LENA: A multipurpose detector for low energy neutrino astronomy and proton decay

Teresa Marrodán Undagoitia
tmarroda@ph.tum.de

Institut E15
Physik-Department
Technische Universität München (Germany)

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Outline

Physics Goals

Low **E**nergy **N**eutrino **A**stronomy

Supernovae Neutrinos

Diffuse Background of Supernovae Neutrinos

Solar Neutrinos

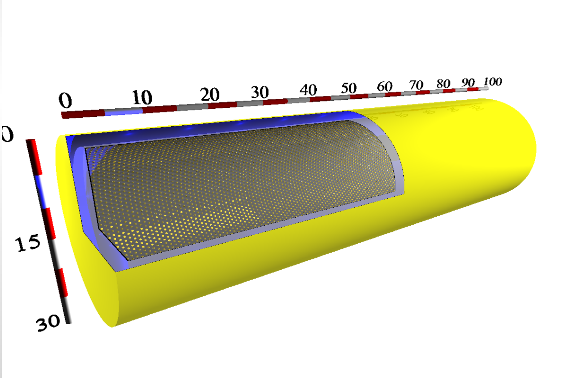
Geoneutrinos

Neutrino Properties

Proton Decay

LENA - Low Energy Neutrino Astronomy

Detector scheme



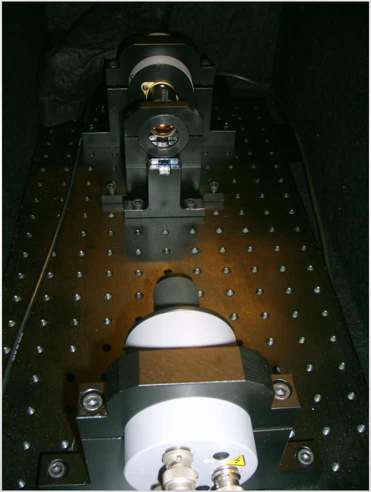
- Size
  - 100 m length × 30 m ∅
- Liquid Scintillator
  - ∼ 50 kton PXE
- Photomultipliers
  - 13 500 units
  - 30% coverage
- Photoelectron yield
  - ∼120 pe/MeV
- Underground location
  - ∼ 4000 m.w.e.

Liquid scintillator measurements at TUM

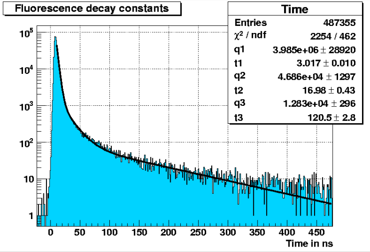
Why liquid scintillators?

- Enables large detector volumes
- Low energy threshold
- Good energy resolution
- Fast detector: good position reconstruction
- Particle separation (α/β)
- High cross section for $\overline{\nu}_e$
- Experience gained with Borexino

Light production

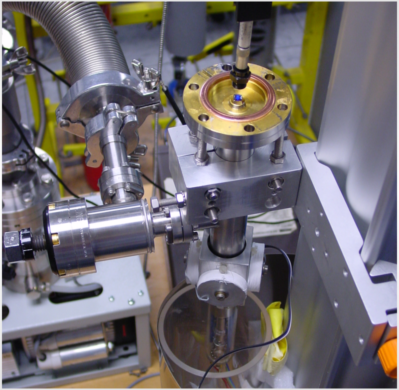


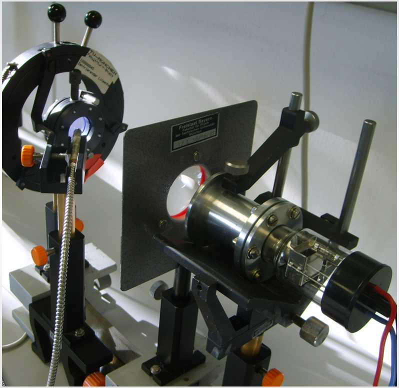
- Number of photons/MeV
- Exponential time constants
  - Dependence on solvent (PXE/LAB/Dodecan)
  - Dependence on wavelength shifter type and concentration (PPO/bisMSB/PMP)



Example for PXE + 2 g/l PPO mixture

Measurements of scintillator emission spectra

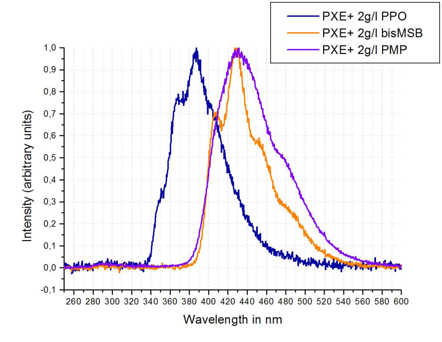


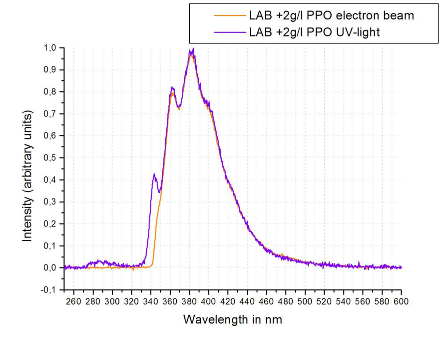


- Electrom beam excitation
- $\sim 10\,\text{keV}$ energy

- UV-light excitation
- Deuterium lamp

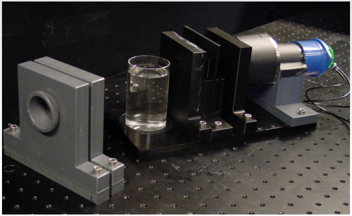
Spectra: first results

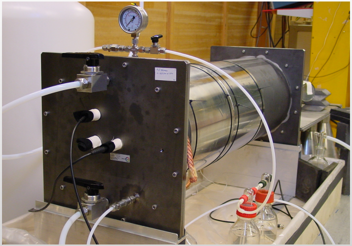




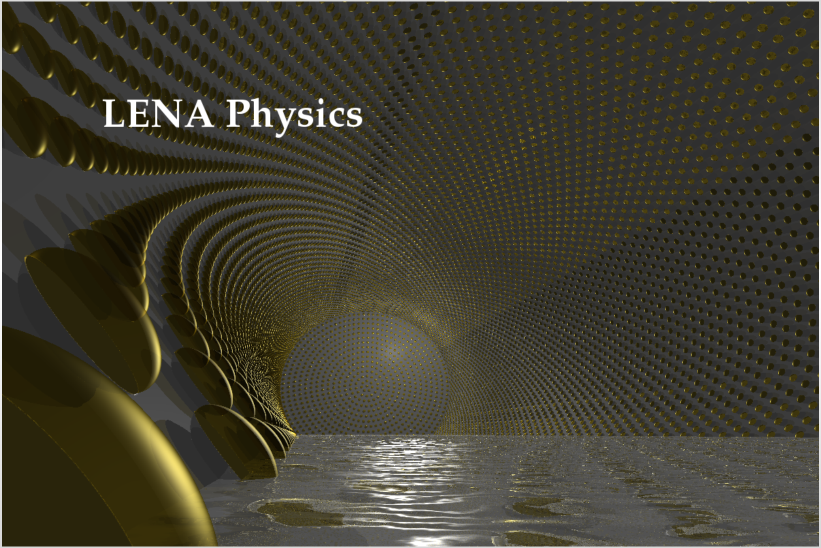
- Comparison of different wavelength shifter emission spectra
- Comparison of UV-light and electron beam excitation methods

Light propagation





- Scattering length
  - Angle dependence of the scattered light
  - Study of polarized and unpolarized light
- Attenuation length
  - Effects of absorption and scattering in the propagation


LENA Physics

Proton Decay

Non supersymmetric Grand Unified Theories

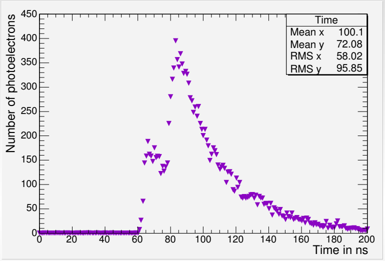
Dominant decay mode: $p \rightarrow e^+\pi^0$ $\tau \sim 10^{36}$ y

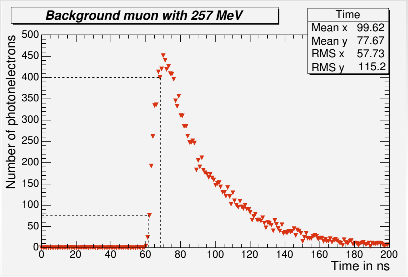
Supersymmetry (SUSY)

Dominant decay mode: $p \rightarrow K^+\overline{\nu}$ $\tau \sim 10^{34}$ y

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

Proton Decay: $p \rightarrow K^+ \overline{\nu}$





Potential of LENA (10 y measuring time)

- For Superkamiokande current limit: $\tau = 2.3 \cdot 10^{33}$ y
  - 40 events in LENA and $\lesssim 1$ background
- No signal in LENA: $\tau > 4 \cdot 10^{34}$ y 90% (C.L)

Phys. Rev. D72 075014 (2005) and hep-ph/0511230

Detection of Supernovae Neutrinos

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

In LENA detector: $\sim$15000 events

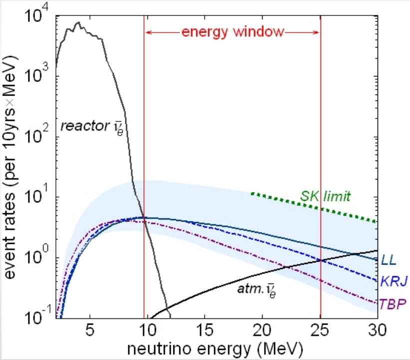
Possible reactions in liquid scintillator

- $\overline{\nu}_e + p \rightarrow n + e^+$; $n + p \rightarrow d + \gamma$ $\sim$9000 events
- $\overline{\nu}_e + {}^{12}\mathrm{C} \rightarrow {}^{12}\mathrm{B} + e^+$; ${}^{12}\mathrm{B} \rightarrow {}^{12}\mathrm{C} + e^- + \overline{\nu}_e$ $\sim$250 events
- $\nu_e + {}^{12}\mathrm{C} \rightarrow e^- + {}^{12}\mathrm{N}$; ${}^{12}\mathrm{N} \rightarrow {}^{12}\mathrm{C} + e^+ + \nu_e$ $\sim$400 events
- $\nu_x + {}^{12}\mathrm{C} \rightarrow {}^{12}\mathrm{C}^* + \nu_x$; ${}^{12}\mathrm{C}^* \rightarrow {}^{12}\mathrm{C} + \gamma$ $\sim$1000 events
- $\nu_x + e^- \rightarrow \nu_x + e^-$ (elastic scattering) $\sim$700 events
- $\nu_x + p \rightarrow \nu_x + p$ (elastic scattering) $\sim$2000 events

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 $> 2\,\sigma$)

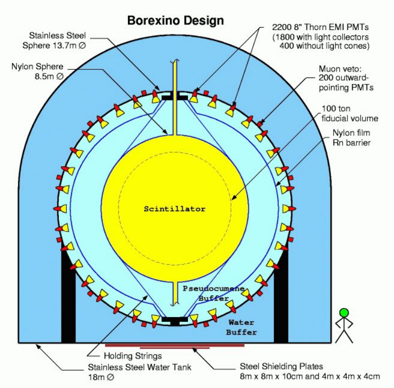
Phys. Rev. D75 023007 (2007) and astro-ph/0701305

Current limit: Super-Kamiokande

- Energy > 19.3 MeV
- Limit for the Flux: $1.2\ \text{cm}^{-2}\ \text{s}^{-1}$

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

Solar Neutrinos



Borexino:
technology test for LENA

Rates of solar neutrino events

In the LENA fiducial volume:

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

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

LAGUNA

Large Apparatus for Grand Unification and Neutrino Astrophysics

- APC, Paris, France
- CEA, Saclay, France
- CPPM, IN2P3-CBRS, Marseille, France
- CUPP, Pyhäsalmi, Finland
- ETHZ, Zürich, Switzerland
- Institute for Nuclear Research, Moscow, Russia
- IPNO, Orsay, France
- LAL, IN2P3-CNRS, Orsay, France
- LPNHE, IN2P3-CNRS, Paris, France
- Max Planck für Kernphysik, Heidelberg, Germany

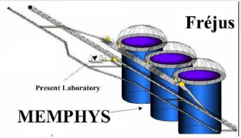
LAGUNA scientific paper, arXiv: 0705.0116 [hep-ph]

- Max Planck für Physik, München, Germany
- Technische Universität München, Germany
- Universidad de Granada, Spain
- Universität Hamburg, Germany
- University of Bern, Switzerland
- University of Helsinki, Finland
- University of Jyväskylä, Finland
- University of Oulu, Finland
- University of Padova, Italy
- University of Silesia, Katowice, Poland
- University of Sheffield, UK

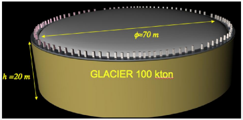
Physics of LAGUNA

- Supernovae 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
- Geophysics: radioactivity of the Earth with geoneutrinos
- Proton decay
- Neutrino Properties
  - Reactor: Precise measurement on $\Delta^2 m_{12}$ and $\sin^2\theta_{12}$
  - Atmospheric neutrinos: Improve $D_{23} \equiv \sin^2\theta_{23} - 1/2$
  - Detectors for accelerator experiments: θ_{13} and δ_{CP}

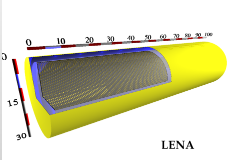
LAGUNA detector concepts



- 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

Summary

- Liquid scintillator developments
  - Experiments to light production: photon yield and timing
  - Study of light propagation: attenuation length and spectra
- Lena physics
  - Good sensitivity for proton decay via $p \rightarrow K^{+}\overline{\nu}$
  - Neutrinos from current supernova explosion
  - Diffuse background of supernova neutrinos
  - Solar neutrino measurements
- LAGUNA initiative has been presented

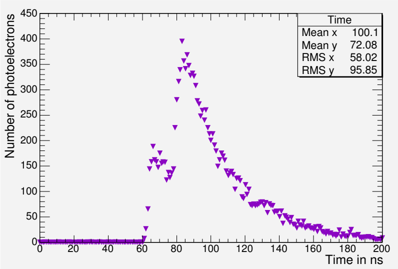
Free Proton Decay: $p \rightarrow K^+\overline{\nu}$

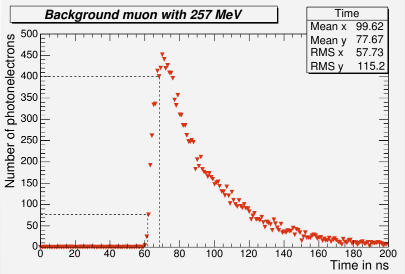
$$T(K^+) = 105 \text{ MeV} \quad \tau(K^+) = 12.8 \text{ ns}$$

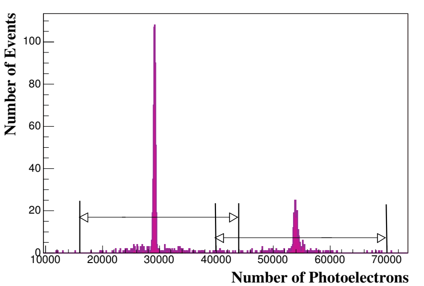
- $K^+ \rightarrow \mu^+\nu_\mu$ 63.43%
- $K^+ \rightarrow \pi^+\pi^0$ 21.13%

Detection efficiency: $\varepsilon_T = 0.65$

Background suppression: B $\sim 5 \cdot 10^{-5}$







- Energy: $\sim$120 pe/MeV
- Two peaks:
  - Kaon + Muon: $\sim$ 260 MeV
  - Kaon + Pions: $\sim$ 460 MeV
- Efficiency: $\varepsilon_E = 0.995$
- Included: protons from ^{12}C

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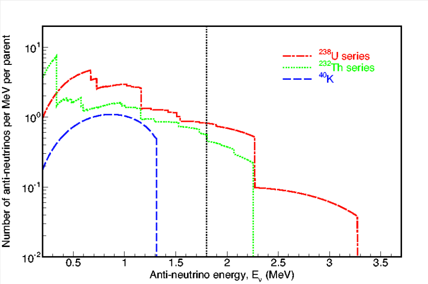
Phys. Rev. D72 075014 (2005) and hep-ph/0511230

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:

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

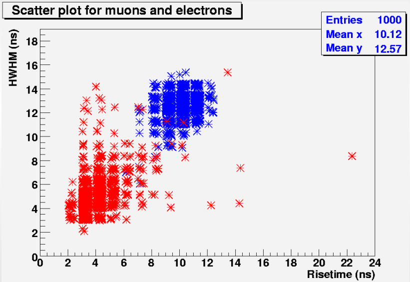
Astropart. Phys. 27 (2007) 21 and hep-ph/0509136

- In LENA detector: $\sim$ (400-4000) events/y

(Scaling KamLAND results)

On-going work: LENA for Betabeams

HWHM (ns) vs. risetime (ns)



Scatter plot for muons and electrons of 1.2 GeV

- Electron/muon separation:
  - Pulse shape discrimination
  - Electron detection from the decay of the muon
- For energies between 0.2 and 1.2 GeV
  - Muon appearance: $\sim$ 90 %
  - Electron background: $\sim$ 0.5 %
- Good energy resolution
- Background due to π or kaon production