Natural NMSSM after LHC Run I

and the Higgsino dominated dark matter scenario

Yang Zhang

Jin Min Yang's Group, Institute of Theoretical Physics, Chinese Academy of Sciences,

Based on arXiv:1606.04416, JHEP08(2016)037

In collaboration with Junjie Cao, Yangle He, Liangliang Shang, Wei Su

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01 Introduction

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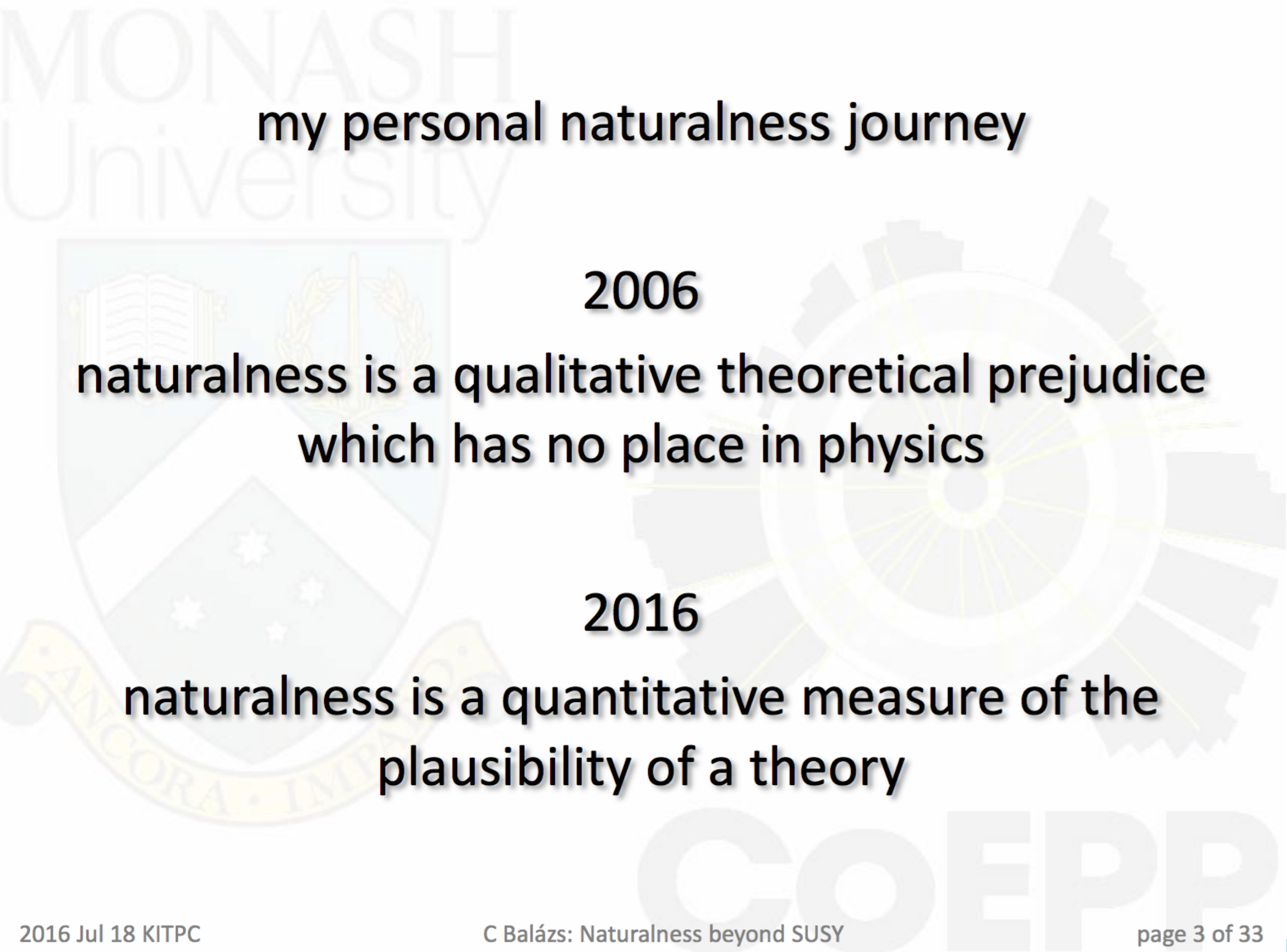

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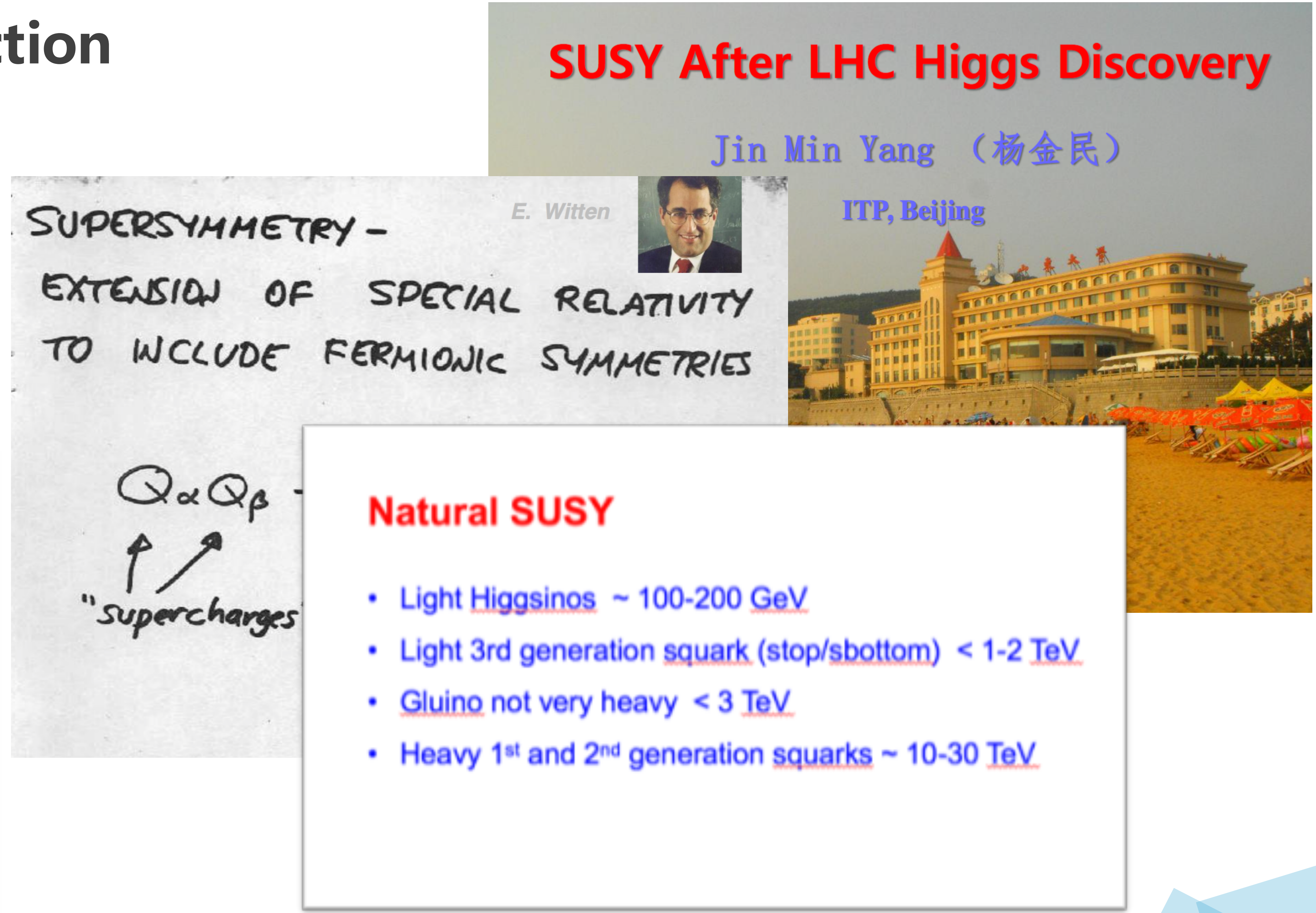
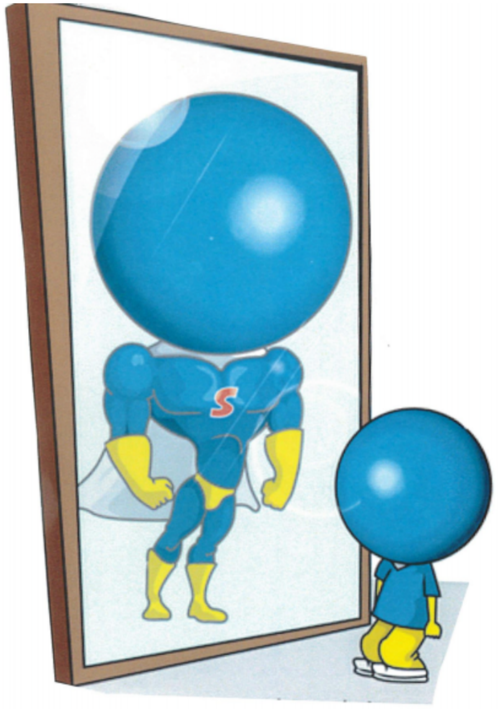
01 Introduction





01 Introduction

In the supersymmetric models such as the MSSM and the Next-to-MSSM, the Z boson mass is given by

$$m_Z^2 = \frac{2(m_{H_d}^2 + \Sigma_d) - 2(m_{H_u}^2 + \Sigma_u)\tan^2\beta}{\tan^2\beta - 1} - 2\mu^2$$

where radiative corrections of the Higgs fields are

$$\tan\beta \equiv v_u/v_d.$$

$$\Sigma_u \simeq \sum_{i=1}^{2} \frac{3Y_t^2}{16\pi^2} \times m_{\tilde{t}_i}^2 \left(\log\frac{m_{\tilde{t}_i}^2}{Q^2} - 1\right)$$

$$\Sigma_d \simeq \sum_{i=1}^{2} \frac{3Y_b^2}{16\pi^2} \times m_{\tilde{b}_i}^2 \left(\log\frac{m_{\tilde{b}_i}^2}{Q^2} - 1\right)$$

$$Q = \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$$

Requiring the individual term to be less than $10m_z^2$ leads to

$$\mu < 200 \text{ GeV},\ m_{\tilde{t}_{1,2}} < 1.5 \text{ TeV} \ \rightarrow\ \text{Natural SUSY}$$

01 Introduction

Natural MSSM

μ problem

Higgsino mass μ is the only dimensionful parameter. its typical size should be of the order of the SUSY breaking scale.

The LHC searches have pushed the masses of gluinos and squarks up to above 1TeV

DM relic density

For Higgsino-dominated DM, its density is usually about one order smaller than its measured value.

For Bino-dominated DM, the correct density can be achieved only in very limited parameter regions of the MSSM.

Higgs Mass

The observed Higgs mass lies beyond its tree-level upper bound m_Z.

The stops should heavier than about 1TeV to provide a large radiative correction to the mass

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SUSY searches with ATLAS detector *Xuai ZHUANG*

The international lecture hall, 2F of the academic exchange center, Shandong University, Weihai 15:30 - 16:00

Summary

- **ATLAS developed a vast program to search for SUSY**
  - **No significant excess seen so far**
  - **More PUB results @here**
- **In canonical scenarios, sensitivity is achieved to ~1.9 TeV gluinos, ~900 GeV stops**
  - **More (EWK) results will be ready for SEARCH CONF**
- **~30 (100) fb-1 data at this year (end of run2), which is very challenging years for SUSY in front of us!**

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01 Introduction

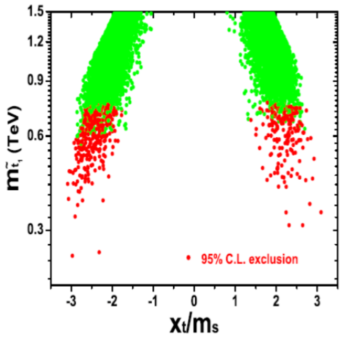
Natural MSSM

SUSY after LHC Higgs discovery *Prof. Jinmin YANG*

The international lecture hall, 2F of the academic exchange center, Shandong University, Weihai 16:00 - 16:30

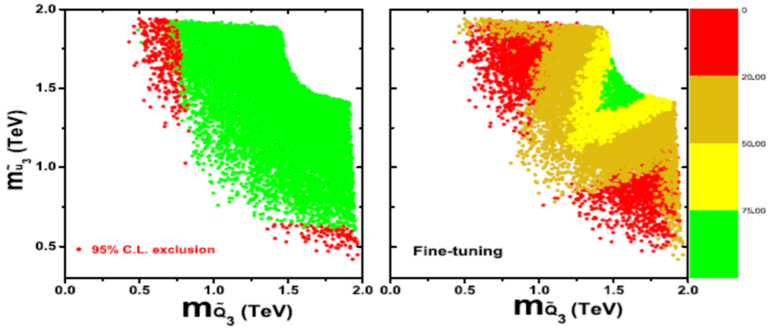
Natural SUSY

arXiv:1308.5307
Han, Hikasa, Wu, Yang, Zhang



Not so natural !
Natural space (light stop) has been excluded

fine-tuning extent



Higgs Mass

The observed Higgs mass lies beyond its tree-level upper bound m_Z.

The stops should heavier than about 1TeV to provide a large radiative correction to the mass

01 Introduction

The **Next-to-MSSM** extends the MSSM by one gauge singlet superfield,

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

The Higgsino mass μ is generated by the vacuum expectation value of $\hat{S}$, and given that all singlet dominated scalars are lighter than about $\nu \cong$ 174GeV, its magnitude can be naturally less than 200GeV.

The additional singlet-dominated DM scenario can not only predict the correct relic density, but also explain the GCE.

The interaction $\lambda\hat{S}\hat{H}_u\hat{H}_D$ can lead to a positive contribution to the squared mass of the SM-like Higgs boson, and if the boson corresponds to the next-to-lightest CP-even Higgs state, its mass can be further lifted up by the singlet-doublet Higgs mixing.

02 Natural NMSSM

The Structure of the NMSSM and Our Scan Strategy

02 Natural NMSSM

For the naturalness of the NMSSM, we consider two fine tuning quantities defined by

$$\Delta_Z = \max_i \left|\frac{\partial \log m_Z^2}{\partial \log p_i}\right|, \quad \Delta_h = \max_i \left|\frac{\partial \log m_h^2}{\partial \log p_i}\right|$$

where h represents the SM-like Higgs boson, p_i denotes SUSY parameters at the weak scale, including

$$\lambda, \ \kappa, \ tan\beta, \ \mu, \ A_\lambda, \ A_\kappa$$

We calculate Δ_Z according to the method in [arXiv:1107.2472] and Δ_h by [arXiv:1107.2472].

$$E_1: \quad m_{H_u}^2 + \mu_{\rm eff}^2 + \lambda^2 v_d^2 + \frac{g_1^2+g_2^2}{4}(v_u^2 - v_d^2) - \frac{v_d}{v_u}\mu_{\rm eff}(A_\lambda + \kappa s) + \frac{3h_t^4 v_u^2}{8\pi^2}\ln\left(M_{\rm stop}^2/m_{top}^2\right) = 0 \,,$$

$$E_2: \quad m_{H_d}^2 + \mu_{\rm eff}^2 + \lambda^2 v_u^2 + \frac{g_1^2+g_2^2}{4}(v_d^2 - v_u^2) - \frac{v_u}{v_d}\mu_{\rm eff}(A_\lambda + \kappa s) = 0 \,,$$

$$E_3: \quad m_S^2 + \kappa A_\kappa s + 2\kappa^2 s^2 + \lambda^2(v_u^2 + v_d^2) - 2\lambda\kappa v_u v_d - \lambda\frac{v_u v_d}{s}A_\lambda = 0 \,,$$

$$0 = \delta E_j = \sum_i \frac{\partial E_j}{\partial p_i^{\rm Susy}}\delta p_i^{\rm Susy} + \frac{\partial E_j}{\partial M_Z}\delta M_Z + \frac{\partial E_j}{\partial \tan\beta}\delta\tan\beta + \frac{\partial E_j}{\partial \mu_{\rm eff}}\delta\mu_{\rm eff}$$

02 Natural NMSSM

We perform a comprehensive scan over the parameter space of the NMSSM

$$0 < \lambda \le 0.75, \quad 0 < \kappa \le 0.75, \quad 2 \le \tan\beta \le 60, \quad 100 \text{ GeV} \le m_{\tilde{l}} \le 1 \text{ TeV},$$
$$100\text{GeV} \le \mu \le 1\text{TeV}, \quad 50 \text{ GeV} \le M_A \le 2 \text{ TeV}, \quad |A_\kappa| \le 2\text{TeV},$$
$$100 \text{ GeV} \le M_{Q_3}, M_{U_3} \le 2 \text{ TeV}, \quad |A_t| \le \min(3\sqrt{M_{Q_3}^2 + M_{U_3}^2}, 5\text{TeV}),$$
$$20\text{GeV} \le M_1 \le 500\text{GeV}, \quad 100\text{GeV} \le M_2 \le 1\text{TeV},$$

with assumptions

- The first two generation squarks equal to 2 TeV.
- The gluino mass is fixed at 2TeV,
- $m_{U_3}{=}m_{D_3}$ and $A_t = A_b$, to tune the mass of the SM-like Higgs boson.
- All soft breaking parameters in the slepton sector are treated as one free parameter, to explain the discrepancy of the measured value of the muon anomalous magnetic moment from its SM prediction.

at the scale of 1TeV.

02 Natural NMSSM

During the scan, we use following constraints to select physical parameter points:

- All the constraints implemented in the package NMSSMTools-4.9.0, including
  - The Z-boson invisible decay,
  - The LEP search for sparticles,
  - The B-physics observables,
  - The discrepancy of the muon anomalous magnetic moment,
  - The dark matter relic density (both upper and lower limits)
  - The LUX limits on the Spin-Independent scattering rate of dark matter with nucleon
- Constraints from the direct searches for Higgs bosons at LEP, Tevatron and LHC.
  - We require that one CP-even Higgs boson acts as the SM-like Higgs boson discovered at the LHC. We implement these constraints with the packages HiggsSignal for 125GeV Higgs data fit and HiggsBounds for non-standard Higgs boson search at colliders. .

02 Natural NMSSM

During the scan, we use following constraints to select physical parameter points:

- Constraints from the fine-tuning consideration:
  - $\Delta_z \leq 50$ and $\Delta_h \leq 50$.
- Constraints from the sparticles searches at the LHC Run-I.
  - Firstly, we implement the constraints in the packages FastLim and SModelS, which provide the preliminary analyses of the ATLAS and CMS groups in their direct searches for sparticles at the LHC Run-I.
  - Secondly, we implement the constraints from the latest searches for electroweakinos and stops by the ATLAS collaboration at the LHC Run-I by detailed Monte Carlo simulation.

02 Natural NMSSM

Table 6. Experiments in the Fastlim database.

Name	Description	$\sqrt{s}$	$\mathcal{L}_{\rm int}(\mathrm{fb}^{-1})$	Ref.
ATLAS-CONF-2013-062	1-2 leptons + 3-6 jets + E_T^{miss} (squarks and gluino)	8TeV	20.3	[75]
ATLAS-CONF-2013-061	0-1 lepton + $\geq$3 b-jets + E_T^{miss} (3rd gen. squarks)		20.1	[76]
ATLAS-CONF-2013-054	0 lepton + $\geq$ 7-10 jets + E_T^{miss} (squarks and gluino)		20.3	[77]
ATLAS-CONF-2013-053	0 lepton + 2 b-jets + E_T^{miss} (sbottom and stop)		20.1	[78]
ATLAS-CONF-2013-048	2 leptons (+ jets) + E_T^{miss} (stop)		20.3	[79]
ATLAS-CONF-2013-047	0 lepton + 2-6 jets + E_T^{miss} (squarks and gluino)		20.3	[80]
ATLAS-CONF-2013-037	1 lepton + 4(1 b-)jets + E_T^{miss} (stop)		20.7	[81]
ATLAS-CONF-2013-024	0 lepton + (2 b-)jets + E_T^{miss} (stop)		20.5	[82]

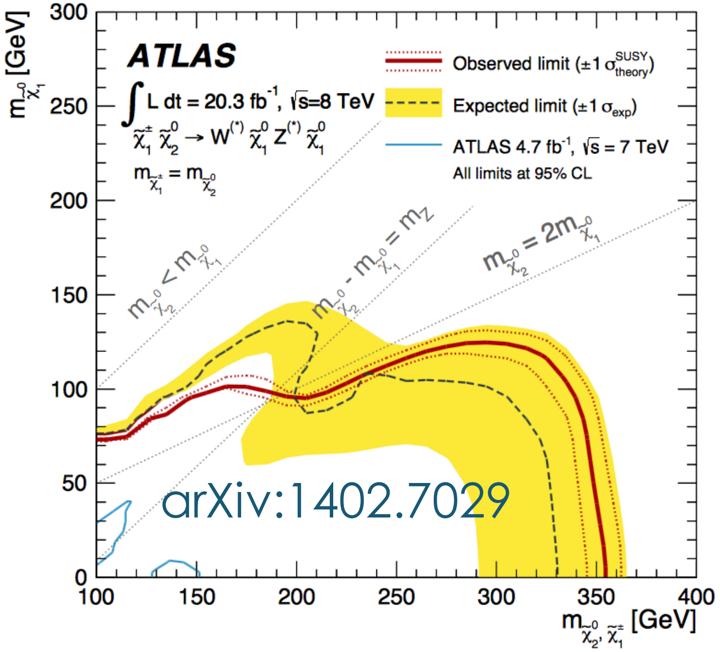
- Direct slepton searches (ATLAS): ATLAS-CONF-2013-049 [83].
- Direct slepton searches (CMS): SUS-12-022 [84], SUS-13-006 [85].
- Electroweakino searches (ATLAS): ATLAS-CONF-2013-028 [86], ATLAS-CONF-2013-035 [87], ATLAS-CONF-2013-036 [88], ATLAS-CONF-2013-093 [89].
- Electroweakino searches (CMS): SUS-12-022 [84], SUS-13-006 [85], SUS-13-017 [90],

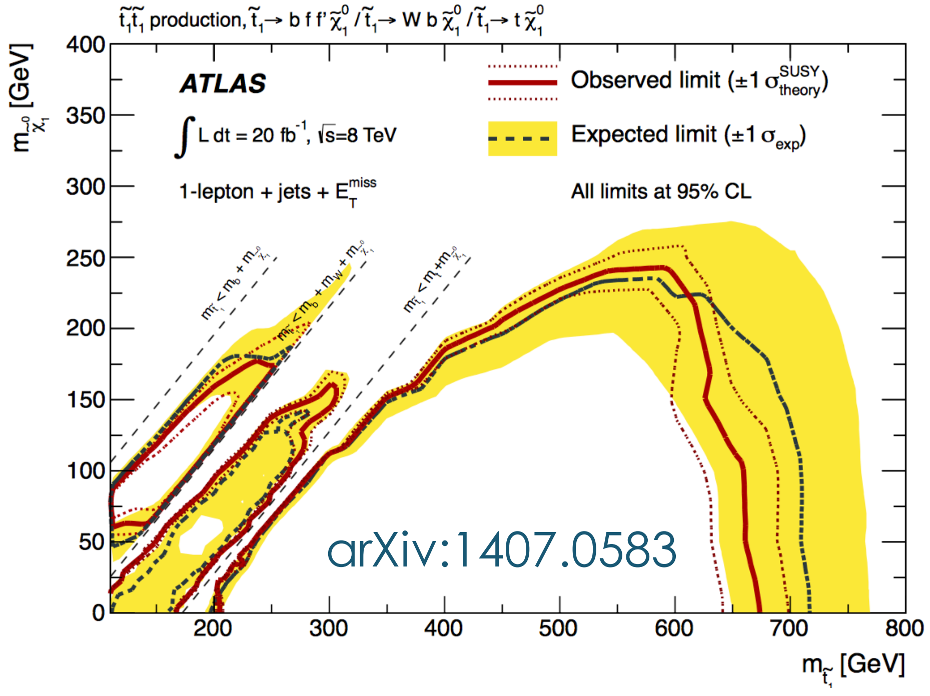
02 Natural NMSSM

The efficiencies or the upper bounds on SUSY signals in the database of the two packages are usually based on certain assumptions, which may not be applied to some parameter points encountered in our scan. For example, if

$$\tilde{t}_1 \to b\tilde{\chi}_1^+ \to bW^{+(*)}\tilde{\chi}_1^0, \quad \tilde{t}_1 \to t\tilde{\chi}_{2,3}^0 \to tX^{0(*)}\tilde{\chi}_1^0$$

there is absolutely no constraint ability.





02 Natural NMSSM

After analyzing the samples that survive the constraints, we find that they can be classified into four types

	Type I	Type II	Type III	Type IV
SM-like Higgs	h_1	h_2	h_2	h_2
Dark Matter	Bino-dominated	Bino-dominated	Singlino-dominated	Higgsino-dominated
R	52 %	54 %	71 %	65 %

The retaining ratio R is defined by R = N_{after}/N_{before} where N_{before} is the number of the samples that satisfy the constraints except for the LHC Run-I sparticles searches, and N_{after} is the number of the samples that further satisfy all the constraints.

02 Natural NMSSM

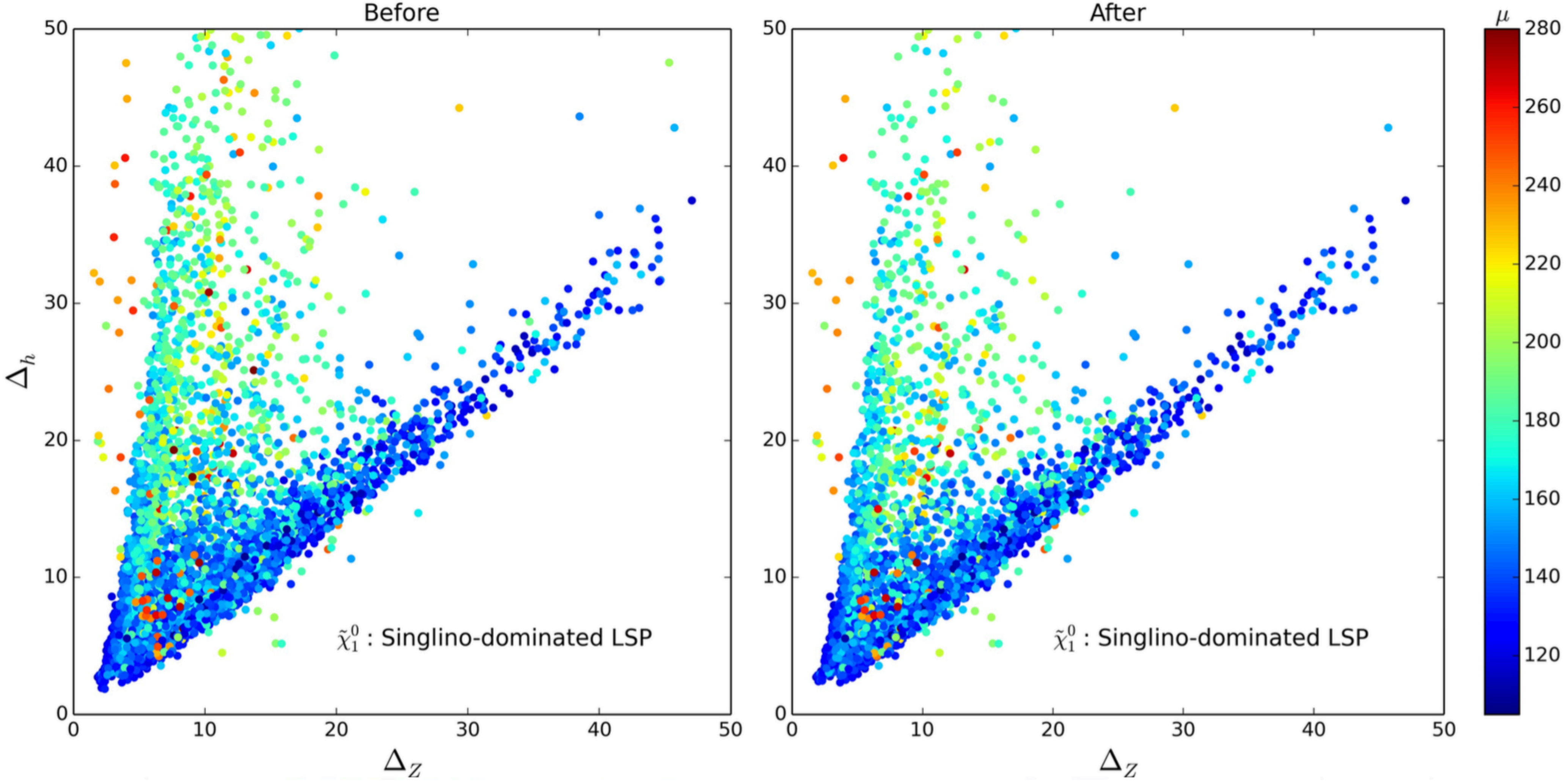
	Type I	Type II	Type III	Type IV
λ	$0. \sim 0.41$ $0. \sim 0.41$	$0. \sim 0.68$ $0. \sim 0.68$	$0. \sim 0.75$ $0. \sim 0.75$	$0.18 \sim 0.71$ $0.18 \sim 0.71$
κ	$0. \sim 0.66$ $0. \sim 0.66$	$0. \sim 0.52$ $0. \sim 0.52$	$0. \sim 0.27$ $0. \sim 0.27$	$0. \sim 0.51$ $0. \sim 0.51$
$\tan\beta$	$3 \sim 60$ $3 \sim 60$	$4 \sim 38$ $4 \sim 38$	$3 \sim 60$ $3 \sim 60$	$3 \sim 18$ $3 \sim 18$
$\mu(\mathrm{GeV})$	$150 \sim 400$ $180 \sim 400$	$115 \sim 370$ $115 \sim 370$	$105 \sim 315$ $105 \sim 315$	$110 \sim 175$ $110 \sim 165$
$M_{Q_3}(\mathrm{GeV})$	$390 \sim 2000$ $570 \sim 2000$	$550 \sim 2000$ $680 \sim 2000$	$450 \sim 2000$ $450 \sim 2000$	$450 \sim 2000$ $620 \sim 2000$
$M_{U_3}(\mathrm{GeV})$	$480 \sim 2000$ $610 \sim 2000$	$530 \sim 2000$ $680 \sim 2000$	$480 \sim 2000$ $580 \sim 2000$	$490 \sim 2000$ $560 \sim 2000$
$M_1(\mathrm{GeV})$	$40 \sim 350$ $40 \sim 350$	$20 \sim 175$ $40 \sim 175$	$45 \sim 500$ $45 \sim 500$	$120 \sim 500$ $120 \sim 500$

The direct search experiments scarcely change the ranges of the input parameters or equivalently speaking the NMSSM can naturally predict m_Z and m_h even after considering the direct search constraints from LHC Run-I.

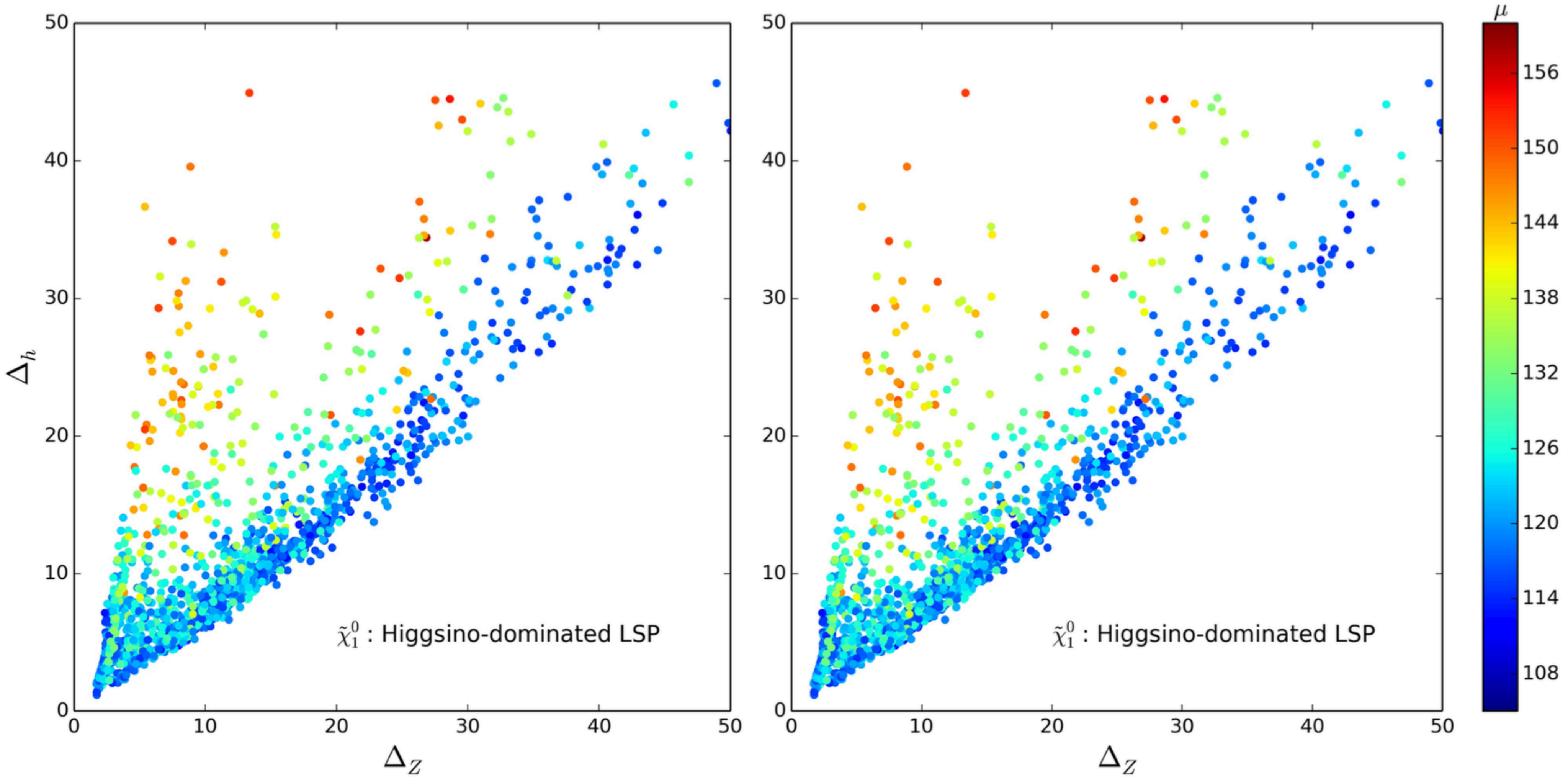
The reason is that the exclusion capability depends on the decay chain of the sparticle and the mass gap between the sparticle and its decay product.

Among the four types of points, the lowest fine-tuning comes from type III and type IV samples.

02 Natural NMSSM



02 Natural NMSSM



03 Higgsino-dominated DM

Key features of the NS scenario with DM
being Higgsino-dominated

03 Higgsino-dominated DM

Because the type IV samples were scarcely studied in previous literatures and also because they have similar (but different) phenomenology to that of the NS scenario in the MSSM, we in the following focus on this type of samples.

para	range	para	range	para	range
$\tan\beta$	$7 \sim 18$ $7 \sim 18$	$m_{\tilde{\chi}_1^0}$	$65 \sim 85$ $65 \sim 85$	A_κ	$-400 \sim -60$ $-400 \sim -60$
κ	$0.15 \sim 0.49$ $0.15 \sim 0.49$	$m_{\tilde{\chi}_2^0}$	$125 \sim 195$ $125 \sim 195$	m_{h_1}	$45 \sim 120$ $45 \sim 120$
λ	$0.28 \sim 0.68$ $0.28 \sim 0.68$	$m_{\tilde{\chi}_3^0}$	$150 \sim 260$ $150 \sim 260$	m_{A_1}	$120 \sim 350$ $120 \sim 350$
μ	$110 \sim 160$ $110 \sim 160$	$m_{\tilde{\chi}_1^\pm}$	$105 \sim 150$ $105 \sim 150$	$m_{H^\pm}$	$800 \sim 2000$ $800 \sim 2000$
A_t	$-5000 \sim 4500$ $-5000 \sim 4500$	$m_{\tilde{t}_1}$	$380 \sim 2050$ $500 \sim 2050$	$m_{\tilde{t}_2}$	$1050 \sim 3100$ $1100 \sim 3100$

$$\frac{2\kappa}{\lambda} \cong 1\sim1.5$$

$$\psi^0 = (-i\tilde{B}^0, -i\tilde{W}^0, \tilde{H}_d^0, \tilde{H}_u^0, \tilde{S}^0)$$

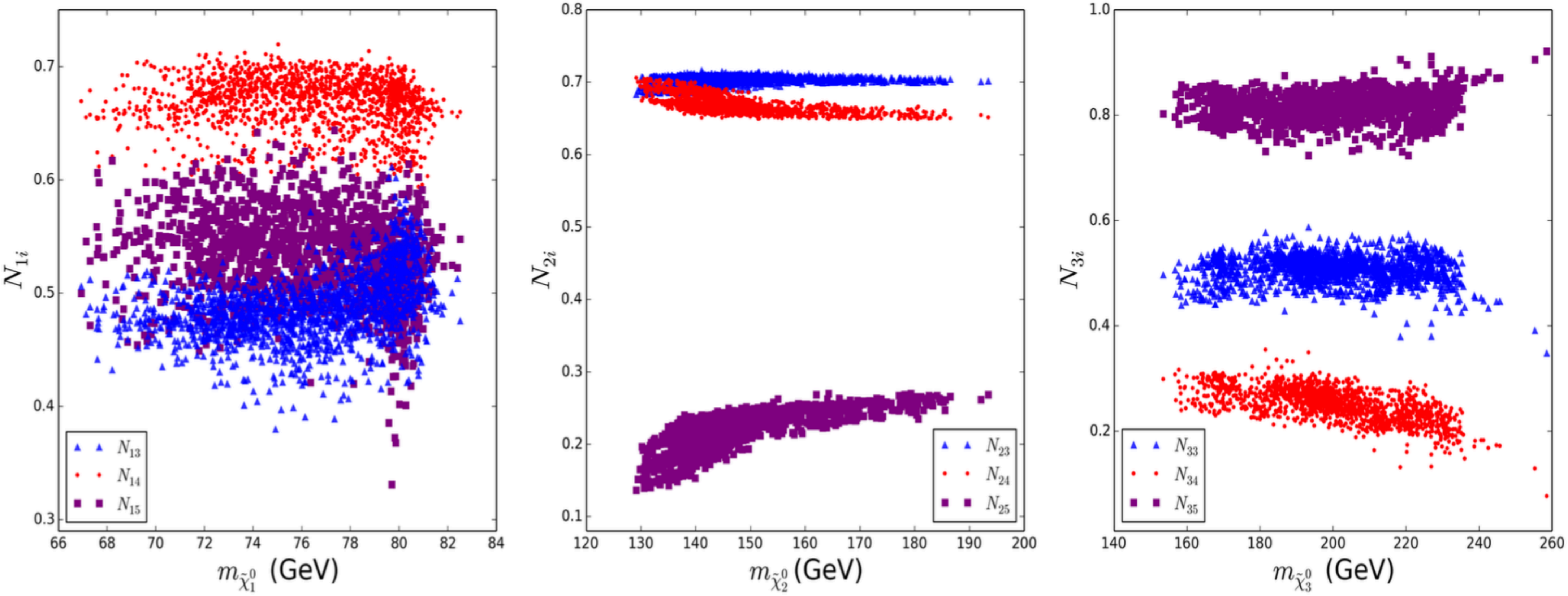
$$\mathcal{M} = \begin{pmatrix} M_1 & 0 & -\frac{g_1 v_d}{\sqrt{2}} & \frac{g_1 v_u}{\sqrt{2}} & 0 \\ & M_2 & \frac{g_2 v_d}{\sqrt{2}} & -\frac{g_2 v_u}{\sqrt{2}} & 0 \\ & & 0 & -\mu & -\lambda v_u \\ & & & 0 & -\lambda v_d \\ & & & & \frac{2\kappa}{\lambda}\mu \end{pmatrix}$$

$$N_{i3} : N_{i4} : N_{i5} \simeq \lambda(v_d\mu - v_u m_{\tilde{\chi}_i^0}) : \lambda(v_u\mu - v_d m_{\tilde{\chi}_i^0}) : (m^2_{\tilde{\chi}_i^0} - \mu^2)$$

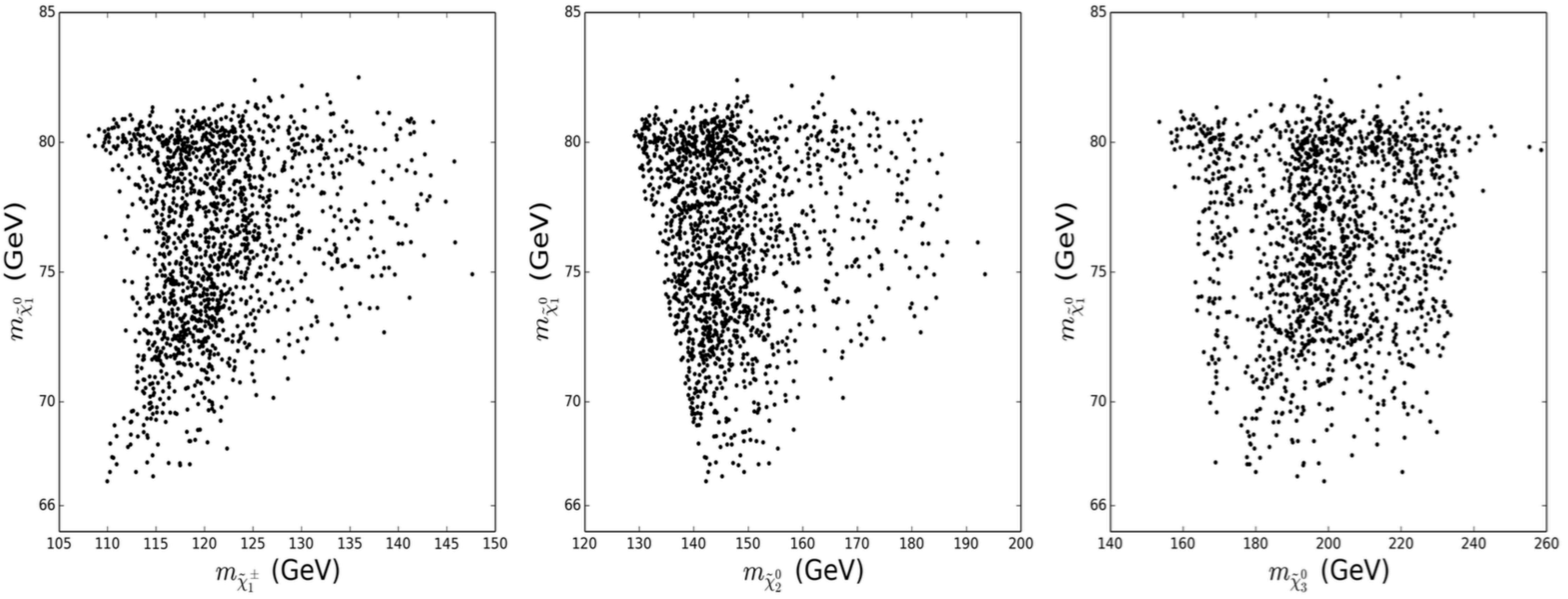
03 Higgsino-dominated DM

- The lightest two neutralinos $\tilde{\chi}_1^0$ and $\tilde{\chi}_2^0$ are Higgsino-dominated, and $\tilde{\chi}_3^0$ is Singlino-dominated. Their masses should satisfy following relations: $m_{\tilde{\chi}_1^0} < |\mu|$, $m_{\tilde{\chi}_2^0} \sim |\mu|$ and $m_{\tilde{\chi}_3^0} > |\frac{2\kappa}{\lambda}\mu| > |\mu|$.
- As far as $\tilde{\chi}_1^0$ is concerned, its largest component comes from $\tilde{H}_u^0$ field. If the splitting between $m_{\tilde{\chi}_1^0}$ and $|\mu|$ is significant, its Singlino component may also be quite large. The importance of the Singlino component is that it can dilute the couplings of $\tilde{\chi}_1^0$ with W and Z bosons, Higgs scalars and SM fermions, and consequently the density of $\tilde{\chi}_1^0$ can coincide with the DM density measured by WMAP and Planck experiments.
- The $\tilde{H}_u^0$ and $\tilde{H}_d^0$ components in $\tilde{\chi}_2^0$ should be comparable, and they are usually much larger than $\tilde{S}^0$ component of $\tilde{\chi}_2^0$, i.e. $|N_{23}| \sim |N_{24}| \gg |N_{25}|$.
- As for $\tilde{\chi}_3^0$, the relation $|N_{35}| > |N_{33}| > |N_{34}|$ usually holds.

03 Higgsino-dominated DM



04 Future detection



$$\mu \leq 160GeV, \text{ 30 GeV} \leq \Delta_{\pm} \leq \text{70 GeV and 50 GeV} \leq \Delta_0 \leq \text{110 GeV}.$$

Detectable at the upgraded LHC.

04

Future detection

Detection at 14 TeV LHC and future Dark Matter Direct Search

04 Future detection

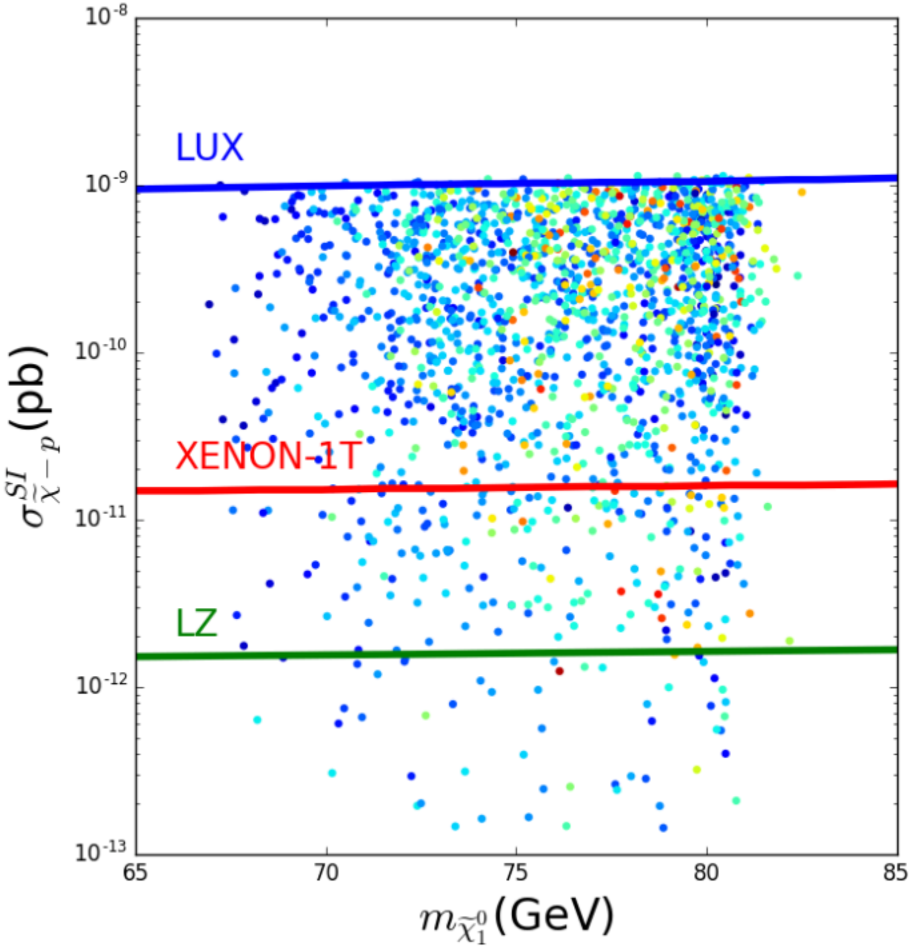
We investigate this issue by considering the neutralino and chargino associated production processes at 14 TeV LHC. For simplicity we adopt 4 benchmark points:

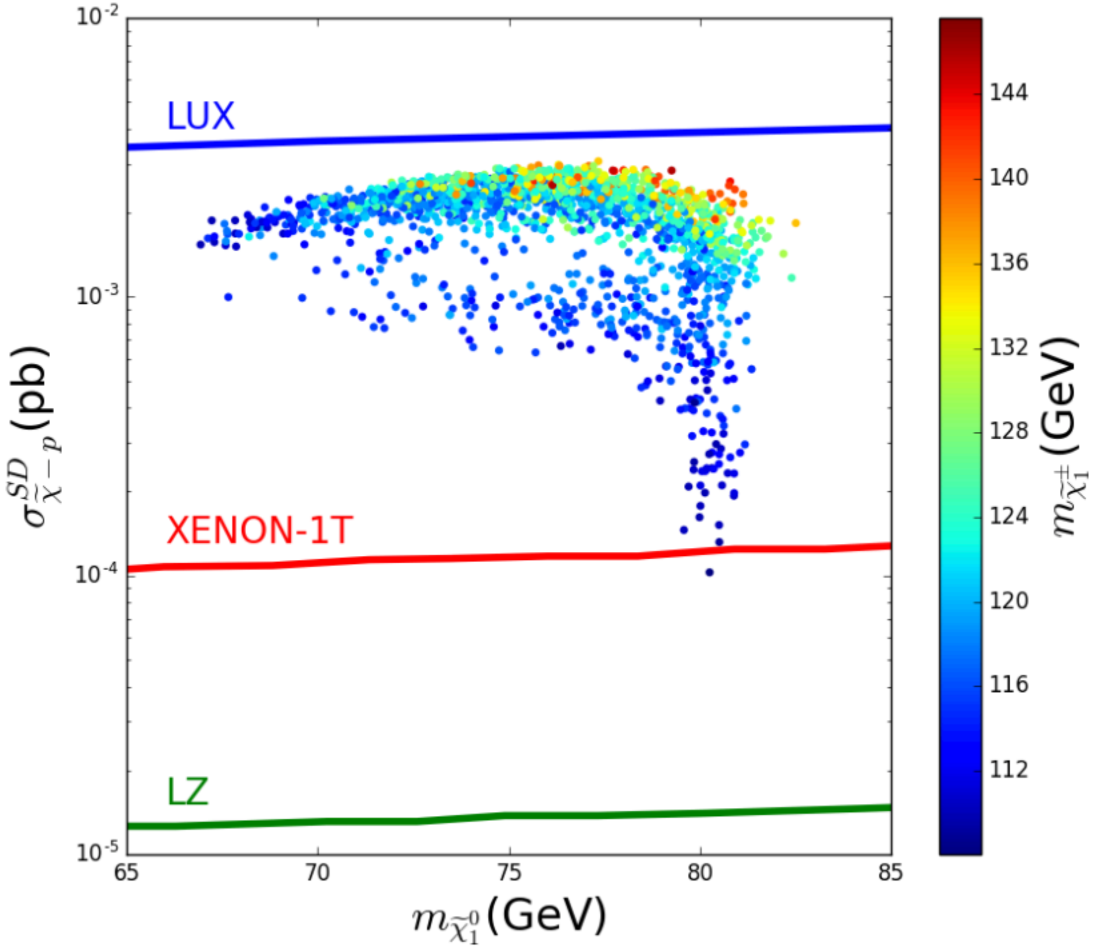
	$m_{\tilde{\chi}_1^0}$	$m_{\tilde{\chi}_2^0}$	$m_{\tilde{\chi}_3^0}$	$m_{\tilde{\chi}_1^\pm}$	$\mathrm{BR}(\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 Z^{(*)})$	$\mathrm{BR}(\tilde{\chi}_3^0 \to \tilde{\chi}_1^0 Z^{(*)})$	$\mathrm{BR}(\tilde{\chi}_1^\pm \to \tilde{\chi}_1^0 W^*)$
P1	80.2	129.1	158.4	108.0	94.2%	9.08%	100%
P2	67.3	142.6	180.0	110.2	94.7%	7.55%	100%
P3	82.5	165.5	219.2	135.9	98.1%	26.3%	100%
P4	74.9	193.4	220.6	147.6	96.2%	6.50%	100%

	30 fb^{-1}		300 fb^{-1}	
P1	$S(\mathrm{bin2}) = 2.09$	$S(\mathrm{bin1}) = 1.75$	$S(\mathrm{bin2}) = 4.59$	$S(\mathrm{bin1}) = 2.54$
P2	$S(\mathrm{bin6}) = 2.88$	$S(\mathrm{bin5}) = 1.44$	$S(\mathrm{bin6}) = 5.58$	$S(\mathrm{bin2}) = 2.96$
P3	$S(\mathrm{bin6}) = 1.71$	$S(\mathrm{bin11}) = 1.01$	$S(\mathrm{bin6}) = 3.31$	$S(\mathrm{bin2}) = 1.82$
P4	$S(\mathrm{bin14}) = 0.32$	$S(\mathrm{bin15}) = 0.21$	$S(\mathrm{bin16}) = 0.42$	$S(\mathrm{bin14}) = 0.34$

$$S = s/\sqrt{b + (\epsilon b)^2} \qquad \epsilon = 10\%$$

04 Future detection





Strong cancelation among the contributions induced by different CP-even Higgs bosons

$$\sigma^{(N)}_{\rm SD} = C^{(N)} \cdot 10^{-38}\ {\rm cm}^2\ \left(N_{13}^2 - N_{14}^2\right)^2$$

$$N_{13}^2 - N_{14}^2 = \frac{\left[1-(m_\chi/\mu)^2\right]\left(1-N_{15}^2\right)\cos 2\beta}{1+(m_\chi/\mu)^2 - 2\,(m_\chi/\mu)\sin 2\beta}$$

Conclusions

Natural NMSSM

The fine tuning of the NMSSM is scarcely affected by the direct searches for SUSY at LHC Run I, and it can still predict Z boson mass and the SM-like Higgs boson mass in a natural way.

Higgsino-dominated DM

The natural SUSY scenario with Higgsino-dominated DM in NMSSM has some special features, such as the component and mass splitting of the neutralino-chargino sector.

Future detection

The upcoming LHC experiments and DM matter direct search experiments can give strong constraints on the natural SUSY scenario with Higgsino-dominated DM in NMSSM .

THANK YOU!

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Jin Min Yang's Group, Institute of Theoretical Physics, Chinese Academy of Sciences,
Based on arXiv:1606.04416, JHEP08(2016)037
In collaboration with Junjie Cao, Yangle He, Liangliang Shang, Wei Su

THANK YOU!

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04+ New Data

papers

Short Title of Paper	Date	√s (TeV)	L (fb^{-1})	Document
1-2 taus + Etmiss NEW	07/2016	13	3.2	1607.05979
di-photon + MET NEW	6/2016	13	3.2	1606.09150
2b + MET NEW	6/2016	13	3.2	1606.08772
LLP (pixel+Tile) NEW	6/2016	13	3.2	1606.05129
1L stop	6/2016	13	3.2	1606.03903
multi b-jets	5/2016	13	3.2	1605.09318
1L 2-6 jets	5/2016	13	3.2	1605.04285
0L 2-6 jets	5/2016	13	3.2	1605.03814
monojet (compressed squarks) NEW	4/2016	13	3.2	1604.07773
LLP with pixel dE/dx	4/2016	13	3.2	1604.04520
2 same sign or 3 leptons	2/2016	13	3.2	1602.09058
0L 7-10 jets	2/2016	13	3.2	1602.06194

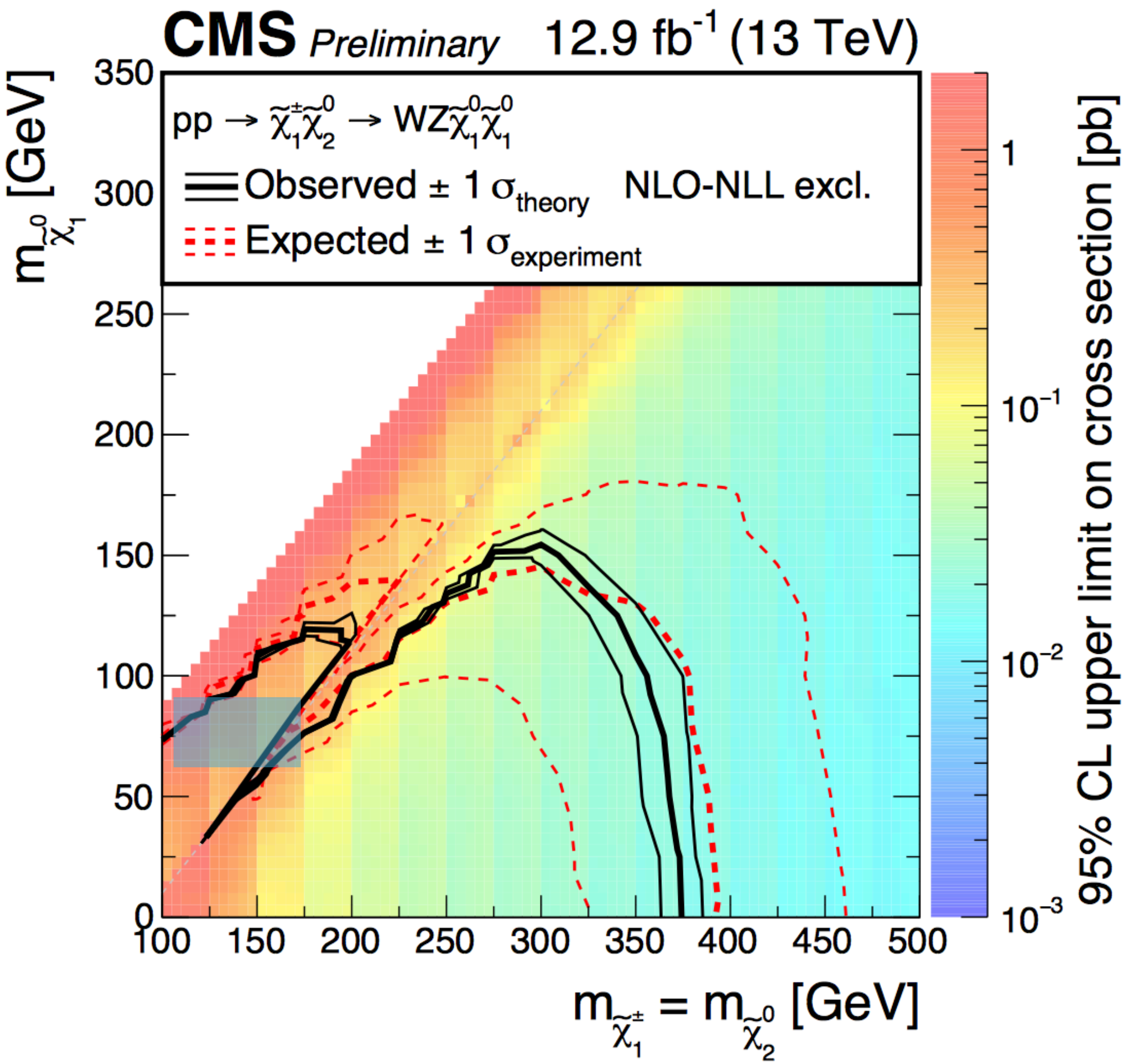
ATLAS have not published their 13 TeV 3 lepton + MET or 2 lepton + MET result.

CMS published the electroweakino search results, but ...

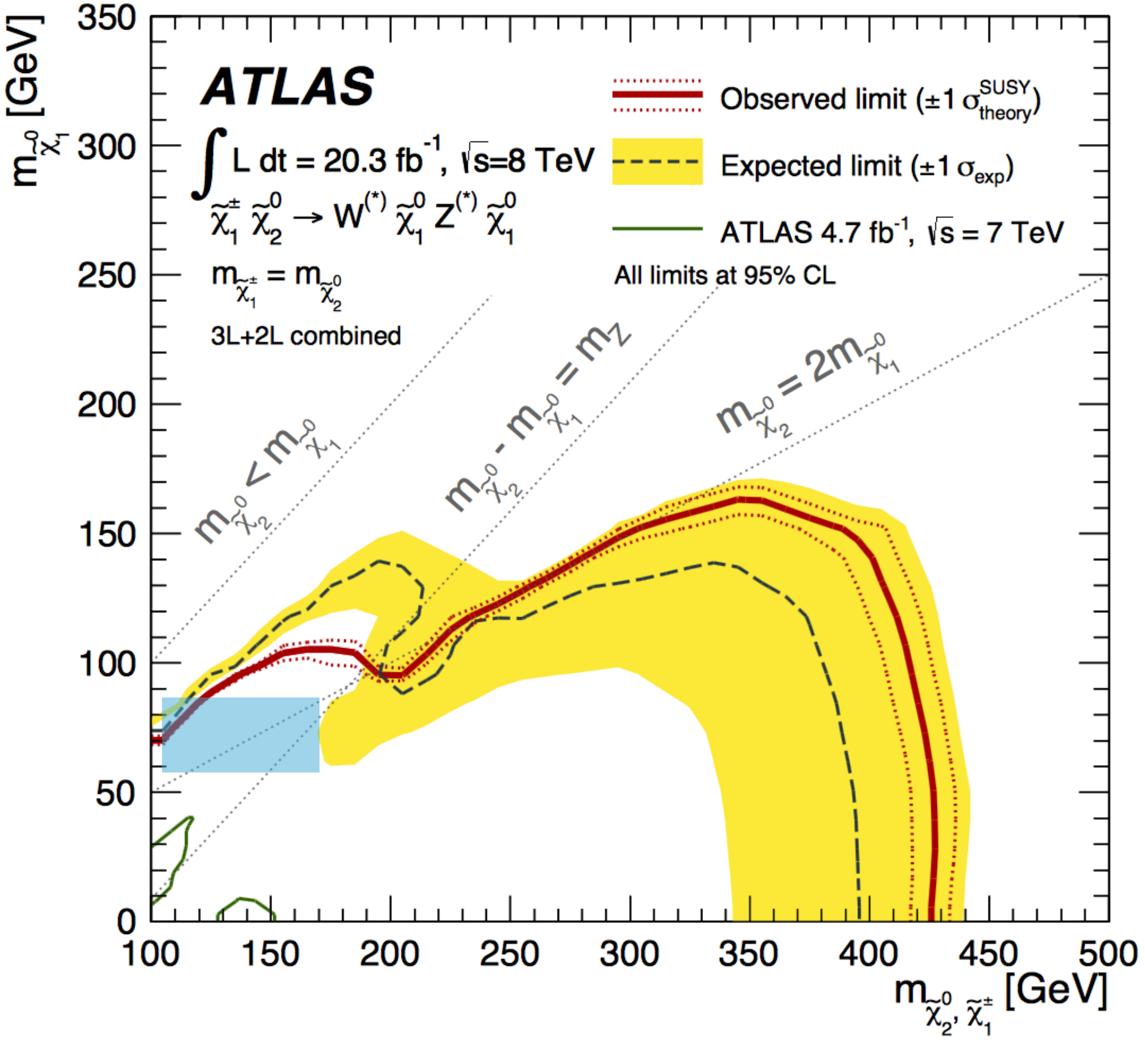
conference notes

Short Title of preliminary conference note/paper	*Date*	*√s (TeV)*	*L (fb^{-1})*	*D*
0L 2-6 jets (squark/gluinos)	8/2016	13	13.3	ATLAS-CONF-2016-078
1L 2-6 jets (squark/gluinos)	8/2016	13	14.8	ATLAS-CONF-2016-054
SS/3L + jets (squarks/gluinos)	8/2016	13	13.2	ATLAS-CONF-2016-037
0/1L + 3b jets (squarks/gluinos)	8/2016	13	14.8	ATLAS-CONF-2016-052
photon + jets	8/2016	13	13.3	ATLAS-CONF-2016-066
stop 0L	8/2016	13	13.3	ATLAS-CONF-2016-077
stop 1L	8/2016	13	13.3	ATLAS-CONF-2016-050
stop 2L	8/2016	13	13.3	ATLAS-CONF-2016-076
stop2 (3L)	8/2016	13	13.3	ATLAS-CONF-2016-038
stop stau	8/2016	13	13.3	ATLAS-CONF-2016-048
4 lepton (RPV EWK)	8/2016	13	13.3	ATLAS-CONF-2016-075
multijet (RPV)	8/2016	13	14.8	ATLAS-CONF-2016-057
Stop to bs (RPV)	8/2016	13	15.6	ATLAS-CONF-2016-084
2L stop	3/2016	13	3.2	ATLAS-CONF-2016-009
2L Z+jets+MET	12/2015	13	3.2	ATLAS-CONF-2015-082

04+ New Data

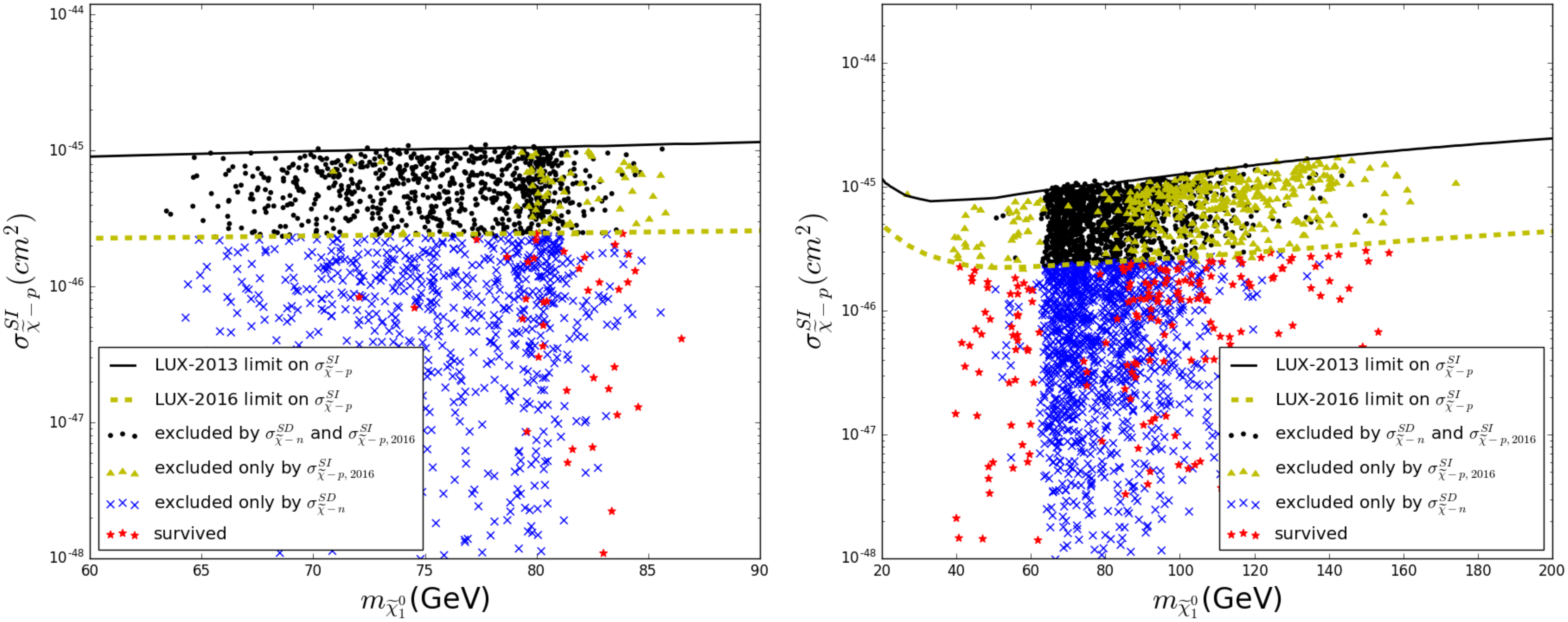


CMS Preliminary
12.9 fb-1 (13 TeV)
pp → χ̃±1χ̃02 → WZχ̃01χ̃01
Observed ± 1 σtheory
NLO-NLL excl.
Expected ± 1 σexperiment
95% CL upper limit on cross section [pb]
m χ̃01 [GeV]
m χ̃±1 = m χ̃02 [GeV]



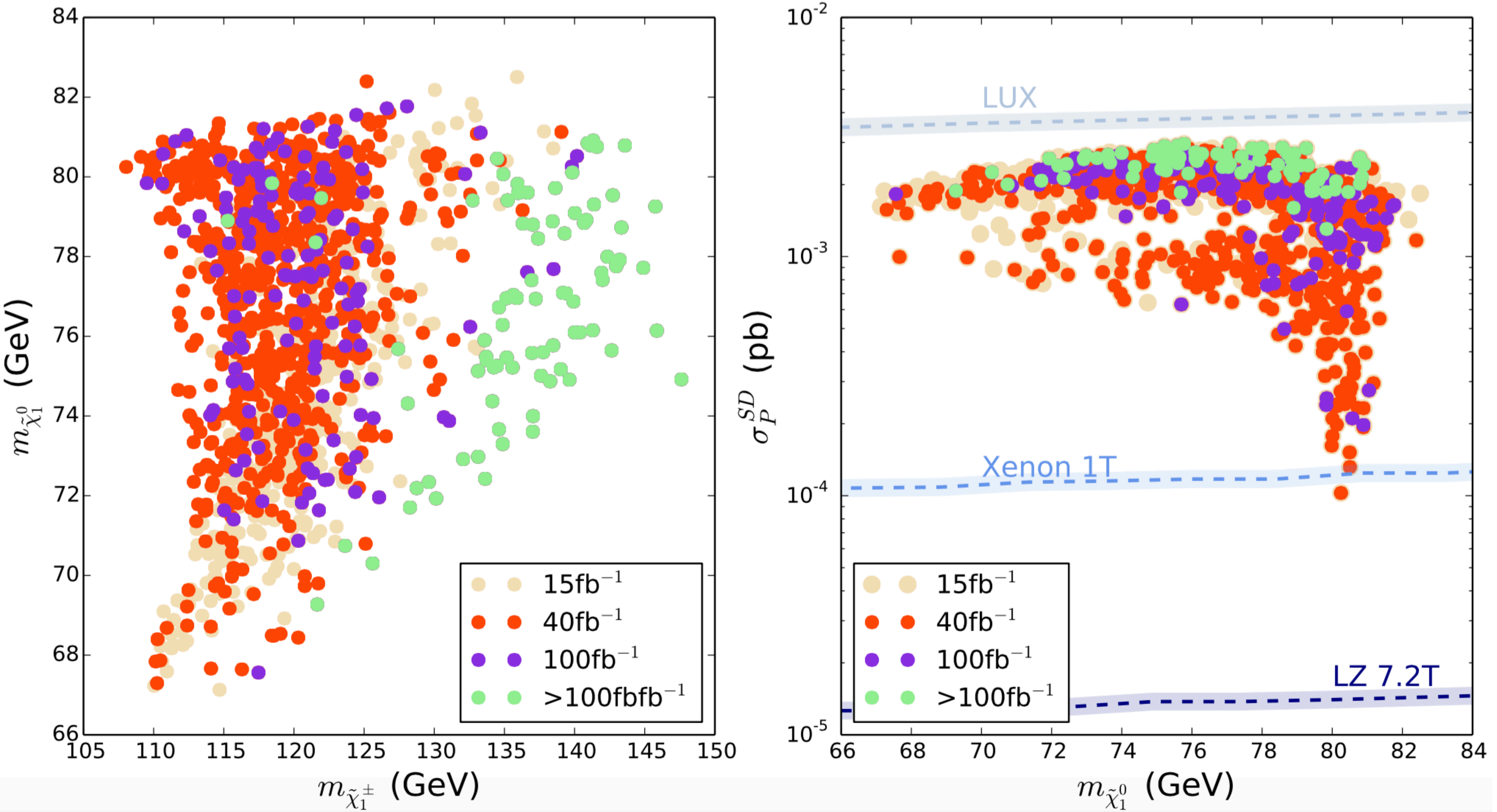
ATLAS
∫L dt = 20.3 fb-1, √s=8 TeV
χ̃±1 χ̃02 → W(*) χ̃01 Z(*) χ̃01
m χ̃±1 = m χ̃02
3L+2L combined
Observed limit (±1 σSUSYtheory)
Expected limit (±1 σexp)
ATLAS 4.7 fb-1, √s = 7 TeV
All limits at 95% CL
m χ̃02 < m χ̃01
m χ̃02 - m χ̃01 = mZ
m χ̃02 = 2m χ̃01
m χ̃01 [GeV]
m χ̃02, χ̃±1 [GeV]

04+ New Data

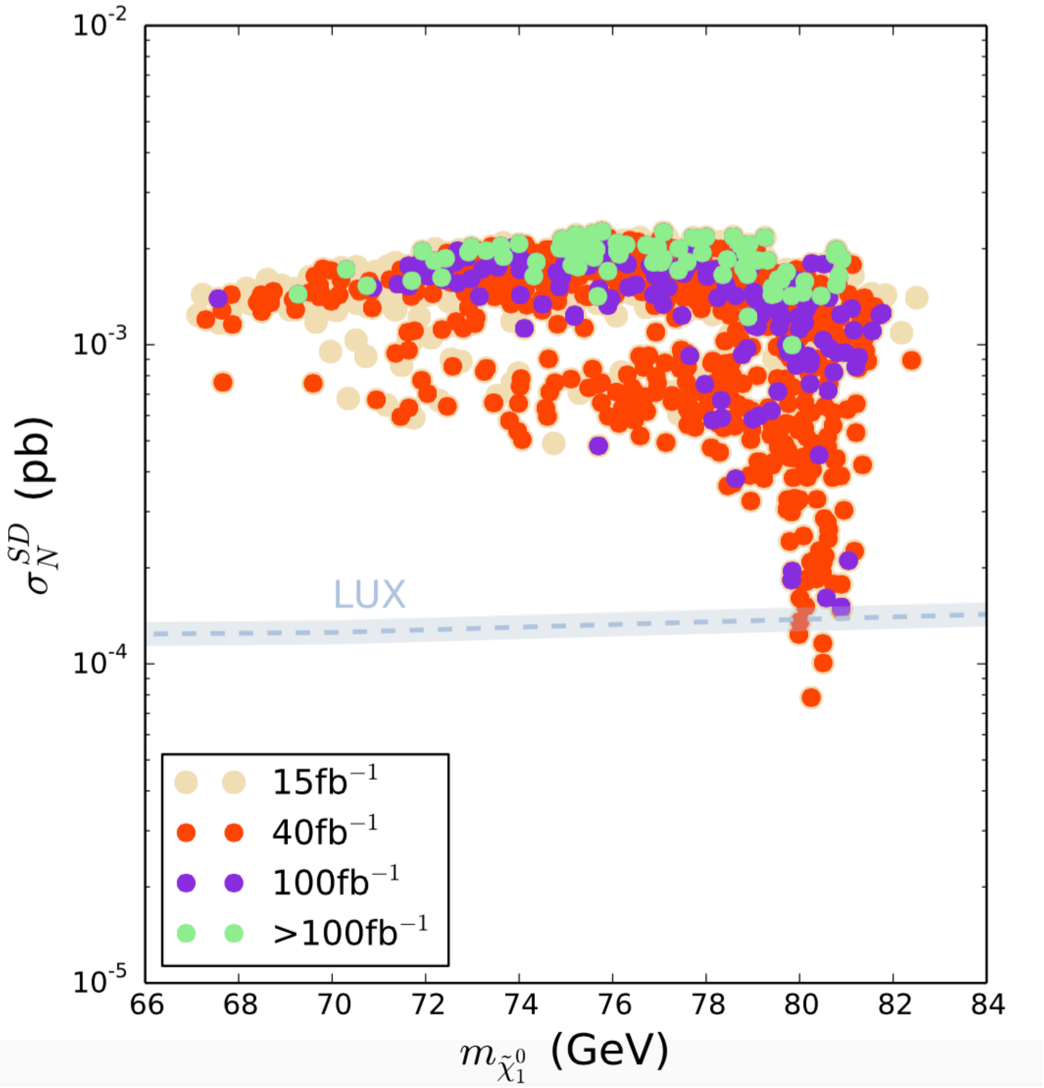


10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
$\sigma^{SI}_{\tilde{\chi}-p}(cm^2)$
60
65
70
75
80
85
90
$m_{\tilde{\chi}_1^0}$(GeV)
LUX-2013 limit on $\sigma^{SI}_{\tilde{\chi}-p}$
LUX-2016 limit on $\sigma^{SI}_{\tilde{\chi}-p}$
excluded by $\sigma^{SD}_{\tilde{\chi}-n}$ and $\sigma^{SI}_{\tilde{\chi}-p,2016}$
excluded only by $\sigma^{SI}_{\tilde{\chi}-p,2016}$
excluded only by $\sigma^{SD}_{\tilde{\chi}-n}$
survived
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
$\sigma^{SI}_{\tilde{\chi}-p}(cm^2)$
20
40
60
80
100
120
140
160
180
200
$m_{\tilde{\chi}_1^0}$(GeV)
LUX-2013 limit on $\sigma^{SI}_{\tilde{\chi}-p}$
LUX-2016 limit on $\sigma^{SI}_{\tilde{\chi}-p}$
excluded by $\sigma^{SD}_{\tilde{\chi}-n}$ and $\sigma^{SI}_{\tilde{\chi}-p,2016}$
excluded only by $\sigma^{SI}_{\tilde{\chi}-p,2016}$
excluded only by $\sigma^{SD}_{\tilde{\chi}-n}$
survived

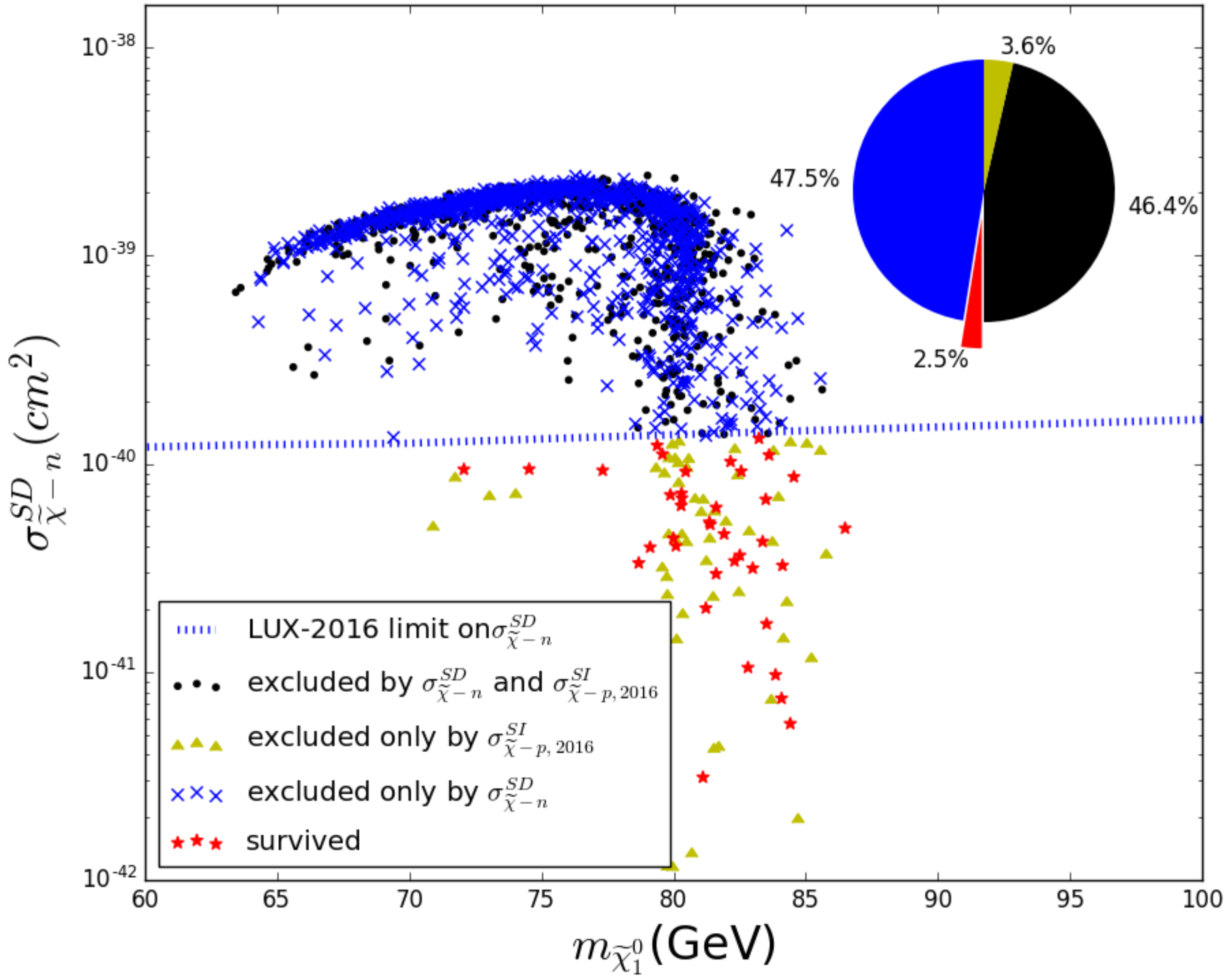
04 Future detection



05 Backup

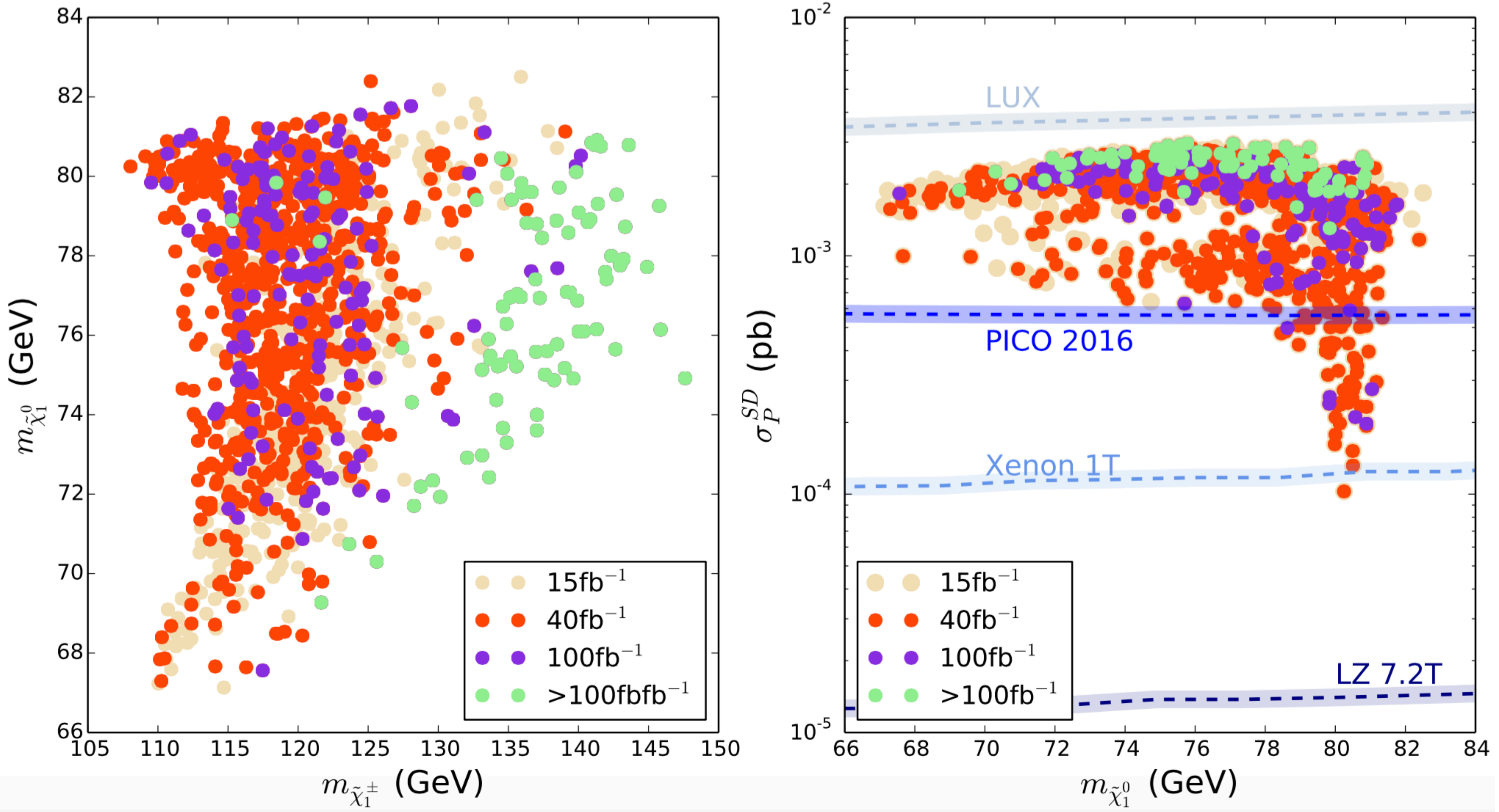


10^{-2}
10^{-3}
10^{-4}
10^{-5}
σ_N^{SD} (pb)
LUX
15fb^{-1}
40fb^{-1}
100fb^{-1}
$>100\text{fb}^{-1}$
66 68 70 72 74 76 78 80 82 84
$m_{\tilde{\chi}_1^0}$ (GeV)



10^{-38}
10^{-39}
10^{-40}
10^{-41}
10^{-42}
$\sigma_{\tilde{\chi}-n}^{SD}\,(cm^2)$
3.6%
47.5%
46.4%
2.5%
LUX-2016 limit on $\sigma_{\tilde{\chi}-n}^{SD}$
excluded by $\sigma_{\tilde{\chi}-n}^{SD}$ and $\sigma_{\tilde{\chi}-p,\,2016}^{SI}$
excluded only by $\sigma_{\tilde{\chi}-p,\,2016}^{SI}$
excluded only by $\sigma_{\tilde{\chi}-n}^{SD}$
survived
60 65 70 75 80 85 90 95 100
$m_{\tilde{\chi}_1^0}$ (GeV)

05 Backup



84
82
80
78
76
74
72
70
68
66
105 110 115 120 125 130 135 140 145 150
$m_{\tilde{\chi}_1^0}$ (GeV)
$m_{\tilde{\chi}_1^\pm}$ (GeV)
$15fb^{-1}$
$40fb^{-1}$
$100fb^{-1}$
$>100fbfb^{-1}$
10^{-2}
10^{-3}
10^{-4}
10^{-5}
66 68 70 72 74 76 78 80 82 84
σ_P^{SD} (pb)
$m_{\tilde{\chi}_1^0}$ (GeV)
LUX
PICO 2016
Xenon 1T
LZ 7.2T
$15fb^{-1}$
$40fb^{-1}$
$100fb^{-1}$
$>100fb^{-1}$

05 Backup

SR0τa bin	m_{SFOS}	m_{T}	$E_{\mathrm{T}}^{\mathrm{miss}}$	3ℓ Z veto
1	12–40	0–80	50–90	no
2	12–40	0–80	>90	no
3	12–40	>80	50–75	no
4	12–40	>80	>75	no
5	40–60	0–80	50–75	yes
6	40–60	0–80	>75	no
7	40–60	>80	50–135	no
8	40–60	>80	>135	no
9	60–81.2	0–80	50–75	ye
10	60–81.2	>80	50–75	n
11	60–81.2	0–110	>75	n
12	60–81.2	>110	>75	n
13	81.2–101.2	0–110	50–90	ye
14	81.2–101.2	0–110	>90	n
15	81.2–101.2	>110	50–135	n
16	81.2–101.2	>110	>135	n
17	>101.2	0–180	50–210	n
18	>101.2	>180	50–210	n
19	>101.2	0–120	>210	n
20	>101.2	>120	>210	n

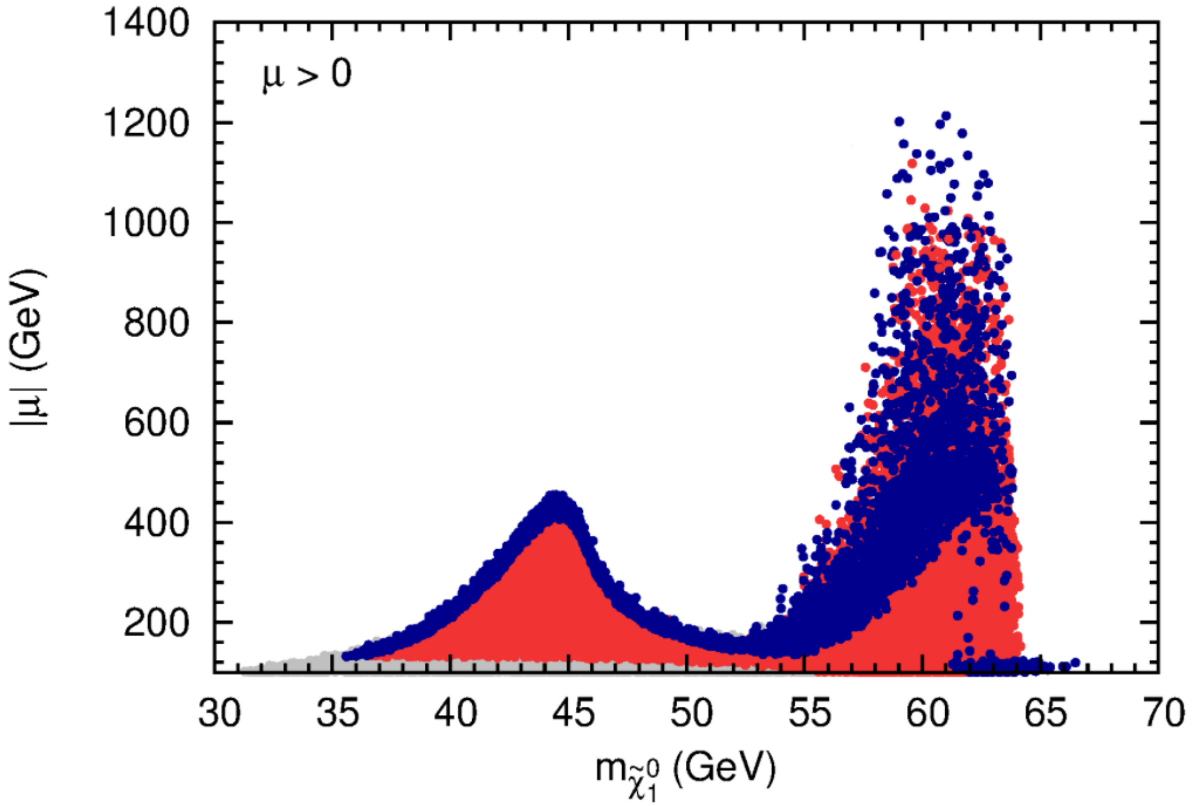
One of the reason may be that the signal region of ATLAS is focus on small m_{SFOS}/m_{ll} and m_T.

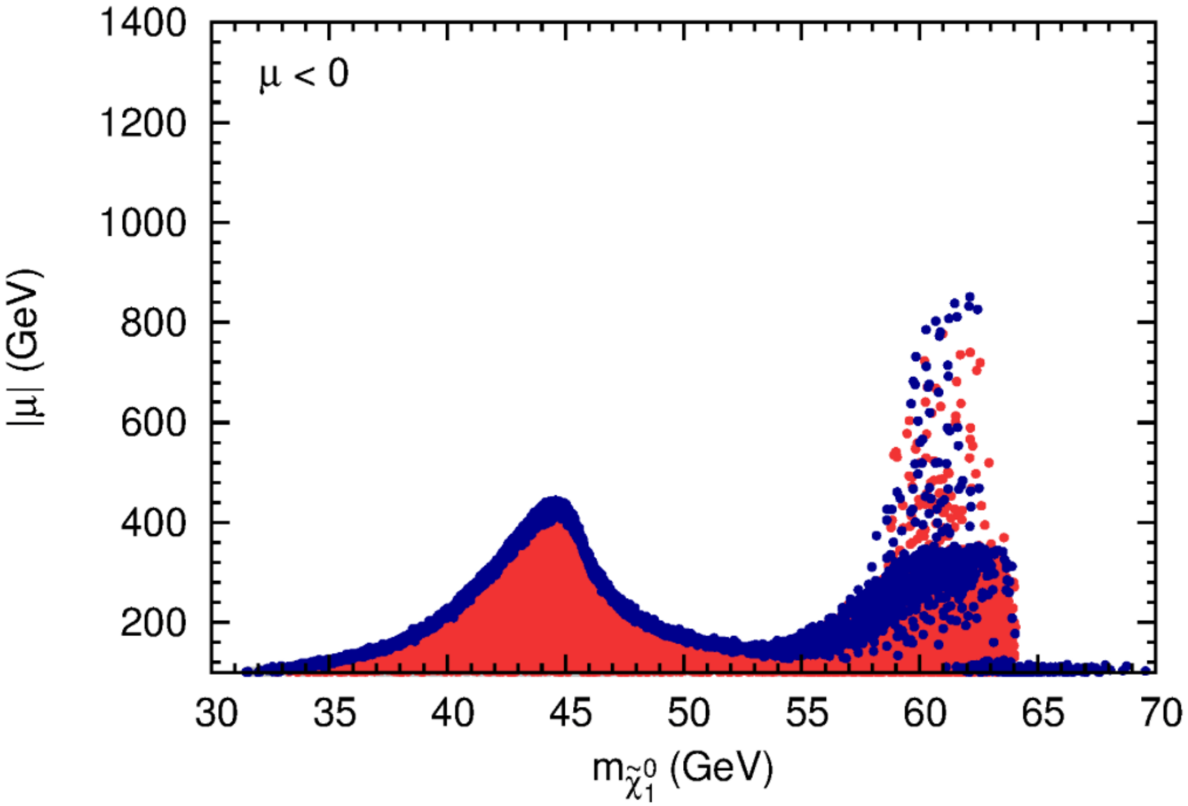
Table 1: Search regions for events with three e or μ that form at least one OSSF pair.

M_{T} (GeV)	$E_{\mathrm{T}}^{\mathrm{miss}}$ (GeV)	$M_{\ell\ell} < 75\,\mathrm{GeV}$	$75\,\mathrm{GeV} \leq M_{\ell\ell} < 105\,\mathrm{GeV}$	$M_{\ell\ell} \geq 105\,\mathrm{GeV}$
0 – 120	50 – 100	SR A01	SR A13	SR A25
	100 – 150	SR A02	SR A14	SR A26
	150 – 200	SR A03	SR A15	SR A27
	>200	SR A04	SR A16	SR A28
120 – 160	50 – 100	SR A05	SR A17	SR A29
	100 – 150	SR A06	SR A18	SR A30
	150 – 200	SR A07	SR A19	SR A31
	>200	SR A08	SR A20	SR A32
>160	50 – 100	SR A09	SR A21	SR A33
	100 – 150	SR A10	SR A22	SR A34
	150 – 200	SR A11	SR A23	SR A35
	>200	SR A12	SR A24	SR A36

05 Backup

arXiv.org > hep-ph > arXiv:1410.5730





01 Introduction

Other advantages of NMSSM:

- The constraints on sparticles in NMSSM is much weaker than in MSSM, if the DM is Singlino-dominated. For example, the branching ratio of the golden channel $\tilde{t}_1 \to t\tilde{\chi}_1$ in the LHC search for a moderately light stop is highly suppressed by

$$\tilde{t}_1 \to b\tilde{\chi}_1^+ \to bW^{+(*)}\tilde{\chi}_1^0, \quad \tilde{t}_1 \to t\tilde{\chi}_{2,3}^0 \to tX^{0(*)}\tilde{\chi}_1^0$$

02 Natural NMSSM

The Next-to-MSSM extends the MSSM by one gauge singlet superfield,

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

where W_F is the superpotential of the MSSM without the μ-term, and the dimensionless parameters λ, κ describe the interactions among the Higgs superfields.

The Higgs potential of the NMSSM is given by the usual F-term and D-term of the superfields as well as the soft breaking terms, which are given by

$$V_{\text{NMSSM}}^{\text{soft}} = m_{H_u}^2 |H_u|^2 + m_{H_d}^2 |H_d|^2 + m_S^2 |S|^2 + (\lambda A_\lambda S H_u \cdot H_d + \frac{1}{3}\kappa A_\kappa S^3 + h.c.)$$

with H_u, H_d and S representing the scalar component fields of $\widehat{H}_u$, $\widehat{H}_d$ and $\hat{S}$ respectively.

Additional to the MSSM, the input parameters are

$$\lambda,\ \kappa,\ (m_{H_u}^2,\ m_{H_d}^2,\ m_S^2,\ A_\lambda),\ A_\kappa$$
$$(\tan\beta,\ \mu,\ M_A)$$

02 Natural NMSSM

The NMSSM predicts five neutralinos, which are the mixtures of the fields Bino $\tilde{B}^0$, Wino $\tilde{W}^0$, Higgsinos $\tilde{H}^0$and Singlino $\tilde{S}^0$. In the basis $\psi^0 = (-i\tilde{B}^0, -i\tilde{W}^0, \tilde{H}_d^0, \tilde{H}_u^0, \tilde{S}^0)$, the neutralino mass matrix is given by

$$\mathcal{M} = \begin{pmatrix} M_1 & 0 & -\frac{g_1 v_d}{\sqrt{2}} & \frac{g_1 v_u}{\sqrt{2}} & 0 \\ & M_2 & \frac{g_2 v_d}{\sqrt{2}} & -\frac{g_2 v_u}{\sqrt{2}} & 0 \\ & & 0 & -\mu & -\lambda v_u \\ & & & 0 & -\lambda v_d \\ & & & & \frac{2\kappa}{\lambda}\mu \end{pmatrix}$$

And the mass eigenstates are denoted by

$$\tilde{\chi}_i^0 = N_{i1}\tilde{B}^0 + N_{i2}\tilde{W}^0 + N_{i3}\tilde{H}_d^0 + N_{i4}\tilde{H}_u^0 + N_{i5}\tilde{S}^0$$

03 Higgsino-dominated DM

Because the type IV samples were scarcely studied in previous literatures and also because they have similar (but different) phenomenology to that of the NS scenario in the MSSM, we in the following focus on this type of samples.

In order to make the essential features of the samples clear, we only consider those that satisfy additionally the condition $M_1, M_2, m_{\tilde{l}} \geq 300$ GeV.

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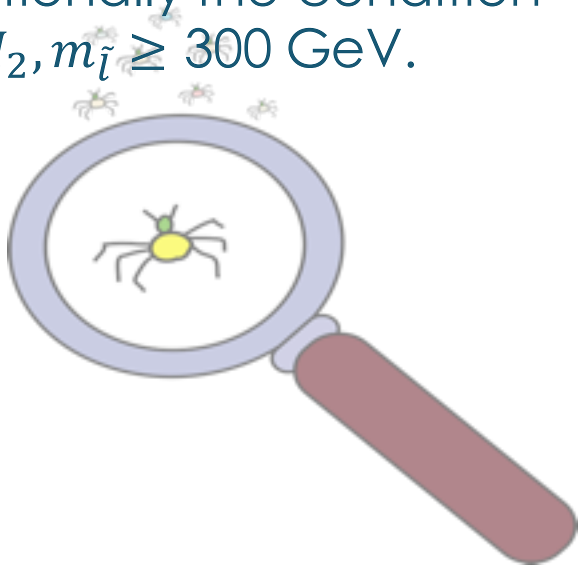
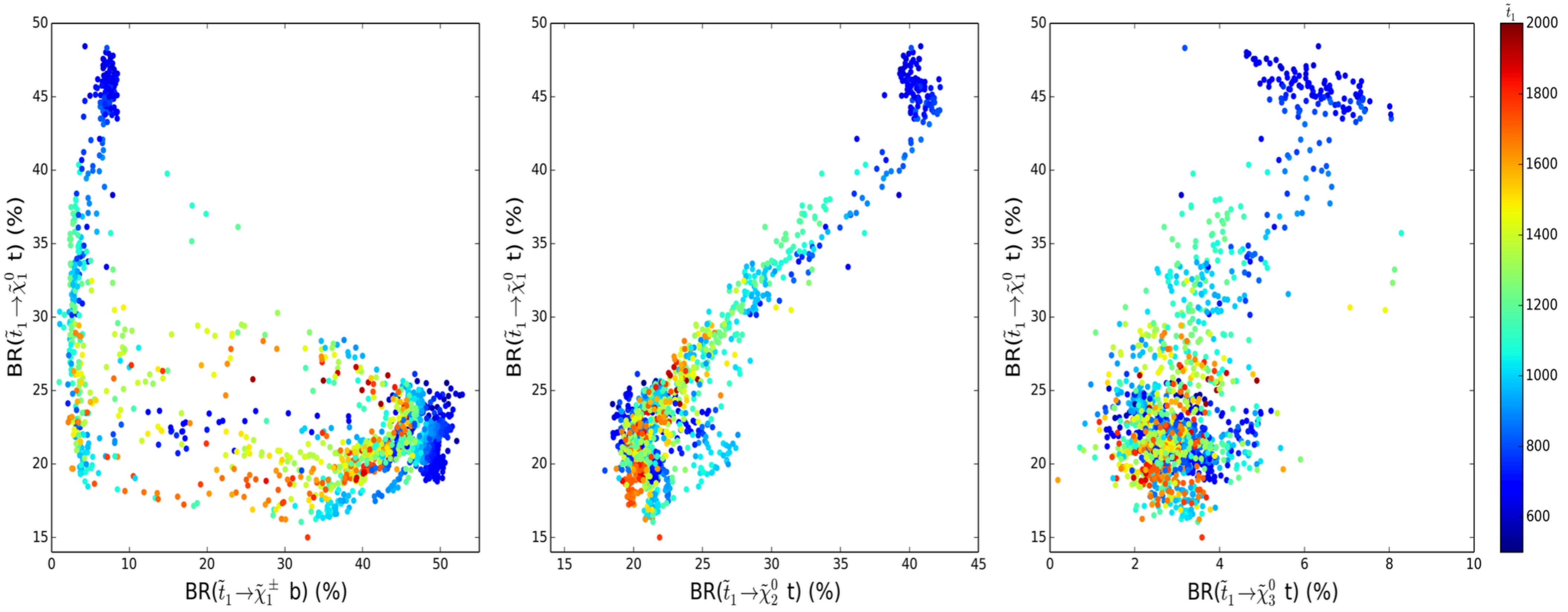


$\frac{2\kappa}{\lambda} \cong 1 \sim 1.5$

$\frac{2\kappa}{\lambda} \cong 1 \sim 1.5$

03 Higgsino-dominated DM



If $\tilde{t}_1$ is $\tilde{t}_R$ dominated and meanwhile $|N_{14}| \simeq |N_{24}|$,
$Br(\tilde{t}_1 \to \tilde{\chi}_1^+ b) : Br(\tilde{t}_1 \to \tilde{\chi}_1^0 t) : Br(\tilde{t}_1 \to \tilde{\chi}_2^0 t) \simeq 2:1:1$

On the other hand, if $\tilde{t}_1$ is $\tilde{t}_L$ dominated,
$Br(\tilde{t}_1 \to \tilde{\chi}_1^0 t) \simeq Br(\tilde{t}_1 \to \tilde{\chi}_2^0 t)$

03 Higgsino-dominated DM

$$\sigma_{\rm SD}^{(N)} = C^{(N)} \cdot 10^{-38}\ {\rm cm}^2\ \left(N_{13}^2 - N_{14}^2\right)^2$$

$$N_{13}^2 - N_{14}^2 = \frac{\left[1 - (m_\chi/\mu)^2\right]\left(1 - N_{15}^2\right)\cos 2\beta}{1 + (m_\chi/\mu)^2 - 2\,(m_\chi/\mu)\sin 2\beta}$$