HIDDeν
Hunting Invisibles: Dark sectors, Dark matter and Neutrinos

ν Electroweak Baryogenesis

Salvador Rosauro Alcaraz, 11/10/21

In collaboration with E. Fernández-Martínez, J. López-Pavón & T. Ota based on JHEP 10 (2020) 063

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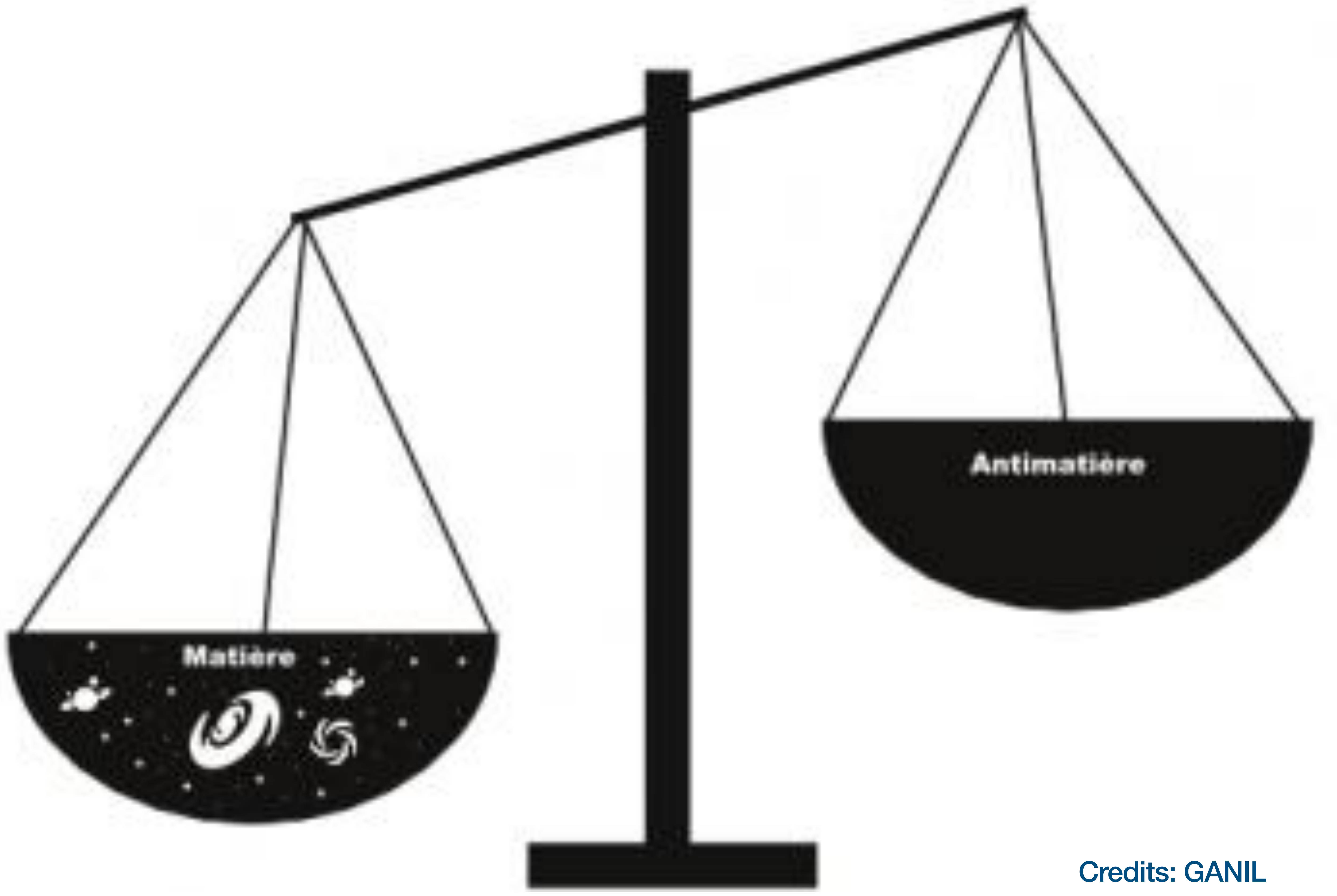
IJCLab
Irène Joliot-Curie
Laboratoire de Physique des 2 Infinis

Introduction

Baryon asymmetry of the Universe



Credits: GANIL

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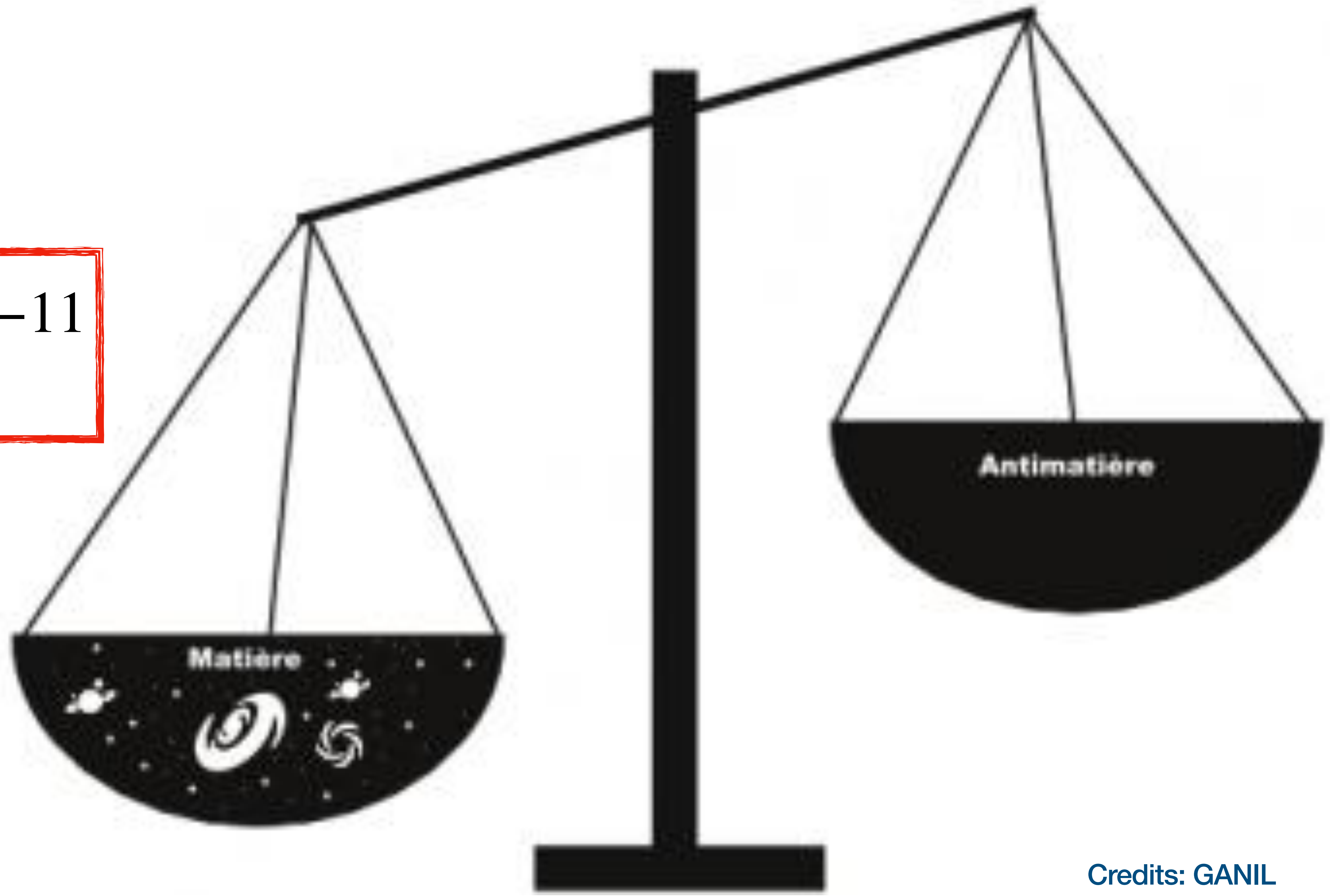
Baryon asymmetry of the Universe

$$Y_B^{obs} = \frac{n_b - n_{\bar{b}}}{s} \simeq (8.59 \pm 0.08) \times 10^{-11}$$



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Generation of a BAU

- C and CP violation
- B violation
- Out-of-equilibrium conditions

A. D. Sakharov, Pisma Zh. Eksp. Teor. Fiz. 5 (1967) 32-35

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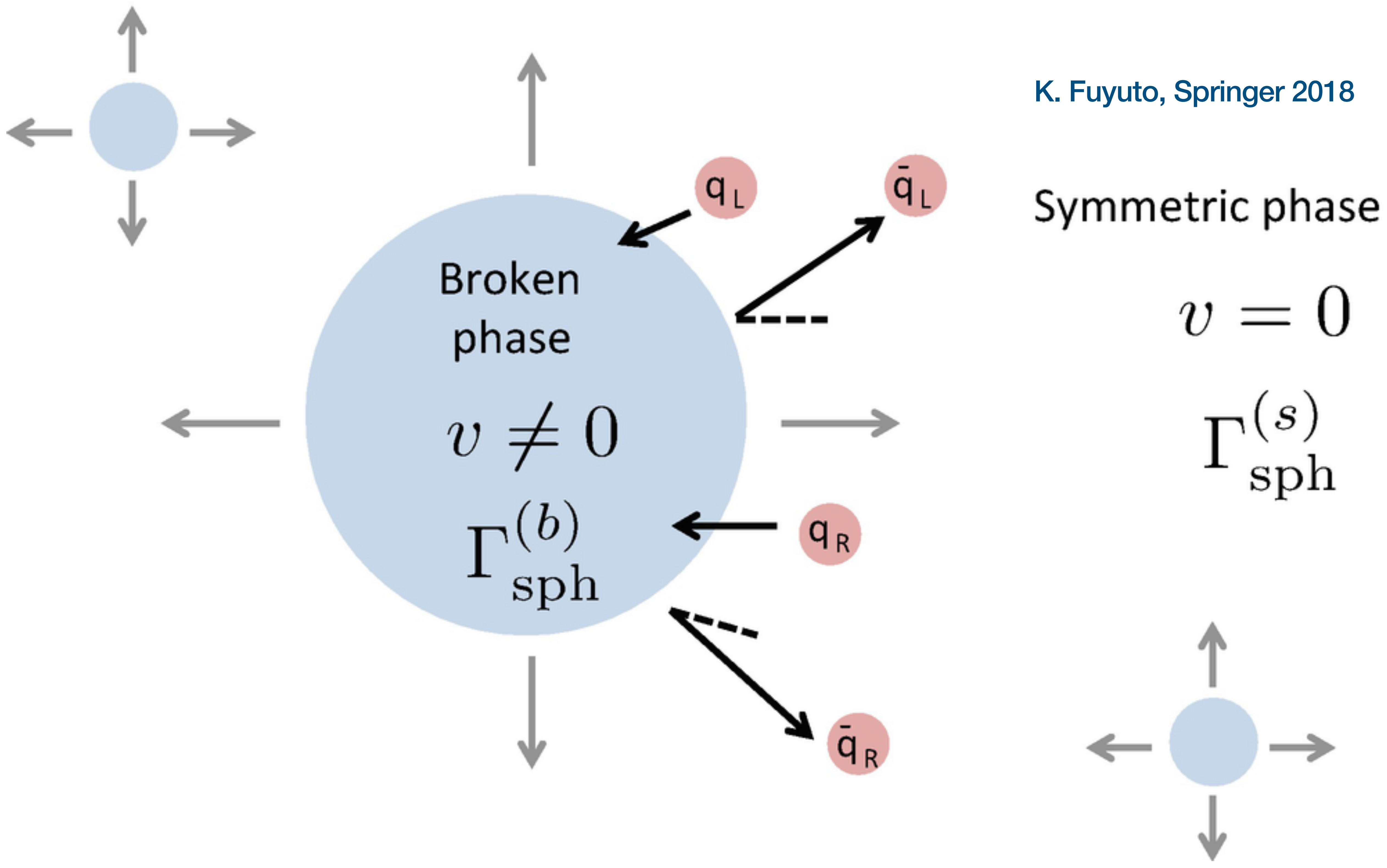

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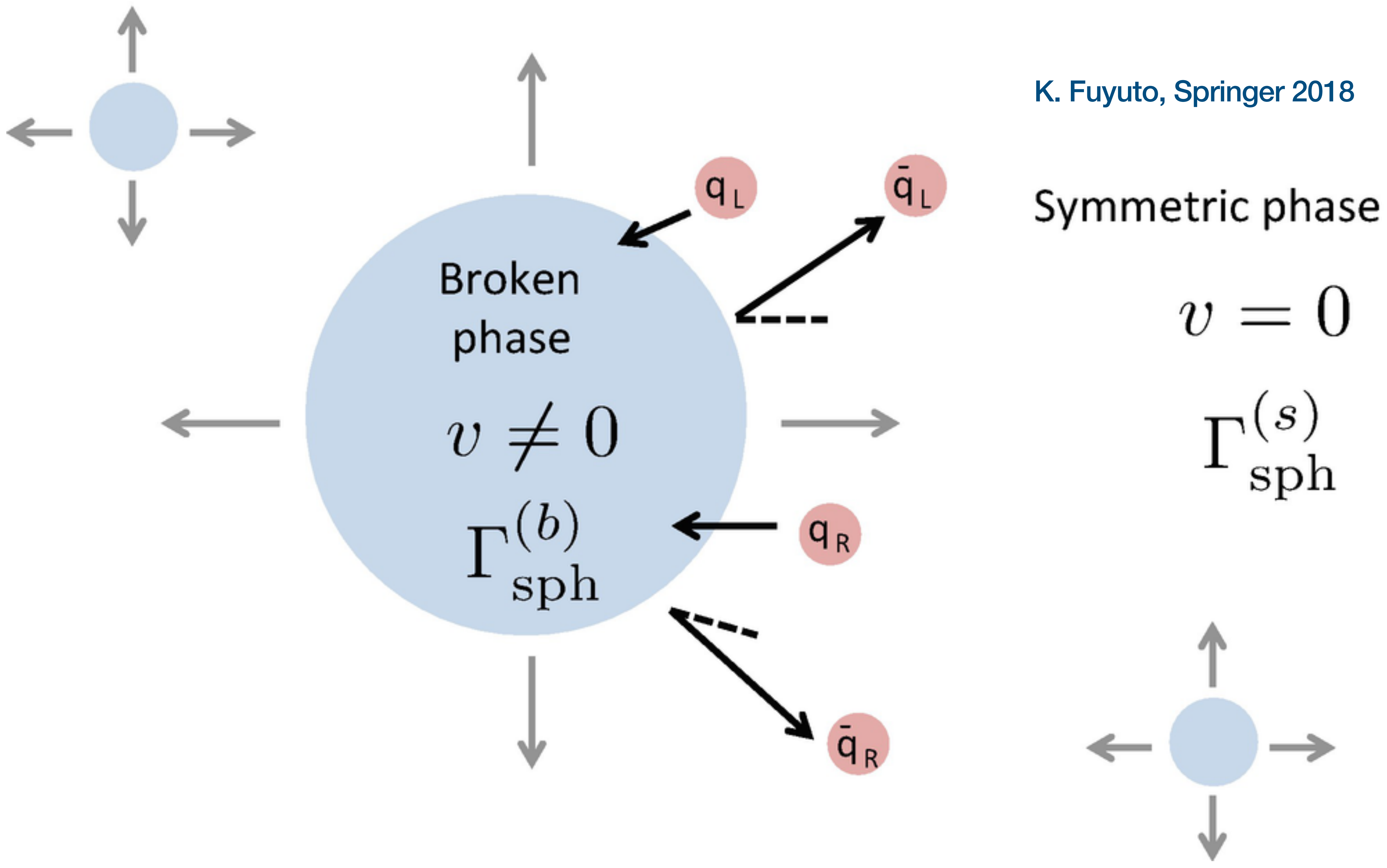

K. Fuyuto, Springer 2018

Electroweak baryogenesis

CP violation from CKM matrix

M. B. Gavela, P. Hernandez, J. Orloff & O. Pene, arXiv:hep-ph/9312215

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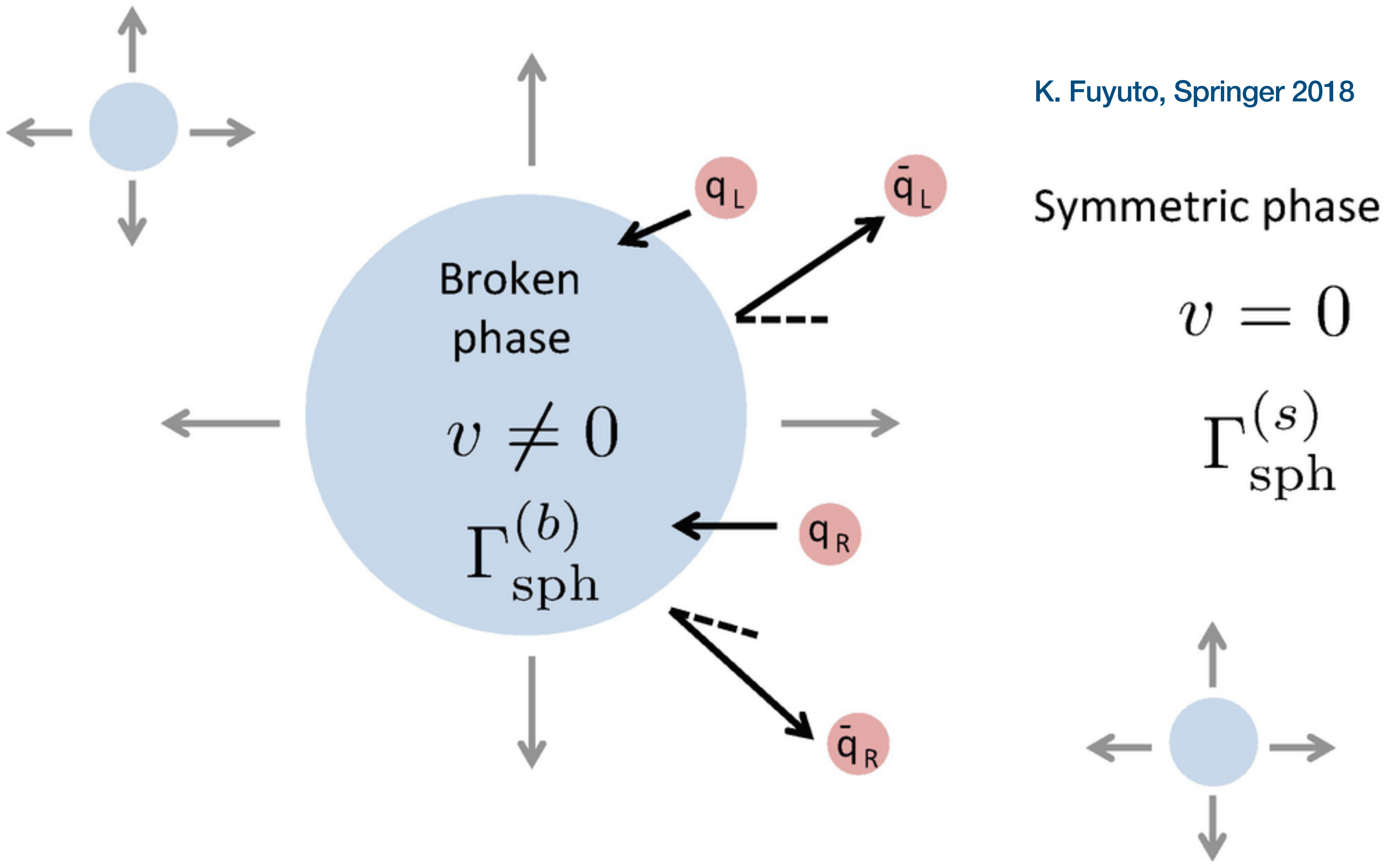

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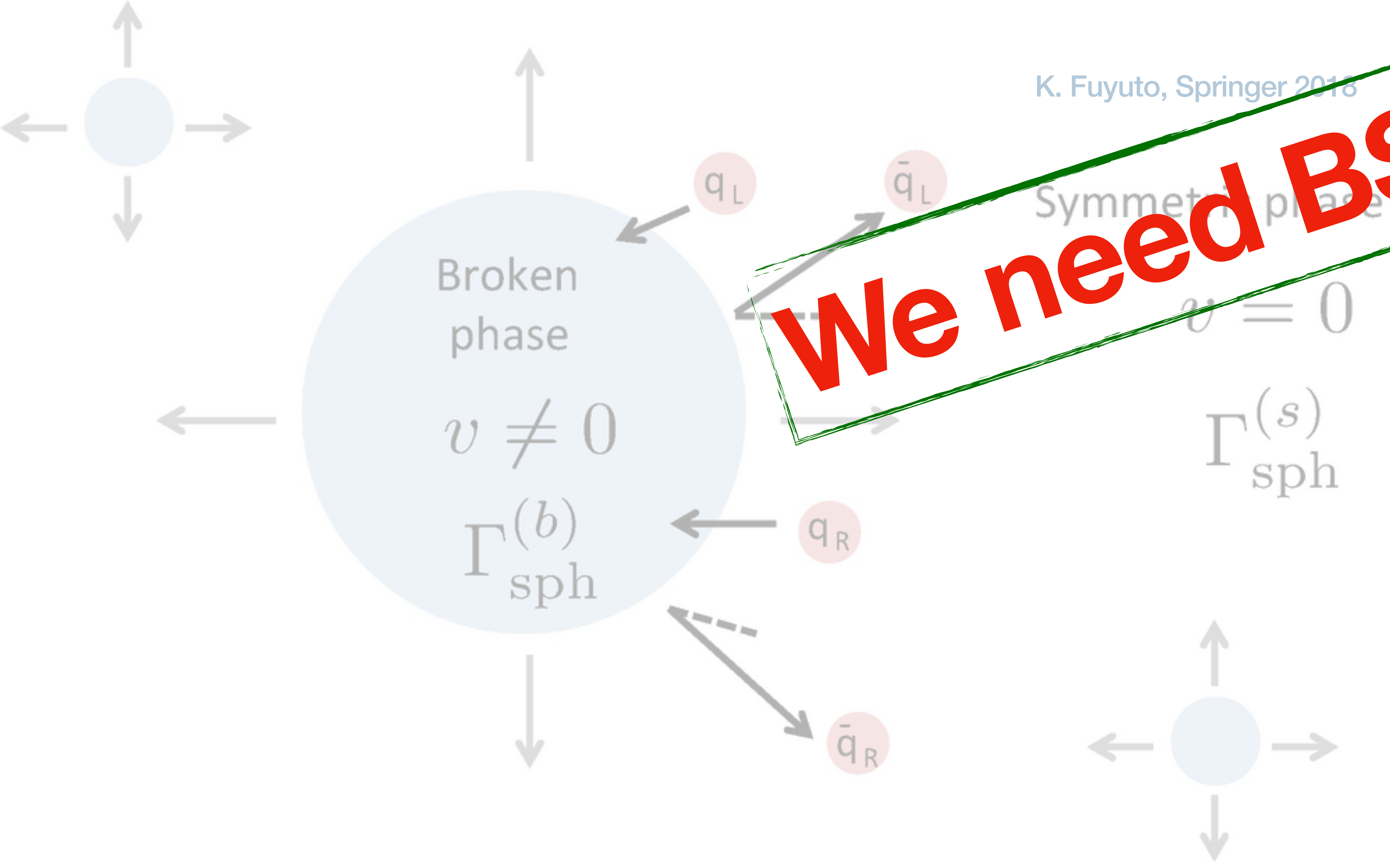

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We need BSM physics

Electroweak baryogenesis with new physics

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$B + L$ violation from sphalerons

Add scalar singlet

M. Dine, P. Huet, R. L. Sigleton, Jr & L. Susskind, Phys. Lett. B257 (1991)
J. R. Espinosa, T. Konstandin & F. Riva, arXiv: 1107.5441

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Generation of a BAU

New sources of CP violation ← •C and CP violation

$B + L$ violation from sphalerons ← •B violation

Add scalar singlet ← •Out-of-equilibrium conditions

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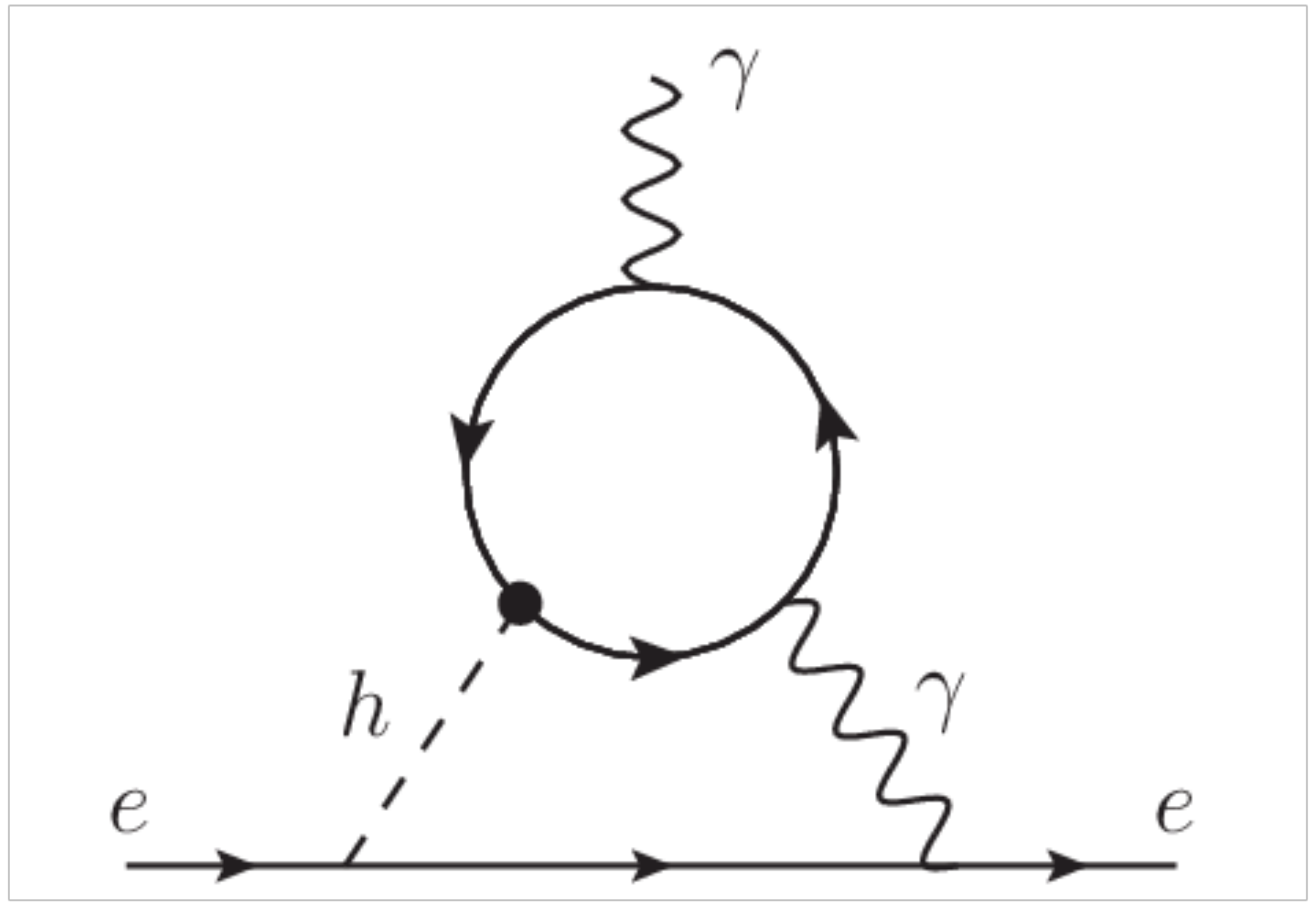
Bounds on new CP violation



G. Panico, M. Riembau, T. Vantalon, arXiv:1712.06337

Tight bounds from the electron's EDM

$$|d_e| < 1.1 \times 10^{-29} e \cdot cm$$

ACME Collaboration, Nature 562 (2018)

Rely on some dark sector to introduce new CP violation

E. Hall, T. Konstandin, R. McGehee, H. Murayama & G. Servant, arXiv: 1910.08068
M. Carena, M. Quirós & Y. Zhang, arXiv: 1811.09719

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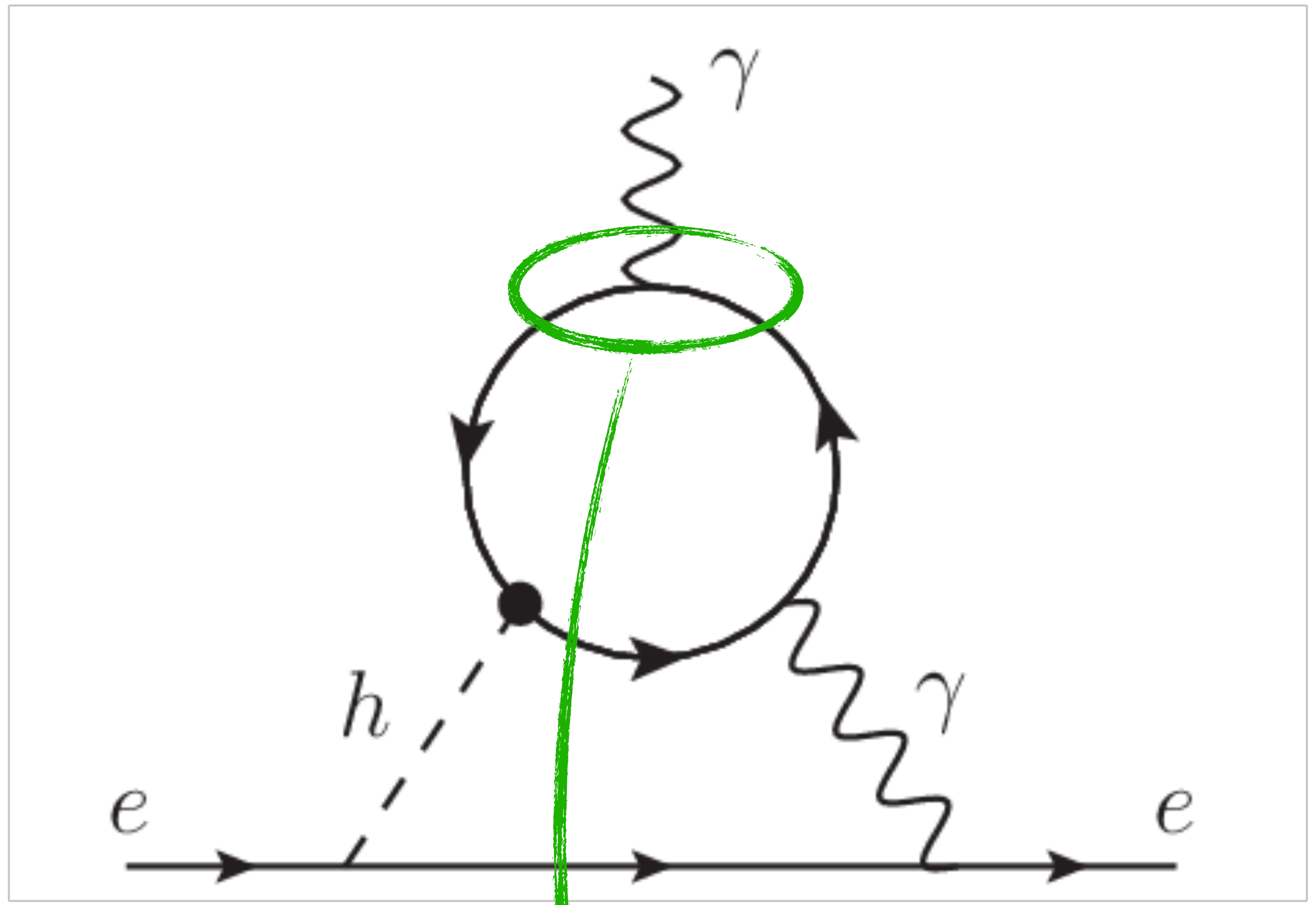

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ν do not couple to γ

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Electroweak baryogenesis and low-scale seesaw

First proposed in
P. Hernandez & N. Rius,
arXiv: hep-ph/9611227

$$\mathscr{L} \supset -\bar{L}_L Y_\nu \tilde{H} N_R - \bar{N}_L \phi Y_N N_R + h.c. - V\left(\phi^* \phi, H^\dagger H\right)$$

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Trigger 1st order
phase transition

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M. Malinsky *et al.*, arXiv:0506296

$$m_\nu \sim \mu_L \theta^2 \qquad \theta \sim \frac{v_H}{\sqrt{2} v_\phi} Y_\nu Y_N^{-1}$$

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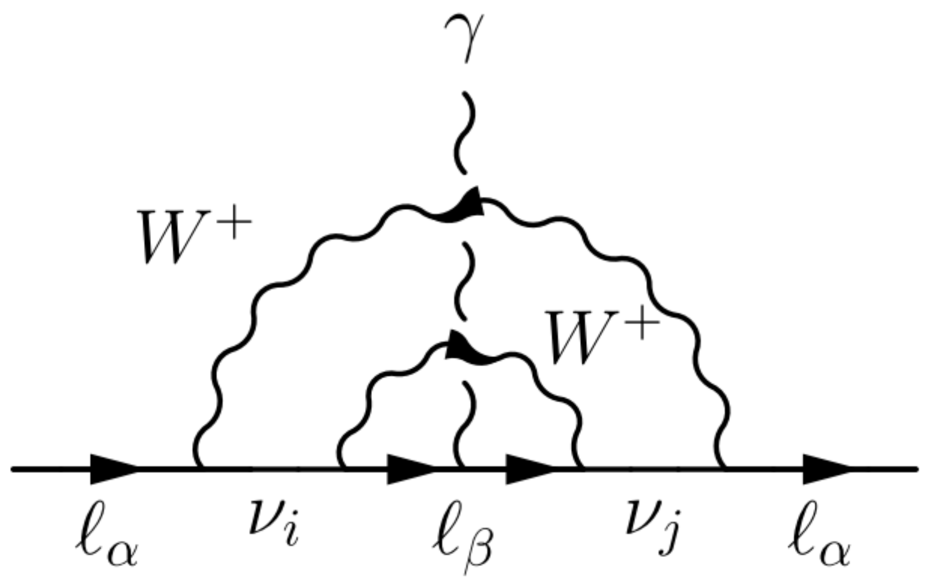
$$\delta_{CP} \propto (M_1^2 - M_2^2)(M_2^2 - M_3^2)(M_3^2 - M_1^2) Im\left[(\theta^\dagger\theta)_{12}(\theta^\dagger\theta)_{23}(\theta^\dagger\theta)_{31}\right]$$

Hierarchical heavy neutrinos



Avoid electric dipole moment bounds
A. Abada & T. Toma, arXiv: 1605.07643

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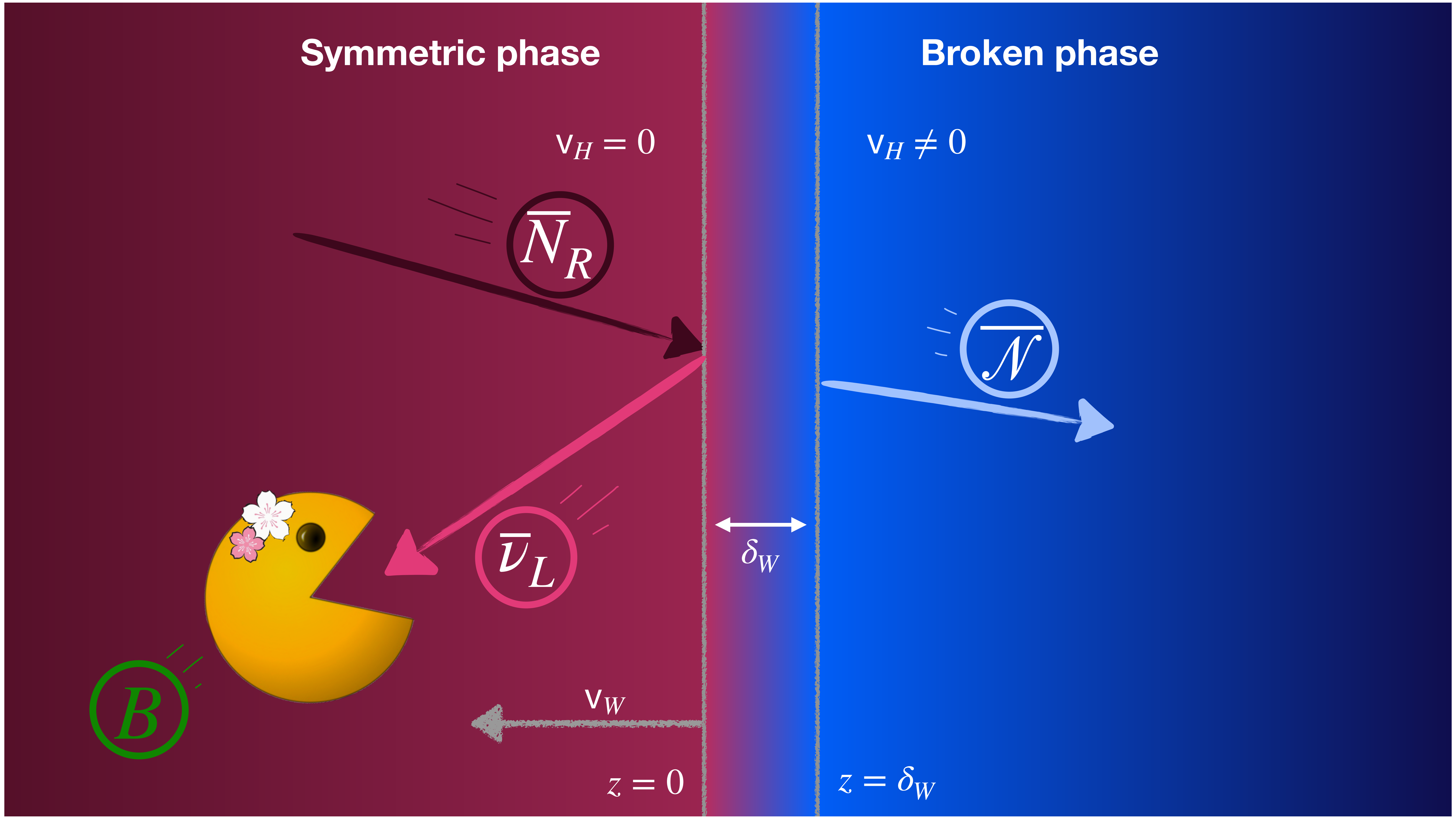
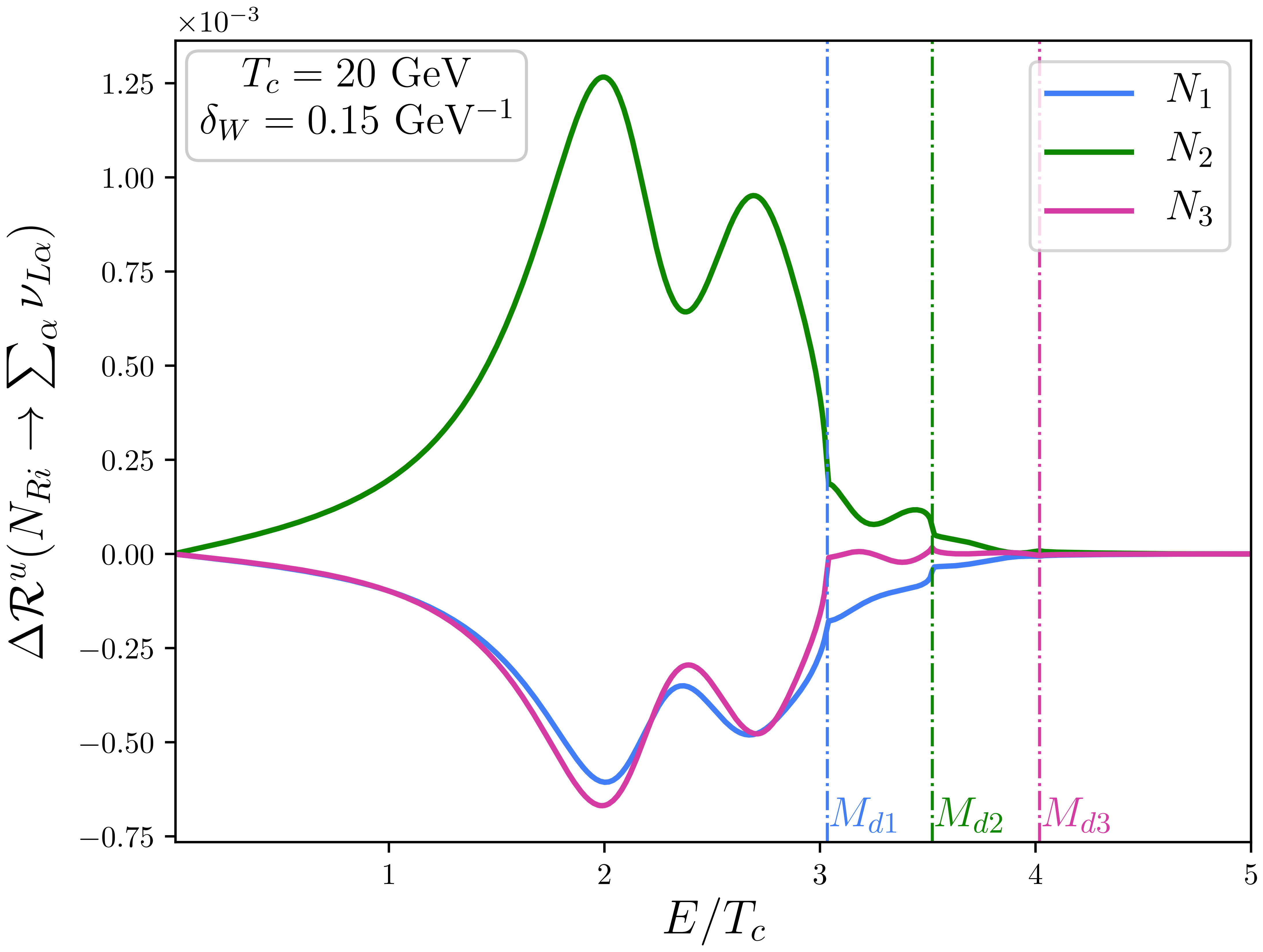
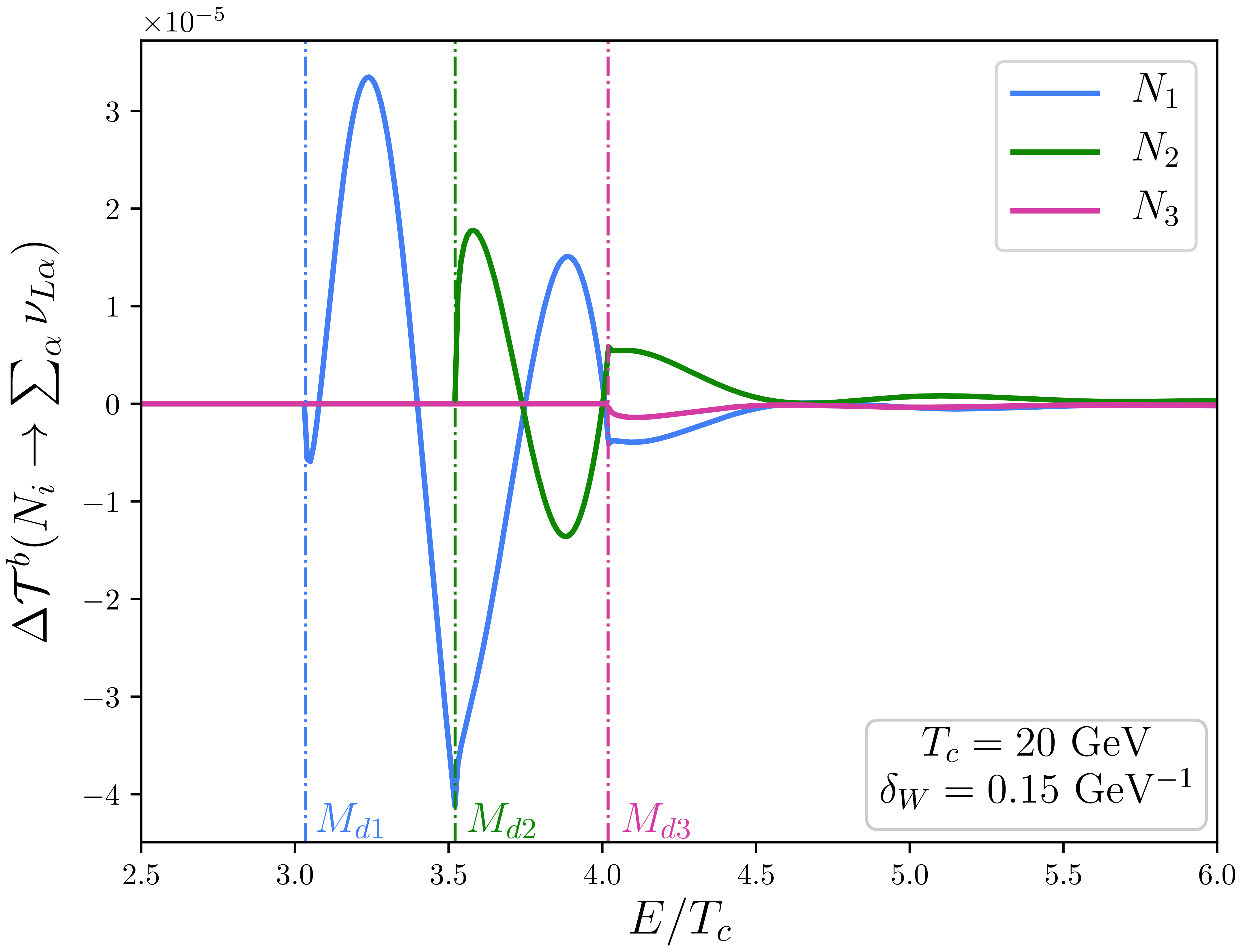


CP asymmetries



Reflection



Transmission

Diffusion equations

Vanilla scenario

M. Joyce, T. Prokopec & N. Turok, arXiv: hep-ph/9410281

$$D_B\partial_z^2 n_B - v_W\partial_z n_B - 3\Gamma_S\mathscr{H}(-z)n_B - \Gamma_S\mathscr{H}(-z)n_L = 0$$

P. Hernandez & N. Rius, arXiv: hep-ph/9611227

$$D_L\partial_z^2 n_L - v_W\partial_z n_L - \Gamma_S\mathscr{H}(-z)n_L - 3\Gamma_S\mathscr{H}(-z)n_B = \xi_L j_\nu \partial_z\delta(z)$$

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Follow the total B and L asymmetries and their conversion through sphalerons

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Follow the total B and L asymmetries and their conversion through sphalerons

$$j_\nu = \frac{1}{\gamma} \sum_{i,\alpha} \int \frac{d^3p}{(2\pi)^3} \left\{ \Delta \mathscr{T}^b(N_i \to \nu_{L\alpha}) \frac{|p_{zi}^b|}{E_i^b} f_i^b(p_i^b) + \Delta \mathscr{R}^u(N_{Ri} \to \nu_{L\alpha}) \frac{|p_{zi}^u|}{E_i^u} f_i^u(p_i^u) \right\}$$

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$$\boxed{B \propto \Gamma_S v_W \xi_L j_\nu \to Y_B = \frac{B}{s(T_c)}}$$

Diffusion equations

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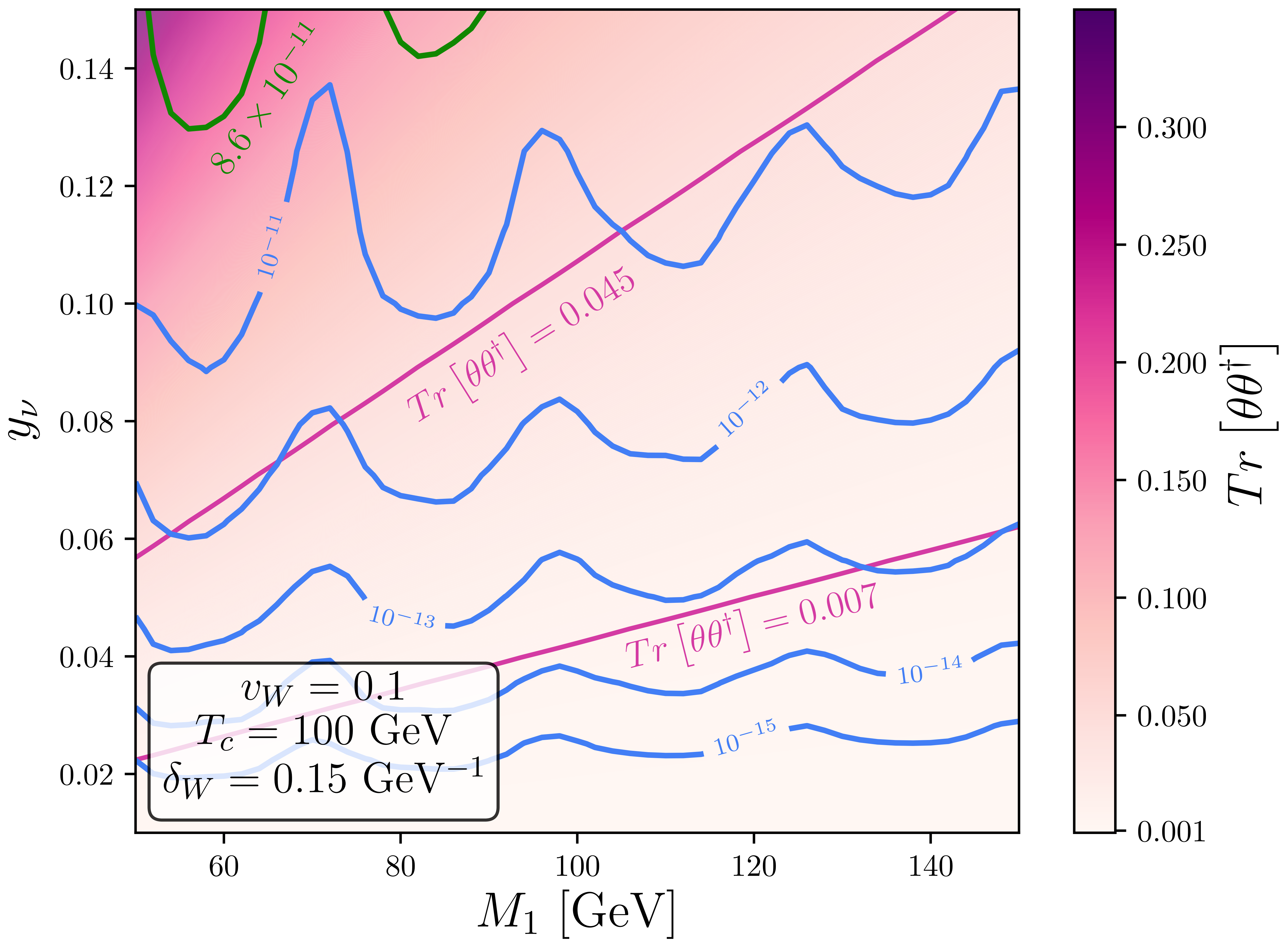

Diffusion equations

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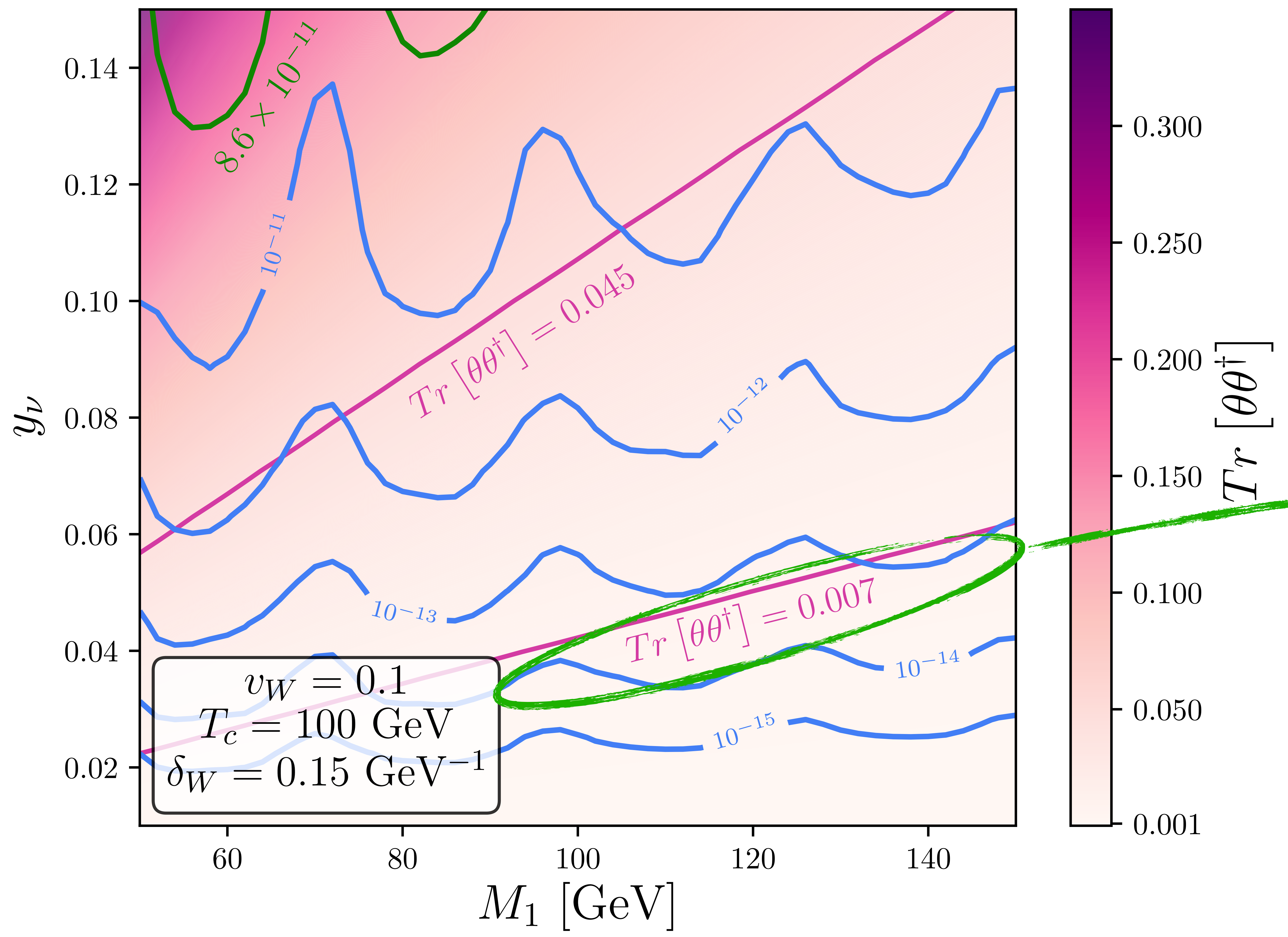
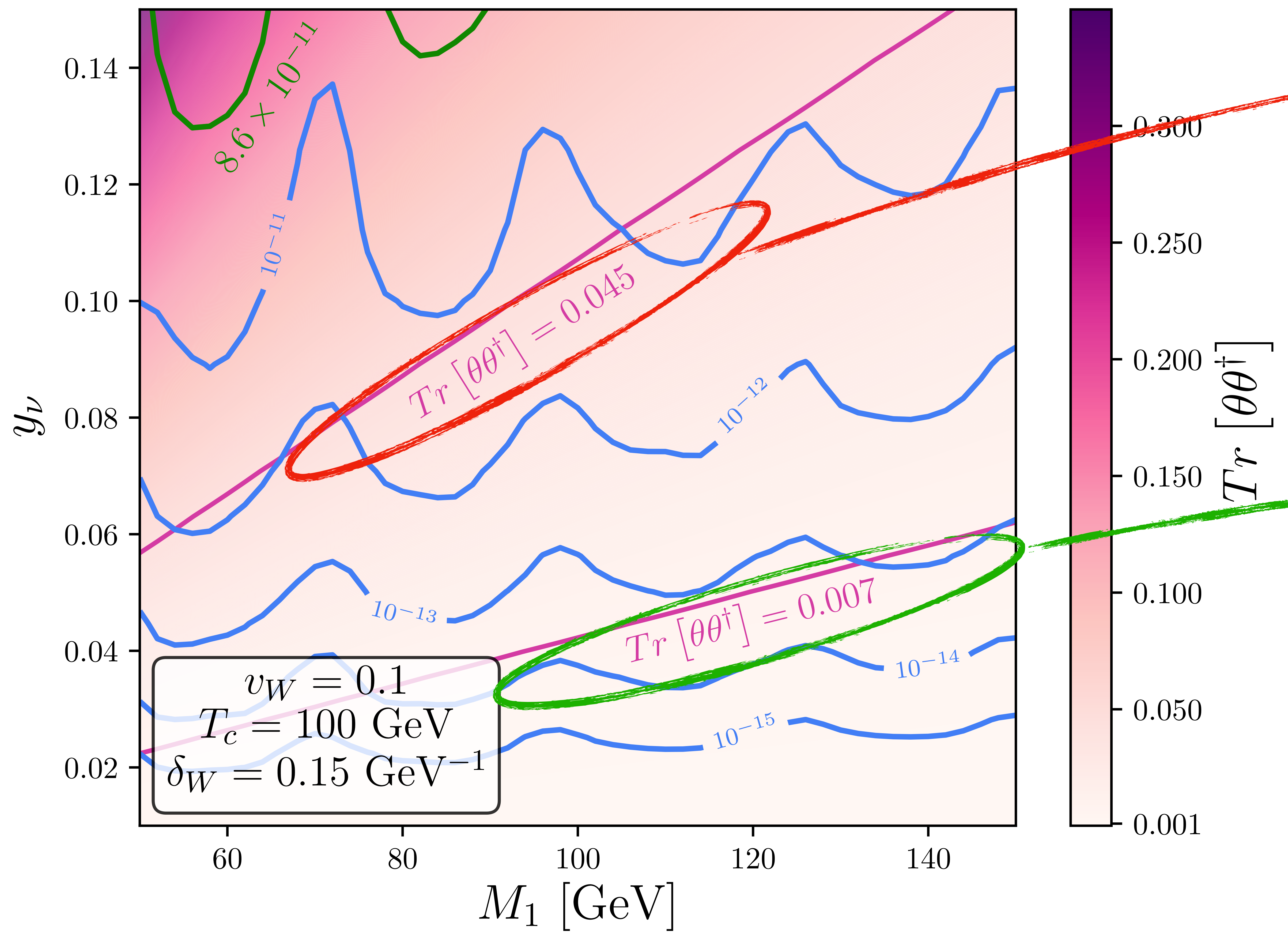


Current bound at 2σ on θ

E. Fernandez-Martinez, J. Hernandez & J. Lopez-Pavon, arXiv: 1605.08774

Diffusion equations

Vanilla scenario

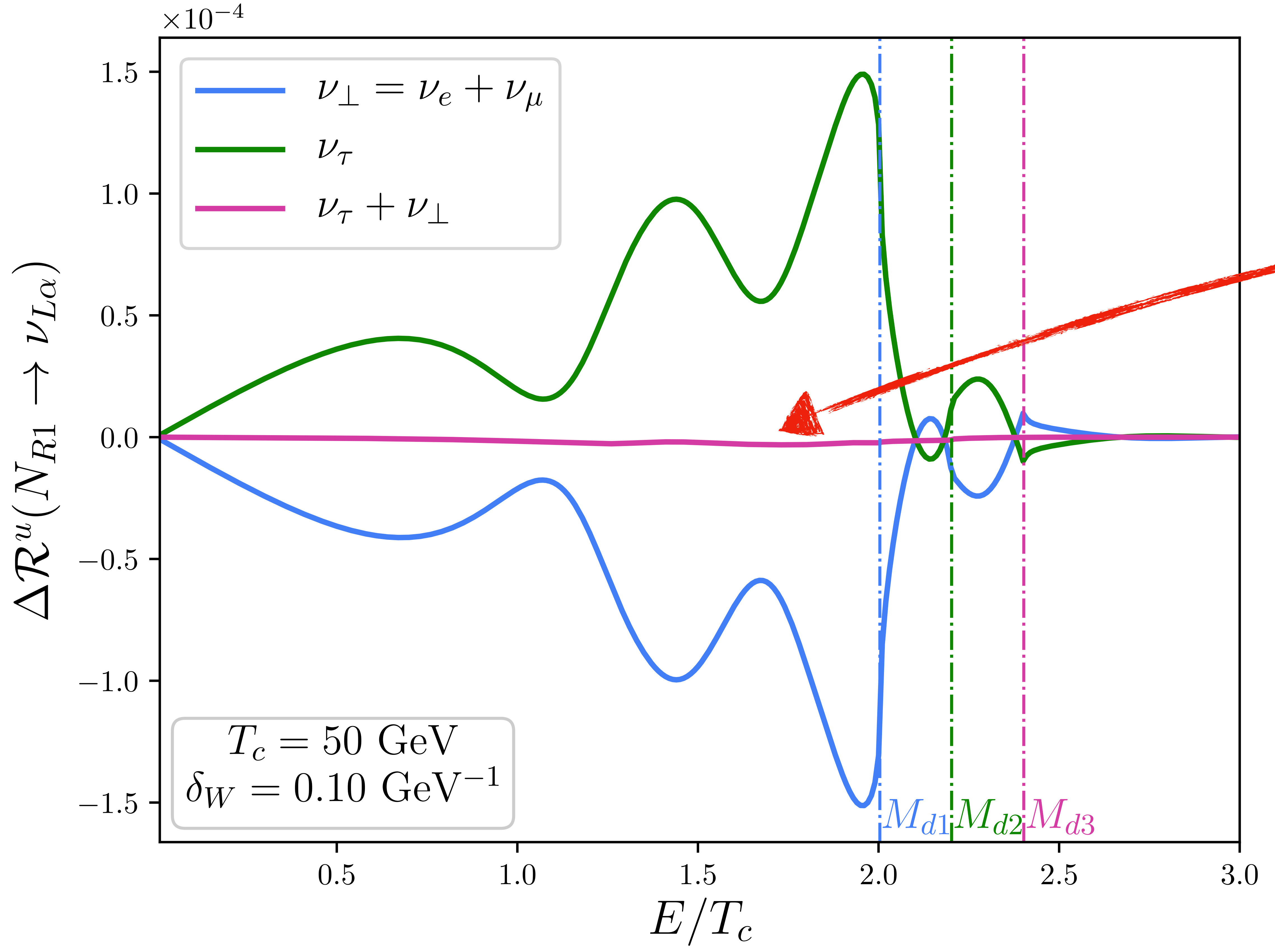


Bound on θ if avoiding the invisible width of the Z boson

Current bound at 2σ on θ

E. Fernandez-Martinez, J. Hernandez & J. Lopez-Pavon, arXiv: 1605.08774

Flavoured CP asymmetries



Reflection

Strong GIM cancellation
when summing over flavours

Diffusion equations

Flavoured scenario

M. Joyce, T. Prokopec & N. Turok,
arXiv: hep-ph/9410281

$$\frac{\Gamma_\tau}{T} \sim 0.28\alpha_W Y_\tau^2 \ll \frac{\Gamma_S}{T} = 9\kappa\alpha_W^5$$

Safe to neglect the wash-out with the τ

Diffusion equations

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$$\frac{\Gamma_{N_{Ri}\nu_{L\alpha}}}{T} \sim \frac{1}{128\pi}\left(Y_t^2 + Y_b^2\right)|(Y_\nu)_{\alpha i}|^2 \sim 0.0024\,|\theta_{\alpha i}|^2 \frac{2M_i^2}{v_H^2}$$

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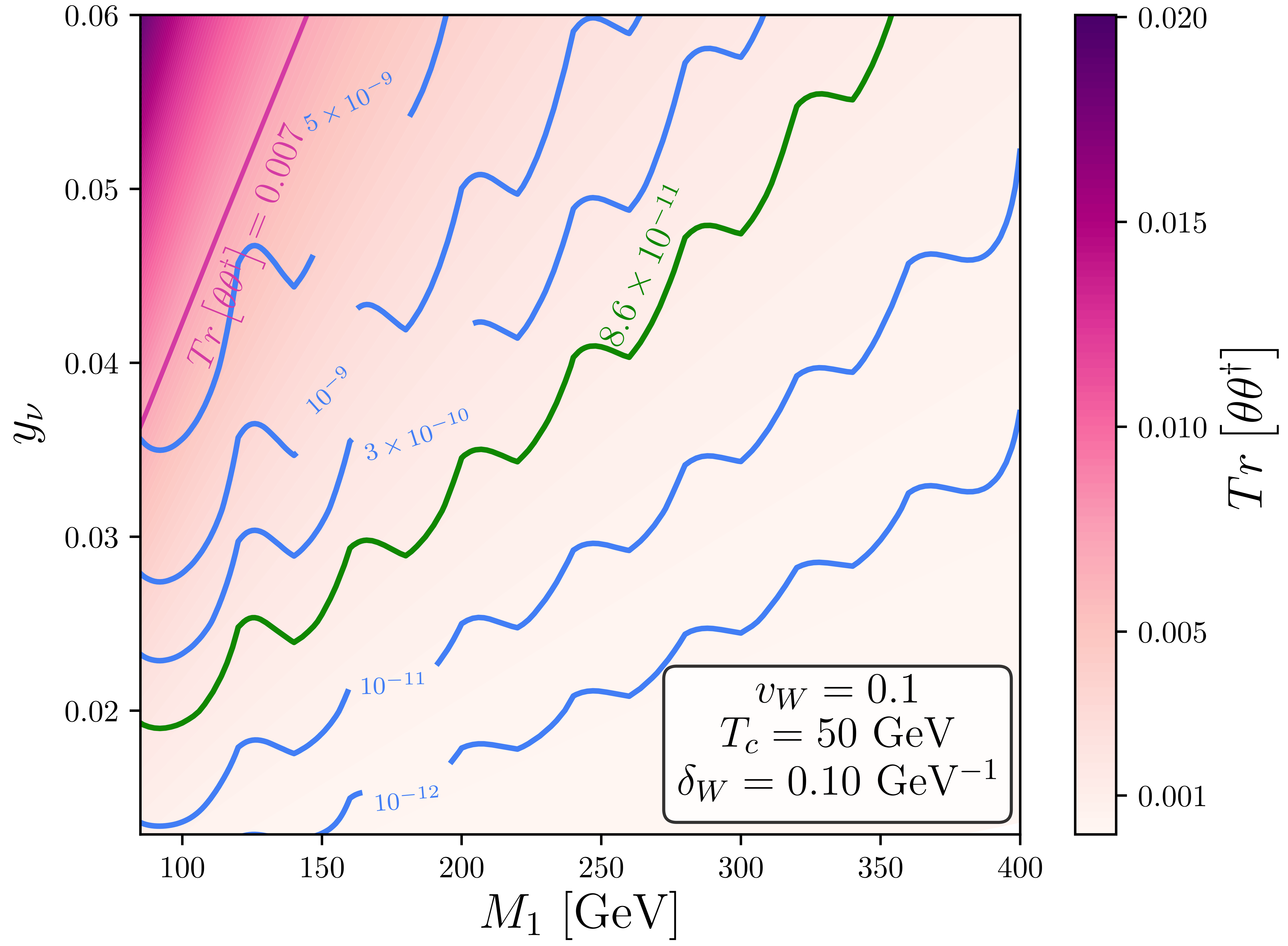
$$M_i \gtrsim 200\ GeV$$

→ We need to include the wash-out from the RH neutrinos

Diffusion equations

Flavoured scenario



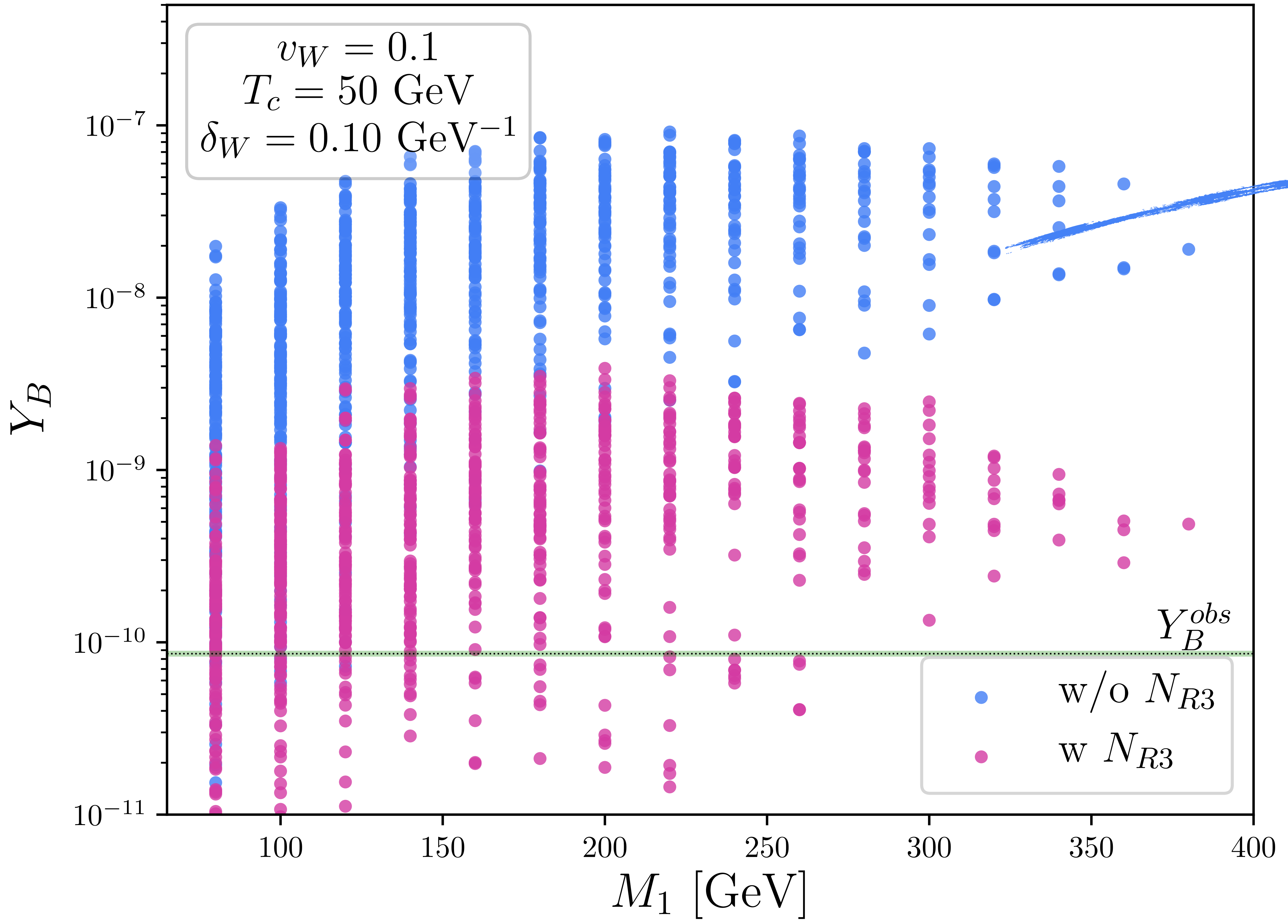
Larger baryon asymmetry:

- Breaking of GIM cancellation
- Introduction of N_R asymmetry, which diffuse more than ν_L

$$N_R \to \nu_L \to B$$

Diffusion equations

Flavoured scenario



Neglect the effect of N_{R3}

Diffusion equations

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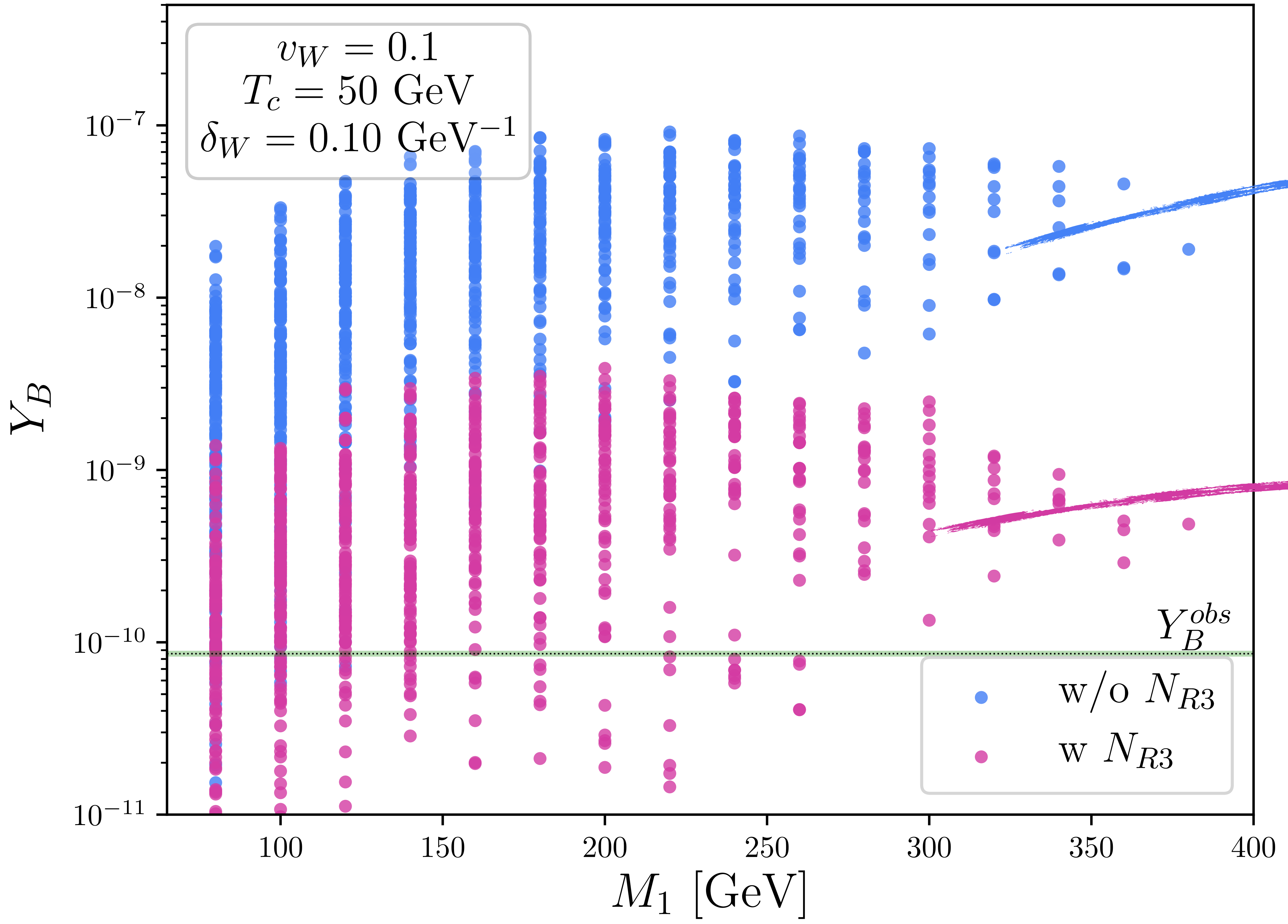

Neglect the effect of N_{R3}

Overestimate the importance of N_{R3}

Conclusions

- Low-scale **neutrino mass mechanism** could help in the **generation** of the **BAU**

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- **Avoid EDM constraints**

- **Flavour effects** play a crucial role in generating the correct BAU

- Explain the **BAU** with states with $M \sim 100\ GeV$ which **significantly mix with active neutrinos**→In reach for **colliders**