Collider signals of W′ and Z′ bosons in the gauge-Higgs unification

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gauge-Higgs unification

$$A_M = (A_\mu, A_y)$$

4D gauge boson — Higgs boson

Higgs boson mass is protected by the gauge symmetry

⟶ **finite Higgs boson mass**

VEV appears as a Wilson line phase

$$e^{i\theta_H} = \exp\left(ig\int_c dy \langle A_y \rangle\right)$$

Hosotani, Phys. Lett. B126 (1983)

Hosotani mechanism

SO(5)×U(1) gauge-Higgs unification

RS metric

$$ds^2 = e^{-2ky}\eta_{\mu\nu}dx^\mu dx^\nu + dy^2$$

Symmetry Breaking

$$SO(5)\times U(1)_X \xrightarrow[\text{boundary condition}]{} SO(4)\times U(1)_X \quad (W_R,\ Z_R)$$
$$\simeq SU(2)_L \times SU(2)_R \times U(1)_X$$
$$\xrightarrow[\text{brane int.}]{} SU(2)_L \times U(1)_Y \quad (W,\ Z,\ \gamma)$$
$$\longrightarrow U(1)_{\rm EM}$$

Hosotani mechanism

Boundary Condition

$$A_\mu(x,-y) = \ PA_\mu(x,y)P^{-1}$$
$$A_y(x,-y) = -PA_y(x,y)P^{-1}$$
$$P = \mathrm{diag}(-1,-1,-1,-1,\ 1)$$

Parameters

1 free parameter : $z_L = e^{kL}$

$z_L = 10^5 \Rightarrow \theta_H = 0.115\ (m_{Z'} \simeq 6\ \mathrm{TeV})$

$z_L = 10^4 \Rightarrow \theta_H = 0.0737 (m_{Z'} \simeq 8\ \mathrm{TeV})$

Couplings and decay width

Couplings are obtained by the overlap integral
not free parameter

Couplings of $W^{(n)}$ to left-handed SM fermions in the unit of $g_w/\sqrt{2}$ for $z_L = 10^5$ $(\theta_H = 0.115)$ case.

	$n=0$	1
(e,ν_e)	1.00019	-0.3455
(μ,ν_μ)	1.00019	-0.3455
(τ,ν_τ)	1.00019	-0.3452
(u,d)	1.00019	-0.3455
(c,s)	1.00019	-0.3454
(t,b)	0.9993	1.2970

different sign

Couplings of Z' to up-type quark in the unit of g_w for $z_L = 10^5$ $(\theta_H = 0.115)$ case.

g^L_{Zuu}	$g^L_{Z^{(1)}uu}$	$g^L_{Z_R^{(1)}uu}$	$g^L_{\gamma^{(1)}uu}$
0.3945	−0.1361	$O(10^{-9})$	−0.1111
g^R_{Zuu}	$g^R_{Z^{(1)}uu}$	$g^R_{Z_R^{(1)}uu}$	$g^R_{\gamma^{(1)}uu}$
−0.1759	−0.7152	0.9846	1.298

Z′ : large couplings

large decay widths

Couplings of $W'WH$ and $Z'ZH$, and partial decay widths of $W' \to WH$ and $Z' \to ZH$.

	Couplings (GeV)	Γ (GeV)
$W^{(1)} \to WH$	$g_w \cos\theta_H \times 255$	42.1
$W_R^{(1)} \to WH$	$g_w \times 266$	43.4
$Z^{(1)} \to ZH$	$\frac{g_w \cos\theta_H}{\cos\theta_W} \times 291$	54.8
$Z_R^{(1)} \to ZH$	$\frac{g_w}{\cos\theta_W} \times 223$	30.7

- $W^{(1)}WZ$, $W_R^{(1)}WZ$, etc are $O(10^{-4})$
- W_R doesn't couples to quarks and leptons

$\theta_H = 0.115$

$z_L = 10^5$	mass (TeV)	Γ (GeV)
$\gamma^{(1)}$	6.01	909
$Z^{(1)}$	6.00	406
$Z_R^{(1)}$	5.67	729
$W^{(1)}$	6.00	187
$W_R^{(1)}$	5.67	87

$\theta_H = 0.0737$

$z_L = 10^4$	mass (TeV)	Γ (GeV)
$\gamma^{(1)}$	8.52	1068
$Z^{(1)}$	8.52	564
$Z_R^{(1)}$	7.92	1058
$W^{(1)}$	8.52	346
$W_R^{(1)}$	7.92	97

Results

- The $W^{(1)}$ couplings to light fermions and to top-bottom are different in signs.
- We found

  $\Gamma(W^{(1)} \to WH) \simeq \Gamma(W^{(1)} \to WZ)$

  $\Gamma(W_R^{(1)} \to WH) \simeq \Gamma(W_R^{(1)} \to WZ)$

  $\Gamma(Z^{(1)} \to ZH) \simeq \Gamma(Z^{(1)} \to WW) + \Gamma(\gamma^{(1)} \to WW)$

  and $\Gamma(Z_R^{(1)} \to ZH) \simeq \Gamma(Z_R^{(1)} \to WW)$.
- A large excess is predicted in $Z' \to \mu\mu$

  For $\theta_H = 0.115$ (Z' mass ~ 6 TeV)

  with the data of 30 fb−1, √s = 13TeV,

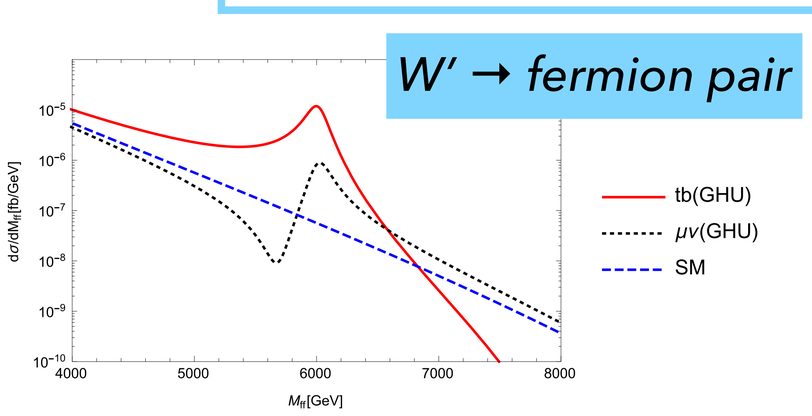
  3 events for bins (GeV) [5000, 6000].
- The unitarity is preserved

  in the WZ final state process

  with 7 digits accuracy.

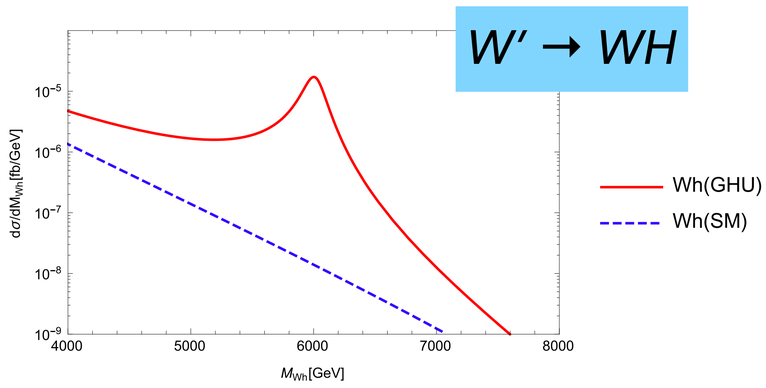
Figures of collider signals

W′ → fermion pair



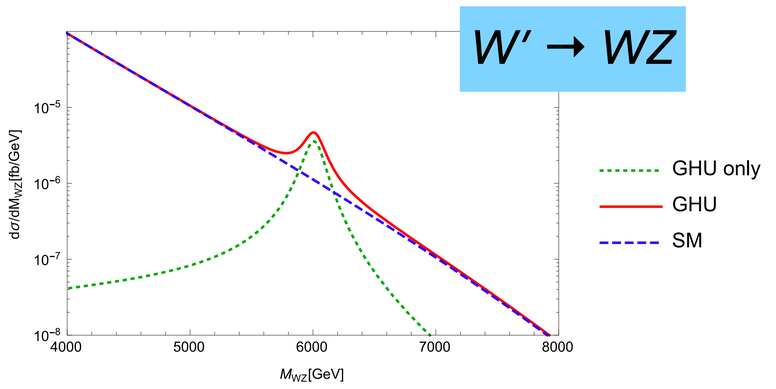
$pp(d\bar{u}) \to \{W^-, W^{(1)-}\} \to b\bar{t}, \mu^-\bar{\nu}_\mu$ differential cross sections $d\sigma/dM_{\rm ff}$ at $\sqrt{s_{pp}} = 14$ TeV for $z_L = 10^5$ $(\theta_H = 0.115)$.

W′ → WH



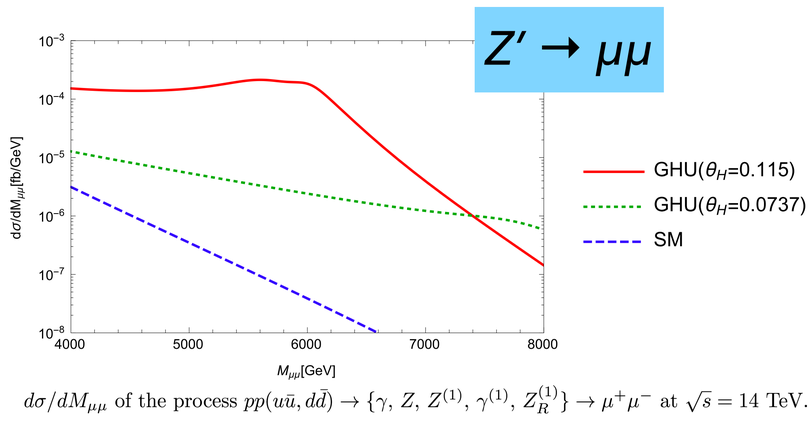
$d\sigma/M_{Wh}$ of the process $pp(d\bar{u}) \to \{W^-, W^{(1)-}\} \to W^-H$ at $\sqrt{s_{pp}} = 14$ TeV for $z_L = 10^5$ $(\theta_H = 0.115)$.

W′ → WZ



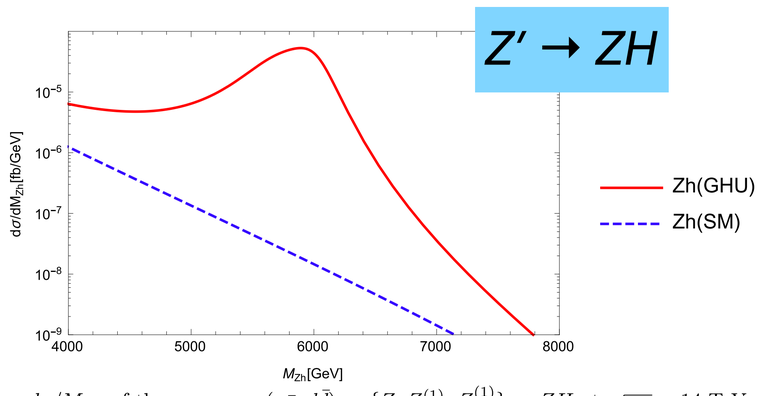
$d\sigma/dM_{WZ}$ of the process $pp(d\bar{u}) \to \{W^-, W^{(1)-}\} \to W^-Z$ at $\sqrt{s_{pp}} = 14$ TeV for $z_L = 10^5$ $(\theta_H = 0.115)$.

Z′ → μμ



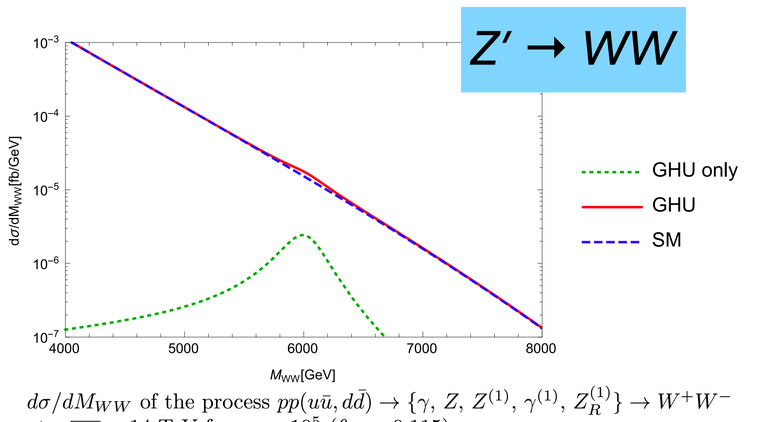
$d\sigma/dM_{\mu\mu}$ of the process $pp(u\bar{u}, d\bar{d}) \to \{\gamma,\ Z,\ Z^{(1)},\ \gamma^{(1)},\ Z_R^{(1)}\} \to \mu^+\mu^-$ at $\sqrt{s} = 14$ TeV.

Z′ → ZH



$d\sigma/M_{Zh}$ of the process $pp(u\bar{u}, d\bar{d}) \to \{Z,\ Z^{(1)},\ Z_R^{(1)}\} \to ZH$ at $\sqrt{s_{pp}} = 14$ TeV for $z_L = 10^5$ $(\theta_H = 0.115)$.

Z′ → WW



$d\sigma/dM_{WW}$ of the process $pp(u\bar{u}, d\bar{d}) \to \{\gamma,\ Z,\ Z^{(1)},\ \gamma^{(1)},\ Z_R^{(1)}\} \to W^+W^-$ at $\sqrt{s_{pp}} = 14$ TeV for $z_L = 10^5$ $(\theta_H = 0.115)$.