e$ signal, both for neutrino and antineutrinos
  - an oscillatory disappearance maybe present in the $\nu-\mu$ signal, so far unknown.
  - Accurate comparison between neutrino and antineutrino related oscillatory anomalies, maybe due to CPT violation.

- In absence of these “anomalies”, the signals of the detectors should be a precise copy of each other for all experimental signatures and without any need of Monte Carlo comparisons.
Conclusions

• ICARUS has now successfully completed the CNGS-2 experiment
• ICARUS-NESSIE is now an approved experiment WA104.
• Both T600 and T150 will become operational with the vigorous CERN support.
• Our vigorously INFN driven programme will be continued, but in a closer International collaboration and as members of the LBNE team.
• We are receiving the consensus and an approval of the CTS.
• ICARUS is the only operational, physics production scale LAr detector and it shall be so for several years to come. We intend to:
  ➢ contribute to the definitive clarification of the “sterile neutrino” story, either at CERN or at FermiLab.
  ➢ collaborate with LBNE during the preparation phase and with a large amount of neutrino events at the appropriate energy
  ➢ our detector as a convenient “near detector” in the LBNE experimental phase.
• The useful lifetime of the ICARUS detector could then be extended to the two next decades to come!
Thank you!