3サイトヒッグスレス模型への Z→ b bbar からの制限

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collaborate with

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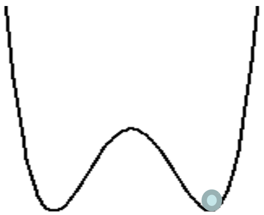
arXiv:0902.3910 [hep-ph]

タウ・レプトン物理研究センター研究報告会 (3.26.2009)

Introduction

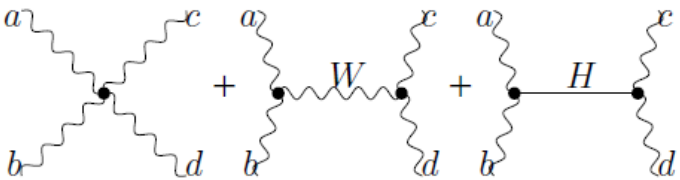
Standard Model describes the phenomenology of elementary particles.

Higgs particle



- SSB of EW symmetry（the origin of mass）
- Unitarize the scattering amplitude of gauge bosons.

$$i\mathcal{M}(W_L^a W_L^b \to W_L^c W_L^d) =$$

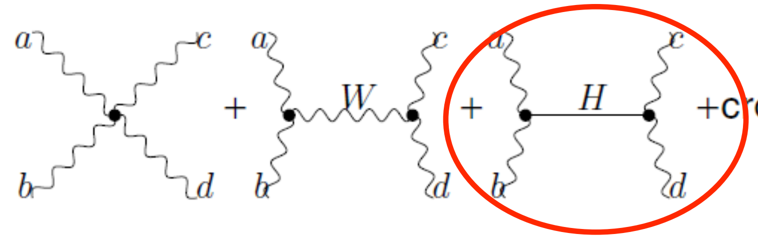


+crossed.

- The precision test indicates $M_h \leq 200$ GeV

標準模型

$$i\mathcal{M}(W_L^a W_L^b \to W_L^c W_L^d) =$$



+crossed.

ヒッグスレス模型

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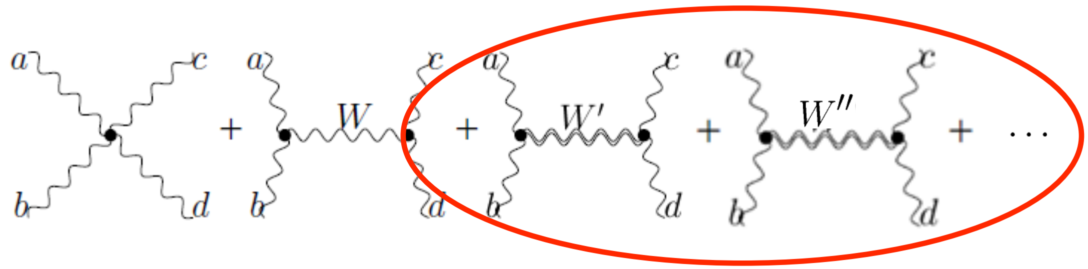

Introduction

Higgs has not appeared yet. ($M_h \geq 114$ GeV)

＝SSB of EW symmetry remains unsolved.

- If Higgs exists
  - naturalness problem $\delta M_H^2 \sim \Lambda^2$
- If Higgs does not exist
  - unitarity problem
  - consistency with EWPT

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Are there any models compatible with EWPT without Higgs ?

→ Higgsless model is one of the candidate.

Contents

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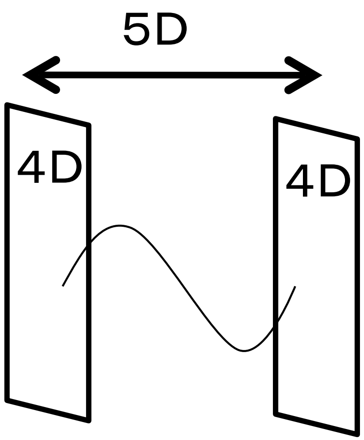
Higgsless model

- is based on 5D gauge theory.
- breaks EW sym. by the boundary conditions for 5th direction.

$$SU(2)_L \times SU(2)_R \times U(1)_{B-L} \to U(1)_{em}$$



$SU(2)_R \times U(1)_{B-L} \to U(1)_Y$ $\quad$ $SU(2)_L \times SU(2)_R \to SU(2)_V$

•Massive particles appear as Kaluza–Klein mode (KK mode)

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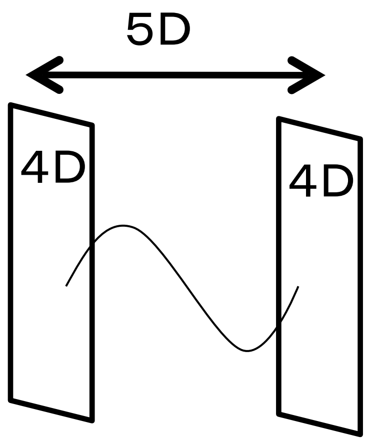

$SU(2)_R \times U(1)_{B-L} \rightarrow U(1)_Y$

$SU(2)_L \times SU(2)_R \rightarrow SU(2)_V$

•Massive particles appear as Kaluza-Klein mode（KK mode）

→ these play the role of Higgs in SM.

- ➢unitarity conservation
- ➢consistency with EWPT

Introduction

Kaluza-Klein mode（KK mode） の説明

•4次元で見たら質量がある
•簡単のため、スカラー場で説明

5次元 massless スカラー場

$$\left(\partial_\mu \partial^\mu - \partial_5 \partial_5\right) \phi(x, y) = 0$$

変数分離 : 4次元＋5次元目

$$\phi(x, y) = \phi(x) f(y)$$

$$\begin{aligned} \Box \phi(x) &= const \times \phi(x) \\ \partial_5 \partial_5 f(y) &= const \times f(y) \end{aligned}$$

← const が質量に相当

Introduction

$$\Box\phi(x) = const \times \phi(x)$$
$$\partial_5\partial_5 f(y) = const \times f(y)$$

$$\phi(x,y) = \phi(x)f(y)$$

例えば次のような境界条件を課す(両端ともにディィレクレ条件)

$$f(0) = 0$$
$$f(\pi R) = 0$$

すると

$$\partial_5\partial_5 f_n(y) = -\left(\frac{n}{R}\right)^2 f_n(y)$$

$$f_n(y) = A\sin\left(\frac{ny}{R}\right)$$

$$n = 1, 2, 3\cdots$$

n = 0 は、f(y)=0 となるので除く

よって

$$\left(\Box + \left(\frac{n}{R}\right)^2\right)\phi_n(x) = 0$$

- n に応じた質量をもつ
- 質量をもったモードが無限個現れる(KK モード)

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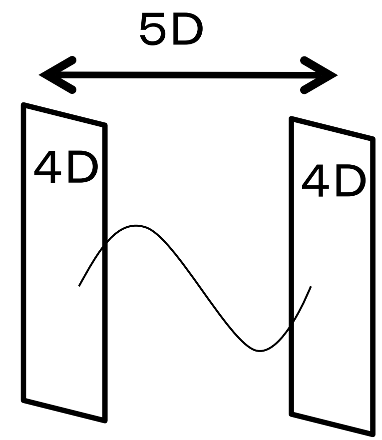

$SU(2)_R \times U(1)_{B-L} \rightarrow U(1)_Y$

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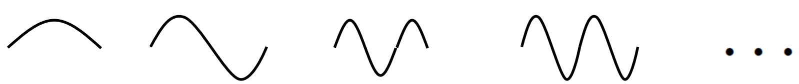

$$W, \quad W', \quad W'', \quad W''' \quad \cdots$$

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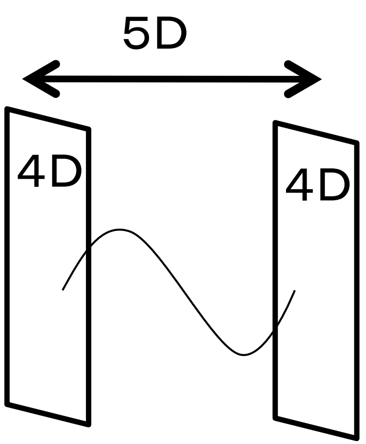

$SU(2)_R \times U(1)_{B-L} \rightarrow U(1)_Y$ $\quad$ $SU(2)_L \times SU(2)_R \rightarrow SU(2)_V$

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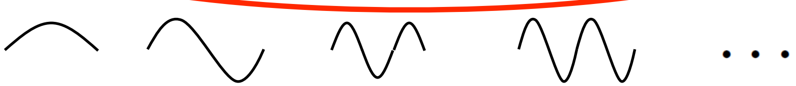

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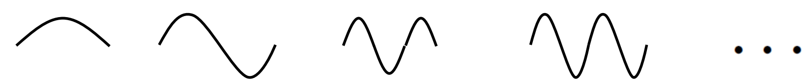

$$W, \quad W', \quad W'', \quad W''' \quad \cdots$$

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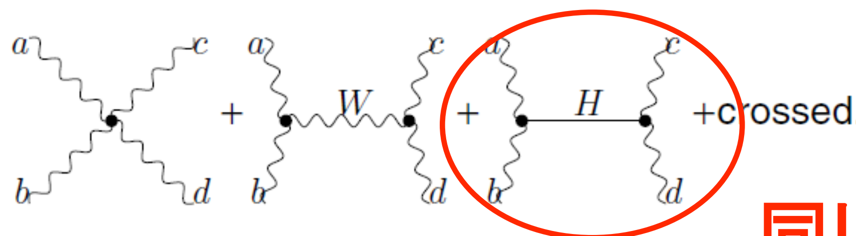

同じ役割

ヒッグスレス模型

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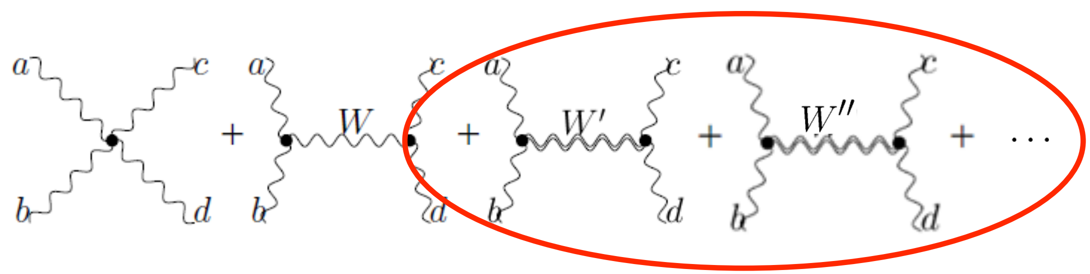
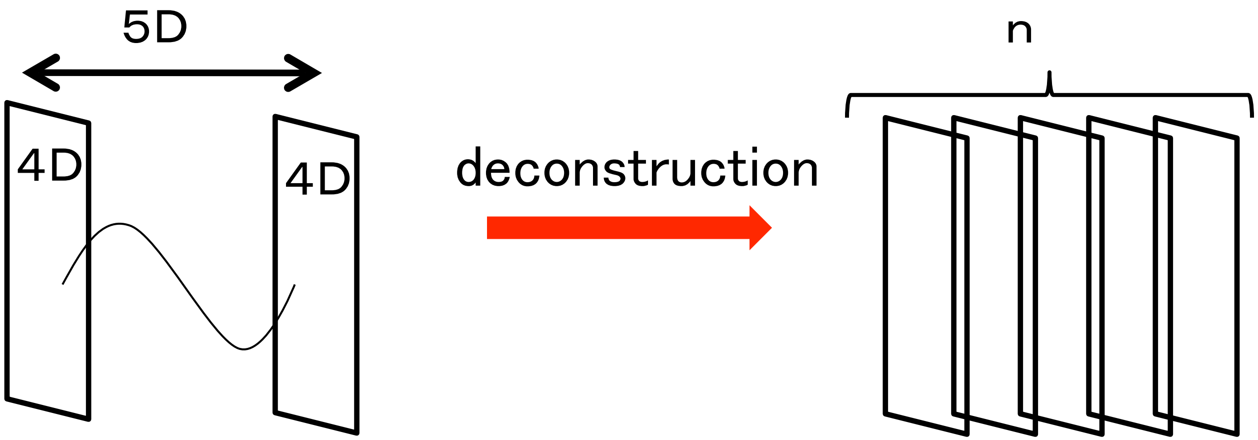


Introduction

Higgsless model

- deconstruction　:　discretion for 5th dim.

　　→ we can treat it as 4D model.



$SU(2)_L \times SU(2)_R \times U(1)_{B-L}$　　　$[SU(2)_L \times SU(2)_R \times U(1)_{B-L}]^n$

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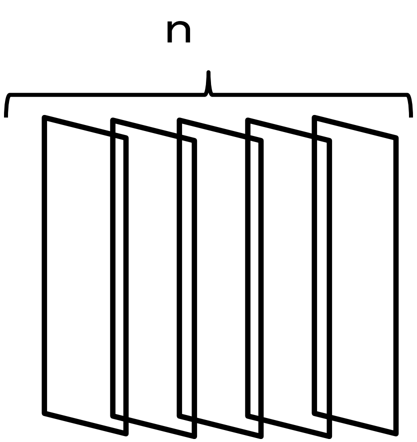

It is enough to analyze as a low energy effective theory

↓

Integrate out of heavy gauge bosons

↓

rough discretion

Boundary conditions

$$SU(2)_L \times U(1)_Y$$
$$\times [SU(2)_L \times SU(2)_R \times U(1)_{B-L}]^{n-2}$$
$$\times SU(2)_V \times U(1)_{B-L}$$
$$\to U(1)_{em}$$

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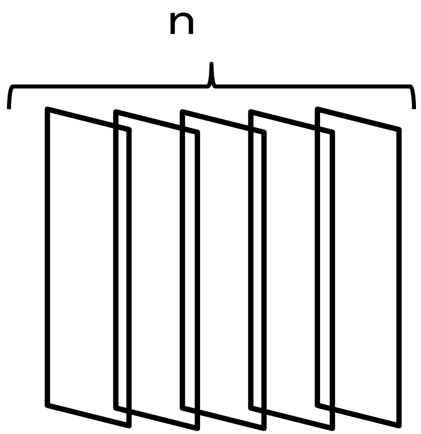
3site Higgsless model

$$SU(2)_0 \times SU(2)_1 \times U(1)_2 \to U(1)_{em}$$



Boundary conditions

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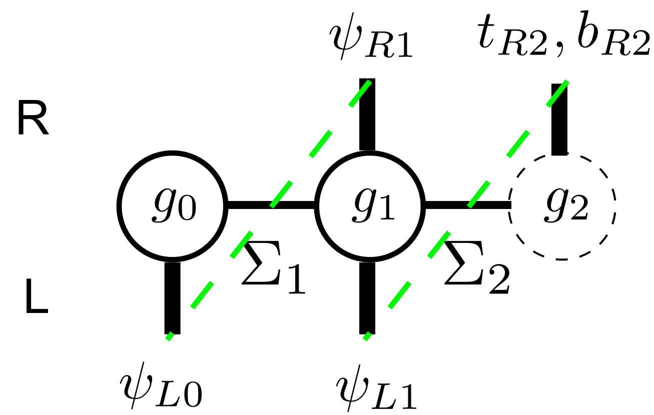
3site Higgsless model

R.S.Chivukula et.al Phys.Rev.D74:075011 (2006)
M.Bando et.al Nucl.Phys. B259 (1985) 493
R.Casalbuoni et.al Phys.Lett.B155(1985) 95

Minimal deconstructed model

$$SU(2)_0 \times SU(2)_1 \times U(1)_2 \to U(1)_{em}$$



NG bosons $\quad \Sigma_i = \exp\left(2i\frac{\pi_i}{f_i}\right)$

gauge bosons $\quad \gamma, W, W', Z, Z'$

fermions $\quad f_{\mathsf{SM}} = \{t, b, c, \cdots\}, F_{\mathsf{heavy}} = \{T, B, C \cdots\}$

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$$SU_0(2) \times SU_1(2) \times U_2(1)$$

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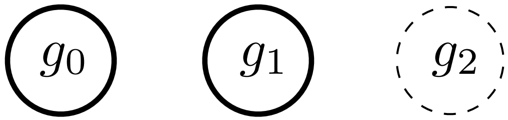

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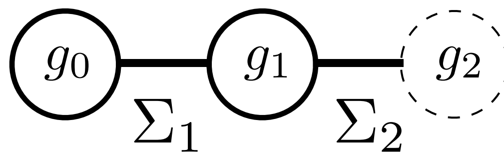

NG bosons
(Non-linear rep.)

$$\Sigma_i = \exp\left(2i\frac{\pi_i}{f_i}\right)$$

$$\Sigma_1 \rightarrow \exp\left(i\frac{\sigma^a}{2}\theta_0^a\right)\Sigma_1 \exp\left(-i\frac{\sigma^a}{2}\theta_1^a\right)$$

$$\Sigma_2 \rightarrow \exp\left(i\frac{\sigma^a}{2}\theta_1^a\right)\Sigma_2 \exp\left(-i\frac{\sigma^a}{2}\theta_2^a\right)$$

$$\frac{1}{v^2} = \frac{1}{f_1^2} + \frac{1}{f_2^2} \qquad (v = 246\ \text{GeV})$$

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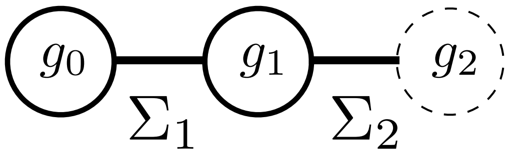

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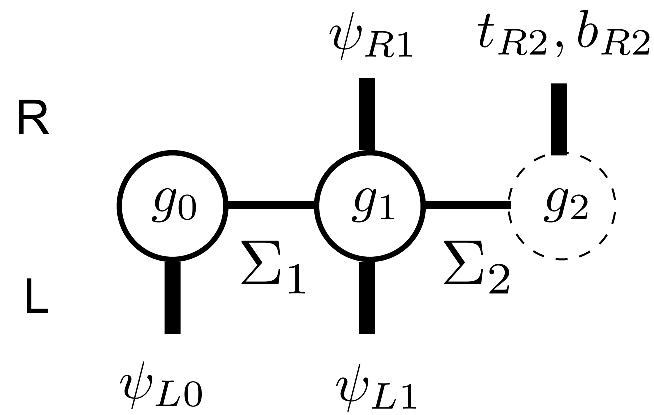

	$SU(2)_0$	$SU(2)_1$	$U(1)_2$	$SU(3)_c$
Ψ_{L0}	2	1	$\frac{1}{6}\ \left(-\frac{1}{2}\right)$	3 (1)
Ψ_{L1}	1	2	$\frac{1}{6}\ \left(-\frac{1}{2}\right)$	3 (1)
Ψ_{R1}	1	2	$\frac{1}{6}\ \left(-\frac{1}{2}\right)$	3 (1)
$\Psi_{R2} = \begin{pmatrix} u_{R2} \\ d_{R2} \end{pmatrix}$	1	1	$\begin{matrix} \frac{2}{3} \\ -\frac{1}{3} \end{matrix}\ \begin{pmatrix} 0 \\ -1 \end{pmatrix}$	3 (1)

$(\ \ )$ means lepton.

3site Higgsless model

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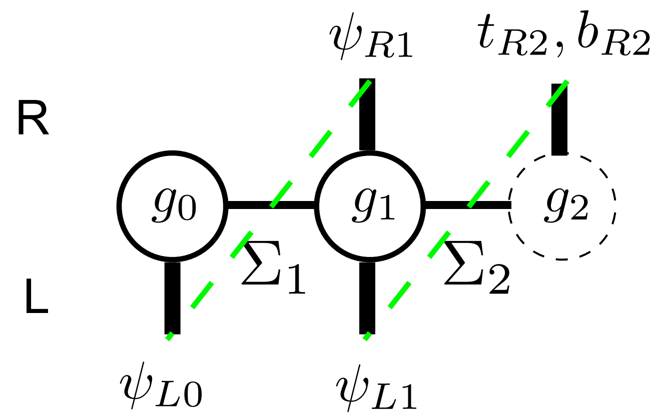

$$-m_1 \bar{\psi}_{L0} \Sigma_1 \psi_{R1} - M \bar{\psi}_{R1} \psi_{L1} - \bar{\psi}_{L1} \Sigma_2 \begin{pmatrix} m_t' & 0 \\ 0 & 0 \end{pmatrix} \begin{pmatrix} t_{R2} \\ b_{R2} \end{pmatrix} + (h.c.)$$

3site Higgsless model

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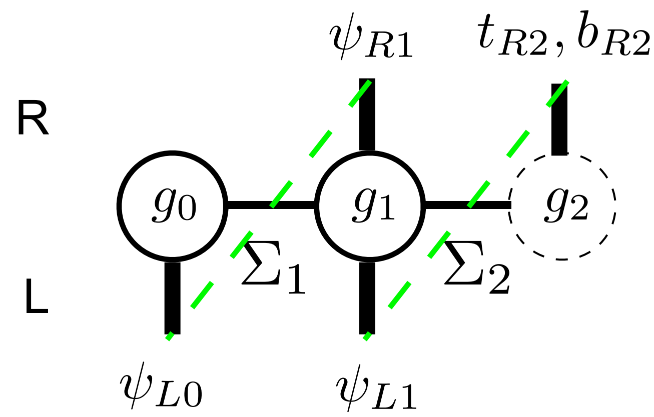

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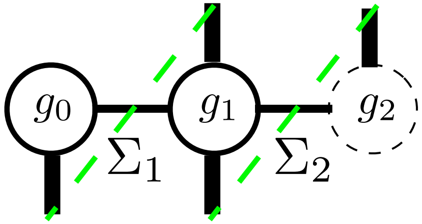
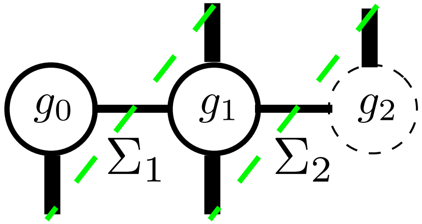


- ✓ 1. Introduction
- ✓ 2. Higgsless model
- ➡ 3. Z b bbar coupling
- 4. Summary

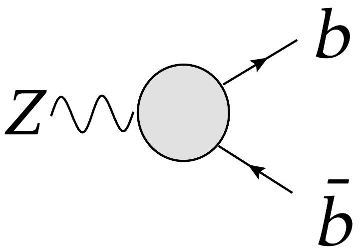
Z b bbar coupling



Z b bbar coupling

- We calclated flavor dependent correction.

$$g_Z \left(-\frac{1}{2} + \delta g_L^{b\bar{b}} + \frac{1}{3} \sin^2 \theta_W \right)$$



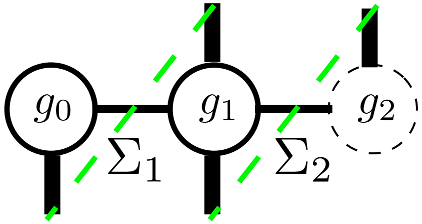
$$(\delta g_L^{b\bar{b}})_{sm} = \frac{m_t^2}{16\pi^2 v^2}$$ (SM correction)

- We used R_b to find the constraint on this model.

$$R_b \equiv \frac{\Gamma(Z \to b\bar{b})}{\Gamma(Z \to \text{hadrons})}.$$

$$\delta R_b^{\text{obs}} \equiv R_b^{\text{obs}} - R_b^{\text{SM}} = (4.5 \pm 6.6) \times 10^{-4}$$

Z b bbar coupling



- The correction in 3site Higgsless model

$$\delta g_L^{b\bar{b}} = \frac{m_t^2}{(4\pi)^2 v^2}\left[1 + \frac{f_1^2 f_2^2}{2(f_1^2+f_2^2)^2}\log\left(\frac{\Lambda^2}{M^2}\right)\right]$$

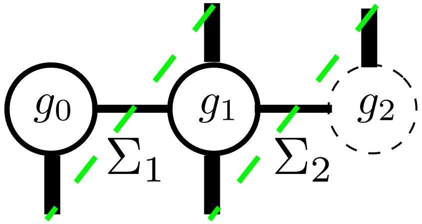
Λ : Cut off scale of this model
M : Dirac mass (Heavy fermion mass)

- We can calculate this by RGE

$$j_L^{a\mu} \supset \left(1 - \frac{\epsilon_L^2 f_2^2}{f_1^2+f_2^2}\right)\bar{\psi}_L \gamma^\mu \frac{\sigma^a}{2}\psi_L$$

: current coupled to Z boson

Z b bbar coupling



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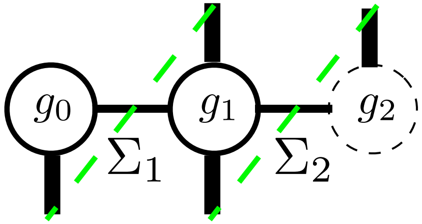
: current coupled to Z boson

Only this term has the flavor dependence

$$\Delta\epsilon_L^2 \equiv \left(\frac{m_1}{M}\right)^2_{3rd}\Bigg|_{\mu=M} - \left(\frac{m_1}{M}\right)^2_{1st}\Bigg|_{\mu=M} = \frac{1}{(4\pi)^2}\frac{m_t'^2}{f_2^2}\left(\frac{m_1}{M}\right)^2 \ln\frac{\Lambda^2}{M^2}$$

Z b bbar coupling



Constraint from R_b

$$R_b \equiv \frac{\Gamma(Z \to b\bar{b})}{\Gamma(Z \to \text{hadrons})}.$$

$$\delta R_b = 2R_b(1-R_b)\frac{g_{bL}}{g_{bL}^2+g_{bR}^2}\delta g_L^{\rm NP}$$

$$\delta g_L^{b\bar{b}} = \frac{m_t^2}{(4\pi)^2 v^2}\left[1+\frac{f_1^2 f_2^2}{2(f_1^2+f_2^2)^2}\log\left(\frac{\Lambda^2}{M^2}\right)\right]$$

→ $\frac{\Lambda}{M} < 4.6 \qquad (95\% \text{ CL})$

We expect a Λ of order 4 TeV or less; $\Lambda \leq 4\pi f_{1,2} \sim 4\text{TeV}$

(Naive dimensional analysis)

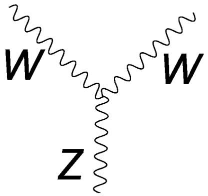
→ $M \geq 1\text{TeV}$

Comparison with EWPT

- constraint from WWZ coupling (LEP)

K.Hagiwara, R.D.Peccei, D.Zeppenfeld, and K.Hikasa, Nucl.Phys. B282,253(1987)

$$M_{W'} \geq 380\text{GeV}$$



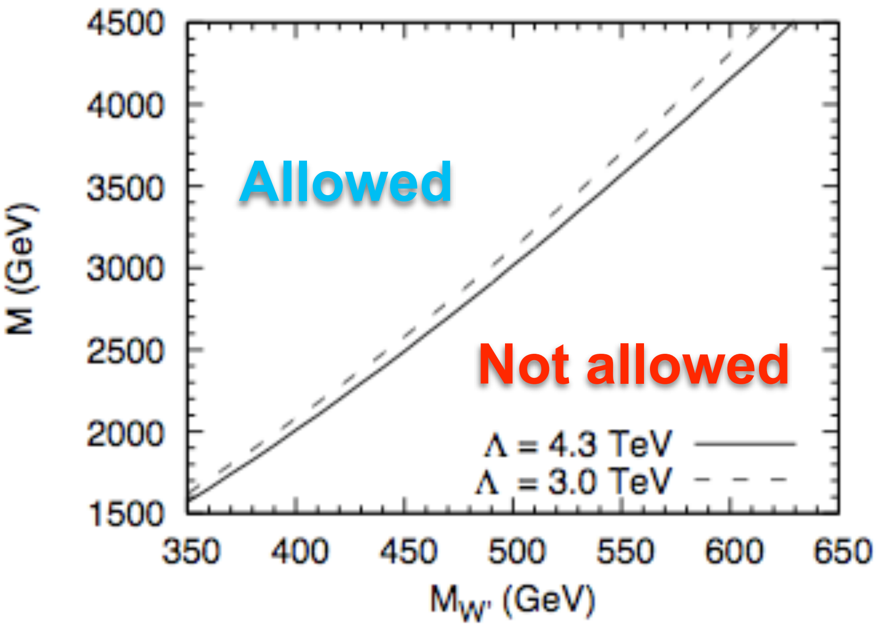
- constraint from ST fit

$$M \geq 1800\text{GeV}$$

- constraint from Z b bbar

$$M \geq 1000\text{GeV}$$

T.A, S.Matsuzaki, M.Tanabashi Phys.Rev.D78:055020,2008



➡ Z b bbar constraint is relatively mild and automatically satisfied.

Contents

Summary

- Higgsless model can break EW symmetry without Higgs particles.
- 3site Higgsless model is a low energy effective theory of Higgsless model.
- Dirac mass is constrained by Z b bbar coupling.
- Constraint from Z b bbar coupling is relatively mild and automatically satisfied with EWPT.

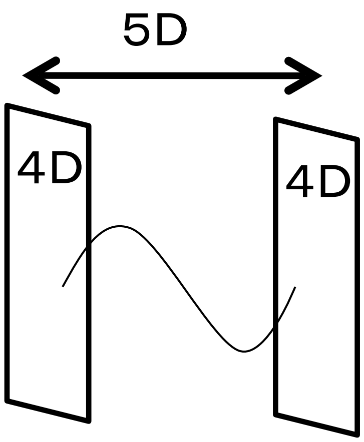
fin

イントロダクション

ヒッグスレス模型

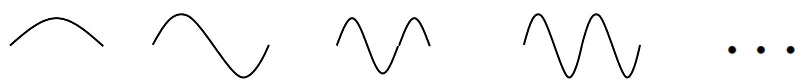
- 5次元のゲージ理論に基づいた模型
- 電弱対称性は5次元方向の境界条件で破る

$$SU(2)_L \times SU(2)_R \times U(1)_{B-L} \to U(1)_{em}$$



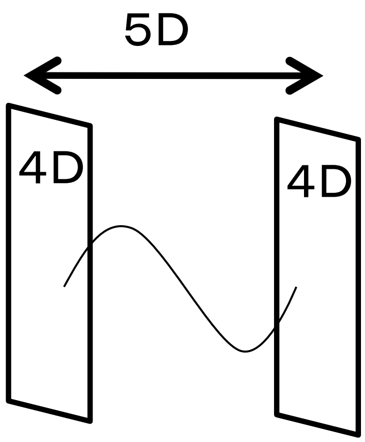
•質量をもった粒子は、カルツァクラインモード(KKモード)として現れる

例



$$W, \quad W', \quad W'', \quad W''' \quad \cdots$$

イントロダクション



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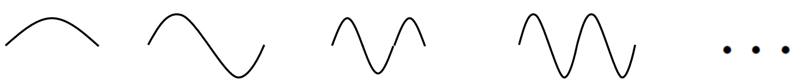

$$W, \quad W', \quad W'', \quad W''' \quad \cdots$$

縦波W散乱のユニタリティーはヒッグスではなく重いゲージ粒子によって保たれる

イントロダクション

標準模型

$$i\mathcal{M}(W_L^a W_L^b \to W_L^c W_L^d) =$$

ヒッグスレス模型

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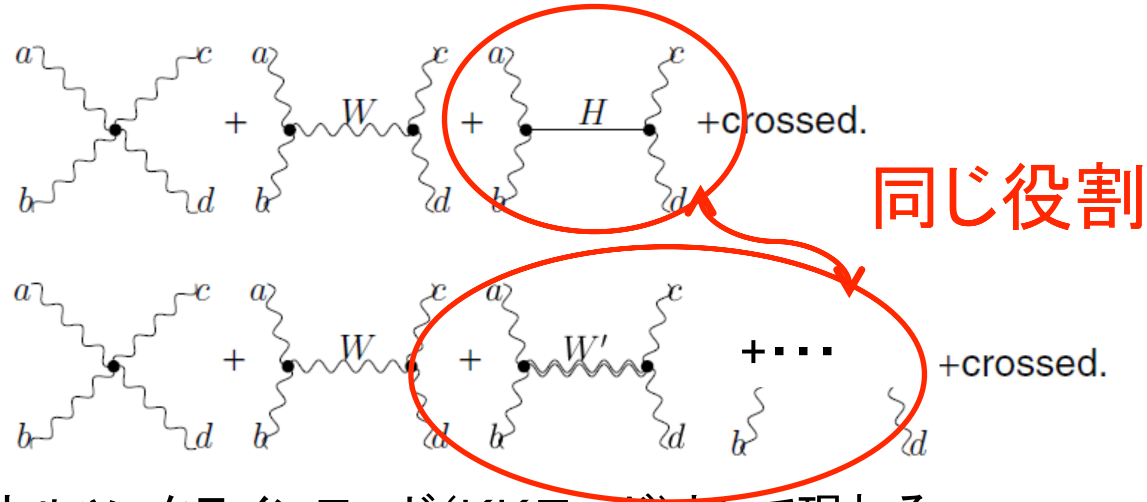

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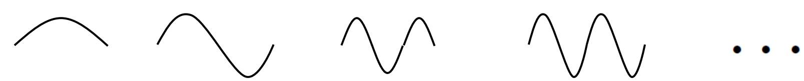

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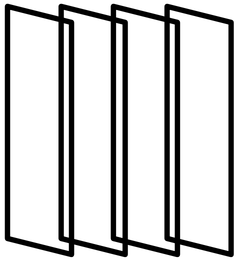
イントロダクション

“スリーサイト”ヒッグスレス模型

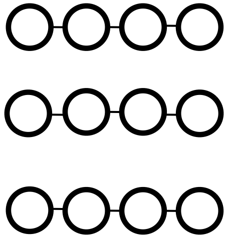


模式化
（ムースダイアグラム）

$SU(2)_L$

$SU(2)_R$

$U(1)_{B-L}$

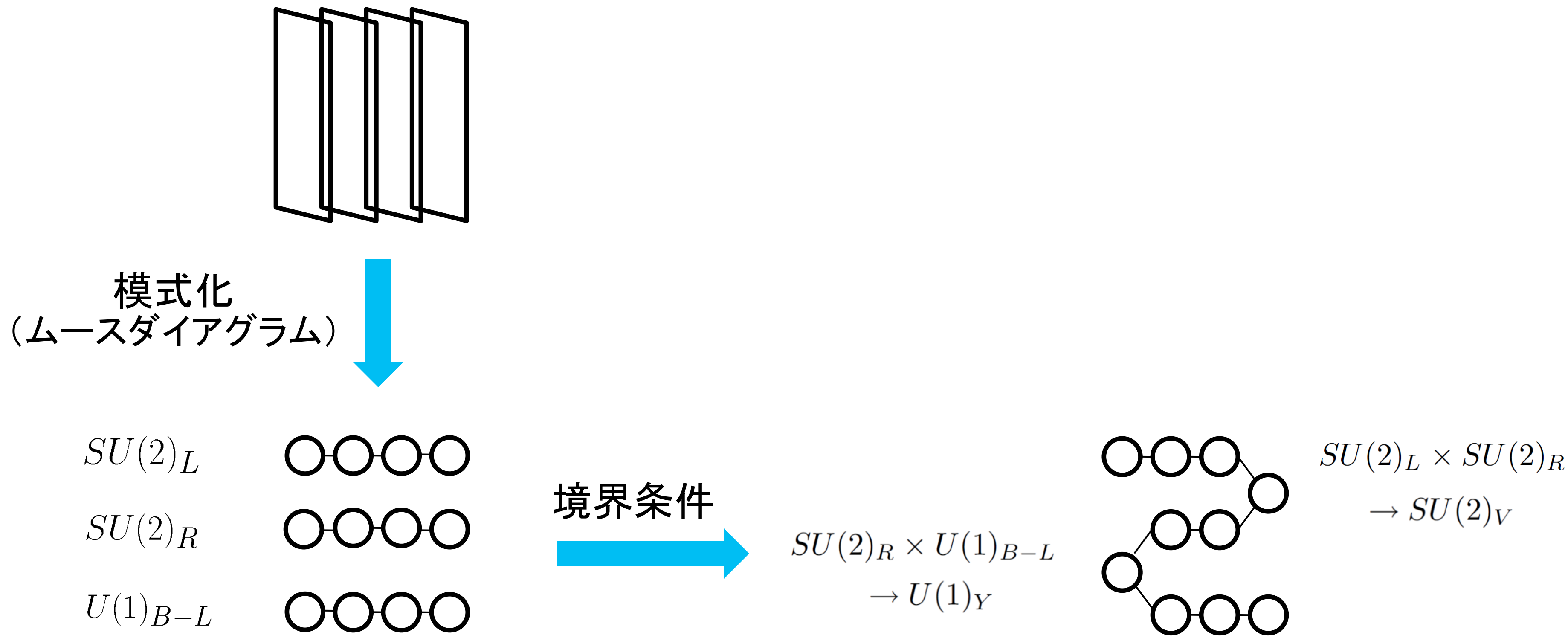


○ : 格子点 （ゲージ場）

— : リンク （非線形表現）

イントロダクション

“スリーサイト”ヒッグスレス模型



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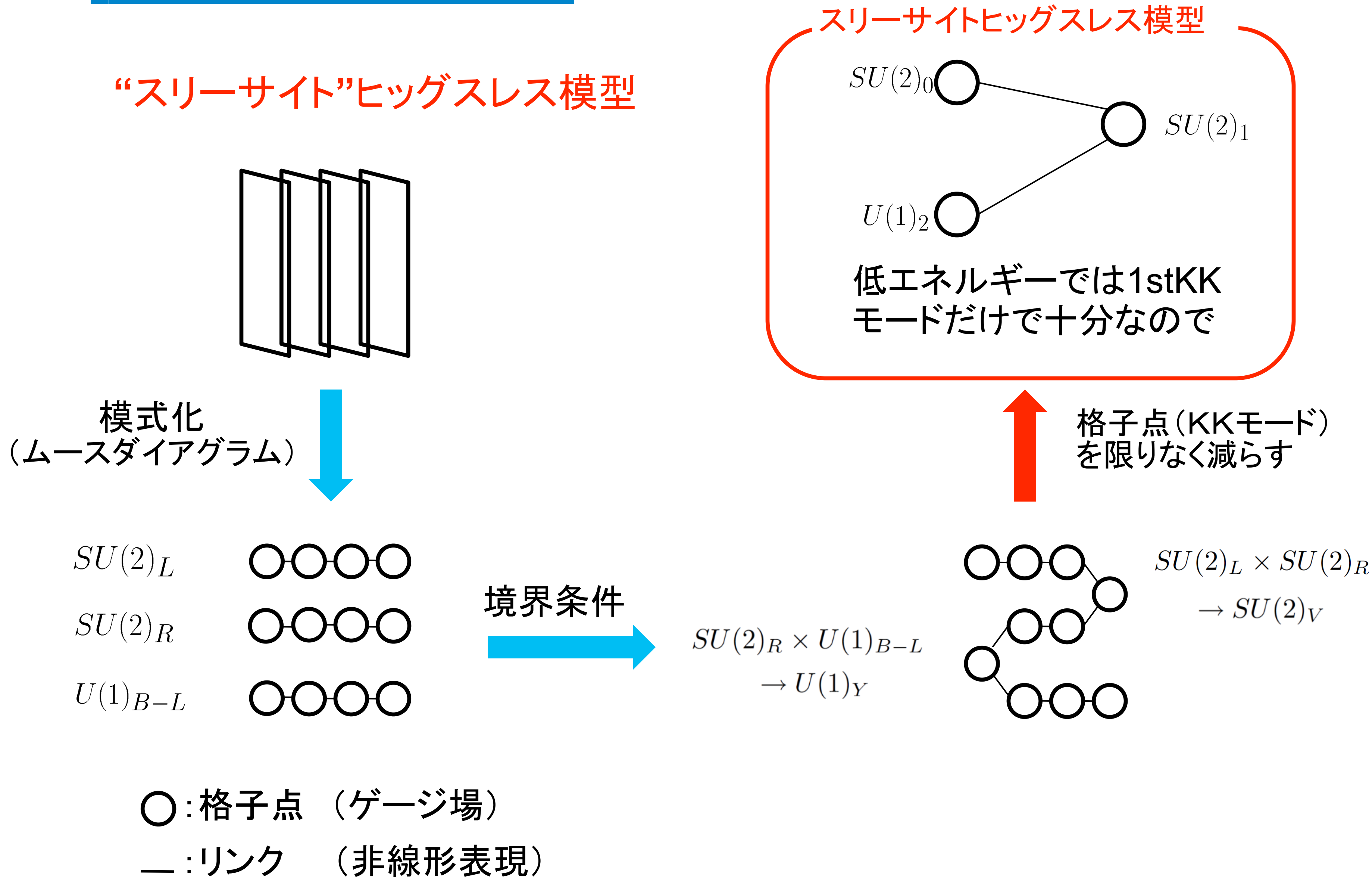
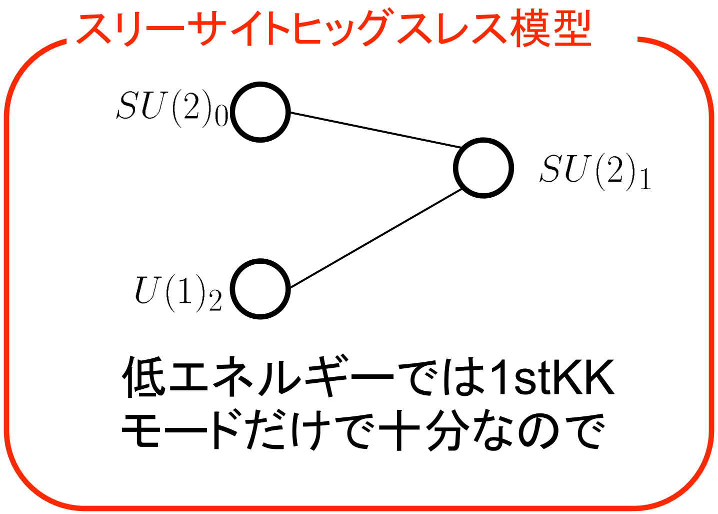
イントロダクション



"スリーサイト"ヒッグスレス模型
模式化
（ムースダイアグラム）
$SU(2)_L$
$SU(2)_R$
$U(1)_{B-L}$
境界条件
$SU(2)_R \times U(1)_{B-L} \rightarrow U(1)_Y$
$SU(2)_L \times SU(2)_R \rightarrow SU(2)_V$
格子点（KKモード）を限りなく減らす
スリーサイトヒッグスレス模型
$SU(2)_0$
$SU(2)_1$
$U(1)_2$
低エネルギーでは1stKKモードだけで十分なので
○：格子点　（ゲージ場）
―：リンク　（非線形表現）

イントロダクション



✓ スリーサイトヒッグスレス模型のパラメータに対する1ループレベルでの制限

➢電弱精密測定からの
- $g_{W'ff}$ への制限
- $M_{W'}$ および M_F への制限

（ これまではトゥリーレベル ← 不十分な精度 ）

スリーサイトヒッグスレス模型

パラメータへの制限

R.S.Chivukula et.al Phys.Rev.D74:075011 (2006)

$$\mathcal{L}_f = \epsilon_L M \bar{\Psi}_{L0}\Sigma_1\Psi_{R1} + M\bar{\Psi}_{R1}\Psi_{L1} + M\Psi_{L1}\Sigma_2\begin{pmatrix}\epsilon_{tR} & \\ & \epsilon_{bR}\end{pmatrix}\begin{pmatrix}t_{R2}\\ b_{R2}\end{pmatrix} + h.c.$$

パラメータへの制限

$$0.095 \leq \epsilon_L \leq 0.30$$

$$380\mathrm{GeV} \leq M_{W'} \leq 1.2\mathrm{TeV}$$

$$1.8\mathrm{TeV} \leq M_F \leq 46\mathrm{TeV}$$

スリーサイトヒッグスレス模型

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- これらは、主にトゥリーレベルでの解析
- 電弱精密測定による制限をつけるには不十分

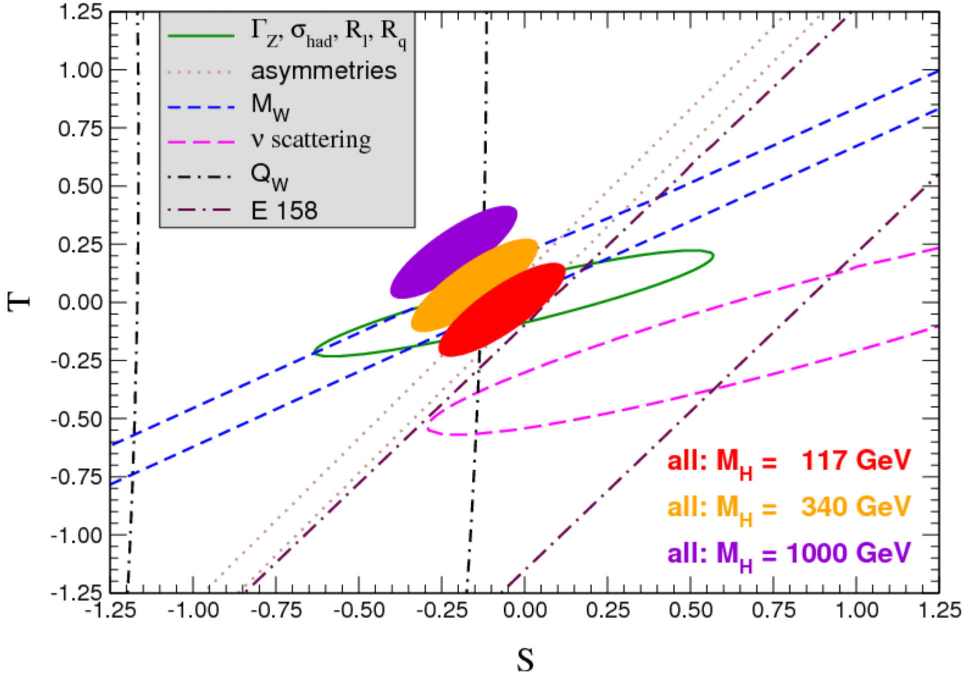
STパラメータ

- フェルミオンの散乱振幅で定義
- 標準模型からのずれを表すのに用いられる

$$-\mathcal{A}_{NC} = e^2\frac{QQ'}{-p^2} + \frac{(I_3 - s^2Q)(I_3' - s^2Q')}{-\left(\frac{s^2c^2}{e^2} - \frac{S}{16\pi}\right)p^2 + \frac{1}{4\sqrt{2}G_F}(1-\alpha T)},$$

$$-\mathcal{A}_{CC} = \frac{(I_+I_-' + I_-I_+')/2}{-\left(\frac{s^2}{e^2} - \frac{S}{16\pi}\right)p^2 + \frac{1}{4\sqrt{2}G_F}},$$

$$Q = I_3 + Y$$



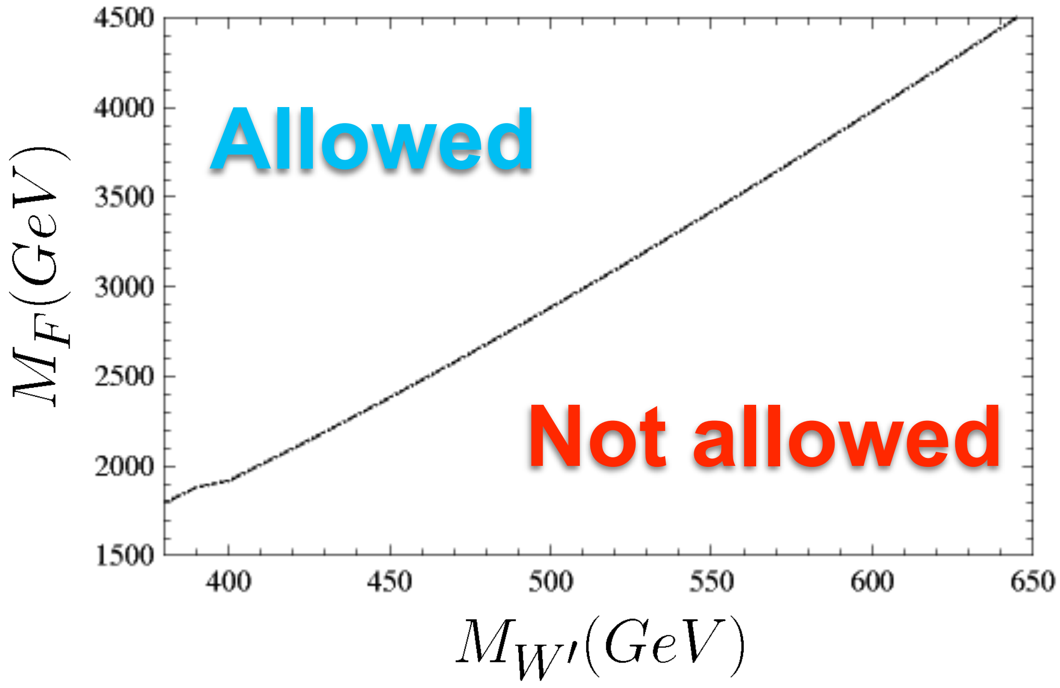
$$S \equiv S_{BSM} - S_{SM}(M_{H,ref})$$

$$T \equiv T_{BSM} - T_{SM}(M_{H,ref})$$

質量への制限

- 重いフェルミオンの質量の下限とW' の質量との関係

$$\alpha T = (\text{const}) \times \left(\frac{G_F}{(4\pi)^2} \frac{M_t^4}{M_F^2} \right) + (\text{bosonic 1-loop})$$

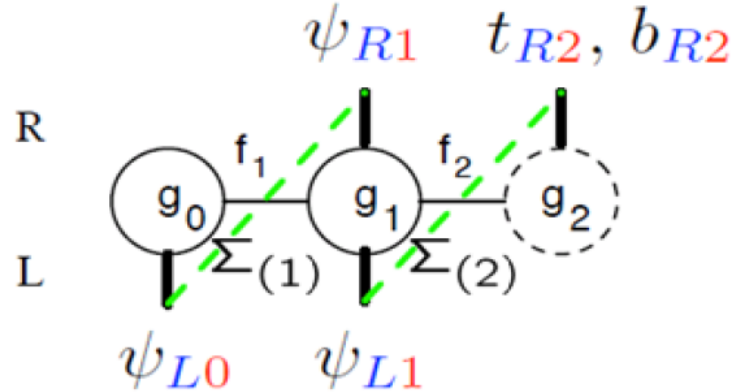


$$380\,\text{GeV} \leq \quad M_{W'}$$
$$1.8\,\text{TeV} \leq \quad M_F$$

スリーサイトヒッグスレス模型

- クォークおよびNGボソンのゲージ対称性
- U(1)の()内は、レプトンの場合

$$\frac{1}{v^2} = \frac{1}{f_1^2} + \frac{1}{f_2^2}$$



	$SU(2)_0$	$SU(2)_1$	$U(1)_2$	$SU(3)_{color}$
Ψ_{L0}	$\square$	$\cdot$	$\frac{1}{6}\ \left(-\frac{1}{2}\right)$	$\square$
Ψ_{L1}	$\cdot$	$\square$	$\frac{1}{6}\ \left(-\frac{1}{2}\right)$	$\square$
Ψ_{R1}	$\cdot$	$\square$	$\frac{1}{6}\ \left(-\frac{1}{2}\right)$	$\square$
$\Psi_{R2} = \begin{pmatrix} u_{R2} \\ d_{R2} \end{pmatrix}$	$\cdot$	$\cdot$	$\begin{matrix} \frac{2}{3} \\ -\frac{1}{3} \end{matrix}\ \begin{pmatrix} 0 \\ -1 \end{pmatrix}$	$\square$
Σ_1	$\square$	$\square^*$	$\cdot$	$\cdot$
Σ_2	$\cdot$	$\square$	$\begin{pmatrix} \frac{1}{2} \\ -\frac{1}{2} \end{pmatrix}^*$	$\cdot$

ゲージボソンの質量

$$\begin{cases} M_W^2 = \dfrac{1}{4}\dfrac{f_1^2 f_2^2}{f_1^2+f_2^2} g_0^2 \left(1 - \dfrac{f_1^4}{(f_1^2+f_2^2)^2}x^2 + \mathcal{O}(x^4)\right) \\ M_{W'}^2 = \dfrac{1}{4}(f_1^2+f_2^2) g_1^2 \left(1 + \dfrac{f_1^4}{(f_1^2+f_2^2)^2}x^2 + \dfrac{f_1^6 f_2^2}{(f_1^2+f_2^2)^4}x^4 + \mathcal{O}(x^6)\right) \end{cases}$$

$$\begin{cases} M_Z^2 = \dfrac{1}{4}\dfrac{f_1^2 f_2^2}{f_1^2+f_2^2} g_0^2 \left((1+t^2) - \dfrac{(f_1^2 - f_2^2 t^2)^2}{(f_1^2+f_2^2)^2}x^2 + \mathcal{O}(x^4)\right) \\ M_{Z'}^2 = \dfrac{1}{4}(f_1^2+f_2^2) g_1^2 \left(1 + \dfrac{f_1^4 + f_2^4 t^2}{(f_1^2+f_2^2)^2}x^2 + \dfrac{f_1^2 f_2^2 (f_1^2 - f_2^2 t^2)^2}{(f_1^2+f_2^2)^4}x^4 + \mathcal{O}(x^6)\right) \end{cases}$$

$$x = \frac{g_0}{g_1} \ll 1$$

$$t = \frac{g_2}{g_0} = \frac{s}{c}$$

スリーサイトヒッグスレス模型

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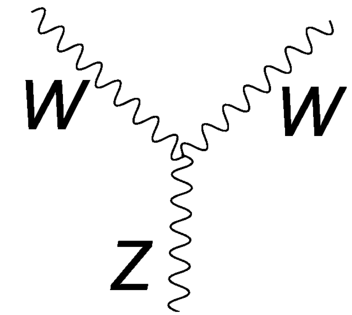
WWZ結合定数の測定からの制限（LEP）



K.Hagiwara, R.D.Peccei, D.Zeppenfeld, and K.Hikasa, Nucl.Phys. B282,253(1987)

スリーサイトヒッグスレス模型

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ユニタリティーへの制限

$$\sqrt{s} \simeq 1.2\text{TeV}$$

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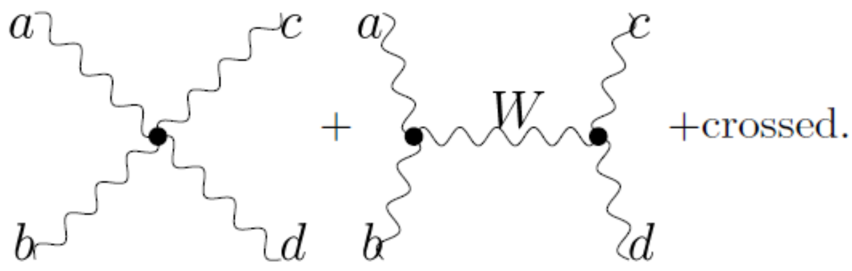

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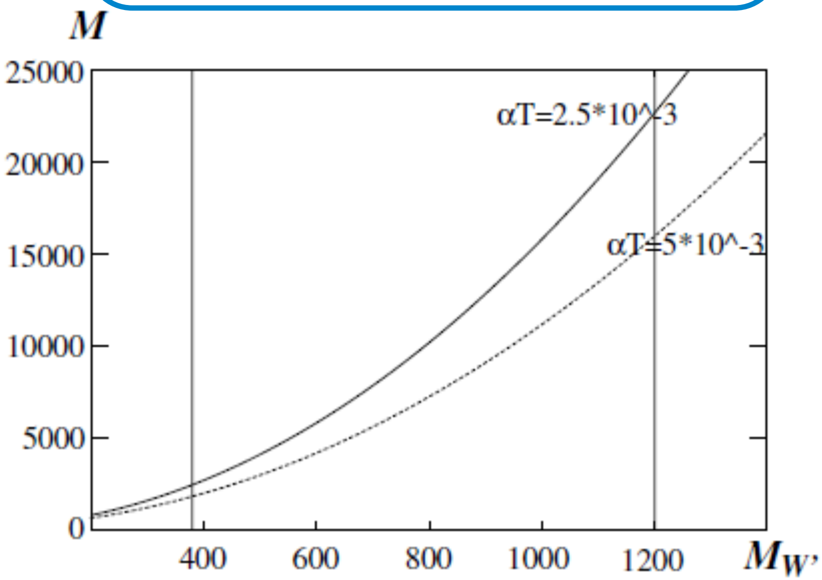
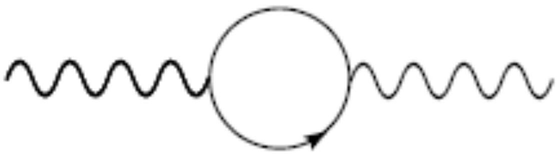


Tパラメータからの制限



- 考慮すべきグラフは他にもある
- 不十分な解析

スリーサイトヒッグスレス模型

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ループの効果 ≦ トゥリーレベル

であるべしという、素朴な次元解析（NDA）