

*ICARUS T600 experiment  
in the underground laboratory in Gran Sasso  
Reconstruction and analysis*

Izabela Kochanek  
on behalf of **ICARUS T600 Collaboration**

---

Institute of Physics, University of Silesia, Katowice  
Laboratori Nazionali del Gran Sasso, INFN, Italy

03 - 10 March 2012  
Rencontres de Moriond Electroweak Interactions and Unified Theories  
La Thuile, Aosta valley, Italy



# *ICARUS T600 Collaboration*

## **Italy**

M. Antonello, P. Aprili, N. Canci, C. Rubbia, E. Segreto, D. Stefan, R. Sulej, C. Vignoli  
**Laboratori Nazionali del Gran Sasso dell'INFN, Assergi**

B. Baibussinov, M. Baldo Ceolin, S. Centro, D. Dequal, C. Farnese, A. Fava, D. Gibin, A. Guglielmi, G. Meng, F. Pietropaolo, F. Varanini, S. Ventura  
**Dipartimento di Fisica e INFN, Universita di Padova, Padova**

P. Benetti, E. Calligarich, R. Dolfini, A. Gigli Berzolari, A. Menegolli, C. Montanari, A. Piazzoli, A. Rappoldi, G.L. Raselli, M. Rosella  
**Dipartamento di Fisica Nucleare e Teorica e INFN, Universita di Pavia, Pavia**

F. Carbonara, A.G. Cocco, G. Fiorillo

**Dipartimenti di Scienze Fisiche, INFN e Universita Federico II, Napoli**

A. Cesana, P. Sala, A. Scaramelli, M. Terrani

**INFN, Sezione di Milano e Politecnico, Milano**

G. Mannocchi, L. Periale, P. Picchi

**Laboratori Nazionali di Frascati (INFN), Frascati**

E. Sergiampietri

**Dipartimento di Fisica, Universita di Pisa, Pisa**

E. Scantamburlo

**Dipartamento di Fisica, Universita di L'Aquila**

## **Switzerland**

A. Ferrari

**CERN, Geneve**

## **Poland**

K. Cieslik, A. Dabrowska, M. Haranczyk, M. Szarska, A. Zalewska

**The Henryk Niewodniczanski Institute of Nuclear Physics, Polish Academy of Science, Krakow**

J. Holeczek, J. Kisiel, I. Kochanek, S. Mania

**Institute of Physics, University of Silesia, Katowice**

J. Lagoda, T. Palczewski, P. Przewlocki, J. Stepaniak, R. Sulej

**A. Soltan Institute for Nuclear Studies, Swierk/Otwock, Warszawa**

P. Plonski, K. Zaremba

**Institute for Radioelectronics, Warsaw University of Technology, Warsaw**

## **USA**

D.B. Cline, S. Otwinowski, H.-G. Wang, X. Yang

**Department of Physics and Astronomy, University of California, Los Angeles**

## **Russia**

A. Dermenev, S. Gninenko, A. Ivashkin, M. Kirsanov

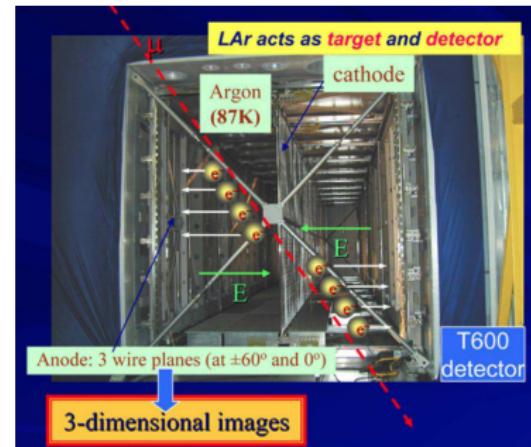
**INR RAS, Moscow**

## *Outline*

- The ICARUS T600 detector
- Physics perspectives
- Preliminary results from data taken during Run 2010/2011
- Summary

The **Liquid Argon Time Projection Chamber** (LAr-TPC), first proposed by C. Rubbia in 1977 [*C.Rubbia : CERN – EP/77 – 08(1977)*] - is a powerful detection technique that can provide a 3D imaging of any ionizing event.

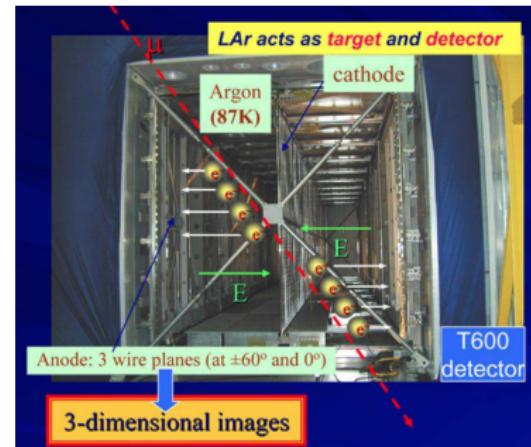
- Two identical T300 modules (2 TPC in each module)
- LAr active mass 476t:
  - $(17.9 \times 3.1 \times 1.5) m^3$  for each TPC
  - max drift length - 1.5m
  - $E_{drift} = 0.5 \text{ kV/cm}$ ,  $v_{drift} = 1.6 \text{ mm}/\mu\text{s}$
  - HV = -75kV
- 3 readout planes/chamber at 0,  $\pm 60$  deg, 3mm plane spacing
  - 53248 wires with length up to 9m, 3mm pitch
  - 2 induction planes, 1 collection
- PMT for scintillation light:
  - (20 + 54) PMT's, 8 " $\emptyset$ "
  - sensible to VUV scintillation light ( $\lambda = 128 \text{ nm}$ ) by applying a wavelength shifter layer (TPB - tetraphenyl-butadiene)



Electrons from ionizing track are drifted in LAr by uniform electric field. They traverse the transparent wire arrays oriented in different directions where induction signals are recorded. Finally electron charge is collected by the third wire plane.

The **Liquid Argon Time Projection Chamber** (LAr-TPC), first proposed by C. Rubbia in 1977 [*C.Rubbia : CERN – EP/77 – 08(1977)*] - is a powerful detection technique that can provide a 3D imaging of any ionizing event.

- Two identical T300 modules (2 TPC in each module)
- LAr active mass 476t:
  - $(17.9 \times 3.1 \times 1.5) m^3$  for each TPC
  - max drift length - 1.5m
  - $E_{drift} = 0.5 \text{ kV/cm}$ ,  $v_{drift} = 1.6 \text{ mm}/\mu\text{s}$
  - HV = -75kV
- 3 readout planes/chamber at 0,  $\pm 60$  deg, 3mm plane spacing
  - 53248 wires with length up to 9m, 3mm pitch
  - 2 induction planes, 1 collection
- PMT for scintillation light:
  - (20 + 54) PMT's, 8 " $\emptyset$ "
  - sensible to VUV scintillation light ( $\lambda = 128 \text{ nm}$ ) by applying a wavelength shifter layer (TPB - tetraphenyl-butadiene)



Electrons from ionizing track are drifted in LAr by uniform electric field. They traverse the transparent wire arrays oriented in different directions where induction signals are recorded. Finally electron charge is collected by the third wire plane.

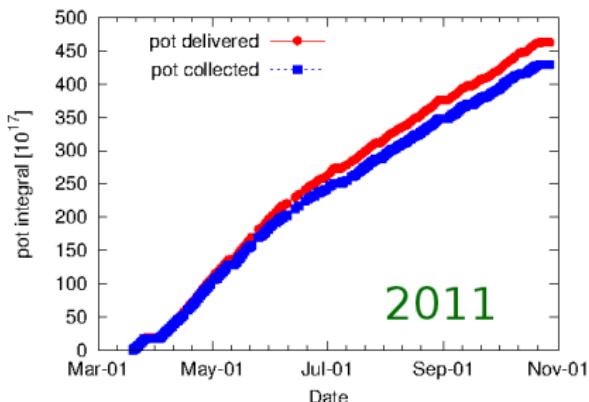
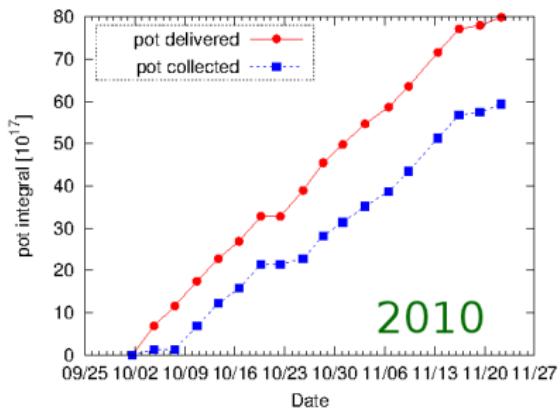
$\tau_{ele} [\text{ms}] = 0.3/N [\text{ppb O}_2 \text{ equivalent}]$   
currently:  $\tau_{ele} \sim 6 [\text{ms}]$ :  $\sim 50 \text{ ppt}$

## *ICARUS T600 physics potential*

- The detector is collecting "bubble chamber like" CNGS neutrino events (beam intensity  $4.5 \times 10^{19}$  pot/year,  $E_\nu \sim 17.4\text{GeV}$ ):
  - 1300  $\nu_\mu$  CC events/year,
  - $\sim 400$  events/year - NC event rate,
  - muons from the rock  $\sim 5500$  events/year,
  - intrinsic beam  $\nu_e$  CC  $\sim 12$  events/year,
  - observation of  $\nu_\tau$  events in the electron channel, using kinematic criteria,
  - search for sterile neutrinos within LSND parameter space, with e-like  $\nu_e$  CC events excess at  $E > 10\text{GeV}$ .
- ICARUS T600: **major milestone** towards the realization of large scale LAr TPC detector.
- The unique imaging capability of ICARUS, its spatial/calorimetric resolutions and  $e/\pi^0$  separation allow "to see" events in a new way.

## CNGS neutrino run in 2010-2011

	2010	2011
time of operation	October - November	March - November
pot deliv (coll)	$8 \times 10^{18}$ ( $5.8 \times 10^{18}$ )	$47.8 \times 10^{18}$ ( $44.4 \times 10^{18}$ )
detector lifetime	up to 90%	93%



2010 data kept as a training/control sample. Physics analysis going on 2011 data.

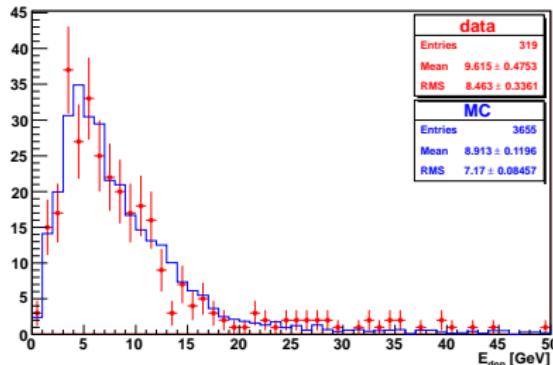
Progress on reconstruction/analysis software shown with examples and distributions obtained with 2010 neutrino data.

# CNGS neutrino run in 2010-2011

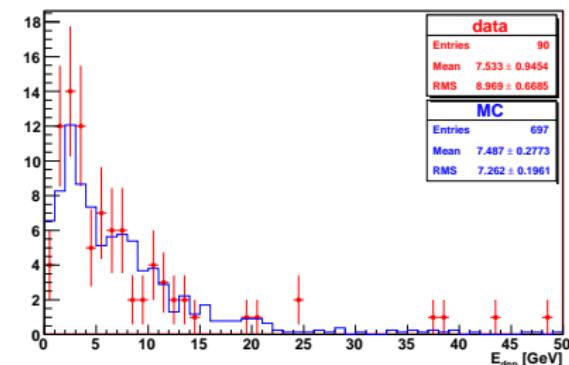
Event Type	2010		2011	
	Collected	Expected	Collected	Expected
$\nu_\mu$ CC	114	129	247	273
$\nu_\mu$ NC	46	42	71	90
$\nu_e$ CC	1	1	-	-
$\nu X C^*$	7	-	37	-
<b>Total</b>	<b>167</b>	<b>171</b>	<b>355</b>	<b>363</b>

- ★ Events at edges, with  $\mu$  track too short to be visually recognized: further analysis needed.

CNGS CC 2010/2011



CNGS NC 2010/2011

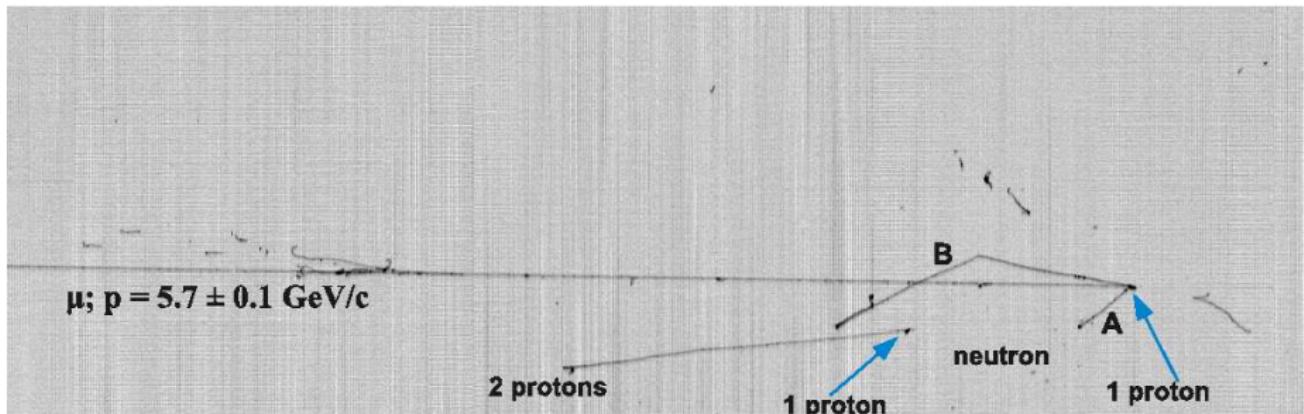


## CNGS CC $\nu_\mu$ interaction

$$E_{deptot} = 3.23 \pm 0.54 \text{ GeV}$$

- ➊  $p_T = 78 \text{ MeV/c}$   
 $P_{tot} = 7 \text{ GeV/c}$
- ➋  $p_T = 154 \text{ MeV/c}$   
 $P_{tot} = 6.5 \text{ GeV/c}$

TRACK	E [MeV]	p [MeV/c]	range [cm]
A ( $\pi$ )	$62 \pm 5$	$145 \pm 7$	18
A ( $\pi$ )	$337 \pm 32$	$455 \pm 32$	18
B ( $\pi$ )	$429 \pm 36$	$550 \pm 38$	92

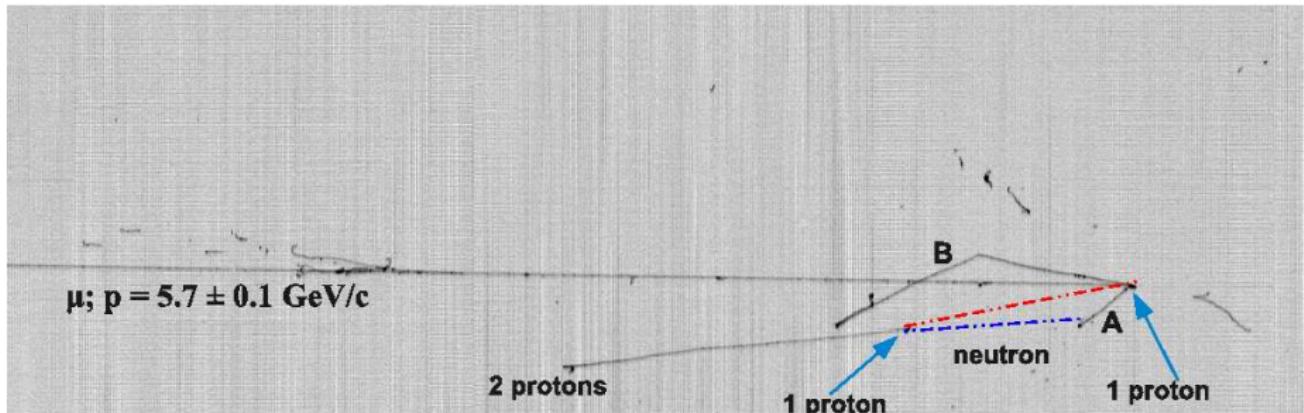


## CNGS CC $\nu_\mu$ interaction

$$E_{deptot} = 3.23 \pm 0.54 \text{ GeV}$$

- 1  $p_T = 78 \text{ MeV/c}$   
 $P_{tot} = 7 \text{ GeV/c}$
- 2  $p_T = 154 \text{ MeV/c}$   
 $P_{tot} = 6.5 \text{ GeV/c}$

TRACK	E [MeV]	p [MeV/c]	range [cm]
A ( $\pi$ )	$62 \pm 5$	$145 \pm 7$	18
A ( $\pi$ )	$337 \pm 32$	$455 \pm 32$	18
B ( $\pi$ )	$429 \pm 36$	$550 \pm 38$	92



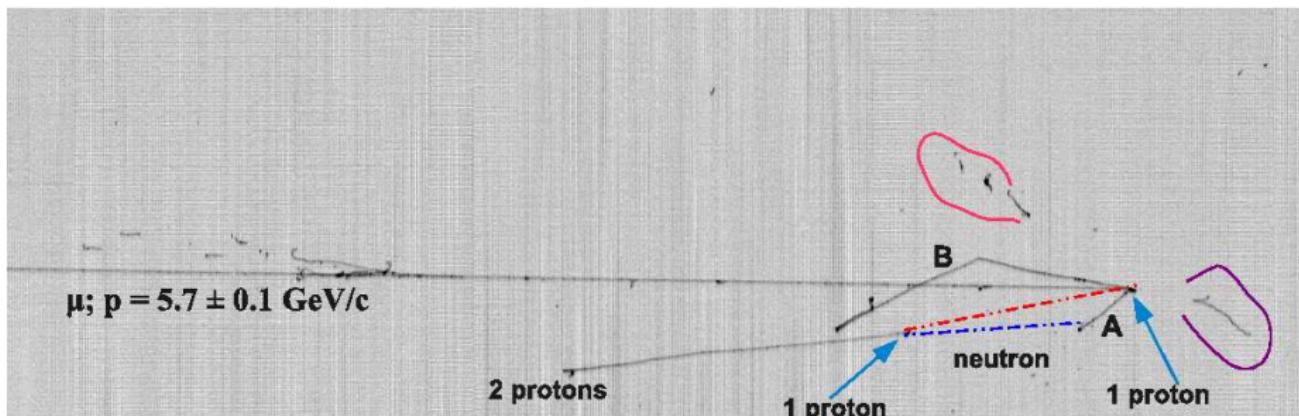
## CNGS CC $\nu_\mu$ interaction

$$E_{deptot} = 3.23 \pm 0.54 \text{ GeV}$$

①  $p_T = 78 \text{ MeV/c}$   
 $P_{tot} = 7 \text{ GeV/c}$

②  $p_T = 154 \text{ MeV/c}$   
 $P_{tot} = 6.5 \text{ GeV/c}$

TRACK	E [MeV]	p [MeV/c]	range [cm]
A ( $\pi$ )	$62 \pm 5$	$145 \pm 7$	18
A ( $\pi$ )	$337 \pm 32$	$455 \pm 32$	18
B ( $\pi$ )	$429 \pm 36$	$550 \pm 38$	92



$dE/dx$  for the first part of the cascades:  $1.99 \text{ MeV/cm}$ ,  $2.1 \text{ MeV/cm}$ .  
Conversion distances:  $14.6 \text{ cm}$ ,  $61.4 \text{ cm}$ .

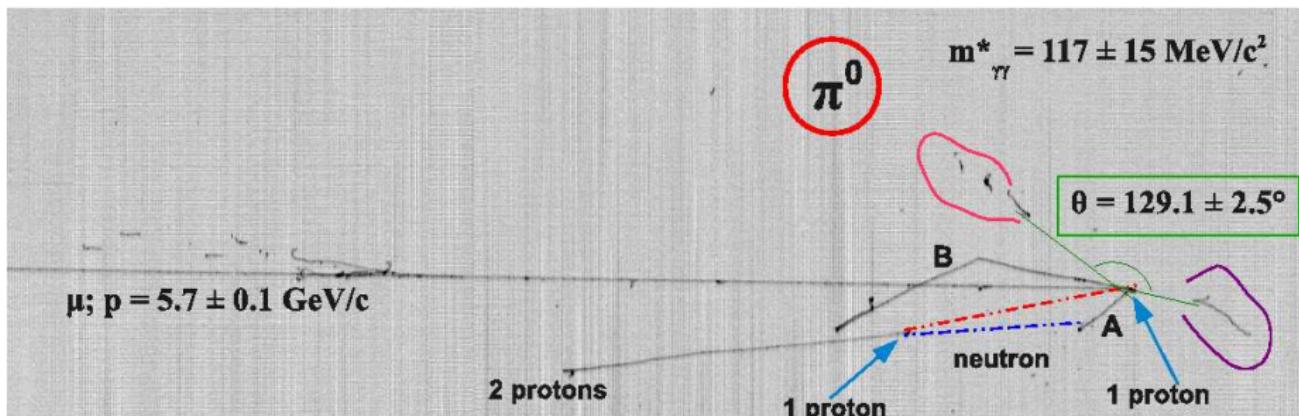
## CNGS CC $\nu_\mu$ interaction

$$E_{depton} = 3.23 \pm 0.54 \text{ GeV}$$

①  $p_T = 78 \text{ MeV/c}$   
 $P_{tot} = 7 \text{ GeV/c}$

②  $p_T = 154 \text{ MeV/c}$   
 $P_{tot} = 6.5 \text{ GeV/c}$

TRACK	E [MeV]	p [MeV/c]	range [cm]
A ( $\pi$ )	$62 \pm 5$	$145 \pm 7$	18
A ( $\pi$ )	$337 \pm 32$	$455 \pm 32$	18
B ( $\pi$ )	$429 \pm 36$	$550 \pm 38$	92



$dE/dx$  for the first part of the cascades:  $1.99 \text{ MeV/cm}, 2.1 \text{ MeV/cm}$ .  
 Conversion distances:  $14.6 \text{ cm}, 61.4 \text{ cm}$ .

## Summary

- ICARUS T600 @ LNGS is taking data with CNGS beam since May 2010.
- The successful assembly and operation of the LAr-TPC is the experimental proof that this technique is well-suited for large scale experiments.  
The ICARUS experiment at the Gran Sasso Laboratory is so far the major milestone towards the realization of a much more massive LAr detector.
- The unique imaging capability of ICARUS, its spatial/calorimetric resolutions, allow to reconstruct and identify events in a new way with regard to previous/current experiments.
- The 2011-2012 run with CNGS  $\nu_\mu$  beam will allow to possibly detect  $\nu_\tau$  appearance events. Interesting physics perspectives also for atmospheric, sterile neutrino and proton decay.