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

Swiss Institute of Particle Physics

Astroteilchenphysik

in Deutschland: Status und Perspektiven 2005

4.–5. Oktober 2005,
DESY, Zeuthen

γ-Astronomie, kosmische Strahlung, Neutrino-Astrophysik,
Neutrinomassen, Dunkle Materie, Gravitationswellen, Kosmologie

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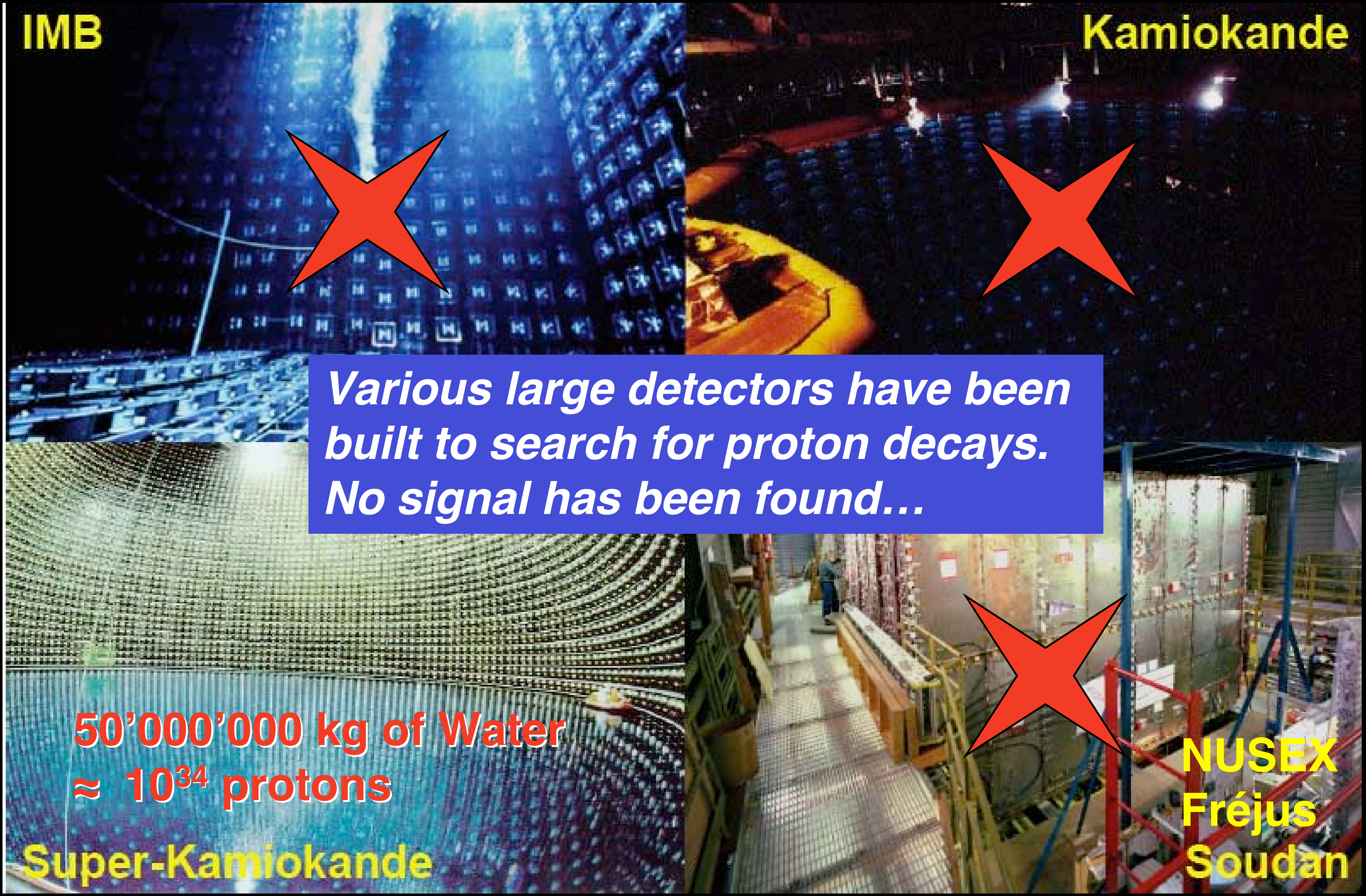
Astroteilchenphysik in Deutschland:
Status und Perspektiven 2005
DESY, Zeuthen 04.-05. Oktober 2005

Large underground detectors for nucleon decay search

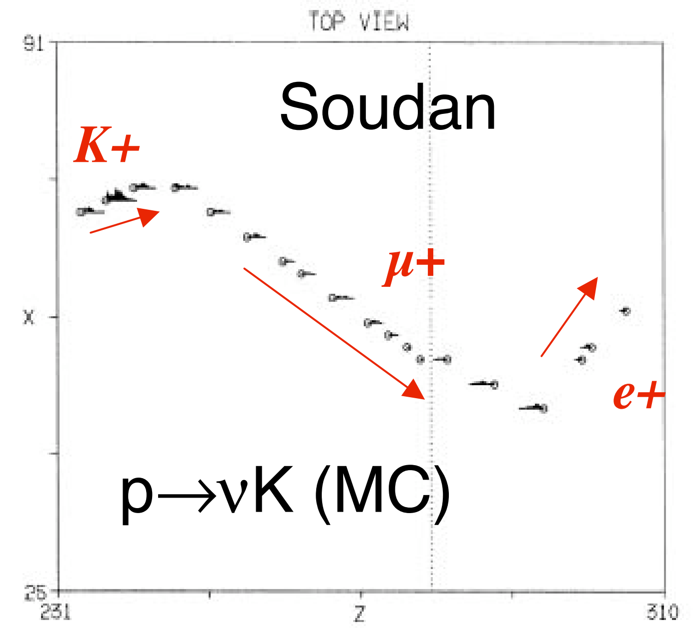


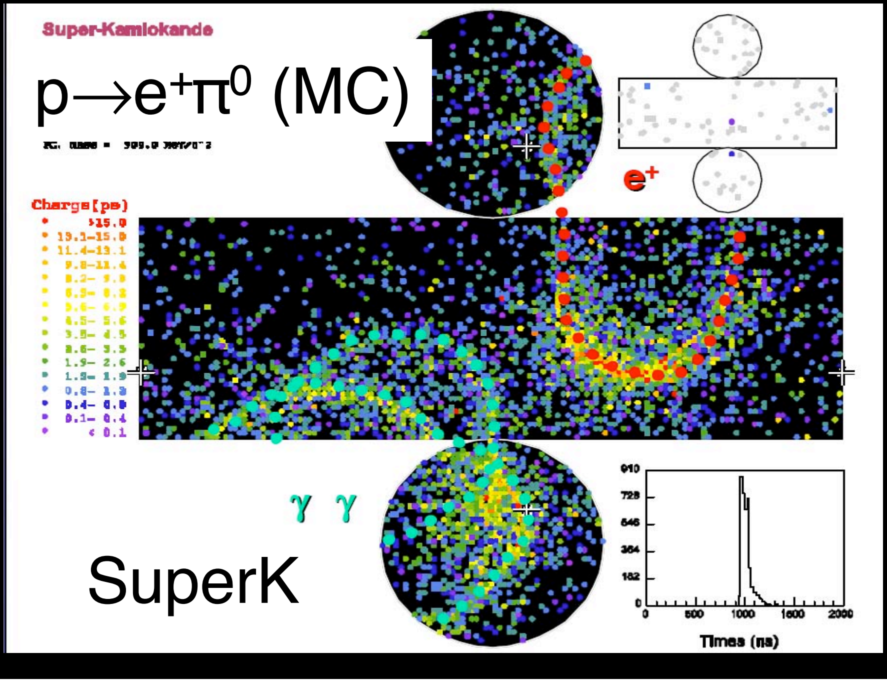
Various large detectors have been built to search for proton decays. No signal has been found…

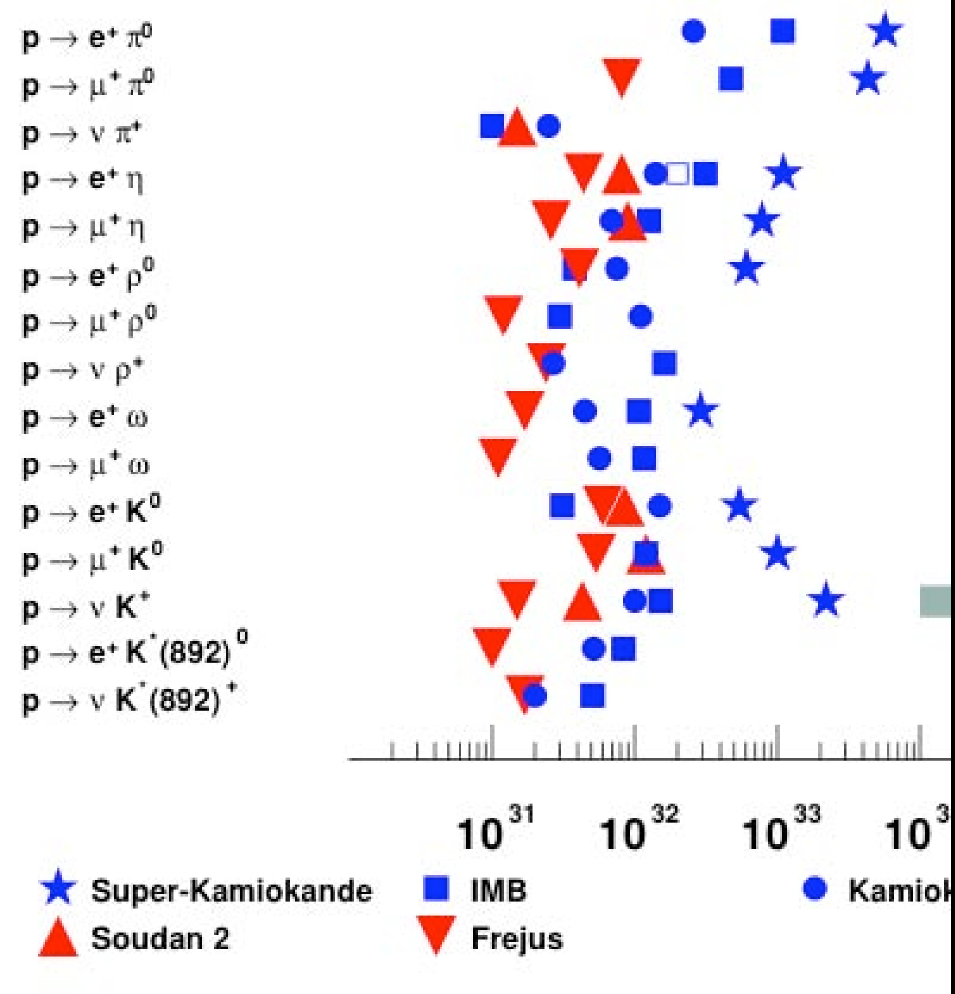
50’000’000 kg of Water
≈ 10^{34} protons

Negative results from proton decay searches…

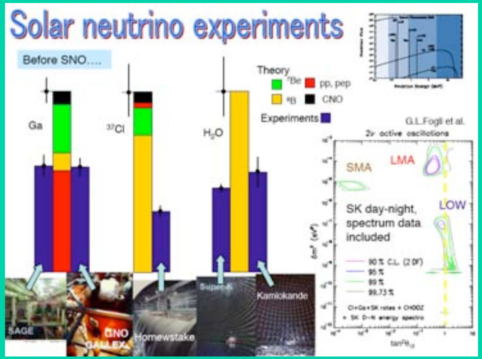
- **Tracking-calorimeters & Water Cerenkov detectors**
- **Best limits above 10^{32} yrs from WC**

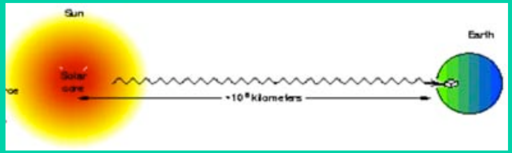


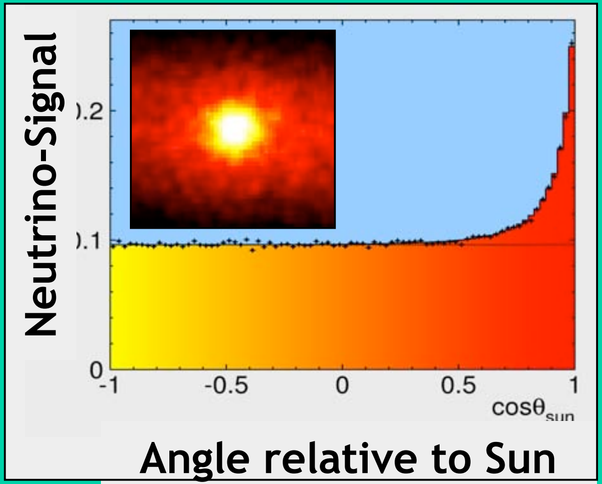


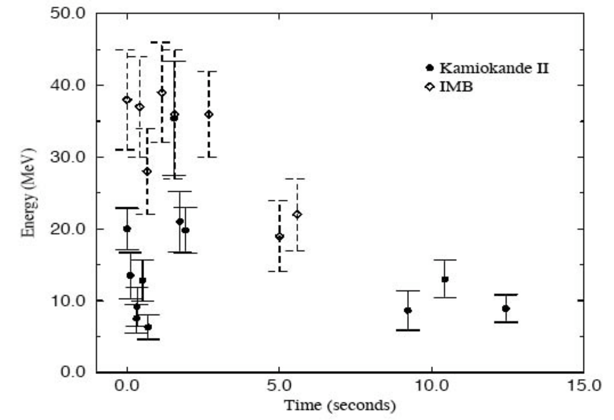


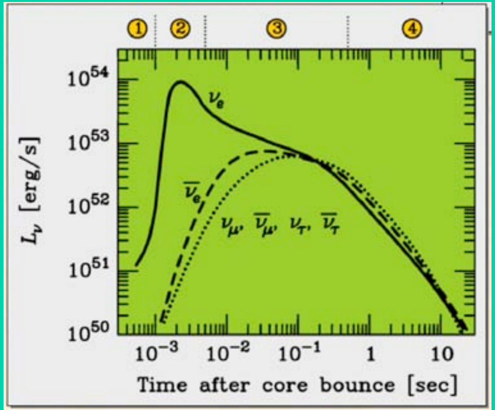
But past success of the field…



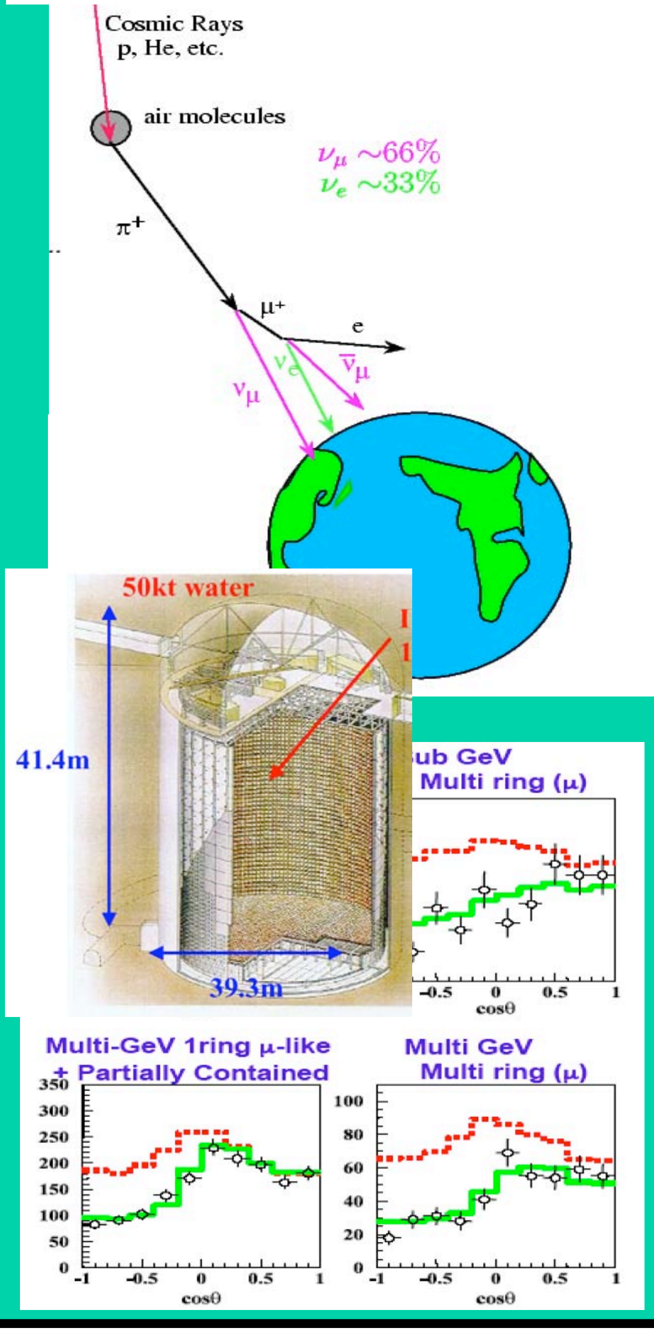








Atmospheric neutrino experiments



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

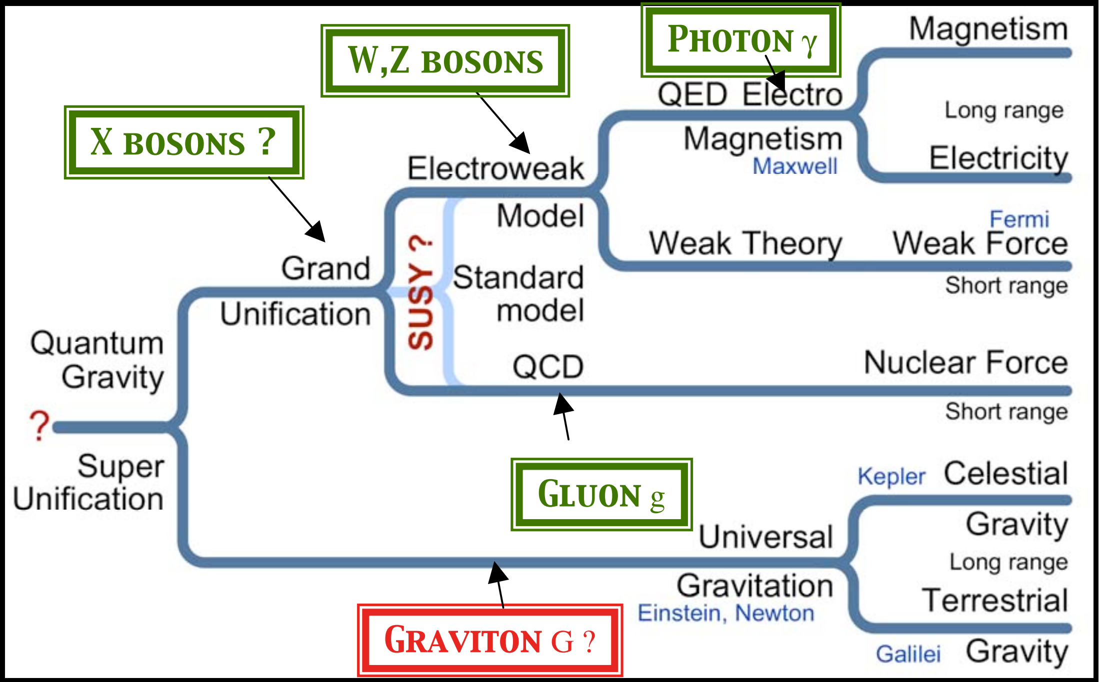
The need for new generation experiments…

Still many unsolved or unachieved issues…

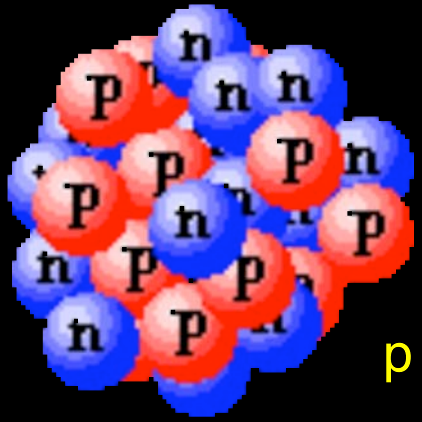
• Baryon number violation	Proton decay
• Gravitational collapse	SN ν
• Star formation in the early universe	Relic SN ν
• Solar thermonuclear fusion processes	Solar - ν
• Neutrino properties	SN - ν, Atm. - ν, LBL - ν
• Geophysical models, Earth density profile	Atm. - ν U, Th - ν

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**



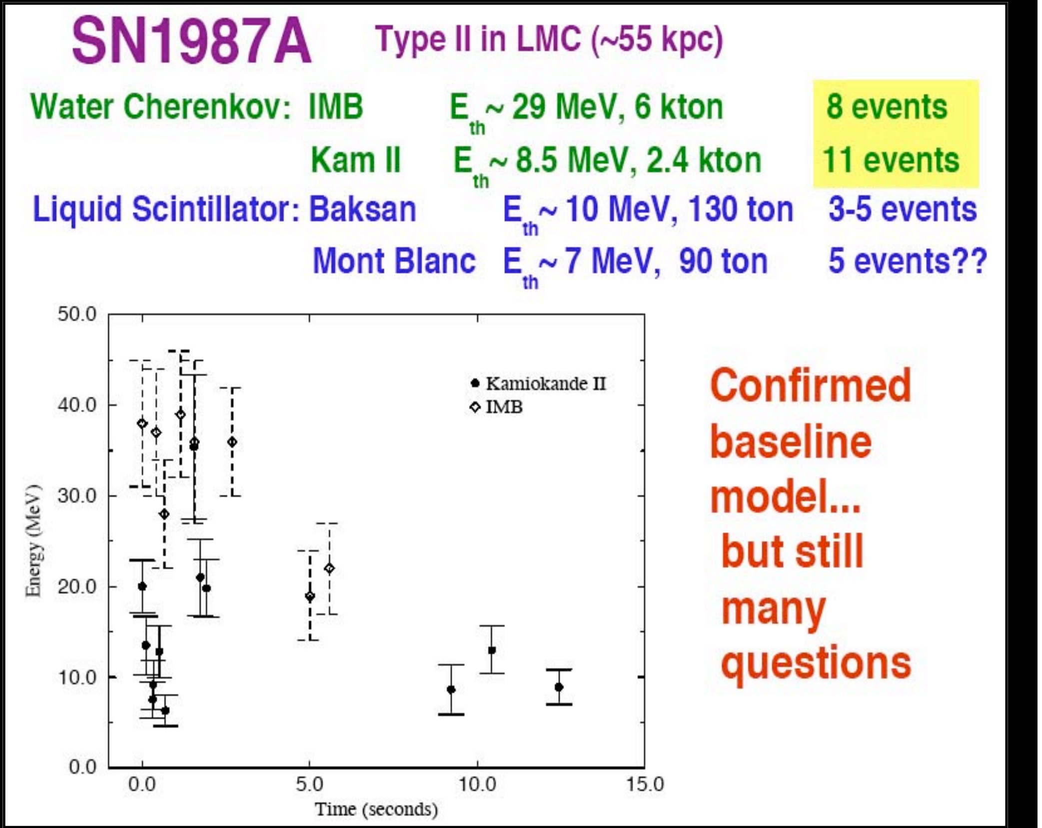
$p \longrightarrow e^+ + \pi^0$

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

The Crab Nebula in Taurus (VLT KUEYEN + FORS2)

ESO PR Photo 40f/99 (17 November 1999)

© European Southern Observatory

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

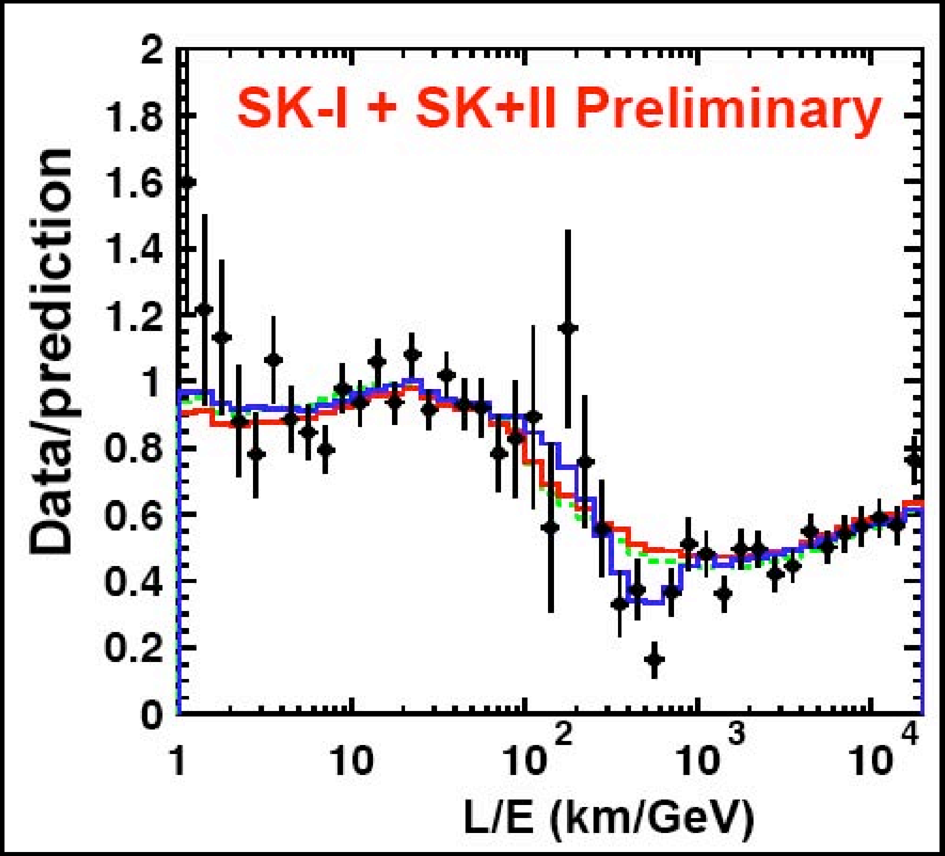
High statistics, precision measurement of flux

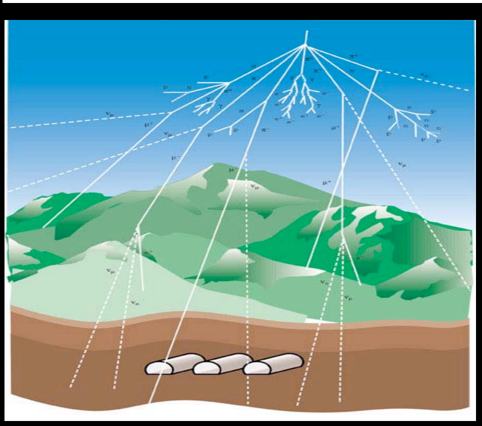
D/N asymmetry

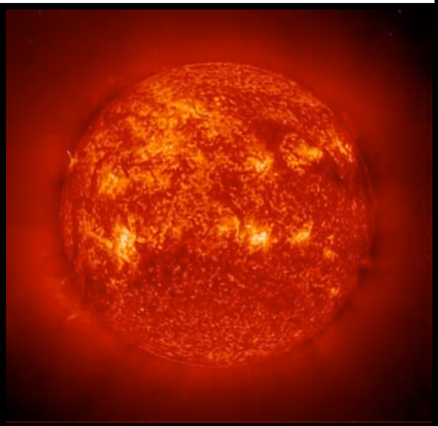
Time variation of flux

Solar flares

…

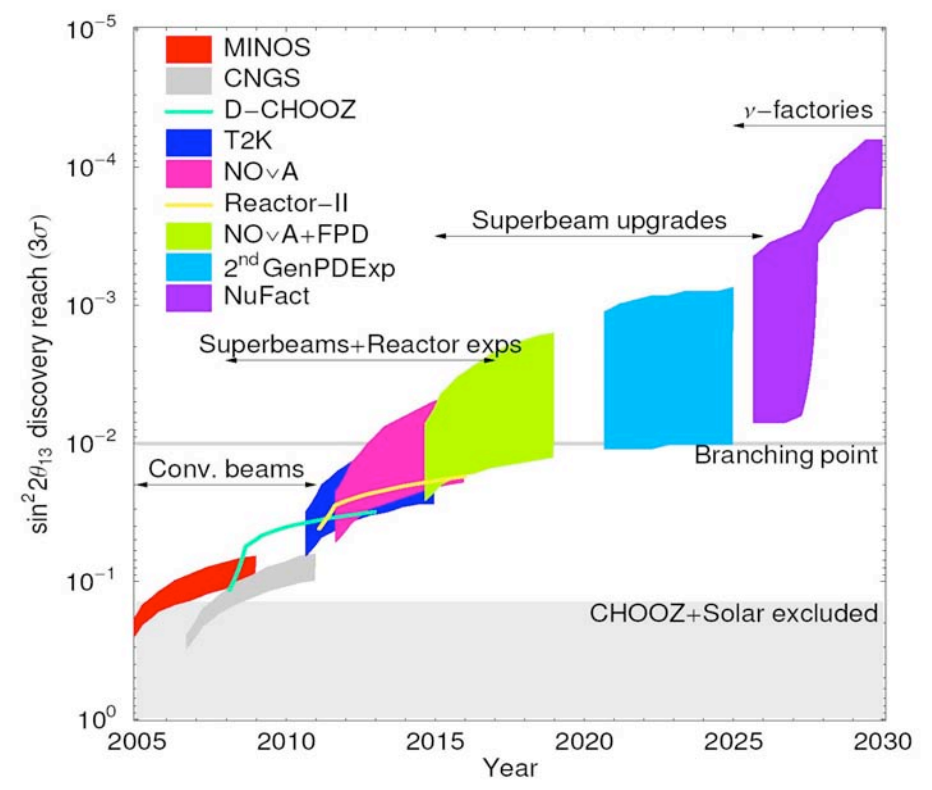






Neutrino properties (with accelerators)

- 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"

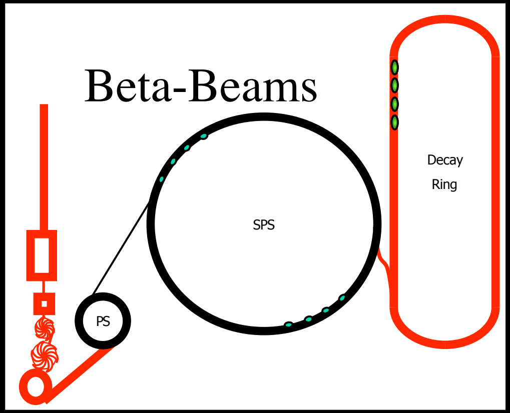


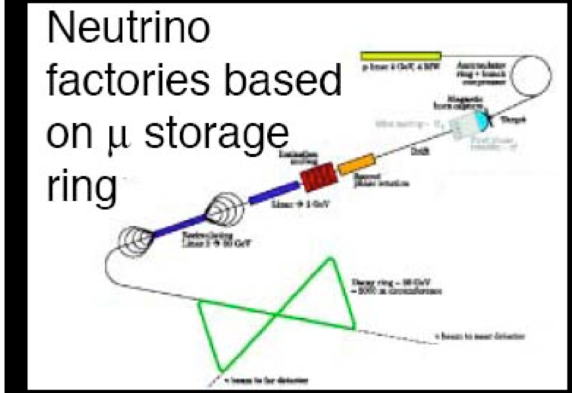
1. Precision measurement:

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

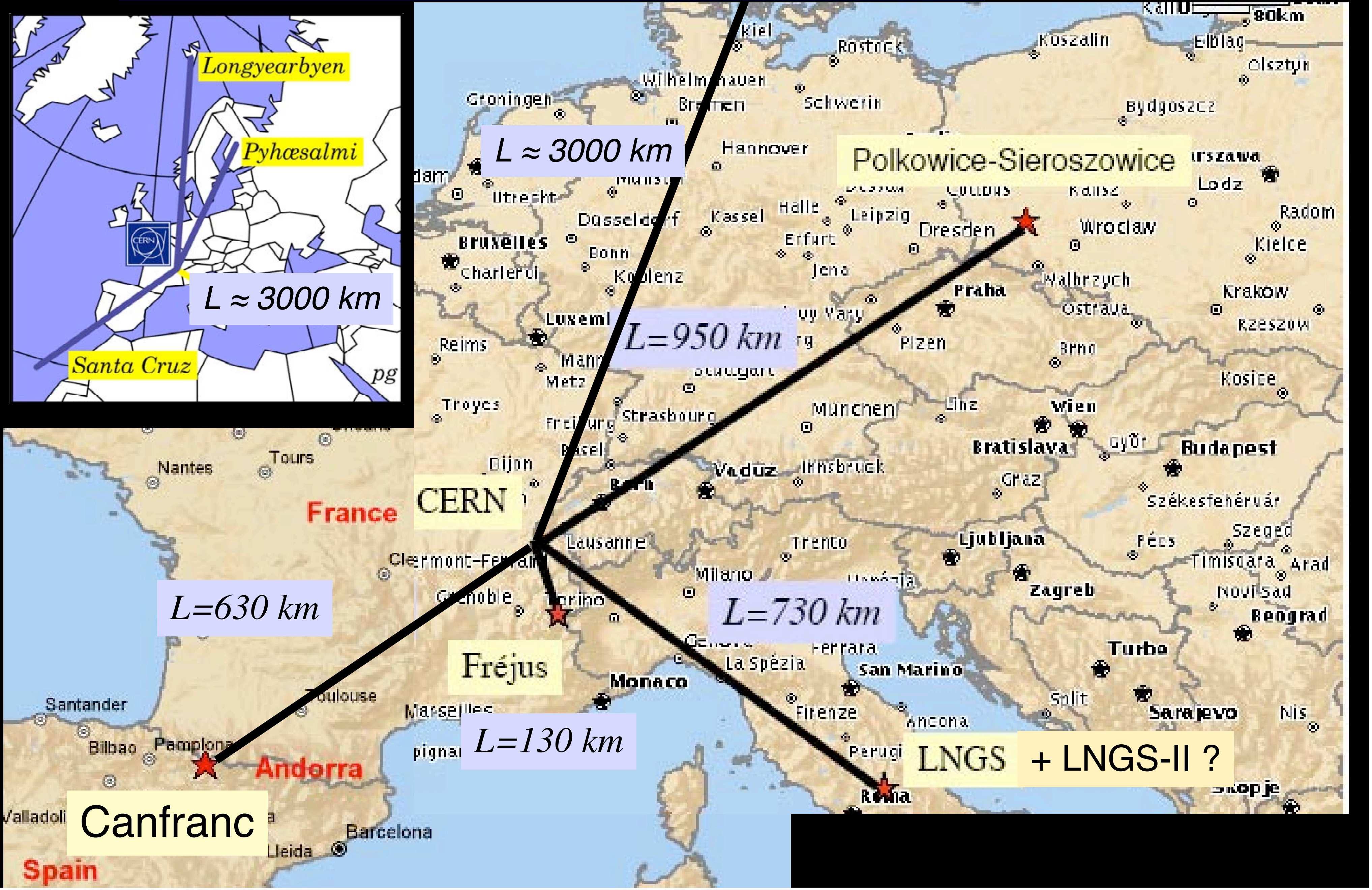
2. Discoveries

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





Examples of baselines from CERN:



Geo-neutrinos

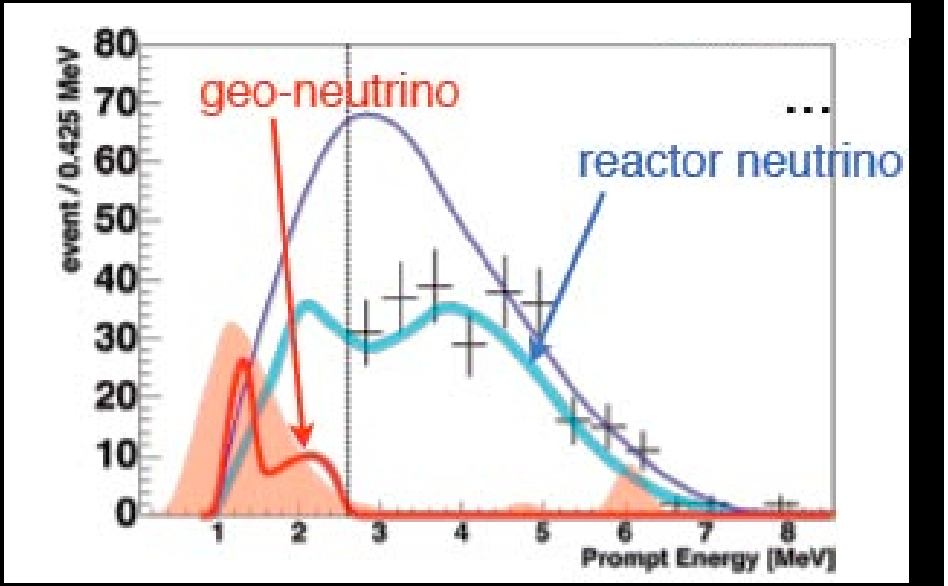
- Geoneutrinos are a new probe to test Earth's interior!

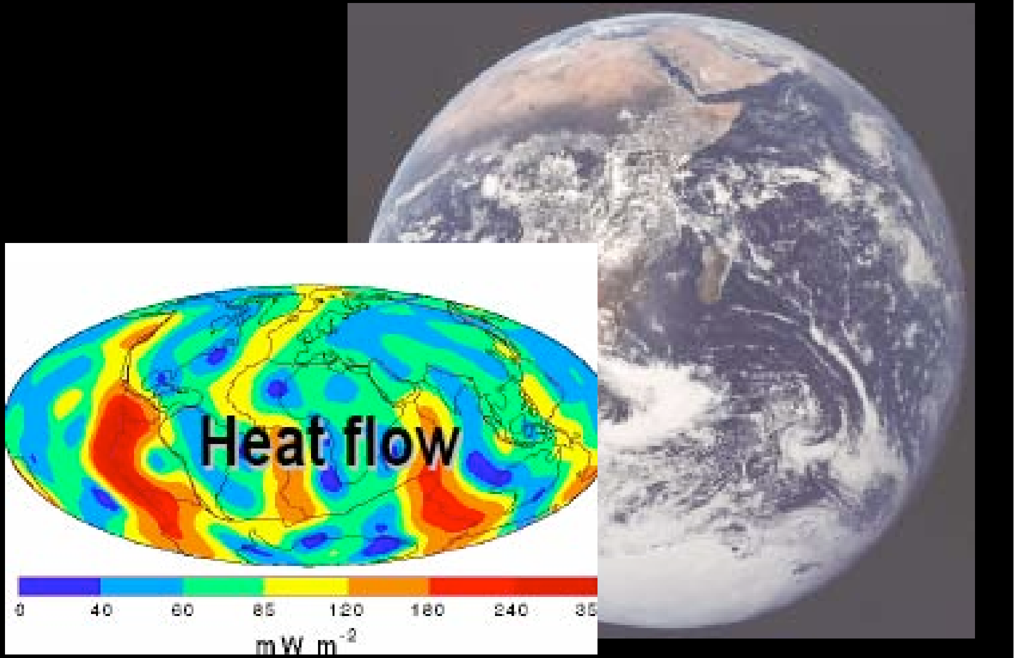
1. Geophysics:

- 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, …

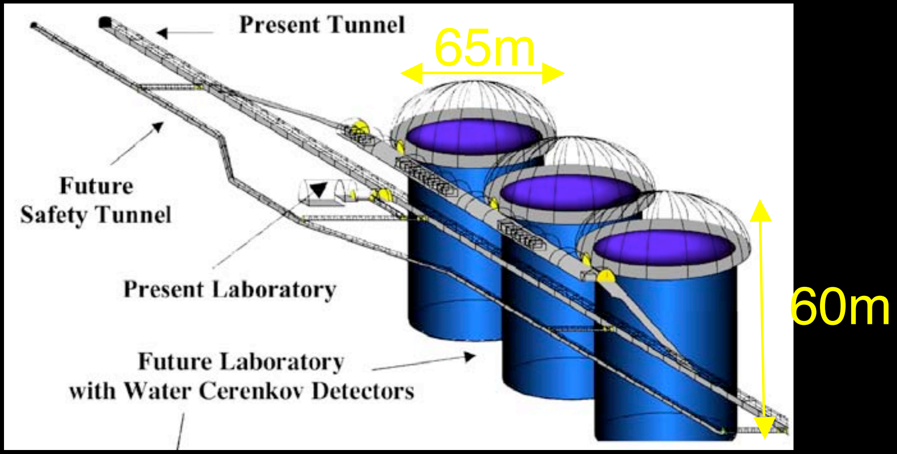




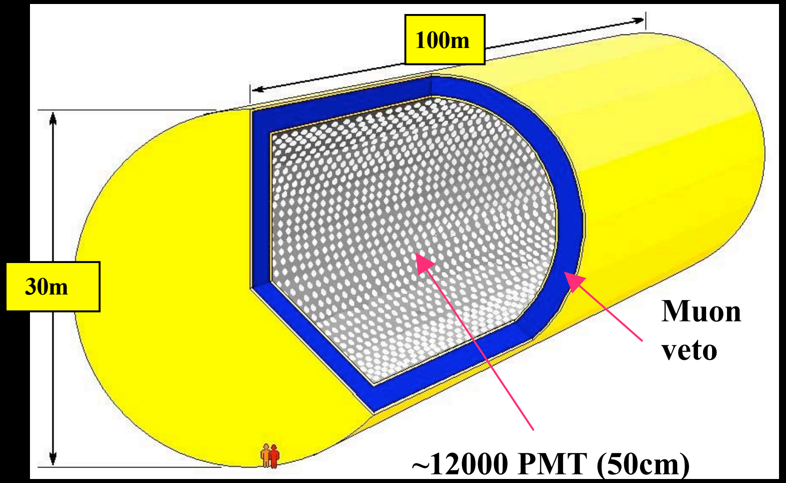
Next generation detectors ?

New large underground detectors

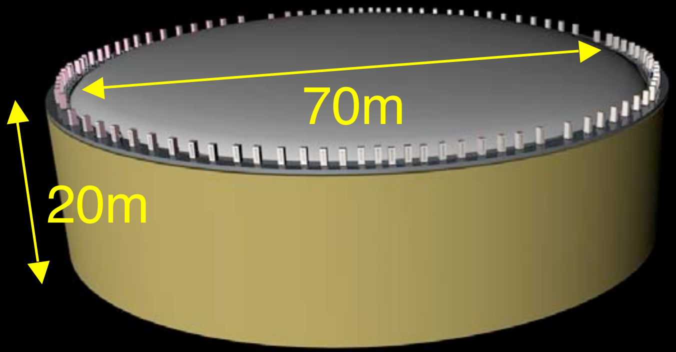
- Three types of large multi-purpose detectors



Water Cherenkov (≈0.5-1 Mton)



Liquid Scintillator (≈50 kton)



Liquid Argon (≈10-100 kton)

- 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.

Preliminary general remarks

- Megaton Water-Cerenkov
  - ➥ Well-proven technology (IMB, K, SK) for large scale. Concept for Megaton scale. Feasible if only PMT cost reduction achievable (?)
  - ➥ Optimal for low energy 1-prong interactions ($E<1$ GeV, single ring)
  - ➥ Broad neutrino astrophysics program and proton decay ($e\pi^0$, νK, …)
  - ➥ Possibility to use with low energy superbeam or betabeam

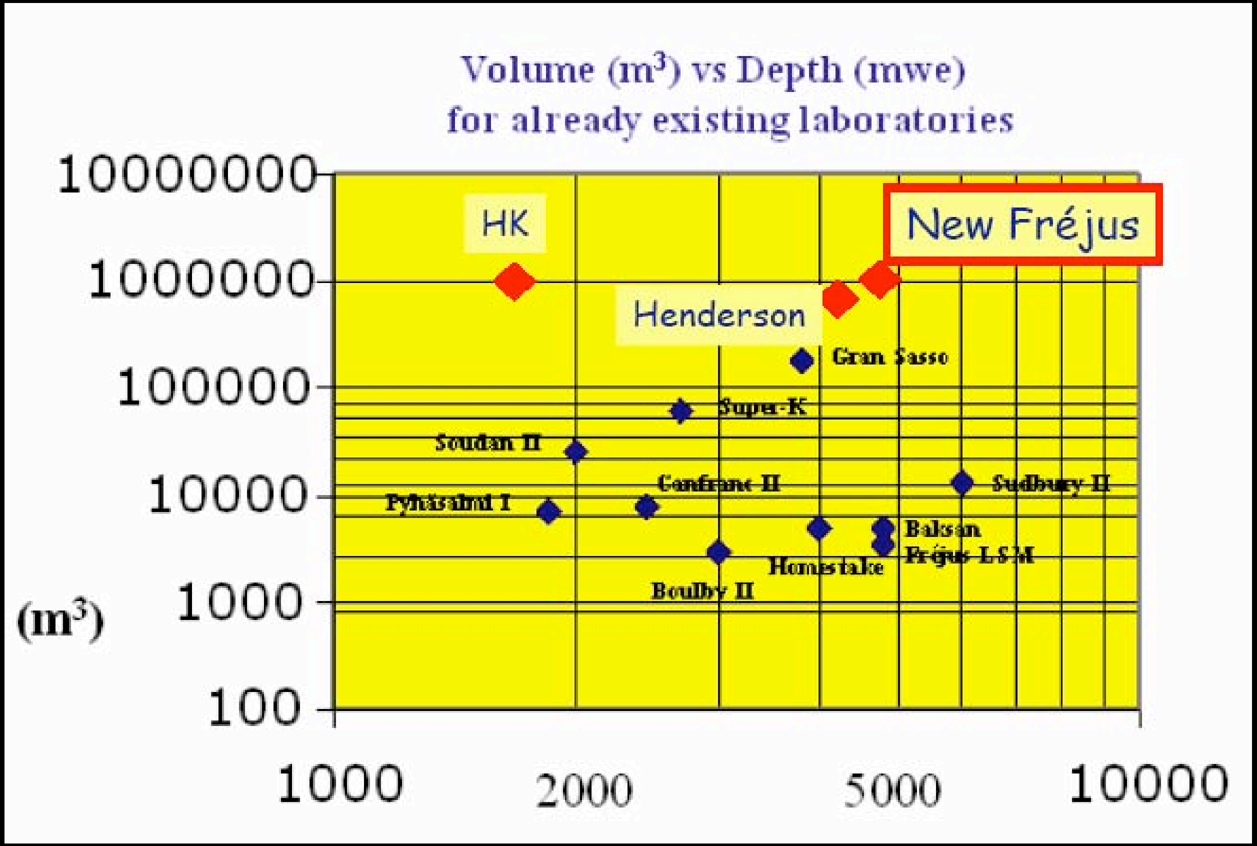
- Large Liquid Scintillator detector
  - ➥ New concept for ≈30 kt detector
  - ➥ Broad neutrino astrophysics program and proton decay (νK, …)
  - ➥ Particularly suited for studying geoneutrinos

- Large Liquid Argon TPC
  - ➥ Electronic bubble chamber developed by ICARUS Collaboration
  - ➥ ICARUS T600 tested on surface
  - ➥ New concept for scalable 1-10-100 kton detectors
  - ➥ Broad neutrino astrophysics program
  - ➥ Excellent technology for proton decay (many channels $e\pi^0$, νK,…)
  - ➥ Possibility to magnetize demonstrated. Large scale under study.
  - ➥ Possibility to use with superbeam, betabeam or neutrino factory

How big a cavern can we construct underground?
A challenge to the mining engineering community

Possible application in the future:
Large underground facility/storage
Large underground living space

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

Water Cerenkov detectors

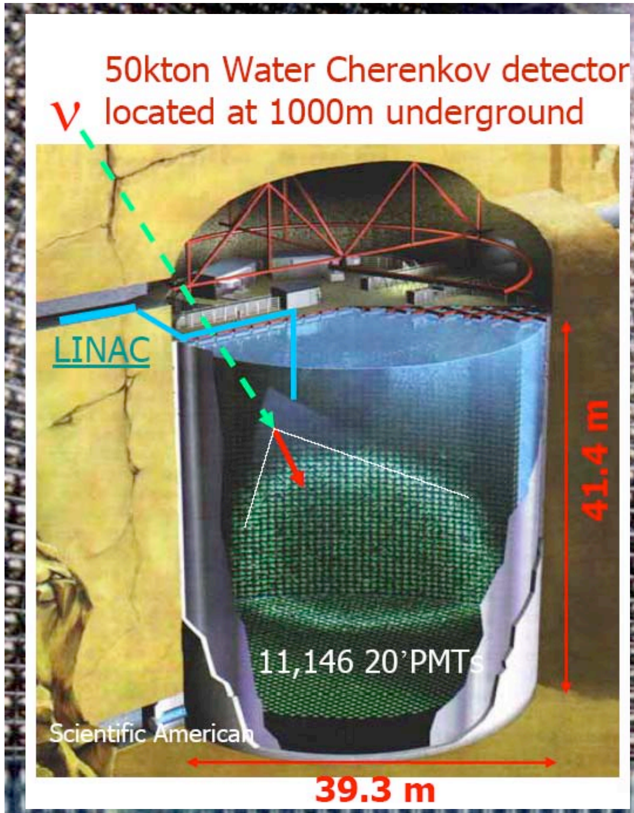
Mton Water Cherenkov Detector

- **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

Superkamiokande in Kamioka Mine (Japan)



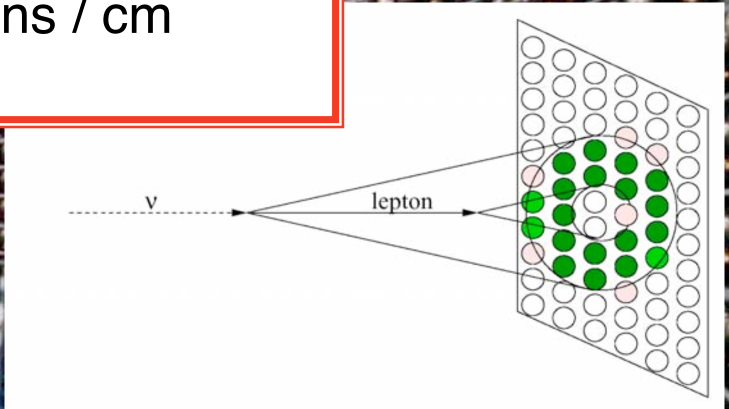
About 170 γ/cm in 350 < λ < 500 nm

With 40% PMT coverage, Q.E.≈20%

Relativistic particle produces

⇒≈14 photoelectrons / cm

⇒≈7 p.e. per MeV

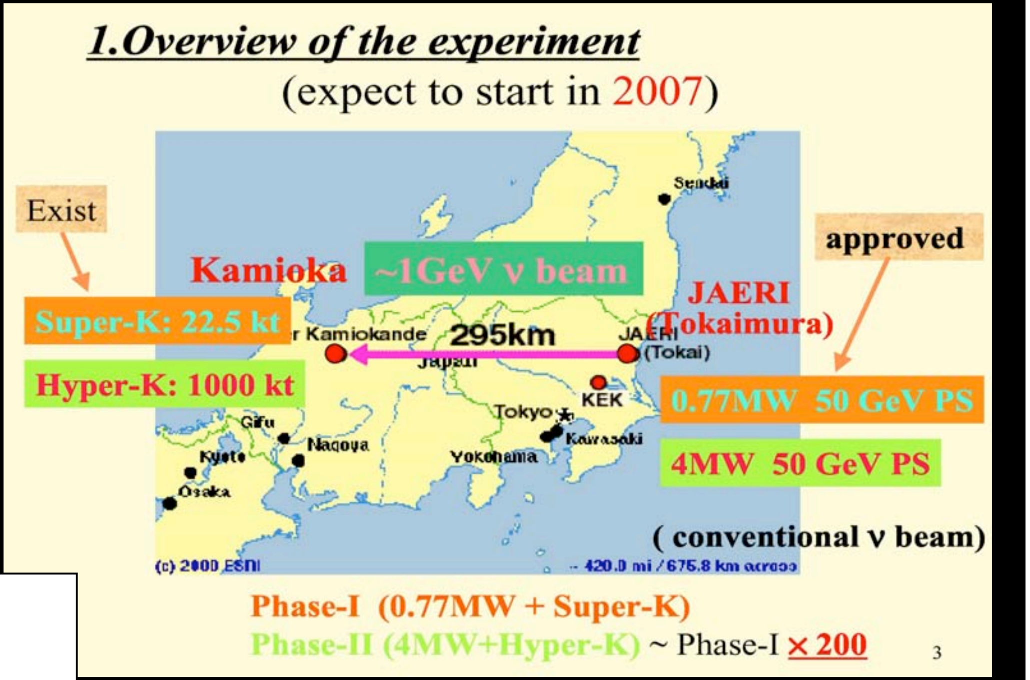


50'000'000 kg of Water

Light produced in Water observed with 11146 20-inch photodetectors

Next-generation water Cherenkov detectors: Hyperkamiokande

1 Million tons detector motivated by
- Proton decay (≈2×10^{35} protons)
- Long baseline Superbeams (CP-violation)
- Atmospheric neutrinos
- Solar neutrinos (if deep enough)
- Supernova neutrinos



1.Overview of the experiment

(expect to start in 2007)

Exist

approved

Kamioka

~1GeV ν beam

JAERI (Tokaimura)

Super-K: 22.5 kt

Hyper-K: 1000 kt

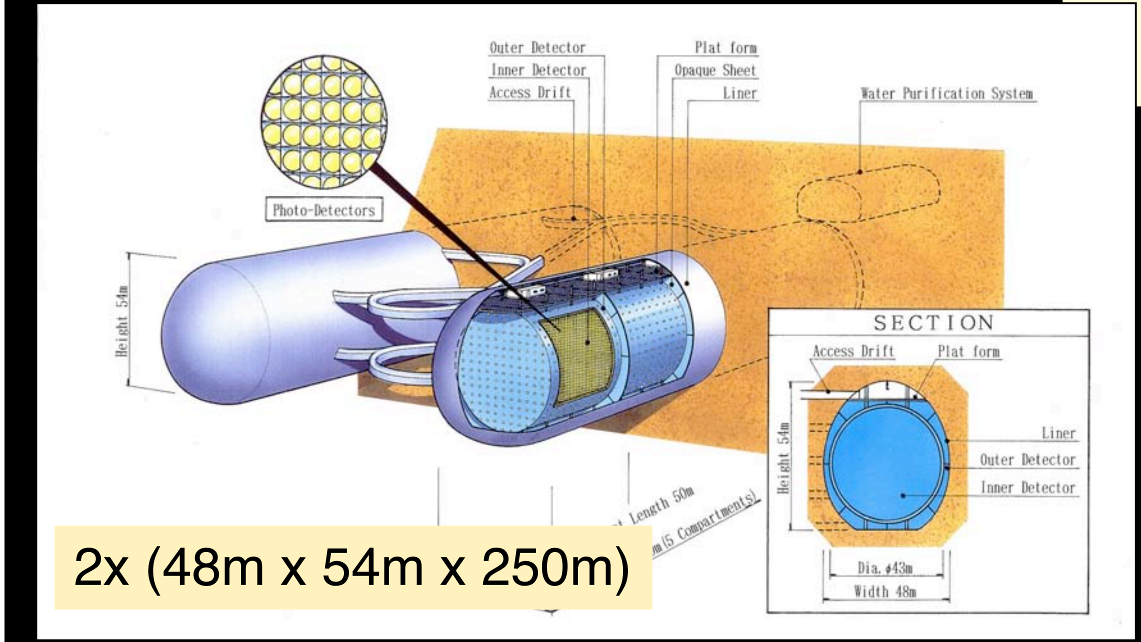
0.77MW 50 GeV PS

4MW 50 GeV PS

(conventional ν beam)

Phase-I (0.77MW + Super-K)

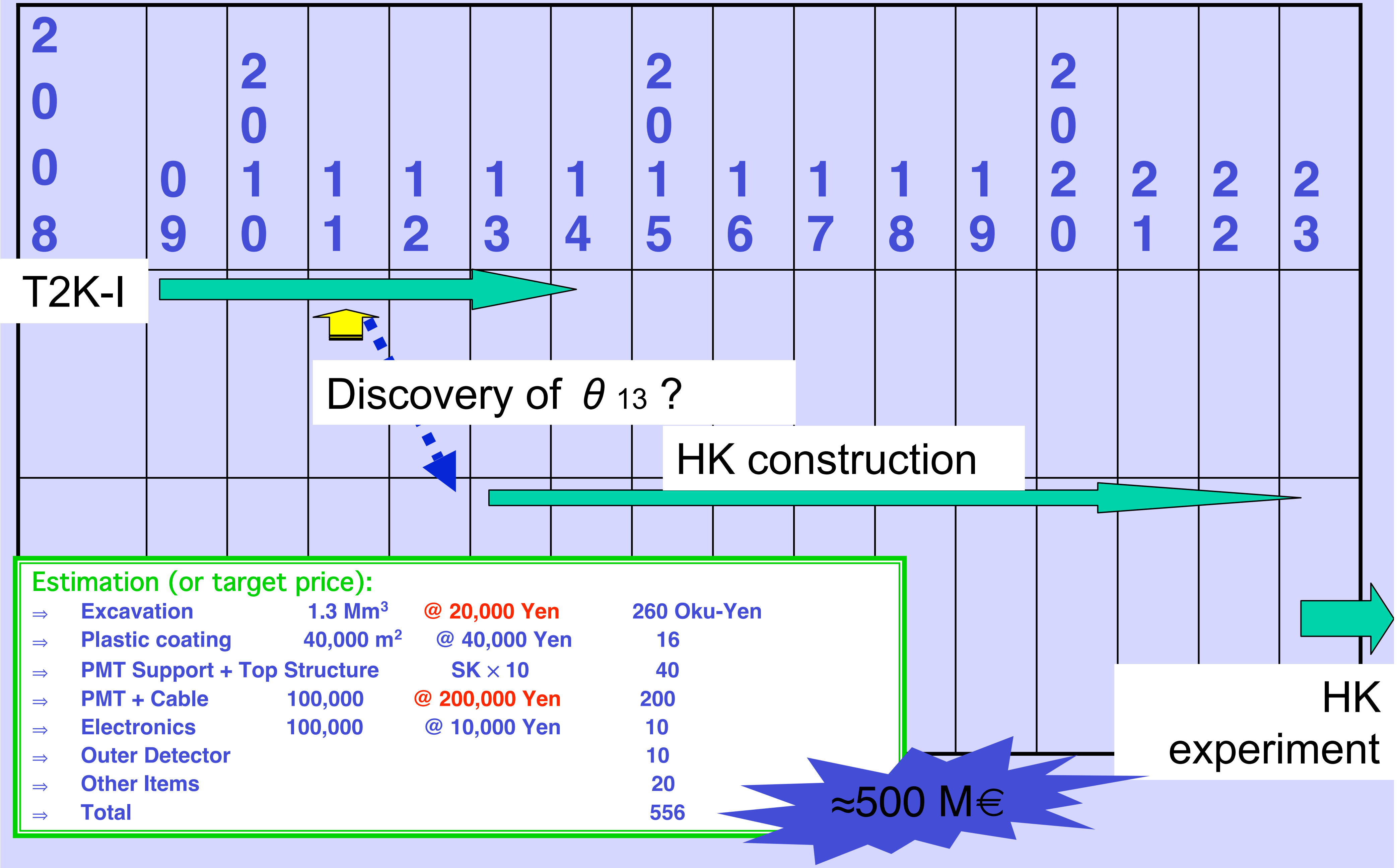
Phase-II (4MW+Hyper-K) ~ Phase-I × 200



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 ?)

Tentative schedule (Japan)



T2K-I

Discovery of θ_{13} ?

HK construction

HK experiment

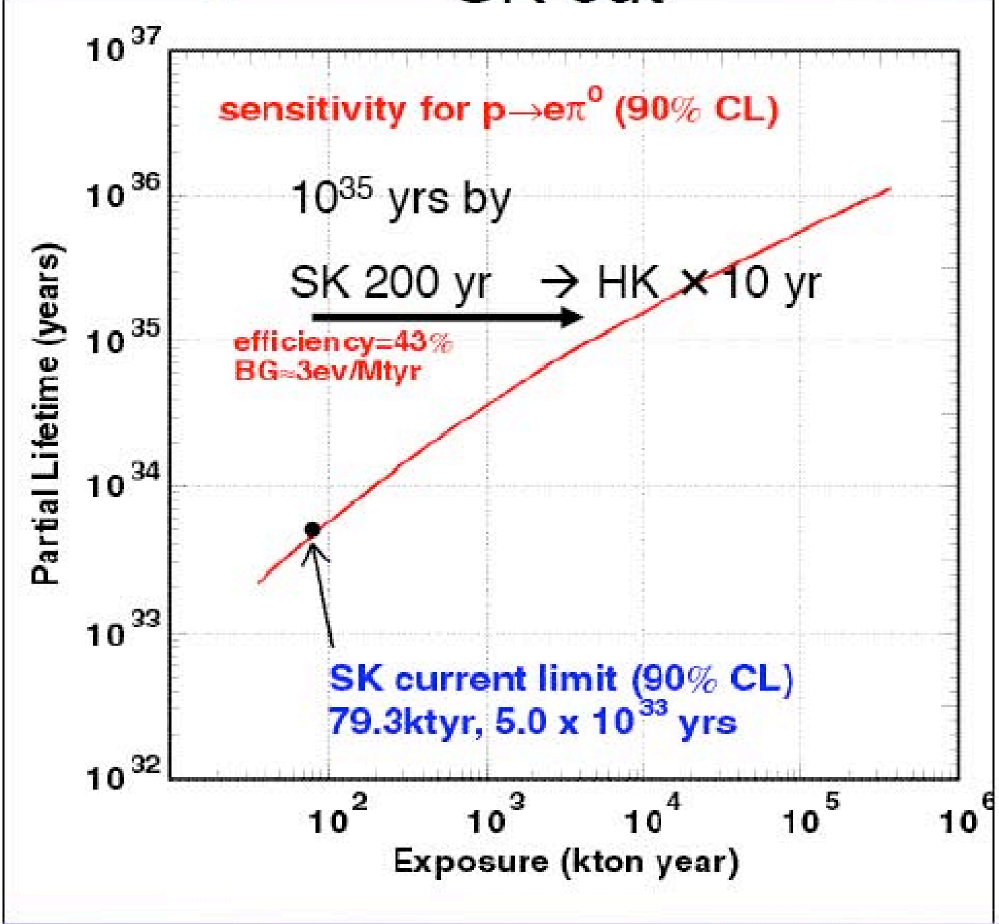
Estimation (or target price):

⇒	Excavation	1.3 Mm^3	@ 20,000 Yen	260 Oku-Yen
⇒	Plastic coating	40,000 m^2	@ 40,000 Yen	16
⇒	PMT Support + Top Structure		SK × 10	40
⇒	PMT + Cable	100,000	@ 200,000 Yen	200
⇒	Electronics	100,000	@ 10,000 Yen	10
⇒	Outer Detector			10
⇒	Other Items			20
⇒	Total			556

≈500 M€

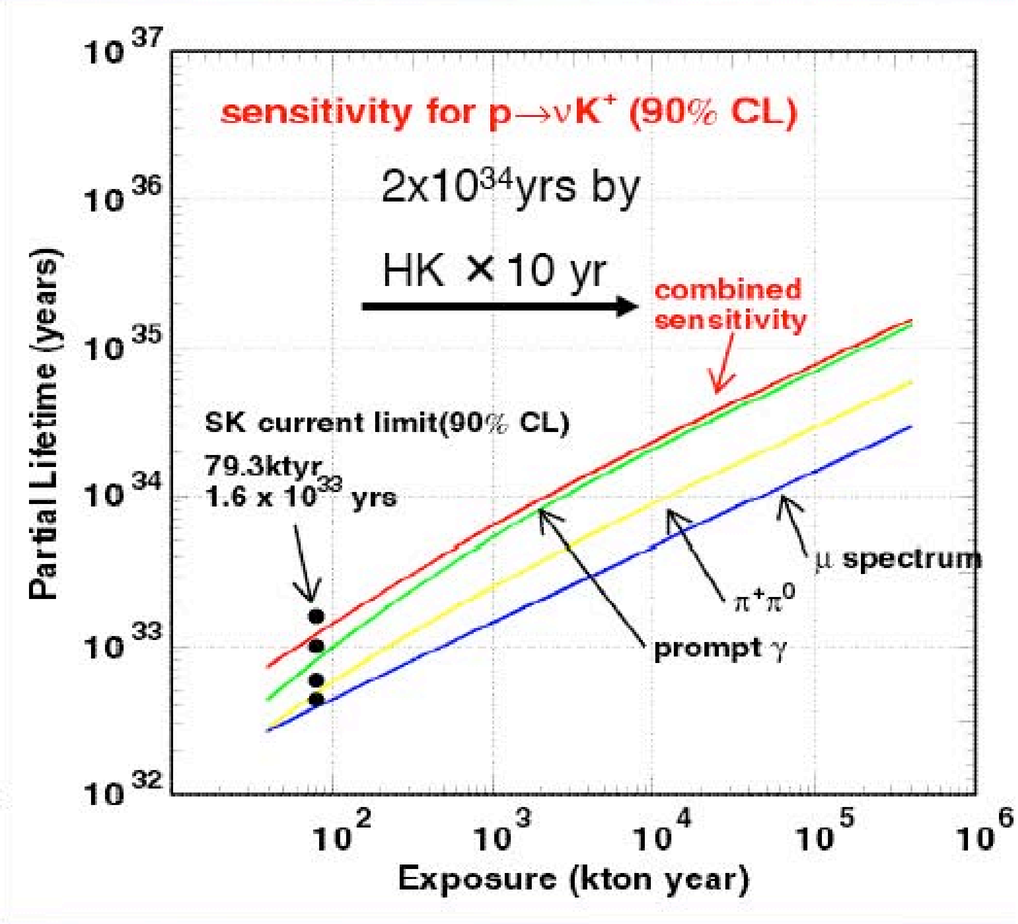
to explore the lifetime above 10^{34} yrs…

SK cut



10^{35} yrs by

SK 200 yr → HK × 10 yr



2×10^{34} yrs by

HK × 10 yr

Assuming performance like in SK

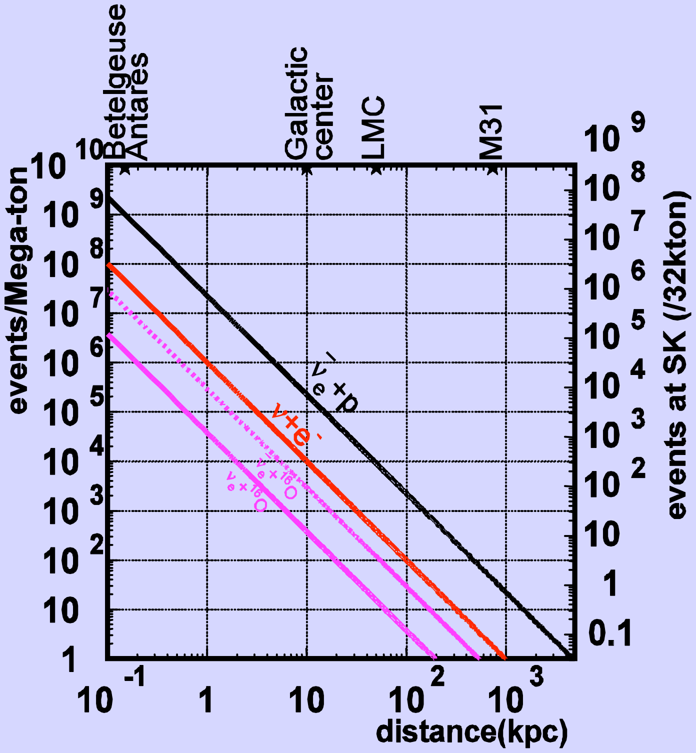
M. Shiozawa

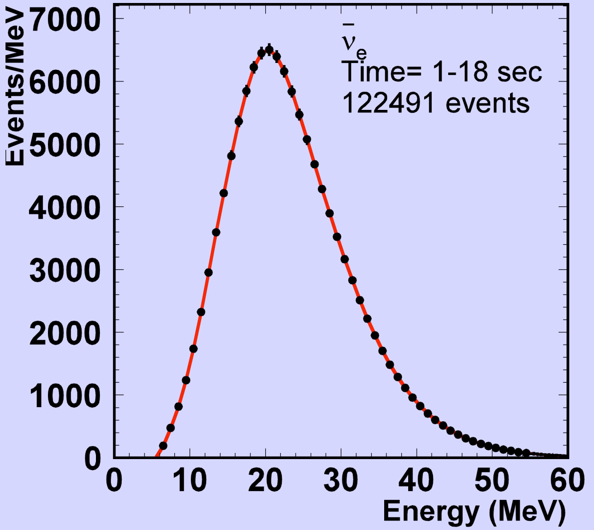
Example: Supernova studies with megaton WC detector

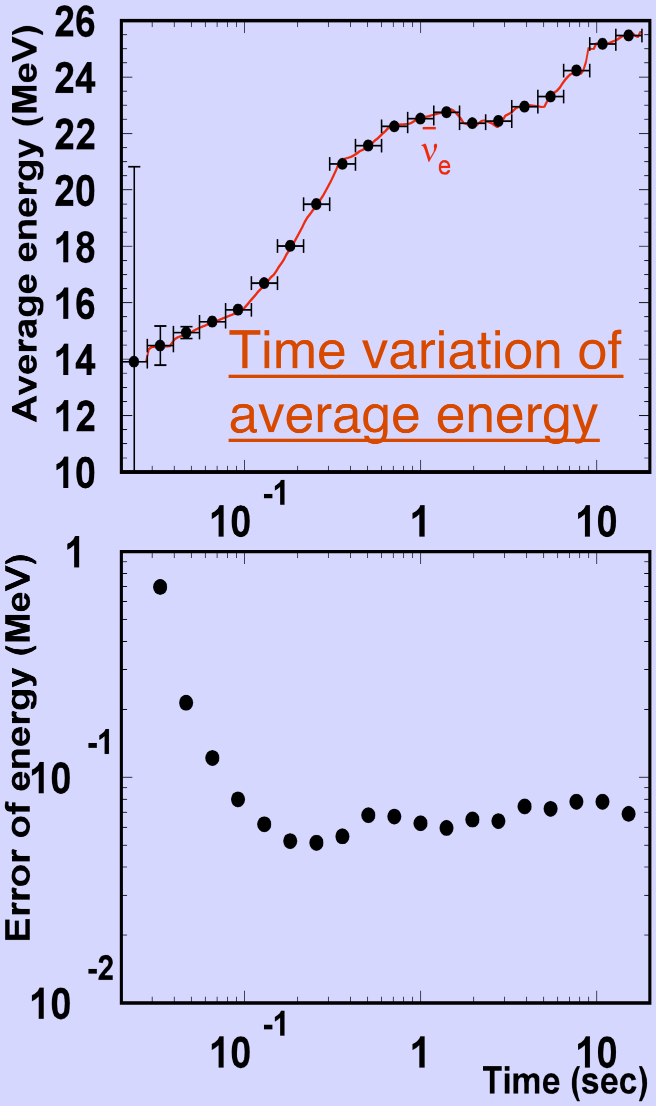
Main sensitivity: anti-neutrino electrons arriving at detector (oscillation!)

Expected number of events

1 Megaton H_2O and d=10 kpc

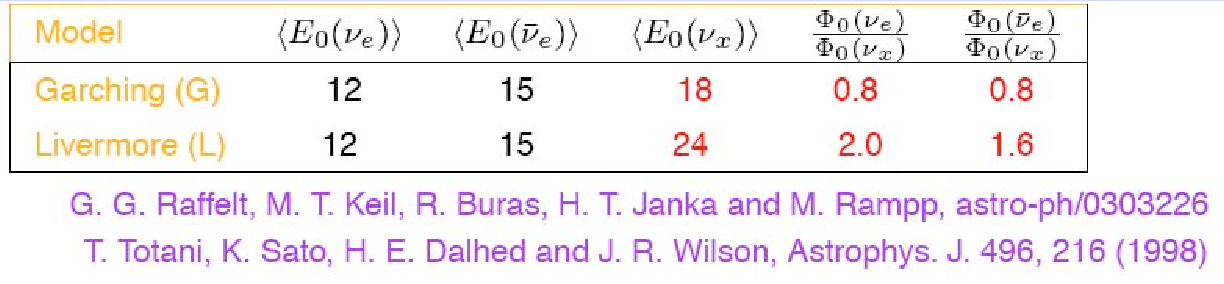






Time variation of average energy

5MeV threshold

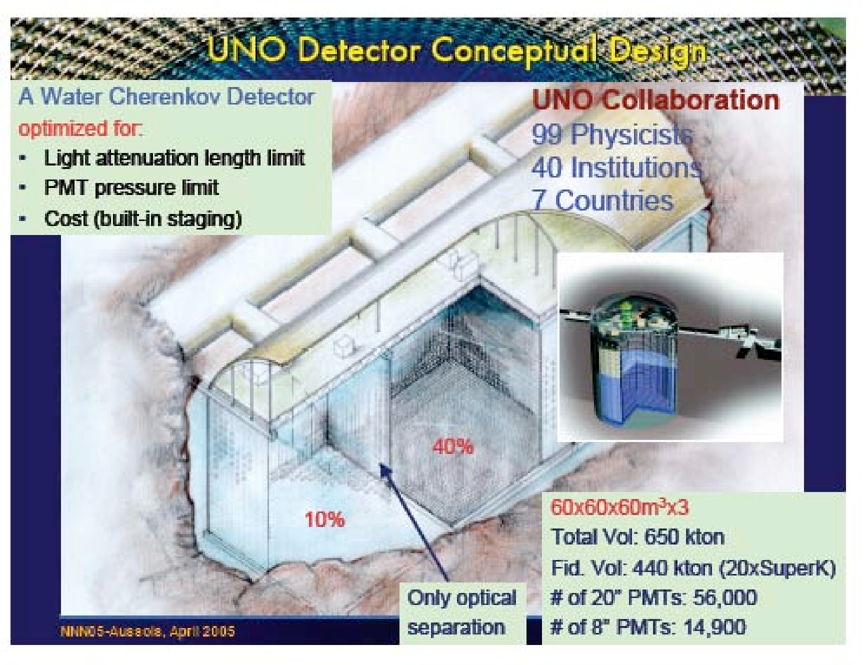


Model	$\langle E_0(\nu_e)\rangle$	$\langle E_0(\bar{\nu}_e)\rangle$	$\langle E_0(\nu_x)\rangle$	$\frac{\Phi_0(\nu_e)}{\Phi_0(\nu_x)}$	$\frac{\Phi_0(\bar{\nu}_e)}{\Phi_0(\nu_x)}$
Garching (G)	12	15	18	0.8	0.8
Livermore (L)	12	15	24	2.0	1.6

G. G. Raffelt, M. T. Keil, R. Buras, H. T. Janka and M. Rampp, astro-ph/0303226

T. Totani, K. Sato, H. E. Dalhed and J. R. Wilson, Astrophys. J. 496, 216 (1998)

Next-generation water Cherenkov detectors (II)



UNO Detector Conceptual Design

A Water Cherenkov Detector optimized for:

- Light attenuation length limit
- PMT pressure limit
- Cost (built-in staging)

UNO Collaboration
99 Physicists
40 Institutions
7 Countries

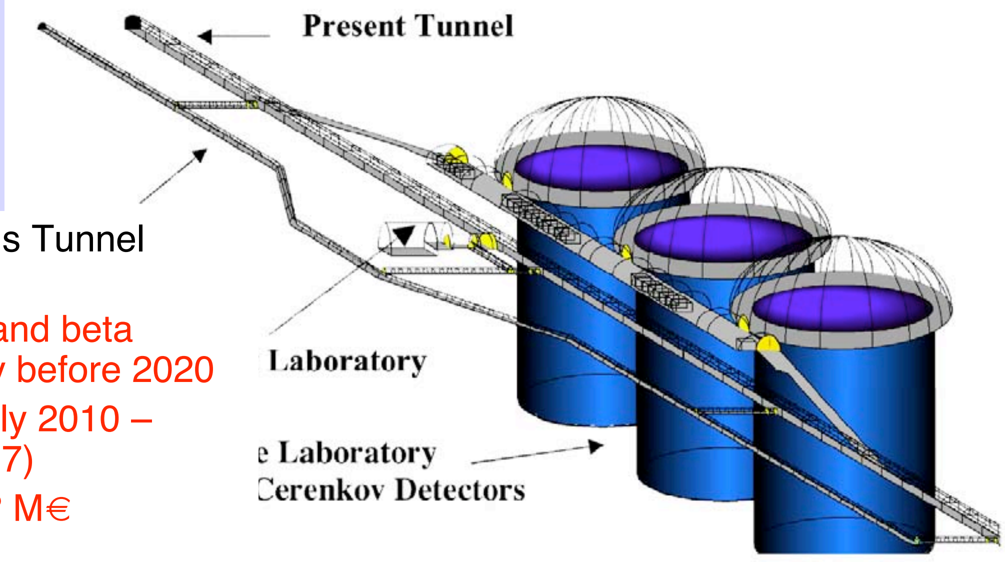
Only optical separation

$60\text{x}60\text{x}60\text{m}^3\text{x}3$
Total Vol: 650 kton
Fid. Vol: 440 kton (20xSuperK)
# of 20" PMTs: 56,000
# of 8" PMTs: 14,900

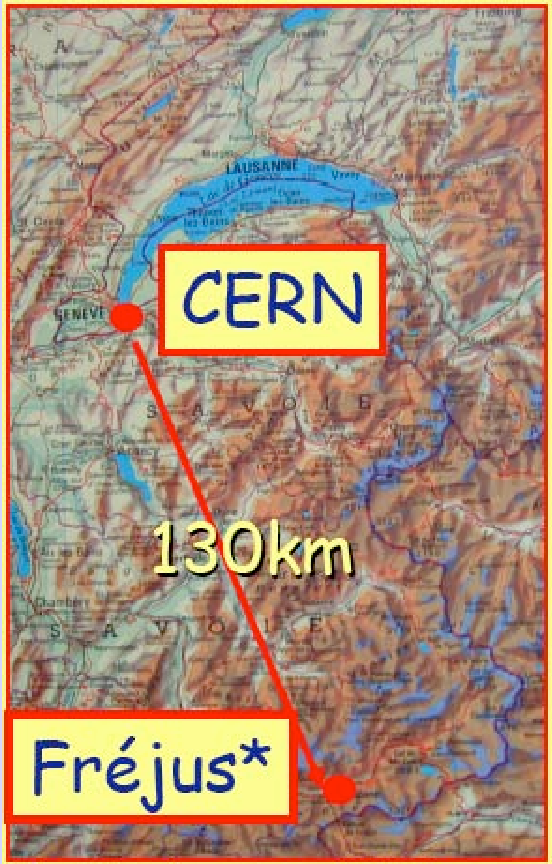
NNN05-Aussois, April 2005

- UNO @ Henderson Mine (USA)
  - DUSEL proposal: 2006
  - Construction: 10 years, wish to start as soon as possible
  - ≈ 500 M$

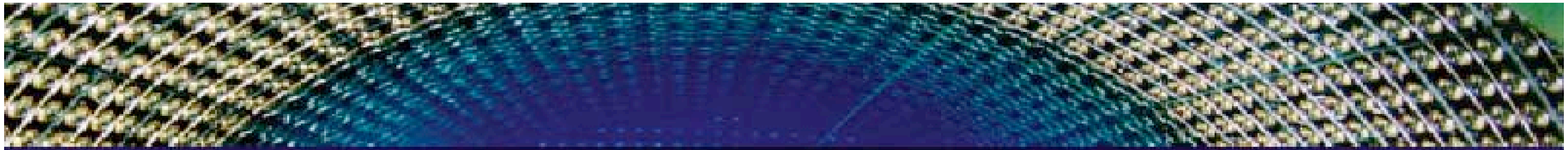
C.K. Jung, "Feasibility of a next generation underground water Cherenkov detector UNO", arXiv:hep-ex/0005046



- European detector @ Frejus Tunnel (France)
  - CERN-based Super and beta beams hopefully ready before 2020
  - Construction: hopefully 2010 – 2019 (first module 2017)
  - New laboratory ≈ ??? M€
  - Detector ≈ 500 M€



*: Modane 4800mwe



Can PMT's be manufactured at a much lower cost?

A challenge to the photo-detector/PMT manufacturers

R&D on photodetectors

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

In each generation one order of magnitude 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	11,146 **(20")**	200,000 **(20")**	56,650 **(20")** **15,000 (8")**

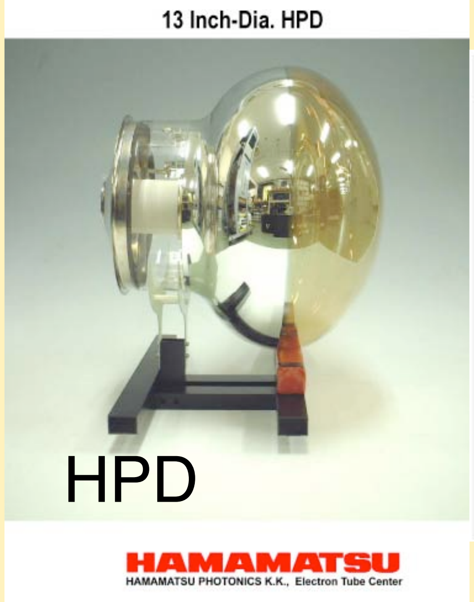
A large fraction (1/2 or more) of the total detector cost comes from the photo-sensors

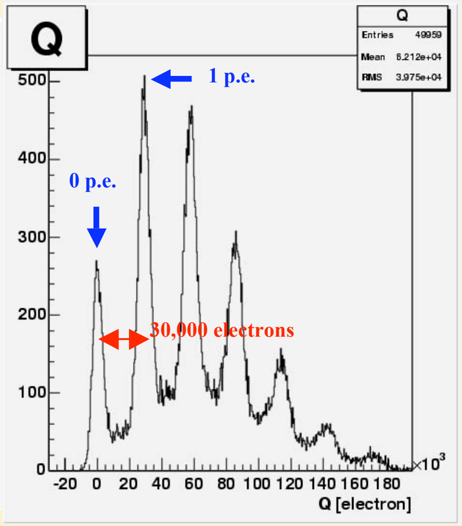
With present 20" PMT's and 40% coverage for the full detector, the cost of a Mton detector could be prohibitive

R&D on photo-sensors, in collaboration with industries to improve:

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

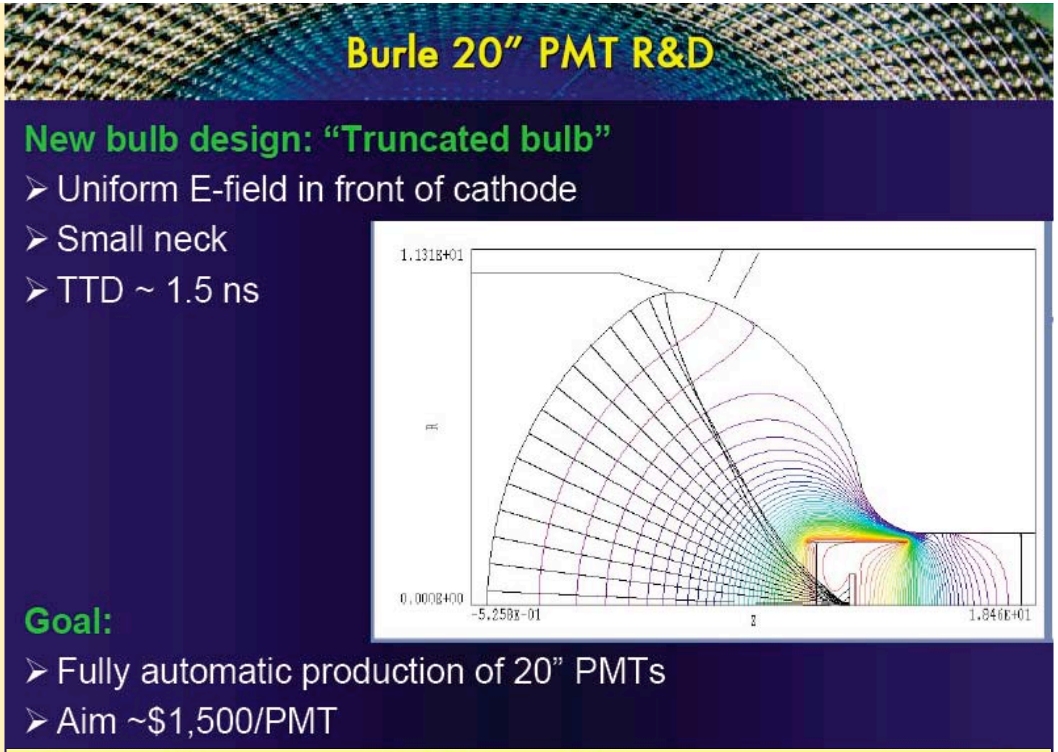
R&D on PMTs





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”) ?



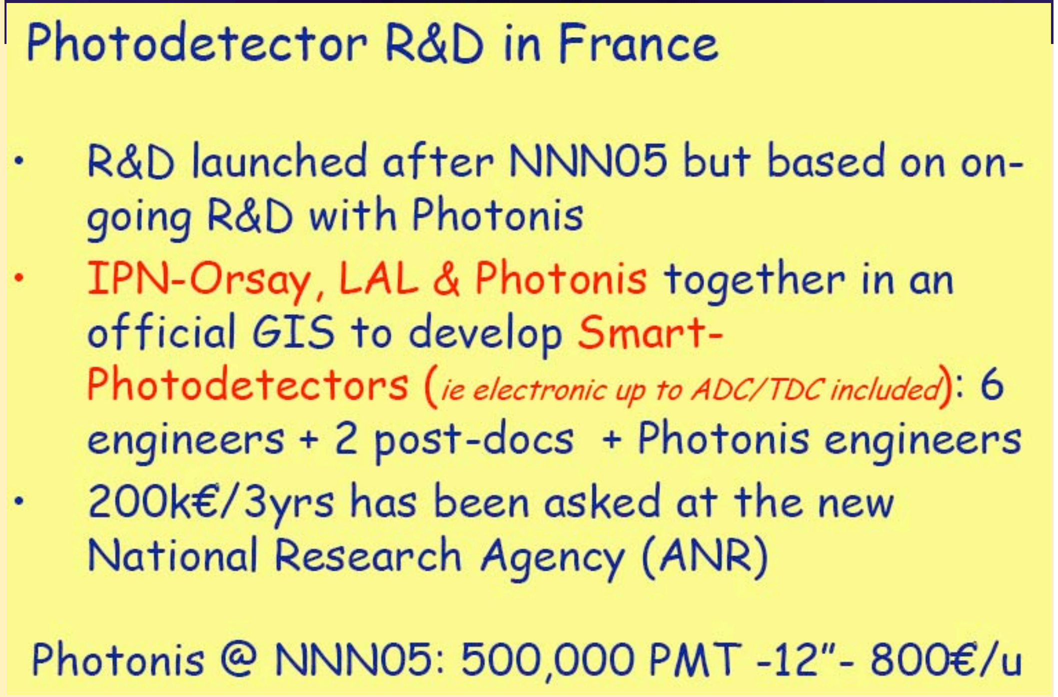
Burle 20” PMT R&D

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

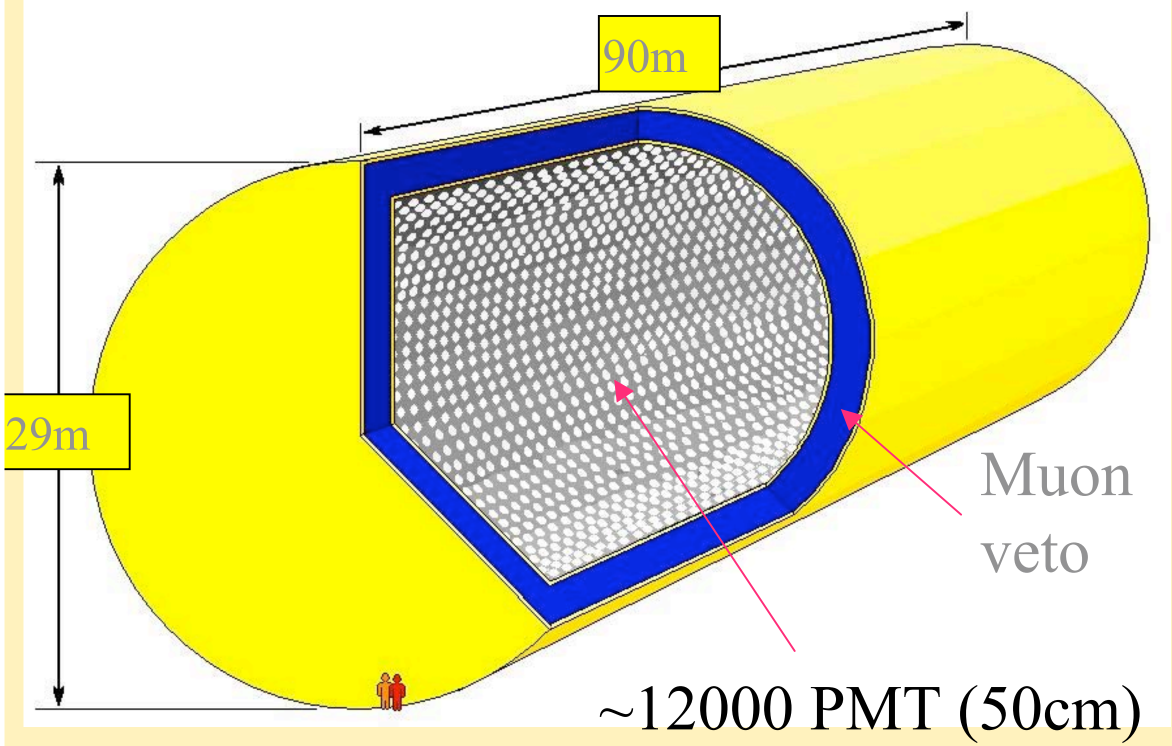
- R&D launched after NNN05 but based on on-going R&D with Photonis
- IPN-Orsay, LAL & Photonis together in an official GIS to develop Smart-Photodetectors (*ie electronic up to ADC/TDC included*): 6 engineers + 2 post-docs + Photonis engineers
- 200k€/3yrs has been asked at the new National Research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

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

Liquid Scintillator detectors

Low Energy Neutrino Astrophysics (LENA)

Conceptual design for a large (~30 kton) liquid scintillator underground detector



Use technology developed for BOREXINO

Scintillator solvent: PXE, non-hazard, flashpoint 145°C, density 0.99, ultrapure

$$\nu + e \rightarrow \nu + e$$

$$\nu + p \rightarrow \nu + p$$

$$\bar{\nu}_e + p \rightarrow n + e^+ \qquad Q = 1.8\,MeV$$

$$\nu + {}^{12}C \rightarrow \nu + {}^{12}C^* \rightarrow \gamma$$

$$\bar{\nu}_e + {}^{12}C \rightarrow {}^{12}B + e^+ \qquad Q = 17.3\,MeV$$

$$\nu_e + {}^{12}C \rightarrow {}^{12}N + e^- \qquad Q = 13.4\,MeV$$

Estimated light yield ~ 100 pe / MeV

K. Hochmuth, T. Marrodan, L. Oberauer, W.Potzel, F. von Feilitzsch
Technische Universität München

Tentative construction site

- Loading of detector via pipeline
- Transport of 30kt 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!

Cost ≈ 100-200 M€

Galactic Supernova neutrino detection with Lena

(1) $\bar{\nu}_e + p \rightarrow e^+ + n$ (Q = 1.8 MeV)

(2) $\bar{\nu}_e + {}^{12}C \rightarrow e^+ + {}^{12}B$ (Q = 13.4 MeV)

Electron Antineutrino spectroscopy ~7800

(3) $\nu_e + {}^{12}C \rightarrow e^- + {}^{12}N$ (Q = 17.3 MeV)

Electron ν spectroscopy ~ 65

(4) $\nu_x + {}^{12}C \rightarrow \nu_x + {}^{12}C^*$ with ${}^{12}C^* \rightarrow {}^{12}C + \gamma$ ($Q = E_\gamma = 15.1$ MeV)

(5) $\nu_x + e^- \rightarrow \nu_x + e^-$ (elastic scattering off electrons) ~ 480

(6) $\nu_x + p \rightarrow \nu_x + p$ (elastic scattering off protons).

Neutral current interactions; info on all flavours ~ 4000 and ~ 2200

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

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

$T(K^+) = 105\ \mathrm{MeV}$

$\tau(K^+) = 12.8\ \mathrm{nsec}$

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

$T(\mu^+) = 152\ \mathrm{MeV}$

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

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

$T(\pi^+) = 108\ \mathrm{MeV}$

electromagnetic shower

$E = 135\ \mathrm{MeV}$

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

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

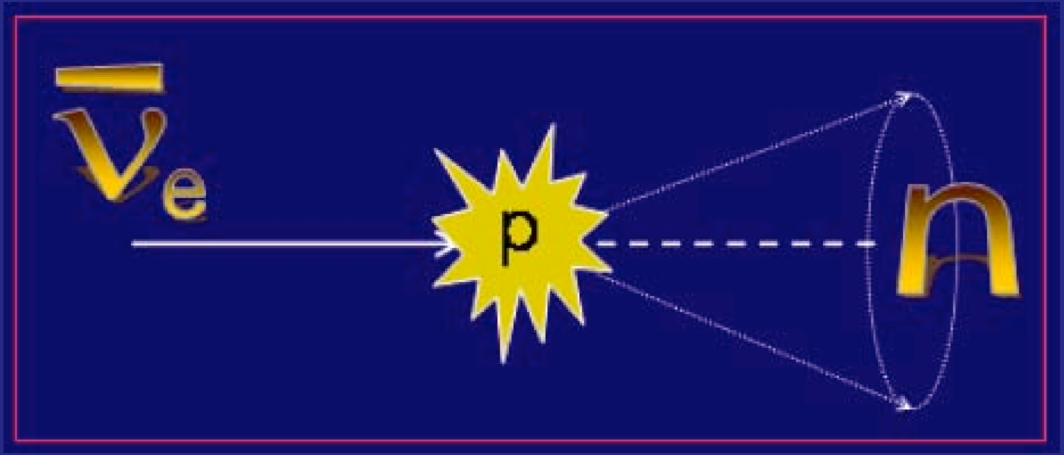
Kaon track is visible (unlike in Water Cerenkov detectors)
Timing structure and excellent energy resolution reduce backgrounds

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

Possibility to detect geo-neutrinos

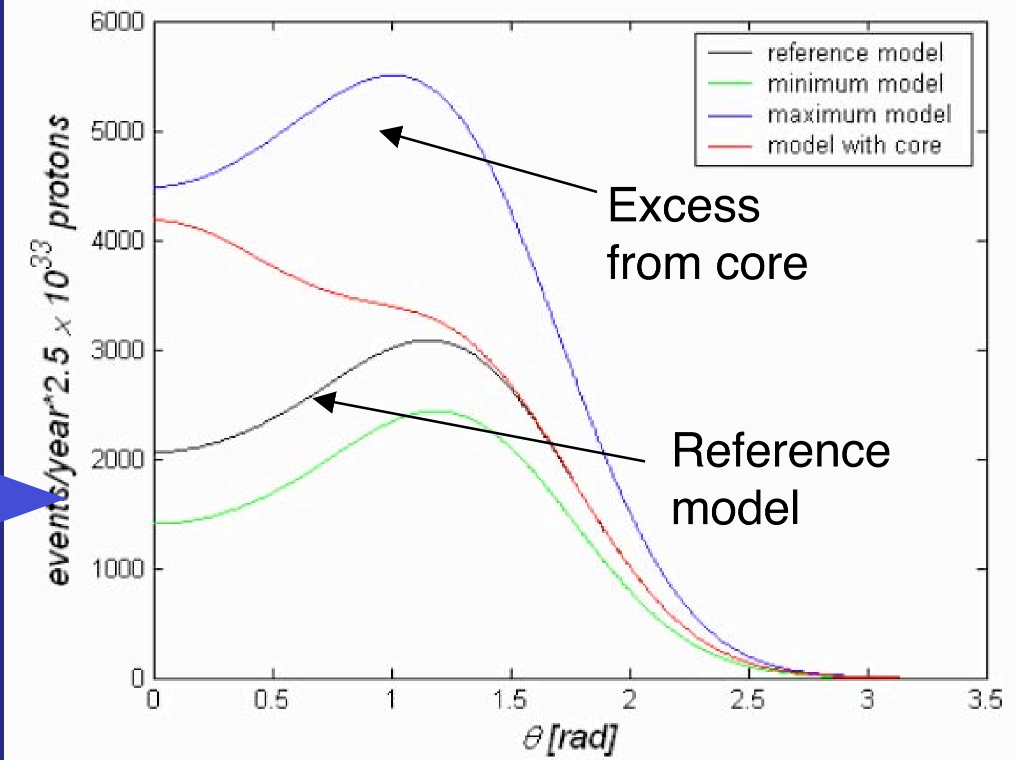
Detection mechanism via the reaction:

$$\bar{\nu}_e + p \rightarrow n + e^+$$



- Full reconstruction gives angular resolution (half cone aperture): ≈26°
- Reconstruction of angular distribution of incoming geoneutrinos
- Backgrounds?

Distinction between different geophysical model possible!



Liquid Argon detectors

Two target mass scales for future projects:

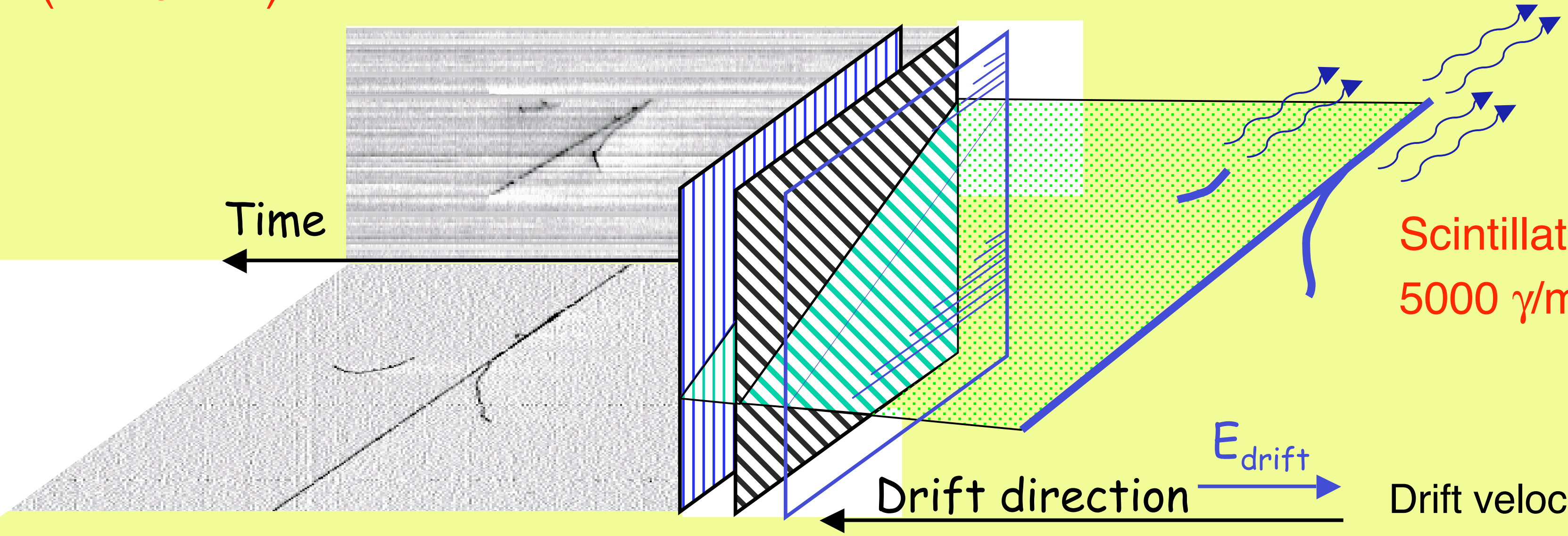
- **100 ton** as near detector in Super-Beams (not discussed here)
- **<u>10-100 kton</u>** for ν oscillation, ν astrophysics, proton decay

The Liquid Argon TPC principle

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

Charge readout planes: Q

UV Scintillation Light: L



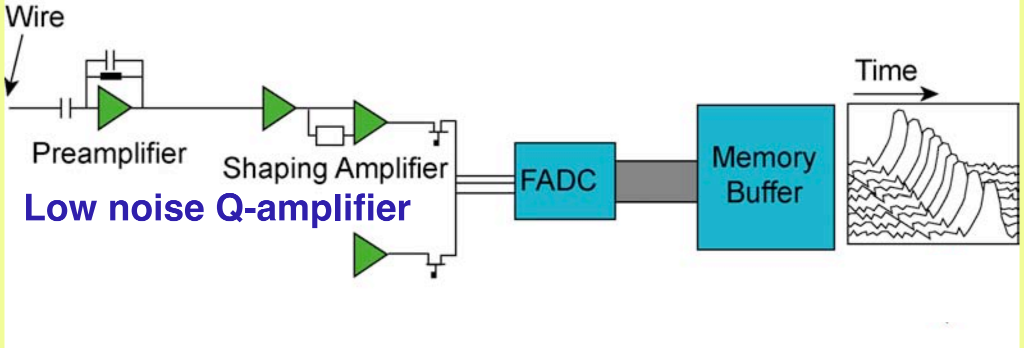
Scintillation light yield ~
5000 γ/mm @ 128 nm

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.

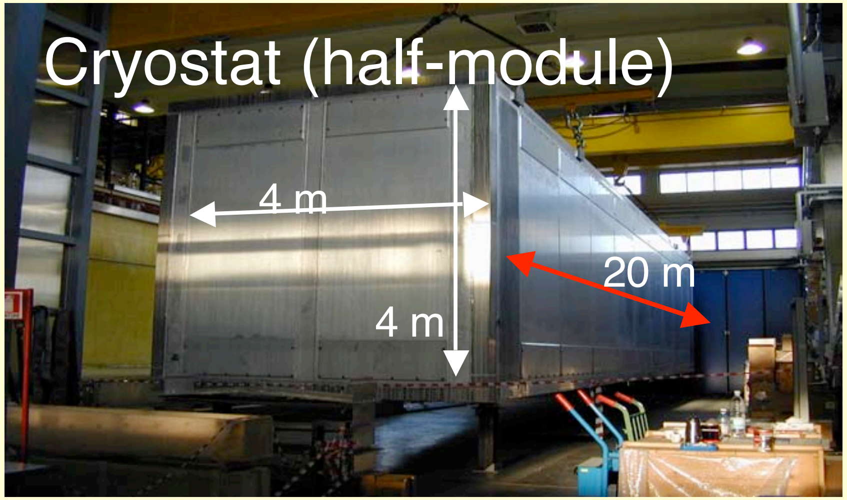


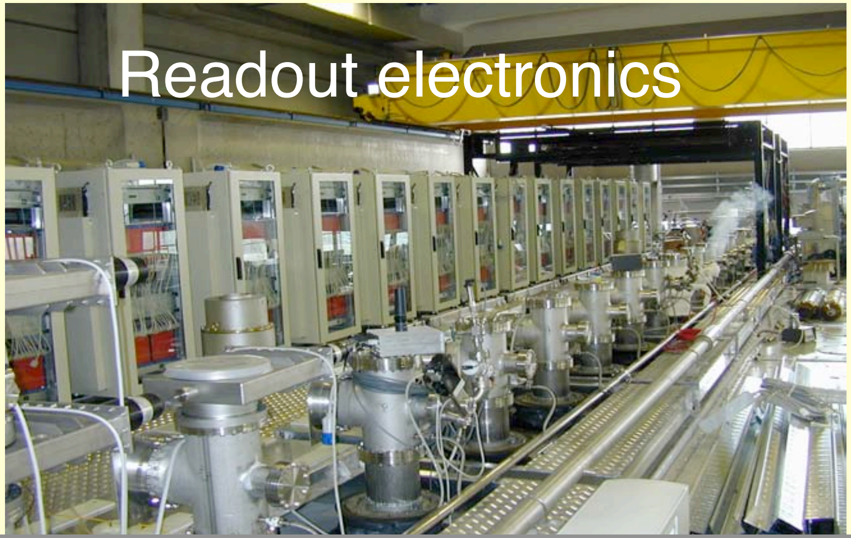
Low noise Q-amplifier

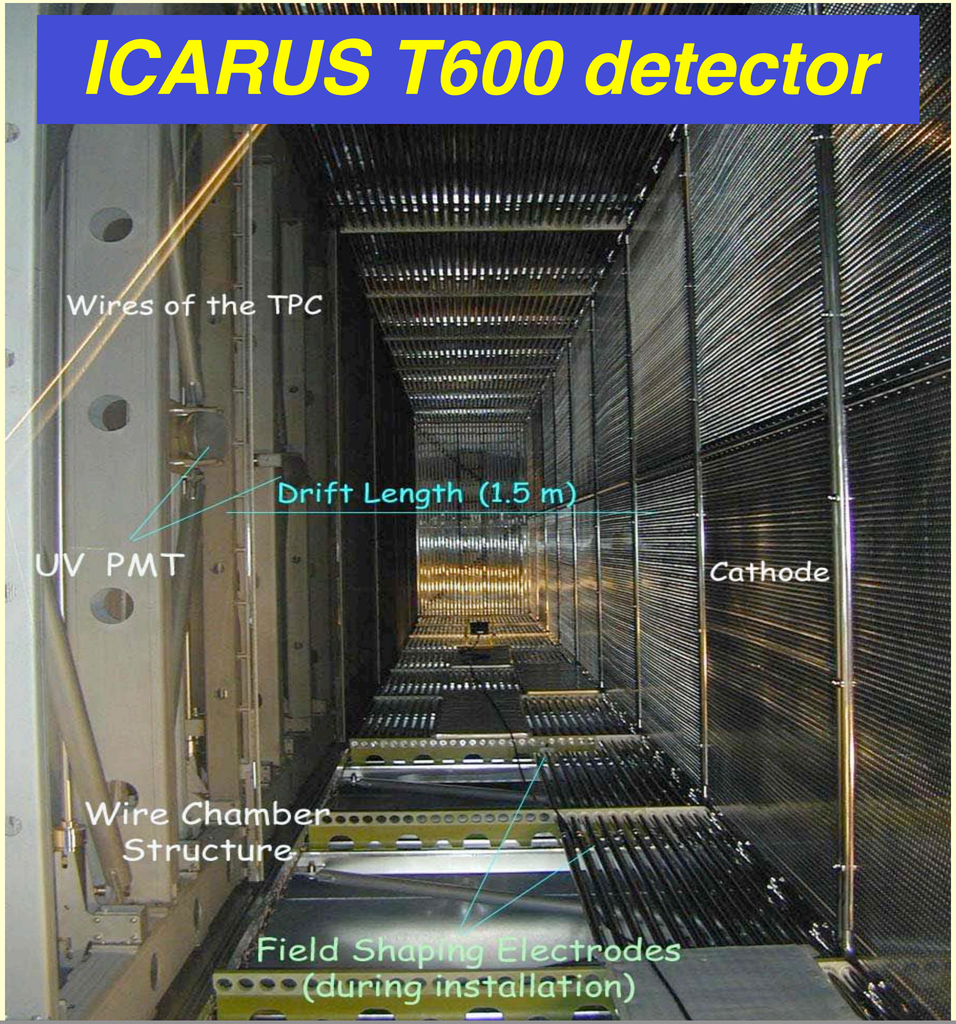
Continuous waveform recording → image

- 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



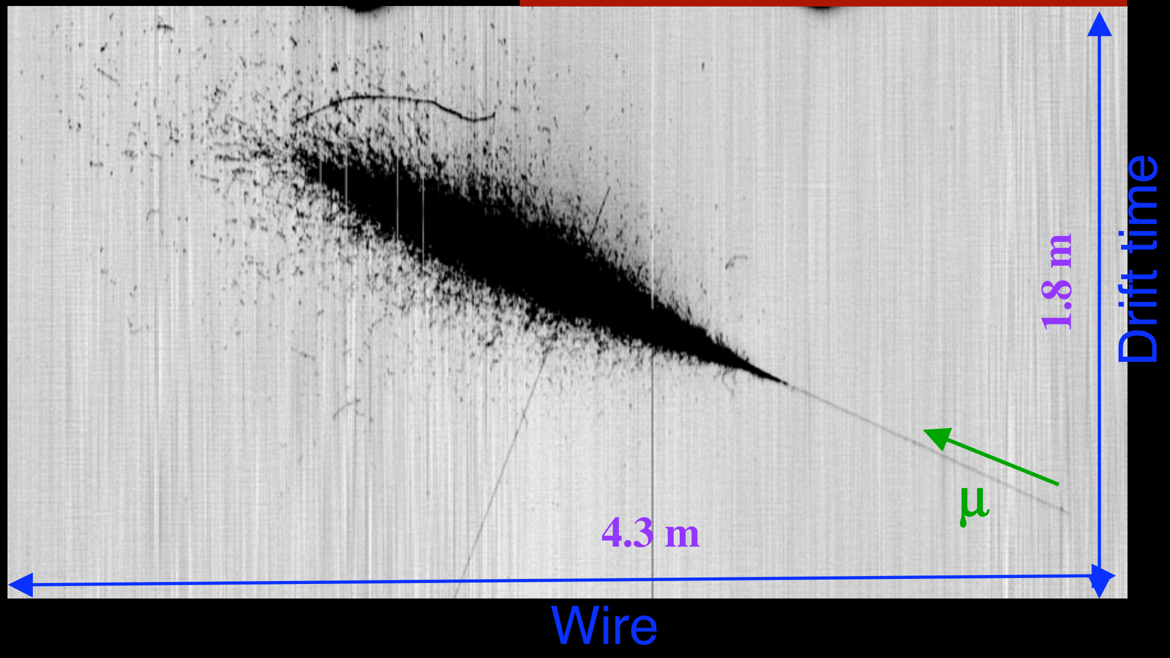




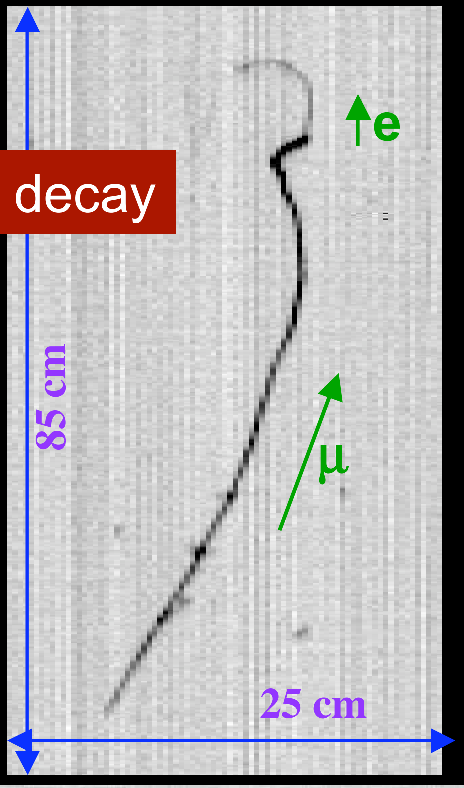
- Design, construction and tests of the ICARUS T600 detector, ICARUS Collab, NIM A527 329 (2004).
- Study of electron recombination in liquid Argon with the ICARUS TPC, ICARUS Collab, NIMA523 275-286 (2004).
- Detection of Cerenkov light emission in liquid Argon, ICARUS Collab, NIM A516 348-363 (2004).
- 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

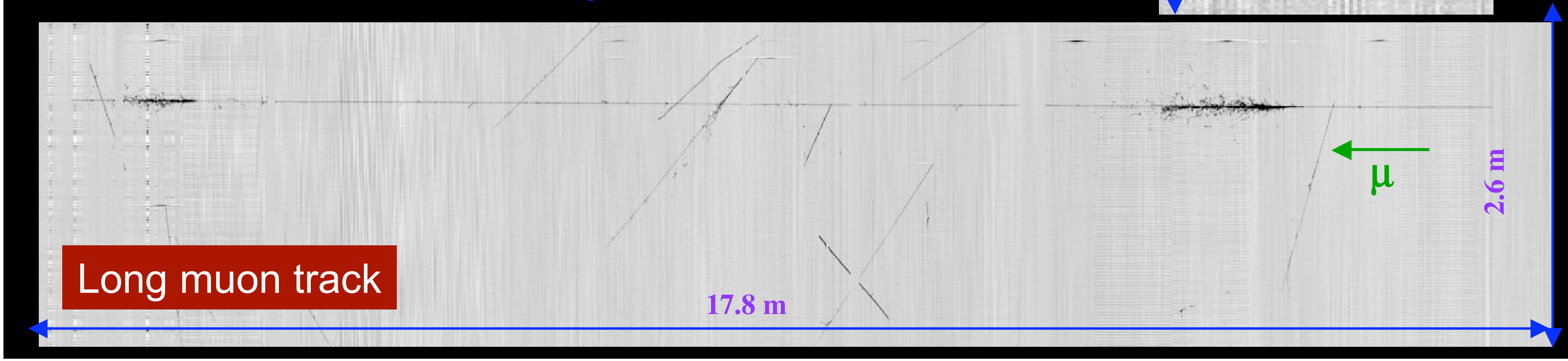
Data from ICARUS T600 test run: 27000 triggers from cosmic ray interactions



Electromagnetic shower



Muon decay



Long muon track

T300 semi-modules transportation from Pavia to Gran Sasso: November-December 2004

Latest event:

- The ICARUS T3000 (3 kton @ LNGS/CNGS) program has suffered serious setbacks in part due to the well-known LNGS closure, which have halted its realization for as much as 3 years.

- The INFN President has communicated in June 2005 to the ICARUS Collaboration the intention **not** to provide the foreseen funds for the first T1200 construction.

- At the same time, INFN encouraged the Collaboration to proceed along with the proposal of a future program focused on the realization of a large mass (~5 kton?) LAr TPC based on a single tank, monolithic-design to be possibly installed in the LNGS territory, as a scalable test module in view of a larger mass facility, in particular meant for proton decay searches.

- In parallel, INFN welcomes and intends to support the commissioning of the existing T600 module (already at LNGS) to mainly act as a demonstrator of the technique in view of future implementations.

Where to go next ? A graded strategy ?

We consider different mass scales:

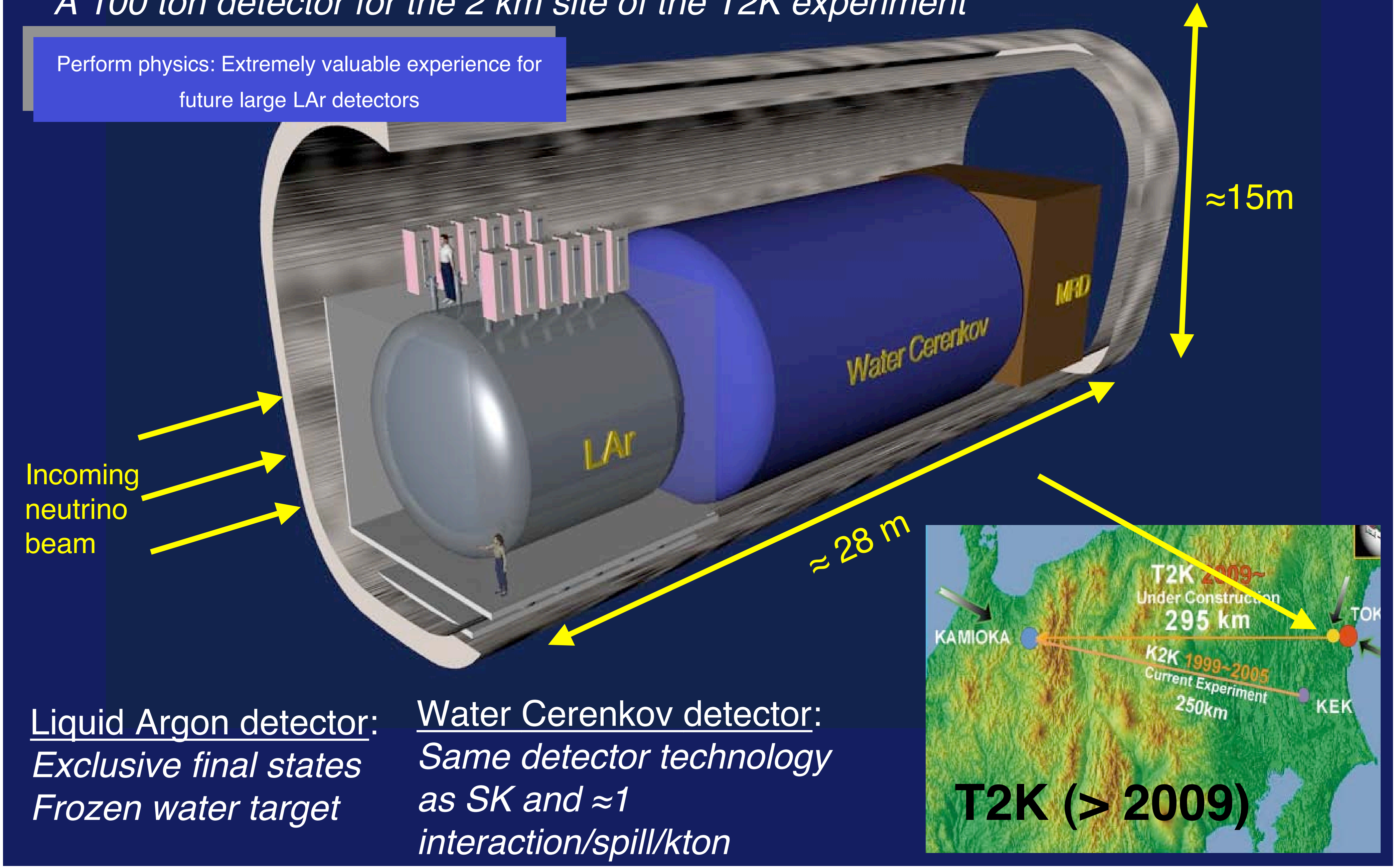
- A O(1 kton) “shallow-depth” demonstrator could be readily envisaged to demonstrate the technical choices. Cost ≈ 10 M€
- A O(10 kton) prototype (10% full-scale) could be readily envisaged as an engineering design test with a physics program of its own. Cost ≈ 80 M€
- A O(100 kton) liquid Argon TPC will deliver extraordinary physics output. It will be an ideal match for a future Superbeam, Betabeam or Neutrino Factory. This program is very challenging. Cost ≈ 400 M€
- An open issue is the necessity of a magnetic field encompassing the liquid Argon volume (only necessary for the neutrino factory). We have demonstrated the possibility to use magnetic field in a small prototype. Cost ≈ +100 M€ ?

- 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.
- Very large liquid Argon TPC chambers, A.Rubbia, NUFACT05, Frascati, Italy, June 2005.

Next milestone of the LAr TPC technique for accelerator neutrino physics?

A 100 ton detector for the 2 km site of the T2K experiment

Perform physics: Extremely valuable experience for future large LAr detectors



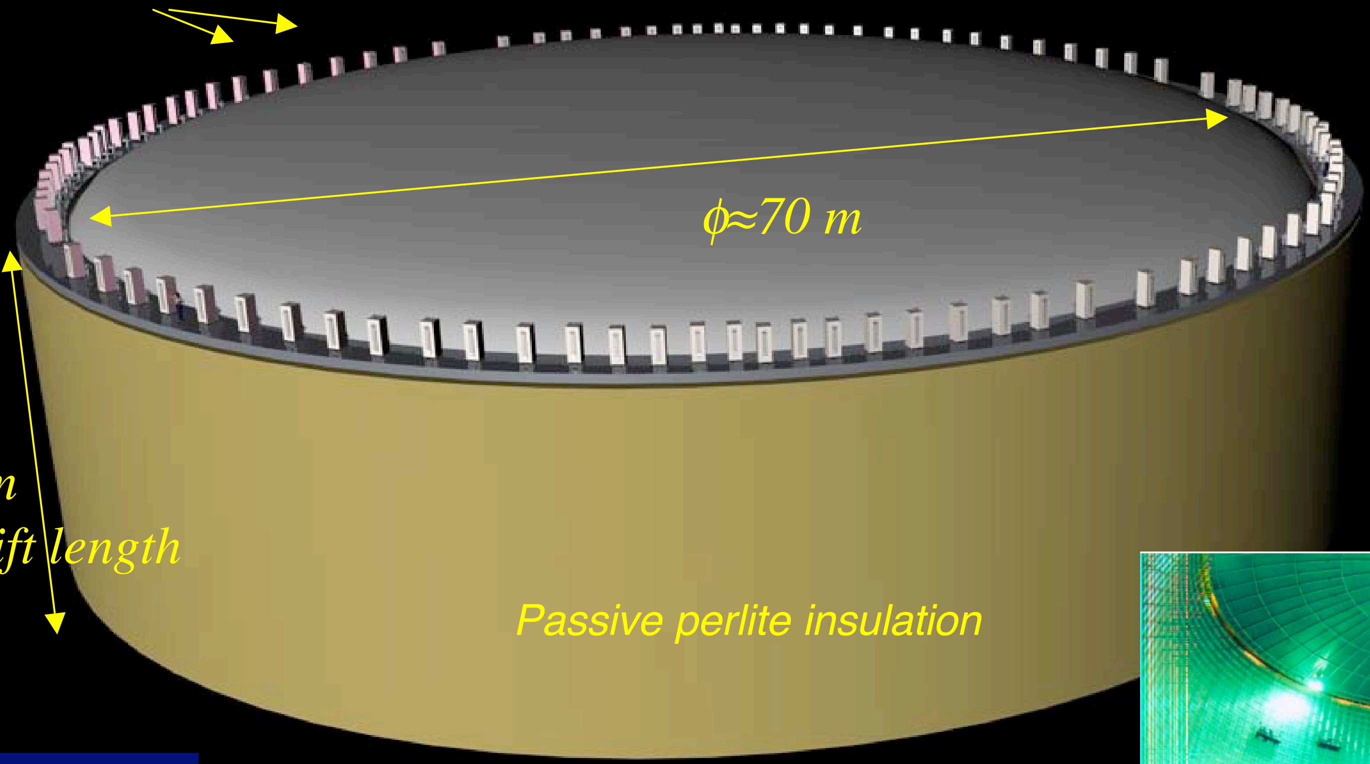
Liquid Argon detector:
Exclusive final states
Frozen water target

Water Cerenkov detector:
Same detector technology as SK and ≈1 interaction/spill/kton

T2K-2km working group (27 institutes, 93 members)

Boston University (USA):	E. Kearns, M. Litos, J. Raaf, J. Stone, L.R. Sulak
CEA Saclay (France):	J. Bouchez, C. Cavata, M. Fechner, L. Mosca, F. Pierre, M. Zito
CIEMAT (Spain):	I. Gil-Botella, P. Ladron de Guevara, L. Romero
Columbia University (USA):	E. Aprile, K. Giboni, K.Ni, M. Yamashita
Duke University (USA):	K. Scholberg, N. Tanimoto, C.W. Walter
ETHZ (Switzerland):	W. Bachmann, A. Badertscher, M. Baer, Y. Ge, M. Laffranchi, A. Meregaglia, M. Messina, G. Natterer, A. Rubbia, T.Viant
ICRR University of Tokyo (Japan):	I. Higuchi, Y. Itow, T. Kajita, K. Kaneyuki, Y. Koshi, M. Miura ,S. Moriyama, N. Nakahata, S. Nakayama, T. Namba, K. Okumura, Y. Obayashi, C. Saji, M. Shiozawa, Y. Suzuki, Y. Takeuchi
INFN Napoli (Italy):	A. Ereditato
INFN Frascati (Italy):	G. Mannocchi
LNGS (Italy):	O. Palamara
Louisiana State University (USA):	S. Dazeley, S. Hatakeyama, R. McNeil, W. Metcalf, R. Svoboda
L'Aquila University (Italy):	F. Cavanna, G. Piano-Mortari
Niewodniczanski Institute Krakow (Poland):	A. Szelc, A. Zalewska
RAS (Russia):	A. Butkevich, S.P. Mikheyev
Silesia University Katowice (Poland):	J. Holeczek, J. Kisiel
Soltan Institute Warszawa (Poland):	P. Przewlocki, E. Rondio
University of California, Irvine (USA):	D. Casper, J. Dunmore, S. Mine, H.W. Sobel, W.R. Kropp, M.B. Smy, M.R. Vagins
University of California, Los Angeles (USA):	D. Cline, M. Felcini, B. Lisowski, C. Matthey, S. Otwinowski
IN2P3 IPN-Lyon (France) :	D. Autiero, Y. Declais, J. Marteau
Universidad de Granada (Spain):	A. Bueno, S. Navas-Concha
University of Sheffield (UK):	P.K. Lightfoot, N. Spooner
Universit`a di Torino (Italy) :	P. Picchi
University of Valencia (Spain):	J.J. Cadenas
University of Washington, Seattle (USA):	H. Berns, R. Gran, J. Wilkes
Warsaw University (Poland):	D. Kielczewska
Wroclaw University (Poland):	J. Sobczyk
Yale University (USA):	A. Curioni, B.T. Fleming

Giant Liquid Argon Charge Imaging ExpeRiment (GLACIER)



Electronic crates

ϕ≈70 m

h =20 m
Max drift length

Passive perlite insulation

12 groups
≈25 people

hep-ph/0402110
Venice, 2003

Single module cryo-tanker based on industrial LNG technology

Cryogenic insulation requires minimal surface/volume: A <u>single very large cryogenic module</u> with aspect ratio ~ 1:1

Do not pursue the ICARUS multi-module approach

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

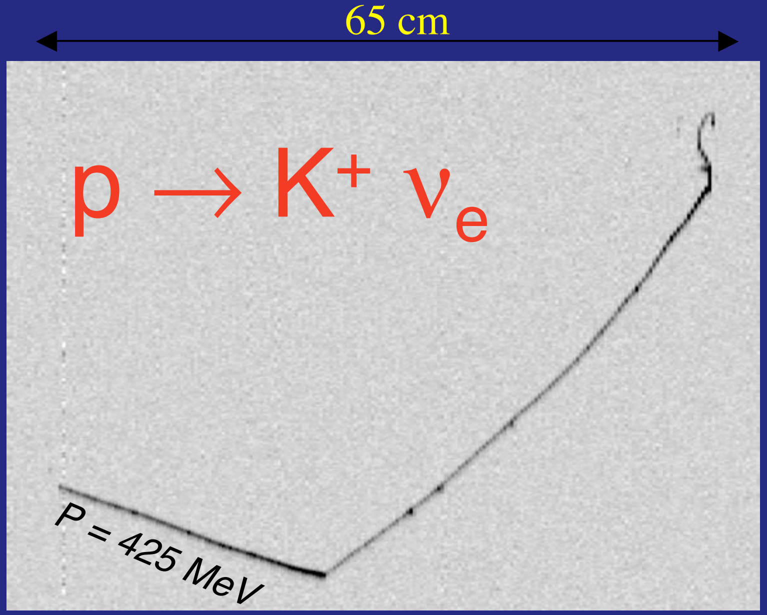
Many thanks to:

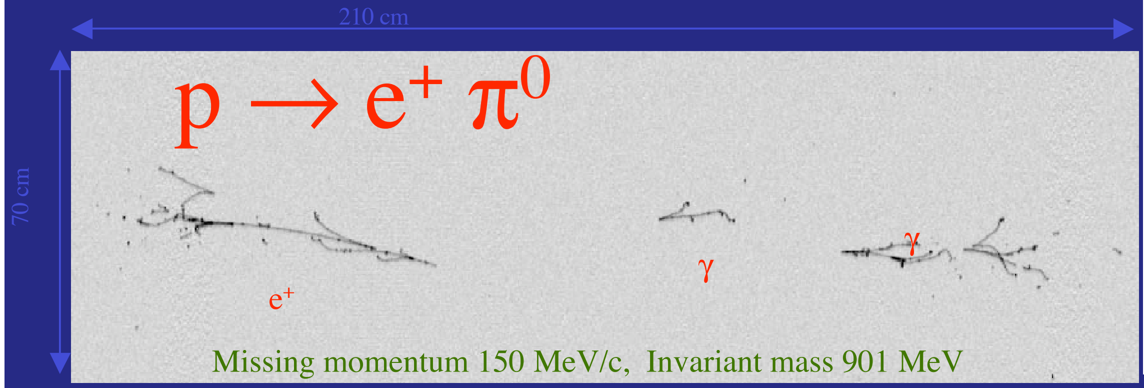
Technodyne Ltd, Eastleigh, UK

CUPRUM (KGHM group), Wroclaw, Poland

CAEN, Viareggio, Italy

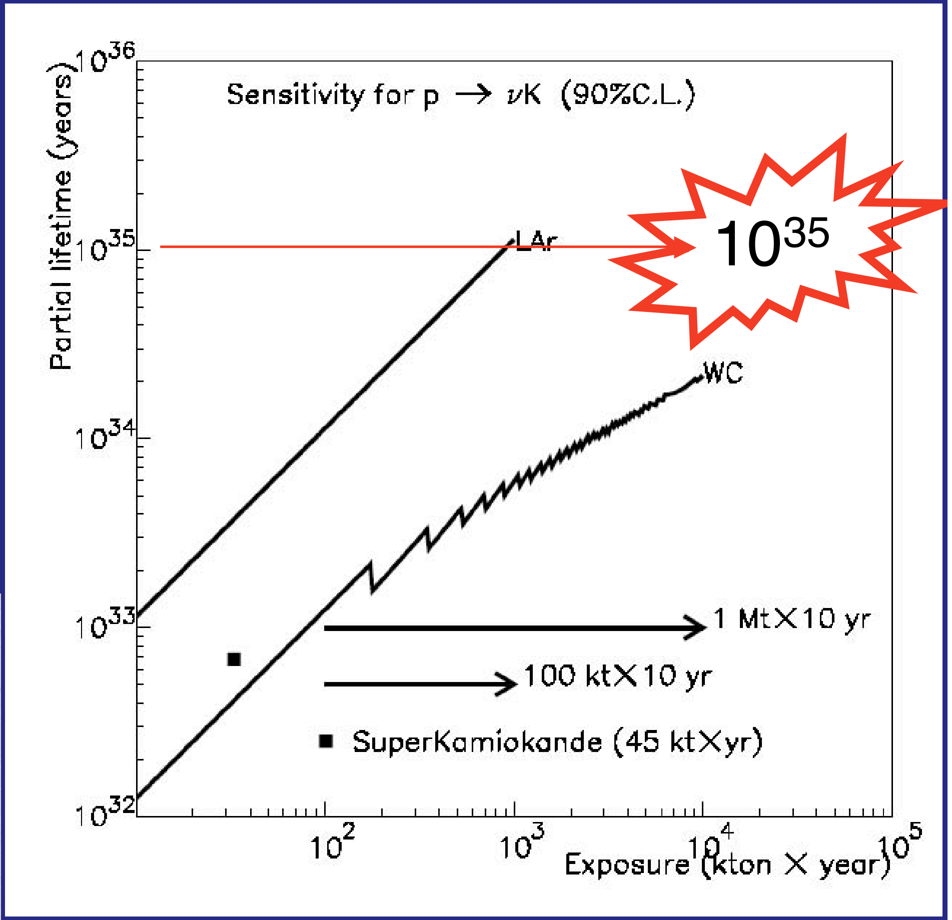
Proton decay examples





Missing momentum 150 MeV/c, Invariant mass 901 MeV

Complementarity



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

Sensitivity to SN type-II neutrinos

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

Qν_eCC = 1.5 MeV

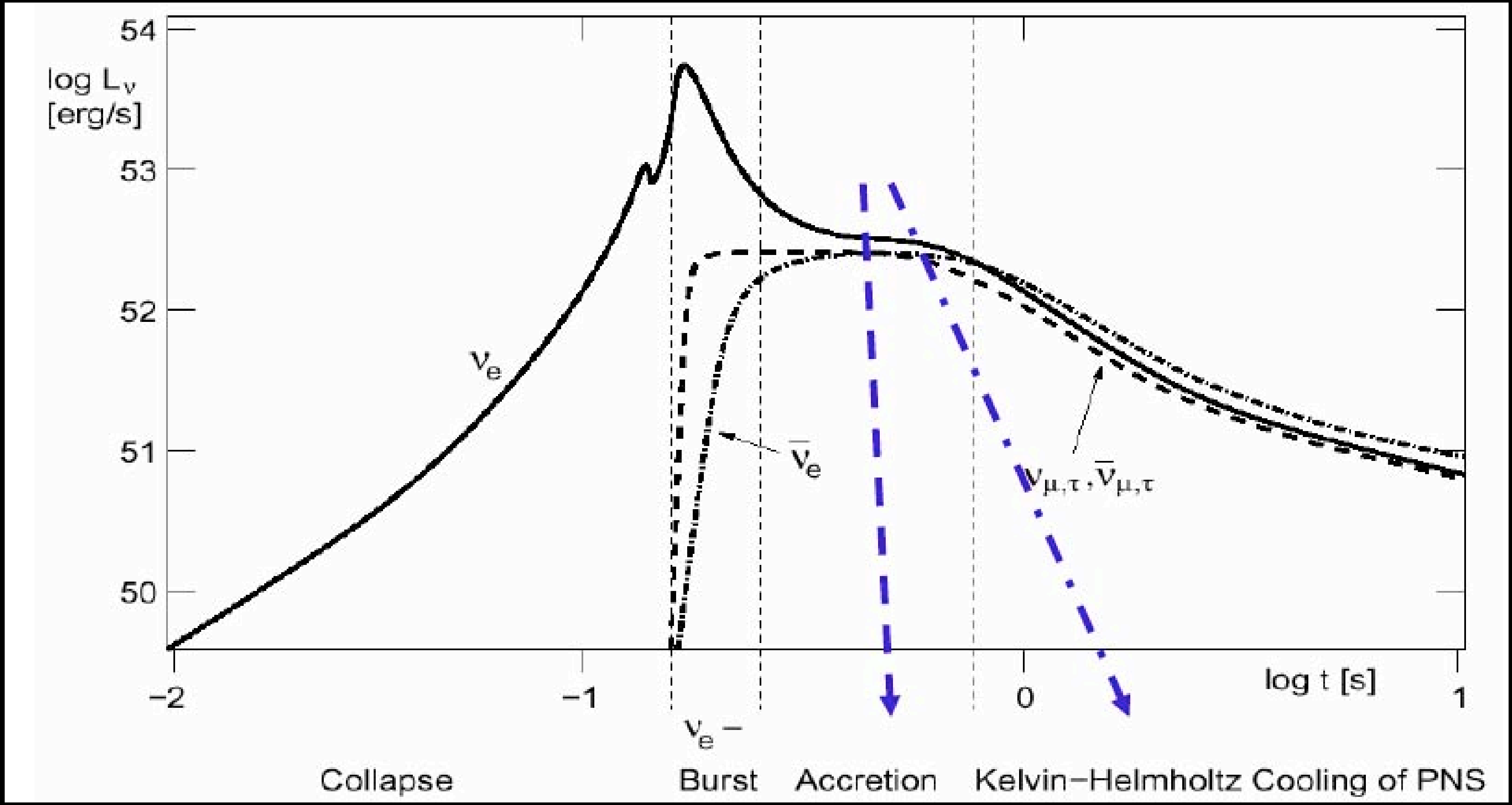
$\overset{(-)}{\nu}_x + e^- \rightarrow \overset{(-)}{\nu}_x + e^-$

$\bar{\nu}_e + {}^{40}Ar \rightarrow {}^{40}Cl^* + e^+$

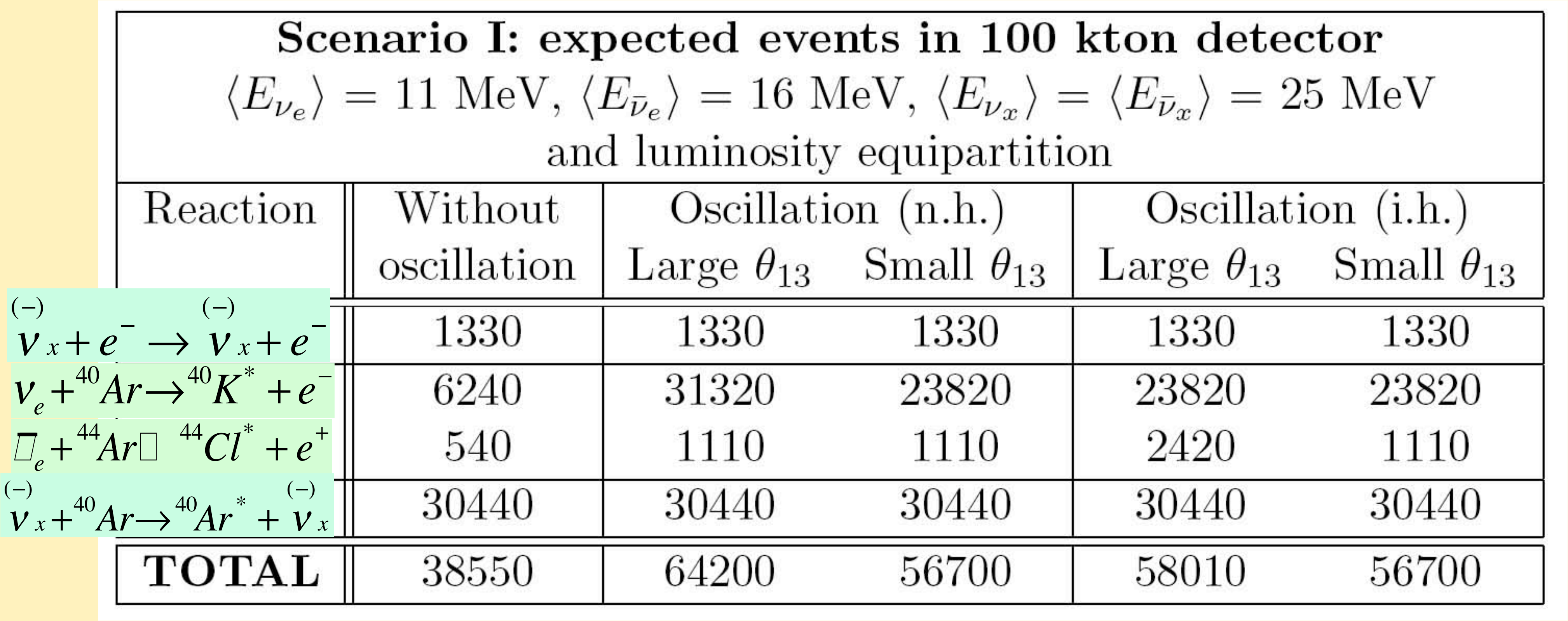
Qν_eCC= 7.48 MeV

$\overset{(-)}{\nu}_x + {}^{40}Ar \rightarrow {}^{40}Ar^* + \overset{(-)}{\nu}_x$

Q_{NC} = 1.46 MeV



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.) Large θ_{13}	Oscillation (n.h.) Small θ_{13}	Oscillation (i.h.) Large θ_{13}	Oscillation (i.h.) 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
$\bar{\nu}_e + {}^{44}Ar \rightarrow {}^{44}Cl^* + e^+$	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

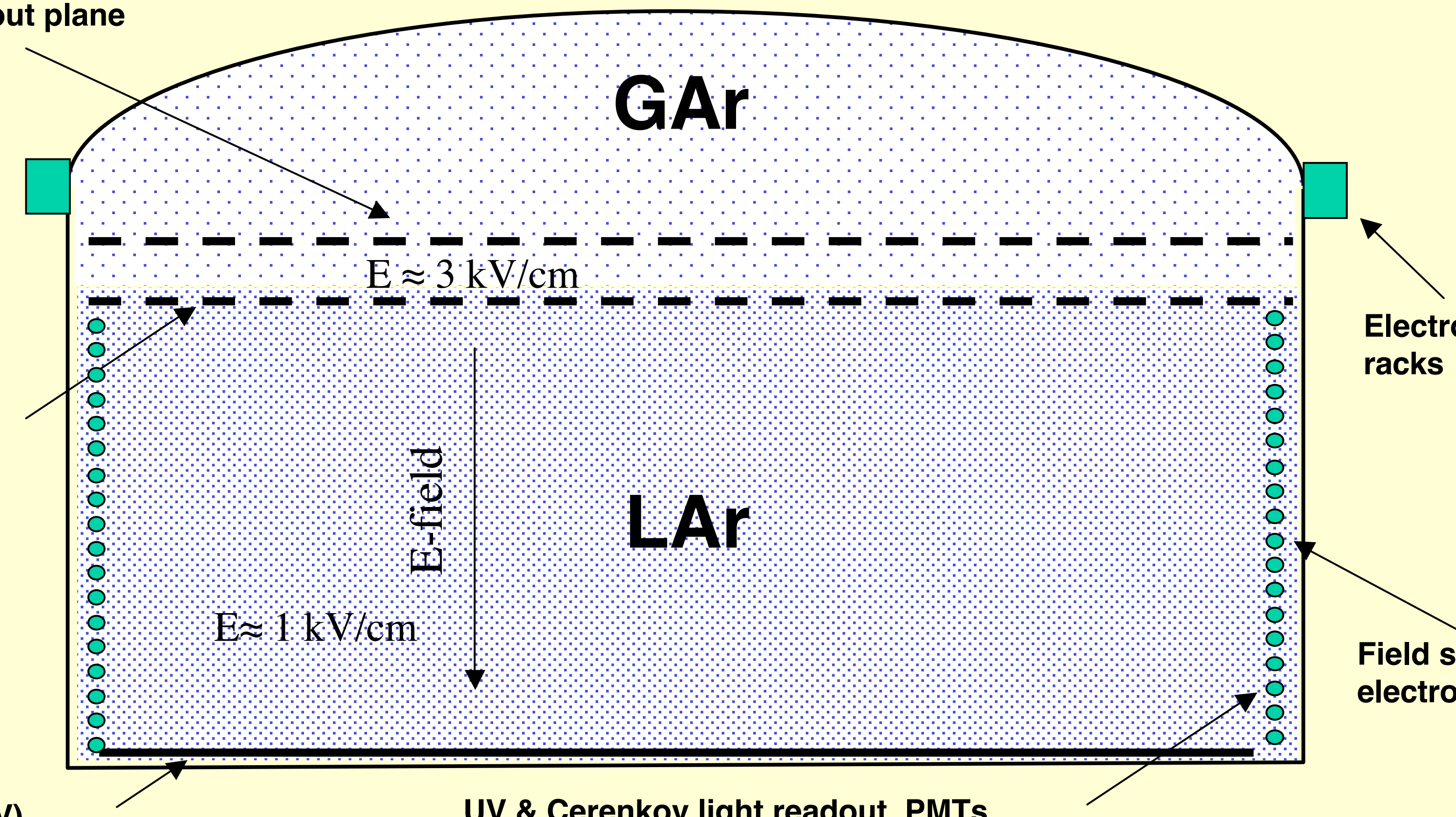
$Q\nu_e CC = 1.5$ MeV $\quad Q\bar{\nu}_e CC = 7.48$ MeV $\quad Q_{NC} = 1.46$ MeV

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**)

A tentative detector layout

Single detector: charge imaging, scintillation, possibly Cerenkov light

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



Charge readout plane

Extraction grid

Electronic racks

Field shaping electrodes

Cathode (- HV)

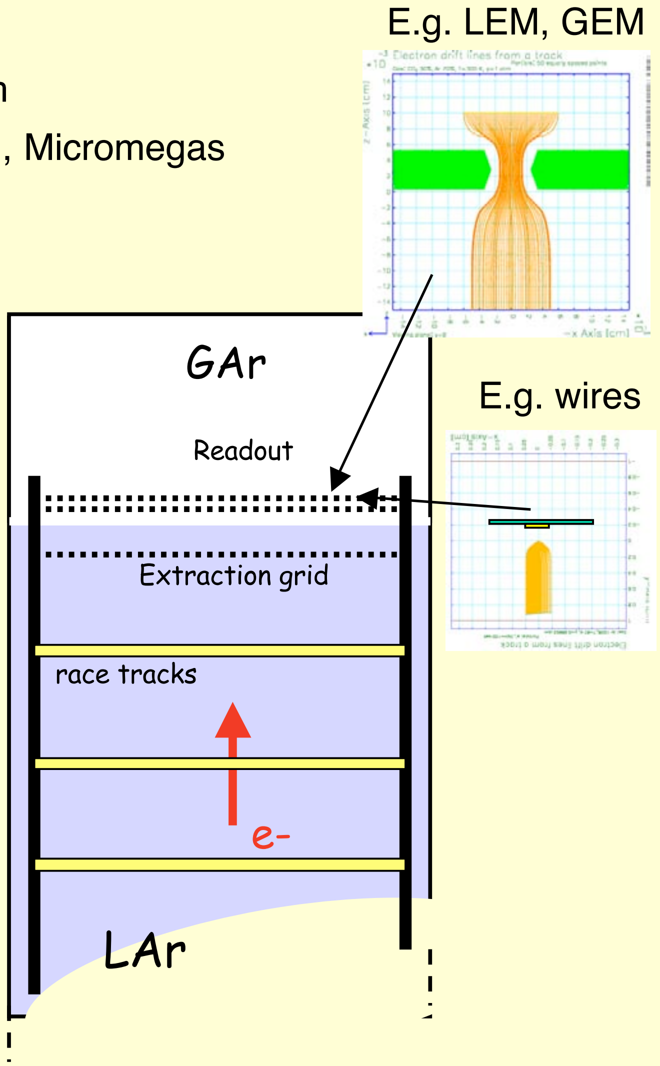
UV & Cerenkov light readout PMTs

Charge extraction, amplification, readout

Detector is running in bi-phase mode TO ALLOW FOR A VERY LONG DRIFT PATH

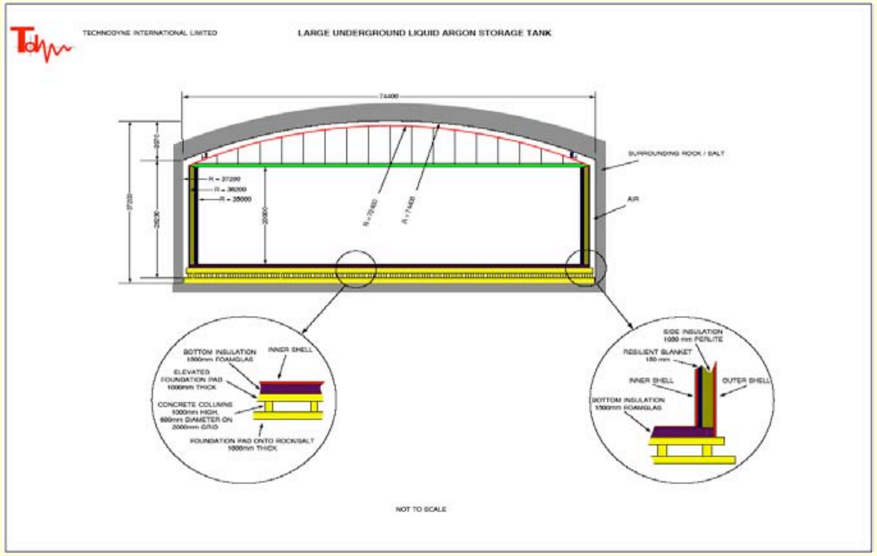
- Long drift (≈ 20 m) ⇒ charge attenuation to be compensated by charge amplification near anodes located in gas phase (18000 e^- / 3 mm for a MIP in LAr)
- Amplification operates in proportional mode
- After maximum drift of 20 m @ 1 kV/cm ⇒ diffusion ≈ readout pitch ≈ 3 mm
- Amplification can be implemented in different ways: wires+pad, GEM, LEM, Micromegas

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, Micromegas… Total area ≈ 3850 m^2**



R&D effort on-going (→2008?)

- Study of suitable charge extraction, amplification and imaging devices
- Understanding of charge drift properties under high hydrostatic pressure
- Realization and test of a 5 m long detector column-like prototype
- Study of prototypes in magnetic field



- Study of large liquid underground storage tank in collaboration with industry, costing
- Study of logistics, infrastructure and safety issues for underground sites
- Study of large scale argon purification

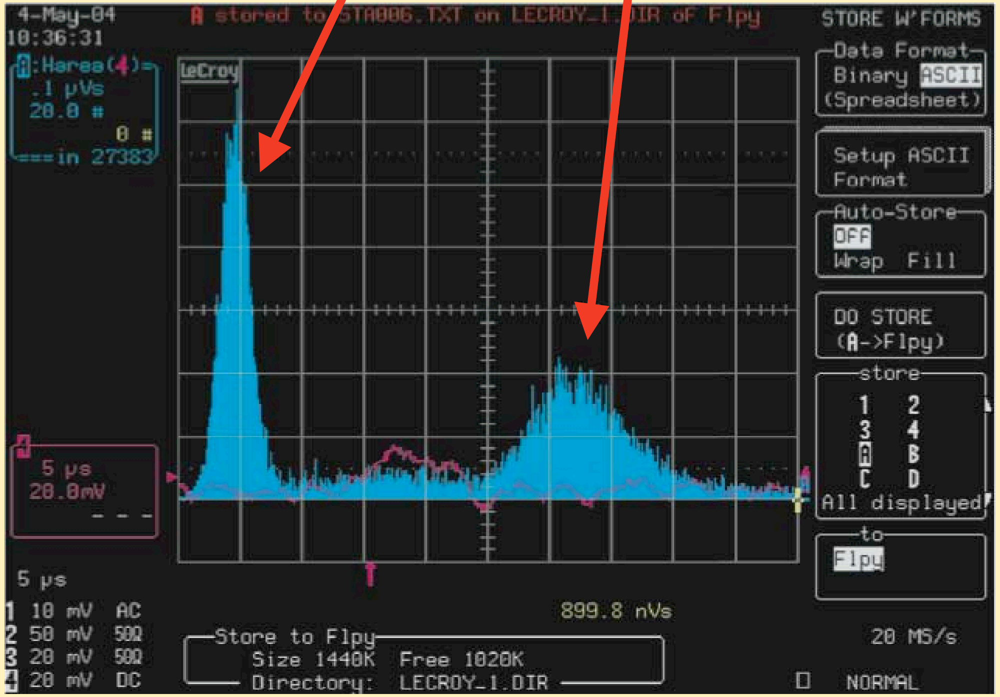
Design with Technodyne (UK)

High gain operation of LEM in pure Ar at high pressure

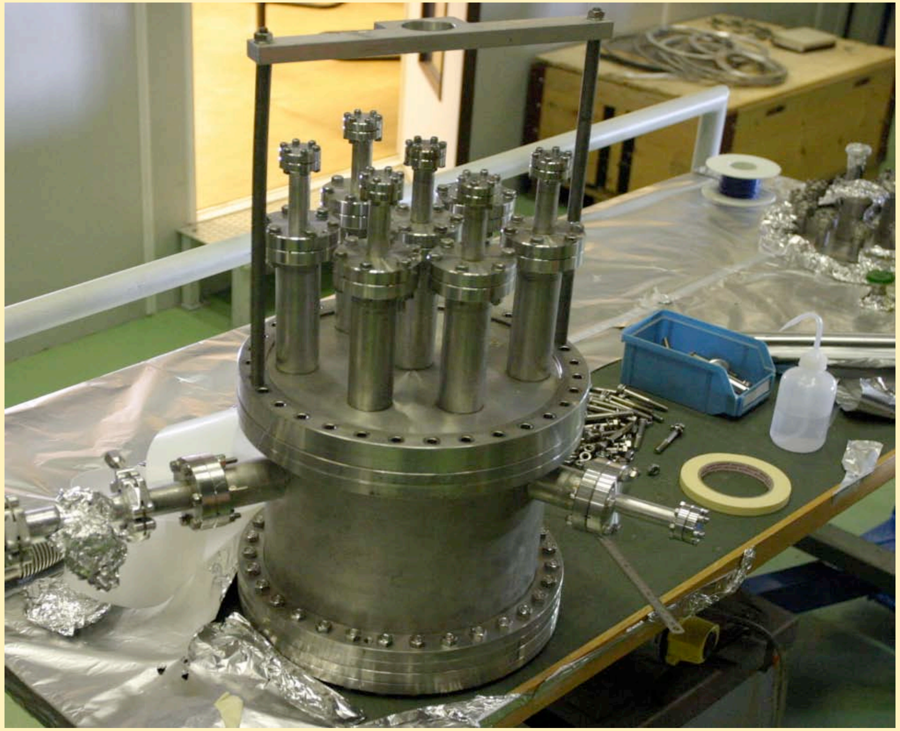
- Fe-55 & Cd-109 sources, Argon 100%
- Varying pressures (from 1 bar up to 3.5 bar)
- Room temperature
- Drift field ≈100V/cm (100% transparency)

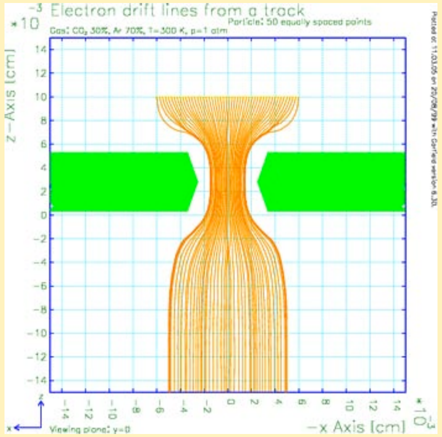
pedestal

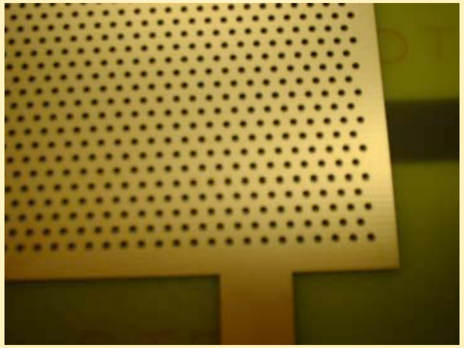
5.7 keV



```
4-May-04        A stored to STA006.TXT on LECROY_1.DIR of Flpy      STORE W'FORMS
10:36:31                                                            Data Format
A:Harea(4)=                                                         Binary ASCII
 .1 µVs                                                             (Spreadsheet)
 20.0 #                                                             Setup ASCII
       0 #                                                          Format
===in 27383                                                         Auto-Store
                                                                    OFF
                                                                    Wrap  Fill
4                                                                   DO STORE
 5 µs                                                               (A->Flpy)
 20.0mV                                                             store
                                                                     1   2
                                                                     3   4
                                                                     A   B
                                                                     C   D
                                                                    All displayed
                                                                    to
 5 µs                                                               Flpy
1 10 mV  AC                          899.8 nVs
2 50 mV  50Ω      Store to Flpy                                     20 MS/s
3 20 mV  50Ω        Size 1440K  Free 1020K
4 20 mV  DC         Directory:  LECROY_1.DIR                  ☐   NORMAL
```

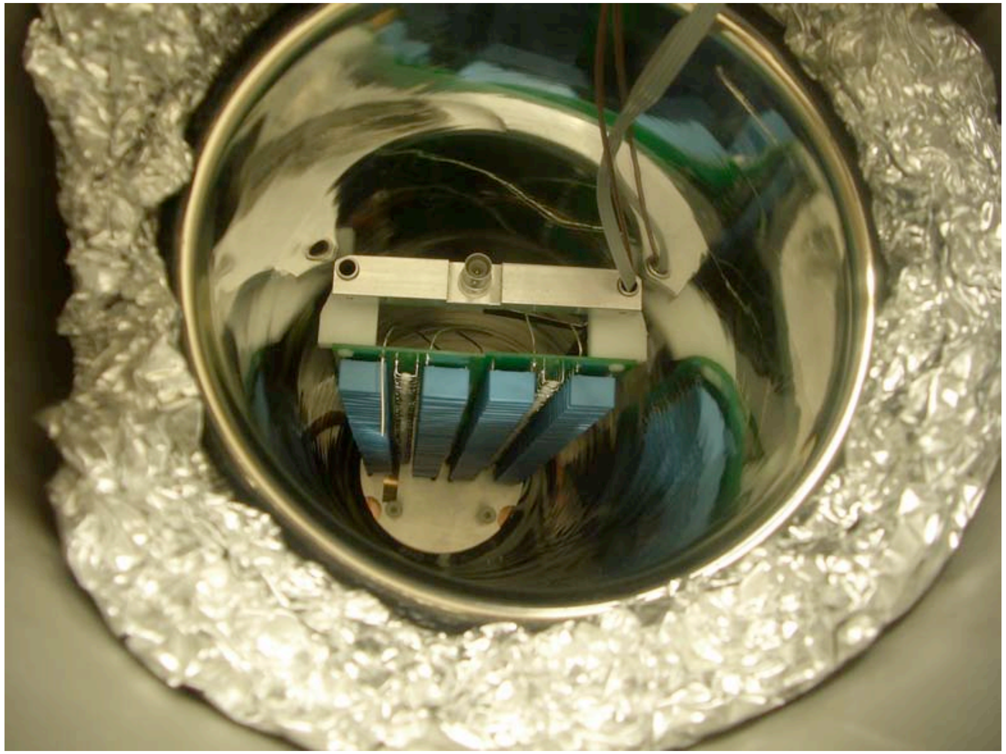


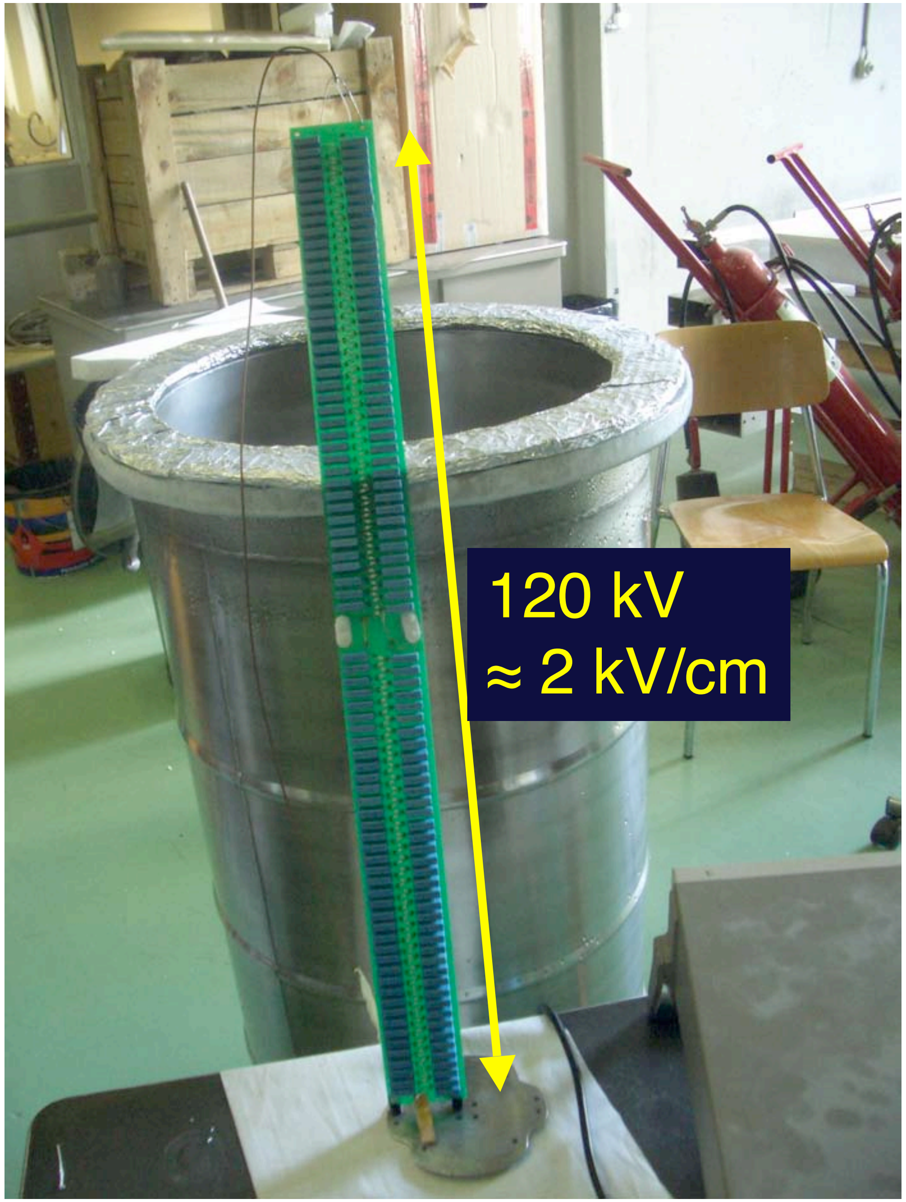




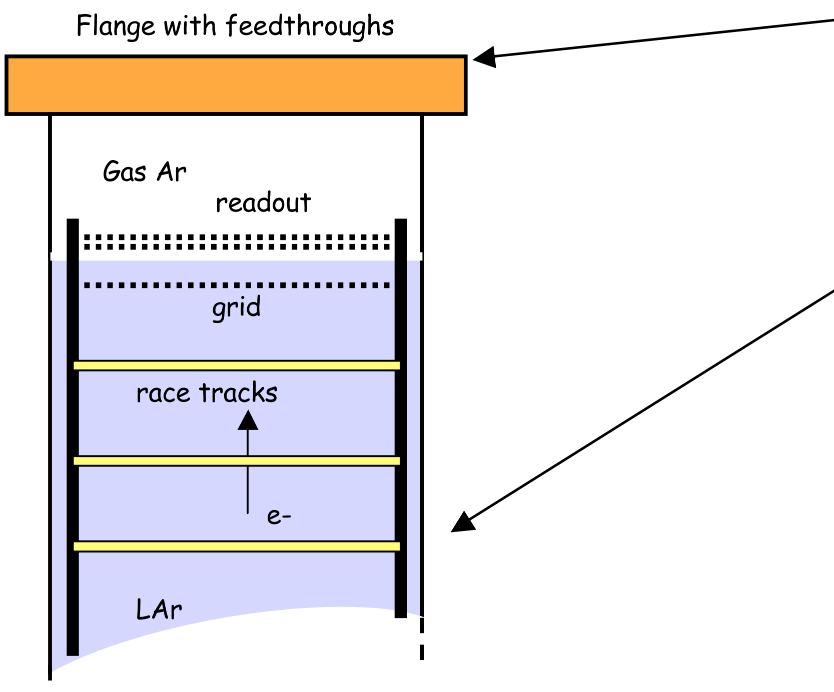
Results from HV tests in cold

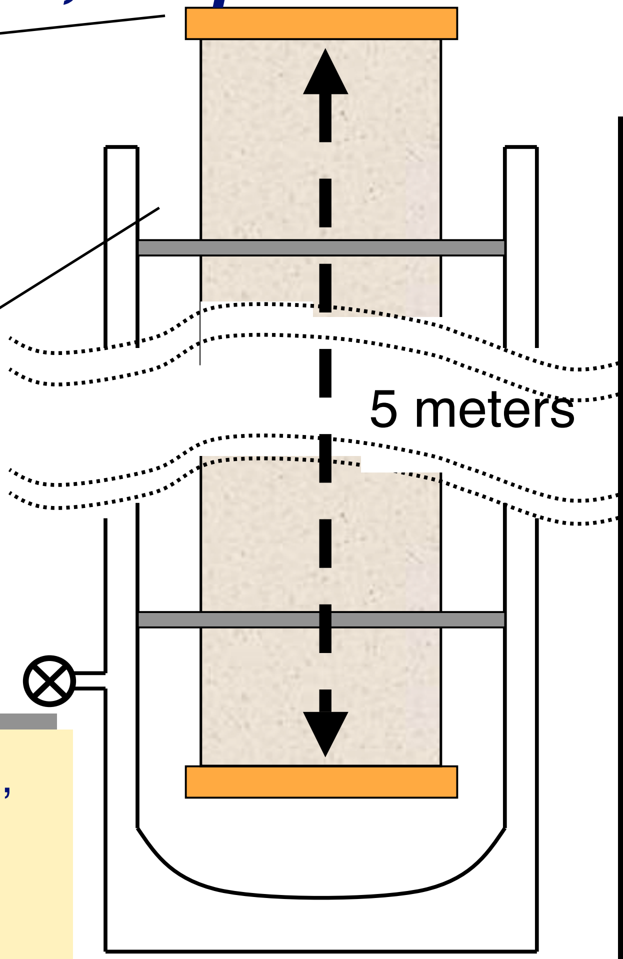
- A large number of tests in cold have been performed in order to assess component choice and stability.
- The largest system successfully operated consisted of 80 stages and reached stable operation up to 120 kV.
- Test to 240 kV (≈4kV/cm) in preparation.

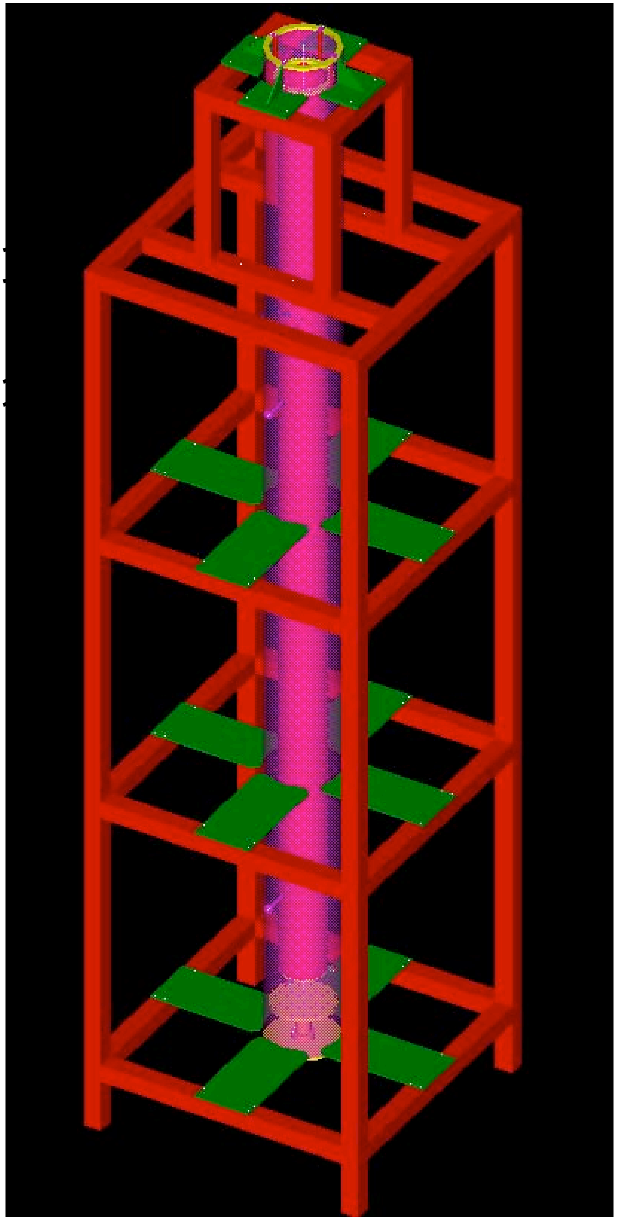




(4) Long drift, extraction, amplification: “ARGONTUBE”







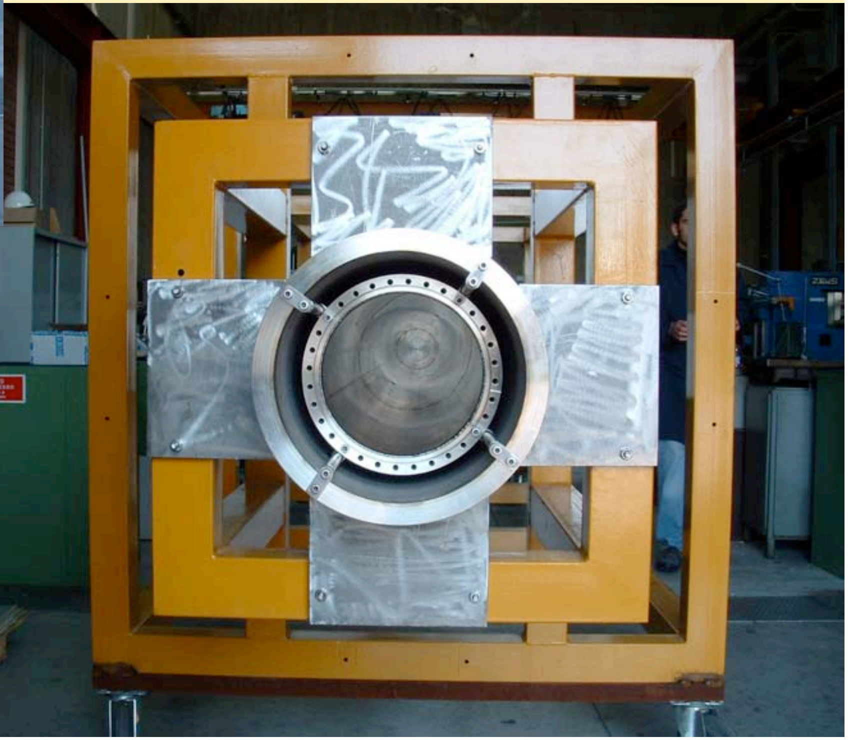
- Full scale measurement of long drift (5 m), signal attenuation and multiplication
- Simulate ‘very long’ drift (10-20 m) by reduced E field & LAr purity
- High voltage test (up to 500 kV)
- Design & assembly:

completed: external dewar, detector container

in progress: inner detector, readout system, …

Results in 2006

Detector in the support structure
(horizontal garage position)



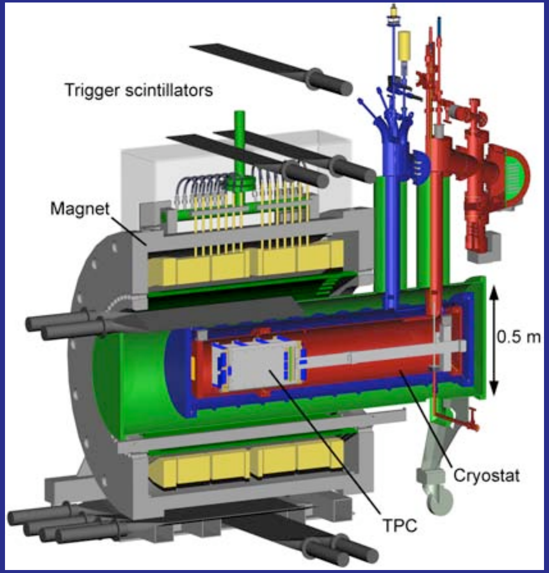
Front view

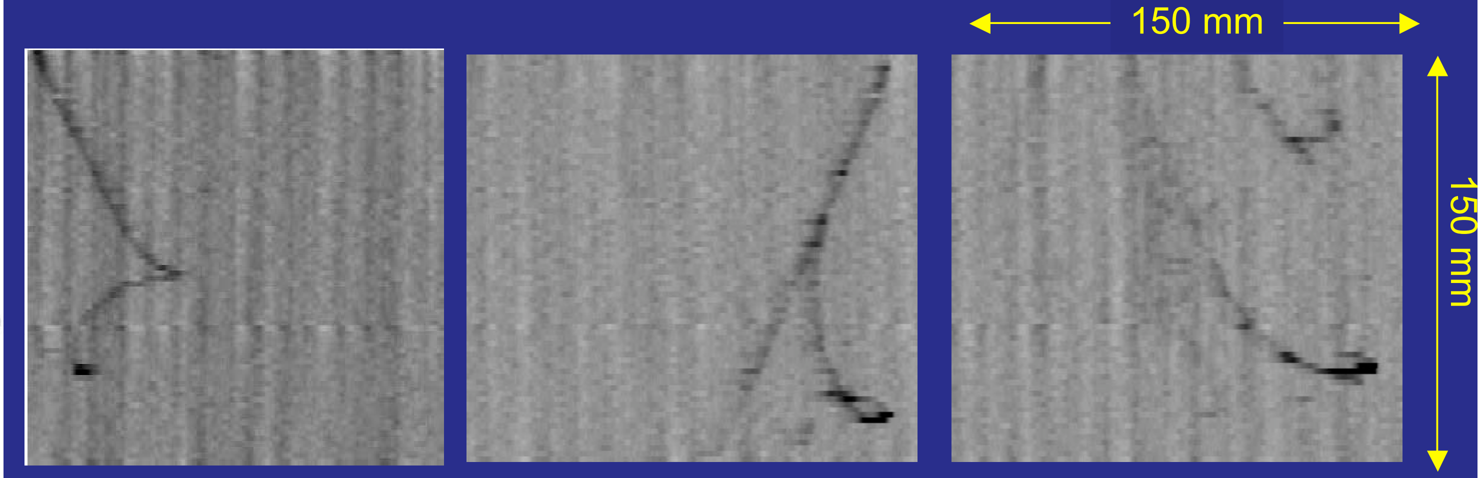
Arrived at ETHZ on September 21st, 2005

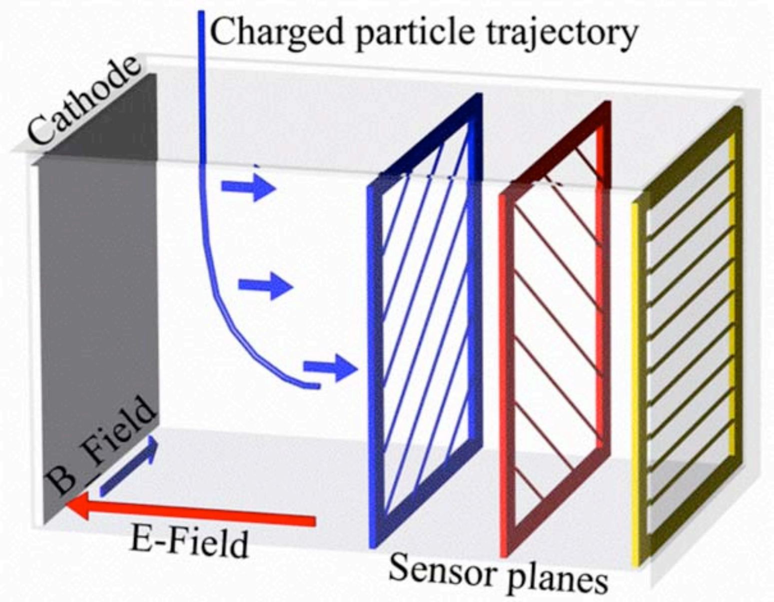
First operation of a 10 lt LAr TPC embedded in a B-field

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

New J. Phys. 7 (2005) 63







Important for e.g. neutrino factory:

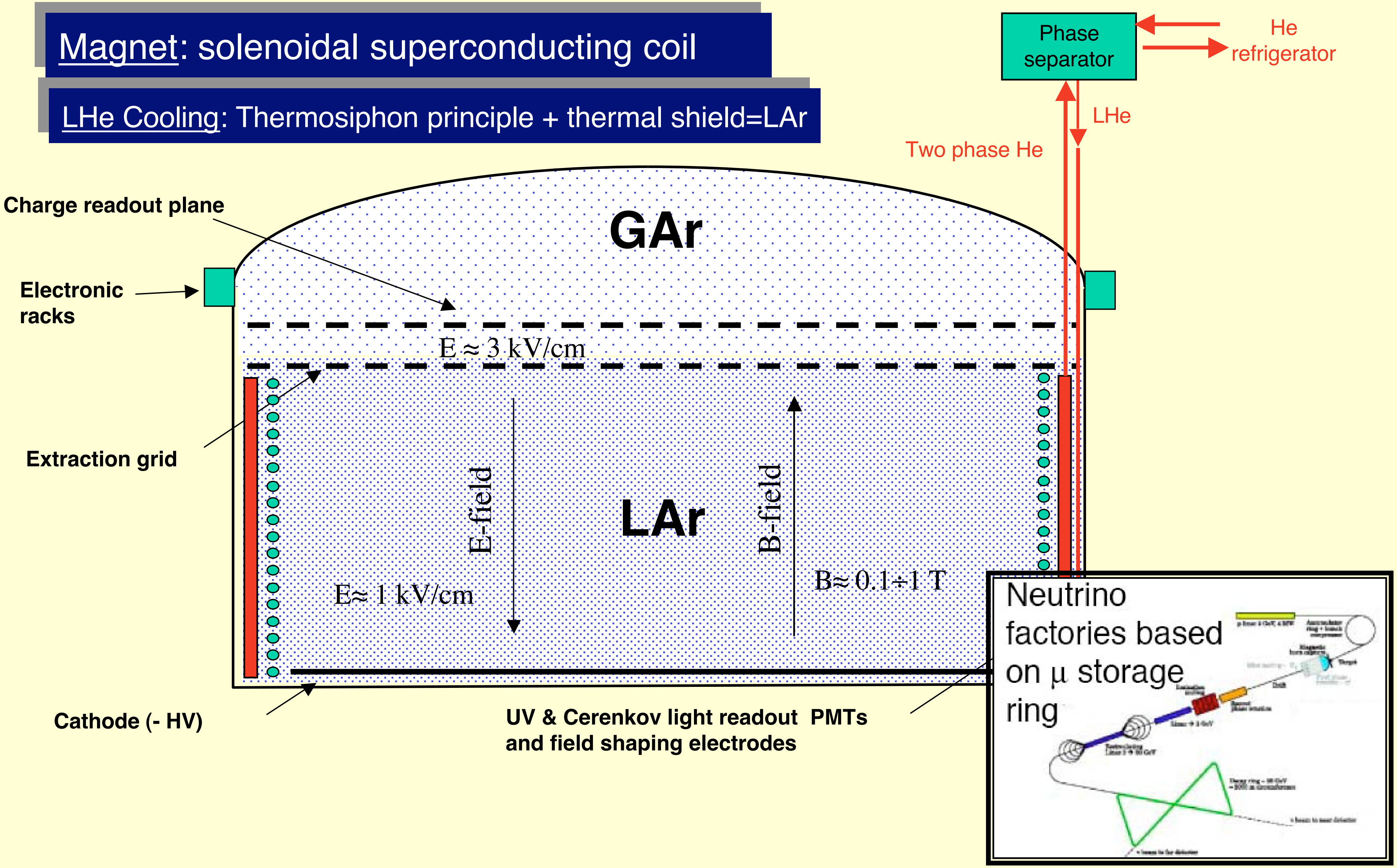
It is possible to directly consider both CP ("**golden**") and T-violation ("**platinum**") searches at a NF. In addition, the "**silver**" mode might kinematically be accessible.

Nucl. Phys. B 631 239; Nucl. Phys. B 589 577;
hep-ph/0402110; hep-ph/0106088

Tentative layout of a large magnetized GLACIER

Magnet: solenoidal superconducting coil

LHe Cooling: Thermosiphon principle + thermal shield=LAr



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 more coordinated EU (and international) efforts.

It is likely that not all new ideas will be realized. All groups must seek to increase forces and reach sufficiently large critical size.

Backup slides