A New Probe of Naturalness

Snowmass on the Pacific
Santa Barbara
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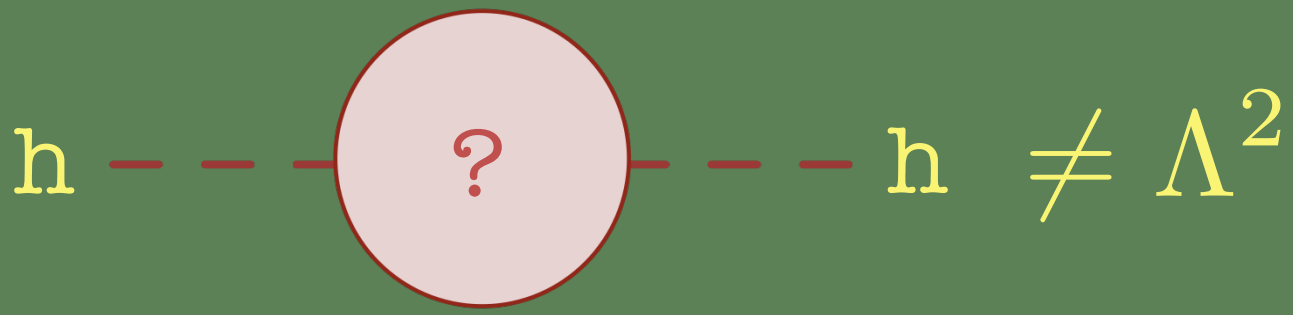
See also: Farina, Perelstein, and Rey-Le Lorier

What is Naturalness?

- No quadratic divergences:



- LHC: SUSY/Stop/KK/t' searches...

- Explore naturalness generally?
  - Must we commit to specific UV-completions?

Generalizing Naturalness

- Staring at this:

- Scalars:

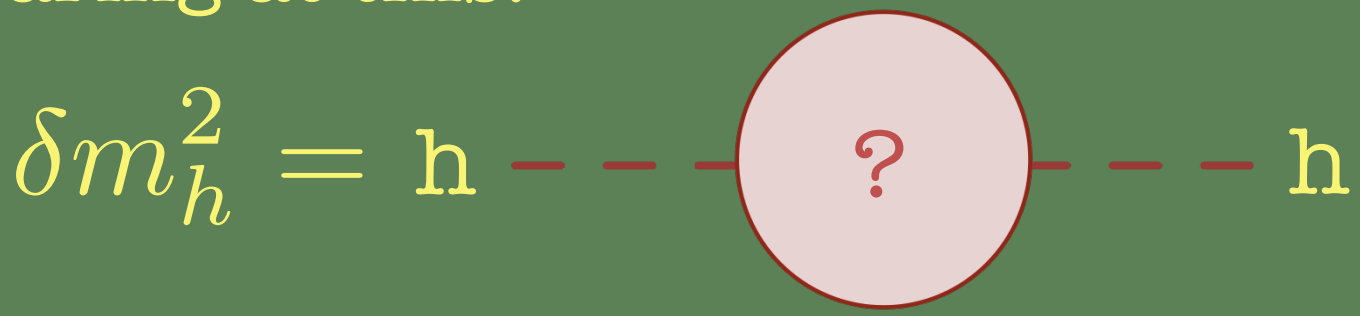
$$\mathcal{L}_{\rm Nat} = \sum_i \left(|\partial_\mu \phi_i|^2 - m_i^2 |\phi_i|^2 - \lambda_i |H|^2 |\phi_i|^2 \right)$$

- Coupling is fixed: $\sum_i \lambda_i = 6\lambda_t^2$

- An effective theory of naturalness!

Physical Effects

- Staring at this:



Physical Effects

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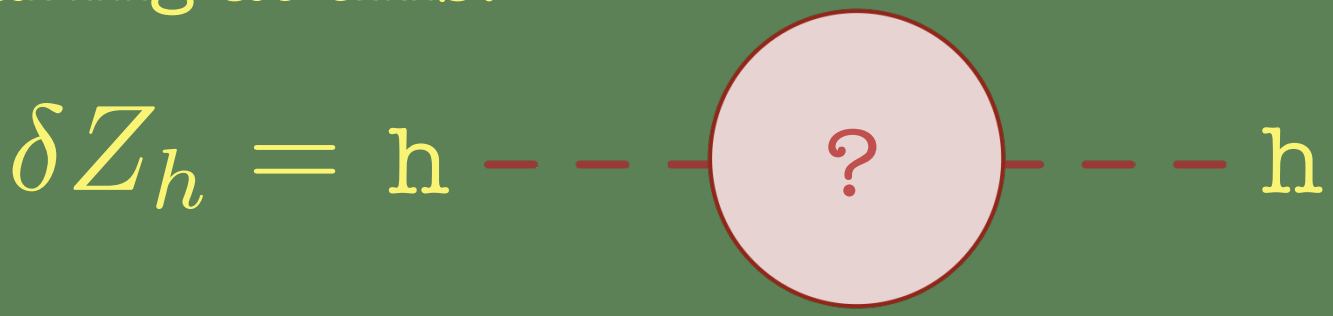
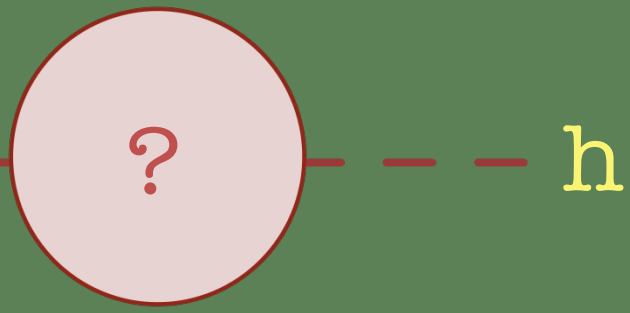


Physical Effects

- Staring at this:

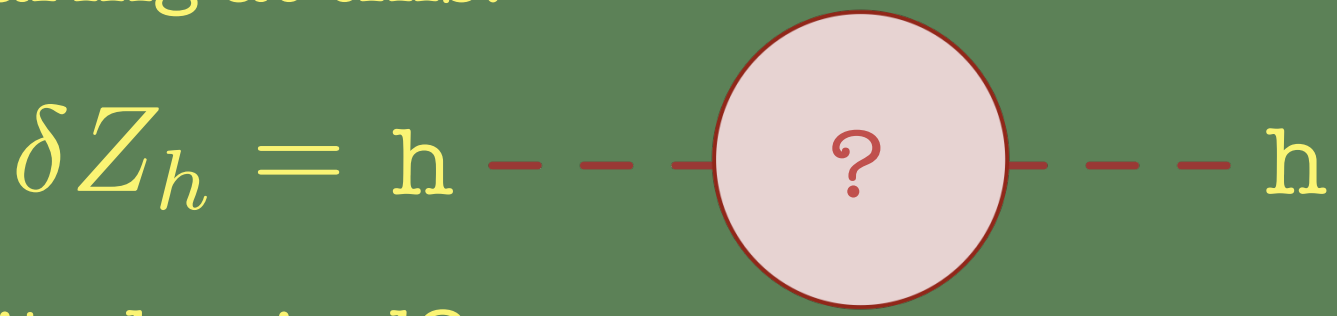
$\delta Z_h =$ 

- Is it physical?

$$\mathcal{L}_{eff} = \frac{c_H}{m_\phi^2}\left(\frac{1}{2}\partial_\mu |H|^2 \partial^\mu |H|^2\right) + \dots$$

Physical Effects

- Staring at this:



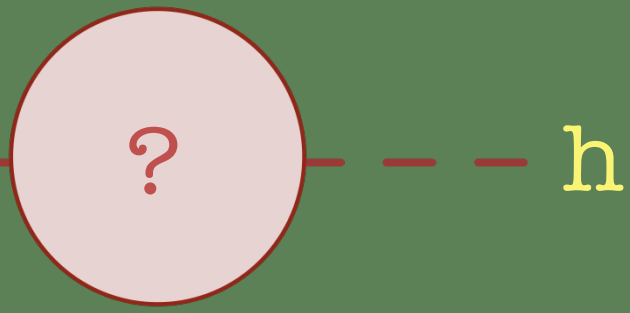
- Is it physical?

$$\mathcal{L} \supset \left(1 + 2v^2 \frac{c_h}{m_\phi^2}\right) \frac{1}{2} \partial_\mu h \partial^\mu h$$

$$+ m_W^2 W^+ W^- + \frac{\sqrt{2}}{v} m_W^2 h W^+ W^-$$

Physical Effects

- Staring at this:

$\delta Z_h =$ 

- Is it physical?

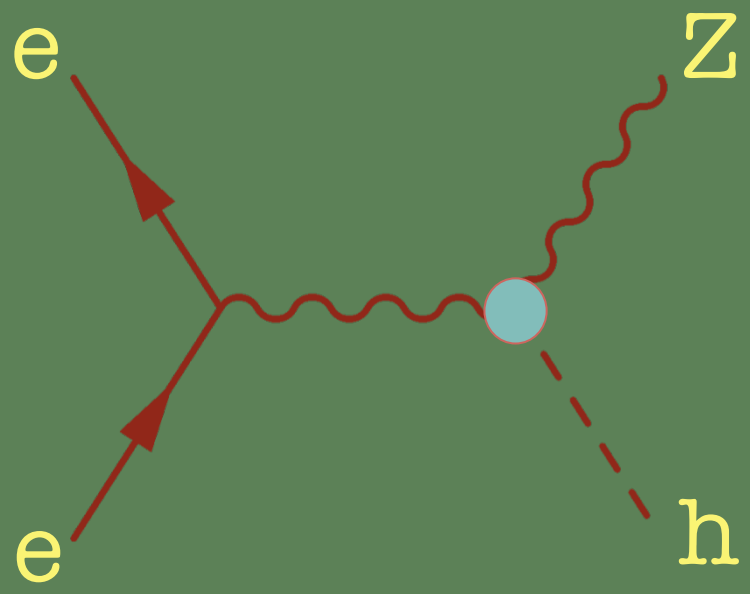
$$\mathcal{L}_{eff} = \frac{c_H}{m_\phi^2}\left(\frac{1}{2}\partial_\mu |H|^2 \partial^\mu |H|^2\right) + \dots$$

- Yes! $\delta c_{hVV} = \delta c_{h\bar{f}f} = c_H v^2/m_\phi^2$

Physical Effects

- But... naturalness: $m_\phi \sim v$

- Need the full calculation, e.g:



- Correction enters via counter-terms.

Measuring Naturalness

- If you happen to care...

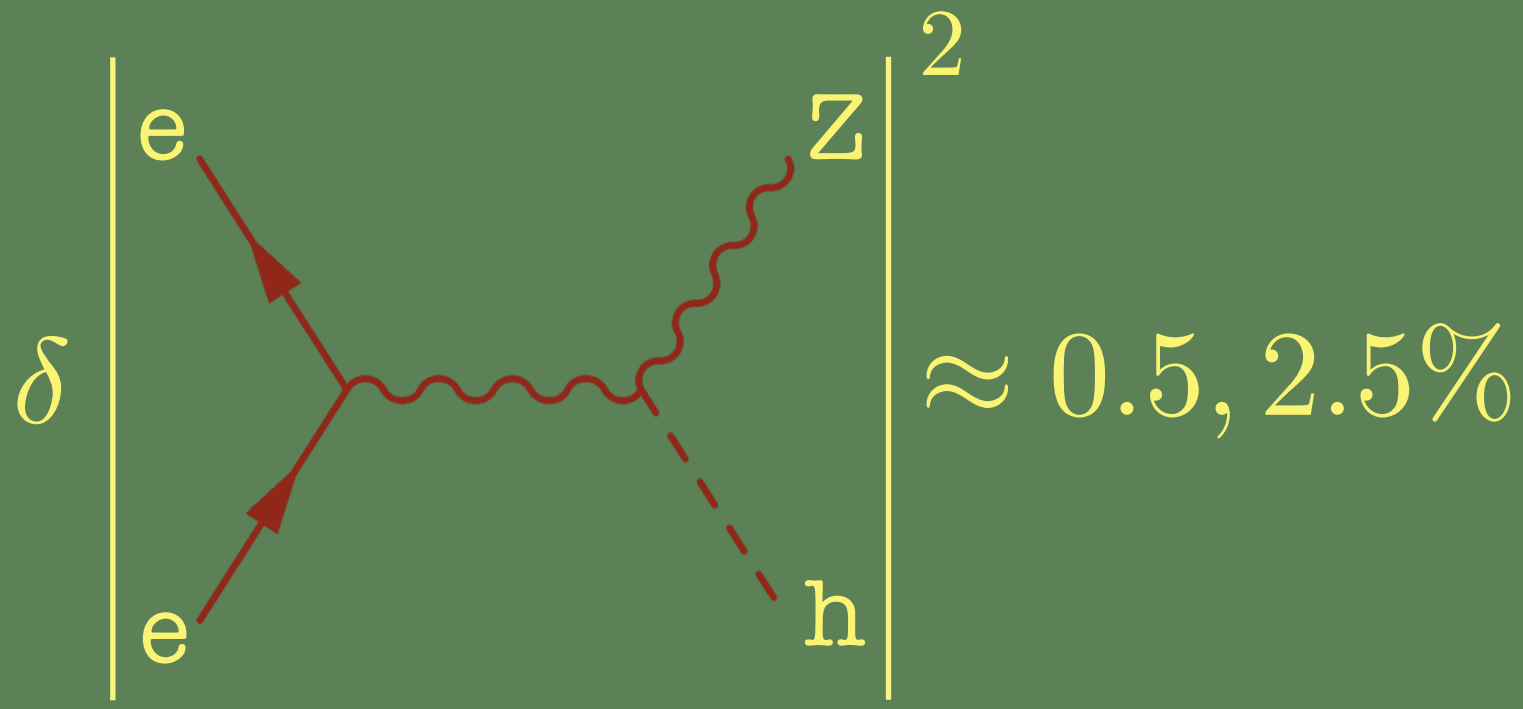
$$\delta c_{hVV} = \frac{9\lambda_t^2 m_t^2}{4\pi^2 n_\phi m_h^2}\left(1 + F\left(\frac{m_h^2}{4m_\phi^2}\right)\right)$$

- Where:

$$F(\tau) = \frac{1}{4\sqrt{\tau(\tau-1)}}\log\left(\frac{1-2\tau-2\sqrt{\tau(\tau-1)}}{1-2\tau+2\sqrt{\tau(\tau-1)}}\right)$$

Measuring Naturalness

- LC offers extraordinary precision!



$$\delta \left| \; \right|^2 \approx 0.5, 2.5\%$$

- Never say never for LHC too...

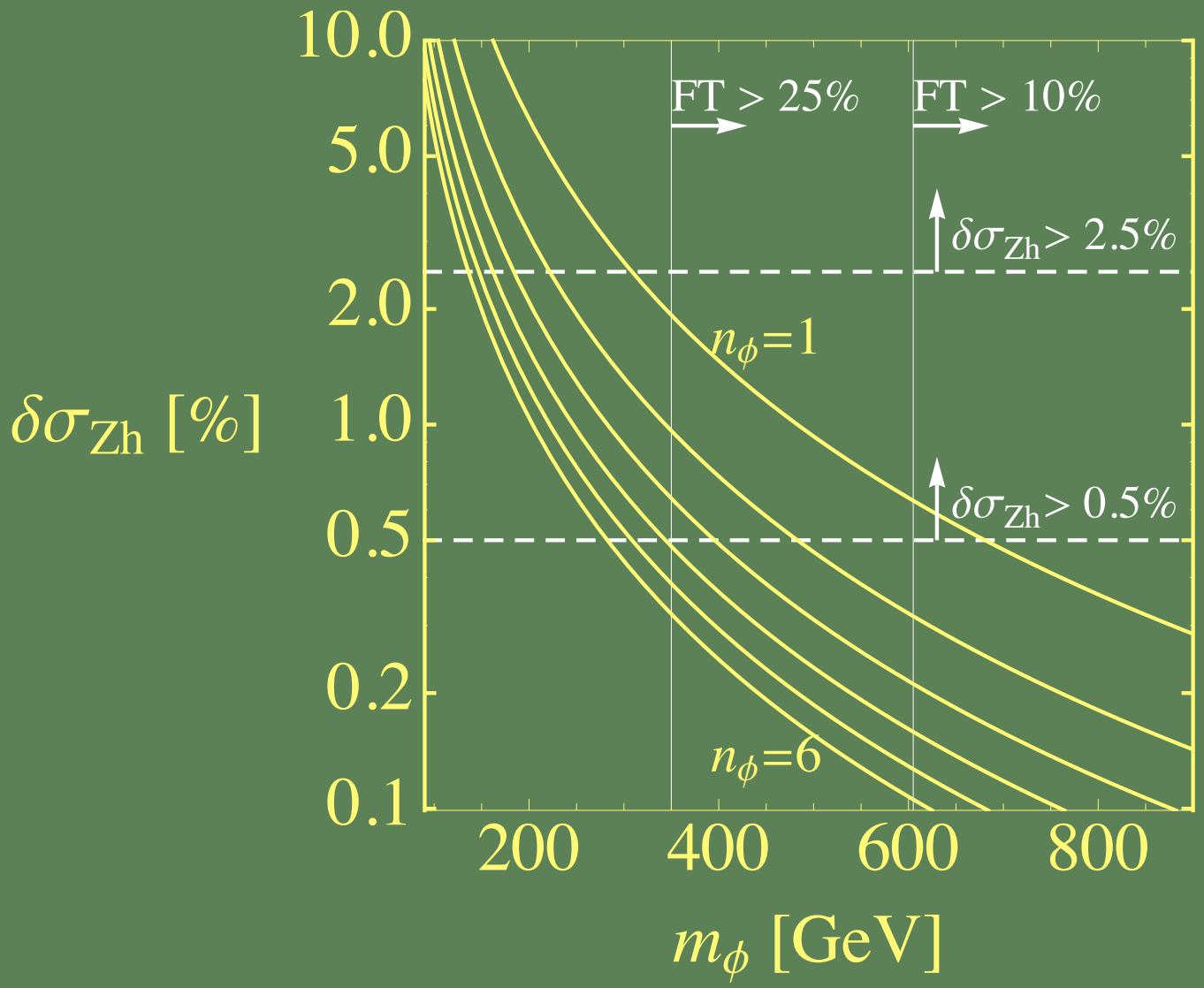
Measuring Naturalness

- Can a LC probe naturalness?

Measuring Naturalness

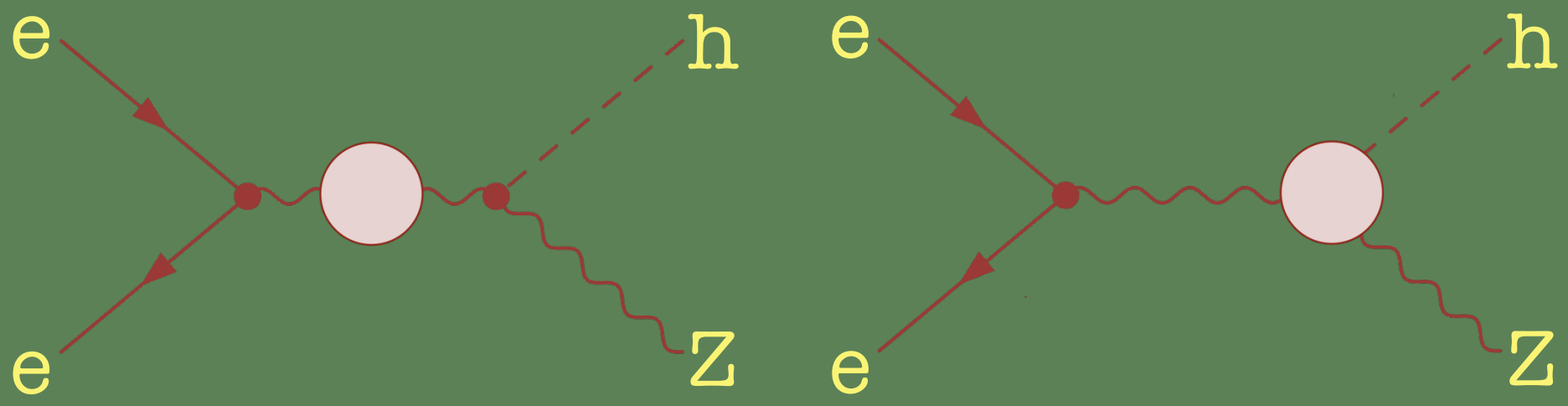
Yes.

Measuring Naturalness



Measuring Naturalness

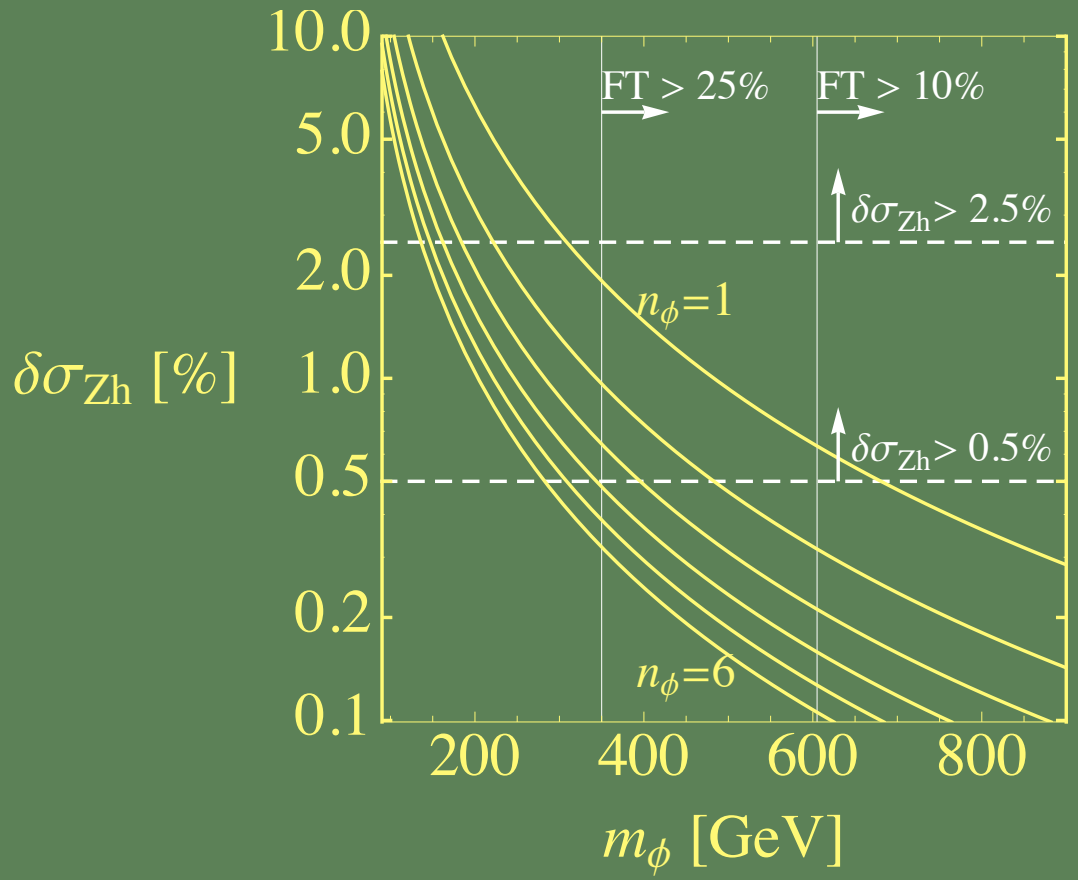
- What if top-partners have EW charges?



- Result still dominated by WF correction!
  - C. Englert and M. M. ($\lambda_t^2 \gg g^2, g'^2$)

Measuring Naturalness

- Applies to all scalar top-partners:



- Regardless of gauge charges!

Conclusions

- Known Natural Theories:
  - SUSY, Composite, Technicolor, UEDs, RS,...
- Under major tension from LHC!

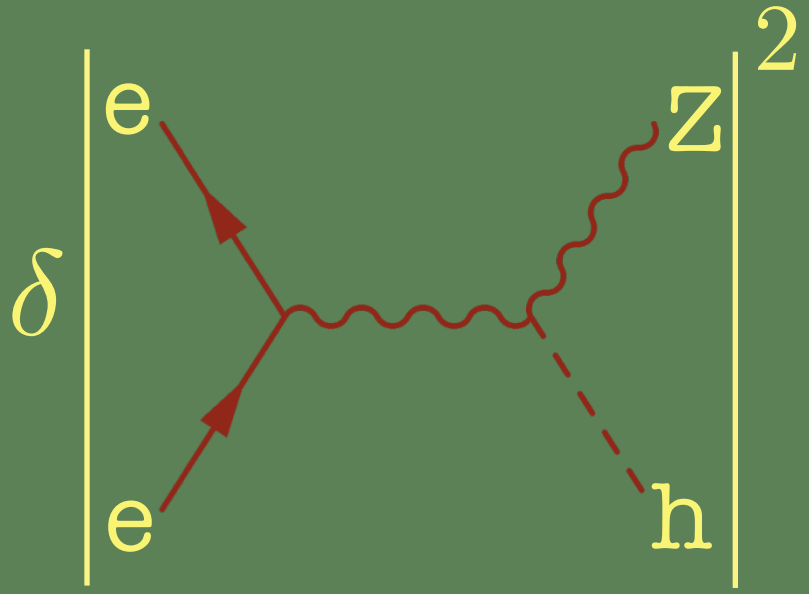
- But weak scale may still be natural
  - Flipped SUSY, Twin Higgs,.. who knows!

- If, so what are generic predictions?

Conclusions

- Goal: Distill Higgs physics from naturalness and test it!

- Linear Collider:



enables exploration of naturalness principle, independent of specific models!