Future applications of the liquid Argon TPC technique

5th Rencontres du Vietnam

Particle Physics and Astrophysics

Marcello Messina - ETHZ-Zurich

Introduction

- Liquid Argon TPC technique: high level of maturity reached thanks to many years of R&D effort conducted by the ICARUS collaboration on various detector prototypes (from few tenth of kg to 3 ton) brought to the successful operation of a **300 ton** module at surface:

  1) long electron drift with high LAr purity
  2) the technique can be scaled to large detector mass (kton)

- ICARUS @ LNGS: ultimate proof of detector imaging performance with astroparticle & neutrino beam events

- As of today, physics is calling for at least two applications of the LAr TPC technique with a monolithic design at two different mass scales:

  ≈ 100 kton: high statistics astrophysical & accelerator neutrinos, proton decay….

  ≈ 100 ton: systematic study of neutrino interactions, near detectors in LBL beams,…

- Work is in progress along these lines of thoughts

  I present here a brief overview of current ideas & activities

- A 100 kton LAr TPC: a detector for the next generation neutrino facility?

  A conceptual design is given and the main features are outlined

The LAr TPC concept and detection principle

ICARUS application

Drift field: 500 V/cm

Drift velocity: 1.5 mm/μs

Maximal drift time: 1 ms

Electron lifetime: > 1 ms

LAr purity: < 0.1 ppb (O_2 equiv.)

3 wire planes (no charge amplification):

1.Plane: Induction 1, horizontal wires (9m)

2.Plane: Induction 2, $+60^0$

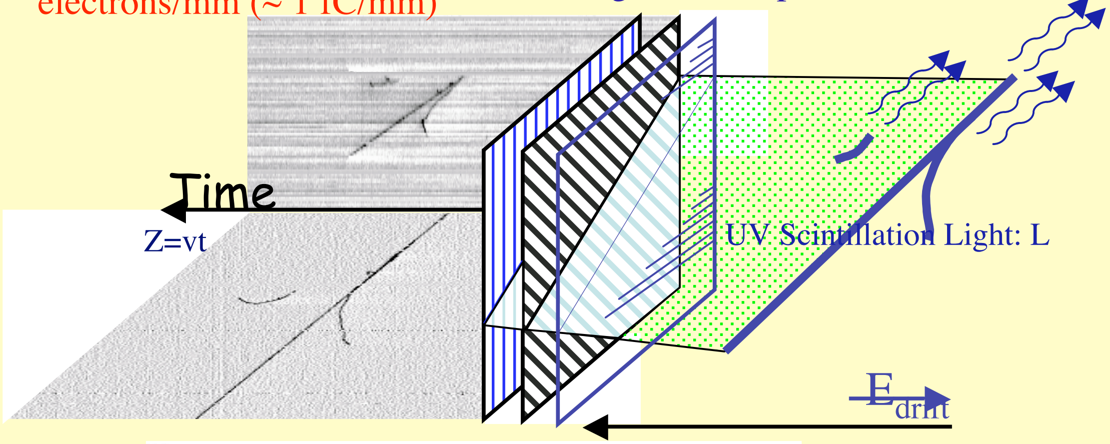
3.Plane: Collection, -60^0

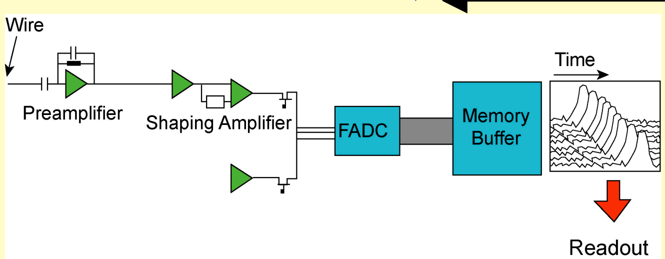
Distance between planes: 3 mm.

Wire pitch: 3 mm.

Charge yield ~ 6000 electrons/mm (~ 1 fC/mm)

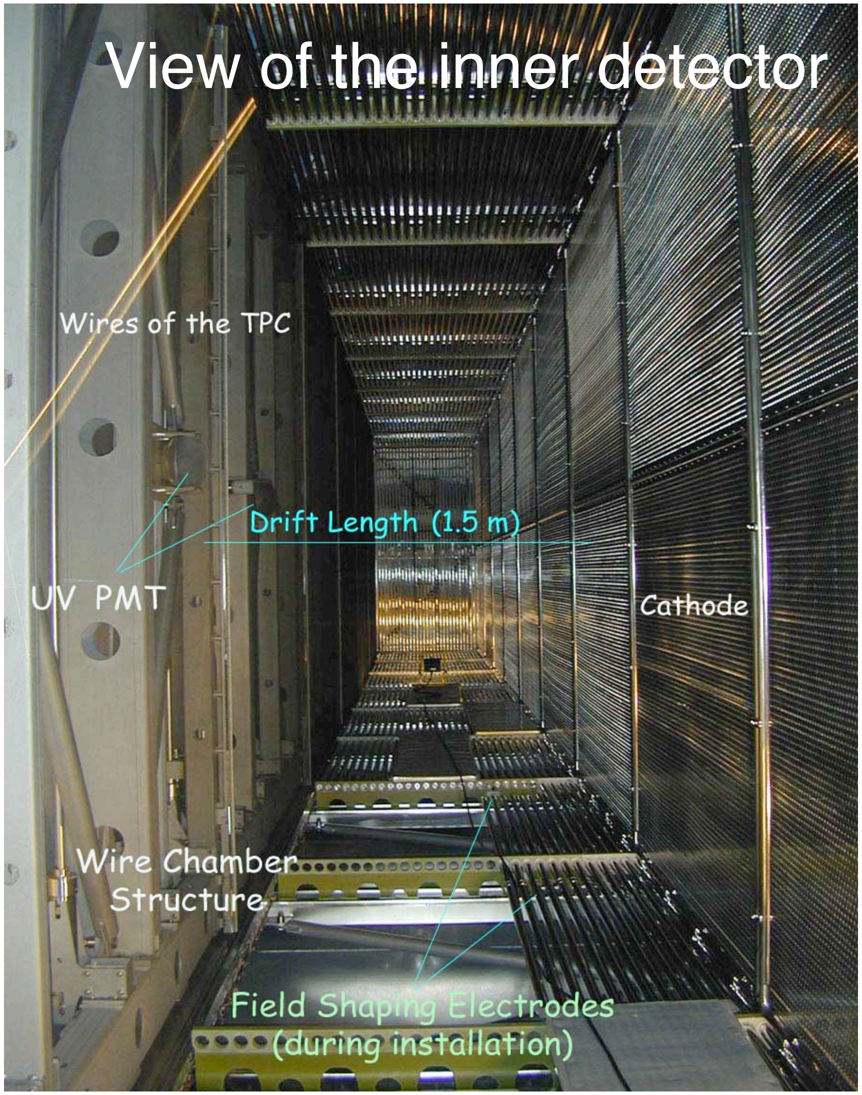
Charge readout planes: Q

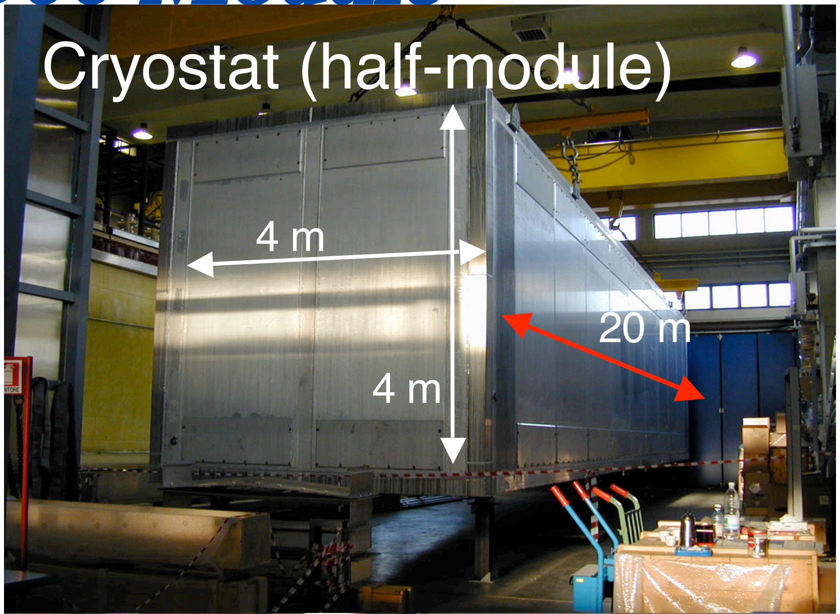


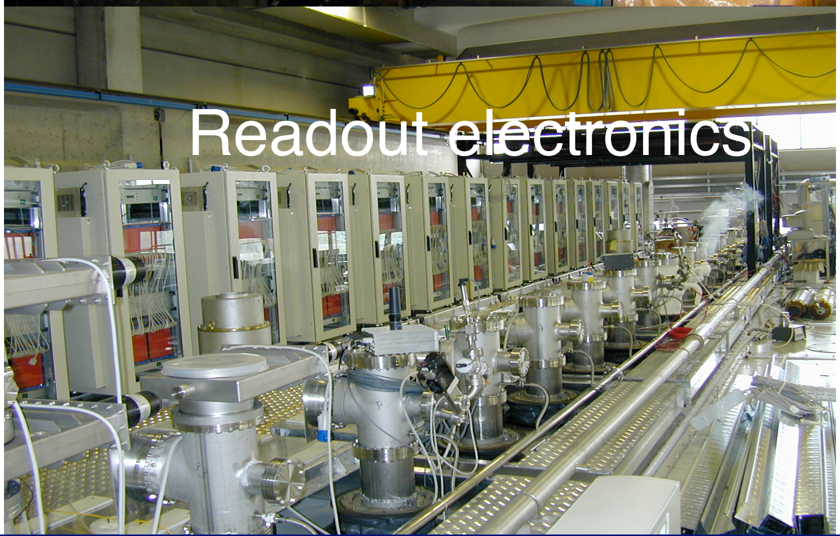


Density (g/cm^3)	1.4
Radiation length (cm)	14.0
Interaction length (cm)	83.6
dE/dx (MeV/cm)	2.1
Refractive index (visible)	1.24
Cerenkov angle	36°
Cerenkov $d^2N/dEdx$ (β=1)	≈ 130 eV^{-1} cm^{-1}
Muon Cerenkov threshold (p in MeV/c)	140
Scintillation (E=0 V/cm)	50000 γ/MeV @ λ=128nm)
Energy for an e-hole pair:	W_e =23.6eV
Energy to create a γ	W_γ =19.5eV

ICARUS T300 Module

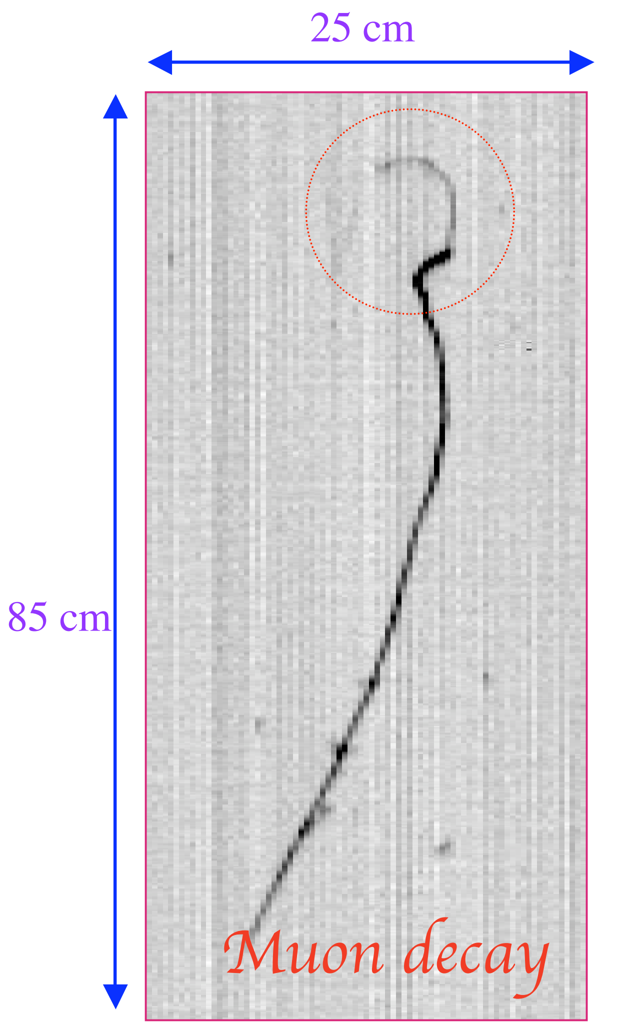






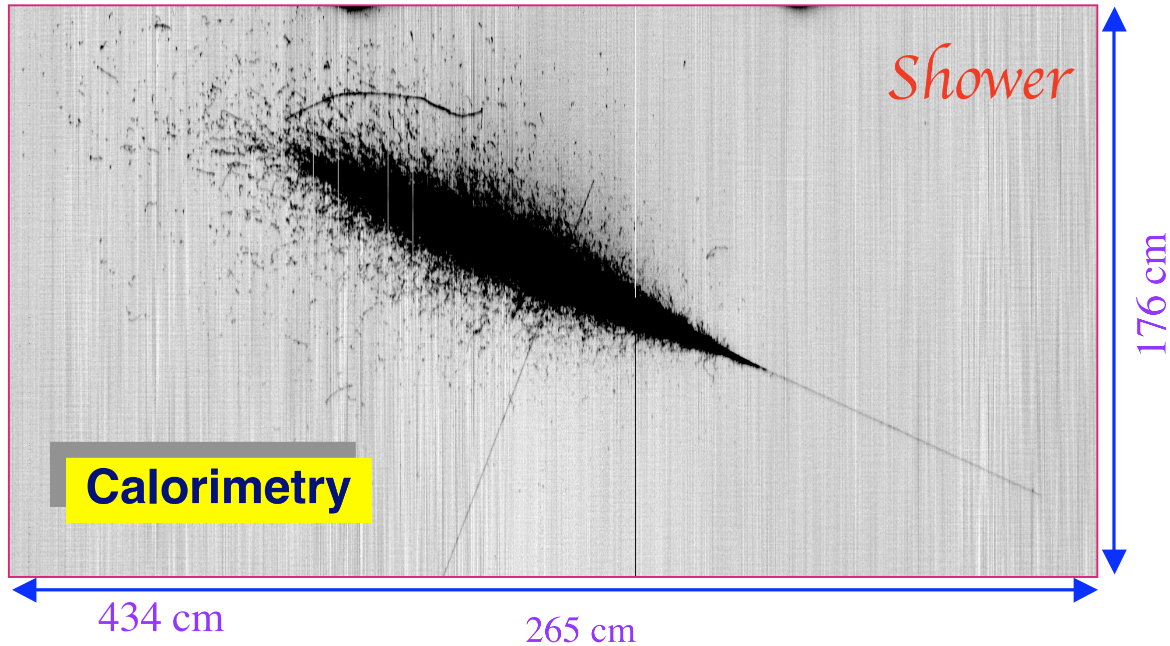
- The Liquid Argon Time Projection Chamber: a new concept for Neutrino Detector, C. Rubbia, CERN-EP/77-08 (1977).
- A study of ionization electrons drifting large distances in liquid and solid Argon, E. Aprile, K.L. Giboni and C. Rubbia, NIM A251 (1985) 62.
- A 3 ton liquid Argon Time Projection Chamber, ICARUS Collab., NIM A332 (1993) 395.
- Performance of a 3 ton liquid Argon Time Projection Chamber, ICARUS Collab., NIM A345 (1994) 230.
- The ICARUS 50 l LAr TPC in the CERN neutrino beam, ICARUS Collab, hep-ex/9812006 (1998).

Cosmic rays events in ICARUS T300

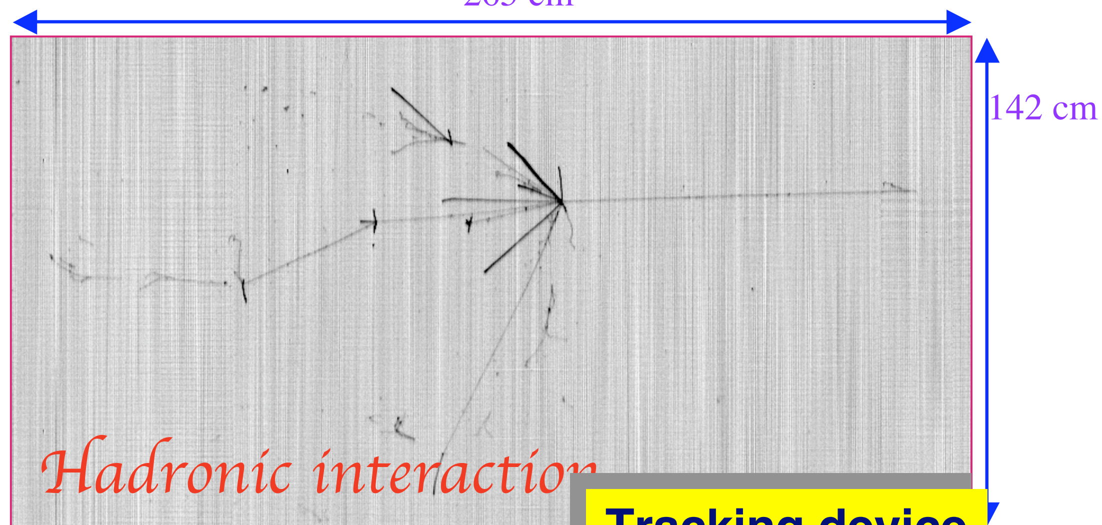


Run 960, Event 4 Collection Left

Measurement of local energy deposition dE/dx



Calorimetry



Run 308, Event 160 Collection Left

Tracking device

Fundamental issues of neutrino physics

- Precision studies of ν interactions
- Near station at LBL facilities

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

100 ton

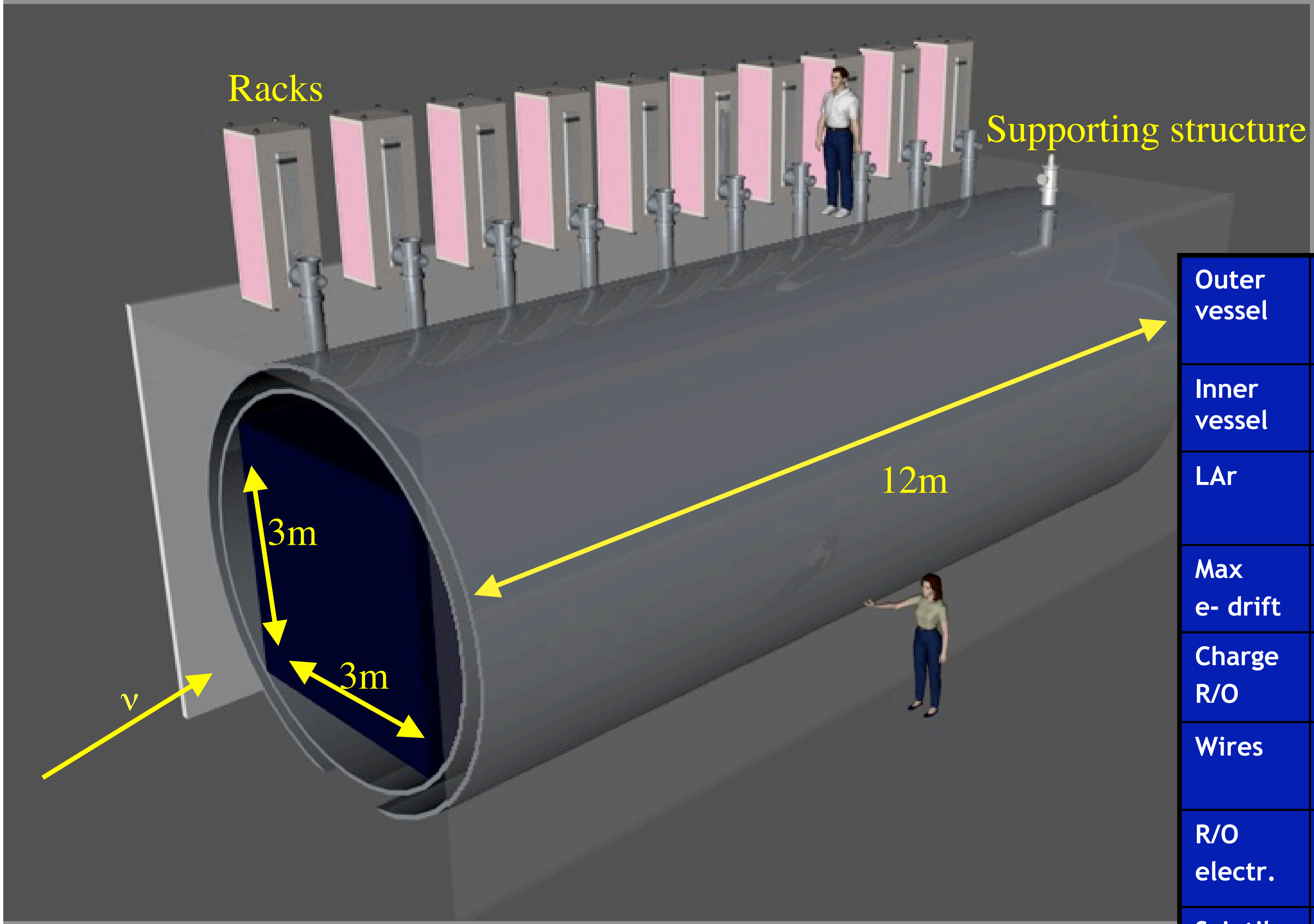
100 kton

Strong synergy and high degree of interplay

Need to coherently develop conceptual ideas within the international community

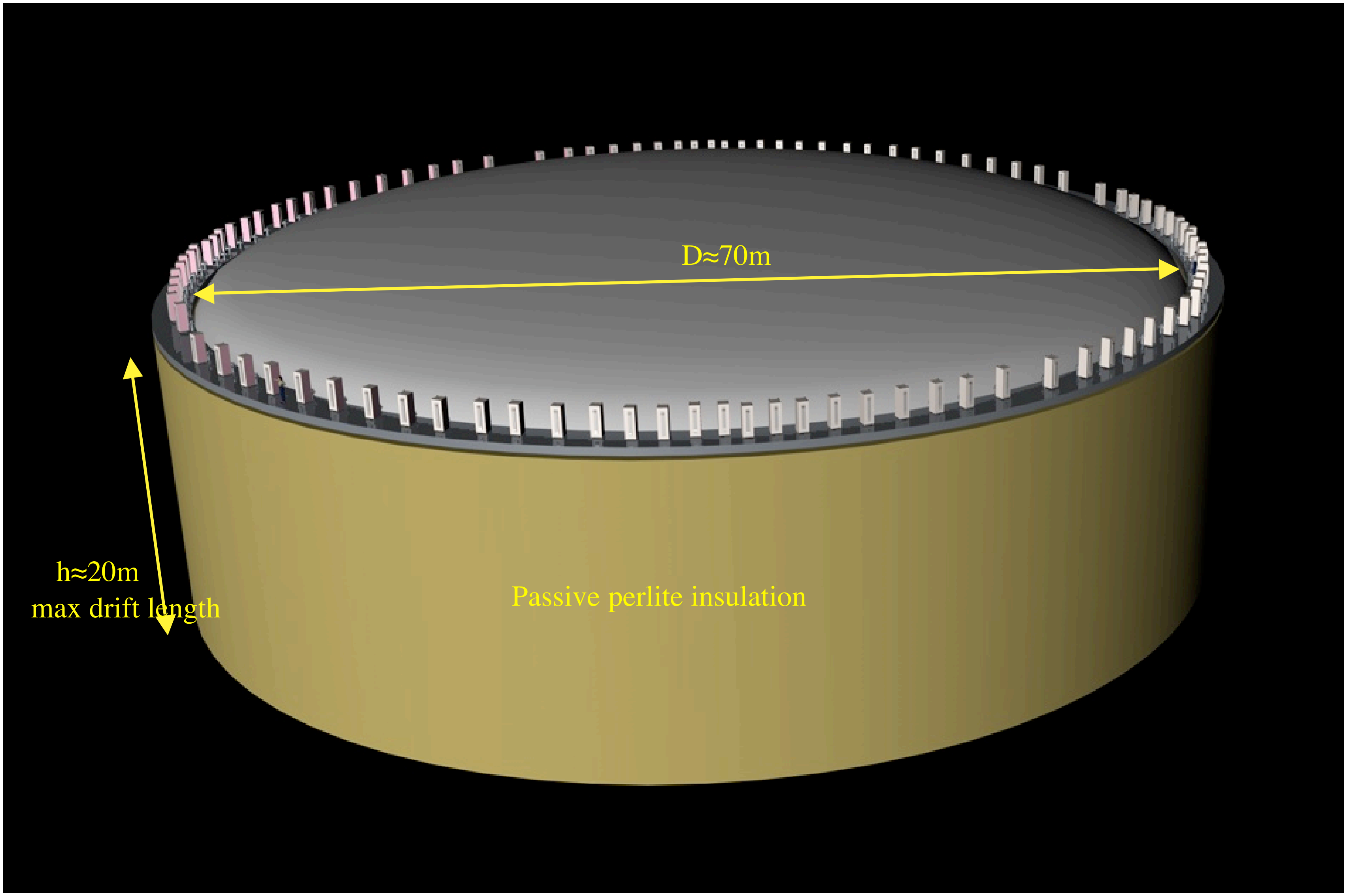
- Experiments for CP violation: a giant liquid Argon scintillation, Cerenkov and charge imaging experiment, A.Rubbia, Proc. II Int. Workshop on Neutrinos in Venice, 2003, hep-ph/040211
- Ideas for future liquid Argon detectors A.Ereditato, A.Rubbia, Proc. of NUINT04, LNGS, March 2004.
- Review of massive underground detectors A.Rubbia, Proc. XI Int. Conf. on Calorimetry in H.E.P., CALOR04, Perugia, March 2004
- A.Ereditato, A.Rubbia April 2004, Memo for the CERN-SPSC Villars meeting, September 2004

Conceptual design of a ~100t LAr TPC for a near detector of a LBL facility



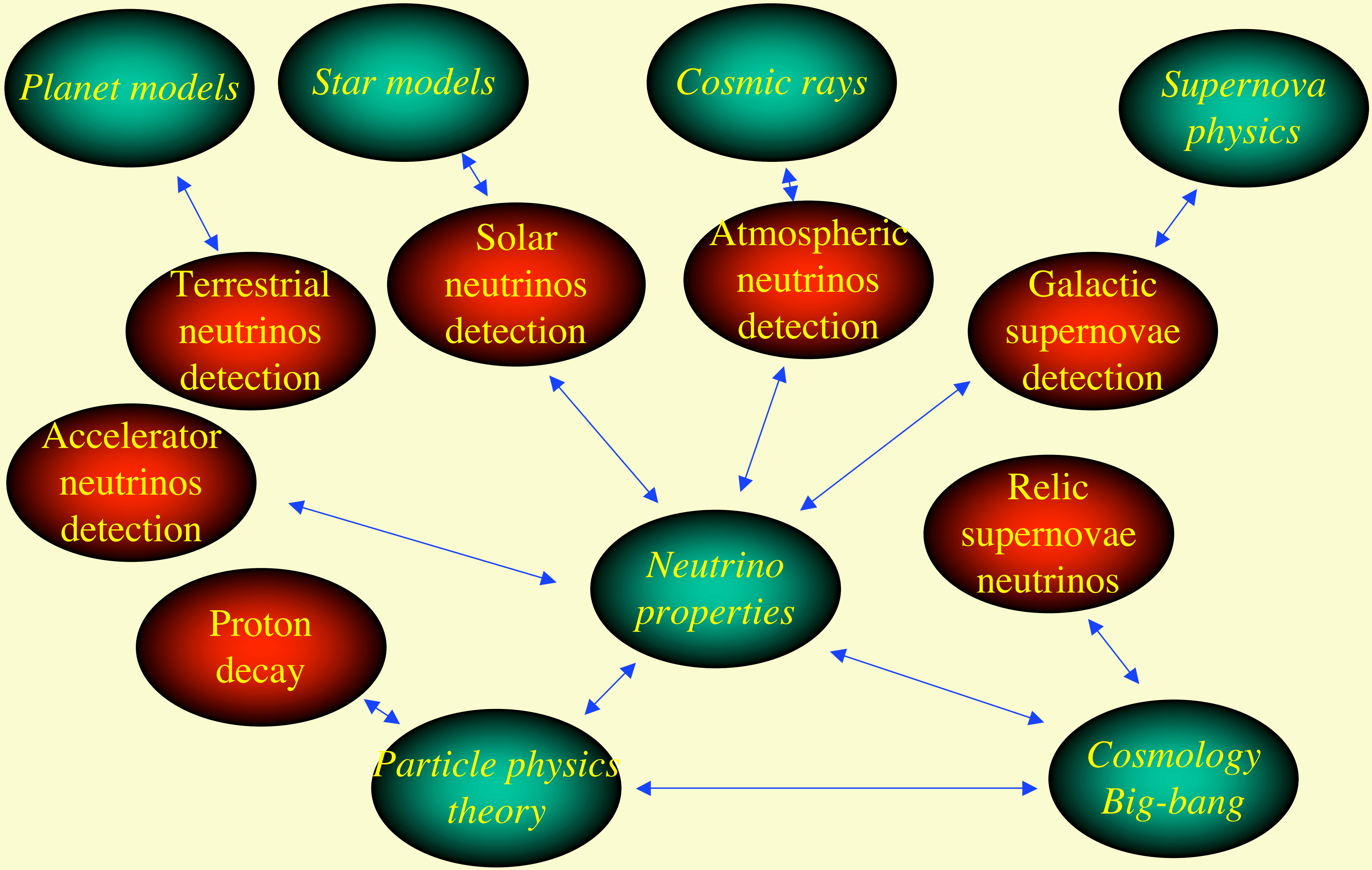
Outer vessel	D ≈ 5m, L≈13m, 15mm thick, weight ≈ 22 t
Inner vessel	Φ≈ 4,2 m, L ≈ 12m, 8 mm thick, ≈ 10 t
LAr	Total ≈ 240 t Fiducial ≈ 100 t
Max e- drift	3 m @ HV=150 kV E = 500 V/cm
Charge R/O	2 views, ± 45° 2 (3) mm pitch
Wires	≈10000 (7000) Φ = 150 μm
R/O electr.	on top of the dewar
Scintil. light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

100 kton liquid Argon TPC detector



A detector for ν astrophysics, ν beams and nucleon decay
Single module cryo-tanker based on Industrial LNG technology

Physics program



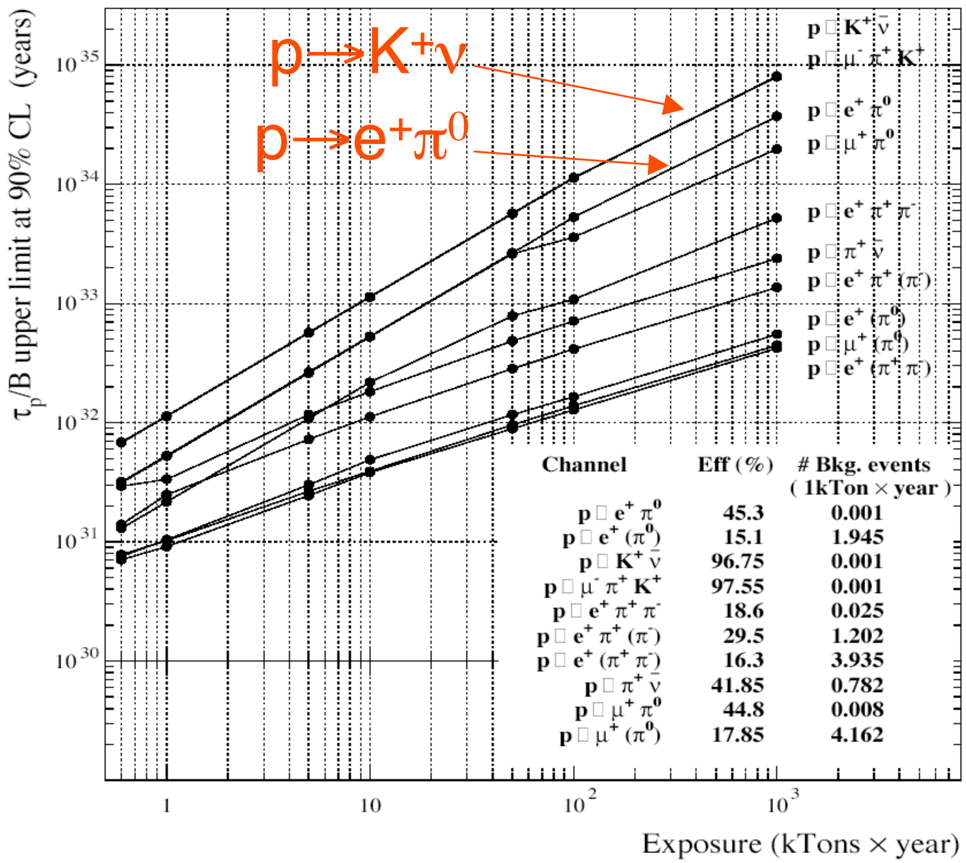
100 kton LAr delivers "megaton-physics"

	Liquid Argon TPC
Total mass	100 kton
$p \to e\,\pi^0$ in 10 years	0.5×10^{35} years ε = 45%, <1 BG event
$p \to \nu\,K$ in 10 years	1.1×10^{35} years ε = 97%, <1 BG event
$p \to \mu\,\pi\,K$ in 10 years	1.1×10^{35} years ε = 98%, <1 BG event
SN cool off @ 10 kpc	38500 (all flavors) (64000 if NH-L mixing)
SN in Andromeda	7 (12 if NH-L mixing)
SN burst @ 10 kpc	380 ν_e CC (flavor sensitive)
SN relic	Yes
Atmospheric neutrinos	10000 events/year
Solar neutrinos	324000 events/year E_e > 5 MeV

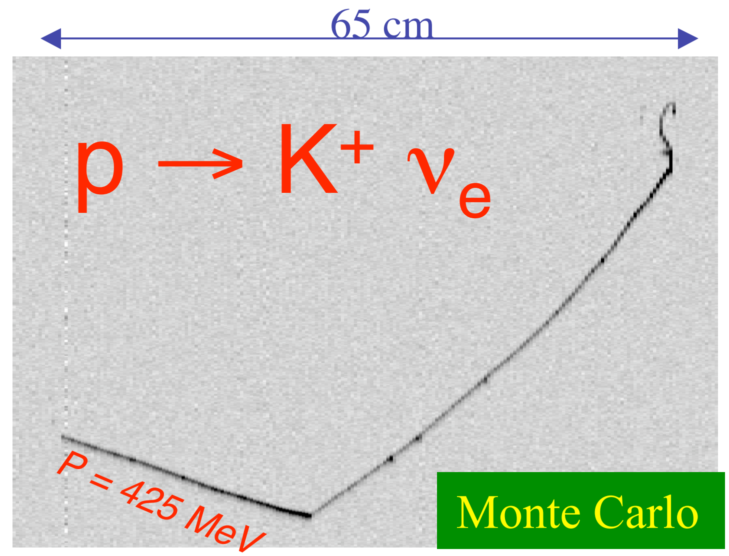
Complementary to Megaton Water Cerenkov detector

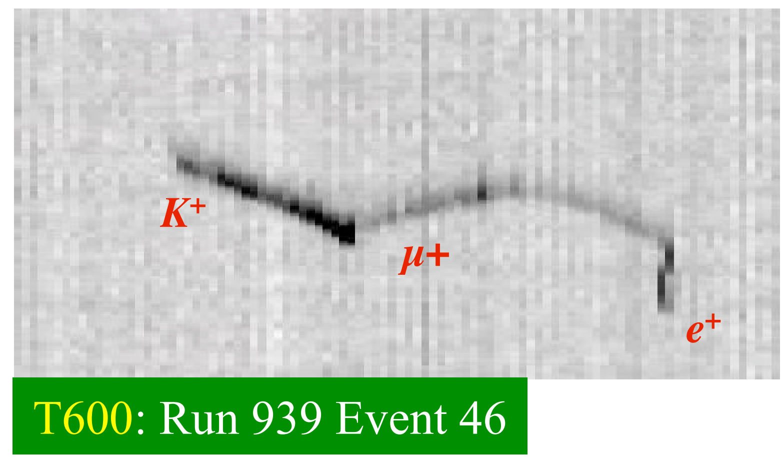
- Review of massive underground detectors A.Rubbia, Proc. XI Int. Conf. on Calorimetry in H.E.P., CALOR04, Perugia, March 2004

Proton decay: sensitivity vs exposure



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

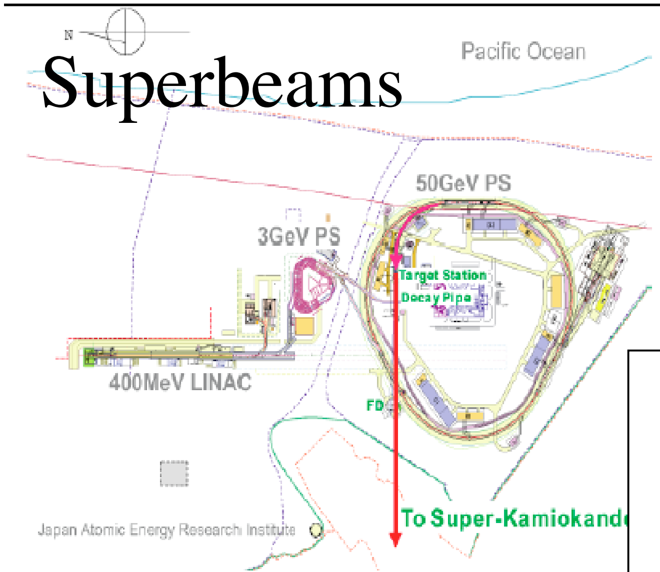




6×10^{34} nucleons $\Rightarrow$

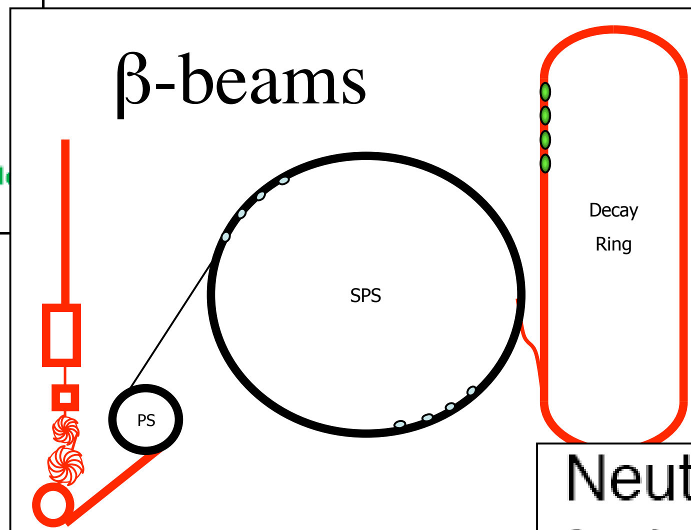
τ_p/Br > ≈10^{34} years × T(yr) × ε @ 90 CL

Neutrinos at accelerators



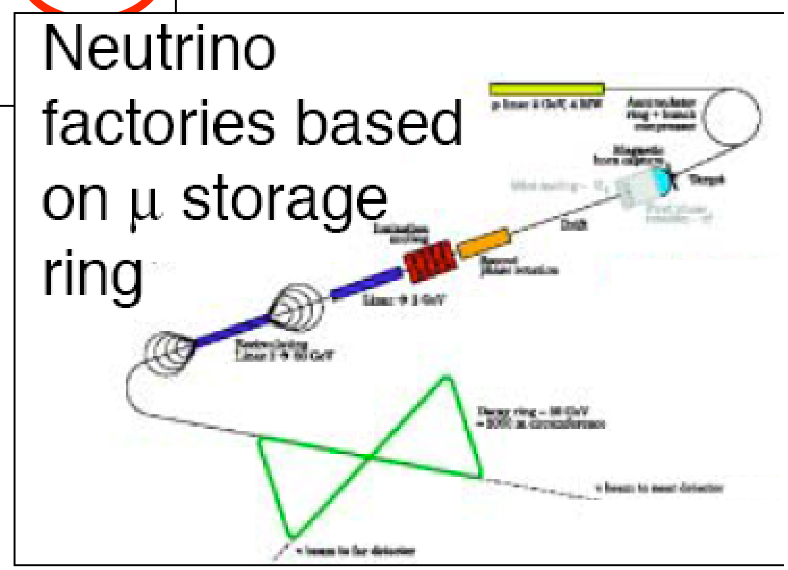
$$\pi^{\pm} \rightarrow \mu^{\pm} \overset{(-)}{\nu}_{\mu}$$

Select focusing sign



$${}^{Z}A \rightarrow {}^{Z\mp1}A \ \beta^{\pm} \ \overset{(-)}{\nu}_{e}$$

Selection



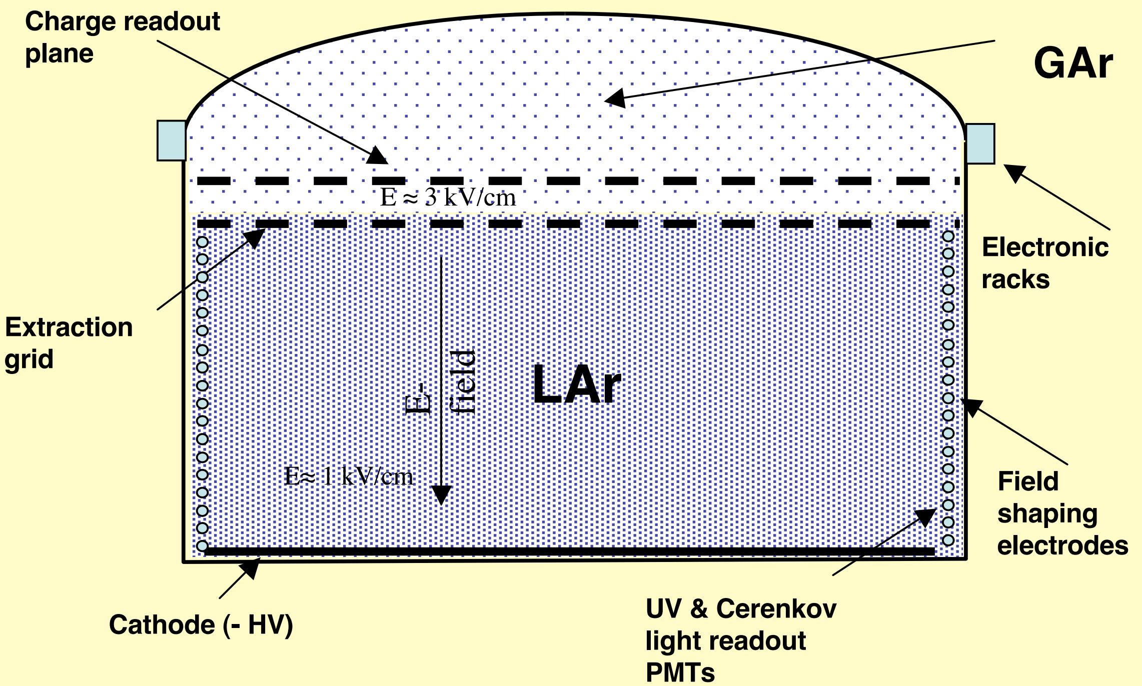
Select ring sign

$$\left.\begin{array}{l} \mu^{-} \rightarrow e^{-}\bar{\nu}_{e}\nu_{\mu} \\ \mu^{+} \rightarrow e^{+}\nu_{e}\bar{\nu}_{\mu} \end{array}\right\}$$

Tentative detector layout

Single detector: charge Imaging, scintillation, Cerenkov light

Dewar	D ≈ 70 m, height ≈ 20 m, perlite insulated, heat input ≈ 5 W/m²
Argon storage	Boiling Argon, low pressure (<100 mbar overpressure)
Argon total volume	73000 m³, ratio area/volume ≈ 15%
Argon total mass	102000 tons
Hydrostatic pressure at bottom	3 atmospheres
Inner detector size	Disc D ≈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



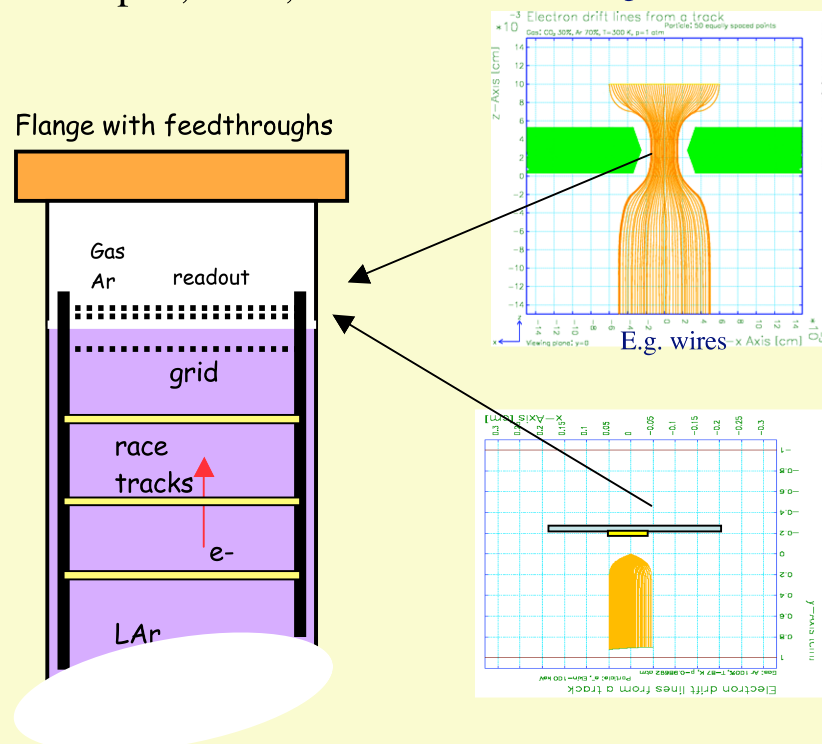
Charge extraction and amplification

Detector runs 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
- Amplification can be implemented in different ways: wires+pad, Gem, Lem

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 ≈ 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 $\tau = 2$ 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, …

E.g., Lem,Gem



Ongoing studies and initial R&D strategy

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

2) Understanding of charge collection under high pressure

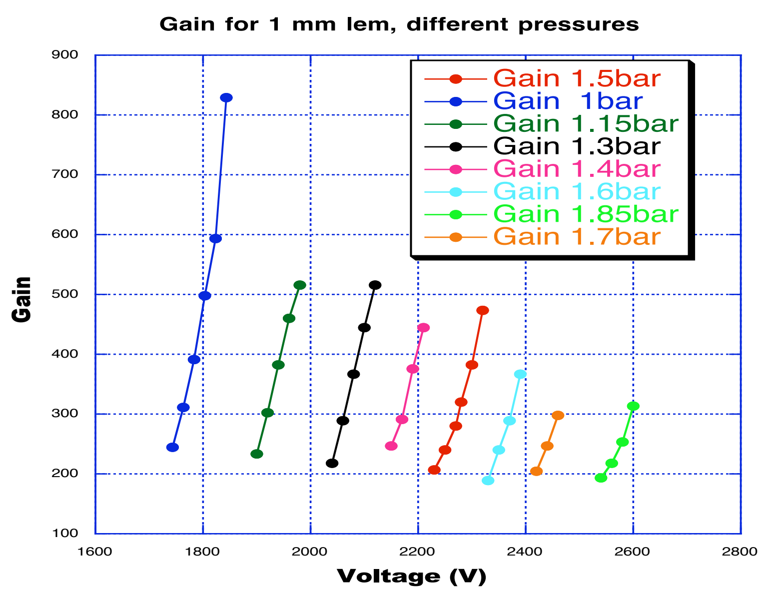
3) Realization and test of a 5 m long detector column-like prototype

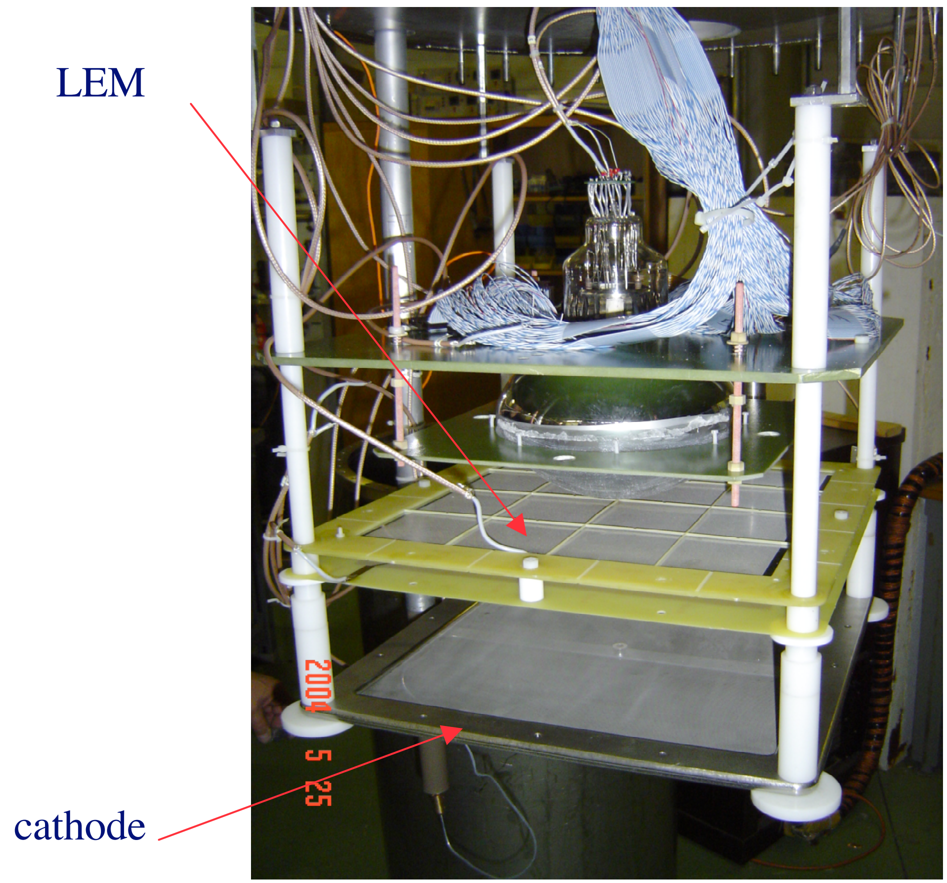
4) Study of LAr TPC prototypes immersed in a magnetic field

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

1) Amplification with self-made Lem

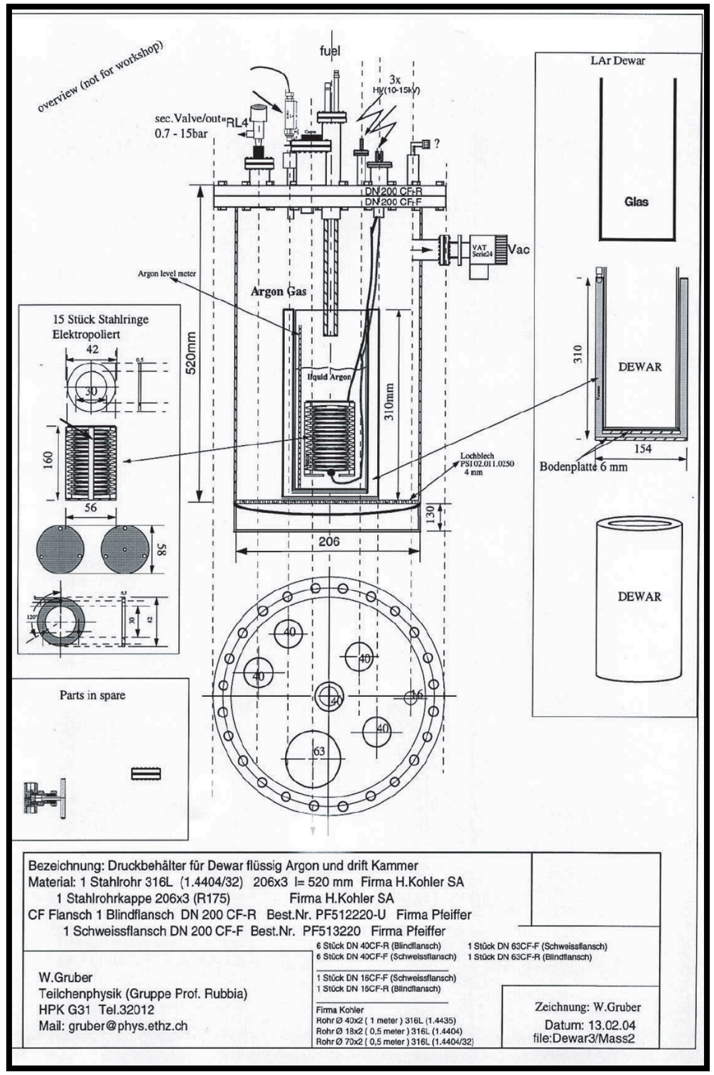
- •Fe source (5.9 keV γ), Argon 100%
- •Three LEM thicknesses: 1, 1.6 and 2.4 mm
- •Varying pressures
- •Room temperature



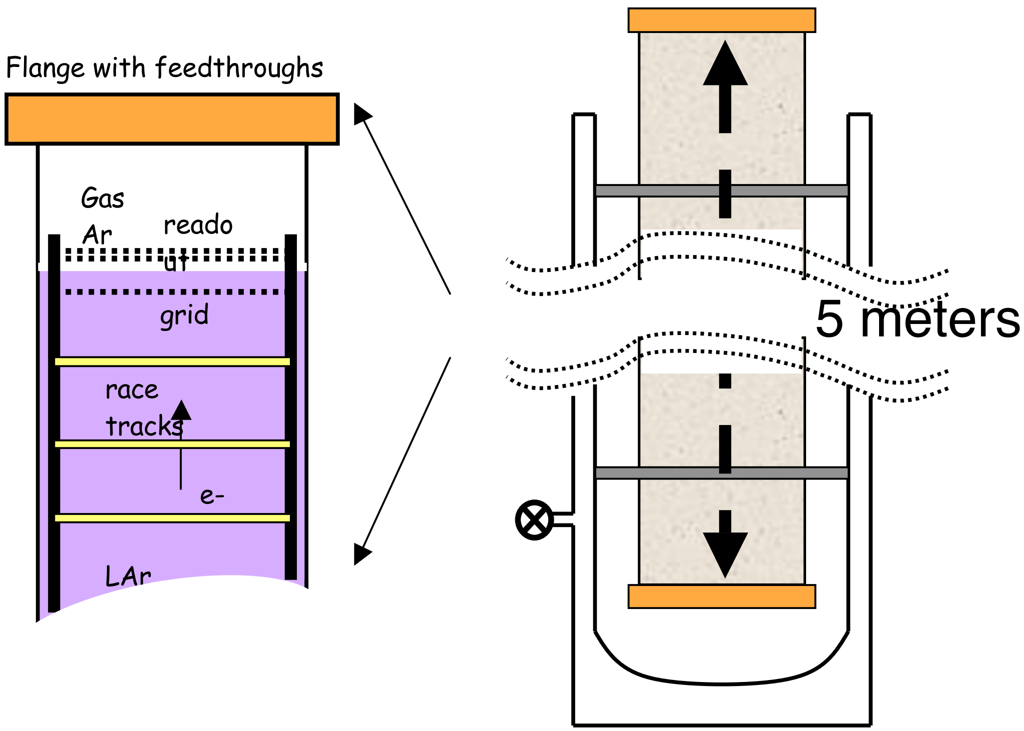


2) High-pressure drift properties

- Future large tankers:
  - Hydrostatic pressure could be quite significant (3-4 atmosphere at the bottom of the tanker)
- Test of electron drift properties in high pressure liquid Argon
  - Important to understand the electron drift properties and imaging under high pressure
- Study in progress
  - Prototype designed
  - Part being assembled at PSI



3) long drift, extraction, amplification

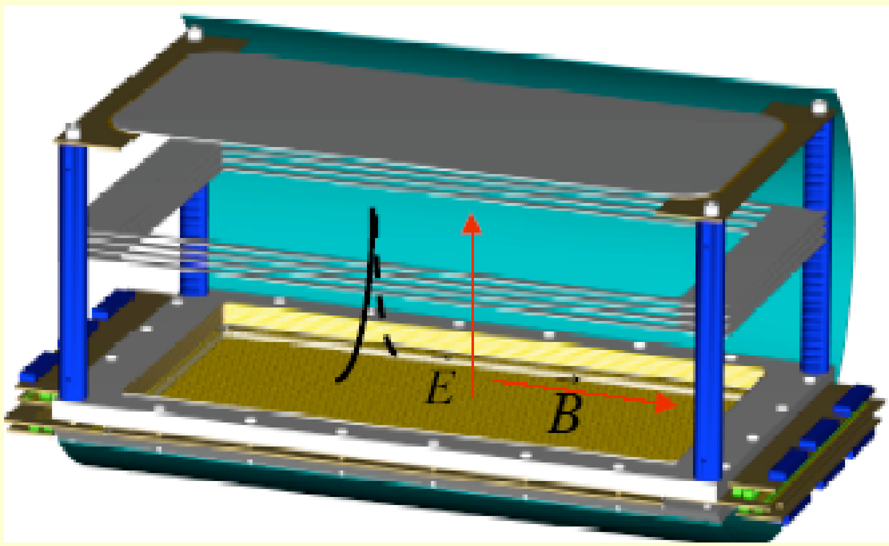


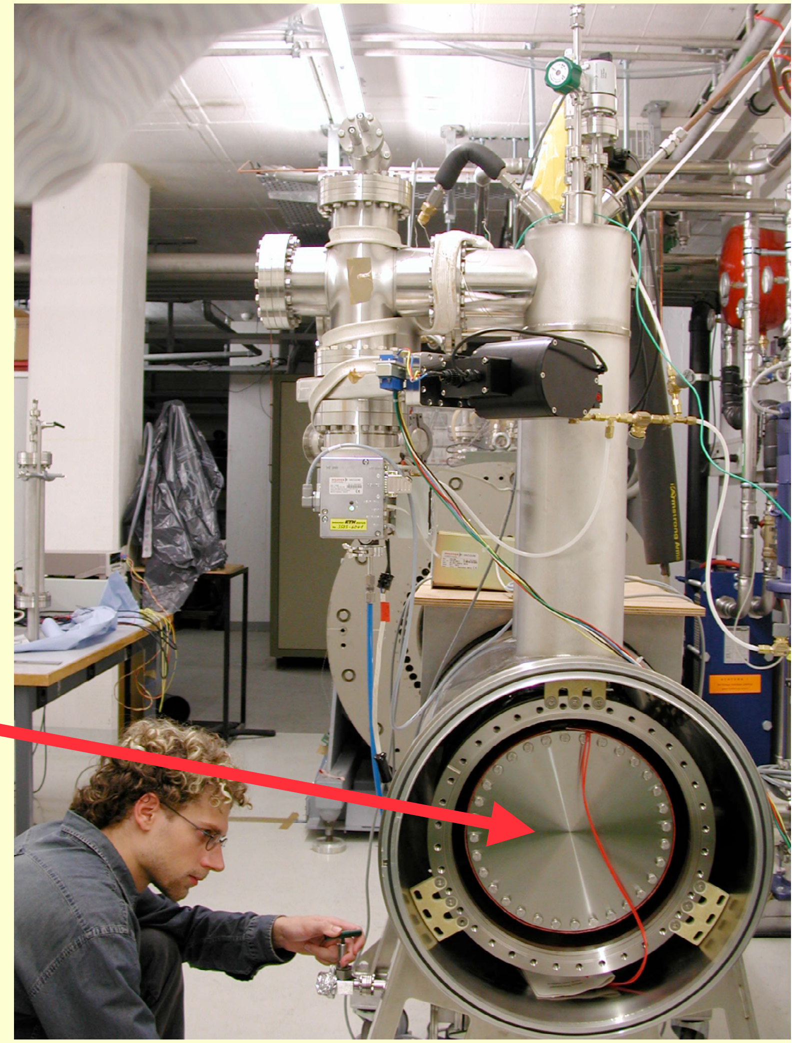
- A full scale measurement of long drift (5 m), signal attenuation and multiplication is planned.
- Simulate 'very long' drift (10-20 m) by reduced E field & LAr purity
- Construction in progress: external dewar, detector container, …
- Power Supply generator(250-500kV) to be hosted "inside". It is a first test for the future application up to 2MV.

The project of the field shaper and the internal chamber is going on.

4) Liquid Argon imaging in B-field

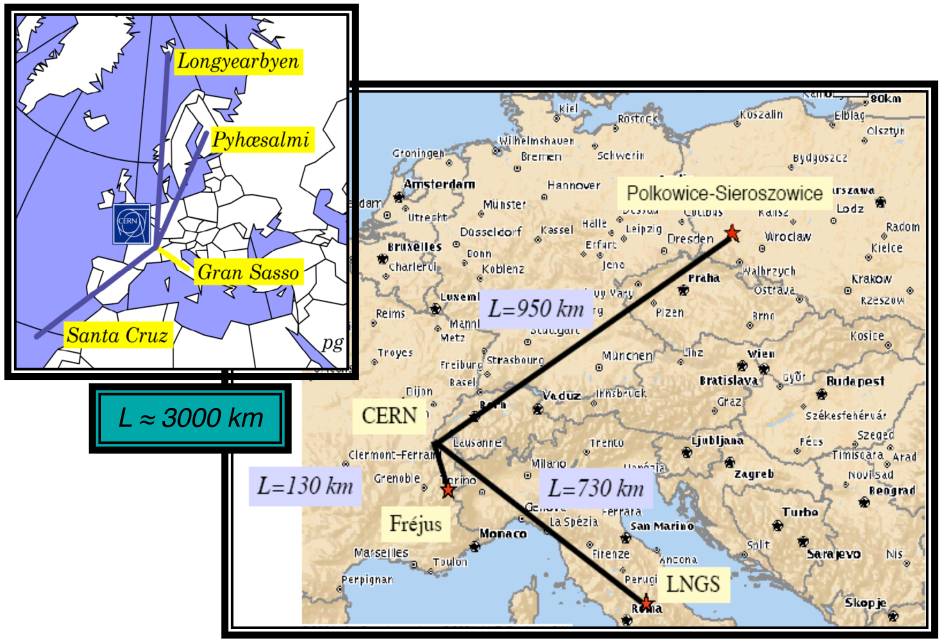
- Small chamber with recycled magnet up to
  B = 0.5 T (230 kW) given by PSI Villigen
- Test program:
  - Check basic imaging in B-field
  - Measure traversing and stopping μ bending
  - Charge discrimination
  - Lorentz angle $\alpha \approx 30$mrad @ E= 500 V/cm, B= 0.5T
- Results expects at the end of 2004

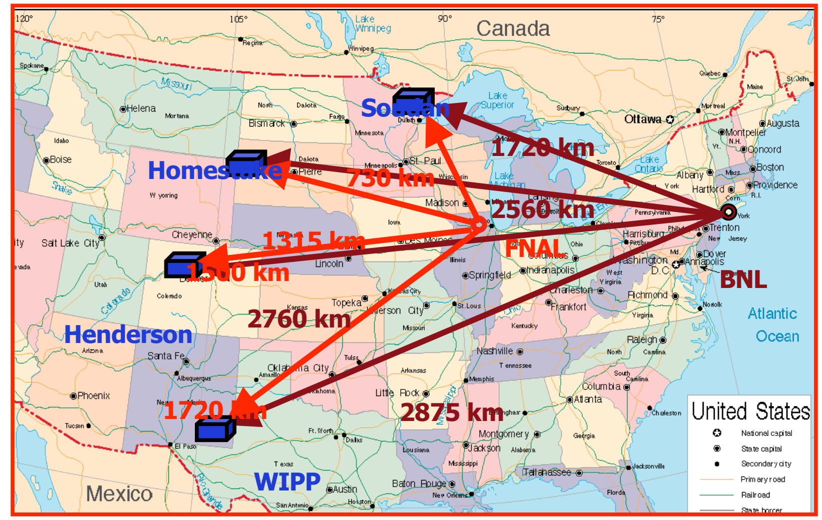


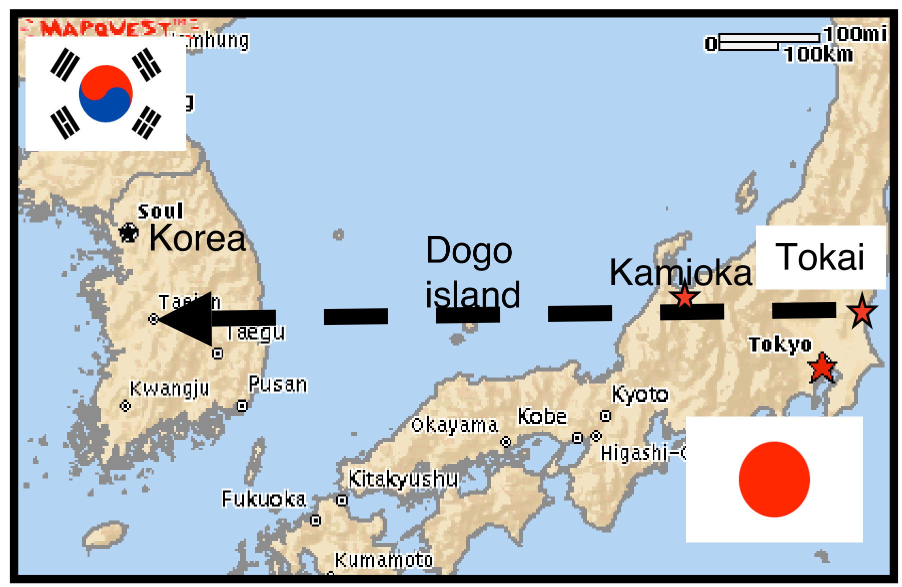


Width 300 mm, height 150 mm, drift length 150 mm

5) Possible (EU) sites for a large mass LAr TPC



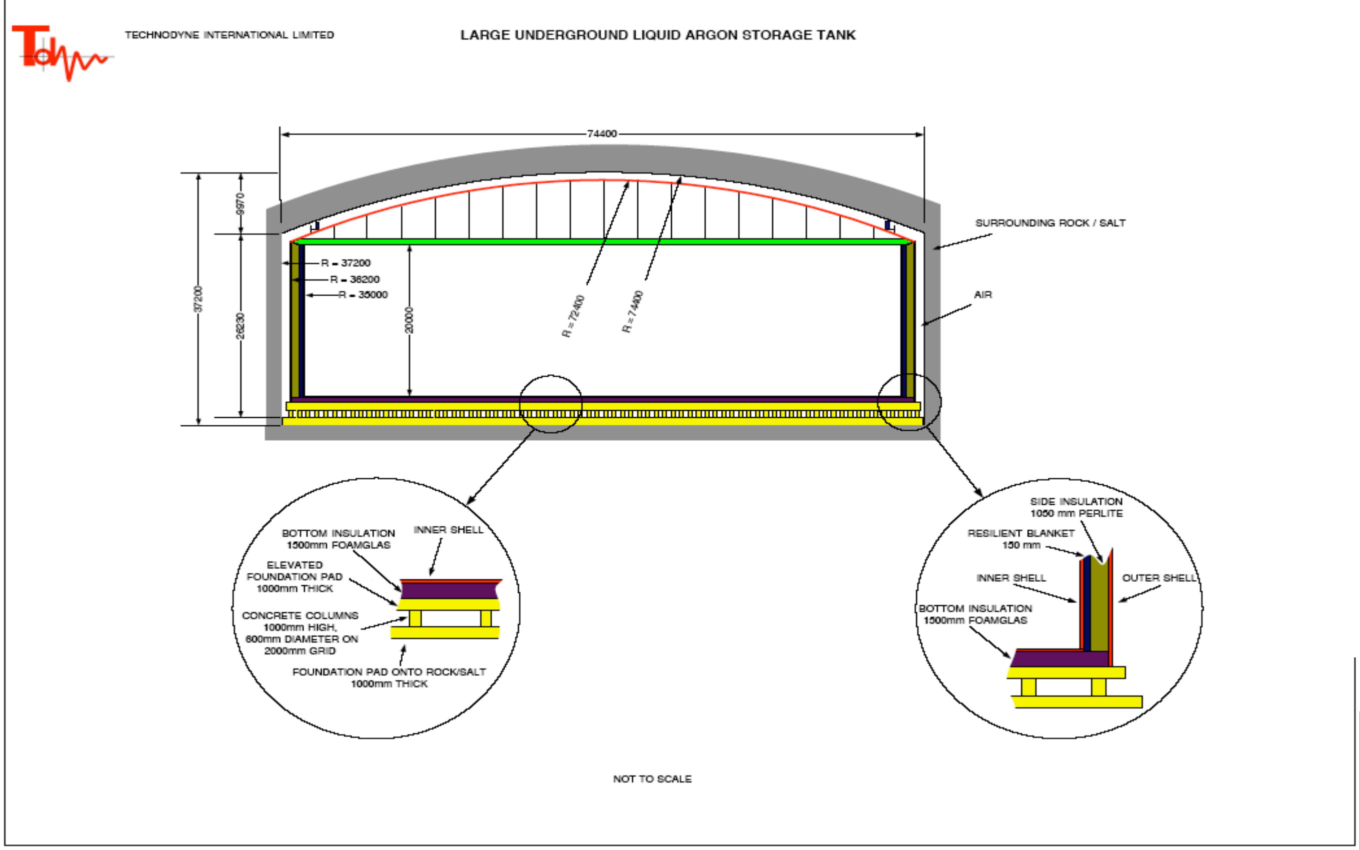




Infrastructure, depth, location, baseline, cavern size…

5)Studies of large underground storage tank

	Project: Large Underground Argon Storage Tank
Issued By: JMH	Document Title: Study report
Date:	



A feasibility study mandated to Technodyne LtD (UK)

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

Outlook and Conclusions

- 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.
- Today, physics is calling for applications at two different mass scales:
  ≈ 100 kton: proton decay, high statistics astrophysical & accelerator neutrinos
  ≈ 100 ton: systematic study of neutrino interactions, near detectors at LBL facilities
- A tentative layout for a 100 kton underground liquid argon detector has been presented based on LNG cryogenic self-refrigerated (boiling) tanker, bi-phase operation for very long drifts with charge imaging, scintillation and Cerenkov light readout. R&D is on-going to ascertain the technical feasibility and performance of this design.
- A 10% full-scale, cost-effective prototype could be envisaged as an engineering design test with a physics program on its own.
- A 100 ton detector in a near-site of an LBL facility is a straight forward and very desirable application of the technique.