Constraints on minimal Z' models from SO(10) GUTs

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Motivation

- Minimal Z' models as low energy limits of SO(10) GUT models.
- Comparing theoretical unification constraints on the space of Z' parameters with experimental constraints from the EWPT and the LHC.
- Taking into account treshold corrections in a potential-independent way.

What is a minimal Z' model ?

- The gauge group is SM x U(1)
- Generator of additional U(1) gauge group is B-L.
- Only in this case (U(1)^2 spanned by Y and B-L) no additional fermions (except for right-handed neutrinos) are needed for anomaly cancelation.
- Z' boson is the gauge boson of additional U(1).

Low energy parametrization

$$L^{abelian} = -\frac{1}{4}\tilde{h}_{ab}F_a^{\mu\nu}F_{b\mu\nu} + \sum_f \bar{\Psi}_f \gamma_\mu \left((X^T)_a^f G_{ab} A_b^\mu\right) \Psi_f + L_{int}^{abelian-scalar}$$

$a, b \in \{1, 2\}$ - indices in $U(1)^2$ algebra

We choose $\widetilde{h}_{ab} = \delta_{ab}$ (at tree level)

$$\left[\begin{array}{c} Y \\ B-L \end{array}\right]^T \left[\begin{array}{cc} g' & g'_{B-L} \\ 0 & g_{B-L} \end{array}\right] \left[\begin{array}{c} B_0^\mu \\ Z_0^{'\mu} \end{array}\right]$$

Standard parametrization

g' is equivalent to g' from the SM

g_{B-L}, g'_{B-L} and $M_{Z'}$ are basic parameters additional with respect to the SM

How are they constrained?

Different (GUT) parametrization

Parametrization, which is natural for SO(10) GUT models is different, than the standard Z' parametrization. After finding constraints from gauge coupling unification in GUT parametrization, one has to make appriopriate transformations to obtain final constraints on g_{B-L} and g'_{B-L}.

Symmetry breaking

Pattern 1 | Pattern 2

$$\begin{tikzcd}[column sep=small] & SO(10) \arrow[dl, "\mu_0"'] \arrow[dr, "\mu_0"] & \\ {}^{*}SU(5)\oplus U(1)_X \arrow[dr, "\mu_1 \gtrsim 10^{16}\ \text{GeV}"] & & {}^{*}SU(3)_c\oplus SU(2)_L\oplus SU(2)_R\oplus U(1)_{B-L} \arrow[dl, "\mu_1"] \\ & \text{Z' group: } SU(3)_c\oplus SU(2)_L\oplus U(1)^2 \arrow[d, "\mu_2"] & \\ & SU(3)_c\oplus SU(2)_L\oplus U(1)_Y \arrow[d, "M_Z"] & \\ & SU(3)_c\oplus U(1)_{EM} & \end{tikzcd}$$

*Intermediate group

Transormation of U(1) generators

There are two diagonal generators of the intermediate group, that are linear combinations of Y and $B-L$:

In Pattern 1: $\begin{bmatrix} \widehat{Y} \\ X \end{bmatrix} = \begin{bmatrix} \frac{\sqrt{15}}{5} & 0 \\ -\frac{\sqrt{10}}{5} & \frac{\sqrt{10}}{4} \end{bmatrix} \cdot \begin{bmatrix} Y \\ B-L \end{bmatrix}$

In Pattern 2: $\begin{bmatrix} R \\ \widehat{B-L} \end{bmatrix} = \begin{bmatrix} 1 & -\frac{1}{2} \\ 0 & \frac{\sqrt{6}}{4} \end{bmatrix} \cdot \begin{bmatrix} Y \\ B-L \end{bmatrix}$

R - third (diagonal) generator of $SU(2)_R$

The running below the μ_1 scale is considered in the $[Y, B-L]$ basis.

Treshold corrections

Integrating out the Z' gauge boson has no influence on the 1-loop running of g', g_2 and g_3. Therefore the Z' boson doesn't need to be integrated out below its mass scale and one can run with g'_{B-L} and g_{B-L} down to M_Z scale.

Treshold corrections from all fermions and scalars in a given model are included in derived constraints. The full set of constraints contains both equations and inequalities. It defines the allowed multidimensional polyhedron in the space of parameters spanned by g'_{B-L}, g_{B-L} and treshold mass parameters. One can project this polyhedron on the 2D plane spanned by g'_{B-L} and g_{B-L} only.

Model 1 Supersymmetric

Higgs sector: $210_H + 54_H + \overline{126}_H + 126_H + 10_H$

Pattern 1: $SO(10) \xrightarrow{\mu_0} SU(5) \oplus U(1)_X \xrightarrow{\mu_1}$ Z' group

allowed by unification

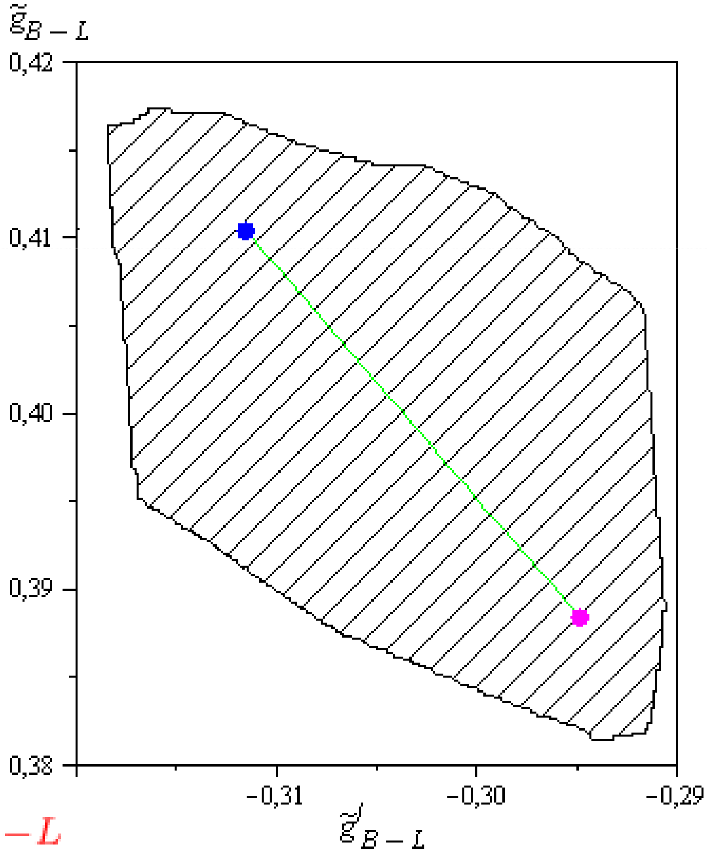
$$M_{210} > 0.1\,\mu_0$$

$$M_{54} > 0.1\,\mu_1$$

$$M_{\text{other fields}} < 0.1\,\mu_1$$

$$\tilde{g}_{B-L} = \frac{g_{B-L}}{g_Z}$$

$$\tilde{g}'_{B-L} = \frac{g'_{B-L}}{g_Z}$$



Benchmark running:

$\mu_0 = \mu_1$

No treshold corrections

In the $[\mu_1, \mu_0]$ interval: All fields

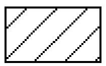
In the $[M_Z, \mu_1]$ interval: MSSM $+ 3 \cdot \nu_R + 2 \cdot \chi_{B-L}$

$\mu_0 = M_{Pl}$

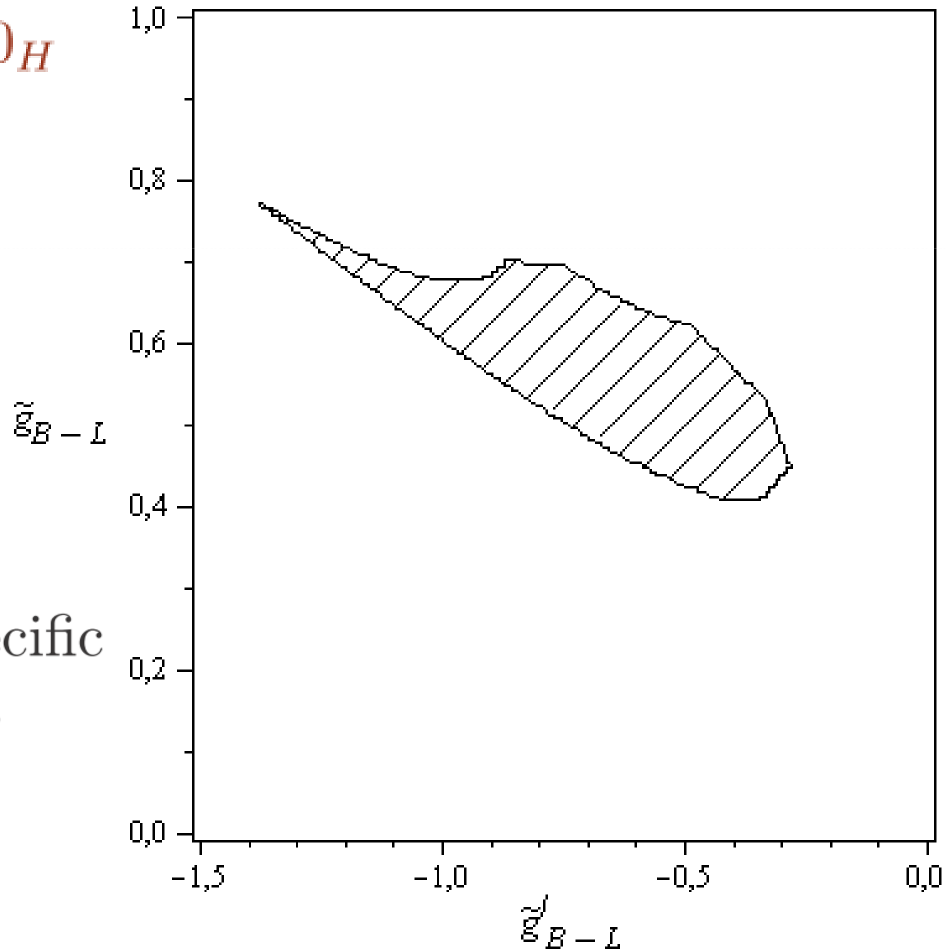
Model 2 Non-Supersymmetric

Pattern 2: $SO(10) \xrightarrow{\mu_0} SU(3)_c \oplus SU(2)_L \oplus SU(2)_R \oplus U(1)_{B-L} \xrightarrow{\mu_1}$ Z' group

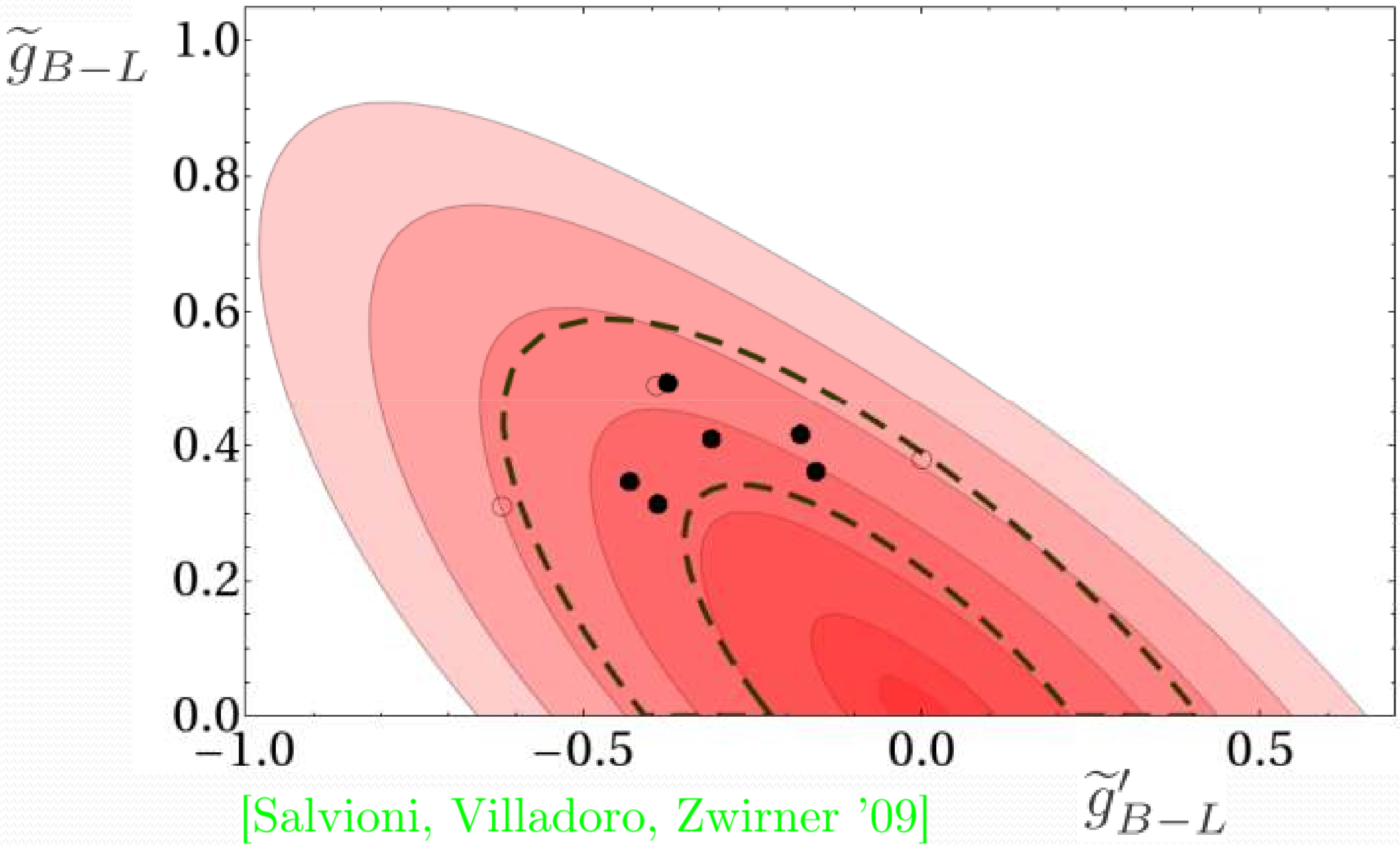
Higgs sector: $45_H^R + 45_H^R + \overline{126}_H + 10_H$



Unification is possible only with specific combinations of treshold corrections



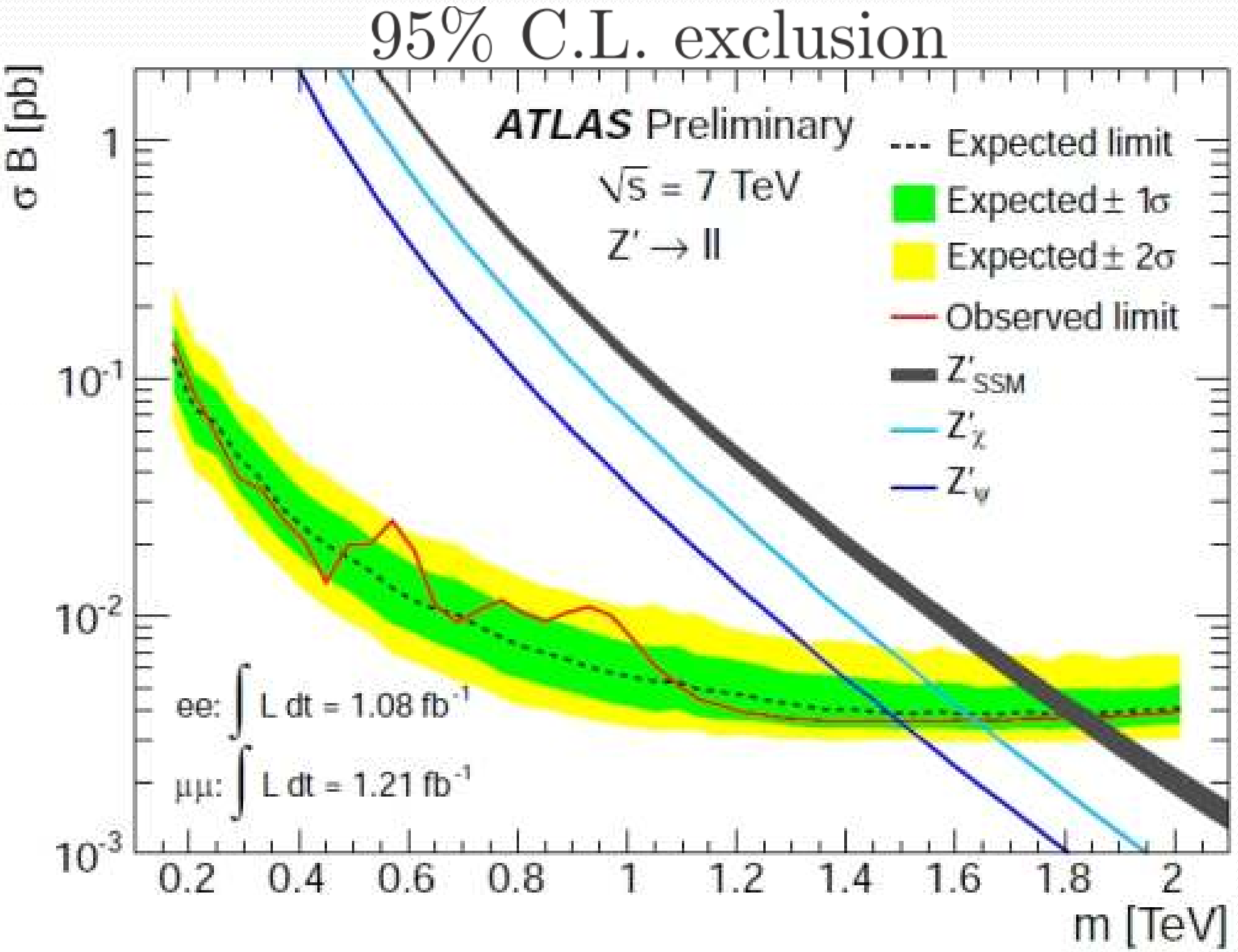
Constraints from LEP II EWPT



[Salvioni, Villadoro, Zwirner '09]

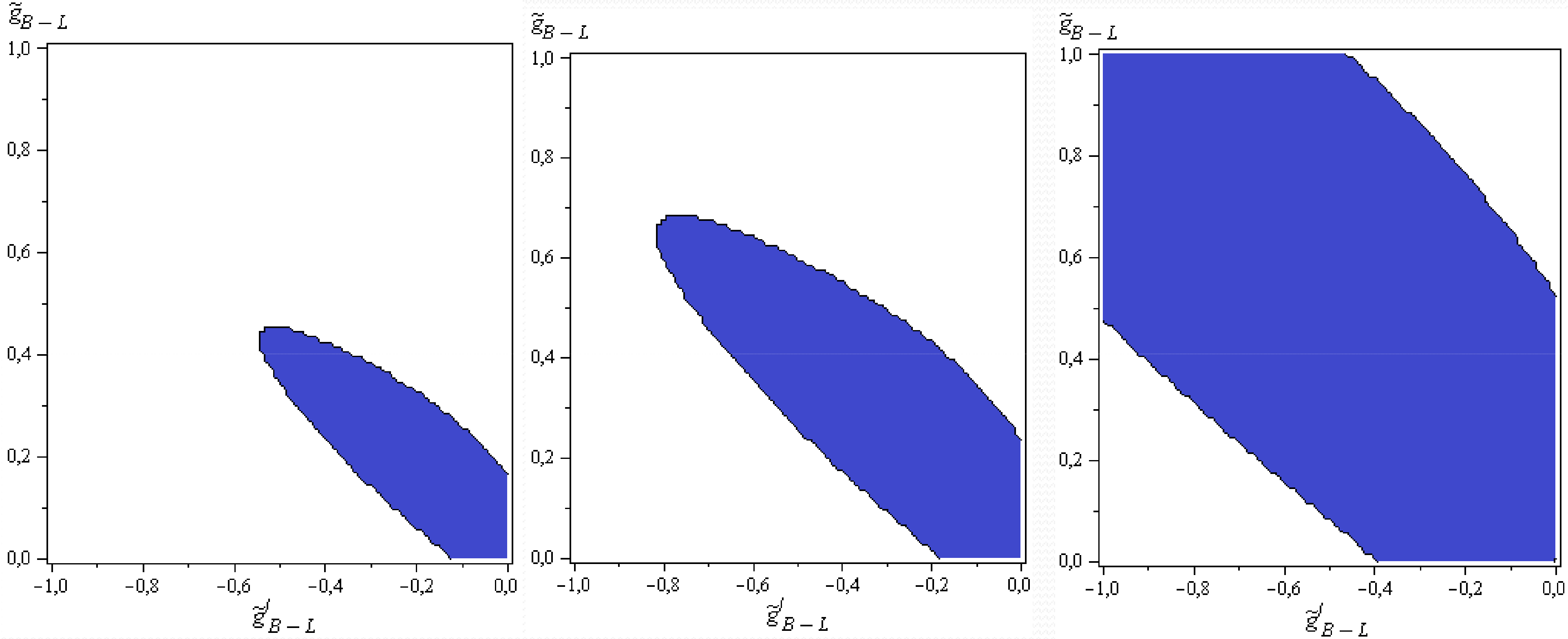
from inner to outer bound: $M_{Z'} \in \{0.2,\ 0.5,\ 1,\ 1.5,\ 2,\ 2.5,\ 3\}$ TeV

Latest constraints from ATLAS



[Charlton (on behalf of the ATLAS Collaboration) EPS-HEP Grenoble '11]

Latest constraints from ATLAS

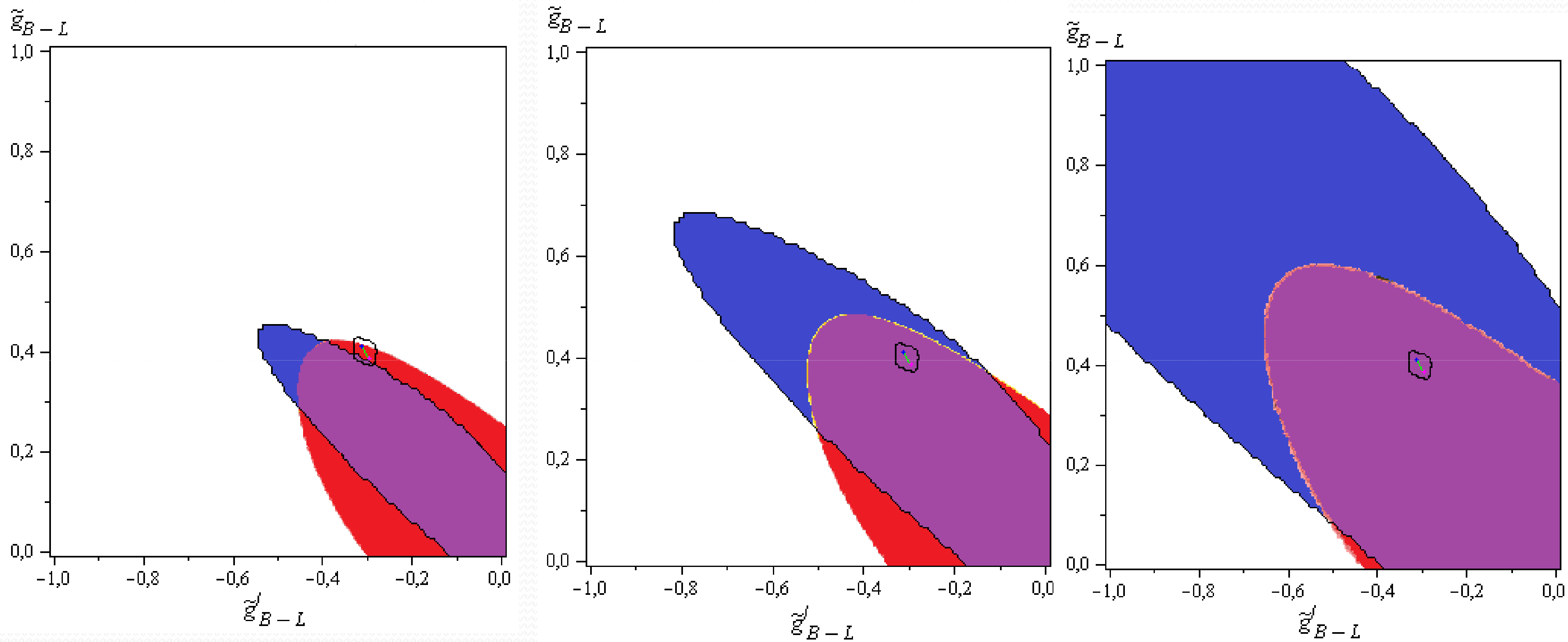


$M_{Z'} = 1.4$ TeV $\quad$ $M_{Z'} = 1.6$ TeV $\quad$ $M_{Z'} = 2$ TeV

σB < Observed limit

σB calculated in narrow width approximation in LO

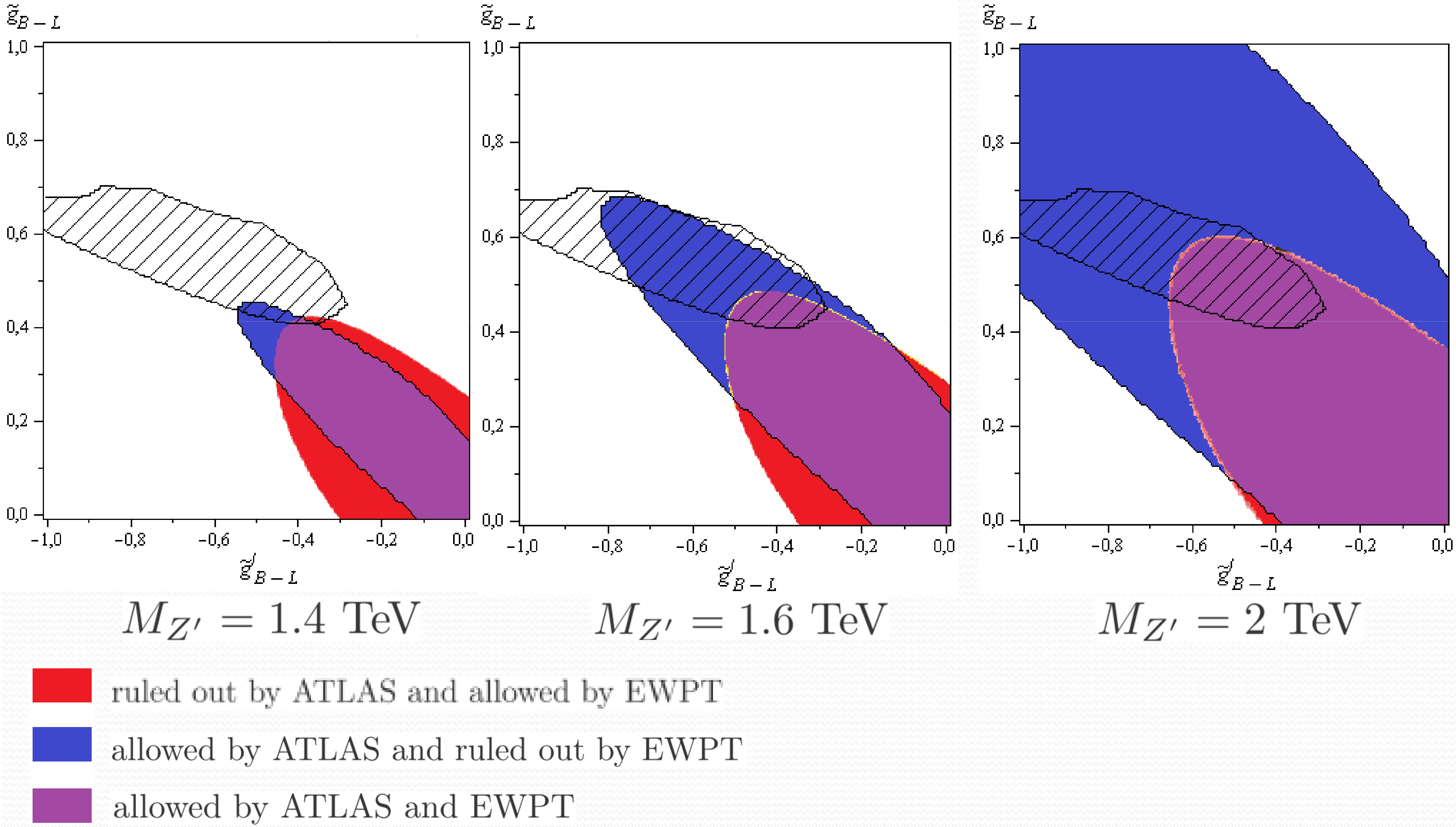
Experimental constraints on Model 1



$M_{Z'} = 1.4$ TeV $\quad$ $M_{Z'} = 1.6$ TeV $\quad$ $M_{Z'} = 2$ TeV

- ruled out by ATLAS and allowed by EWPT
- allowed by ATLAS and ruled out by EWPT
- allowed by ATLAS and EWPT

Experimental constraints on Model 2



Summary and conclusions

- Grand Unification can significantly constrain the space of parameters in Z' models, but unknown treshold corrections can give additional freedom.
- LHC still didn't find any Z', but there are new, stronger limits.
- For a given symmetry breaking pattern and a field content, one can find potential-independent, lower bound on Z' mass.
- Presented methods can be used beyond minimal Z' models unless there are 3 or more U(1)'s at the same range of scales.

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