O(1) GeV DM in SUSY and a very light pseudoscalar at the LHC

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in collaboration with
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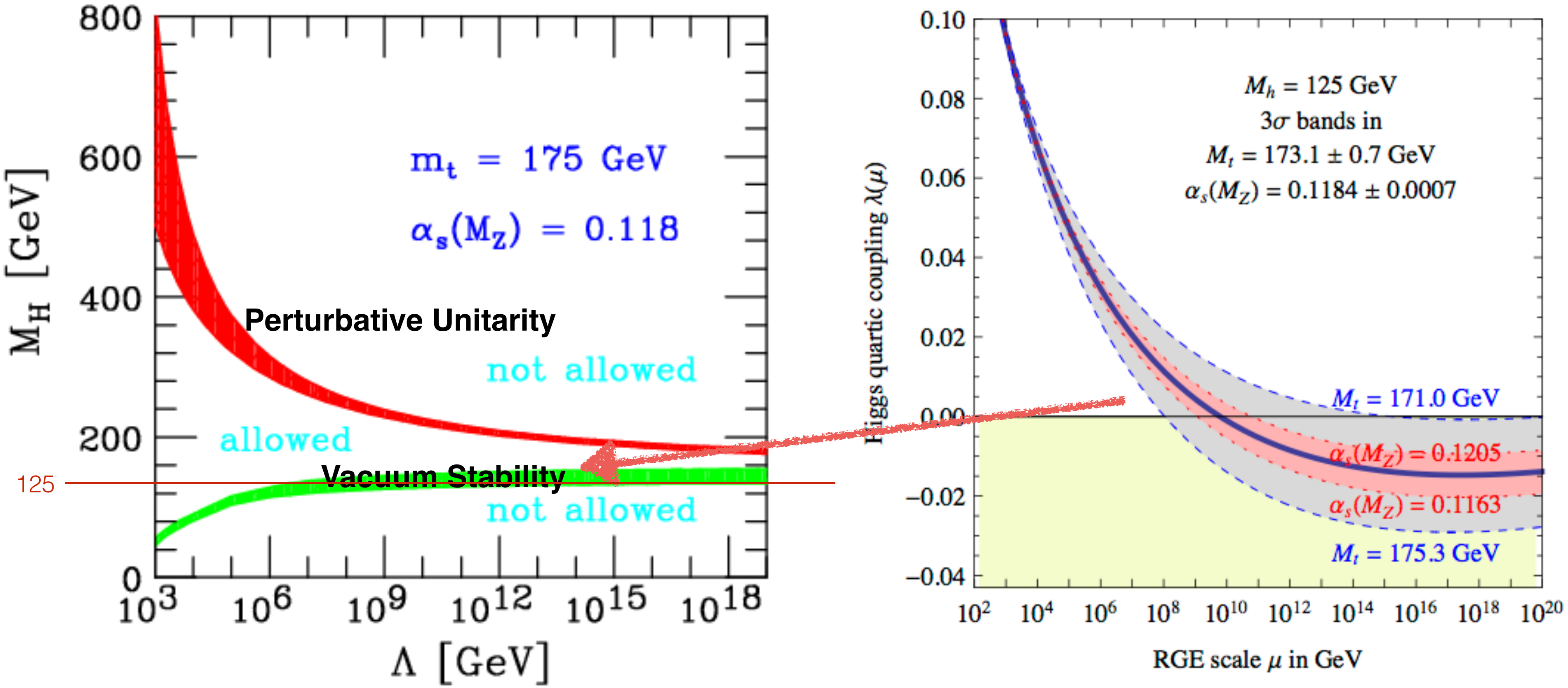
Higgs is found. Then what else?



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- 125 GeV is quite a safe mass if we consider SM as the effective theory below 100 ~ 1000 TeV.
- And LHC has so far seen no remarkable observation to be regarded as a new physics signal.
- But still we keep our positions and waiting for some news.

Higgs is found. Then what else?

- Attempts to survey the structure of our vacuum or universe are going on.
- Hierarchy Problem - SUSY, Composite Higgs, Twin Higgs, Extra D, etc.
- Dark Matter
- Neutrino Oscillation
- Other Precision measurements: B-physics, neutron EDM, muon g-2, etc.

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SUSY Model of SM particles

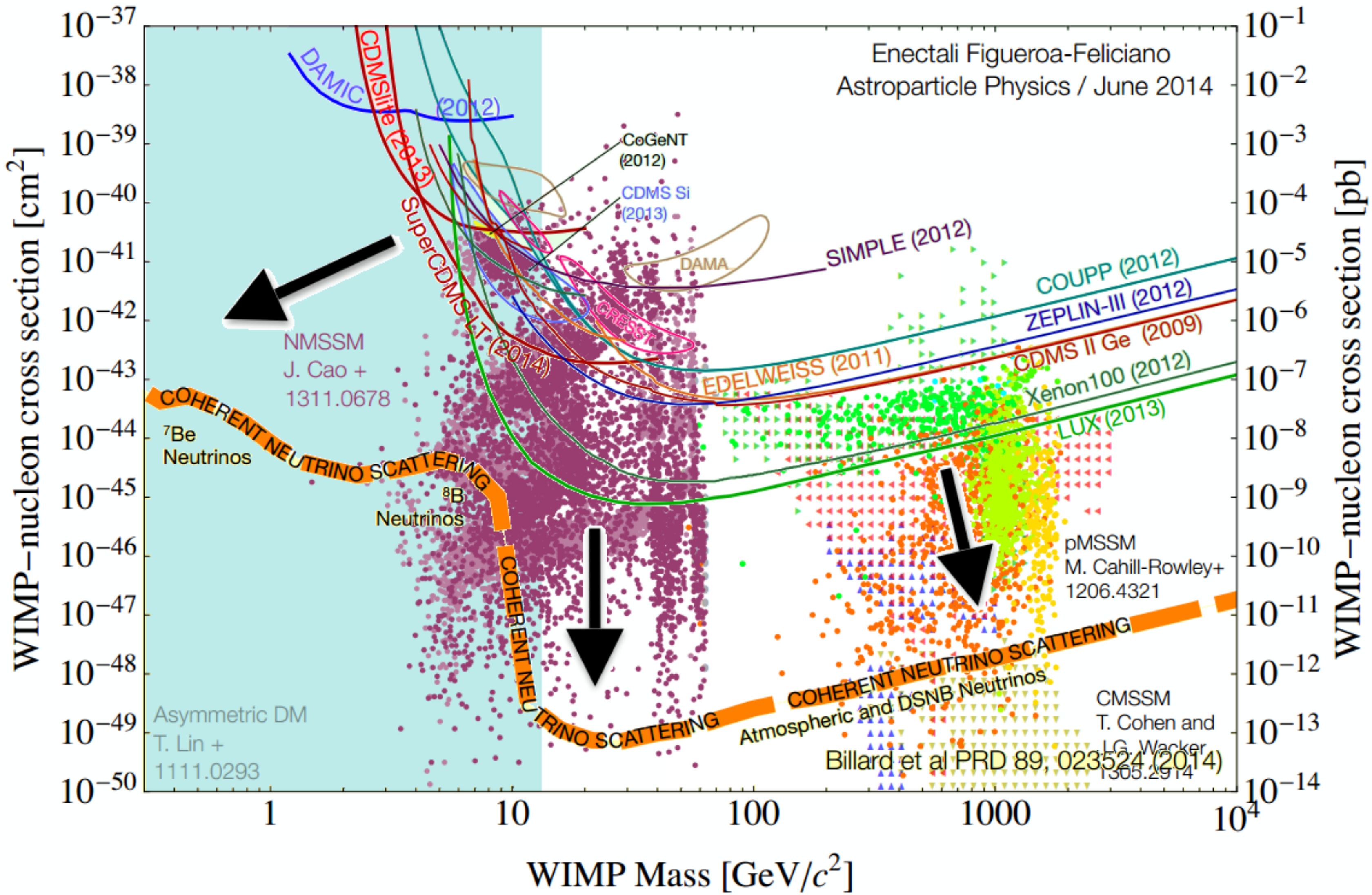
- Theoretically sound and predictive model
- Rich in phenomenological implications:
  3 neutral Higgs, DM candidate (LSP neutralino with R-parity)
- However, no evidence at all in the LHC Run I.
- Because m_h^2 requires a large radiative correction from the stops, and it implies $m_{\rm soft}$ ~ TeV or X_t (A_t) ~ multi TeV.
- Large fine-tuning between $m_{H_i}^2, \mu$ and M_Z .

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

DM might be just around the corner of Higgs

- SUSY suggests a good DM candidate (LSP with R-Parity).
- But the DM search is getting challenged more.

DM might be just around the corner of Higgs



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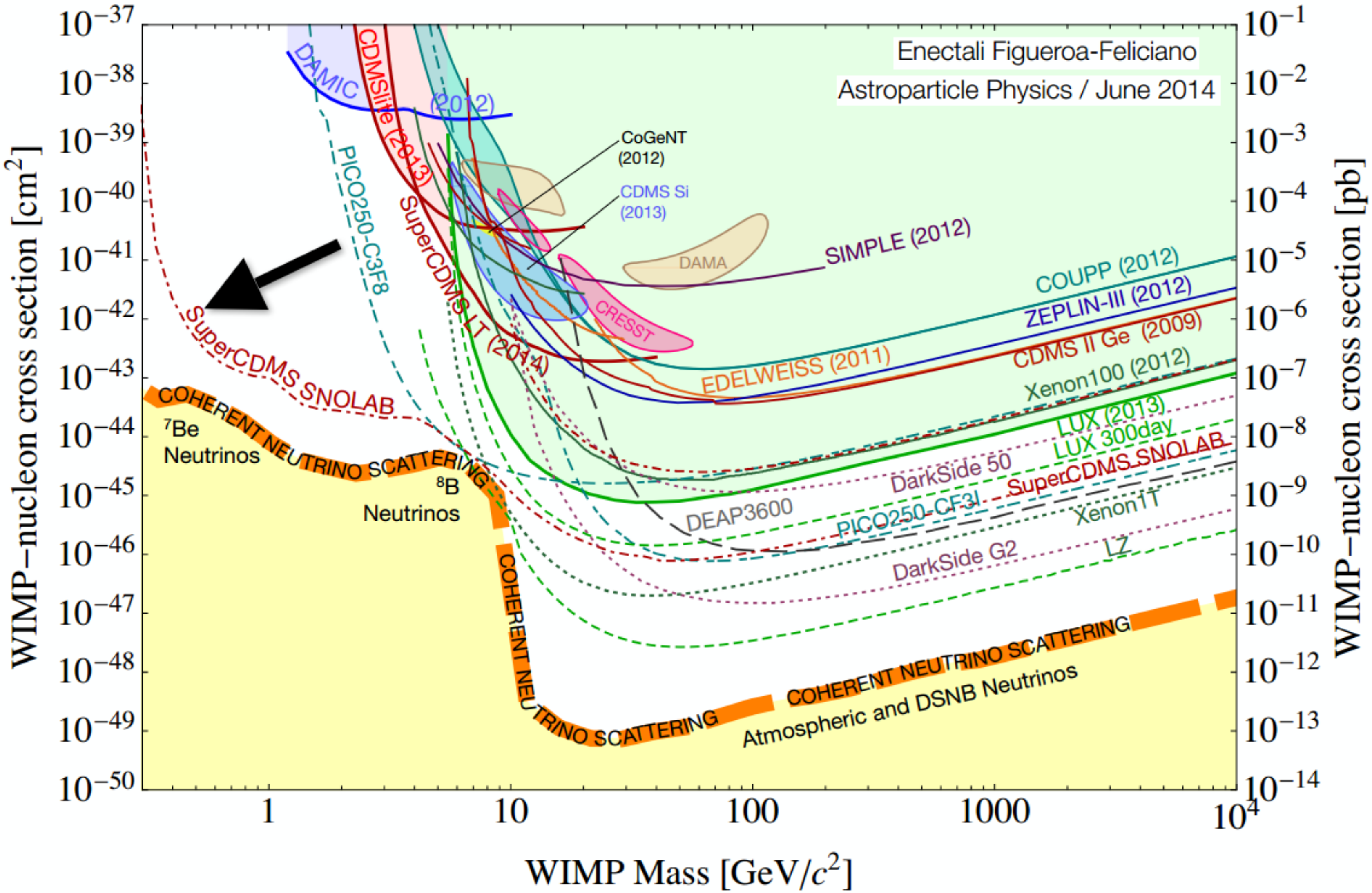

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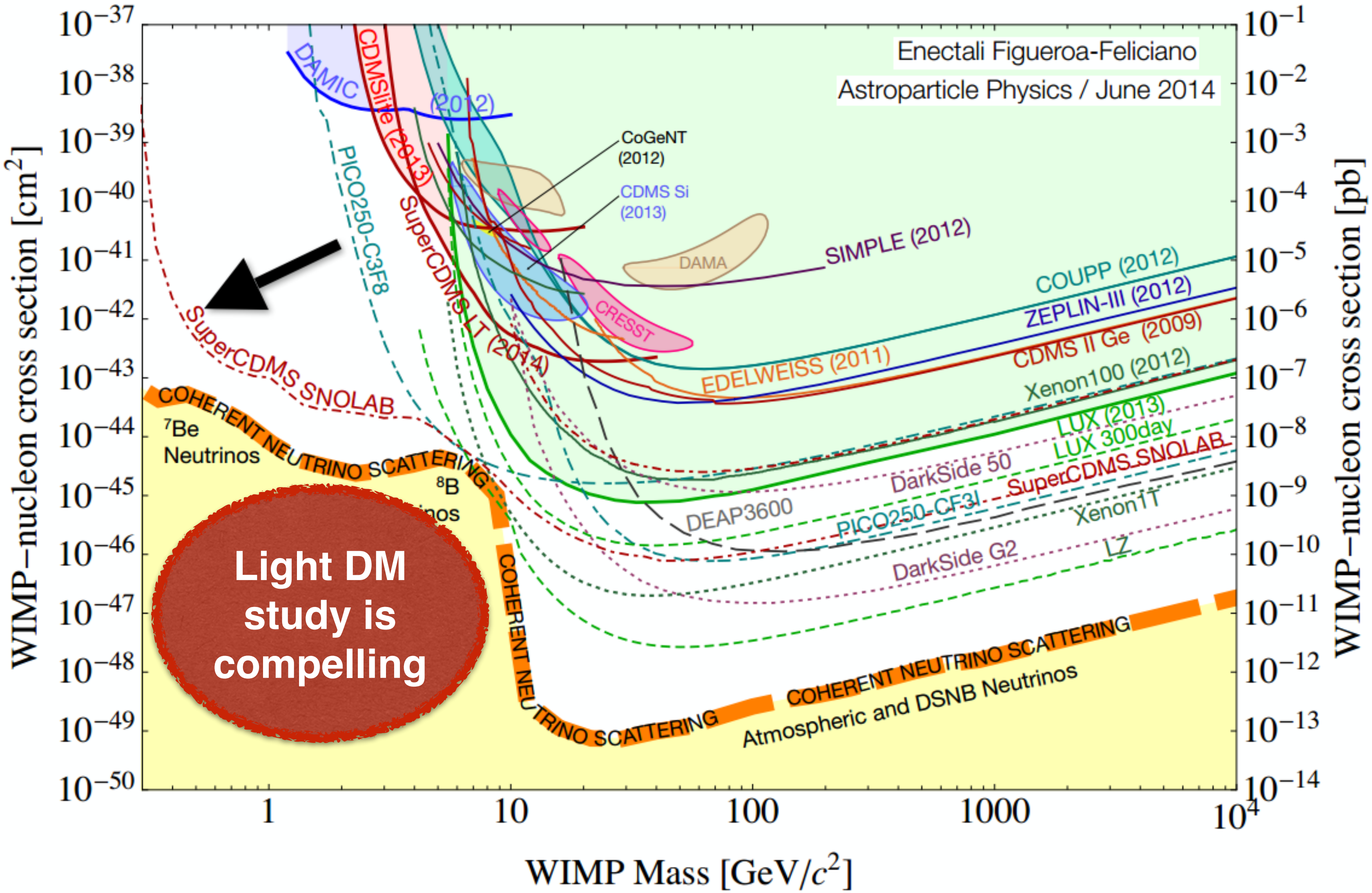
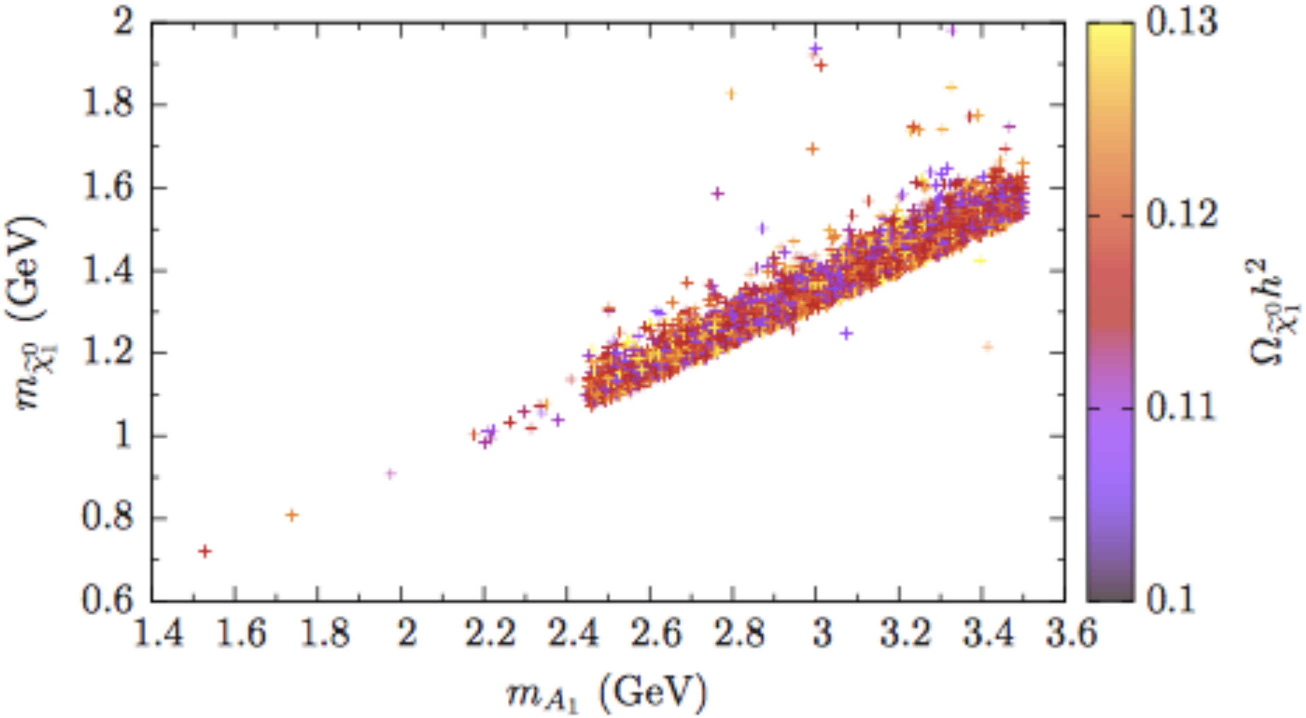


How to realize light DM in SUSY

- It is difficult to realize an O(1) GeV DM in the MSSM
  -> But in the NMSSM, it is possible. (1504.05085)



NMSSM setup for singlino DM

- Next-to-Minimal Supersymmetric extension of the Standard Model

- Introduces a SM singlet superfield to reduce the fine-tuning of the Higgs mass. And all mass scales are introduced at the SUSY breaking scale.

$$W \supset \mu H_u H_d \qquad V \supset B\mu h_u h_d$$

MSSM → NMSSM

$$W \supset \lambda S H_u H_d + \frac{\kappa}{3} S^3 \qquad V \supset \lambda A_\lambda S h_u h_d$$

- Light singlino-like DM is decoupled from the higgsino states. ($\kappa s \ll \mu_{\rm eff}$)

$$\begin{array}{cccc} m_{\tilde{B},\tilde{W}} & & m_{\tilde{H}_{u,d}} & m_{\tilde{S}} \end{array}$$
$$\begin{pmatrix} \cdots & & & \\ & 0 & -\mu_{\rm eff} & -\lambda v_u \\ & -\mu_{\rm eff} & 0 & -\lambda v_d \\ & -\lambda v_u & -\lambda v_d & 2\kappa s \end{pmatrix}$$

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- Strong mass correlation between $m_{\tilde{\chi}_1^0}$ and $m_{A_1^0}$ (~ κs) for a large $\tan\beta$.

$$m^2_{A_1^0} \simeq \lambda(A_\lambda + 4\kappa s)\frac{v^2 \sin^2 2\beta}{2s} - 3\kappa s A_\kappa$$

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- Light singlino-like DM is decoupled from the higgsino states. ($\kappa s \ll \mu_{\rm eff}$)

- Strong mass correlation between $m_{\tilde{\chi}_1^0}$ and $m_{A_1^0}$ (~ κs) for a large $\tan\beta$.
  ⇒ Light singlino and light pseudo-scalar can be easily realized.

Parameter Scan and Benchmark Points

- Relic abundance consistent with PLANCK 2015 data.
  ⇨ Necessity to enhance the annihilation channel of LSP
  ⇨ Resonant s-channel process: $\tilde{\chi}_1^0\tilde{\chi}_1^0 \to A_1^0 \to f\bar{f}$
  H_1^0: p-wave suppressed
  $2m_{\tilde{\chi}_1^0} = m_{A_1^0}$ ~ 3 GeV

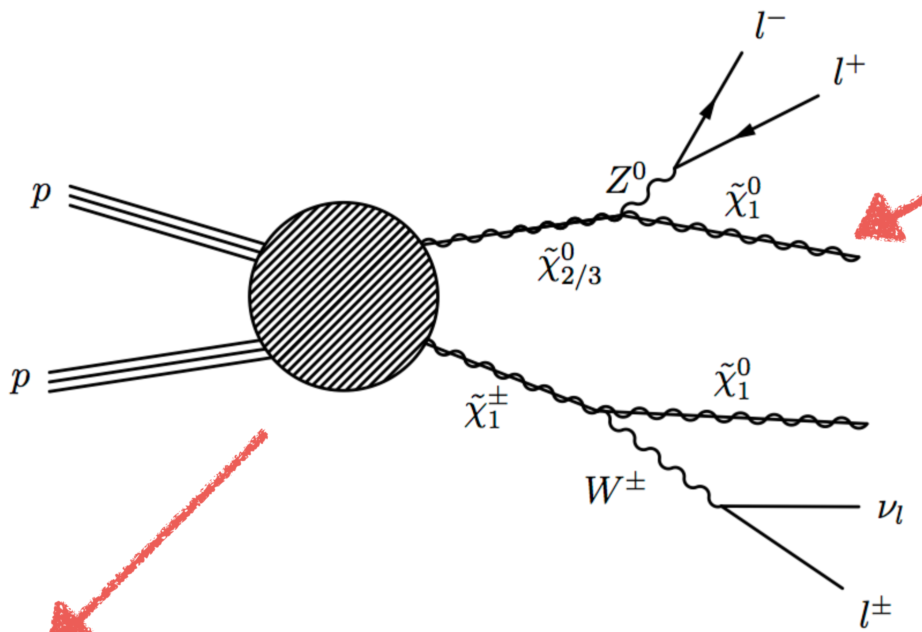
- Rare B meson decay constraints.

- LEP Electroweak Precision Test.

- Etc.

LHC search

- How to optimally survey BPs in the collider:
  BP1 and 2 have distinguishable features at the LHC.



2.7σ significance level expected at the LHC Run II

	BP1	BP2
Masses		
$m_{\tilde{\chi}_1^0}$ (GeV)	1.0025	1.4081
$m_{\tilde{\chi}_2^0}$ (GeV)	189.09	170.13
$m_{\tilde{\chi}_3^0}$ (GeV)	−201.67	−182.27
$m_{\tilde{\chi}_1^\pm}$ (GeV)	194.97	167.72
m_{A_1} (GeV)	2.1776	2.9856
m_{H_2} (GeV)	124.12	125.79
Branching Ratios		
$BR(\tilde{\chi}_2^0 \to Z\tilde{\chi}_1^0)$	0.634	0.603
$BR(\tilde{\chi}_2^0 \to A_1\tilde{\chi}_1^0)$	0.004	0.089
$BR(\tilde{\chi}_3^0 \to Z\tilde{\chi}_1^0)$	0.736	0.704
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$BR(A_1 \to \mu^+\mu^-)$	0.039	0.087

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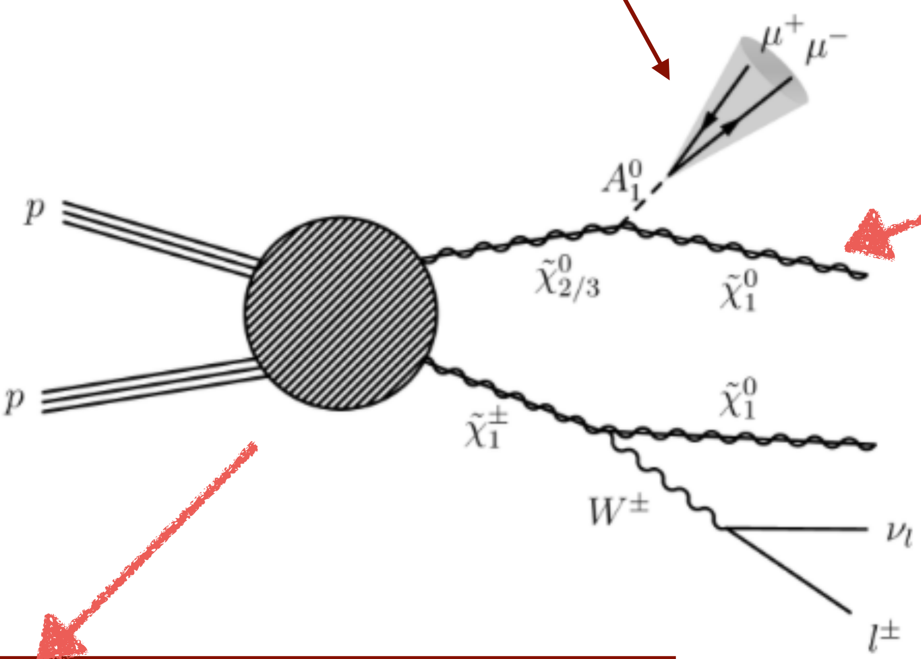
Highly collimated and $m_{\mu\mu} < 5\ \mathrm{GeV}$.



S/B ~ 15 expected at the LHC Run II

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Summary

- Higgs mass implies that the simplest implementation of SUSY still requires a fine-tuning. NMSSM may help to ameliorate the tension.
- DM search calls for back-up by the LHC data.
- NMSSM accommodates O(1) GeV DM via the decoupled singlet sector, and sometimes produces the collimated objects which is easily missed out.
- A proper treatment for them may catch priceless events at the LHC Run II.
- Thank you.