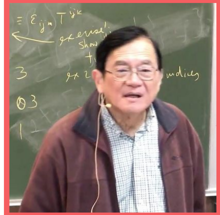




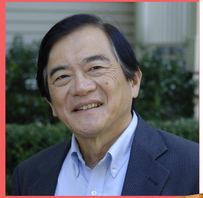



Cooking up a Baryon Asymmetry:

Leptogenesis in the Zee Model



By Adam






Obligatory background story before the recipe

- The universe is clearly made of matter, not antimatter
- The Standard Model can't explain this very well…
- …but BSM physics might be able to

A matter-dominated universe

??? years • Serves 8 billion

Ingredients

- Baryon number-violation
- C- and CP-violation
- Interactions out of equilibrium

Preparation

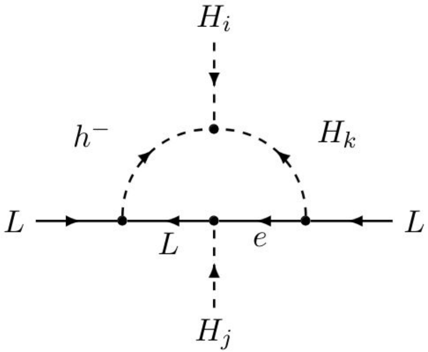
1. Preheat universe using big bang
2. Add standard model particles
3. Add secret ingredient (new physics)
4. Wait up to 13.77 billion years

Introducing... the Zee Model!

- Extend the Standard Model with:
  - a **second Higgs doublet** H_2, and
  - a new **charged scalar** h^-
- New interactions:

$$\mathcal{L} \supset -\left(\mu H_1 \epsilon H_2 h^- + f_{\alpha\beta} \overline{\widetilde{L}_\alpha} L_\beta h^+ + \overline{L}(Y_1^\dagger H_1 + Y_2^\dagger H_2) e_R + \text{H.c.}\right)$$

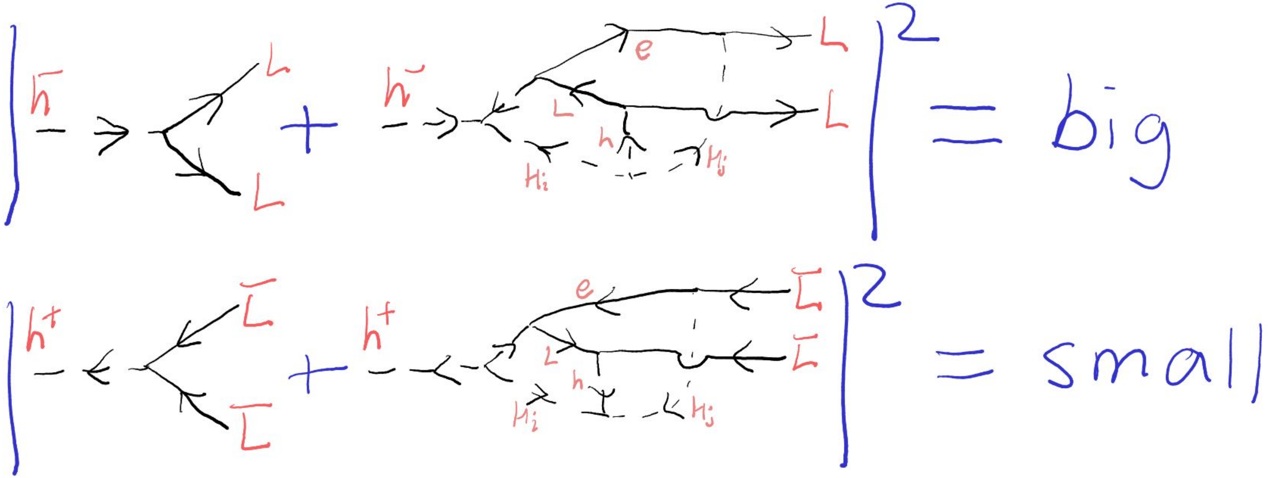
- Neutrino masses generated at one-loop:



CP Violating Decays

- Interference with two-loop diagrams can produce CP violation:

$$\Gamma(h^- \to LL) > \Gamma(h^+ \to \overline{L}\,\overline{L})$$



✅ C- and CP-violation

✅ Decays out of equilibrium

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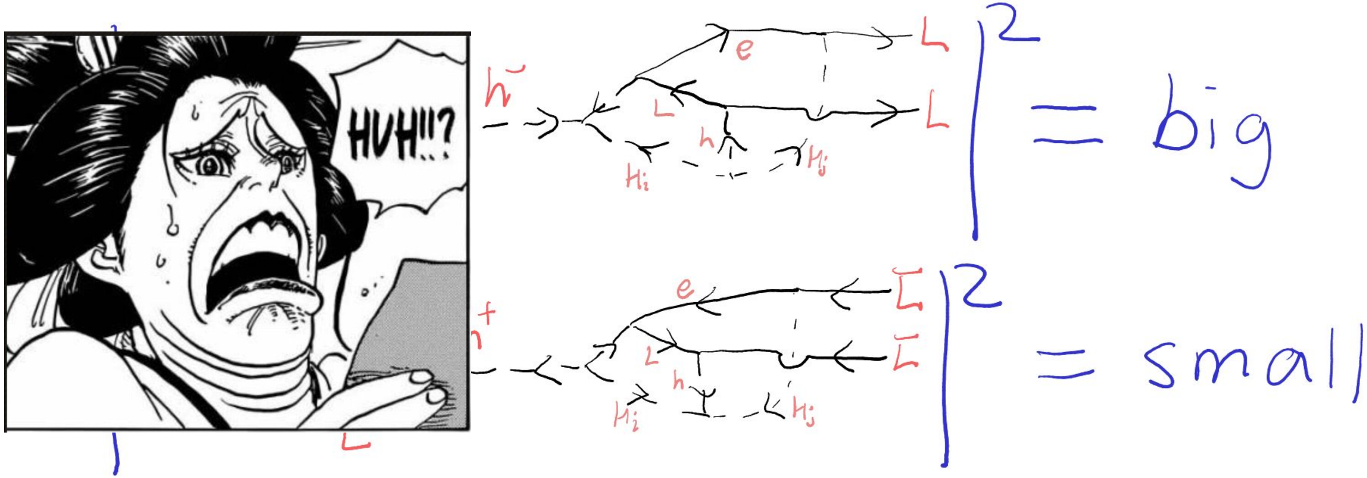
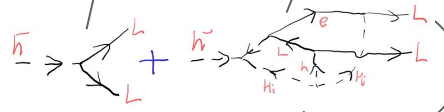


Cutting Rules

$$\mathcal{M} = c_0\mathcal{A}_0 + c_1\mathcal{A}_1$$



- It turns out there is an easier way to do this:

$$\Gamma(h^- \to LL) - \Gamma(h^+ \to \overline{L}\,\overline{L}) \propto \mathrm{Im}(c_0^* c_1)\,\mathrm{Im}(\mathcal{A}_0^*\mathcal{A}_1)$$

P.S. Coupling constants NEED an imaginary part for CP violation

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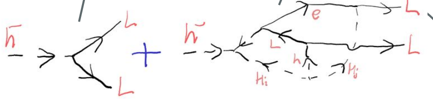

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- The amplitude becomes imaginary precisely when intermediate particles go on-shell

$$\frac{1}{p^2 - m^2 + i\varepsilon} = \mathrm{PV}\frac{1}{p^2 - m^2} - i\pi\delta(p^2 - m^2)$$

- To get the imaginary part we "cut" the diagram in all possible ways
- ⇒ **CUTTING RULES!!**

Cutting Rules

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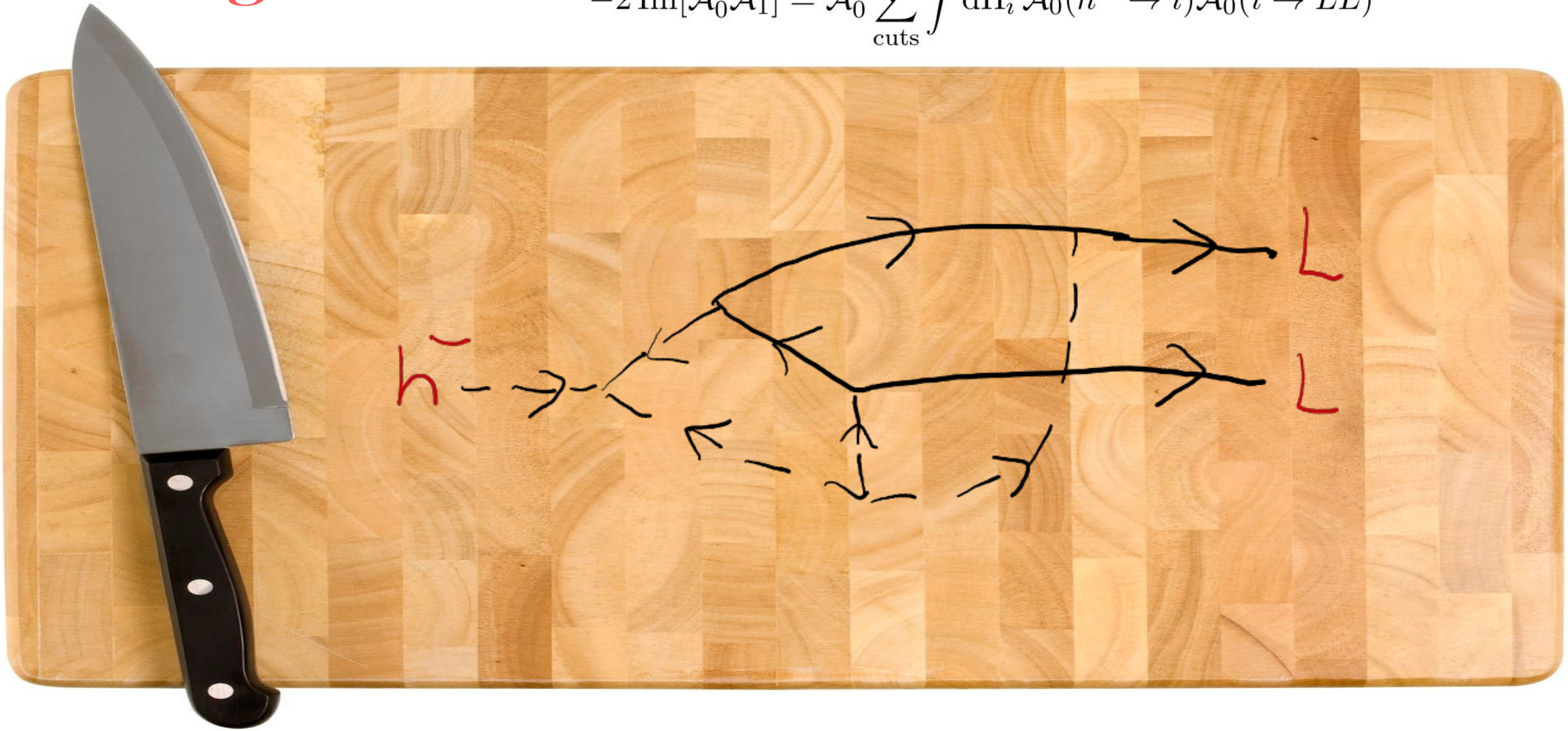
$$-2\,\mathrm{Im}[\mathcal{A}_0^* \mathcal{A}_1] = \mathcal{A}_0^* \sum_{\mathrm{cuts}} \int \mathrm{d}\Pi_i\, \mathcal{A}_0(h^- \to i) \mathcal{A}_0(i \to LL)$$



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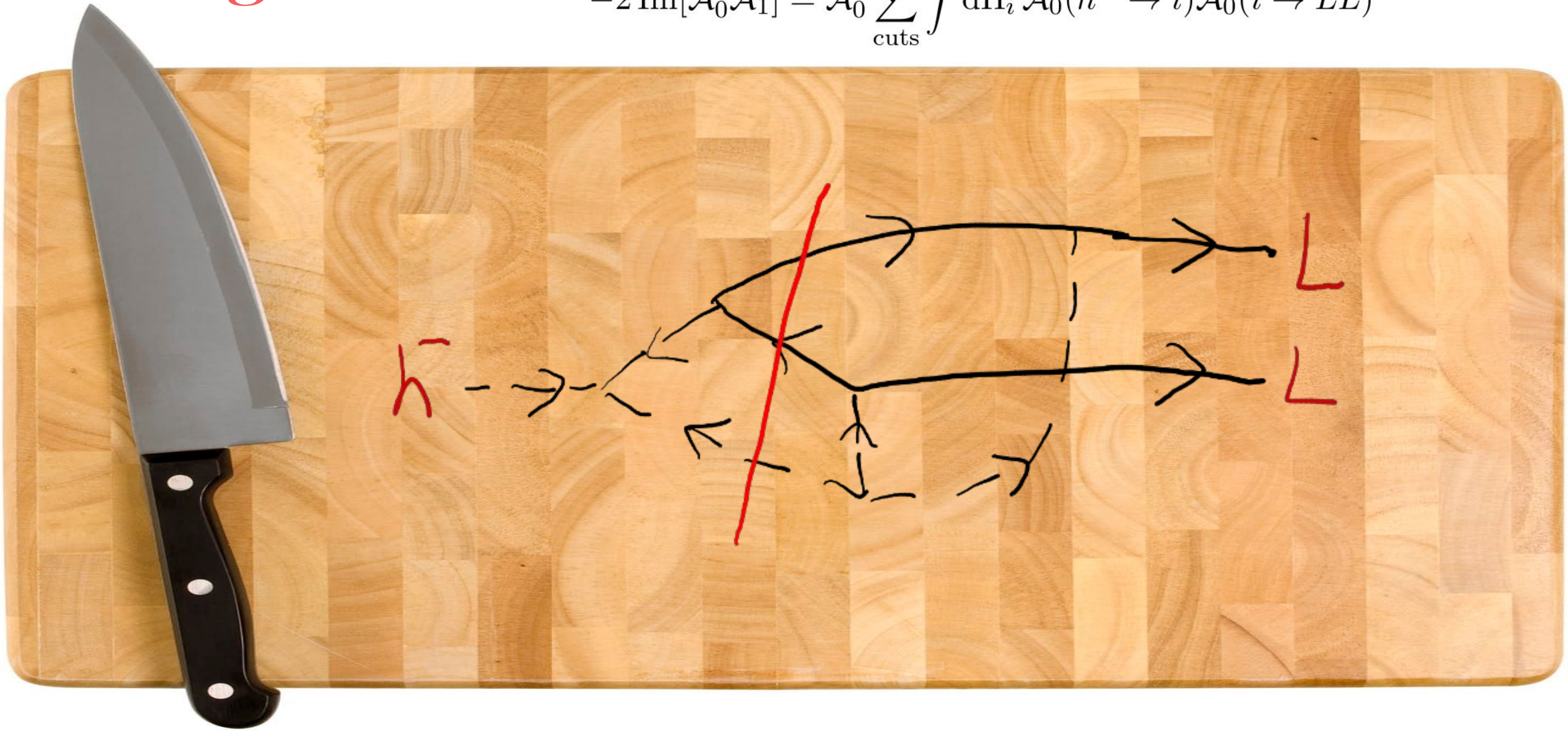

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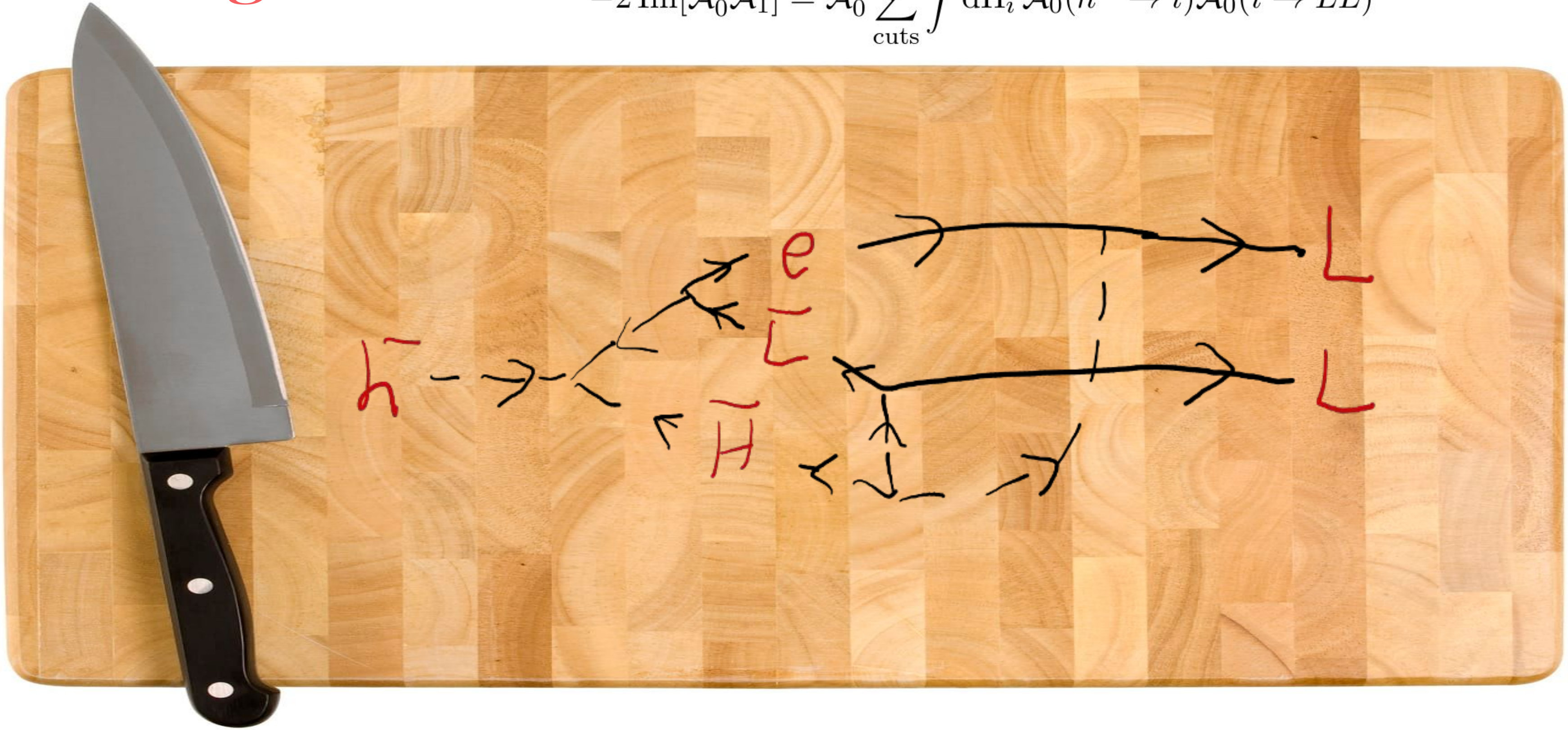

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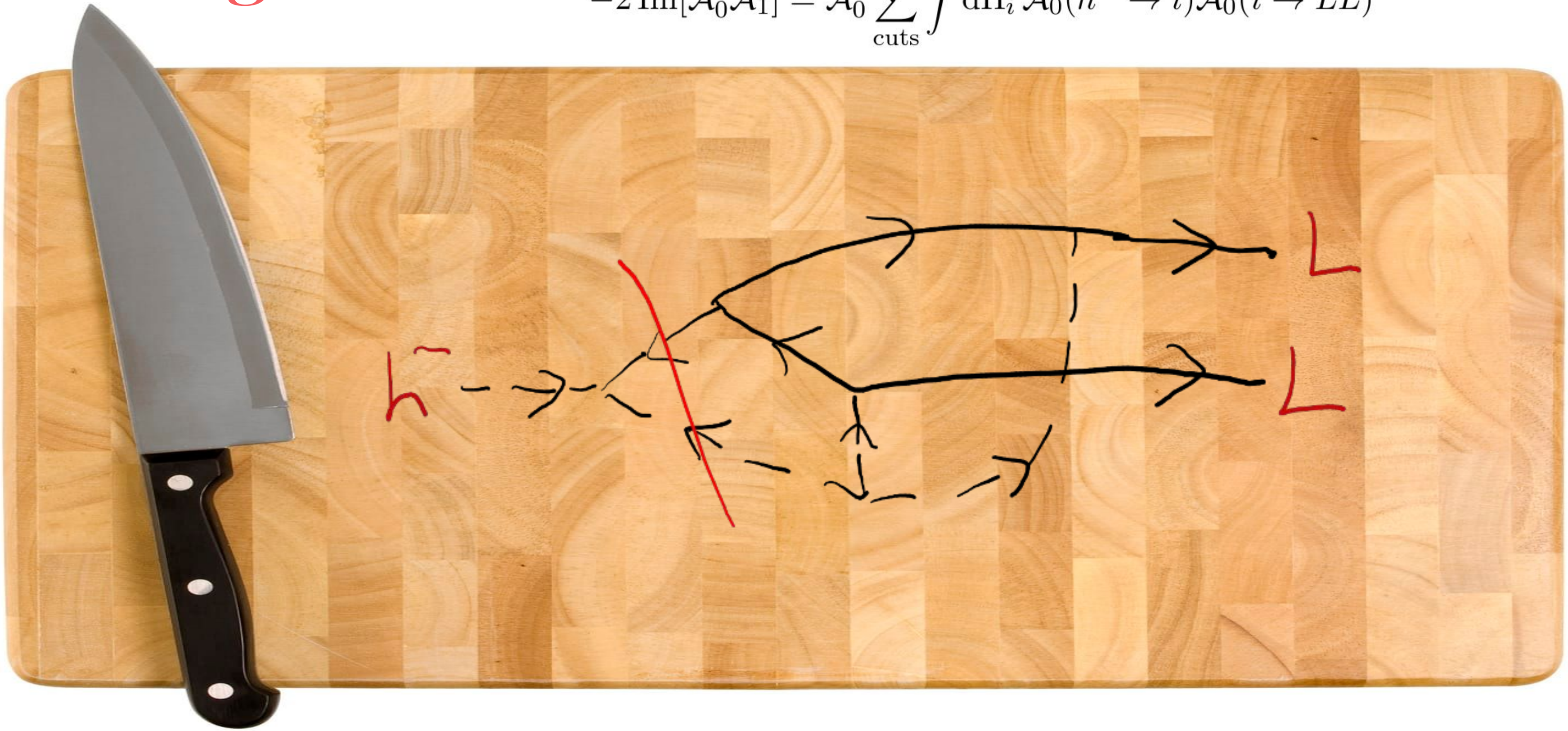

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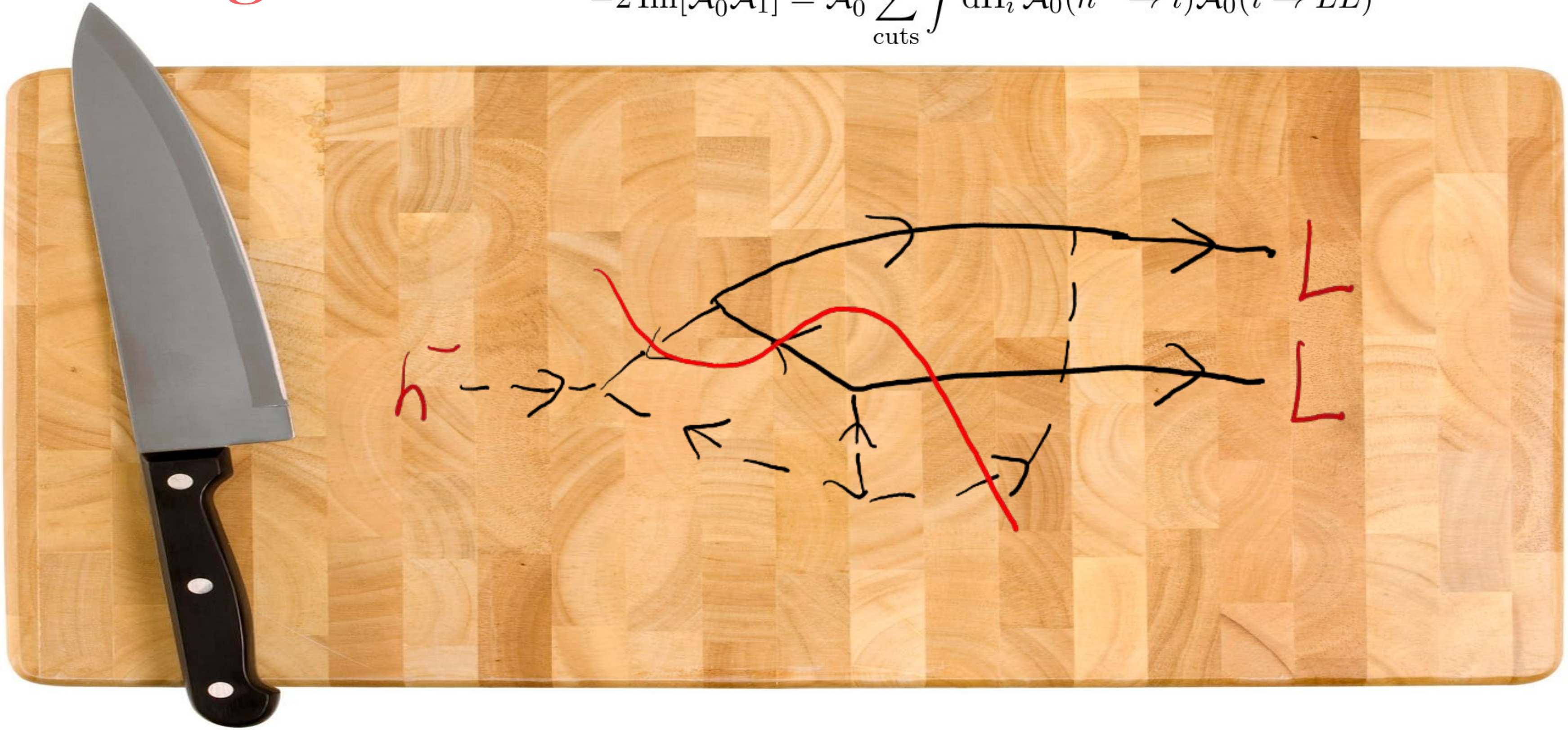

Altogether...

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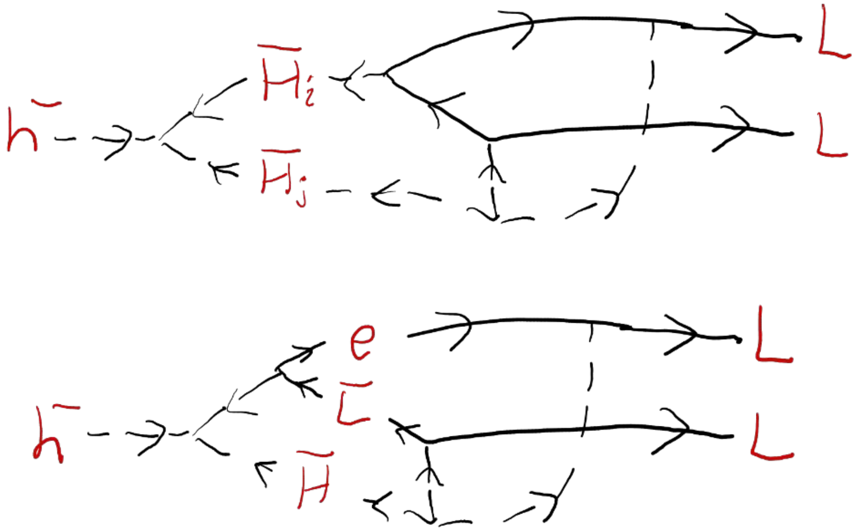
- Two nonzero contributions:



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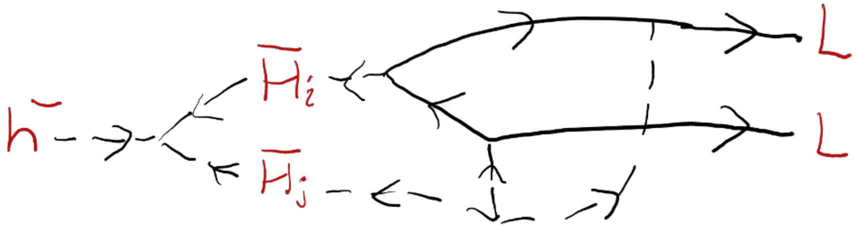

IR divergence!!!!! 😞

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Boltzmann Equation

- If we want to do this properly we should track lepton number asymmetry using the Boltzmann equation

$$\frac{\mathrm{d}n_{B-L_\alpha}}{\mathrm{d}t} + 3Hn_{B-L_\alpha} \sim -\sum_\beta \Delta\Gamma(h^- \leftrightarrow L_\alpha L_\beta) - \sum_{\beta,i} \Delta\Gamma(h^- \leftrightarrow H_i L_\alpha e_\beta) + \sum_{\beta,i} \Delta\Gamma(h^- \leftrightarrow \overline{H}_i \overline{L}_\alpha e_\beta).$$

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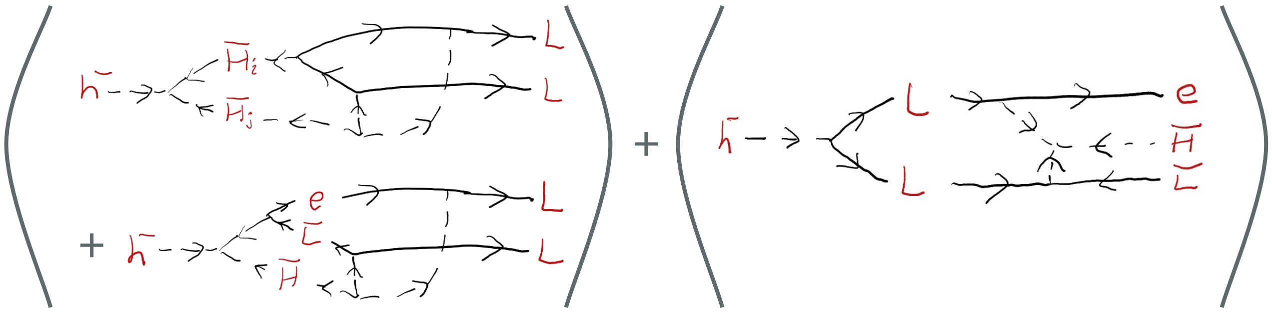
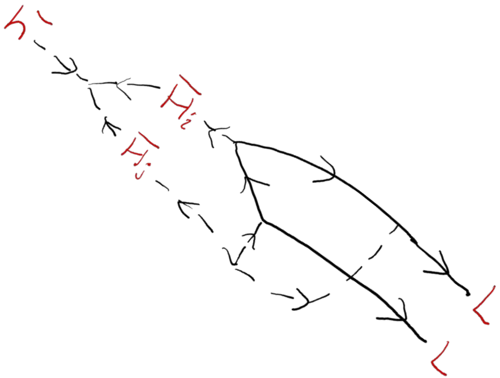
= - 

= finite

(we hope)

Summary



- Universe is made of matter
- Zee model might give us this using CP violating decays of a heavy scalar
- We compute CP asymmetries using cuts in diagrams
- Hopefully result is finite

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Chee Sheng Fong

Thanks!

Backup - all cuts