Illustration by Sandbox Studio, Chicago with Corinne Mucha

The Center for Neutrino Physics

VIRGINIA TECH

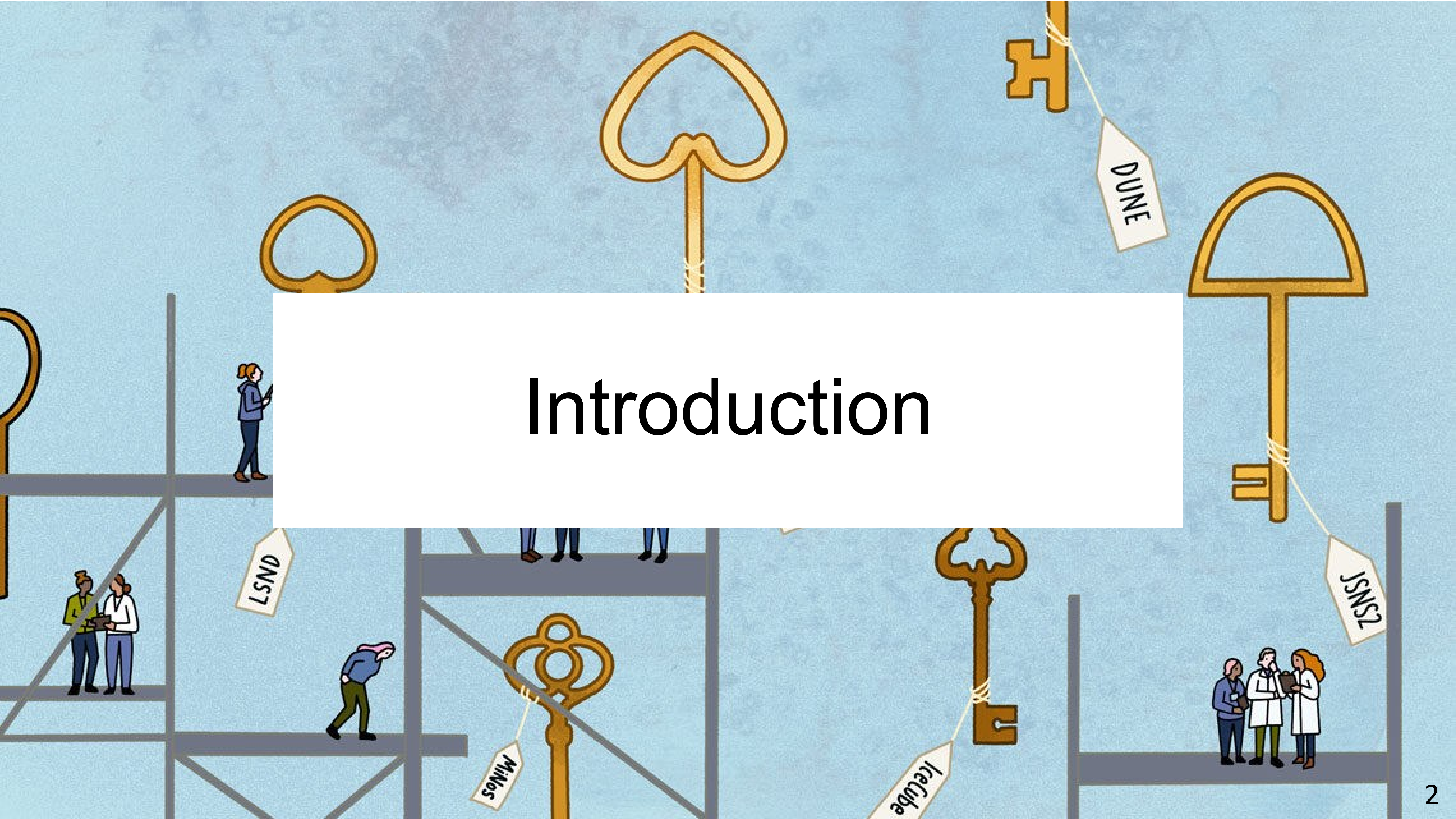
Heavy Neutral Lepton Decay

Yulun Li

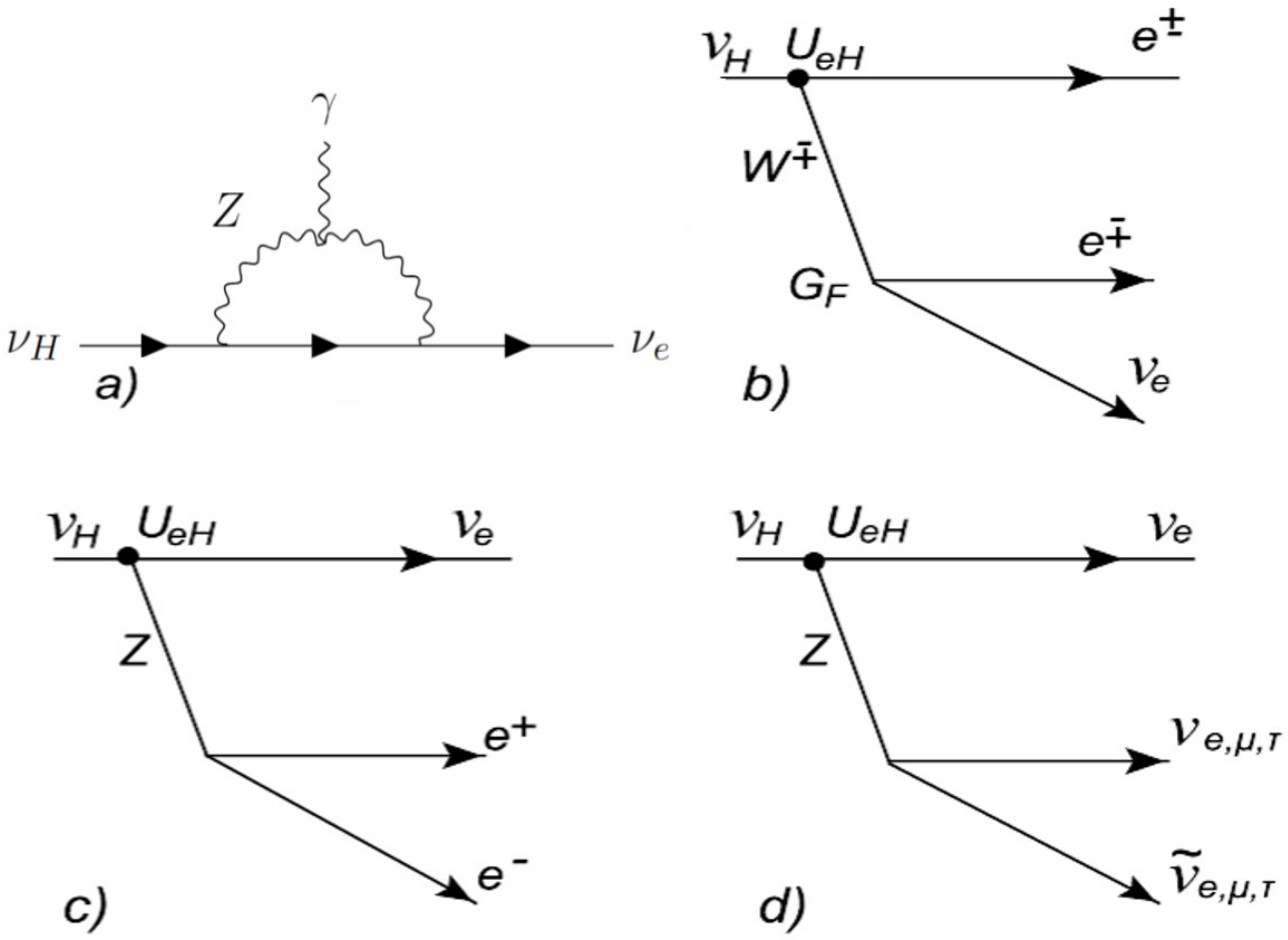
Advisor: Professor Huber

CNP Day 2024

Introduction

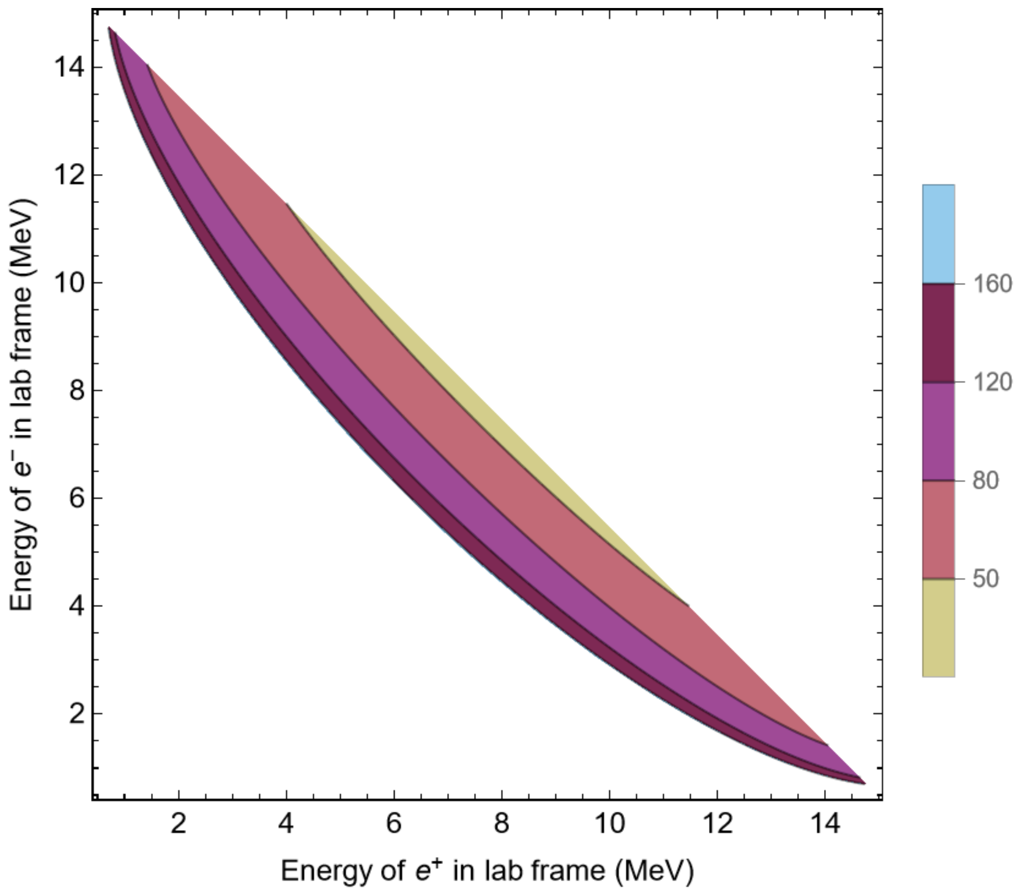


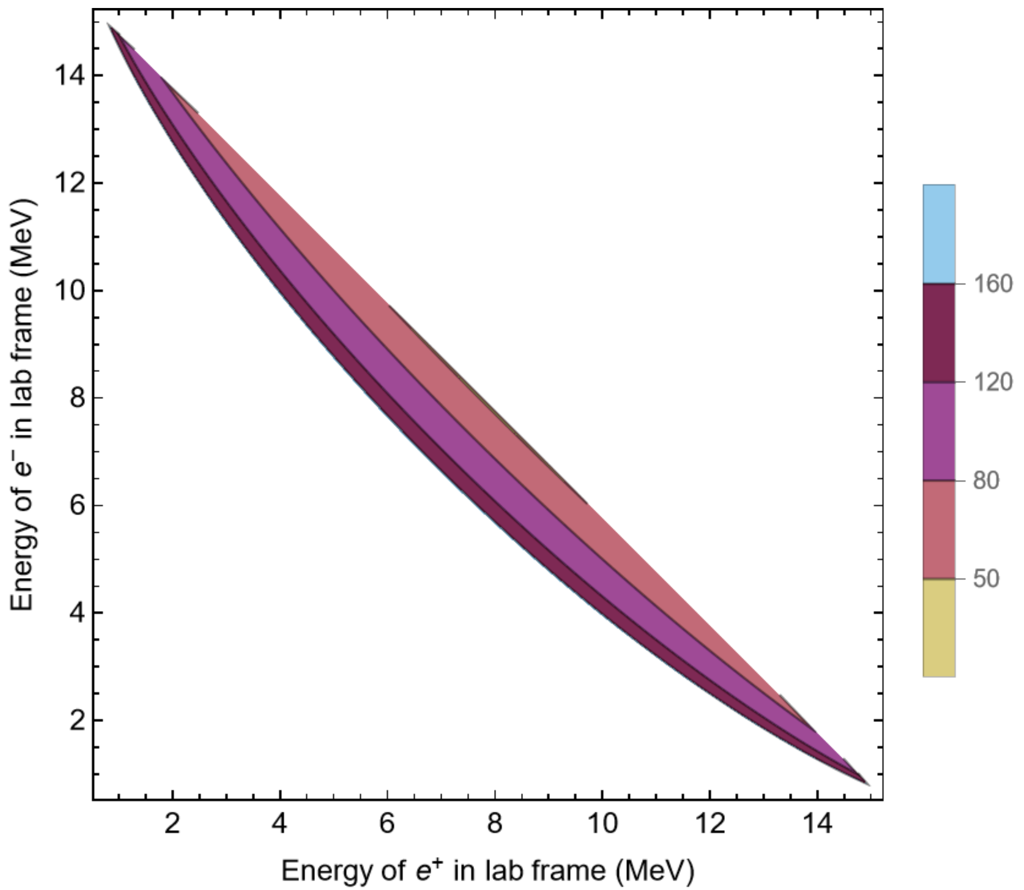
Heavy Neutral Lepton (MeV) decay



- $\nu_H \rightarrow \nu_e + \gamma$
- $\underline{\nu_H \rightarrow \nu_e + e^+ + e^-}$
- $\nu_H \rightarrow \nu_e \nu_i \tilde{\nu}_i$ (Invisible)

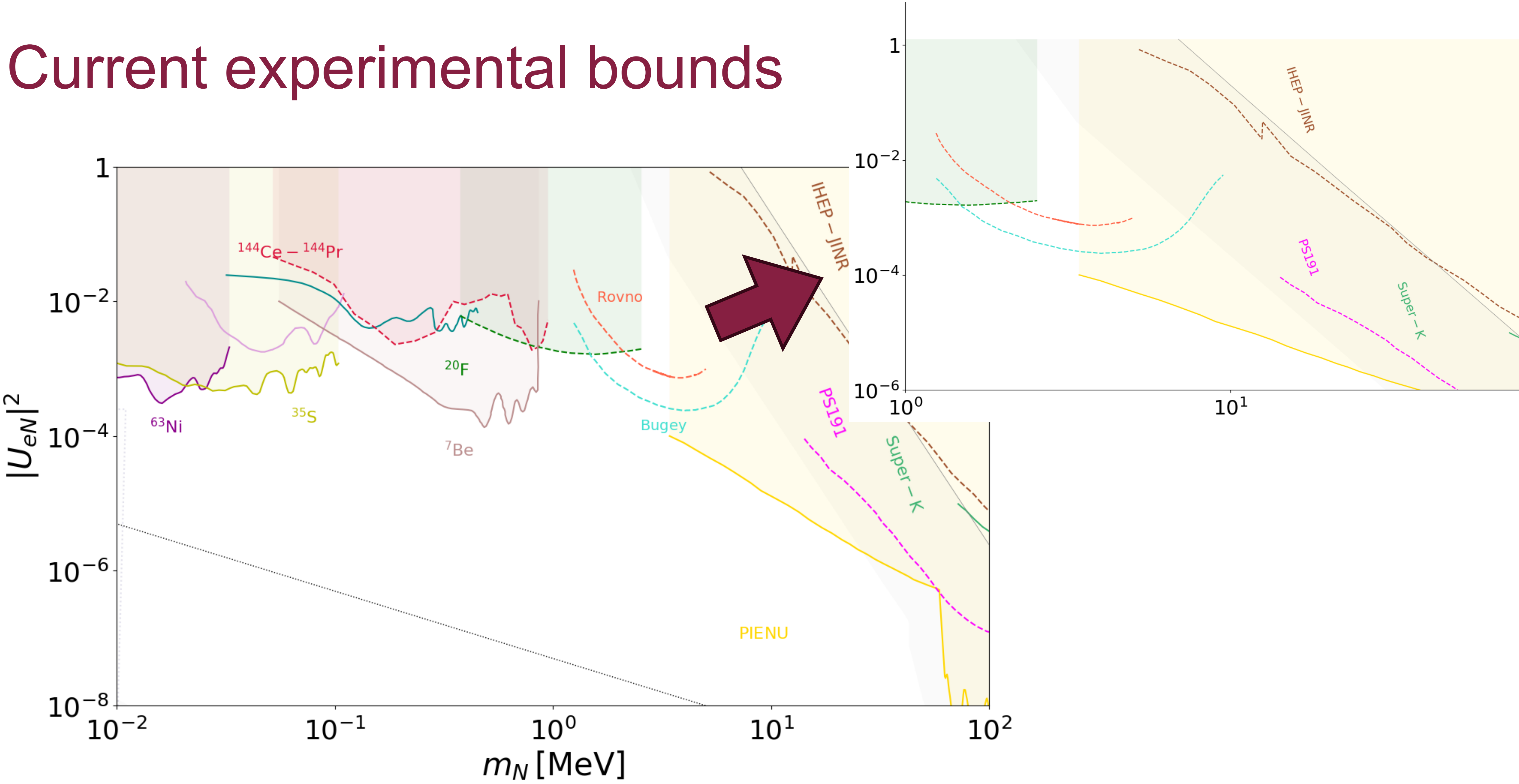
Can we see the signature in the experiment?





The opening angle (degree) of $e^+ e^-$ in the lab frame assuming $E_{\nu_H} = 4\, m_{\nu_H} = 16$ MeV. The two plots assumes different outgoing neutrino's angle with HNL. Left plot: $\cos\theta = \cos\theta_{min}$; right plot: $\cos\theta = \cos\theta_{min} + 0.7$.

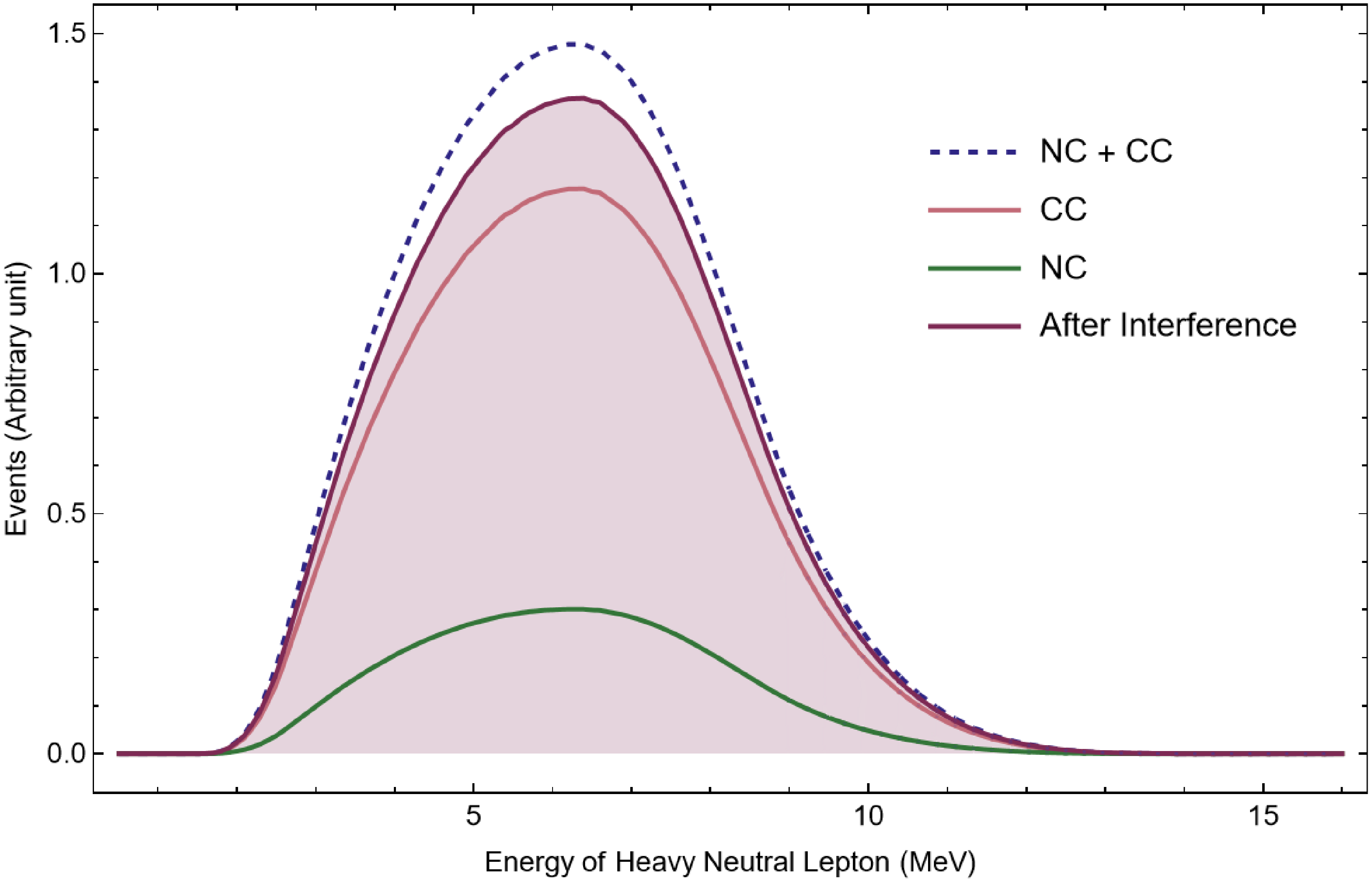
Current experimental bounds



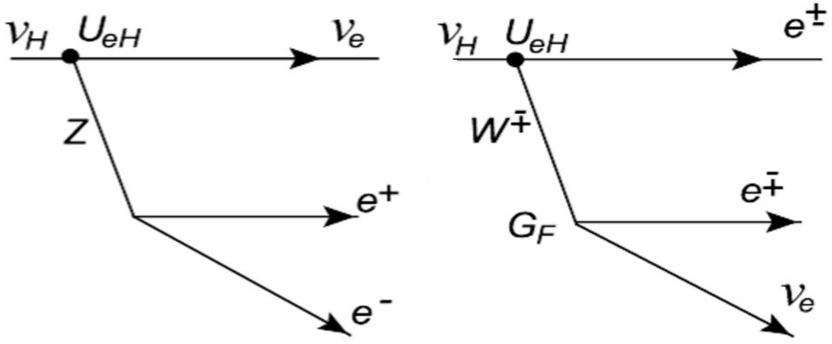
Courtesy of Bolton, Deppisch

Interference Effect into Account

Interference between NC and CC[1] channels



- This is a comparison between the CC channel, NC channel, their interfered channel (in shade), and their incoherently summed channel (dashed).



1. NC: Neutral Current; CC: Charged Current.

Expected decay width with correct interference

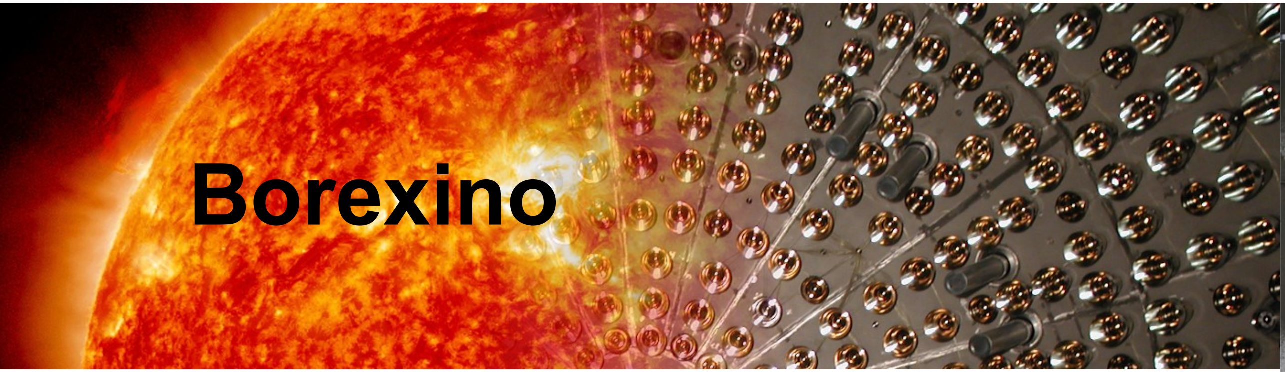
$$\Gamma_0 = \frac{G_F^2 m_{\nu_H}^5}{192\pi^3}, \qquad \frac{d^2\Gamma}{dl^0 d\cos\theta} = \Gamma_0 |U_{s1}|^2 \frac{d^2\overline{\Gamma}}{dl^0 d\cos\theta}$$

$$\frac{d^2\overline{\Gamma}}{dl^0 d\cos\theta} = 2(1-Q^2)^2\sqrt{1-\frac{4m_e^2}{Q^2}}\frac{1}{Q^2}\Big\{ \Big[X^1\Big(Q^2+2Q^4-2m_e^2(Q^2-1)\Big)-6ZQ^2m_e^2\Big] - |\vec{s}|\cos\theta\Big[X\Big(Q^2-2Q^4+2m^2(1+Q^2)\Big)+6ZQ^2m_e^2\Big]\Big\}$$

1. $X = [(g_V+1)^2 + (g_A+1)^2]$, $Y = [(g_V+1)(g_A+1)]$, and $Z = [(g_V+1)^2 - (g_A+1)^2]$.

Sensitivities of Experiments

Experiments we considered

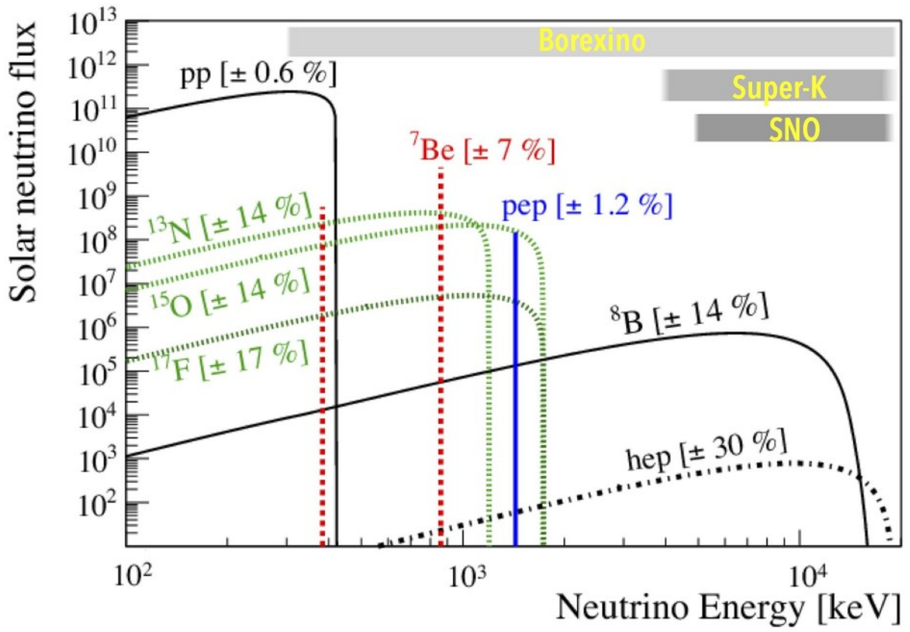


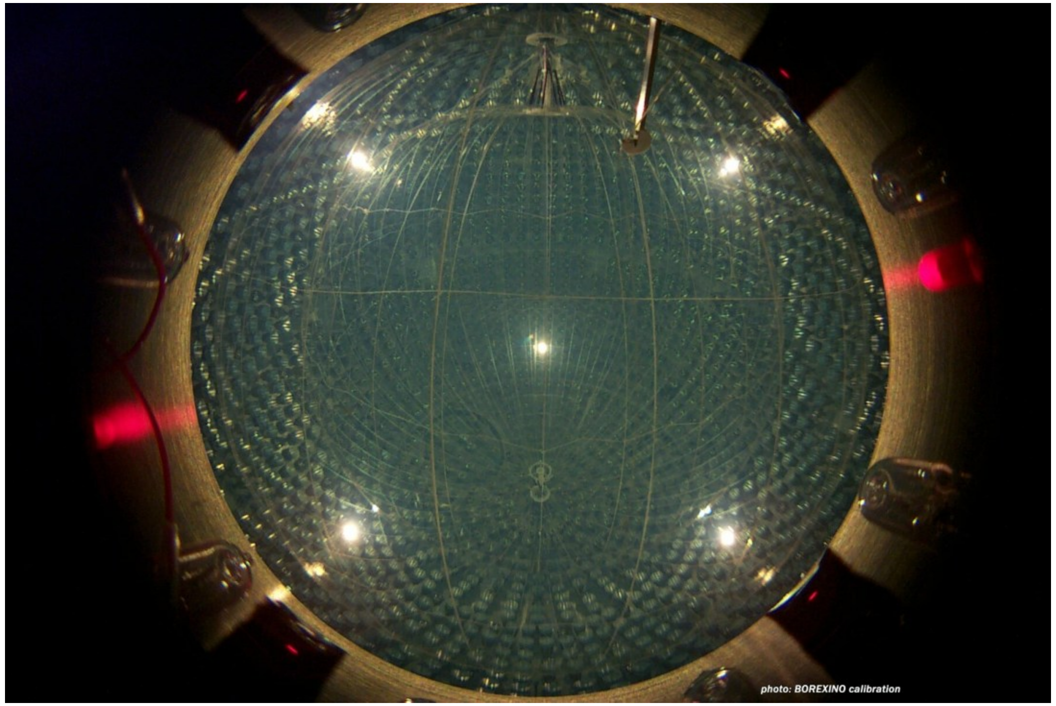
DAEδALUS
IsoDAR

DARWIN

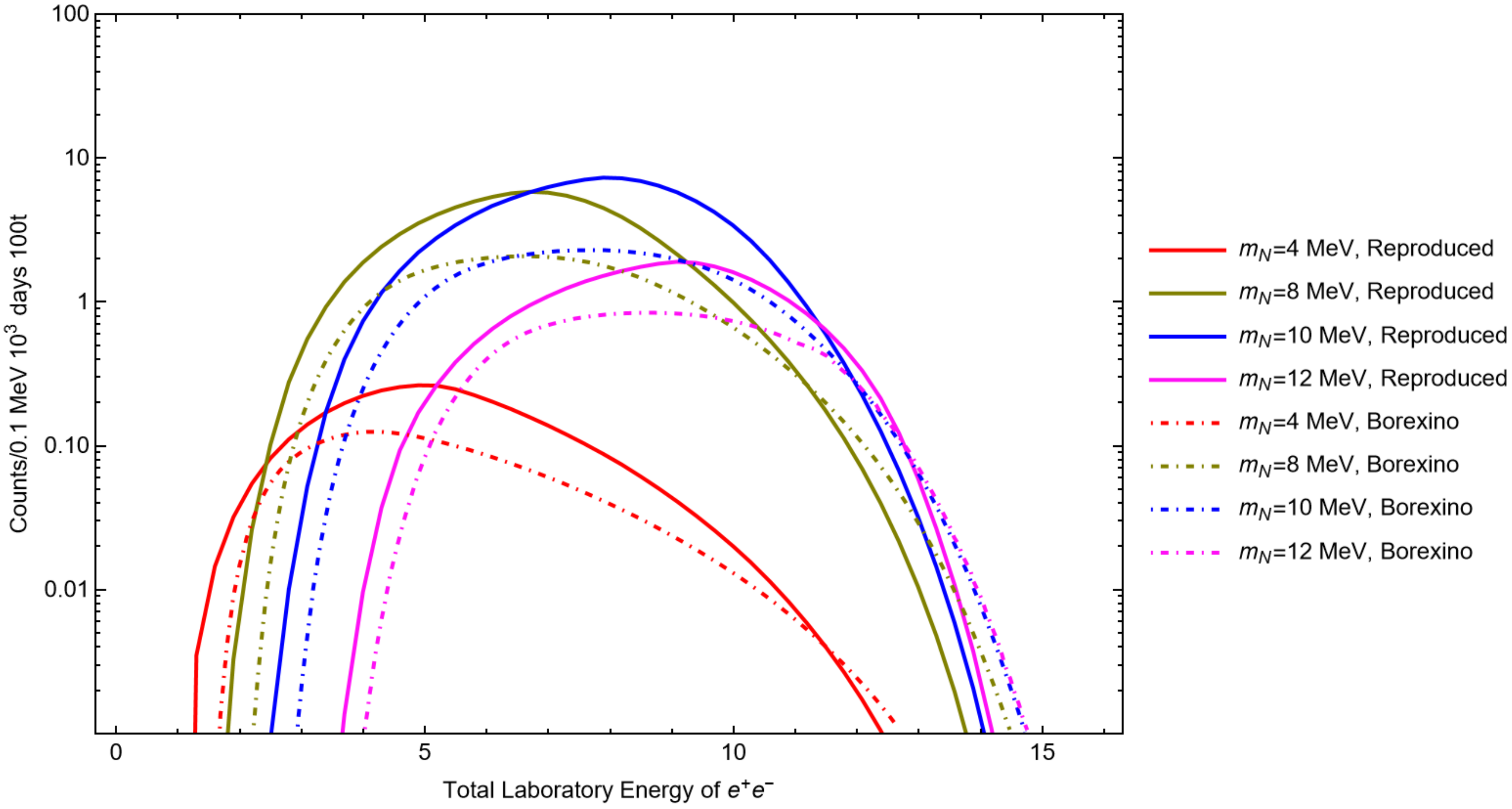
Borexino Experiment

- Deep underground particle physics experiment to study low energy (sub-MeV) solar neutrinos.
- 100 ton scintillator experiment (fiducial volume)
- 446 Exposure dates



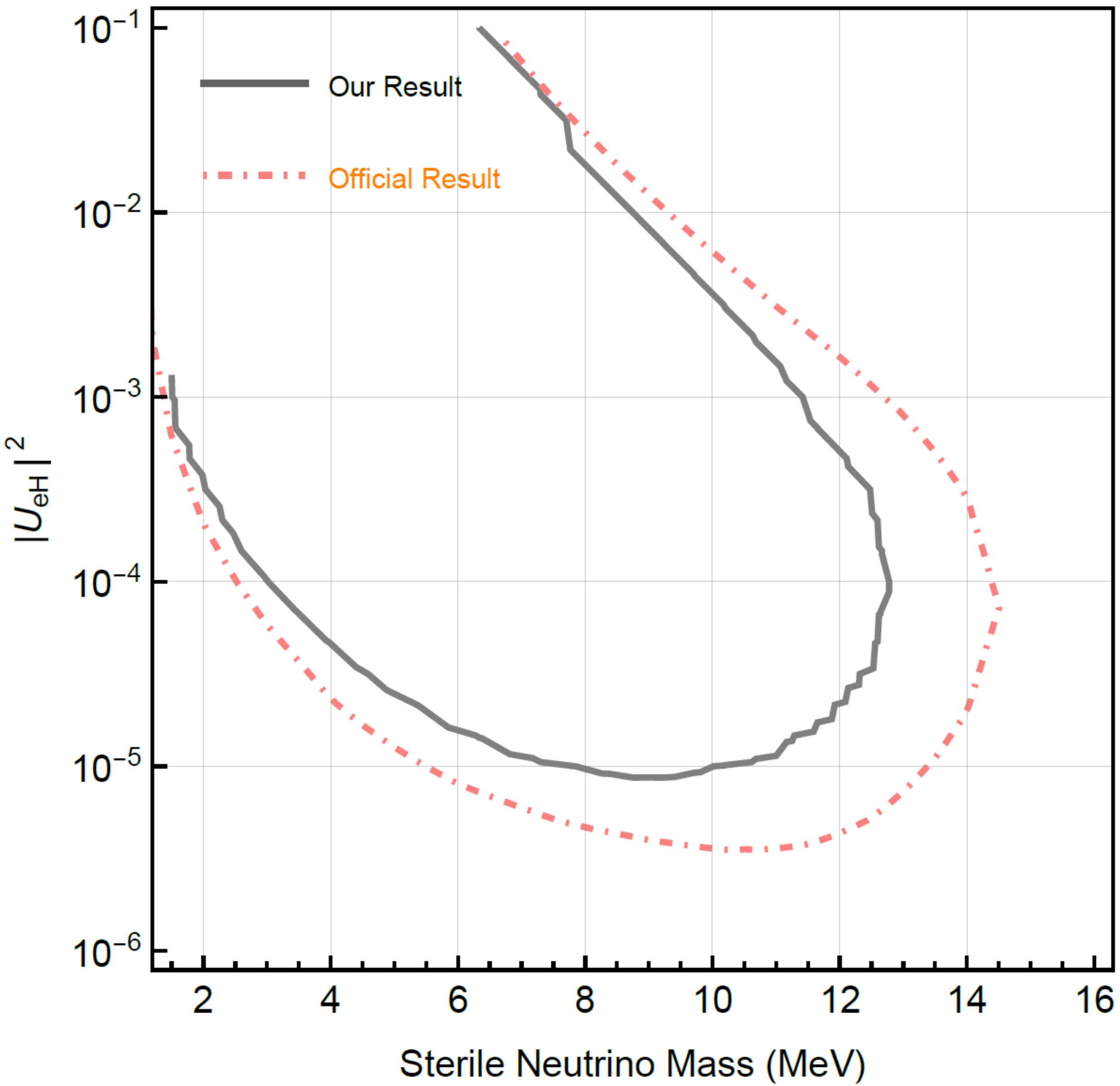


Expected events from the decay

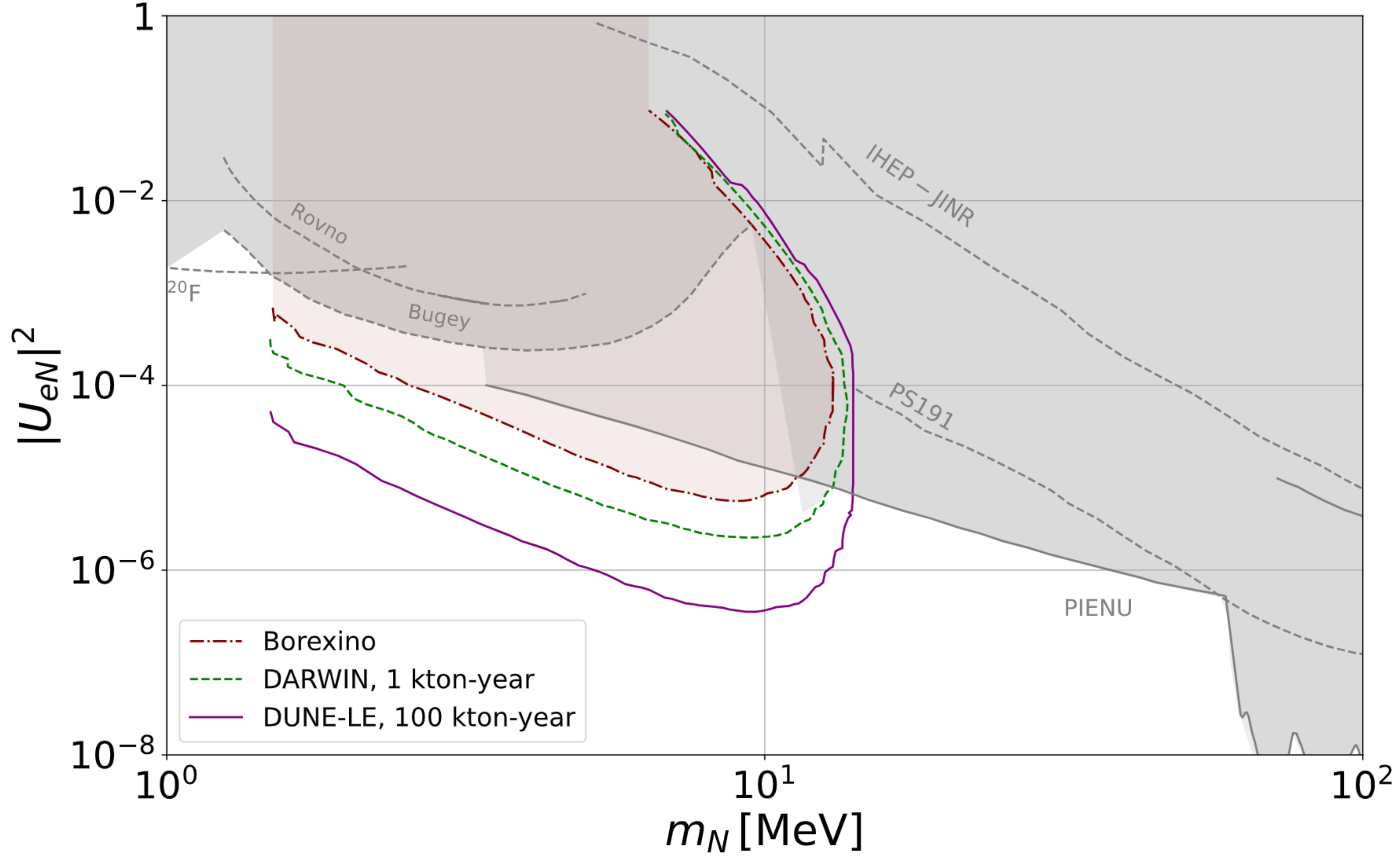


Bellini et al (2013).

Our imposed bounds compared with Borexino’s



Our imposed bounds for this interaction



Summary

- We presented our closed-form calculations of heavy neutral lepton decay which correctly considered interference.
- The sensitivities from the solar neutrino gets more significant if increasing the detector’s volume.
- Lab neutrino’s (isotope decay-at-rest or beta decay) sensitivity stops increasing at a point when increasing detector’s volume further.
- Liquid argon detector has less background compared to scintillator.
- The sensitivity increases when increasing the running time.

Thank You

Yemilab (Backup slide 1)

- 1.16 kton fiducial volume
- Running for 5 years (with 4 years reactor ON if considering ISODAR)
- Bin size: 100 keV
- Assumed background from
- Poisson likelihood
- Energy resolution $6.4\%/(\sqrt{[E(\mathrm{MeV})]})$
- 32% Efficiency

DUNE-LE (Backup slide 2)

- 40 kton fiducial volume of liquid argon (just for fun)
- Running for 5 years
- Bin size: 300 keV
- Assumed the background to be well constrained
- Poisson likelihood
- Energy resolution 1.53%/$(\mathrm{E}(\mathrm{MeV}))$

Darwin (Backup slide 3)

- 0.2 kton fiducial volume of liquid argon
- Running for 5 years
- Bin size: 160 keV
- Assumed the background to be well constrained
- Poisson likelihood
- Energy resolution 1.53%/$(\mathrm{E}(\mathrm{MeV}))$