Low Energy SUSY in light of LHC Higgs Data

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Outline

1 Introduction to Higgs & SUSY

- LHC Higgs Data
- The nature of Higgs
- Higgs indicates SUSY
- SUSY and models

BBC News Nov 19, 2012

SUSY may not be dead, but these latest results have certainly put it into hospital

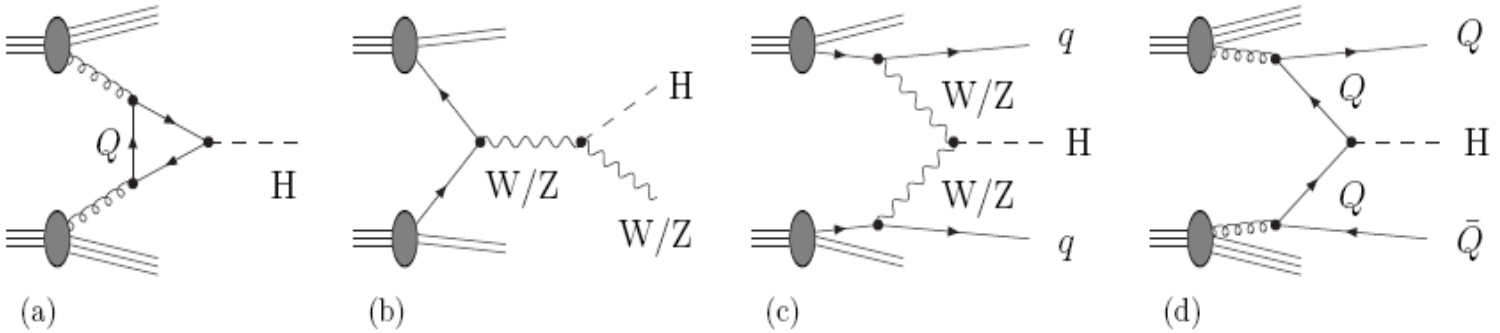
2 Status of low energy SUSY

- Status of some SUSY models
- Further probes of SUSY

3 Conclusion

1 Introduction to Higgs & SUSY

- **Higgs production at LHC:**



- **Higgs decays:**

$b\bar{b}$	56%	$\tau^+\tau^-$	6.2%	$\gamma\gamma$	0.23%
WW^*	23%	ZZ^*	2.9%	γZ	0.16%
gg	8.5%	$c\bar{c}$	2.8%	$\mu^+\mu^-$	0.02%

• LHC Higgs Data

Red (Moriond)

Black (Dec, 2012)

	$H \to \gamma\gamma$	$H \to ZZ^*$	$H \to WW^*$	$H \to \tau\tau$	$VH(H \to b\bar{b})$
Atalas	1.6 ± 0.3	1.5 ± 0.4	1.4 ± 0.6	0.8 ± 0.7	-0.4 ± 1.0
	$1.8 \pm 0.3^{+0.29}_{-0.21}$	1.3 ± 0.4	1.5 ± 0.6	0.7 ± 0.7	-0.4 ± 1.1
CMS	$0.78^{+0.28}_{-0.26}$	$0.91^{+0.30}_{-0.24}$	0.76 ± 0.21	1.1 ± 0.4	1.3 ± 0.6
	1.56 ± 0.46	$0.8^{+0.35}_{-0.28}$	0.74 ± 0.25	0.72 ± 0.52	2.2σ excess

So far, we can say Higgs has been discovered.

The newly discovered particle:

- **can it be spin-2 ?**
- **can it be CP-odd ?**
- **can it be a dilaton ?**

Nima Arkani-Hamed

- **If the Higgs turns out to have spin two, he'll quit physics.**
- **If the Higgs turns out to be a techni-dilaton, he'll kill himself.**

• • • • • • • • •

The nature of Higgs boson:

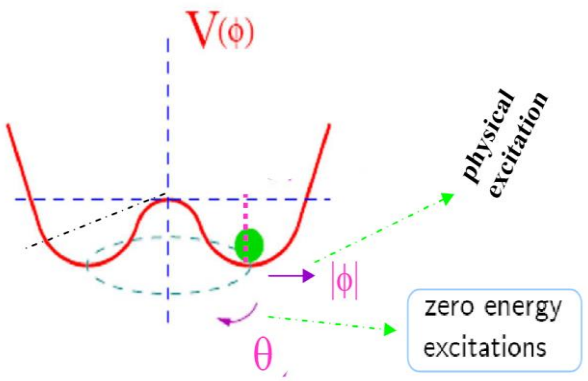
Spontaneous Symmetry Breaking

Goldstone Boson (massless)

eaten by guage boson

Massive Gauge Boson

Higgs Boson (massive)



a light fundamental Higgs boson

- **indicates SUSY**

Why ?

Reason-1:

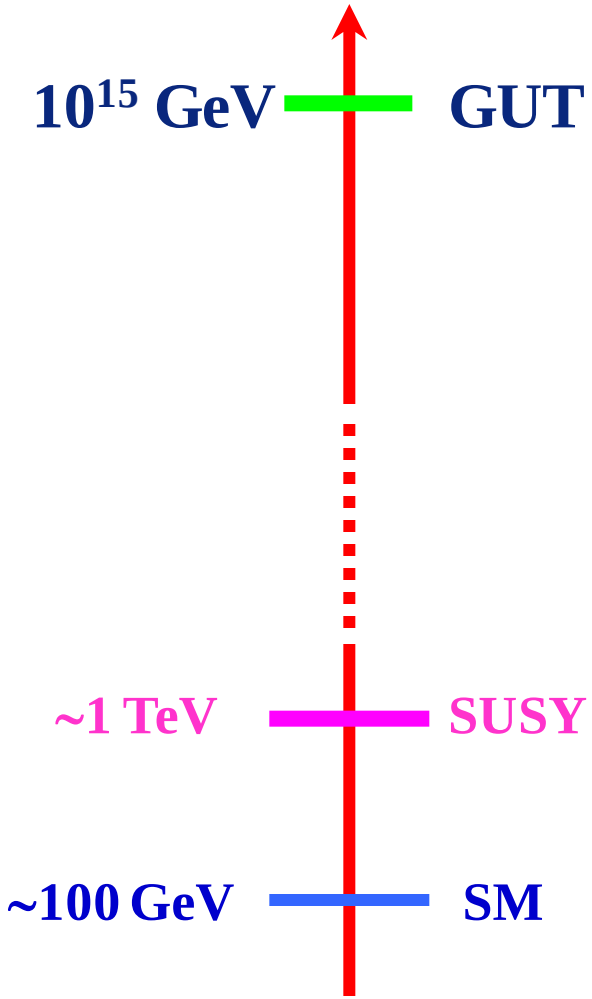
Higgs mass 125 GeV --- signal of SUSY

$M_h < 135$ GeV in MSSM

$M_h < 150$ GeV in any low energy SUSY model

In SM Higgs mass is a free parameter

Reason-2: Fine-tuning Problem



If SM valid up to GUT scale, the theory has extreme fine-tuning !

$$m_h^2 = m_0^2 - \delta m_h^2$$

100 GeV **bare** Λ^2 /52

1693，Newton

'Gravitation law consistent with static universe ?'

as hard as to make the sharpest needle stand upright on its point upon a looking-glass.

this unnatural state of affairs could be set by a divine power.

Reason-3:

125 GeV Higgs --- vacuum not stable --- need SUSY

Short Sharp Science

Cutting-edge science, cut up

Higgs may spell doom, unless supersymmetry saves us

20:35 20 February 2013

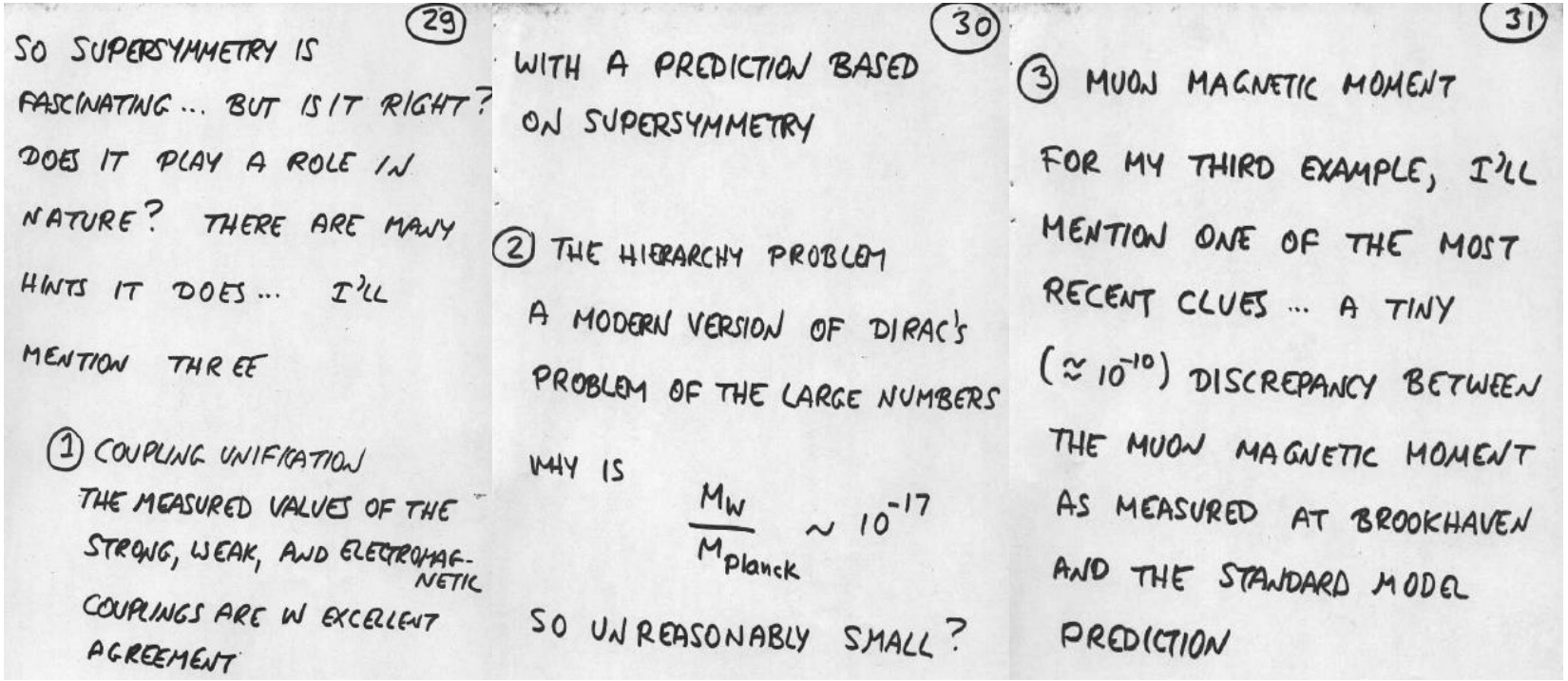
Is the Higgs boson a herald of the apocalypse? That's the suggestion behind a theory, developed more than 30 years ago, that is back in the headlines this week. According to physicists, the mass of the Higgs-like particle announced last summer supports the notion that our universe is teetering on the edge of stability, like a pencil balanced on its point.

"It may be that the universe we live in is inherently unstable," Joseph Lykken, of the Fermi National Accelerator Laboratory in Batavia, Illinois, said on Monday at a meeting of the American Association for the Advancement of Science. "At some point, billions of years from now, it's all going to be wiped out."

WHY SUPERSYMMETRY?

- Naturalness **(Higgs-related)**
- Gauge Coupling Unification
- Dark Matter

Edward Witten



29

SO SUPERSYMMETRY IS FASCINATING ... BUT IS IT RIGHT? DOES IT PLAY A ROLE IN NATURE? THERE ARE MANY HINTS IT DOES ... I'LL MENTION THREE

(1) COUPLING UNIFICATION
THE MEASURED VALUES OF THE STRONG, WEAK, AND ELECTROMAGNETIC COUPLINGS ARE IN EXCELLENT AGREEMENT

30

WITH A PREDICTION BASED ON SUPERSYMMETRY

(2) THE HIERARCHY PROBLEM
A MODERN VERSION OF DIRAC'S PROBLEM OF THE LARGE NUMBERS

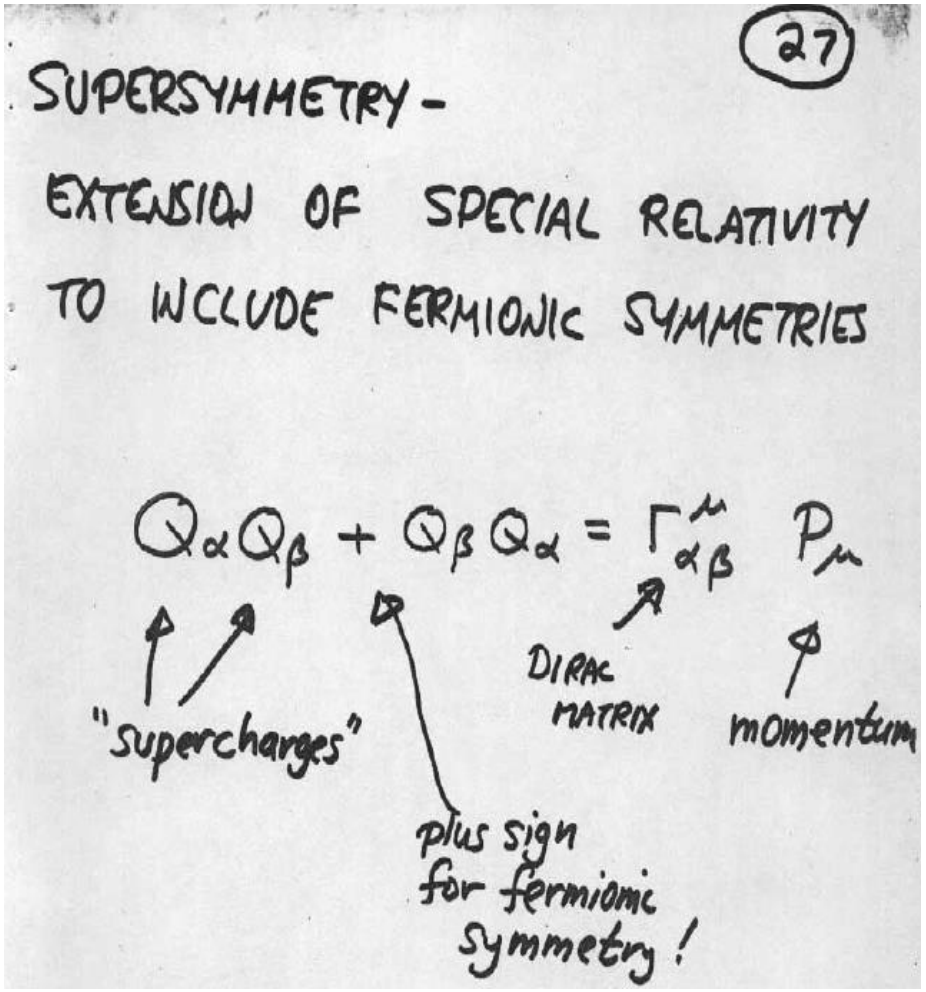
WHY IS $\frac{M_W}{M_{Planck}} \sim 10^{-17}$

SO UNREASONABLY SMALL?

31

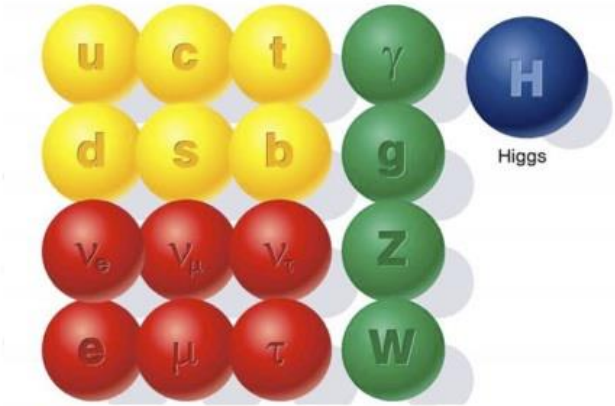
(3) MUON MAGNETIC MOMENT
FOR MY THIRD EXAMPLE, I'LL MENTION ONE OF THE MOST RECENT CLUES ... A TINY ($\approx 10^{-10}$) DISCREPANCY BETWEEN THE MUON MAGNETIC MOMENT AS MEASURED AT BROOKHAVEN AND THE STANDARD MODEL PREDICTION

What is SUSY ?



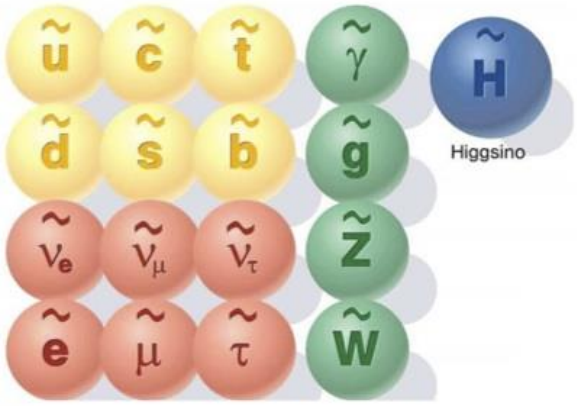
Edward Witten

The known world of Standard Model particles



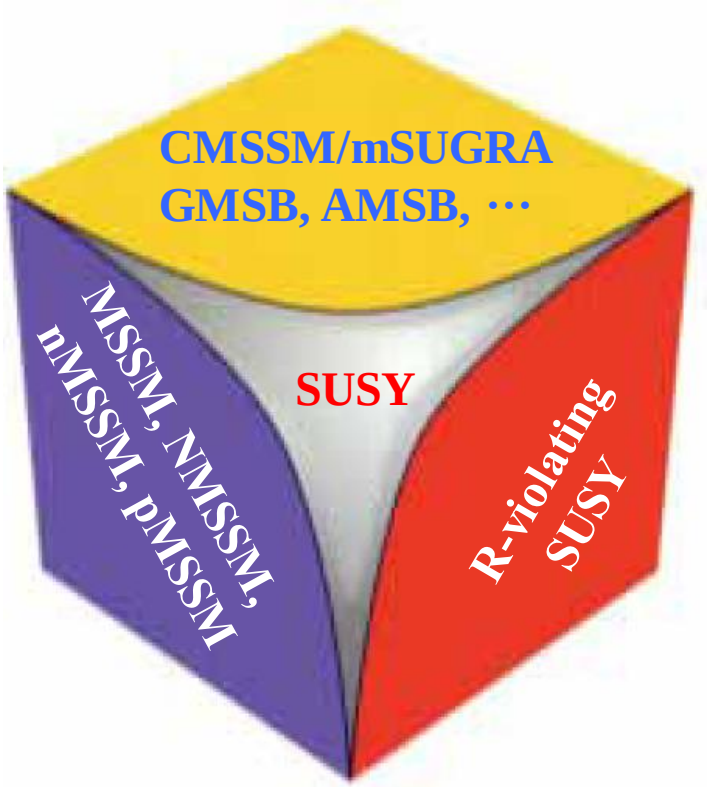
- quarks
- leptons
- force carriers

The hypothetical world of SUSY particles



- squarks
- sleptons
- SUSY force carriers

SUSY models on the market:



$$W_{\mathrm{MSSM}} = W_F + \mu \hat{H}_u \cdot \hat{H}_d,$$

$$W_{\mathrm{NMSSM}} = W_F + \lambda \hat{H}_u \cdot \hat{H}_d \hat{S} + \frac{1}{3}\kappa \hat{S}^3,$$

$$W_{\mathrm{nMSSM}} = W_F + \lambda \hat{H}_u \cdot \hat{H}_d \hat{S} + \xi_F M_n^2 \hat{S},$$

$$W_F = Y_u \hat{Q} \cdot \hat{H}_u \hat{U} - Y_d \hat{Q} \cdot \hat{H}_d \hat{D} - Y_e \hat{L} \cdot \hat{H}_d \hat{E}$$

Why NMSSM ?

- Dynamical solution to μ-problem
- Solve little hierarchy problem
- Theoretically motivated

E6 models (superstring-inspired)

↓ **string scale**

SO(10) × U(1) × ···

↓

at low energy: **S, H_u, H_d + heavy particles**

U(1) global PQ

to break U(1) PQ

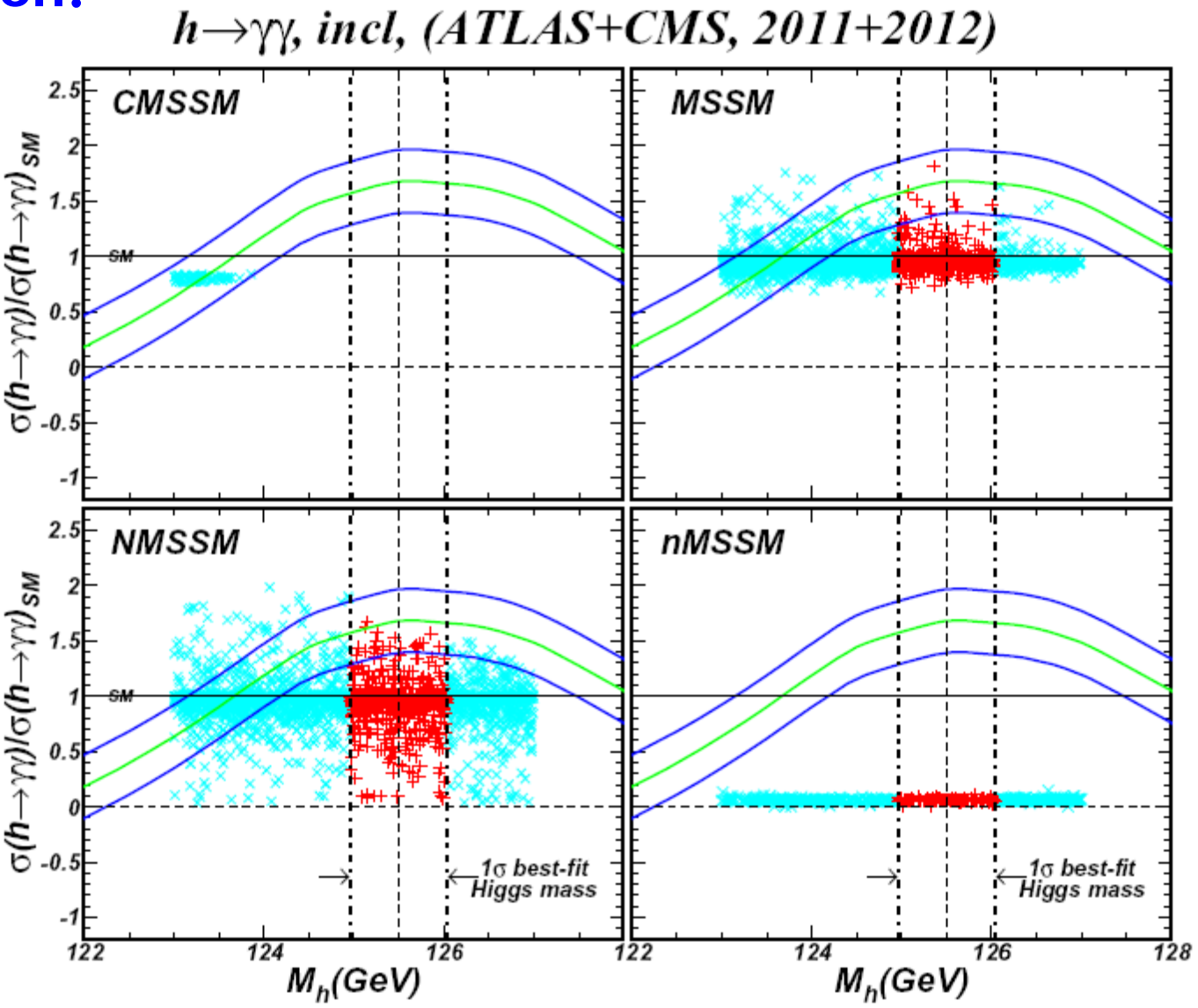
- **cubic term** $\frac{\kappa}{3}\hat{S}^3$ **(NMSSM)**
- **tadpole** $\xi_F M_n^2 \hat{S}$ **(nMSSM)**

2 Status of low energy SUSY

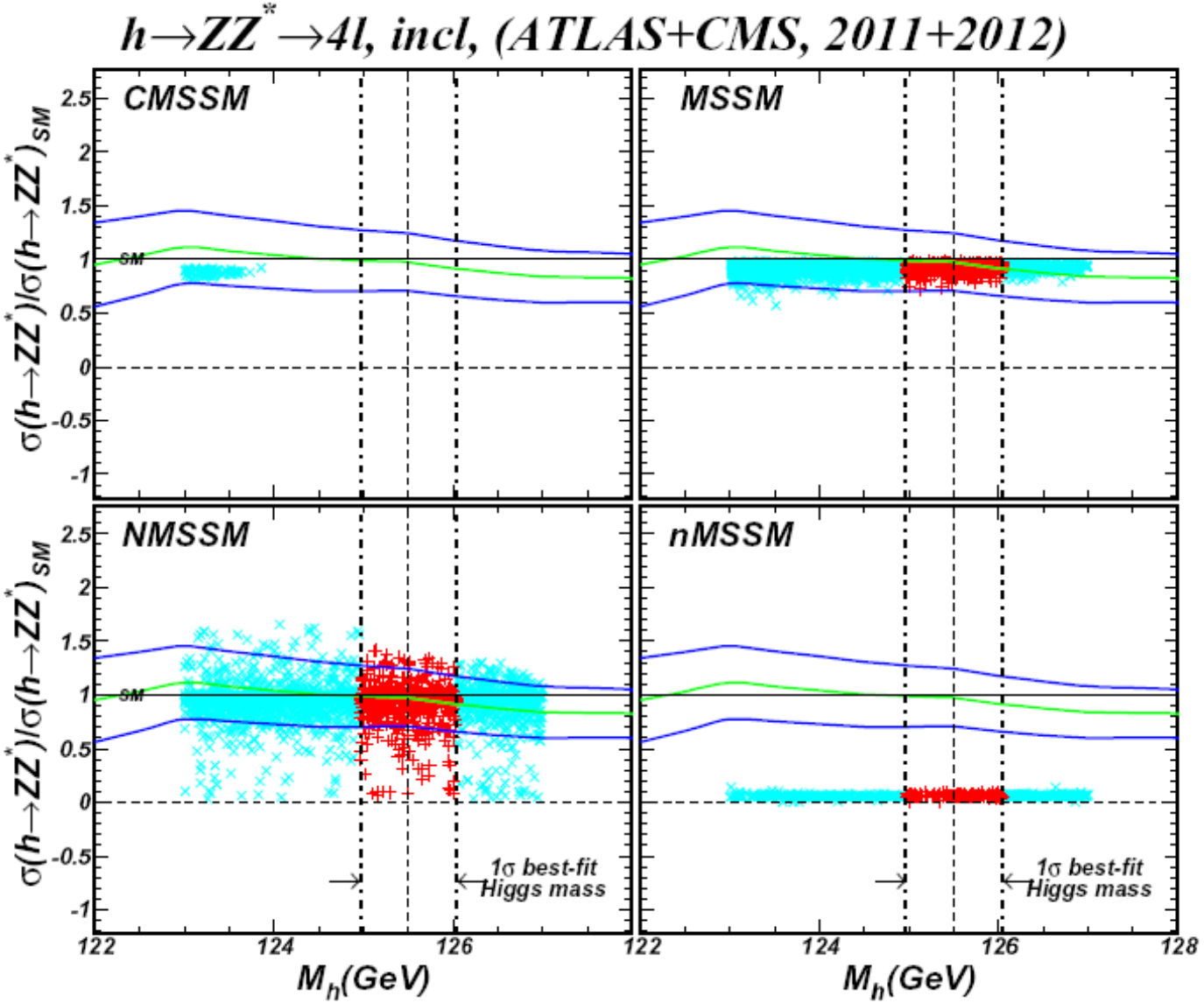
arXiv:1207.3698; 1202.5821
Cao, Heng, Yang, Zhu

- Consider various SUSY mdoels
- Consider all experimental constraints，scan the parameter space
- Examine the allowed parameter space

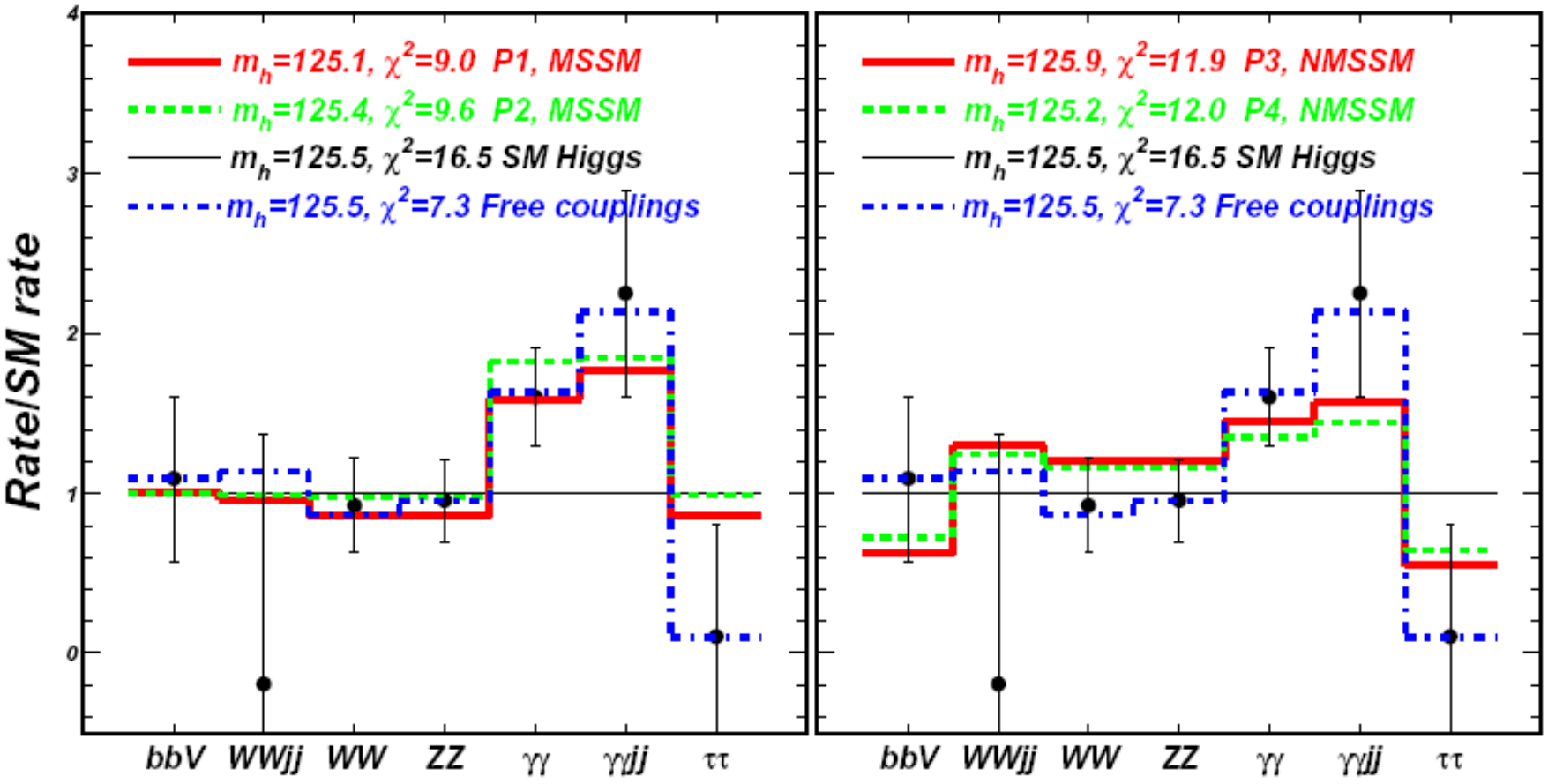
diphoton：


h→γγ, incl, (ATLAS+CMS, 2011+2012)
CMSSM
MSSM
NMSSM
nMSSM
σ(h→γγ)/σ(h→γγ)SM
SM
1σ best-fit Higgs mass
Mh(GeV)
122
124
126
128

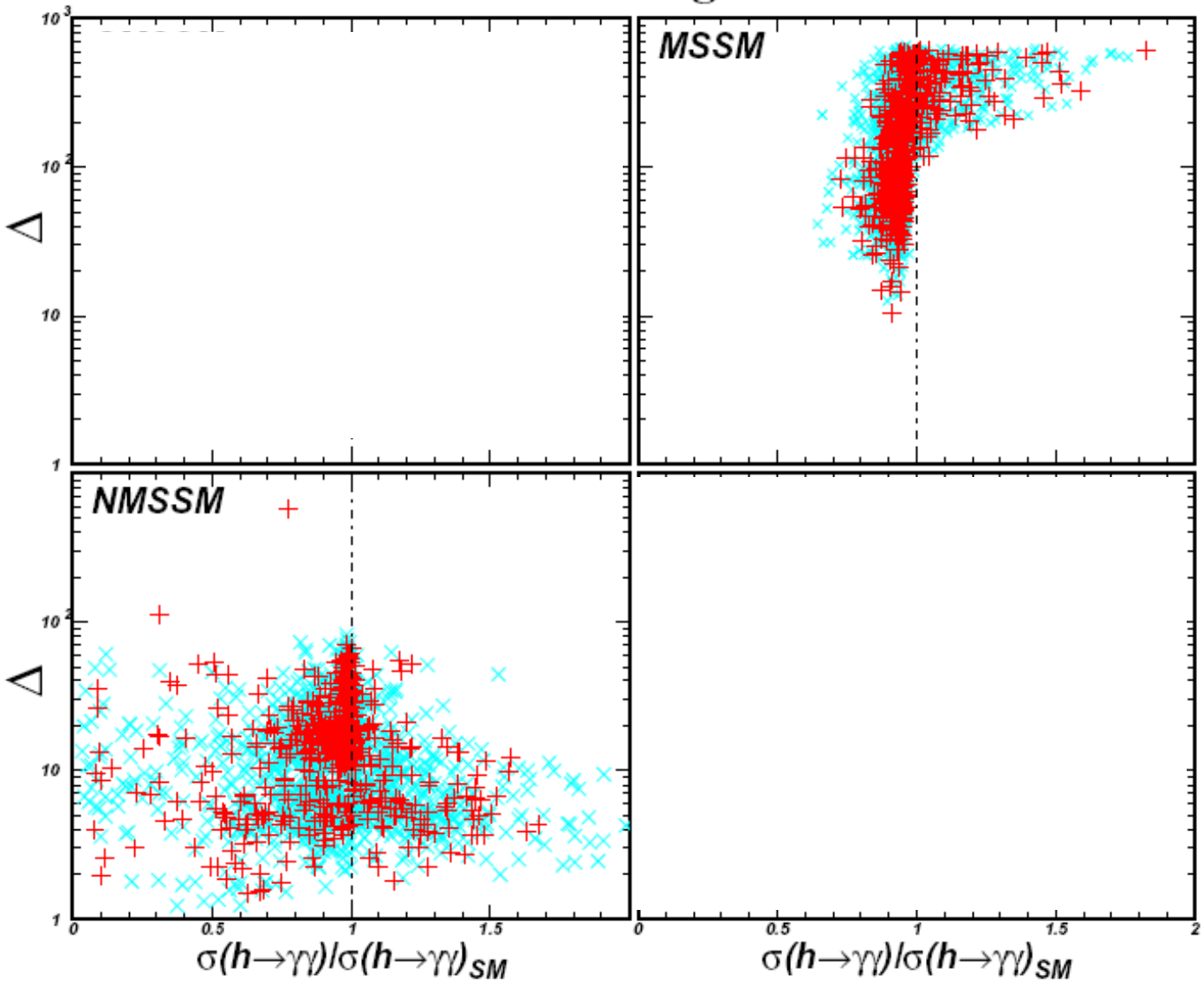
ZZ*:


h→ZZ*→4l, incl, (ATLAS+CMS, 2011+2012)
CMSSM
MSSM
NMSSM
nMSSM
σ(h→ZZ*)/σ(h→ZZ*)SM
SM
1σ best-fit Higgs mass
Mh(GeV)

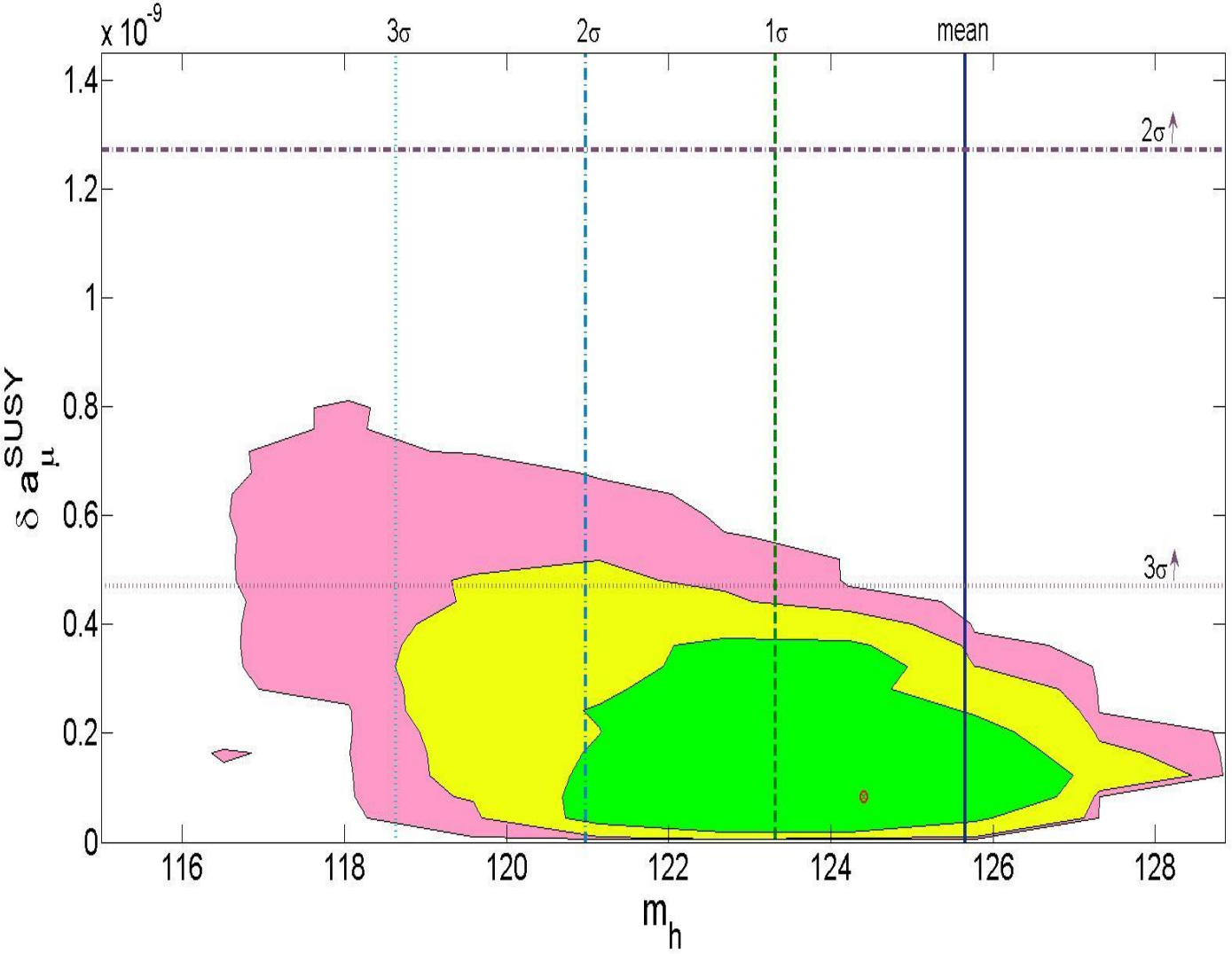
All channels：



Fine-tuning


MSSM
NMSSM
Δ
Δ
10^3
10^2
10
1
0
0.5
1
1.5
2
$\sigma(h\to\gamma\gamma)/\sigma(h\to\gamma\gamma)_{SM}$
$\sigma(h\to\gamma\gamma)/\sigma(h\to\gamma\gamma)_{SM}$

More about CMSSM/mSUGRA：



So, confronted with LHC data:

Nathan Seiberg

Aspen 2013

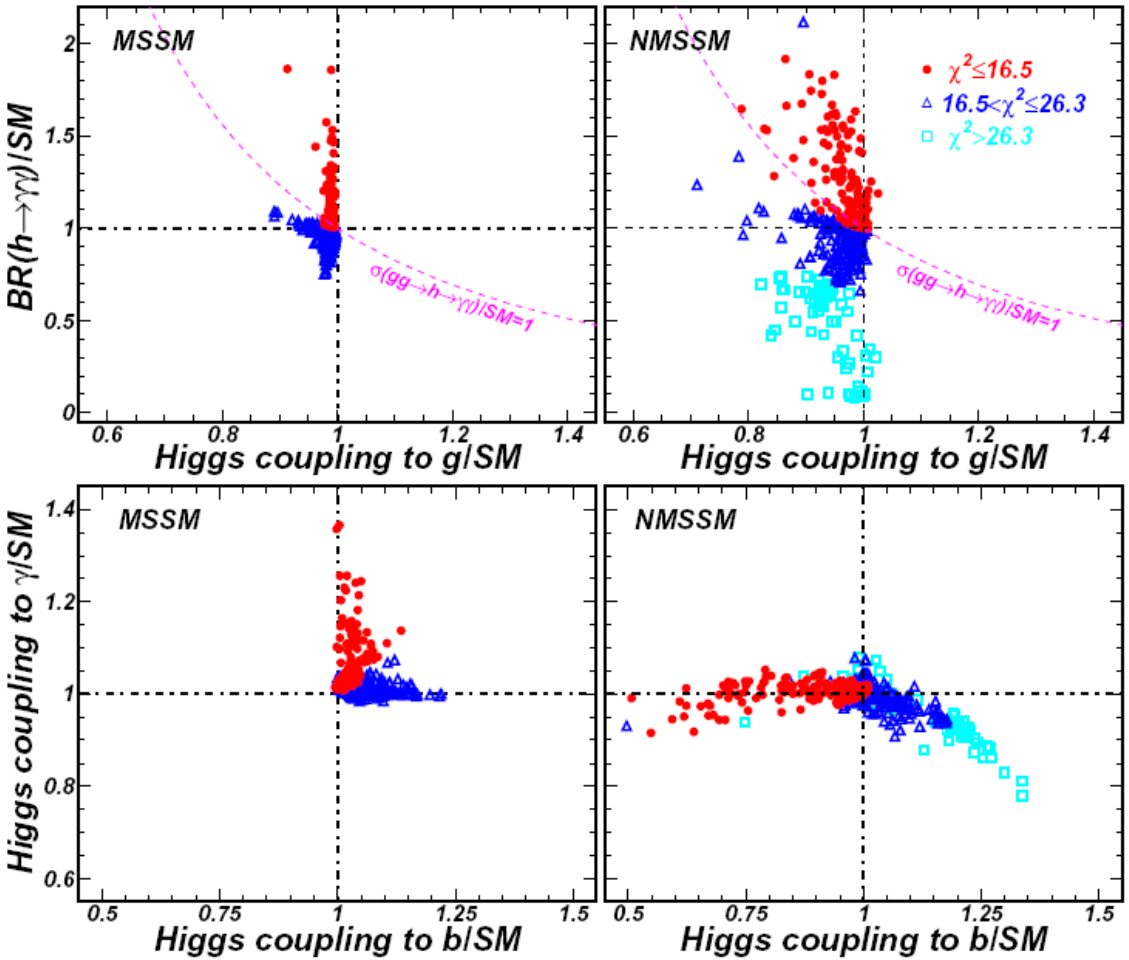
It is hard to make SUSY fully natural.

In the MSSM the Higgs self-coupling is related to the gauge coupling. Hence:

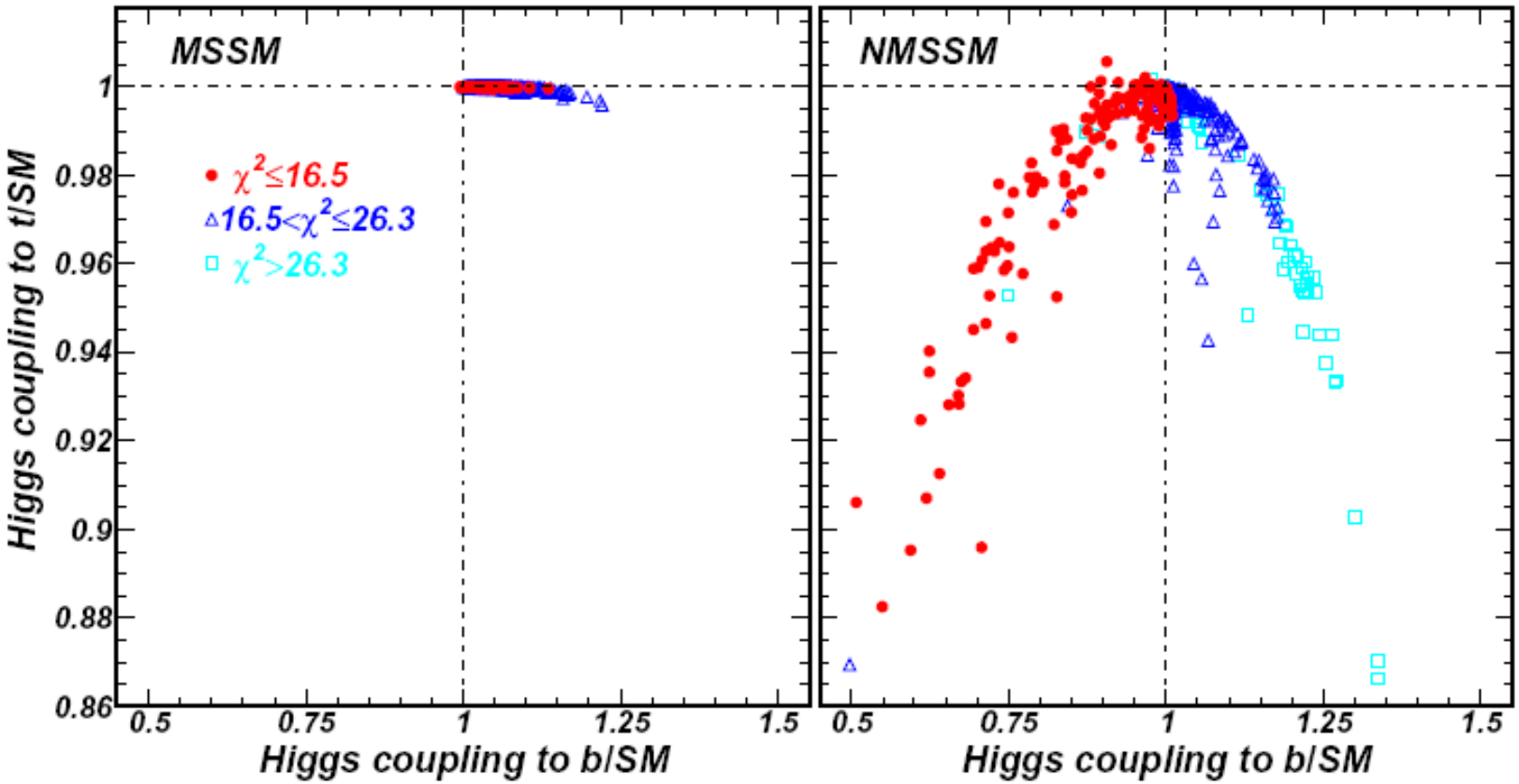
- At tree level $m_{Higgs} \leq m_Z$
- Radiative corrections can lift the Higgs mass, but for reaching 125GeV we need
  - Heavy stop
  - Large A-terms
  - Going beyond the minimal model

Further Probes of SUSY

Through measuring Higgs couplings:

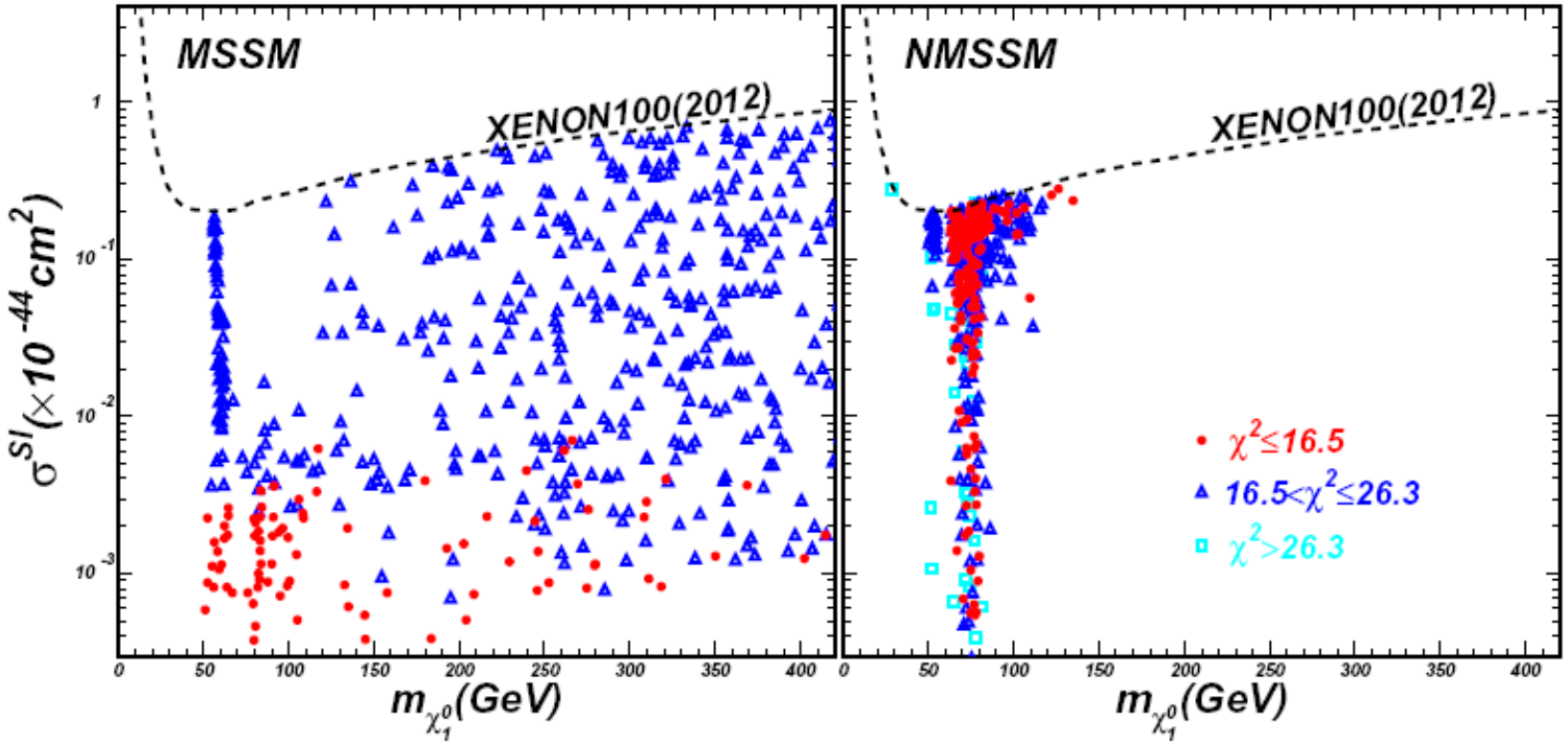


arXiv:1207.3698;
Cao, Heng, Yang, Zhu



Yukawa couplings to top and bottom

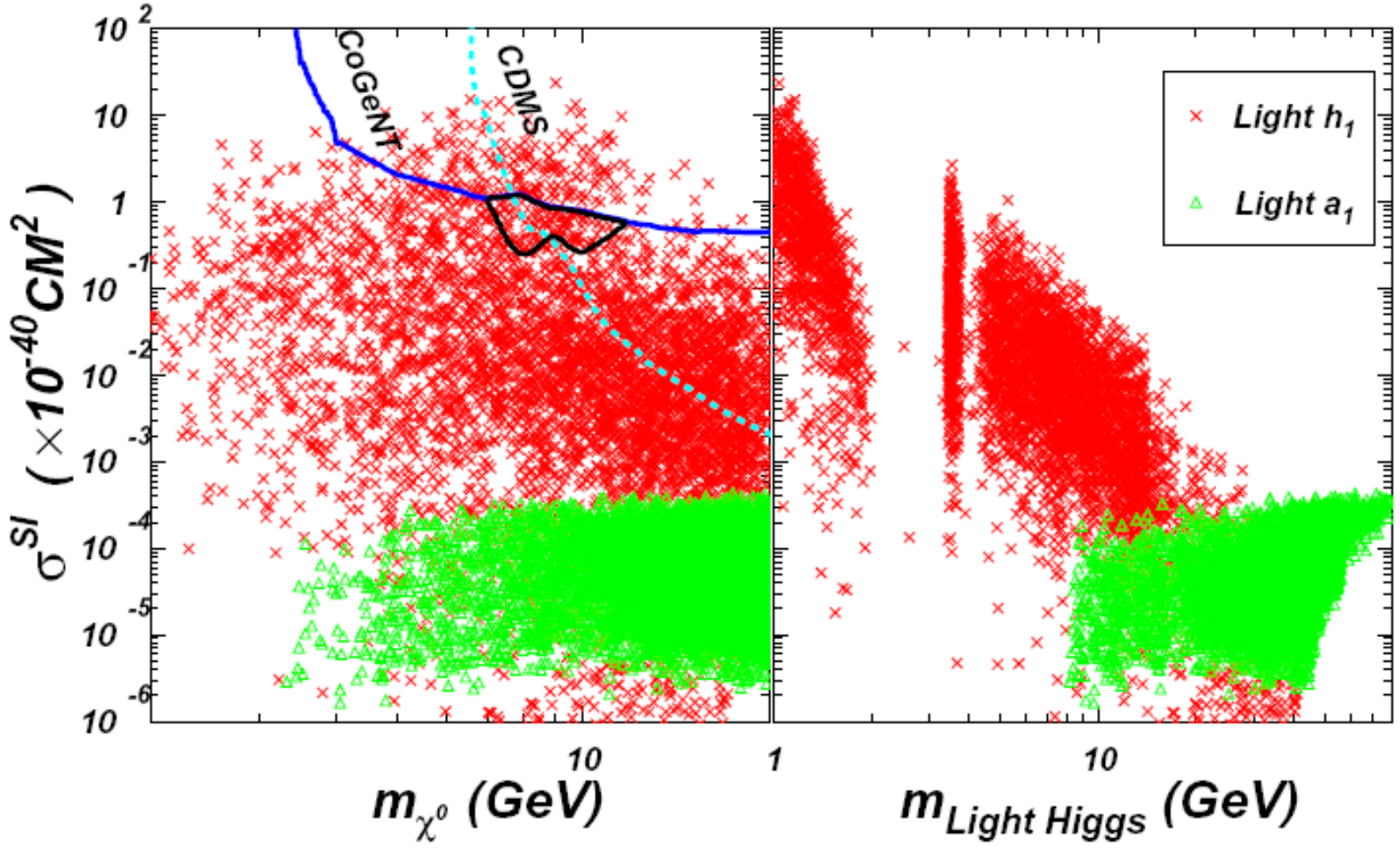
Through dark matter detection:



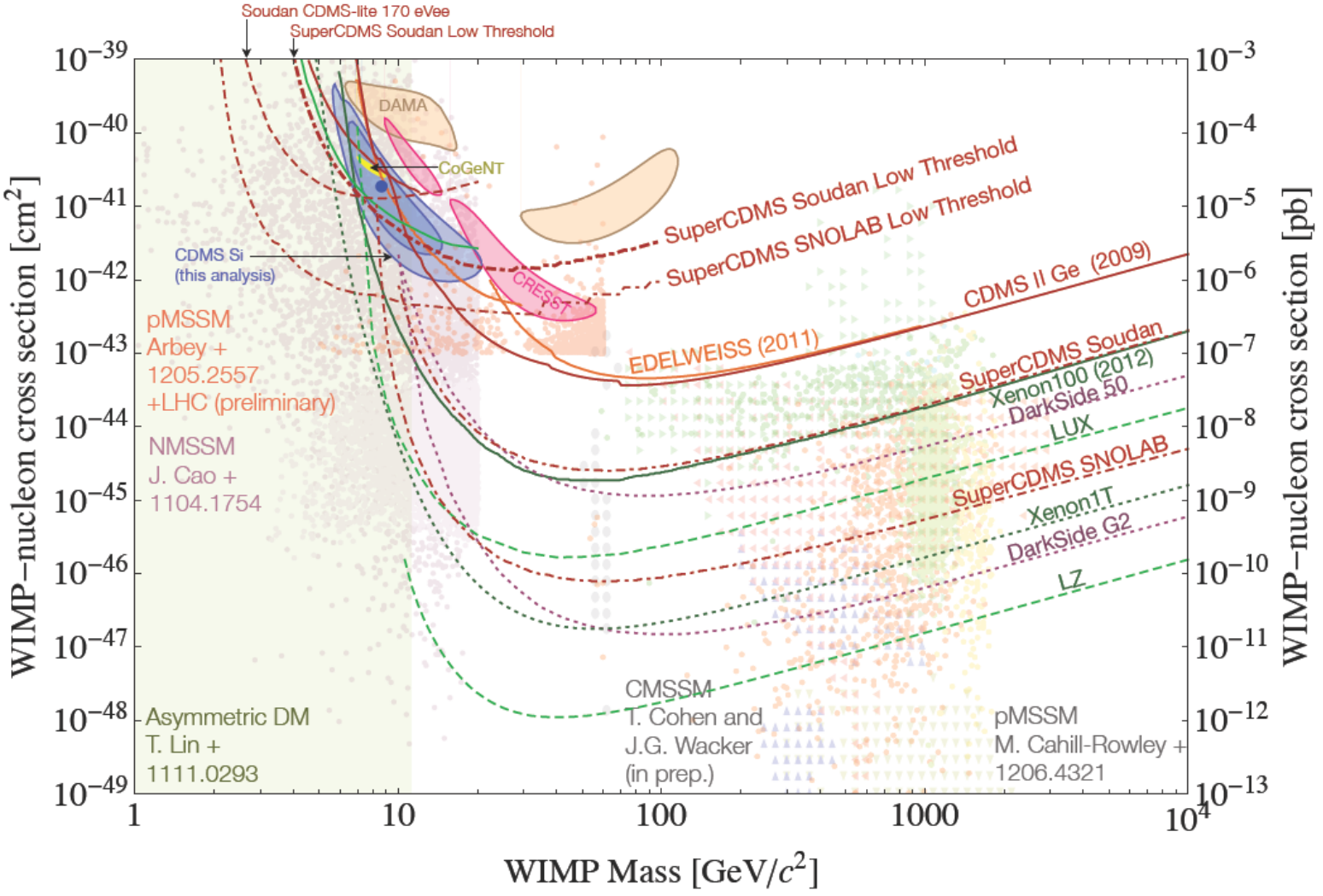
light dark matter (8-10 GeV) ?

arXiv:1104.1754
Cao, Hikasa, Wang, Yang

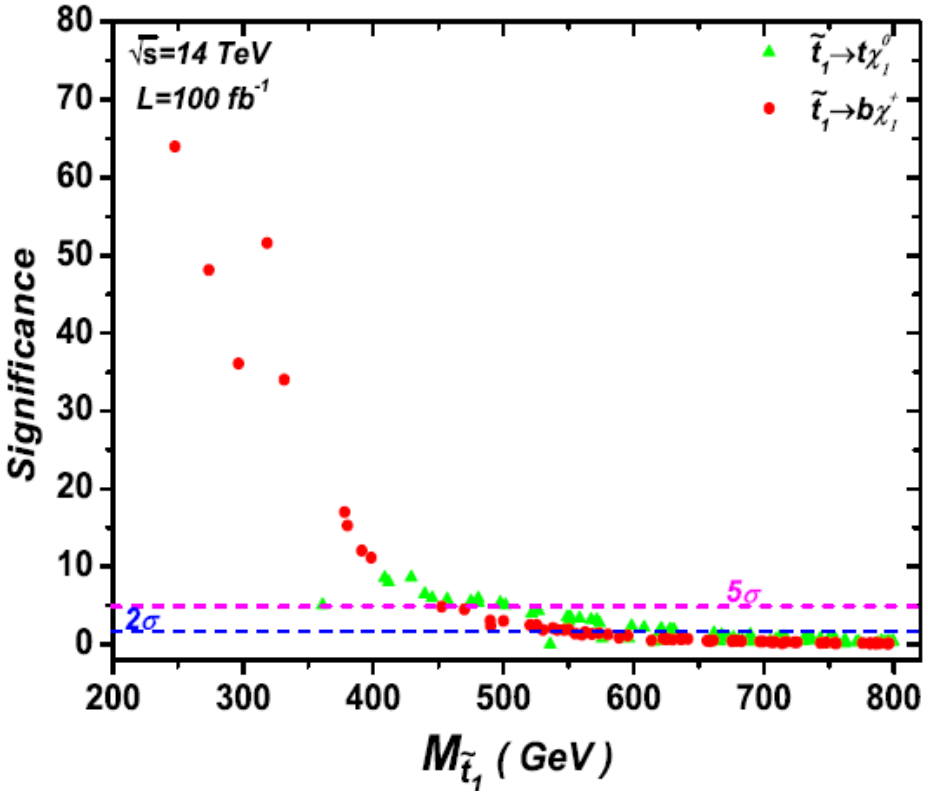
NMSSM



May 17, 2013
CDMS talk at FNAL
(by E. Figueroa-Feliciano)



Search for stop pair at LHC:



arXiv:1206.3865

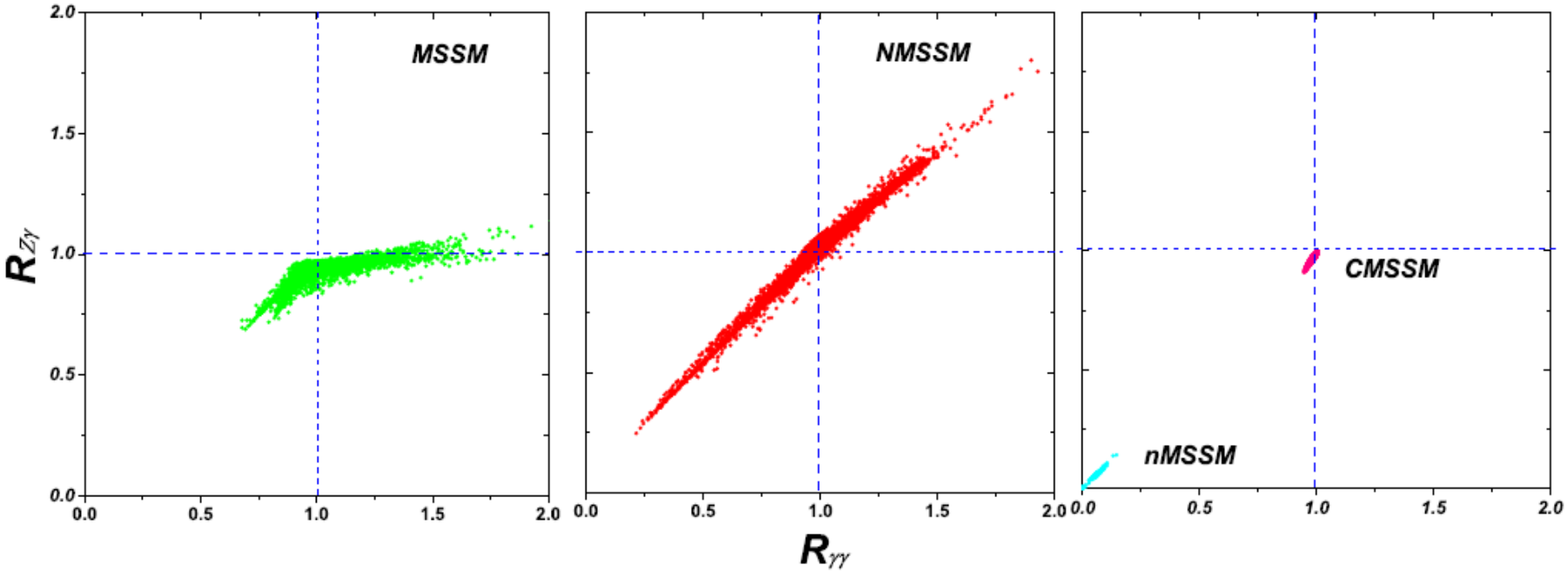
Cao, Han, Wu, Yang, Zhang

Study $Z\gamma$ versus $\gamma\gamma$ at LHC:

$$R_{Z\gamma} \equiv \frac{\sigma(pp \to h \to Z\gamma)}{\sigma_{\rm SM}(pp \to h \to Z\gamma)}$$

$$R_{\gamma\gamma} \equiv \frac{\sigma(pp \to h \to \gamma\gamma)}{\sigma_{\rm SM}(pp \to h \to \gamma\gamma)}$$

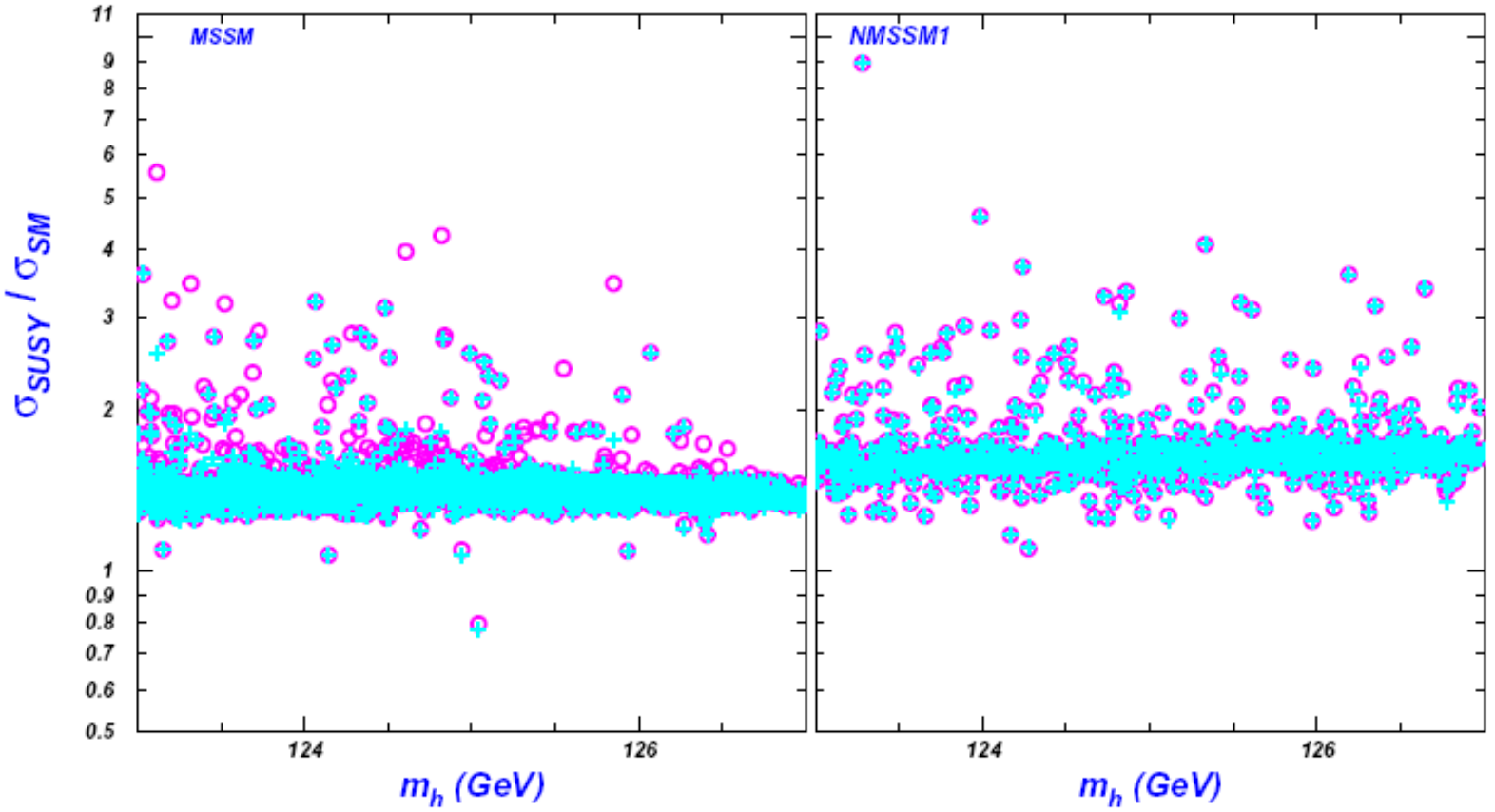
arXiv:1301.4641
Cao, Wu, Wu, Yang



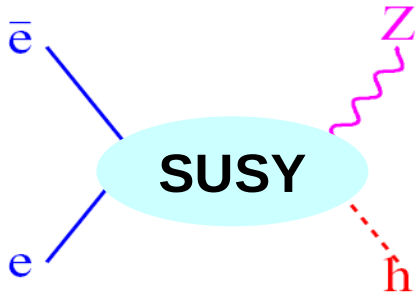
Study Higgs pair production at LHC:

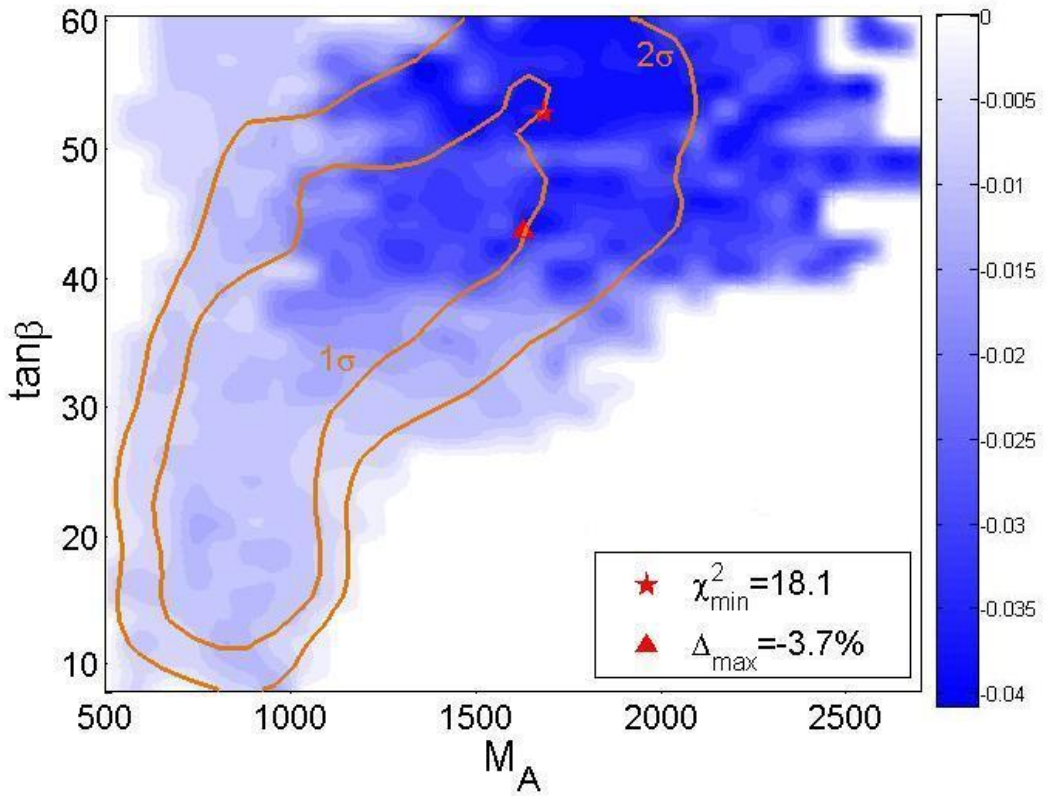
arXiv:1301.6437

Cao, Heng, Shang, Wan, Yang



Think about Higgs-factory:



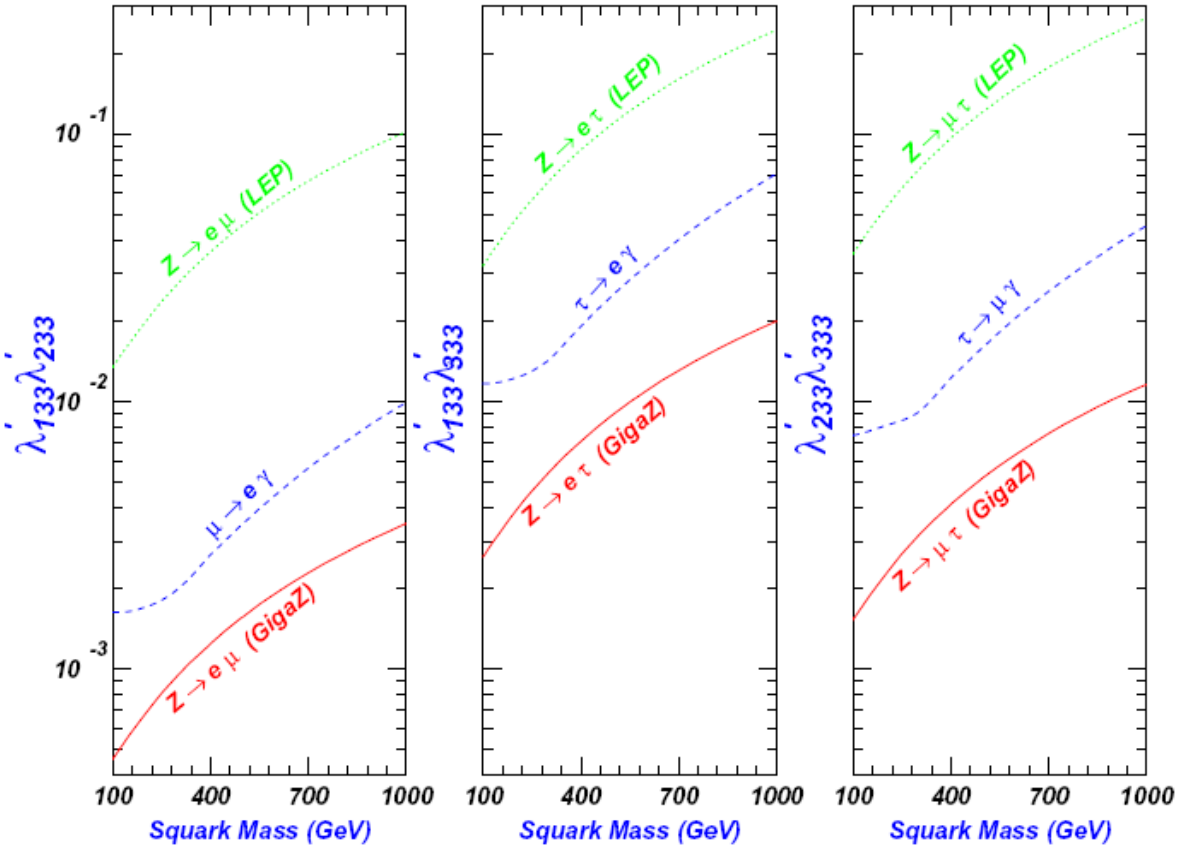


C.Han, L.Wu, P.Wu, JMY,
work in progress

How about Z-factory ?

more than 10^9 Z-bosons

JMY, arXiv: 1006.2594



3 Conclusion

Confronted with LHC Higgs data:

- **Some SUSY models are healthy**
- **Some SUSY models need to be sent to hospital**

LHC, HL- LHC, Higgs factory can further probe SUSY:

- **Through measuring Higgs couplings**
- **Through some rare processes (hh, $Z\gamma\cdots$)**
- **Through stop pair production**

Dark matter detection expt (XENON) can interplay

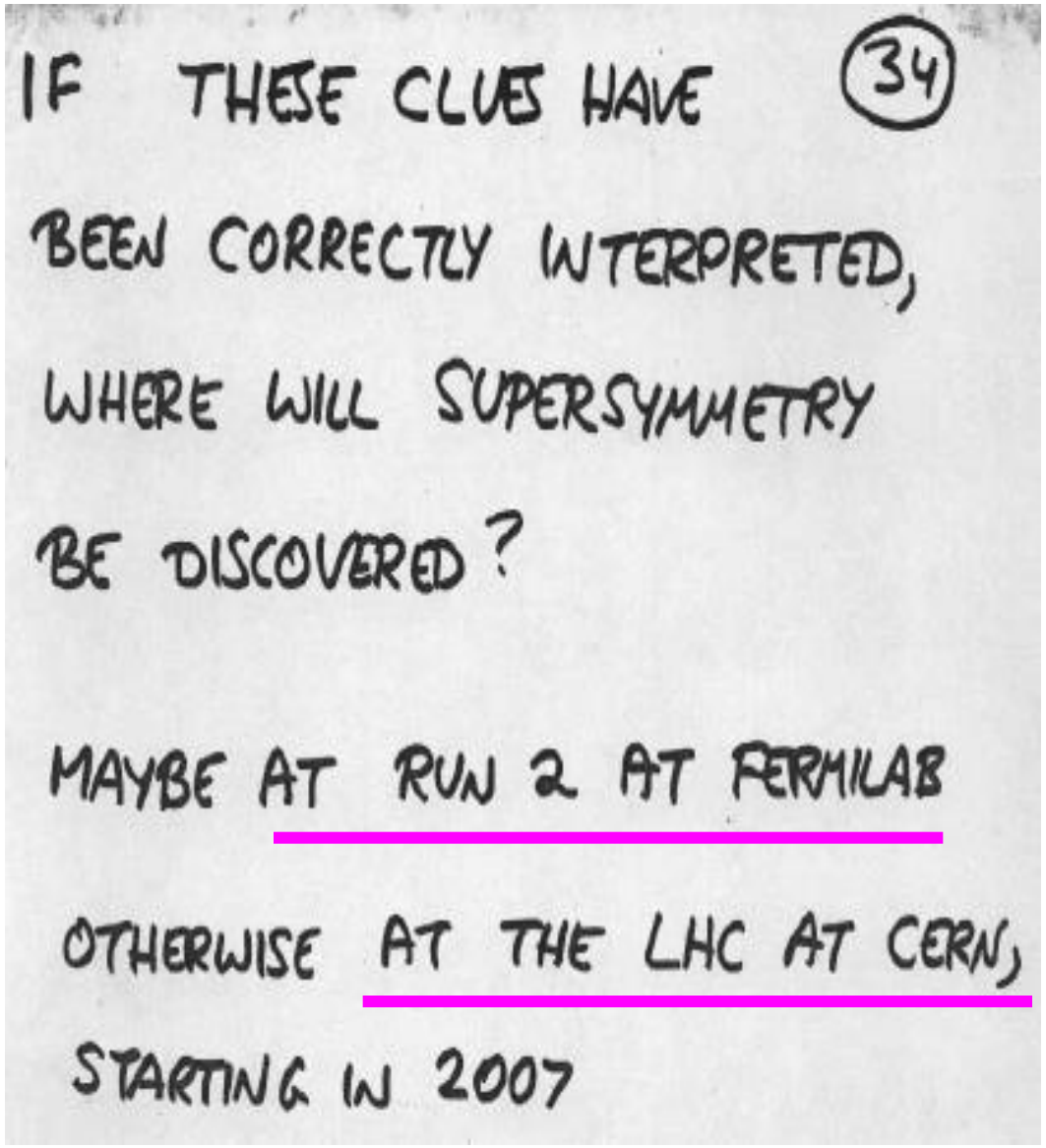
After all,

when and where

can SUSY be discovered?

Where ?

Edward Witten



When ?

Frank Wilczek

On SUSY, Frank Wilczek is still a believer, based on the renormalization group calculation he was a co-author of back in 1981. If no SUSY turns up at the next LHC run though, even he will throw in the towel:

I cannot believe this success is an accident. But in science faith is a means, not an end. Supersymmetry predicts new particles, with characteristic properties, that will come into view as the LHC operates at higher energy and intensity. The theory will soon undergo a trial by fire. It will yield gold – or go up in smoke.

He has a bet with Garrett Lisi that superparticles will be detected by July 8, 2015.

Thanks