Higgs-SUSY-Dark Matter: An Overview

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2012.2.22

Outline

1 Introduction

2 What is Higgs boson

3 Higgs boson and SUSY

4 Implication of Higgs hint at 125 GeV

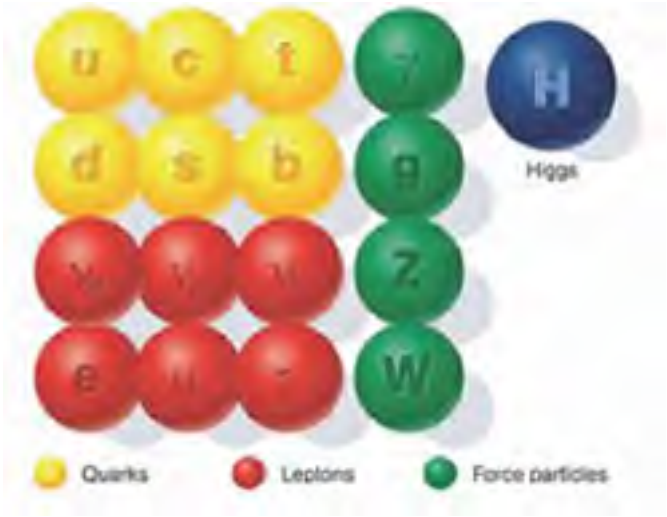
5 Dark matter and SUSY

6 Higgs-dark matter-SUSY: joint study

7 Outlook

1 Introduction

SM: $SU(3) \times SU(2) \times U(1)$

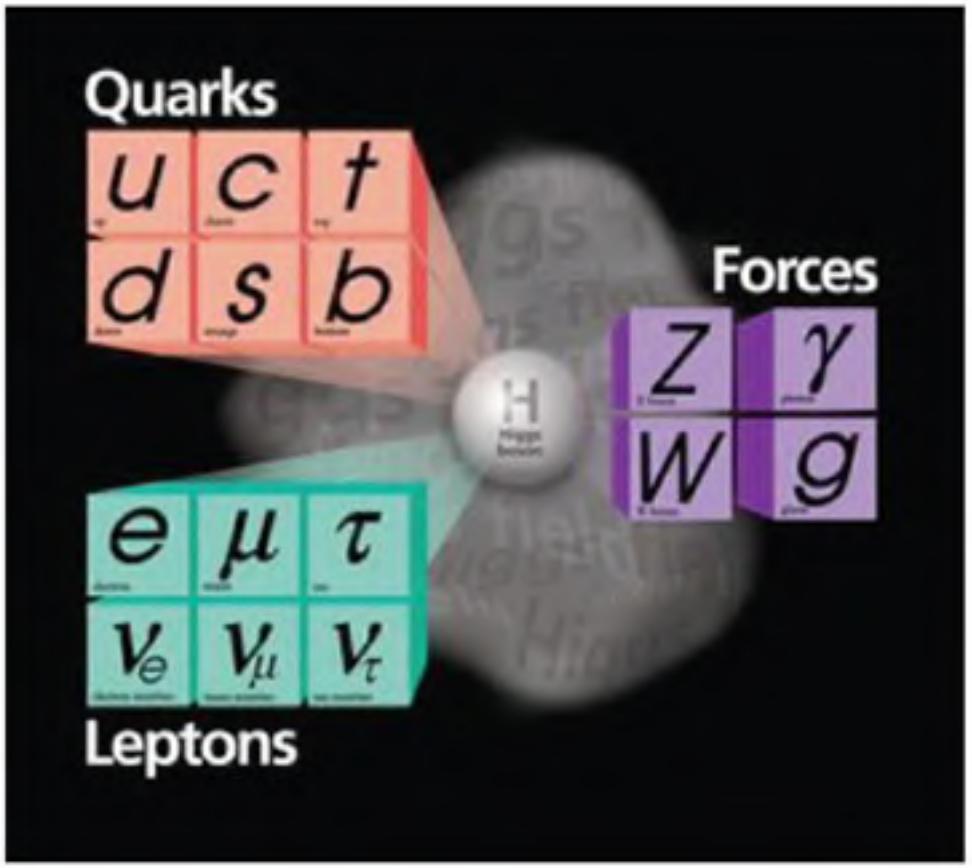


- very simple
- extremely successful
- a zoo of Nobel prizes

Higgs: the last missing piece !

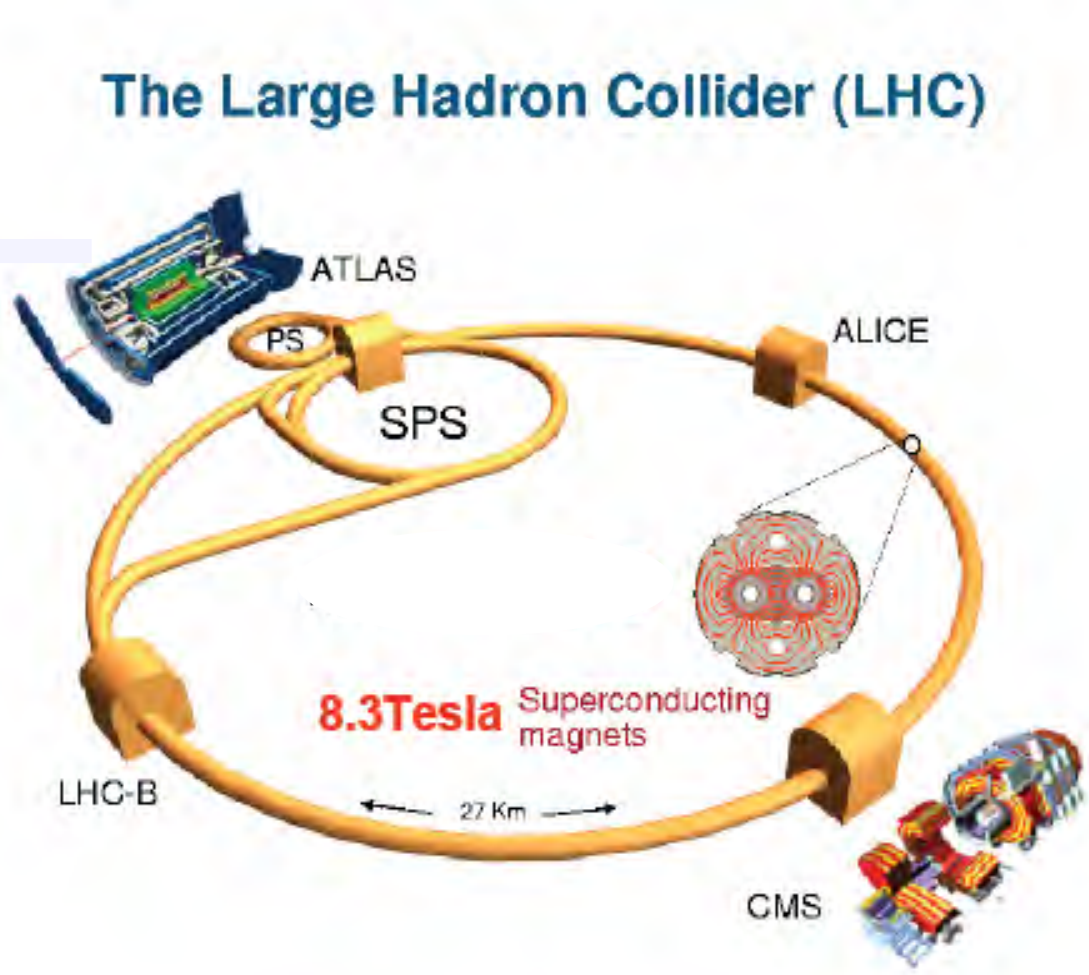
Higgs is called God particle

黑格斯 – 上帝粒子 – 质量起源

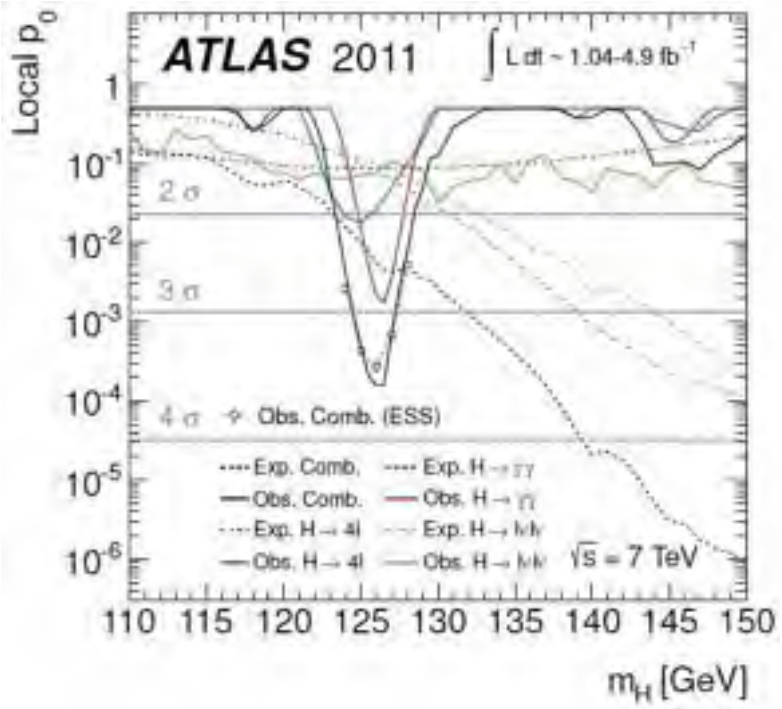


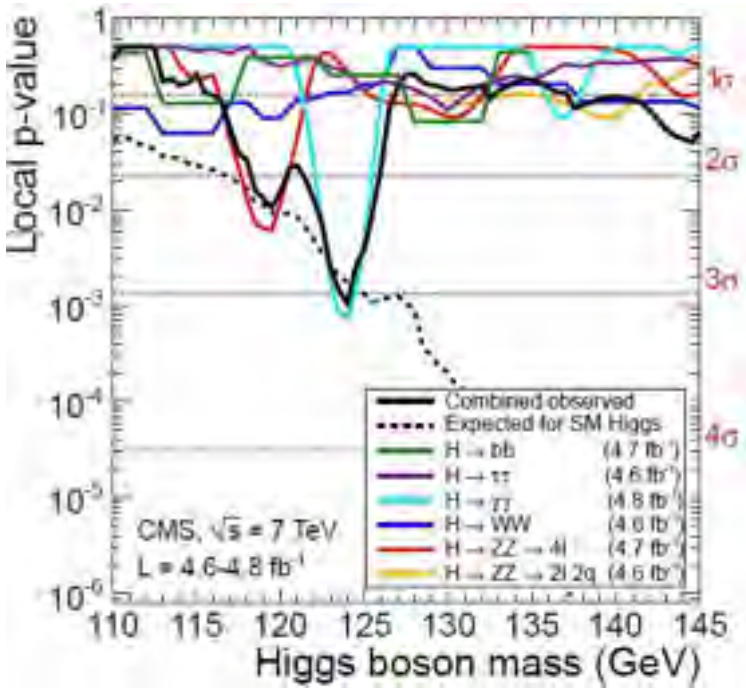
Higgs is now being hunted at LHC

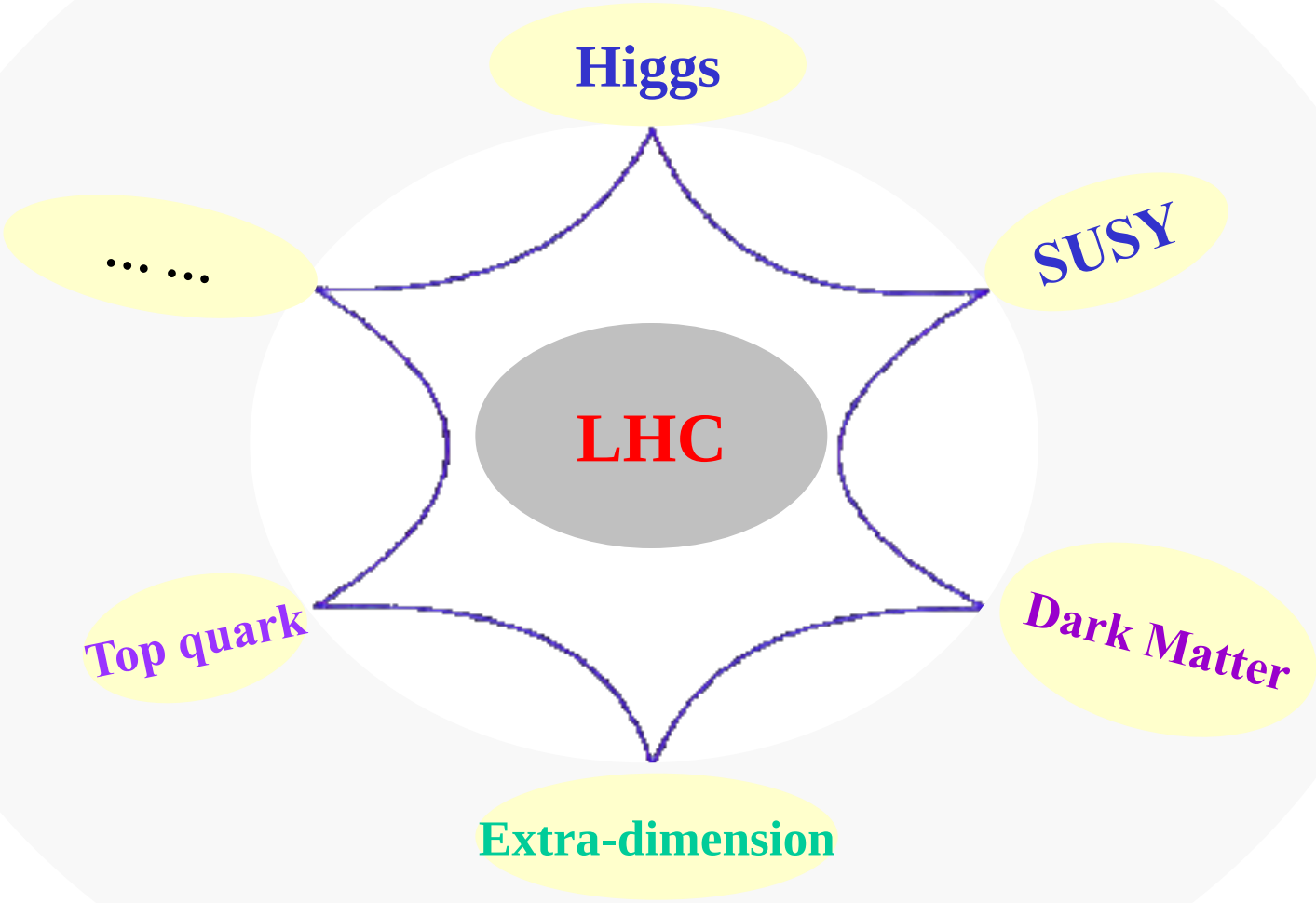
1850 physicists
150 universities
34 countries



Higgs hint at LHC: 3-sigma at 125 GeV



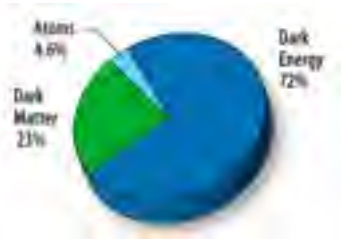



Higgs
SUSY
… …
LHC
Top quark
Dark Matter
Extra-dimension

3 old topics: now the most important and urgent in hep

- **Dark matter:**

  Fritz Zwicky, 1933

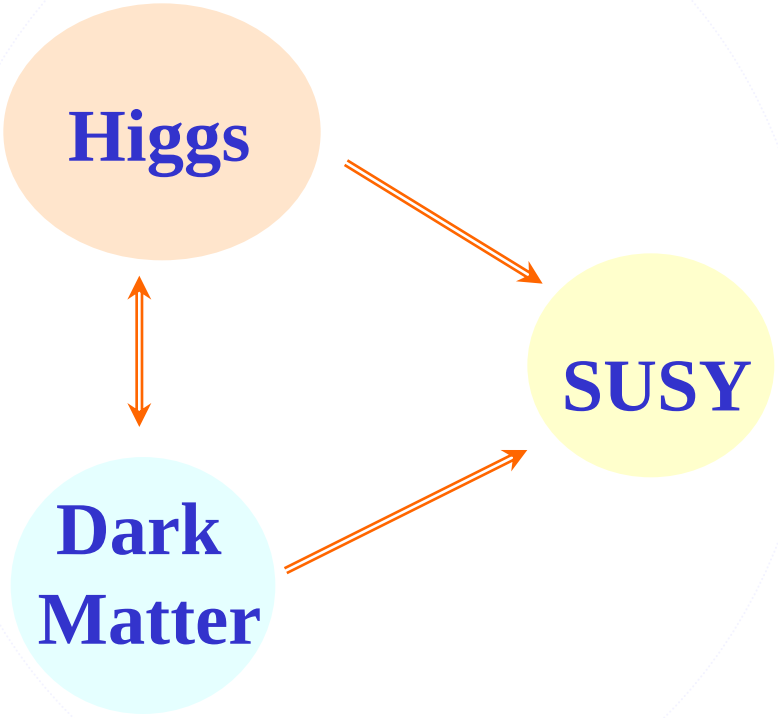


- **Higgs boson:**

  Higgs, Englert, Brout,
  Guralnik, Hagen, Kibble, 1964

- **Supersymmetry:**

  Golfand, Likhtman, 1971
  Wess, Zumino, 1974



一台大戏

听听大牛人是咋说的

2 What is Higgs boson

黑格斯究竟是朗格回事儿啊？

对称性自发破缺

Spontaneous Symmetry Breaking

Goldstone Boson

(massless)

Higgs Boson

(massive)

$$\mathcal{L} = \partial_\mu \phi^\dagger \partial^\mu \phi - V(\phi)$$

$$V(\phi) = -\mu^2 \phi^\dagger \phi + \lambda \left(\phi^\dagger \phi\right)^2$$

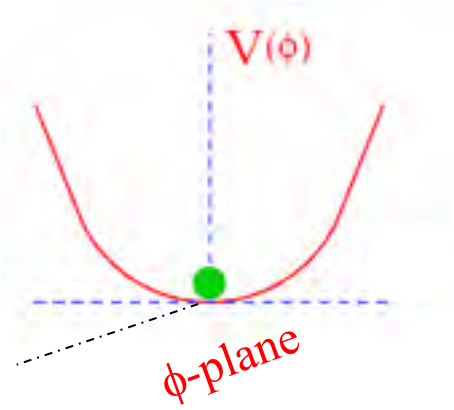
It has U(1) symmetry:

$$\phi(x) \longrightarrow e^{i\alpha} \phi(x)$$

Look at the vacuum state:

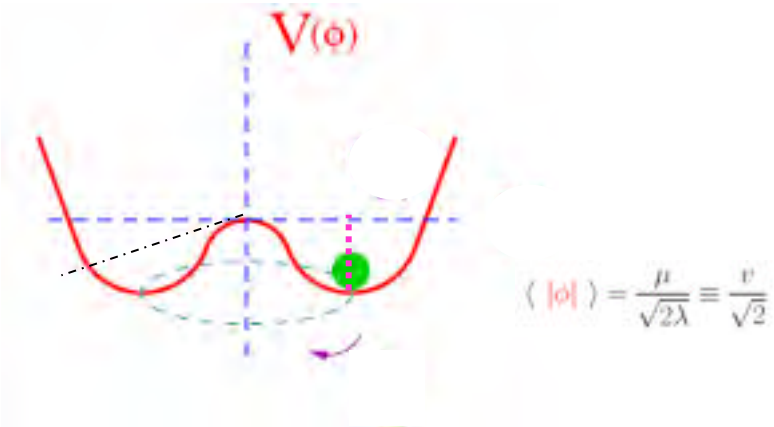
$$V(\phi) = -\mu^2 \phi^\dagger \phi + \lambda \left(\phi^\dagger \phi\right)^2$$

$\mu^2 < 0$



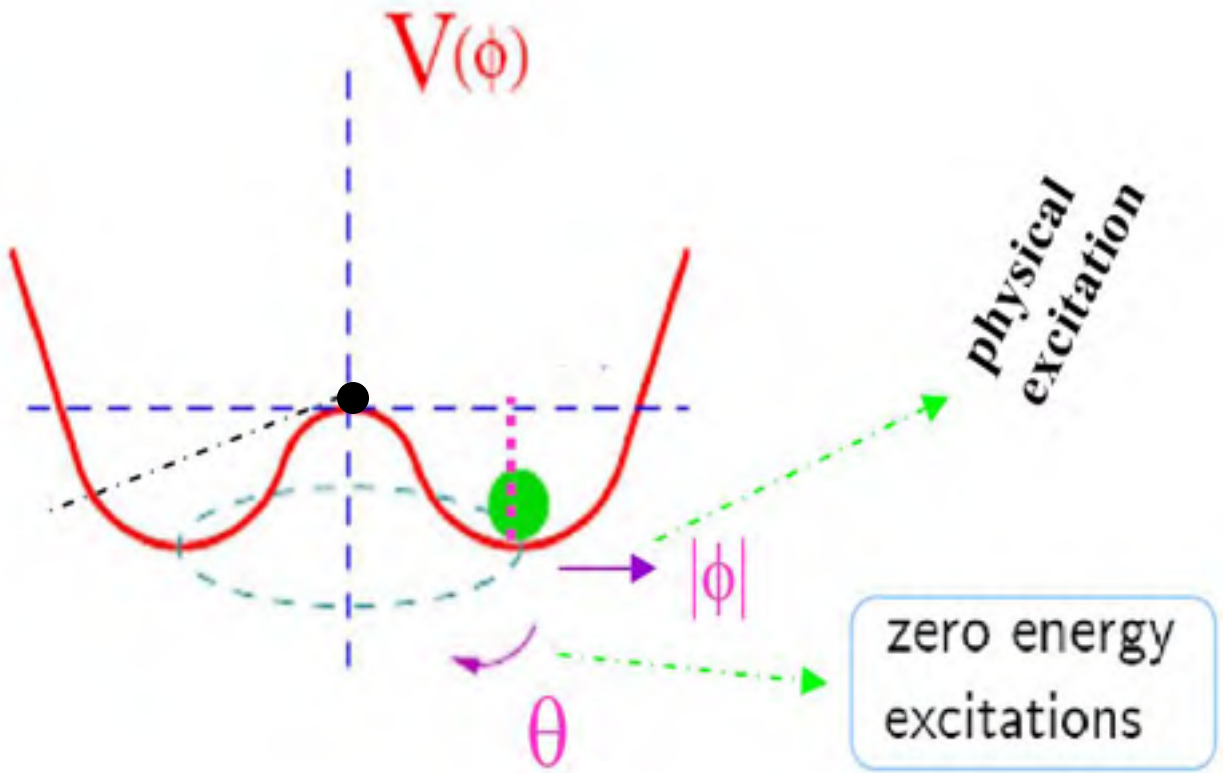
vacuum state has U(1) symm

$\mu^2 > 0$



vacuum state does not have U(1) symm

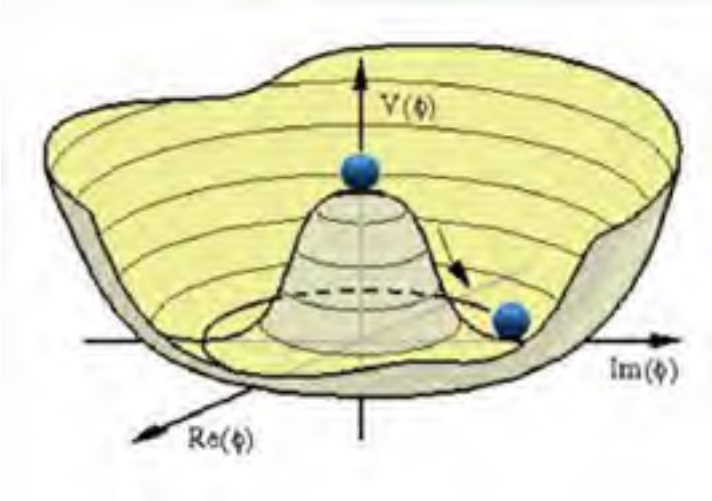
$\mu^2 > 0$



In the Standard Model (SM):

$$V(\phi) = -\mu^2 \phi^\dagger \phi + \lambda \left(\phi^\dagger \phi\right)^2$$

$$\phi = \begin{pmatrix} iG^+ \\ \frac{v+h-iG^0}{\sqrt{2}} \end{pmatrix}$$



3 Goldstone bosons are eaten by gauge bosons

what left is a Higgs boson

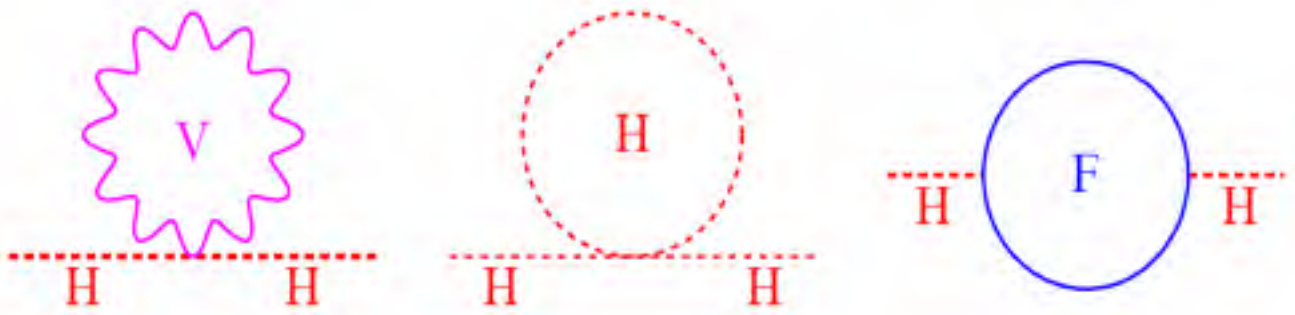
3 Higgs boson and SUSY

那黑格斯这厮跟超对称又有啥关系？

If Higgs boson exists:

- **SM is not a natural, comfortable place for Higgs**
- **SUSY is a paradise for Higgs**

  ---a peaceful, harmonious place for Higgs



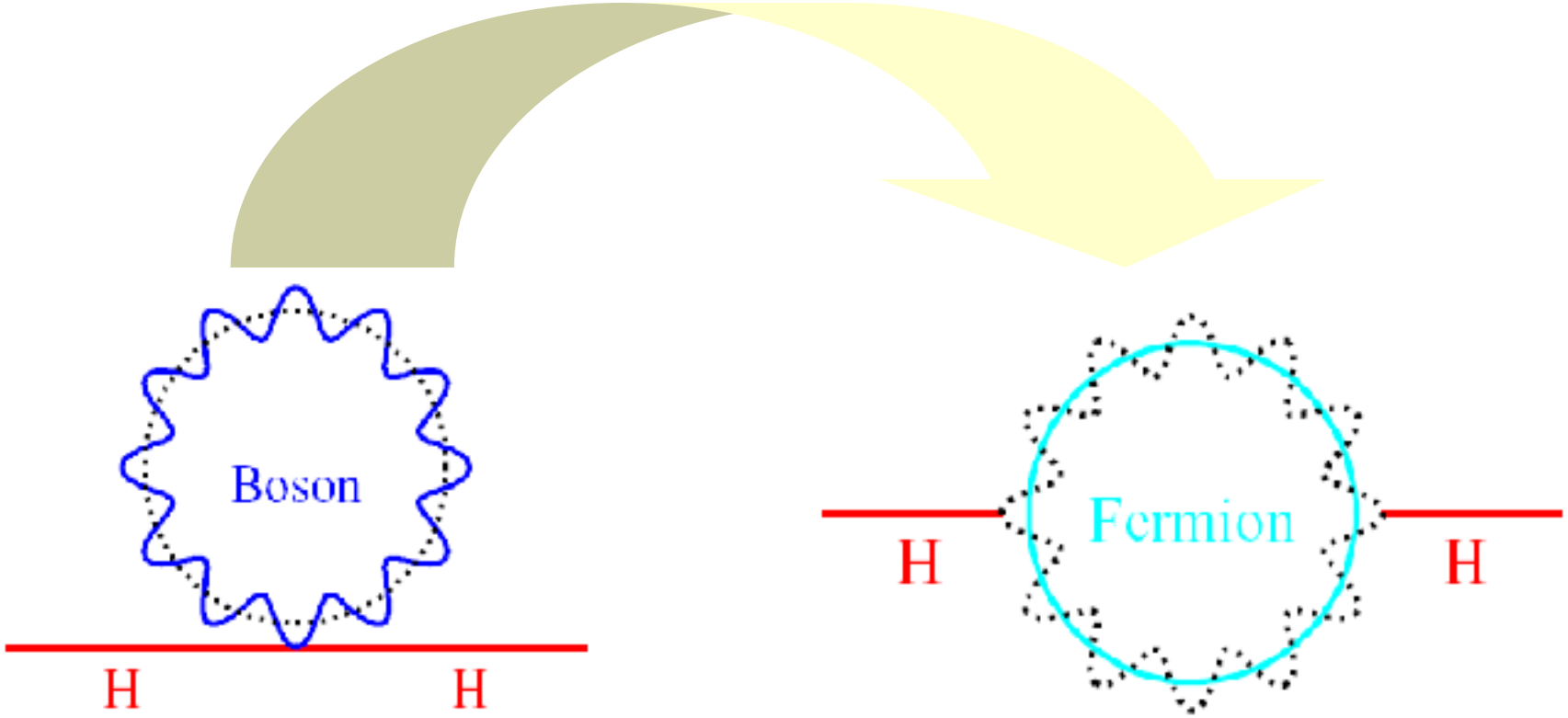
$$M_h^2 = M_0^2 + \delta M_h^2$$

$(100\ \mathrm{GeV})^2$ $\qquad$ Λ^2

$\mathrm{fine-tuning}\ M_0^2\ \mathrm{in\ case\ of}\ \Lambda \gg M_W$

If $\Lambda \sim M_{planck}$, then the fine-tuning is like 'fine-tuning a gun on the Earth to shoot a rabit on the Moon' .

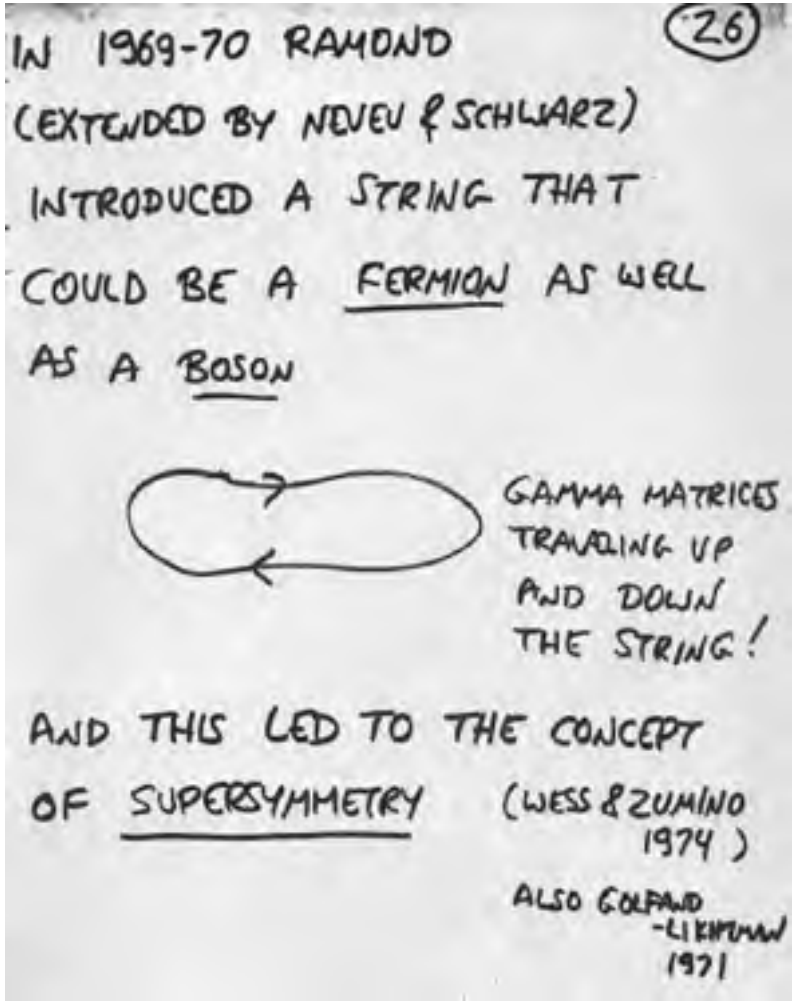
SUSY

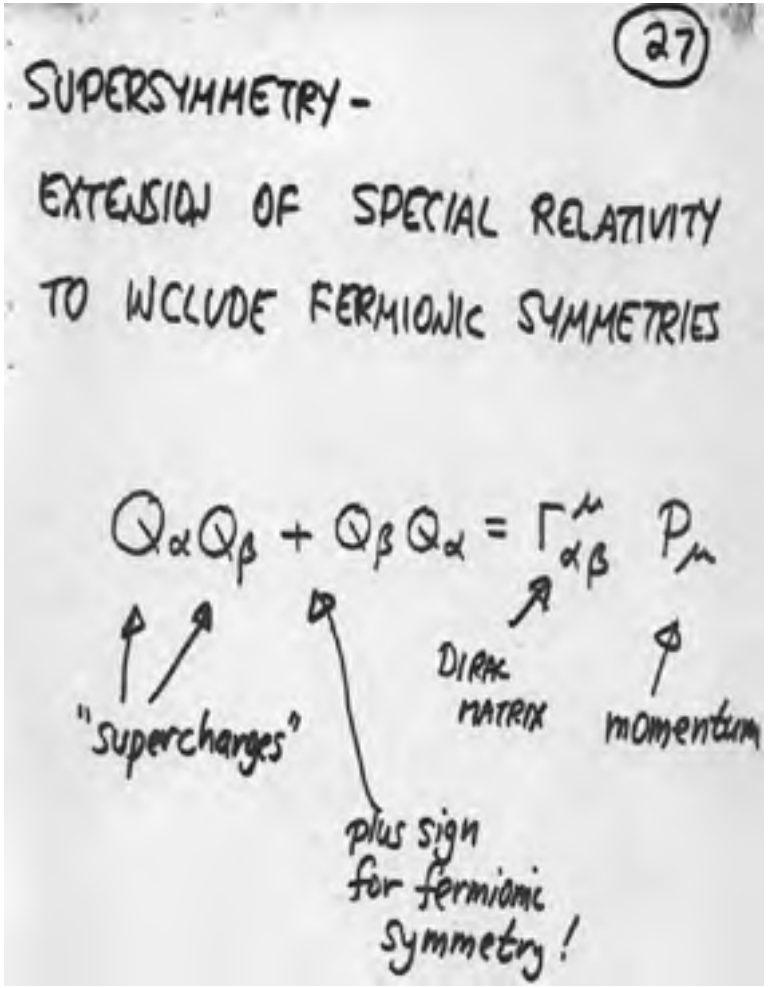


What is SUSY ?

Edward Witten

当今的爱因斯坦，牛啊！





Virtues of SUSY:

Edward Witten

* SUSY can make a "small" Higgs mass natural

* SUSY is part of a larger vision of physics, not just a technical solution

* measured value of $\sin^2\theta_W$ favors SUSY GUT's

* survives electroweak tests

* heavy top mass, as needed

➢ cosmic dark matter (WIMP)

drawbacks of supersymmetry

Edward Witten

The most obvious drawback is simply that supersymmetry hasn't been found yet, though we have been hoping for a long time.

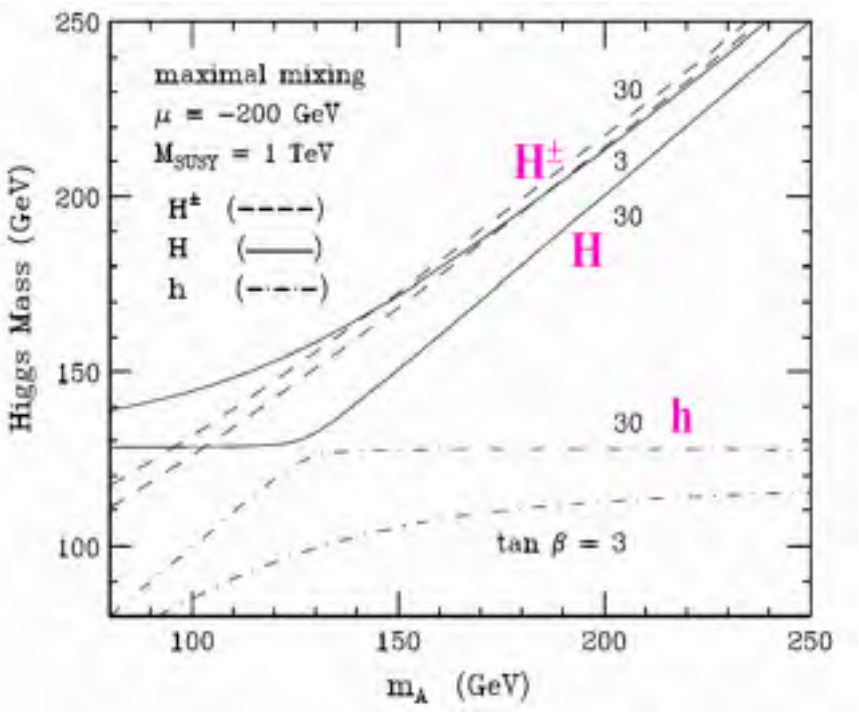
It is disappointing that we have not found SUSY yet, but for the most part it is perhaps not too surprising....

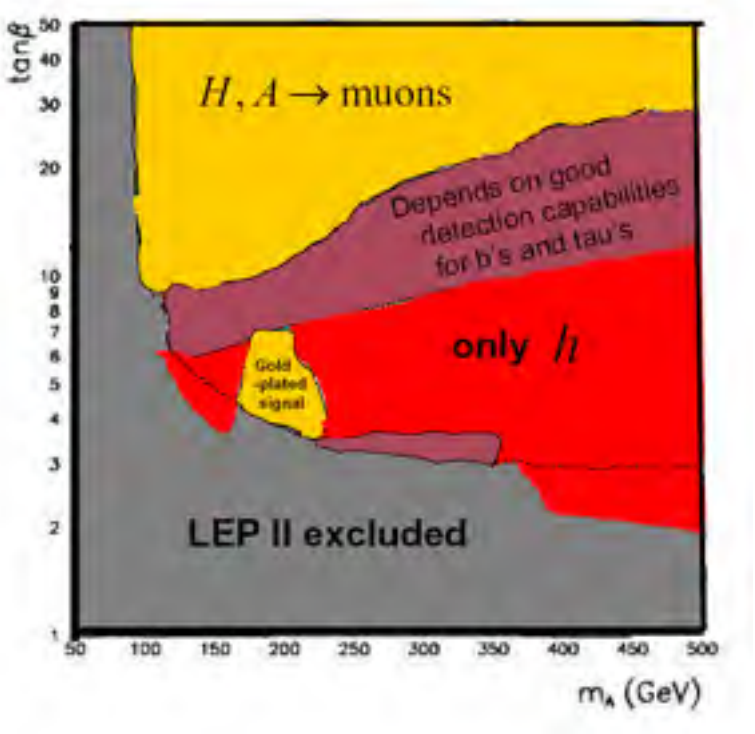
If charged superpartners are just a little bit above M_Z, we would not have seen them yet.

Superpartners get masses from electroweak breaking *and* SUSY breaking so it is natural for them to be a bit above the Z, which gets mass only from electroweak breaking.

超对称还有毛病？俺咋没听说

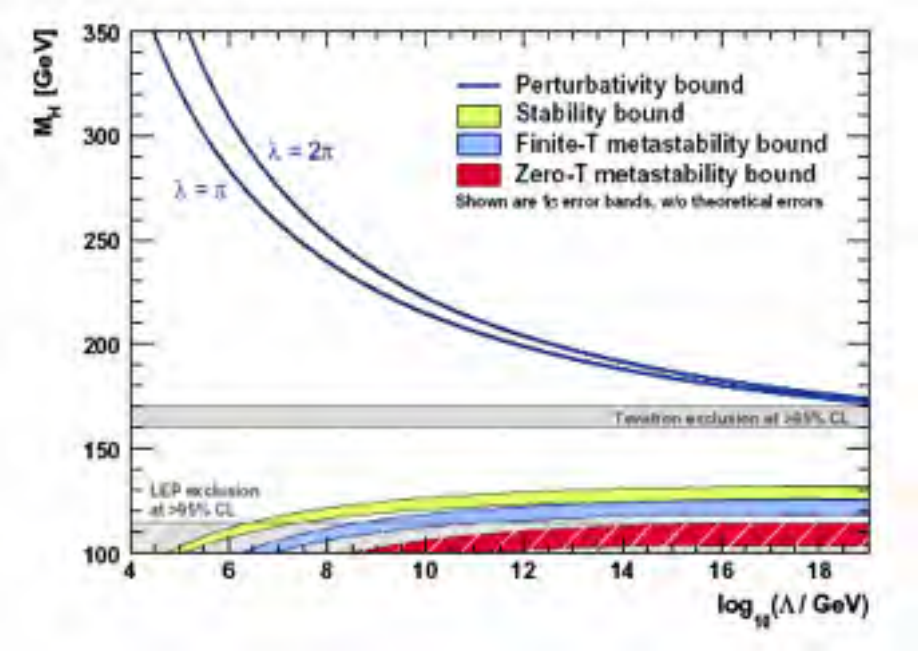
SUSY predicts 5 Higgs bosons:

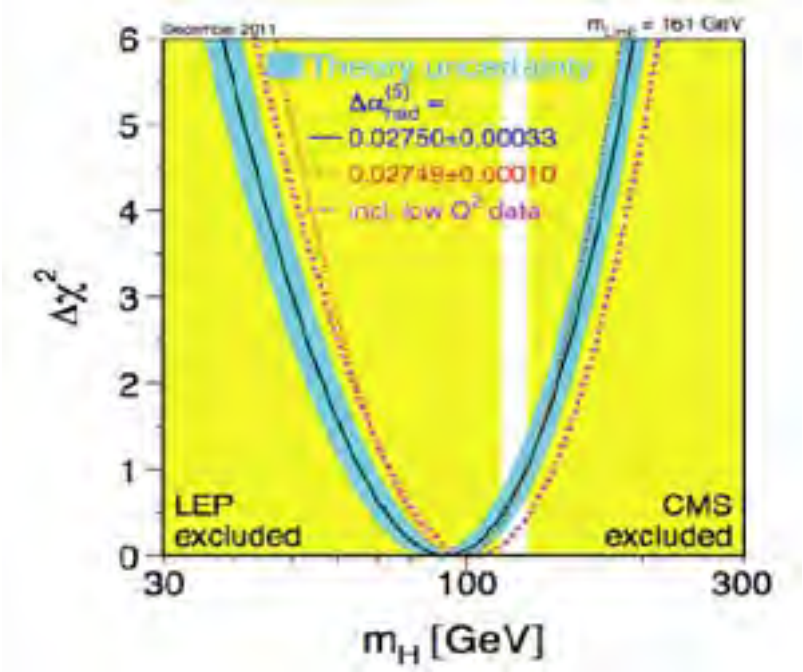




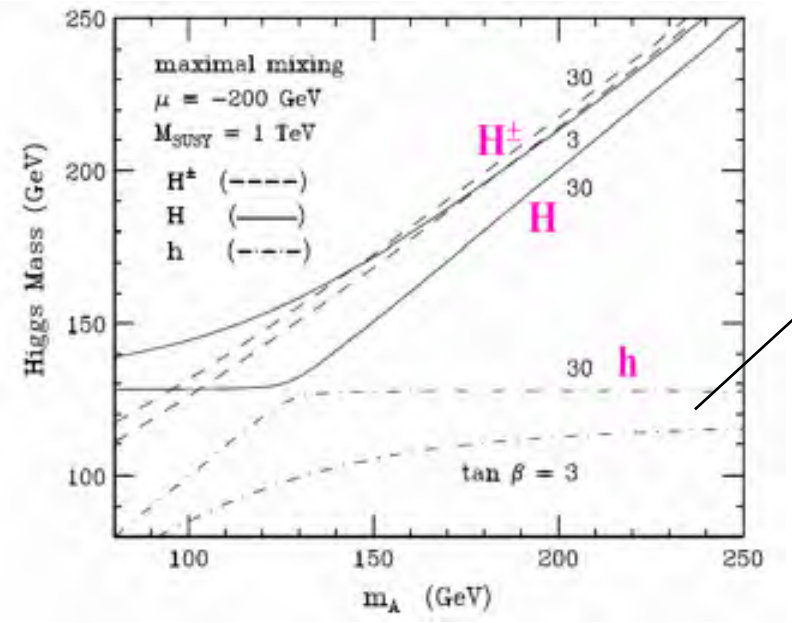
4 Implication of Higgs hint at 125 GeV

SM:





SUSY:



M_h < 90 GeV at tree-level

M_h < 130 GeV at loop-level

125 GeV Higgs:

is OK in SUSY, but not so comfortable for SUSY (needs loop effects)

Let's check Higgs mass in some SUSY Models:

MSSM

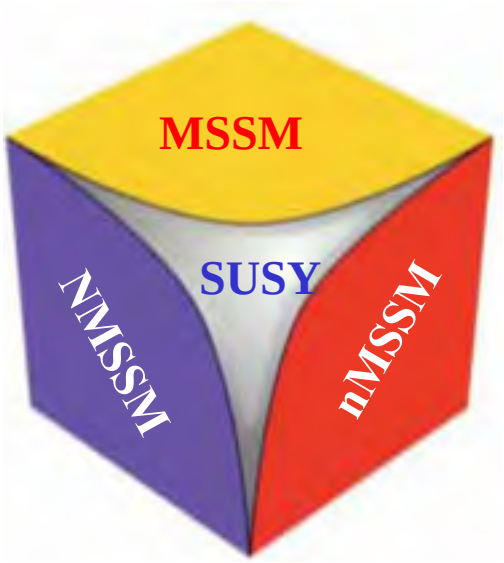
NMSSM

nMSSM

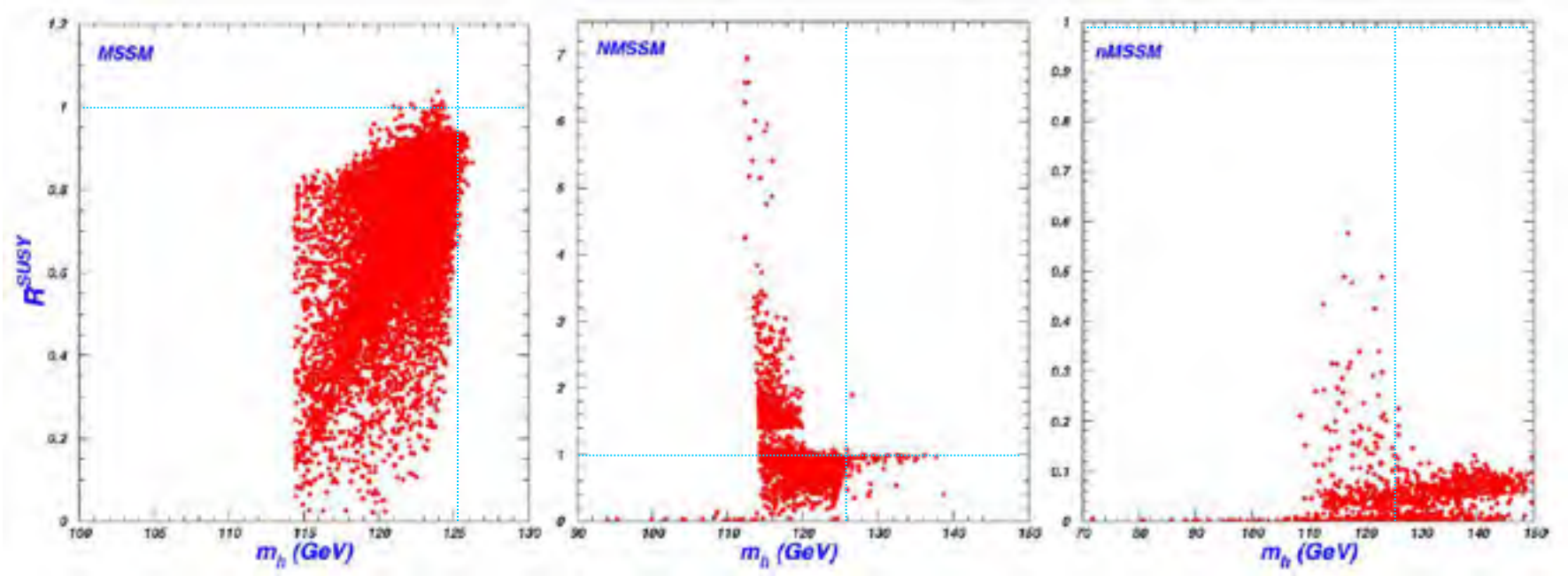
CMSSM

mSUGRA

. . . .

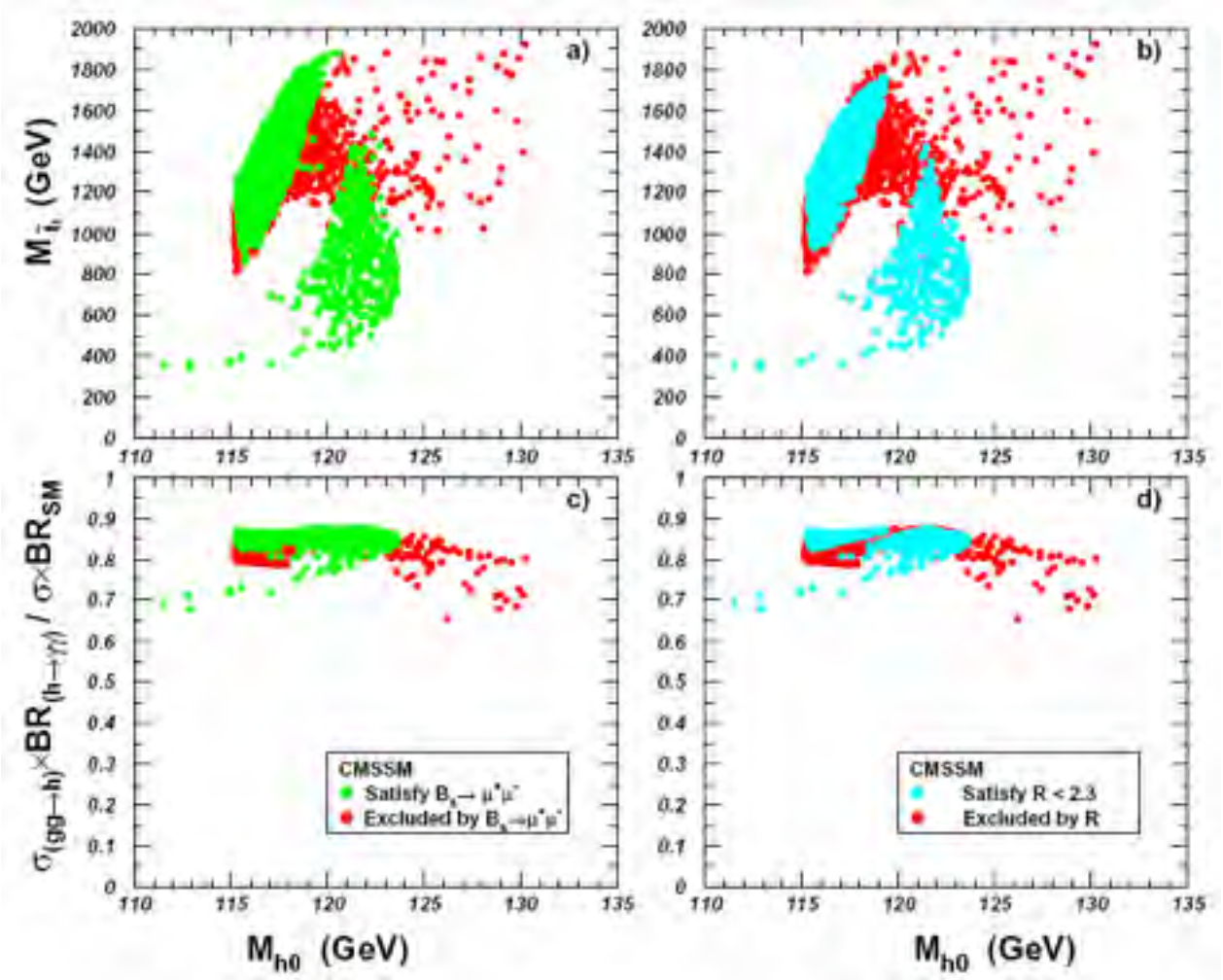


Higgs mass in MSSM, NMSSM, nMSSM (125 GeV OK !)



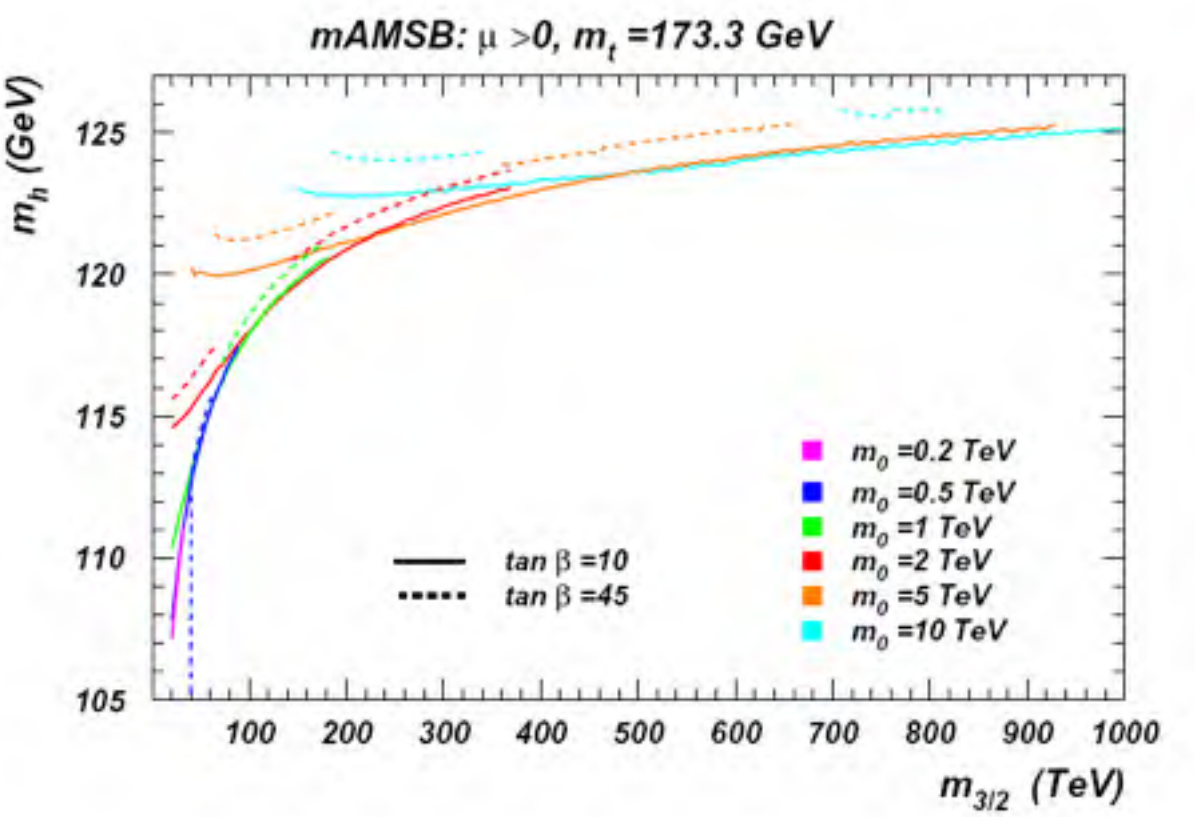
Cao, Heng, Liu, Yang, arXiv:1103.0631

Higgs mass in CMSSM/mSUGRA (<124 GeV)



Cao, Heng, Li, Yang, arXiv:1112.4391

Higgs mass in AMSB (<125 GeV)



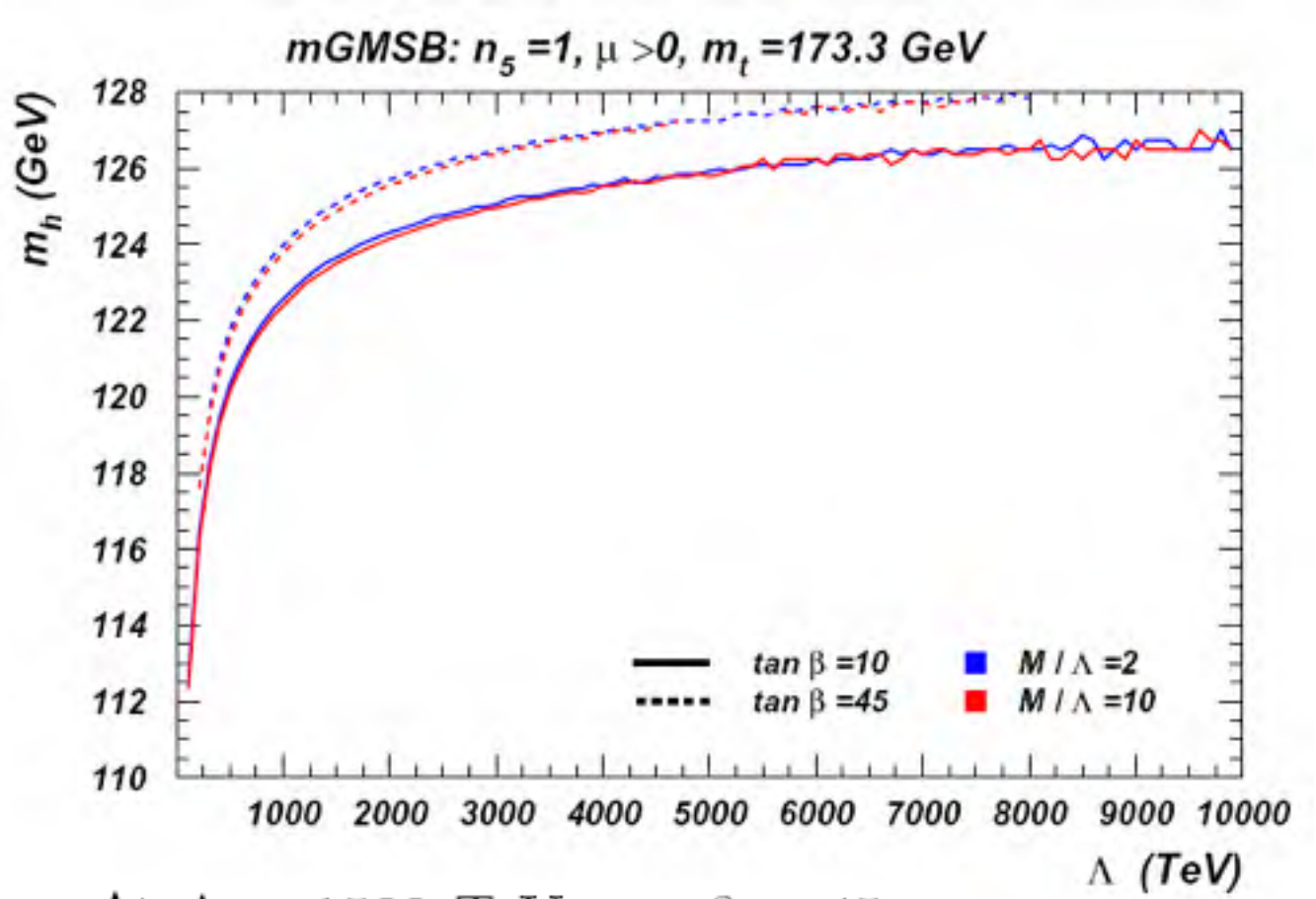
At $m_{3/2} = 600$ GeV and $\tan\beta = 45$

$m_{\tilde{g}} \sim 10$ TeV, $m_{\tilde{t}_1} \sim 9$ TeV

extreme electroweak fine-tuning

Baer, Barger, Mustafayev, arXiv:1202.4038

Higgs mass in GMSB (<125 GeV)



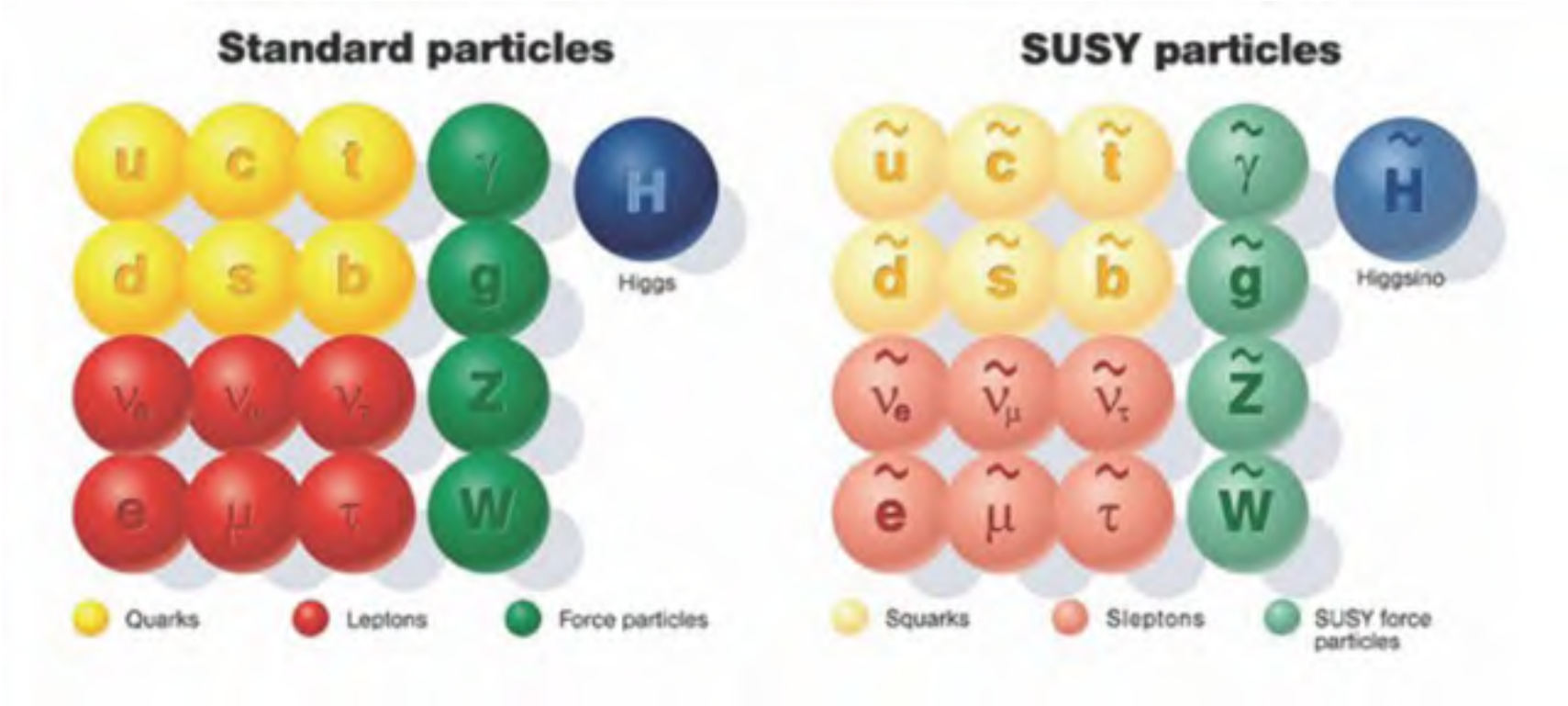
At $\Lambda = 1500$ TeV, $\tan\beta = 45$

$m_{\tilde{g}} \sim 10$ TeV, $m_{\tilde{t}_1} \sim 12$ TeV

extreme electroweak fine-tuning

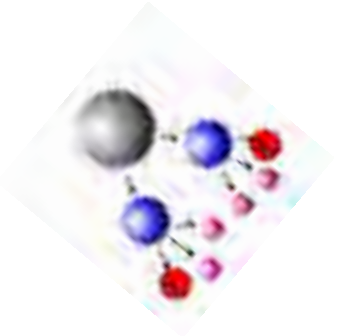
Baer, Barger, Mustafayev, arXiv:1202.4038

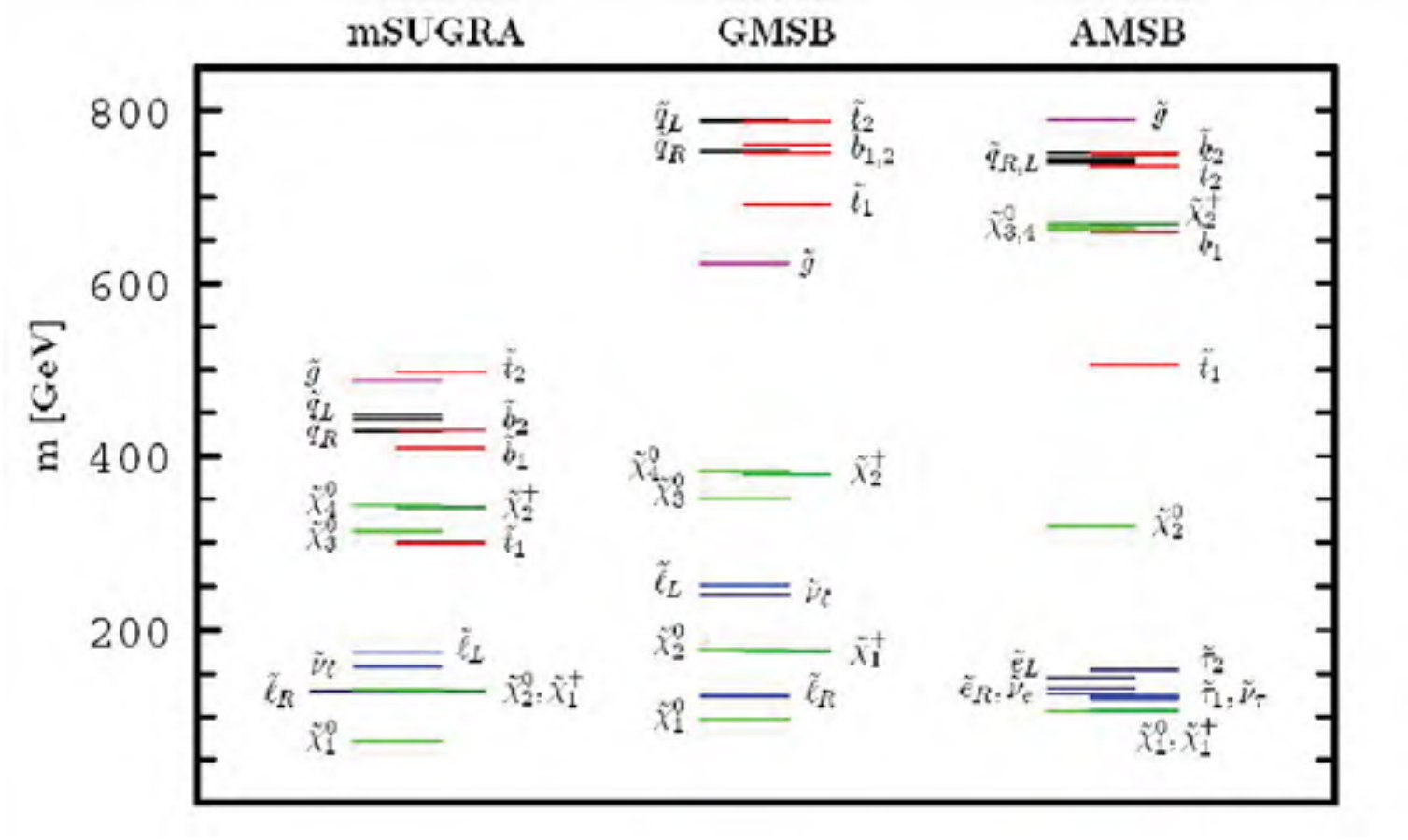
5 Dark matter and SUSY



Super particles decay except the lightest one (LSP)

$\tilde{\chi}_1^0$

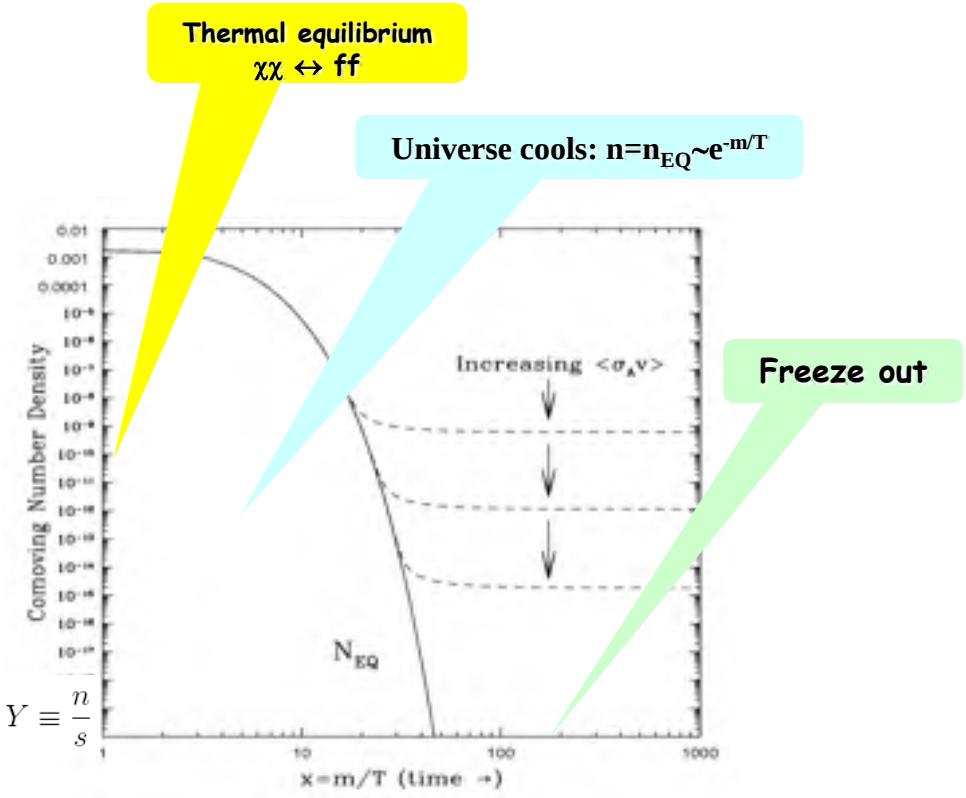




$\tilde{\chi}_1^0$ is a perfect WIMP

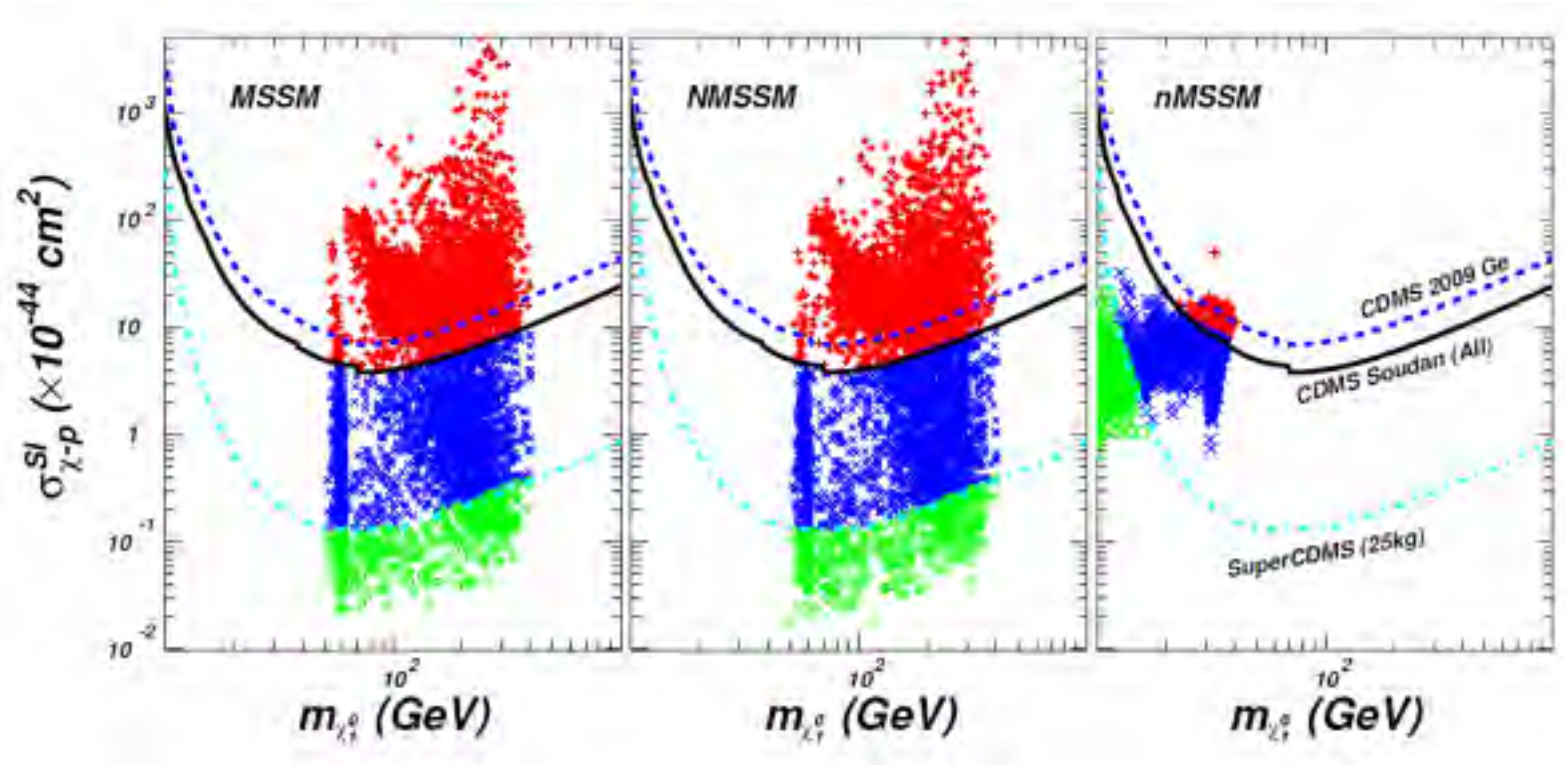
relic density (WMAP)

$$0.0945 < \Omega h^2 < 0.1287$$



6 Higgs--dark matter--SUSY: joint study

- SUSY ----- dark matter experiments



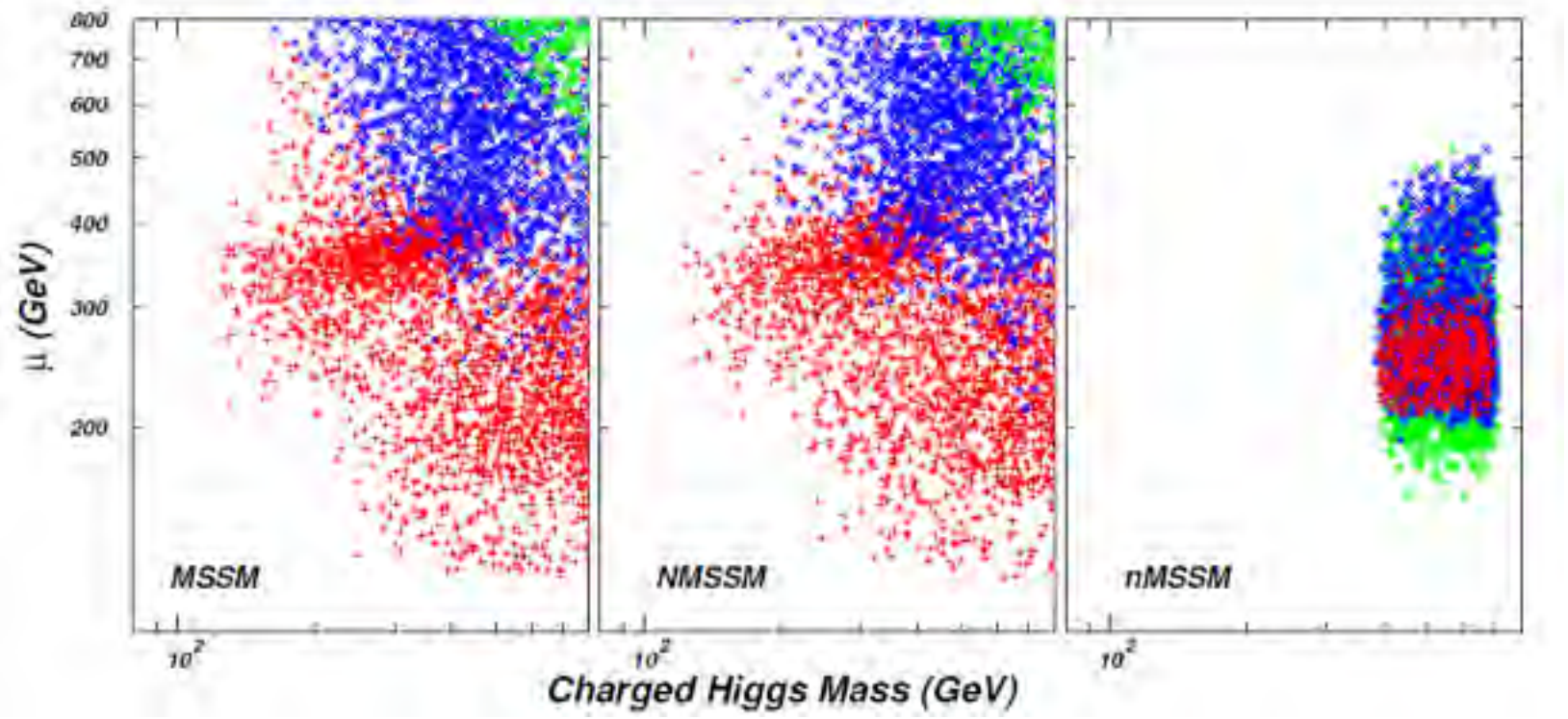
Cao, Hikasa, Wang, Yang, Yu, arXiv:1005.0761

Red: CDMS-II covered region

Blue: SuperCDMS(25kg)/XENON100 (6000 kg-day)

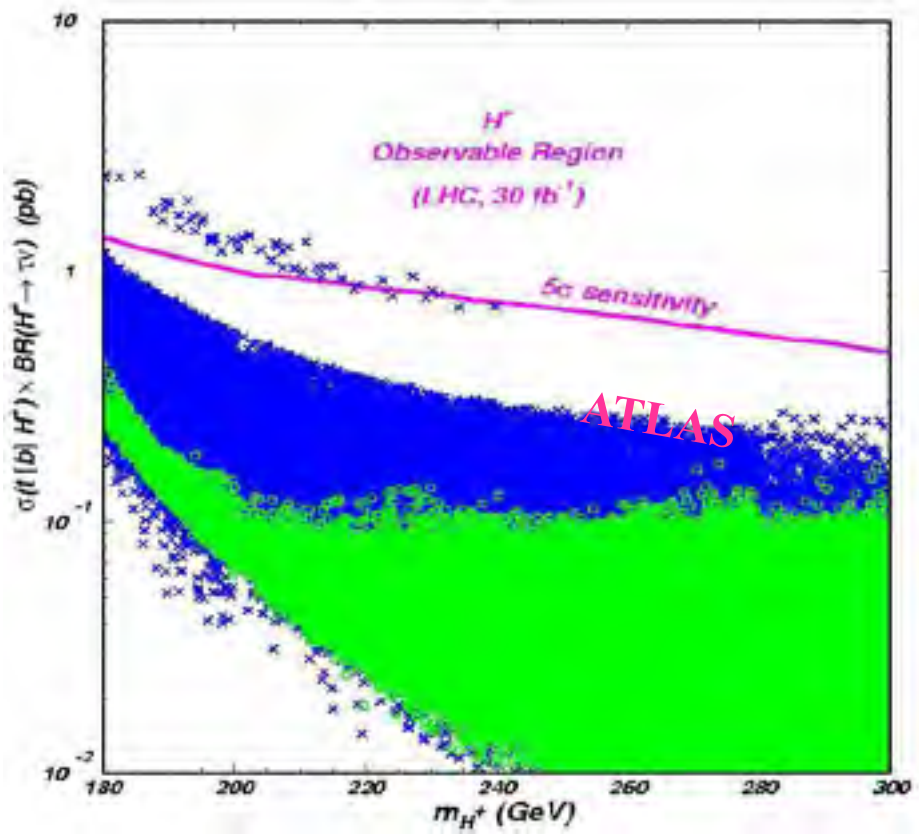
Green: beyond SuperCDMS/XENON100

- **Dark matter expt results: impact on charged-Higgs**



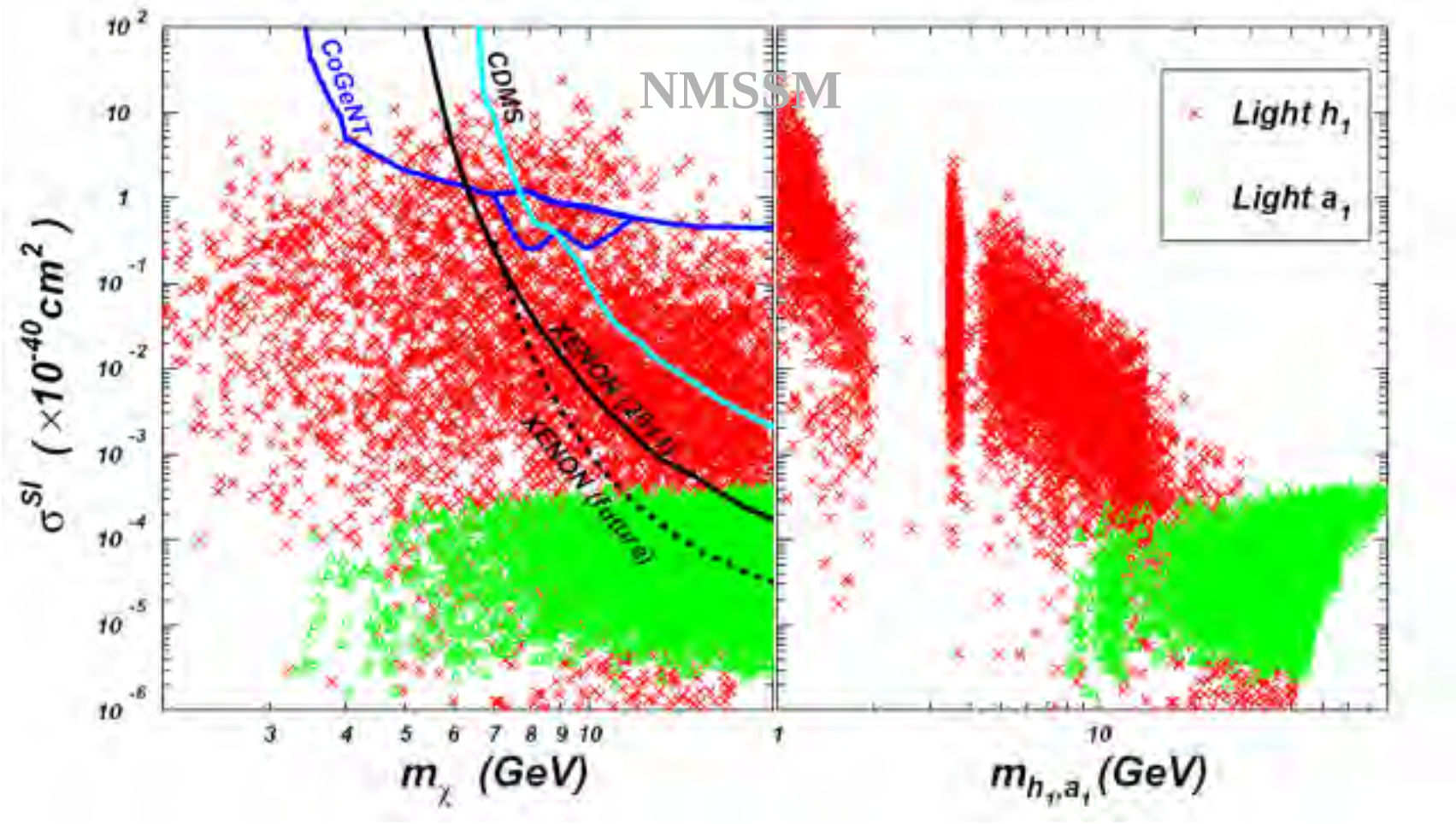
Cao, Hikasa, Wang, Yang, Yu, arXiv:1006.4811

• **Dark matter expt results: impact for LHC search of charged-Higgs**



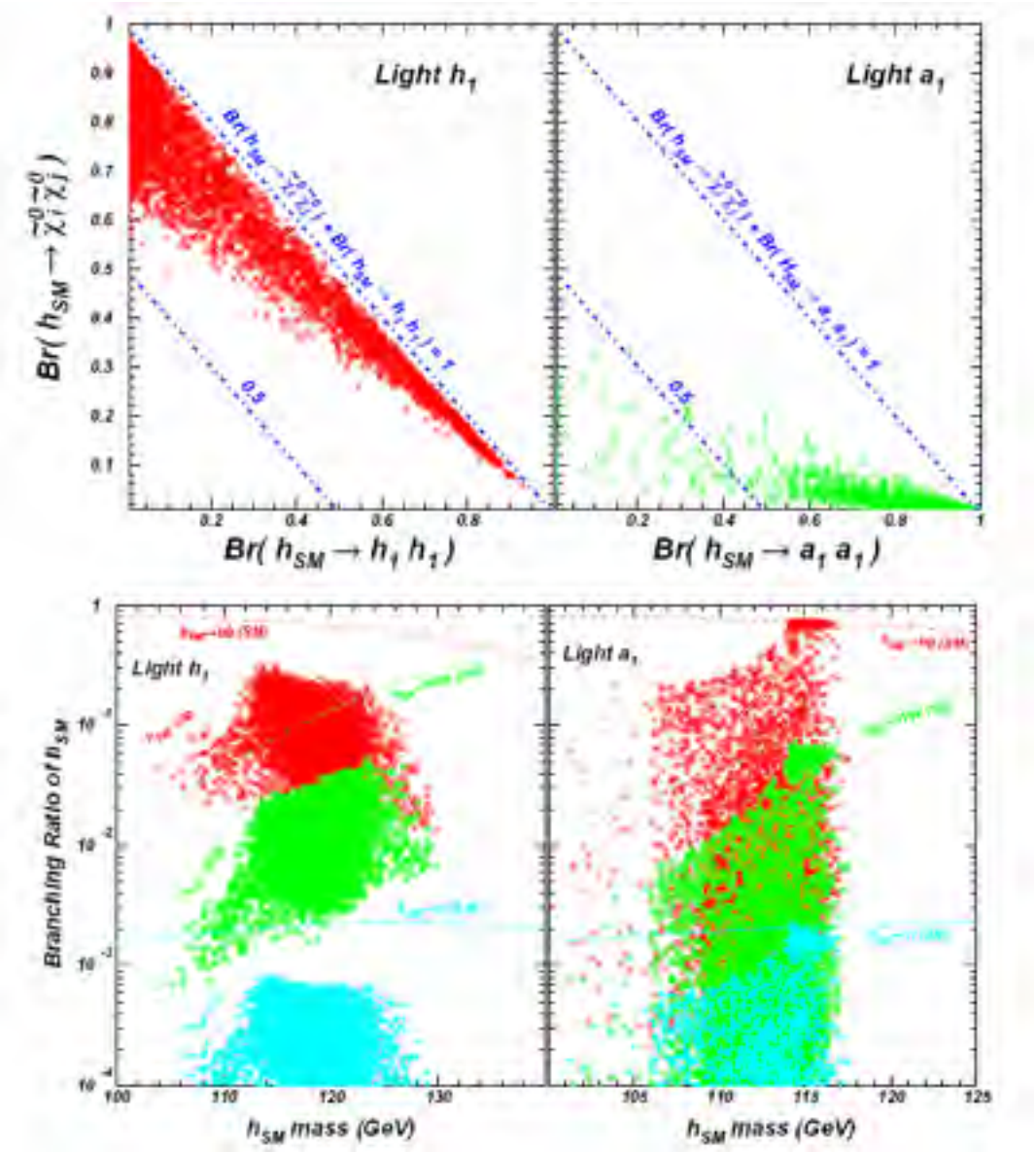
Cao, Hikasa, Wang, Yang, Yu, arXiv:1006.4811

• **light DM from CoGeNT: implication on SUSY and Higgs**



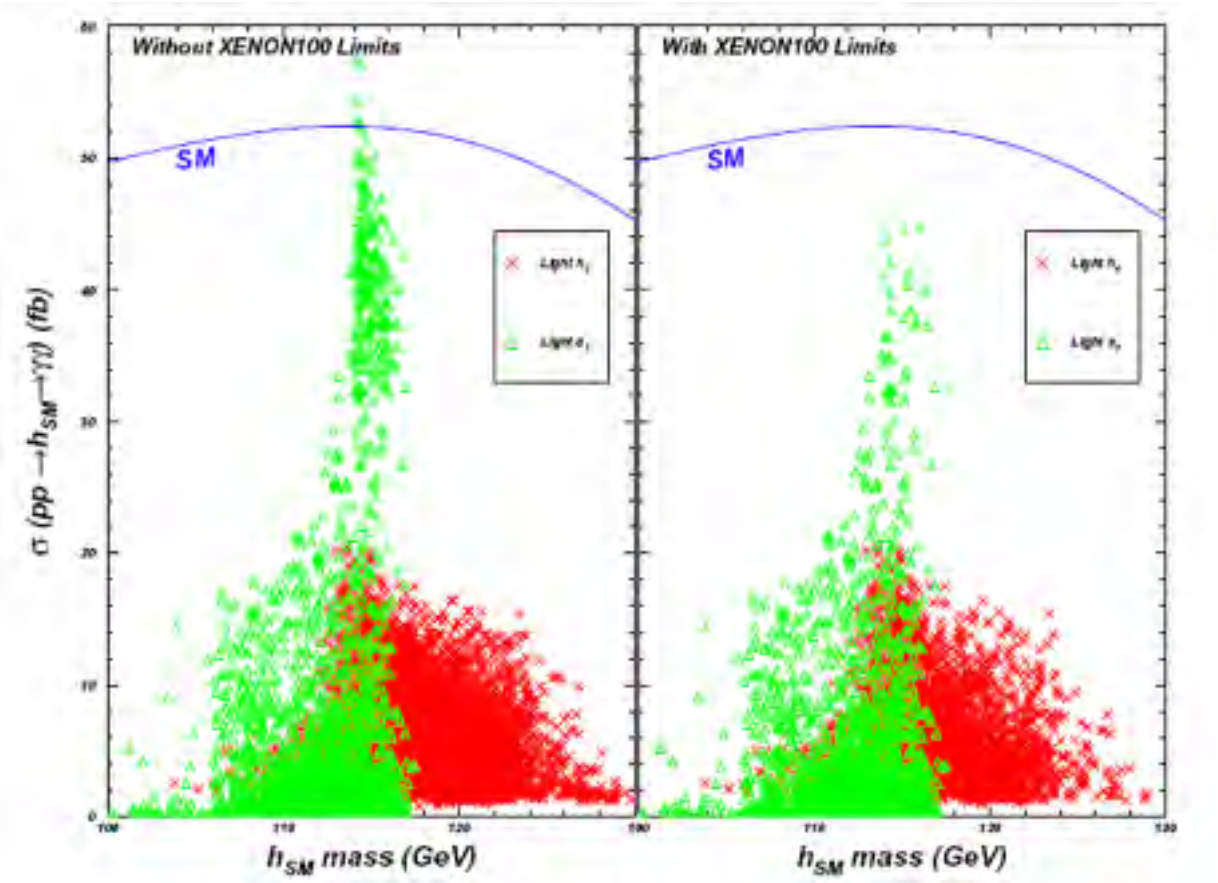
Cao, Hikasa, Wang, Yang, arXiv:1104.1754

Then, SM-like Higgs: new (exotic) decay modes open



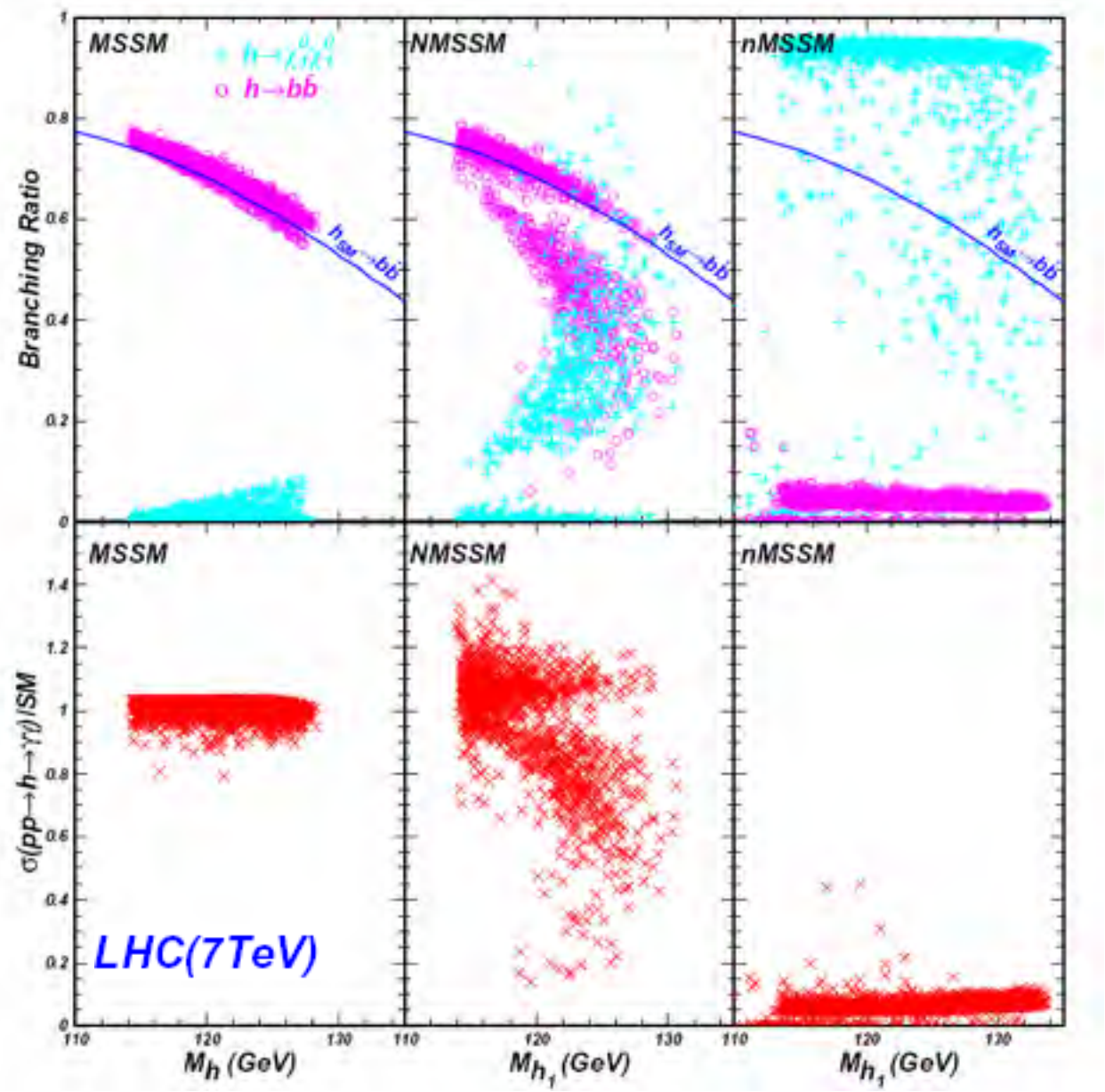
Cao, Hikasa, Wang, Yang, arXiv:1104.1754

SM-like Higgs: di-photon signal is suppressed at LHC



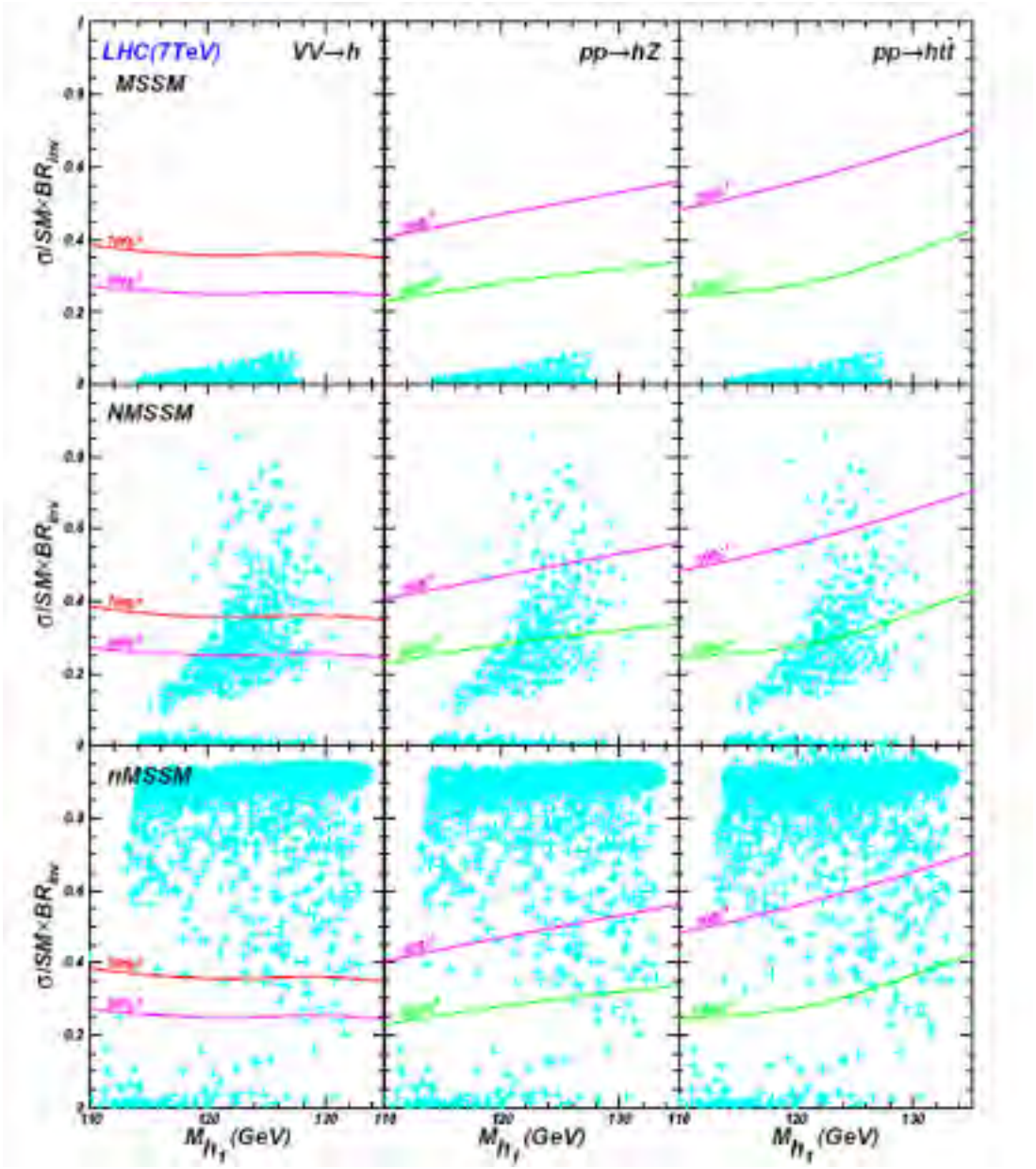
Cao, Hikasa, Wang, Yang, arXiv:1104.1754

Higgs decay to dark matter in SUSY



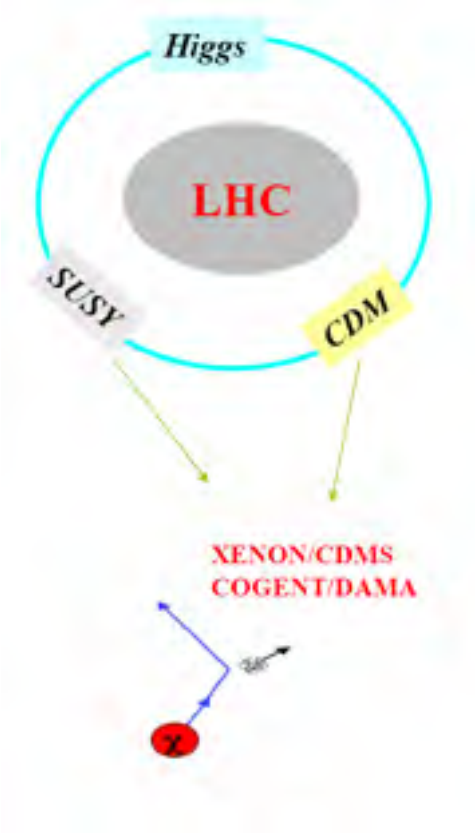
Cao, Heng, Yang, Zhu, in progress

Higgs decay to dark matter in SUSY: detectable at LHC ?



Cao, Heng, Yang, Zhu, in progress

7 Conclusion and Outlook



- **Higgs, dark matter and SUSY: entangled**
- **Interplay of LHC and dark matter detection expts**

- **Higgs discovery is near to us (this or next year ?)**
- **Dark matter discovery or exclusion: in 10 years**
- **SUSY discovery or exclusion: in 10 years**


Higgs, Dark Matter, SUSY

Thanks !