Low energy neutrino astronomy and nucleon decay searches with next generation large underground detectors: an overview

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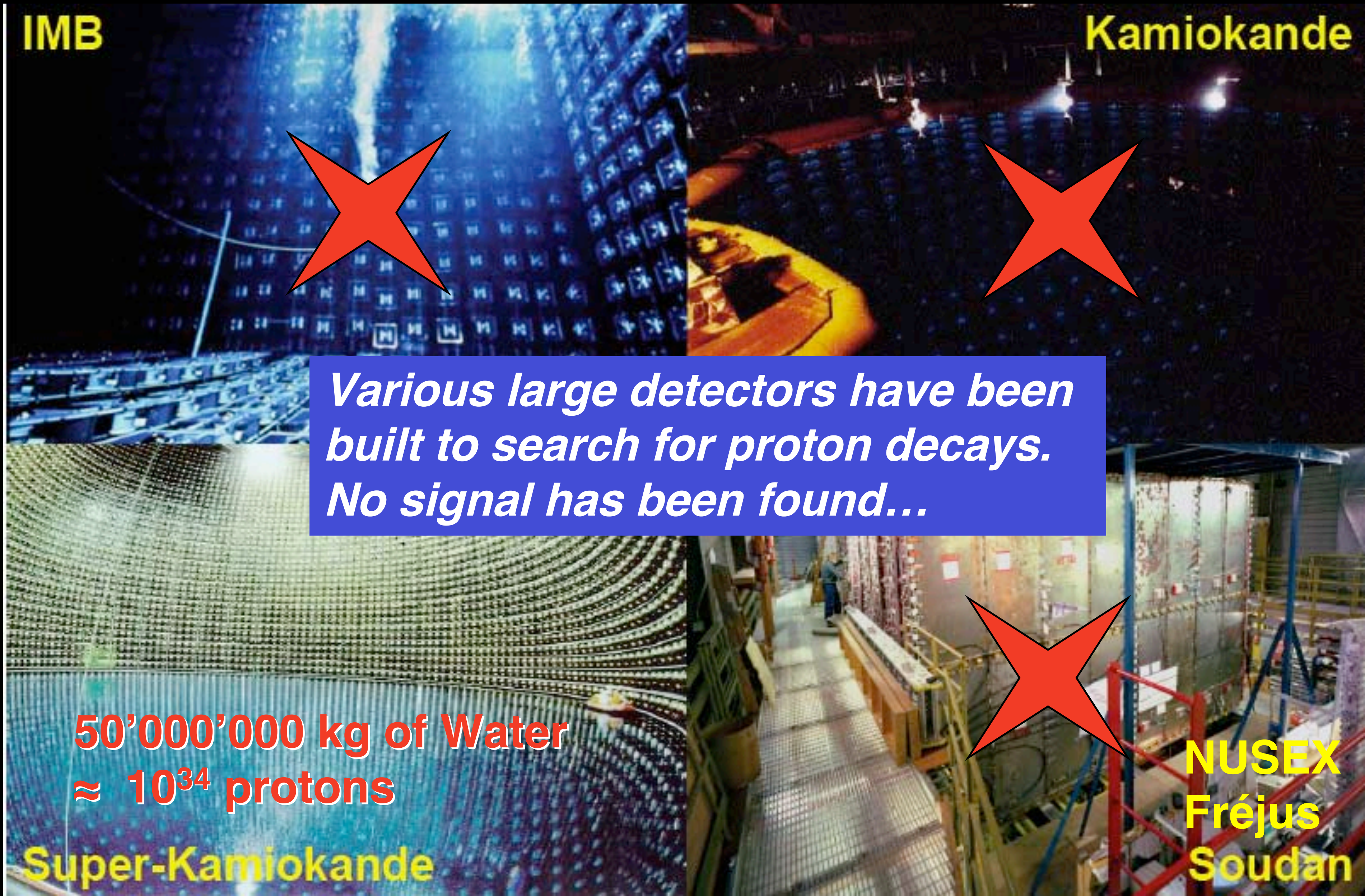
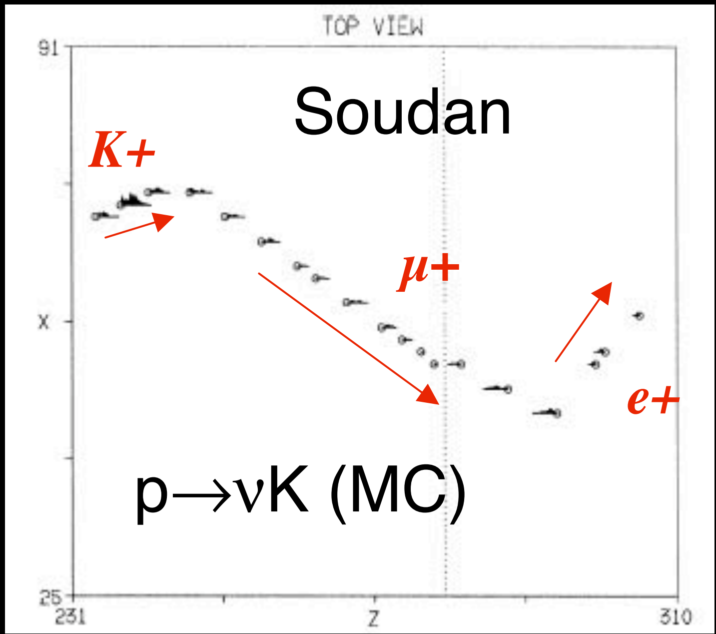
European Astroparticle Physics, Town Meeting
Munich, November 23rd to 25th, 2005

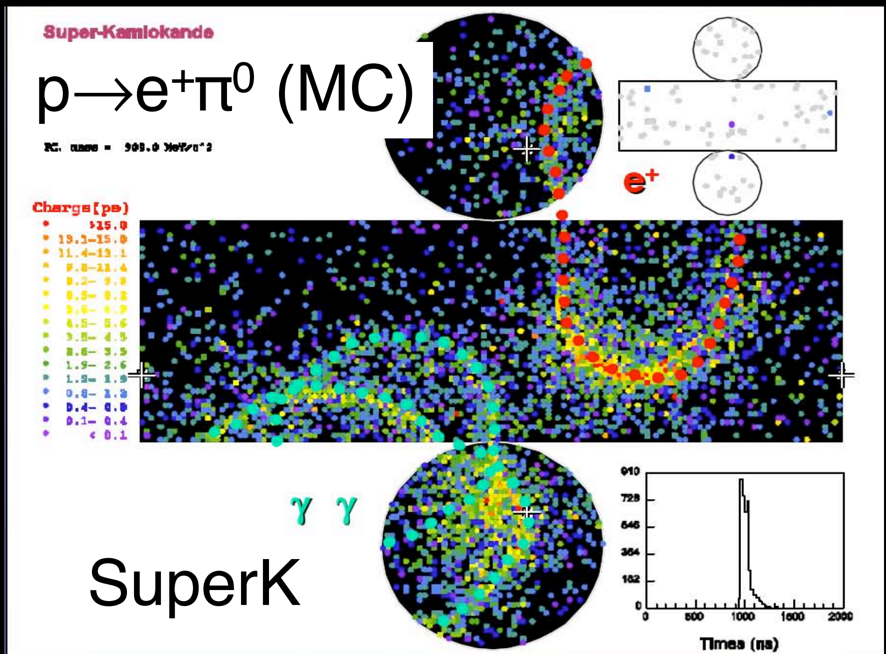
Large underground detectors for nucleon decay searches

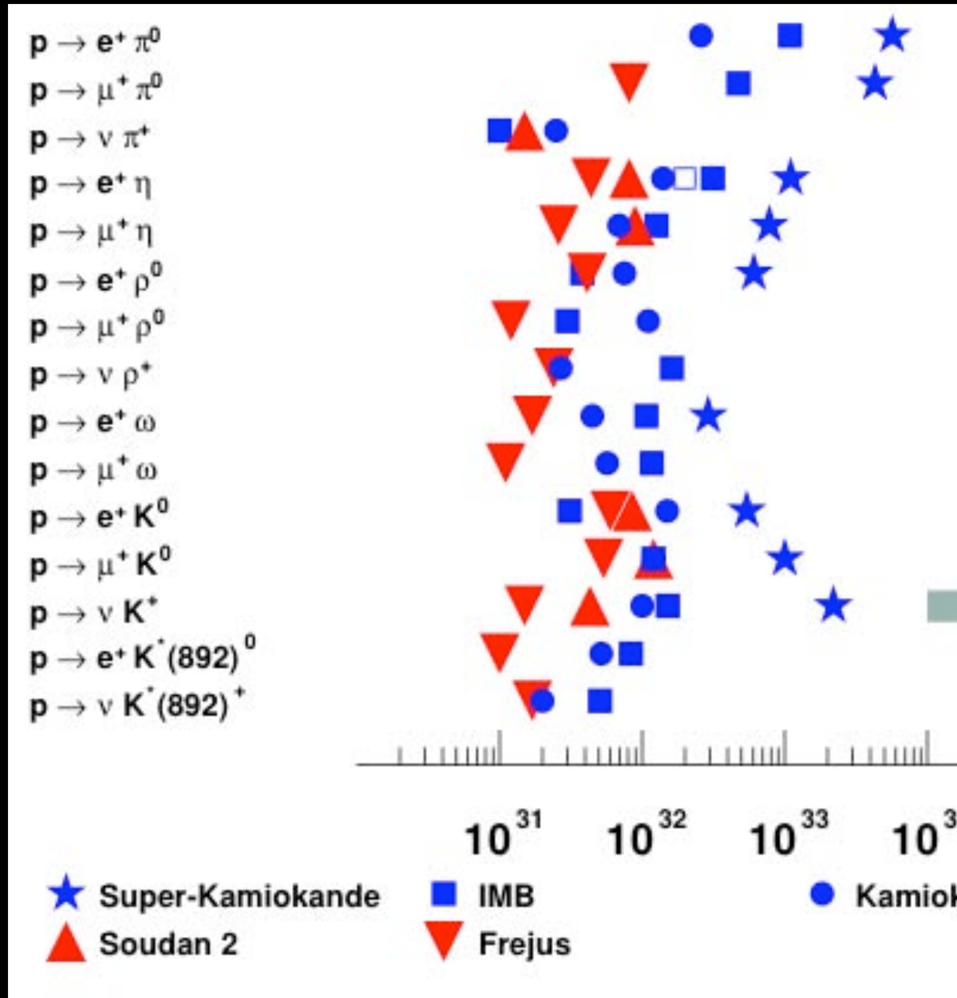


Negative results from proton decay searches…

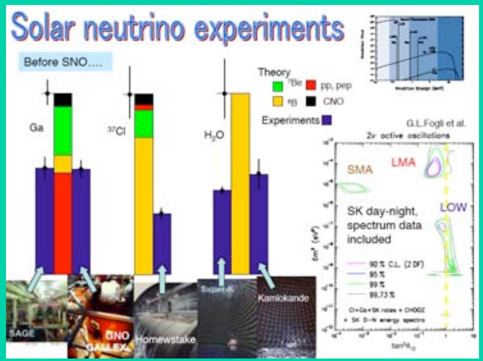
- **Tracking-calorimeters & Water Cerenkov detectors**
- **Best limits above 10^{32} yrs from WC**

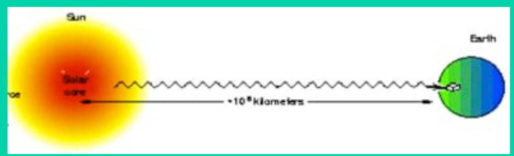


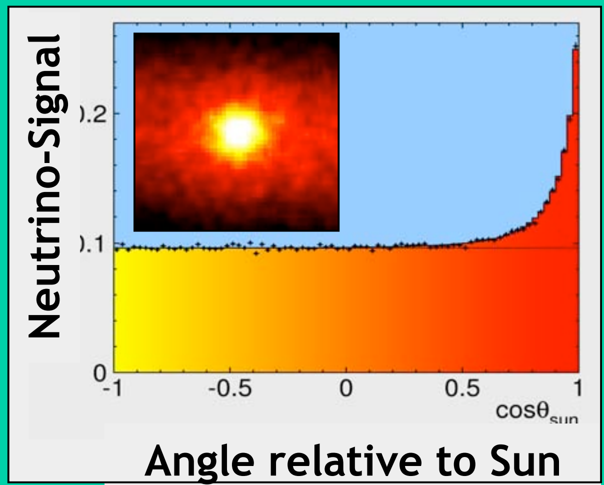


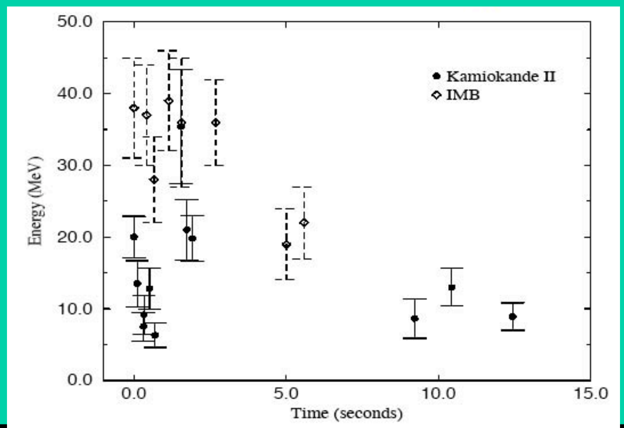


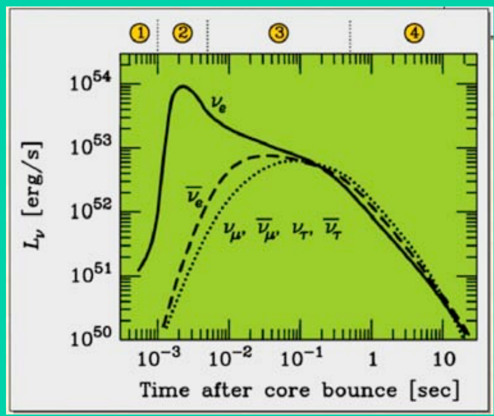
But past success of the field…





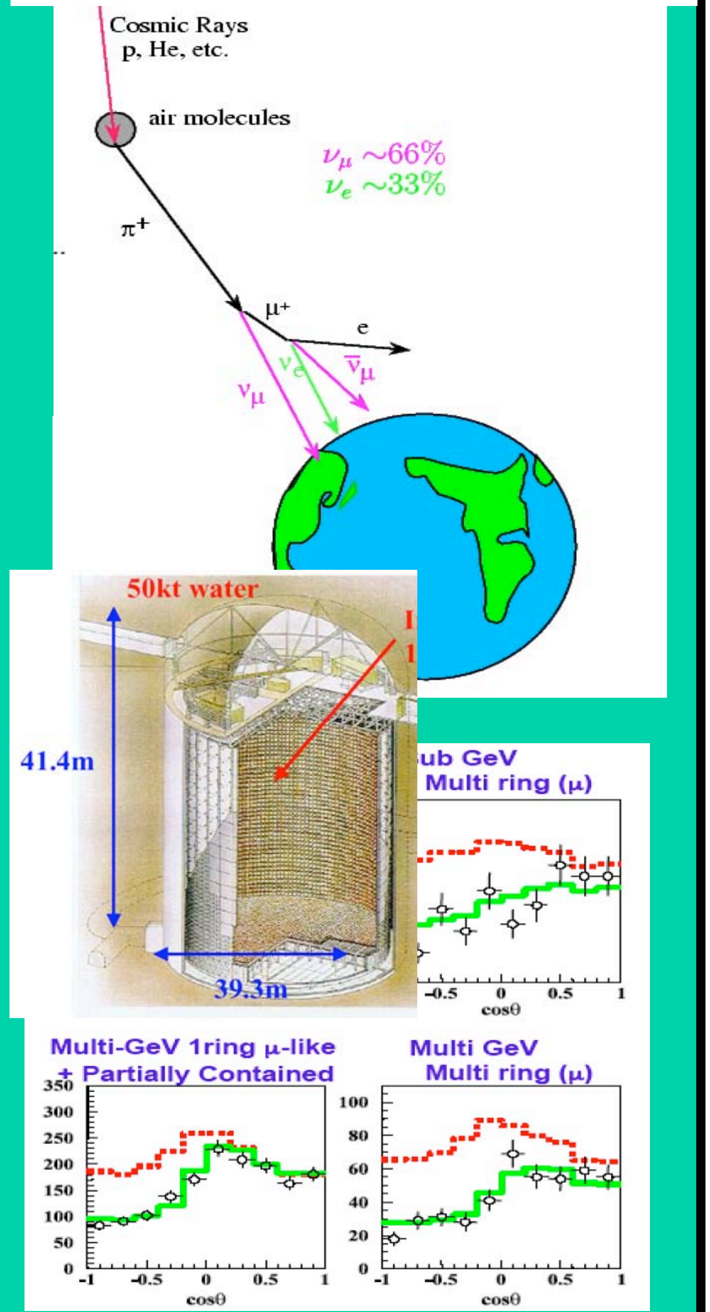






- •Solar neutrino deficit
- •Detection of SN-1987A (Nobel Koshiba)
- •Discovery of atmospheric neutrino oscillations

Atmospheric neutrino experiments



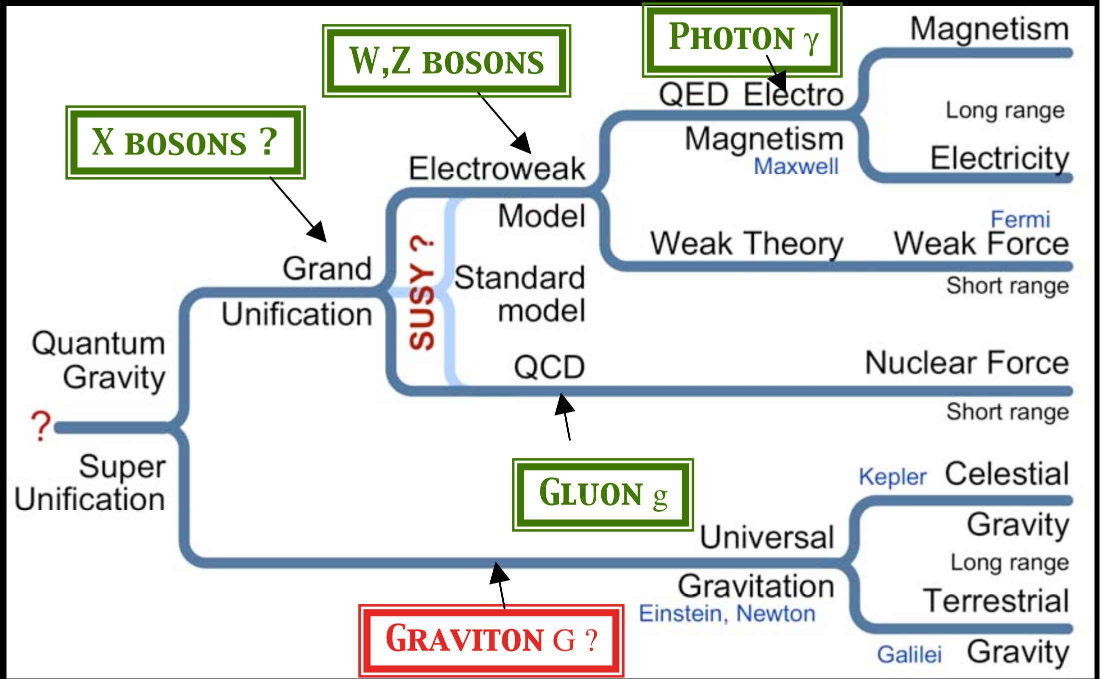
The need for new generation experiments…

Still many unsolved or unachieved issues…

• **Baryon number violation**	**Proton decay**
• **Gravitational collapse**	**SN ν**
• **Star formation in the early universe**	**Relic SN ν**
• **Solar thermonuclear fusion processes**	**Solar - ν**
• **Neutrino properties**	**SN - ν,** **Atm. - ν,** **LBL - ν**
• **Geophysical models, Earth density profile**	**Atm. - ν** **U, Th - ν**

Nucleon (proton) decay

- The understanding of the Grand Unification is one of the most challenging still-open goal of particle physics!

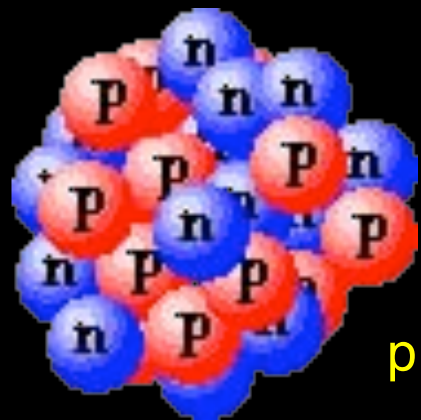


1. Baryon number violation:

- Unification of electroweak and strong force
- New fundamental symmetry between quarks & leptons
- Transmutation between quarks and leptons: proton unstable

2. Grand-Unification scheme

- Depends on SUSY or no-SUSY
- What are the branching fractions?
- **$p \to e^+\pi^0$, νK^+, other decay modes**



$p \longrightarrow e^+ + \pi^0$

Supernova type-II neutrinos

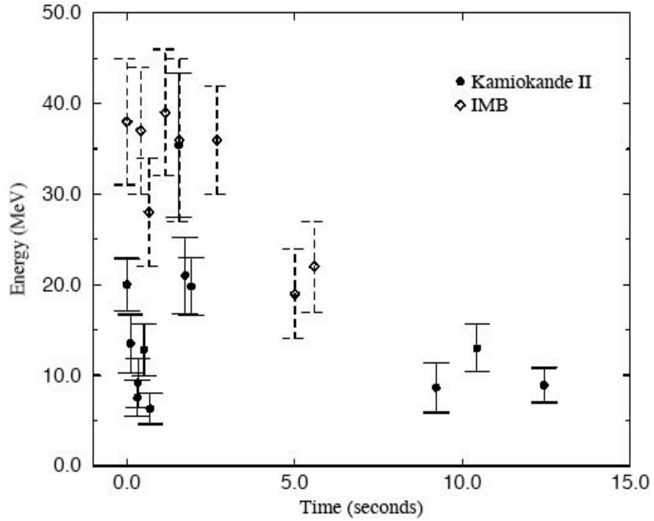
- Access supernova and neutrino physics simultaneously
- Decouple supernova & neutrino properties via different detection channels

1. Supernova physics:

- Gravitational collapse mechanism
- Supernova evolution in time
- Cooling of the proto-neutron star
- Nucleosynthesis of heavy elements
- Black hole formation
- Exotic effects

SN1987A Type II in LMC (~55 kpc)

Water Cherenkov:	IMB	E_{th} ~ 29 MeV, 6 kton	8 events
	Kam II	E_{th} ~ 8.5 MeV, 2.4 kton	11 events
Liquid Scintillator:	Baksan	E_{th} ~ 10 MeV, 130 ton	3-5 events
	Mont Blanc	E_{th} ~ 7 MeV, 90 ton	5 events??



Confirmed baseline model... but still many questions

2. Neutrino properties

- Neutrino mass (time of flight delay)
- Oscillation parameters (flavor transformation in SN core and/or in Earth): Type of mass hierarchy and θ_{13} mixing angle

3. Early alert for astronomers

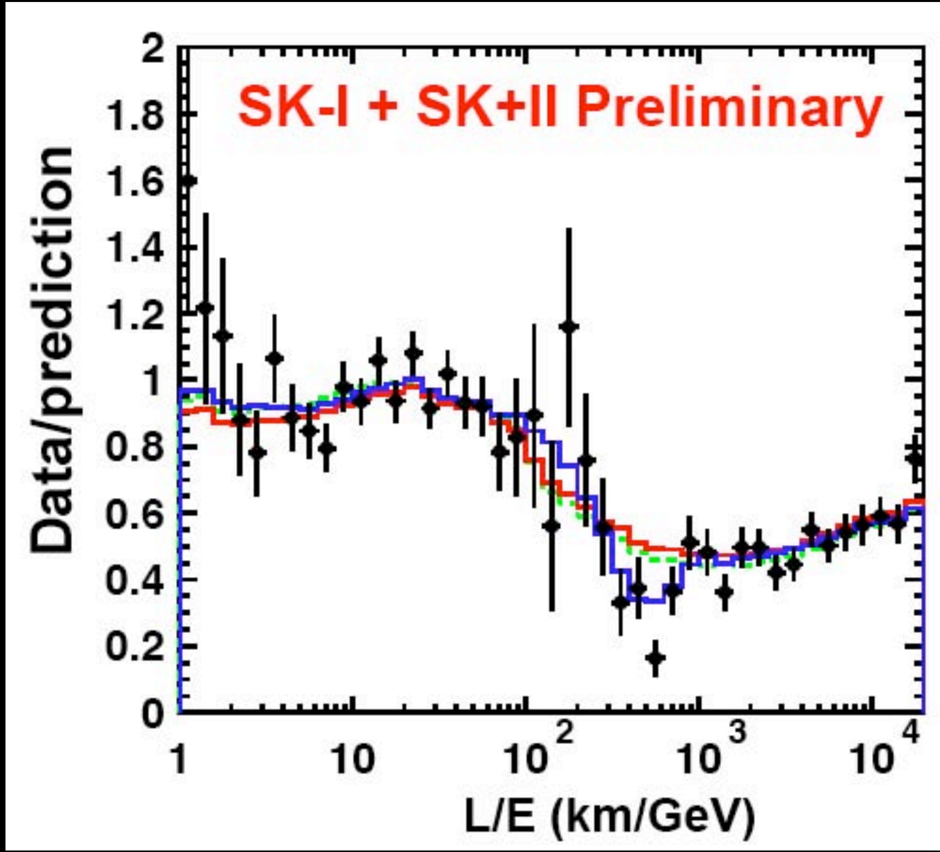
- Pointing to the supernova

Neutrino properties (w/o accelerators)

- Astrophysical neutrinos observation with more statistics and improved detection method will be important

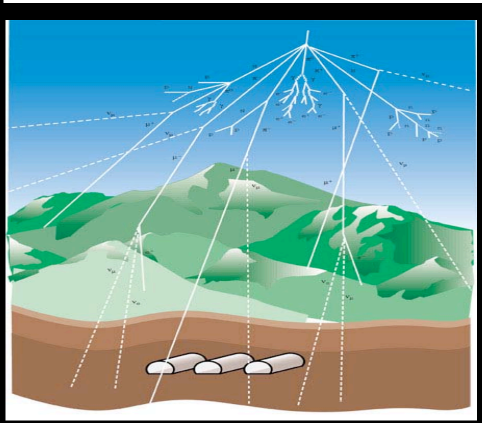
1. Atmospheric neutrinos:

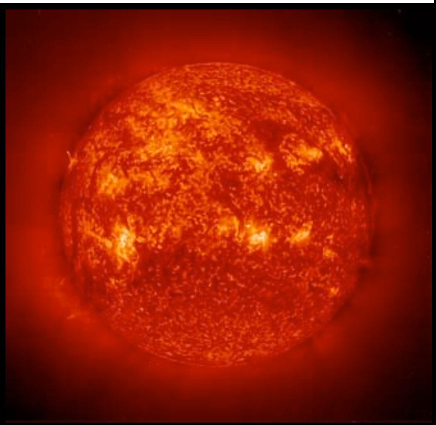
High statistics, from observation to precision measurements
L/E dependence
Sterile neutrinos and tau appearance
Electron appearance θ_{13}
Earth matter effects and sign of Δm^2_{23}
CP-violation



2. Solar neutrinos

High statistics, precision measurement of flux
D/N asymmetry
Time variation of flux
Solar flares
…





Geo-neutrinos

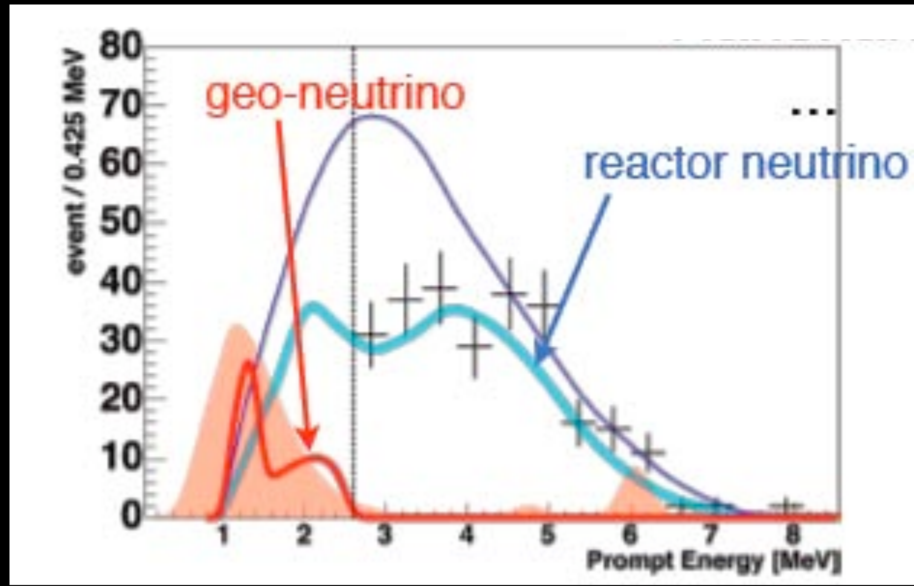
●Geoneutrinos are a new probe to test Earth's interior!

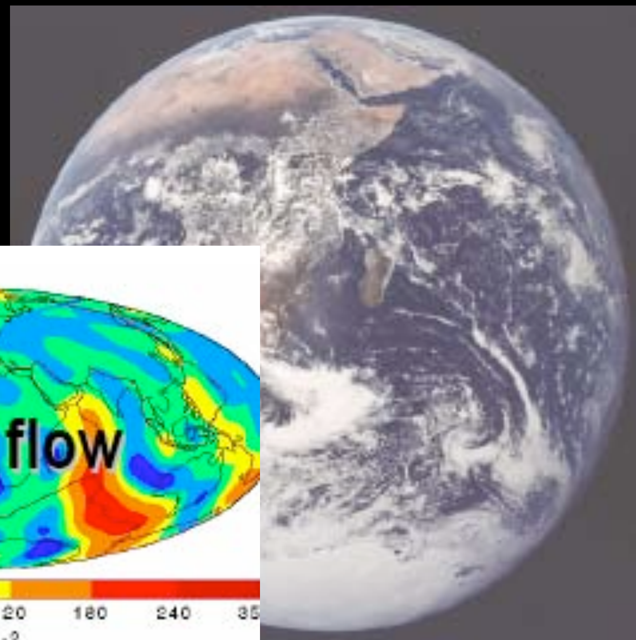
1. Geophysics:

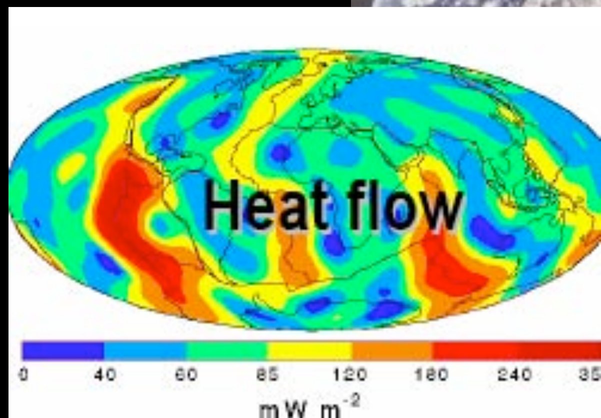
- Test the U/Th/K content in Earth (mantle, core)
- How much heat is primordial?
- Get the distribution of radioactive elements through the earth
- Test if there are radioactive elements in the core (^{40}K?)
- Any other (nuclear reactor in core?)

2. In particular, HEAT

- What is the source of terrestrial heat flow?
- Understanding Earth's heat is fundamental for explaining many phenomena like e.g. volcanoes, earthquakes, …

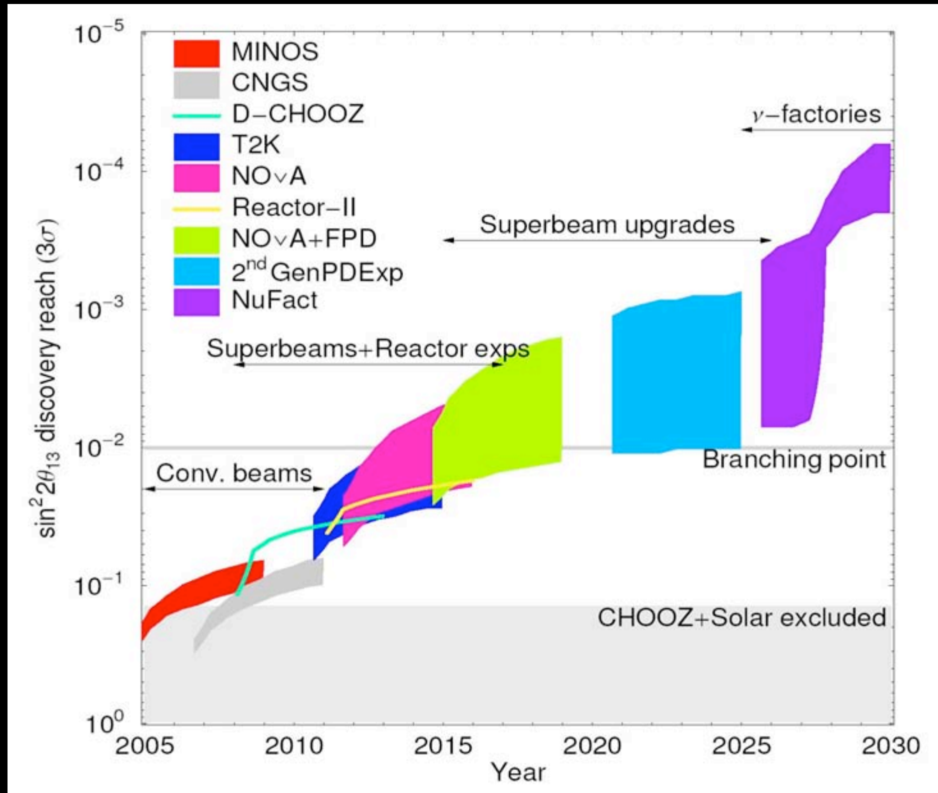






Neutrino properties (with accelerators)

- A very broad programme at various new neutrino facilities extending over many decades!
- Includes conventional beams, superbeams, beta-beams and neutrino factories.
- Each step benefits from results of previous one
- Require >MW "proton driver"

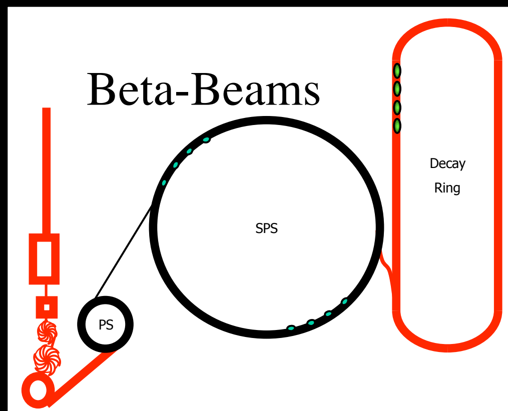


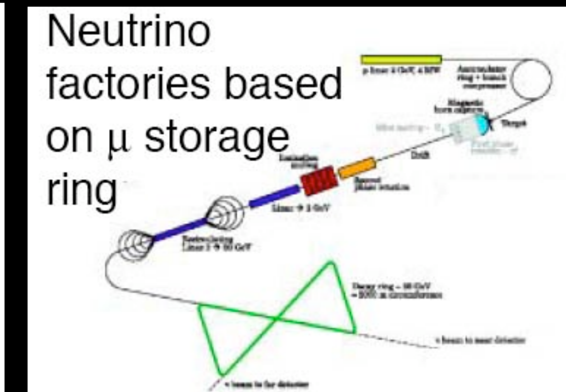
1. Precision measurement:

- ➥ Precision measurement of (θ_{23}, Δm^2_{32}) with error < 1%
- ➥ Measure Earth-matter effects

2. Discoveries

- ✓ θ_{13}
- ✓ sign(Δm^2_{32})
- ✓ δ_{CP}

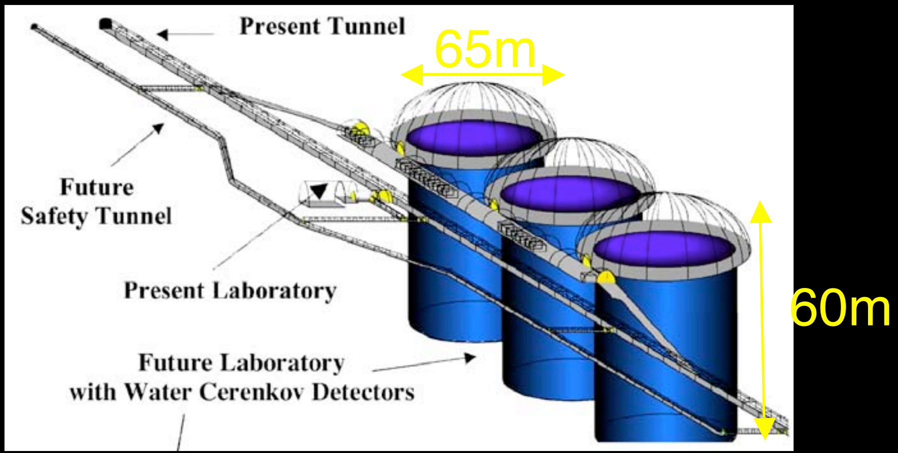




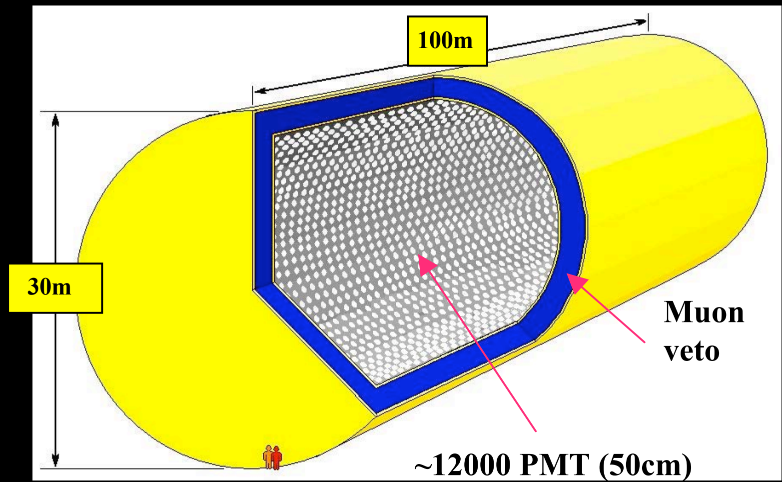
Next generation detectors ?

New large underground detectors in Europe ?

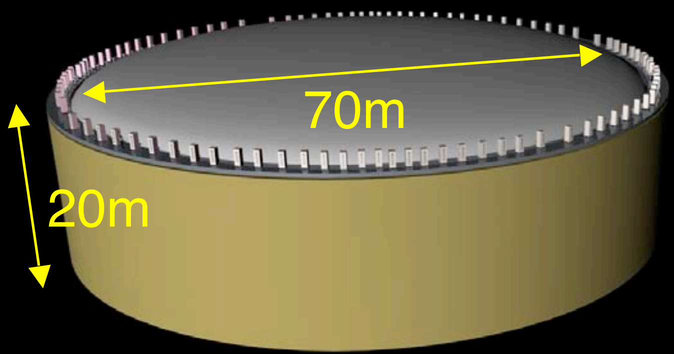
- Three types of large multi-purpose detectors



Water Cherenkov (≈0.5 → 1 Mton)
MEMPHYS



Liquid Scintillator (→ 50 kton)
LENA



Liquid Argon (≈10→100 kton)
GLACIER

- In the context of future LBL, different types (large magnetic iron detector, large fully active & segmented scintillator detectors) have been considered, however, are not discussed here.

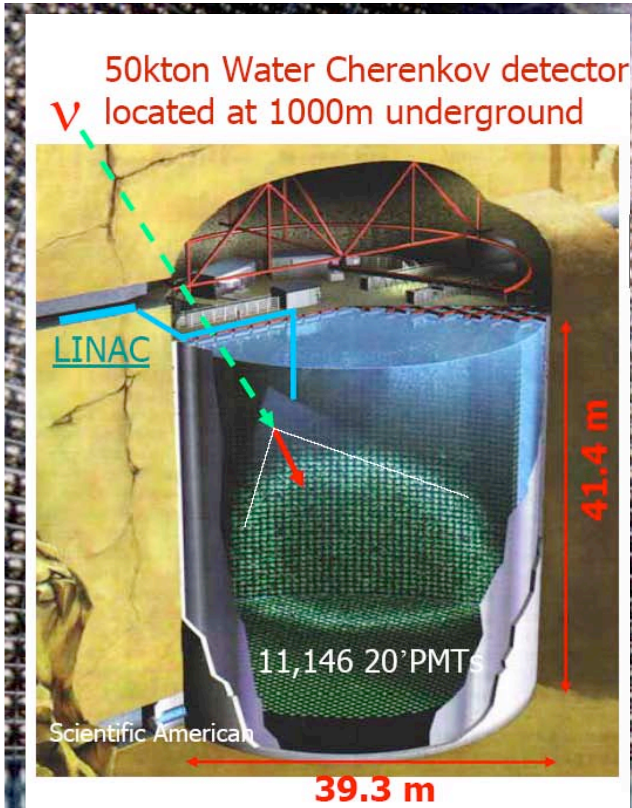
Water Cerenkov detectors

Mton Water Cherenkov Detector

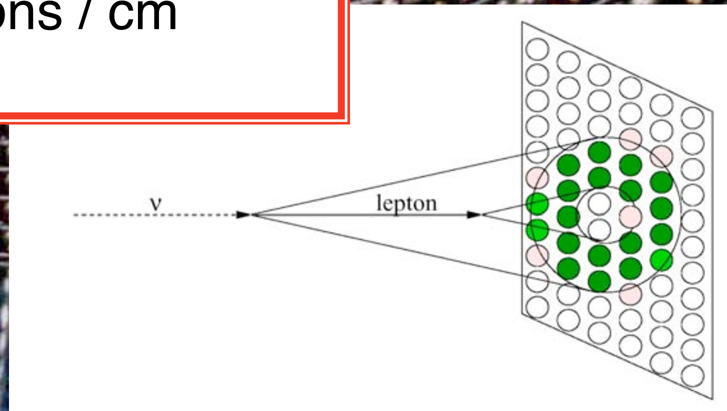
- **Concept of a Mton water Cherenkov detector dates back to 1992**
  - ➥M. Koshiba: “DOUGHNUTS” Phys. Rep. 220 (1992) 229
- **Concept of Hyper-Kamiokande was first presented at NNN99 @ SUNY**
  A recent write-up:
  - ➥K. Nakamura, Int. J. Mod. Phys. A18 (2003) 4053
- **Similar American concept:**
  - ➥ **C.K. Jung, “Feasibility of a next generation underground water Cherenkov detector UNO”, arXiv:hep-ex/0005046**

Well-proven technology (IMB, K, SK) for large scale (however currently no wide expertise in Europe)

Superkamiokande in Kamioka Mine (Japan)



About 170 γ/cm in 350 < λ < 500 nm
With 40% PMT coverage, Q.E.≈20%
Relativistic particle produces
⇒≈14 photoelectrons / cm
⇒≈7 p.e. per MeV

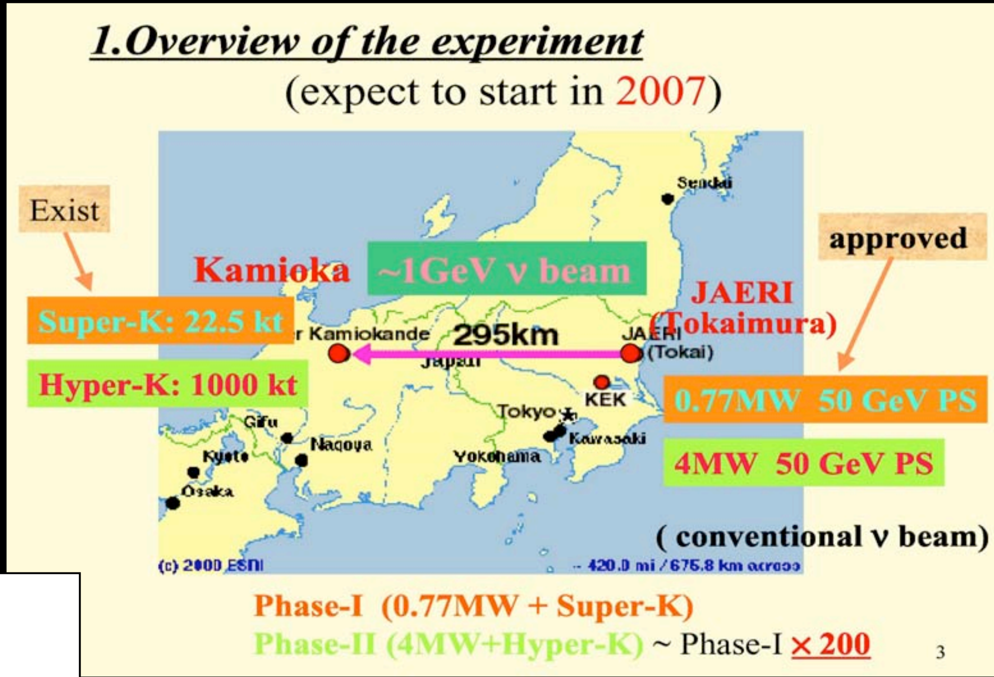


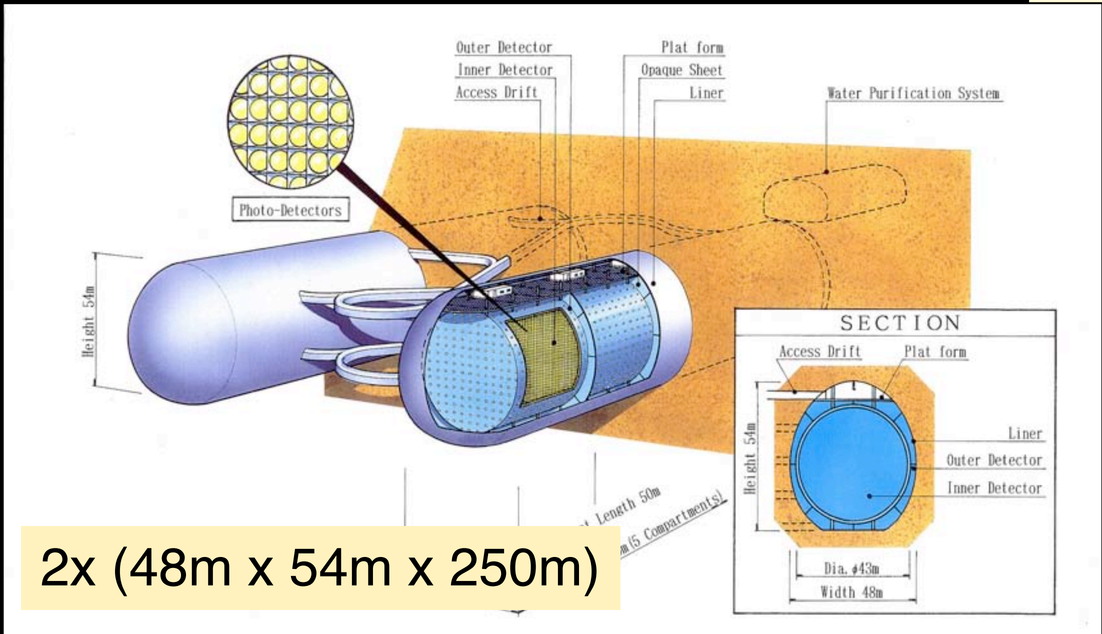
PMT enclosure (after accident)

50’000’000 kg of Water
Light produced in Water observed with 11146 20-inch photodetectors

The Japanese project: Hyperkamiokande

1 Million tons detector motivated by
- Proton decay (≈2x10^{35} protons)
- Long baseline T2K superbeam (CP-violation)
- Atmospheric neutrinos
- Supernova neutrinos
- Solar neutrinos



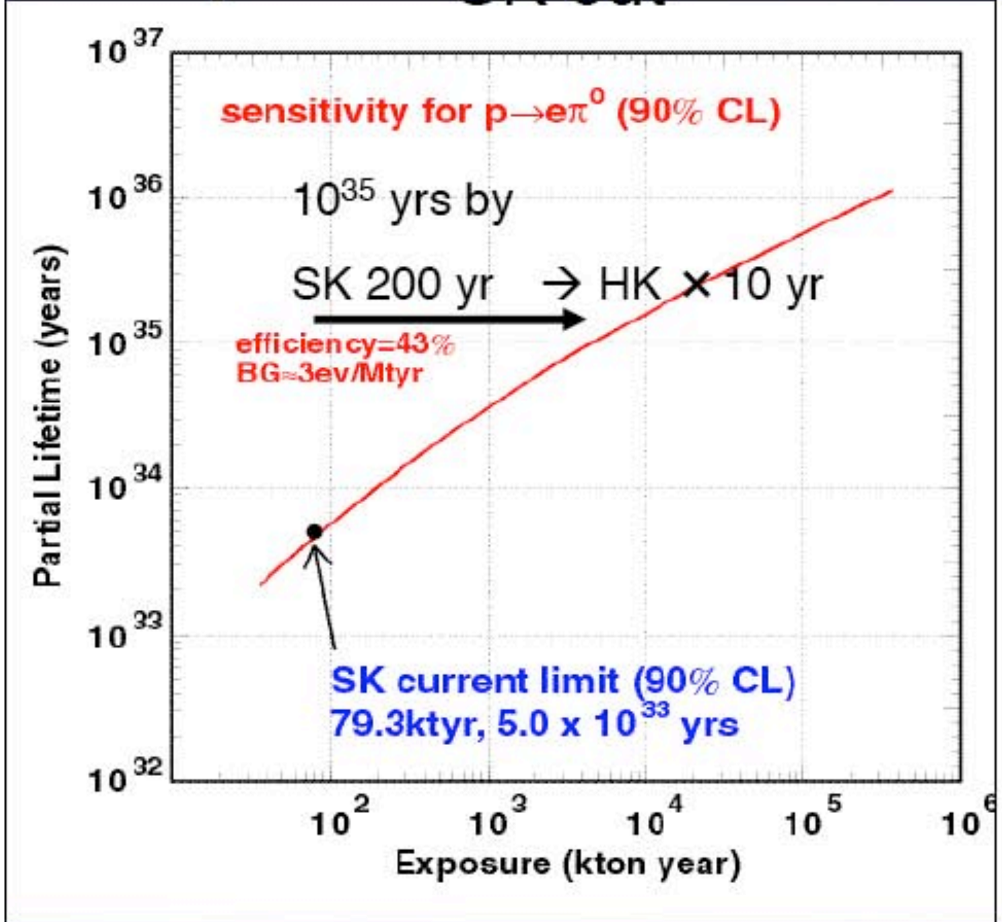


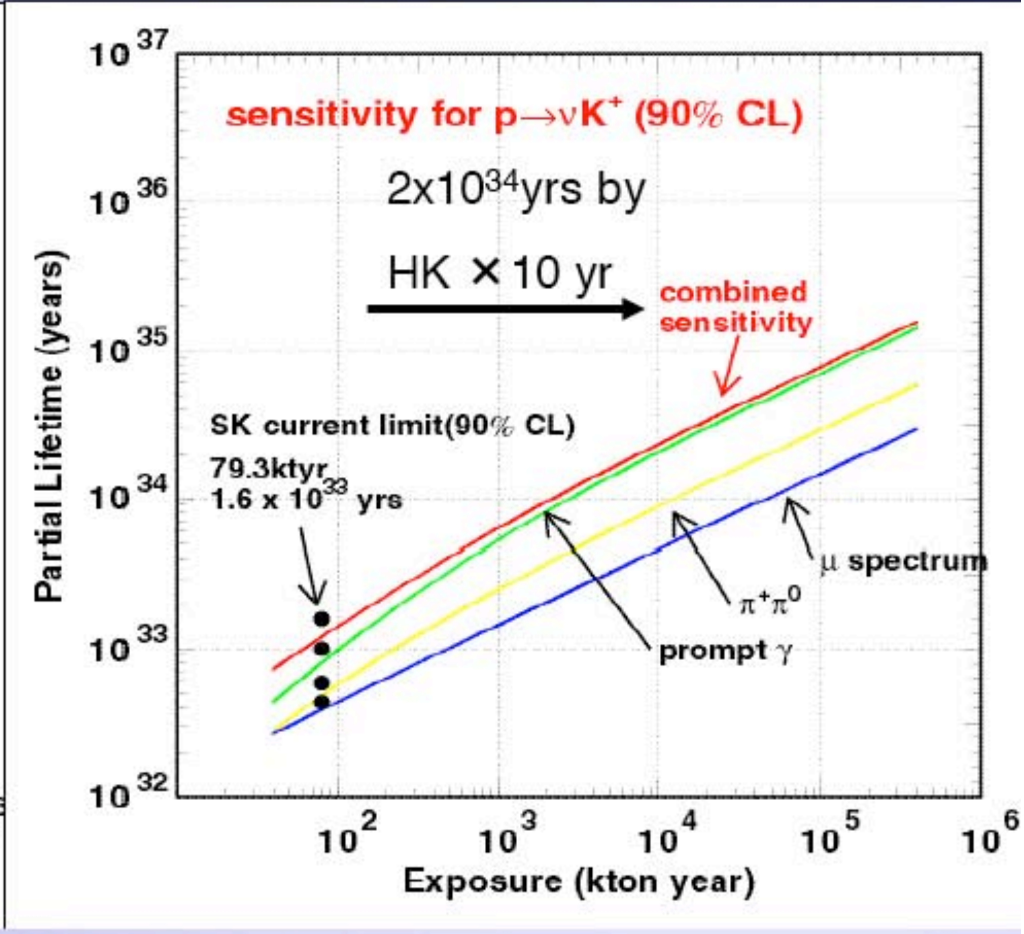
2x (48m x 54m x 250m)

Status:
- Location defined (Toshibora Mine)
- Cavern study performed
- Photodetector R&D on-going
- >100’000 PMTs needed
- Major issue: cost reduction!
- Hope to construct following results from T2K-Phase 1 (2013-2022 ?)

to explore the lifetime above 10^{34} yrs…

SK cut





Assuming performance like in SK

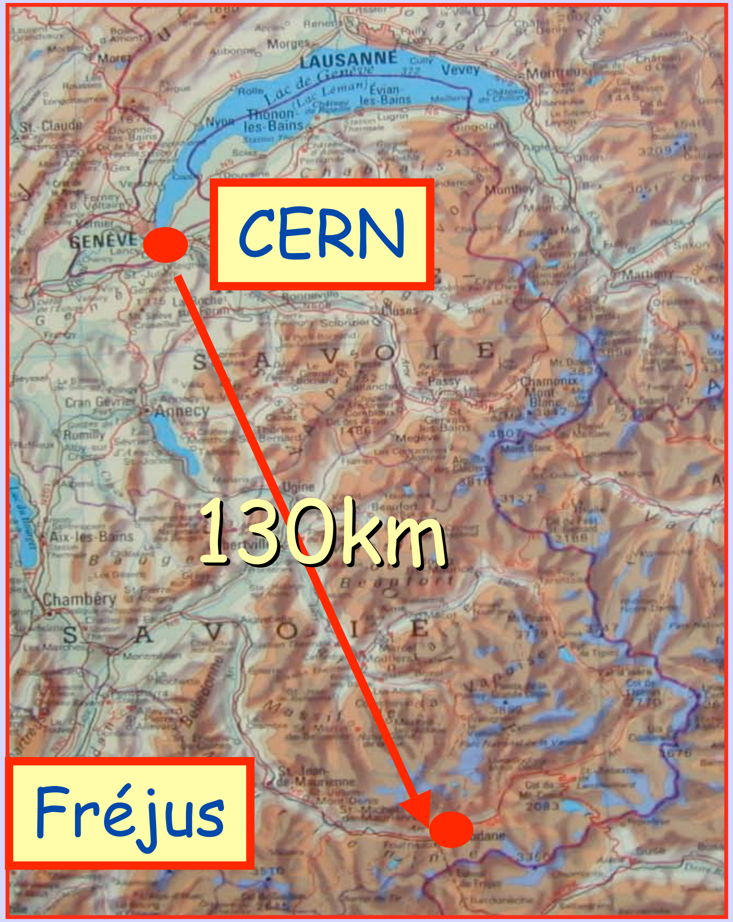
M. Shiozawa

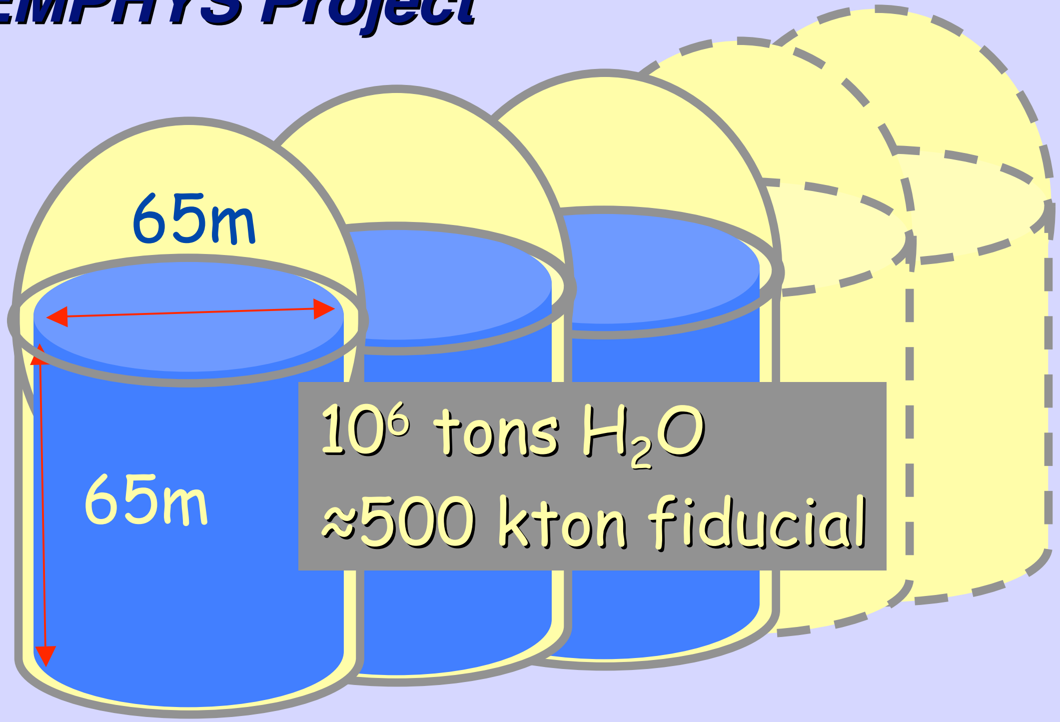
European WC concept:

MEMPHYS

Megaton water Cerenkov at Fréjus

The MEMPHYS Project





Water Cerenkov modules at Fréjus

CERN-Fréjus distance ⇔ unique opportunity for very intense, low energy (≈300 MeV) beam (Super-beam and Beta-beam)

- Concept emerged considering new potential neutrino sources at CERN (low energy super Beam, Beta Beam). This requires construction of the new high-intensity proton driver SPL and the EURISOL facility at CERN.
- In addition, Nucleon Decay, Super Novae Neutrinos (burst & relic), Solar & Atmospheric Neutrinos like in the Japanese study

A new very large laboratory in Europe ?

Excavation engineering pre-study
has been done for 5 shafts

1) the best site (rock quality) is found in the middle of the mountain, at a depth of 4800 mwe : a really good chance !

2) of the two considered shapes : "tunnel" and "shaft", the "shaft (= well) shape" is strongly preferred

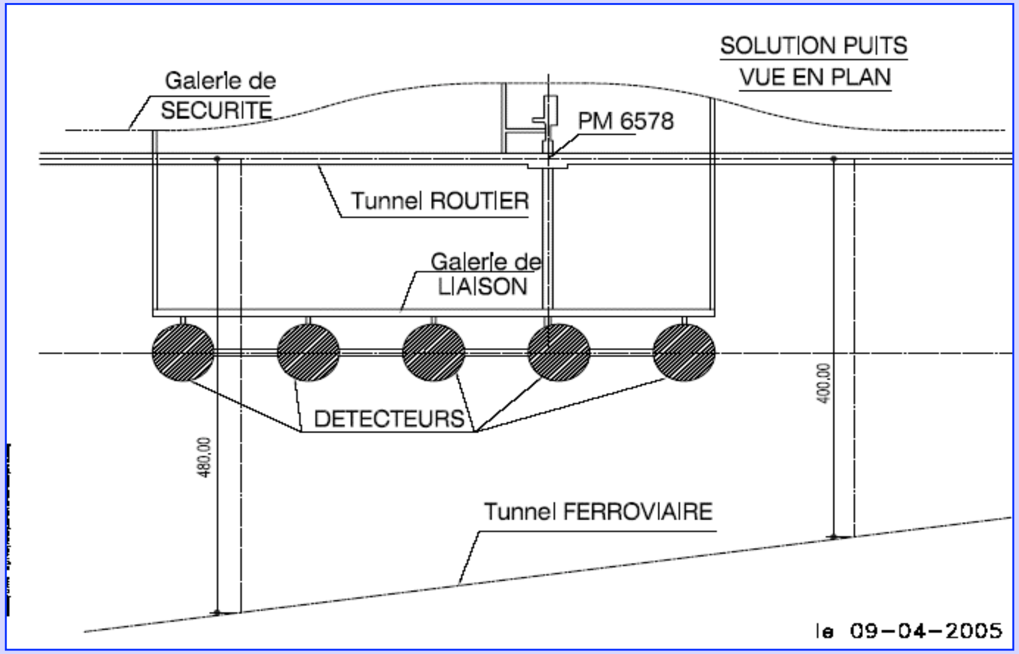
3) Cylindrical shafts are feasible up to :

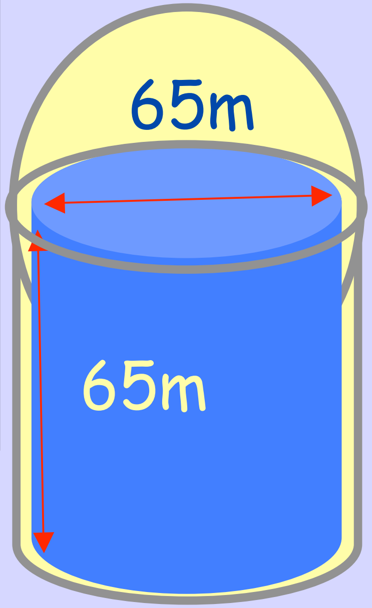
a diameter $\Phi = 65$ m and a full height $h = 80$ m ($\approx 250\ 000\ m^3$)

4) with "egg shape" or "intermediate shape" the volume

of the shafts could be still increased

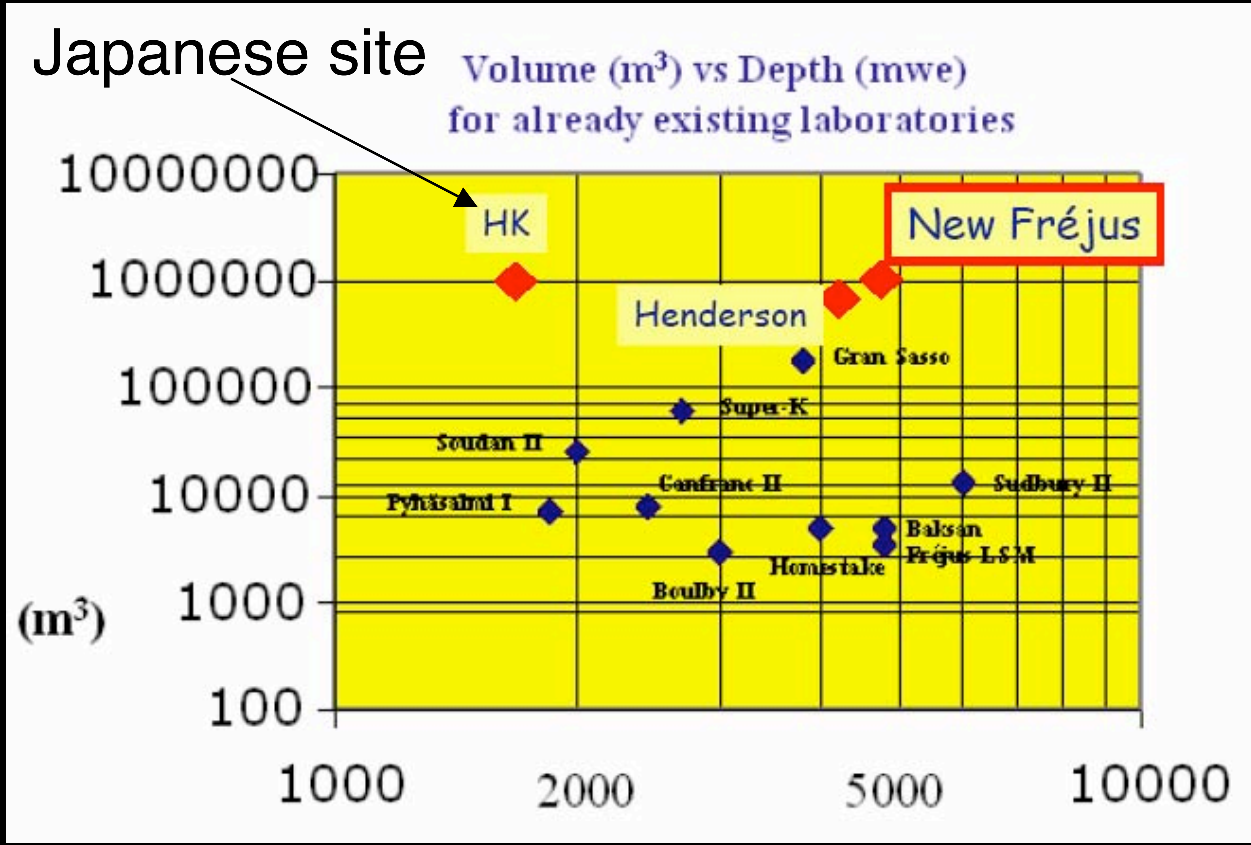
5) The estimated cost is ≈ 80 M€ X Nb of shafts





1 module ≈ 4 x SK
≈ 100kT fiducial mass)
equipped with a large number of Photodetectors
(eg. 50,000 PMTs 12")

Characteristics for Large Excavations

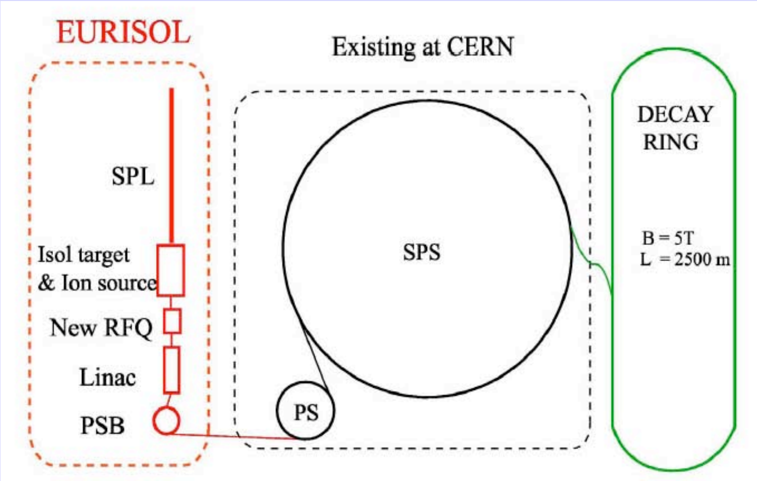


- **Rock type / rock chemistry**
  - ➥ Creep & solubility are the principal issues
- **Rock quality / In situ stress**
  - ➥ Commonly influences costs by a factor of 2 to 4, could make a site unfeasible
- **Access / rock removal**
  - ➥ Can influence costs significantly, but is very site dependent

Outstanding non-accelerator physics goals

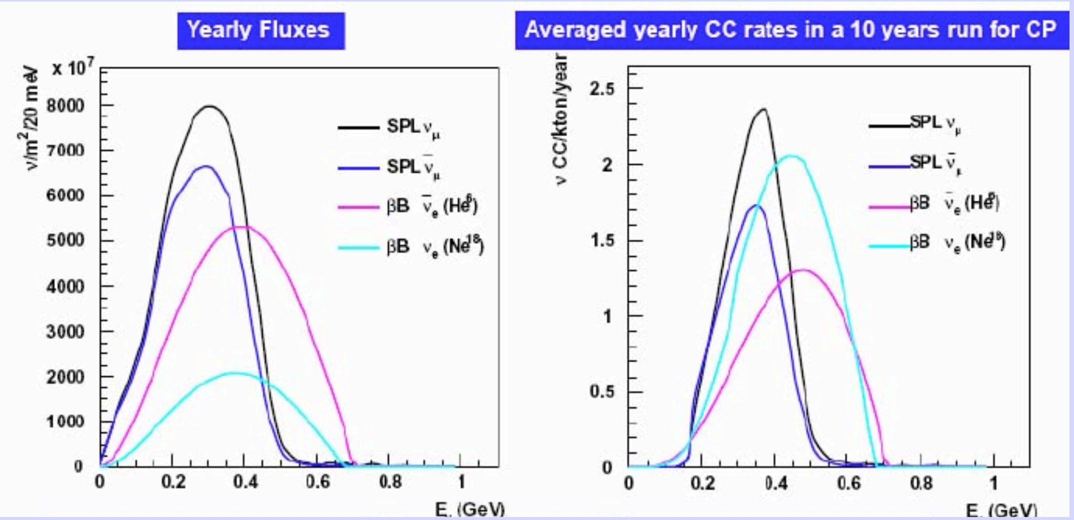
	Water Cerenkov
Total mass	500 kton
$p \to e\,\pi^0$ in 10 years	1.2×10^{35} years ε= 17%, ≈ 1 BG event
$p \to \nu K$ in 10 years	1.5×10^{34} years ε= 8.6%, ≈ 30 BG events (requires threshold below 6 MeV)
$p \to \mu \pi K$ in 10 years	No
SN cool off @ 10 kpc	150000 (mostly $\bar{\nu}_e p \to e^+ n$)
SN in Andromeda	40 events
SN burst @ 10 kpc	≈250 ν-e elastic scattering
SN relic in 10 years	250 evts (2500 when Gd-loaded)
Atmospheric neutrinos	56000 events/year
Solar neutrinos	E_e > 7 MeV (requires low threshold, e.g. 40% coverage)

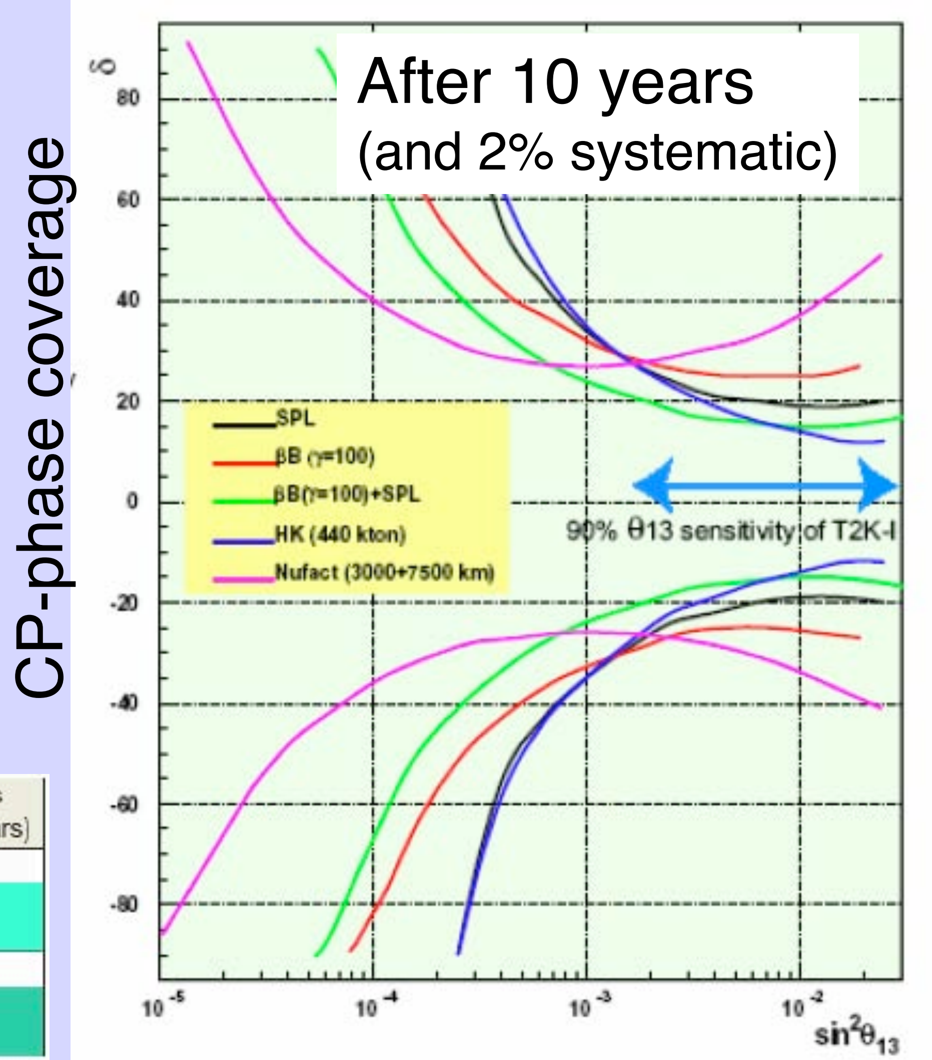
Physics program with new CERN low energy beams



Search for $\nu_e \rightarrow \nu_\mu$ oscillations with beta-beams:

- easier detector task (μ detection)
- however, need good event reconstruction: pions in NC can fake muons
- low energy makes pion production below Cerenkov threshold





	Fluxes @ 130 km $\nu/m^2/yr$	$\langle E_\nu \rangle$ (GeV)	CC rate (no osc) events/kton/yr	$\langle E_\nu \rangle$ (GeV)	Years	Integrated events (440 kton × 10 years)
			SPL Super Beam			
ν_μ	$11.80 \cdot 10^{11}$	0.29	121.7	0.36	2	107127
$\overline{\nu}_\mu$	$9.66 \cdot 10^{11}$	0.28	23.1	0.35	8	81164
			Beta Beam			
$\overline{\nu}_e(\gamma = 100)$	$10.92 \cdot 10^{11}$	0.40	46.0	0.46	5	101262
$\nu_e(\gamma = 100)$	$4.06 \cdot 10^{11}$	0.38	65.4	0.44	5	143887

R&D on photodetectors

IMB / KamiokaNDE ⇒ Super-K ⇒ Hyper-K / UNO

In each generation <u>one order of magnitude</u> increase in mass

	Super-K	Hyper-K	UNO
Total mass [kton]	**50**	**2 x 500**	**650**
Fiducial mass [kton]	**22.5**	**2 x 270**	**440**
Size	**Φ41 m x 39 m**	**2 x Φ43 m x 250 m**	**60 m x 60 m x 180 m**
Photo-sensor coverage [%]	**40**	**40**	**≈ 40 (5 MeV threshold) ≈ 10 (10 MeV threshold)**
PMT's	<u>11,146</u> **(20")**	<u>200,000</u> **(20")**	<u>56,650</u> **(20") 15,000 (8")**

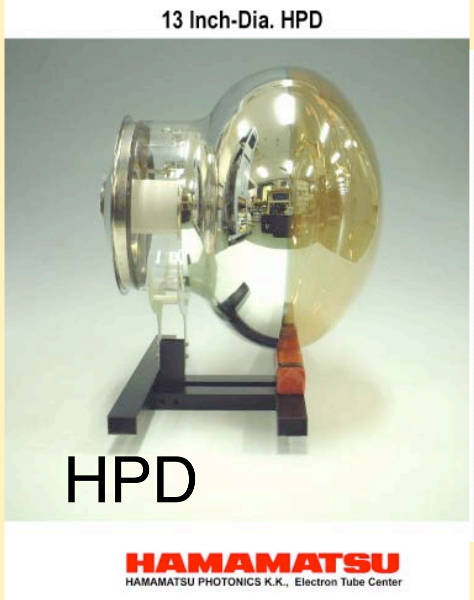
A large fraction (1/2 or more) of the total detector cost comes from the photo-sensors

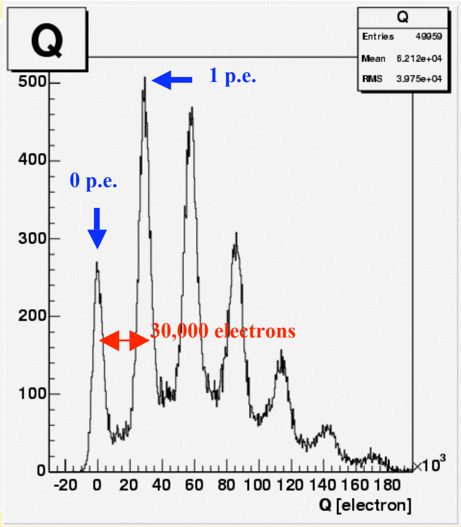
**With present 20" PMT's and 40% coverage for the full detector,
the cost of a Mton detector could be prohibitive**

<u>R&D on photo-sensors, in collaboration with industries</u> to improve:

- **cost**
- **production rate**: affects construction time and may give serious storage problems
- **performance:** time resolution (ν vertex), single photon sensitivity (ring reconstruction)

R&D on PMTs





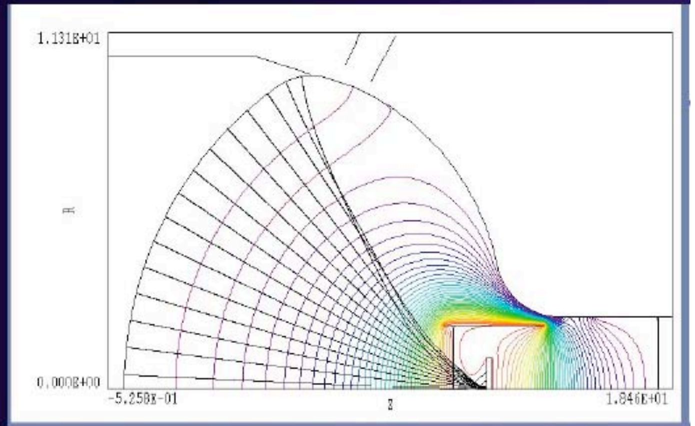
Japan: 200'000Y per 20" PMT
USA: $1500 per 20" PMT
EU: 800€ per 12" PMT

What is the optimal PMT size?
Include electronics ("smart") ?

Burle 20" PMT R&D

New bulb design: "Truncated bulb"

- Uniform E-field in front of cathode
- Small neck
- TTD ~ 1.5 ns



Goal:

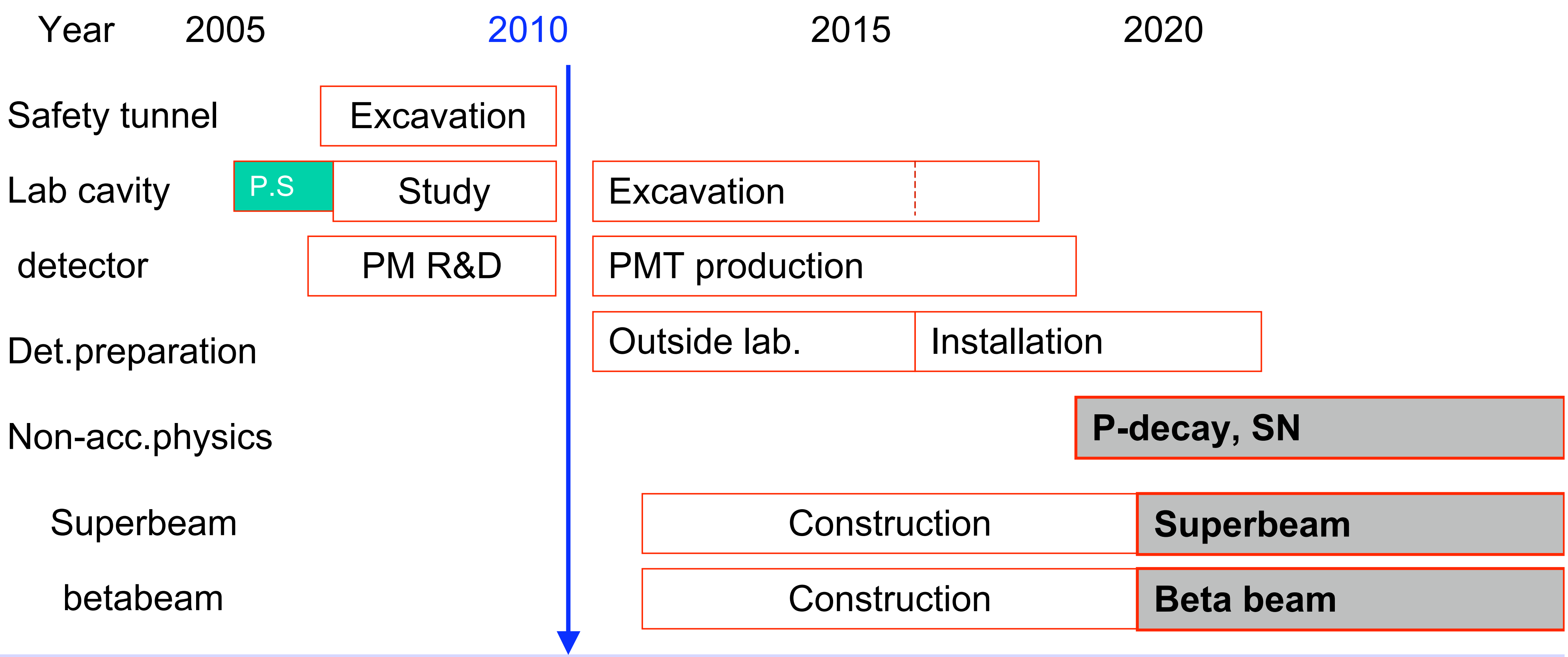
- Fully automatic production of 20" PMTs
- Aim ~$1,500/PMT

Photodetector R&D in France

- R&D launched after NNN05 but based on on-going R&D with Photonis
- IPN-Orsay, LAL & Photonis together in an official GIS to develop Smart-Photodetectors (*ie electronic up to ADC/TDC included*): 6 engineers + 2 post-docs + Photonis engineers
- 200k€/3yrs has been asked at the new National Research Agency (ANR)

Photonis @ NNN05: 500,000 PMT -12"- 800€/u

A possible schedule for Fréjus



strongly bound to future strategy of CERN

- decision for cavity digging
- decision for CERN SPL construction
- decision for EURISOL site at CERN

Liquid Scintillator detectors

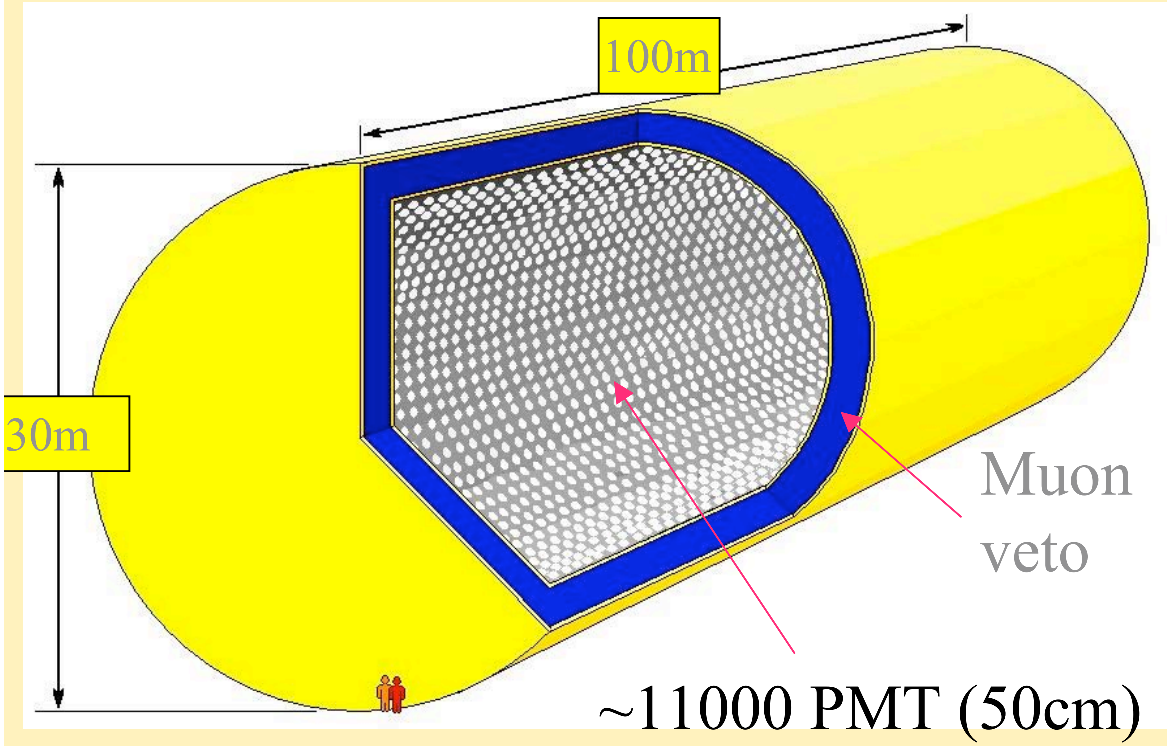
Concept:

Low Energy Neutrino Astrophysics (LENA)

TU Munich, Germany (F. von Feilitzsch and L. Oberauer)
Univ. Hamburg, Germany (C. Hagner)
CUPP, Finland (J. Peltoniemi)
Univ. Jyväskylä, Finland (J. Aysto)
INR, Russia (L. Bezrukov)

Low Energy Neutrino Astrophysics (LENA)

Conceptual design for a large (~50 kton) liquid scintillator underground detector



Use technology developed for BOREXINO

Scintillator solvent: PXE ($C_{16}H_{18}$), non-hazard, flashpoint 145°C, density 0.99, ultrapure.
Assumed attenuation length ≈ 12 m @430 nm

Estimated light yield ~ 110 pe / MeV

Total number of photomultiplier ~ 11000 (30% coverage)

Tentative construction site

- Loading of detector via pipeline
- Transport of 50kt PXE via railway
- No fundamental security problem with PXE!
- No fundamental problem for excavation
- Standard technology (PMT, electronics, …)
- Other possibility: PYLOS in Mediterranean sea

CENTRE FOR UNDERGROUND PHYSICS IN PYHÄSALMI MINE

Underground mine

~ 1450 m depth, low radioactivity, low reactor ν– background !

Access via trucks

LENA seems feasible in Pyhäsalmi!

Non-accelerator physics goals

	Water Cerenkov	LENA
Total mass	500 kton	50 kton
$p \to e\,\pi^0$ in 10 years	1.2×10^{35} years ε= 17%, ≈ 1 BG event	?
$p \to \nu K$ in 10 years	1.5×10^{34} years ε= 8.6%, ≈ 30 BG events (requires threshold below 6 MeV)	4×10^{34} years ε= 65%, <1 BG event
$p \to \mu\pi K$ in 10 years	No	?
SN cool off @ 10 kpc	150000 (mostly $\overline{\nu}_e p \to e^+ n$)	20000 (all flavors)
SN in Andromeda	40 events	5 events
SN burst @ 10 kpc	≈250 ν-e elastic scattering	≈30 events
SN relic	250 evts (2500 when Gd-loaded)	20-40
Atmospheric neutrinos	56000 events/year	≈5600
Solar neutrinos	E_e > 7 MeV (requires low threshold, e.g. 40% coverage)	?
Geo-neutrinos	?	≈3000 events/year

Supernova neutrino detection

Electron Antineutrino spectroscopy

- $\overline{\nu}_e + p \rightarrow n + e^+$ (Q=1.8 MeV)
  $n + p \rightarrow d + \gamma$; $E_\gamma = 2.2$ MeV ~8700 events
- $\overline{\nu}_e + {}^{12}\mathrm{C} \rightarrow {}^{12}\mathrm{B} + e^- +$ (Q=17.3 MeV)
  ${}^{12}\mathrm{B} \rightarrow {}^{12}\mathrm{C} + e^+ + \overline{\nu}_e$; $\tau_{1/2} = 20.20$ ms ~494 events

Electron neutrino spectroscopy

- $\nu_e + {}^{12}\mathrm{C} \rightarrow e^- + {}^{12}\mathrm{N}$ (Q=13.4 MeV)
  ${}^{12}\mathrm{N} \rightarrow {}^{12}\mathrm{C} + e^+ + \nu_e$; $\tau_{1/2} = 11.00$ ms ~85 events

Neutral current interactions; info on all flavours

- $\nu_x + {}^{12}\mathrm{C} \rightarrow {}^{12}\mathrm{C}^* + \nu_x$
  with ${}^{12}\mathrm{C}^* \rightarrow {}^{12}\mathrm{C} + \gamma$; $E_\gamma = 15.11$ MeV ~2925 events
- $\nu_x + e^- \rightarrow \nu_x + e^-$ (elastic scattering) ~610 events
- $\nu_x + p \rightarrow \nu_x + p$ (elastic scattering)
  Detector energy threshold: $E_{th} = 0.2$ MeV ~7370 events

Total ≈ 20000 events

Event rates for a SN type IIa in the galactic center (10 kpc)

$P \to K^+ \nu$ event structure:

$T(K^+) = 105$ MeV

$\tau(K^+) = 12.8$ nsec

$K^+ \to \mu^+ \nu$ (63.5 %)

$T(\mu^+) = 152$ MeV

$\mu^+ \to e^+ \nu \nu$ ($\tau = 2.2$ μs)

$K^+ \to \pi^+ \pi^0$ (21.2 %)

$T(\pi^+) = 108$ MeV

electromagnetic shower

$E = 135$ MeV

$\pi^+ \to \mu^+ \nu$ ($T = 4$ MeV)

$\mu^+ \to e^+ \nu \nu$ ($\tau = 2.2$ μs)

Kaon track is visible (unlike in Water Cerenkov detectors)
Timing structure and excellent energy resolution reduce backgrounds

>4x10^{34} yrs in 10 years (≈1 event background)

Liquid Argon detectors

Two target mass scales for future projects:

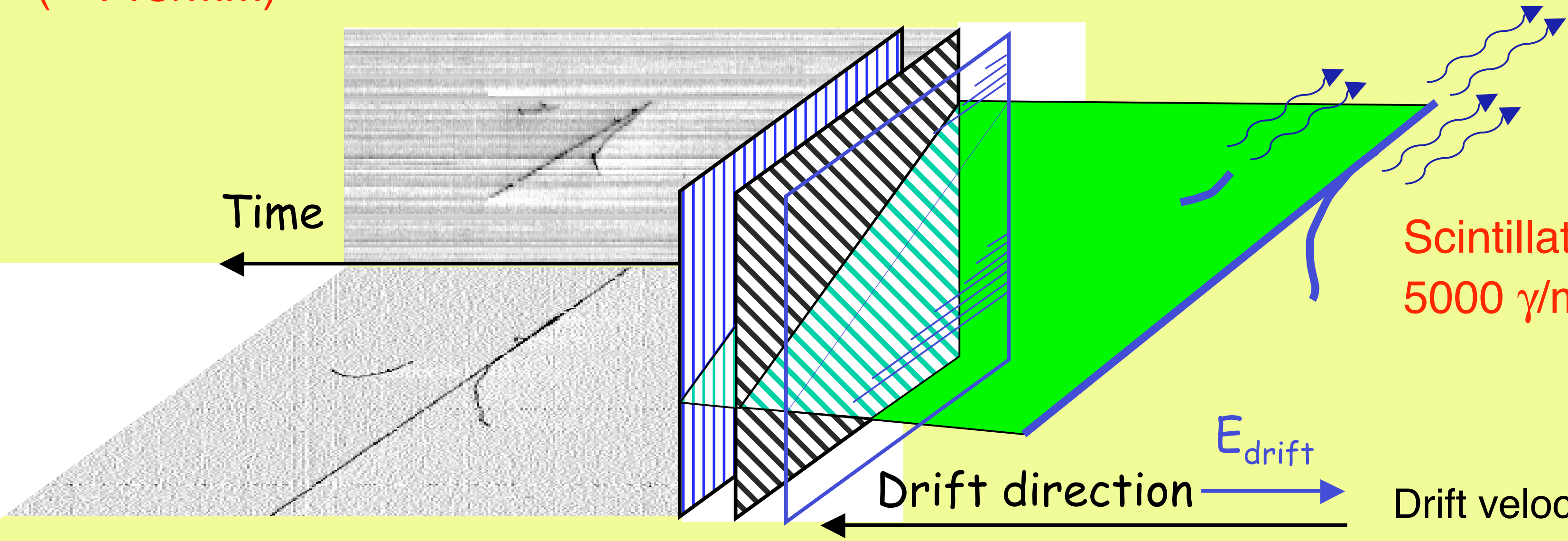
- **100 ton** as near detector in Super-Beams (not discussed here)
- <u>**10-100 kton**</u> for ν oscillation, ν astrophysics, proton decay

The Liquid Argon TPC principle

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

Charge readout planes: Q

UV Scintillation Light: L



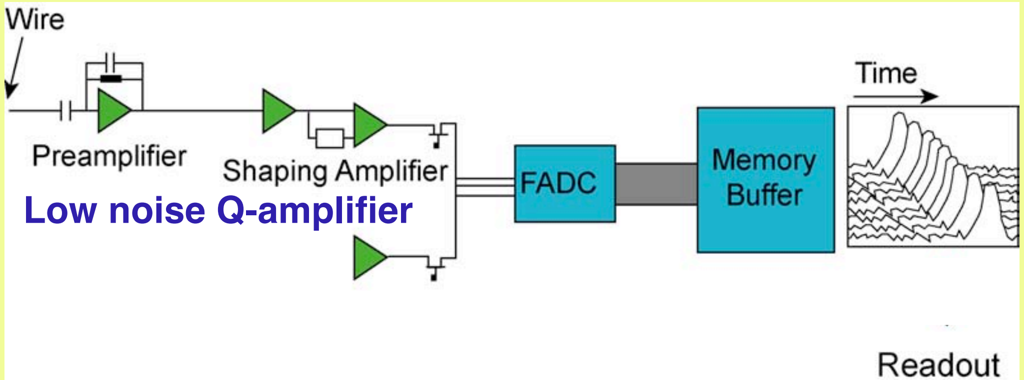
Scintillation light yield ~ 5000 γ/mm @ 128 nm

Drift velocity ≈ 2 mm/μs @ 1 kV/cm

Drift electron lifetime:

$$\tau \approx 300\mu s \times \frac{1\,ppb}{N(O_2)}$$

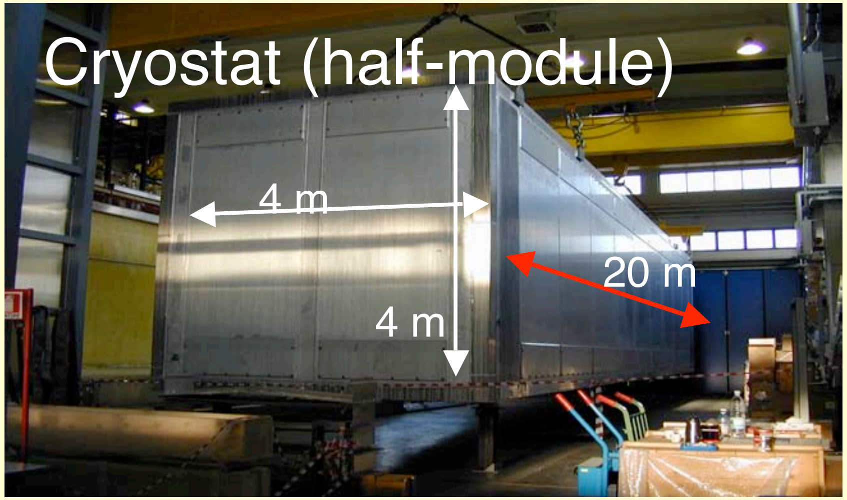
Purity < 0.1ppb O_2-equiv.

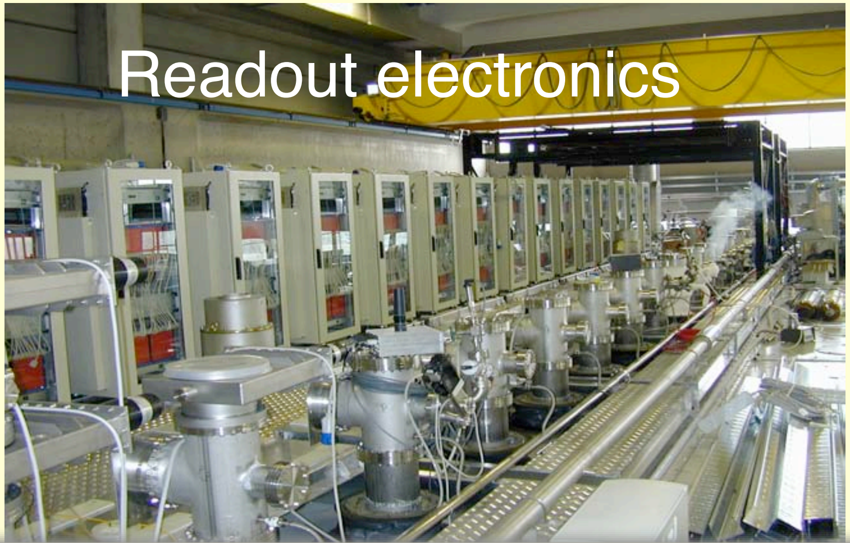


Continuous waveform recording → image

- 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).

ICARUS T600 detector

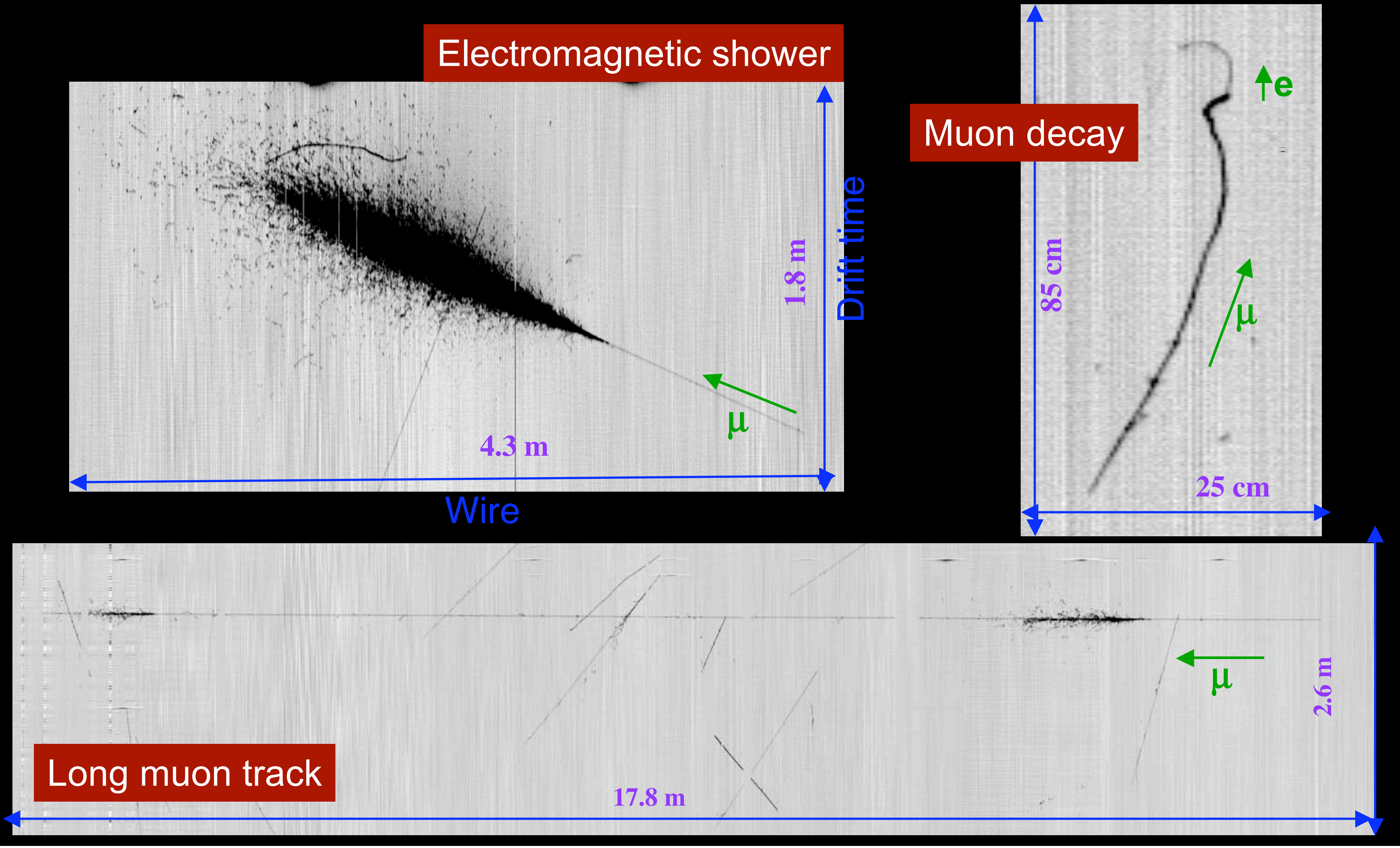




- Design, construction and tests of the ICARUS T600 detector, ICARUS Collab, NIM A527 329 (2004).
- Study of electron recombination in liquid Argon with the ICARUS TPC, ICARUS Collab, NIMA523 275-286 (2004).
- Detection of Cerenkov light emission in liquid Argon, ICARUS Collab, NIM A516 348-363 (2004).
- Analysis of the liquid Argon purity in the ICARUS T600 TPC, ICARUS Collab, NIM A516 68-79 (2004).
- Observation of long ionizing tracks with the ICARUS T600 first half module, ICARUS Collab, NIM A508 287 (2003).
- Measurement of the muon decay spectrum with the ICARUS liquid Argon TPC, ICARUS Collab, EPJ C33 233-241 (2004).

Liquid Argon TPC: Electronic bubble chamber

Data from ICARUS T600 test run: 27000 triggers from cosmic ray interactions

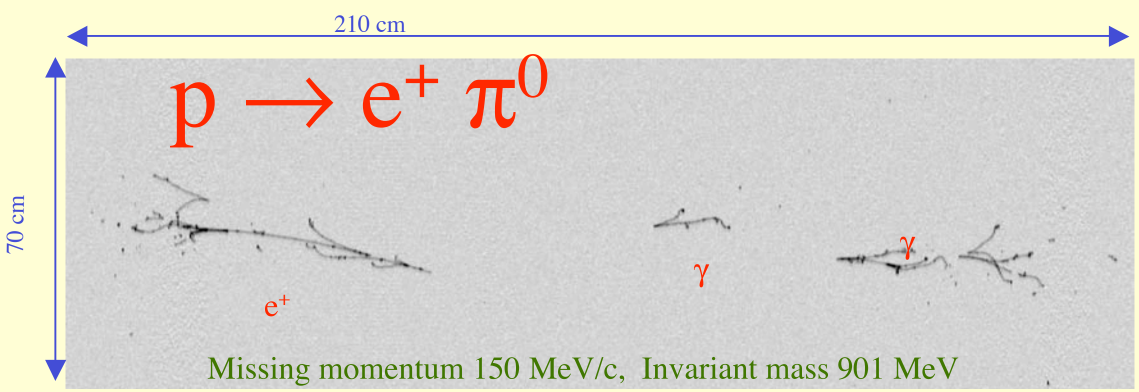


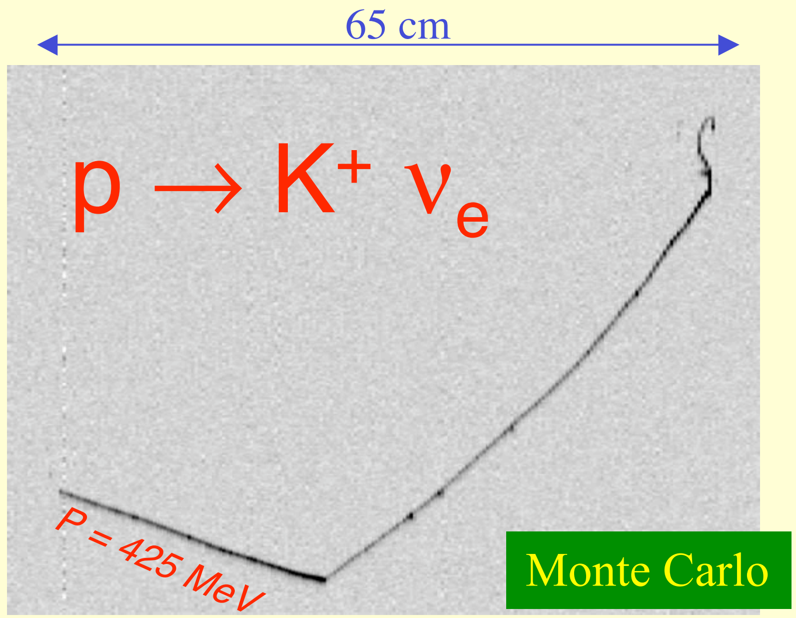
Outstanding non-accelerator physics goals

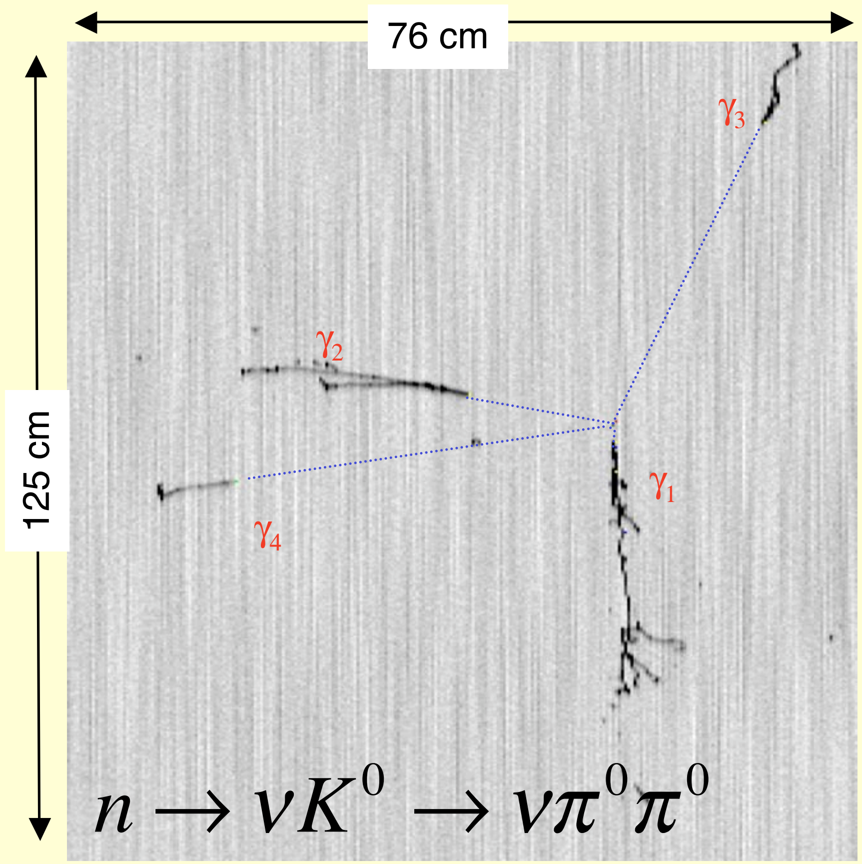
The relevant mass scale is nowadays in the range $10 \rightarrow 100$ kton

	Water Cerenkov	Liquid Argon TPC
Total mass	650 kton	100 kton
$p \rightarrow e\,\pi^0$ in 10 years	1.6×10^{35} years ε= 17%, ≈ 1 BG event	0.5×10^{35} years ε= 45%, <1 BG event
$p \rightarrow \nu K$ in 10 years	0.2×10^{35} years ε= 8.6%, ≈ 37 BG events	1.1×10^{35} years ε= 97%, <1 BG event
$p \rightarrow \mu\pi K$ in 10 years	No	1.1×10^{35} years ε= 98%, <1 BG event
SN cool off @ 10 kpc	194000 (mostly $\bar{\nu}_e p \rightarrow e^+ n$)	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 (40% coverage)	324000 events/year E_e > 5 MeV

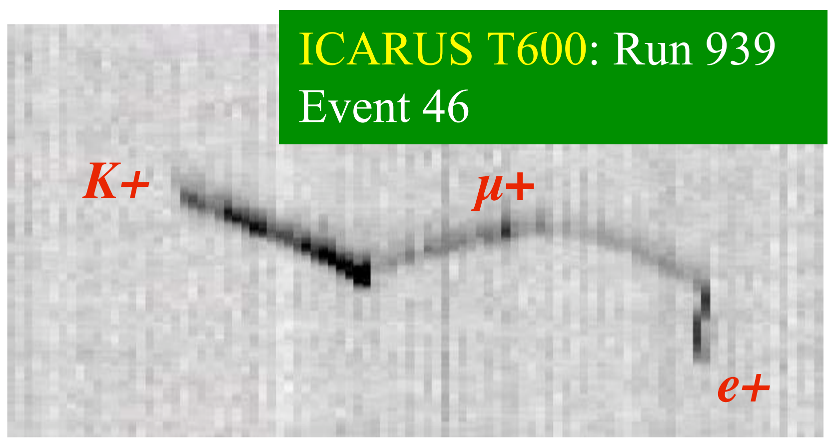
Nucleon decay: a unique way to image these events!







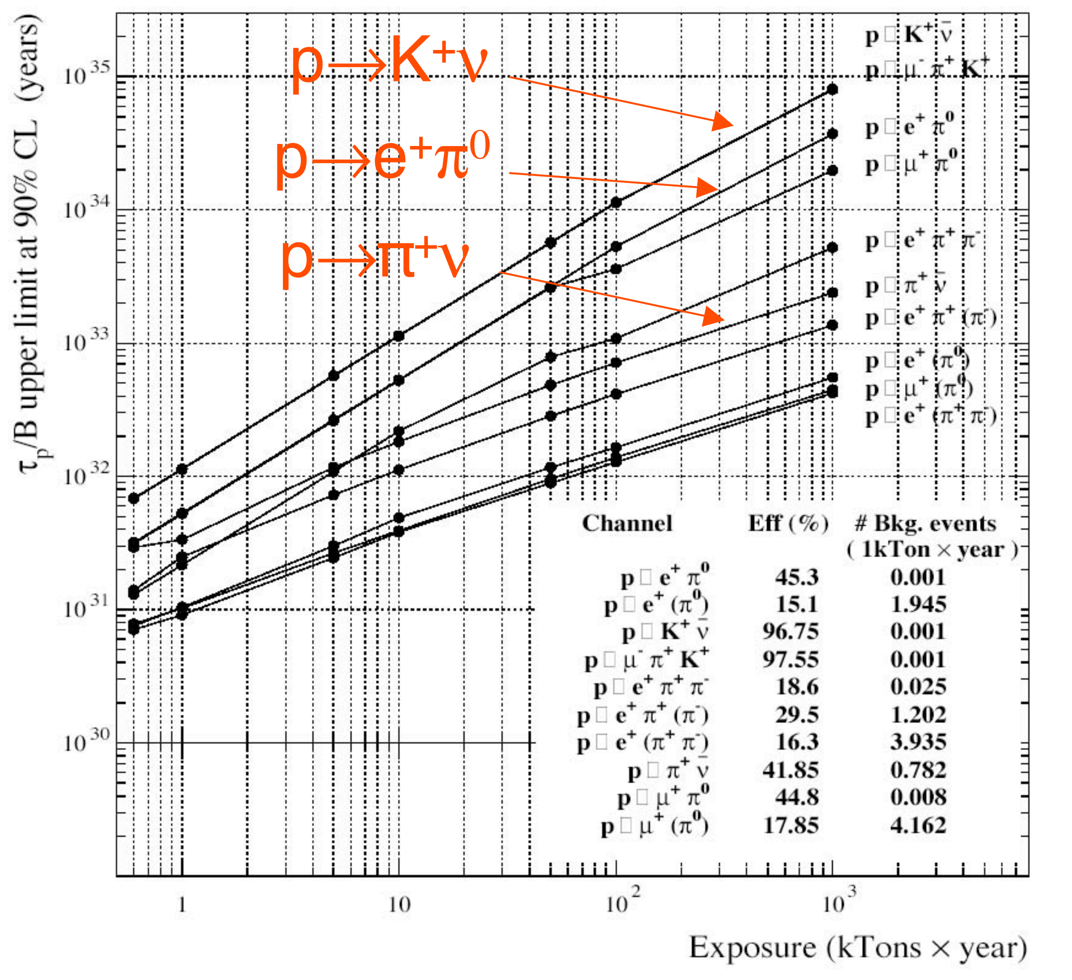
"Single" event detection capability



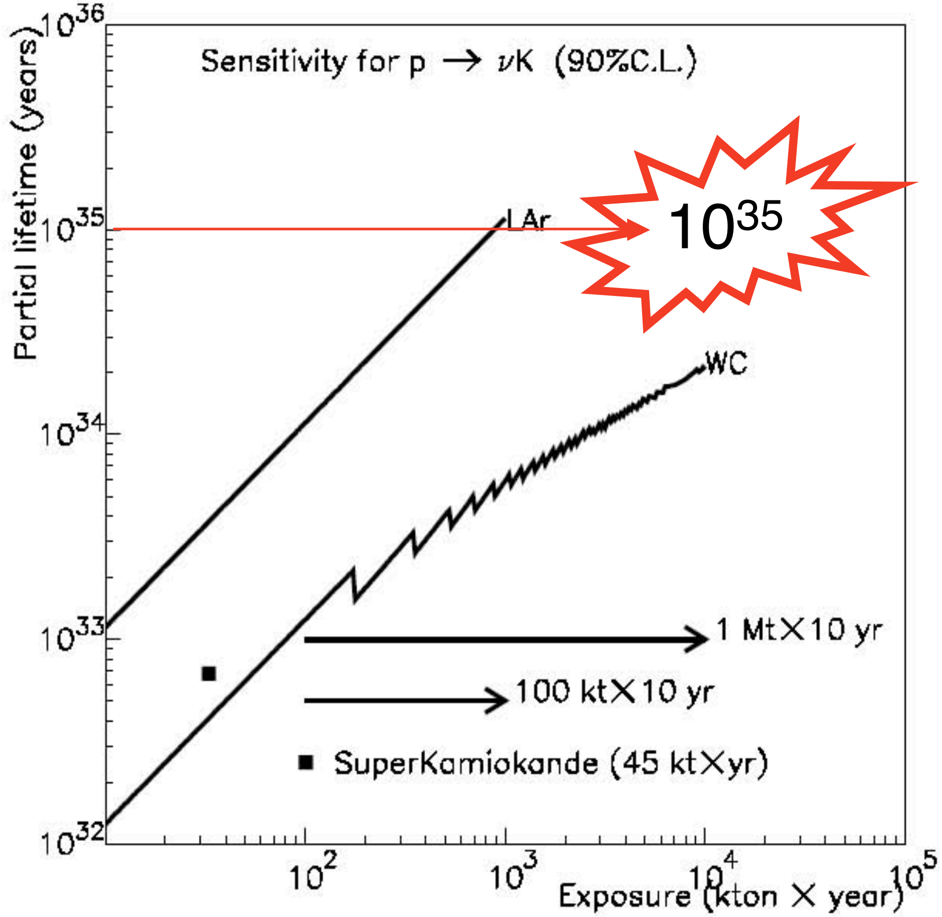
Such level of imaging accuracy is only possible with the LAr TPC technique!

Proton decay sensitivity

Many channels accessible



Complementarity



LAr TPC provides ultimate fine-grain tracking and calorimetry as necessary for proton decay searches

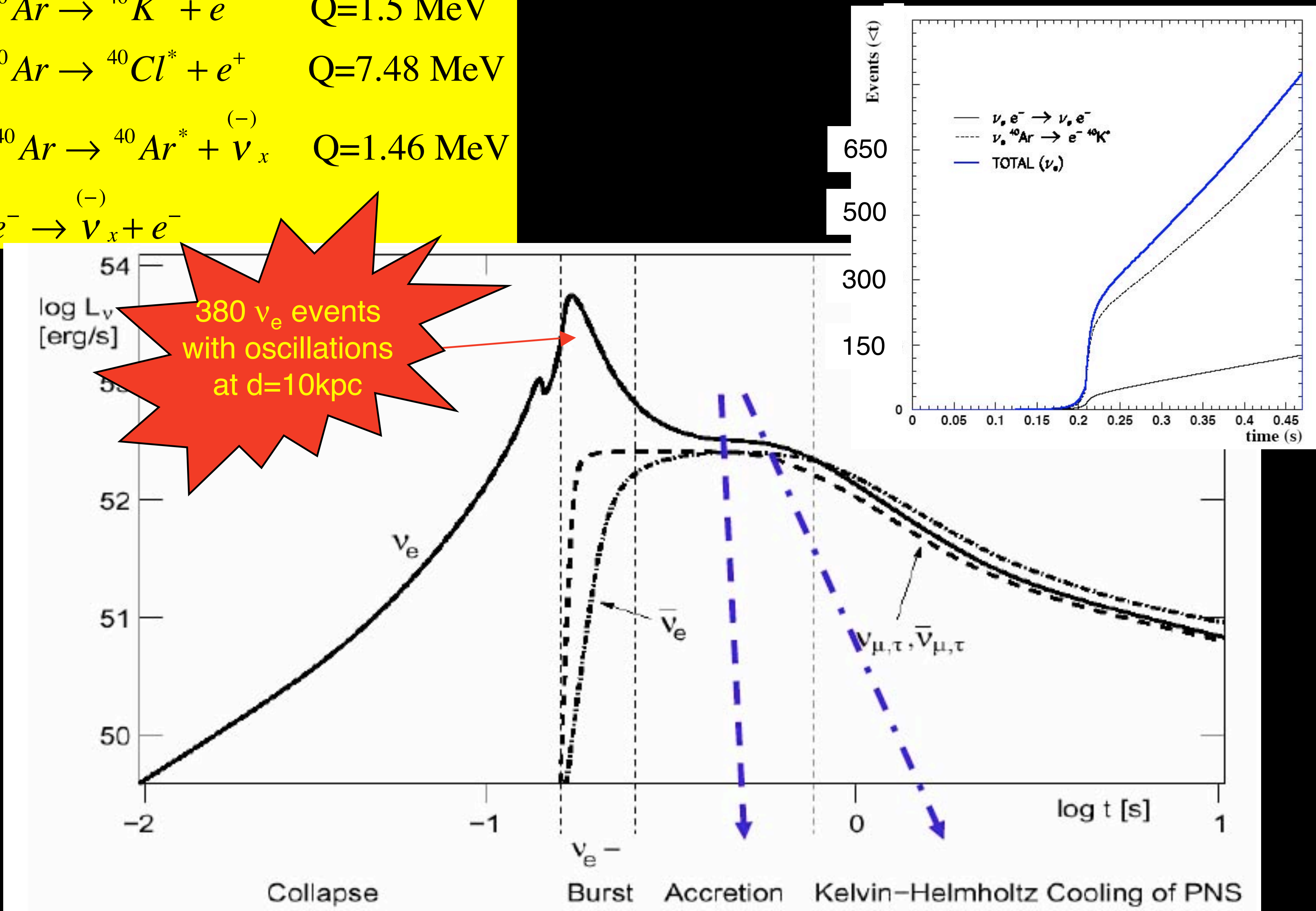
Sensitivity to SN type-II neutrinos

$$\nu_e + {}^{40}Ar \rightarrow {}^{40}K^* + e^- \qquad \text{Q=1.5 MeV}$$

$$\bar{\nu}_e + {}^{40}Ar \rightarrow {}^{40}Cl^* + e^+ \qquad \text{Q=7.48 MeV}$$

$$\overset{(-)}{\nu}_x + {}^{40}Ar \rightarrow {}^{40}Ar^* + \overset{(-)}{\nu}_x \qquad \text{Q=1.46 MeV}$$

$$\overset{(-)}{\nu}_x + e^- \rightarrow \overset{(-)}{\nu}_x + e^-$$



Supernova events: cooling phase detection

Scenario I: expected events in 100 kton detector $\langle E_{\nu_e}\rangle = 11$ MeV, $\langle E_{\bar{\nu}_e}\rangle = 16$ MeV, $\langle E_{\nu_x}\rangle = \langle E_{\bar{\nu}_x}\rangle = 25$ MeV and luminosity equipartition					
Reaction	Without oscillation	Oscillation (n.h.)		Oscillation (i.h.)	
		Large θ_{13}	Small θ_{13}	Large θ_{13}	Small θ_{13}
$\overset{(-)}{\nu}_x + e^- \rightarrow \overset{(-)}{\nu}_x + e^-$	1330	1330	1330	1330	1330
$\nu_e + {}^{40}Ar \rightarrow {}^{40}K^* + e^-$	6240	31320	23820	23820	23820
$\bar{\nu}_e + {}^{40}Ar \rightarrow {}^{40}Cl^* + e^+$	540	1110	1110	2420	1110
$\overset{(-)}{\nu}_x + {}^{40}Ar \rightarrow {}^{40}Ar^* + \overset{(-)}{\nu}_x$	30440	30440	30440	30440	30440
TOTAL	38550	64200	56700	58010	56700

For a SN at a distance d=10 kpc

$Q\nu_e CC = 1.5$ MeV $Q\bar{\nu}_e CC = 7.48$ MeV $Q_{NC} = 1.46$ MeV

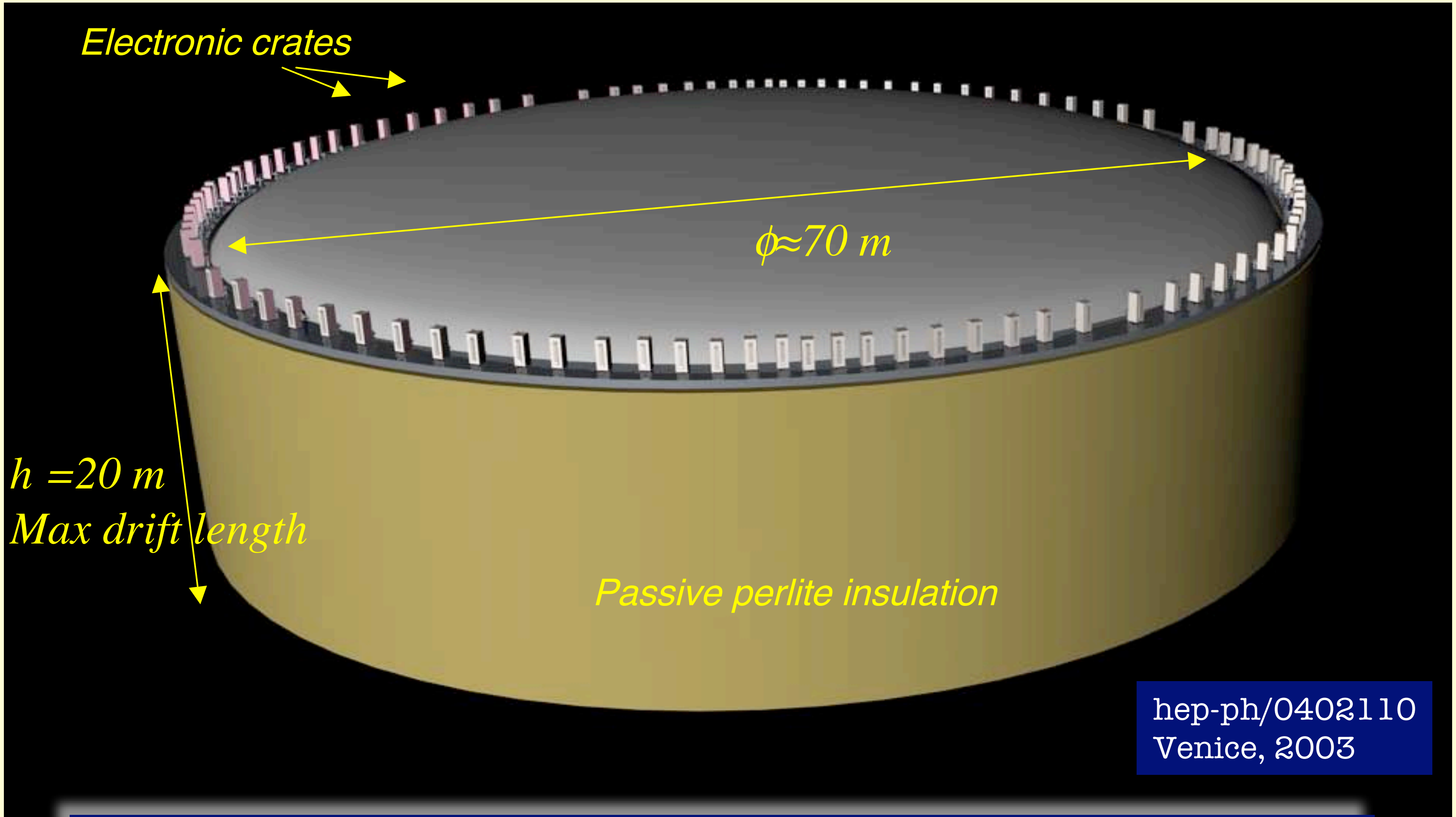
Possibility to statistically separate the various channels by a classification of the associated **photons from the K, Cl or Ar deexcitation** (specific spectral lines for **CC** and **NC**) or by the **absence of photons** (**ES**)

Concept:

The Giant Liquid Argon Charge Imaging ExpeRiment (GLACIER)

- 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, Italy, hep-ph/0402110
- Ideas for future liquid Argon detectors, A. Ereditato and A.Rubbia, Proc. Third International Workshop on Neutrino-Nucleus Interactions in the Few GeV Region, NUINT04, March 2004, Gran Sasso, Italy, **Nucl.Phys.Proc.Suppl.139:301-310,2005,** hep-ex/0409034
- Ideas for a next generation liquid Argon TPC detector for neutrino physics and nucleon decay searches, A. Ereditato and A.Rubbia, Proc. Workshop on Physics with a Multi-MW proton source, May 2004, CERN, Switzerland, submitted to SPSC Villars session
- Very massive underground detectors for proton decay searches, A.Rubbia, Proc. XI Int. Conf. on Calorimetry in H.E.P., CALOR04, Perugia, Italy, March 2004, hep-ph/0407297
- Liquid Argon TPC: mid & long term strategy and on-going R&D, A.Rubbia, Proc. Int. Conf. on NF and Superbeam, NUFACT04, Osaka, Japan, July 2004
- Liquid Argon TPC: a powerful detector for future neutrino experiments, A.Ereditato and A. Rubbia, HIF05, La Biodola, Italy, May 2005, hep-ph/0509022
- Neutrino detectors for future experiments, A.Rubbia, Nucl. Phys. B (Proc. Suppl.) 147 (2005) 103.
- Conceptual Design of a scalable milti-kton superconducting magnetized liquid argon TPC, A. Ereditato and A. Rubbia, hep-ph/0510131.

A 100 kton liquid Argon TPC detector



Single module cryo-tanker based on industrial LNG technology

A "general-purpose" detector for superbeams, beta-beams and neutrino factories with broad non-accelerator physics program (SN ν, p-decay, atm ν, …)

GLACIER people (12 groups, ≈25 people)

ETHZ (CH):	A. Badertscher, L. Knecht, M. Laffranchi, A. Meregaglia, M. Messina, G. Natterer, P.Otiougova, A. Rubbia, J. Ulbricht
Granada University (Spain):	A. Bueno, J. Lozano, S. Navas
INP Krakow (Poland):	A. Zalewska
INFN Naples (Italy):	A. Ereditato
INR Moscow (Russia):	S. Gninenko
IPN Lyon (France):	D. Autiero, Y. Déclais, J. Marteau
Sheffield University (UK):	N. Spooner
Southampton University (UK):	C. Beduz, Y. Yang
US Katowice (Poland):	J. Kisiel
UPS Warszawa (Poland):	E. Rondio
UW Warszawa (Poland):	D. Kielczewska
UW Wroclaw (Poland):	J. Sobczyk

Many thanks to:

Technodyne Ltd, Eastleigh, UK

CUPRUM (KGHM group), Wroclaw, Poland

CAEN, Viareggio, Italy

Tanker

In Collaboration with industry, we have shown that extrapolation from LNG technology to LAr is possible

Cryogenic storage tankers for LNG

***L**NG = **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

Cooling by "auto-refrigeration"

Study of large underground storage tank

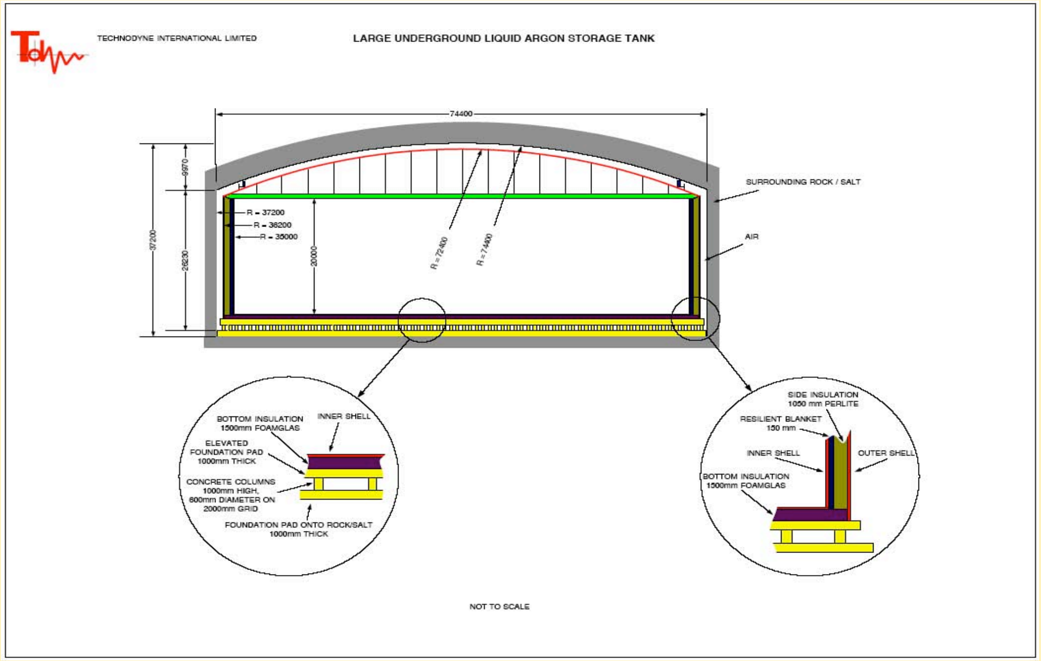
Project: Large Underground Argon Storage Tank

Document Title: Study

A feasibility study mandated to Technodyne LtD (UK)

Study duration:

February - December 2004



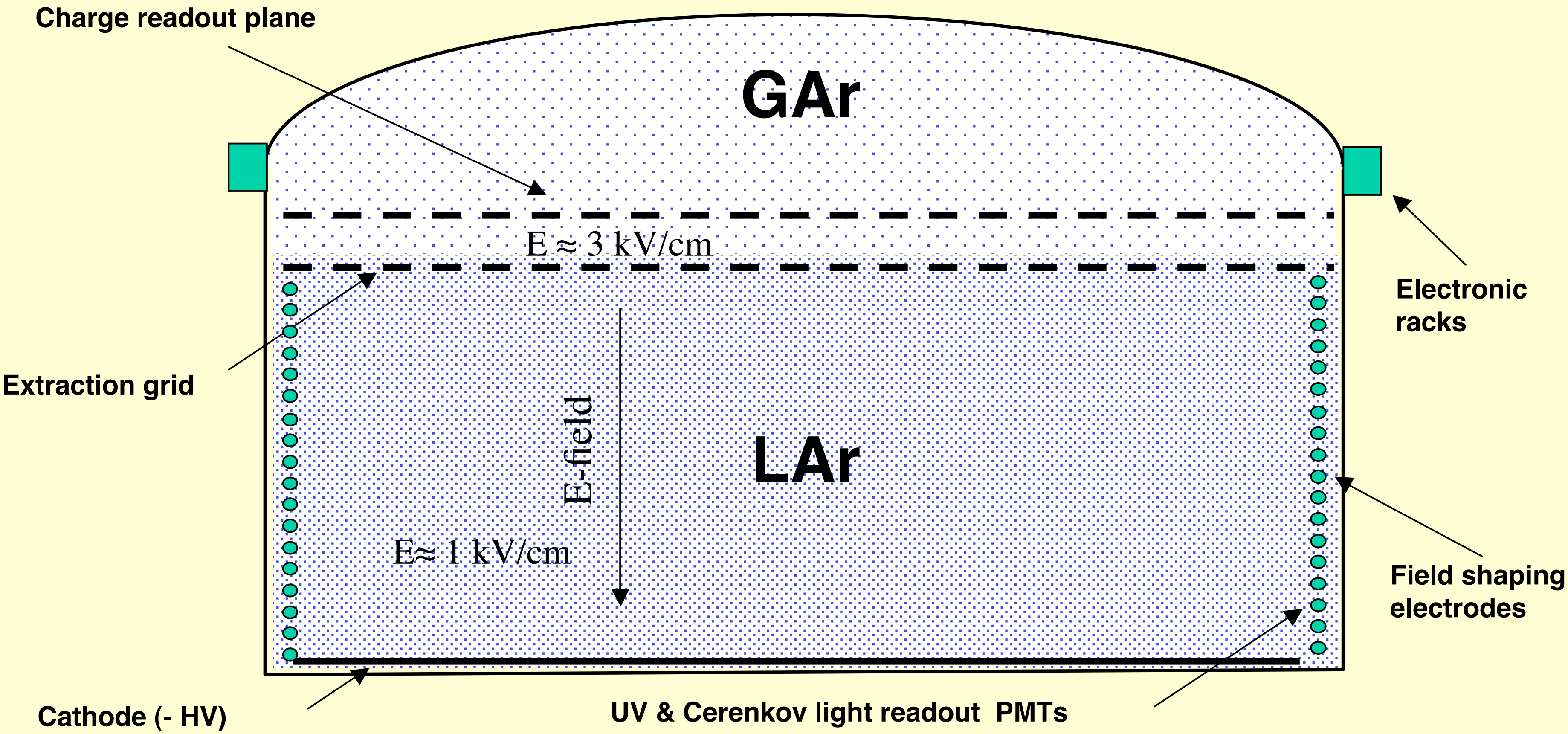
Detector layout

A “simple” scalable detector layout

A tentative detector layout

<u>Single detector</u>: charge imaging, scintillation, possibly Cerenkov light

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 ϕ ≈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

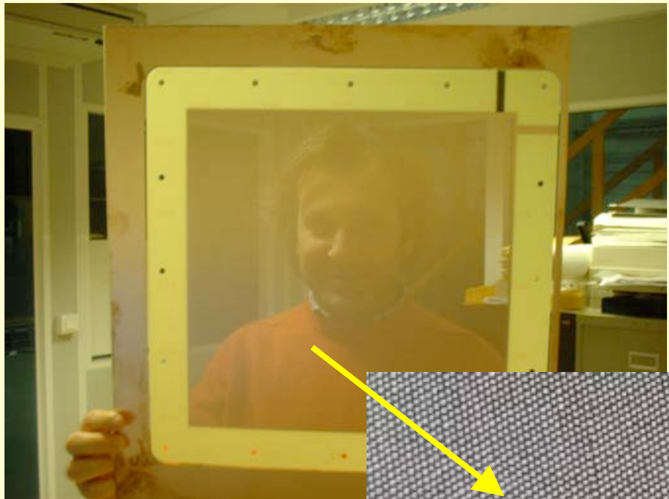


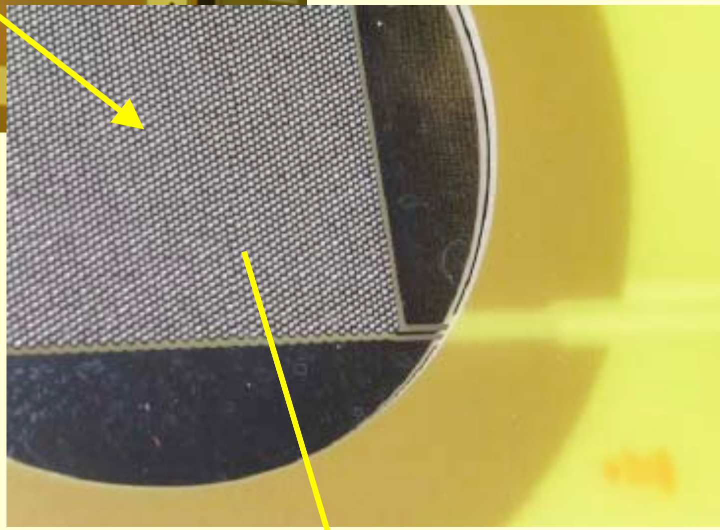
Charge extraction, amplification, readout

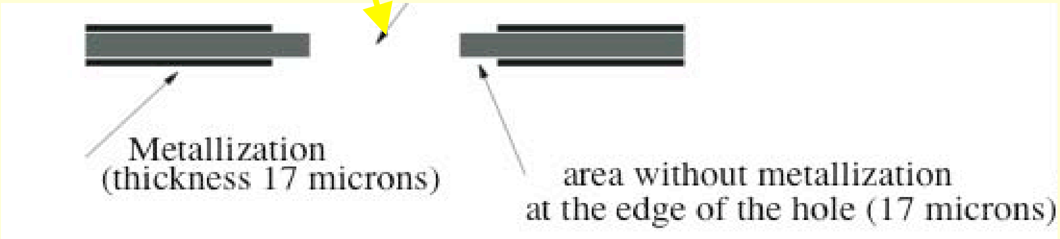
A new method for readout to allow for a very long drift path, potentially cheaper electronics and avoid use of readout wires

•Thick-LEM (vetronite Cu coated + holes): sort of macroscopic GEM. Easier to operate at cryogenic temperature.

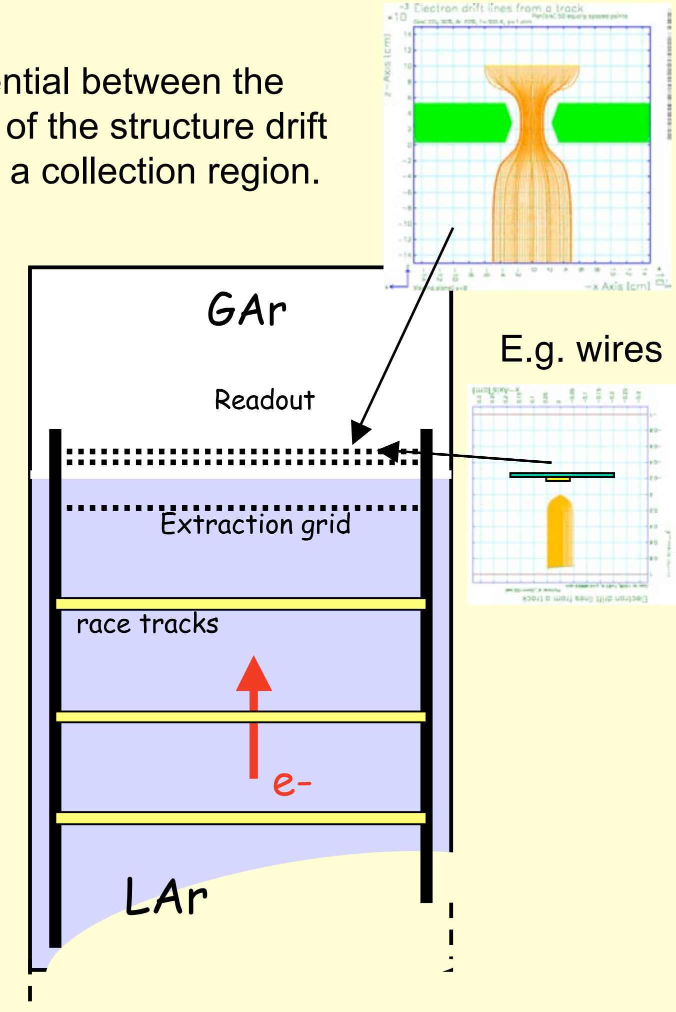
•On application of a difference of potential between the two electrodes, electrons on one side of the structure drift into the holes, multiply and transfer to a collection region.





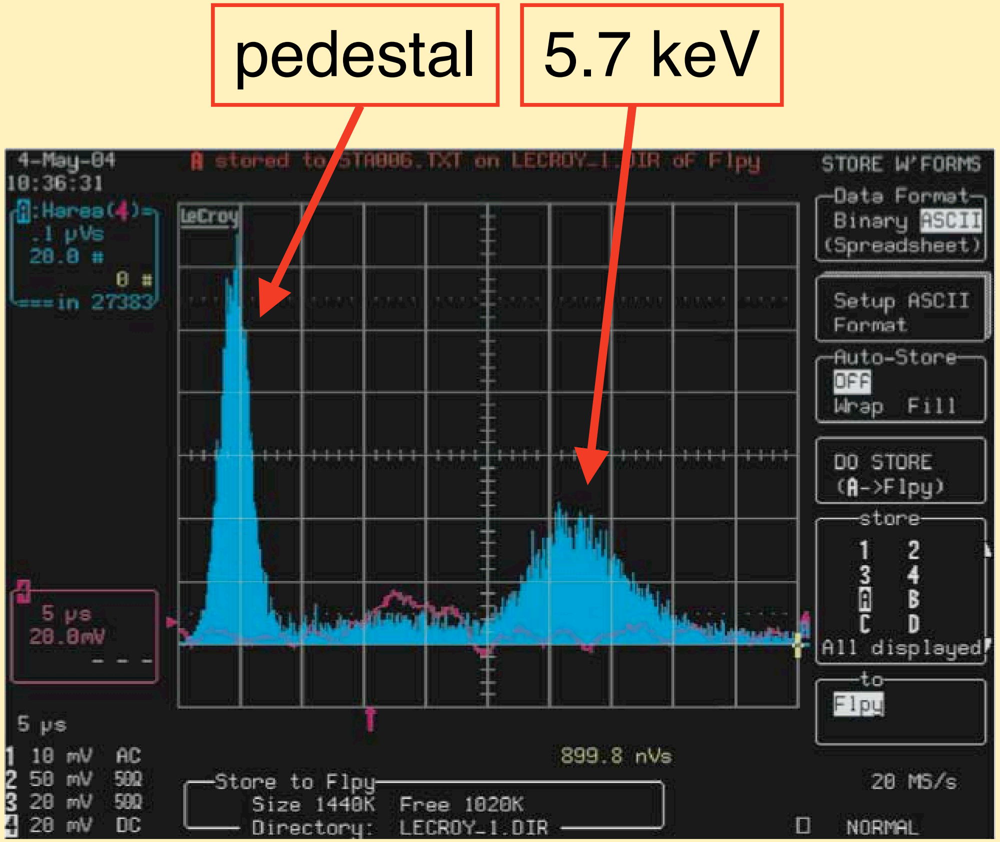


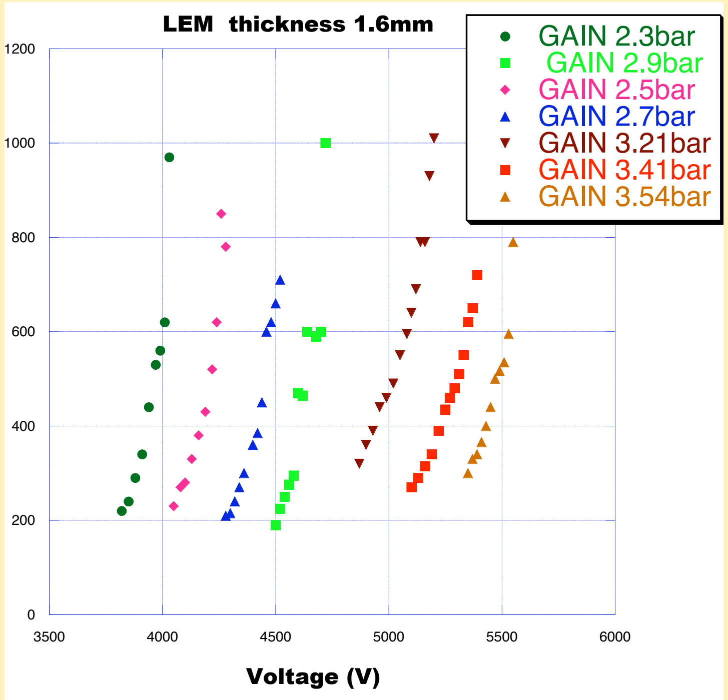
Thick-LEM



High gain operation of LEM in pure Ar at high pressure

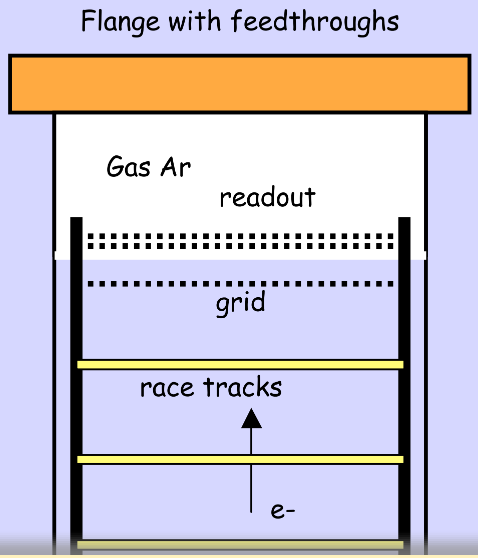
Gain up to ≈800 possible even at high pressure (good prospects for operation in cold)
Resolution ≈ 28% FWHM for Fe-55 source
Good agreement with GARFIELD simulations (confirm shower confinement)





- Fe-55 & Cd-109 sources, Argon 100%
- Varying pressures (from 1 bar up to 3.5 bar)
- Room temperature

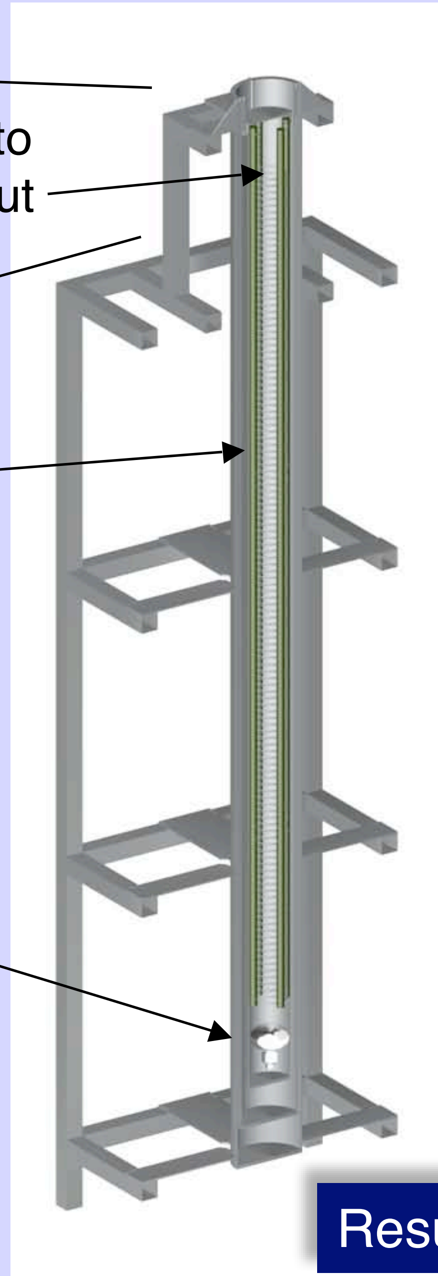
R&D for long drift, extraction, amplification: "ARGONTUBE"



Extraction from LAr to GAr and LEM readout

Field shaping electrodes

8" PMT
ET 9357FLA



5 meters

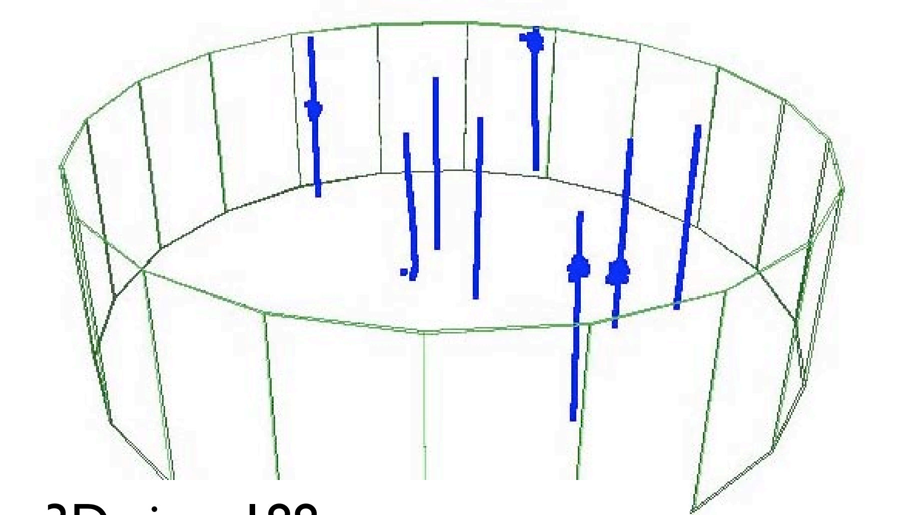
- Full scale measurement of long drift (5 m), signal attenuation and multiplication
- Simulate 'very long' drift (10-20 m) by reduced E field & LAr purity
- High voltage test (up to 500 kV)

Results in 2006

Detector depth: “shallow” ?

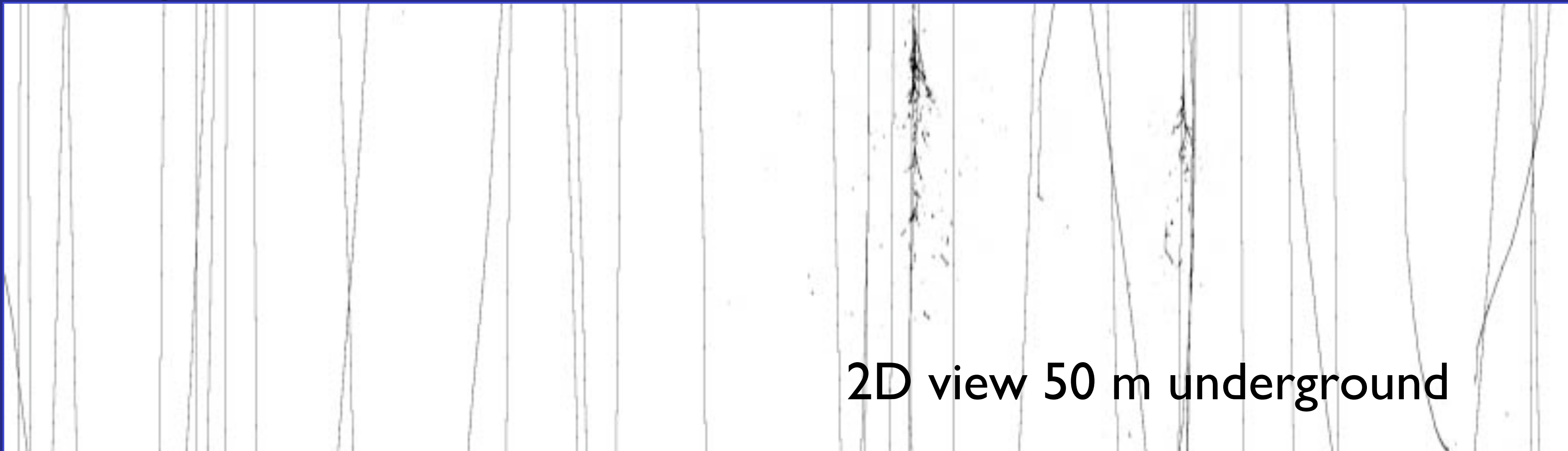
Detector depth

- Because of the high granularity of the LAr TPC technique, it is possible to consider a shallow depth operation of large detectors



3D view 188 m underground

Depth rock	Total crossing muons (E> 1GeV) per 10ms	Fiducial mass after slice of size D around each muon is vetoed D=10 cm
Surface	**13000**	…
50 m	**100**	50 kton
188 m	**3.2**	98 kton
1 km w.e	**0.65**	100 kton
2 km w.e	**0.062**	100 kton
3 km w.e	**0.010**	100 kton



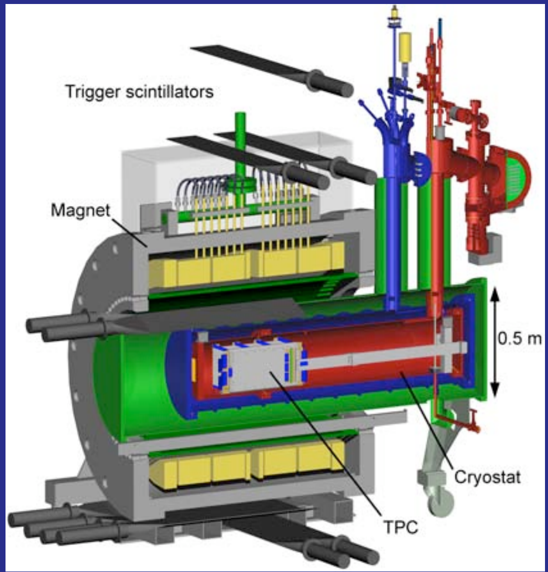
2D view 50 m underground

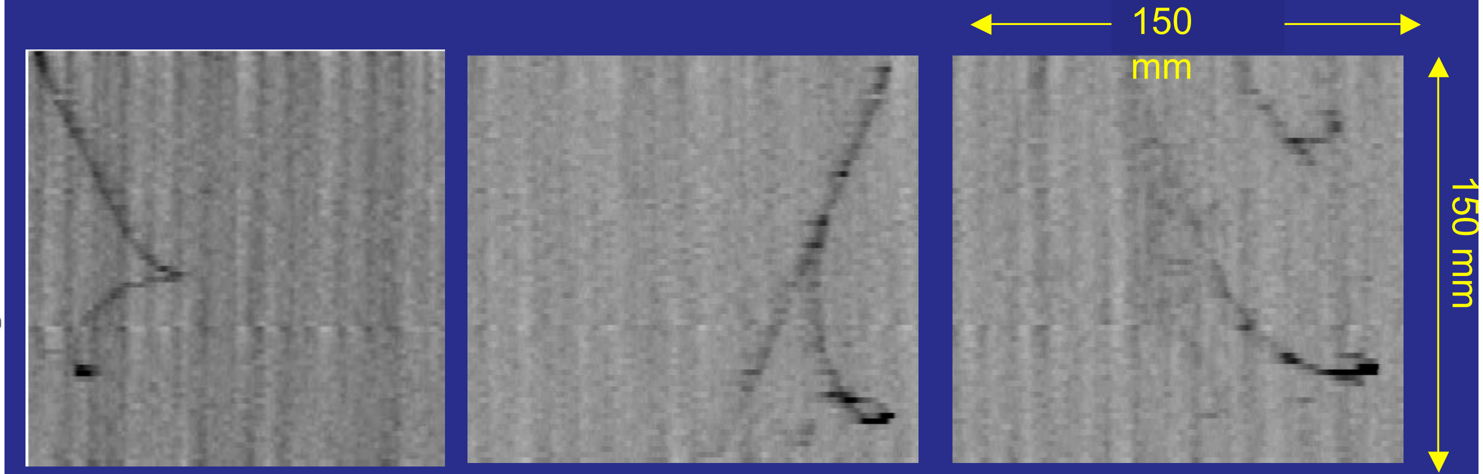
Magnetic field

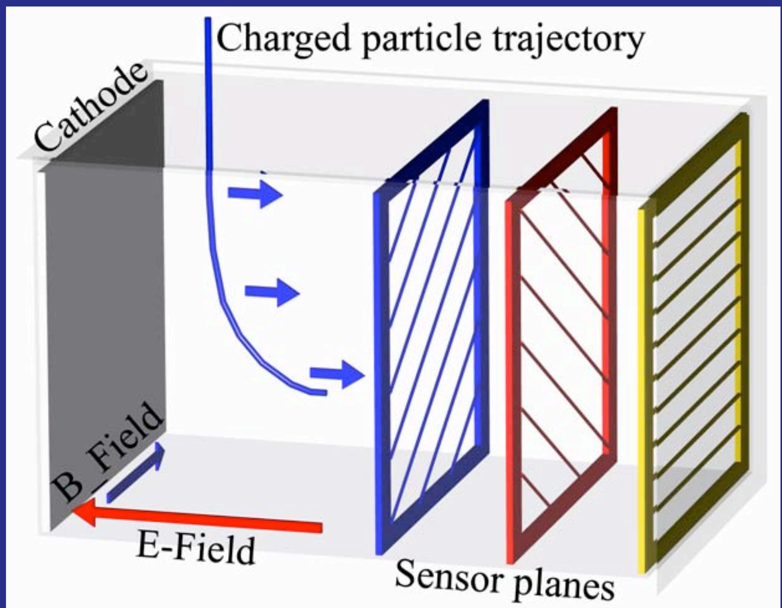
First operation of a 10 lt LAr TPC embedded in a B-field

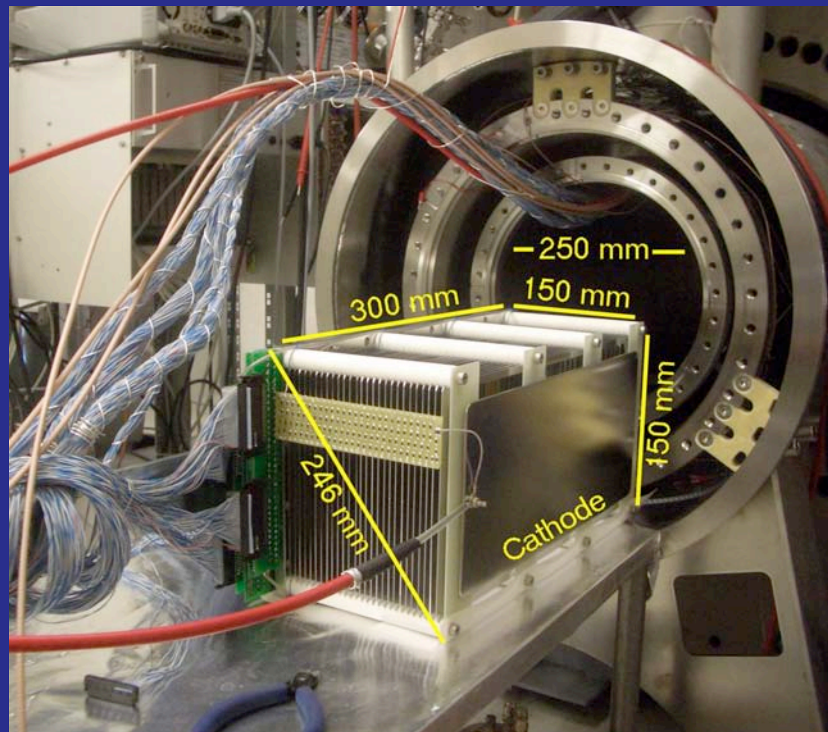
First real events in B-field (B=0.55T):

New J. Phys. 7 (2005) 63





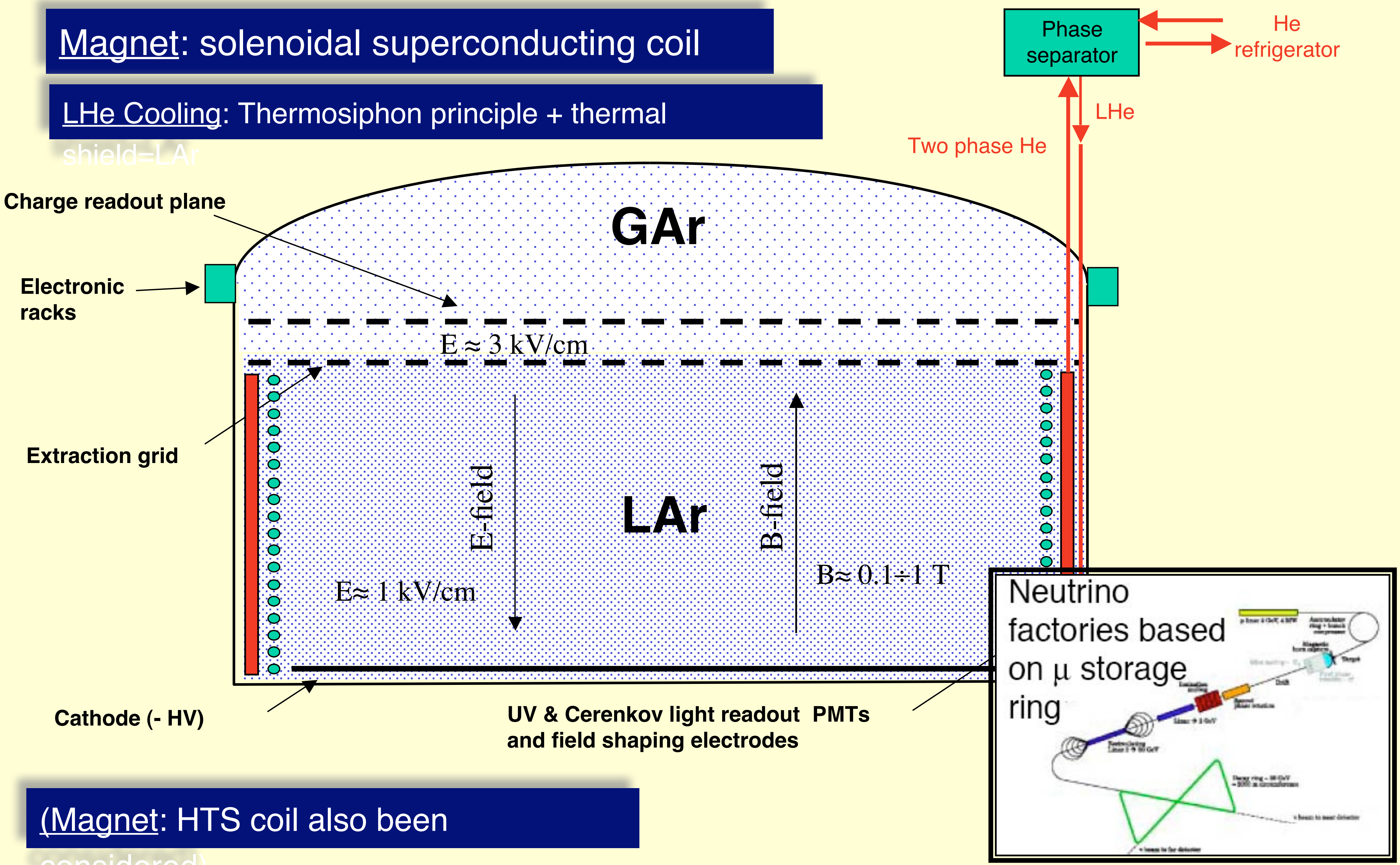




Tentative layout of a large magnetized GLACIER

Magnet: solenoidal superconducting coil

LHe Cooling: Thermosiphon principle + thermal shield=LAr



(Magnet: HTS coil also been considered)

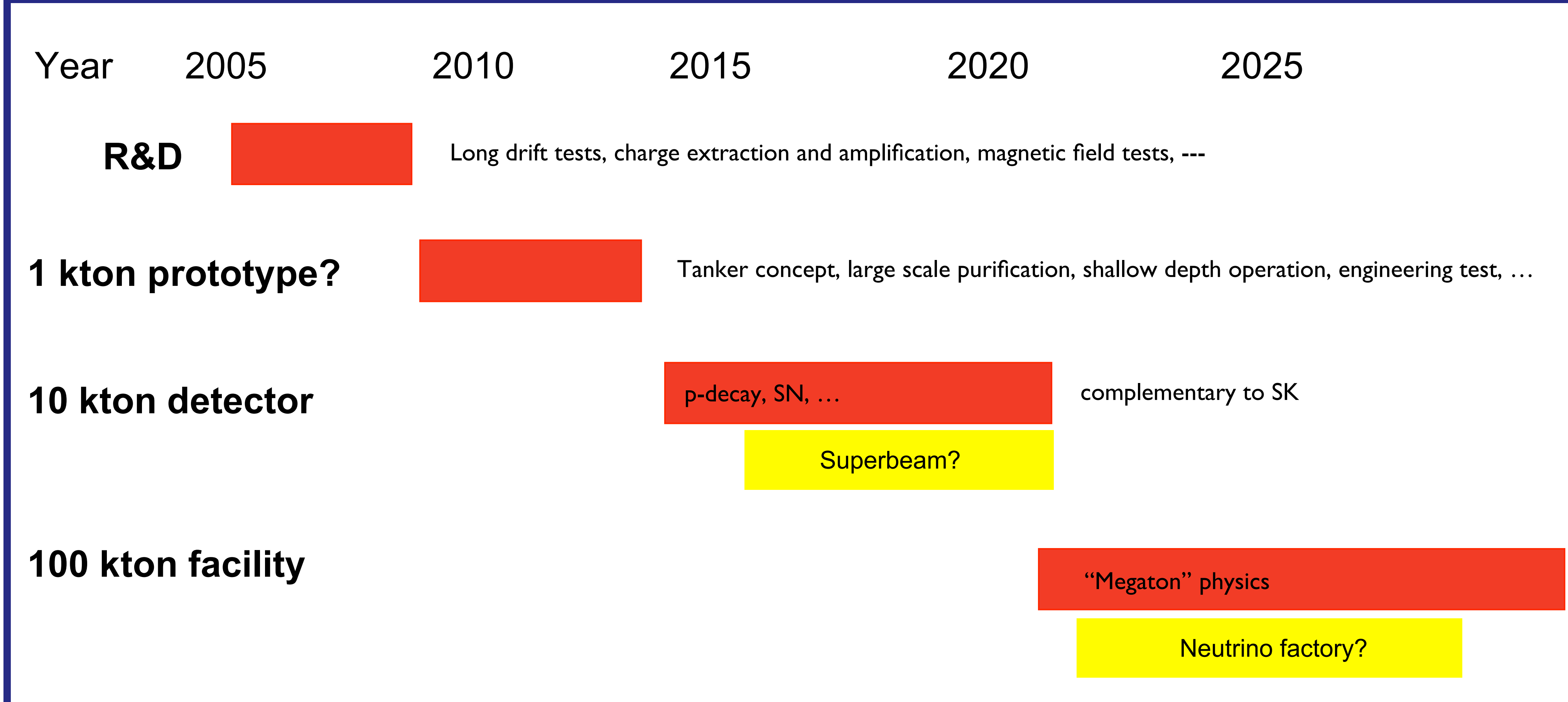
Tentative coil parameters

Other examples: ALEPH, CDF, ATLAS Toroids, AMS-II

	10 kton LAr			100 kton LAr			ATLAS solenoid	CMS
Magnetic induction (T)	0.1	0.4	1.0	0.1	0.4	1.0	2.0	4.0
Solenoid diameter (m)	30			70			2.4	6
Solenoid length (m)	10			20			5.3	12.5
Magnetic volume (m^3)	7700			77000			21	400
Stored magnetic energy (GJ)	0.03	0.5	3	0.3	5	30	0.04	2.7
Magnetomotive force (MAt)	0.8	3.2	8	1.6	6.4	16	9.3	42
Radial magnetic pressure (kPa)	4	64	400	4	64	400	1600	6500
Coil current (kA)	30 (I/I_c=50%)						8	20
Total length conductor (km)	2.5	10	25	12	57	117	5.6	45
Conductor type	NbTi/Cu normal superconductor, T=4.4K							

(Detailed magnetic, mechanical, thermal and quench analysis yet to be performed…)

Guideline for future large scale LAr technology development



Where do we go next ?

Outlook

Concepts for new generation large underground detectors are being developed

A lot of work is going on

⇓

Very interesting times
for the future of low energy neutrino physics and proton decay searches.

Work done by individual groups and proto-collaborations.
Requires support by the respective institutions and much more coordinated EU (and international) efforts.

A coherent and coordinated EU wide effort is recommended, in particular, taking into account the unique technological expertise in Europe and the other existing or planned programs in the rest of the World.

Some ideas for potential FP7 activities

- **Networking activities**
  - A1) Physics potential of Large Deep Underground experiments in both non-accelerator and accelerator sectors
  - A2) Underground Laboratories for very large detectors : best strategies for excavation, access and equipments (ventilation, air-conditioning, power supply, etc.)
  - A3) Safety optimisation in Very Large Underground Facilities
  - etc…

- **Joint Research Activities**
  - B1) Development of low-cost photo-sensors for Cerenkov and scintillation processes in optical and DUV regions, of different types (vacuum or gaseous) (in connection with industry)
  - B2) Development of solutions for low-cost readout electronic for a large number of channels
  - B3) Development of large scale liquid purification systems
  - B4) Technical feasibility and safety of large underground liquid containers (tanker)
  - B5) Site definition and local studies for large scale caverns with large underground apparatuses (rock/salt quality, access requirements, ventilation systems, power supply, …)
  - etc...

- **Design studies**
  - Detailed costing of large facilities ?

Backup slides