Neutrino mass and lifetime from core-collapse Supernova

F.Pompa, F.Capozzi, O.Mena, M.Sorel (PRL 129,121802, 2022)

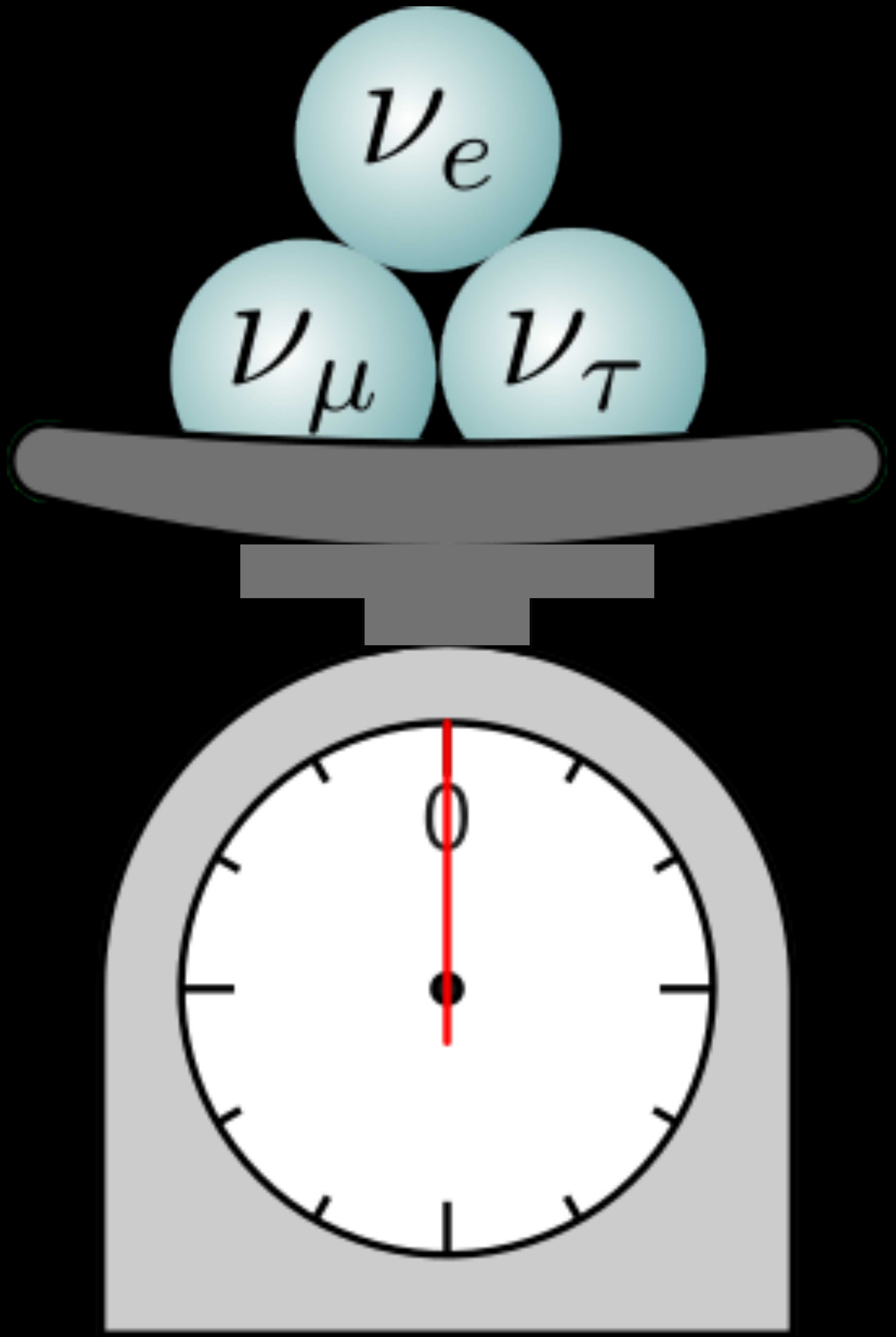
F.Pompa, O.Mena (arXiv:2310.05474)

YOUNGST@RS - Interacting dark sectors in astrophysics, cosmology, and the lab

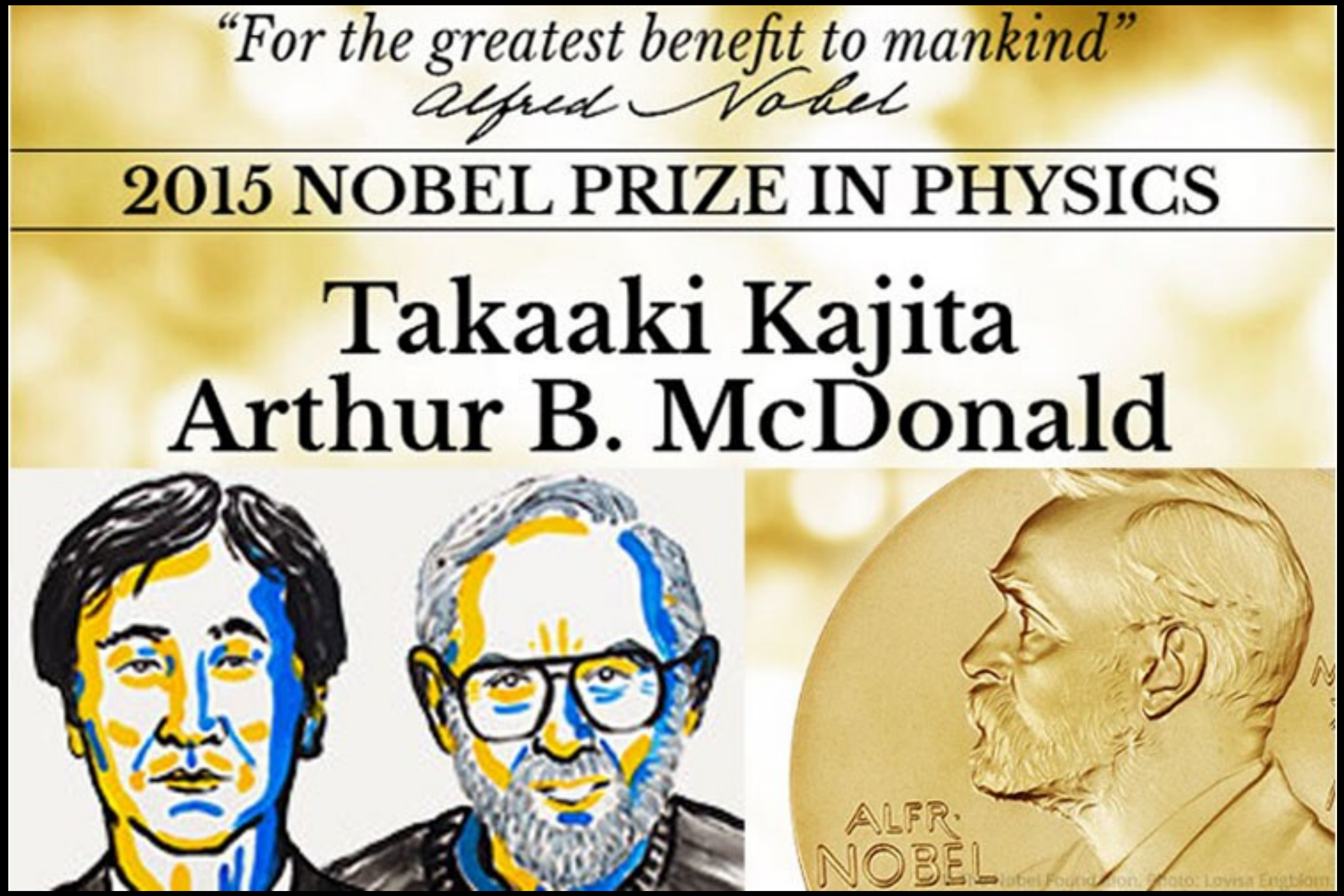
09/11/2023

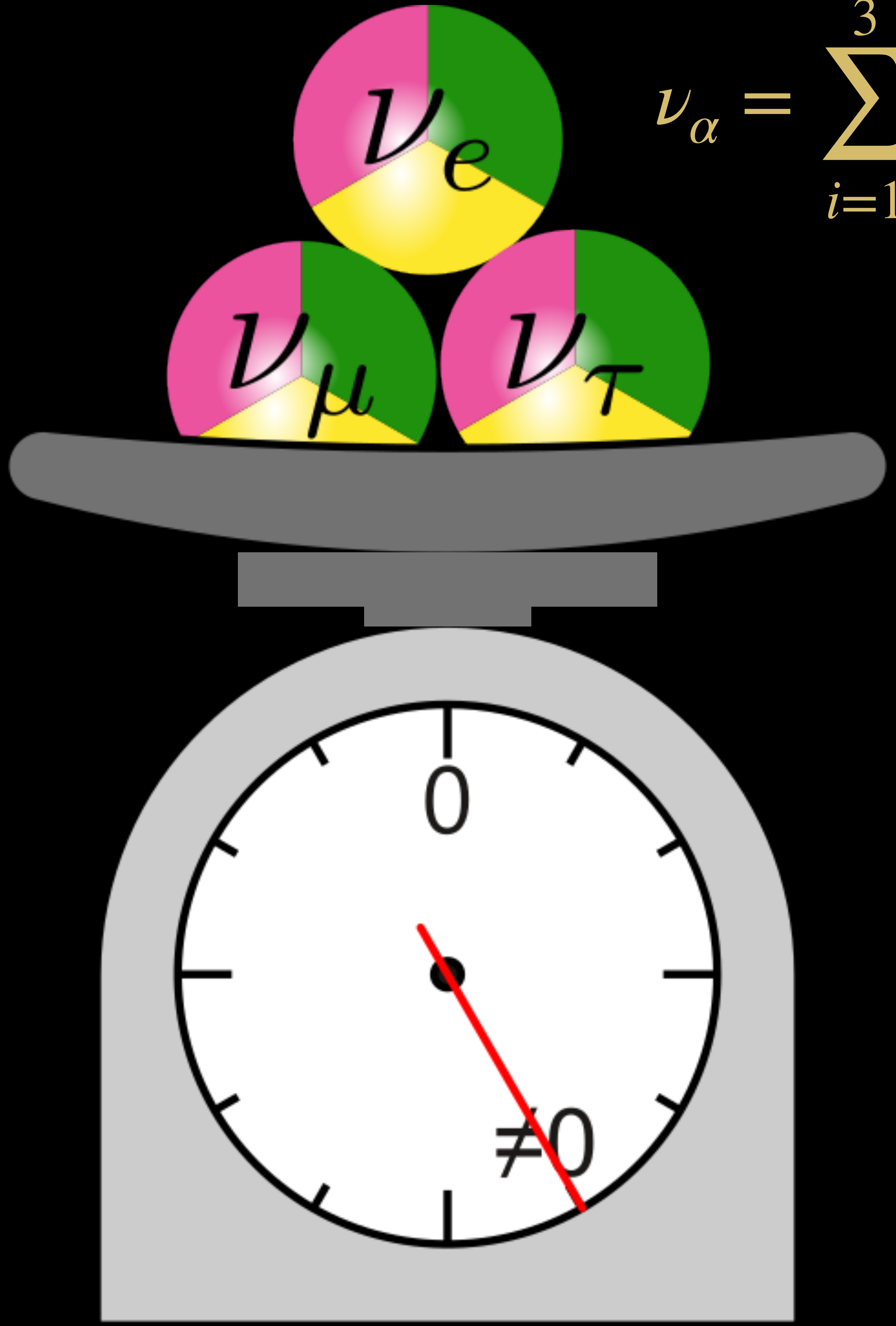
Federica Pompa - fpompa@ific.uv.es

Neutrino mass



Neutrino mass





$$\nu_\alpha = \sum_{i=1}^{3} U_{\alpha i}\, \nu_i$$

Neutrino mass

From cosmology:

E.Di Valentino,S.Gariazzo,O.Mena (PRD 104,083504, 2021)

$\sum m_\nu < 0.09 \div 0.12$ eV (95% CL)

From kinematic measurements:

KATRIN Collaboration (2021)

KATRIN $\Rightarrow m_\beta < 0.8$ eV (90% CL)

From $0\nu\beta\beta$ measurements:

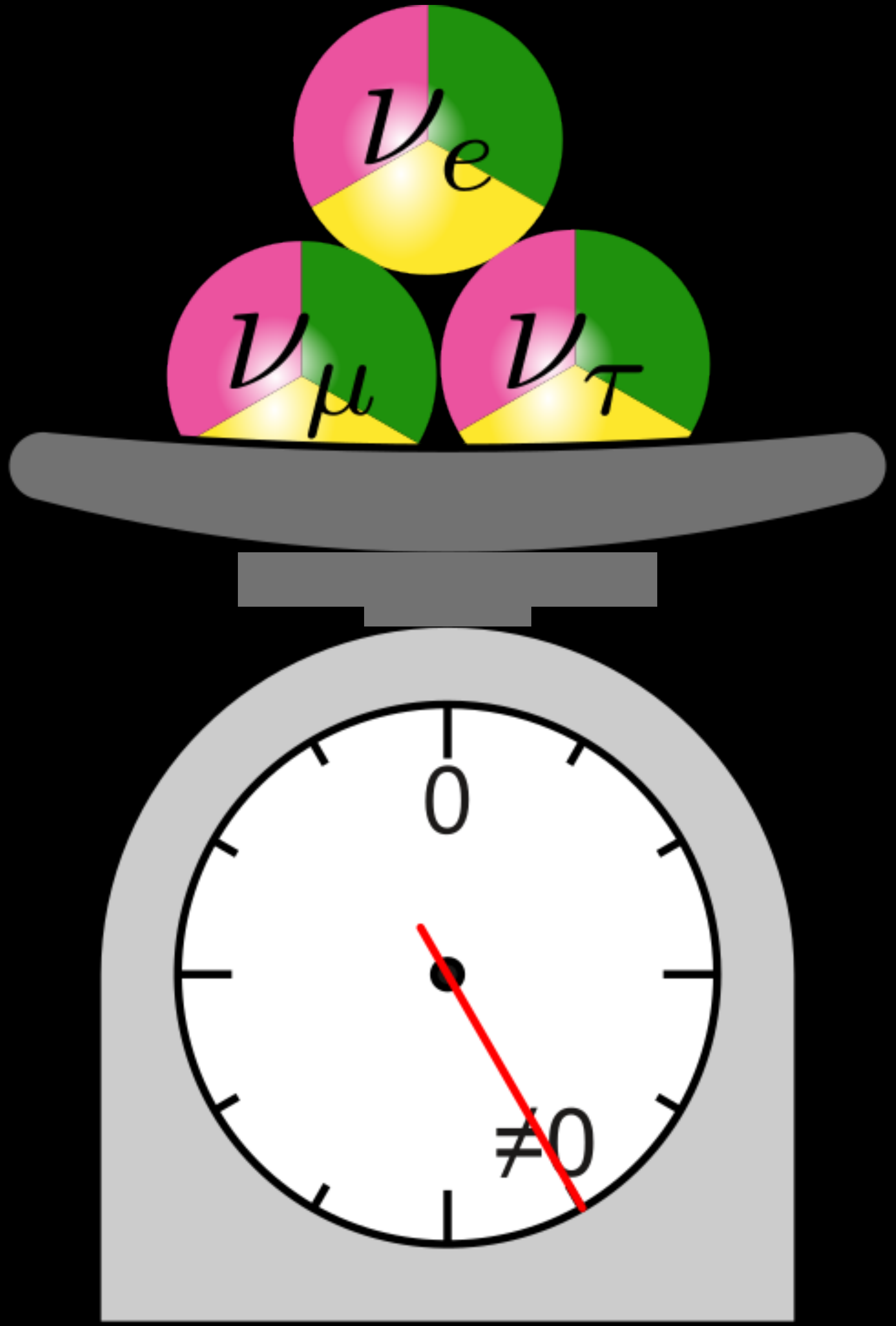
KamLAND-Zen Collaboration (PRL 130,051801, 2022)

KamLAND-Zen $\Rightarrow m_{\beta\beta} < 0.16$ eV (90% CL)

Time-of-flight constraints:

G.Pagliaroli,F.Rossi-Torres,F.Vissani (Astropart.Phys.Vol33,2010)

Kamiokande-II (SN1987A) $\Rightarrow m_\nu < 5.8$ eV (95% CL)



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Planck+lensing +Pantheon	Σm_ν [eV]
+ DR12 *BAO only*	< 0.116
+ DR12 *BAO+RSD*	< 0.118
+ DR16 *BAO only*	< 0.158
+DR16 *BAO+RSD*	< 0.101
+DR12 *BAO only* + DR16 *BAO only*	< 0.121
+DR12 *BAO only* + DR16 *BAO+RSD*	< 0.0866
+DR12 *BAO+RSD* + DR16 *BAO only*	< 0.125
+DR12 *BAO+RSD* + DR16 *BAO+RSD*	< 0.0934

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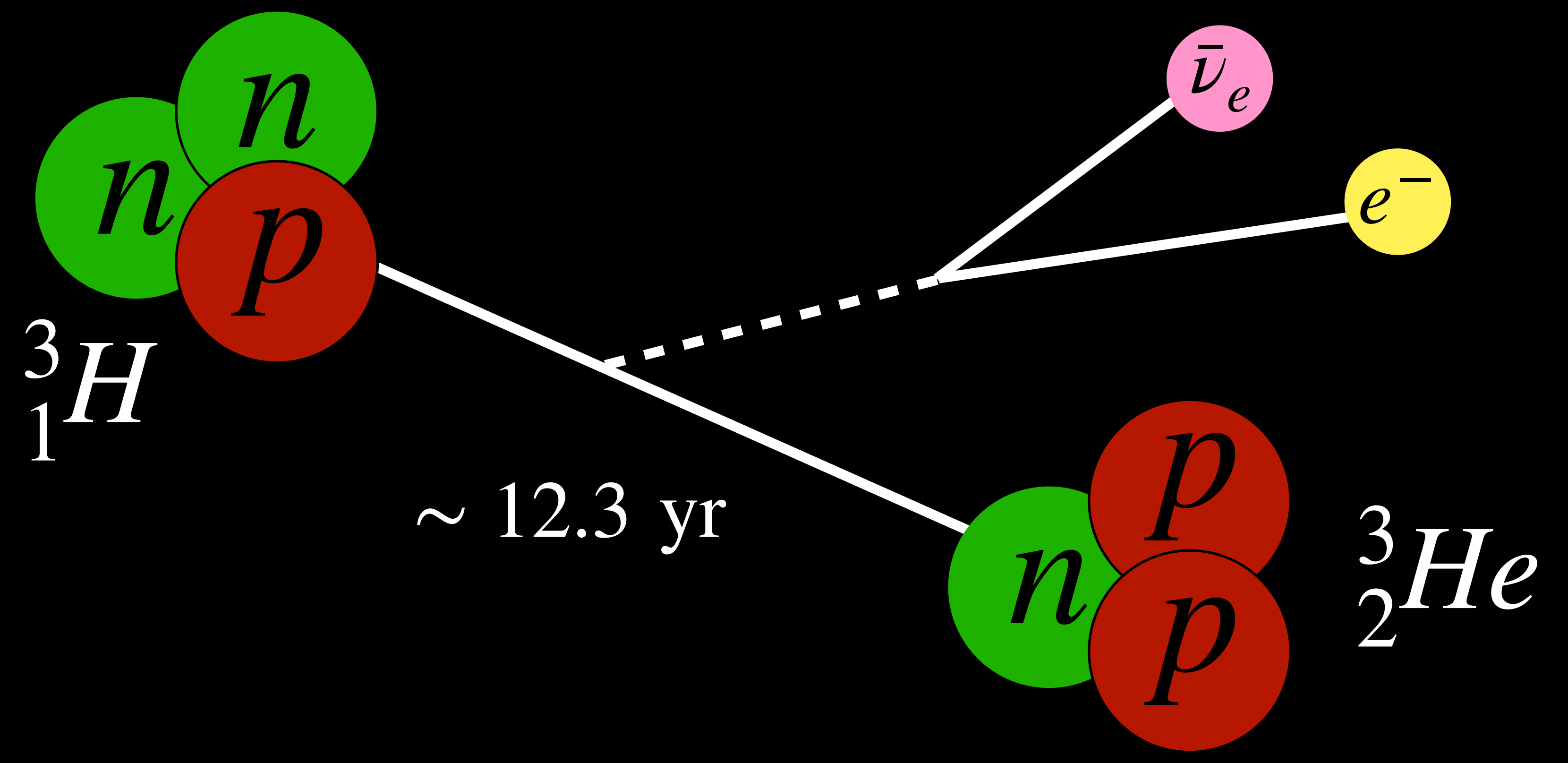

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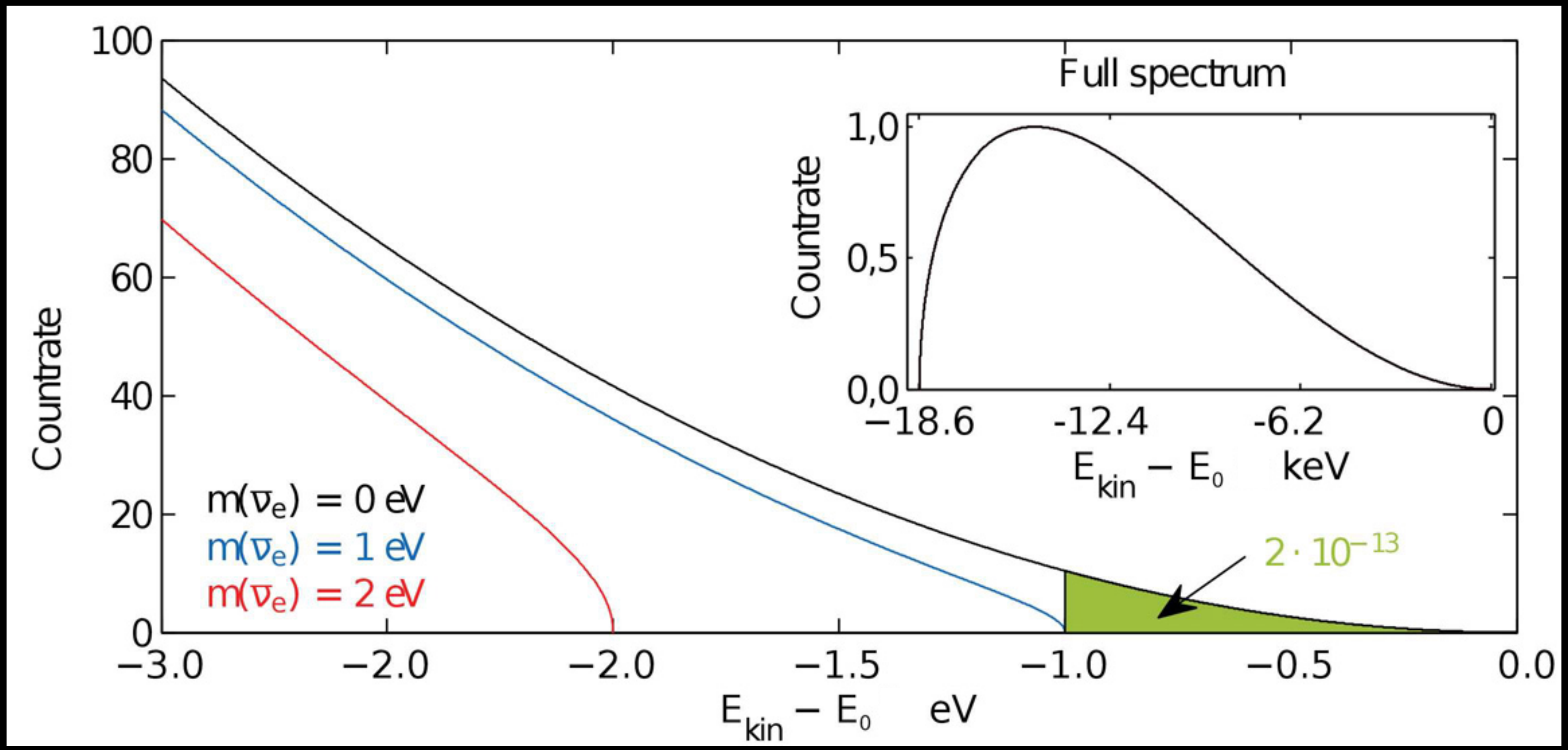

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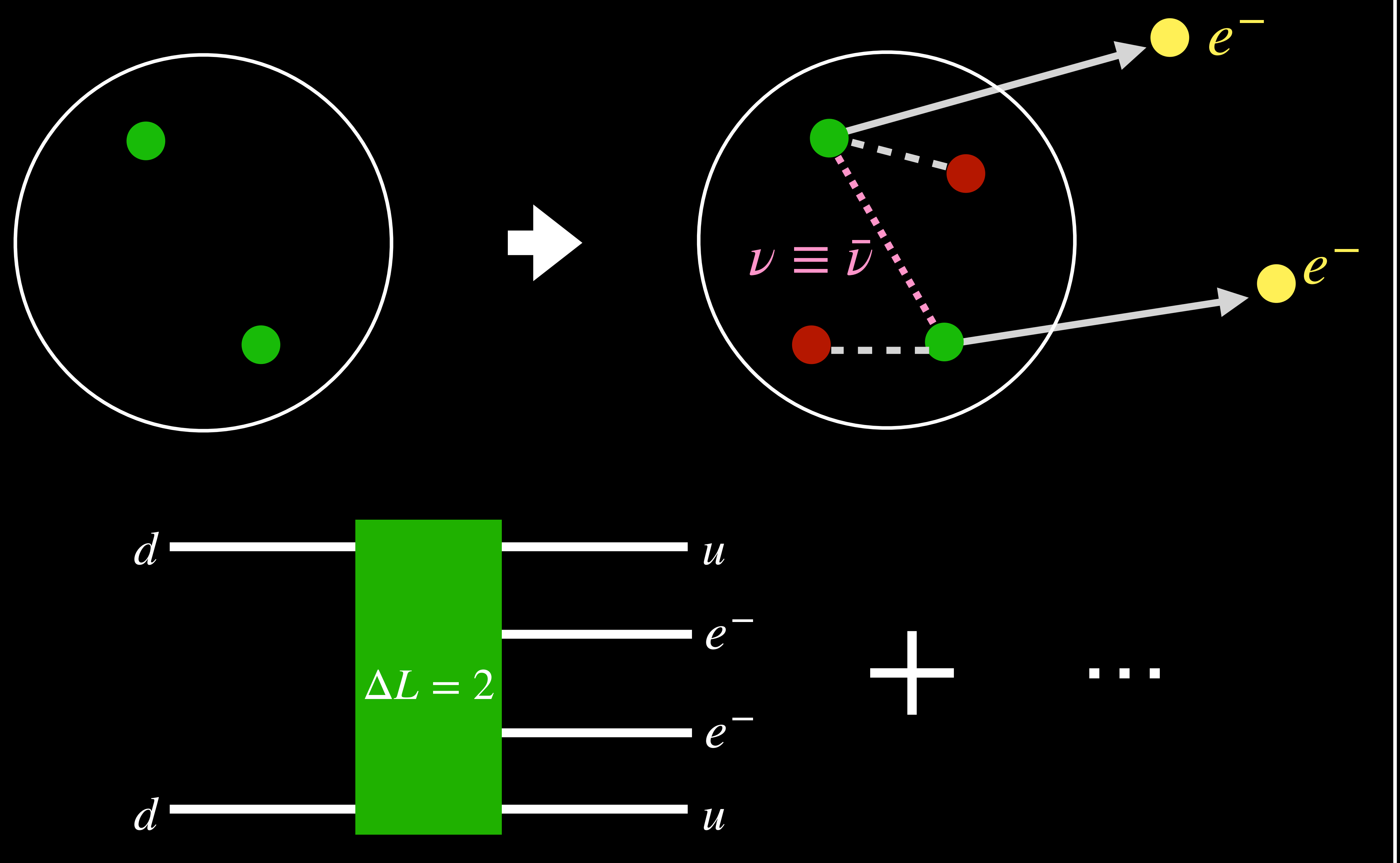

$$\Gamma = G_{0\nu} M_{0\nu}^2 \, \varepsilon(\Delta L = 2)$$

$$m_{\beta\beta} = \sum_i |U_{ei}|^2 m_i$$

Nuclear Models dependence!
Majorana neutrino assumption!

Neutrino mass

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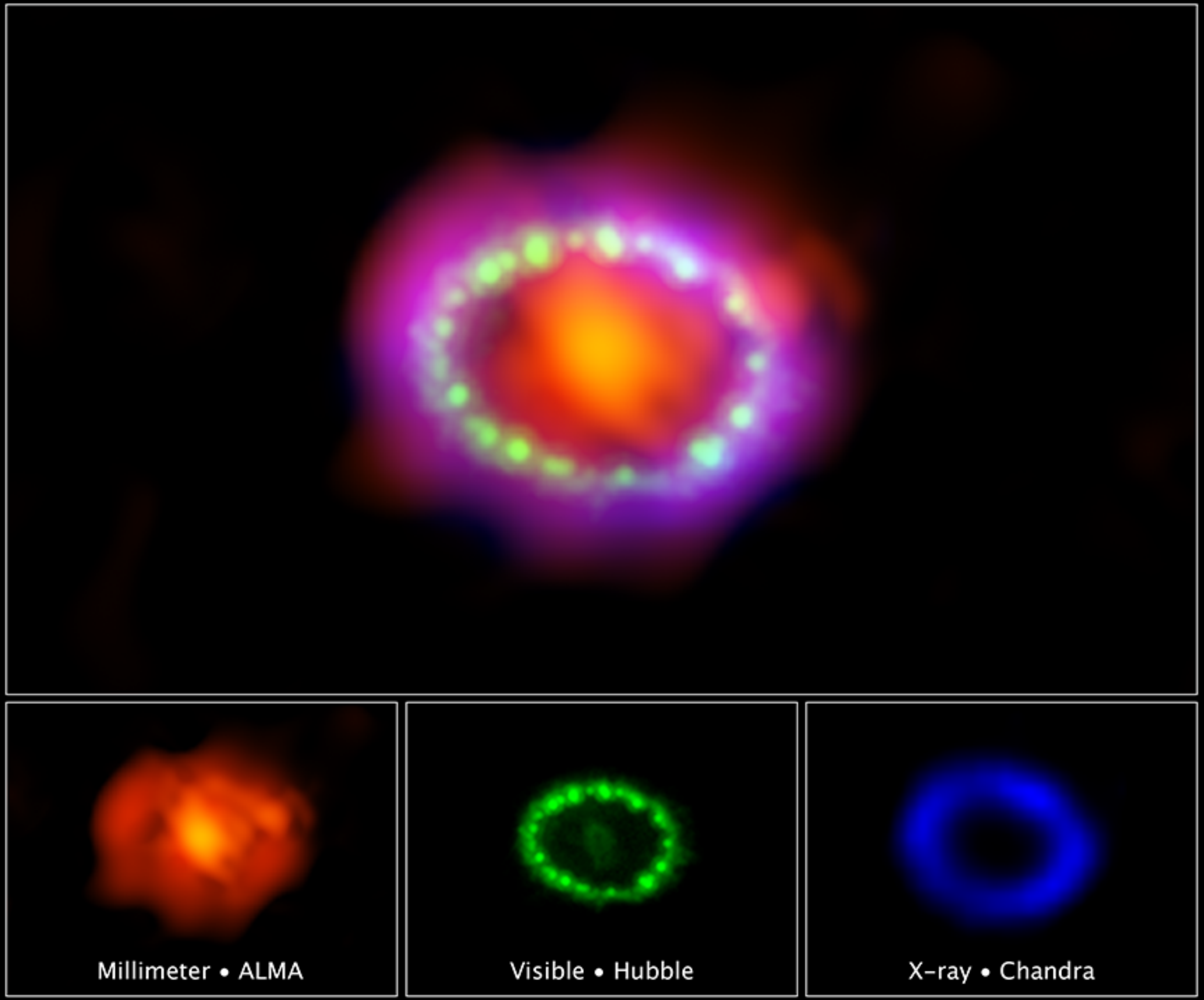


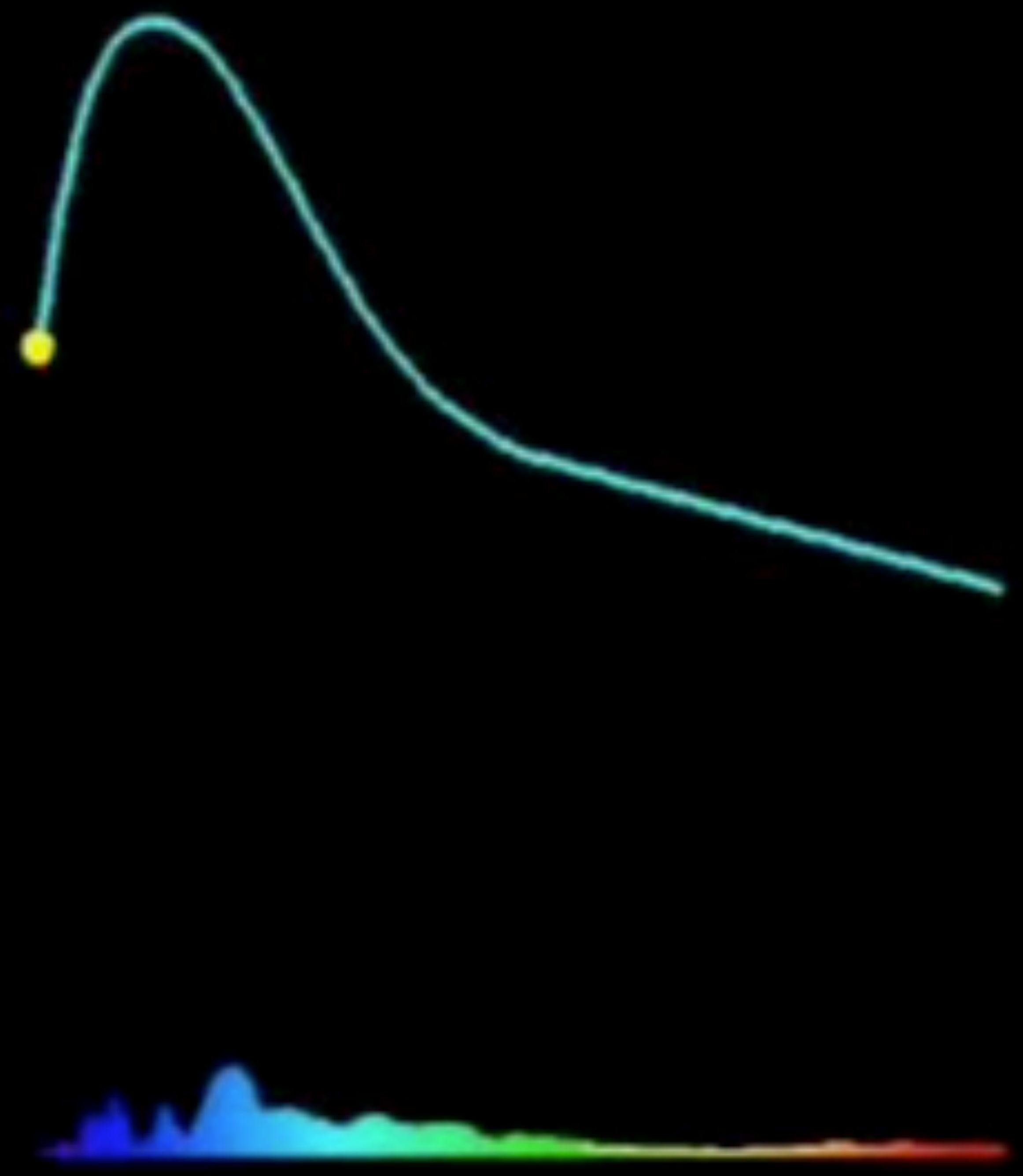
Alma (Eso/Naoj/Nrao), Nasa/Esa Hubble Space Telescope, Nasa Chandra X-Ray Observator

Why Supernovae?

1

Already observed!

Neutrino signal from SN1987A



Why Supernovae?

1

Already observed!

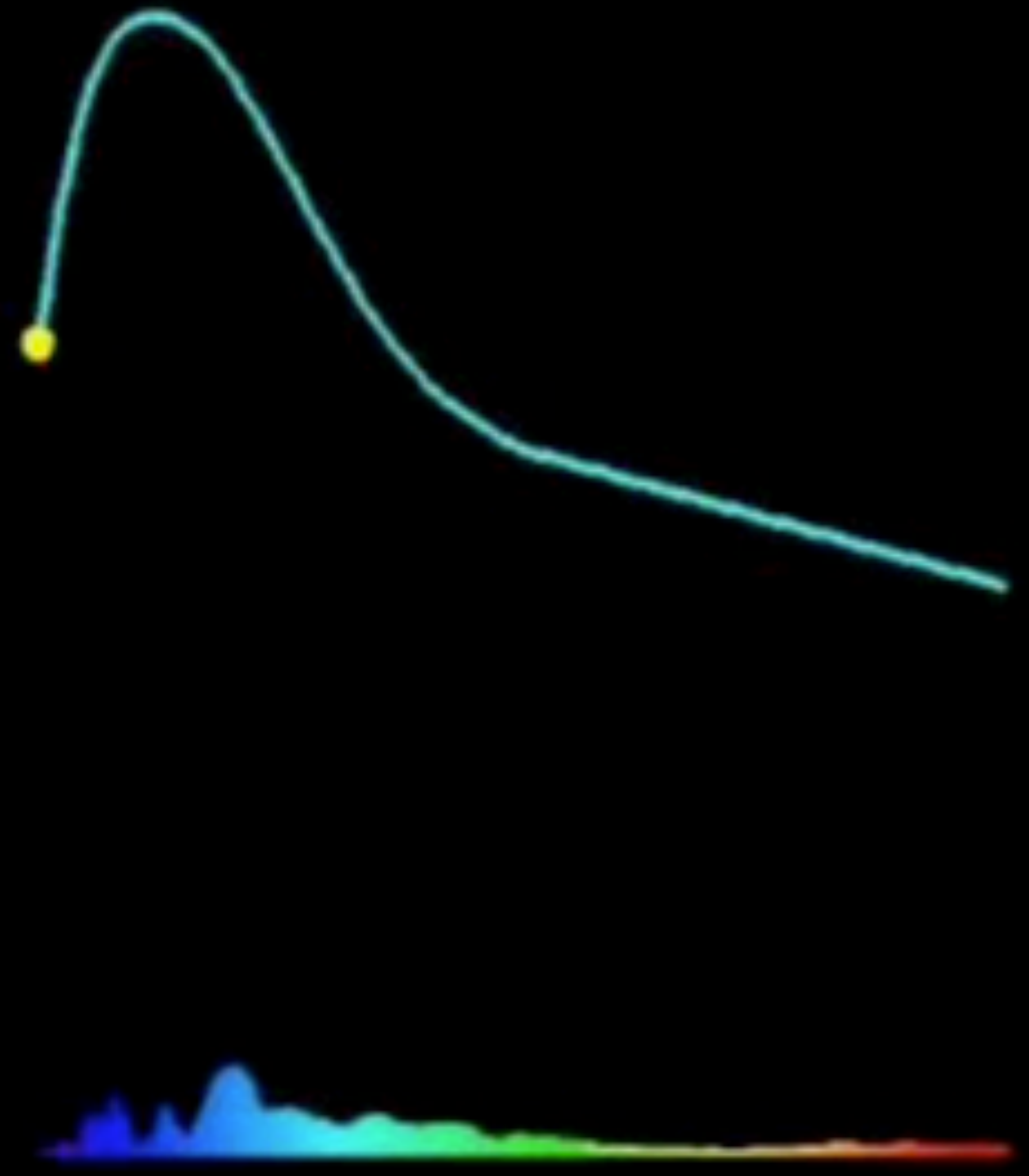
Neutrino signal from SN1987A

2

Neutrinos factories…

~99% energy released through neutrinos fluxes

… and not only!



Why Supernovae?

1 **Already observed!**

Neutrino signal from SN1987A

2 **Neutrinos factories…**

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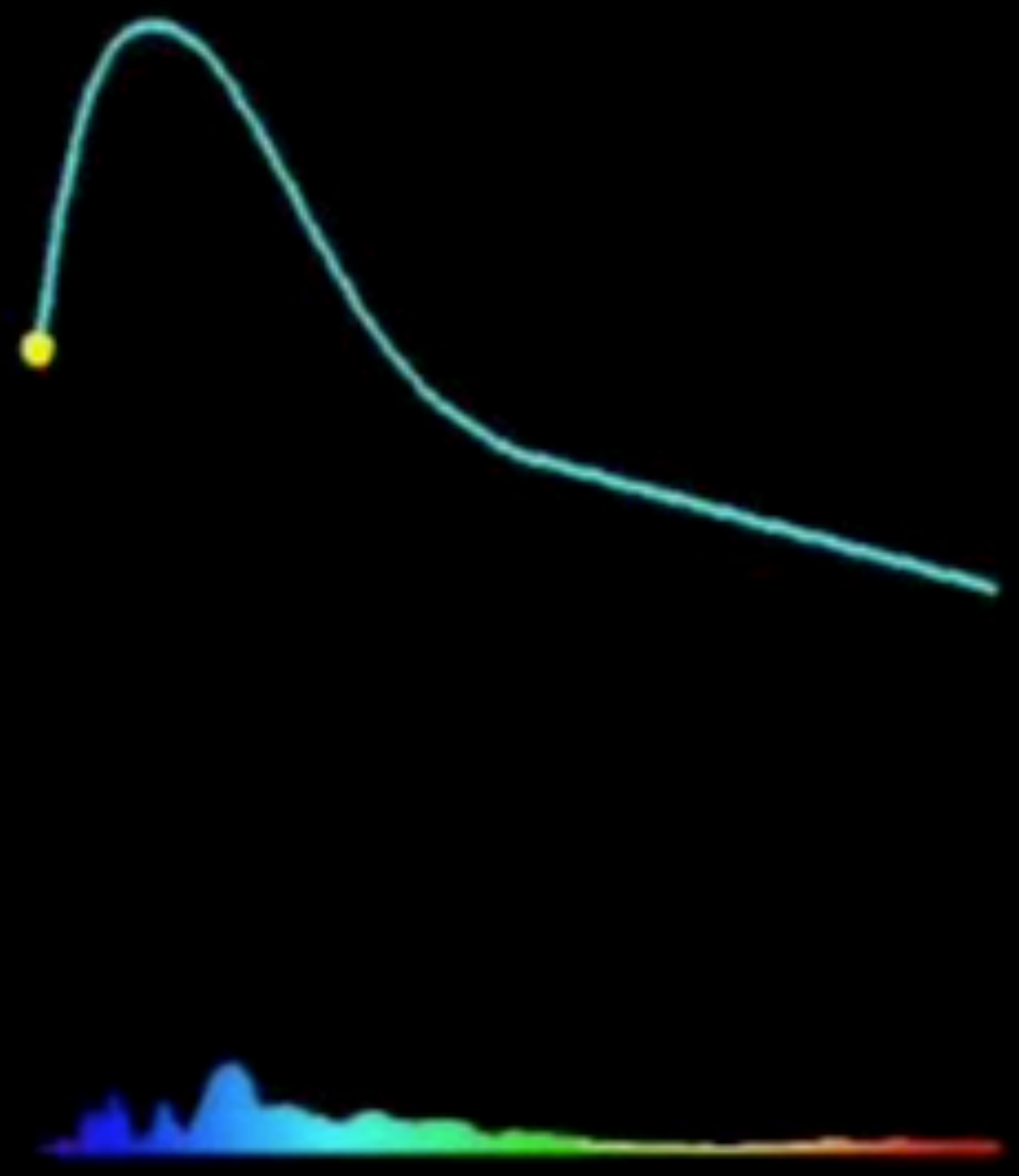
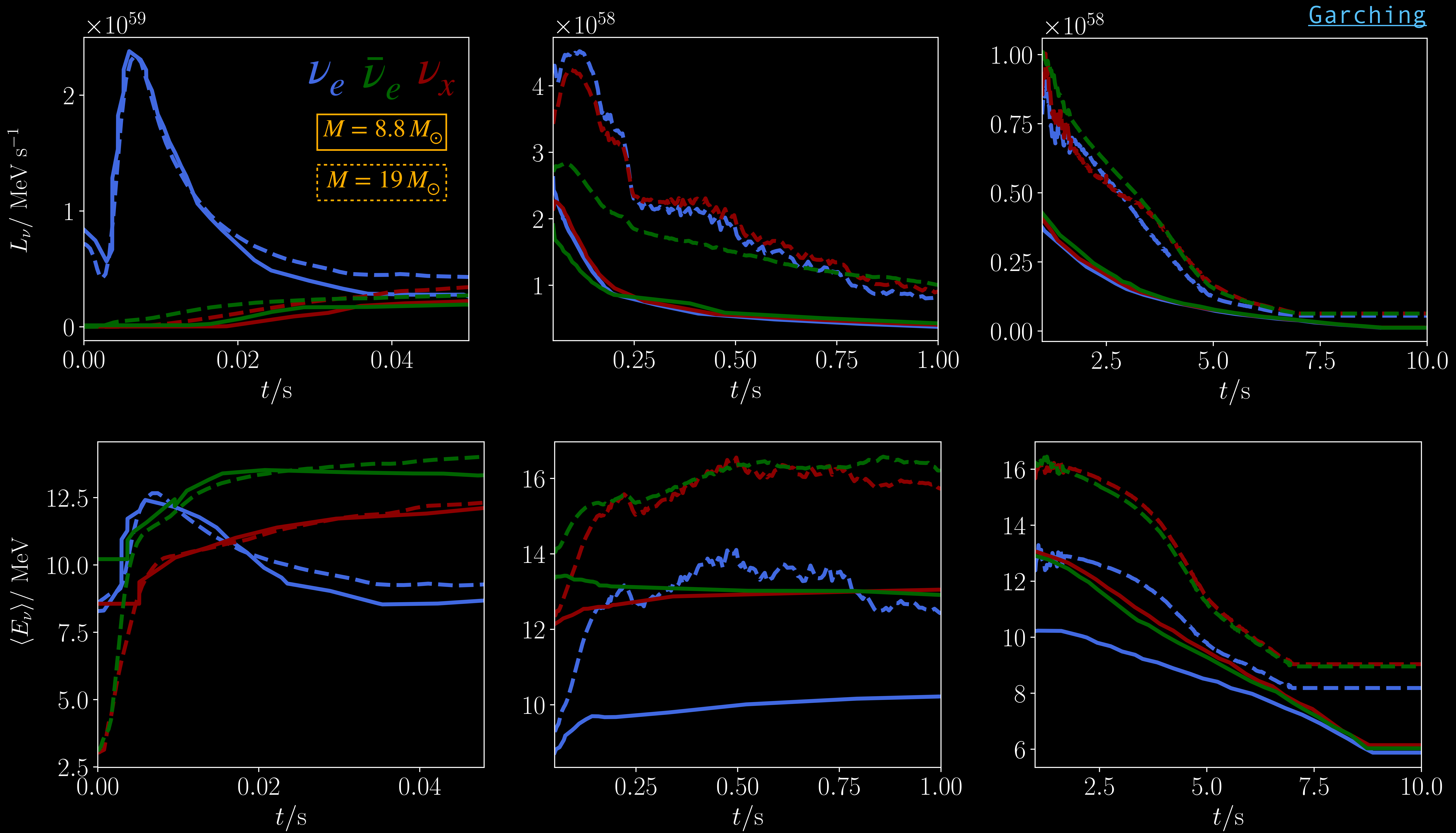
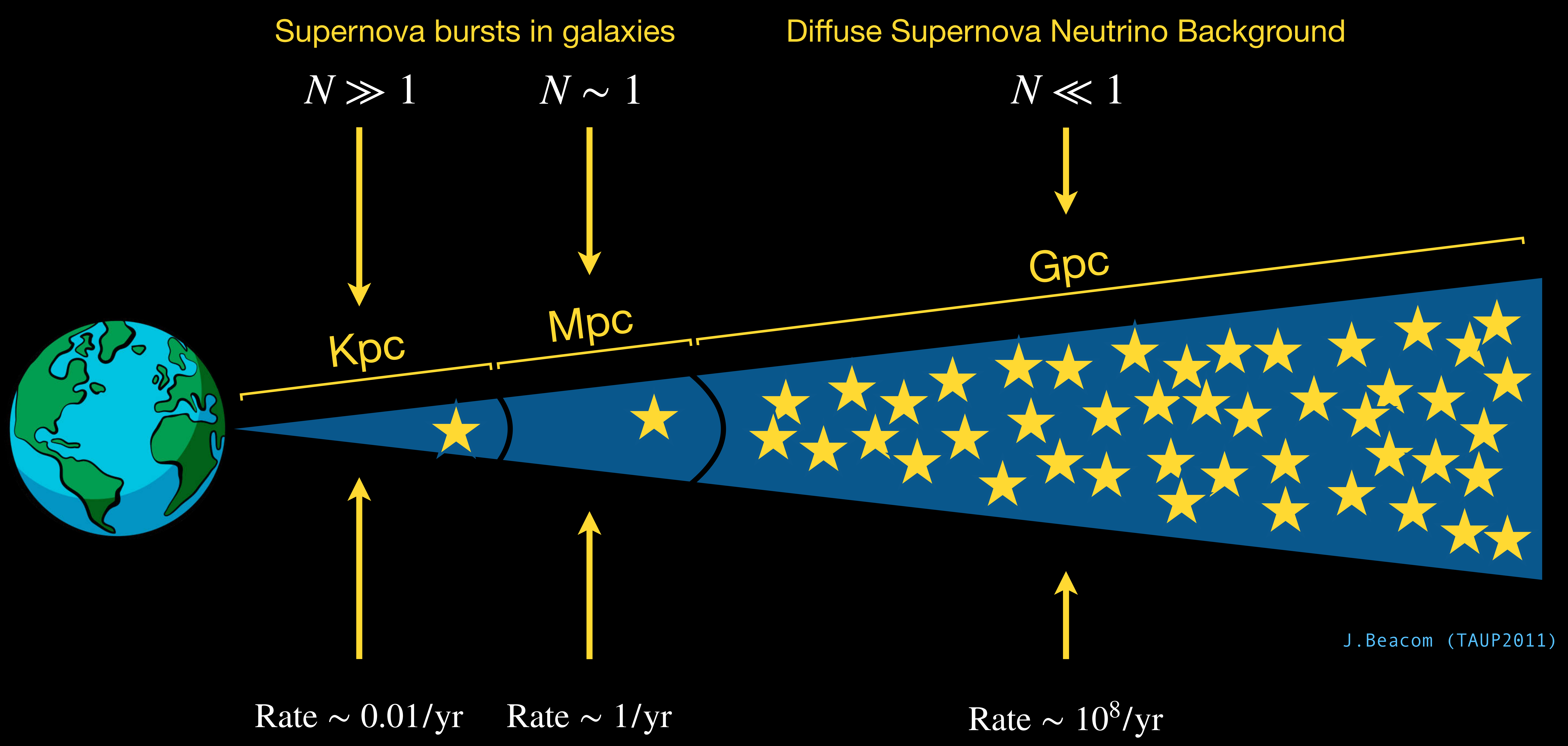
… and not only!

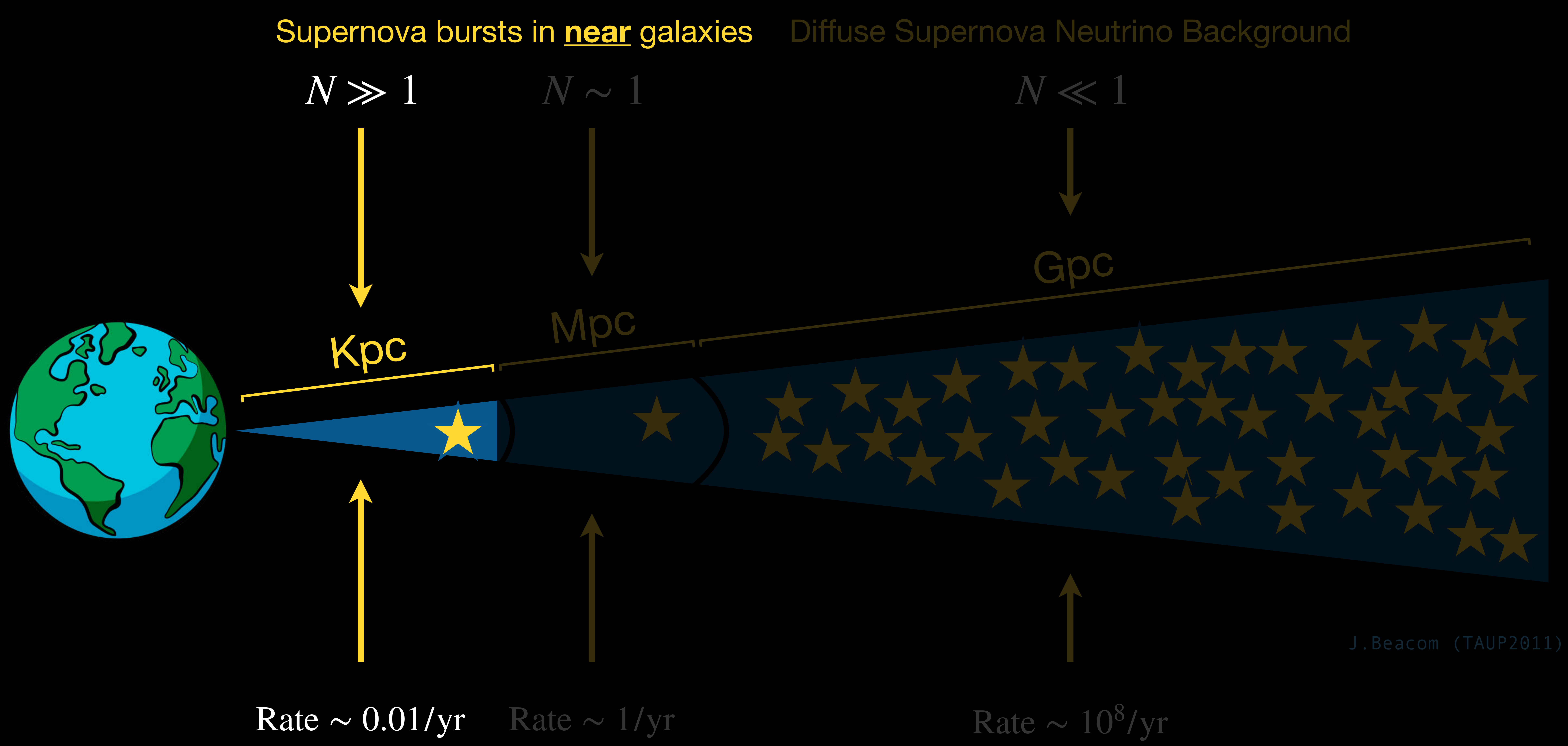


3 **Cosmic Laboratories**

unique opportunity to study interactions of elementary particles where new physics may be present


Garching
$\times 10^{59}$
$\times 10^{58}$
$\times 10^{58}$
ν_e $\bar{\nu}_e$ ν_x
$M = 8.8\,M_\odot$
$M = 19\,M_\odot$
L_ν/ MeV s^{-1}
$\langle E_\nu \rangle$/ MeV
t/s


Supernova bursts in galaxies
Diffuse Supernova Neutrino Background
$N \gg 1$
$N \sim 1$
$N \ll 1$
Kpc
Mpc
Gpc
J.Beacom (TAUP2011)
Rate $\sim 0.01/\mathrm{yr}$
Rate $\sim 1/\mathrm{yr}$
Rate $\sim 10^8/\mathrm{yr}$

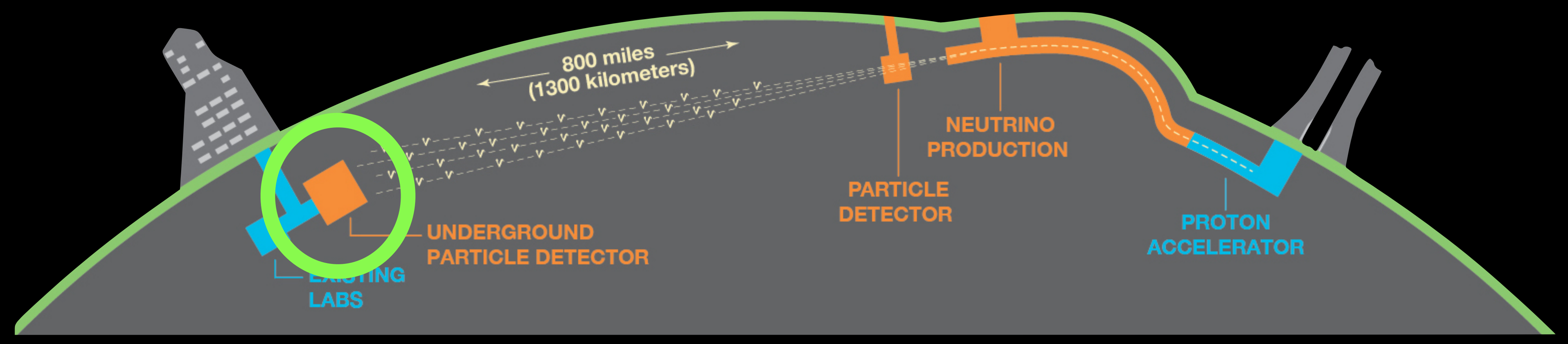


Supernova bursts in **near** galaxies
Diffuse Supernova Neutrino Background
$N \gg 1$
$N \sim 1$
$N \ll 1$
Kpc
Mpc
Gpc
J.Beacom (TAUP2011)
Rate ~ 0.01/yr
Rate ~ 1/yr
Rate $\sim 10^8$/yr

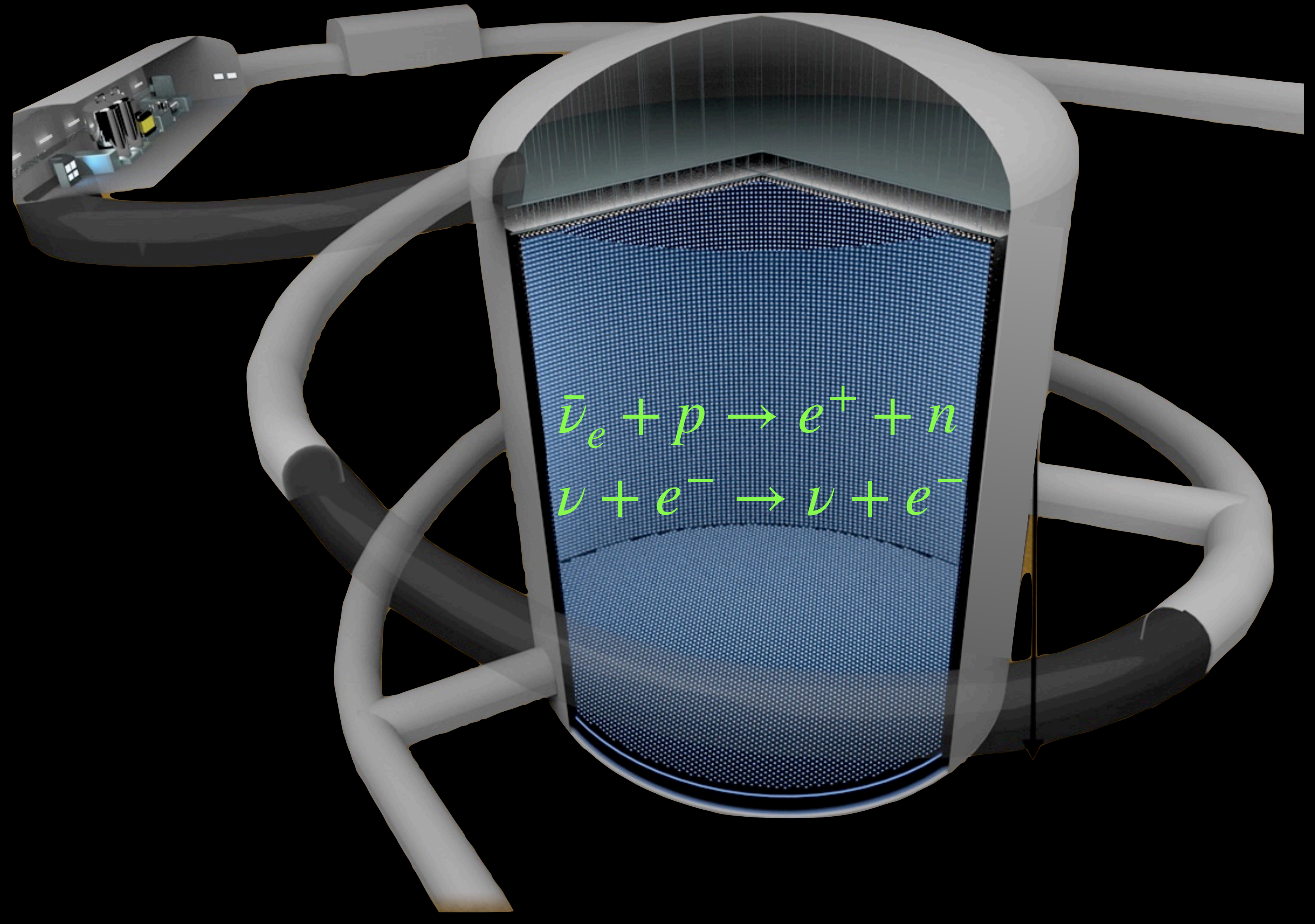
$$R(t,E) = \quad N_{\text{target}}\ \epsilon(E) \quad \sigma_{\text{sec}}(E) \quad \Phi_\nu(t,E)$$

$$R(t, E) = \boxed{N_{\text{target}}\ \epsilon(E)}\ \boxed{\sigma_{\text{sec}}(E)}\ \Phi_\nu(t, E)$$

Detector **Interaction**



$\nu_e + {}^{40}Ar \rightarrow e^- + {}^{40}K^*$

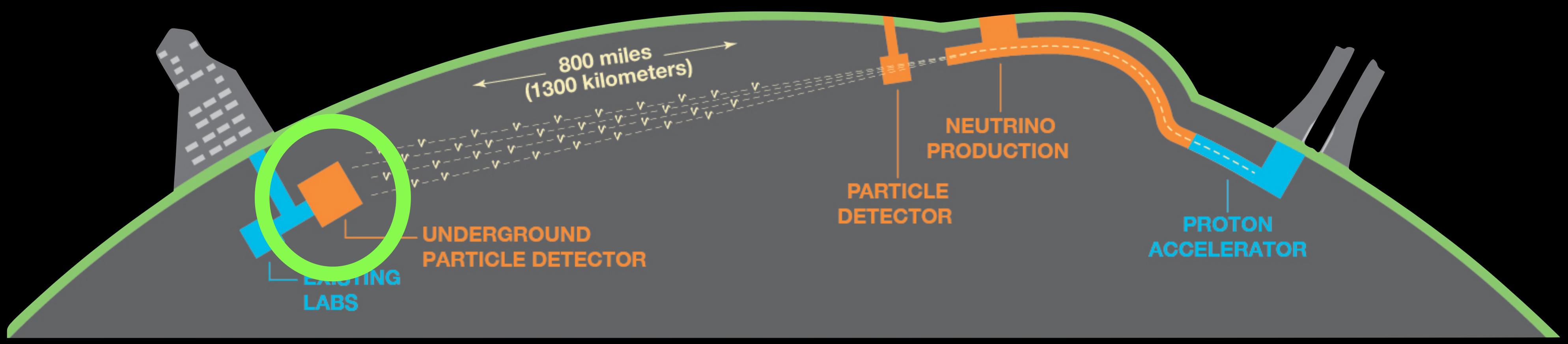


$\bar{\nu}_e + p \rightarrow e^+ + n$

$\nu + e^- \rightarrow \nu + e^-$

$$R(t,E) = \boxed{N_{\text{target}}\ \epsilon(E)}\ \boxed{\sigma_{\text{sec}}(E)}\ \boxed{\Phi_\nu(t,E)}$$

Detector — **Interaction** — **Source (and propagation!)**



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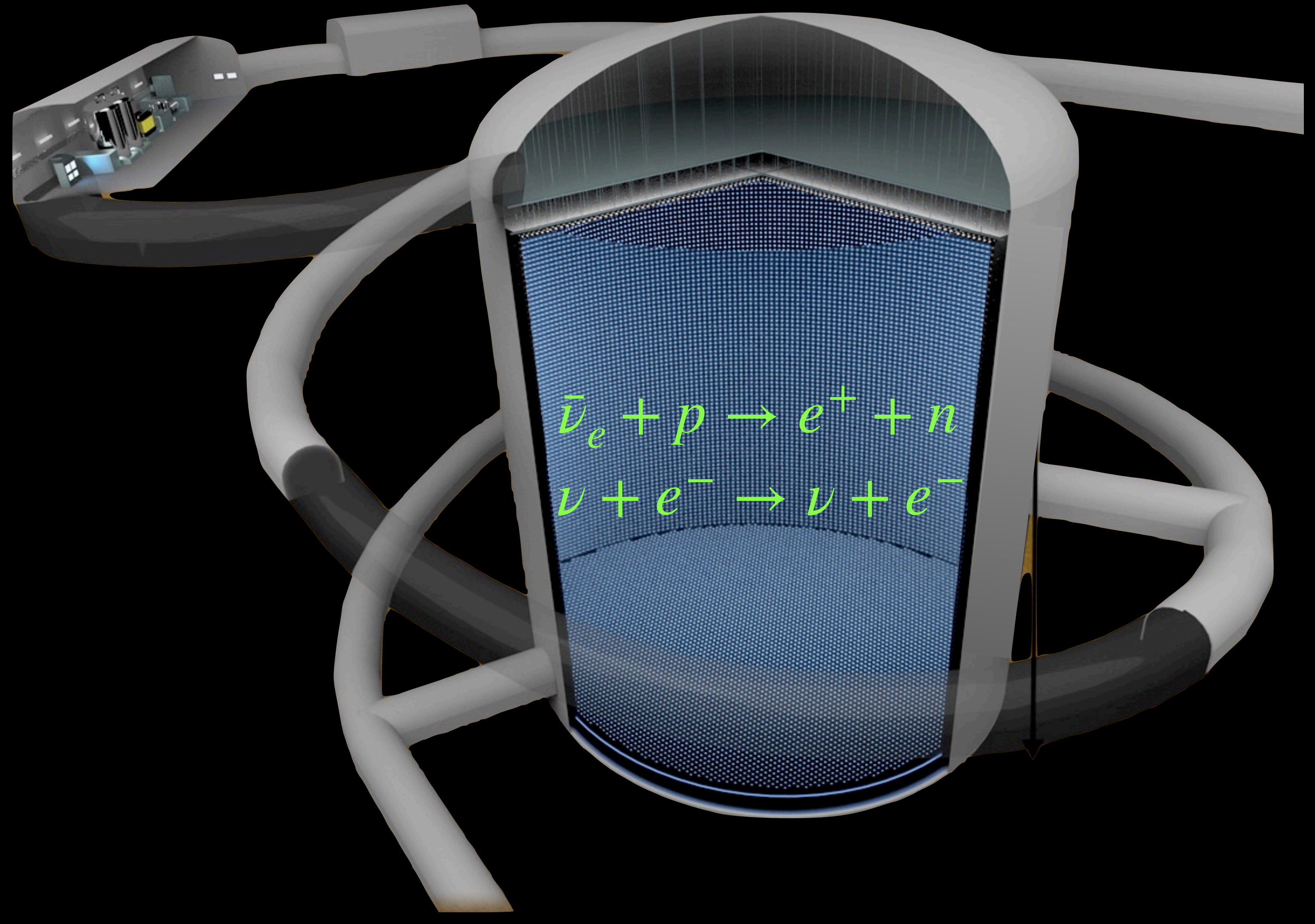


Mikheyev-Smirnov-Wolfenstein effect

A.S.Dighe,A.Y.Smirnov(PRD 62,033007, 2000)

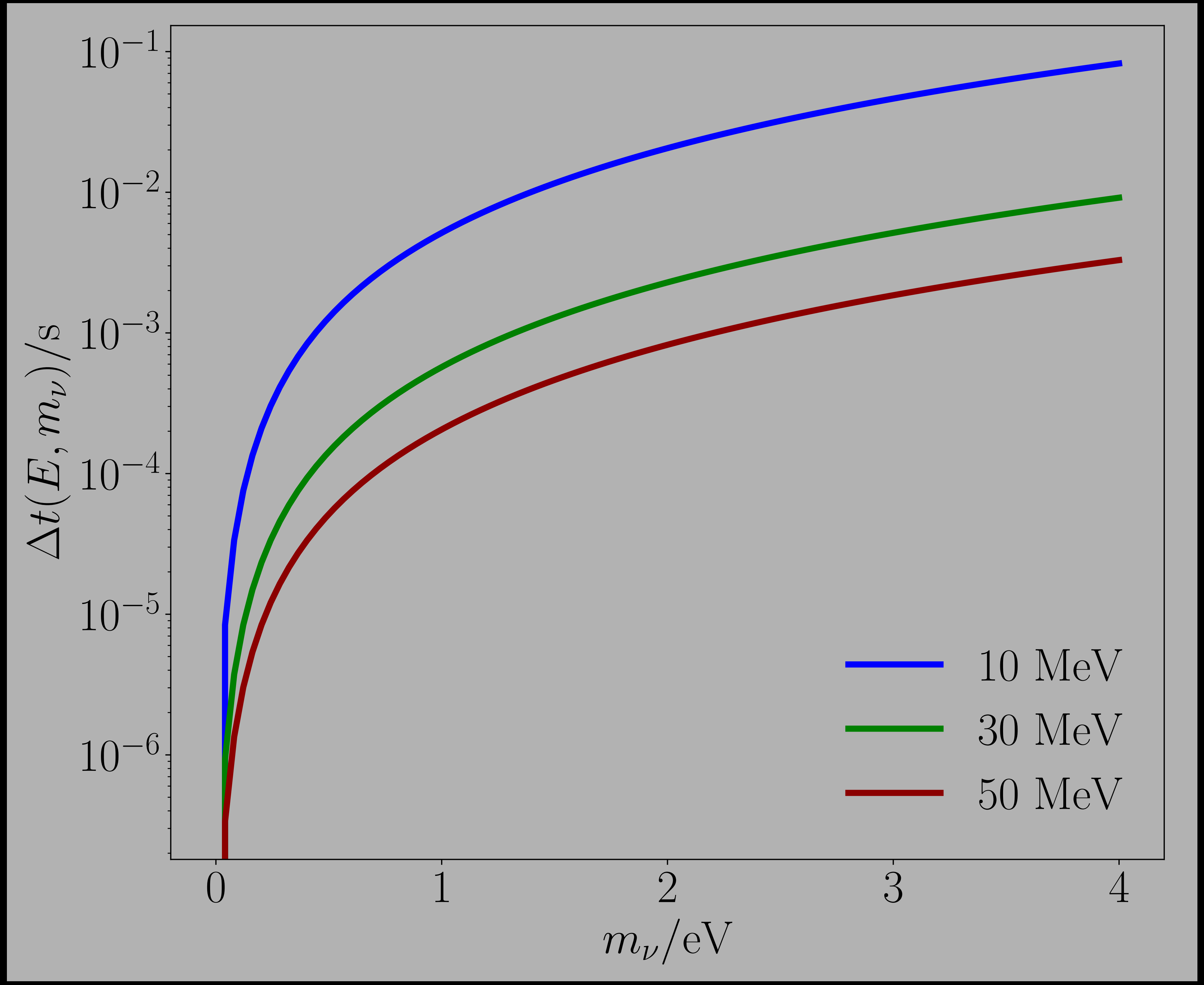
$$\Phi_{\nu_e} = p\ \Phi^0_{\nu_e} + (1-p)\ \Phi^0_{\nu_x}$$

$$\Phi_{\nu_x} = \frac{1}{2}[(1-p)\ \Phi^0_{\nu_e} + (1-p)\ \Phi^0_{\nu_x}$$

	p	$\bar{p}$
NO	$\lvert U_{e3}\rvert^2$	$\lvert U_{e1}\rvert^2$
IO	$\lvert U_{e2}\rvert^2$	$\lvert U_{e3}\rvert^2$

Effect of m_ν

D = 10 kpc



$$\Delta t_i(m_\nu) = \frac{D}{2c}\left(\frac{m_\nu}{E_i}\right)^2$$

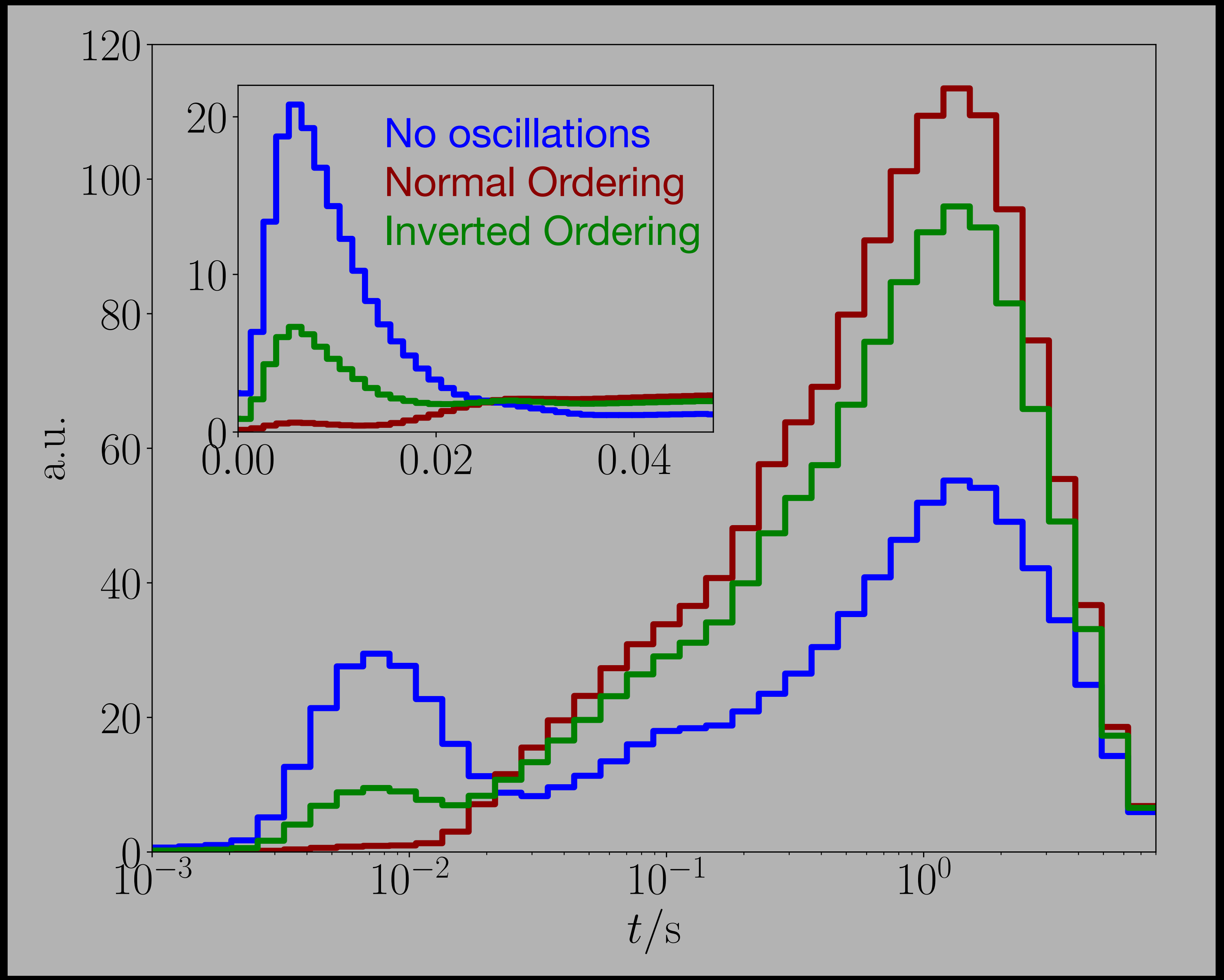
$$t_i = \delta t_i + t_{\mathrm{off}} - \Delta t_i(m_\nu)$$

@the detector

@the source

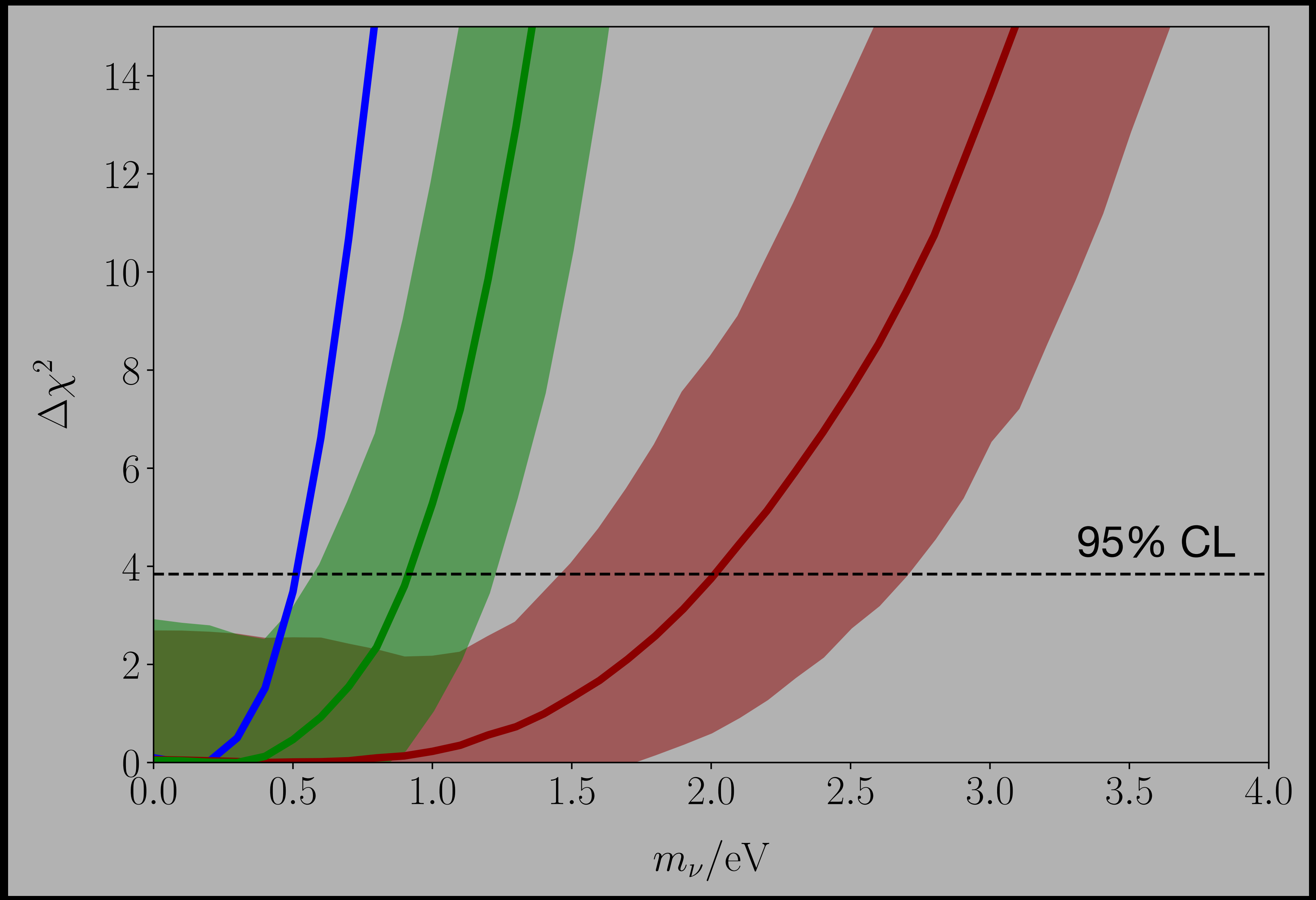
offset time (detector)

DUNE: *D* = 10 kpc



10 s	50 ms
~ 845	~ 201
~ 1372	~ 54
~ 1222	~ 95

$M = 8.8\,M_\odot$



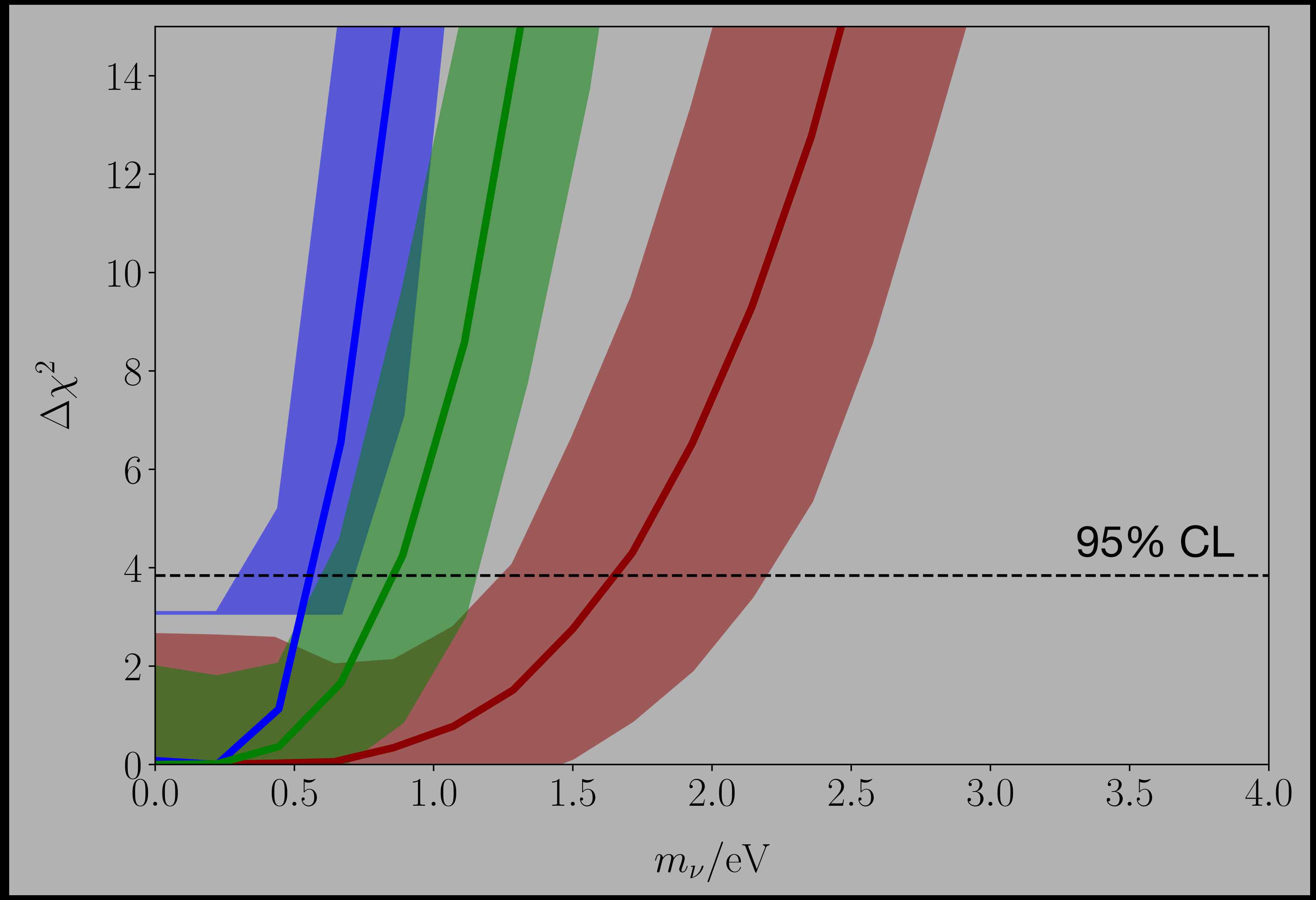
$m_\nu \leq 0.51^{+0.20}_{-0.19}$ eV

$m_\nu \leq 0.91^{+0.30}_{-0.33}$ eV

$m_\nu \leq 2.01^{+0.69}_{-0.55}$ eV

$M = 19\,M_\odot$

10 s	50 ms
~ 3644	~ 200
~ 5441	~ 88
~ 4936	~ 120

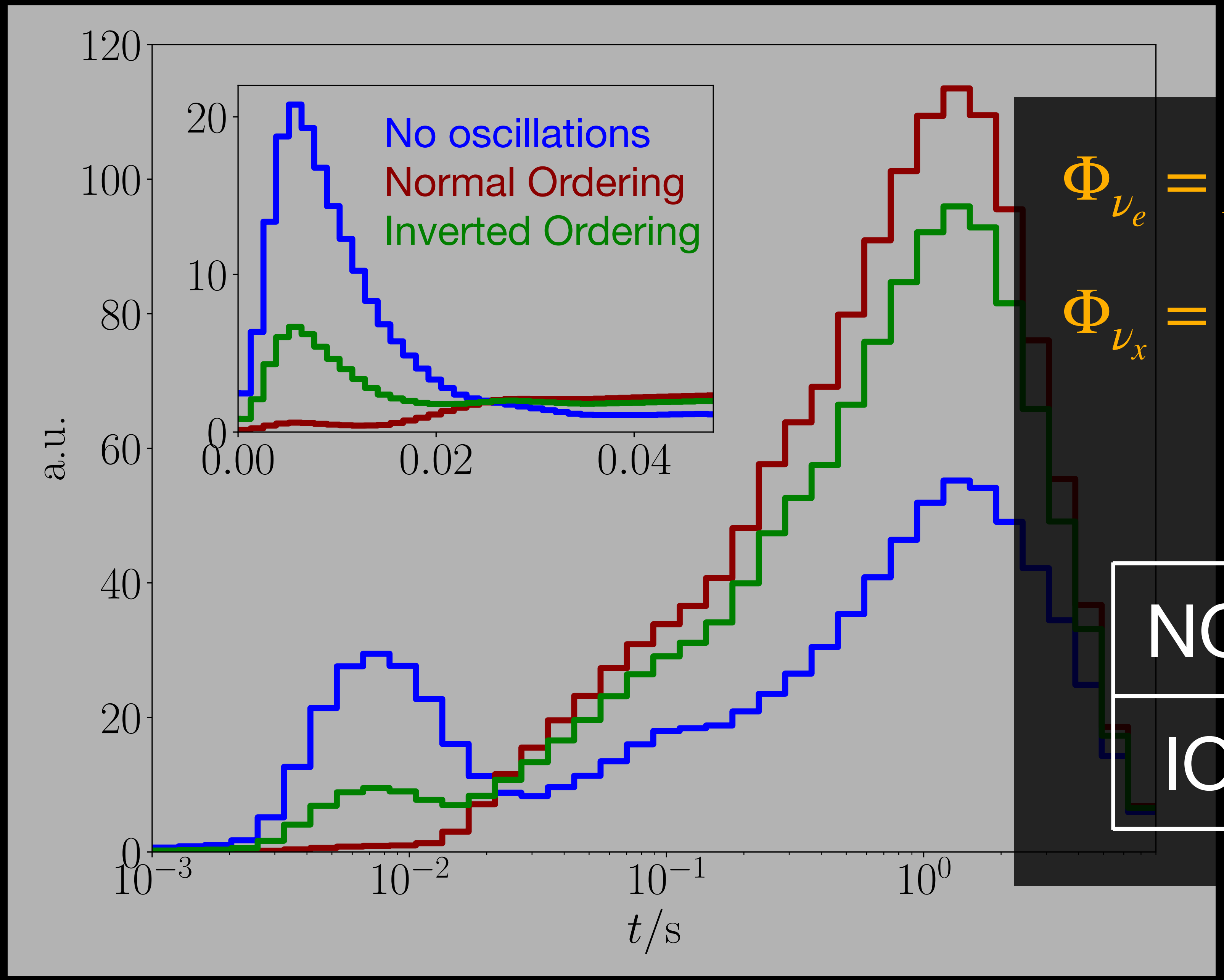


$m_\nu \leq 0.56^{+0.20}_{-0.21}$ eV

$m_\nu \leq 0.85^{+0.30}_{-0.25}$ eV

$m_\nu \leq 1.65^{+0.54}_{-0.40}$ eV

DUNE: D = 10 kpc



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	p	$\bar{p}$
NO	$\lvert U_{e3}\rvert^2$	$\lvert U_{e1}\rvert^2$
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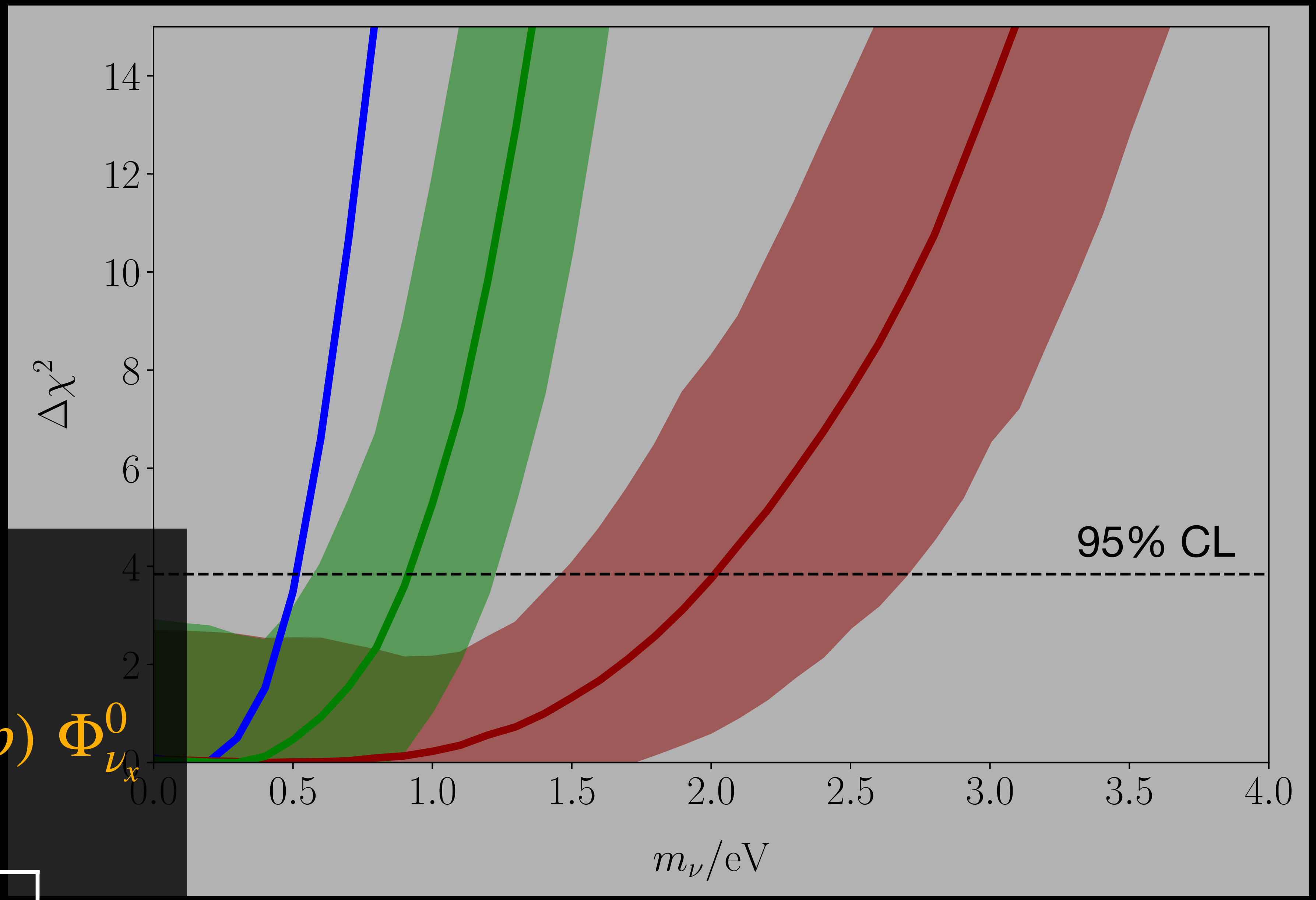

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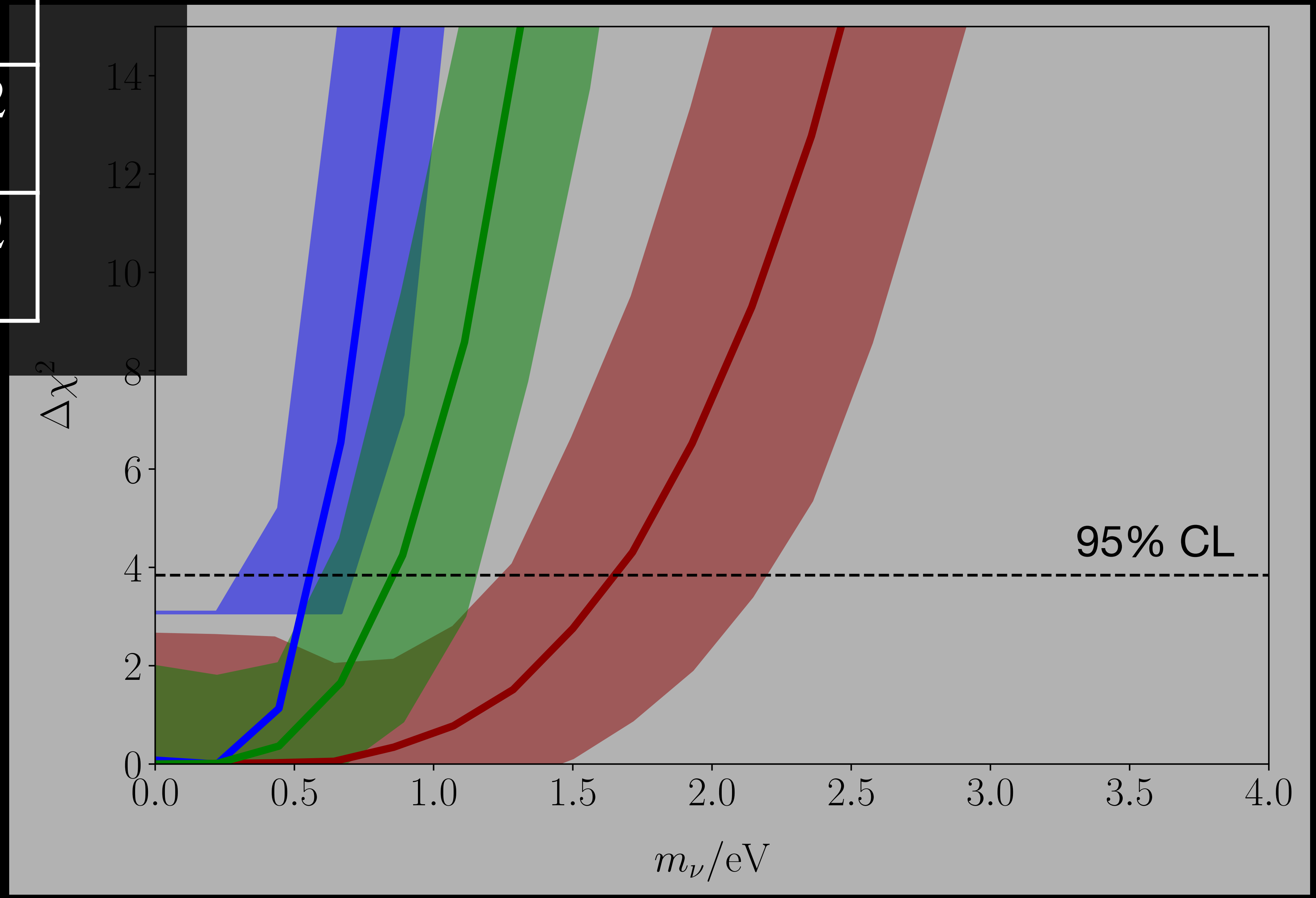

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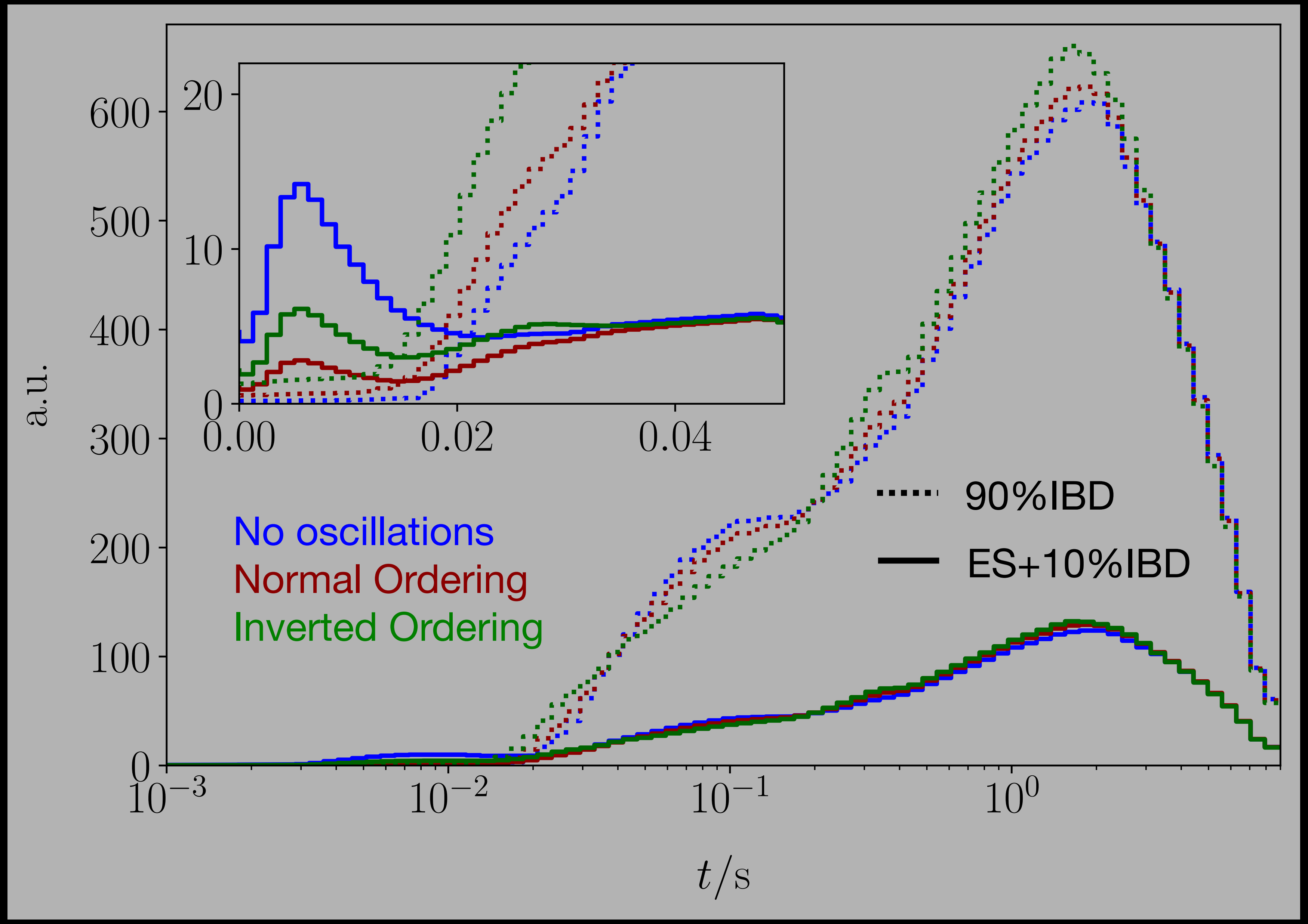
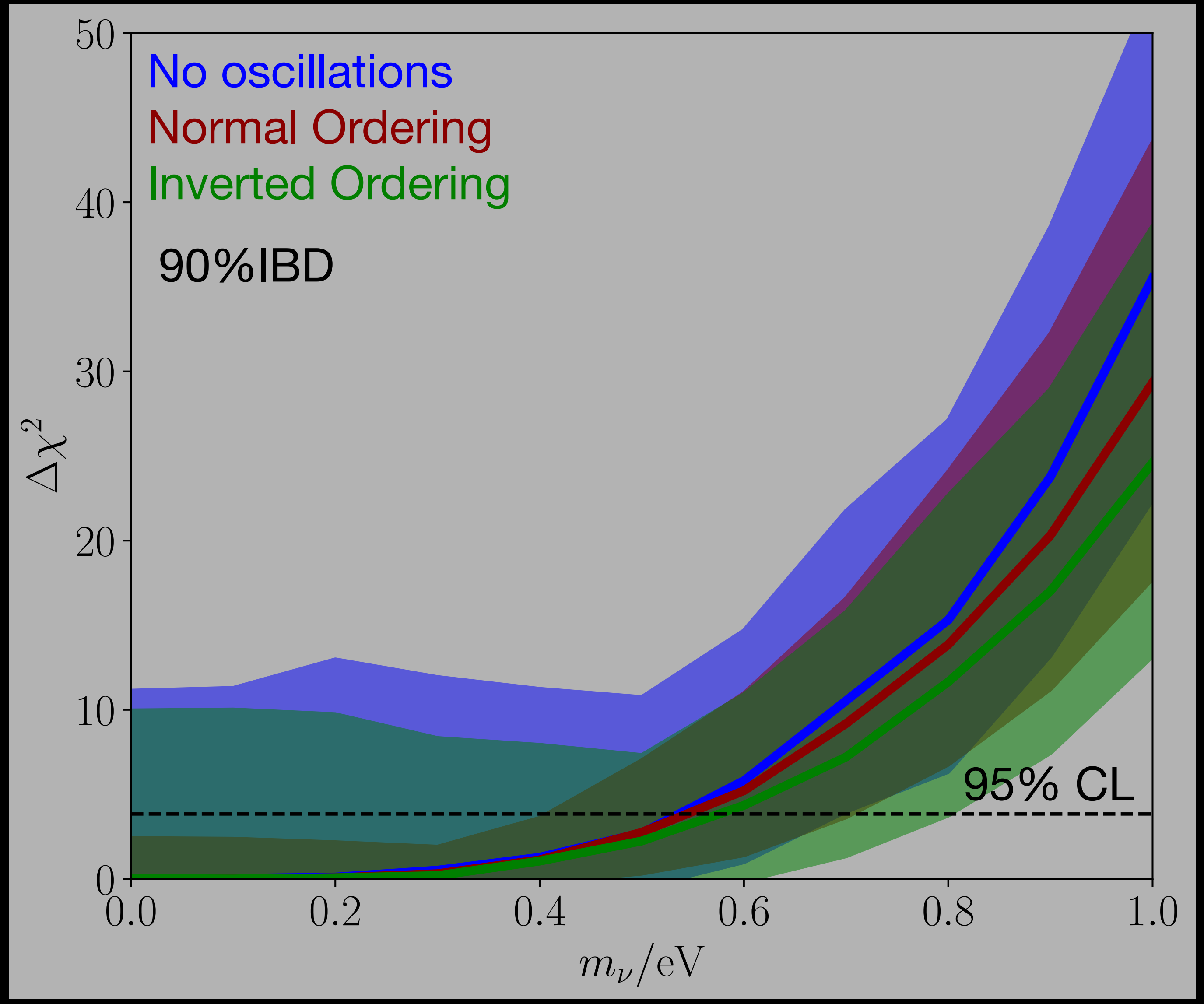
HK: D = 10 kpc





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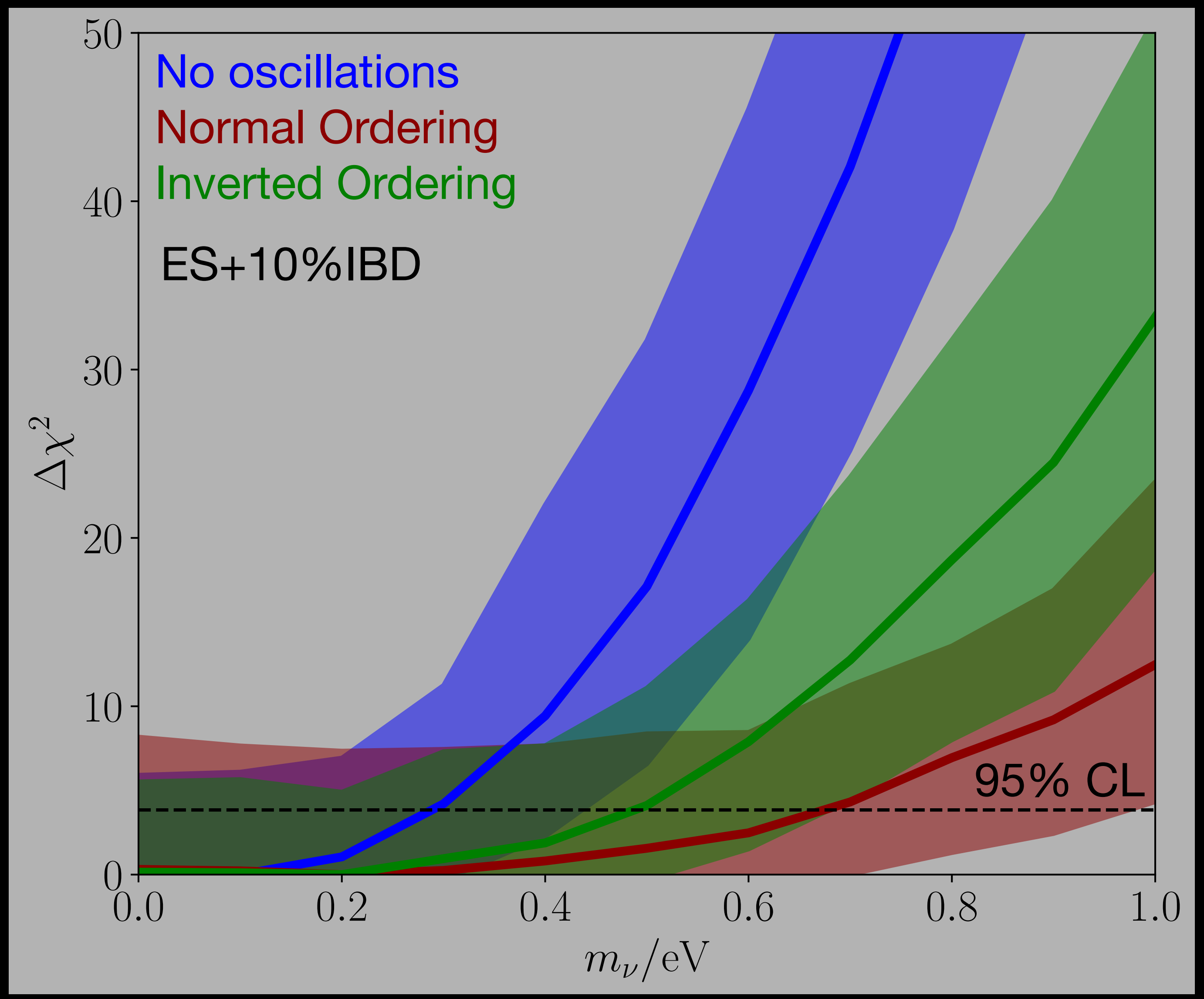

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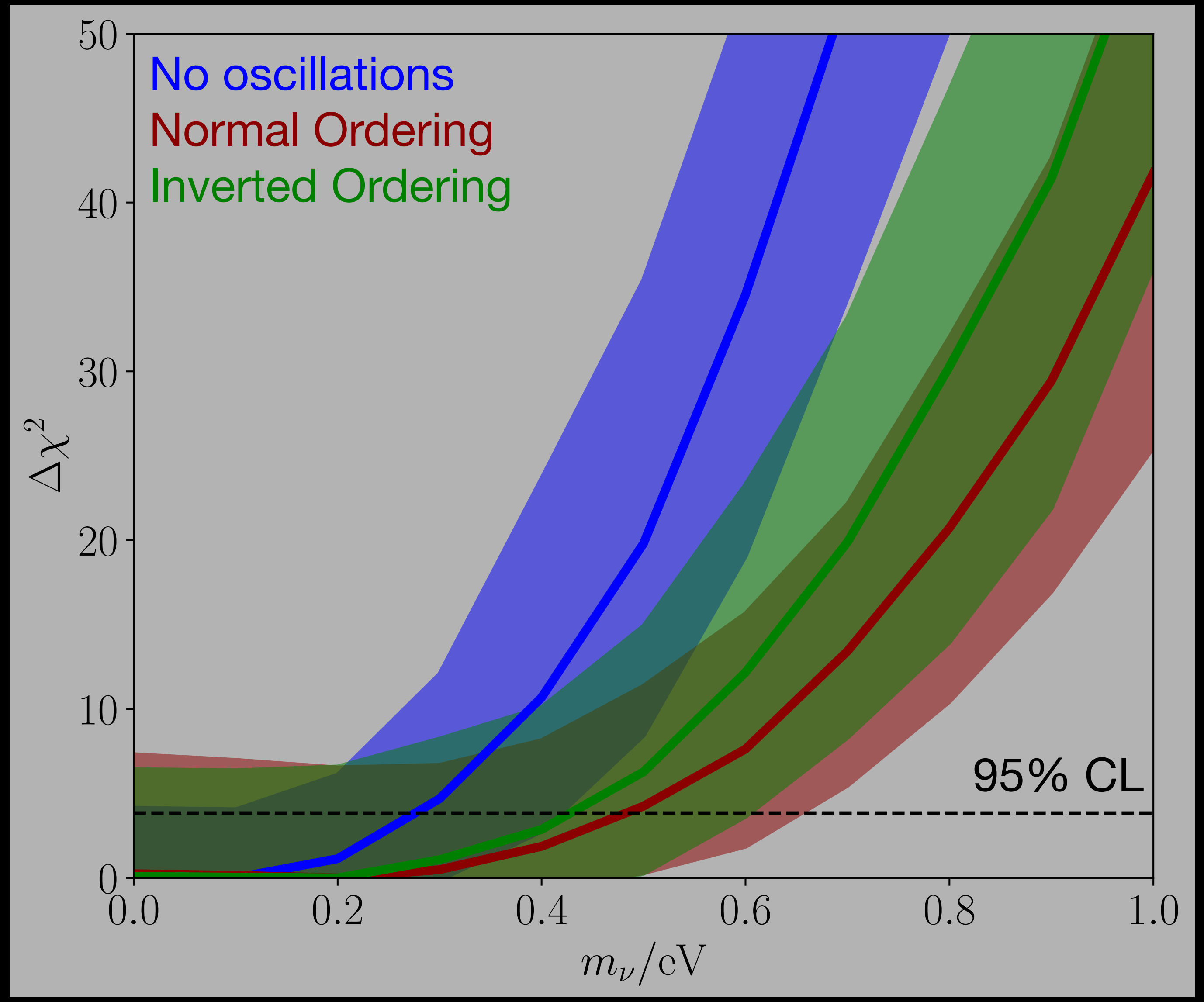

$M = 8.8\,M_\odot$	10 s	50 ms
90%IBD	16003	414
ES+10%IBD	3462	249
90%IBD	16223	466
ES+10%IBD	3419	130
90%IBD	16678	573
ES+10%IBD	3491	178

ν invisible decay

A.de Gouvêa, I.Martinez-Soler, M.Sen (Phys.Rev.D 101 4, 043013)

$$\Phi(E,t) \sim \boxed{\exp\left(- \frac{D\ m_{\nu_i}}{E_\nu\ \tau_{\nu_i}} \right)} \Phi_0(E,t)$$

$$\nu_h \longrightarrow \nu_l\ \gamma$$

$$\nu_h \longrightarrow \nu_l\ \nu_l\ \nu_l$$

ν invisible decay

[A.de Gouvêa, I.Martinez-Soler, M.Sen (Phys.Rev.D 101 4, 043013)](#)

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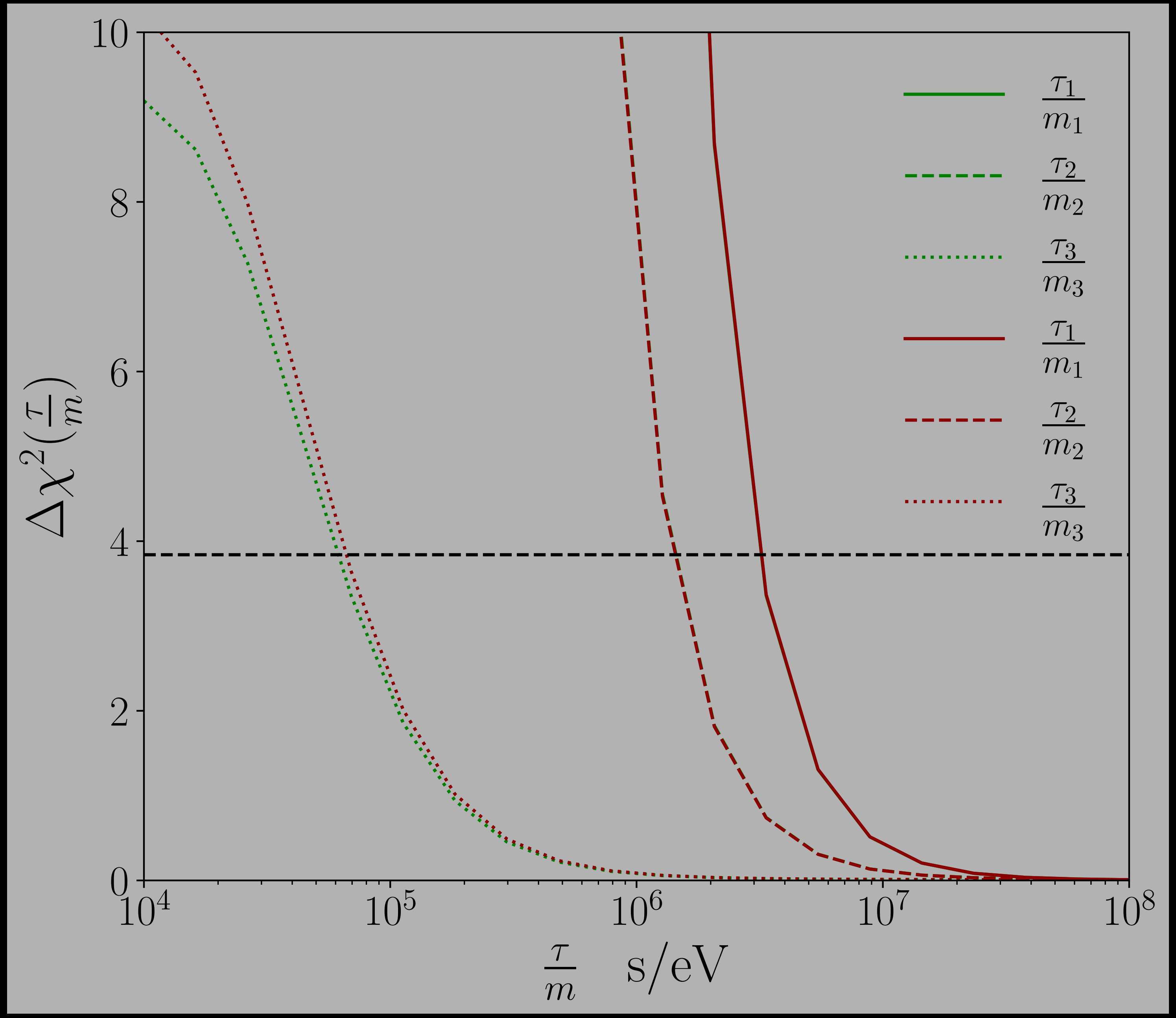
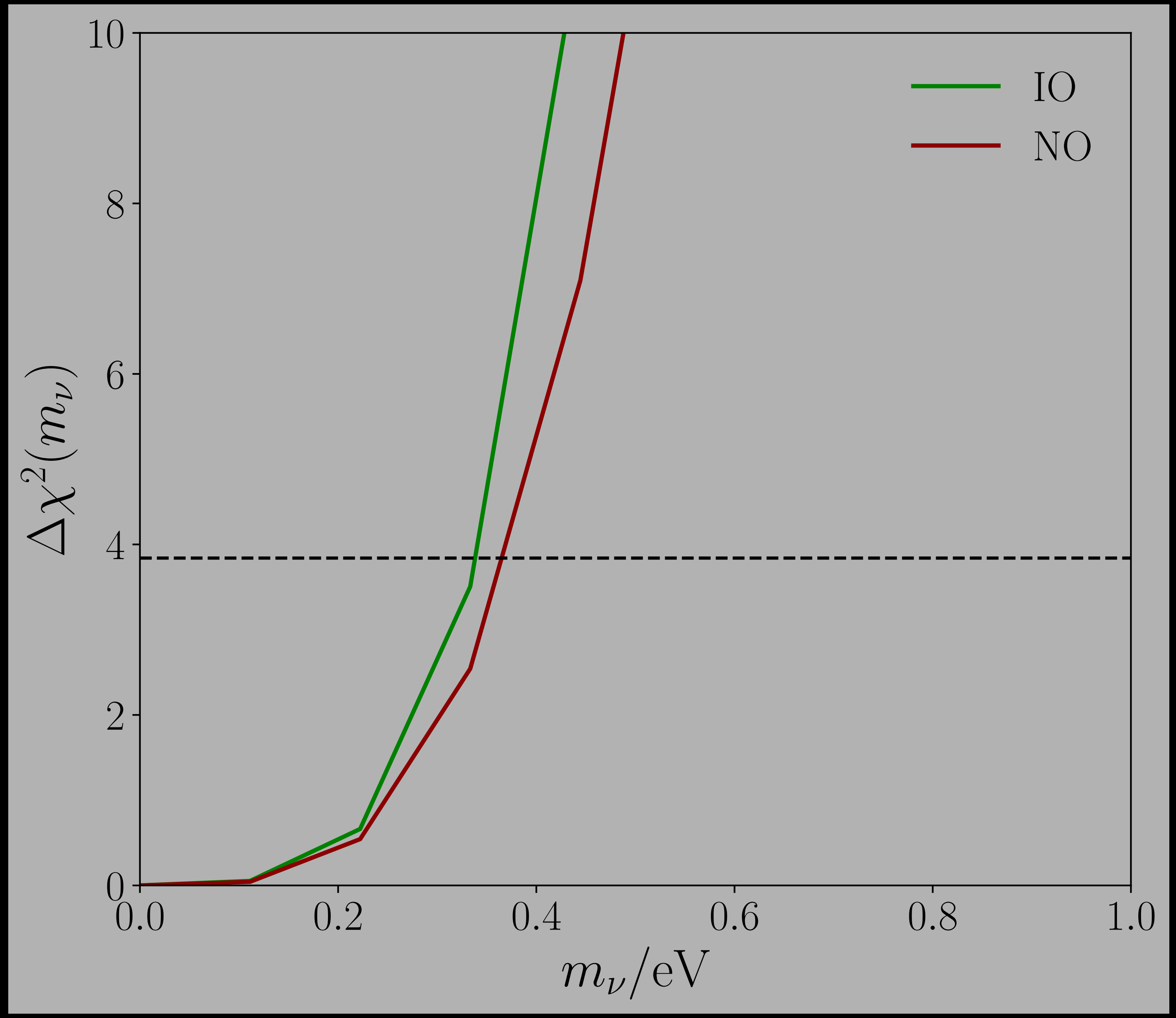
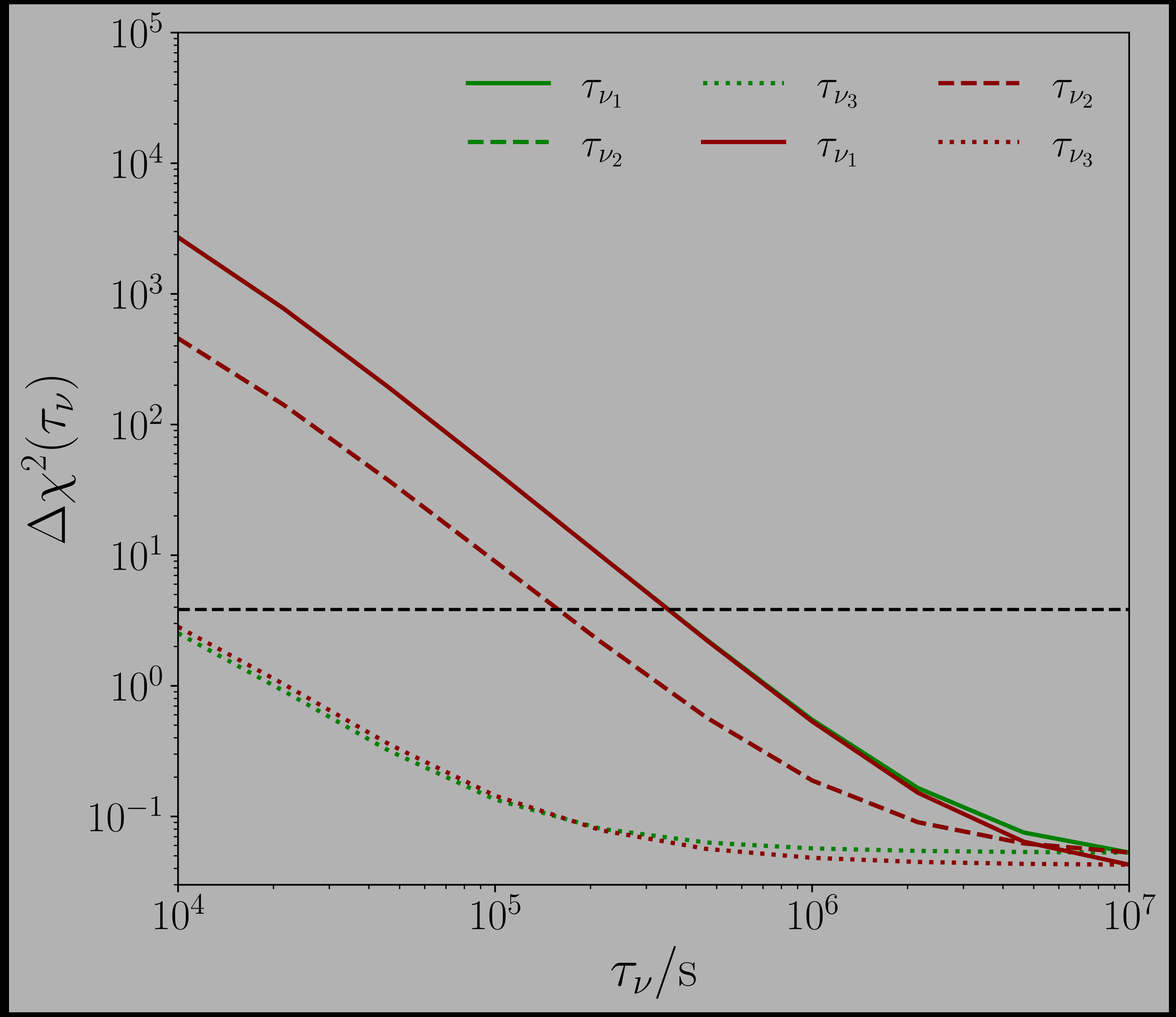


$$\frac{\tau_1}{m_1} \gtrsim 3\times 10^6 \text{ s/eV}$$



$$m_\nu < 0.35 \text{ eV}$$



$$\tau_1 \gtrsim 4\times 10^5 \text{ s}$$

Take-home message

With future neutrino observatories looking at Supernovae:

- **Impact of neutronization peak detection on neutrino mass constraints**
  complementary (and independent) measurement to laboratory and cosmology

- **Exploring neutrino invisible decays**
  Bounds improved and independent on mass ordering
  Simultaneous mass and lifetime constraints

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HIDDeν
Hunting Invisibles: Dark sectors, Dark matter and Neutrinos