The NMSSM, naturalness and dark matter

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DESY

in collaboration with
T. Gherghetta, A. Medina, M. A. Schmidt, T. Trott
[1212.5243], [1401.8291], [1502.07173]

Outline

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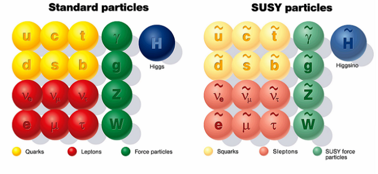
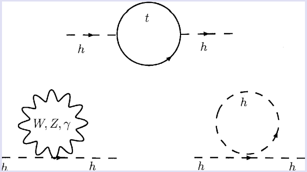
Supersymmetry is great!



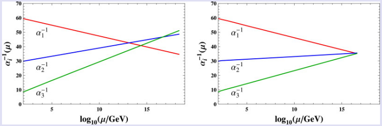
Solution to the hierarchy problem



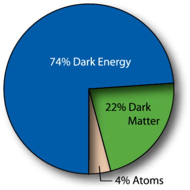
$$\Delta m_H^2 = \frac{\lambda_S}{16\pi^2}\left[\Lambda_{UV}^2 - 2m_S^2 \ln\frac{\Lambda_{UV}}{m_S} + \dots\right]$$

$$\Delta m_H^2 = -\frac{|\lambda_f|^2}{16\pi^2}\left[\Lambda_{UV}^2 + \dots\right]$$

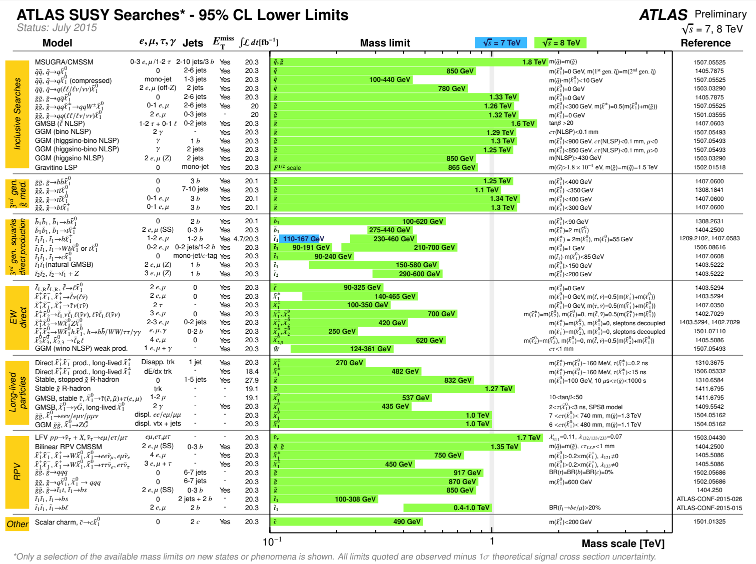
Gauge coupling unification



Dark matter candidate



But the LHC doesn't see any superpartners...



Fine-tuning

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hiding superpartners at LHC $\Rightarrow$ (typically) higher soft masses
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Fine-tuning measure

Quantify status of SUSY as solution to hierarchy problem [Barbieri,Giudice (1988)]:

$$\Delta \equiv \max_i \left| \frac{d \log v^2}{d \log \xi_i} \right| \qquad (\xi_i \text{ are the input parameters at } \Lambda_{\text{mess}})$$

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- Scan over 19-parameter space of pMSSM [Cahill-Rowley et al. (2012)]: Typically have $\Delta \gtrsim 500$.
- For NMSSM (with some model building, see below), we find large regions in parameter space with $\Delta \lesssim 20$.

Another nuisance: Why is the Higgs so heavy?

- Focus on Higgs with SM-like couplings (as implied by experiment):

$$\Rightarrow \quad V \simeq -m^2 h^2 + \sigma h^4 \quad \Rightarrow \quad \langle h \rangle \simeq \sqrt{\frac{m^2}{2\sigma}} \quad \text{and} \quad m_h^2 = 4m^2$$

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- Better: Raise σ already at tree-level. E.g. consider NMSSM = MSSM + singlet S and

$$W \supset \lambda S H_u H_d \quad \Rightarrow \quad V \supset \lambda^2 (h_u^0 h_d^0)^2$$

Outline

Our Study [1212.5243]

Assumptions to minimize fine-tuning:

- NMSSM with largish λ
- split sparticle spectrum
- low messenger scale ($\Lambda_{\mathrm{mess}} = 20\,\mathrm{TeV}$)
- do not worry about UV completion of this model

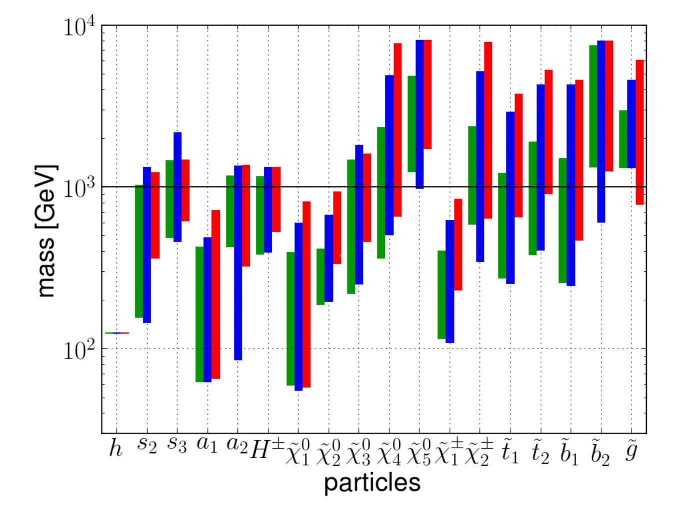
Markov-Chain Monte-Carlo scan of the parameter space.

Optimised to find "Golden Region" of small fine-tuning:

$$\Delta^v \equiv \max_i \left| \frac{d \log v^2}{d \log \xi_i} \right|$$

fine-tuning better than 5%
$\Leftrightarrow \; \Delta^v < 20$

Sparticle spectrum



Take-home numbers: Find stop masses up to 1.2 TeV and gluino masses up to 3 TeV consistent with 5% fine-tuning!

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Higgs couplings and naturalness [1401.8291]

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- Here instead consider the additional Higgses in NMSSM which affect Higgs couplings at tree-level.

Higgs couplings in the NMSSM

- Rotate Higgs fields h_u^0, h_d^0 into basis h, H where only h obtains vev.
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- Mass matrix in basis (h, H, s):

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- $\Rightarrow$ More SM-like Higgs couplings require more tuning.

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- Idea: Transform fine-tuning measure to new basis of input parameters

$$\Delta(m_{H_u}^2, m_{H_d}^2, m_s^2, a_\lambda, a_\kappa, \lambda, \kappa) \;\rightarrow\; \Delta(v, \tan\beta, \lambda, \kappa, m_H^2, m_s^2, m_{hs}^2)$$

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$$\Delta \;\approx\; f(\tan\beta, \lambda, \kappa) \cdot \frac{m_H^2}{v^2}$$

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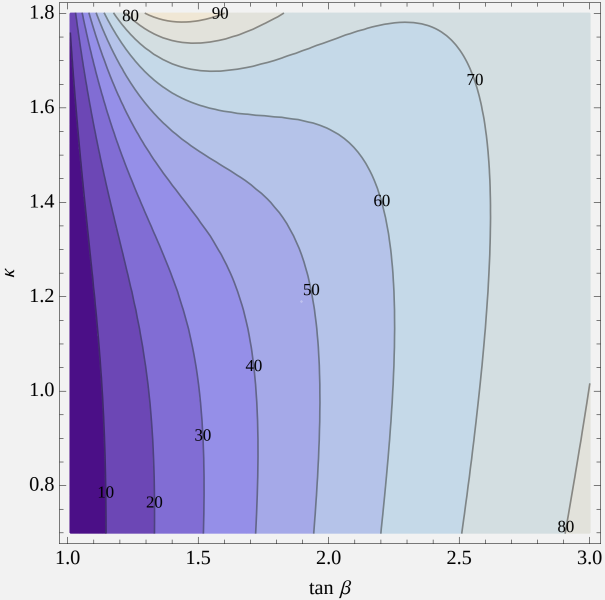
- Next trade m_H^2 for the r's:

$$\Delta \;\approx\; \tilde{f}(\tan\beta, \lambda, \kappa) \cdot \begin{cases} (1 - r_u)^{-1} \\ (1 - r_d)^{-1} \\ (1 - r_v)^{-1/2} \end{cases}$$

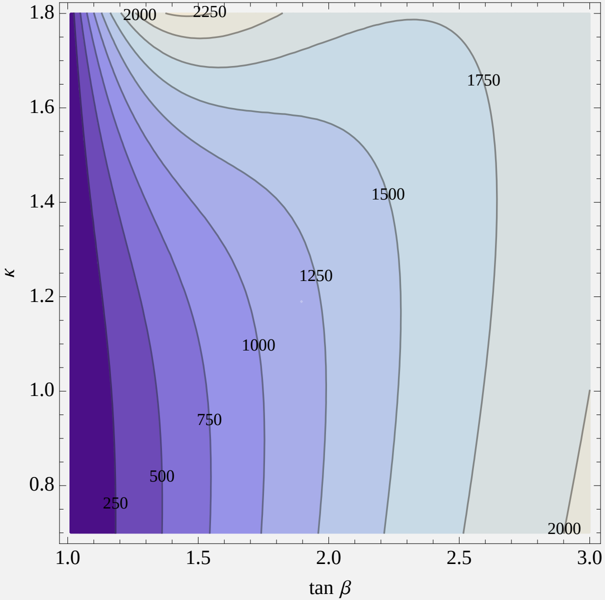
LHC at 14 TeV and 300 fb^{-1}

Fix λ via Higgs mass $\Rightarrow$ Δ function of $\tan\beta$, κ and either r_u, r_d or r_v.



ILC at 1 TeV and 1000 fb^{-1}

Fix λ via Higgs mass $\Rightarrow$ Δ function of $\tan\beta$, κ and either r_u, r_d or r_v.



Outline

The NMSSM and the γ-ray excess [1502.07173]

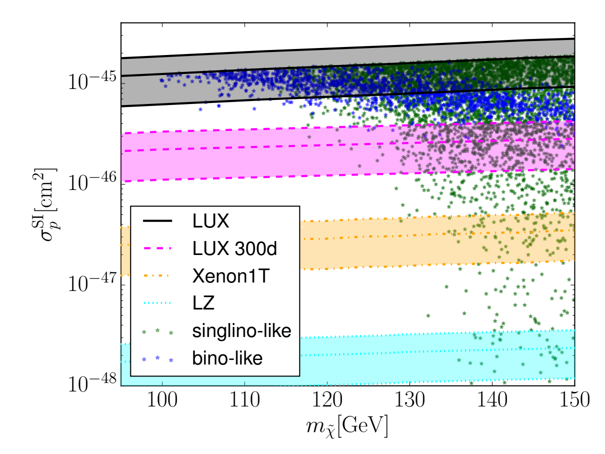
Excess of γ-rays found around galactic center.

- Morphology consistent with dark matter annihilation, flux consistent with typical cross sections.
- Spectrum well fit by
  - $\mathrm{DM\,DM} \to b\bar{b}$ with dark matter mass $30 - 70\,\mathrm{GeV}$
  - $\mathrm{DM\,DM} \to \mathrm{Higgs\,Higgs}$ or $\mathrm{Higgs\,pseudoscalar}$ close to threshold

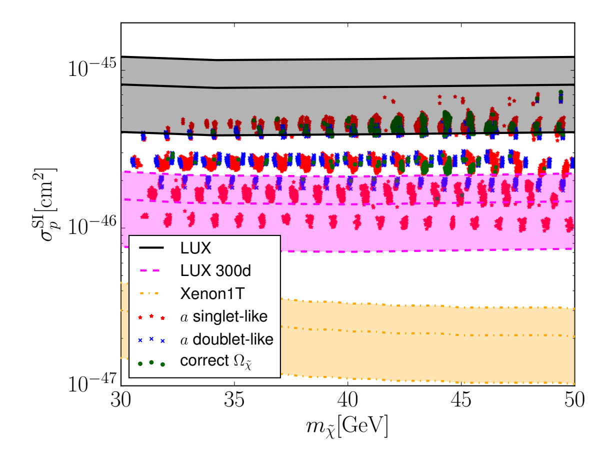
Can the LSP reproduce the signal?

- Which mediator for annihilation? s-channel via Higgs $\to$ p-wave suppressed, via Z $\to$ helicity suppressed $\Rightarrow$ pseudoscalar mediator
- Need annihilation on resonance for $b\bar{b}$-channel, close to threshold for $\mathrm{Higgs\,pseudoscalar}$-channel. $\Rightarrow$ light pseudoscalar
- In MSSM this is in strong conflict with collider limits. $\Rightarrow$ NMSSM
- Composition of the LSP? Wino- and Higgsino-dominated LSP underproduced, in conflict with direct- and indirect-detection bounds. $\Rightarrow$ bino- or singlino-dominated LSP

Parameter scan for Higgs pseudoscalar-channel:



Parameter scan for $b\bar{b}$-channel:



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- Same model can explain γ-ray excess from galactic center.
- This can be tested at running and future direct-detection experiments.

Thank you very much for your attention.