

Dark Radiation from Neutrino Mixing after BBN

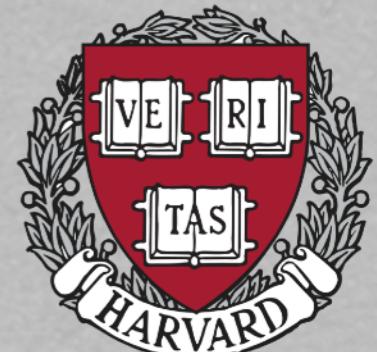
Pheno 2023, University of Pittsburgh

May 9th, 2023

arXiv: [2301.10792](https://arxiv.org/abs/2301.10792)

Melissa Joseph, Martin Schmaltz, Neal Weiner

Daniel Aloni



Why Dark Radiation?

Daniel Aloni, Boston University & Harvard University

Why Dark Radiation?

Why not?
Dark energy, dark matter

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CMB

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Dark energy, dark matter
LSS
CMB
NGB, Chiral
fermions,
Gauge bosons

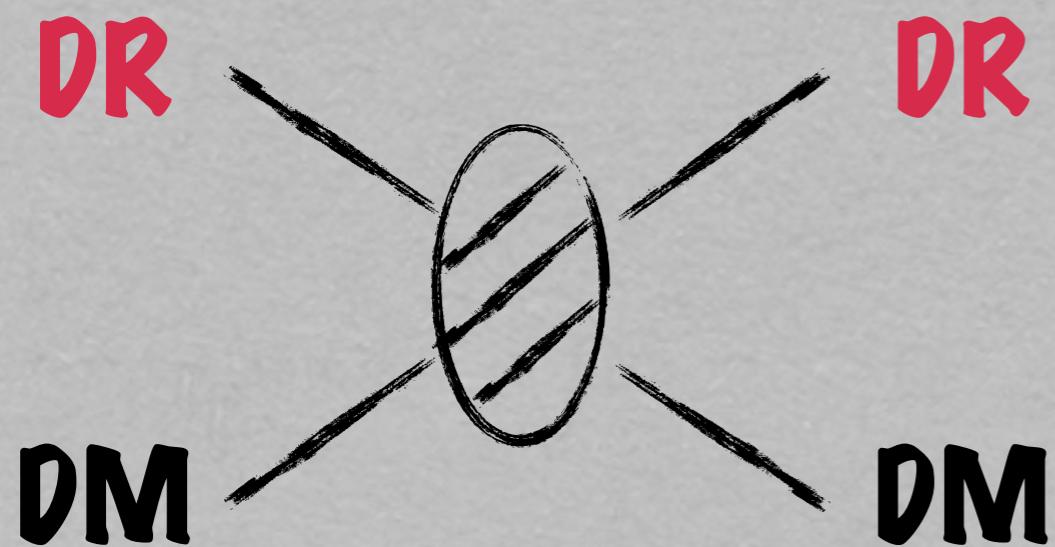
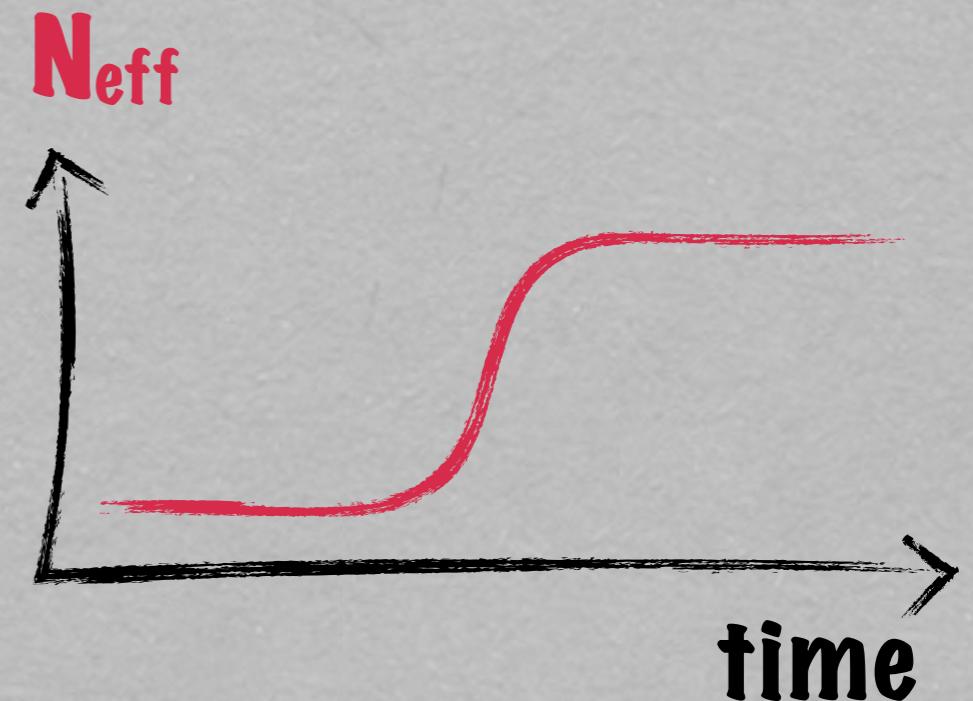
Why Dark Radiation?

Why not?
Dark energy, dark matter
LSS
CMB
Anomalies?
Dark energy, dark matter
NGB, Chiral
fermions,
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A step in understanding the...

...Hubble tension

(**DA**, A. Berlin, M. Joseph, M. Schmaltz,
N. Weiner **2111.00014**)



...S₈ tension

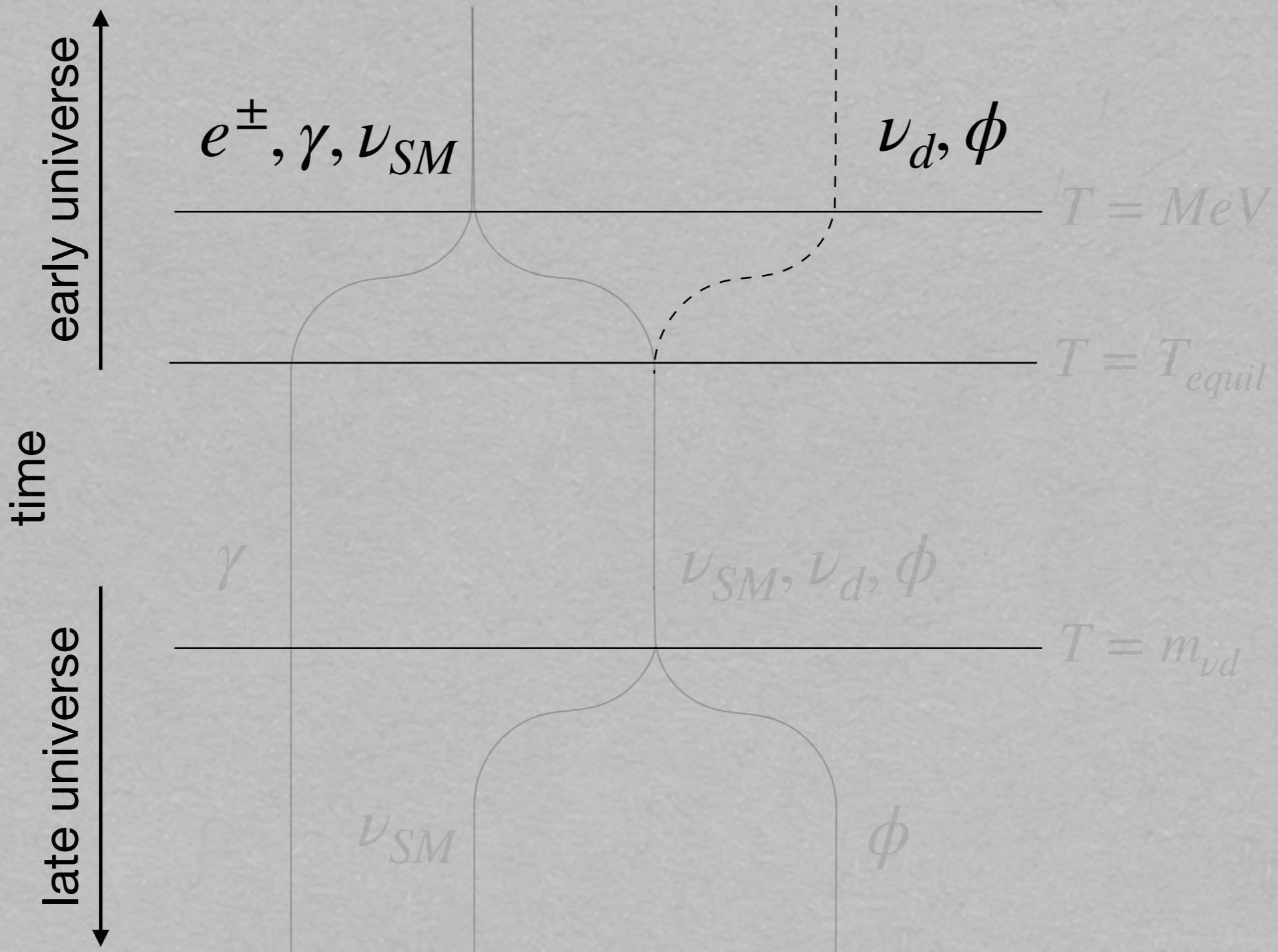
(**DA**, M. Joseph, M. Schmaltz,
E. N. Sivarajan,
N. Weiner **2207.03500**)

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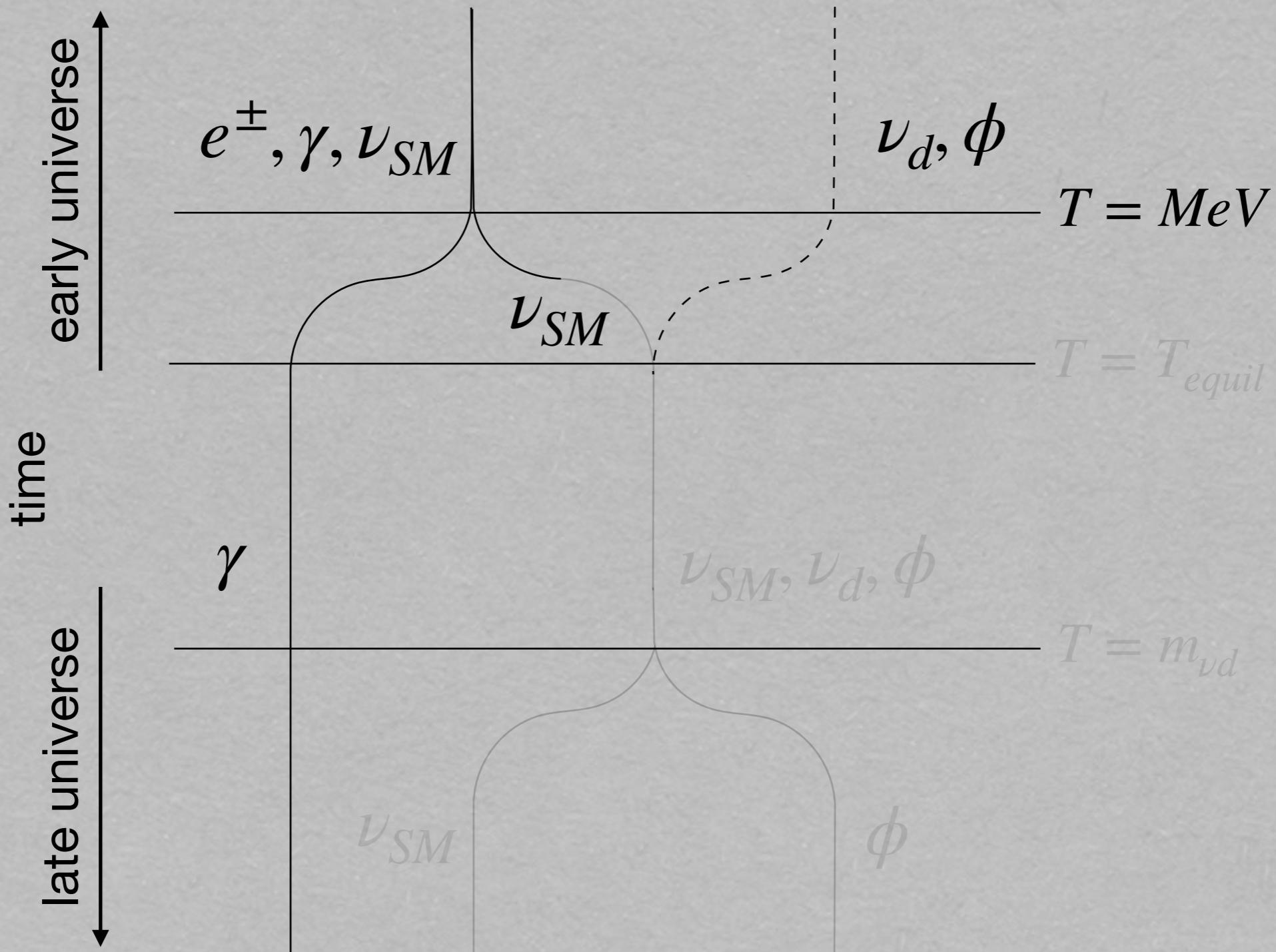
(DA, Melissa Joseph, Martin Schmaltz, Neal Weiner 2301.10792)

- Where this Dark radiation came from?
- What about the BBN constraints?

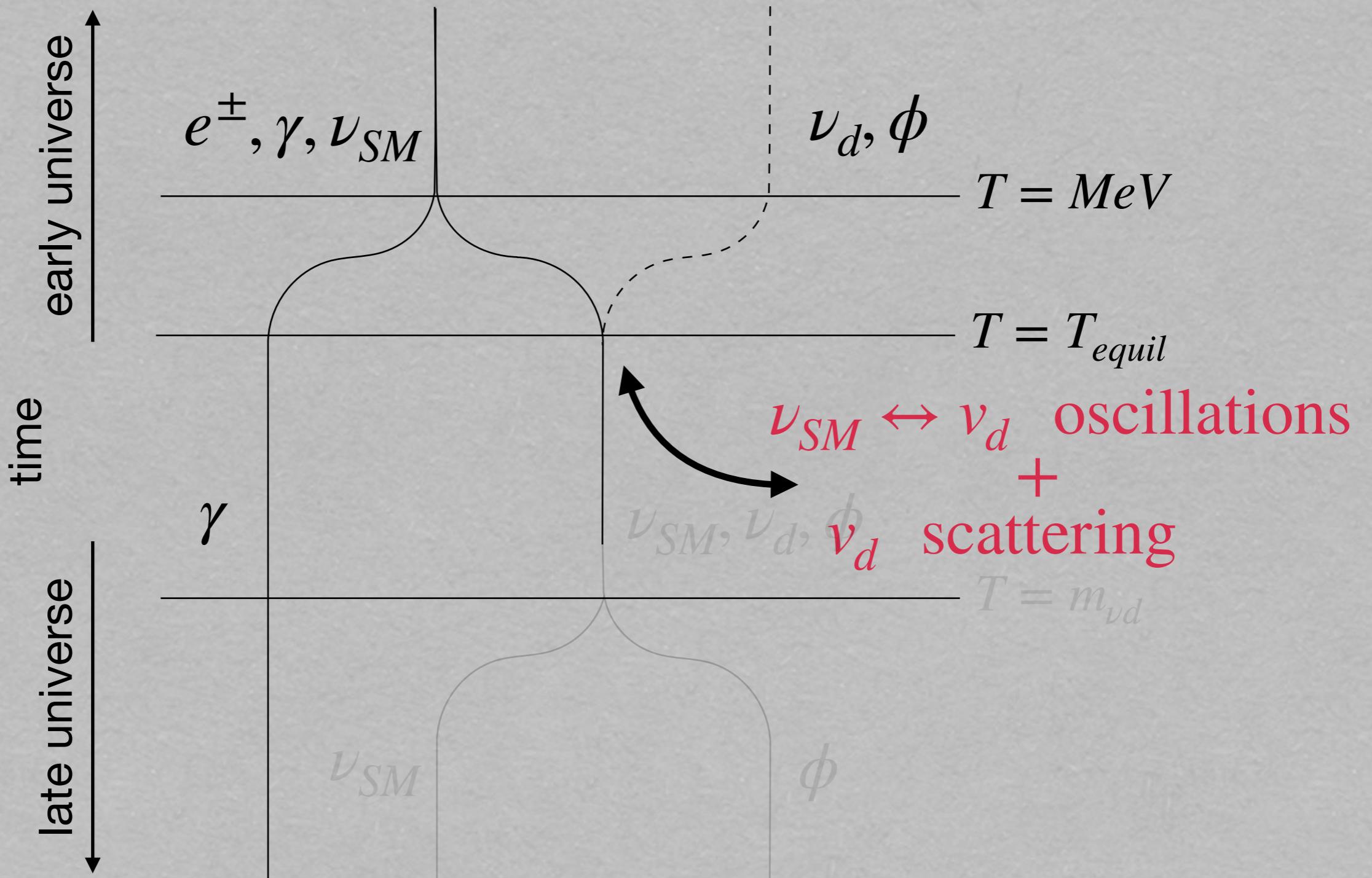
The History



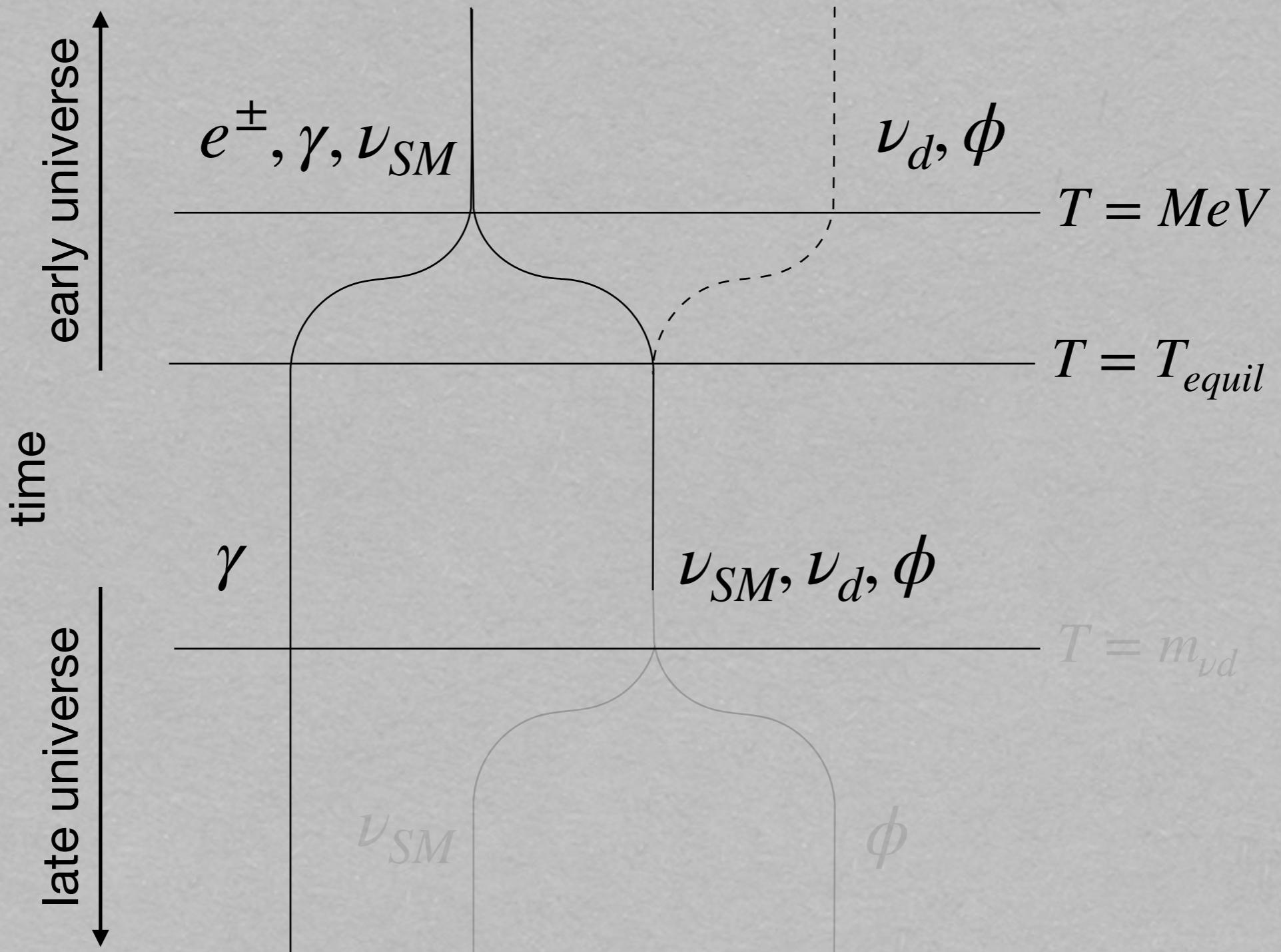
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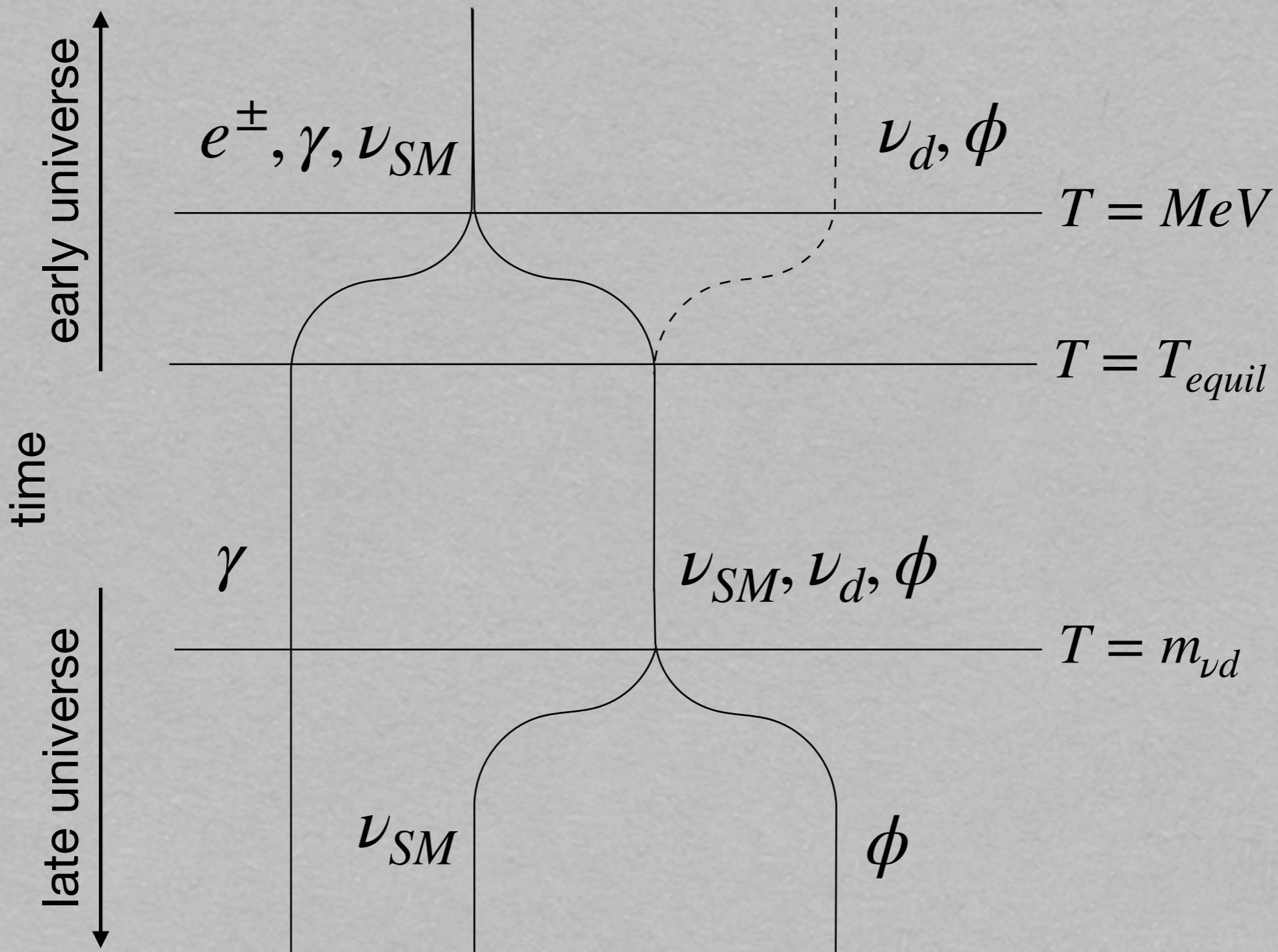
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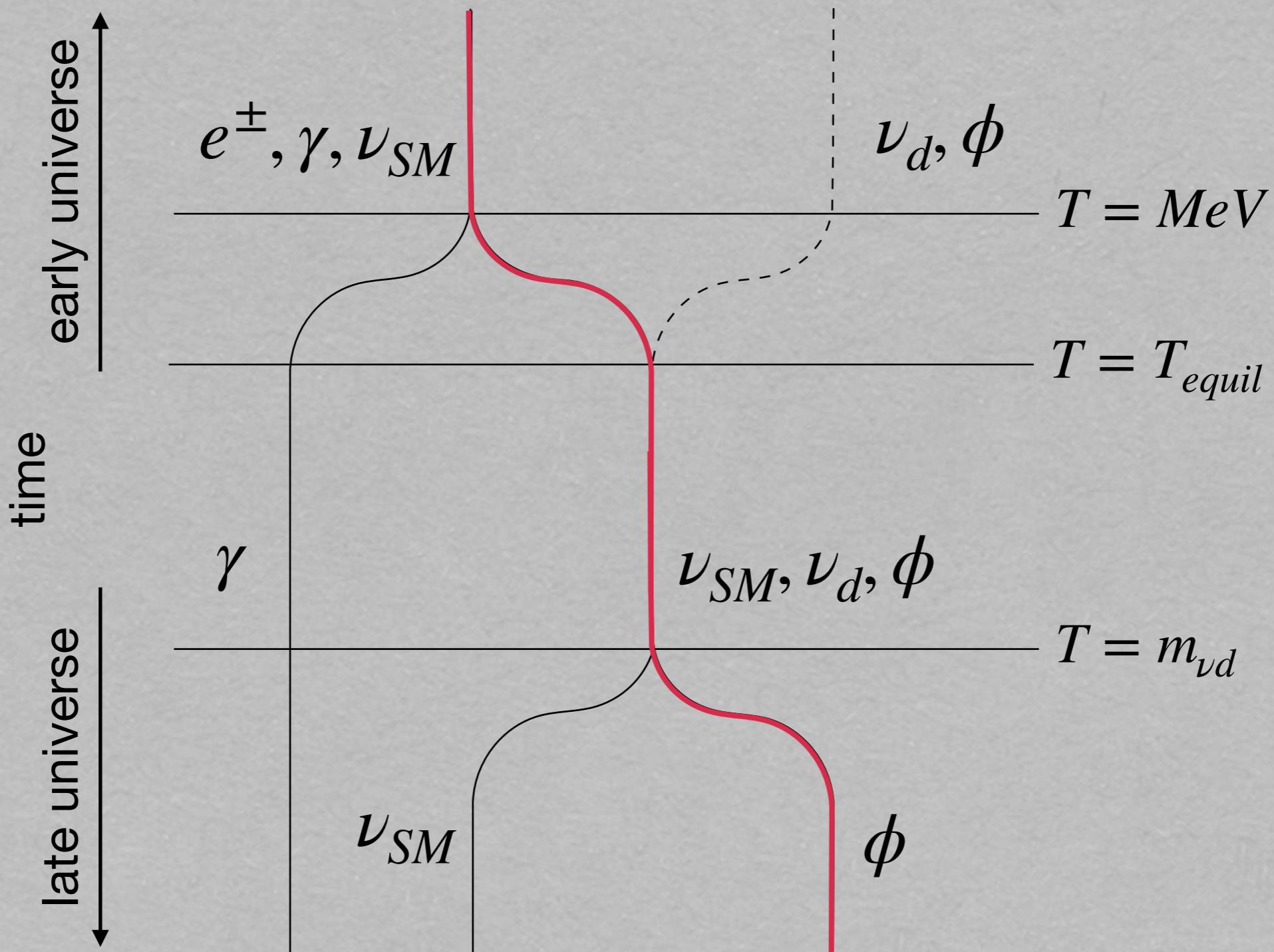
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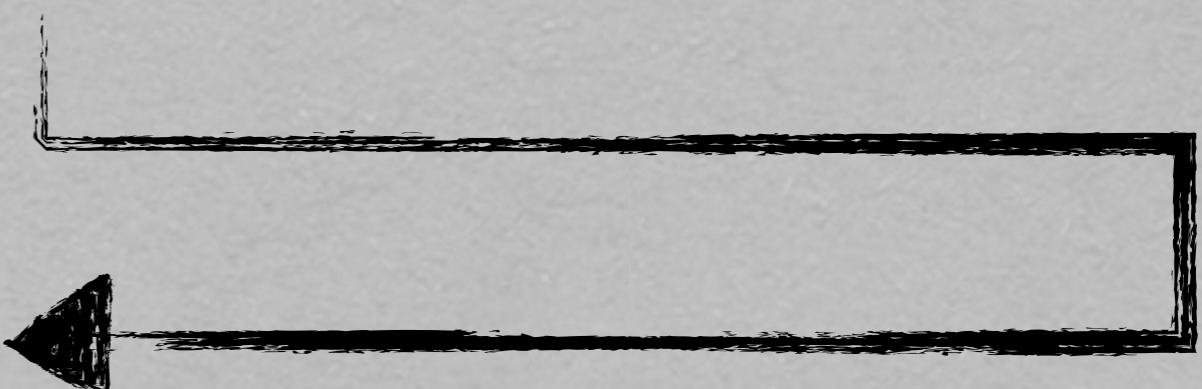
How does it work?

$$\Gamma_{\nu_{SM} \rightarrow \nu_d}(E) = \frac{1}{2} \sin^2 2\theta_m \frac{\Gamma_{int.}}{2}$$

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$$\frac{\sin^2 2\theta_0}{\sin^2 2\theta_m} = \left(\cos 2\theta_0 + \tilde{\star} \frac{G_F^2 T^6}{m_{\nu_d}^2} + \tilde{\#} \alpha_d \frac{T^2}{m_{\nu_d}^2} \right)^2 + \sin^2 2\theta_0$$

How does it work?

$$\left\langle \Gamma_{\nu_{SM} \rightarrow \nu_d} \right\rangle \sim \frac{\sin^2 2\theta_0 (\star G_F^2 \textcolor{red}{T}^5 + \# \alpha_d^2 \textcolor{red}{T})}{\left(\cos 2\theta_0 + \tilde{\star} \frac{G_F^2 \textcolor{red}{T}^6}{m_{\nu_d}^2} + \tilde{\#} \alpha_d \frac{\textcolor{red}{T}^2}{m_{\nu_d}^2} \right)^2 + \sin^2 2\theta_0}$$

How does it work?

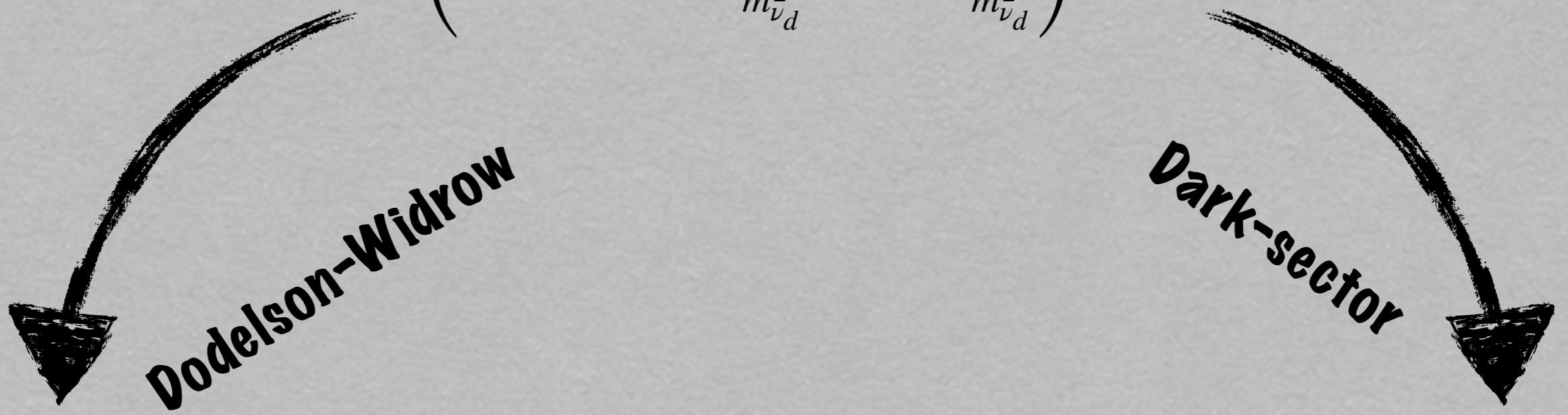
$$\left\langle \Gamma_{\nu_{SM} \rightarrow \nu_d} \right\rangle \sim \frac{\sin^2 2\theta_0 (\star G_F^2 \textcolor{red}{T}^5 + \# \alpha_d^2 \textcolor{red}{T})}{\left(\cos 2\theta_0 + \tilde{\star} \frac{G_F^2 \textcolor{red}{T}^6}{m_{\nu_d}^2} + \tilde{\#} \alpha_d \frac{\textcolor{red}{T}^2}{m_{\nu_d}^2} \right)^2 + \sin^2 2\theta_0}$$

 Dodelson-Widrow

$$\frac{\Gamma}{H} \sim \frac{\theta_0 M_{pl} m_{\nu_d}^4}{G_F^2 \textcolor{red}{T}^9}$$

How does it work?

$$\left\langle \Gamma_{\nu_{SM} \rightarrow \nu_d} \right\rangle \sim \frac{\sin^2 2\theta_0 (\star G_F^2 T^5 + \# \alpha_d^2 T)}{\left(\cos 2\theta_0 + \tilde{\star} \frac{G_F^2 T^6}{m_{\nu_d}^2} + \tilde{\#} \alpha_d \frac{T^2}{m_{\nu_d}^2} \right)^2 + \sin^2 2\theta_0}$$

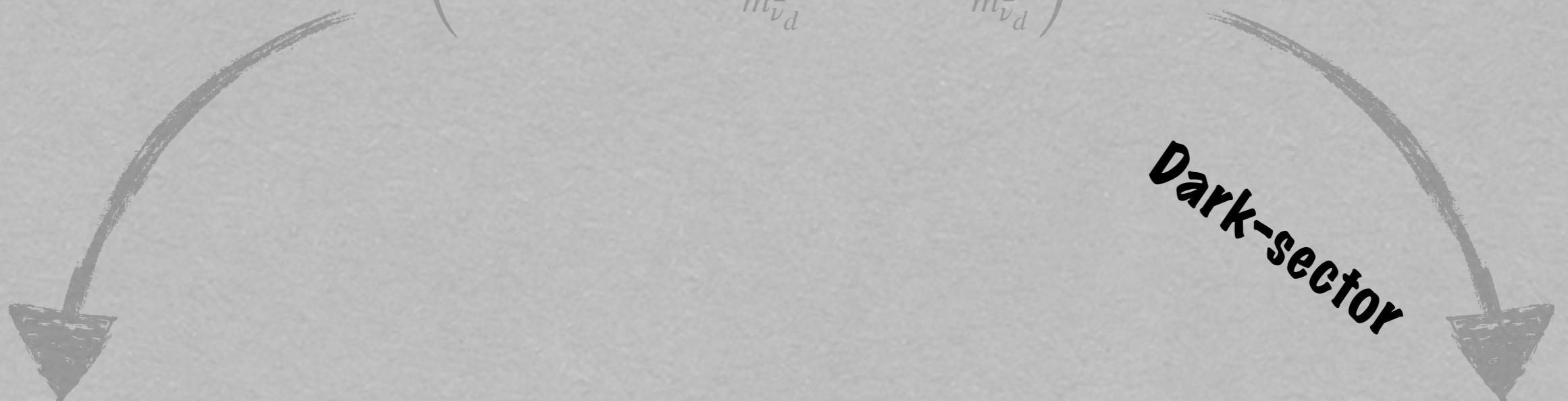


$$\frac{\Gamma}{H} \sim \frac{\theta_0 M_{pl} m_{\nu_d}^4}{G_F^2 T^9}$$

$$\frac{\Gamma}{H} \sim \frac{\theta_0 M_{pl} m_{\nu_d}^4}{T^5}$$

How does it work?

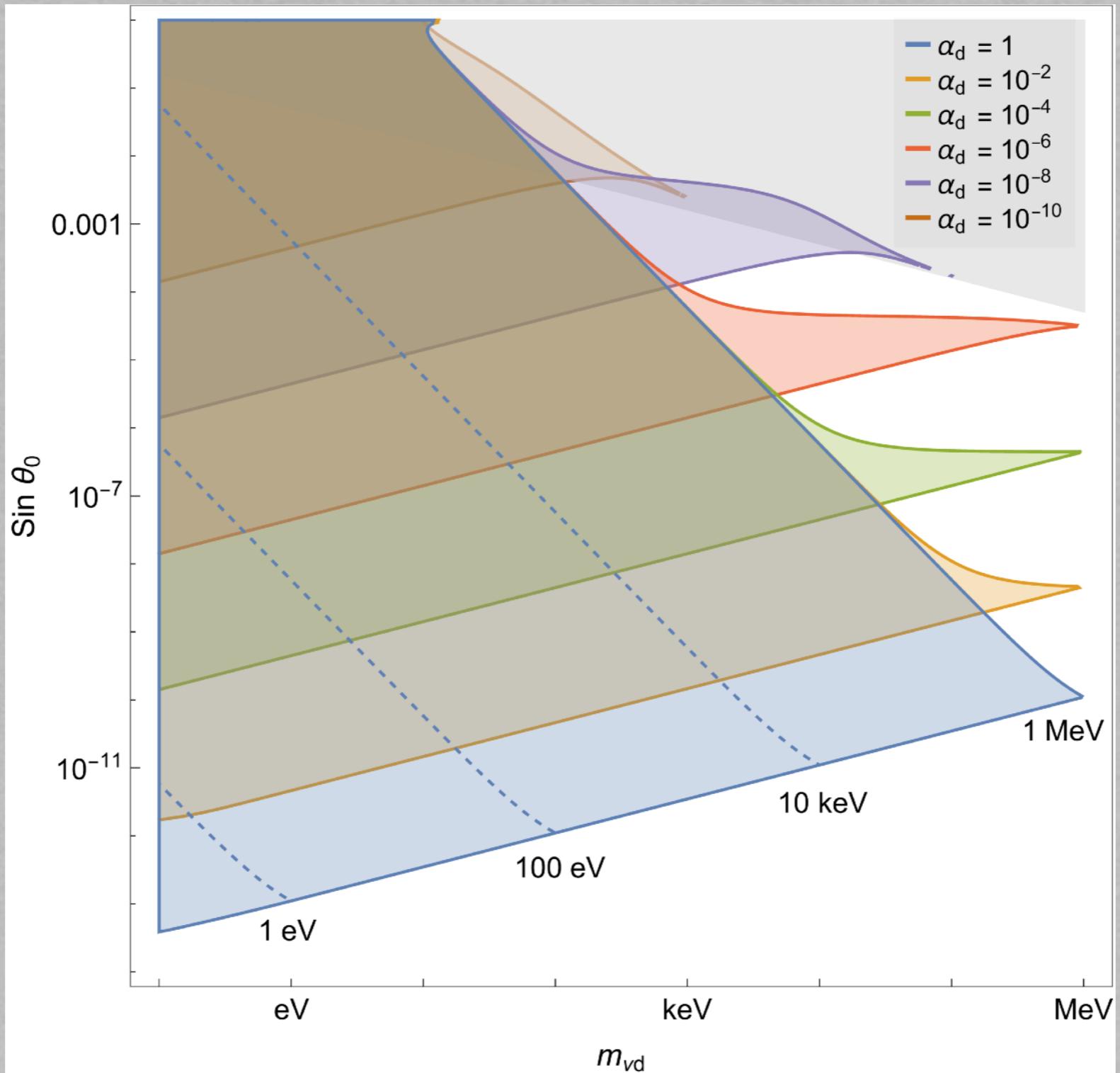
$$\left\langle \Gamma_{\nu_{SM} \rightarrow \nu_d} \right\rangle \sim \frac{\sin^2 2\theta_0 (\star G_F^2 T^5 + \# \alpha_d^2 T)}{\left(\cos 2\theta_0 + \tilde{\star} \frac{G_F^2 T^6}{m_{\nu_d}^2} + \tilde{\#} \alpha_d \frac{T^2}{m_{\nu_d}^2} \right)^2 + \sin^2 2\theta_0}$$



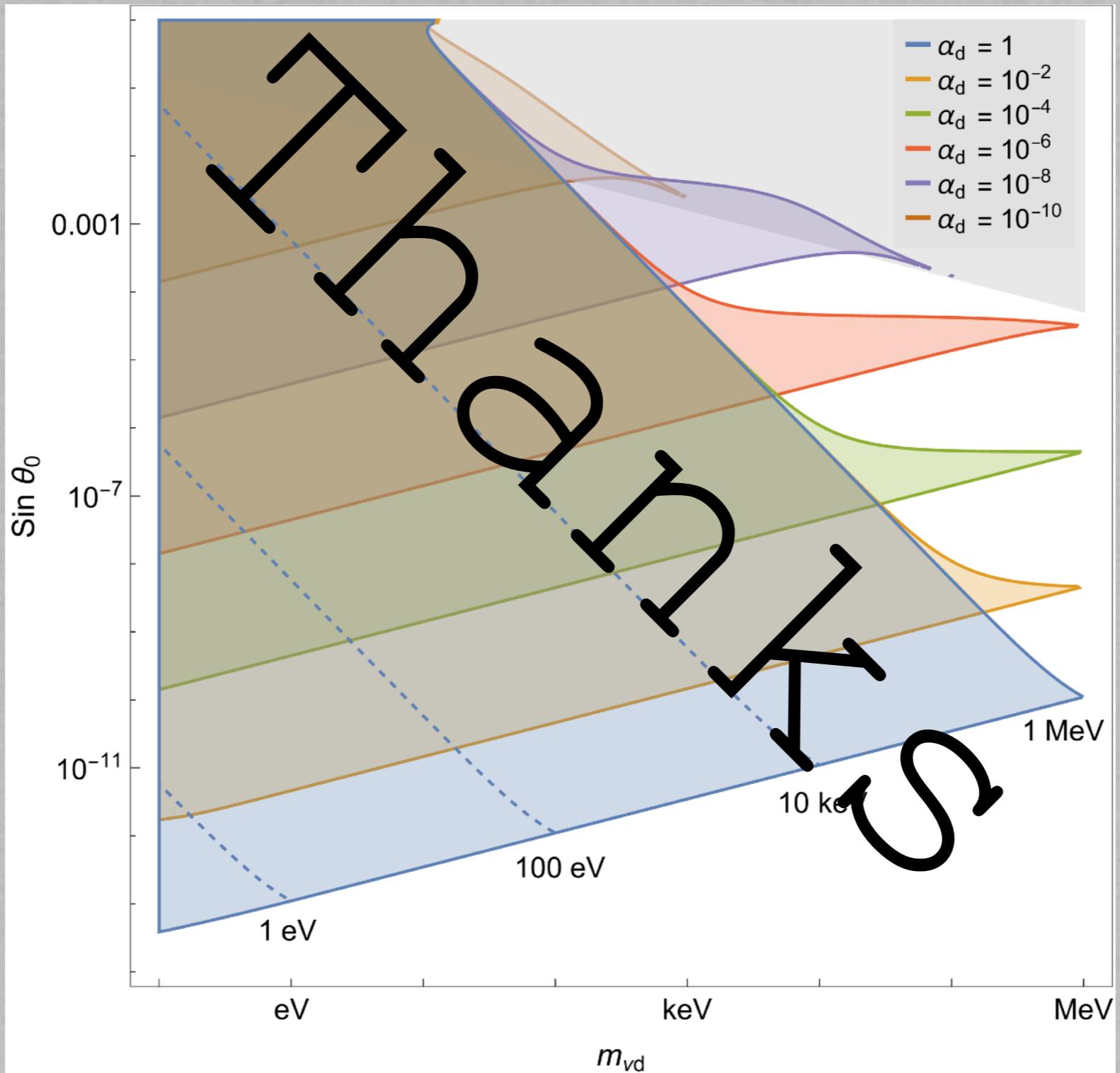
$$T_{\text{equil}} = m_{\nu_d} \left[\theta_0^2 \frac{M_{pl}}{m_{\nu_d}} \right]^{1/5}$$

$\frac{\Gamma}{H} \sim \frac{\theta_0 M_{pl} m_{\nu_d}^4}{T^5}$

Take home message



Take home message



Thanks

How does it work?

