JIGSAW, 22-26 February 2010
Tata Institute of Fundamental Research, Mumbai

Detecting the QCD phase transition using SN neutrinos

:: arXiv: 0912.2568 – with Tobias Fischer, Shunsaku Horiuchi, Matthias Liebendoerfer, Alessandro Mirizzi, Irina Sagert, Jurgen Schaffner-Bielich ::

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Outline

- **Paradigm:** Phase transition driven SN explosion
- **Model :** QCD phase transition at low critical density
- **Prediction:** Luminosities, Energies
- **Testability:** Icecube and Super-Kamiokande
- **Implications:** Possible constraints on the model

Supernova Explosions

Core-Collapse Supernova Mechanisms

	Introduced by:
Neutrino Mechanism	[Colgate & White '66, Arnett '66, Wilson '85, Bethe & Wilson '85]
Magnetorotational Mechanism	[LeBlanc & Wilson '70, Bisnovatyi-Kogan et al. '76, Meier et al. '76, Symbalisty '84]
Acoustic Mechanism	[proposed by Burrows et al. '06, '07; not yet confirmed by other groups/codes]

Magneto-Viscous Mechanism

[Akiyama et al. '03, Thompson et al. '05]

Phase-Transition-Induced Mechanism

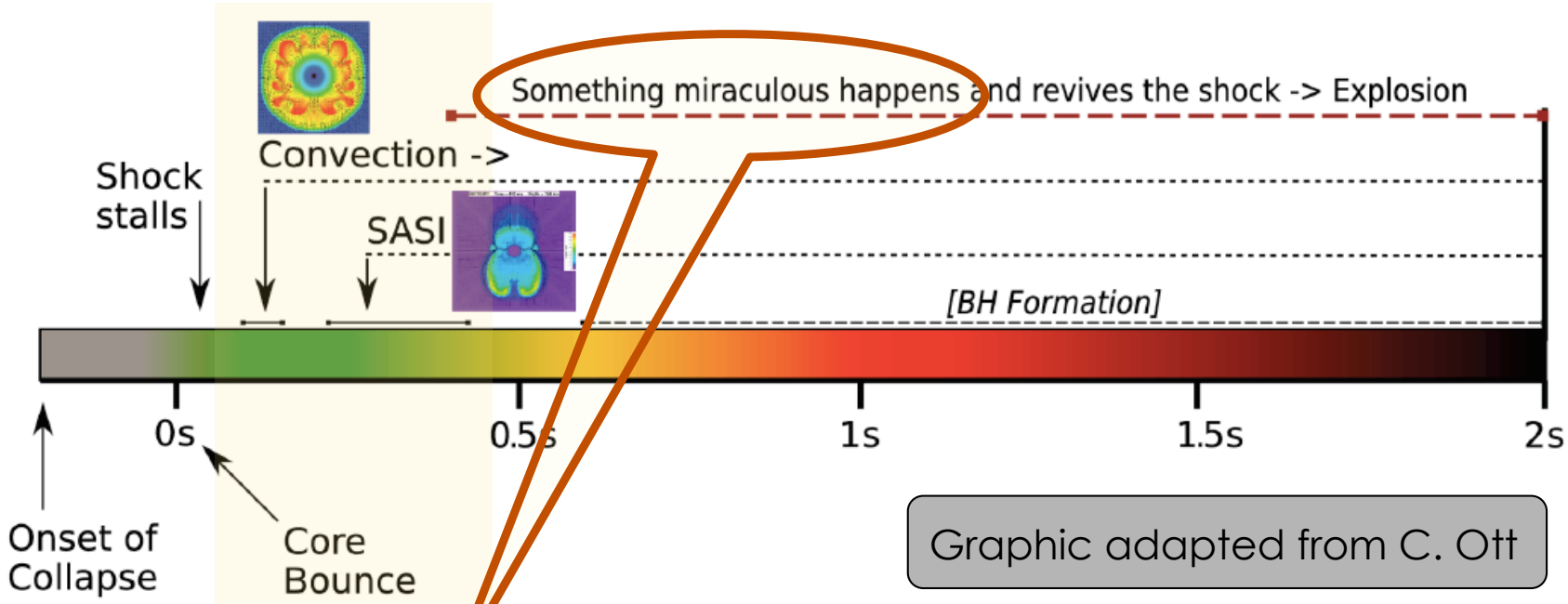
[Migdal et al. '71, Sagert et al. '09]

Talks by A. Mirizzi and T. Lund at JIGSAW-2010

This Talk…

Slide by C. Ott at JIGSAW-2010

Core Collapse Timeline



Graphic adapted from C. Ott

Something Miraculous = Phase Transition ?

QCD transition driven SN explosions

- Hadrons melt to Quarks
- First order, with Latent Heat emitted
- Mixed phase with bubbles/nucleation
- QCD phase transition in SN at early times - if the critical density is low

Sagert et al., arXiv:0809.4225

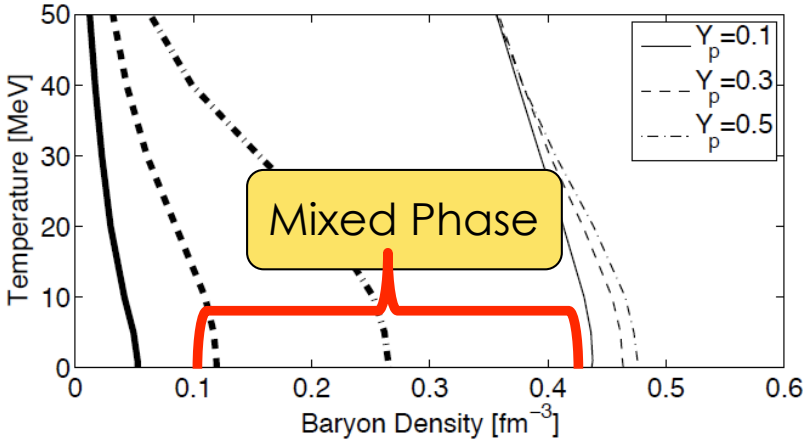
- Emitted energy produces a 2^{nd} shock
- Shock goes through already deleptonized matter
- Produces loads of anti-ν_e and explosion!

Model Parameters

- Quark/Hadron Matter = MIT bag
- 3 parameters: B, m_s, α_s
- B = 162 MeV; should be 145-200 MeV
- EOS (Shen) gives n_{crit}=0.12 fm^{-3}

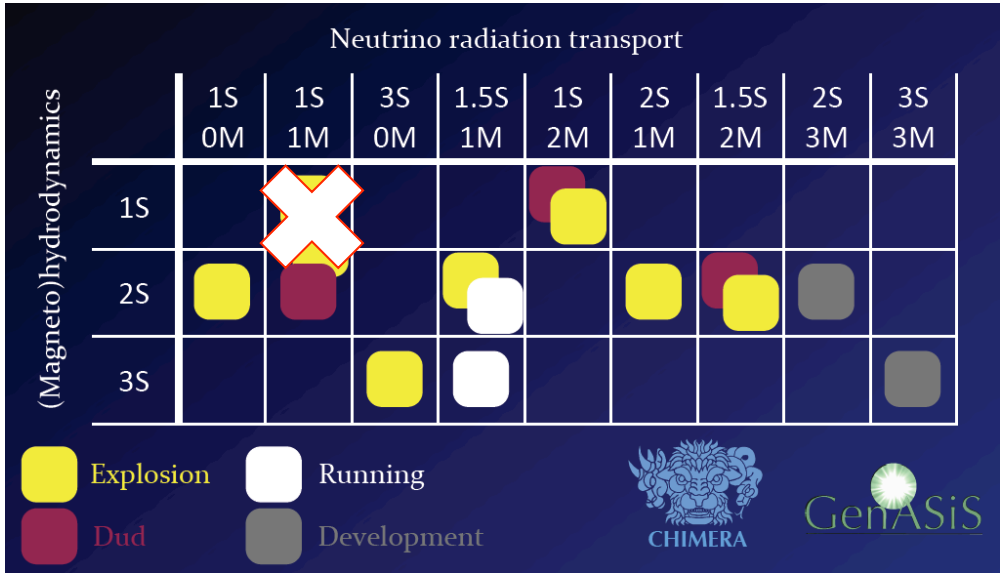
Sagert et al., arXiv:0809.4225

- Typical times for nucleation = 100 ms
- Onset-End of mixed phase
- Happens at core bounce



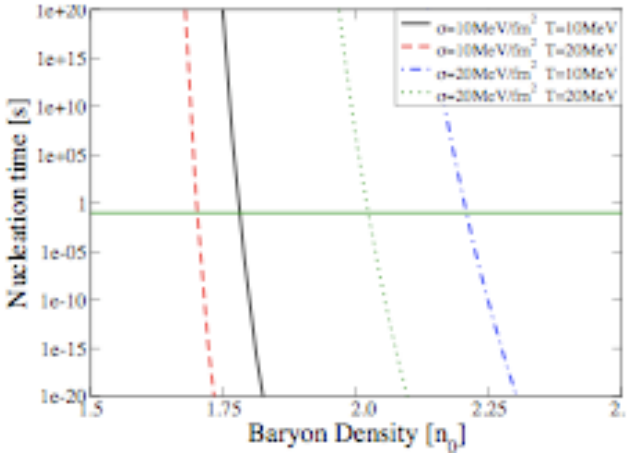
Simulation: Technical Caveats

- **Sophistication:**
  - **Spherically Symmetric**



C. Cardall, Slide at JIGSAW-2010

- **EOS:**
  - **Nucleation Time**



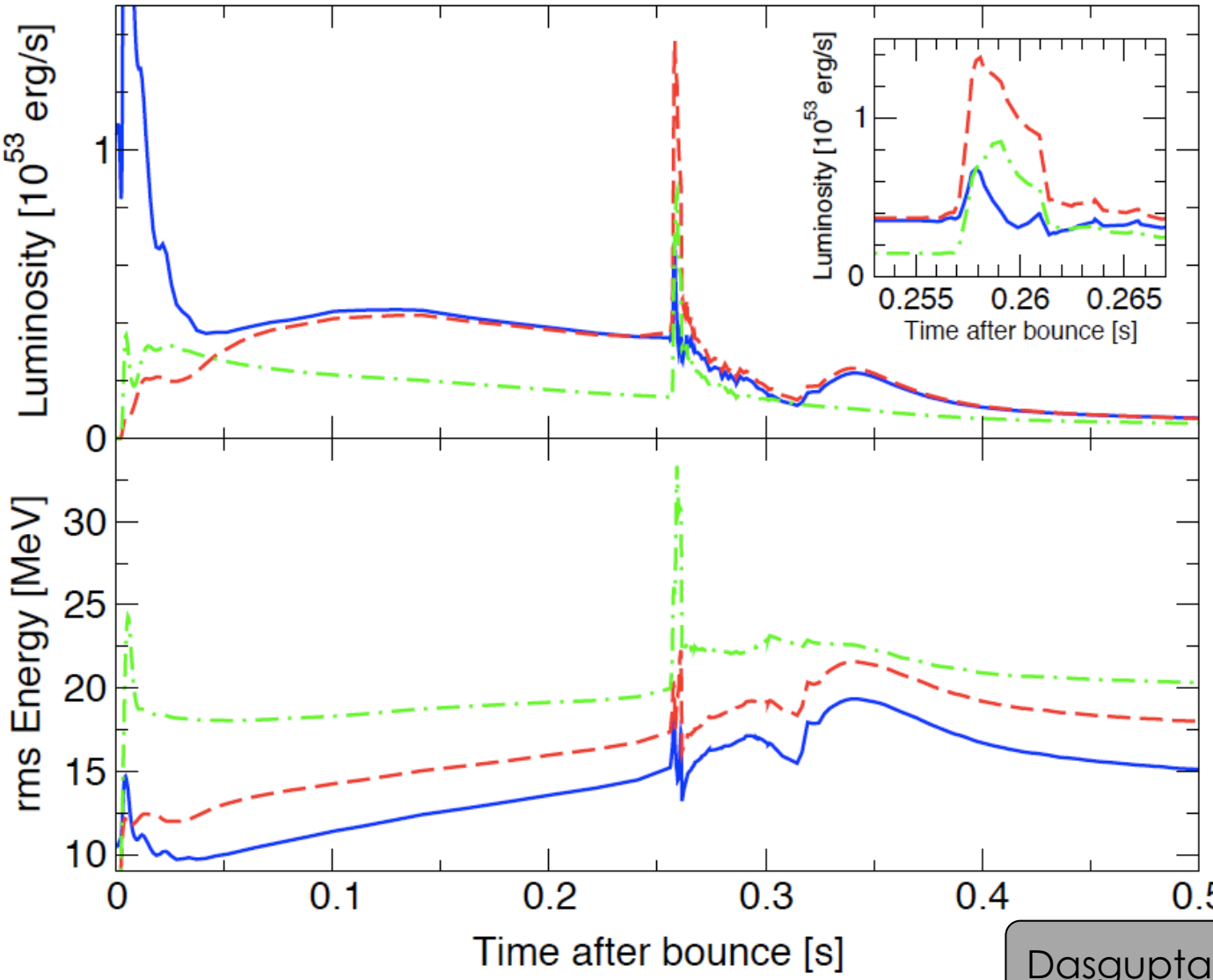
Mintz et al., arXiv:0910.3927

  - **Phases could be more complicated**

Constraints on this model

- **Neutron Star mass measurements:**
  - Model predicts 1.5 $M_\odot$ in the observed range
  - Can be somewhat larger with more complicated EOS
- **RHIC:**
  - Critical density low…but RHIC constraint doesn't apply
  - Isospin is very different! This is neutron rich matter
- **Strange quark stars:**
  - This model doesn't allow absolutely stable strange quark matter

Predicted Neutrino Fluxes



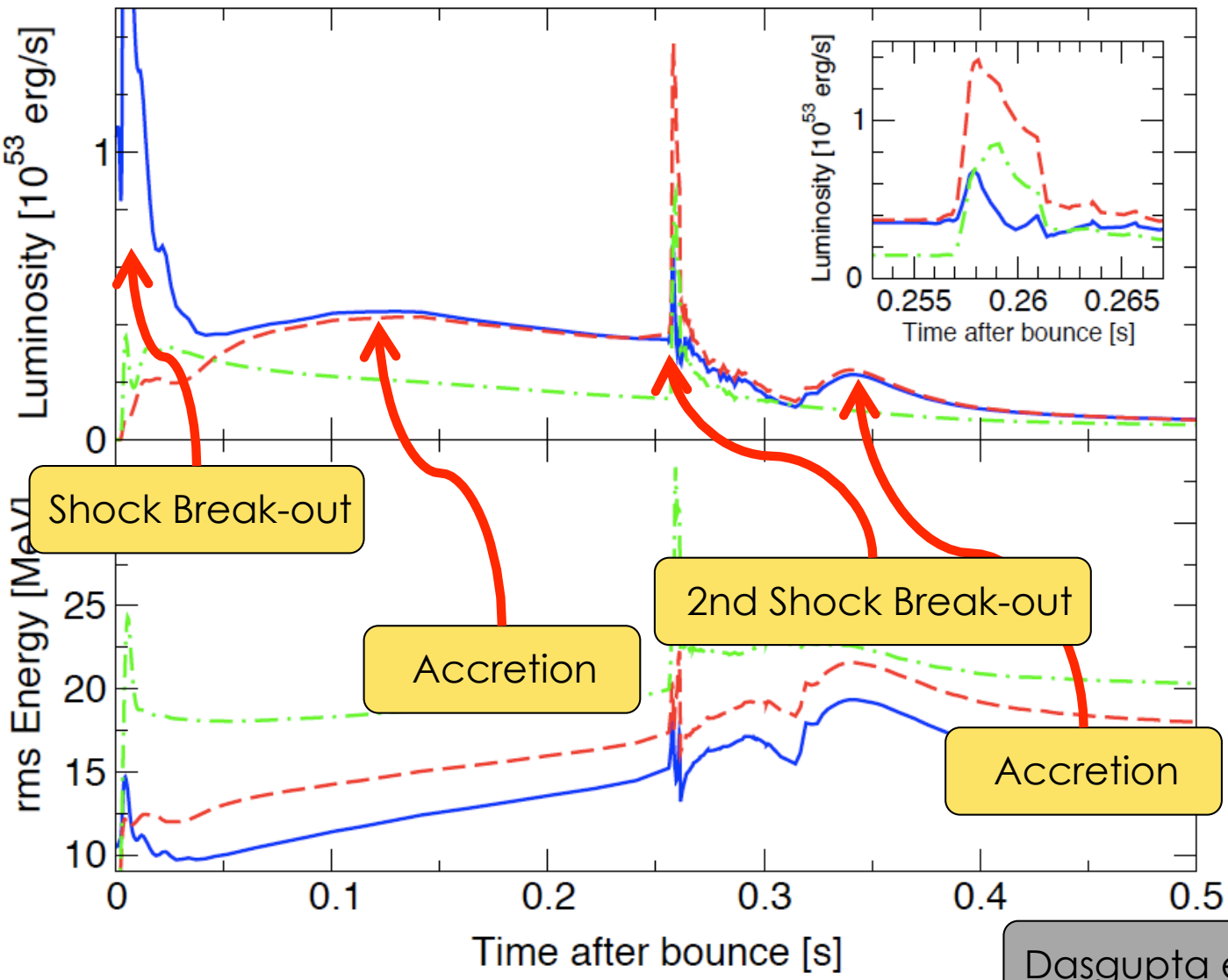
ν_e

anti-ν_e

ν_x

Dasgupta et al., arXiv:0809.4225

Predicted Neutrino Fluxes



ν_e

anti-ν_e

ν_x

Dasgupta et al., arXiv:0809.4225

Icecube Detector Response

- **Icecube with 4800 DOMs**

Talks by T. Griesel and T. Kowarik at JIGSAW-2010

- **Signal = correlated increase of "noise"**
- **Only calorimetric info. No spectral info**
- **Photon Count Rate**

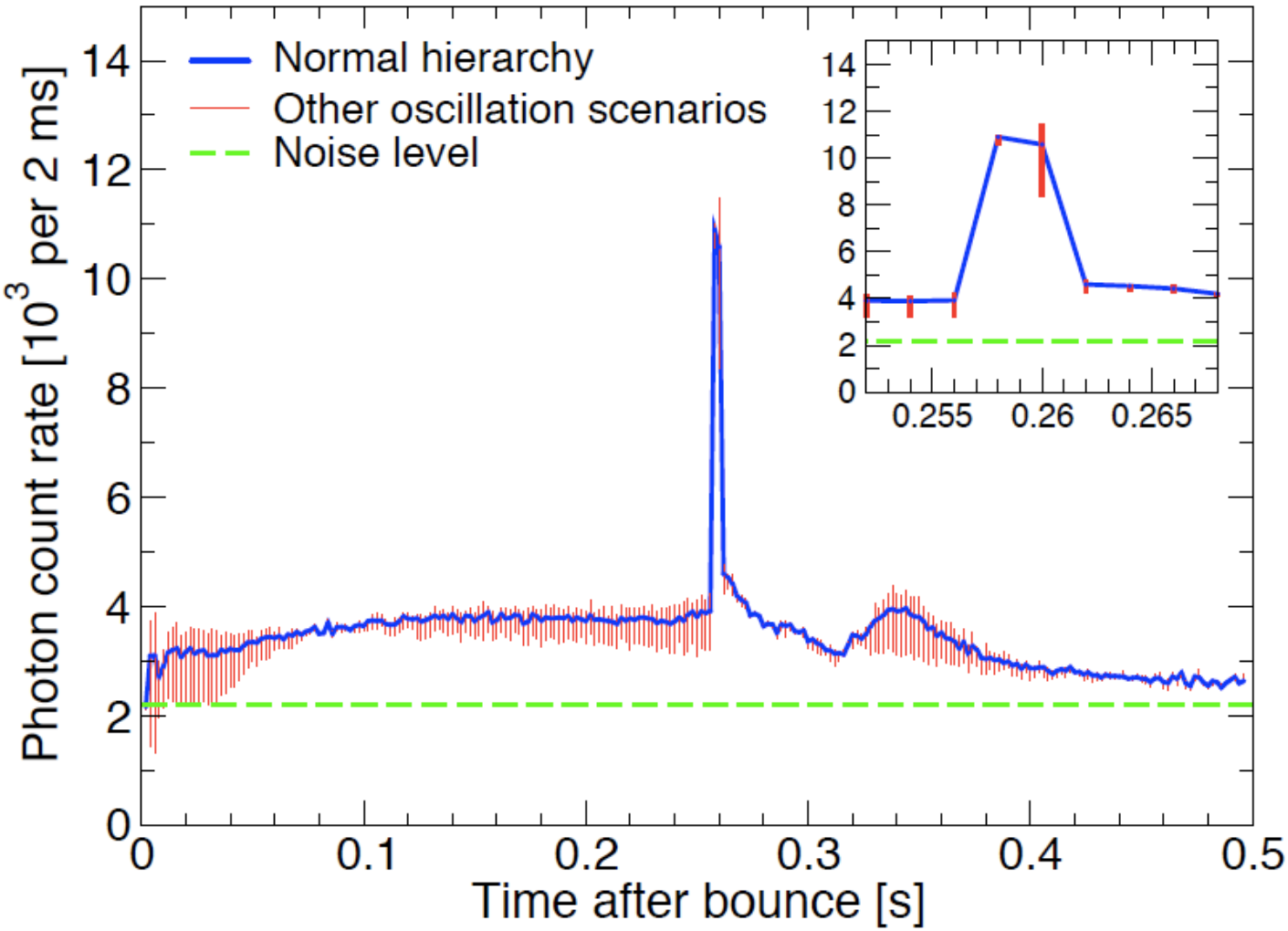
Halzen and Raffelt, arXiv:0908.2317

$$R_{\bar{\nu}_e} = 1860 \ \text{bin}^{-1} L_{53} \ d_{10}^{-2} \ \langle E_{15}^3 \rangle / \langle E_{15} \rangle^3$$

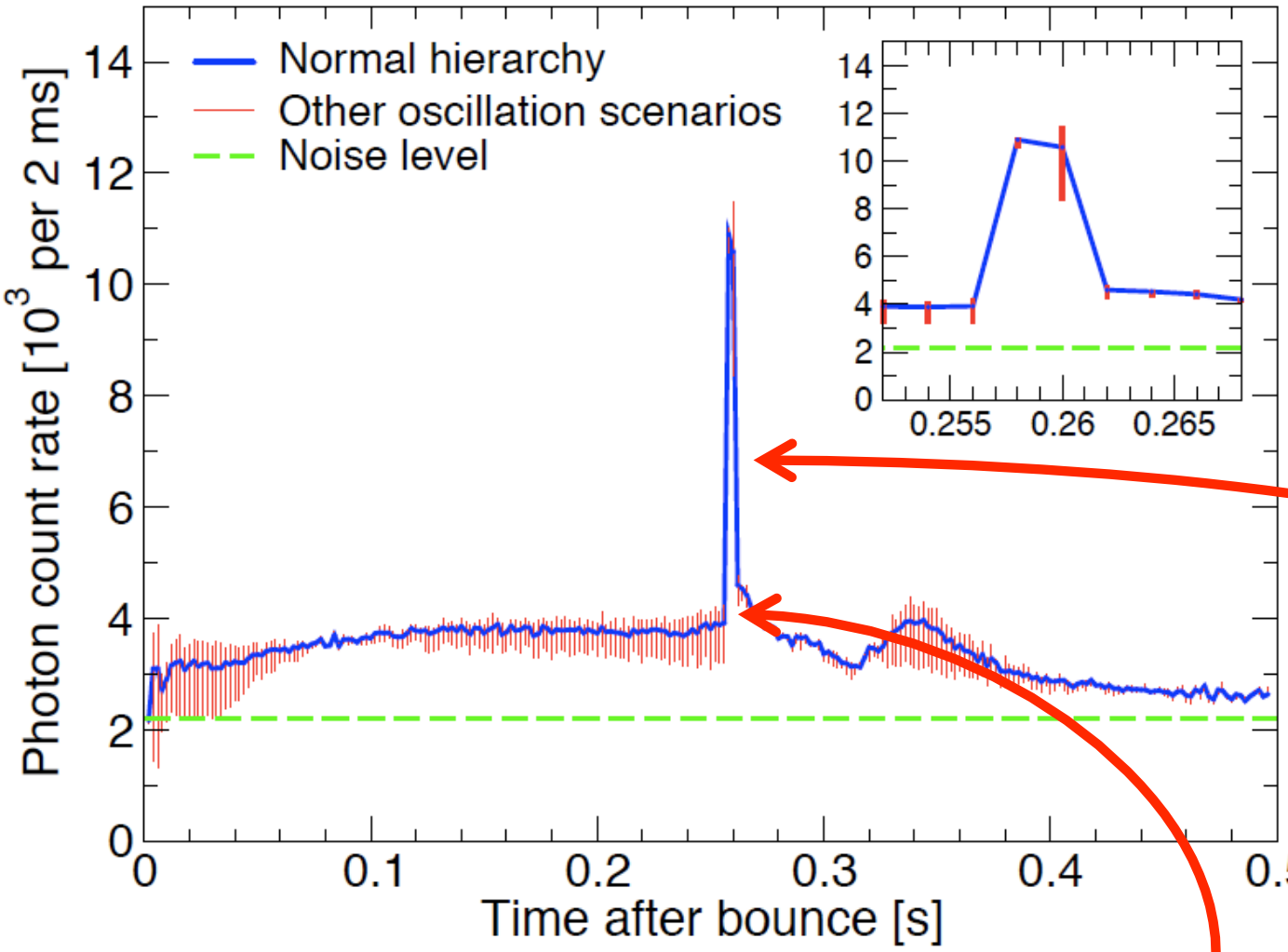
Neutrino Flux*Cross-section*Energy deposited

- **Time-binning of 2 ms/bin…more on that soon!**

Signal at Icecube



Signal at Icecube

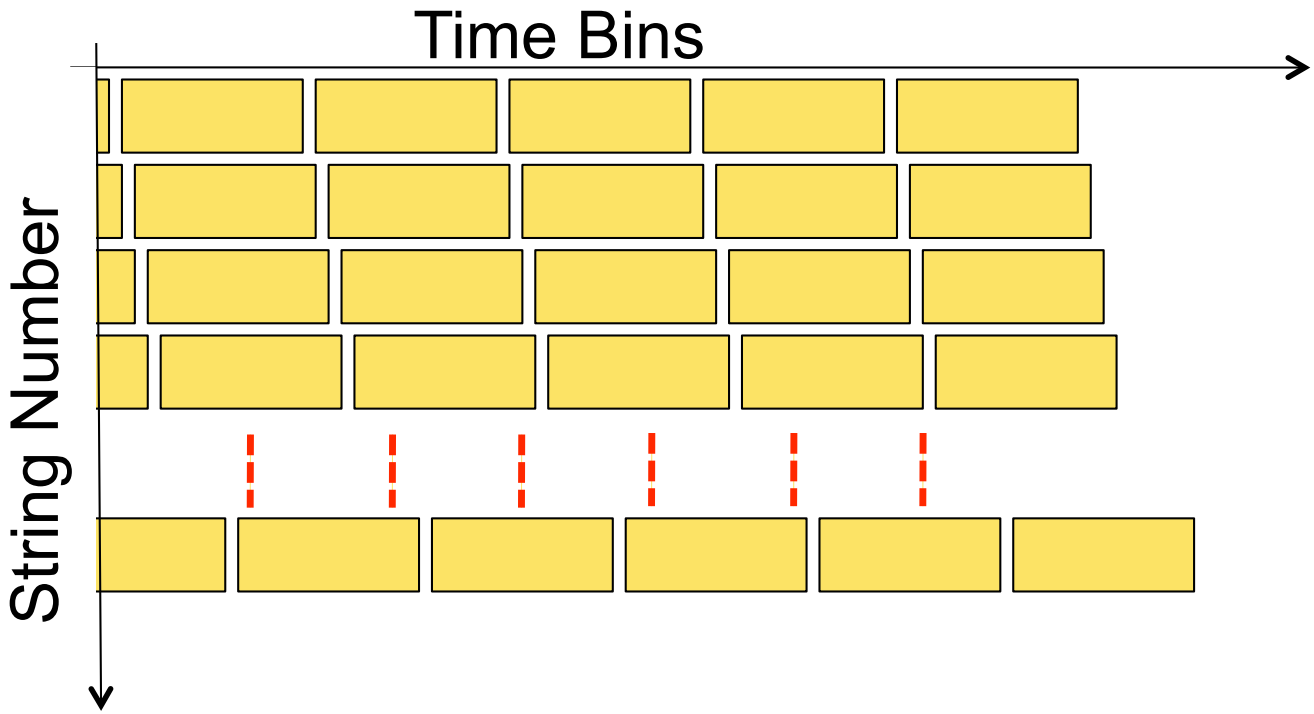


2nd Shock Break-out

Width = ~5ms

Sub-sampling at Icecube?

- **Signal can be huge. How about treating each string as a separate detector? Staggered in time…**



Thanks for discussions: Beacom and Halzen

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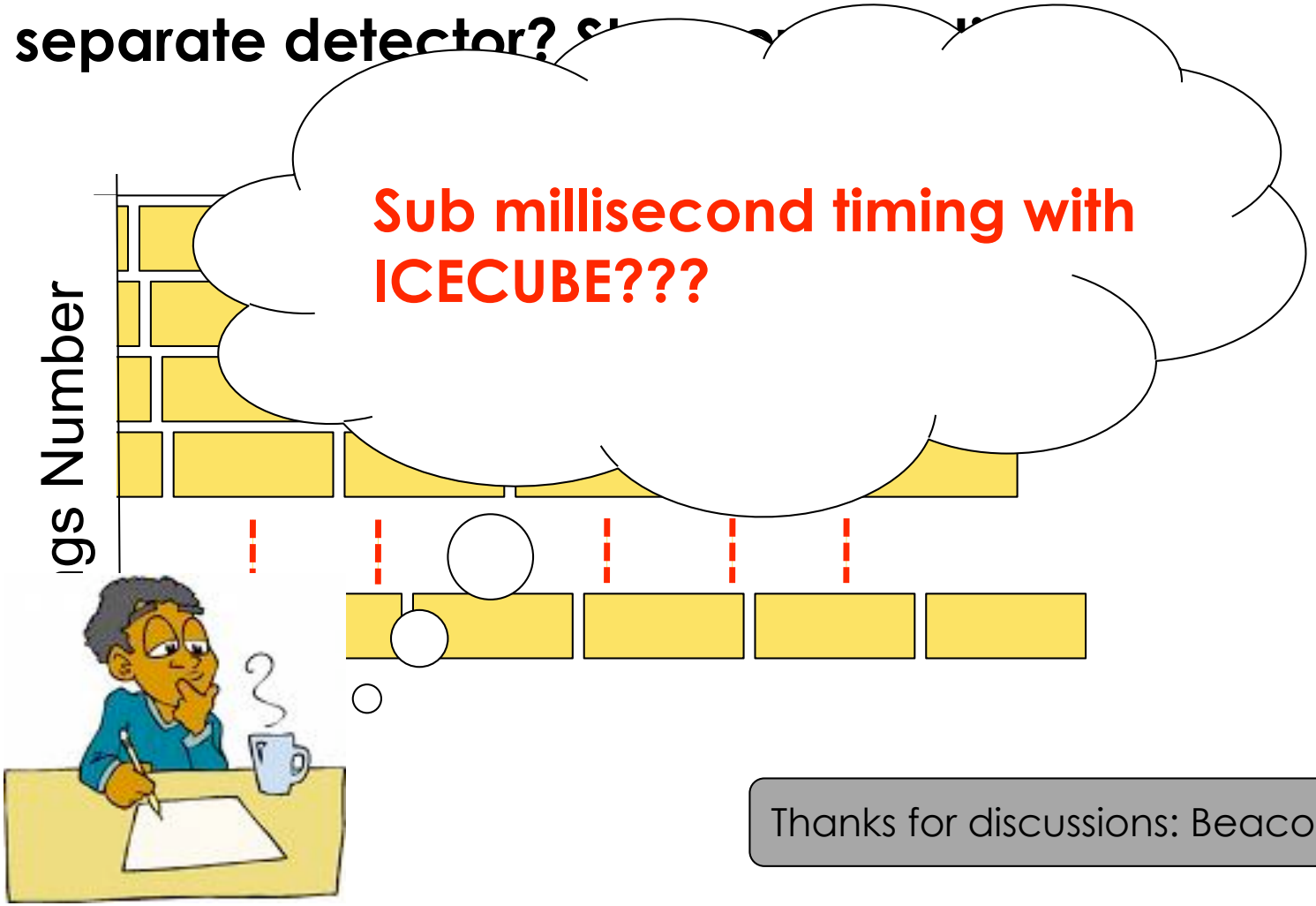
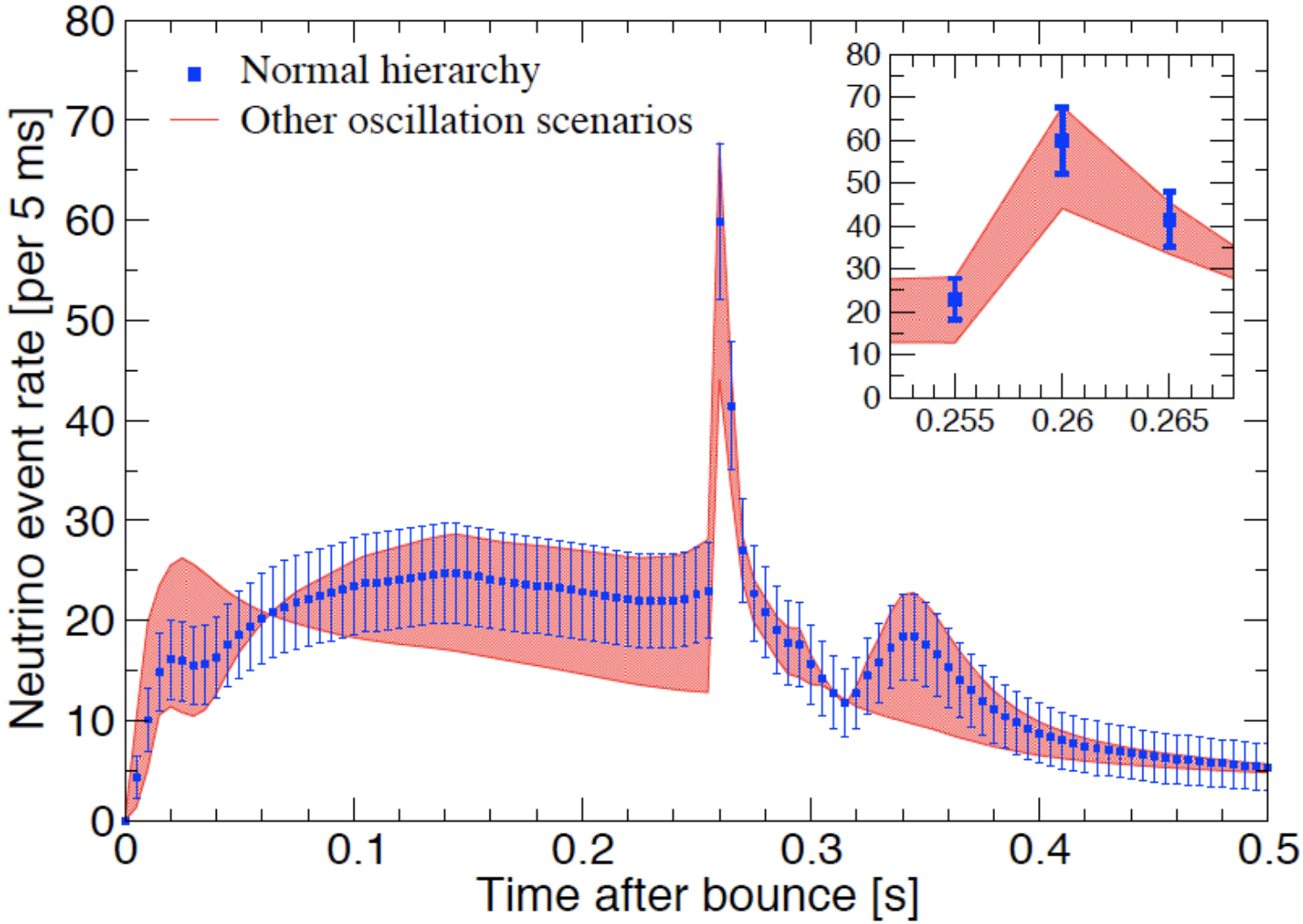
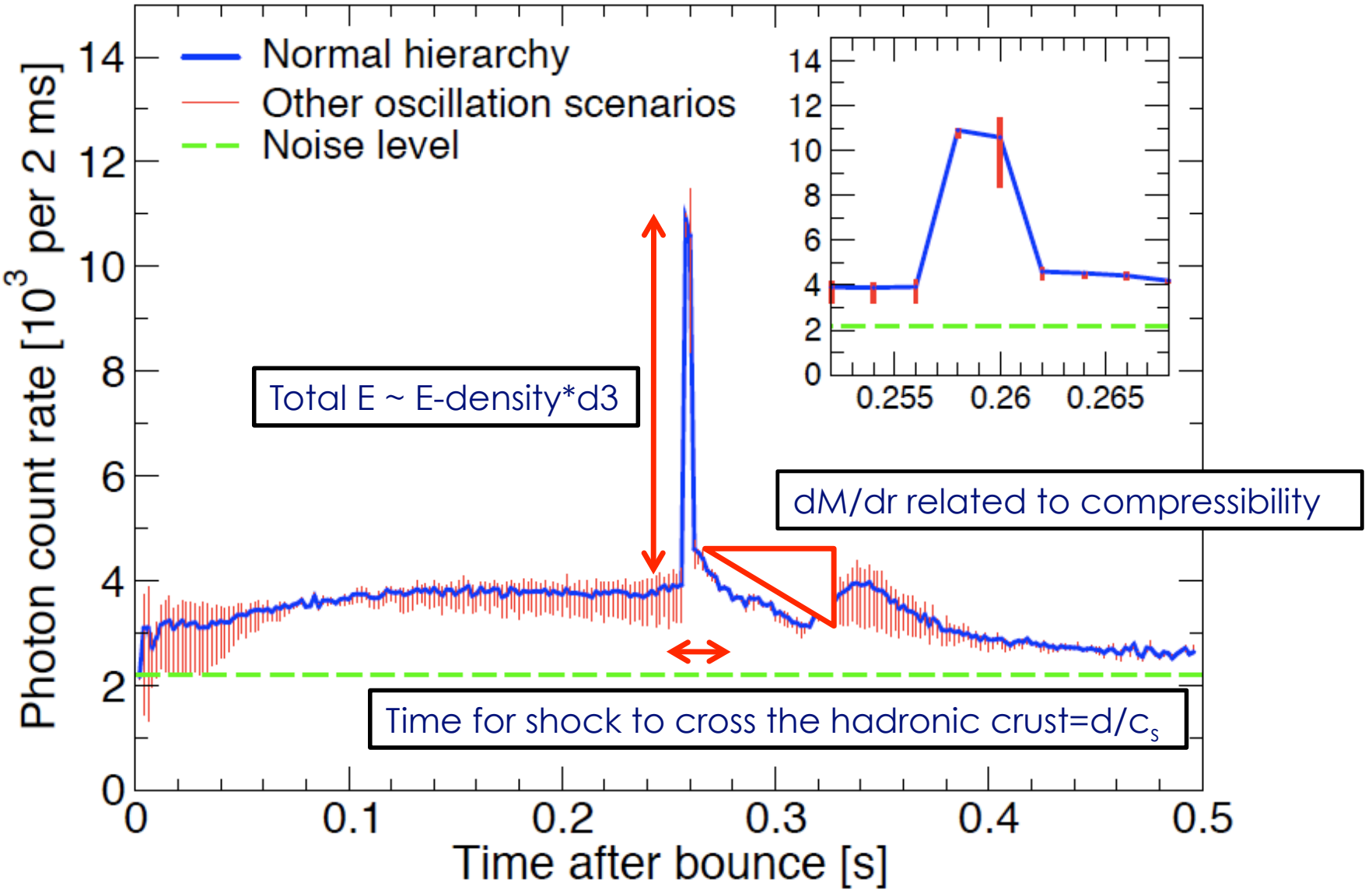


Thanks for discussions: Beacom and Halzen

Signal at Super-Kamiokande



What could we learn?



Implications

- Detection of SN
- Some phase transition/quick release of energy
- Early transition, and with large release of energy
- Constraints between ε, κ, c_s at Hadron/Quark matter phase transition
- We can constrain these models or falsify them (Or could some other phase transition also mimic this signal ???)

Thanks!!!