Proton decay and neutrino astrophysics with the future LENA detector

Teresa Marrodán Undagoitia
tmarroda@ph.tum.de

Institut E15
Physik-Department
Technische Universität München

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Outline

1. LENA physics and design
2. Proton decay and particle physics in LENA
3. Neutrino astronomy
4. Liquid scintillator measurements
5. Summary

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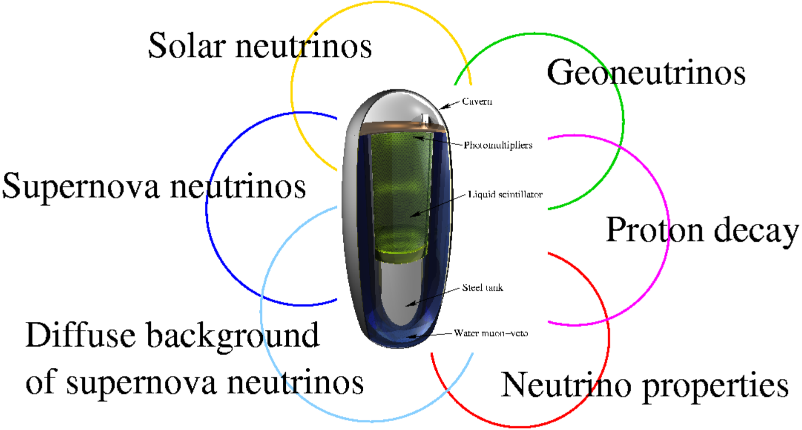
Low Energy Neutrino Astronomy



DETECTOR LAYOUT

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

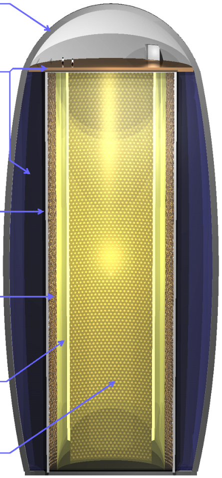
Muon Veto
plastic scintillator panels (on top)
Water Cherenkov Detector
1,500 phototubes
100 kt of water
reduction of fast
neutron background

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

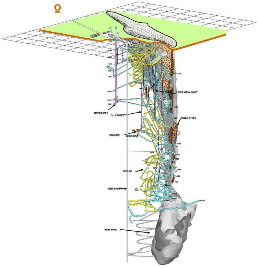
Nylon Vessel
parting buffer liquid
from liquid scintillator

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

- Pre-feasibility study: Pyhäsalmi site



-> Talk by Guido Nuijten

- Studies for other sites: on-going within LAGUNA DS

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Proton decay

- Theoretically favored modes
  - $p \rightarrow e^+\pi^0$
  - $p \rightarrow K^+\overline{\nu}$ -> clear signature in liquid scintillators

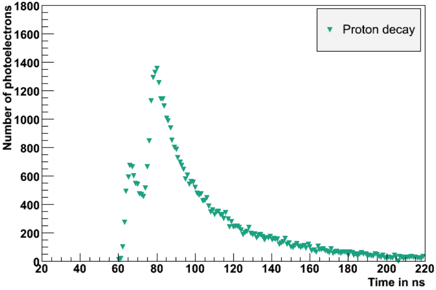
- Predicted lifetimes: $\tau \sim 10^{34}$ y

- Super-Kamiokande best limits:
  $\tau(p \rightarrow e^+\pi^0) \gtrsim 5.4 \cdot 10^{33}$ y (90% C.L.)
  $\tau(p \rightarrow K^+\overline{\nu}) \gtrsim 2.3 \cdot 10^{33}$ y (90 % C.L.)

Free proton decay $p \rightarrow K^+ \overline{\nu}$

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

- $K^+ \rightarrow \mu^+ \nu_\mu$ 63.43%
  - $T(\mu^+) = 152$ MeV
- $K^+ \rightarrow \pi^+ \pi^0$ 21.13%
  - $T(\pi^+) = 108$ MeV
  - $T(\pi^0) = 110$ MeV



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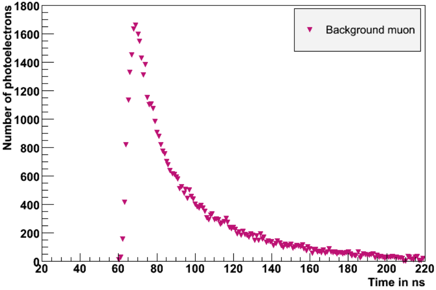
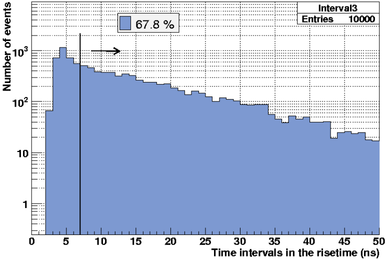
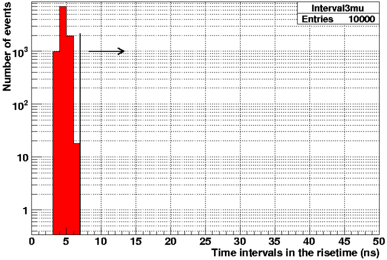
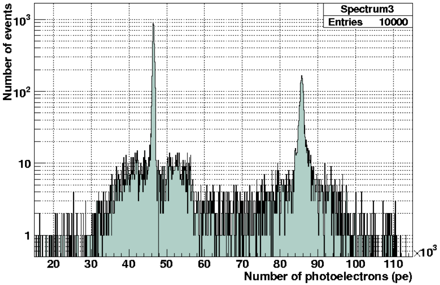


Background rejection





- Pulse-shape analysis on the risetime
- proton decay efficiency of $\sim$ 65%



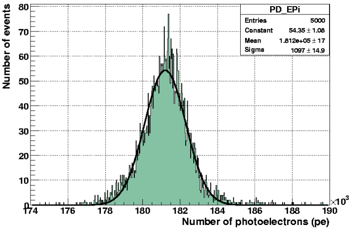
- Energy spectrum (180 pe/MeV)
- Two peaks:
  - Kaon + Muon: ~ 257 MeV
  - Kaon + Pions: ~ 459 MeV
- Efficiency: $\varepsilon_E = 0.995$
- Included: protons from ^{12}C

Potential of LENA (10 y measuring time)

- For Superkamiokande current limit: $\tau = 2.3 \cdot 10^{33}$ y
  - About 40 events in LENA and $\lesssim 1$ background
- Limit at 90% (C.L) for no signal in LENA:
  - $\tau > 4.1 \cdot 10^{34}$ y with $\epsilon = 65\%$

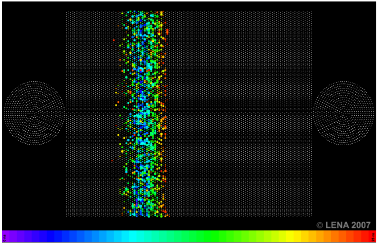
Phys. Rev. D 72, 075014 (2005)

Proton decay $p \rightarrow e^+\pi^0$

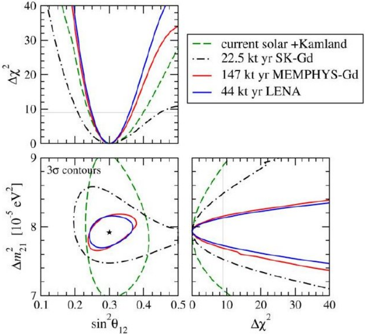


- First calculation:
  - Good energy resolution of LS (< 1%)
  - Narrow energy cut: $B < 1$ event/y
    $\rightarrow$ Low efficiency ($\epsilon =$12%)
  - Achievable sensitivity in 1 year:
    $\tau \sim$ few 10^{32} y

- Possible improvement:
  - background discrimination via *"tracking"*
  - fast scintillator and electronics required



Reactor neutrinos with LENA



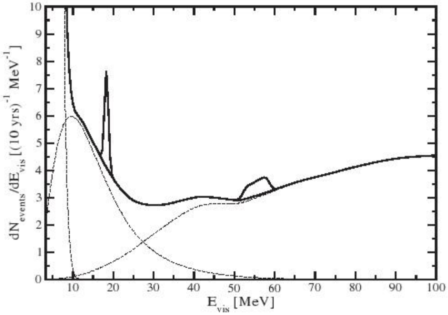
S. T. Petcov and T. Schwetz, Phys. Lett. B642, 487 (2006)

- Determination of θ_{12} and Δm^2_{12}
  - For the Fréjus location
  - After one year measuring time, 3σ precision on oscillation parameters: $\rightarrow$ 20% on θ_{12} and 3% on Δm^2_{12}

J. Kopp *et al.*, JHEP 01, 053 (2007)

- Using a mobile $\overline{\nu}_e$ source (e.g. a nuclear powered ship)
  - For an underwater detector location $\rightarrow$ $\sin^2 2\theta_{13} < 0.004$ after about 3 years

Indirect dark matter search



$\overline{\nu}_e$ energy spectrum in 10 y

S. Palomares-Ruiz and S. Pascoli, Phys. Rev. D 77, 025025 (2008)

- Annihilation of light WIMPs

$$\chi\chi \rightarrow \nu\overline{\nu}$$

  - Clear signature of $\overline{\nu}_e$ in liquid scintillator
  - Background from reactor, atmospheric and diffuse supernove neutrinos

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Supernova detection

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

In LENA detector: ~15000 events

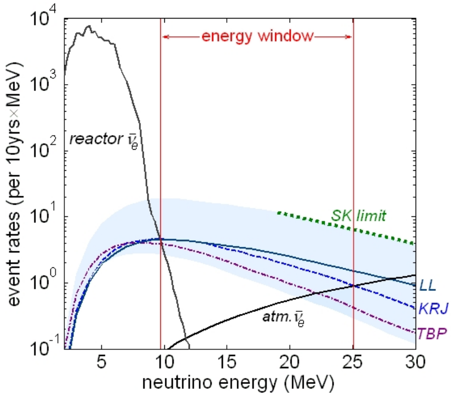
Possible reactions in liquid scintillator

- $\overline{\nu}_e + p \rightarrow n + e^+$; $n + p \rightarrow d + \gamma$ ~ 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

Diploma thesis by J.M.A. Winter (TU München)

Diffuse Background of Supernovae Neutrinos

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



In LENA detector: (44 kt f.v.)

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

Event rate in 10 y:

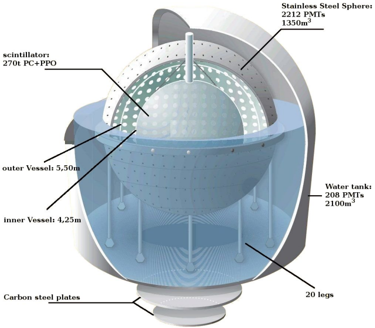
- LL: $\sim$ 110 events
- TBP: $\sim$ 60 events

(discrimination power at $> 2\,\sigma$)

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

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
- 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}

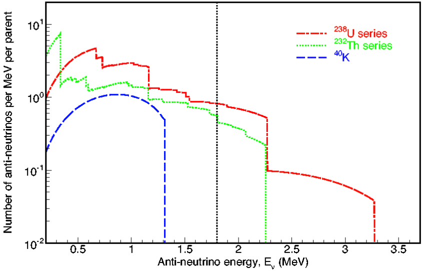
Geoneutrinos

- 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

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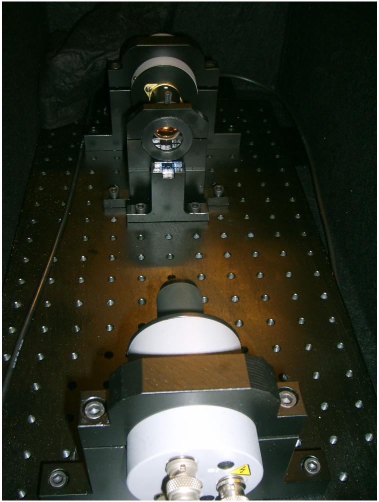
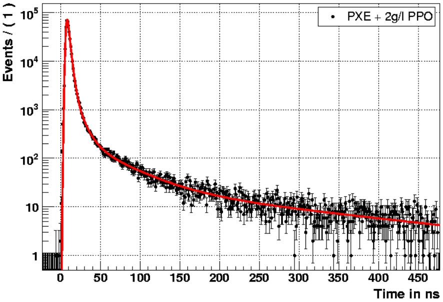
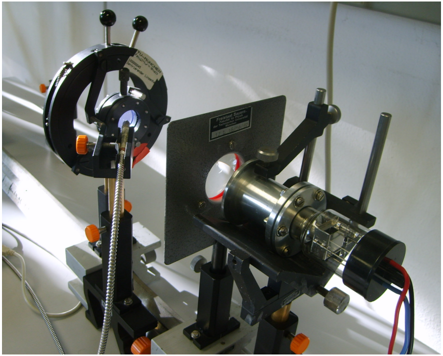
Fluorescence decay-time measurements



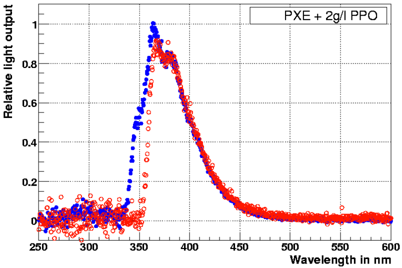
- Motivation: PD identification
- Photon counting method
- ^{54}Mn source: 834 keV γ's
- PMT's time jitter: $\sigma = 0.9$ ns



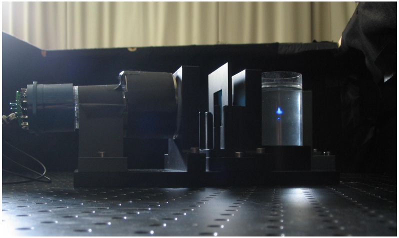
Scintillator spectra: UV-Lamp



- UV-radiation: D_2 lamp
- Spectroscopy of the emitted light
- Ocean optics spectrometer



Light propagation



- Scattering length $\lambda_s \sim 15\,\mathrm{m}$
  - Angle dependence of the scattered light
  - Study of polarized and unpolarized light

- Attenuation length $\lambda \sim 10\,\mathrm{m}$
  - Effects of absorption and scattering in the propagation

$$\frac{1}{\lambda} = \frac{1}{\lambda_s} + \frac{1}{\lambda_a}$$

- Planned measurement:
  - Scintillator quenching

- R&D on liquid scintillators

-> Talk by Christian Buck

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Summary

- Lena physics
  - Good sensitivity for proton decay via $p \rightarrow K^{+}\overline{\nu}$
  - Reactor neutrinos and indirect DM search
  - Supernova neutrinos
  - Solar neutrino measurements
- Liquid scintillator developments
  - Experiments to light production: fluorescence and spectroscopy
  - Study of light propagation: scattering and attenuation lengths