Future detectors for low energy neutrino astronomy: LAGUNA, LENA and Hano-hano

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Reims 21.10.09

Outline

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1. LAGUNA physics and detector concepts
2. LENA physics and design
3. Hano-hano project
4. Organic scintillators
5. Summary

LAGUNA

Large Apparatus for Grand Unification and Neutrino Astrophysics

- European underground laboratory design study (2008 – 2010) funded with 1.7 ME by the EU
- Study of six possible locations:
  - Canfránc (Spain)
  - Fréjus (France)
  - Boulby (England)
  - Pyhäsalmi (Finland)
  - Sieroszewice (Poland)
  - Slanic (Romania)

Scientific paper: D. Autiero *et al.*, JCAP 0711, 011 (2007)

Physics of LAGUNA: Proton Decay

Non supersymmetric Grand Unified Theories

Dominant decay mode: $p \to e^+\pi^0$ $\tau \leq 1.4 \cdot 10^{36}$ y

Supersymmetry (SUSY)

Dominant decay mode: $p \to K^+\overline{\nu}$ $\tau \sim (0.3 - 3) \cdot 10^{34}$ y

Extra dimensions (6D)

Dominant decay mode: $p \to e^+\pi^0$ $\tau \sim 10^{35}$ y

(Limits from P. Nath 2006 and S. Raby 2002)

- Superkamiokande: $\tau(p \to e^+\pi^0) \gtrsim 8.2 \cdot 10^{33}$ y (90% C.L.)
  $\tau(p \to K^+\overline{\nu}) \gtrsim 2.3 \cdot 10^{33}$ y (90 % C.L.)

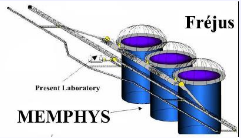
Physics of LAGUNA: Low Energy Neutrino Astrophysics

- Supernova explosion
  - High statistics in the energy spectrum of different ν-flavours
  - Time evolution of the neutrino emission
  - Neutrino properties: oscillation parameters
- Diffuse background of supernova neutrinos
  - Understanding of the explosion mechanism of a SN
- Solar neutrinos
  - High statistics measurements
- and Geophysics
  - Measuring radioactivity of the Earth with geoneutrinos

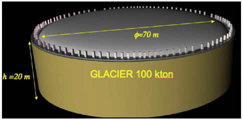
Physics of LAGUNA: Neutrino Properties

- Atmospheric neutrinos:
    - Improve the measurement of $\sin^2\theta_{23}$
- Reactor:
    - Precise measurement on $\Delta^2 m_{12}$ and $\sin^2\theta_{12}$
- Detectors for accelerator experiments: θ_{13} and δ_{CP}
    - Beta beams
    - Super beams
    - Neutrino factories

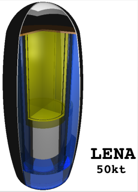
LAGUNA detector concepts



- MEMPHYS - MEgaton Mass PHYSics
  - 80 m heigth $\times$65 m $\varnothing$
  - $\sim$500 kt water Cherenkov detector
  - 81 000 PMTs per shaft (30% coverage)



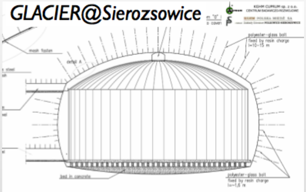
- GLACIER - Giant Liquid Argon Charge Imaging ExpeRiment
  - 20 m heigth $\times$70 m $\varnothing$
  - $\sim$ 100 kt liquid Ar TPC
  - Light (28 000 PMTs) + charge readout

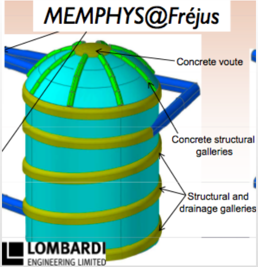


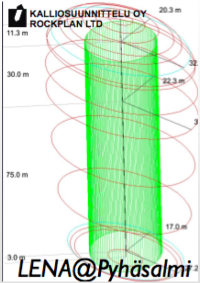
- LENA - Low Energy Neutrino Astronomy
  - 100 m long $\times$ 30 m $\varnothing$
  - $\sim$ 50 kt liquid scintillator
  - 13 500 PMTs for 30% coverage

Typical questions addressed in LAGUNA:

- rock mechanics of caverns
- design of tanks in relation to sites
- overburden vs. detector options
- logistic: transport, access, delivery of liquids
- safety (tunnel vs. mine) and environment (rock removal)
- relative costs







LAGUNA Design Study

- Design Study (EU funded): 2008 - 2010
- Prioritize the sites and down-select: July 2010
- Prioritize detector options: 2011 - 2012
- Phase 1 construction: 2012 - 2016

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DETECTOR LAYOUT

Cavern
height: 115 m, diameter: 50 m
shielding from cosmic rays: ~4,000 m.w

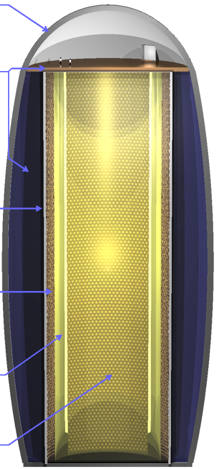
Muon Veto
plastic scintillator panels (on top)
Water Cherenkov Detector
1,500 phototubes
100 kt of water
reduction of fast
neutron background

Steel Cylinder
height: 100 m, diameter: 30 m
70 kt of organic liquid
13,500 phototubes

Buffer
thickness: 2 m
non-scintillating organic liquid
shielding external radioactivity

Nylon Vessel
parting buffer liquid
from liquid scintillator

Target Volume
height: 100 m, diameter: 26 m
50 kt of liquid scintillator



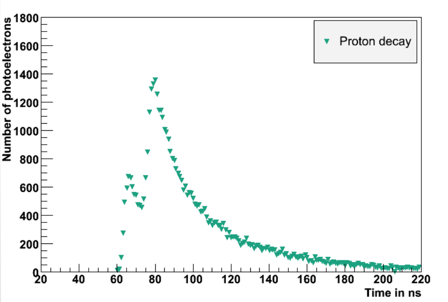
vertical design is favourable in terms of rock pressure and buoyancy forces

Low Energy Neutrino Astronomy

- Size: 100 m length × 30 m ∅
- 50 kt of organic scintillator
- ∼15 000 photosensors (including water veto)
- About 180 pe/MeV light yield
- Current design: vertical cylinder

Proton decay $p \to K^+\overline{\nu}$

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



Potential of LENA in 10 y:

- For Superkamiokande current limit: $\tau = 2.3 \cdot 10^{33}$ y
  - About 40 events and $\lesssim$ 1 bg
- Limit at 90% (C.L) for no detected signal:
  - $\tau > 4 \cdot 10^{34}$ y

Phys. Rev. D, 72, 075014 (2005) and hep-ph/0511230

Supernova detection

8 $M_\odot$ ($3 \cdot 10^{53}$ erg) at D = 10 kpc (galactic center)

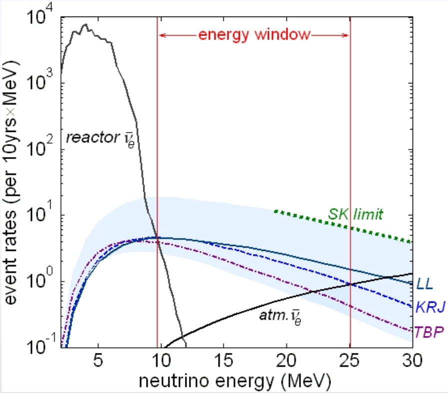
In LENA detector: ~15000 events

Possible reactions in liquid scintillator

- $\overline{\nu}_e + p \rightarrow n + e^+$; $n + p \rightarrow d + \gamma$ ~ 7 500 - 13 800
- $\overline{\nu}_e + {}^{12}\mathrm{C} \rightarrow {}^{12}\mathrm{B} + e^+$; ${}^{12}\mathrm{B} \rightarrow {}^{12}\mathrm{C} + e^- + \overline{\nu}_e$ ~ 150 - 610
- $\nu_e + {}^{12}\mathrm{C} \rightarrow e^- + {}^{12}\mathrm{N}$; ${}^{12}\mathrm{N} \rightarrow {}^{12}\mathrm{C} + e^+ + \nu_e$ ~ 200 - 690
- $\nu_x + {}^{12}\mathrm{C} \rightarrow {}^{12}\mathrm{C}^* + \nu_x$; ${}^{12}\mathrm{C}^* \rightarrow {}^{12}\mathrm{C} + \gamma$ ~ 680 - 2 070
- $\nu_x + e^- \rightarrow \nu_x + e^-$ (elastic scattering) ~ 680
- $\nu_x + p \rightarrow \nu_x + p$ (elastic scattering) ~ 1 500 - 5 700

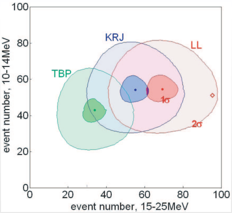
Diffuse Background of Supernova Neutrinos

$\overline{\nu}_e$-neutrino spectrum



In LENA detector: (44 kt f.v.)
Event rate in 10 y:

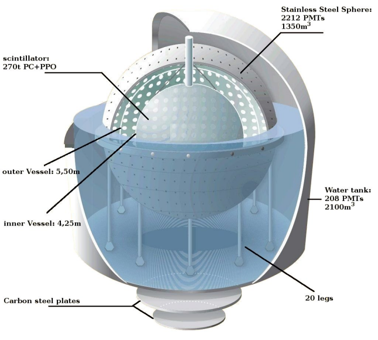
- LL: ∼ 110 events
- TBP: ∼ 60 events



M. Wurm *et al.*, Phys. Rev. D75 023007 (2007)

Information about Star Formation Rate for $(0 < z < 1)$

Solar neutrinos



- Borexino experiment

-> First ^{7}Be neutrino measurement (2007)

Rates of solar neutrino events

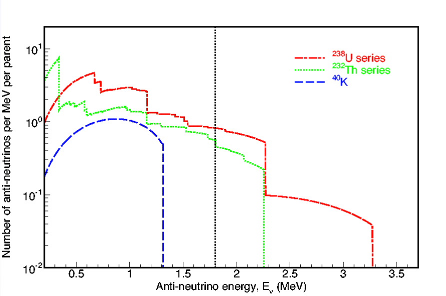
In the LENA fiducial volume:

$$18 \cdot 10^3 \text{ m}^3$$

- ^{7}Be ν's: $\sim$ 5400 d^{-1}
  - Small time fluctuations (1-2 % amplitude detectable at 3σ)
- pep ν's: $\sim$ 150 d^{-1}
  - Information about the pp-flux $\rightarrow$ Solar luminosity in ν's
- CNO ν's: $\sim$ 210 d^{-1}
  - Important for heavy stars
- ^{8}B ν's: CC on ^{13}C: $\sim$ 360 y^{-1}

Geoneutrinos

- Unexplained source of heat flow on Earth
- Unknown contribution of natural radioactivity
- How are ^{238}U, ^{232}Th distributed in core, mantle and crust?



In liquid scintillator:

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

K. Hochmuth *et al.*, Astropart. Phys. 27 (2007) 21

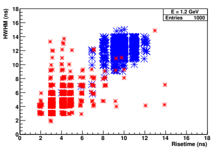
- In LENA detector: $\sim$ (400-4000) events/y (Scaling KamLAND results)
- ^{238}U/^{232}Th separation due to spectral form

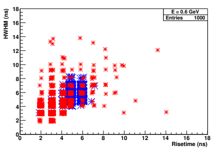
Neutrino oscillations

- Reactor neutrinos $\overline{\nu}_e$
  - Determination of θ_{12} and Δm^2_{12} at Fréjus

    S. T. Petcov and T. Schwetz, Phys. Lett. B642, 487 (2006)
  - Determination of θ_{13} at an underwater location

    J. Kopp *et al.*, JHEP 01, 053 (2007)
- Neutrinos from accelerators
  - Evaluation of muon/electron separation





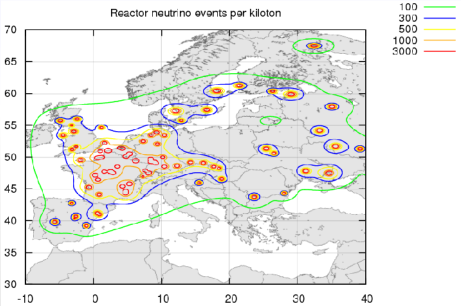
  - Evaluation of track reconstruction

    J. Learned (arXiv:0902.4009) and J. Peltoniemi

Detector location

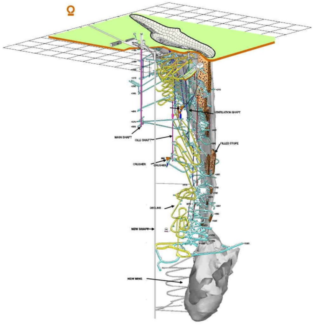
- Deepness: $\sim 4\,000$ m.w.e.
  - Fast neutron background for DSN-$\overline{\nu}$ signal
  - ^{11}C background for solar neutrinos
- Reactor neutrinos
  - Background for DSN
  - Signal for an oscillation experiment

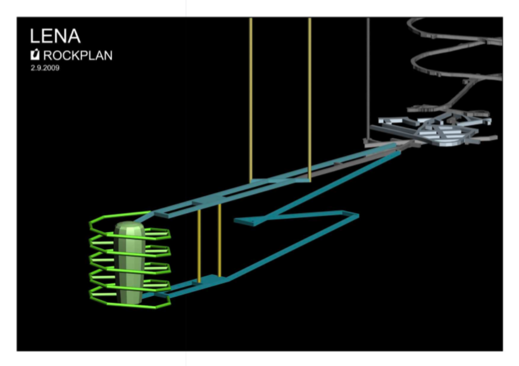
Reactor neutrinos in Europe



from J. Peltoniemi and K. Loo

Pre-feasibility study:
Pyhäsalmi mine
(Finland)



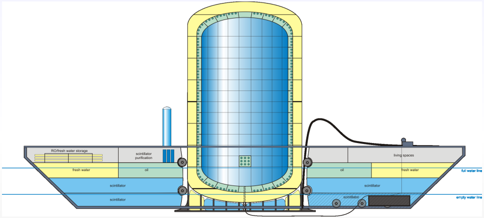


Rockplan study of excavation at 4 000 m.w.e.

- Stability of the cavity
- Tunnels, access ...

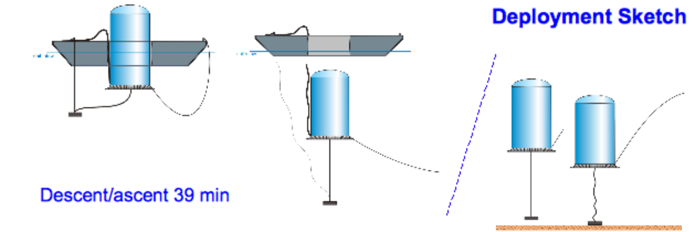
Outline

Hano-hano detector



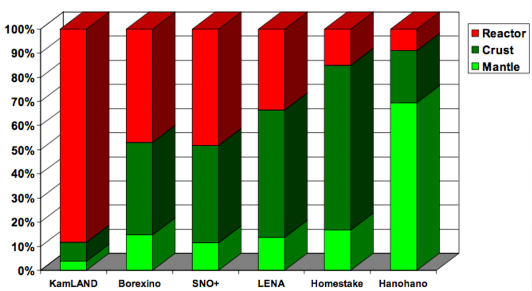
- A deep ocean $\overline{\nu}_e$ observatory
  - multiple deployments
  - water shield against cosmic rays
  - variable L/E detection distance

- J. Learned, S. Dye and B. McDonough
- Joined work with LENA: meeting in July 09 at TU-Munich



- Studied vessel design up to 100 kilotons, based upon cost, stability, and construction ease.
  - Construct in shipyard
  - Fill/test in port
  - Tow to site, can traverse Panama Canal
  - Deploy 4-5 km depth
  - Recover, repair or relocate, and redeploy

Geoneutrino physics with Hano-hano

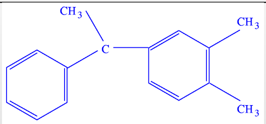
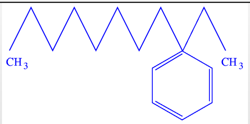


- Determination of the geoneutrino flux at different locations
- Possibility to learn about radiactivity in crust and mantle

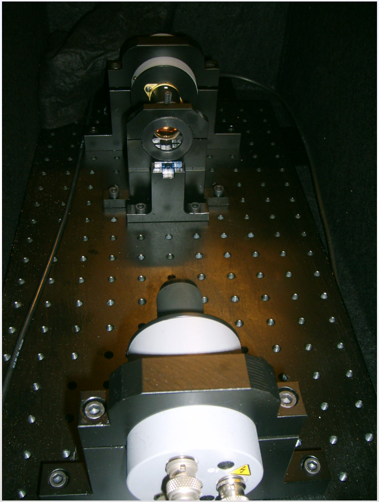
Outline

Why liquid scintillators for neutrino experiments?

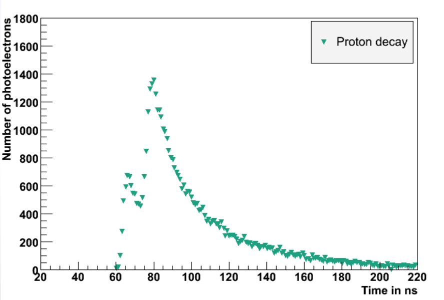
- Enable large detector volumes ($\sim$ ton)
- Low energy threshold ($\sim$ hundreds of keV)
- Good energy resolution (<10% at 1 MeV)
- Fast detector: position reconstruction ($\sim$ cm)
- Particle discrimination (α/β)

PXE: phenyl-o-xylylethan	LAB: linear-alkyl-benzene
	

Fluorescence decay-time measurements

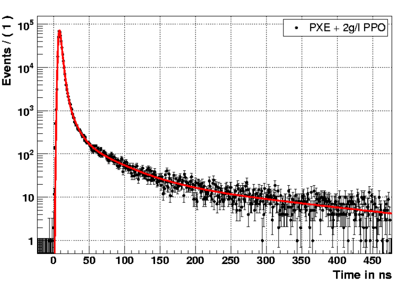


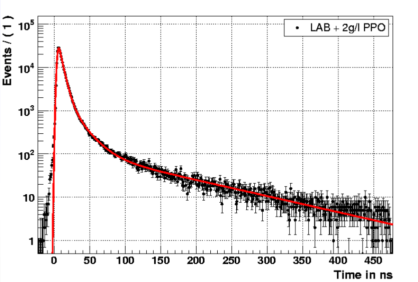
- Motivation: PD identification



- Photon counting method
- ^{54}Mn source: 834 keV γ's
- PMT's time jitter: $\sigma = 0.9$ ns

Photon emission distribution

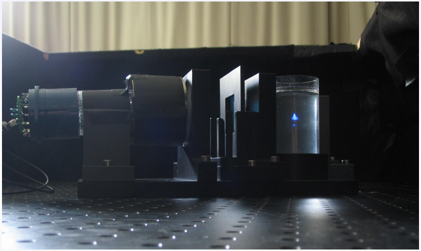




- A short constant τ_1, 2-8 ns -> 60 to 95% of the light
- Mixtures based on LAB are slower than those with PXE
- Influence of the τ_1 on the proton decay sensitivity
  - $\tau > 4.2 \cdot 10^{34}$ y for $\tau_1 = 3$ ns
  - $\tau > 3.5 \cdot 10^{34}$ y for $\tau_1 = 6$ ns

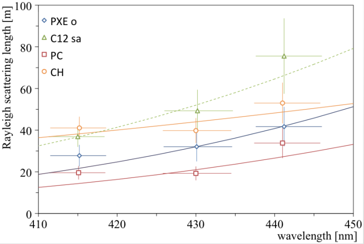
Rev. Sci. Instrum. 80, 043301 (2009)

Scattering length measurements



- Results @ 430 nm

Scintillator	λ_s in m
PXE	22 ± 3
LAB	25 ± 3
Dodecan	35 ± 5



- LED light source
- Detection with PMTs
- Selection of the wavelength with color filters

Outline

Summary

- LAGUNA
  - Ongoing design study for site investigation
  - Final report July 2010
- LENA
  - Physics capabilities presented: neutrino astronomy and particle physics
  - Technical feasibility seems promising
- Hano-hano
  - Main goal is the detection of geoneutrinos
  - Technical feasibility studies

First estimation of LENA total costs

1. Laboratory costs — 75 M€
   - Excavation costs, total 47 M€
   - Site investigations + surface infrastructure 6 M€
   - HEVAC costs, total 22 M€
2. Detector costs — 222 M€
   - Construction costs, total 37 M€
   - Liquid handling 10 M€
   - PMTs (including electronics) 75 M€
   - Liquid scintillator (50 kT) 100 M€
3. Design and consulting costs — 30 M€

   Reservations (risk, unforeseen 25%) — 82 M€

- Total (0% VAT) — 409 M€