# Right-handed neutrino dark matter in the minimal gauged B-L model

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# § Introduction

# Who is DM ?

- SM

  None

- minor changed SM

  - $\nu$ with $m_\nu \neq 0$

    if $\nu = \nu_L$, hot DM and $\Omega h^2 \ll 0.1$

    if $\nu = \nu_R$, still possible

  - axion

- including WIMPs

  Neutralino, Sneutrino, …

  - $m_{DM} = \mathcal{O}(10^2)$ GeV
  - thermal relic $\Omega_{DM} h^2 \simeq 0.1$
  - Discrete sym. has to be imposed

# § Higgs portal dark matter

# Gauge singlet scalar dark matter

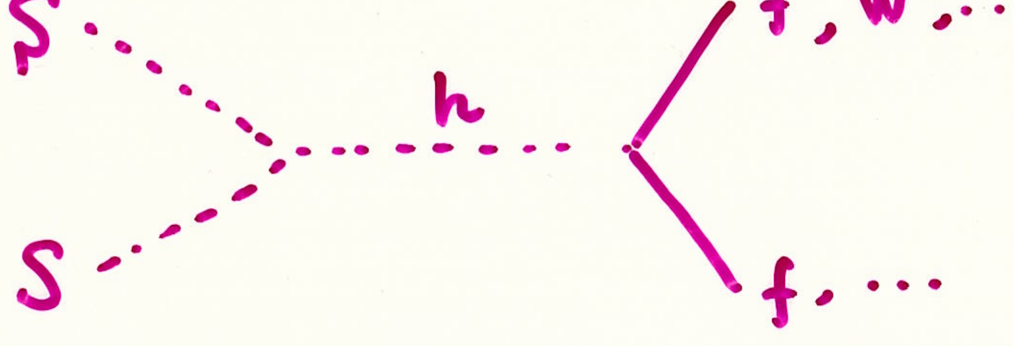
J. McDonald 1994, ...

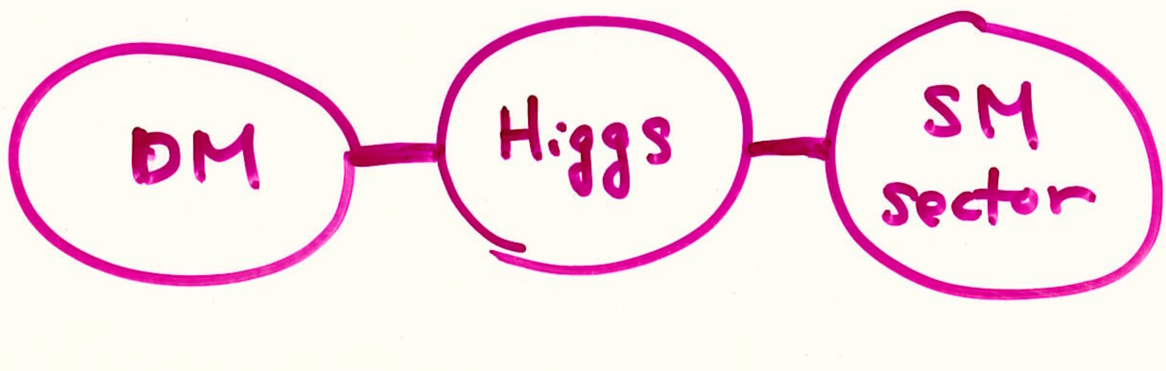
## Lagrangian

$$\mathcal{L} = \mathcal{L}_{SM}$$
$$+ \frac{1}{2}(\partial S)^2 - \frac{m_0^2}{2} S^2 - \frac{\lambda_S}{4} S^4$$
$$+ (-\lambda) S^2 |\Phi|^2$$

invariant under $S \to -S$

## Dark matter



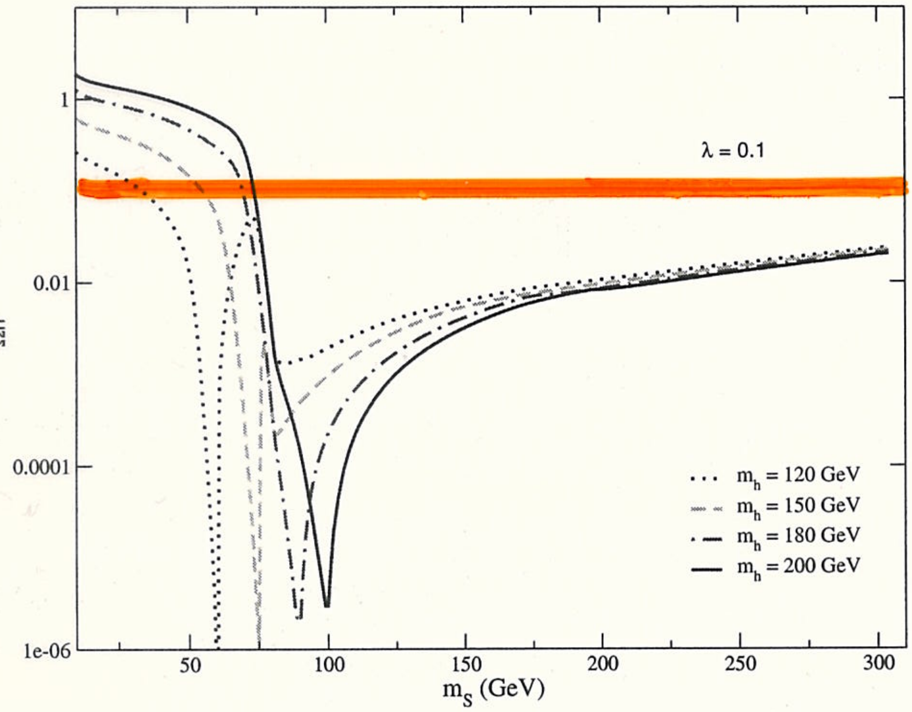



Figure 1: The dark matter density as a function of $m_S$ for $\lambda = 0.1$ and different values of the higgs mass.

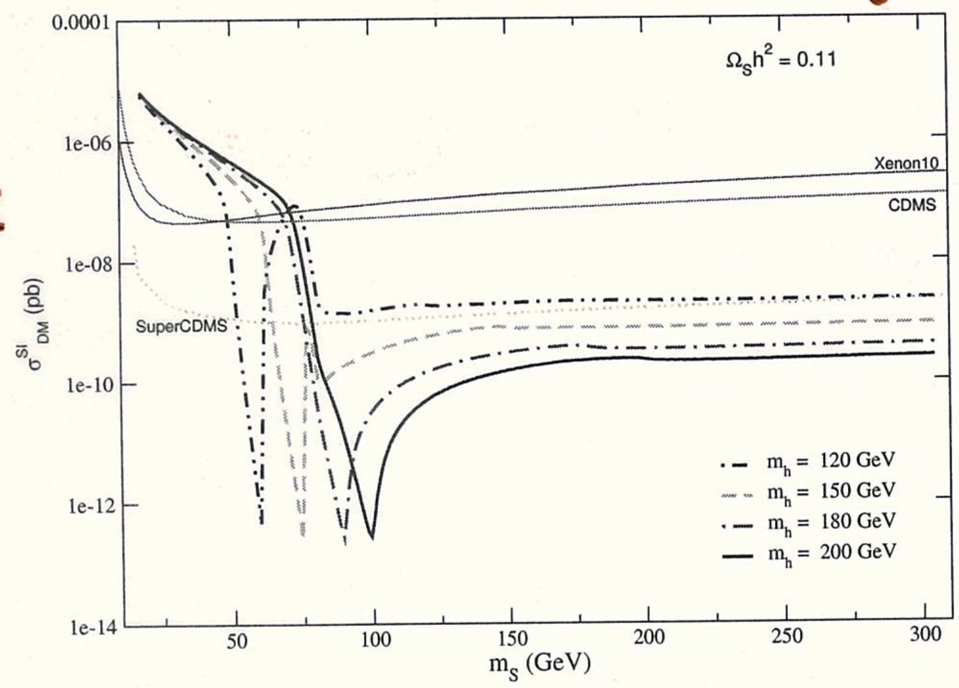



Figure 3: The spin-independent proton-singlet cross section as a function of $m_S$ for different values of the higgs mass. The thin lines show the present constraint from XENON10 and CDMS. The dotted line corresponds to the expected sensitivity of SuperCDMS. Along the lines $\Omega_S h^2 = 0.11$.

## § Two missings in SM of particle physics

1. Neutrino mass

2. Dark matter candidate

# Minimal $U(1)_{B-L}$ model

gauge symmetry

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

particle contents

- SM particles
- $U(1)_{B-L}$ gauge boson $\longrightarrow Z'$
- $U(1)_{B-L}$ higgs $\longrightarrow H$
- Three RH neutrinos

# Dark matter in the minimal $U(1)_{B-L}$ model

What is massive and neutral ?

$(\nu_L)$, $h$, $Z$

$N$, $H$, $Z'$

Which is stable ?

Nothing !

[ Note

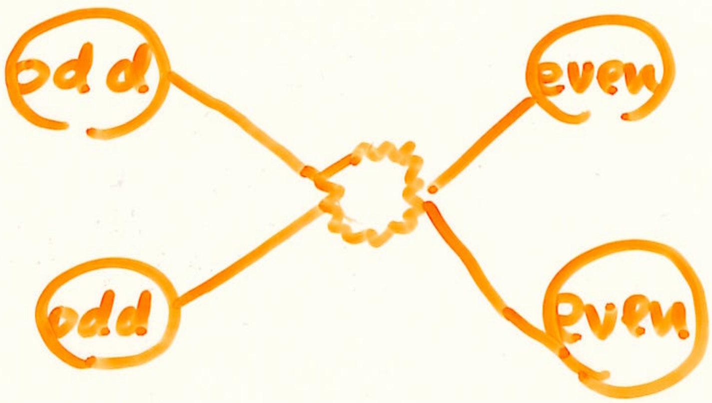
Sterile $\nu$ DM is possible...

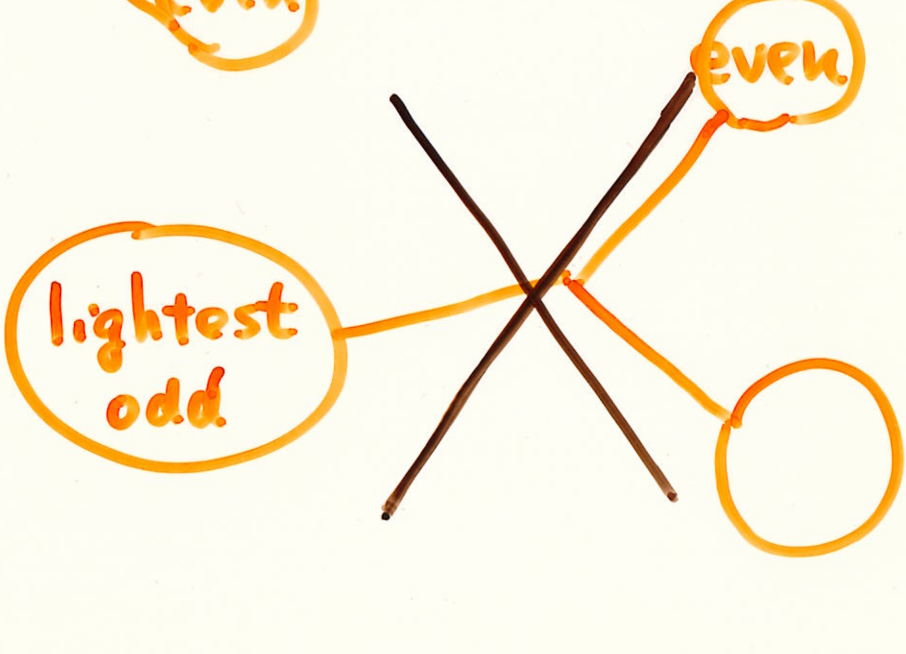
Khalil and Seto (2008) ]

# Discrete symmetry (Parity) for WIMPs

ex) 1. R-parity in SUSY

2. $Z_2$-parity in e.g. gauge singlet DM (J. McDonald, … )



# Who can be $Z_2$-odd ?

- $Z'$ …. No
- $H$ ….. No

$$V \supset |\Phi|^2 |\tilde{\Phi}|^2$$

- $N$ …. No

$$(m_\nu)_{ij} = \sum_k y_{ik} y_{kj} \frac{v^2}{M_{N_k}}$$

from $\bar{L}_i y_{ik} \tilde{\Phi} N_k$

to explain $\Delta m^2_{atm}$ and $\Delta m^2_{sol}$

# Who can be $Z_2$-odd ?

- $Z'$ .... No
- $H$ ..... No

$V \supset |\Phi|^2 |\tilde{\Phi}|^2$

- $N$ .... ~~No~~ Yes

$$(m_\nu)_{ij} = \sum_k^{2} y_{ik} y_{kj} \frac{v^2}{M_{N_k}}$$

from $\bar{L}_i y_{ik} \tilde{\Phi} N_k$

to explain $\Delta m_{atm}^2$ and $\Delta m_{sol}^2$

**two Ns are enough**

3 − 2 = 1

anomaly ν-osc. can be $Z_2$-odd

## § RH neutrino dark matter

# Thermal relic density of RH neutrino

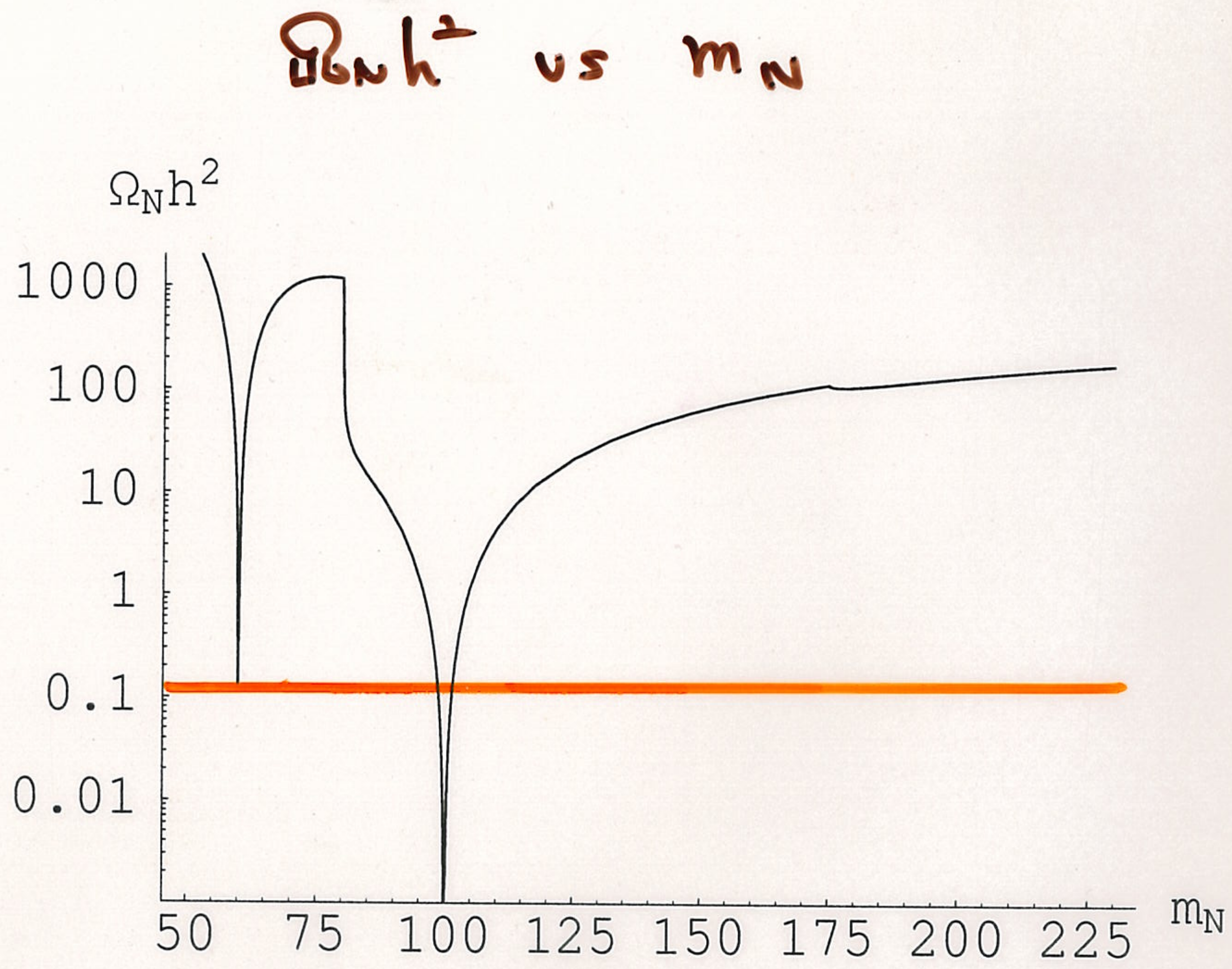
Annihilation

$\rightarrow f\bar{f}$

$\nu_L, \ell, q, \nu_R$

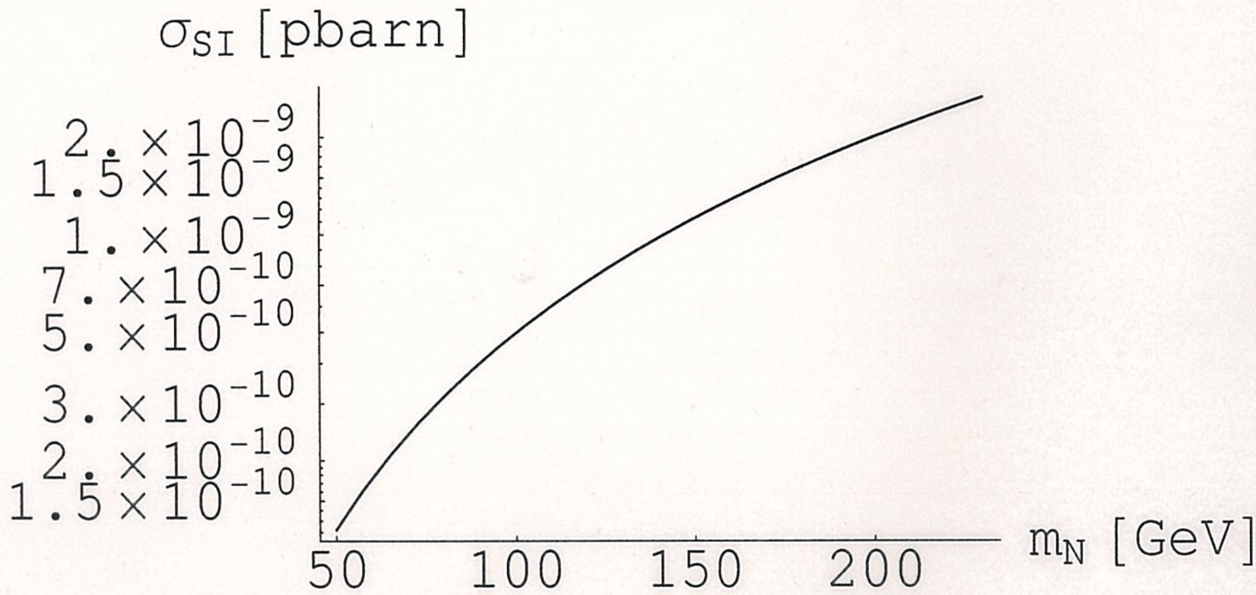
$\rightarrow W^+W^-, ZZ$

$\rightarrow hh, hH, HH$




. 1: The thermal relic density of RH neutrino dark matter as a function of its ma
$M_h, M_H, M_{Z'}, \sin\theta) = (4000\text{GeV}, 120\text{GeV}, 200\text{GeV}, 1000\text{GeV}, 0.7)$.

$\sigma_{SI}$ vs $m_N$




The spin independent scattering cross section with a proton for $\sin\theta = 0.7$. All paramet

e as these used in the previous section.

## § Summary

We consider the minimal $U(1)_{B-L}$ model

naively no WIMP

With $Z_2$-parity,

Only one WIMP : N

- $\Omega_N h^2 \simeq 1 \iff m_N \simeq \frac{m_h}{2}$ or $\frac{m_H}{2}$

  DM mass $\rightleftharpoons$ a higgs mass

- $\sigma_{SI} \sim 10^{-10}$ pb

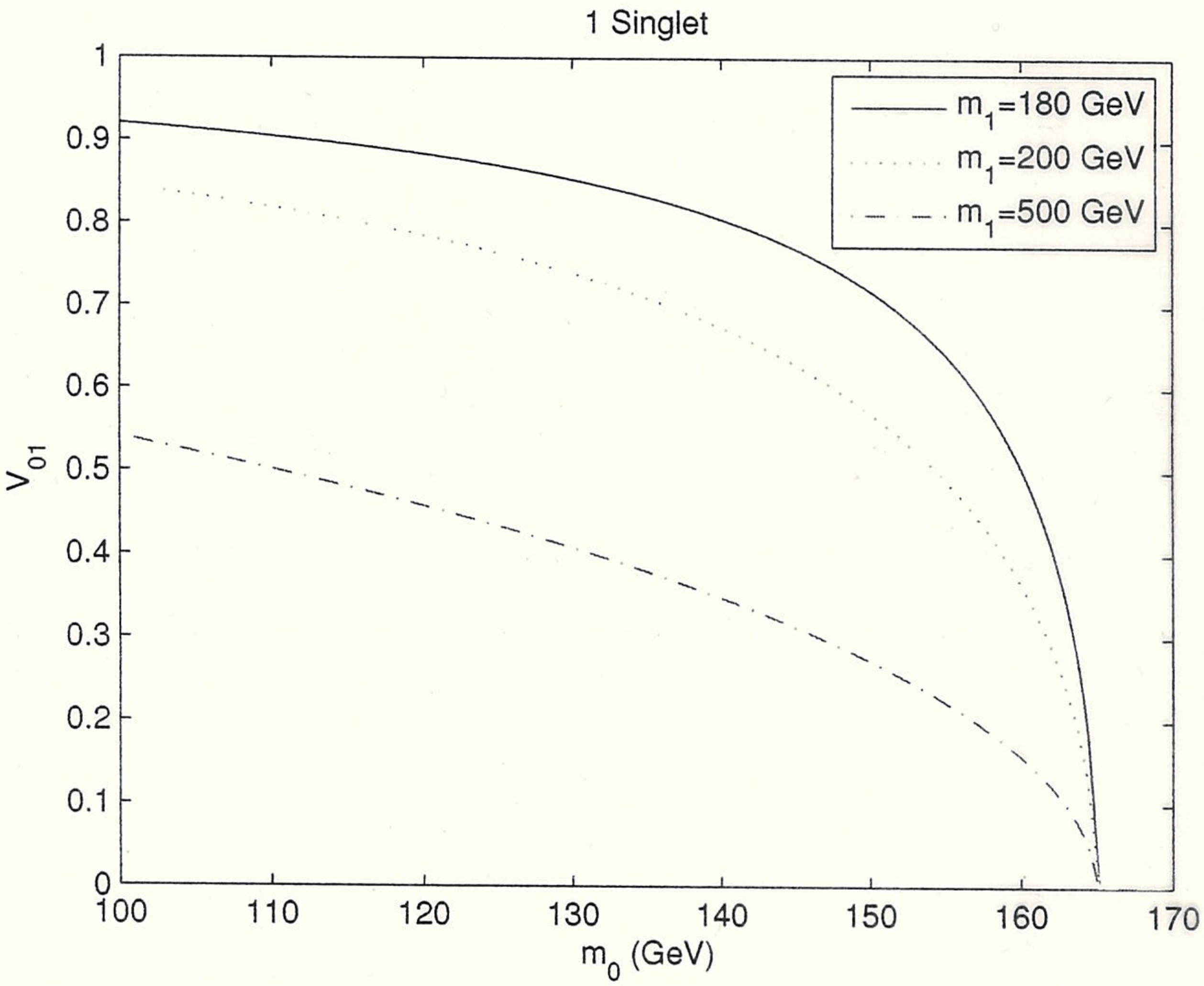
  within reach of 1 T detector.

# Experimental bounds

## Z′

$$\frac{M_{Z'}}{g_{B-L}} \gtrsim 7\ \text{TeV} \quad (\text{Cacciapaglia et. al. '06})$$
$$6\ \text{TeV} \quad (\text{Carena et al '04})$$

## Higgs




wed region (at 95% confidence level) in a model with one additional singl
$SU(2)_L$ doublet. The lightest (heavier) scalar is $m_0$ ($m_1$) and the mix
q. 4. The region below the curves is allowed by fits to $S, T$ and $U$.