LENA performance: Astroparticle and geophysics

Hamburg, 14 June 2012

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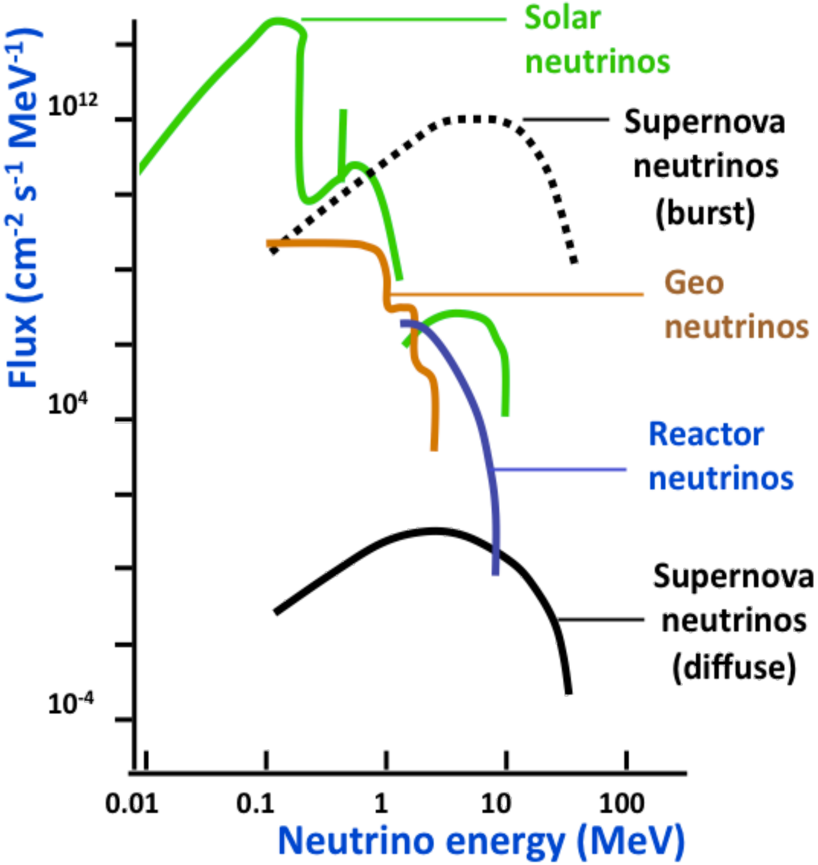
Neutrino signal at low energies

Natural sources

- Galactic Supernova neutrinos 10^4/SN
- Diffuse Supernova neutrinos 10/yr
- Solar neutrinos 10^4/d
- Dark matter annihilation
- Geoneutrinos 10^3/yr

Man-made sources

- Reactor neutrinos $10^{3\text{-}4}$/yr
- Radioactive sources 10^4/MCi
- Pion decay-at-rest beams



Supernova neutrinos

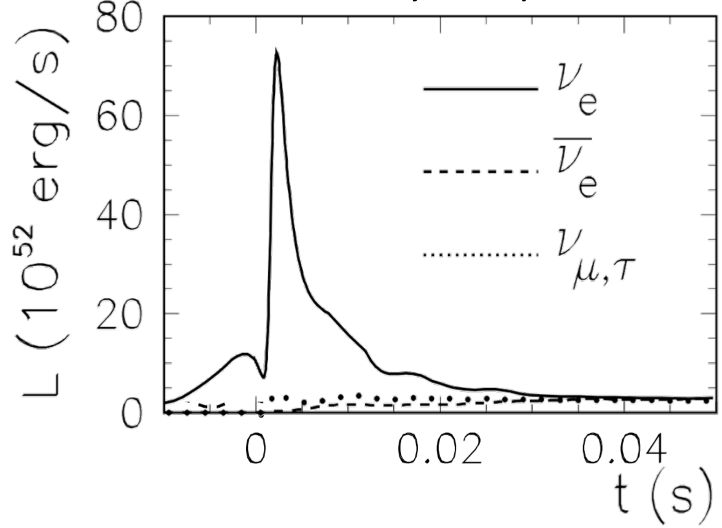
SN neutrinos in LENA

ν_e from neutronisation burst

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

For galactic SN (10kpc, 8M$_\odot$, <E$_\nu$>=14MeV):
ca. 2x10^4 events in 44kt target

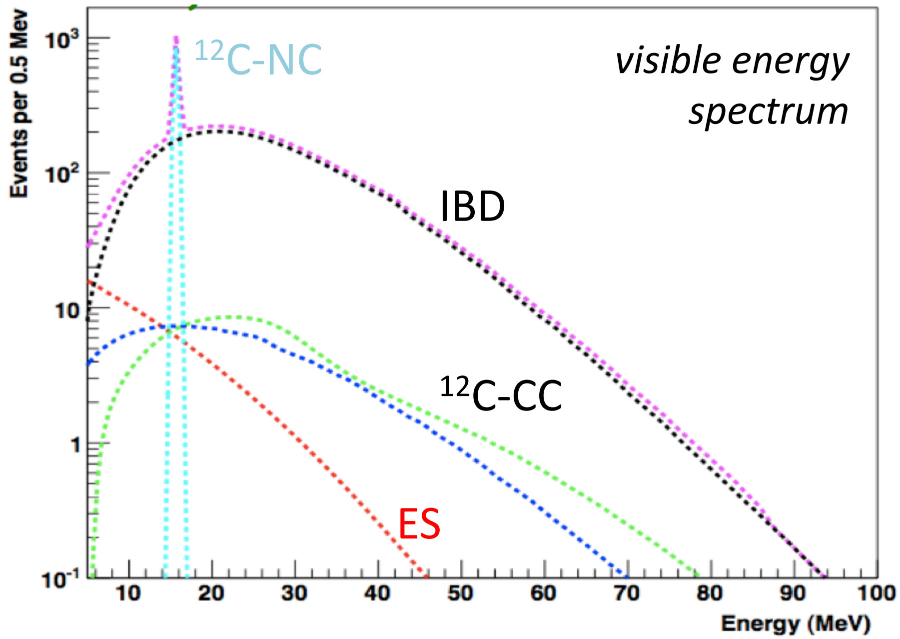
ν flux around core collapse
→ ~10^2 ev. by νe/νp-scat.+^{12}C

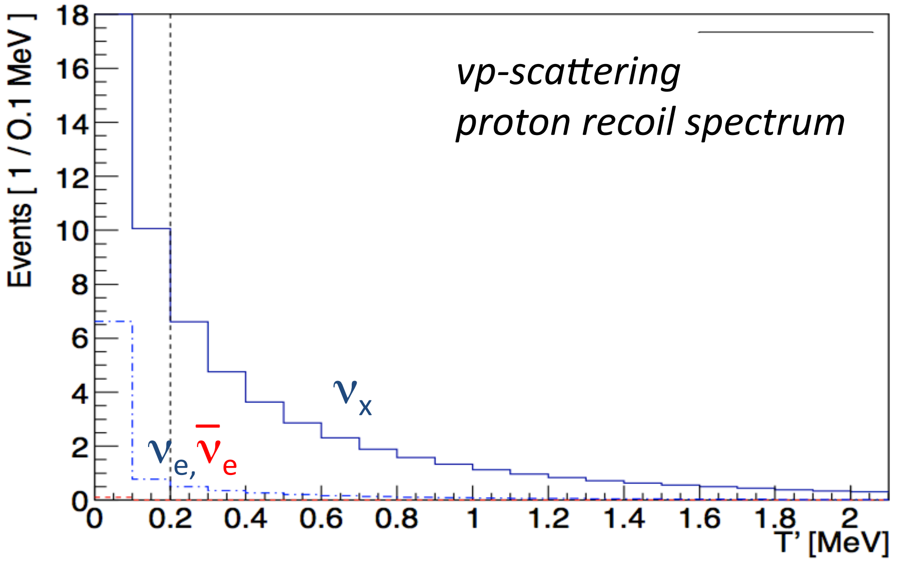


Channel		Events	Threshold (MeV)	Spectrum
$\bar{\nu}_e\, p \rightarrow n\, e^+$	CC	1.3x10^4 *	1.8	✓
$\nu_e\, {}^{12}C \rightarrow {}^{12}N\, e^-$	CC	3.4x10^2	17.3	(✓)
$\bar{\nu}_e\, {}^{12}C \rightarrow {}^{12}B\, e^+$	CC	1.8x10^2	13.4	(✓)
$\nu\, {}^{12}C \rightarrow {}^{12}C^*\, \nu$	NC	1.0x10^3	15.1	✗
$\nu\, p \rightarrow p\, \nu$	NC	2.6x10^3	1.0	✓
$\nu\, e^- \rightarrow e^-\, \nu$	NC CC	6.2x10^2	0.2	✓

**roughly 2x the rate in Super-Kamiokande*

Expected signal from SN neutrinos





Signal above 10 MeV

- dominated by inverse beta decay
- coincidence signals allow to tag IBD and ^{12}C-CC reactions
- $^{12}C+\nu_e/\bar{\nu}_e$ separation by simultaneous fit to energy and decay spectra
- γ-peak from ^{12}C-NC reaction

→ **LENA can resolve the different interaction channels!**

Signal at 1 MeV

- dominated by ν-proton scattering
- sensitive on threshold by ^{14}C-decay
- extract νe-scattering by PSD?

→ **νp-scattering unique feature of liquid scintillator detectors**

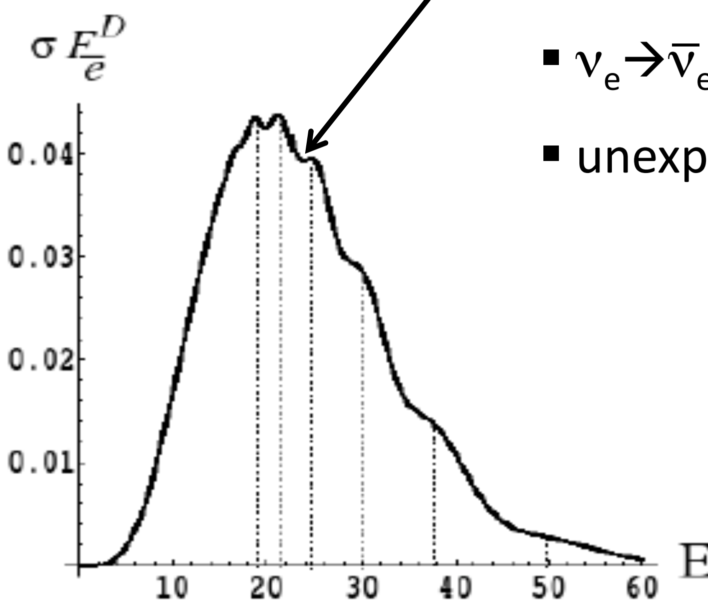
Expected physics output from SN neutrinos

Astrophysics

- detailed information on core-collapse (ν energy, flavor, time-profile)
  - initial neutronization burst
  - features of cooling phase
  - explosion shock-wave
- signals from dim SNe, black hole formation
- IBD: pointing to obscured SNe
- SNEWS, grav. wave exp.

Neutrino physics

- neutrino mass hierarchy by
  - neutronization burst
  - resonant flavor conversion in stellar envelope
  - Earth matter effect
  - signal rise time
- collective oscillations
- $\nu_e \rightarrow \bar{\nu}_e$ conversion
- unexpected effects ...



Diffuse SN neutrinos in LENA

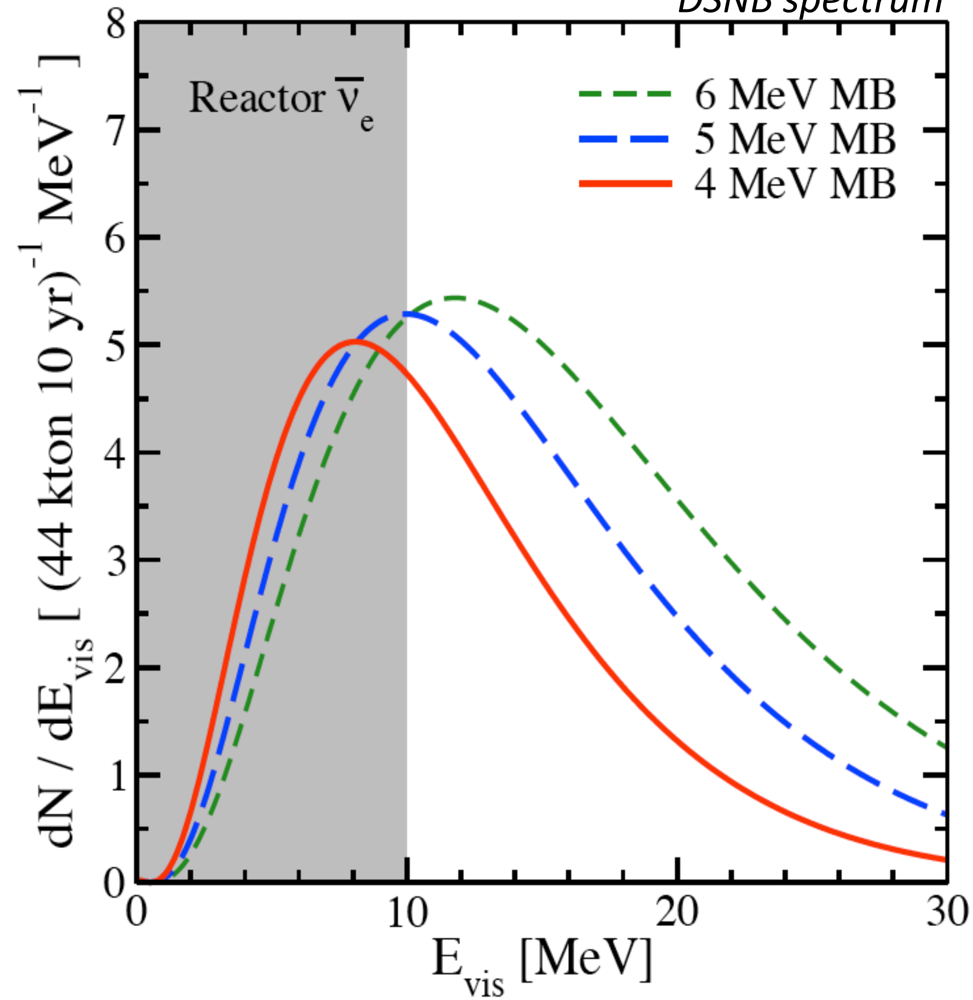
Regular galactic Supernova rate:
1-3 per century

Alternative access:

- isotropic ν background generated by SN on cosmic scales
- redshifted by cosmic expansion
- flux: 100/cm^2s of all flavours
- rate too low for detection in current neutrino experiments *(best limit by Super-Kamiokande)*

In LENA: 2-20 $\bar{\nu}_e$ per year (50kta)

DSNB spectrum



Backgrounds for DSN search in LENA

Detection via Inverse Beta Decay

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

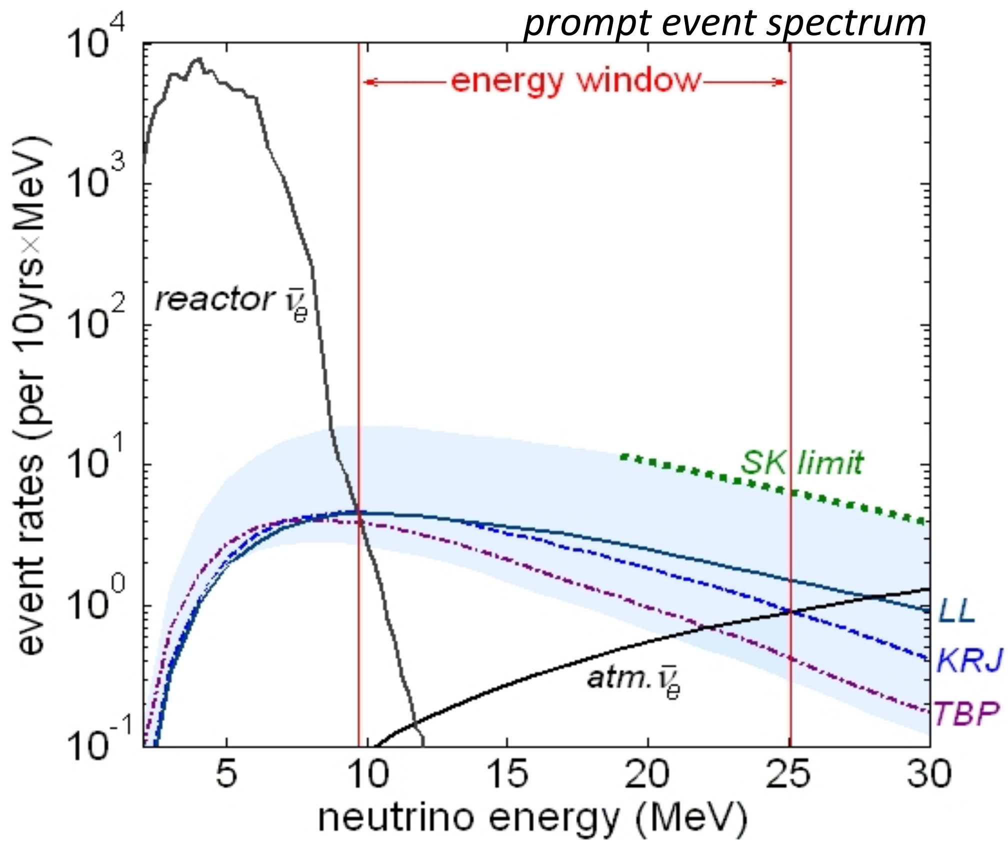
neutron tagging allows discrimination of most single-event bg limiting the detection in SK

Remaining Background Sources

- reactor and atmospheric $\bar{\nu}_e$'s
- cosmogenic backgrounds:
  – fast neutrons and ^{9}Li: μ veto
  – atmospheric ν NC events: PSD

Scientific Gain

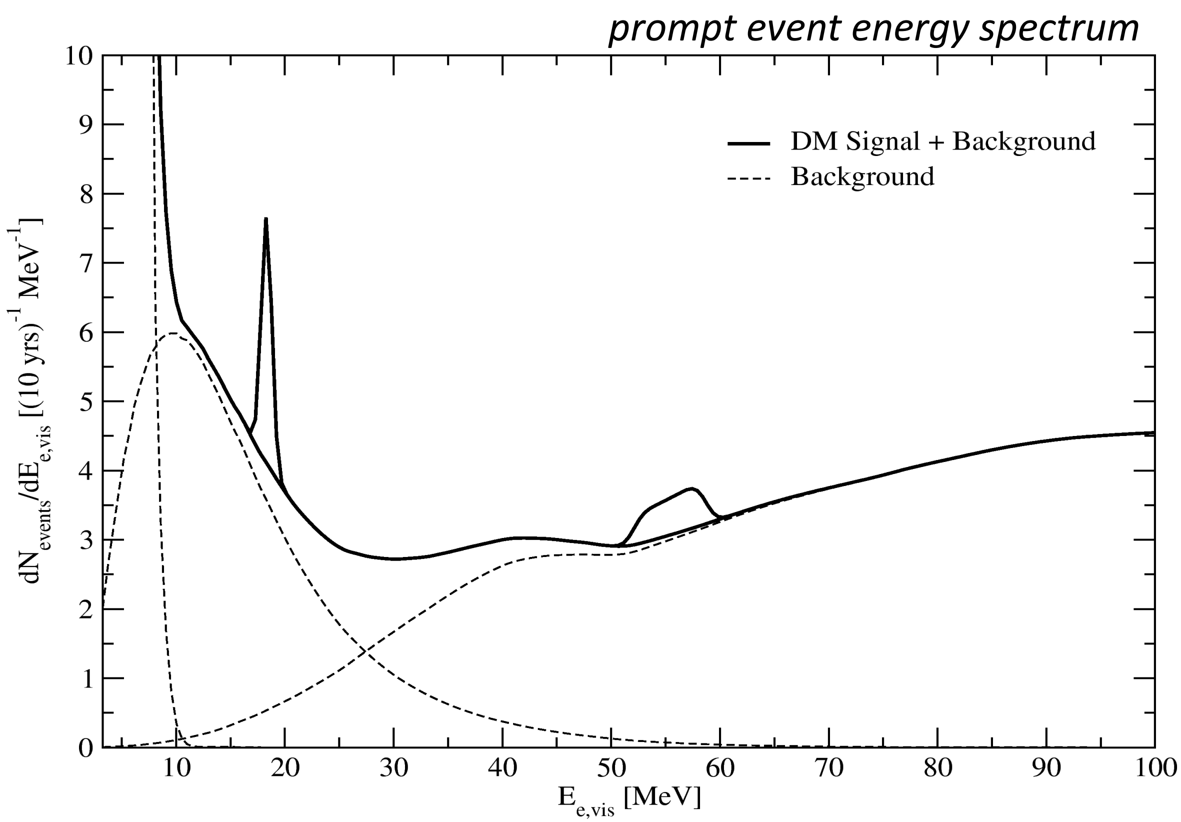
- first detection of DSN
- average SNν spectrum
- fraction of dim/failed SNe (?)



Expected events: ~10² in 10 yrs
(in energy window from 10-25MeV

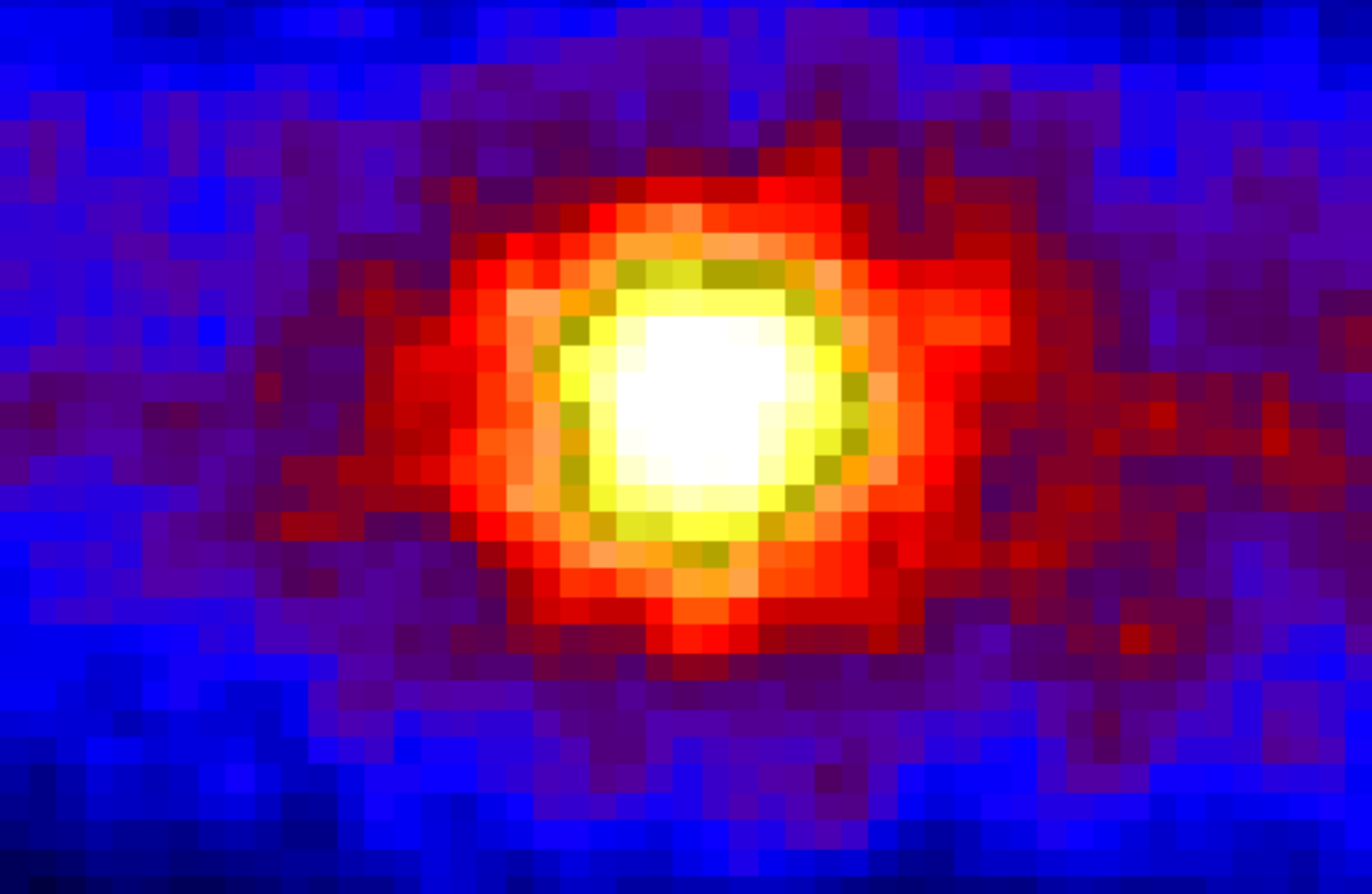
~2x of GADZOOKS! expectation

Indirect light dark matter search



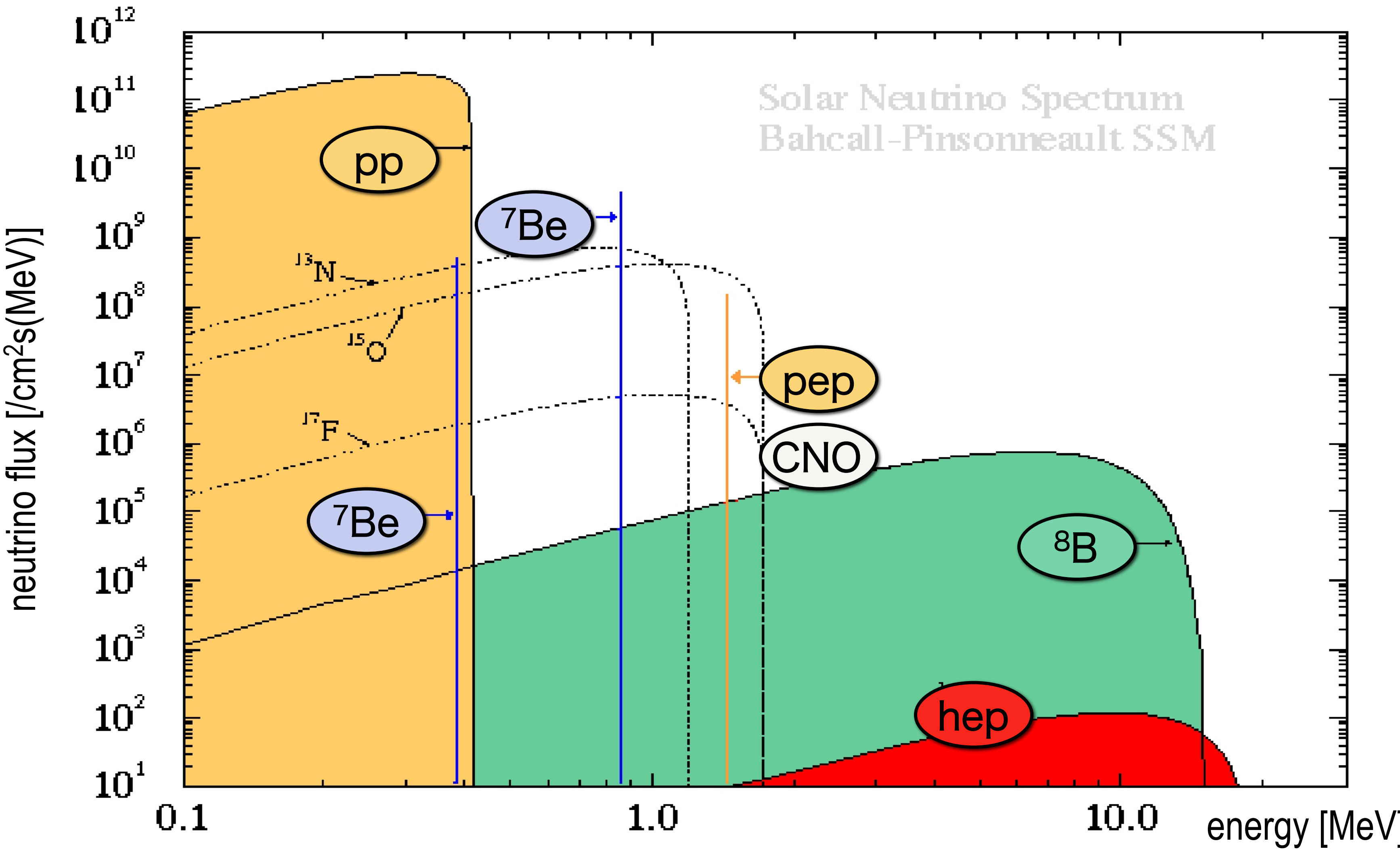
- low background level in IBD allows to search for $\bar{\nu}_e$ from $\chi\bar{\chi} \rightarrow \nu_e \bar{\nu}_e$
- signature for annihilation: peak at $E = m_\chi$, with m_χ = 10 ... 100 MeV.

Solar neutrinos



Solar neutrino signal in LENA

Liquid scintillator:
– low energy threshold (~200 keV)
– required level of radiopurity

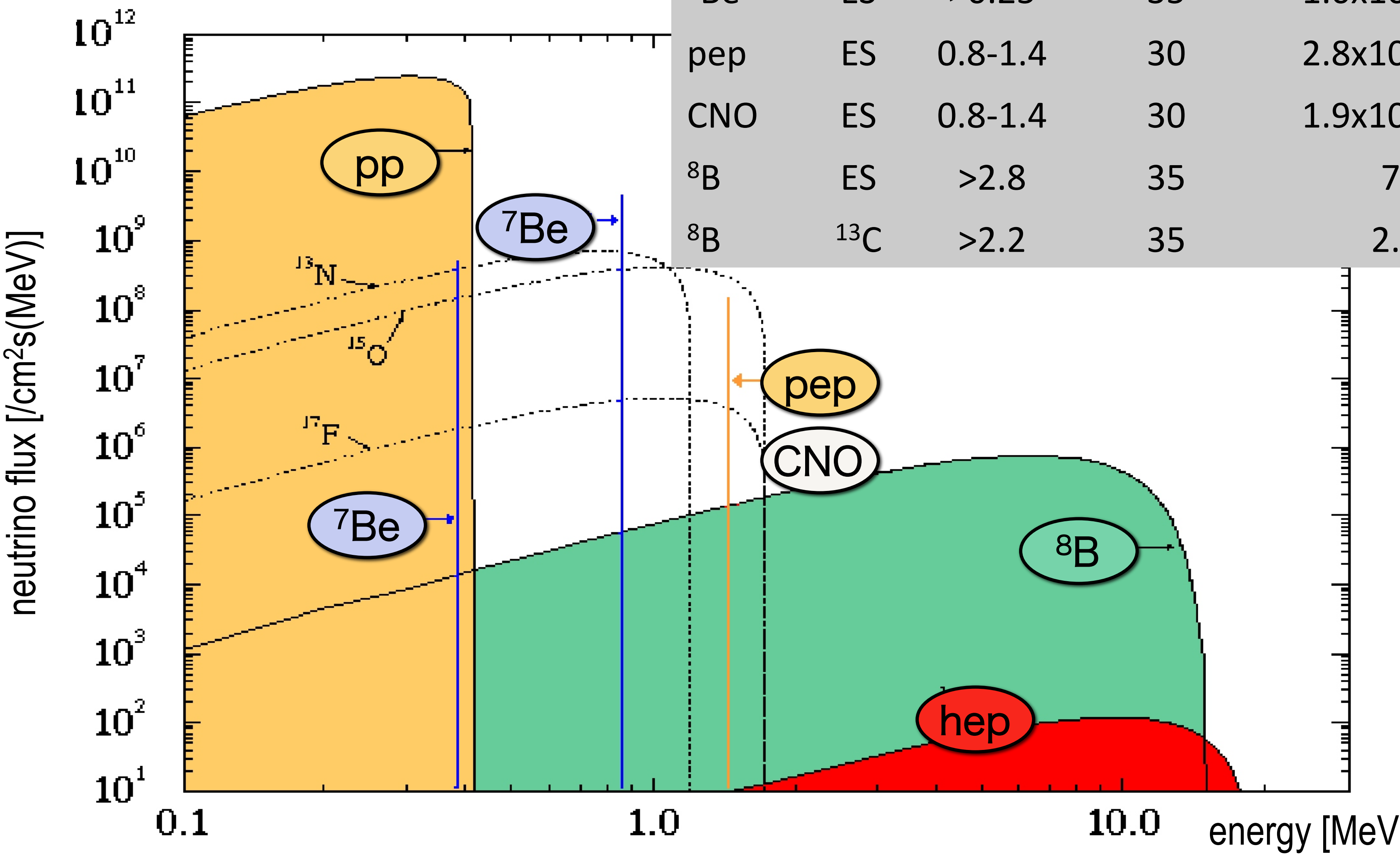


Solar neutrino signal in LENA

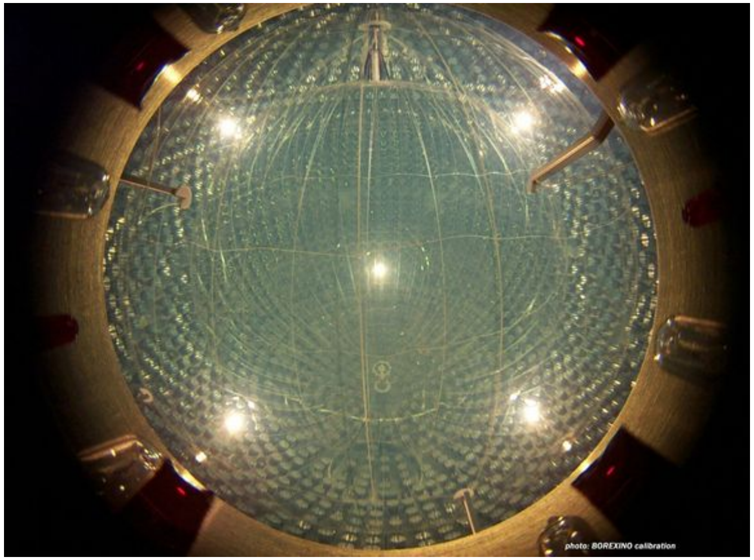
Liquid scintillator: – low energy thr

– required level (

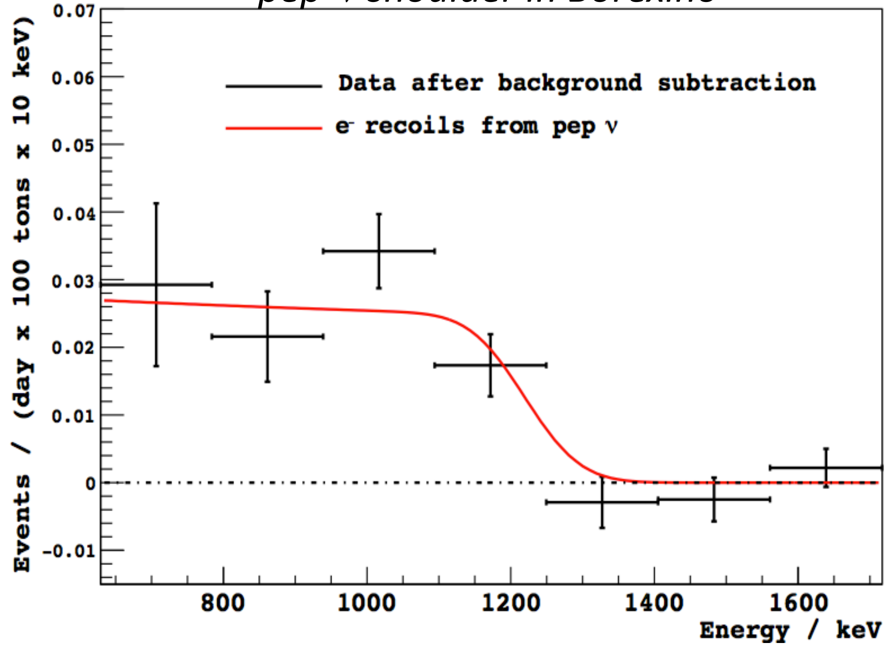
Source	Ch	E (MeV)	M_{fid} (kt)	Rate (d^{-1})
^{7}Be	ES	>0.25	35	$1.0x10^4$
pep	ES	0.8-1.4	30	$2.8x10^2$
CNO	ES	0.8-1.4	30	$1.9x10^2$
^{8}B	ES	>2.8	35	79
^{8}B	^{13}C	>2.2	35	2.4



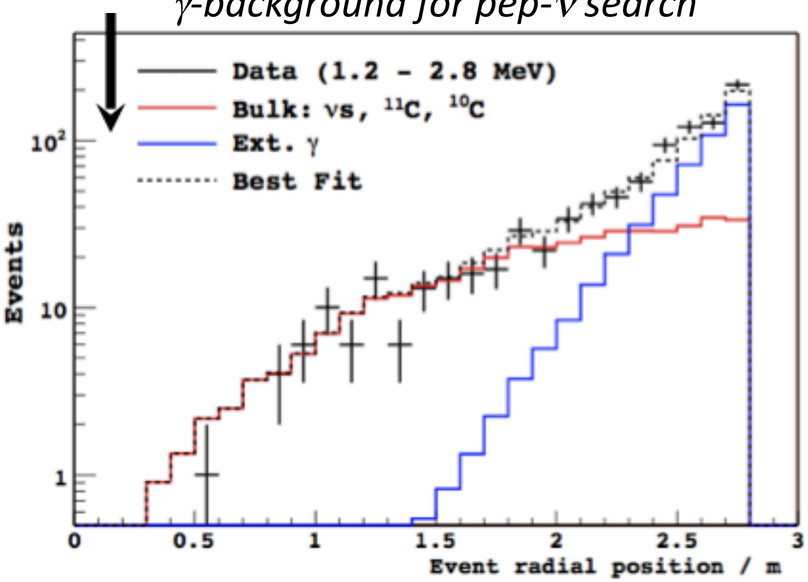
Gain compared to Borexino



pep-ν shoulder in Borexino



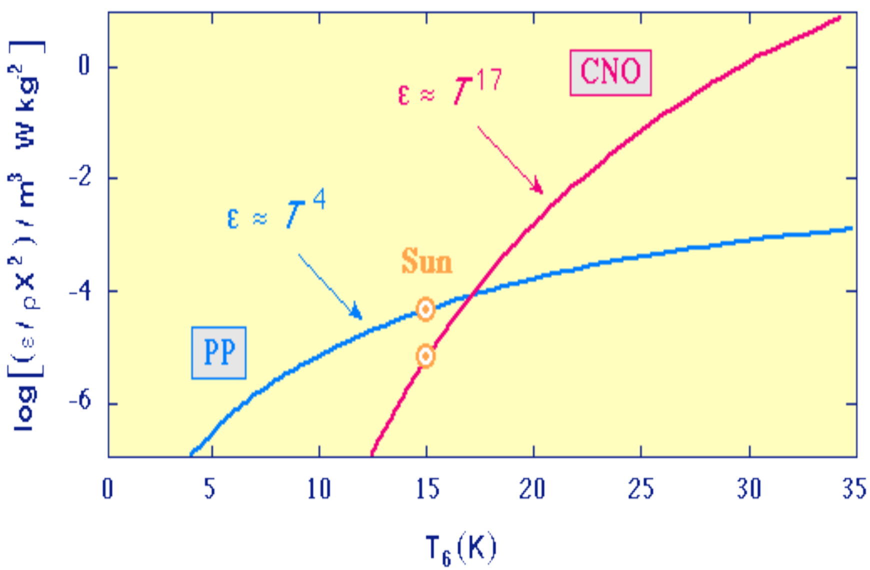
γ-background for pep-ν search



Borexino → LENA

- fiducial volume: >300 times larger
- 4000 mwe at Pyhäsalmi → cosmic backgrounds reduced by factor 3-5
- lower external γ background

Physics programme for solar neutrinoss

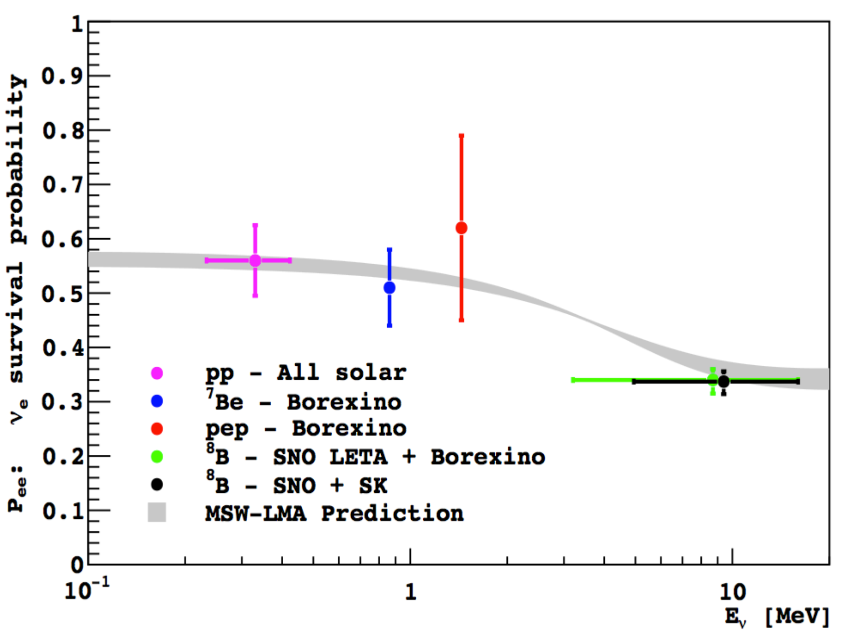


Astrophysics

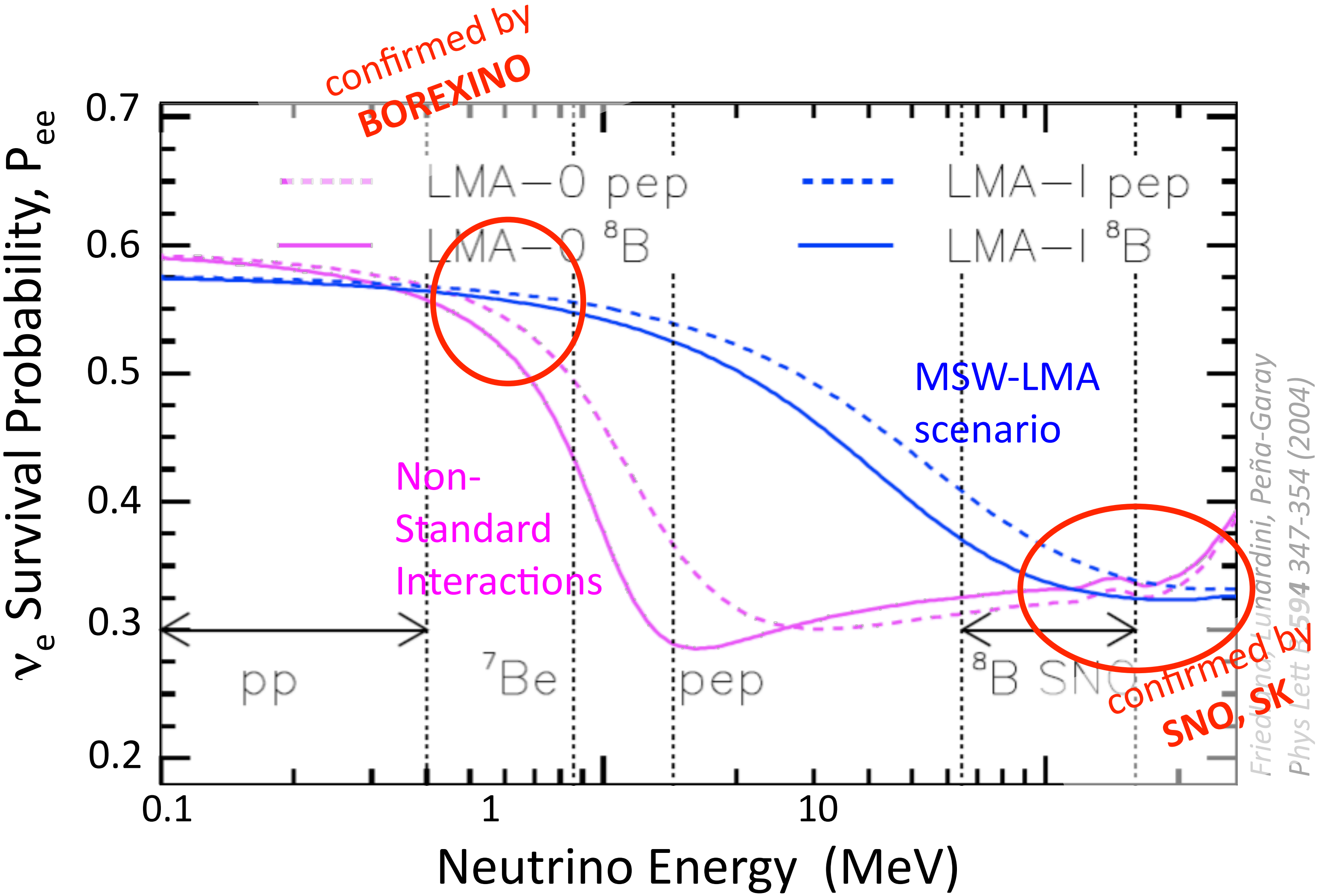
- contribution of CNO cycle to solar fusion rate
- metallicity of solar core
- presence of time variations in solar neutrino flux (10^{-3} level) → helioseismic g-modes ...

Neutrino physics

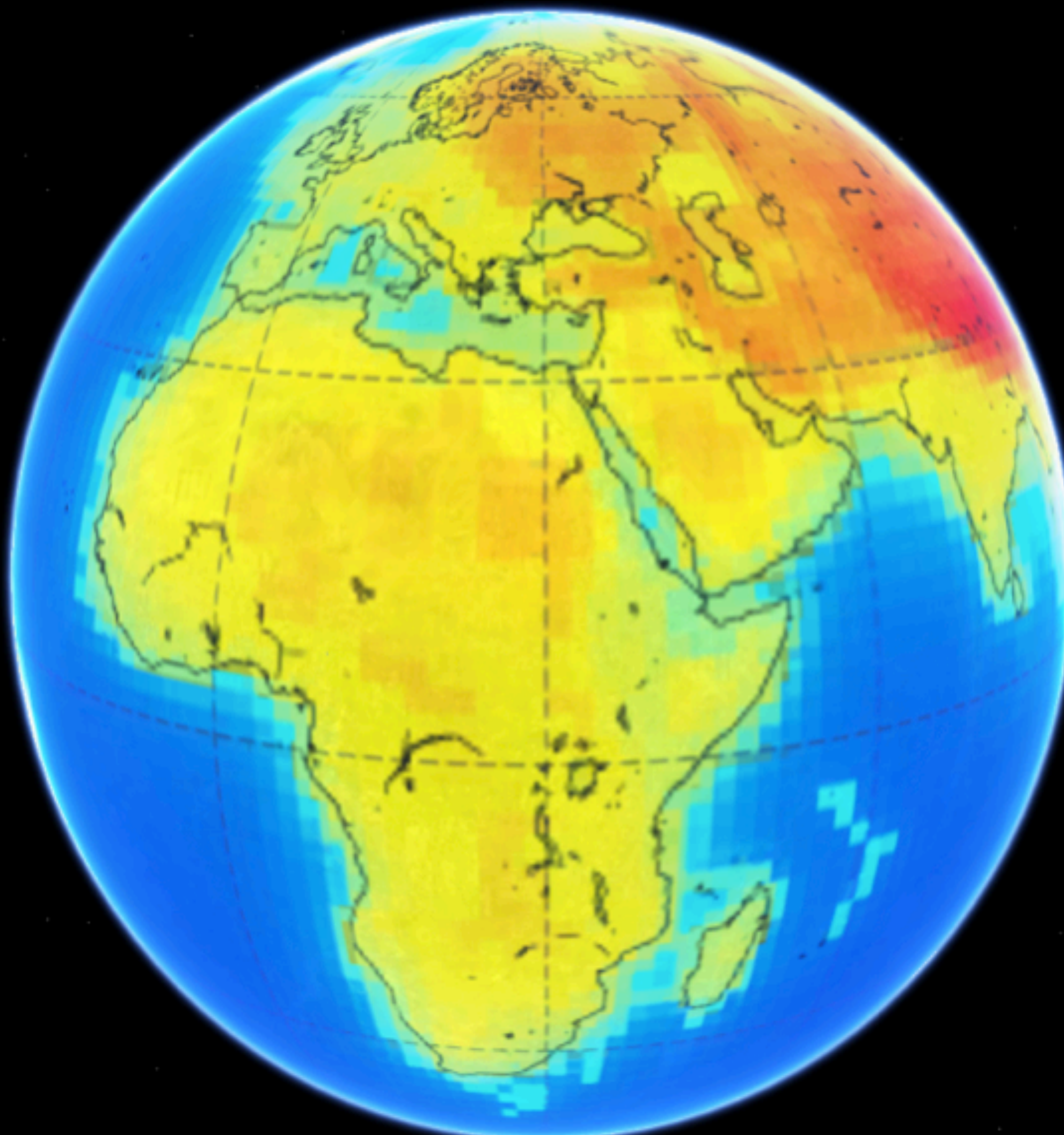
- precision measurement of P_{ee} in the matter-vacuum transition region (1-5 MeV) by pep and ^{8}B (CC) on ^{13}C → non-standard interactions etc.
- $\nu_e \rightarrow \bar{\nu}_e$ conversion



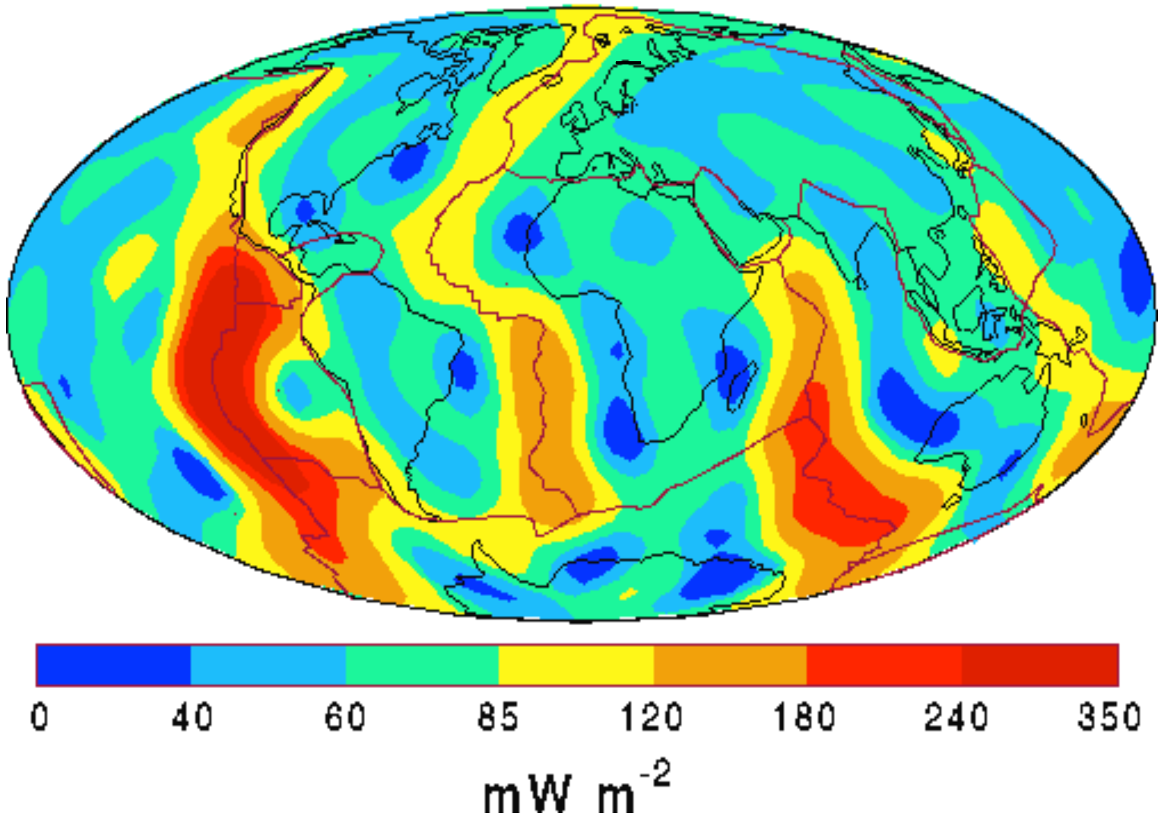
Pee in matter-vacuum transition region



Geoneutrino emission by crust and mantle



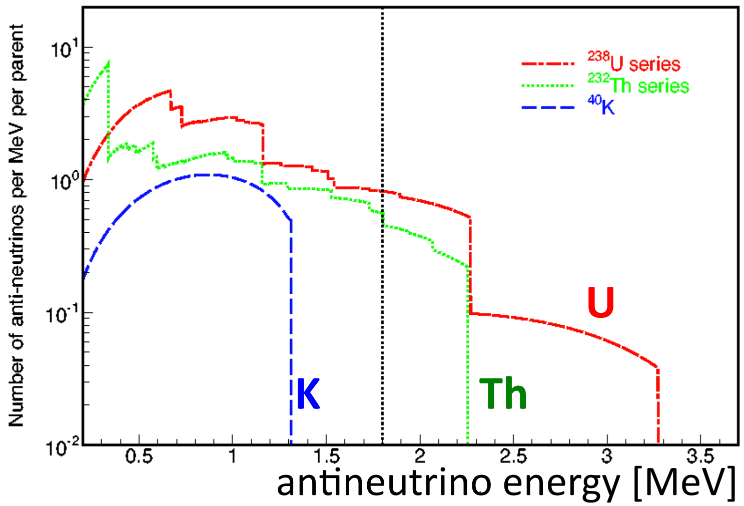
The Earth heat flow problem

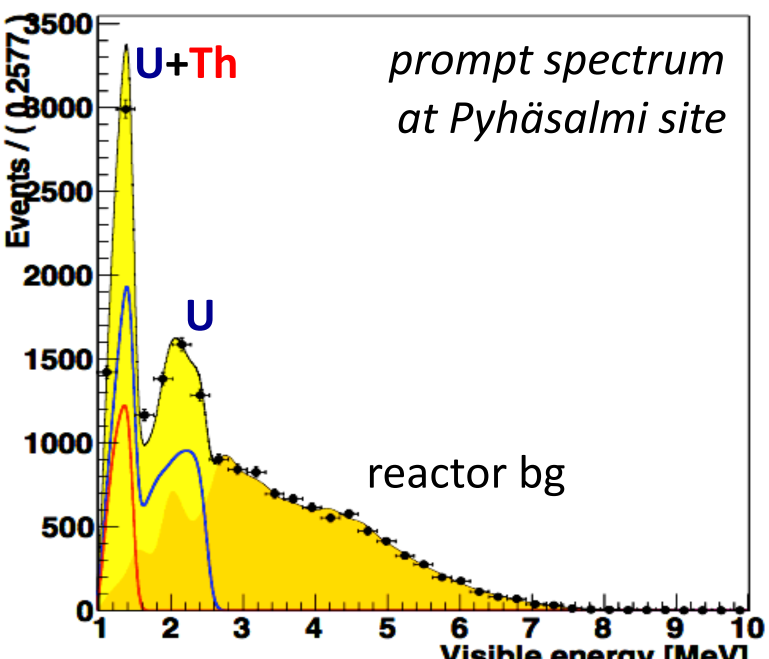


From surface measurement, the thermal power is determined to 47±2 TW.
Models determine the heat from radioactive decays of U, Th, K to 12-30 TW.

Is there a difference? And what accounts for the deficit?

Detection of geoneutrinos in LENA





IBD threshold of 1.8 MeV (only LS)

$\bar{\nu}_e$ by U/Th decay chains

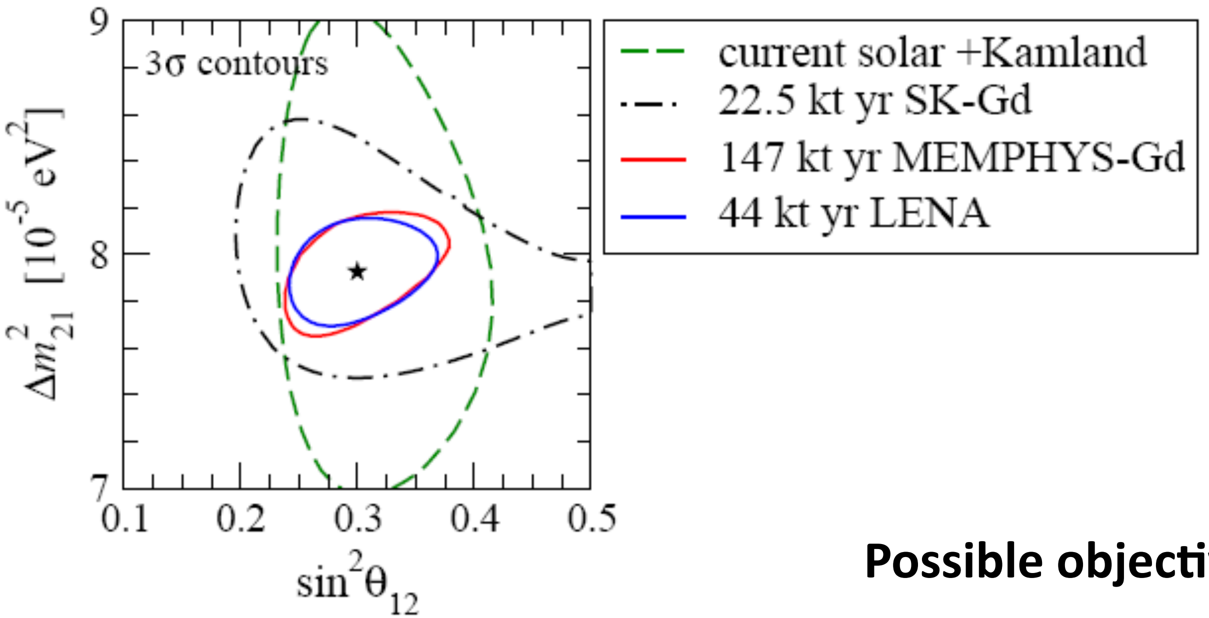
At Pyhäsalmi

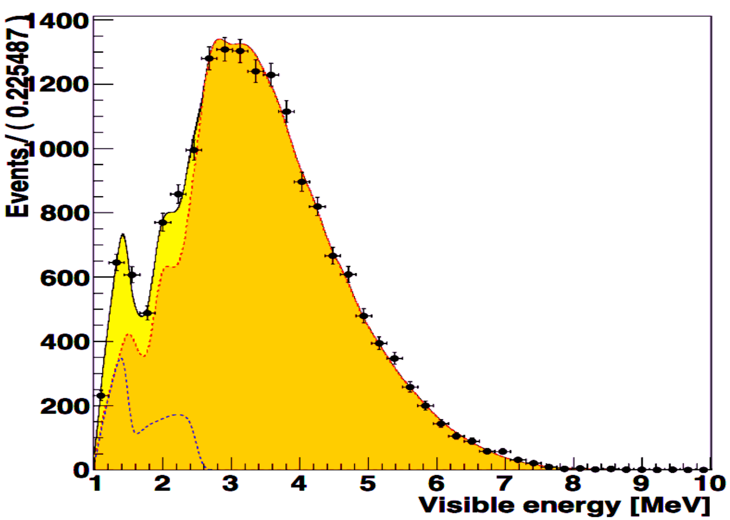
- expected geo-ν rate 2×10^3 yr^{-1}
- reactor-ν background 7×10^2

Scientific Gain

- contribution of U/Th decays to Earth's total heat flow → 1%
- relative ratio of U/Th → 5%
  → geochemistry: U/Th = 3.5 ... 4
- with several detectors at different sites: disentangle oceanic/continental crust
- test for hypothetical georeactor

Reactor neutrinos





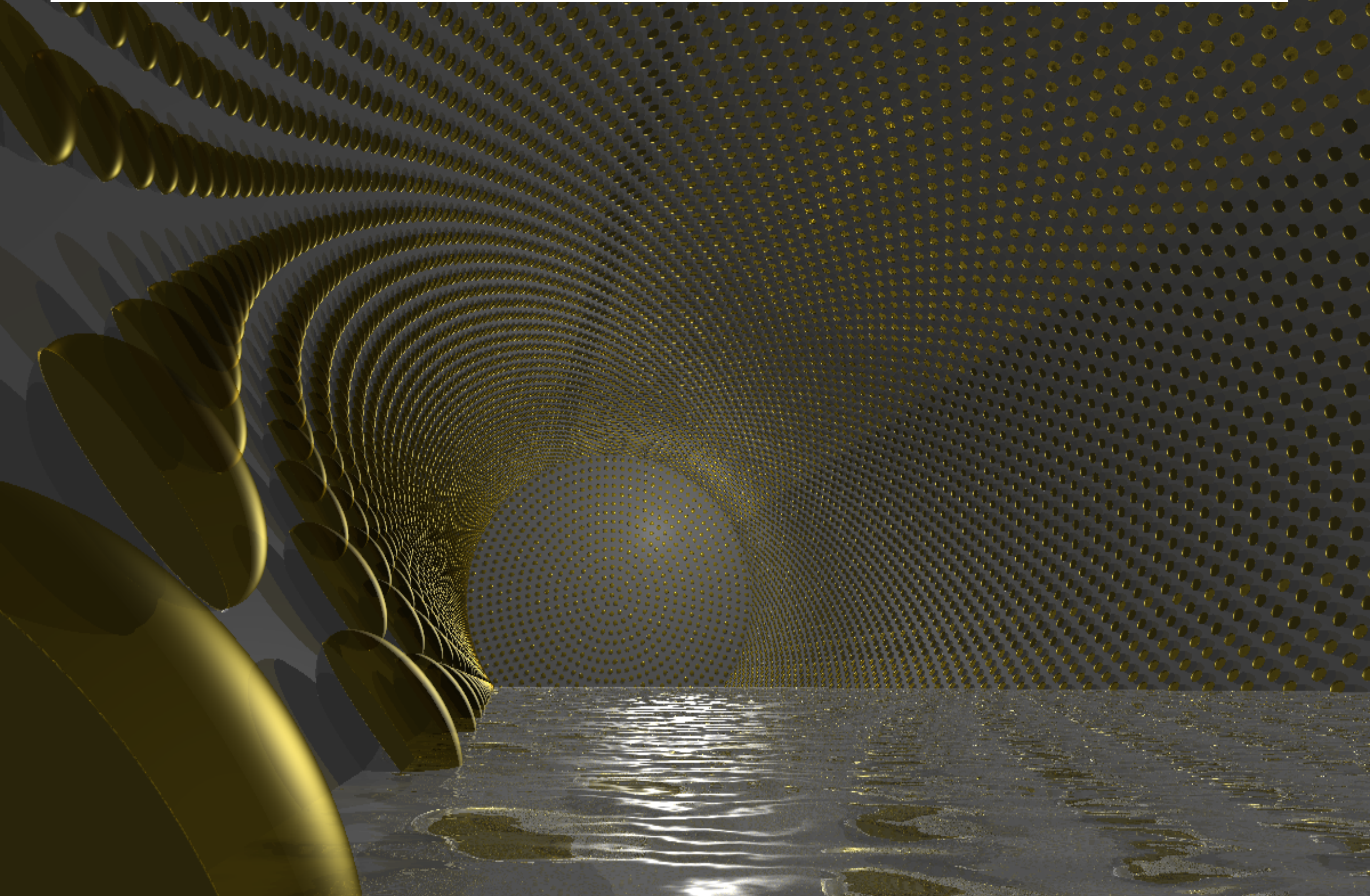
Possible objectives

- Precision measurement of solar oscillation parameters, esp. Δm^2_{12}

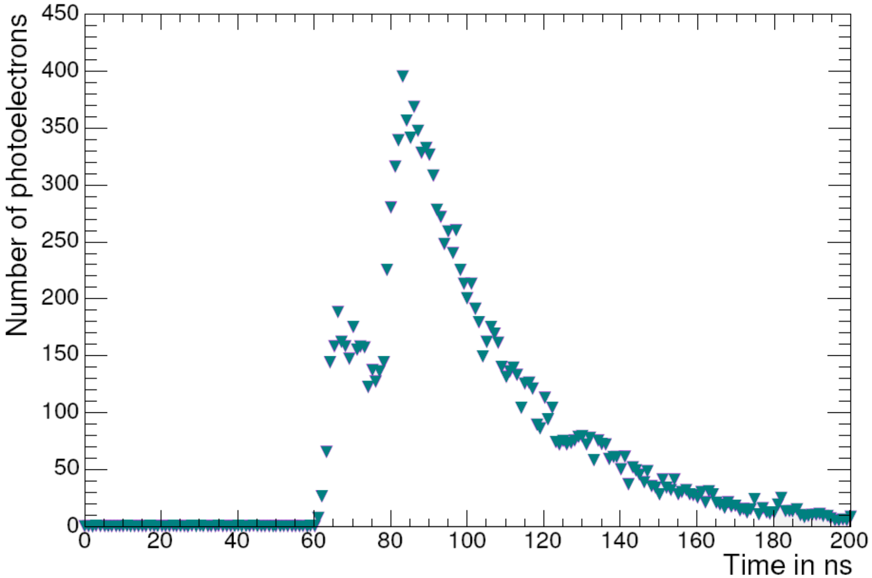
  @ Fréjus: $\sin^2 2\theta_{12}$ ~ 10% (3σ)
  Δm^2_{12} ~ 1% (3σ)

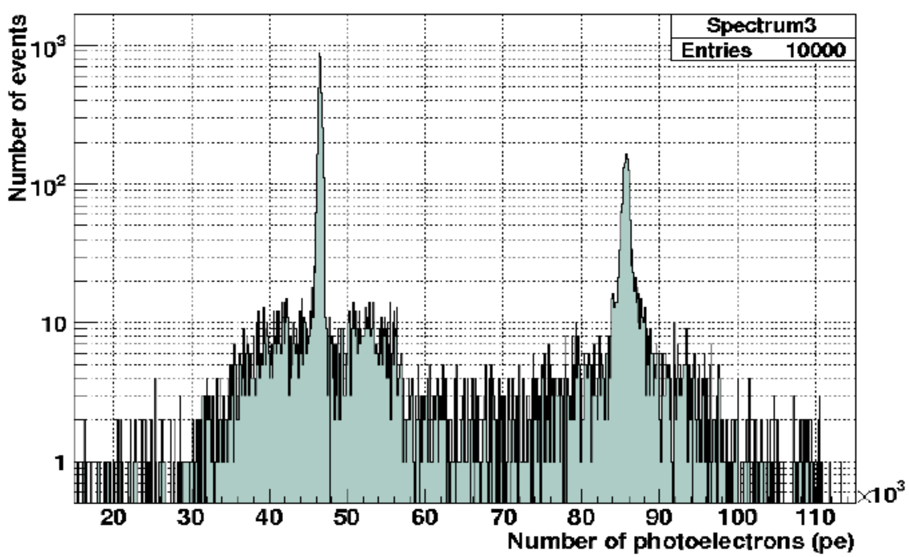
- Neutrino mass hierarchy by Δm^2_{13}-Δm^2_{23} interference in $P_{ee}(x)$ (but optimum distance is 60 km)

Nucleon decay search



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





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

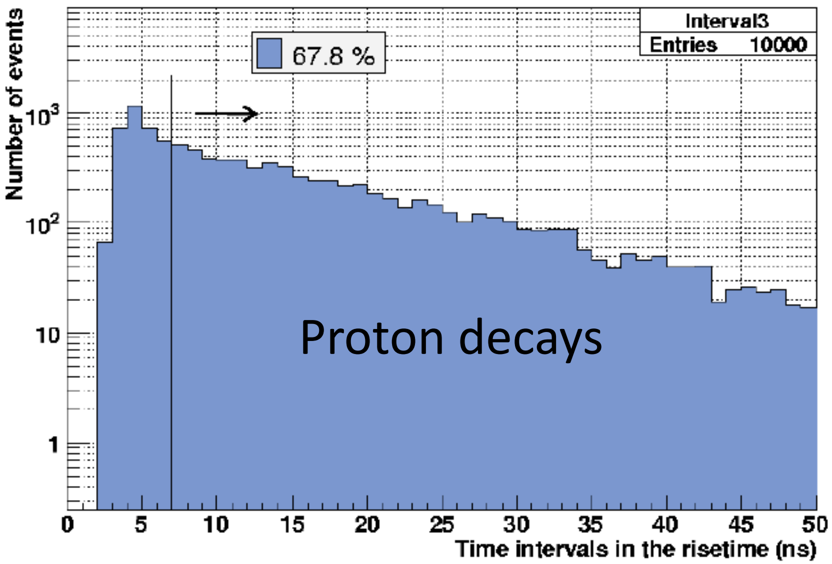
$\hookrightarrow \mu^+ \nu_\mu \,/\, \pi^0 \pi^+$

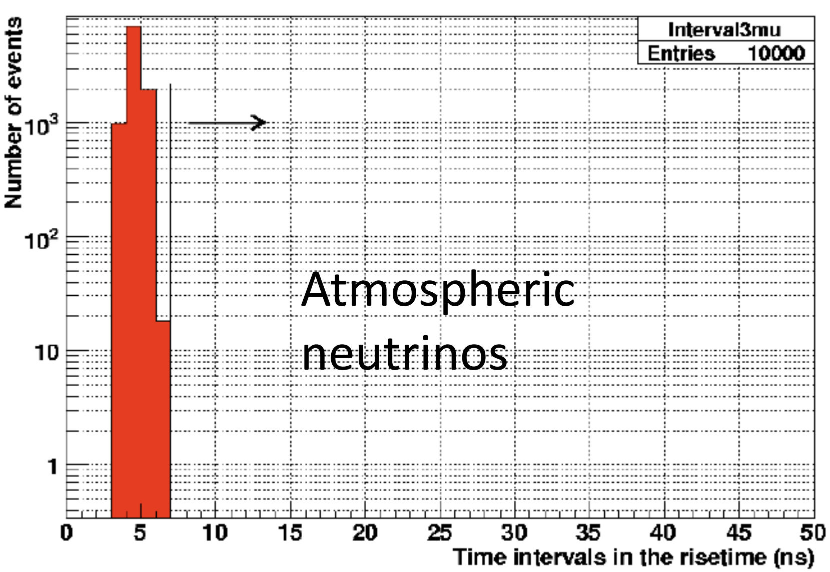
coincidence: τ_K = 13 ns

energy: 250-450 MeV

modified by Fermi motion for ^{12}C

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





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

↳ $\mu^+\nu_\mu$ / $\pi^0\pi^+$

coincidence: τ_K = 13 ns

energy: 250-450 MeV

modified by Fermi motion for ^{12}C

Background

atmospheric ν's rejected

by rise time cut: **efficiency 0.67**

hadronic channels: <1.2 per 1Mt·yr

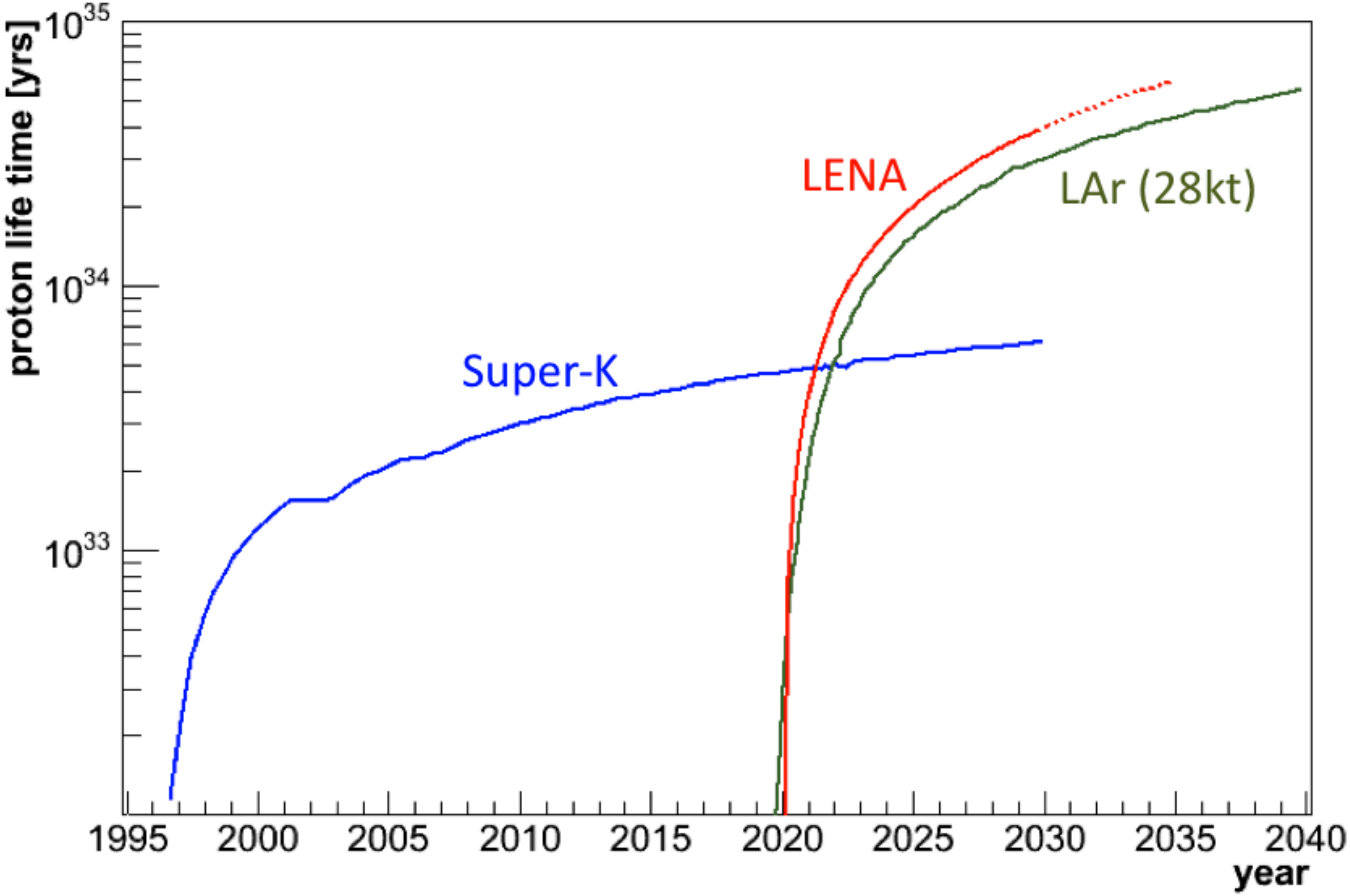
(producing kaons) @ 4kmwe

Current SK limit: 2.3×10^{33} yrs

Limit for LENA if no event is observed in 10yrs (0.5 Mt·yrs):

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

Sensitivity curves of other experiments



More details

The next-generation liquid-scintillator neutrino observatory LENA

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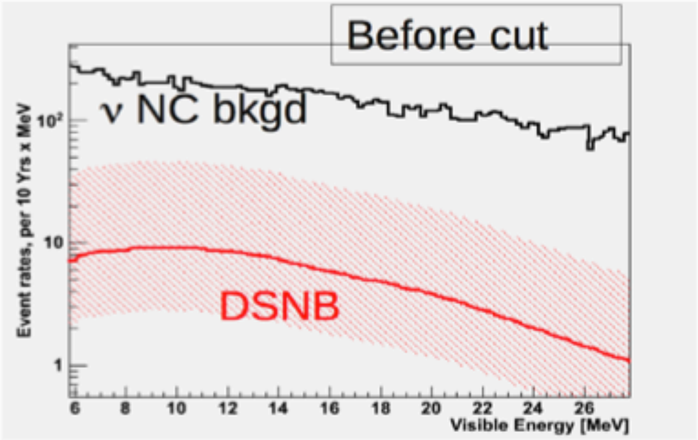
Backup Slides

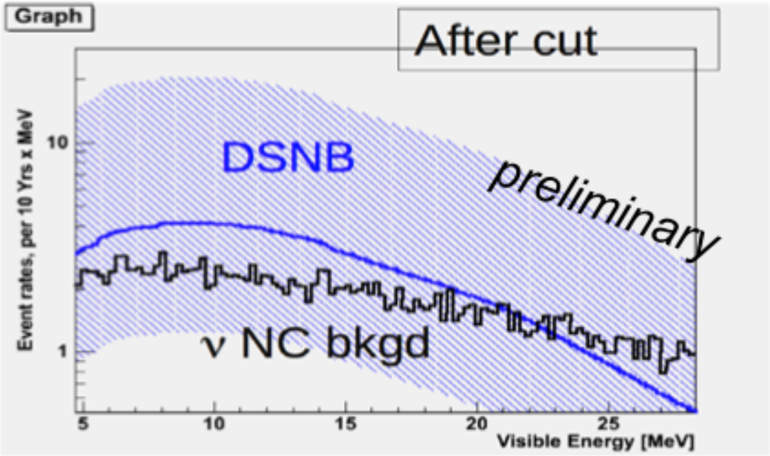
DSNB atmospheric ν NC background

- Cosmogenic produced neutrons
  - no problem if d > 4000 mwe
  - < 0.2 events / year
- Cosmogenic produced beta-neutron emitter (e.g. ^{9}Li)
  - no problem if d > 4000 mwe
  - < 0.1 events / year
- Atmospheric neutrino CC reaction
  - 10 < E / MeV < 30
- **Atmospheric neutrino NC reaction** – neutron production
  - data from KamLAND

n-scattering TOF exp. at MLL (Garching)

severe bg: reduction by pulse shape discrimination and/or statistical subtraction ?
Laboratory experiments indicate that a strong bg-reduction can be achieved !

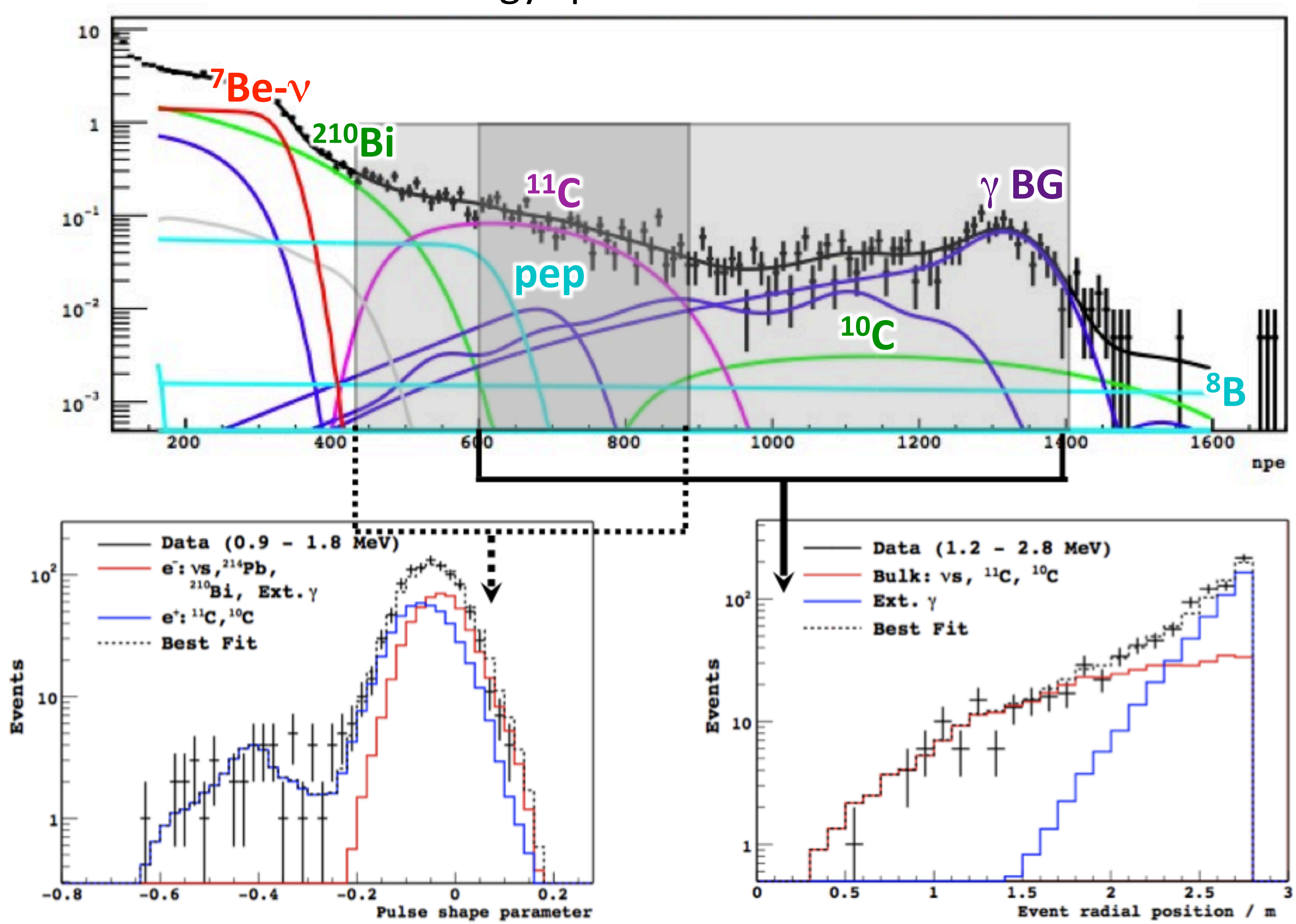




***Preliminary** results: Monte-Carlo simulation based on recent results of PSD parameter on LAB scintillators*

Multivariate analysis in pep region

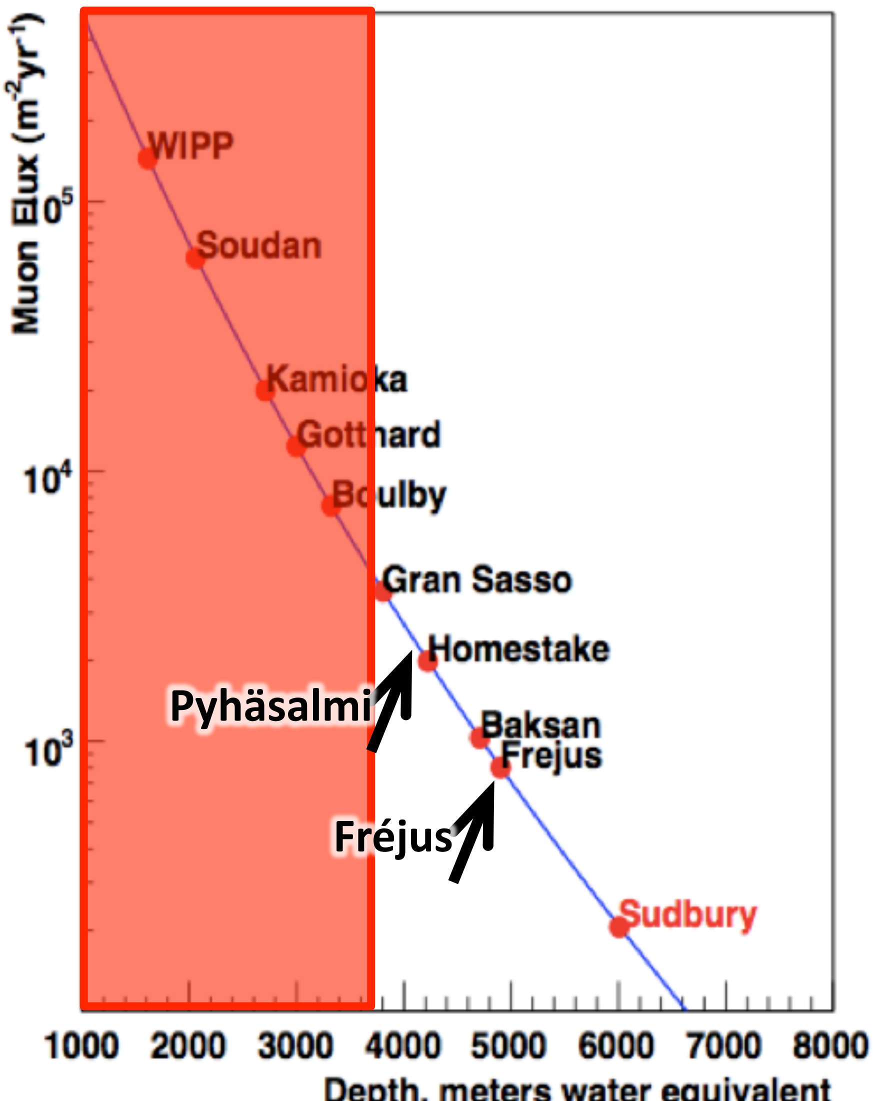
Fit to energy spectrum in FV after TFC veto

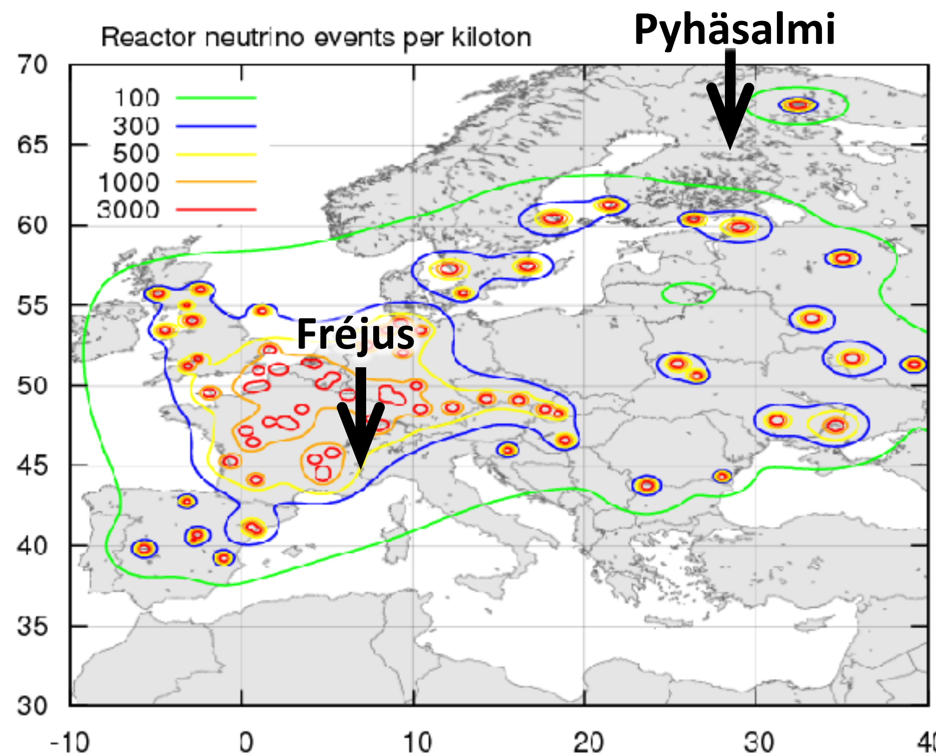


electron/positron pulse shape

external γ background

Cosmic vs. reactor background



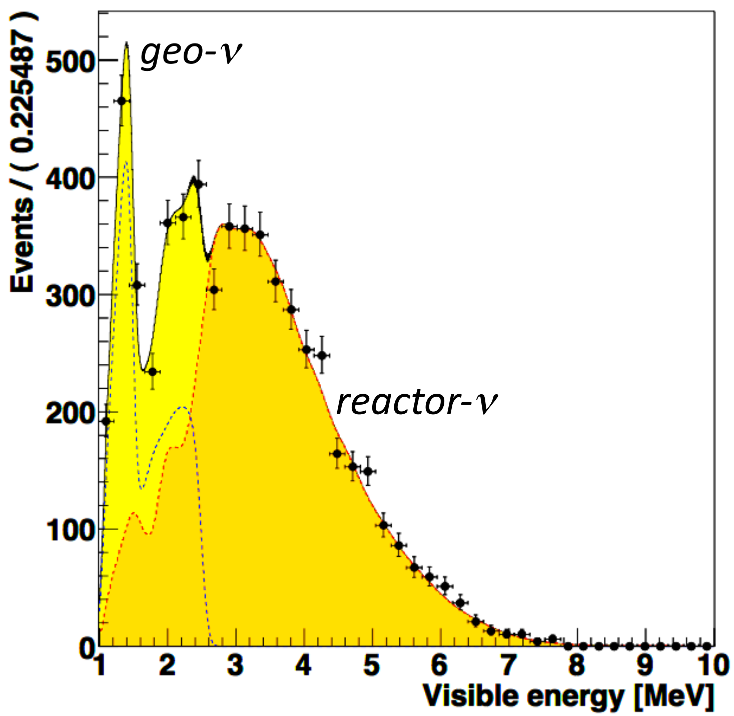


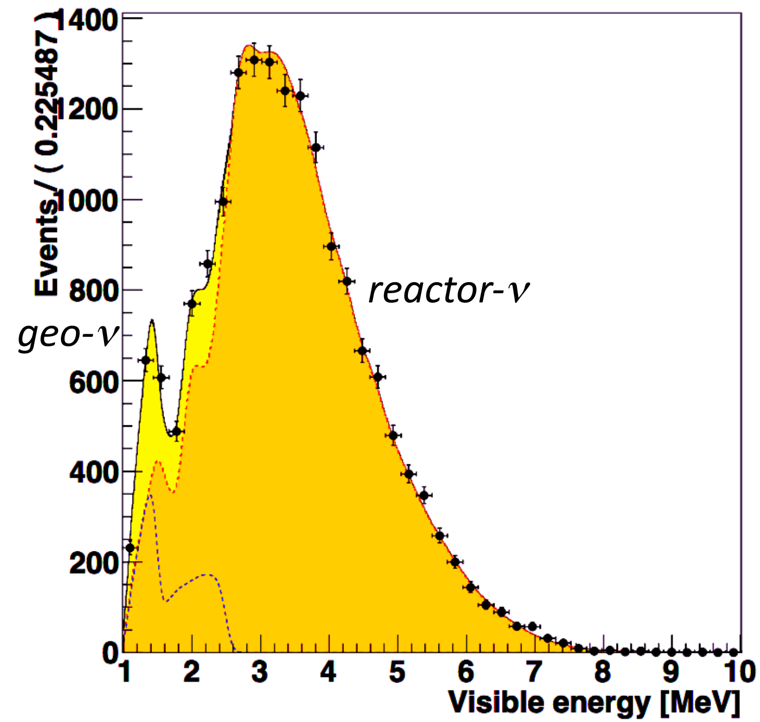
Possible LENA sites

- Pyhäsalmi:
  favorable for geo-νs and DNSB
- Fréjus:
  better shielding from cosmic rays

Geoneutrinos and reactor background

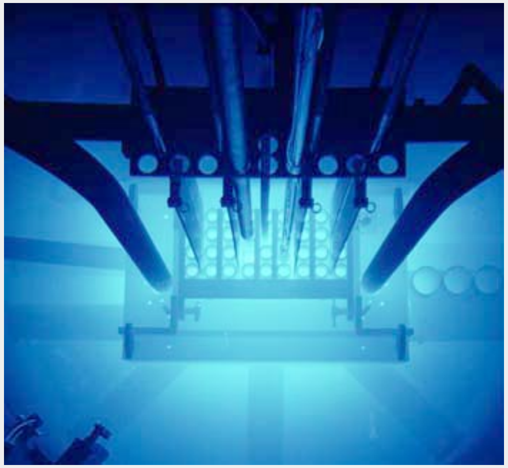
Event rates for 44 kt years of exposure.





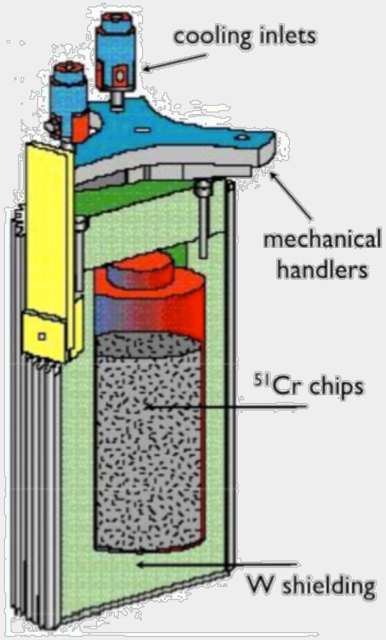
Pyhäsalmi vs. Fréjus

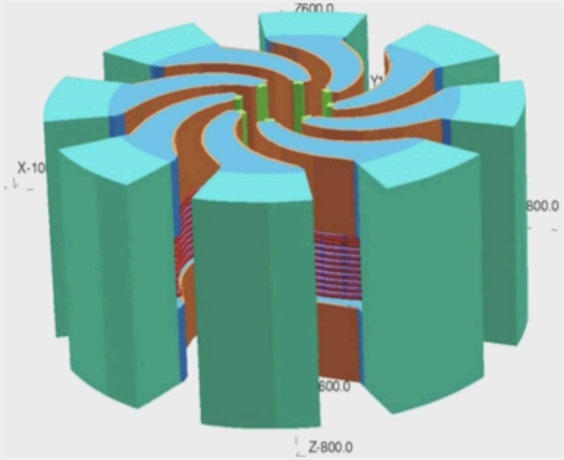
Short-baseline neutrino oscillations



Reactor neutrinos

Radioactive sources





Pion decay-at-rest sources

Low-energy $\overset{(-)}{\nu}_e$ sources → liquid scintillator detectors are the best option!

Neutrino oscillometry

Concept: Short-baseline oscillation experiments using neutrinos from radioactive sources.

Radioactive neutrino sources

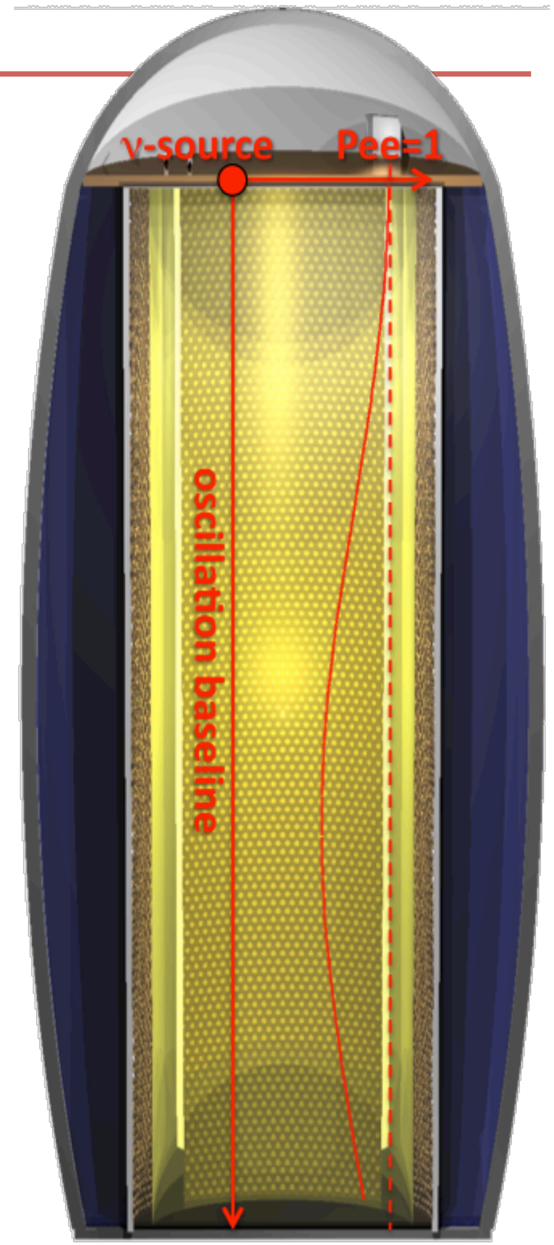
- ν_e (monoenergetic) from EC sources: ^{51}Cr, ^{37}Ar
- $\overline{\nu}_e$ (E=1.8-2.3MeV) from ^{90}Sr (^{90}Y), ^{144}Ce
- large activity necessary for ν_e: 1MCi or more

Oscillation baseline

- for Δm^2_{32} (θ_{13}): 750m for ^{51}Cr (747keV)
- for Δm^2_{41} (sterile): 1.3m

Scientific objectives

- check $P_{ee}(r)$ if θ_{13} is relatively large
- check CPT for ν and $\overline{\nu}$
- very sensitive in sterile ν searches ($\sin^2 2\theta \approx 10^{-3}$)



Test of sterile neutrino scenarios

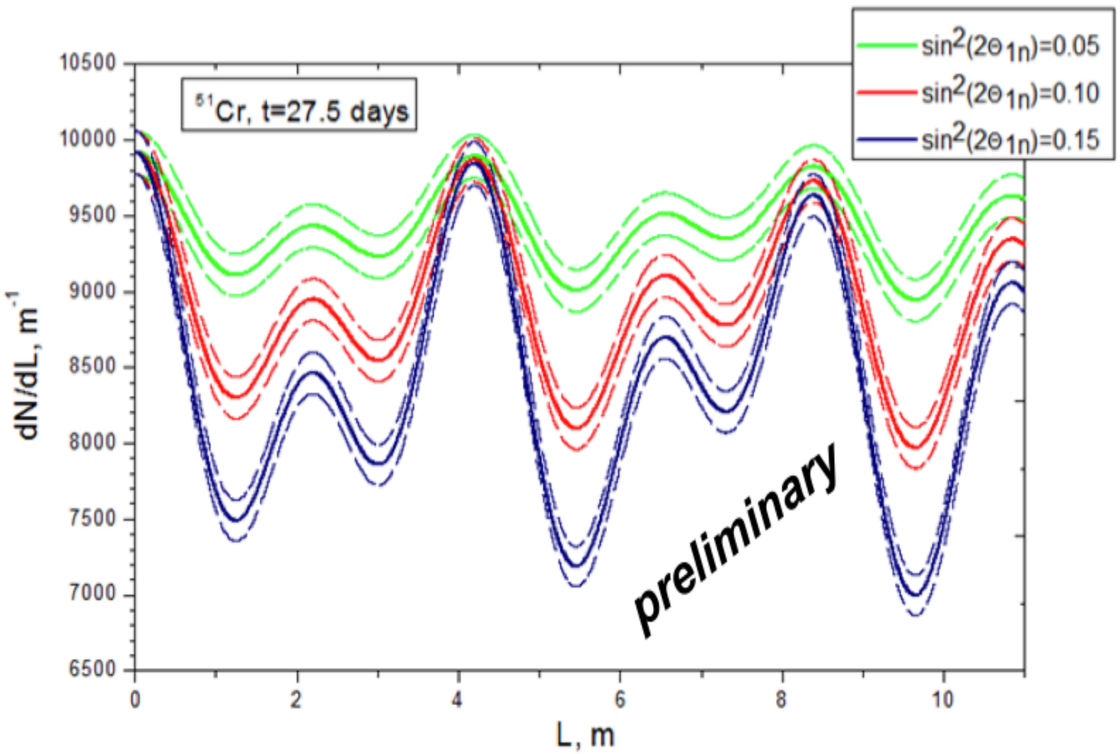


Fig. 8. Oscillometry curves for the case of three active and two sterile neutrinos in the (3+2) scenario with mass parameters proposed in [6]. In the figure top (green), middle (red) and bottom (blue) curves correspond to $sin^2(2\theta_{1n}) = 0.05; 0.10; 0.15$, respectively, with n=4, 5. The dashed lines indicate the statistical uncertainties (1σ). Input parameters are $(T_e)_{th}$ = 200 keV, R_0 = 11 m, exposure - 27.5 days, ^{51}Cr-source intensity – 5 MCi. The background from solar neutrinos is taken from the BOREXINO experiment [26] as 0.5 events/day·t.