Leptogenesis: the initial conditions problem

Based on: E. Bertuzzo, P. Di Bari, L. M. - arXiv:1007.1641+ N.P.B

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Leptogenesis: a short introduction

Two problems:

- CMBR: $\eta_0 := \left.\frac{n_B - \bar{n}_B}{n_\gamma}\right|_0 = (6.21 \pm 0.16)\, 10^{-10}$
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Leptogenesis!

One solution:

$$\mathscr{L} = \mathscr{L}_{SM} + i\overline{N_{Ri}}\gamma_\mu \partial^\mu N_{Ri} - h_{\alpha i}\overline{\ell_{L\alpha}} N_{Ri}\tilde{\phi} - \frac{1}{2}\overline{N^c_{Ri}} M^R_{ij} N_{Rj} + H.c$$

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S.B. + Heavy R.H.N.

$-m^D_{\alpha i}\overline{\nu_{L\alpha}} N_{Ri}$ $\quad [M^R] \gg [m^D]$

Type I Seesaw:

$$M_{\text{light}} \simeq -m^D (M_R)^{-1} (m^D)^T$$

$$M_{\text{heavy}} \simeq M^R$$

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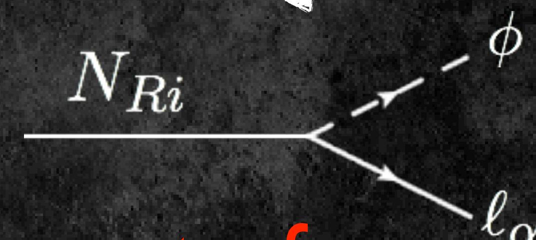
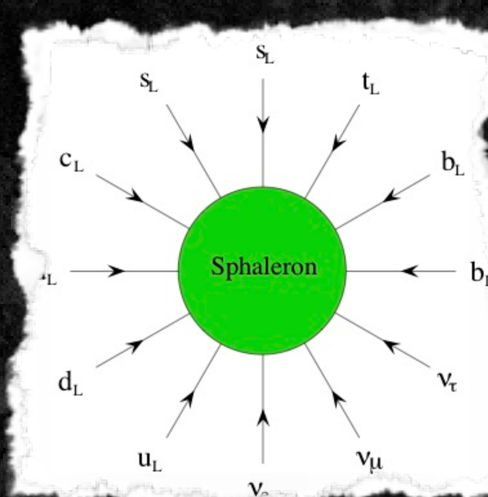


out of eq. ~~CP~~ decays

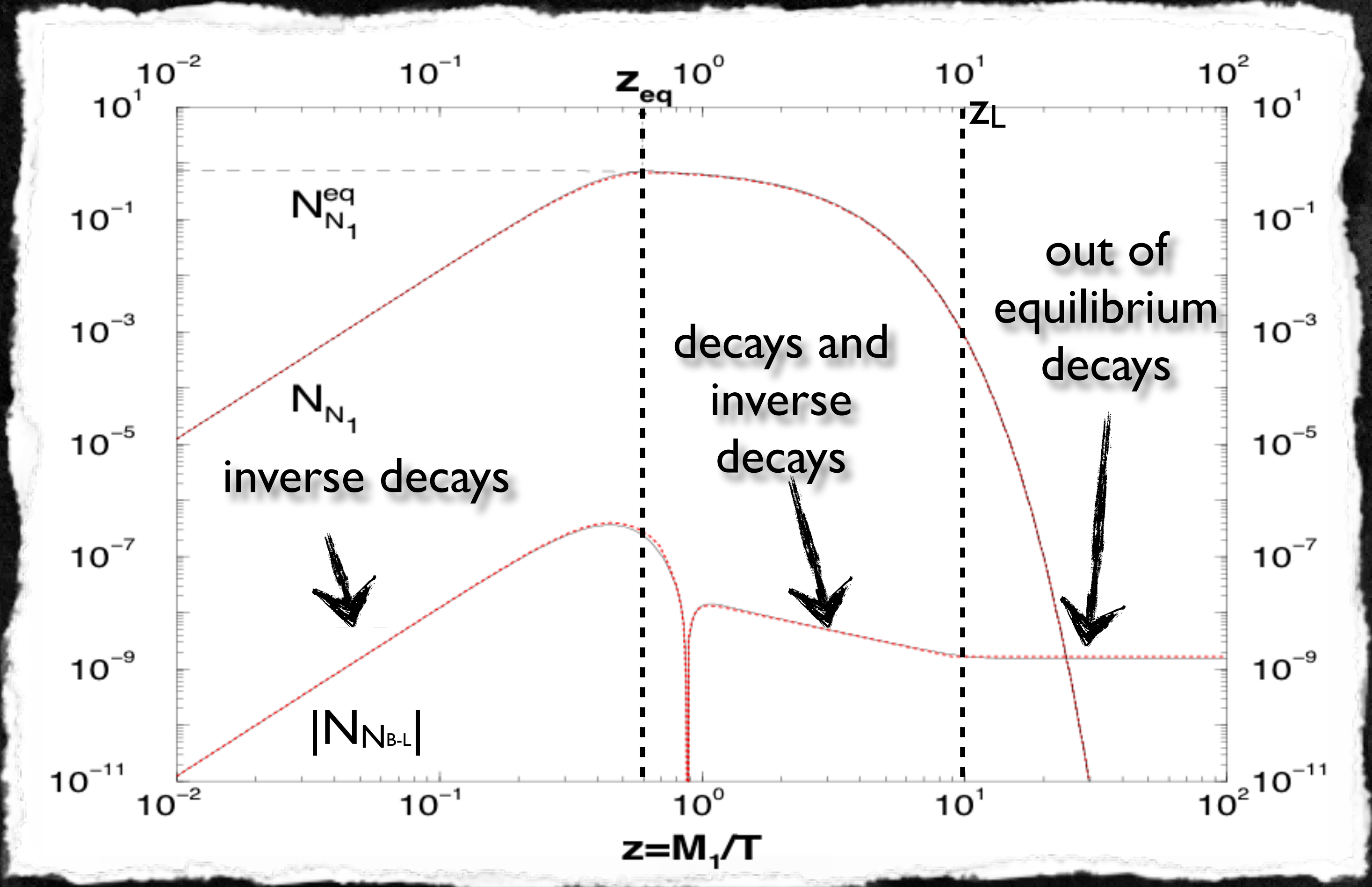
+



$\Delta(B\text{-}L) \neq 0 \rightarrow \Delta B \neq 0$

A simple picture: N_1 Leptogenesis

No flavour effects, *strong washout* regime: N_1 dominates



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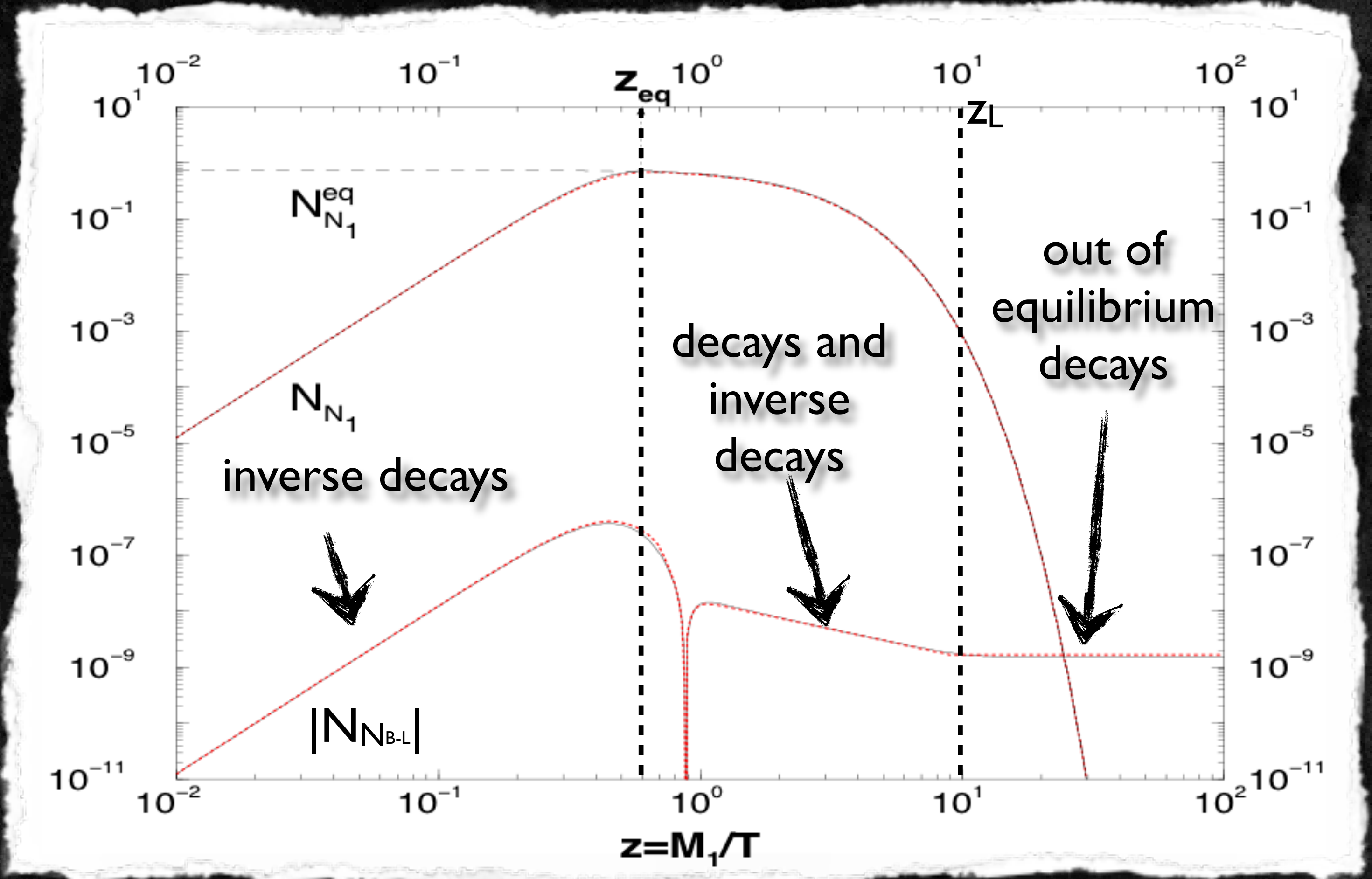

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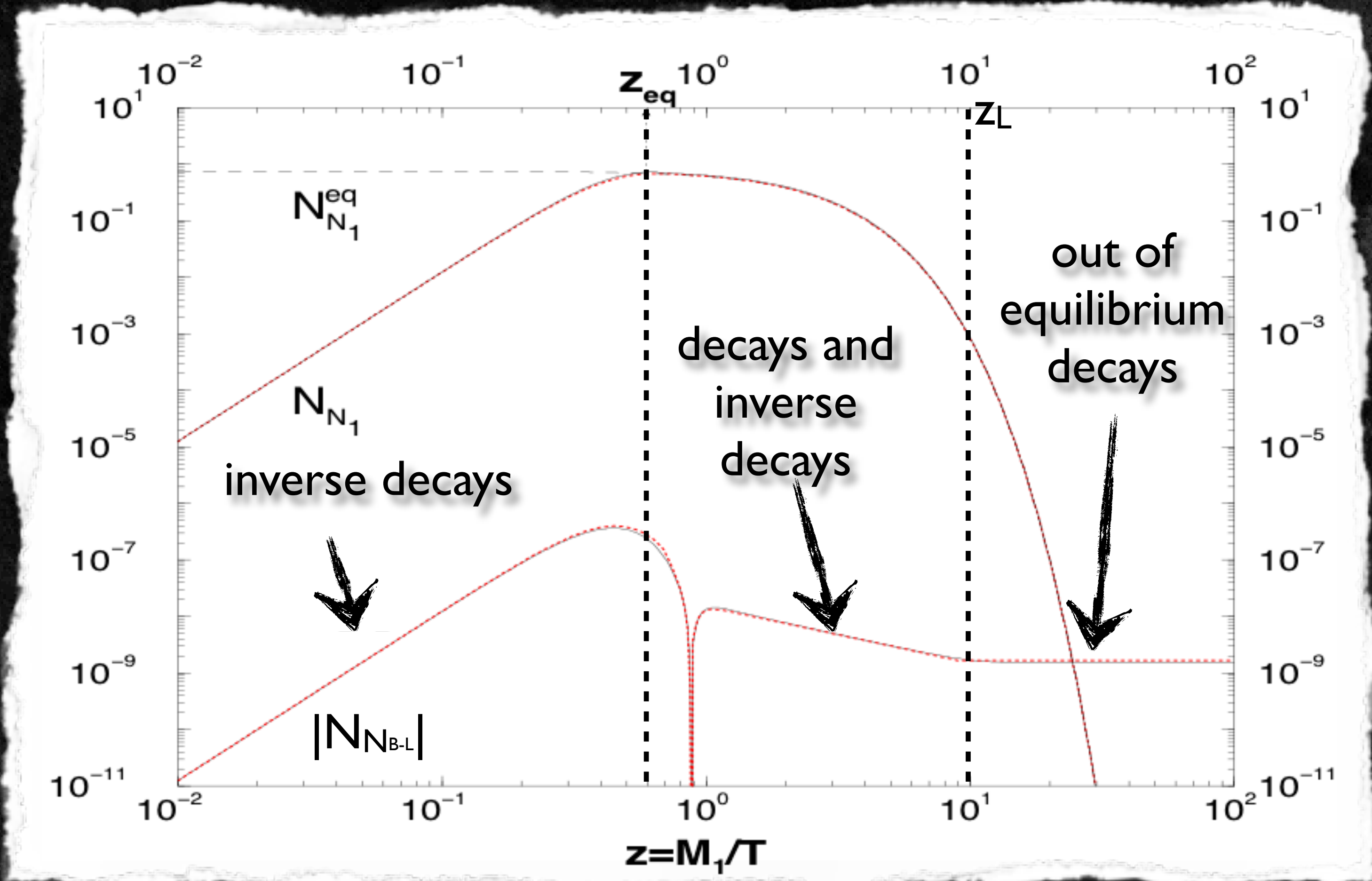

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$$\frac{dN_{\rm B-L}}{dz} = \epsilon D_1 \left(N_{N_{\rm R1}} - N^{\rm eq}_{N_{\rm R1}} \right) - N_{\rm B-L} W_1(z)$$

Competition in the Boltzmann's equation regulated by one parameter: K_1

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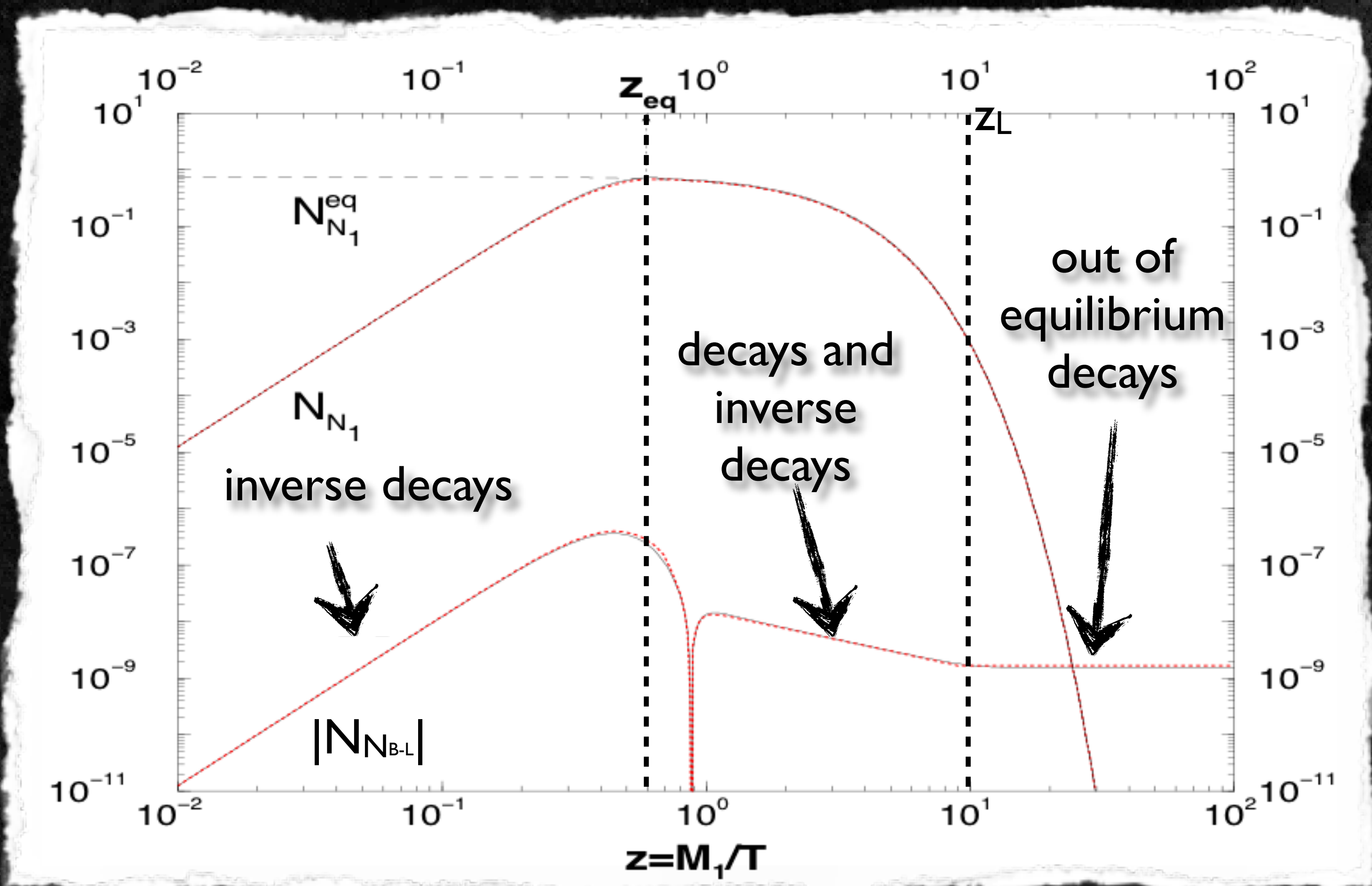

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$$K_j = \frac{\Gamma_{D_j}}{H(z_j = 1)} \equiv \frac{\tilde{m}_j}{m_*} \qquad j = 1, 2, 3$$

$$\tilde{m}_j := \frac{\left((m^D)^\dagger m^D \right)_{jj}}{M_j} \qquad m_* := \frac{16\pi^{5/2}\sqrt{g^*}}{3\sqrt{5}} \frac{v^2}{M_{Pl}} \simeq 1.08 \times 10^{-3}$$

dependence on light neutrinos parameters → *Test Seesaw mechanism through Leptogenesis!*

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Easy achievement in unflavoured models:

$$\frac{dN^p_{B-L}}{dz_j} = -N^p_{B-L} W_j(z_j) \longrightarrow N^{p,f}_{B-L} = N^{p,i}_{B-L} e^{-\frac{3\pi}{8}(K_1+K_2+K_3)}$$

strong washout regime - $K_j >> 1$ *- guarantees strong thermal Leptogenesis.*

Not so easy considering *flavour effects*!

Heavy and light flavours

Heavy flavour states: $N_{\rm Ri} \to |\ell_i\rangle + \phi$

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Charged leptons' Yukawa interaction: depending on the *temperature regime* can be fast enough to break $|\ell_i\rangle$'s coherence

→ *If so, a washout process involves all components in the incoherent mixture obtained!*

Strong thermal Leptogenesis??

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- For every mass pattern *check successful strong thermal leptogenesis:*
  - $w(T < T_{\rm lept}) \ll 10^{-8} \longleftarrow N^{p,i}_{B-L} \sim \mathcal{O}(1)$ $\qquad w(T) := N^{p,f}_{B-L}(T) \,/\, N^{p,i}_{B-L}$
  - $\eta_{\rm lept} = \eta_0$

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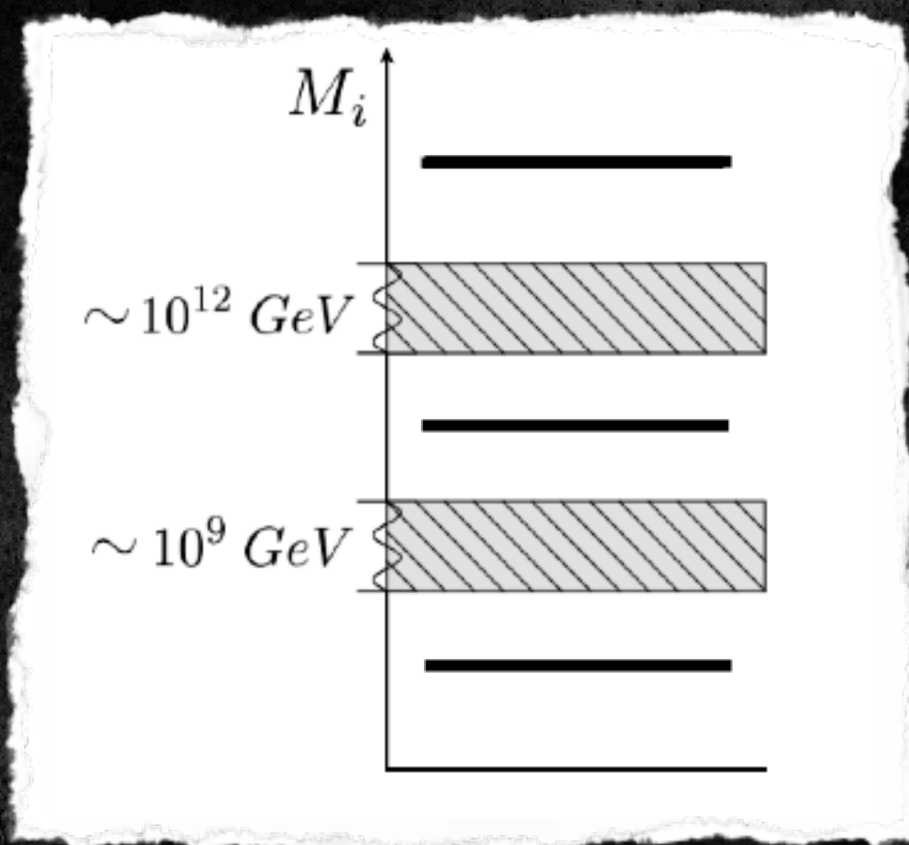

Tauon N_2-dominated scenario: $M_3 > 10^{12}$ GeV $> M_2 > 10^9$ GeV $> M_1$

The τ-N_2 scenario step by step

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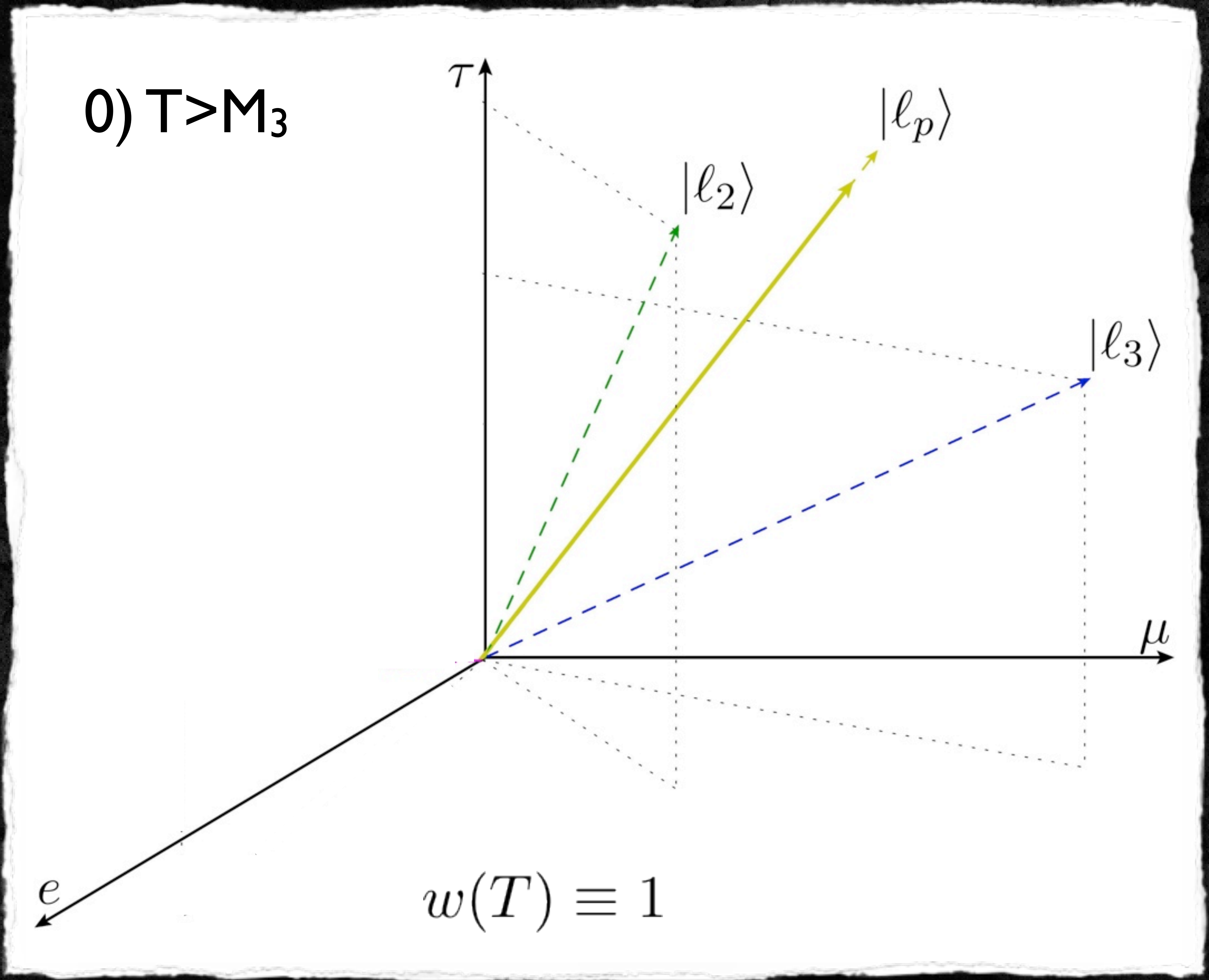
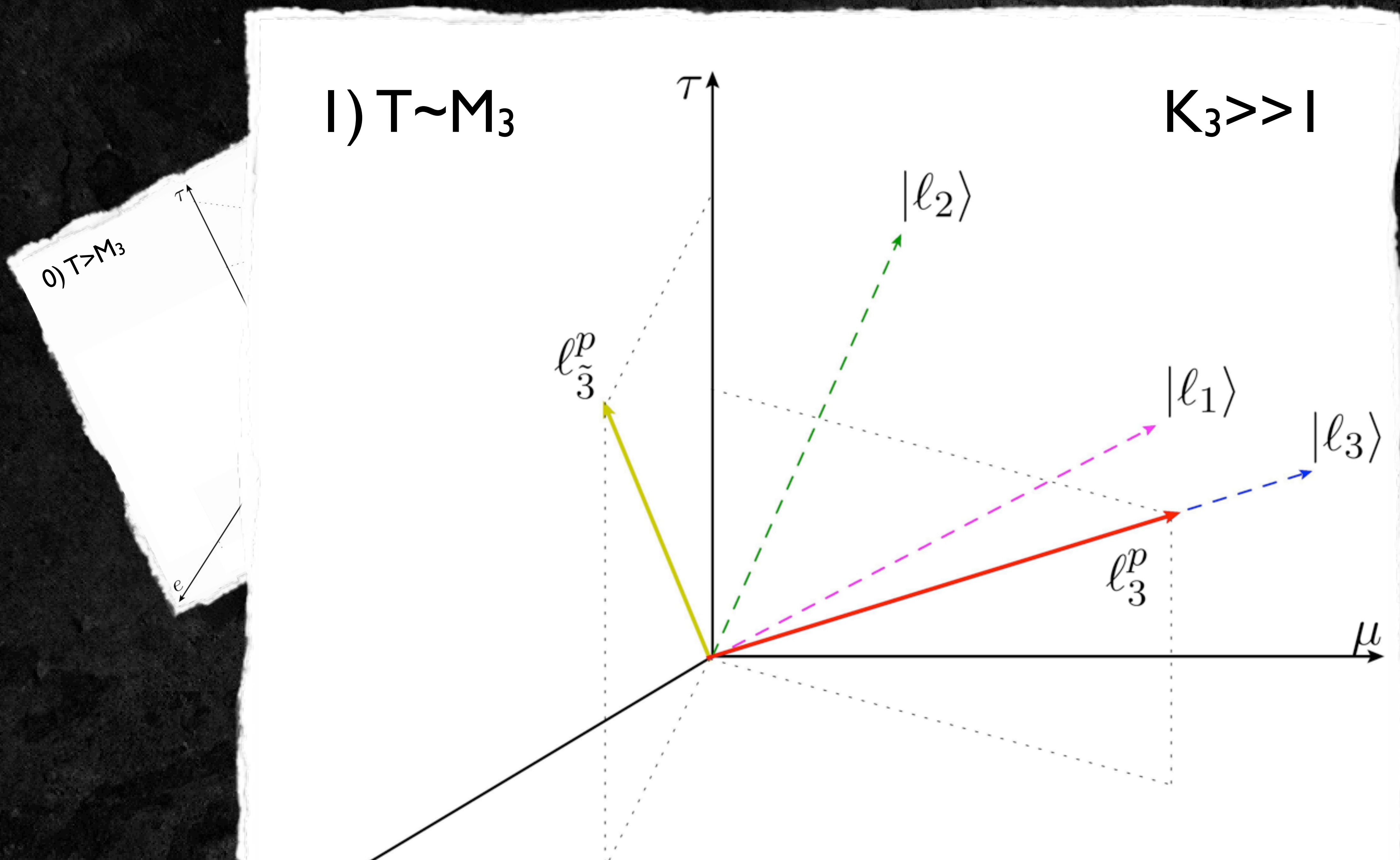


Before Leptogenesis' onset. Preexistent leptons in yellow

The τ-N_2 scenario step by step



$$w(T) = 1 - p_{p3}(1 - e^{-\frac{3\pi}{8}K_3}) \simeq 1 - p_{p3}$$

N_{R3}'s processes are active. Components in red are washed out

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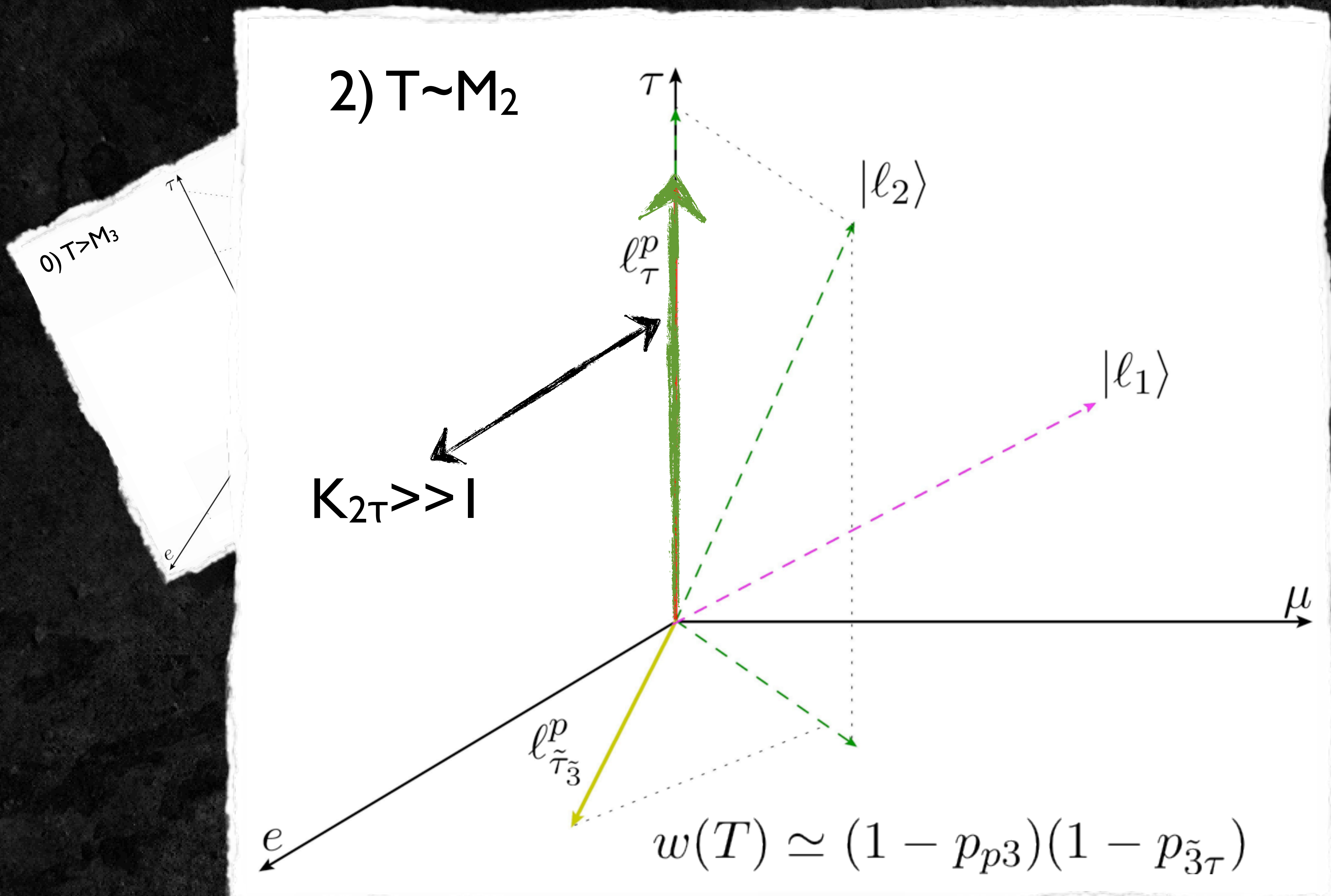
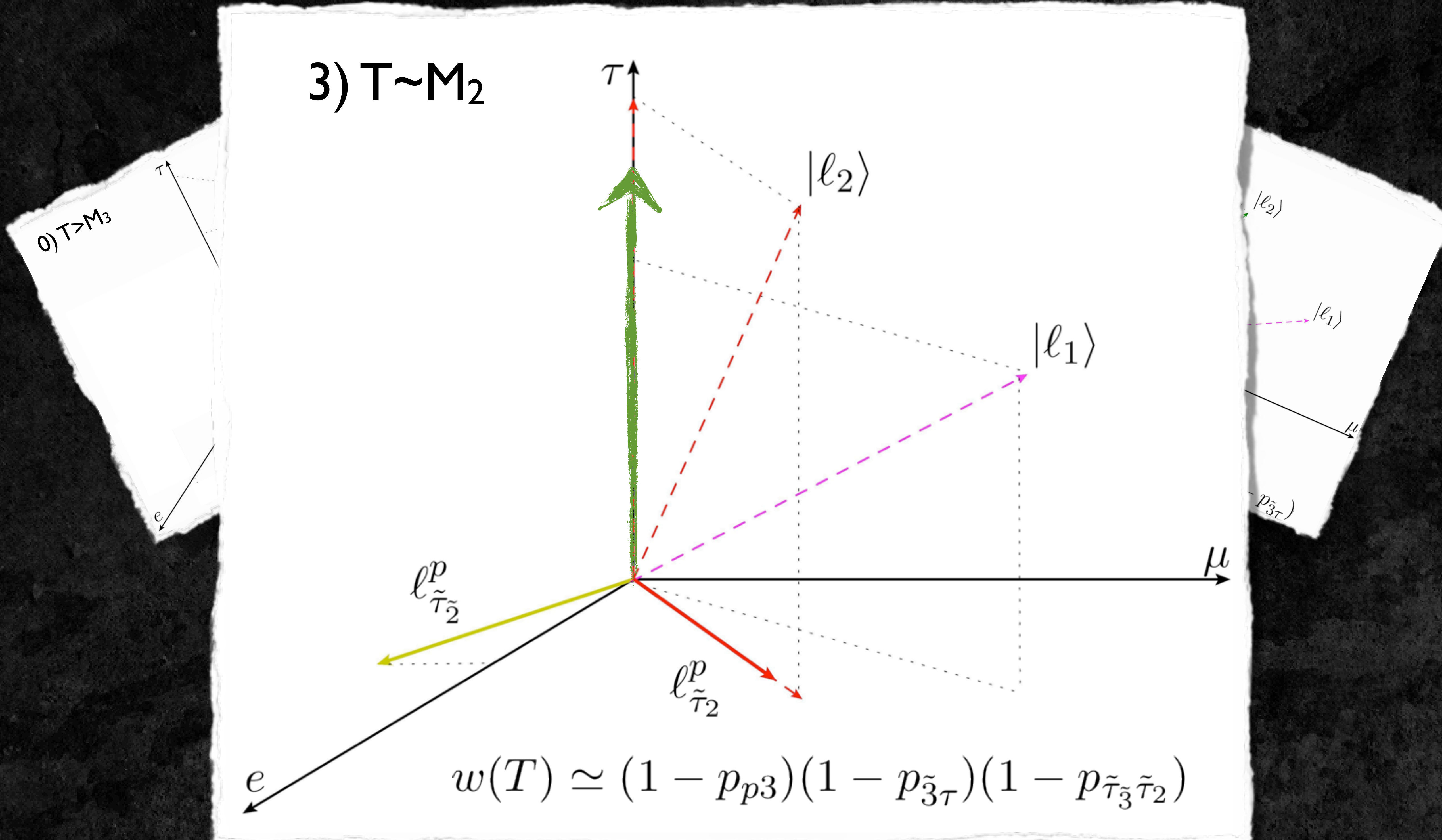


τ-Yukawa interactions break the heavy flavour state's coherence. The asymmetry along τ is now a pure Leptogenesis product

The τ-N_2 scenario step by step



Washout by the other component. Residual preexistent leptons are confined on the e-μ plane

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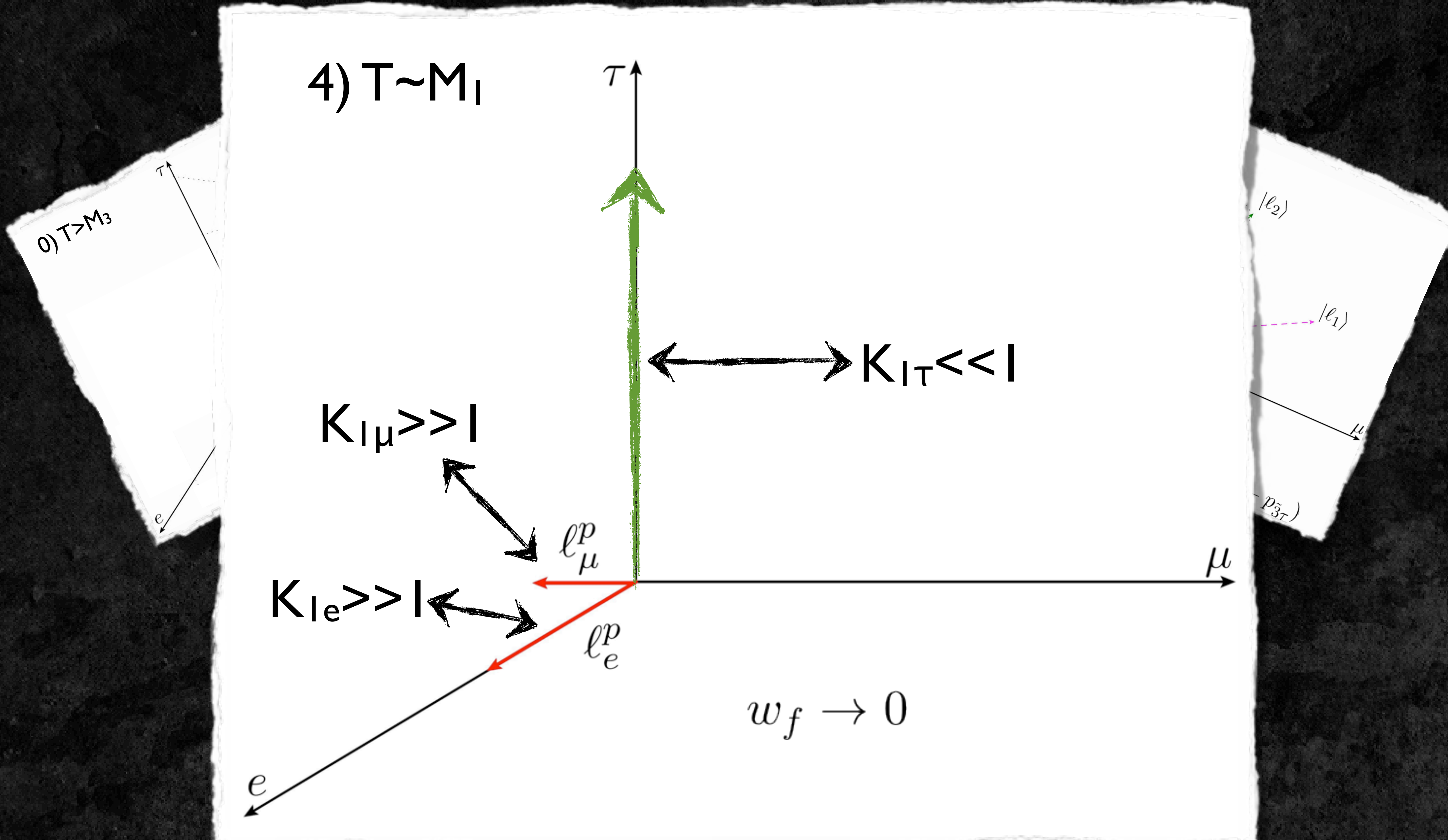

N_{R1} processes: strong washout on the e-μ plane only. The remaining preexistent asymmetry is erased maintaining the produced one

Epilogue

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- *Leptogenesis* explains the *observed BAU* and, via the seesaw mechanism, the *neutrino mass scale* in a natural way
- Considering *flavour effects* the *problem of initial conditions* in Leptogenesis has *no trivial solution* anymore
- Heavy neutrinos' *mass pattern* plays a key role in the analyses, defining *different scenarios*
- *Successful strong Leptogenesis* is realised only via the *tauon N_2-dominated* setup - natural within SO(10) GUTs
- Working hypotheses:
  - three RH neutrinos
  - hierarchical RH neutrino spectrum
  - minimal type I seesaw, no SuSy