A new take on dark matter in Little Higgs models

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Based on arXiv:1304:7835
Written in collaboration with
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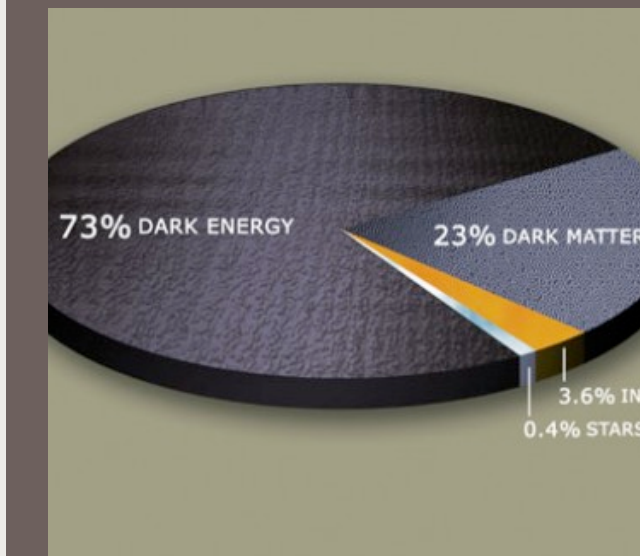
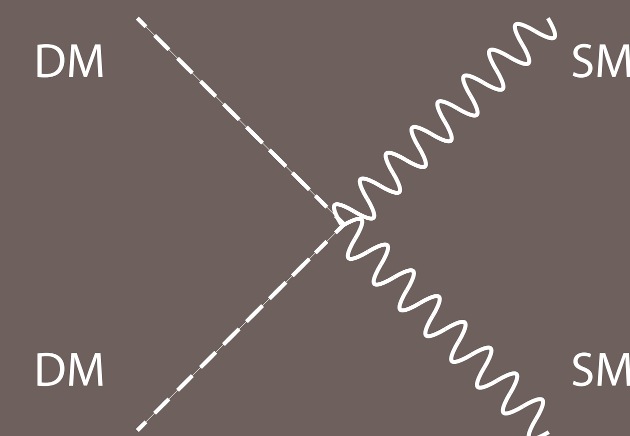
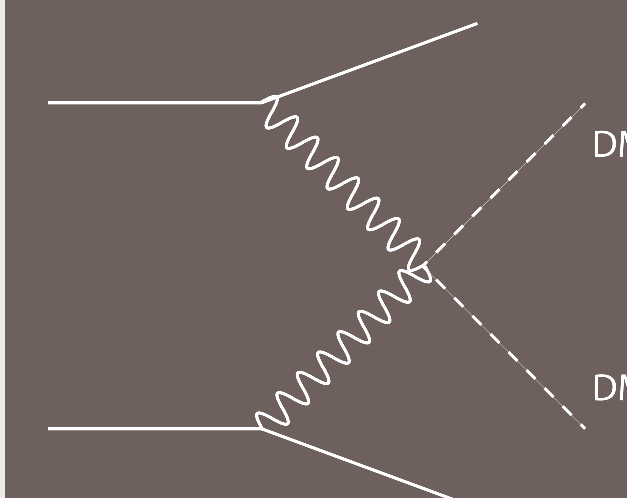






Overview

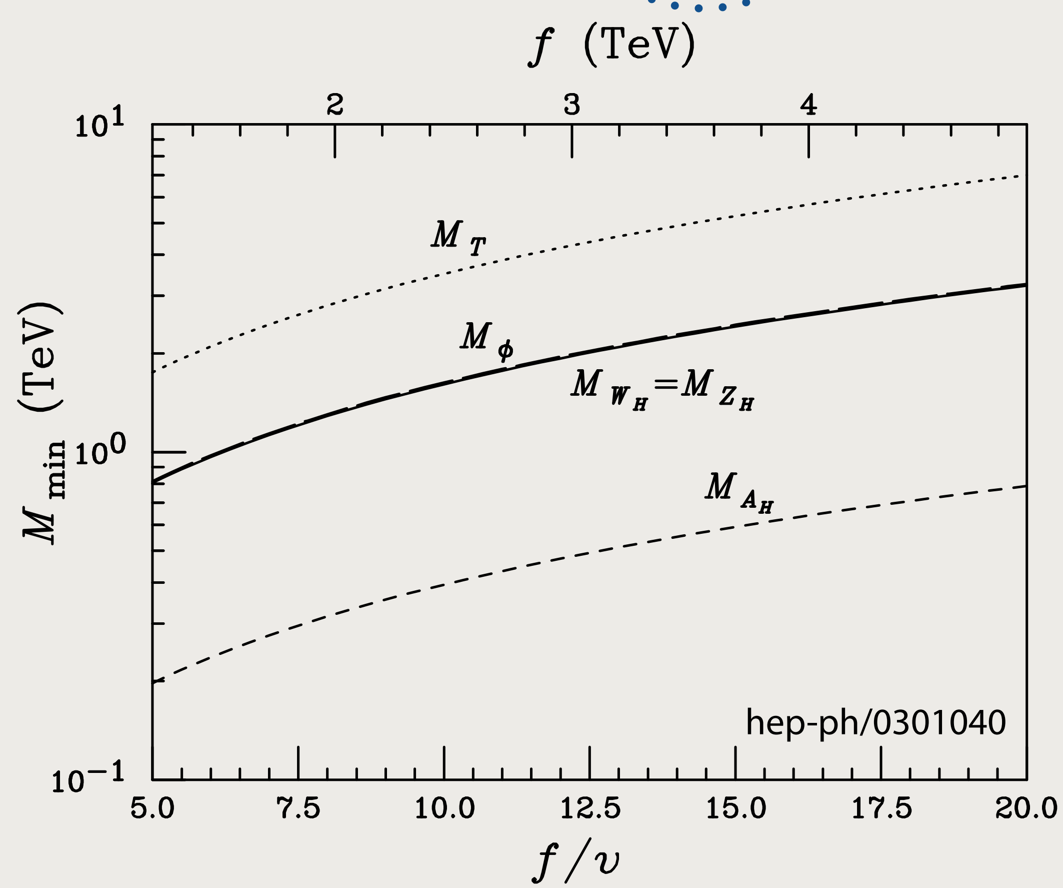
- Motivation
- Dark Little Higgs Models
- Next to Littlest Higgs

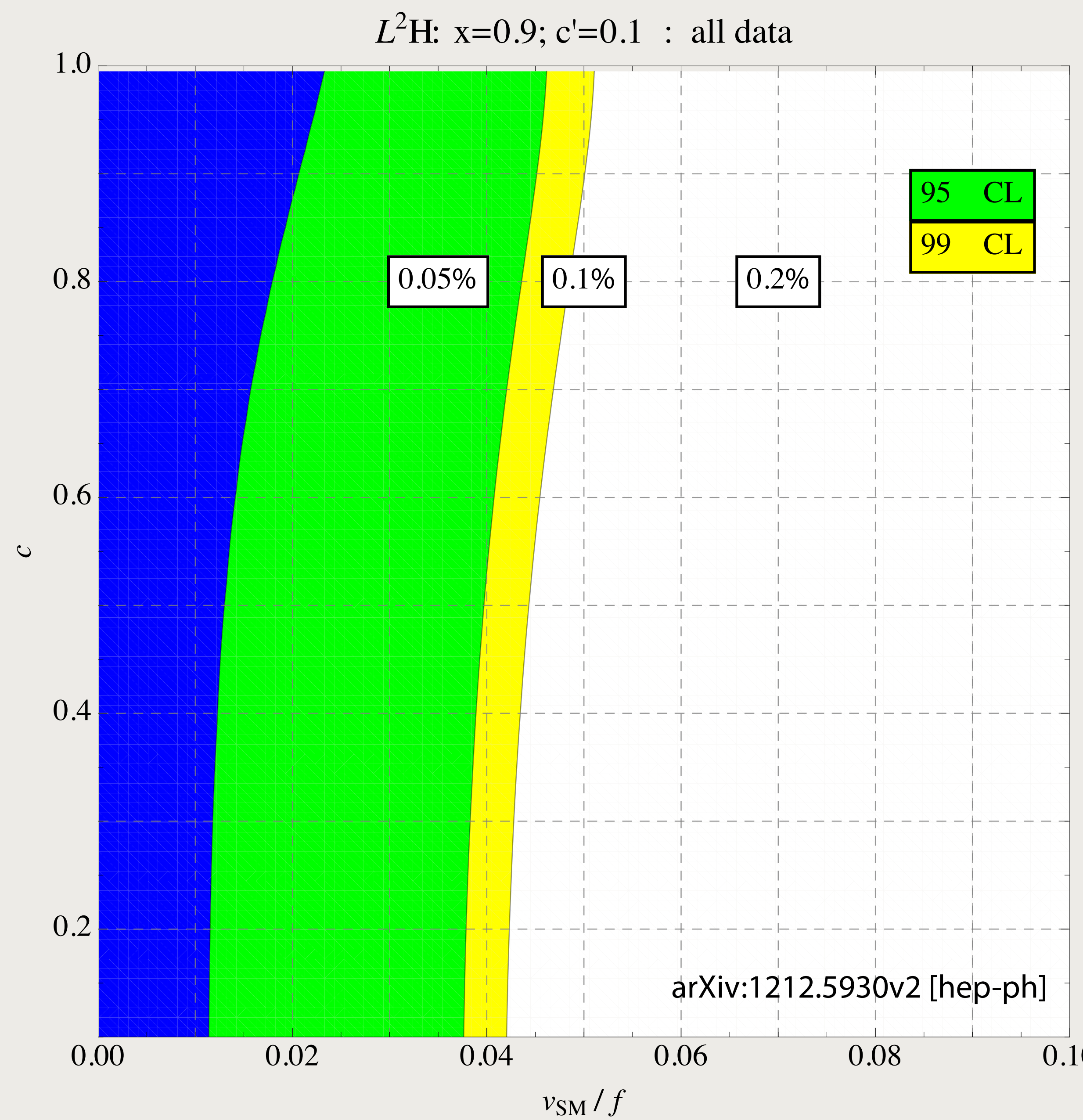
Littlest Higgs Model

- Constraints

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

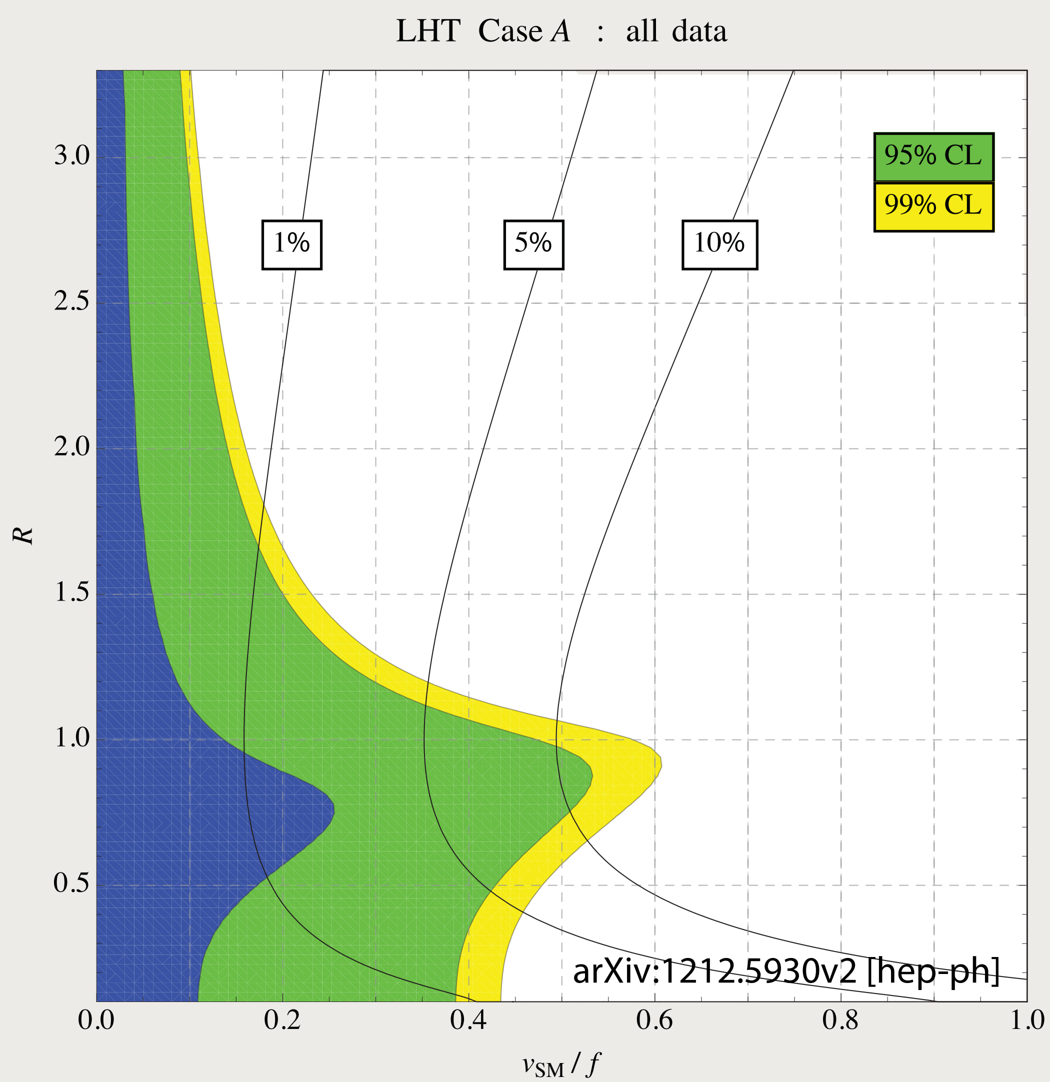
$$M_{W_H} \gtrsim m_w \frac{2f}{v}$$

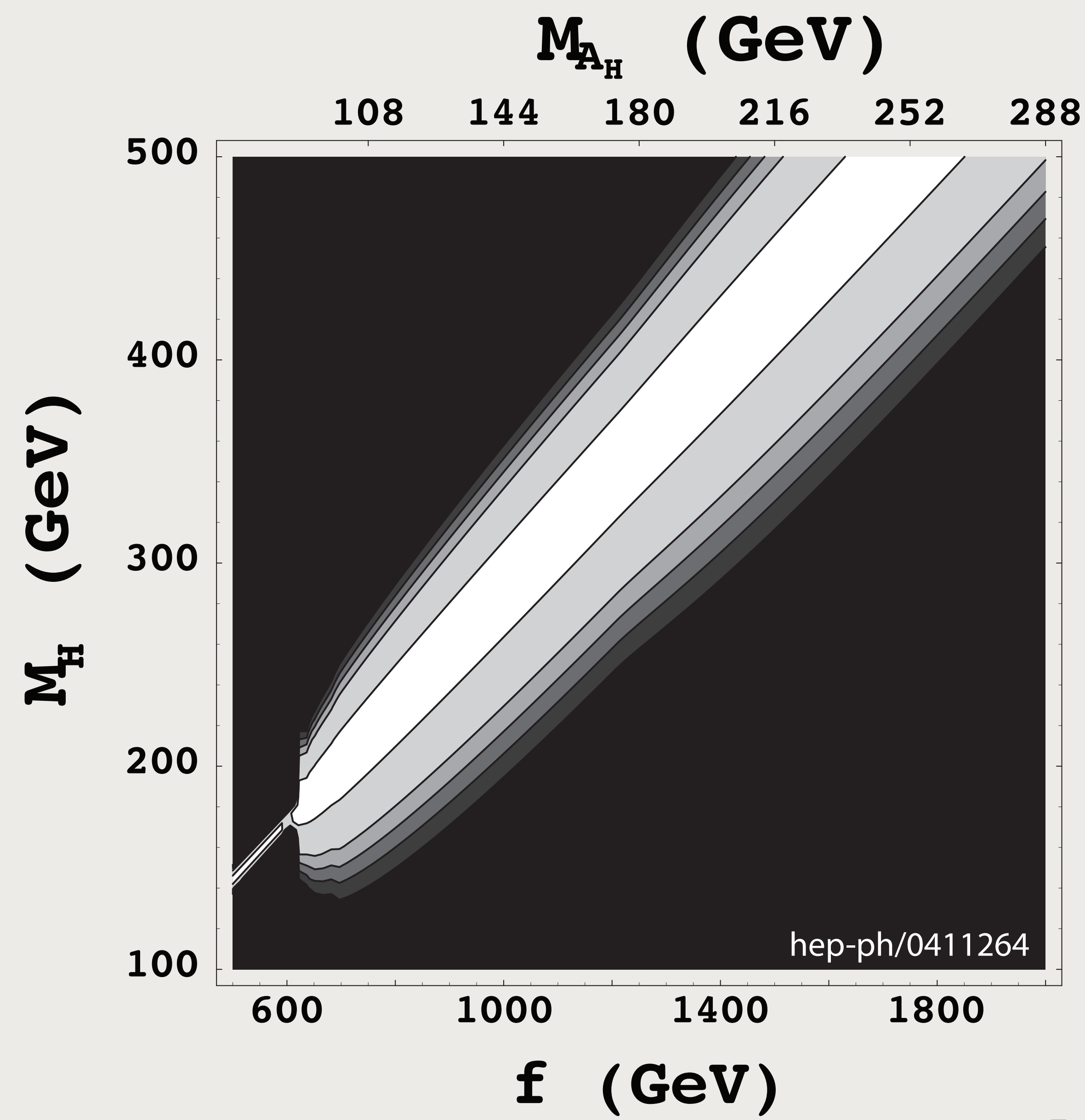




Littlest Higgs with T-Parity

- EWPO relaxed
- Light Higgs limits DM viability





Dark Little Higgs

- Question: Can we resolve (some of) the constraints on Little Higgs models, while introducing dark matter, all without T-parity?

- Claim: Yes.

Dark Little Higgs

- Little Higgs-ing the Inert Doublet Models

- Separate W' and T masses:
  - Introduce second (duplicate) global symmetry (arXiv:1006.1356)
    - G_Σ/H_Σ breaking at scale f
    - G_Δ/H_Δ breaking at scale F (>f)
  - Both global symmetries gauged the same
  - *Fermions transform only under H_Σ*

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

Next to Littlest Higgs

- Add to scalar kinetic terms

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

- Yukawa interactions unchanged

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

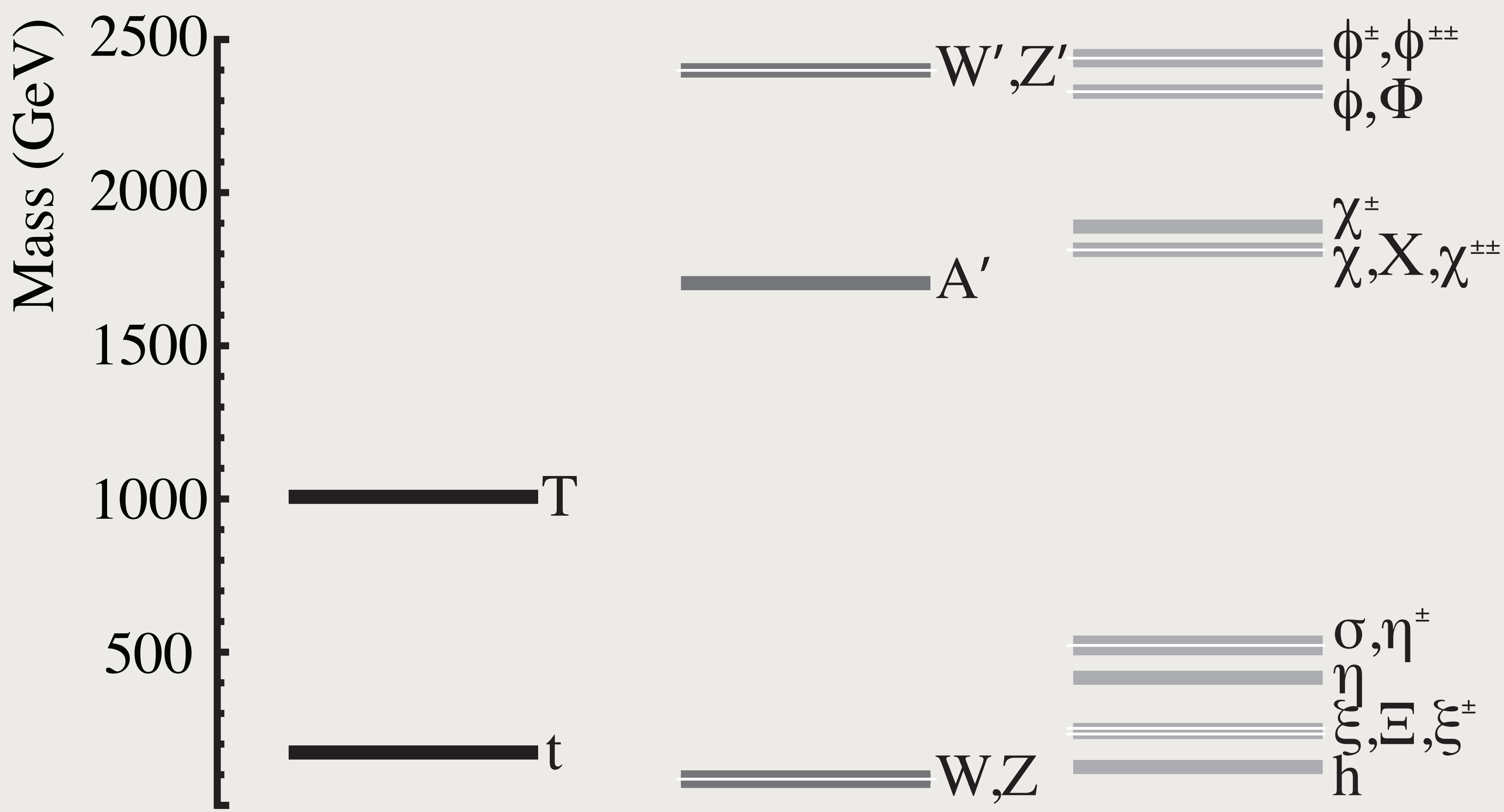
- Coleman-Weinberg potential

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

Phenomenology of NLH

- Sample spectrum

	Σ	Δ
2 ℂ doublets	h	ξ
2 ℂ triplets	ϕ	χ
1 ℝ triplet	η	
1 ℝ singlet	σ	



Dark Matter Mass Splitting

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

- λ_5 term not generated from CW potential

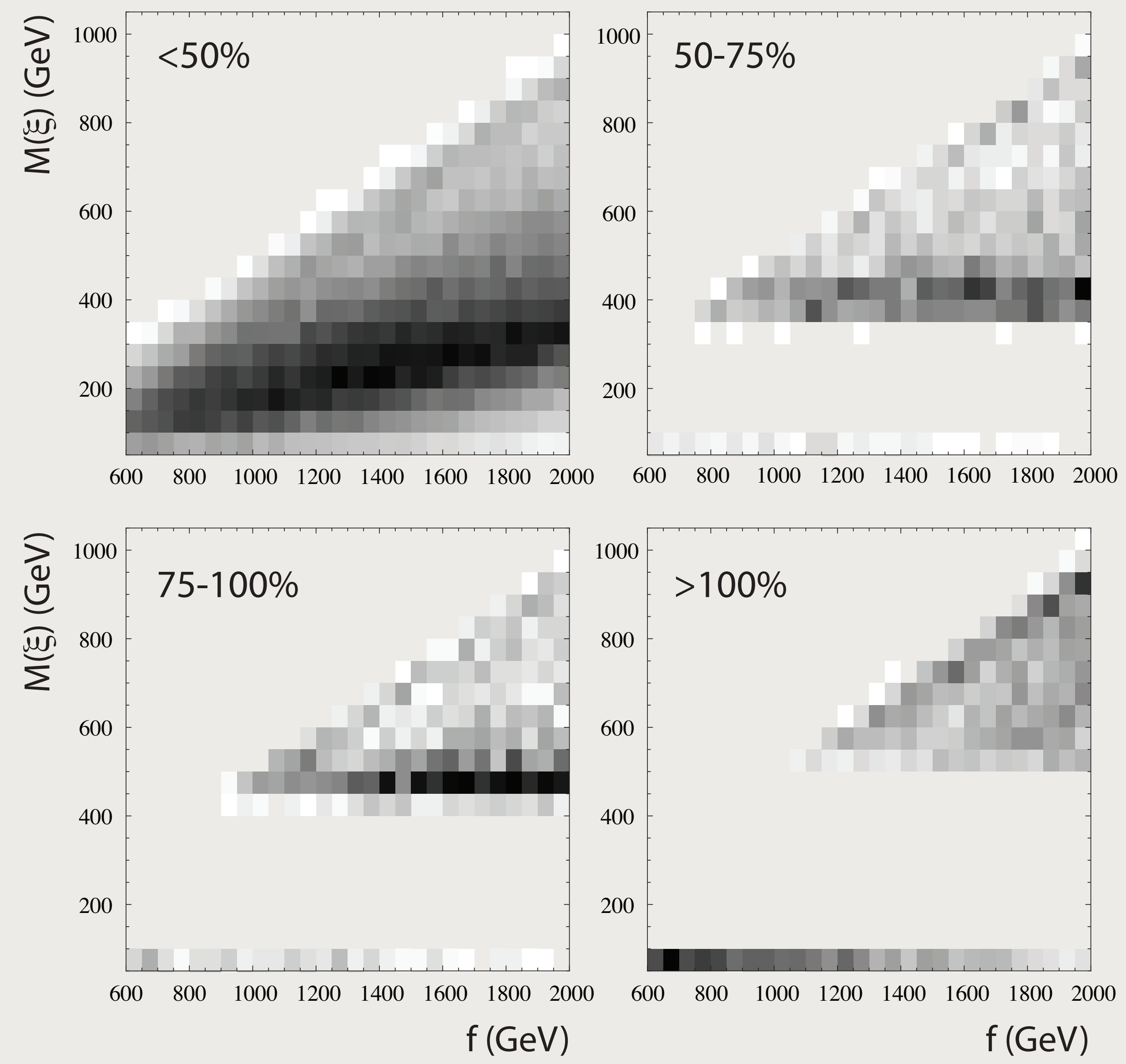
$$V_{\Sigma\Delta} = -\lambda_{\Sigma\Delta} f^2 F^2 \mathrm{Tr}[T_{\Sigma\Delta}(\Sigma - \Sigma_0) T_{\Sigma\Delta}(\Delta - \Delta_0)^\dagger] + \mathrm{h.c.}$$

- $T_{\Sigma\Delta} = n_1 \,\mathrm{Diag}[1,1,0,0,0] + n_2 \,\mathrm{Diag}[0,0,0,1,1]$
- Need ΔM_{DM} > few hundred keV, so $\lambda_{\Sigma\Delta}$ small ($\lambda_{\Sigma\Delta}=0.02 \rightarrow \Delta M_{DM} \sim$ few GeV)

Phenomenology of NLH

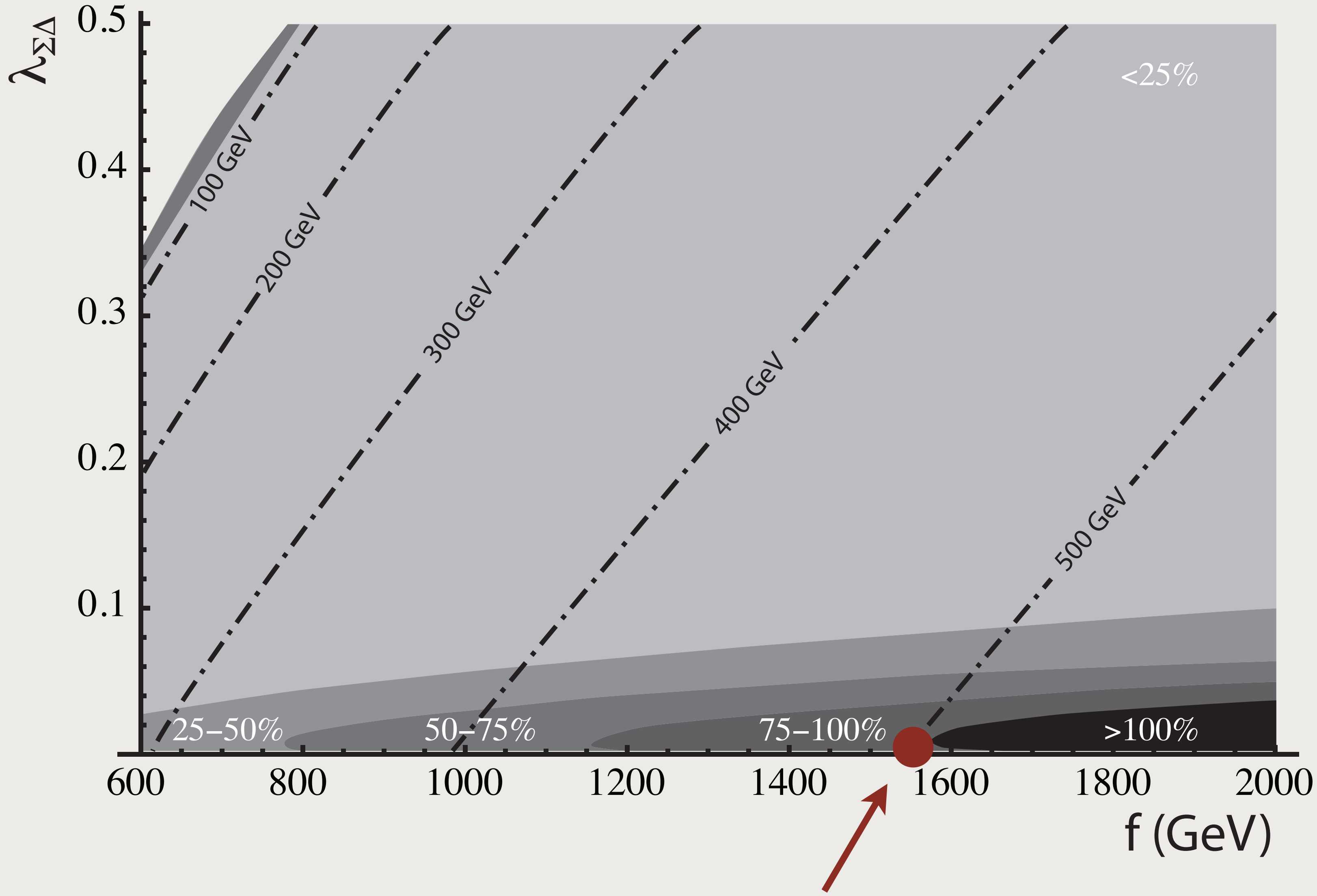
- $\Omega h^2 = 0.1189$ (Planck results) arXiv:1303.5076
- Monte Carlo parameters & use MicrOMEGAs
- 130k parameter sets:

$\Omega h^2/\Omega h^2_{Planck}$	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 & $\lambda_{\Sigma\Delta}$



(f, $\lambda_{\Sigma\Delta}$)=(1550 GeV, 0.02)

s=0.24
s′=0.24
s_t=0.25
F=3000 GeV
a=1, a′=1

M(ξ)=505 GeV
ΔM(ξ) = 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

Thank you!

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

Backup Slides

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Little Higgs Models

- Non-linear sigma model w/ collective symmetry breaking
- New states cancel quadratic divergences
  - $t \leftrightarrow T$
  - $W/Z \leftrightarrow W'/Z'$
- EWSB induced from top loop contributions to Higgs mass

Littlest Higgs Model

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

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

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

Littlest Higgs with T-Parity

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

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Next to Littlest Higgs

- $SU(5)_\Sigma/SO(5)_\Sigma$

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

$SU(5)_\Delta/SO(5)_\Delta$

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

	Σ	Δ	
2 $\mathbb{C}$ doublets	h	ξ	
2 $\mathbb{C}$ triplets	ϕ	χ	
1 $\mathbb{R}$ triplet	$\rightarrow\eta\leftarrow$		(α)
1 $\mathbb{R}$ singlet	$\rightarrow\sigma\leftarrow$		(β)

Positive Singlet Mass

- $M_\sigma^2 < 0$, leads to singlet vev (bad!)
- Introduce new term:

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

- $T_\Delta = \mathrm{Diag}[0,0,1,0,0]$