TESTING THE LIGHT DARK MATTER SCENARIO OF THE MSSM AT THE 14 TEV LHC

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1 INTRODUCTION

- How light can neutralino dark matter can be after the $\sqrt{s} = 7 + 8$ TeV run data?

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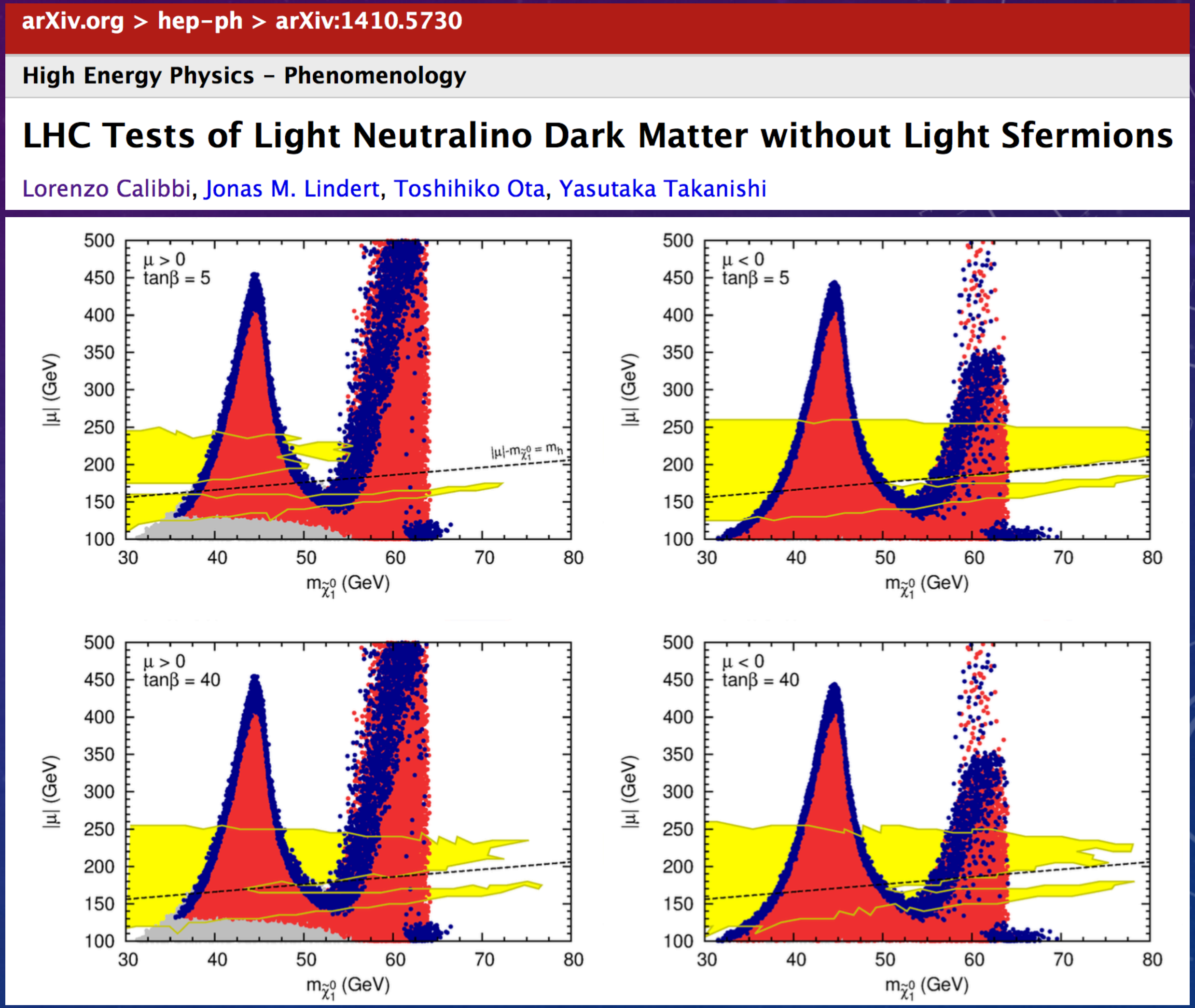
- How light can neutralino dark matter can be after the $\sqrt{s} =$ 14 TeV run data?

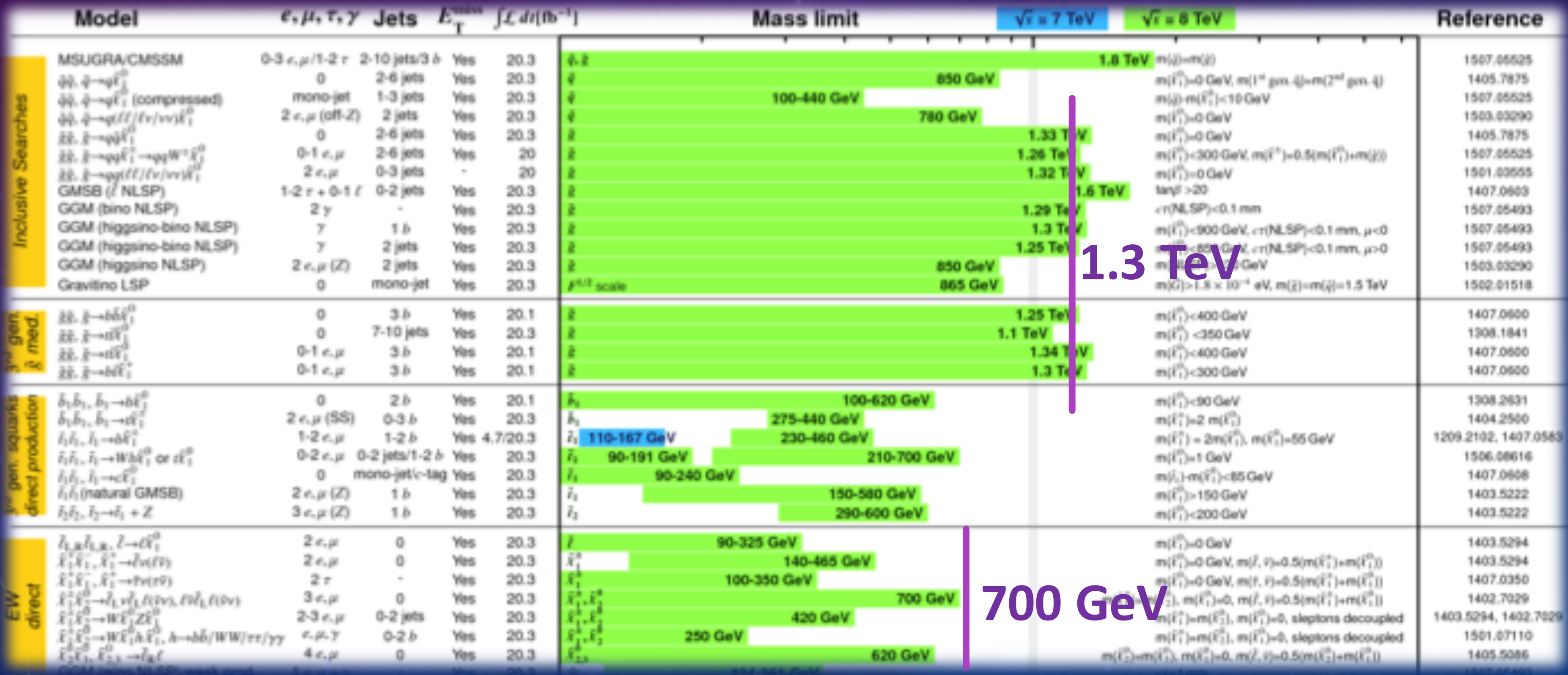


CONTENT

- 1 Introduction
- 2 The light dark matter scenario of the MSSM
- 3 Numerical scan and constraints
- 4 Future testing of light dark matter scenario
- 5 Conclusion

1 INTRODUCTION

- The lack of evidence for SUSY particles at the first phase of LHC has given stringent lower limits on the their mass:



1 INTRODUCTION

- Searches have been started at the new round of experiments at higher energies (13 TeV). It is widely expected that much heavier sparticles will be explored very soon, which will be helpful to improve our understanding on some fundamental questions about nature.
- Obviously, discussing the potential of the future LHC experiments to test the MSSM is an important task for both theorists and experimentalists.
- In some fundamental theories such as the minimal supergravity theories, the EW sector tends to be significantly lighter than the colored sector.

1 INTRODUCTION

- The light EW sector can
  - be compatible with the constraints from low energy processes as well as from the direct searches for the sparticles at the colliders,
  - help to solve some experimental anomalies such as the discrepancy of the measured muon anomalous magnetic moment from its SM prediction,
  - explain the Galactic Center γ-ray Excess observed by the Fermi-LAT,
  - meet the minimal tree-level requirement posed by naturalness.

1 INTRODUCTION

- However, a light Higgsino-like DM can not account for the full amount of the observed relic density of the DM since it annihilated too efficiently in early universe.
- Consequently, simultaneous presence of light Bino and Higgsinos, which will mix to form a light DM, is the minimal ingredient of a natural MSSM.

$$\mathcal{L}_{\tilde{\chi}^0_i\tilde{\chi}^0_j Z} = \frac{g}{2c_W} Z_\rho \overline{\tilde{\chi}^0_i}\gamma^\rho \left[O^{ZL}_{ij}\mathrm{P}_L + O^{ZR}_{ij}\mathrm{P}_R\right]\tilde{\chi}^0_j,$$

$$\mathcal{L}_{\tilde{\chi}^0_i\tilde{\chi}^0_j h} = \frac{g}{2} C^h_{ij}\, h\overline{\tilde{\chi}^0_i}\tilde{\chi}^0_j,$$

$$O^{ZL}_{ij} = -\frac{1}{2}N_{i3}N^*_{j3} + \frac{1}{2}N_{i4}N^*_{j4}, \quad O^{ZR}_{ij} = -O^{ZL*}_{ij}$$

$$C^h_{ij} = \frac{1}{2}\left[(N_{i2} - N_{i1}\tan\theta_W)(\sin\alpha N_{j3} + \cos\alpha N_{j4}) + (i \leftrightarrow j)\right].$$

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

2 THE LIGHT DARK MATTER SCENARIO OF THE MSSM

- To concentrate on the lower bound of DM, we simplify the parameter space as following:
  - the masses of gluino and the first two generation of squarks are fixed to 2 TeV ,
  - for the third generation squarks, we assume $m_{U_3} = m_{D_3}$ and $A_t = A_b$,
  - the soft parameters in slepton are set as $m_{L_{1,2,3}} = m_{E_{1,2,3}} = A_\tau$.
- The remained free parameters are scanned in the following parameter space at 2 TeV scale :

$$2 < \tan\beta < 60,\ 10\ \text{GeV} < M_1 < 100\ \text{GeV}, 100\ \text{GeV} < M_2 < 1000\ \text{GeV},$$
$$100\ \text{GeV} < \mu < 1500\ \text{GeV},\ 50\ \text{GeV} < M_A < 2\ \text{TeV}$$
$$|A_t| < 5\ \text{TeV},\ 200\ \text{GeV} < m_{Q_3}, m_{U_3} < 2\ \text{TeV},\ 100\ \text{GeV} < m_L < 2\ \text{TeV}.$$

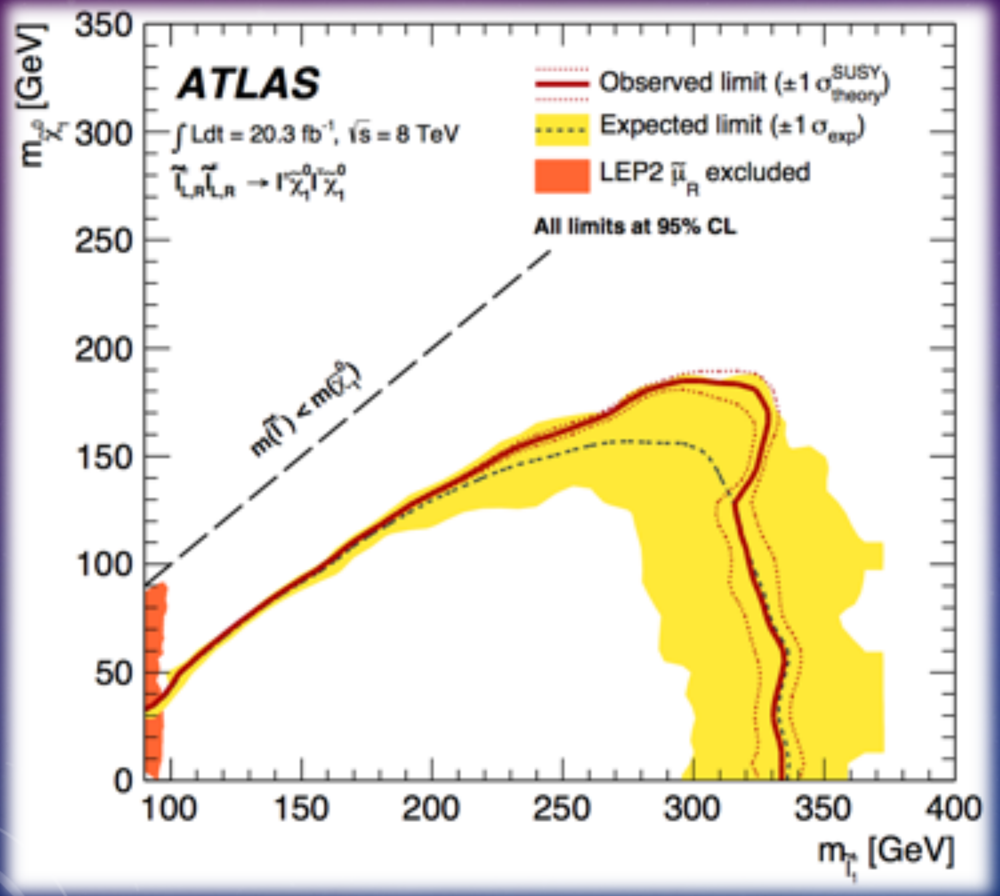
2 THE LIGHT DARK MATTER SCENARIO OF THE MSSM

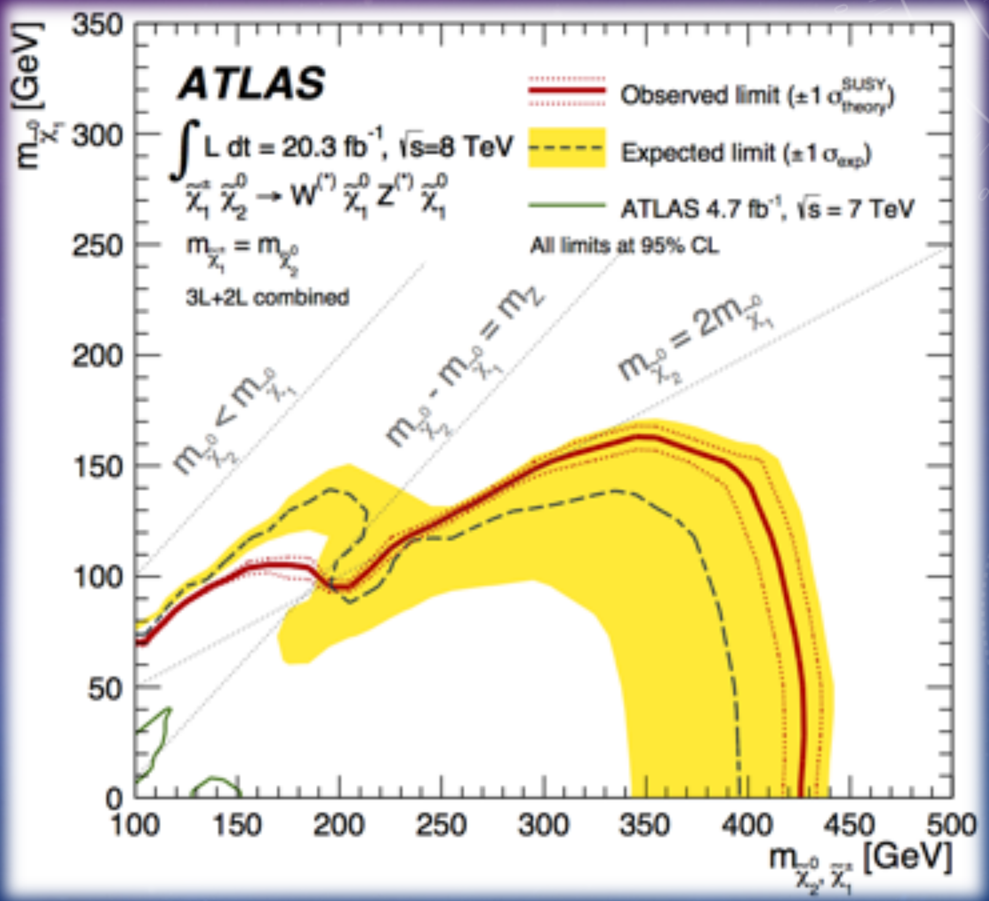
- In our scan, we impose the following constraints :
  - DM relic density. We require that the relic abundance smaller than the 3σ upper limits of the PLANCK and WMAP 9-year data, i.e. $\Omega h^2 < 0.131$, where a 10% theoretical uncertainty is included. It will be meaningless if the sample has few contribution to the relic density. Thus we also put a lower limit $\Omega h^2 > 0.01187$.
  - DM direct searches. The result of LUX experiment is took into consideration by requiring the σ_P^{SI} of neutralino DM multiplied by the ratio of Ωh^2 to 0.1187 under the exclusion bound at \$90\%\$ C.L

2 THE LIGHT DARK MATTER SCENARIO OF THE MSSM

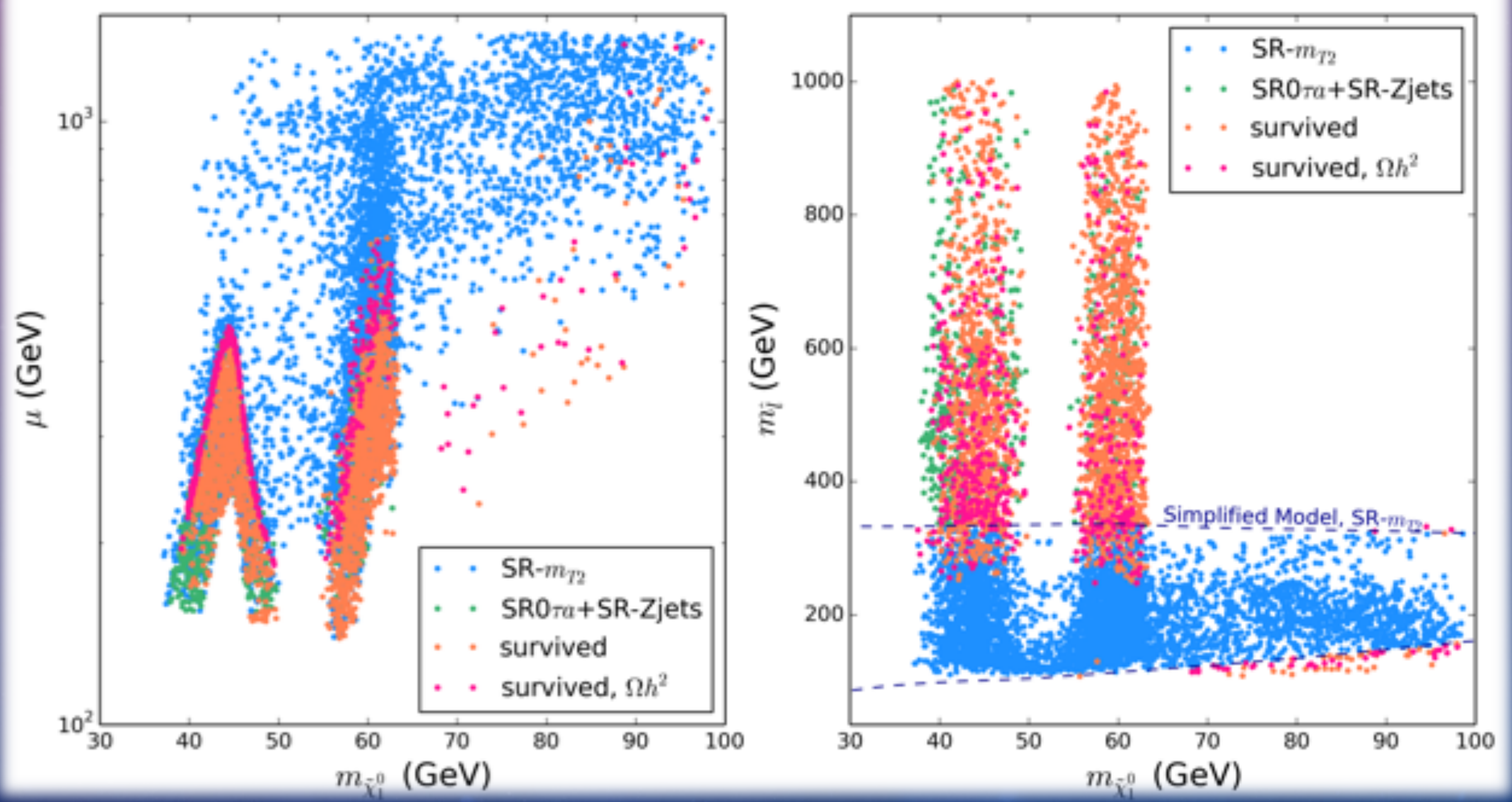
- In our scan, we impose the following constraints :
  - The constraints from the LEP, including $m_{\tilde{\chi}_1^{\pm}} > 103$ GeV, $m_{\tilde{l}} > 99.9$ GeV, and $\Gamma_{z \to \tilde{\chi}_1^0 \tilde{\chi}_1^0} < 1.71$ MeV.
  - Higgs sector. We used the package HiggsBounds and HiggsSignal to considerate the constraints of Higgs sector. We require the fit for the signal rates of SM-like Higgs to the data from Tevetron and LHC at 2σ level.
  - The muon anomalous magnetic moment, $12.7 < \alpha_\mu^{SUSY} < 44.7$.
  - The constraints of B-physics and the precision electroweak observables, such as decays $B \to X_s \gamma$, $B_s \to \mu^+ \mu^-$, $B_d \to X_s \mu^+ \mu^-$, $B^+ \to \tau^+ v$ and ρ_l, $sin^2\theta_{eff}^l$, m_W R_b.

2 THE LIGHT DARK MATTER SCENARIO OF THE MSSM





3 NUMERICAL SCAN AND CONSTRAINTS



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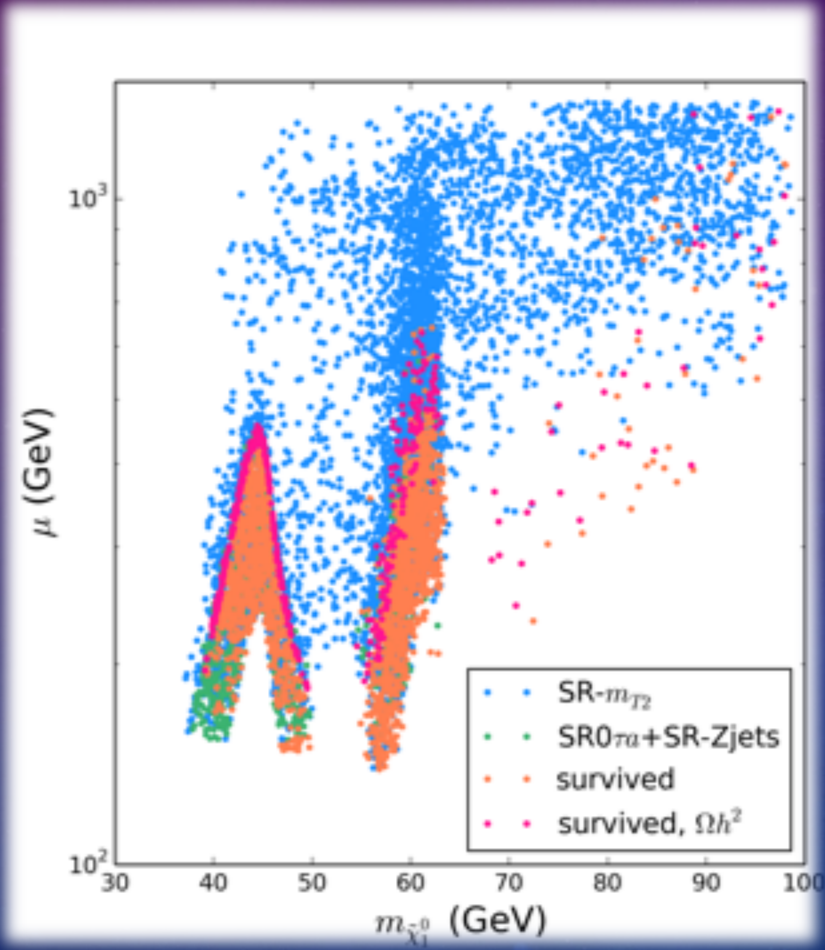

- The red and orange points fulfill the all the constraints explained above.
- The survived samples show clearly two peaks around $m_Z/2$ and $m_h/2$.

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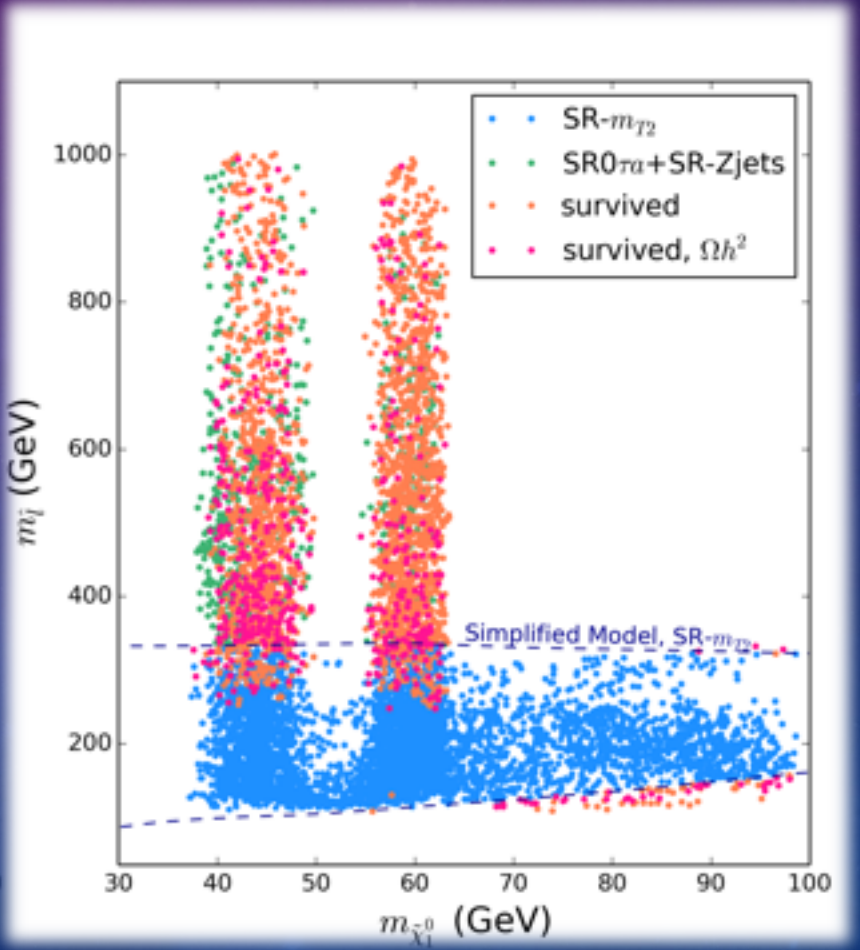
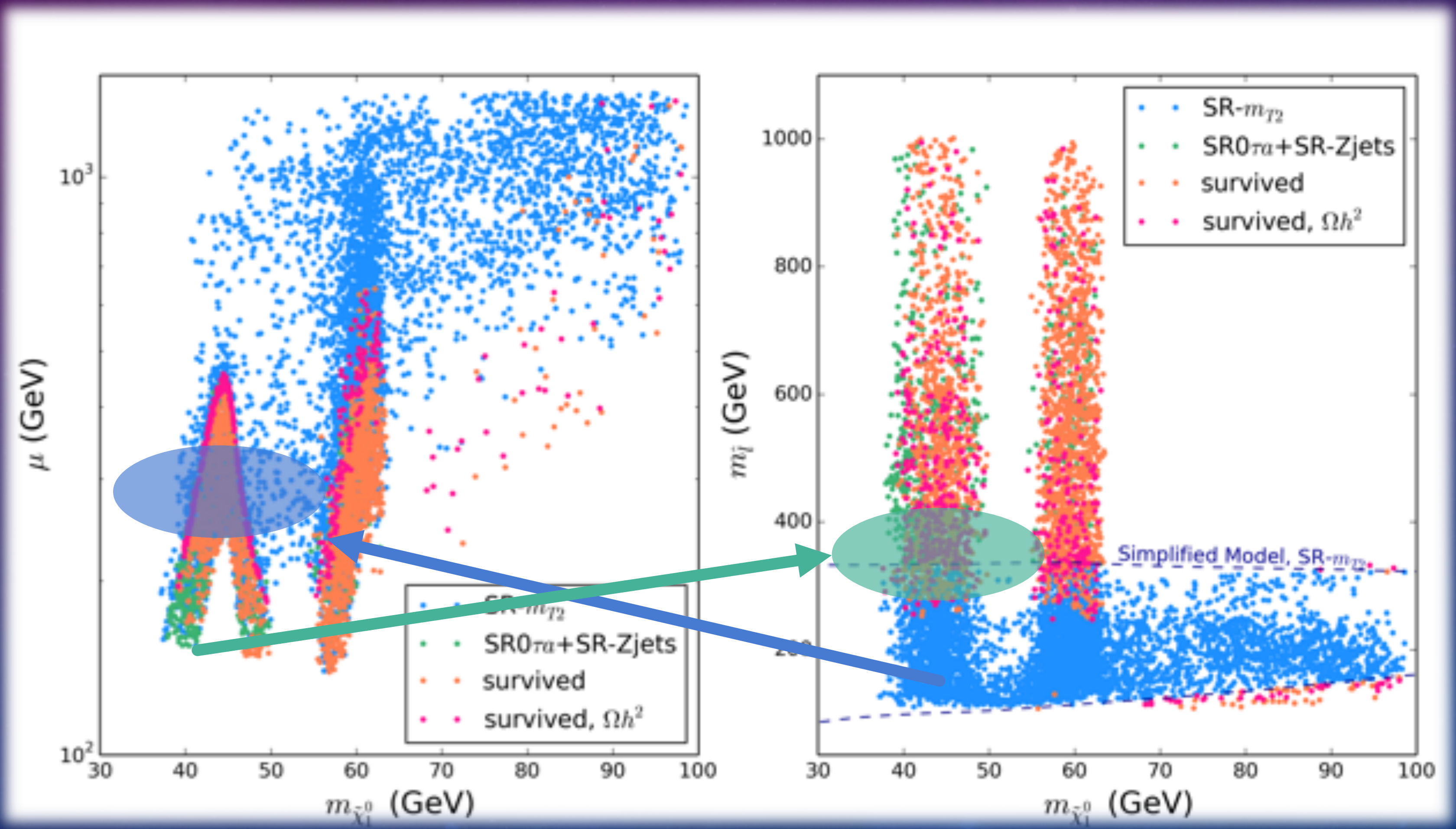
3 NUMERICAL SCAN AND CONSTRAINTS

- The most samples that in the early universe the DM annihilation by a light slepton are excluded by the $2l + E_T^{miss}$ search.
- For the survived samples, the slepton has nothing to do with the relic density.
- The survived samples in the excluded region of SR-m_{T2} for simplified model have the spectrum that Higgsino mass lighter than slepton mass.

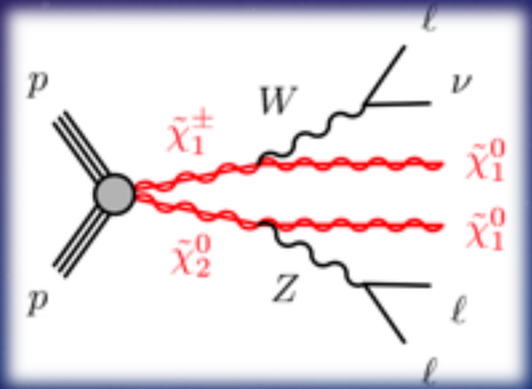


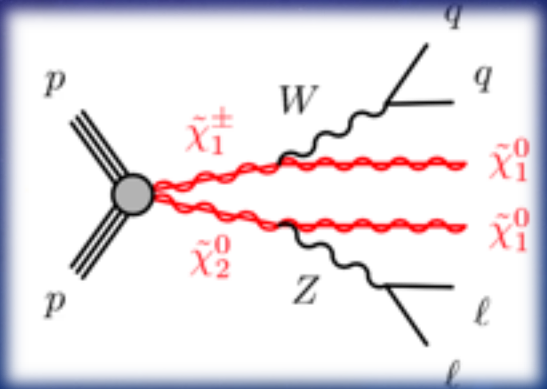
4 FUTURE TEST OF LIGHT DARK MATTER SCENARIO

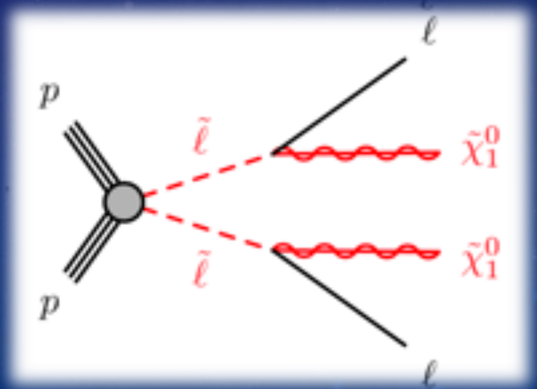


4 FUTURE TEST OF LIGHT DARK MATTER SCENARIO

- Monte Carlo simulation Tools:
  - MG5_aMC/MadEvent for generating hard events;
  - Pythia for parton showering and hadronization;
  - Delphes for fast simulation of the ATLAS detector;
  - CheckMATE for implement the cut of searches for direct production of charginos, neutralinos and sleptons.







4 FUTURE TEST OF LIGHT DARK MATTER SCENARIO

- To obtain accurate background events, we first calculate each background process at both the 8TeV LHC and 14TeV LHC by directly simulation to get the their ratio. Then we multiply the ratio to the background at the 8TeV LHC, which was provided in the ATLAS report.

SR	N_j	$\Delta m_{ll,Z}$	$E_{T,rel}^{miss}$	P_T^{ll}	m_{T2}	ΔR_{ll}	m_{jj}	WW	ZV	Other	Total
m_{T2}^{90}	0	> 10	–	–	> 90	–	–	1.71	1.36	0.26	3.33
m_{T2}^{120}	0	> 10	–	–	> 120	–	–	0.12	0.44	0.00	0.57
m_{T2}^{150}	0	> 10	–	–	> 150	–	–	0.02	0.19	0.00	0.21
Zjets	≤ 2	< 10	>80	>80	–	[0.3,1.5]	[50,100]	0.02	0.14	0.03	0.19

4 FUTURE TEST OF LIGHT DARK MATTER SCENARIO

SR0τa	m_{SFOS}	m_T	E_T^{miss}	m_{3l}	VVV	WZ	ZZ	t	h	$t\bar{t}$	Total
1	12-40	0-80	50-90	no	0.03	1.11	0.11	0.02	0.07	1.05	2.41
2	12-40	0-80	>90	no	0.01	0.28	0.01	0.01	0.03	0.11	0.45
3	12-40	>80	50-75	no	0.02	0.66	0.03	0.00	0.07	0.22	1.00
4	12-40	>80	>75	no	0.06	0.45	0.02	0.02	0.05	0.48	1.08
5	40-60	0-80	50-75	yes	0.02	0.52	0.13	0.01	0.04	0.65	1.37
6	40-60	0-80	>75	no	0.02	0.33	0.02	0.00	0.04	0.33	0.76
7	40-60	>80	50-135	no	0.08	0.64	0.05	0.00	0.11	0.61	1.49
8	40-60	>80	>135	no	0.02	0.04	0.00	0.02	0.04	0.08	0.20
9	60-81.2	0-80	50-75	yes	0.02	1.40	0.12	0.02	0.03	0.79	2.40
10	60-81.2	>80	50-75	no	0.04	1.09	0.05	0.02	0.02	0.29	1.51
11	60-81.2	0-110	>75	no	0.06	1.75	0.07	0.07	0.04	0.99	2.98
12	60-81.2	>110	>75	no	0.07	0.34	0.01	0.02	0.02	0.16	0.63
13	81.2-101.2	0-110	50-90	yes	0.14	52.16	2.60	0.56	0.23	10.73	66.41
14	81.2-101.2	0-110	>90	no	0.10	19.95	0.56	0.44	0.15	0.42	21.62
15	81.2-101.2	>110	50-135	no	0.11	5.13	0.35	0.13	0.04	0.21	5.98
16	81.2-101.2	>110	>135	no	0.05	0.47	0.01	0.02	0.00	0.03	0.59
17	>101.2	0-180	50-210	no	0.34	4.80	0.24	0.12	0.13	2.01	7.65
18	>101.2	>180	50-210	no	0.06	0.28	0.01	0.02	0.01	0.04	0.44
19	>101.2	0-180	>210	no	0.02	0.13	0.00	0.00	0.00	0.08	0.24
20	>101.2	>180	>210	no	0.01	0.02	0.00	0.00	0.00	0.04	0.09

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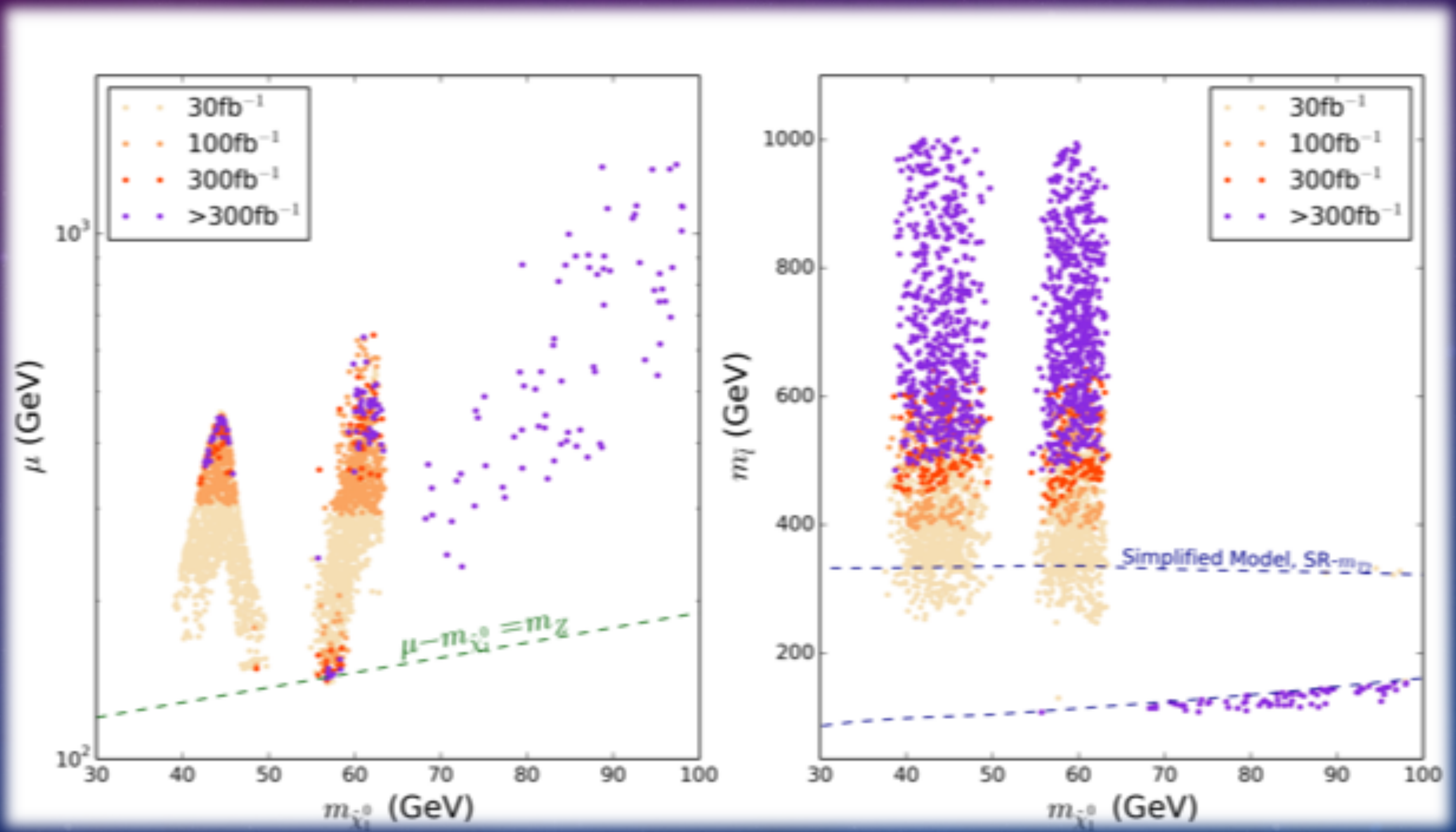

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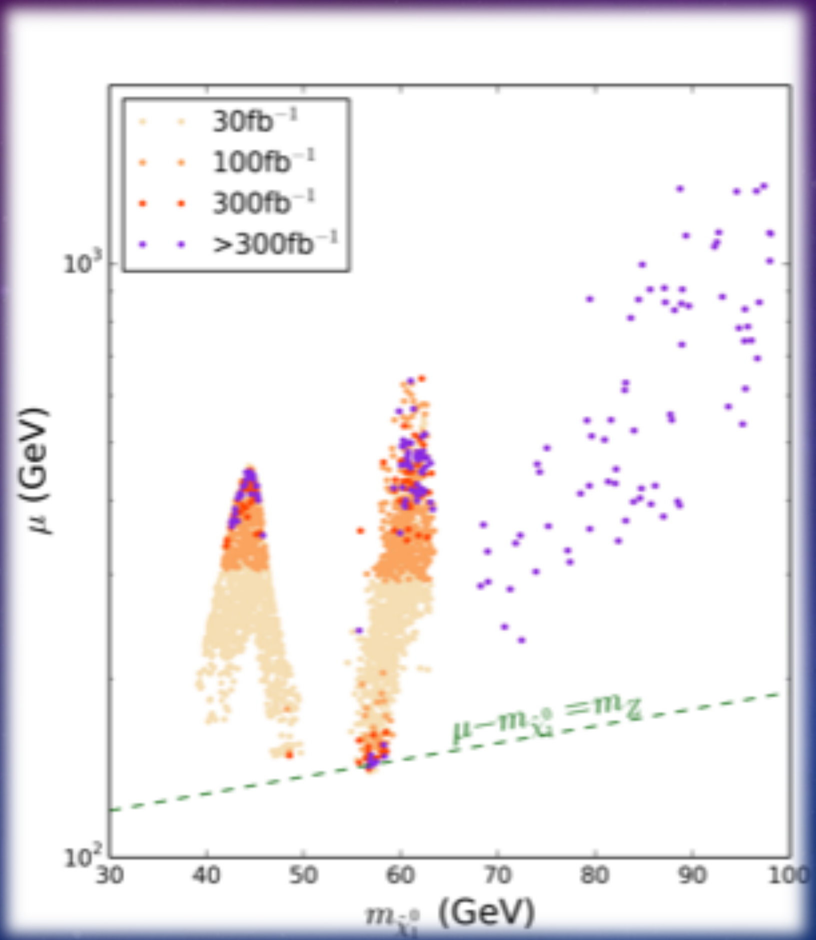
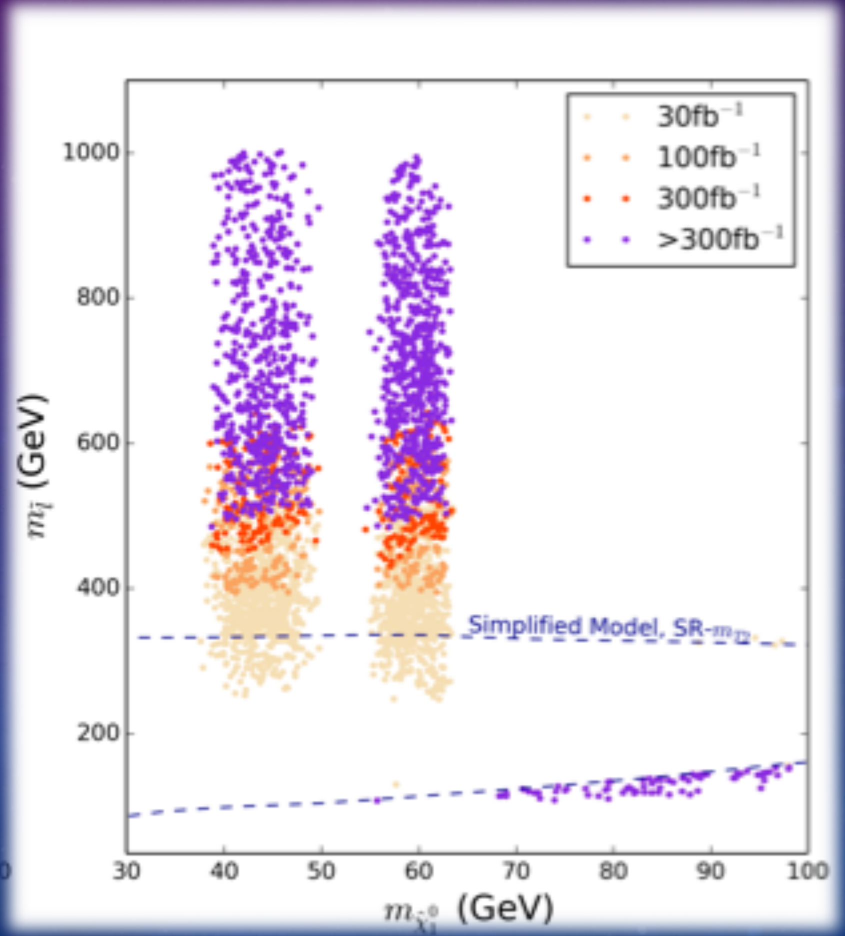


- Using $30fb^{-1}$ of collision data at $\sqrt{s} = 14$ TeV LHC, a lot of points can be excluded.
- With higher integrated luminosity, more samples can reach the 95% C.L. limit.
- But at the top and the right bottom of the m_Z resonances, some samples are hard to be excluded.

4 FUTURE TEST OF LIGHT DARK MATTER SCENARIO

- For the samples above the current excluded region, the exclusion limit enhance with more data.
- The mass of slepton are exluded to about 400 GeV, 450 GeV and 500 GeV at 95% C.L. with 30 fb^{-1}, 100 fb^{-1}, 300 fb^{-1} respectively.
- For the lower right points, these signal regions still have no sensitive because of mass splitting.



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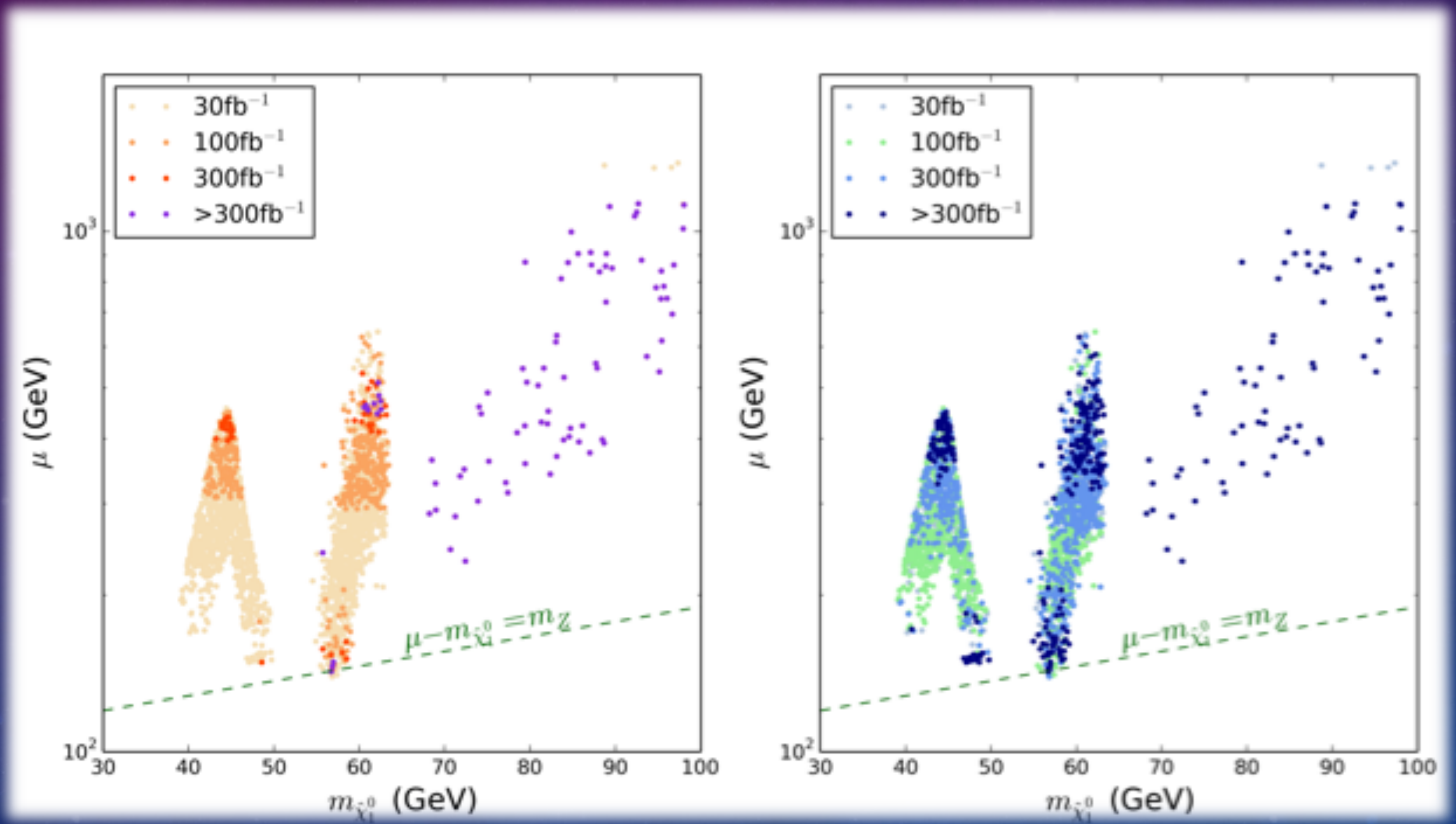

5 CONCLUSION

- The purpose of this study is to show that the light dark matter scenario of the MSSM is easy to be tested at LHC Run-II by searches for electroweakly interacting SUSY particles .
- If there is still no corresponding excess at Run-II, one should careful in dealings with light dark matter of MSSM. According our predictions, the samples in MSSM of $m_{\tilde{\chi}_1^0} < 50$ GeV, which means the main annihilation mode of dark matter go through an s-channel Z boson, will be excluded at 95% C.L. by the data of 300 fb^{-1} at the 14 TeV LHC.
- These predictions are rough but conservative.

Thank you!

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Future dark matter direct searches