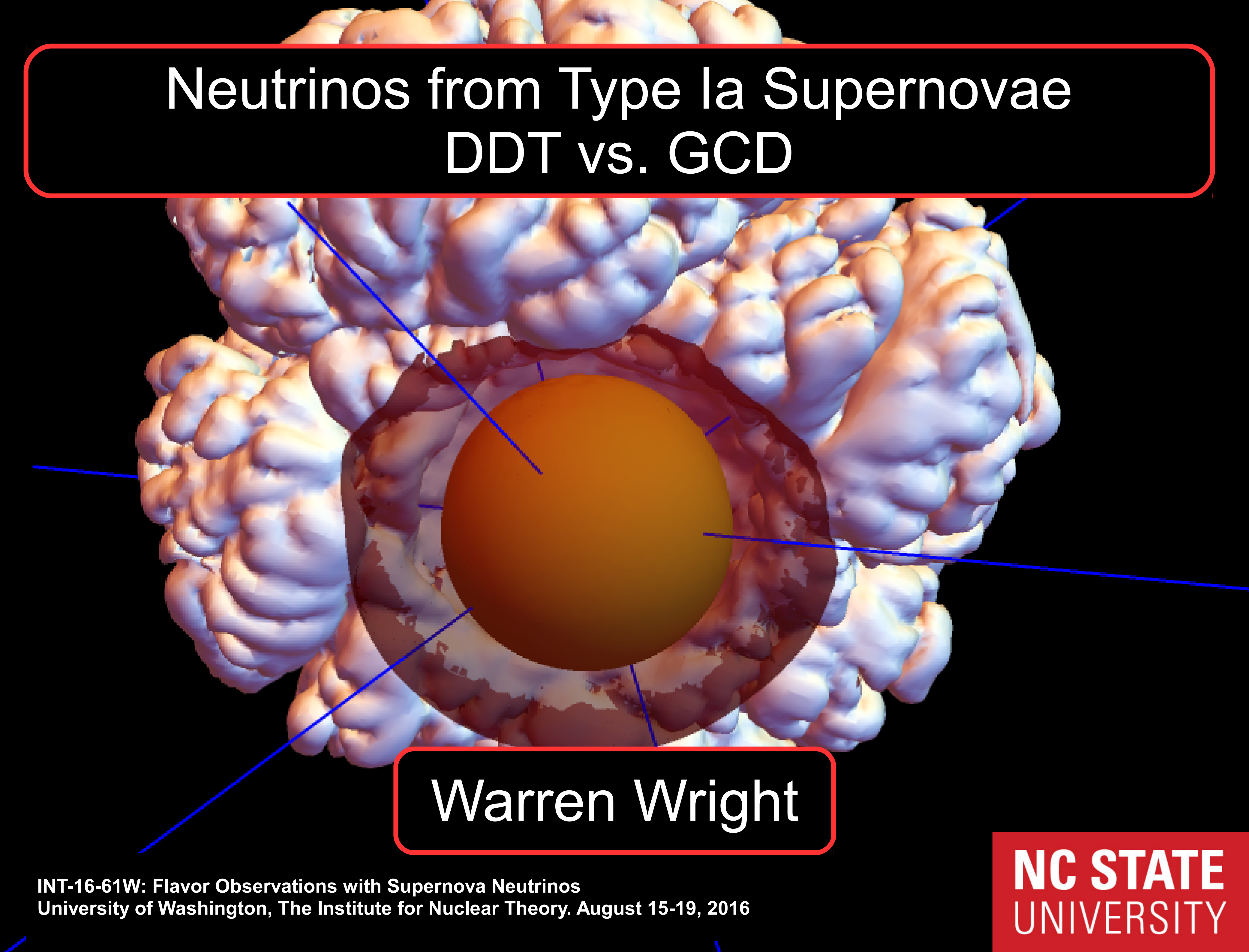
Neutrinos from Type Ia Supernovae
DDT vs. GCD



Warren Wright

INT-16-61W: Flavor Observations with Supernova Neutrinos
University of Washington, The Institute for Nuclear Theory. August 15-19, 2016

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- Motivation
- Method
  - Production
  - Oscillation
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Collaborators:
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Thanks to:
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Papers:
- PRD 94, 025026
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Motivation

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Neutrinos from Type Ia Supernovae DDT vs. GCD

Conference focus:

Supernova neutrinos …
carry unique flavor information …
crucial for understanding:

- neutrino oscillations
- explosion mechanism
- Nucleosynthesis

Motivation

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Why Type Ia?

SNeIa useful for:
- Standard candles
- Universe expansion measurements

We don't know the
- progenitors
- explosion mechanism

The Galactic SN Ia rate as given by Adams et al.
- $1.4^{+1.4}_{-0.8}$ per century
- and is 30% of the total supernovae rate

Astrophys. J. 778, 164 (2013)

SNeIa neutrinos could give explosion mechanism

Motivation

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Why is determining the explosion mechanism hard?

- Pure Detonation: Too little intermediate mass elements
- Pure Deflagration: Hard to explode

Available Explosion Mechanisms

- Delayed-Detonation Transition model (DDT)
- Gravitationally Confined Detonation model (GCD)
- Pure Turbulent Deflagration model (PTD)
- Pulsational (Reverse) Detonation (PD/PRD)
- ...

Leung *et al* (1507.08549)

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Method: Production

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Start with → **Seed Deflagration**

Carbon Oxygen White Dwarf

$$M = 1.4\ \mathrm{M_{Sun}}$$

$$\rho_{\mathrm{center}} = 2.9 \times 10^9\ \mathrm{g/cm^3}$$

$$r = 2 \times 10^8\ \mathrm{cm}$$

$$T = 5 \times 10^5\ \mathrm{K}$$

$$Y_e = 0.498886$$

Seed Deflagration

↓ DDT: 100
GCD: 1

Hydro Evolution

↓ Thermonuclear
SN code: LEAFS

Detonation Transition

↓ Different for
DDT and GCD

NuLib

Seitenzahl *et al.*
MNRAS.429.1156S (2013)
A&A (2016) or arXiv:1606.00089

Production: DDT

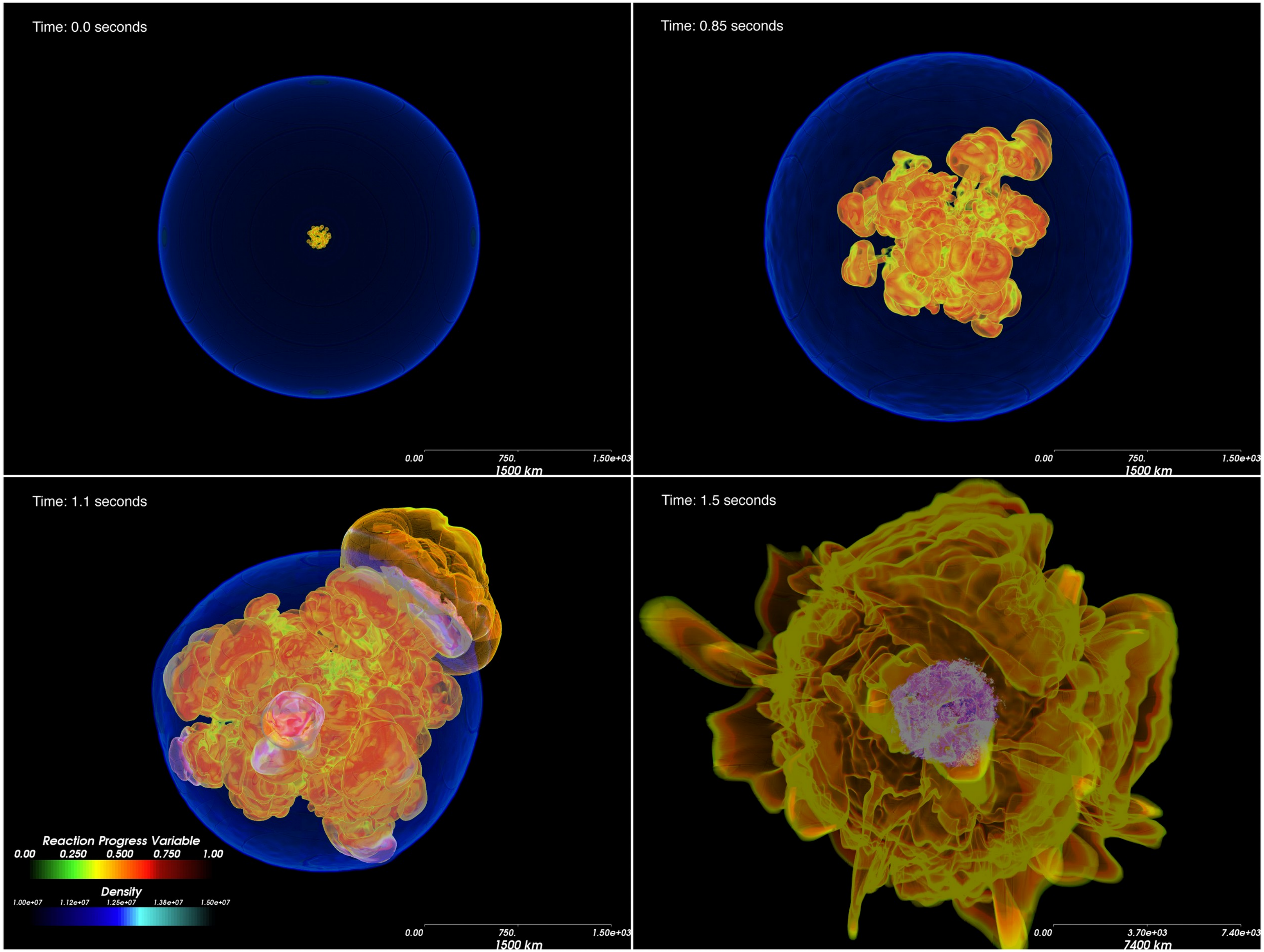

Image Credit: http://www.flash.uchicago.edu/site/gallery/stills/Supernovae/DDT/ASCFlashCenter_DDT_8km63_4panel_FLAMEDENS.jpg

Production: GCD

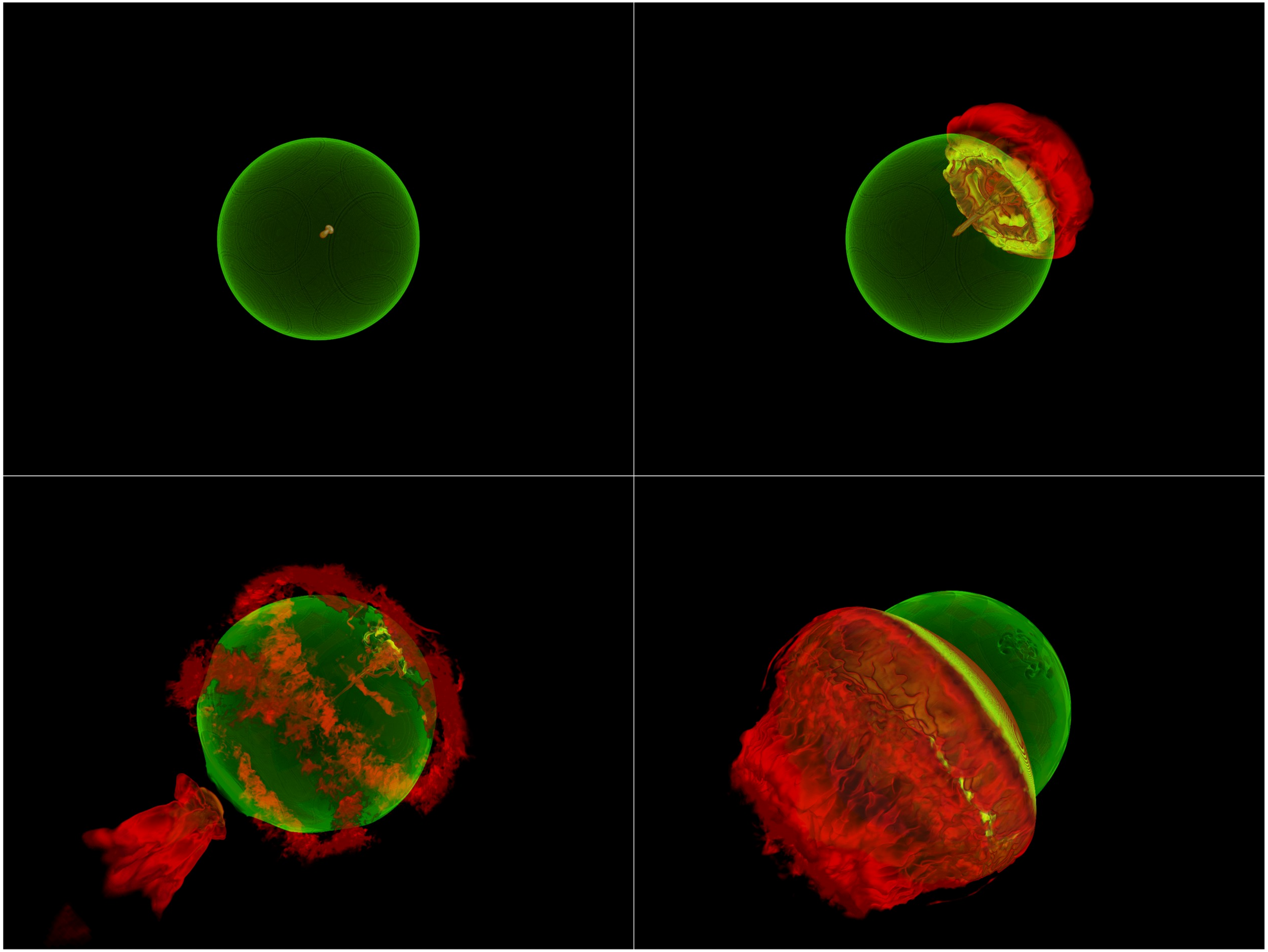

Image Credit: http://www.flash.uchicago.edu/site/gallery/stills/Supernovae/GCD/ASCFlashCenter_GCD_4panel_TEMPDENS.jpg

Neutrino Production

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Assumptions:

- Only cells in NSE (T9>3) produce neutrinos.
- Neutrinos are only produced by:
  - electron or positron capture on nuclei or nucleons (weak)
  - electron positron annihilation (thermal)

NuLib:

- Postprocess simulation to get emissivity spectra.
  - Weak: Effective neutrino spectra with average energy chosen to match tabulated rates
  - Thermal: From Burrows, Reddy and Thompson

Sullivan *et al.* (1508.07348)
Burrows *et al.* (astro-ph/0404432)

Production: DDT

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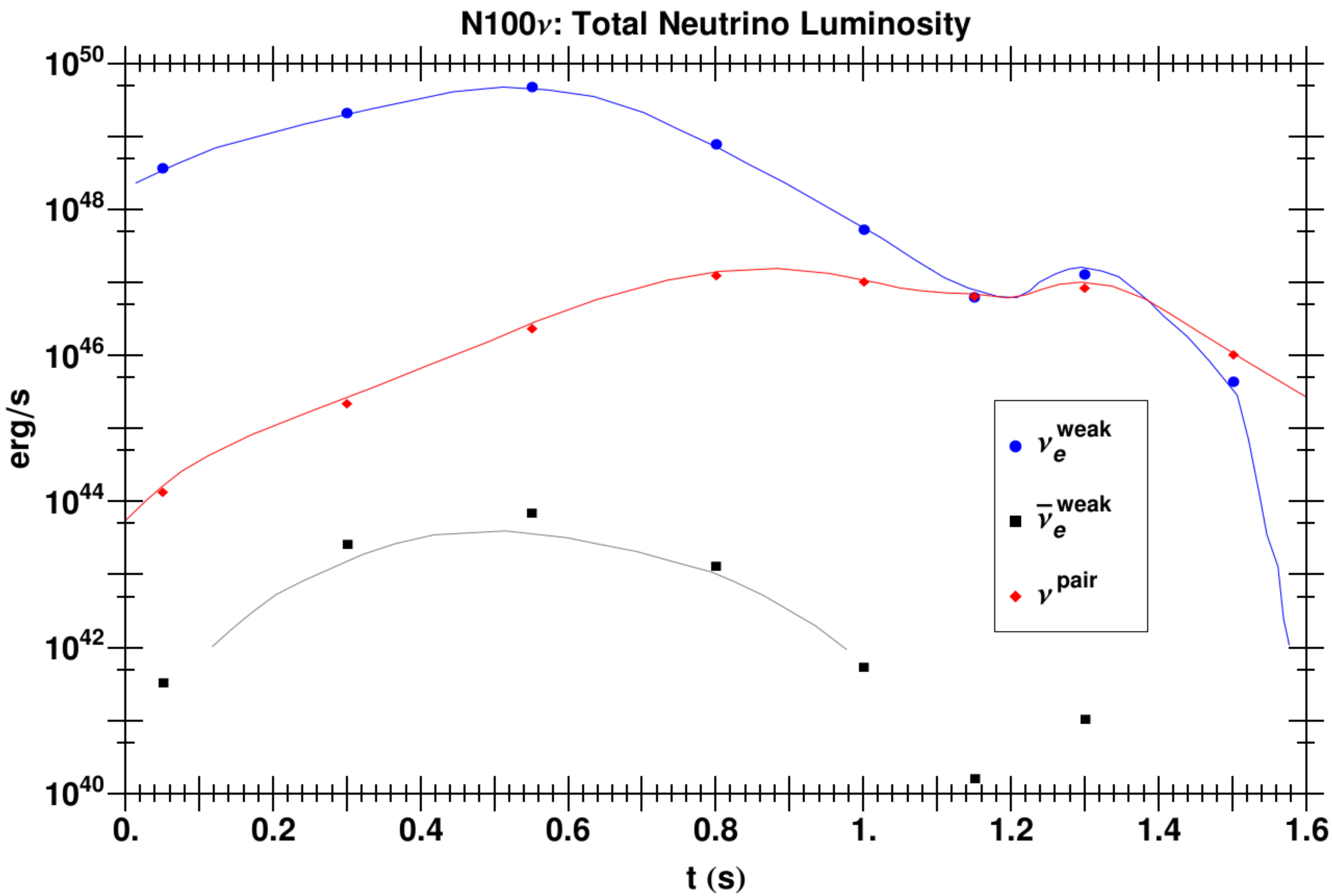

Phys. Rev. D 94, 025026

Production: DDT vs GCD

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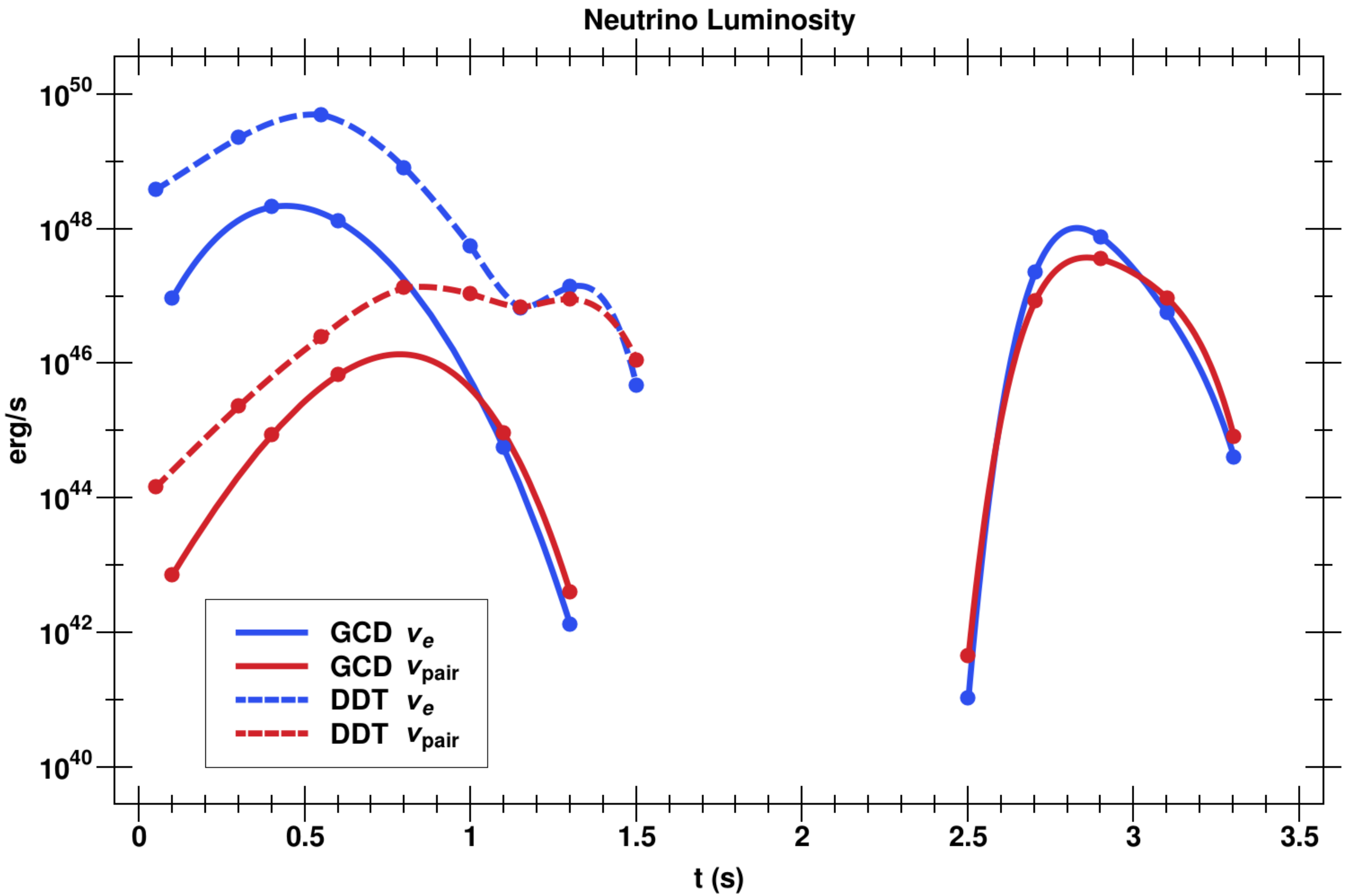

Production: DDT Spectrum

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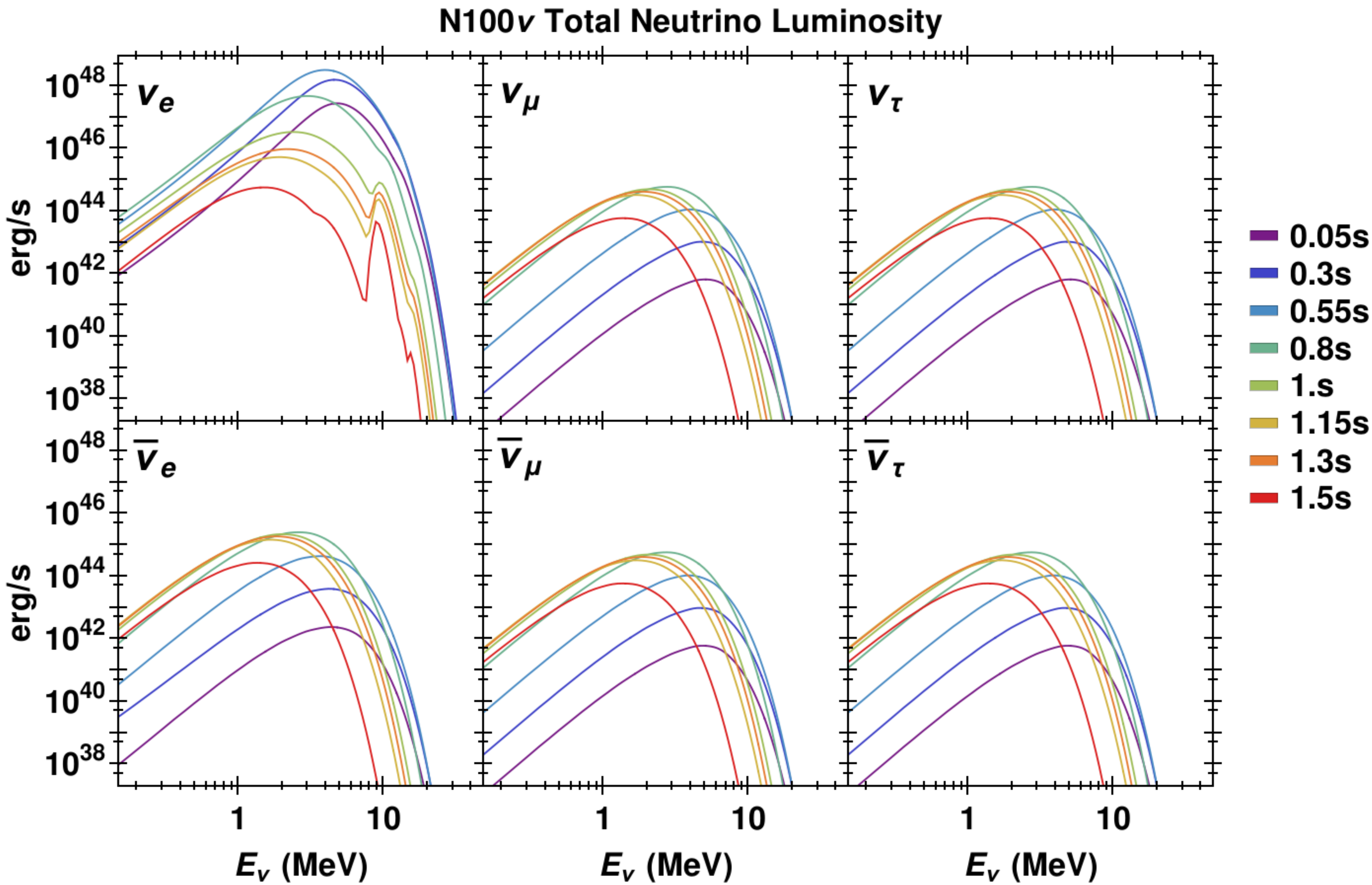

Production: DDT Spectrum

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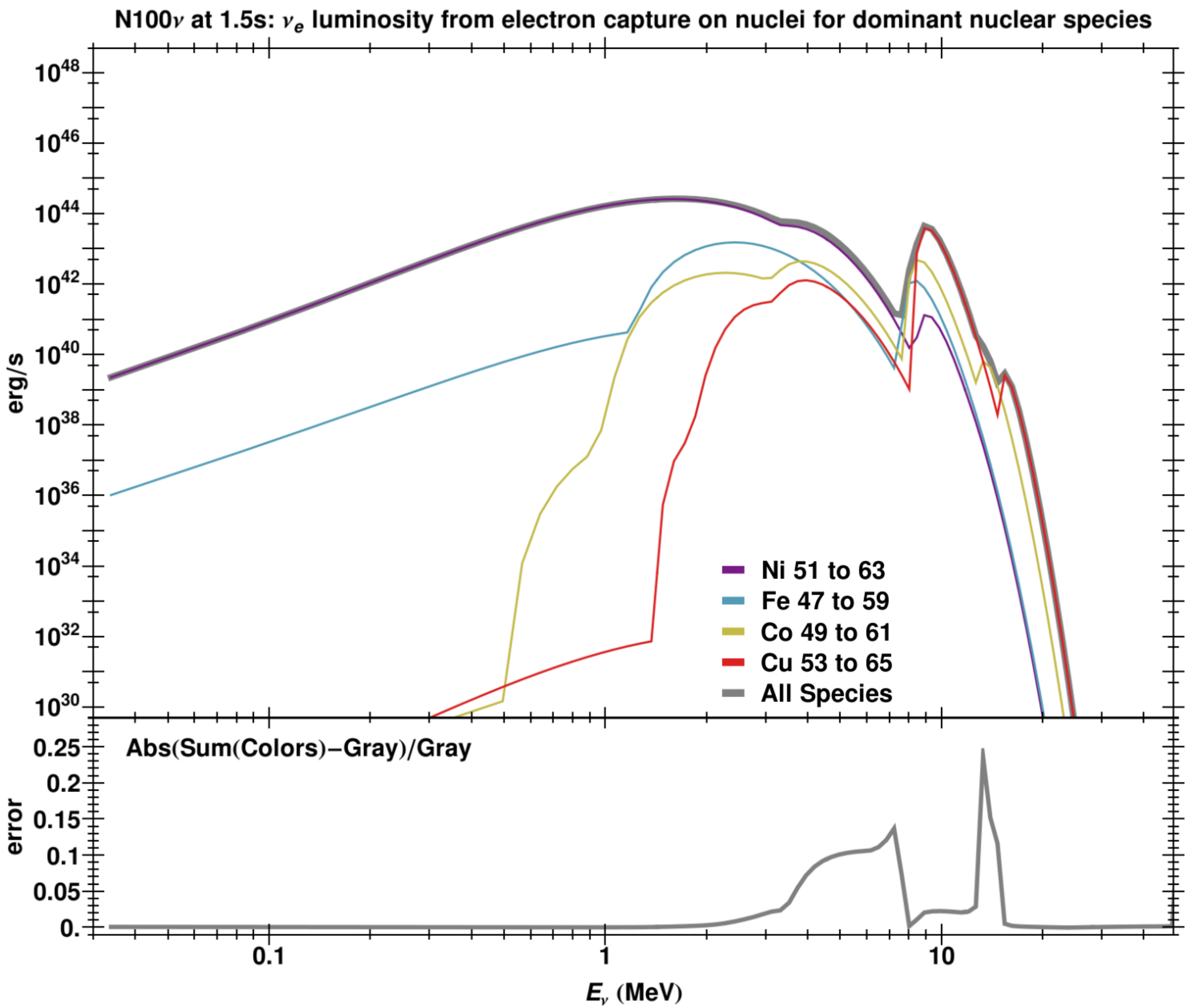

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Oscillated Flux

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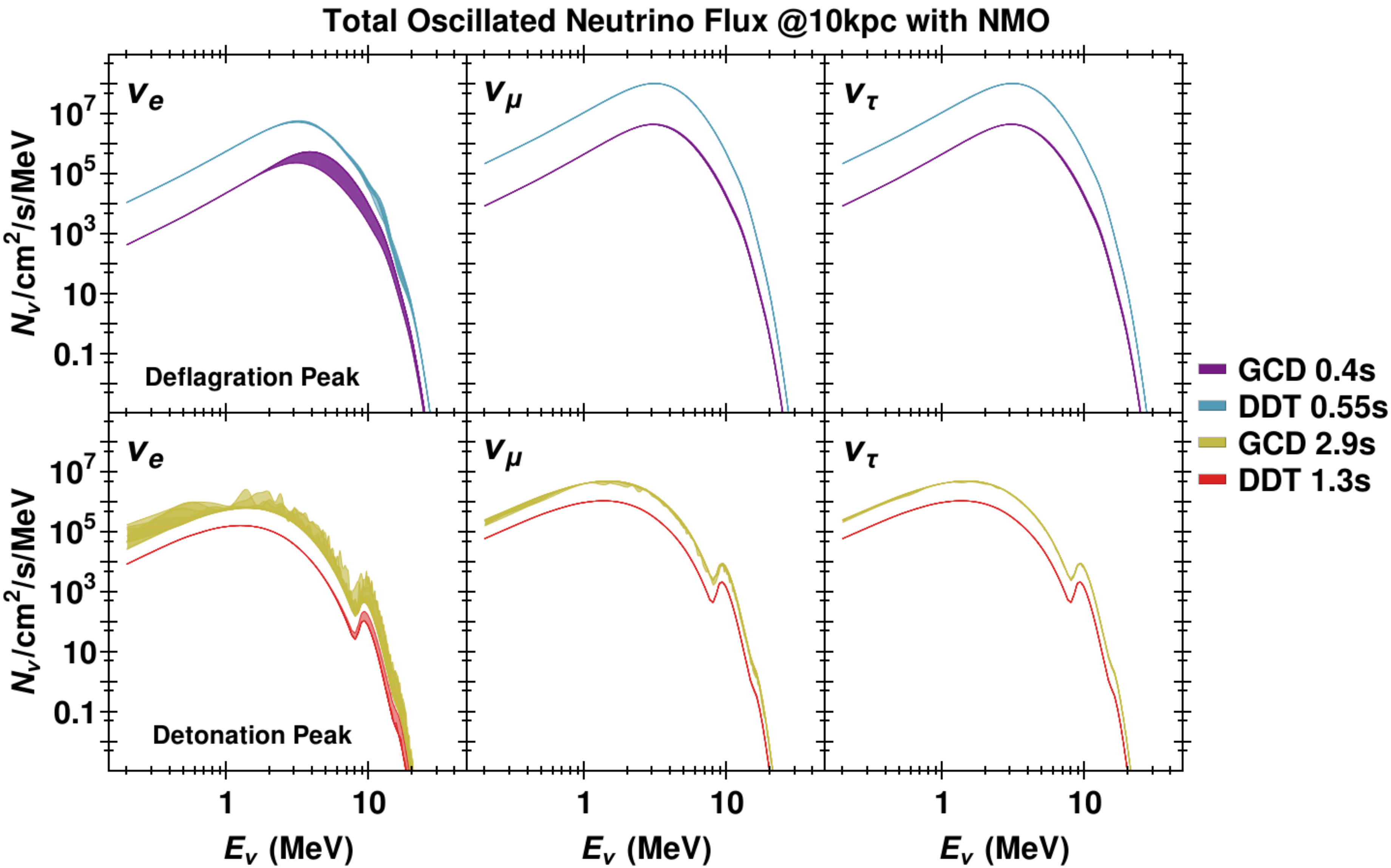

just MSW non-adiabatic density discontinuities

Oscillation Probabilities

Main Neutrino Oscillation Effects:

1)Introduce line-of-sight dependence

2)Generally oscillate ν_e into ν_μ & ν_τ

3)Mix spectral features

4)Non-Adiabatic

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Interaction Events

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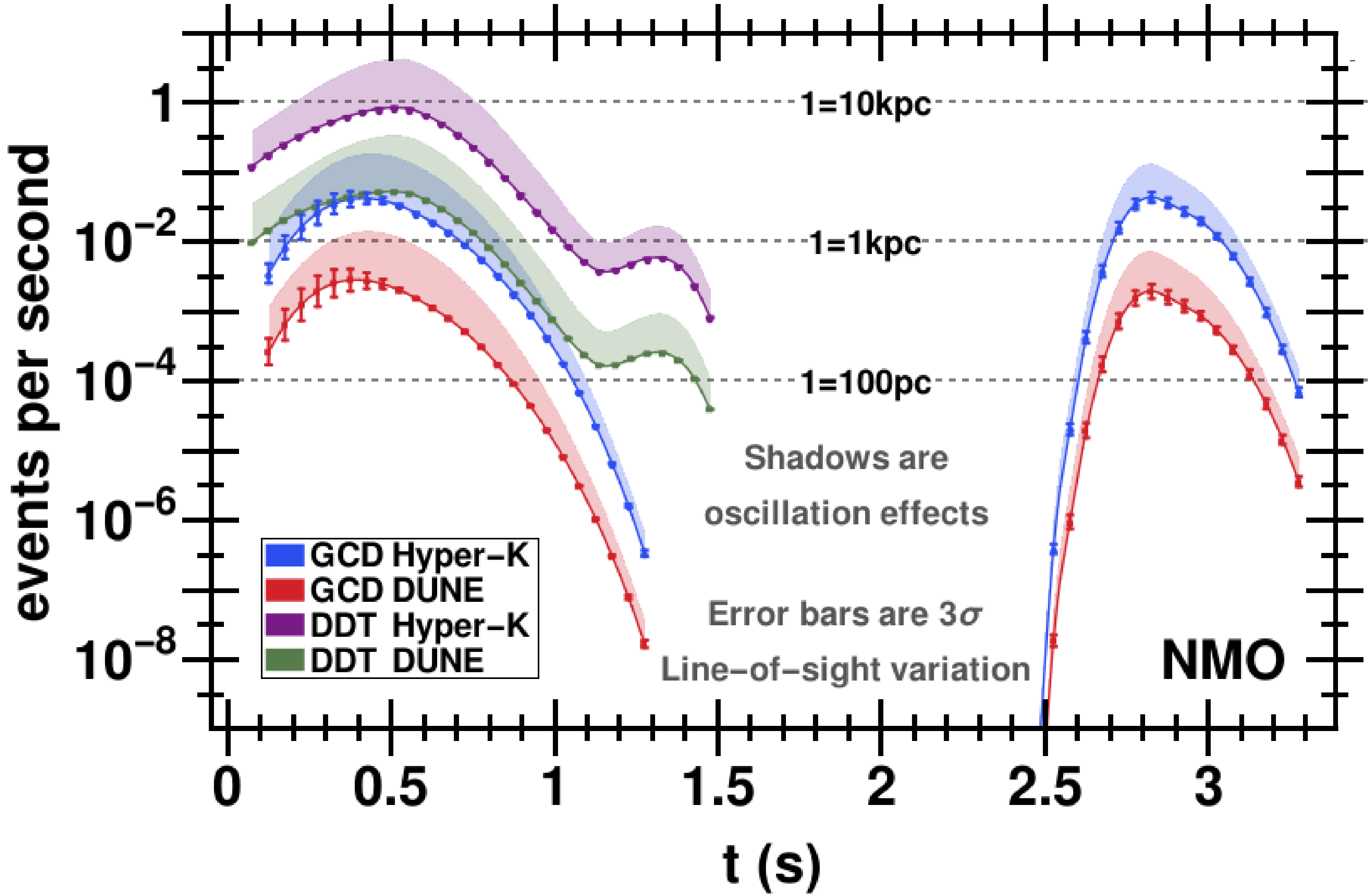

Using SNOwGLoBES Energy Integrated

Interaction Events

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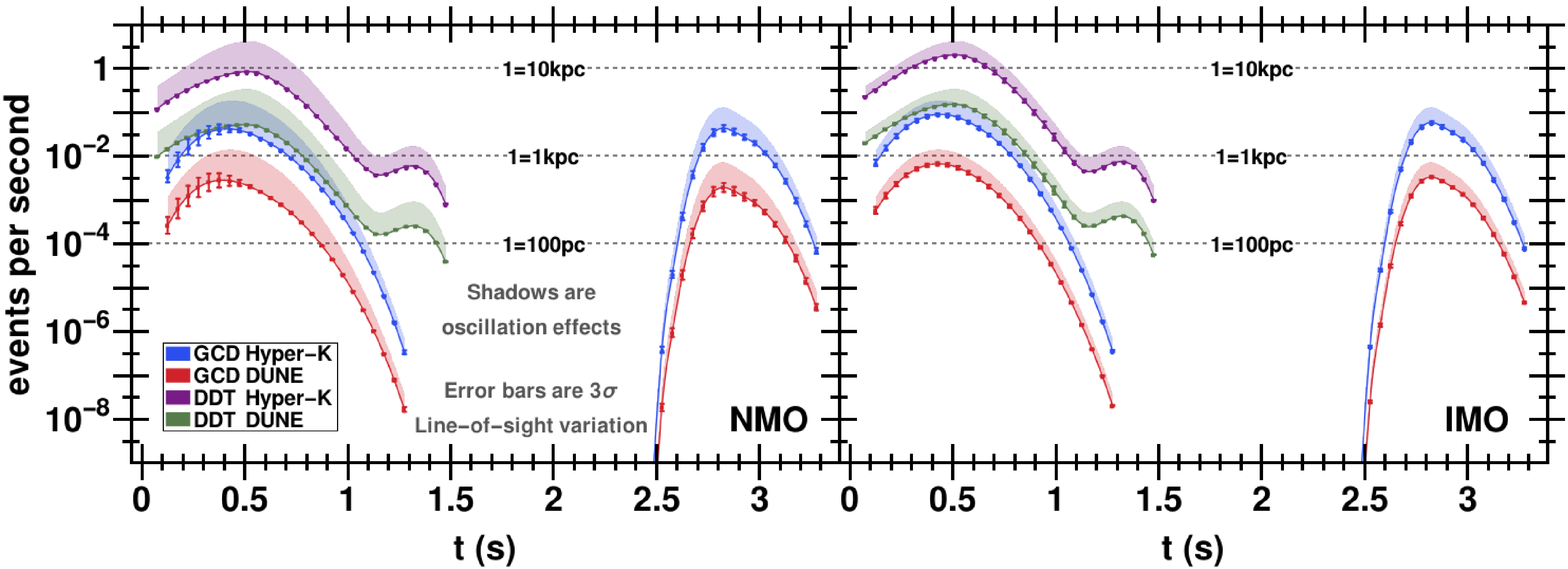

Detection Summary

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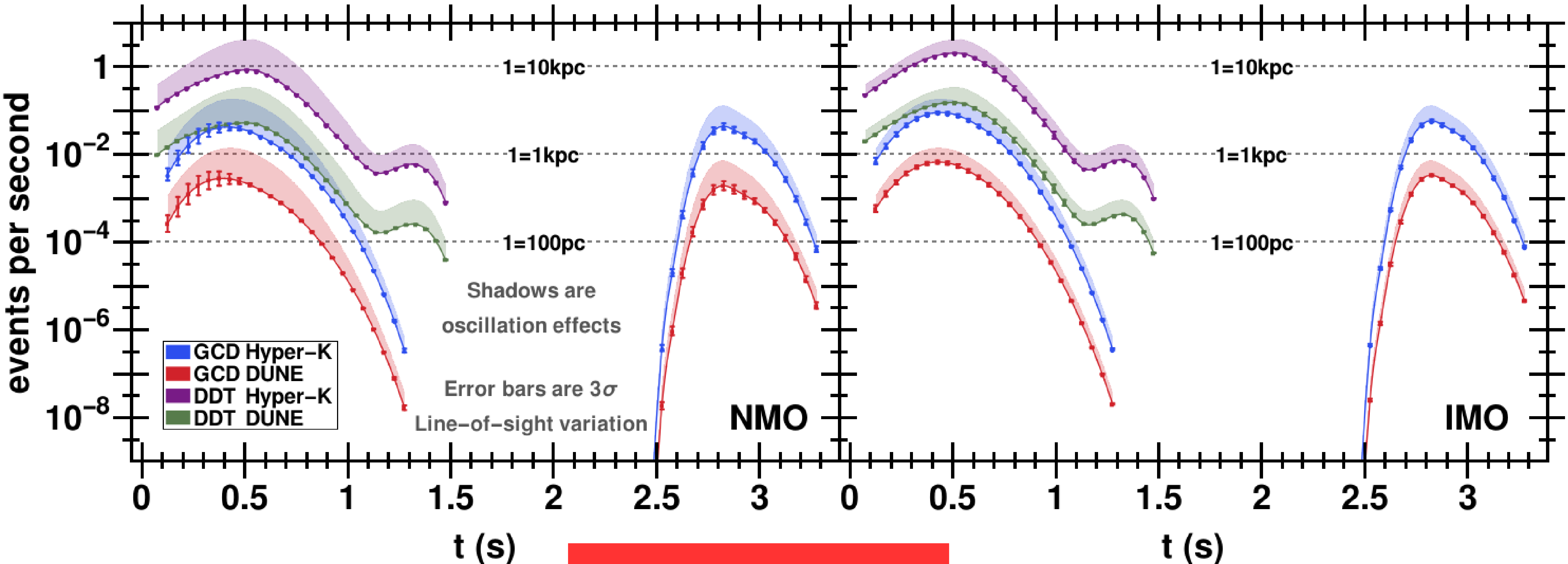

DDT vs. GCD:

1) Geometry ✘
2) Luminosity ✔
3) Timing ✔

SNeIa needs D < 1kpc for Hyper-K to classify a SN as GCD or DDT

Conclusion

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- Type Ia Supernova are:
  - Universe defining
  - "Frequent" — 30%
  - Have an unknown explosion mechanism
- SNeIa neutrinos can help determine the explosion mechanism.
- Discrimination by:
  - Total event rate: SNeIa within 1kpc @ Hyper-K — Threshold?
  - Spectral features: need next^2 gen detectors

Thank you

Backup

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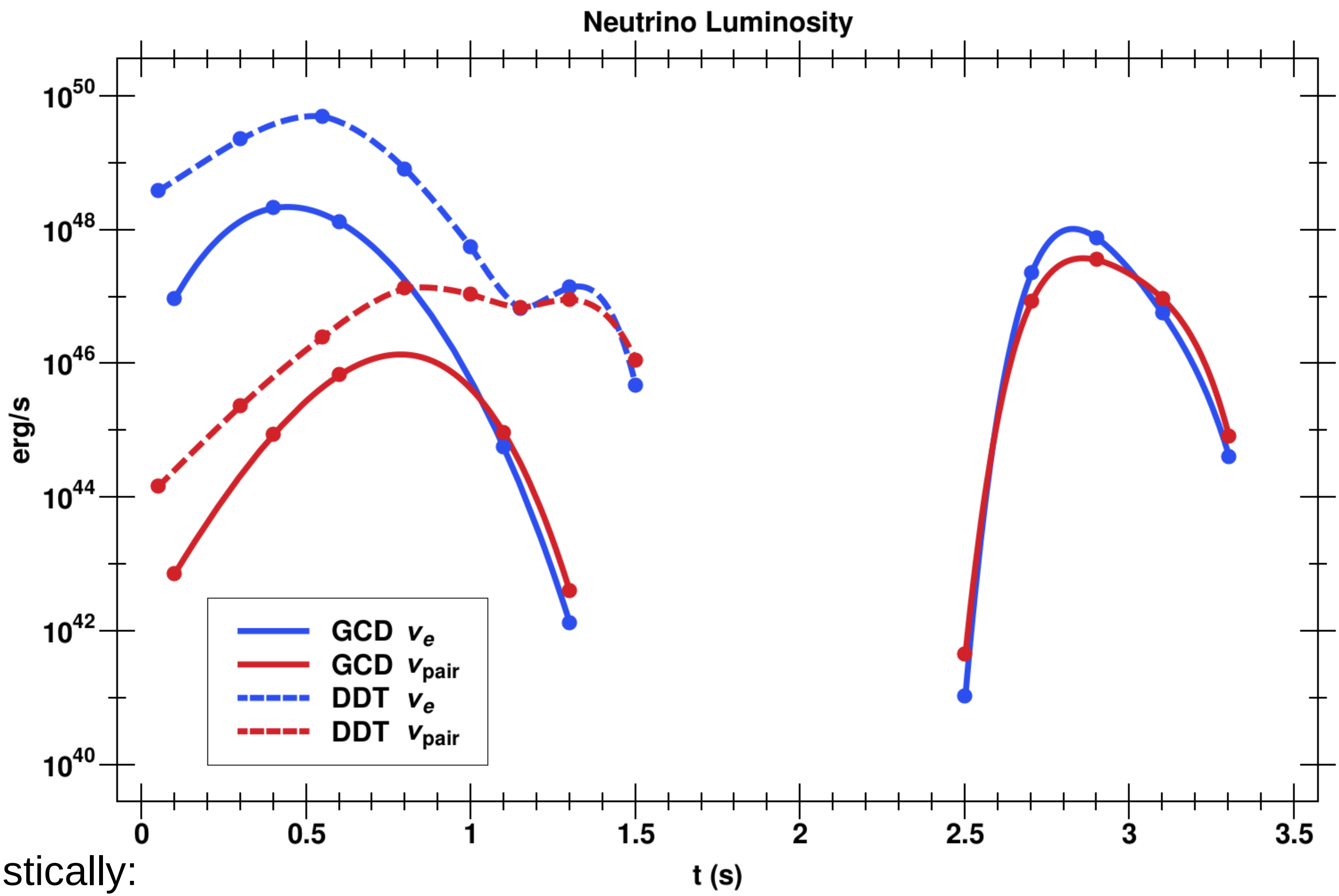
Result Summary



Optimistically:

SNeIa needs D < 1kpc for Hyper-K to classify a SN as GCD or DDT

Method: Production

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Start with:

2 Carbon Oxygen White Dwarfs:

- Both with same mass, central density, radius, temperature, composition and electron fraction.
- Both start with seeded deflagration sparks: DDT: 100 & GCD: 1.
- Both hydrodynamically evolved with the thermonuclear supernova code LEAFS, on a 512^3 spatial grid.

$$M = 1.4\ \mathrm{M_{Sun}}$$

$$\rho_{\mathrm{center}} = 2.9 \times 10^9\ \mathrm{g/cm^3}$$

$$r = 2 \times 10^8\ \mathrm{cm}$$

$$T = 5 \times 10^5\ \mathrm{K}$$

$$Y_e = 0.498886$$

Different transition to detonation

Seitenzahl *et al.*
MNRAS.429.1156S (2013)
A&A (2016) or arXiv:1606.00089

Production: GCD Spectrum

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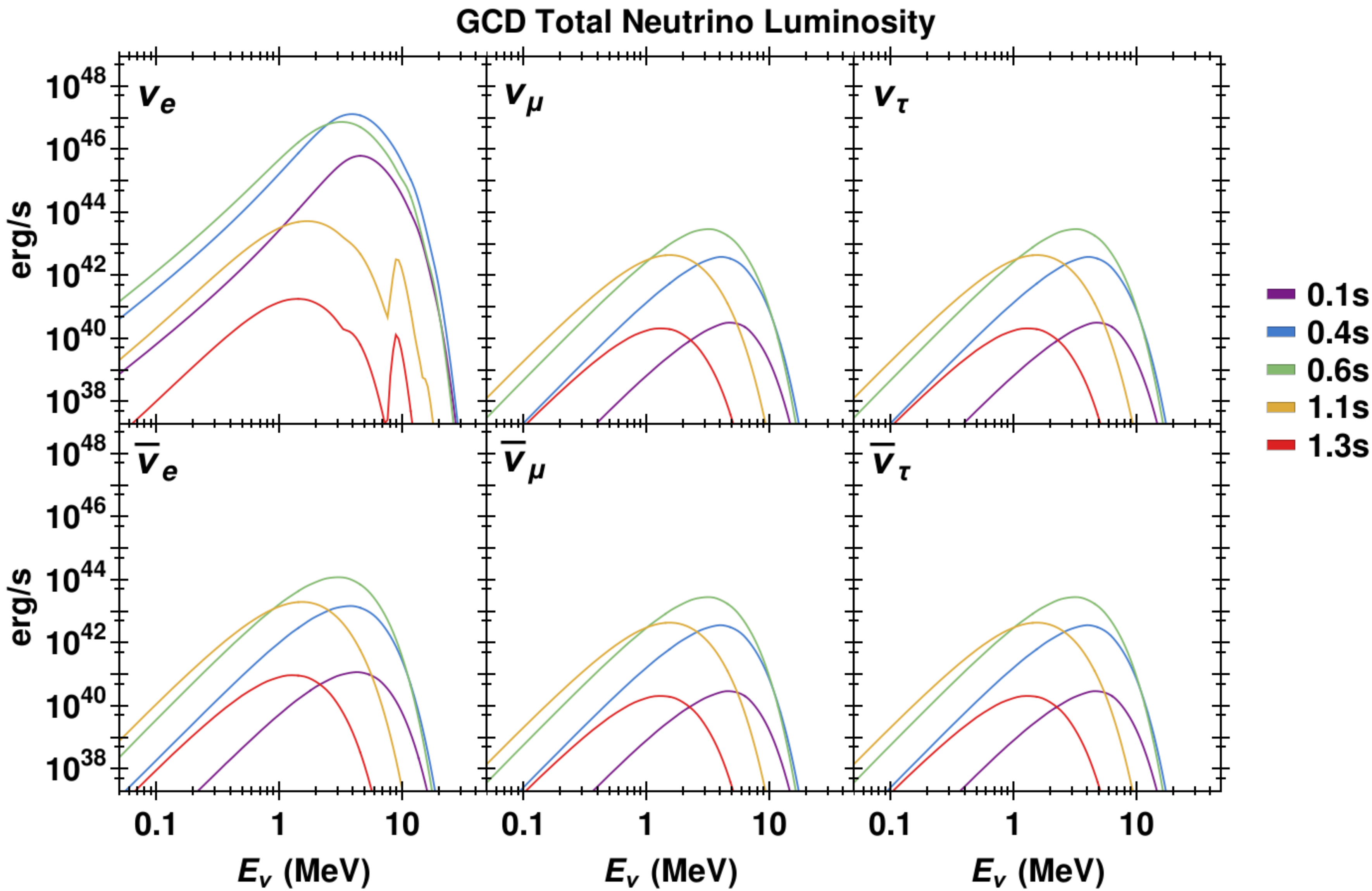
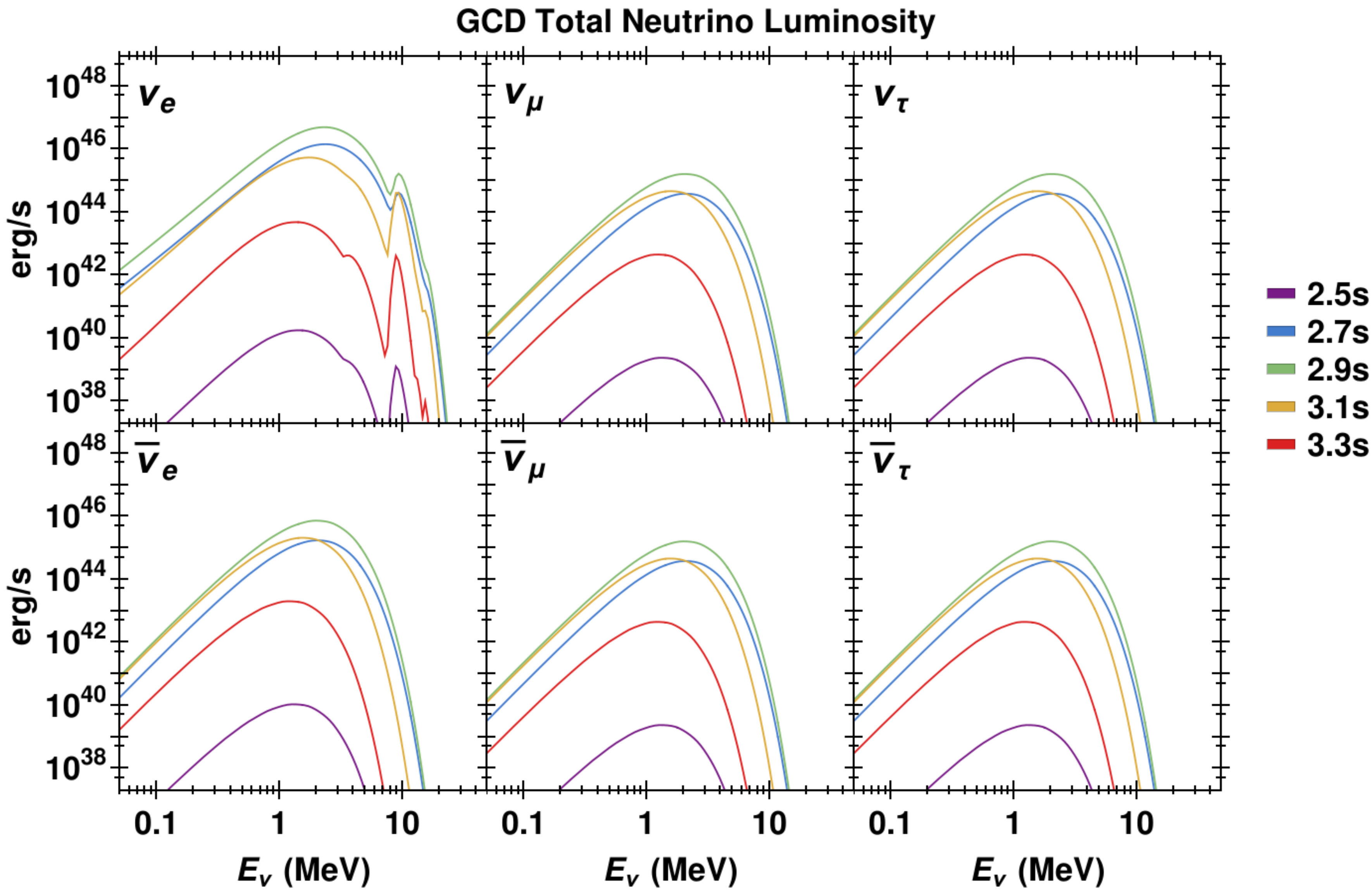


Production: GCD Spectrum



Production: DDT vs GCD

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Model	Deflagration time	Deflagration erg/s	Detonation time	Detonation erg/s	Total erg
DDT	0.53 s	5.1×10^{49}	1.32 s	2.3×10^{47}	2.0×10^{49}
GCD	0.45 s	2.3×10^{48}	2.82 s	1.8×10^{48}	1.2×10^{48}

DDT vs. GCD:
1) Geometry
2) Luminosity
3) Timing

Method: Oscillation

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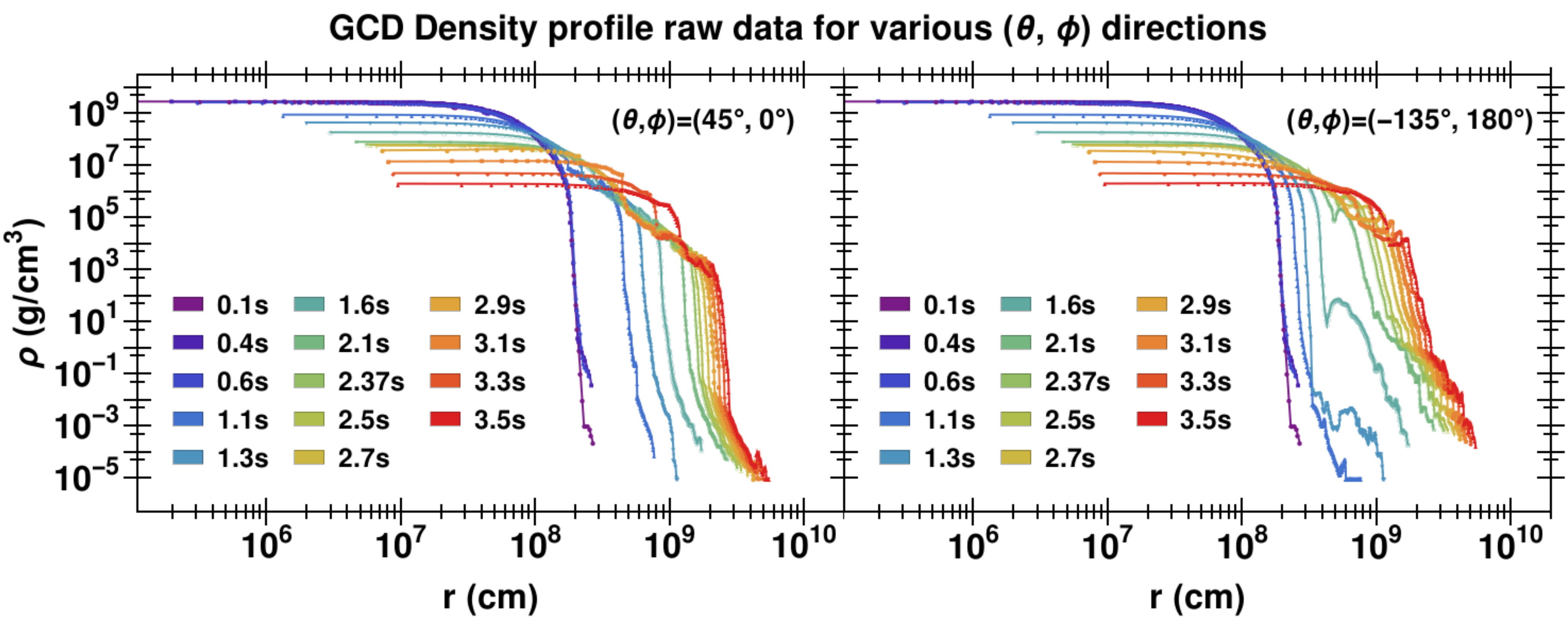
- Using hydro simulation data, retrieve density and electron fraction trajectories, (8 for DDT and 10 for GCD).
- Insert discontinuities at deflagration and detonation flame edges.
- Numerically calculate oscillation probabilities by solving the Schrödinger equation without assuming adiabatic evolution.

Oscillation



Oscillation Phenomenology

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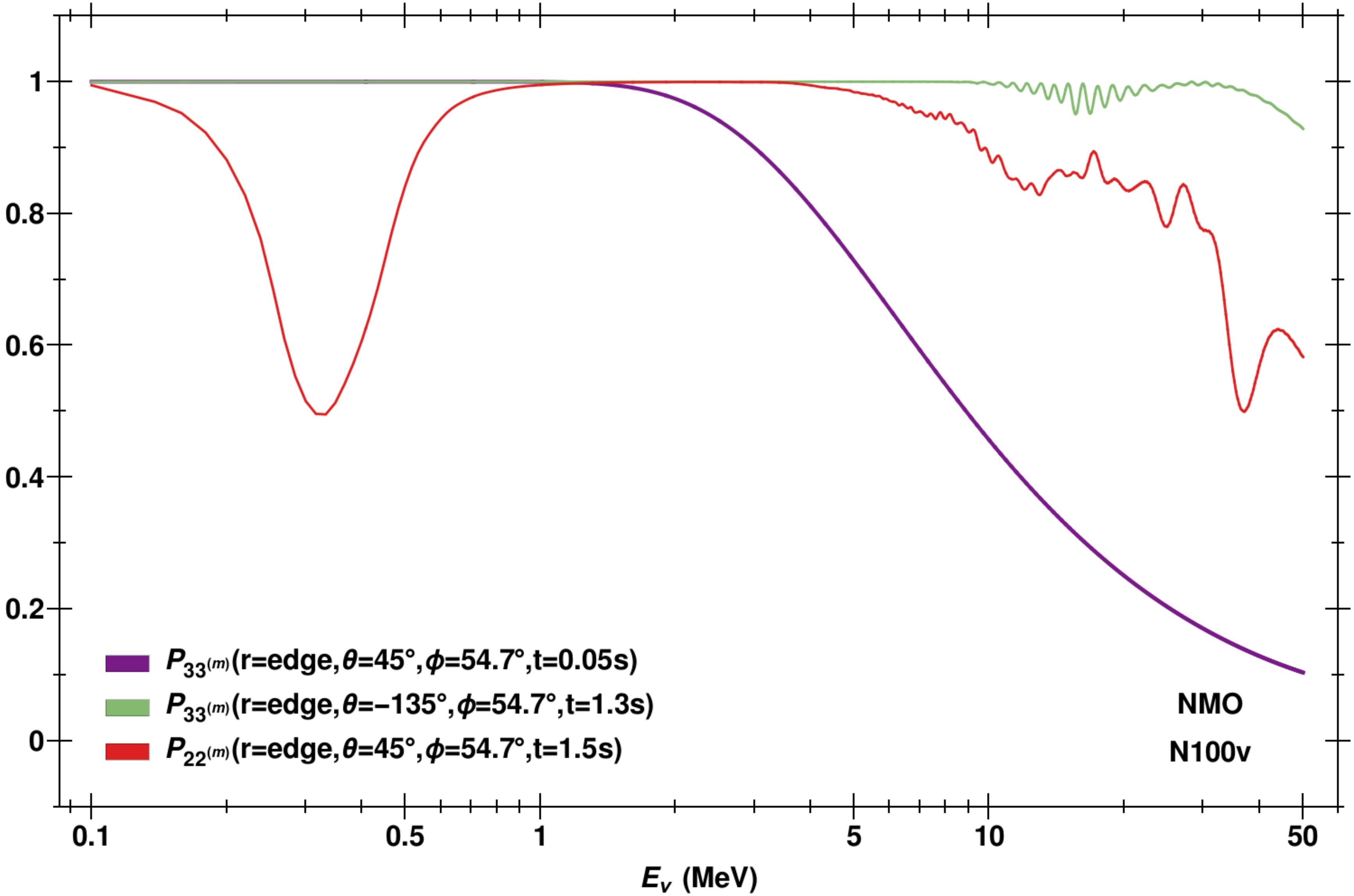

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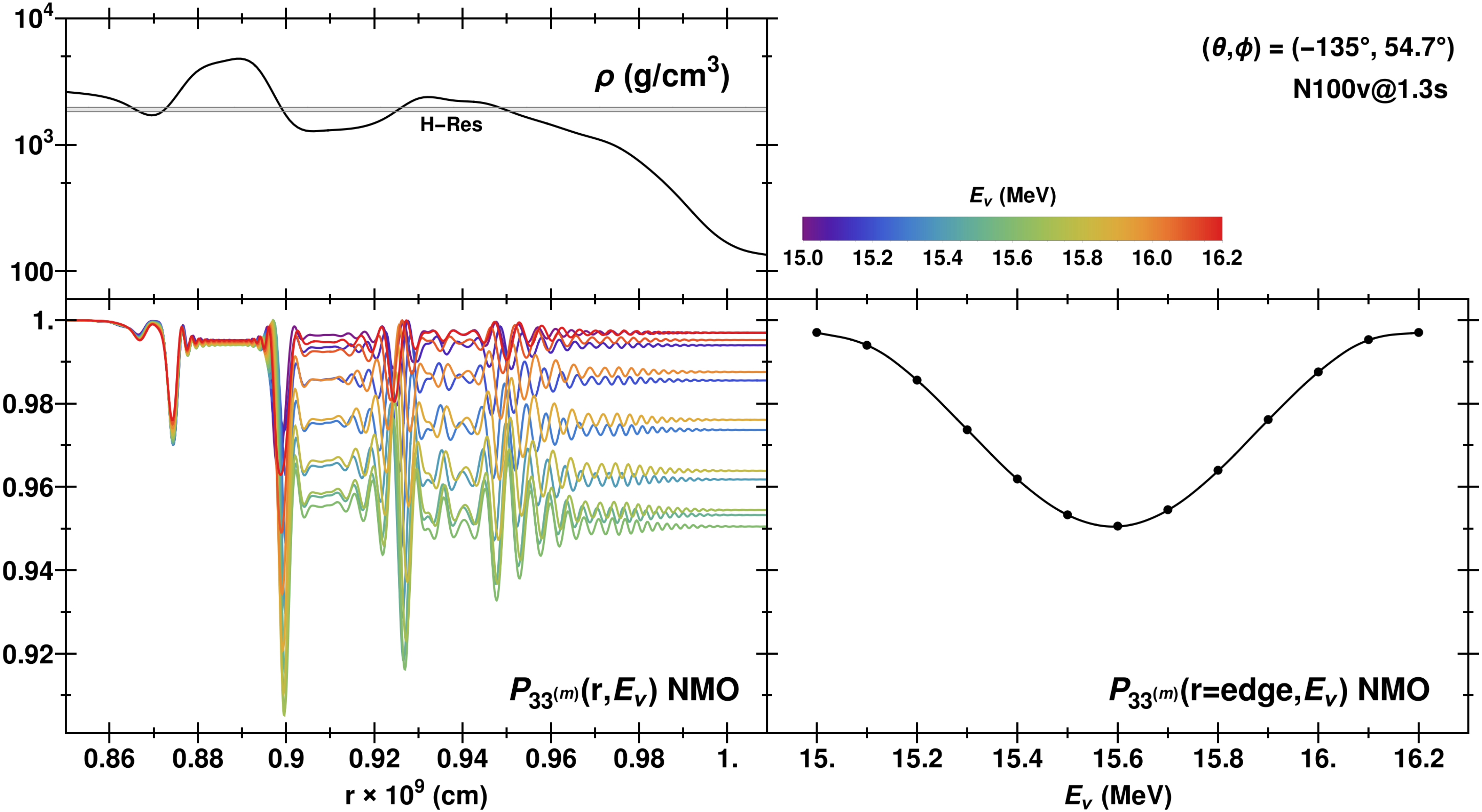

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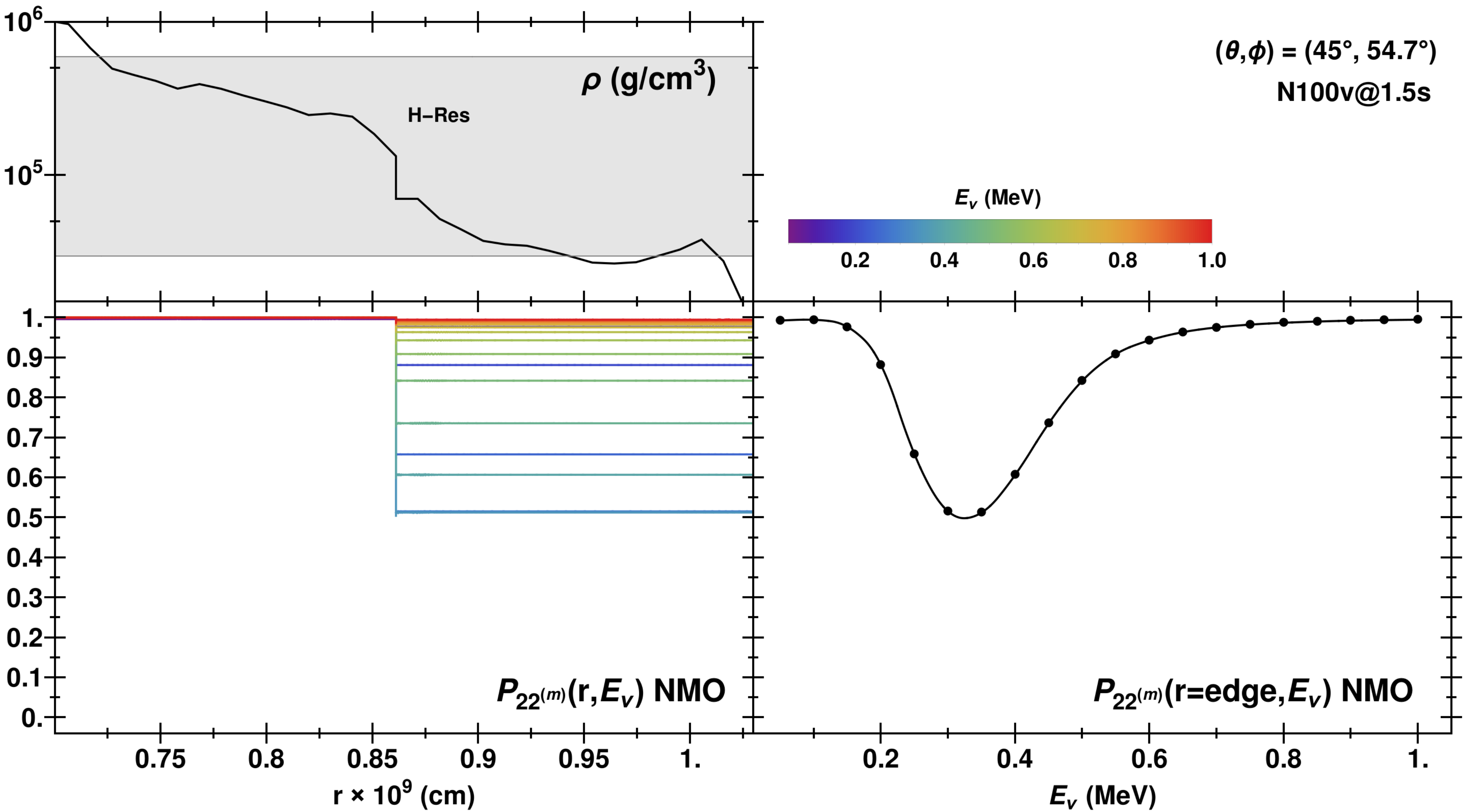

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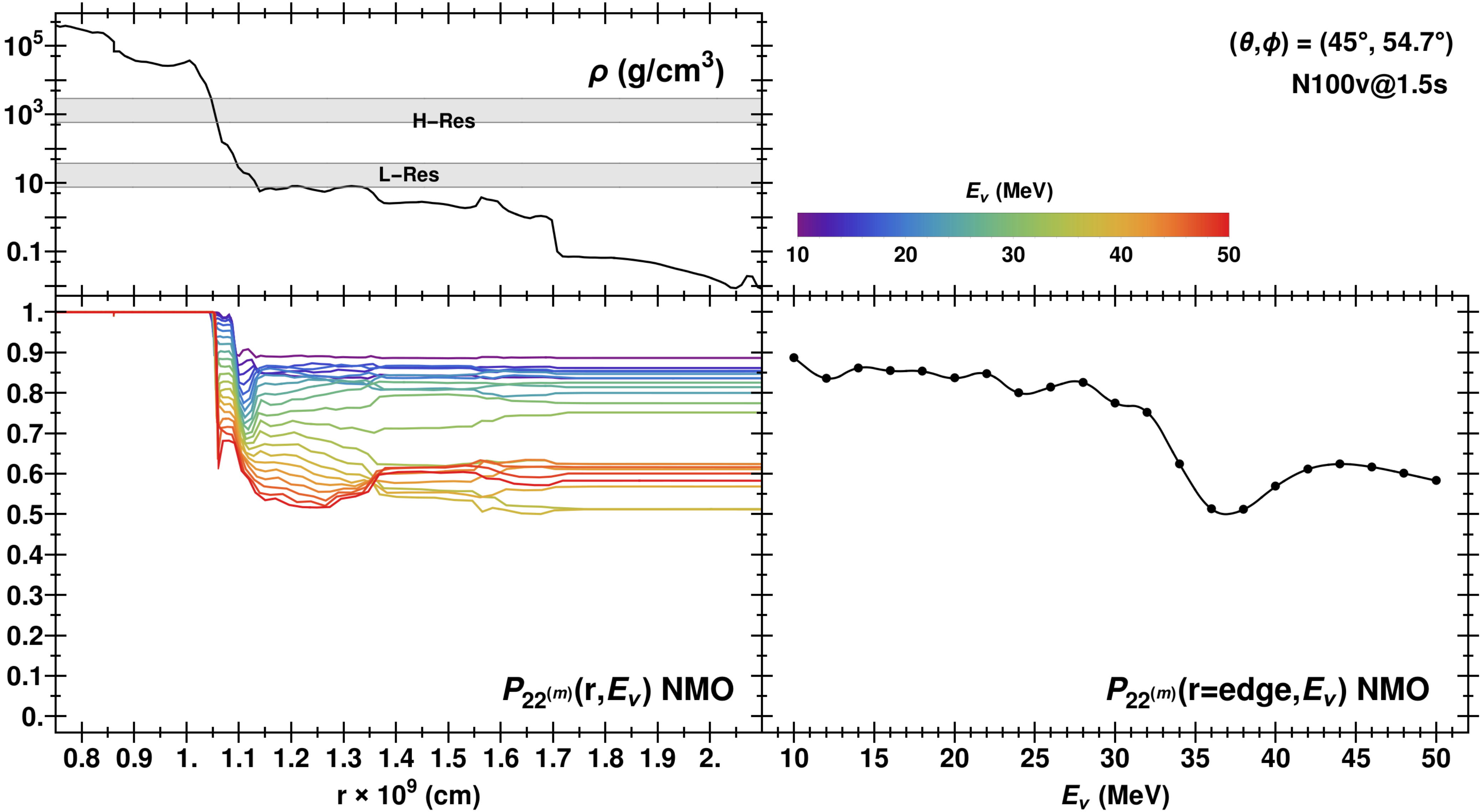

Oscillation Probabilities

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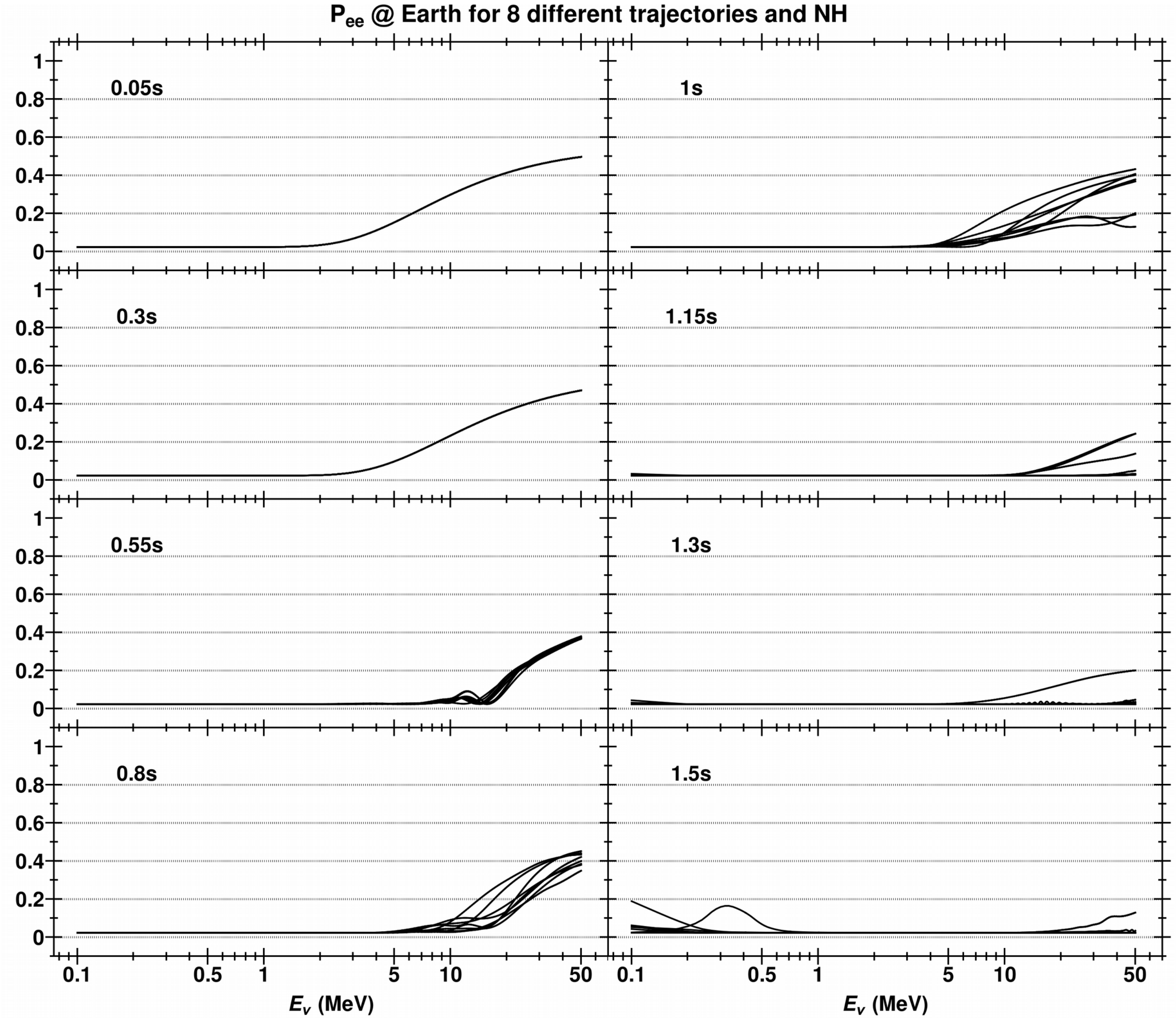
DDT



Oscillation Probabilities

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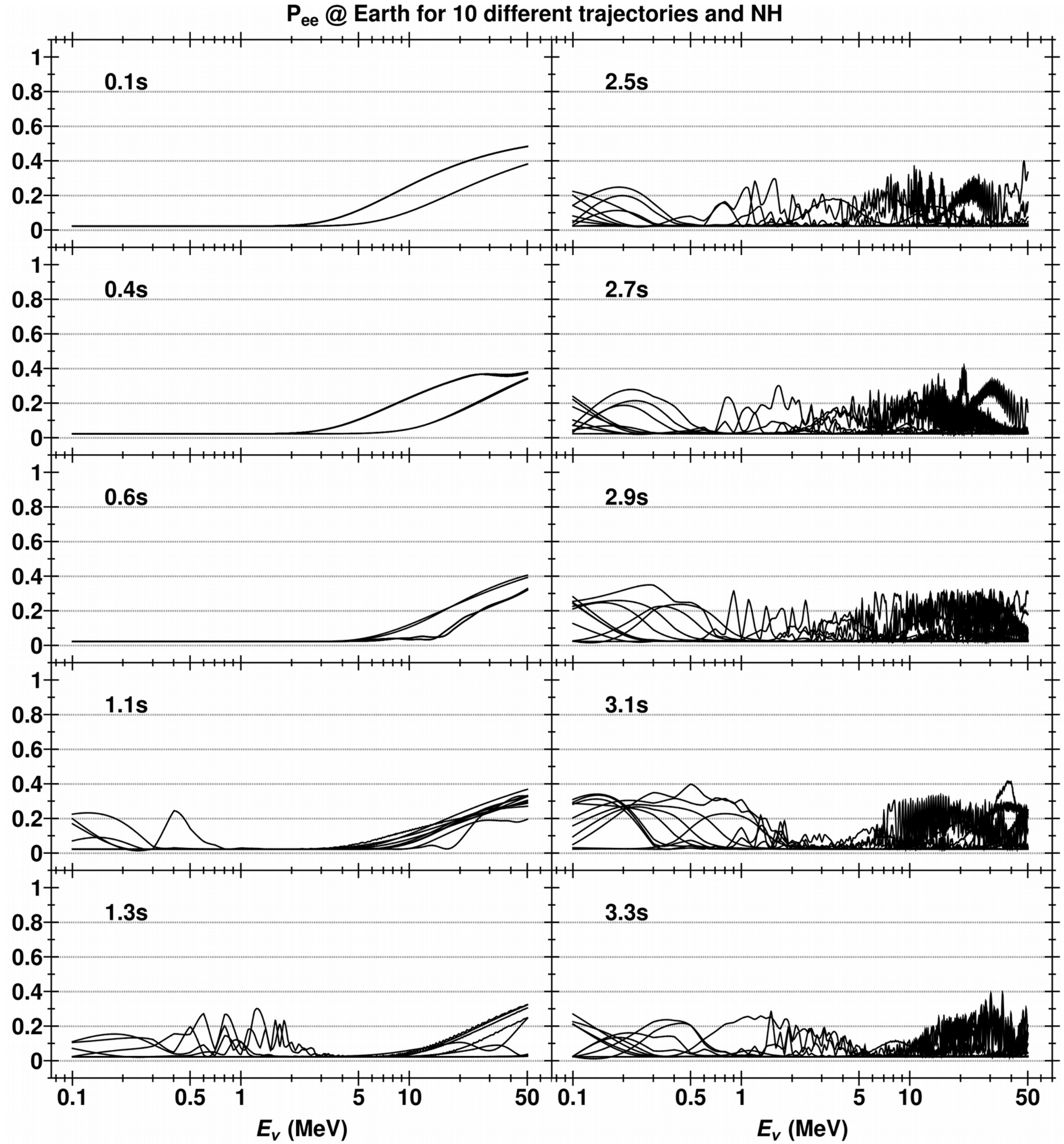
GCD



Detection

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- **Fold oscillation probabilities with luminosities to get the time, line-of-sight, energy, mass ordering, and flavor dependent neutrino flux on Earth.**
- **Use SNOwGLoBES to calculate the event rates in JUNO, Super-K, Hyper-K, and DUNE.**
- **Use the flux and calculate the low-energy event rate in IceCube and compare to background.**

Detector	**Type**	**Mass (kt)**
Super-Kamiokande like: 30% phototube coverage	Water Cherenkov	50
Hyper-Kamiokande like	Water Cherenkov	560
DUNE like detector	Liquid Ar	40
JUNO like detector	Scintillator	20
IceCube	Water Cherenkov	3500*

Interaction Events

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DDT

Detector	NMO	IMO	Unoscillated
Super-K	0.034	0.076	0.154
Hyper-K	0.378	0.868	1.725
DUNE	0.025	0.066	0.138
JUNO	0.014	0.032	0.063
IceCube*	0.286	0.660	1.320

GCD

Detector	NMO	IMO	Unoscillated
Super-K	0.002	0.004	0.009
Hyper-K	0.027	0.048	0.100
DUNE	0.002	0.003	0.007
JUNO	0.001	0.002	0.004
IceCube*	0.021	0.033	0.069

* Note that the numbers of interactions quoted for IceCube are after background subtraction

Interaction Events

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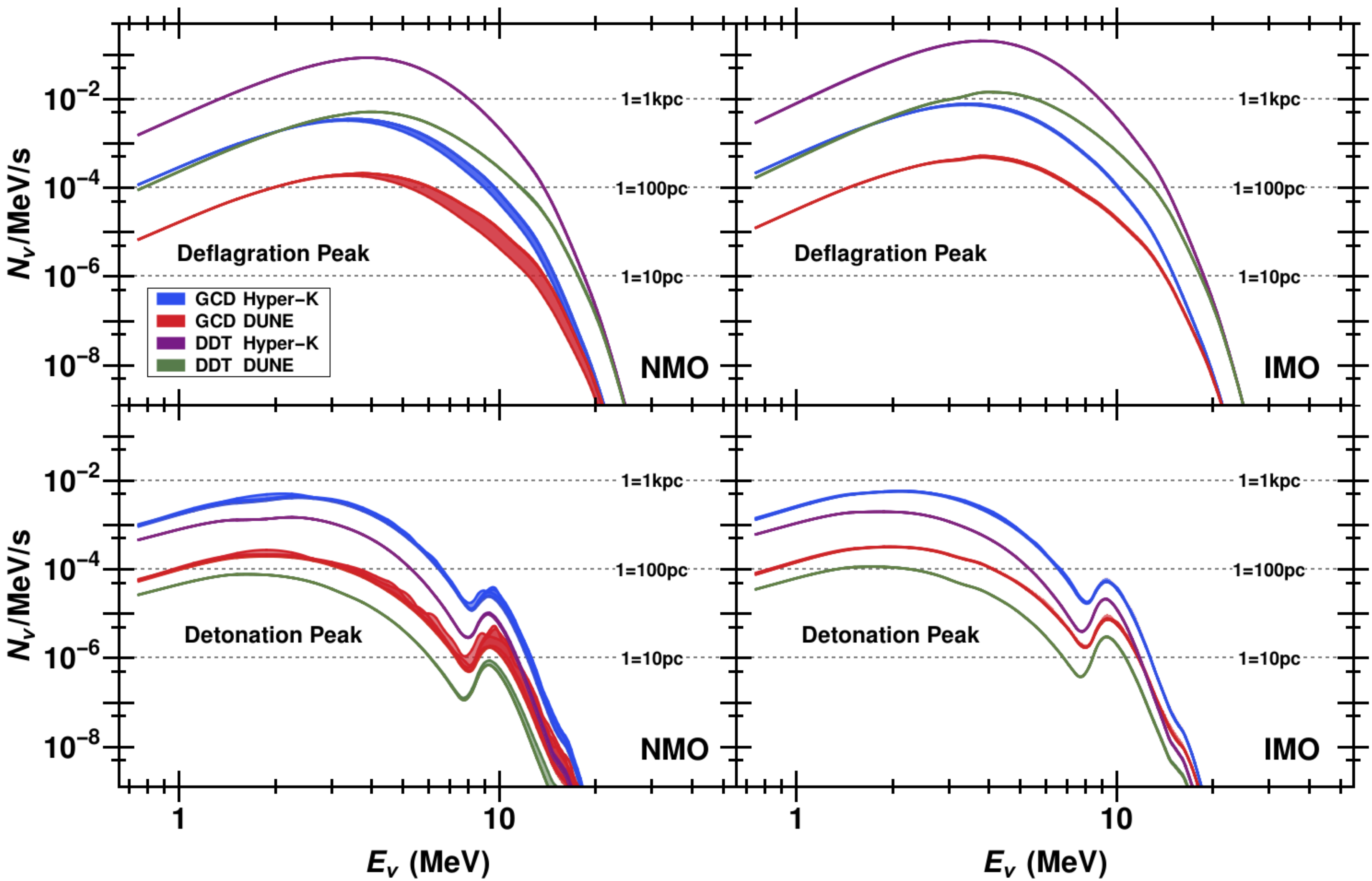
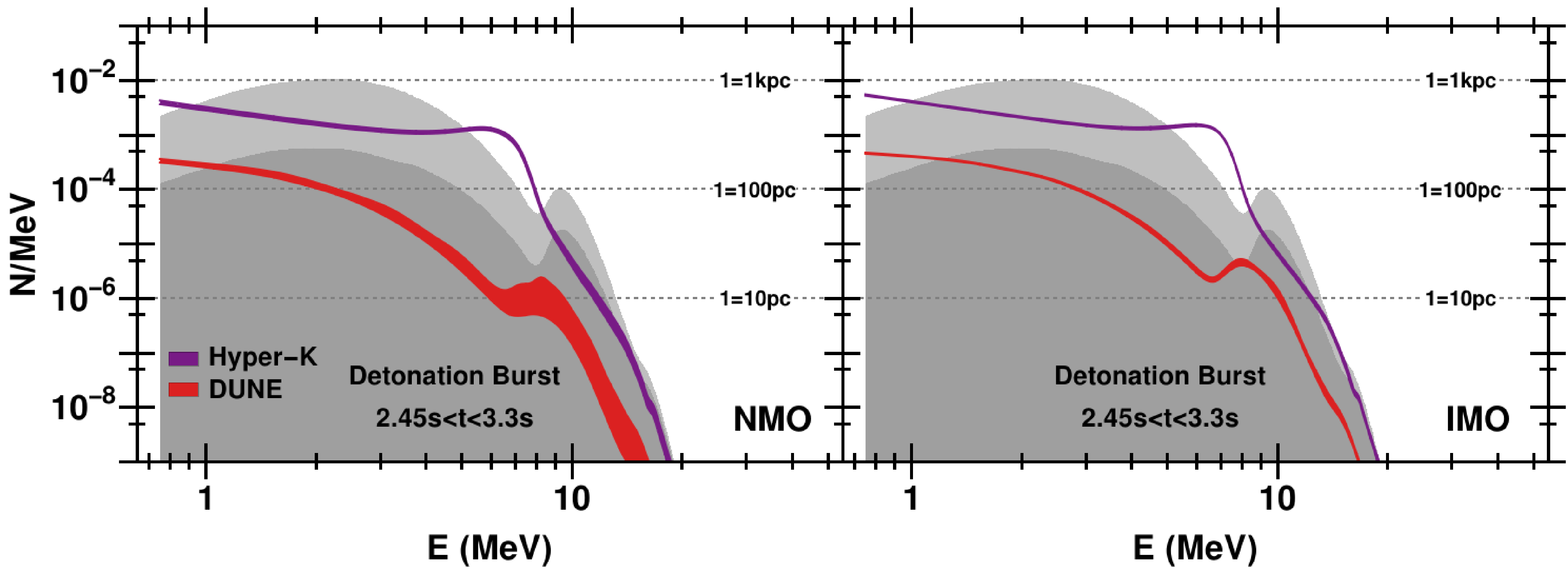


Detector Events



Detector Events

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