Search for the Proton Decay

in the large liquid Scintillation Detector LENA

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Outline

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Physics Goals

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

- Supernovae Neutrinos
- Geoneutrinos
- Relic Supernovae Neutrinos
- Dark Matter
- Solar Neutrinos
- Neutrino Properties

Proton Decay

- Baryon number violation

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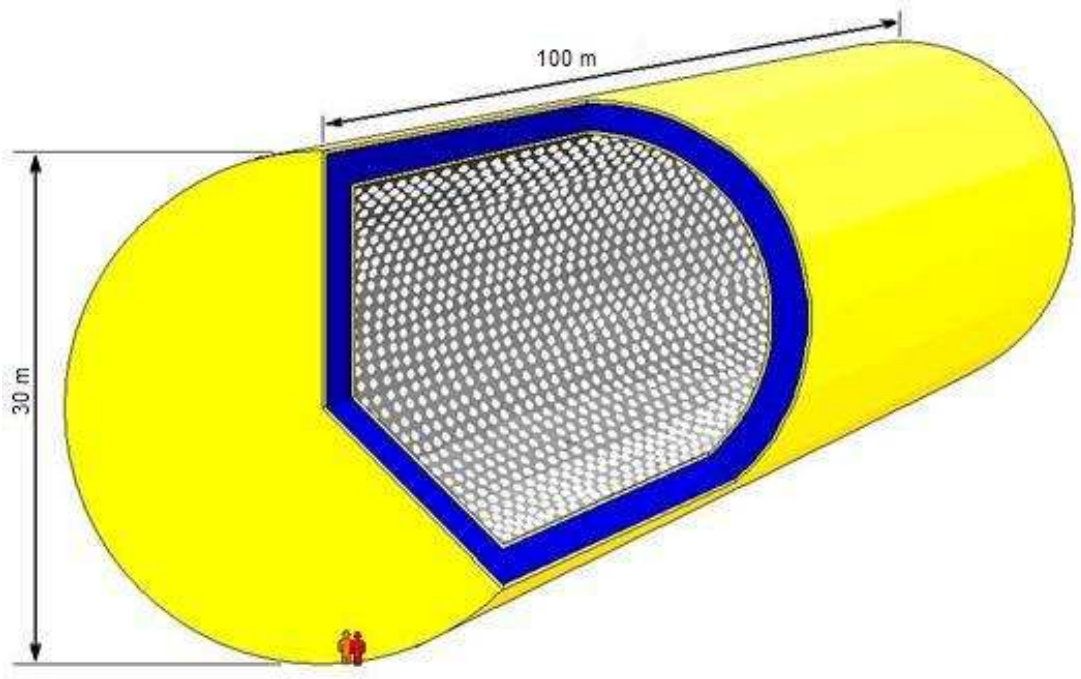
Proposed LENA Detector



Volume

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

Liquid Scintillator

45.000 ton PXE

Photomultipliers

12.000 units 30% surface

Photoelectron yield

110 pe/MeV

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Possible Locations

’Centre for Underground Physics’ in Pyhäsalmi

’Nestor Base’
close to the coast at Pylos

Proton Decay: Theoretical Predictions

GUT SU(5)

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

- Superkamiokande: $\tau \gtrsim 5.4 \cdot 10^{33}$ y (90% C.L.)

Supersymmetry (SUSY)

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

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

Supergravity

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

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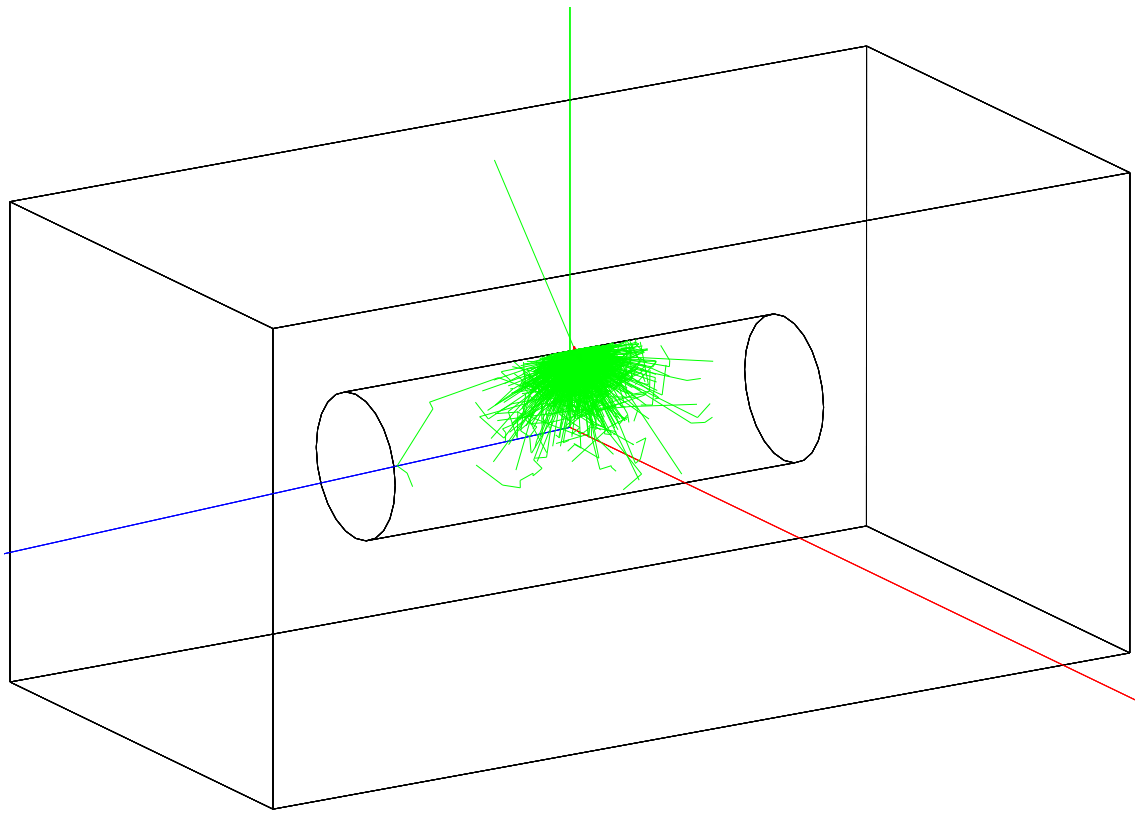
Simulation with Geant4



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

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Free Proton Decay

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
- $\pi^+ \rightarrow \mu^+\nu_\mu$ $\pi^0 \rightarrow \gamma\gamma$

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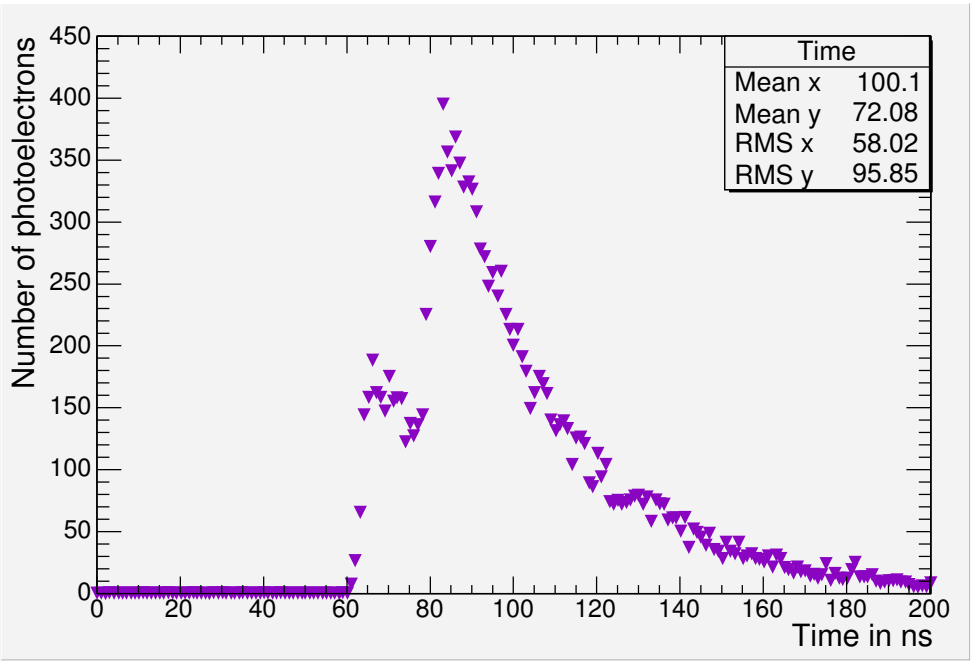
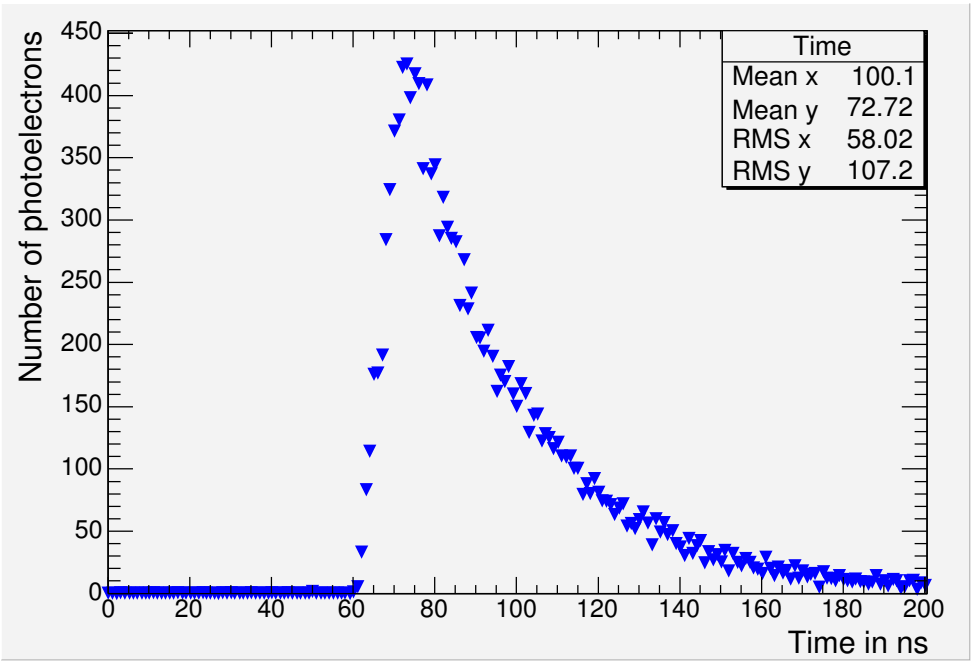
Signals of Proton Decay in LENA

- Kaon decay after 18 ns



- Kaon decay after 5 ns



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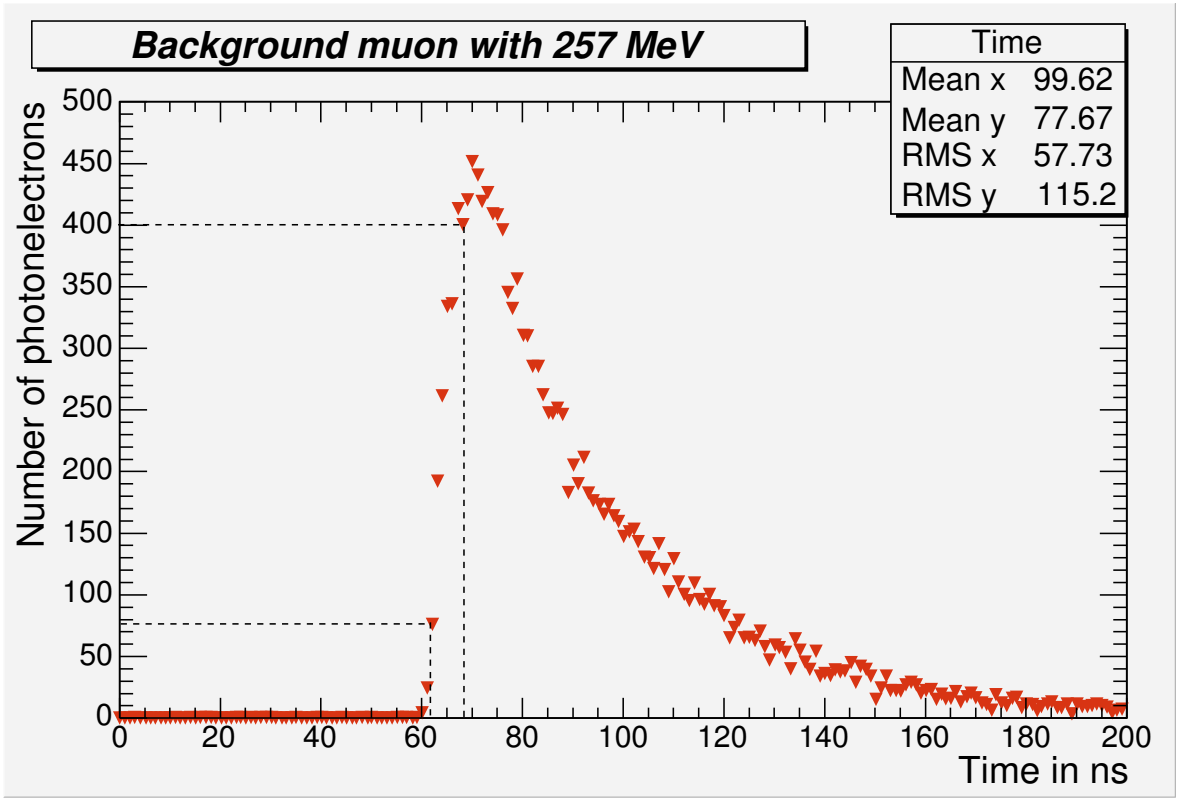
Background: Muon Production by Atmospheric ν_μ



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

Background rate from Superkamiokande

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

- Pulse shape analysis
  - Risetime

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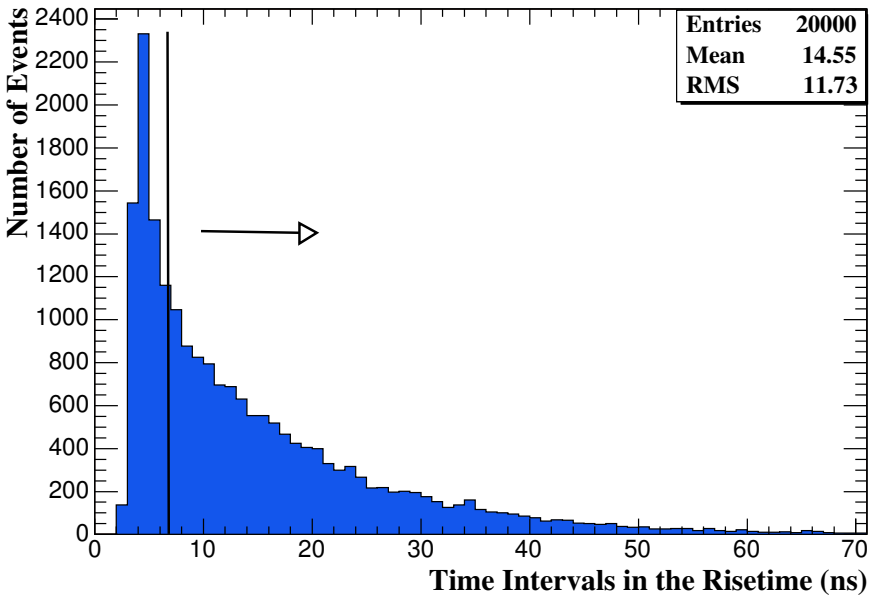
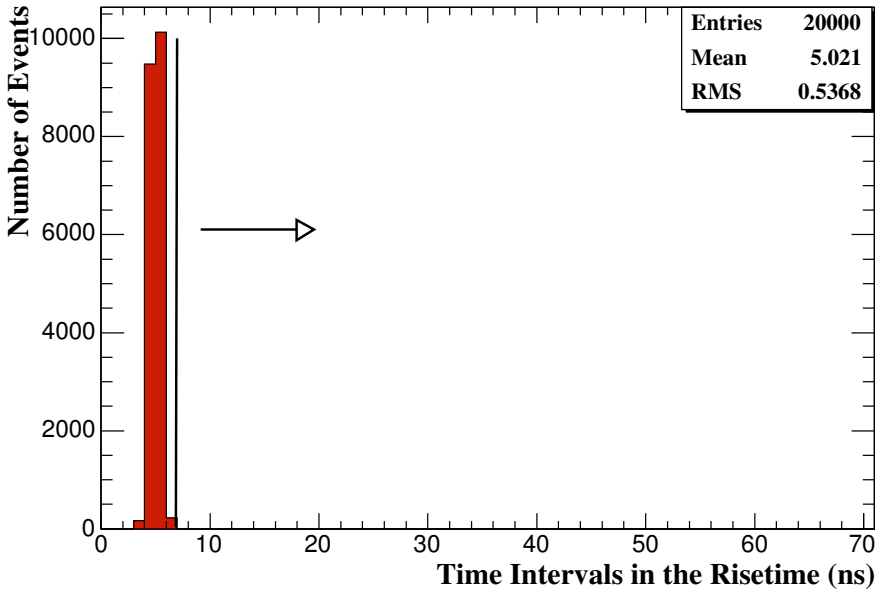
Background Rejection: Time Cut

- Efficiency: $\varepsilon_T = 0.65$





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

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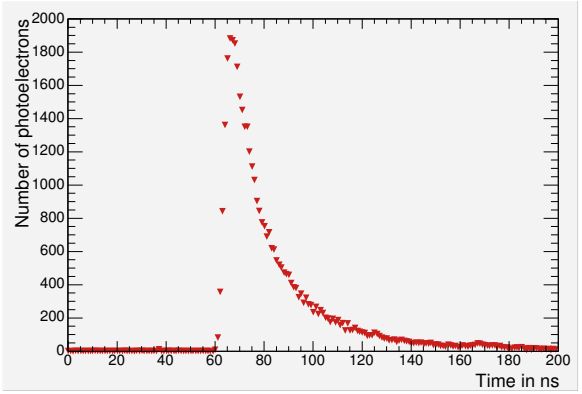
Background: Hadron Production by Atmospheric ν_μ

Pion Production

- $\nu_\mu + p \rightarrow \mu^- + \pi^+ + p'$
  - $\pi^+ \rightarrow \mu^+ + \nu_\mu \quad \tau_{\pi^+} = 26$ ns
  - $\mu^+ \rightarrow e^+ + \nu_e + \overline{\nu}_\mu$

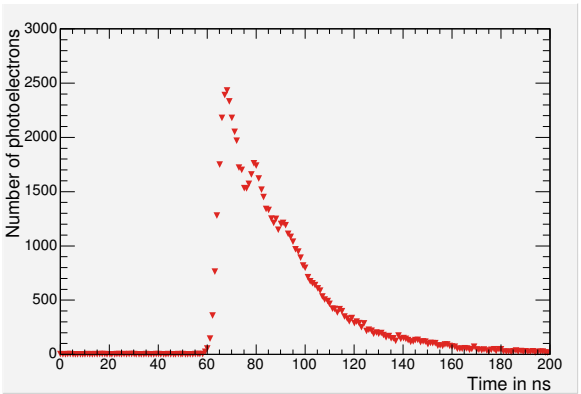


Kaon Production

- ΔS=1 CC:
  $\nu_\mu + p \rightarrow \mu^- + K^+ + p$
- ΔS=0 CC:
  $\nu_\mu + n \rightarrow \mu^- + K^+ + \Lambda^0$
  - $\Lambda^0 \rightarrow p + \pi^- \quad \tau_{\Lambda^0} = 0.26$ ns
  - $\Lambda^0 \rightarrow n + \pi^0$

  $\nu_\mu + n \rightarrow \mu^- + K^+ + \Lambda^0 + \pi^0$

Calculated background rate: $0.064\ \mathrm{y}^{-1}$



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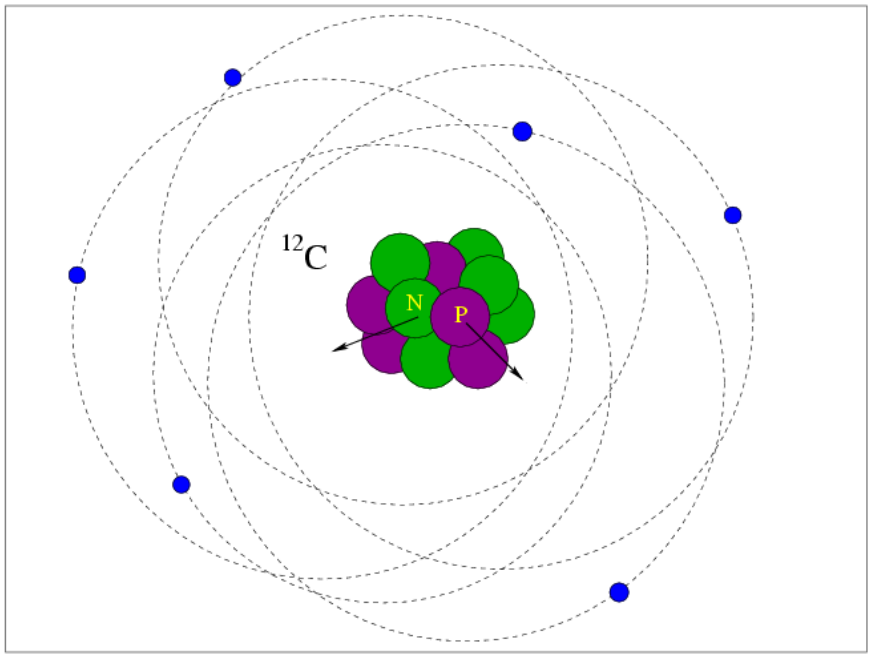
Protons from ^{12}C: Nuclear Effects



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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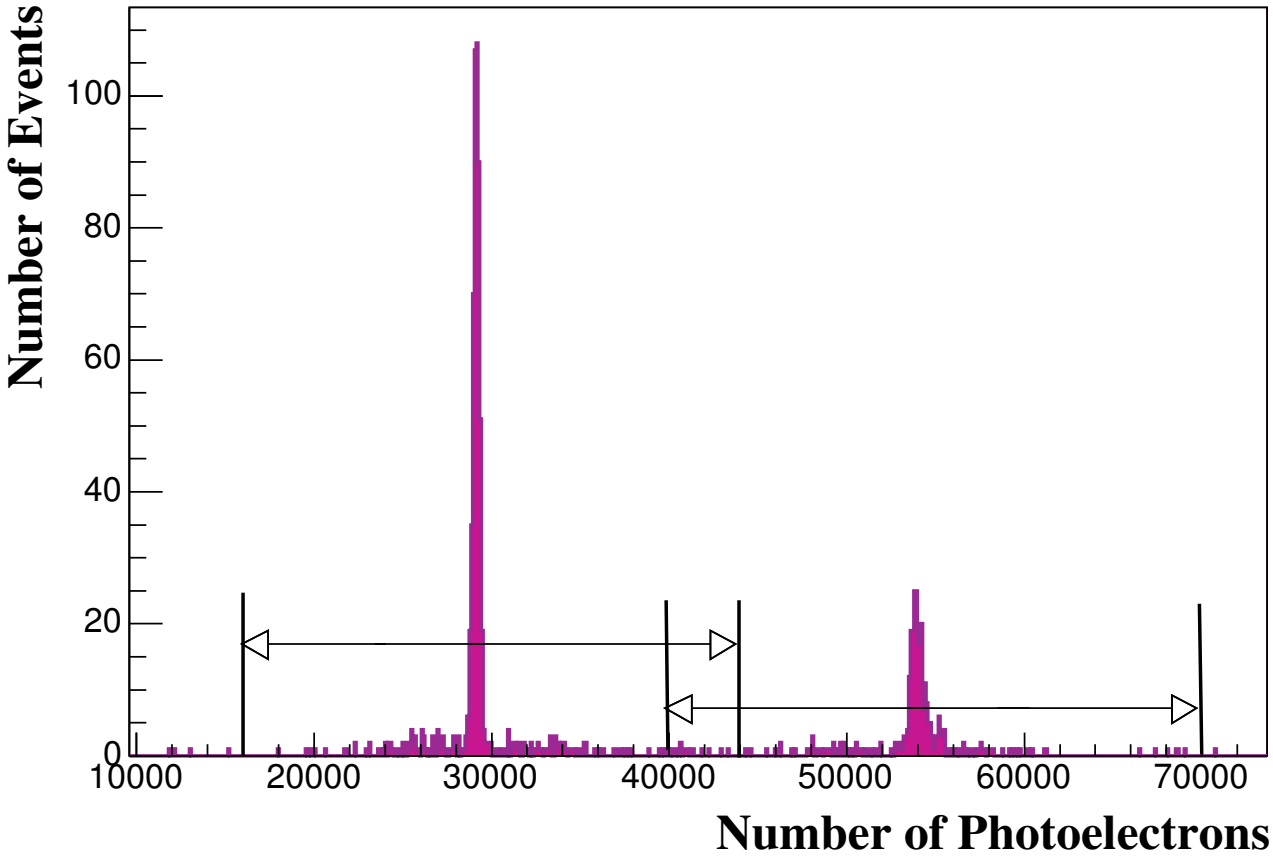
Background Rejection: Energy cut



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

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Proton Decay Sensitivity

- Activity of proton decay: $A = \varepsilon N_p t_m / \tau$
- 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
  - $\lesssim$ 1 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
  - Search for other proton decay channels
  - Detector design studies
  - LENA project proposal
  - Technical feasibility studies

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International interest in LENA type detector

- Groups interested
  - TU Munich, Germany (F. von Feilitzsch and L. Oberauer)
  - Univ. Hamburg, Germany (C. Hagner)
  - CUPP, Finland (J. Peltoniemi)
  - Univ. Jyväskylä, Finland (J. Aysto)
  - INR, Russia (L. Bezrukov)

- Similar Initiatives
  - R. Svoboda (Proton Decay with liquid scintillation detectors)
  - HSD (Hyper-Scintillation-Detector) Kimballton mine, Virginia, USA

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