Potential of the large liquid-scintillator detector LENA in particle and astrophysics

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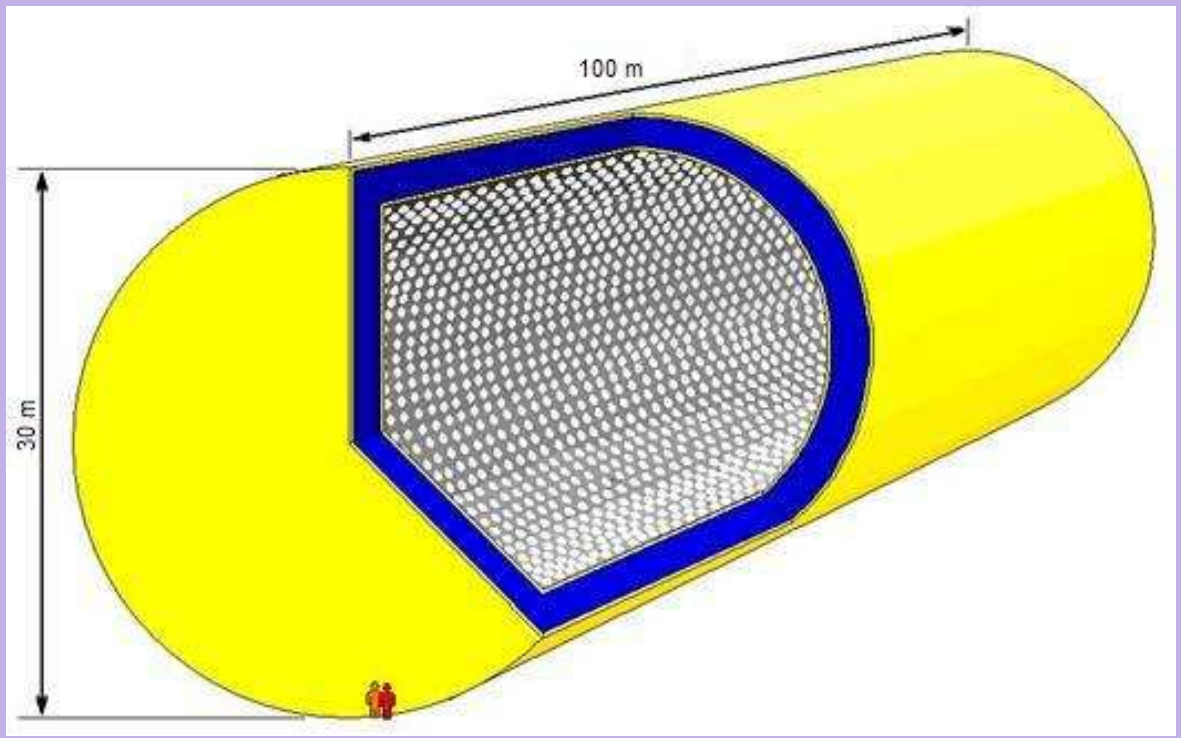
Dortmund 30.03.06

Outline

Proposed LENA Detector

Detector scheme



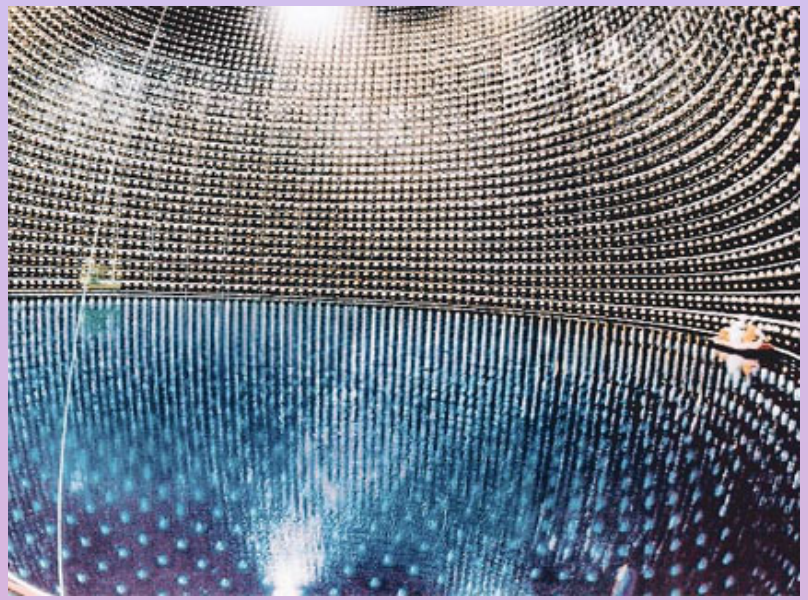
- Size
  - $\sim$ 100 m length
  - 30 m $\varnothing$
- Liquid Scintillator
  - 45.000 ton PXE
- Photomultipliers
  - 12 000 units
  - 30% coverage
- Photoelectron yield
  - 110 pe/MeV
- Underground location
  - Preferred site: Mine in Pyhäsalmi (Finland)

Supernovae Neutrinos

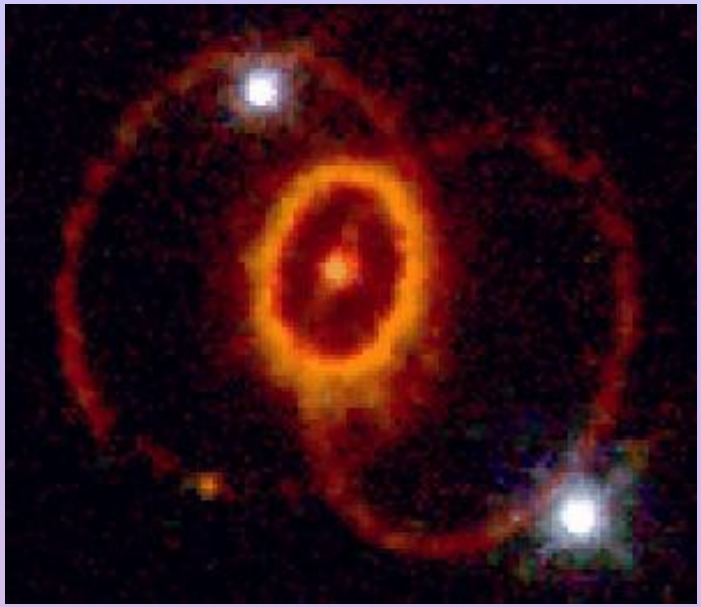
First SN measurement:

SN1987A

- Kamiokande: 11 events
- IMB: 8 events



Superkamiokande



- D = 10 kpc (center of our galaxy)
- 8 $M_\odot$ ($\Delta E = 2.65 \cdot 10^{53}$ erg)

In LENA detector:
$\sim$20000 events

Detection of Supernovae Neutrinos

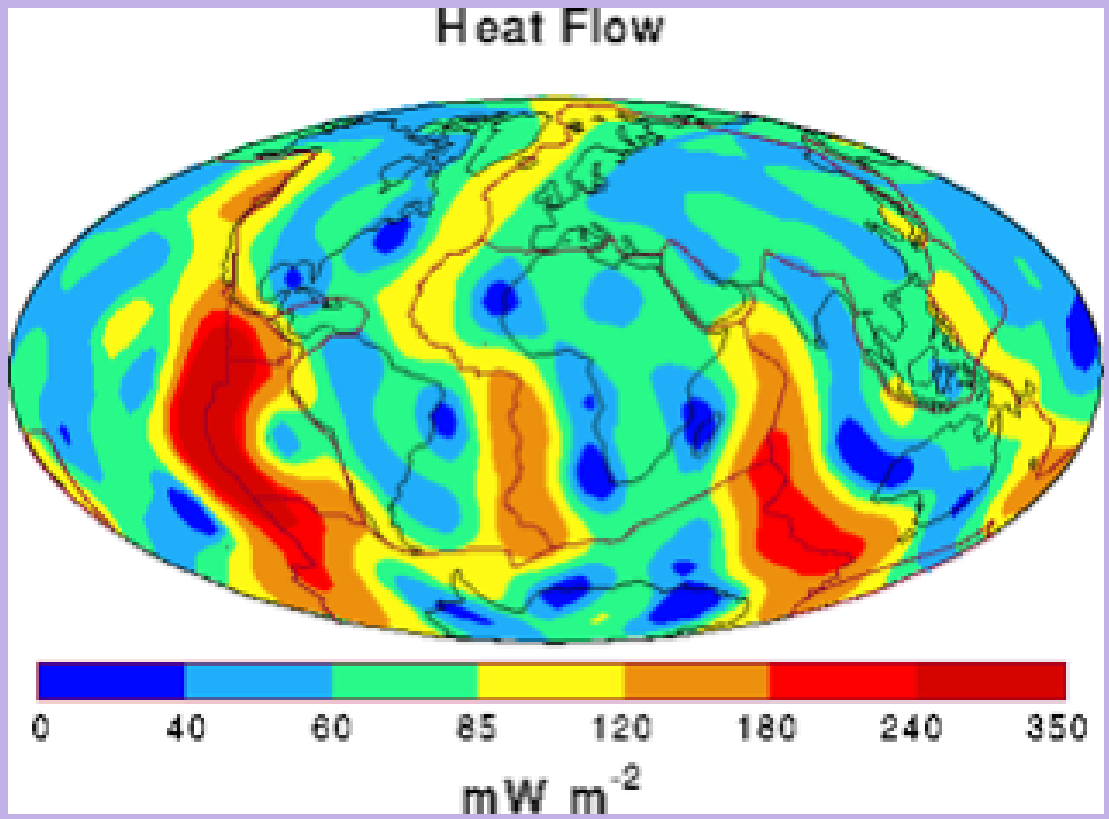
Possible reactions in liquid scintillator

- $\overline{\nu}_e + p \rightarrow n + e^+$ (Q=1.8 MeV)
  $n + p \rightarrow d + \gamma$; $E_\gamma = 2.2$ 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
- $\nu_e + {}^{12}\mathrm{C} \rightarrow e^- + {}^{12}\mathrm{N}$ (Q=13.4 MeV)
  ${}^{12}\mathrm{N} \rightarrow {}^{12}\mathrm{C} + e^+ + \nu_e$; $\tau_{1/2} = 11.00$ ms ~85 events
- $\nu_x + {}^{12}\mathrm{C} \rightarrow {}^{12}\mathrm{C}^* + \nu_x$
  with ${}^{12}\mathrm{C}^* \rightarrow {}^{12}\mathrm{C} + \gamma$; $E_\gamma = 15.11$ MeV ~2925 events
- $\nu_x + e^- \rightarrow \nu_x + e^-$ (elastic scattering) ~610 events
- $\nu_x + p \rightarrow \nu_x + p$ (elastic scattering) ~7370 events

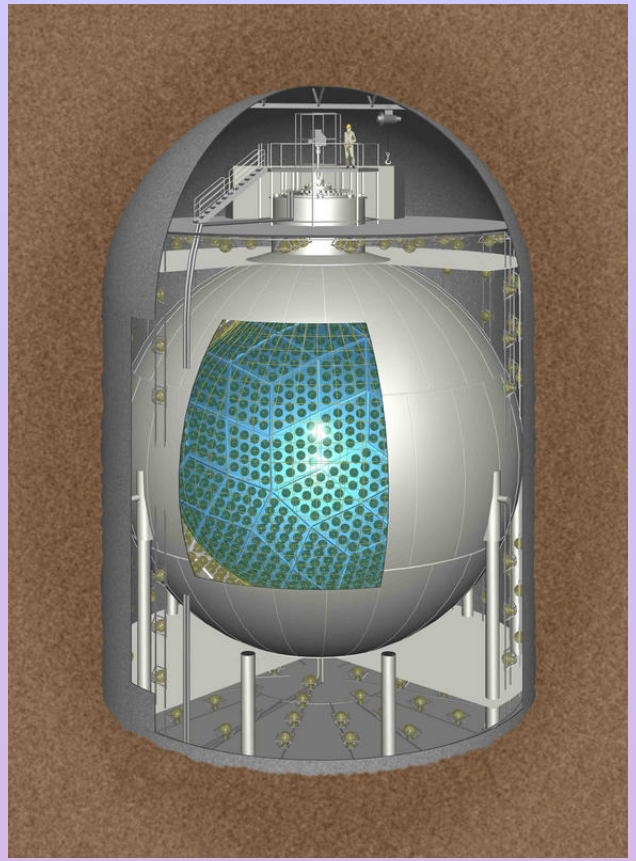
Geoneutrino Problem

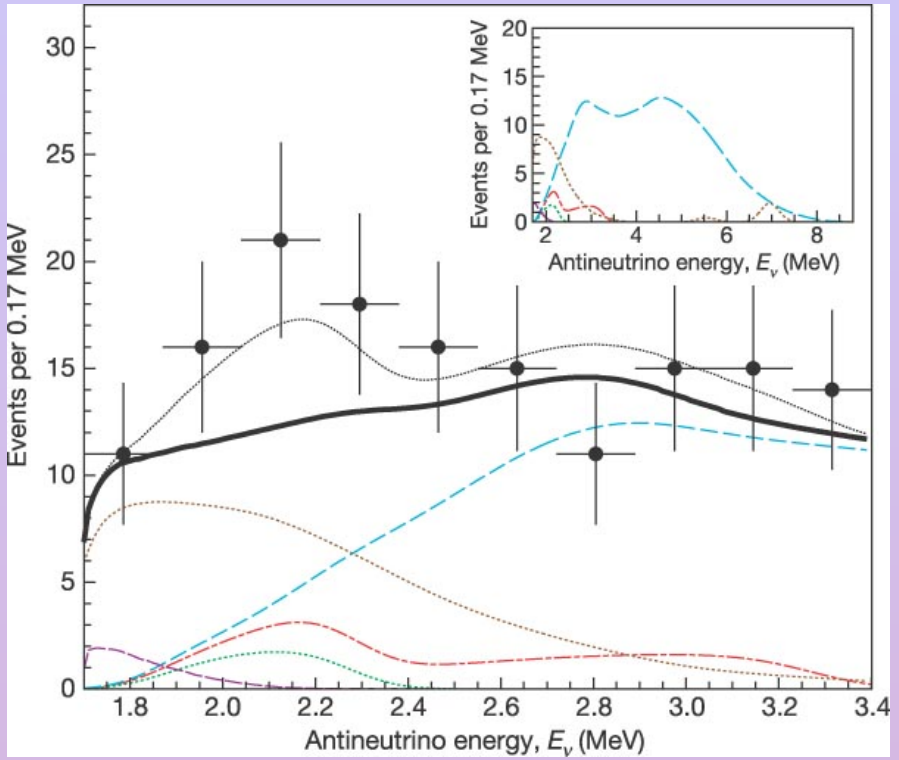
- Unexplained source of heat flow on Earth
- Unknown contribution of natural radioactivity
- How are ^{238}U, ^{232}Th distributed in core, mantle and crust?
- Detection of $\bar{\nu}_e$ from ^{238}U, ^{232}Th decay chains
- Is it possible to have a nuclear reactor in the center of the Earth?

Heat flow map



Geoneutrino First Detection: KamLAND Experiment





- $\overline{\nu}_e + p \rightarrow n + e^+$
- 4.5 - 54.2 events at 90% C.L.
- Detector measuring time: 749.1$\pm$0.5 d

- In LENA detector: $\sim$ 1500 events/y

Proton Decay: Theoretical Predictions

Grand Unified Theories GUT's

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

Supersymmetry (SUSY)

Dominant decay mode: $p \to K^+\overline{\nu}$ $\quad \tau \sim 10^{35}$ y

Extra dimensions (6D)

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

String models

Dominant decay mode: $p \to e^+\pi^0$ $\quad \tau \sim (0.8 - 1.9) \cdot 10^{36}$ y

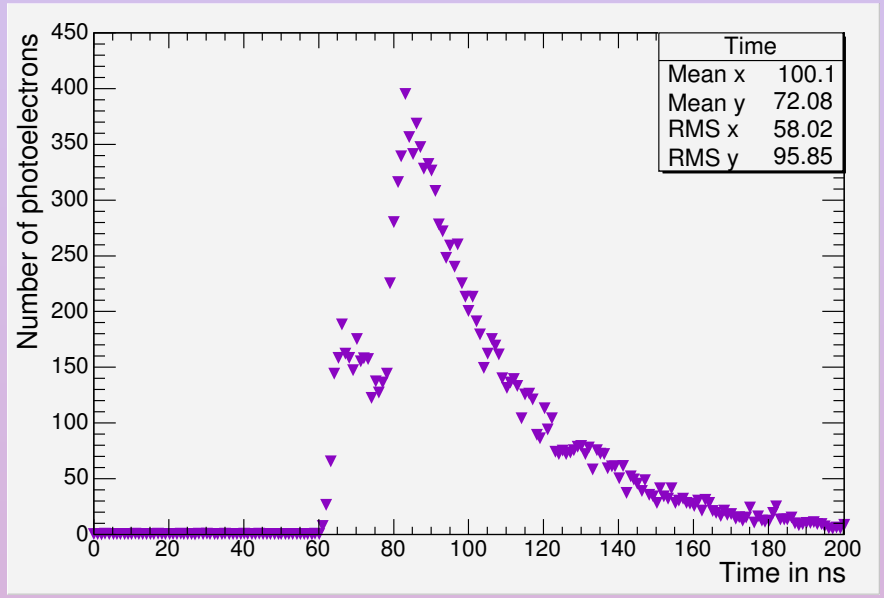
- Superkamiokande: $\tau(p \to e^+\pi^0) \gtrsim 5.4 \cdot 10^{33}$ y (90% C.L.)
  $\tau(p \to K^+\overline{\nu}) \gtrsim 2.3 \cdot 10^{33}$ y (90 % C.L.)

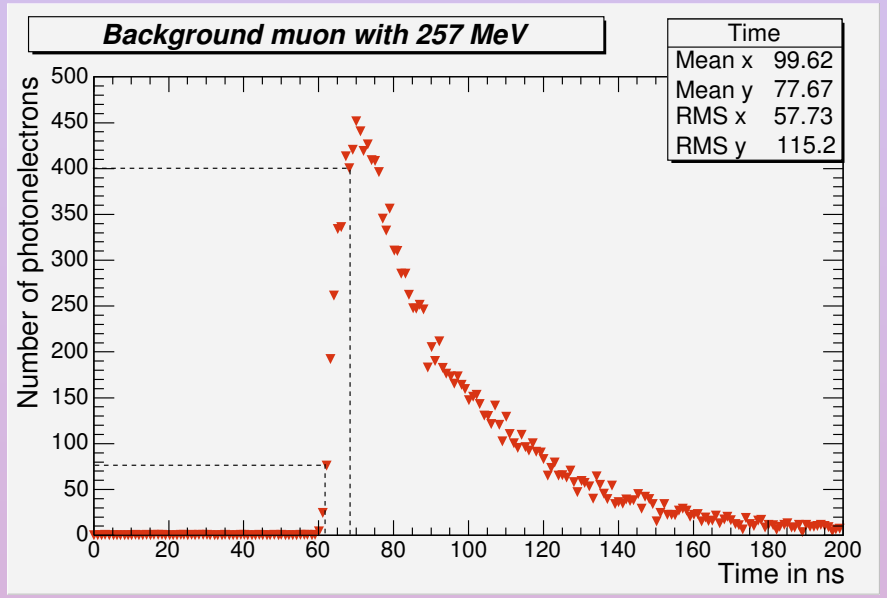
Free Proton Decay

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

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

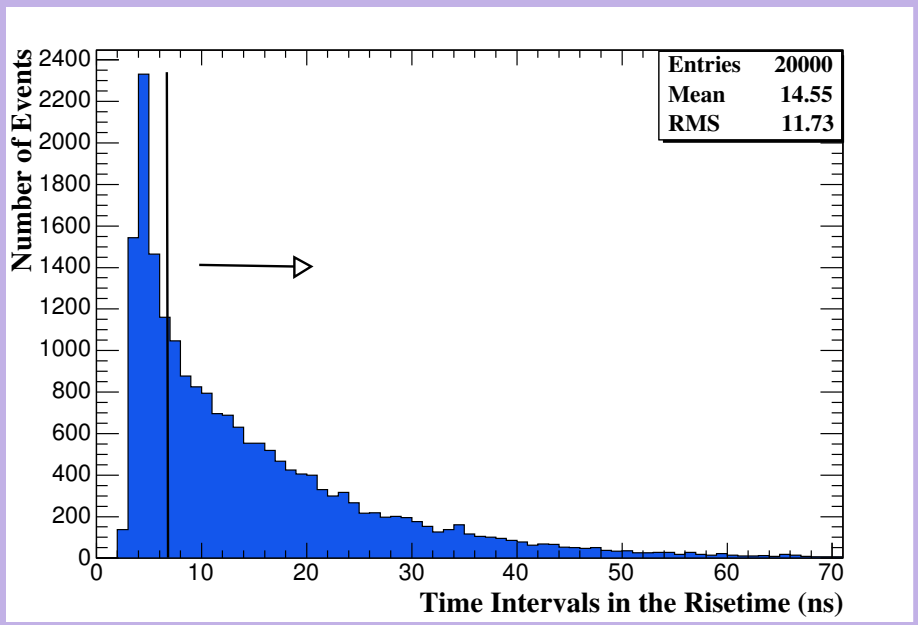
- $K^+ \rightarrow \mu^+\nu_\mu$ 63.43%
  - $T(\mu^+) = 152$ MeV
- $K^+ \rightarrow \pi^+\pi^0$ 21.13%
  - $T(\pi^+) = 108$ MeV
  - $T(\pi^0) = 110$ MeV



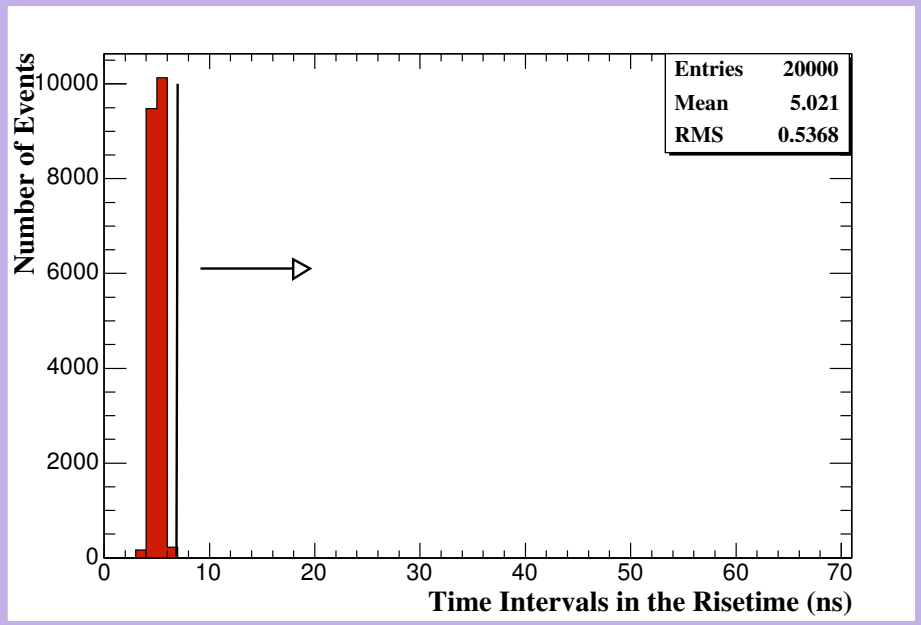


Background Rejection: Time Cut

Detection efficiency: $\varepsilon_T = 0.65$

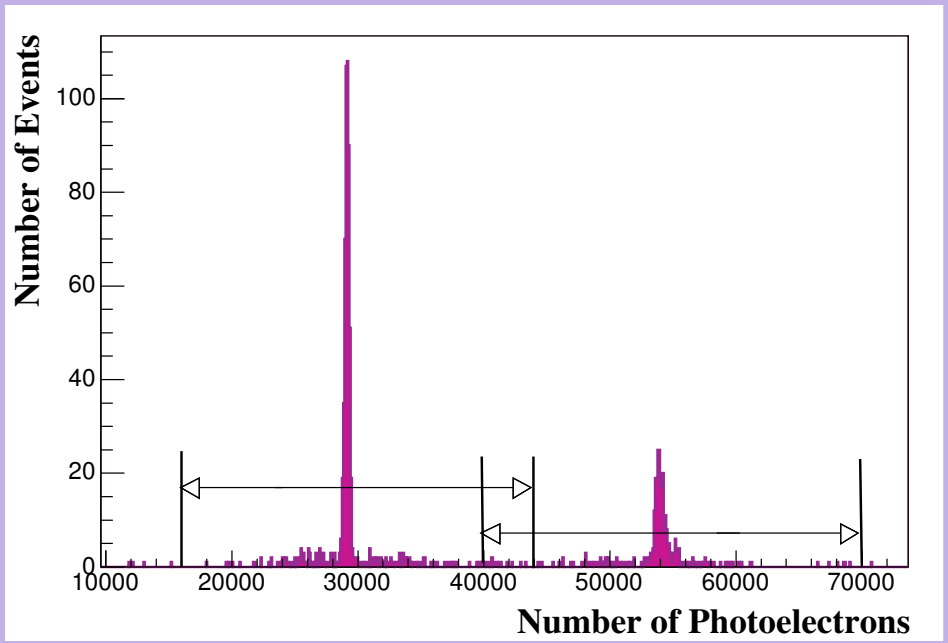


Background suppression: $B \sim 5 \cdot 10^{-5}$



Background Rejection: Energy cut

Energy spectrum (110 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
  - 40 events in LENA und $\lesssim 1$ background
- No signal in LENA:
  - $\tau > 4 \cdot 10^{34}$ y 90% (C.L)

Summary

- Technical feasibility studies very promising
- Flavour sensitivity and energy spectrum in supernovae neutrino measurements
- Diffuse background of supernovae neutrinos:
  Next Talk by Michael Wurm
- Measurement of solar neutrinos
- High statistics on geoneutrino flux ($\sim$ 1500 events/y)
- A proton lifetime of $\tau \sim 4 \cdot 10^{34}$ y reachable in LENA
  (Phys. Rev. D 72 (2005) 075014; hep-ph/0511230)