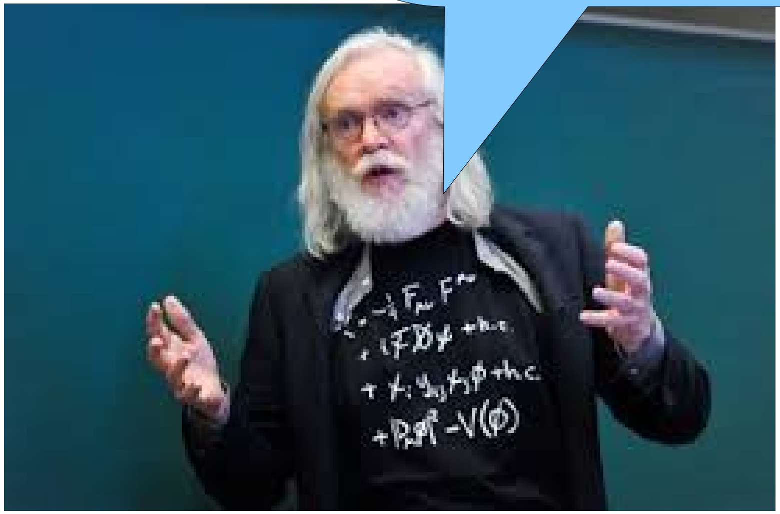
Thoughts about SUSY naturalness.

...and the SUSY WIMP...

Kai Schmidt-Hoberg

“SUSY anywhere is better than SUSY nowhere!”



Partially based on

1603.09347
1701.03480

HELMHOLTZ ASSOCIATION

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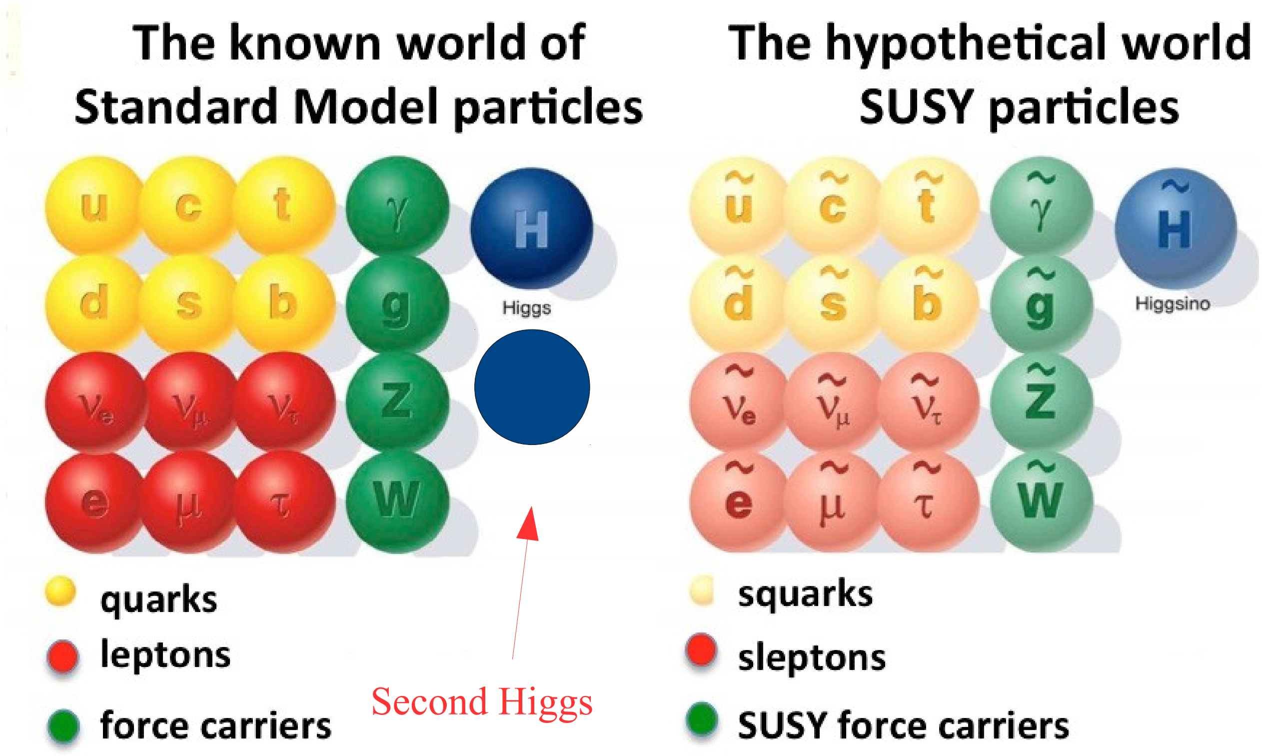
DESY

SUSY → MSSM (this talk)

- A SUSY partner for each SM particle with Δs=1/2 with **the same mass**



- SUSY broken in nature
- Breaking mechanism unknown, parameterized by soft terms

MSSM

- Field content fixed: theory specified by superpotential and soft terms

superfields

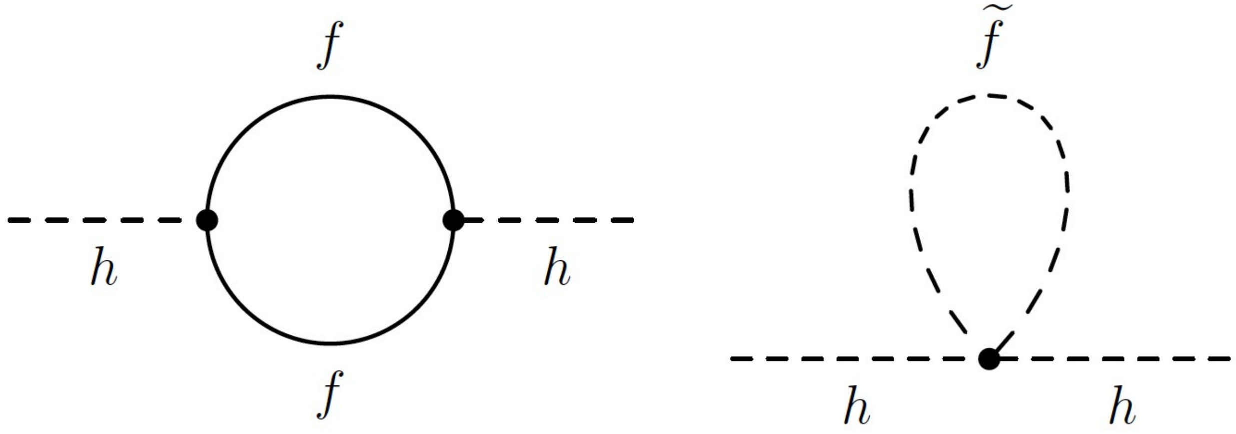
$$W_{\text{MSSM}} = \overline{u}\mathbf{y_u}QH_u - \overline{d}\mathbf{y_d}QH_d - \overline{e}\mathbf{y_e}LH_d + \mu H_u H_d$$

$$L_{SB} = -\frac{1}{2}\sum_a M_a \bar{\lambda}_a \lambda_a - \sum_i m^2_{\tilde{\Phi}_i} |\tilde{\Phi}_i|^2 + T_u H_u \tilde{Q}\tilde{u} + T_d H_d \tilde{Q}\tilde{d} + T_e H_d \tilde{L}\tilde{e} + B_\mu H_u H_d$$

- Many new parameters (>100) but likely not independent

Why we like(d) SUSY

- **>** Hierarchy problem: stabilizes the weak against the Planck scale



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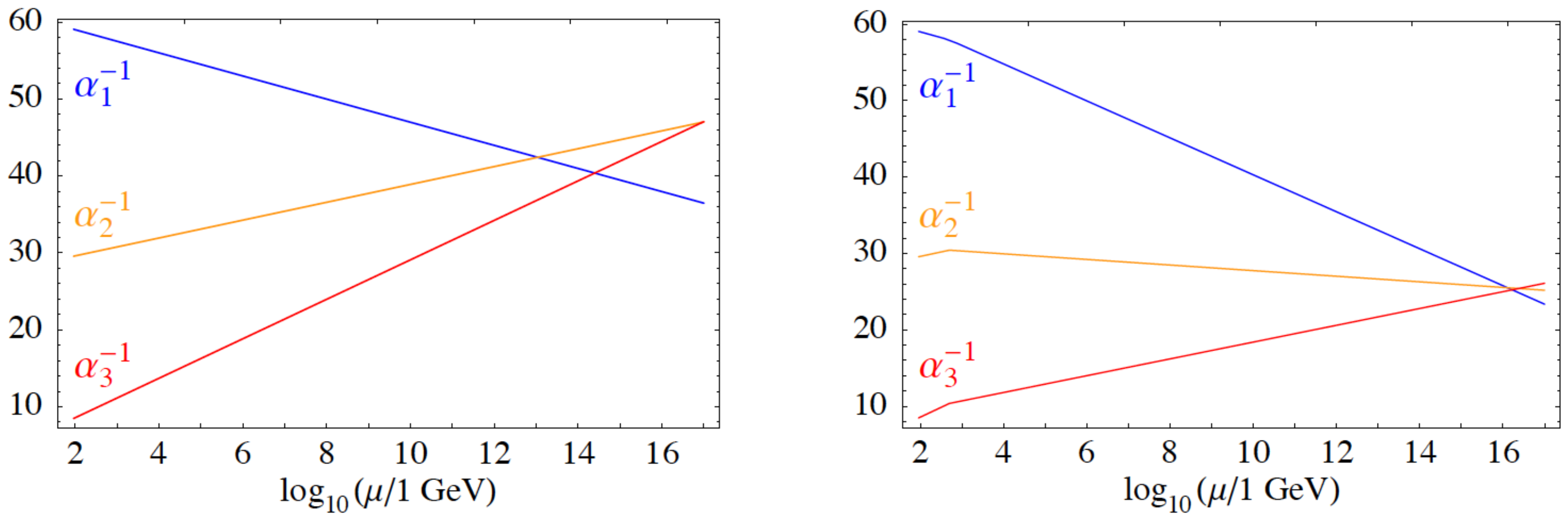

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...somebody still owes me...

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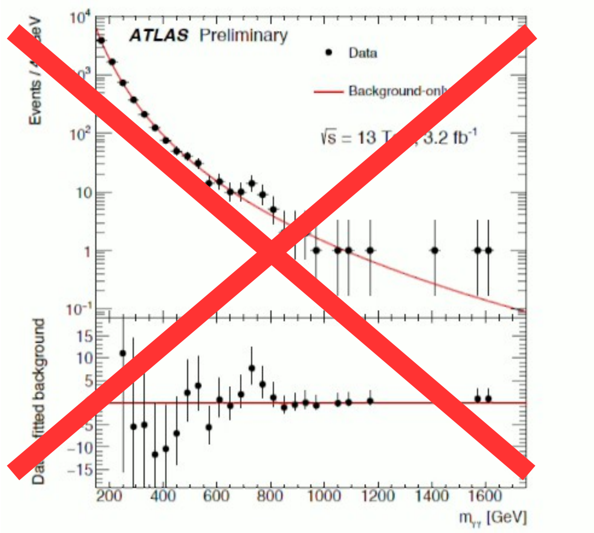
- Also hard to get 750 GeV diphoton excess ;-)



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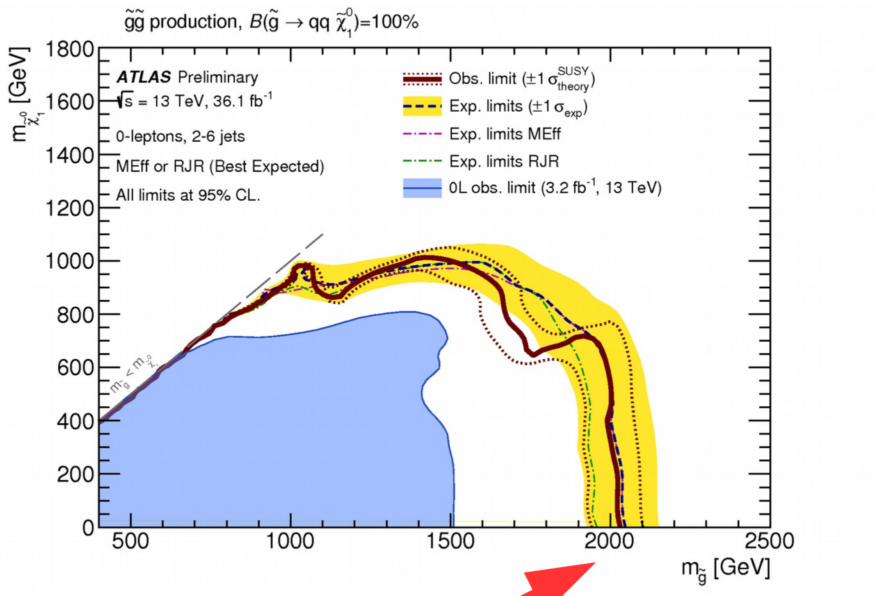
- So why do people get worried?



~ 2 TeV

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NATURALNESS!

DM naturalness in the MSSM

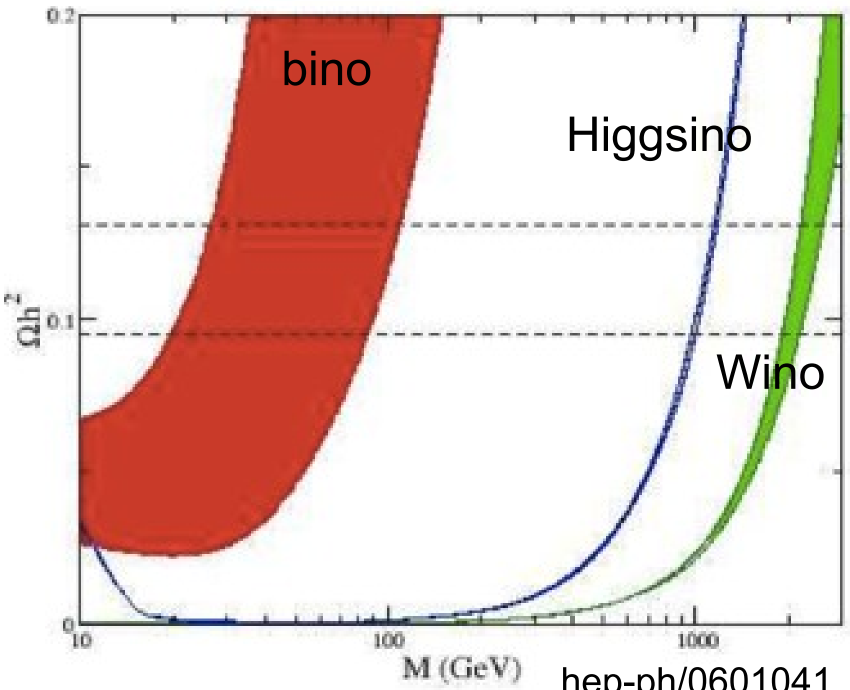
> How naturally can the dark matter relic abundance be achieved?

Often universal gaugino masses assumed at high scale, at low scale M3:M2:M1 ~ 6:2:1 → bino LSP

Bino: Typically need to finely tune relic density via coannihilations or resonances :-(

2-3 TeV Wino challenged by ID
Mariengela Lisanti et al 1307.4082

1 TeV Higgsino looking good :-)



hep-ph/0601041

EW naturalness in the MSSM

- How naturally can we achieve the correct Higgs vev?
- Electroweak vev (or m_Z) determined by SUSY parameters (from minimization condition for scalar potential)

$$\frac{m_Z^2}{2} = \frac{m_{H_d}^2 - m_{H_u}^2 \tan^2\beta}{\tan^2\beta - 1} - \mu^2 \simeq -m_{H_u}^2 - \mu^2$$

- Cancellation (tuning) needed for large SUSY masses
- How to quantify this?

$$\Delta_p \equiv \frac{\partial \ln v^2}{\partial \ln p} = \frac{p}{v^2}\frac{\partial v^2}{\partial p}$$

'sensitivity measure'

- Large Δ implies large tuning

The usual story

- What does this tell us about a natural SUSY spectrum?
- μ is a superpotential parameter and hardly runs: $\mu_{EW} \sim \mu_{GUT}$

$$\Delta_\mu \sim \frac{2\mu^2}{M_Z^2}$$

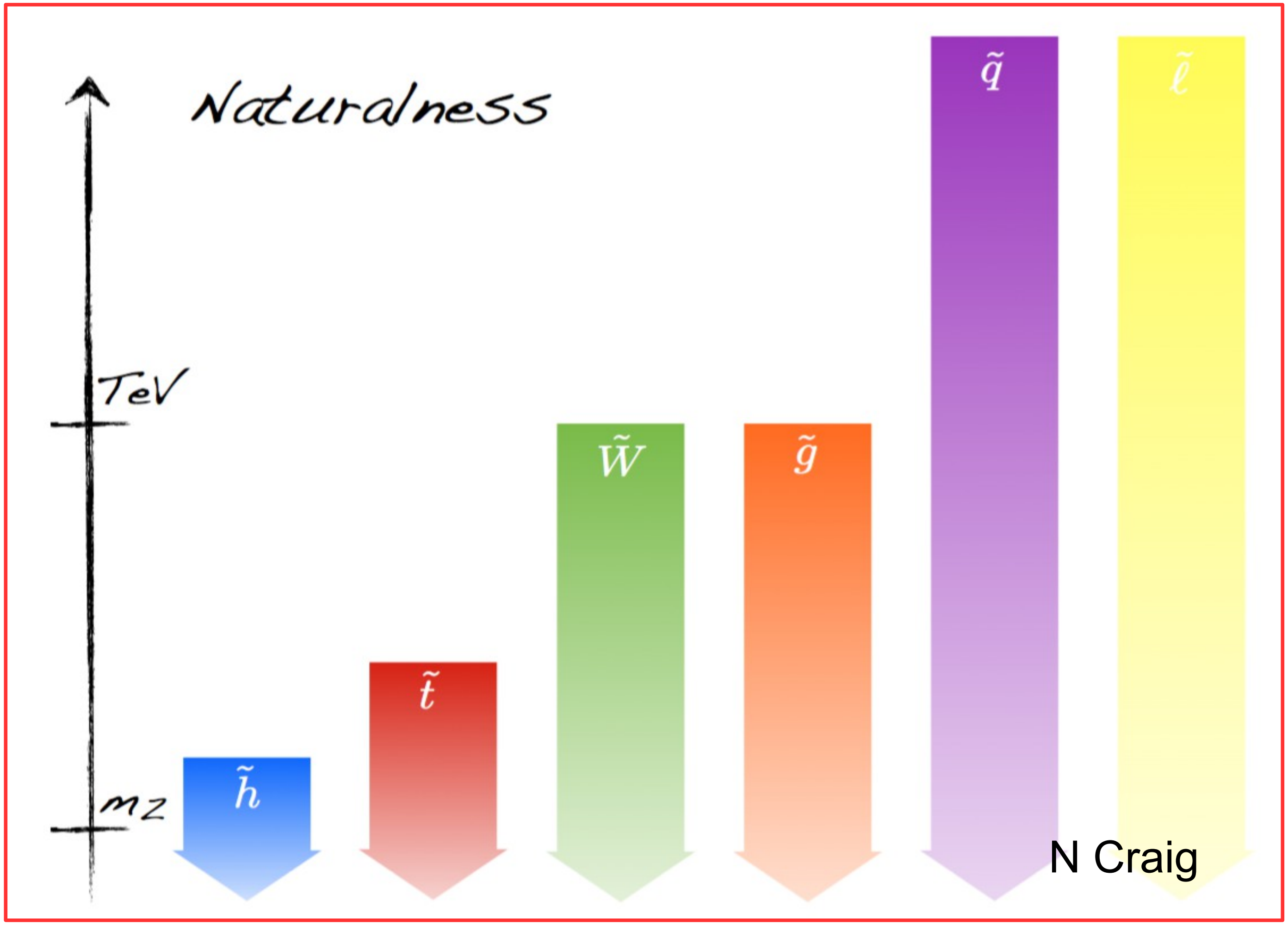
Higgsino mass ~ $\mu \sim 1$ TeV $\rightarrow$ $\Delta \sim 250$

- "Natural SUSY requires light Higgsino"
- What about the m_{Hu} part?
- Loop effects introduce a large sensitivity to stop and gluino masses

$$\delta m_{H_u}^2 = -\frac{3y_t^2}{4\pi^2} m_{\tilde{t}}^2 \ln\left(\Lambda/m_{\tilde{t}}\right)$$

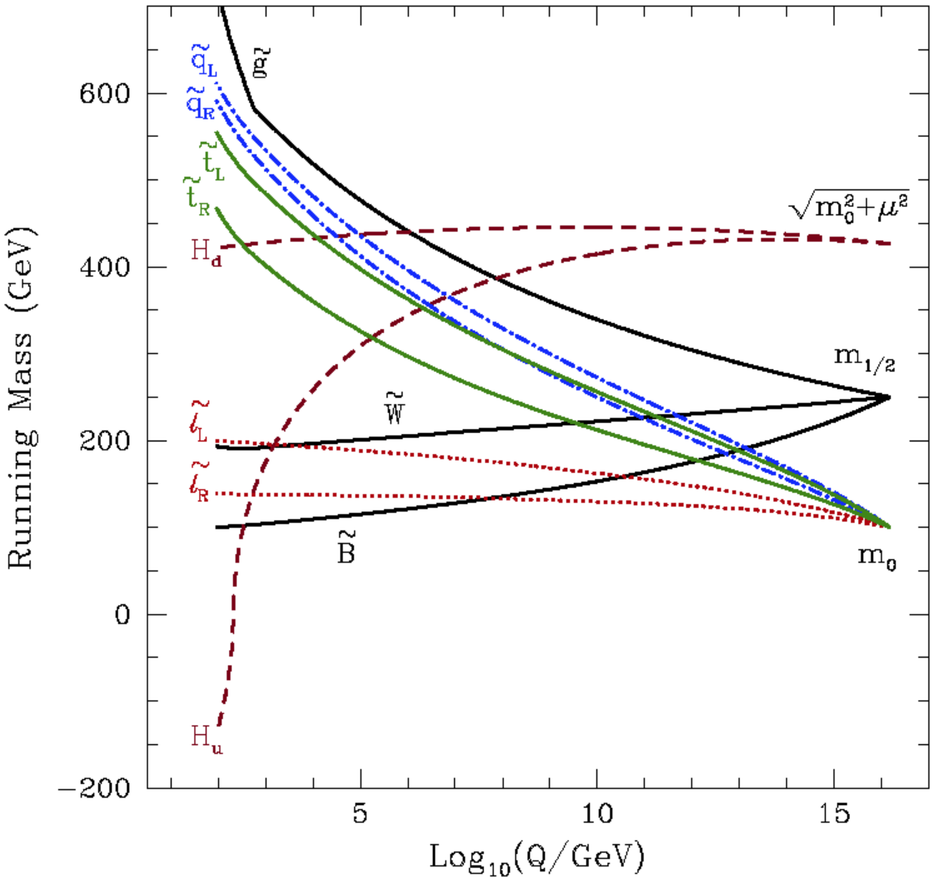
$$\delta m_{\tilde{t}}^2 = \frac{2g_s^2}{3\pi^2} m_{\tilde{g}}^2 \ln\left(\Lambda/m_{\tilde{g}}\right)$$

The 'natural SUSY' spectrum



High scale SUSY

- In many models SUSY breaking at high scale in hidden sector
- Often some universality
- Take into account running to predict SUSY spectrum at the electroweak scale.



EW naturalness in the MSSM – the GUT picture

- Starting from the high scale, all soft terms contribute to m_{Hu} and m_Z

$$
\begin{aligned}
m_Z^2 \simeq\ & -2.18\mu^2 + 3.84M_3^2 + 0.32M_3M_2 + 0.047M_1M_3 - 0.42M_2^2 \\
& +0.011M_2M_1 - 0.012M_1^2 - 0.65M_3A_t - 0.15M_2A_t \\
& -0.025M_1A_t + 0.22A_t^2 + 0.004M_3A_b \\
& -1.27m_{H_u}^2 - 0.053m_{H_d}^2 \\
& +0.73m_{Q_3}^2 + 0.57m_{U_3}^2 + 0.049m_{D_3}^2 - 0.052m_{L_3}^2 + 0.053m_{E_3}^2 \\
& +0.051m_{Q_2}^2 - 0.11m_{U_2}^2 + 0.051m_{D_2}^2 - 0.052m_{L_2}^2 + 0.053m_{E_2}^2 \\
& +0.051m_{Q_1}^2 - 0.11m_{U_1}^2 + 0.051m_{D_1}^2 - 0.052m_{L_1}^2 + 0.053m_{E_1}^2 ,
\end{aligned}
$$

- We don't just want m_{Hu} to be small, but every contribution to it. Assuming no correlations among the terms, need rather light stops and gluinos

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$m_i^2 = m_0^2$

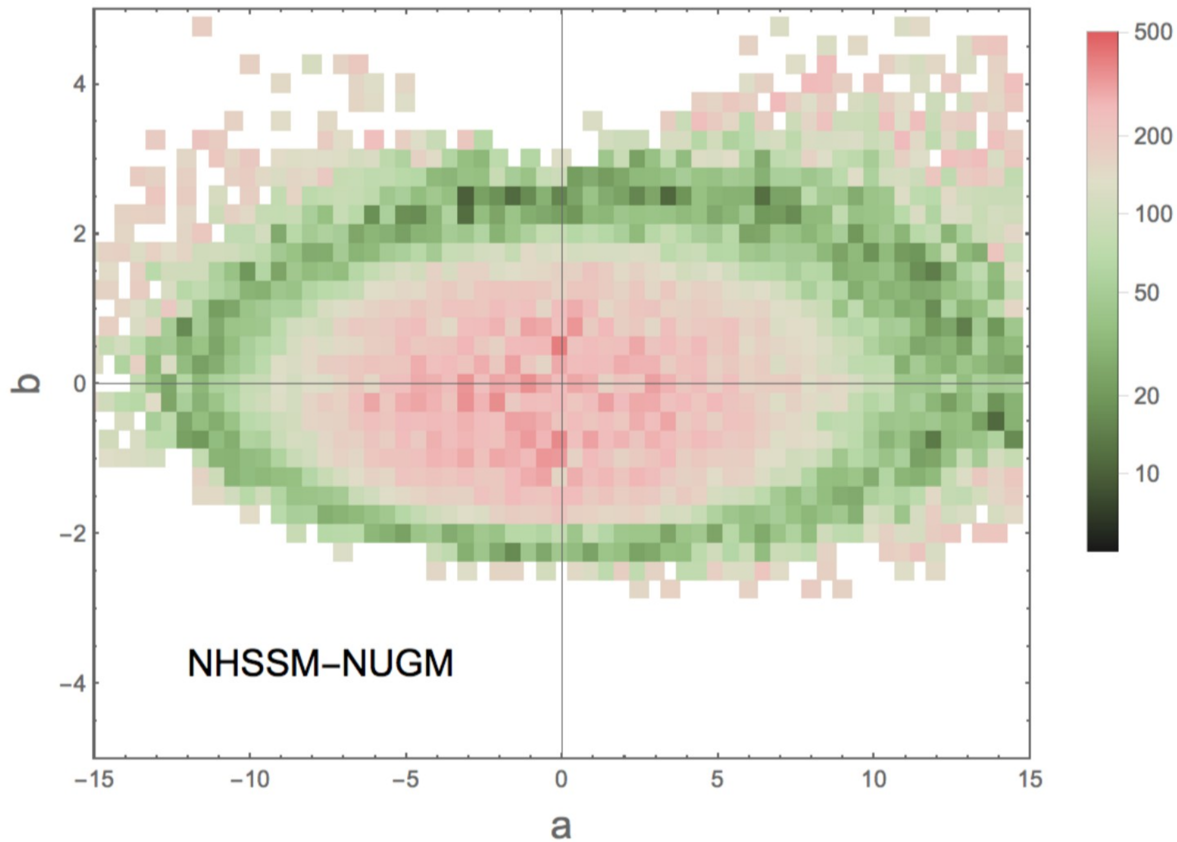
~0.01 m_0^2

- We don't just want m_{Hu} to be small, but every contribution to it. Assuming no correlations among the terms, need rather light stops and gluinos
- But we know correlations should be present…
- Example: the scalar focus point.

The gaugino focus point

- Assume fixed ratios of gaugino masses
- Possible also in GUTs   Horton, Ross, 0908.0857

$$M_1 = a \cdot m_{1/2}$$
$$M_2 = b \cdot m_{1/2}$$
$$M_3 = m_{1/2}$$



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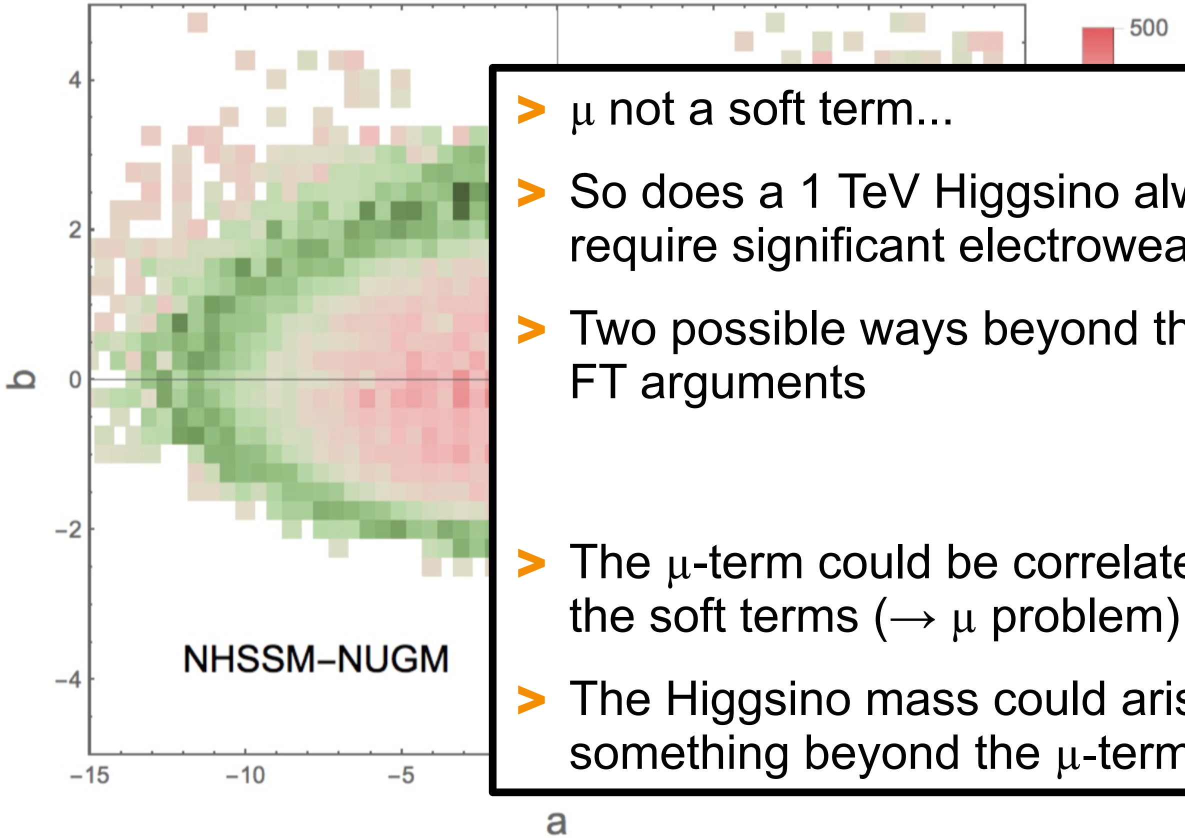

- μ not a soft term...
- So does a 1 TeV Higgsino always require significant electroweak tuning?
- Two possible ways beyond the naive FT arguments
- The μ-term could be correlated with the soft terms (→ μ problem)
- The Higgsino mass could arise from something beyond the μ-term

A new contribution to the Higgsino mass

> Non-standard SUSY breaking terms (in the classification of S Martin: 'maybe-soft')

$$\mathscr{L}_{NH} = \mu' \tilde{h}_d \tilde{h}_u + T'_{u,ij} h_d^* \tilde{u}_{R,i}^* \tilde{q}_j + T'_{d,ij} h_u^* \tilde{d}_{R,i}^* \tilde{q}_j + T'_{e,ij} h_u^* \tilde{e}_{R,i}^* \tilde{l}_j + \text{h.c.}$$

Girardello, Grisaru (1982)

> μ' contributes to the Higgsino mass ($m_h \sim \mu + \mu'$) but does not enter the scalar potential

> Now putting everything together...

Embedding this into a model

- Studied different MSSM variants with GUT boundary conditions

	$m^2_{h_u}$	$m^2_{h_d}$	M_1	M_2	M_3	μ'	A'_0
CMSSM	m_0^2	m_0^2	$m_{1/2}$	$m_{1/2}$	$m_{1/2}$	-	-
MSSM-NUHM	$m^2_{h_u}$	$m^2_{h_d}$	$m_{1/2}$	$m_{1/2}$	$m_{1/2}$	-	-
MSSM-NUGM	m_0^2	m_0^2	$a \cdot m_{1/2}$	$b \cdot m_{1/2}$	$m_{1/2}$	-	-
CNHSSM	m_0^2	m_0^2	$m_{1/2}$	$m_{1/2}$	$m_{1/2}$	μ'	A'_0
NHSSM-NUHM	$m^2_{h_u}$	$m^2_{h_d}$	$m_{1/2}$	$m_{1/2}$	$m_{1/2}$	μ'	A'_0
NHSSM-NUGM	m_0^2	m_0^2	$a \cdot m_{1/2}$	$b \cdot m_{1/2}$	$m_{1/2}$	μ'	A'_0

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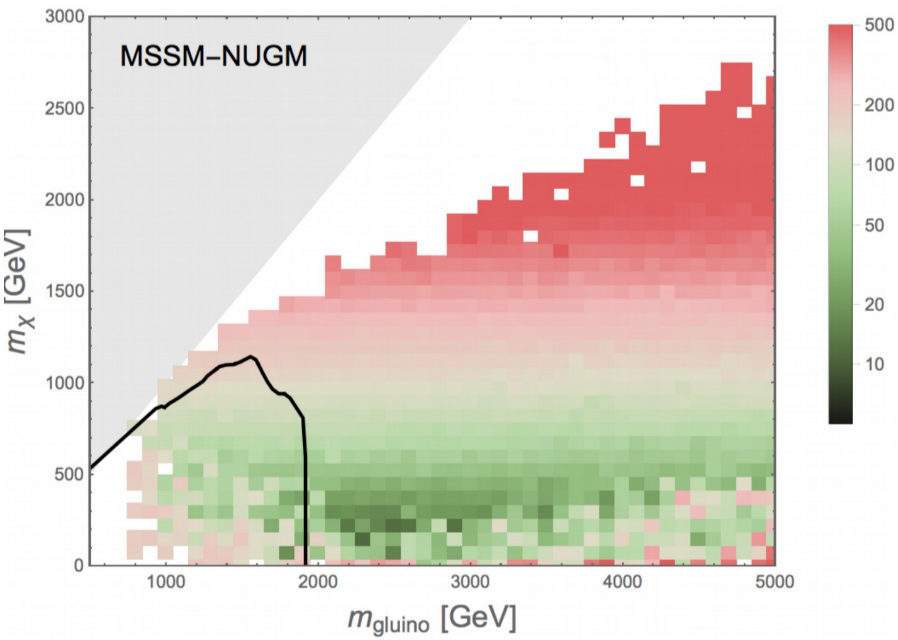
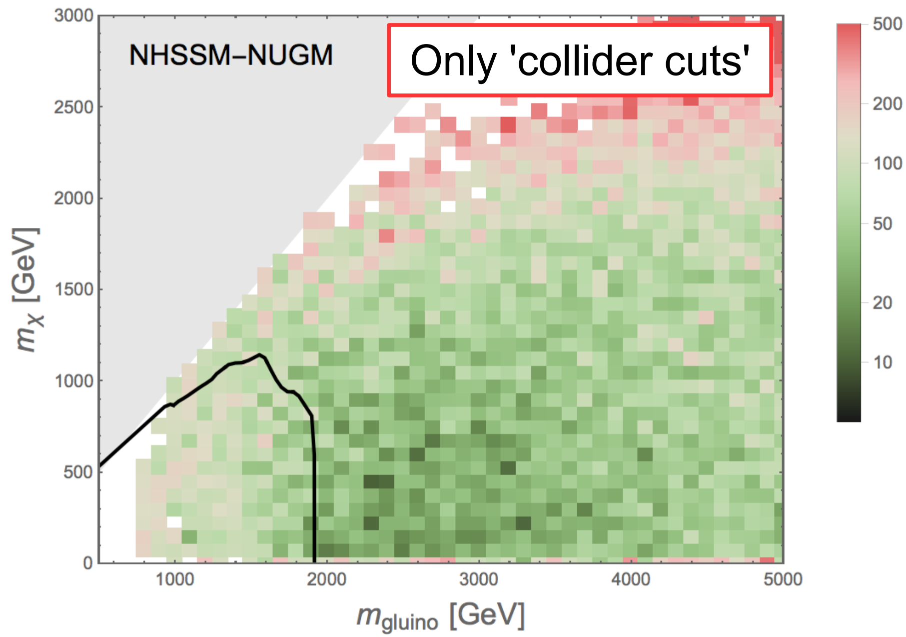
Results non-universal gaugino masses

- Region of small FT can be well beyond LHC reach

$\mu'=0$





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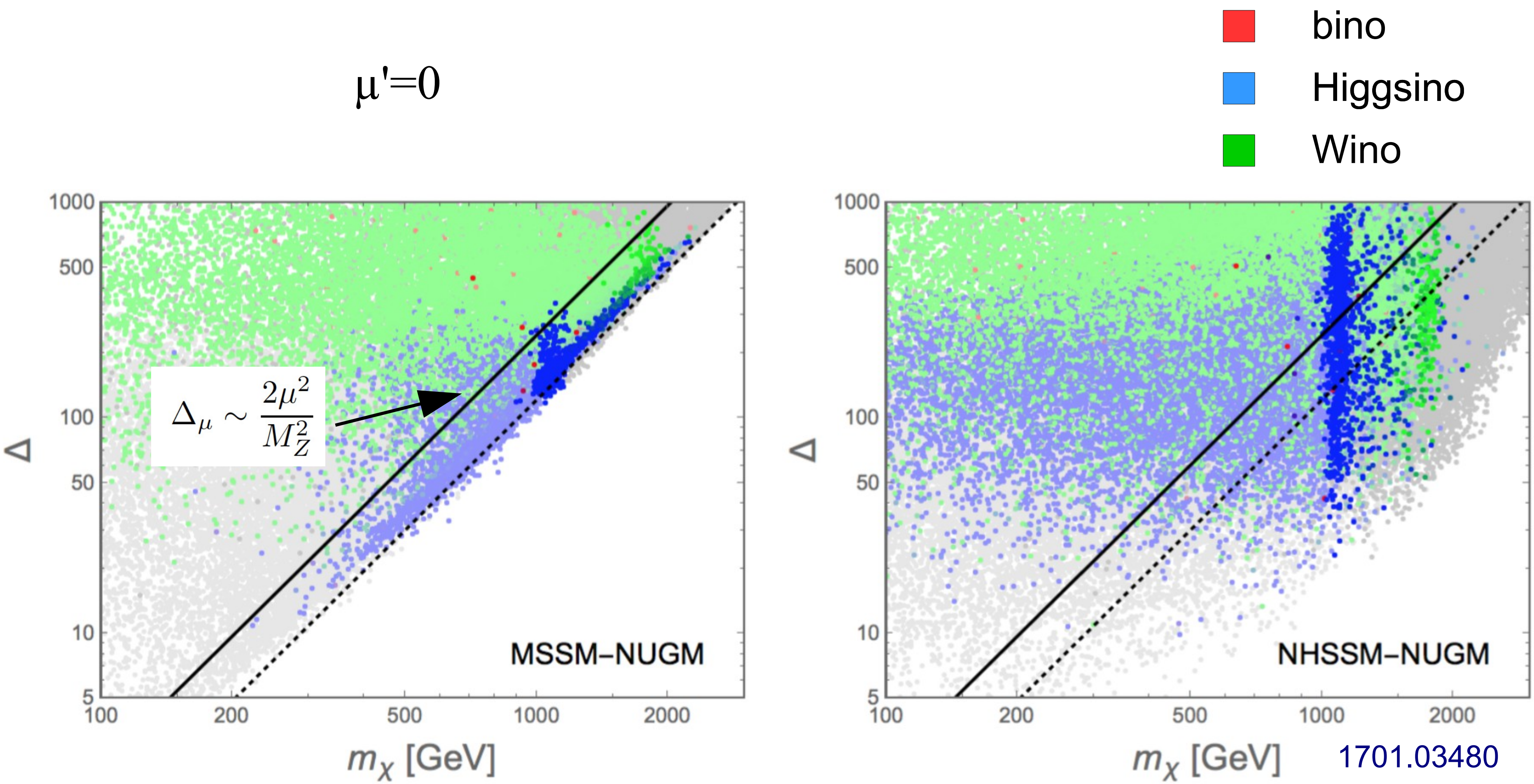
- Allowing for DM underabundance FT can be as small as 10.

Results non-universal gaugino masses

- A 1 TeV Higgsino can be quite natural

μ'=0



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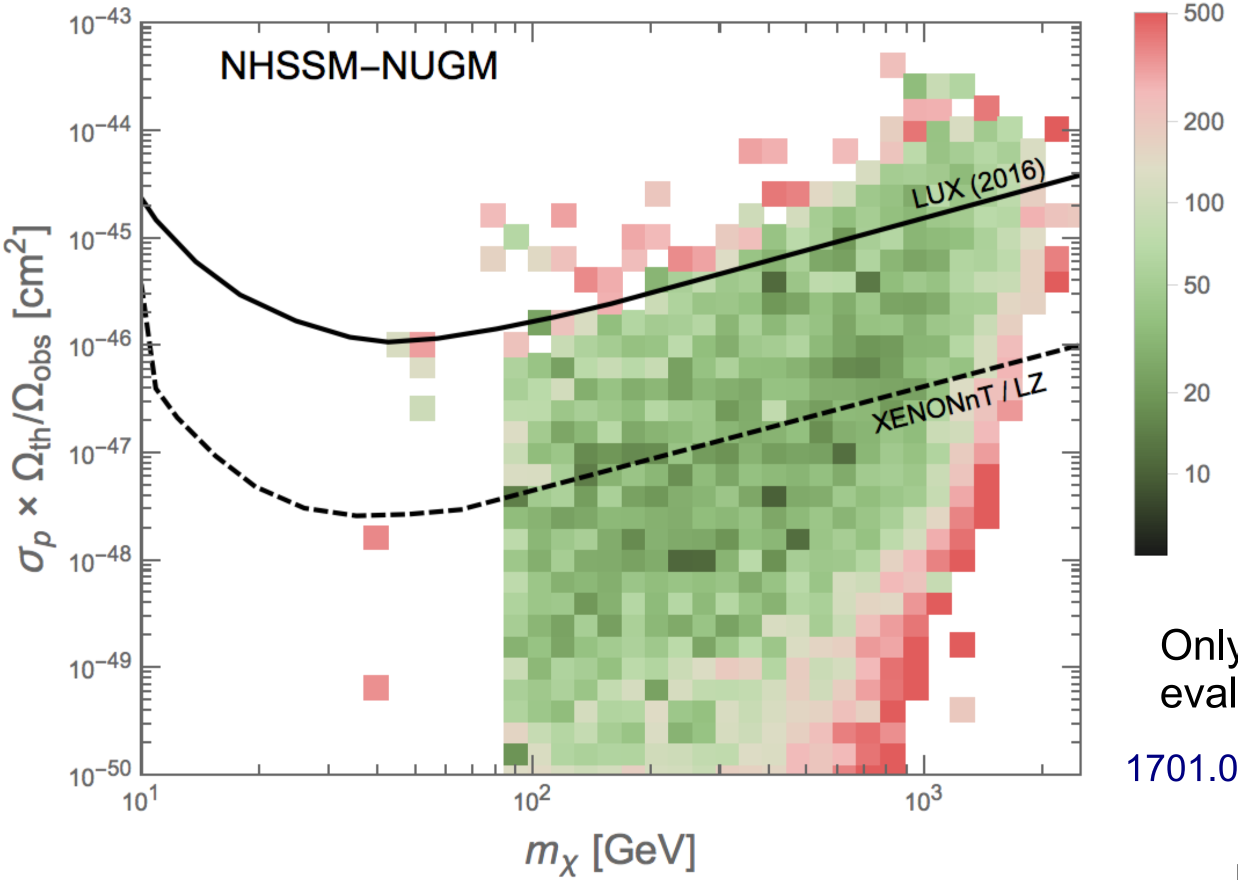
Prospects for direct detection

- Prospects for direct detection
- No lower bound on relic abundance (and rescaled) – other DM component



Only tree-level evaluation

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Prospects for direct detection

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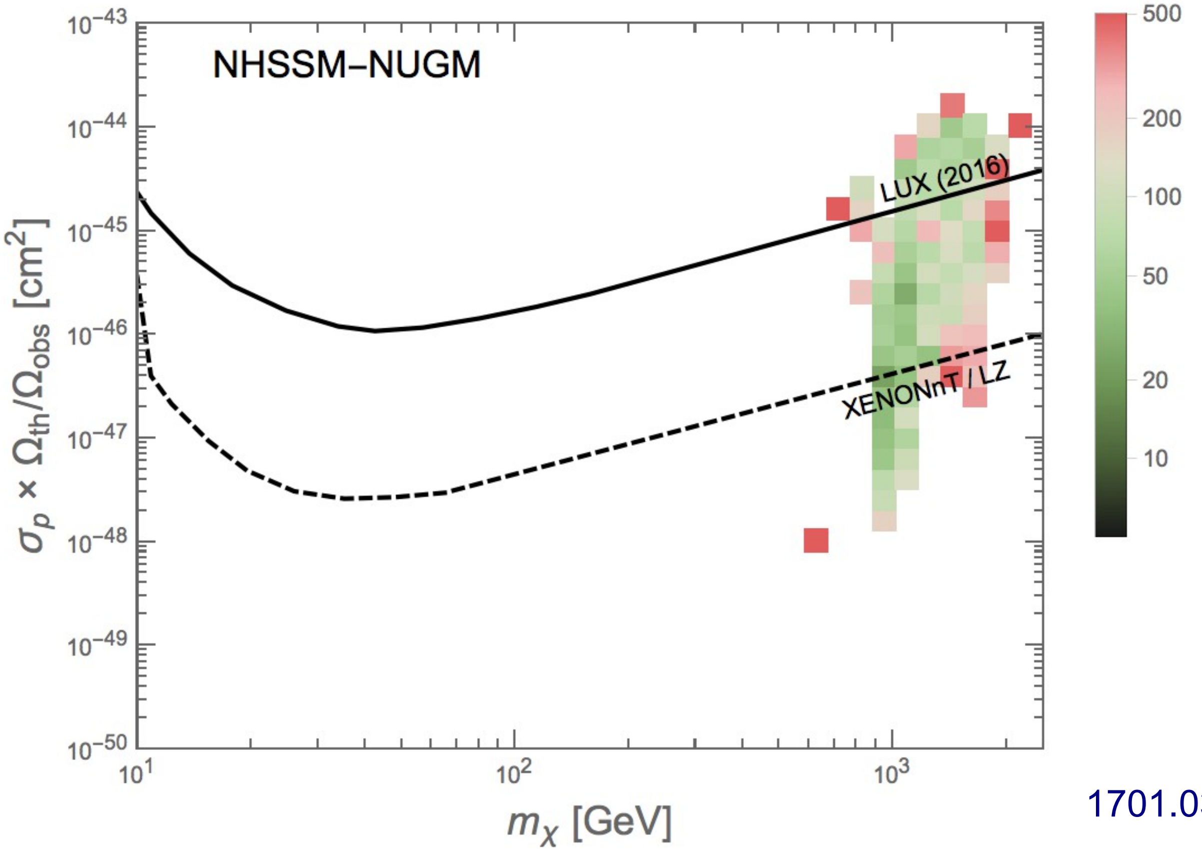
- Correct (thermal) relic abundance



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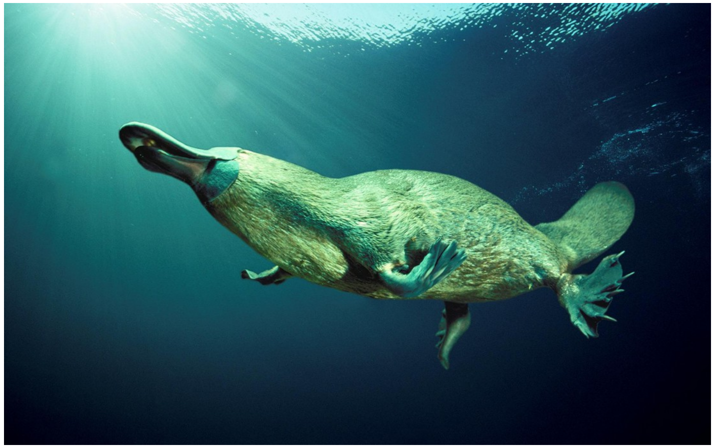
Summary

- What looks unnatural from an IR perspective **might** still look natural from the UV
- Extra Higgsino mass contribution μ' could help
- To do: build a UV model



- 'natural' SUSY could well be beyond the LHC reach
- Good chances at direct detection experiments to find it

Summary

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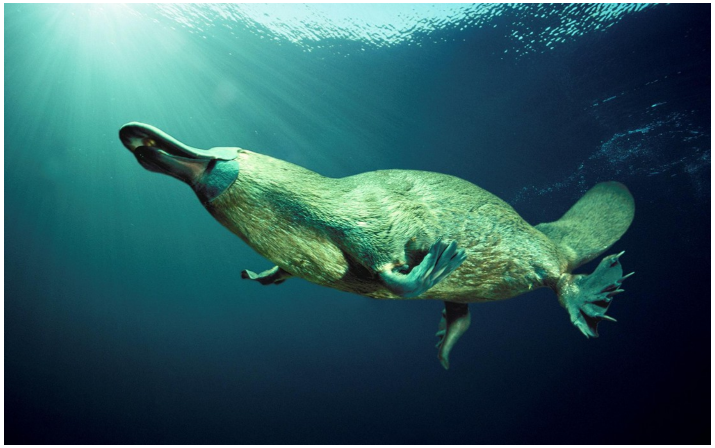
Thank you!



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