

# BBN disintegration constraints from neutrino injections

Invisibles25 Workshop

2nd September 2025

Based on [2505.01492](#)

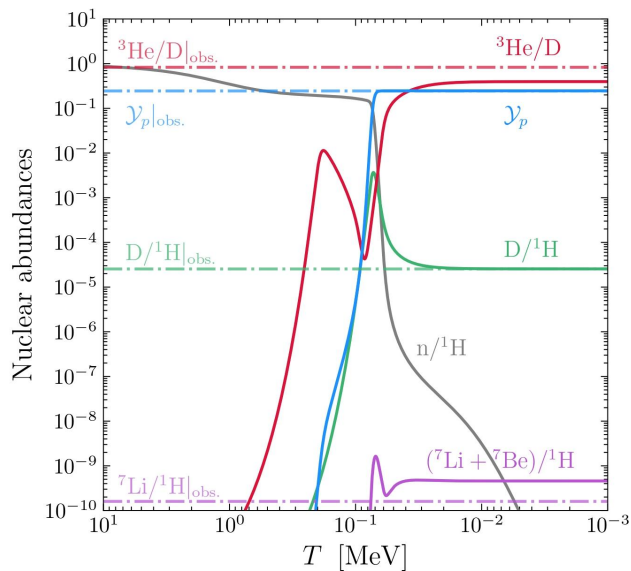
Sara Bianco

*In collaboration with: P. F. Depta, J. Frerick, T. Hambye, M. Hufnagel, and K. Schmidt-Hoberg*

---

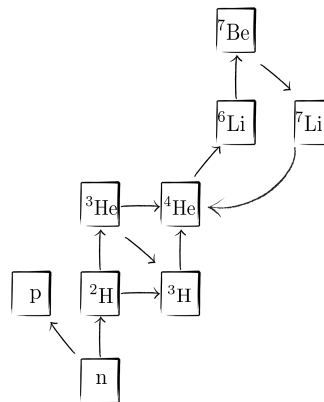
# Introduction: Big Bang Nucleosynthesis

BBN describes the production of light elements in the early Universe.



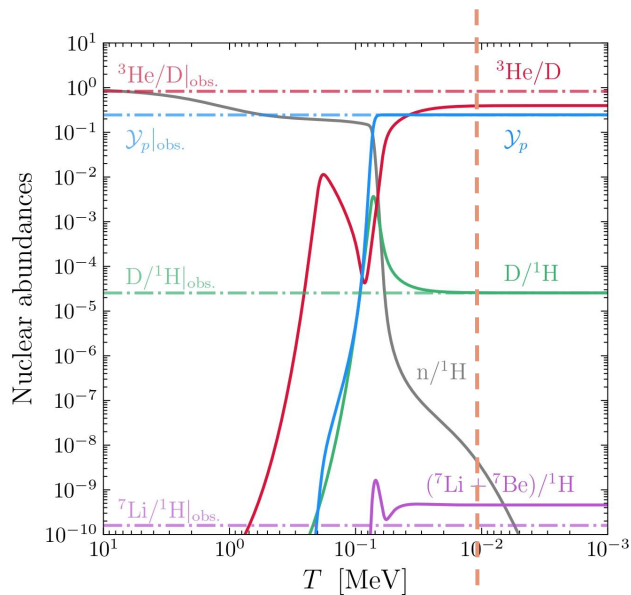
Credits to P. F. Depta

$$t \sim 1\text{s} - 10^4\text{s} \iff T \sim \text{MeV} - 10\text{keV}$$



# Introduction: Big Bang Nucleosynthesis

BBN describes the production of light elements in the early Universe.



Credits to P. F. Depta

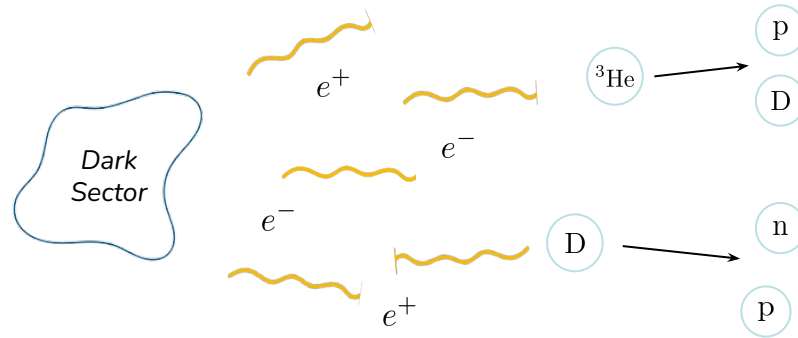
Reach their asymptotic values ~ **10 keV**.

However, even at later times, injections of **electromagnetic** and **hadronic** material can alter the BBN abundances.

How?

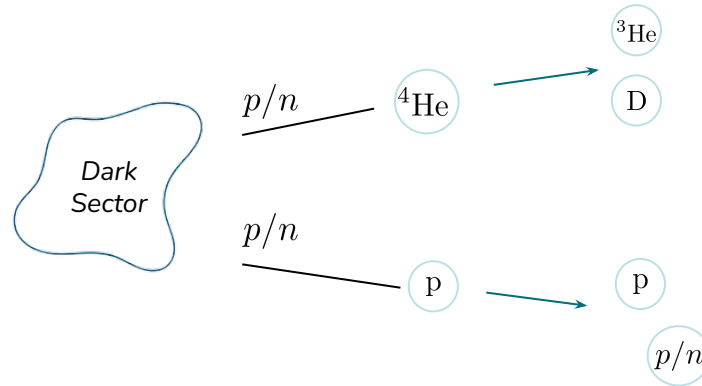
# Introduction: Photodisintegration

The *late-time* injection of *high-energetic* EM particles into the SM plasma induces an EM cascade that leads to non-thermal parts of the photon, electron, and positron spectra.



# Introduction: Hadrodisintegration

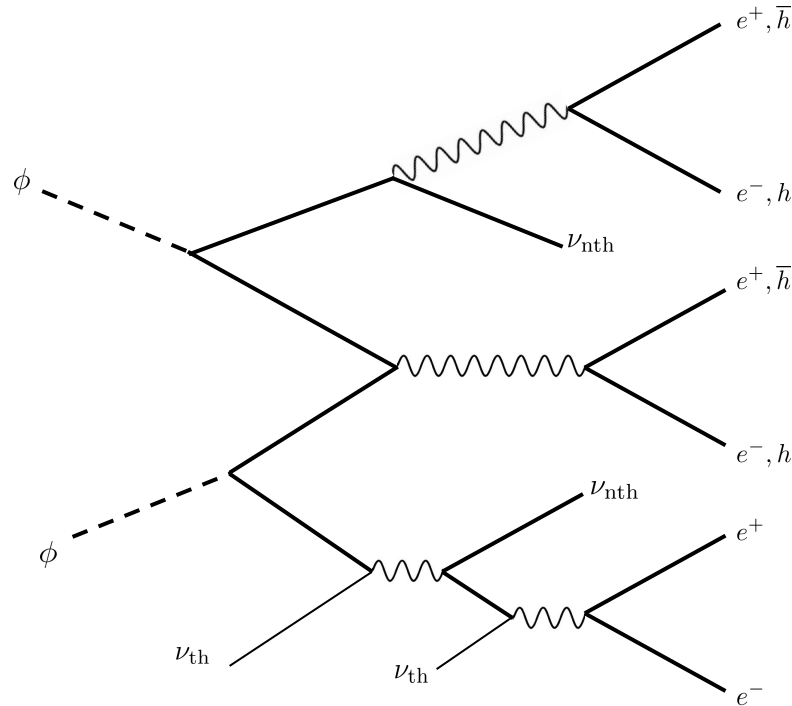
Similarly to photodisintegration, hadrodisintegration describes the late-time destruction of the light elements, this time driven by hadrons.



# A quick overview of the neutrino cascade

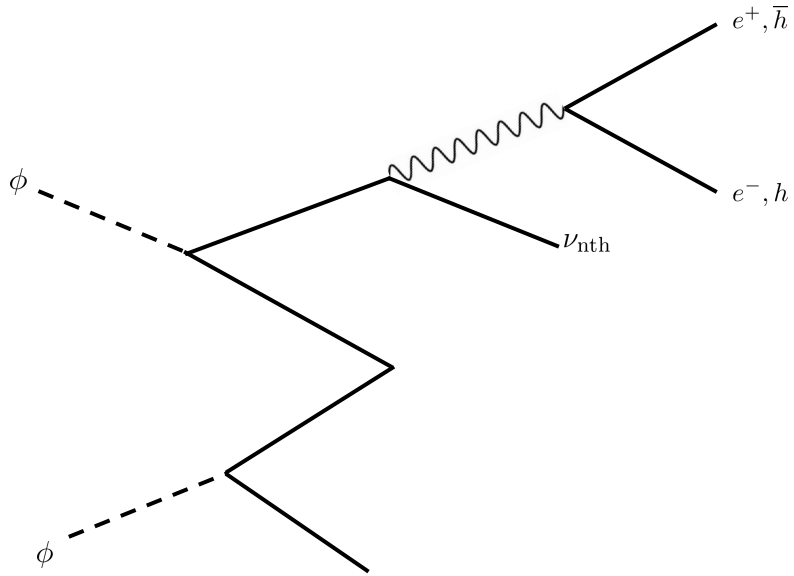
We consider some relic  $\phi$  with lifetime  $\tau_\phi > 10^4$ s.

We are interested in studying the effect of the **neutrino cascade** that follows these decays.

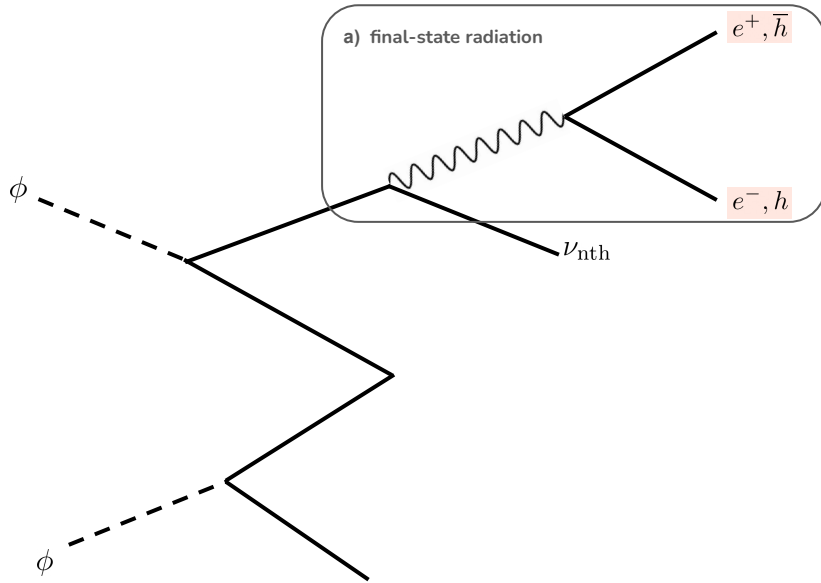


# A quick overview of the neutrino cascade

---



# A quick overview of the neutrino cascade

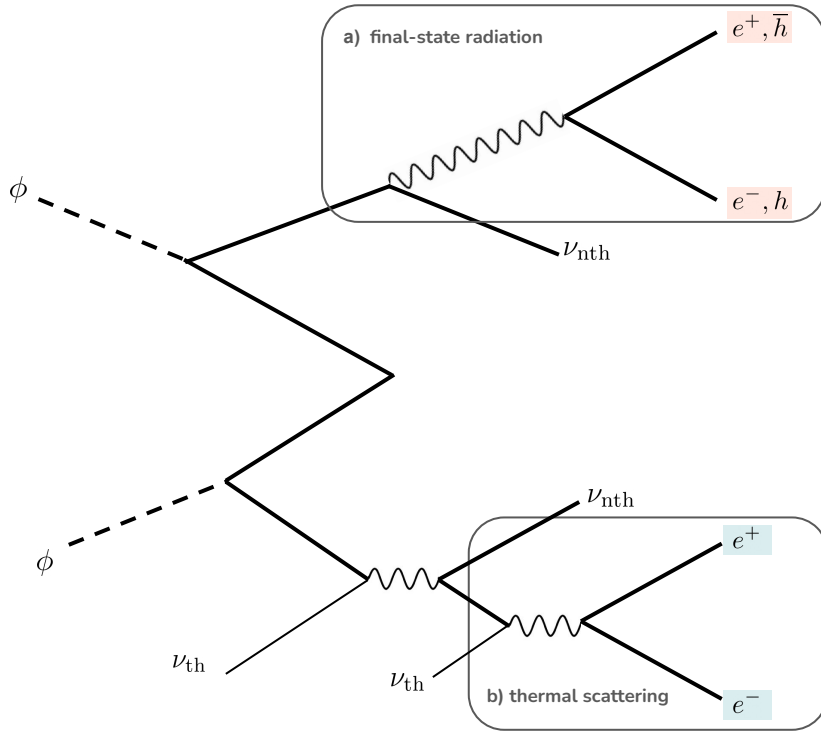


## a) Final-state radiation (FSR)

Decay particle produce a neutrino emitting a W- or Z-boson

→ EW shower that leads to **EM** and **HD** injections

# A quick overview of the neutrino cascade



## a) Final-state radiation (FSR)

Decay particle produce a neutrino emitting a W- or Z-boson

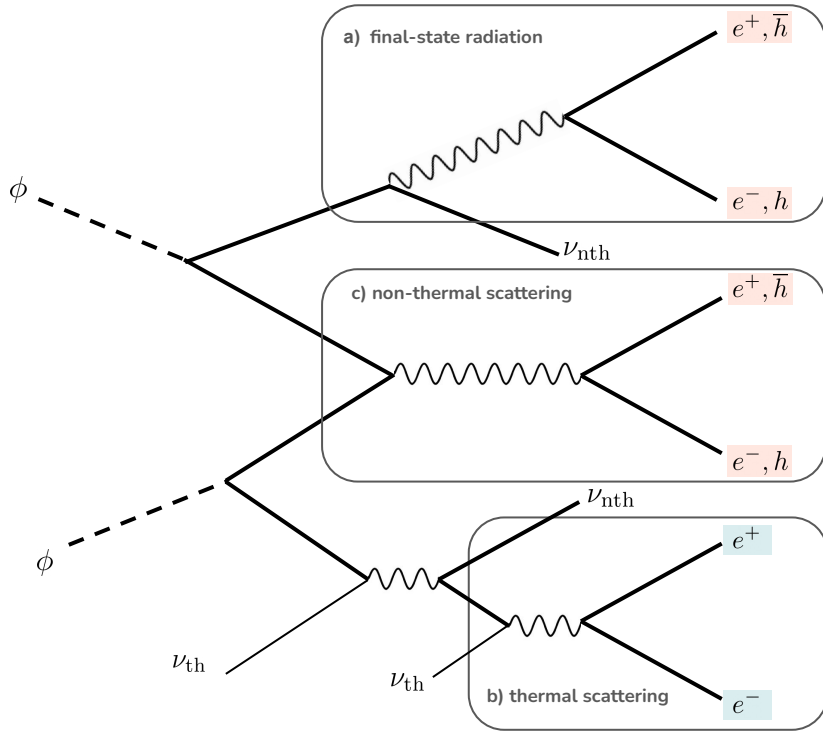
→ EW shower that leads to **EM** and **HD** injections

## b) Thermal scattering

Interactions with neutrino from the background

→ **EM** injections

# A quick overview of the neutrino cascade



## a) Final-state radiation (FSR)

Decay particle produce a neutrino emitting a W- or Z-boson

→ EW shower that leads to **EM** and **HD** injections

## b) Thermal scattering

Interactions with neutrino from the background

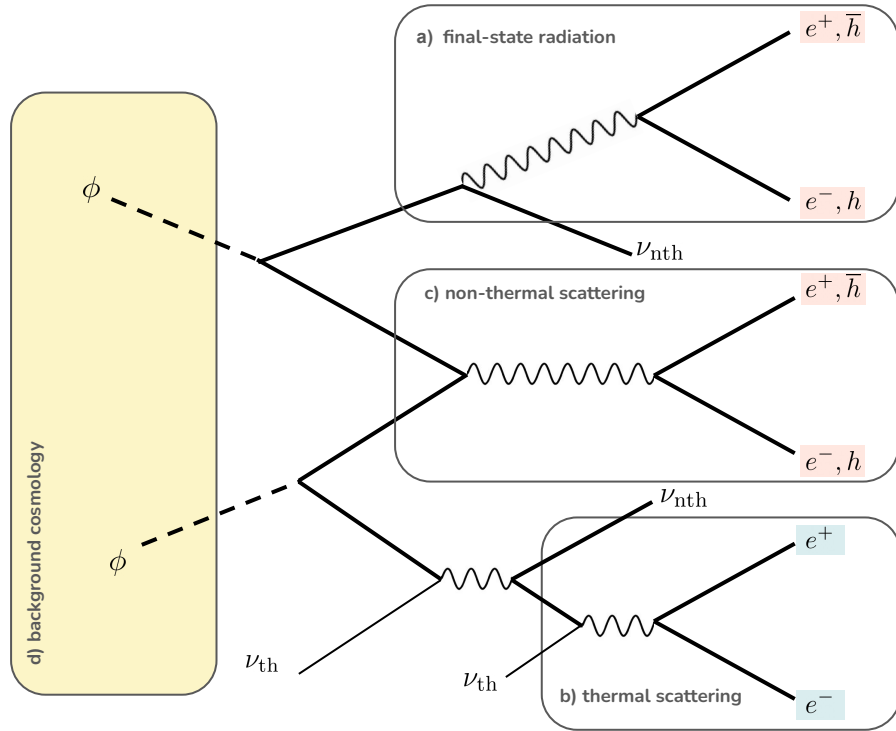
→ **EM** injections

## c) Non-thermal scattering

Interactions with other non-thermal neutrinos

→ **EM** and **HD** injections

# A quick overview of the neutrino cascade



## a) Final-state radiation (FSR)

Decay particle produce a neutrino emitting a W- or Z-boson

→ EW shower that leads to **EM** and **HD** injections

## b) Thermal scattering

Interactions with neutrino from the background

→ **EM** injections

## c) Non-thermal scattering

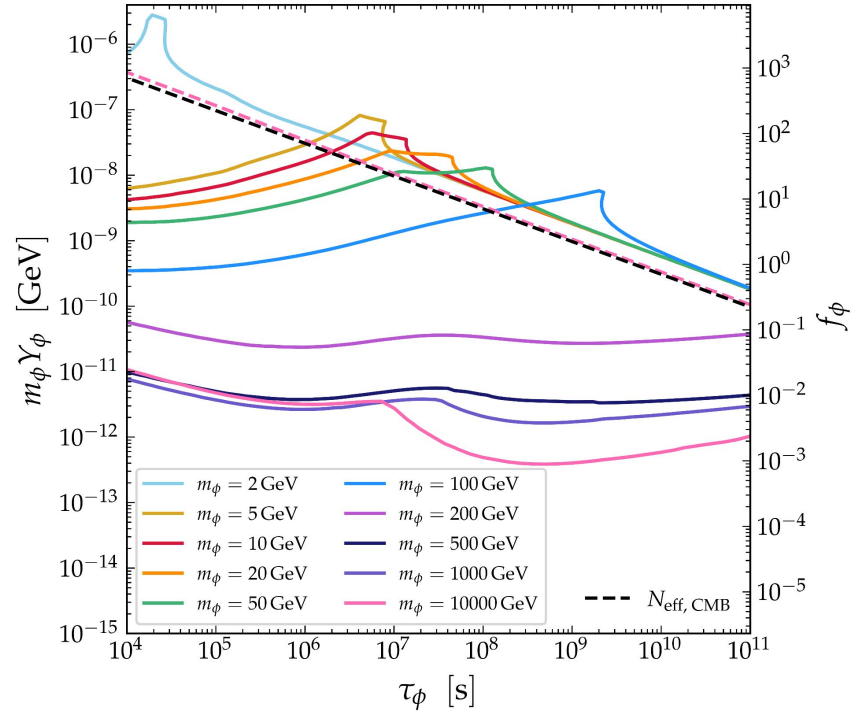
Interactions with other non-thermal neutrinos

→ **EM** and **HD** injections

## d) Background cosmology

The presence of an additional relic will modify the thermal history of the universe.

# Results





Backup slides

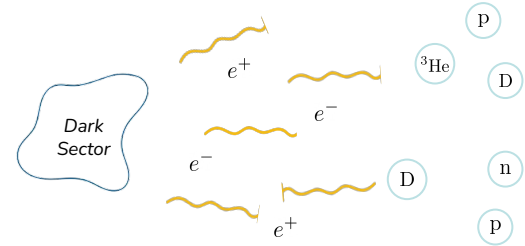
# Introduction: Photodisintegration

The *late-time* injection of *high-energetic* EM particles into the SM plasma induces an EM cascade that leads to non-thermal parts of the photon, electron, and positron spectra.

High-energy photons with energies above the pair-production threshold:

$$E_{e^\pm}^{\text{th}} \simeq m_e^2 / (22T)$$

are efficiently depleted via **double-photon pair creation** ( $\gamma\gamma_{\text{th}} \rightarrow e^+e^-$ ).



»» As a result, photodisintegration can only occur if  $E_N^{\text{th}} \lesssim E_{e^\pm}^{\text{th}}$

*At these T, BBN has already finished and we can simply factor out the two processes.*

	T (keV)	$E^{\text{th}}$ (MeV)
D	5.34	2.22
$^3\text{H}$	1.90	6.26
$^3\text{He}$	2.16	5.49
$^4\text{He}$	0.60	19.81
$^6\text{Li}$	3.21	3.70
$^7\text{Li}$	4.81	2.47
$^7\text{Be}$	7.48	1.59



Publicly available code [2011.06518](https://github.com/hep-mh/acropolis), P. F. Depta, M. Hufnagel, and K. Schmidt-Hoberg.

<https://github.com/hep-mh/acropolis/tree/main/acropolis>

# Neutrino injections

★ Thermal scattering of the form  $\nu\nu_{\text{th}} \rightarrow e^+e^-$

Note on thresholds and timescales. In order to inject electron-positron pairs:

$$E_{ee} \sim \frac{m_e^2}{T} \gtrsim 26 \text{ MeV} \left( \frac{10 \text{ keV}}{T} \right)$$

For heavier particles we need:

$$E_{\mu\mu/\pi\pi} \sim \frac{m_{\mu/\pi}^2}{T} \gtrsim (1.1/1.8) \text{ TeV} \left( \frac{10 \text{ keV}}{T} \right)$$

for such high  $E$ , limits are dominated by FSR!

It can happen that, depending on the energy of the injected neutrino, the scattering time is faster than the Hubble time:

$$t_H \sim \frac{1}{H(T)} \sim \frac{m_P}{T^2} \sim 1 \text{ s} \left( \frac{T}{\text{MeV}} \right)^{-2}$$
$$t_{\text{th}} \sim \frac{1}{G_F^2 T^4 E} \sim 10^{-3} \text{ s} \left( \frac{T}{\text{MeV}} \right)^{-4} \left( \frac{E}{10 \text{ GeV}} \right)^{-1}$$

$t_{\text{th}} < t_H \rightarrow$

$$E \gtrsim 100 \text{ GeV} \left( \frac{10 \text{ keV}}{T} \right)^2$$

# Neutrino injections

★ Thermal scattering of the form  $\nu\nu_{\text{th}} \rightarrow e^+e^-$

We can compute the interaction rate:

$$\Gamma_{ee}(T, E) = \frac{g_\nu}{16\pi^2 E^2} \int_0^\infty d\epsilon f_{\nu,\text{th}}(\epsilon) \int_0^{4E\epsilon} ds s \cdot \sigma_{ee}(s) \xrightarrow{s \ll m_Z^2} \sigma(s) = \Sigma(s) \frac{G_F^2 s}{6\pi}$$

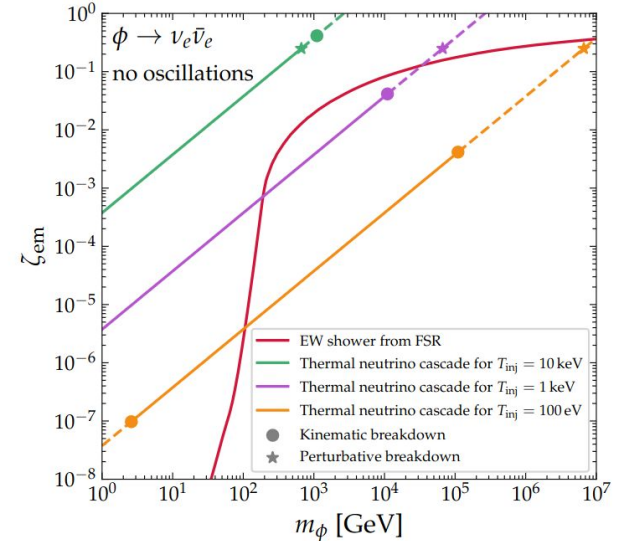
Assuming for simplicity  $m_e = 0$ ,  $\Sigma(s) = \text{const.} \equiv \Sigma_\infty$

$$\Gamma_{ee}(T, E) \stackrel{m_e=0}{\simeq} \frac{7\pi}{90} \Sigma_\infty G_F^2 E T_\nu^4$$

Let us now introduce the quantity:

$$d\zeta_{\text{em}} \simeq \frac{E(t)}{E_{\text{inj}}} \Gamma_{ee}(t) dt$$

as **fraction of EM energy** that is transferred into the plasma in a certain time  $dt$ .



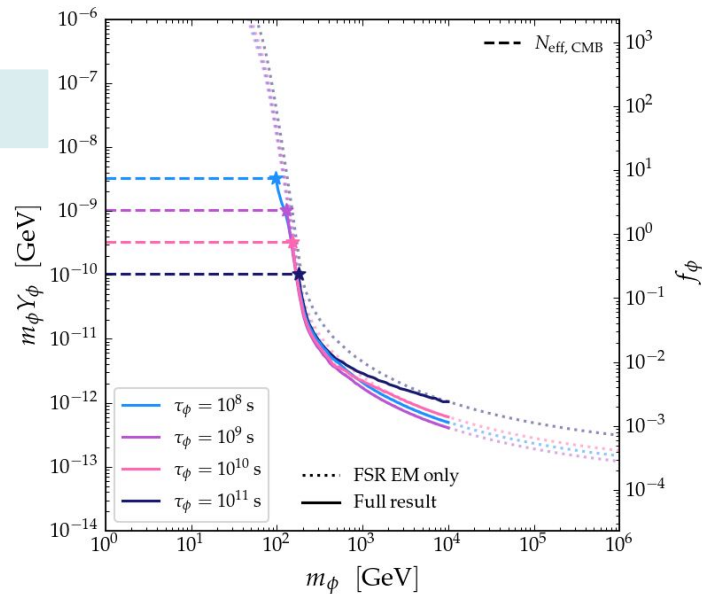
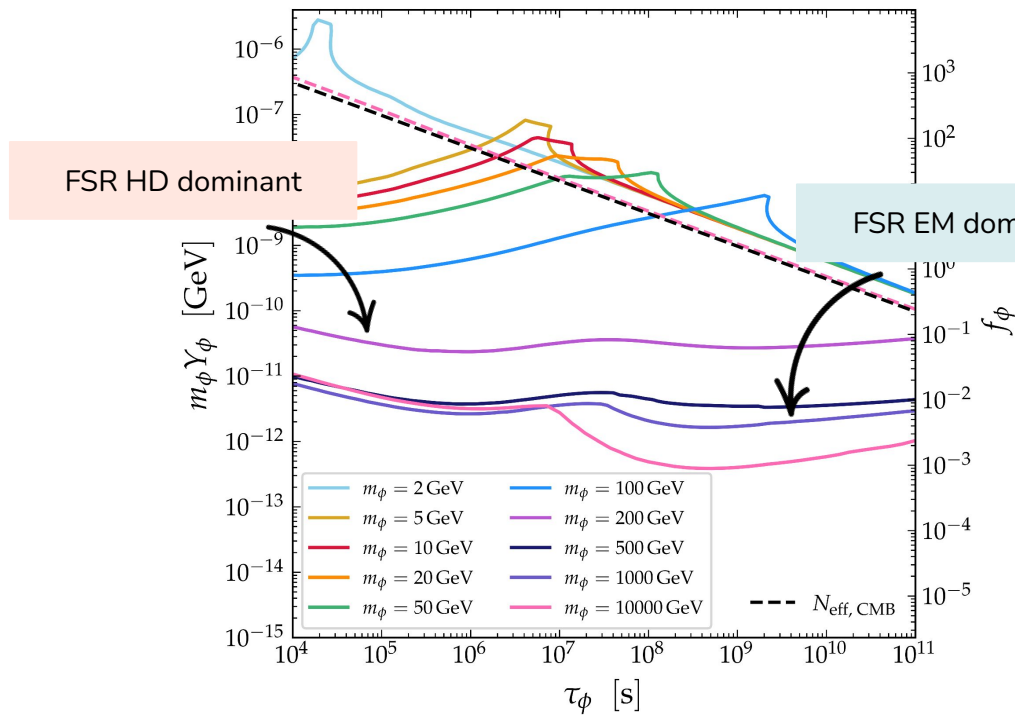
# A note on model-building

---

Possible realization of this scenario include:

- ★ **Majoron**, with loop-suppressed decay into electrons.
- ★ **Gauge boson coupled to two sterile neutrinos** + seesaw mixing
- ★ Neutral component of a **scalar triplet** of hypercharge 2
- ★ Decay into one neutrino and one DS state is potentially also relevant.

# Results



# Results

