Solar Neutrino Detection in LENA

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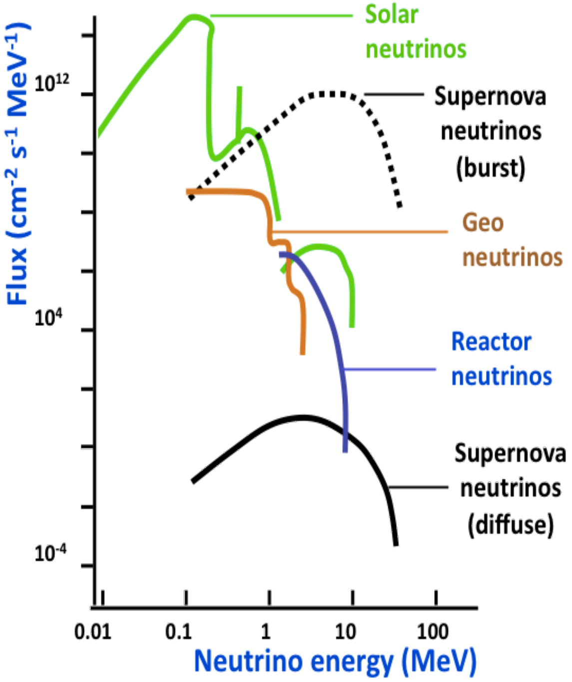
Content

- LENA and its physics program (overview)
- Solar neutrino detection in LENA
- Background considerations
- Search on small time variations with ^{7}Be neutrinos
- Neutrino electron scattering
    - pep- and CNO neutrinos ?
- CC – Neutrino detection on ^{13}C
    - test of MSW effect ?

LENA (Low Energy Neutrino Astronomy)

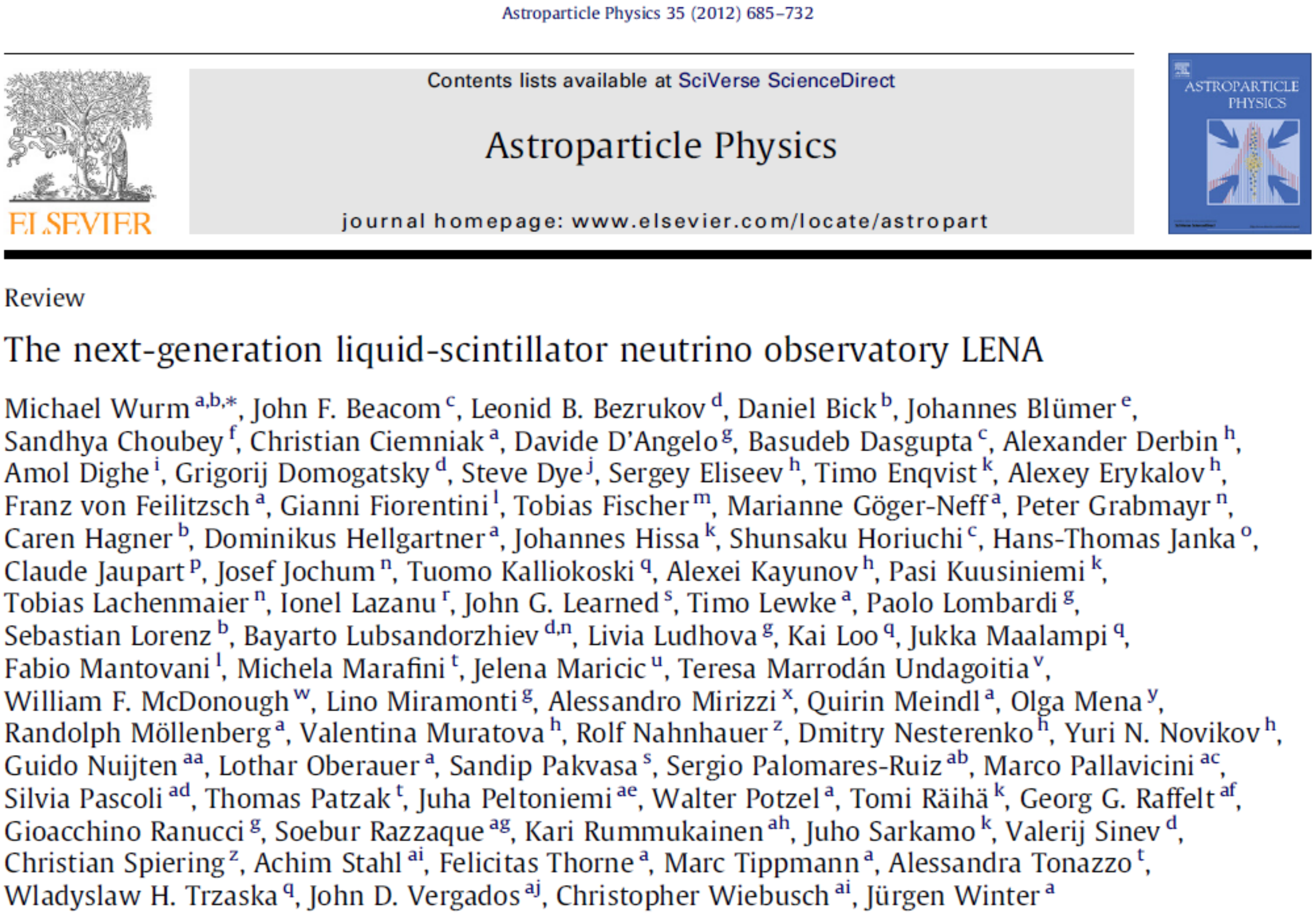
50 kt liquid scintillator detector

LENA – part of the European design study of the LAGUNA-LBNO consortium



Neutrino Sources	Rates
▪ Galactic Supernova neutrinos	10^4/SN
▪ Diffuse Supernova neutrinos	10/yr
▪ Solar neutrinos	10^4/d
▪ Geoneutrinos	10^3/yr
▪ Reactor neutrinos	10^{3-4}/yr
▪ Proton decay search	
▪ Long baseline oscillations (CP violation, mass hierarchy)	
▪ Neutrino oscillometry	10^4/Mci
▪ Pion decay-at-rest beam	
▪ Indirect dark matter search	

LENA Whitepaper published recently



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journal homepage: www.elsevier.com/locate/astropart

Review

The next-generation liquid-scintillator neutrino observatory LENA

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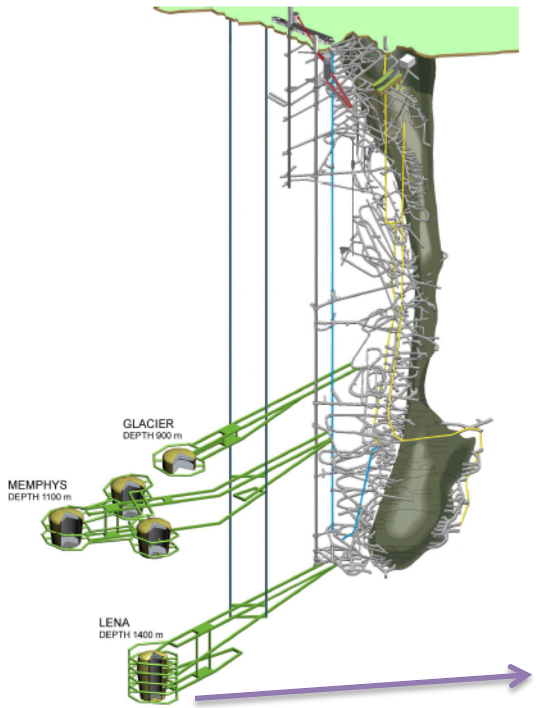
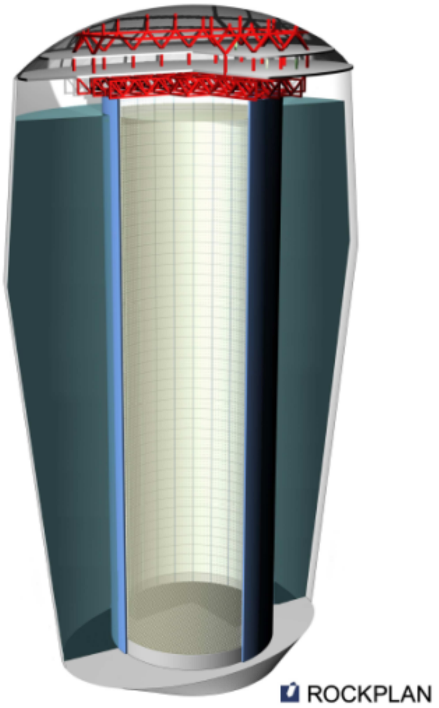
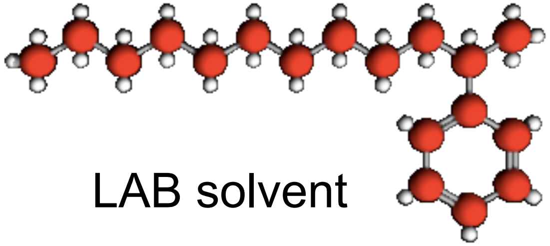
Astroparticle Physics 35 (2012) 685-732

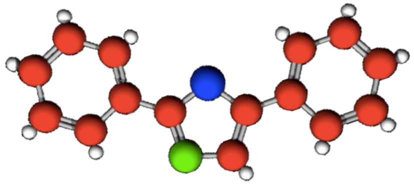
Technology: Status & Development







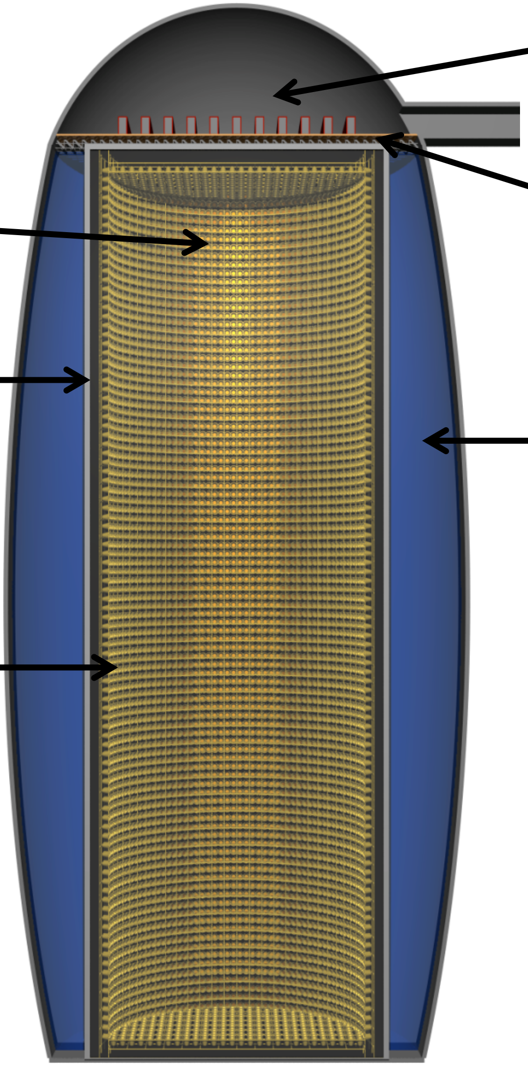
LAB solvent



3 g/l PPO

Properties of LAB	
Chemical data	
Chemical formula	$C_{18}H_{30}$
Molecular weight	241
Density	0.863 kg/l
Viscosity	4.2 cps
Flash Point	140 °C
HMIS ratings	
Health	1
Flammability	1
Reactivity	0
Optical parameters	
Index of refraction	1.49
Attenuation length	~15 m
Absorption length	40 m
Abs.-reemission length	60 m
Rayleigh scattering length	40 m

LENA Detector Design (Pyhäsalmi Option)



Electronics Hall
dome of 15m height

Top Muon Veto
vertical muon tracking

Liquid Scintillator
Active Mass = 50.8kt of LAB

Concrete Tank (+Steel Sheets)
r = 16m, h = 100m
Wall Thickness = 60cm
Total Mass = 69.1kt of LAB

Water Cherenkov Veto
2000 12´´PMTs, D_{min} > 2m
fast neutron shield
inclined muons

PMT Support Structure
Inner face at r = 14m, h = 96m

Egg-Shaped Cavern
about 200000 m^3

about 30,000 12‘‘-PMTs
with Winston cones
optical coverage: 30%

Rock Overburden
4000 mwe

Muon flux = 1/5 LNGS

Detector Lifetime foreseen: > 30 years

Solar neutrino detection in LENA

- Elastic neutrino electron scattering

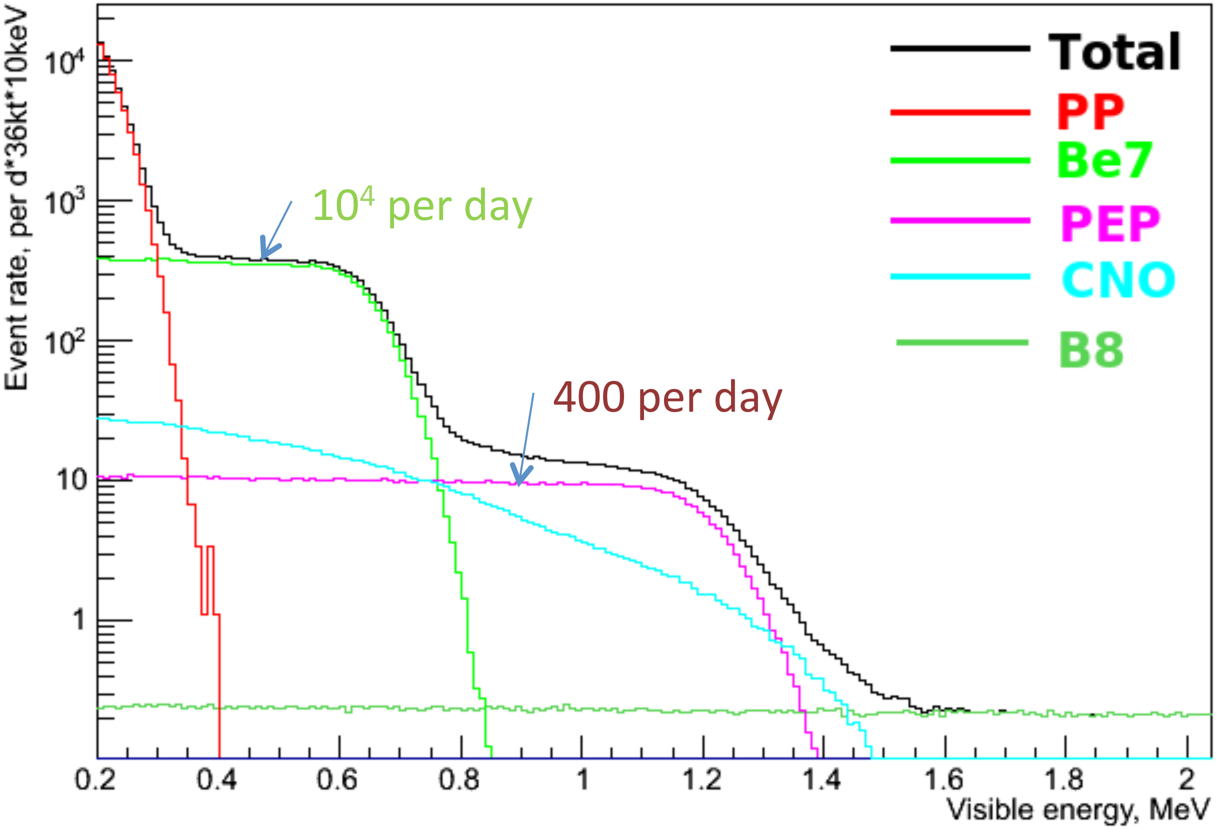
  as in Borexino, SNO+

  in principle all solar neutrino branches

- CC – reaction $\nu_e(^{13}C, ^{13}N)e^-$

  for solar ^8B - neutrinos

Elastic neutrino scattering

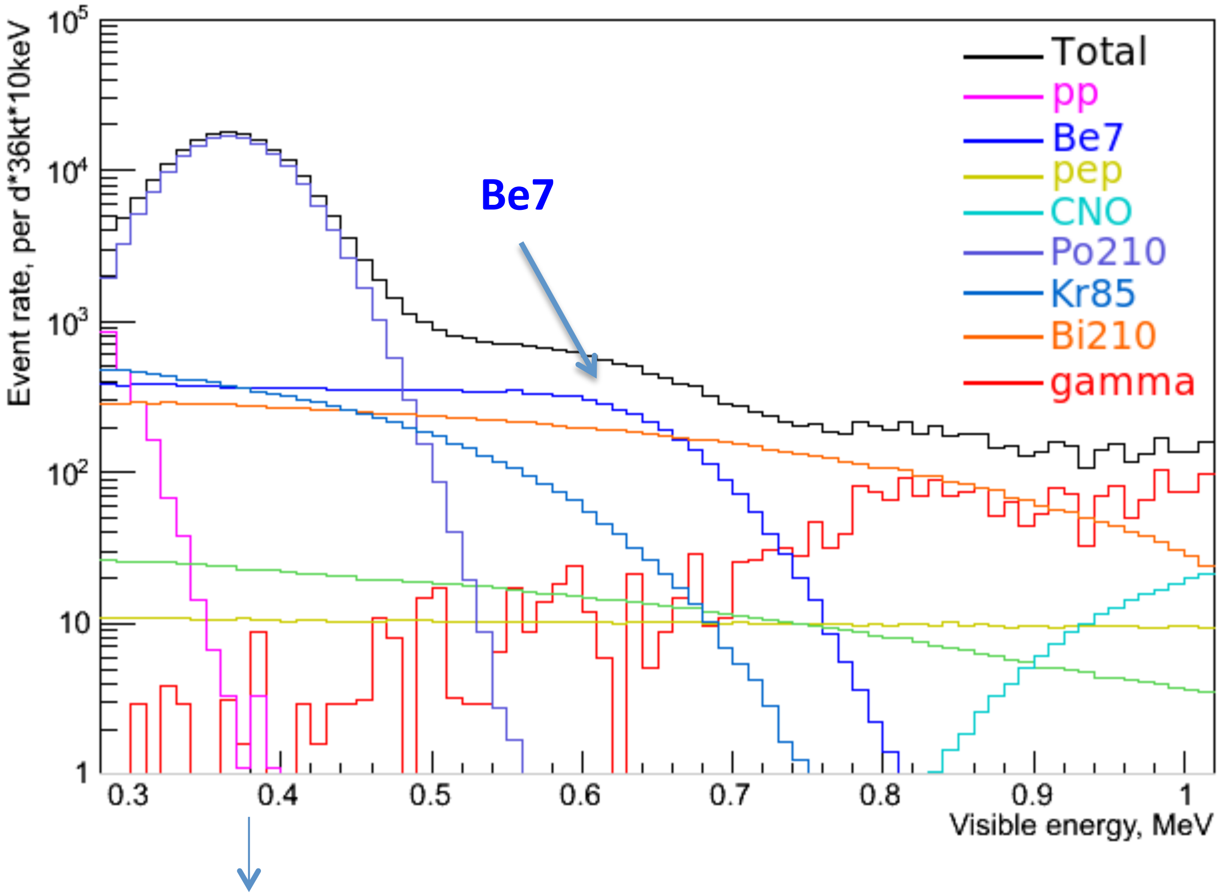


10^4 per day

400 per day

Rates for a nominal fiducial mass of 36 kton

Low E spectrum with backgrounds



^{210}Po position with k_b = 0.107 mm/MeV (alpha) – from Double-Chooz exp. (to be confirmed)

Background rates:

Po210: 488.8 c/(d*100t)
Bi210: 41.6 c/(d*100t)
Kr85: 34.8 c/(d*100t)

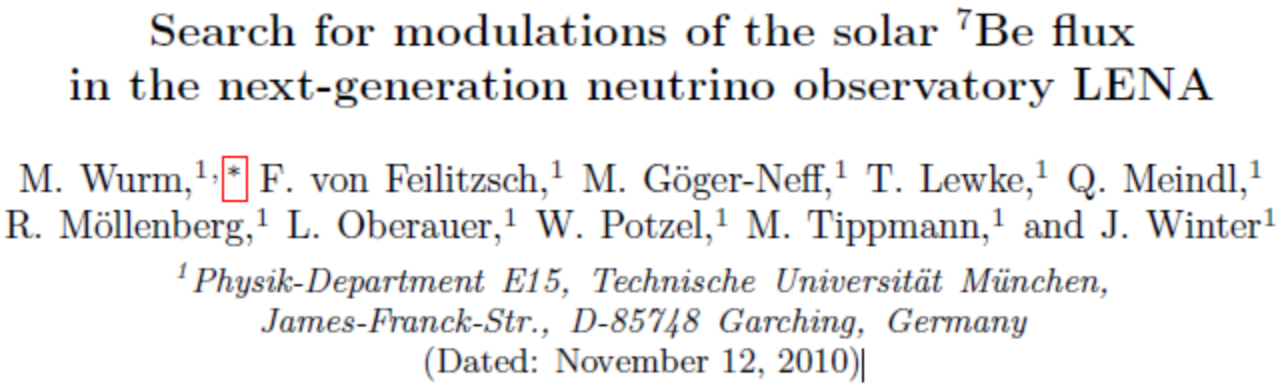
...all from Borexino 2011 paper

C11: 5.6 c/(d*100t)
C10: 0.11 c/(d*100t)
Be11: 0.007 c/(d*100t)

Cosmogenic bg = 1/5 Borexino

Search on small periodic variations

The high statistics in the ^{7}Be – rate allows to search on small periodic flux variations



Search for modulations of the solar ^{7}Be flux in the next-generation neutrino observatory LENA

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R. Möllenberg,[1] L. Oberauer,[1] W. Potzel,[1] M. Tippmann,[1] and J. Winter[1]
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James-Franck-Str., D-85748 Garching, Germany

(Dated: November 12, 2010)

Motivation: *Day/Night Matter effect, Correlations to the solar cycle, Helioseismic waves in the neutrino-sphere...*

Search on small periodic variations

$$N(t) = N_0 \cdot (1 + A \cdot \sin(t/T + \varphi))$$

„Lomb-Scargle“ power P to find modulations:

$$P = \frac{1}{\sqrt{2\sigma^2}} \left(\frac{\left[\sum_{i=1}^{n} w_i (N(t_i) - N_0) \cos\left(2\pi \frac{t_i - \phi}{T}\right)\right]^2}{\sum_{i=1}^{n} w_i \cos^2\left(2\pi \frac{t_i - \phi}{T}\right)} + \frac{\left[\sum_{i=1}^{n} w_i (N(t_i) - N_0) \sin\left(2\pi \frac{t_i - \phi}{T}\right)\right]^2}{\sum_{i=1}^{n} w_i \sin^2\left(2\pi \frac{t_i - \phi}{T}\right)} \right)$$

here we use $w = w_i$ (they all cancel)

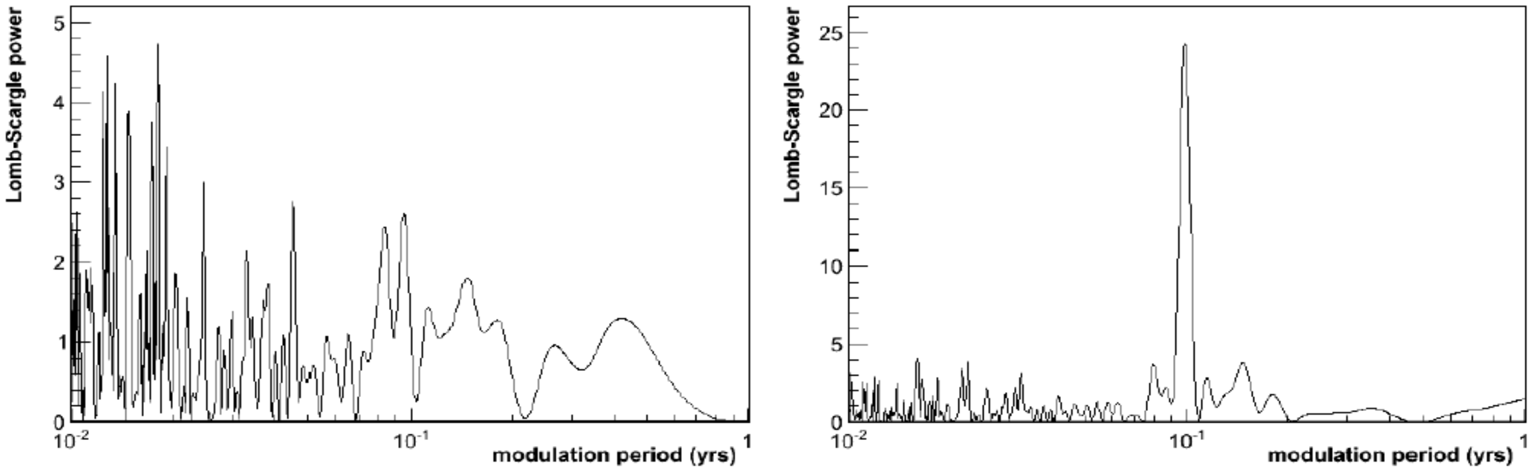


FIG. 2: Lomb-Scargle periodigrams for a MC data set of 2 years measurement time. *Left:* White noise spectrum. *Right:* A modulation of 2 % relative amplitude and a period of 0.1 years was included. A corresponding peak is visible at the indicated period, that is also clearly exceeding the regular white noise level.

Sensitivities

Day / Night effect $A = 10^{-3}$ sensitivity could be reached

Gravity driven helioseismic waves are confined to the inner regions of the Sun

Do they exist? SOHO hints to a $f = 220{,}7\ \mu\mathrm{Hz}$ signal

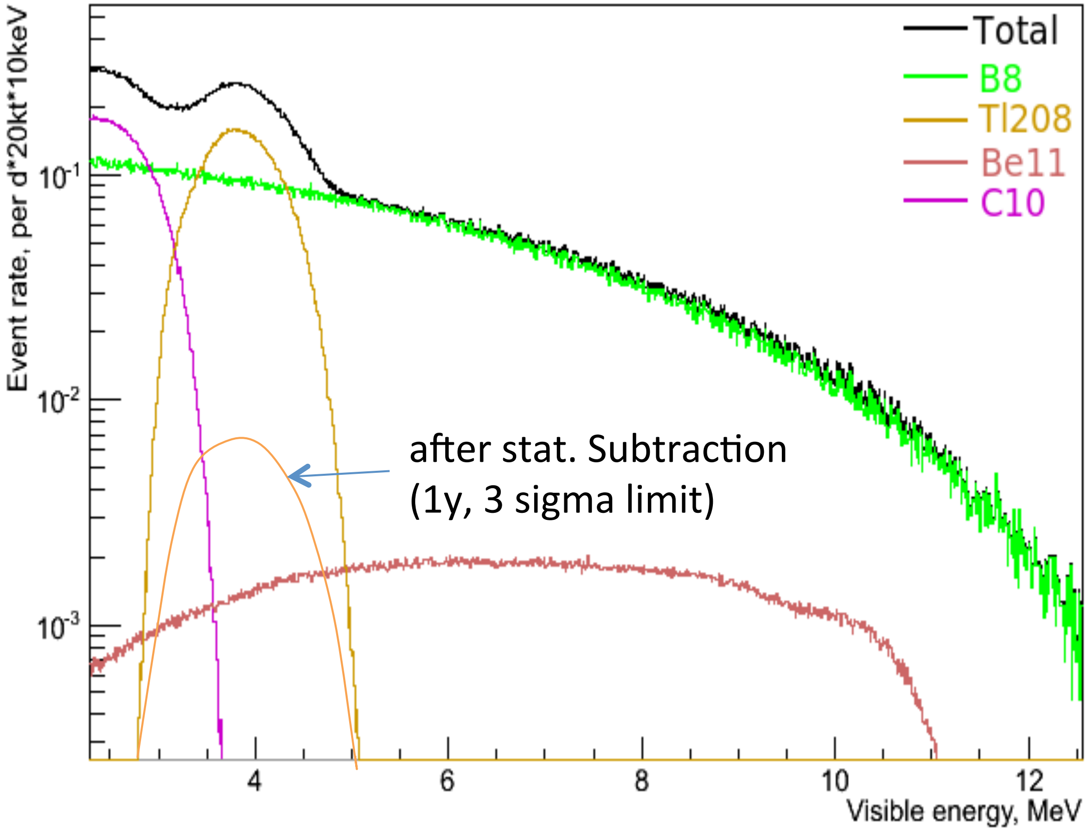
A. Jimenez and R. A. Garcia, Astrophys. J. Suppl. **184**, 288 (2009), astro-ph/0908.0562.

Current best limit on a corresponding solar neutrino modulation comes from SNO $A < 0.1$

SNO Collaboration, B. Aharmim *et al.*, Astrophys. J. **710**, 540 (2010), astro-ph/0910.2433.

With LENA sensitivites of $A \sim 0.005$ could be reached

^{8}B-neutrino detection



after stat. Subtraction
(1y, 3 sigma limit)

Rate: 38 / (day 20 kton)

Roadmap for a low E measurement:

- Fid. Mass 20 kton (kill ext. Gammas)
- ^{10}C cosmogenic background direct rejection via muon veto
- ^{208}Tl intrinsic background statistical substraction via Bi-Po counting

(here Borexino value from 2007 is assumed)

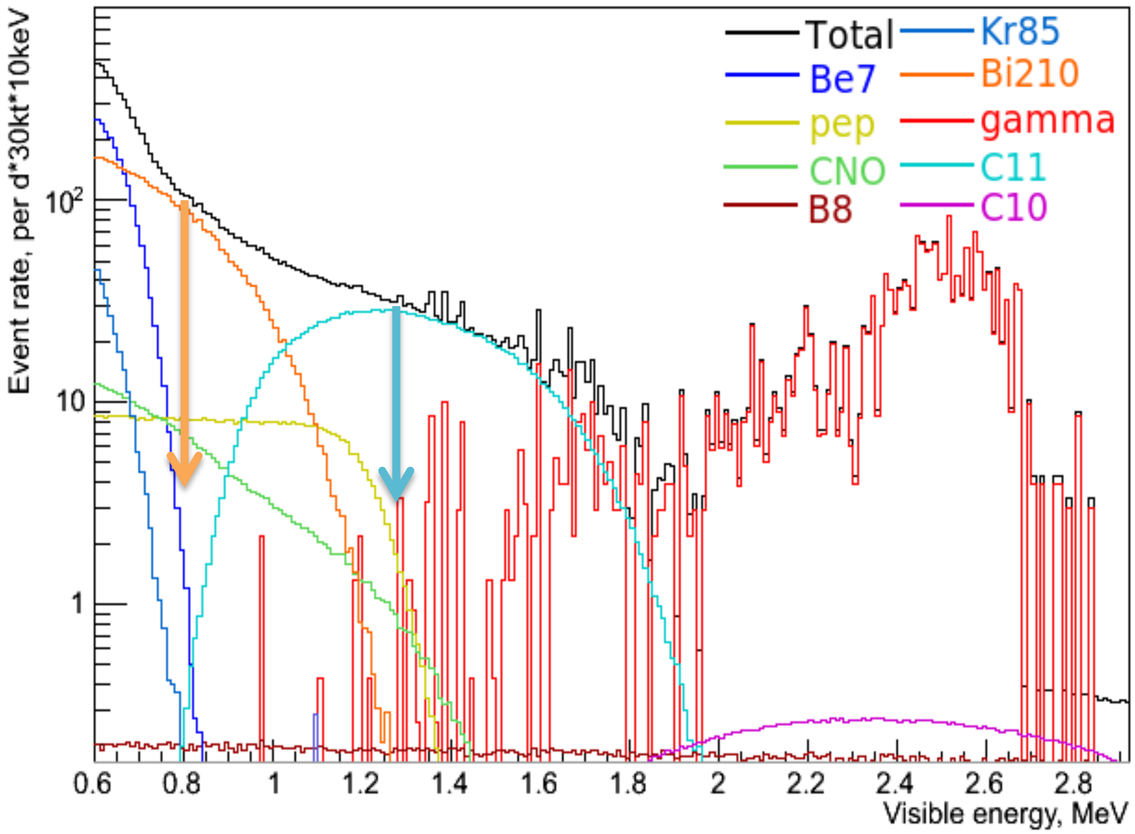
After 1 y: remaining bg rate (3σ limit) < 10^{-2}

If ^{208}Tl bg in LENA = 100 x Borexino

-> signal / bg ~ 1

(after 1 year, 3 sigma limit)

pep- and CNO neutrinos



Rate pep: 342 (day 30 kton)
Rate CNO: 156 (day 30 kton)

Roadmap for successful pep and CNO measurement:

- Fid. Mass 30 kton (kill ext. gammas)
- Reduce cosmogenic ^{11}C via 3-fold coinc. by factor 10
- Tag ^{210}Bi (the „big enemy“) via ^{210}Po alpha counting (saecular equilibrium necessary)
- Subtract ^{210}Bi statistically
- Win pep and CNO if LENA ^{210}Bi bg < **10 - 10^2** Borexino bg
- Separate pep and CNO via spectral analysis (pep – „shoulder“)

1. Summary

- High statistics ^{7}Be - measurements allows to search for very small periodic fluctuations (1 y in LENA = 200 y in Borexino)

- ^{8}B – neutrino measurement at low E (3 MeV) possible
  20 kton fiducial mass
  ^{208}Tl background < 10^2 Borexino

- CNO – and pep - neutrino measurement possible (albeit not easy) in an „optimistic realistic“ scenario:
  30 kton fiducial mass
  ^{210}Bi background < 10 - 10^2 Borexino

The ^{13}C - reaction

cc – reaction: $\nu_e + {}^{13}\mathrm{C} \rightarrow {}^{13}\mathrm{N(gnd)} + e^-$

$Q = 2.22$ MeV ⇒ only ^{8}B solar neutrinos are detectable

$E_e = E_\nu - Q + m_e$ ⇒ Neutrino spectroscopy by an event to event basis

$$\sigma(E_\nu) = \frac{2\pi^2 \ln 2}{m_e^5 \cdot ft} p_e E_e F(Z, E_e) = 0.2167 \times 10^{-43}\mathrm{cm}^2 \frac{p_e E_e}{\mathrm{MeV}^2} F(Z, E_e)$$

very well known from

$$^{13}\mathrm{N} \rightarrow {}^{13}\mathrm{C} + \nu_e + e^+ \qquad \tau = 862.6 \text{ s.} \qquad \log(ft/\mathrm{s})^{\mathrm{exp}} = 3.667 \pm 0.001$$

This offers *delayed coincidence* technique for LENA (prompt + delayed signal)
$E_{\text{vis, delayed}}$ = [1.02 MeV, 2.22 MeV]
very efficient for *background rejection*

A. Ianni et al. (2005), J. Arafune et al. (1989), M. Fukugita et al., (1990)

^{13}C – event rate in LENA

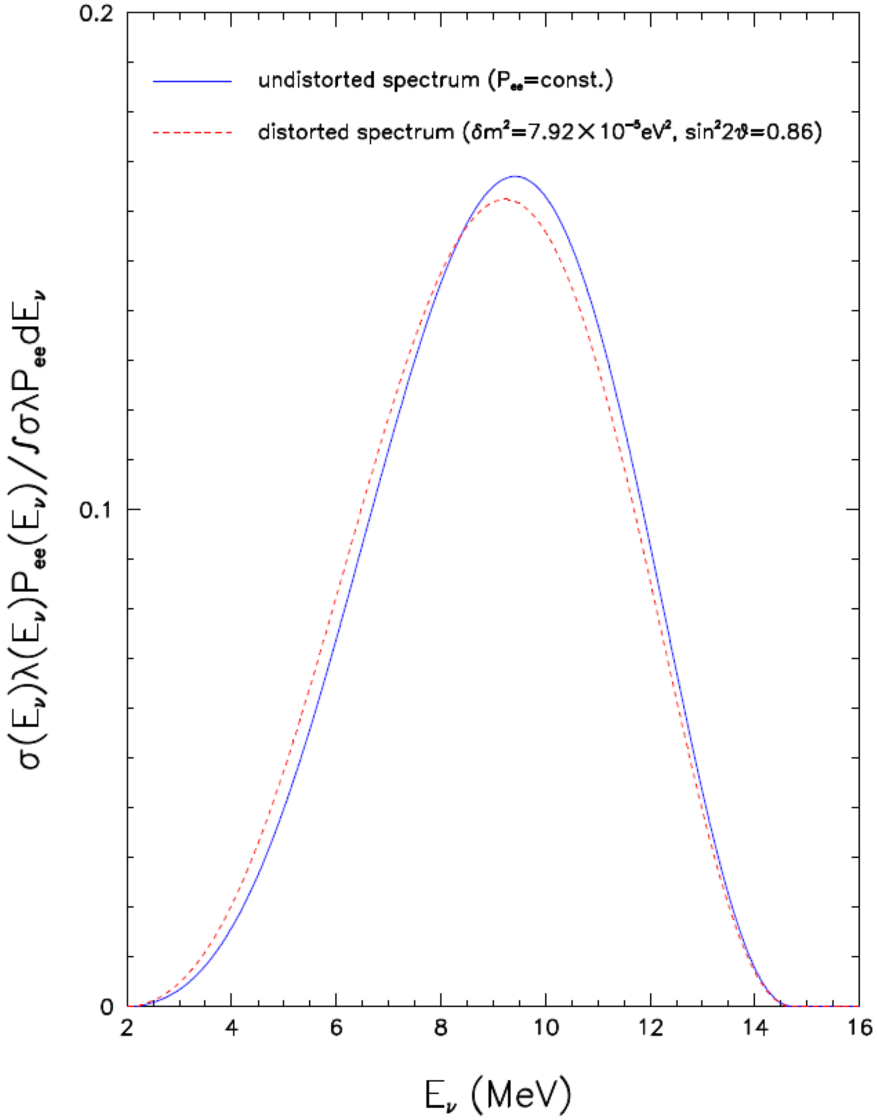
Natural abundance of ^{13}C: $y = 1.07\ \%$
Number of ^{13}C nuclei (50 kton LAB scint.): $n_{13} = 2.4 \times 10^{31}$
Solar ^{8}B neutrino flux: $\Phi = 5.8 \times 10^{6}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
Survival probability (MSW effect): $p_{ee} = 0.3$
Average cross section for solar ^{8}B neutrinos: $\langle\sigma\rangle = 8.57 \times 10^{-43}\ \mathrm{cm}^{2}$

Event rate (without cuts): $R = n_{13}\, \Phi\, p_{ee} \langle\sigma\rangle \sim 3$ / day

Preliminary Monte-Carlo studies suggest:
$M_{\mathrm{fiducial}} \sim 30$ kton
Detection efficiency ~ 0.75 $R_{\mathrm{Lena}}(2.2\ \mathrm{MeV}) \sim 1.2$ / day

What can we do with this signal ?

Shape and Rate Analysis on ^{13}C-events



Spectral distribution $S(E_\nu)$ of prompt energy deposition (normilized to unity)

$S(E_\nu) = \Phi(E_\nu) \times p_{ee}(E_\nu) \times \sigma(E_\nu)$

Blue: undistorted spectrum (p_{ee}=const)

Red: distorted due to MSW effect

$E_\nu < 8$ MeV spectral rise
$E_\nu > 8$ MeV spectral decrease

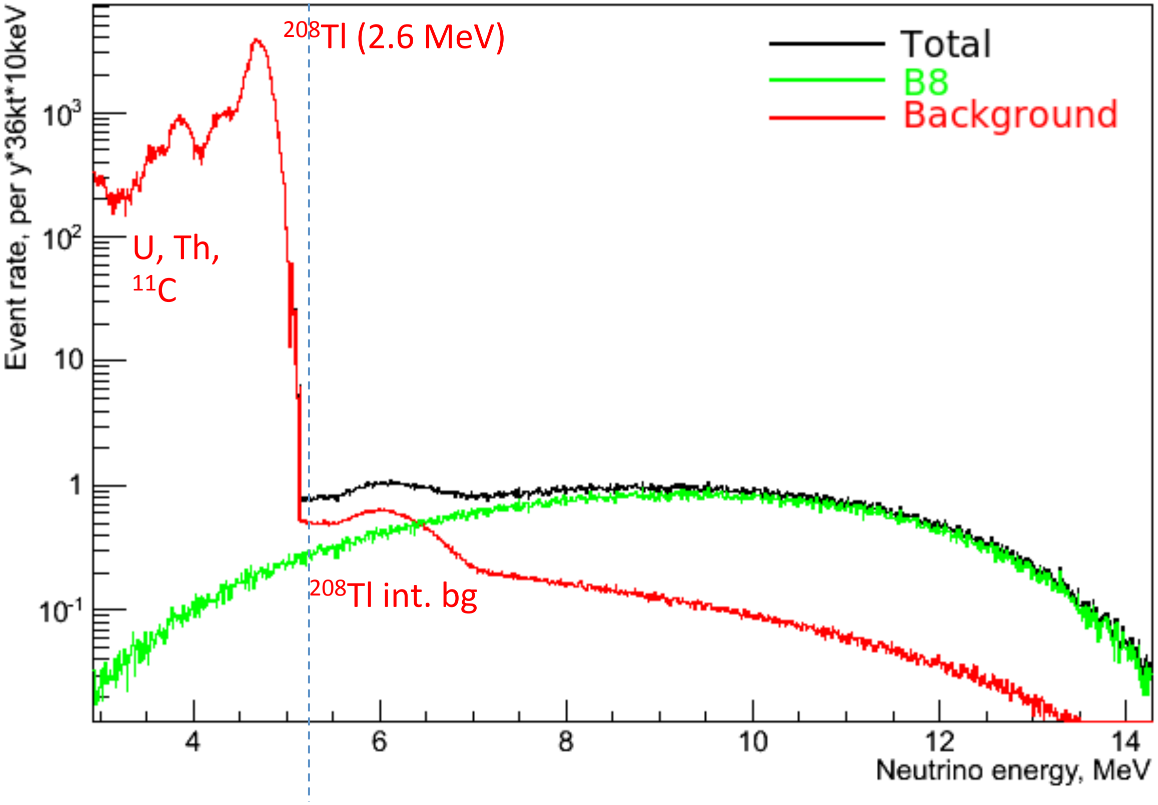
here: no energy resolution included

In principle: **Sensitive test of MSW effect !**

Ianni, D. Montanino, F. Villante, Phys. Lett. B627 (2005) 38

Background considerations

Accidental coincidences



Cuts:

Fiducial 36 kton

Time 3 x τ

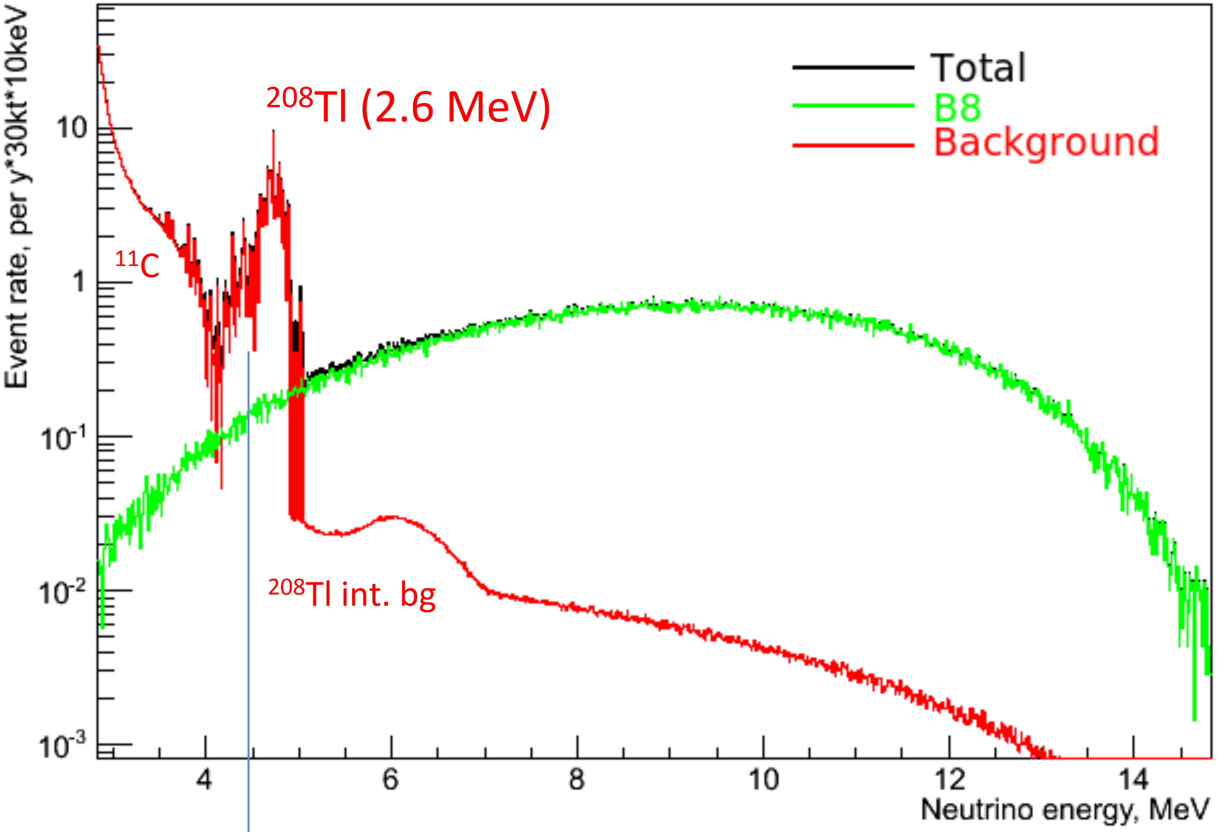
Position 30 cm

Efficiency 75 %

No statistical subtraction

Accidental coincidences

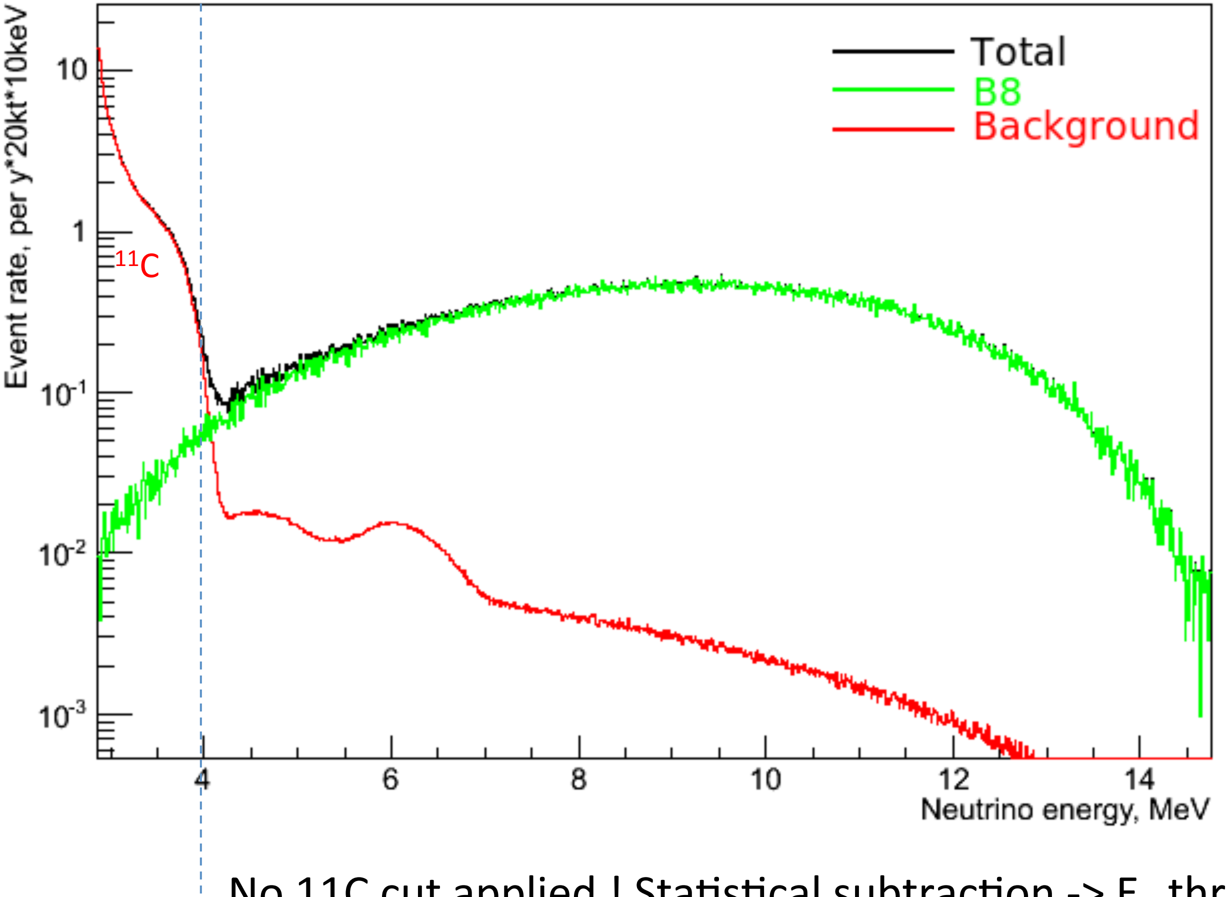
Same cuts, but now 30 kton fiducial
R ~ 425 / y (after cuts)



Statistical subtraction (after 1y) yields
Signal / Background ~ 1 (4 to 5 MeV)

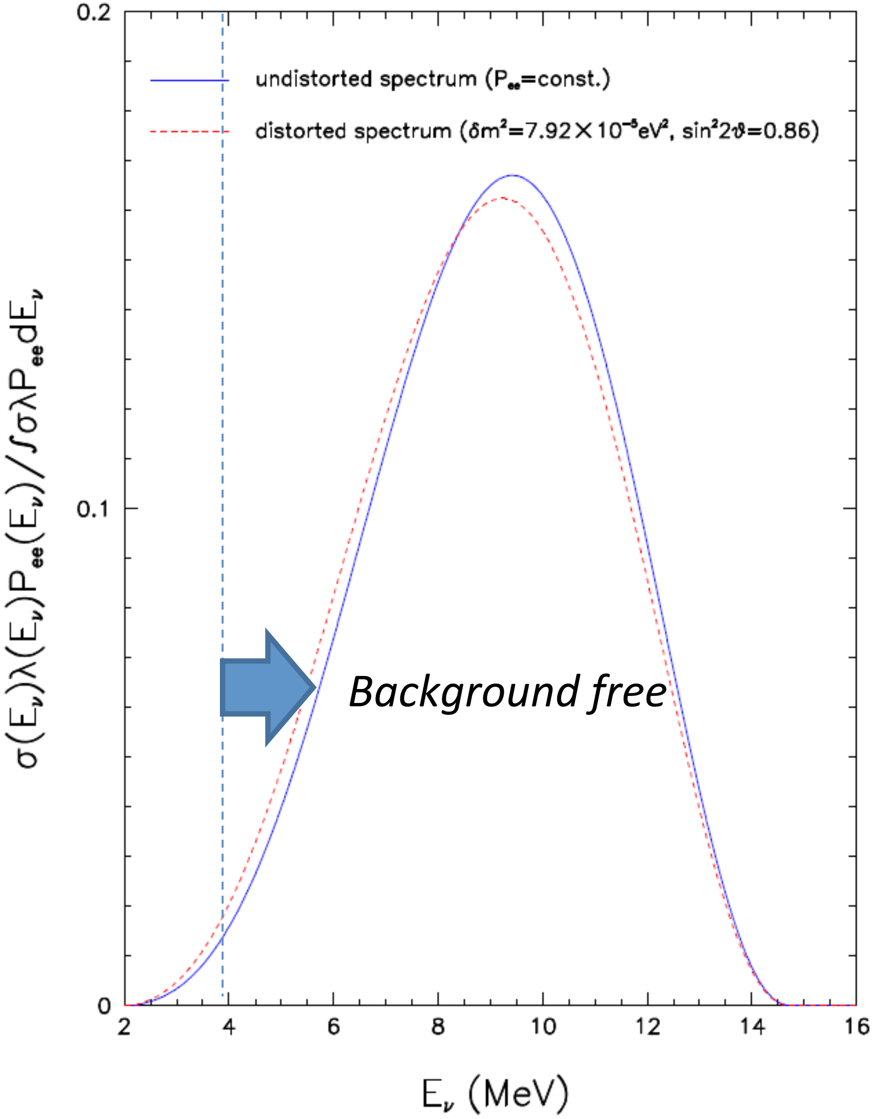
Accidental coincidences

Same cuts, but now 20 kton fiducial
R ~ 285 / y (after cuts)



No 11C cut applied ! Statistical subtraction -> E_ν threshold below 4 MeV (E_{vis} = 1.8 MeV)

Shape and Rate Analysis on ^{13}C-events



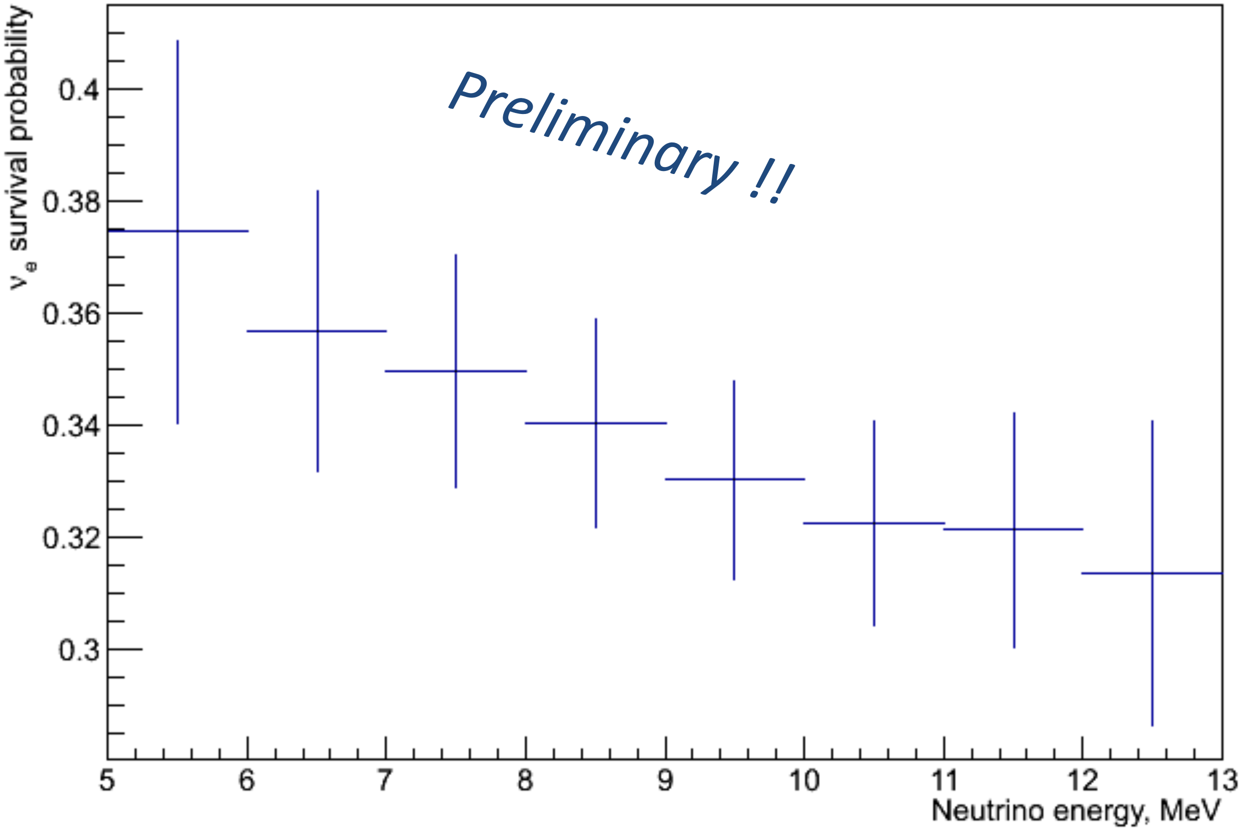
Dominant part of the spectrum is available without restriction due to background

The fiducial cut has to be optimized by the real experiment, but realistically it will be between 20 and 30 kton

The expected event rate will be between 285 and 425 per year after all cuts

How well can we test MSW?
Work still under progress

Survival probability P_{ee}



Only ^{13}C charged current reaction

150 kton years exposition

Standard MSW effect assumed

This and the spectrum of ν−e scattering will be used as input for a *combined analysis*. Work under progress...

Conclusions

LENA and solar neutrino detection

- Very high statistics in ^{7}Be allows to search for small flux fluctuations
- CNO- and pep-neutrino measurement possible, if ^{210}Bi bg < 10 to 100 (Borexino)
- Solar ^{8}B-spectrum from 3 MeV via elastic scattering off electrons, if ^{208}Tl bg < 100 (Borexino)
- Solar ^{8}B-spectrum via ^{13}C charged current reaction from 4 MeV (~ 425 counts / year)
- Test of the MSW-effect via a combined analysis of ν-e scattering and ^{13}C cc reaction

Background calculations and spectral analysis by Randolph Möllenberg (TUM)

Spare slights

Input parameter of calculations

The solar neutrino fluxes according to astro-ph/0412440v3 (BS05(AGS,OP) were used [cm^-2 s^-1]:
pp: 6.06e10
pep: 1.45e8
hep: 8.25e3
7Be: 4.34e9
8B: 4.51e6
13N: 2.01e8
15O: 1.45e8
17F: 3.25e6

The MSW effect was included according to hep-ph/0404083, distribution of the neutrino sources according to astro-ph/0412440v3 (values of the mixing matrix were choosen according to pdg 2012).

Background rates:

Po210: 488.8 counts/(day*100t)
Bi210: 41.6 counts/(day*100t)
Kr85: 34.8 counts/(day*100t)
C11: 28.0 counts/(day*100t)
according to the Borexino Be7 paper from 15.07.2011 (the used data was recorded between 16.05.2007 and 02.05.2010).

C10: 0.54 counts/(day*100t)
Be11: 0.035 counts/(day*100t)
Tl208: 0.084 counts/(day*100t)
according to the Borexino B8 paper (29.4.2010)

The background rates for the cosgenically produced isotopes C10,C11 and Be11 we reduced by a factor of 5, due to the reduced muon flux at phyhäsalmi

C14: 3e6 counts/(day*100t) according to Alimonti, G.; et al. (1998). "Measurement of the 14C abundance in a low-background liquid scintillator". Physics Letters B 422 (1–4): 349–358

Event rates:

elastic neutrino scattering:

Be7: 8.6e3 counts/(day*36kt) (above 300 keV)
pep: 342 counts/(day*30kt) (above 700 keV)
CNO: 156 counts/(day*30kt) (above 700 keV)
B8: 38 counts/(day*20kt) (above 3 MeV)

C13 channel:

above 4 MeV (75% detection efficiency)
B8: 283 counts/(y*20kt)

Alpha beta discrimination was applied (95% beta acceptance, 99.7% alpha discrimination)

kb values:
e-: 0.15 mm/MeV
alpha: 0.107 mm/MeV

according to measurements of the DC veto scintillator (Thesis "Ionization quenching by Low Energy Electrons in the Double Chooz Scintillators by Stefan Wagner, and measurements by Christian Abele)