LHC data and aspects of new physics

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PHYSICS

Outline

1. Need for new physics

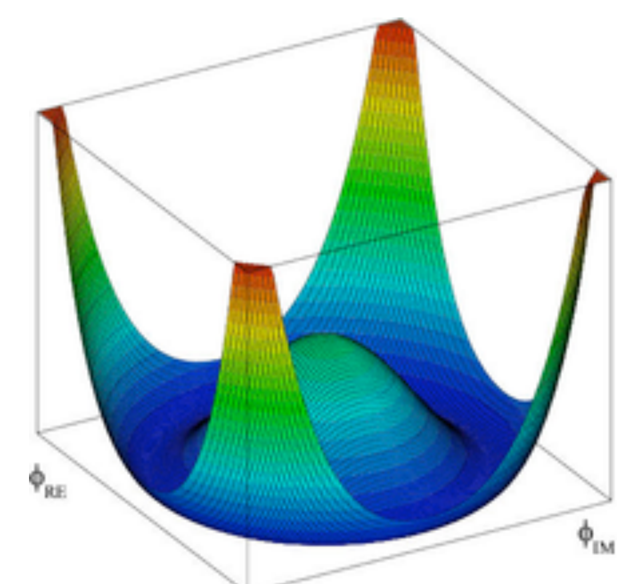
2. LHC data and a new physics model example
(T. Alanne et al. 1303.3615)

3. Paradigm shift?
(M. Heikinheimo et al. arXiv: next Monday...)

1. The need for new physics

$$\mathcal{L}_H = (D_\mu\phi)^\dagger D^\mu\phi - V(\phi)$$

$$V(\phi) = \mu^2\phi^\dagger\phi + \frac{1}{4}\lambda\left(\phi^\dagger\phi\right)^2, \quad \mu^2 < 0.$$



The discovery: A SM Higgs boson exists

$$\mathcal{L}_{\rm eff} = a_V \frac{2m_W^2}{v_w} h W_\mu^+ W^{-\mu} + a_V \frac{m_Z^2}{v_w} h Z_\mu Z^\mu - a_f \sum_{\psi=t,b,\tau} \frac{m_\psi}{v_w} h \bar{\psi}\psi$$

$$+ a_{V'} \frac{2m_{W'}^2}{v_w} h W_\mu'^+ W'^{-\mu} - a_S \frac{2m_S^2}{v_w} h S^+ S^-,$$

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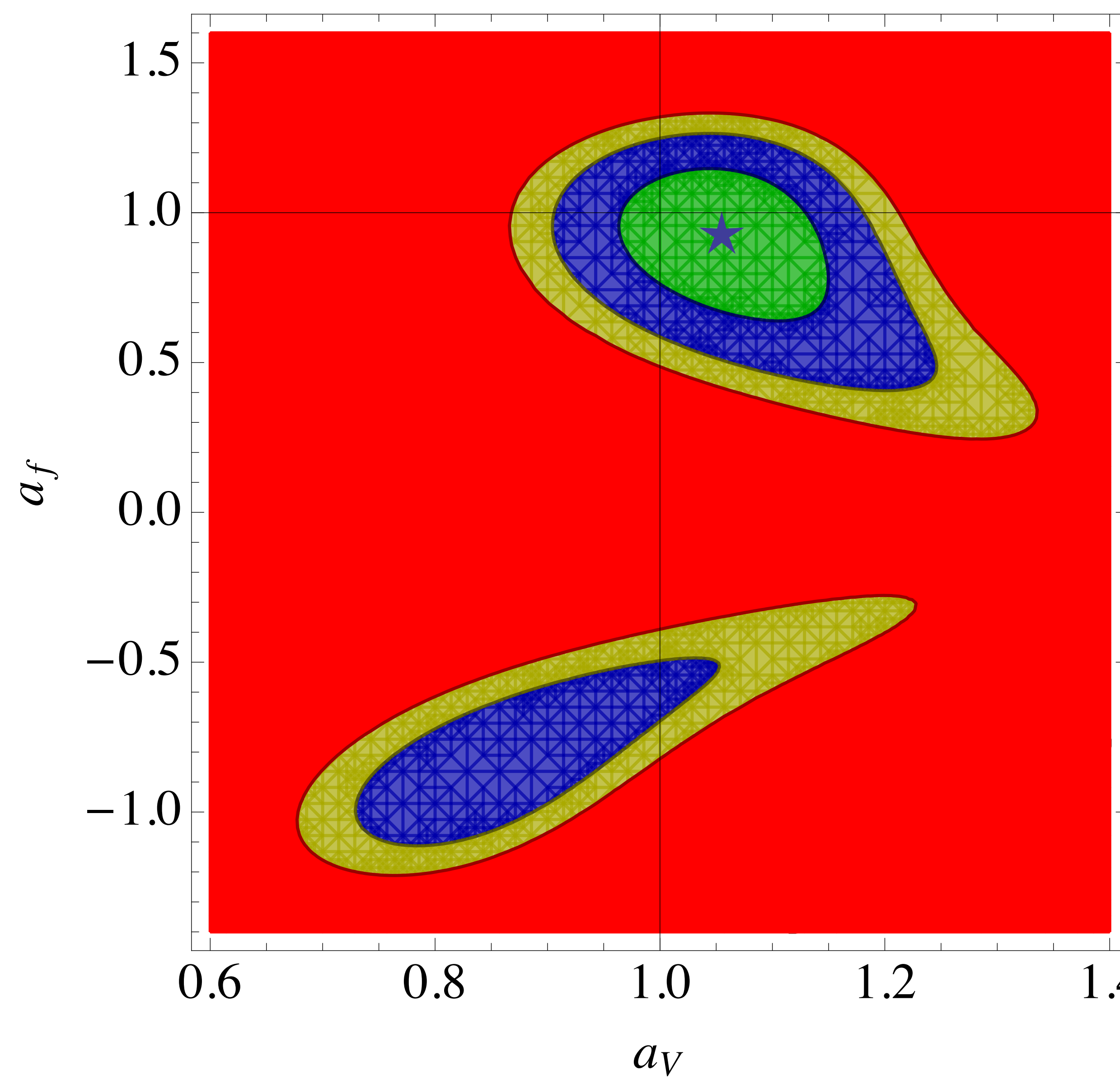
$$a_{V'} = 0$$
$$a_S = 0$$

Data: post-Moriond '13



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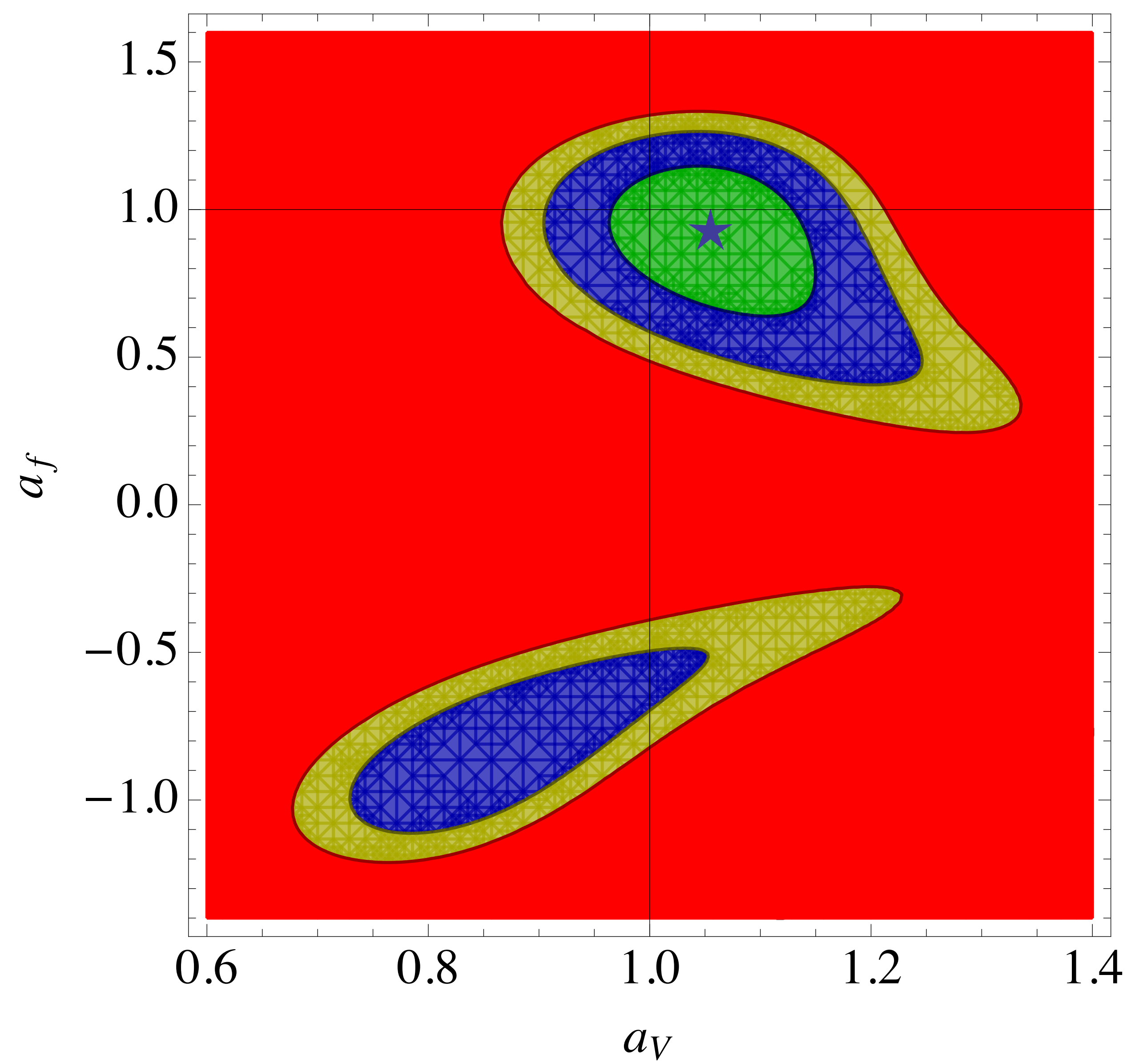
SM corresponds to

$$a_V = a_f = 1$$
$$a_{V'} = a_S = 0$$



Giardino et al., (2013),
Ellis & You (2013),
Djouadi & Moreau (2013),
Falkowski et al. (2013),
Alanne et al. (2013),
.
.

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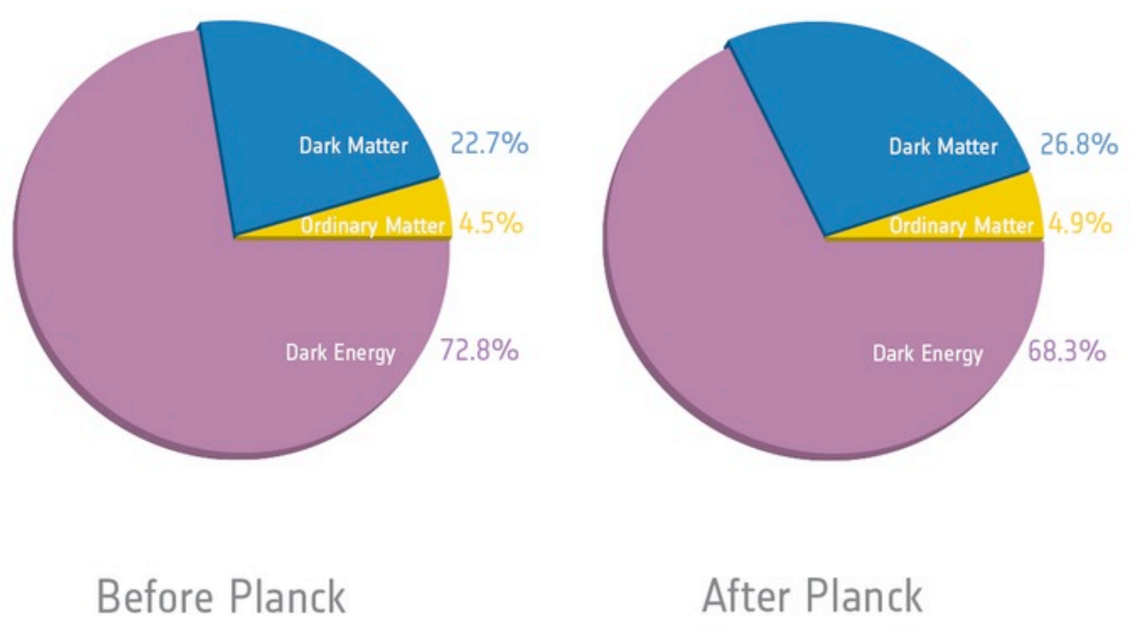
Further puzzles:

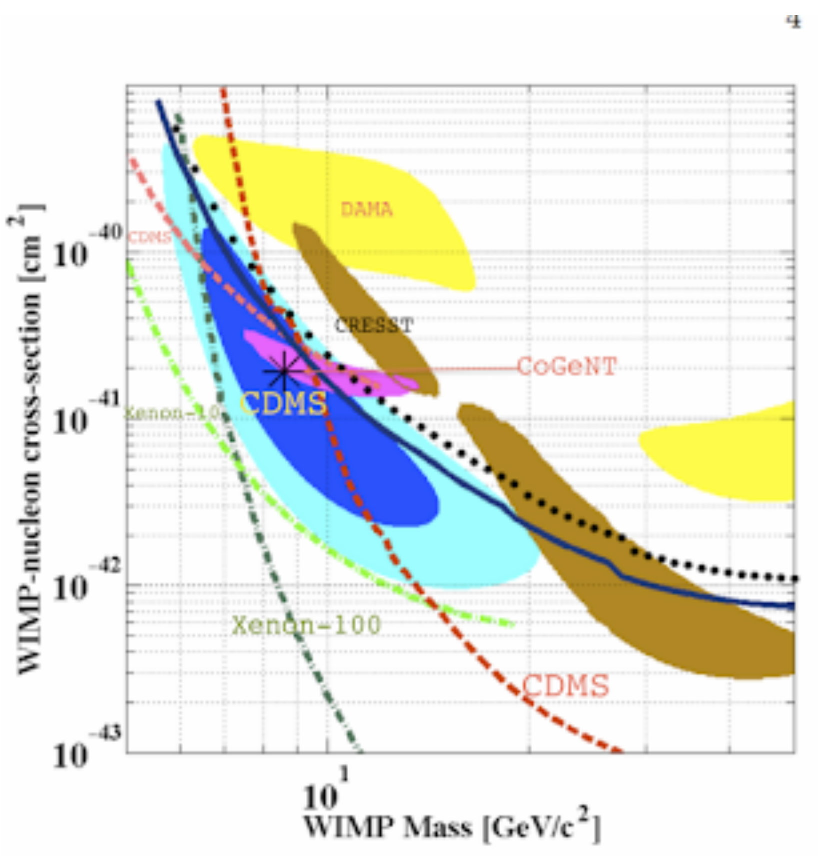
Dark matter?

Origin of matter over antimatter?

Neutrino masses?

Flavor physics?





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$$v_{\mathrm{weak}} \sim F_\pi$$

2. Example of a viable model

A BSM model: bosonic NMWT

Antola et al. (2009), Fukano et al. (2011), Alanne et al. (2013)

$$\mathcal{L}_{\rm TC} = -\frac{1}{4}F^a_{\mu\nu}F^{a\mu\nu} + \overline{Q}(i\gamma^\mu D_\mu)Q$$

+

$$\mathcal{L}_{\rm Higgs} = D_\mu H^\dagger D^\mu H - m_H^2 H^\dagger H - \frac{\lambda_H}{3!}\left(H^\dagger H\right)^2$$

$$SU(2)\times SU(2) \to SU(2)$$

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A simple model for EW symmetry breaking and fermion masses

$$v_w^2 = v^2 + f^2 + 2c_3 y_{TC} f v = (246\ \mathrm{GeV})^2\ , \quad \langle M \rangle = \frac{f}{\sqrt{2}}\ , \quad \langle H \rangle = \frac{v}{\sqrt{2}}$$

8 parameters: $\lambda_H, \lambda_M, c_1, c_2, c_3, c_4, y_{\mathrm{TC}}, v$

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Theory constraints:

$\lambda_H, \lambda_M > 0\ ; \quad \lambda_H + \lambda_M > 2\,(c_2 + c_4 \lambda_H)\, y_{TC}.$

Pheno constraints:

$$m_{h^0} = 125 \pm 1\ \text{GeV}\ ,\ m_{H^\pm} = m_{A^0} > 100\ \text{GeV}\ ,\ m_{H^0} > 600\ \text{GeV}\ ,$$

$$S = 0.04 \pm 0.09\ ,\ T = 0.07 \pm 0.08\ ,\ r(S,T) = 88\%\ ,\ m_{A^0}, m_{H^0} < 5\Lambda_{TC}\ .$$

Random scan:

$$0 < \lambda_H, \lambda_M < (4\pi)^2\ ,\ 2\pi < |c_1|, |c_2|, |c_3^{-1}|, |c_4^{-1}| < 8\pi\ ,\ |c_3 y_{TC}| < 1$$

$$|y_t| < 4\pi\ ,\ f = \pm\sqrt{v_w^2 - v^2\,(1 - c_3^2 y_{TC}^2)} - v c_3 y_{TC}\ , |v| < v_w (1 - c_3^2 y_{TC}^2)^{-1/2}$$

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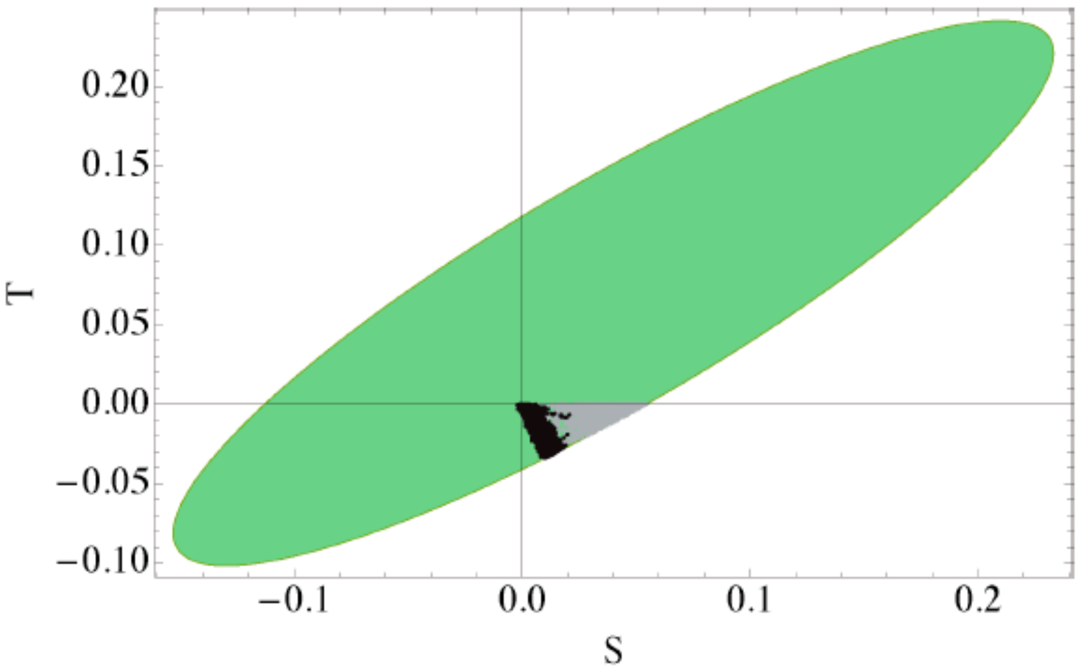

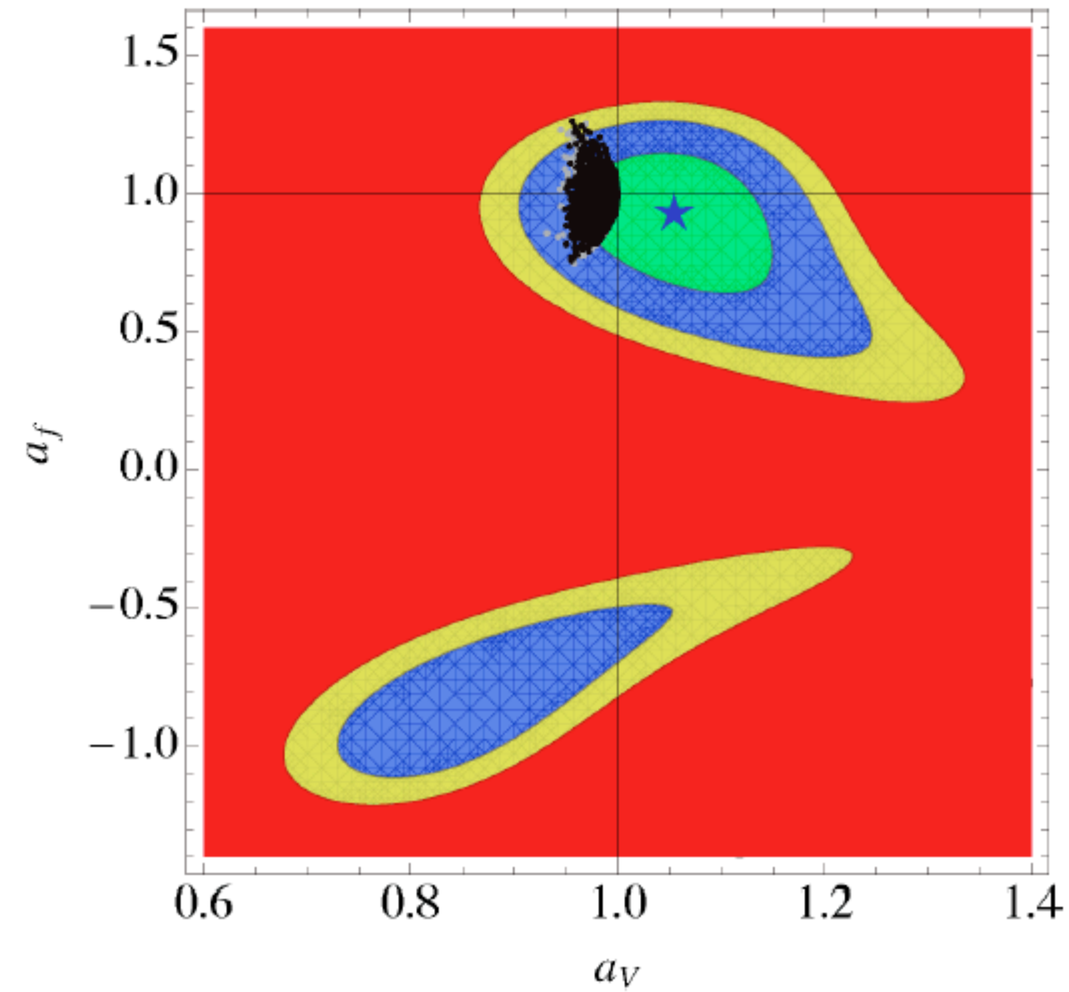

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To distinguish BTC from 2HDM: Vector mesons

$$+ \ m^2 \ \mathrm{Tr}\left[C_{\mathrm{L}\mu}^2 + C_{\mathrm{R}\mu}^2\right] + \frac{1}{2}\mathrm{Tr}\left[D_\mu M D^\mu M^\dagger\right] - \tilde{g}^2 \ r_2 \ \mathrm{Tr}\left[C_{\mathrm{L}\mu} M C_{\mathrm{R}}^\mu M^\dagger\right]$$

$$- \ \frac{i \ \tilde{g} \ r_3}{4}\mathrm{Tr}\left[C_{\mathrm{L}\mu}\left(M D^\mu M^\dagger - D^\mu M M^\dagger\right) + C_{\mathrm{R}\mu}\left(M^\dagger D^\mu M - D^\mu M^\dagger M\right)\right] \ + \ \frac{\tilde{g}^2 s}{4}\mathrm{Tr}\left[C_{\mathrm{L}\mu}^2 + C_{\mathrm{R}\mu}^2\right]\mathrm{Tr}\left[M M^\dagger\right]$$

$$C_{\mathrm{L}\mu} \equiv A_{\mathrm{L}\mu} - \frac{g}{\tilde{g}}\widetilde{W}_\mu \ , \quad C_{\mathrm{R}\mu} \equiv A_{\mathrm{R}\mu} - \frac{g'}{\tilde{g}}\widetilde{B}_\mu$$

(Belyaev et al. 2008)

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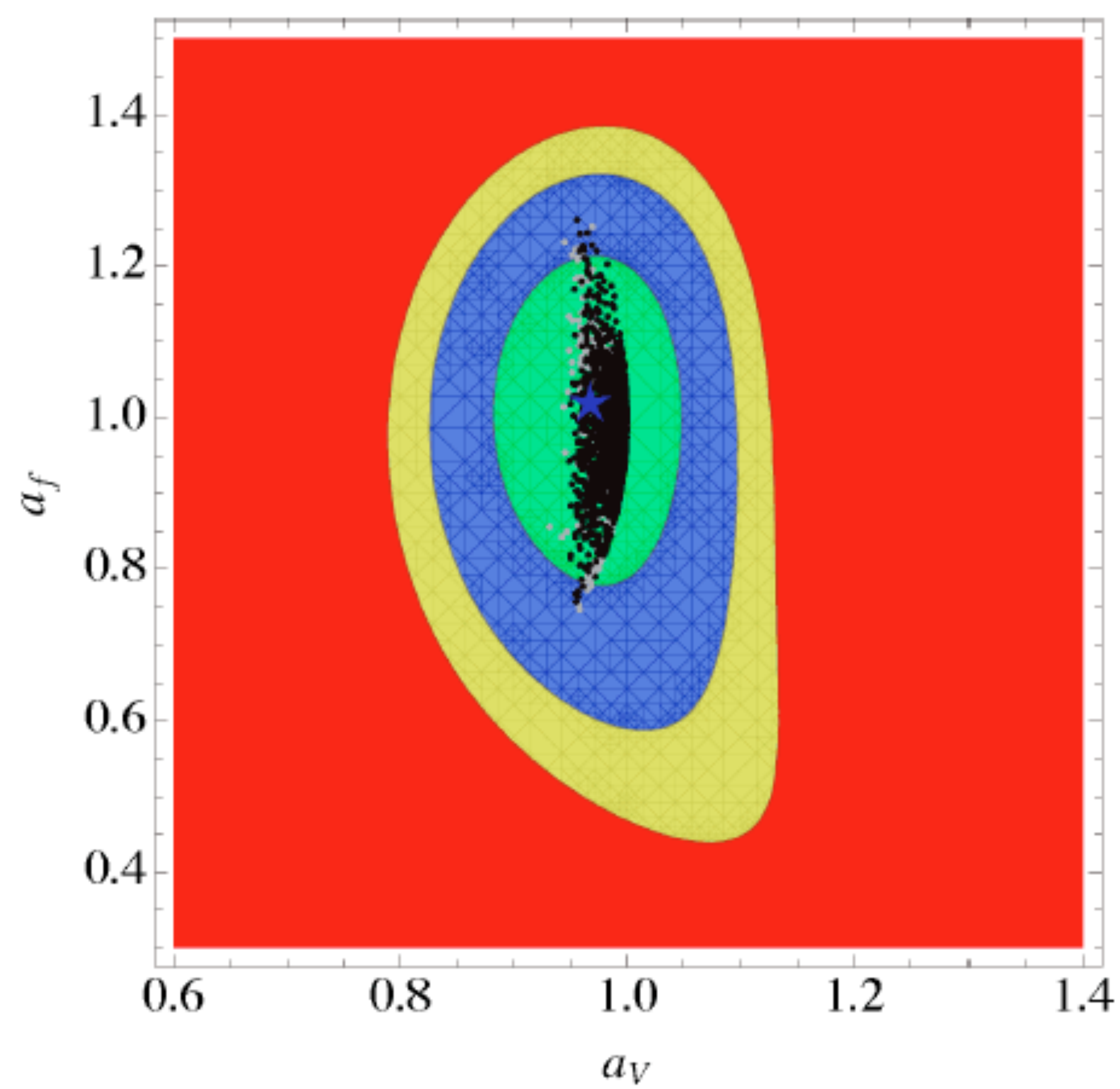
$$m_{W'} \sim 1\,\mathrm{TeV}$$

OK with ATLAS search on sequential W'



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The naturality paradigm (simplified):

- New physics needed to explain the origin of $v_{\rm weak} \sim F_\pi$

- Typically implies a rich spectrum around $\Lambda \sim 4\pi F_\pi$

- SM is an eff. theory below Λ
  No hierarchy problem

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  No hierarchy problem

But SM never had the hierarchy problem!

(-- all radiative corrections are logarithmic if
there is no physical scale above EW scale.)

3. A paradigm shift?

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weakly coupled dark matter,
and have no obvious new dofs (beyond Higgs)?

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(Compare with the copernican principle in cosmology)

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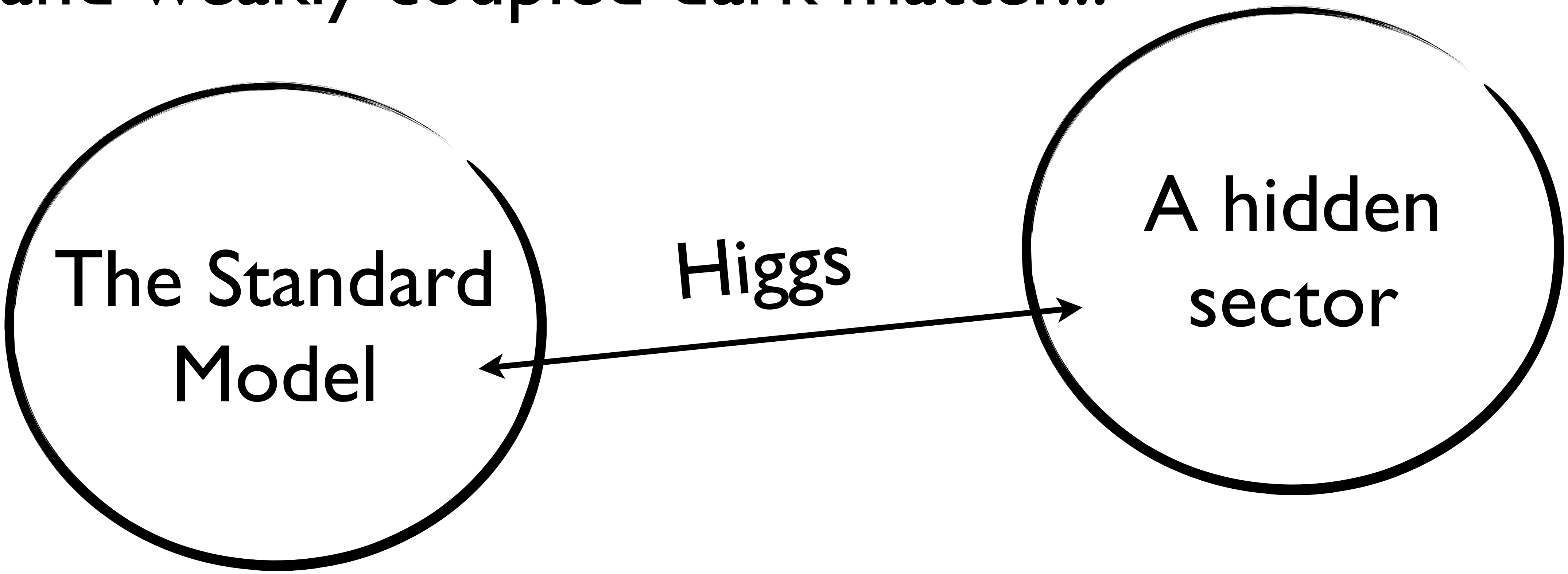

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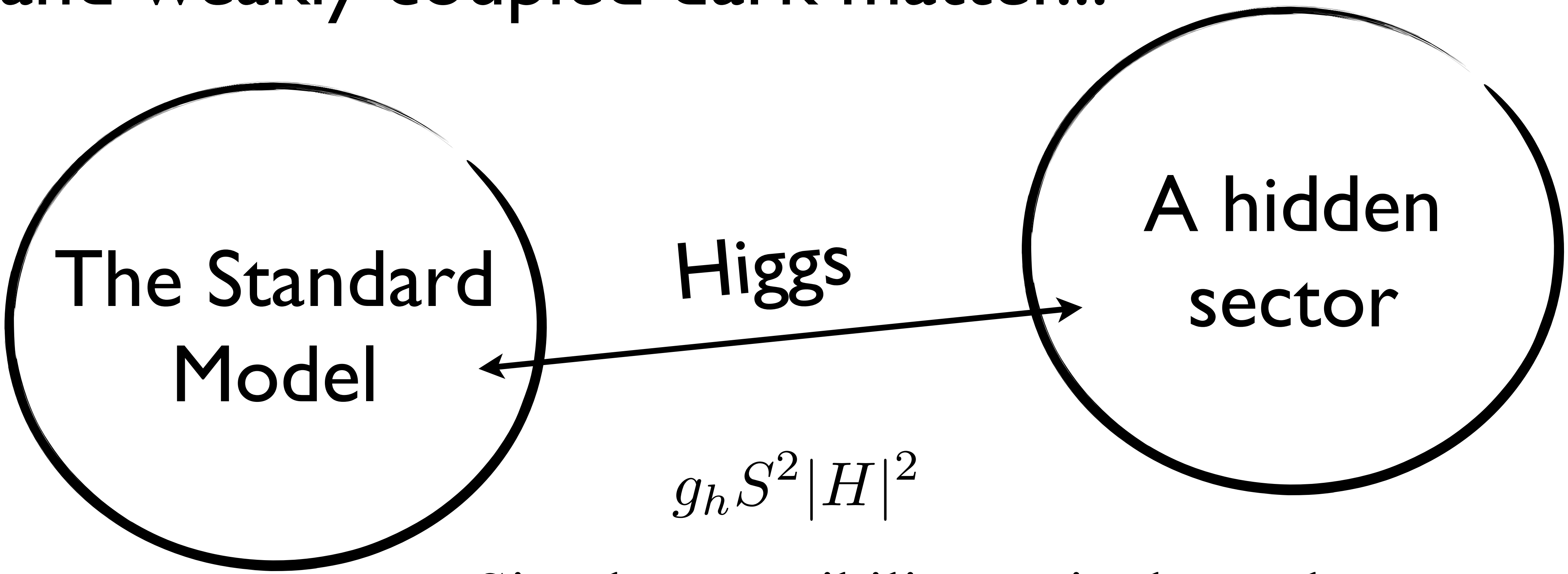

Simplest possibility: a singlet scalar

(e.g. Silveira & Zee 85, Mcdonald 94,...)

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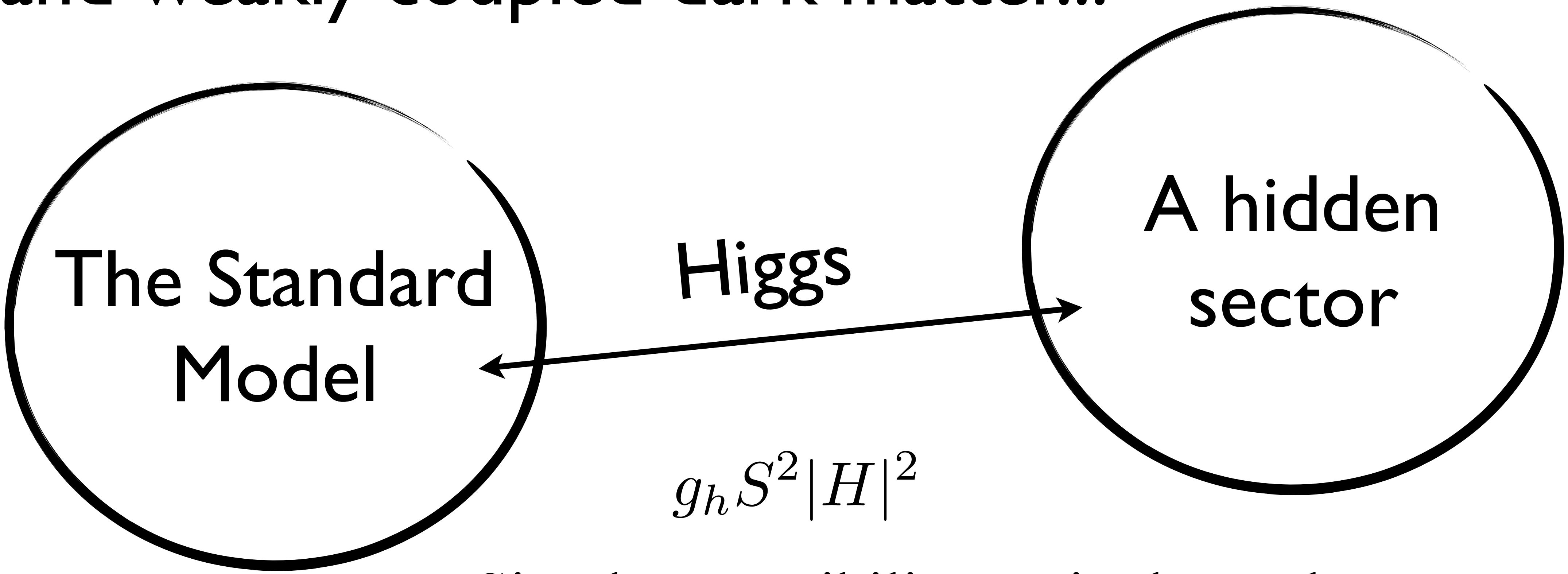

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A novel possibility: complex scalar with U(1) charge & BEC.
Leads to EW scale and protects it from radiative corrections.

(Sannino, Tuominen 2003)

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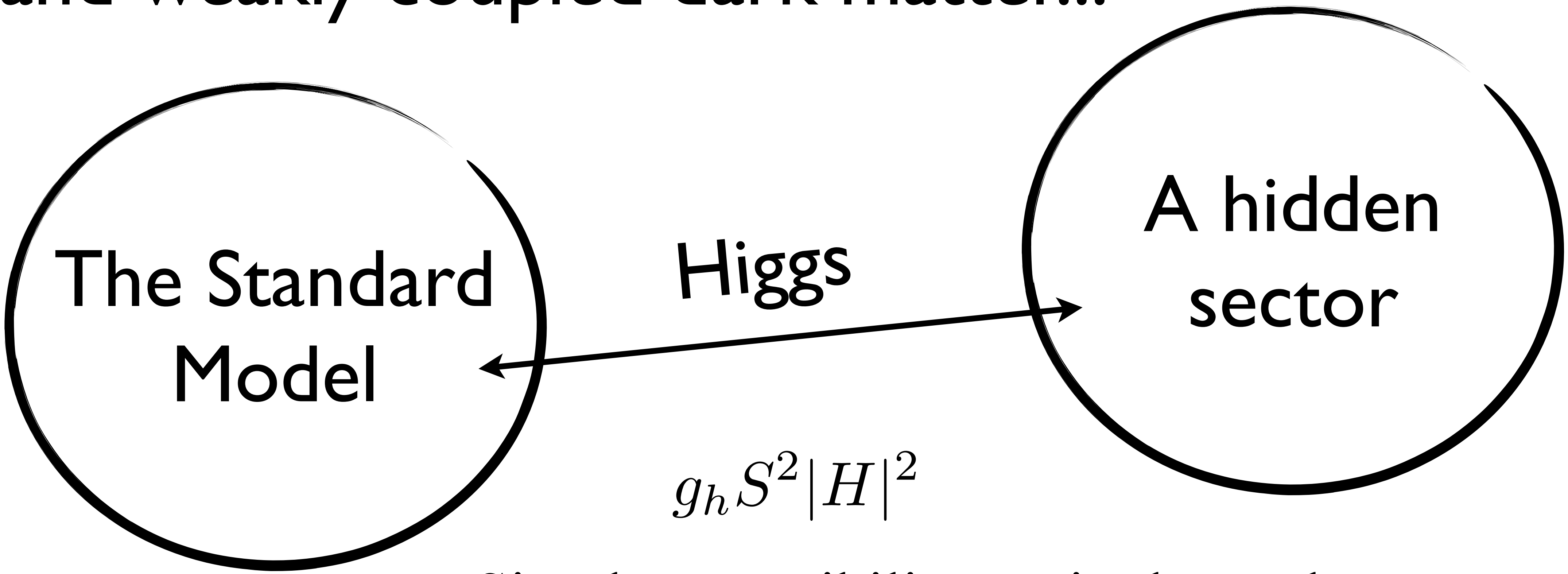

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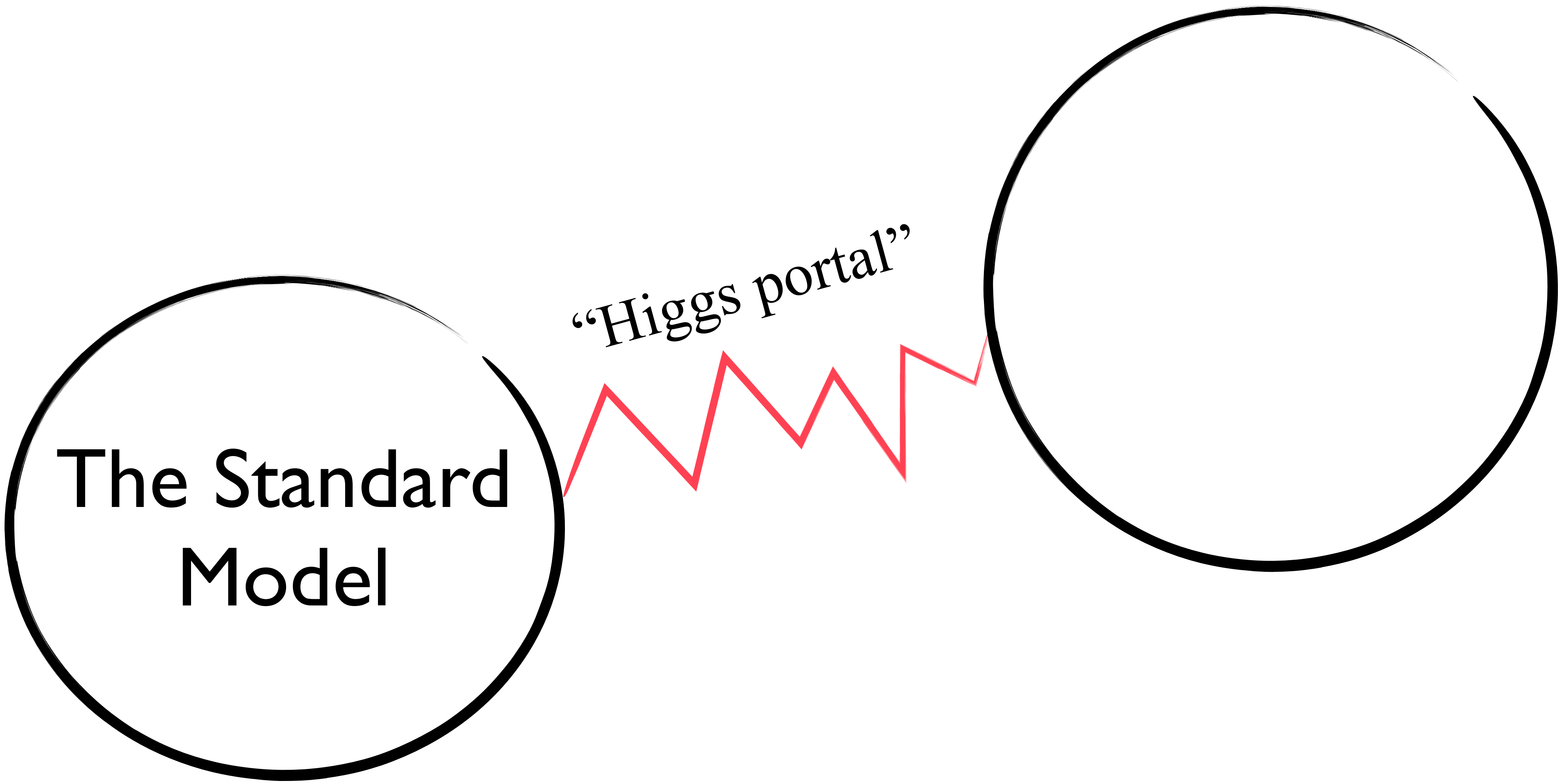
Combine this picture with scale invariance.

Example (toy) model: Dark (Techni)color



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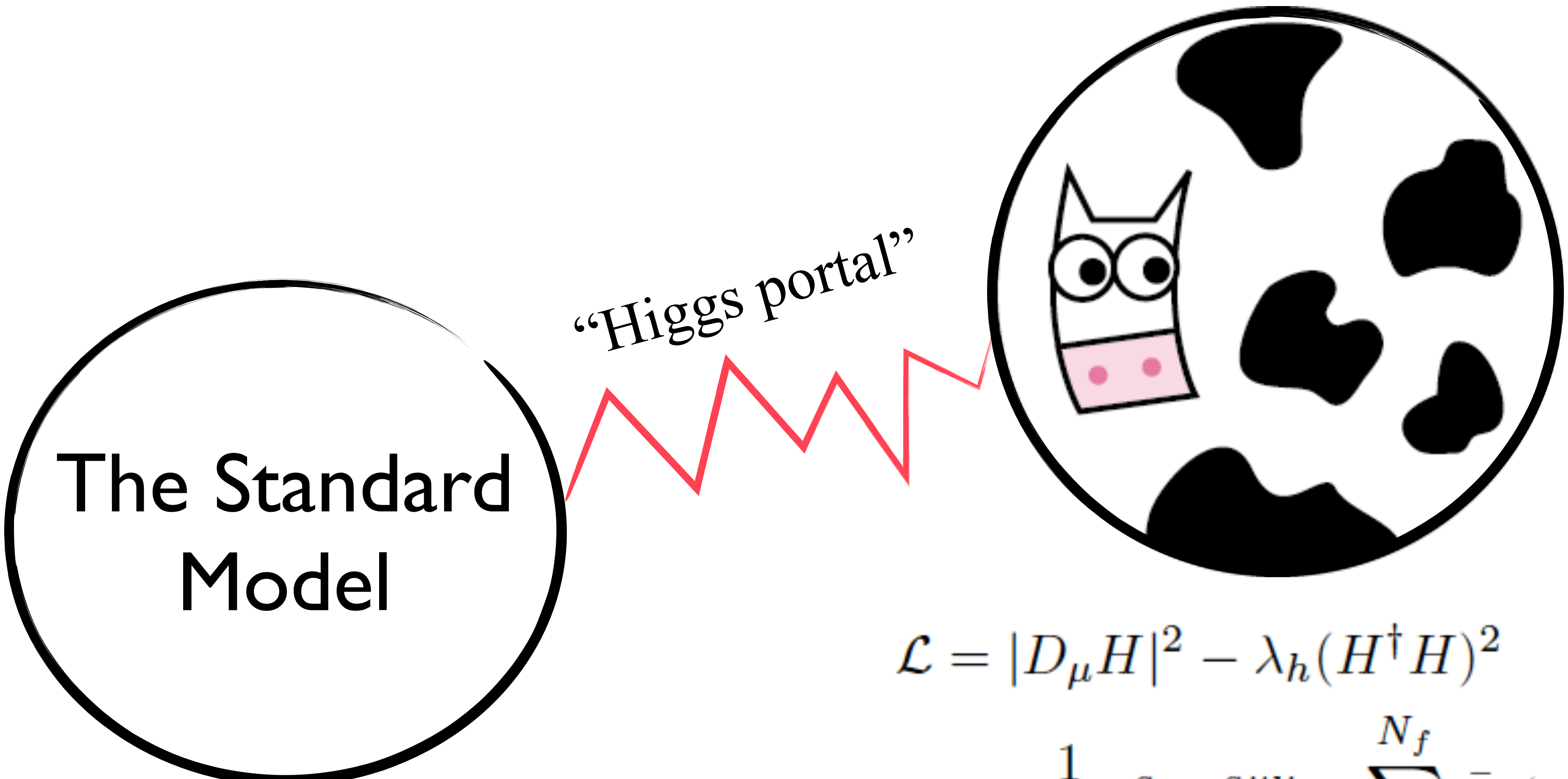

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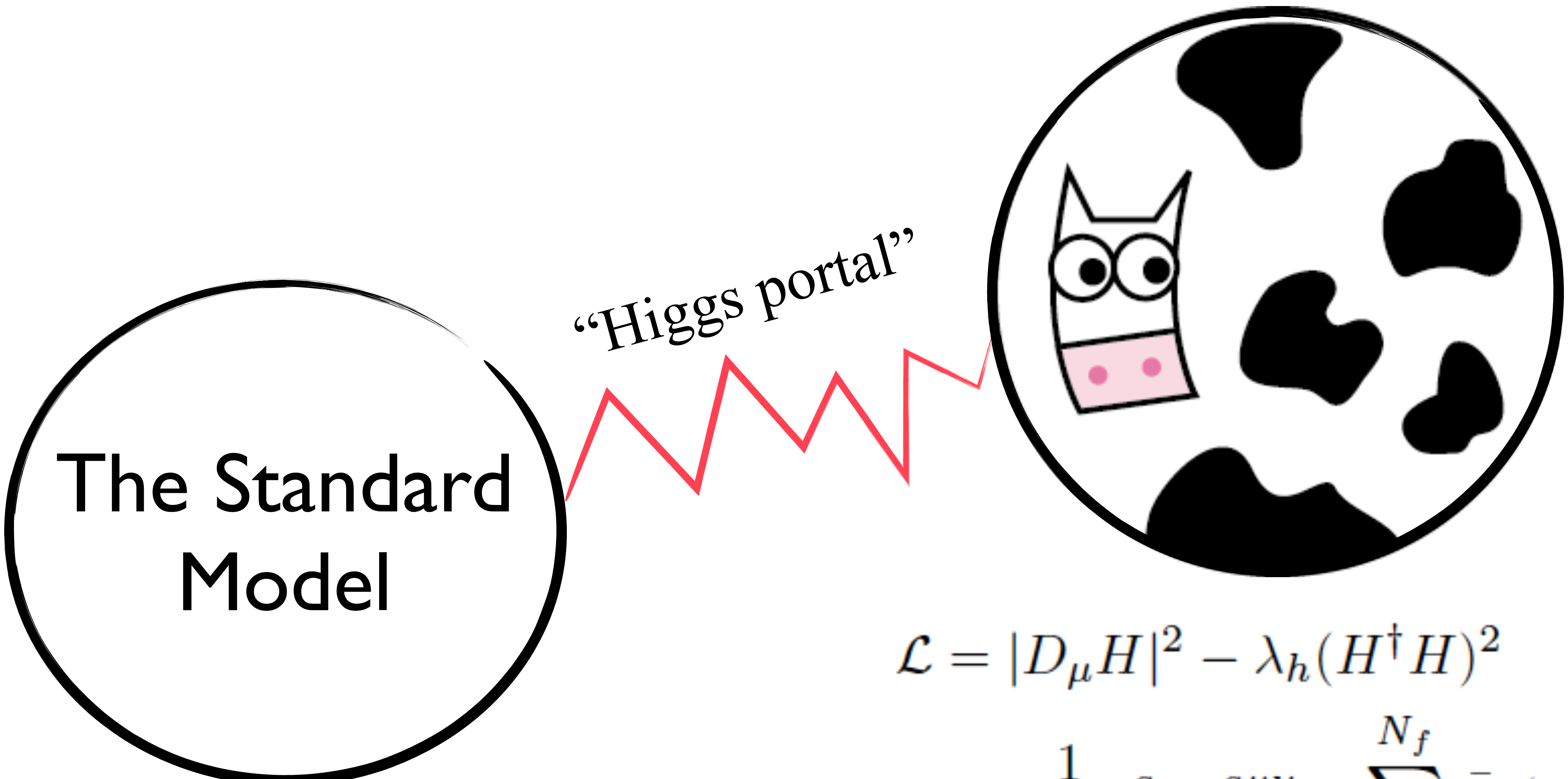

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No explicit scales.
Dynamical breaking: $\langle \bar{Q} Q \rangle \sim v_\sigma^3$

(Hur & Ko, 2011; Heikinheimo et al. 2013)

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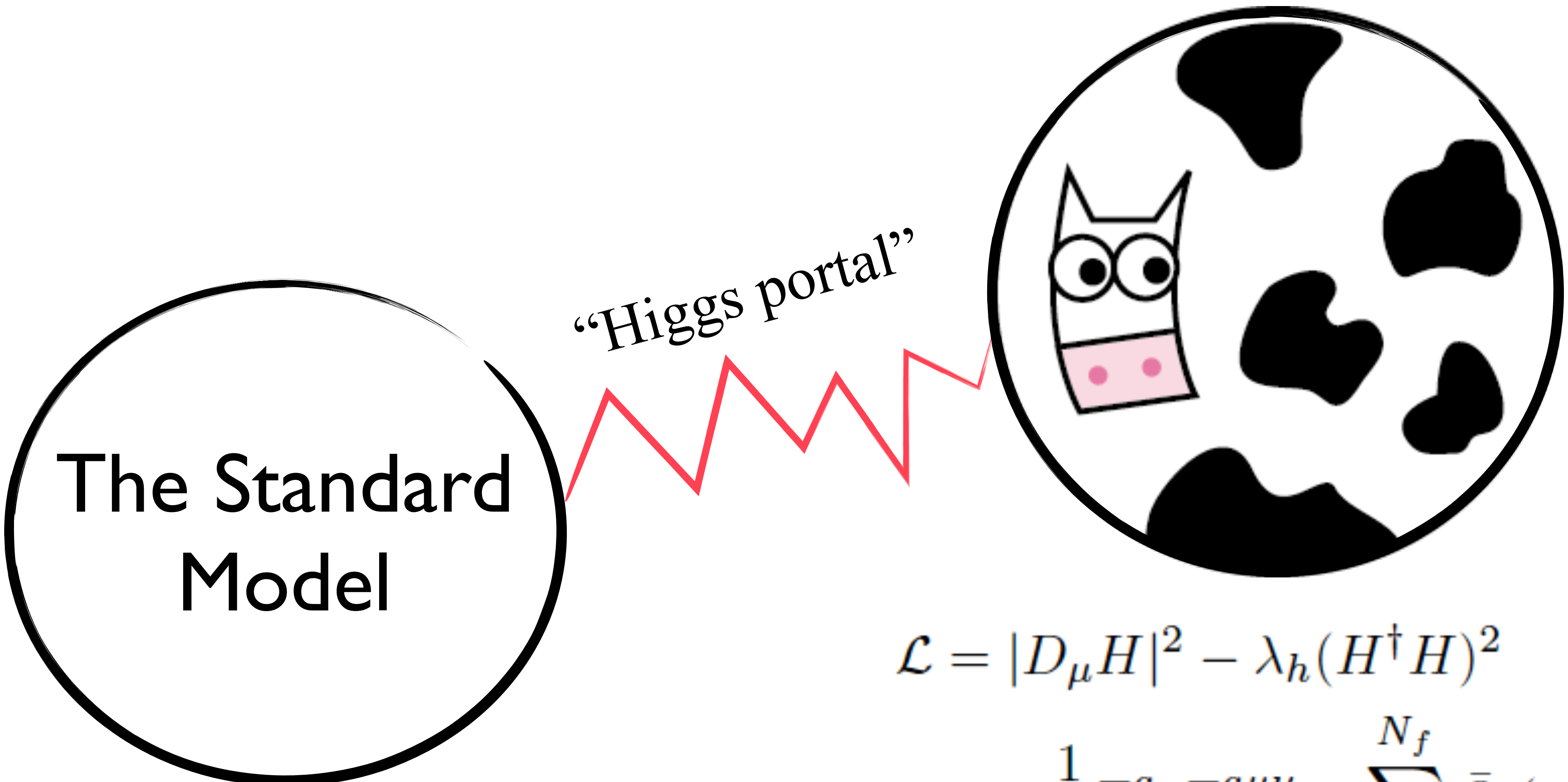

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$$\langle s \rangle = \alpha v_\sigma ,$$
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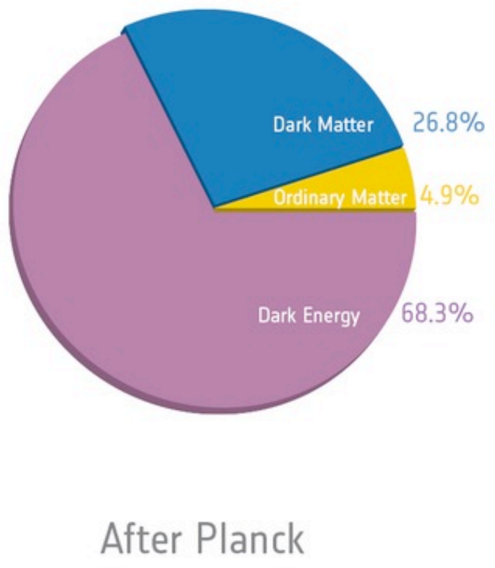
Several novel dark matter candidates:
- Lightest (pseudo) goldstone boson
- Lightest dark baryon



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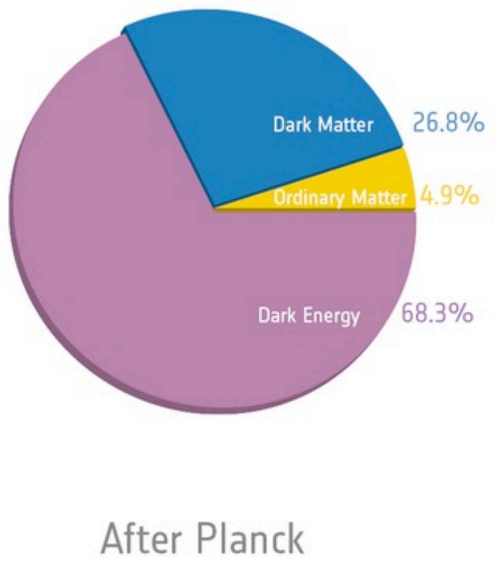

Maybe we should consider a dark *sector?*

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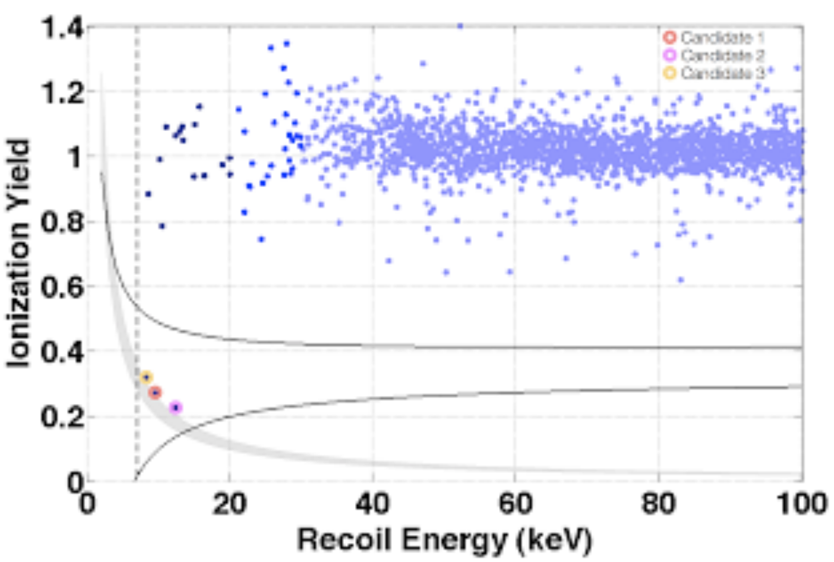
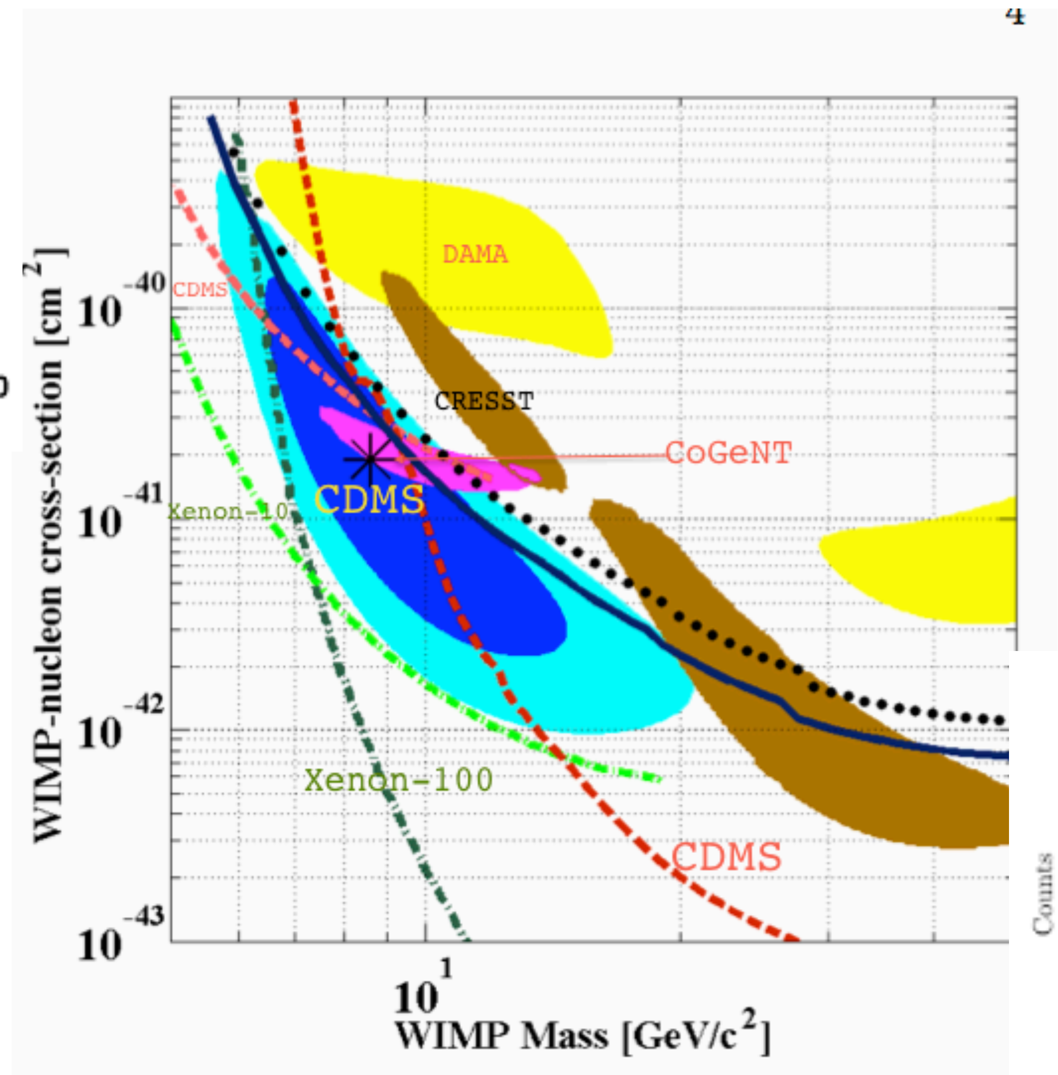
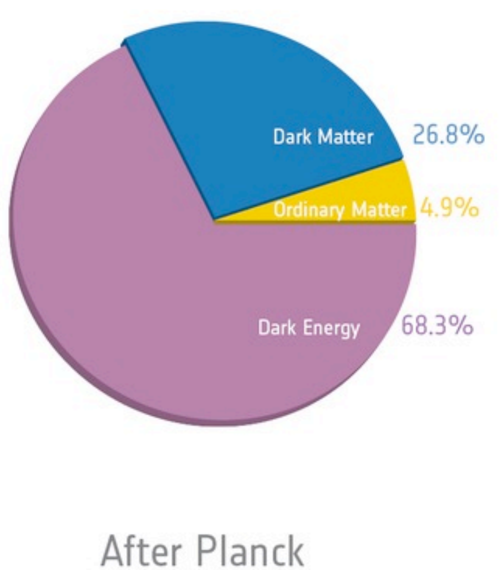
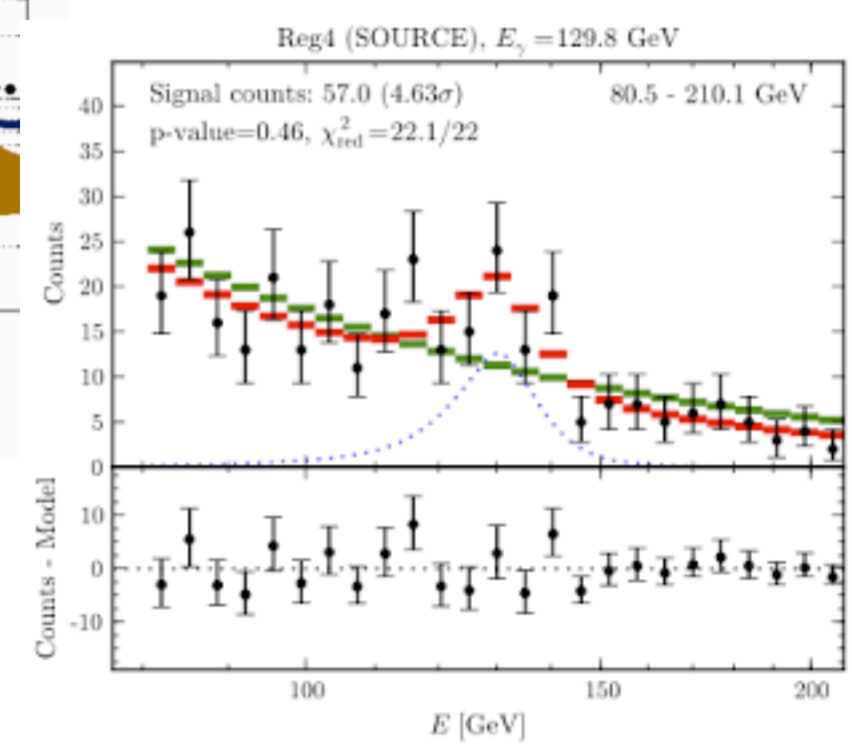


(CDMS collab. 2012)







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(Weniger, 2012)

Conclusions

Discovery of only SM-like Higgs leads to stringent cuts in theory space.

Origin of Fermi scale remains unexplained; need new physics.

Some traditional models of DEWSB remain viable
and predict states accessible to LHC.

New directions needed?; revised paradigm of naturality?; a sector of dark matter?

(Quasi) Conformal (gauge) theories expected to play a major role.