Z' measurements in Higgsless models at the LHC

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Motivation

Higgs boson has not been discovered.

In the Standard model without Higgs boson,
$W_L W_L$ scattering violates tree-level unitarity @ $\sqrt{s} \sim 1$TeV.

➡ There are Two possibility at $\sqrt{s} \sim 1$ TeV

- Non-perturbative
- Perturbative

Motivation

Two possibility at $\sqrt{s}$ ~ 1 TeV

- **Non-perturbative**

  There is no resonance < 1 TeV

  - Technicolor ...

- **Perturbative**

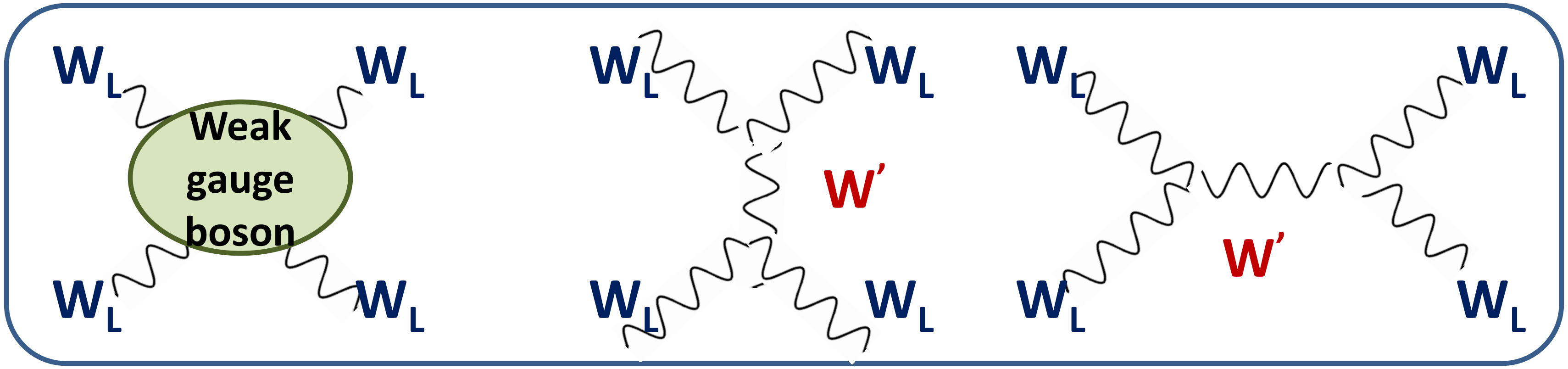
  New resonance should appear < 1TeV to unitarize $W_L W_L$ scattering.

We focus on this possibility in this study.

- **Perturbative:** New resonance should appear (< 1TeV) to unitarize $W_L W_L$ scattering.

  - SPIN 0 --- Higgs (SM, SUSY, ...) (H)
  - SPIN 1 --- Higgsless model (W', Z' ,...)

  Spin 1 resonances will be responsible to restore the unitarity of $W_L W_L$ scattering.



(Similar to Unitarity of π π scattering is restored by ρ meson)

- **Perturbative:** New resonance should appear (< 1TeV) to unitarize $W_L W_L$ scattering.

  - SPIN 0 --- Higgs (SM, SUSY, …) (H)
  - SPIN 1 --- Higgsless model (W’, Z’ ,…)

(H) or (W’ & Z’) should appear (< 1TeV) in perturebative TeV new theory.

Discovery & measurements of the spin 1 resonances are very important to interpret TeV new physics at LHC.

Our study Measurements of spin 1 resonance (Z’) mass using MAOS momentum

Feature of spin 1 resonances

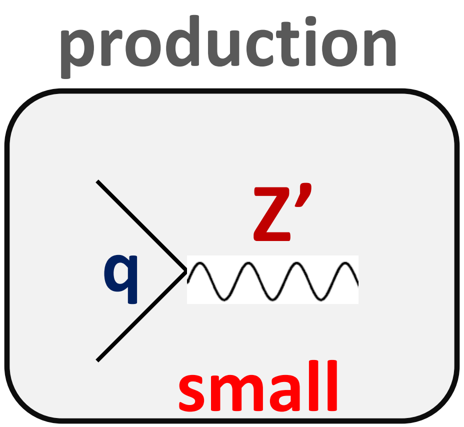
Features of spin 1 resonance in this study

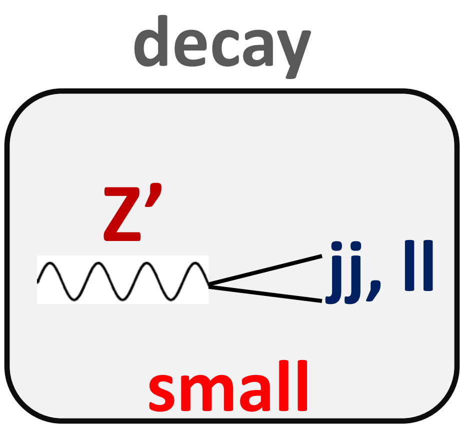
- Couple to weak gauge bosons
- Massive $\lesssim$ 1 TeV

  in order to avoid the unitarity violation.
- Coupling with fermions should be small

  in order to avoid the constrains from EWPM.

Following couplings should be small ➡





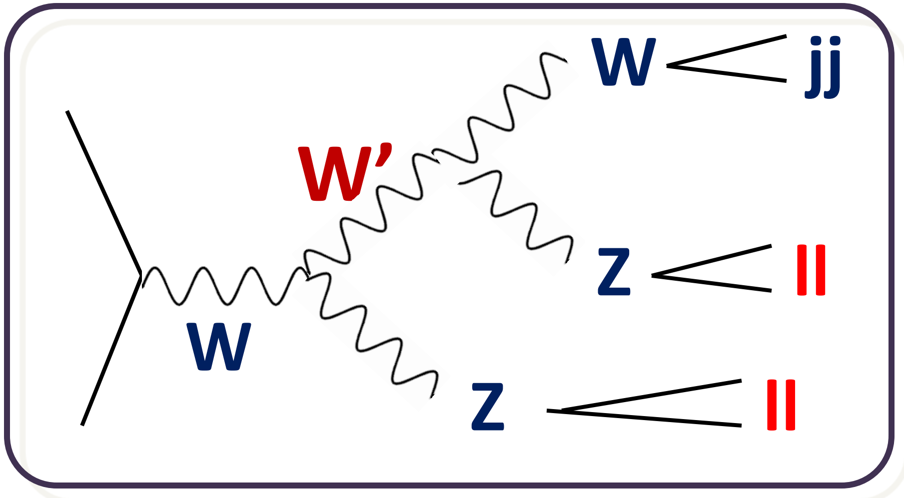
The example of this type scenario:

3-site Higgsless model, …

measurements of spin 1 resonances

W’ mass measurement

The final state is WZZ → lllljj



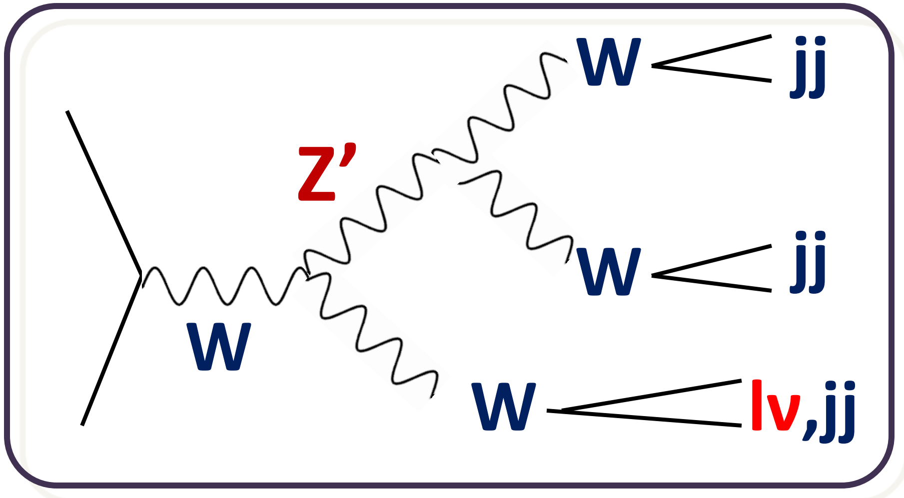
For example, He, Kuang, Qi, Zhang, Belyaev, Chivukula, Christensen, Pukhov and Simmons, arXiv.0708.2588 [hep-ph], Belyaev, arXiv.0711.1919 [hep-ph]

➡ W’ mass can be reconstructed well.

On the other hand, …

Z’ mass measurement

The final state is WWW

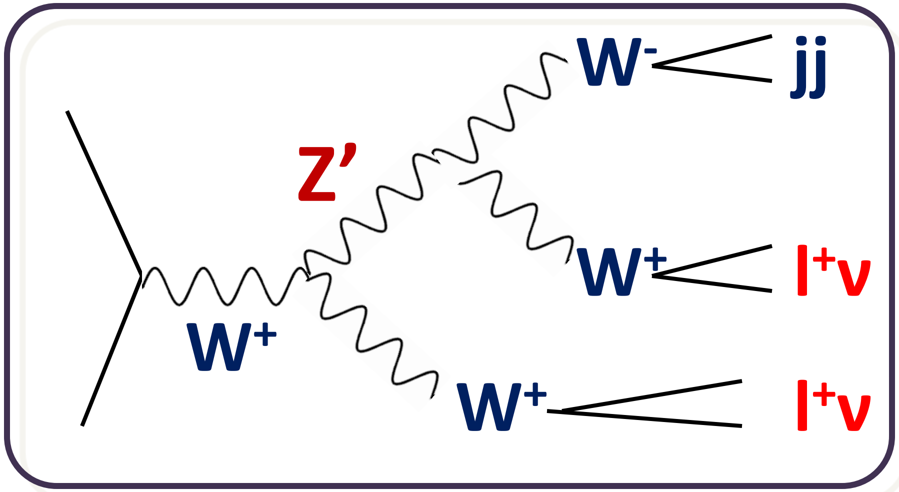


In events in which many hadronic decay W, W reconstruction is difficult due to contamination.

➡ **Z’ mass measurement is very difficult.**

Z’ mass measurement

The final state is WWW



Using same sign lepton + jj(~mW) mode, SM BG is small.

However, Z’ mass can be only determined by endpoint of M(llj) due to final 2 ν.

Tao Han et.al. (PRD80,095010)

We study to measure Z’ features using MAOS momentum.

(In this conference, MAOS has already introduced by Prof. K. Choi.)

From MAOS momentum, we can reconstruct 2 neutrino 4-momentum. Thus, the measurement of the Z’ peak is also possible!

Short review of MAOS momentum

M_{T2} Assisted On-Shell (MAOS) momentum

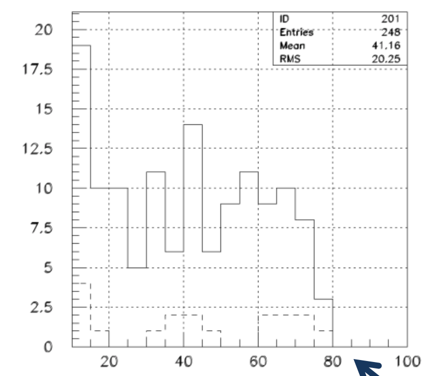
$$WW \to l(p)\nu(k)l'(q)\nu'(l)$$

W. S. Cho, et. al. PRD79,031701
K. Choi, et. al. PRD80, 073010

$$M_{T2} \equiv \min_{\mathbf{k}_T+\mathbf{l}_T=\not{\mathbf{p}}_T} \left[\max\left\{M_T^{(1)}, M_T^{(2)}\right\}\right] \leq M_W$$

$$\left(M_T^{(1)}\right)^2 = 2\left(|\mathbf{p}_T||\mathbf{k}_T| - \mathbf{p}_T\cdot\mathbf{k}_T\right) \quad \left(M_T^{(2)}\right)^2 = 2\left(|\mathbf{q}_T||\mathbf{l}_T| - \mathbf{q}_T\cdot\mathbf{l}_T\right)$$

$$\begin{aligned} M_{T2}(\mathbf{p}_T, \mathbf{q}_T, \not{\mathbf{p}}_T) &= \sqrt{2\left(|\mathbf{p}_T||\mathbf{k}_T^{\rm maos}| - \mathbf{p}_T\cdot\mathbf{k}_T^{\rm maos}\right)} \\ &= \sqrt{2\left(|\mathbf{q}_T||\mathbf{l}_T^{\rm maos}| - \mathbf{q}_T\cdot\mathbf{l}_T^{\rm maos}\right)}, \\ \not{\mathbf{p}}_T &= \mathbf{k}_T^{\rm maos} + \mathbf{l}_T^{\rm maos}. \end{aligned}$$



m_W

MAOS momentums should satisfy following relations:

1. $(k_{\rm maos})^2 = (l_{\rm maos})^2 = 0$ **2.** $(p + k_{\rm maos})^2 = (q + l_{\rm maos})^2 = M_W^2$

$$\mathbf{k}_T^{\rm maos} = -\mathbf{q}_T \qquad k_L^{\rm maos}(\pm) = \frac{1}{|\mathbf{p}_T|^2}\left[p_L A \pm \sqrt{|\mathbf{p}_T|^2 + p_L^2}\sqrt{A^2 - |\mathbf{p}_T|^2|\mathbf{k}_T^{\rm maos}|^2}\right]$$

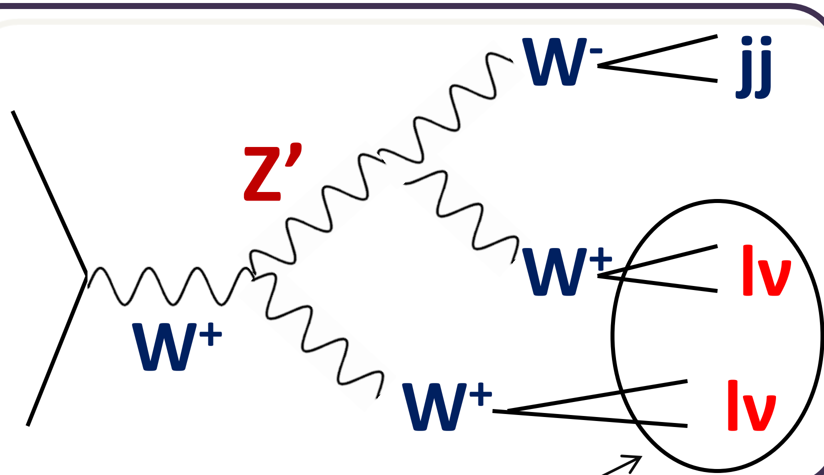
$$\mathbf{l}_T^{\rm maos} = -\mathbf{p}_T \qquad l_L^{\rm maos}(\pm) = \ldots \qquad A \equiv M_W^2/2 + \mathbf{p}_T\cdot\mathbf{k}_T^{\rm maos}$$

At the M_{T2} endpoint,

$$\mathbf{k}_{\rm maos} = \mathbf{k}_{\rm true}, \quad \mathbf{l}_{\rm maos} = \mathbf{l}_{\rm true}$$

measurements of spin 1 resonances using MAOS momentum

Results Example: Z' (350GeV) in 3-site Higgsless model



Cross section ~ 850 fb

BG: WWW ~ 30 fb,
WWZ ~ 8 fb,...

We use M_{T2} for this part.

From this M_{T2} endpoint, we reconstruct 4-momenta of 2ν.

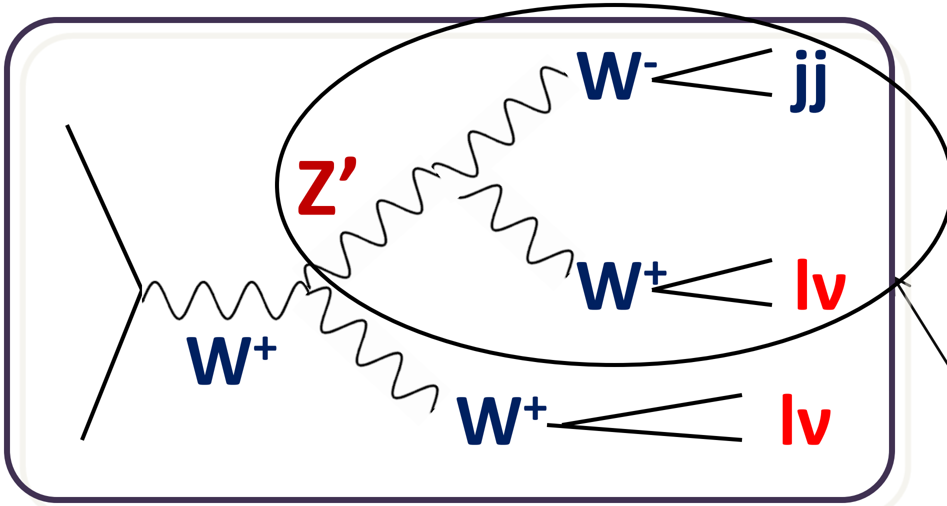
Main CUT:

P_{T1} > 125 GeV

65GeV < m_W < 95GeV

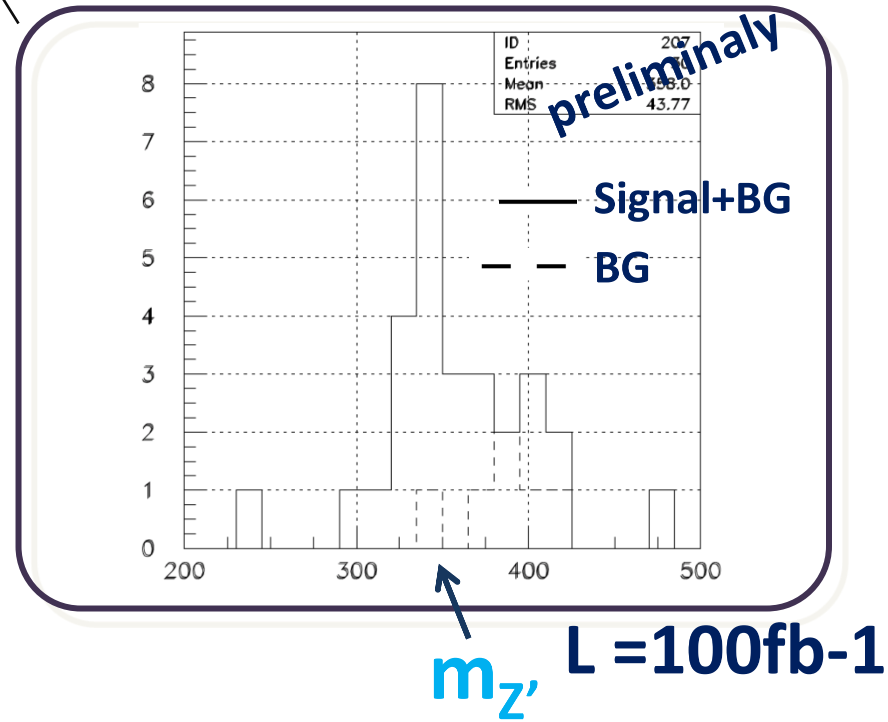
W boson can be reconstructed by lepton and reconstructed neutrino from MAOS momentum.

Results Example: Z' (350GeV) in 3-site Higgsless model



Finally, we reconstructed 4-momemtum of Z' from WW.

We use 2W which the invariant mass is smaller.



Reconstructed 2 W (from jj & lν) shows Z' mass peak!

Summary

- Appearance of W’, Z’ (decay to W boson) is one of the possibility in the LHC experiments.

- Z’ (decay to W boson) measurements are difficult because the final state is WWW.

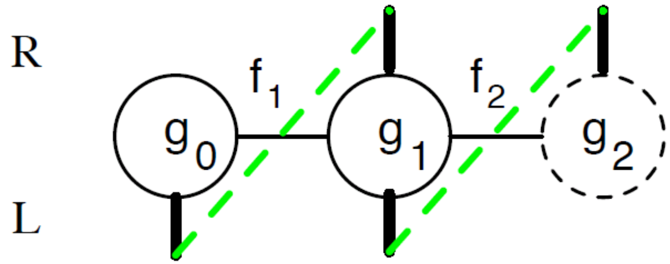
- Z’ (decay to W boson) peak can be measured using MAOS momentum.

⇒
  - Mass measurement become easier
  - Coupling measurement become easier

backup

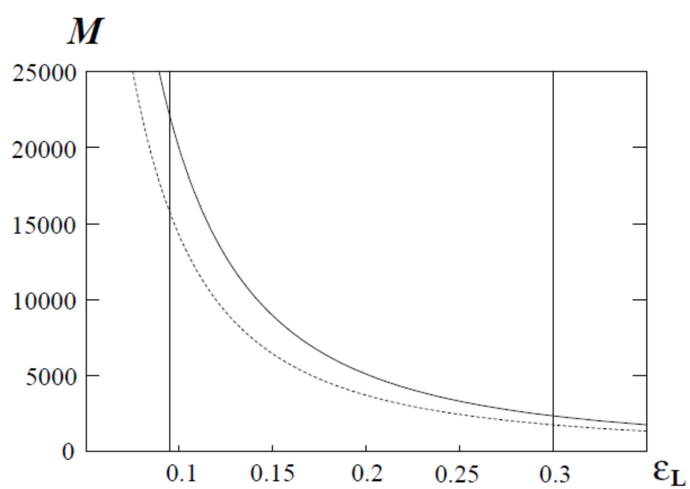
Three Site Model

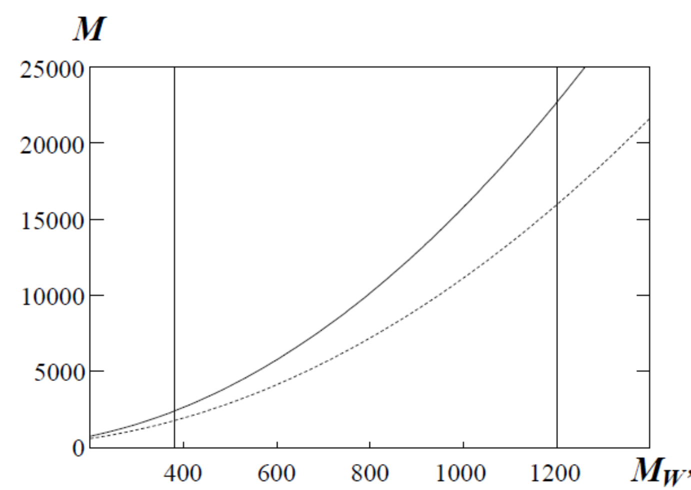
R.S. Chivukula et. al. PRD80,073010

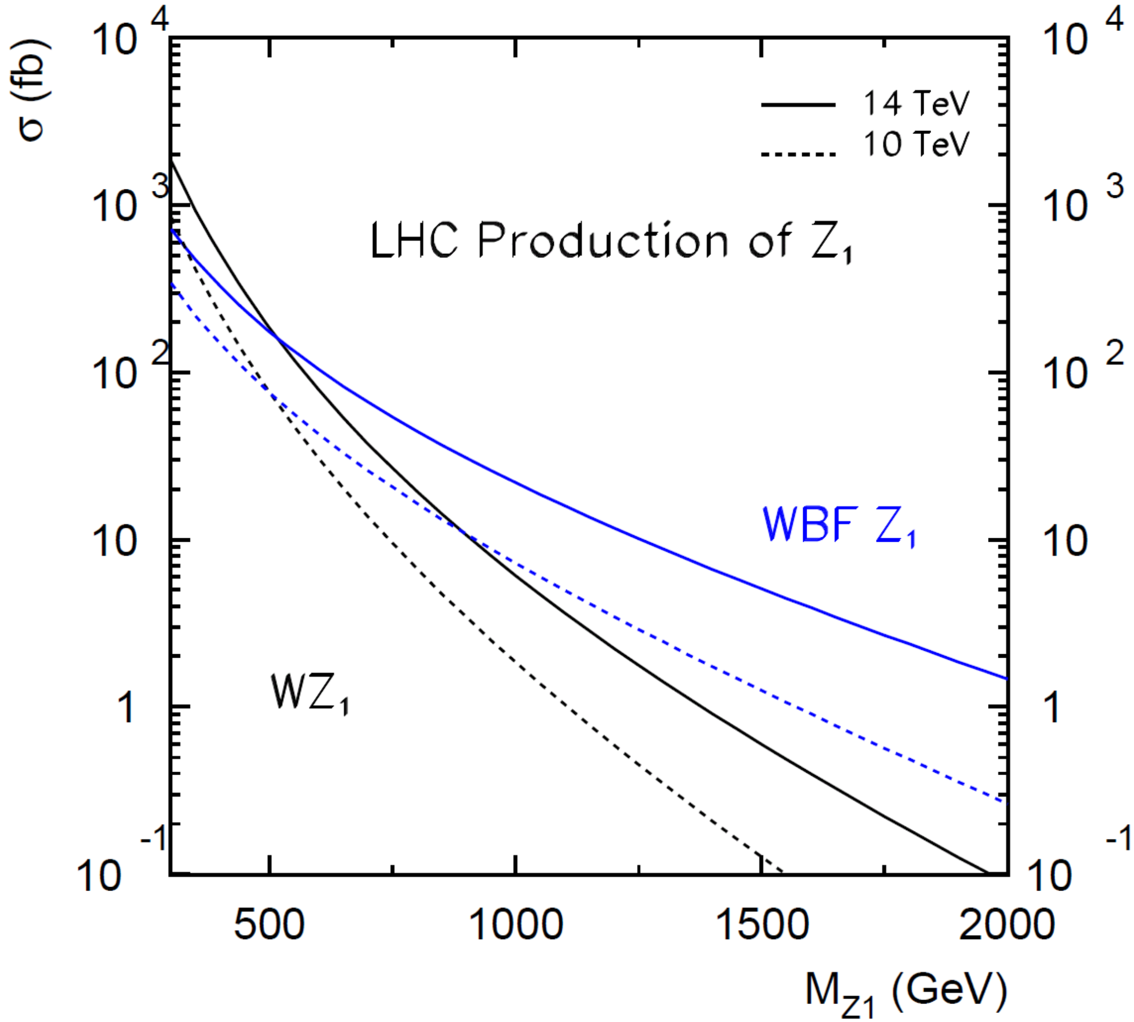


The model incorporates an $SU(2) \times SU(2) \times U(1)$ gauge group, and 2 nonlinear $(SU(2) \times SU(2))/SU(2)$ sigma models in which the global symmetry groups in adjacent sigma models are identified with the corresponding factors of the gauge group.

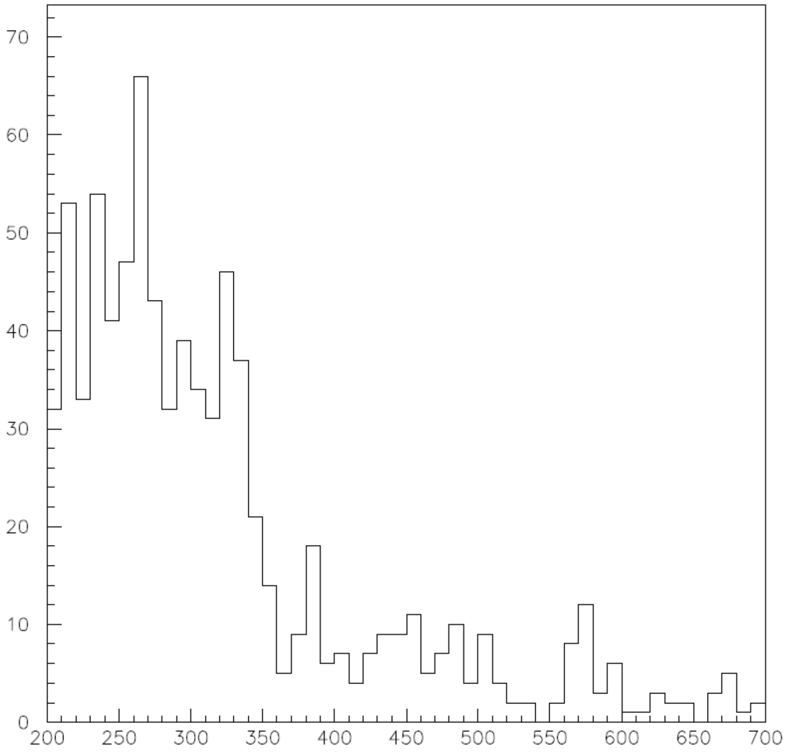
$$\mathcal{L}_f = \sqrt{2}\tilde{\lambda} v \left[\varepsilon_L \, \bar{\psi}_{L0} \Sigma_1 \psi_{R1} + \bar{\psi}_{R1} \psi_{L1} + \bar{\psi}_{L1} \Sigma_2 \begin{pmatrix} \varepsilon_{uR} & \\ & \varepsilon_{dR} \end{pmatrix} \begin{pmatrix} u_{R2} \\ d_{R2} \end{pmatrix} + h.c. \right]$$







Tao Han et.al. (PRD80,095010)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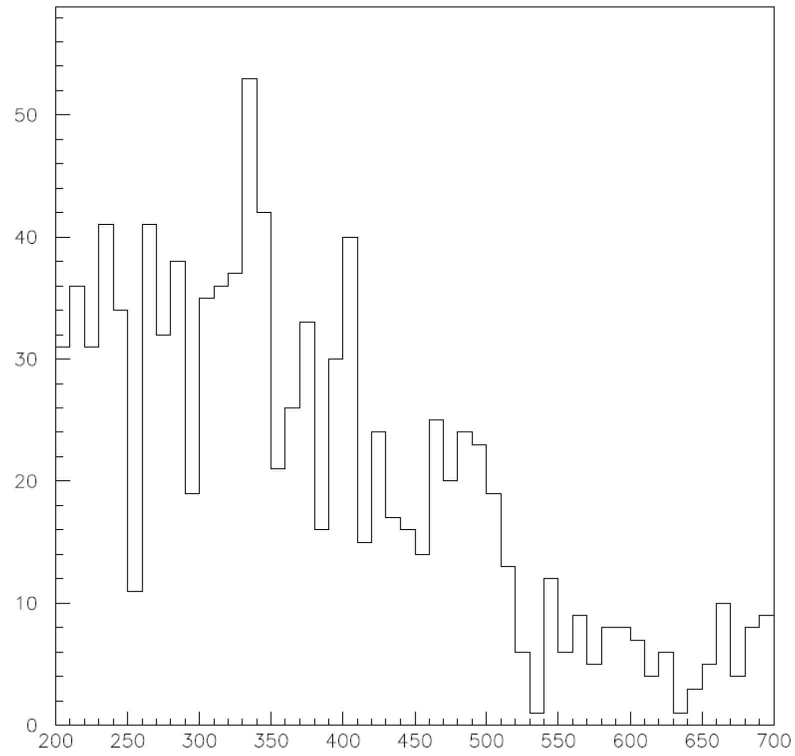
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He, Kuang, Qi, Zhang, Belyaev, Chivukula, Christensen, Pukhov and Simmons
arXiv.0708.2588 [hep-ph]
Belyaev, arXiv.0711.1919 [hep-ph]