One Loop Correction to the ρ Parameter in Higgsless Models

by
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Higgsless Models

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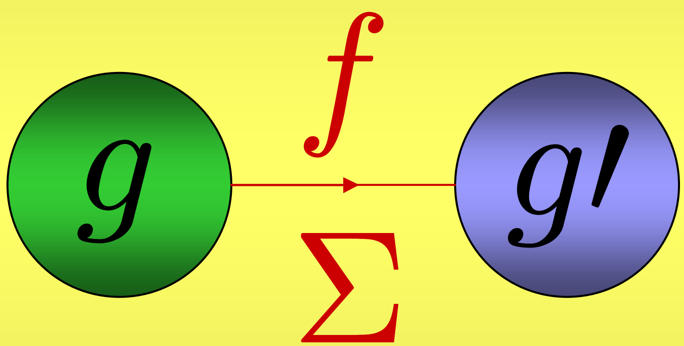
- literally break the electroweak symmetry without producing a Higgs boson,
- are effective field theories,
- may be viewed as “dual” to models of dynamical symmetry breaking, such as walking technicolor.

"Minimal" Higgsless Models

- The "Standard Model" Higgsless



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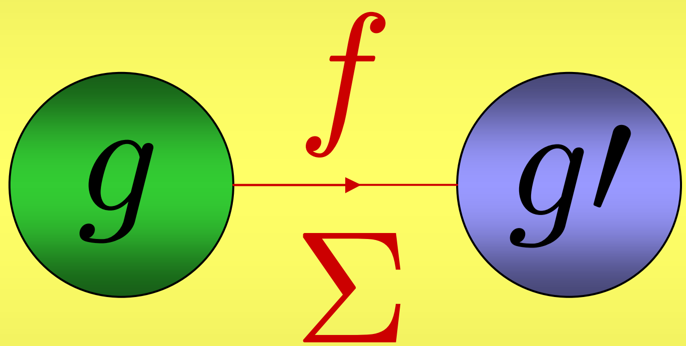

$$\mathcal{L} = -\frac{1}{4} W^{a}_{\mu\nu} W^{a\mu\nu}$$

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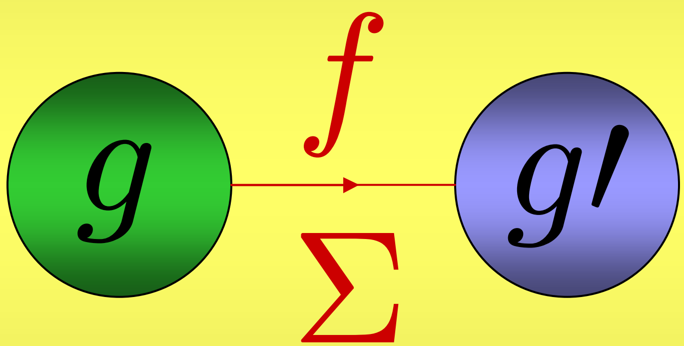

$$\mathcal{L} = -\frac{1}{4}W^a_{\mu\nu}W^{a\mu\nu} - \frac{1}{4}B_{\mu\nu}B^{\mu\nu}$$

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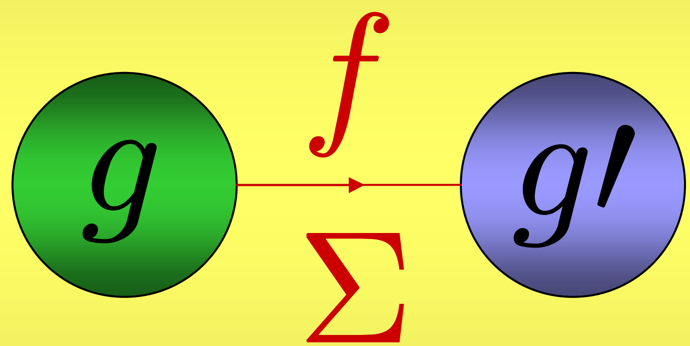

$$\mathcal{L} = -\frac{1}{4}W^a_{\mu\nu}W^{a\mu\nu} - \frac{1}{4}B_{\mu\nu}B^{\mu\nu}$$

$$+\frac{4}{f^2}\left(D^\mu\Sigma\right)^\dagger D_\mu\Sigma$$

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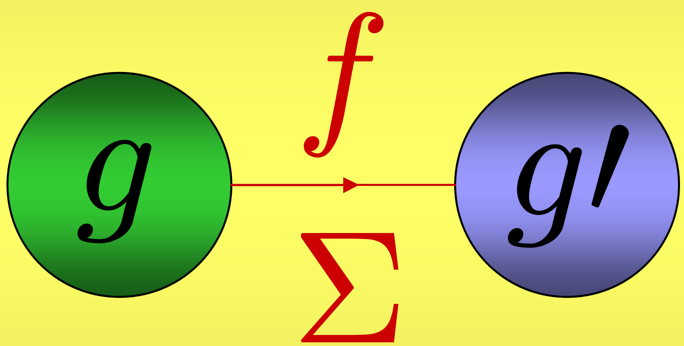

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$$+ \frac{4}{f^2} \left(D^\mu \Sigma \right)^\dagger D_\mu \Sigma \qquad \Sigma = e^{i\pi^a T^a}$$

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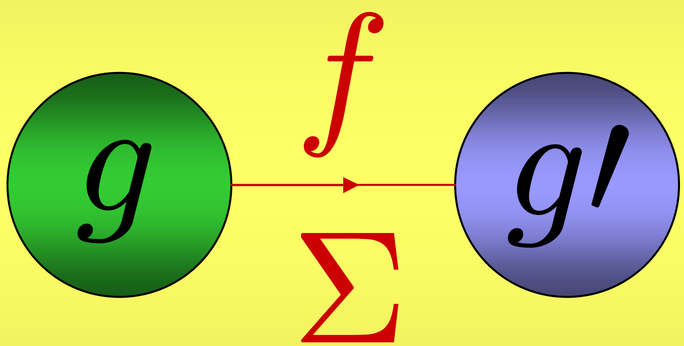
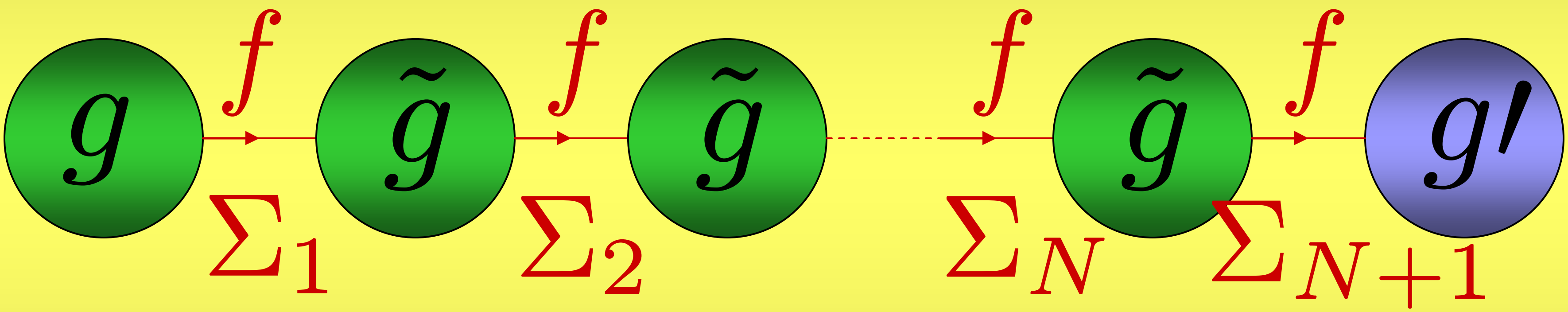


- It is a non-renormalizable theory. Example, unitarity of $W_L^+ W_L^-$ scattering is violated at 1.6 TeV.

"Minimal" Higgsless Models

- N- Site Higgsless Model



$$\mathcal{L} = -\frac{1}{4}\sum_{j=0}^{N} W^a_{j\mu\nu} W_j^{a\mu\nu} - \frac{1}{4} B_{\mu\nu} B^{\mu\nu}$$

$$+\frac{4}{f^2}\sum_{j=1}^{N+1} \left(D^\mu \Sigma_j\right)^\dagger D_\mu \Sigma_j$$

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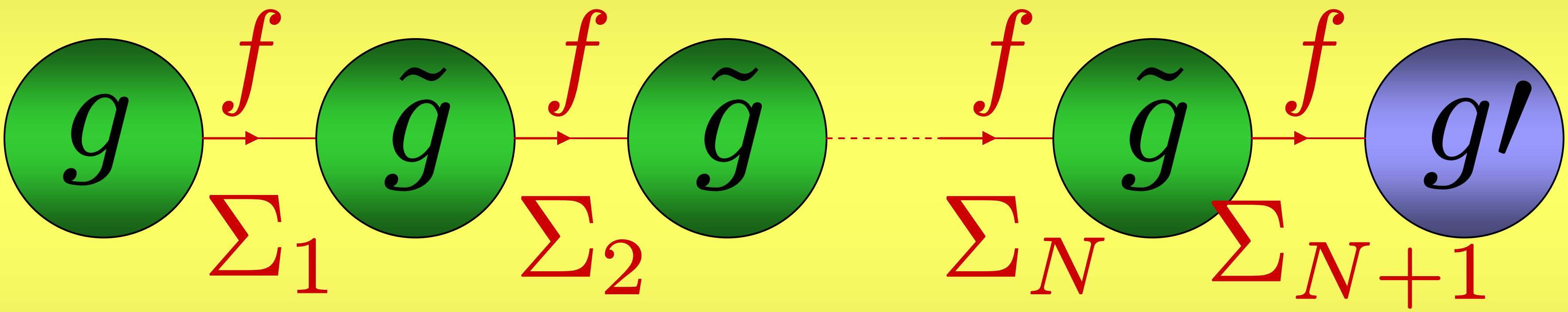

- Approximate SM on the end sites.

$$g^2 \ll \tilde{g}^2 \qquad g'^2 \ll \tilde{g}^2$$

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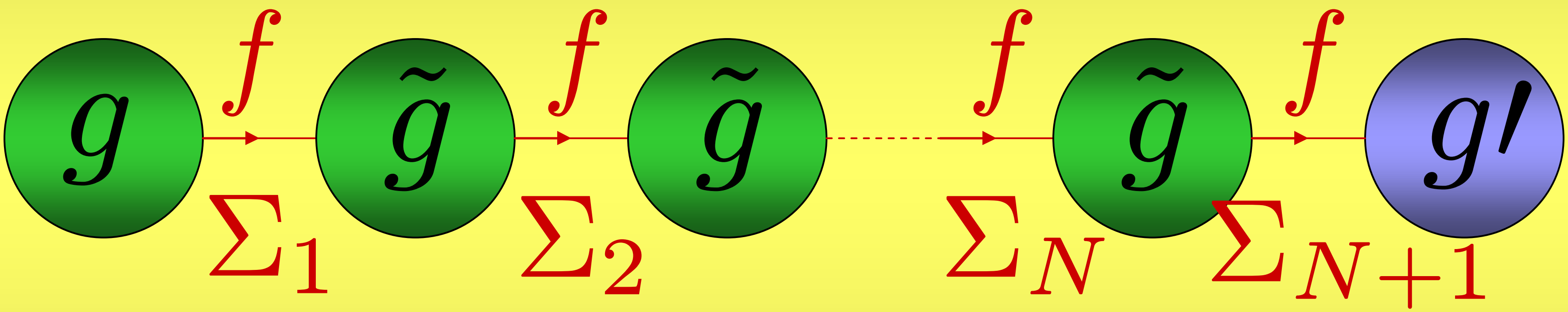

- Approximate SM on the end sites. SM is recovered for $f,\ \tilde{g} \to \infty$.

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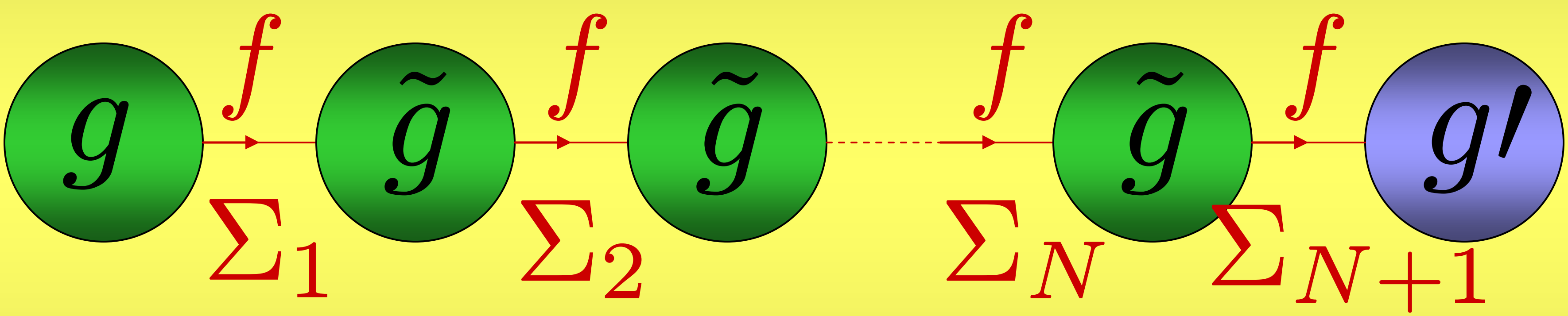
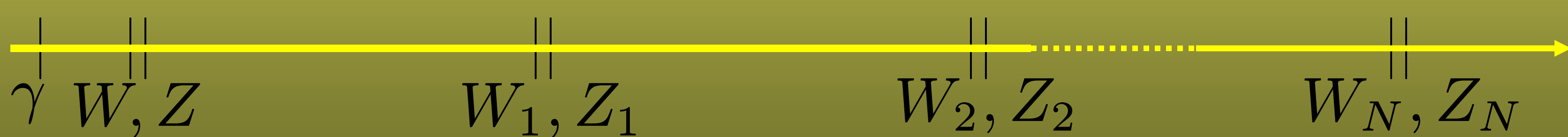


- Flat background with “brane” kinetic terms $\longrightarrow$ approx. equally spaced states.



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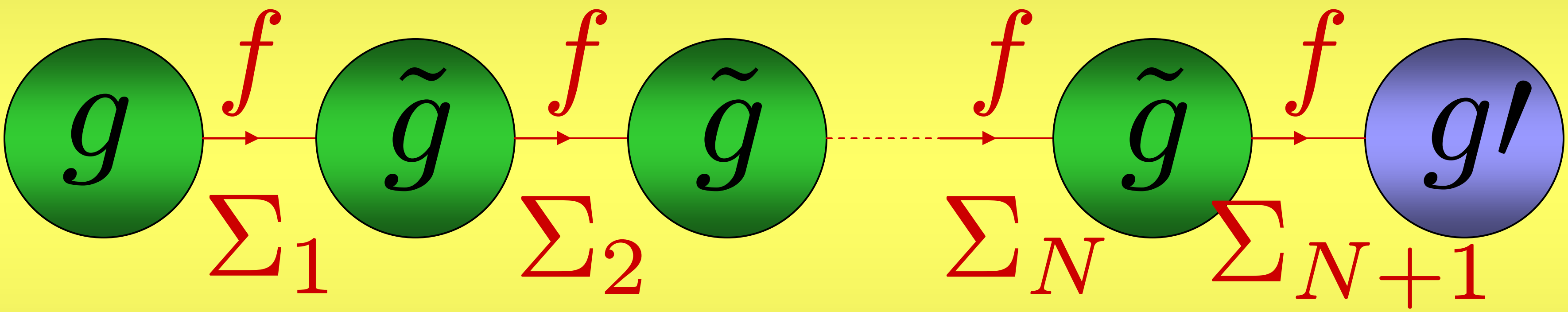
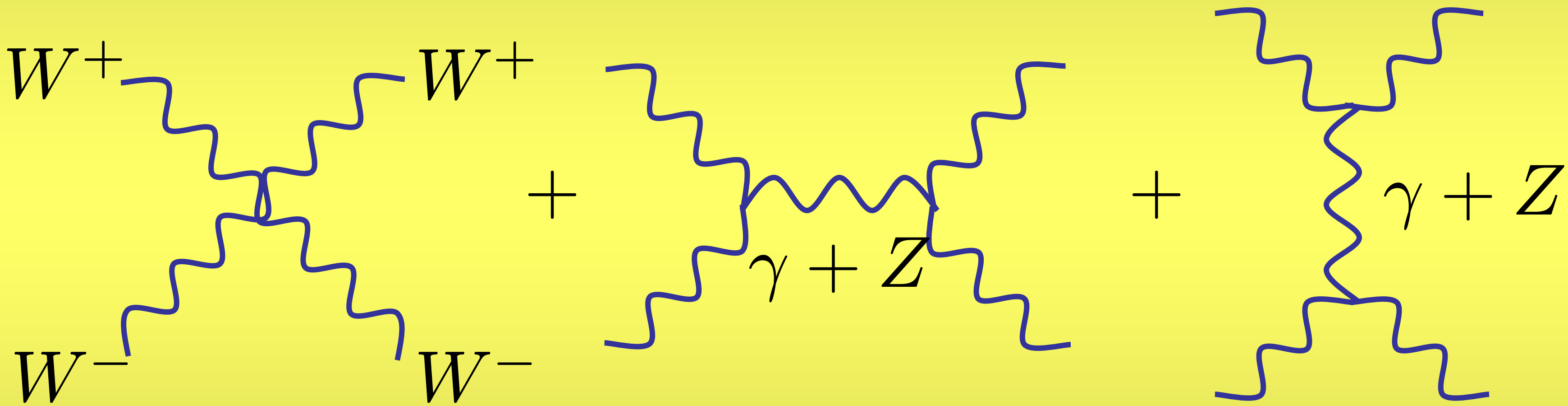


- $N \to \infty, f \sim \sqrt{N+1}, \tilde{g} \sim \sqrt{N+1}$ $\longrightarrow$ extra-dimensional model, with flat background and large brane kinetic terms.

Delay of Unitarity Violation

- Example: $\mathrm{W}_L^+ W_L^-$ elastic scattering.



$$\sim \frac{g^2}{2}\left(\frac{E}{m_W}\right)^2$$

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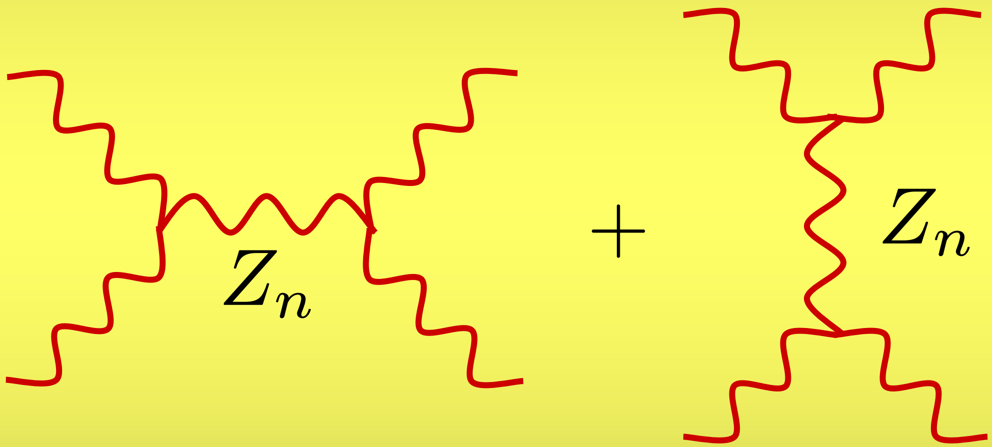
$$+\sum_{n=1}^{N}$$



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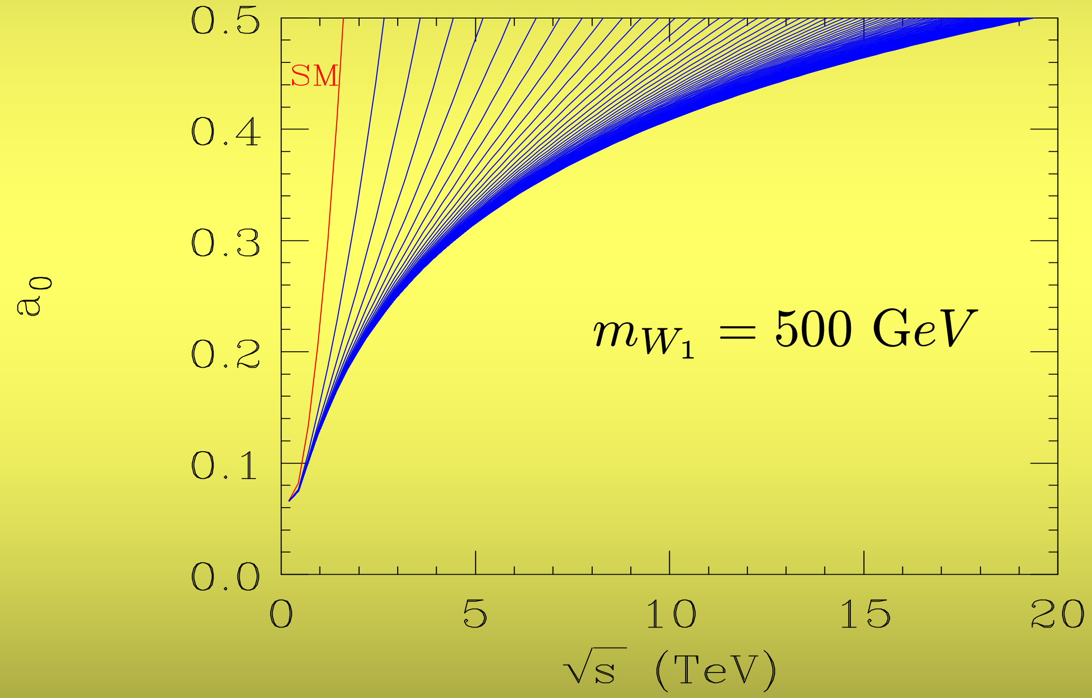

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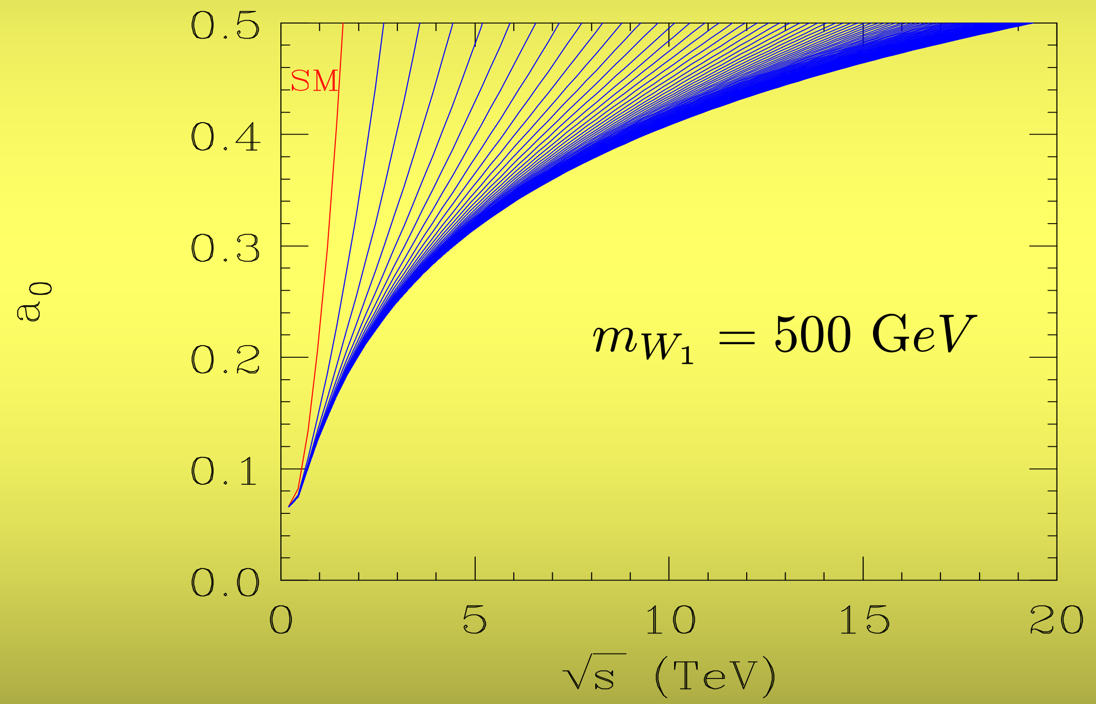

- Upper bound on m_{W_1} : $m_{W_1} \lesssim 1$ TeV .

Delay of Unitarity Violation

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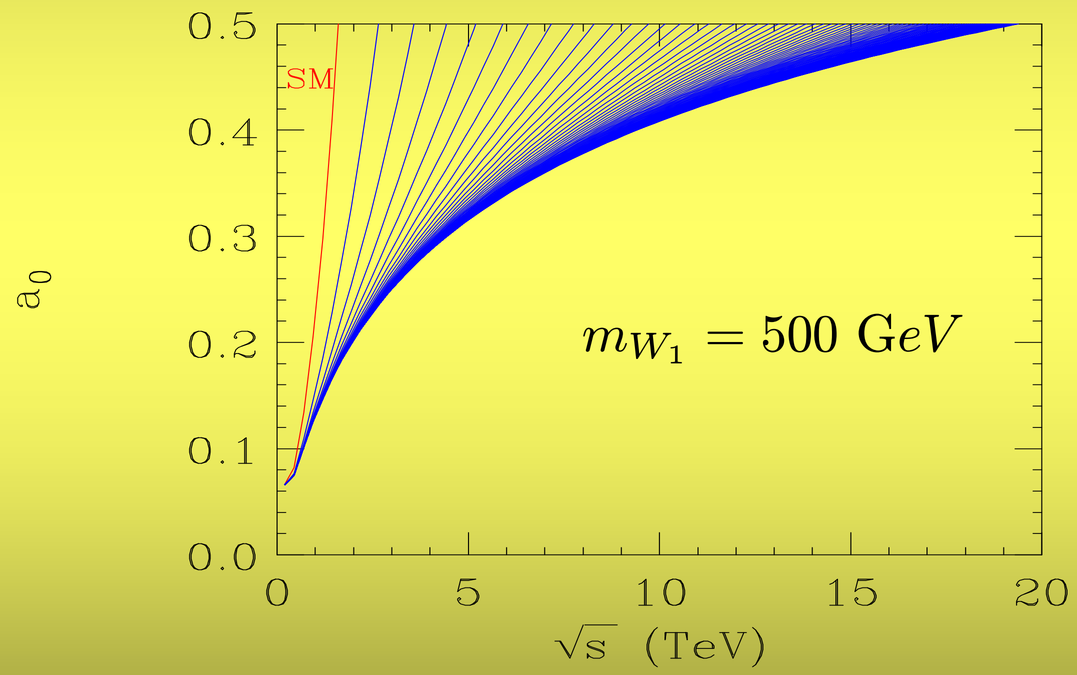
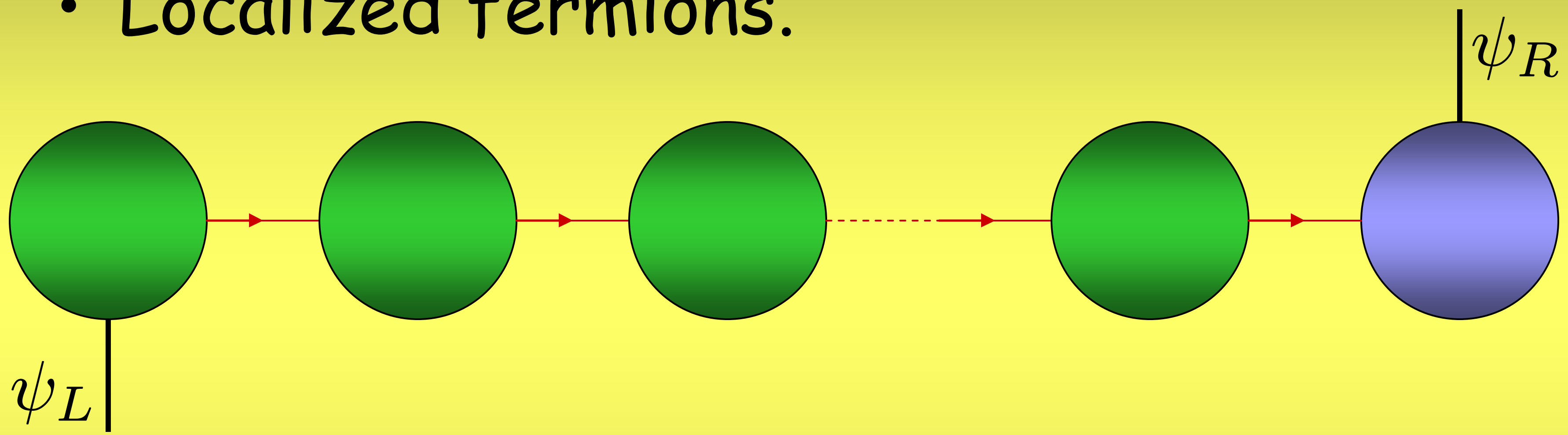


- However a coupled channel analysis gives much lower bounds.

Coupling of Matter Fields

- Localized fermions.



$$\psi_L = \begin{pmatrix} u_L \\ d_L \end{pmatrix} \quad \psi_R = \begin{pmatrix} u_R \\ 0 \end{pmatrix} + \begin{pmatrix} 0 \\ d_R \end{pmatrix}$$

Coupling of Matter Fields

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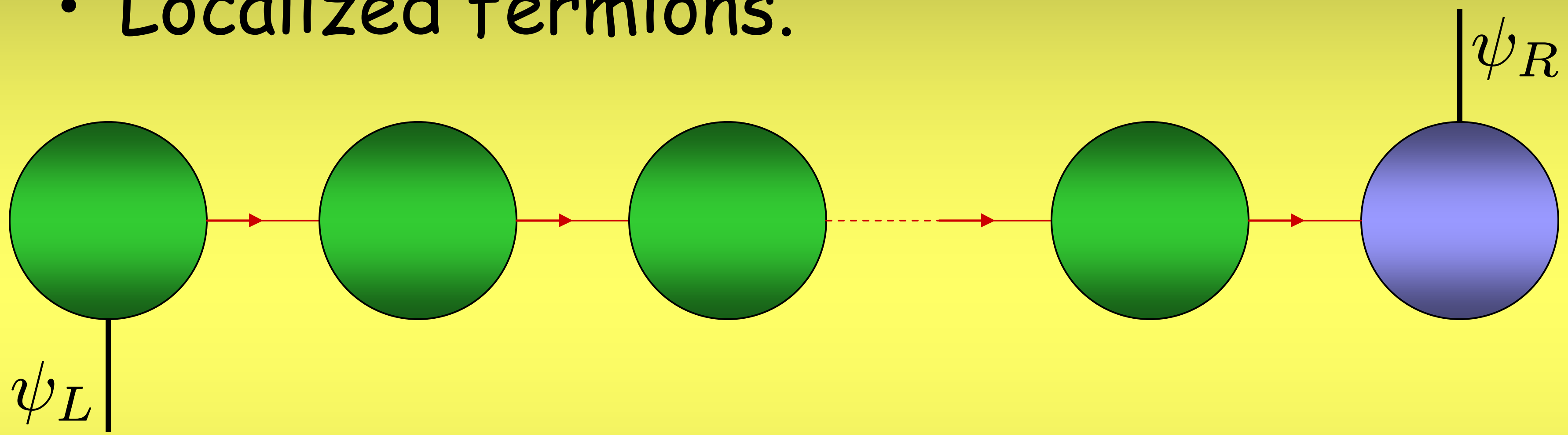

- Notice: ψ_L couples to both first and last sites. Non local from a deconstructed point of view, fine in theory space.

Coupling of Matter Fields

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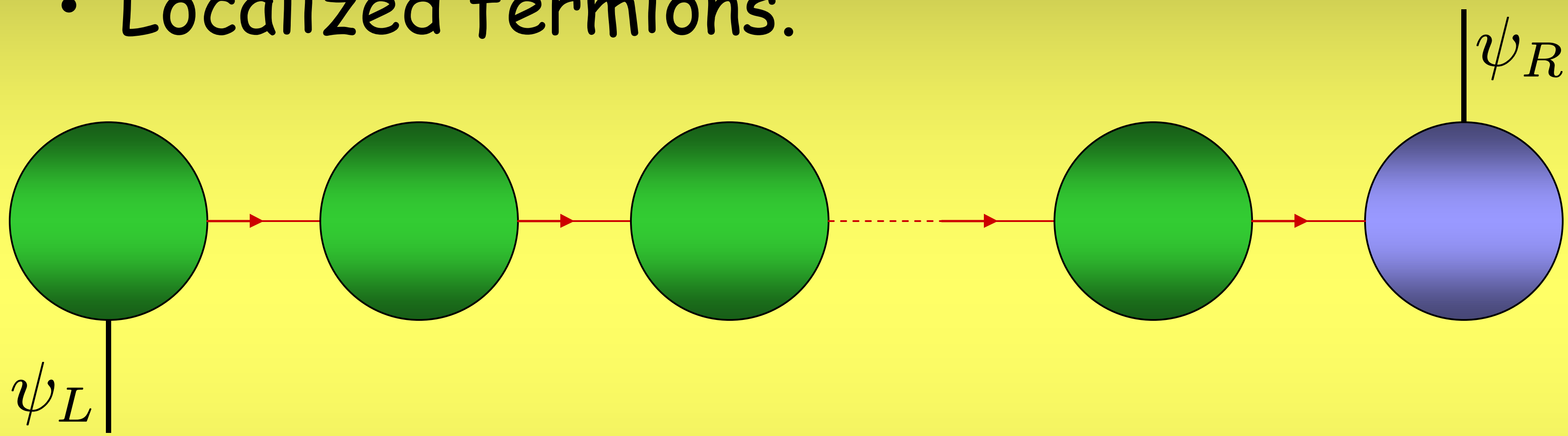

- Also, mass term from chain of Σ fields $\rightarrow$ Wilson line in continuum limit $\longrightarrow$ non-local in 5D

$$\mathcal{L}_{Yukawa} = \bar{\psi}_L \Sigma_1 \Sigma_2 \cdots \Sigma_{N+1} \psi_R + \text{h.}c.$$

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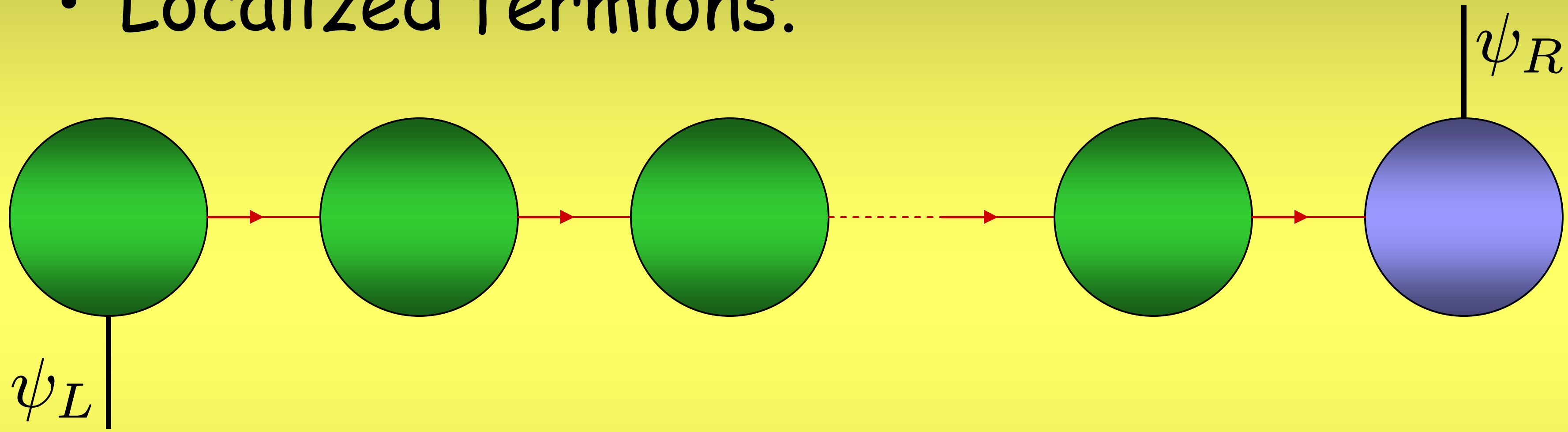

- To order $(m_W/m_{W_1})^2$ the corrections are purely oblique: $W \sim Y \sim (m_W/m_{W_1})^4$.

Coupling of Matter Fields

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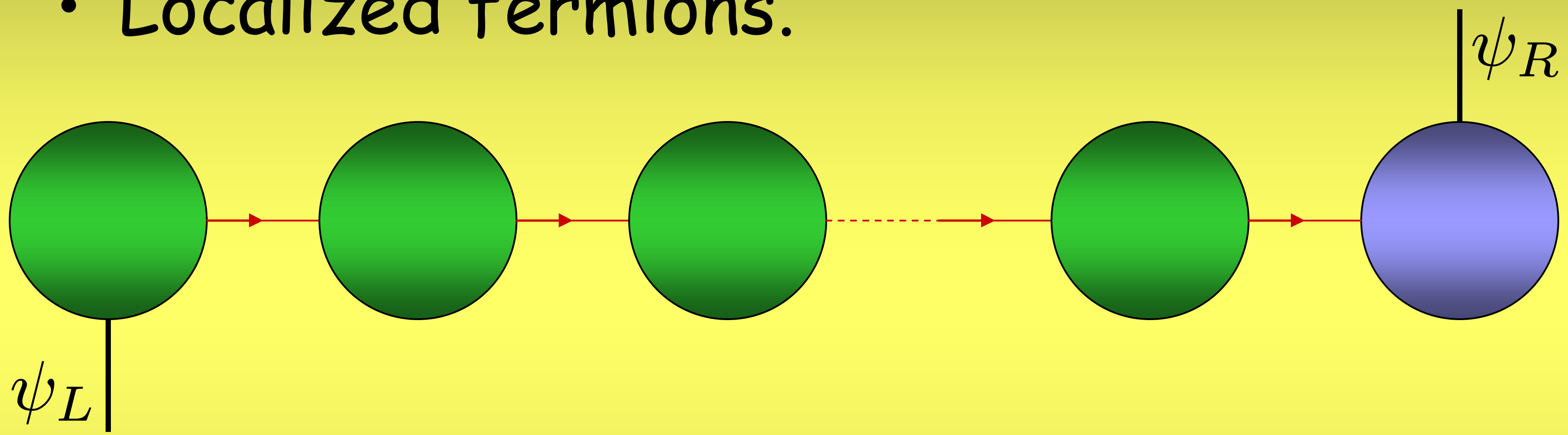
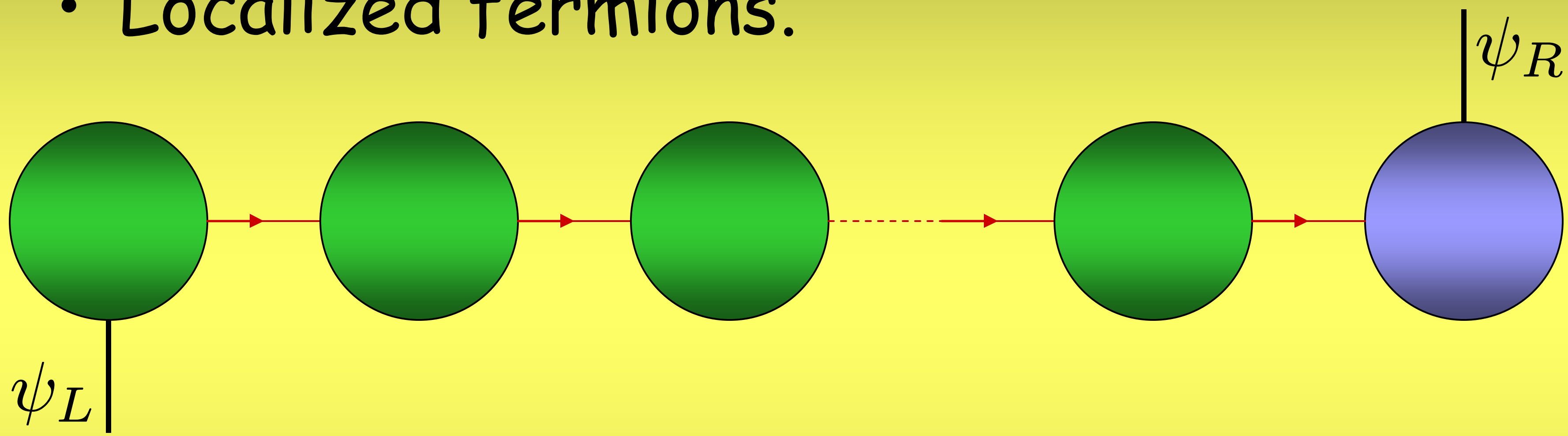


- At tree level:

$$\alpha S \sim \left(\frac{m_W}{m_{W_1}}\right)^2, \; \alpha T \simeq 0, \; \alpha U \simeq 0$$

Coupling of Matter Fields

- Localized fermions.

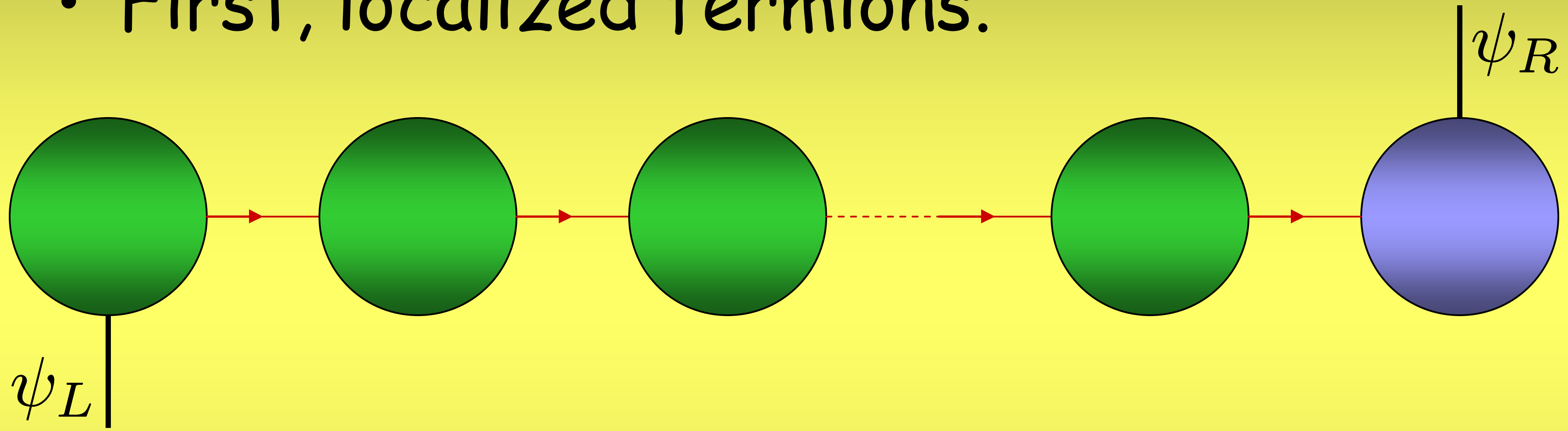


- Also, because of custodial symmetry:

$$\Delta\rho \equiv \rho - 1 = 0$$

Coupling of Matter Fields

- First, localized fermions.

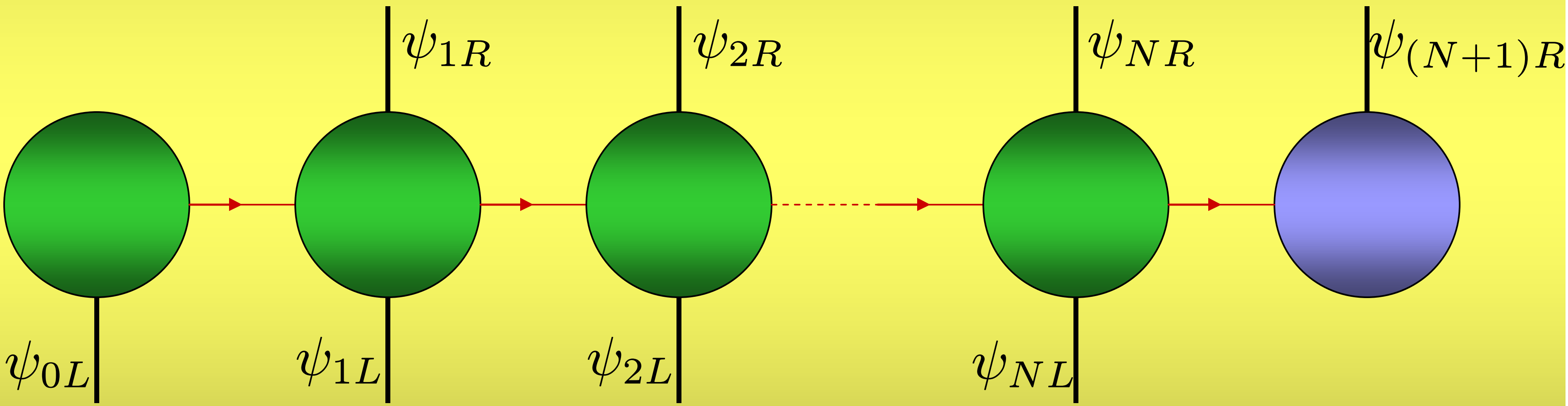


- General result for localized fermions (Chivukula et al., 2004) :

$$S - 4\cos\theta_W T \gtrsim \mathcal{O}(1)$$

Coupling of Matter Fields

- Delocalized fermions.



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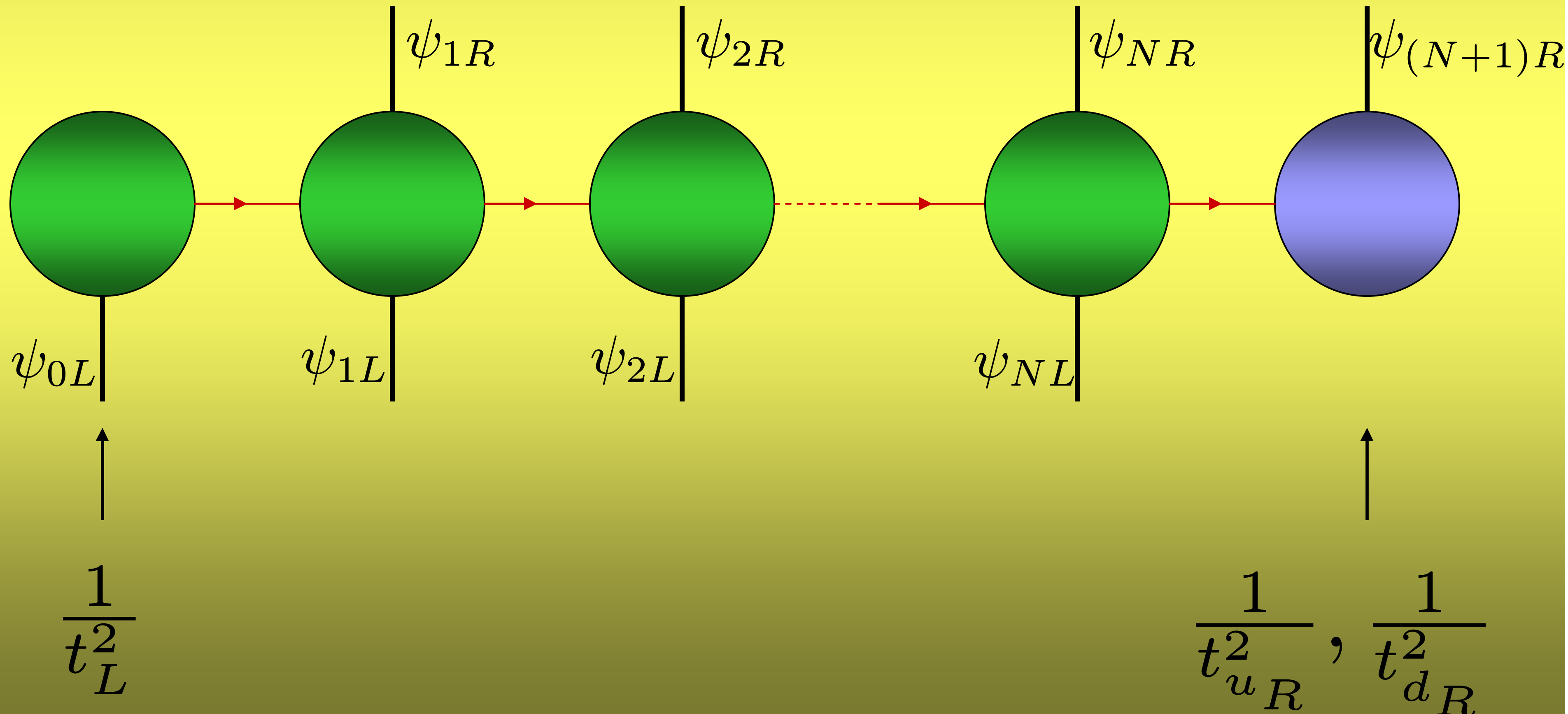

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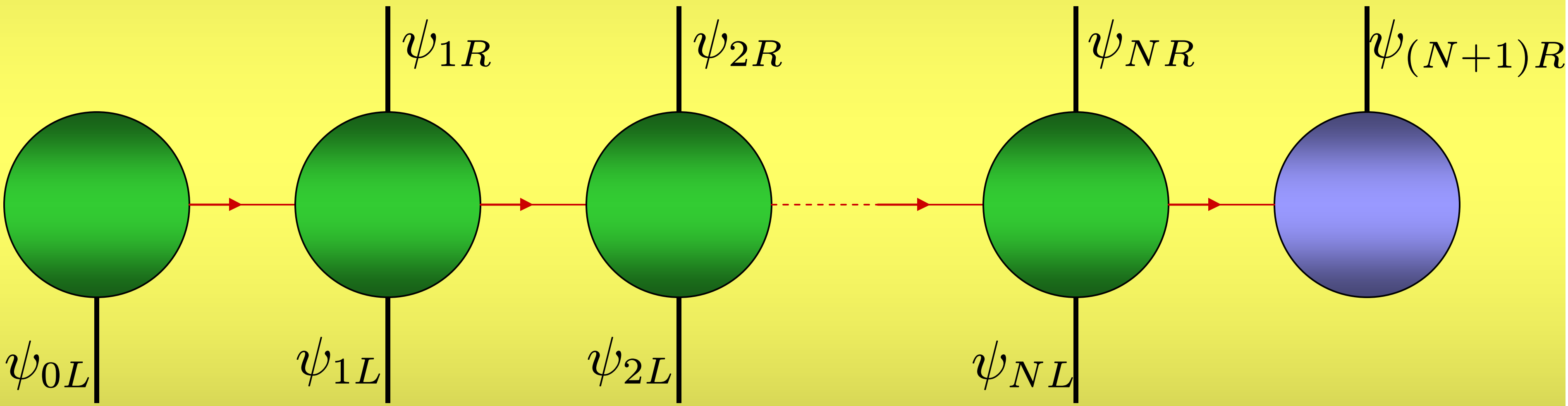

- $t_L =$ amount of SM left-handed fermion delocalization, t_{u_R} , $t_{d_R} =$ amount of SM right-handed fermion delocalization.

Coupling of Matter Fields

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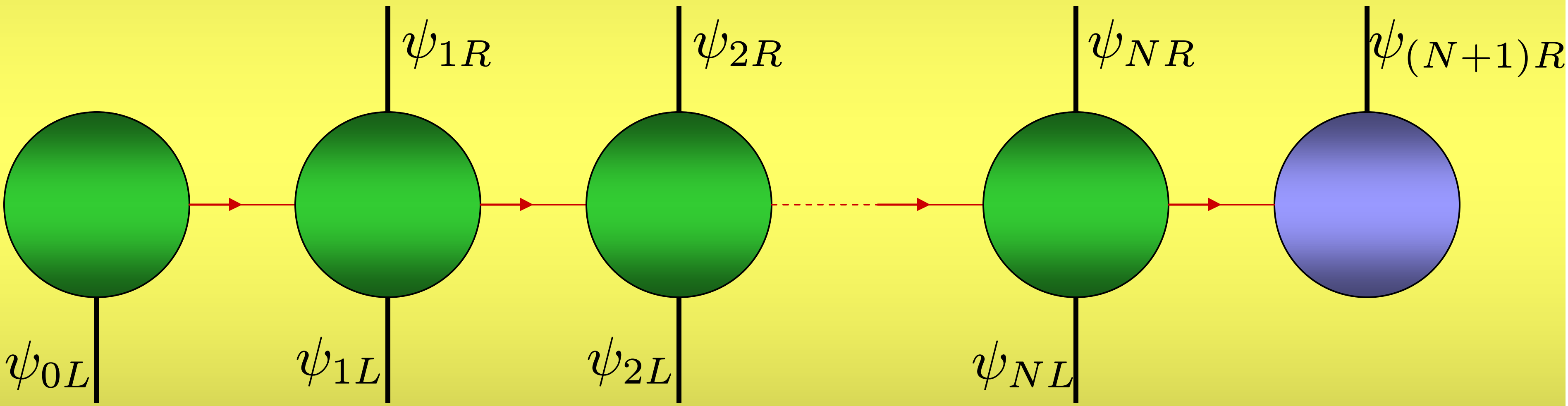

- SM fermions mostly ψ_{0L} and $\psi_{(N+1)R}$.

Coupling of Matter Fields

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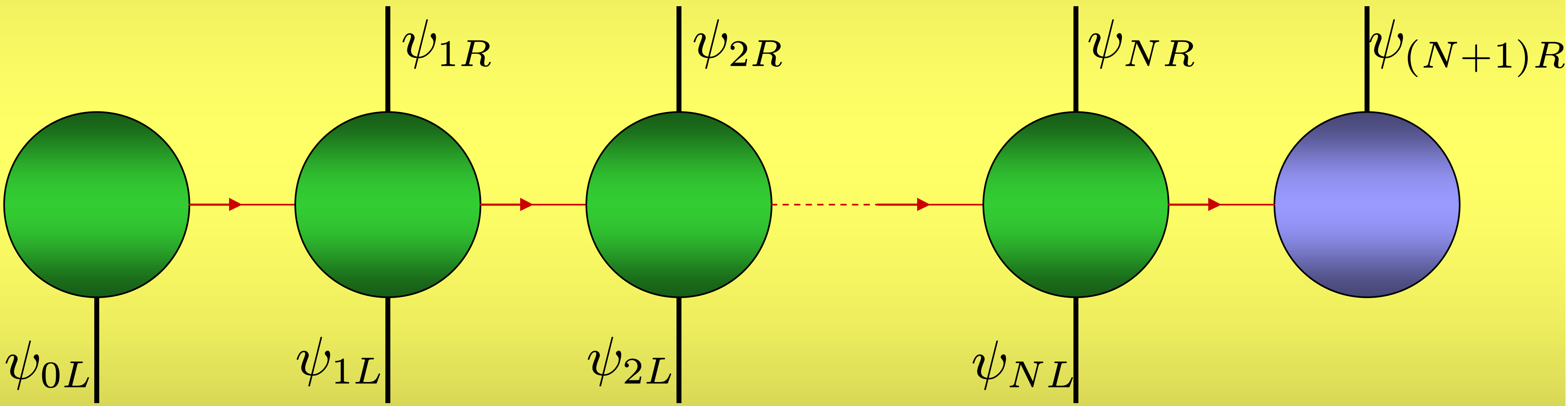

- Local mass terms.

Coupling of Matter Fields

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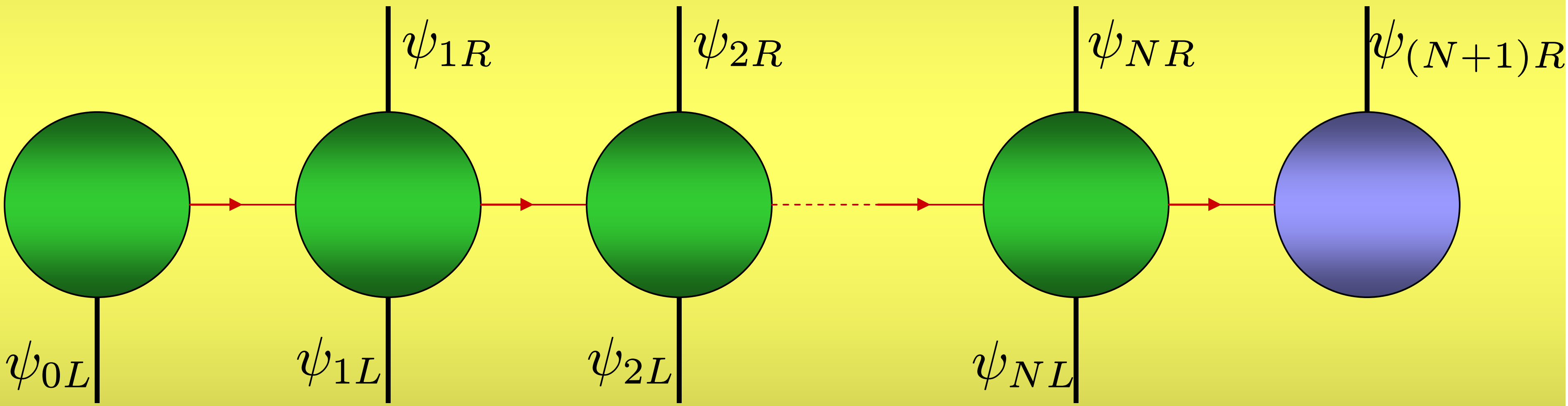

- Local mass terms.

$$M\bar{\psi}_{jL}\Sigma_{j+1}\psi_{(j+1)R} + \text{h.}c.$$

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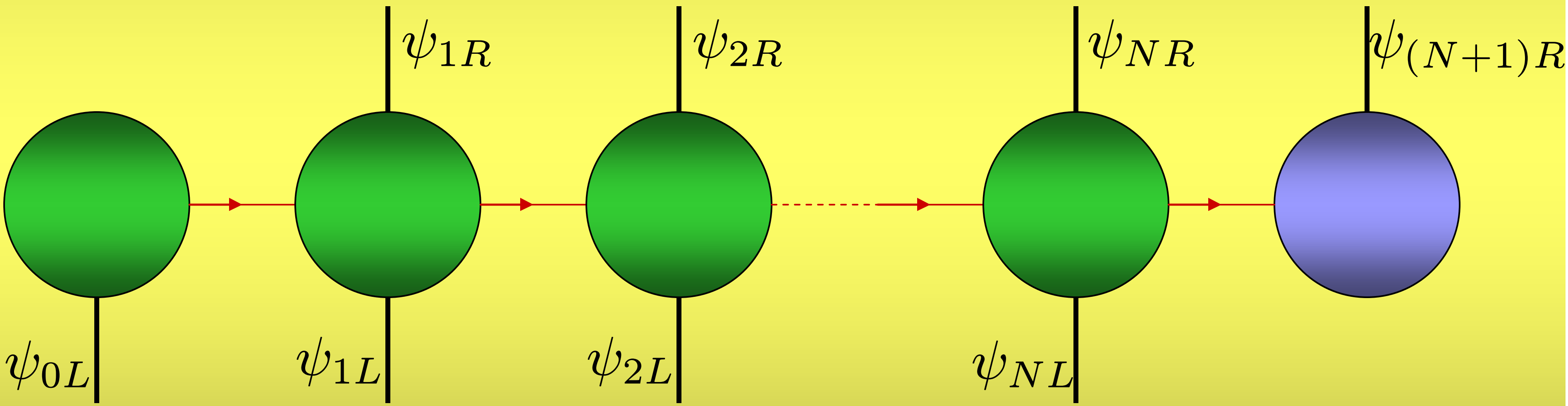

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$M\bar{\psi}_{jL}\Sigma_{j+1}\psi_{(j+1)R} + \mathrm{h.}c.$ $\qquad$ $M\bar{\psi}_{jL}\psi_{jR} + \mathrm{h.}c.$

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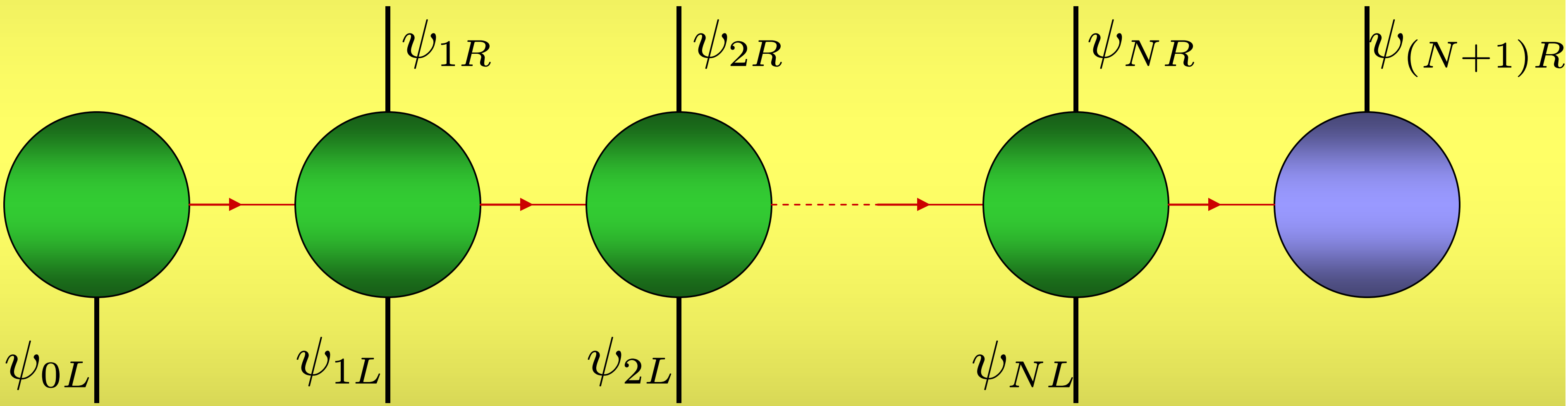

- $M \neq f$ $\longrightarrow$ Gauge and fermion mass scales independent.

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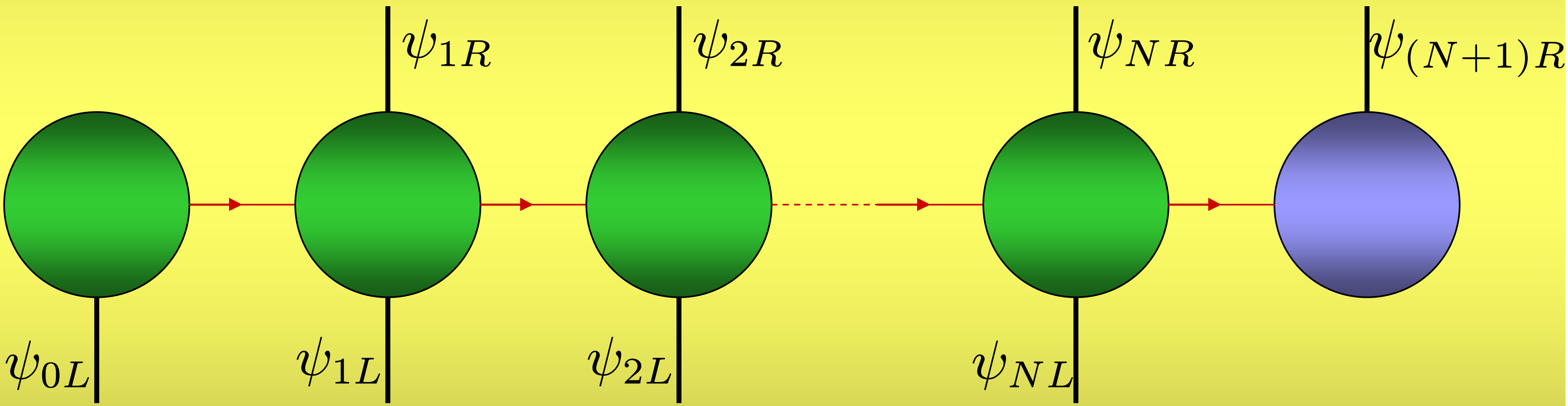

- If $t_L \sim m_W/m_{W_1}$, S can be tuned to zero.

Coupling of Matter Fields

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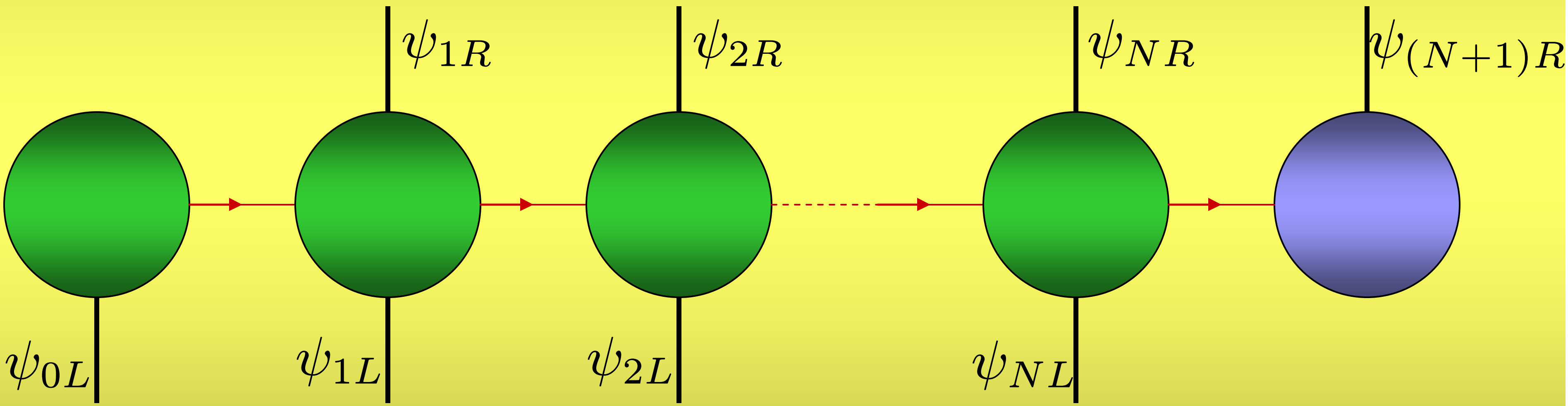

- At tree level:

$$S = 0,\ T \simeq 0,\ U \simeq 0$$
$$\Delta\rho = 0$$

Coupling of Matter Fields

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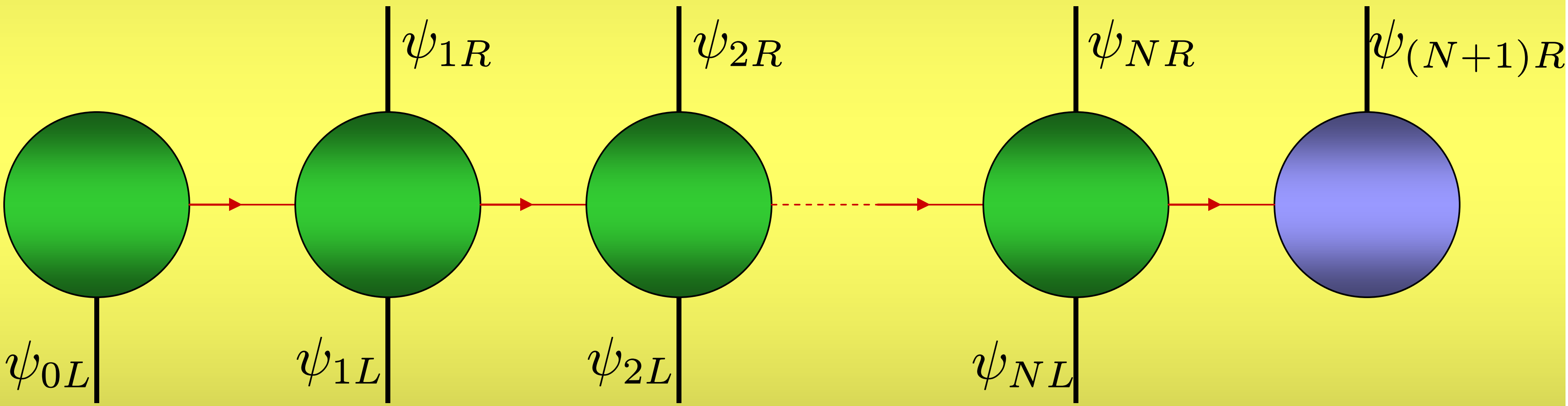

- With t_L fixed, fermion masses uniquely determined by t_{u_R}, t_{d_R}.

Coupling of Matter Fields

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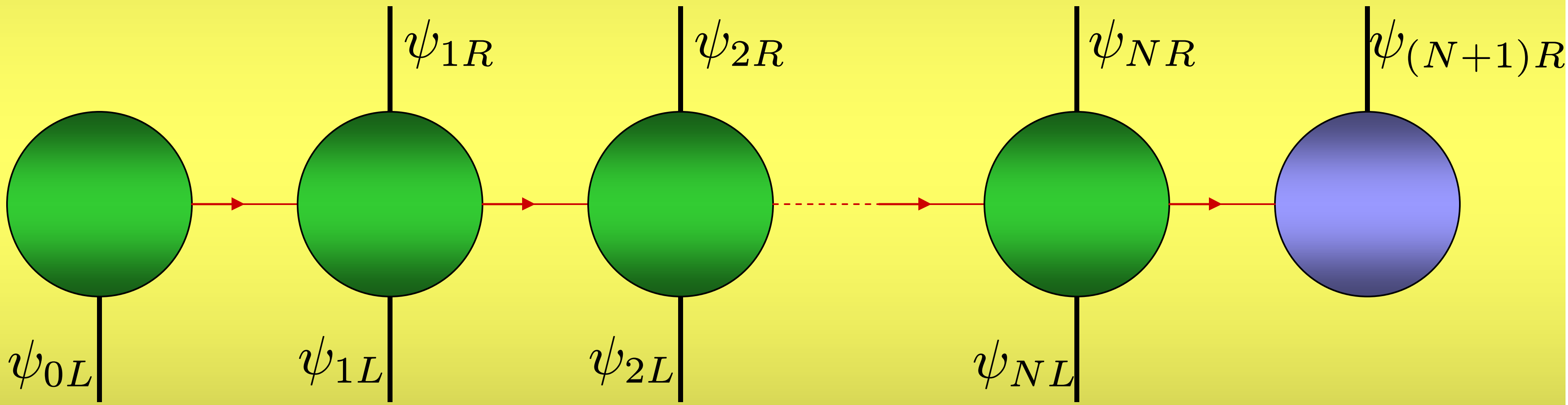

- Therefore, the only BSM parameter are the gauge and fermion mass scales, f and M .

One Loop Correction to ρ

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- It can be compared to experimental data: lower bound on the fermion sector mass scale, M.
- Only the top-bottom loops give non-negligible contributions.
- $\Delta\rho \to 0$ as $t_{t_R} \to t_{b_R}$. Setting $t_{b_R} = 0$, leading order new physics contribution of order $t_{t_R}^4$.

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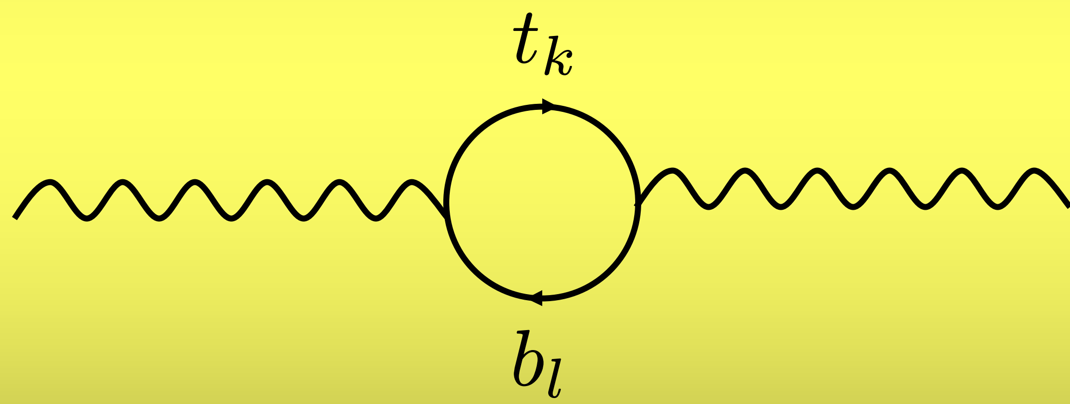
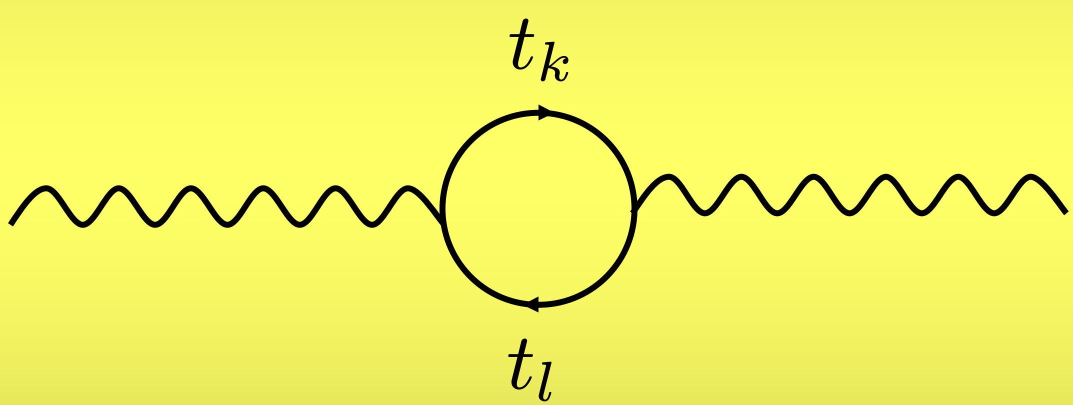
$\Pi_{11} =$



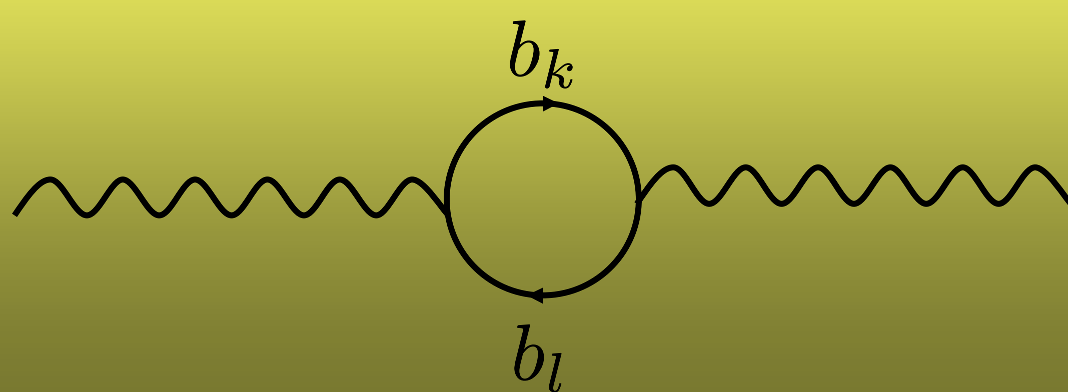
One Loop Correction to

- $\Delta\rho \neq 0$ arises from $\Pi_{11}(0) - \Pi_{33}(0) \neq 0$.

$2\Pi_{33} =$



$+$



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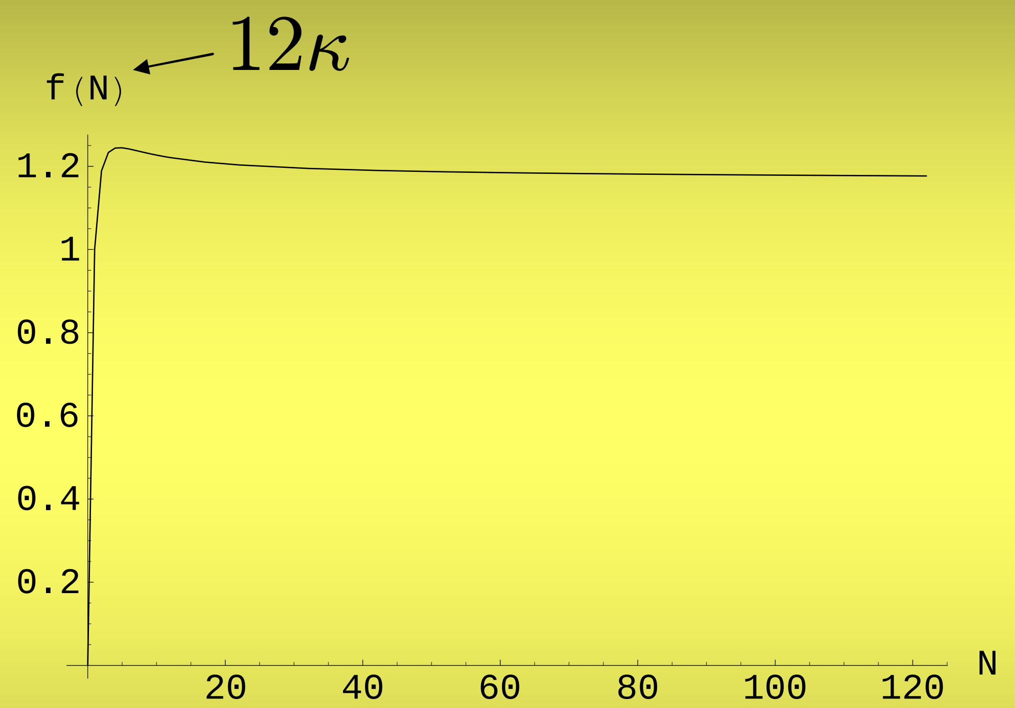
- The analytical calculation of $\Delta\rho$ has been made for $N = 1$ and $N \to \infty$.
- The arbitrary form of $(\Delta\rho)_{new}$, for arbitrary N, is

$$(\Delta\rho)_{new} = \frac{12\kappa}{16\pi^2} \frac{t_{t_R}^4 M^2}{v^2}$$

One Loop Correction to ρ



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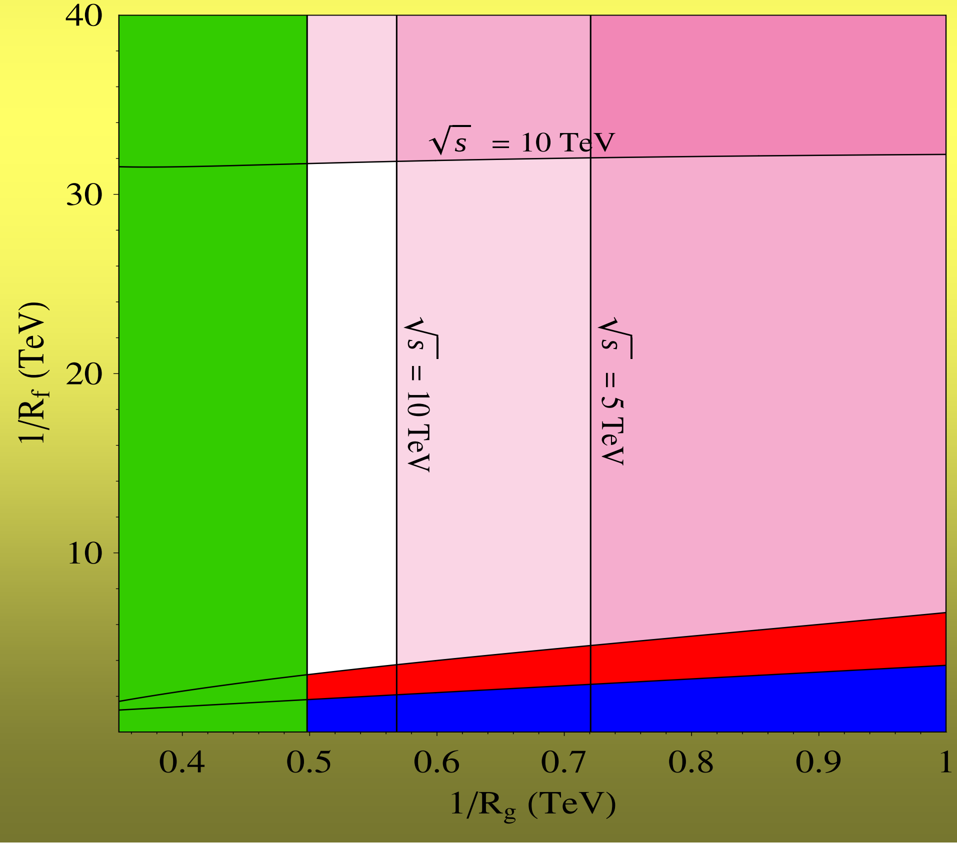
- Therefore the theory needs to be UV completed long before reaching the lightest fermion excited mode.

One Loop Correction to ρ

- There are also other bounds on the gauge and fermion mass scales.



$\longleftarrow N \to \infty$

Conclusions

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Conclusions

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- $\hat{S}$ can be tuned to zero by appropriately delocalizing the fermion fields.
- Fermionic one-loop corrections to the ρ parameter are cutoff independent.
- They impose a strong lower bound on the fermion mass scale: a UV completion is needed before the first heavy mode.