

# Hunting for the Cosmic Neutrino Background

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JCAP 01 (2023), 003



# Contents

- What is the  $CvB$ ?

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- What is the CvB?
- How might we go about detecting it?

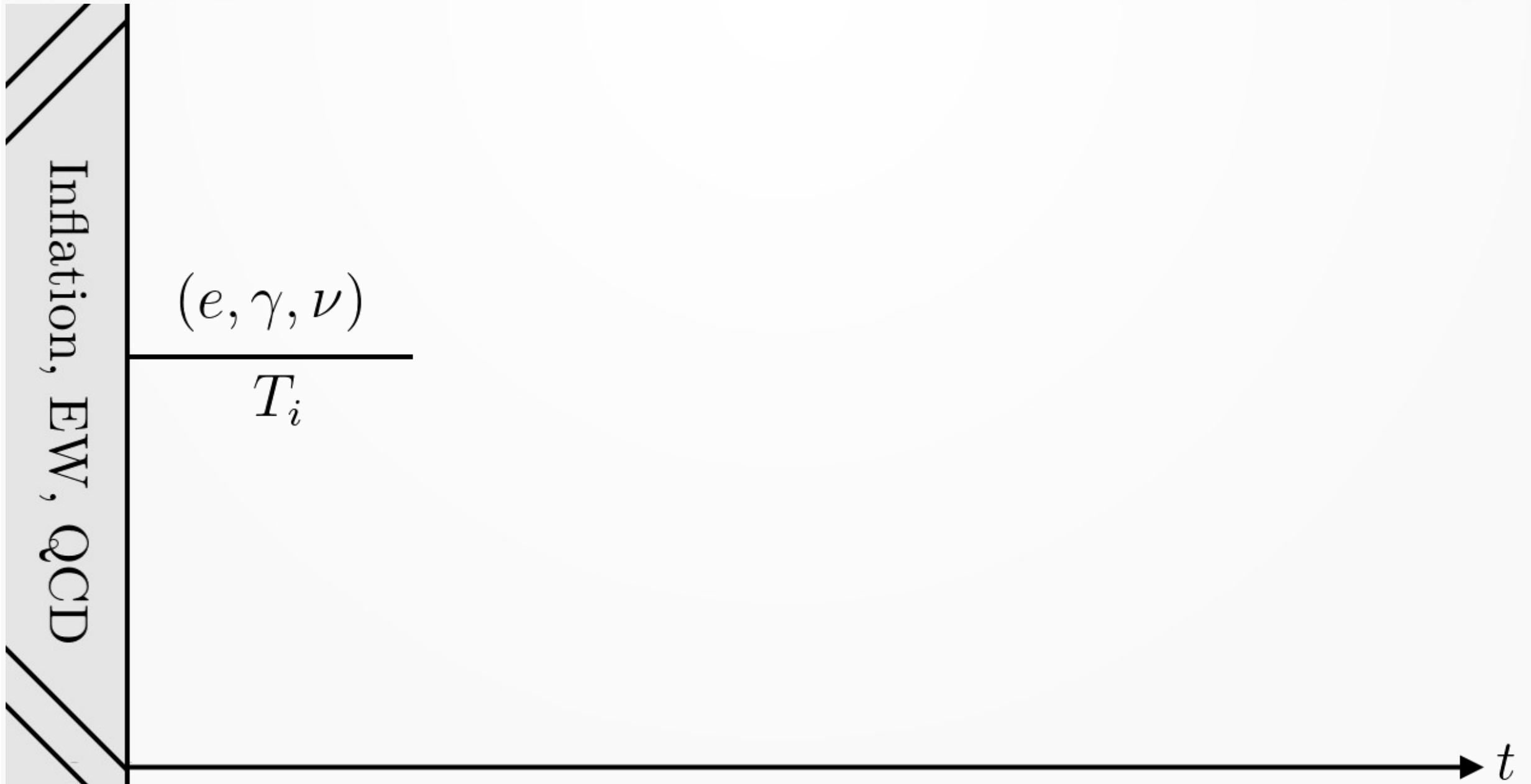
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- How might we go about detecting it?
  - PTOLEMY
  - Coherent scattering
  - Stodolsky effect
  - Accelerator

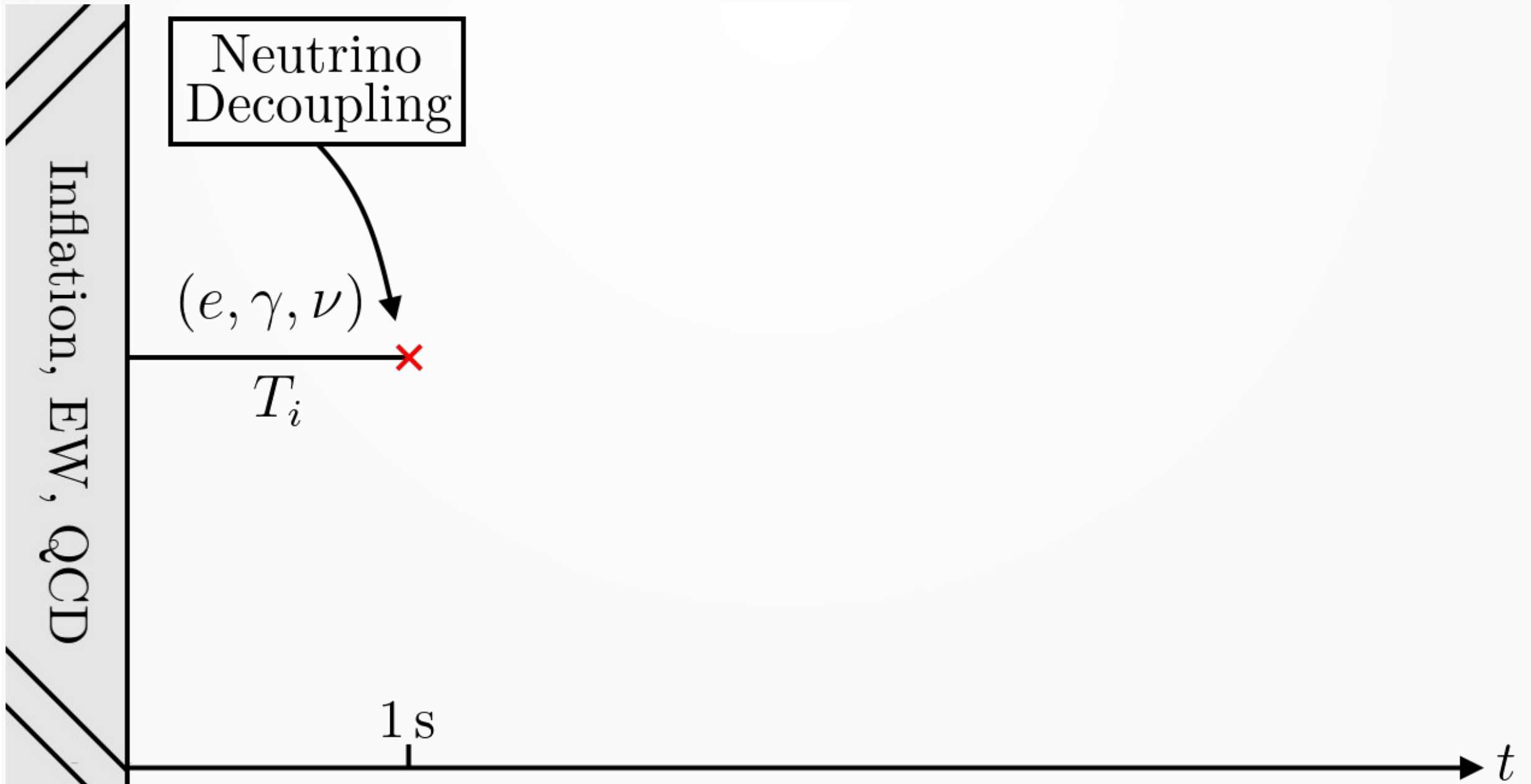
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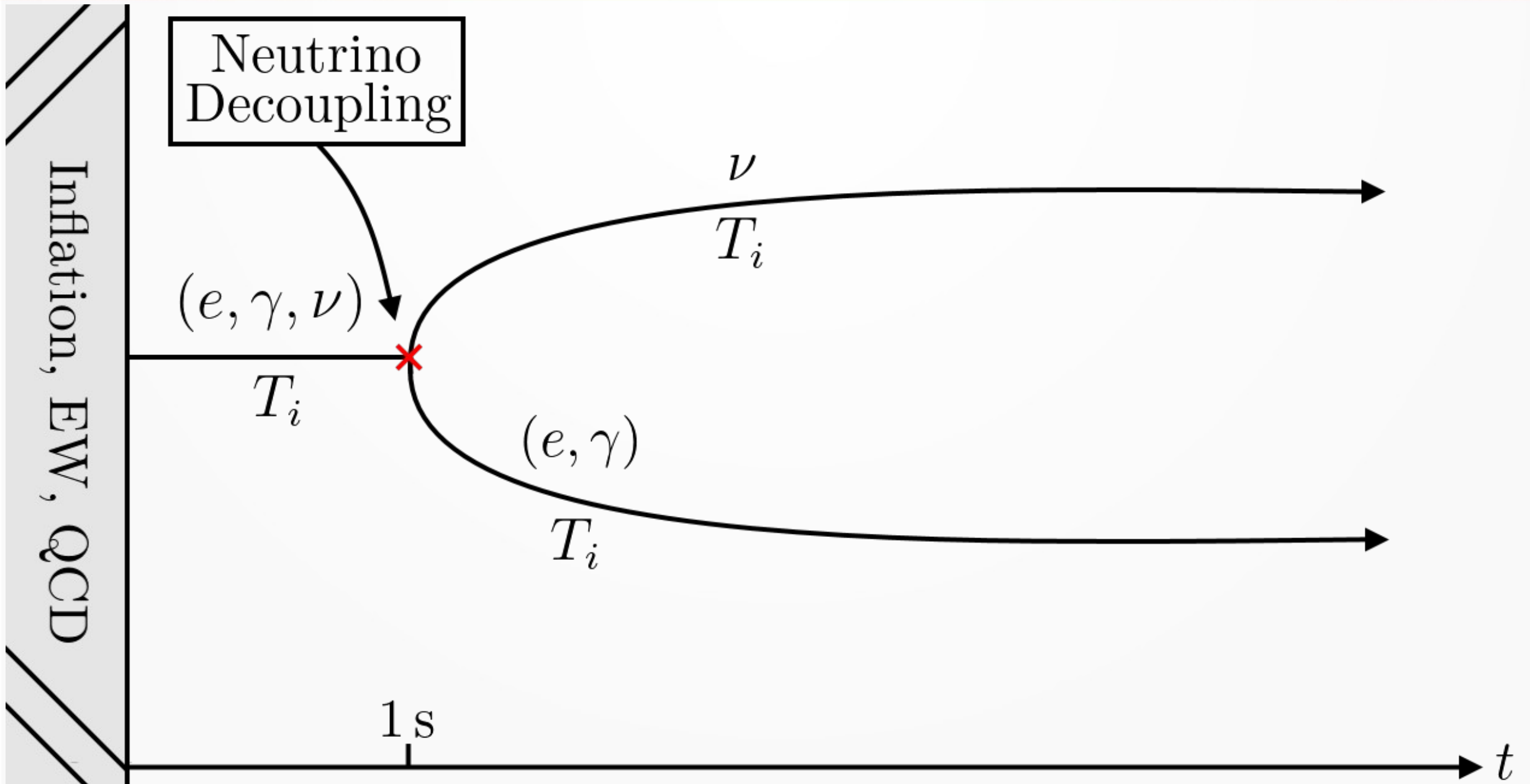
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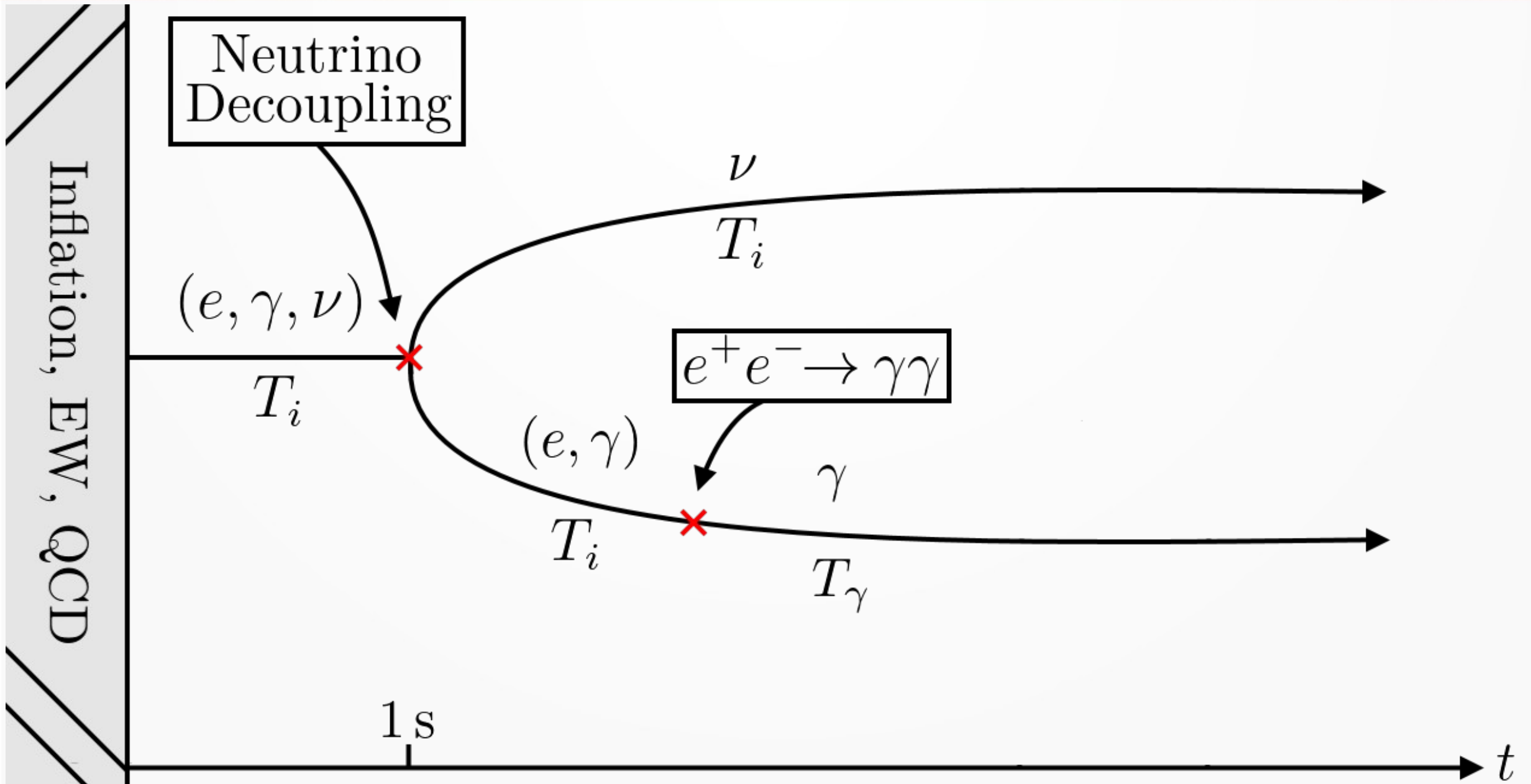
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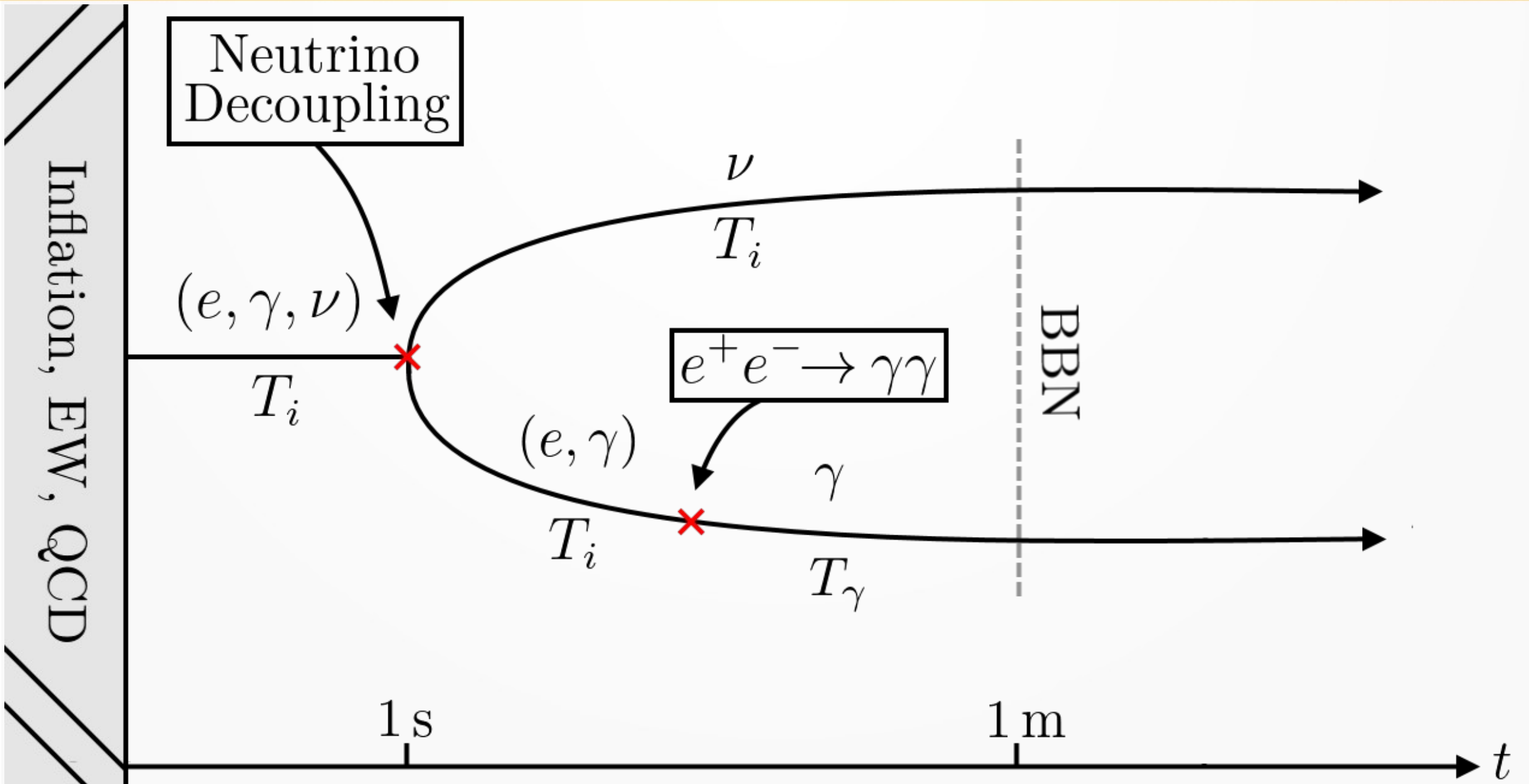
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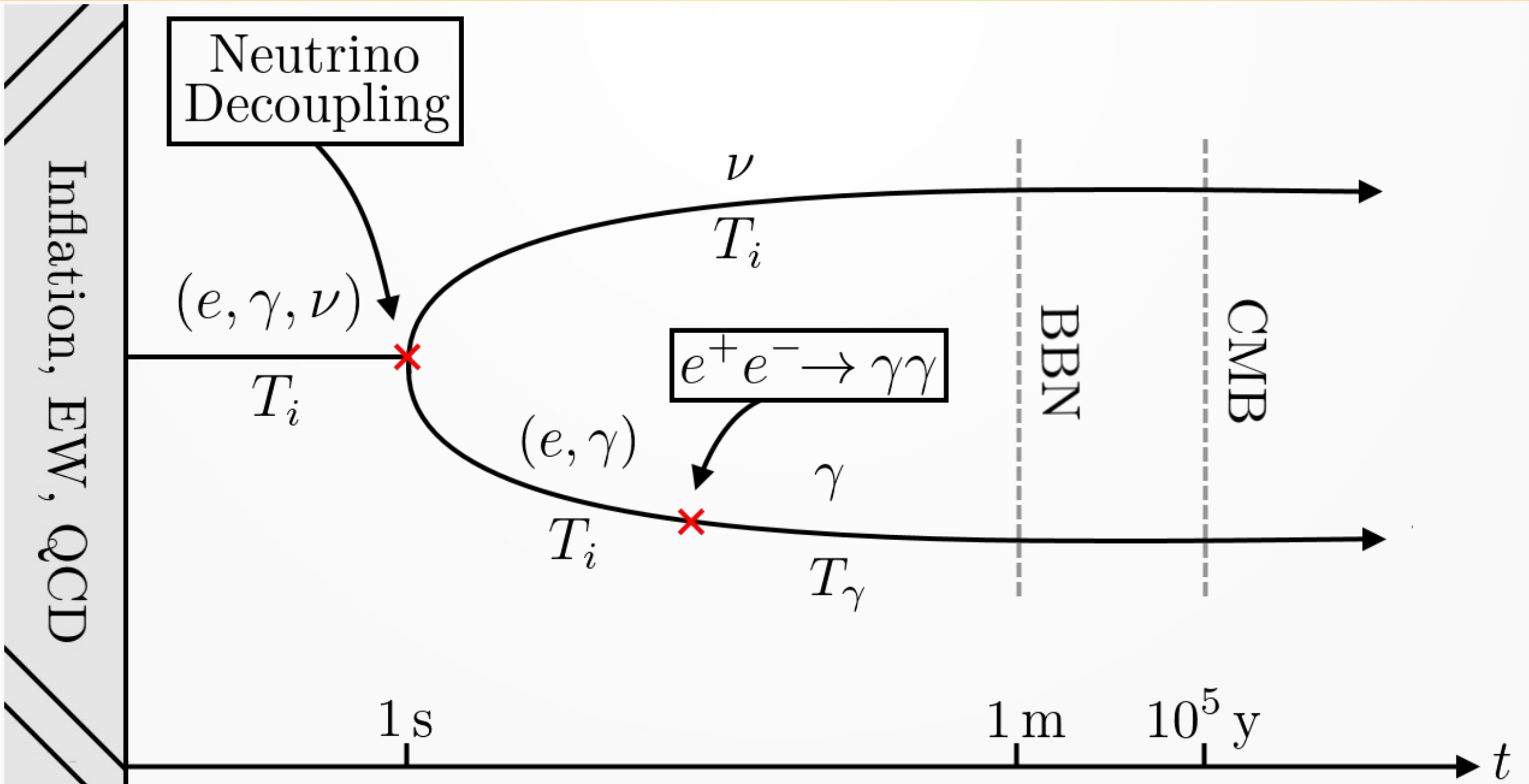
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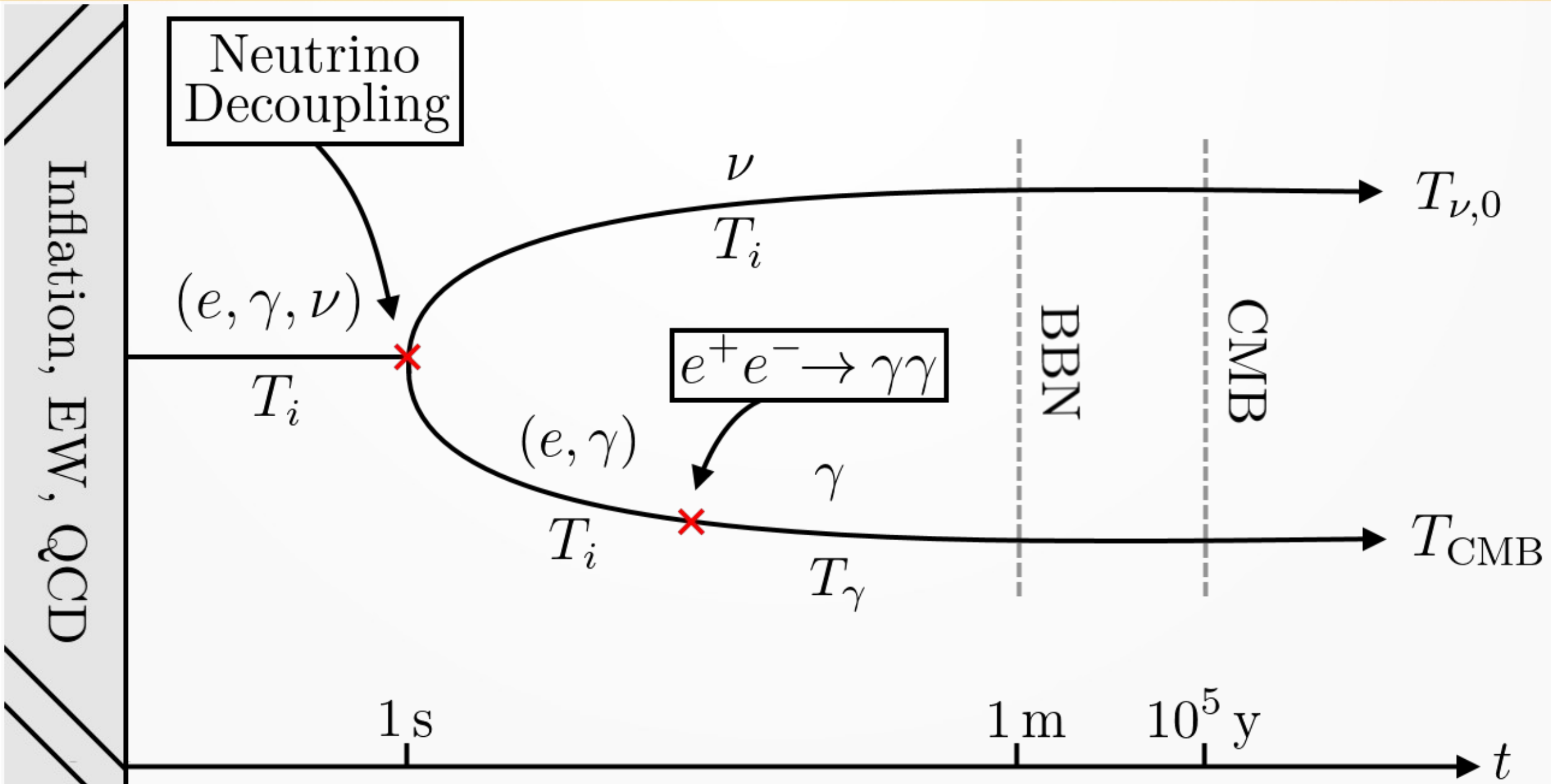
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# The CνB today

- Redshifted to temperature:

$$T_{\nu,0} = \left( \frac{4}{11} \right)^{\frac{1}{3}} T_{\text{CMB}}$$

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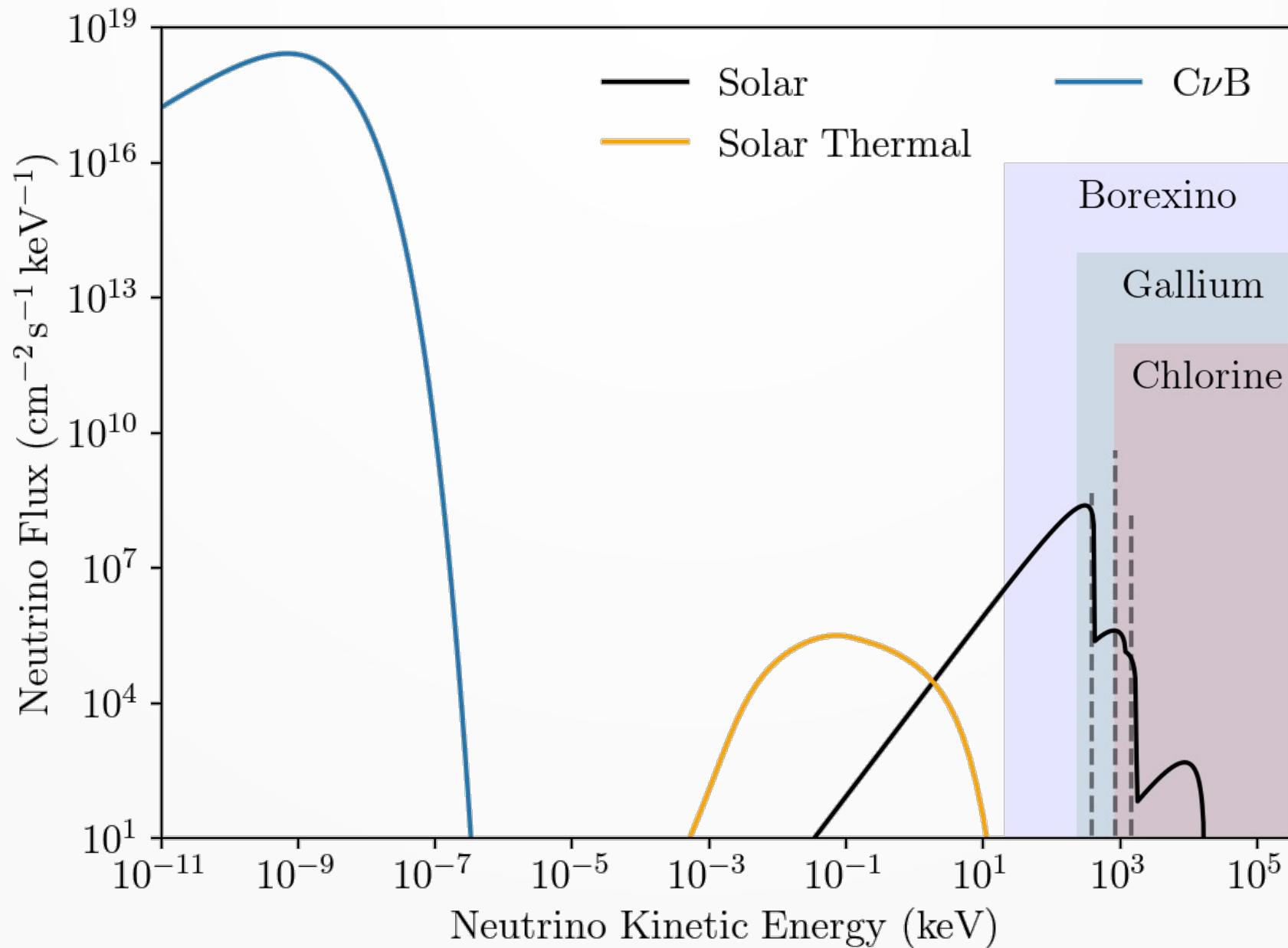
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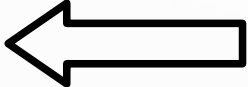
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- May be overdense, *e.g.* clustering, decays to neutrinos

# The CνB today



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# How to detect the CvB

- Threshold:

- 

- 

- Event rate:

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-

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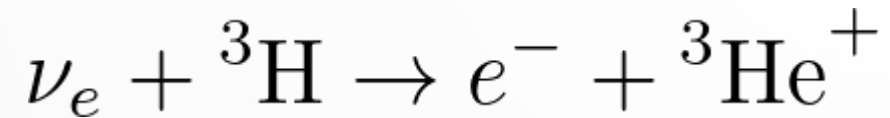
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# How to detect the CvB

- Threshold:
  - Look for thresholdless process
  - Find some way to bridge it
- Event rate:
  - Use a huge number of targets
  - Increase the cross section

# The PTOLEMY experiment

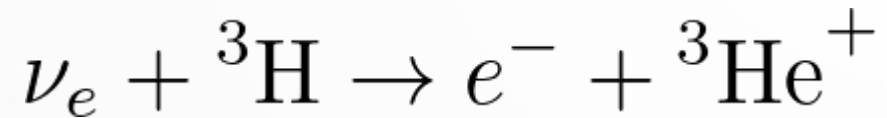
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[1] S. Weinberg, Phys. Rev. **128**, 1457 (1962)

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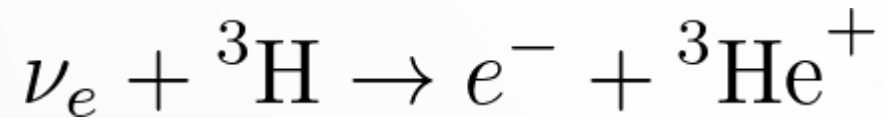
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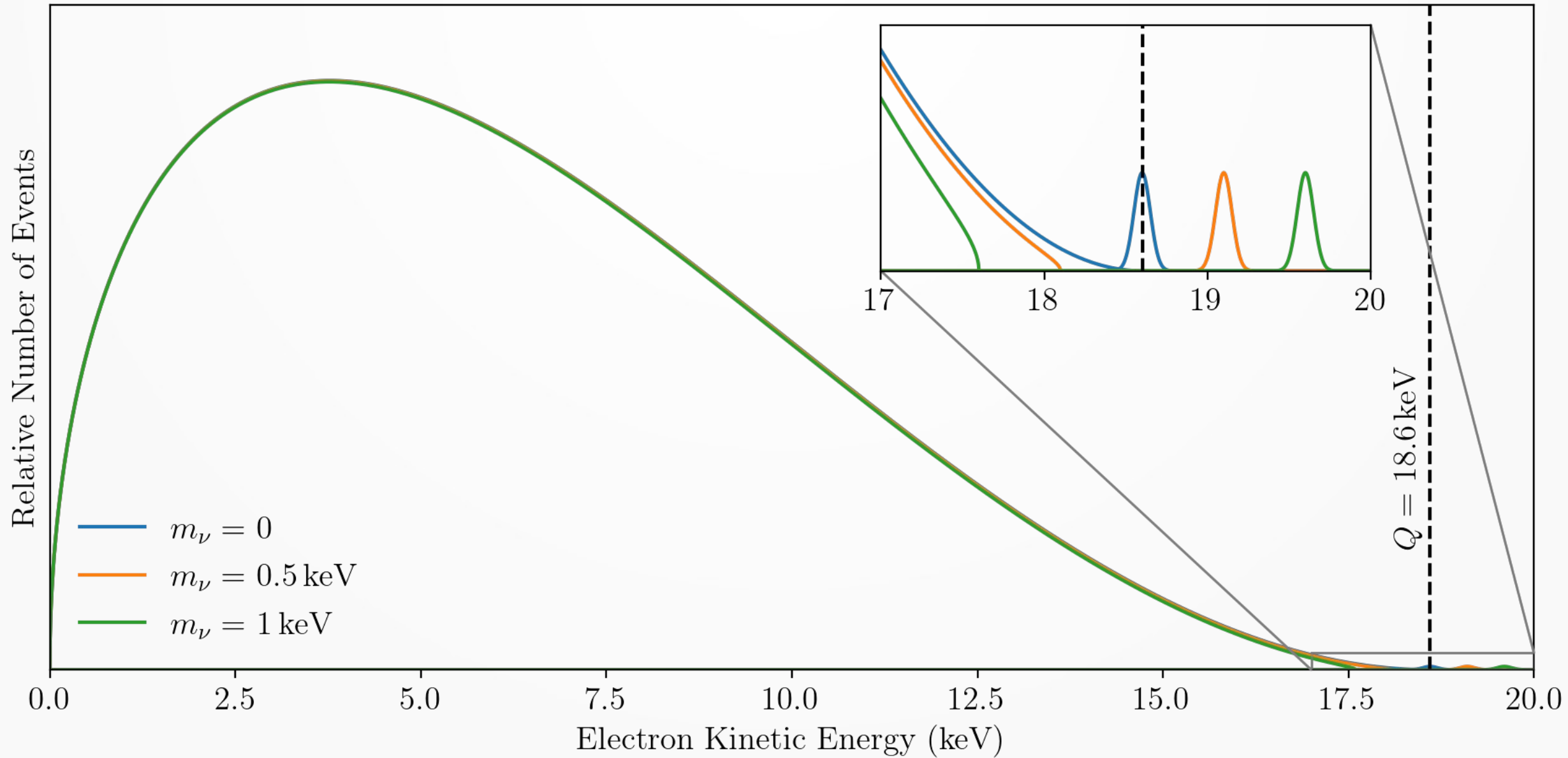


- This process has no threshold
- Tritium already well understood from neutrino mass experiments



[1] S. Weinberg, Phys. Rev. **128**, 1457 (1962)

# PTOLEMY



# The PTOLEMY experiment

- Neutrino capture cross section [2]:

$$\langle \sigma \beta_\nu \rangle \propto G_F^2 E_e p_e \sim 10^{-45} \text{ cm}^2$$

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$$R = N_T n_\nu \langle \sigma v_\nu \rangle \sim 4 \text{ y}^{-1}$$

- This event rate is doubled for Majorana neutrinos

[2] A. Long, C. Lunardini and E. Sabancilar, JCAP **08**, 038 (2014)

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- cf. KATRIN, uses  $\sim 300\mu\text{g}$  of tritium [3]

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$$m_{\nu_h} \gtrsim 50 \text{ meV}$$

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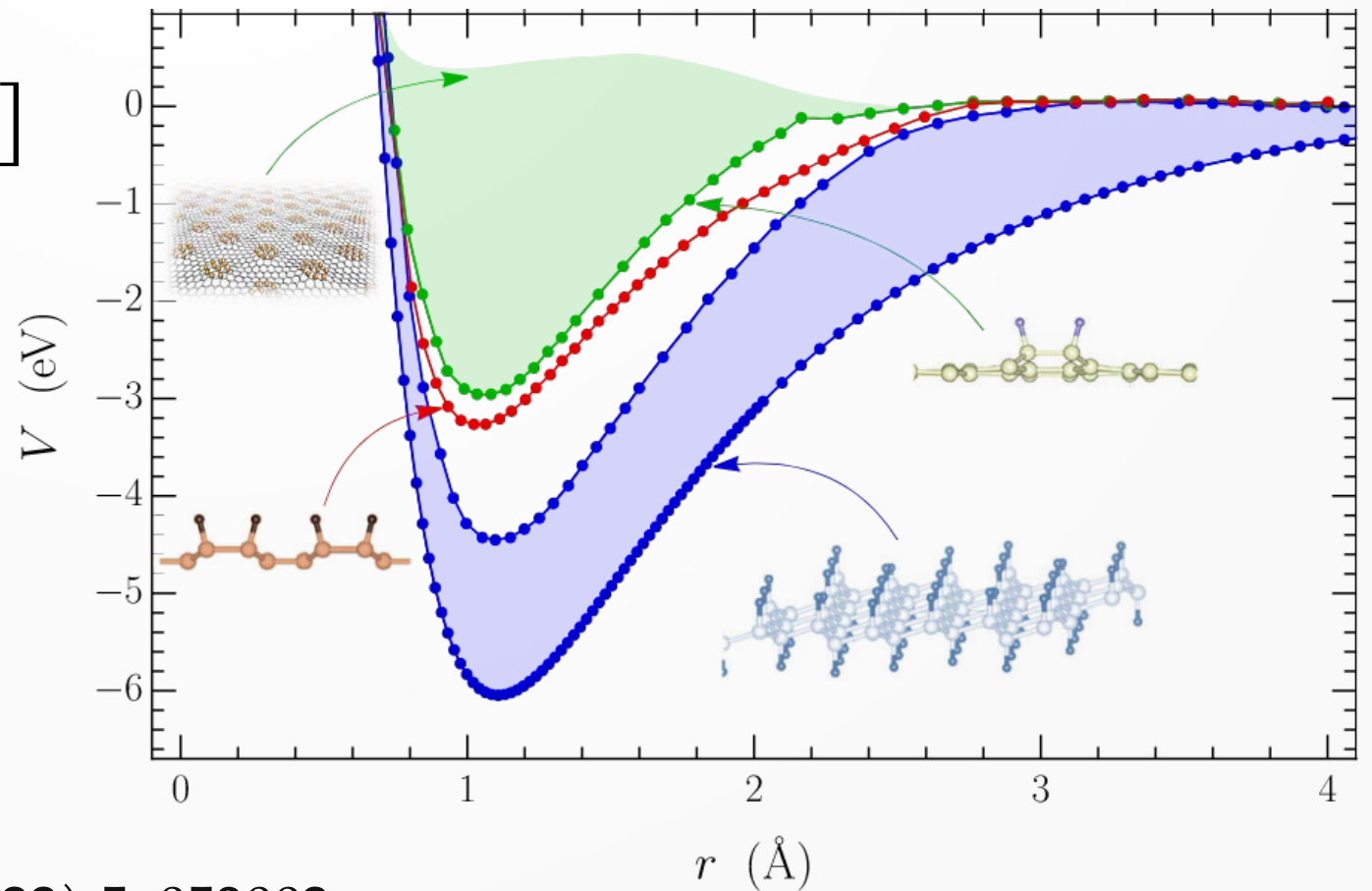
- PTOLEMY should at least see something!

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- Obtaining and storing 100g of tritium
- Graphene substrate [4]



[4] PTOLEMY, Phys. Rev. D **106** (2022) 5, 053002

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$$\Delta x \simeq 0.1 \text{ \AA}$$

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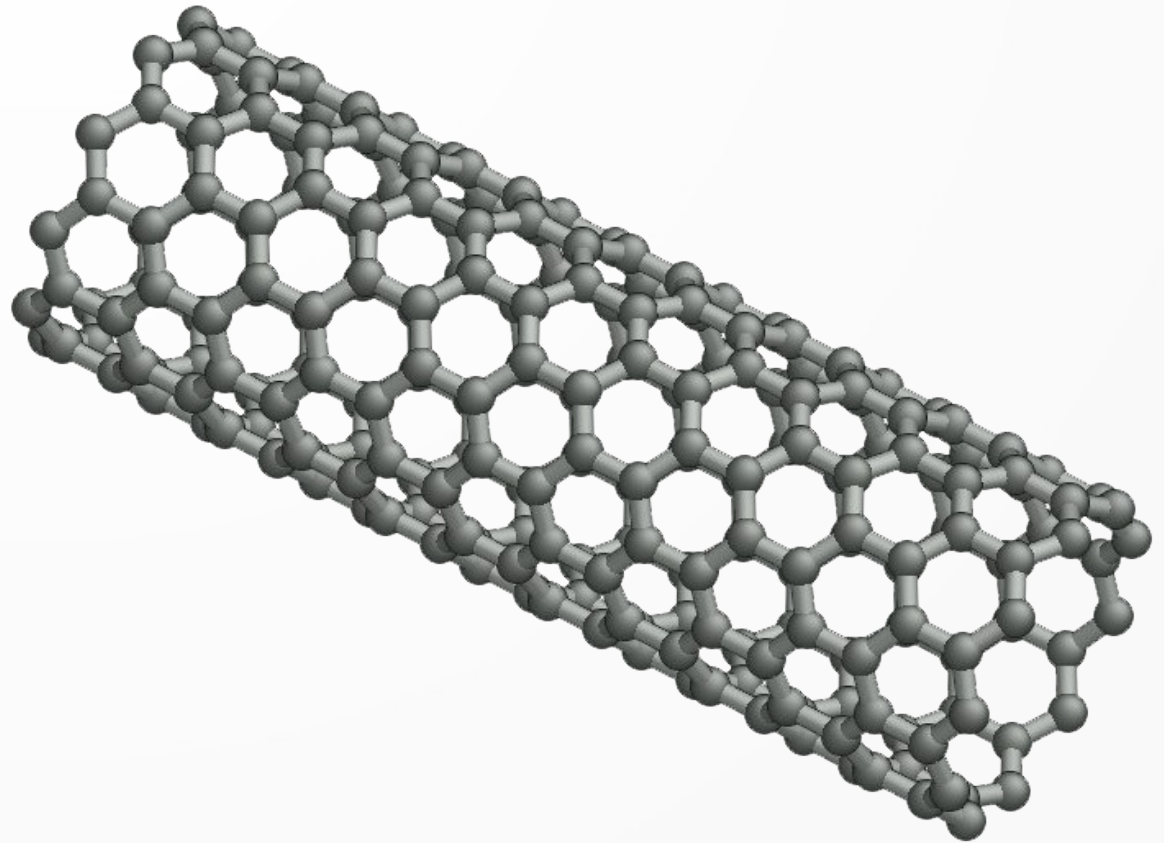
$$\Delta E_e \simeq 480 \text{ meV}$$

$$\Delta E_e \gg 2m_{\nu_h}$$

- No longer guaranteed to see anything!

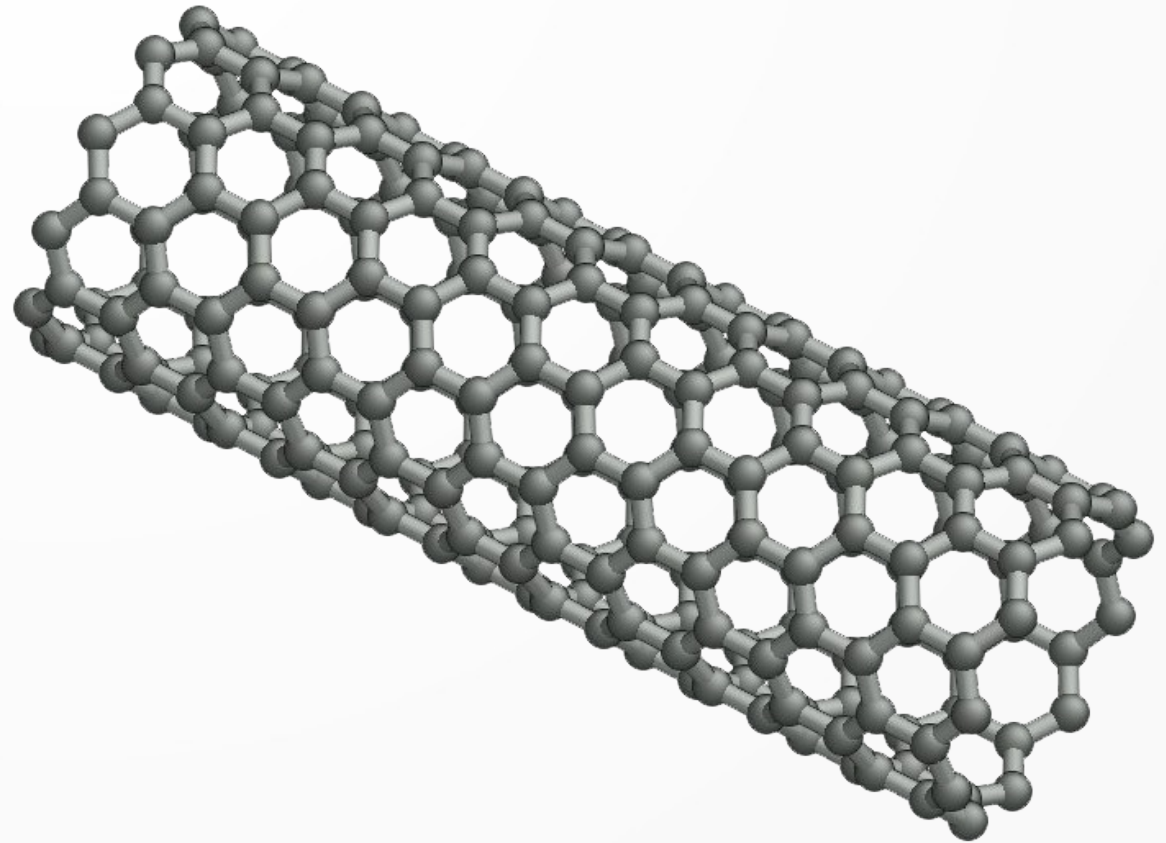
# So now what?

- Carbon nanotubes?



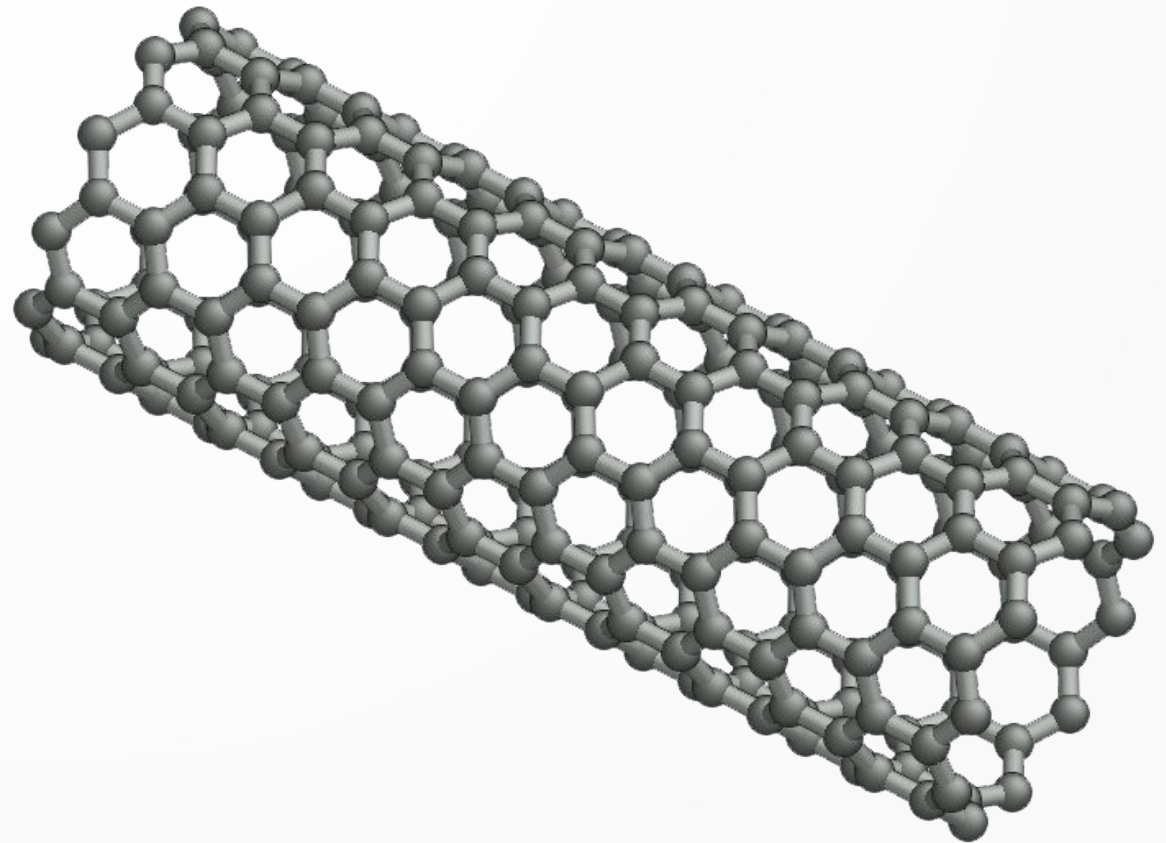
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# So now what?

- Carbon nanotubes?
- Allow tritium to *slide*
- Increases  $\Delta x$ !



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# Coherent scattering

- Coherent scattering (Opher '74, ... , JS '21):

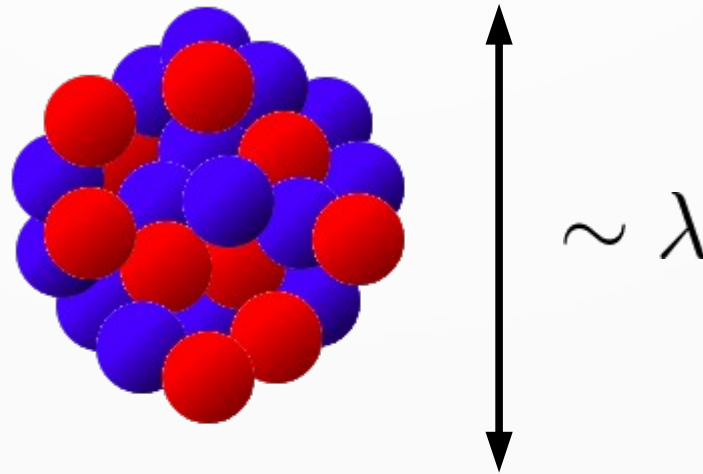
$$\nu + X \rightarrow \nu + X$$

# Coherent scattering

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- Wavelength of order target size:



# Coherent scattering

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# Coherent scattering

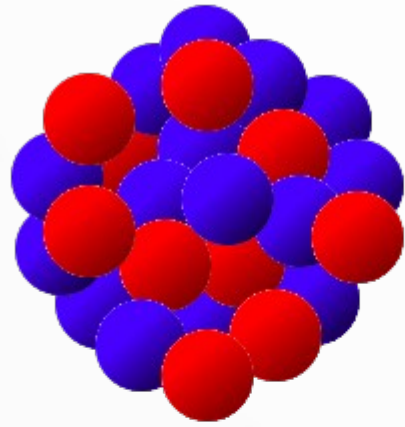
- Neutrino “sees” a larger charge:

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- Significantly enhanced event rates:

$$\Gamma \sim N_T \longrightarrow \Gamma_{\text{coh}} \sim N_T^2$$

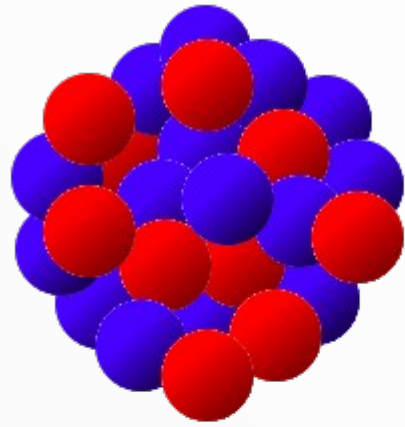
# Coherent scattering



$$\lambda \sim \text{fm}$$

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$$\lambda \sim \text{mm}$$

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- So why don't we see anything?

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$$a_\nu \simeq 10^{-28} \left( \frac{m_\nu}{0.1 \text{ eV}} \right)^2 \text{ cm s}^{-2}$$

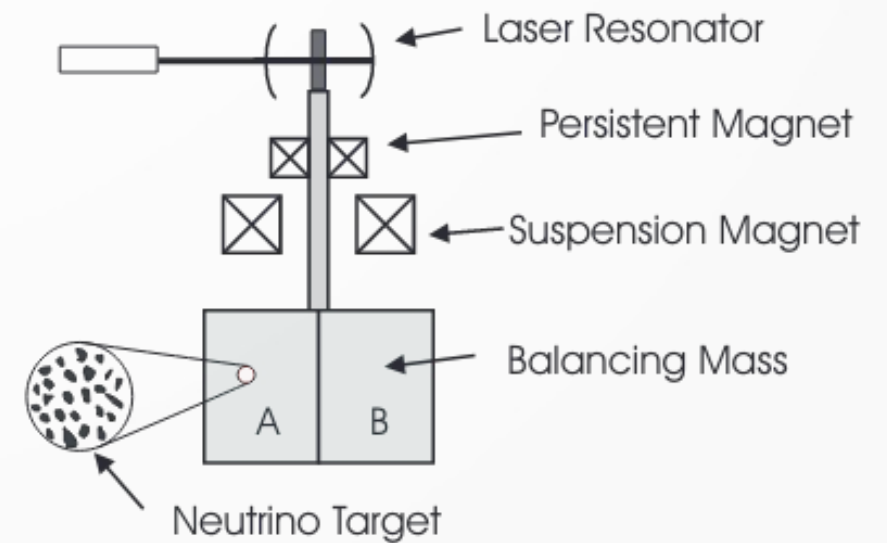


Fig: C. Hagmann, arXiv:astro-ph/9905258

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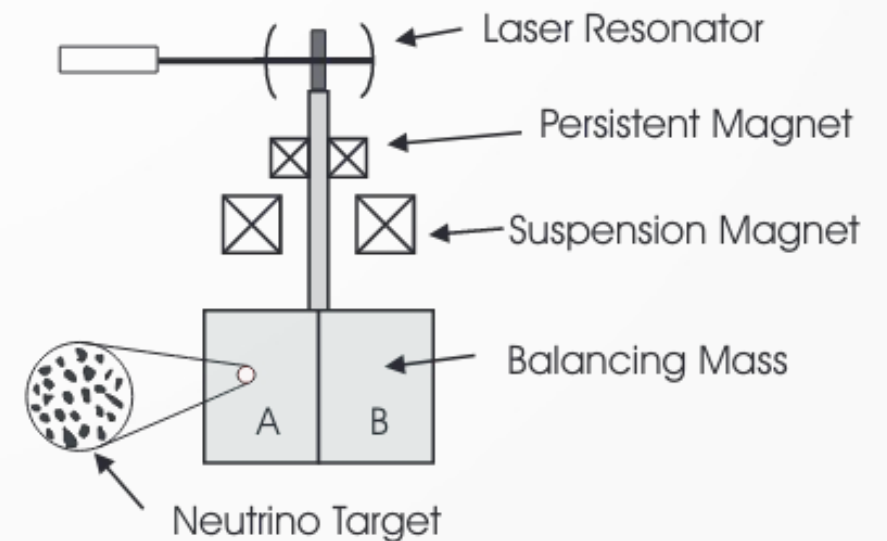


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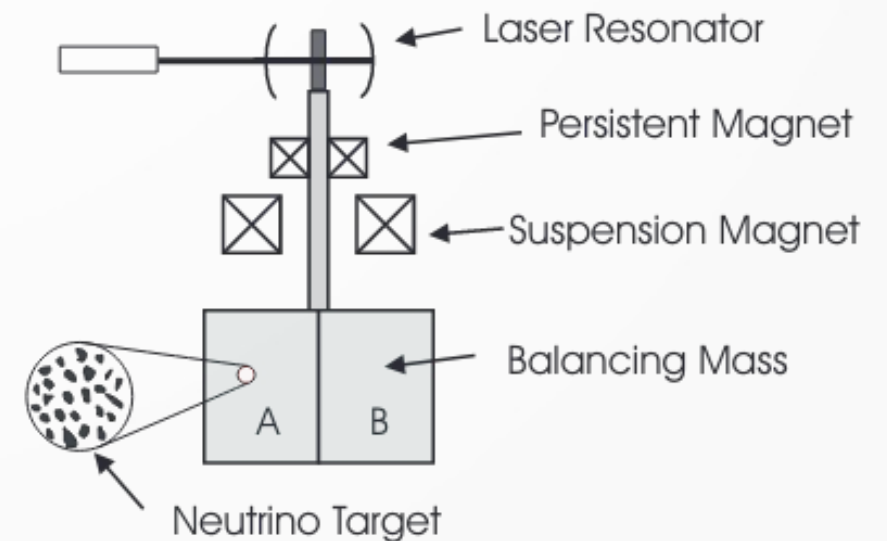
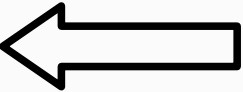


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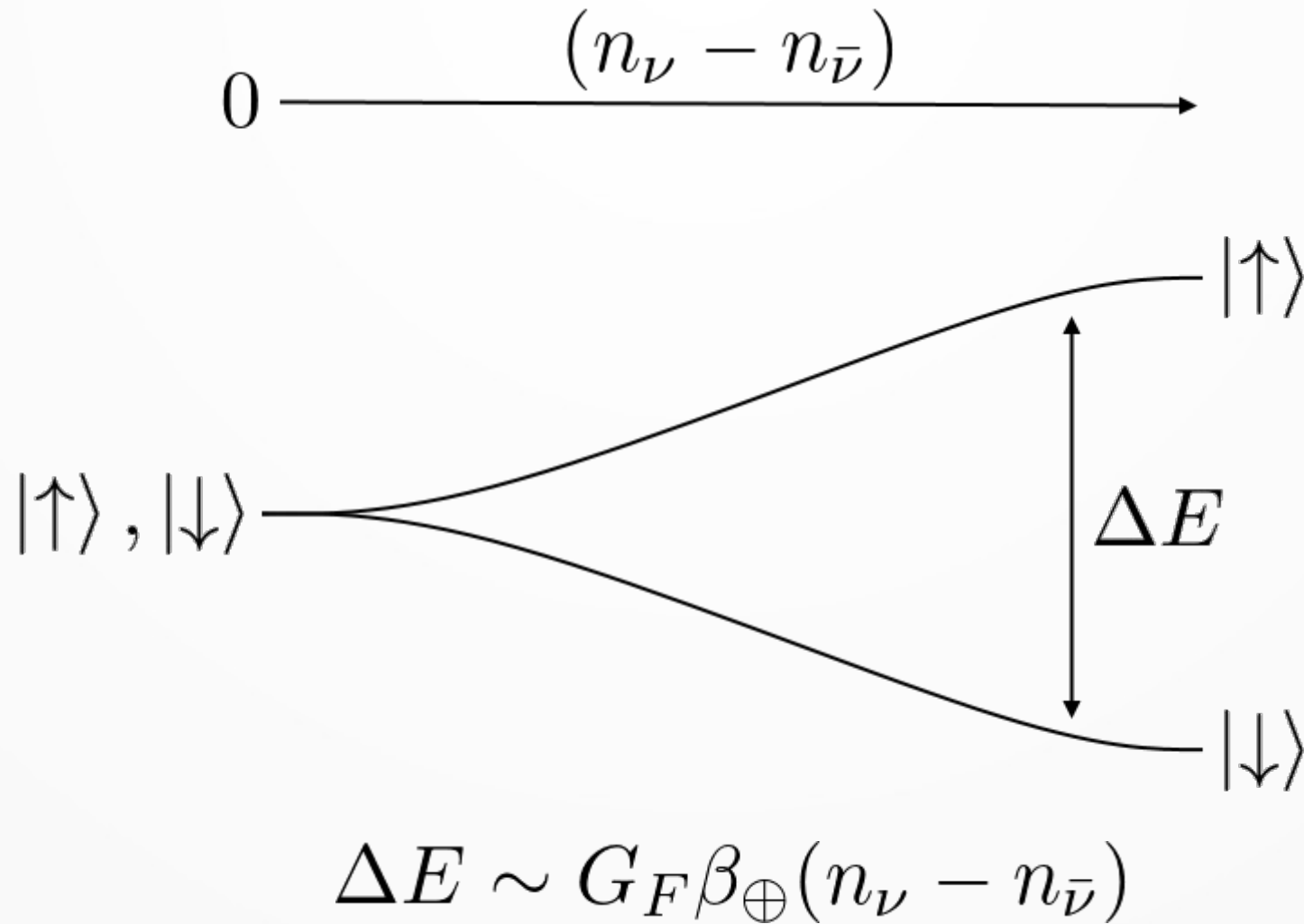
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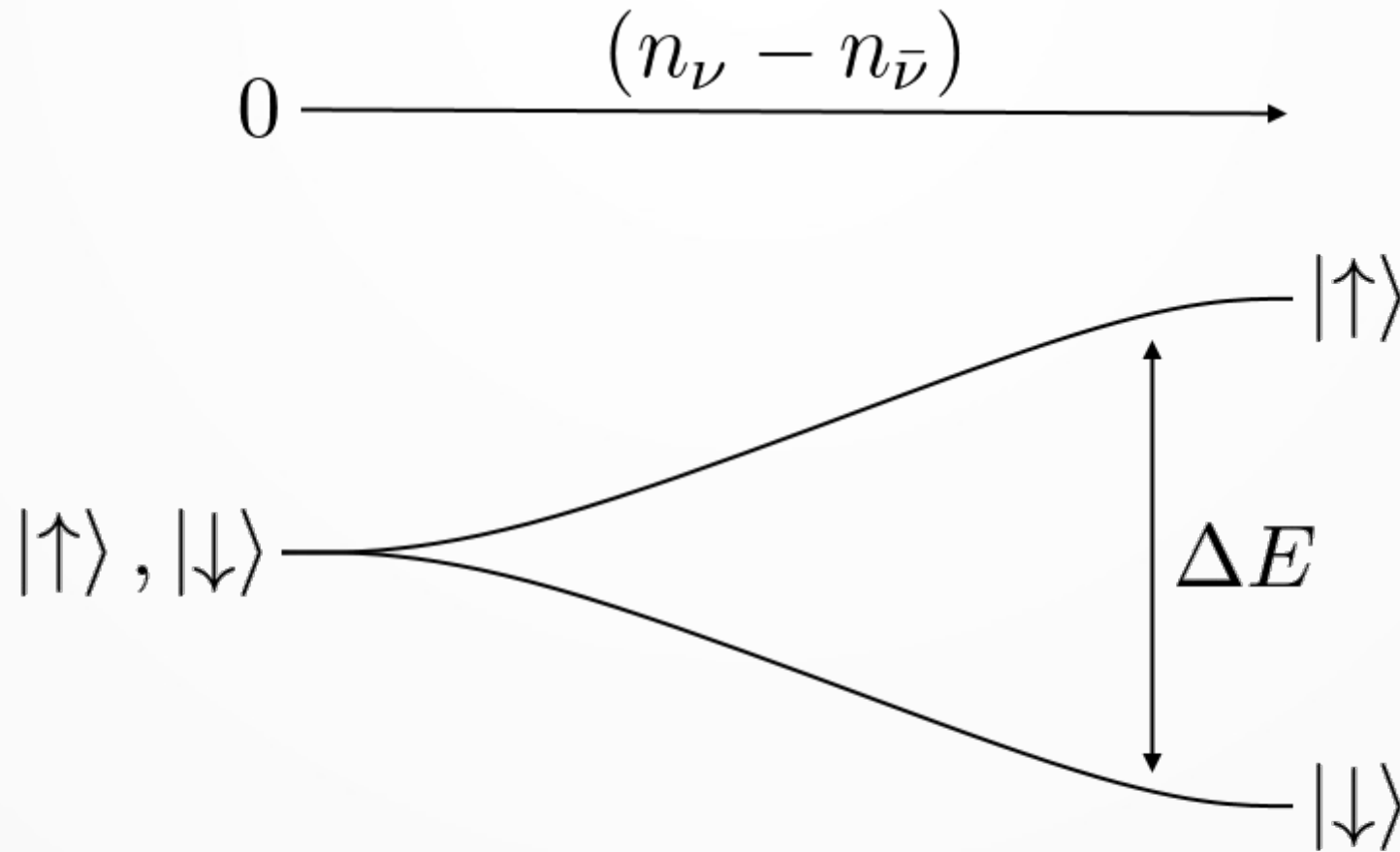
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- Analogous to the Zeeman effect
- Only\* effect linear in  $G_F$  (Cabibbo '82, Langacker '83)

# Stodolsky effect

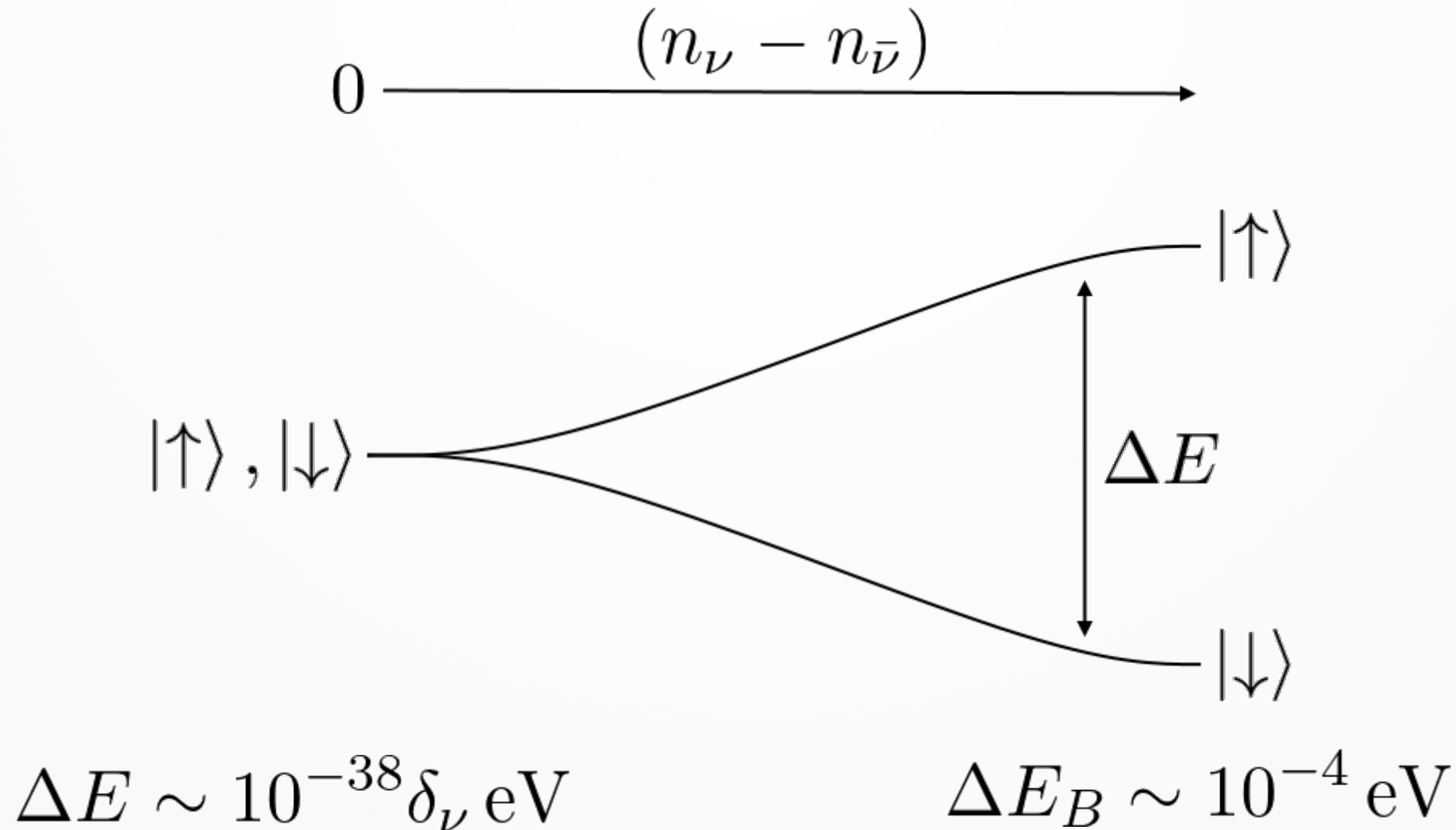


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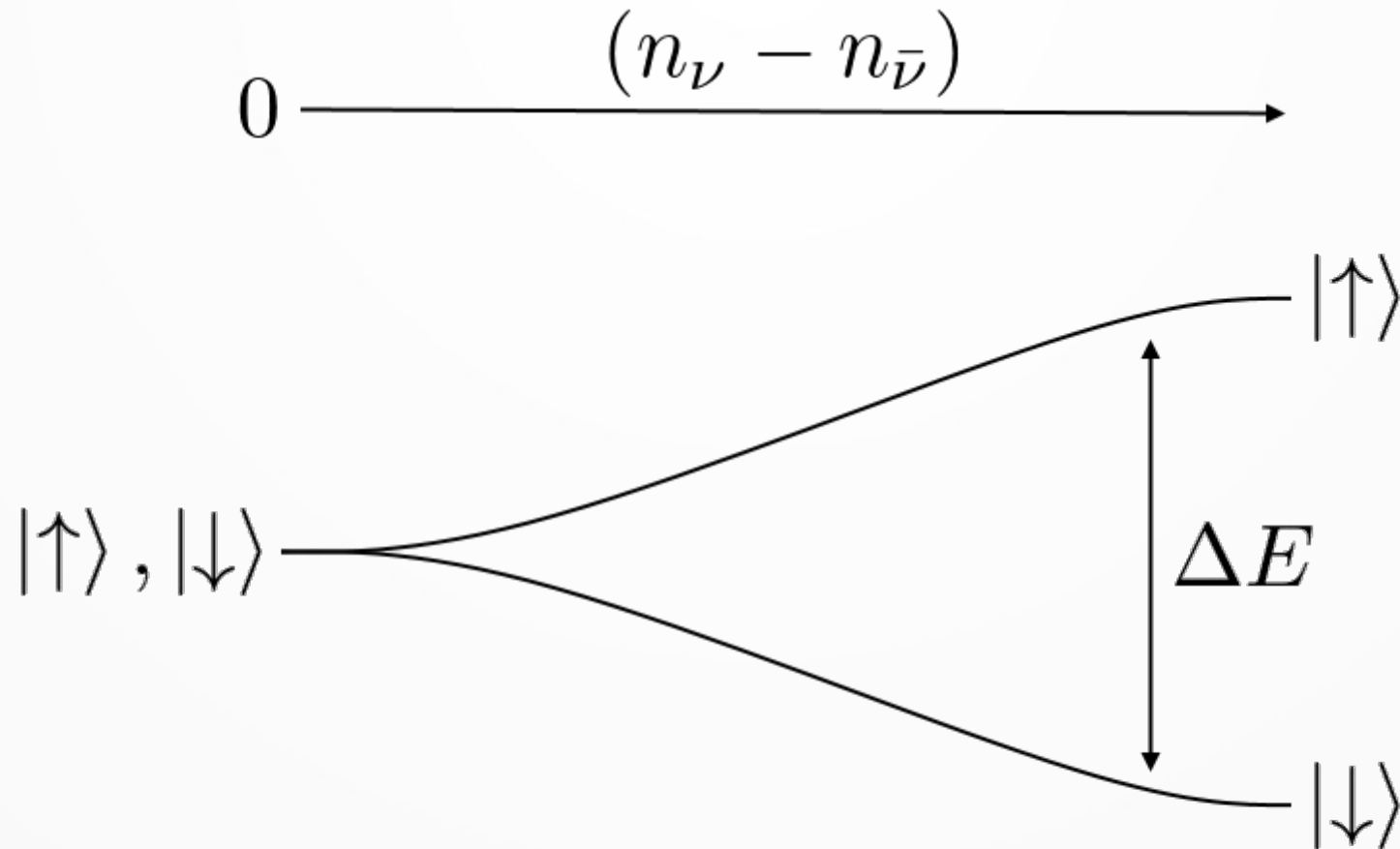


$$\Delta E \sim 10^{-38} \delta_\nu \text{ eV}$$

# Stodolsky effect



# Stodolsky effect



- Also an effect that depends on helicity asymmetry

# Stodolsky effect

- So how do we see it?

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- Spin precession:

$$\frac{dS_{\perp}}{dt} = i[H, S_{\perp}] \neq 0$$

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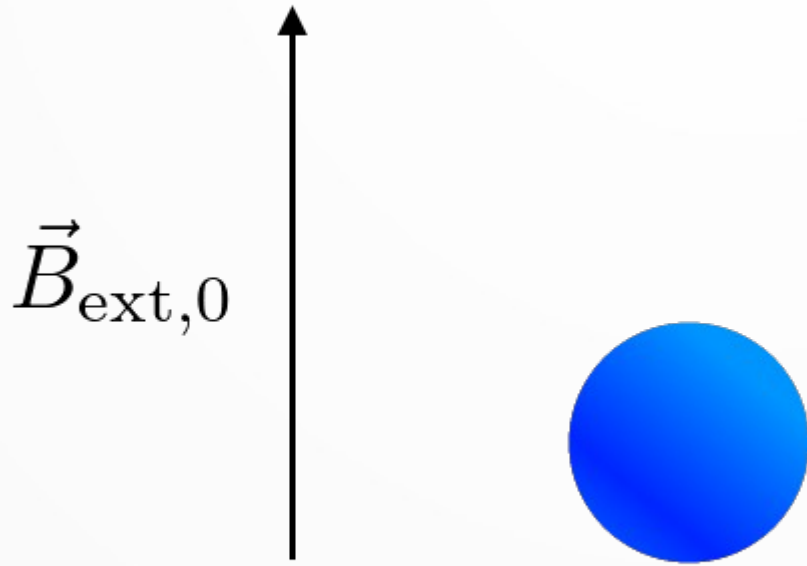
- Two observables:
- Magnetisation [6]:

$$\frac{dS_{\perp}}{dt} \neq 0 \implies \frac{dB_{\perp}}{dt} \neq 0$$

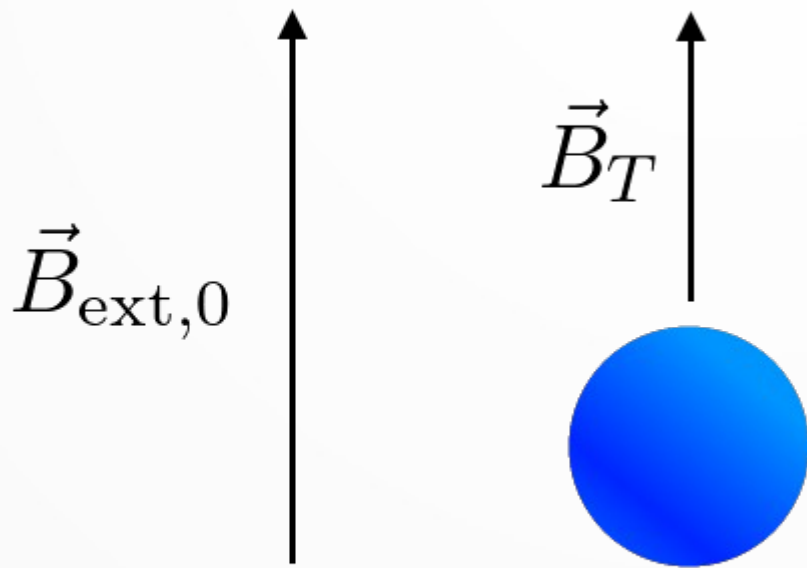
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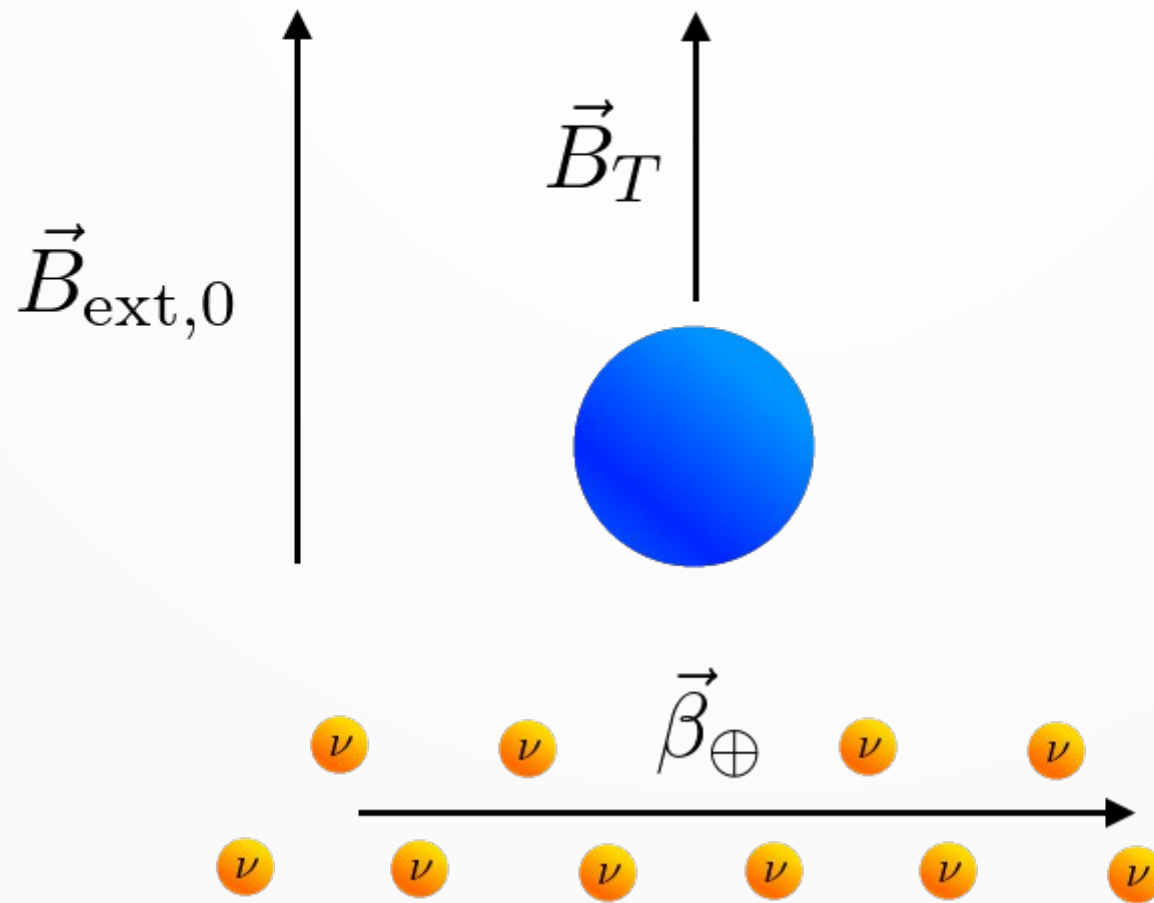
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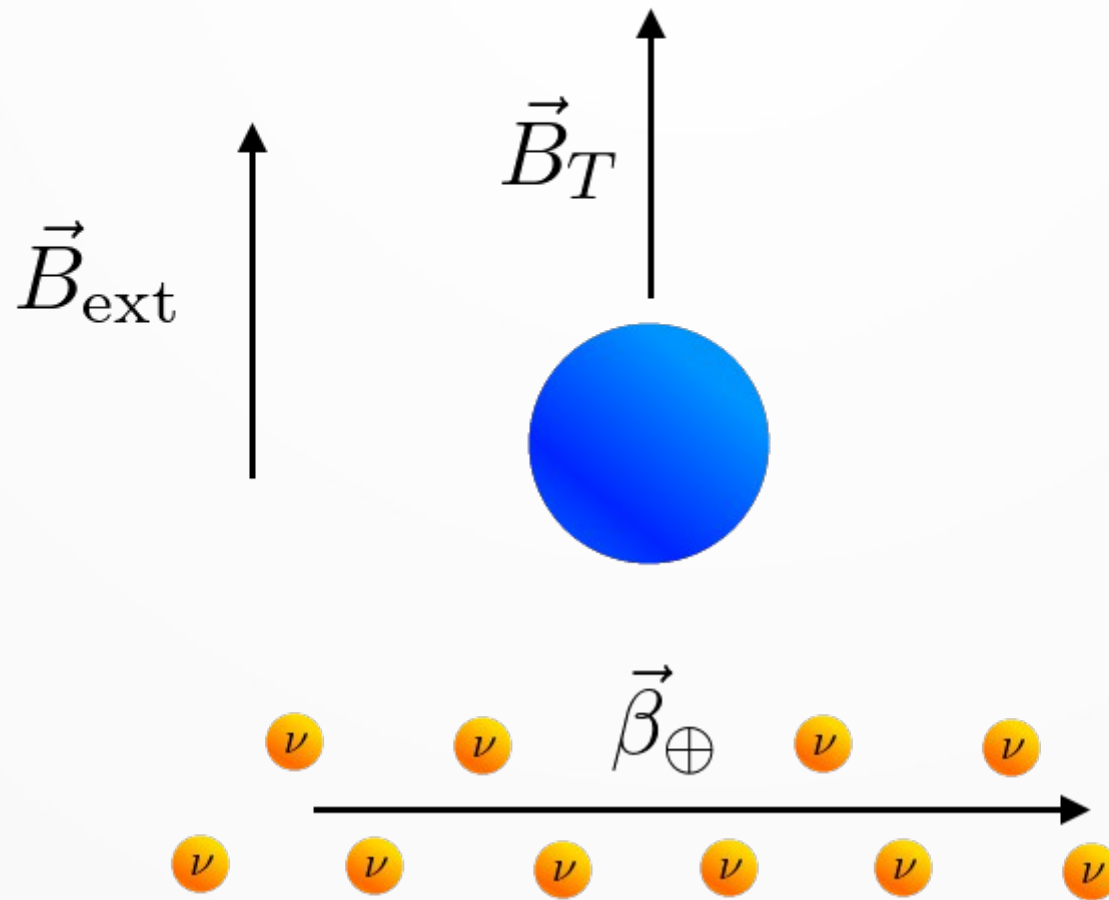
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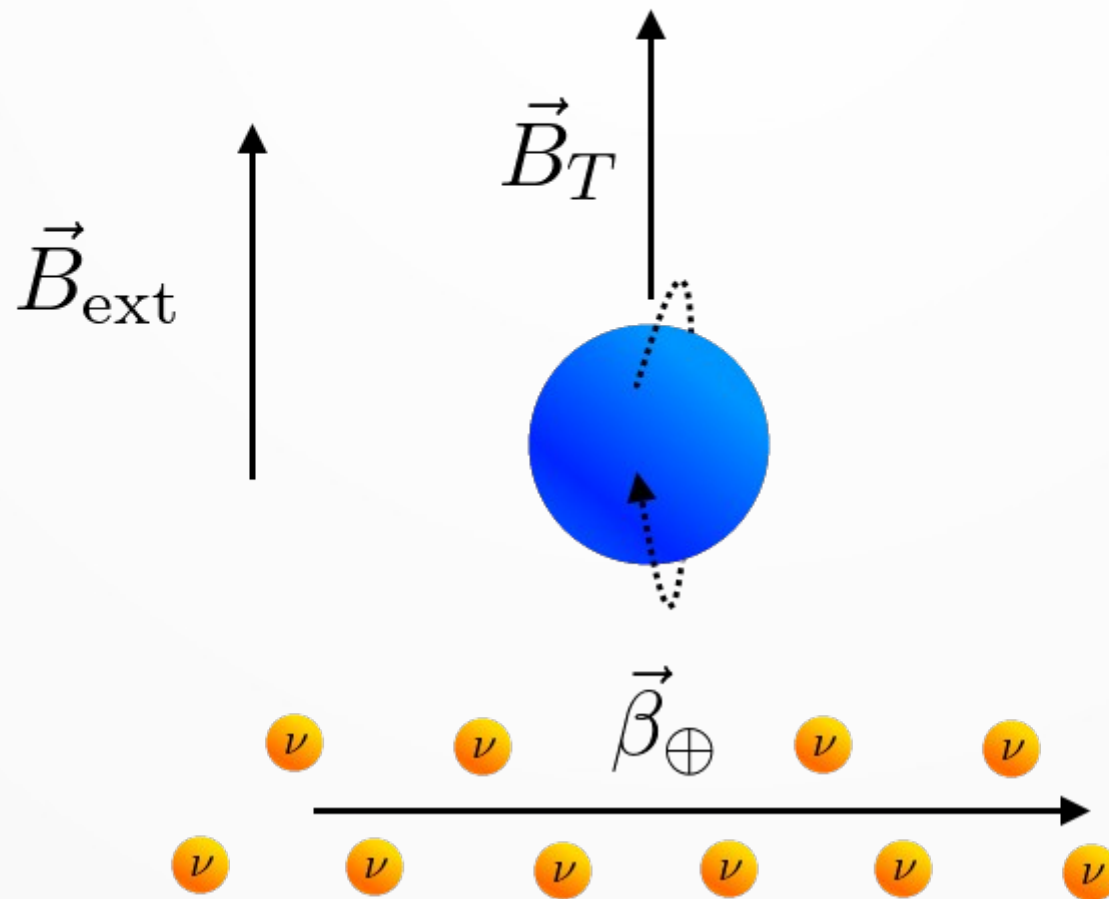
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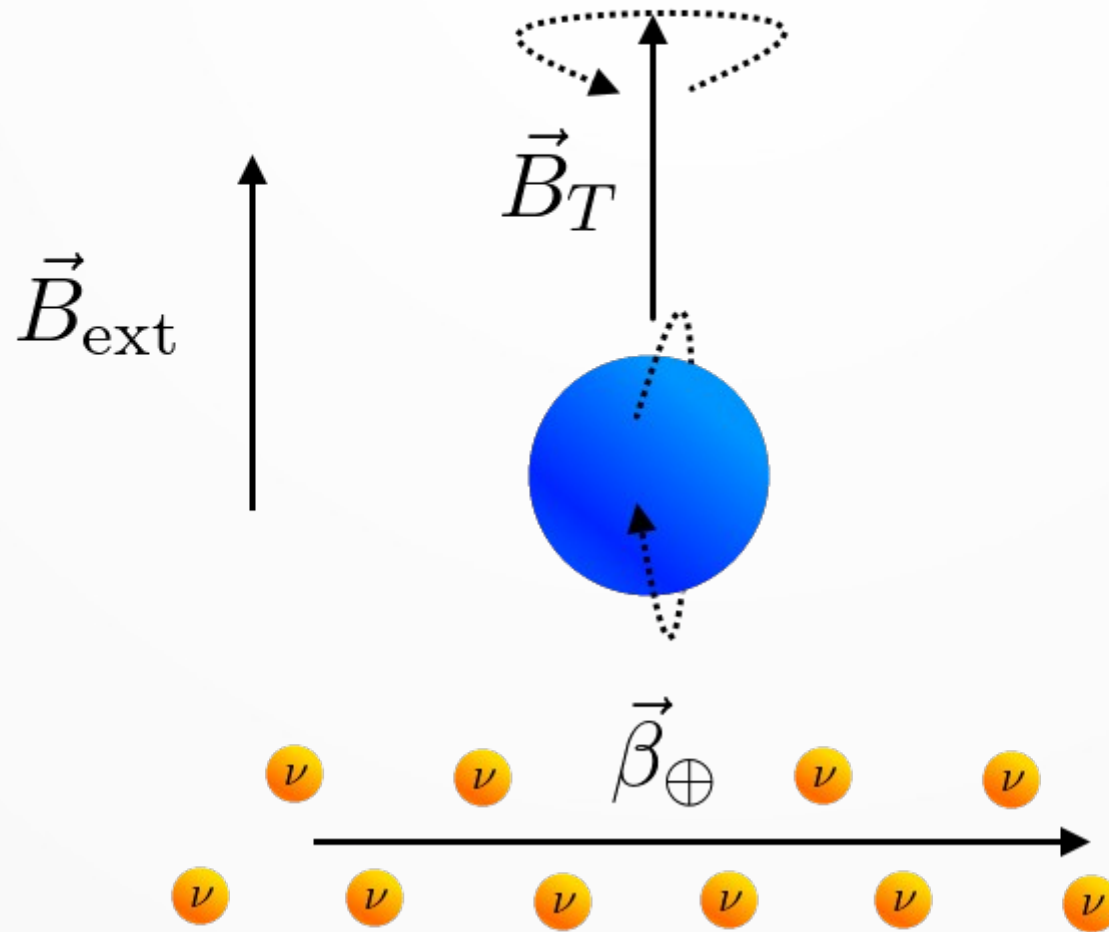
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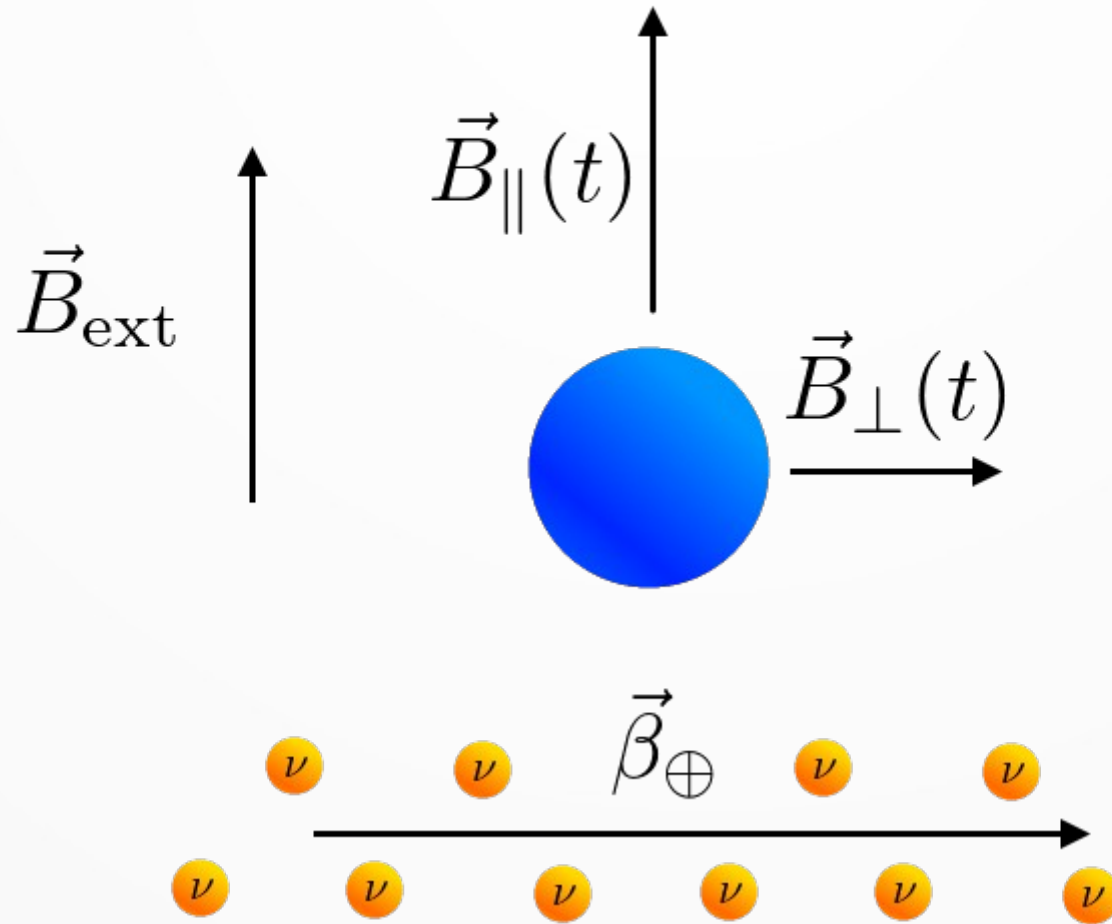
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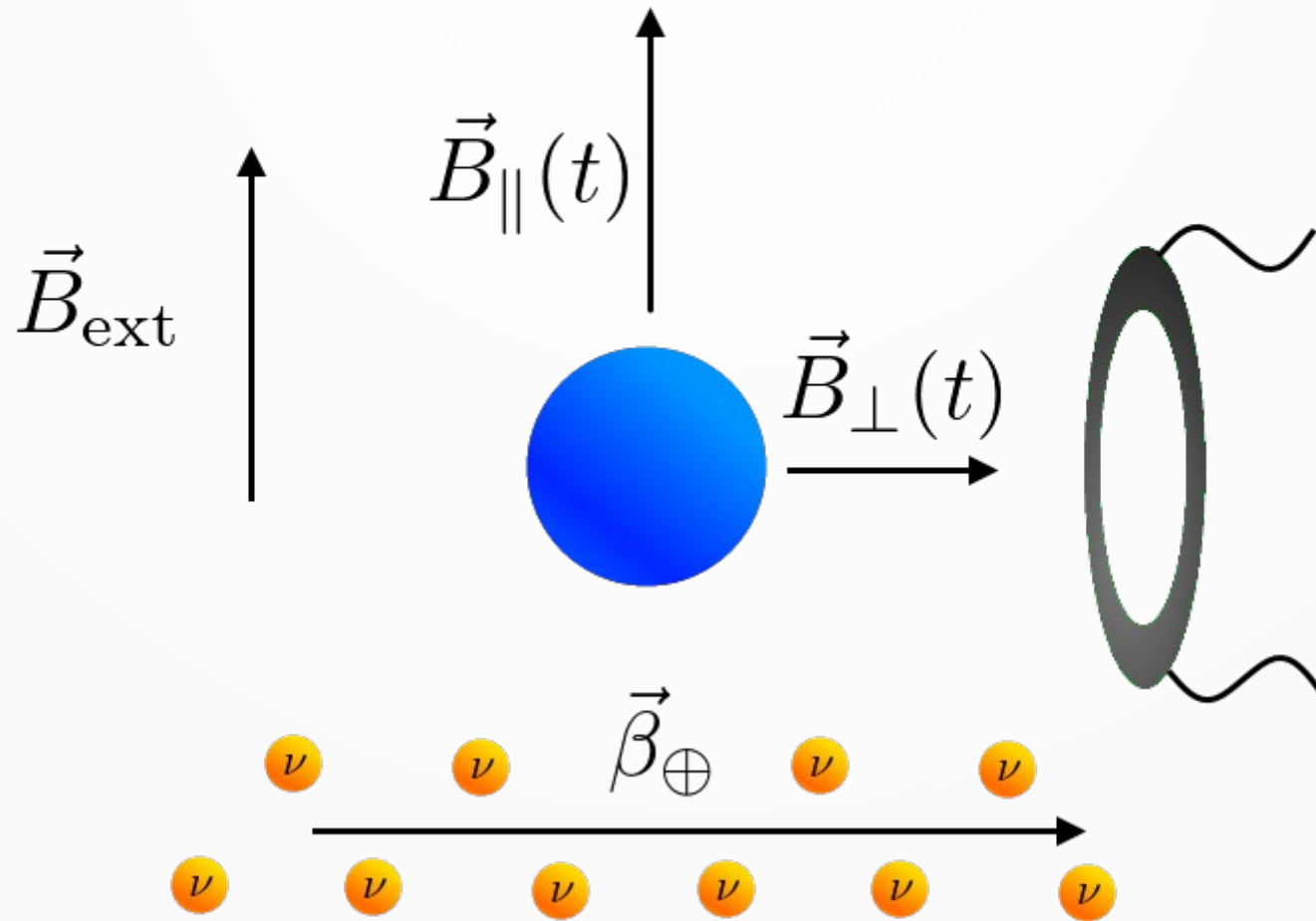
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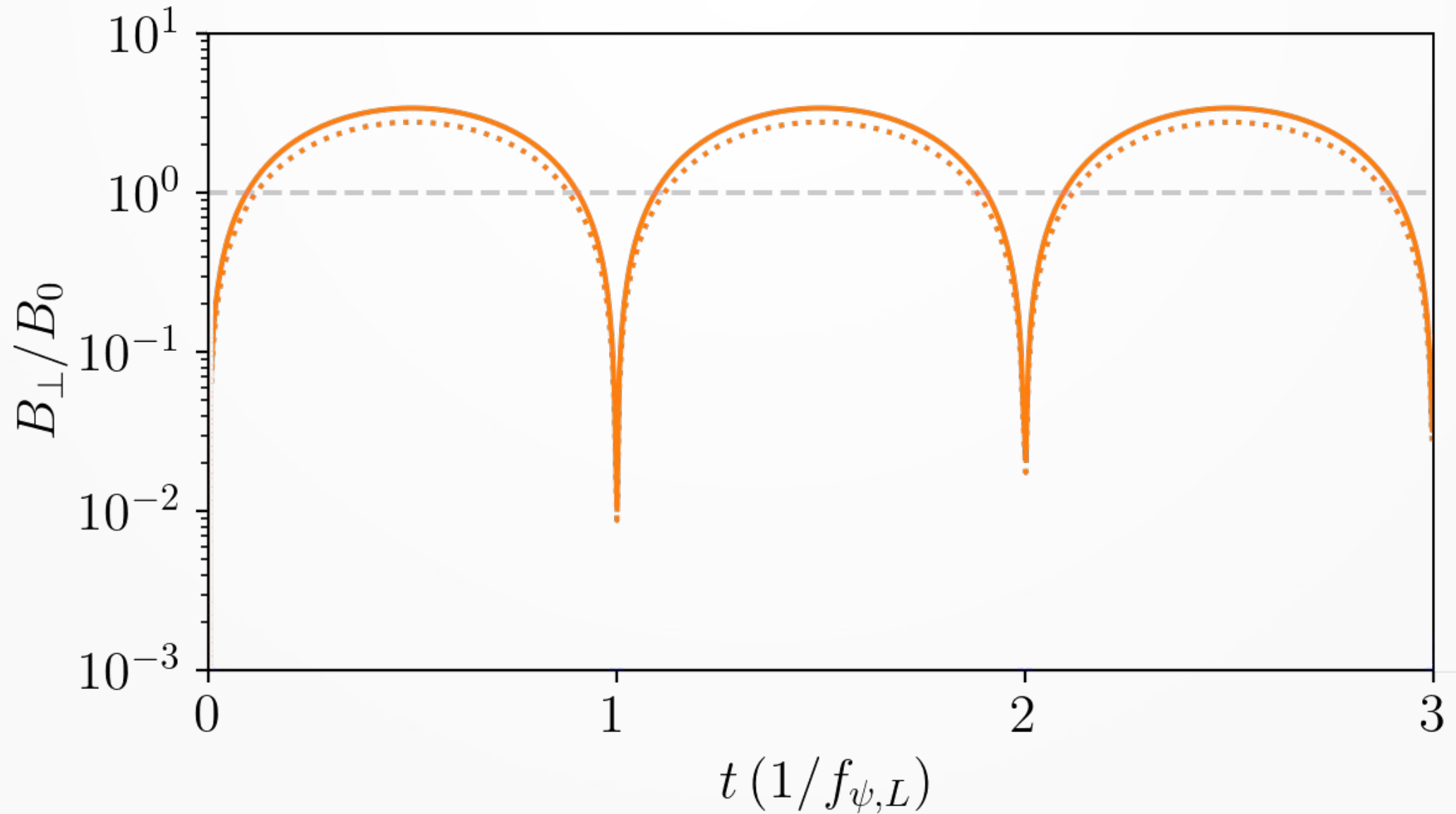
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- Helicity asymmetry term? 3 orders of magnitude larger!

# Stodolsky effect

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- BBN constraint:

$$\delta_\nu = \delta_h \lesssim 10^{-2}$$

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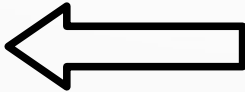
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- Still a way off, but better than coherent

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# Accelerator

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# Accelerator

- PTOLEMY-on-a-beam?

$$\langle \sigma \beta_\nu \rangle \propto G_F^2 E_e p_e \sim 10^{-45} \text{ cm}^2$$

- Doesn't really work...

$$E_\nu = \frac{m_\nu}{M} E_{\text{beam}} \implies E_{\text{beam}} \sim \mathcal{O}(\text{PeV})$$

- Thresholded processes?

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- e.g. Z-resonance:  $\nu + \bar{\nu}_{C\nu B} \rightarrow Z \rightarrow ?$
- Vastly larger cross section:  $\sigma \propto \frac{1}{M_Z^2} \propto G_F$

# Accelerator

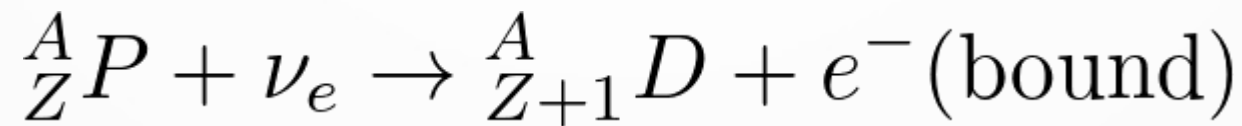
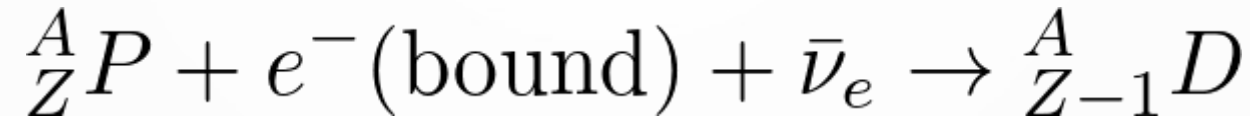
- Accelerator experiment [7]:

$${}^A_Z P + e^- (\text{bound}) + \bar{\nu}_e \rightarrow {}^A_{Z-1} D$$

$${}^A_Z P + \nu_e \rightarrow {}^A_{Z+1} D + e^- (\text{bound})$$

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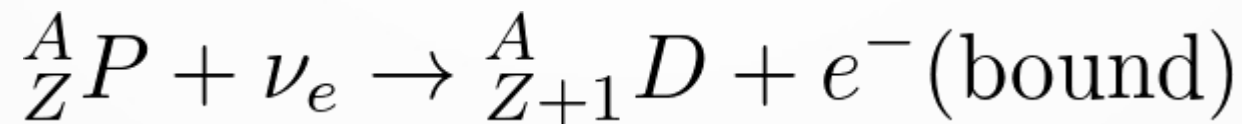
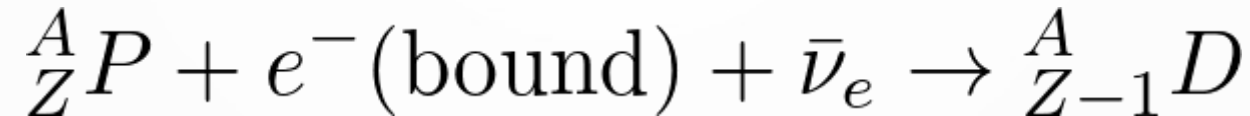


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$$\sigma_{\text{peak}} \propto \frac{1}{Q^2} \text{Br}(D \rightarrow P)$$

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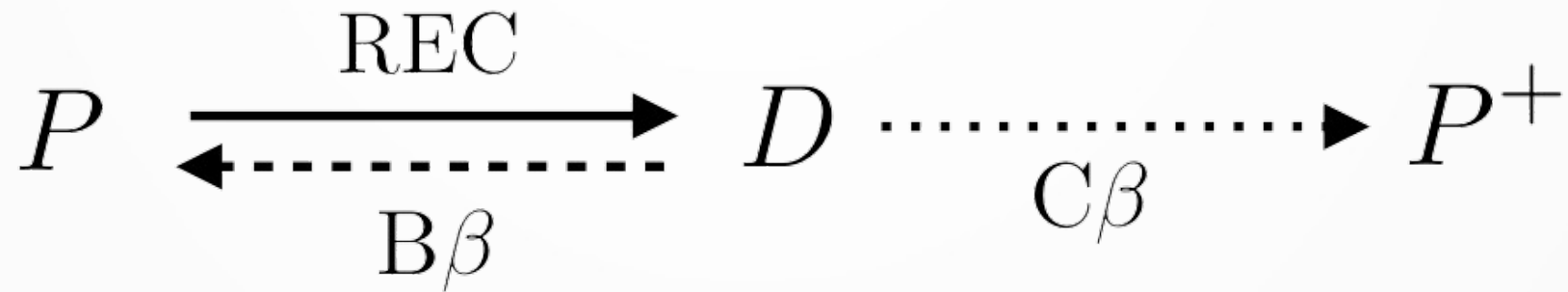


- Huge cross section on resonance:

$$\sigma_{\text{peak}} \simeq 10^{-15} \left( \frac{1 \text{ keV}}{Q} \right)^2 \text{Br}(D \rightarrow P) \text{ cm}^2$$

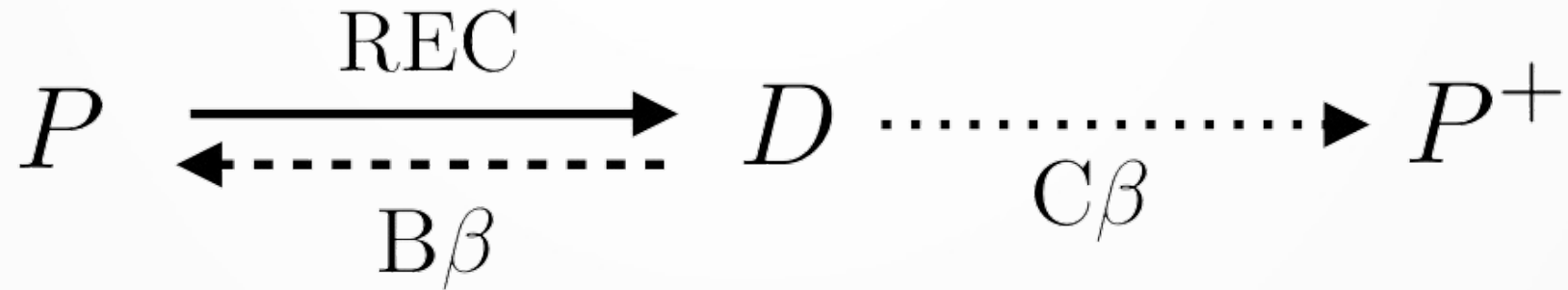
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- Resonant electron capture:

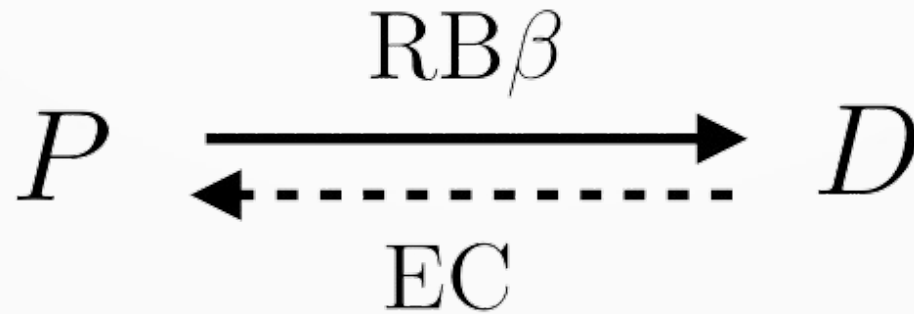


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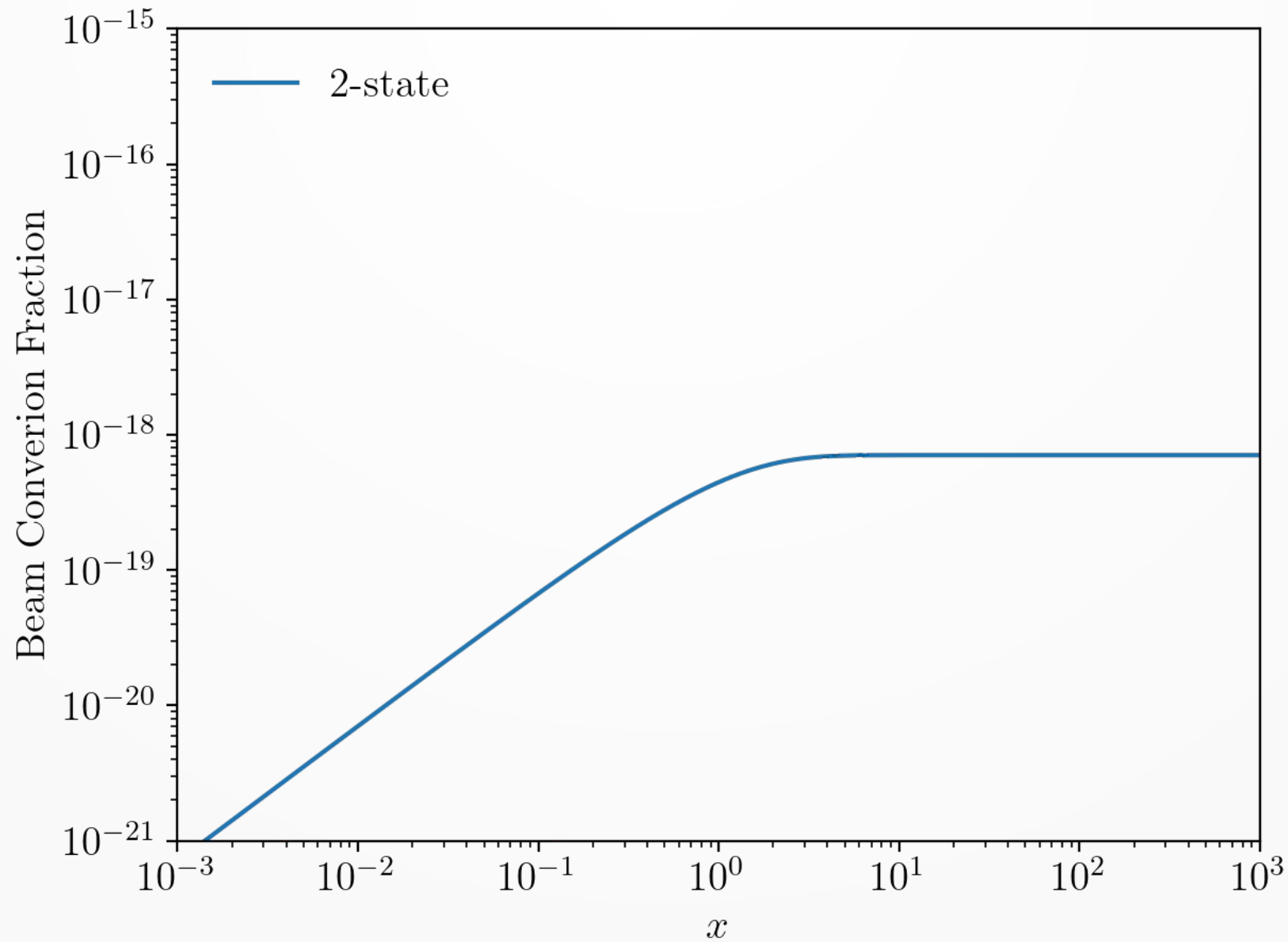
- Resonant electron capture:



- Resonant bound beta decay:



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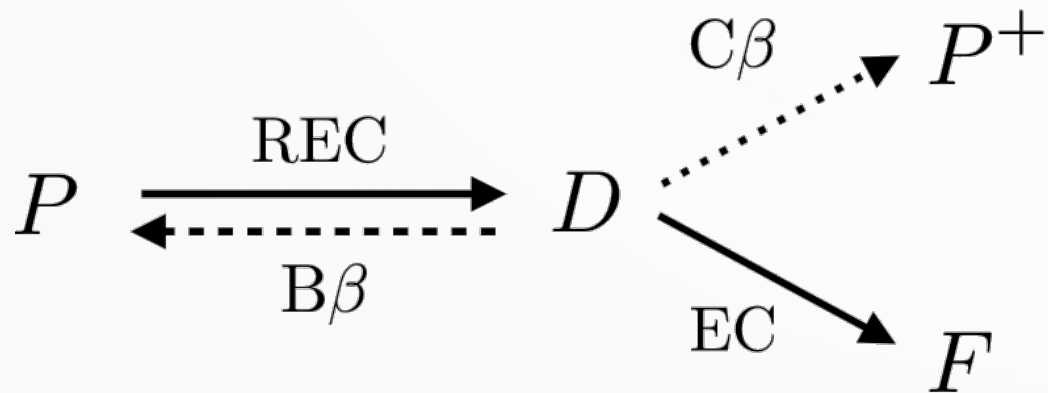
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- Final state that differs from the initial state:

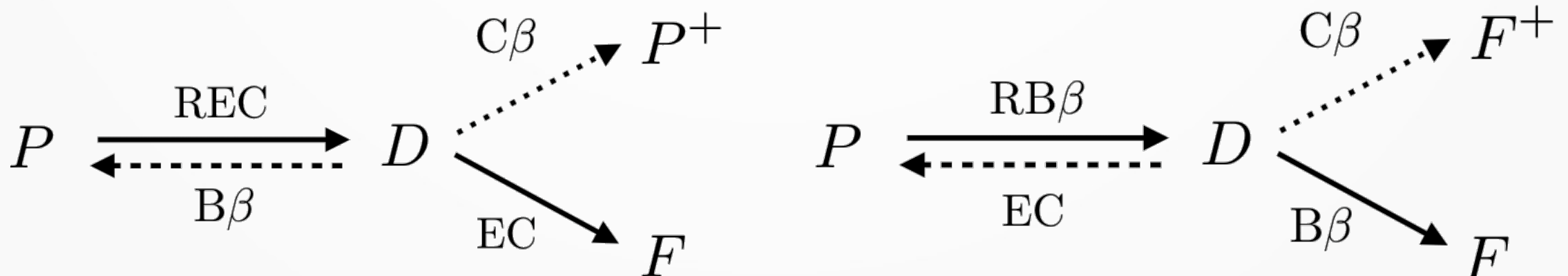
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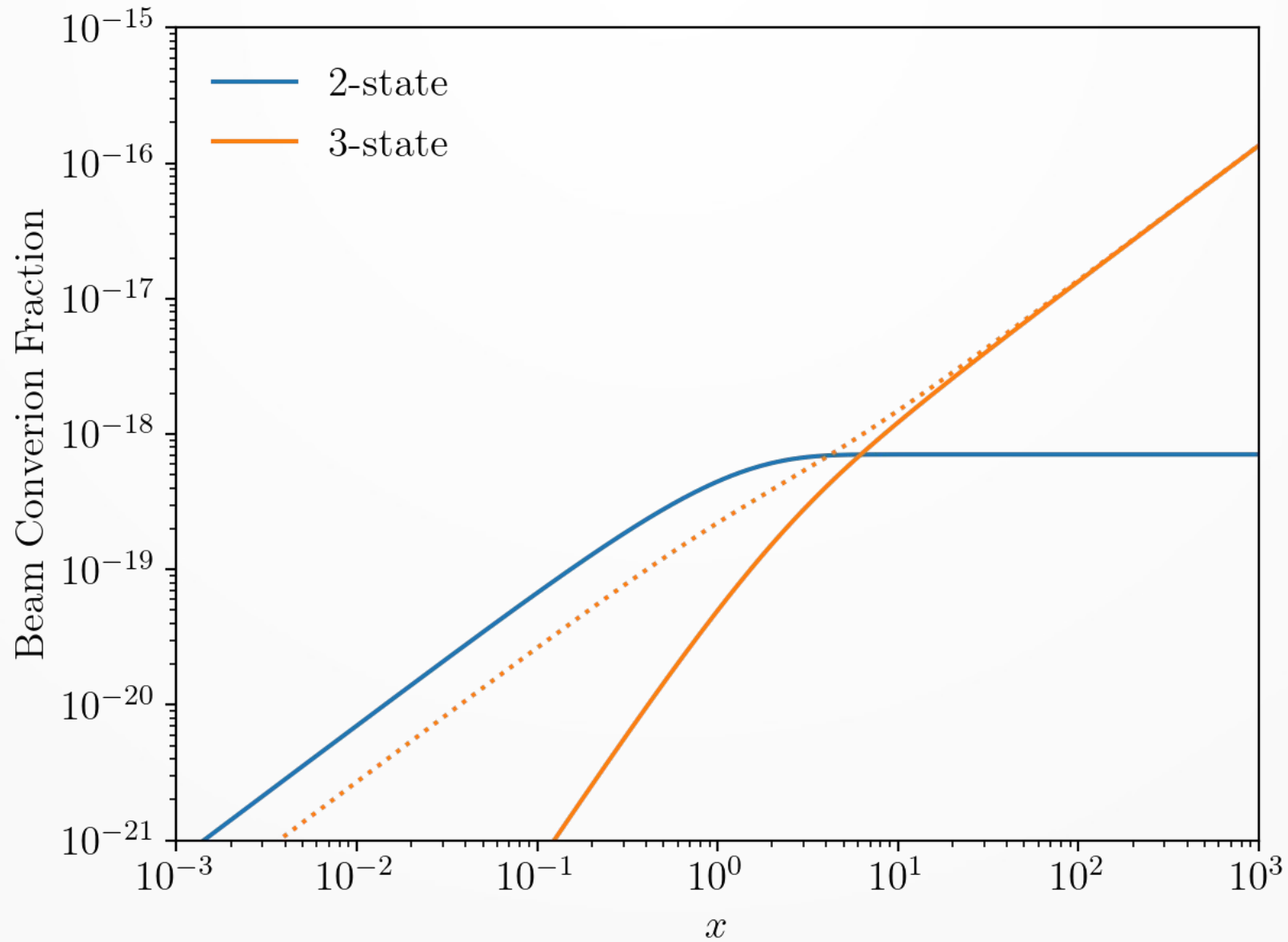


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$$Q \simeq 10 \text{ keV} \quad \frac{E}{A} \simeq 100 \text{ TeV} \quad N_D \simeq 10^{-12}$$

- In general:

$$N_D \sim \frac{1}{Q^7} \implies Q \sim 0.1 \text{ keV}$$

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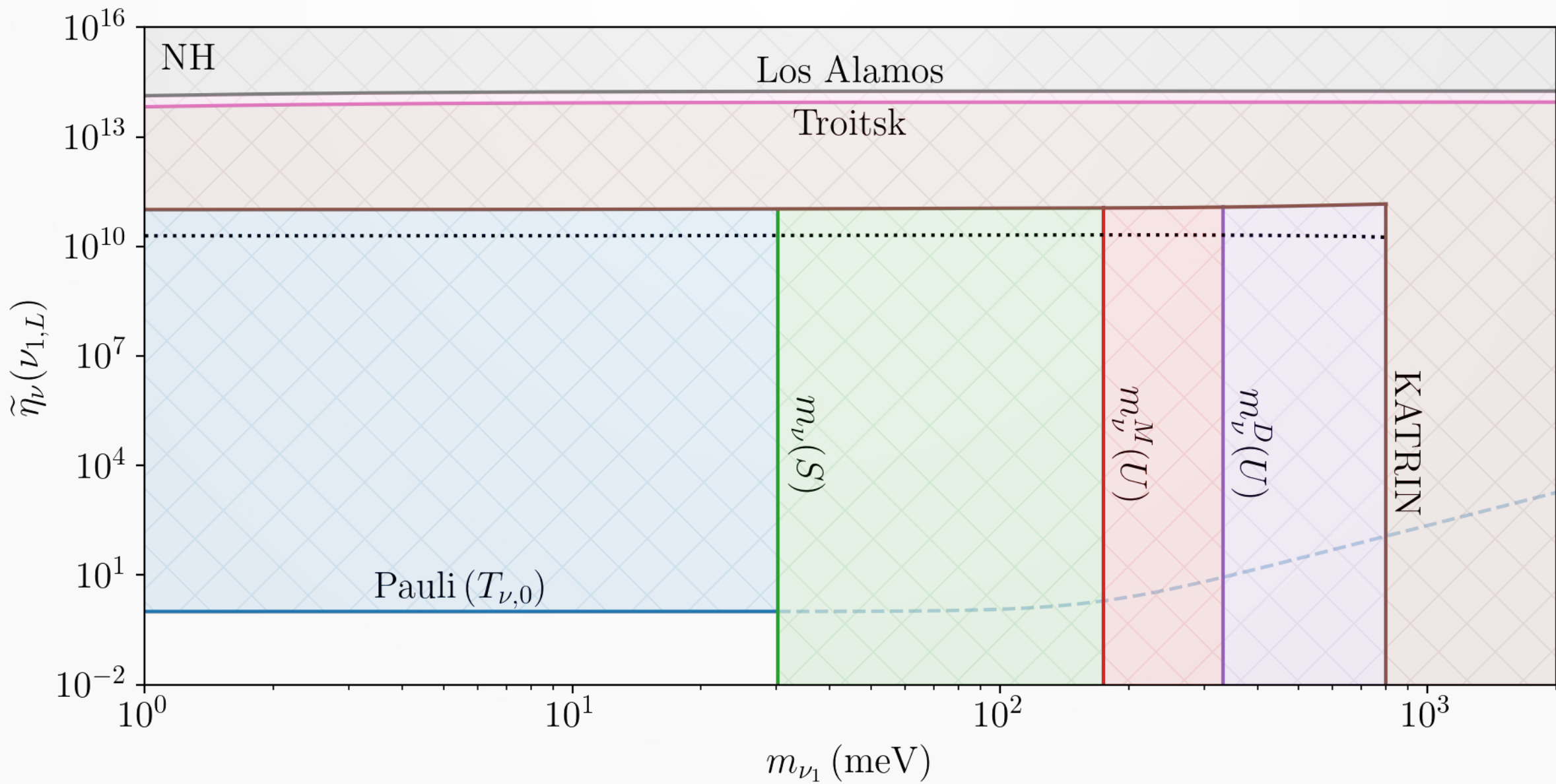
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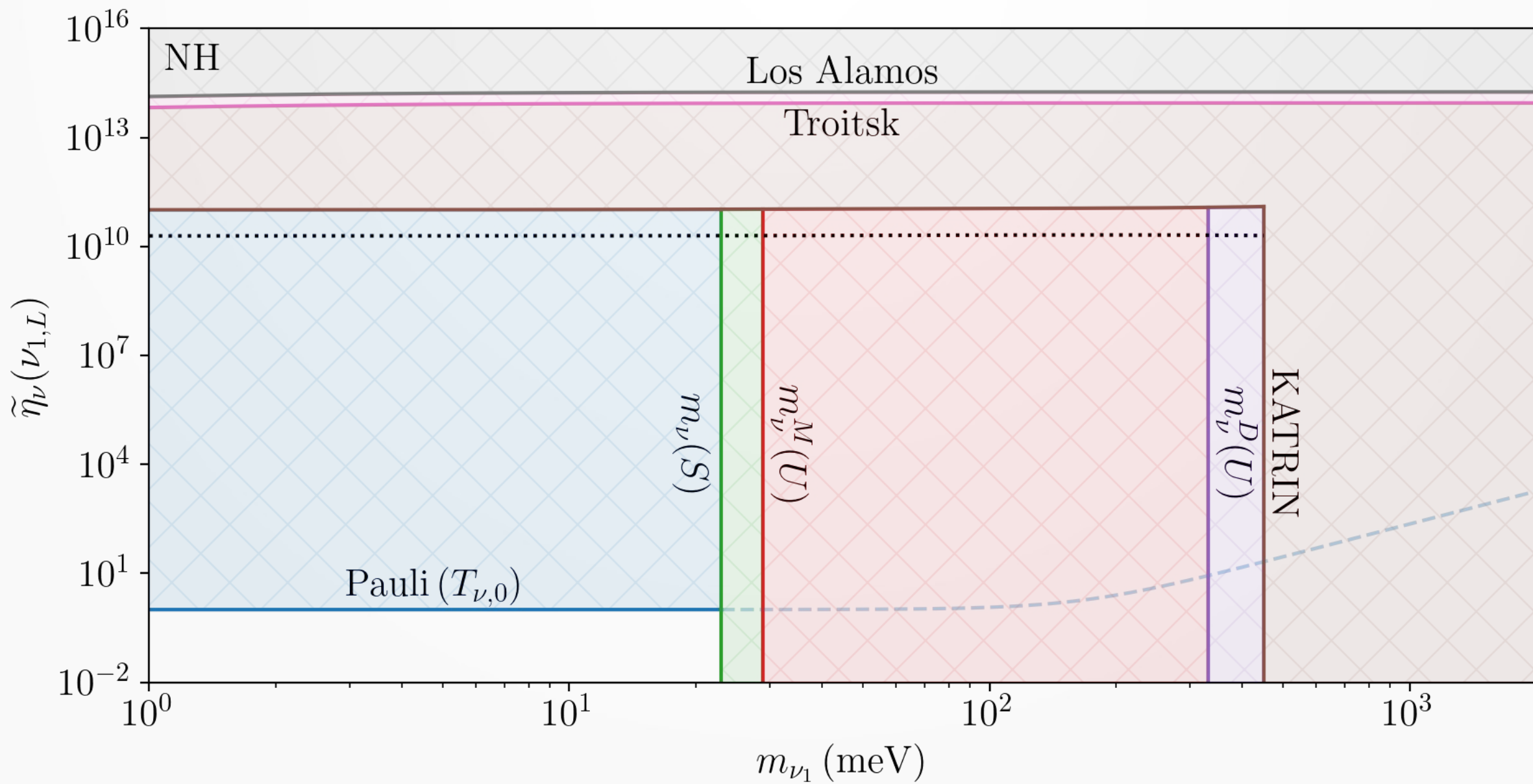
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- Mapping out the allowed parameter space lets us find the best detection proposal!

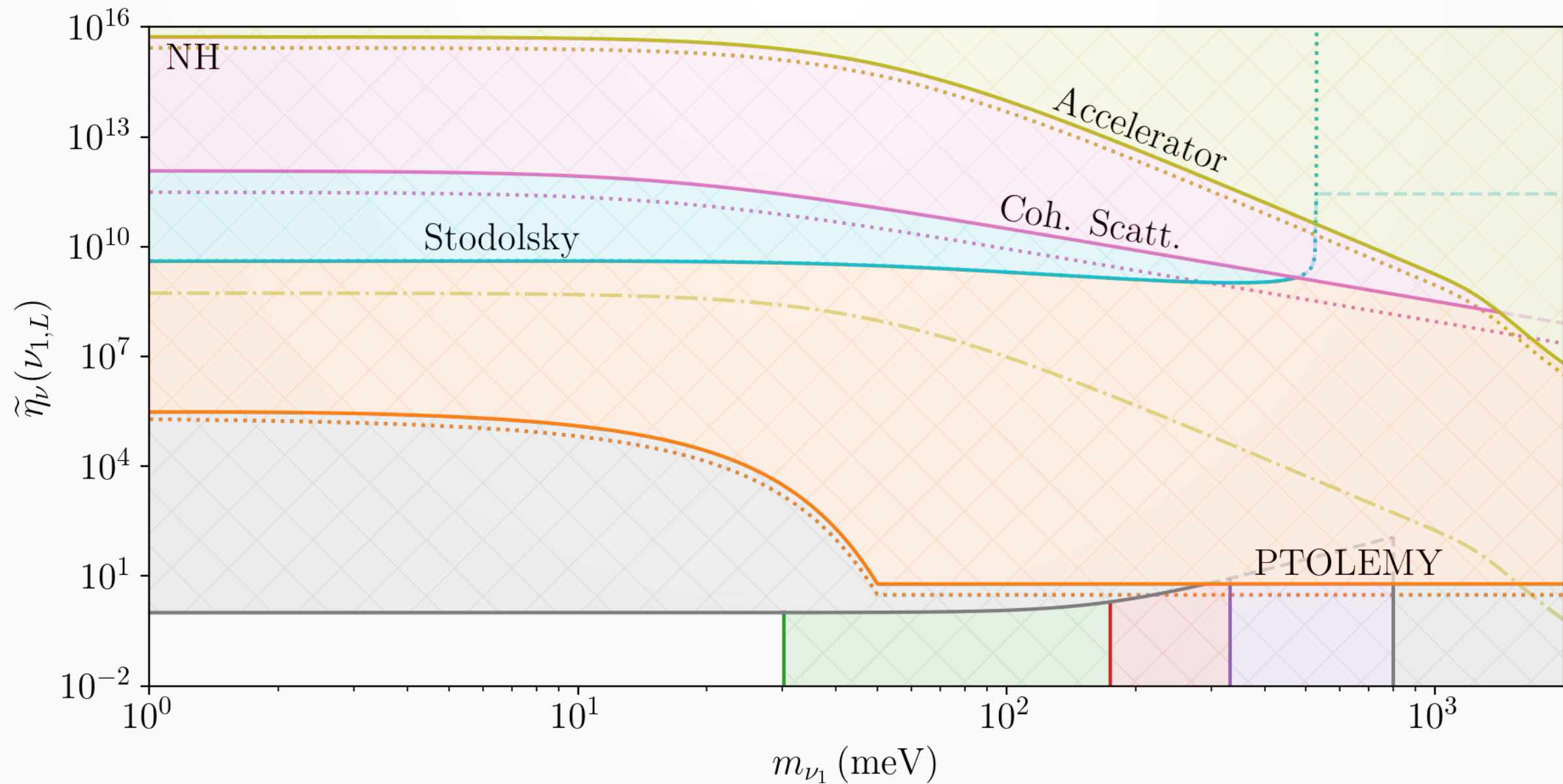
# Constraints (old)



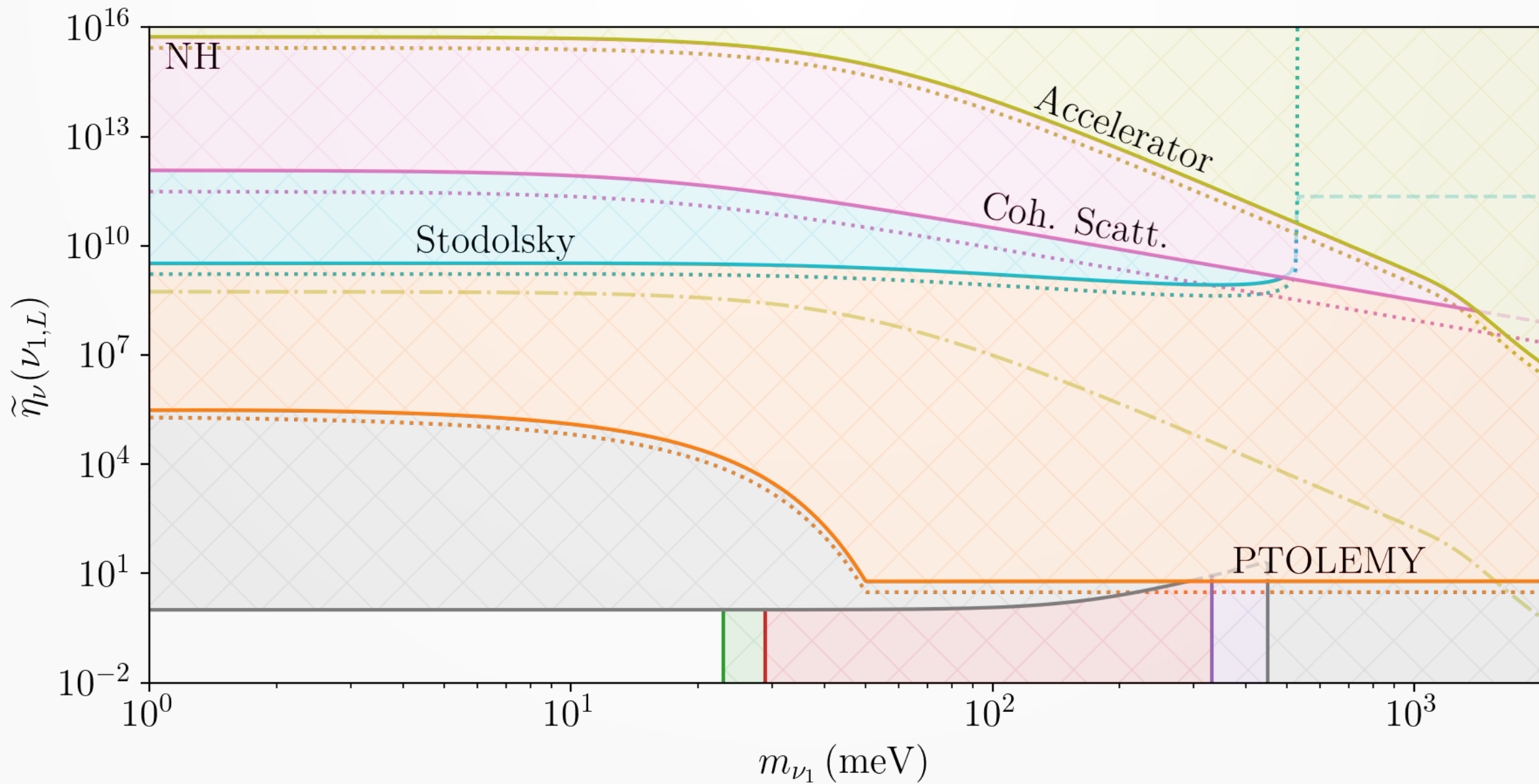
# Constraints (new)



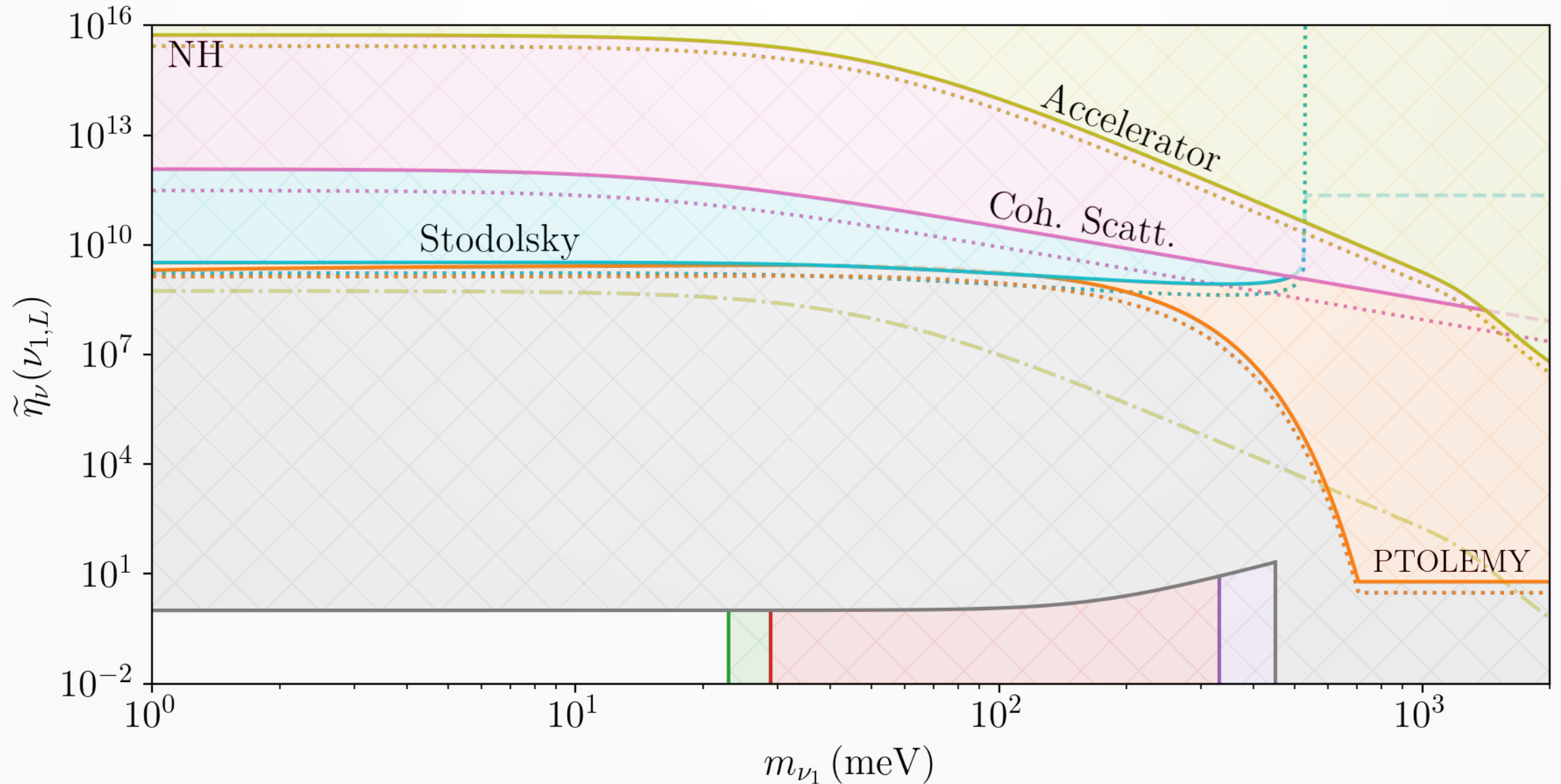
# Sensitivity (old)



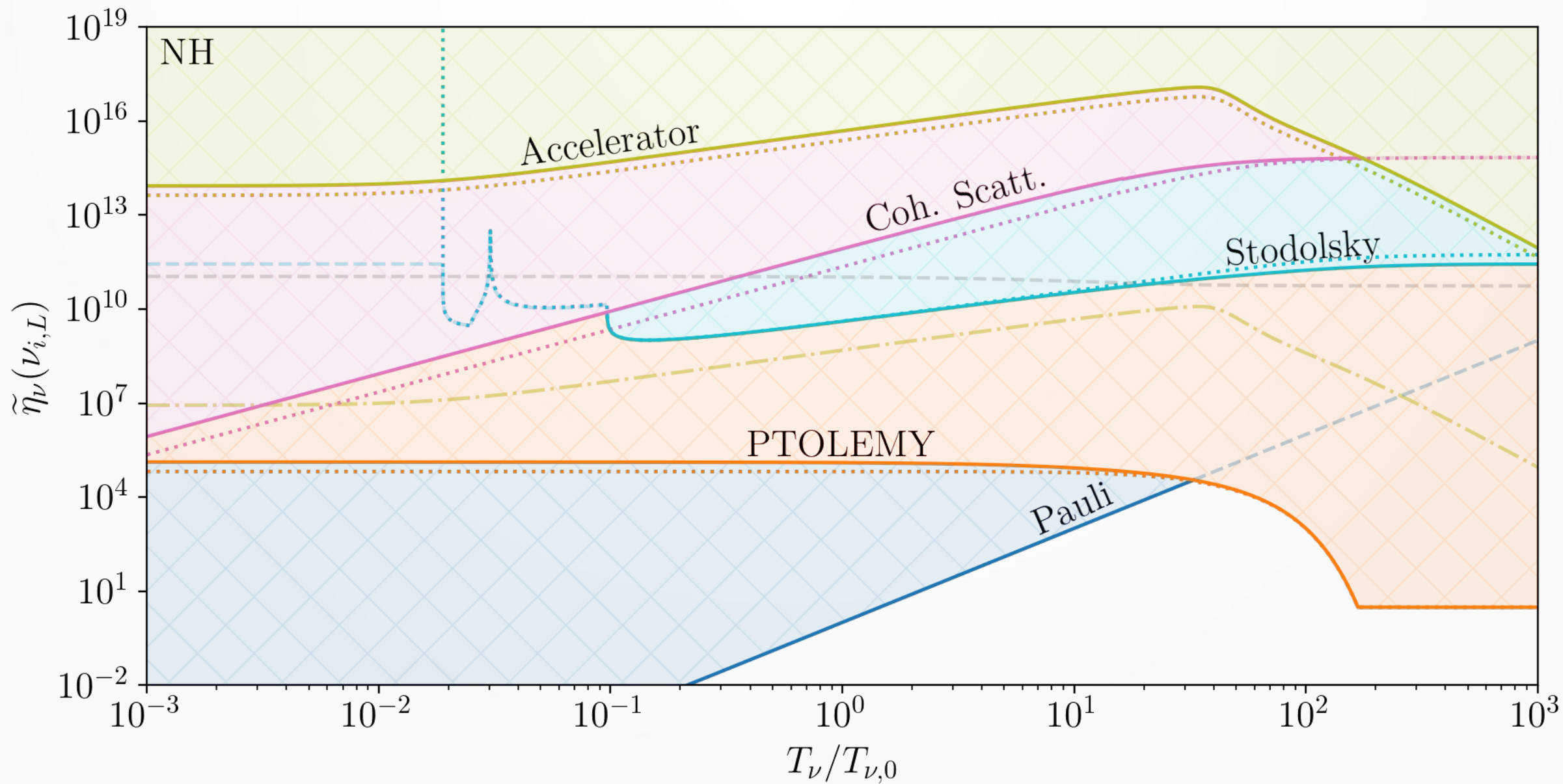
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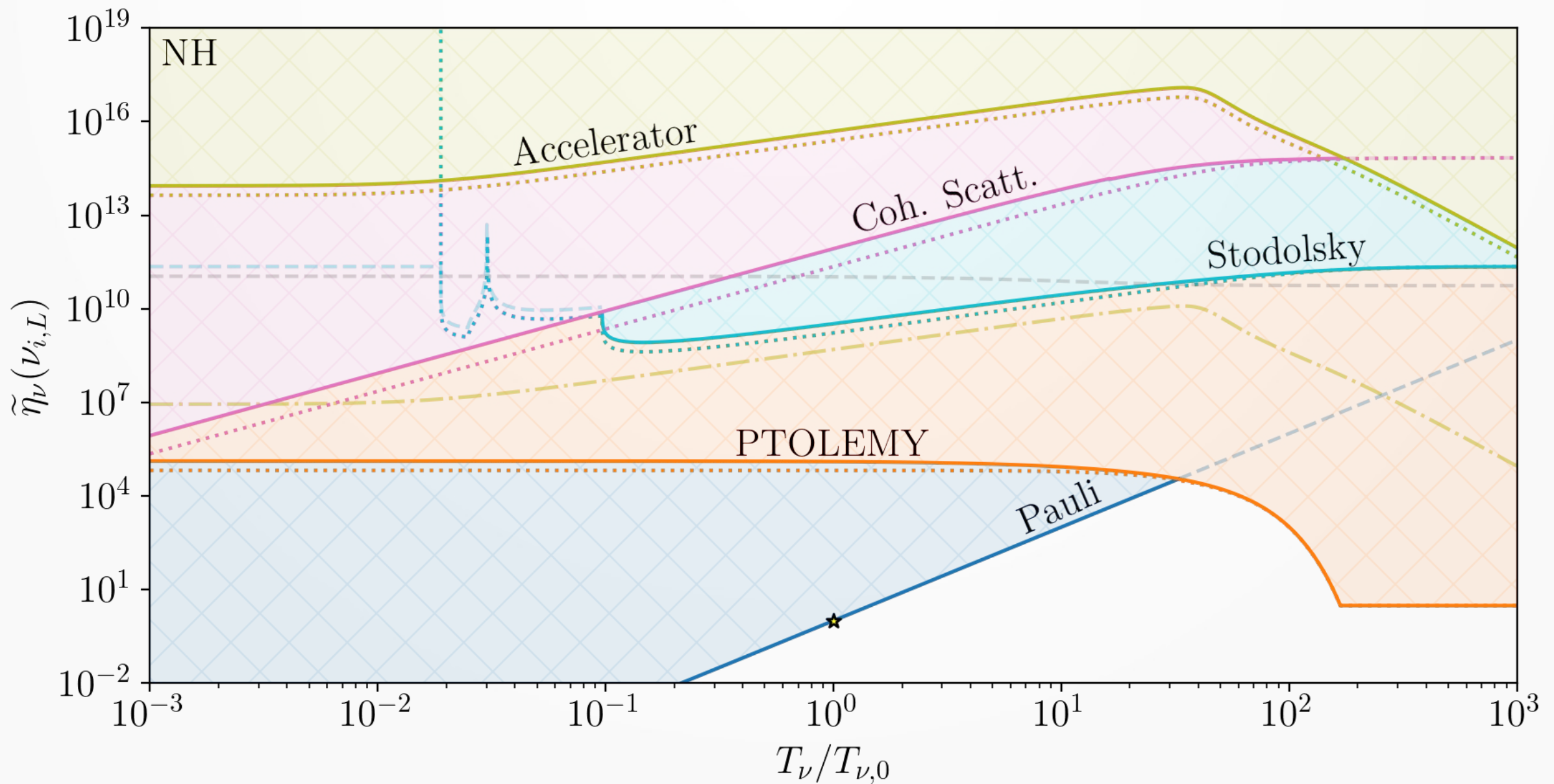
# Sensitivity (new) + uncertainty



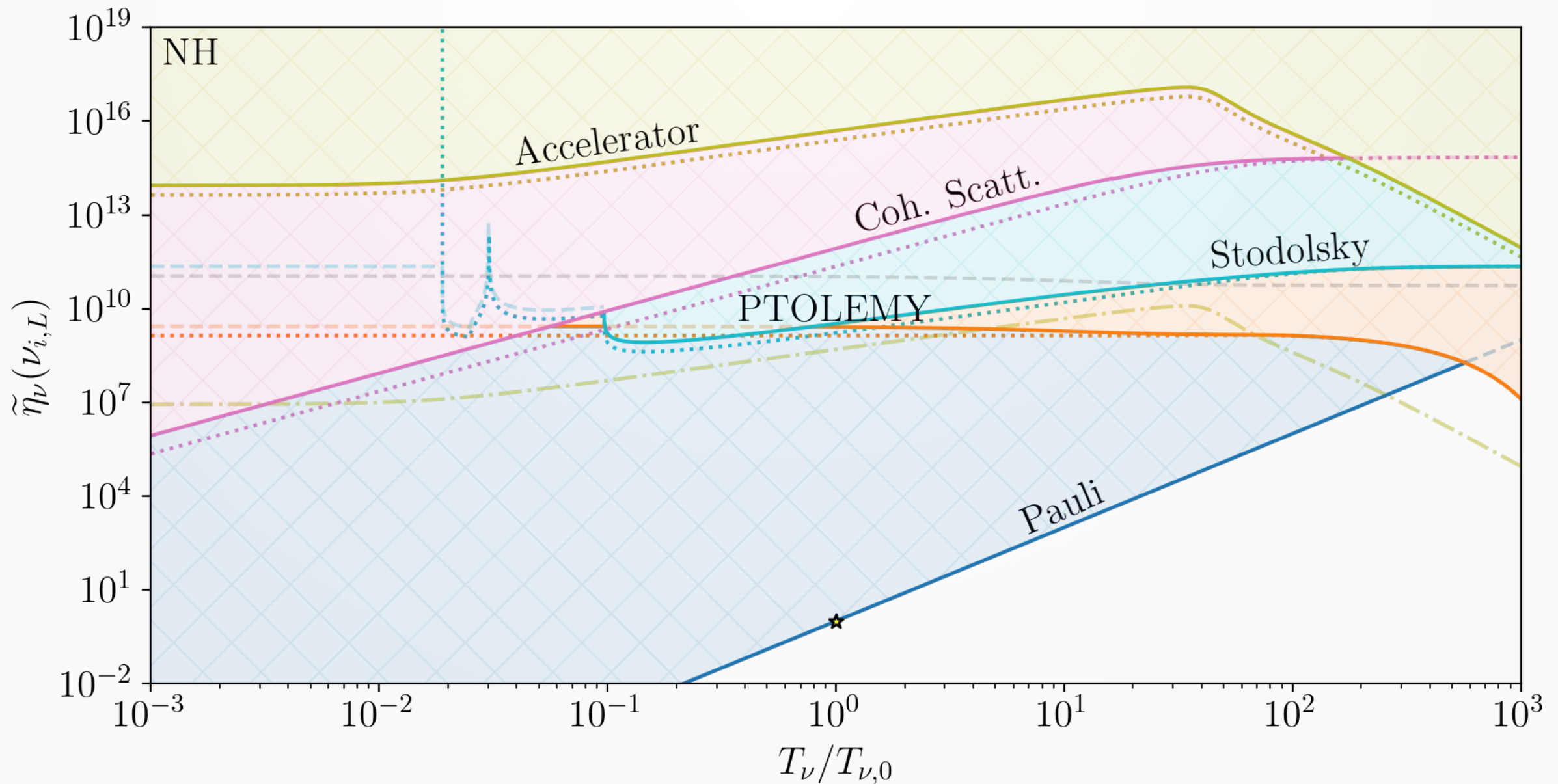
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- Detecting the  $C\nu B$  could reveal a wealth of new physics
- Detection made difficult by neutrino properties
- Many exciting proposals to detect the  $C\nu B$ !

Thank you!  
Questions?