An Alternative to the Standard Electroweak Symmetry Breaking Model

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YITP Lunchtime Meeting (2/6/2008)

Masses and Forces

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- For this purpose, crucial things to know are masses of the elementary particles and forces between them
- Standard Model (SM) of the elementary particles, by adopting so-called gauge principle, beautifully explains the three of four forces which are known to be exist in nature

Masses and Forces

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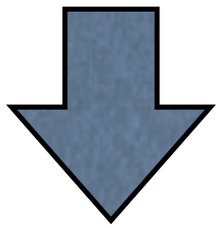

There is a new physics beyond
(or alternative to) the SM

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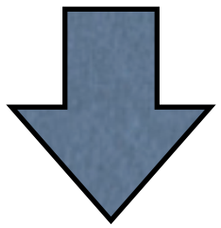
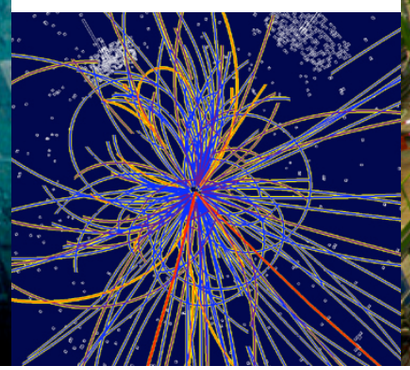
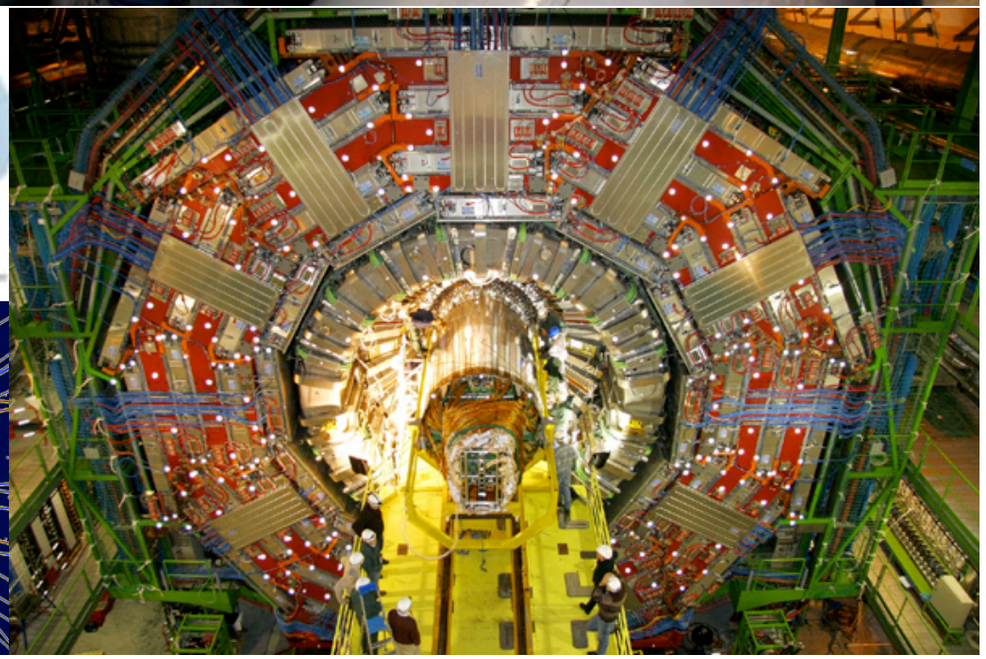


There is a new physics beyond
(or alternative to) the SM

But, so far, we have had only few clues of what the new physics should be . . .

The situation will drastically change in a few years because the LHC experiment at CERN will begin operation this year!





Origin of Masses = Origin of EWSB

- EW gauge bosons are massless without the EWSB
- Mass terms of fermions : $m\bar{\psi}_L\psi_R$

  SM fermions are chiral under the EW gauge group --> fermions are also massless without EWSB

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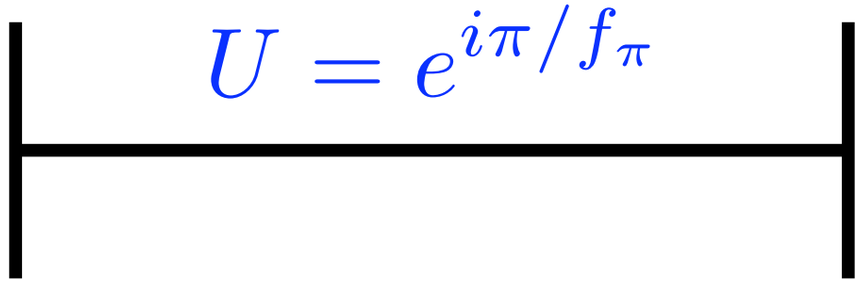
By the way,

We know the example of the chiral symmetry breaking

Pions are NG bosons associated with

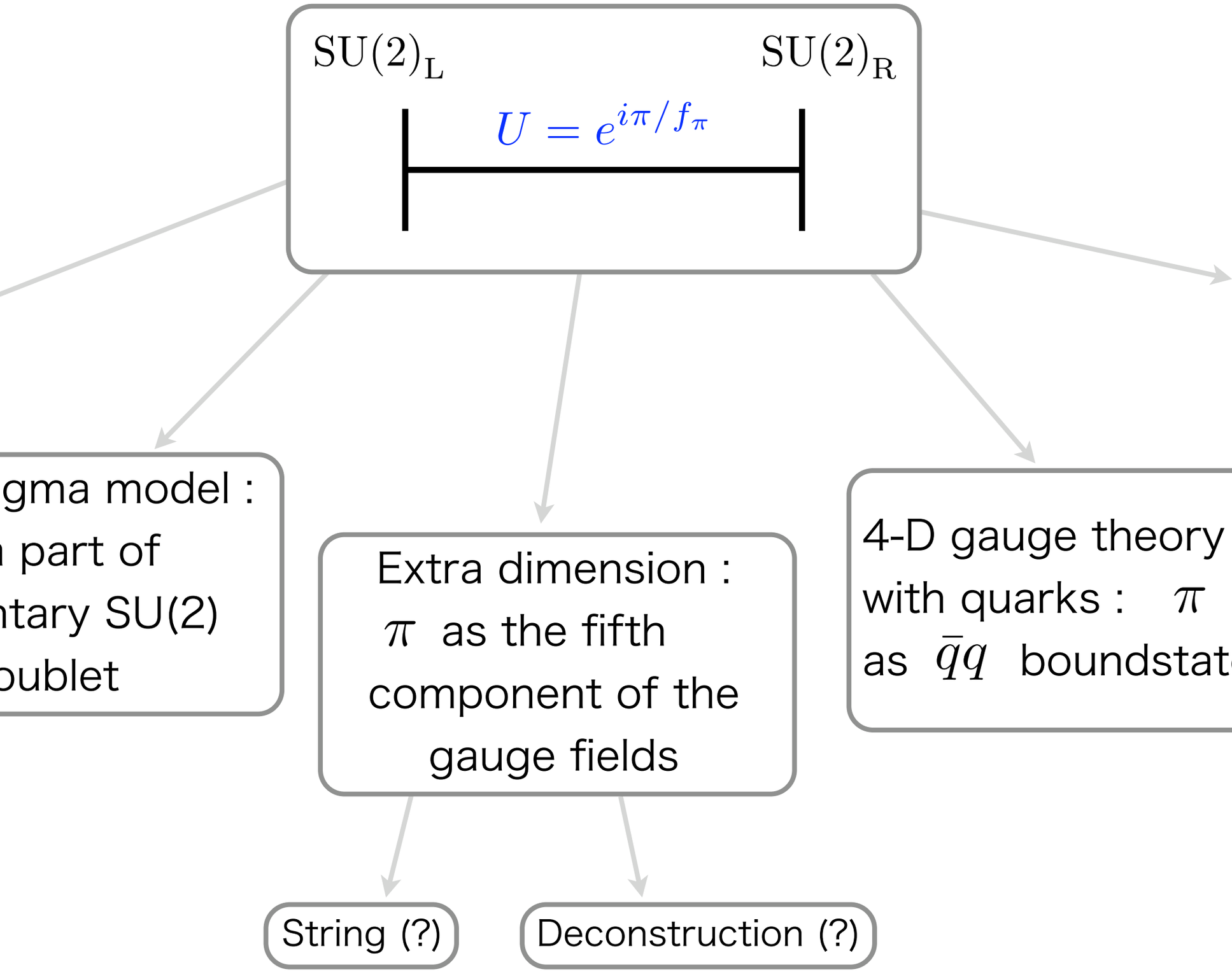
$$(\mathrm{SU}(2)_\mathrm{L} \otimes \mathrm{SU}(2)_\mathrm{R})/\mathrm{SU}(2)_\mathrm{V}$$

$\mathrm{SU}(2)_\mathrm{L}$ $\mathrm{SU}(2)_\mathrm{R}$



$$\mathcal{L} = \frac{f_\pi^2}{4} \mathrm{Tr}\left[(\partial_\mu U)^\dagger (\partial^\mu U) \right]$$

Possible UV completions



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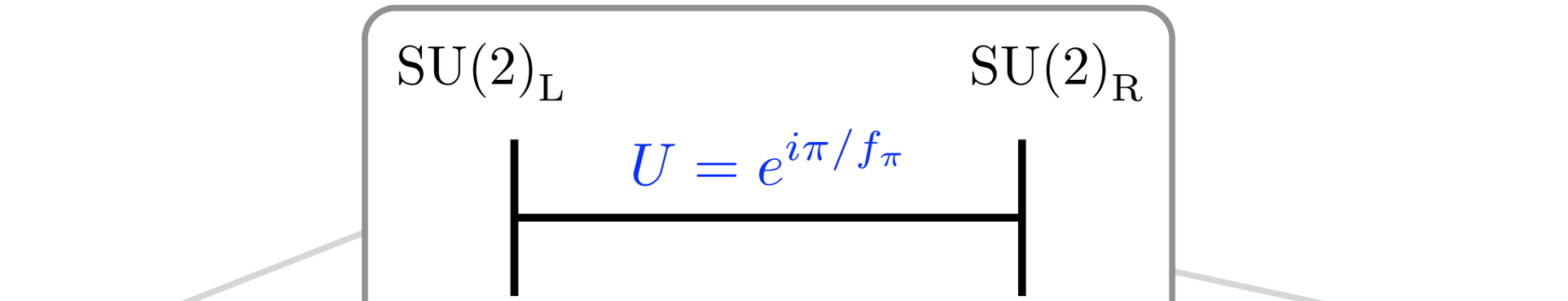


Linear sigma model : π as a part of elementary SU(2) doublet

Extra dimension : π as the fifth component of the gauge fields

4-D gauge theory with quarks : π as $\bar{q}q$ boundstates

QCD

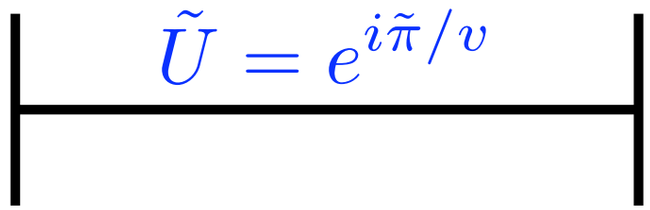
String (?)

Deconstruction (?)

EWSB sector

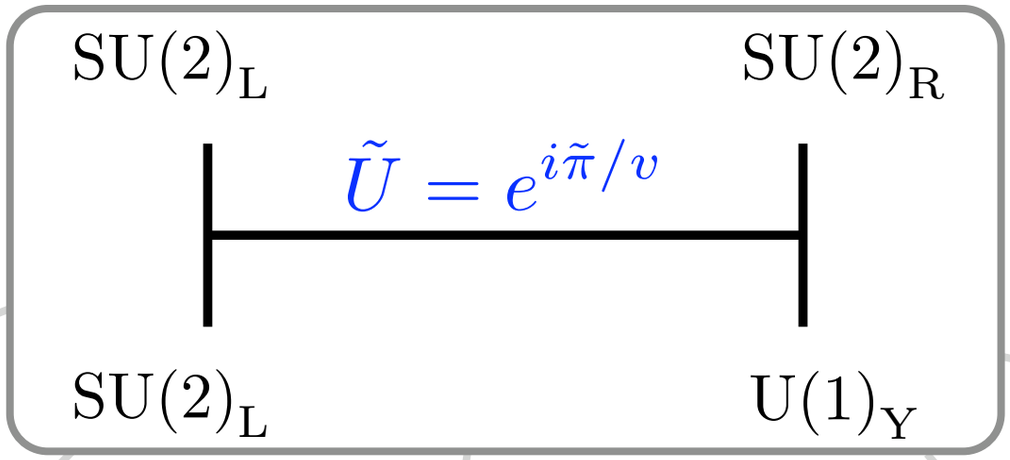
Almost the same structure as that of low energy effective theory of QCD

Global : $\mathrm{SU(2)_L}$ $\mathrm{SU(2)_R}$



Local : $\mathrm{SU(2)_L}$ $\mathrm{U(1)_Y}$

UV completions?



Linear sigma model : $\tilde{\pi}$ as a part of elementary SU(2) doublet

Extra dimension : $\tilde{\pi}$ as the fifth component of the gauge fields

4-D gauge theory with quarks : $\tilde{\pi}$ as $\bar{q}q$ boundstates

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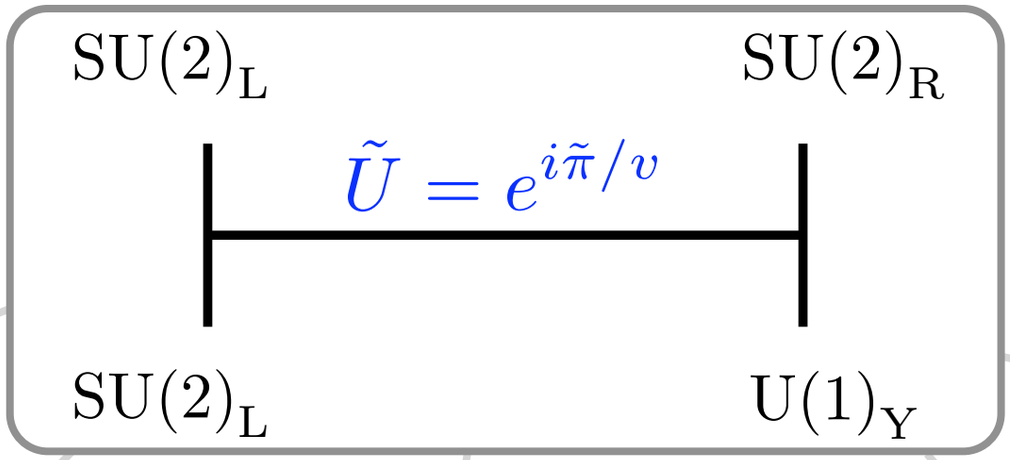

Linear sigma model : $\tilde{\pi}$ as a part of elementary SU(2) doublet

"Standard" Model

Extra dimension : $\tilde{\pi}$ as the fifth component of the gauge fields

String (?)

Deconstruction (?)

4-D gauge theory with quarks : $\tilde{\pi}$ as $\bar{q}q$ boundstates

Why don't we follow the beautiful success of QCD ?

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Need perturbativity ?

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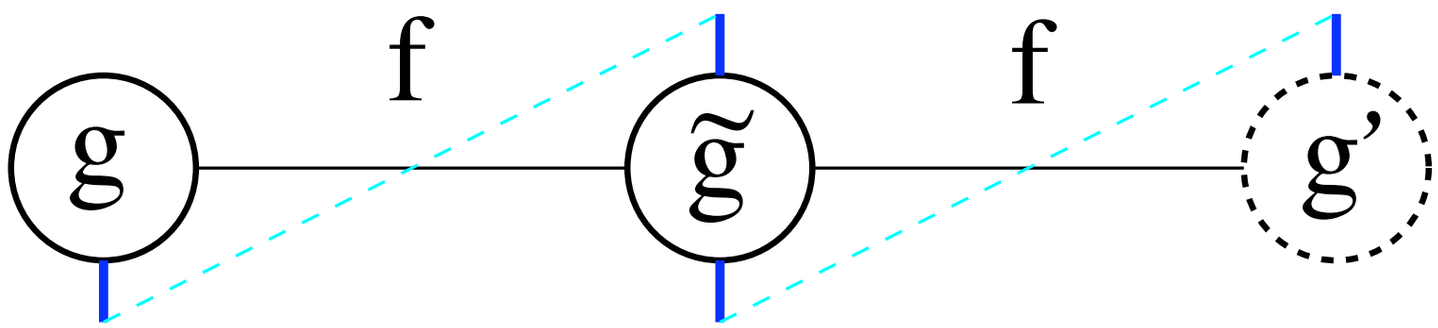
Let us introduce "rho meson"

(= Z', W' bosons)

(Unitarity of pi-pi scattering is improved by the rho meson exchange)

Three Site Higgsless Model

Chivukula, Coleppa, Di Chiara, Simmons, He, Kurachi, Tanabashi, PRD 74, 075001 (2006)



Four dimensional gauge invariant Lagrangian which includes

- $SU(2) \times SU(2) \times U(1)$ gauge fields (Circles)

  → $\gamma,\ W,\ Z,\ W',\ Z'$

- $(SU(2) \times SU(2))\,/SU(2)$ non-linear sigma fields (Links)

  Eaten by massive gauge fields

- Two left and right handed fermions (Vertical lines) for each flavor

  → SM fermions and their heavy partners

Three Site Higgsless Model (Gauge Sector)

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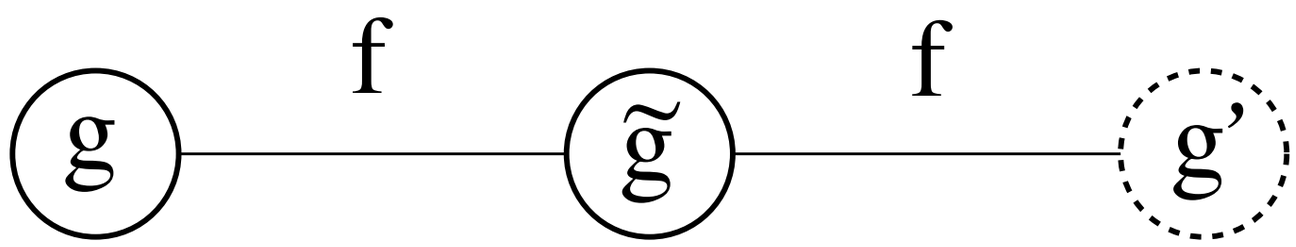


This theory is in the same class as models of extended EW gauge symmetries

Casalbuoni et. al., Phys. Lett. B155 (1985) 95
Casalbuoni et. al., Phys. Rev. D53 (1996) 5201–5221

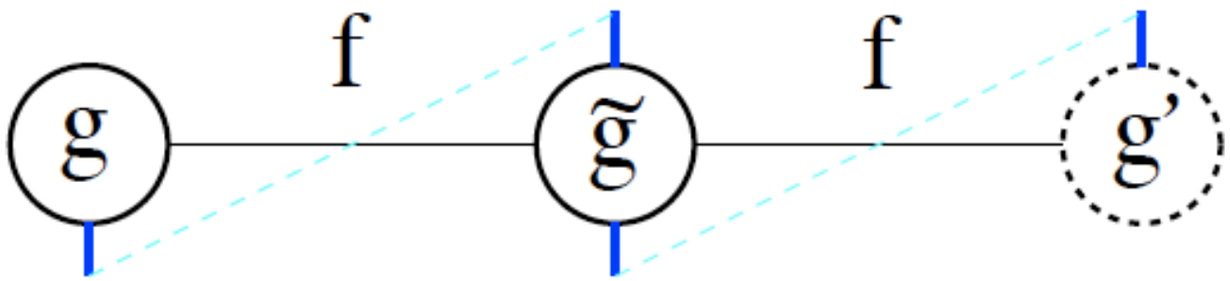
motivated by models of Hidden Local Symmetry

Bando, Kugo, Uehara, Yamawaki, Yanagida, Phys. Rev. Lett. 54 (1985) 1215
Bando, Kugo, Yamawaki, Nucl. Phys. B259 (1985) 493
Bando, Fujiwara, Yamawaki, Prog. Theor. Phys. 79 (1988) 1140
Bando, Kugo, Yamawaki, Phys. Rept. 164 (1988) 217–314.

Three Site Higgsless Model (Fermion Sector)

Chivukula, Coleppa, Di Chiara, Simmons, He, Kurachi, Tanabashi, PRD 74, 075001 (2006)

$$\psi_{R1} = \begin{pmatrix} u_{R1} \\ d_{R1} \end{pmatrix} \qquad \begin{matrix} u_{R2} \\ d_{R2} \end{matrix}$$



$$\psi_{L0} = \begin{pmatrix} u_{L0} \\ d_{L0} \end{pmatrix} \qquad \psi_{L1} = \begin{pmatrix} u_{L1} \\ d_{L1} \end{pmatrix}$$

$$\mathcal{L}_{mass} = M \left[\varepsilon_L \bar{\psi}_{L0} U_1 \psi_{R1} + \bar{\psi}_{R1} \psi_{L1} + \bar{\psi}_{L1} U_2 \begin{pmatrix} \varepsilon_{uR} & \\ & \varepsilon_{dR} \end{pmatrix} \begin{pmatrix} u_{R2} \\ d_{R2} \end{pmatrix} \right] + h.c.$$

Fermion mass matrix

$$M_u \;=\; M \begin{pmatrix} \varepsilon_L & 0 \\ 1 & \varepsilon_{uR} \end{pmatrix}$$

For $d,\ c,\ s,\ t,\ b$ quarks, $\varepsilon_{uR} \;\to\; \varepsilon_{dR},\ \varepsilon_{cR},\ \varepsilon_{sR},\ \varepsilon_{tR},\ \varepsilon_{bR}$

$e,\ \mu,\ \tau$, leptons, $\;\to\; \varepsilon_{eR},\ \varepsilon_{\mu R},\ \varepsilon_{\tau R}$

Ideal delocalization

$$\varepsilon_L^2 \;\simeq\; \tfrac{1}{2}\tfrac{g_0^2}{g_1^2} \;\; \left(\equiv x^2/2 \;\ll\; 1\right)$$

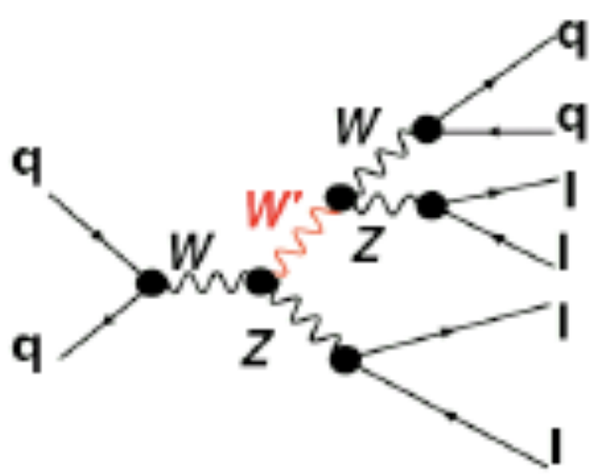
— a *choice* we make in building the model in order to minimize precision electroweak corrections

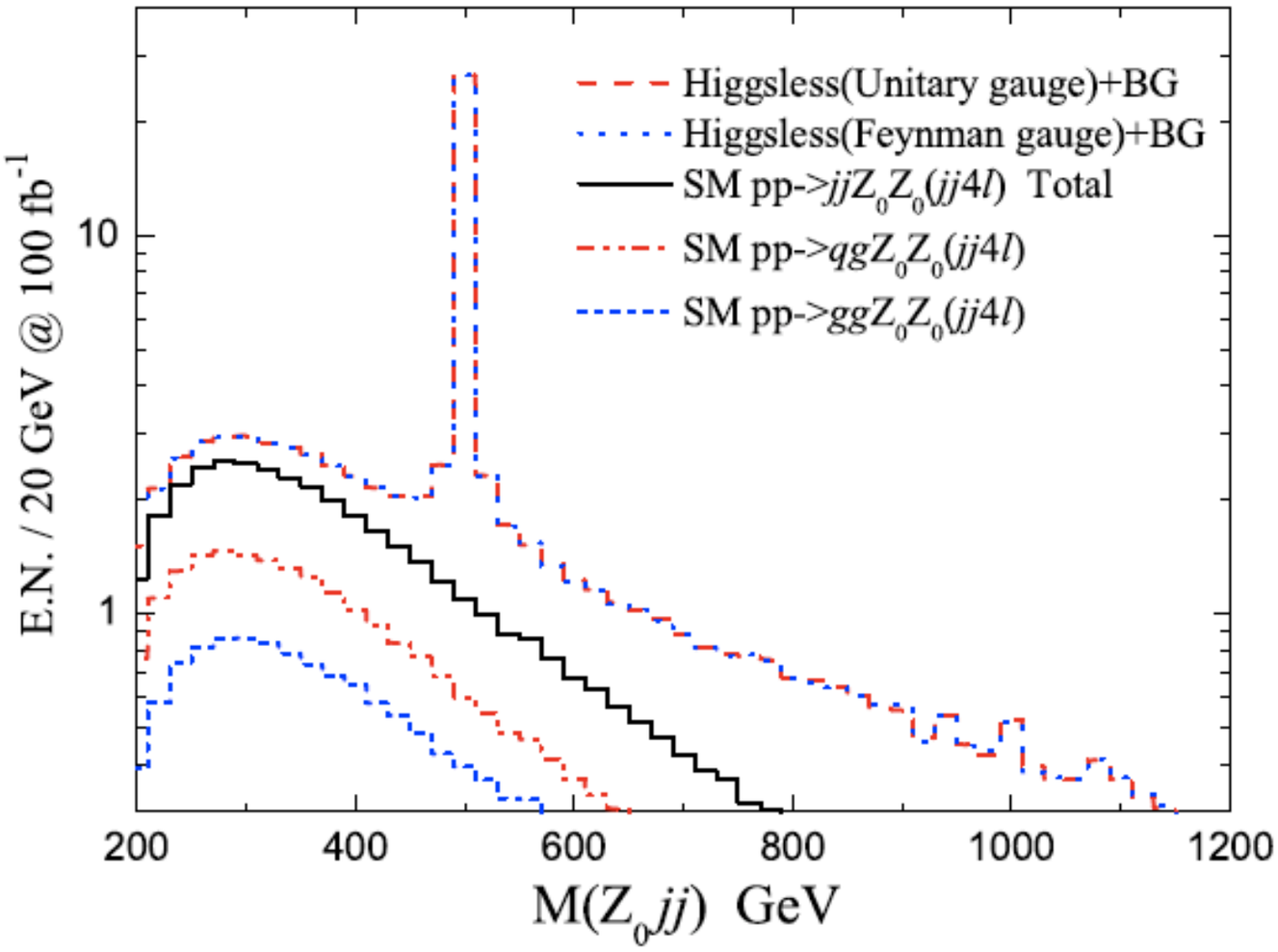
LHC Signatures

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

Belyaev, arXiv.0711.1919 [hep-ph]

Discovering the W' boson via $pp \to (W)^* \to (W')^* Z \to WZZ$





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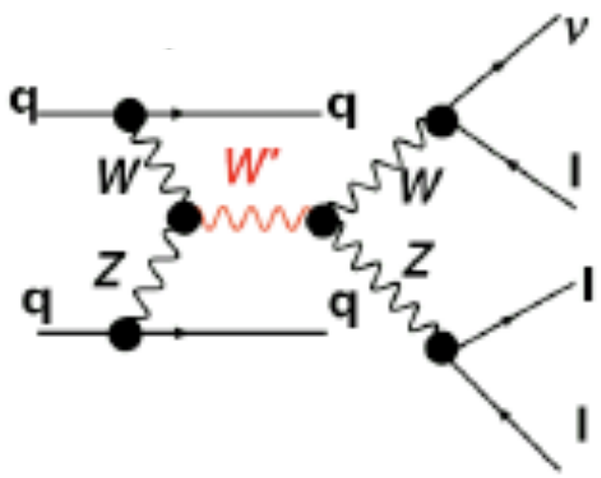

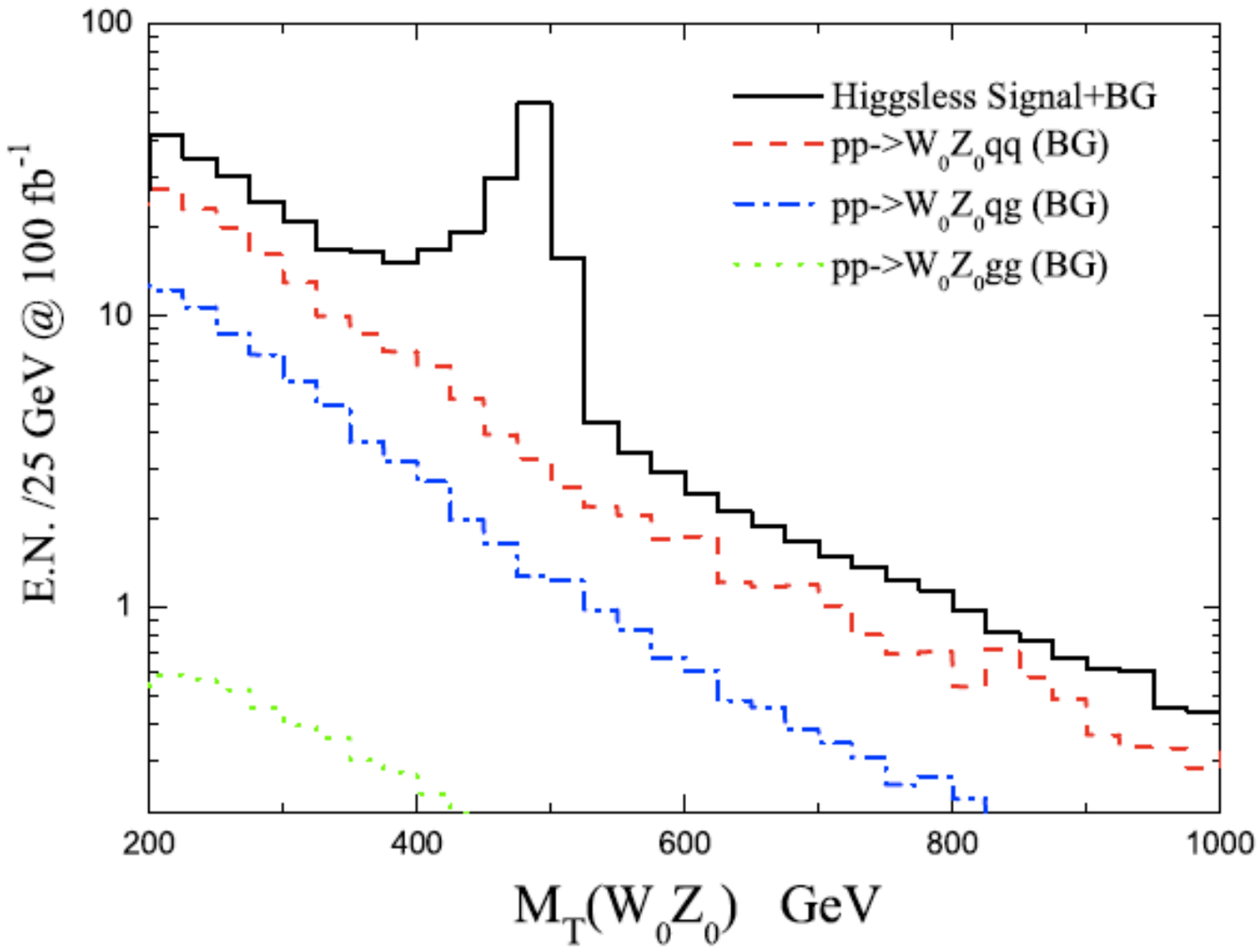

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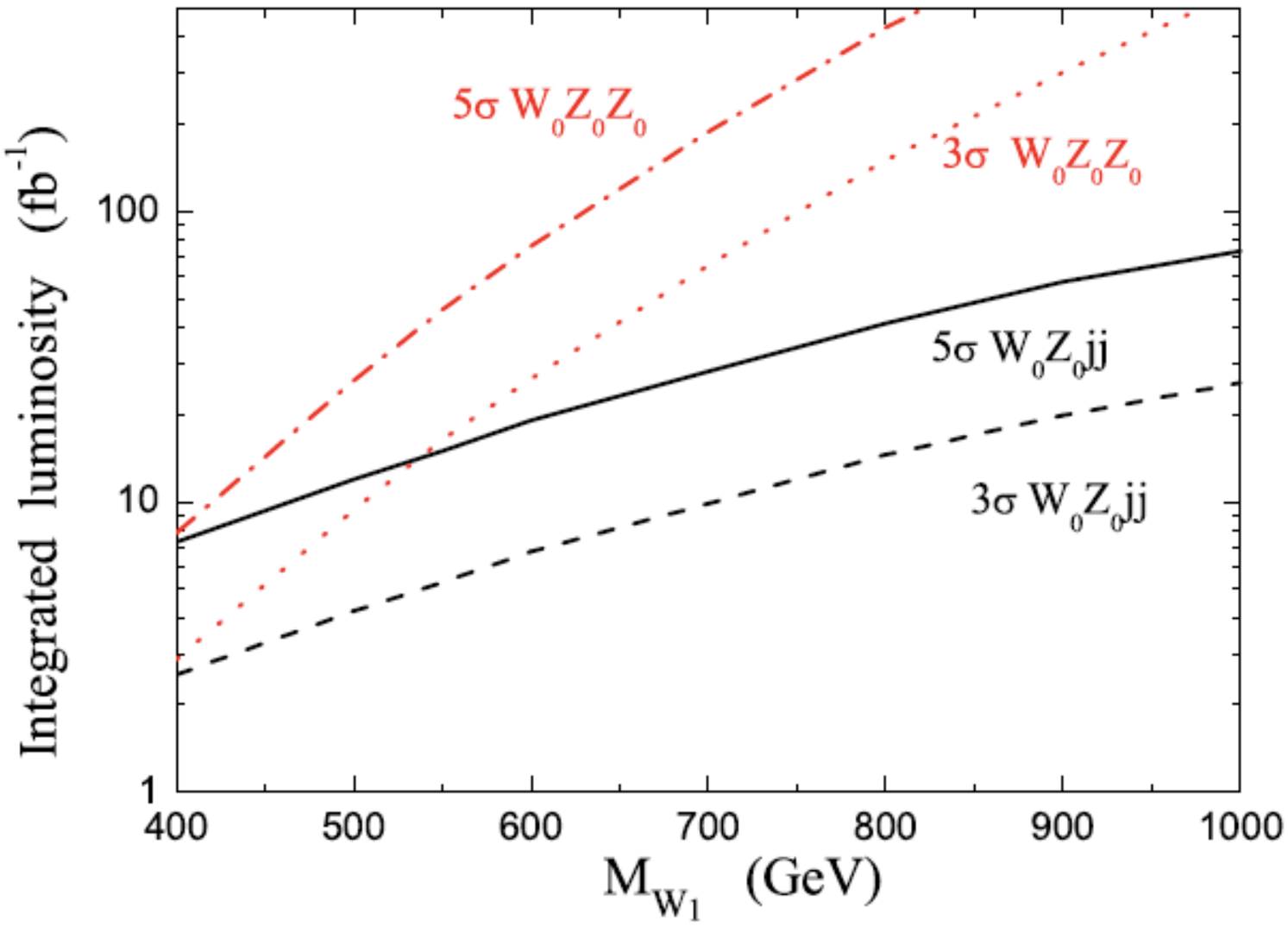
- Integrated luminosities required for 3σ and 5σ detection of W' signals as a function of $M_{W'}$

Heavy gauge boson W' can be discovered within the first few years' run at the LHC



Summary

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Standard Model is not the only scenario
for the Electroweak symmetry breaking