Baryon Asymmetry

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Place

Location: The Hong Kong University of Science and Technology
Address: Hong Kong, China

Files

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Date: **28 Jun 19:30 - 21:30**

Description

Discussion Leader: Pasquale Di Bari (University of Southampton, United Kingdom)

Timetable | Contribution List

Wed 28/06

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19:00

Electroweak Baryogenesis — *Thomas KONSTANDIN*
The Hong Kong University of Science and Technology — 19:30 - 19:45

20:00

Unifying Inflation with the Axion, Dark Matter, Baryogenesis and the Seesaw Mechanism — *Carlos TAMARIT*

Baryogenesis from Right-Handed Neutrino Oscillations — *Takehiko ASAKA*
The Hong Kong University of Science and Technology — 20:10 - 20:25

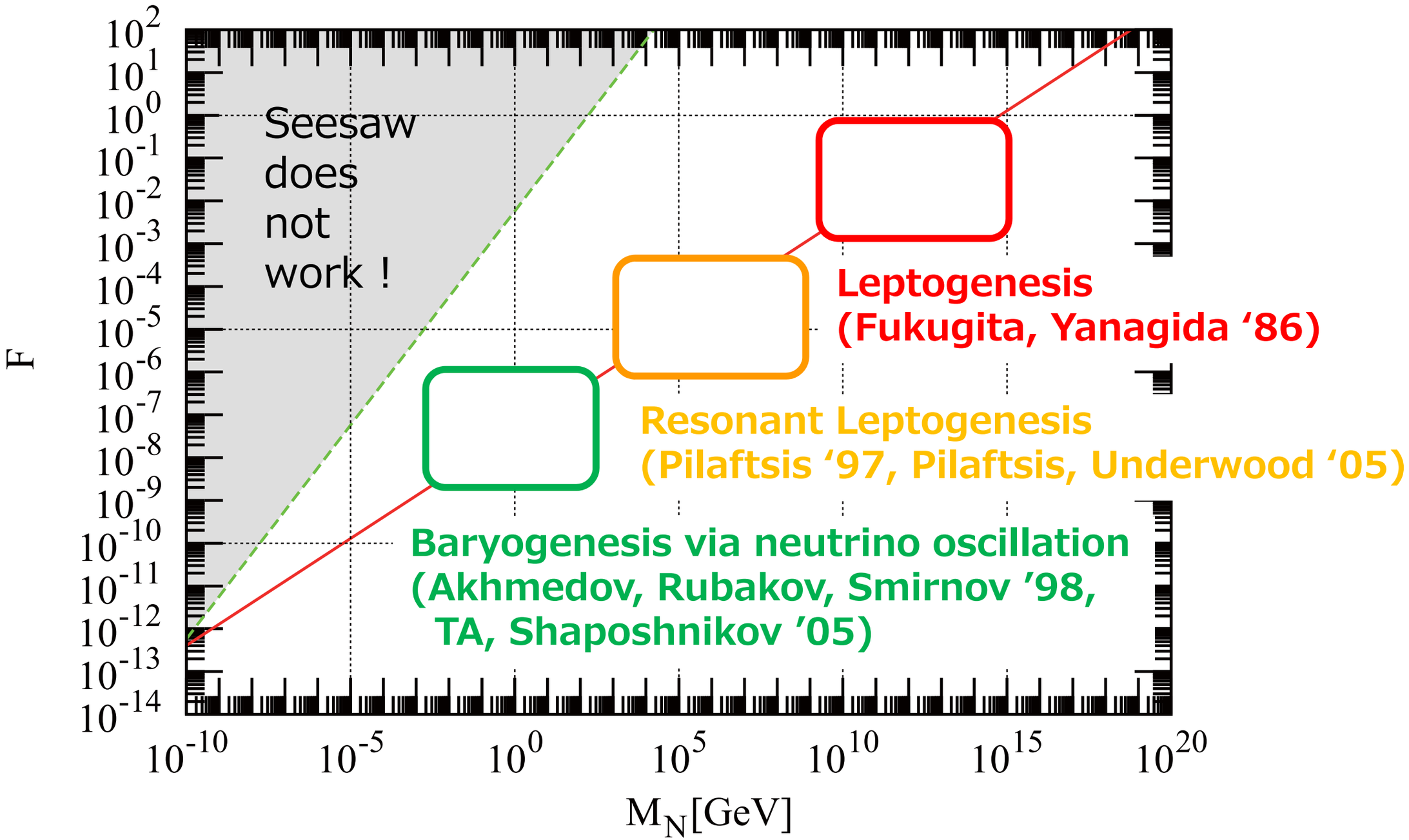
Leptogenesis from Realistic Models — *Chee Sheng FONG*
The Hong Kong University of Science and Technology — 20:30 - 20:45

21:00

Models on the Origin of Ordinary and Dark Matter — *Peihong GU*
The Hong Kong University of Science and Technology — 20:50 - 21:05

Yukawa coupling and Majorana mass

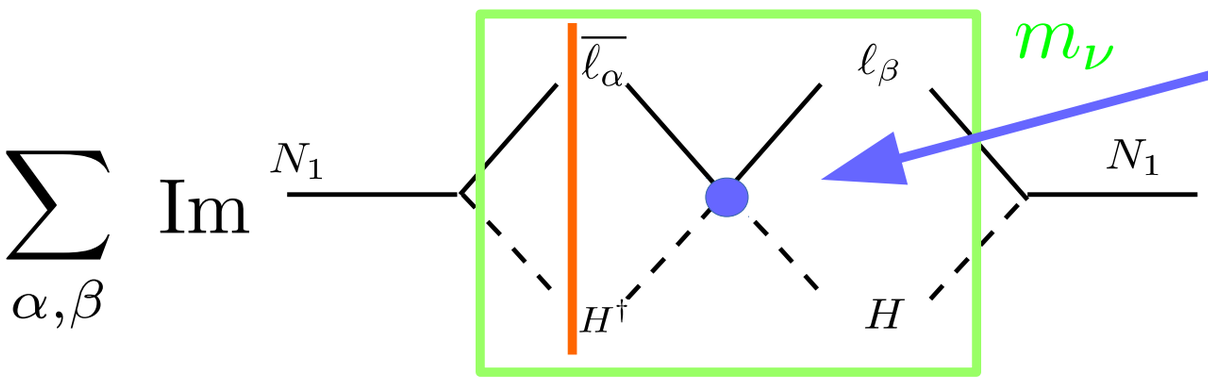
Explain baryon asymmetry of the universe too!



Restrictions from neutrino masses

- CP violation is tied to neutrino mass scale

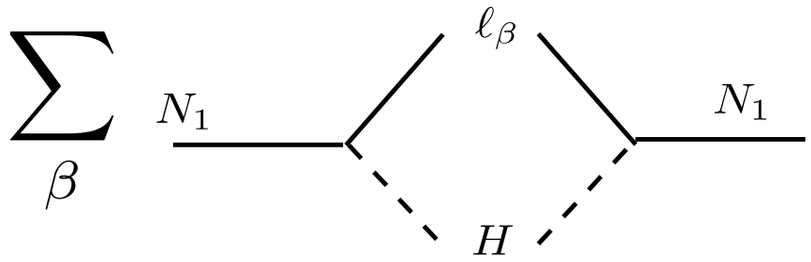
$$\epsilon \equiv \frac{\sum_{\alpha,\beta} \mathrm{Im}}{\sum_{\beta}}$$



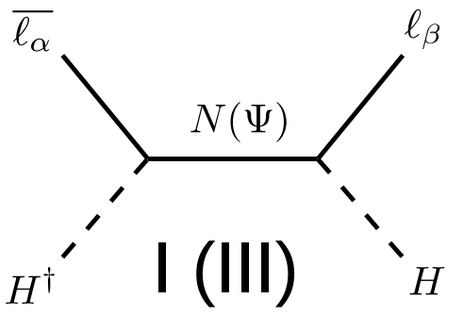
m_ν

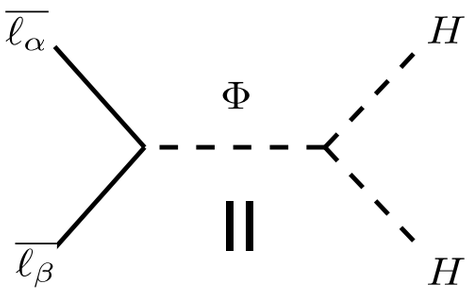
Heavier states

Phases from kinematic & couplings



$$|\epsilon| \sim \frac{1}{16\pi} \frac{m_\nu M_1}{v^2}$$





$$|\epsilon| \gtrsim 10^{-7} \Longrightarrow M_1 \gtrsim 3 \times 10^9 \left(\frac{0.05\,\mathrm{eV}}{m_\nu}\right) \mathrm{GeV}$$

[Davidson & Ibarra (hep-ph/0202239)]

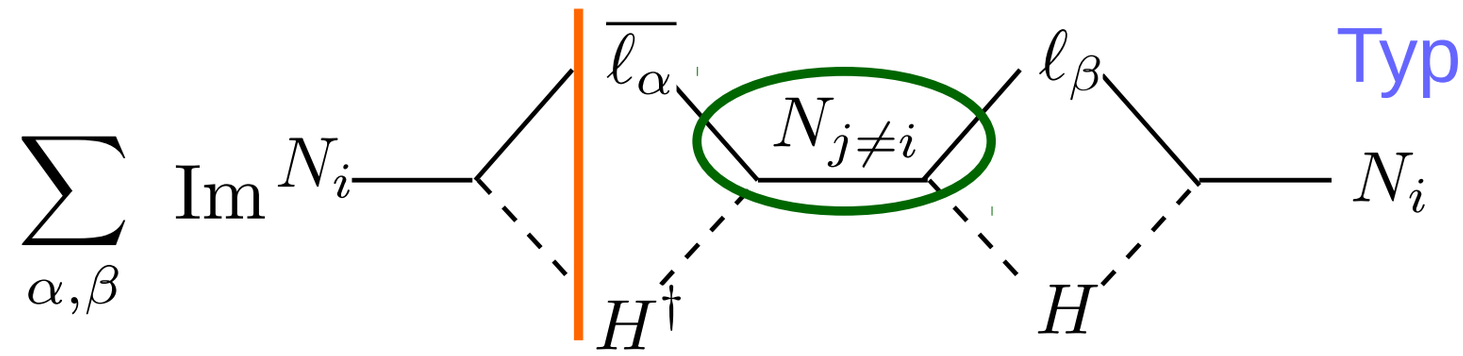
Caveats

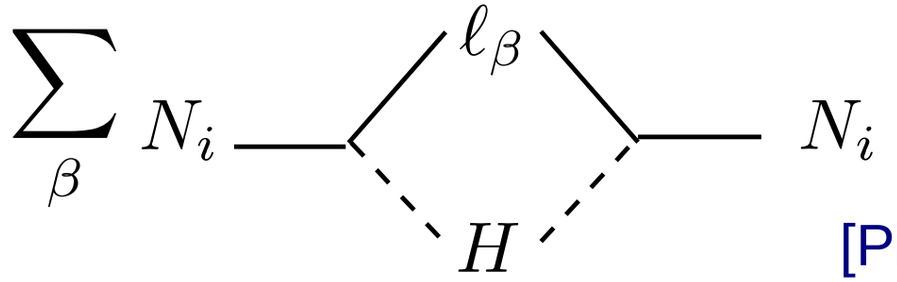
$$M_i \sim M_j$$

- "Heavier states" not much heavier → ***resonant enhancement***

Type I seesaw

$$\epsilon_i \equiv \frac{\sum_{\alpha,\beta} \mathrm{Im}}{\sum_{\beta}}$$





[Pilaftsis (hep-ph/9707235)]

$$\epsilon_i \sim \frac{1}{16\pi}\frac{m_\nu M_i}{v^2} \times \sum_j \sin(\phi_i - \phi_j)\frac{(M_i^2 - M_j^2)M_j^2}{(M_i^2 - M_j^2)^2 + M_i^2\Gamma_j^2}$$

Can go as low as possible i.e. $M_i > 132\,\mathrm{GeV}$ (more later)

Doesn't apply on those which rely on different physical mechanisms...

Resonant leptogenesis

[Pilaftsis (hep-ph/9707235)] [Pilaftsis & Underwood (hep-ph/0309342)]

- The right-handed neutrinos are quasi-degenerate to enhance the CP violation from self energy corrections
- Can be probed at LHC & CLFV [Bray, Lee & Pilaftsis (hep-ph/0702294)]
- Quasi-degeneracy $M_2 - M_1 = \mu \ll M_{1,2} \approx M$ due to
  - Approximate family symmetry (ok)
  - Soft SUSY breaking terms (ok)
  - Approximate lepton number (*difficult*)

[Grossman et al. (hep-ph/0307081)]
[D' Ambrosio et al. (hep-ph/0308031)]
[Review (hep-ph/1107.5312)]

Difficult because mass degeneracy is tied to CP violation!

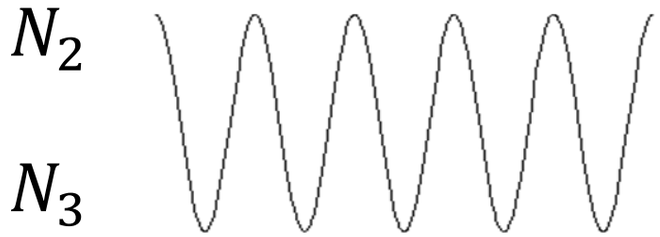
$$M_2 - M_1 = \mu \qquad\qquad |\epsilon| \propto \mu$$

Baryogenesis via neutrino oscillation

- **Oscillation of RH neutrinos can be a source of BAU**

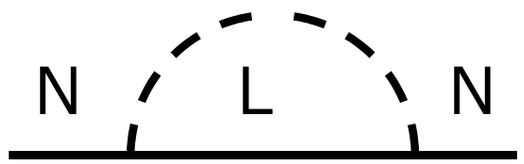
  Akhmedov, Rubakov, Smirnov ('98) / TA, Shaposhnikov ('05)

  - Oscillation starts at $\boldsymbol{T_{osc} \simeq (M_0\, M_N\, \Delta M)^{1/3}}$

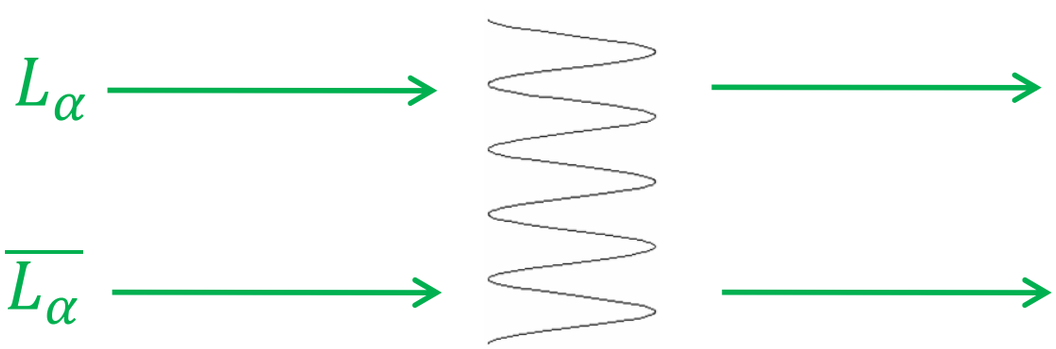


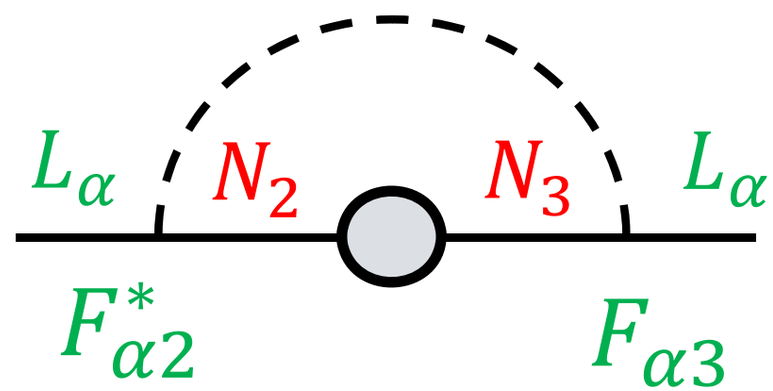
$\Leftarrow$ $V_N = \dfrac{T^2}{8\,k} F^\dagger F$

Medium effects

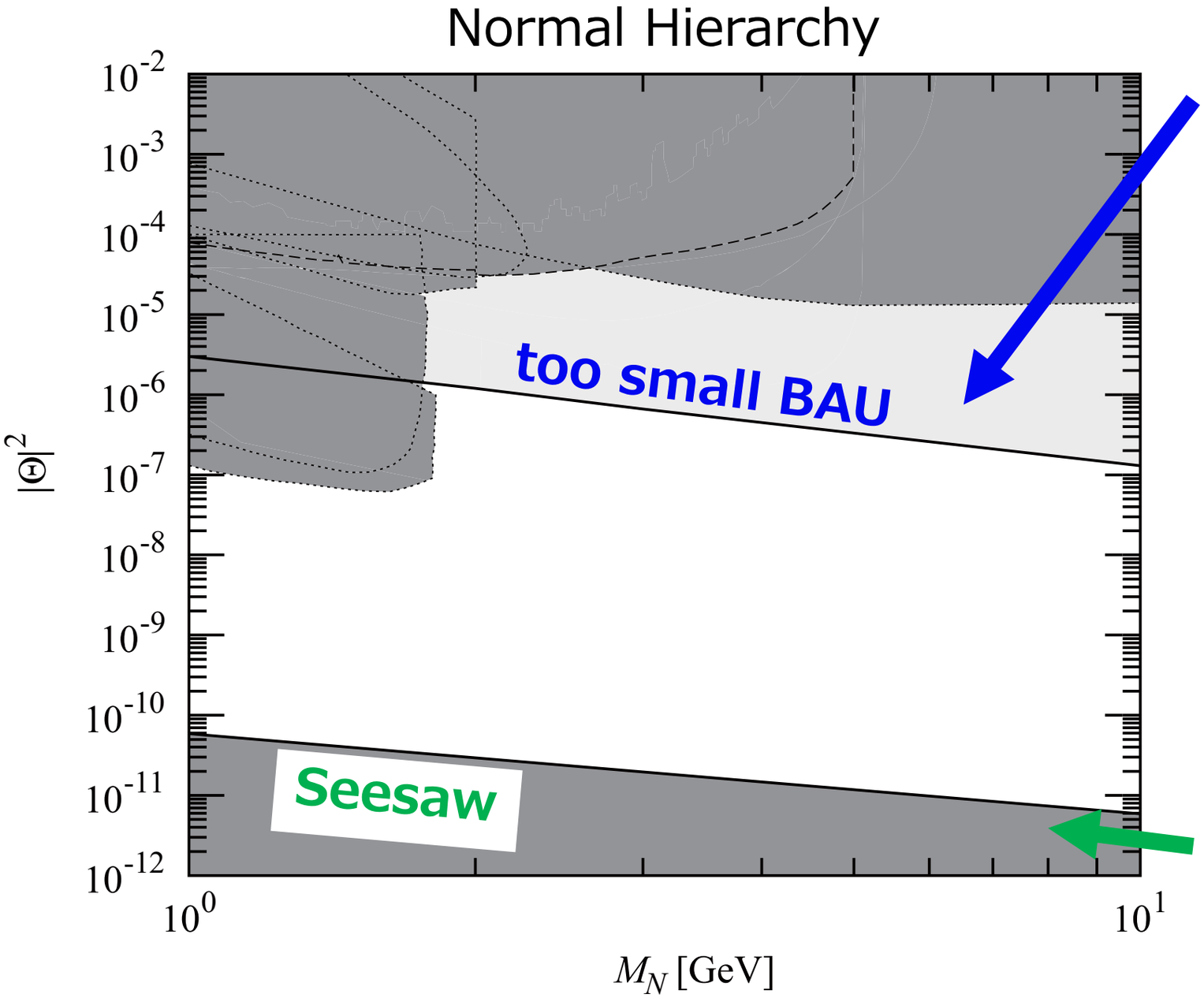


  - Asymmetries are generated since evolution rates of L_α and $\overline{L_\alpha}$ are different due to CPV





Baryogenesis region



Bound from BAU

to avoid strong washout

Canetti, Shaposhnikov '10 [arXiv:1006.0133]

Drewes, Garbrecht, Gueter, Klaric '16 [arXiv:1609.09069]

TA, Eijima, Ishida, Minogawa, Yoshii '17 [to appear]

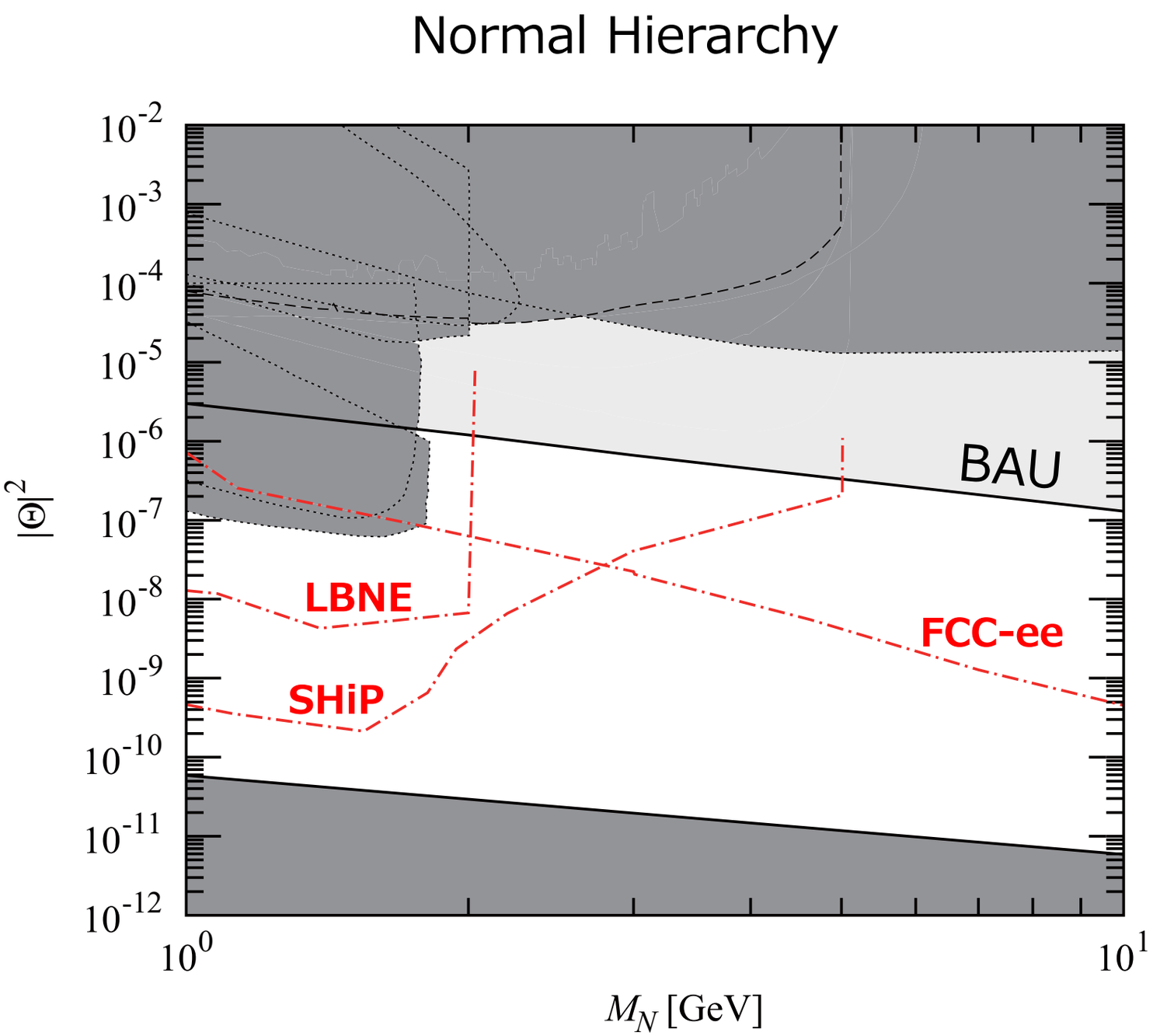
See also a poster #16 by Juraj Klaric

Bound from Seesaw

to explain neutrino masses

$$|\Theta|^2 > \frac{\Sigma m_i}{2\, M_N}$$

Sensitivities by future searches

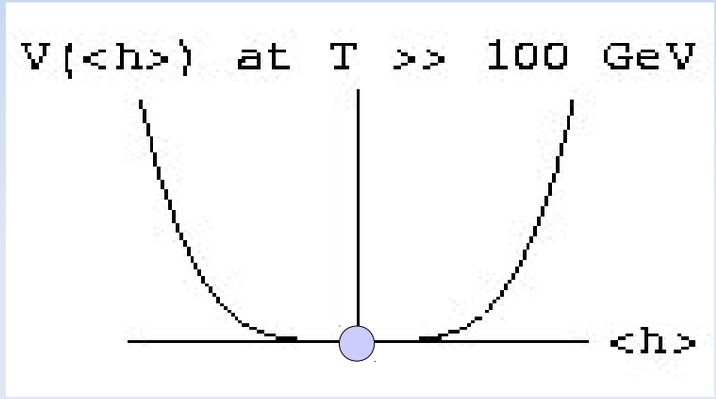


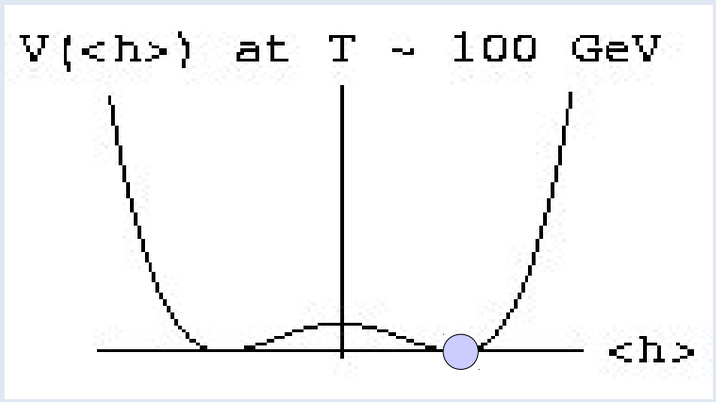
Sensitivity for $|\Theta_\mu|^2$

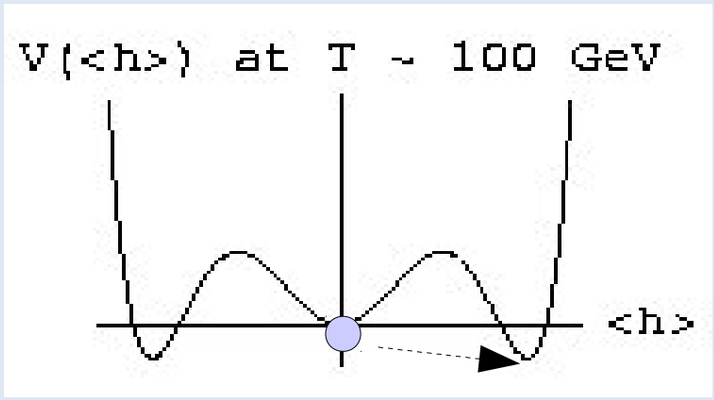
- LBNE (DUNE)
  N decay inside near detector
  Adams et al '13 [arXiv:1307.7335]
- SHiP
  beam dump exp.
  Anelli et al '13 [arXiv:1504.04956]
- FCC-ee at Z-pole
  displaced vertex of N decay
  Blondel, Graverini, Serra, Shaposhnikov (FCC-ee study team) '14 [arXiv:1411.5230]

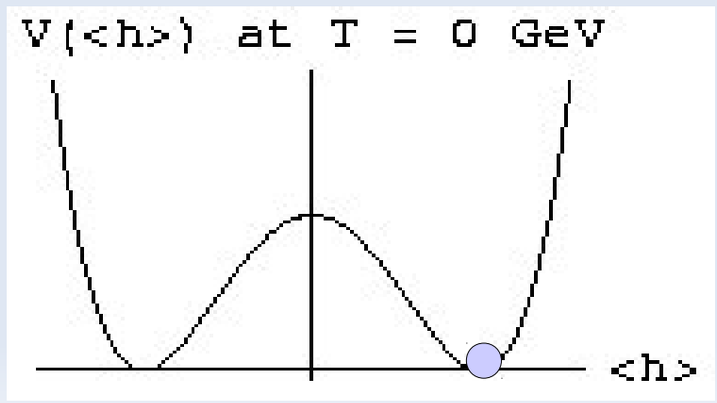
First-order phase transition

The free energy (as a function of the Higgs vev) decides the nature of the phase transition:







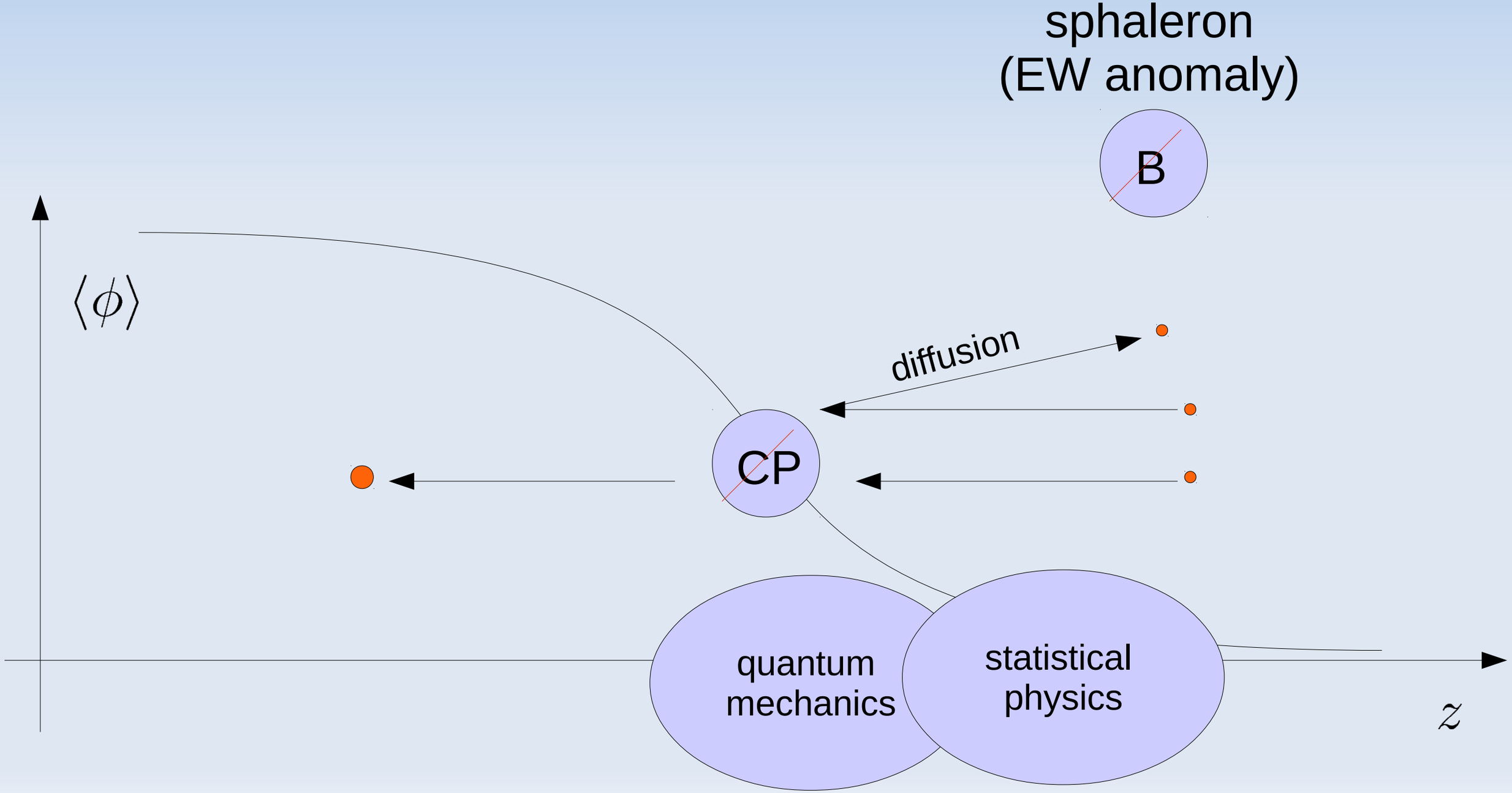


second-order PT
crossover

first-order PT

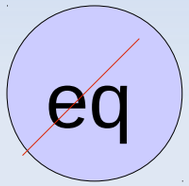
What are the challenges?

[Kuzmin, Rubakov, Shaposhnikov '85]
[Cohen, Kaplan, Nelson '93]



Pre LHC EWBG

Before LHC, the main focus was on supersymmetric models.



Strong first-order electroweak phase transition from light stops

$$m_{\tilde{t}} \lesssim m_t$$

NMSSM *[Menon, Morrisey, Wagner ’04]*
[Huber, TK, Prokopec, Schmidt ’06]

U’(1) MSSM *[Kang, Langacker, Li, Liu ’04]*

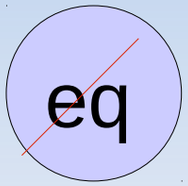
CP violation
From the chargino sector

$$m_{\chi^\pm} < 200\,\mathrm{GeV}$$

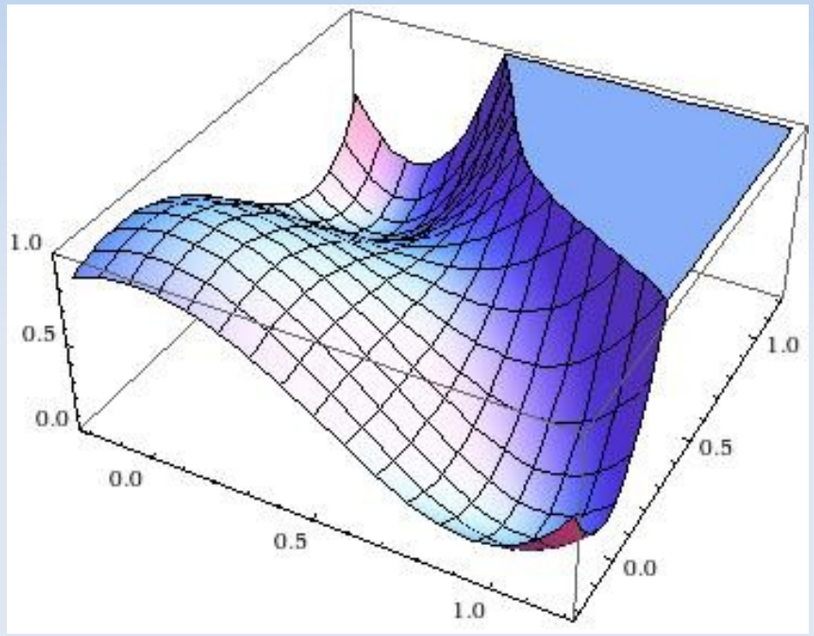
problematic, also because of EDMs

EWBG in the LHC era

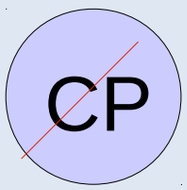
After LHC run II, the focus in EWBG is more on minimal models:



Strong first-order electroweak phase transition from extended scalar sector



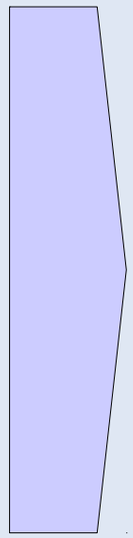
Two Higgs doublet model



CP violation
from the Higgs sector

Singlet extension with a low cutoff

CP violation
from the dim-5 top-singlet operators



new dof
low cutoff
in principle testable

Composite Higgs models

The Higgs could be a Pseudo-Goldstone boson of a broken global symmetry

QCD: $$\frac{SU(2)_L \times SU(2)_R}{SU(2)_V} \to 3\pi$$

The broken symmetry will determine the light degrees of freedom and their quantum numbers

$$\frac{SO(5)}{SO(4)} \to H$$

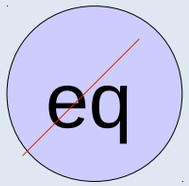
but also

$$\frac{SO(6)}{SO(5)} \to H + S \qquad \frac{SO(6)}{SO(4) \times SO(2)} \to 2H$$

[Kaplan, Georgi '84]

Ingredients

Two ingredients of baryogenesis are missing in the Standard Model. These are provided in models that have an additional singlet in the low energy effective description



Strong first-order electroweak phase transition $V(s,h)$

CP violation from dimension-five operators

$$\mathcal{L} \ni y_t \bar{\psi}_Q H \psi_t + \frac{\tilde{y}_t}{f} S \bar{\psi}_Q H \psi_t + h.c.$$

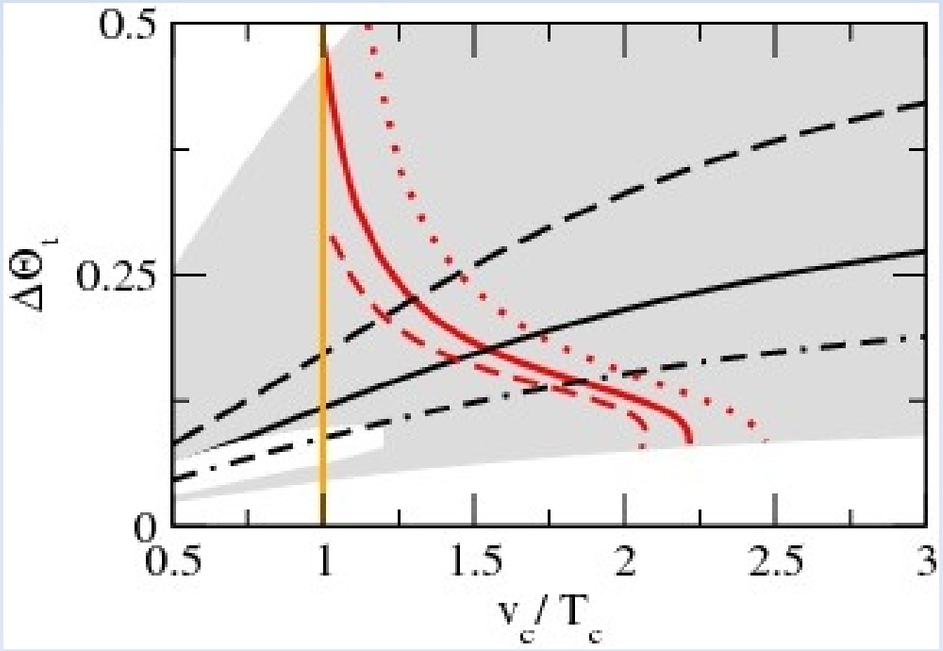
$$\Im(y_t \tilde{y}_t^*) \neq 0$$

Baryogenesis

$$\Delta\theta_t \simeq \frac{\Im(y_t \tilde{y}_t^*)}{y_t y_t^*} \frac{\Delta s}{f}$$

$$\Delta\theta_t \gtrsim 0.15$$

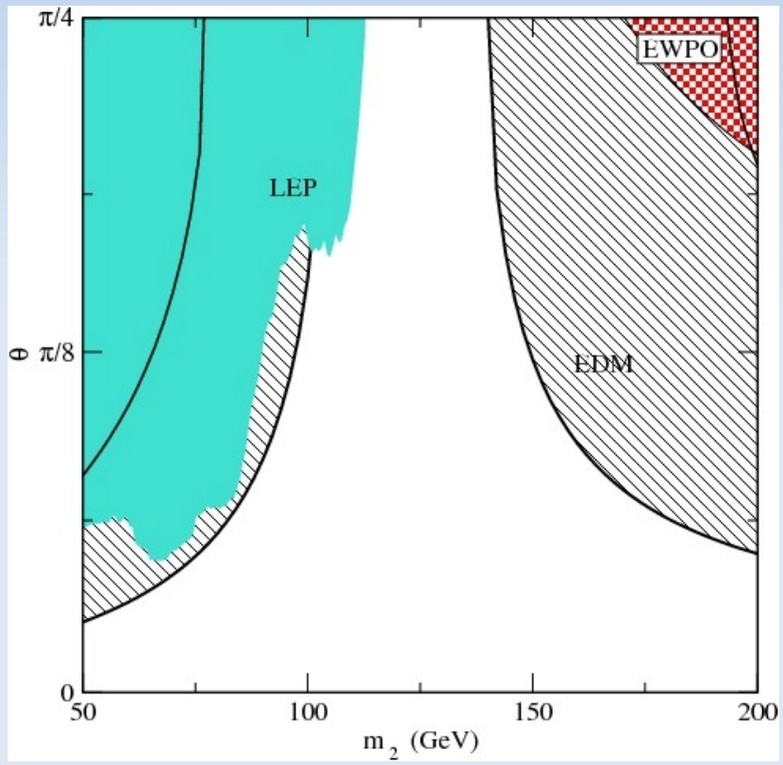
$$m_s = 130\,\mathrm{GeV}$$
$$m_h = 120\,\mathrm{GeV}$$



strength of CP violation

strength of the phase transition

~ Higgs-singlet mixing ~ CP violation



singlet mass

[Espinosa, Gripaios, TK, Riva '11]

CPV is mostly present during the phase transition and does not require sizable mixing the broken phase → nightmare scenario