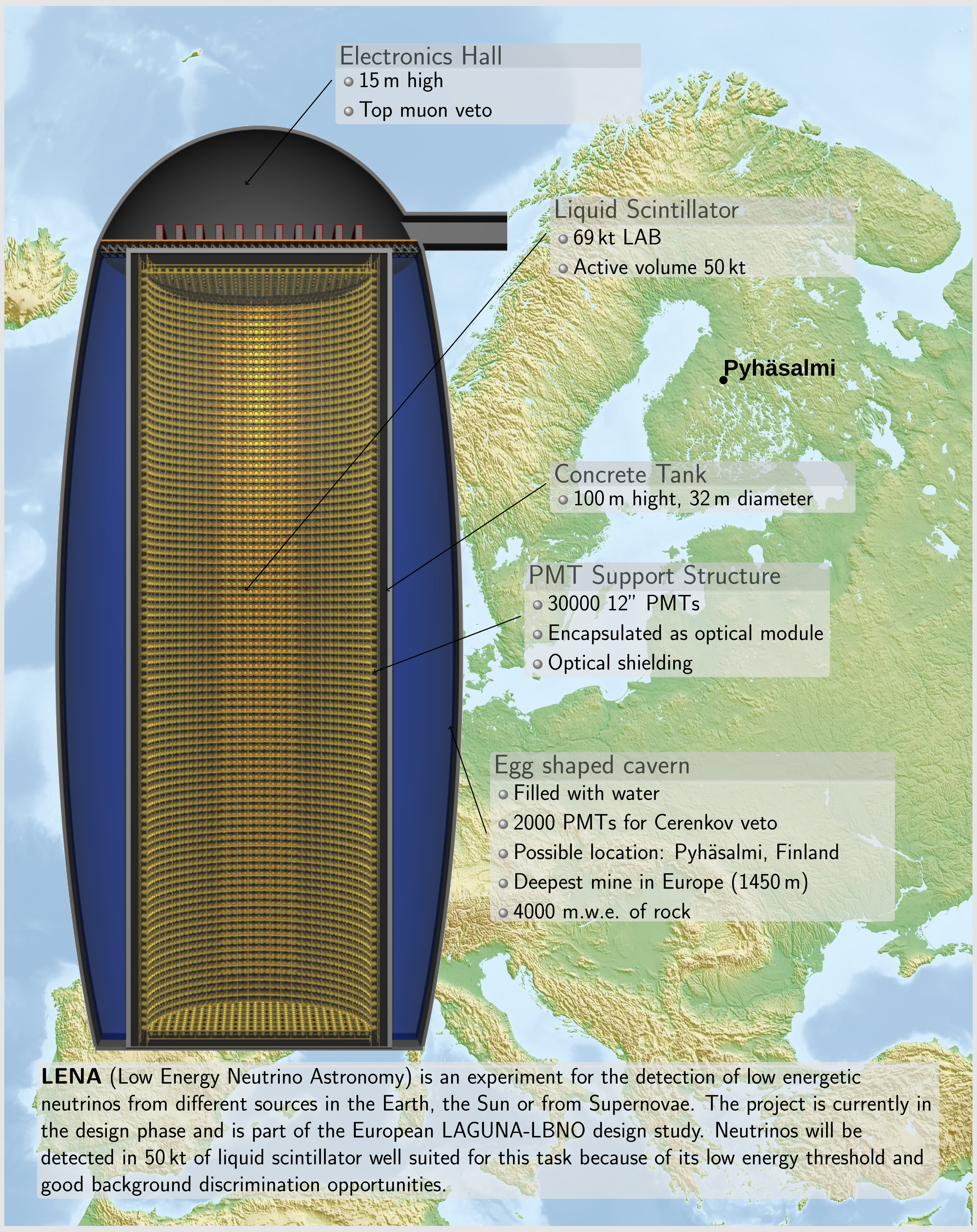
Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

New Prospects and Improvements in the Analysis for Low Energy Neutrinos in LENA

Daniel Bick for the LENA Working Group

The Lena Detector



Electronics Hall
- 15 m high
- Top muon veto

Liquid Scintillator
- 69 kt LAB
- Active volume 50 kt

Concrete Tank
- 100 m hight, 32 m diameter

PMT Support Structure
- 30000 12" PMTs
- Encapsulated as optical module
- Optical shielding

Egg shaped cavern
- Filled with water
- 2000 PMTs for Cerenkov veto
- Possible location: Pyhäsalmi, Finland
- Deepest mine in Europe (1450 m)
- 4000 m.w.e. of rock

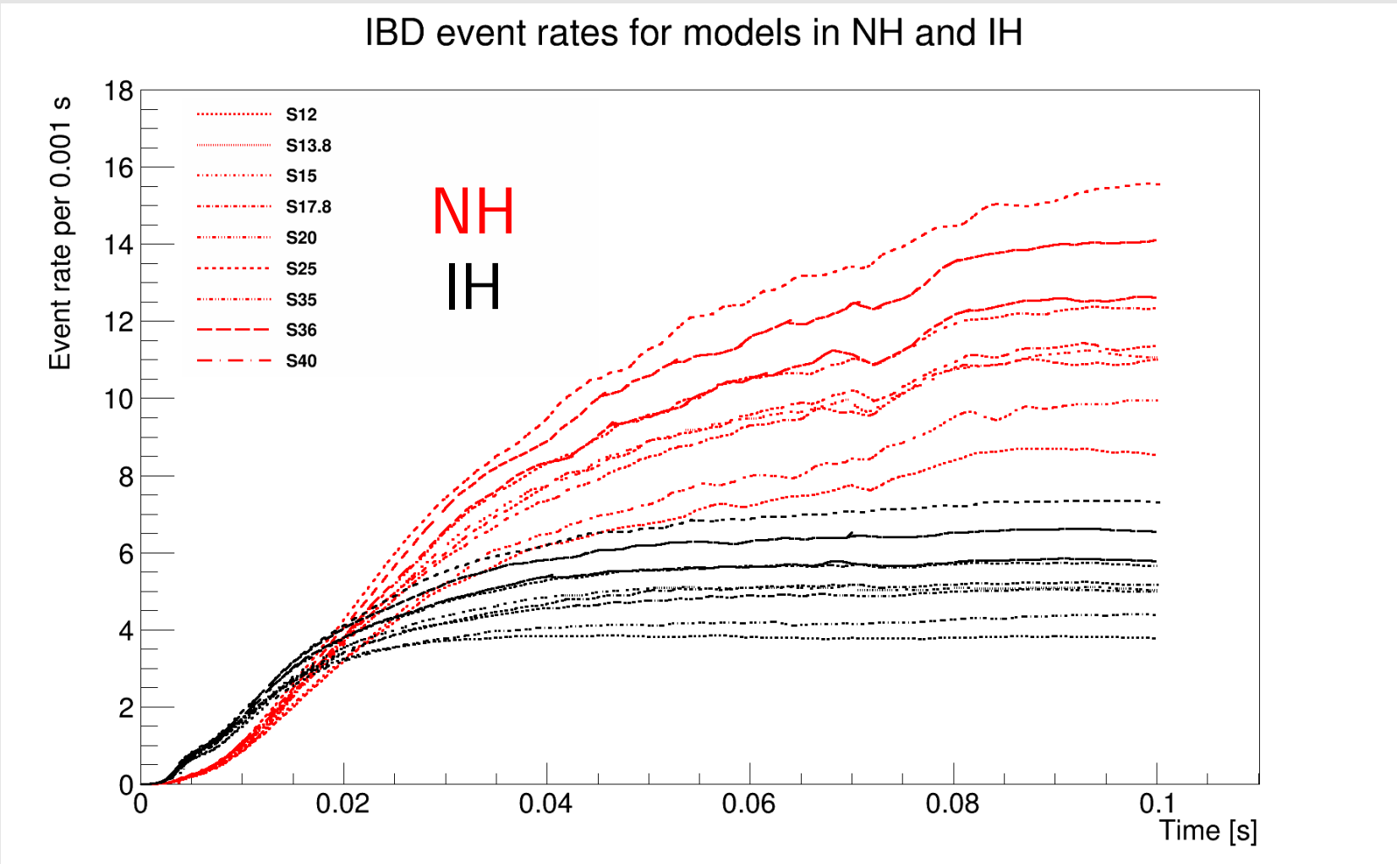
LENA (Low Energy Neutrino Astronomy) is an experiment for the detection of low energetic neutrinos from different sources in the Earth, the Sun or from Supernovae. The project is currently in the design phase and is part of the European LAGUNA-LBNO design study. Neutrinos will be detected in 50 kt of liquid scintillator well suited for this task because of its low energy threshold and good background discrimination opportunities.

Mass Hierarchy from Supernova Risetimes

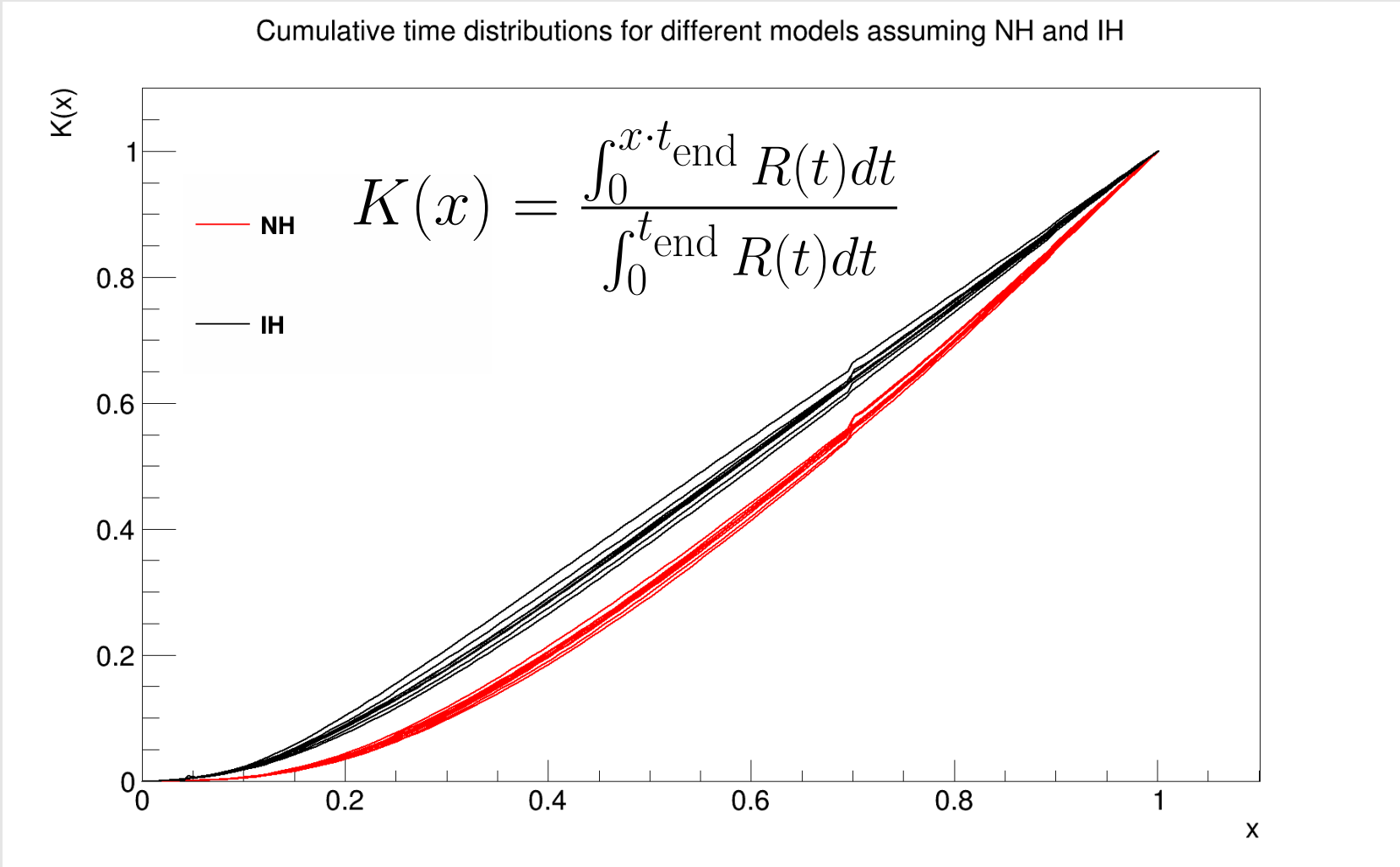
Neutrino flavor conversions

- Emitted neutrinos oscillate during propagation
- Self-induced and MSW oscillation effects occur at different SN radii → independent
- Early postbounce ($<\sim 0.2\,\mathrm{s}$) $n_e >> n_\nu$ completely suppresses collective oscillation
- **NH:** $F_{\bar{\nu}_e} = \cos^2\theta_{12}F^0_{\bar{\nu}_e} + \sin^2\theta_{12}F^0_{\bar{\nu}_x}$
  $\approx 0.68F_{\bar{\nu}_e} + 0.32F_{\bar{\nu}_x}$
- **IH:** $F_{\bar{\nu}_e} = F^0_{\bar{\nu}_x}$
  → complete swap of spectra for $\bar{\nu}_e$
- Possible Earth matter effects negligible

- SN at 10 kpc distance
- $\bar{\nu}_e$ detection via inverse β-decay



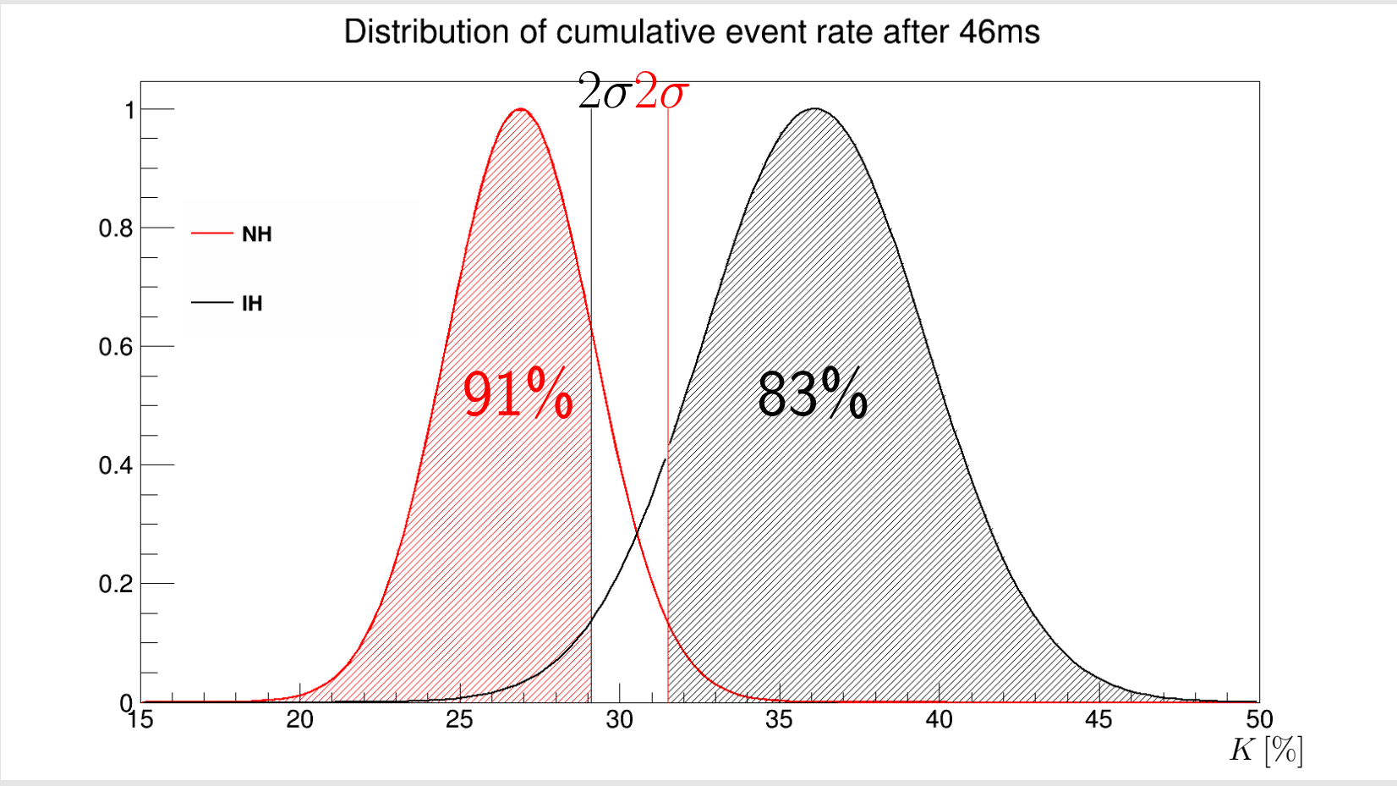
Investigation of integrated number of events vs. time



K after $46\,\mathrm{ms}$ ($t_\mathrm{end} = 100\,\mathrm{ms}$)

Model	Rate in NH [%]	Rate in IH [%]
s12	29 ± 2	40 ± 3
s13.8	26 ± 2	35 ± 3
s15	27 ± 2	37 ± 3
s17.8	26 ± 2	35 ± 3
s20	28 ± 2	37 ± 3
s25	25 ± 2	33 ± 2
s35	27 ± 2	36 ± 3
s36	27 ± 2	36 ± 3
s40	27 ± 2	36 ± 3
Average	26.9 ± 2.3	36.1 ± 3.5

- Largest distance of K between NH and IH at 46 ms
- Different input models → Gaussian distribution
- Use 2σ lines to separate
- NH: 91% of models inside domain
- IH: 83% of models inside domain
- 2.3% chance of misidentification
- Work ongoing



The LENA Working Group

TECHNISCHE UNIVERSITÄT MÜNCHEN
JYVÄSKYLÄN YLIOPISTO
RWTH AACHEN UNIVERSITY
JOHANNES GUTENBERG UNIVERSITÄT MAINZ
Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

Diffuse Supernova Neutrino Background

- Only 1 - 3 galactic supernovae per century
- Isotropic SN neutrino background on cosmic scales
- Information on average neutrino spectrum
- Redshifted by cosmic expansion
- Expected flux: $100\,\nu/\mathrm{s}/\mathrm{cm}^2$

Expected DSNB Events after 10 years

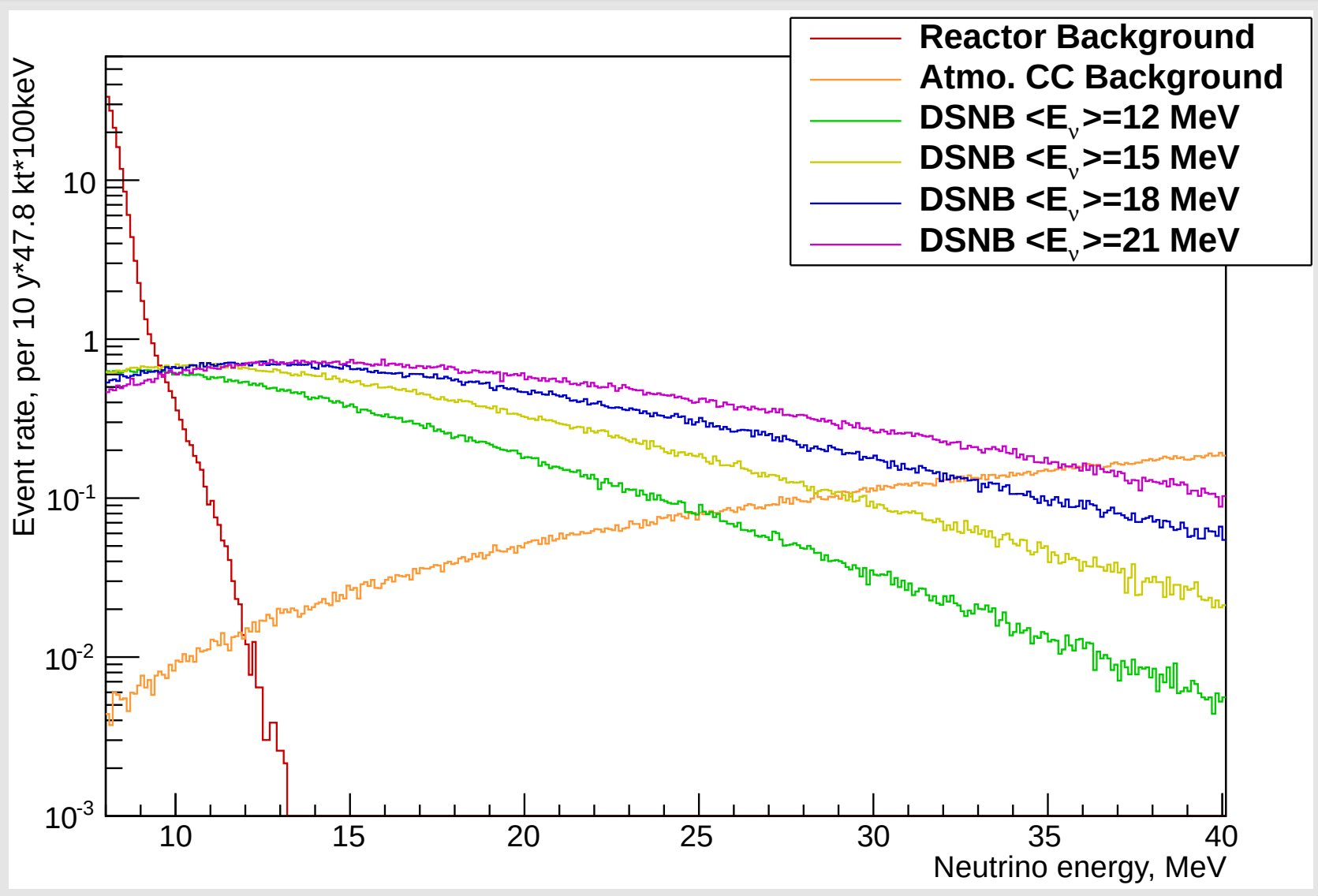
Energy window: 9.5 – 25 MeV

$\langle E_\nu \rangle$	**DSNB Events**
12 MeV	48.2
15 MeV	69.2
18 MeV	85.1
21 MeV	95.1

$+11.3$ Events from Reactor and Atmospheric $\bar{\nu}_e$

Possible detection channel:
$\bar{\nu}_e$ via inverse β-decay

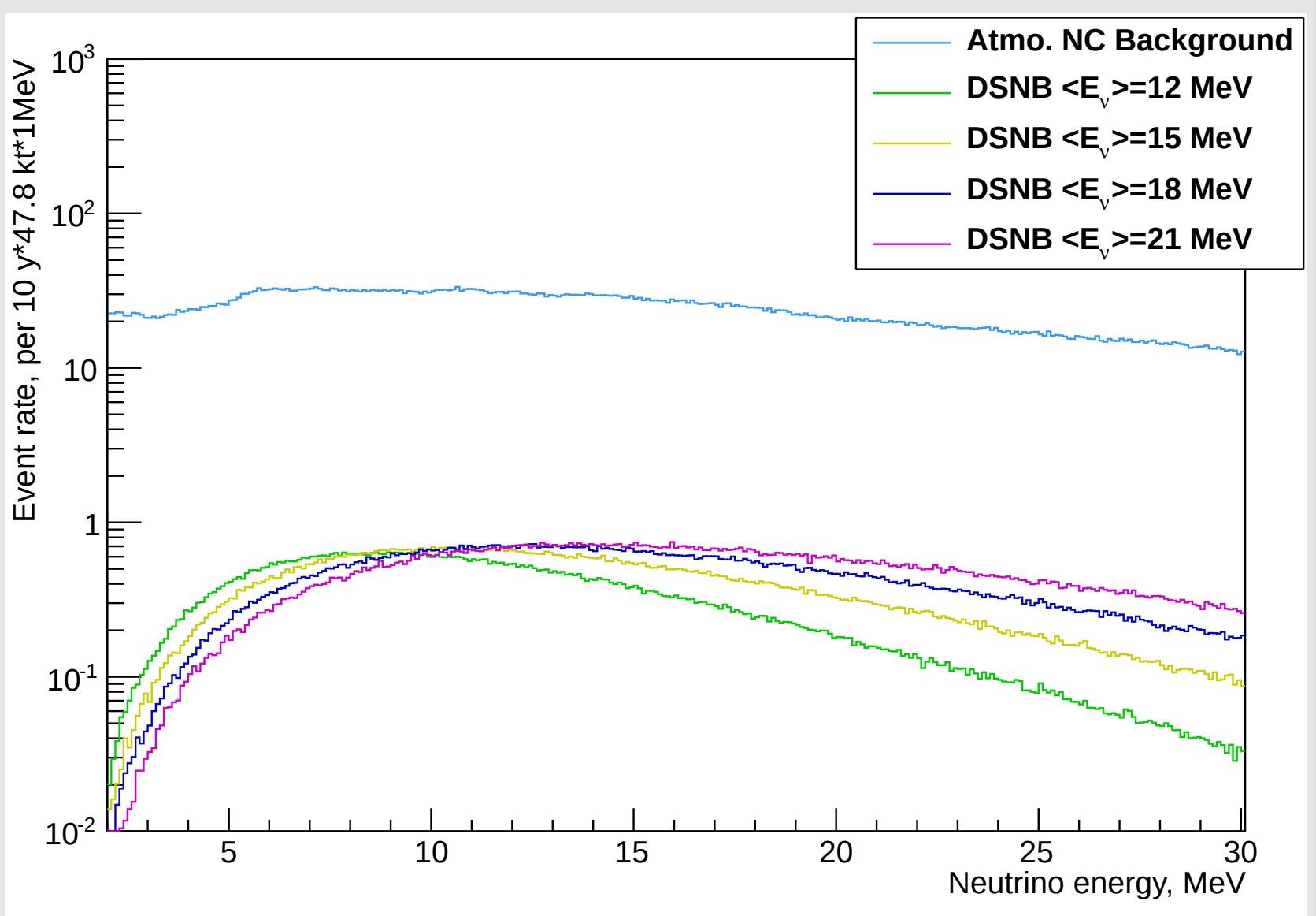
Simulated $\bar{\nu}_e$ spectrum at Pyhäsalmi



The DSNB is the dominant source for $\bar{\nu}_e$ in the energy region between ~ 9.5 and $25\,\mathrm{MeV}$. While there is only a small background from other $\bar{\nu}_e$ sources, neutron scattering reactions can create a prompt signal which is followed by the capture of the neutron mimicking the inverse β-decay (IBD). There are two neutron related background sources in LENA:

Atmospheric NC Background

- Reaction of atmospheric neutrinos with Carbon inherent to the scintillator can mimic the IBD
- Prompt signal from scattering of neutron on protons and carbon
- Delayed signal of neutron capture
- Most dominant process: $\nu_x + {}^{12}\mathrm{C} \rightarrow \nu_x + n + {}^{11}\mathrm{C}$



- Efficient background reduction necessary
- Pulse shape discrimination

Muon Induced Background

Two processes that can mimic IBD:
Excited states of ^{8}He and ^{9}Li produced through spallation

- ^{8}**He** max. visible energy of 7.6 MeV below ROI
- ^{9}**Li** 10^3 events expected in energy window (10 y)
  ⇒ veto 2 m around muon track for 2.5 s reduces background to 0.1 with a loss of 0.2% of signal

Fast neutrons produced in the surrounding rock

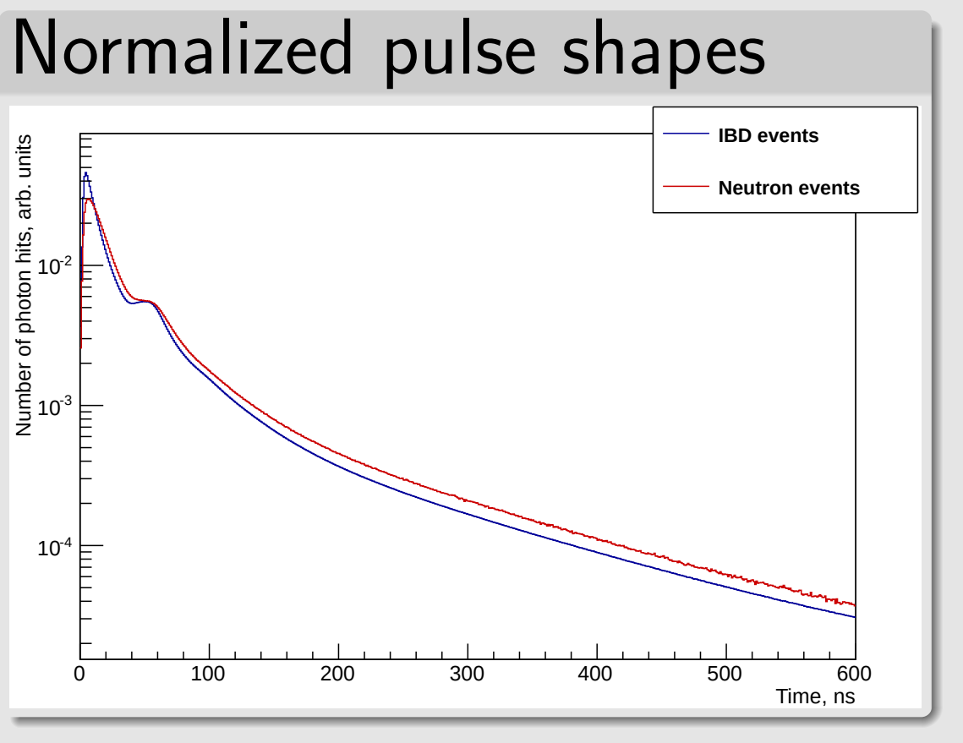
- DSNB signal and fast neutron background after 10 years for $\langle E_\nu \rangle = 12\,\mathrm{MeV}$ for different fiducial volumes:

Radius [m]	**Background**	**Signal**
13.5	492 ± 4	48.2
13.0	169 ± 2	44.7
12.5	62 ± 1	41.3
12.0	26 ± 1	38.1
11.5	11 ± 1	35.0
11.0	4.9 ± 0.4	32.0

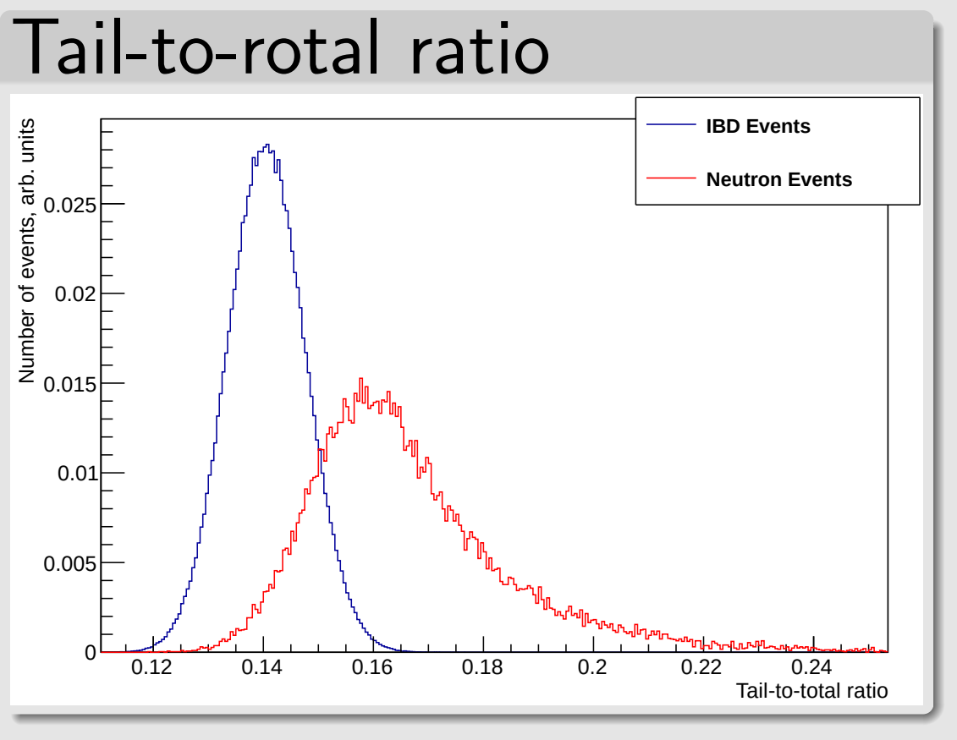
- Fast neutron background can be reduced to 4.9 events years by reducing the fiducial mass to 30 kt.

Pulse shape analysis of neutron versus IBD events

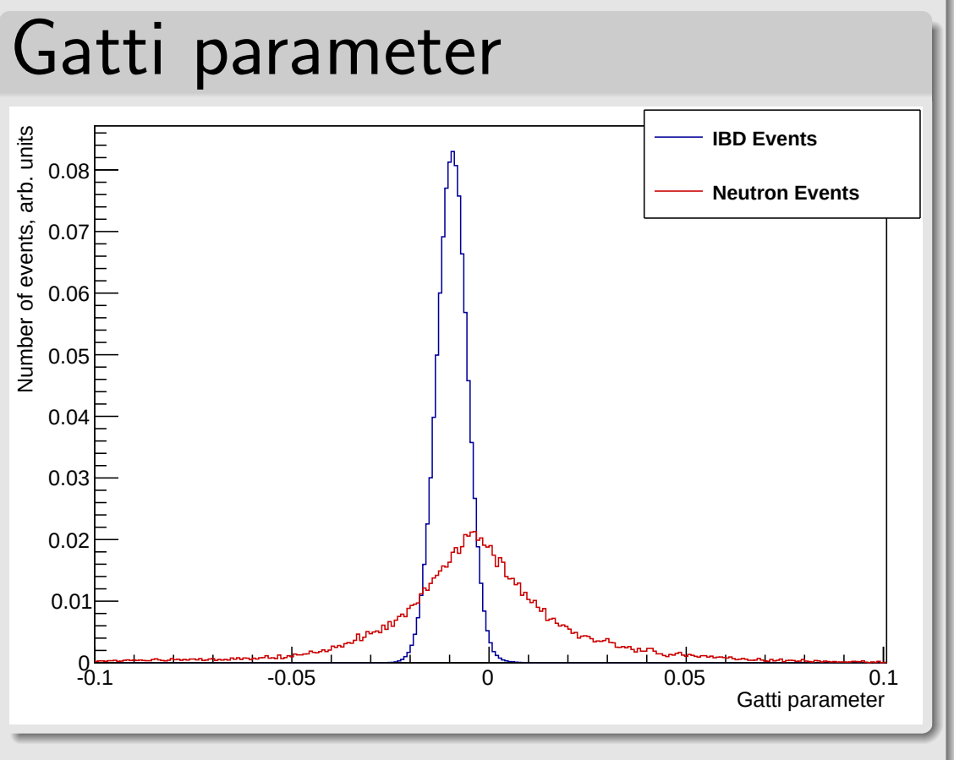
Normalized pulse shapes



Tail-to-rotal ratio



Gatti parameter



Pulse Shape Discrimination Efficiency

Signal/Background for $\langle E_\nu \rangle = 12\,\mathrm{MeV}$ after 10 years

Acceptance	**Atm. NC rate**	**Signal**
95%	1001	42.5
90%	378	40.2
80%	155	35.8
55%	43.5	24.6
50%	34.4	22.4
45%	27.4	20.1
40%	21.8	17.9

- Allows also to increase fast neutron fiducial volume cut to 44.3 kt

Detection Potential

- Application of PSD cut with 40% IBD acceptance
- DSNB Events: 17.9 for $\langle E_\nu \rangle = 12\,\mathrm{MeV}$ to 35.2 for $\langle E_\nu \rangle = 21\,\mathrm{MeV}$

Tot. Background

source	**rate**
reactor ν	2.0
atm. $\bar{\nu}_e$	2.2
^{9}Li	< 0.01
fast n	1.8
atm. NC	21.8
Σ	27.8

Expected detection significance for different background uncertainties

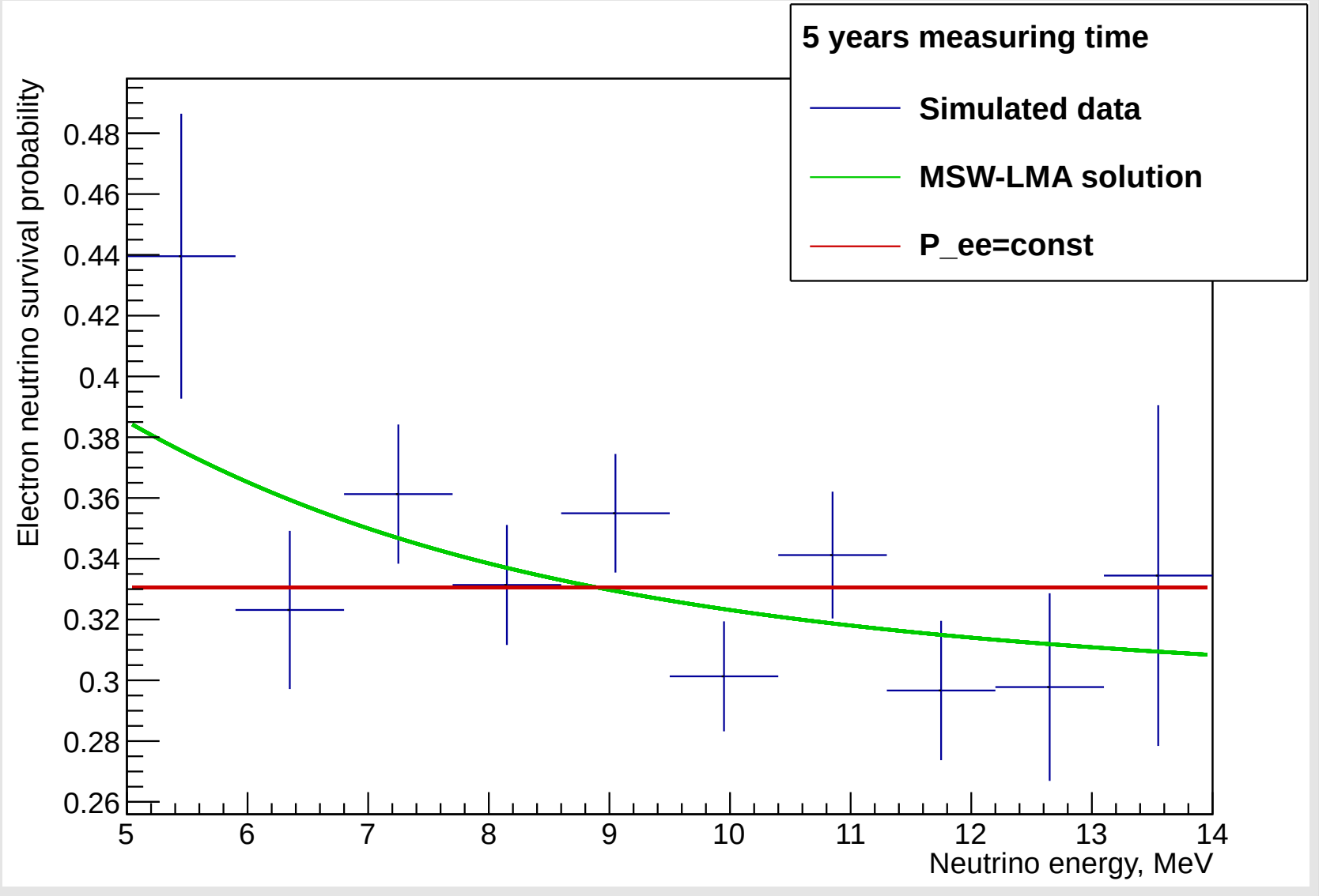
$\langle E_\nu \rangle$	5%	10%	25%
12 MeV	3.0σ	2.7σ	1.9σ
15 MeV	4.0σ	3.7σ	2.6σ
18 MeV	4.9σ	4.4σ	3.1σ
21 MeV	5.4σ	4.9σ	3.5σ

Solar ^{8}B Neutrinos

- 10^5 simulations of five year long measurements
- Independent analyses for ES and ^{13}C Channel
- Followed by combined analysis

^{13}C Channel

Event by event reconstruction of E_ν possible

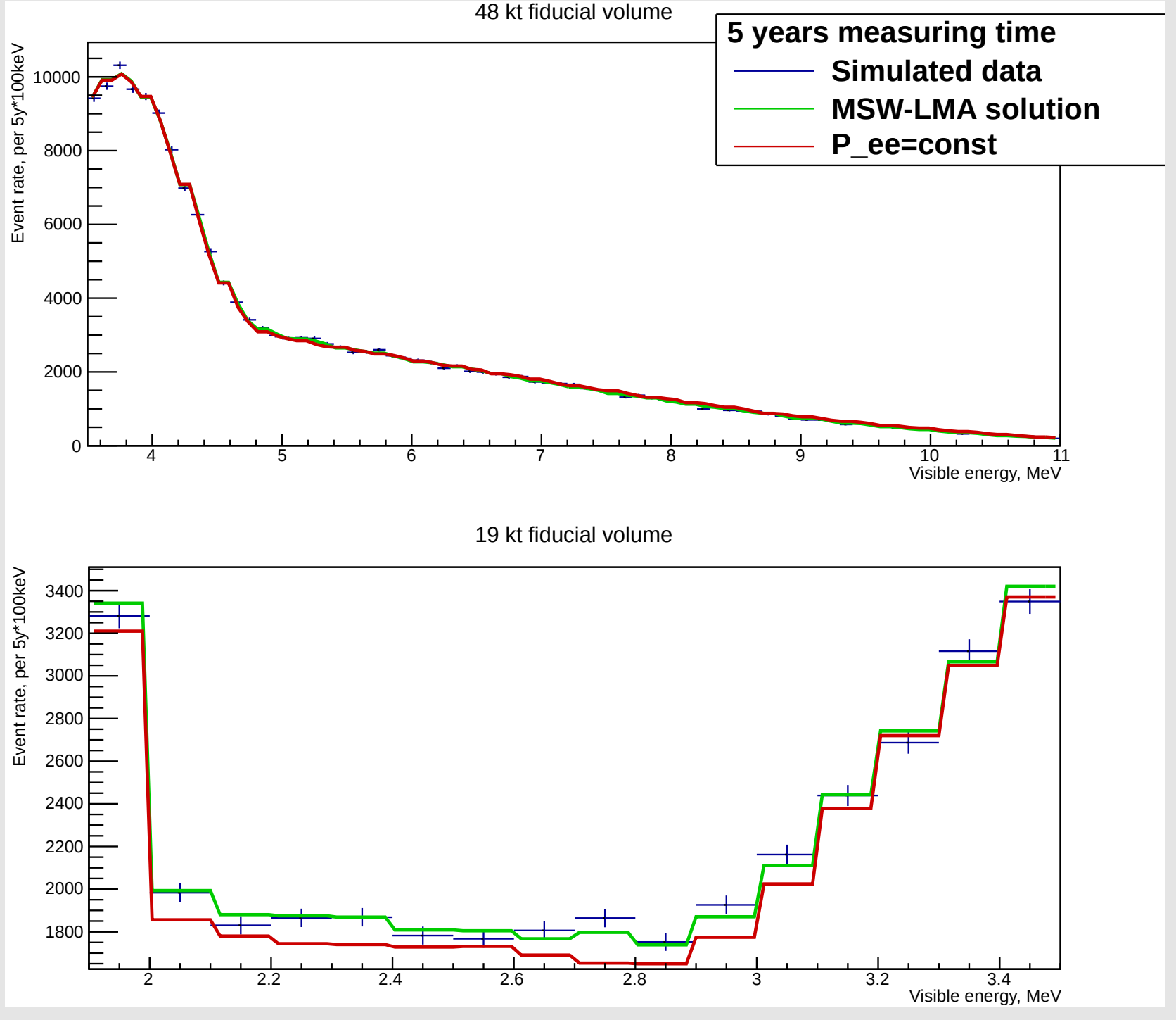


- Upturn of P_{ee} visible but low significance due to low statistics

- Measurement of ^{8}B down to 2 MeV possible
- Allows measurement of the P_{ee} transition region
- Assumed radiopurity as in Borexino
- Measurement still possible with two orders of magnitude lower radiopurity

Elastic Scattering Channel

Event by event reconstruction of E_ν **not** possible



- Different fiducial volumes depending on energy
- Spectral fit

Probabilities for excluding a constant P_{ee} assuming the MSW-LMA prediction

Measuring time	3σ	5σ
1 year	40.5%	2.5%
2 years	94.9%	43.4%
3 years	99.9%	92.5%
4 years	100%	99.8%
5 years	100%	100%

Further Reading

- M. Wurm *et al.* [LENA Collaboration], "The next-generation liquid-scintillator neutrino observatory LENA," Astropart. Phys. **35** (2012) 685 [arXiv:1104.5620 [astro-ph.IM]].
- R. Möllenberg, "Monte Carlo Study of Solar 8B Neutrinos and the Diffuse Supernova Neutrino Background in LENA," PhD Thesis TU Munich (2013).