SUPER-ICANOE

Presented by Antonio Bueno (ETHZ)

ICARUS Collaboration

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NNN00-Fermilab Nucleon Decay and Neutrino Detector Workshop
August 7-8, 2000
Fermi National Accelerator Laboratory
Batavia, Illinois, USA

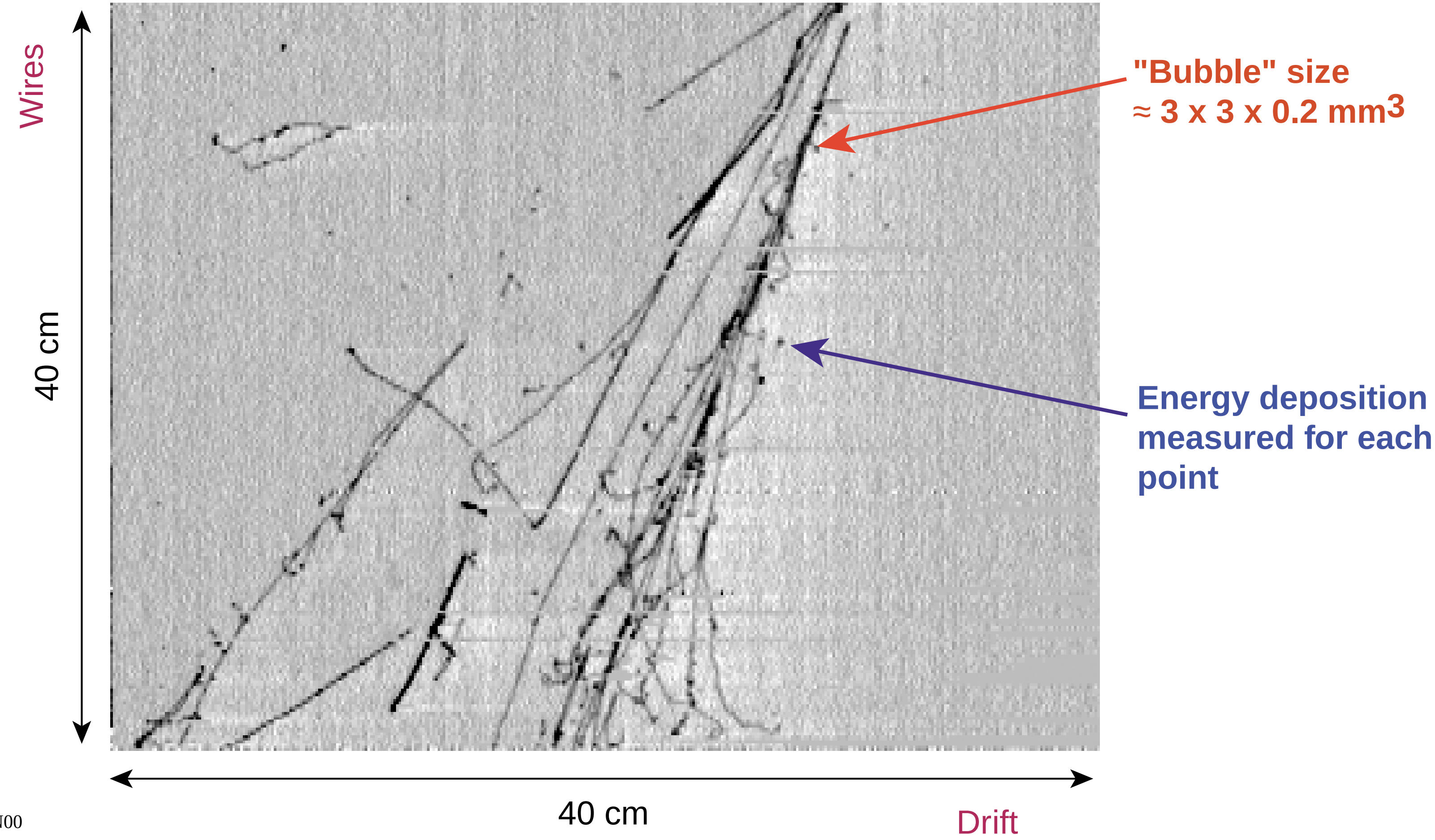
New challenges

- High-energy physics is now facing the new challenge of thinking of a new generation of experiments beyond the current accelerator & non-accelerator ones in order to:
  - ⇨ **Improve significantly the sensitivity to nucleon decay in the range of 10^{34} years**
  - ⇨ **Allow transcontinental very long-baseline (L>1000km) oscillations experiments with full event reconstruction**
  - ⇨ **Continue to observe solar, atmospheric neutrinos with higher statistics & better resolution**

Need to further develop high-granularity detectors with masses in the range of ten's-of-ktons !

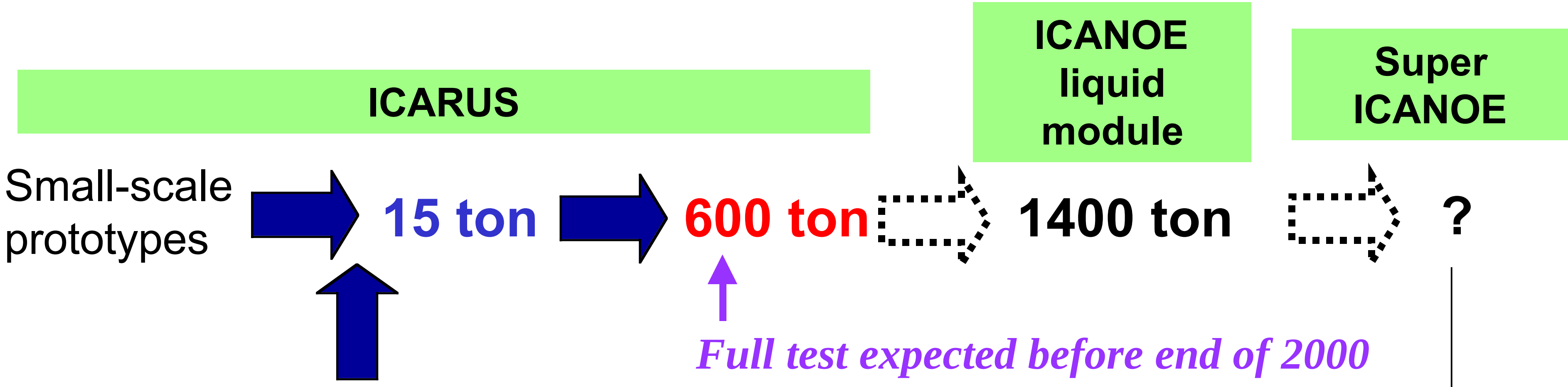
Liquid argon imaging TPC

- 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.



ICARUS state of the art

- 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.



Cooperation with specialized industries:

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

A case study for this workshop

ICARUS 15 ton (10m^3) prototype

- A recent major step of the R&D program has been the construction and operation of a **10m^3 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"*

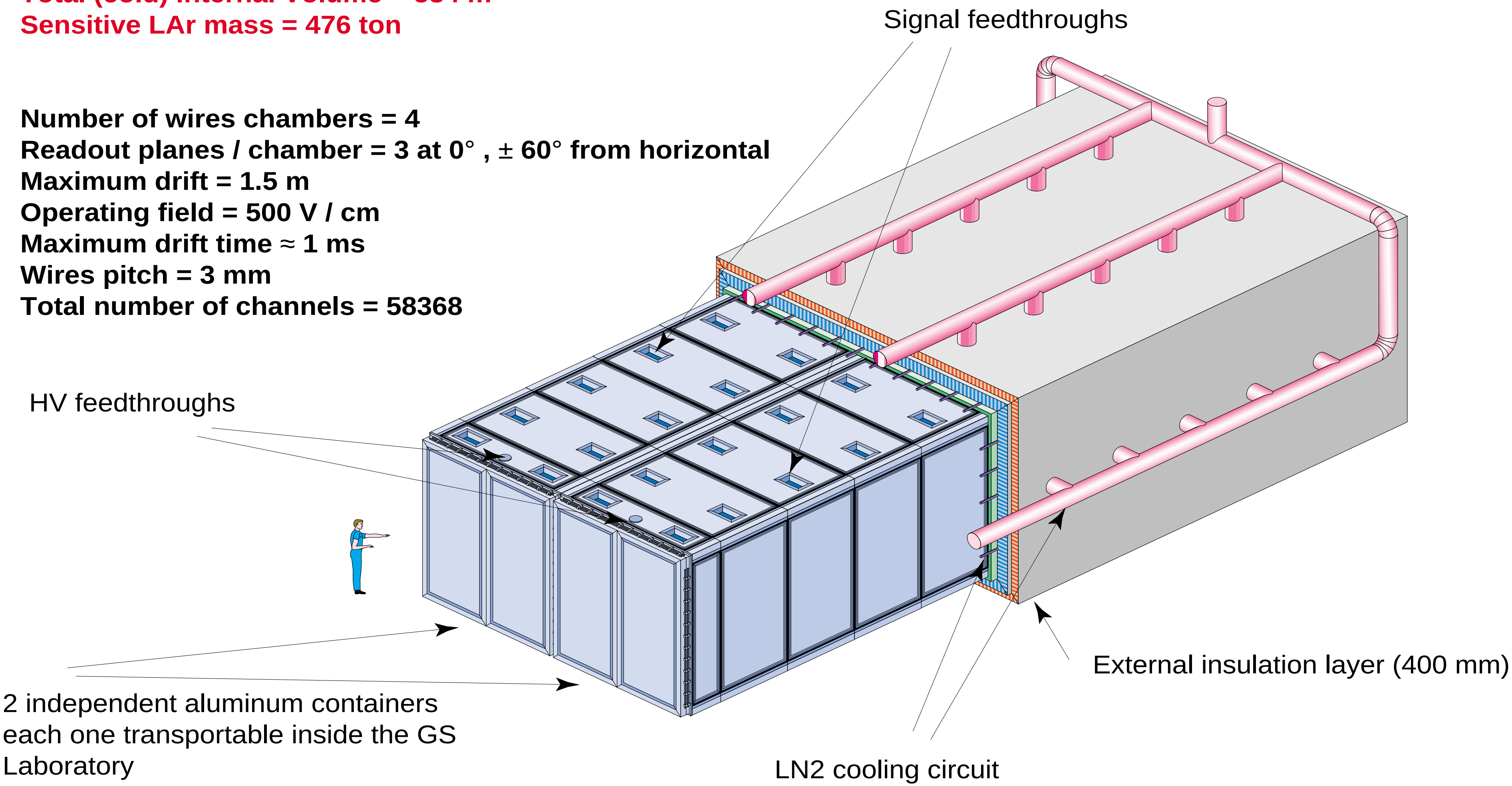
T15 installation @ LNGS (Hall di Montaggio)

The ICARUS T600 module

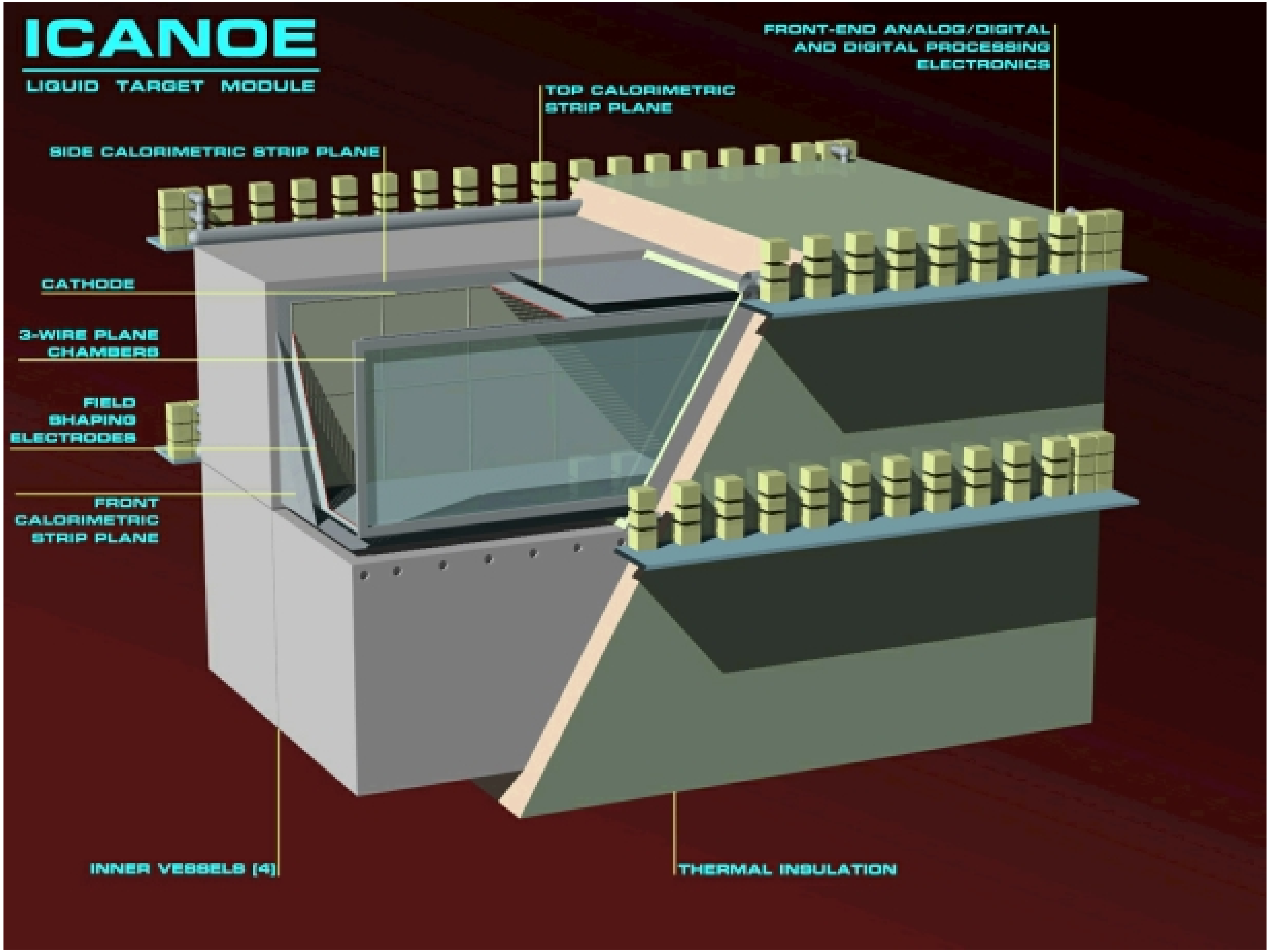
Under construction

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 m^3
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



The ICANOE T1400 module



Design considerations

What we get for 30 ktons:

- **Number of targets for nucleon stability:**
  - 2×10^{34} nucleons $\Rightarrow$ τ_p **(10^{33} years) > 3.6** $\times$ **T(yr)** $\times\ \varepsilon$ @ 90 C.L.
- **Neutrino factory:**
  - **7000** ν_μ CC per 10^{20} μ @ L = 7400 km
- **Atmospheric:**
  - **6000** atm CC events / year
  - ≈**30** ν_τ CC /year from oscillations
- **Solar:**
  - ≈**50000** solar neutrinos / year @ E > 5 MeV

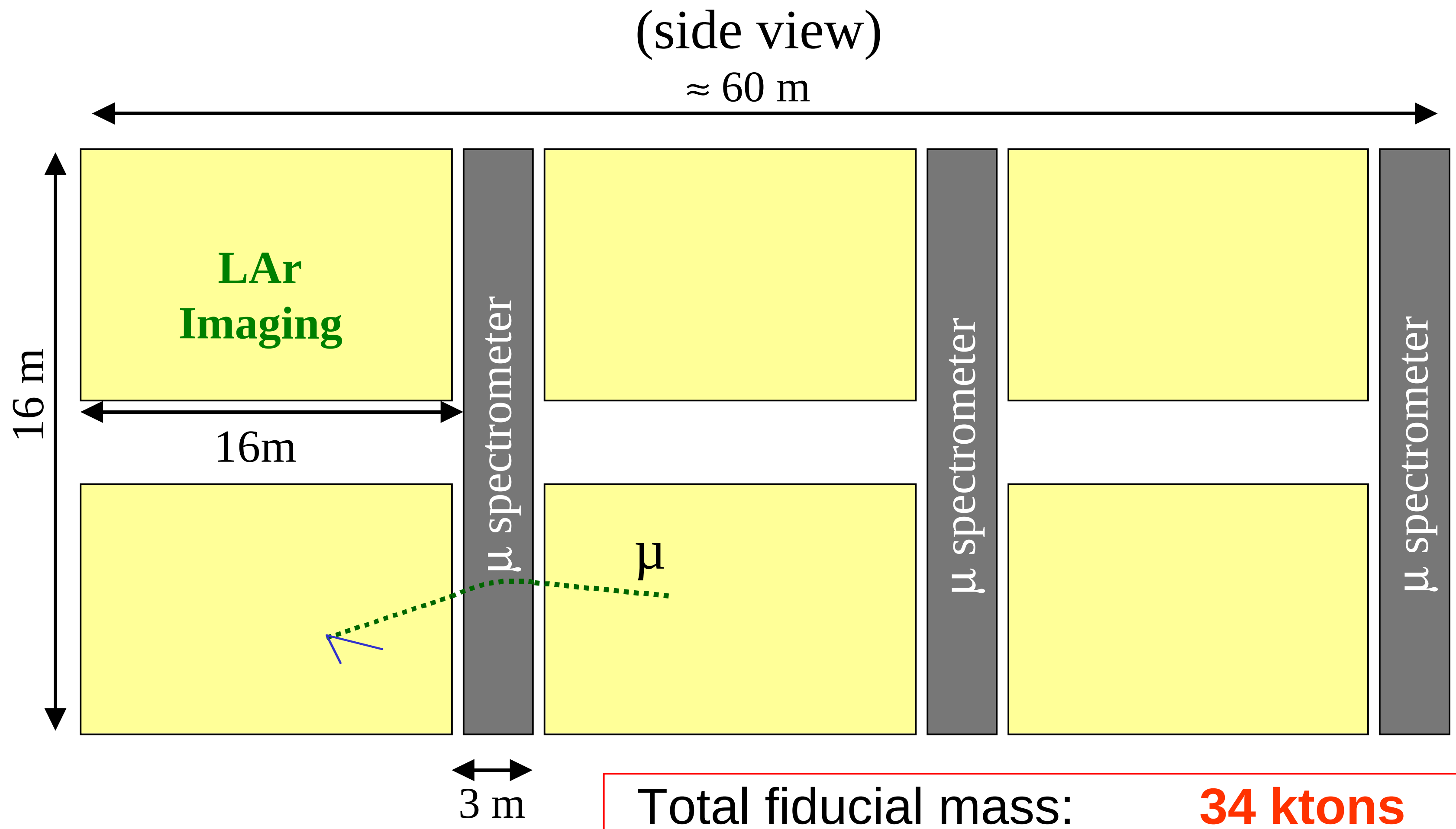
Of course, MASS is not the whole story!

➨ **We want the factor MASS × EFFICIENCY high and BACKGROUNDS low!!!**

Design option: Modular

- The ICARUS detector can be built in **very large sizes** and after having been developed in laboratory units, the liquid argon technology is now fully industrialized
  - ⇨ **Modules can be “ordered” to the producer**
- As a case study, the simplest way to extend the mass is to **replicate** a large number of times the current ICANOE supermodule
  - ⇨ **Conservative cost estimate (from ICANOE proposal):**
    ≈ 13 M$ / supermodule (1400 tons)
  - ⇨ **Total for 24 supermodules:** **≈310 M$ ⇒ 34 ktons**
- **Cost reduction** possible by further geometry optimization
  - ⇨ **c.f. SUPERICARUS proposal CERN/SPSC 98-33**
- Other options: fill existing cavern e.g. SuperK ?

Possible baseline configuration

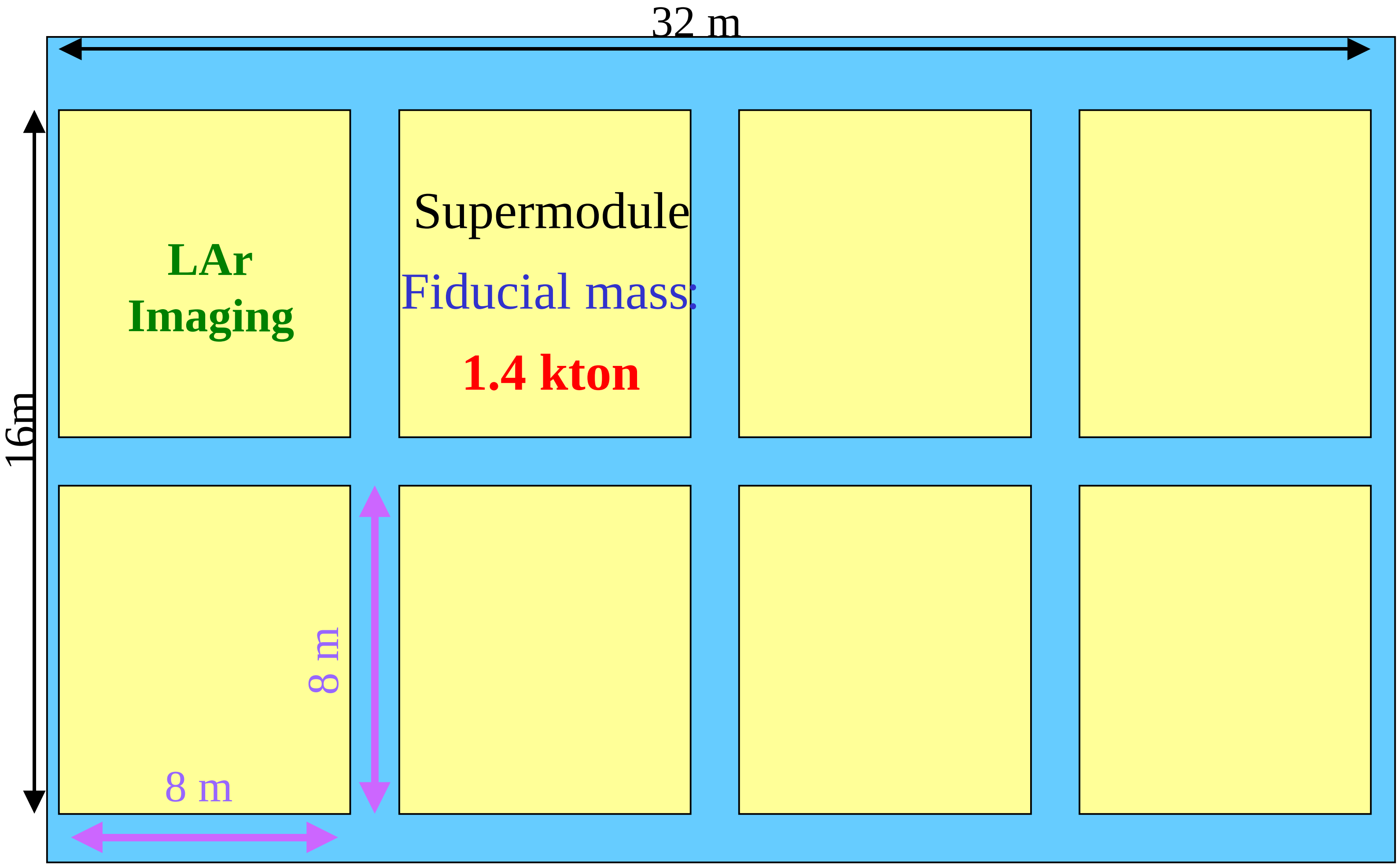


SuperICANOE
(case study for this workshop)

Total fiducial mass:	**34 ktons**
wires/supermodule:	**53248**
channels/supermodule:	**26624**
maximum drift length:	**4 m**

Possible baseline configuration

(front view)



Three arrays of eight supermodules: 24 supermodules in total

Design limitations?

- Detector is a surface detector, so gain in volume/surface ratio
  - ⇨ **Like Water Cerenkov**
- Practical limitations for size of monolithic supermodule (1000 m^3 for ICANOE)
  - ⇨ **Drift length**
    - Can one drift longer than currently assumed 4 meters? ⇒ R&D
  - ⇨ **Readout-wires length is not a limiting factor**
    - Variable geometry chambers (spring system tested in T15)
    - Diameter 150 μm
    - Eventually, limited by wire capacitance (noise)
  - ⇨ **Quantity of Argon**
    - ≈30 kt is equivalent to the Italian production in one year
    - However, Argon not "used", just "stored" in the experiment
  - ⇨ **Safety issues**
    - In critical area like LNGS lab, a monolithic volume of 1000 m^3 seems to be a limit ⇒ this constraint most likely relaxed in other sites

Physics potential (I)

Proton decay

- **Large variety of decay modes accessible**
  - ⇒ ***study branching ratios free of systematics***
- **Background free searches for even for 30 years running!!!**
  - ⇒ ***linear gain in sensitivity with exposure***
- **In case of negative results:**
  - ⇒ $\tau_p > O(10^{34-35}$ years) ***in 10 years of data taking***

Atmospheric neutrinos

- **Observation free of experimental biases!**
  - —*Detection down to production thresholds*
  - —*Complete event final state reconstruction*
  - —*Measurement of all neutrino flavors in all modes (CC & NC)*
- **Excellent resolution on L/E reconstruction**
- **Direct τ appearance search**

Physics potential (II)

Neutrinos from accelerators (ν factory)

- **Precise measurement of Δm^2_{23}, Θ_{23}, Θ_{13}**
- **Matter effects, sign of Δm^2_{23}**
- **First observation of $\nu_e \rightarrow \nu_\tau$ (unitarity of mixing matrix)**
- **CP violation**

Solar neutrinos

- **Energy threshold: 5 MeV**
- **Large statistics, high precision measurements**
- **Experimental signal**

Absorption

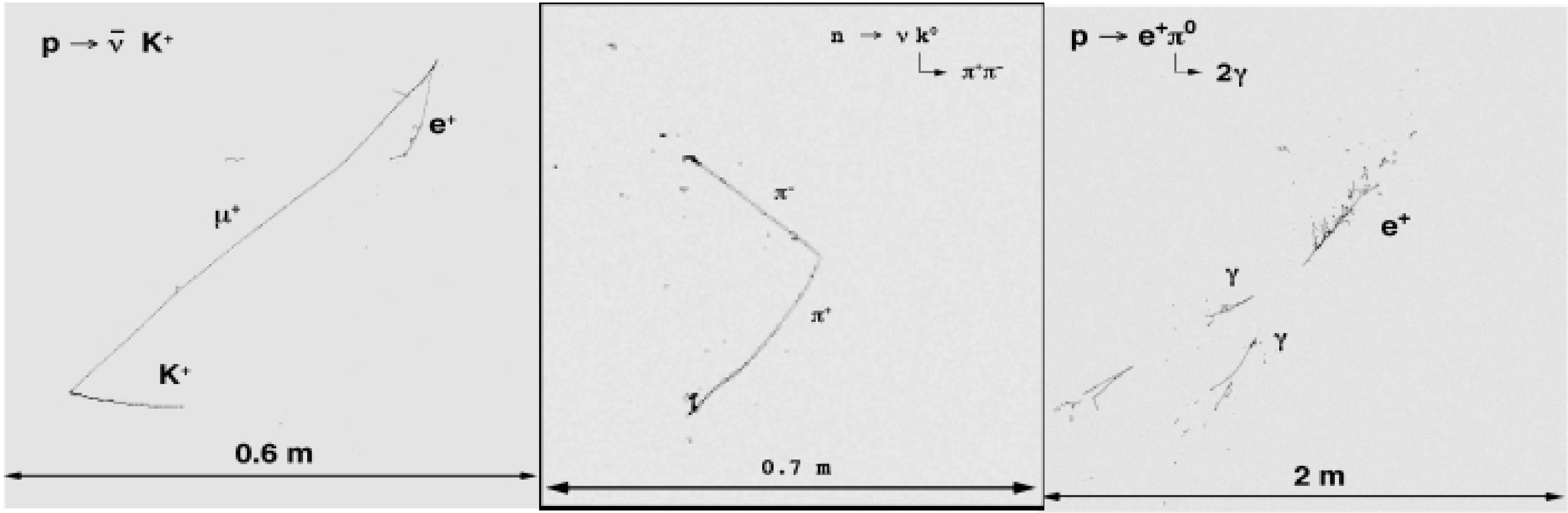
$$\nu_e + {}^{40}Ar \rightarrow e + {}^{40}K^*$$

Elastic

$$\nu_e + e \rightarrow \nu_e + e$$

Supernovae

Nucleon decay search



Thanks to excellent tracking and particle *id* capabilities

LAr unique tool for

Extremely efficient background rejection

High detection efficiency

p→e$^+$ π^0 decay mode

Exposure: 1000 kton x year

Cuts	$e+\pi^0$ Argon	$e+\pi^0$ Oxygen	ν_e CC	$\bar{\nu}_e$ CC	ν_μ CC	$\bar{\nu}_\mu$ CC	ν NC	$\bar{\nu}$ NC
Initial	100%	100%	59861	11707	106884	27273	64705	29612
One π^0	54%	70%	5277	1696	11160	4388	6223	2278
One e	54%	70%	5277	1696	7	< 1	< 1	< 1
$T_p < 100$ MeV	53%	68%	2505	1256	< 1	< 1	< 1	< 1
$0.8 <$ Inv Mass < 1.05 GeV	38%	53%	306	204	< 1	< 1	< 1	< 1
Total Momentum < 0.25 GeV	19%	24%	1	< 1	< 1	< 1	< 1	< 1

Overall efficiency in Argon

Overall efficiency in Oxygen

Full simulation of backgrounds

$p \to K^+ \bar{\nu}$ decay mode

Exposure: 1000 kton x year

Cuts	$K + \bar{\nu}$	ν NC	$\bar{\nu}$ NC
Initial	100%	64705	29612
No primary $\pi^{\pm}$	99.4%	55481	26033
No primary π^0	98.7%	48397	23265
Only one kaon	98.5%	108	22
Total Energy < 0.65 GeV	85%	< 1	< 1

Full simulation of backgrounds

Limits on proton mean life (τ_p)

10 years @ SuperICANOE

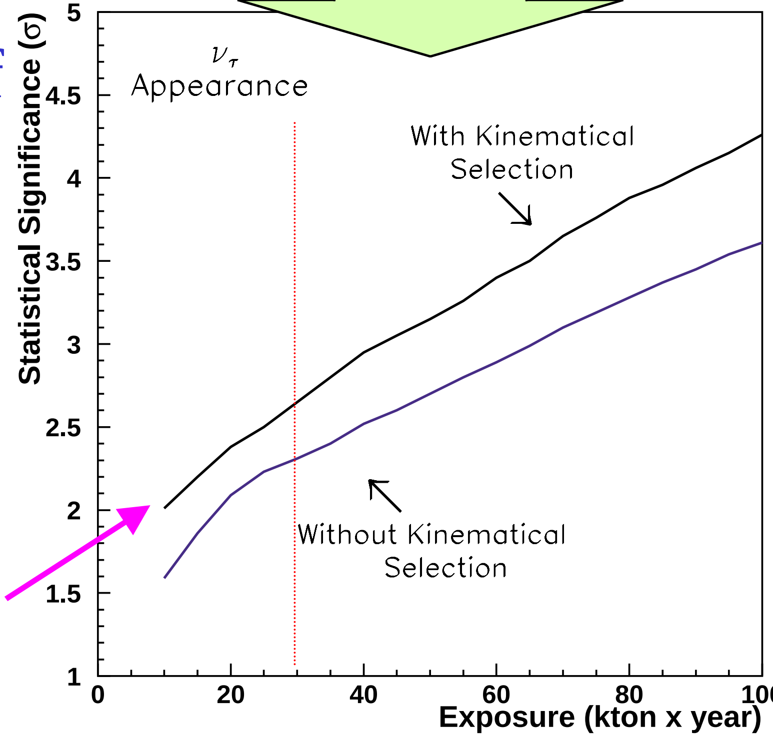
Exposure: 300 kton × year				
	$p \to e^+\pi^0$		$p \to K^+\bar{\nu}$	
	Efficiency (%)	τ_p (years)	Efficiency (%)	τ_p (years)
No nucl. reinteractions	42	1.5×10^{34}	85	3.1×10^{34}
Nucl. reinteractions (FLUKA)	19	6.8×10^{33}	85	3.1×10^{34}
Exposure: 1000 kton × year				
	$p \to e^+\pi^0$		$p \to K^+\bar{\nu}$	
	Efficiency (%)	τ_p (years)	Efficiency (%)	τ_p (years)
No nucl. reinteractions	42	5.0×10^{34}	85	1.0×10^{35}
Nucl. reinteractions (FLUKA)	19	2.3×10^{34}	85	1.0×10^{35}

30 years @ SuperICANOE

Atmospheric direct τ appearance

- Search for ***ν_τCC at high energy*** (τ threshold)
  - ***–30 ν_τCC/year expected***
- Compare NC(top) to NC(bottom) at high energy
  - –Requires good discrimination of NC event direction
- Exploit precise measurement of all final state particles
  - – Count events as a function of visible energy
  - **–Improved discrimination by a study of the event kinematical properties**

>3σ effect
after **two years of data taking**



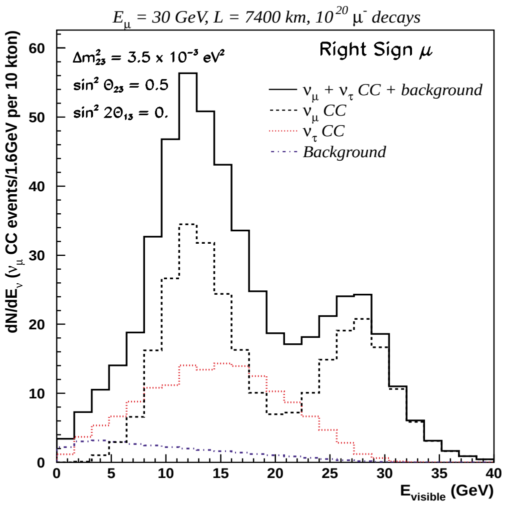
ICANOE proposal

Event classes at a ν factory

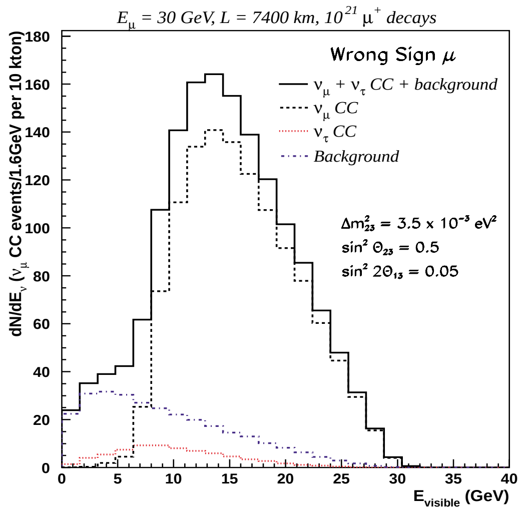
Ideal detector able to measure **12 different oscillation processes**

A. Bueno, M. Campanelli, A. Rubbia, hep-ph/0005007

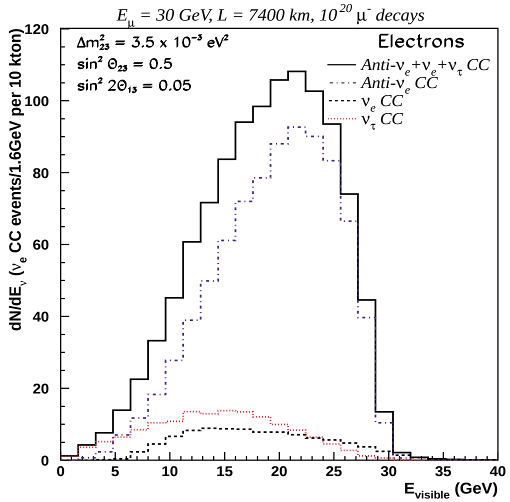
LAr imaging allows precise identification of all oscillation processes



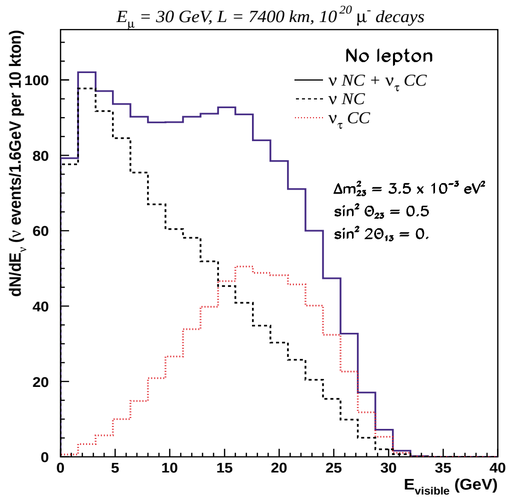
Right sign muons



Wrong sign muons



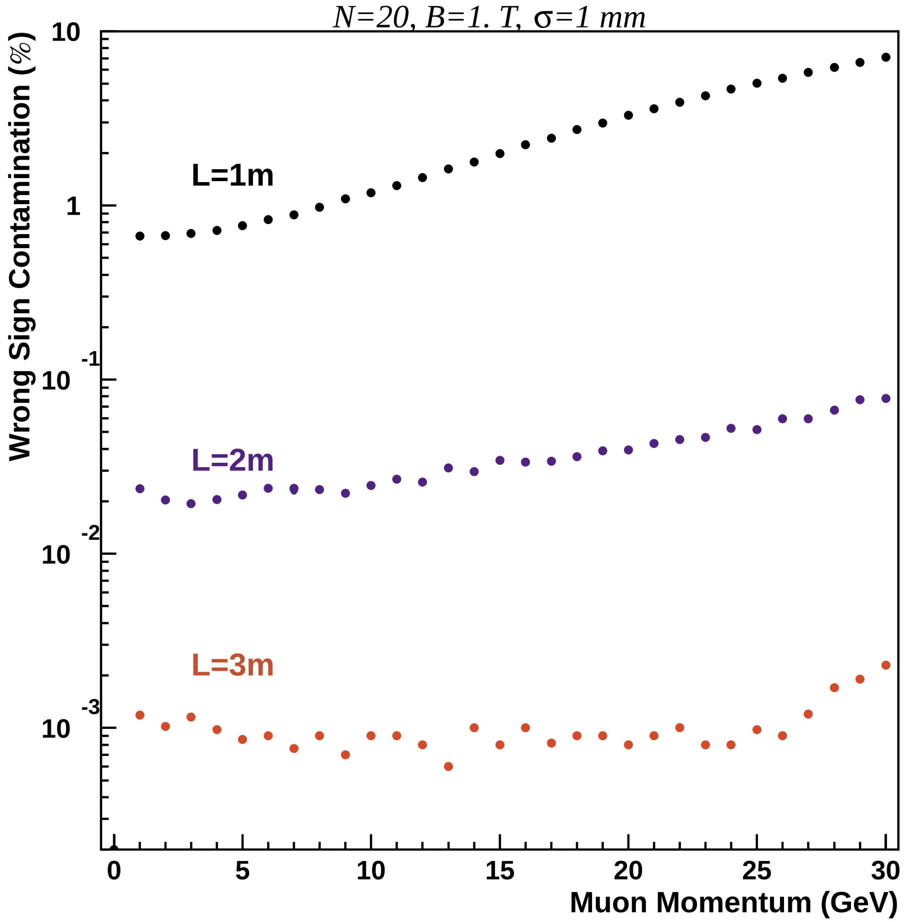
Electrons



No lepton

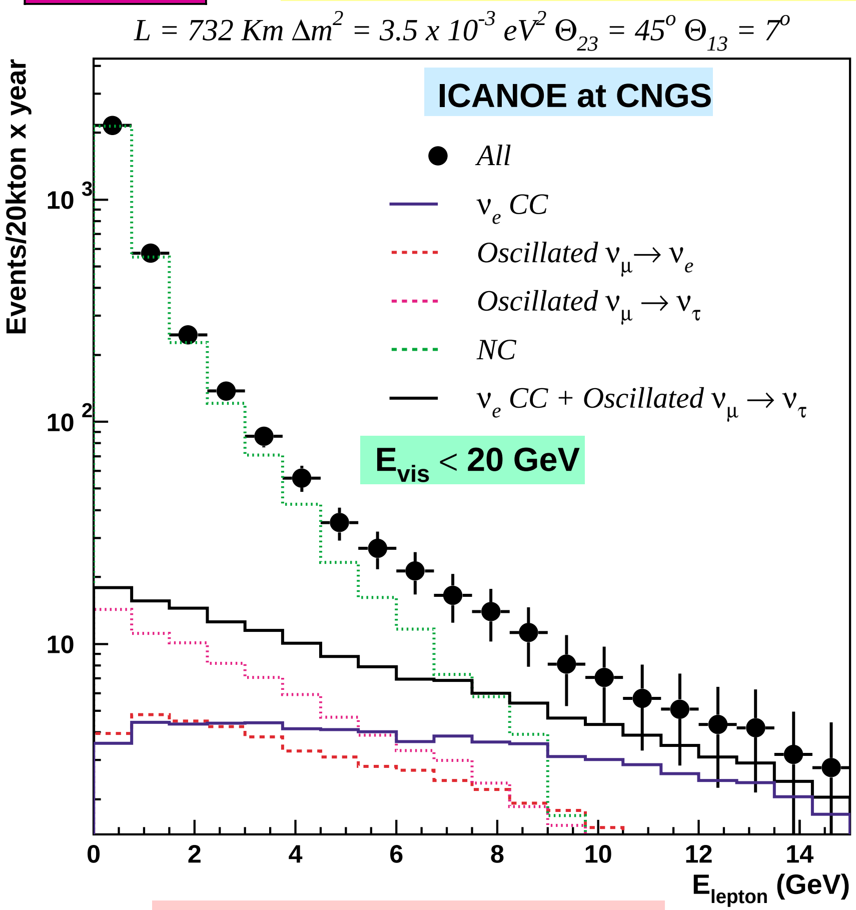
Muon identification

- μ momentum resolution:
  - ⇨ 20% for a 3m long Fe spectrometer with B=1T
- Wrong sign contamination
  - ⇨ Charge confusion: ~10^{-5}
- Large detection efficiency for low energy beam
  - ⇨ μ detection threshold (dE/dx = 240 MeV/m)

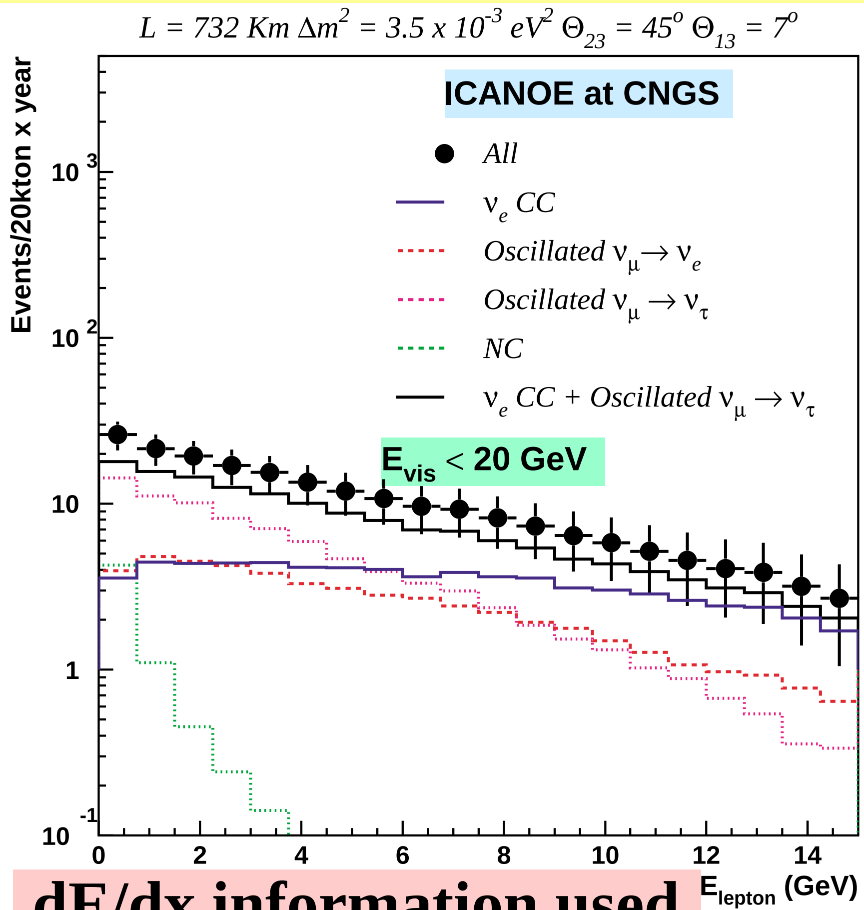


ν_e CC versus ν NC discrimination (I)

NC → γ converting within 3 cm (10 samples) from primary vertex considered as electron candidate



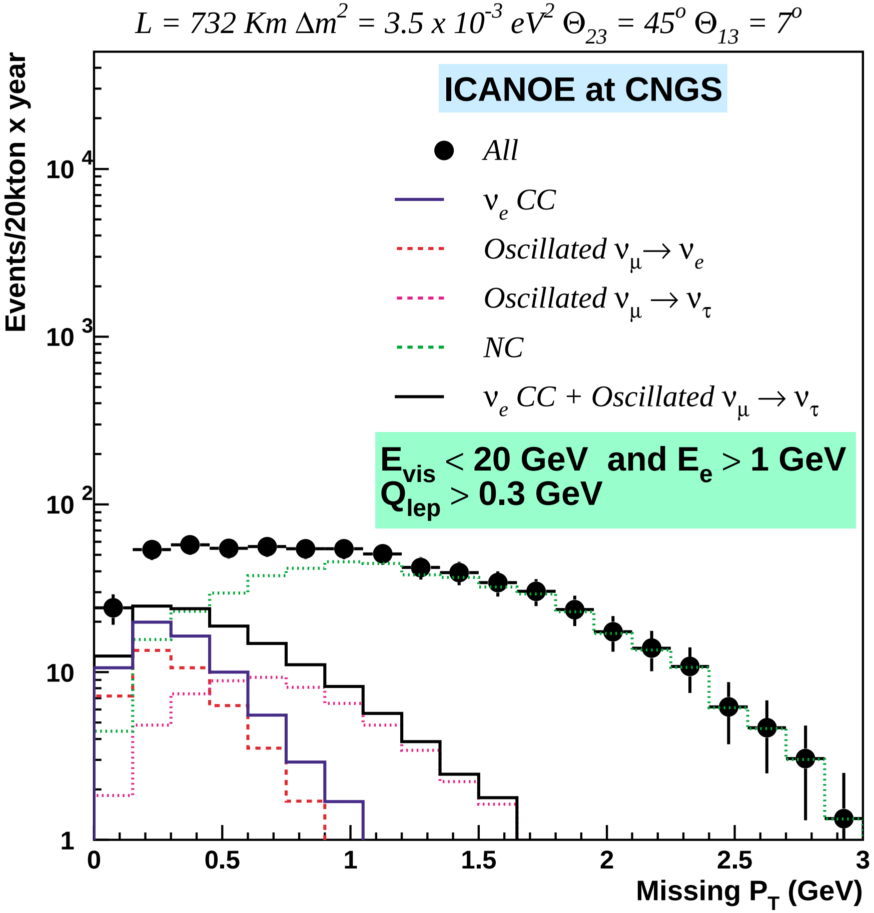
NO dE/dx information used



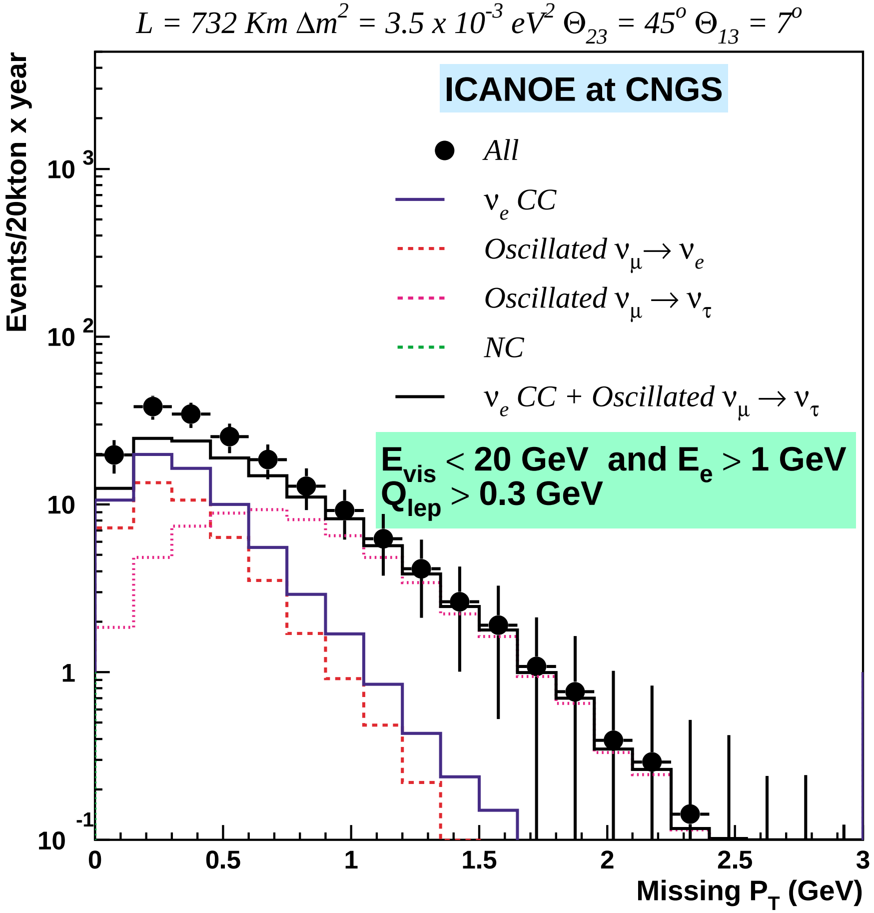
dE/dx information used
Single vs double m.i.p. algorithm provides **>500 rejection factor**

ν_e CC versus ν NC discrimination (II)

NC rejection → Additional discrimination power provided by event kinematics



NO dE/dx information used



dE/dx information used

Solar neutrinos

Rates for
34ktons
and $E_e > 5$ MeV

Signal

Elastic channel

$$\nu_e + e \rightarrow \nu_e + e$$ ~ 10000 events/year

Neutrino absorption

$$\nu_e + {}^{40}Ar \rightarrow e + {}^{40}K^*$$ ~ 45000 events/year

Super allowed process ⇒ larger cross section

Large statistics, high precision measurements

Conclusions

- Liquid Argon imaging technology allows
  - ⇨ **Very high granularity**
  - ⇨ **Very large mass detectors**
  - ⇨ **Bubble-chamber-like detector**
- It has been *successfully tested* on large prototypes (50l, 3T, 15Ton prototype)
  - ⇨ **Has now entered the fully industrialized era (T600)**
- Timescale:
  - ⇨ **T600 first cool-down planned before end 2000**
  - ⇨ **ICANOE proposal been discussed @ CNGS**
- ***The road to SuperICANOE is open...***