LENA Project

First Feasibility Studies

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Outline

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Outline

Physic Goals

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

Supernovae Neutrinos

- Study of the gravitational collapse of a heavy star

Relic Supernovae Neutrinos

- Study of star formation in the early universe

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Physic Goals

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

Solar Neutrinos

- Precision measurement of thermonuclear fusion processes
- Search for flux variations

Geoneutrinos

- Tests of geophysical models with anti-neutrino spectroscopy
- Is there a natural nuclear reactor in the centre of the earth?

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Physic Goals

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

Neutrino Properties

- Long-baseline neutrino oscillation experiments

Proton Decay

- Search for baryon number violation

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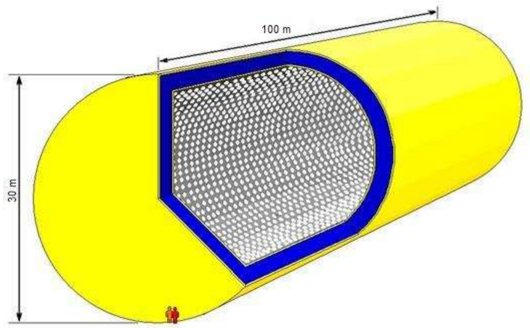
Proposed LENA Detector



Volume

$\sim$ 100 m length $\times$ 30 m $\varnothing$

Liquid Scintillator

45.000 ton PXE

Photomultipliers

12.000 units 30% surface

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Possible Locations

’Centre for Underground Physics’ in Pyhasalmi

’Nestor Base’
close to the coast at Pylos

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Proton Decay: Theoretical Predictions

GUT SU(5)

Dominant decay mode: $p \rightarrow e^{+}\pi^{0}$ $\tau \sim 10^{31}$ y

- Superkamiokande: $\tau \gtrsim 5.10^{33}$ y (90% C.L.)

SUSY SU(5)

Dominant decay mode: $p \rightarrow K^{+}\overline{\nu}$ $\tau \lesssim 10^{35}$ y

- Superkamiokande: $\tau \gtrsim 2.3 \cdot 10^{33}$ y (90 % C.L.)

Supergravity SU(5)

Dominant mode: $p \rightarrow \pi^{+}\overline{\nu}$ BR: 65.7 %
Second mode: $p \rightarrow K^{+}\overline{\nu}$ BR: 33.5 %

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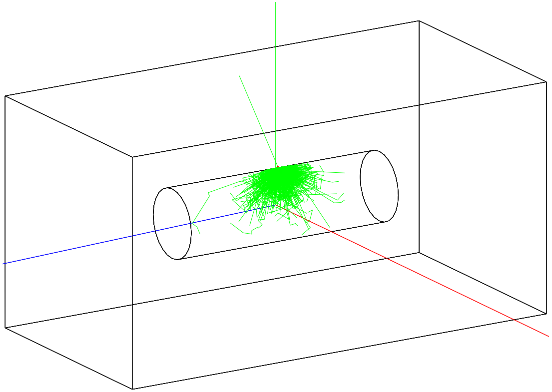
Simulation with Geant4

Geant 4



- Monte Carlo calculations
- Scintillation
- Quenching factors
  - Birk's formula
- Photomultipliers:
  - Time jitter $\sigma = 1$ ns
  - Efficiency: $\varepsilon = 0.17$

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Free Protons

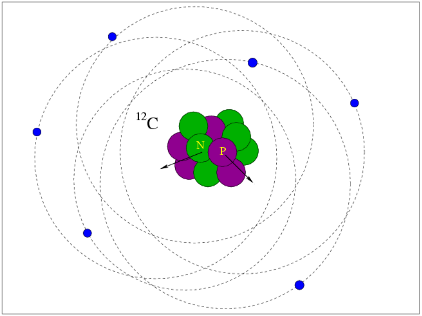
Event Structure: $p \rightarrow K^{+}\overline{\nu}$

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

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

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

Protons from ^{12}C



Binding energy

- S-state: $\sim$ 37 MeV
- P-state: $\sim$ 16 MeV

Fermi Motion

- Momenta up to $\sim$ 250 MeV/c

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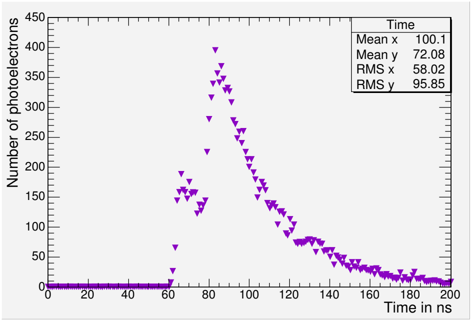
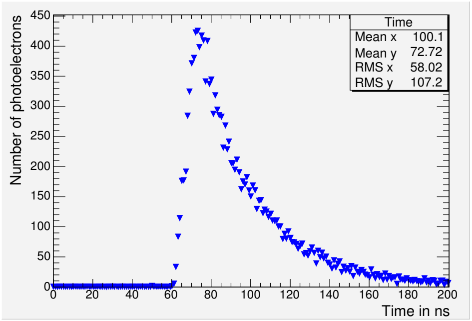
Signals of Proton Decay in LENA





- Kaon decay after 18 ns
- Kaon decay after 5 ns

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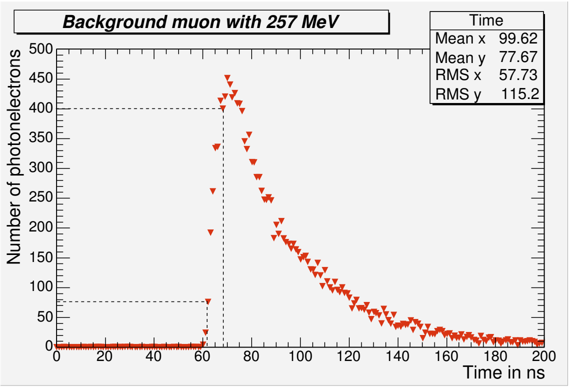
Muon Production by Atmospheric ν_μ



- $\nu_\mu + N \to \mu^- + N'$

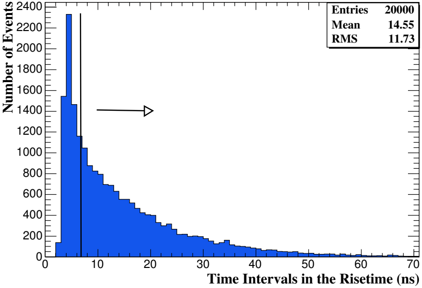
Background rate from Superkamiokande

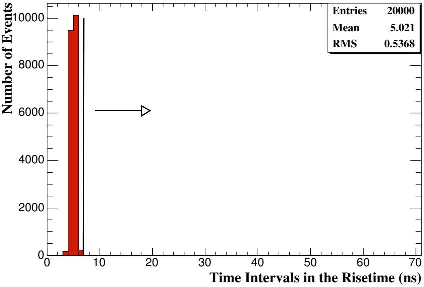
$\Gamma = 4.8 \cdot 10^{-2}$ $(MeV^{-1}kt^{-1}y^{-1})$

- Pulse shape analysis
  - Risetime

Background Rejection: Time Cut

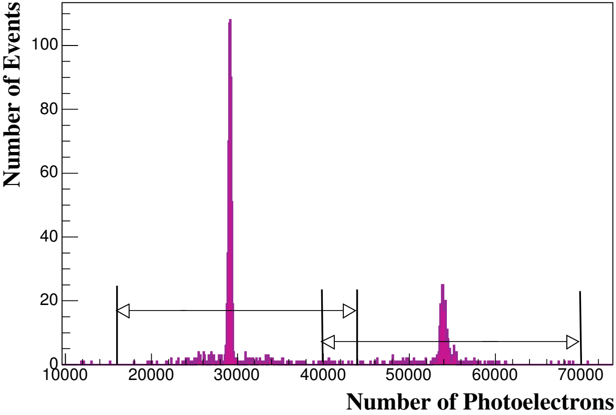
- Efficiency: $\varepsilon_T = 0.65$





- Background suppression: $B \sim 2 \cdot 10^{-4}$

Background Rejection: Energy cut



- Two peaks:
  - Kaon + Muon $\sim$ 257 MeV
  - Kaon + Pions $\sim$ 459 MeV
- Efficiency: $\varepsilon_E = 0.995$

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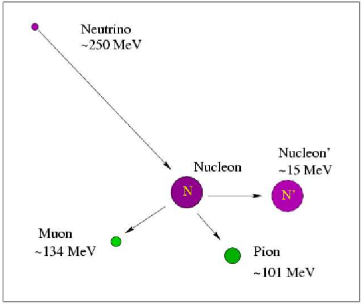
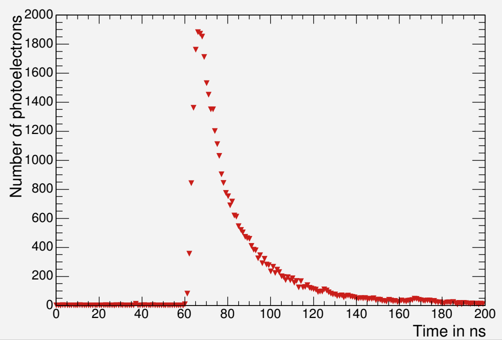
Hadron Production by Atmospheric ν_μ

Pion Production

- $\nu_\mu + N \rightarrow \mu^- + \pi^+ + N'$
  - $\pi^+ \rightarrow \mu^+ + \nu_\mu$
  - $\mu^+ \rightarrow e^+ + \nu_e + \overline{\nu}_\mu$



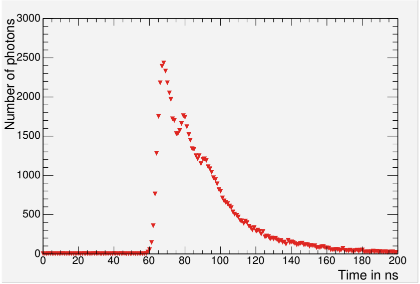


Hadron Production by Atmospheric ν_μ

Kaon Production

- $\Delta S=0$ CC:
  $\nu_\mu + n \rightarrow \mu^- + K^+ + \Lambda^0$
  - $\Lambda^0 \rightarrow p + \pi^-$ $\tau_{\Lambda^0} = 0.26$ ns
    $\Lambda^0 \rightarrow n + \pi^0$

  $\nu_\mu + n \rightarrow \mu^- + K^+ + \Lambda^0 + \pi^0$
- $\Delta S=1$ CC:
  $\nu_\mu + p \rightarrow \mu^- + K^+ + p$
- $\Delta S=0$ NC:
  $\nu_\mu + p \rightarrow \nu_\mu + K^+ + \Lambda^0$



- 200 MeV Muon
- 40 MeV Kaon
- 20 MeV Lambda

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Proton Decay Sensitivity

- Activity of proton decay: $A = \epsilon N_p t_m / \tau$
- Total efficiency: $\varepsilon = \varepsilon_E \cdot \varepsilon_T = 0.65$
- Protons in the detector: $N_p = 1.4 \cdot 10^{34}$
- Measuring time: t_m = 10 y

Potential of LENA

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

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Summary and Outlook

- Conclusion

A factor 10 in proton lifetime reachable in LENA

- Outlook
  - Rearch for other channels
  - Other physics
  - Technical feasibility studies
  - International interest in LENA type detector