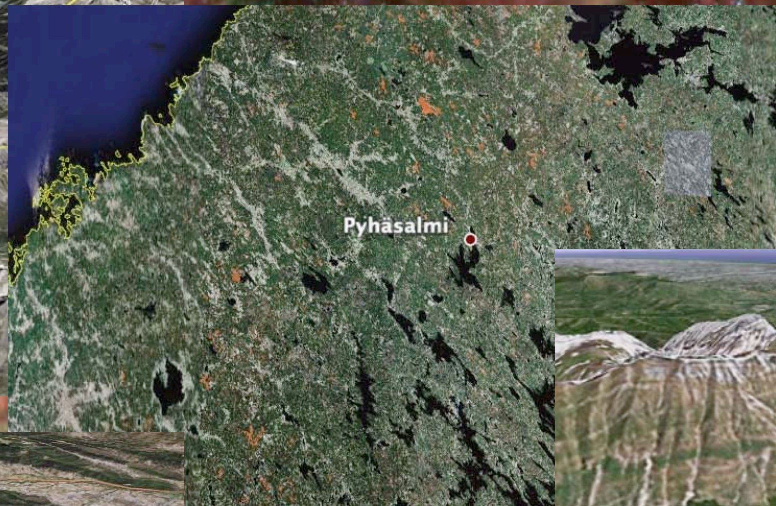
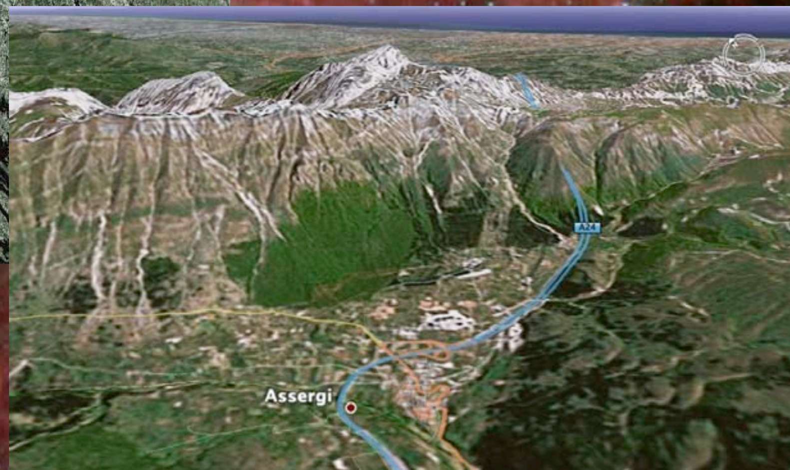
LAGUNA: a Joint Liquid Scintillator / Liquid Argon / Water Cherenkov Design Study





André Rubbia (ETH Zürich)

8th International Workshop on Neutrino Factories, Superbeams and Betabeams
UC Irvine (USA) - August 24th-30th, 2006

What it is ? Who is it?

LAGUNA : Large Apparati for Grand Unification and Neutrino Astrophysics

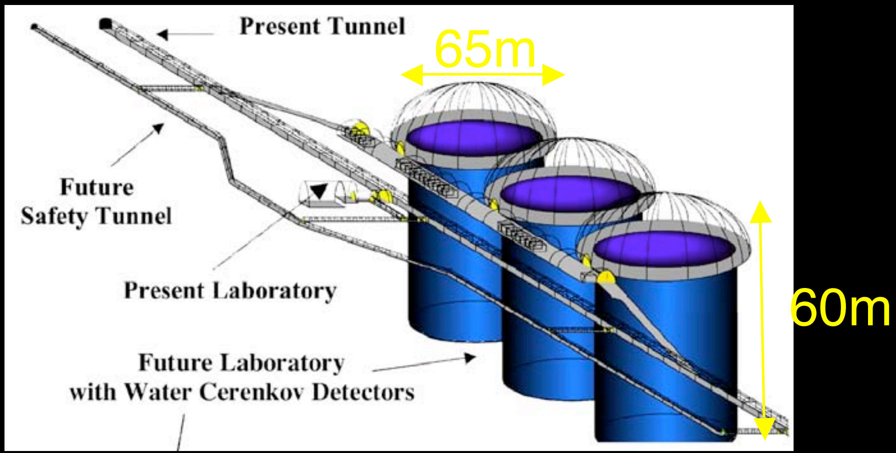
List of people: J. Aystö, A. Badertscher, A. de Bellefon, L. Bezrukov, J. Bouchez, A. Bueno, J. Busto, JE. Campagne, C. Cavata, R. Chandrasekharan, S. Davidson, J. Dumarchez, T. Enqvist, A. Ereditato, F. von Feilitzsch, S. Gninenko, M. Göger-Neff, C. Hagner, K. Hochmuth, S.Katsanevas, L. Kaufmann, J. Kisiel, T. Lachenmaier, M. Laffranchi, M. Lindner, J. Lozano, A. Meregaglia, M. Messina, M. Mezzetto, L. Mosca, S. Navas, L.Oberauer, P. Otyougova, T. Patzak, J. Peltoniemi, W. Potzel, G. Raffelt, A. Rubbia, N. Spooner, A. Tonazzo, T.M. Undagoitia, C. Volpe, M. Wurm, A. Zalewska, R. Zimmermann

From MEMPHYS, LENA and GLACIER groups

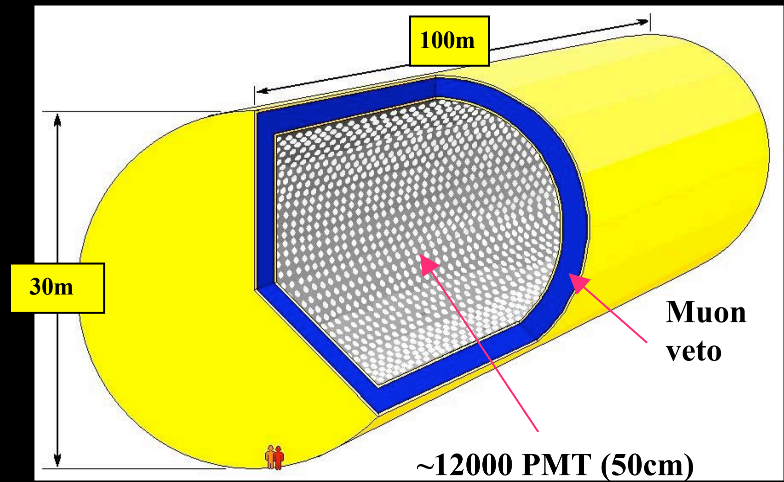
Open

Large Underground detectors considered in LAGUNA

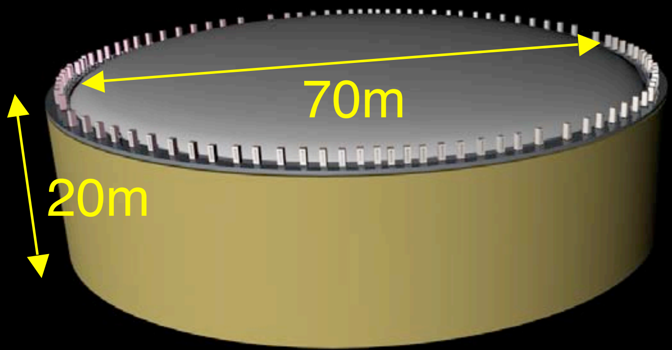
- Three types of large multi-purpose underground detectors with astrophysical program



Water Cherenkov (≈0.5 → 1 Mton)
MEMPHYS



Liquid Scintillator (→ 50 kton)
LENA



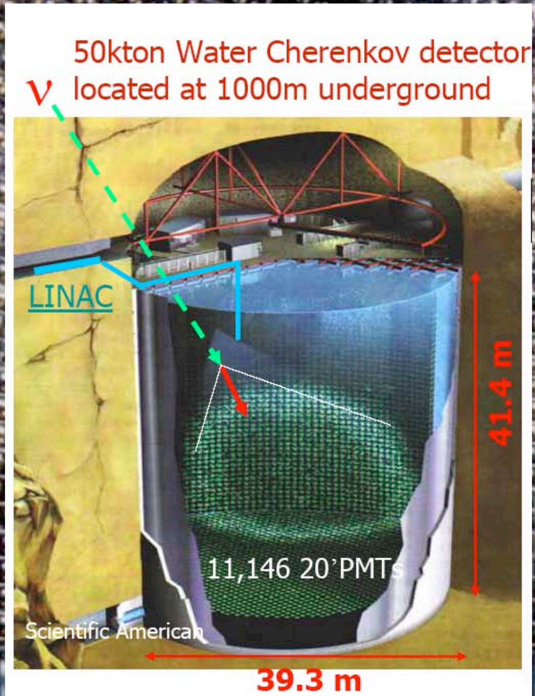
Liquid Argon (≈10→100 kton)
GLACIER

The need for next generation very large experiments…

A broad particle and astroparticle physics program

- **Baryon number violation** — **Proton decay**
- **Astroparticle physics**
  - Gravitational collapse — **Supernova - ν**
  - Early alert for astronomers — **Supernova -ν**
  - Star formation in the early universe — **Relic SN -ν**
  - Solar thermonuclear fusion processes — **Solar - ν**
  - Indirect dark matter searches — **Muons, ν**
- **Neutrino properties** — **Supernova - ν, Atmospheric - ν, Long baseline - ν**
- **Geophysical models, Earth density profile** — **Atmospheric - ν, Geo - ν**

MEgaton Mass PHYSics (MEMPHYS)

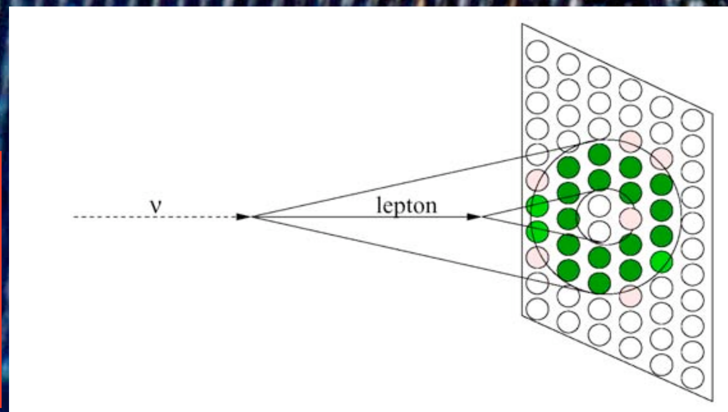


1 shaft ≈ 215 kton H_2O

3 shafts ≈ 500 kton fiducial

For more details on MEMPHYS, see
A. de Bellefon et al., arXiv:hep-ex/0607026.

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



Proposed LENA Detector

Low Energy Neutrino Astrophysics

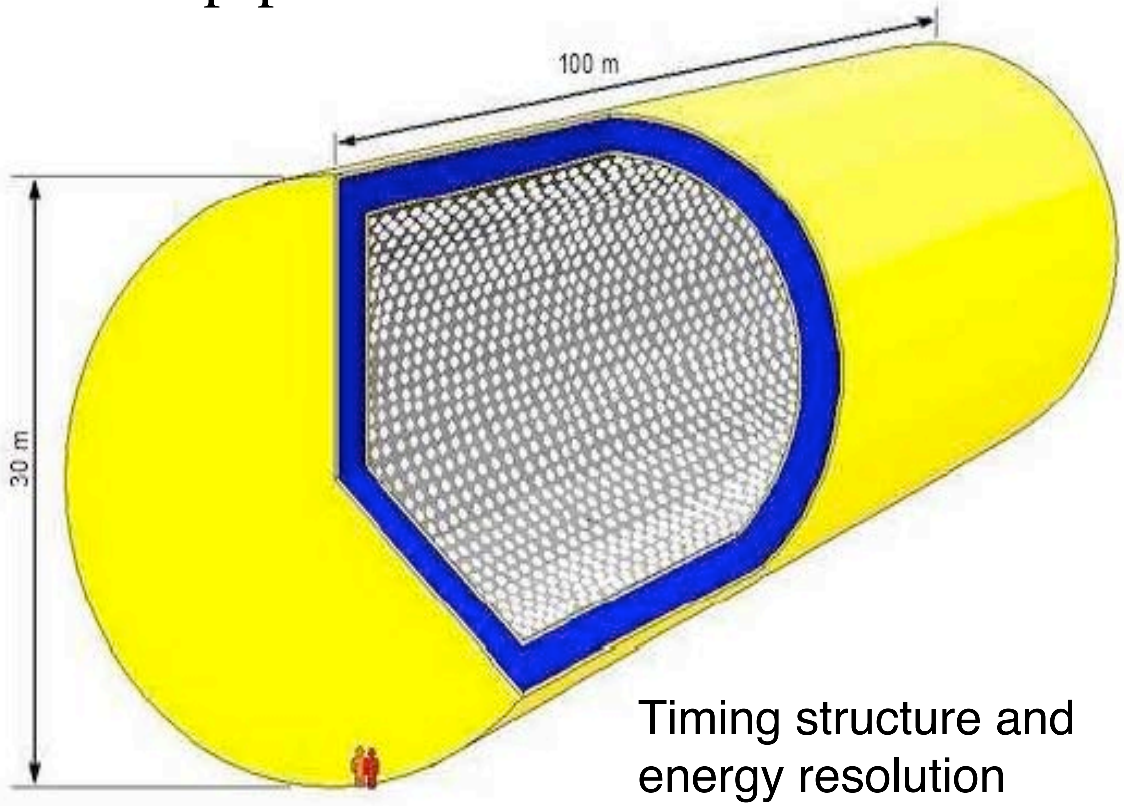
BOREXINO technology

PXE ($C_{16}H_{18}$), non-hazard, flashpoint 145°C,

density 0.99, ultrapure.

Assumed attenuation length ≈ 12 m @430 nm

See hep-ph/0605229



Timing structure and energy resolution

Volume

∼ 100 m length × 30 m ∅

Liquid Scintillator

45.000 ton PXE

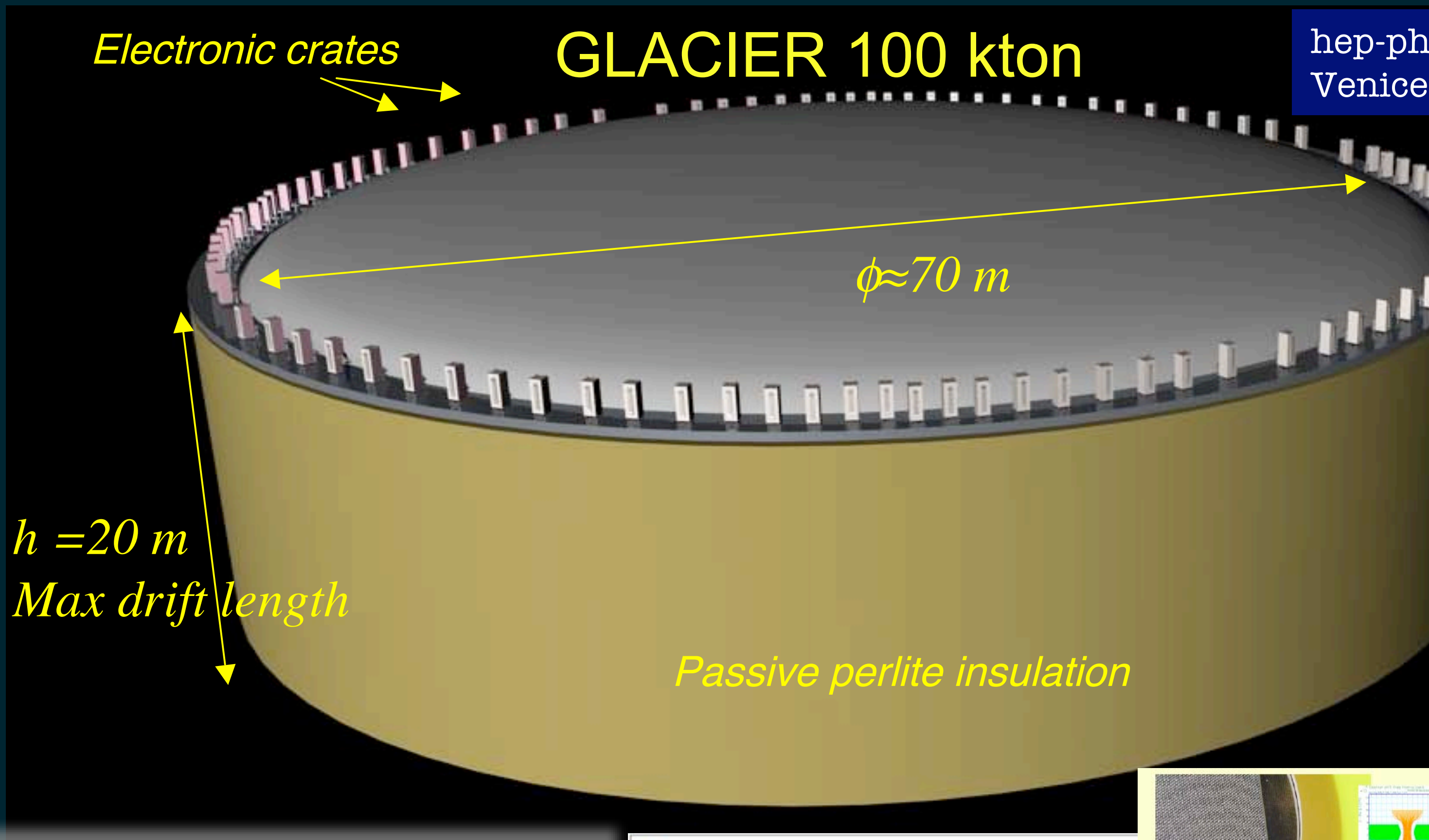
Photomultipliers

12.000 units 30% surface

Photoelectron yield

110 pe/MeV

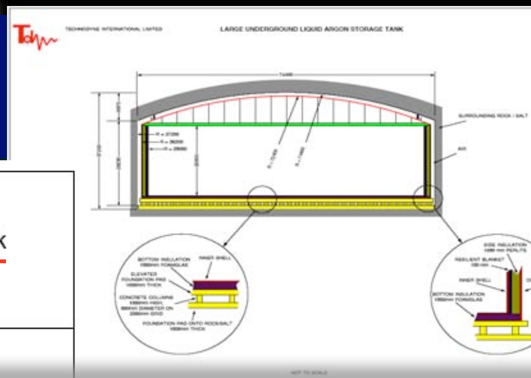
Giant Liquid Argon Charge Imaging ExpeRiment



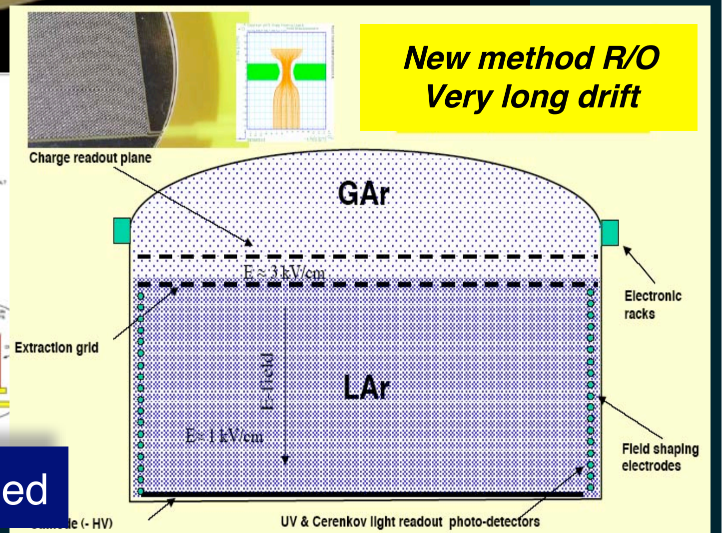
Single module cryo-tanker based on industrial LNG technology

Project: Large Underground Argon Storage Tank

A feasibility study mandated to Technodyne Ltd (UK): Feb-Dec 2004



Could potentially be magnetized



Nucleon (proton) decay

- *Very challenging still-open goal of particle physics!*

1. Grand-Unification:

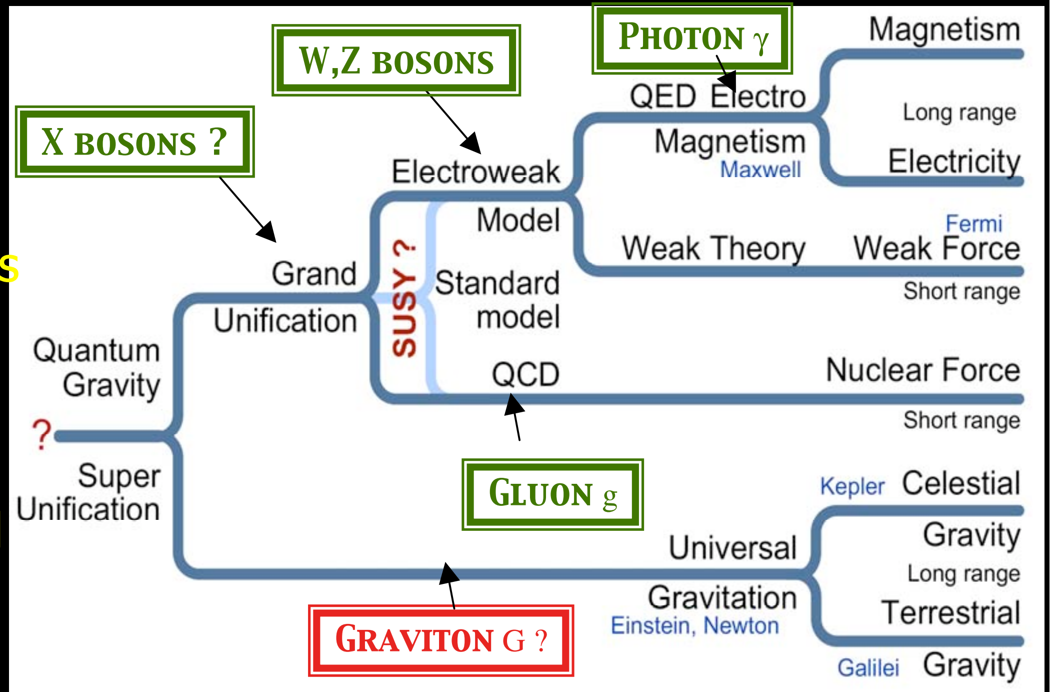
Fundamental symmetry between quarks & leptons, transmutation between quarks and leptons: proton unstable

Explain electric charges of elementary fermions

Help simple models of fermion masses and mixing

Motivates SUSY and SUSY predicts LSP as dark matter

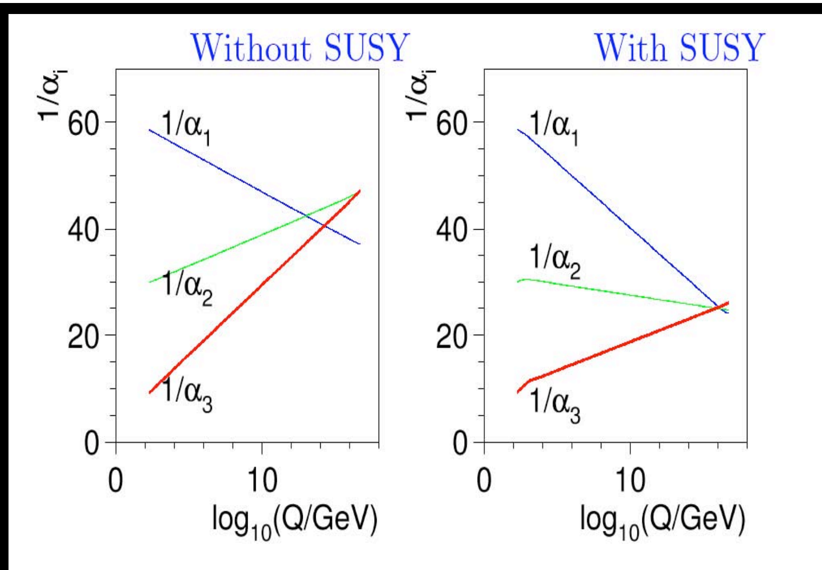
Motivates see-saw (N_R) and explains tiny neutrino masses

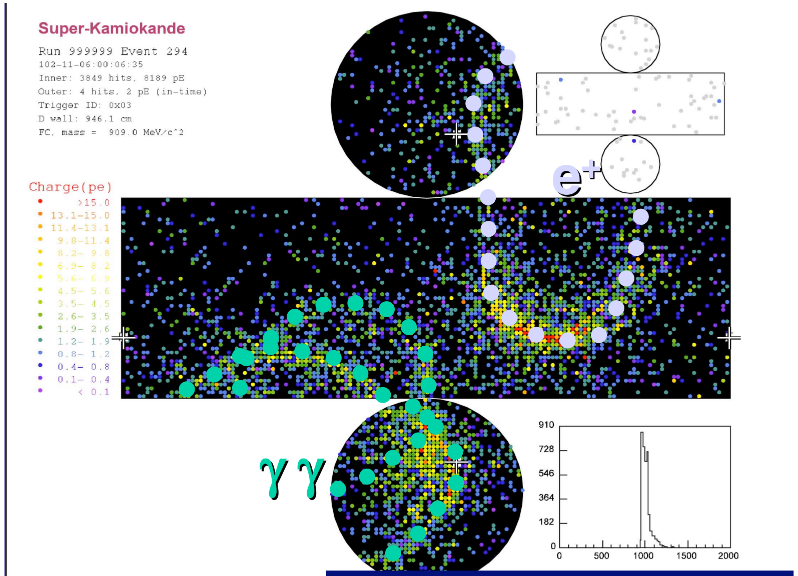


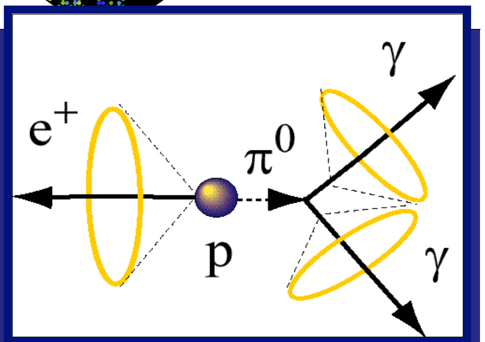
2. Proton decay

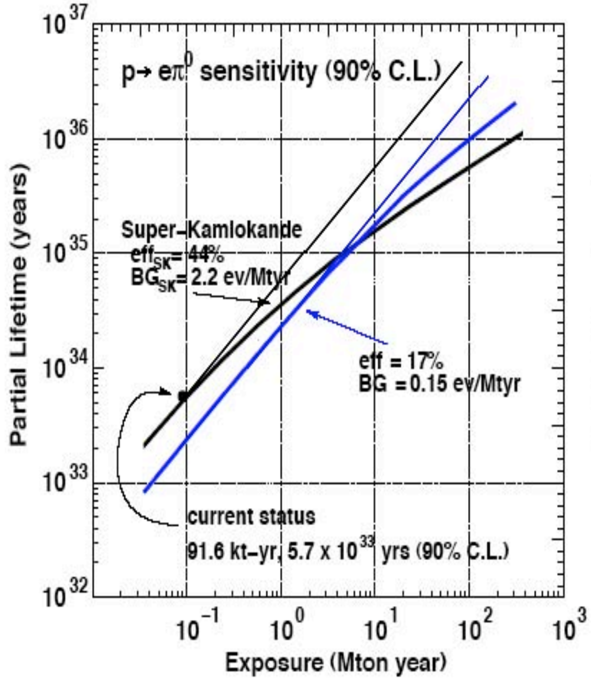
Rate driven by dim-5 & 6 operators and wildly depends on model

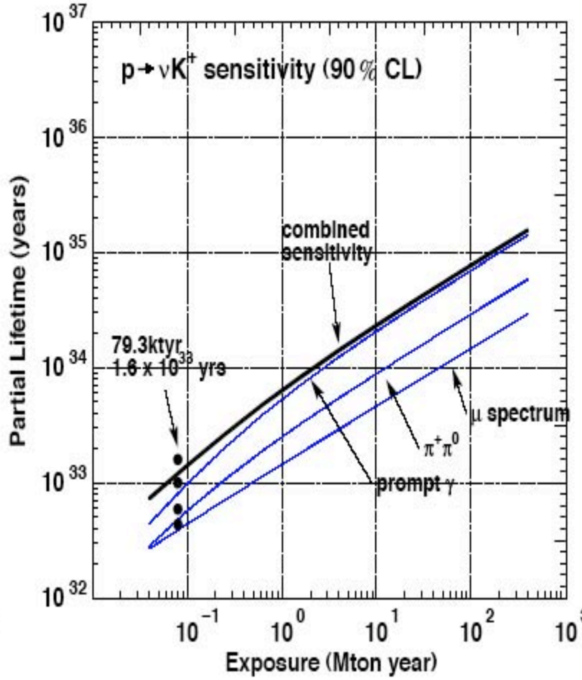
What are the branching fractions? $p \to e^+\pi^0$, νK^+, other decay modes? $\nu\pi^+$, $e\gamma$, $\mu\gamma$, …







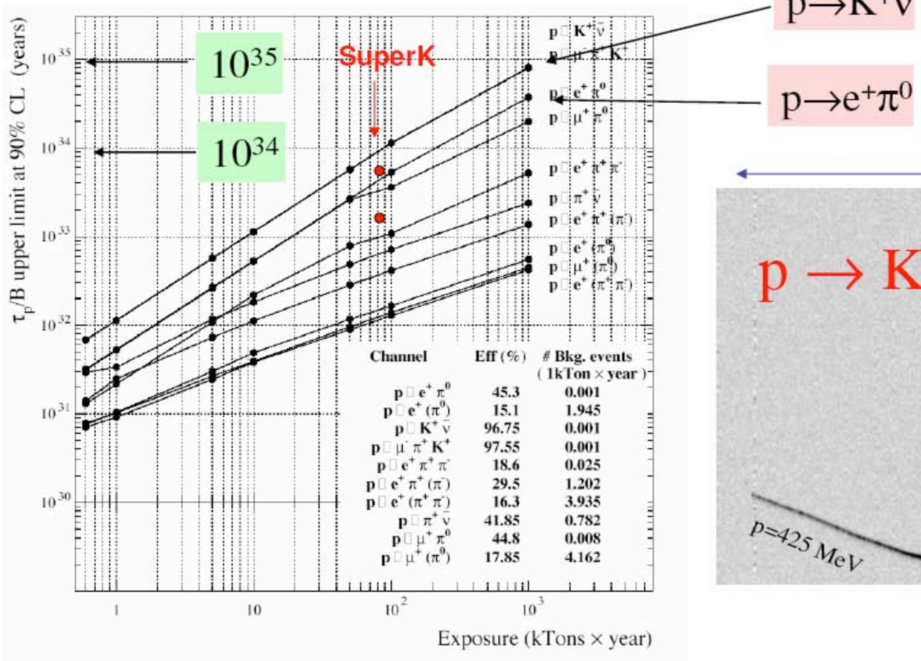




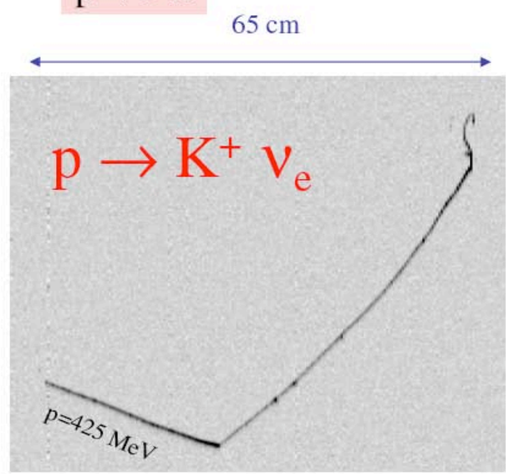
Sensitivities of Water

and LiqAr to proton decay

p-decay is a bit like the Higgs-boson: we don't know if it exists nor the mass, but if it does and is within reach, we know what it would look like



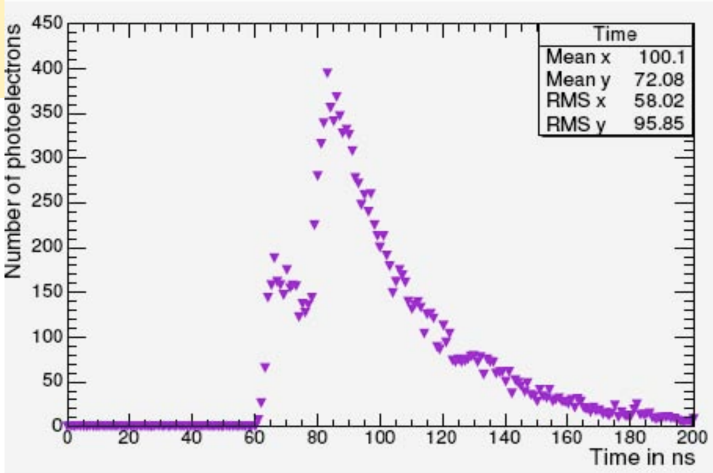
LAr



Proton decay search in LENA

See hep-ph/0511230

- Kaon decay after 18 ns



Event Structure: $p \to K^+ \overline{\nu}$

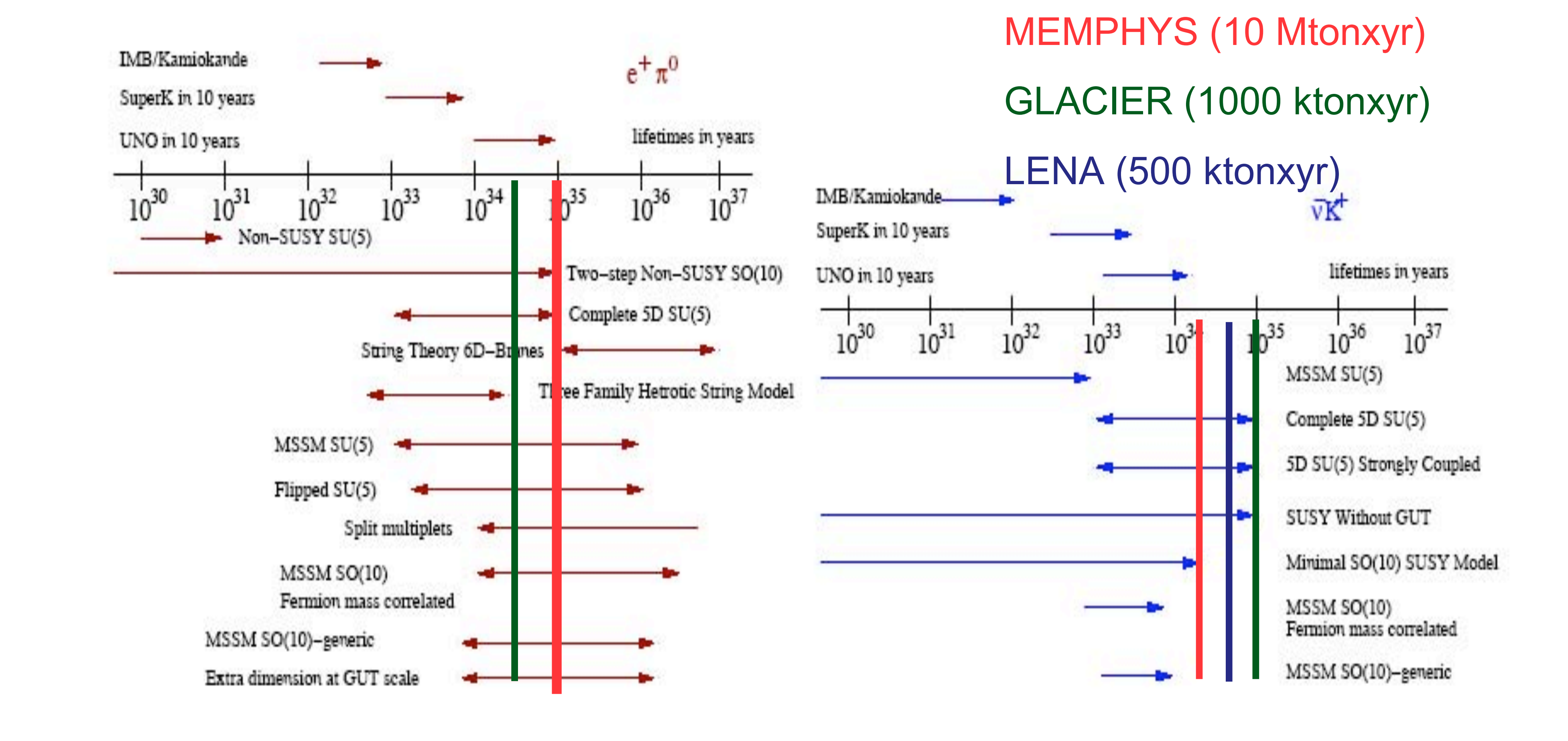
$$T(K^+) = 105\ \text{MeV}$$
$$\tau(K^+) = 12.8\ \text{ns}$$

- $K^+ \to \mu^+ \nu_\mu$ 63.43%
  - $T(\mu^+) = 152$ MeV
  - $\tau(\mu^+) = 2.2\ \mu$s
- $\mu^+ \to e^+ \nu_e \overline{\nu}_\mu$

- $K^+ \to \pi^+ \pi^0$ 21.13%
  - $T(\pi^+) = 108$ MeV
  - $\tau(\pi^+) = 26$ ns
  - $T(\pi^0) = 110$ MeV
  - $\tau(\pi^0) = 8.4 \cdot 10^{-8}$ ns
- $\pi^+ \to \mu^+ \nu_\mu$ $\pi^0 \to \gamma\gamma$

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

How does it compare to theoretical expectation?



Higher dimension models (eg. 6D SO(10)) not included

Definitively not exhaustive.

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
- Burst detection
- Cooling of the proto-neutron star
- Shock wave propagation
- Black hole formation?

2. Neutrino properties

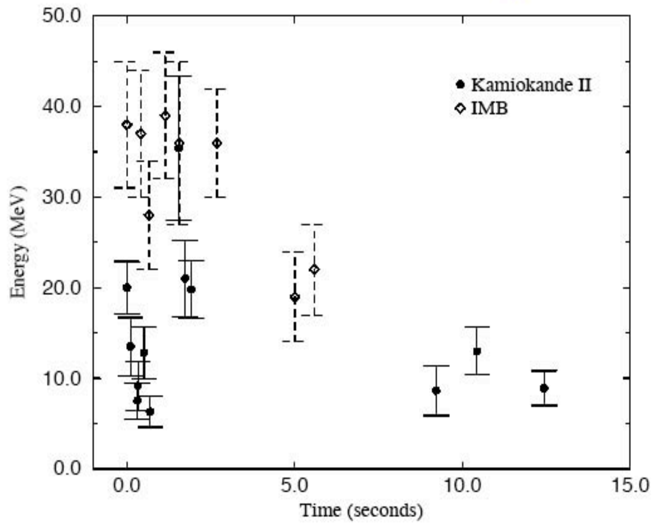
- Neutrino mass (time of flight delay)
- Oscillation parameters (flavor transformation in SN core and/or in Earth): Type of mass hierarchy and θ_{13} mixing angle

3. Early alert for astronomers

- Pointing to the supernova

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

Supernova detection in WC

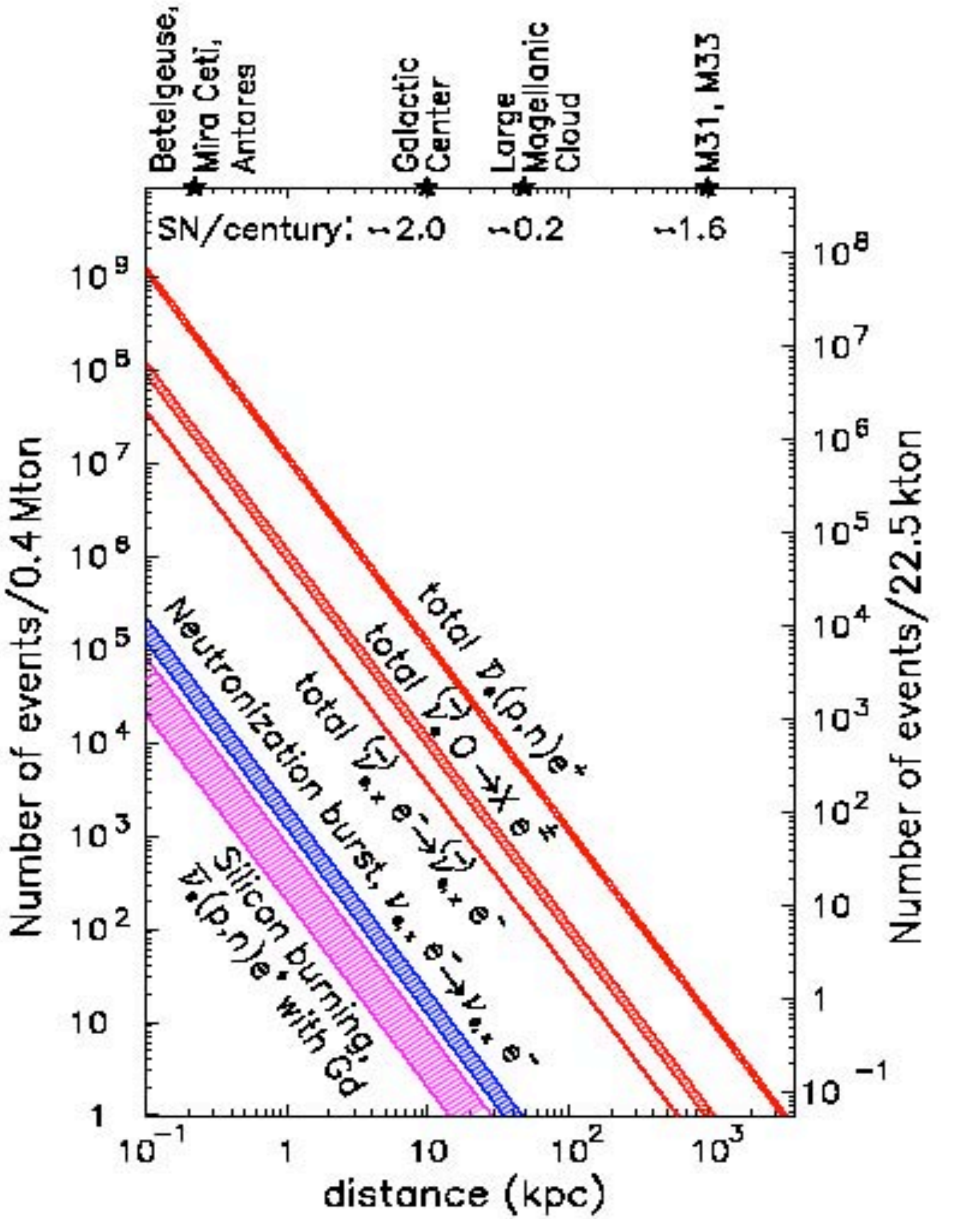
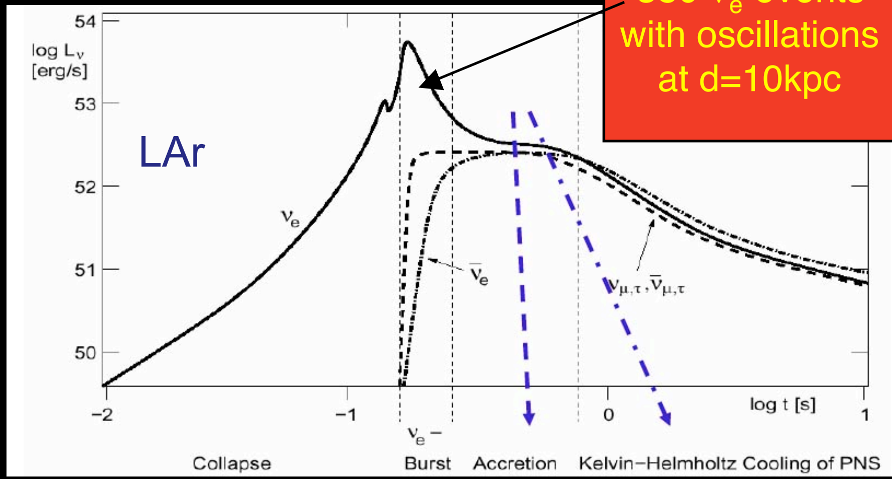


FIG. 6: Number of events expected in 0.4 Mton detector (left y-axis) or in a SK-like detector (right y-axis) as a function of the supernova distance, for various interaction channels. See the text for details.

Complementarity

380 ν_e events with oscillations at d=10kpc



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

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

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

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

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}
ELAS	1330	1330	1330	1330	1330
ν_e**CC**	6240	31320	23820	23820	23820
$\bar{\nu}_e$**CC**	540	1110	1110	2420	1110
NC	30440	30440	30440	30440	30440
TOTAL	38550	64200	56700	58010	56700

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**)

Supernova neutrino detection in 50 kton scintillator

Electron Antineutrino spectroscopy

- $\overline{\nu}_e + p \rightarrow n + e^+$ (Q=1.8 MeV)
  $n + p \rightarrow d + \gamma; \quad E_\gamma = 2.2$ 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

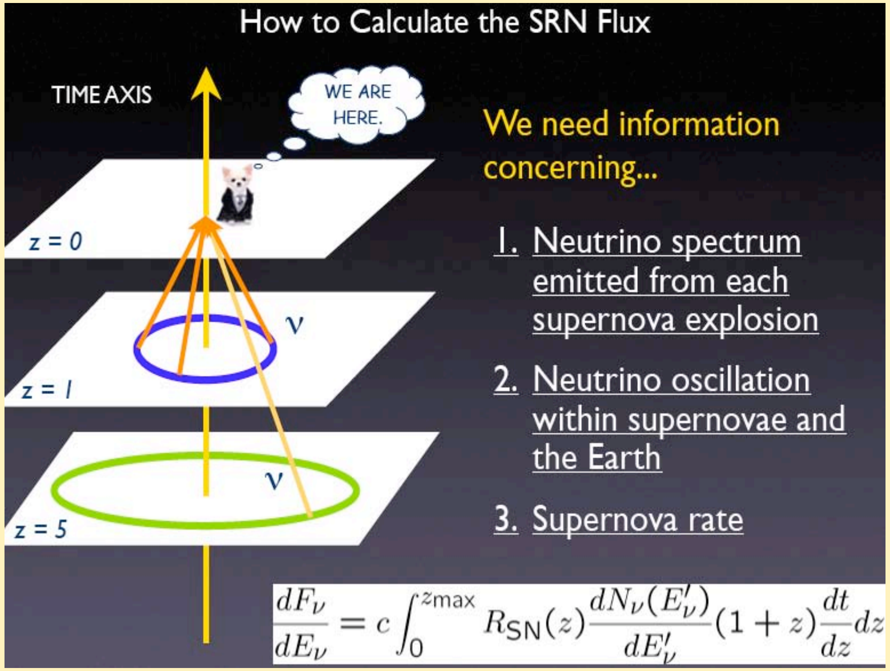
- $\nu_x + {}^{12}\mathrm{C} \rightarrow {}^{12}\mathrm{C}^* + \nu_x$
  with ${}^{12}\mathrm{C}^* \rightarrow {}^{12}\mathrm{C} + \gamma; \quad E_\gamma = 15.11$ MeV ~2925 events

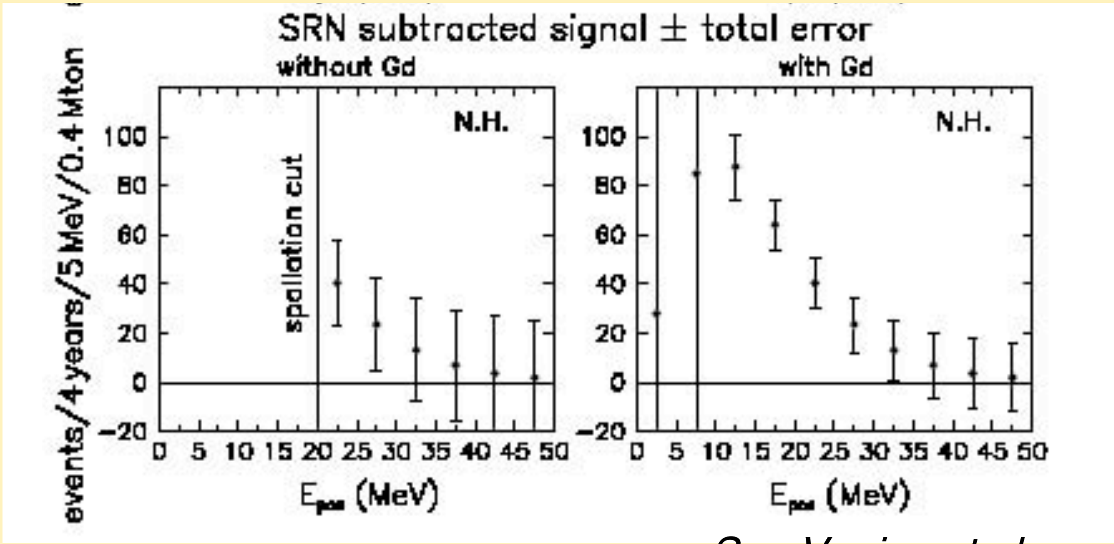
- $\nu_x + e^- \rightarrow \nu_x + e^-$ (elastic scattering) ~610 events

- $\nu_x + p \rightarrow \nu_x + p$ (elastic scattering)
  Detector energy threshold: $E_{th} = 0.2$ MeV ~7370 events

Event rates for a SN type IIa in the galactic center (10 kpc) ***Total ≈ 20000 events***

Relic supernova neutrinos





See Vagins et al, GADZOOKS

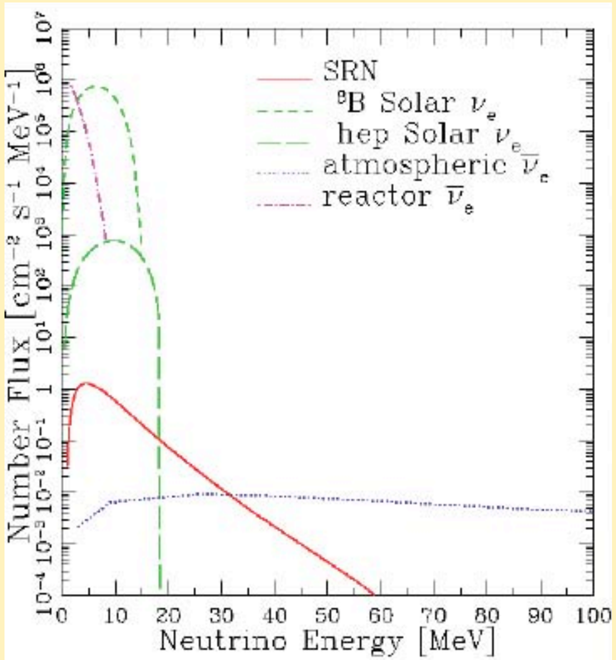
In LENA detector:
(44 kt fiducial volume)

- $\overline{\nu}_e + p \rightarrow n + e^+$
- $n + p \rightarrow d + \gamma$
  - $E_\gamma = 2.2$ MeV

Event rate in 10 y:

- LL: ~ 42 events
- TBP: ~ 20 events

(discrimination power at 90% C.L.)



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

$$16\ \mathrm{MeV} \leq E_e \leq 40\ \mathrm{MeV}$$

	mass hierarchy	θ_{13}	$P(\nu_e \to \nu_e)$	$P(\bar{\nu}_e \to \bar{\nu}_e)$
I	normal	large	$\sin^2\theta_{13}$	$\cos^2\theta_{12}$
II	inverted	large	$\sin^2\theta_{12}$	$\sin^2\theta_{13}$
III	normal/inverted	small	$\sin^2\theta_{12}$	$\cos^2\theta_{12}$

57 events for 500 kton-years and scenario I (4σ)
43 events for 500 kton-years and II or III

Neutrino properties (w/o accelerators)

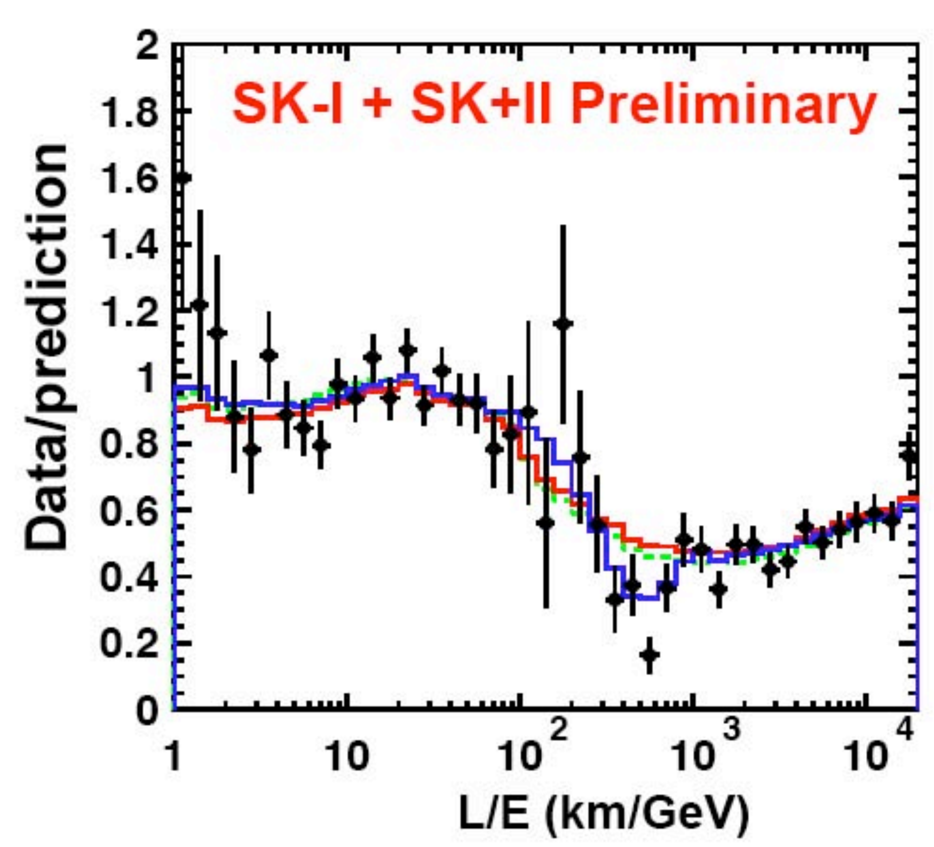
●Astrophysical neutrinos observation with more statistics and improved detection method will be important

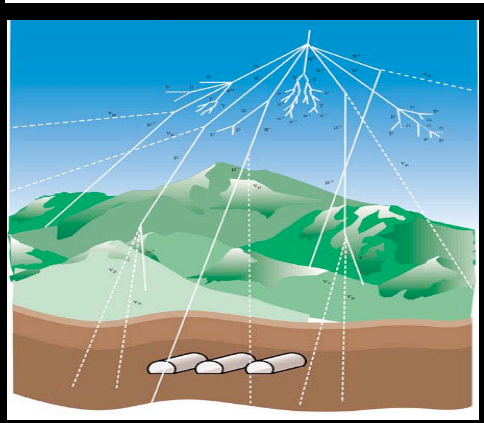
1. Atmospheric neutrinos:

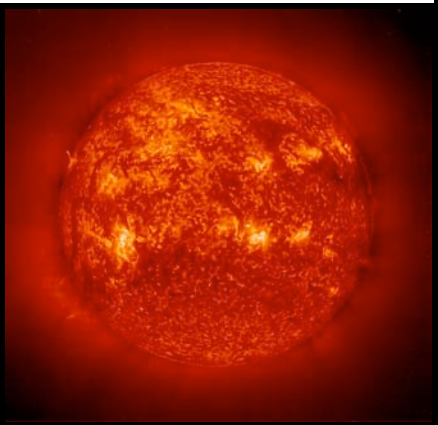
High statistics, from observation to precision measurements
L/E dependence
Sterile neutrinos and tau appearance
Electron appearance θ_{13}
Earth matter effects and sign of Δm^2_{23}
CP-violation

2. Solar neutrinos

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



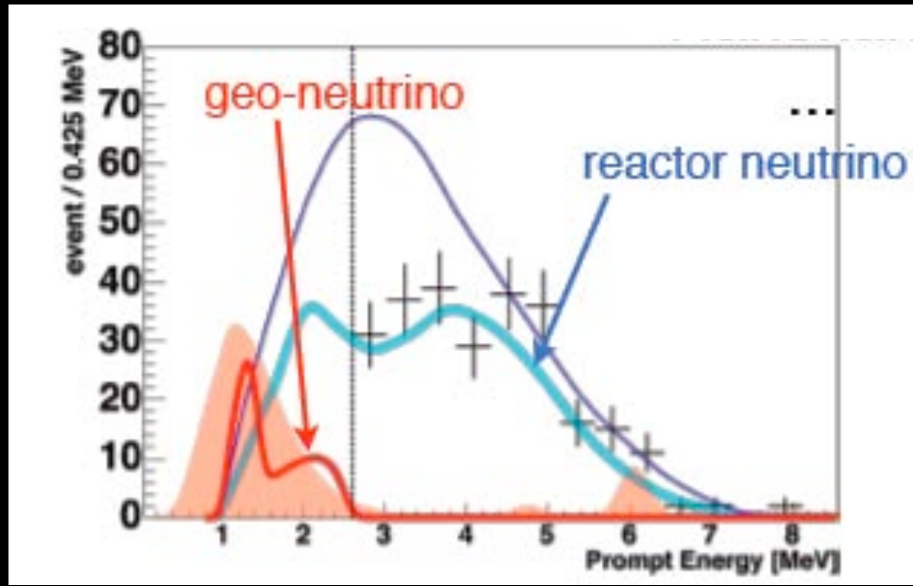


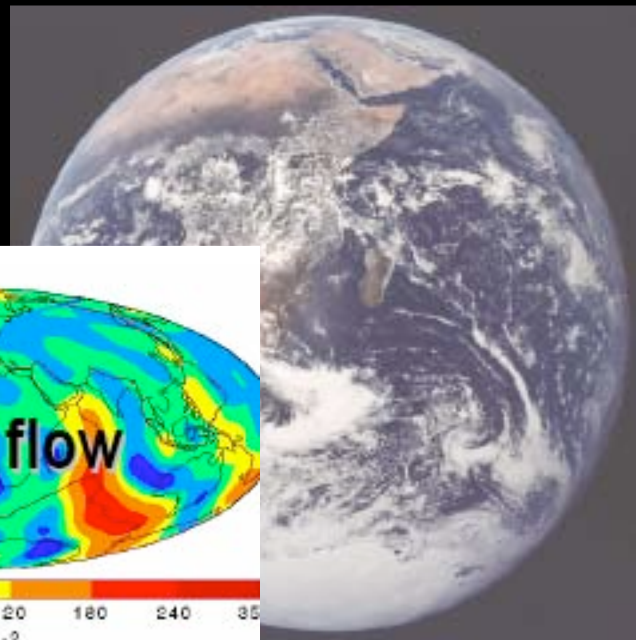


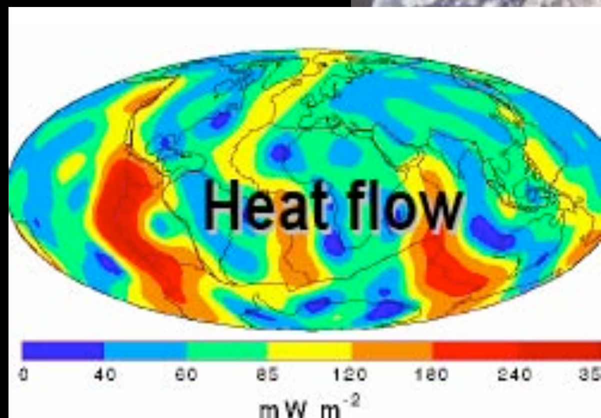
Geo-neutrinos

●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, …







Outstanding non-accelerator physics goals

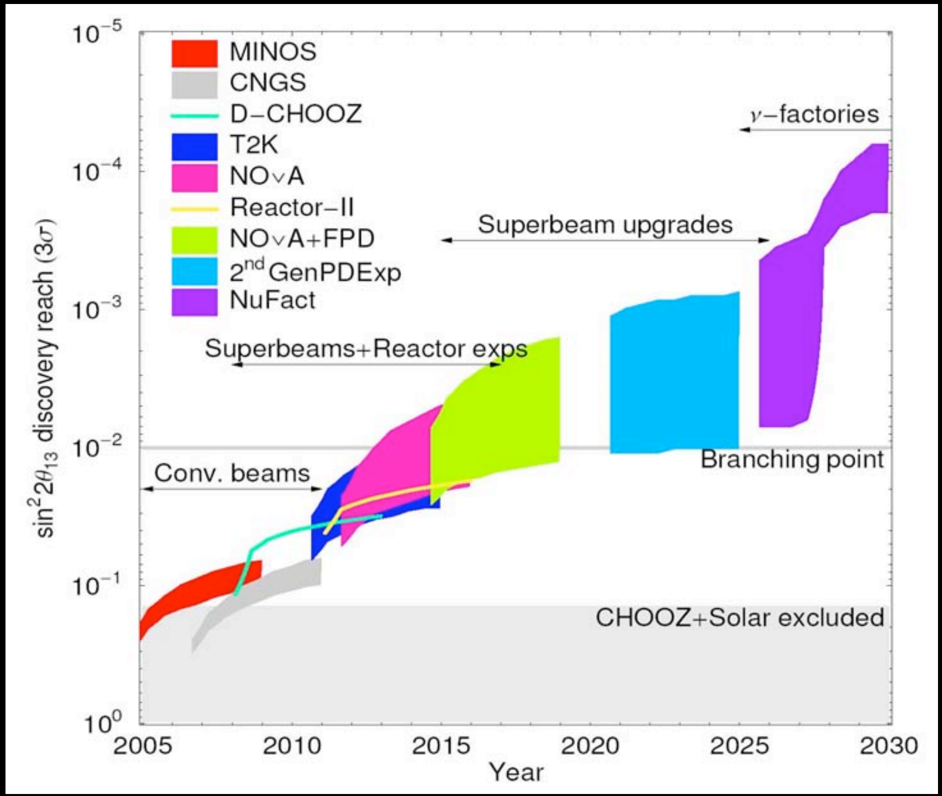
Comparison among liquids: which combination provides maximal physics output?

	Water Cerenkov	Liquid Argon TPC	Liquid Scintillator
Total mass	500 kton	100 kton	50 kton
$p \rightarrow e\,\pi^0$ in 10 years	1.2×10^{35} years ε= 17%, ≈ 1 BG event	0.5×10^{35} years ε= 45%, <1 BG event	?
$p \rightarrow \nu K$ in 10 years	0.15×10^{35} years ε= 8.6%, ≈ 30 BG events	1.1×10^{35} years ε= 97%, <1 BG event	0.4×10^{35} years ε= 65%, <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)	20000 (all flavors)
SN in Andromeda	40 events	7 (12 if NH-L mixing)	4 events
SN burst @ 10 kpc	≈250 ν-e elastic scattering	380 ν_e CC (flavor sensitive)	≈30 events
SN relic	250(2500 when Gd-loaded)	50	20-40
Atmospheric neutrinos	56000 events/year	≈11000 events/year	5600/year
Solar neutrinos	91250000/year	324000 events/year	?
Geoneutrinos	0	0	≈3000 events/year

Clear complementarity between techniques !

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"

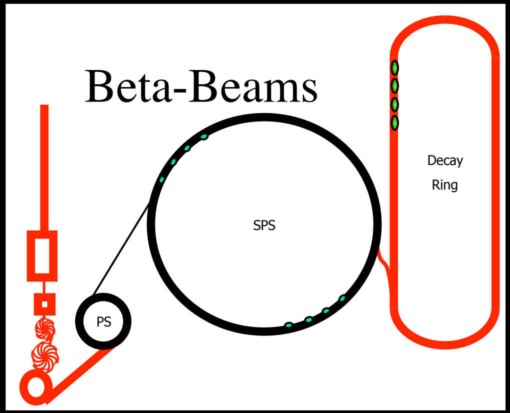


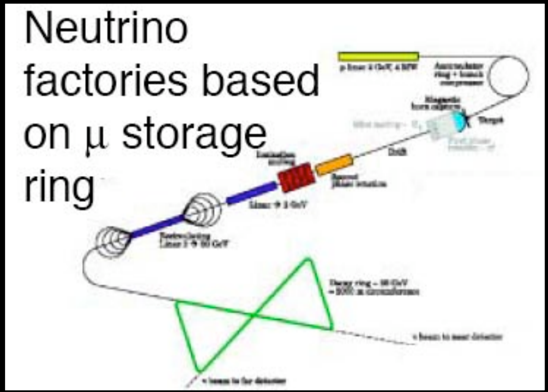
1. Precision measurement:

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

2. Discoveries

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





Outstanding physics has a cost…

$$FOM \stackrel{?}{=} \frac{M\varepsilon}{€}$$

- "The cost of knowledge"
- Detector costs w/o excavation:
  - ➥ MEMPHYS ≈ 350 M€ / 500 kton fiducial
  - ➥ GLACIER ≈ 300 M€ / 100 kton (including merchant price of 100 kton of LAr)
  - ➥ LENA ≈ 150 M€ / 50 kton
- Excavation underground laboratory assuming good rock quality **(J. Peltoniemi)**:
  - ➥ Underground laboratory: typ. 200 €/m^3
  - ➥ Access construction
    - ☛Wide decline (tunnel, ramp) with heavy truck access: 2000€/m
    - ☛Narrow tunnel: 1000 €/m
    - ☛Shaft (7m) 5000 €/m, (2m) 1000 €/m
    - ☛Dedicated lift to surface: 2-10 M€
  - ➥ Detector cavern:
    - ☛MEMPHYS: 240M€ (Fréjus study)
    - ☛GLACIER : 10-30 M€ depending on depth
    - ☛LENA: 10-15 M€ deep underground
- **Scale of cost / project ≈ 200-600 M€**
  - ➥ According to industry, ≈10% of final cost should be devoted to design!

European context for LAGUNA

- ApPEC is the Astroparticle Physics Coordination in Europe (similar to ECFA, NuPEC, CERN SG). Represents large funding agencies for APP in Belgium, France, Germany, Greece, Italy, Netherlands, Spain, Switzerland and UK (soon Poland).

- The ASPERA ERA-Net (European Research Area-Network) of ApPEC has been funded and gives a “legal status” to ApPEC. Through it, national Funding Agencies are committed to spend fraction of their budgets in common projects
  - ➥ **In the pipeline: KM3 in Mediterranean, CTA for HE γ astronomy, GW detection**

- The ApPEC Steering Committee has mandated the Peer Review Committee to write a Roadmap. The ApPEC roadmap recommendation concerning large neutrino detectors:
  - ➥ *We recommend that a new large European infrastructure is put forward, as a future international multi-purpose facility on the 10^5-10^6 ton scale for improved studies of proton decay and of low-energy neutrinos from astrophysical origin. The three detection techniques being studied for such large detectors in Europe, Water-Cherenkov, Liquid Scintillator and Liquid Argon, should be evaluated in the context of a common design study which should also address the underground infrastructure and the possibility of an eventual detection of future accelerator neutrino beams. This design study should take into account worldwide efforts and converge, on a time scale of 2010, to a common proposal.*

- The design study could lead to the European Strategy Forum on Research Infrastructures (ESFRI) process.

LAGUNA is a coordinated European effort

- At the ApPEC "Munich meeting" held on November 2005, a coordinated effort among the 3 "liquids" has been proposed and accepted. Large detectors like Water Cherenkov, Liquid Scintillator and Liquid Argon present important physics complementarities and also a lot of common R&D needs. They have to work in synergy.

- The purpose is to develop conceptual designs for European large scale liquid detectors into coherent and well-coordinated EU wide efforts towards a common physics goal and solving common problems together, taking into account the unique technological expertise in Europe and the other existing or planned programs in the world, such that mature designs and credible scenarios can be proposed around 2010.

- During the last months, an effort has been made to consolidate these ideas into a format compatible with potential EU Framework Programme FP7 instruments. The idea is to submit a common EU design study on the three liquids by beginning of 2007.

- This effort, although oriented towards a potential infrastructure in Europe, should allow Europeans to contribute in a coherent way and possibly with better impact, to the on-going discussions worldwide (e.g. NNN workshops).

LAGUNA DS: Progress report

- ApPEC Town-Meeting Munich, November 2005
- A series of working meeting were held
  - ➥ Munich, 24th of April 2006
  - ➥ Munich, 2nd of June 2006
  - ➥ Paris, 21st of July 2006
  - ➥ <u>Next</u>: Zurich, October 12th, 2006
- A scientific case document (≈50 pages) has been drafted.
- A detector conceptual design document is meant to be prepared.
- A list of preliminary Working Packages, in a possibly suitable form for the FP7 DS, has been prepared.
- The FP7 DS request has to be written until beginning 2007 (depending on exact time schedule of EU).

Proposed working packages for LAGUNA DS

WP1: Tank instrumentation
Light/charge detection, electronics, HV

WP2: Underground tanks
Design, geometry, support structure, materials, insulation, underground assembly

WP3: DAQ & Calibration
DAQ, data analysis, slow controls

WP4: Cosmics, Local Backgrounds, Materials
In-situ measurements, external/internal backgrounds, simulations, coordination with ILIAS

WP5: Sites
Feasibility of large excavations, access, local conditions, site preselection

WP6: Liquids
Production, handling, purification, filling, long-term stability, gases

WP7: Safety & environment
Infrastructure, risk analysis (earthquakes, fire, liquid evaporation, …)

WP8: Physics & simulations
Physics potential of the facility

WP1

Tank Instrumentation

Addressing scaling-up issues
(mainly cost)

R&D on photodetection (MEMPHYS)
(industrial reduction of cost)

•Common R&D IN2P3-PHOTONIS in the context of a “GIS” (PHOTONIS recently acquired DEP and BURLE)

•Axes of collaboration:

- •Smart ensembles (all electronics up to ethernet included) of standard 12” photodetectors. A cost minimum?
- •Flat UV detectors for LiqAr

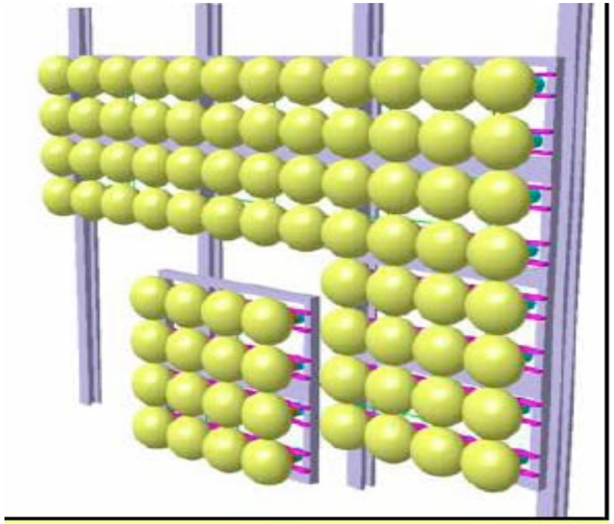
•Trying to lower the industrial cost is fundamental

•HAMAMATSU develops HPD’s

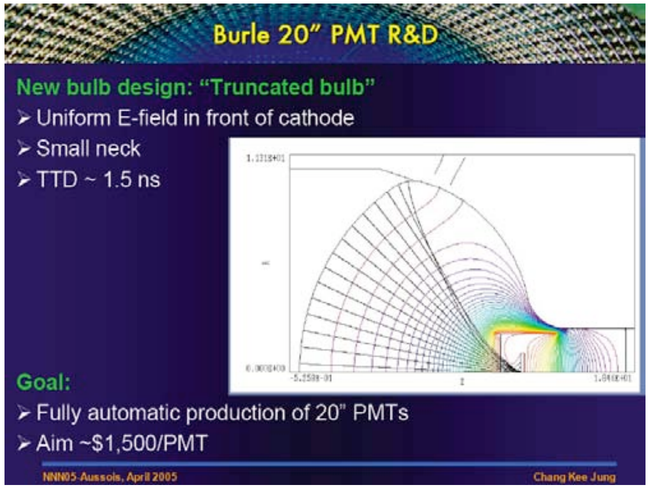
•BURLE truncated bulb PMT’s

Table 3: Preliminary cost estimate of the MEMPHYS detector

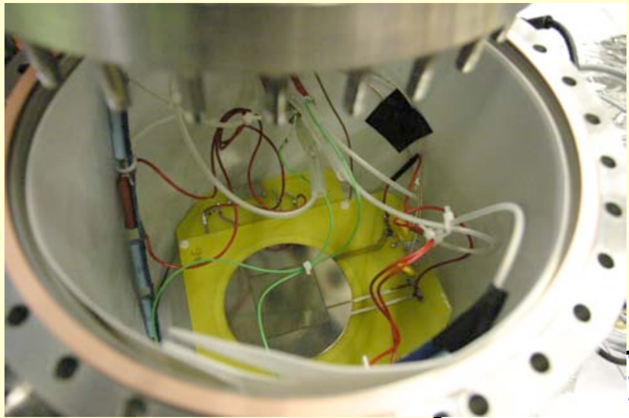
3 Shafts	240 ME
Total cost of 250k 12” PMTs	250 ME
Infrastructure	100 ME
Total	590 ME



	20“	<=>	12“	
●Diameter	20“	<=>	12“	
●projected area	1660		615	cm^3
●QE(typ)	20		24	%
●CE	60		70	%
●Cost	2500		800	€
●Cost/p.e/cm	13		8	€

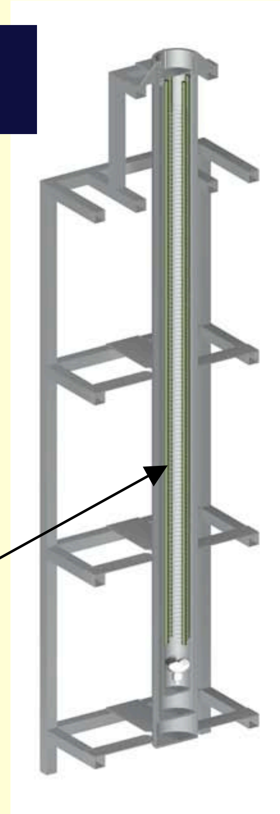


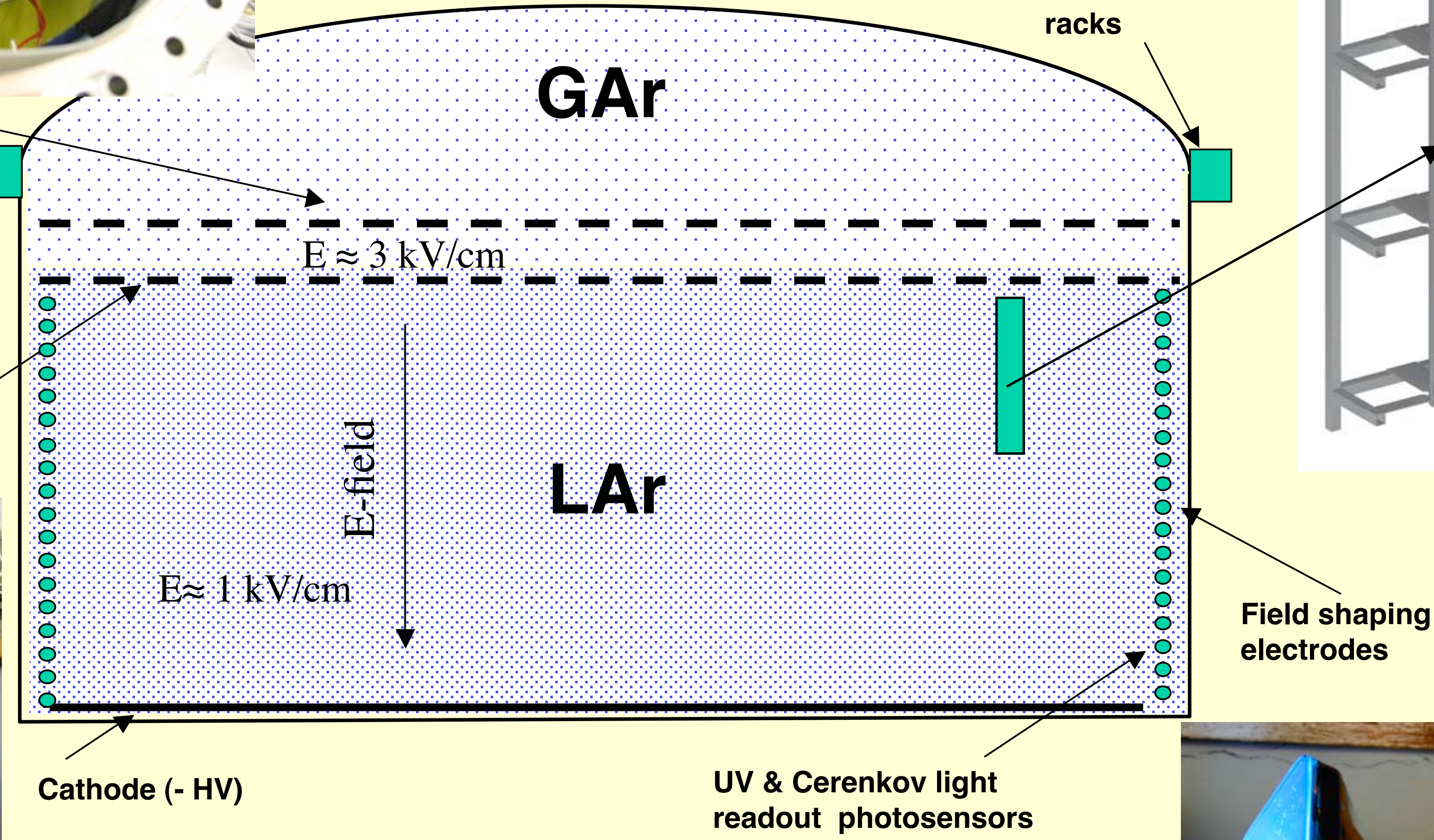
R&D on scalability of liquid Argon detectors (GLACIER)

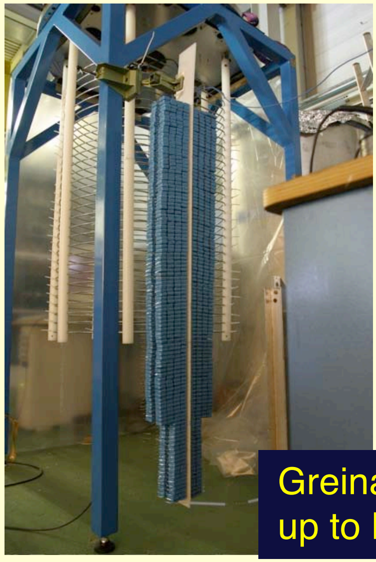


Charge readout with extraction & amplification for long drifts

ArgonTube: 5 m drift test



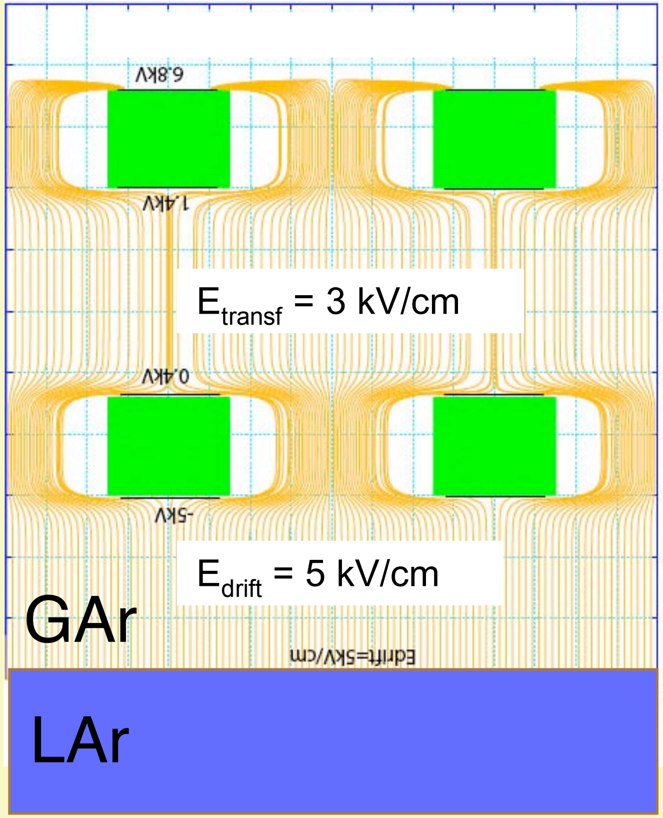




Greinacher voltage multiplier up to MV

Large area DUV sensitive photosensors

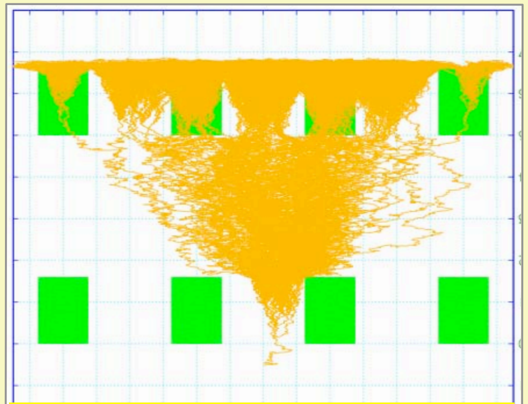
Charge readout: Thick Large Electron Multiplier (LEM)

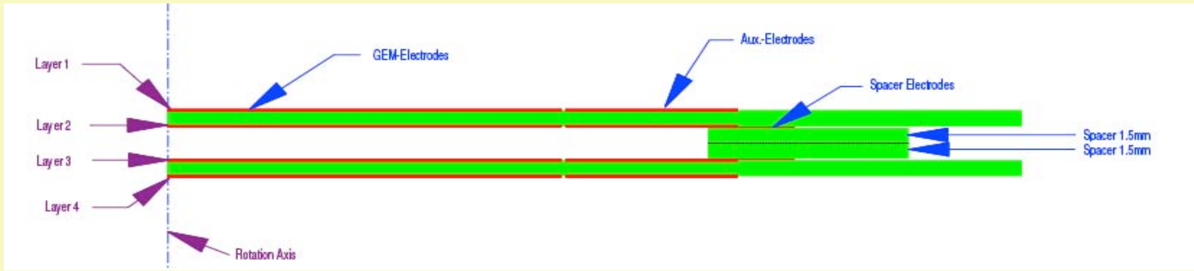


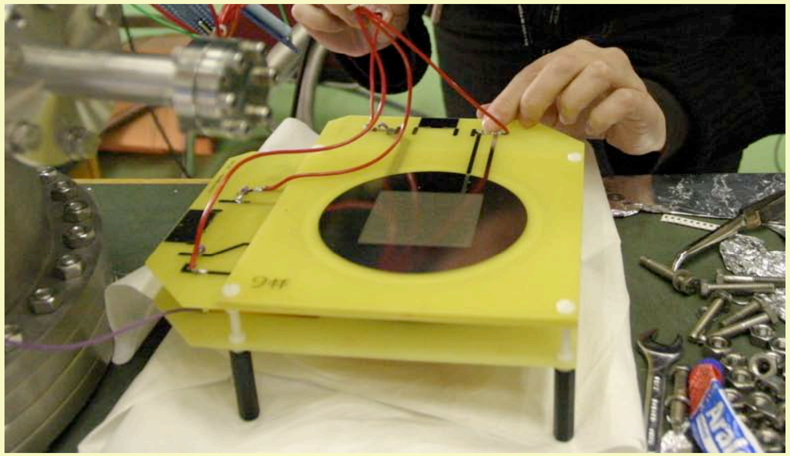
Thick-LEM: Vetronite with holes, coated with copper

→ macroscopic GEM
→ easier to operate at cryogenic temperatures

→ hole dimensions: 500 μm diameter, 800 μm distance


Simulation of avalanche





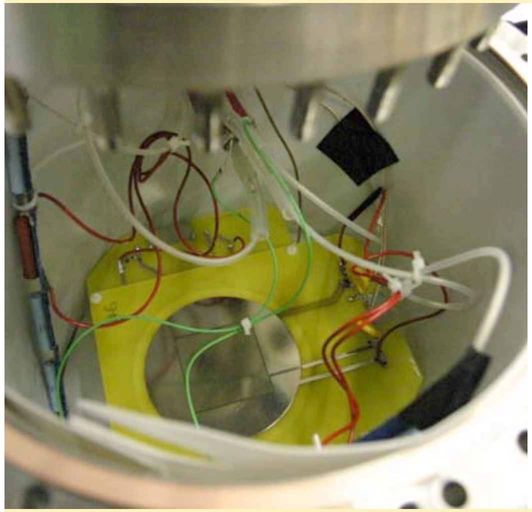
- Thickness: 1.5 mm
- Amplification hole diameter = 500 μm
- Distance between centers of neighboring holes = 800 μm

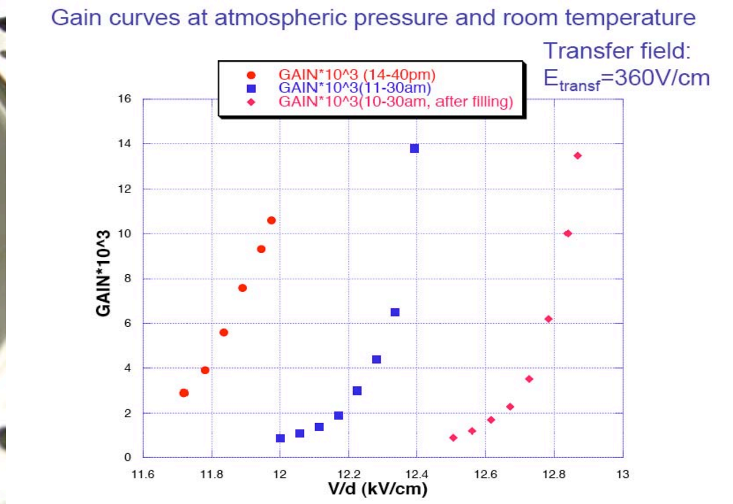
→ Distance between stages: 3 mm

→ Avalanche spreads into several holes at second stage

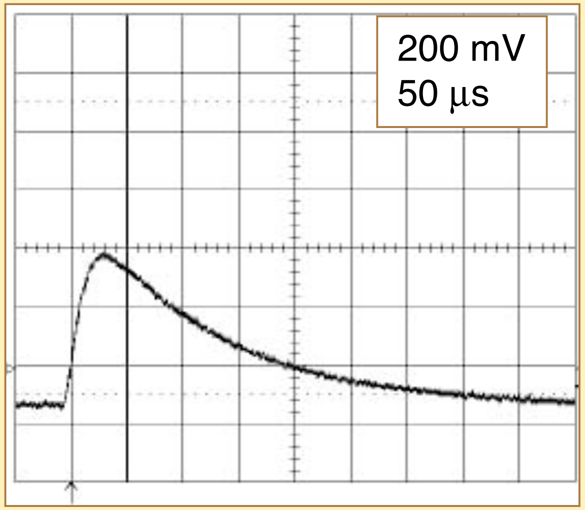
→ Higher gain reached as with one stage, with good stability

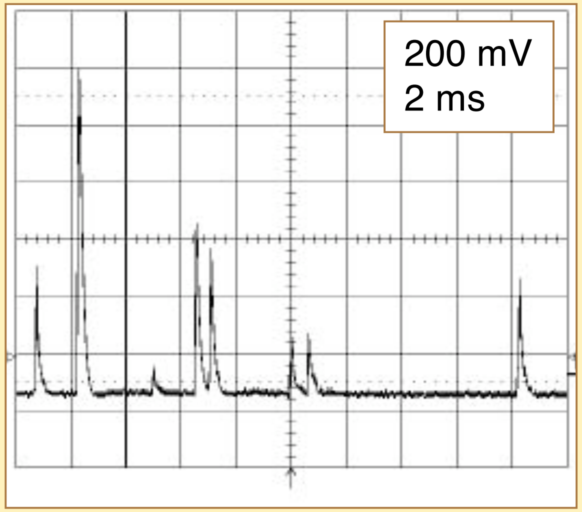
Two-stage LEM: measurements and prospects



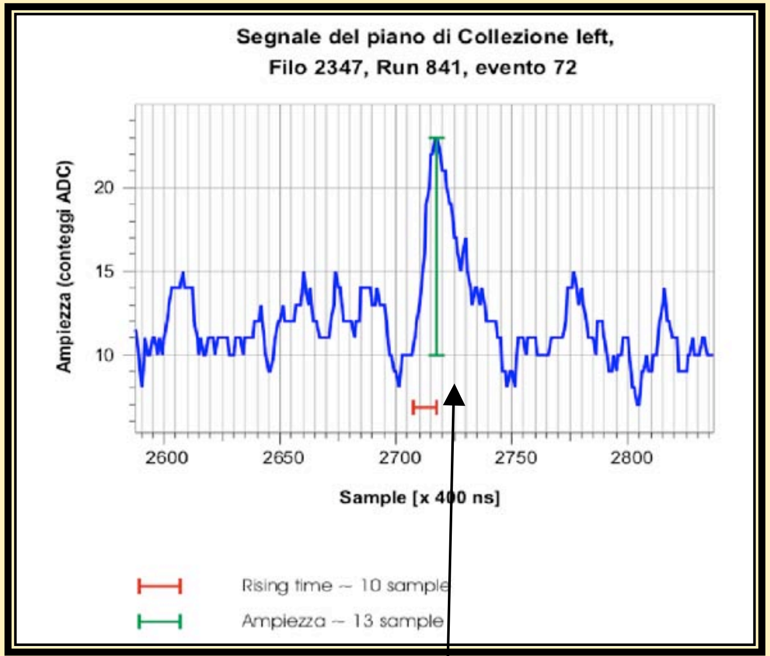


Shapes from Fe^{55} radioactive source (5.8 keV, event rate about 1kHz) of the signals from double-stage LEM system have a very clean S/N ratio.





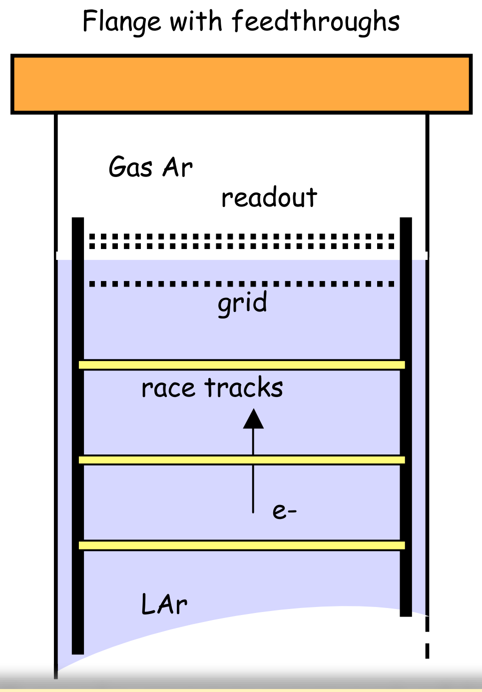
MIP signal in ICARUS T300



This technique solves the non-scalability of the traditional wire readout used in ICARUS
E.g. MIP signal @ ≈2 MeV/cm has poor S/N !

Full imaging TPC with LEM to be tested in 1 ton prototype @ CERN

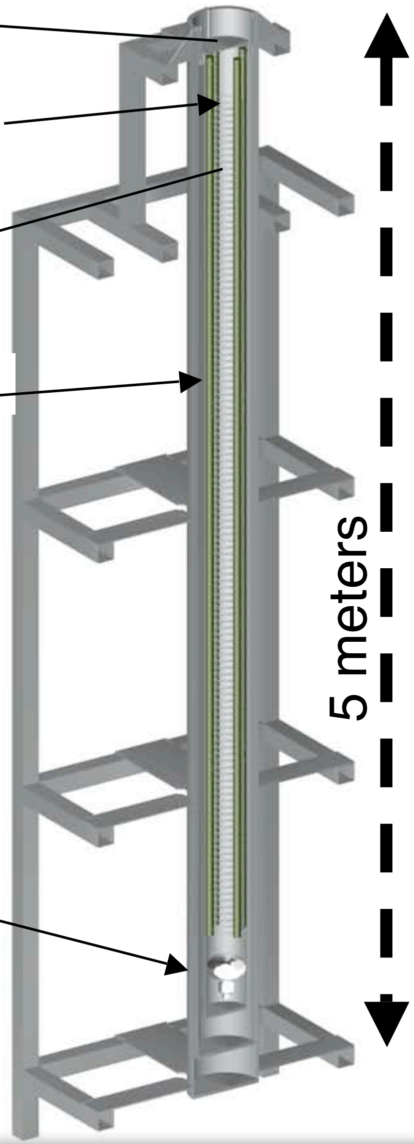
Long drift, extraction, amplification: "ARGONTUBE"

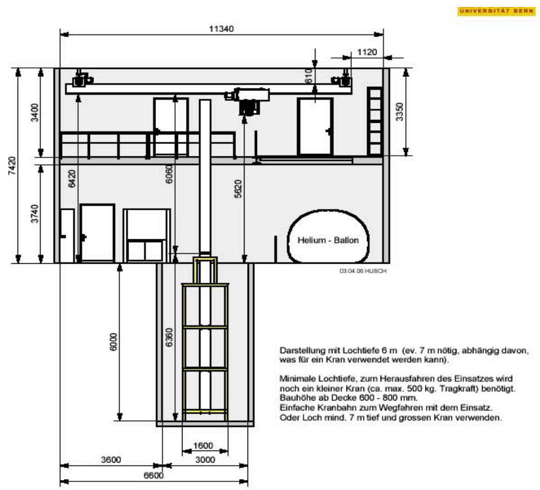


Extraction from LAr to GAr and LEM readout

Field shaping electrodes

8" PMT ET 9357FLA





- 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)
- Measurement Rayleigh scatt. length and attenuation length vs purity
- Design & assembly:

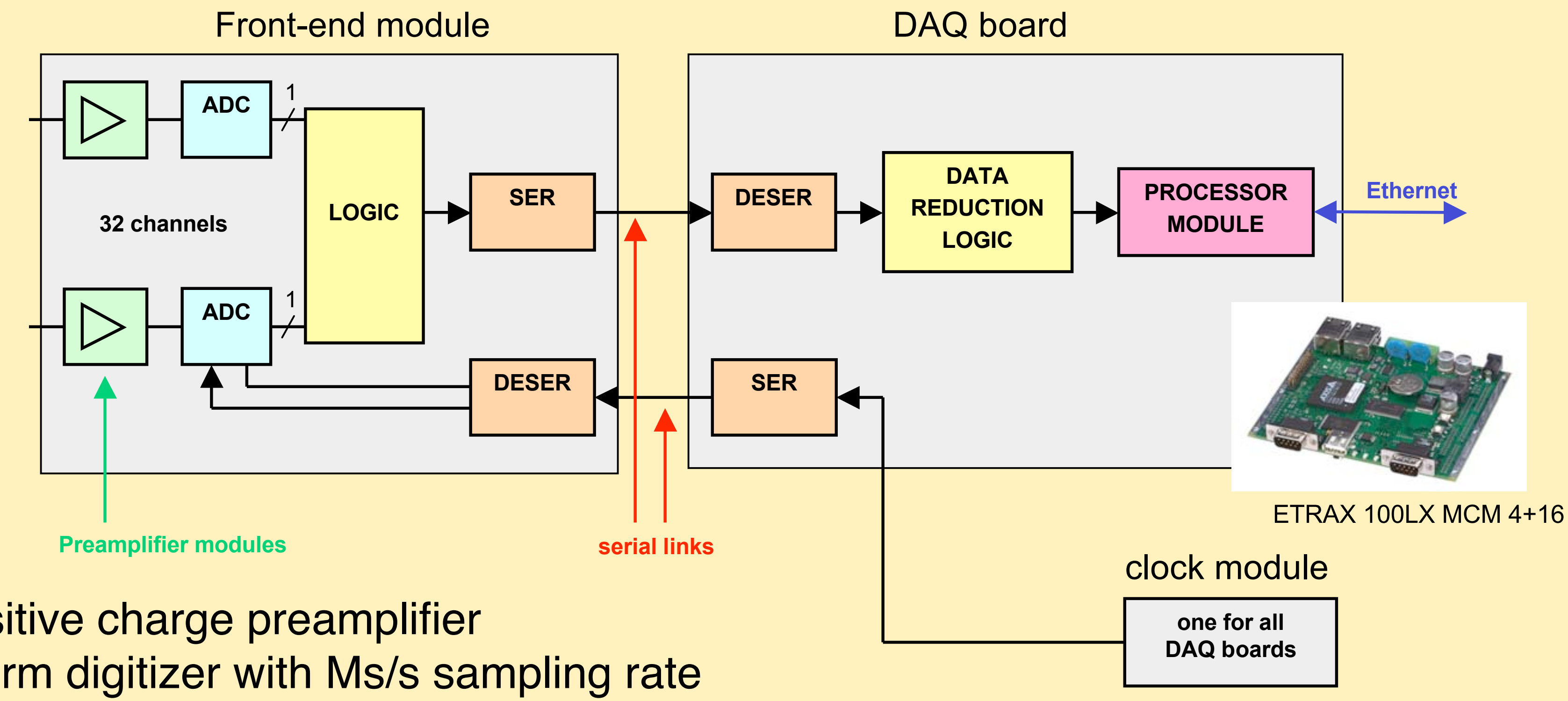
completed: external dewar, detector container

in progress: digging of hole in ground, …

Install at the U. of Bern

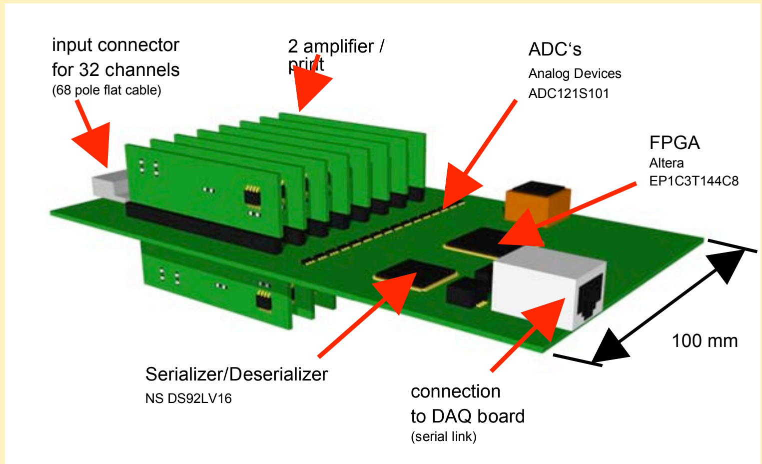
In Collaboration between Univ. Bern & ETHZ & Granada

Large number of channels waveform digitizers



- fC-sensitive charge preamplifier
- Waveform digitizer with Ms/s sampling rate
- Zero suppression
- No dead-time
- Embedded processor for high level data compression and network connection
- Many channels / unit
- Affordable (<50€/channel)

Need >100K channels



26.06.2006
Max Hess

WP2

Underground Tanks

Study the constructability large underground tanks
Study their operability underground

Tanks above surface

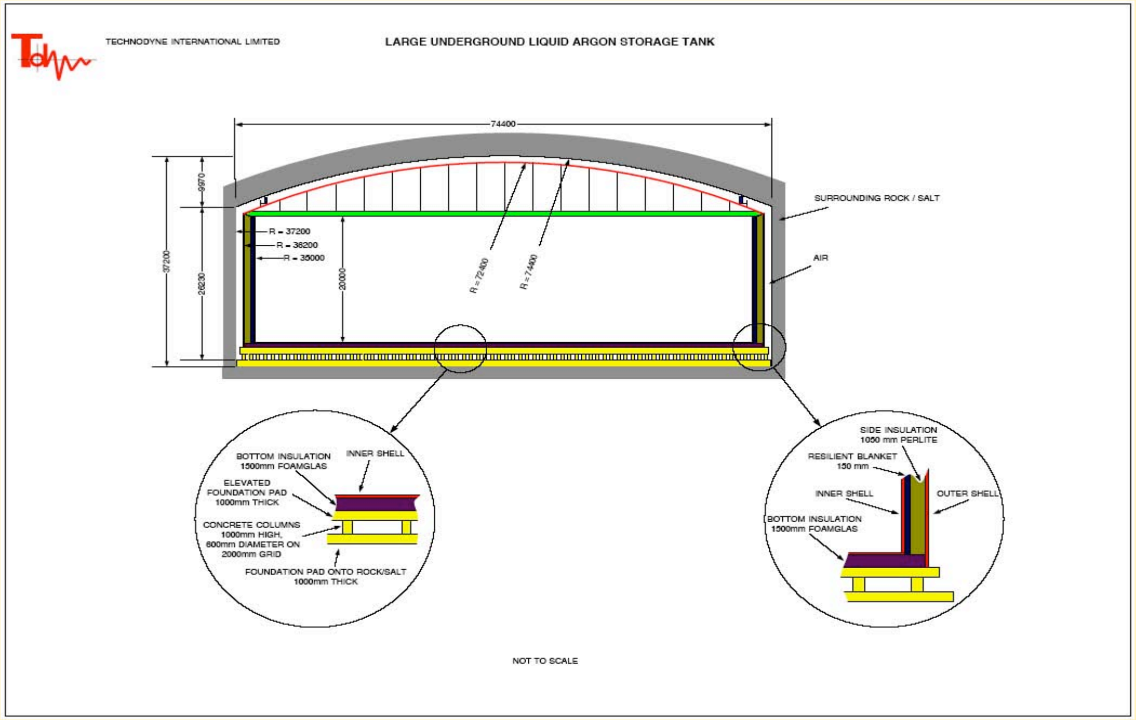
- Rules defined in Part 4-2 of EUROCODE 3 **(EUROCODES = The rules for design in civil engineering on a new, pan-European basis)**
- Provides principles and application rules for the structural design of vertical cylindrical above ground steel tanks for the storage of liquid products with the following characteristics
  - ➥ Characteristic internal pressures above the liquid level not less than -100mbar and not more than 500 mbar
  - ➥ Design metal temperature in the range of -50ºC to +300ºC. For tanks constructed using austenitic stainless steel, the design metal temperature may be in the range of -165ºC to +300ºC;
  - ➥ Maximum design liquid level not higher than the top of the cylindrical shell.
  - ➥ EN 1993-4-2 is concerned only with the requirements for resistance and stability of steel tanks. Other design requirements are covered by
    - ☛ **prEN 14015 for ambient temperature tanks;**
    - ☛ **prEN 14620 for cryogenic tanks;**
    - ☛ **prEN 1090 for fabrication and erection considerations**.These other requirements include foundations and settlement, fabrication, erection and testing, functional performance, and details like man-holes, flanges, and filling devices.
  - ➥ Provisions concerning the special requirements of seismic design are provided in EUROCODE 8, Part 4, which complements the provisions of EUROCODE 3 specifically for this purpose. The design of a supporting structure for a tank is dealt with in EN 1993-1-1. The design of an aluminum roof structure on a steel tank is dealt with in EN 1999-1-5.

Study of large underground storage tank

Project: Large Underground Argon Storage Tank

Document Title: Study

A feasibility study mandated to Technodyne LtD (UK): a unique opportunity!



Study duration:

February - December 2004

Tanks located underground

- Worldwide for LNG storage the largest above ground tank that has been built to date is the 180,000m^3 tank at Senboku Japan. The industry also perceives the requirement to increase the capacity to above 200,000m^3 in the near future. It is feasible to increase the tank capacities of Concrete / 9% Ni Steel storage tank designs to capacities above 200,000 m^3

- Underground tanks contemplated for physics experiments are <u>relatively small</u> compared to those used by the petro-chemical industry for <u>above ground</u> storage of materials.

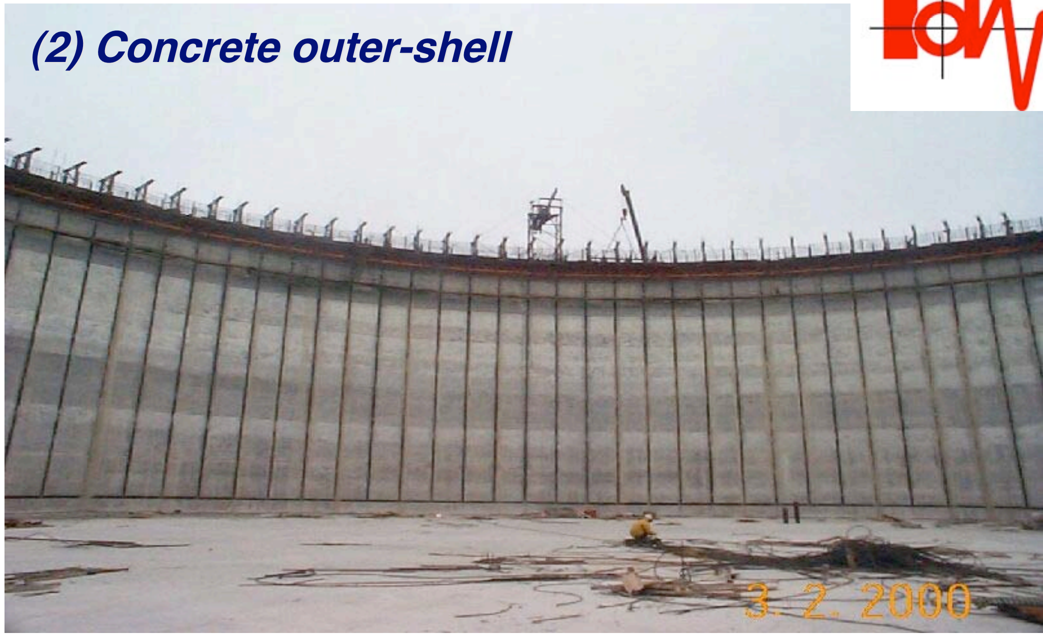
- **<u>Outcome of study with Technodyne</u>**: The principles used in the design of above ground storage tanks should be readily transferable to an underground scenario.

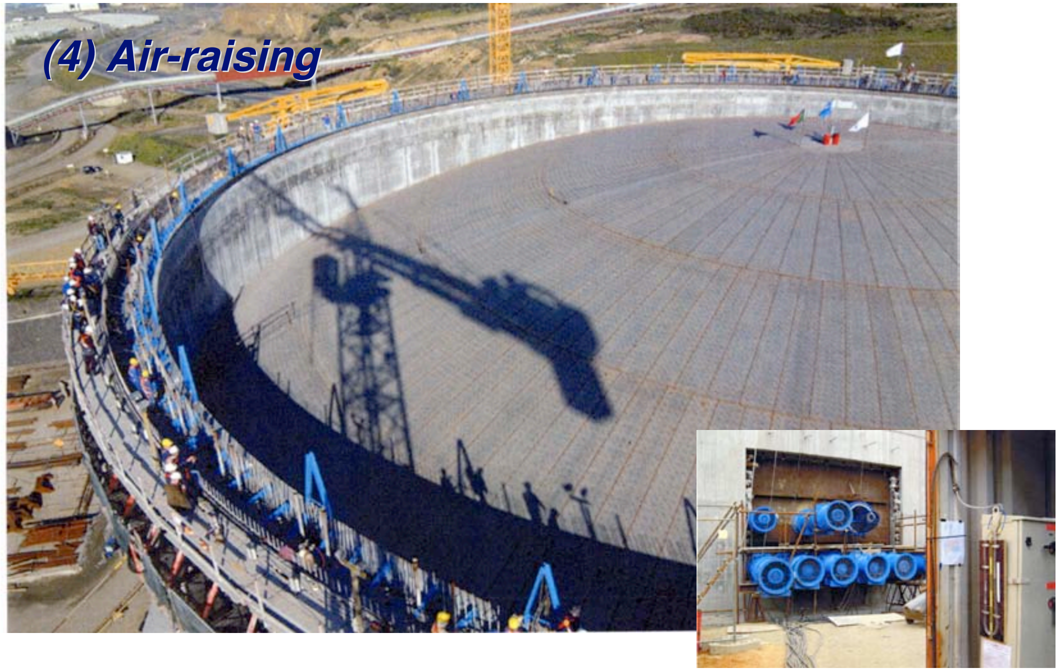
- Extra considerations will obviously have to be taken into account when underground however, other design considerations such as wind loading and solar heating effects are eliminated from the above ground case.

Underground construction

- In an above ground scenario the large tanks described above are usually constructed using common civil construction techniques. As there is no restriction on headroom the use of large cranes is normal. In the underground scenario it is less likely that there will be enough headroom to allow the use of large cranes. The domed roof is normally constructed on the bottom of the tank and then raised and welded in place using air pumped into the vessel.
- This technique is commonly used when manufacturing these types of tank and does not present a problem underground. The only requirement being a supply of electricity to power the air fans needed to raise the roof.
- An alternative technique could then to be employed where the roof is built first together with the top ring of the shell. The assembly would then be jacked up about 3m and the next lower ring installed. Successive ring welding / jacking operations would be performed until the shell is completed without the use of a large crane. This is a common technique for large diameter oil storage tanks.
- The order of construction of the tank would be as follows:
  - ☛1. Base
  - ☛2. Roof and deck
  - ☛3. Outer shell
  - ☛4. Base insulation
  - ☛5. Inner shell base
  - ☛6. Inner shell
  - ☛7. Insulation

Erection of a tank above surface





Tank budgetary costing

- The estimated costs tabulated below are for an inner tank of radius 35m and height 20m, an outer tank of radius 36.2m and height 22.5m. The product height is assumed to be 19m giving a product mass of 101.8 k tonnes.

Item	Description	Size	Million Euros
1	Steel	3400 tonnes	11.6
2	Insulation	16200 m^3	2.6
3	Concrete	9000 m^3	2.7
4	Electro-polishing	38000 m^2 Plate 20.5 km weld	8.2
5	Construction design / labour		18.8
6	Site equipment / infrastructure		9.8
	Total		**53.7**
6	Underground factor		2.0
	Underground tank cost		107.4

Too conservative?

Design study will address additional cost for underground construction

WP5

Sites

Study the feasibility of very large excavations including access
Compare local conditions
Pre-select suitable sites

WP5: Site investigation

- Work closely with Integrated Large Infrastructure for Astroparticle Science ILIAS-N2-WG1
  - And respective WG in ILIAS-next
  - ILIAS N2: propose to organise a technical meeting on site expansions and technical issues in November 2006

- Pre-feasibility studies
    - Partially done (Fréjus, Pyhäsalmi)
    - Extend to LNGS, Sieroszowice, …
    - Green fields
  - Report on constructability: possible show-stoppers

- Feasibility studies (for all sites)

  Including thorough rock sampling, rock simulations
  - Pre-plan for construction
  - Cost estimates
  - Site pre-selection

- Final goal $\Rightarrow$ Detailed plans for site construction

Where?

IUS

Institute of Underground Science in Boulby mine, UK

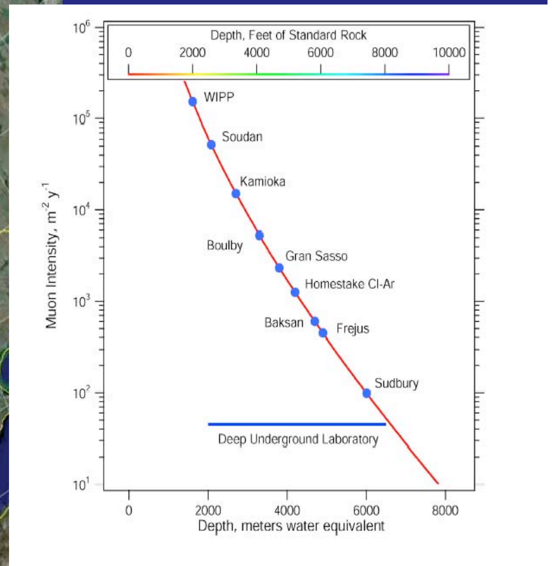
Laboratoire Souterrain de Modane, France

CENTRE FOR UNDERGROUND PHYSICS IN PYHÄSALMI MINE

Currently there is no available sight to host very large scale detectors in Europe!

- New facilities will have to be excavated or old one extended
- What depth?
- What other synergies? (beamline distance)
- What is the distance from reactors?

Polkowice-Sieroszowice



LSC

Laboratorio Subterraneo de Canfranc, Spain

LNGS

Laboratori Nazionali del Gran Sasso, Italy

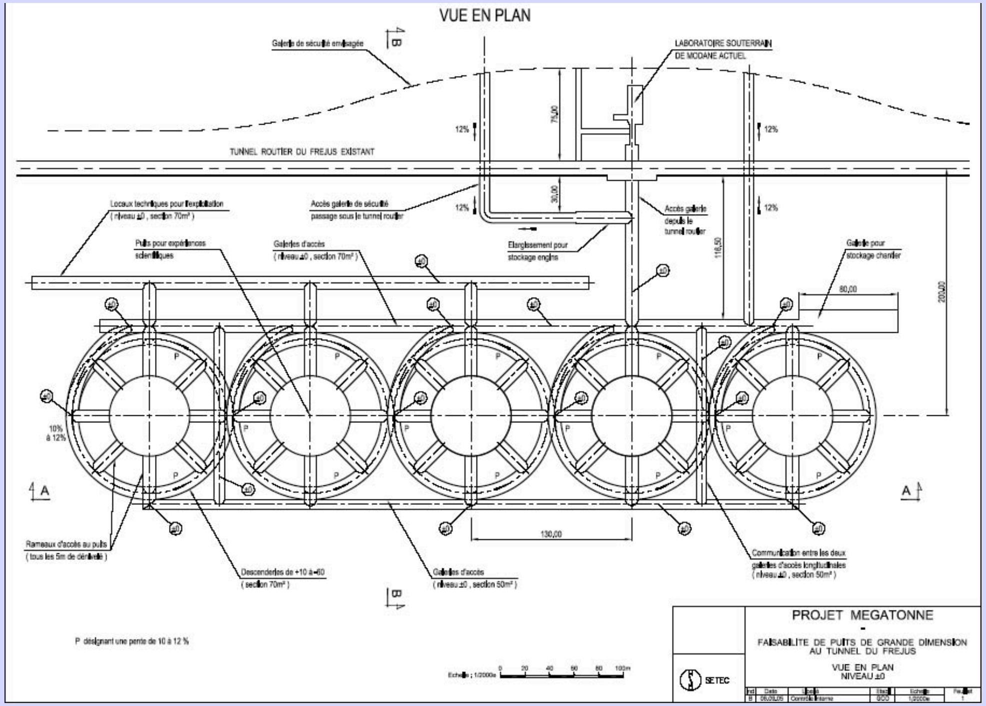
Very preliminary sites vs experiments

		Mt Water Cerenkov	Liquid Scintillator	Liquid Argon
Fréjus	Tunnel / hard rock	√ √ √	√ √	√ √
Gran Sasso	Tunnel / soft rock	√	√ √	√ √
Canfranc	Tunnel	?	?	?
Pyhäsalmi	Mine / hard rock	√	√ √ √	√ √
Boulby	Mine / salt (potash)	?	?	?
Polkowice - Sieroszowice	Mine / salt & rock	√	√ √	√ √ √
Green fields	Own shaft / Hard rock	√	√	√ √

√ √ √ primary interest; √ √ probably; √ unlikely; ? unknown

Pre-feasibility study in the central region of Fréjus tunnel

Excavation engineering pre-study has been done by SETEC & STONE companies



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

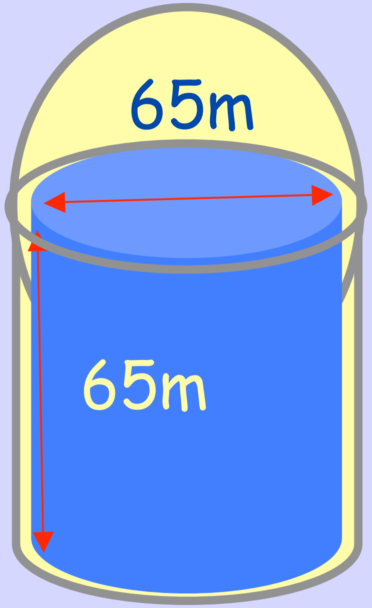
2) of the two considered shapes : “tunnel” and “shaft”, the “shaft (= well) shape” is strongly preferred

3) Cylindrical shafts are feasible up to :

a diameter Φ = 65 m and a full height h = 80 m (≈ 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



Scenarios:

3 shafts ≈ 450 ktons H2O

4 shafts ≈ 600 ktons H2O

+1 shaft ≈ 100 kton LAr ?

Sieroszowice mine (Poland) - big salt cavern

Copper – 6^{th} position
in the world's exploitation ranking

Silver – 2^{nd} position
But also Salt

A. Zalewska

Volume (100x15x20) m^3

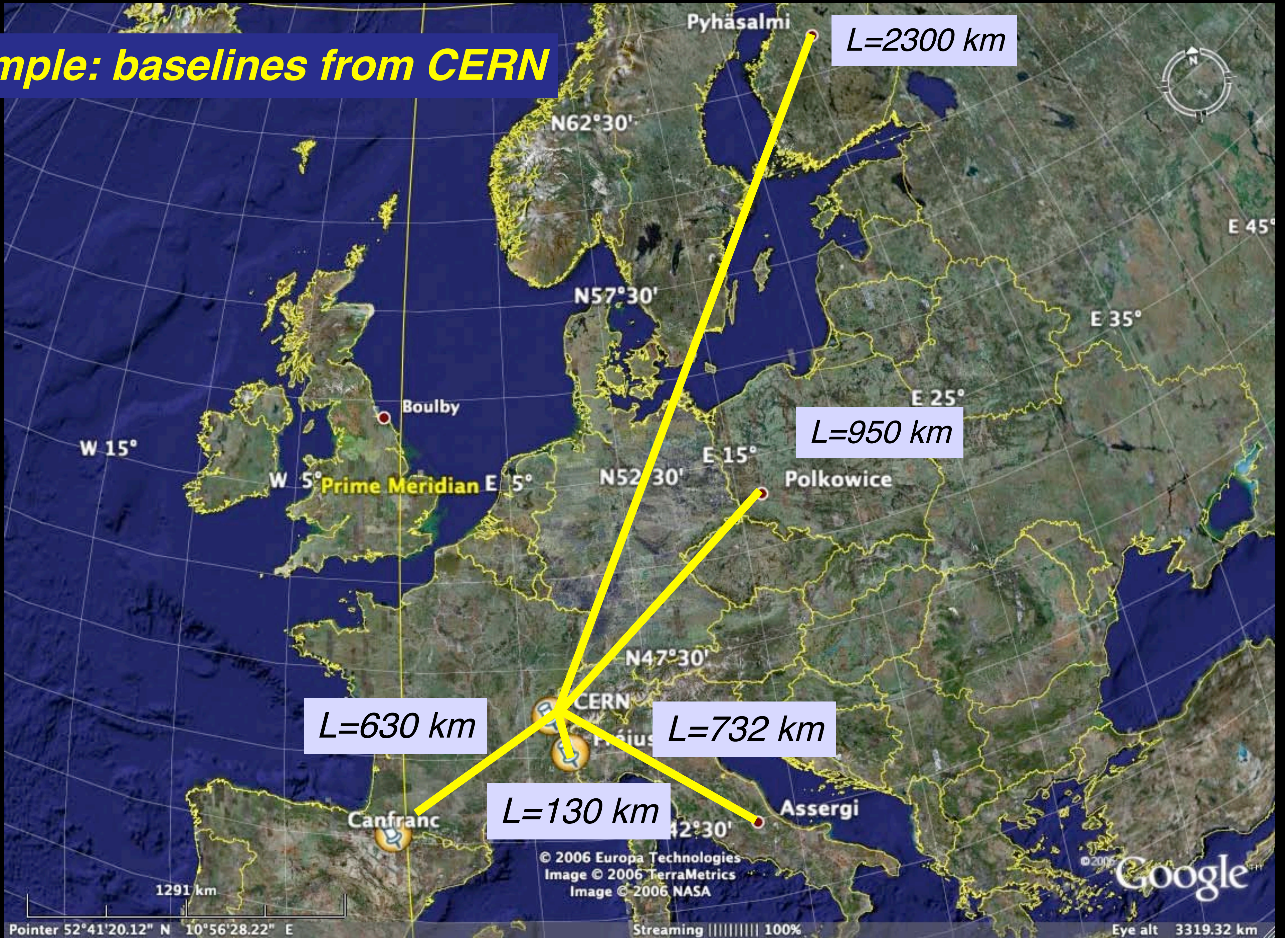
Depth ~950 m from a surface

Salt layer ~70 m thick

Temperature ~35^0C

Very good radioactive background conditions

Example: baselines from CERN



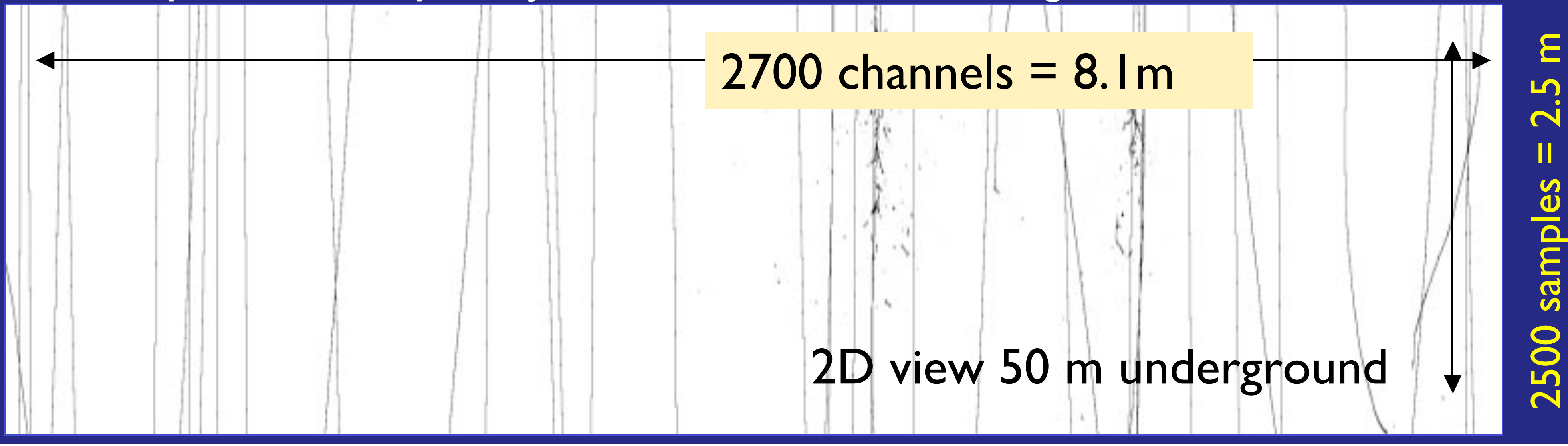
Anywhere ? Shallow depth in green field

If rock is well known and <u>very good quality</u> in a given site, a new hole in virgin ground can be considered:

- 200 m depth relatively “easy”
- Excavation cost ≈ 5-10 M€ for shaft and ≈20M€ for 100 kton LAr experimental hall
- 1400 m possible ≈ +20 M€ (J. Peltoniemi)

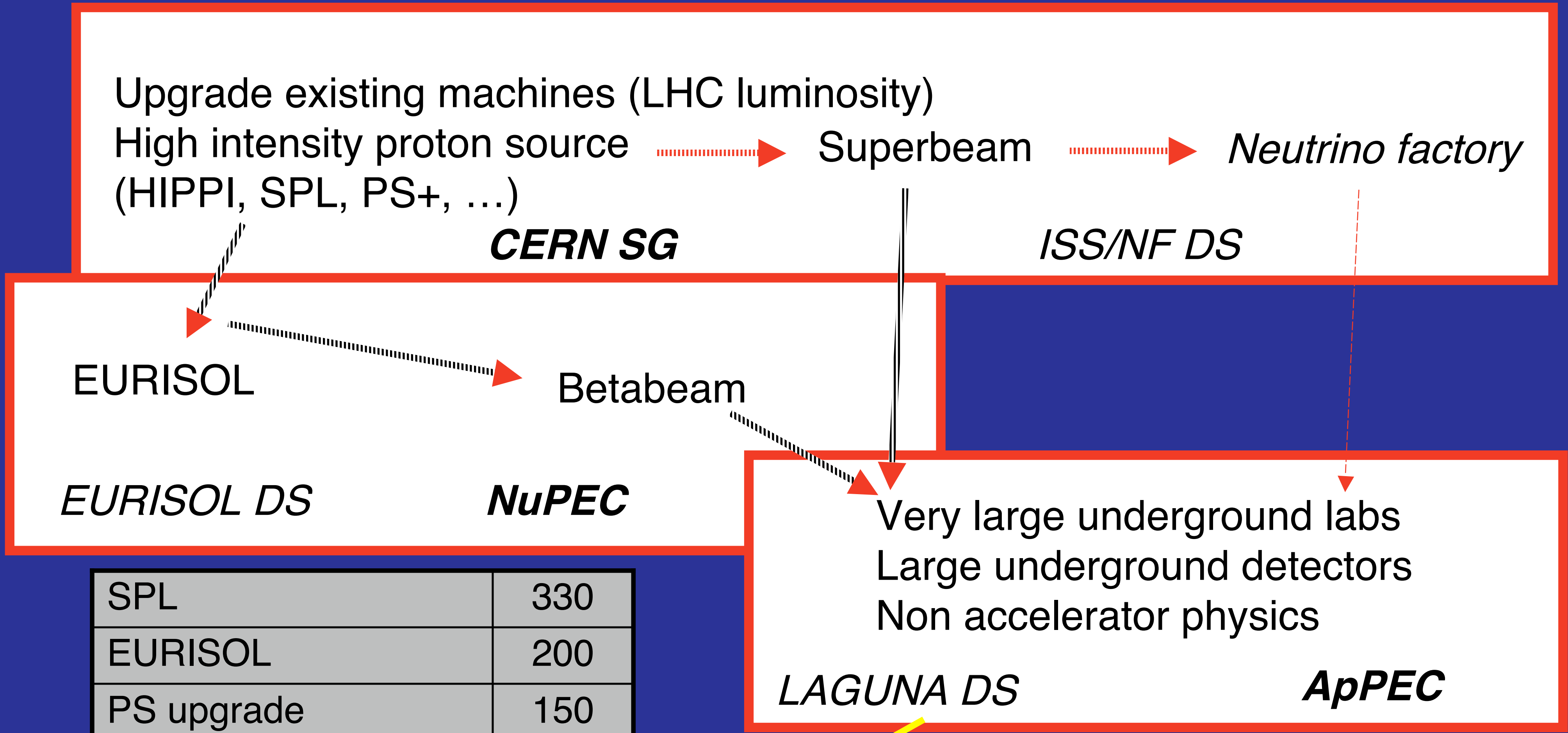
Depth rock	**Total crossing muons (E> 1GeV) per 10ms**	**Fiducial mass after slice of size D around each muon is vetoed**
		D=10 cm
Surface	**13000**	…
50 m	**100**	50 kton
188 m	**3.2**	98 kton
1 km w.e	**0.65**	100 kton
2 km w.e	**0.062**	100 kton
3 km w.e	**0.010**	100 kton

Example of occupancy in LAr @ 50 m underground:



Outlook

Overall picture of activities (and dreams…)



SPL	330
EURISOL	200
PS upgrade	150
Superbeam	70
β decay ring	340
Lab + detectors	500
Total	**1500**

Rough cost in M€ (no manpower, no contingencies)

Outlook

- Around 2011-2012 after a few years of running of LHC and T2K&NovA, there will be a new landscape concerning supersymmetry, unification, and hopefully the last unknown neutrino mixing angle θ_{13}.

- These will also be the times of world distribution of new very large infrastructures.

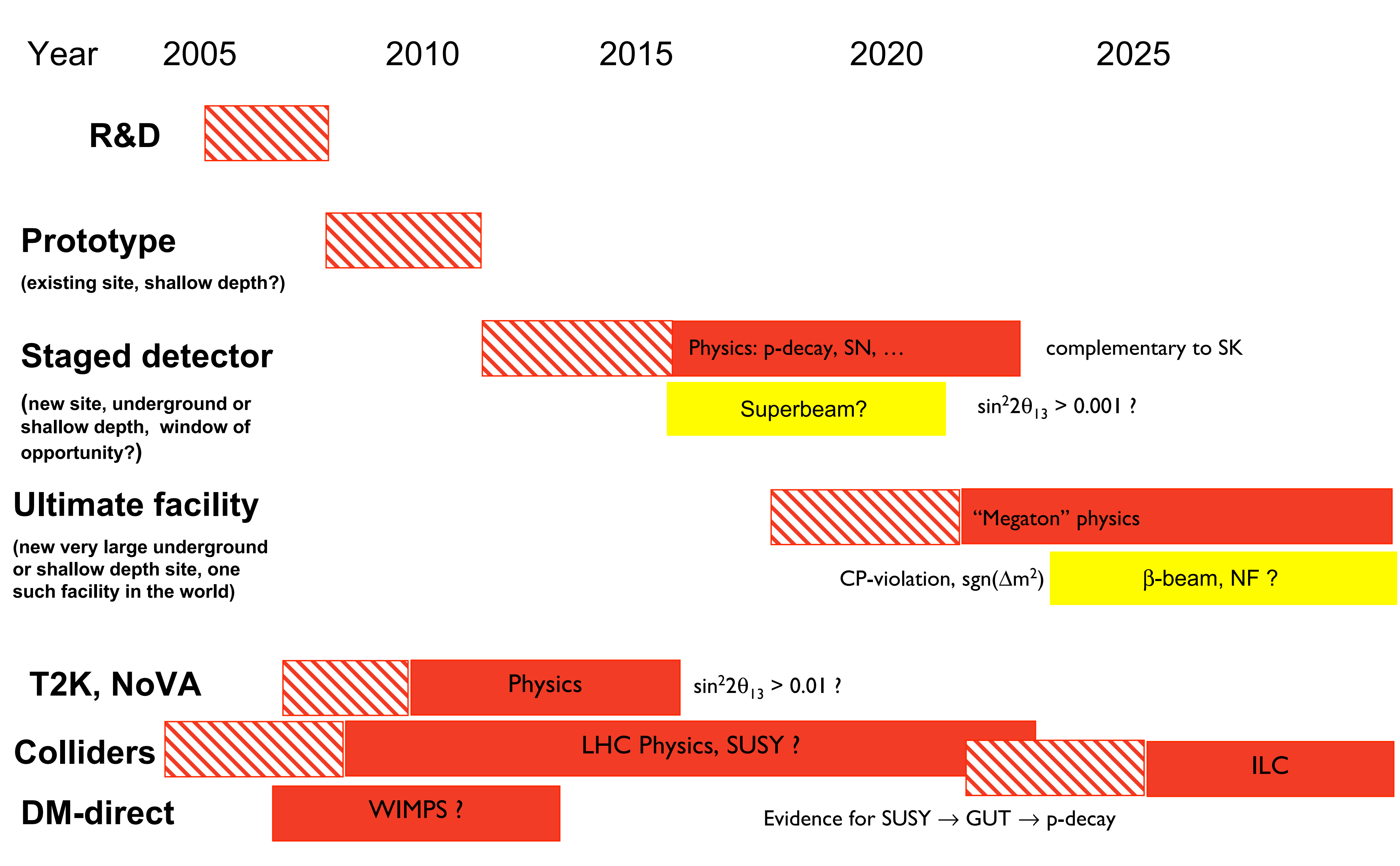
- Large detectors like Water Cherenkov, Liquid Scintillator and Liquid Argon present important physics complementarities (e.g flavours of proton decay, type of neutrinos in supernova searches) and also a lot of common R&D needs (cavities, photodetection). They will work in synergy.

- In Europe a common design study for FP7 will help reach the required critical mass needed to study the three options with the required level of details. Worldwide coordination (e.g. NNN workshops) will benefit from a better coordinated EU effort.

- The large underground detector physics program concerns both non-accelerator/astroparticle physics and neutrino accelerator physics. THIS IS A GREAT ASSET and it will be taken properly into account.

Backup slides

Possible sequence of events



Rough Cost Estimate in MEuro for GLACIER

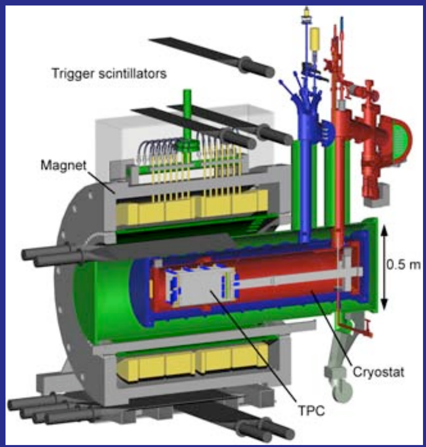
Item	100 kton	10 kton
LNG tanker (see notes 1-2)	50÷100	20 ÷ 30
Merchant cost of LAr (see note 3)	100	10
Refilling plant	25	10
Purification system	10	2
Civil engineering + excavation	30	5
Forced air ventilation	10	5
Safety system	10	5
Inner detector mechanics	10	3
Charge readout detectors	15	5
Light readout	60 (with Č)	2 (w/o Č)
Readout electronics	10	5
Miscellanea	10	5
Total	340 ÷ 390	≈ 80 ÷ 90

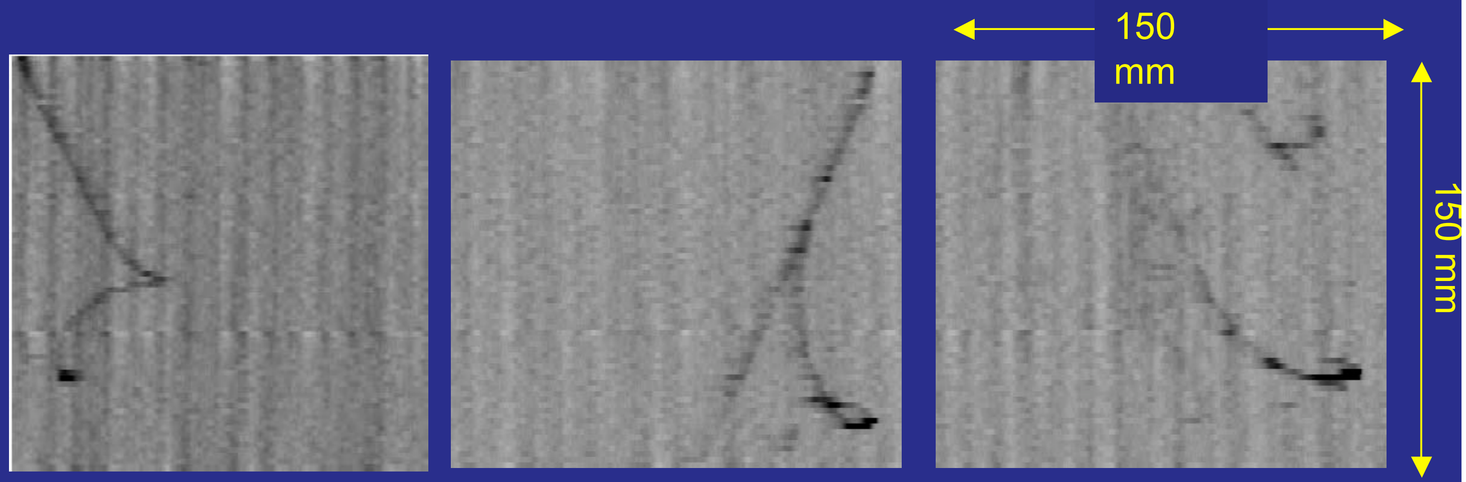
Notes:
(1) Range in cost of tanker comes from site-dependence and current uncertainty in underground construction
(2) Cost of tanker already includes necessary features for LAr TPC (surface electropolishing, hard roof for instrumentation, feed-throughs,…)
(3) LAr Merchant cost ≠ production cost. Fraction will be furnished from external companies and other fraction will be produced locally (by the refilling plant)

Small scale test 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
NIM A 555 (2005) 294





New test: small test solenoid built wit HTS wire (American Superconductor)

Made of 4 pancakes, total HTS wire length: 80m

Temperature	LN_2 (77K)	LAr (87K)
Max. applied current	145 A	80 A
On-axis B-field	0.2 T	0.11 T
Coil resistance at 4A	6 μΩ	6 μΩ