Signatures of Composite Right-handed Singlets in Gauge-Higgs Unification Models

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Work with M. Peskin

- Is there a calculable, predictive approach to composite Higgs?
  $\longrightarrow$ Models in Randall-Sundrum geometry
  as a dual description of a new strong sector.
- Particularly, the Gauge-Higgs unification framework:
  $\longrightarrow$ Higgs as A_5^A, a partner of a vector field.
- Then the Higgs boson is related to bulk gauge symmetry in 5D and therefore GHU models are very restricted and predictive.
- Under this framework, we have studied how to generate the 2nd order phase transition in Higgs phase diagram. arXiv:1709.07909
- A thorough study of the parameter space in SO(5) x U(1) with the correct Higgs potential will be also available soon!

- Still, lots of model-building freedom:
  $\longrightarrow$ Even within a specific choice of global symmetry and matter representation, the additional matter content can vary significantly.

- In this talk, I will discuss the universal signatures of fermion compositeness in $e^+e^- \to b\bar{b}$ in the following settings.
  1) Gauge-Higgs Unification model in SO(5) x U(1).
  2) Top quark as the main driving force of EWSB.
  3) Light flavor mass generation through UV mixing.

5D Geometry

AdS5 bulk

UV

$k = 1/z_0 \sim 100 \text{ TeV}$

UV cutoff scale

IR

$k_R = 1/z_R \sim 2-3 \text{ TeV}$

Scale of the strong interaction

SO(5) x U(1) Model

Agashe, Contino, Pomarol

SM gauge symmetry

$SU(2)_L \times U(1)_Y$

AdS5 bulk

$SO(5) \times U(1)_X$

Custodial symmetry protects T

$SO(4) \times U(1)_X$

UV

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UV cutoff scale

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Scale of the strong interaction

$SO(5)/SO(4)$: Higgs as Goldstone bosons (A_5 zero mode)

$$Y = T_R^3 + X \quad \text{and} \quad Q = T_L^3 + T_R^3 + X$$

Typical masses in this setting : $Z' \sim 2.4 k_R$ top partner $0.5 \sim 0.7 k_R$

Dynamical EWSB by the Top Quark

- The top quark drives the EWSB
  through the large top-induced radiative Higgs potential.
- Then, t_L, t_R should be in the same multiplet.
  For example, the top quark embedding in 4 of SO(5) should be

$$\Psi_t = \begin{bmatrix} t_L(++) \\ b_L(++) \\ t_R(--) \\ b'_R(-+) \end{bmatrix}_{1/6}$$

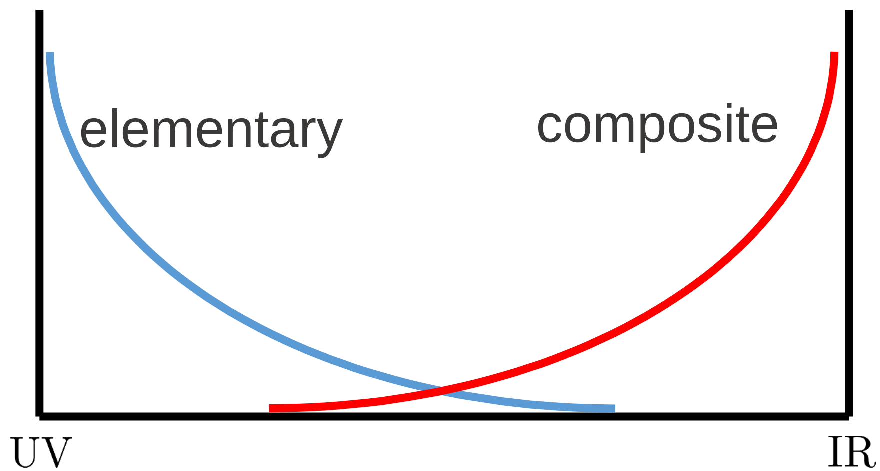
Higgs in SO(5)/SO(4) pairs up
the left and right-handed zero-modes
and make the top massive.

No zero-mode to match b_L

- Tune v^2/f^2 using a competing top partner multiplet;
  see **arXiv:1709.07909 [hep-ph]**

Fermion Partial Compositeness

- Parametrize 5D fermion mass term: $c = m_{5D}/k$
  Then, c determines 5D profile of the massless mode.



	$c < -1/2$	$-1/2 < c < 1/2$	$1/2 < c$
L	IR	IR	UV
R	UV	IR	IR

- Note the same c for t_L and t_R.
- m_t is determined by $c_t,\ v^2/f^2,\ k_R$

Natural Mass Hierarchy between top & bottom

- To generate bottom quark mass, consider an additional multiplet Ψ_b

$$\Psi_t = \begin{bmatrix} t_L(++) \\ b_L(++) \\ t_R(--) \\ b'_R(-+) \end{bmatrix}_{1/6} \qquad \Psi_b = \begin{bmatrix} t'_L(-+) \\ b'_L(-+) \\ t'_R(-+) \\ b_R(--) \end{bmatrix}_{1/6}$$

Natural Mass Hierarchy between top & bottom

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$$\Psi_t = \begin{bmatrix} t_L(++) \\ b_L(++) \\ t_R(--) \\ b'_R(-+) \end{bmatrix}_{1/6}$$

$\sin\beta$

$$\Psi_b = \begin{bmatrix} t'_L(-+) \\ b'_L(-+) \\ t'_R(-+) \\ b_R(--) \end{bmatrix}_{1/6}$$

- Mix it with Ψ_t on the UV boundary, so that the Higgs pairs up b_L and b_R through $\sin\beta$.
- With $c_t < c_b$, the left-handed zero-modes in Ψ_t are more composite than those in Ψ_b.
  This mismatch suppresses the effect of mixing $\sin\beta$.

Natural Mass Hierarchy between top & bottom

- Indeed, explicit calculation shows that for $c_t < c_b$

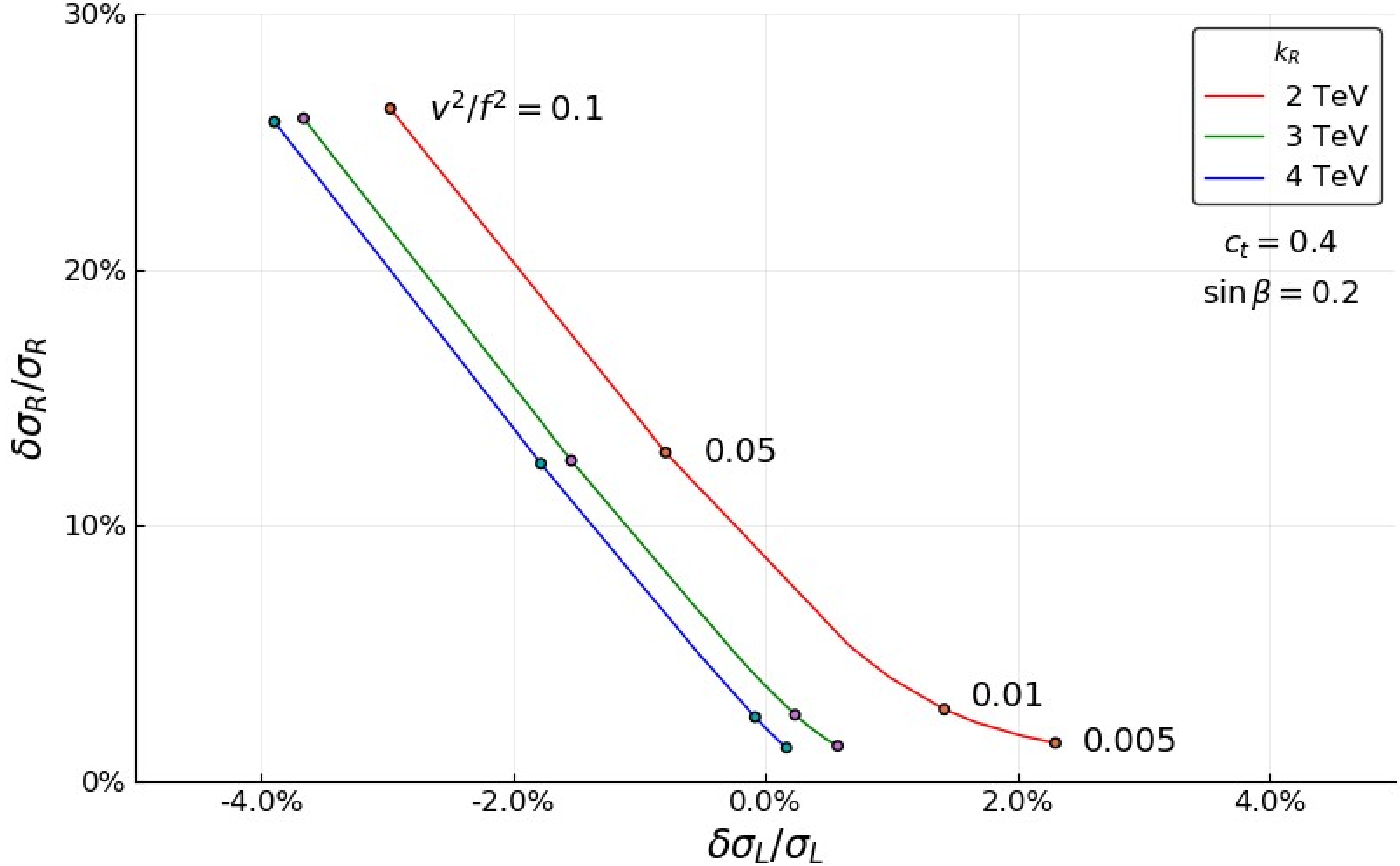
$$\frac{m_b^2}{m_t^2} \sim \tan^2\beta \times \left(\frac{z_0}{z_R}\right)^{2(c_b - c_t)}$$

- β of order-one can still give a large mass hierarchy.
- Contrary to the left-handed zero-modes,
  bigger c_b means a very composite b_R.
  → possibly, sizable coupling deviation which can be
  probed at future colliders like ILC. cf. Funatsu, Hatanaka, Hosotani, Orikasa

Signatures in $\mathbf{e_L^- e_R^+ \to b_L \bar{b}_R, b_R \bar{b}_L}$

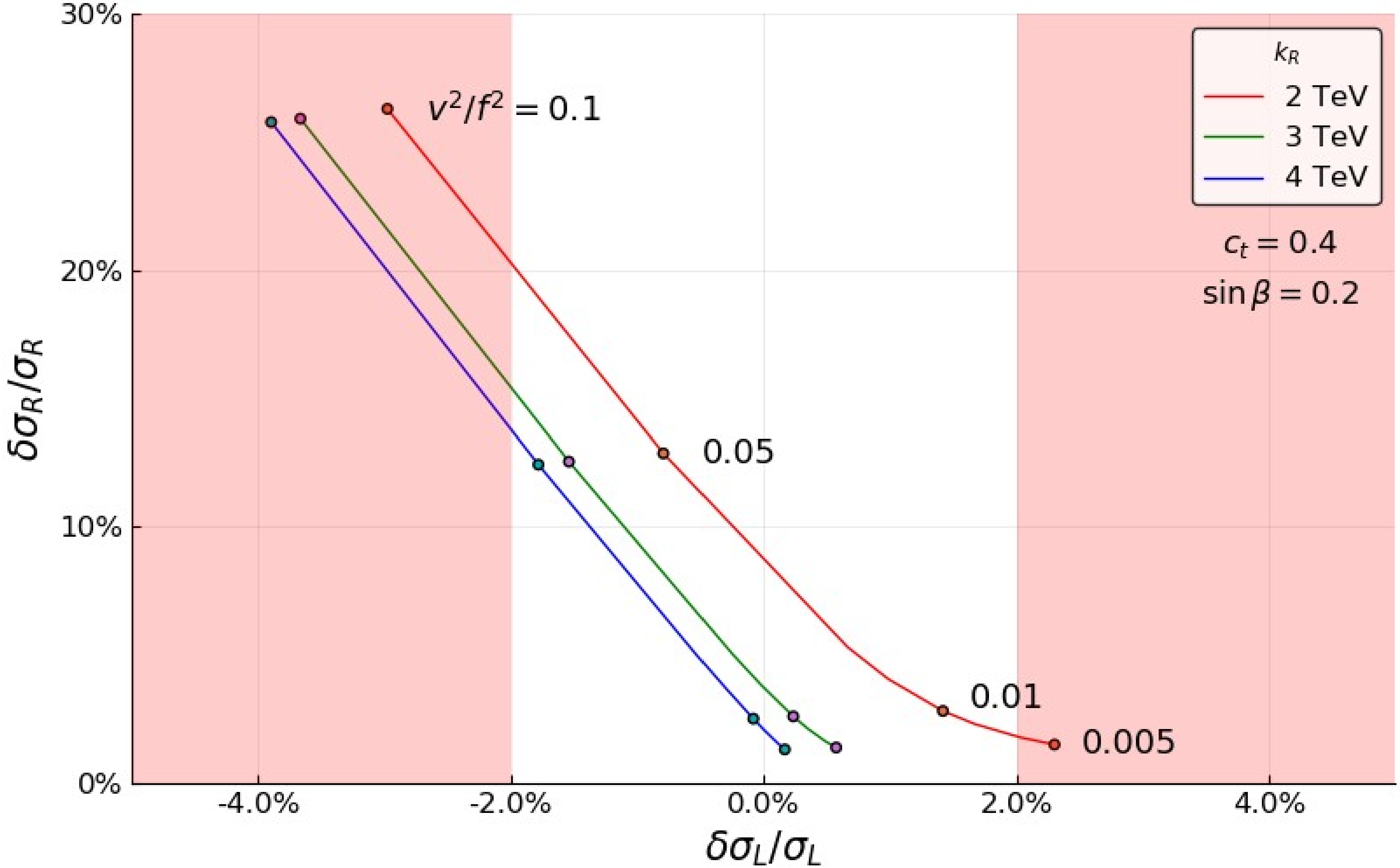
- 5 parameters determine the cross section
  - $\sqrt{s},\ \sin\beta,\ c_t,\ v^2/f^2,\ k_R$
  - Same pattern remains with varying $\sin\beta$.
    For a moment, let's choose $\sin\beta = 0.2$
  - First look at $\sqrt{s} = 250\ \mathrm{GeV}$.

$e_L^- e_R^+ \to b_L \bar{b}_R, b_R \bar{b}_L$ at 250GeV



Also, dependence on c_t is very weak.

$\mathbf{e_L^- e_R^+ \to b_L \bar{b}_R, b_R \bar{b}_L}$ at 250GeV



By Z pole observables, systems with fine-tuning ≥ 5% are not acceptable.

Fermion Embedding in 5 of SO(5)

- Custodial symmetry for $Z \to b_L \bar{b}_R$ Agashe, Contino, Da Rold, Pomarol

$$\Psi_t = \begin{bmatrix} \begin{pmatrix} \chi_t(-+) & t_L(++) \\ \chi_b(-+) & b_L(++) \end{pmatrix} \\ t_R(--) \end{bmatrix}_{2/3} \qquad \Psi_b = \begin{bmatrix} \begin{pmatrix} t'(-+) & \chi_b(-+) \\ b'(-+) & \psi_b(-+) \end{pmatrix} \\ b_R(--) \end{bmatrix}_{-1/3}$$

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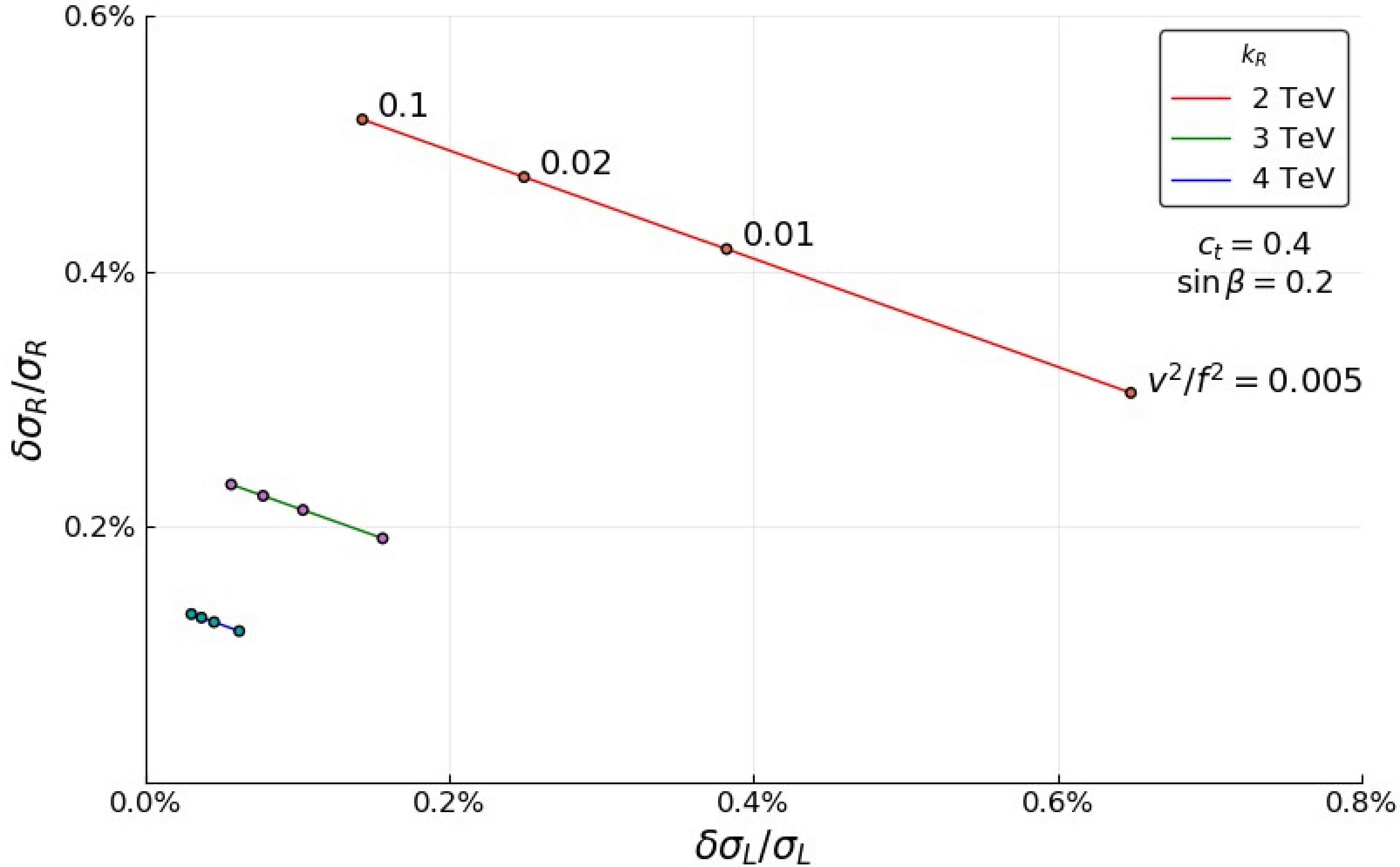
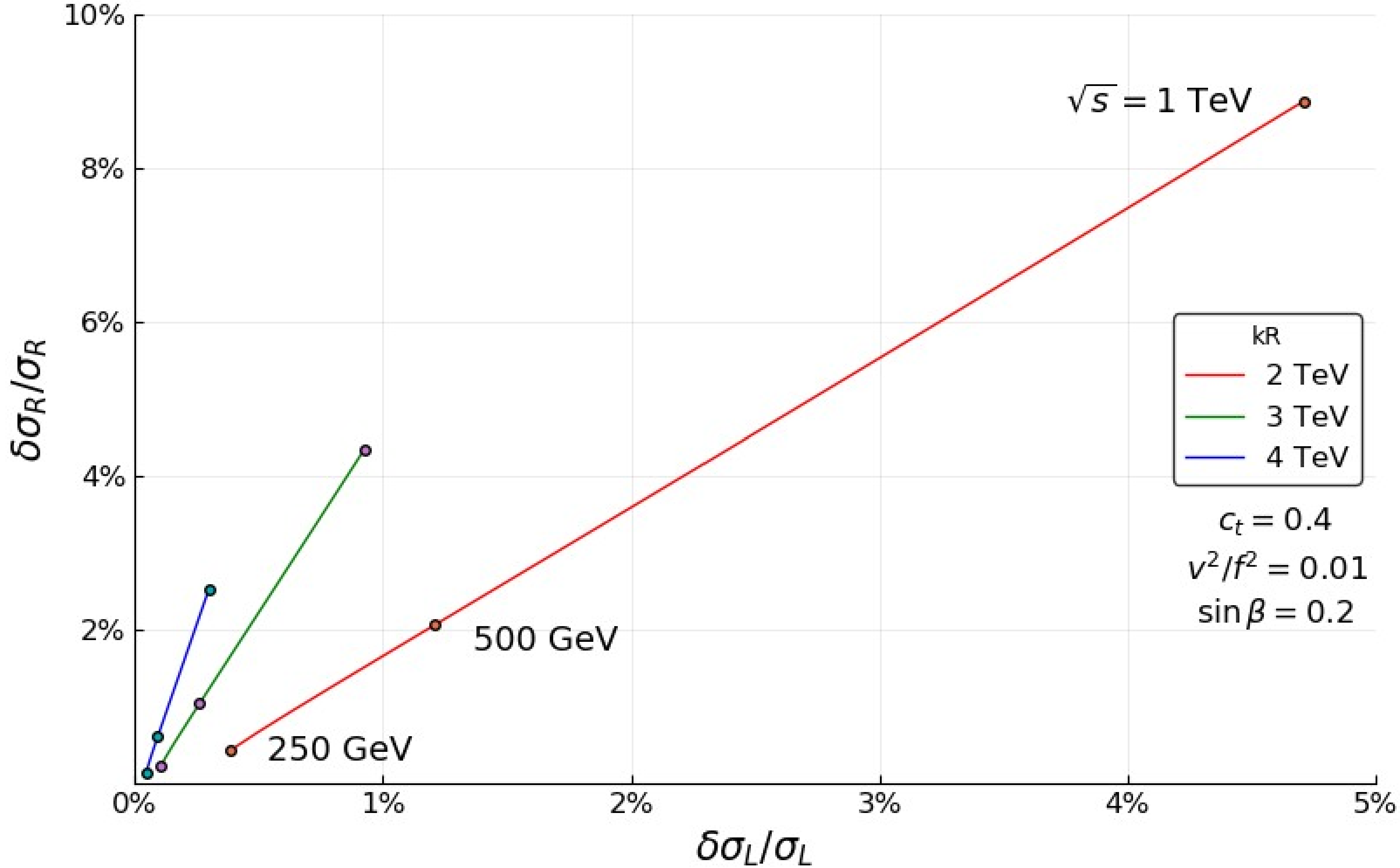
$\sin\beta$

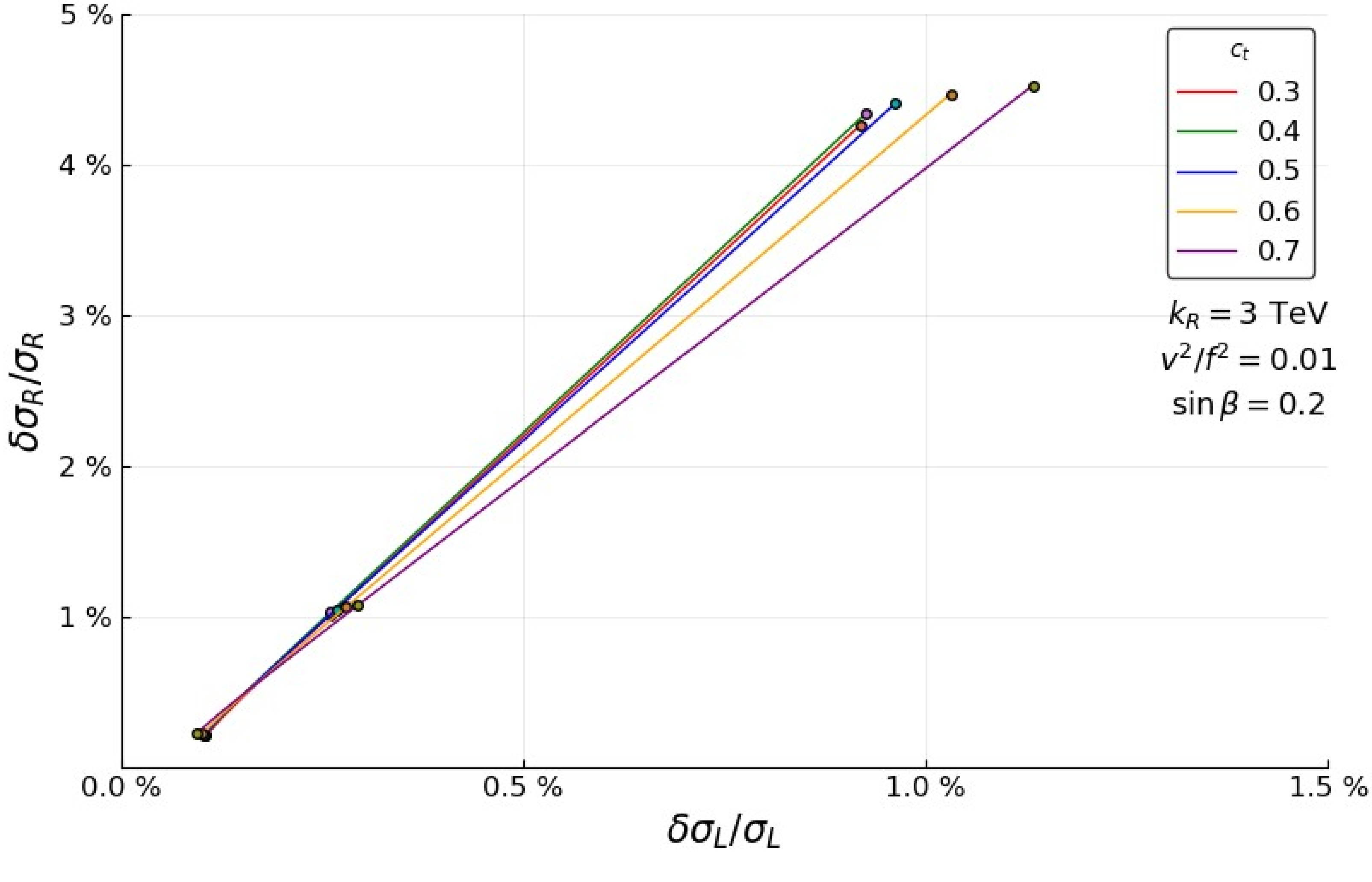
$\mathbf{e_L^- e_R^+ \to b_L \bar{b}_R, b_R \bar{b}_L}$ at 250GeV



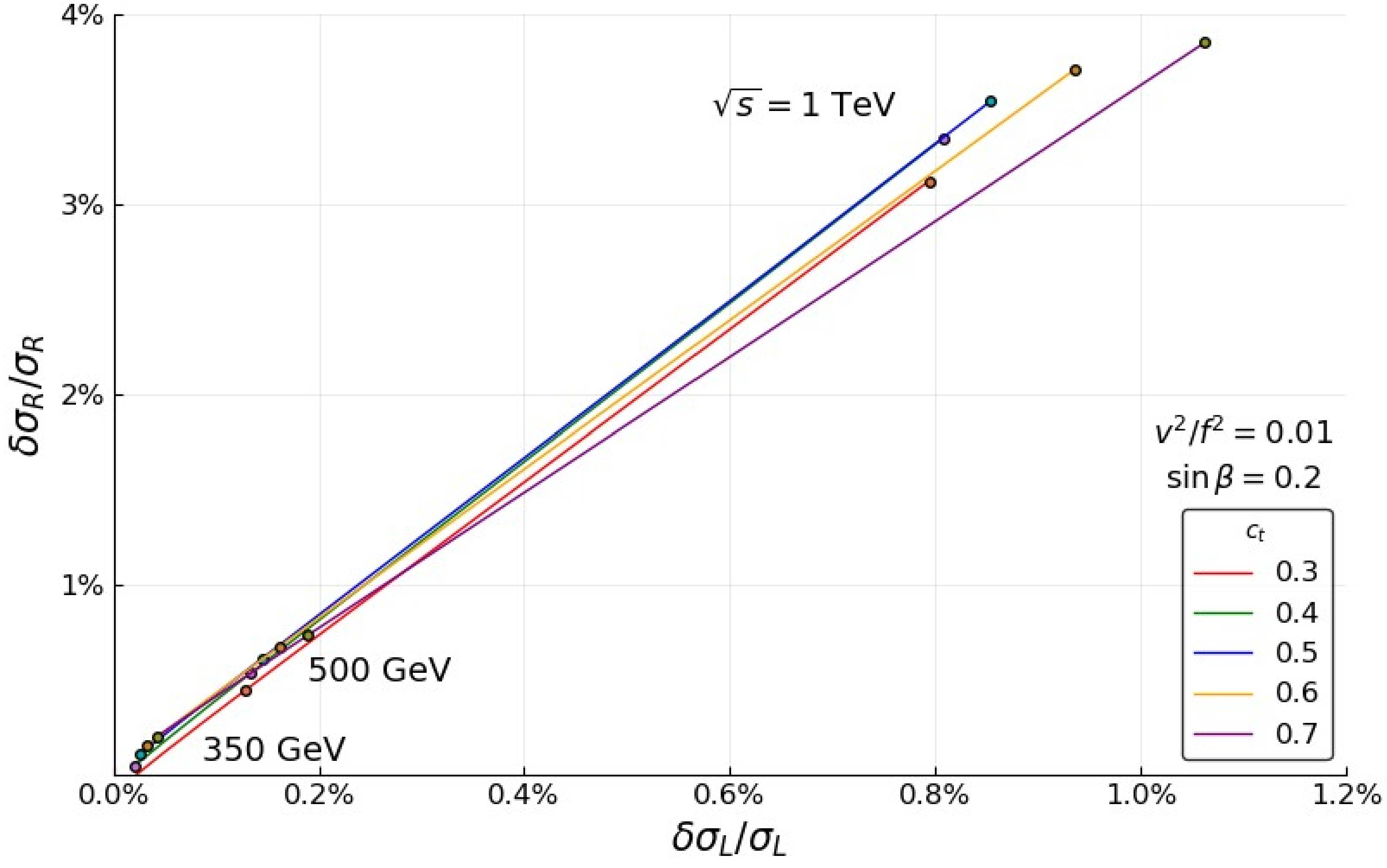
$e^-_L e^+_R \to b_L \bar{b}_R, b_R \bar{b}_L$ in running $\sqrt{s}$



$\mathbf{e_L^- e_R^+ \to b_L \bar{b}_R, b_R \bar{b}_L}$ in running $\sqrt{s}$



$e_L^- e_R^+ \to t_L \bar{t}_R, t_R \bar{t}_L$ in running $\sqrt{s}$



Summary

- Gauge-Higgs unification based in AdS5 gives a calculable and predictive approach to a 4D composite Higgs model.
- We find that distinct signals in $e^+e^- \to b\bar{b}$ depend only on bottom quark quantum number assignments.
- Deviations scale with k_R, but are only weakly dependent on c parameters.
- Models in 4 of SO(5) are strongly constrained, but still allowed with ~5% tuning. Possibly discoverable at 250GeV.
- Models in 5 of SO(5) show negligible deviations at 250GeV. However, at bigger $\sqrt{s}$, a sizable deviation appears and it can be complementary to measurements of top quark deviations.

THANK YOU