Status of Supersymmetry after LHC Run 1

Lian-Tao Wang
University of Chicago

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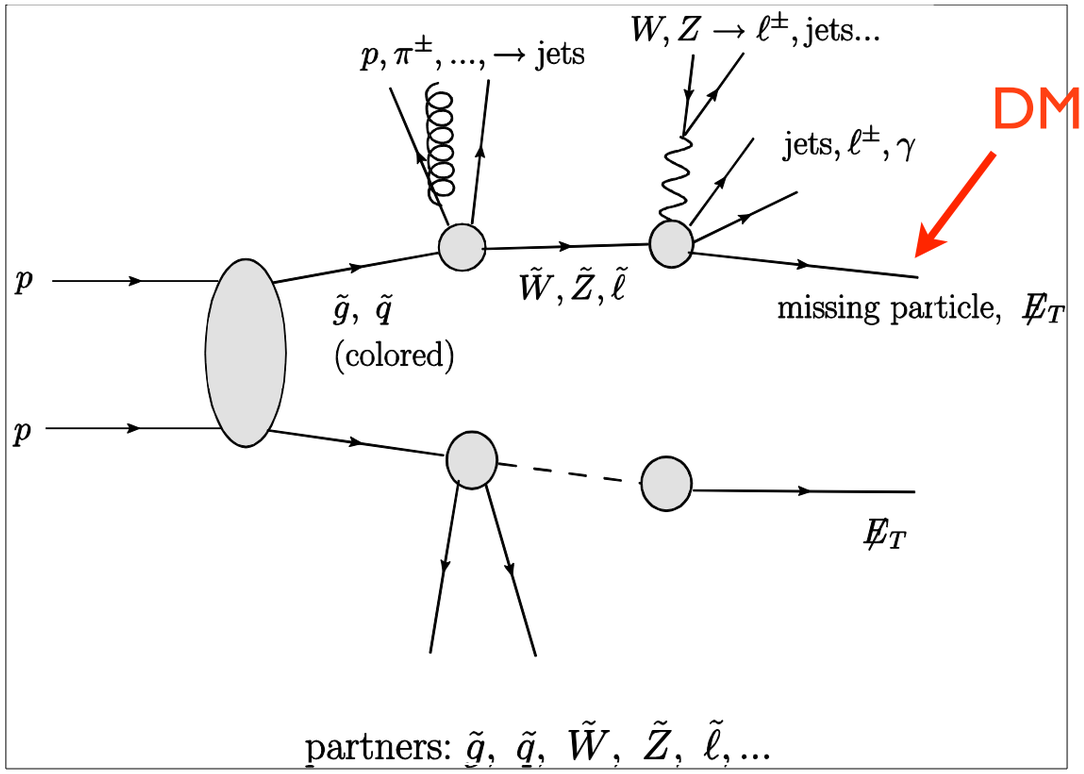
- Has been the primary target for new physics search for the last 30 years.
- Would be the answer to (almost) all our questions and puzzles.
- Every time there was some "excess", we thought it was SUSY.
- And, there is a beautiful minimal model of SUSY, the MSSM.
  - Often, we think MSSM = SUSY.

Spectacular signal promised.



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- Long decay chain, rich final states.

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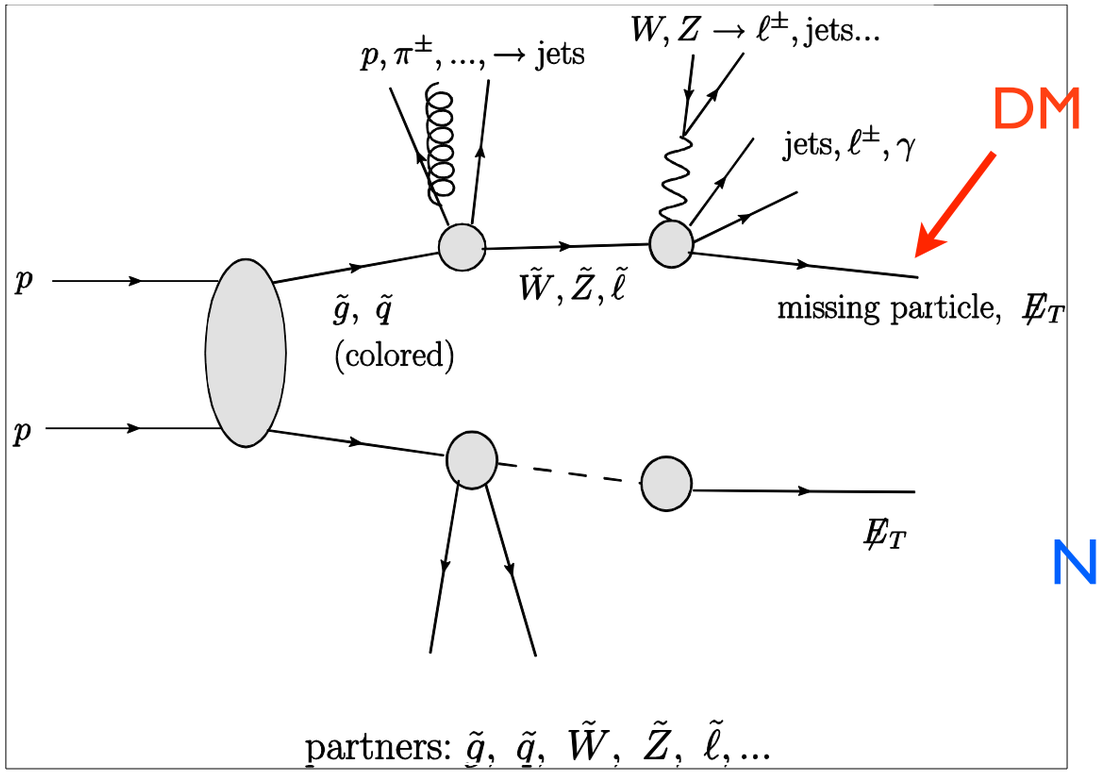
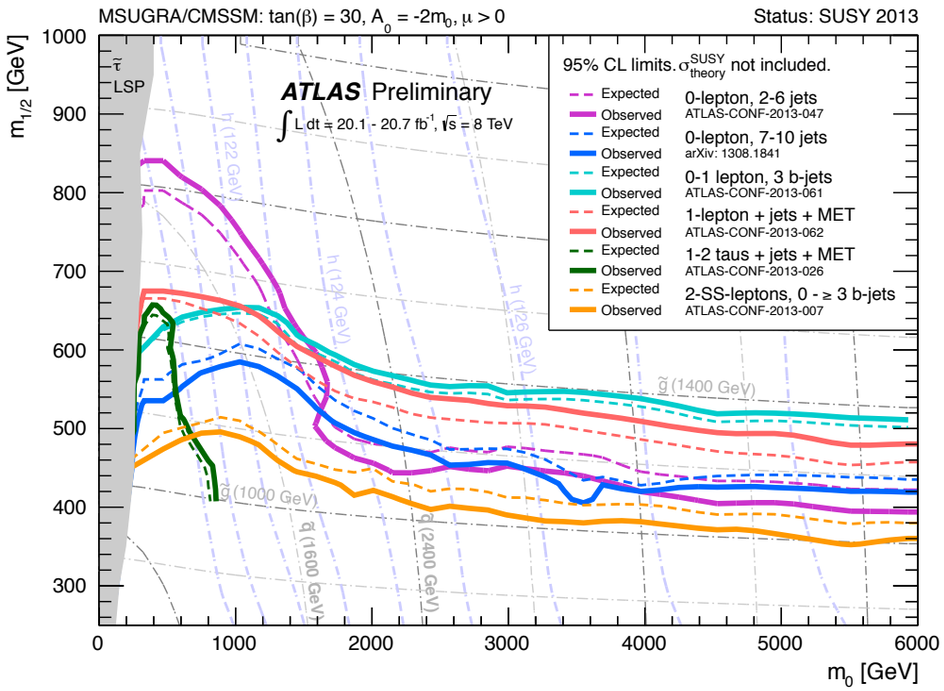


No discovery yet



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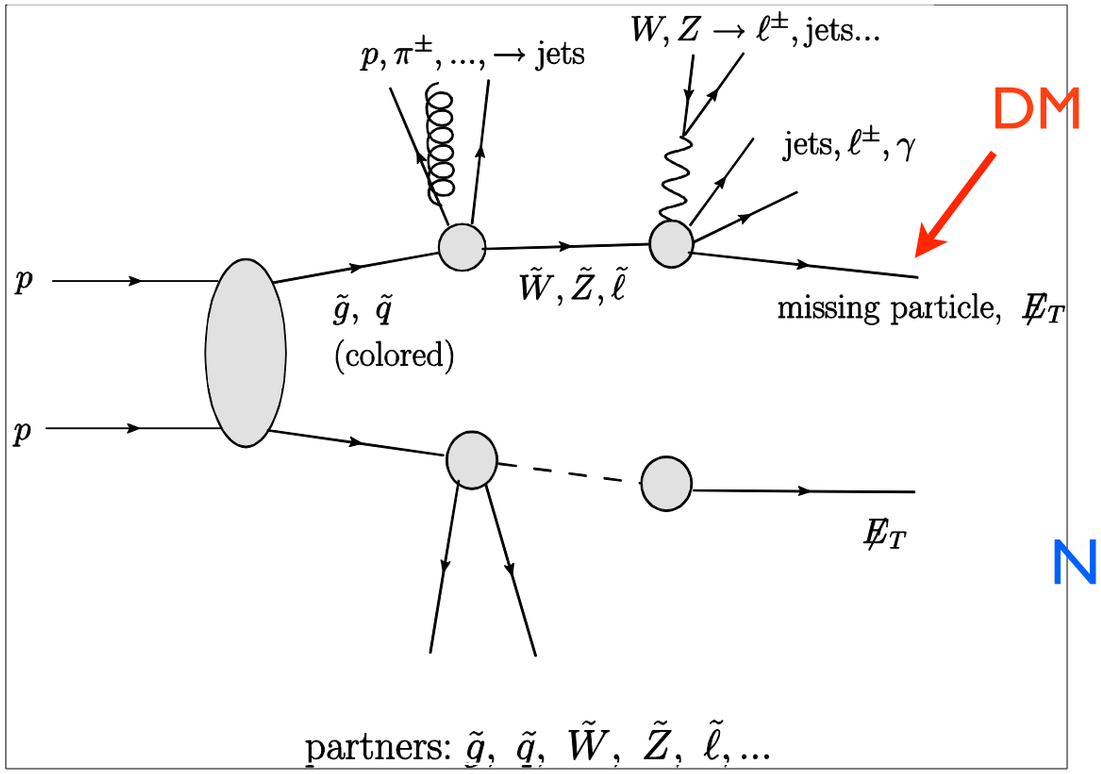

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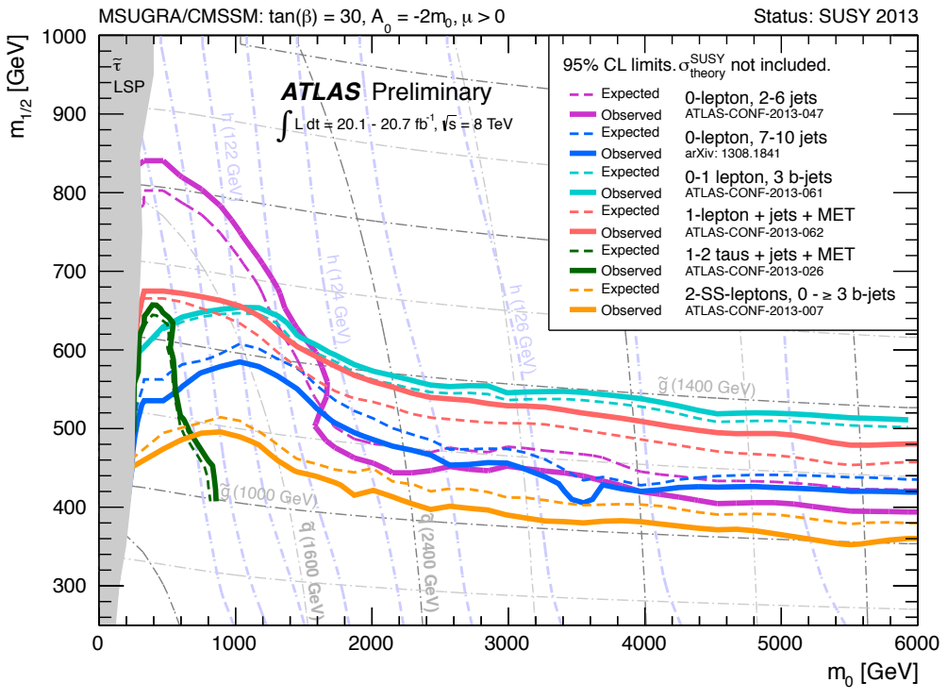

Of course, still plausible at the LHC, will keep looking.
Higher energy ⇒ higher reach

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Is Supersymmetry Dead?

The grand scheme, a stepping stone to string theory, is still high on physicists' wish lists. But if no solid evidence surfaces soon, it could begin to have a serious PR problem

By Davide Castelvecchi | April 25, 2012 | 32

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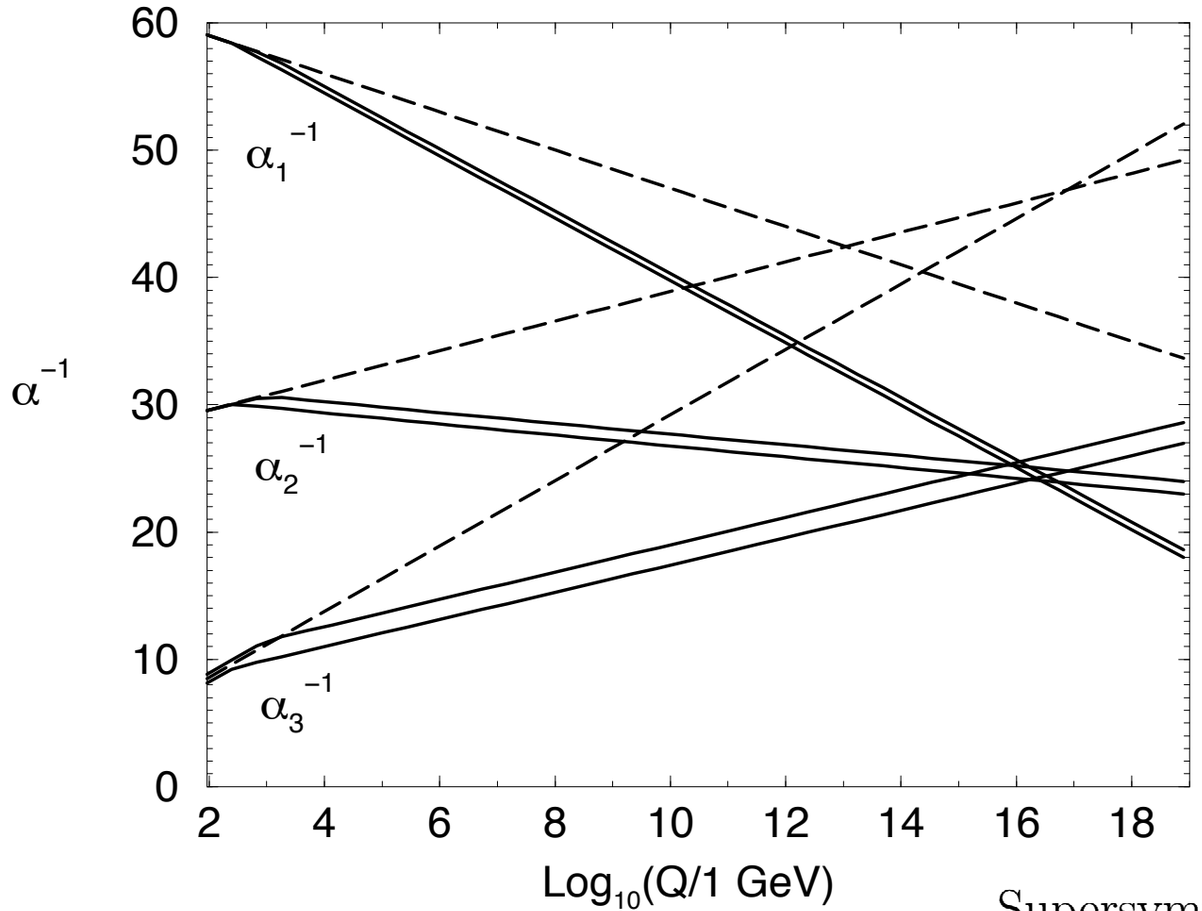
I will try to give my answer.
Warning: will be subjective!

Why do we like SUSY: beyond Einstein

- A unique extension of space-time symmetry.
- Our (only) chance of going beyond Einstein.
- In some sense, it has to be part of the fundamental theory.

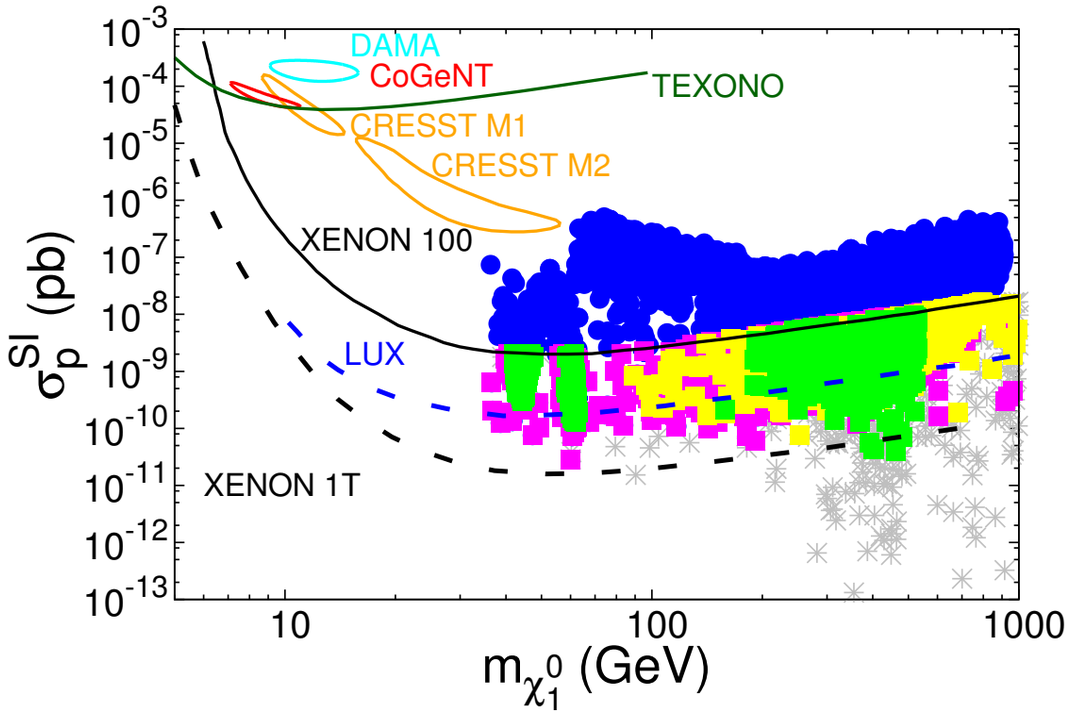
- It is a broken symmetry.
- That's fine. But, this fact does not lead to predictions about where SUSY may be.

Why do we like SUSY: Unification



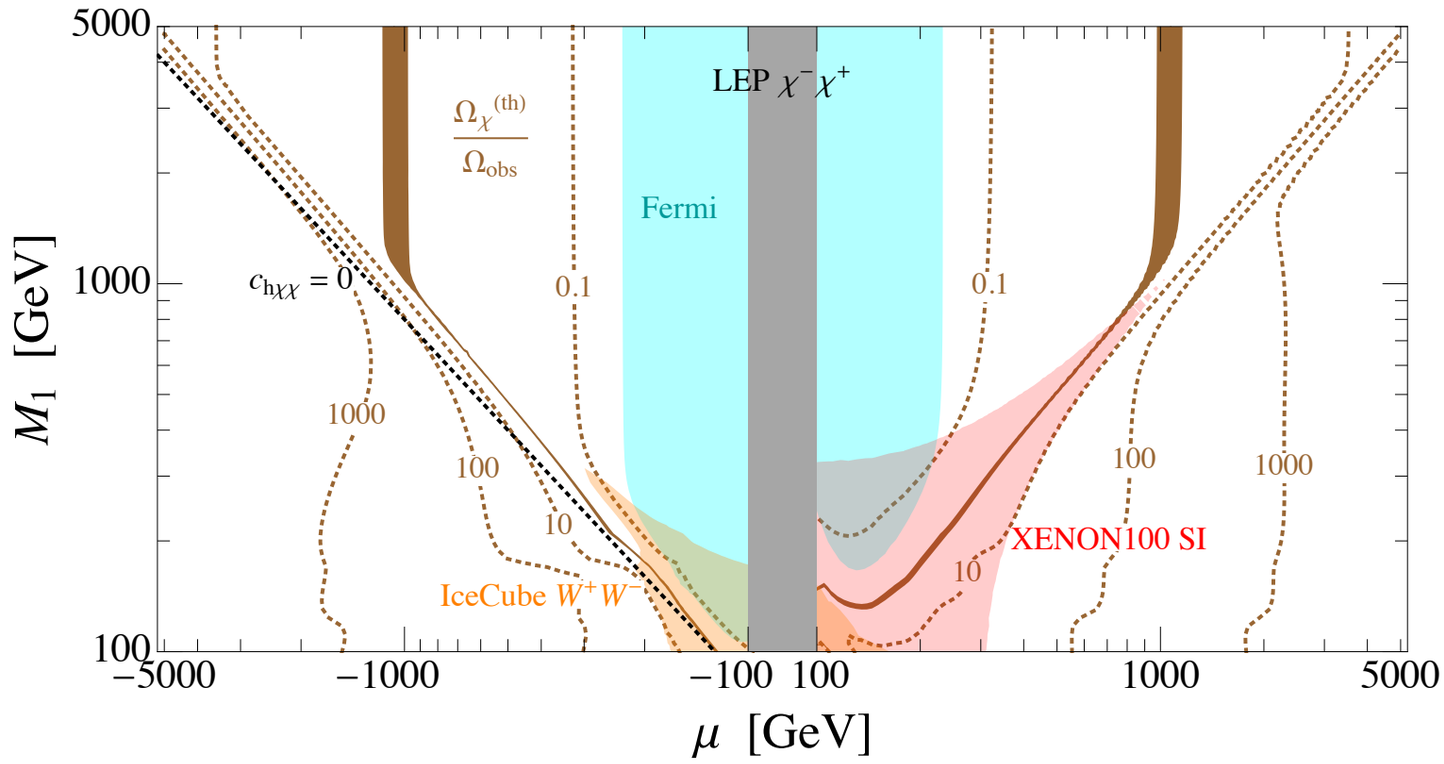
- Not affected by the current limits.
- A feature we would like to keep when considering extensions.

Why do we like SUSY: dark matter



Cheung, Hall, Pinner, Ruderman, 1211.4873

Han, Liu, Natarajan, 1303.3040



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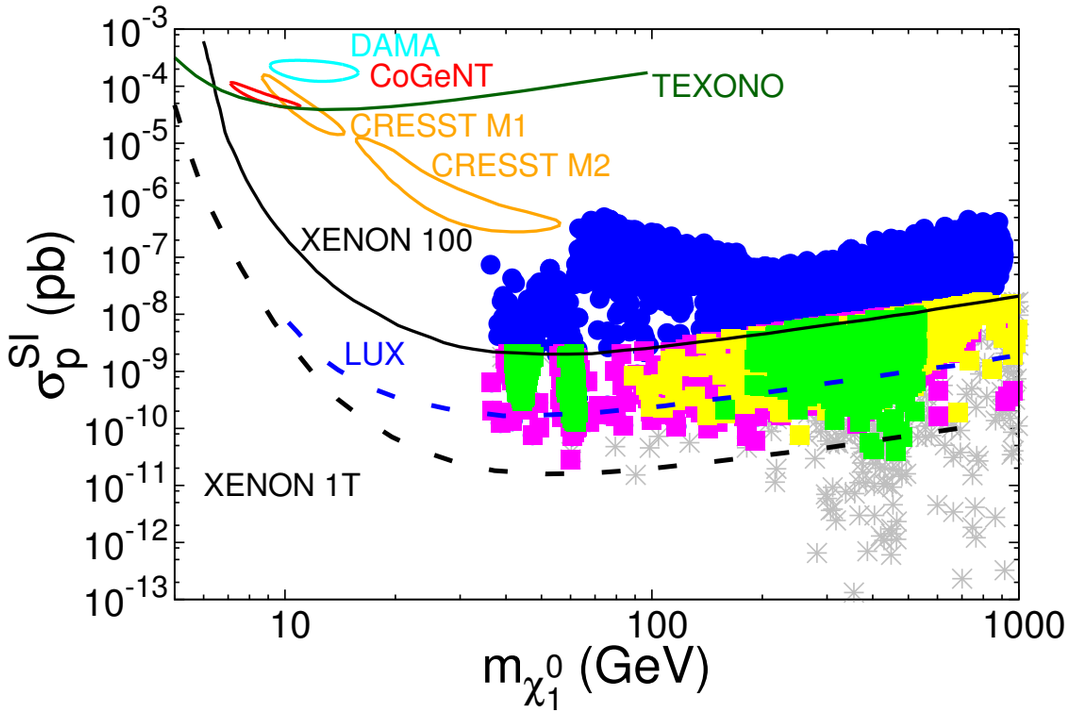

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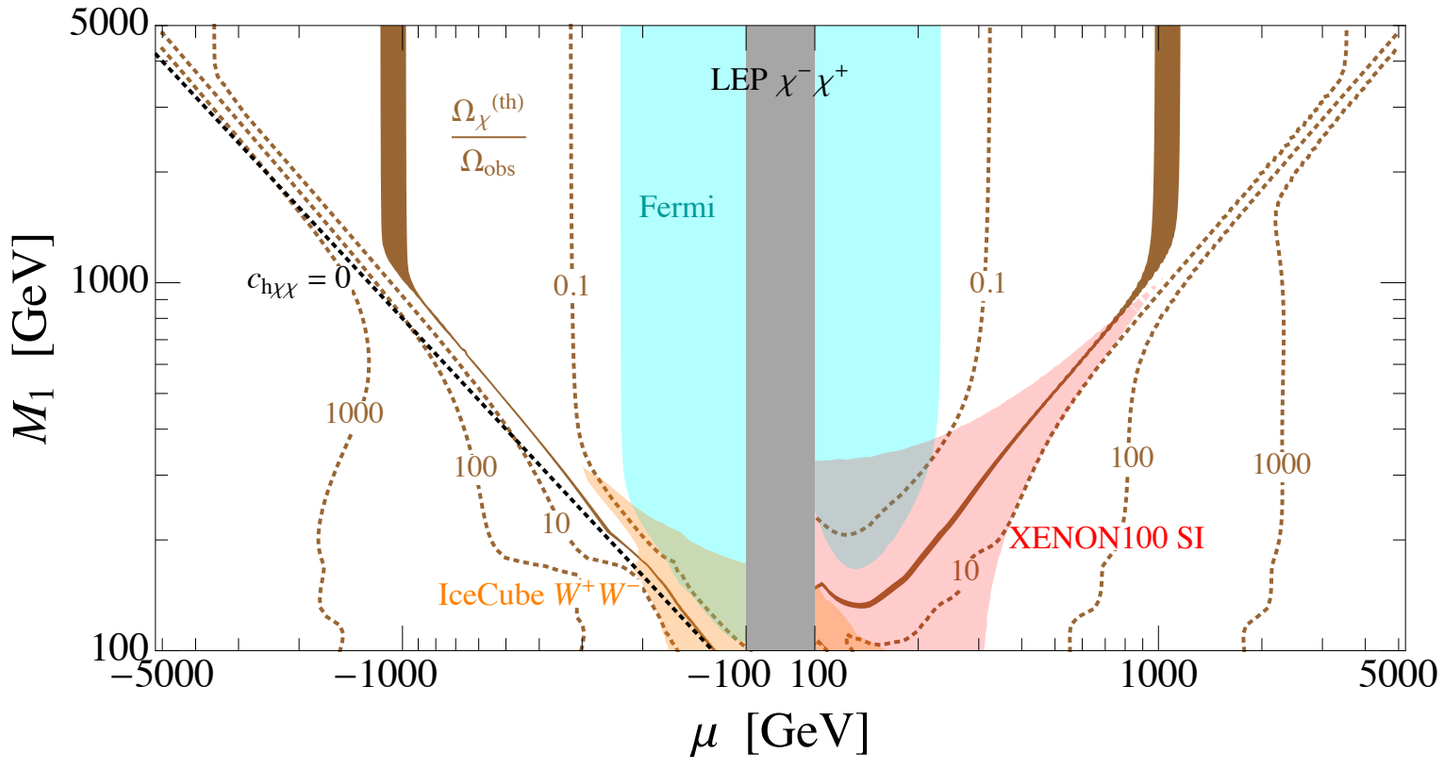
Constraints are getting stronger

Cheung, Hall, Pinner, Ruderman, 1211.4873



Possible scenarios (not over-closing)

- Higgsino $\lesssim$ TeV
- Wino $\lesssim$ 3 TeV
- Well temper: $\tilde{h},\ \tilde{W},\ \tilde{B}$ — $\Delta M \sim$ several % $\times M_{\rm DM}$

Arkani-Hamed, Delgado, Giudice, hep-ph/0601041

- Coannihilation: $\tilde{\tau},\ \tilde{q},\ \tilde{t}, \ldots$, $\tilde{B}$ — $\Delta M \sim$ several % $\times M_{\rm DM}$
- Funnel: $2\ M_{DM} \approx M_X$ X= A, H...

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Common feature:
very small mass splitting "compressed"

$$\tilde{h},\ \tilde{W},\ \tilde{B} \quad \Delta M \sim \text{ several } \% \times M_{\rm DM}$$

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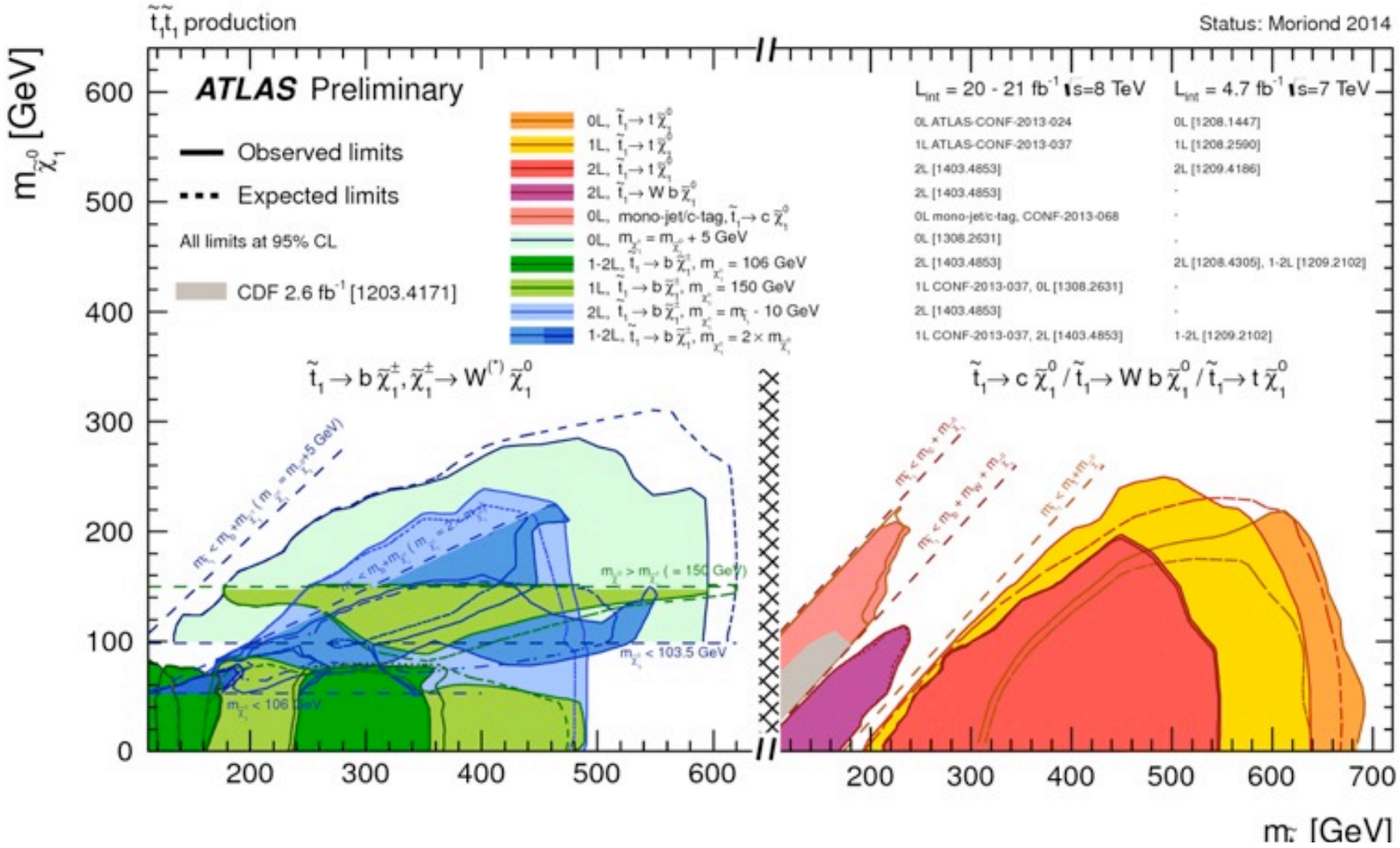
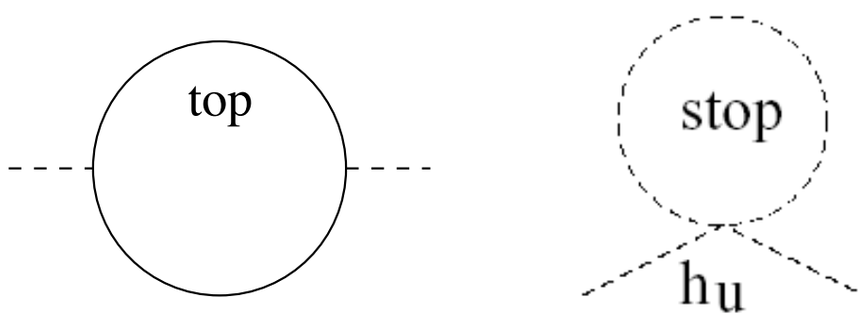
Why do we like SUSY: naturalness



- Stop limit is not too strong yet (I think).
  - Borderline being too tuned.



Still, want lighter stop. Loopholes?

- Yes, if stop don't decay "normally".
- Stealth.
- RPV.
- Compressed
- Not stop, top partner not even colored
- ...

m_h = 126 GeV vs SUSY (MSSM).

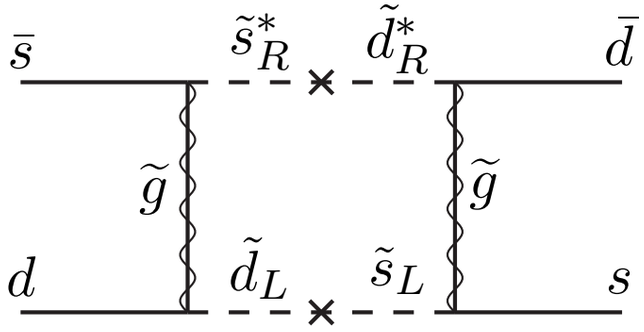
- Minimal SUSY model (MSSM)
  - Higgs mass controlled by SM gauge interactions.

$$m_h^2 = m_Z^2 \cos^2 2\beta + \text{loop} \qquad \text{loop} \propto \log\left(\frac{M_{\text{SUSY}}}{M_{\text{top}}}\right)$$

  - m_h = 126 GeV needs $M_{SUSY} \gg M_{top}$

- In MSSM, Higgs mass gives some of the strongest limits on SUSY parameter space!

Actually, other "problems" existed long ago



Kaon mixing,
e.g. Martin "Supersymmetry primer"

$$\frac{|\mathrm{Re}[m^2_{\tilde{s}^*_R \tilde{d}_R} m^2_{\tilde{s}^*_L \tilde{d}_L}]|^{1/2}}{m^2_{\tilde{q}}} < \left(\frac{m_{\tilde{q}}}{1000\ \mathrm{GeV}}\right) \times \begin{cases} 0.0016 & \text{for } m_{\tilde{g}} = 0.5 m_{\tilde{q}}, \\ 0.0020 & \text{for } m_{\tilde{g}} = m_{\tilde{q}}, \\ 0.0026 & \text{for } m_{\tilde{g}} = 2 m_{\tilde{q}}. \end{cases}$$

- SUSY flavor/CP problem (last century).
  - Most straightforward conclusion: scalars probably would be heavy, 10s - 100s TeV!
- Perhaps not surprising we have not seen the scalar superpartners.

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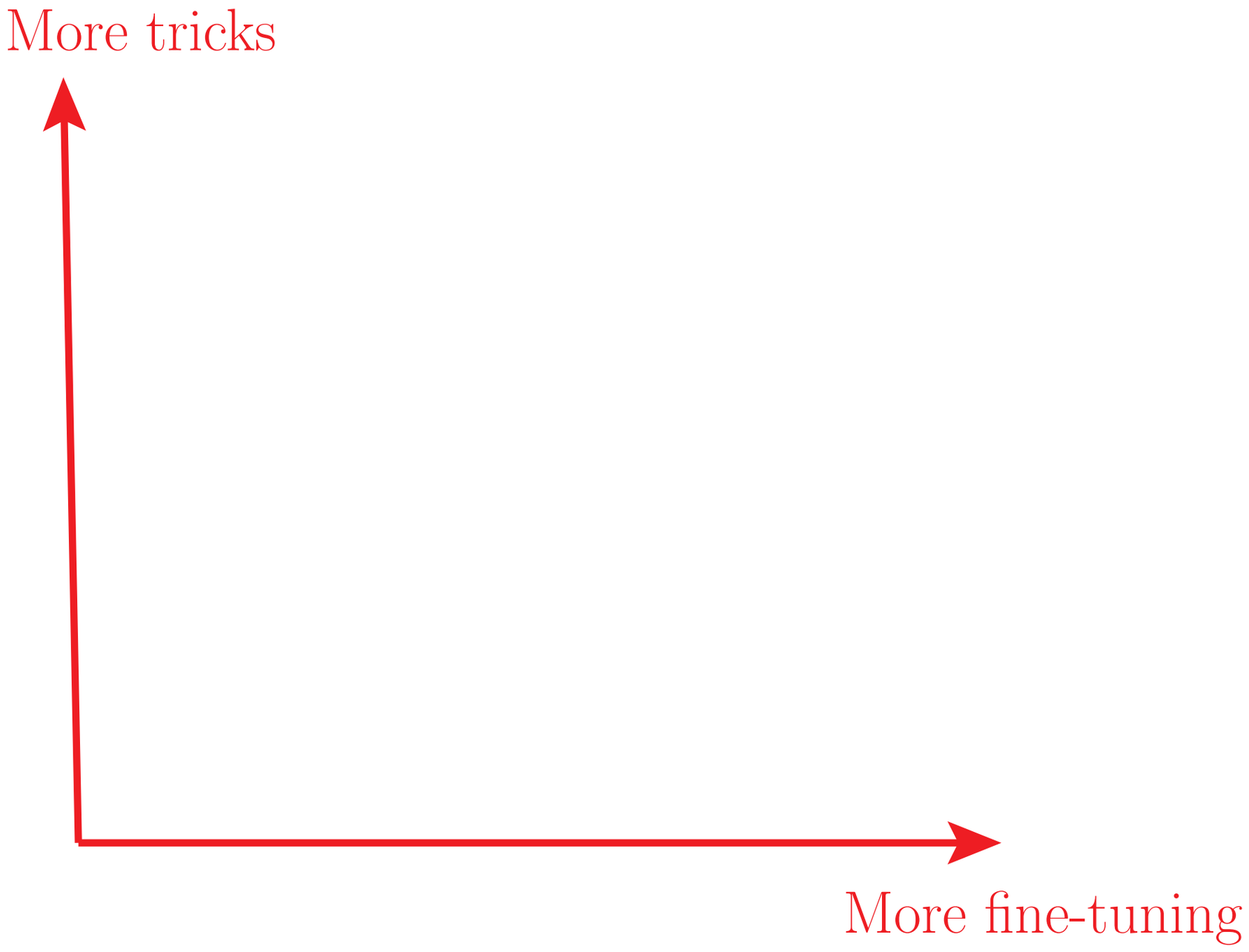
- However, it may be time to take a step back...

Which direction to go?



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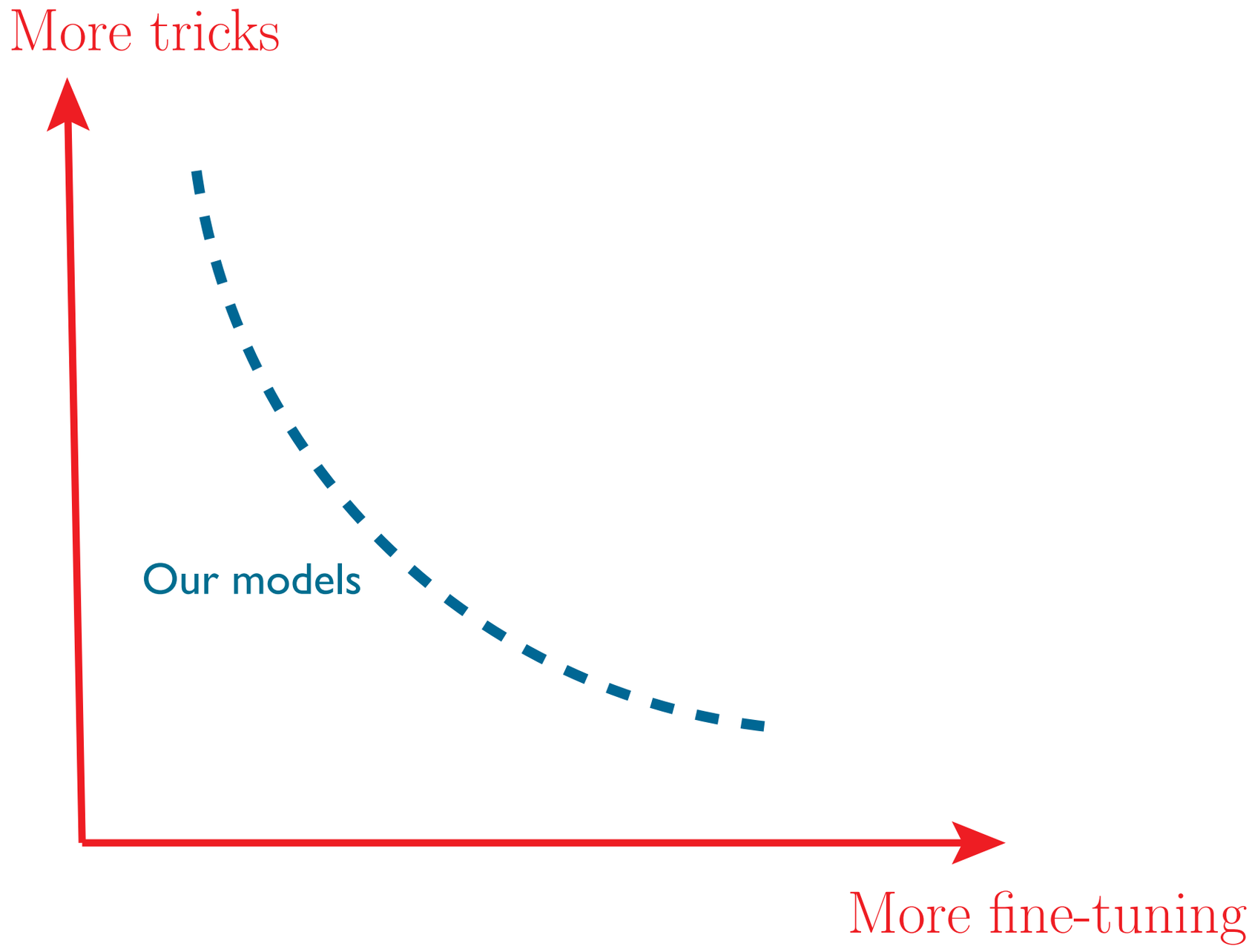

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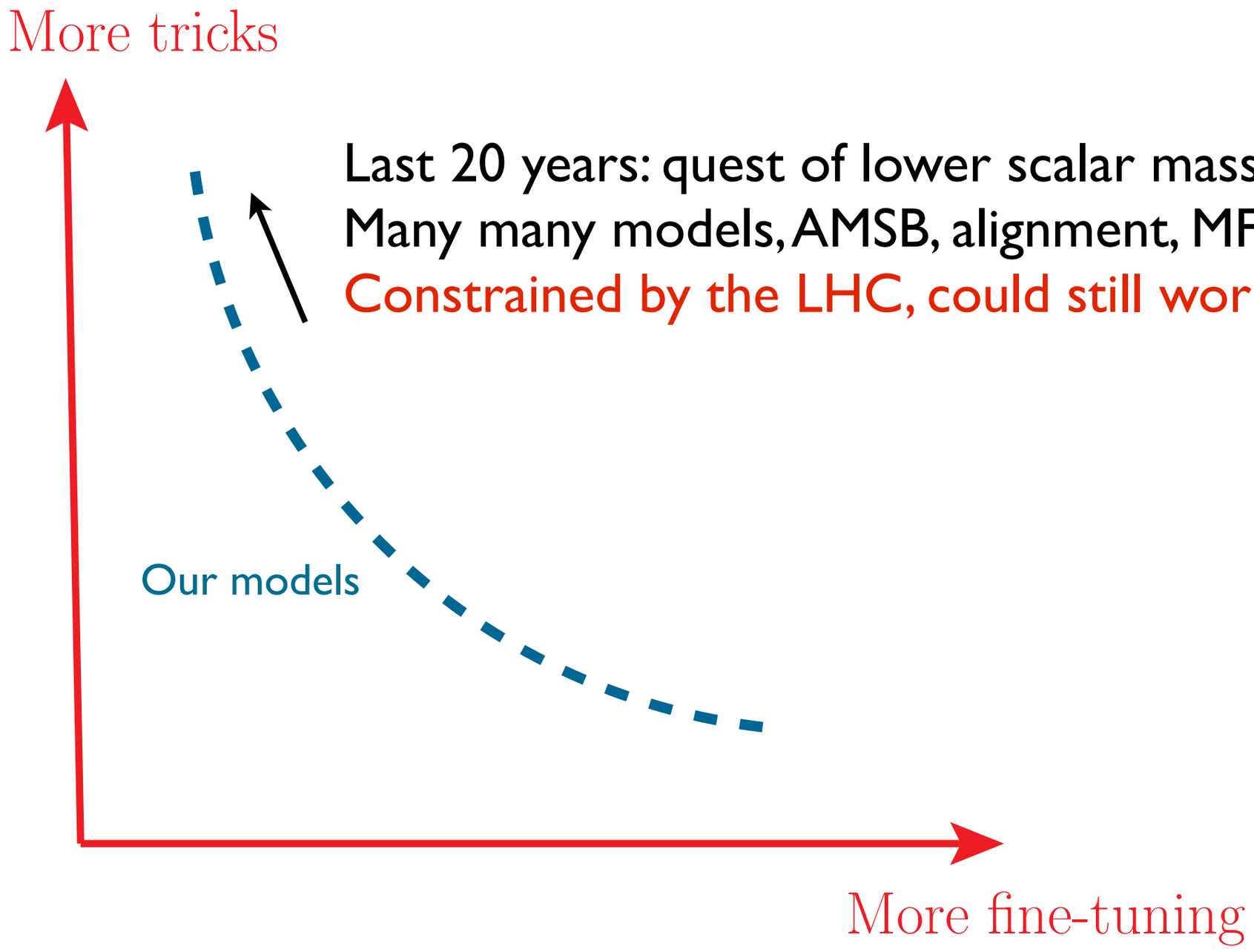

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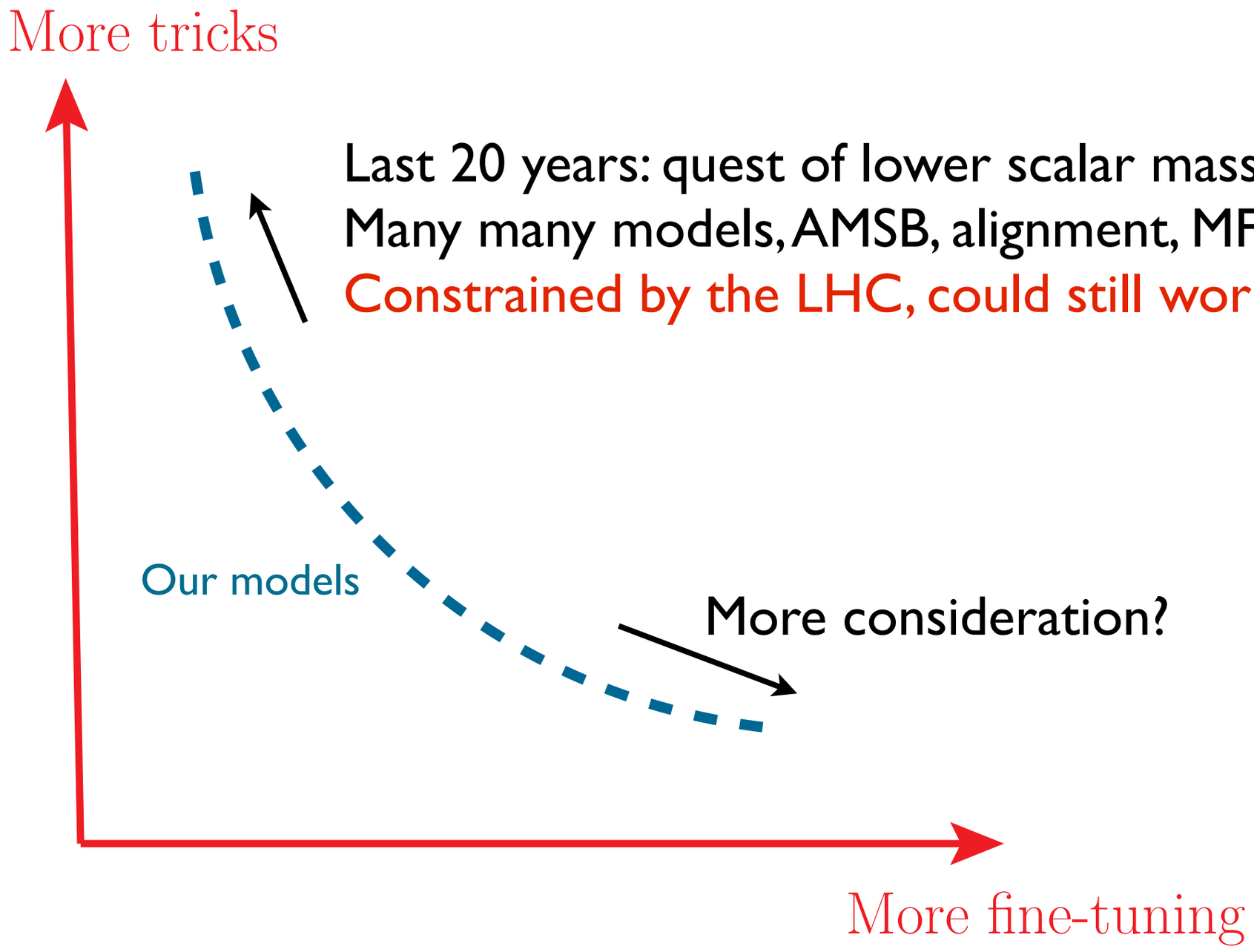

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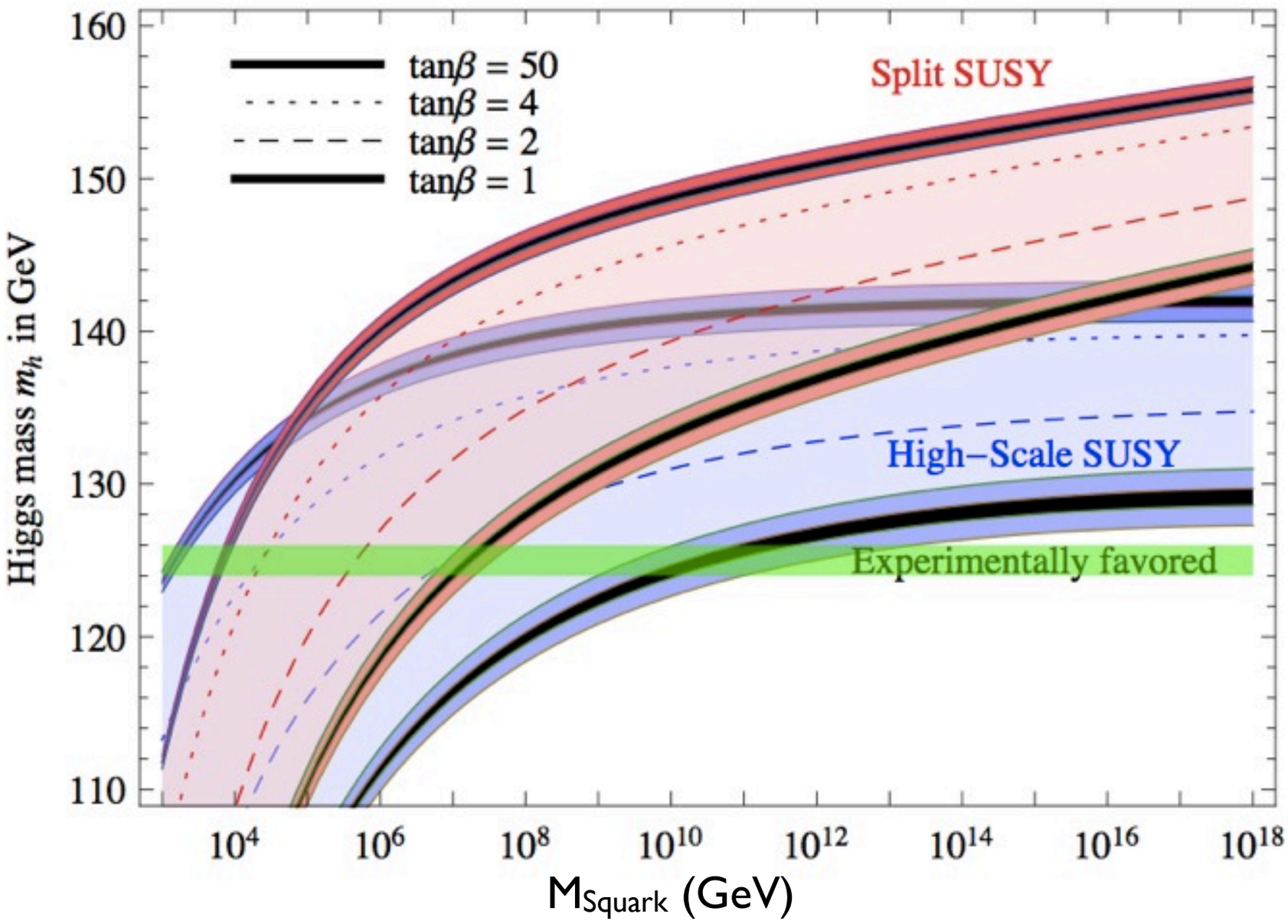
- Higgs mass.

Heavy scalar, the simplest scenario



Giudice, Strumia, 2011

A promising scenario for the LHC

Mini-split, spread, zprime-mediation, ...

Heavy squarks

$m_{\tilde{t},\tilde{b}} < m_{\tilde{u},\tilde{d}}$

$\tilde{u},\ \tilde{d},\ \ldots$

$\tilde{t},\ \tilde{b}$

10s - 100s TeV

$\tilde{g}$

TeV-ish

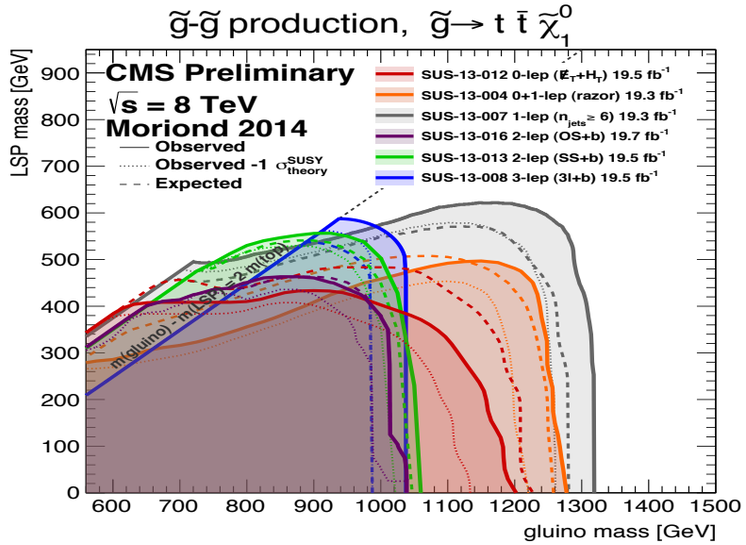
Light gaugino

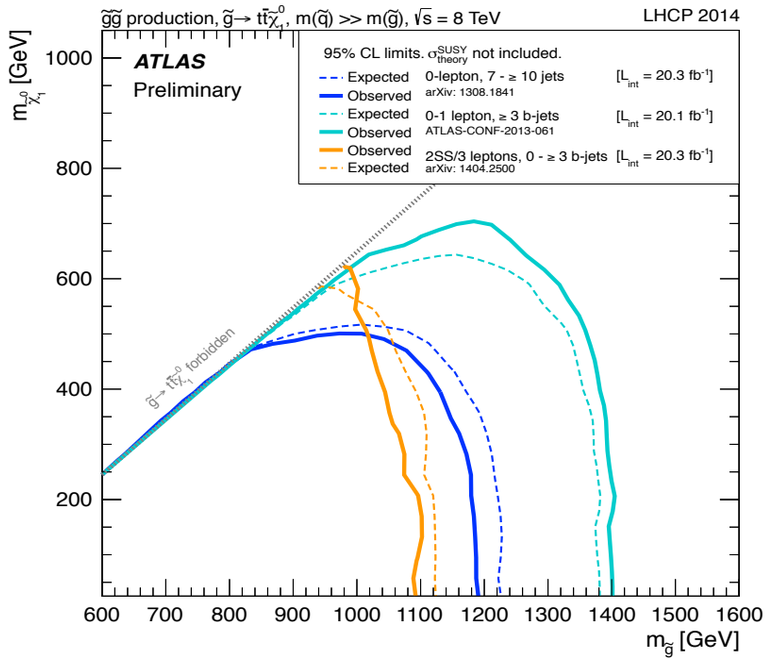
$\tilde{N}\ \tilde{C}^{\pm}$

Fermionic partners still tend to be light.

LHC signal

$pp \to \tilde{g}\tilde{g} \to t\bar{t}t\bar{t},\ t\bar{t}b\bar{b},\ t\bar{t}t\bar{b}\ \ldots$





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  - Non-thermal production.
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One example

Minimal flavor violation (MFV) + RPV

Nikolidakis and Smith, 0710.3129, Csaki, Grossman, Heidenreich, 1111.1239

- R-parity violation a good way to "hide" SUSY.

- MFV, all flavor violation coming from SM yukawa couplings.
  - A good framework to address the SUSY flavor problem.

- Imposing MFV on R-parity breaking couplings?
  - MFV+RPV can satisfy all the constraints on RPV!

- For example, the often studied udd coupling would be

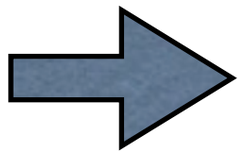
$$W_{\rm BNV} = \frac{1}{2}\, w''(Y_u\,\bar{u})(Y_d\,\bar{d})(Y_d\,\bar{d})$$

Flavored Dark Matter

[Batell, Pradler, Spannowsky]
[Batell, Lin, Wang]

Basic Idea: Give dark matter a flavor!

- MFV implies a Z3 symmetry, *flavor triality*, under which all SM fields are neutral and Dark Matter is charged



MFV can stabilize Dark Matter!

Example model:

$$W = \lambda \, X_i \, Y \, \bar{u}^i$$

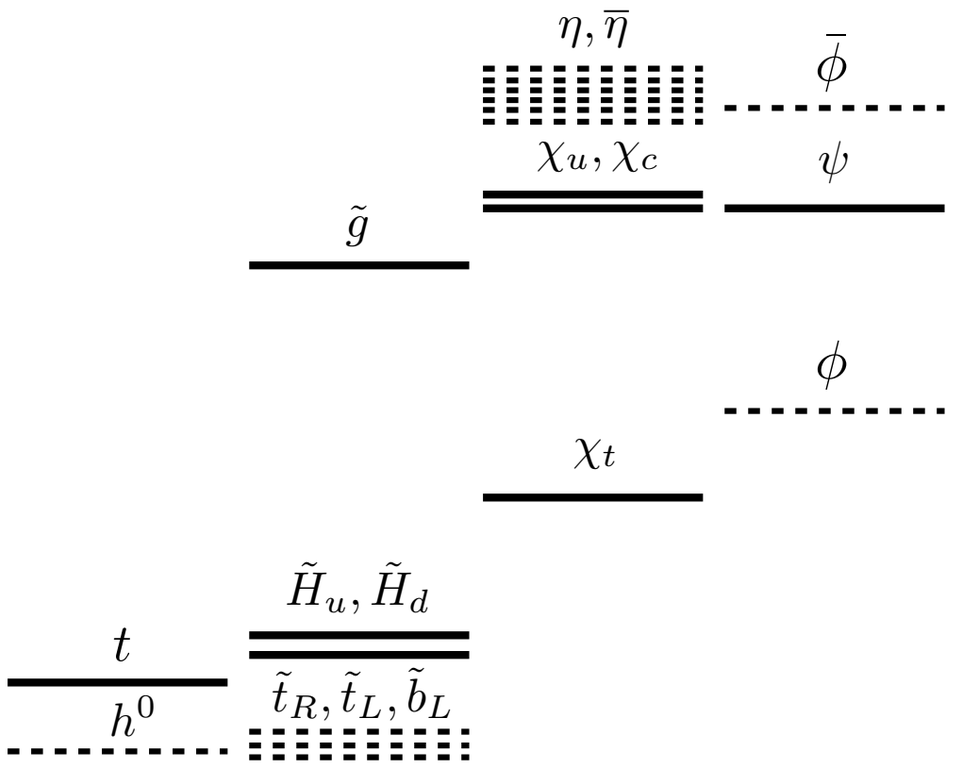
Dark Matter (3 flavors)

Mediator

up-type quark (3 flavors)

Can make viable models of Dark Matter!

At the LHC



$$pp \to \phi_Y \phi_Y^*, \;\; \phi_Y \to t + \chi$$

But not the stop.

$$pp \to \psi_Y \bar{\phi}_Y, \;\; \psi_Y \to \tilde{t} + \chi$$

$$\tilde{t} \to jj \;\; (udd \; \mathrm{RPV})$$

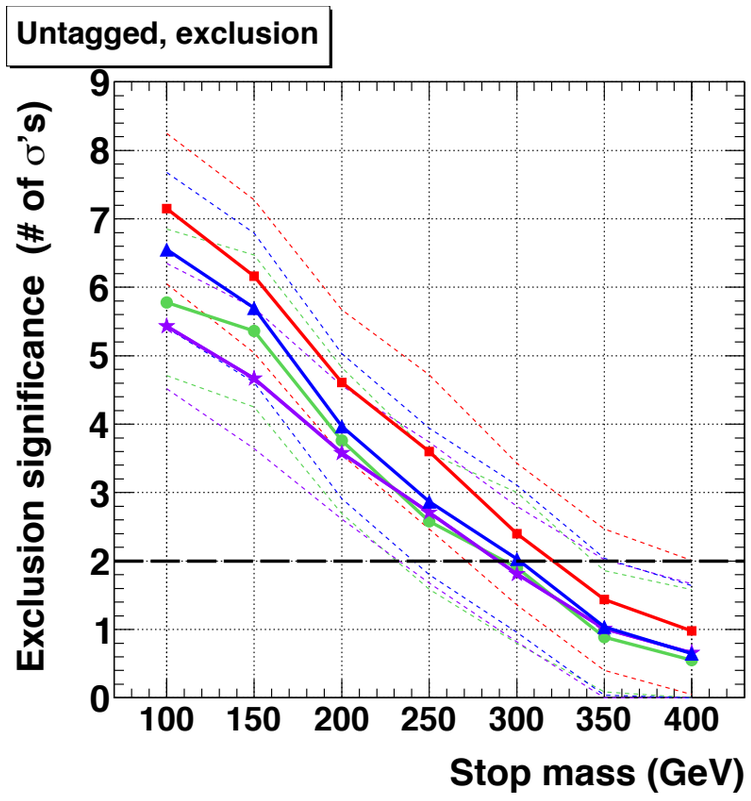
"hidden" stop

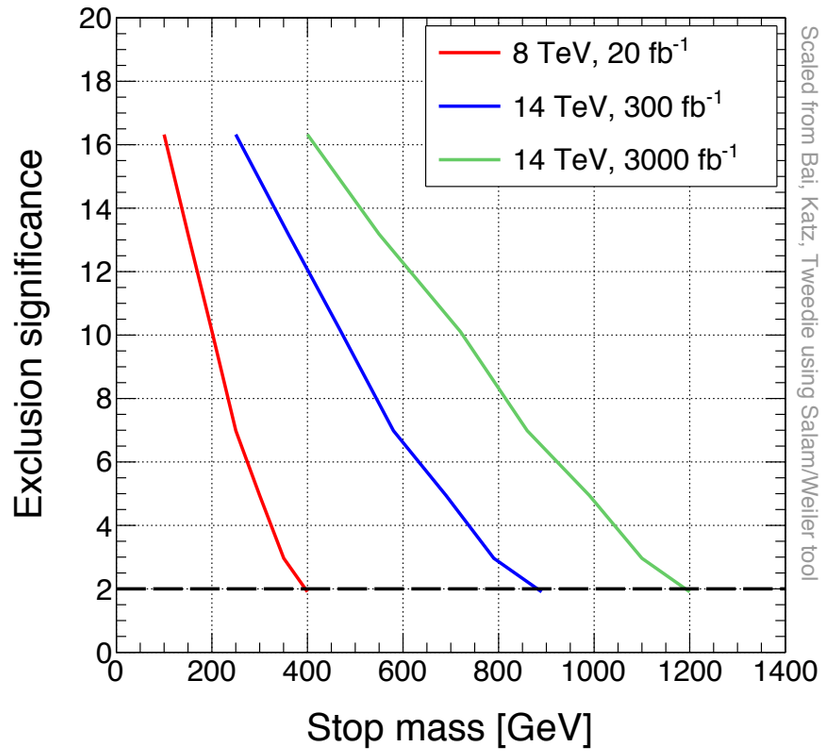
- May find "heavy stop", but theory is natural.

Conclusions

- Is SUSY still a promising scenario?
- Yes. "Good old" SUSY signal could be just around the corner.
- But, more likely, the appearance of SUSY may be different than we thought.
- Not as natural as we expected. (still solves the big hierarchy problem)
- Or, not as minimal as we thought, spectrum can be surprising.
- Experiments can tell us!

"best" stop hiding, RPV with udd





Estimated by scaling up using parton luminosity

Salam and Weiler

http://collider-reach.web.cern.ch/collider-reach/