Neutrino mass hierarchy from the rise time of a SN burst in LENA

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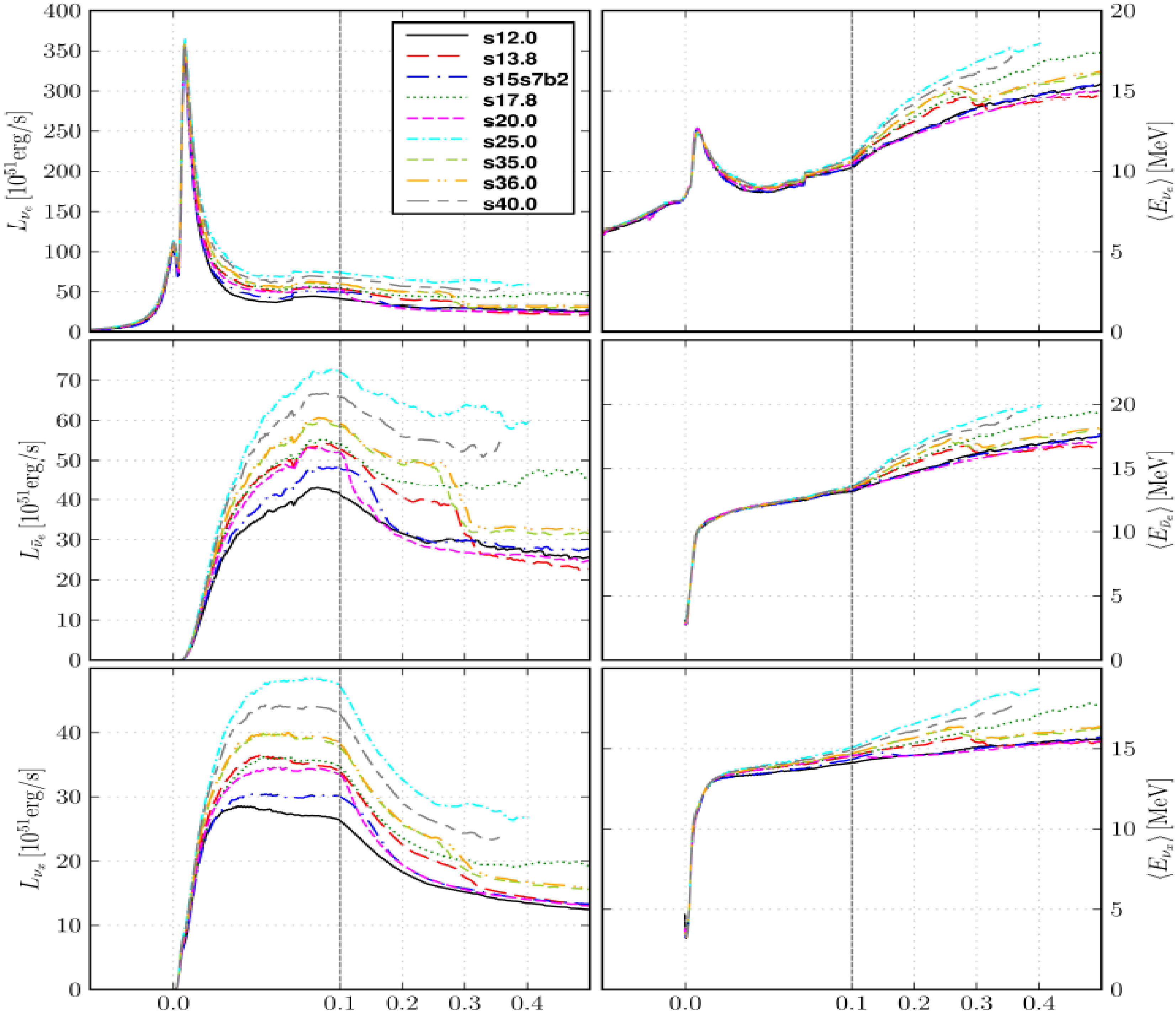
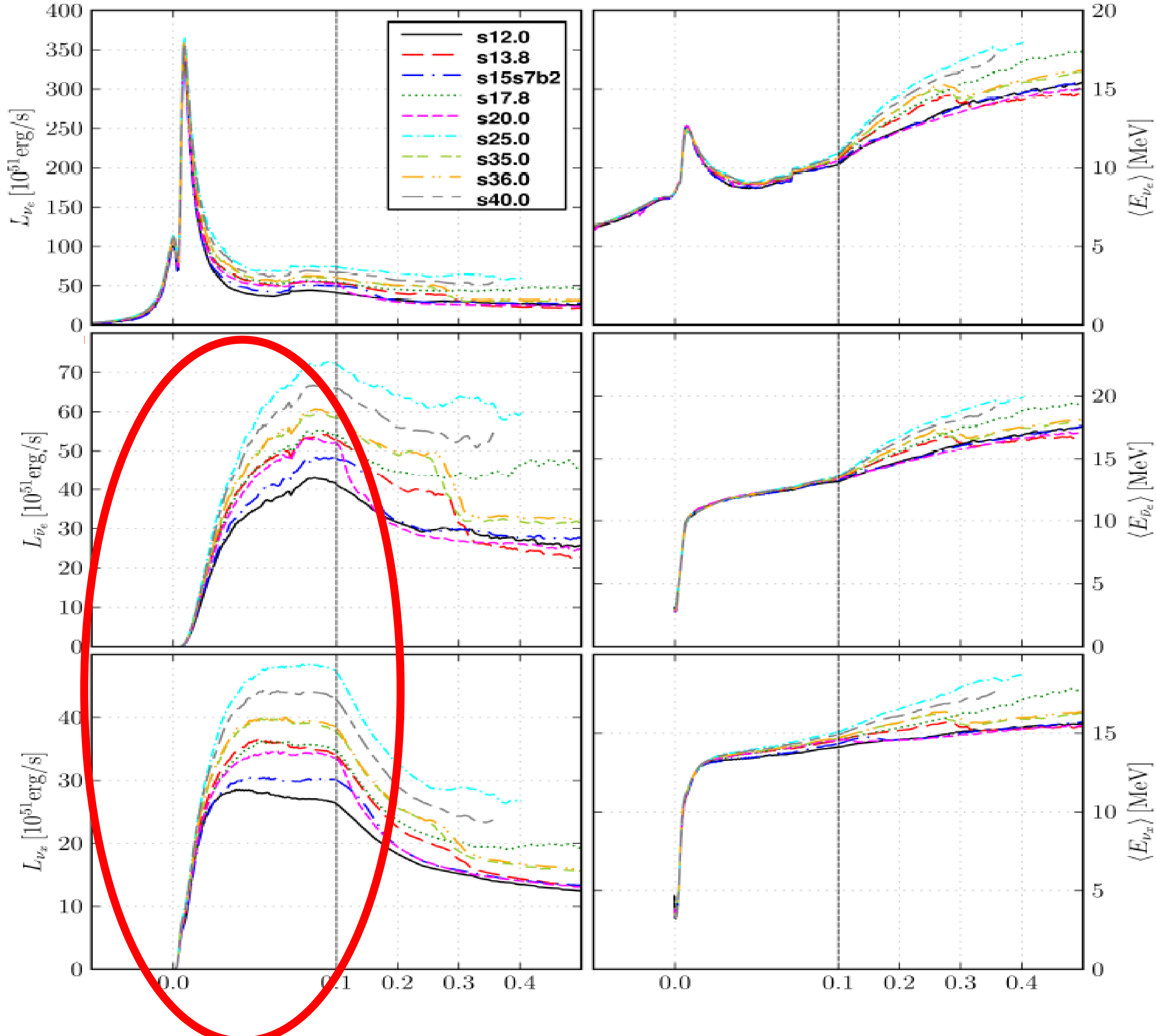
DER FORSCHUNG | DER LEHRE | DER BILDUNG

„Probing the neutrino mass hierarchy with the rise time of a supernova burst“

Serpico et al., arxiv:1111.4483



s12.0
s13.8
s15s7b2
s17.8
s20.0
s25.0
s35.0
s36.0
s40.0
L_{ν_e} [10^{51}erg/s]
$L_{\bar{\nu}_e}$ [10^{51}erg/s]
L_{ν_x} [10^{51}erg/s]
$\langle E_{\nu_e} \rangle$ [MeV]
$\langle E_{\bar{\nu}_e} \rangle$ [MeV]
$\langle E_{\nu_x} \rangle$ [MeV]
0.0
0.1
0.2
0.3
0.4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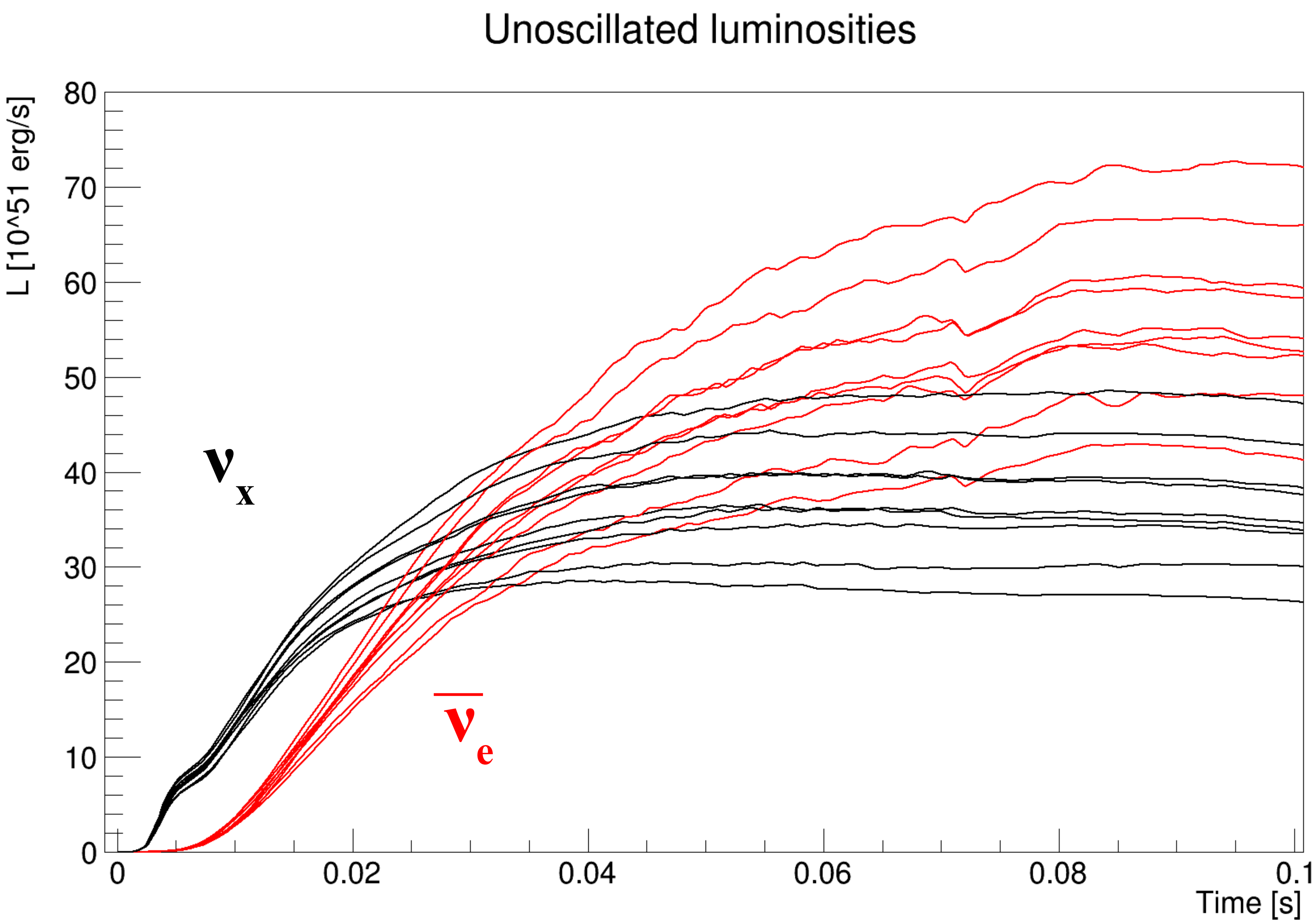
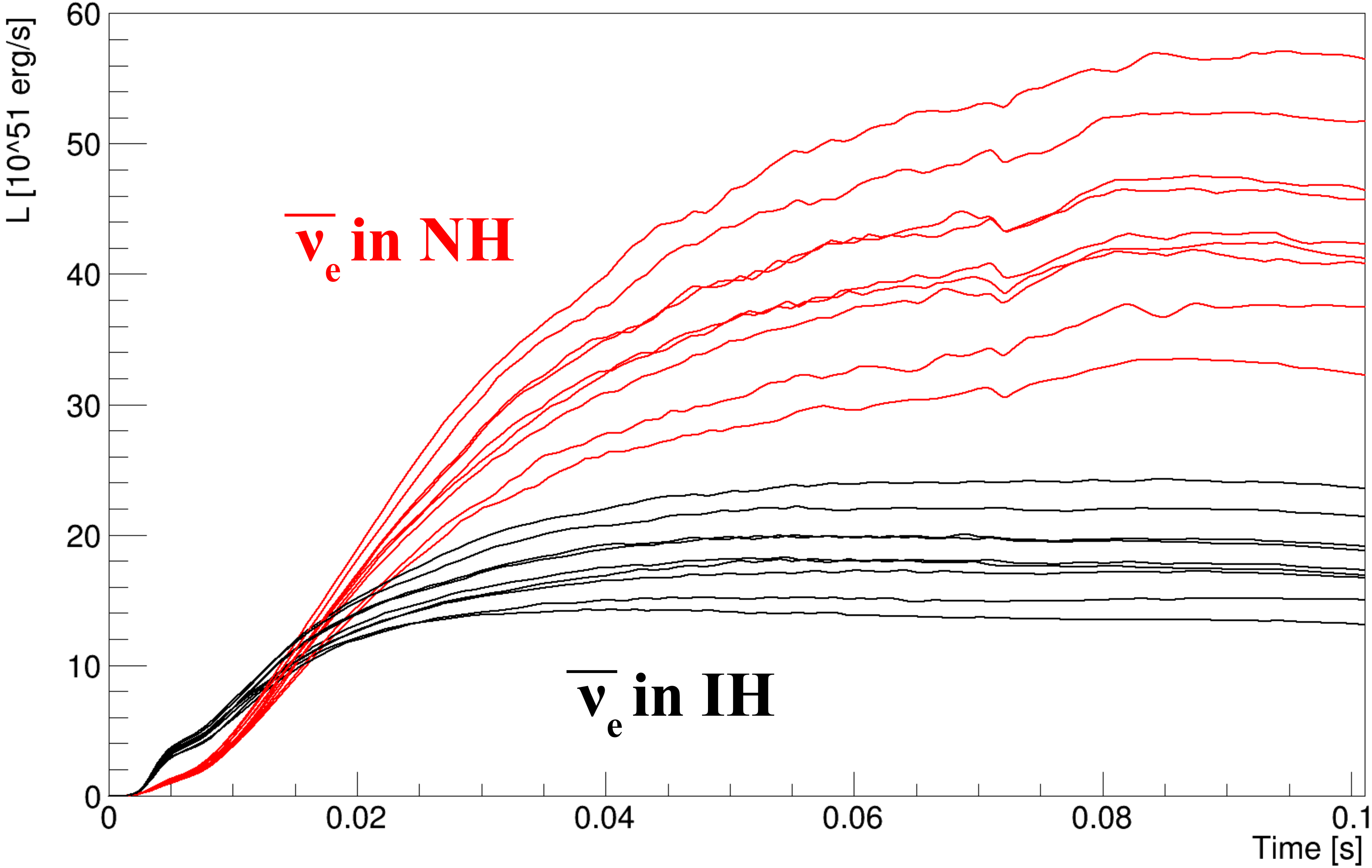


Unoscillated luminosities
L [10^51 erg/s]
80
70
60
50
40
30
20
10
0
0
0.02
0.04
0.06
0.08
0.1
Time [s]
ν_x
$\bar{\nu}_e$

Neutrino flavor conversions

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

Oscillated luminosities

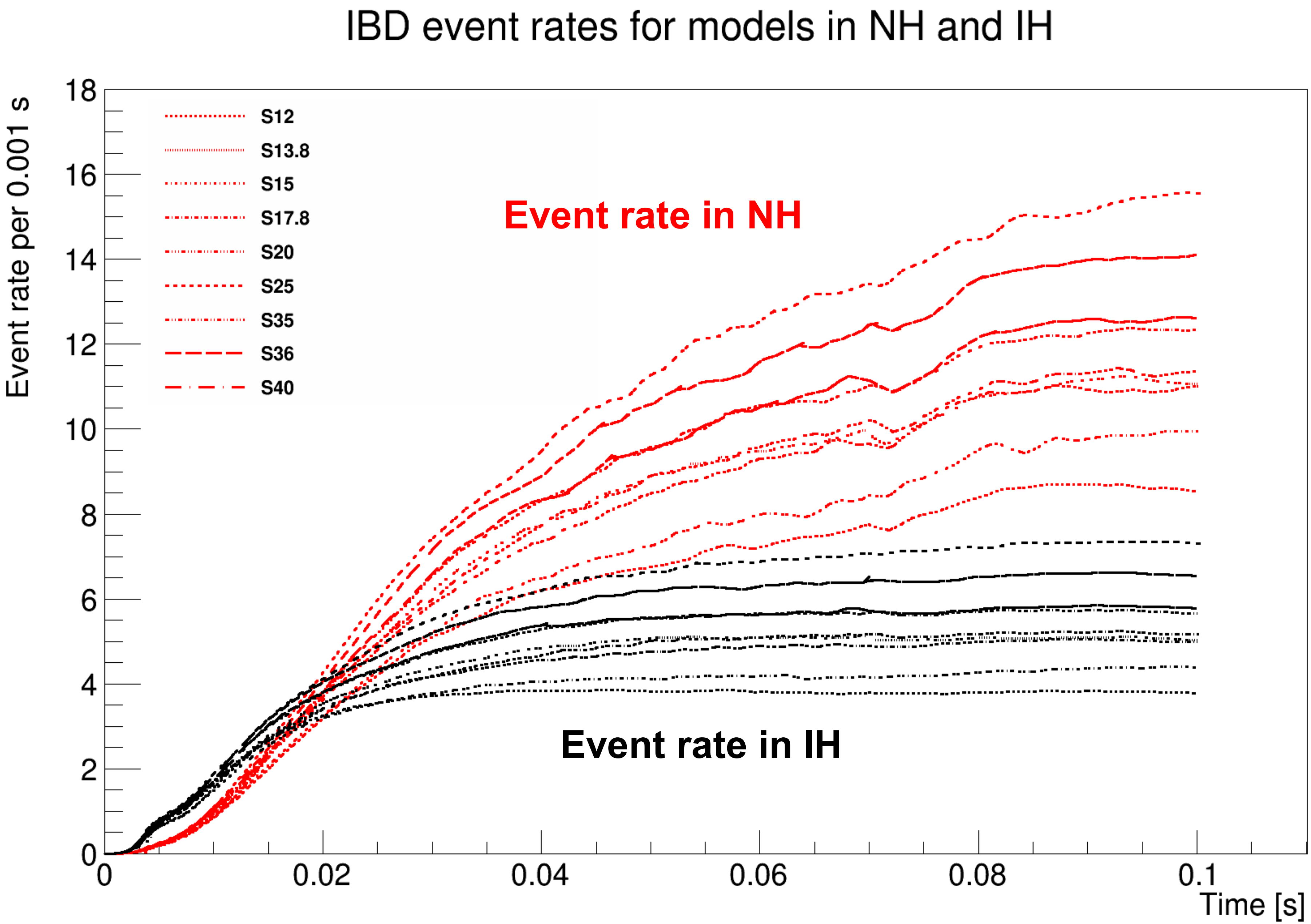


Inverse beta decay (IBD)

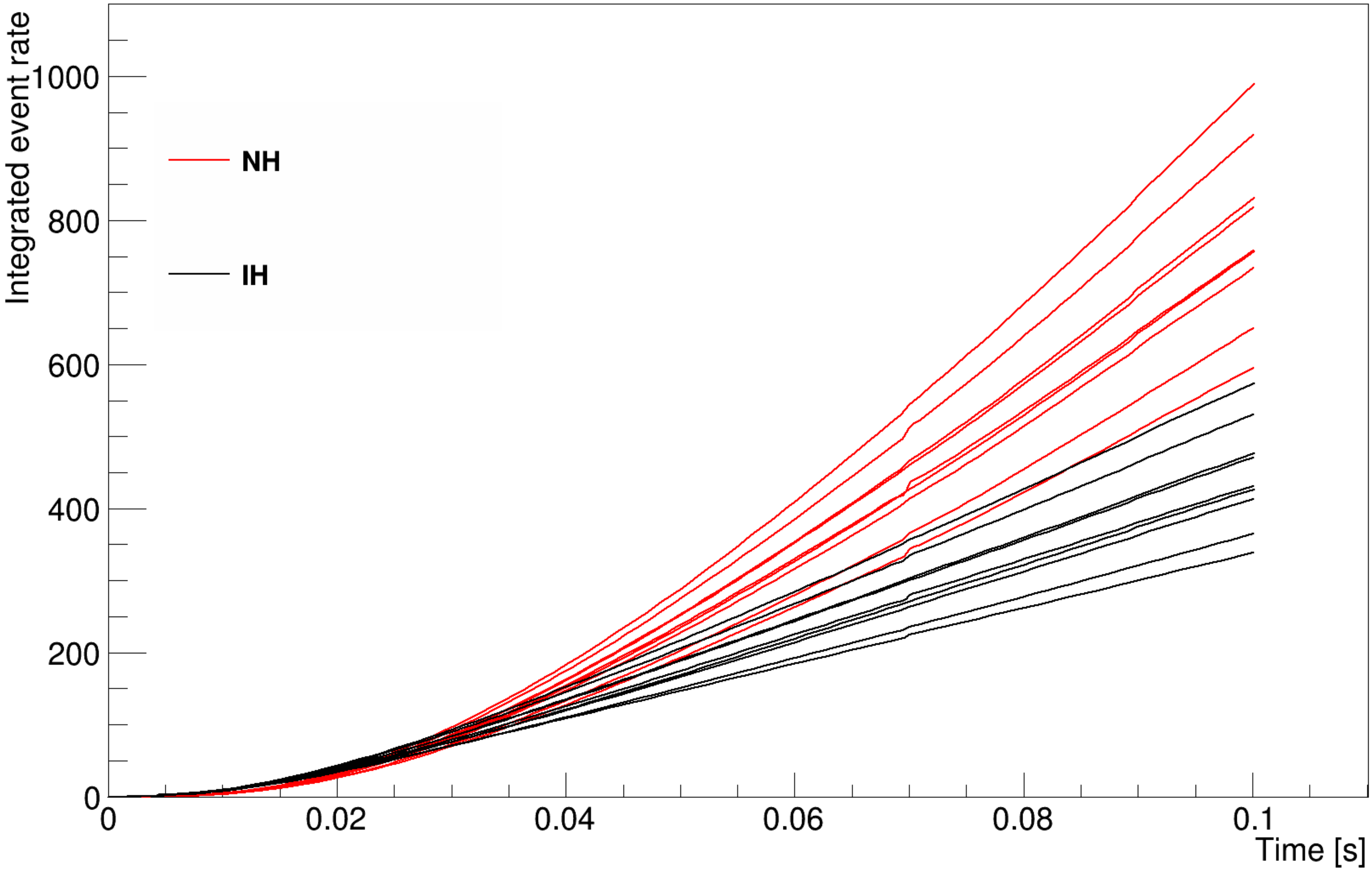
- $\bar{\nu}_e + \mathrm{p} \rightarrow \mathrm{n} + e^+$
- “Golden” detection channel in LENA
- Low energy threshold (1.8 MeV)
- High statistic
- Very good discrimination efficiency against other detection channels (>99%)

Calculate IBD event rate in LENA

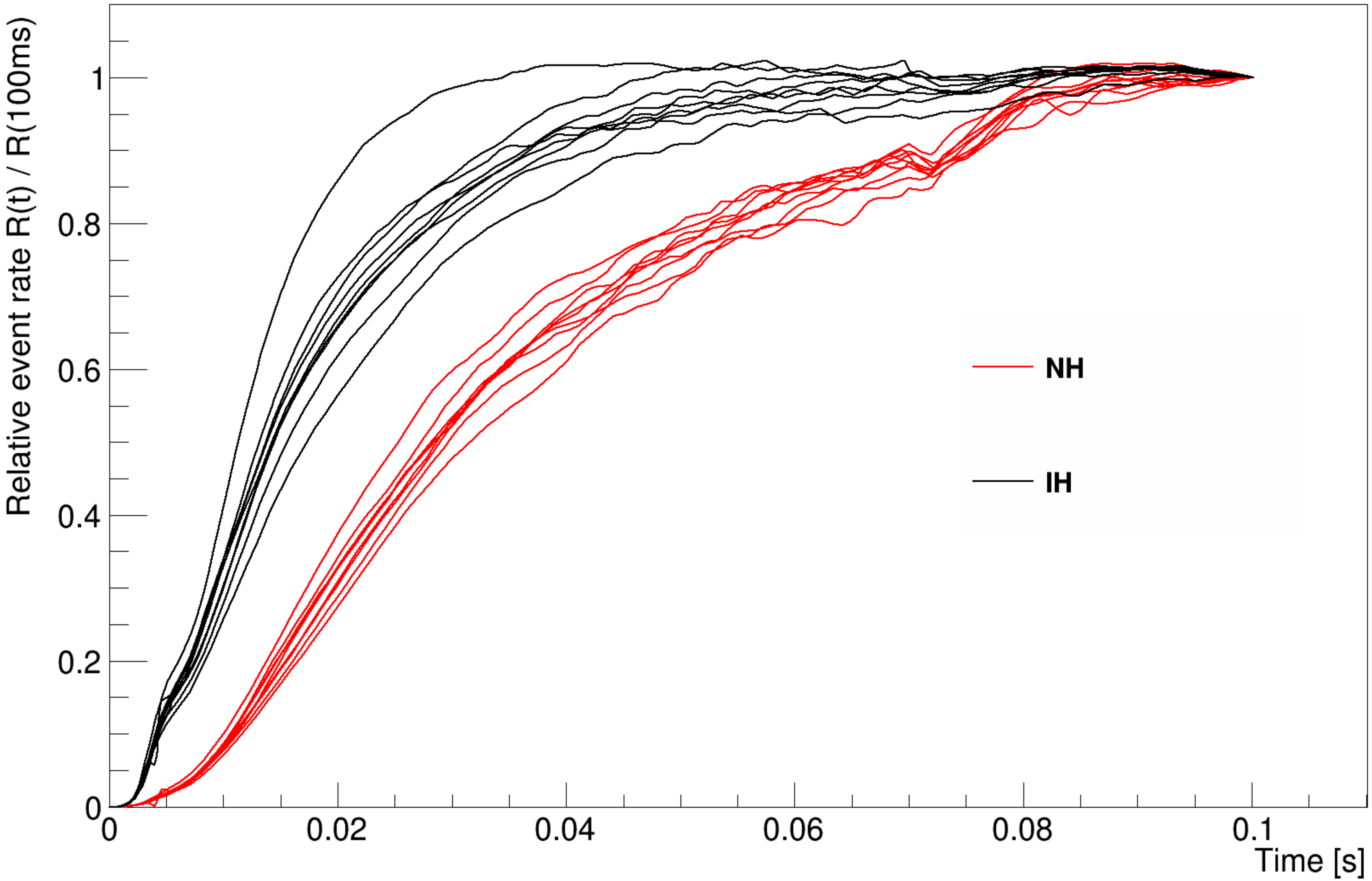
- Event rate depends on: (oscillated) $\overline{\nu}_e$ flux at Earth, IBD cross-section, number of protons in LENA
- Assumed 10 kpc distance of SN
- Assumed 50 kt of LAB as target
- $$N_{Events} = \int_{E_{thr}} dE\ F(E)\ \sigma(E)\ N_p$$


IBD event rates for models in NH and IH
Event rate per 0.001 s
Time [s]
S12
S13.8
S15
S17.8
S20
S25
S35
S36
S40
Event rate in NH
Event rate in IH
0
2
4
6
8
10
12
14
16
18
0.02
0.04
0.06
0.08
0.1

Integrated IBD event rates for models in NH and IH



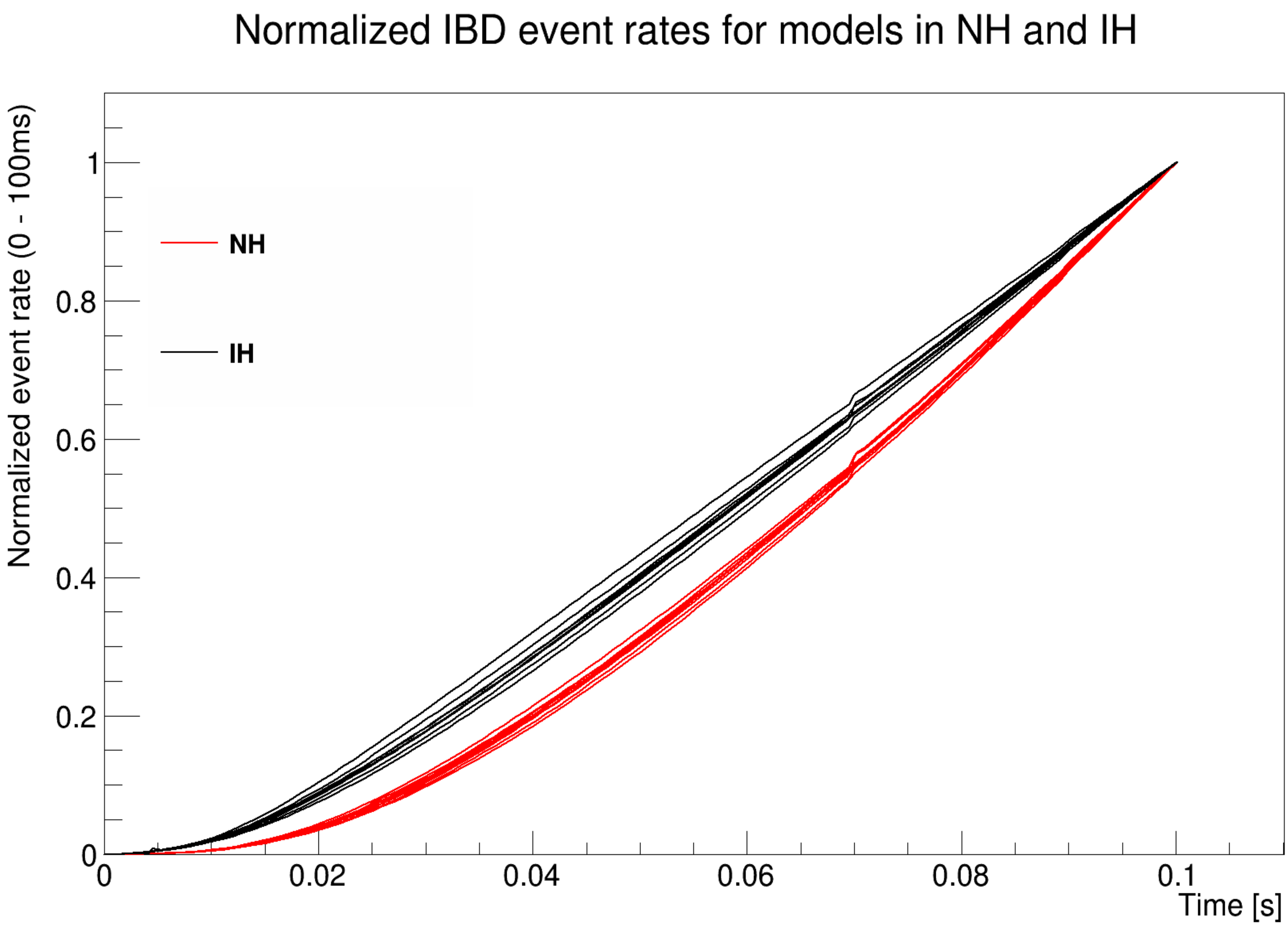
Relative IBD event rates for models in NH and IH



Normalized Event Rate

- $$K(x) = \frac{\int_0^{x \cdot t_{end}} dt R(t)}{\int_0^{t_{end}} dt R(t)}$$

- With K(0) = 0, K(1) = 1, x ∈ [0,1]



Normalized IBD event rates for models in NH and IH
Normalized event rate (0 - 100ms)
Time [s]
NH
IH
0
0.2
0.4
0.6
0.8
1
0
0.02
0.04
0.06
0.08
0.1

Normalized event rate after ~46ms

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 (8.5%)	36.1 ± 3.5 (9.7%)

Metric in function space

- $\mathcal{D}_\infty(K_i^A, K_j^B) = \max_{x \in [0;1]} \left| K_i^A(x) - K_j^B(x) \right|$
- A, B = NH, IH   i, j = different Models

Distances of the models

$$\langle d\rangle(K_i^A, B) = \frac{1}{N}\sum_{j=1}^{N} \mathcal{D}_\infty(K_i^A, K_j^B) \quad (B \neq A),$$

$$\langle d\rangle(K_i^A, A) = \frac{1}{N-1}\sum_{j\neq i} \mathcal{D}_\infty(K_i^A, K_j^A),$$

$$d_{\min}(K_i^A, B) = \min_j \mathcal{D}_\infty(K_i^A, K_j^B) \quad (B \neq A),$$

$$d_{\min}(K_i^A, A) = \min_{j\neq i} \mathcal{D}_\infty(K_i^A, K_j^A),$$

Parameters

- Average distance:

$$\langle\Delta\rangle(K_i^A) \;\equiv\; \langle d\rangle(K_i^A\,, B) - \langle d\rangle(K_i^A\,, A)$$

- Minimal distance:

$$\Delta_{\min}(K_i^A) \;\equiv\; d_{\min}(K_i^A\,, B) - d_{\min}(K_i^A\,, A)$$

Distance between models

NH Model	Average distance	Minimal distance
s12	0.041	0.021
s13.8	0.089	0.07
s15	0.083	0.062
s17.8	0.088	0.07
s20	0.076	0.055
s25	0.090	0.071
s35	0.083	0.063
s36	0.082	0.061
s40	0.086	0.063
	0.079	0.06

Distance between models

IH Model	Average distance	Minimal distance
s12	0.088	0.078
s13.8	0.067	0.056
s15	0.084	0.074
s17.8	0.061	0.052
s20	0.082	0.070
s25	0.031	0.024
s35	0.078	0.067
s36	0.080	0.068
s40	0.072	0.059
	0.071	0.061

Outlook

- Optimize parameters?
- Use proton channel for normalization(?)
- Use more models (http://www.stellarcollapse.org/)

Thank you for your attention

SN Detection Channels in LENA

Channel	Type	Reaction	Subsequent Reaction	E_{thr} [MeV]
IBD	CC	$\bar{\nu}_e + p \rightarrow n + e^+$	$n + p \rightarrow d + \gamma$	1.8
$\bar{\nu}_e$ - ^{12}C	CC	$\bar{\nu}_e + {}^{12}C \rightarrow e^+ + {}^{12}B$	${}^{12}B \rightarrow {}^{12}C + e^- + \bar{\nu}_e$	14.4
ν_e - ^{12}C	CC	$\nu_e + {}^{12}C \rightarrow e^- + {}^{12}N$	${}^{12}N \rightarrow {}^{12}C + e^+ + \nu_e$	17.3
NC - ^{12}C	NC	$\nu + {}^{12}C \rightarrow \nu + {}^{12}C^*$	${}^{12}C^* \rightarrow {}^{12}C + \gamma$	15.1
ν - e	NC	$\nu + e^- \rightarrow \nu + e^-$	-	(0.2)
ν - p	NC	$\nu + p \rightarrow \nu + p$	-	(0.2)

Number of Events

- 50 kT of LAB, 10 kpc, GVKM flux

Channel	Type	Number of Events
IBD	CC	9250
ν-p	NC	4179
NC-^{12}C	NC	1296
ν-e	NC	496
ν_e-^{12}C	CC	468
$\bar{\nu}_e$-^{12}C	CC	459
Total number of events:		**16148**

Channel Discrimination Results

Tagging efficiency: correctly identified / true number of events

Over efficiency: falsely identified / correctly identified

Channel	Type	Tagging efficiency	Over efficiency
IBD	CC	>99.9%	<0.1%
CC-^{12}C	CC	99%	1%
NC total:		99%	1%
NC-^{12}C	NC	>99%	2%
ν-p	NC	98%	3%
ν-e	NC	~67%	~9%

Distinction between CC-^{12}C channels: error of about 7%