# Classically conformal B-L extended Standard Model and phenomenology

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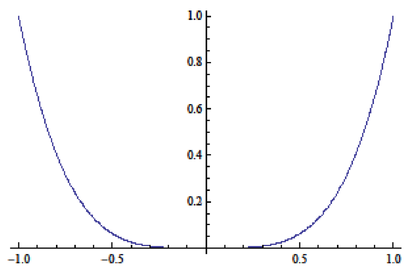
## Coleman-Weinberg mechanism in SM

**We consider classically conformal Standard Model.**

Tree level potential

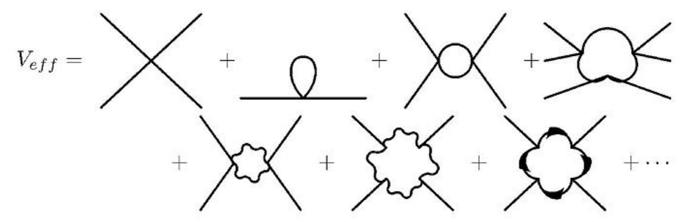
$$V(H) = \frac{\lambda_H}{4}\left(H^\dagger H\right)^2$$

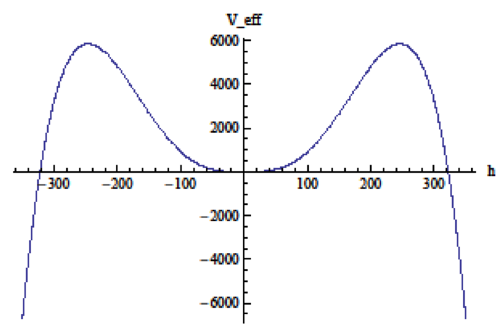


There is no electroweak symmetry breaking at the classical level.
We need to consider origin of the symmetry breaking.

**Coleman-Weinberg Mechanism**
(radiative symmetry breaking)

1 loop effective potential






In the classically conformal SM, due to the large top mass the effective potential is rendered unstable, and CW mechanism does not work.

## Classically conformal B-L extended model

### Gauge symmetry

$$SU(3)_c \times SU(2)_L \times U(1)_Y \times U(1)_{B-L}$$

### Particle contents

| | SU(3)$_c$ | SU(2)$_L$ | U(1)$_Y$ | U(1)$_{B-L}$ | $Z_2$ |
|---|---|---|---|---|---|
| $q_L^i$ | **3** | **2** | +1/6 | +1/3 | + |
| $u_R^i$ | **3** | **1** | +2/3 | +1/3 | + |
| $d_R^i$ | **3** | **1** | −1/3 | +1/3 | + |
| $\ell_L^i$ | **1** | **2** | −1/2 | −1 | + |
| $\nu_R^i$ | **1** | **1** | 0 | −1 | + |
| $\nu_R^3$ | **1** | **1** | 0 | −1 | − |
| $e_R^i$ | **1** | **1** | −1 | −1 | + |
| $H$ | **1** | **2** | +1/2 | 0 | + |
| $\Phi$ | **1** | **1** | 0 | +2 | + |

### New particles

right-handed neutrino $\nu_R$
Three generations of right-handed neutrinos are necessarily introduced to make the model free from all the gauge and gravitational anomalies.

singlet scalar $\phi$
The SM singlet scalar works to break the U(1)B-L gauge symmetry by its VEV.

### Lagrangian

Yukawa sector

$$\mathcal{L} \supset -Y_D^{ij}\overline{\nu_R^i}H^\dagger l_L^j - \frac{1}{2}Y_N^i\Phi\overline{\nu_R^{ic}}\nu_R^i + h.c.$$

See-Saw mechanism associates with B-L symmetry breaking.

Potential

$$V(H,\phi) = \lambda_H\left(H^\dagger H\right)^2 + \lambda\left(\phi^\dagger\phi\right)^2 + \lambda'\left(\phi^\dagger\phi\right)\left(H^\dagger H\right)$$

The mass terms are forbidden by classical conformal invariance.

**Assumption**(Flat Potential)

$$\lambda_H = \lambda' = 0$$
$$g_1 \sim g_{B-L}$$

at planck scale

→ $\lambda'$ is very small and negative $(\sim O(10^{-3}))$

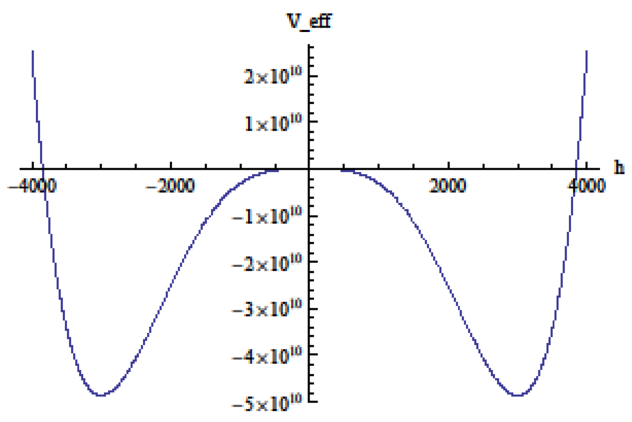
We can consider the standard model sector and the B-L sector separately, because the scalar mixing term is very small.

## Symmetry Breakings

● The B-L symmetry is broken by the CW mechanism.

1 loop effective potential in our model

$$V_{eff} =$$




$$\alpha_{B-L}^2 - \frac{1}{96}\sum\alpha_N^{i2} > 0$$

● The Electroweak symmetry is broken by VEV of B-L Higgs.

Once the B-L symmetry is broken, the SM Higgs doublet mass is generated through the mixing term between H and Φ in the scalar potential.

$$V(h) \sim \frac{\lambda_H}{4}h^4 + \frac{\lambda'}{4}M^2h^2$$

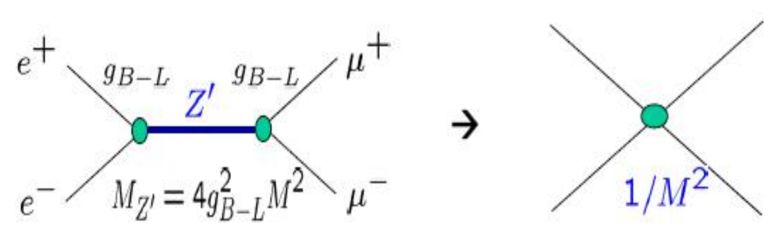
Effective tree-level mass squared is induced, and if λ' is negative, EW symmetry breaking occurs as usual in the SM.

$$M = \sqrt{\frac{m_h^2}{|\lambda'|}} \sim \text{few TeV}$$

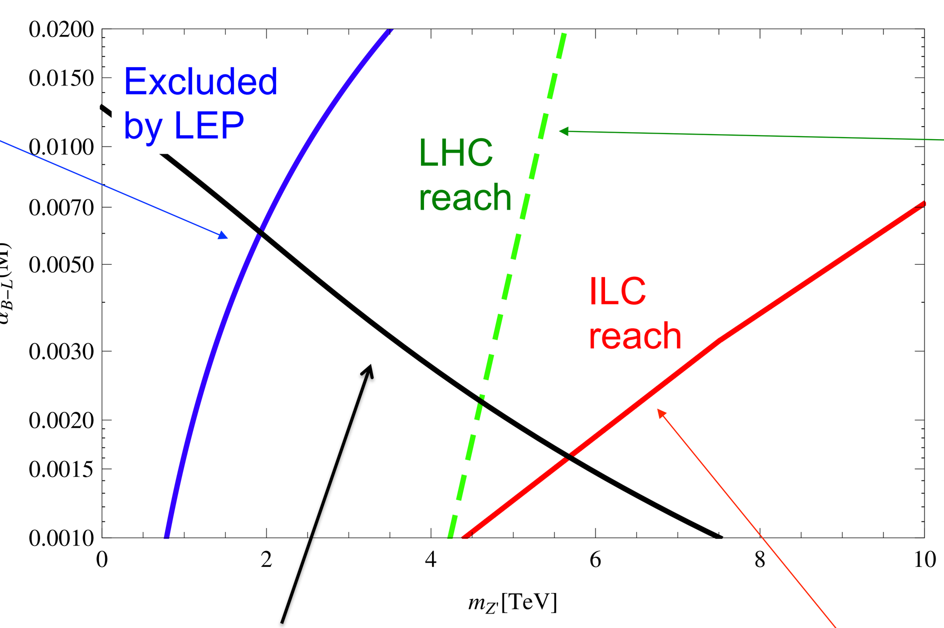
## Prediction of our model

### LEP

LEP experiments provided a severe constraint.



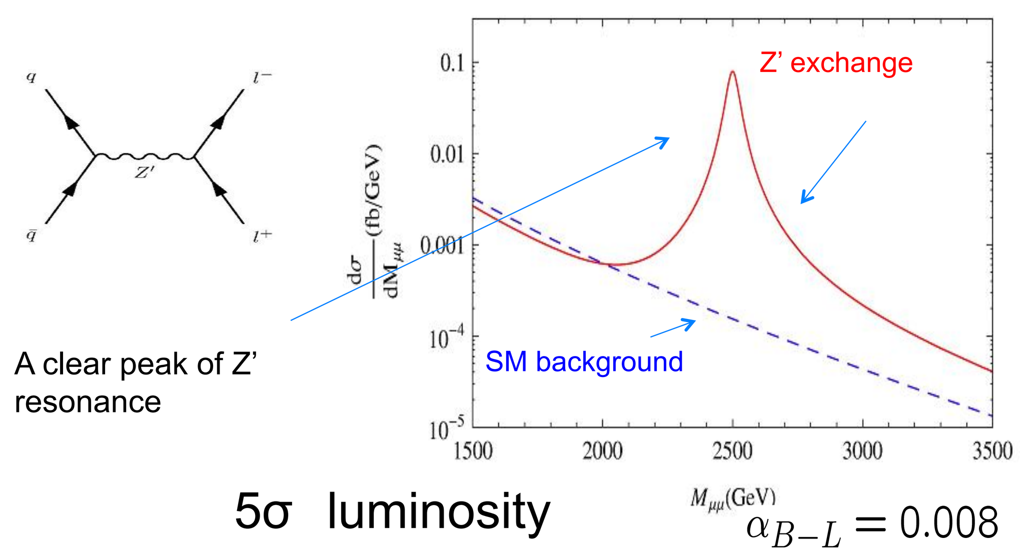

$$M = \frac{m_{Z'}}{\sqrt{16\pi\alpha_{B-L}}} \geq 3TeV$$




**Model prediction**

Flat potential

### LHC




5σ luminosity

$\sqrt{s} = 14TeV$ $100fb^{-1}$

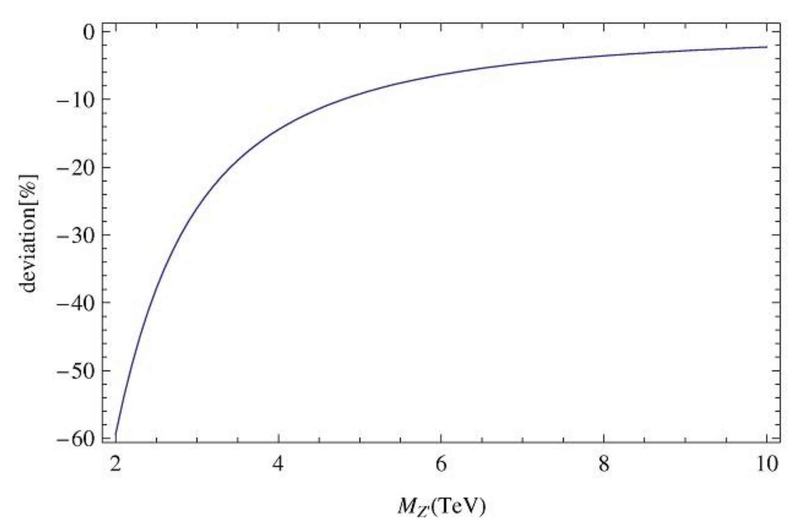
$\alpha_{B-L} = 0.008$
$m_{Z'} = 2.5TeV$

We calculate the dilepton production cross section through the Z' boson exchange together with the SM processes mediated by Z boson and photon.

### ILC

$$\frac{\sigma(e^+e^- \to \gamma, Z, Z' \to \mu^+\mu^-)}{\sigma_{SM}(\sigma(e^+e^- \to \gamma, Z \to \mu^+\mu^-)} - 1$$

Assuming the ILC is accessible to 1% deviation, the TeV scale Z' boson can be discovered at ILC.




$\sqrt{s} = 1TeV$

Z' boson mass is bounded by flat potential ⇒ $m_{Z'} \sim a\ few\ TeV$

stability condition for the effective potential ⇒ $\sum_i m_{N_i}^4 < \sqrt{\frac{3}{2}}m_{Z'}^4$

the symmetry breaking occurs under the balance between the tree-level quartic coupling and the terms generated by quantum correction ⇒ $\left(\frac{m_\phi}{m_{Z'}}\right)^2 \sim \frac{6}{\pi}\left(\alpha_{B-L} - \frac{1}{96}\frac{\sum\alpha_N^{i2}}{\alpha_{B-L}}\right) < 0.03$

$\alpha_{B-L} < 0.015$