

# Beyond the 3-Site Higgsless Model

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May 11, 2009

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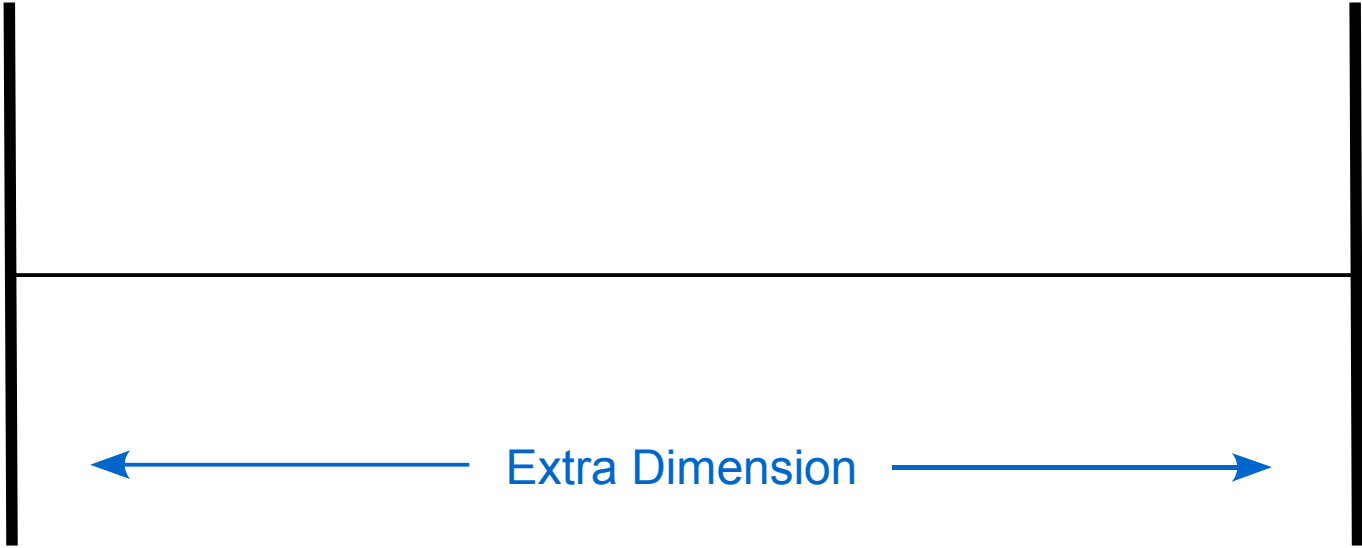
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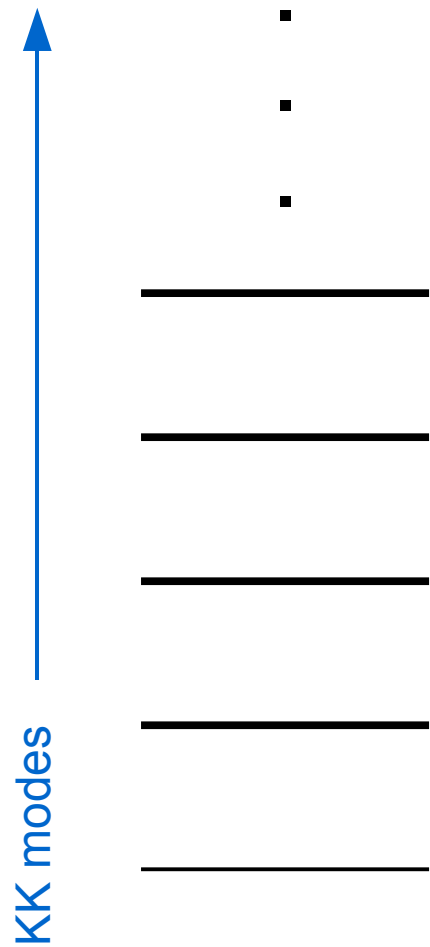
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Nagoya University

Boundary conditions  
can break  
electroweak symmetry.



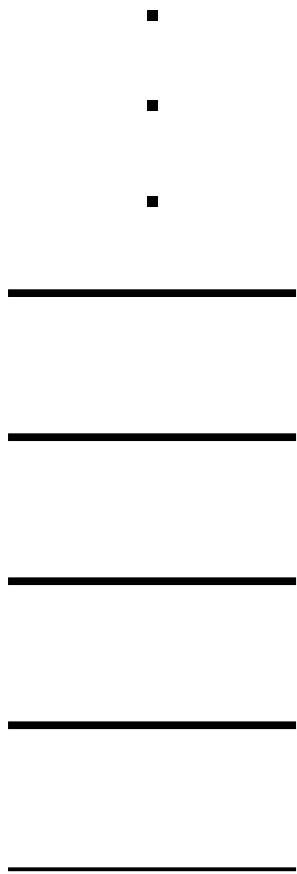
Extra Dimension



Higgsless extra dimensions  
produce towers of resonances.

Higgsless theories have sum rules.

↑  
KK modes



$$g_{WWWW} - g_{\gamma WW}^2 - \sum_i g_{Z_i WW}^2 = 0$$

$$4 g_{WWWW} M_W^2 - 3 \sum_i g_{Z_i WW}^2 M_{Z_i}^2 = 0$$

As a result, the  $s^2$  and  $s$  growth of the amplitude cancels.

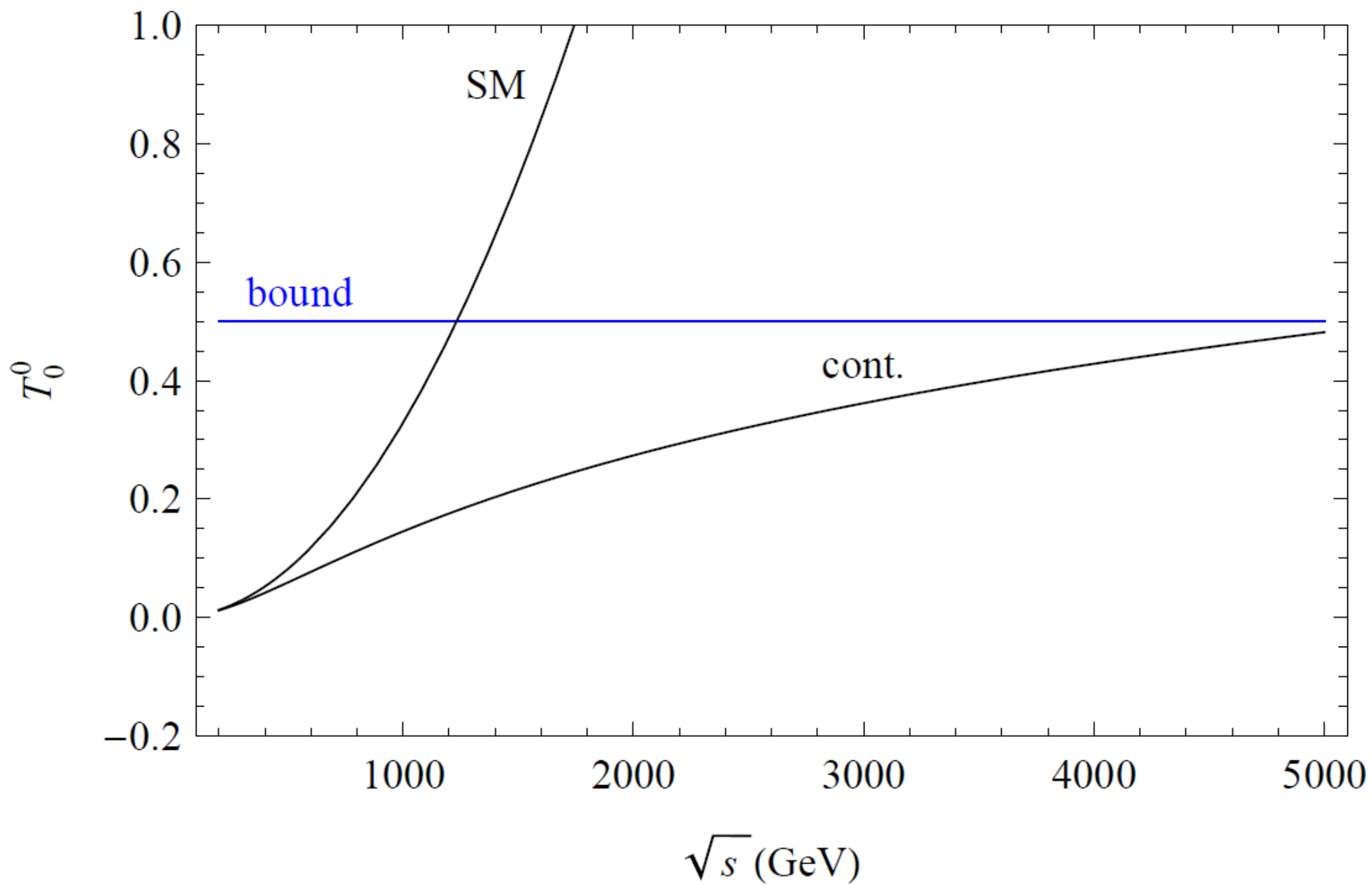
↑  
KK modes

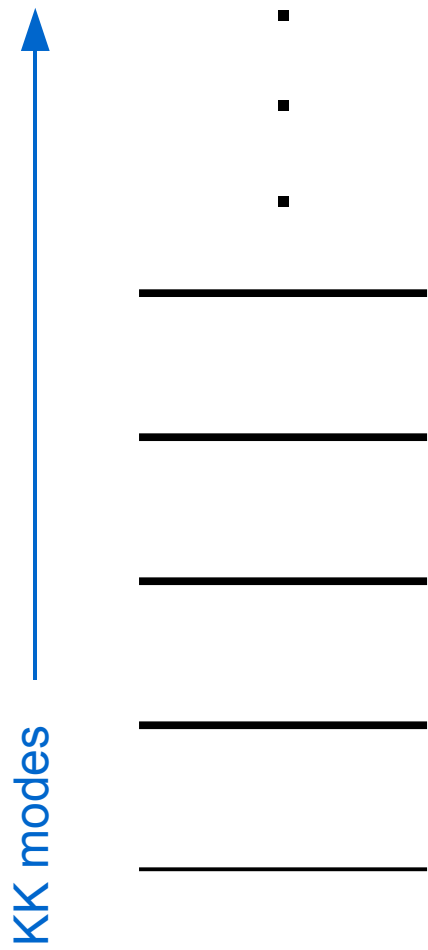
⋮

$$s^2 (g_{WWWW} - g_Y^2 WW - \sum_i g_{Z_i WW}^2) = 0$$

$$s (4 g_{WWWW} M_W^2 - 3 \sum_i g_{Z_i WW}^2 M_{Z_i}^2) = 0$$

$$V_L V_L \rightarrow V_L V_L$$





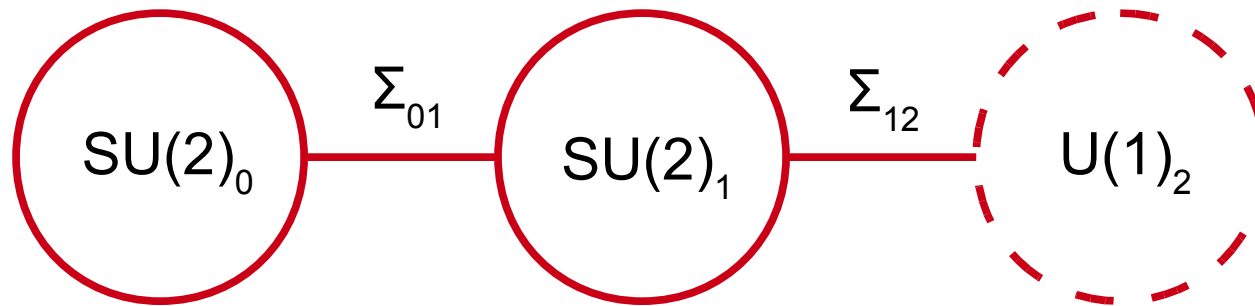
The low energy phenomenology is dominated by the lowest mode.

# Minimal Higgsless Model

—  $Z', W'$   
—  $Z, W$



# Minimal Higgsless Model or 3-Site Model



————  $Z', W'$

————  $Z, W$

PLB 155, 95 (1985)  
PRD 74, 075011 (2006)

...

The first sum rule is still satisfied.  
The  $s^2$  growth still cancels.

$$g_{WWWW} - g_{\gamma WW}^2 - g_{ZWW}^2 - g_{Z'WW}^2 = 0$$

————  $Z', W'$   
————  $Z, W$

The first sum rule is still satisfied.  
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$$g_{WWWW} - g_{\gamma WW}^2 - g_{ZWW}^2 - g_{Z'WW}^2 = 0$$

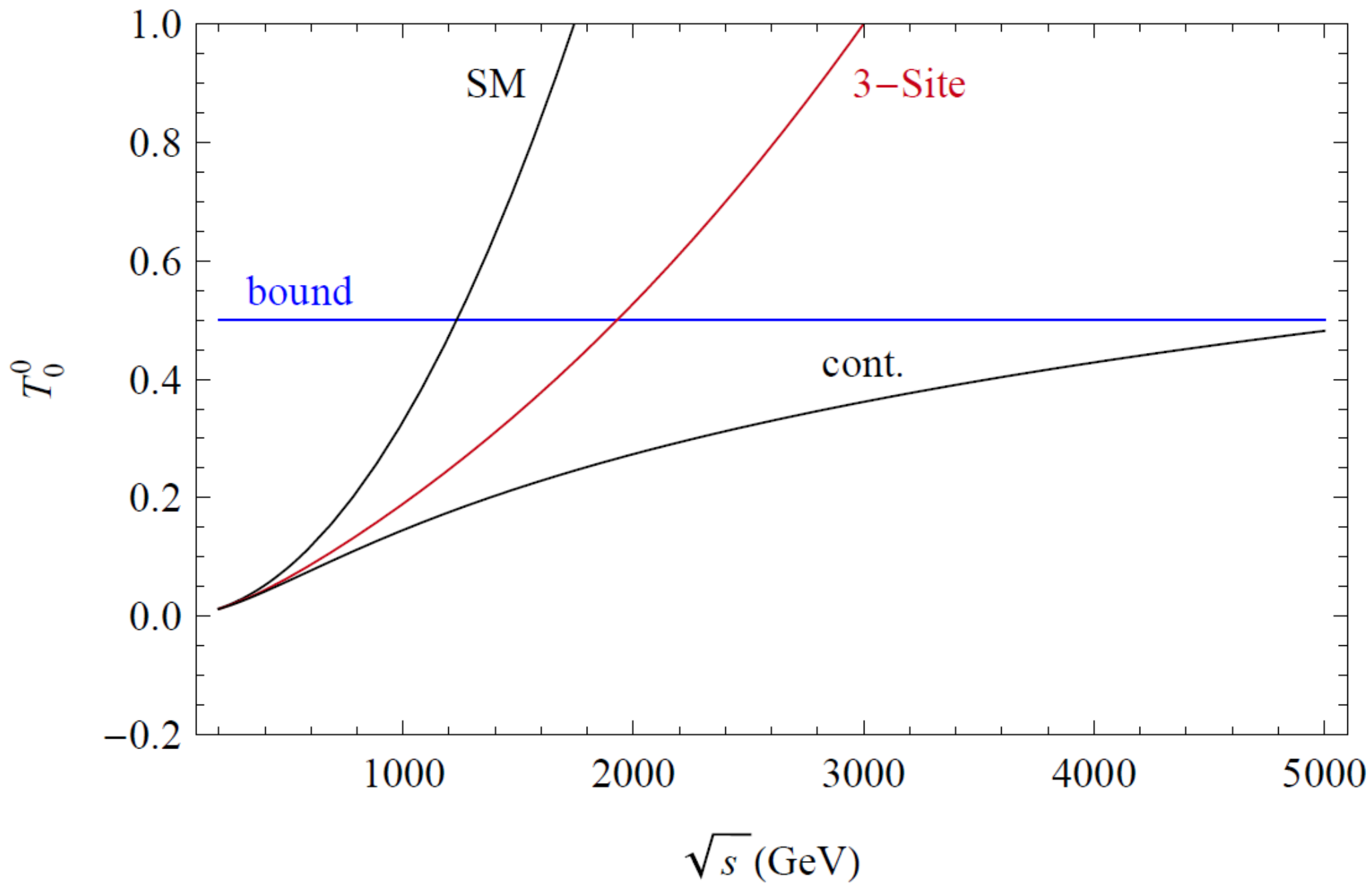
The second sum rule is not satisfied.  
The  $s$  growth does not cancel.

$$4 g_{WWWW} M_W^2 - 3 g_{ZWW}^2 M_Z^2 - 3 g_{Z'WW}^2 M_{Z'}^2 = 4 g_{\pi\pi\pi\pi} \frac{M_W^4}{v^2}$$

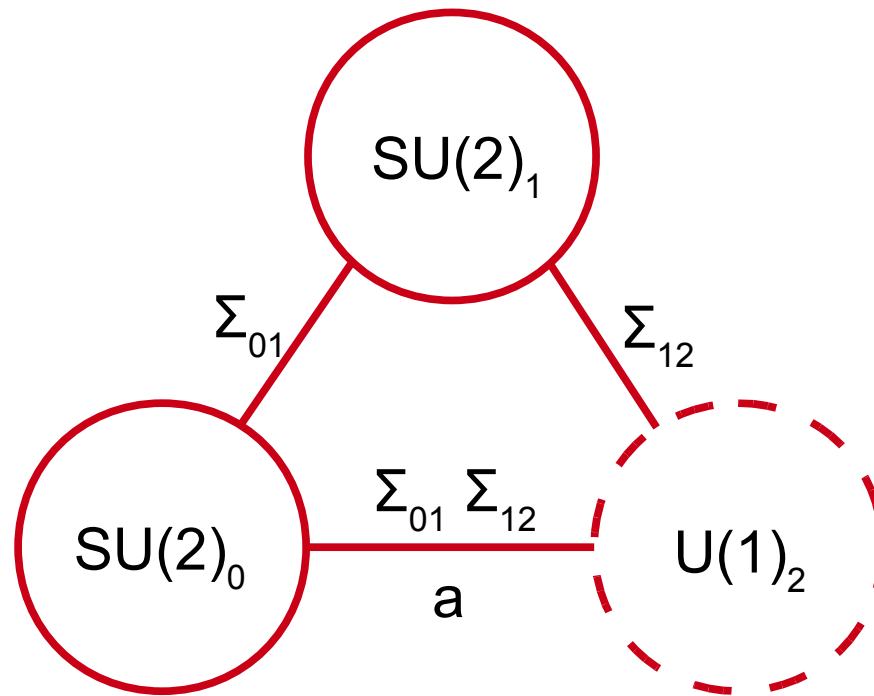
————  $Z', W'$

————  $Z, W$

$$V_L V_L \rightarrow V_L V_L$$



# Triangle 3-Site Model



—  $Z', W'$

—  $Z, W$

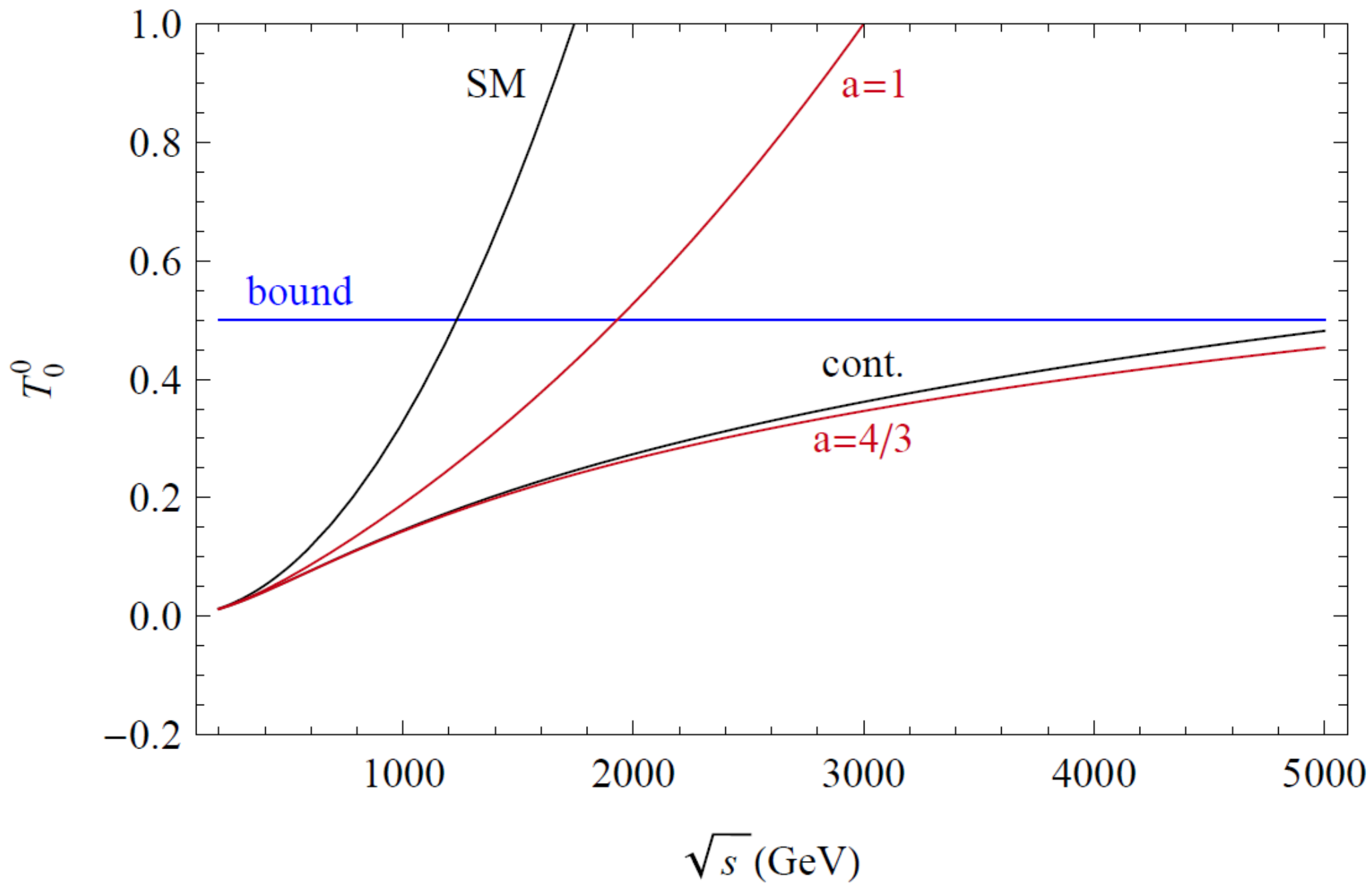
The second sum rule is satisfied for  $a=4/3$ .  
The s growth does cancel.

$$4 g_{WWWW} M_W^2 - 3 g_{ZWW}^2 M_Z^2 - 3 g_{Z',WW}^2 M_{Z'}^2 \propto (1 - \frac{3}{4} a)$$

—————  $Z', W'$

—————  $Z, W$

$V_L V_L \rightarrow V_L V_L$



**Model**

(Triangle 3-Site Model)



**FeynRules**

TeX

FeynArts

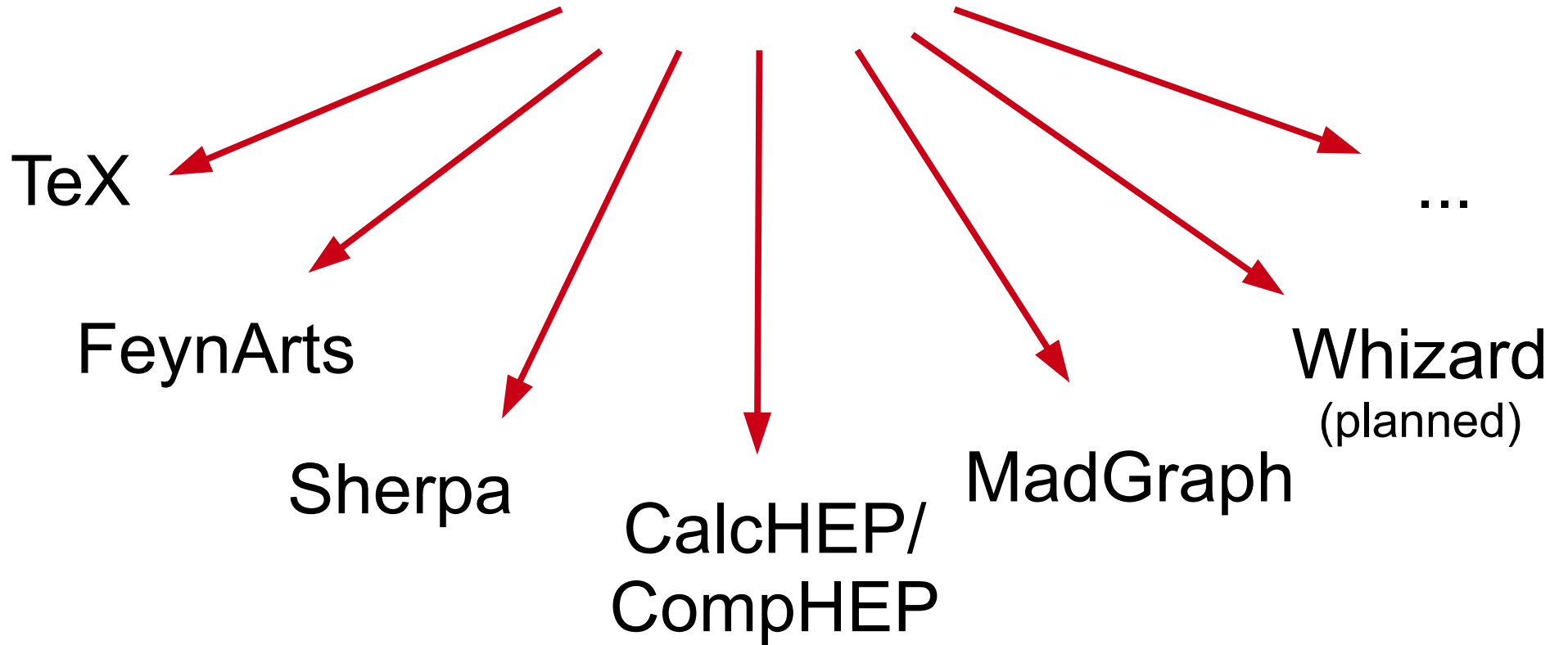
Sherpa

CalcHEP/  
CompHEP

MadGraph

Whizard  
(planned)

...





New physics could cause  
deviations in  $g_{ZWW}$ .

$$g_{ZWW} = e \frac{c_W}{s_W} (1 + \Delta g_1^Z)$$

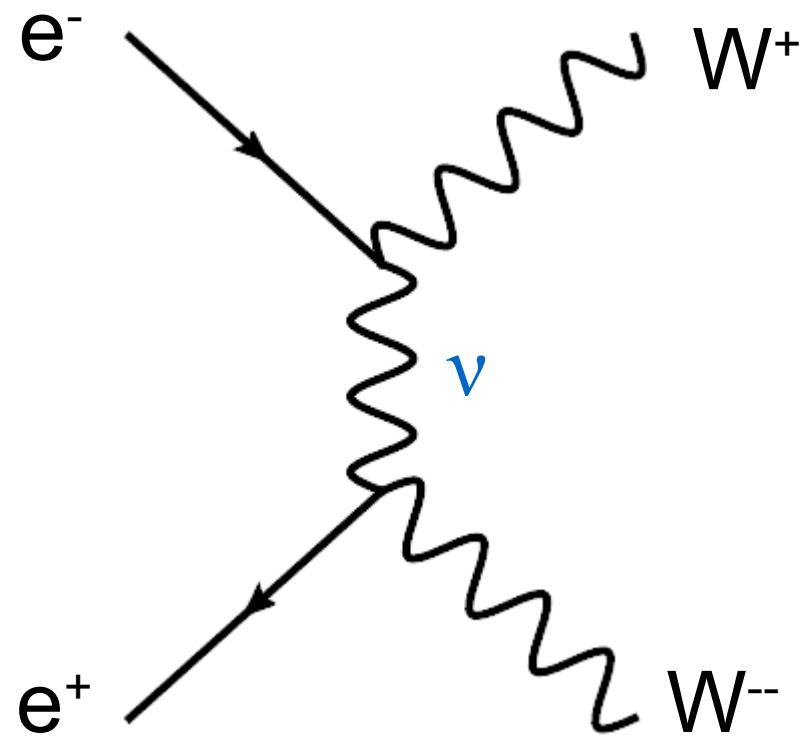
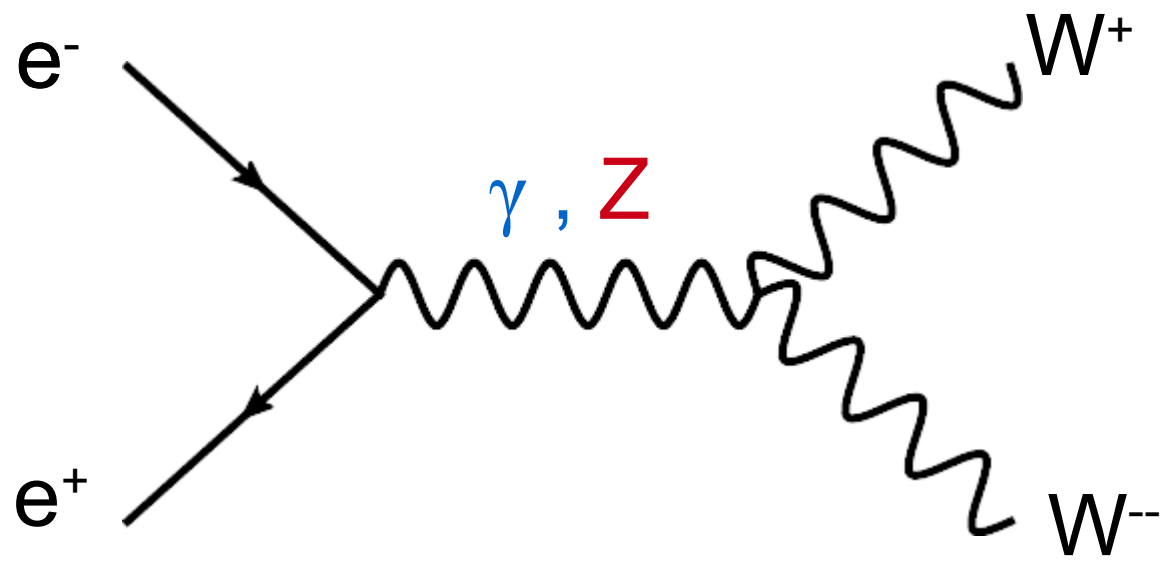
New physics could cause  
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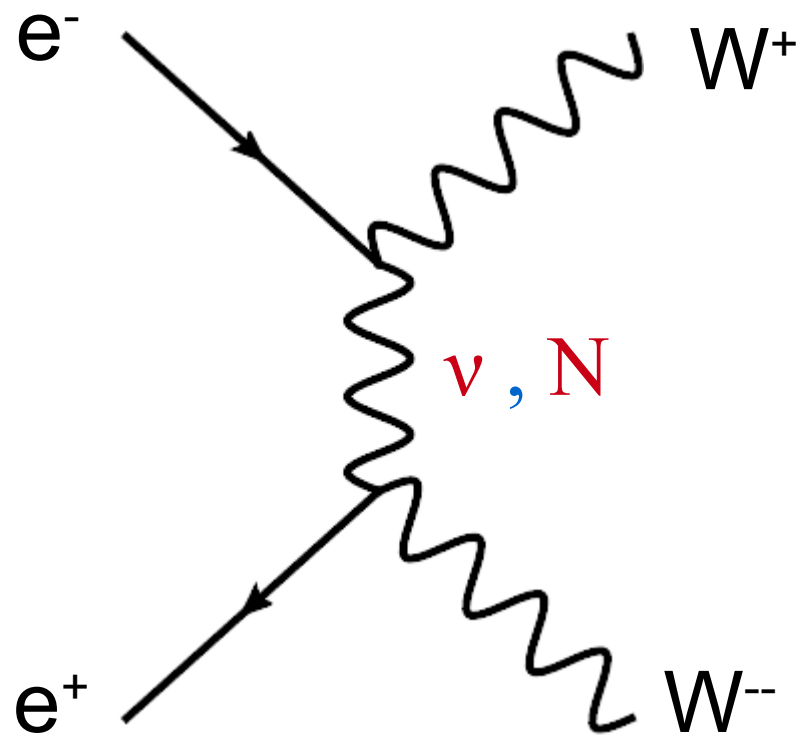
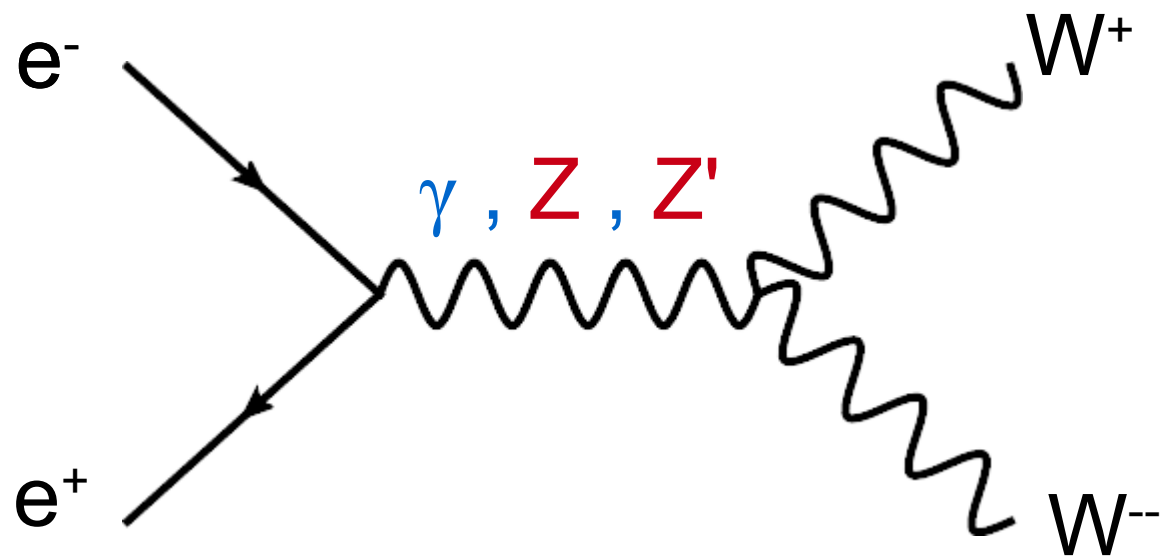
$$g_{ZWW} = e \frac{c_W}{s_W} (1 + \Delta g_1^Z)$$

LEP placed a bound  
on these deviations.

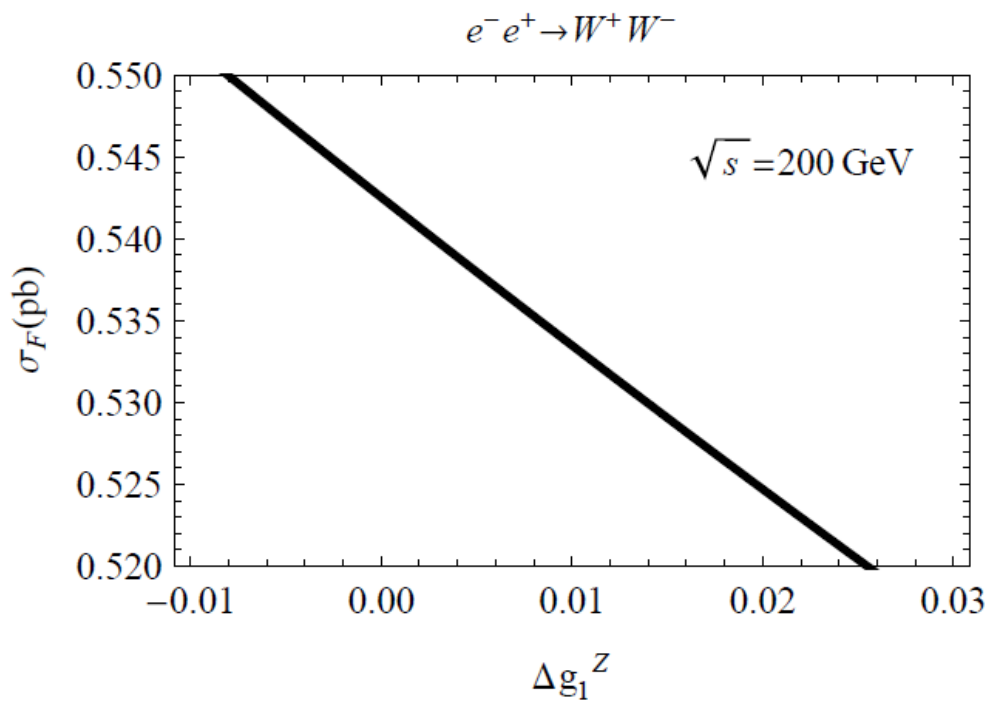
$$-0.054 < \Delta g_1^Z < 0.028$$

@ 95% cl

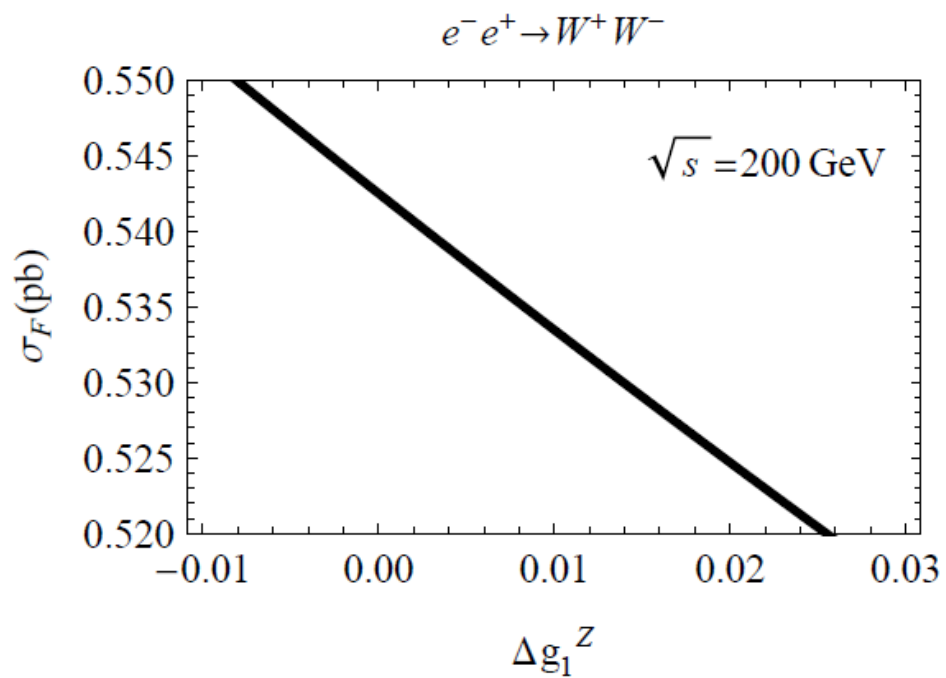




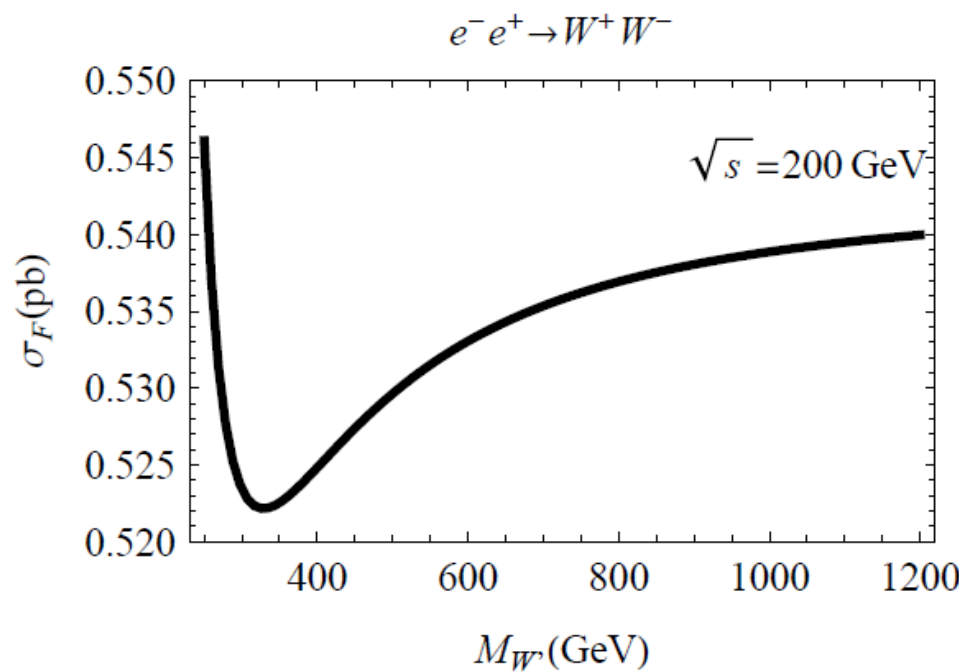
SM (+ $\Delta g_1^Z$ )



SM (+ $\Delta g_1^Z$ )

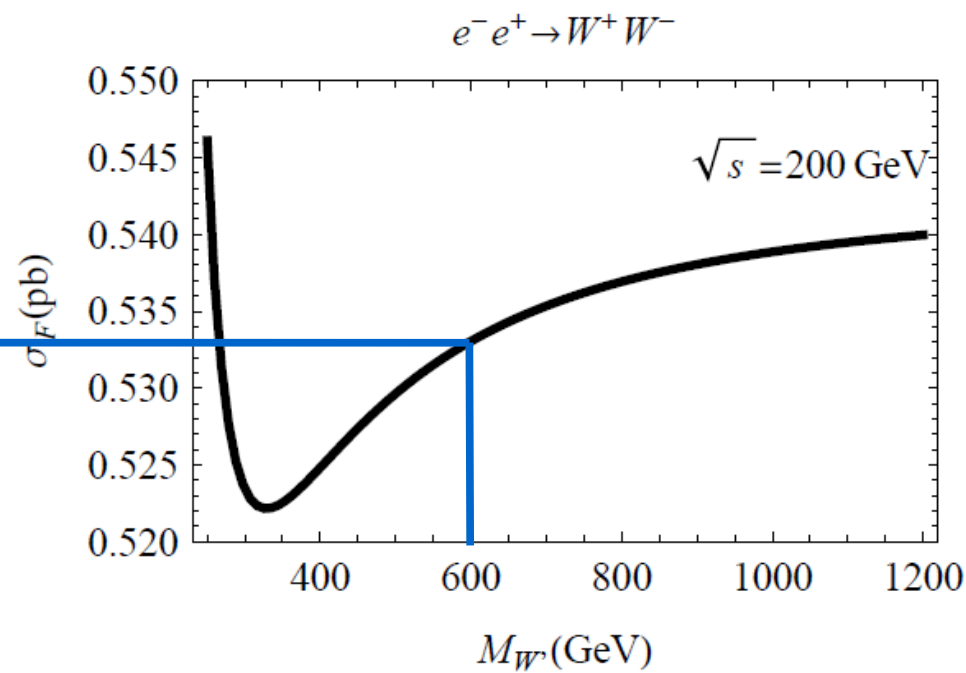
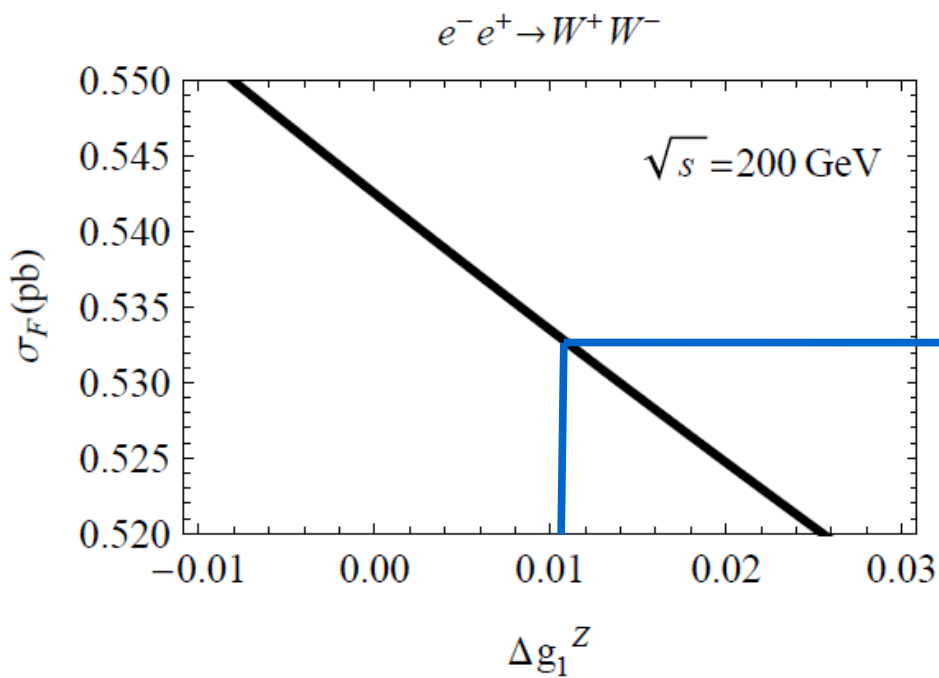


Triangle 3-Site Model

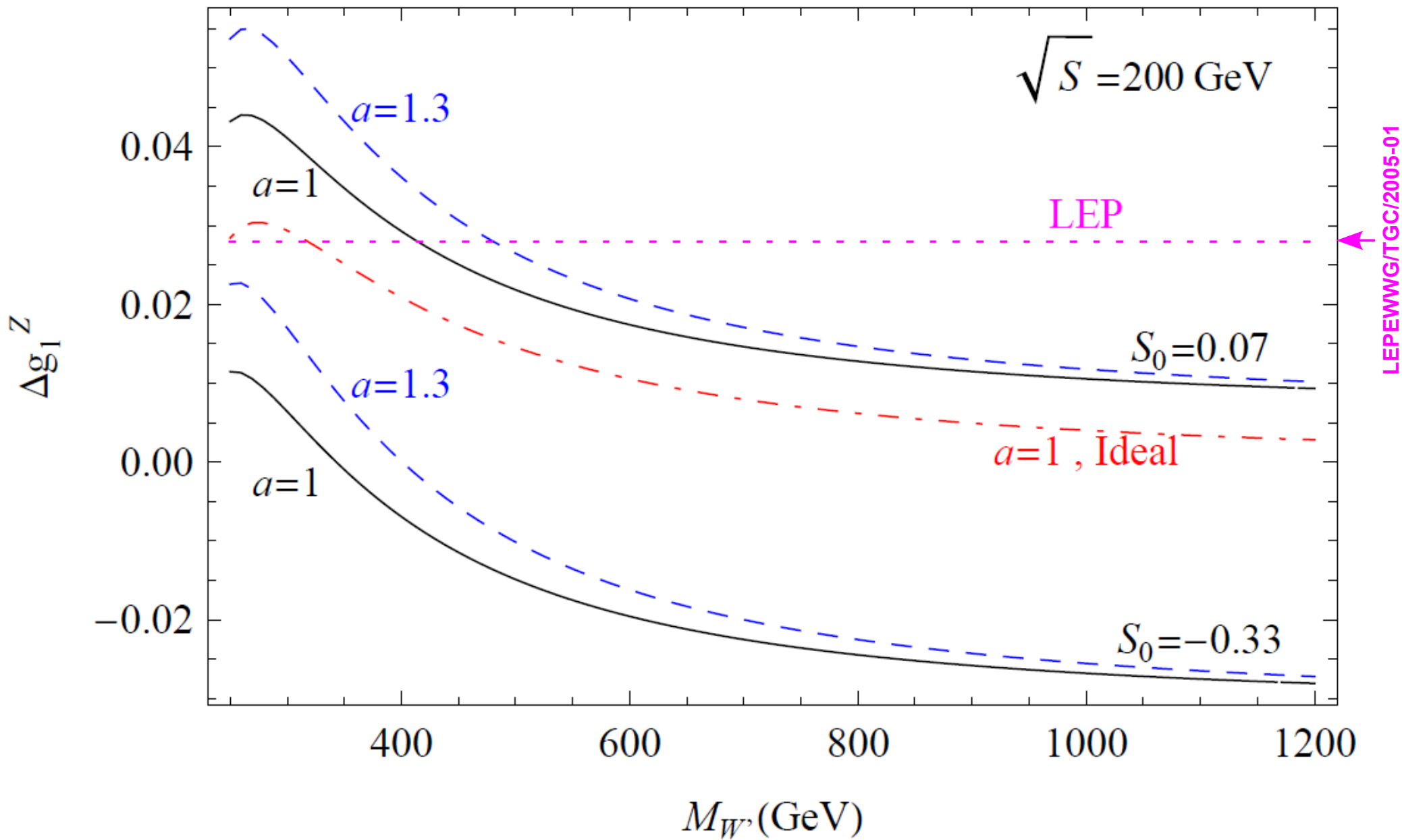


SM (+ $\Delta g_1^Z$ )

Triangle 3-Site Model

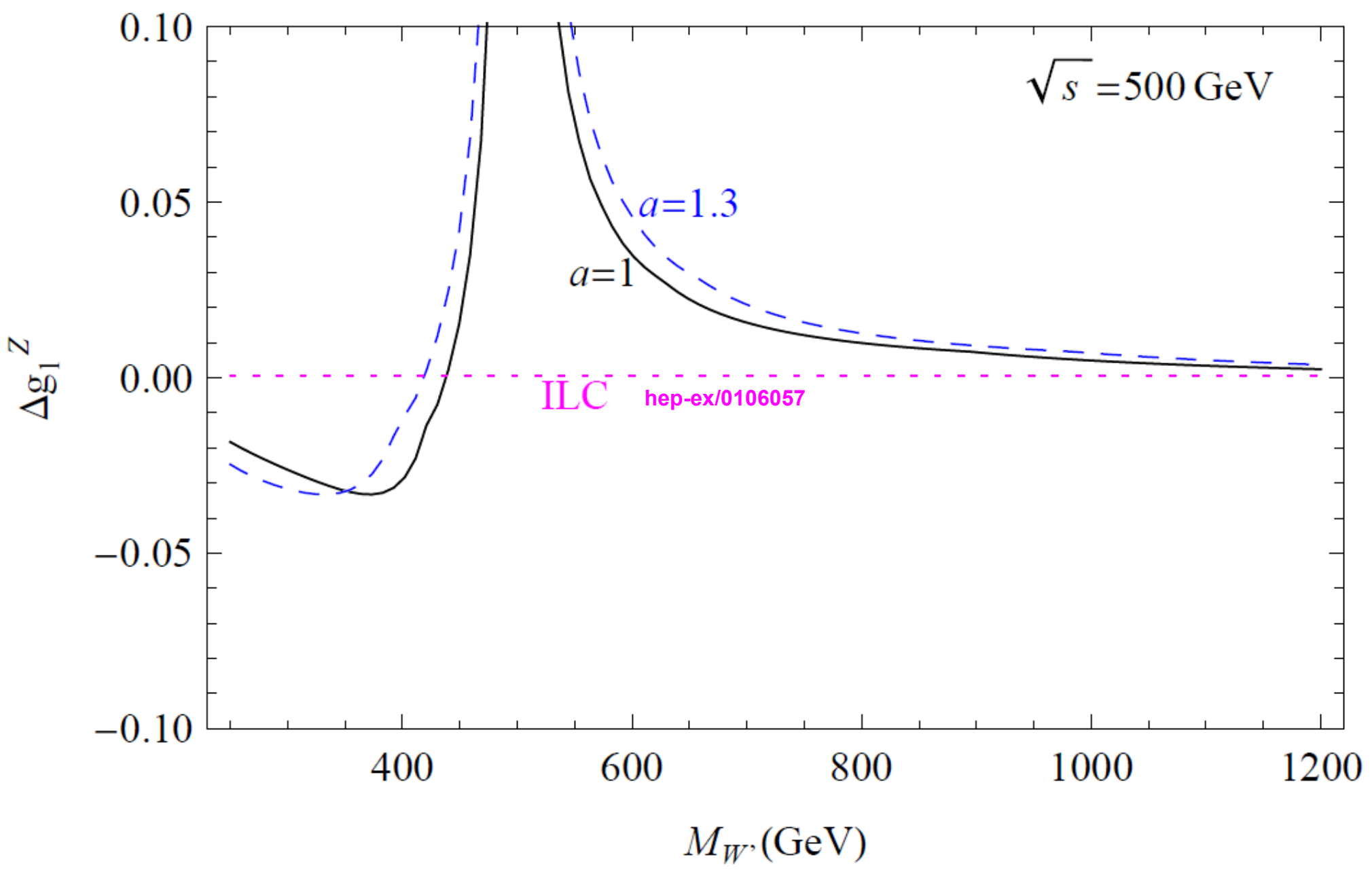


$$e^-e^+ \rightarrow W^+W^-$$

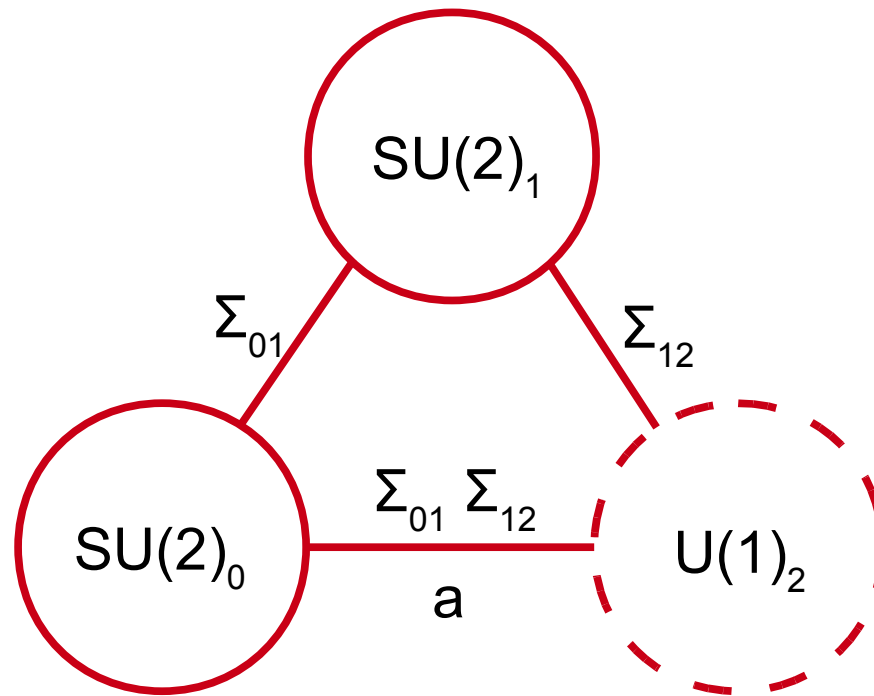




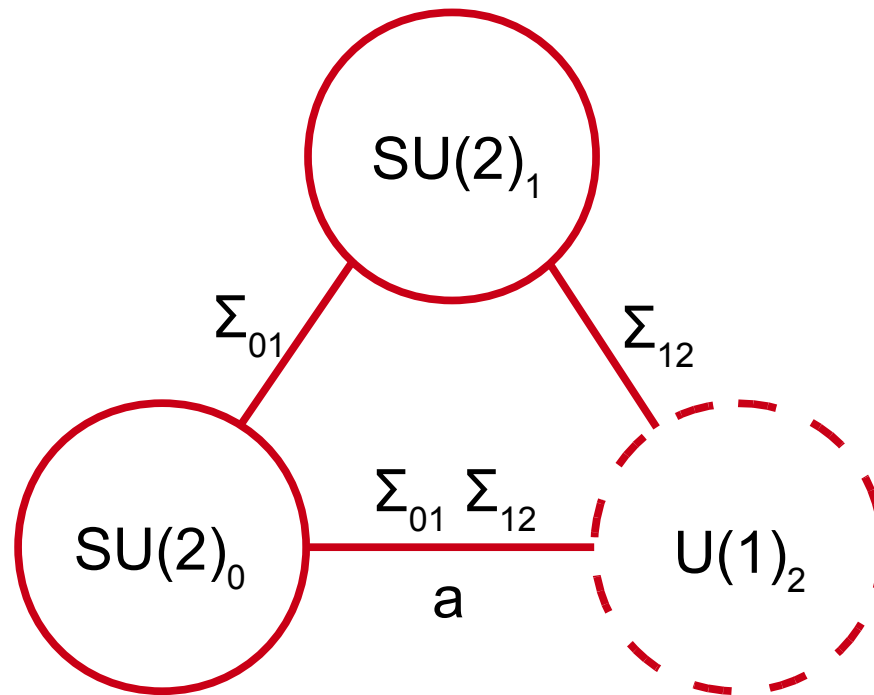
$$e_+^- e_-^+ \rightarrow W^+ W^-$$



# Triangle 3-Site Model



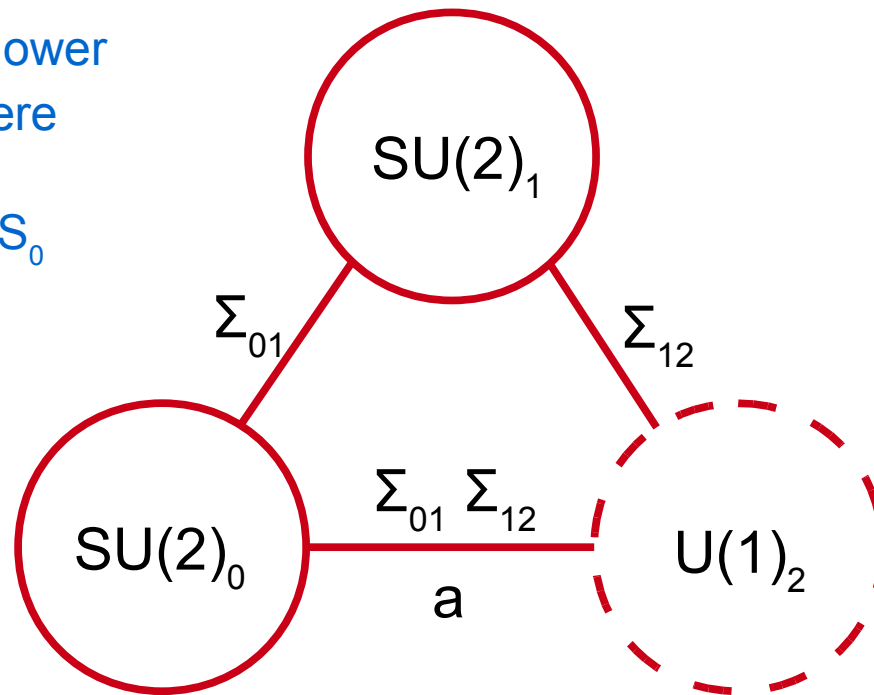
## Triangle 3-Site Model



- $a=4/3$  corresponds more closely with continuum Higgsless models and has better unitarity properties.

## Triangle 3-Site Model

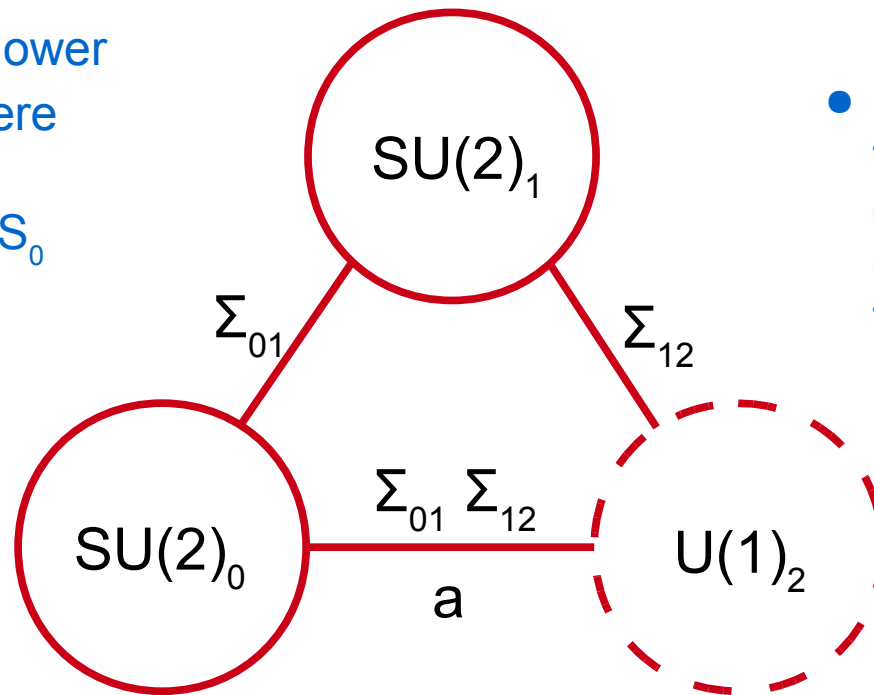
- LEP (via  $\Delta g_1^Z$ ) puts a lower bound on  $M_W$ , somewhere between 250 GeV and 475 GeV depending on  $S_0$  and  $a$ .



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- LEP (via  $\Delta g_1^Z$ ) puts a lower bound on  $M_W$ , somewhere between 250 GeV and 475 GeV depending on  $S_0$  and  $a$ .



- The ILC will be sensitive to this model for the entire range of  $M_W$ .
- It may be able to measure the value of 'a' and thus distinguish between a continuum Higgsless theory and a “moose” model.

- $a=4/3$  corresponds more closely with continuum Higgsless models and has better unitarity properties.