# Stability and Leptogenesis in the Left-Right Symmetric See-Saw Mechanism

Tomas Hällgren
KTH, Stockholm

in collaboration with E. Akhmedov, M. Blennow, T. Konstandin, and T. Ohlsson

SUSY07, Karlsruhe

# Outline

1. Left-Right symmetric See-Saw model
   - Introduction
   - See-Saw inversion
2. Selecting See-Saw solutions
   - Stability
   - Leptogenesis

# Motivation

- Given light neutrino mass matrix $m_\nu$ and Yukawa coupling $y$ $\longrightarrow$ 8 possible triplet Yukawa couplings $f$ in left-right symmetric models.

Akhemdov, Frigerio, '05

- Use finetuning criterion and viability of leptogenesis to break degenaracy

Hosteins, Lavignac, Savoy, '06
Akhmedov, Blennow, Hällgren, T.K., Ohlsson, '06

# Left-right symmetric model

The left-right symmetric framework is based on the gauge group

$$SU(3)_{\text{color}} \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}.$$

It contains the following Higgs multiplets

- $\Phi(2,2,0)$
- $\Delta_L(3,1,-2)$
- $\Delta_R(1,3,2)$

- $\langle \Phi^0 \rangle = v$
- $\langle \Delta_L^0 \rangle = v_L$
- $\langle \Delta_R^0 \rangle = v_R$

The neutral components of the Higgs fields obtain vacuum expectation values from spontaneous symmetry breaking.

# Type I+II See-Saw mechanism

Spontaneous symmetry breaking $\longrightarrow$ light neutrino mass matrix

$$m_\nu = f_L - \frac{1}{\mu} y f_R^{-1} y^T, \qquad (1)$$

where $f_{L,R}$ = left/right triplet Yukawa copulings and $\mu = \frac{v_R}{v_L v^2}$.

We will consider the special case $f_L = f_R$ and $y = y_u$

# See-Saw inversion

For given $m_\nu$ and $y$ there exist for $N$ flavors, $2^N$ solutions for triplet Yukawa matrix $f$.
AKHEMDOV, FRIGERIO, '05

In particular, $N = 3 \rightarrow 8$ solutions.

# See-Saw inversion

In the one generation case, simple solutions for $f$

$$f_{1,2} = \frac{m_\nu}{2v_L} \pm \frac{1}{v_L}\sqrt{\frac{m_\nu^2}{4} + \frac{y^2}{\mu}}, \tag{2}$$

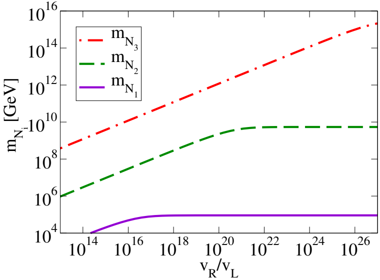
Analytic expressions also for $N = 3$ case.

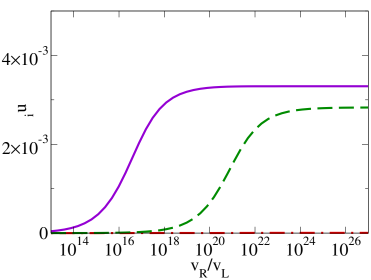
# Type I or type II dominance

- In the $N = 3$ case, the solutions are labelled as $('\pm, \pm, \pm')$ for type I $(+)$, or type II $(-)$ see-saw dominance of corresponding eigenvalue in large $\mu$ limit.
- Solve for eigenvalues and mixing angles for the eight solutions

# Type I dominance

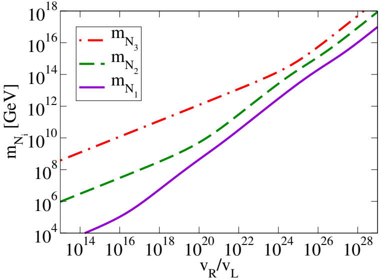
Pure type I solution ('$- - -$'). Large spread in the right-handed masses. Mixing angles suppressed.

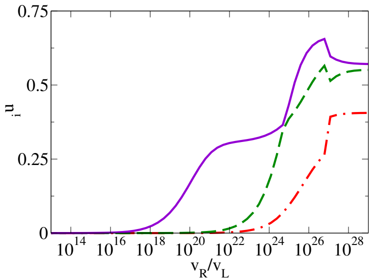


# Type II dominance

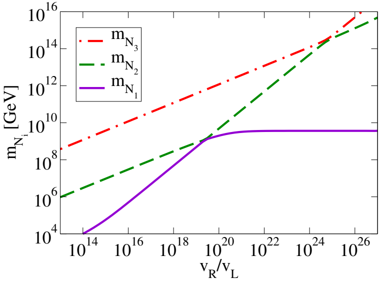
Pure type II solution ('+ + +'). No large spread in eigenvalues. Mixing angles unsuppressed.

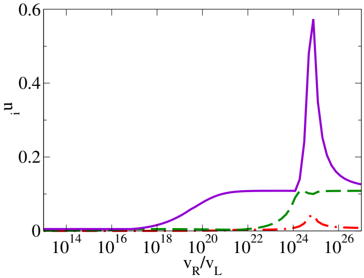


# Mixed solutions

In addition there are six mixed type I+II cases.



# Breaking the eight-fold degeracy

Since all solutions give the same $m_\nu$ we need some criteria to discriminate among solutions.

- Stability/finetuning
- Viability of leptogenesis

# Stability measure

Akhmedov, Blennow, Hällgren, T.K., Ohlsson, '06

To quantify tuning we use the following stability measure

$$Q = \left| \frac{\det f}{\det m_\nu} \right|^{1/3} \sqrt{\sum_{k,l=1}^{2N} \left( \frac{\partial m_l}{\partial f_k} \right)^2} \, .$$

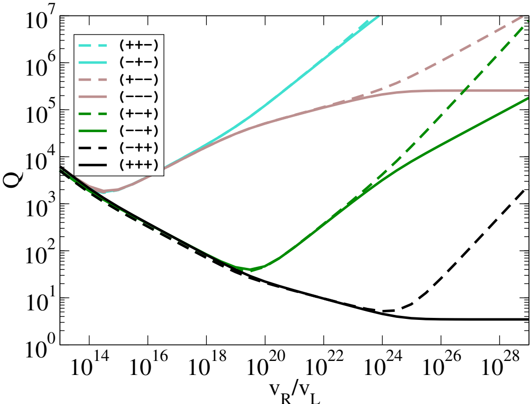
where $m_l$ and $f_k$ determine the light and heavy neutrino mass matrices according to

$$f = \sum_k (f_k + i f_{k+N}) T_k, \quad m_\nu = \sum_k (m_k + i m_{k+N}) T_k,$$

and $T_k$, $k \in [1, 6]$, form a normalized basis of the complex symmetric $3 \times 3$ matrices.

# Stability results

The plot of the stability measure depends only on the light neutrino mass scale and its hierarchy ($m_0 = 0.1$ eV, normal hierarchy).
Only the hierarchy in $y$ is important. Mixing in $y$ is not essential.



# Leptogenesis

The observed baryon-to-entropy ratio is

$$\eta_B = (6.1 \pm 0.2) \times 10^{-10}$$

In leading order, the produced baryon asymmetry can be parametrized by

$$\eta_B = \sum_i \eta_i \epsilon_{N_i}$$

where $\eta_i$ denotes the efficiency factor of the decays of the $i$th right-handed neutrino and $\epsilon_{N_i}$ the CP asymmetry in its decays into leptons and Higgs particles

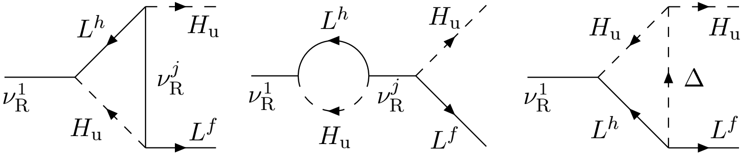
$$\epsilon_{N_i} = \frac{\Gamma(N_i \to l\,H) - \Gamma(N_i \to \bar{l}\,H^*)}{\Gamma(N_i \to l\,H) + \Gamma(N_i \to \bar{l}\,H^*)} .$$

# CP asymmetry

Antusch, King, '04

Hambye, Senjanovic, '03

Decay CP asymmetry results from intereference of tree-level and one-loop diagrams.



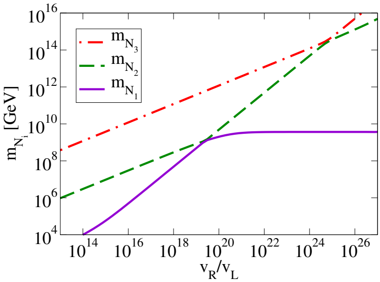

(a) (b) (c)

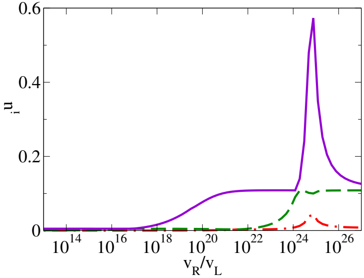
In the limit $m_{N_1} \ll m_{N_2}, m_\Delta$ the asymmetry can be written

$$\epsilon_{N_1} = \frac{3m_{N_1}}{16\pi v^2} \frac{\mathrm{Im}[(y^\dagger\,(m_\nu^{\mathrm{I}} + m_\nu^{\mathrm{II}})y^*)_{11}]}{(y^\dagger y)_{11}}\,.$$

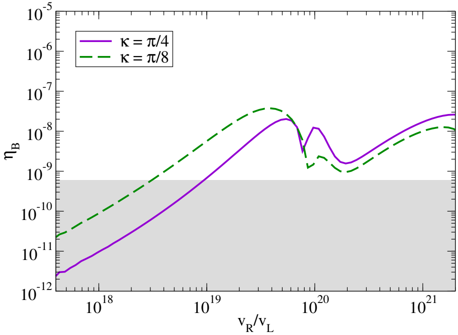
# Leptogenesis

- Numerical solution of the Boltzmann equations
- Additional Majorana phases in type I+II scenario can improve leptogenesis.
- Resonance effects close to mass crossing points.
- Leptogenesis favors the four solutions ('$\pm, \pm, +$')



# Leptogenesis




The numerical evaluation for the three-flavor case gives for the solution '$- - +$' ( $m_0 = 0.1$ eV, $y = y_u$ ).

Akhmedov, Blennow, Hällgren, T.K., Ohlsson, '06

# Summary and Conclusions

| | $\pm + +$ | $\pm - +$ | $\pm \pm -$ |
|---|---|---|---|
| Stability | $v_R/v_L > 10^{18}$ | $v_R/v_L \simeq 10^{20}$ | disfavored |
| Leptogenesis | $v_R/v_L > 10^{18}$ | $v_R/v_L > 10^{18}$ | excluded |
| Gravitinos | $v_R/v_L < 10^{21}$ | unconstrained | unconstrained |

In total, stability and leptogenesis constraints in this case the left-right symmetric framework to the four solutions of type '$\pm \pm +$' and $v_R/v_L = 10^{18} \div 10^{21}$.

This talk was based on:

*Stability and Leptogenesis in the Left-Right Symmetric See-Saw Mechanism*, JHEP 04022 (2007), E. Akhmedov et. al.