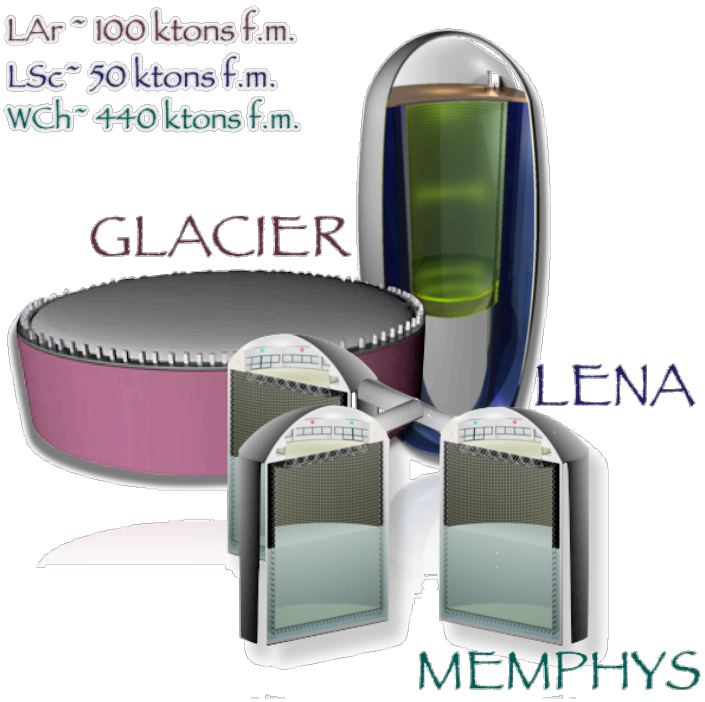
# Low-energy neutrino astronomy in LENA

Low energy neutrinos
TAUP Conference
Asilomar Conf Grounds
Monday, 9 Sep 2013

Michael Wurm
Universität Tübingen
on behalf of the LENA working group

# Future large-volume neutrino detectors

*In Europe: LAGUNA-LBNO*




**Proposed detector technologies**

- Liquid Argon TPC (20+ kt)
- Water Cherenkov (500 kt)
- Liquid Scintillator (50 kt)

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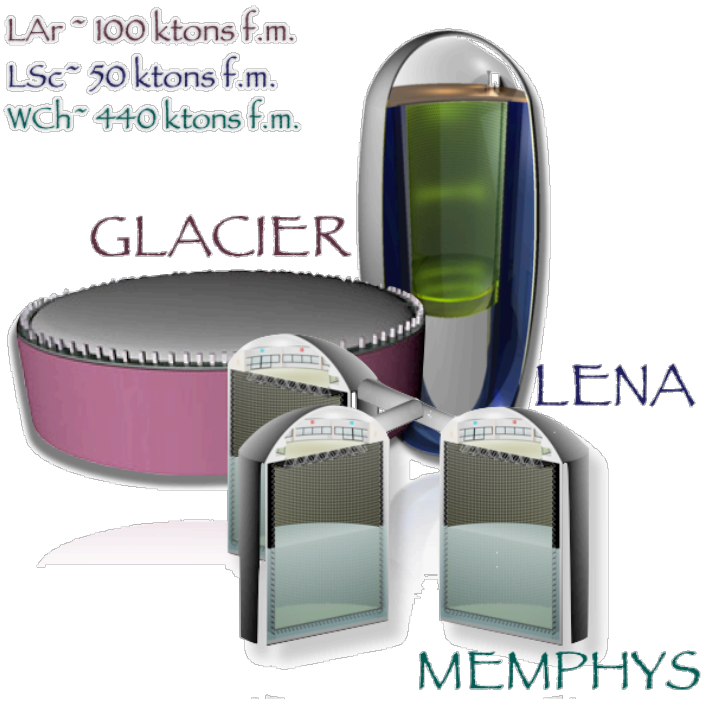


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## *Physics program*

**Observation of astrophysical neutrino sources**

- solar fusion
- core-collapse supernovae
- dark matter annihilation ν's

**ν oscillations (hierarchy, $\delta_{CP}$)**

- neutrino beams
- atmospheric ν's
- pion DAR

**Search for nucleon decay**

**Geoneutrino observation**

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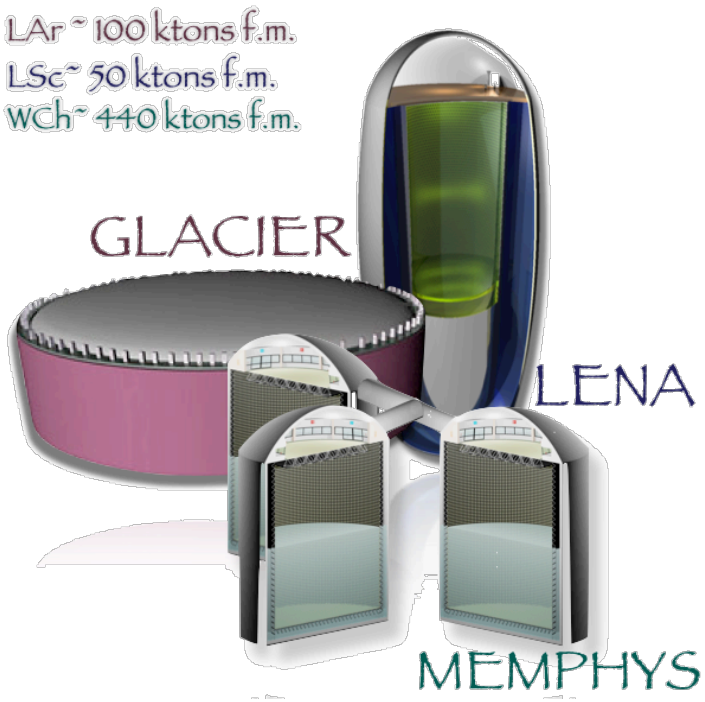


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**Search for nucleon decay**

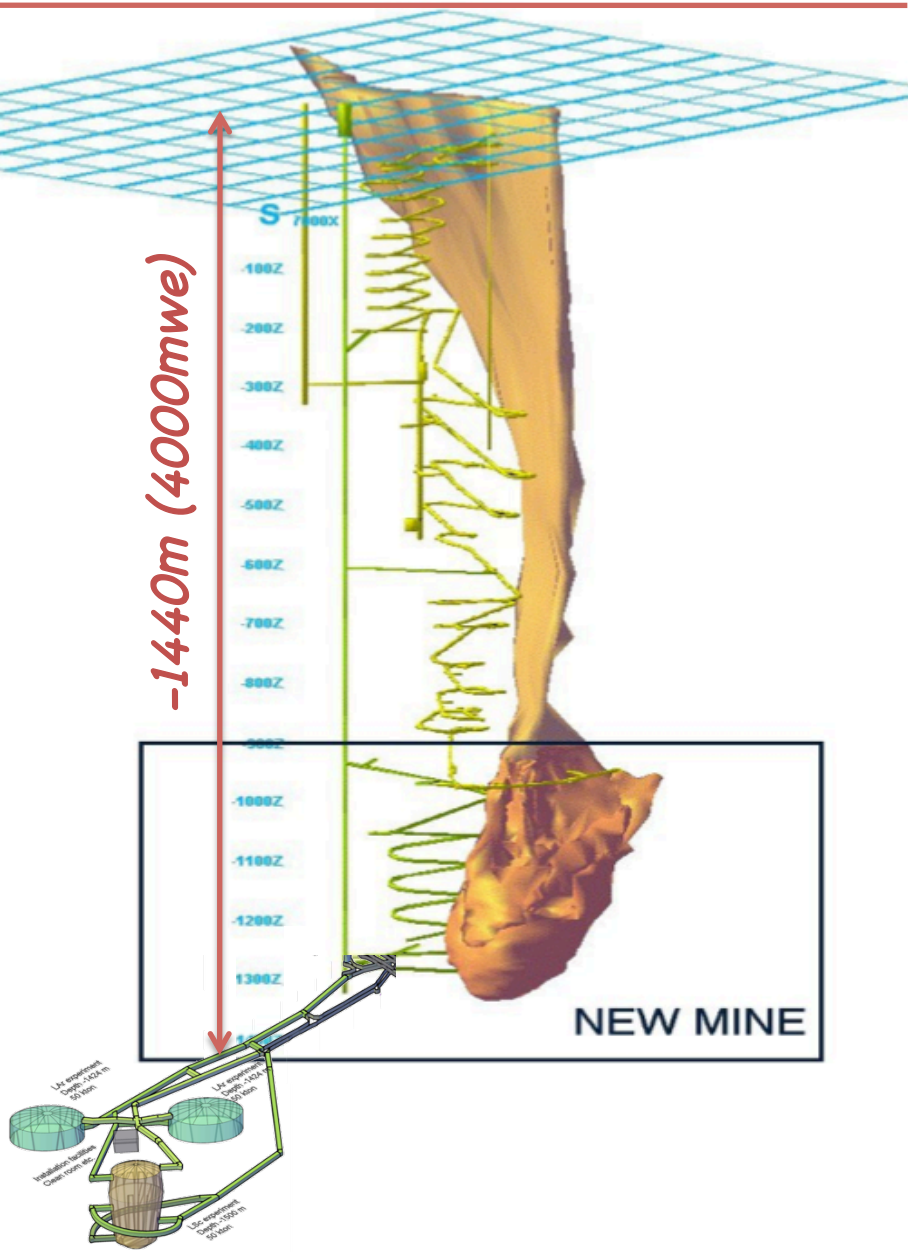
**Geoneutrino observation**

→ *core program of liquid-scintillator detectors*

– Low energy threshold

– Low background

# LENA at the Pyhäsalmi mine (Finland)



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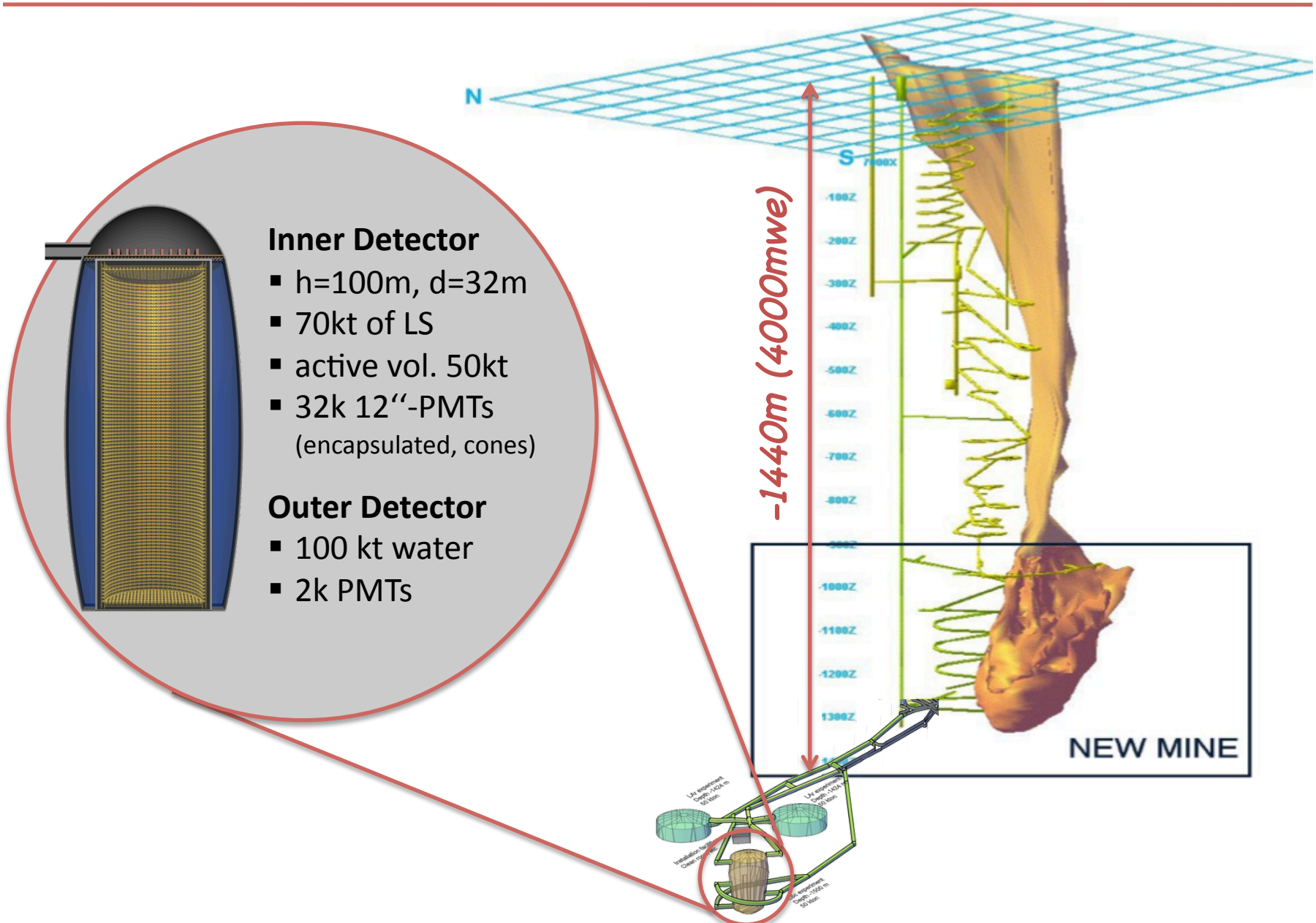
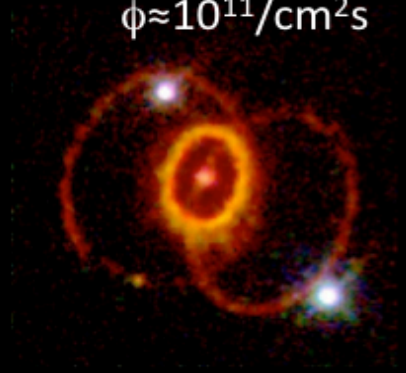


# Observation of astrophysical neutrinos in LENA

$\chi\chi \rightarrow \nu\bar{\nu}$

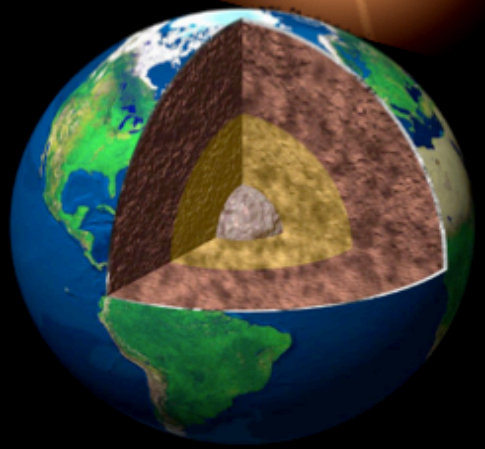
***Dark Matter Annihilation***

***Galactic Supernovae***
gravitational collapse
$\langle E \rangle \approx 15$MeV
d≈10kpc
$\phi \approx 10^{11}/cm^2s$



galactic
cosmic

***Sun***
H burning
E<18MeV
$\phi \approx 10^{10}/cm^2s$



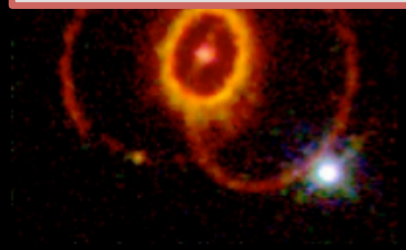
***Geoneutrinos***
natural U/Th
E<3.4MeV
$\phi \approx 10^{6}/cm^2s$

***SNν background***
all SN for z→5
$\langle E \rangle \approx 10$MeV
$\phi \approx 10^{2}/cm^2s$

# Observation of astrophysical neutrinos in LENA

*Supernova ν burst*

- ~$2 \times 10^4$ ev in 6 channels
  *E,t,flavor*-resolved signal
- study of core-collapse
- ν properties (MH)

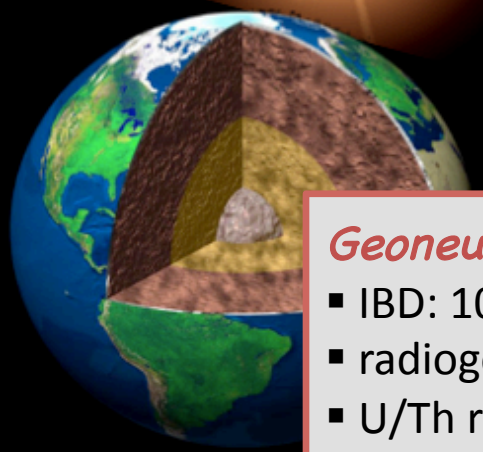


galactic

cosmic

*Solar neutrinos*

- ~$10^4$ ve -scatters per day
- CC-$^{13}$C: ~$10^3$ per year
- study of solar interior (*Z*)
- neutrino properties



*Geoneutrinos*

- IBD: $10^4$ in 10 yrs
- radiogenic heat at 1%
- U/Th ratio at 5%

*Diffuse SN background*

- IBD: ~$10^2$ in 10 yrs
- average spectral shape
- fraction of dark SN

# Solar neutrino signal in LENA

*What can LENA achieve beyond Borexino/SNO(+)? → Three examples*

- Search for **time modulations in $^{7}$Be-ν flux**
- Low-energy $^{8}$B-ν's for **survival probability in vacuum-matter transition region**
- CNO-ν flux for **CNO fusion rate** and indirectly **solar metallicity**

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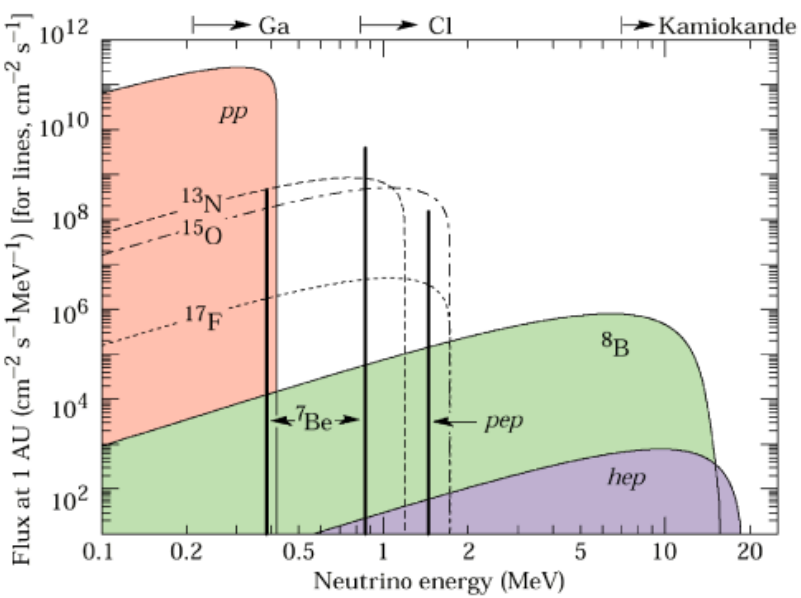
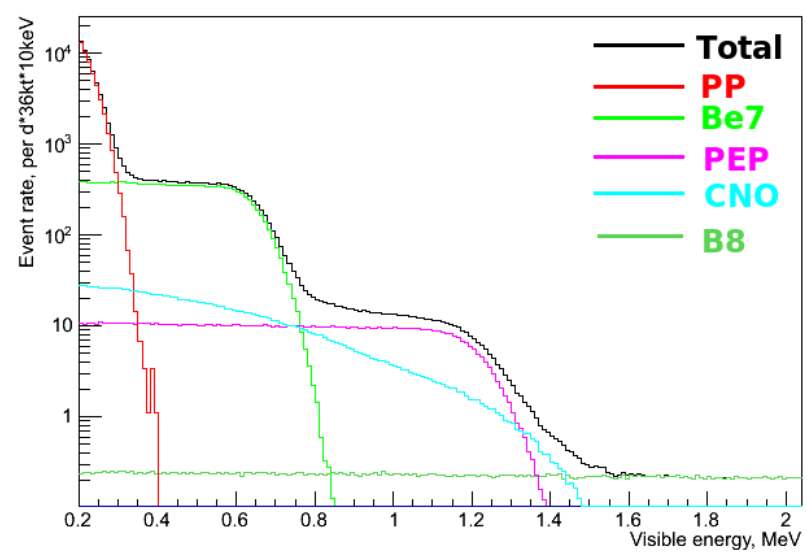
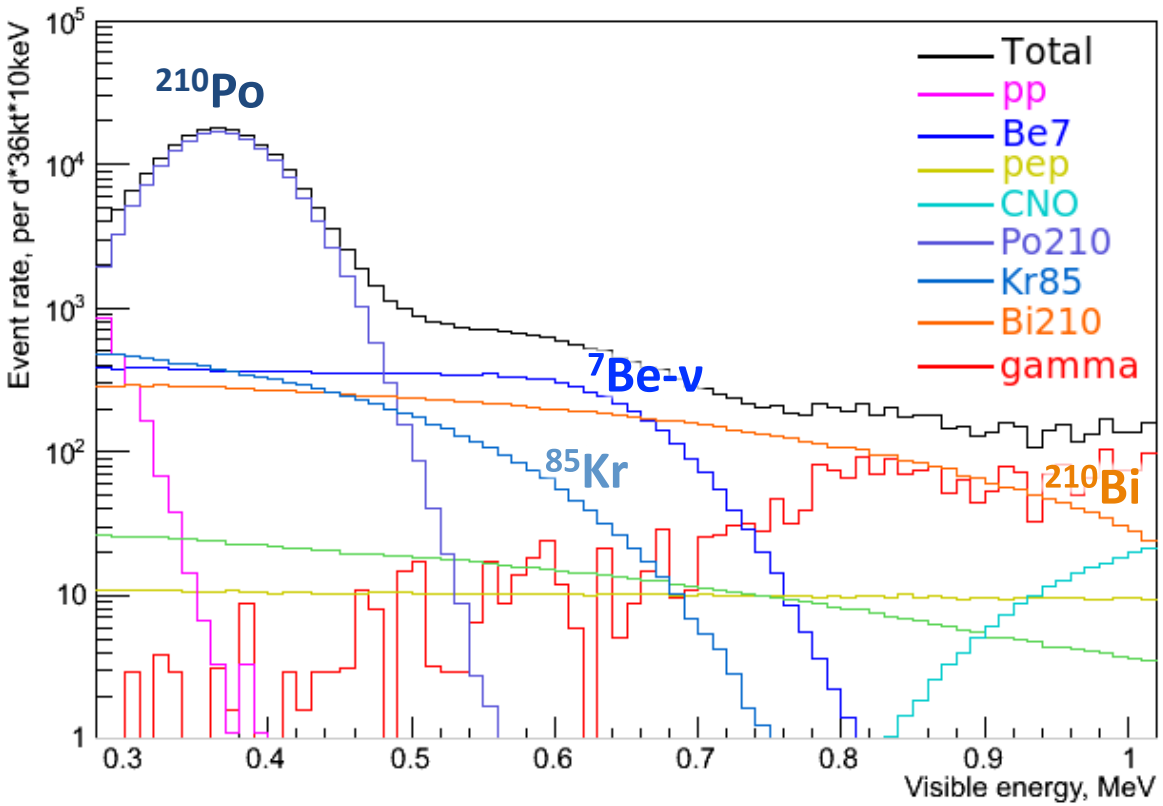
*solar neutrino spectrum*




*electron recoil spectrum in LENA*



# Detection of $^{7}$Be neutrinos in LENA




**Fiducial volume:** 36kt
radius: 12m

**Signal rate:**

$^{7}$Be-ν: $1.7 \times 10^{4}$ /day

**Background rates:**

$^{210}$Po: $1.8 \times 10^{5}$
$^{210}$Bi: $1.5 \times 10^{4}$
$^{85}$Kr: $1.3 \times 10^{4}$

*... based on latest $^{7}$Be paper by Borexino [arxiv:1104.1816]*

***Absolute rate measurement***

→ statistics won't matter

→ hard to surpass Borexino in terms of systematics (~3%)

# Search for time variations in the $^7$Be flux

Rate modulations of type: $N(t) = N_0 \cdot (1 + A \cdot \sin(t/T + \varphi))$

→ *relative measurement: most systematics cancel!*

*(Possible) causes of periodic modulations of ν flux*

- **Day/Night effect?** A = 0.1% predicted by MSW-LMA
- **Helioseismic g-modes?** present limit by SNO: *A* < 10% *(90%CL)*
- **Correlations to solar cycle?** T ≈ 11 yrs
- **others?**

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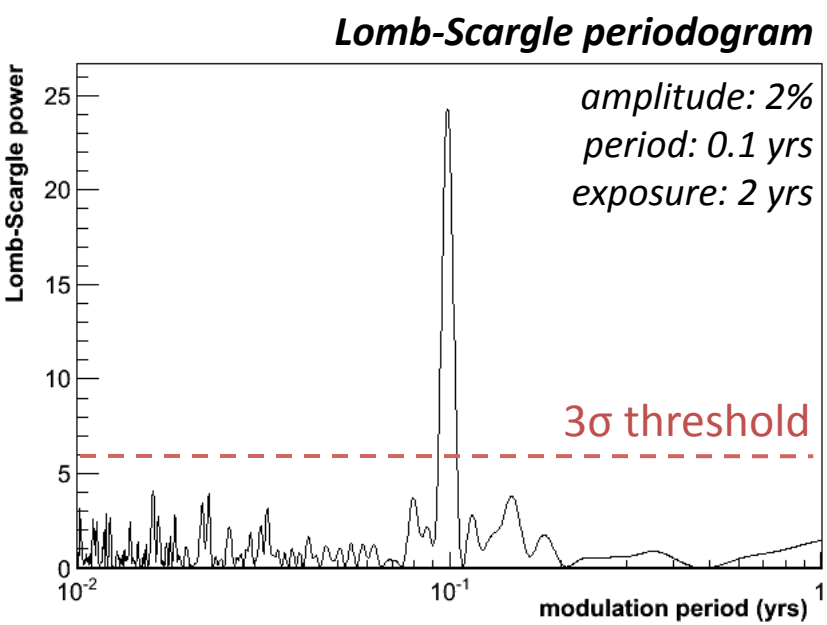


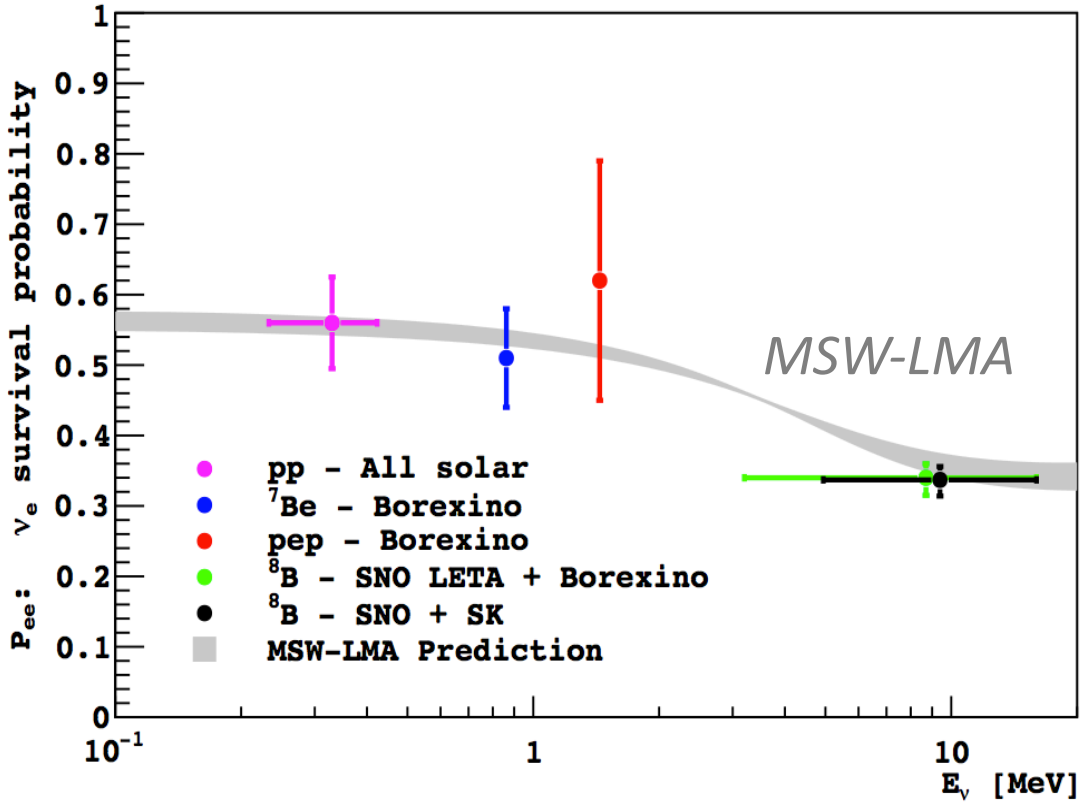

*Expected sensitivity in LENA*

→ **90% chance for a 3σ discovery if relative amplitude is *$\mathcal{O}(10^{-3})$***

- *derived by Lomb-Scargle analysis*
- *depends on modulation frequency and measurement time*

*[arXiv:1012.3021]*

# $P_{ee}(E)$ in the MSW-LMA transition region




- current data in agreement with MSW-LMA predictions
- not much data in vacuum-matter transition region

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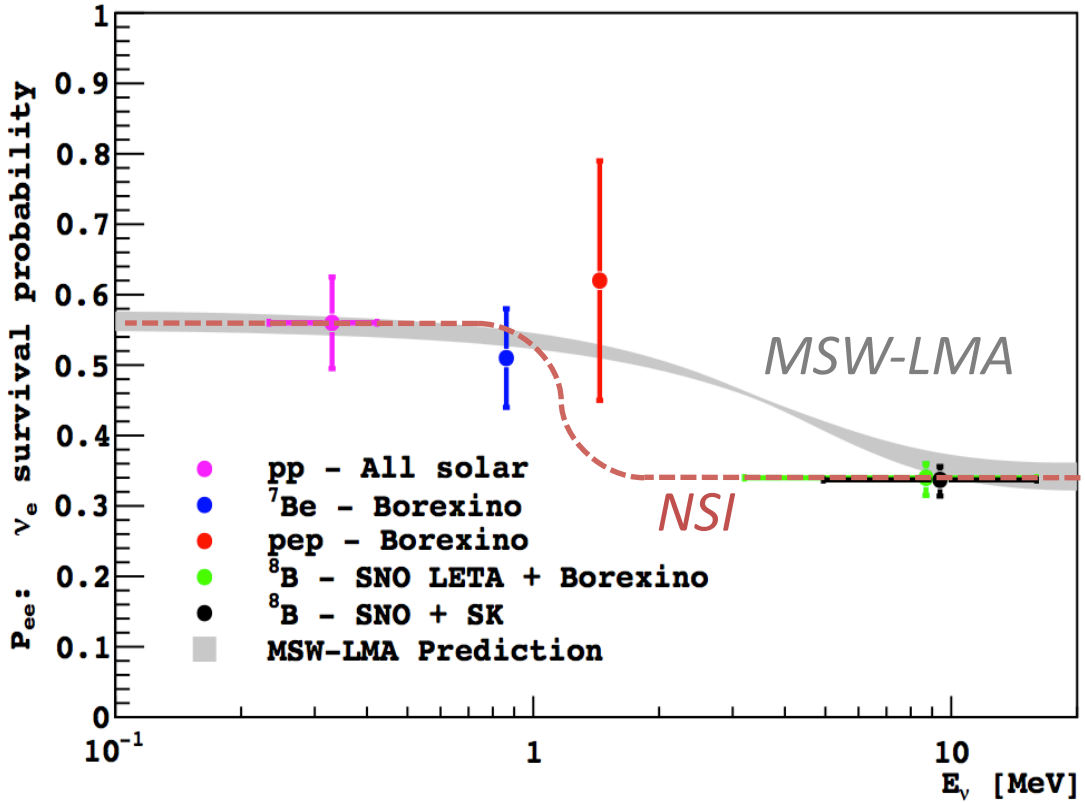
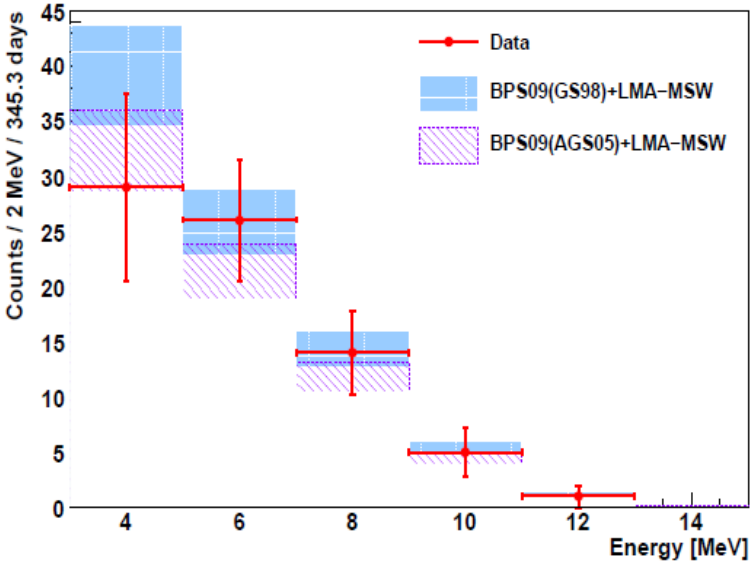
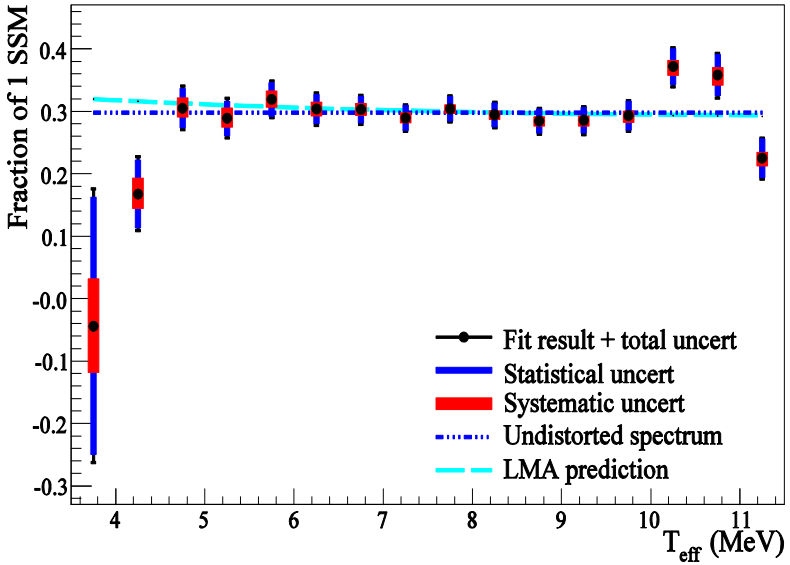



- current data in agreement with MSW-LMA predictions
- not much data in vacuum-matter transition region
- alternative course of $P_{ee}(E)$ → NSI? light sterile ν's ($m_\nu$≈0.1eV) ?

  *[e.g. Friedland et al. (2004); Holanda, Smirnov - arXiv:1012.5627]*

# Are there hints from current $^8$B-$\nu$ analyses?



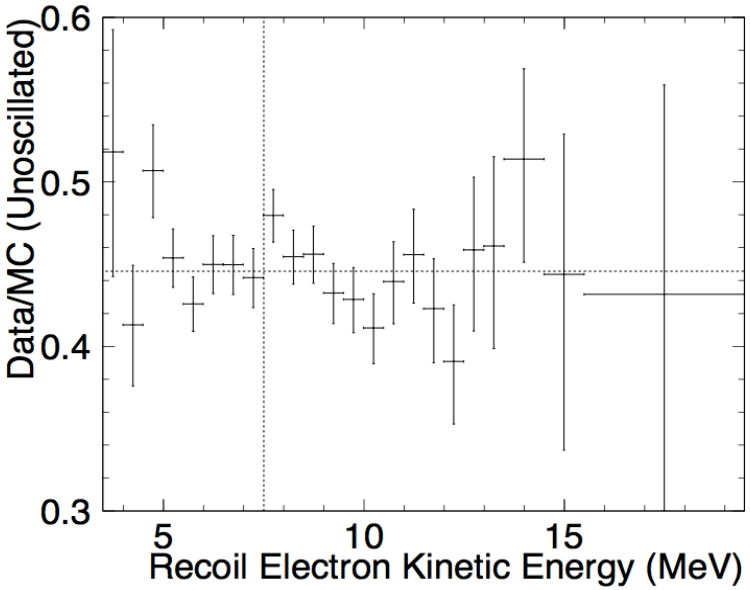




***Borexino (ES)***

*arXiv:0808.2868*

***SNO-LETA (CC)***

*arXiv:0910.2984*

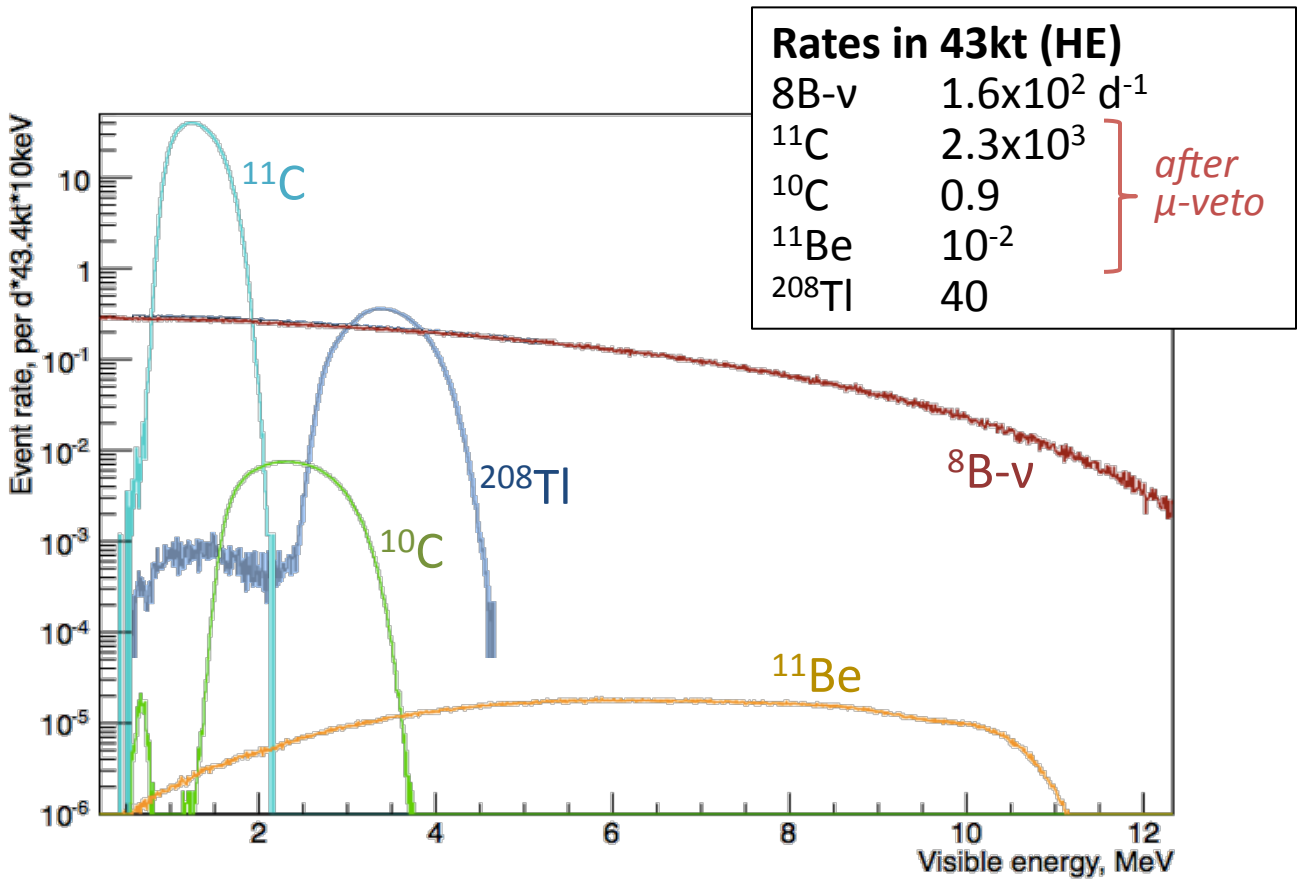



***SK-IV (ES)***

*arXiv:1307.3686*

→ *see the poster by Richard Bonventre*

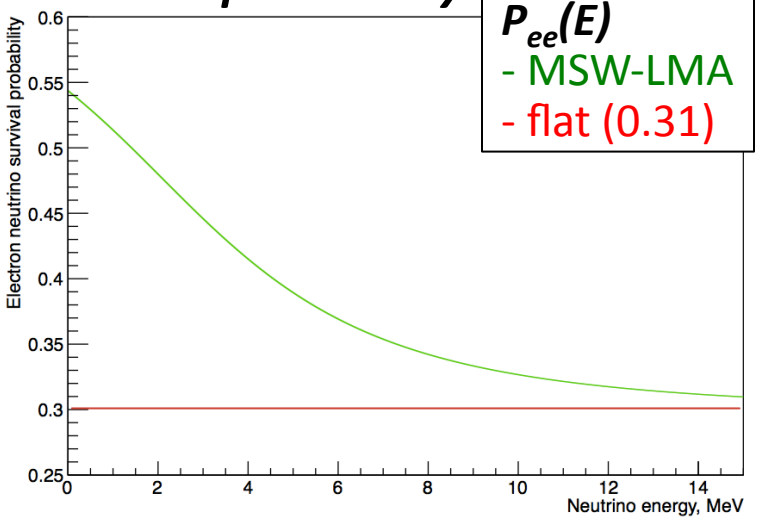
# Detection of $^{8}$B-$\nu$'s in LENA: *νe*-scattering



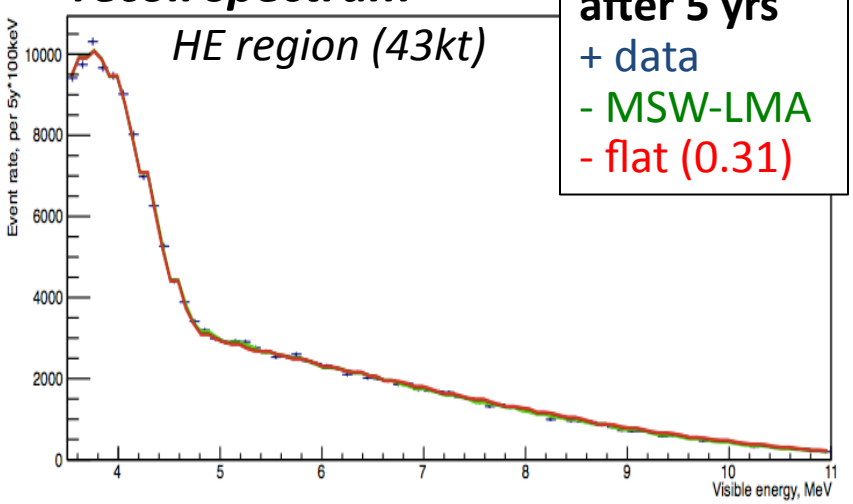

- μ-based veto for cosmogenic $^{11}$C,$^{10}$C,$^{11}$Be → **threshold at 2.2 MeV**
- **external γ bg ($^{208}$Tl):** <1 d$^{-1}$ in LE fiducial volume (*R*=9m, *m*=19kt)
- $^{208}$Tl in LS counted by $^{212}$Bi/Po's and statistically subtracted

# LENA's sensitivity for the spectral up-turn

***survival probability***




***recoil spectrum***

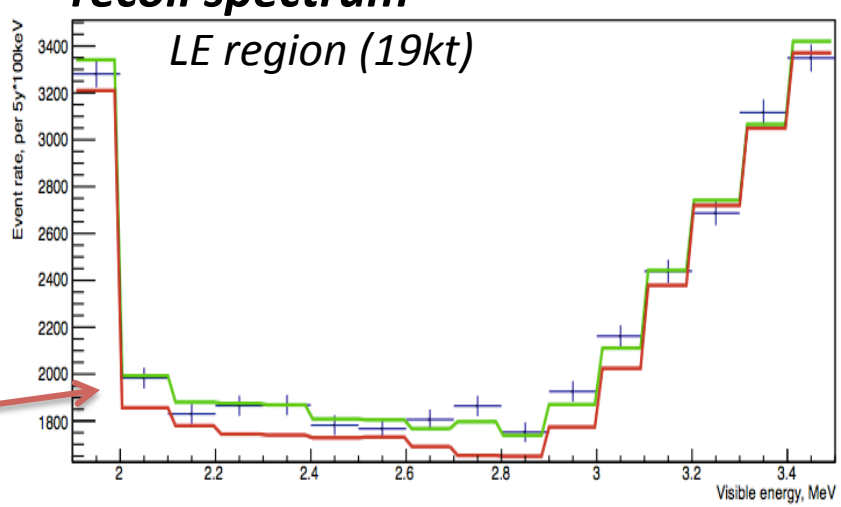



***Generic analysis:*** *(R. Möllenberg, TUM)*
***flat $P_{ee}$ vs. MSW-LMA***

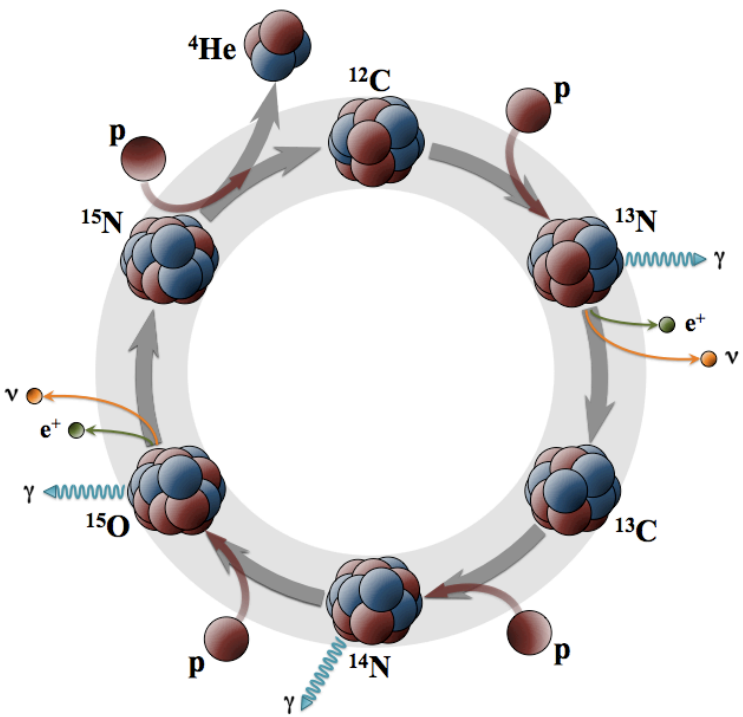
- no effect at high recoil energies
- main sensitivity in low-energy region (2-3.5MeV)

→ ***discrimination of the models at 5σ level after 3-5 yrs***

***recoil spectrum***



# CNO fusion rate and solar metallicity




- subdominant in the Sun (<2%)
- large rate uncertainty from SSM and nuclear physics (~16%)
- Best direct limit on ν flux by Borexino: $\phi_{exp}<1.5\phi_{SSM}$ (95%CL)

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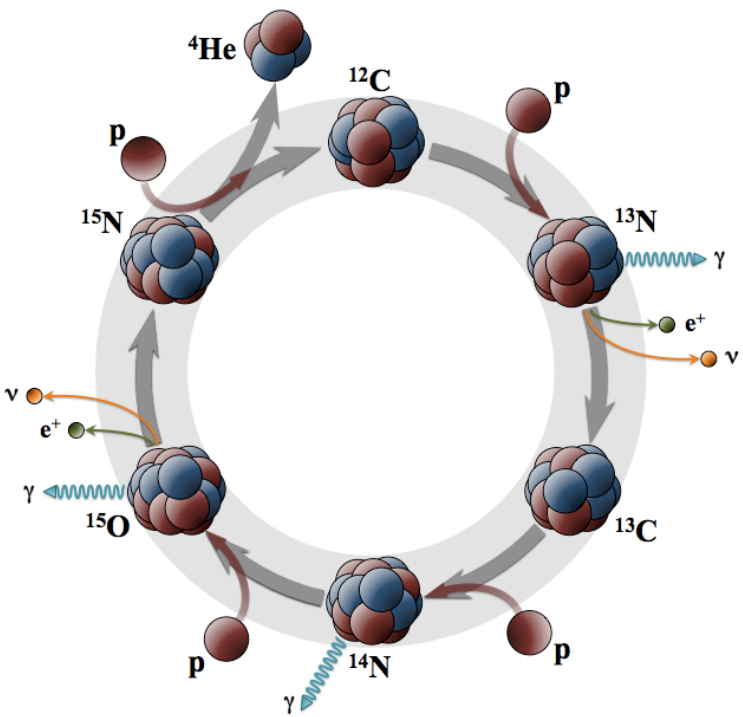


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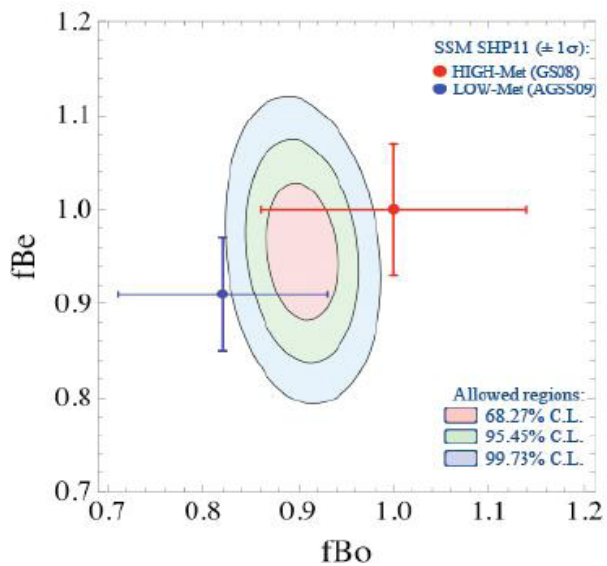
*What to learn from a CNO flux measurement?*

- CNO fusion dominant in heavier/older stars
- CNO rate very sensitive on solar metallicity *Z*

→ high vs. low *Z*: $\Delta\phi$ ~ 35%

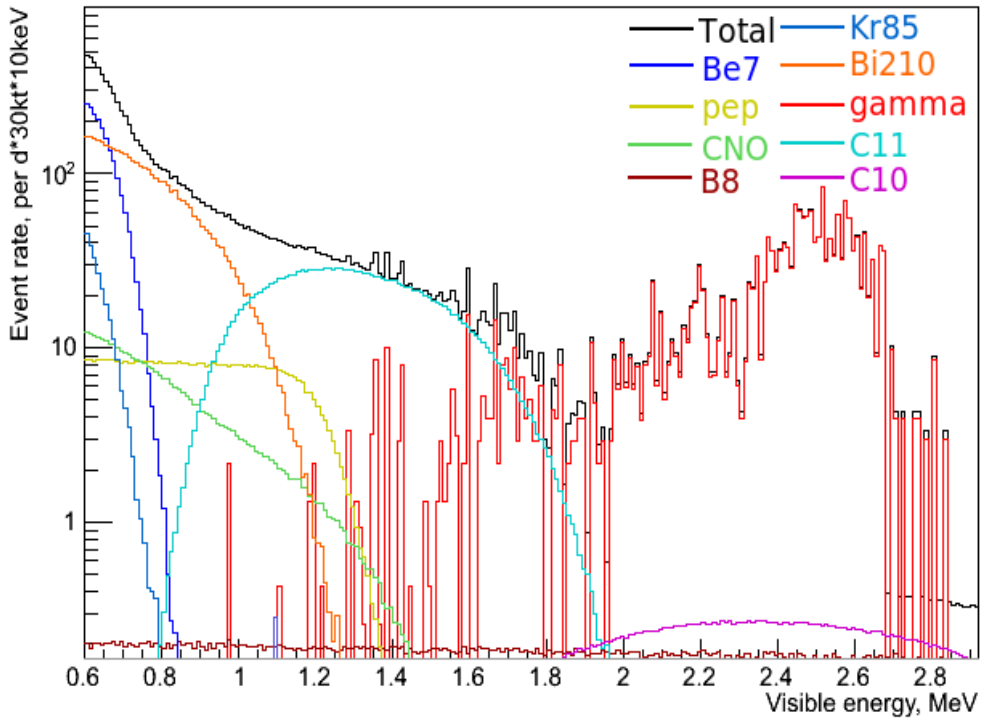



SSM predictions of $^7$Be/$^8$B ν flux for high and low metallicity (SSM)

***vs.***

data from SNO & Borexino

# Improved sensitivity to CNO/pep-ν's?




**Event rates in 30kt**

- pep ν's $3.4 \times 10^2$ /day
- CNO ν's $1.6 \times 10^2$
- $^{11}C$ $5.6 \times 10^3$
- $^{210}Bi$ $1.5 \times 10^4$

*Can LENA do better than Borexino and SNO+?*

- Larger target mass (30kt) → **greater statistics**
- **Improved self-shielding** from external γ-rays
- Greater rock overburden → **reduced $^{11}C$ background** ($\phi_{\mu,Py} \approx 1/4\ \phi_{\mu,LNGS}$)

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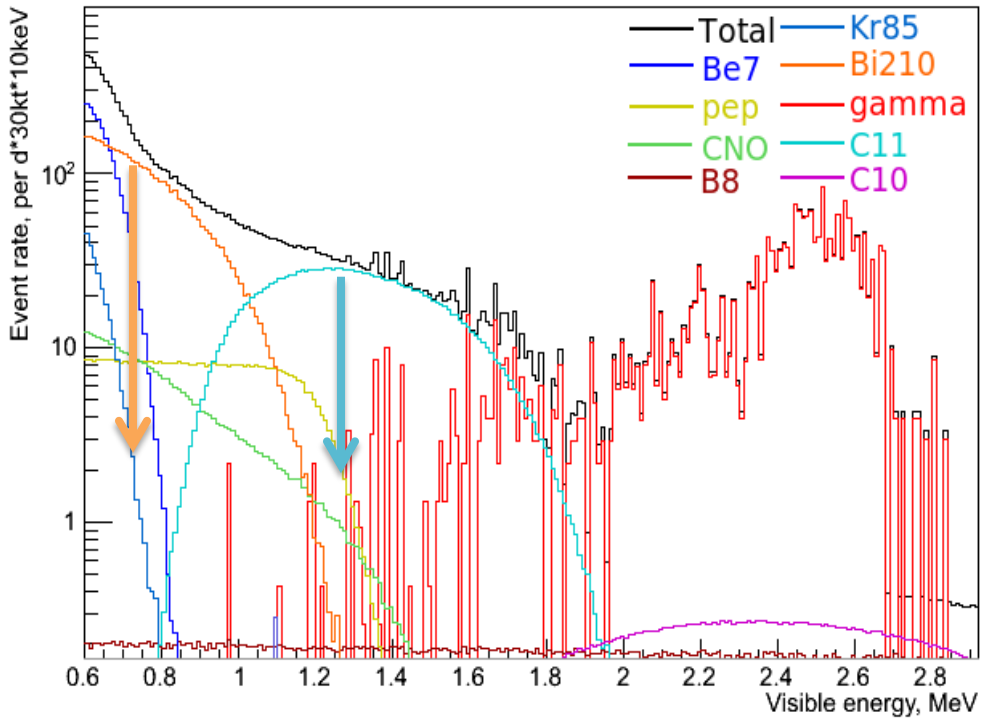


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**Background reduction cuts**

- 3-fold coincidence veto for $^{11}C$ → reduction by factor ~10
- Statistical subtraction of $^{210}Bi$ via $^{210}Po$ α counting

# Conclusions

A liquid-scintillator detector on the scale of 50 kt will be a multipurpose ν observatory:

- astrophysical neutrinos
- neutrino oscillation physics
- nucleon decay search

Beyond the results of Borexino, SK & SNO(+), solar neutrino observation in LENA will reveal new insights by searching for ...

- flux modulations in $^{7}$Be neutrino flux
- neutrinos from the CNO cycle
- the spectral up-turn at low $^{8}$B ν energies

**Thank you for your attention!**

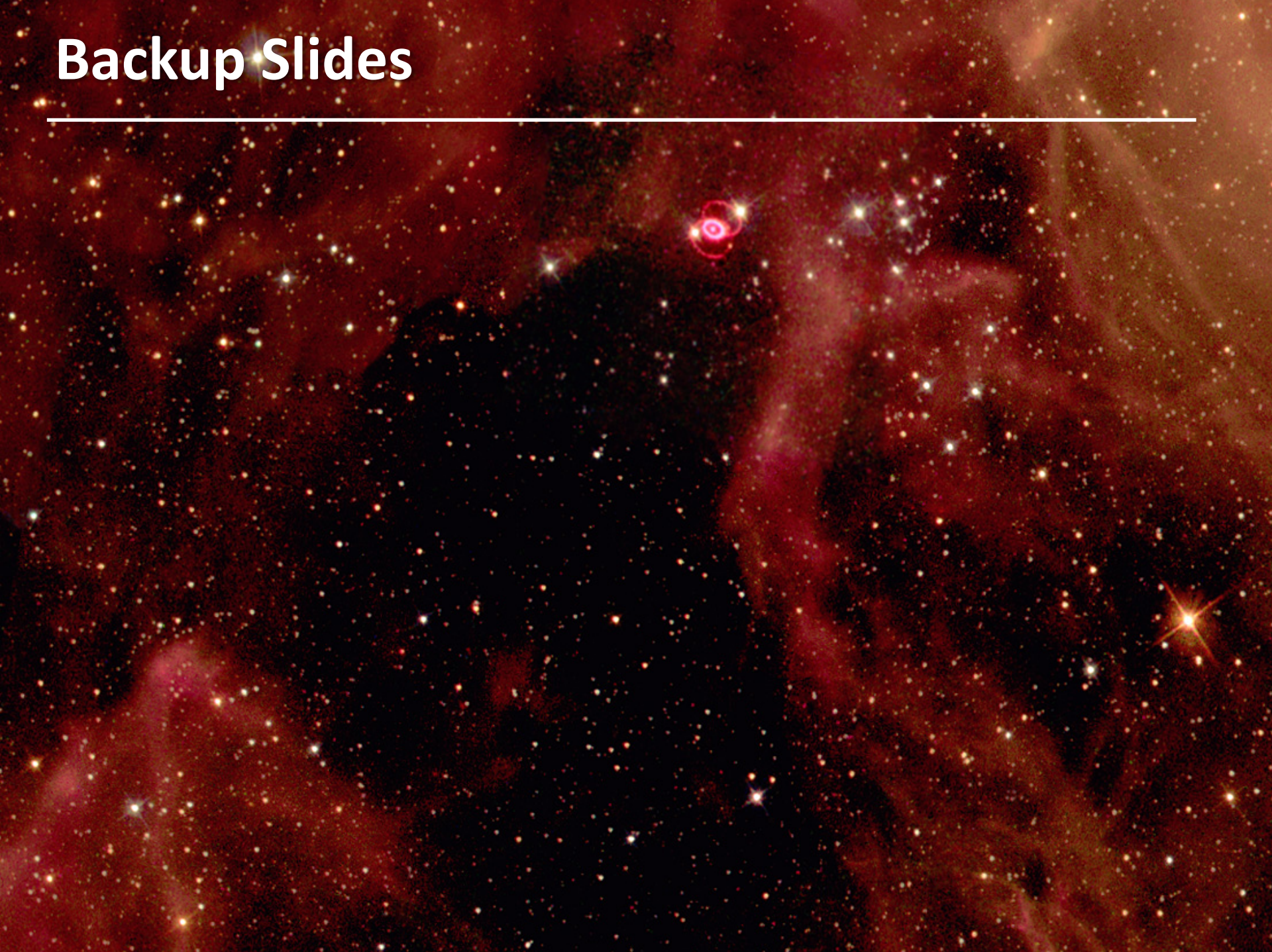
# Further reading

## The next-generation liquid-scintillator neutrino observatory LENA

Michael Wurm,[1,2,*] John F. Beacom,[3] Leonid B. Bezrukov,[4] Daniel Bick,[2] Johannes Blümer,[5] Sandhya Choubey,[6] Christian Ciemniak,[1] Davide D'Angelo,[7] Basudeb Dasgupta,[3] Amol Dighe,[8] Grigorij Domogatsky,[4] Steve Dye,[9] Sergey Eliseev,[10] Timo Enqvist,[11] Alexey Erykalov,[10] Franz von Feilitzsch,[1] Gianni Fiorentini,[12] Tobias Fischer,[13] Marianne Göger-Neff,[1] Peter Grabmayr,[14] Caren Hagner,[2] Dominikus Hellgartner,[1] Johannes Hissa,[11] Shunsaku Horiuchi,[3] Hans-Thomas Janka,[15] Claude Jaupart,[16] Josef Jochum,[14] Tuomo Kalliokoski,[17] Pasi Kuusiniemi,[11] Tobias Lachenmaier,[14] Ionel Lazanu,[18] John G. Learned,[19] Timo Lewke,[1] Paolo Lombardi,[7] Sebastian Lorenz,[2] Bayarto Lubsandorzhiev,[4,14] Livia Ludhova,[7] Kai Loo,[17] Jukka Maalampi,[17] Fabio Mantovani,[12] Michela Marafini,[20] Jelena Maricic,[21] Teresa Marrodán Undagoitia,[22] William F. McDonough,[23] Lino Miramonti,[7] Alessandro Mirizzi,[24] Quirin Meindl,[1] Olga Mena,[25] Randolph Möllenberg,[1] Rolf Nahnhauer,[26] Dmitry Nesterenko,[10] Yuri N. Novikov,[10] Guido Nuijten,[27] Lothar Oberauer,[1] Sandip Pakvasa,[28] Sergio Palomares-Ruiz,[29] Marco Pallavicini,[30] Silvia Pascoli,[31] Thomas Patzak,[20] Juha Peltoniemi,[32] Walter Potzel,[1] Tomi Räihä,[11] Georg G. Raffelt,[33] Gioacchino Ranucci,[7] Soebur Razzaque,[34] Kari Rummukainen,[35] Juho Sarkamo,[11] Valerij Sinev,[4] Christian Spiering,[26] Achim Stahl,[36] Felicitas Thorne,[1] Marc Tippmann,[1] Alessandra Tonazzo,[20] Wladyslaw H. Trzaska,[17] John D. Vergados,[37] Christopher Wiebusch,[36] and Jürgen Winter[1]

[1] *Physik-Department, Technische Universität München, Germany*
[2] *Institut für Experimentalphysik, Universität Hamburg, Germany*
[3] *Department of Physics, Ohio State University, Columbus, OH, USA*
[4] *Institute for Nuclear Research, Russian Academy of Sciences, Moscow, Russia*
[5] *Institut für Kernphysik, Karlsruhe Institute of Technology KIT, Germany*
[6] *Harish-Chandra Research Institute, Allahabad, India*

# Backup Slides



# Search for time variations in the $^7$Be flux

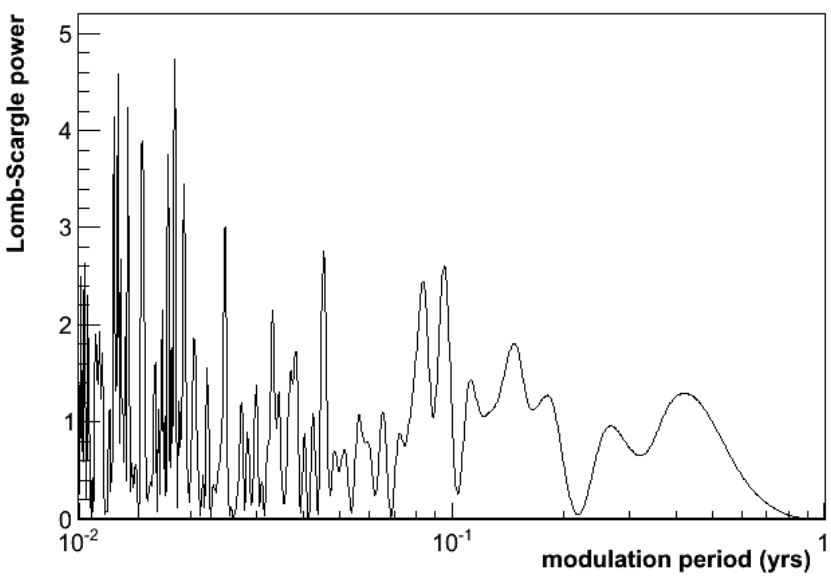
Rate modulations of type: $N(t) = N_0 \cdot (1 + A \cdot \sin(t/T + \varphi))$

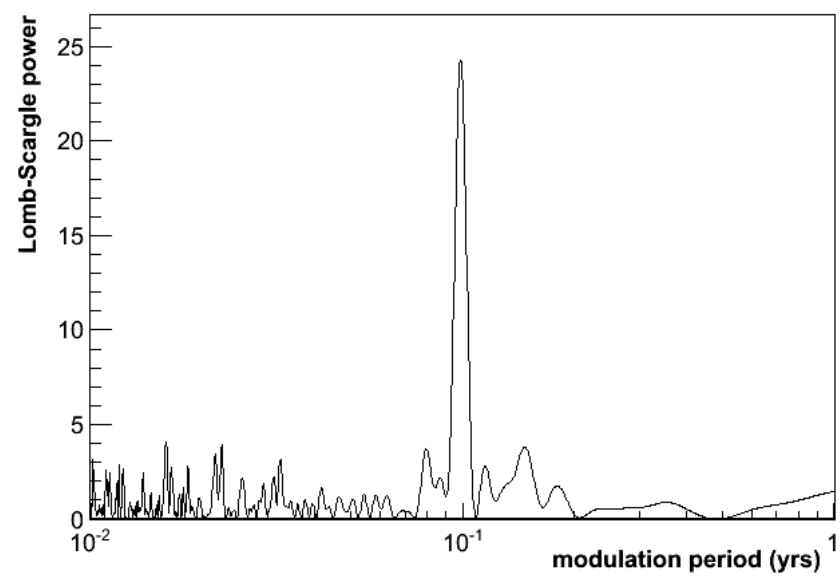
→ *relative measurement: most systematics cancel!*

**Lomb-Scargle analysis:** Power *P* of a modulation with period *T*

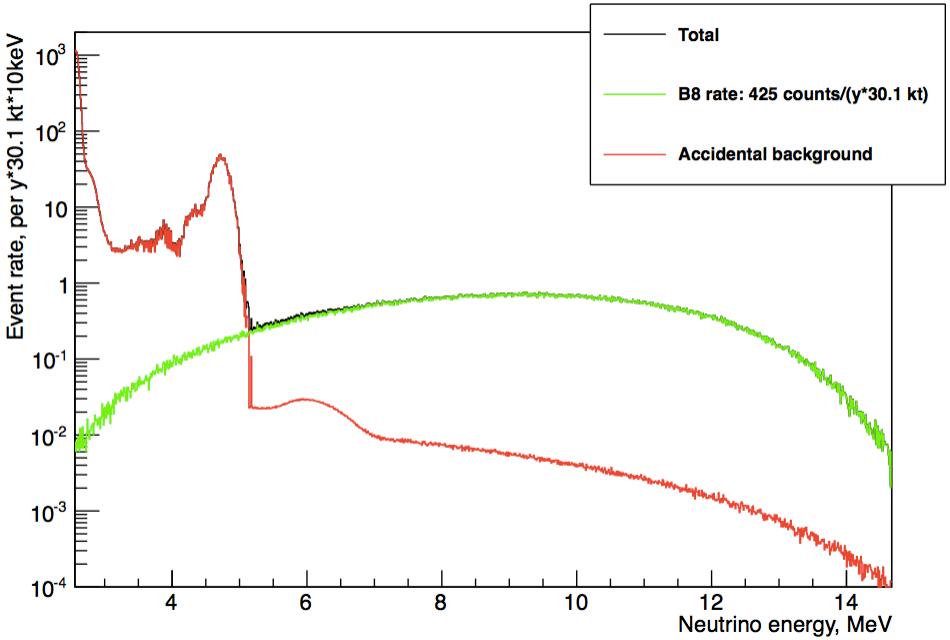
$$P = \frac{1}{\sqrt{2\sigma^2}} \left( \frac{\left[\sum_{i=1}^{n} w_i (N(t_i) - N_0) \cos\left(2\pi \frac{t_i - \phi}{T}\right)\right]^2}{\sum_{i=1}^{n} w_i \cos^2\left(2\pi \frac{t_i - \phi}{T}\right)} + \frac{\left[\sum_{i=1}^{n} w_i (N(t_i) - N_0) \sin\left(2\pi \frac{t_i - \phi}{T}\right)\right]^2}{\sum_{i=1}^{n}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

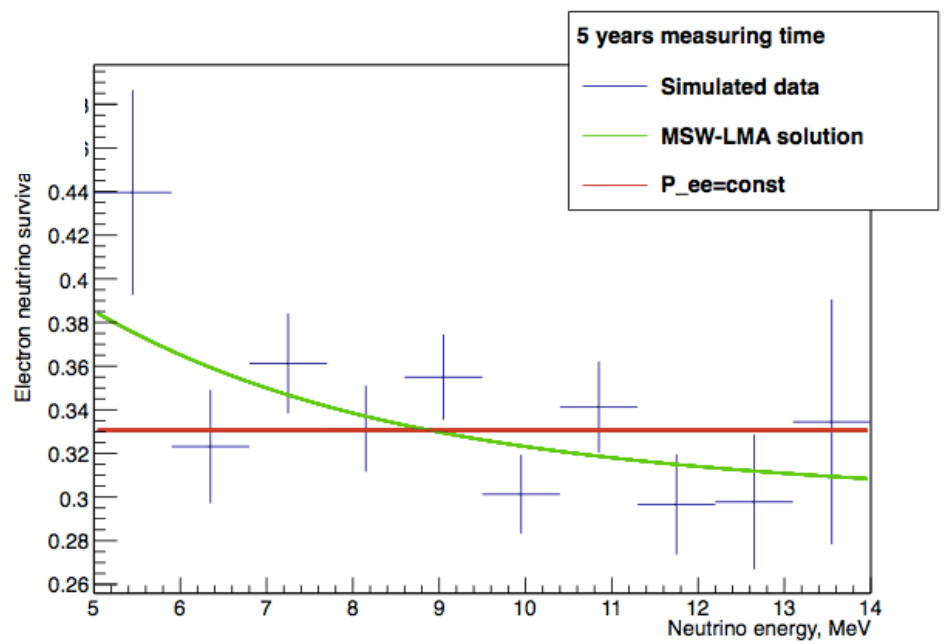
**Sample periodigrams:** White noise vs. modulation with 2% amplitude (2 years)



# Detection of $^{8}$B-$\nu$'s in LENA: $^{13}C(\nu_e,e)^{13}N$




- Event rate: 425 per year
- delayed coincidence with $^{13}N$ re-decay ($T_{1/2}$=862s) → substantial bg reduction
- accidental background dominates signal for $E_\nu$<5MeV

- LE region sensitive to $P_{ee}(E)$
- Statistics not sufficient to reach high significance for discrimination