Present and future of neutrino (beam) oscillation experiments

Heavy Quarks and Leptons Workshop

Puerto Rico, June 2004

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(special thanks to André Rubbia)

Where are we now

What do we know about neutrino masses and mixing ?

- there exist 3 ‘light’ neutrinos (LEP)
- masses from direct measurements are small (limits from tritium & cosmology)
- neutrino mix (oscillations) → they are massive; PMNS matrix (3 x 3)
- oscillation parameters: 2 large mixing angles $\theta_{sol} \sim \theta_{12}$, $\theta_{atm} \sim \theta_{23}$

  2 independent mass splittings: $\Delta m^2_{sol} \sim \Delta m^2_{12}$

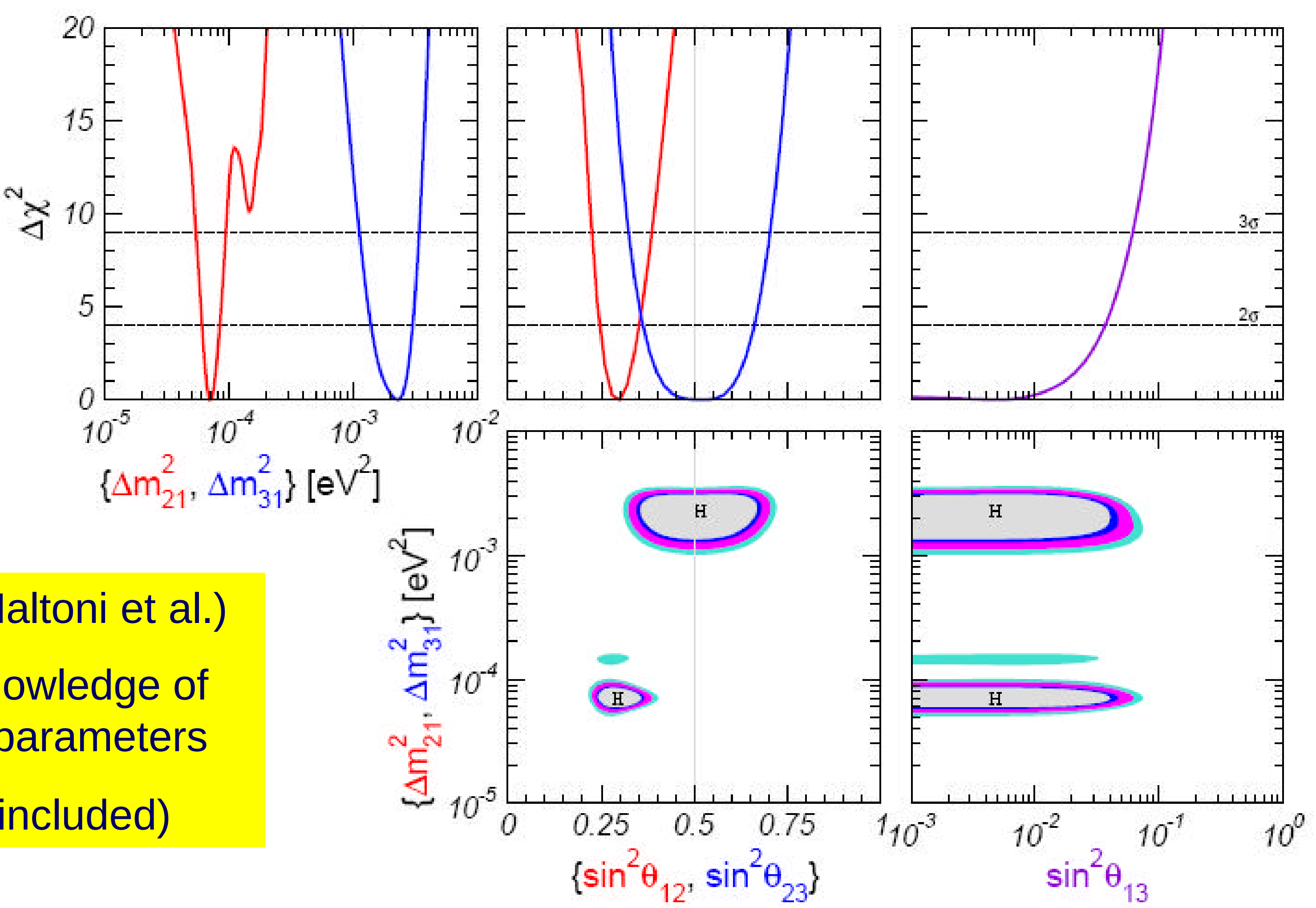
  (masses are small, indeed) $\Delta m^2_{atm} \sim \Delta m^2_{23}$

What we do not know…

- absolute mass values (why are they small ?)
- why θ_{12} and θ_{32} angles are large and θ_{13} seems very small or null ?
- Is mass hierarchy the same as for charged leptons (sign of Δm^2_{23})
- Is there any CP violating phase in the mixing matrix ?

IMPORTANT NOTE: in all this I assume that there is no LSND effect !

Wait for MiniBoone…



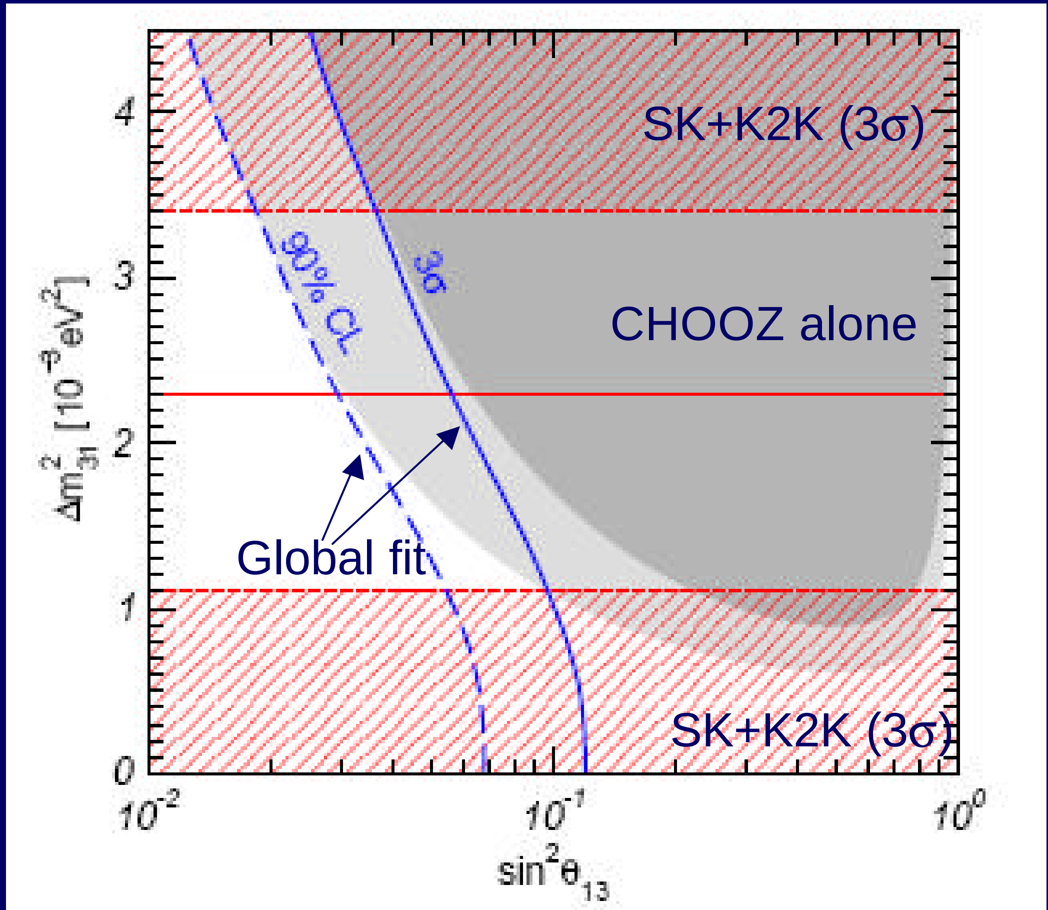
Global fit (Maltoni et al.)

our best knowledge of oscillation parameters

(all data included)

parameter	best fit	2σ	3σ	5σ
Δm^2_{21} [10^{-5}eV^2]	6.9	6.1–8.4	5.4–9.4	2.1–29
Δm^2_{31} [10^{-3}eV^2]	2.3	1.4–3.0	1.1–3.4	0.68–4.4
$\sin^2\theta_{12}$	0.30	0.25–0.35	0.23–0.39	0.16–0.47
$\sin^2\theta_{23}$	0.52	0.36–0.66	0.32–0.70	0.26–0.78
$\sin^2\theta_{13}$	0.005	≤ 0.037	≤ 0.061	≤ 0.13

In particular, estimate of θ_{13} upper bound



Global fit (Maltoni et al.)

CHOOZ, solar, Kamland

+ atmospheric and K2K

Objective of planned and future neutrino beam experiments:

- accurately measure the two Δm^2 , θ_{12} and θ_{23}
- find the value of θ_{13} from P(n_m-n_e)
- show CP violating effects (without matter effects)
- show matter effects (without CP violation effects) → hierarchy

Neutrino mixing matrix and general 3 neutrino oscillation probability

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix} \begin{pmatrix} e^{i\alpha_1/2}\,\nu_1 \\ e^{i\alpha_2/2}\,\nu_2 \\ \nu_3 \end{pmatrix}$$

$$\begin{aligned} P(\nu_\ell \to \nu_{\ell'}) &= \Big|\sum_i U_{\ell i} U^*_{\ell' i} e^{-i(m_i^2/2E)L}\Big|^2 \\ &= \sum_i |U_{\ell i} U^*_{\ell' i}|^2 + \Re \sum_i \sum_{j \neq i} U_{\ell i} U^*_{\ell' i} U^*_{\ell j} U_{\ell' j} e^{i\frac{|m_i^2 - m_j^2| L}{2E}} \end{aligned}$$

For the important case of $P(\nu_\mu \to \nu_e)$ oscillations, we have…

$$P(\nu_\mu \to \nu_e) = \Sigma_{i=1,4} P_i$$

$$P_1 = \sin^2\theta_{23}\sin^2 2\theta_{13}\left(\frac{\Delta_{13}}{B_\pm}\right)^2 \sin^2\frac{B_\pm L}{2}$$ atmospheric part

$$P_2 = \cos^2\theta_{23}\sin^2 2\theta_{12}\left(\frac{\Delta_{12}}{A}\right)^2 \sin^2\frac{AL}{2}$$ solar part

$$P_3 = J\cos\delta\left(\frac{\Delta_{12}}{A}\right)\left(\frac{\Delta_{13}}{B_\pm}\right)\cos\frac{\Delta_{13}L}{2}\sin\frac{AL}{2}\sin\frac{B_\pm L}{2}$$ interference

$$P_4 = \mp J\sin\delta\left(\frac{\Delta_{12}}{A}\right)\left(\frac{\Delta_{13}}{B_\pm}\right)\sin\frac{\Delta_{13}L}{2}\sin\frac{AL}{2}\sin\frac{B_\pm L}{2}$$ interference

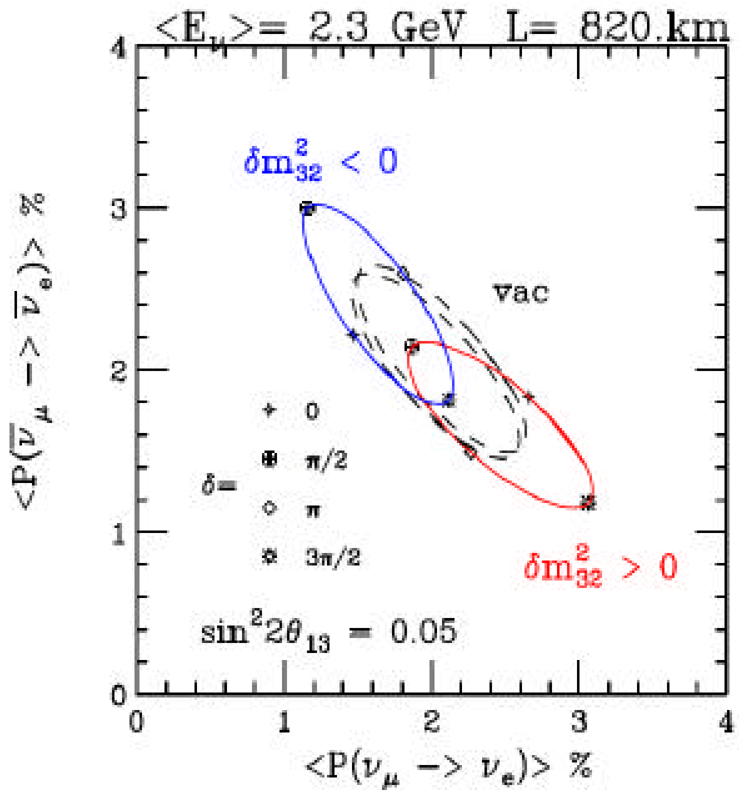
where

$$\Delta_{ij} = \frac{\Delta m^2_{ij}}{2E_\nu}$$
$$A = \sqrt{2}G_F n_e$$
$$B_\pm = |A \pm \Delta_{13}|$$
$$J = \cos\theta_{13}\sin 2\theta_{12}\sin 2\theta_{13}\sin 2\theta_{23}$$

and the $\pm$ signifies neutrinos or antineutrinos

In vacuum, at leading order:

$$P(\nu_\mu \to \nu_e) \propto \sin^2 2\theta_{13}\sin^2\theta_{23}\sin^2\frac{\Delta m^2_{23}L}{4E}$$



Measuring CP violating effects

Best method:

$$A_{CP} = \frac{P(\overline{\nu}_e \to \overline{\nu}_\mu) - P(\nu_e \to \nu_\mu)}{P(\overline{\nu}_e \to \overline{\nu}_\mu) + P(\nu_e \to \nu_\mu)} \simeq \frac{\sin 2\theta_{12}}{\sin \theta_{13}} \cdot \sin\delta \cdot \sin \frac{\Delta m^2_{12} L}{4E}$$

it requires: Δm^2_{12} and $\sin 2q_{12}$ large (LMA solar): OK !

larger effects for long L: matter and 2nd osc.max

however…

$$P(\nu_\mu \to \nu_e) \propto \sin^2 2\theta_{13} \qquad A_{CP} \propto \frac{1}{\sin \theta_{13}}$$

$\sin^2 2q_{13}$ small: low statistics and large asymmetry

$\sin^2 2q_{13}$ large: high statistics and small asymmetry

impact on the detector design

…and:

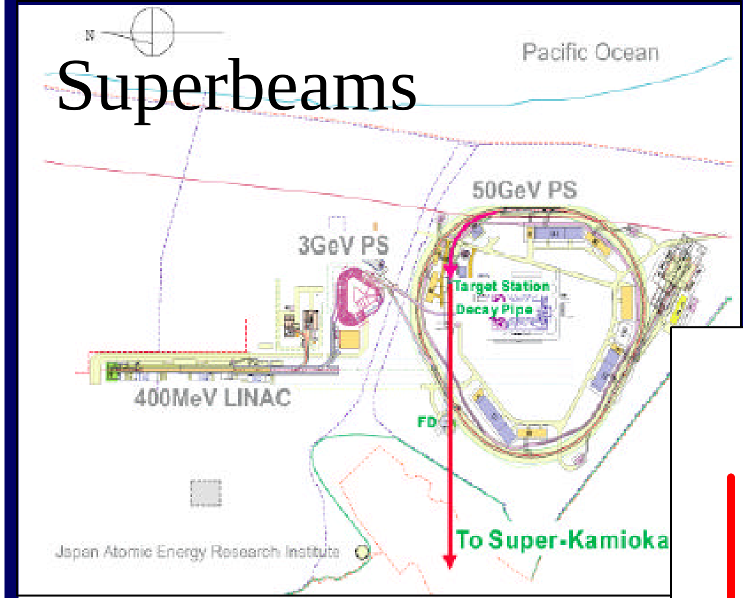
$$P(\nu_\mu \to \nu_e) \propto \sin^2 \frac{\Delta m^2_{23} L}{4E}$$

oscillations are governed by Δm^2_{atm} , L and E:

E » 5 GeV → L » 3000 km

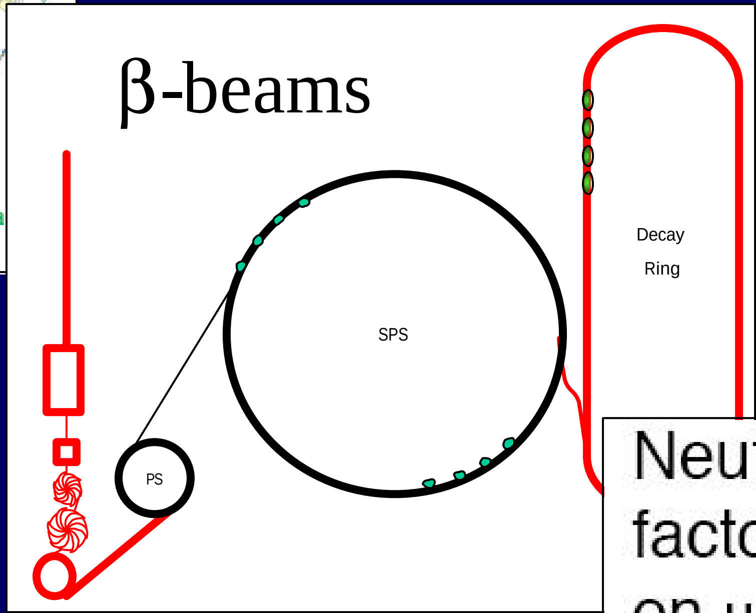
flux too low with a conventional LBL beam

High intensity neutrinos facilities



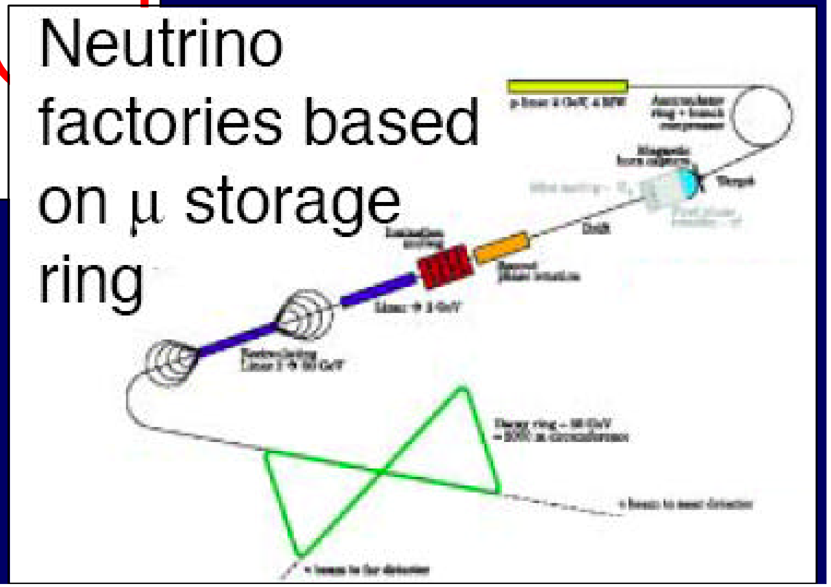
$$p^{\pm} \rightarrow m^{\pm} \overset{(-)}{n}_m$$

Select focusing sign



$${}^{Z}A \rightarrow {}^{Z\mp 1}A \; b^{\pm} \; \overset{(-)}{n}_e$$

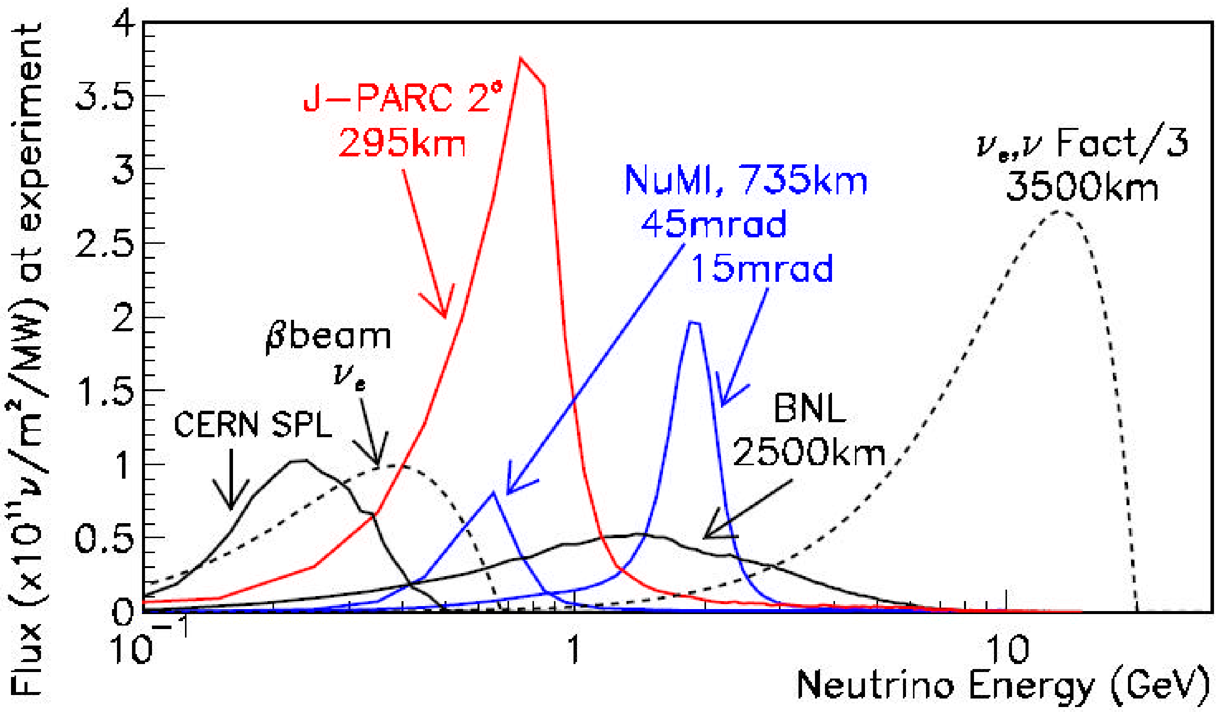
Select ion



Select ring sign

$$\left.\begin{array}{l} m^{-} \rightarrow e^{-}\bar{n}_e n_m \\ m^{+} \rightarrow e^{+} n_e \bar{n}_m \end{array}\right\}$$

Future neutrino beams



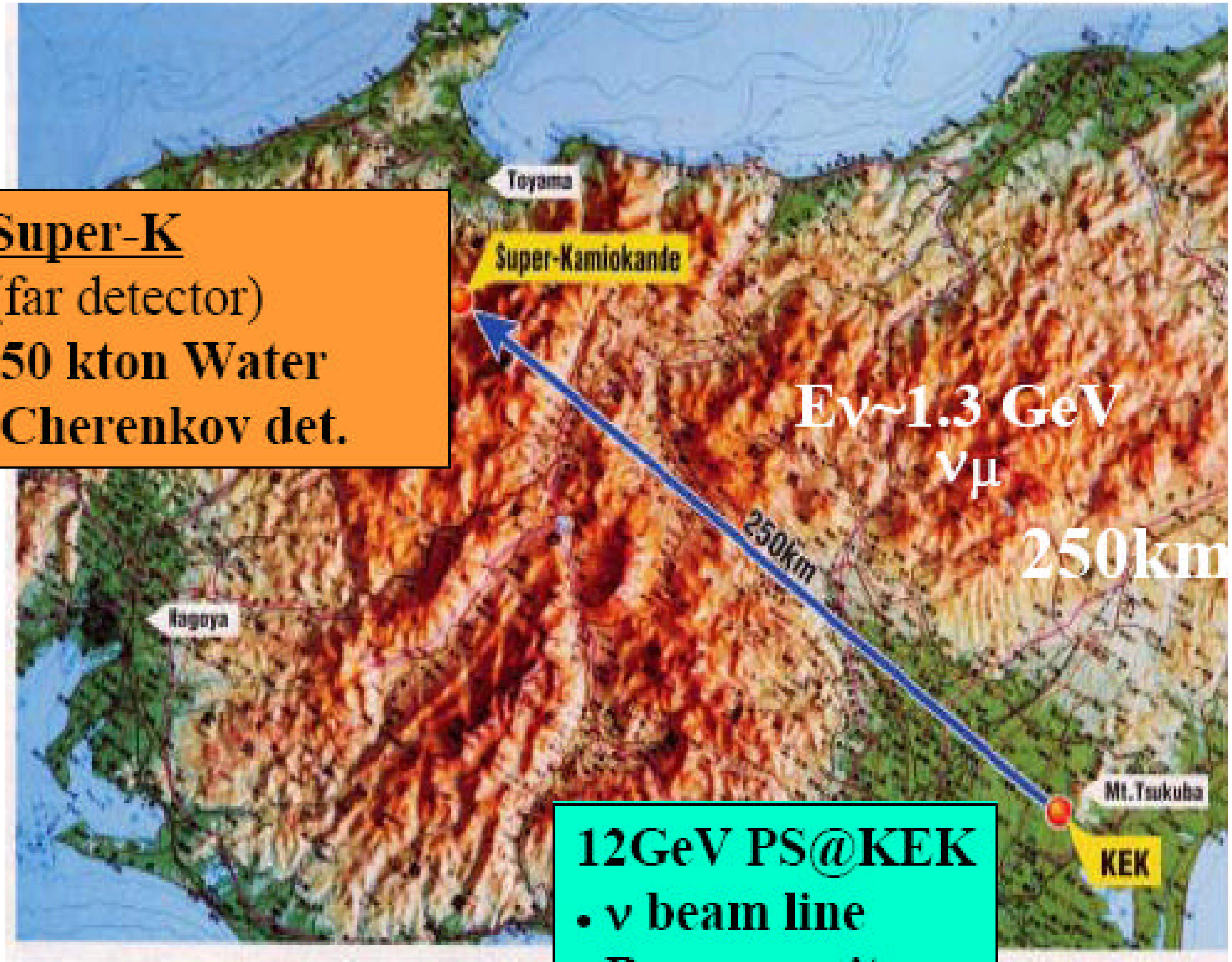
Outstanding goals

Physics	Value of $\sin^2 2\theta_{13}$ $> 4 \times 10^{-2}$	$> 1 \times 10^{-2}$	$> 10^{-3}$	$> 10^{-4}$
Seeing $\theta_{13} \neq 0$	MINOS CNGS	Conventional Superbeams Phase I	Conventional Superbeams Phase II	ν Factory $L \geq 3500$ km
Mass Hierarchy	Combinations of Phase I Superbeams	Combinations of Phase II Super/β-beams	Combinations of ν Factory and Super/β-beams	ν Factory $L \sim 7700$ km
Evidence for CP-violation	Combinations of Phase I Superbeams	Combinations of Phase II Super/β-beams	Combinations of ν Factory and Super/β-beams	Combinations of ν Factory 2 baselines

Back from the future: work in progress…

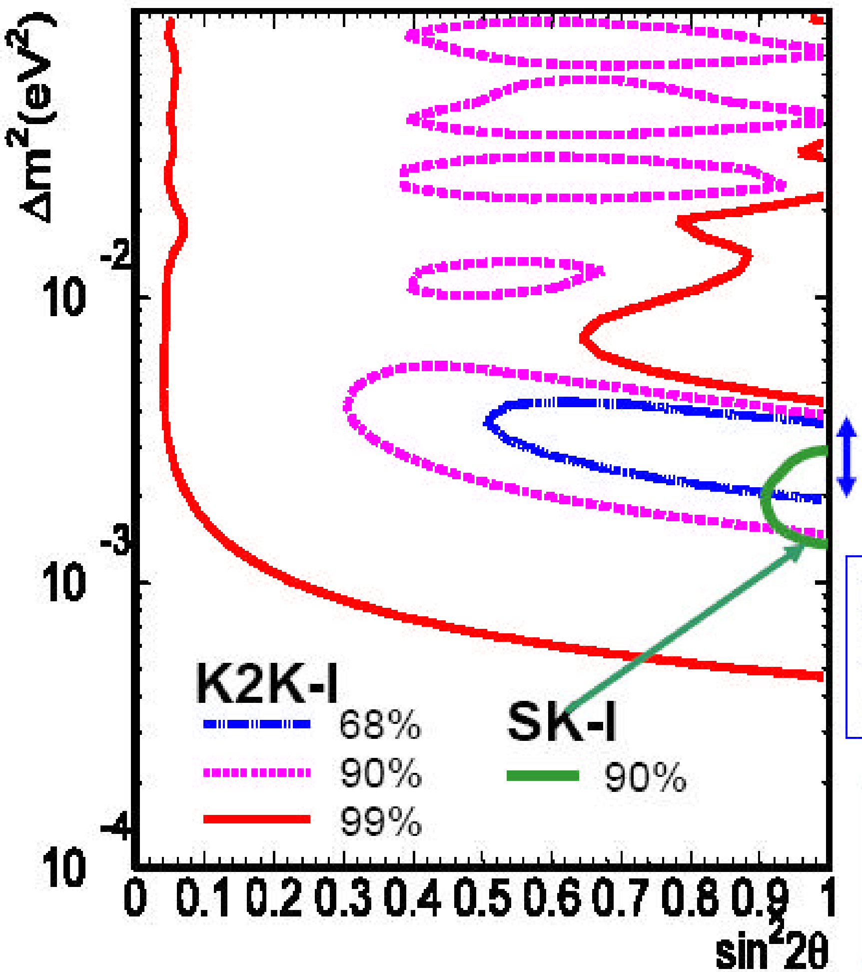
K2K: the mother of all LBL experiments

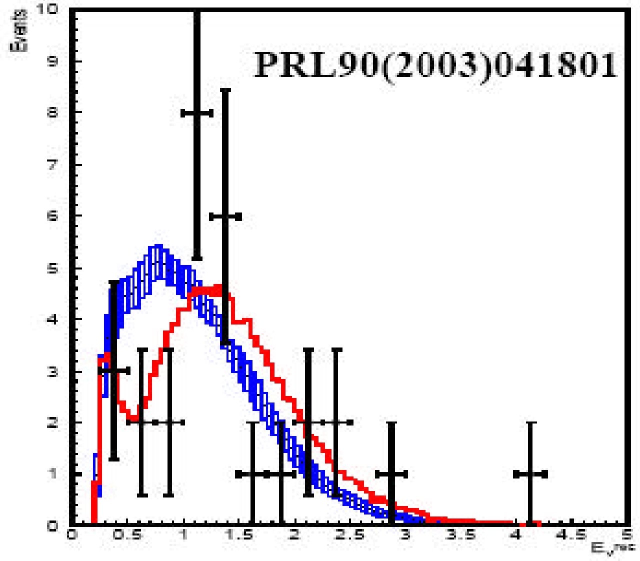
Super-K
(far detector)
50 kton Water Cherenkov det.



12GeV PS@KEK
- ν beam line
- Beam monitor
- Near detectors

SK plus K2K



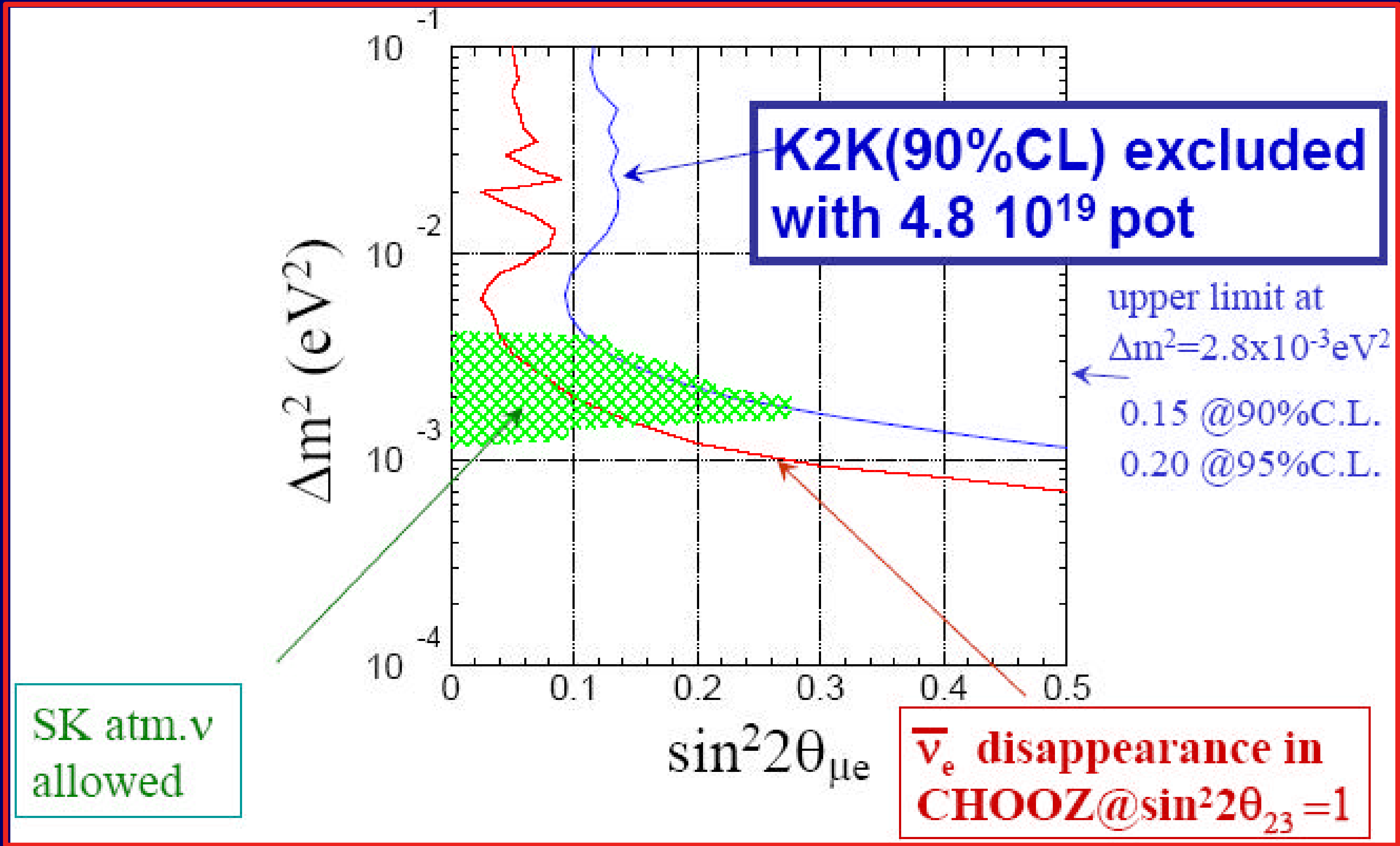


K2K 90%CL
1.5~3.9x10^{-3}eV^2
@ $\sin^2 2\theta=1$

Atm. 90% CL
$\sin^2 2\theta > 0.9$
$1.3\times10^{-3} < \Delta m^2 < 3.0\times10^{-3}$eV^2

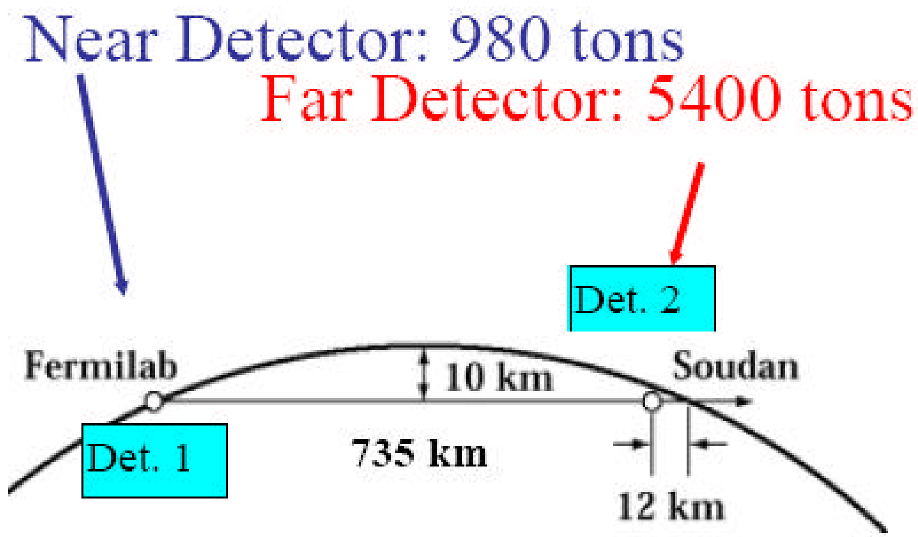
The two experiments agree well: full mixing and Δm^2 in the range of 1-3 eV^2

K2K looking for electron appearance



Next to come on duty:MINOS in the NuMi neutrino beam

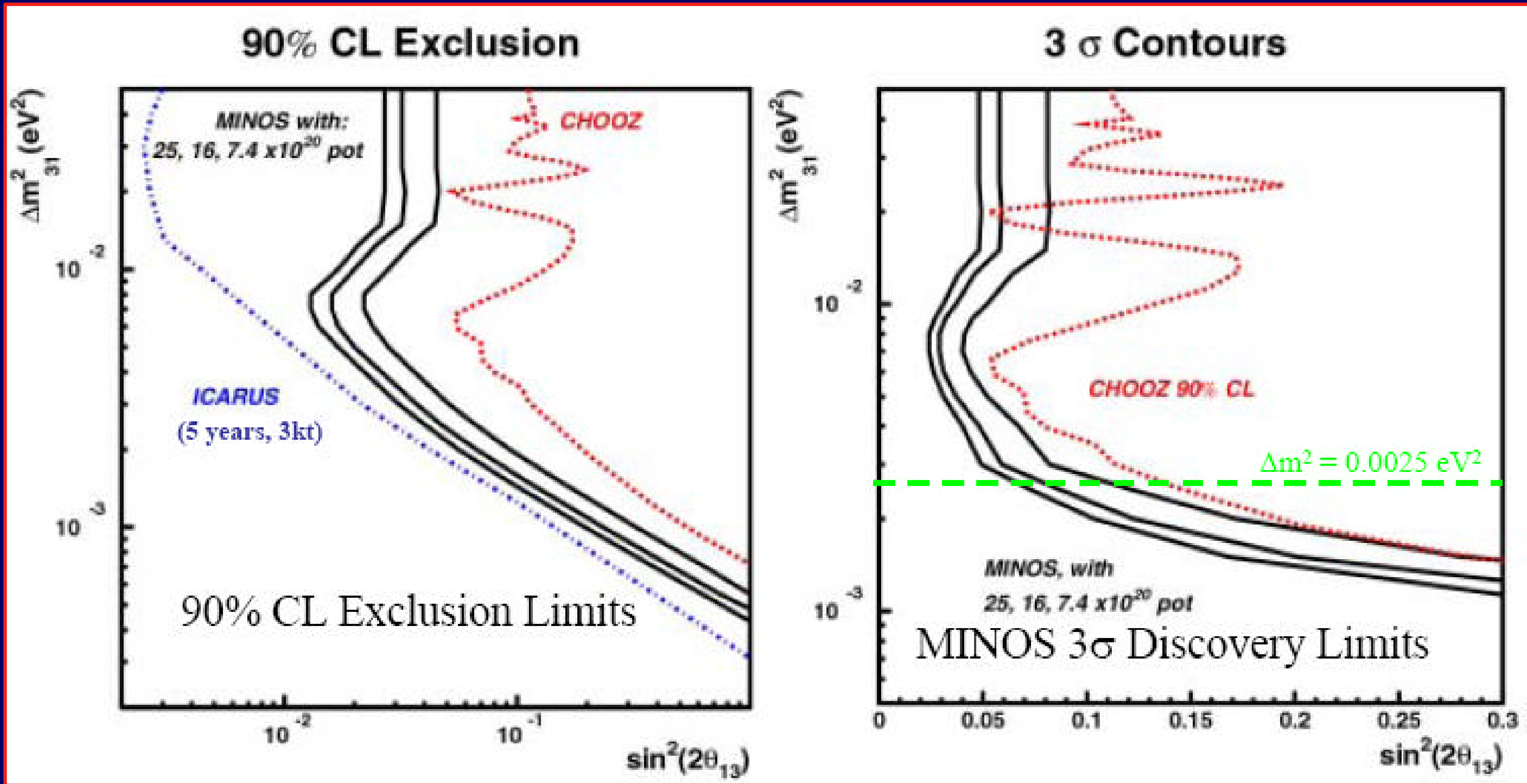
Start 2005



Magnetized steel/scintillator calorimeter

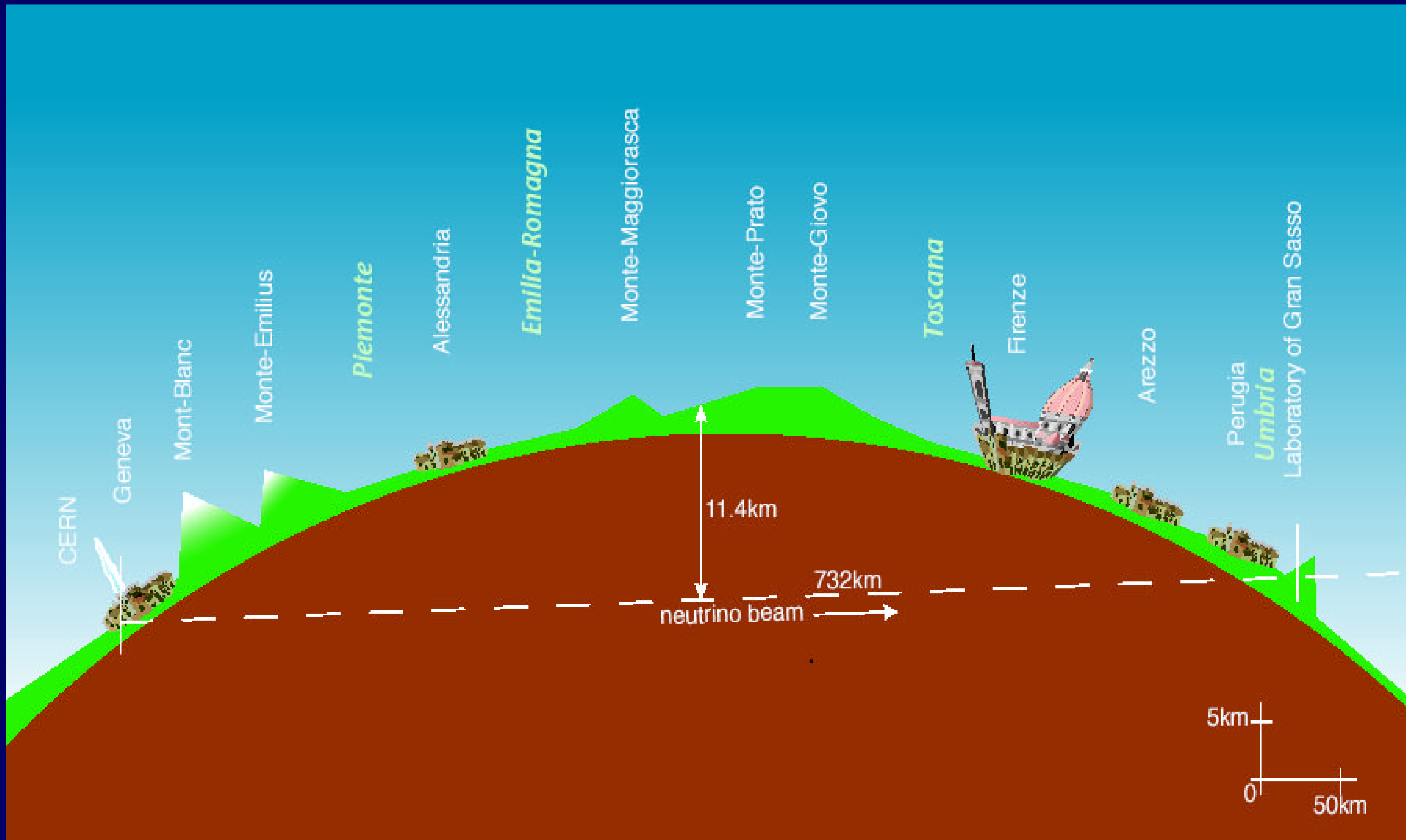
- low E neutrinos (few GeV): ν_μ disappearance experiment
- 4 x10^{20} pot/y → 2500 ν_μ CC/year
- compare Det1-Det2 response vs E → in 2-6 years sensitivity to Δm^2_{atm}

electron appearance in MINOS



τ appearance at LNGS in the CNGS beam

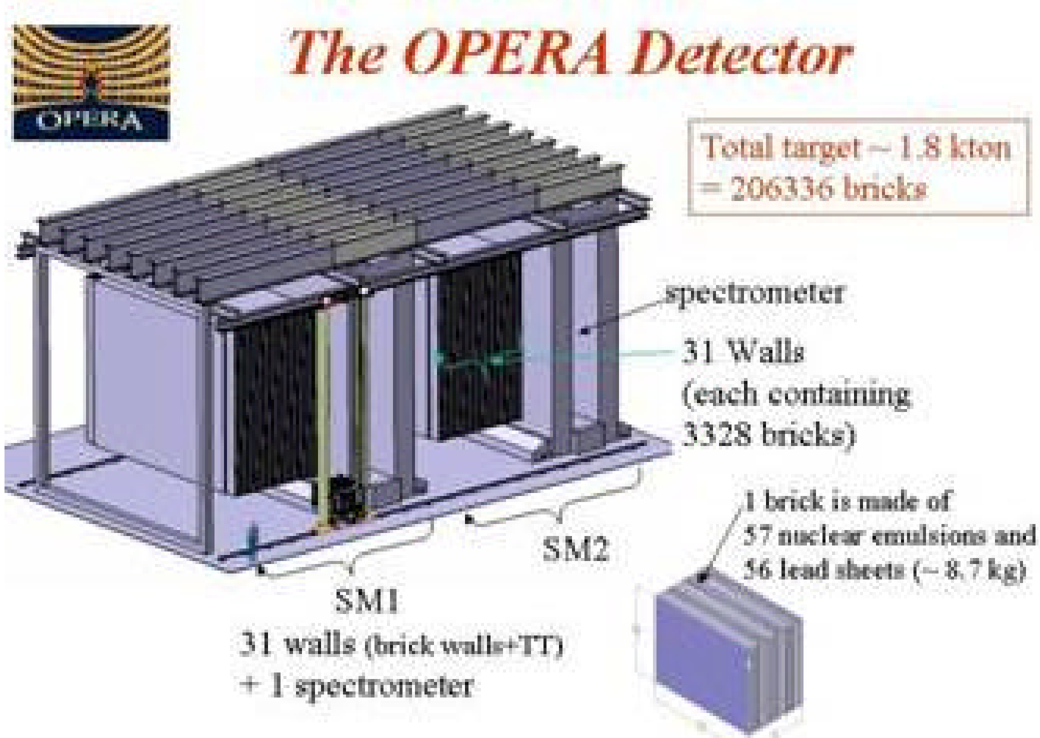
Start 2006



- **High energy beam: <E> of about 20 GeV: tau appearance search**
- **4.5 x10^{19} pot/year from the CNGS. In the hypothesis of no oscillation:**
- **2600 ν_μ CC/year per kton detector mass**
- **Assuming ν_μ - ν_τ oscillation, with parameters $\sin^2 2\theta = 1$ and $\Delta m^2 = 2.5 \times 10^{-3}$ eV^2:**

  15 ν_τ CC/year per kton
- **construction well advanced: in schedule. Two experiments: OPERA and ICARUS**

The OPERA experiment at LNGS: the rebirth of the emulsion technique



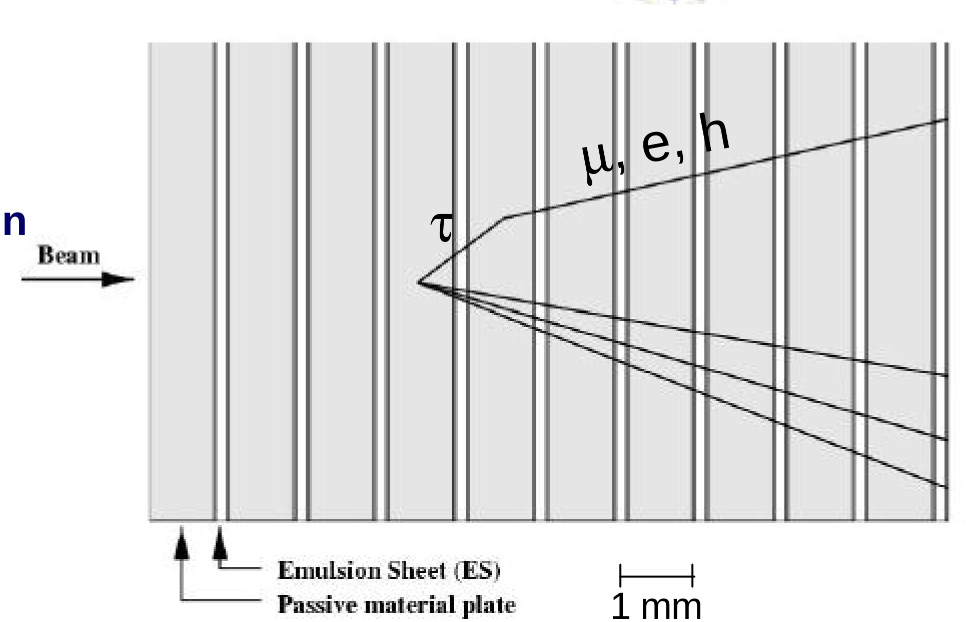
- detector: 1800 ton emulsion/lead bricks (ECC technique) complemented by tracking scintillator planes and two muon spectrometers
- industrial emulsion production and handling
- need huge scanning power/speed: > tens of automatic microscope running in parallel @ 10 cm^2/hour (advances of the technique)

- Low BG experiment: (<1 ev.) τ track reconstruction

- Low statistics: about 10 events/5 years at nominal CNGS intensity @ SK parameter values: statistics goes like $(\Delta m^2)^2$

- Aim at beam intensity increase

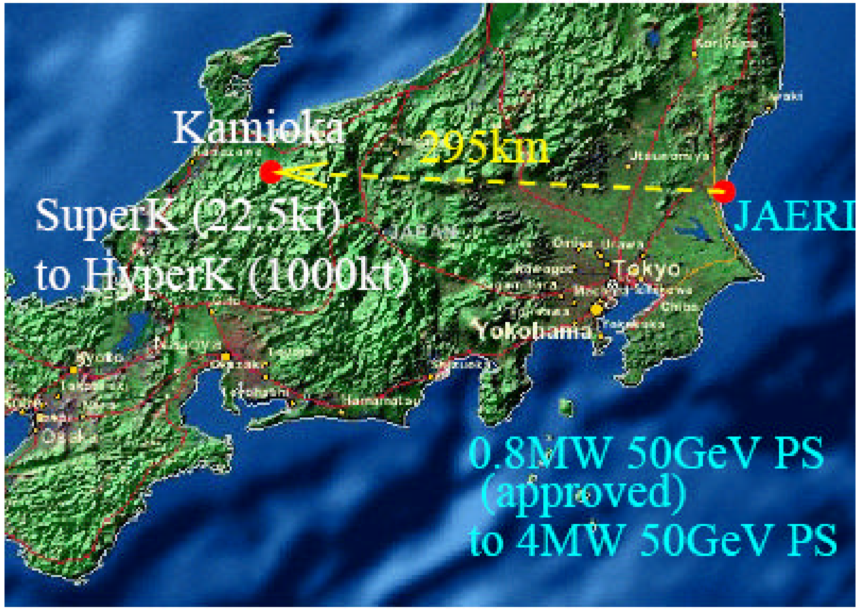
- Installation in progress



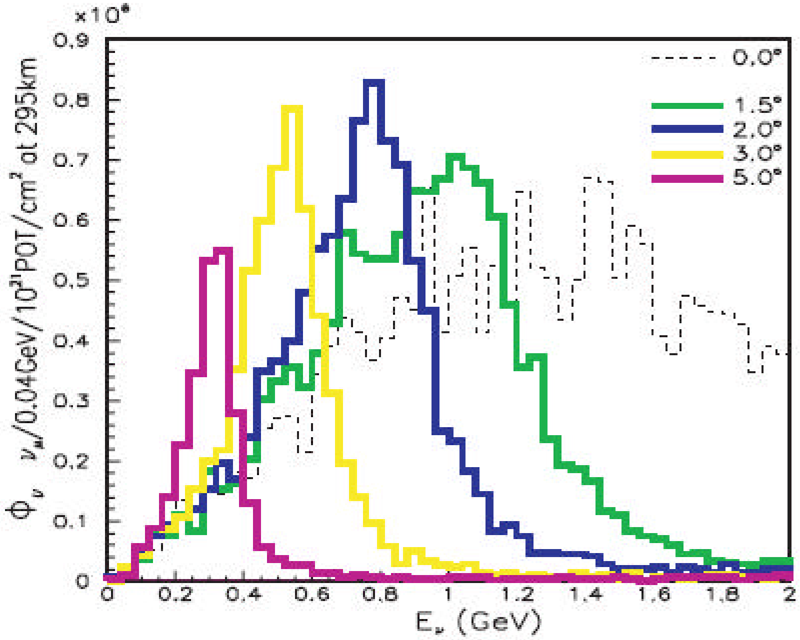
Measure θ_{13}

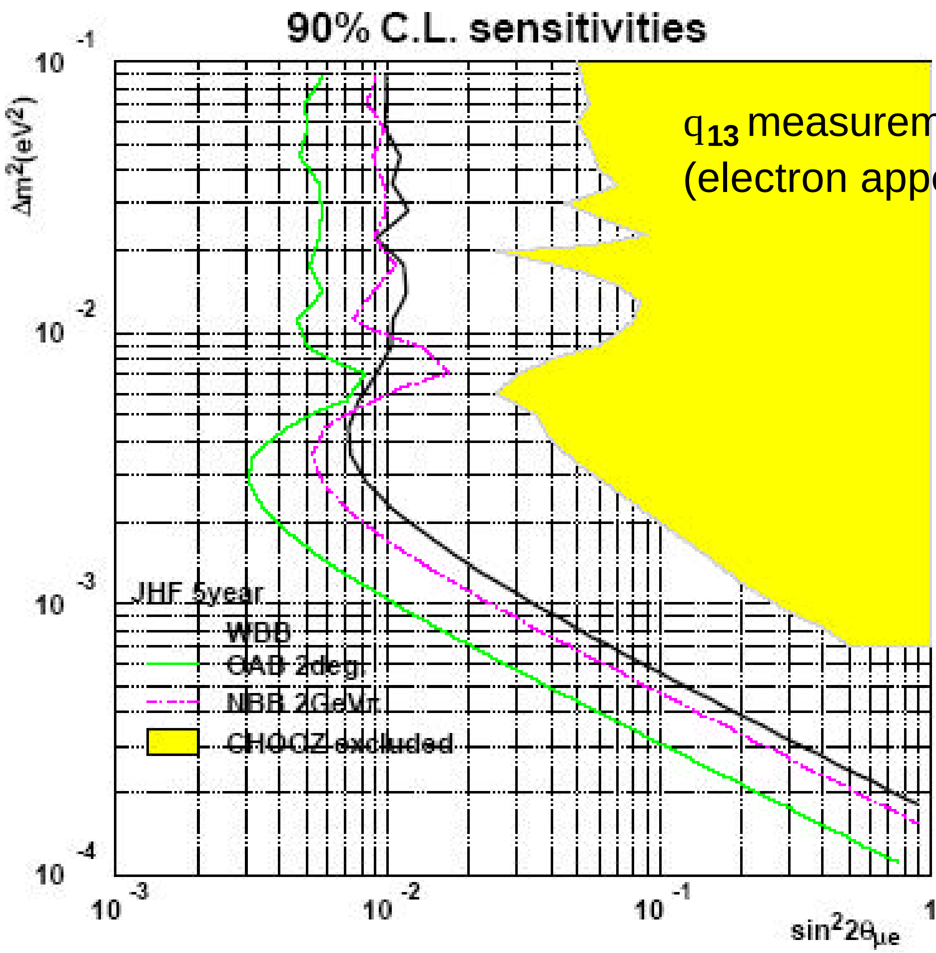
Off-axis beam in Japan, another experiment with SK: T2K

Start 2009



- low E_ν (<1 GeV) Super-Beam: 10^{21} pot/year
- @ 2° → 3000 ν_μ CC/year (x10 w.r.t. K2K)
- SK plus two near detectors (280 m and 2 km)

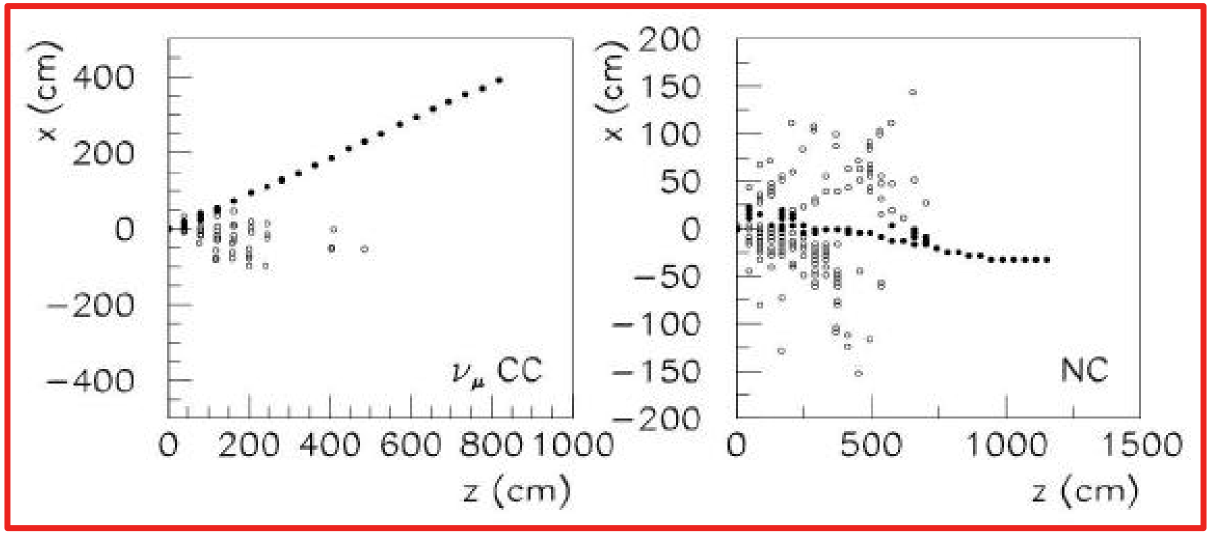


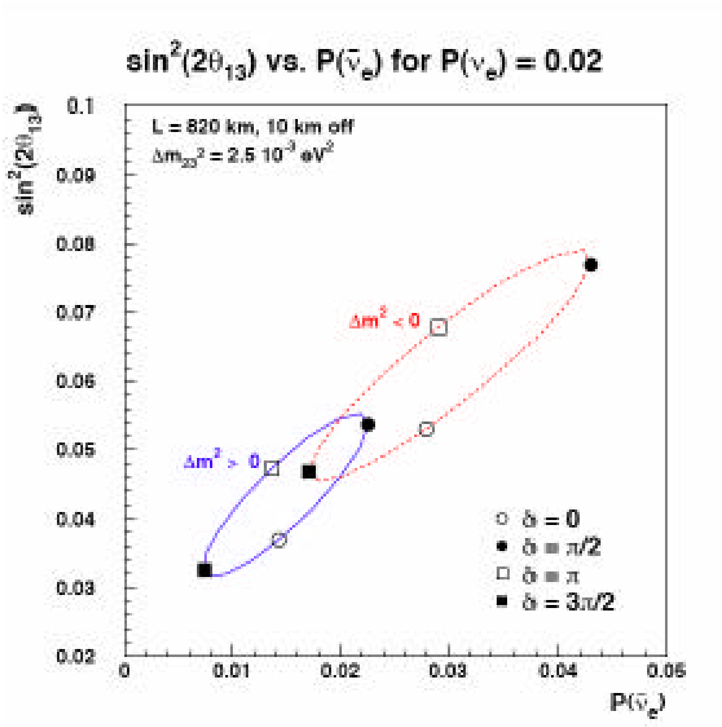


θ_{13} measurement
(electron appearance)

An off-axis experiment in the NuMI beam: NoνA

- recent proposal (March 04); nominal NuMI beam: 0.4 MW
- far detector: 50 kton @ Ash River (MN) 810 km from Fermilab (12 km, 14 mrad off-axis)
- technique: particleboard/liquid scintillator with fiber/APD R/O
- near detector: same as far, 1 ton fid. mass; also use MINERVA ?

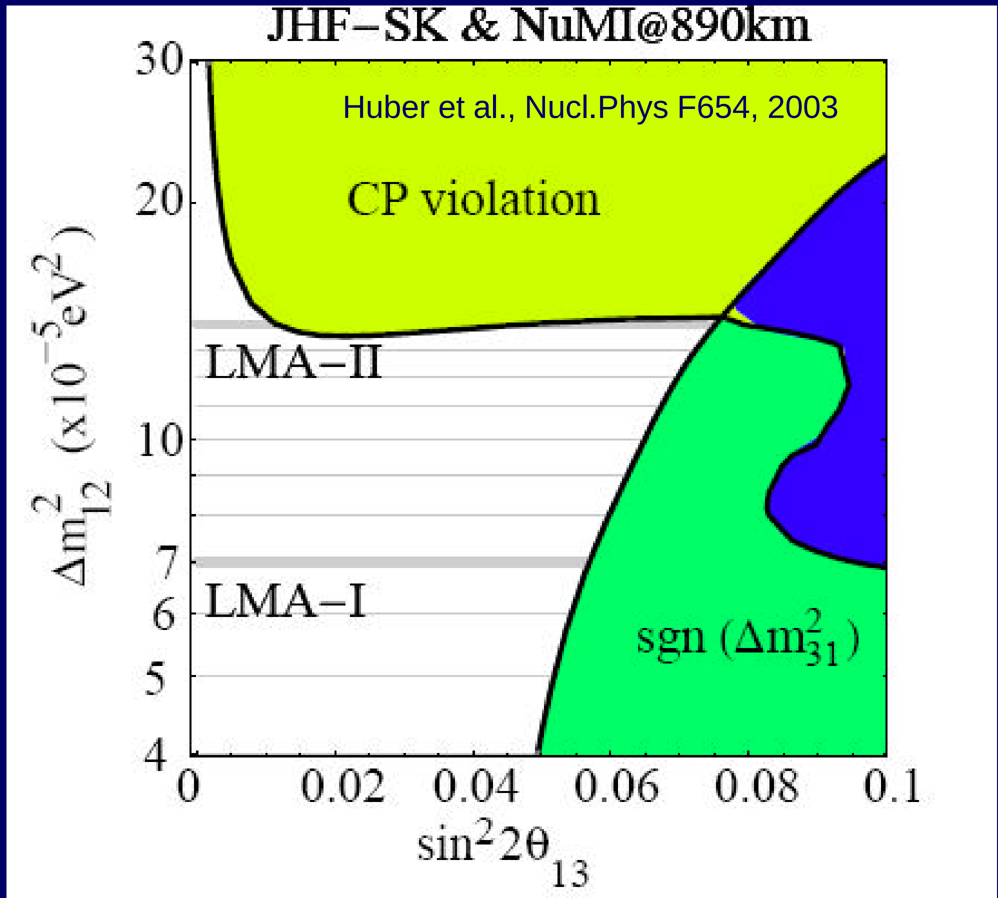




Conventional detector design: well known technique of low density fine grained calorimeters (CHARM II at CERN)

cost of about $150 M

With some chance, next generation experiments on θ_{13} could measure mass hierarchy and CP effects



Pin down CP phase and mass hierarchy

More distant future: Super-Beams, Beta-Beams, n-fact

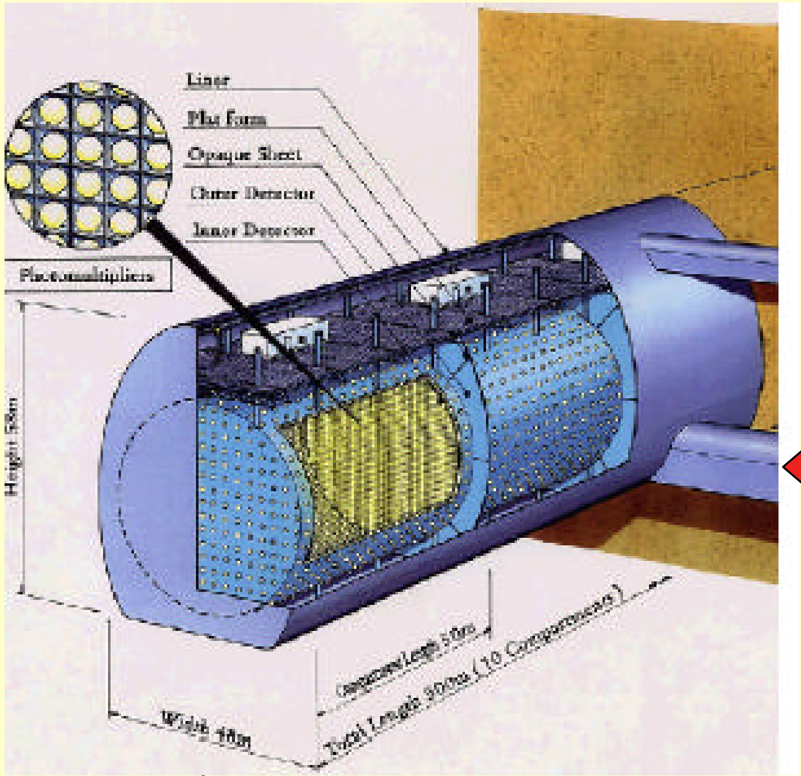
Start 2015 -2020

Outstanding goal: detect CP violation (if q_{13} not zero!)

high intensity is a must; two approaches on **L/E** :

long/high (e.g. BNL-Fermilab projects):
- matter effects increase signal (E_{max1}/E_{max2})
- CP effects increase with L (3π/2 vs π/2)

short/low (e.g. CERN-SPL to Frejus):
- below threshold for BG (? …Fermi motion)
- atmospheric neutrino BG
- antineutrino x-section small



DETECTORS

500-1000 kton Water Cerenkov ‘a la SK’ (Hyper-K, UNO) are considered as baseline

Rationale: exploit a well known technique
aim at a ‘reasonable’ cost

HOWEVER….

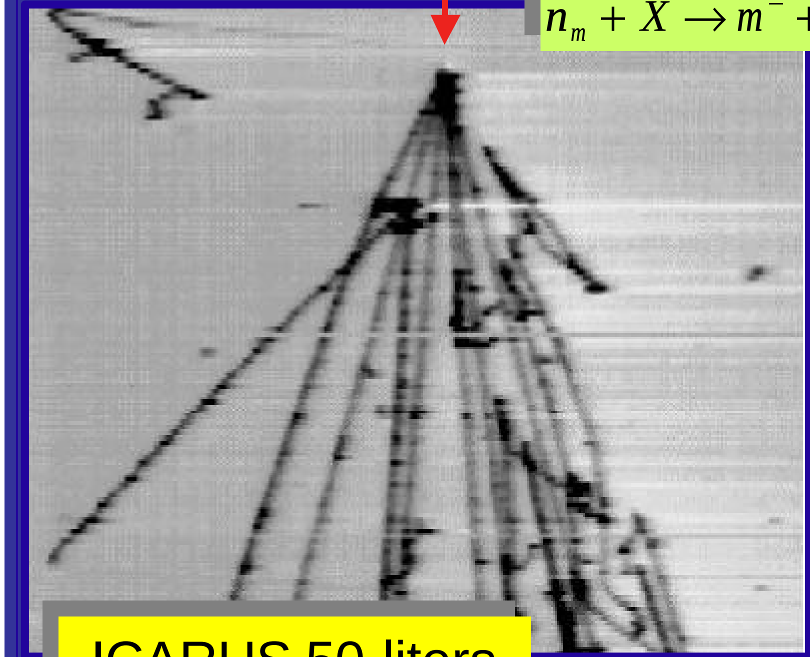
…liquid Argon instead of liquid water ?

See A.E. and A. Rubbia

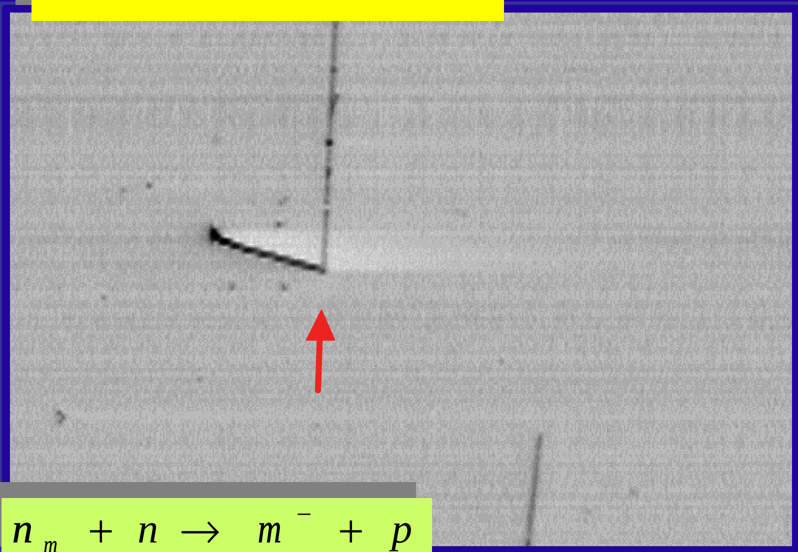
Contribution to the Workshop on Physics with a Multi-MW Proton Source, CERN, 25-27 May 2004

Real neutrino events observed by LAr TPC and water Cerenkov

$n_m + X \rightarrow m^- + many\ prongs$

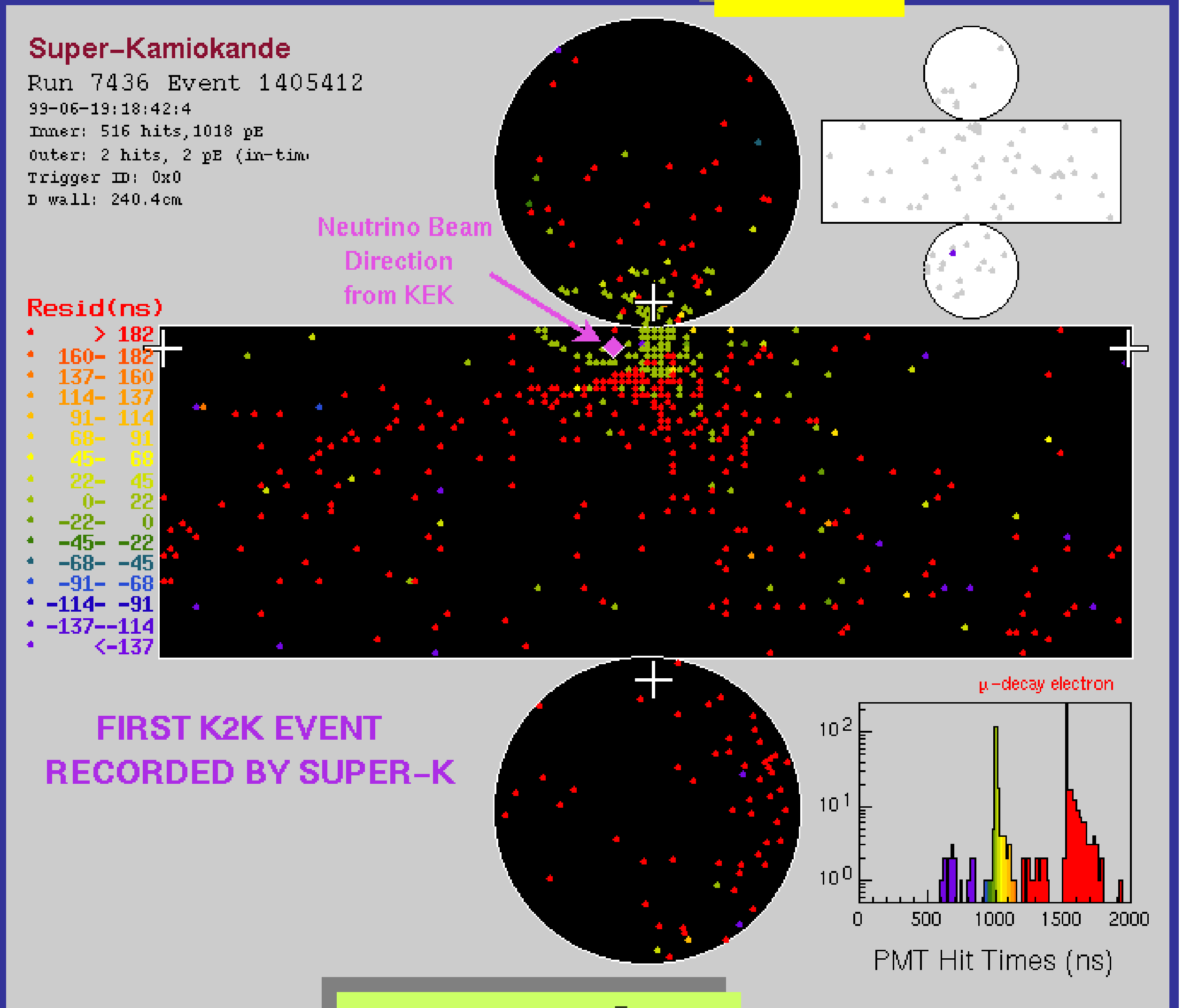


ICARUS 50 liters



$n_m + n \rightarrow m^- + p$

K2K

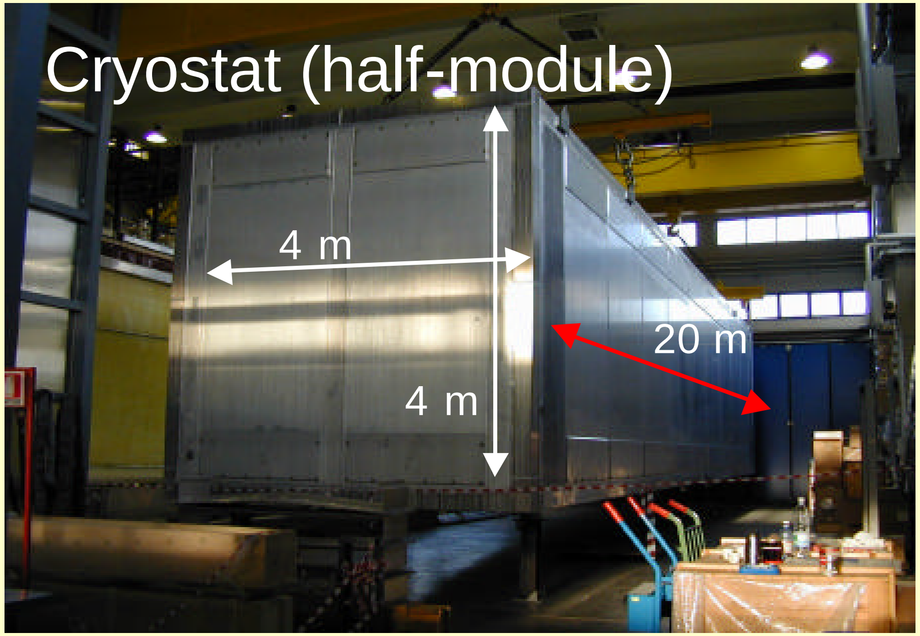


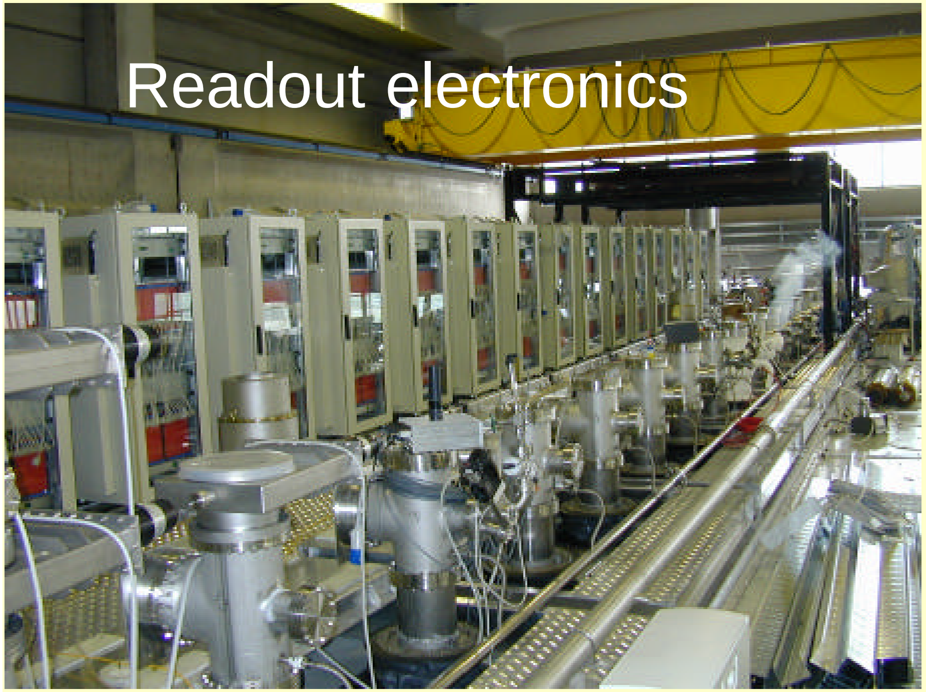
$n_m + n \rightarrow m^- + p$

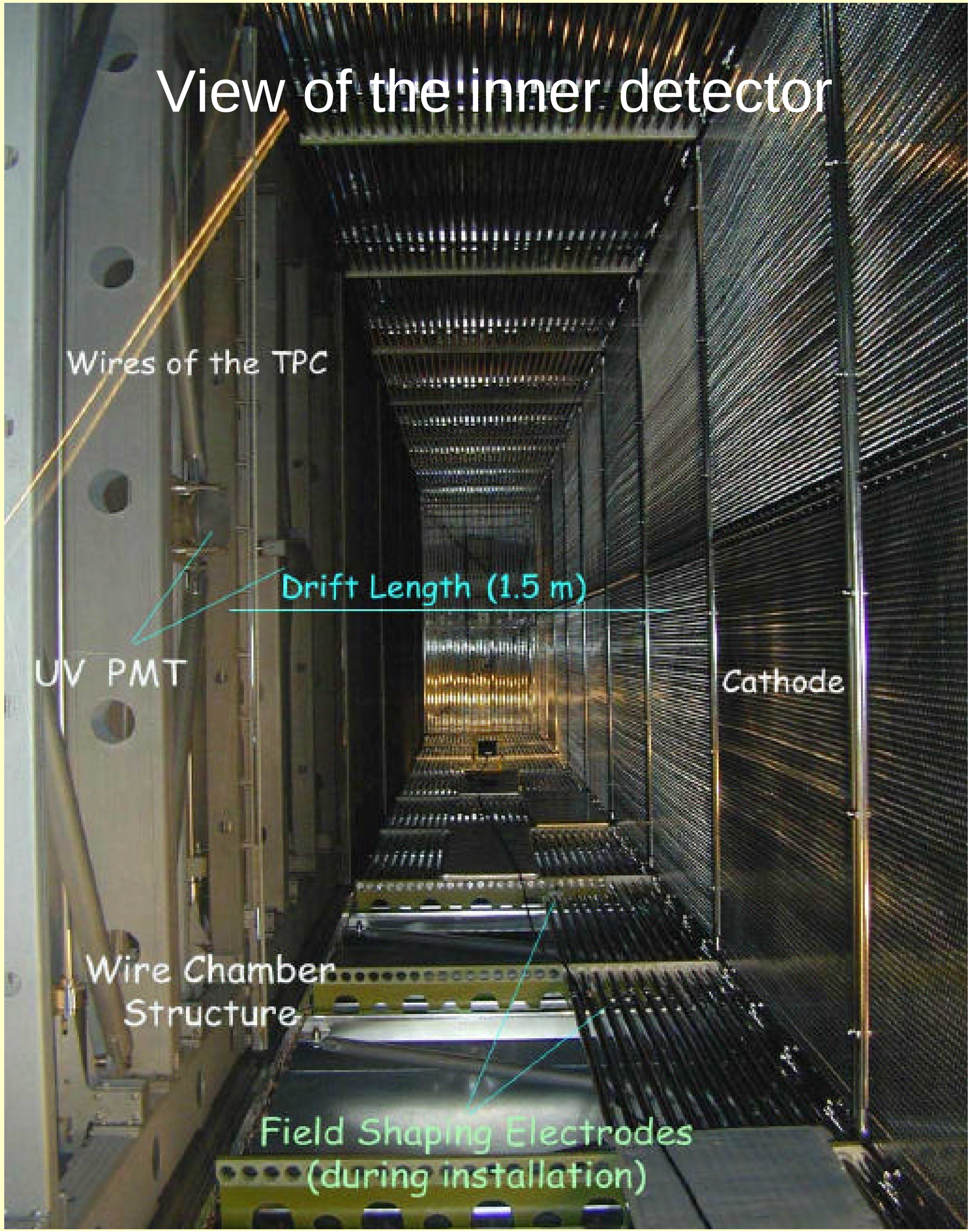
LAr TPC story…

- 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): <u>LAr TPC conceived and proposed</u>
- 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): <u>T600 installation and commissioning at LNGS</u>
- …

ICARUS T300 detector







Liquid Argon medium properties

	Water	Liquid Argon
Density (g/cm³)	1	1.4
Radiation length (cm)	36.1	14.0
Interaction length (cm)	83.6	83.6
dE/dx (MeV/cm)	1.9	2.1
Refractive index (visible)	1.33	1.24
Cerenkov angle	42°	36°
Cerenkov $d^2N/dEdx$ (b=1)	~ 160 eV^{-1} cm^{-1}	~ 130 eV^{-1} cm^{-1}
Muon Cerenkov threshold (p in MeV/c)	120	140
Scintillation (E=0 V/cm)	No	Yes (~ 50000 g/MeV @ l=128nm)
Long electron drift	Not possible	Possible (μ = 500 cm^2/Vs)
Boiling point @ 1 bar	373 K	87 K

When a charged particle traverses LAr:

1) Ionization process

W_e = 23.6 ± 0.3 eV

2) Scintillation (luminescence)

W_γ = 19.5 eV

UV “line” (λ=128 nm ⇔ 9.7 eV)

No more ionization: Argon is transparent

Only Rayleigh-scattering

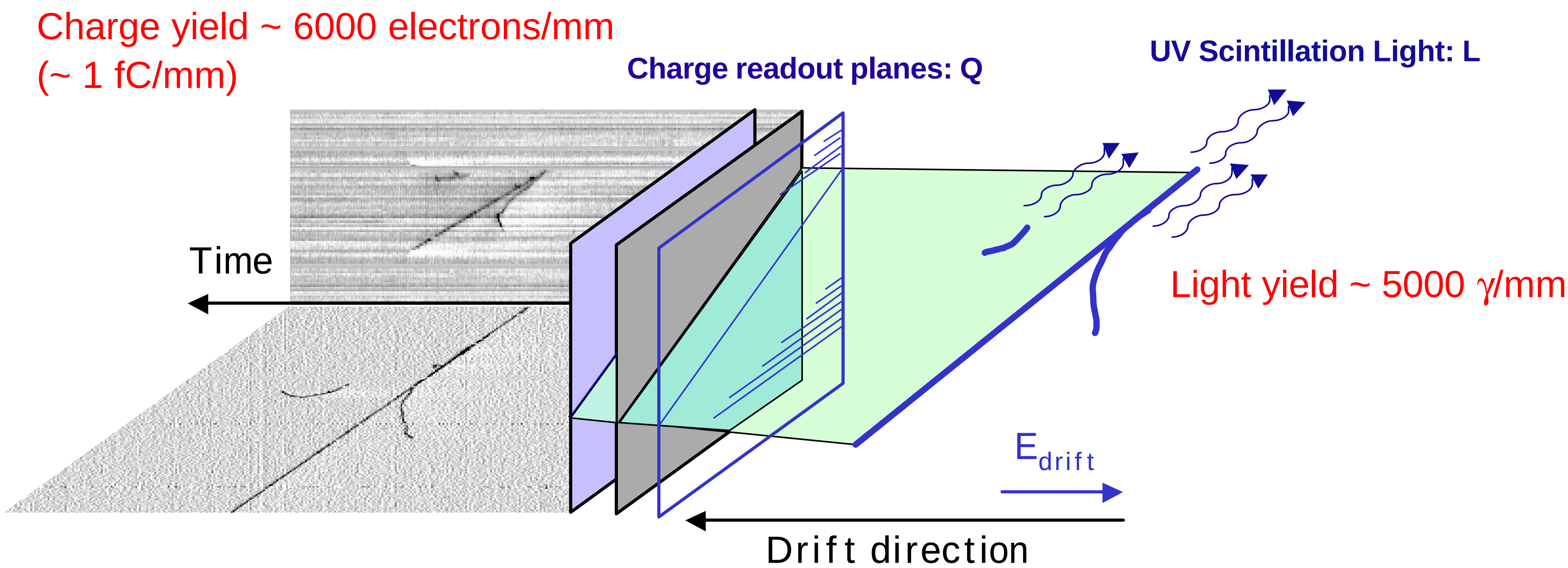
3) Cerenkov light (if relativistic particle)

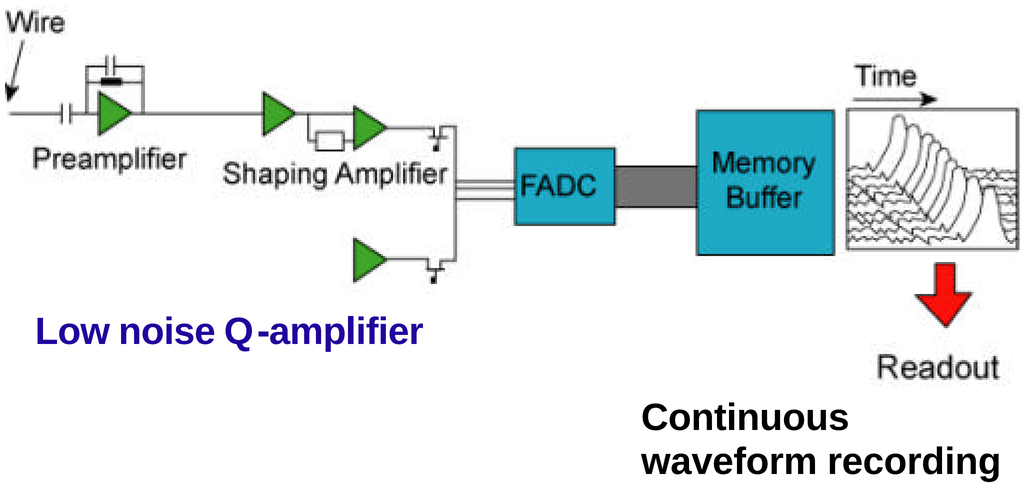
☞ **Charge**

☞ **Scintillation light (VUV)**

☞ **Cerenkov light (if b>1/n)**

The Liquid Argon TPC principle



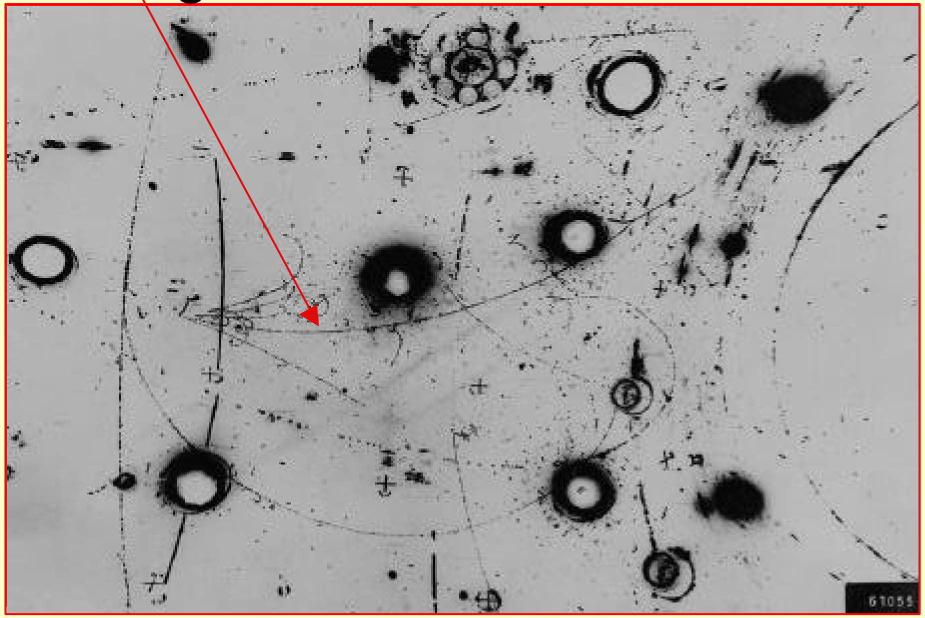
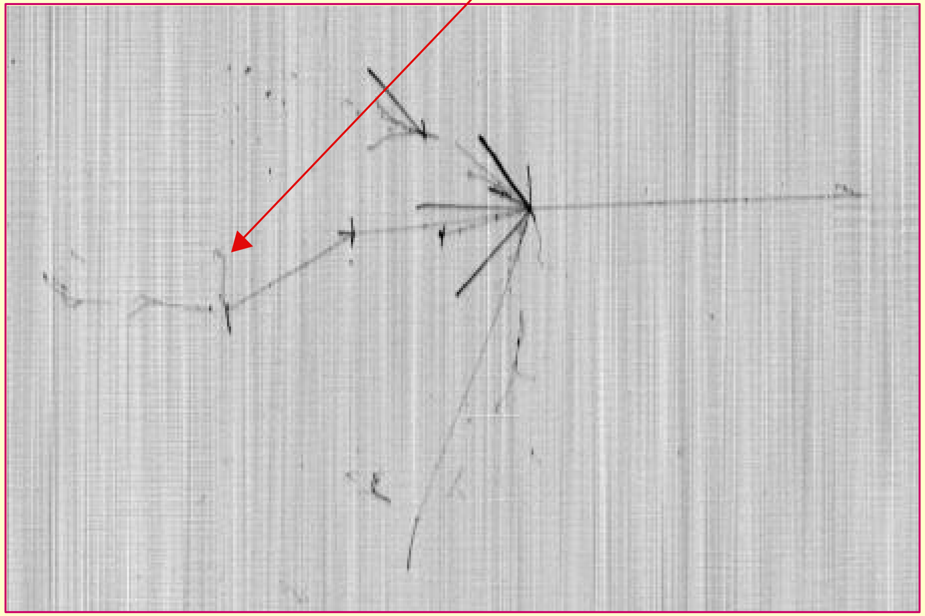


- High density
- Non-destructive readout
- Continuously sensitive
- Self-triggering
- t_0 available (scintillation)

…an electronic bubble chamber

Bubble diameter ~ 3 mm (diffraction limited)

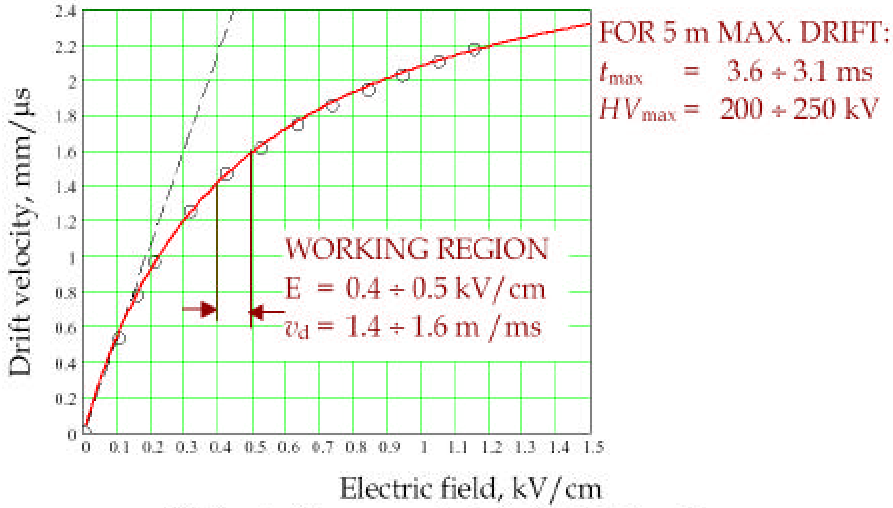
Bubble size ~ 3x3x0.4 mm^3

Gargamelle bubble chamber	ICARUS electronic chamber
	

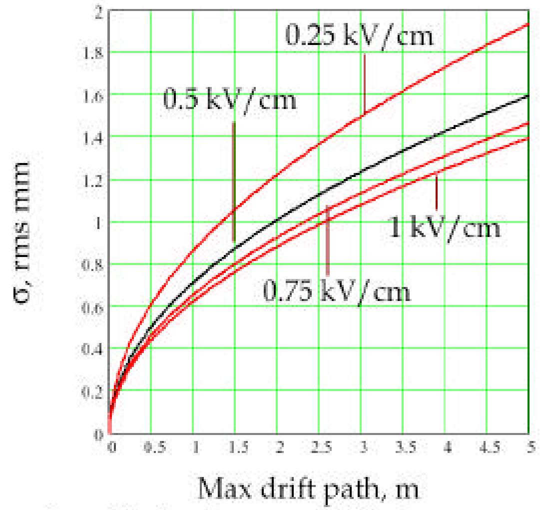
Medium	*Heavy freon*	
Sensitive mass	3.0	ton
Density	1.5	g/cm^3
Radiation length	11.0	cm
Collision length	49.5	cm
dE/dx	2.3	MeV/cm

Medium	*Liquid Argon*	
Sensitive mass	Many ktons	
Density	1.4	g/cm^3
Radiation length	14.0	cm
Collision length	54.8	cm
dE/dx	2.1	MeV/cm

Electron drift properties in liquid Argon



Drift velocity versus electric field in liquid argon



Longitudinal rms diffusion spread versus drift paths at different electric field intensities

$$\sigma_D = \sqrt{2 \cdot D \cdot \frac{x}{v_d}}$$

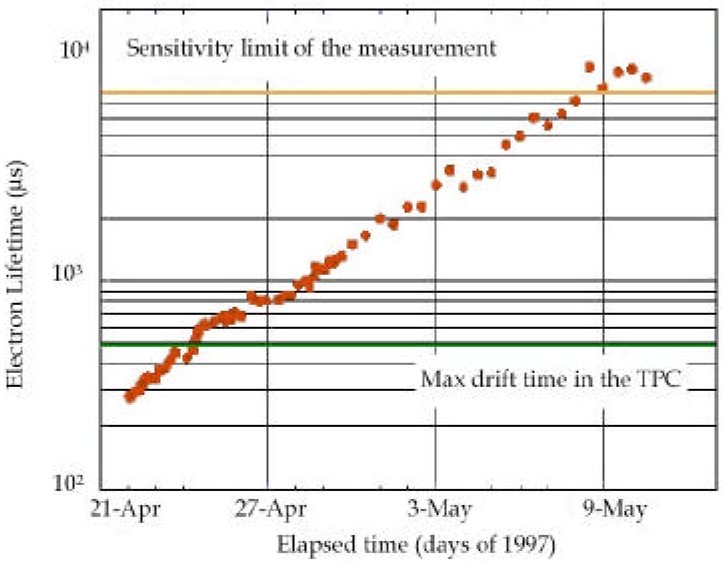
$D = 4.06\ cm^2/s$

$\sigma_D = 0.9\ mm \cdot \sqrt{T_D[ms]}$

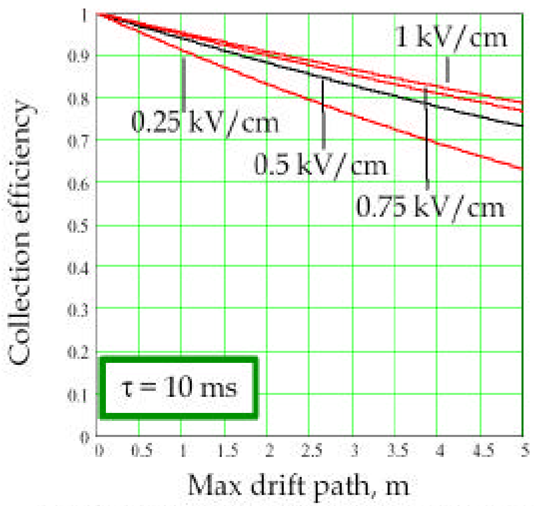
Longitudinal rms diffusion spread at 0.5 kV/cm

Average $\langle\sigma_D\rangle$ = 1.1 mm

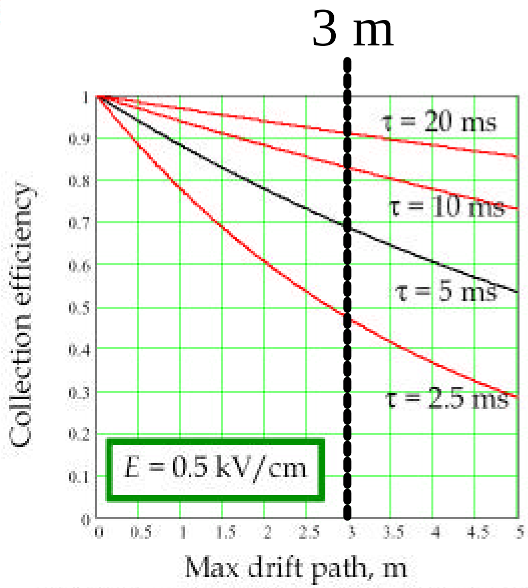
Maximum σ_{Dmax} = 1.6 mm



Purification rate for the 50L TPC

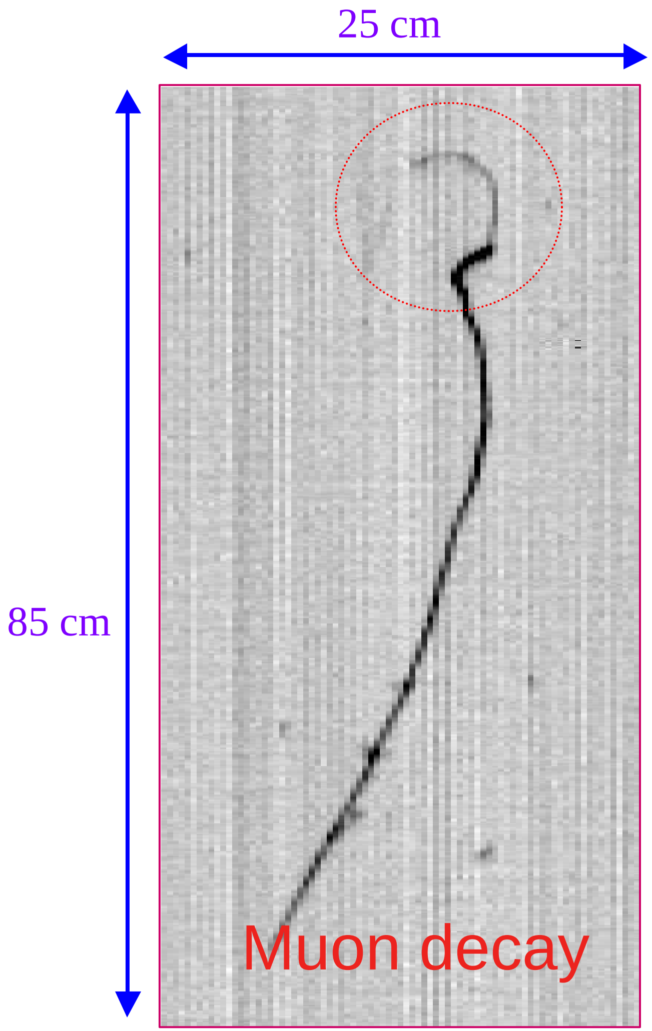


Drifting charge attenuation versus drift paths at different electric field intensities (τ = 10 ms)



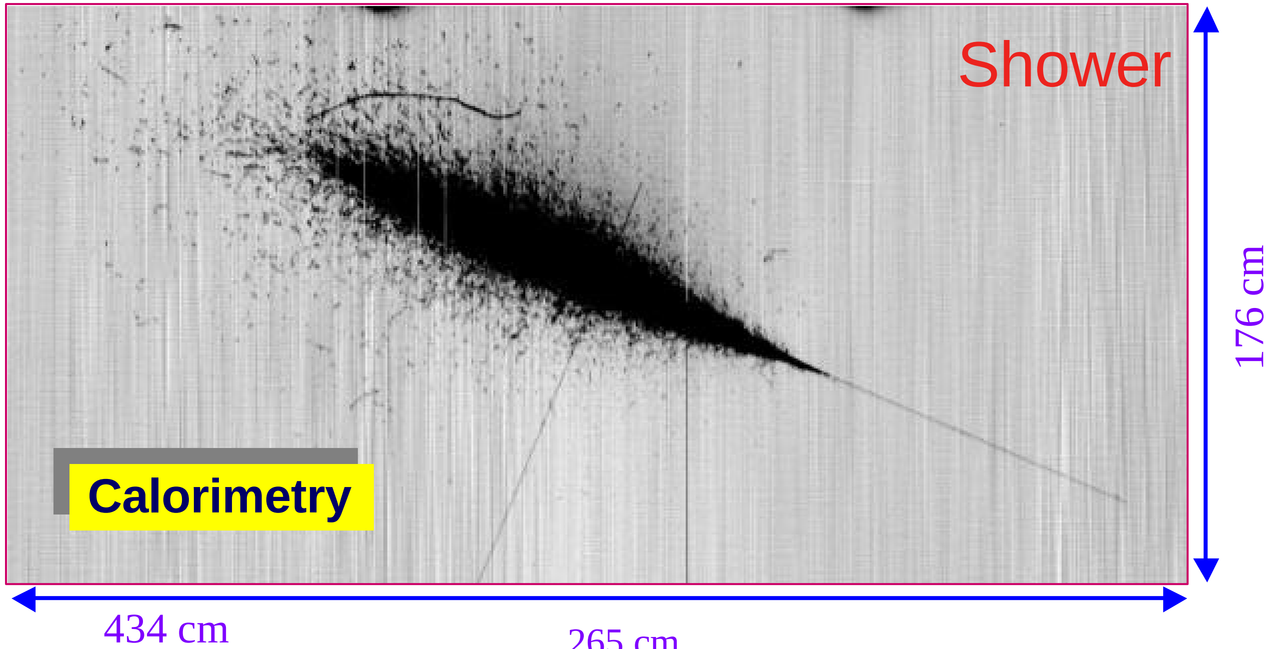
Drifting charge attenuation versus drift path at different electron lifetimes (E = 0.5 kV/cm)

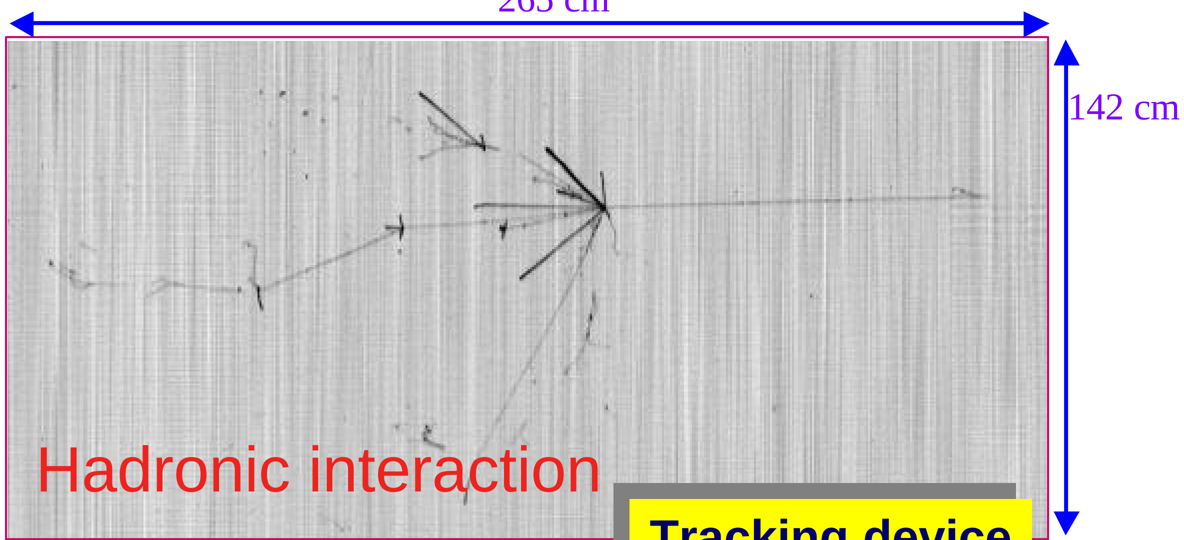
Cosmic rays events in the ICARUS T300



Run 960, Event 4 Collection Left

Measurement of local energy deposition dE/dx

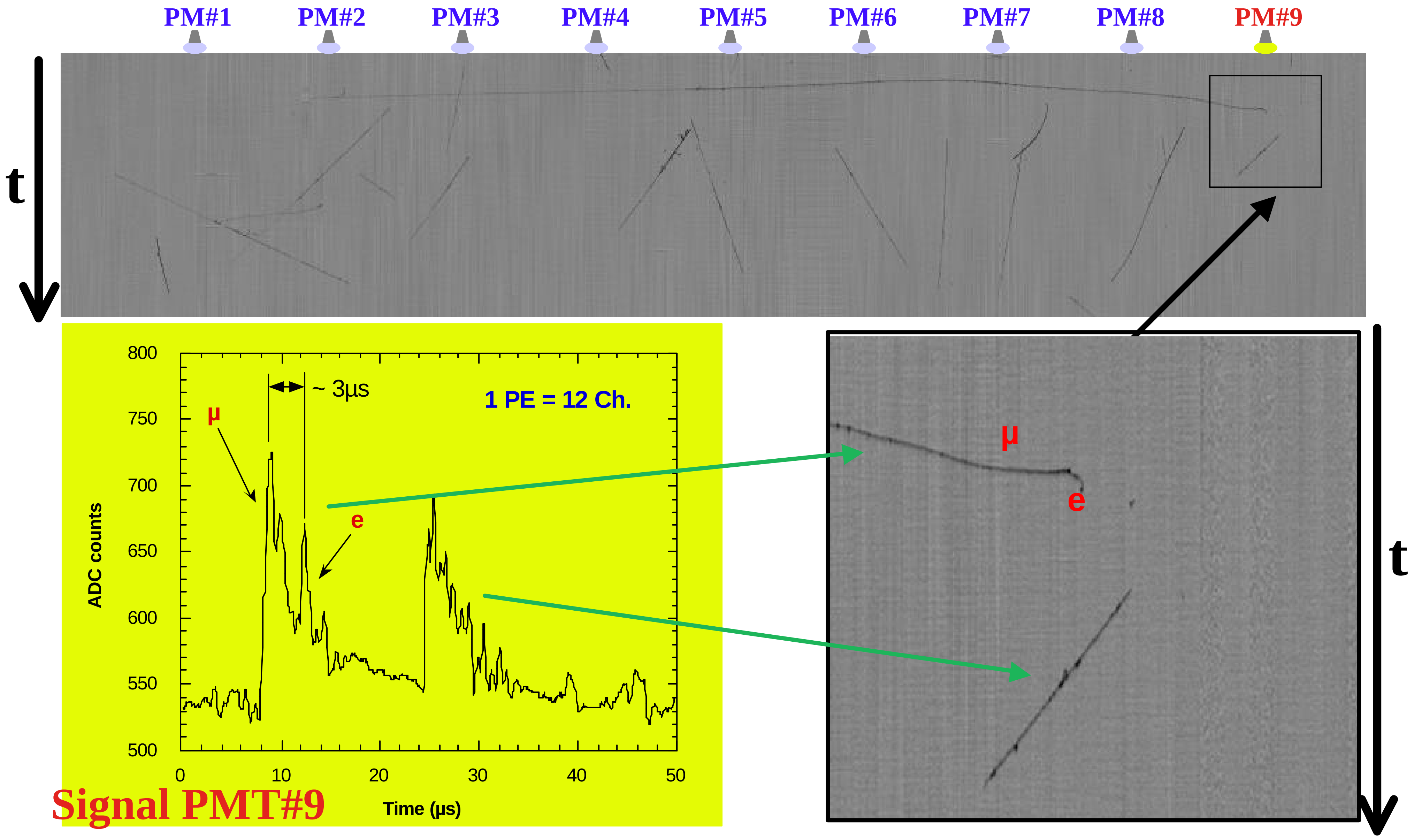




Tracking device

Run 308, Event 160 Collection Left

VUV scintillation light readout



Liquid Argon TPC:

physics calls for applications at two different mass scales

100 ton

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

100 kton

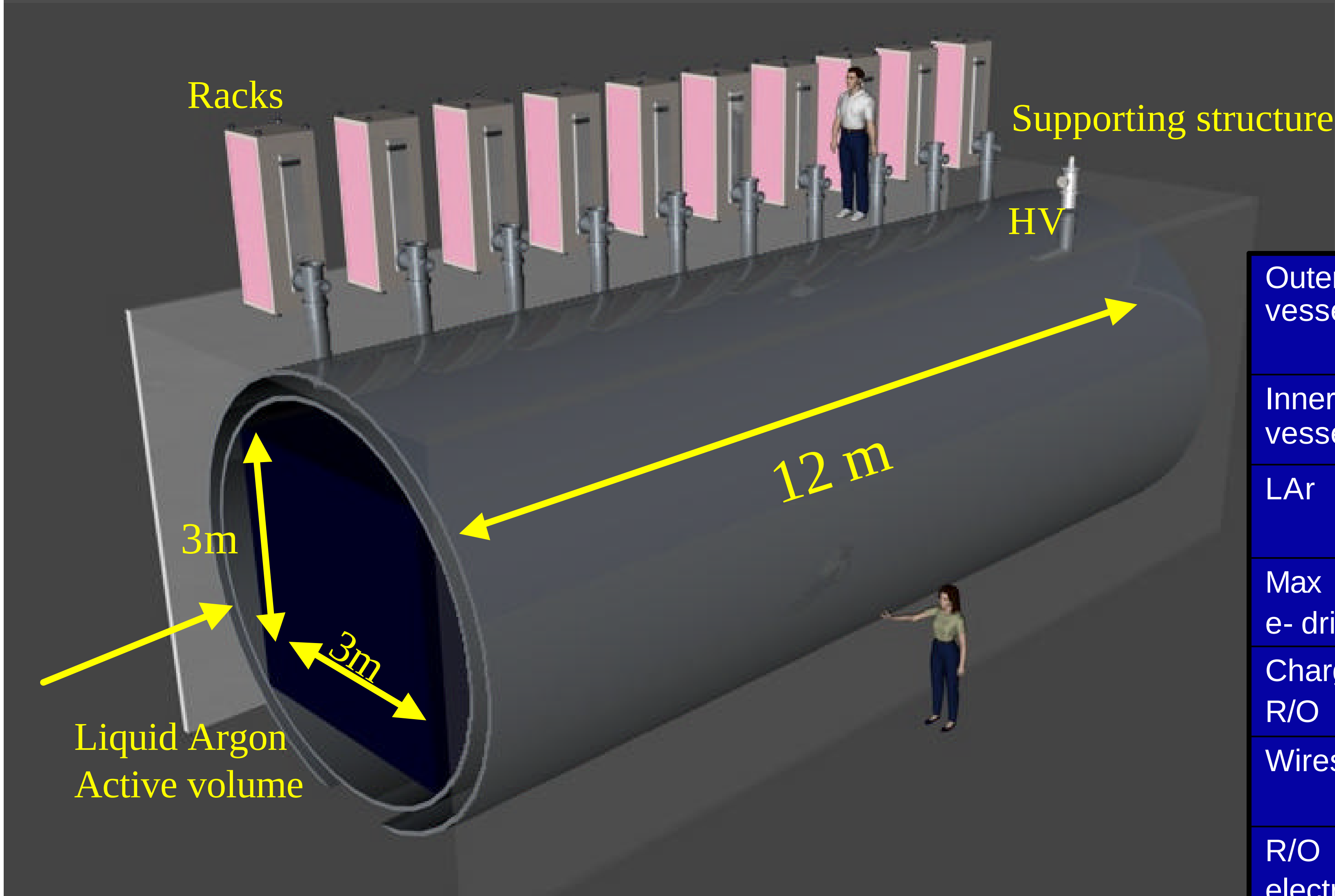
- Ultimate nucleon decay searches
- Astroparticle physics
- CP violation in neutrino mixing

Strong synergy and high degree of interplay

Ideas for a next generation liquid Argon TPC detector for neutrino physics and nucleon decay searches, A.Ereditato, A.Rubbia, Memo to the SPSC, April 2004.

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

a possibility to be further explored

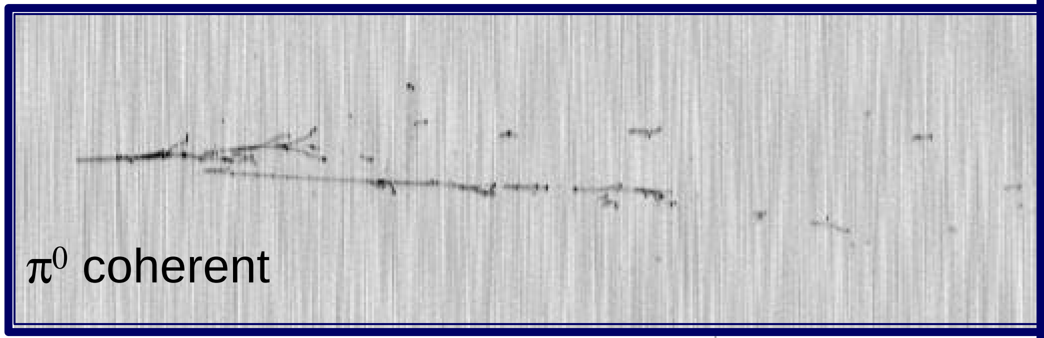


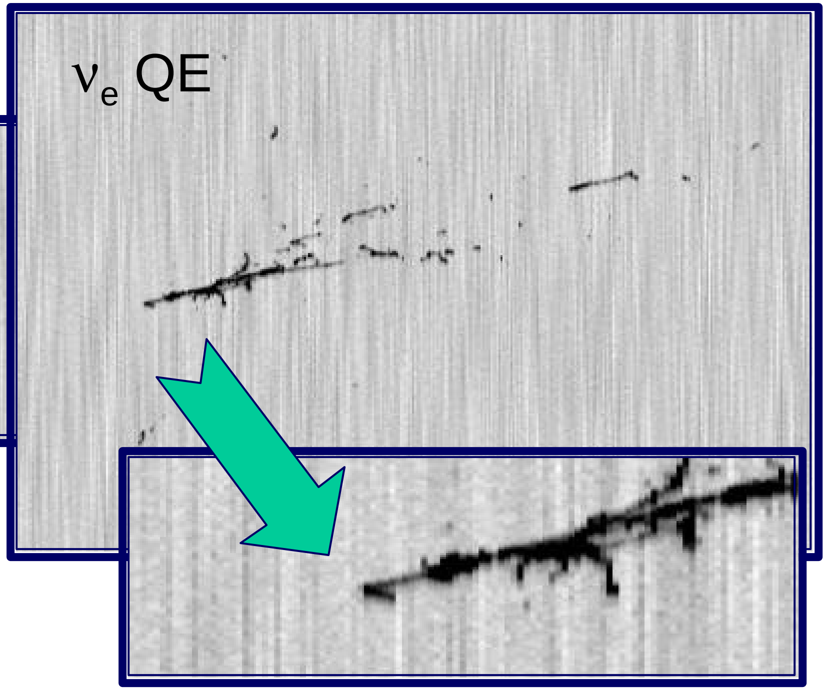
Outer vessel	ϕ ˜ 5m, L˜13m, 15mm thick, weight ˜ 22 t
Inner vessel	ϕ ˜ 4,2 m, L ˜ 12 m, 8 mm thick, ˜ 10 t
LAr	Total ˜ 240 t Fiducial ˜ 100 t
Max e- drift	3 m @ HV=150 kV E = 500 V/cm
Charge R/O	2 views, ± 45° 2 (3) mm pitch
Wires	˜10000 (7000) f = 150 µm
R/O electr.	on top of the dewar
Scintill. light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

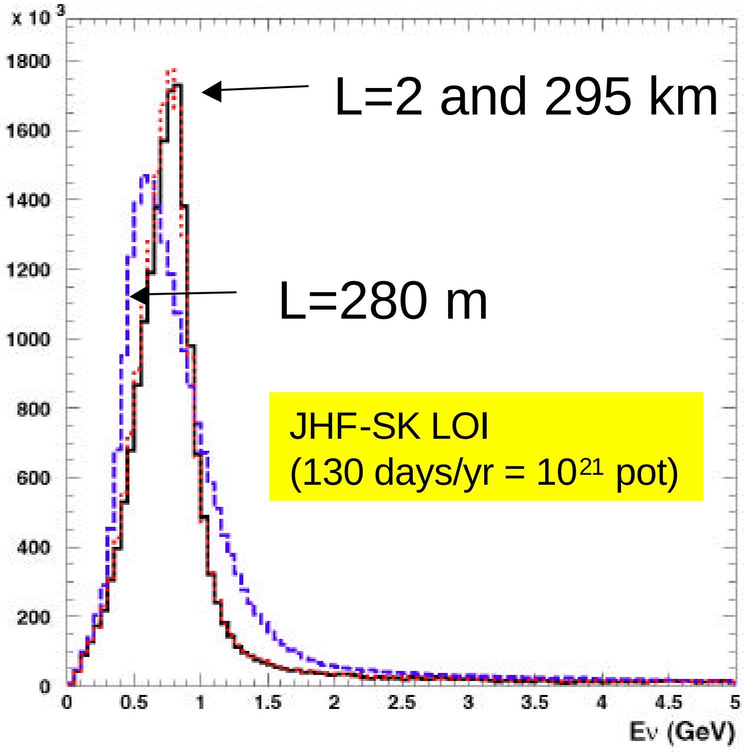
Ideas for future liquid Argon detectors
A.Ereditato, A.Rubbia, to appear in Proc. of NUINT04, LNGS, March 2004

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

full simulation, digitization, and noise inclusion



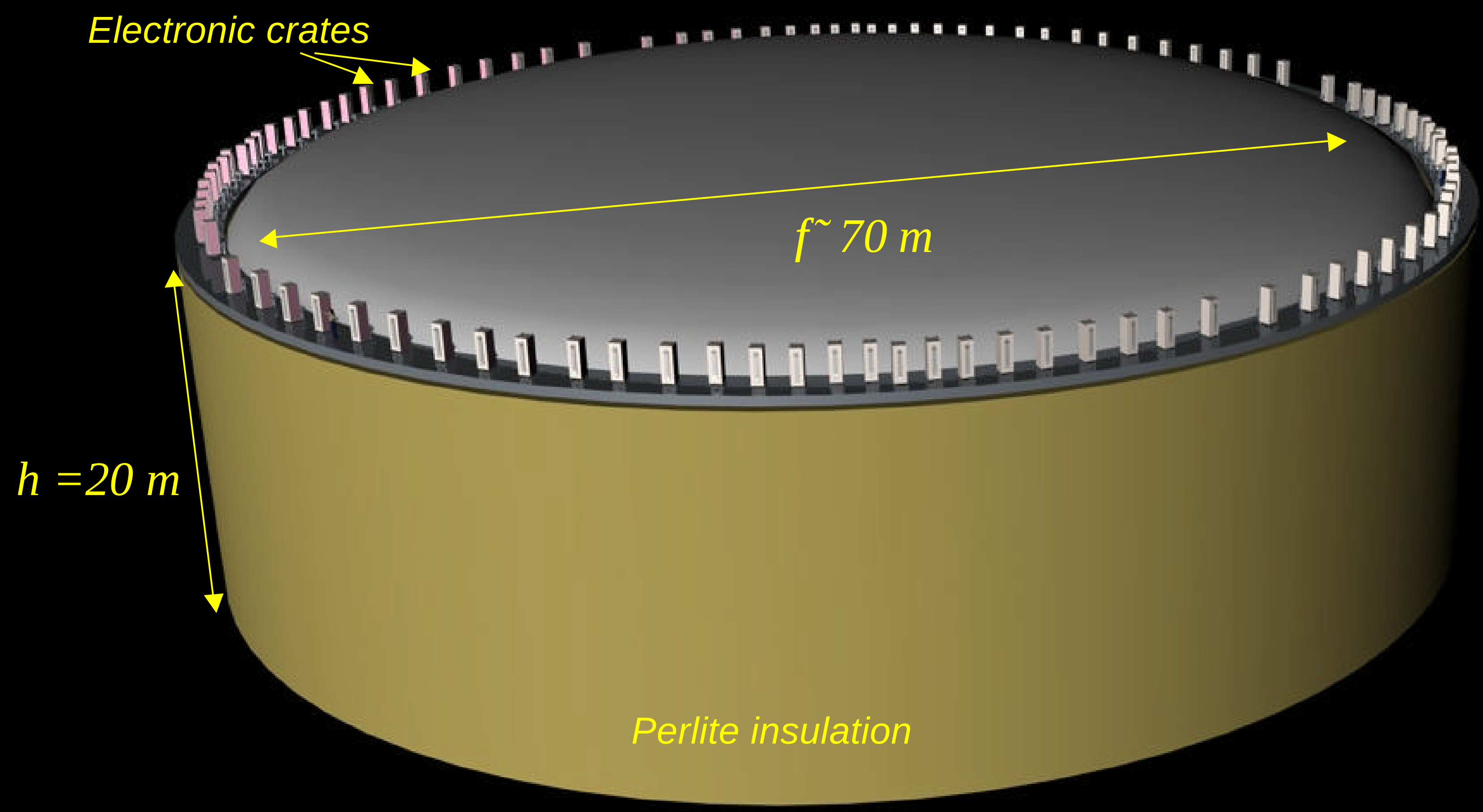




For example: 100 ton @ L=2000 m

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

100 kton liquid Argon TPC detector



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

	Water Cerenkov (UNO)	Liquid Argon TPC
Total mass	650 kton	100 kton
Cost	˜ 500 M$	Under evaluation
p ® e p^0 in 10 years	10^{35} years e = 43%, ˜ 30 BG events	$3x10^{34}$ years e = 45%, 1 BG event
p ® n K in 10 years	$2x10^{34}$ years e = 8.6%, ˜ 57 BG events	$8x10^{34}$ years e = 97%, 1 BG event
p ® m p K in 10 years	No	$8x10^{34}$ years e = 98%, 1 BG event
SN cool off @ 10 kpc	194000 (mostly $\overline{n}_e$p ® 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 n-e elastic scattering	380 n_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)

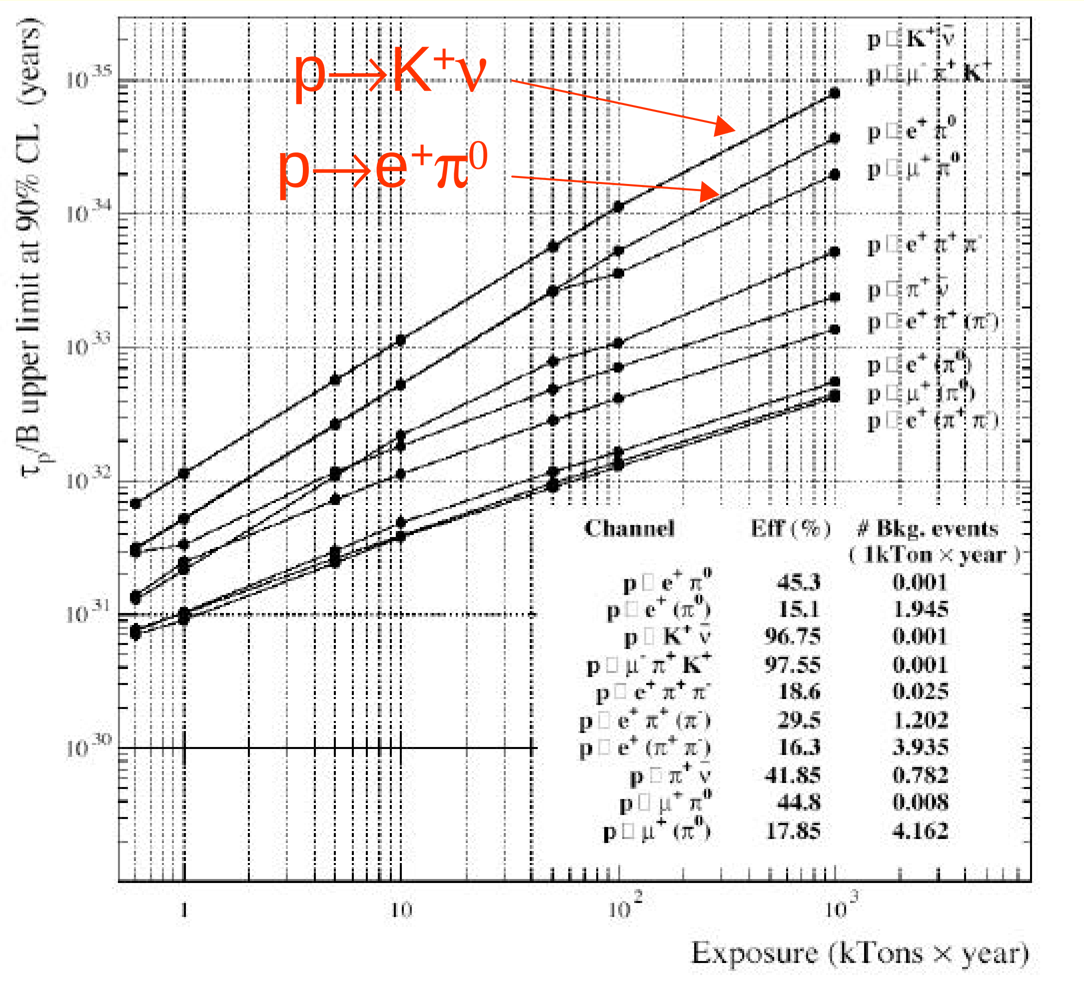
Review of massive underground detectors
A.Rubbia, Proc. XI Int. Conf. on Calorimetry in H.E.P., CALOR04, Perugia, March 2004

Operation of a 100 kton LAr TPC in a future neutrino facility:

Super-Beam: 460 ν_μ CC per 10^{21} 2.2 GeV protons @ L = 130 km

Beta-beam:15000 ν_e CC per 10^{19} ^{18}Ne decays with γ=75

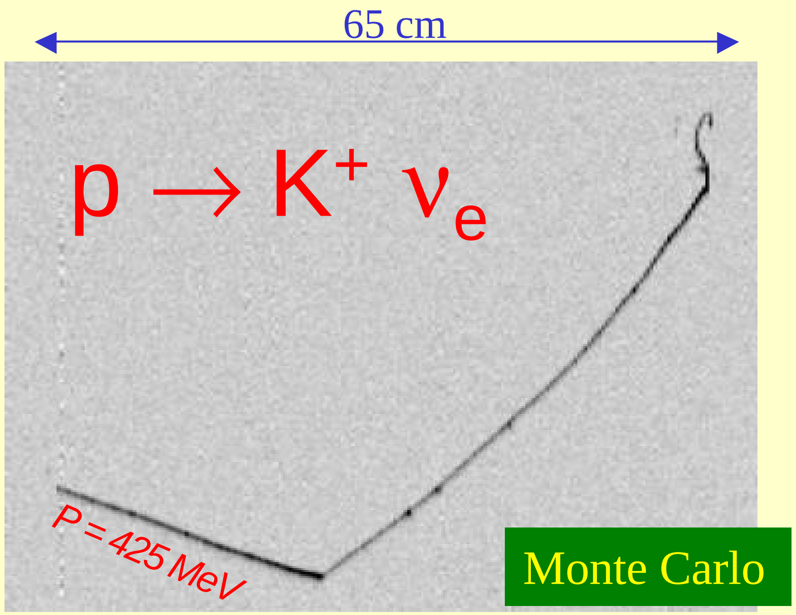
Proton decay: sensitivity vs exposure



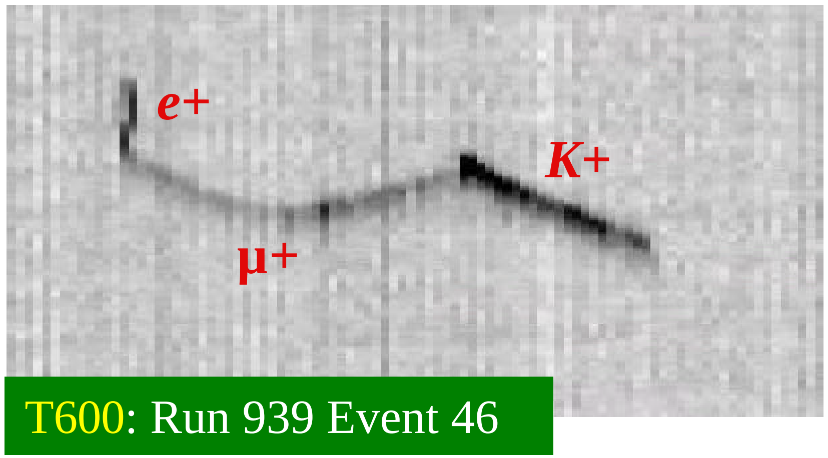
Channel	Eff (%)	# Bkg. events (1kTon × year)
$p \to e^+\pi^0$	45.3	0.001
$p \to e^+(\pi^0)$	15.1	1.945
$p \to K^+\bar{\nu}$	96.75	0.001
$p \to \mu^-\pi^+K^+$	97.55	0.001
$p \to e^+\pi^+\pi^-$	18.6	0.025
$p \to e^+\pi^+(\pi^-)$	29.5	1.202
$p \to e^+(\pi^+\pi^-)$	16.3	3.935
$p \to \pi^+\bar{\nu}$	41.85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

6×10^{34} nucleons $\Rightarrow$

$\tau_p/Br > \sim 10^{34}$ years $\times$ T(yr) $\times\ \epsilon$ @ 90 CL

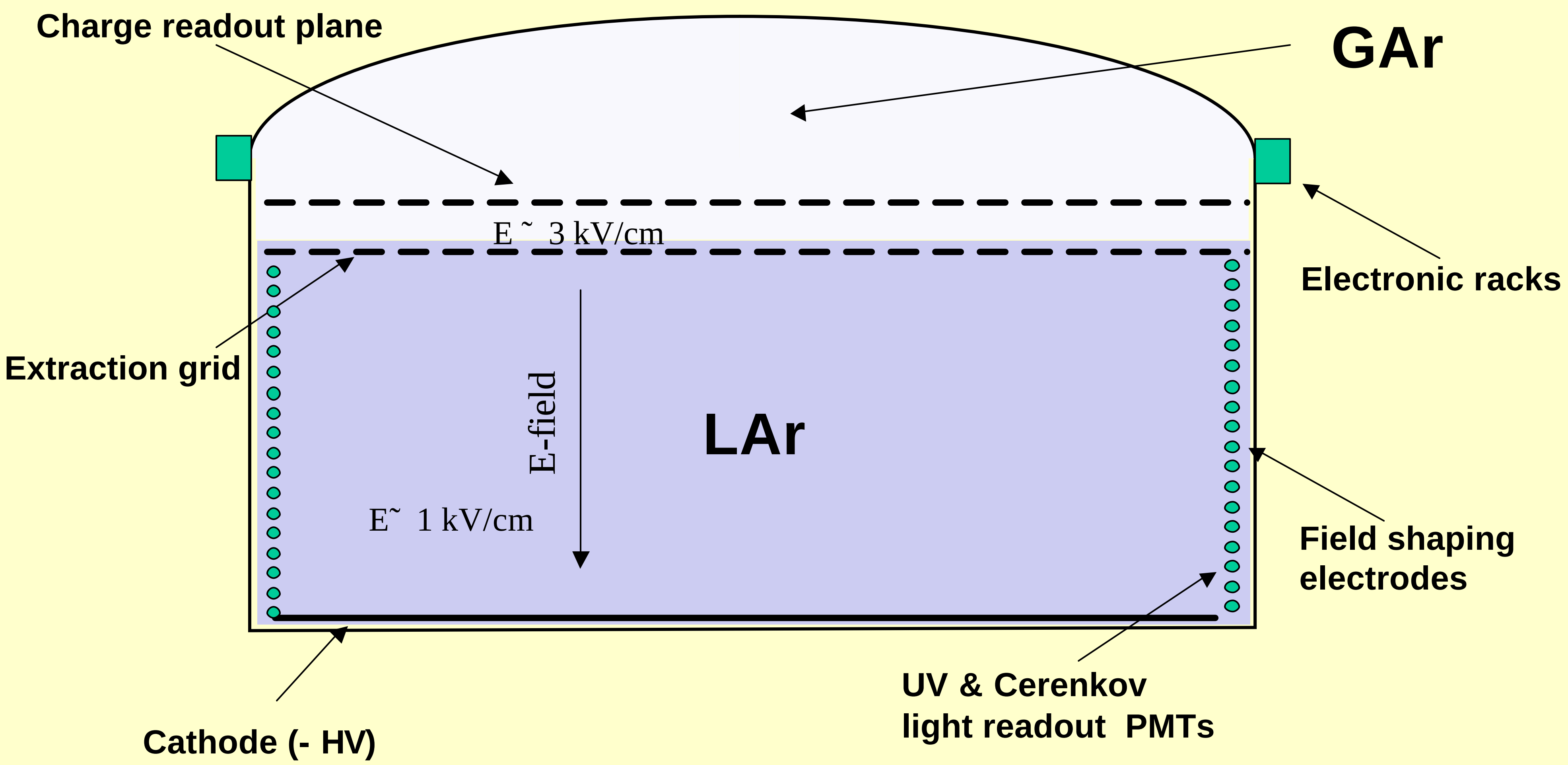


"Single" event detection capability



A tentative detector layout…

Single detector: charge imaging, scintillation, Cerenkov light



…and a tentative parameter list

Dewar	ϕ ~ 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 ~ 15%
Argon total mass	102000 tons
Hydrostatic pressure at bottom	3 atmospheres
Inner detector dimensions	Disc f ~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 g counting capability

Charge extraction, amplification, readout

Detector is running in bi-phase mode

- Long drift (~ 20 m) ⇒ 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 ⇒ diffusion ~ readout pitch ~ 3 mm

Electron drift in liquid	**20 m maximum drift, HV = 2 MV for E = 1 kV/cm, v_d ~ 2 mm/μs, max drift time ~ 10 ms**
Charge readout view	**2 perpendicular views, 3 mm pitch, 100000 readout channels**
Maximum charge diffusion	**s ~ 2.8 mm (v2Dt$_{max}$ for D = 4 cm^2/s)**
Maximum charge attenuation	**$e^{-(tmax/t)}$ ~ 1/150 for t = 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 (f ~ 30 mm) + pad readout, GEM, LEM, …**

Cryogenic storage tankers for LNG

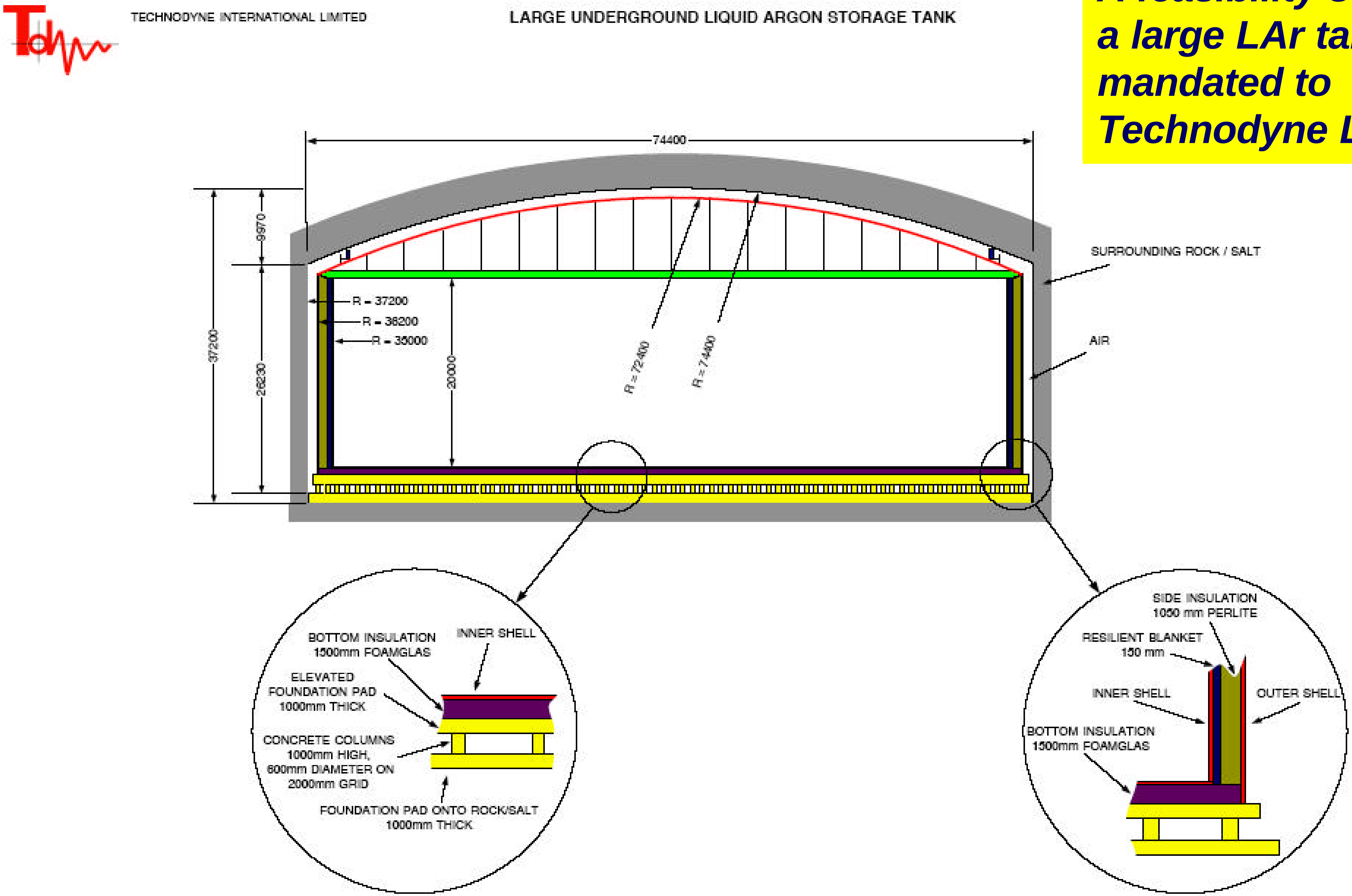
***LNG = L**iquefied **N**atural **G**as*

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

Shell Global Solutions

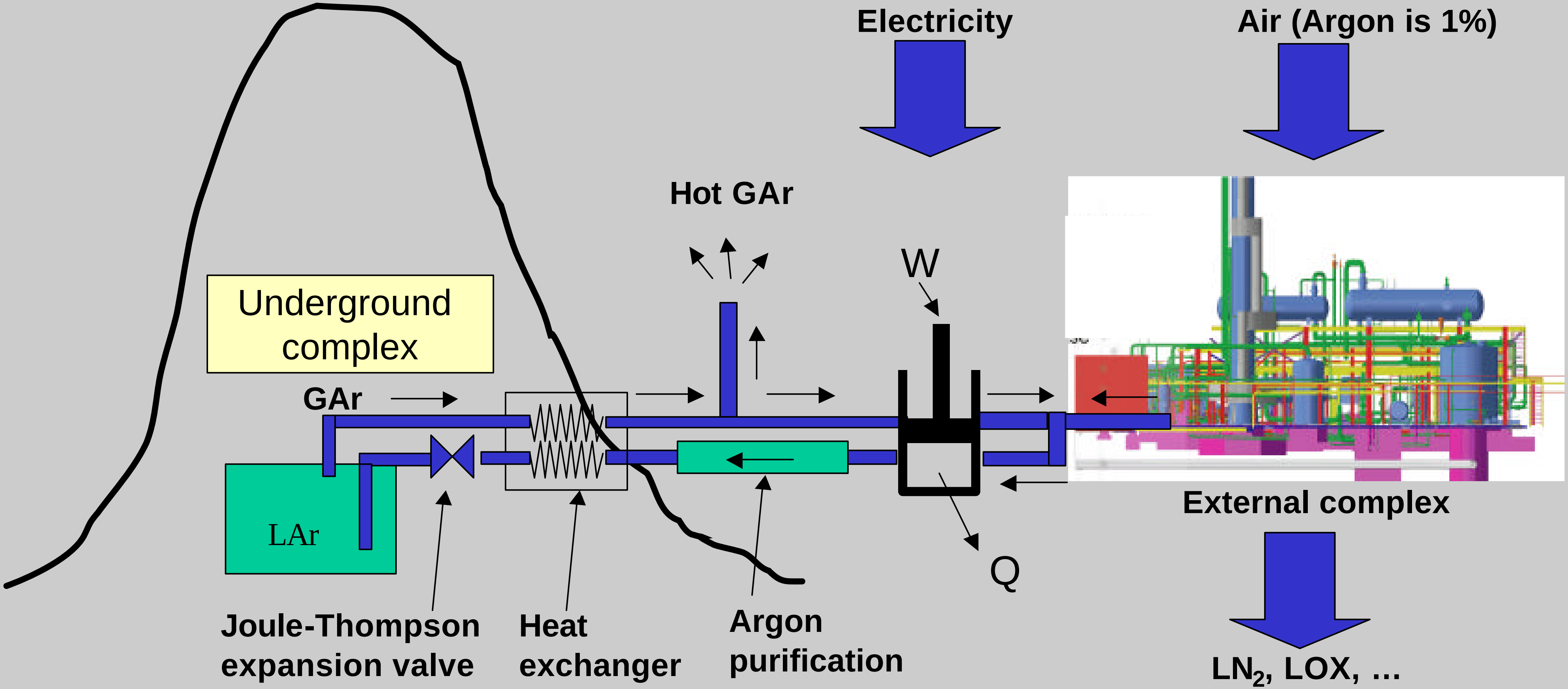
A feasibility study for a large LAr tanker mandated to Technodyne LtD (UK)



Work in progress: Underground storage, engineering issues, process system & equipment, civil engineering consulting, safety, cost & time

Process system & equipment

- Filling speed (100 kton): 150 ton/day → 2 years to fill, 10 years to evaporate !!
- Initial LAr filling: decide most convenient approach: transport LAr or in situ cryogenic plant
- Tanker 5 W/m^2 heat input, continuous re-circulation (purity)
- Boiling-off volume at regime: 30 ton/day: refilling



100 kton detector: milestones

- **Nov 2003: Venice Workshop**
  - Basic concepts: LNG tanker, signal amplification, single detector for charge imaging, scintillation and Cerenkov light readout
  - Design given for proton decay, astrophysics ν's, Super-Beams, Beta-Beams
  - Stressed the need for detailed comparison: 1 Mton water versus 100 kton LAr detector
- **Feb 2004: Feasibility study launched for underground liquid Argon storage**
  - Industry: Technodyne (UK) mandated for the study (expert in LNG design)
  - Design provided as input to the Fréjus underground lab study
  - Salt mine in Poland being investigated as well as other possible sites
- **March 2004: NUINT04 Workshop**
  - Identification of a global strategy: synergy between ‘small’ and ‘large’ mass LAr TPC
  - Intent to define a coherent International Network to further develop the conceptual ideas
- **April 2004 : Memo to the SPSC in view of the Villars special session (Sept. 2004)**
- **May 2004 : CERN Workshop on a future Multi MW proton source**
  - Envision a possible 10 kton full scale prototype (10% of the full detector)
  - Physics applications underground (proton decay) or at surface (neutrino beam)

Ongoing studies and initial R&D strategy

Engineering studies, dedicated test measurements, detector prototyping, simulations, physics performance studies in progress:

1) Study of suitable charge extraction, amplification and imaging devices

2) Understanding of charge collection under high pressure

3) Realization and test of a 5 m long detector column-like prototype

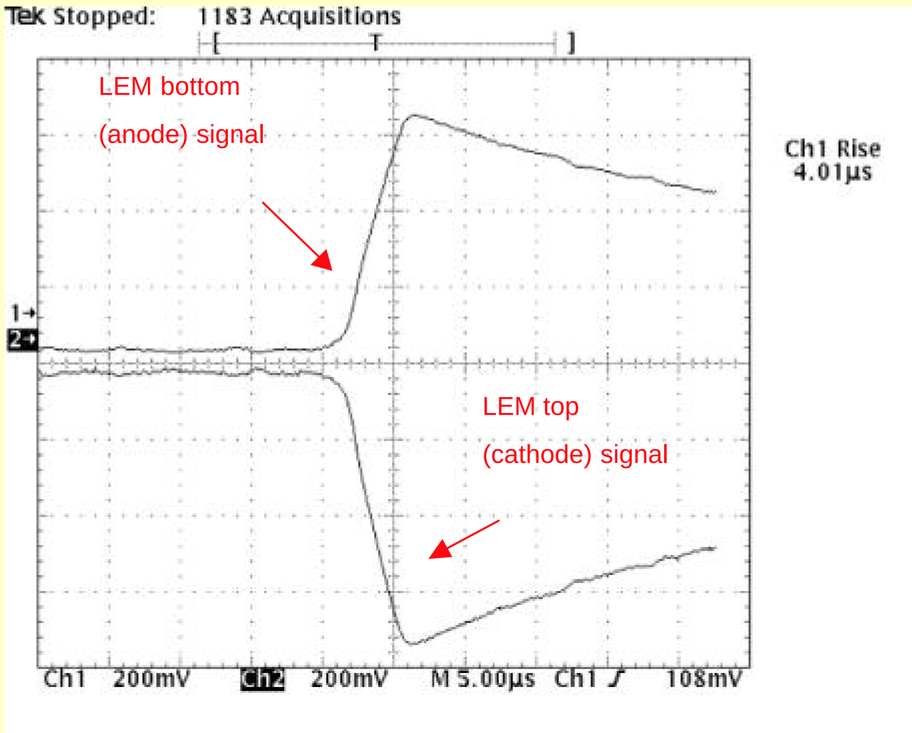
4) Study of LAr TPC prototypes immersed in a magnetic field

5) Study of logistics, infrastructure and safety issues for underground sites

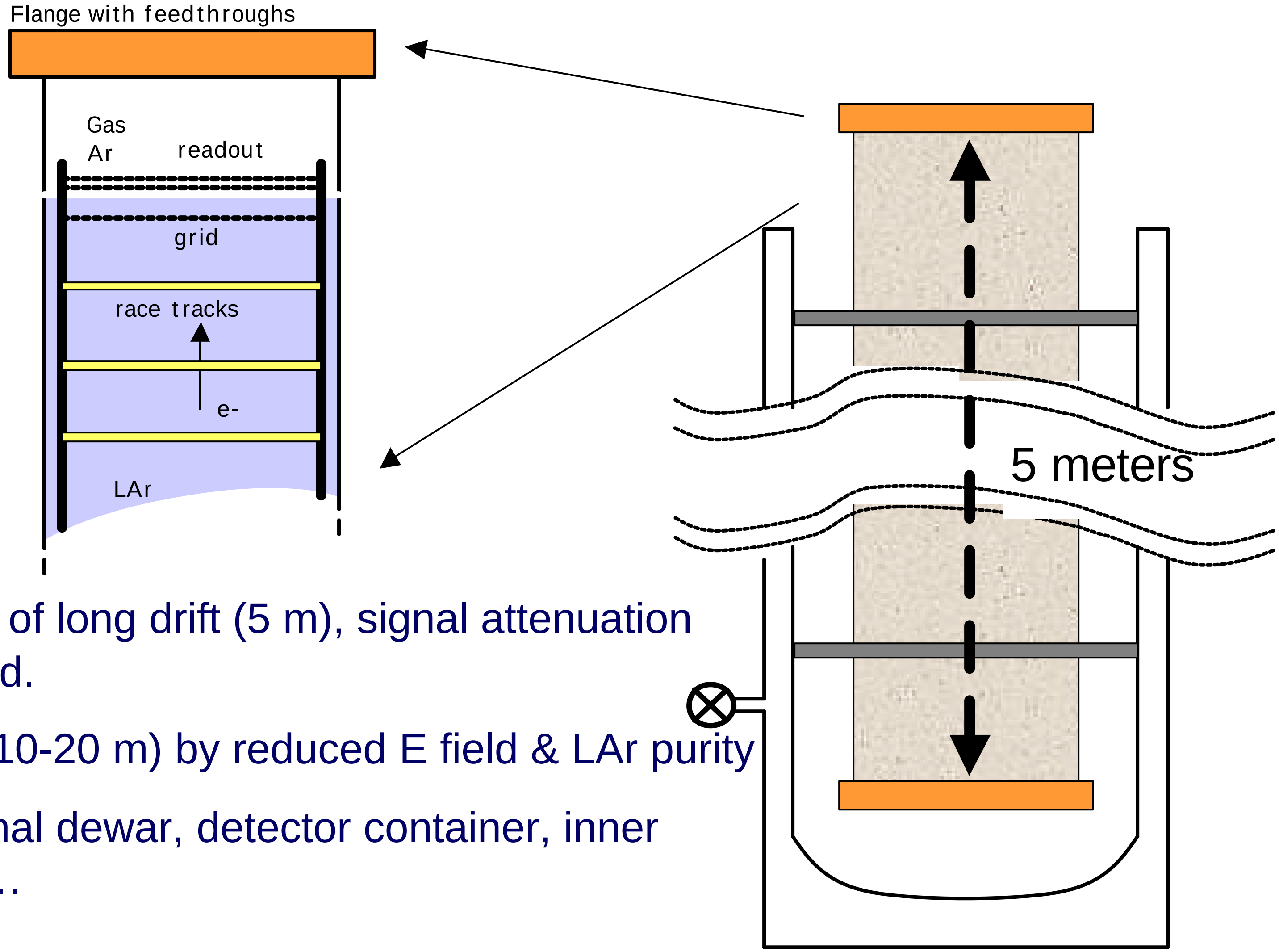
R&D example 1: amplification with Large Electron Multiplier (LEM)

P. Jeanneret et al.,
NIM A 500 (2003) 133-143

- **A large scale GEM (x10) made with ultra-low radioactivity materials (copper plated on virgin Teflon)**
  - In-house fabrication using automatic micro-machining
  - Modest increase in V yields gain similar to GEM
  - Self-supporting, easy to mount in multi-layers
- **Resistant to discharges (lower capacitance by segmentation)**
  - Cu on PEEK under construction (zero out-gassing)

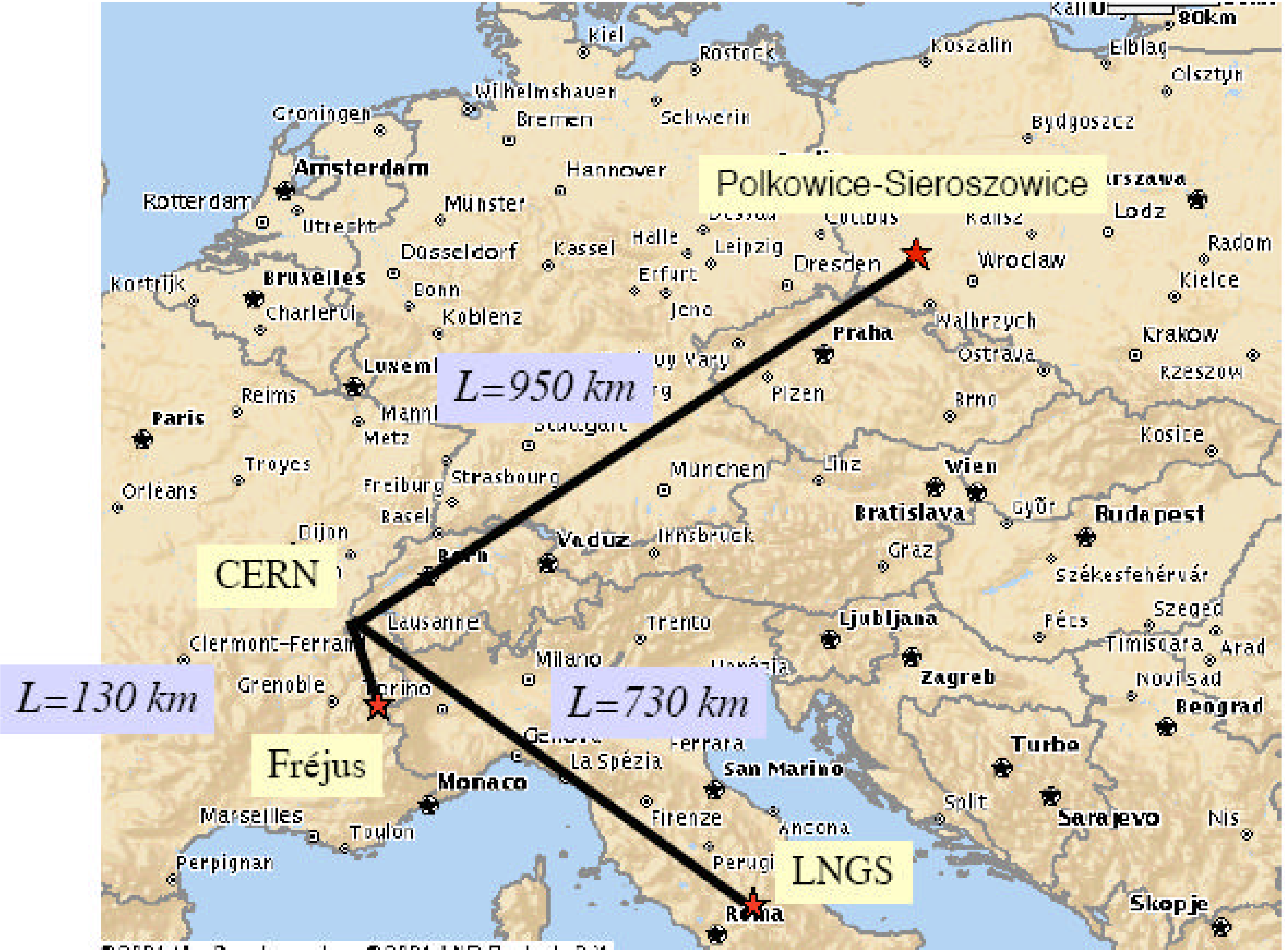


R&D example 2: long drift, extraction, amplification: test module



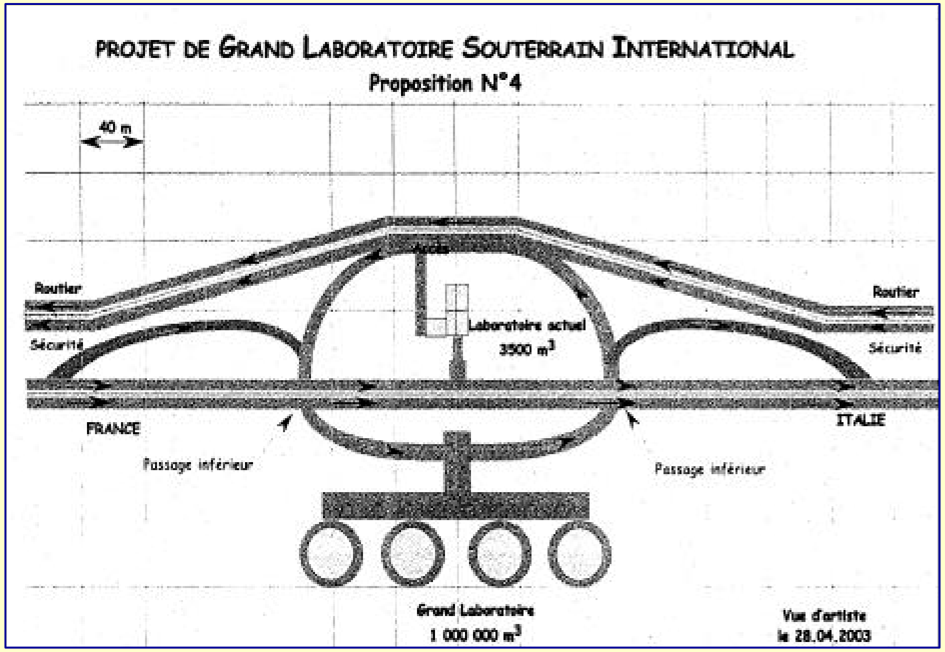
- A full scale measurement of long drift (5 m), signal attenuation and multiplication is planned.
- Simulate 'very long' drift (10-20 m) by reduced E field & LAr purity
- Design in progress: external dewar, detector container, inner detector, readout system, …

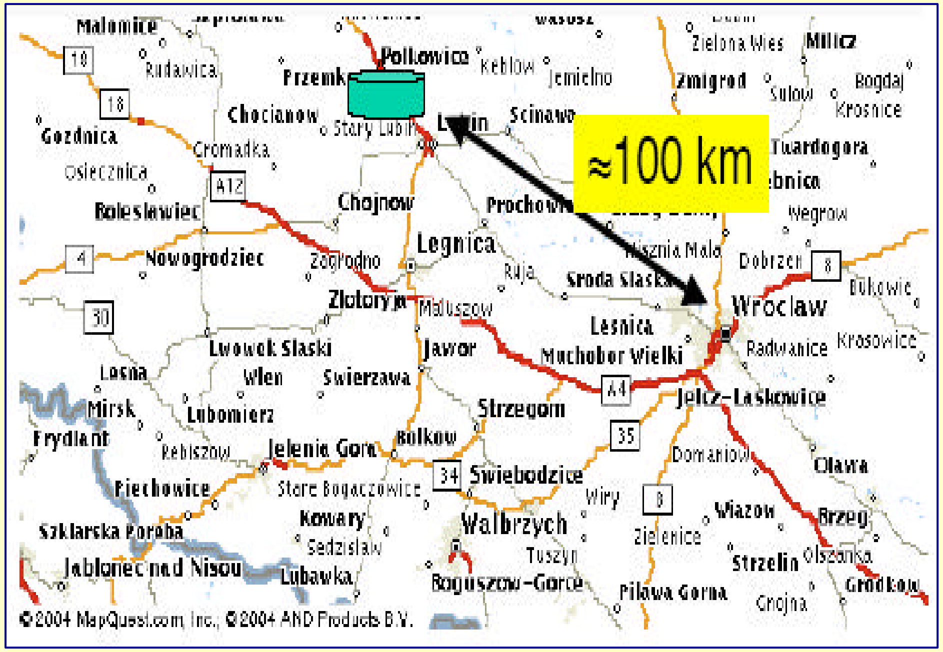
Possible detectors sites in Europe



Two different site topologies

1. **Hall access via highway tunnel tunnel (Fréjus laboratory project)**
2. **Deep mine-cavern with vertical access (CUPRUM mines, Polkowice-Sieroszowice)**





- cooperation agreement: IN2P3/CNRS/DSM/CEA & INFN
- international laboratory for underground physics
- easy access
- safety issues (highway tunnel)
- caverns have to be excavated

- mines by one of the largest world producers of Cu and Ag
- salt layer at ˜1000 m underground (dry)
- large caverns exist for a ˜ 80000 m^3 (100 kton LAr) detector
- geophysics under study
- access through vertical shaft

Argon-Net

● The further developments of the LAr TPC technique, eventually finalized to the proposal and to the realization of actual experiments, could only be accomplished by an international community of colleagues able to identify and conduct the required local R&D work and to effectively contribute, with their own experience and ideas, to the achievement of ambitious global physics goals. In particular, this is true for a large 100 kton LAr TPC detector that would exploit next generation neutrino facilities and perform ultimate non-accelerator neutrino experiments.

● We are convinced that, given the technical and financial challenges of the envisioned projects, the creation of a Network of people and institutions willing to share the responsibility of the future R&D initiatives, of the experiment's design and to propose solutions to the still open questions is mandatory.

● The actions within the Network might include the organization of meetings and workshops where the different ideas could be confronted, the R&D work could be organized and the physics issues as well as possible experiments could be discussed. One can think of coherent actions towards laboratories, institutions and funding agencies to favor the mobility of researchers, to support R&D studies, and to promote the visibility of the activities and the dissemination of the results.

So far colleagues from 21 institutions have already expressed their Interest in joining Argon-Net, to act as 'nodes' of the network

Conclusions and Outlook

- The evidence for neutrino oscillations has opened the way to precision studies of the mixing matrix with accelerator neutrino experiments.
- The generation of running and planned experiments will contribute to narrow-down the errors on the oscillation parameters. The next generation will allow to pin down a non vanishing value of θ_{13}.
- The detection of matter and of CP violating effects will likely require another generation of experiments using high intensity (> MW) neutrino facilities with very massive detectors. At present, two options being considered: a 500-1000 kton water Cerenkov detectors (a la SK) and a 100 kton liquid Argon TPC.
- The liquid Argon TPC imaging has reached a high level of maturity thanks to many years of R&D effort conducted by the ICARUS collaboration. The plan is to operate the kton mass scale detector at LNGS with the ICARUS project.
- The technique is suitable for applications at very different different mass scales:
  - 100 kton: proton decay, high statistics astrophysical & accelerator neutrinos
  - 100 ton: systematic study of neutrino interactions, near detectors at LBL facilities
- In particular, a 100 kton, monolithic LAr TPC based on the industrial technology of LNG tankers and on the bi-phase operation is conceivable. R&D studies are in progress and a global strategy is being defined, possibly envisioning the construction of a 10% mass full scale prototype.
- Look forward to the creation of a dedicated world-wide Network on the LAr TPC technique.