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Canada's national laboratory for particle and nuclear physics
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A new take on dark matter in Little Higgs models

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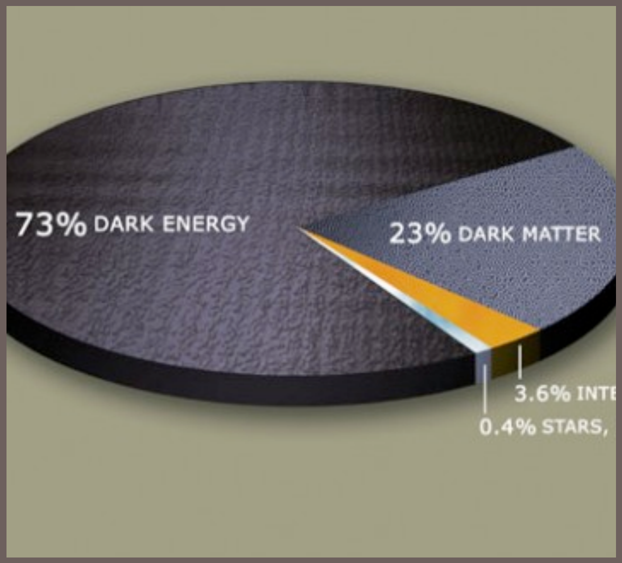
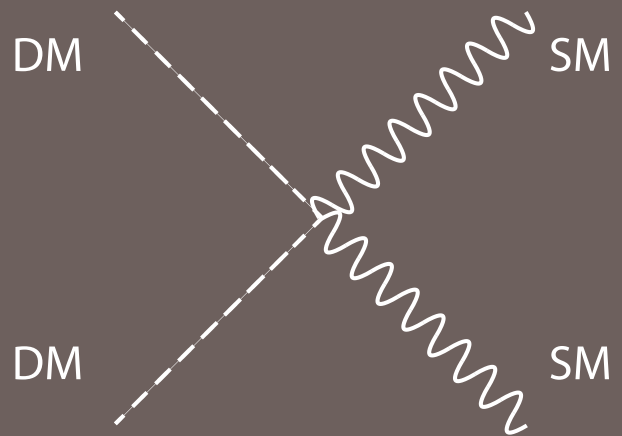
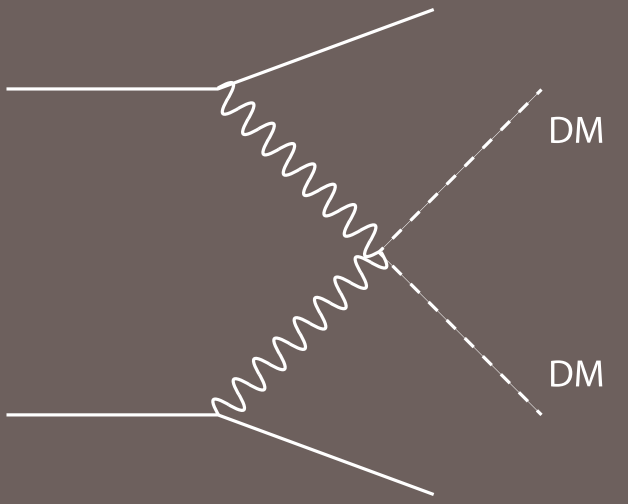
Based on arXiv:1304.7835
In collaboration with Travis Martin, TRIUMF







Overview

- Collective Symmetry Breaking
- Motivation
- Dark Little Higgs Models
- Next to Littlest Higgs

Collective Symmetry Breaking

- Little Higgs models are extensions of the Standard Model (SM) that stabilize the electroweak scale with a light Higgs boson.

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Collective Symmetry Breaking

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Collective Symmetry Breaking

- Little Higgs models are extensions of the Standard Model (SM) that stabilize the electroweak scale with a light Higgs boson.

- Fine tuning problem is solved by embedding the SM Higgs boson within a non-linear sigma field and introducing new heavy gauge bosons and fermions.

- Scalar potential undergoes collective symmetry breaking → leads to cancellation of quadratic divergences.

Collective Symmetry Breaking

- Toy Model:
  - Broken Global Symmetry at a scale f:

$$SU(3) \to SU(2)$$

  - Parametrize Nambu–Goldstone bosons (NGBs):

$$\Sigma(x) = \frac{1}{f} exp\left(\frac{2i\pi^a(x)X^a}{f}\right)\Sigma_0 \qquad \Sigma_0 = (0, 0, f)$$

  - Dynamics are determined by:

$$\mathcal{L}_{\rm kin} = f^2 \partial_\mu \Sigma^\dagger \partial^\mu \Sigma$$

Collective Symmetry Breaking

- Toy Model:
  - Would like to identify one of the NGBs with the SM-like Higgs boson... 4/5 degrees of freedom.
  - Need to incorporate gauge interactions: This is done by gauging a subgroup of the full SU(3) symmetry:

$$\partial_\mu \to D_\mu = \partial_\mu - igW_\mu^a(x)Q^a$$

  - Mass term and quartic self-interaction are radiatively generated:

$$\mu^2 \sim \frac{g^2}{16\pi^2}\Lambda^2, \quad \lambda \sim \frac{g^2}{f^2}\frac{1}{16\pi^2}\Lambda^2$$

  - Theory valid up to $\Lambda \sim 4\pi f$.

Collective Symmetry Breaking

- Toy Model:
  - A Higgs mass below 245 GeV requires f~200-300 GeV: $\Lambda \sim 3\ \mathrm{TeV}$
  - However EWPD requires $\Lambda \sim 10\ \mathrm{TeV}$... We now have a 125 GeV SM-like Higgs boson.
  - Can this toy model be modified such that one-loop quadratic divergent corrections to Higgs mass vanish?

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Collective Symmetry Breaking

- Toy Model:
  - Follow same idea of G/H breaking at a scale f:
  - However a subgroup $G_1 \times G_2 \times \ldots$is gauged, each containing an $SU(2) \times U(1)$ subgroup.
  - Furthermore each of the G_i commutes with a subgroup of G that acts non-linearly on the Higgs.
  - Full $G_1 \times G_2 \times \ldots$ needs to be gauged for SM-like Higgs boson to acquire a mass... Non-vanishing quantum corrections must be proportional to all gauge couplings.

Little Higgs Models

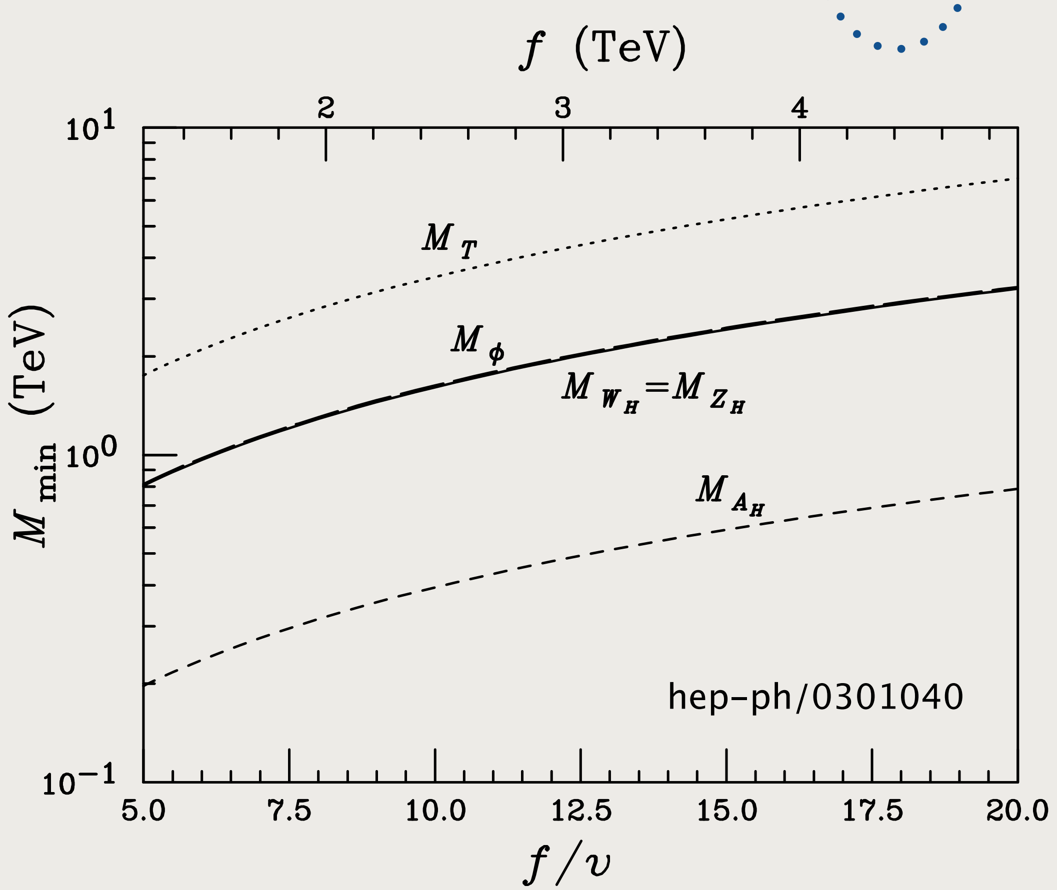
- Non–linear sigma model w/ collective symmetry breaking: $SU(5)/SO(5)$
- New states cancel quadratic divergences
  - t ↔ T
  - W/Z ↔ W'/Z'
- EWSB induced from top loop contributions to Higgs mass

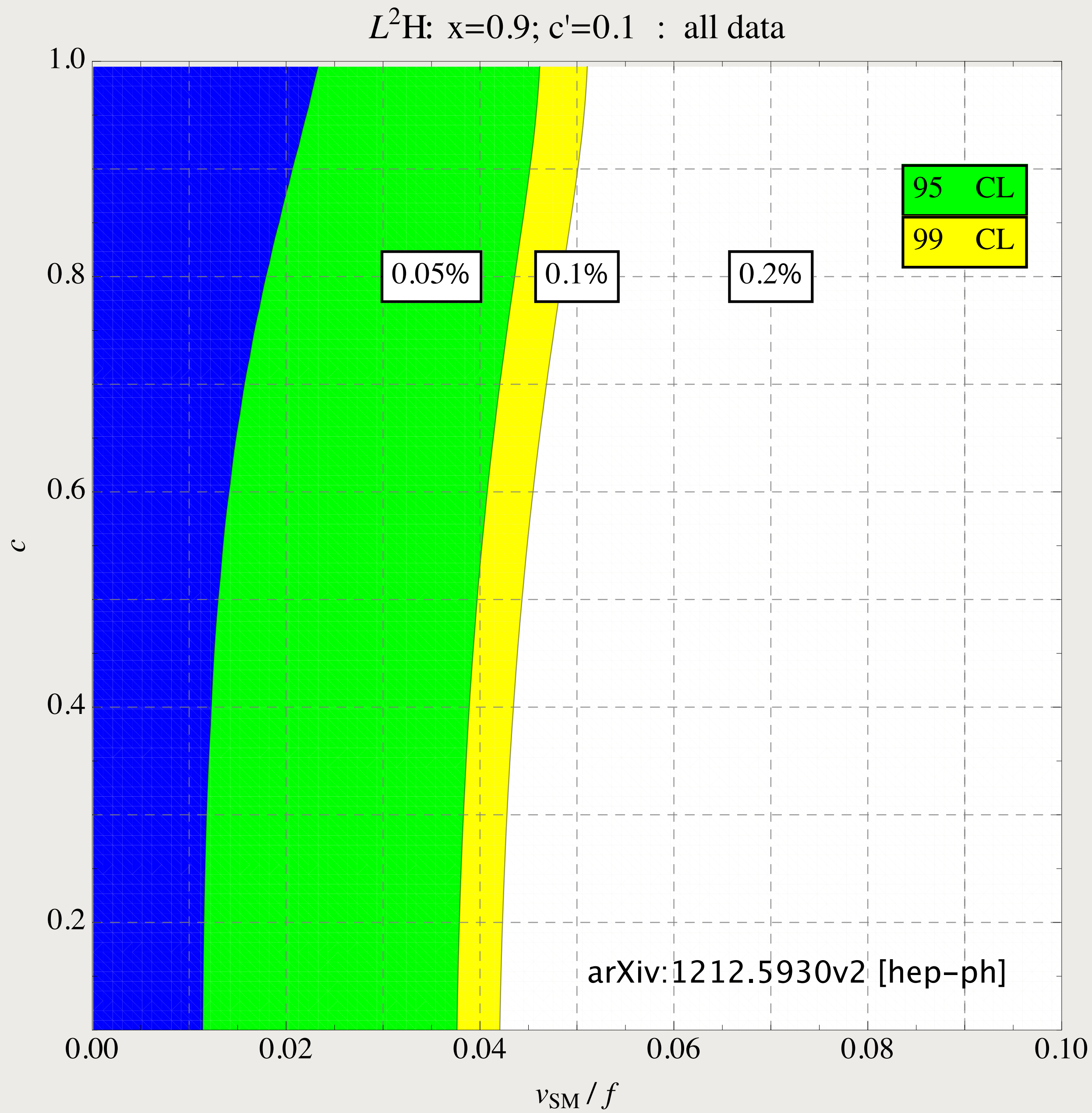
Littlest Higgs Model

- Constraints

$$M_T \gtrsim m_t \frac{2f}{v}$$

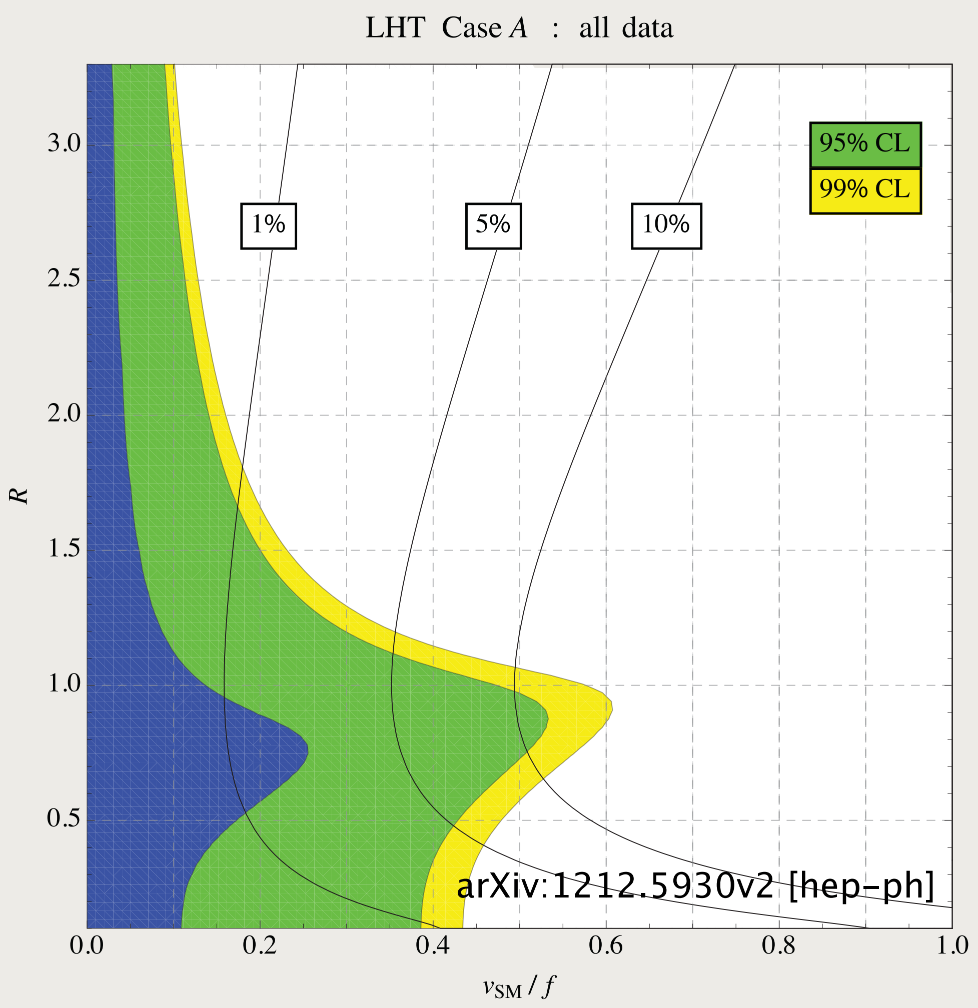
$$M_{W_H} \gtrsim m_W \frac{2f}{v}$$

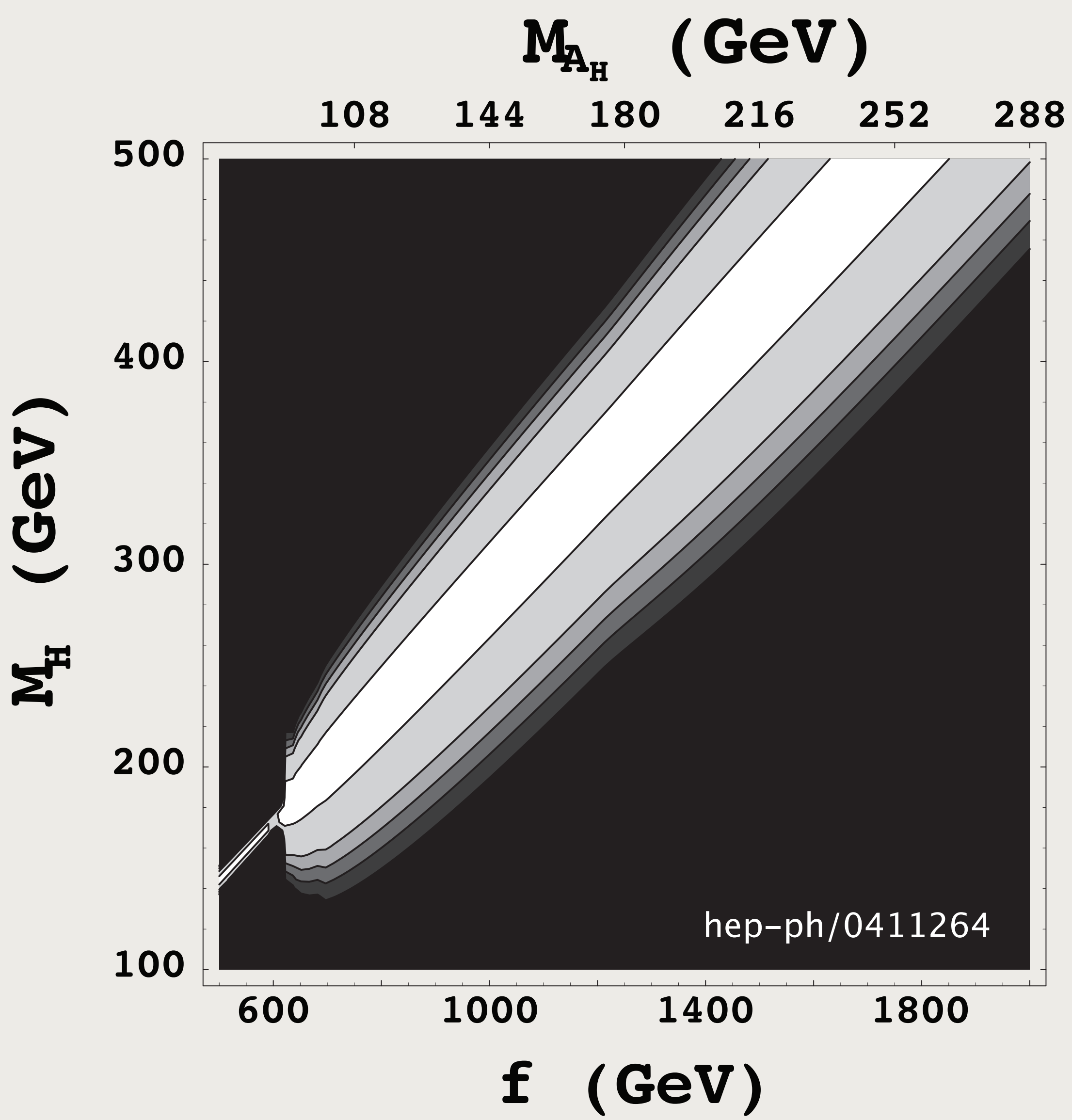




Littlest Higgs with T-Parity

- EWPO relaxed
- Light Higgs limits DM viability





Dark Little Higgs

- Question: Can we resolve (some of) the constraints on the Littlest Higgs and introduce dark matter, all without introducing T–parity?
- Claim: Yes.

Dark Little Higgs

- Separate W' and T masses.
- Little Higgs-ing the Inert Doublet Models.

Dark Little Higgs

- Little Higgs-ing the Inert Doublet Models

- Separate W' and T masses: (arXiv:1006.1356)
  - Introduce second (duplicate) coset space
    - G_S/H_S breaking at scale f
    - G_D/H_D breaking at scale F ($>f$)
  - Both global symmetries gauged the same
  - Fermions transform only under H_S

- $M_{W'}^2 \sim$ Const. $(f^2 + F^2)$ $M_T^2 \sim$ Const. (f^2)

Next to Littlest Higgs

- $SU(5)_S/SO(5)_S$

$$\Pi_\Sigma = \begin{pmatrix} 0 & h^\dagger/\sqrt{2} & \phi^\dagger \\ h/\sqrt{2} & 0 & h^*/\sqrt{2} \\ f & h^T/\sqrt{2} & 0 \end{pmatrix} + (Q_1^a - Q_2^a)\eta^a + \sqrt{5}(Y_1 - Y_2)\sigma$$

$SU(5)_D/SO(5)_D$

$$\Pi_\Delta = \begin{pmatrix} 0 & \xi^\dagger/\sqrt{2} & \chi^\dagger \\ \xi/\sqrt{2} & 0 & \xi^*/\sqrt{2} \\ \chi & \xi^T/\sqrt{2} & 0 \end{pmatrix} + (Q_1^a - Q_2^a)\alpha^a + \sqrt{5}(Y_1 - Y_2)\beta$$

	Σ		
2h doublets	h	ξ	
2 ꜧ triplets	ϕ	χ	
1 $\mathbb{R}$ triplet	$\rightarrow \eta \leftarrow$		(a)
1 $\mathbb{R}$ singlet	$\rightarrow \sigma \leftarrow$		(b)

Next to Littlest Higgs

- Add to scalar kinetic terms

$$L_K = \frac{f^2}{8} \mathrm{Tr}[(D_\mu \Sigma)(D^\mu \Sigma)^\dagger] + \frac{F^2}{8} \mathrm{Tr}[(D_\mu \Delta)(D^\mu \Delta)^\dagger]$$

- Yukawa interactions unchanged

$$L_Y = \frac{1}{2}\lambda_1 f \epsilon_{ijk} \epsilon_{xy} \chi_i \Sigma_{jx} \Sigma_{ky} u_3'^c + \lambda_2 f \tilde{t}\tilde{t}'^c + h.c.$$

- Coleman–Weinberg potential

$$V_{CW} = \frac{\Lambda^2}{32\pi^2} \mathrm{Str}[M^2(\Sigma,\Delta)] + \frac{1}{64\pi^2} \mathrm{Str}[M^4(\Sigma,\Delta)\left(\log\left(\frac{M^2(\Sigma,\Delta)}{\Lambda^2}\right) - \frac{1}{2}\right)]$$

Dark Matter Mass Splitting

$$V = \mu_1^2|H_1|^2 + \mu_2^2|H_2|^2 + \lambda_1|H_1|^4 + \lambda_2|H_2|^4 + \lambda_3|H_1|^2|H_2|^2 + \lambda_4|H_1^\dagger H_2|^2 + \lambda_5 \mathrm{Re}\,[(H_1^\dagger H_2)^2]$$

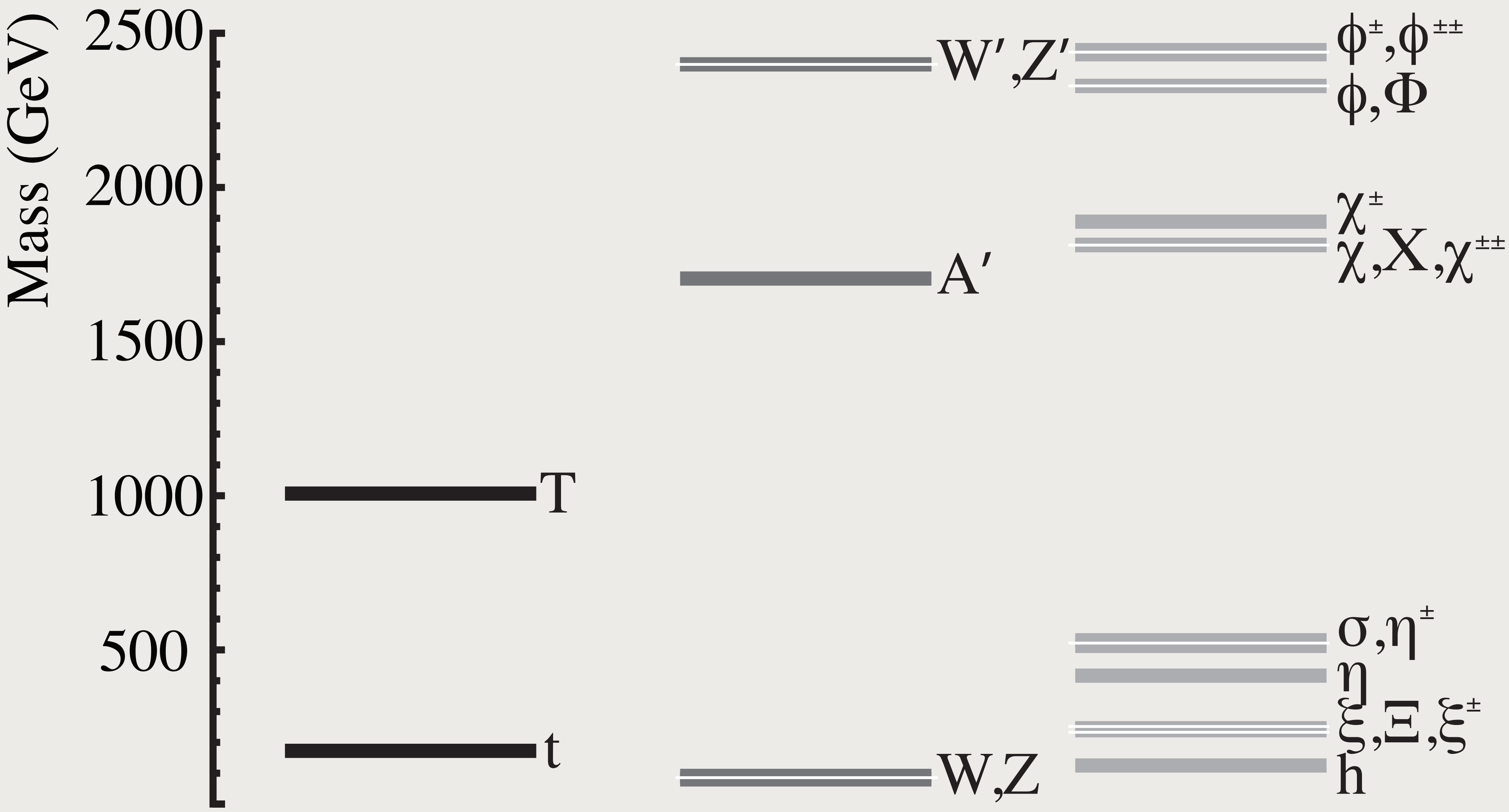
- λ_5 term not generated from CW potential

$$V_{\Sigma\Delta} = -\lambda_{\Sigma\Delta} f^2 F^2 \,\mathrm{Tr}\,[\,T_{\Sigma\Delta}(\Sigma - \Sigma_0)\,T_{\Sigma\Delta}(\Delta - \Delta_0)^\dagger] + \text{h.c.}$$

- $T_{\Sigma\Delta} =$ n_1 Diag[1,1,0,0,0] + n_2 Diag[0,0,0,1,1]
- Need DM_ξ > few hundred keV, so l_{SD} small ($\lambda_{\Sigma\Delta}$ =0.02 → DM_ξ ~ few GeV)

Phenomenology of NLH

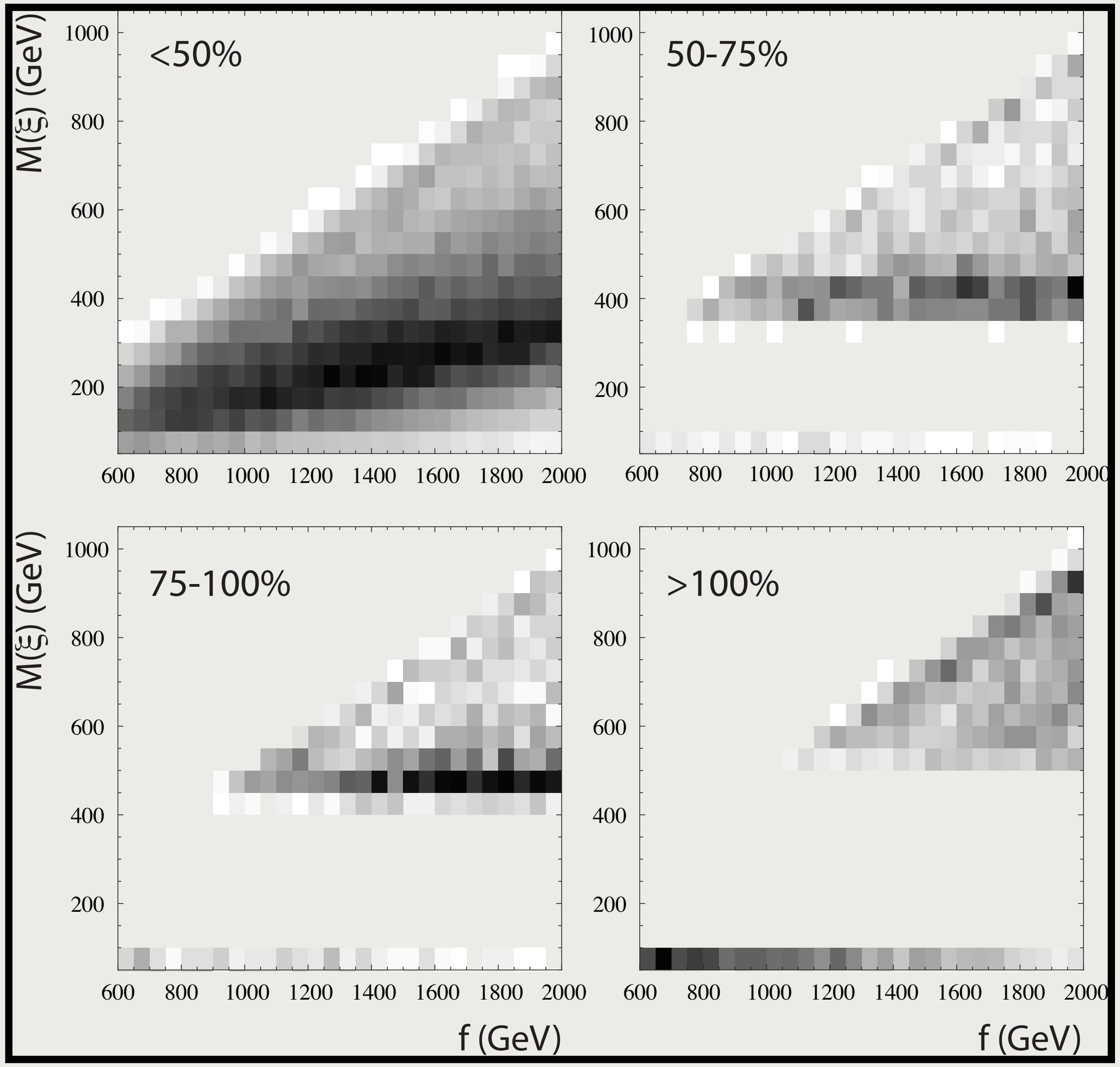
- Sample spectrum



Phenomenology of NLH

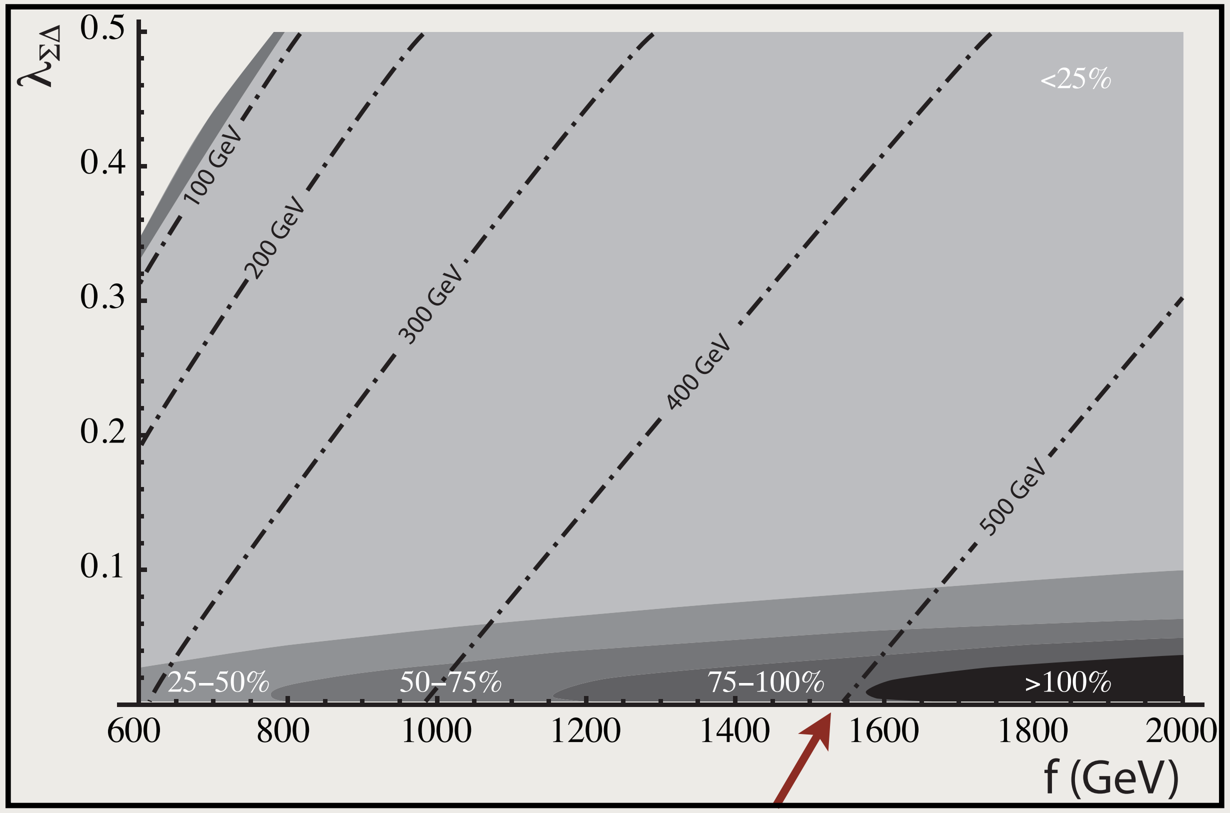
- $\Omega h^2 = 0.1189$ (Planck results) arXiv:1303.5076
- Monte Carlo parameters & use MicrOMEGAs
- 130k parameter sets:

$\Omega h^2/\Omega h^2_{Planck}$	Events
0%–25%	61%
25%–50%	4.4%
50%–75%	2.0%
75%–100%	1.2%
>100%	2.6%
N/A	28.8%



Phenomenology of NLH

- Fix all parameters, vary f & $\lambda_{\Sigma\Delta}$
  - s=0.24, s'=0.24
  - s_t=0.25
  - F=3000 GeV
  - a=1, a'=1



$M_\xi = 505$ GeV

- f=1550 GeV
- $\lambda_{\Sigma\Delta}$ =0.02 → $\mathrm{DM}_\xi = 4.7$ GeV
- $\Omega h^2 = 0.116$

$$\xi\xi \to ZZ \ : \ 77.3\%$$
$$\xi\xi \to hh \ : \ 19.1\%$$
$$\xi\xi \to t\bar{t} \ : \ 3.5\%$$

Summary

- New class of Little Higgs models
- Motivates Inert Doublet models
- Can account for full relic abundance with ~500 GeV dark matter
- Relax precision constraints

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Thank you!

- Acknowledgements
  :
  - Heather Logan
  - Thomas Grégoire
  - David Morrissey

Backup Slides

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Littlest Higgs Model

- SU(5)/SO(5), breaking at scale f ~ O(TeV)
- Gauge $[SU(2)xU(1)]^2$
- One loop log: $m^2 h^2$

$$\mu^2 = \frac{\lambda}{16\pi^2} M_\phi^2 \log\frac{\Lambda^2}{M_\phi^2} + \frac{3}{64\pi^2}\left(3g^2 M_{W'}^2 \log\frac{\Lambda^2}{M_{W'}^2} + g'^2 M_{B'}^2 \log\frac{\Lambda^2}{M_{B'}^2}\right) - \frac{3\lambda_t^2}{8\pi^2} m_T^2 \log\frac{\Lambda^2}{m_T^2}$$

- New particle content:
  - Vector quark – T
  - Gauge partners – A_H, Z_H, $W_H^\pm$
  - Scalars – f^0, $f^\pm$, $f^{\pm\pm}$

Littlest Higgs with T-Parity

- T-Parity: Z_2 symmetry $g_1 = g_2$ $g_1' = g_2'$
  - T-Even:
    - H, $W^\pm$, Z, g, $u/d/e/n$, Q_+
  - T-Odd:
    - f, $W_H^\pm$, Z_H, A_H, Q_-
- Triplet vev forbidden
- Avoid precision constraints from W_H/Z_H

Positive Singlet Mass

- $M_s^2 < 0$, leads to singlet vev (bad!)

- Introduce new term:

$$V_\Delta = \lambda_\Delta F^4 \, Tr\, [T_\Delta (\Delta - \Delta_0) T_\Delta (\Delta - \Delta_0)^\dagger]$$

- T_D = Diag[0,0,1,0,0]