Wash-in Leptogenesis

as a New Framework for Baryogenesis

Based on : V. Domcke (CERN), KK, K. Mukaida (KEK), K, Schmitz (CERN), M. Yamada (Tohoku),
Phys. Rev. Lett 126 (2021) 201802 (arXiv: 2011.09347[hep-ph])

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Courtesy: H. Oide

Sakharov's condition ('67 Sakharov) ··· necessary condition for the BAU.

1. B-violation
2. C & CP-violation
3. Deviation from thermal equilibrium

Heavy particle decay in B/C&CP-violating way easily satisfies this condition.

e.g.) GUT gauge boson/Higgs boson decay

('78 Yoshimura, '78 Dimopoulous & Suskind, '79 Toussaint+, '79 Weinberg, '79 Barr+, ···)

Well-motivated model.

We have understood the origin of the matter-antimatter asymmetry of the Universe, though difficult to prove it experimentally···?

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The story is not so simple.

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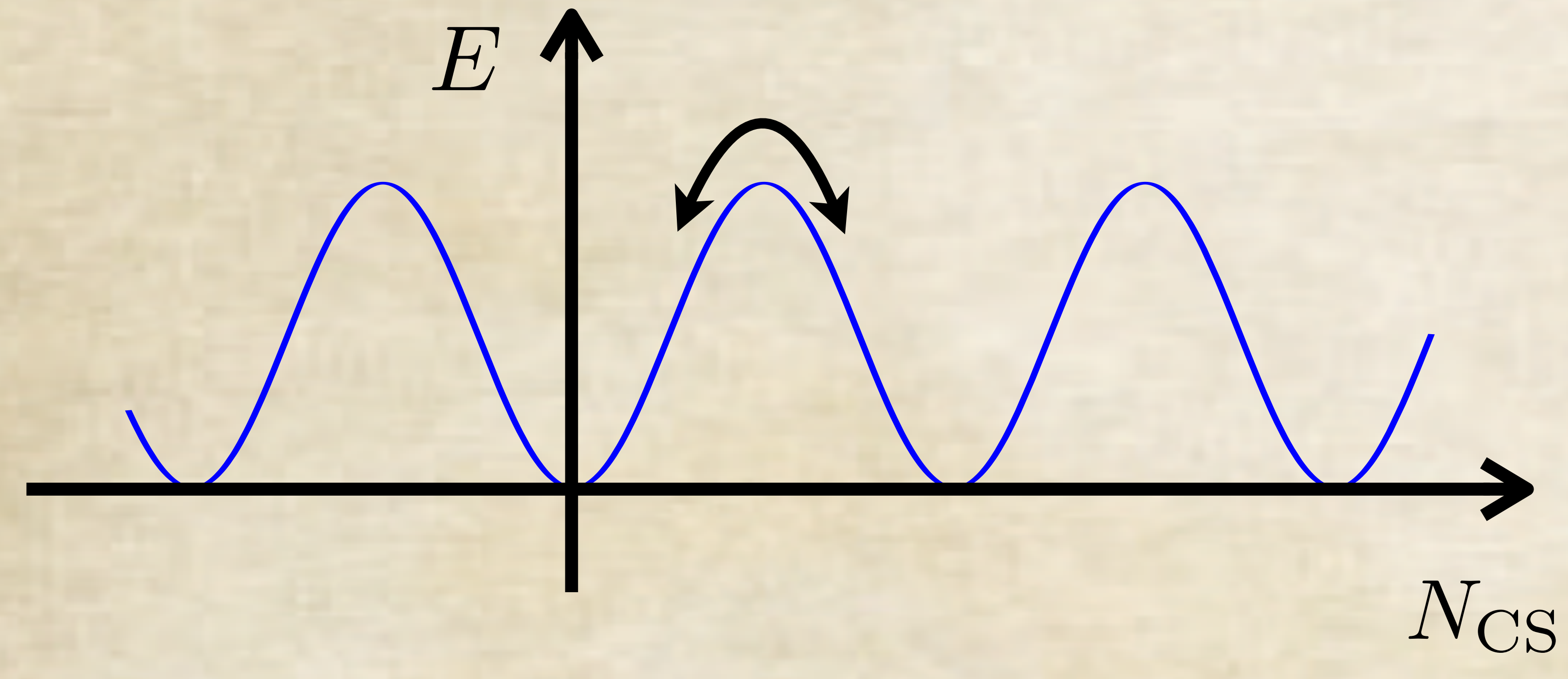
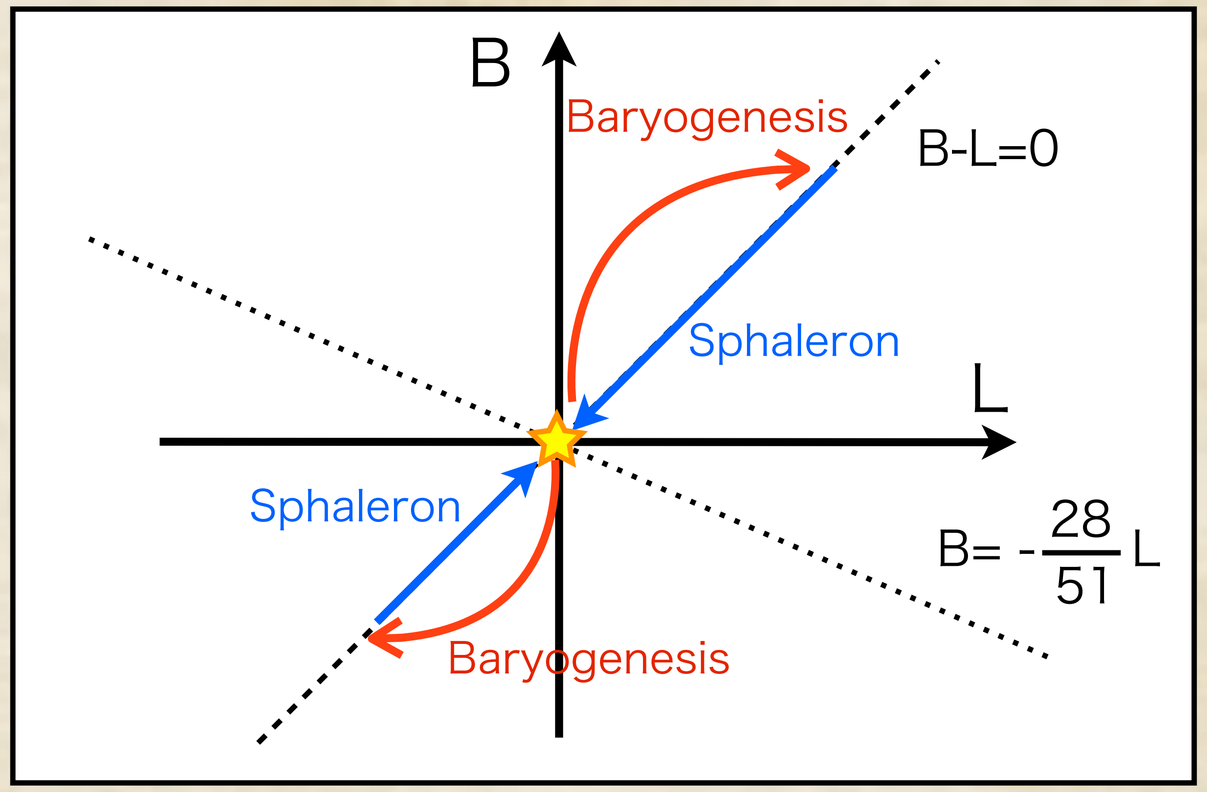
Electroweak sphaleron ('84 Klinkhamer & Manton)

⋯ washes out B+L asymmetry ('85 Kuzmin, Rubakov & Shaposhnikov).

killed SU(5) GUT baryogenesis.



$$\Delta N_{CS} \propto \Delta B = \Delta L$$



Options thus far:

- Generate B-L asymmetry (much) before EWSB.
- Generate B(+L) asymmetry after EWSB

First option⋯

need to violate B-L asymmetry,

exact (non-anomalous) symmetry of the SM.

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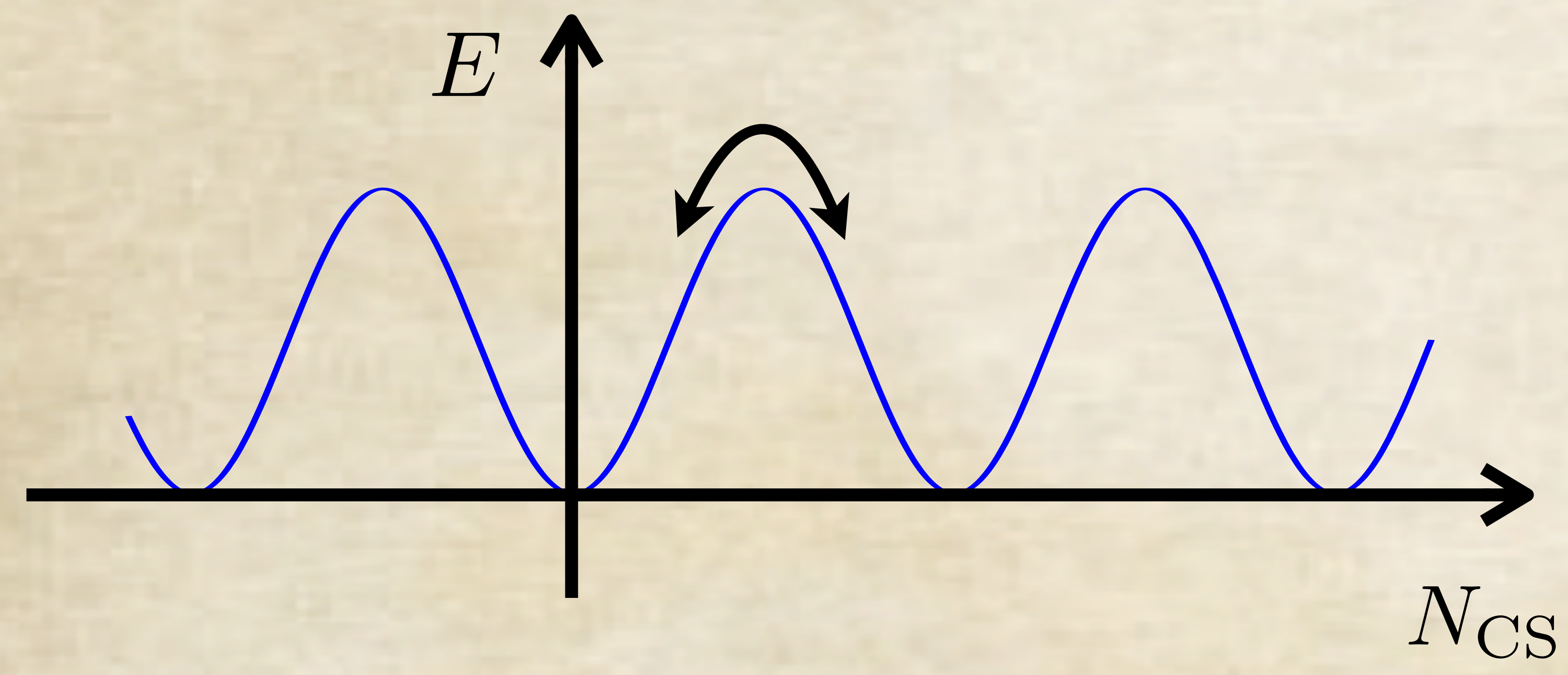

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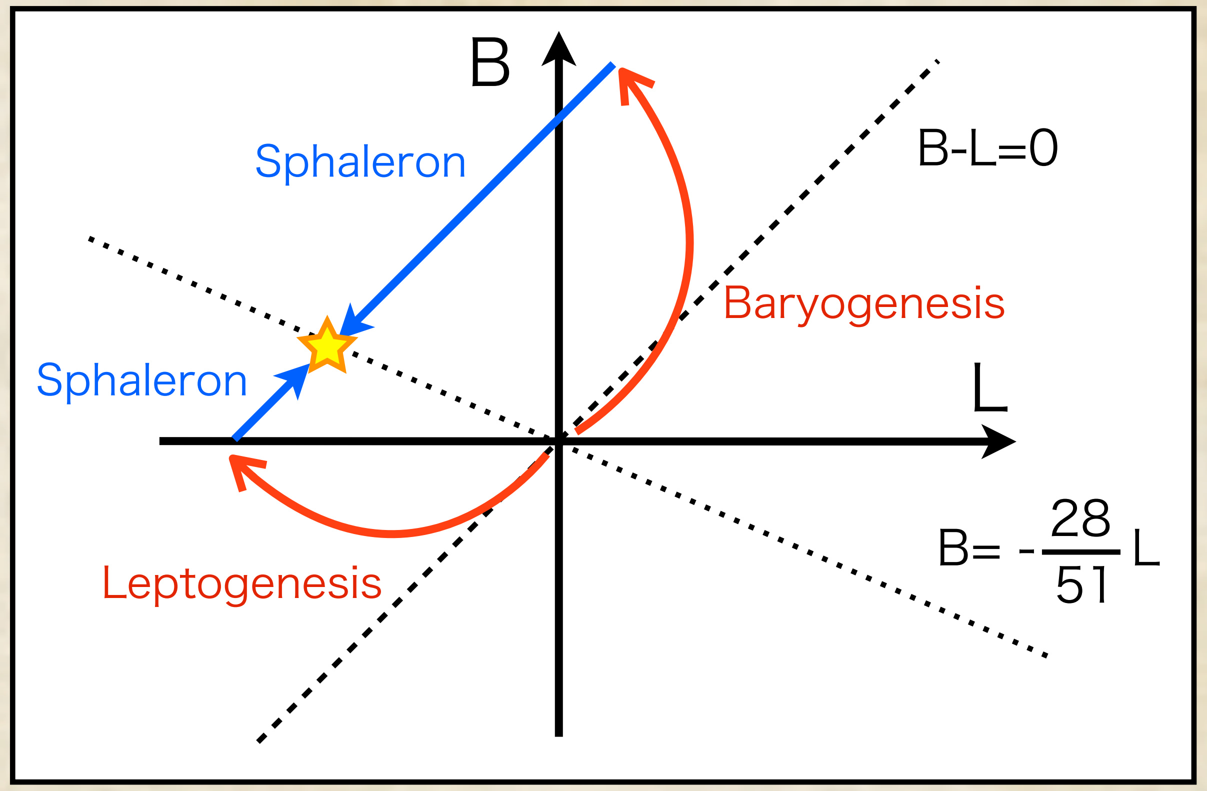

Options thus far:

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need to violate B-L asymmetry,

exact (non-anomalous) symmetry of the SM.

Right-handed neutrinos can be naturally introduced.

(Leptogenesis; '86 Fukugita & Yanagida)

But BAU from their decay needs severe conditions on the CP-violation and right-handed neutrino mass.

(See e.g., '05 Buchmüller, Di Bari, & Plumacher)

Courtesy: H. Oide

An issue in the B+L washout by EW sphalerons.

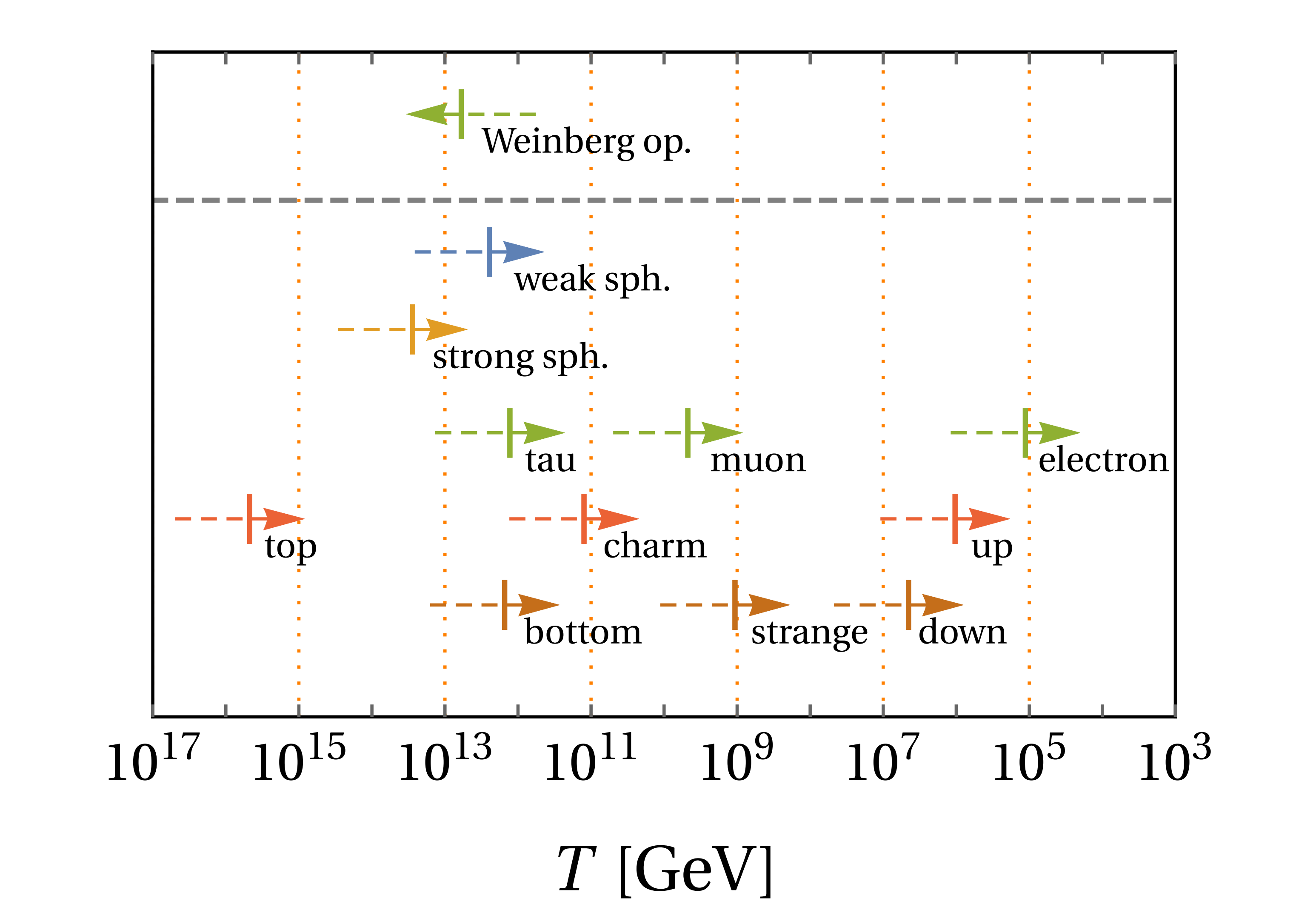
It completes when the electron Yukawa gets in equilibrium @ $T \lesssim 100\mathrm{TeV}$

('92 Campbell+)

Approx. conserved quantities prevents from the completion of washout.

@lower temp., the SM has only B/3-Li as a global conserved quantities

@higher temp., many other global conserved quantities appear, depending on temp.



Equilibrium temperature of Yukawa/sphalerons

(Figure from '20 Domcke+)

	T[GeV]	y_e	y_{ds}	y_d	y_s	y_{sb}	y_μ	y_c	y_τ	y_b	WS	SS	y_t
(v)	$(10^5, 10^6)$	q_e	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
(iv)	$(10^6, 10^9)$	q_e	$q_{2B_1-B_2-B_3}$	q_{u-d}	✓	✓	✓	✓	✓	✓	✓	✓	✓
(iii)	$(10^9, 10^{11-12})$	q_e	$q_{2B_1-B_2-B_3}$	q_{u-d}	q_{d-s}	$q_{B_1-B_2}$	q_μ	✓	✓	✓	✓	✓	✓
(ii)	$(10^{11-12}, 10^{13})$	q_e	$q_{2B_1-B_2-B_3}$	q_{u-d}	q_{d-s}	$q_{B_1-B_2}$	q_μ	q_{u-c}	q_τ	q_{d-b}	q_B	✓	✓
(i)	$(10^{13}, 10^{15})$	q_e	$q_{2B_1-B_2-B_3}$	q_{u-d}	q_{d-s}	$q_{B_1-B_2}$	q_μ	q_{u-c}	q_τ	q_{d-b}	q_B	q_u	✓

List of conserved quantities at several temperature regime

('21 Domcke, KK+)

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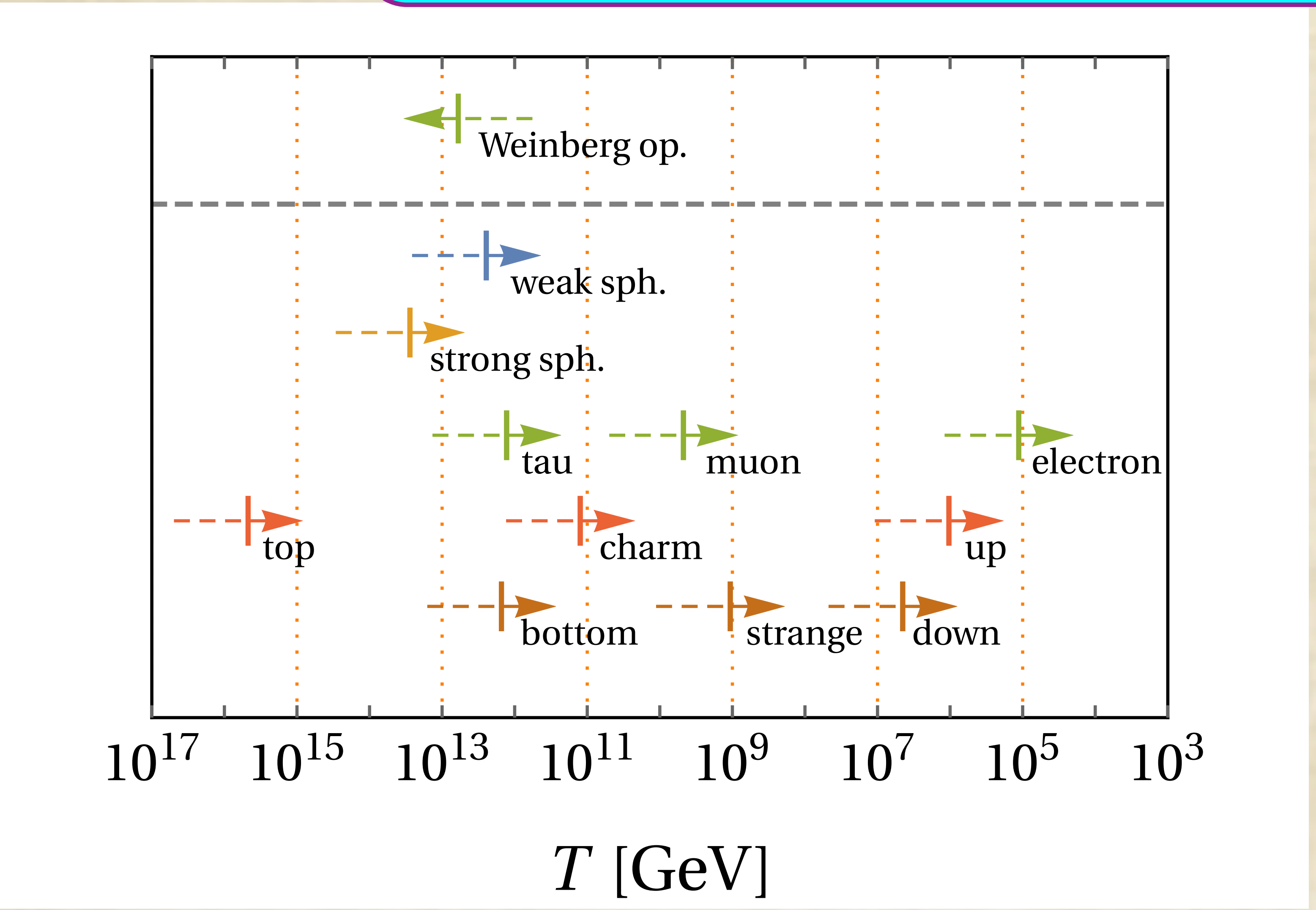
@lov

@hig g on temp.

Something can be implemented after the generation of asymmetry with B-L=0, before the completion of washout for net B generation.



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List of conserved quantities at several temperature regime

('21 Domcke, KK+)

Once initial asymmetry is generated by a “genesis” mechanism, one can determine the conserved charges and evolution of each particle asymmetries redistributed in a la Turner & Harvey (’90)’s way.

Yukawa: $\mu_{u_R} = \mu_{H_0} + \mu_{u_L}$

Sphaleron: $3N_f \sum_q \mu_q + \sum_l \mu_{=} 0$

$$\mu_i = \sum_C \tilde{S}_{iC} \mu_C$$

or

$$\mu_\alpha = \sum_C S_{\alpha C} \mu_C$$

μ_i : chemical potential for each particle

μ_C : chemical potential for conserved charge

μ_α : chemical potential for approx. conserved charge, such as B or B+L

From this calculation we obtain the well-known formula $\mu_B = \frac{28}{79} \mu_{B-L}^{\mathrm{ini}}$ after the electron Yukawa equilibration.

Courtesy: H. Oide

Once we introduce the right-handed neutrinos,
the way how asymmetries are redistributed changes.

We might expect the L asymmetry is induced.

(also see ’02 Fukugita & Yanagida)

New equilibrium condition:

$$\mu_{L_\alpha} + \mu_H = \mu_{N_R^i}$$

When the right-handed neutrinos are almost massless,
the L-violating effect should not be relevant.

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New equilibrium condition:

$$\mu_{L_\alpha} + \mu_H = \mu_{N_R^i} \longrightarrow 0 \qquad \text{when } T \simeq m_{N_R}$$

When the right-handed neutrinos become massive,
the L-violating effects should be effective.

At this point, $\Delta_i \equiv B/3 - L_i$ are not conserved charge.

$$(\alpha = L_\alpha + H)$$

$$\mu_\alpha = \sum_C S_{\alpha C}\mu_C \;\Rightarrow\; 0 = \sum_{C\neq\Delta_i} S_{\alpha C}\mu_C + \sum_i S_{\alpha\Delta_i}\mu_{\Delta_i} \;\Rightarrow\; \mu_{\Delta_i} = \sum_C S^{-1}_{\alpha\Delta_i} S_{\alpha C}\mu_C$$

B-L asymmetry is induced in the system (and fixed quickly)!

We name it
"wash-in" process.

Courtesy: H. Oide

Once we introduce the right-handed neutrinos,

the w

	T_{B-L} [GeV]	Index α	μ_e	$\mu_{2B_1-B_2-B_3}$	μ_{u-d}	μ_{d-s}	$\mu_{B_1-B_2}$	μ_μ	μ_{u-c}	μ_τ	μ_{d-b}	μ_B	μ_u	$\mu_{\Delta_\perp}$
(v)	$(10^5, 10^6)$	e, μ, τ	$-\frac{3}{10}$	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
(iv)	$(10^6, 10^9)$	e, μ, τ	$-\frac{3}{17}$	0	$-\frac{7}{17}$	✗	✗	✗	✗	✗	✗	✗	✗	✗
(iii)	$(10^9, 10^{11-12})$	$\parallel_\tau, \tau$	$\frac{142-225P_\tau}{247}$	0	$-\frac{123}{247}$	$-\frac{82}{247}$	$\frac{123}{494}$	$\frac{142-225P_\tau}{247}$	✗	✗	✗	✗	✗	$\frac{225}{247}$
(ii)	$(10^{11-12}, 10^{13})$	$\parallel$	$\frac{-23P+7}{30}$	$\frac{1}{5}$	$-\frac{3}{5}$	$-\frac{1}{6}$	$-\frac{3}{10}$	$\frac{-23P+7}{30}$	$\frac{3}{10}$	$\frac{-23P+7}{30}$	$-\frac{4}{15}$	$\frac{23}{90}$	✗	$\frac{23}{30}$
(i)	$(10^{13}, 10^{15})$	$\parallel$	$\frac{-3P+1}{4}$	$\frac{1}{6}$	$-\frac{5}{6}$	$-\frac{1}{4}$	$-\frac{1}{4}$	$\frac{-3P+1}{4}$	$\frac{1}{4}$	$\frac{-3P+1}{4}$	$-\frac{1}{3}$	$\frac{1}{6}$	$\frac{1}{3}$	$\frac{3}{4}$

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B-L asymmetry is induced in the system (and fixed quickly)!

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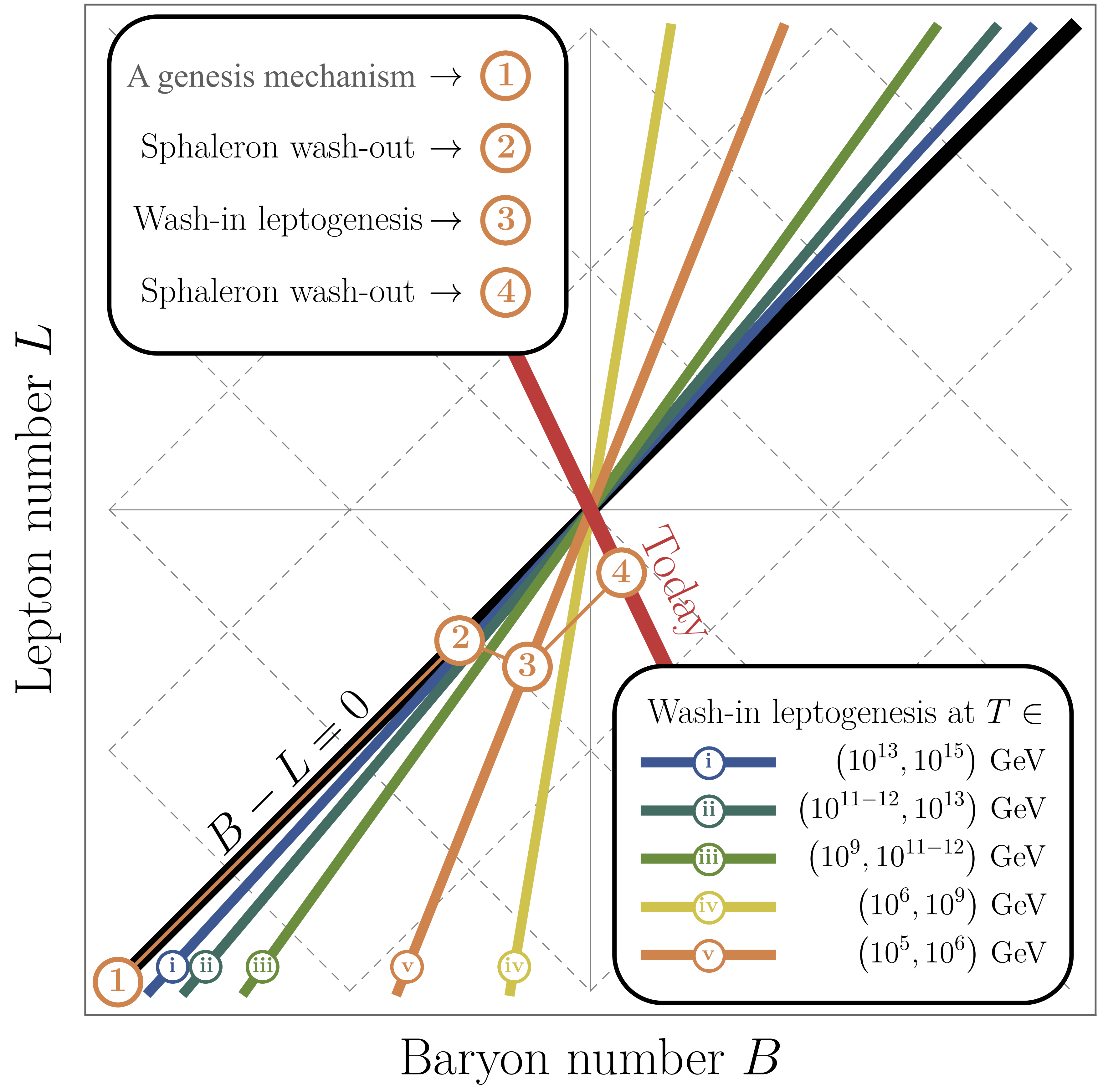
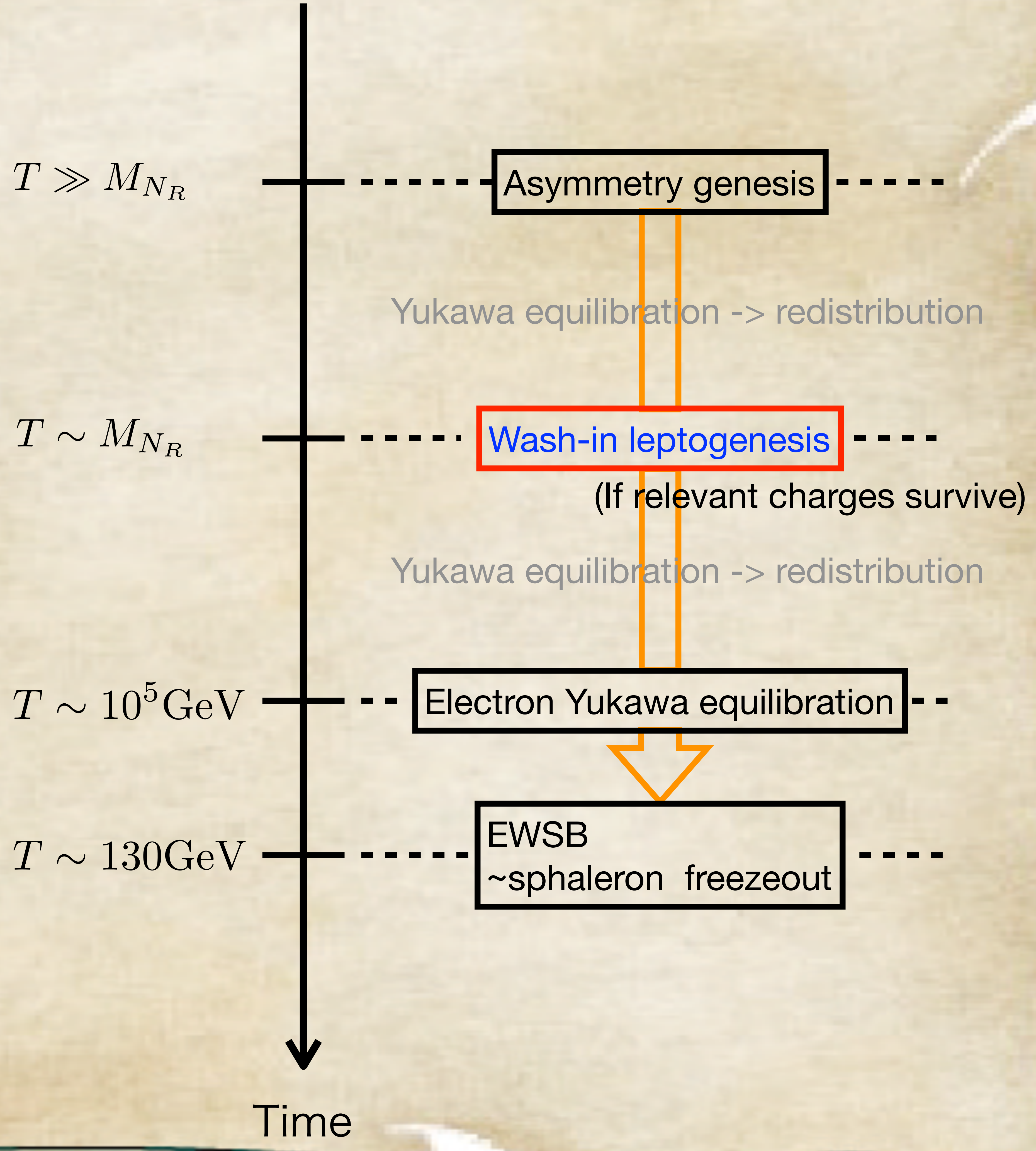
The way how B and L asymmetry is redistributed



('21 Domcke, KK+)



Courtesy: H. Oide

Advantages of wash-in leptogenesis

- Sakharov's condition does not have to be satisfied simultaneously.

  C&CP-violation/Deviation from equilibrium: asymmetry genesis @high temp.

  (not have to be B-L)

  B-L violation: Right-handed neutrino decoupling @ $T \simeq m_{N_R}$

  # RHN sector does not have to violate C & CP.

- Depending on the initial asymmetries, wash-in works with relatively light RHNs.

  can be consistent with naturalness $m_{N_R} \lesssim 10^7 \mathrm{GeV}$ (Vissani bound ('98))

  and also the neutrino option ('17 Brivio & Trott)

  c.f.) The vanilla leptogenesis requires $m_{N_R} \gtrsim 10^9 \mathrm{GeV}$ (Davidson-Ibarra bound ('02))

Courtesy: H. Oide

Applications/Realizations

- SU(5) GUT baryogenesis from the GUT Higgs decay

B+L but not B-L asymmetry is generated.
Wash-in helps to avoid the sphaleron washout.
Lowest RHN mass for the wash-in depends on the decay ratio of the GUT Higgs.

- Axion inflation

$\phi Y_{\mu\nu}\tilde{Y}^{\mu\nu}$ coupling generate both B+L asym. and hypermagnetic helicity through chiral anomaly.
They can annihilate each other at a later time.
Wash-in prevents from the complete cancellation of B+L and helicity.

Final baryon asymmetry is the summation of the B+L with wash-in
and hypermagnetic helicity decay at EWSB. (Domcke, KK+, in prep.)

(See also F. Uchida's talk)

Courtesy: H. Oide

Summary

- Wash-in leptogenesis is a new framework for baryogenesis.

- It uses the redistribution of the asymmetries with the RHN mass term, between the asymmetry generation and completion of would-be sphaleron washout.

- The idea is based on the fact that the Sakharov's condition does not have to be satisfied simultaneously.

- Relatively light RHN can be useful, consistent with naturalness problem and neutrino option.

- SU(5) GUT baryogenesis and baryogenesis from axion inflation is rescued, but the idea does not have to be limited to these examples.

Courtesy: H. Oide