Non-SUSY BSM Theory

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UC Davis

Introduction

Reasons to believe in new physics accessible to LHC:

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- Naturalness of Higgs mass

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Independent of SUSY!

“The SUSY train is late.”

— G. Altarelli, 2001

Naturalness

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• "Naturalness" is the requirement that m_h is not the result of a large unexplained cancelation.

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Example: $m_{\tilde{t}} \sim 100$ TeV

$\Rightarrow$ threshold correction $\Delta m_h^2 \sim 10^5 \times (125\ \text{GeV})^2$

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Compute loop effects in terms of observable quantities
$\Rightarrow$ no quadratic dependence on heavy masses.

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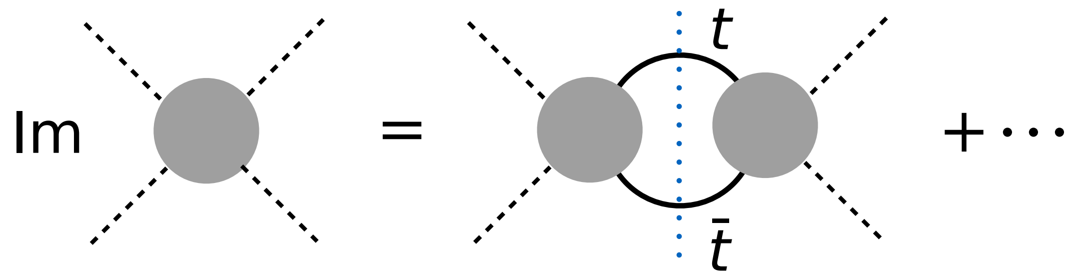

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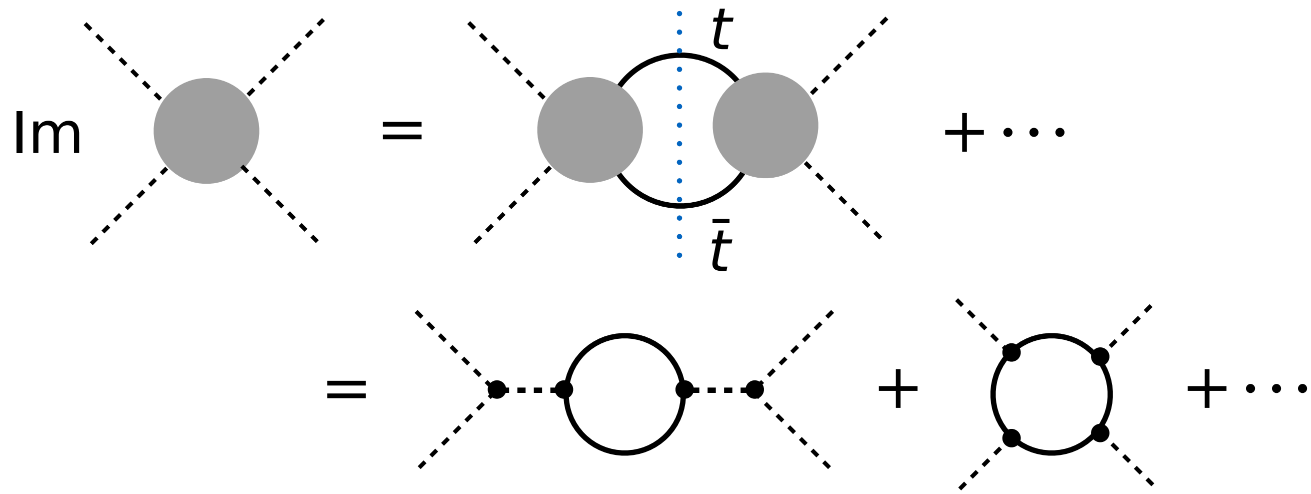

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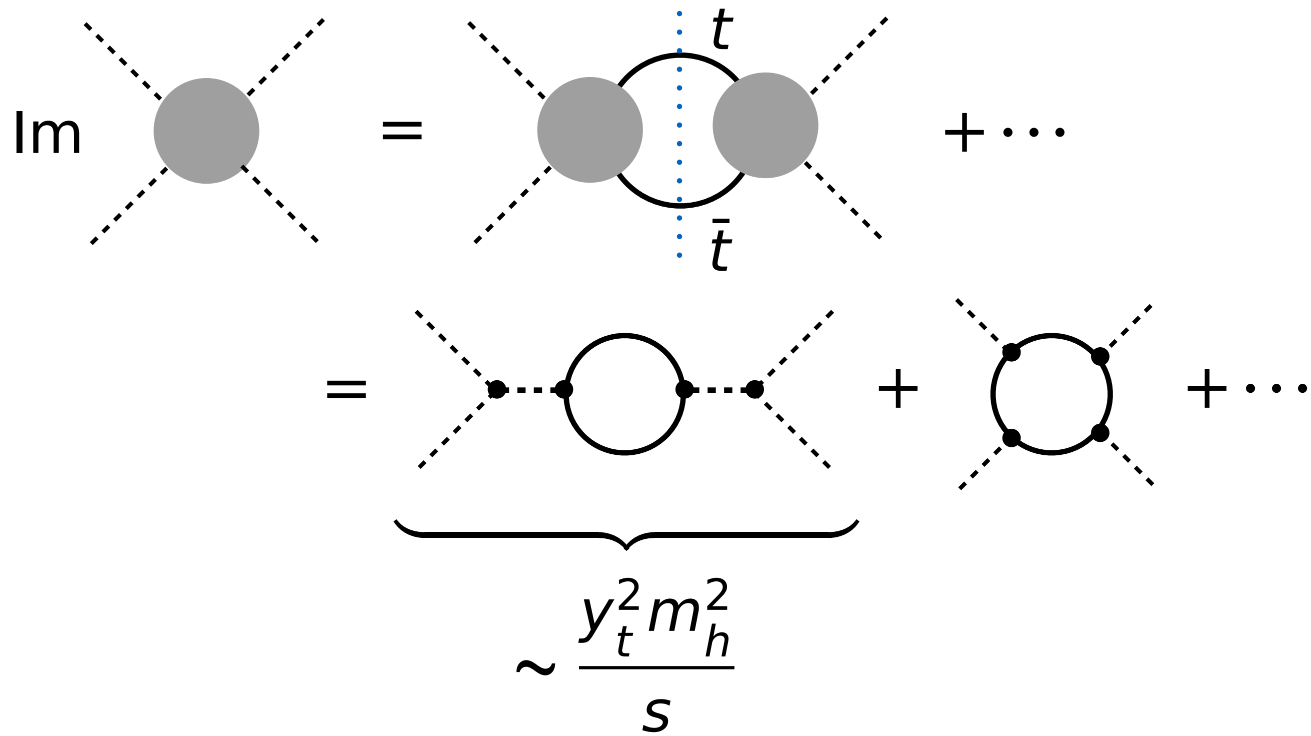

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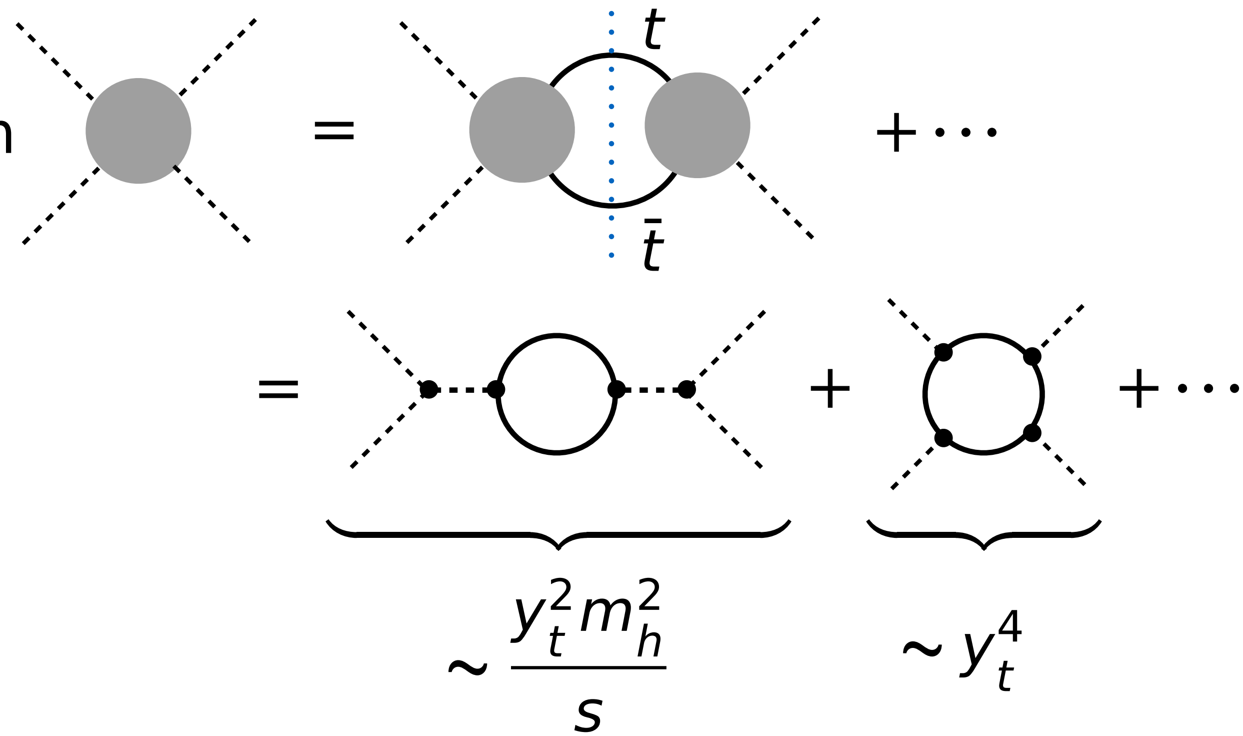

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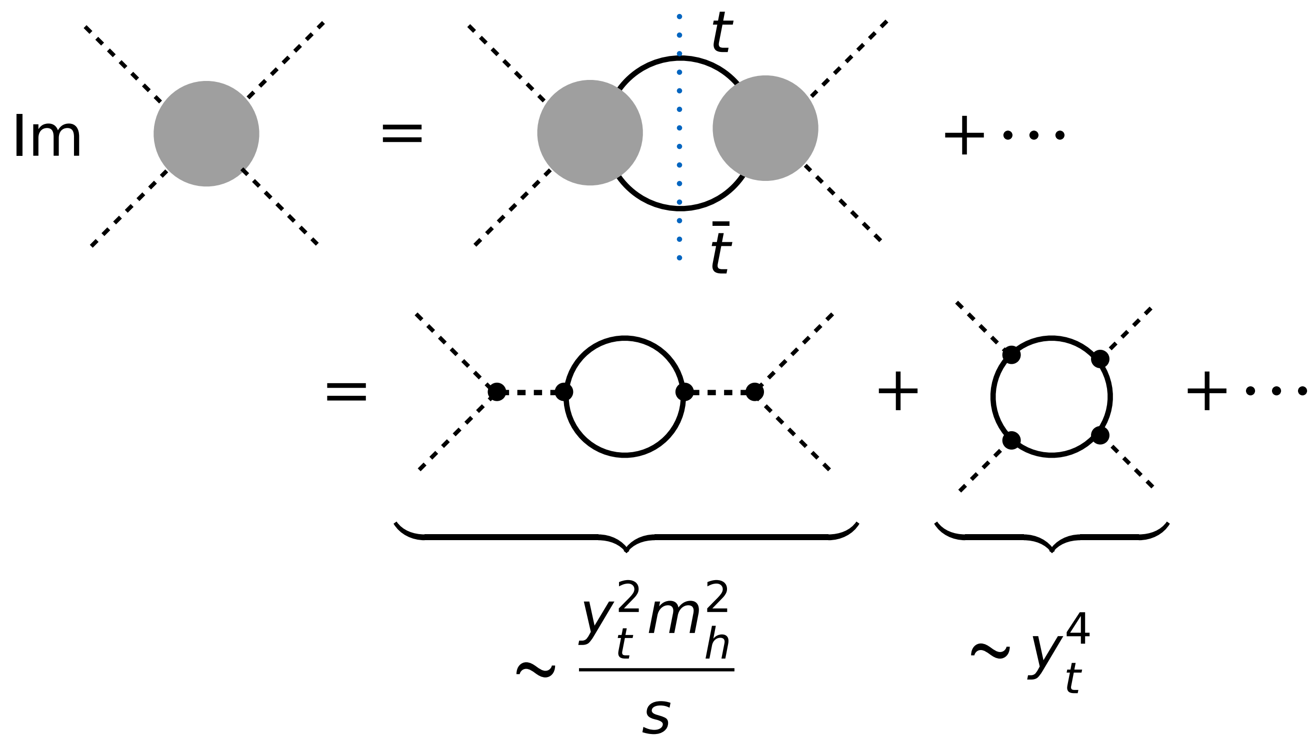

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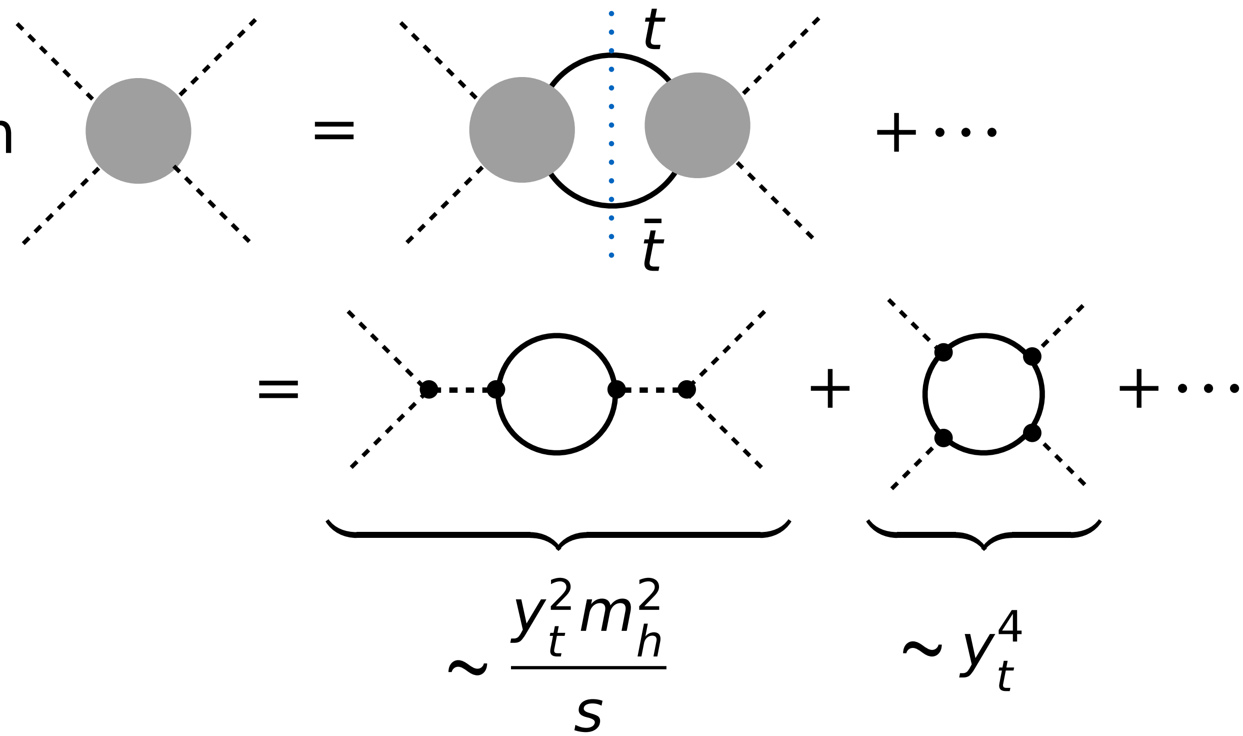

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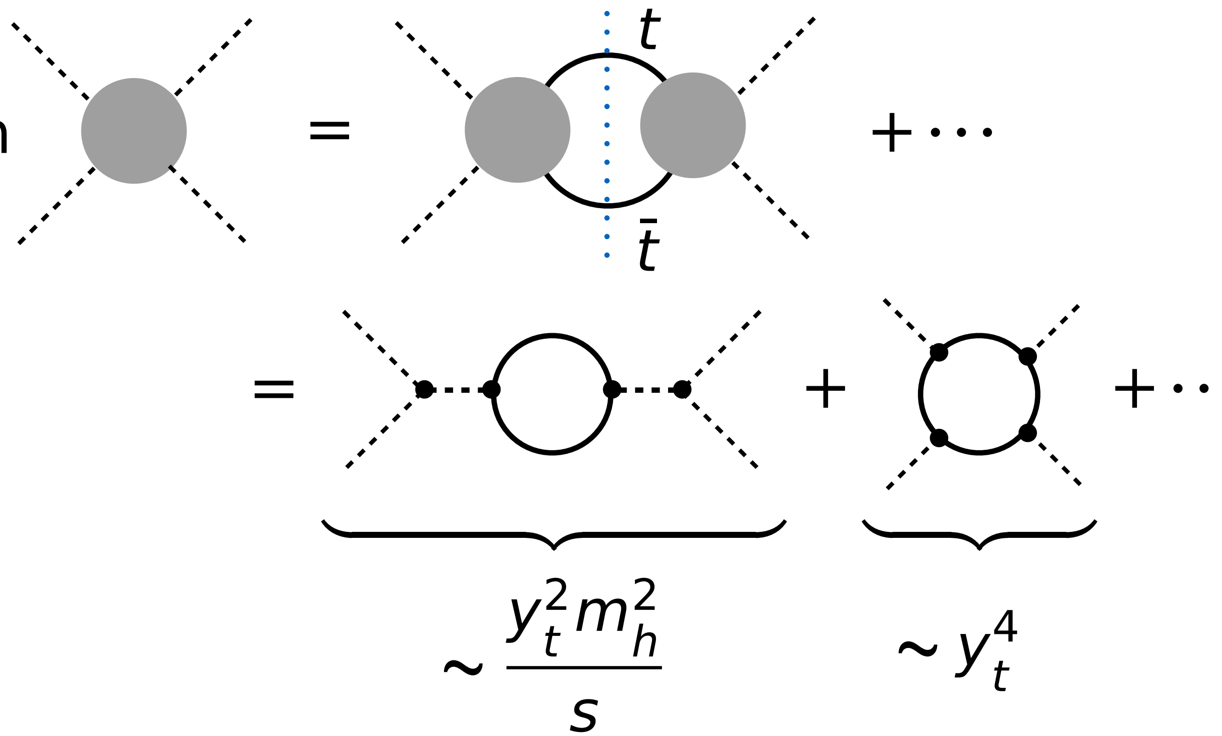

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$\Rightarrow$ can write once-subtracted dispersion relation

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My conclusion: think harder!

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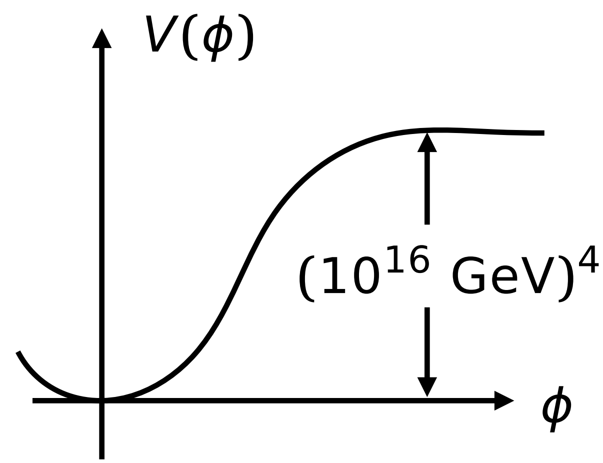

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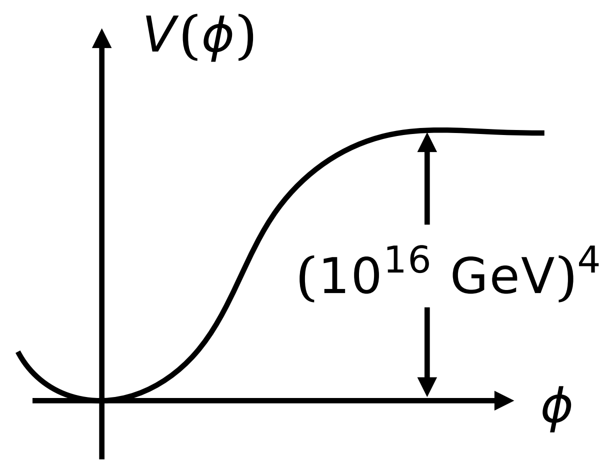

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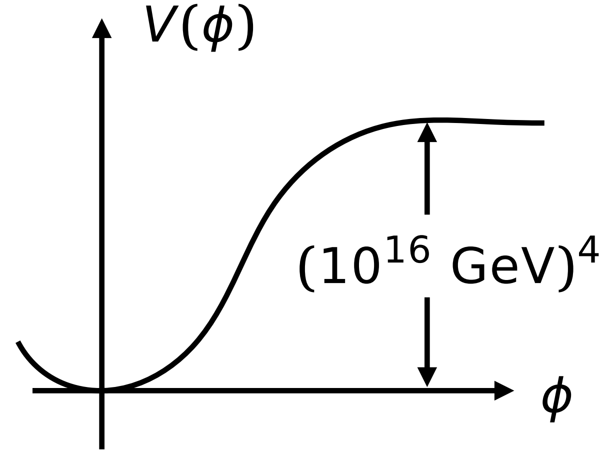

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Gauge unification, ν masses, flavor, ... have *simplest* explanation in terms of physics at scales $\gg$ TeV.

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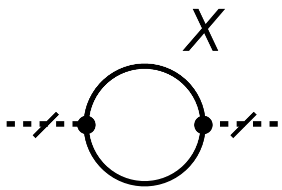
Naturalness requires a mechanism to prevent physics at high scales from contributing to m_h^2.

$\Delta m_h^2 =$



$$\sim \frac{\lambda^2 m_X^2}{16\pi^2}$$

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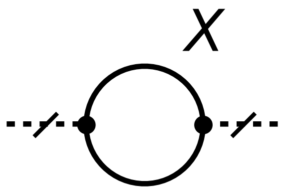
$\Delta m_h^2 =$  $\sim \dfrac{\lambda^2 m_X^2}{16\pi^2}$

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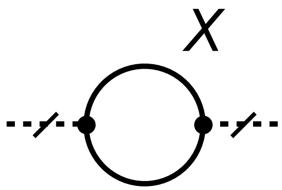
$\Delta m_h^2 =$  $\sim \dfrac{\lambda^2 m_X^2}{16\pi^2}$

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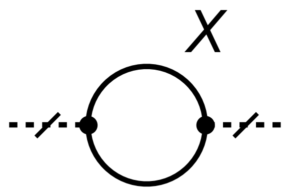
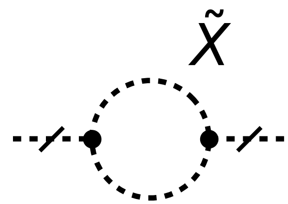
SUSY: $\Delta m_h^2 =$ 

$+$ 

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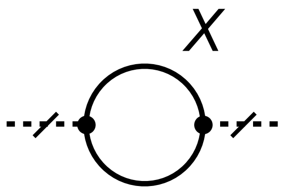
$\Delta m_h^2 =$ 

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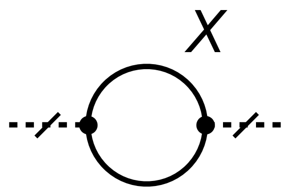
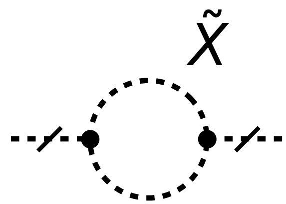
SUSY: $\Delta m_h^2 =$ 

$+$ 

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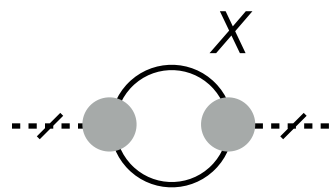
Compositeness: $\Delta m_h^2 =$ 

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$\Lambda =$ scale of form factors

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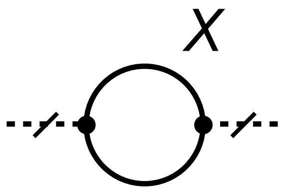
$\Delta m_h^2 =$ 

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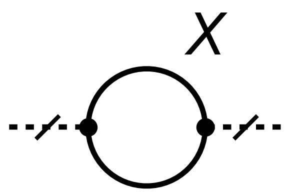
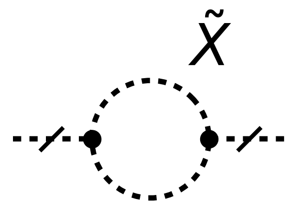
SUSY: $\Delta m_h^2 =$ 

$+$ 

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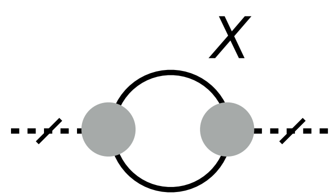
Compositeness: $\Delta m_h^2 =$ 

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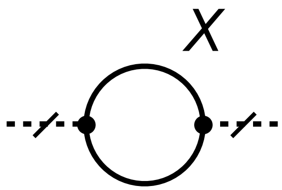
$\Delta m_h^2 =$ 

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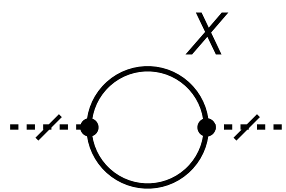
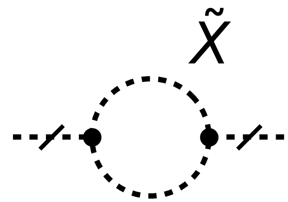
SUSY: $\Delta m_h^2 =$ 

$+$ 

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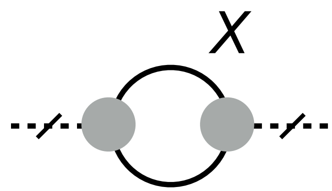
Compositeness: $\Delta m_h^2 =$ 

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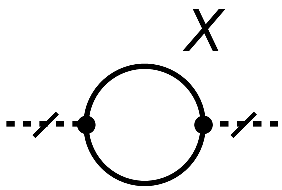
$\Delta m_h^2 =$ 

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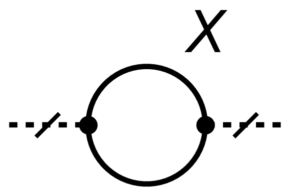
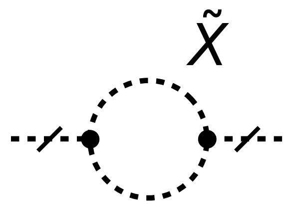
SUSY: $\Delta m_h^2 =$ 

$+$ 

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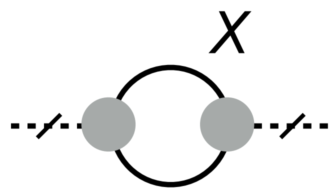
Compositeness: $\Delta m_h^2 =$ 

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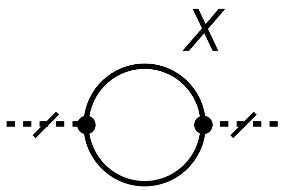
$\Delta m_h^2 =$  $\sim \dfrac{\lambda^2 m_X^2}{16\pi^2}$

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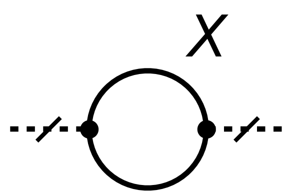
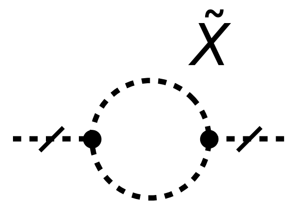
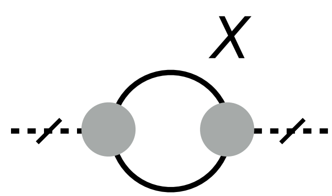
SUSY: $\Delta m_h^2 =$  $+$  $+ \cdots \sim \dfrac{\lambda^2}{16\pi^2}\left(m_X^2 - m_{\tilde{X}}^2\right)$

Compositeness: $\Delta m_h^2 =$  $\sim \dfrac{\lambda \Lambda^2}{16\pi^2}$

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Motivates $\Lambda \sim$ TeV

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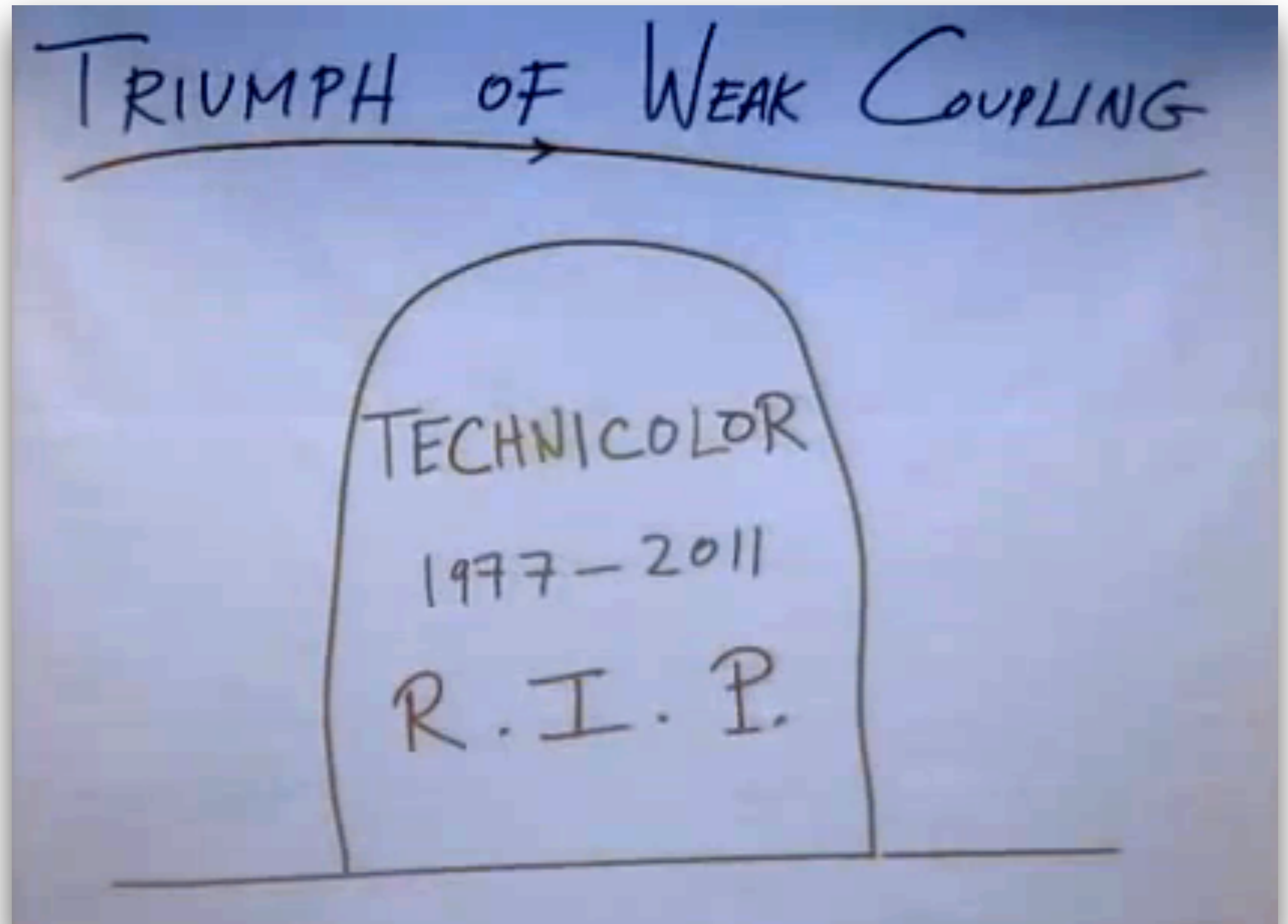

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PNGB Higgs

Georgi, Kaplan, 1984

⋮

Contino, Nomura, Pomarol, 2003

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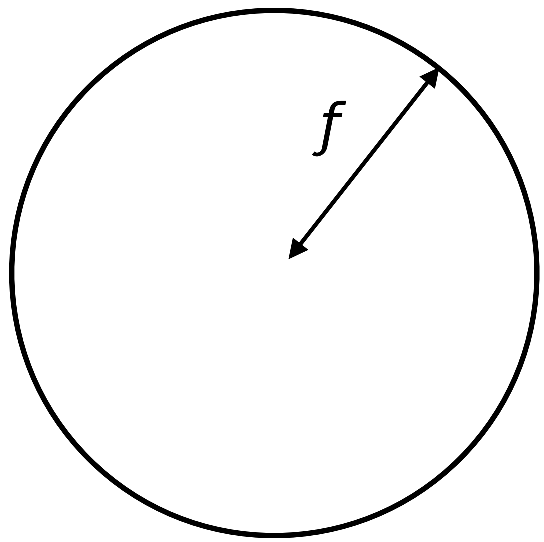

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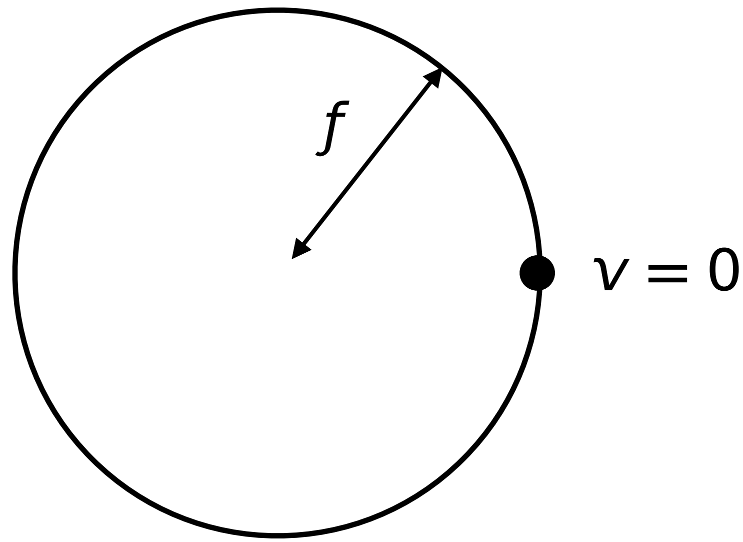

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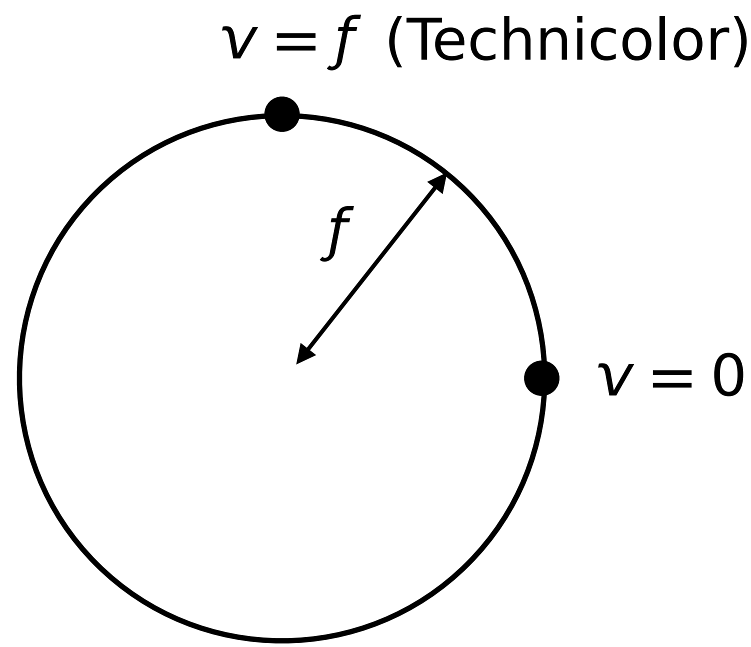

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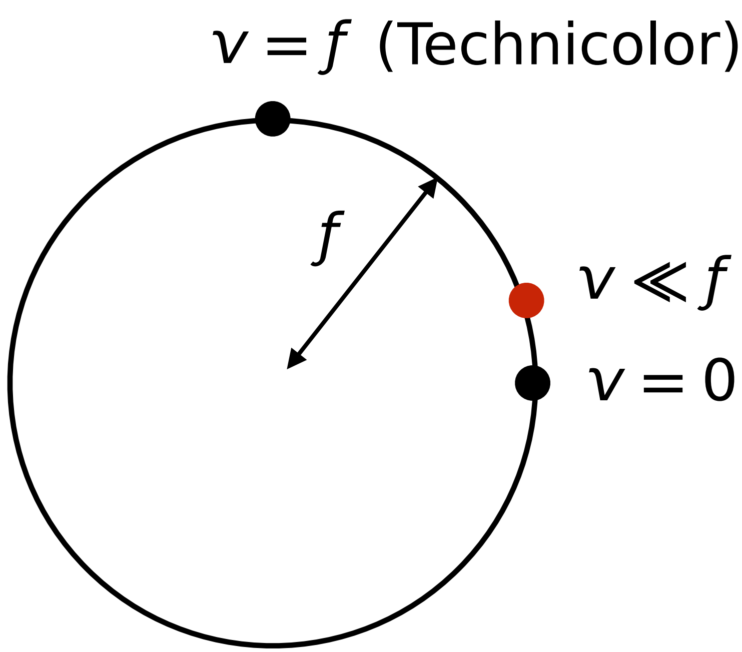

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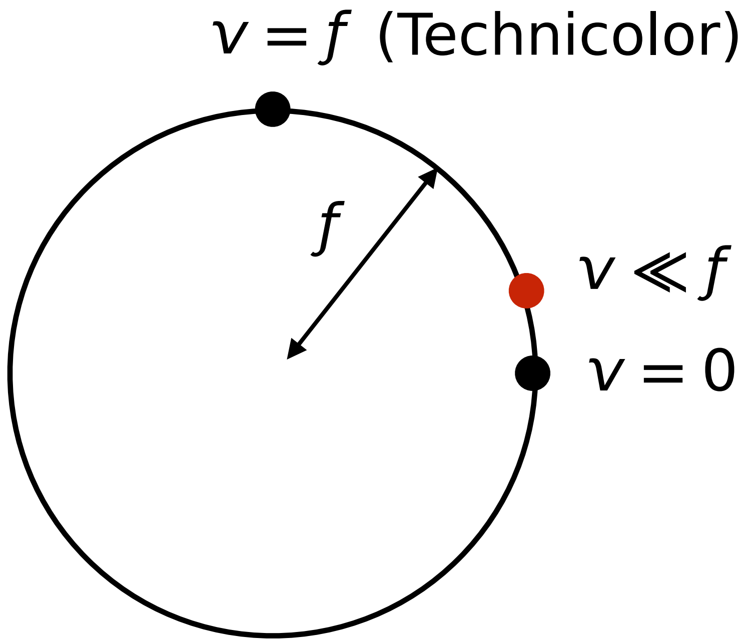

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PNGB Higgs

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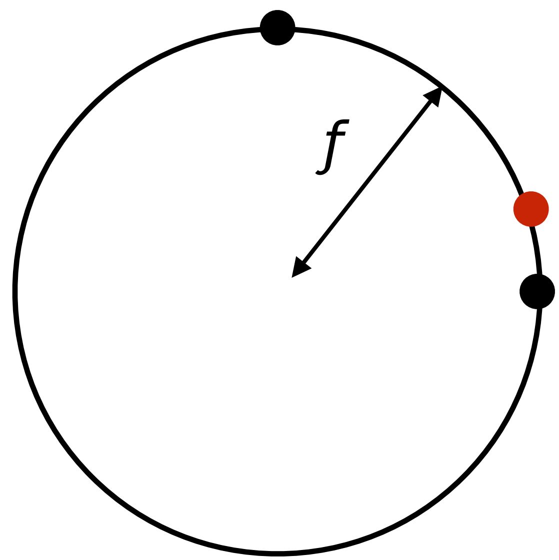

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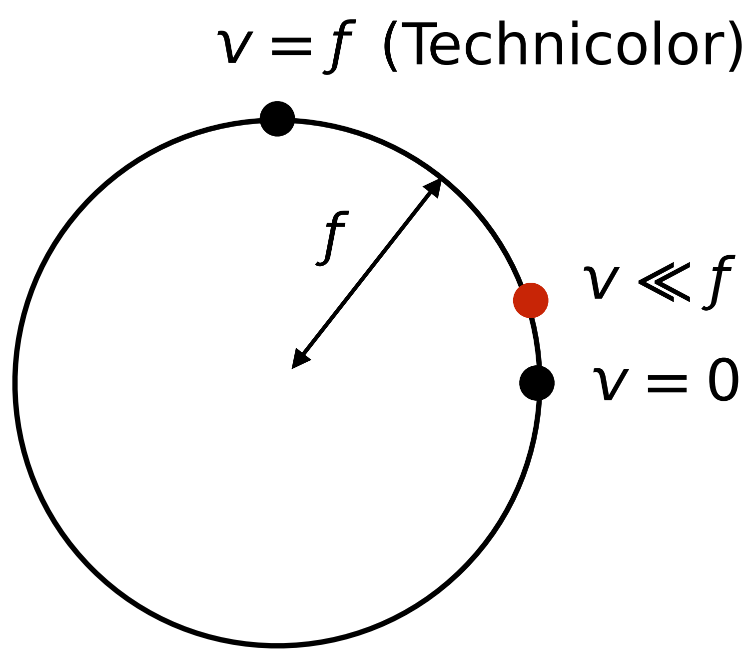

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⇒ precision Higgs coupling measurements directly probe tuning in PNGB Higgs models

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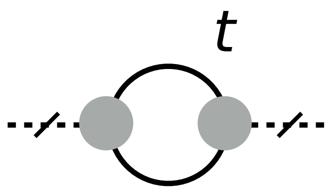
Top quark is a potential additional source of tuning:



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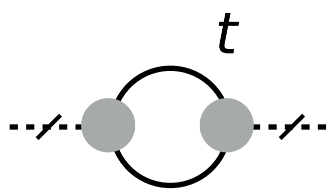

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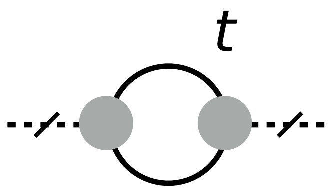

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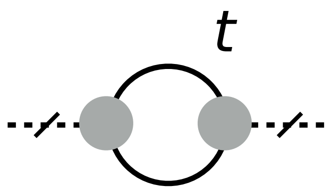

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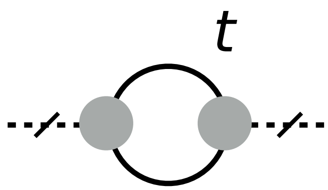

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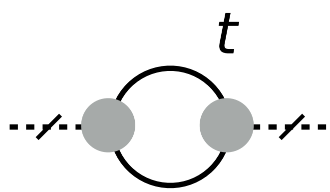

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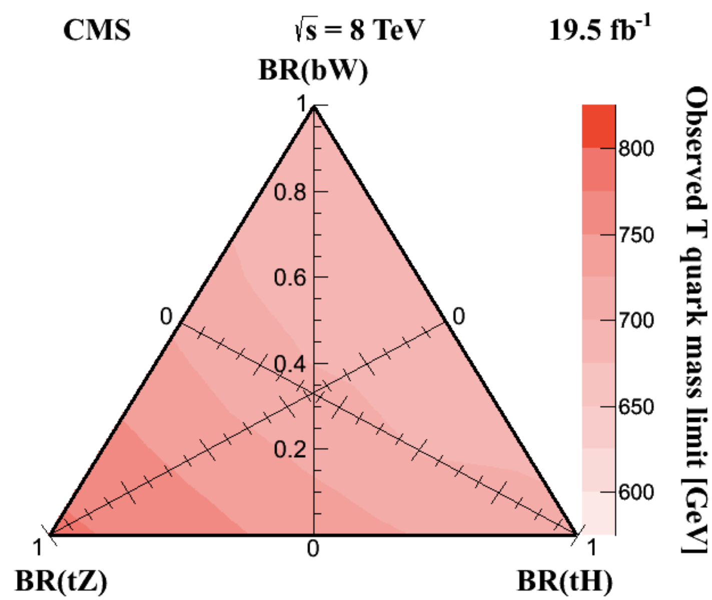

BMSSM Higgs

Naturalness ⇒ Higgs mass too small in MSSM

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- F terms (NMSSM, ...)
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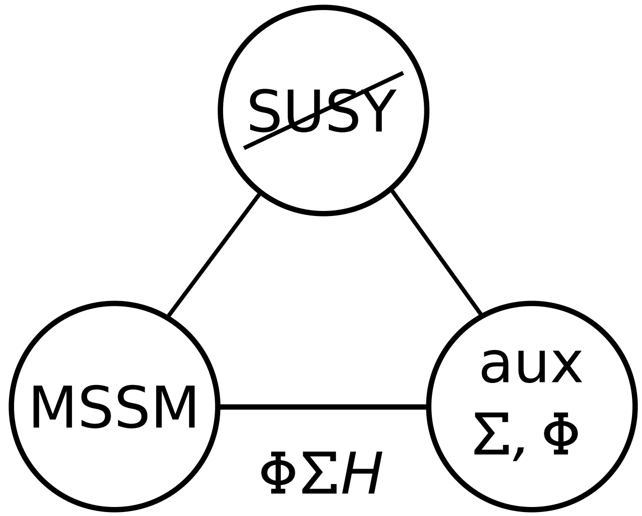
Another possibility:

- Higgs tadpole from “auxiliary” Higgs sector

SUSY + Technicolor

Azatov, Galloway, ML, 2012



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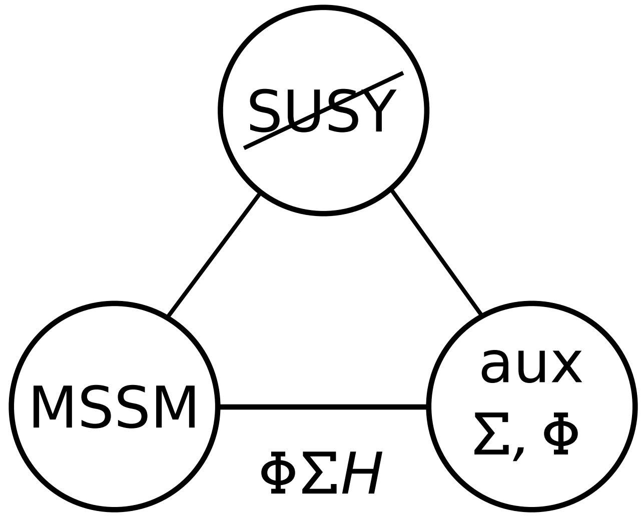

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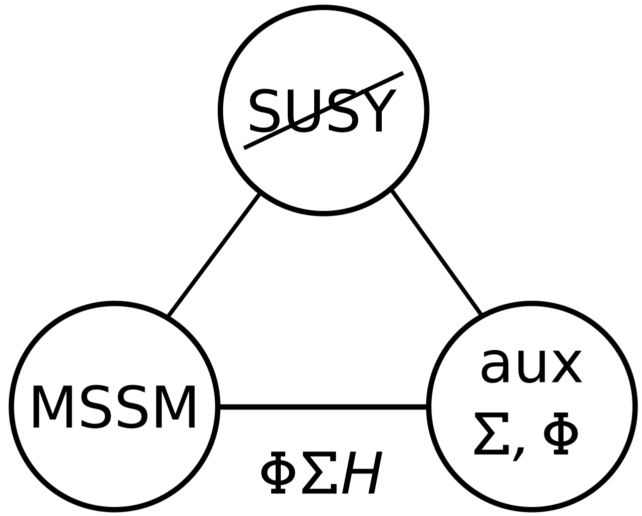

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$$V_{\text{eff}} \simeq m_H^2 H^\dagger H + \kappa H^\dagger e^{i\Pi/f} \begin{pmatrix} 0 \\ f \end{pmatrix} + \text{h.c.}$$

$$m_H^2 > 0 \quad \Rightarrow \quad v = \frac{\kappa f}{m_H^2}$$ "induced EWSB"

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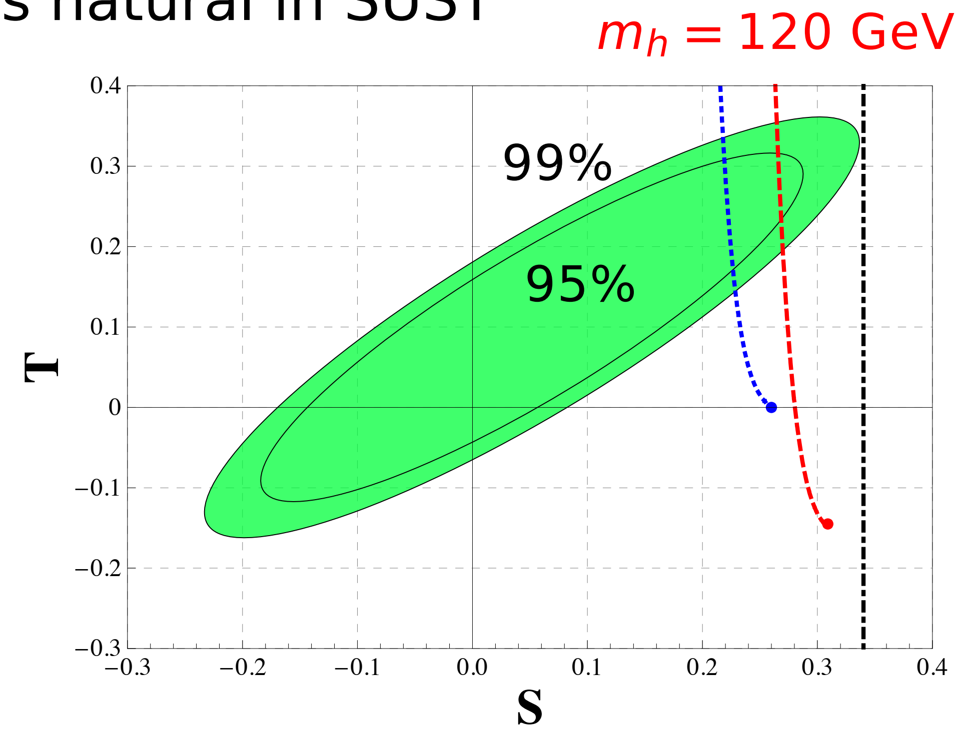

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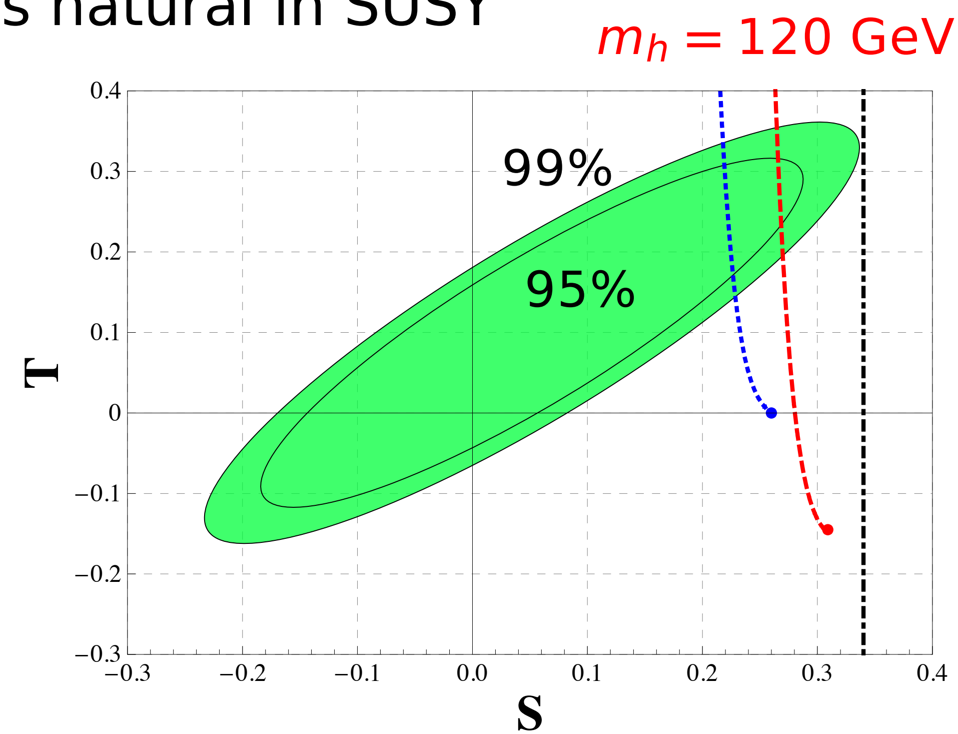

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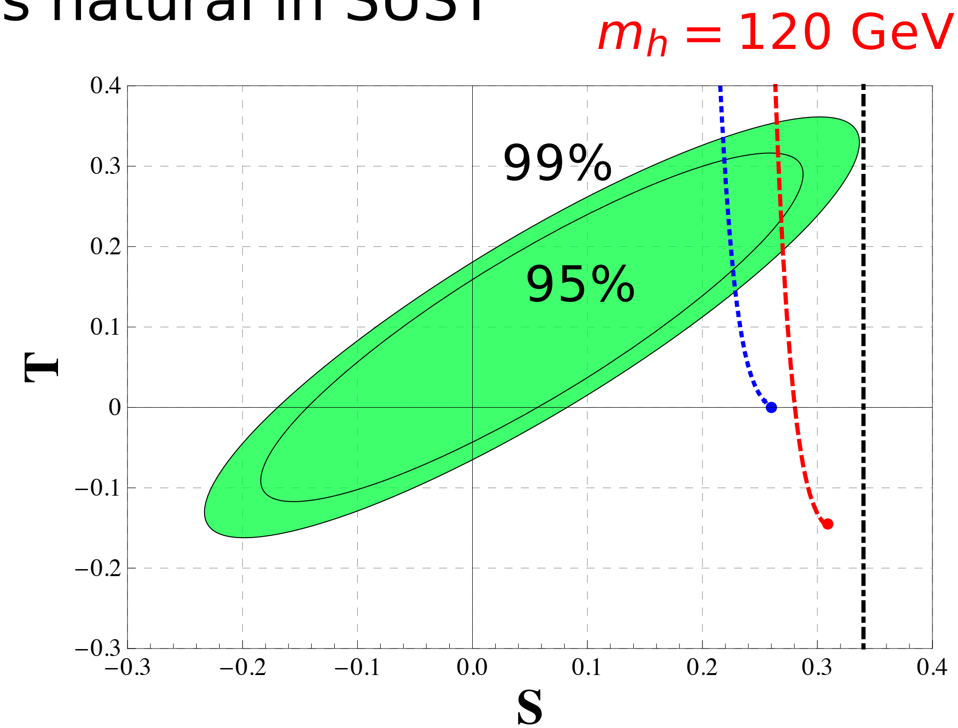

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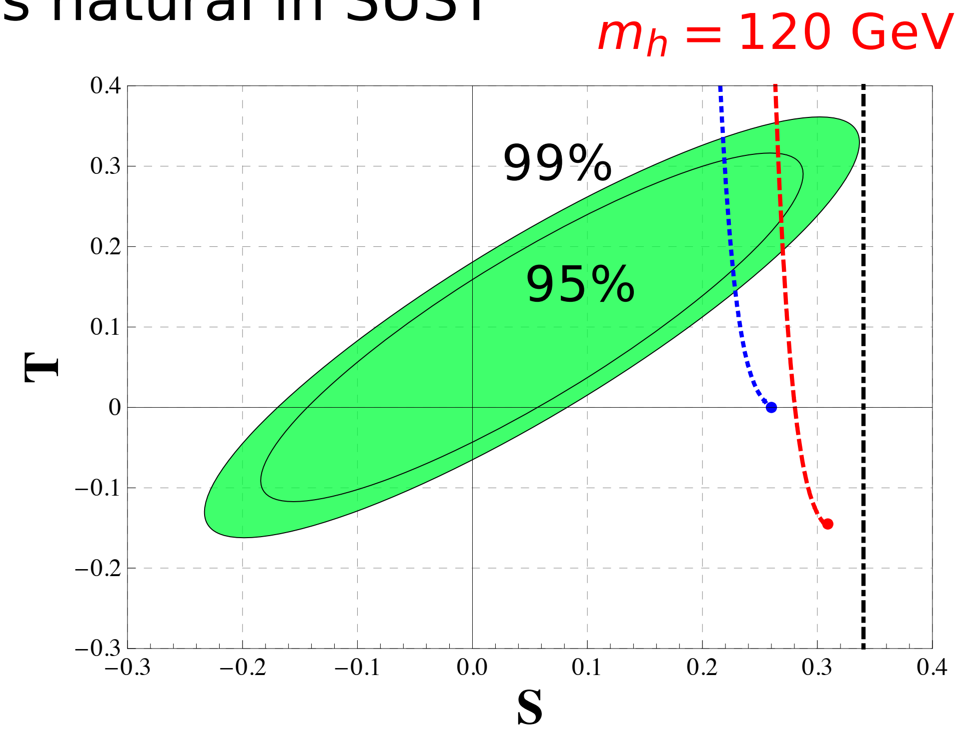

SUSY + Technicolor

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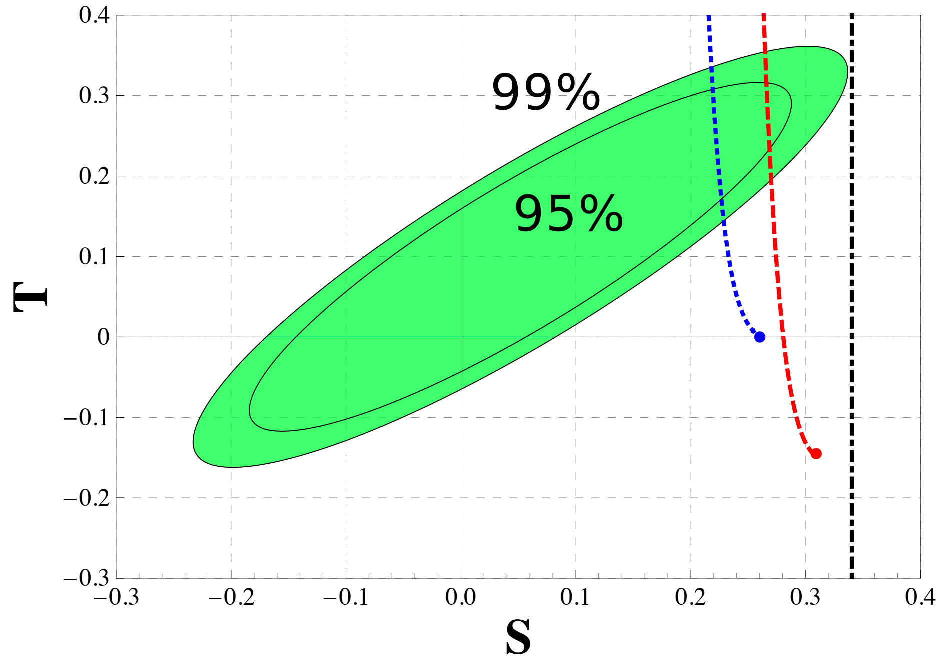

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- Non-minimal Higgs signals

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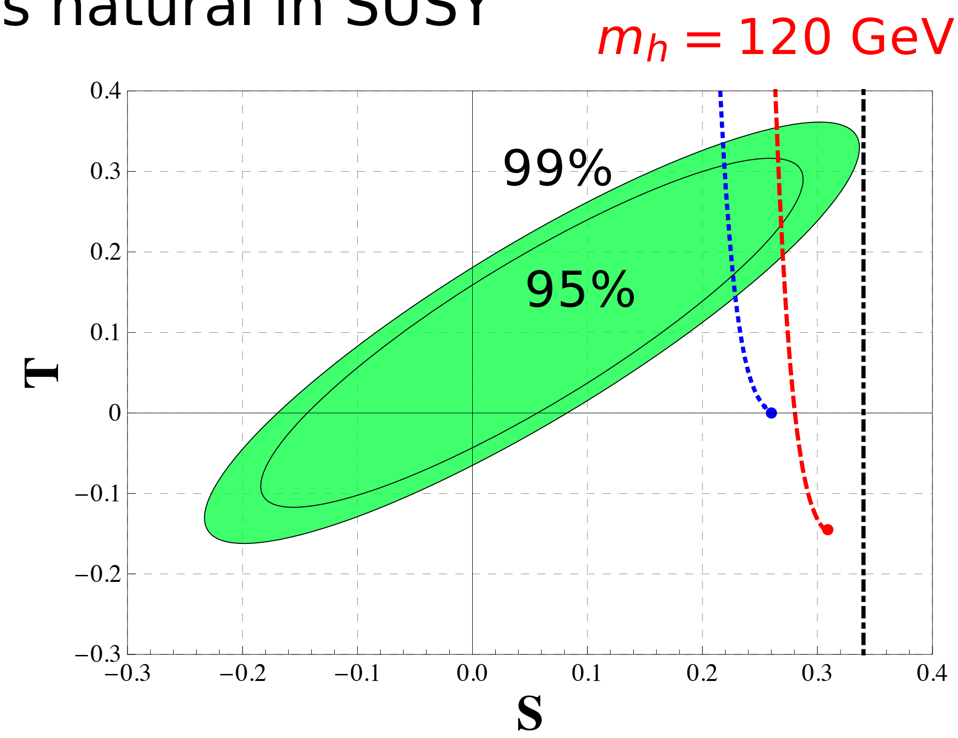

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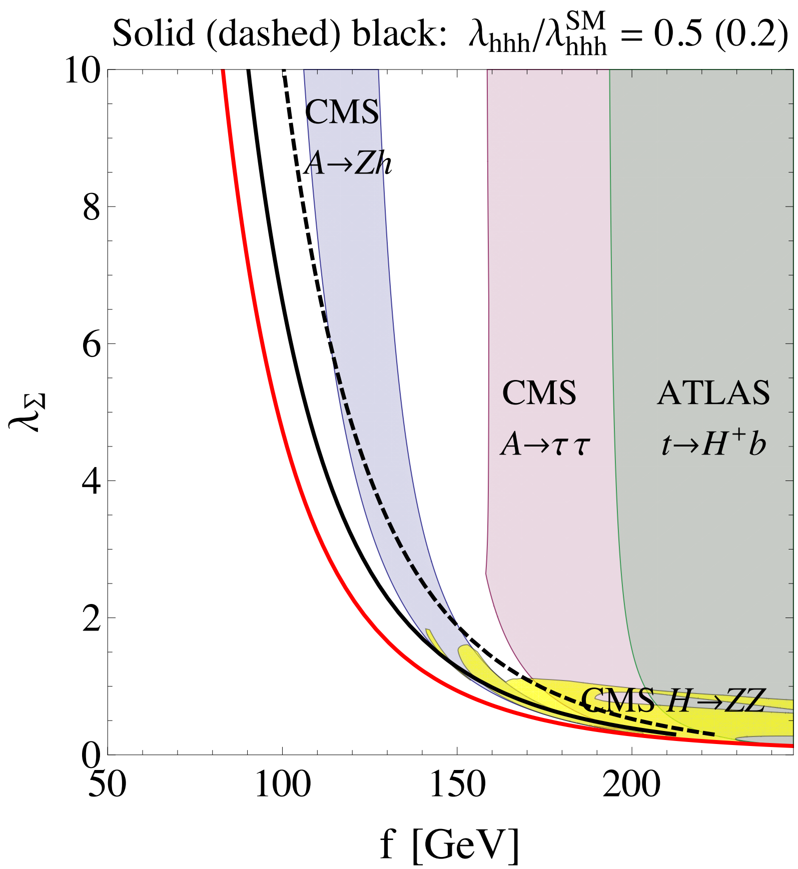
Galloway, ML, Tsai, Zhao, 2014

Can also construct perturbative calculable models



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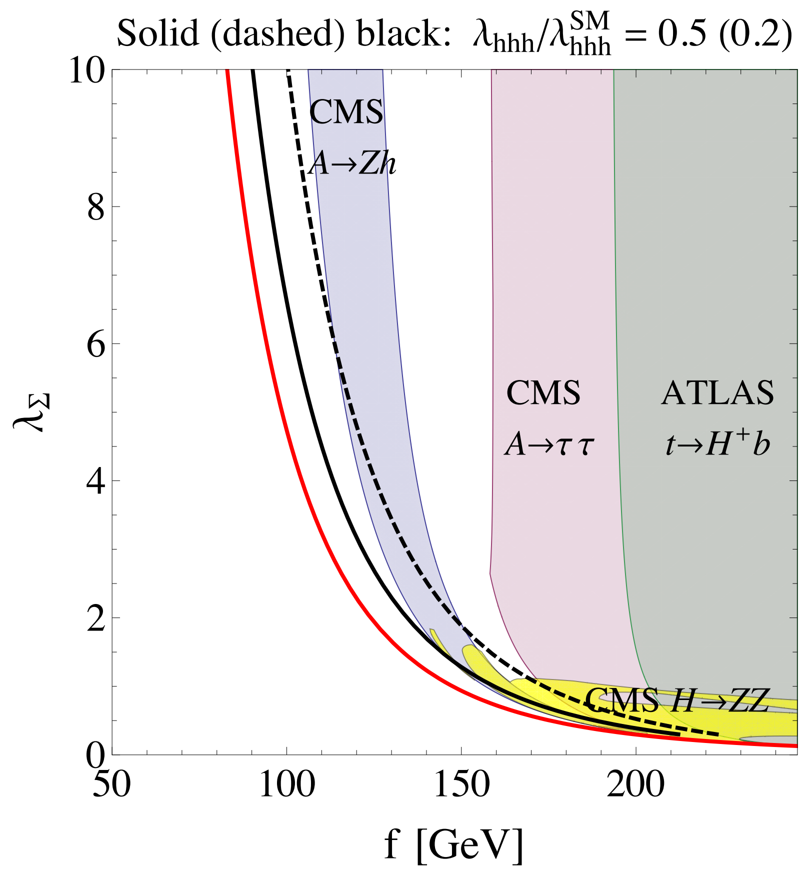

General message: SUSY naturalness motivates BMSSM Higgs

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It exists. It is BSM.

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⇒ search for effective interactions coupling SM with SM

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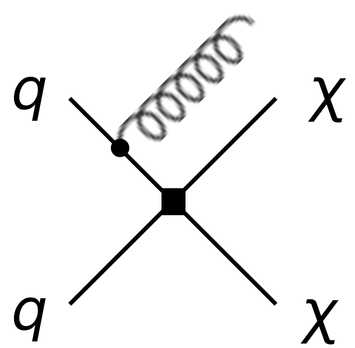
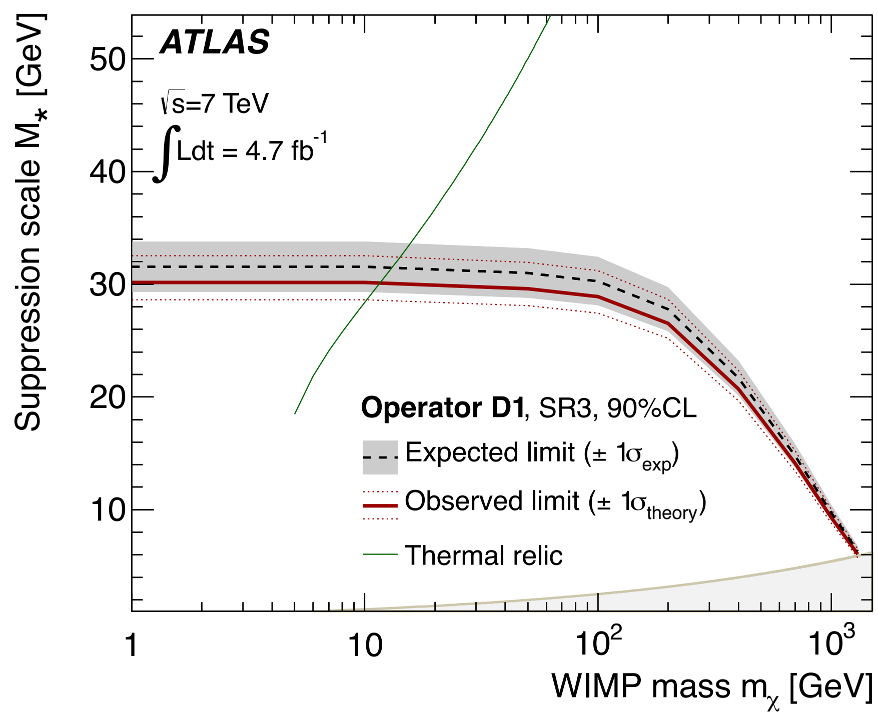


⇒ monojet signal



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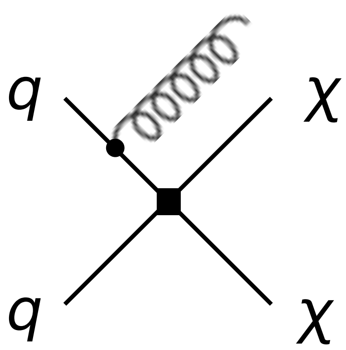

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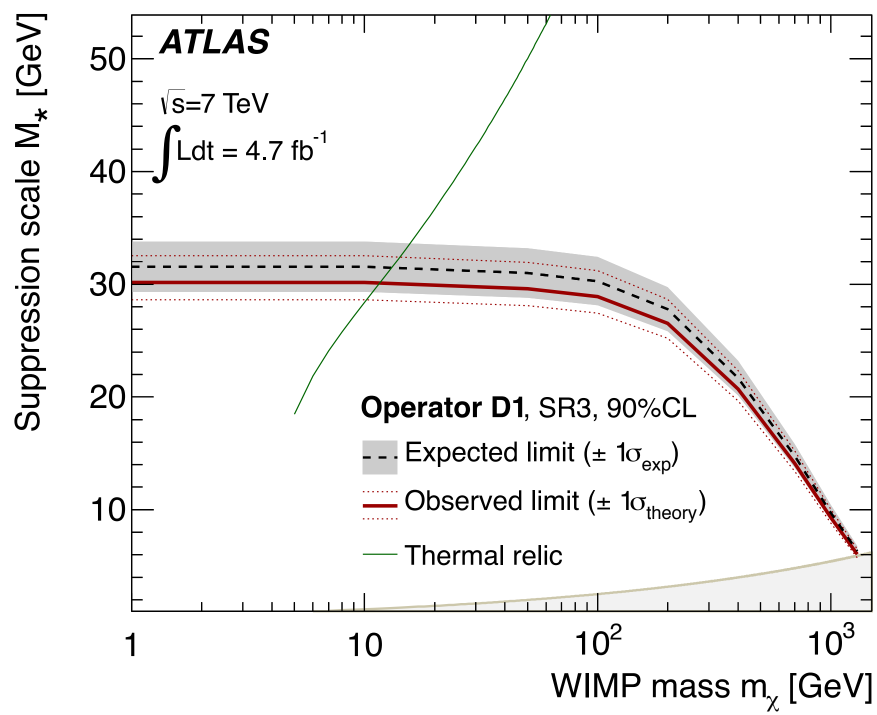

Generalized to mono-X searches . . .

Effective WIMPs

Chang, Hutchinson, Edezath, ML 2013

An, Wang, Zhang, 2013

Bai, Berger, 2013

Relic abundance motivates *renormalizable* couplings to SM.

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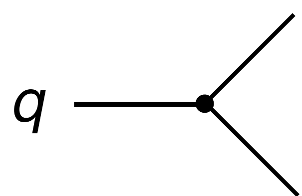

$\chi =$ singlet dark matter

$Q =$ SM partner

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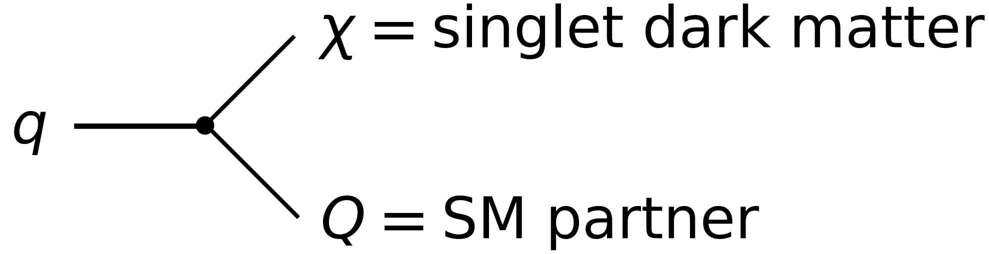
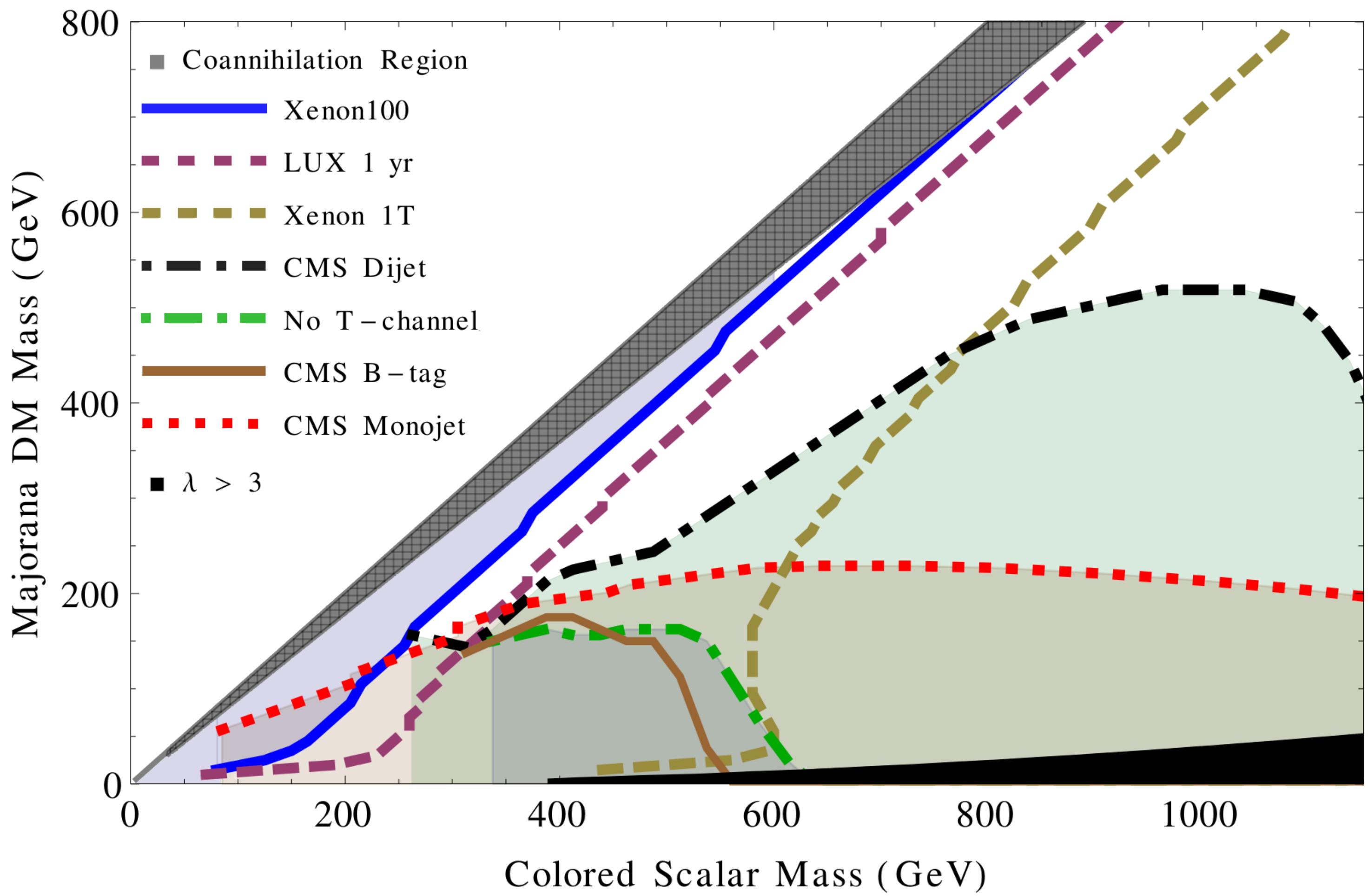


Fix coupling by requiring correct relic abundance

$\Rightarrow$ parameterized by m_χ, m_Q

Effective WIMPs

Majorana fermion dark matter



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