Evolution of coupling constants in $SU(6)$ Gauge-Higgs Grand Unification

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GUT Idea

- SM Gauge Groups

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- Take from Measurement

$$g_i(\mu_0 = m_Z) \overset{\text{RGE}}{\Longrightarrow} \text{"Running" to scale } \mu \tag{4}$$

GUT Idea

- $\alpha_i = \frac{g_i^2}{4\pi}$

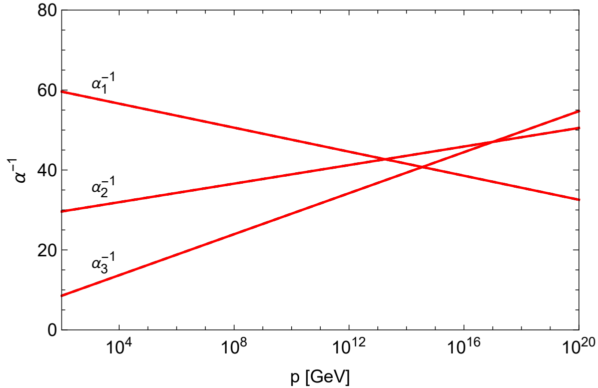

Figure 1: Running of couplings in the SM

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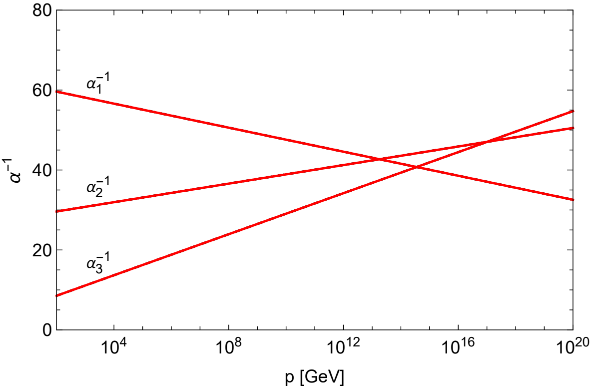
- Near unification around: $M_{\mathrm{GUT}} \sim 10^{15}\,\mathrm{GeV}$



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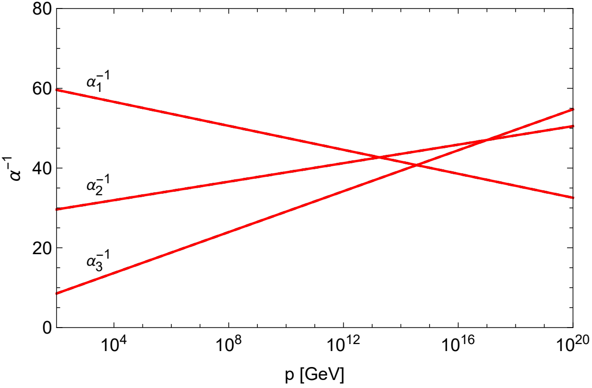
GUT Idea

- $\alpha_i = \frac{g_i^2}{4\pi}$
- Near unification around: $M_{\mathrm{GUT}} \sim 10^{15}\,\mathrm{GeV}$
- Unify in GUTs e.g. Georgi-Glashow Model $SU(5)$
- $A_\mu^a \to \begin{cases} G_\mu, W_\mu, B_\mu \\ X_\mu \end{cases}$



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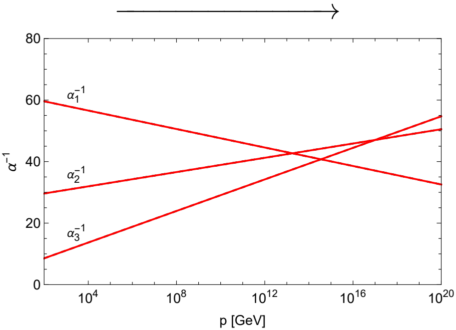

Figure 2: Running of couplings in the SM

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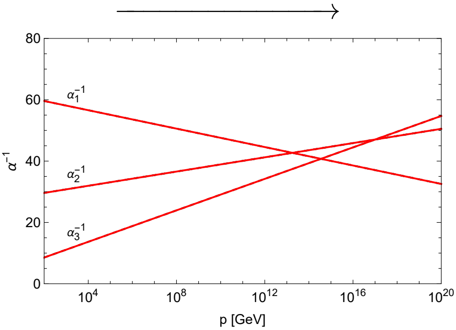

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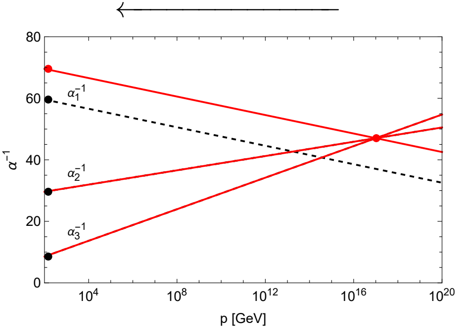

Figure 3: Prediction of low energy values

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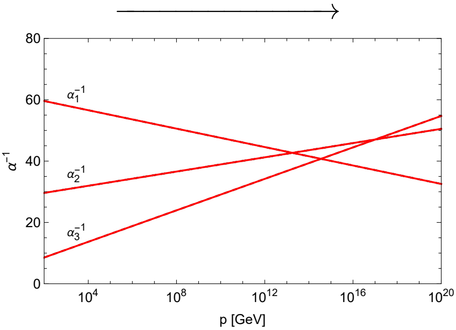

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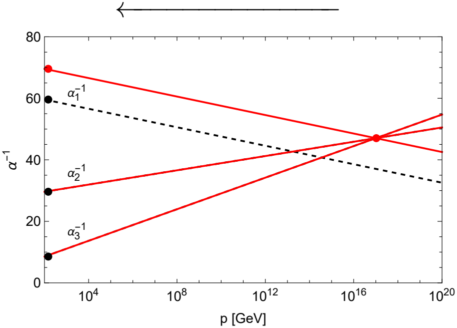

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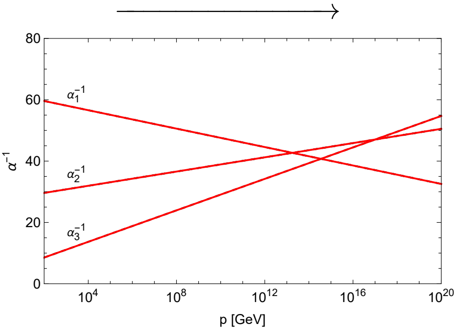

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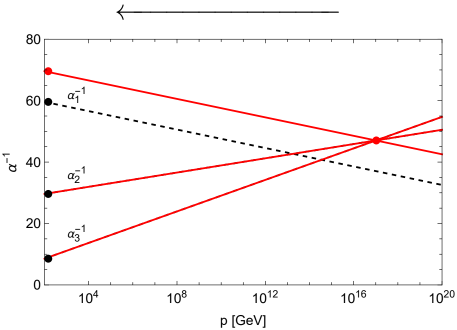

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- Prediction: $SU(5)$: $s_W^2(m_Z) = 0.207$ (Meas. $s_W^2(m_Z) = 0.23120$)

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Randall-Sundrum models

- Slice of AdS_5: $z \in \left[\frac{1}{k}, \frac{1}{T}\right]$

arxiv/hep-ph/9905221

- Conformally flat metric:

$$\mathrm{d}s^2 = \left(\frac{1}{kz}\right)^2 \left(\eta_{\mu\nu}\mathrm{d}x^\mu \mathrm{d}x^\nu - \mathrm{d}z^2\right) \tag{6}$$

Figure 4: RS space

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- $k \sim M_{\mathrm{Pl.}}$
- Planck-brane
- UV-brane

- $T \sim \mathrm{TeV}$
- TeV-brane
- IR-brane

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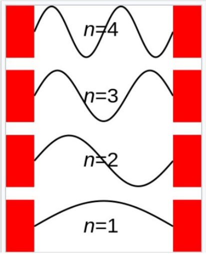

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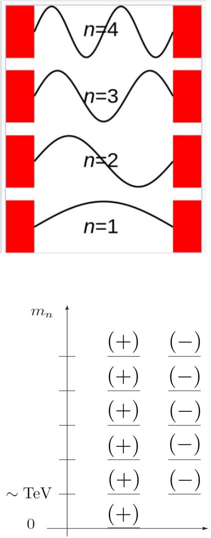

Figure 5: KK decomp.

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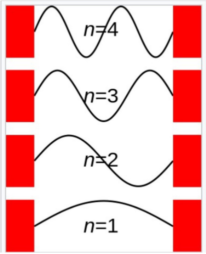
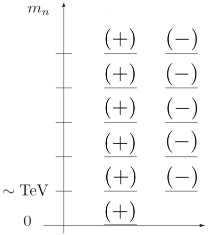
- Non-abelian $A_\mu^a \rightarrow$ symm. reduction on boundaries





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Randall-Sundrum models

- AdS/CFT correspondence

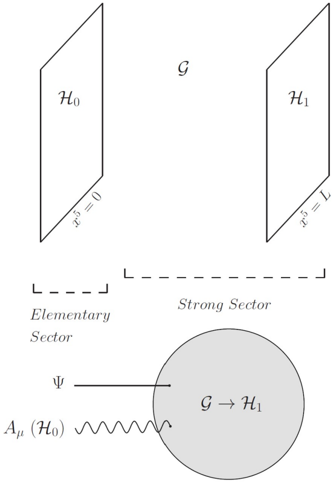
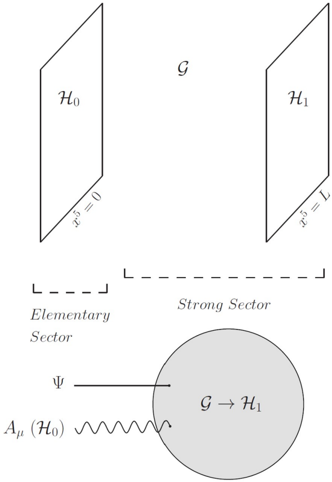


Figure 6: AdS/CFT correspondence

Randall-Sundrum models

- AdS/CFT correspondence
- Dual to class of 4D composite Higgs theories
- fix $A_\mu\left(x, \frac{1}{k}\right)$, integrate out bulk



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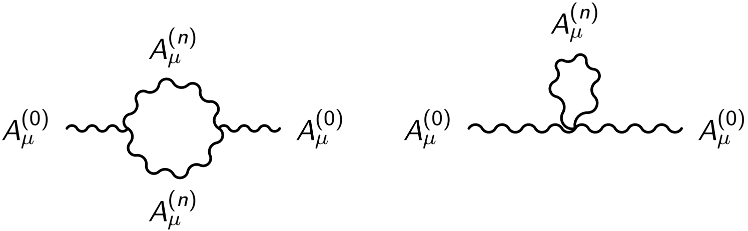

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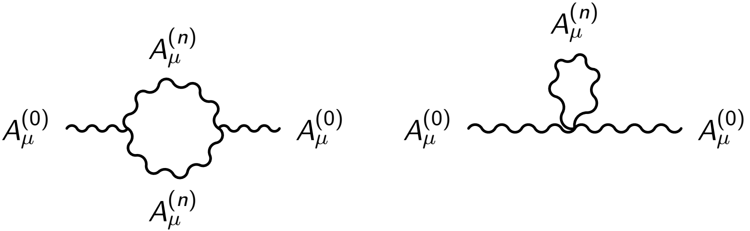

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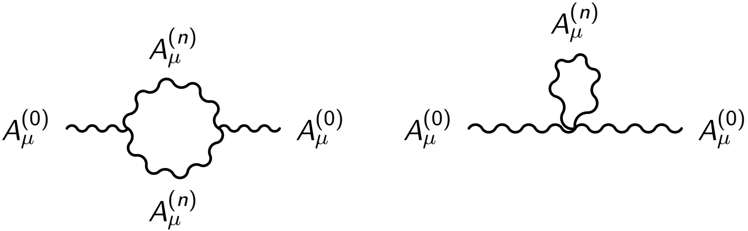

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- But: Zero mode becomes strongly coupled above TeV scale!

Running in RS: Planck-brane correlator

- Planck-brane correlator

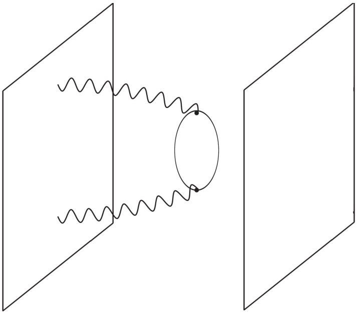
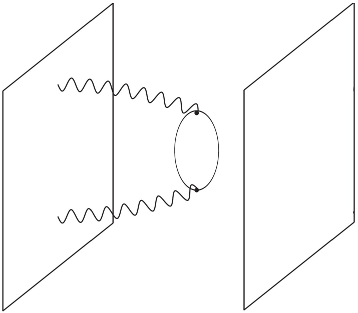


Figure 7: Planck-brane correlator

Running in RS: Planck-brane correlator

- Planck-brane correlator
- Work with full 5D propagators



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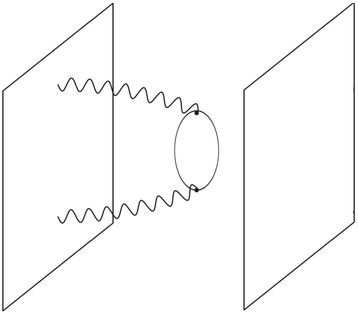

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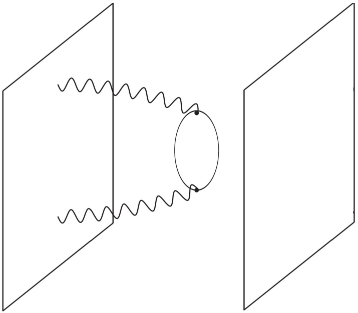

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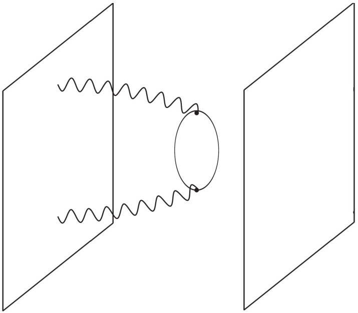
Quick intuition

Only modes with a significant overlap with the Planck-brane contribute (localization!)



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arxiv/2104.07366

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- Gauge-Higgs $H(1,2)_{-1/2}$
- scalar LQ $(3,1)_{-1/3}$
- scalar singlet $(1,1)_0$

$$A_5 = \left(\begin{array}{ccc|cc|c} (--) & (--) & (--) & (-+) & (-+) & (++) \\ (--) & (--) & (--) & (-+) & (-+) & (++) \\ (--) & (--) & (--) & (-+) & (-+) & (++) \\ \hline (-+) & (-+) & (-+) & (--) & (--) & (++) \\ (-+) & (-+) & (-+) & (--) & (--) & (++) \\ \hline (++) & (++) & (++) & (++) & (++) & (++) \end{array}\right)$$

$$A_5 = \left(\begin{array}{ccc|cc|c} (--) & (--) & (--) & (+-) & (+-) & (++) \\ (--) & (--) & (--) & (+-) & (+-) & (++) \\ (--) & (--) & (--) & (+-) & (+-) & (++) \\ \hline (+-) & (+-) & (+-) & (--) & (--) & (++) \\ (+-) & (+-) & (+-) & (--) & (--) & (++) \\ \hline (++) & (++) & (++) & (++) & (++) & (++) \end{array}\right)$$

arxiv/2104.07366

Minimal $SU(6)$ GHGUT

- Gauge-Higgs
  $H(1,2)_{-1/2}$
- scalar LQ
  $(3,1)_{-1/3}$
- scalar singlet
  $(1,1)_0$

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(--) & (--) & (--) & (-+) & (-+) & (++) \\
(--) & (--) & (--) & (-+) & (-+) & (++) \\
(--) & (--) & (--) & (-+) & (-+) & (++) \\
\hline
(-+) & (-+) & (-+) & (--) & (--) & \color{red}{(++)} \\
(-+) & (-+) & (-+) & (--) & (--) & \color{red}{(++)} \\
\hline
(++) & (++) & (++) & \color{red}{(++)} & \color{red}{(++)} & (++)
\end{array}\right)$$

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(--) & (--) & (--) & (+-) & (+-) & (++) \\
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\hline
(++) & (++) & (++) & (++) & (++) & {\color{red}(++)}
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$$A_5 = \left(\begin{array}{ccc|cc|c}
(--) & (--) & (--) & (+-) & (+-) & (++) \\
(--) & (--) & (--) & (+-) & (+-) & (++) \\
(--) & (--) & (--) & (+-) & (+-) & (++) \\
\hline
(+-) & (+-) & (+-) & (--) & (--) & (++) \\
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\hline
(++) & (++) & (++) & (++) & (++) & {\color{red}(++)}
\end{array}\right)$$

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Running of $SU(6)$ GHGUT

- $X/Y(+,-)$ complete SM bosons to $SU(5)$ multiplet
- no differential running
- no intersection

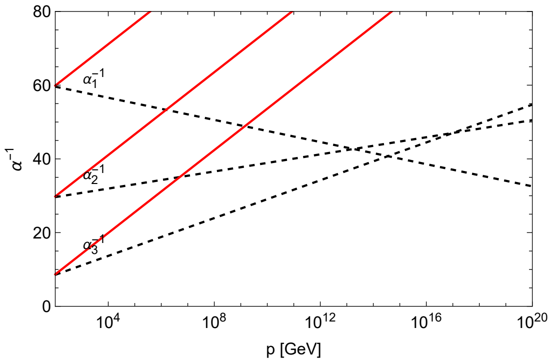

Figure 8: Running of $G_{\mathrm{SM}}^{(\mathrm{IR})}$

Running of $SU(6)$ GHGUT

- $X/Y(+,-)$ complete SM bosons to $SU(5)$ multiplet
- no differential running
- no intersection
- Inconsistent!

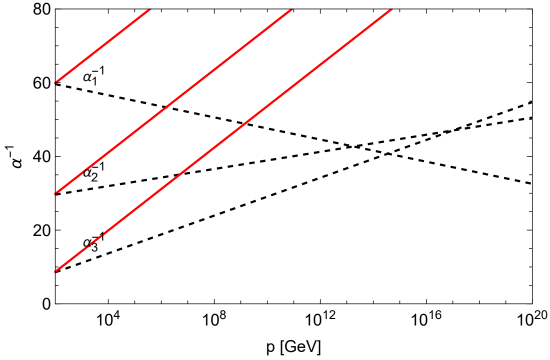

Figure 8: Running of $G_{\mathrm{SM}}^{(\mathrm{IR})}$

Running of $SU(6)$ GHGUT

- $X/Y(-,+)$ don't contribute

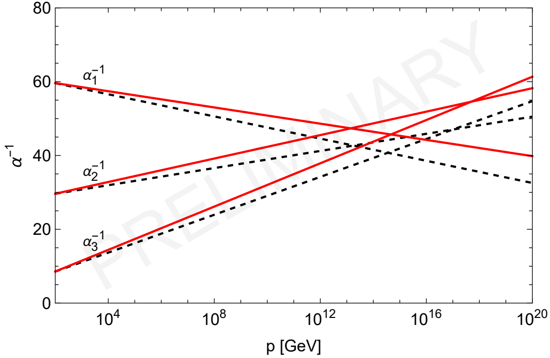

Figure 9: Running of $G_{\mathrm{SM}}^{(\mathrm{UV})}$

Running of $SU(6)$ GHGUT

- $X/Y(-,+)$ don't contribute
- t_R, Q_L^3, τ_R (IR localized) don't contribute

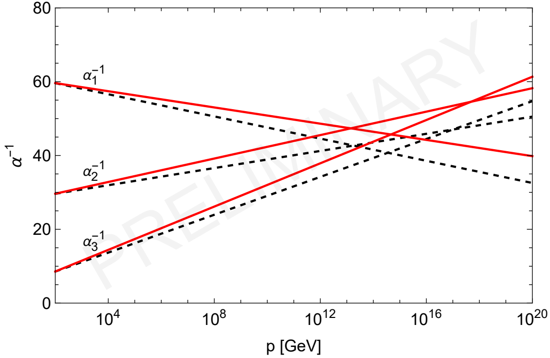

Figure 9: Running of $G_{\mathrm{SM}}^{(\mathrm{UV})}$

Running of $SU(6)$ GHGUT

- $X/Y(-,+)$ don't contribute
- t_R, Q_L^3, τ_R (IR localized) don't contribute
- Gauge-Higgs H (IR localized) doesn't contribute

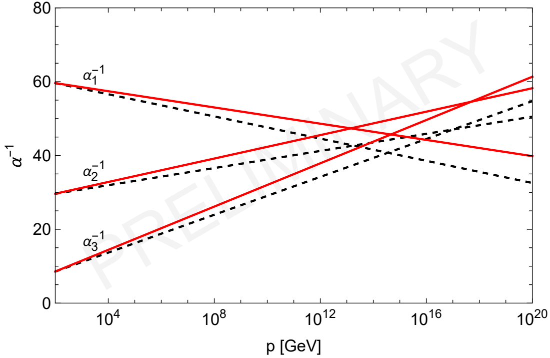

Figure 9: Running of $G_{\mathrm{SM}}^{(\mathrm{UV})}$

Running of $SU(6)$ GHGUT

- $X/Y(-,+)$ don't contribute
- t_R, Q_L^3, τ_R (IR localized) don't contribute
- Gauge-Higgs H (IR localized) doesn't contribute
- $SU(6)$ GHGUT: $s_W^2(m_Z) = 0.203$ (prel.) GG $SU(5)$: $s_W^2(m_Z) = 0.207$ Meas. $s_W^2(m_Z) = 0.23120$

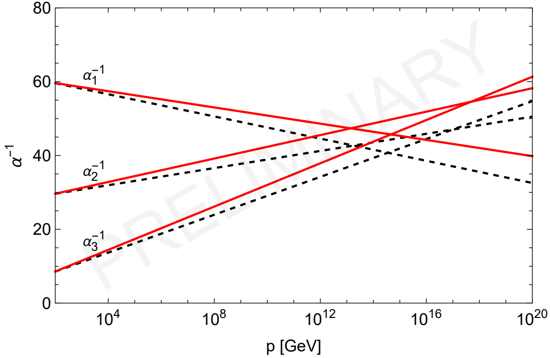

Figure 9: Running of $G_{\rm SM}^{\rm (UV)}$

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Summary

- Use Planck-brane correlators to calculate running of gauge couplings for high scales in RS spaces

- Running of $SU(6)$ GHGUT similar to 4D Georgi-Glashow $SU(5)$

- $SU(6)$ GHGUT:
  $s_W^2(m_Z) = 0.203$ (prel.)

  GG $SU(5)$: $s_W^2(m_Z) = 0.207$

  Meas.: $s_W^2(m_Z) = 0.23120$

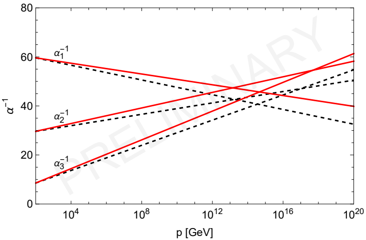

Figure 10: Running of $G_{\rm SM}^{\rm (UV)}$

Backup slides

Minimal $SU(6)$ GHGUT

- SM fermion spectrum (+ RH neutrino)
- Three exotic fermions

$$\begin{aligned} 20 \rightarrow & q_L'(3,2)^{+,-}_{1/6} \oplus (3^*,1)^{+,-}_{-2/3} \oplus e_L^{c\prime}(1,1)^{+,-}_{1} \\ & (3^*,2)^{+,-}_{-1/6} \oplus u_R(3,1)^{-,-}_{2/3} \oplus (1,1)^{+,-}_{-1}, \\ 15 \rightarrow & q_L(3,2)^{+,+}_{1/6} \oplus (3^*,1)^{-,+}_{-2/3} \oplus e_L^{c}(1,1)^{+,+}_{1} \\ & d_R'(3,1)^{-,+}_{-1/3} \oplus l_R^{c\prime}(1,2)^{-,+}_{1/2}, \\ 6 \rightarrow & d_R(3,1)^{-,-}_{-1/3} \oplus l_R^{c}(1,2)^{-,-}_{1/2} \oplus \nu_L^{c}(1,1)^{+,+}_{0}, \\ 1 \rightarrow & \nu_L^{c\prime}(1,1)^{+,-}_{0}. \end{aligned} \tag{11}$$

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RS renormalization

- Divergence structure

$$c\Lambda F_{MN}F^{MN} + \left[\lambda_k \delta\left(z - \frac{1}{k}\right) + \lambda_T \delta\left(z - \frac{1}{T}\right)\right] \log(\Lambda) F_{\mu\nu}F^{\mu\nu} \quad (12)$$

- Planck-brane correlator $\rightarrow$ absorb divergences in $\lambda_k(\mu)$
- include in classical (tree-level) action $\rightarrow$ shift sim. to threshold effects