- Neutrino meetings are always exciting and this one is no exception…
  – Superb data, impressive Physics results mainly from Super-Kamiokande, K2K, SNO, Kamland
- Looking back to the talks I realized neutrinos are (obviously) the big stars of this meeting… but not the only ones…


Large Format PMT Lineup
8 inch
10 inch
13 inch
20 inch
HAMAMATSU


Are there any other new detector ideas in there?
Living in the Dark Side

L

I

BENASQUE

E X E L O U N X

A C W T L I D P

U I E U D E E

T T R T R R

I I N I A G I

F N A O R R M

U G T N G O E

L I O U N

V N N T

& E D S

A. Bueno University of Granada

Terrestrial and Cosmic Neutrinos, leptogenesis and Cosmology

Benasque

2004, July 4 -- July 23

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)

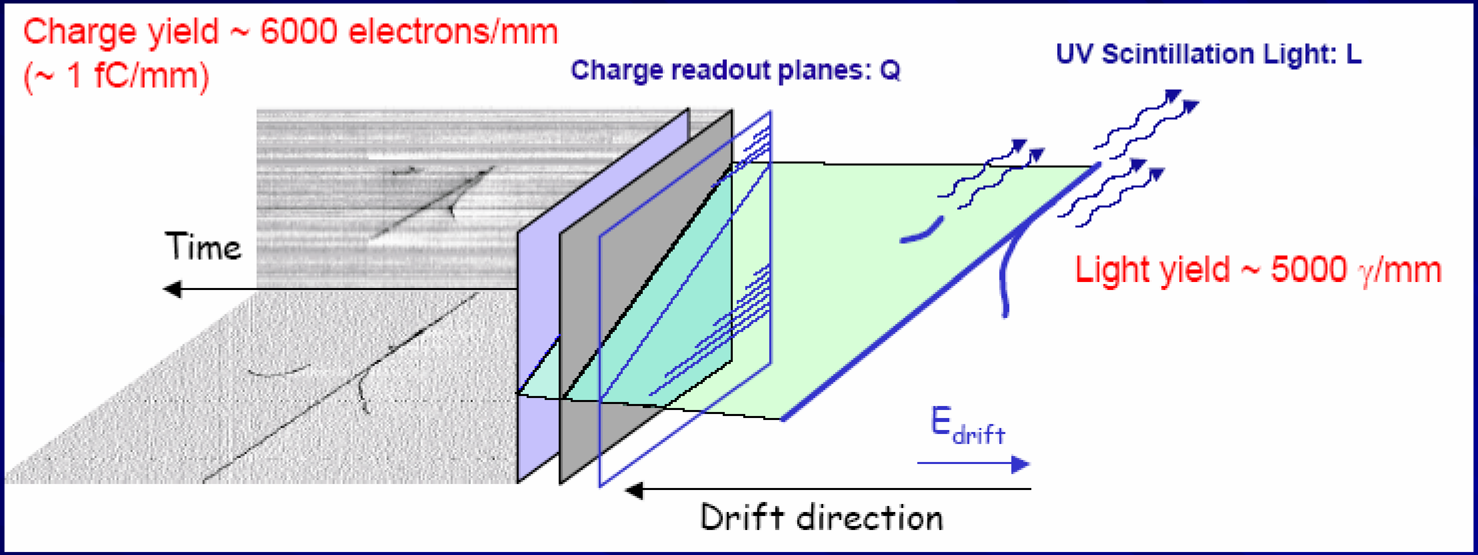
Summary of LAr TPC Studies

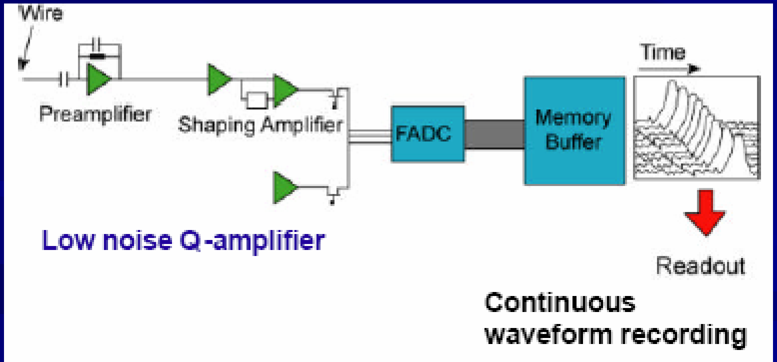
LAr TPC story…

• L.W.Alvarez (late 60'):	noble liquids for position sensitive detectors
• T.Doke (late 60'):	systematic studies of noble liquids properties
• W.J.Willis & V.Radeka (70'):	large calorimeters for HEP experiments
• C.Rubbia (1977):	LAr TPC conceived and proposed
• E.Aprile, C.Giboni, C.Rubbia (1985):	high purity → long drift distances
• ICARUS Coll. (1993-1994):	3 ton LAr TPC prototype
• ICARUS Coll. (1998):	Neutrino detection at CERN with a 50 l LAr TPC
• ICARUS Coll. (2001):	cosmic-ray test of the 300 ton industrial module
• ICARUS Coll. (2003-2004):	detector/physics papers from the T300 test
• ICARUS Coll. (2004-2005):	T600 installation and commissioning at LNGS

- … **Discussion on possible LAr TPCs follow-ups**

The LAr TPC Working Principle



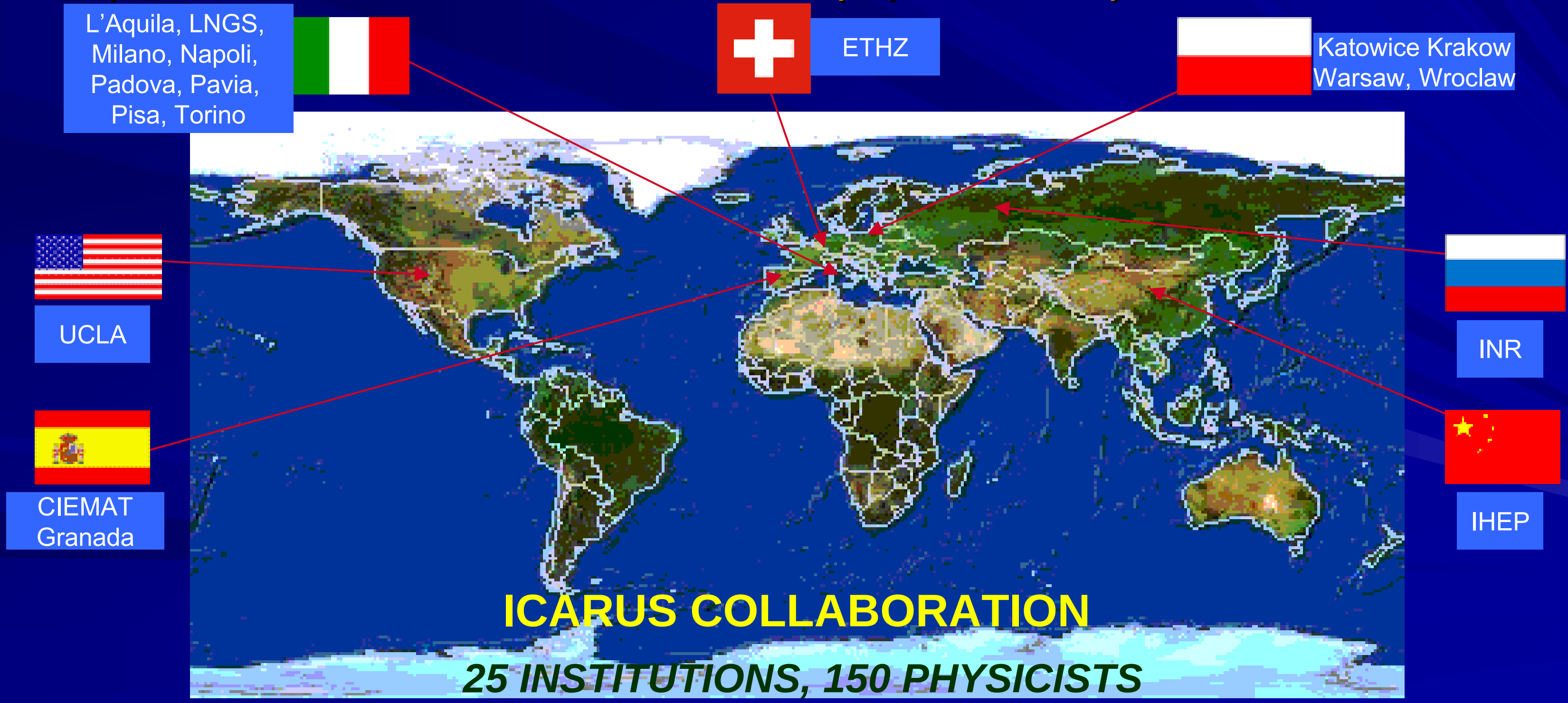


- Continuously sensitive
- Self-triggering
- t0 provided by scintillation light

The ICARUS Collaboration

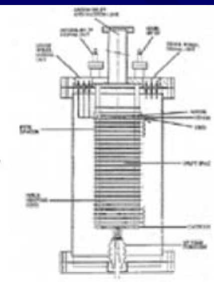
- Research project jointly approved by INFN and CERN
  - CERN/SPSC 2002-027 (SPSC-P-323) LNGS-EXP 13/89

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



The path to massive liquid argon detectors

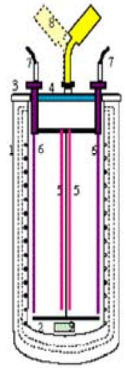
Originally proposed by C. Rubbia (CERN-EP/77-08)



24 cm drift wires chamber

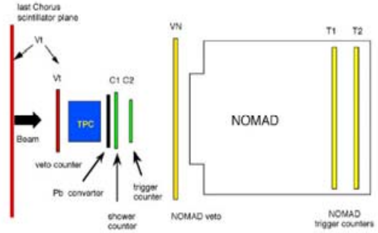
1987: First LAr TPC. Proof of principle. Measurements of TPC performances.

3 ton prototype



1991-1995: First demonstration of the LAr TPC on large masses. Measurement of the TPC performances. TMG doping.

Lab activities:



50 litres prototype
1.4 m drift chamber

1997-1999: Neutrino beam events measurements. Readout electronics optimization. MLPB development and study 1.4 m drift test.

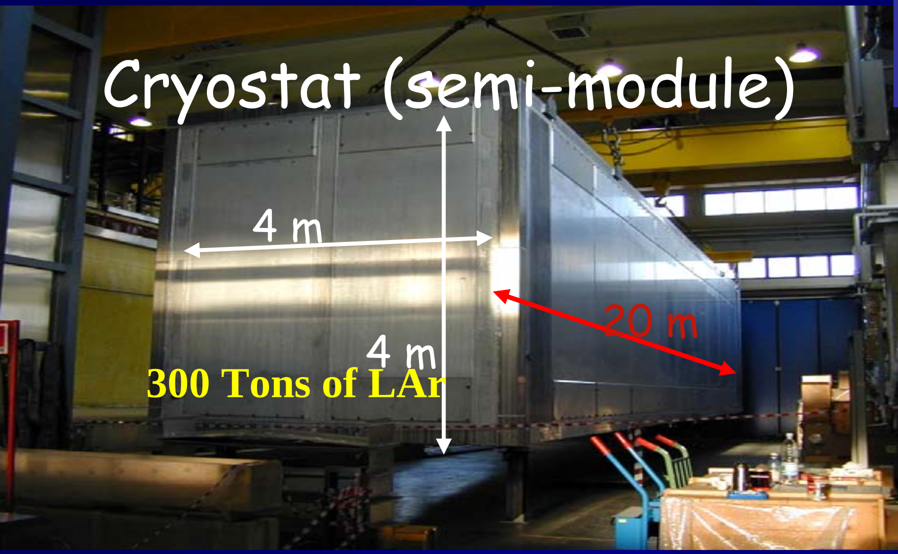
10 m^3 industrial prototype

1999-2000: Test of final industrial solutions for the wire chamber mechanics and readout electronics.

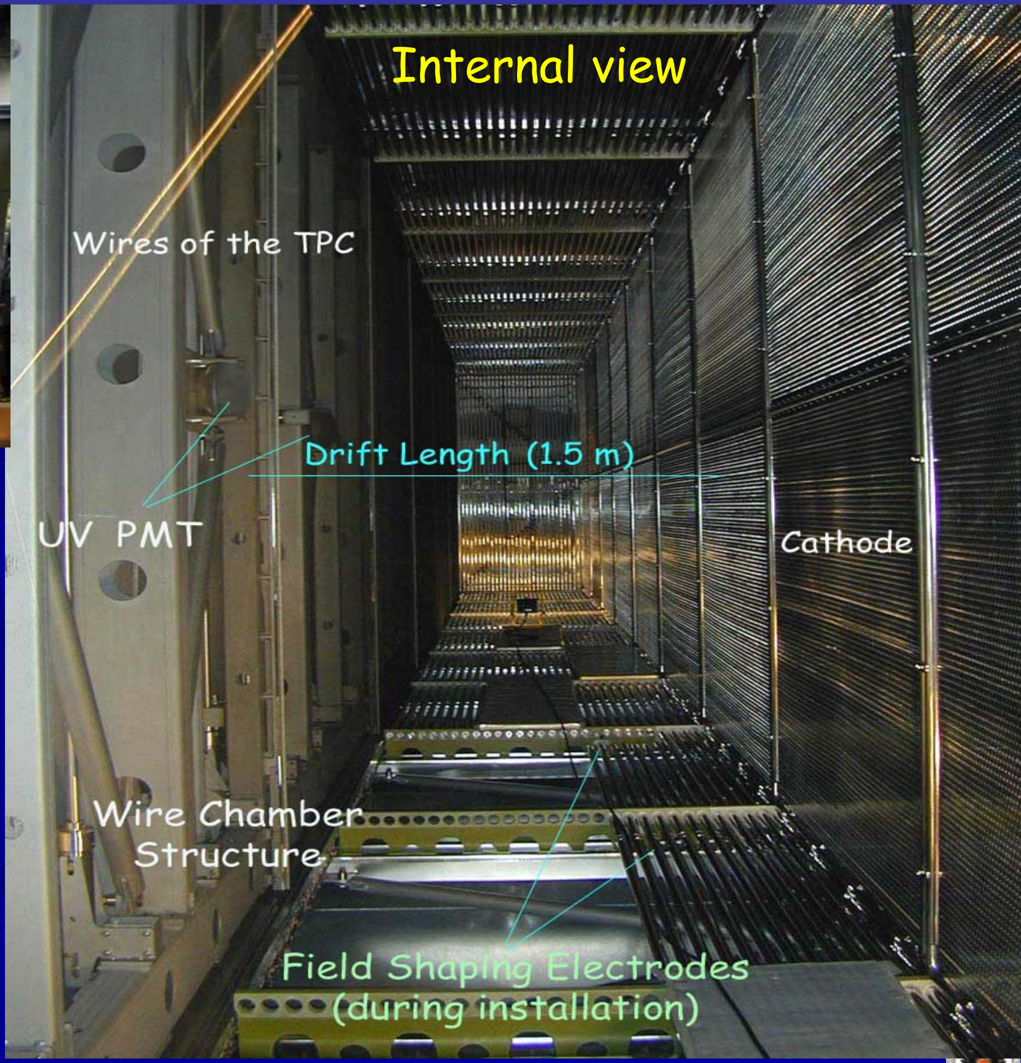
T600 detector

Cooperation with specialized industries:

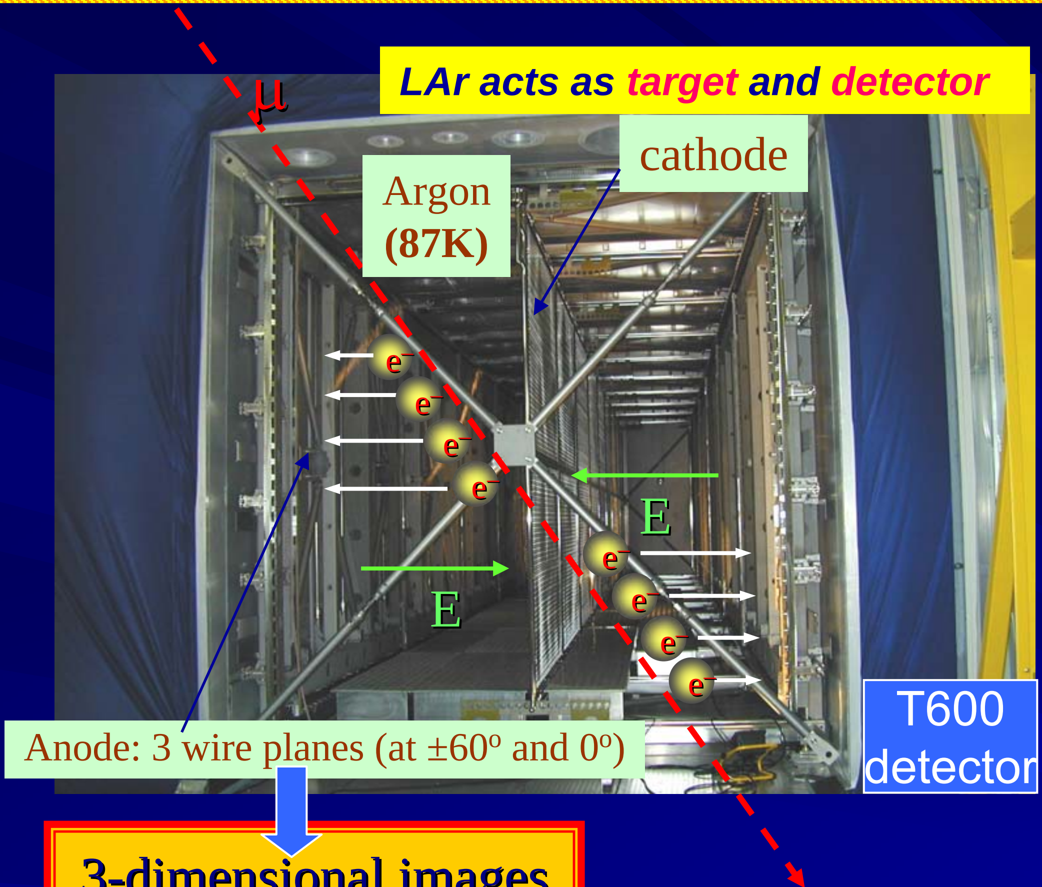
The T600 Detector



ICARUS T300

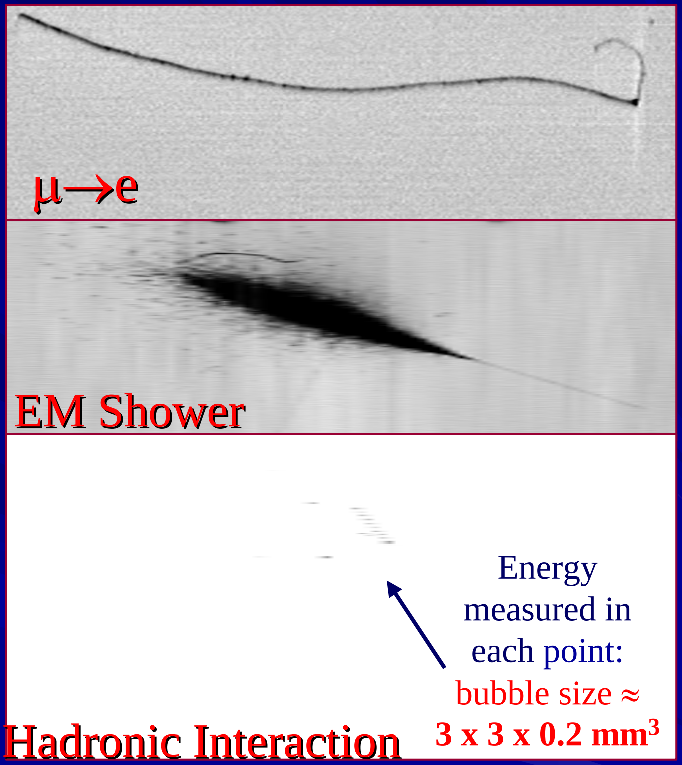


Electronic Bubble Chamber

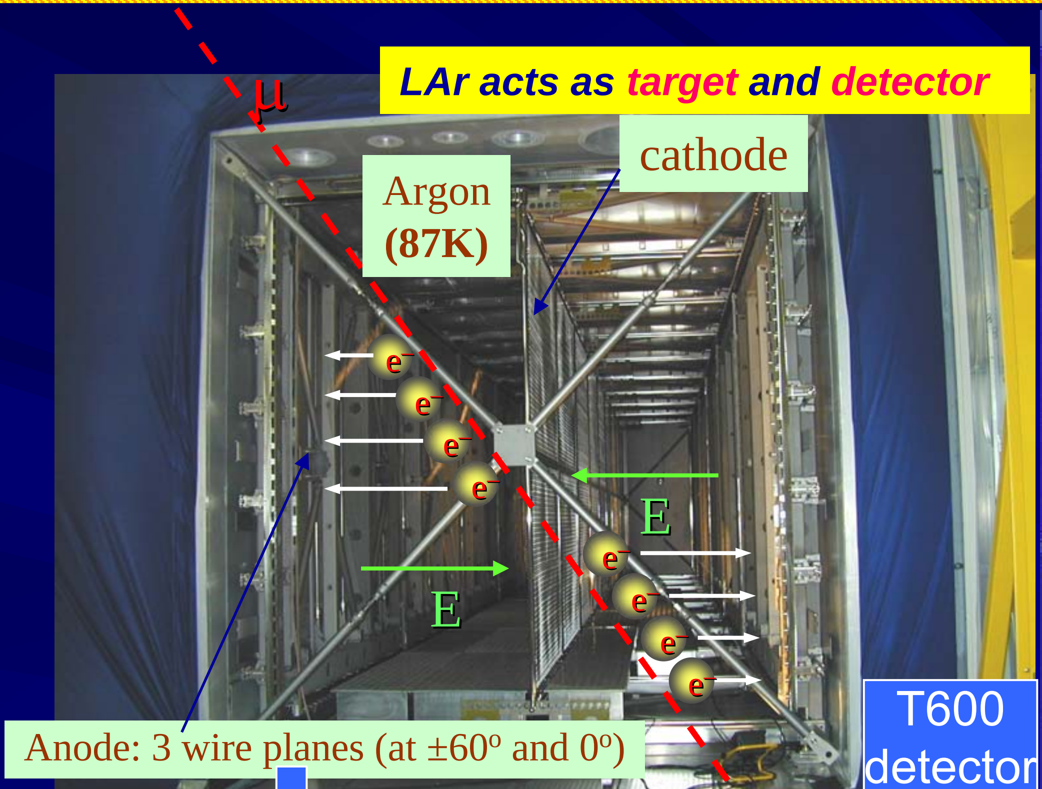


3-dimensional images

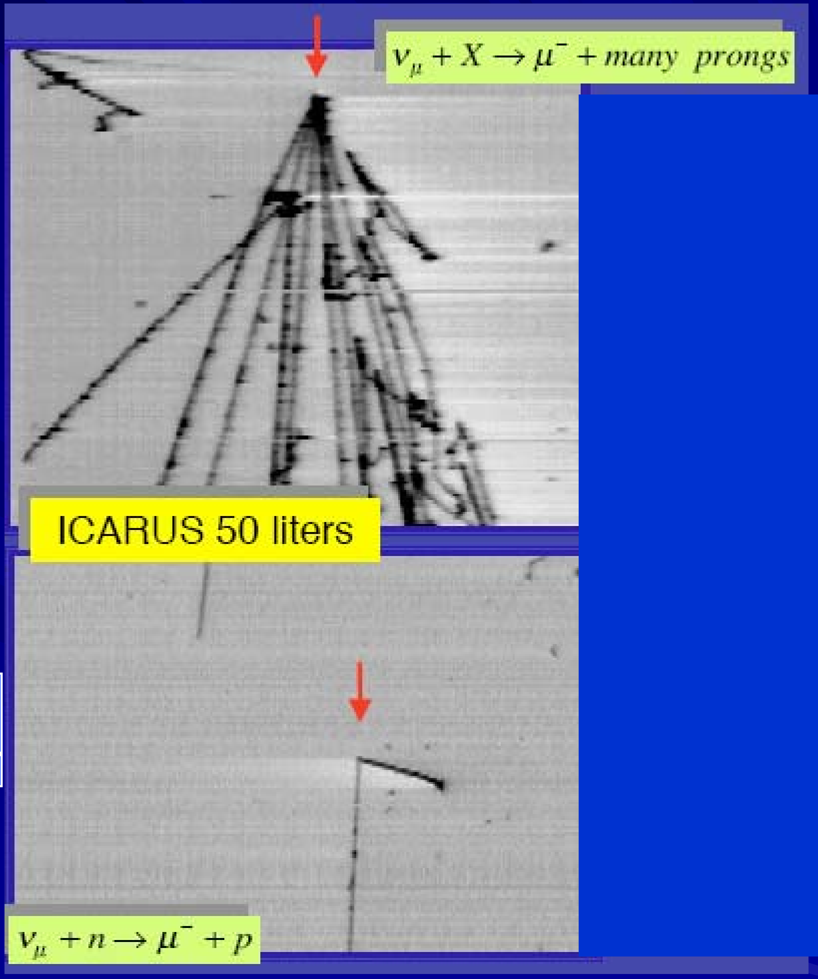
Real Events



Electronic Bubble Chamber



3-dimensional images



After many years of R&D at lab scale…

The road for construction of very massive detectors at industrial level is now open!

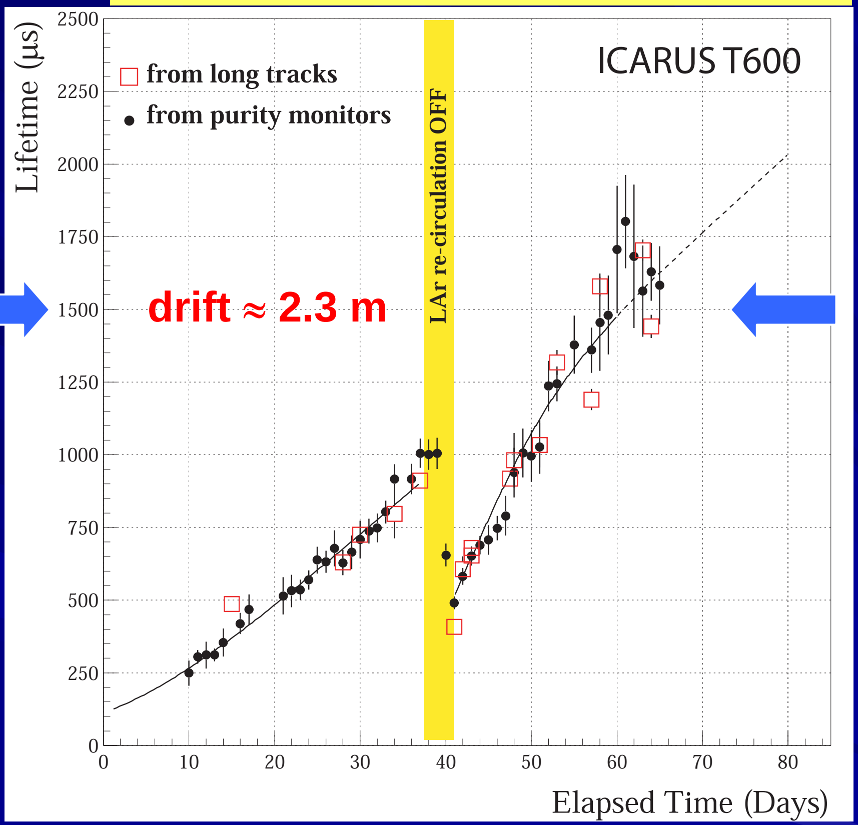
T600 Detector: Cosmic Ray Data

- 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

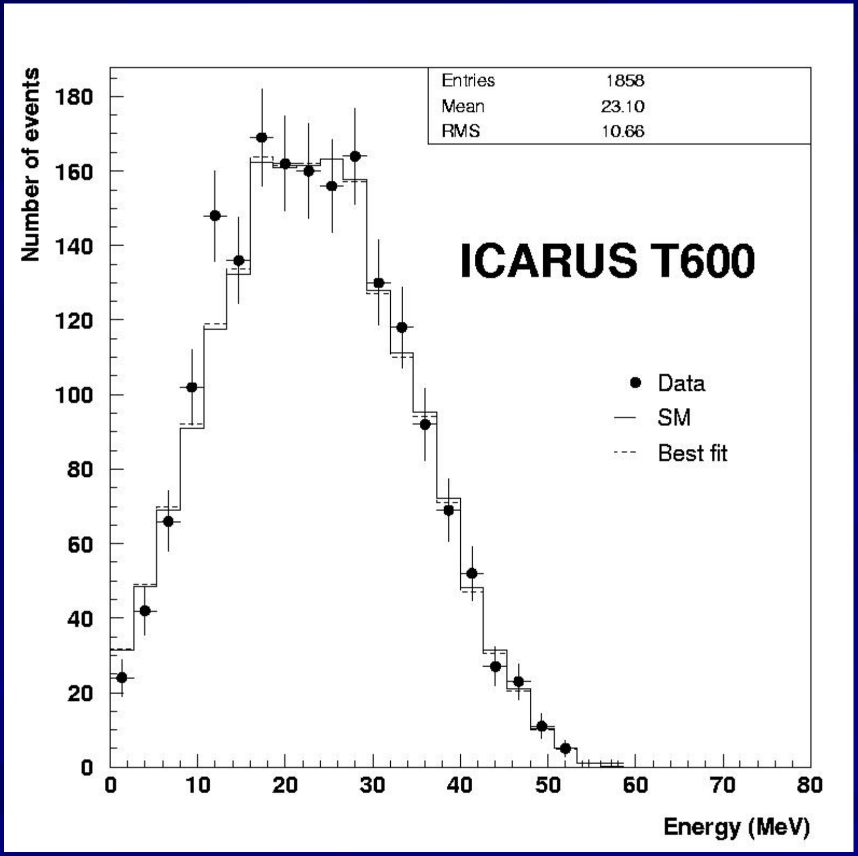
- Long drift distances demand ultra pure Argon
  - Impurities: 0.1 ppb Oxygen-equivalent
- Two independent and complementary methods to measure the LAr purity:
  - **Purity Monitors** : *on-line* information on a fixed position of the chamber (*punctual* measurement).
  - **Muon tracks**: *off-line*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

V_{drift}= 1.56 mm / μs @ 0.5 kV/cm



Liquid Argon is a <u>mature</u> 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

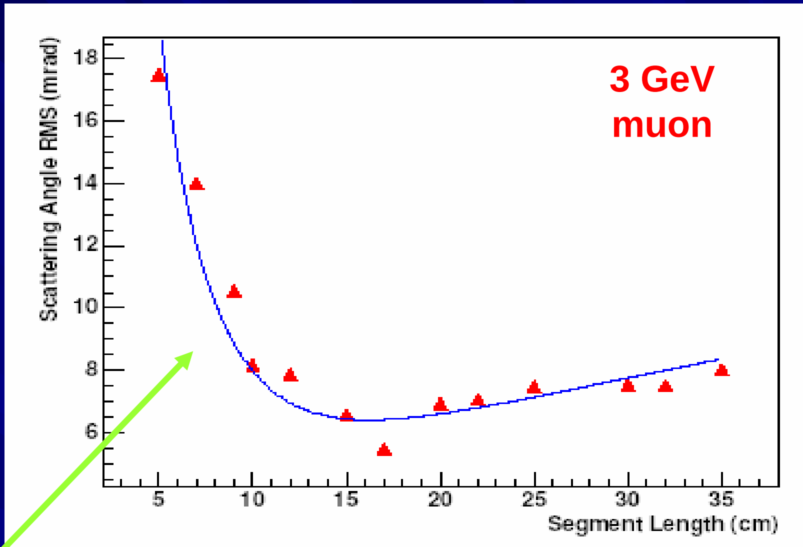
$$\frac{\sigma(E)}{E} = \frac{11\,\%}{\sqrt{E}} \oplus 2\%$$

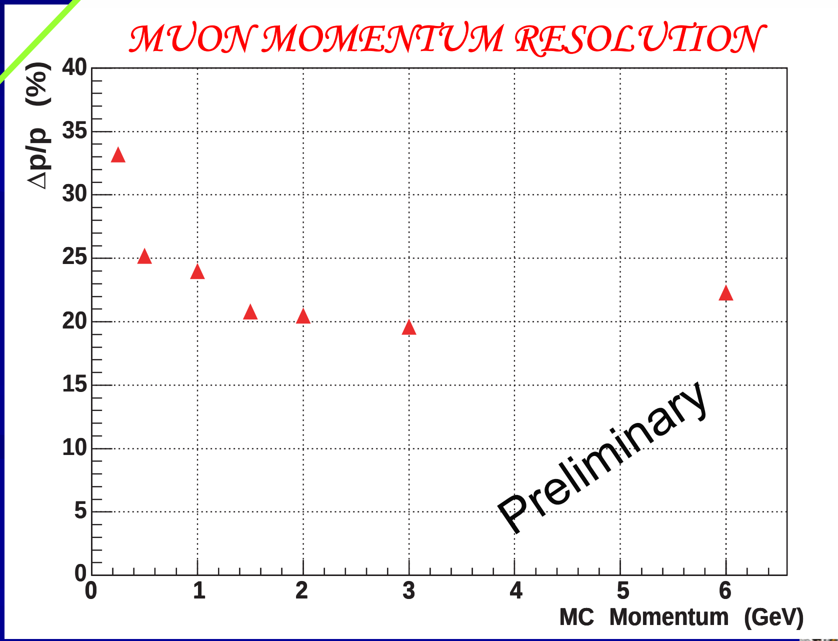
Momentum measurement: Multiple Scattering

- 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:

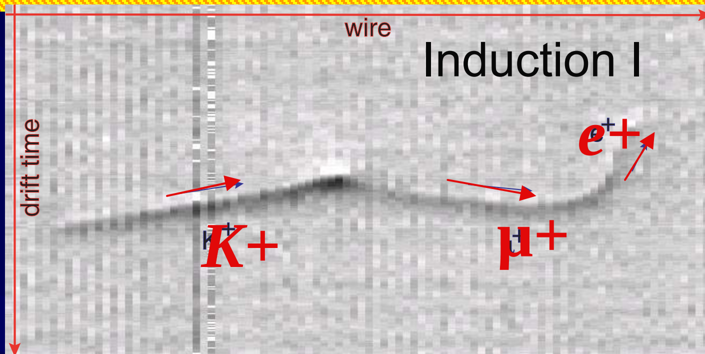
$$\left(\vartheta_{meas}^{RMS}\right)^2 = \left(\vartheta_0^{RMS}\right)^2 + \left(\vartheta_{noise}^{RMS}\right)^2; \quad \vartheta_0^{RMS} \propto \sqrt{L_{seg}} / p; \quad \vartheta_{noise}^{RMS} \propto L_{seg}^{-3/2}$$

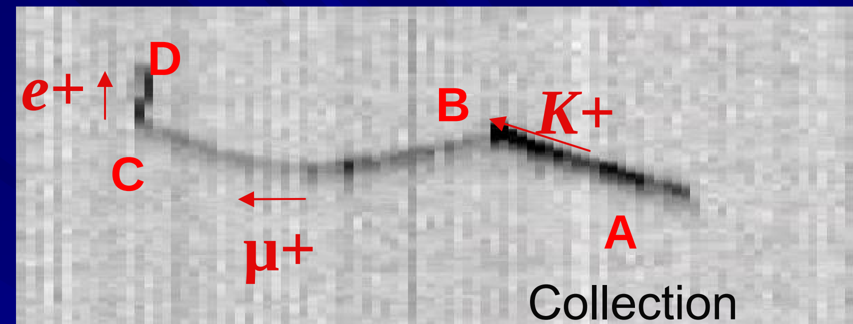
- Momentum extracted from fit over a sample of different segment lengths
- Resolutions ≈20-25%
- Future analysis…
  - Resolution improvement with alternative methods (e.g. Kalman Filter)?
  - Validate conclusions with real data: large sample of stopping muons



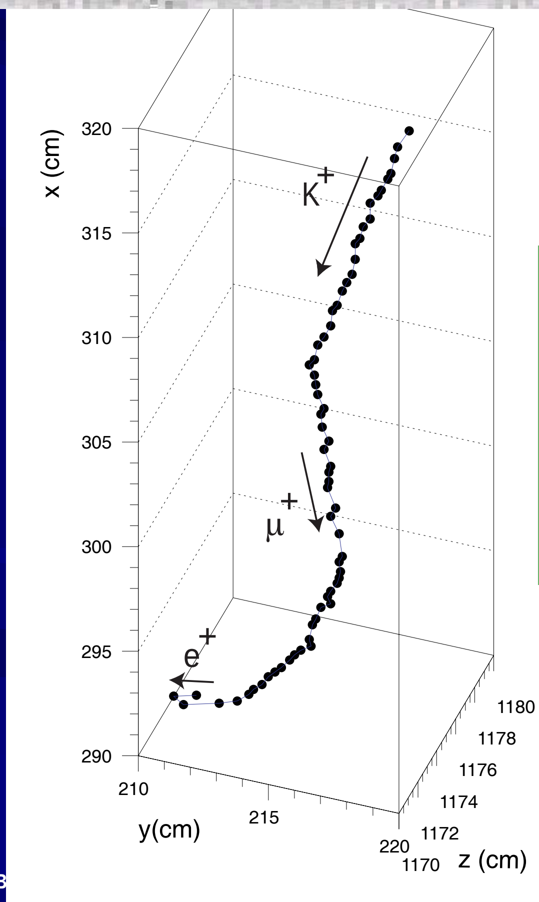


Particle Identification

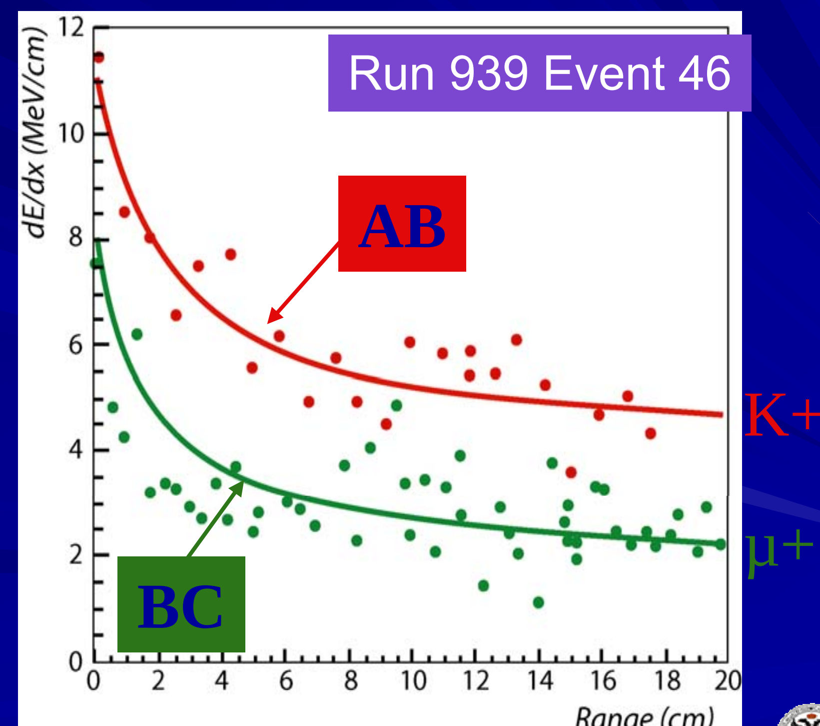




$$K^{+}[AB] \rightarrow \mu^{+}[BC] \rightarrow e^{+}[CD]$$

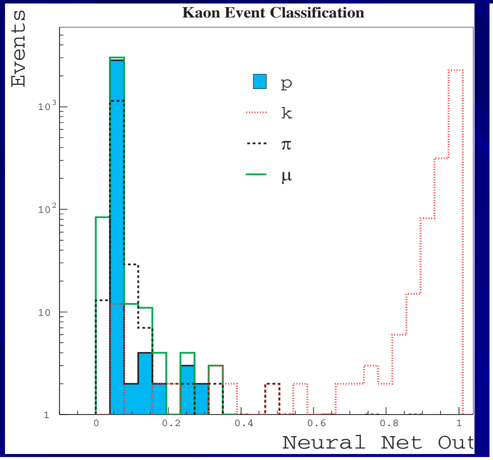


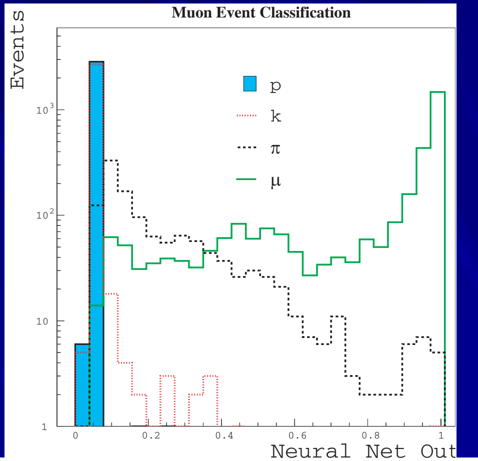
3D reconstruction allows to compute **dE/dx** and **range**

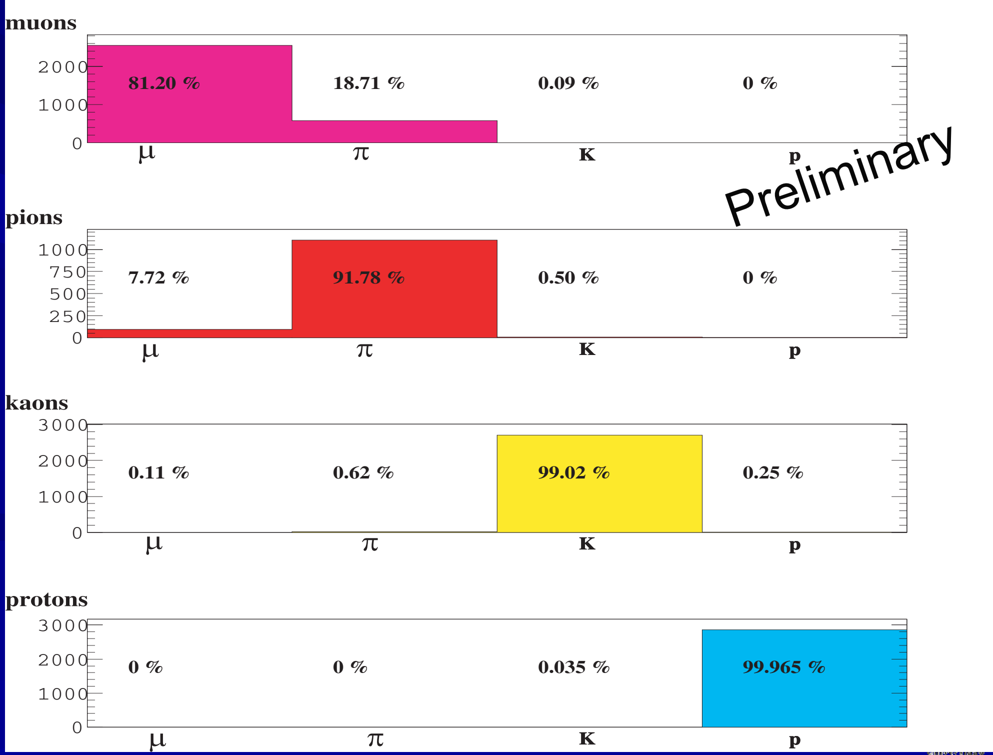


Particle Identification

- 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
  - <u>Key issues</u>:
    - 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
  - First approach to the T3000 project

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 in its “dry” version

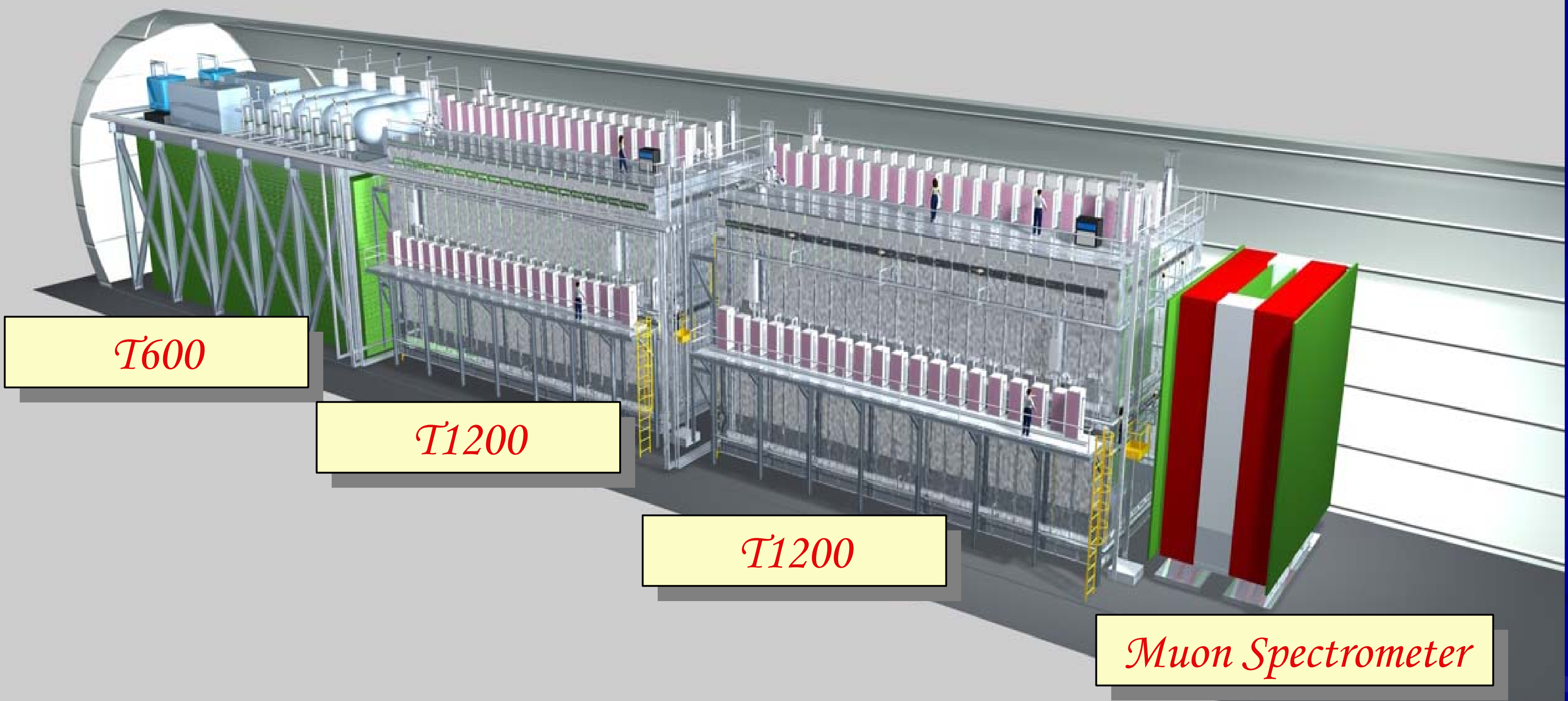
Future LAr TPC Detectors

Detector	Drift Distance (m)	Mass (Ktons)	Magnetic Field
ICARUS T600	**1.5** **(demonstration that distances up to 3 m are feasible)**	0.6	NO
ICARUS T3000	**3**	3	NO
100 tons	**3**	0.1	??
LANNDD	**4-8**	50-100	Eventually, yes
GLACIER	**20** **(operation in bi-phase mode)**	100	Eventually, yes

We're here

ICARUS T3000 + Muon Spectrometer

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



LNGS-EXP 13/89 Add. 3/03

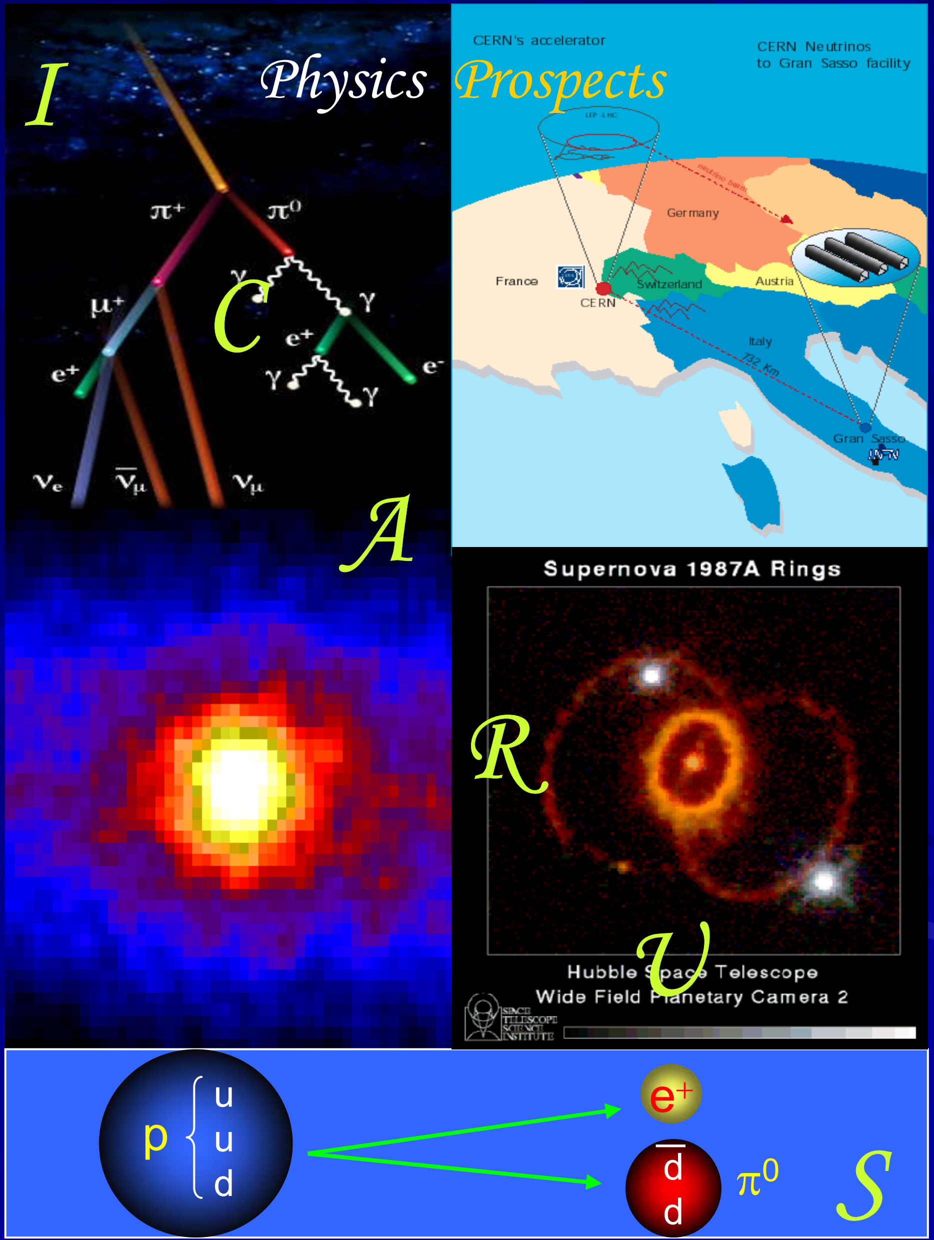
CERN/SPSC 2003-030

SPSC-P-323-Add. 1

Construction strategy:
"Cloning" the successfully operated T600 module

A Rich Physics Programme

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



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: 1.5 < Δm^2 < 3.4 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
$\tau \rightarrow e$	3.7	9	13	23	0.7
$\tau \rightarrow \rho$ DIS	0.6	1.5	2.2	3.9	< 0.1
$\tau \rightarrow \rho$ 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

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

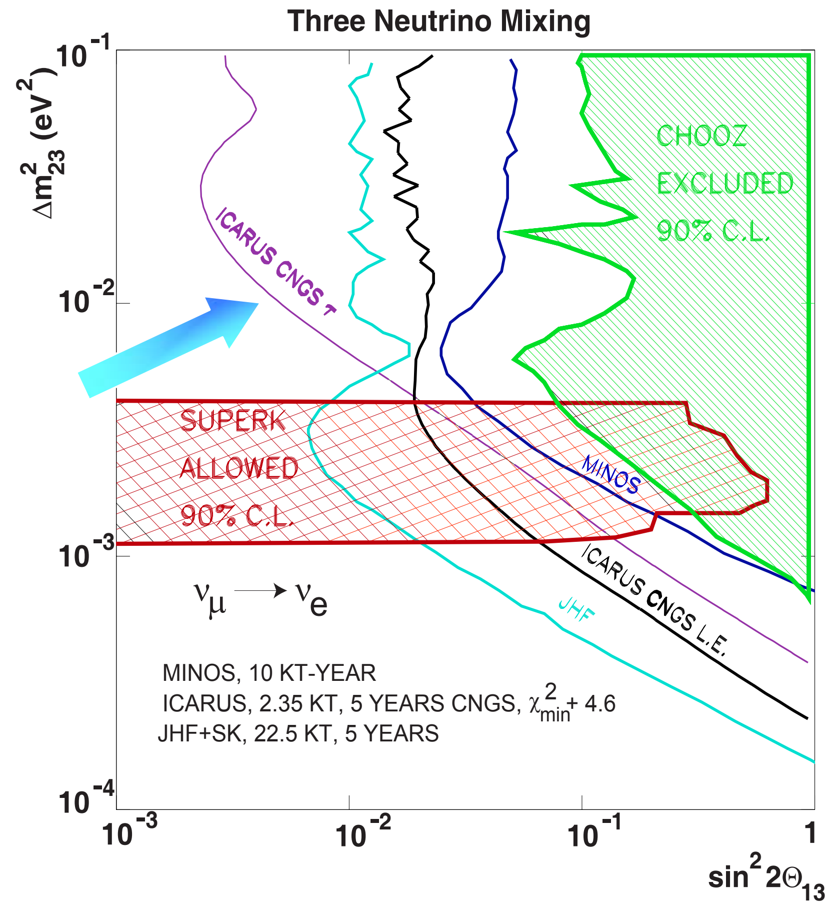
- Natural ν_e contamination 1%
- Limited by CNGS statistics

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

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

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

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



Electron-π^0 Rejection

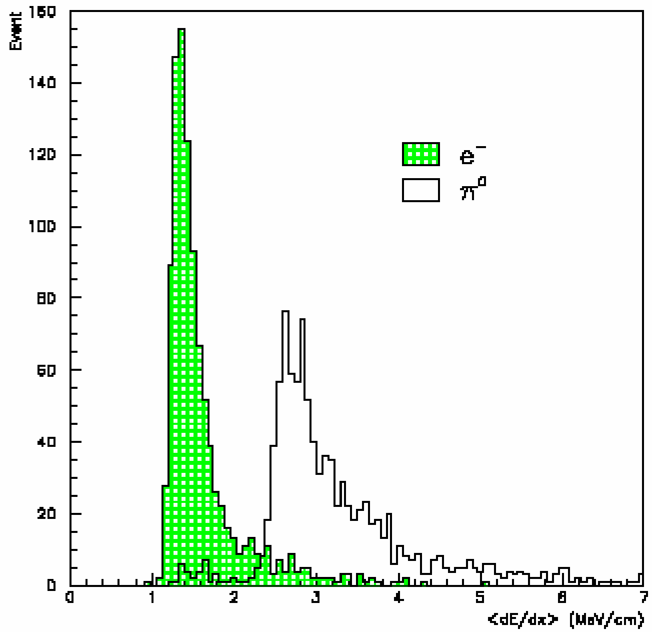


Figure 3: The $< dE/dx >$ distribution of the first 8 wires for 1000 simulated 1 GeV electrons (hatched area) and pions (blank area). 90% electrons and 3.7% pions are obtained when the $< dE/dx >= 2.21 MeV/cm$ cut is applied.

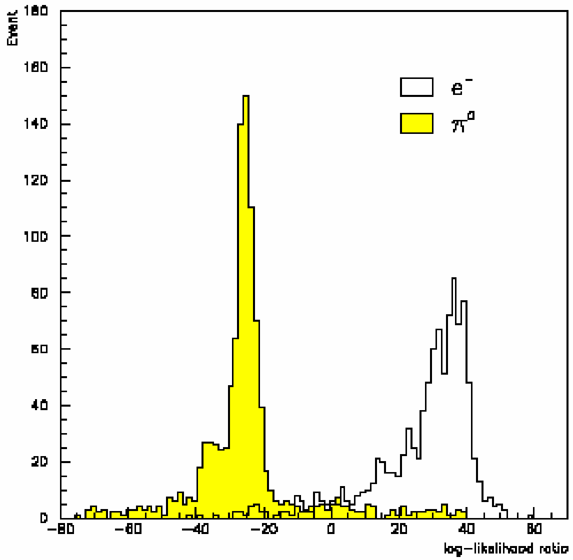


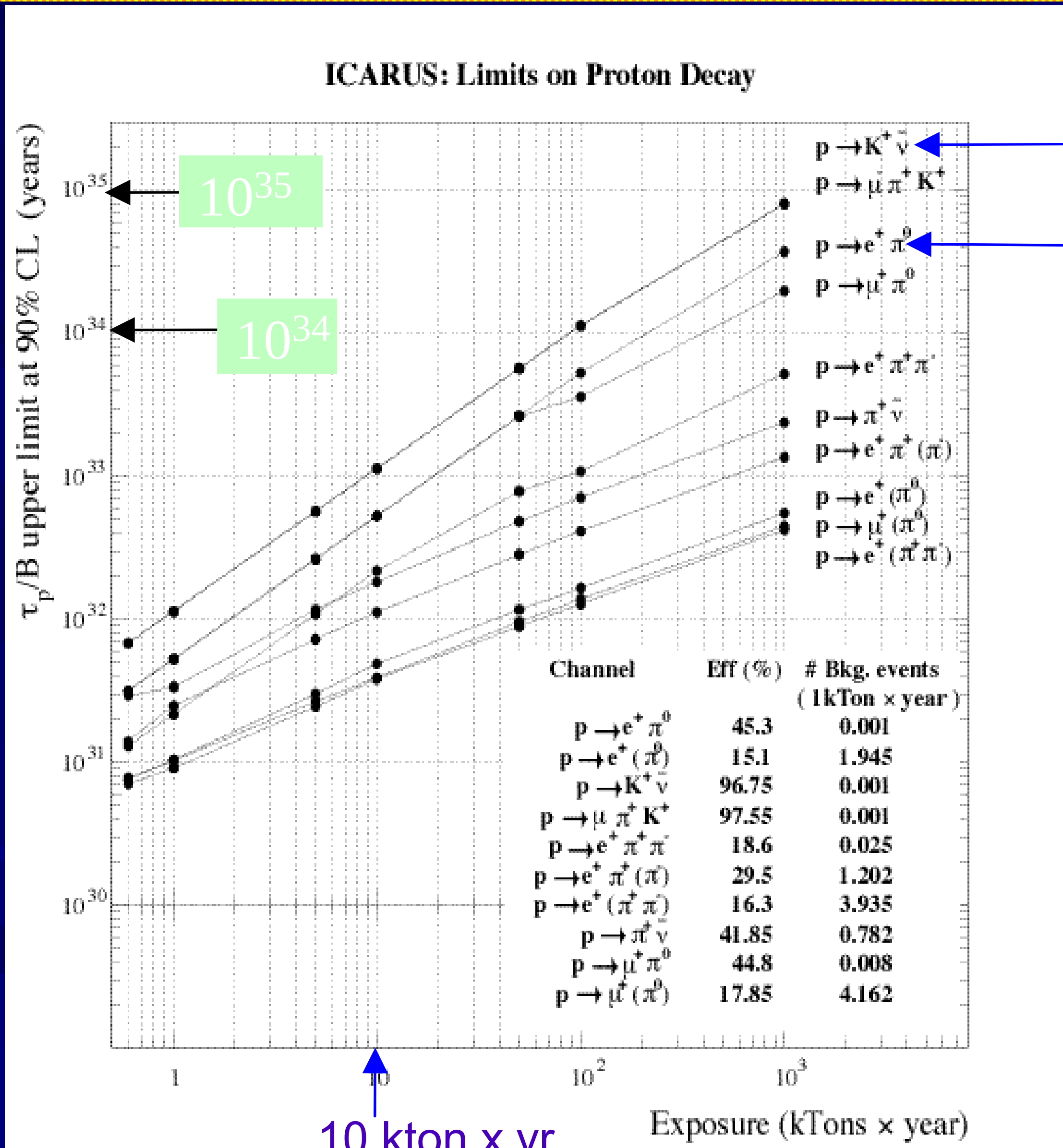
Figure 6: The distribution of the log-likelihood ratio sum for the same events studied by dE/dx method. A similar π^0 rejection is achieved: 4.8% pions and 90% electrons survive the cut $\sum_{i=1}^{16} ln(L_e^i/L_\pi^i) = 7.5$ (see the text).

Combining imaging (identify pions converting 1cm away from primary vertex) + dE/dx method we expect to have a π^0 contamination of **0.2%**

Determination of the oscillaton parameters

Parameter	Current measurement (90 % C.L.)	Expected measurement with ICARUS
Δm^2_{23} (eV^2)	$1.5 < \Delta m^2_{23} < 3.4 \times 10^{-3}$	$2.5 \pm 0.4 \times 10^{-3}$
$\sin^2 2\theta_{23}$	>0.92	0.9 ± 0.1
$\sin^2 2\theta_{13}$	<0.14	0.09 ± 0.04

Nucleon decay sensitivity



Channel	Eff (%)	# Bkg. events (1kTon × year)
$p \to e^+ \pi^0$	45.3	0.001
$p \to e^+ (\pi^0)$	15.1	1.945
$p \to K^+ \bar{\nu}$	96.75	0.001
$p \to \mu^- \pi^+ K^+$	97.55	0.001
$p \to e^+ \pi^+ \pi^-$	18.6	0.025
$p \to e^+ \pi^+ (\pi^-)$	29.5	1.202
$p \to e^+ (\pi^+ \pi^-)$	16.3	3.935
$p \to \pi^+ \bar{\nu}$	41.85	0.782
$p \to \mu^+ \pi^0$	44.8	0.008
$p \to \mu^+ (\pi^0)$	17.85	4.162

$\tau_p (p \to K^+ \nu) >$ **5.7 × 10 ^{32} yrs**
$\tau_p (p \to e^+ \pi^0) >$ **2.7 × 10 ^{32} yrs**

Background free !!

5 kTon × year

*Sensitivity grows essentially **linearly** with exposure for all considered channels.*

Nuclear effects in signal: fully embedded in FLUKA nuclear model

A. Bueno (Granada University)

Comparison with Super Kamiokande

SuperK results compiled by M.Goodman for NNN02, Jan 2002

Channel		Eff. (%)	Observed (evts.)	Bkg. (evts.)	Exposure (kTon×yr)	τ/B limit (10^{32} yr)	Needed Exp. to reach SK (kTon×yr)
$p \to e^+ \pi^0$	SuperK	43	0	0.2	79	$50 \to 30$ [1 evt]	
	ICARUS	45	–	0.005	5	2.7	94
$p \to K^+ \bar{\nu}$	SuperK				79	$19 \to 13$ [1 evt]	
prompt γ μ^+	SuperK	8.7	0	0.3		$10 \to 7$	
$K^+ \to \pi^+ \pi^0$	SuperK	6.5	0	0.8		$7.5 \to 5$	
	ICARUS	97	–	0.005	5	5.7	17
$p \to \mu^+ \pi^0$	SuperK	32	0	0.4	79	$37 \to 24$ [1 evt]	
	ICARUS	45	–	0.04	5	2.6	102

Channel		Eff. (%)	Observed (evts.)	Bkg. (evts.)	Exposure (kTon×yr)	τ/B limit (10^{32} yr)	Needed Exposure to reach PDG'02 (kTon×yr)
$p \to \mu^- \pi^+ K^+$	ICARUS	98	–	0.005	5	5.7	2.1
$p \to e^+ \pi^+ \pi^-$	ICARUS	19	–	0.125	5	1.1	3.8
$p \to \pi^+ \bar{\nu}$	ICARUS	42	–	4	5	1.2	0.5
$p \to e^+ \pi^+ (\pi^-)$	ICARUS	30	–	6	5	0.7	
$p \to e^+ (\pi^+ \pi^-)$	ICARUS	16	–	20	5	0.2	
$n \to e^- K^+$	ICARUS	96	–	0.005	5	6.9	0.24
$n \to \mu^- \pi^+$	ICARUS	45	–	0.12	5	3.2	1.6
$n \to e^+ \pi^-$	ICARUS	44	–	0.04	5	3.2	2.5
$n \to \pi^0 \bar{\nu}$	ICARUS	45	–	2.4	5	2	2.4
$n \to \mu^- (\pi^+)$	ICARUS	21	–	15	5	0.4	
$n \to e^+ (\pi^-)$	ICARUS	26	–	27	5	0.4	

Solar neutrinos: Expected rates

Solar model: **BP2000** ν flux used

^8B $5.15 \times 10^6/cm^2/s$

hep $9.3 \times 10^3/cm^2/s$ (BP98: 2.10)

(No oscillation hypothesis)

Electron energy threshold (MeV)	Solar neutrino events (1kton × year)		
	Elastic	Fermi	Gamow-Teller
0.0	782806	2011	4541
1.0	4560	1978	3287
2.0	1854	1848	3111
3.0	1465	1588	2762
4.0	1114	1212	2250
5.0	809	784	1644
5.5	676	579	1336
6.0	557	397	1042
6.5	450	247	774
7.0	358	135	540
7.5	278	63	349
8.0	212	26	205
8.5	156	10	107
9.0	112	5	49
9.5	77	3	20
10.0	51	2	8
10.5	32	2	4
11.0	19	1	3

$T_{thresh} = 5$ MeV

Solar neutrinos: expected background

T600 module

Electron energy threshold (MeV)	Neutron capture events per year		
	E_{cells} > 0 KeV	E_{cells} > 50 KeV	E_{cells} >150 KeV
0.0	6553	6520	6121
1.0	5295	5295	5275
2.0	4430	4417	4273
3.0	2700	2674	1855
4.0	1107	1075	865
5.0	131	118	72
5.5	20	20	20
6.0	13	13	13
6.5	7	7	7
7.0	7	7	6
7.5	5	5	3
8.0	1	1	1

T_{thresh} = 5 MeV

Full simulation of neutron capture events on **natural Ar**

Supernova: Expected rates

Assume Fermi-Dirac energy spectra and no oscillations

$$\langle E_{\nu_e} \rangle = 11 MeV, \langle E_{\bar{\nu}_e} \rangle = 16 MeV, \langle E_{\nu_{\mu,\tau}} \rangle = 25 MeV, \langle E_{\bar{\nu}_{\mu,\tau}} \rangle = 25 MeV$$

Reaction		T (MeV)	$< E_\nu >$ (MeV)	Expected events 1.2 ktons	Expected events 5 ktons
Elastic					
	$\nu_e e^-$	3.5	11	8	33
	$\bar{\nu}_e e^-$	5	16	3	14
	$(\nu_\mu + \nu_\tau) e^-$	8	25	3	11
	$(\bar{\nu}_\mu + \bar{\nu}_\tau) e^-$	8	25	2	9
	total νe^-			16	67
Absorption					
	ν_e ^{40}Ar (Fermi)	3.5	11	28	118
	ν_e ^{40}Ar (GT)	3.5	11	41	170
Absorption					
	$\bar{\nu}_e$ ^{40}Ar (Fermi)	5	16	?	?
	$\bar{\nu}_e$ ^{40}Ar (GT)	5	16	?	?
Total				85	355

Table 1: Expected neutrino rates for a supernova at a distance of 10 kpc, releasing an energy of 3×10^{53} ergs (no threshold on the electron energy has been applied).

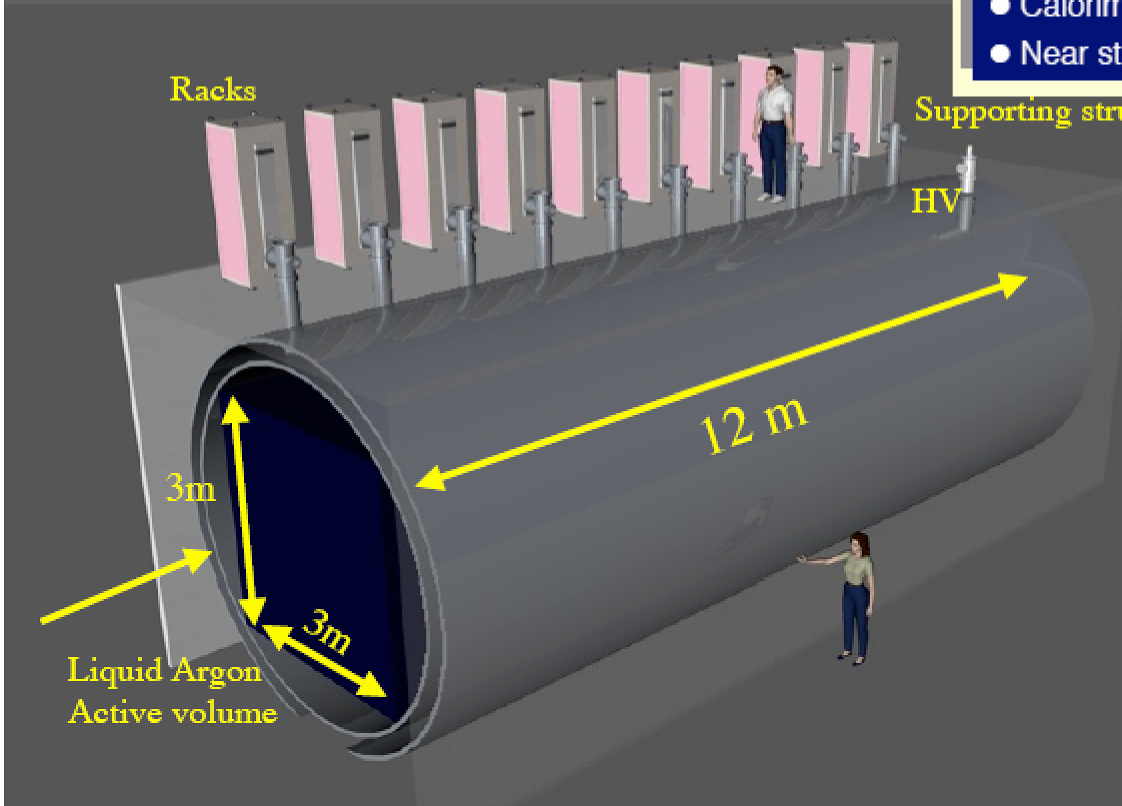
Antineutrino electron absorption not yet included!

100 ton detector

Conceptual design of a ~100 ton LAr TPC for a near station in a LBL facility:

a possibility being further explored

- Precision studies of ν interactions
- Calorimetry
- Near station in LBL facilities



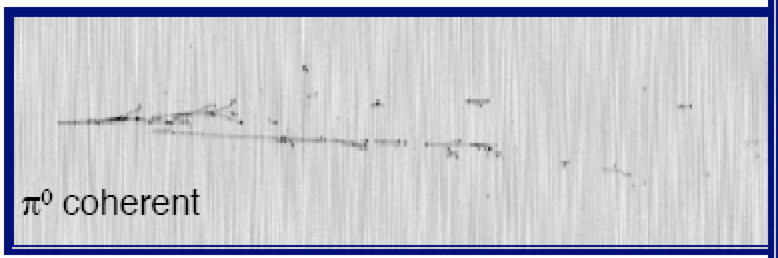
Outer vessel	$\phi \approx$ 5m, L≈13m, 15mm thick, weight ≈ 22 t
Inner vessel	$\phi \approx$ 4,2 m, L ≈ 12 m, 8 mm thick, ≈ 10 t
LAr	Total ≈ 240 t Fiducial ≈ 100 t
Max e- drift	3 m @ HV=150 kV E = 500 V/cm
Charge R/O	2 views, ± 45° 2 (3) mm pitch
Wires	≈10000 (7000) $\phi = 150\ \mu m$
R/O electr.	on top of the dewar
Scintill. light	Also for triggering
B-field	possible

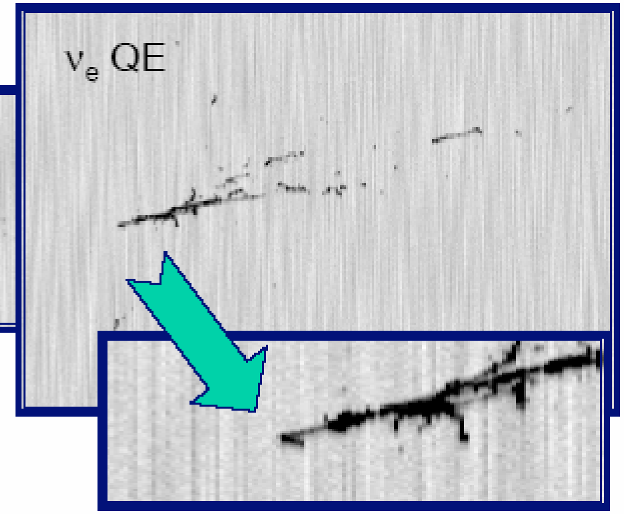
Ideas for future liquid Argon detectors
A.Ereditato, A.Rubbia, to appear in Proc. of NUINT04, LNGS, March 2004

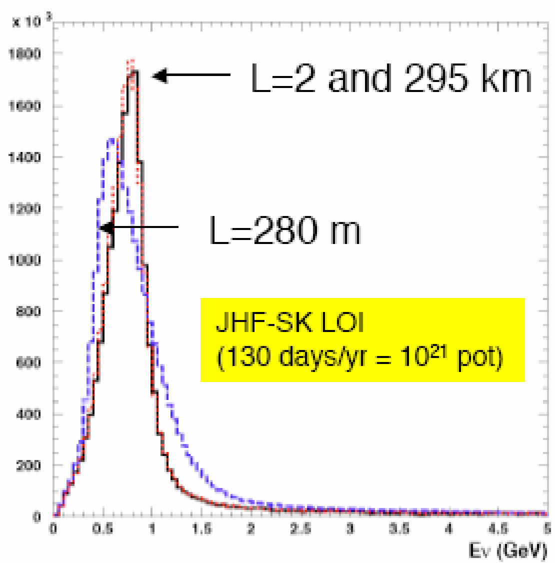
100 ton LAr TPC at T2K ?

T2K would provide an ideal & high intensity beam for such a ≈100 ton detector

full simulation, digitization, and noise inclusion



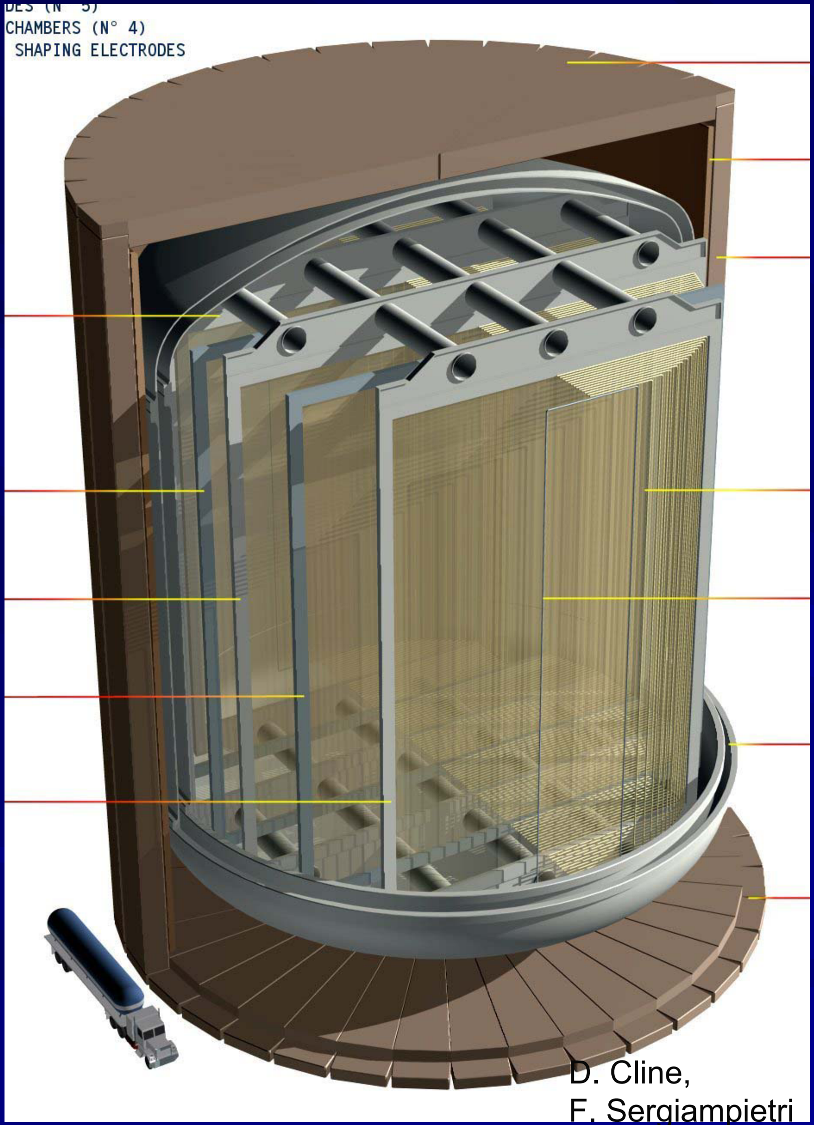




For example: 100 ton @ L=2000 m

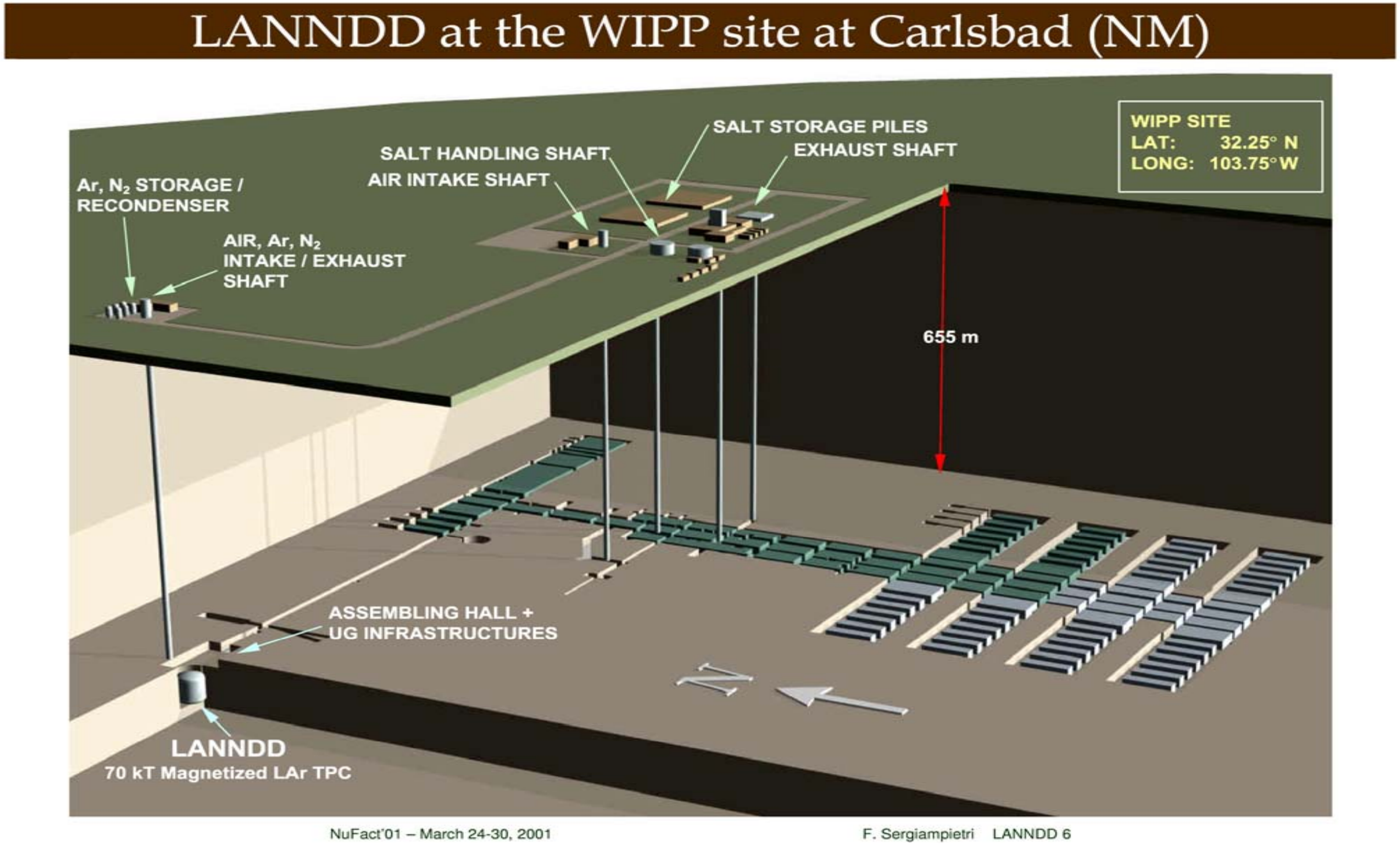
Beam	E_{peak}(GeV)	ν_μ	ν_e
OA2	0.7	300000/yr 0.1/spill	5800/yr 45/day

LANNDD



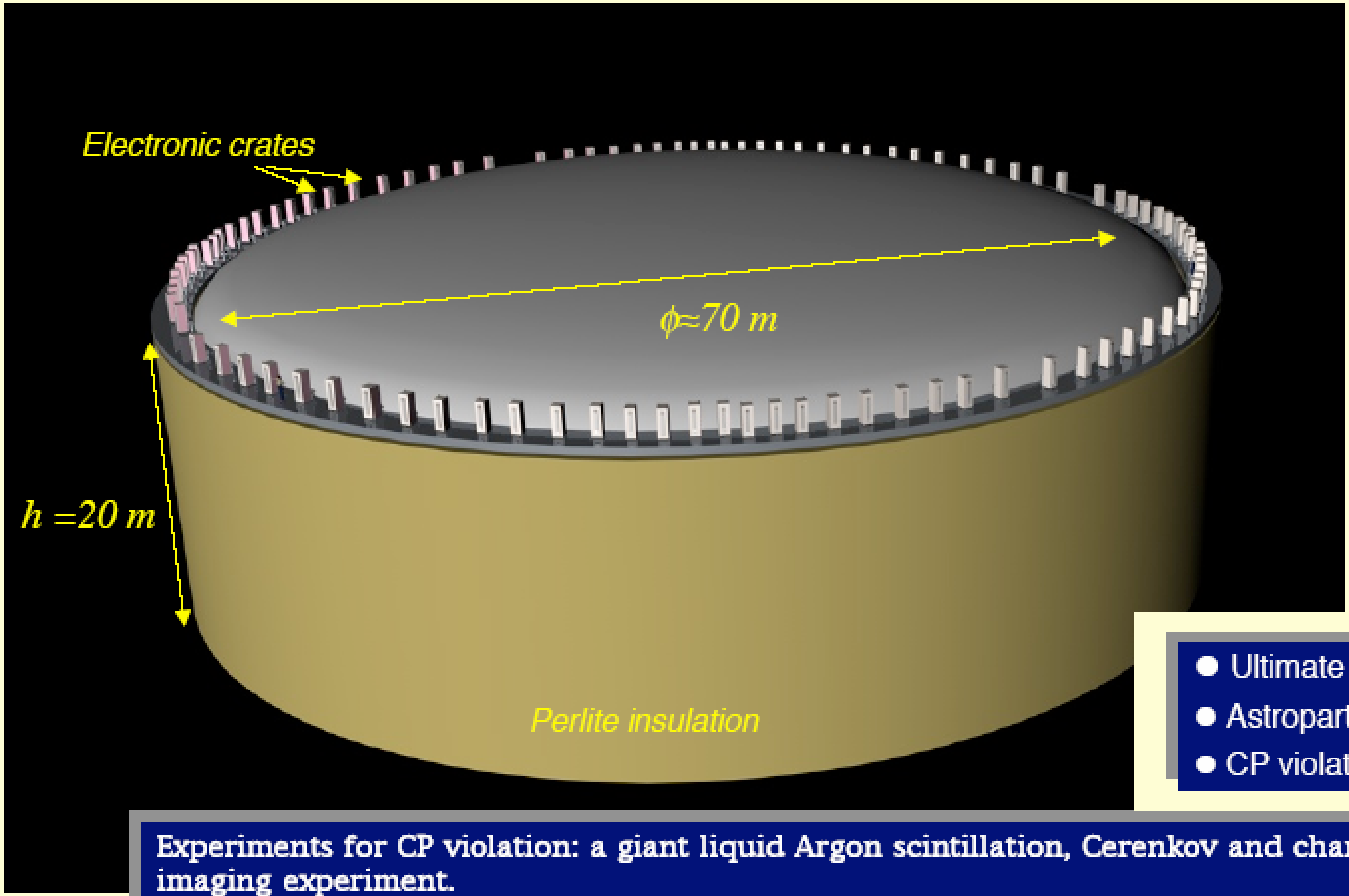
- 50-100 kton detector
- Magnetized Liquid Argon TPC
- 4-8 meters drift distances

LANNDD


LANNDD at the WIPP site at Carlsbad (NM)
WIPP SITE
LAT: 32.25° N
LONG: 103.75° W
SALT STORAGE PILES
EXHAUST SHAFT
SALT HANDLING SHAFT
AIR INTAKE SHAFT
Ar, N2 STORAGE / RECONDENSER
AIR, Ar, N2 INTAKE / EXHAUST SHAFT
655 m
ASSEMBLING HALL + UG INFRASTRUCTURES
N
LANNDD
70 kT Magnetized LAr TPC
NuFact'01 – March 24-30, 2001
F. Sergiampietri LANNDD 6

The ultimate LAr TPC Detector?

100 kton liquid Argon TPC detector



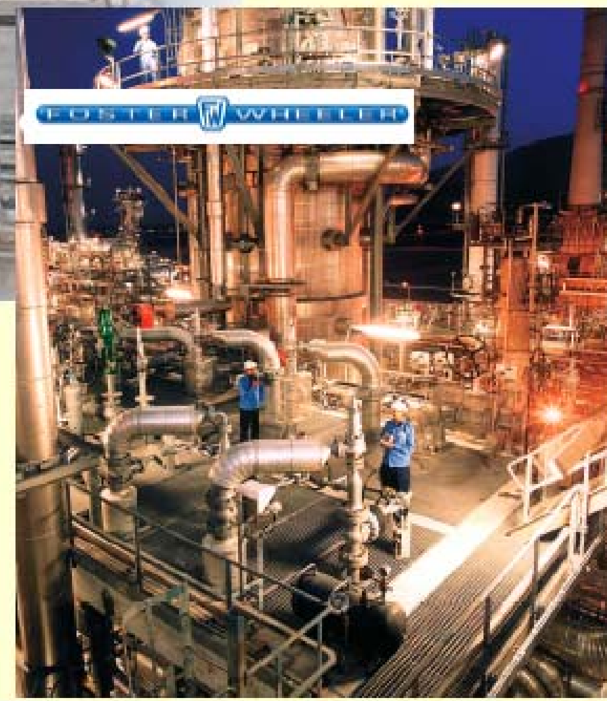
- Ultimate nucleon decay searches
- Astroparticle physics
- CP violation in neutrino mixing

Experiments for CP violation: a giant liquid Argon scintillation, Cerenkov and charge imaging experiment.
A.Rubbia, Proc. II Int. Workshop on Neutrinos in Venice, 2003, hep-ph/0402110

Industrial Solutions

LNG = Liquefied Natural Gas

Cryogenic storage tankers for LNG



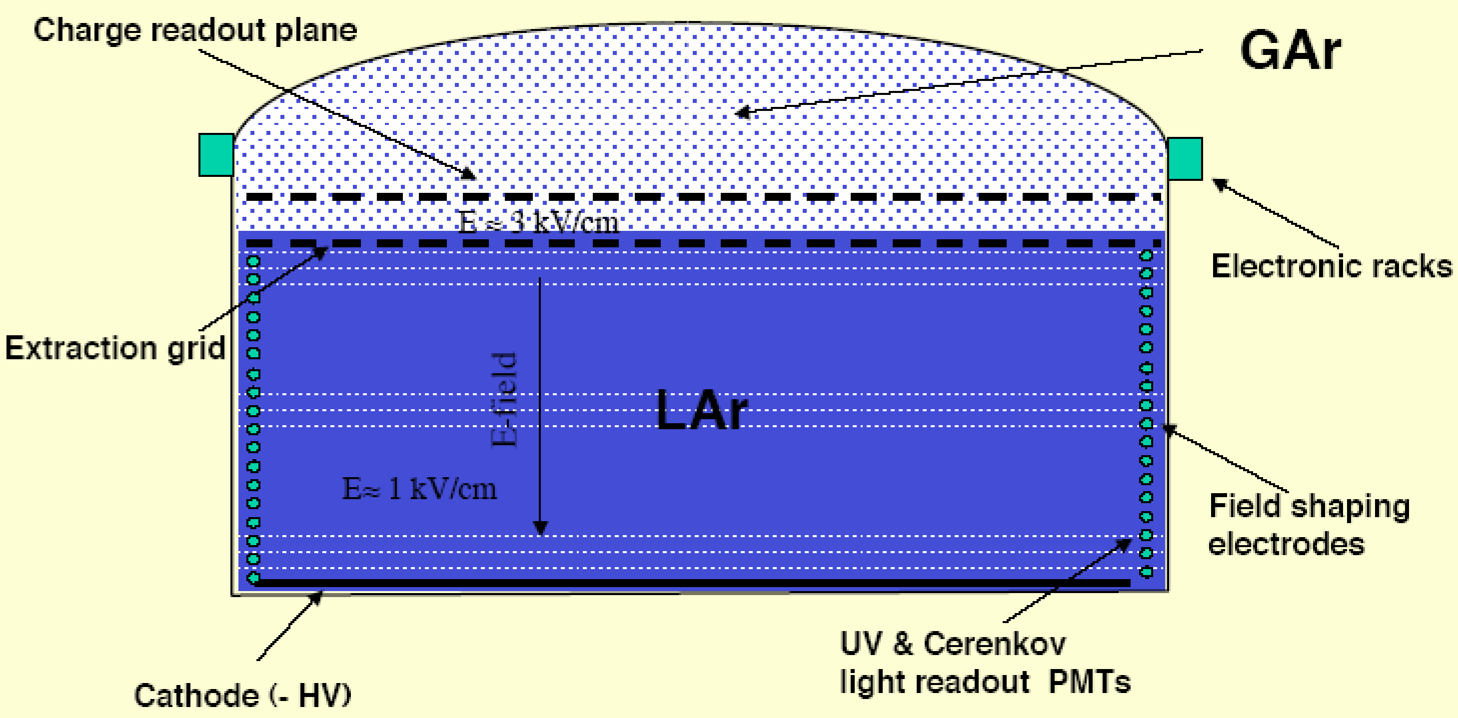
About 2000 cryogenic tankers exist in the world, with volume up to ≈ 200000 m^3

Process, design and safety issues already solved by petrochemical industry

Detector Layout

A tentative detector layout

Single detector: charge imaging, scintillation, Cerenkov light



Operation in Bi-Phase Mode

Charge extraction, amplification, readout

Detector is running in **BI–PHASE MODE**

- Long drift ($\approx$ 20 m) $\Rightarrow$ charge attenuation to be compensated by charge amplification near anodes located in gas phase (18000 e^- / 3 mm for a MIP in LAr)
- Amplification operates in proportional mode
- After maximum drift of 20 m @ 1 kV/cm $\Rightarrow$ diffusion $\approx$ readout pitch $\approx$ 3 mm

Electron drift in liquid	20 m maximum drift, HV = 2 MV for E = 1 kV/cm, $v_d \approx$ 2 mm/μs, max drift time $\approx$ 10 ms
Charge readout view	2 perpendicular views, 3 mm pitch, 100000 readout channels
Maximum charge diffusion	$\sigma \approx$ 2.8 mm ($\sqrt{2Dt_{max}}$ for D = 4 cm^2/s)
Maximum charge attenuation	$e^{-(t_{max}/\tau)} \approx$ 1/150 for τ = 2 ms electron lifetime
Needed charge amplification	From 100 to 1000
Methods for amplification	Extraction to and amplification in gas phase
Possible solutions	Thin wires ($\phi \approx$ 30 μm) + pad readout, GEM, LEM, …

Tentative Parameter List

Dewar	$\phi \approx 70$ m, height ≈ 20 m, perlite insulated, heat input ≈ 5 W/m^2
Argon storage	Boiling Argon, low pressure (<100 mbar overpressure)
Argon total volume	73000 m^3, ratio area/volume $\approx$ 15%
Argon total mass	102000 tons
Hydrostatic pressure at bottom	3 atmospheres
Inner detector dimensions	Disc $\phi \approx 70$ m located in gas phase above liquid phase
Charge readout electronics	100000 channels, 100 racks on top of the dewar
Scintillation light readout	Yes (also for triggering), 1000 immersed 8“ PMTs with WLS
Visible light readout	Yes (Cerenkov light), 27000 immersed 8“ PMTs of 20% coverage, single γ counting capability

Physics with a 100 Kton LAr TPC

	Water Cerenkov (UNO)	Liquid Argon TPC
Total mass	650 kton	100 kton
Cost	≈ 500 M$	Under evaluation
$p \to e\,\pi^0$ in 10 years	10^{35} years ε= 43%, ≈ 30 BG events	3×10^{34} years ε= 45%, 1 BG event
$p \to \nu K$ in 10 years	2×10^{34} years ε= 8.6%, ≈ 57 BG events	8×10^{34} years ε= 97%, 1 BG event
$p \to \mu\pi K$ in 10 years	No	8×10^{34} years ε= 98%, 1 BG event
SN cool off @ 10 kpc	194000 (mostly $\bar{\nu}_e p \to e^+ n$)	38500 (all flavors) (64000 if NH-L mixing)
SN in Andromeda	40 events	7 (12 if NH-L mixing)
SN burst @ 10 kpc	≈330 ν-e elastic scattering	380 ν_e CC (flavor sensitive)
SN relic	Yes	Yes
Atmospheric neutrinos	60000 events/year	10000 events/year
Solar neutrinos	E_e > 7 MeV (central module)	324000 events/year E_e > 5 MeV

Review of massive underground detectors
A.Rubbia, Proc. XI Int. Conf. on Calorimetry in H.E.P., CALOR04, Perugia, March 2004