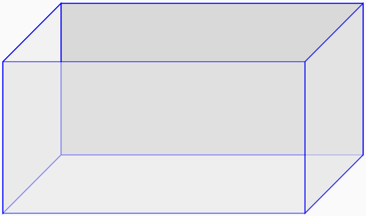
Leptogenesis through a Scalar Field UV Completion of the Weinberg Operator

Matthew S. Fox
Advisor: Brian Shuve

15 October 2019

Harvey Mudd College

What's the (Anti)matter



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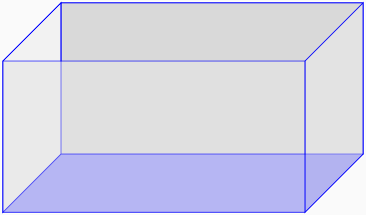

cold

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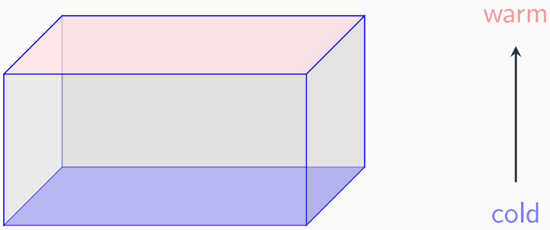

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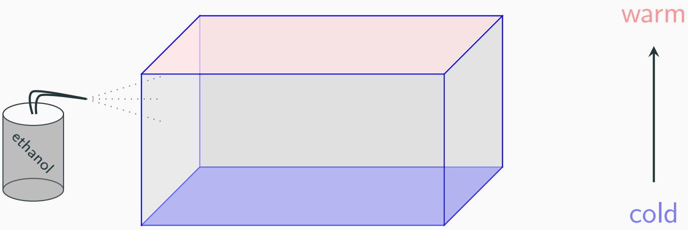

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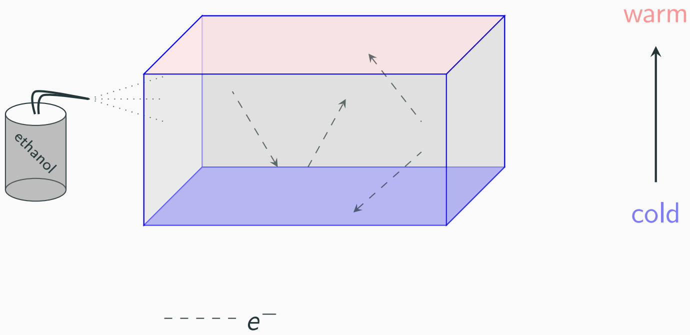

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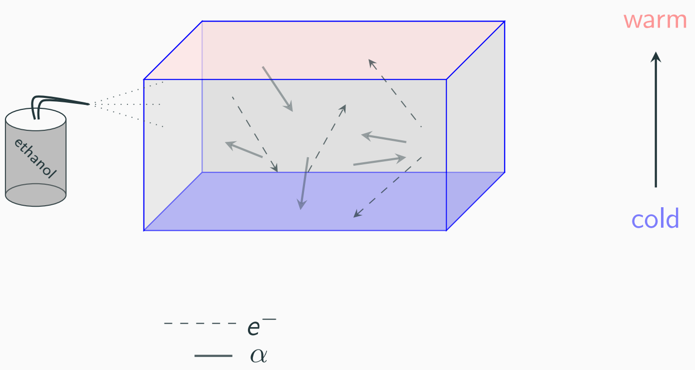

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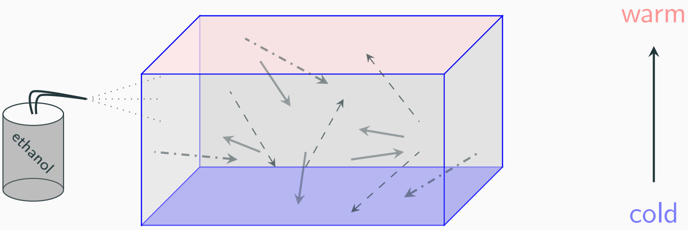
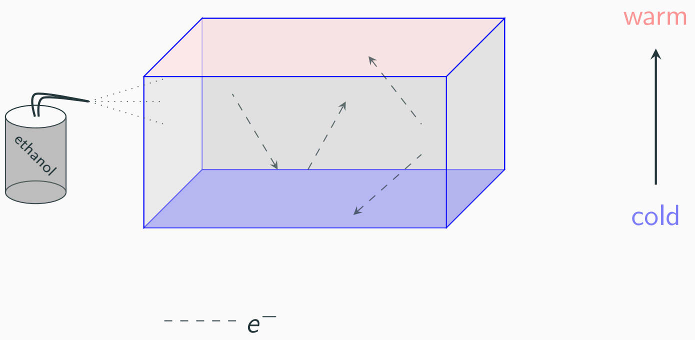


- - - - - e^-
——— α
-·-·-· μ^-

What's the (Antimatter)



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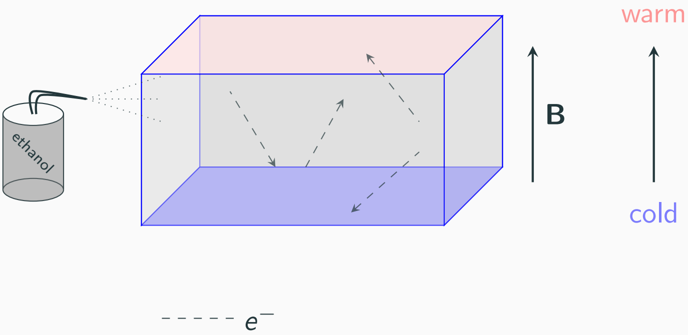

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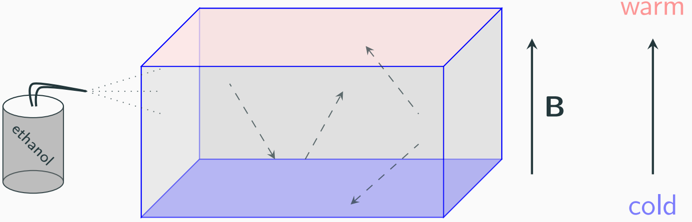

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$$\mathbf{F}_{e^-} = (-e)\mathbf{v} \times \mathbf{B}$$

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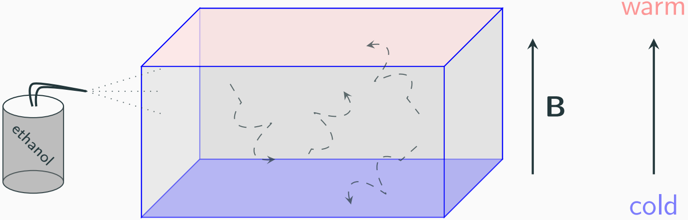

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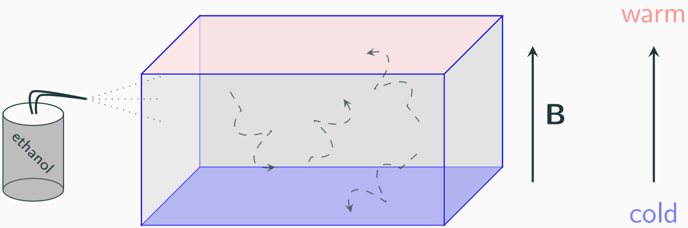

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Carl Anderson (1932) observed mirrored “electron” spirals

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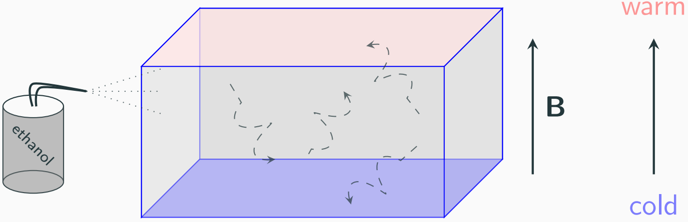

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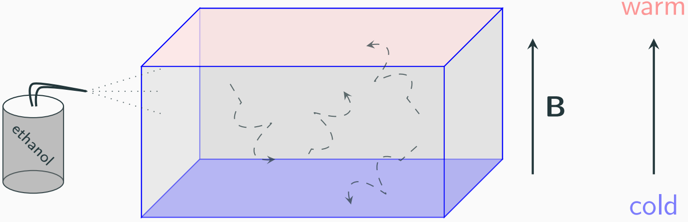

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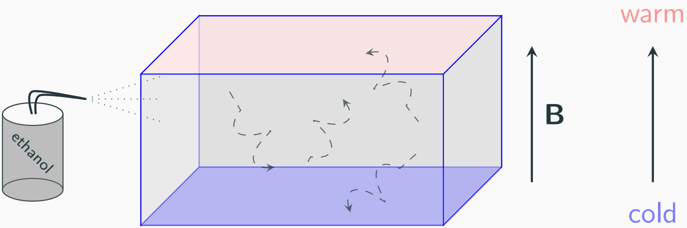

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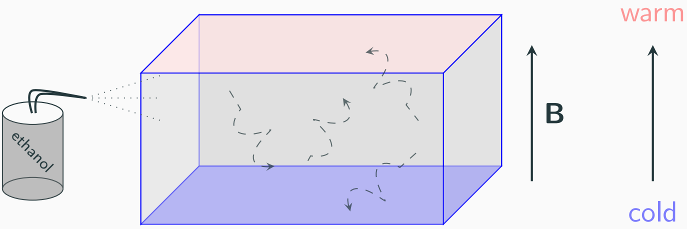

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Particles and Fields

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Classically, particles generate fields, with which systems interact

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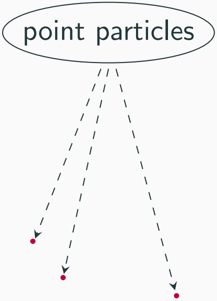

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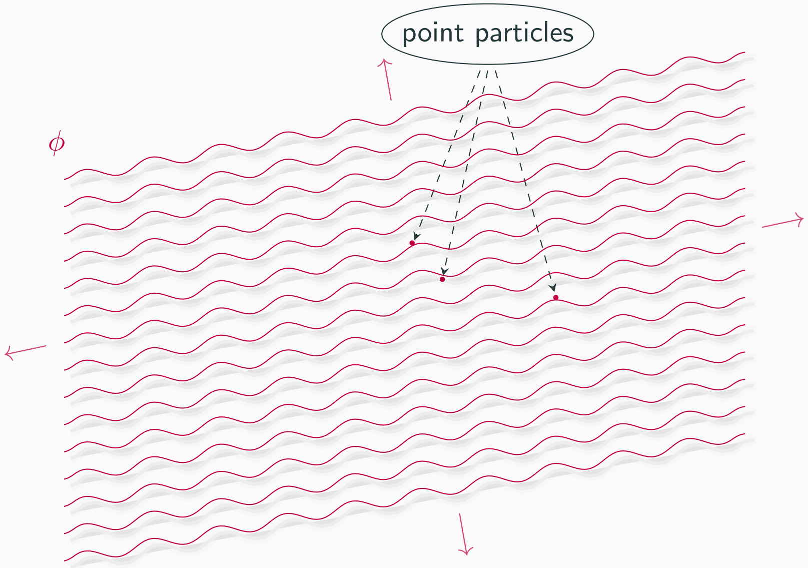

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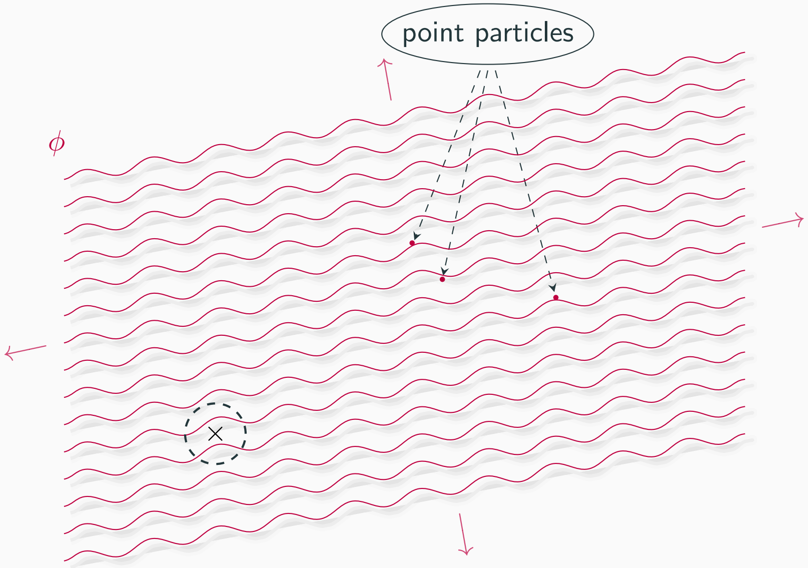

Particles and Fields

In quantum field theory (QFT), excitations in fields yield particles

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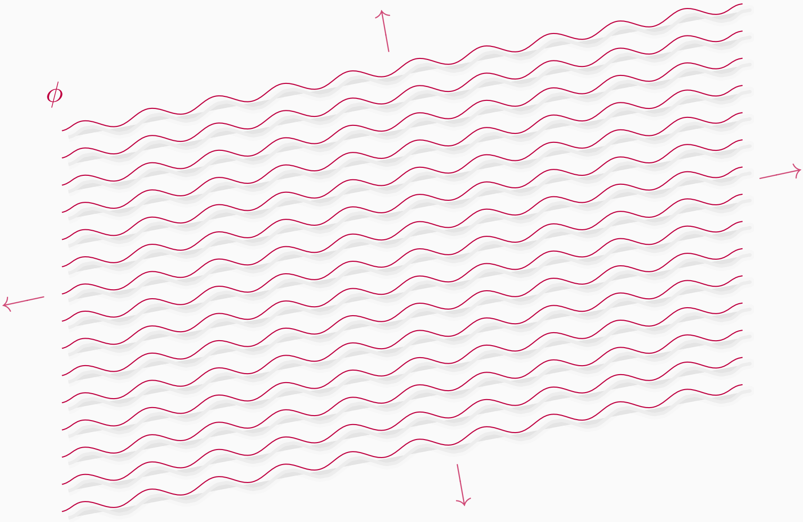

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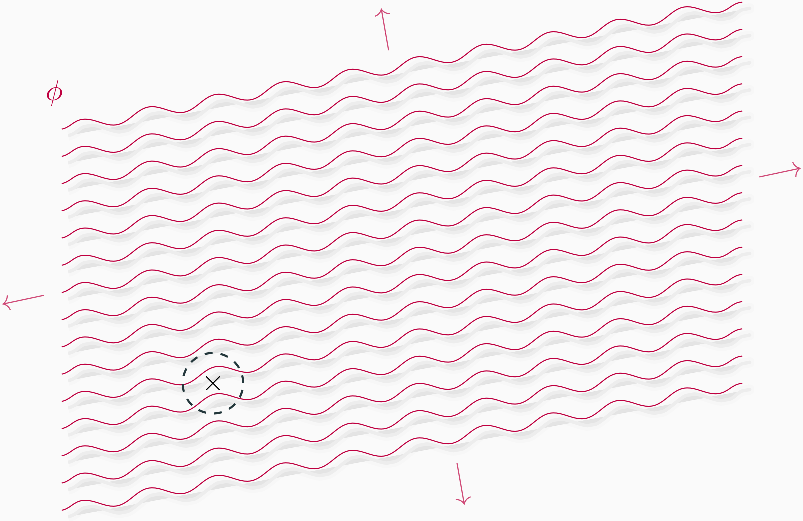

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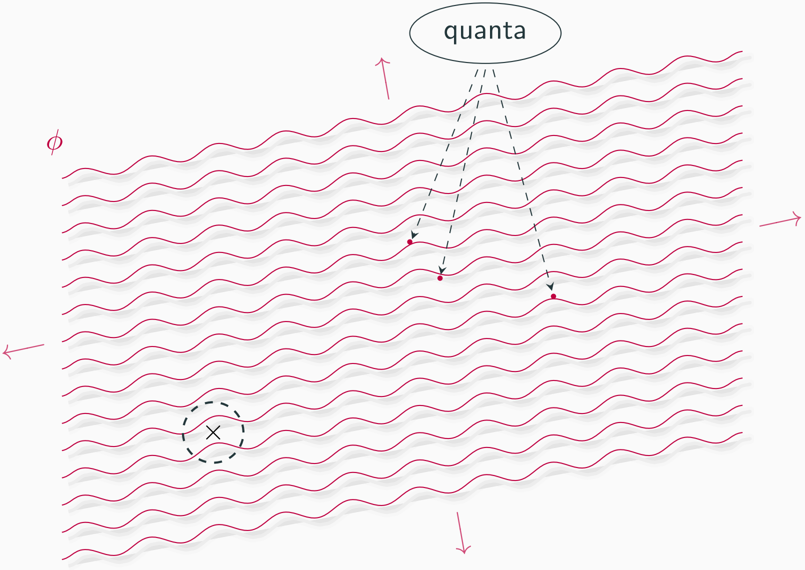

Particles and Fields

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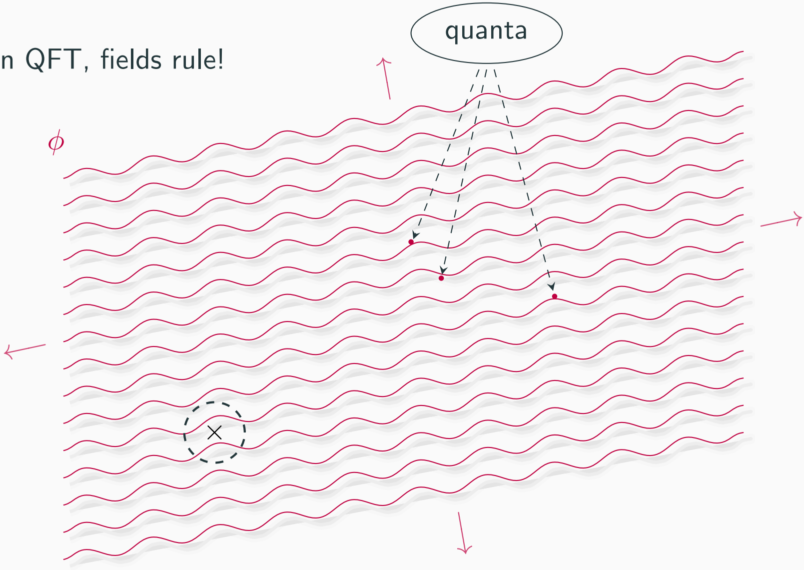
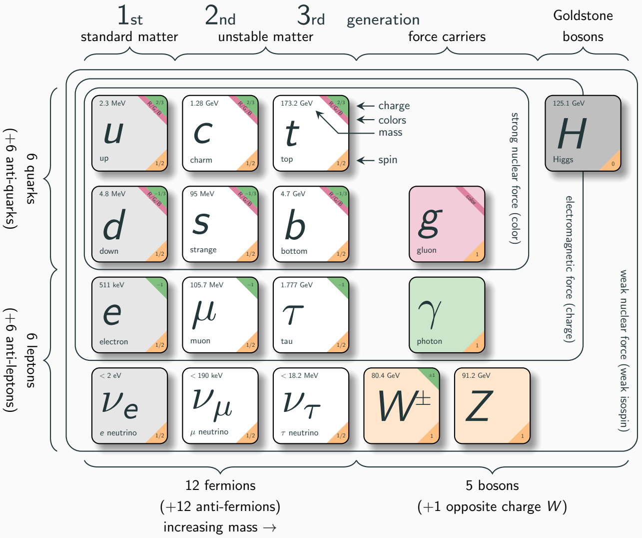
In QFT, fields rule!



The Standard Model (SM) and Beyond



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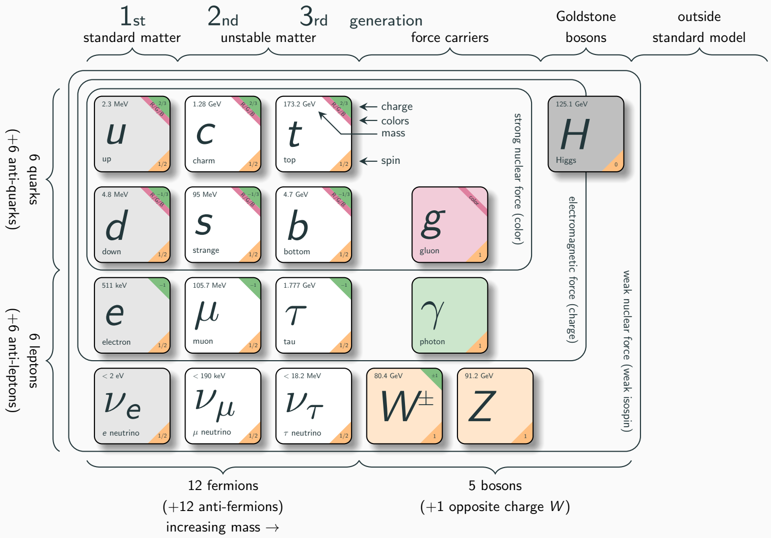

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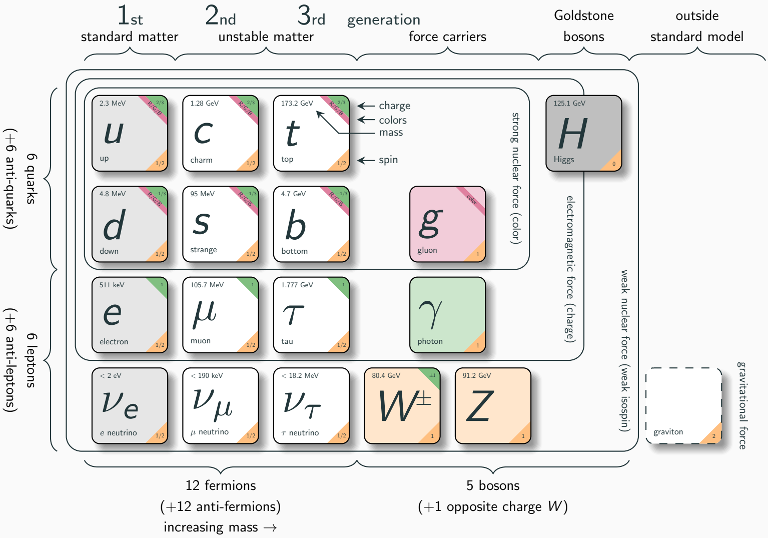

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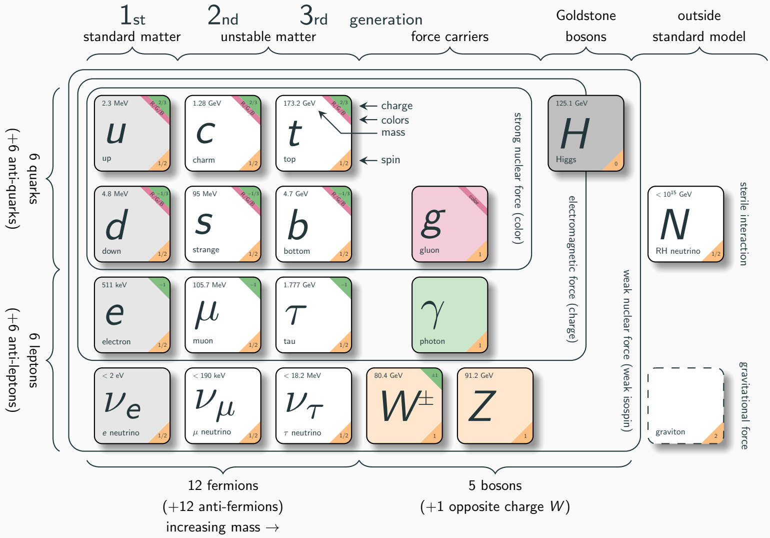

Neutrino Physics: Helicity

According to SM, neutrinos have spin-1/2

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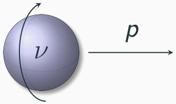

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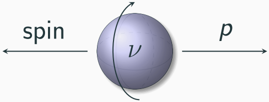

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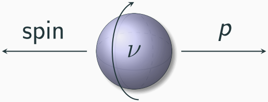

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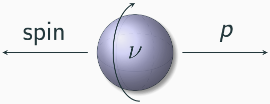

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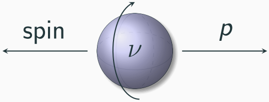

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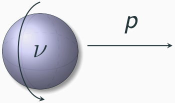

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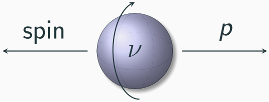

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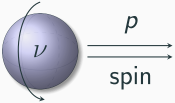

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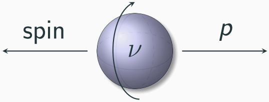

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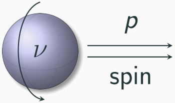

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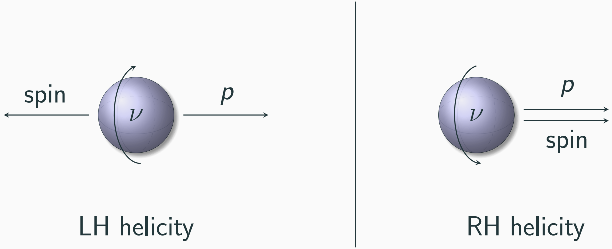

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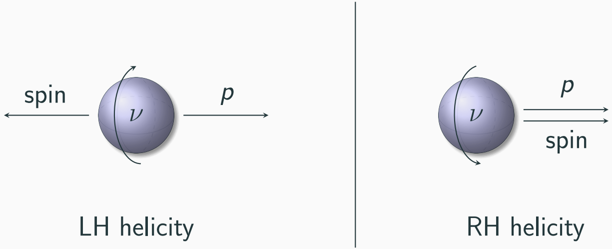

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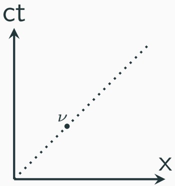

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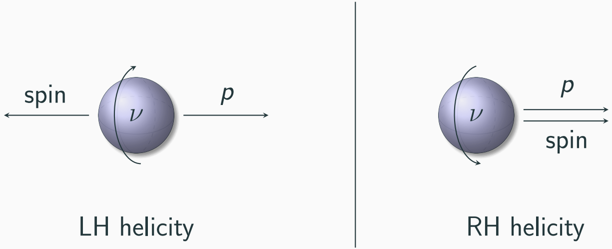

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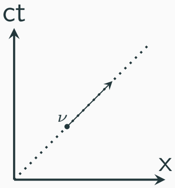

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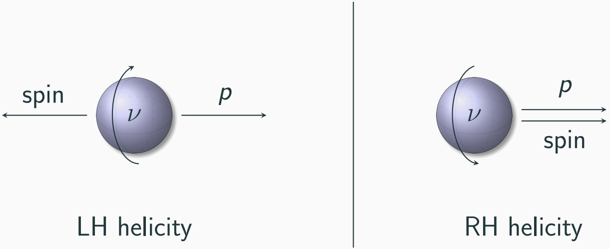

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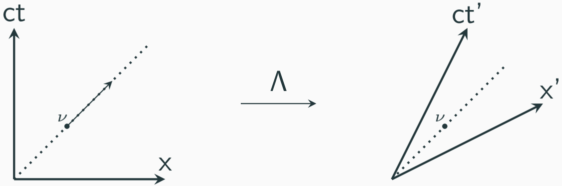

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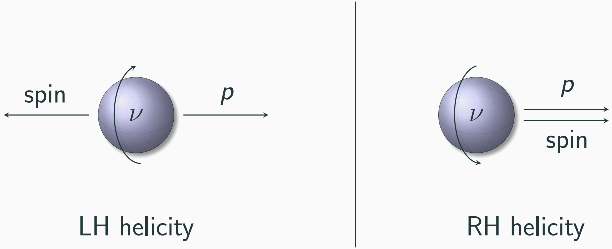

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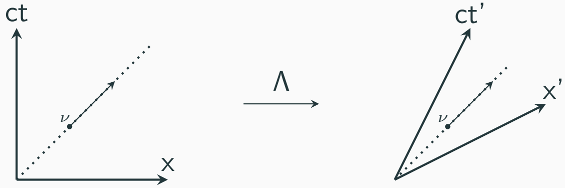

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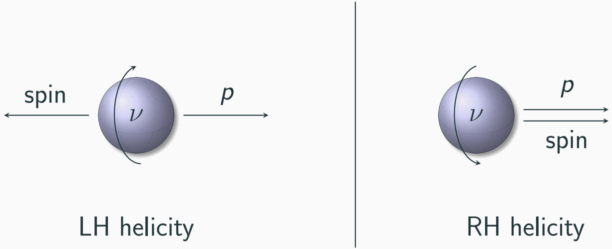

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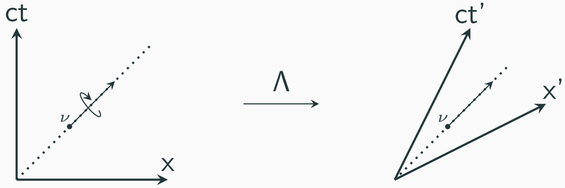

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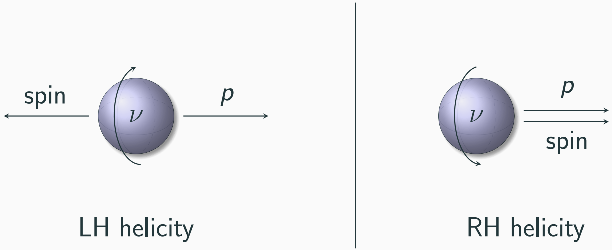

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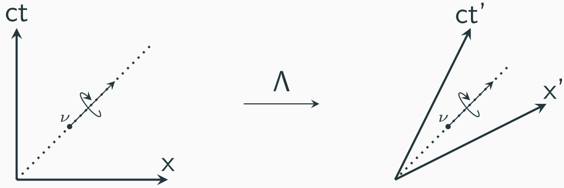

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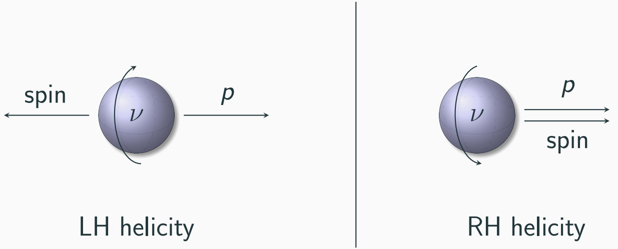

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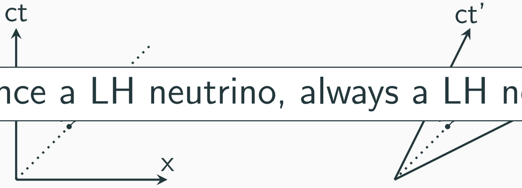

Once a LH neutrino, always a LH neutrino!

Neutrino Physics: Neutrino Oscillations

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mass < 190 keV

ν_μ

μ neutrino

1/2

Neutrino Physics: Neutrino Oscillations

mass $<$ 190 keV

ν_μ

μ neutrino

1/2

$$|\nu_\mu\rangle = \mathbf{U}_{\mu k}|\nu_k\rangle$$

Neutrino Physics: Neutrino Oscillations

mass < 190 keV
ν_μ
μ neutrino
1/2

definite flavor

$$|\nu_\mu\rangle = \mathbf{U}_{\mu k}|\nu_k\rangle$$

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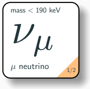

definite flavor

definite mass

$$|\nu_\mu\rangle = \mathbf{U}_{\mu k}|\nu_k\rangle$$

Neutrino Physics: Neutrino Oscillations

mass < 190 keV
ν_μ
μ neutrino
1/2

mass < 18.2 MeV
ν_τ
τ neutrino
1/2

definite flavor

definite mass

$$|\nu_\mu\rangle = \mathbf{U}_{\mu k}|\nu_k\rangle$$
$$|\nu_\tau\rangle = \mathbf{U}_{\tau k}|\nu_k\rangle$$

Neutrino Physics: Neutrino Oscillations

mass < 190 keV
ν_μ
μ neutrino
1/2

mass < 18.2 MeV
ν_τ
τ neutrino
1/2

mass < 2 eV
ν_e
e neutrino
1/2

definite flavor

definite mass

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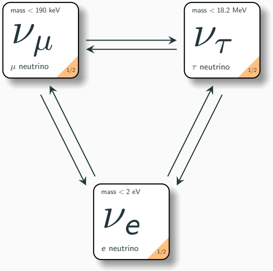
Neutrino Oscillations



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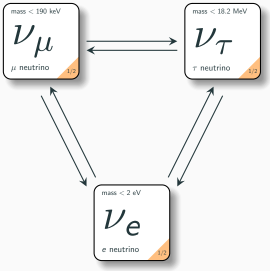

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$$\Pr(\nu_e \to \nu_\mu) \sim \sin^2\left[k\left(m_1^2 - m_2^2\right)\right]$$

Neutrino Physics: Neutrino Oscillations

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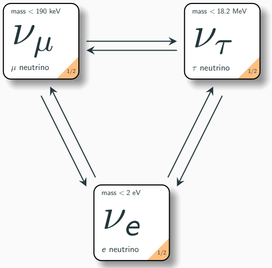

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$$\Pr(\nu_e \to \nu_\mu) \sim \sin^2\left[k\left(m_1^2 - m_2^2\right)\right]$$

Experiments show $\Pr(\nu_e \to \nu_\mu) > 0$

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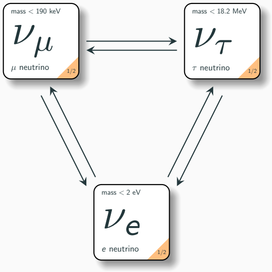

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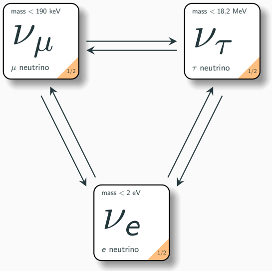
Experiments show $\Pr(\nu_e \to \nu_\mu) > 0$

$$\boxed{m_1 \neq m_2}$$

Neutrino Physics: Neutrino Oscillations

Neutrino Oscillations



definite flavor

definite mass

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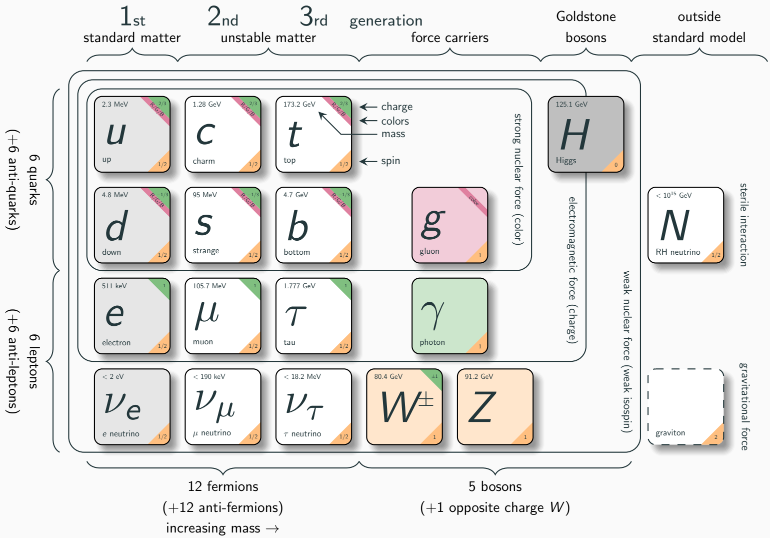
Conclusion: neutrinos have mass!

The Standard Model (SM) and Beyond



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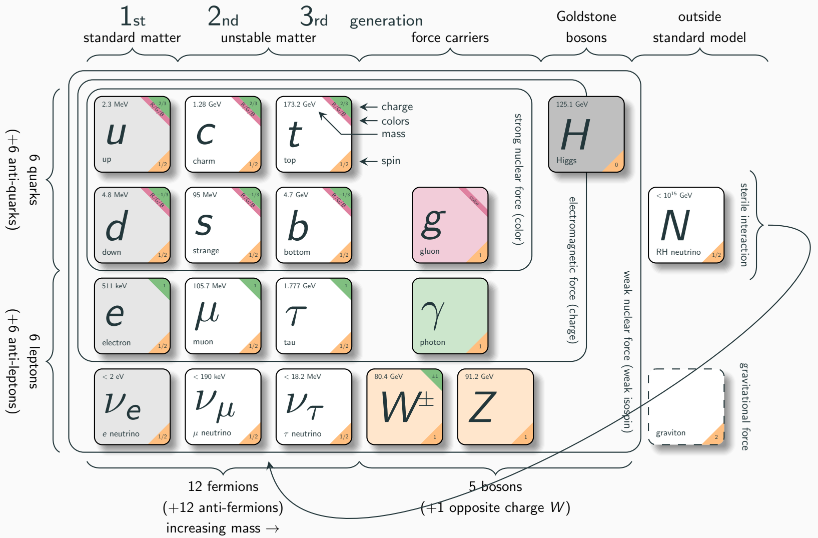

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A viable **leptogenesis** mechanism!

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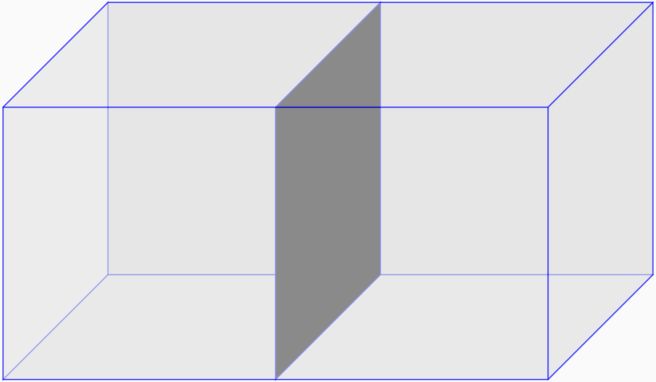

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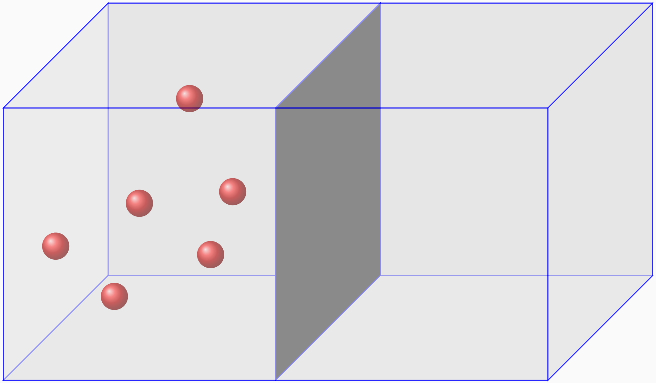

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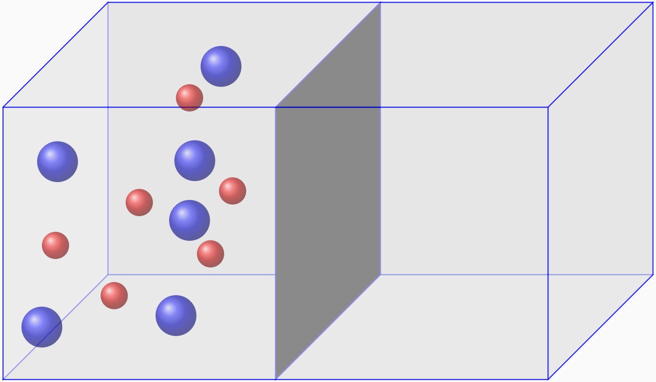

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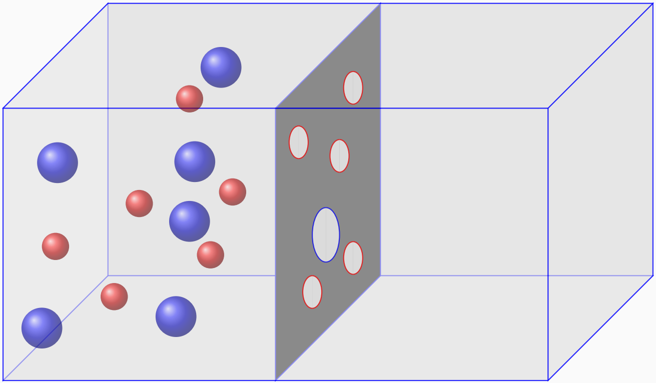

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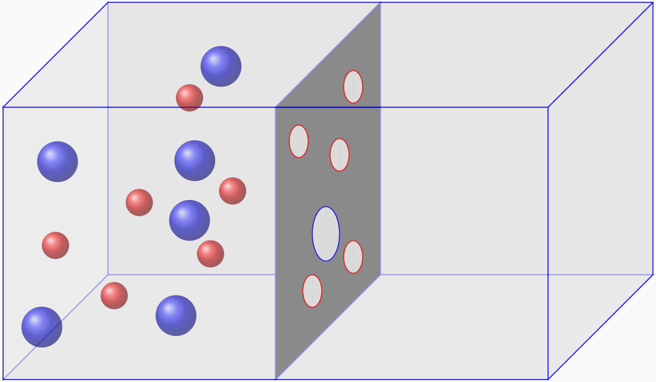

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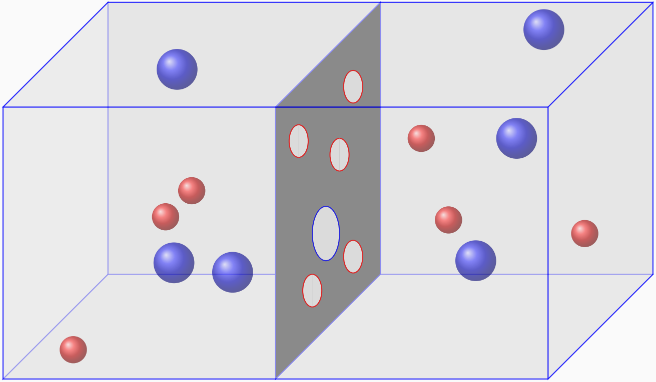

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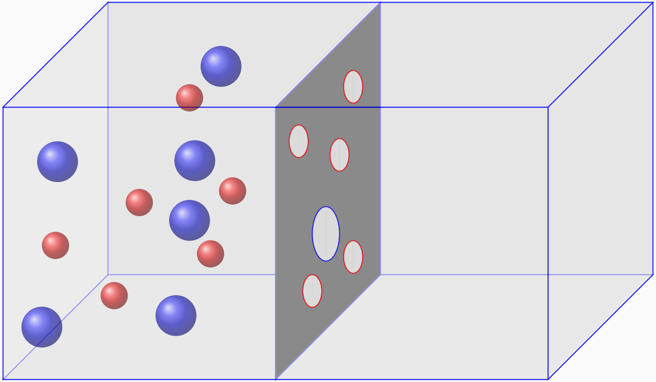

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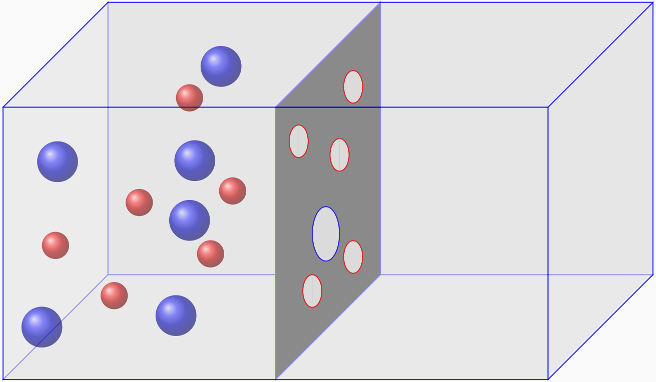
For some $t = t_{\text{critical}} < \infty$, equilibrium has not been attained



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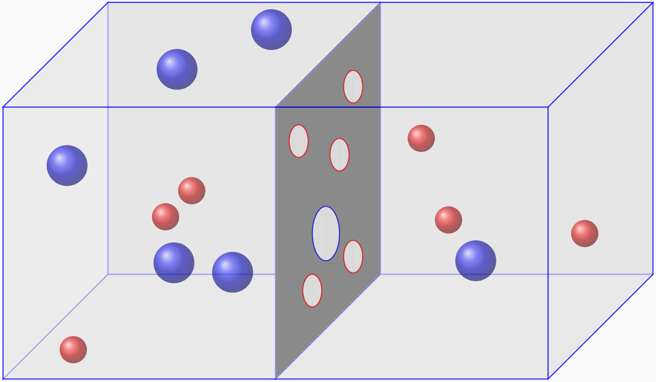

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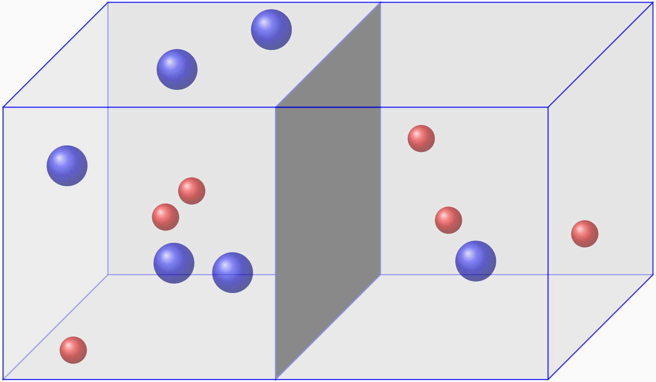

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$$\mathcal{L}_{\mathsf{SM}} = -\frac{1}{2}\partial_\nu g^a_\mu \partial_\nu g^a_\mu - g_s f^{abc}\partial_\mu g^a_\nu g^b_\mu g^c_\nu - \frac{1}{4}g_s^2 f^{abc} f^{ade} g^b_\mu g^c_\nu g^d_\mu g^e_\nu + \frac{1}{2} i g_s^2 (\bar{q}^\sigma_i \gamma^\mu q^\sigma_j) g^a_\mu + \bar{G}^a \partial^2 G^a + g_s f^{abc} \partial_\mu \bar{G}^a G^b g^c_\mu - \partial_\nu W^+_\mu \partial_\nu W^-_\mu - M^2 W^+_\mu W^-_\mu - \frac{1}{2}\partial_\nu Z^0_\mu \partial_\nu Z^0_\mu - \frac{1}{2c_w^2} M^2 Z^0_\mu Z^0_\mu - \frac{1}{2}\partial_\mu A_\nu \partial_\mu A_\nu$$

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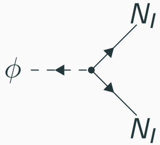
$\mathcal{L}_E =$ 

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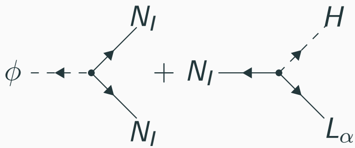

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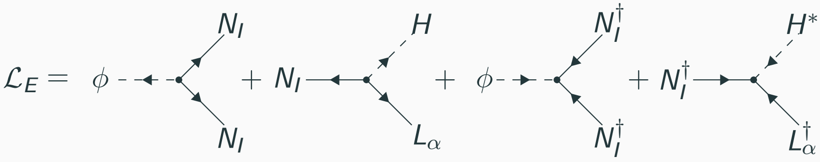

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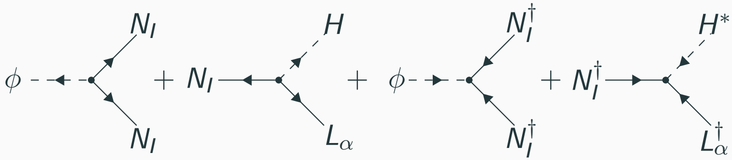

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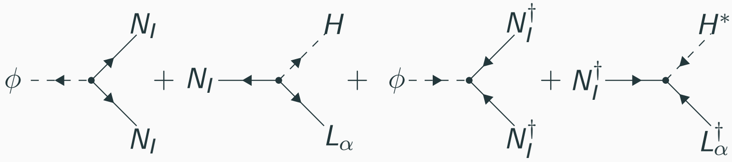

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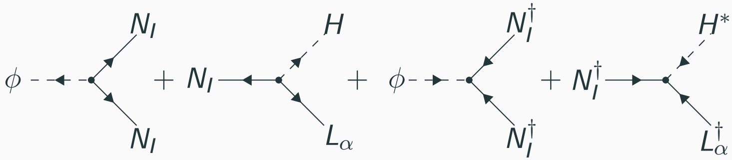

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What is ϵ in our model?

Acknowledgements

- Prof. Brian Shuve (Harvey Mudd College)
- Dr. Carlos Tamarit (Technische Universität München)