Introduction to the Cosmic Neutrino Background

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IP3

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Contents

- What is the CνB?
- Why are we interested in its detection?
- How might we go about detecting it?

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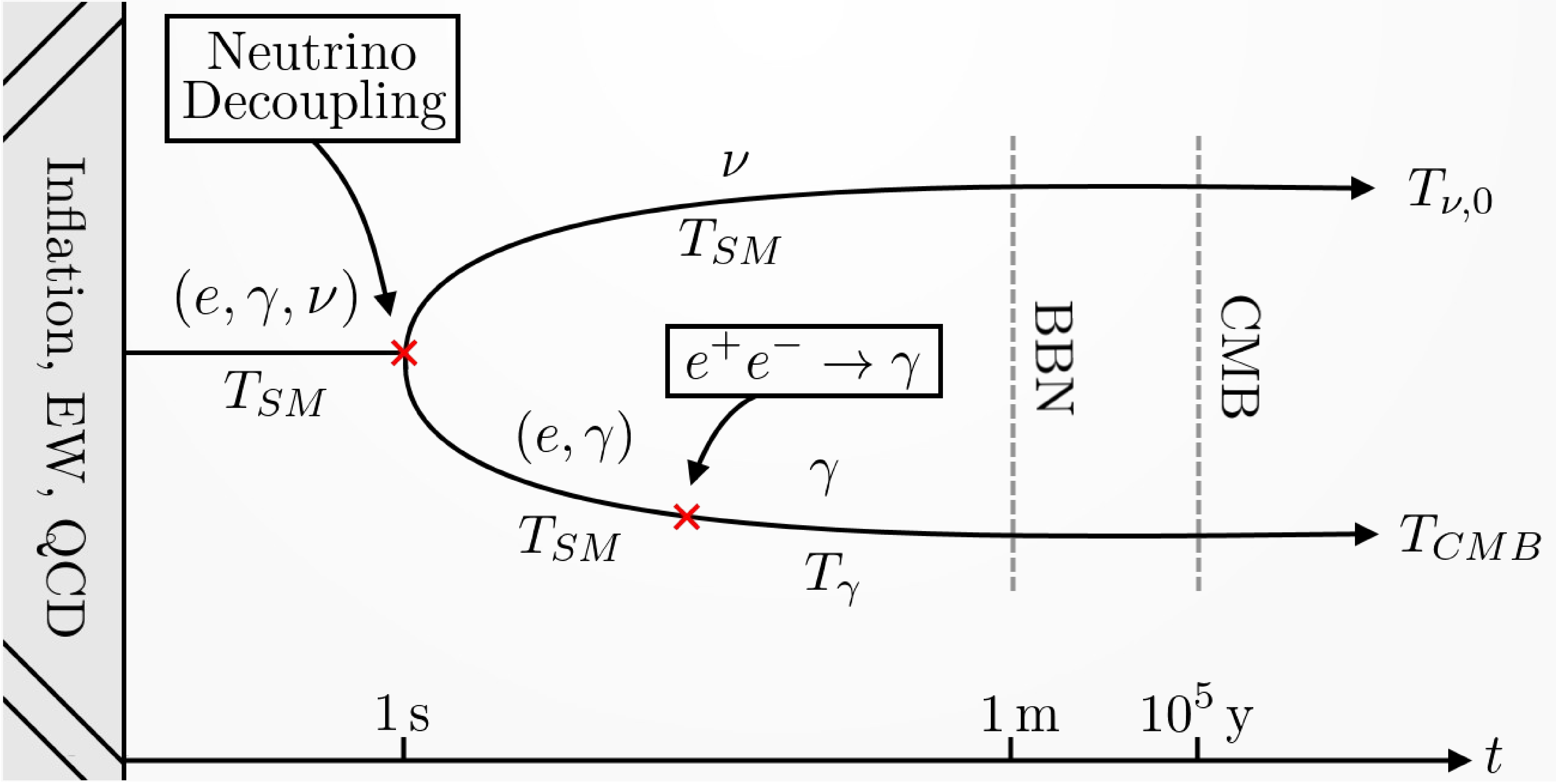

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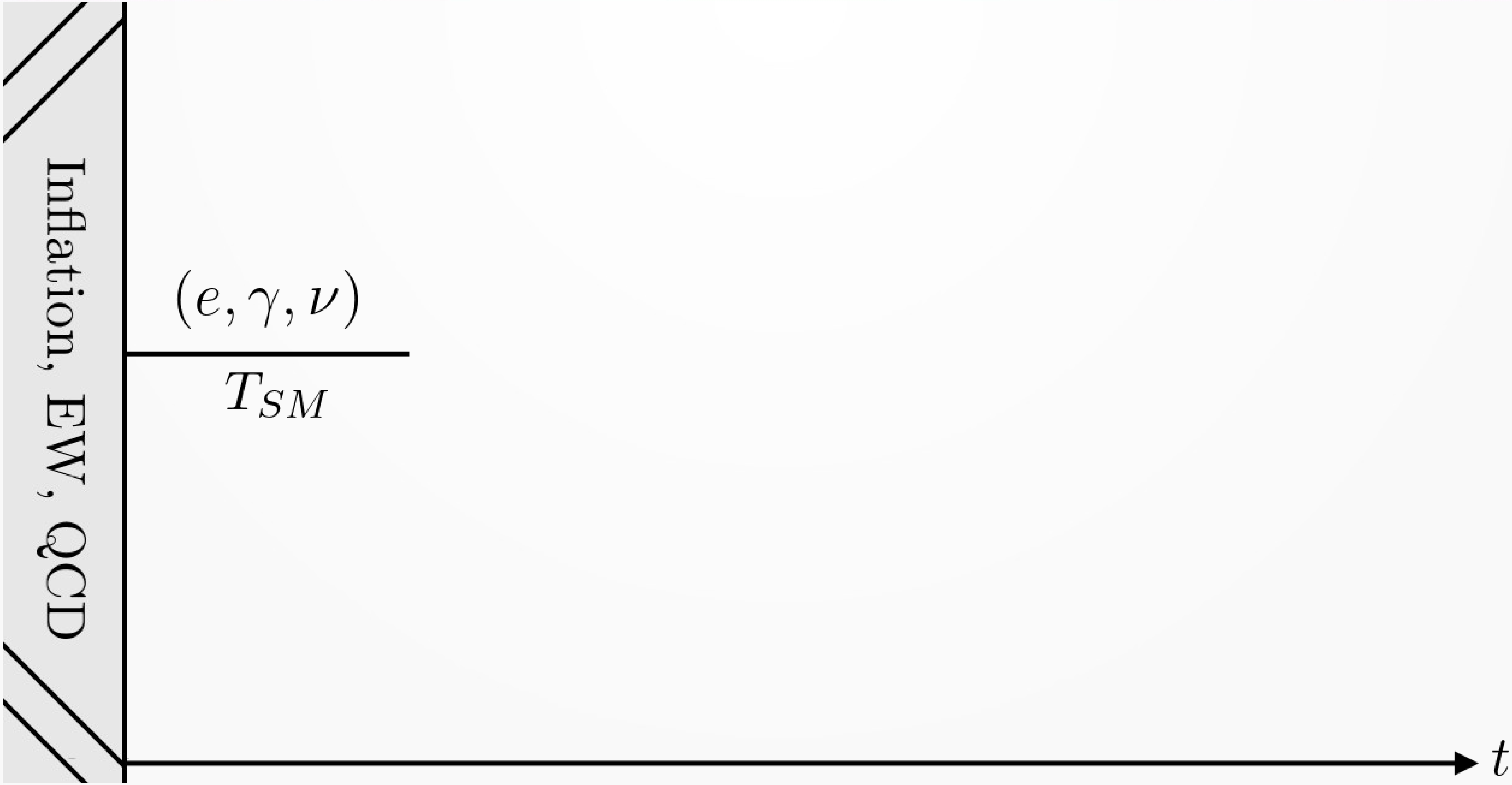

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$$e + \gamma \rightarrow e + \gamma$$

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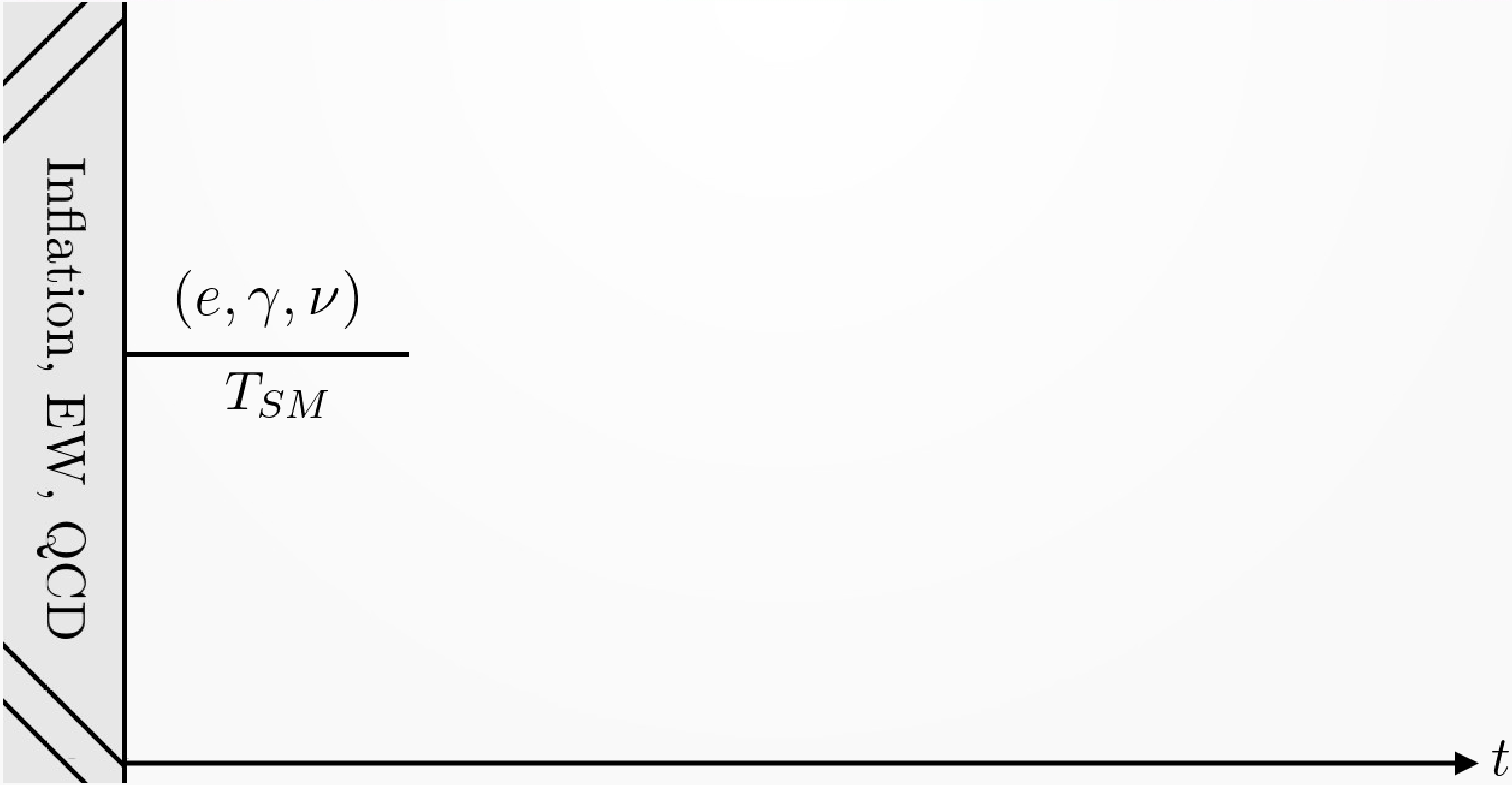
- Electrons and photons are kept in equilibrium through EM interactions:

$$e + \gamma \rightarrow e + \gamma \qquad e^+ + e^- \leftrightarrow \gamma$$

- Neutrinos and electrons are kept in equilibrium through weak interactions:

$$\nu + e \rightarrow \nu + e \qquad \nu + \bar{\nu} \leftrightarrow e^+ + e^-$$

What is the CνB?



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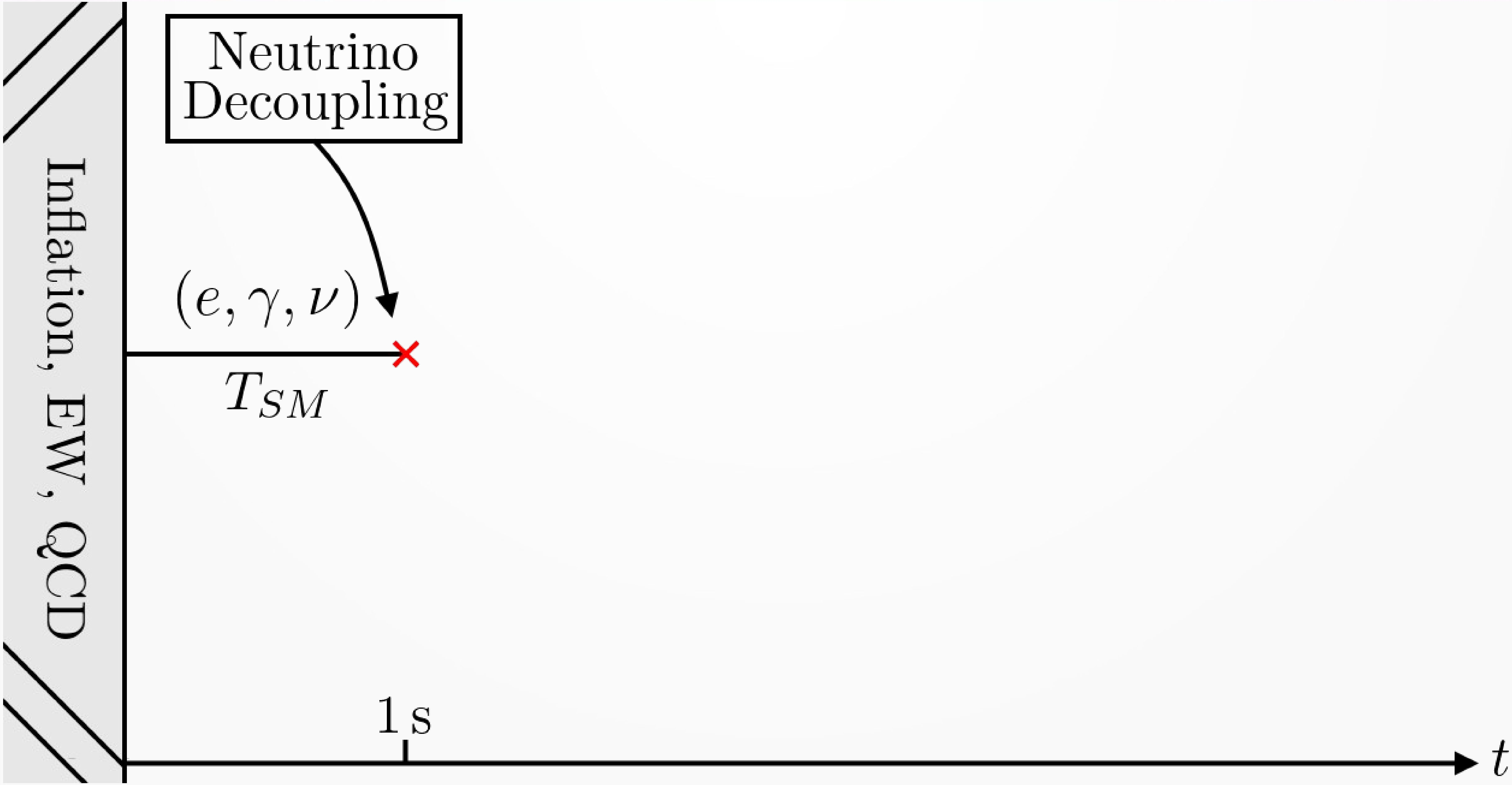

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- Neutrino interaction rate is $\Gamma_\nu \propto \sigma_\nu n_\nu$

$$\sigma_\nu \propto G_F^2 T_{SM}^2 \qquad\qquad n_\nu \propto \int \frac{d^3 p_\nu}{e^{\frac{p_\nu}{T_\nu}} + 1} \propto T_{SM}^3$$

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$$\rho \propto \sum_{e,\gamma,\nu} \int \frac{p_i \, d^3 p_i}{e^{\frac{p_i}{T_i}} \pm 1} \propto T_{SM}^4$$

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$$t_{\rm dec} = \frac{1}{2H} \sim 1\,\mathrm{s}$$

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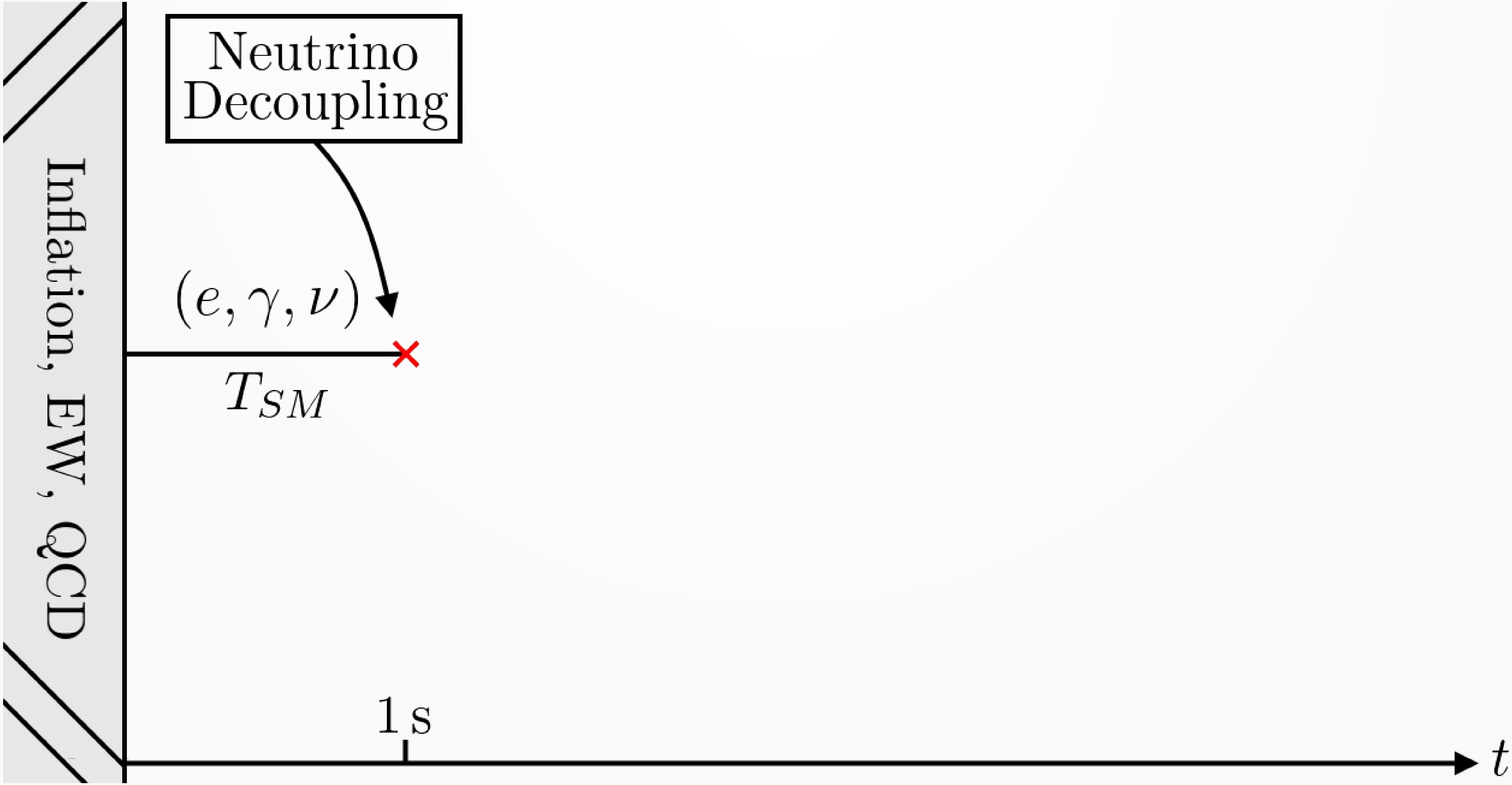

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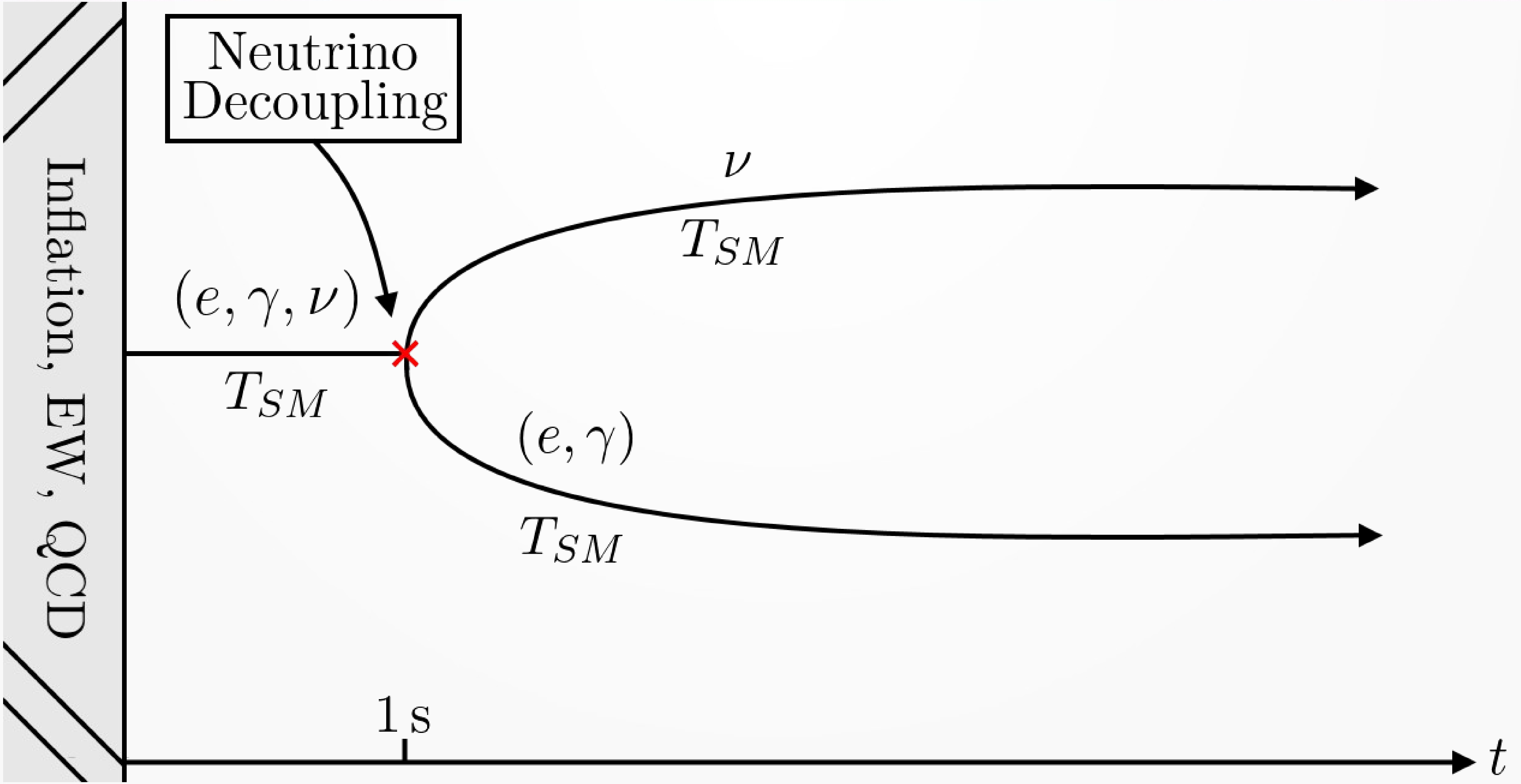

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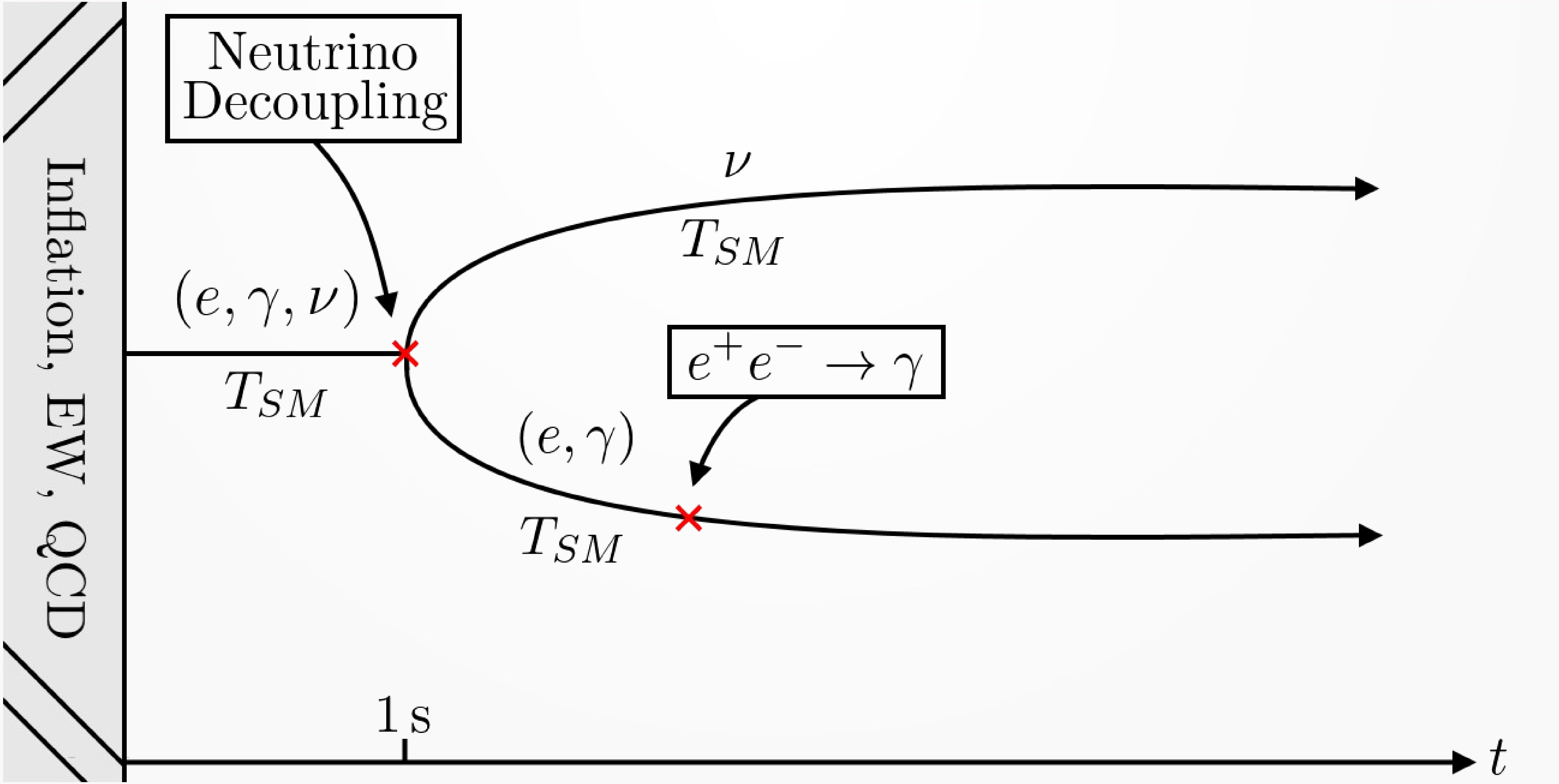

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- $E_\gamma < 1.02\,\text{MeV}$:

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- This process changes the photon temperature!

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- In a comoving volume, total entropy is conserved:

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- Entropy before and after annihilation needs to be the same:

$$g_s^*(T_{SM})\, T_{SM}^3 = g_s^*(T_\gamma)\, T_\gamma^3$$

- In general:

$$g_s^*(T) = \sum_{\text{bosons}} g_i + \frac{7}{8} \sum_{\text{fermions}} g_i$$

What is the CνB?

- Before annihilation:

$$g_s^*(T_{SM}) = \underbrace{2}_{\gamma} + \frac{7}{8}(\underbrace{2 \times 2}_{e})$$

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- After annihilation:

$$g_s^*(T_\gamma) = 2$$

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$$\frac{11}{2} T_{SM}^3 = 2 T_\gamma^3$$

- Recalling that the neutrinos are still at T_{SM}:

$$\boxed{T_\nu = \left(\frac{4}{11}\right)^{\frac{1}{3}} T_\gamma}$$

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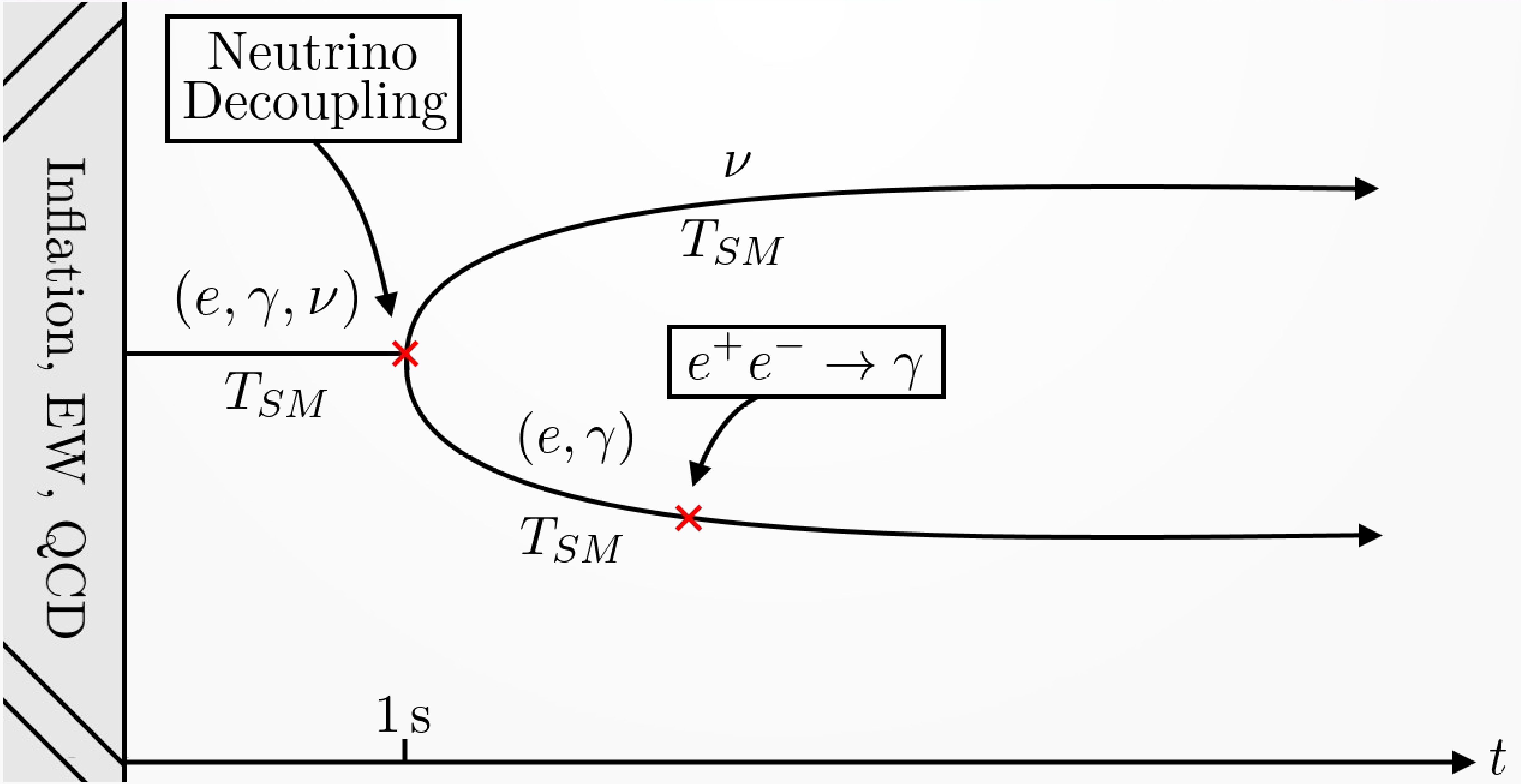

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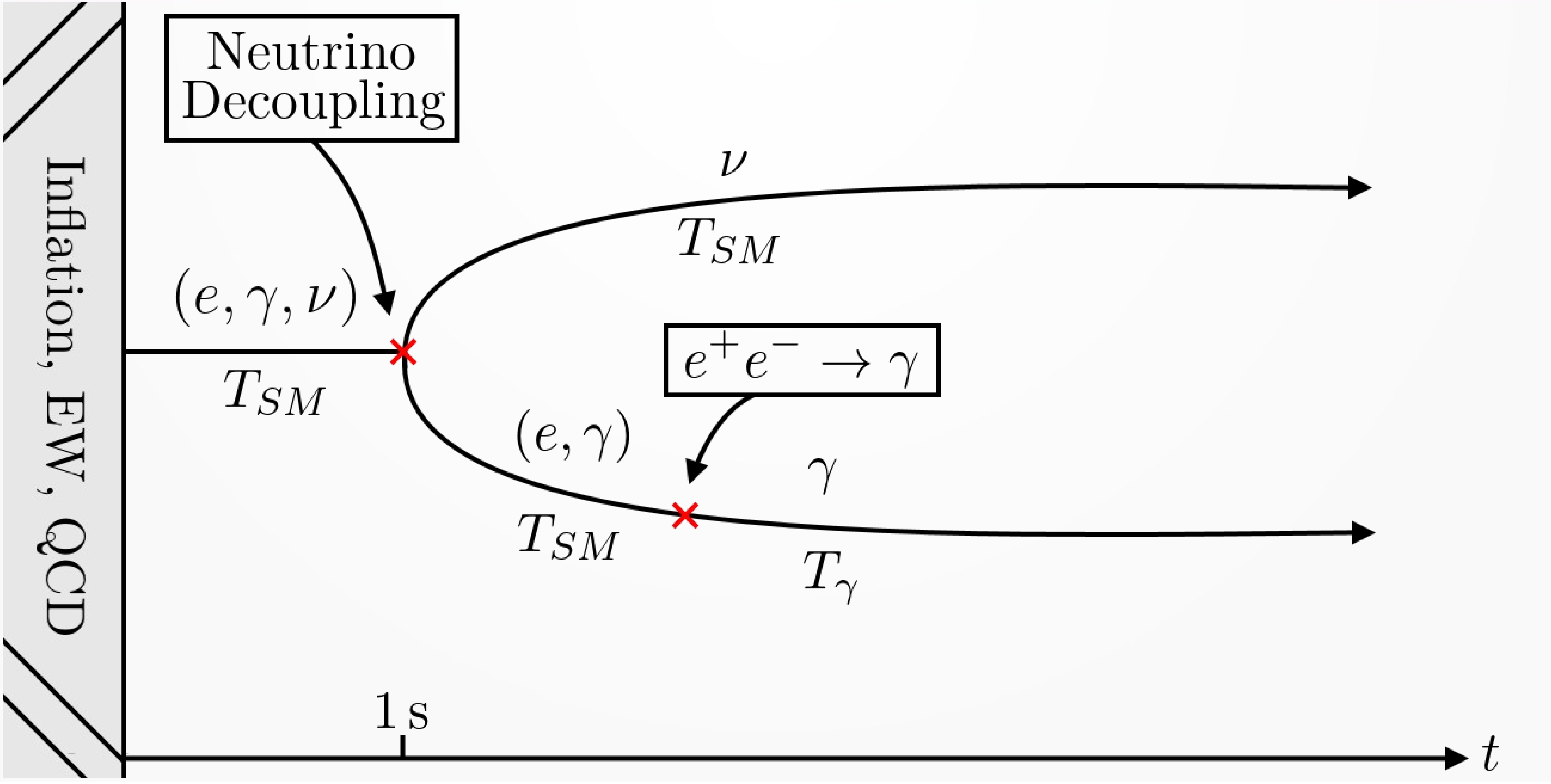

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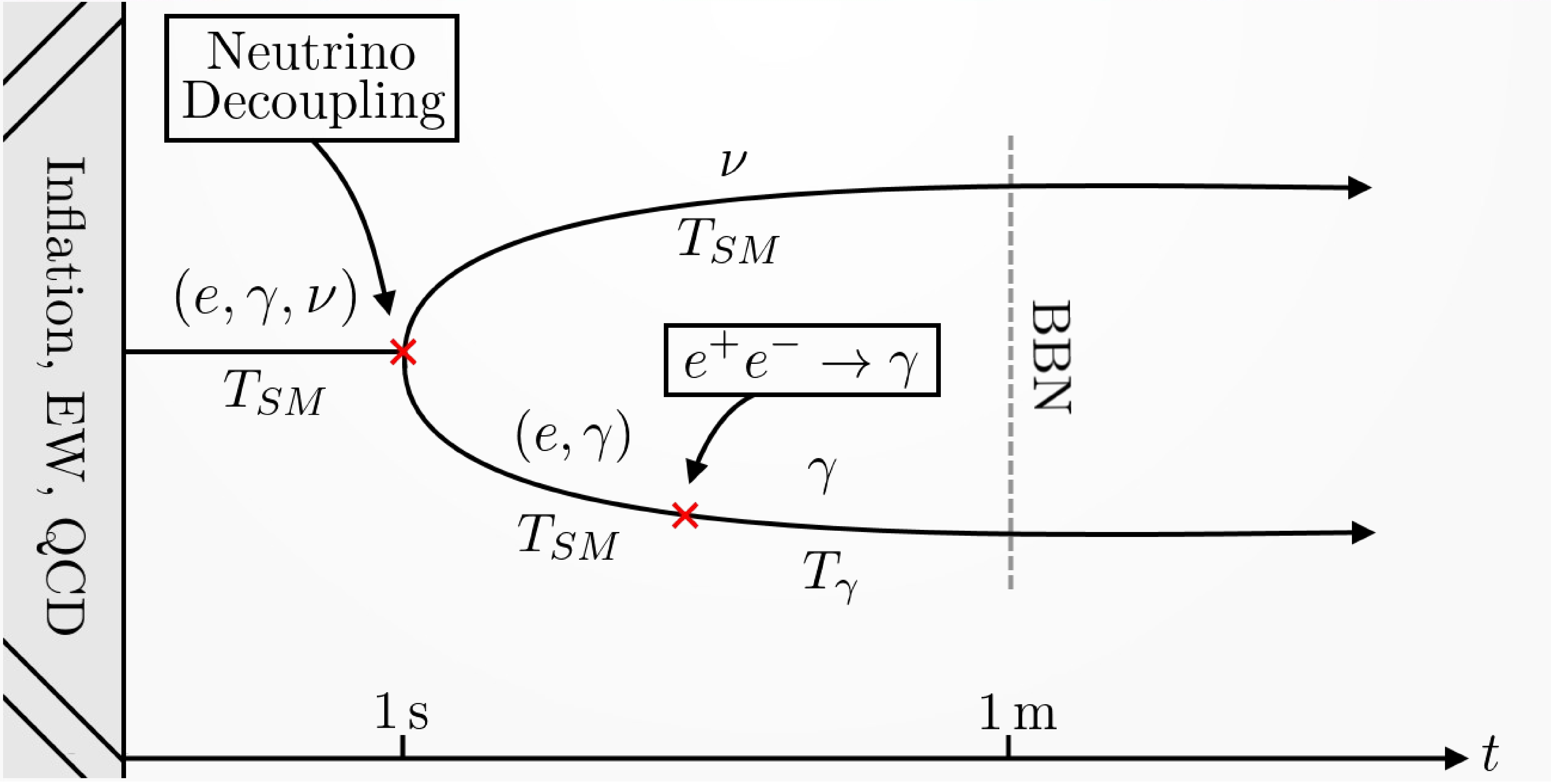

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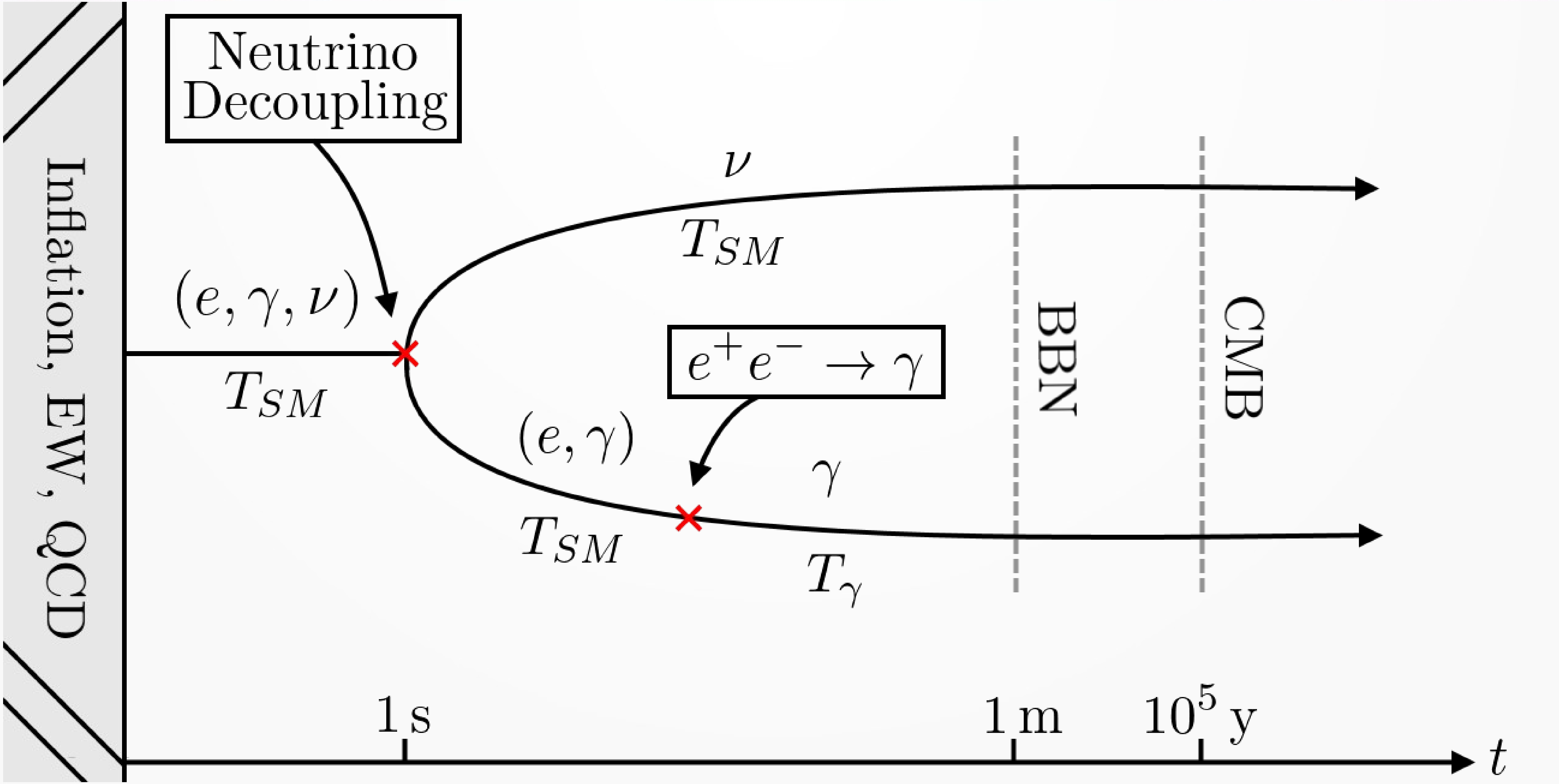

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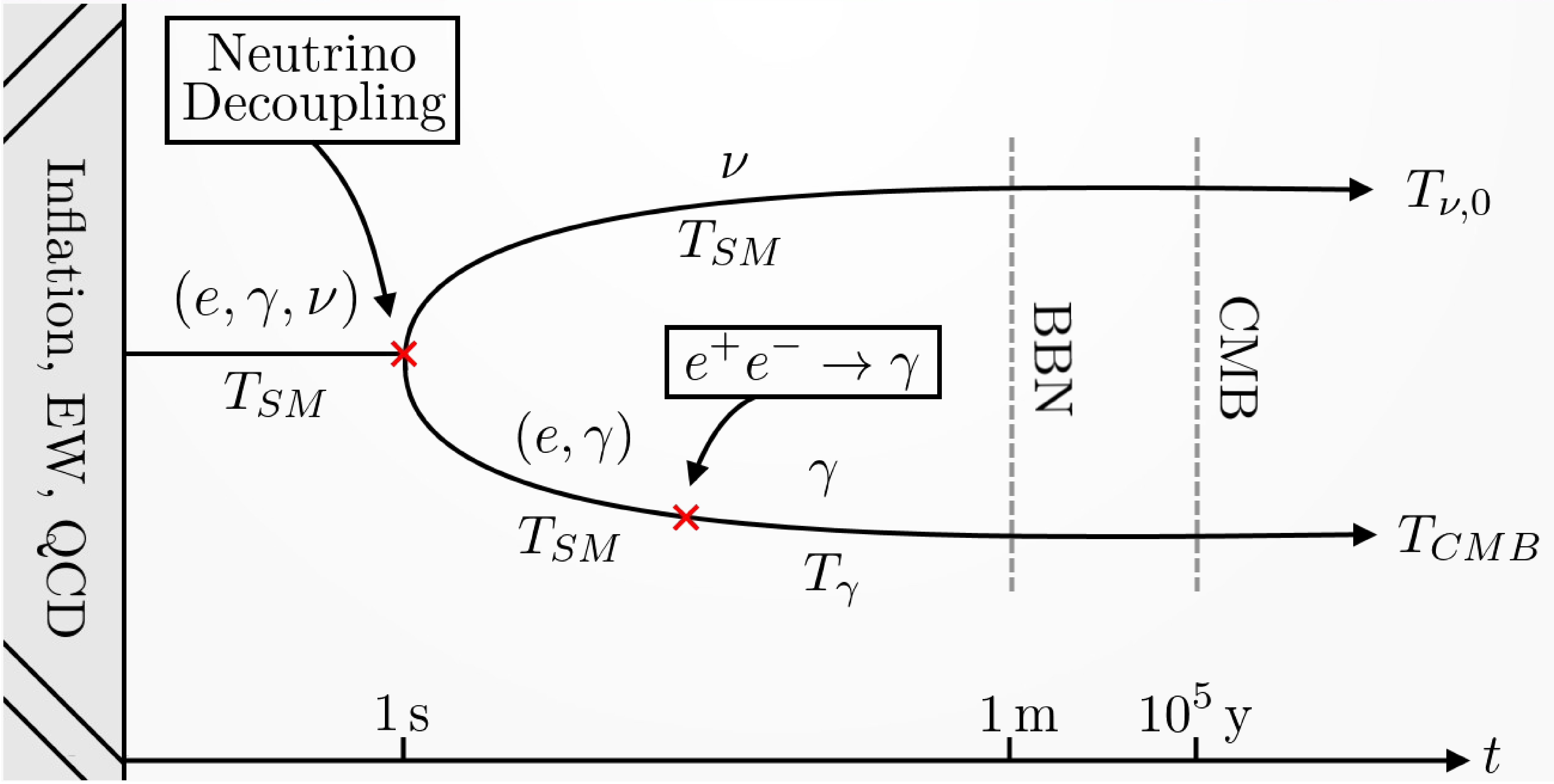

The CνB today

- Redshifted to temperature:

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

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- At least two neutrinos states are non-relativistic!
- Exist today as freely propagating mass eigenstates

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- This may lead to CDM profile, overdensities, helicity mixing etc.

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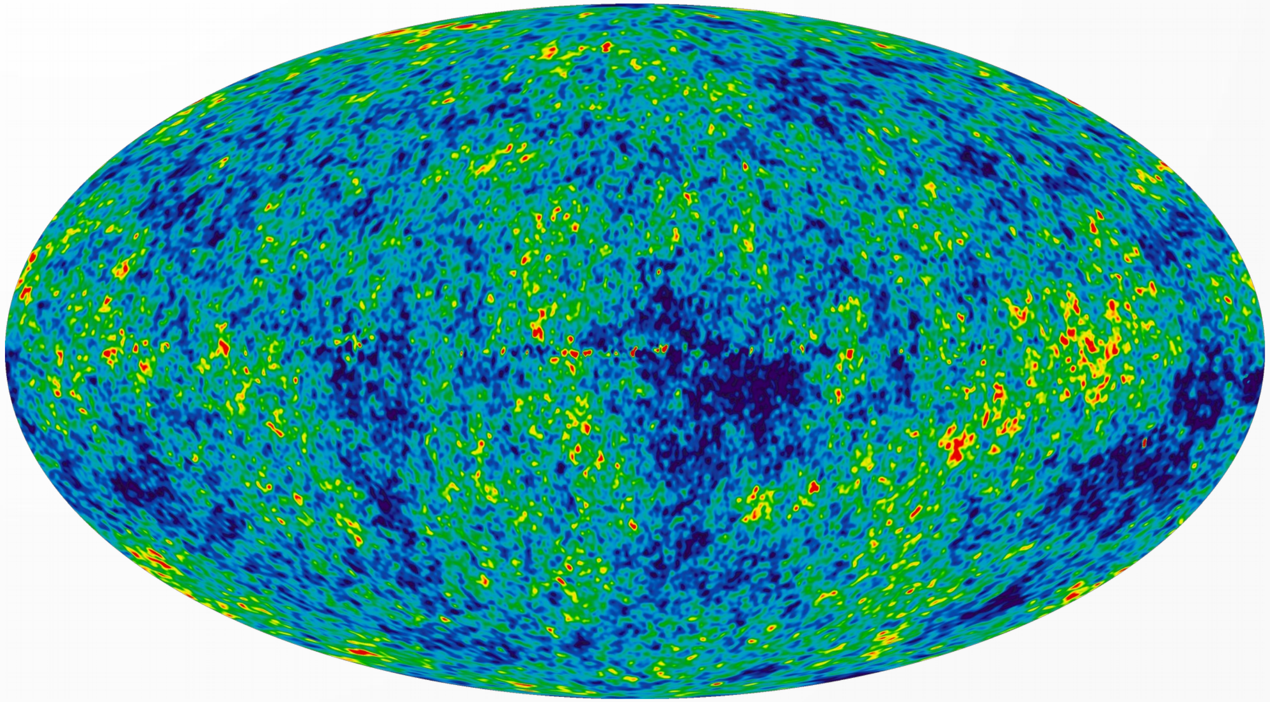
Why detect the CνB?

- The CMB is the furthest we can currently look back through time



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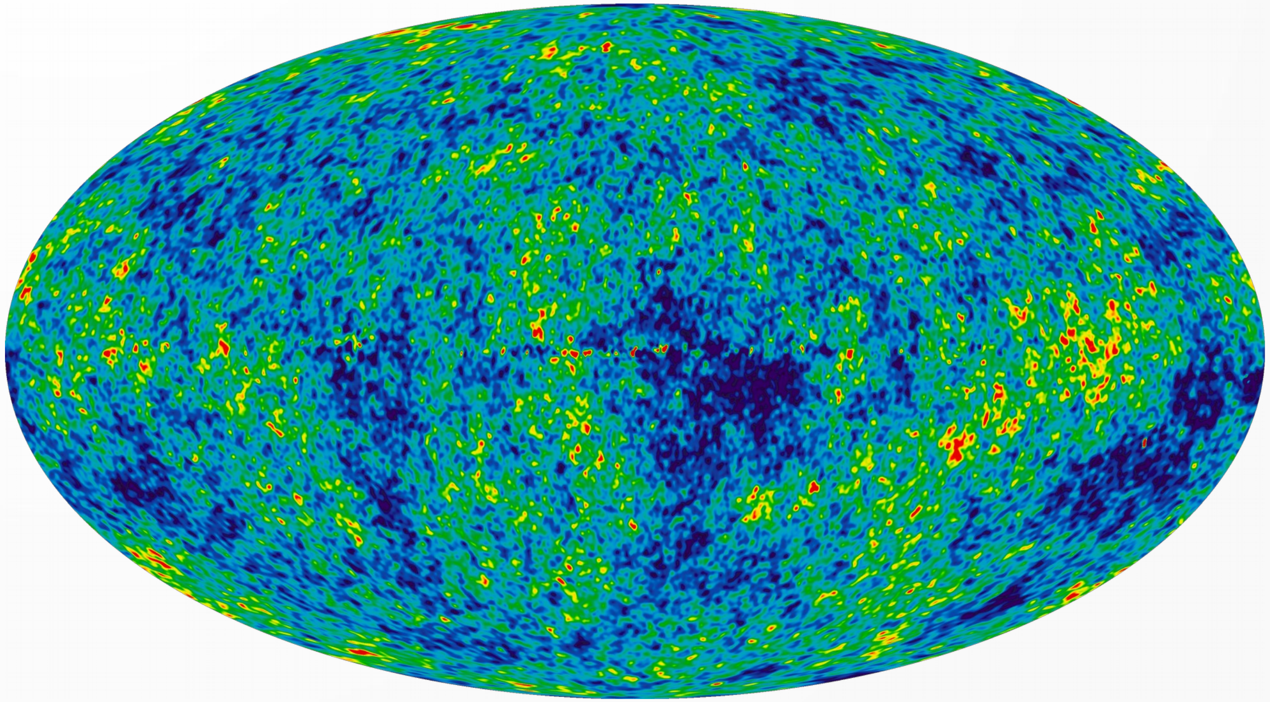

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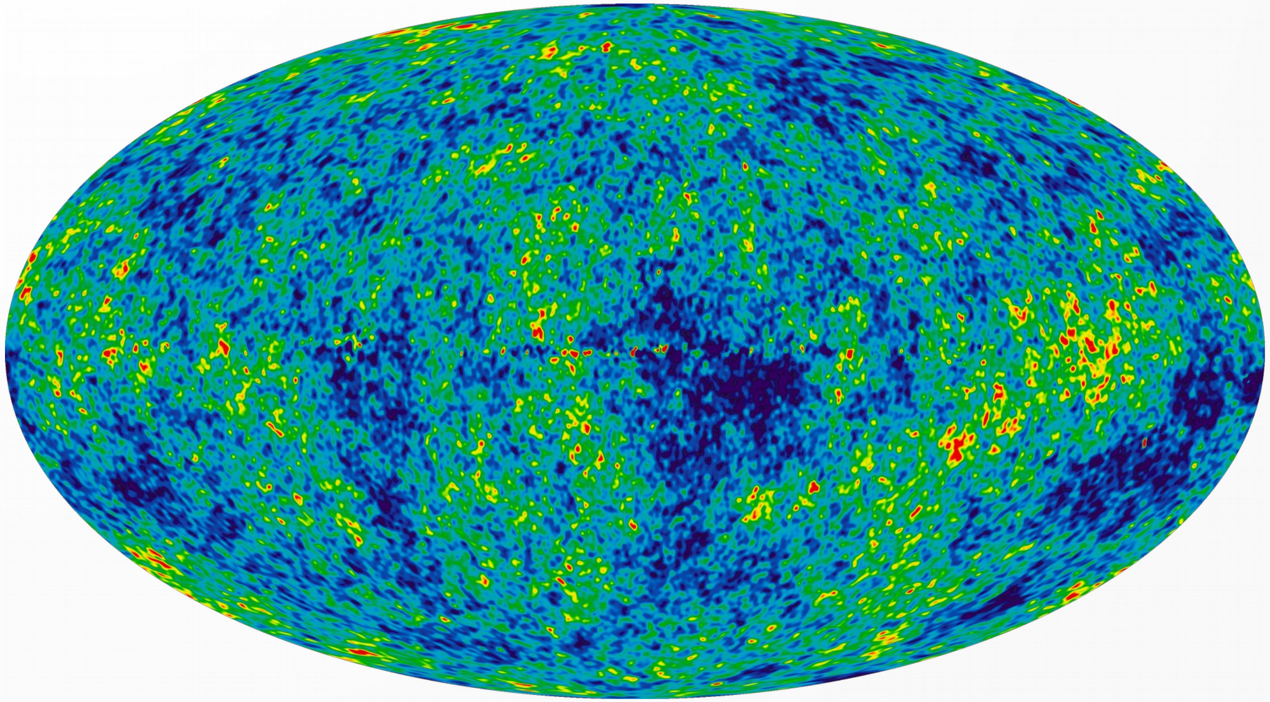
- A rare source of non-relativistic neutrinos!

- Perhaps they're not there at all



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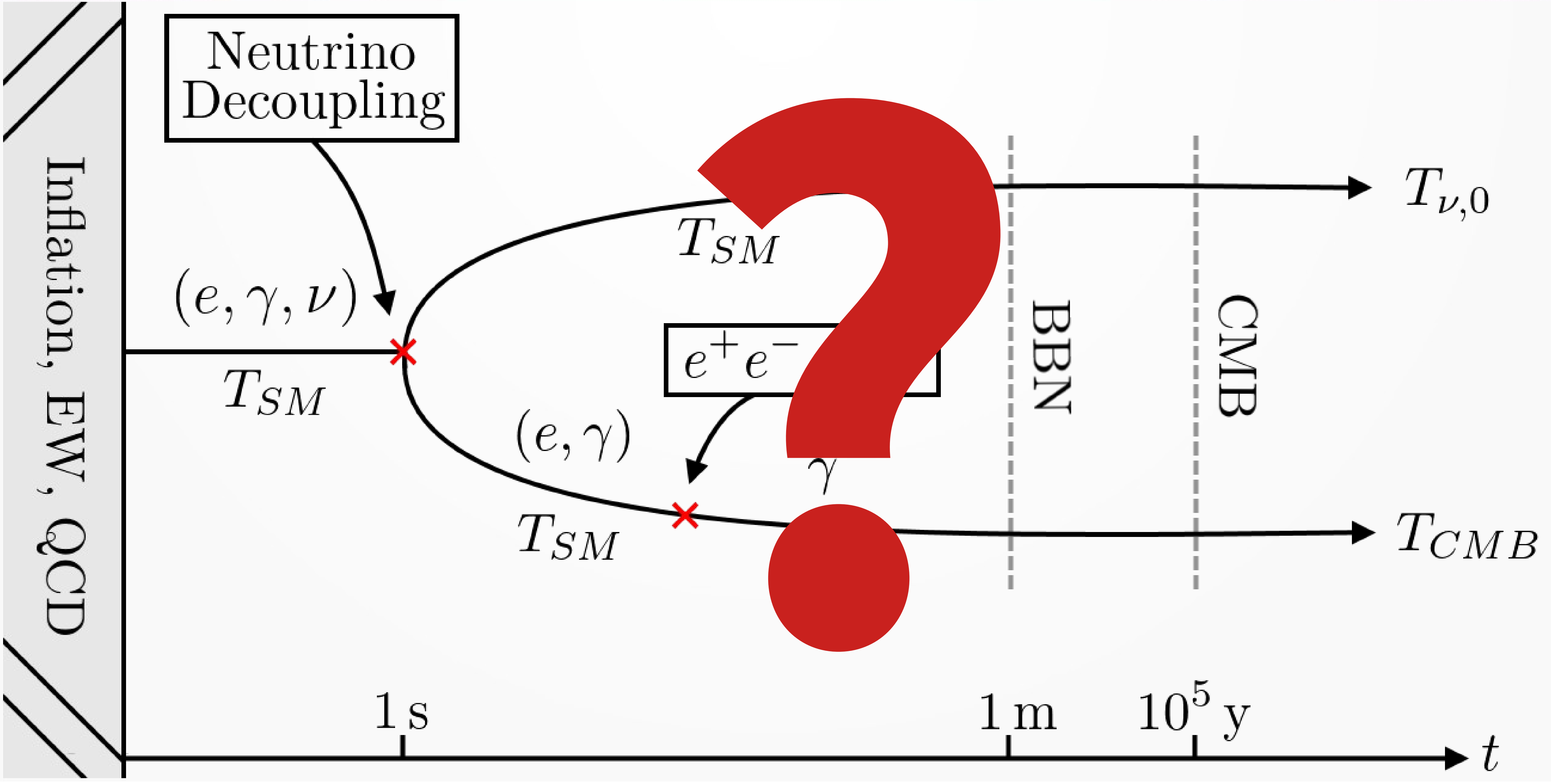

So…why haven't we detected them yet?

- Neutrinos are notoriously hard to look for…

$$\sigma_\nu \sim G_F^2 E_\nu^2 \sim 5 \cdot 10^{-50} \left(\frac{E_\nu}{1\,\mathrm{keV}} \right)^2 \mathrm{cm}^2$$

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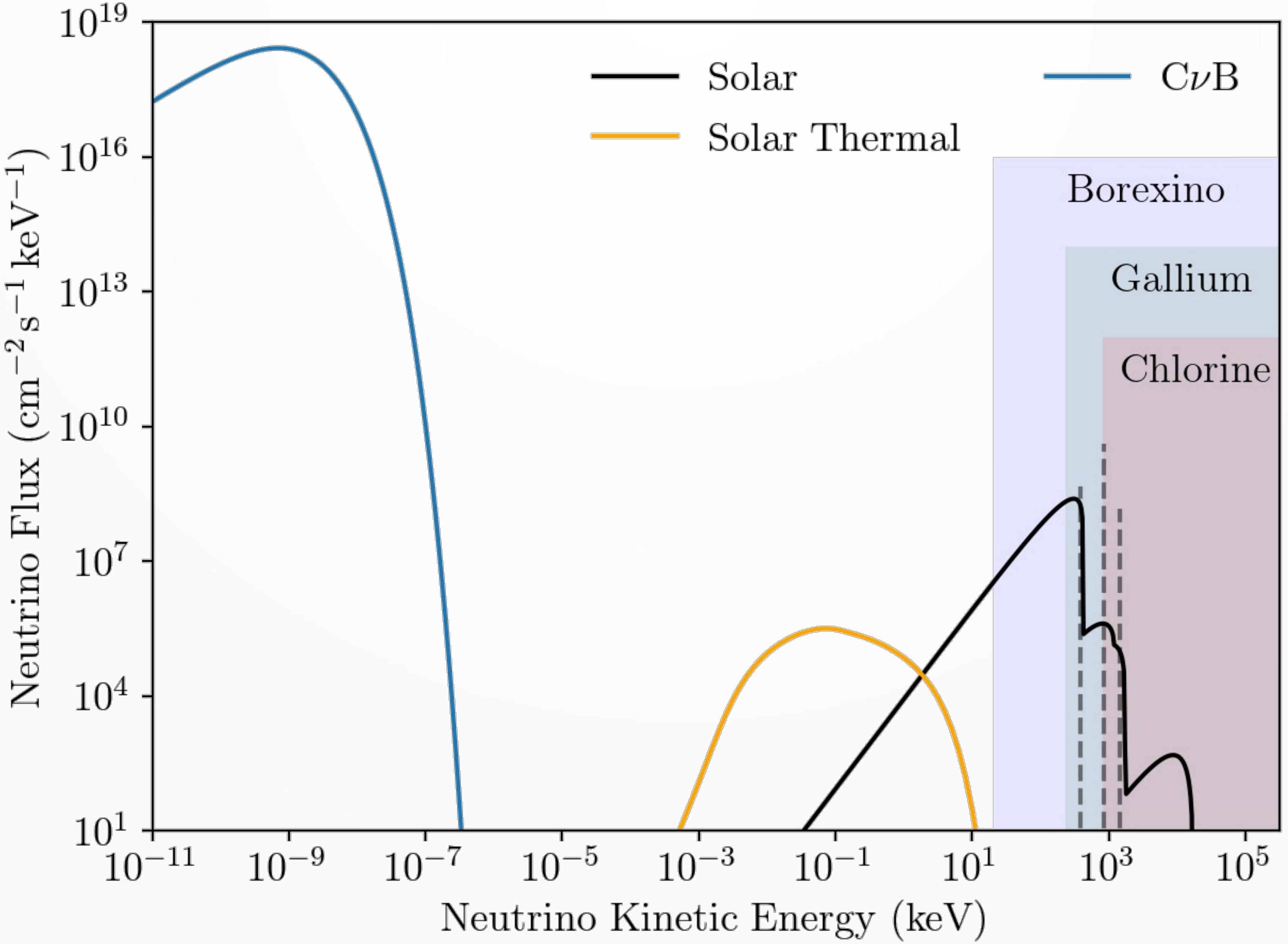
- Existing neutrino detection experiments have thresholds:

$$\bar{\nu}_e + p + (1.8\,\mathrm{MeV}) \rightarrow e^- + n$$

But...there is hope!



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- Threshold:
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- Threshold:
  - Remove it completely!
  - Find some way to bridge it

- Event rate:
  - Use a huge number of targets
  - Increase the cross section

How might we detect the CνB?

- PTOLEMY experiment (Weinberg '62):

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- Stodolsky effect (Stodolsky '75, Duda '01)

How might we detect the CνB?

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$$^{A}_{Z}P + e^{-}(\text{bound}) + \bar{\nu}_e \to {}^{A}_{Z-1}D$$

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- Exclusion principle (Takahashi '09)

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- Detecting the CνB could reveal a wealth of new physics
- Detection made difficult by neutrino properties
- Many exciting proposals to detect the CνB!

Thank you!
Questions?