Large-Volume Liquid-Scintillator Detectors

ANT 09
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LENA

Low-**E**nergy **N**eutrino **A**strophysics

Liquid Scintillator
ca. 50kt PXE/LAB

Inner Nylon Vessel
radius: 13m

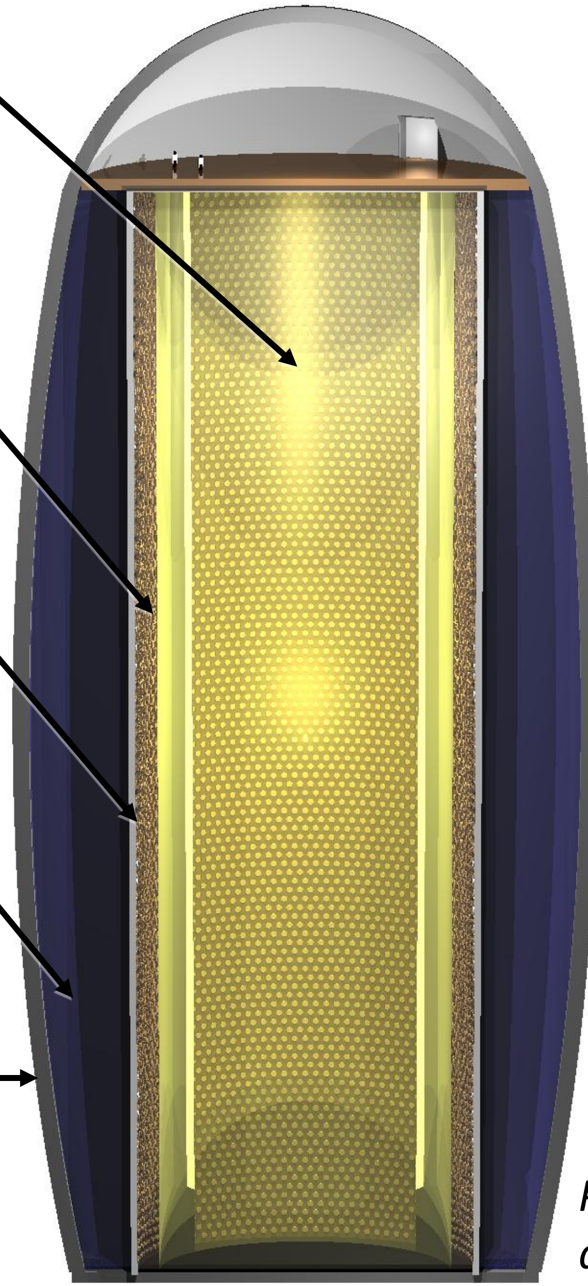
Buffer Region
inactive, $\Delta r = 2$m

Steel Tank, 13500 PMs
r = 15m, h = 100m,
optical coverage: .3

Water Cherenkov Veto
1500 PMTs, $\Delta r > 2$m
fast neutron shield

Egg-Shaped Cavern
about 10^8 m^3

Overburden: 4000 mwe



Pyhäsalmi design

organic liquid:
in total 70kt

diameter governed by scintillator transparency

PM config optimization
PMm^2

Detector Specifications

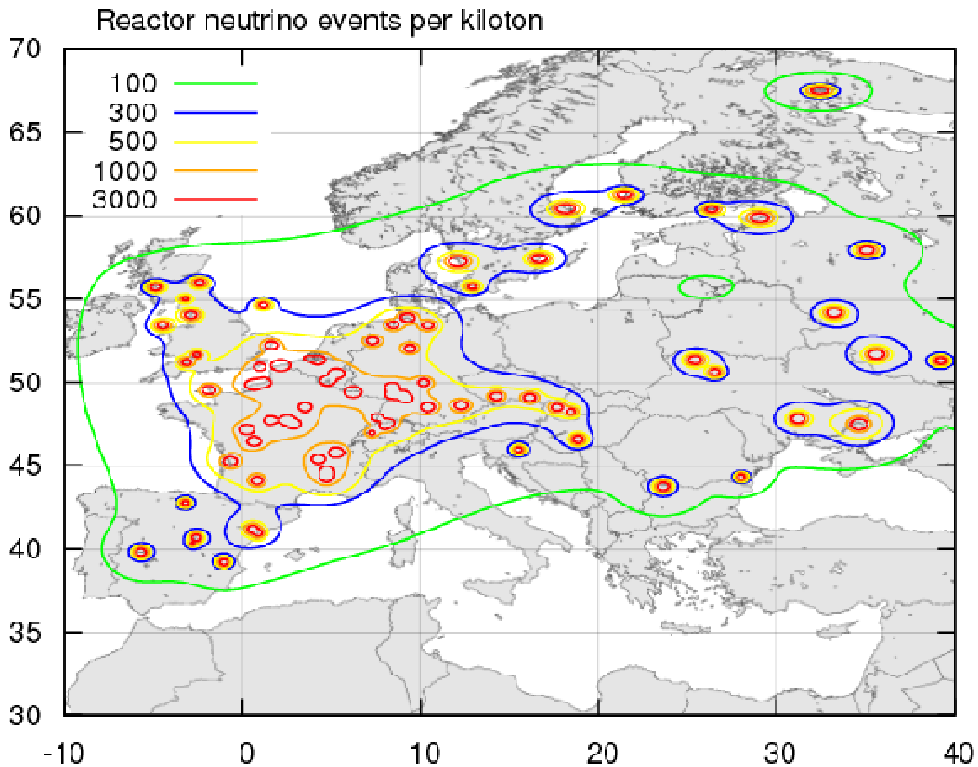
for low energy neutrino events

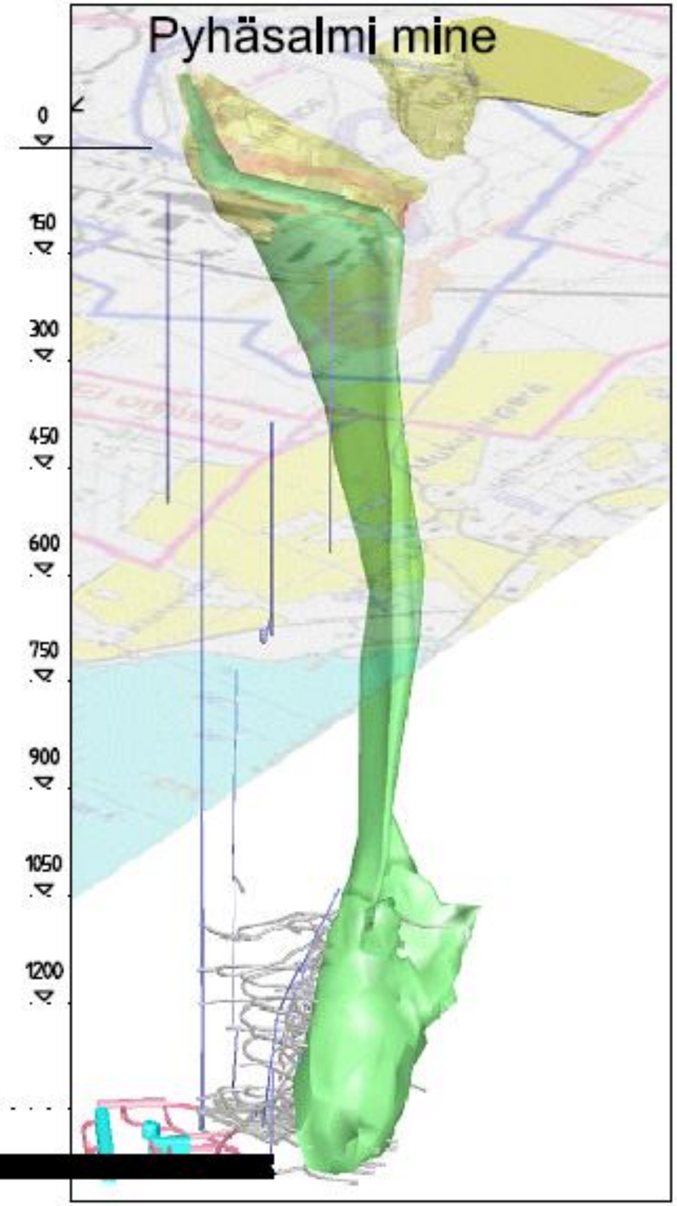
	solar ν_e	$\bar{\nu}_e$
Target mass (kt)	25	50
Energy Resolution (%) *@ 1MeV*	4 – 7 (3.3)	
Detection Threshold (MeV)	<0.1	1.8
Effective Threshold (MeV)	>0.5	1.8

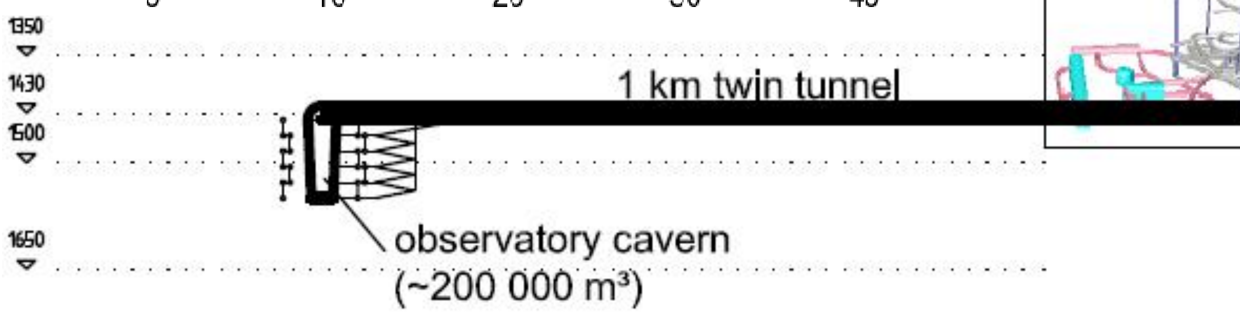
Detector Locations

Requirements:

- depth vs. physics
- remote from reactors
- liquid-scintillator safety





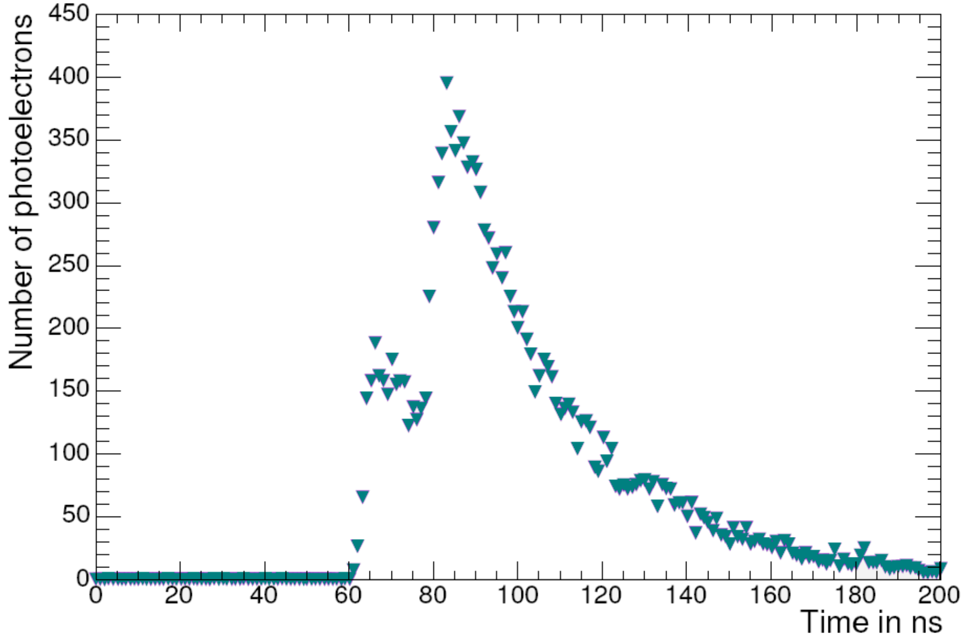


Physics Objectives

- Proton decay
- Galactic Supernova neutrinos
- Diffuse Supernova neutrinos
- Geoneutrinos
- Solar neutrinos
- Atmospheric neutrinos
- Neutrino/Beta beam
- Reactor neutrinos
- Indirect dark matter search

…

Proton Decay into $K^+\bar{\nu}$



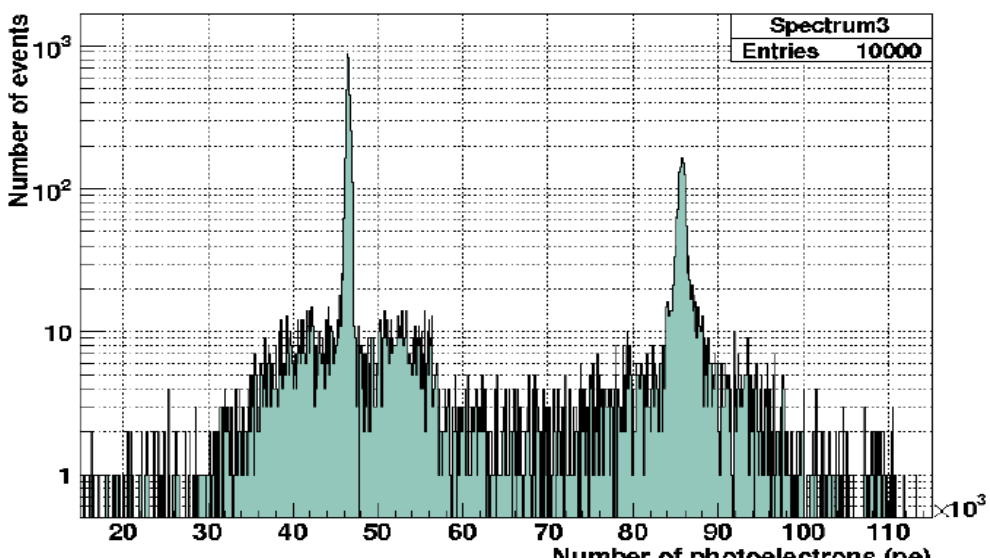
Signature $p \rightarrow K^+ \bar{\nu}$

$\hookrightarrow \mu^+\nu_\mu \,/\, \pi^0\pi^+$

coincidence: τ_K = 13 ns

energy: 250-450 MeV

modified by Fermi motion for ^{12}C



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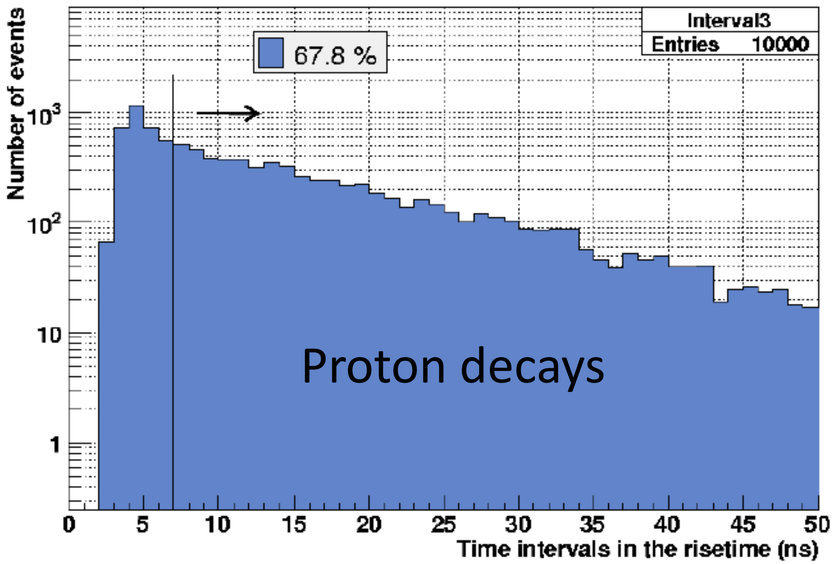

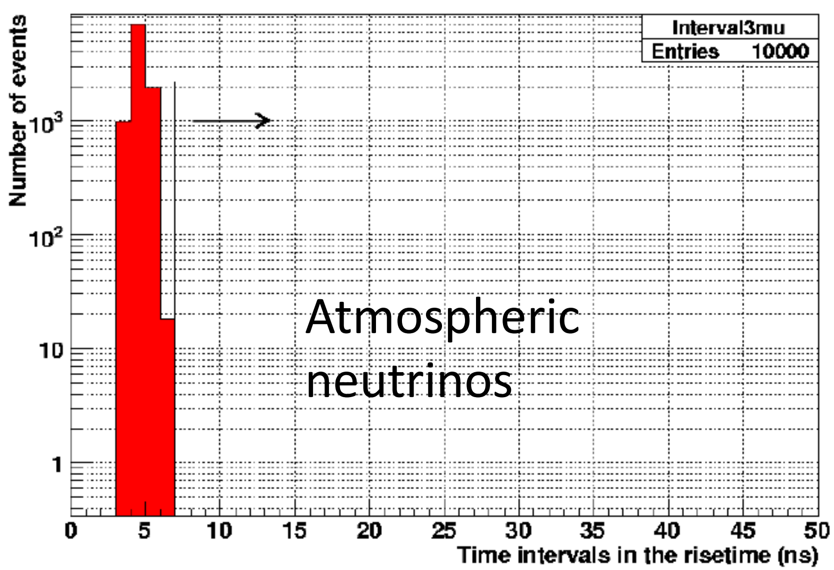

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Background

atmospheric ν's rejected

by rise time cut: **efficiency .67**

hadronic channel: <1 per 1Mta

(Kaon production) @ 4kmwe

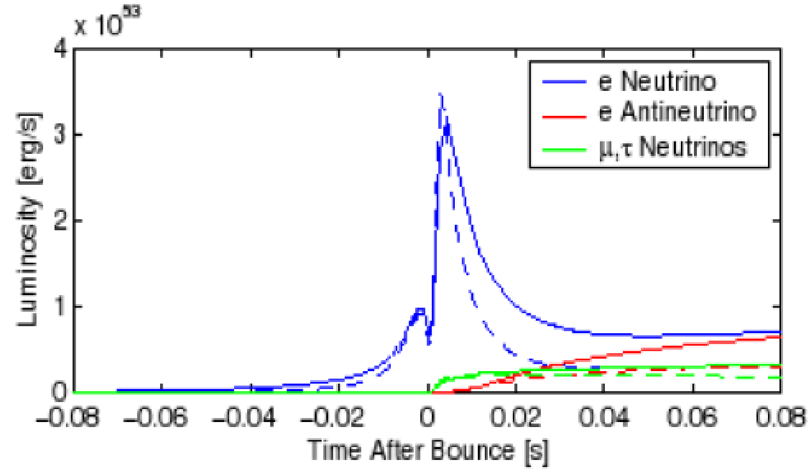
Current SK limit: 2.3×10^{33} a

Limit for LENA if no event is observed in 10a (0.5Mta):

$\tau_p > 4 \times 10^{34}$ a *(90%C.L.)*

Galactic SN Neutrinos in LENA

ν_e from neutronisation burst
$\nu\bar{\nu}$ pairs of all flavors
from protoneutronstar cooling



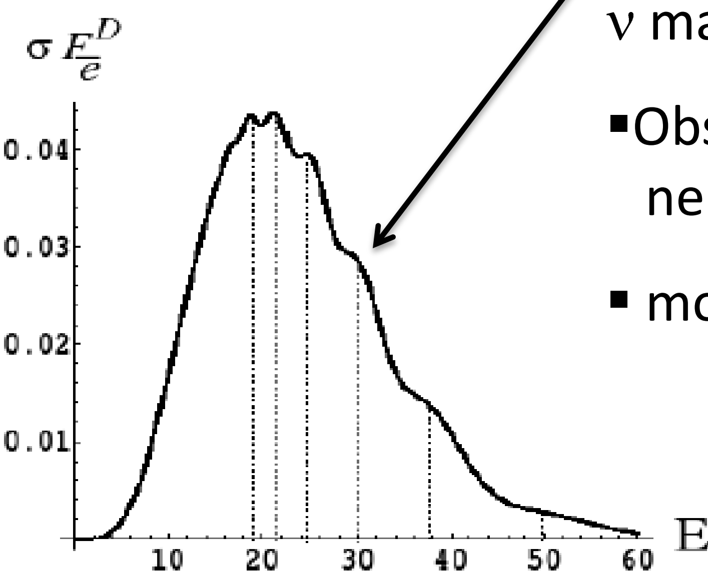
For "standard" SN (10kpc, $8M_\odot$):
ca. 13k events in 50kt target

Channel	Rate	Threshold (MeV)	Spectrum
$\nu_e\, p \rightarrow n\, e^+$	8900	1.8	✓
$\nu_e\, {}^{12}C \rightarrow {}^{12}N\, e^-$	200	17.3	(✓)
$\nu_e\, {}^{12}C \rightarrow {}^{12}B\, e^+$	130	13.4	(✓)
$\nu\, {}^{12}C \rightarrow {}^{12}C^*\, \nu$	860	15.1	✗
$\nu\, p \rightarrow p\, \nu$	2200	1.0	✓
$\nu\, e^- \rightarrow e^- \nu$	700	0.2	✓

Scientific Gain of SN Observation

Astrophysics

- Observe neutronisation burst
- Cooling of the neutron star
flavor-dependent spectra
and luminosity, time-dev.
- Propagation of the shock wave
by envelope matter effects
- SNEWS



Neutrino physics

- Survival probability of ν_e in neutronisation burst
$P_{ee} \approx 0 \rightarrow$ normal mass hierarchy
- Resonant flavor conversions in the SN envelope: hierarchy, θ_{13}
- Earth matter effect:
ν mass hierarchy, θ_{13}
- Observation of collective neutrino oscillations
- more exotic effects ...

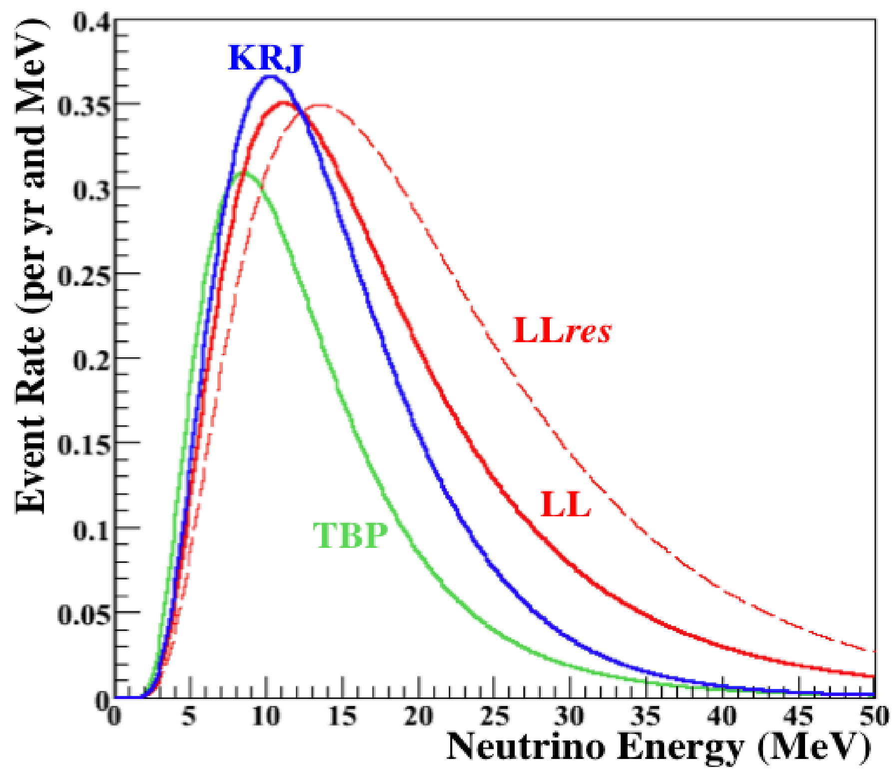
Diffuse SN Neutrinos in LENA

Regular galactic Supernova rate:
1-3 per century

Alternative access:

- isotropic ν background generated by SN on cosmic scales
- redshifted by cosmic expansion
- flux: 100/cm^{2}s of all flavours
- rate too low for detection in current neutrino experiments

In LENA: 4-30 $\bar{\nu}_e$ per year (50kta)



Background in Liquid Scintillators

Detection via Inverse Beta Decay

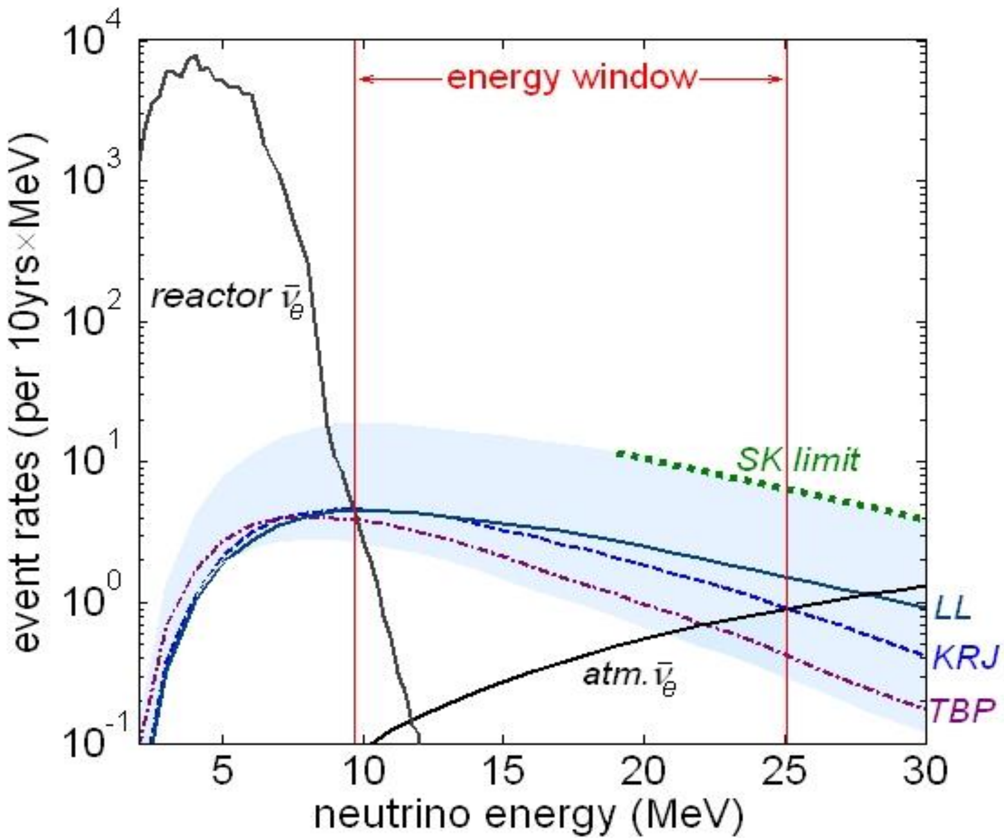
$\bar{\nu}_e + p \rightarrow n + e^+$

allows discrimination of most single-event background limiting the detection in SK

Remaining Background Sources

- reactor and atmospheric $\bar{\nu}_e$'s
- cosmogenic βn-emitters: ^{9}Li
- fast neutrons
- solar $\bar{\nu}_e$'s

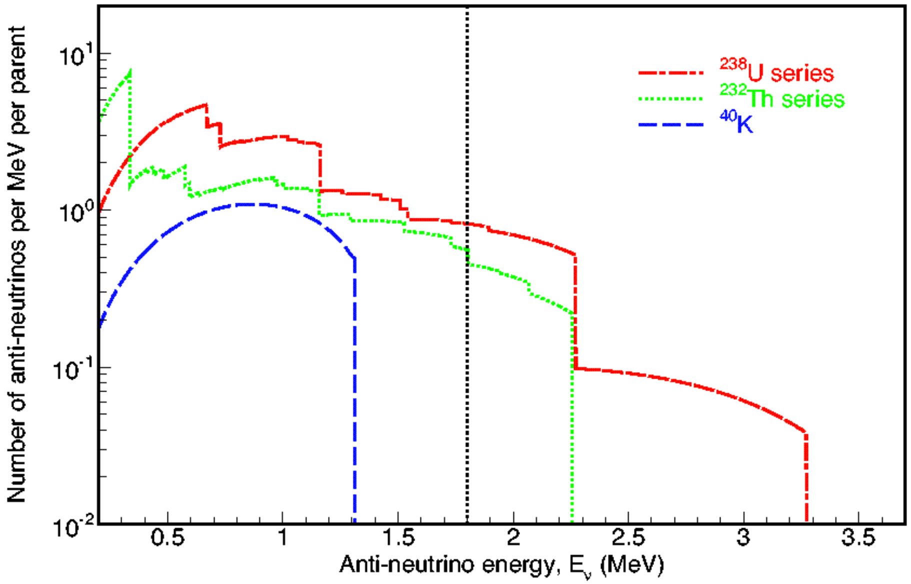
Expected rate: **2-20 ev/50kta**
(in energy window from 10-25MeV)

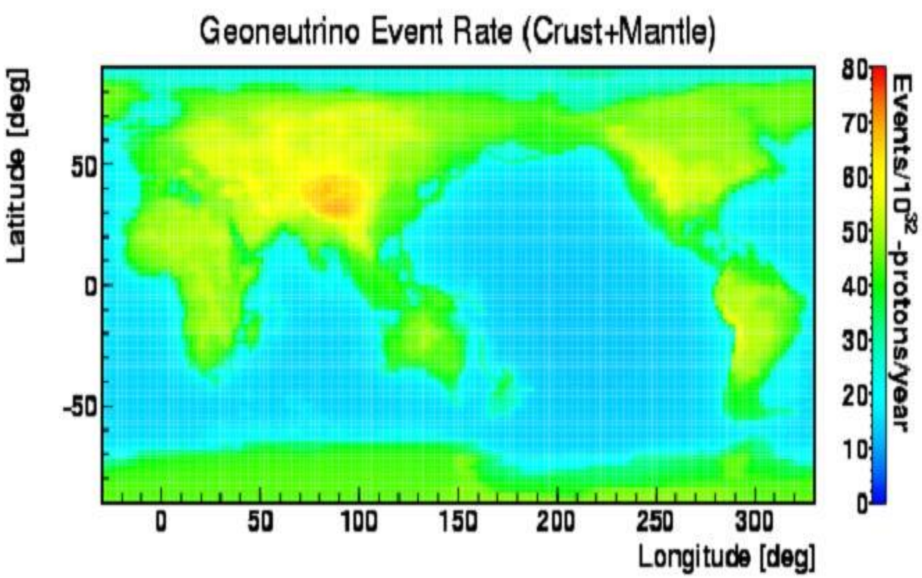


Scientific Gain

- first detection of DSN
- information on SNν spectrum

Geoneutrinos





IBD threshold of 1.8 MeV

ν_e by U/Th decay chains

At Pyhäsalmi

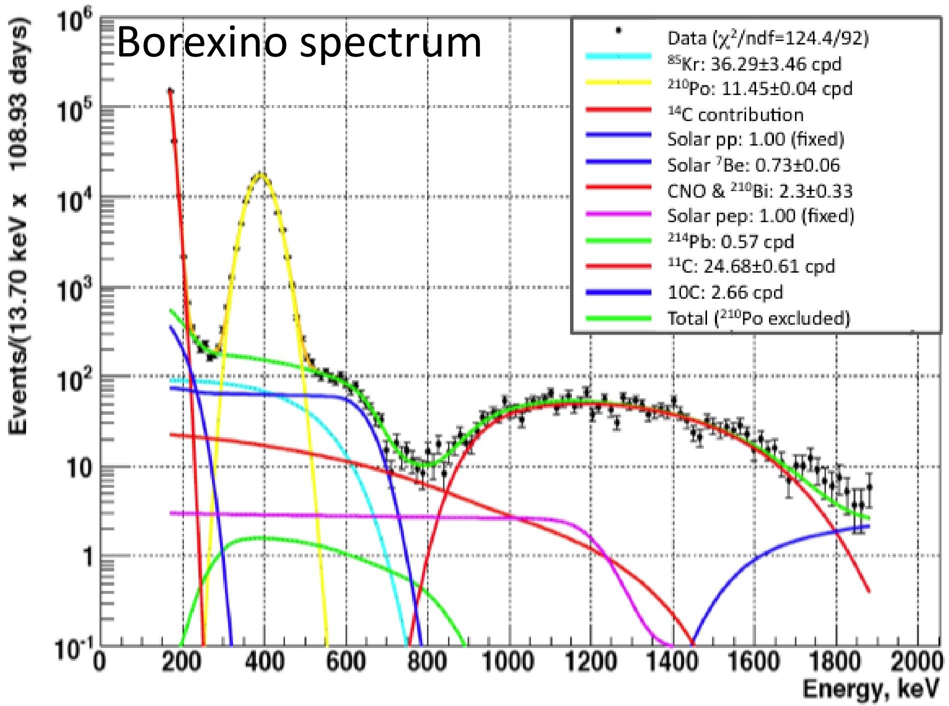
expected rate $2\text{x}10^3$ / 50 kta

reactor-ν bg 700

Scientific Gain

- determine Urey-ratio
- measure relative contributions of U and Th decay chains
- with several detectors at different sites: disentangle oceanic/continental crust
- hypothetical georeactor

Solar Neutrinos in LENA



Channel	Source	Neutrino Rate $[\mathrm{d}^{-1}]$ BPS08(GS)	BPS08(AGS)
νe	pp	24.92 ± 0.15	25.21 ± 0.13
	pep	365 ± 4	375 ± 4
	hep	0.16 ± 0.02	0.17 ± 0.03
	^{7}Be	4984 ± 297	4460 ± 268
	^{8}B	82 ± 9	65 ± 7
	CNO	545 ± 87	350 ± 52
^{13}C	^{8}B	1.74 ± 0.16	1.56 ± 0.14

- **pp:** solar ν luminosity
  very hard even in Borexino
- **^{7}Be:** solar metallicity Z, search for rate modulations
  depends on radiopurity
- **pep:** Survival probability in the MSW-vacuum transition region
  depends on depth (^{11}C bg)
- **^{8}B:** Z, onset of MSW effect for energies between 2 and 5 MeV
  also cosmogenics
- **CNO:** solar Z, stellar evolution
  like pep

... assuming 18kt fiducial volume

Summary

- a large-volume liquid-scintillator detector is a multipurpose neutrino observatory
- very rare event search as well as high-statistics measurements of (astrophysical) sources
- main virtues are good energy resolution, excellent background suppression and low detection threshold
- technique already tested in “prototypes“ like KamLAND and Borexino and is scalable to the envisioned detector dimensions