Supernova Neutrinos in IceCube - an Appetizer

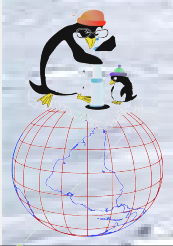
JIGSAW 2010, Mumbai

-

Thomas Kowarik

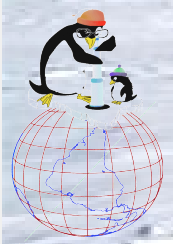
IceCube

JOHANNES GUTENBERG UNIVERSITÄT MAINZ



Outline

- Supernova Simulation Framework USSR
- Models and their Signatures
- Oscillation Scenarios in IceCube

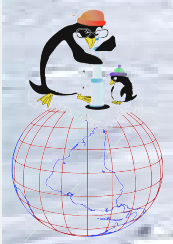


Unified Supernova Simulation Routine
USSR

Framework to simulate supernova signals in IceCube-like detectors

Functionality:

- Reads in neutrino luminosities and spectra
  - ➔ new models are easy to implement
  - ➔ can use every time binning
  - ➔ energy binning adjustable (default=0.1MeV)
  - ➔ input spectra described by functions (so far)



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  - ➔ vaccuum mixing, MSW resonances, earth matter
  - ➔ simple sn shockwaves, simplified collective mode

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  - → inverse beta decay, electron scattering, oxygen interactions

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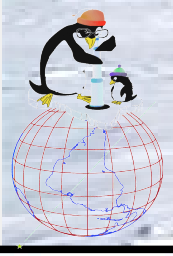
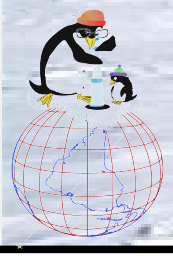
- Applies oscillation scenarios
  - → vaccuum mixing, MSW resonances, earth matter
  - → simple sn shockwaves, simplified collective mode
- Estimates interaction probability in the ice
  - → inverse beta decay, electron scattering, oxygen interactions
- Derives the signal
  - → input: effective volume
  - → rescale with distance, number of DOMs, . . .



USSR
Included Supernova Models

- Lawrence-Livermore-model (the classic) - *Astrophys.J. 496 (1998) 216-225*
  (20 solar masses; only approximate spectral information; up to 15s after bounce)
- Garching 8.8 solar masses ONeMg core - *Astron. Astrophys. 450 (2006) 345*
  (precise spectral information; LS and WH; short timescale)
- Garching 8.8 solar masses ONeMg core – *arXiv:0912.0260 (thanks to H.-Th. Janka)*
  (precise spectral information; up to 9/25s; different neutrino opacities)
- Garching 15 solar masses SASI - *A&A 496, 475-494 (2009)*
  (information not precise; no spectral info; LS and WH; 1D, integrated, north; short)
- 10 solar masses QCD and hadronic EoS - *Phys. Rev. Lett. 102, 081101 (2009)*
  (no spectral information; short)
- 40 solar masses direct black hole - *ApJ 667 382-394 (2007)*
  (full length; LS and Shen EoS; rare)
- Supernova type Ia - *AIP Conf. Proc. Vol. 847, pp. 406-408*
  (weak neutrino signal)

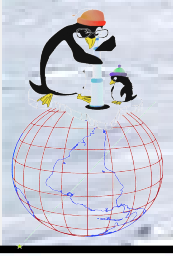


USSR
Interaction Channels

Inverse beta-decay (~93%):

$$\sigma(E_{\nu_e}, E_e) = |\vec{p}_e| \, E_e \, E_{\nu_e}^{-0.07056 + 0.02018 \ln E_{\nu_e} - 0.001953 \ln^3 E_{\nu_e}} \times 10^{-47} \, \mathrm{m}^2$$

Phys. Lett. B564, pp. 42-54 (2003)



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Electron scattering (~3.5%):

$$\frac{d\sigma}{dy}(E_\nu, E_e) = \frac{2 G_\mathrm{F} m_e E_\nu}{\pi} \left(\varepsilon_\mp^2 + \varepsilon_\pm^2 (1-y)^2 - \varepsilon_+ \varepsilon_- \frac{m_e}{E_\nu} y \right)$$

J. Phys. G: Nucl. Part. Phys. 29 2629 (2003)

USSR
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J. Phys. G: Nucl. Part. Phys. 29 2629 (2003)

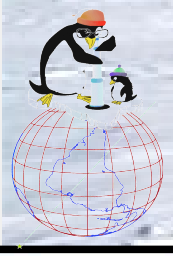
Oxygen Interactions (~3.5%):

$$\sigma_{\nu_e, {}^{16}\mathrm{O}}(E_{\nu_e}) = 1.3 \times 10^{-47} (E_{\nu_e} - 15.4\,\mathrm{MeV})^{\frac{3}{2}}\ \mathrm{m}^2$$

$$\sigma_{\nu_e, {}^{18}\mathrm{O}}(E_{\nu_e}) = 2.0 \times 10^{-49} (E_{\nu_e} - 1.66\,\mathrm{MeV})^{\frac{3}{2}}\ \mathrm{m}^2$$

$$\sigma_{\bar{\nu}_e, {}^{16}\mathrm{O}}(E_{\bar{\nu}_e}) = 1.1 \times 10^{-47} (E_{\nu_e} - 11.4\,\mathrm{MeV})^{\frac{3}{2}}\ \mathrm{m}^2$$

Phys. Rev. D36, 2283 (1987)

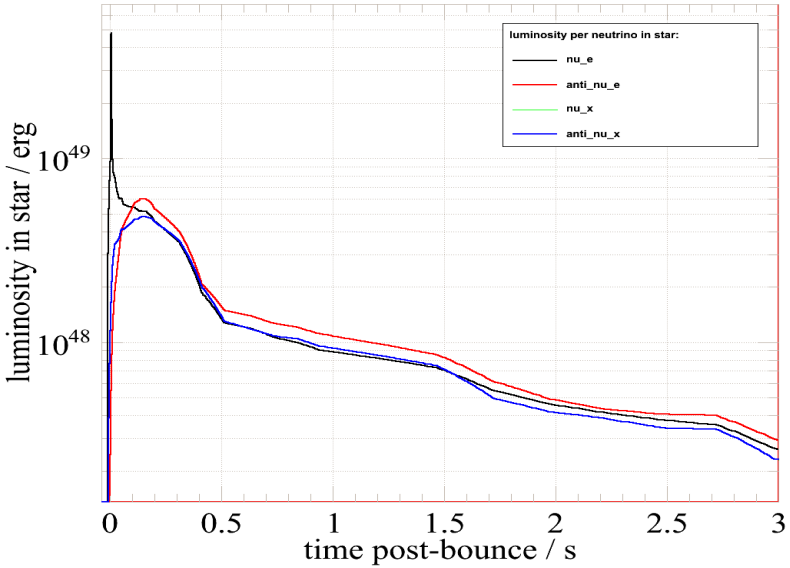


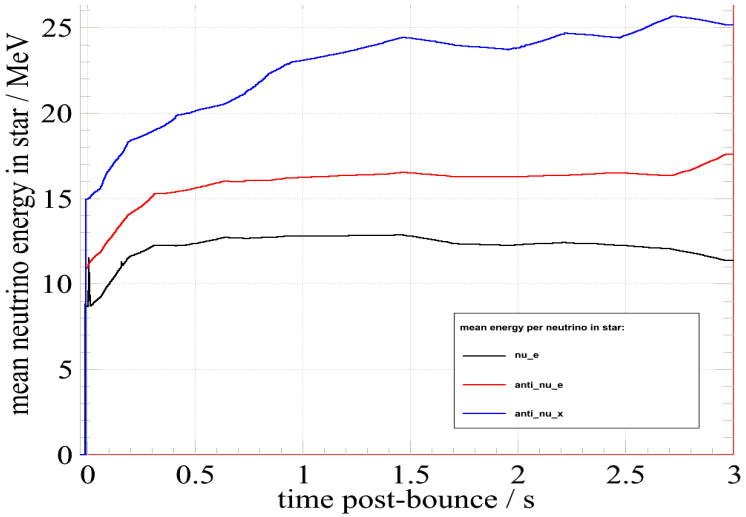
Model Signatures

Models to investigate:

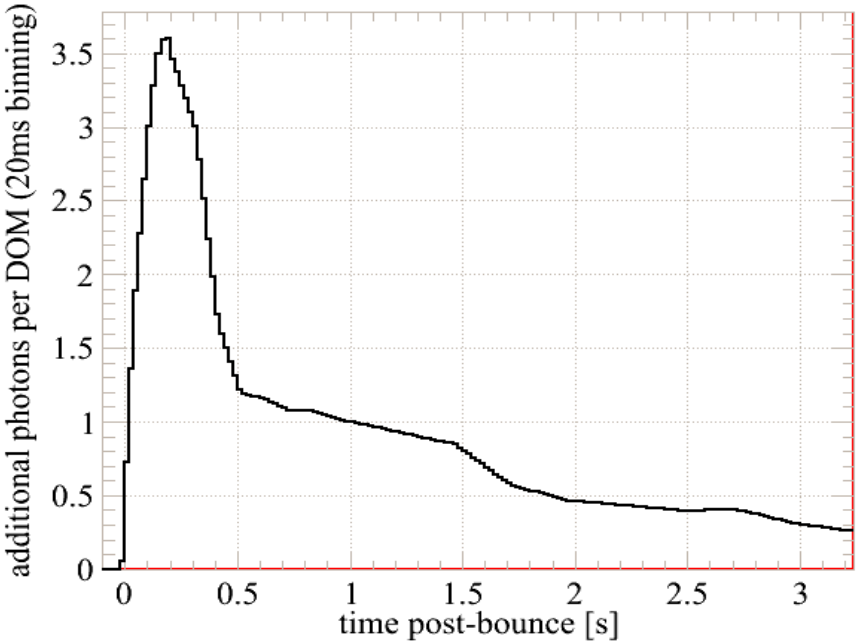
- Lawrence-Livermore
- Garching 8.8 solar masses ONeMg core
- Garching 15 solar masses SASI
- 40 solar masses direct black hole

Model Signatures
Lawrence-Livermore



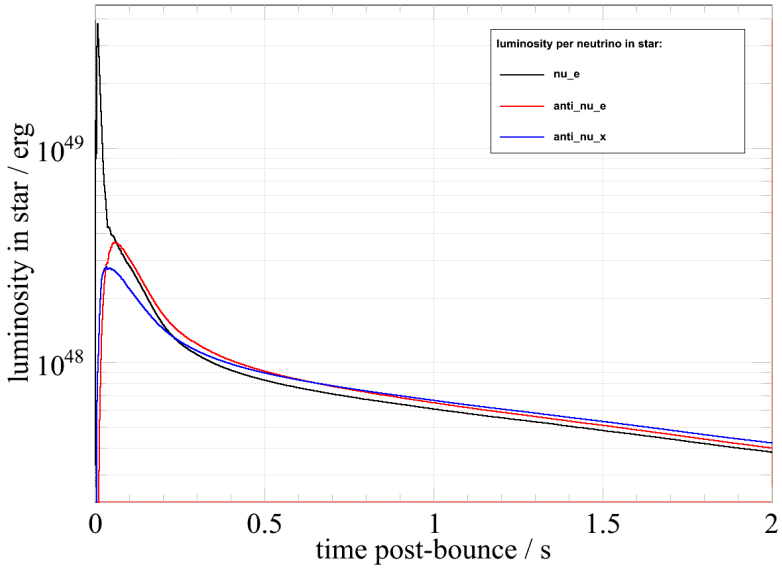


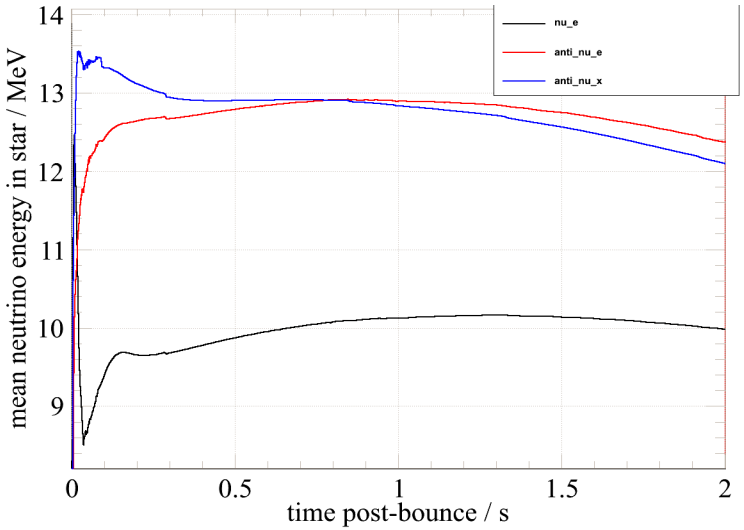
until recently, the only longterm simulation



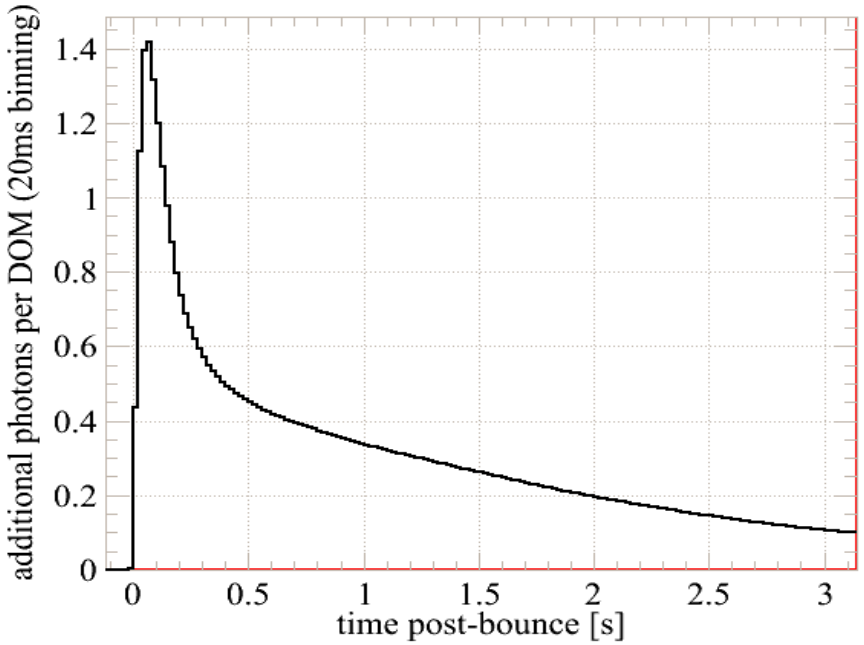
no MSW
no collective
10 kpc

Model Signatures
Garching ONeMg – long simulation



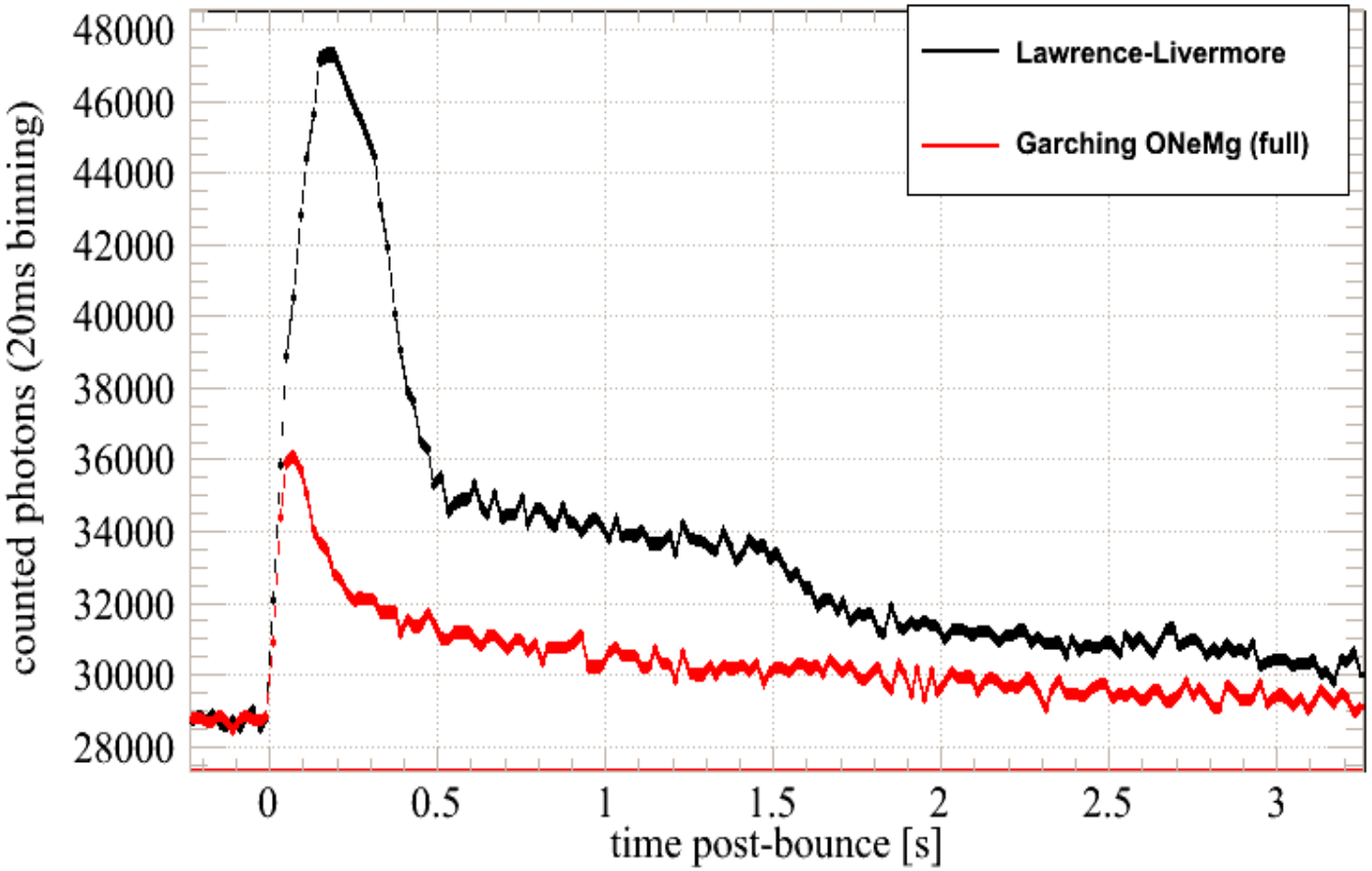


ONeMg simulation with full neutrino opacities



no MSW
no collective
10 kpc

Model Signatures
Lawrence-Livermore vs. Garching ONeMg



Photons counted in 3s:

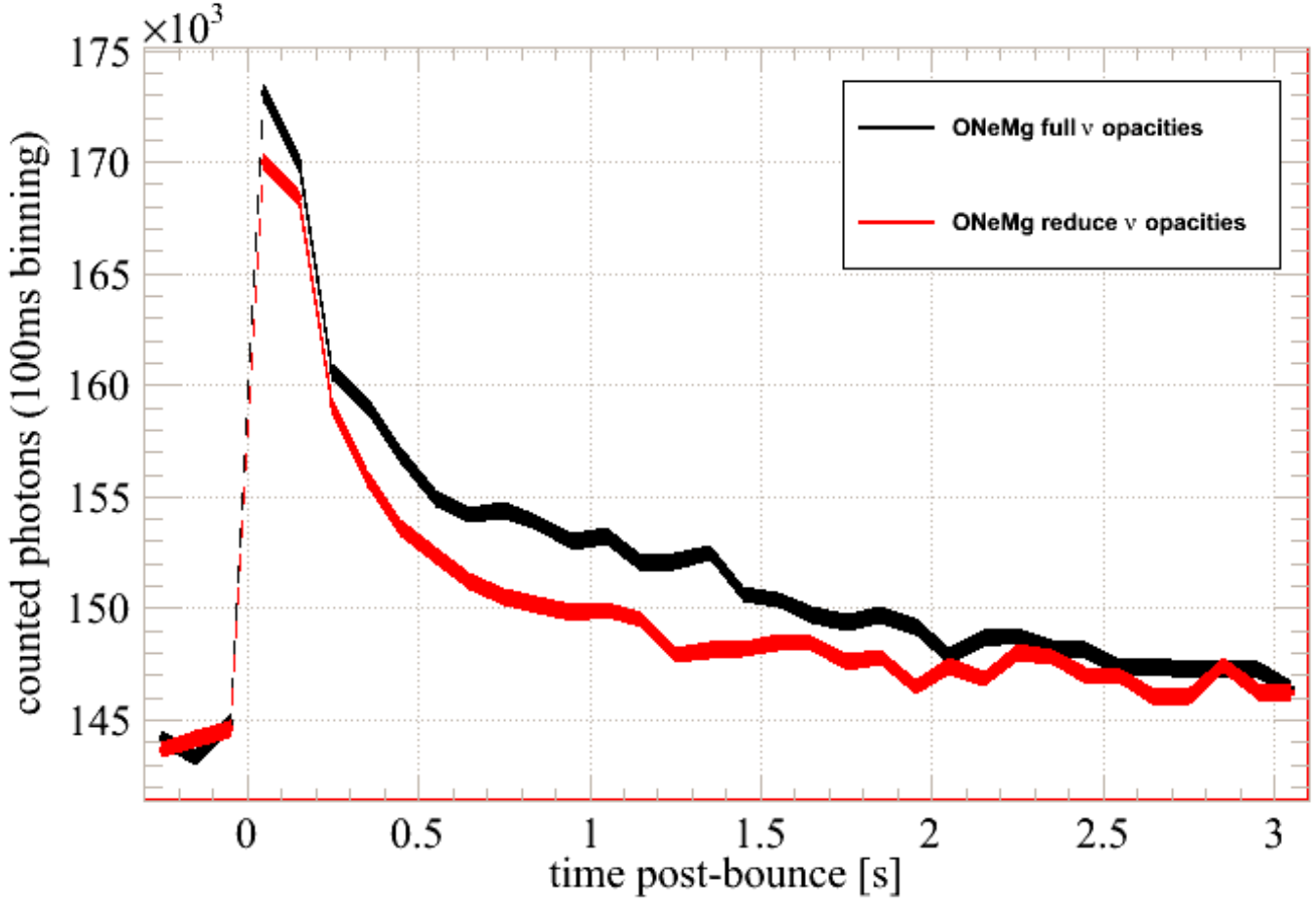
Law.-Liv.: ~6.5 x 10^5

ONeMg (full): ~2.5 x 10^5

no MSW
no collective
10 kpc

Model Signatures

Garching ONeMg – Full vs. Reduced ν Opacities



Photons counted in 3s:

ONeMg (full): ~2.5 x 10^5

ONeMg (reduced): ~1.6 x 10^6

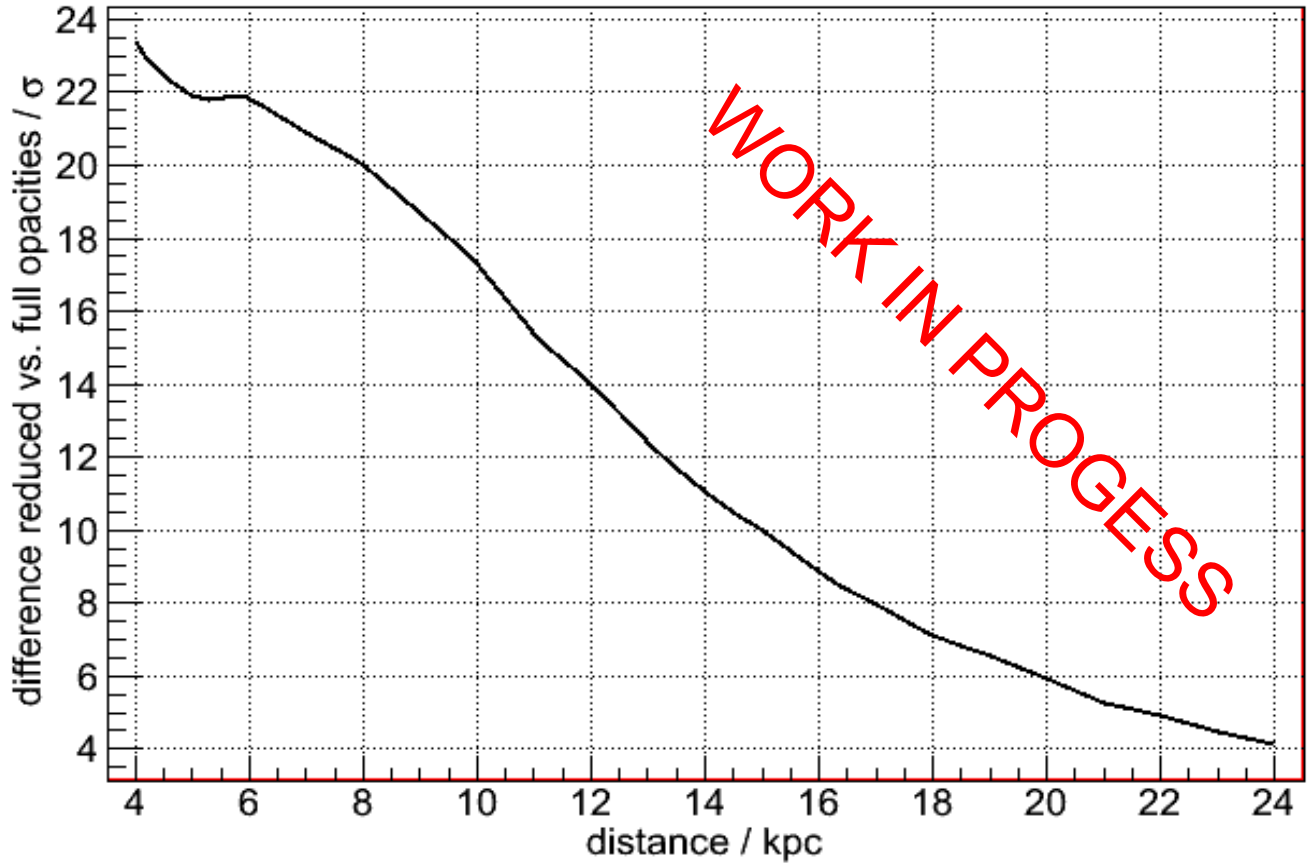
no MSW
no collective
10 kpc

Model Signatures

Garching ONeMg – Full vs. Reduced ν Opacities

Use likelihood method to estimate separability

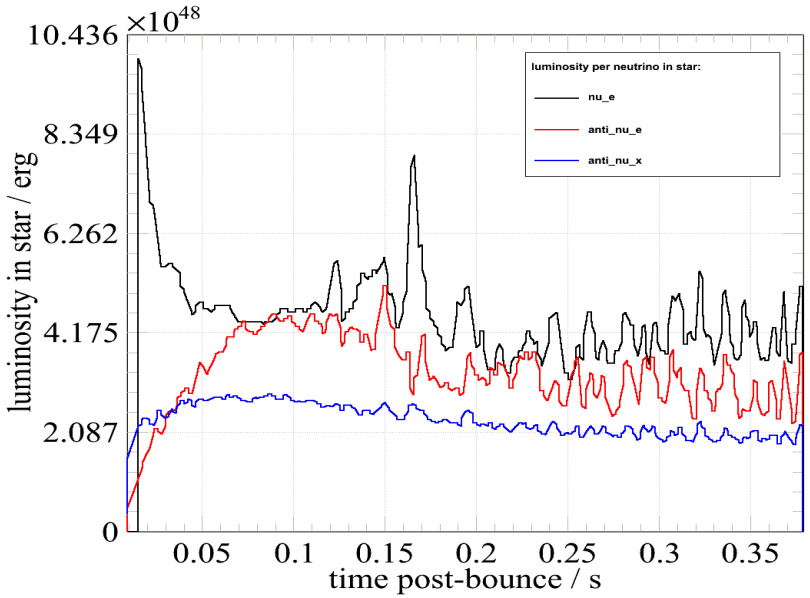
– *(A Hitchhikers Guide through the IceCube Detector by T. Griesel)*

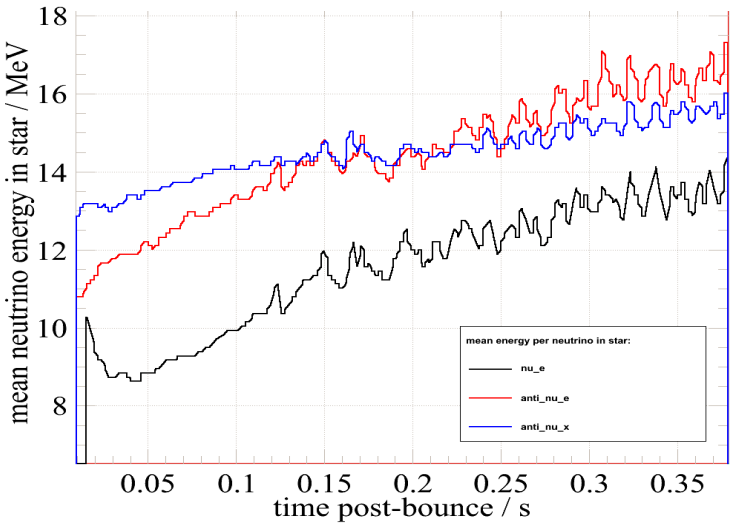


no MSW
no collective

Model Signatures

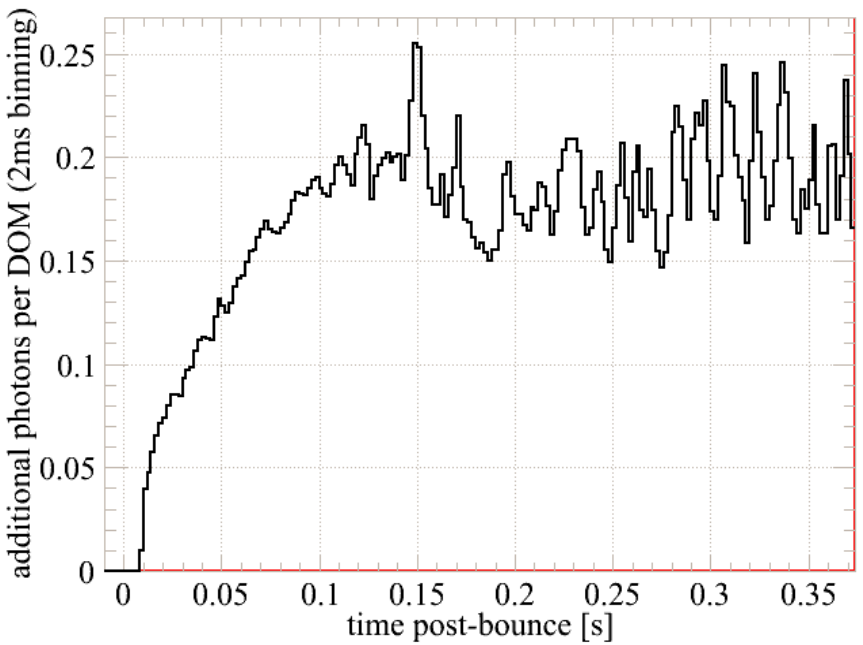
15 Solar Masses Garching SASI (North Pole)





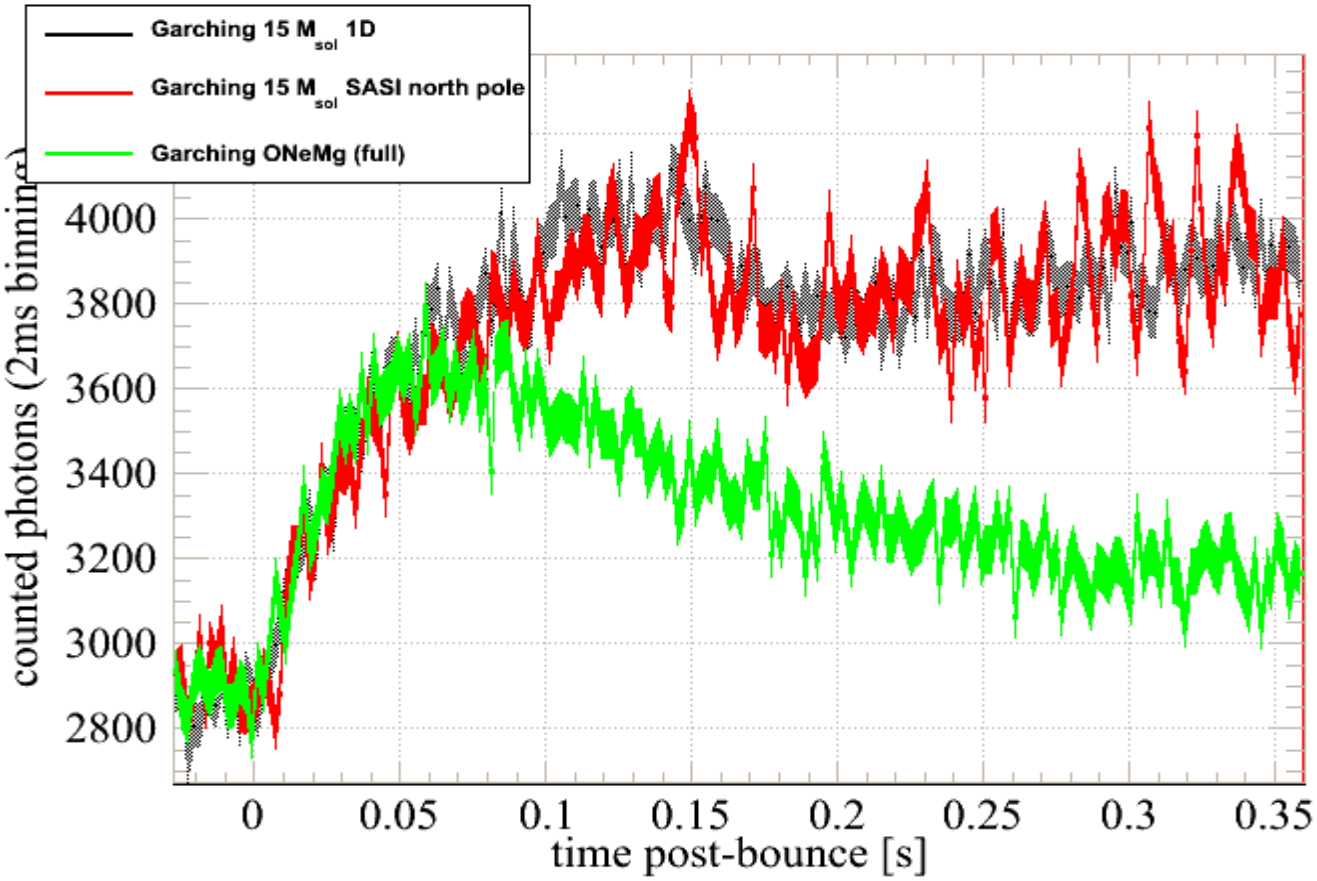
⇒

Can SASI fluctuations be seen in IceCube?



no MSW
no collective
10 kpc

Model Signatures
Garching ONeMg vs. SASI

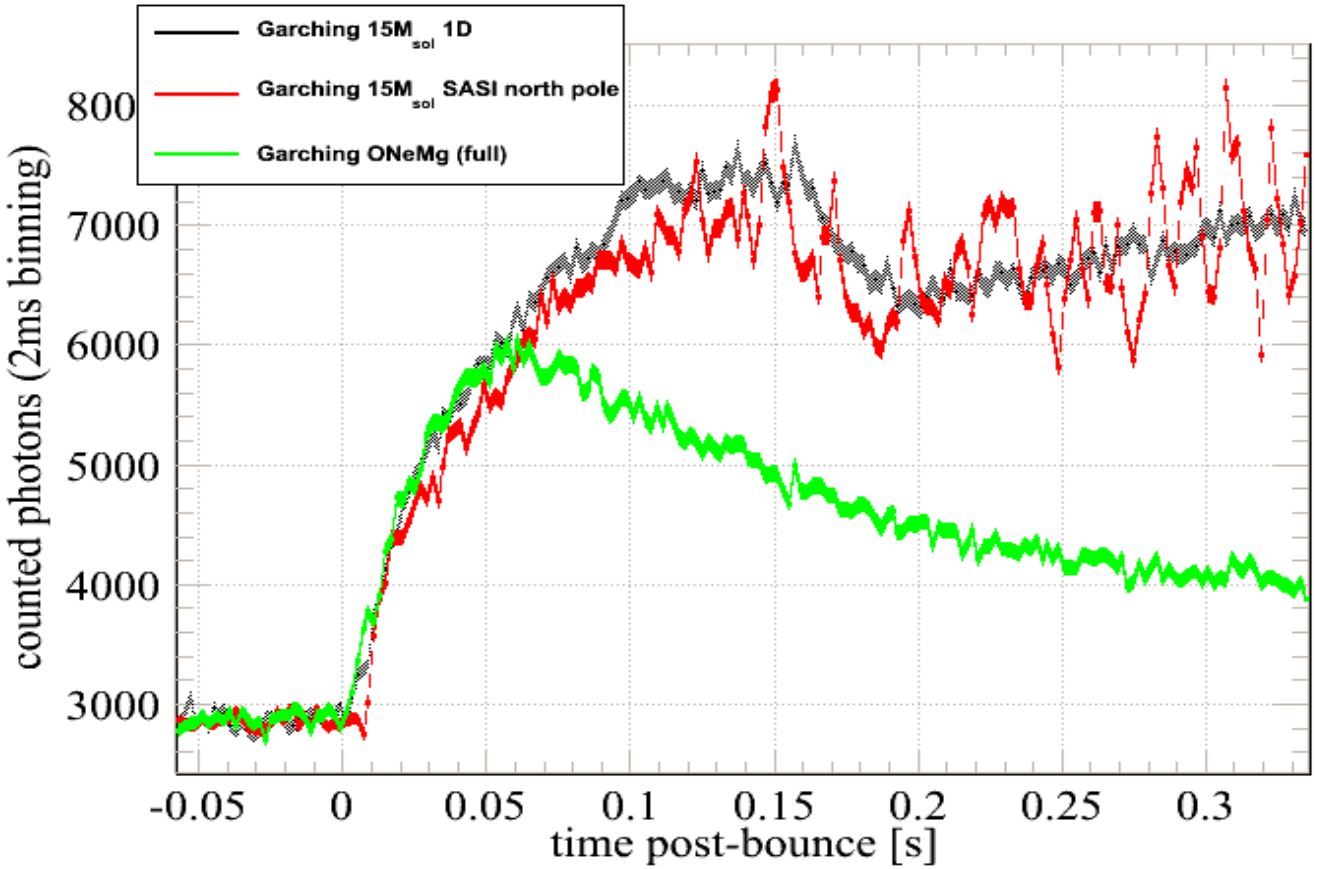


Photons counted in 350ms:

15 M_{sol} 1D:	~1.7 x 10^5
15 M_{sol} SASI NP:	~1.6 x 10^5
ONeMg (full):	~7.7 x 10^4

no MSW
no collective
10 kpc

Model Signatures
Garching ONeMg vs. SASI



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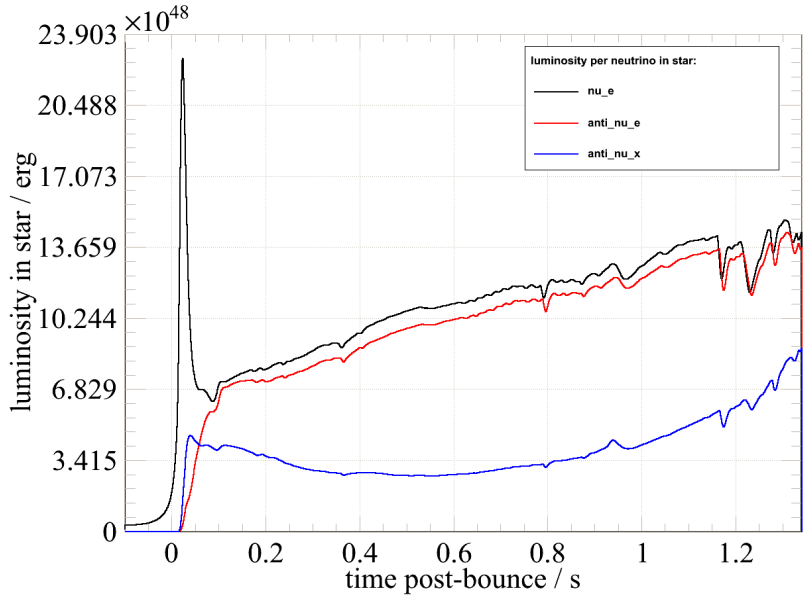
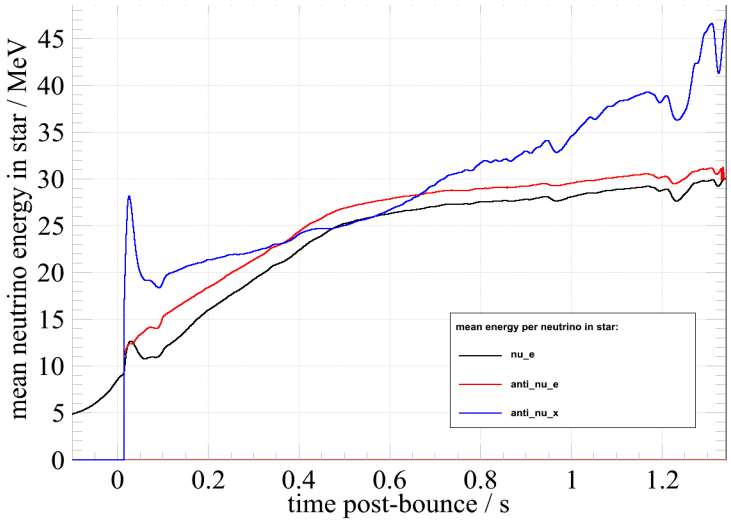
no MSW
no collective
5kpc

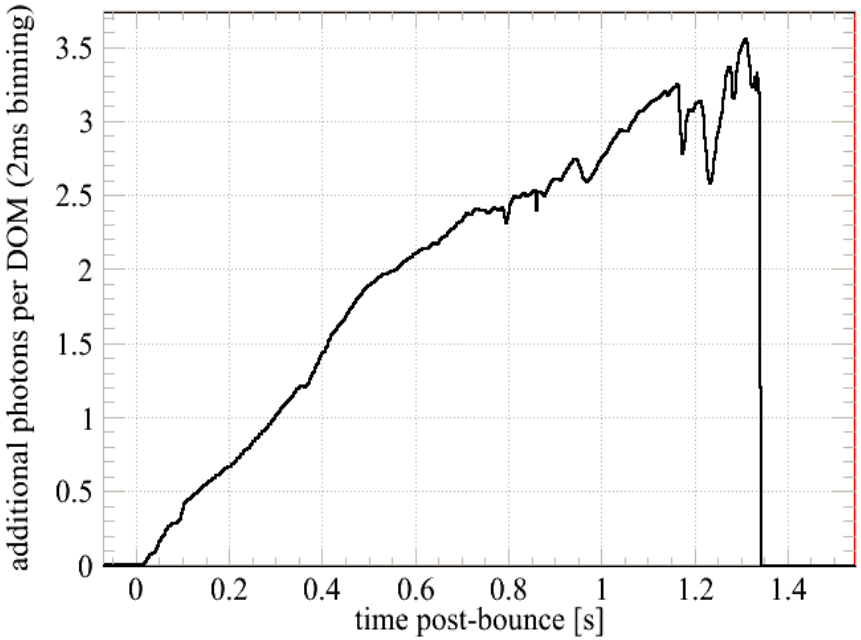
Model Signatures
Direct Black Hole





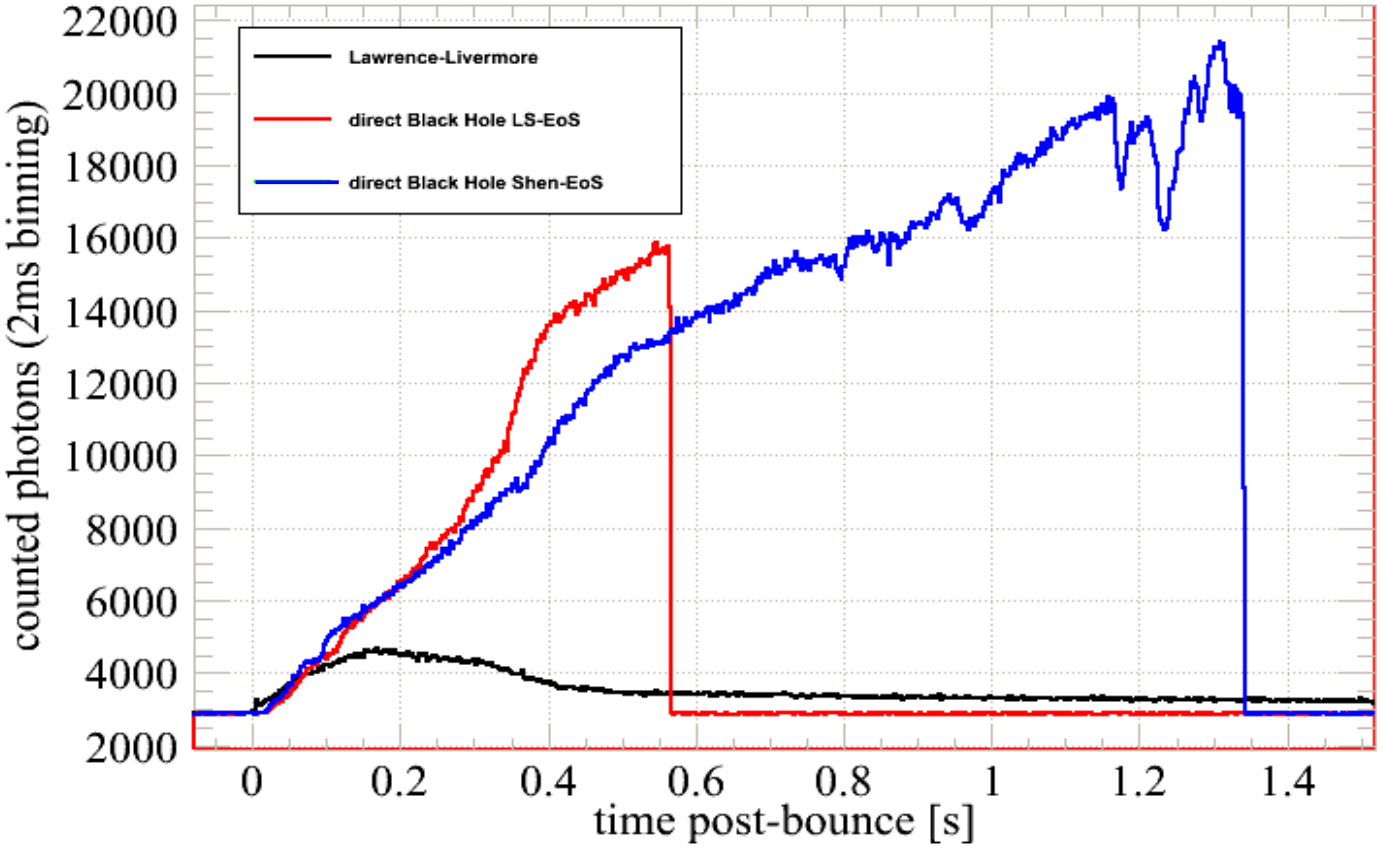
Direct black hole creation for
40 M_{sol} progenitor for Shen-EoS

⇒



no MSW
no collective
10 kpc

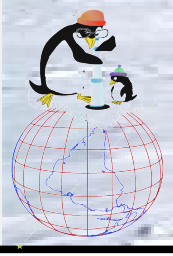
Model Signatures
Direct Black Hole – LS vs. Shen EoS



Photons counted in 1.4s:

Lawrence Livermore:	~4.9 x 10^5
direct black hole (LS-EoS):	~1.8 x 10^6
direct black hole (Shen-EoS):	~6.9 x 10^6

no MSW
no collective
10 kpc

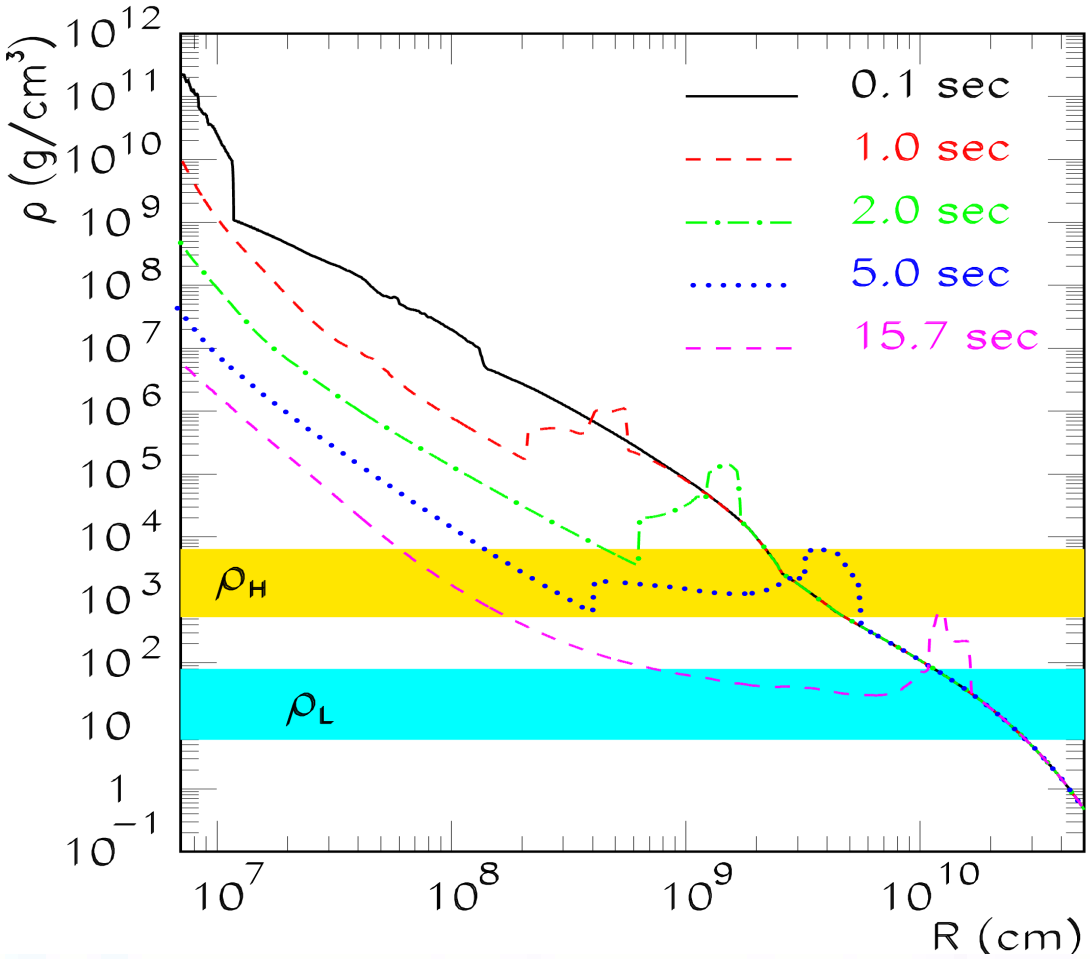


Oscillation Scenarios

Oscillation scenarios to investigate:

- Simple supernova shockwave propagation
- Collective oscillation – a startup
- Earth matter oscillations

Simple Supernova Shockwaves
Overview



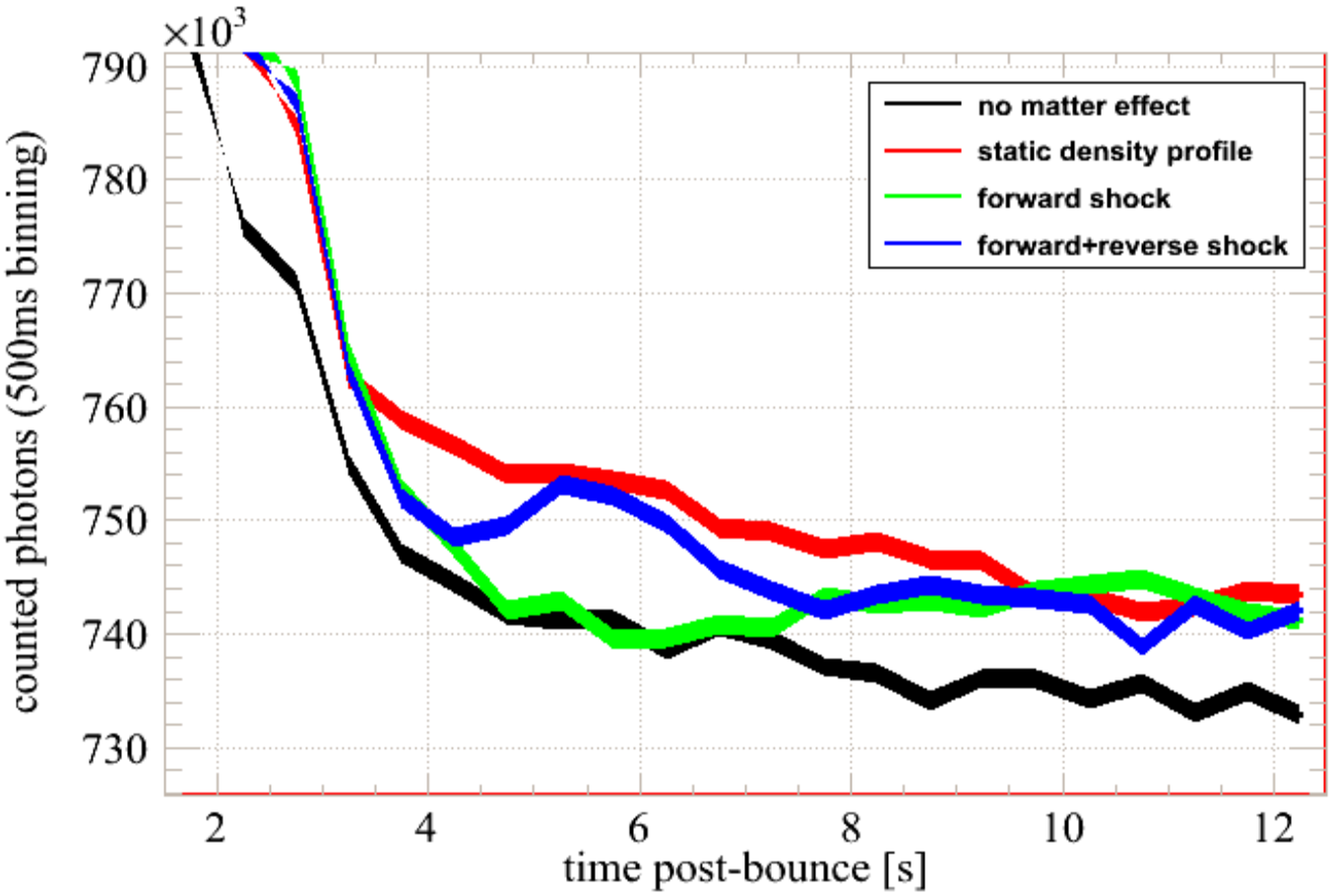
simple shockwave description

JCAP 0409, 015 (2004)

Special thanks to R. Tomás

Simple Supernova Shockwaves
Signature in IceCube

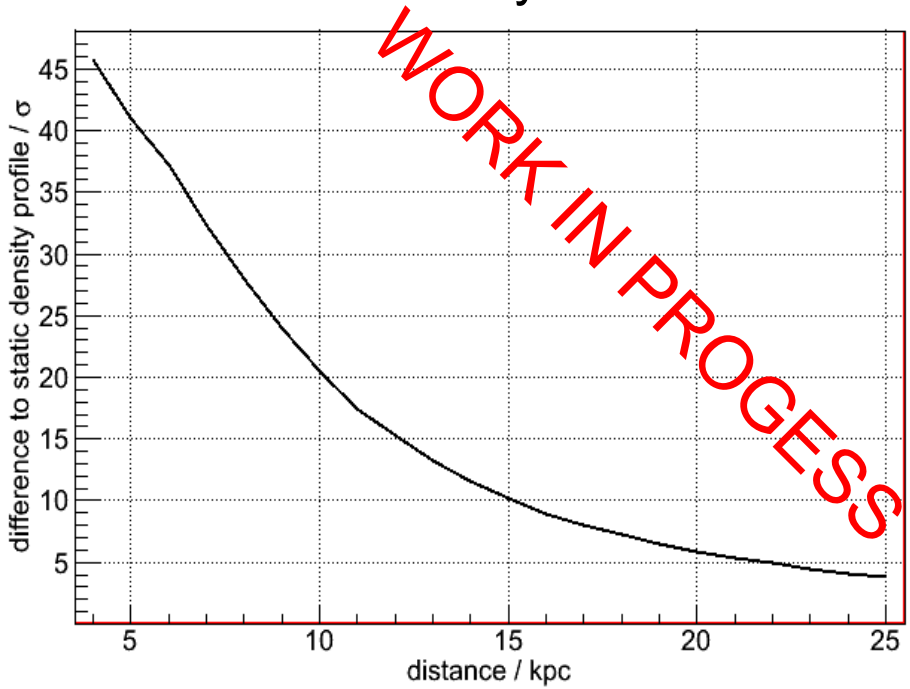
inverted hierarchy
$\sin^2 2\theta_{13} = 0.01$
10 kpc



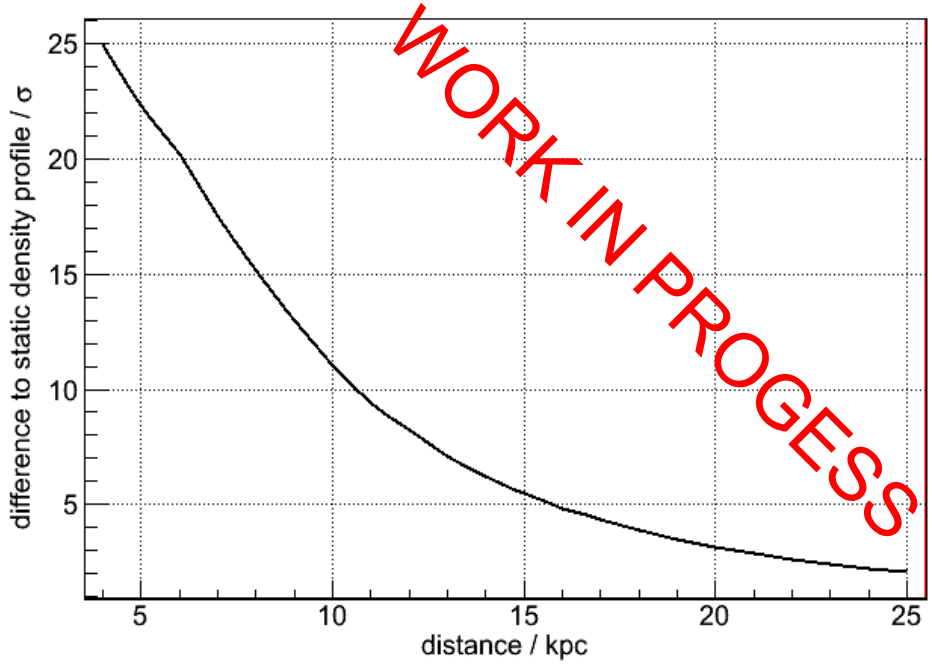
Simple Supernova Shockwaves
Separability in IceCube

inverted hierarchy
$\sin^2 2\theta_{13} = 0.01$

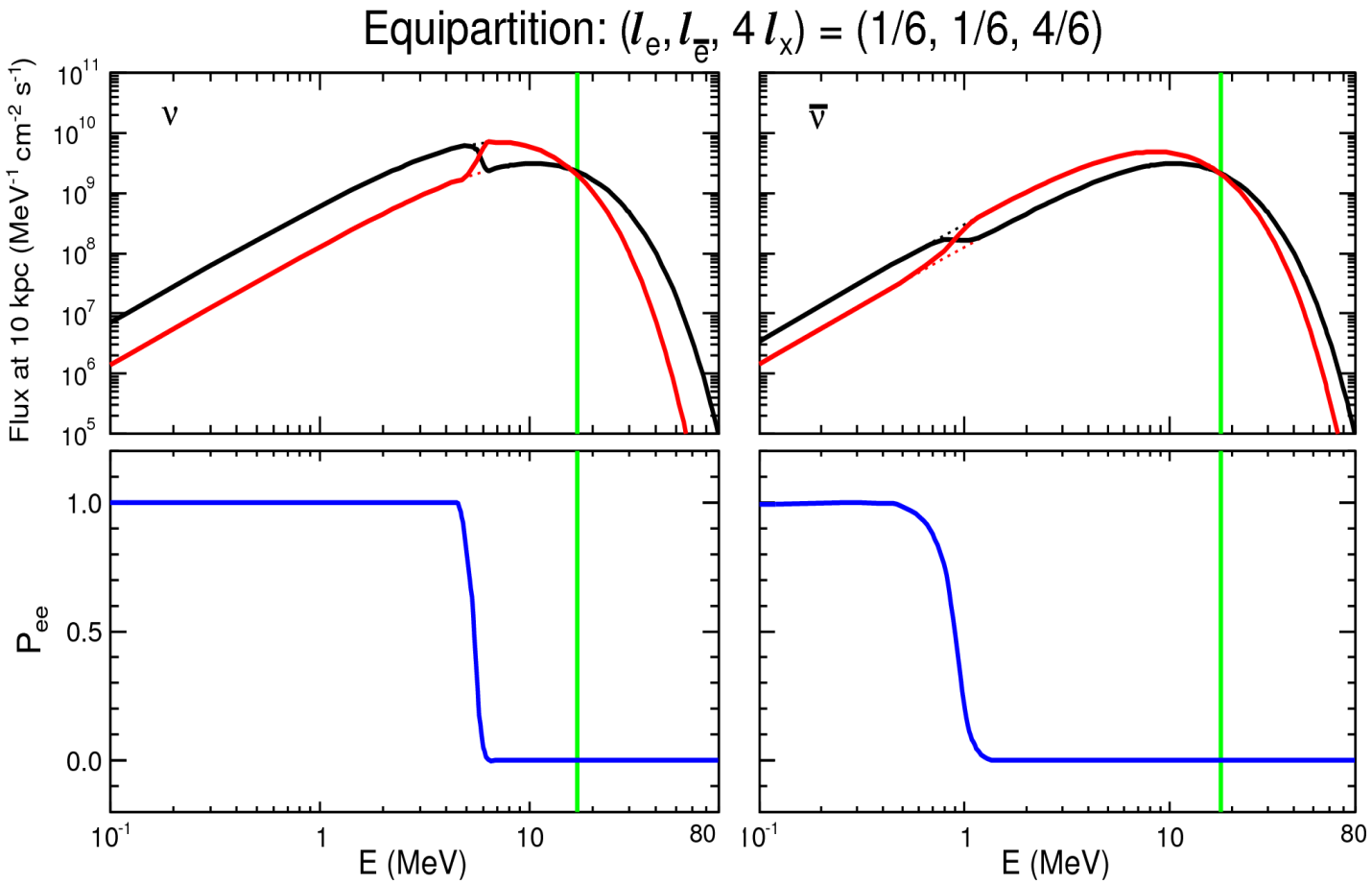
Forward shock only vs. no shock



Forward+reverse shock vs. No shock



Collective Effects
Luminosity Equipartition



Neutrino spectra at 0.5s

Thermal spectrum

10:12:15MeV

at 0.5s (cooling phase)

(here: luminosity equipartition)

JCAP10(2009)002

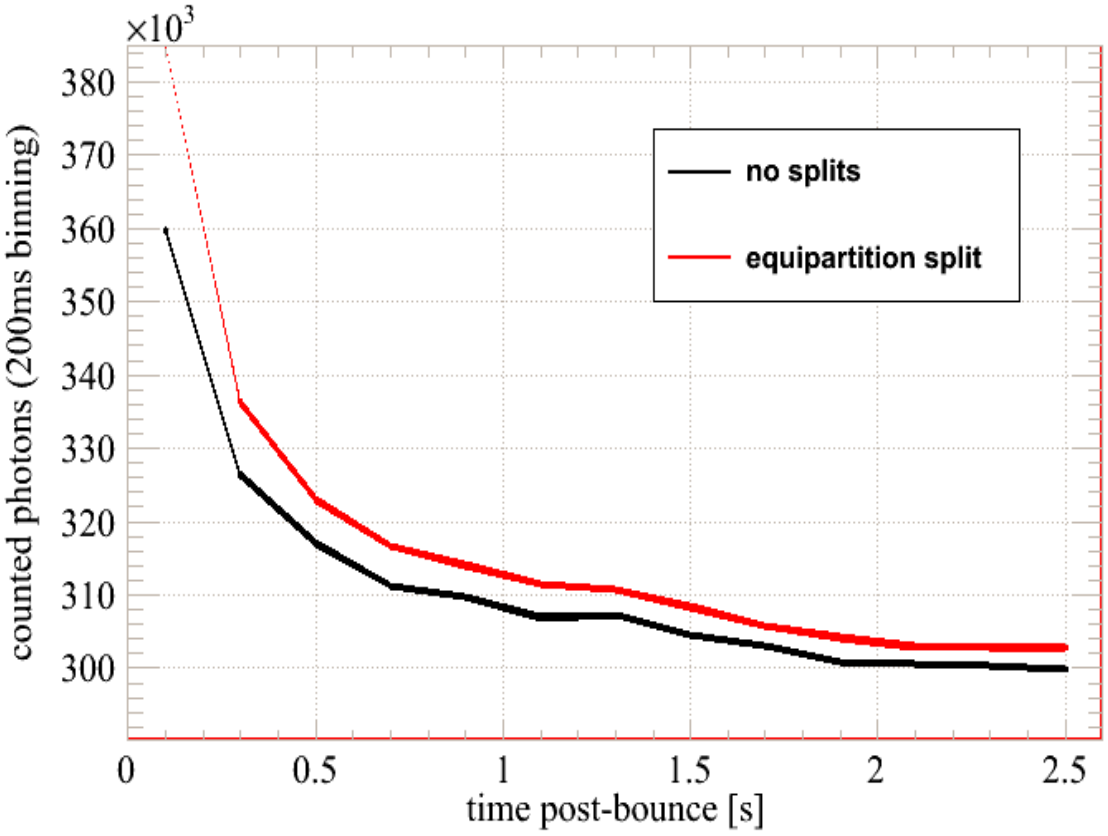
Special thanks to I. Tamborra

Collective Effects
Equipartition Signature in IceCube

inverted hierarchy
$\sin^2 2\theta_{13} = 10^{-6}$
10 kpc

Use spectra as input

Use luminosities from Garching ONeMg (full)

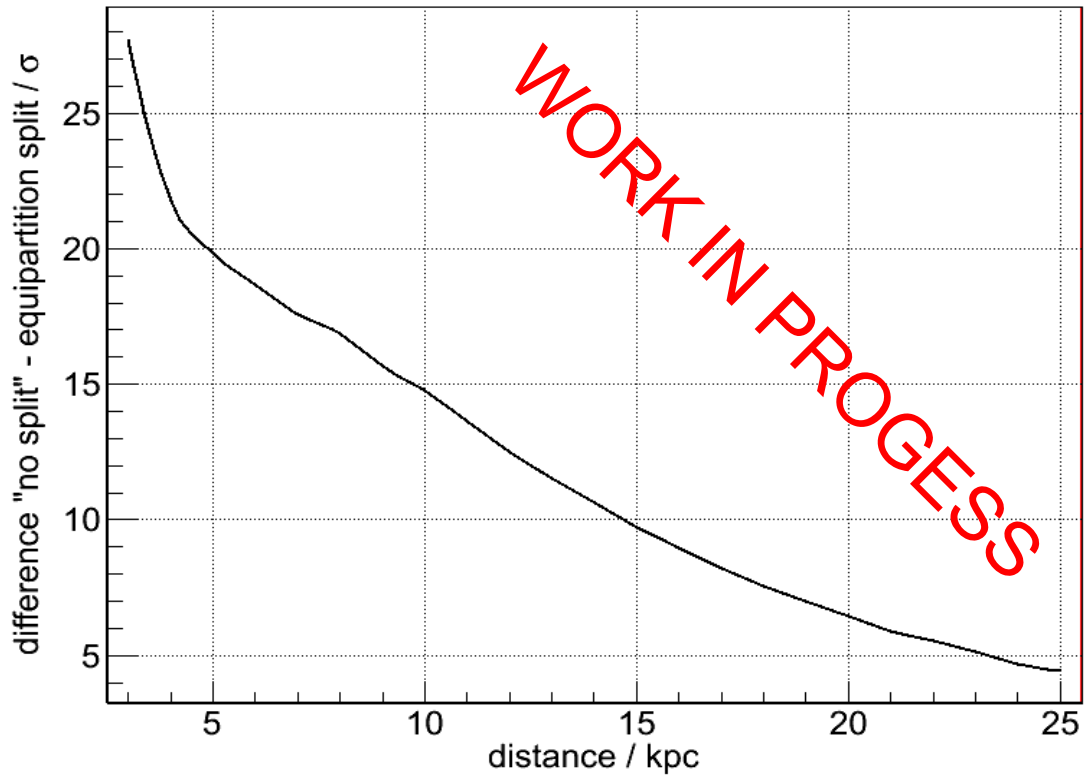


Collective Effects
Equipartition Separability in IceCube

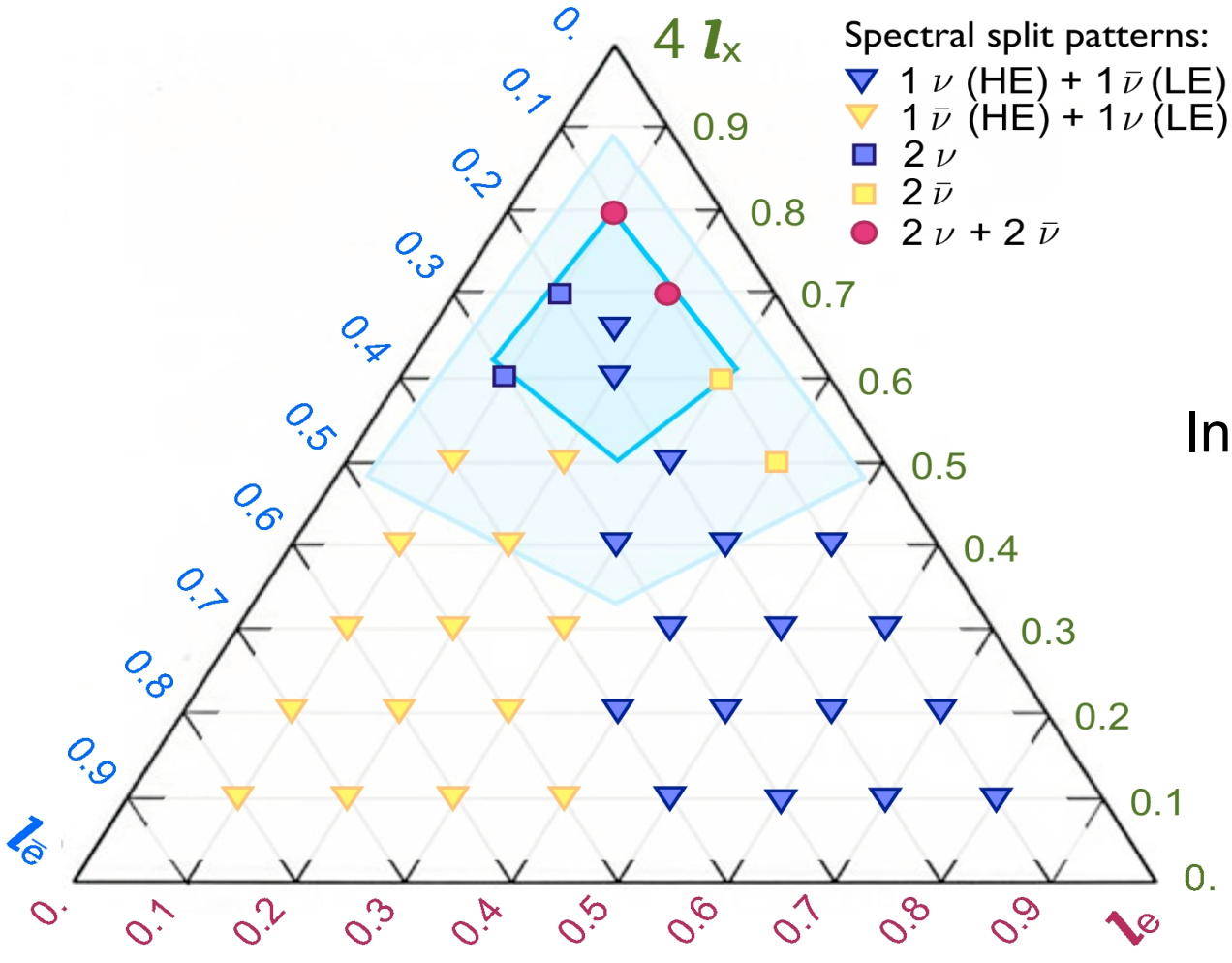
inverted hierarchy
$\sin^2 2\theta_{13} = 10^{-6}$
10 kpc

Use spectra as input

Use luminosities from Garching ONeMg (full)



Collective Effects
Ternary Luminosity Diagram



Investigate multiple spectra

JCAP10(2009)002

Special thanks to I. Tamborra

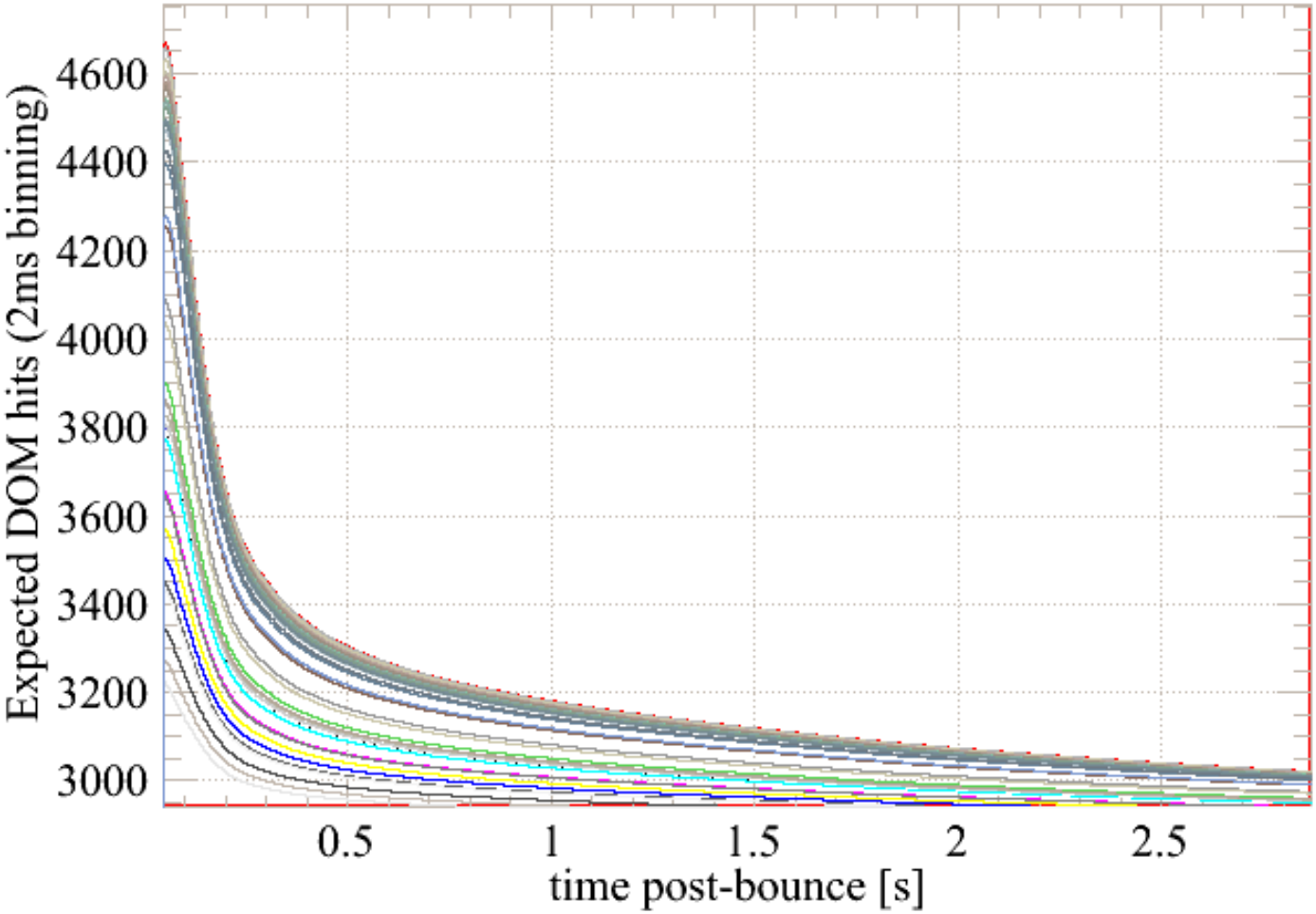
Collective Effects

Ternary Luminosity Diagram – I³ Expectations

inverted hierarchy

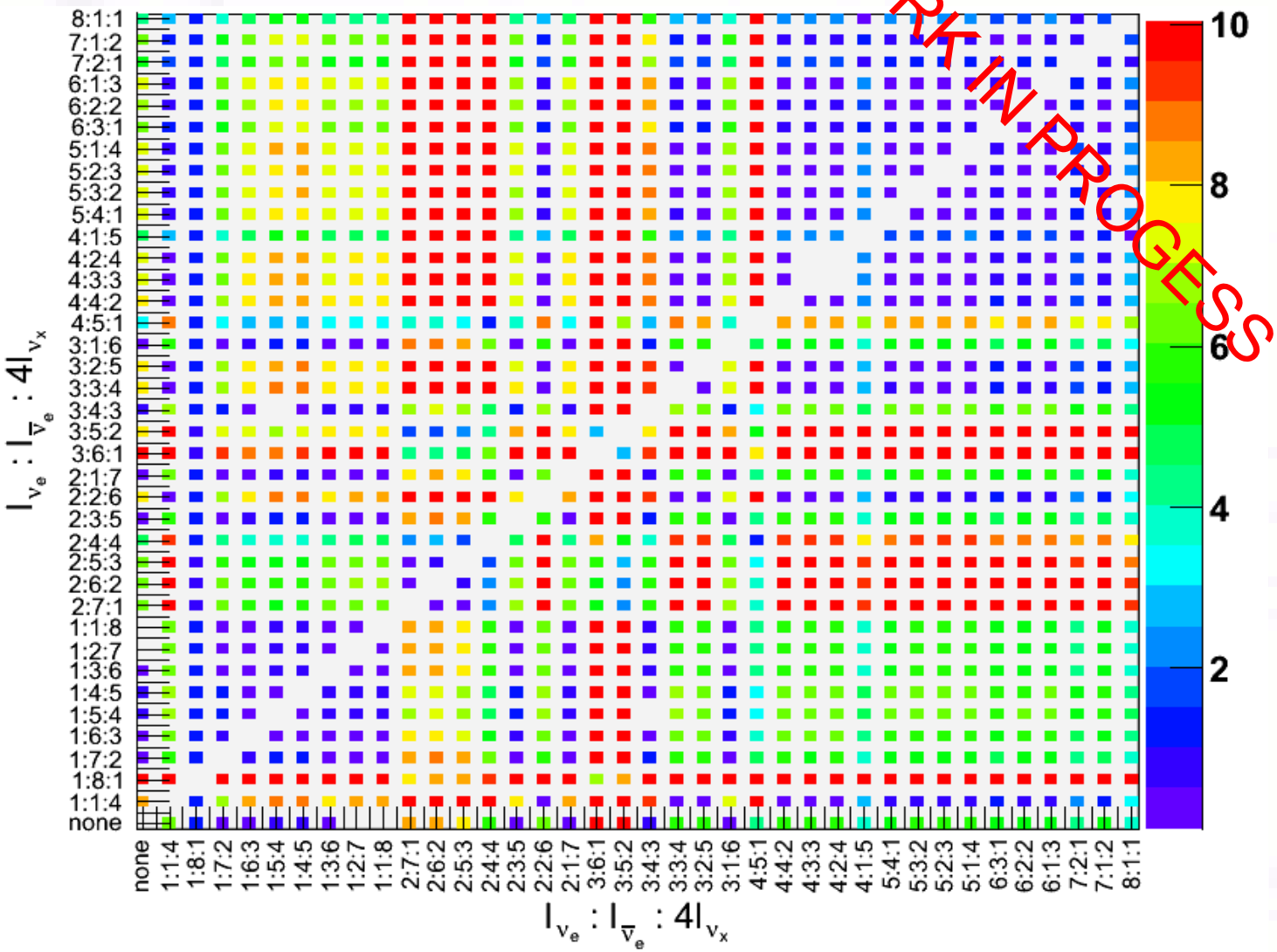
$\sin^2 2\theta_{13} = 10^{-6}$

10 kpc



Collective Effects

Ternary Luminosity Diagram – Separability in I^3



inverted hierarchy

$\sin^2 2\theta_{13} = 10^{-6}$

10 kpc

Collective Effects

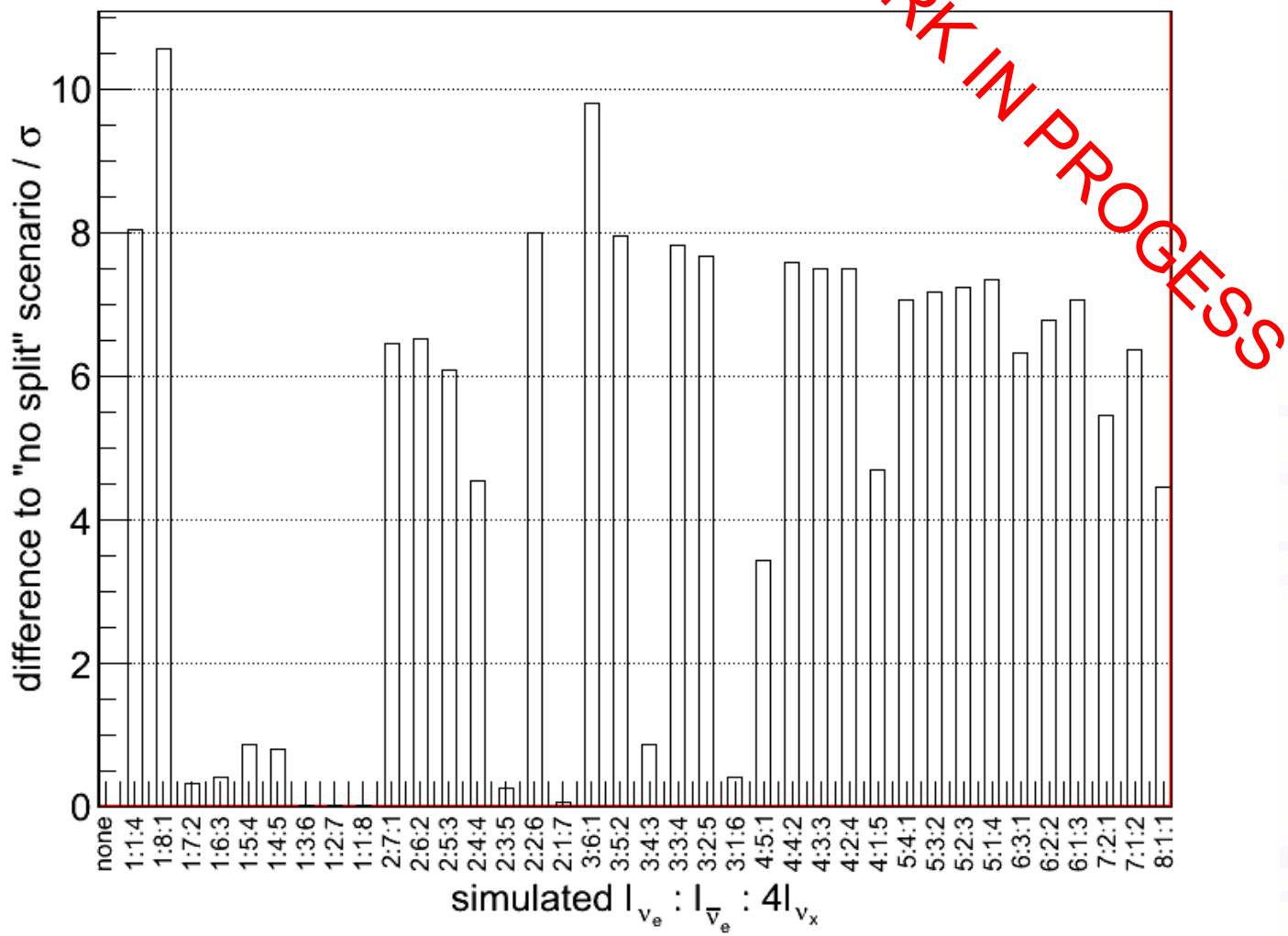
Ternary Luminosity Diagram – Separability in I^3

inverted hierarchy

$\sin^2 2\theta_{13} = 10^{-6}$

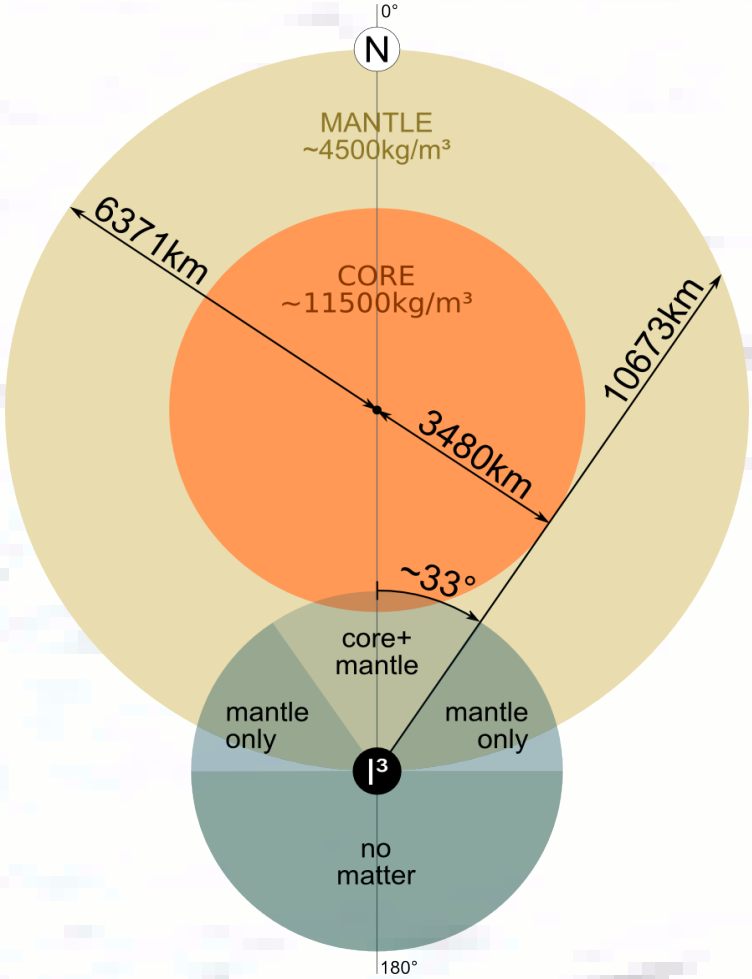
10 kpc

WORK IN PROGESS



Earth Matter Oscillations
Overview

Simple picture for earth matter oscillations



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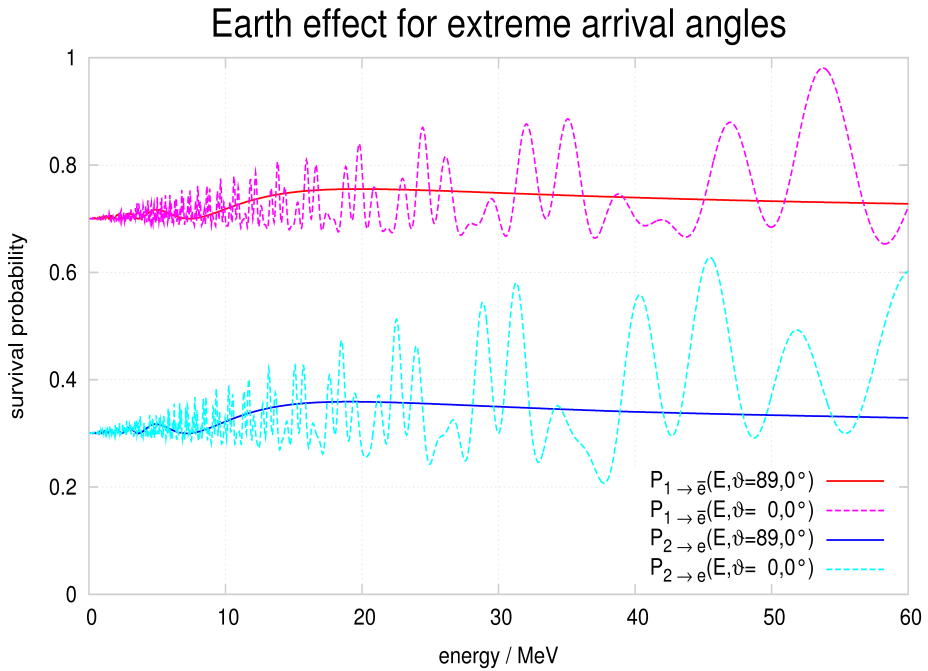
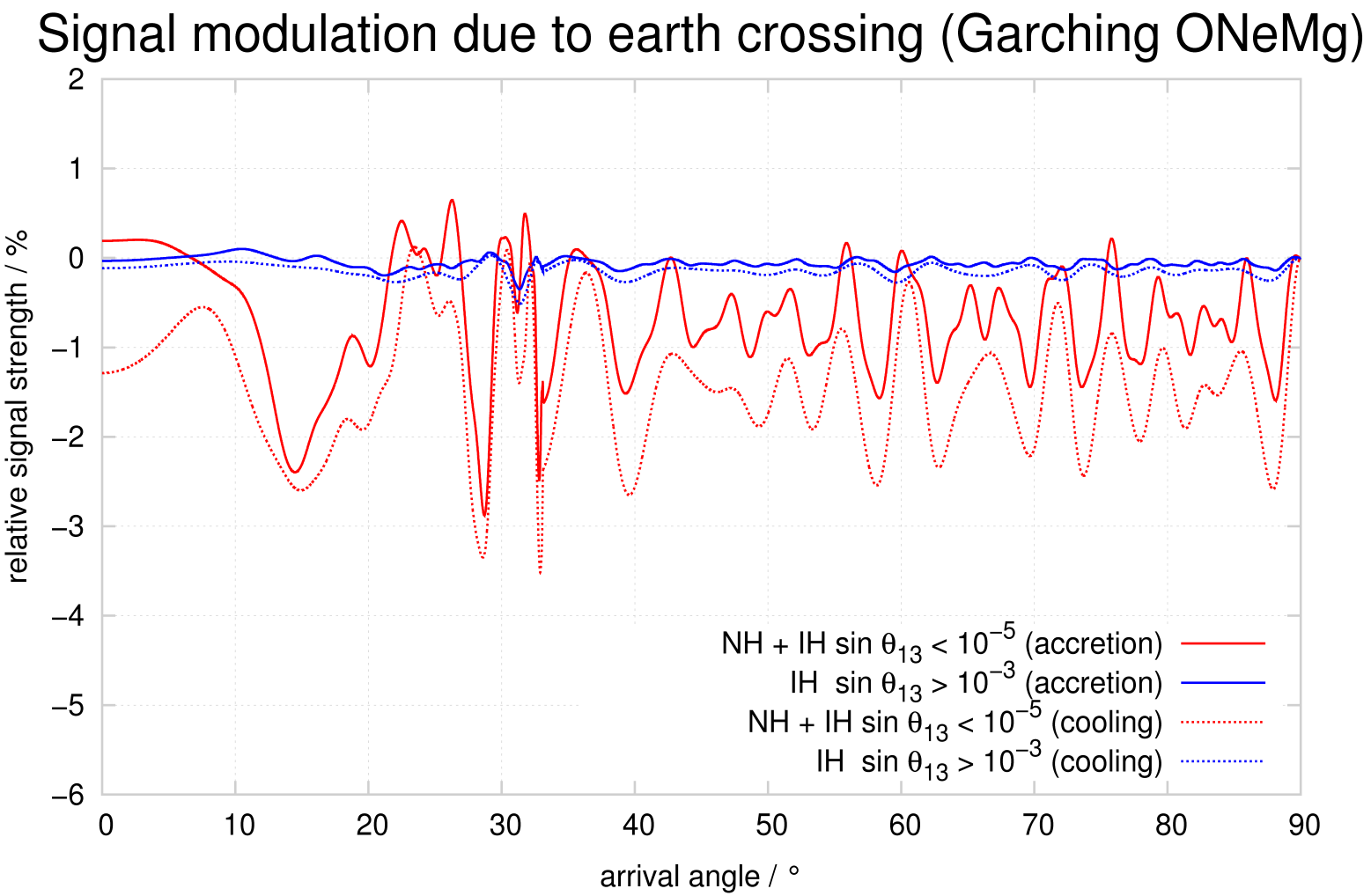
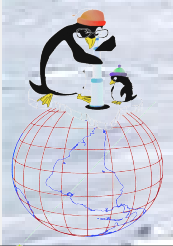


USSR

Earth Effect – I³ Signal Modulation





Outlook

- Finalize separability
- Include more models . . .
- Include more complicated sn matter fluctuations
- Continue on collective oscillation signatures
- Wait for the main dish . . .