Challenging Dark Matter scenarios at the LHC

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Columbus, September 24th 2016

Dark Matter in minimal SUSY scenarios

Pure state (Wino, Bino, Higgsino)

Gravitino

Well-tempered neutralino

Stau-Neutralino co-annihilation

Chargino-Neutralino co-annihilation

Stop-Neutralino co-annihilation

Talk by Nausheen

...

What challenges are we facing to experimentally test all these scenarios?

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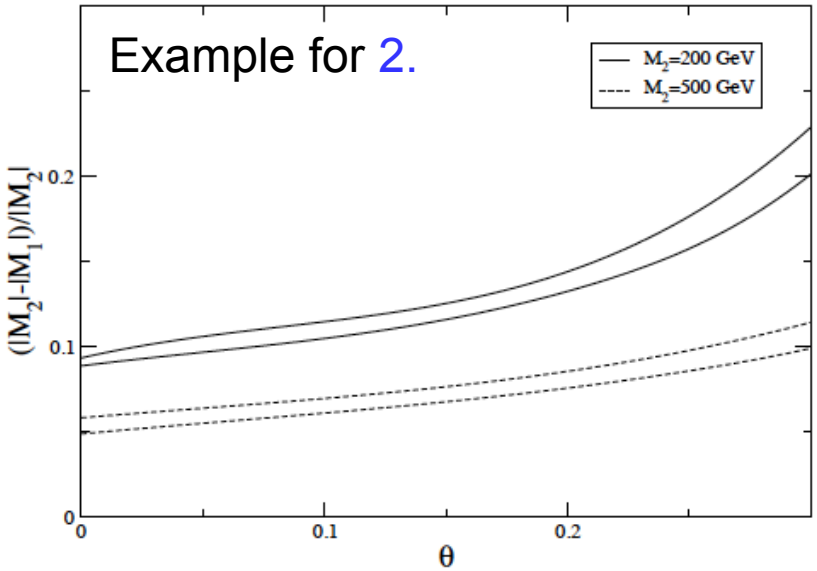
Squeezed SUSY neutralino Dark Matter

In the MSSM, a small number of free parameters determines the neutralino spectrum: M_1, M_2, μ, $\tan\beta$

"Tempering" ...

DM is a mixture of

1. Higgsino - Bino or
2. Wino - Bino



Arkani-Hamed, Delgado, Giudice, hep-ph/0601041

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"Tempering" ...

DM is a mixture of

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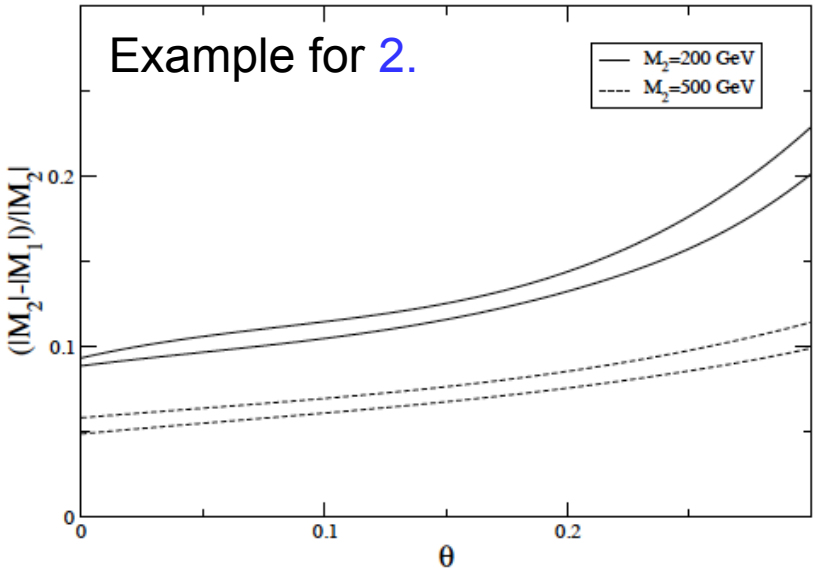
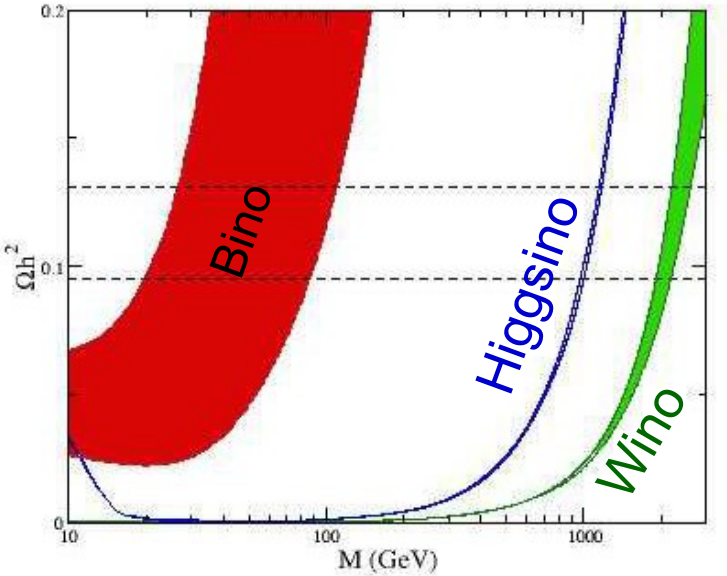
… or not "tempering"

DM is

1. a Higgsino or
2. a Wino or
3. a Bino pure state





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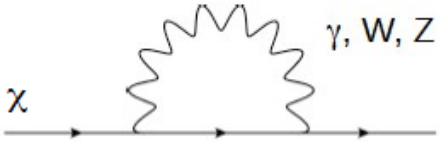
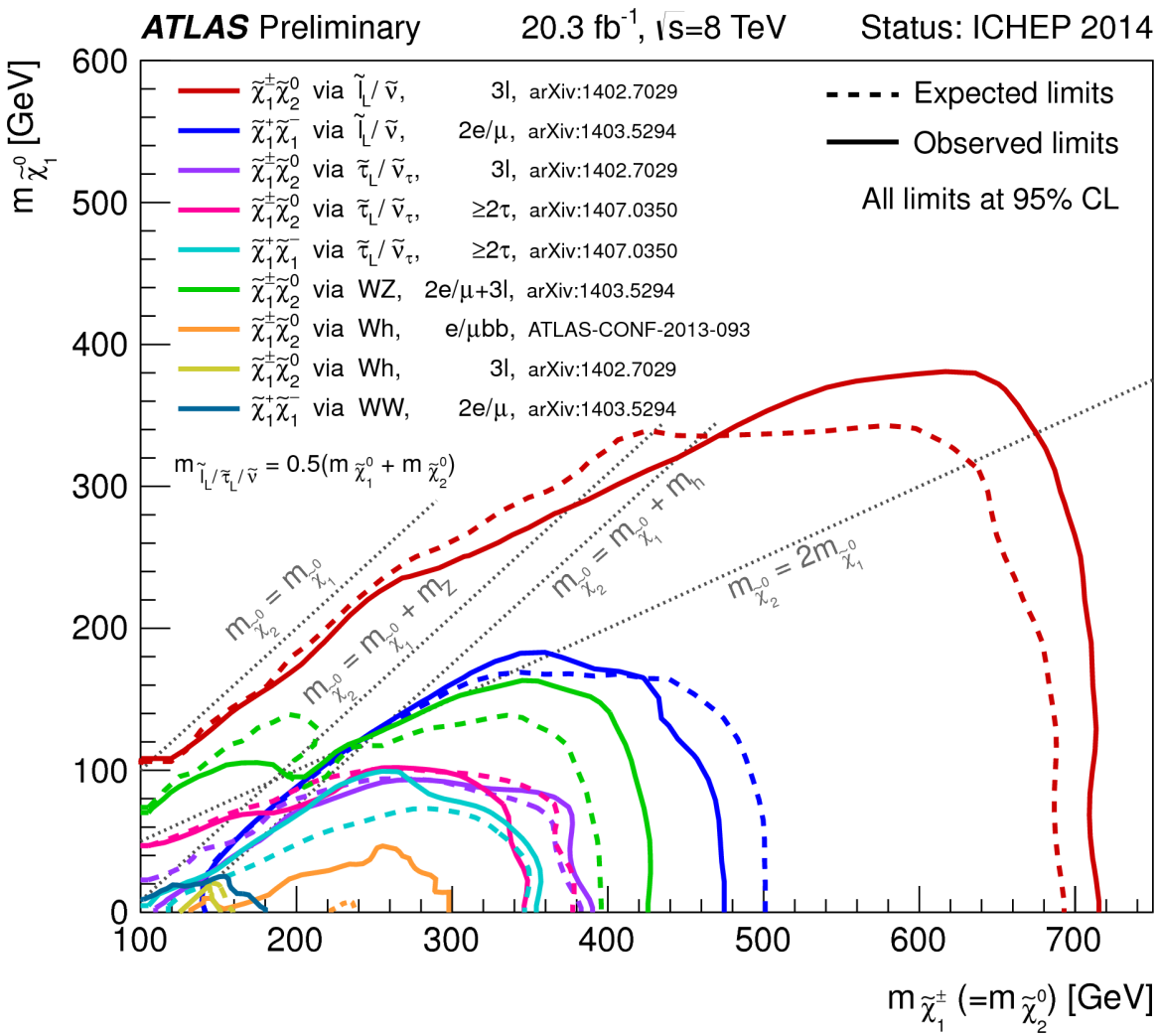


$$m_{\tilde{H}^\pm} - m_{\tilde{H}^0} \simeq 355 \text{ MeV}$$

$$m_{\tilde{W}^\pm} - m_{\tilde{W}^0} \simeq 166 \text{ MeV}$$

Many SUSY searches but …

At the end of Run I:



New search strategies?

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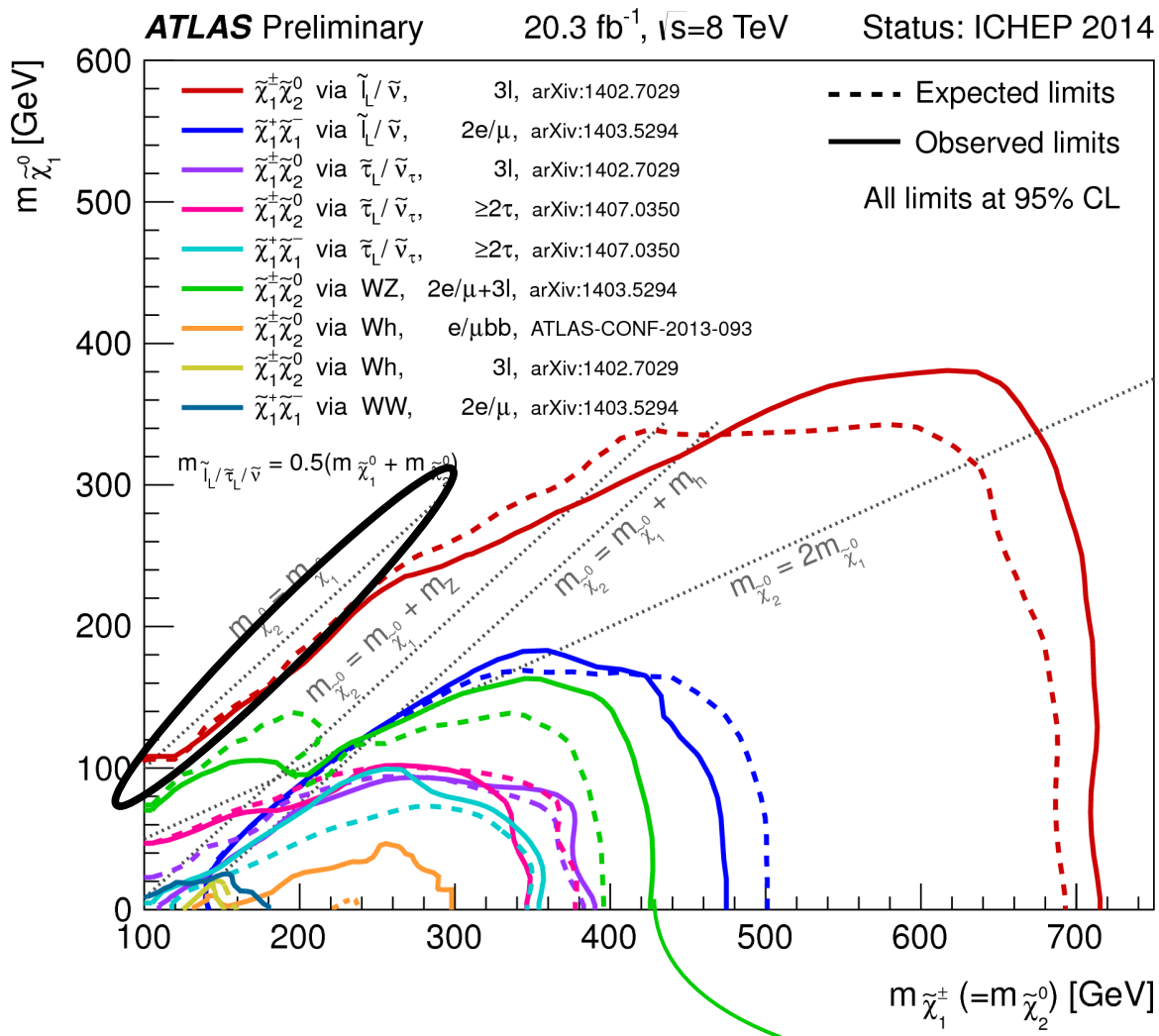
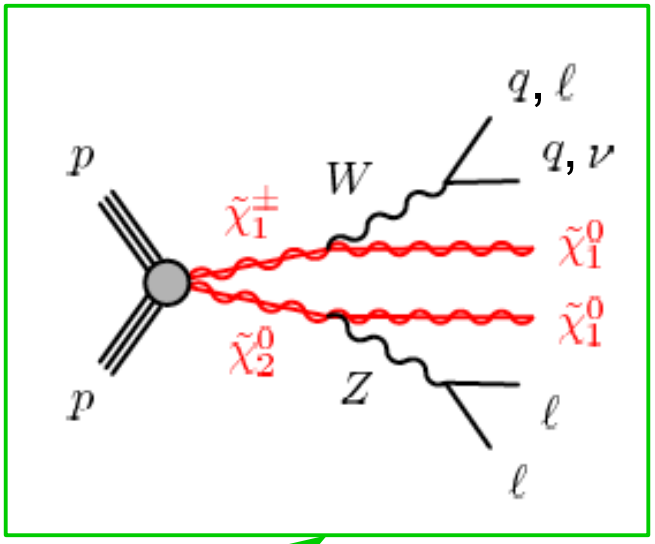
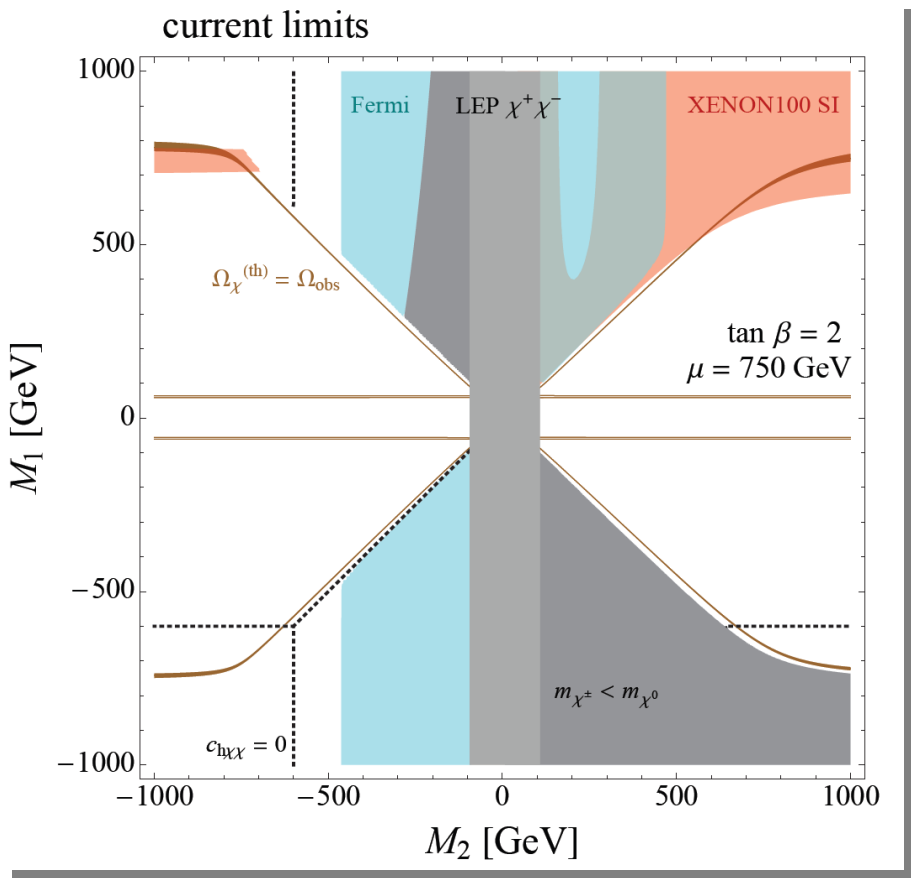


The decay products are softer and softer for more and more squeezed scenarios

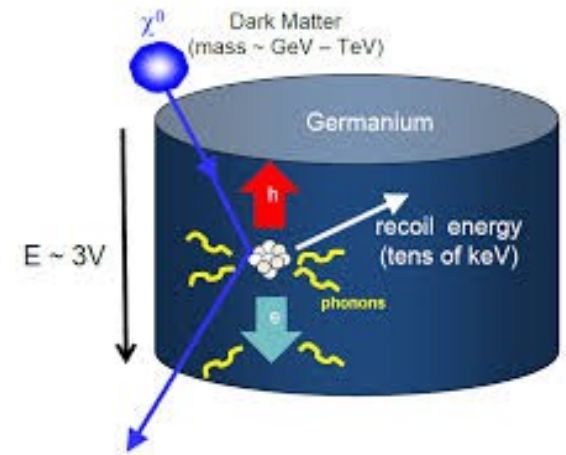


New search strategies?

Direct detection blind spots



Cheung, Hall, Pinner, Ruderman, 1211.4873



$$\mathcal{L} \supset \frac{c_{h\chi\chi}}{2} h \left(\chi\chi + \chi^\dagger\chi^\dagger\right)$$

$$\sigma_{\rm SI} = 8 \times 10^{-45}{\rm cm}^2 \left(\frac{c_{h\chi\chi}}{0.1}\right)^2$$

m_χ	condition	signs
M_1	$M_1 + \mu \sin 2\beta = 0$	$\mathrm{sign}(M_1/\mu) = -1$
M_2	$M_2 + \mu \sin 2\beta = 0$	$\mathrm{sign}(M_2/\mu) = -1$
$-\mu$	$\tan\beta = 1$	$\mathrm{sign}(M_{1,2}/\mu) = -1$
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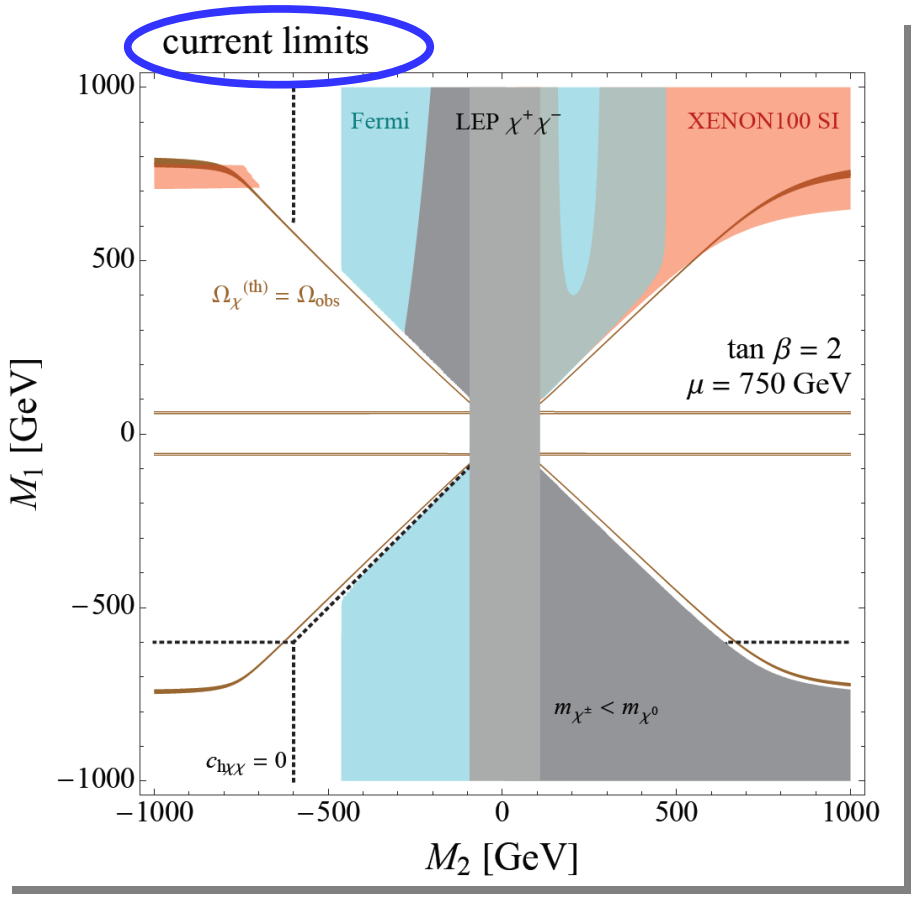
Direct detection blind spots



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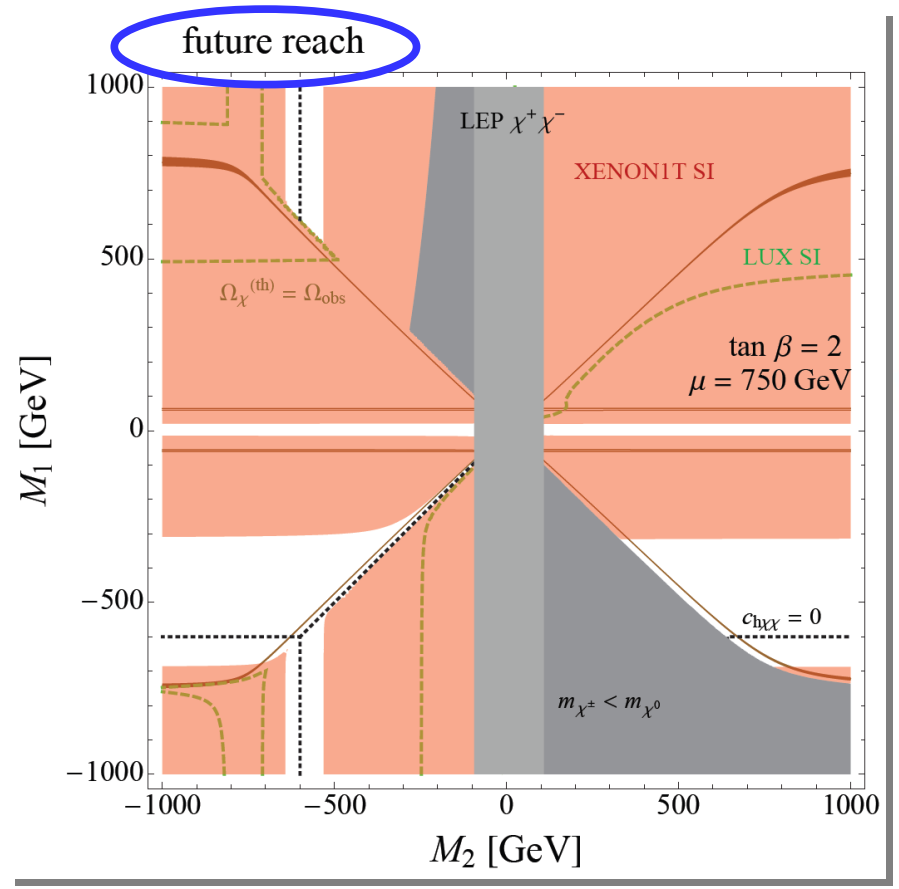

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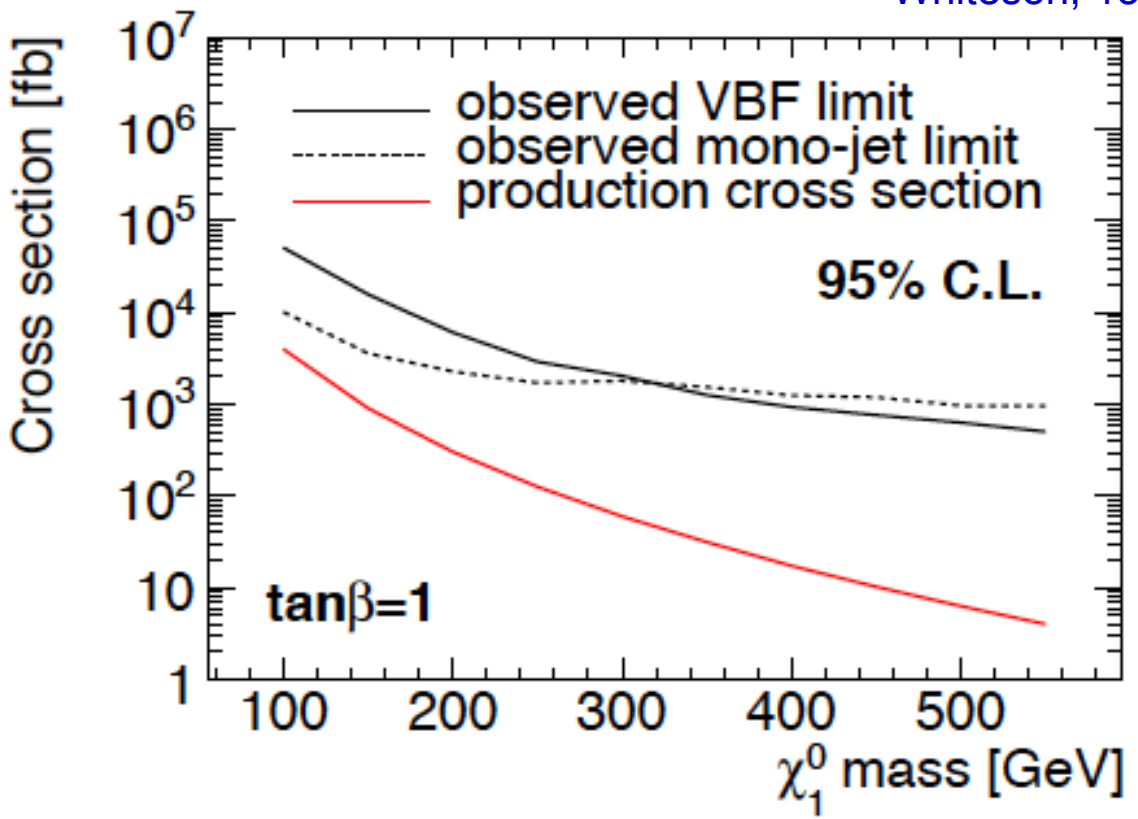
Mono-jet or VBF?

Going back to Antonio's talk ...

Asking for a boosted Initial State Radiation (ISR) jet or two vector boson fusion (VBF) jets can facilitate the detection of these squeeze electroweak particles. However ...

EW cross section is quite small, after asking for additional (very boosted) objects

Nelson, Tanedo, Whiteson, 1509.08485



Combination of strategies

- In the coming years of the LHC, it will be important to have a program for

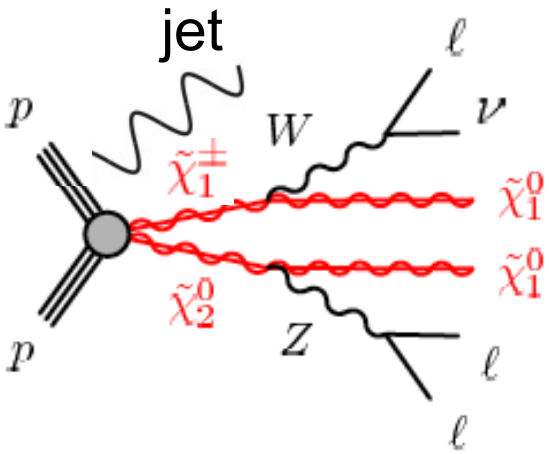
Mono-X + something and VBF + something

Lower thresholds **New** **Lower thresholds** **New**

- Our proposal: ISR jet + 3 (soft) leptons

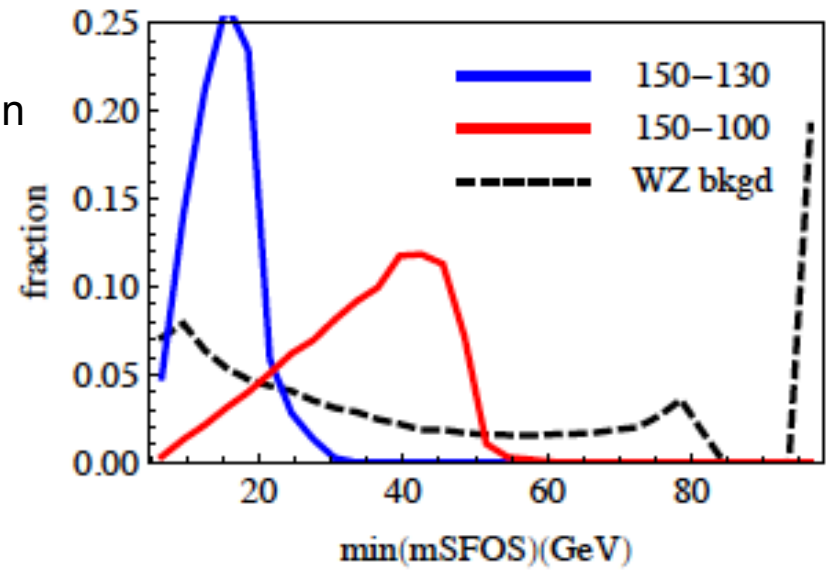
  - Possible trigger: 3 soft leptons (/muons)

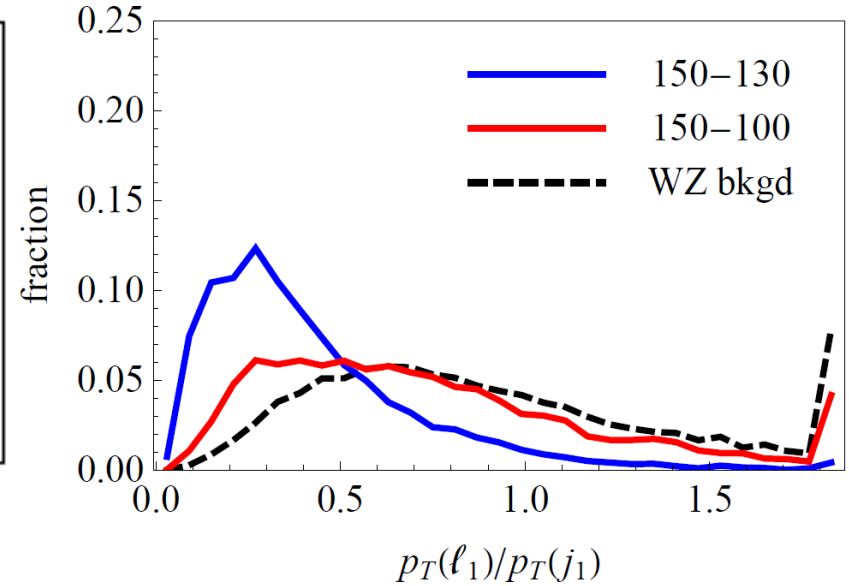
  - Kinematics:
    - Large angle between MET and ISR jet
    - Small invariant mass of (opposite sign) lepton pairs
    - Relatively small MET and lepton p_T

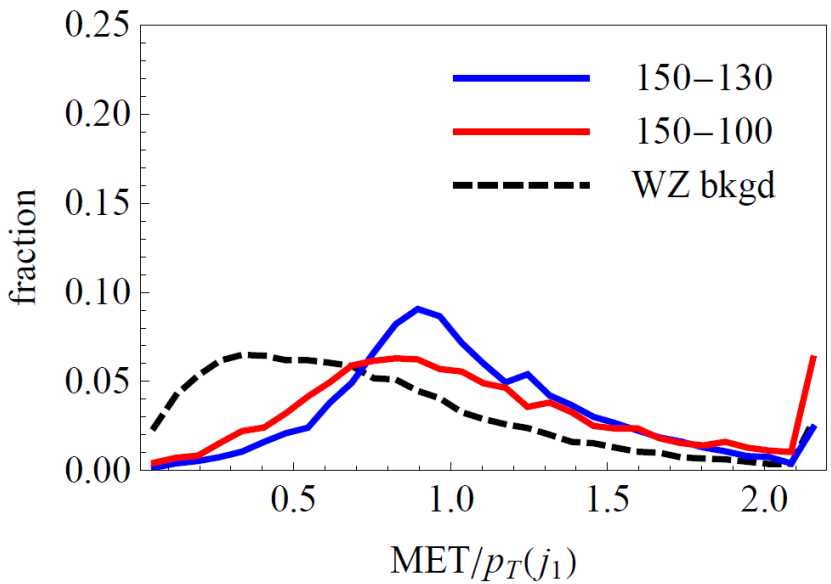


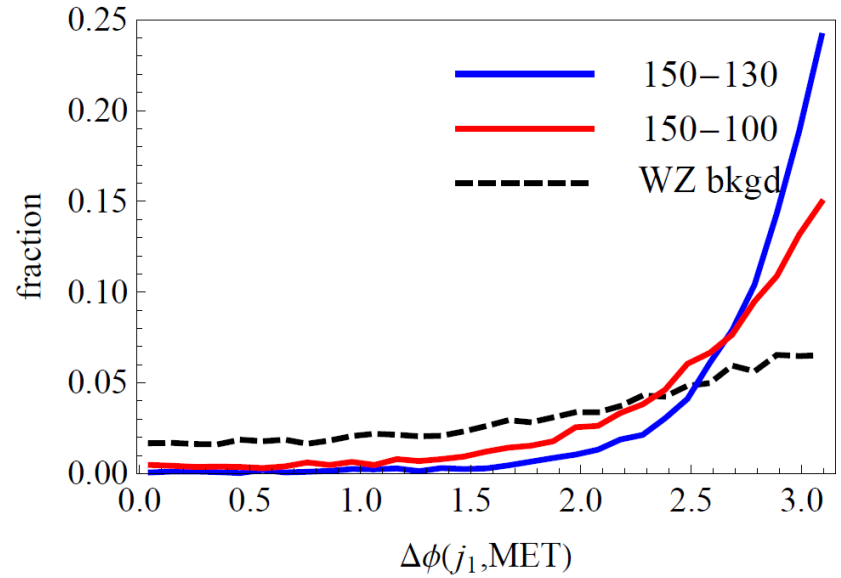
Some distributions

SFOS =
same flavor
opposite sign





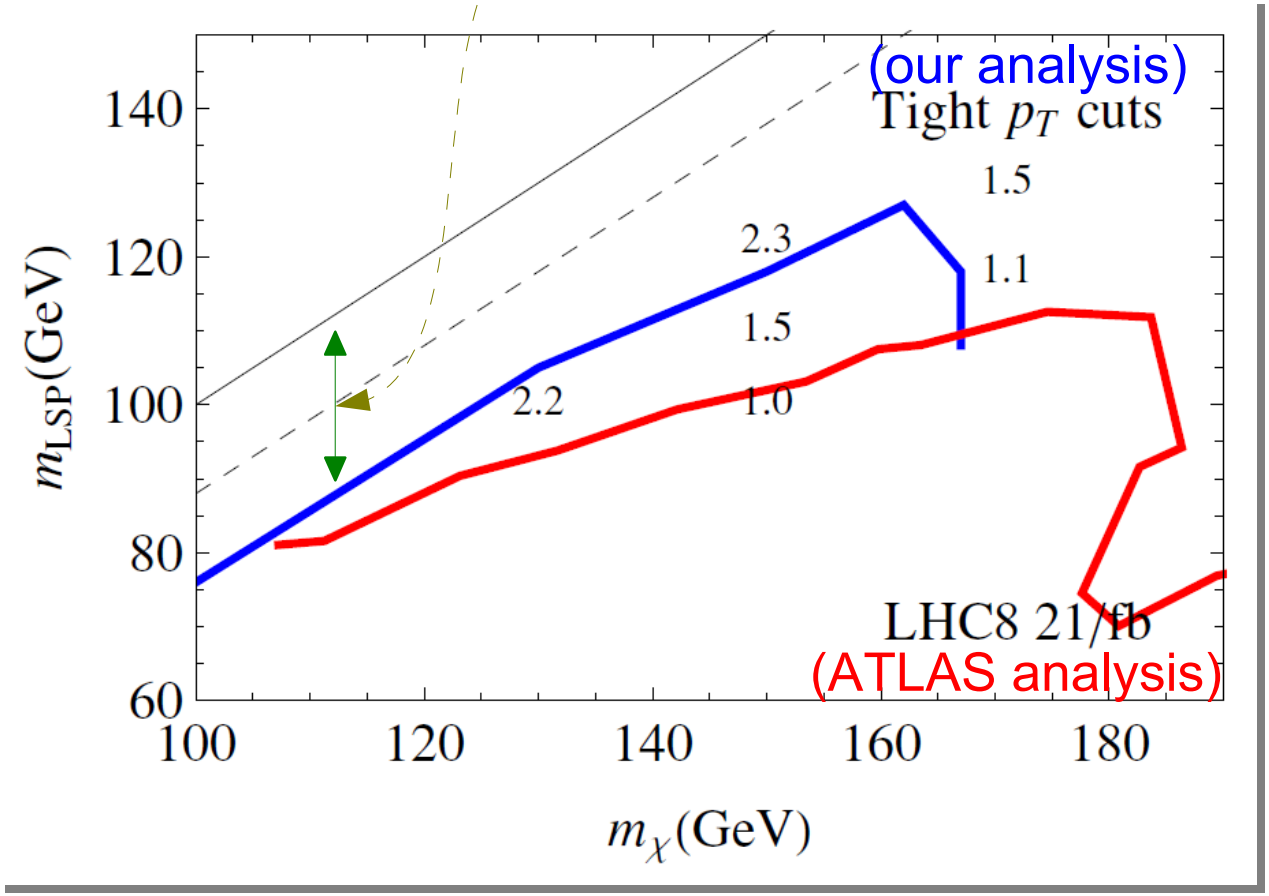




S.G., S.Jung, L-T.Wang, 1307.5952

Probing un-explored parameter space

Main issue in this region
is the requirement min(mSFOS) > 12GeV



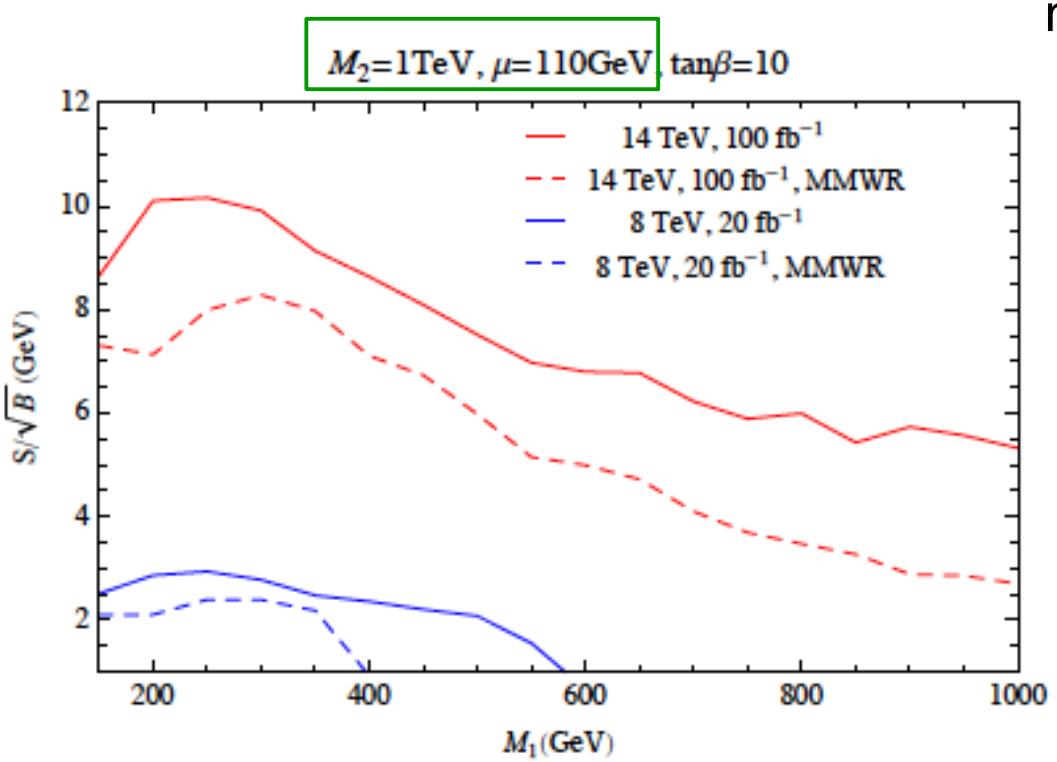
S.G., S.Jung, L-T.Wang, 1307.5952

Complementarity: ISR jet + 2 (soft) leptons

Several NLSP decay modes populate this signature:

$$pp \to \chi_1^\pm \chi_1^\mp + j \to \ell^+\ell'^-\nu\bar{\nu}\chi_1^0\chi_1^0 + j$$
$$pp \to \chi_2^0\chi_1^0 + j \to \ell^+\ell^-\chi_1^0 + j$$
$$pp \to \chi_1^\pm\chi_2^0 + j \to \ell^+\ell^- jj\chi_1^0\chi_1^0 + j,\ \ell^+\ell^-\ell'^\pm\nu\chi_1^0\chi_1^0 + j$$

- The leptons do not have necessarily opposite sign
- Different trigger strategy: mono-jet trigger



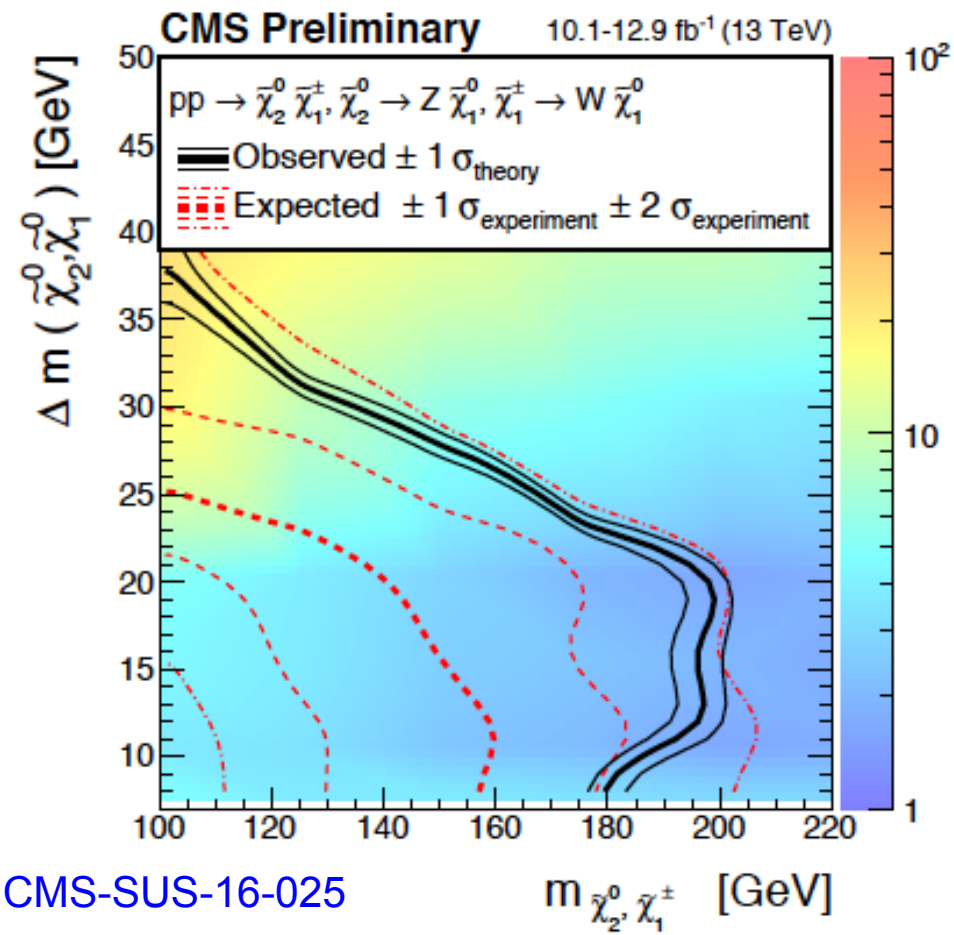
M_{X1}~96 GeV,	M_{X1}~104 GeV,	M_{X1}~105 GeV,
M_{X2}~115 GeV,	M_{X2}~113 GeV,	M_{X2}~113 GeV,
$M_{chargino}$~108 GeV	$M_{chargino}$~108 GeV	$M_{chargino}$~108 GeV

Han, Kribs, Martin, Menon, 1401.1235

CMS soft lepton analysis at Run II

New CMS analysis announced at ICHEP '16

2 opposite sign leptons + 1 jet
(p_{Tl} thresholds as low as 3.5GeV for the subleading muon!)



CMS-SUS-16-025

Open questions:
What would be the performance of a

- more inclusive jet + (soft) lepton(s) (1,2,3,4) analysis?

- VBF + (soft) lepton(s) (1,2,3,4) analysis?

Pure DM states: Winos

Going towards more squeezed EW scenarios...

Winos pure states can be DM for m ~ 3TeV

- $m_{\tilde{W}^\pm} - m_{\tilde{W}^0} \simeq 166 \text{ MeV}$ ⟶ No visible particles from the decay of the charged state

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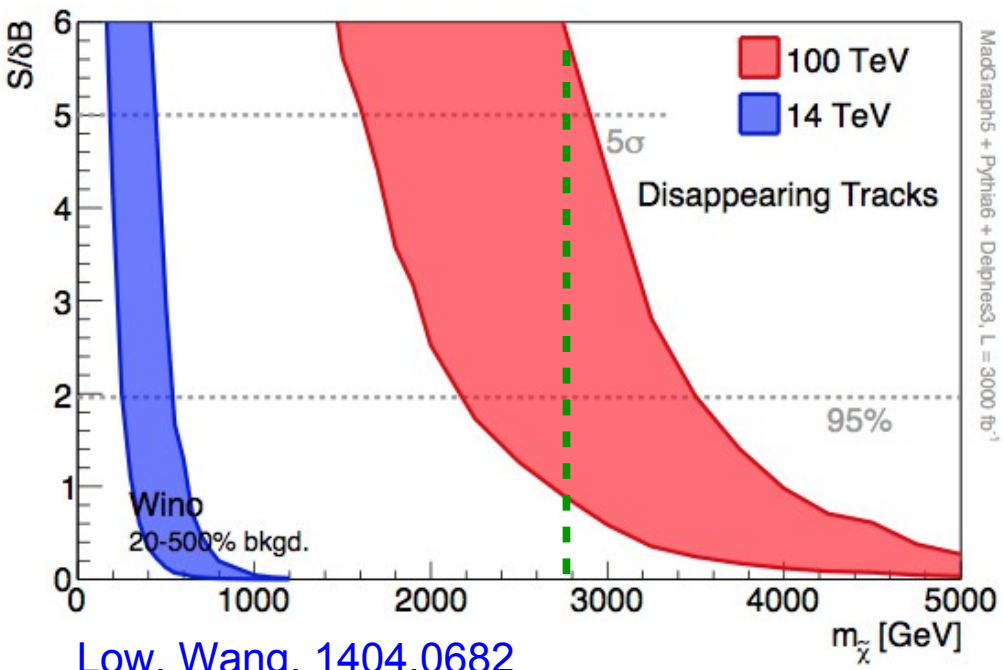
- "Sweet spot" for disappearing tracks $\chi^\pm \to \chi^0 \pi^\pm$



Low, Wang, 1404.0682

Also indirect DM detection through gamma rays can much more powerfully constrain this scenario (Fermi, HESS, ...)

See eg.
Cohen et al., 1307.4082
Fan, Reece, 1307.4400
Baumgart et al., 1412.8698

Pure DM states: Higgsinos

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Higgsinos pure states are the <u>most challenging case:</u> m ~ 1TeV

- $m_{\tilde{H}^\pm} - m_{\tilde{H}^0} \simeq 355\ \mathrm{MeV}$ and relatively small production (smaller than for Winos)

  No visible particles from the decay of the charged state

- Disappearing track bounds are/will be relatively weak

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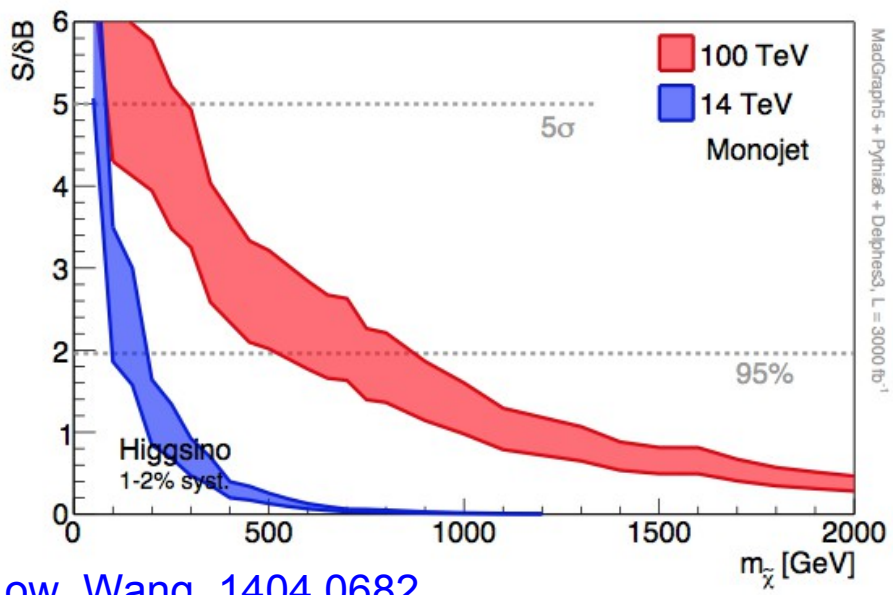
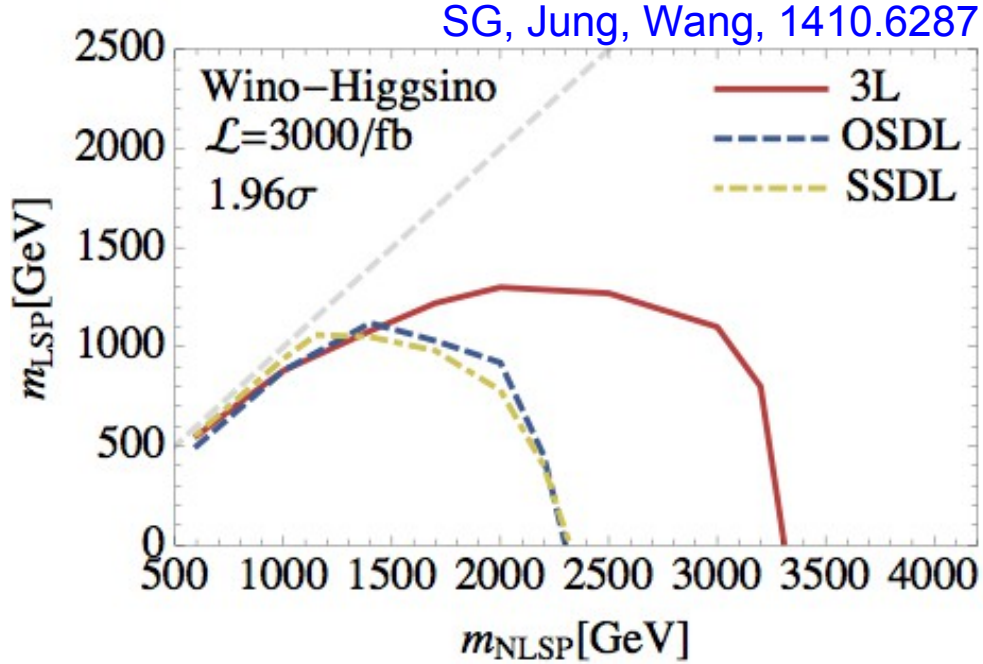
- Other strategies:



Low, Wang, 1404.0682

SG, Jung, Wang, 1410.6287



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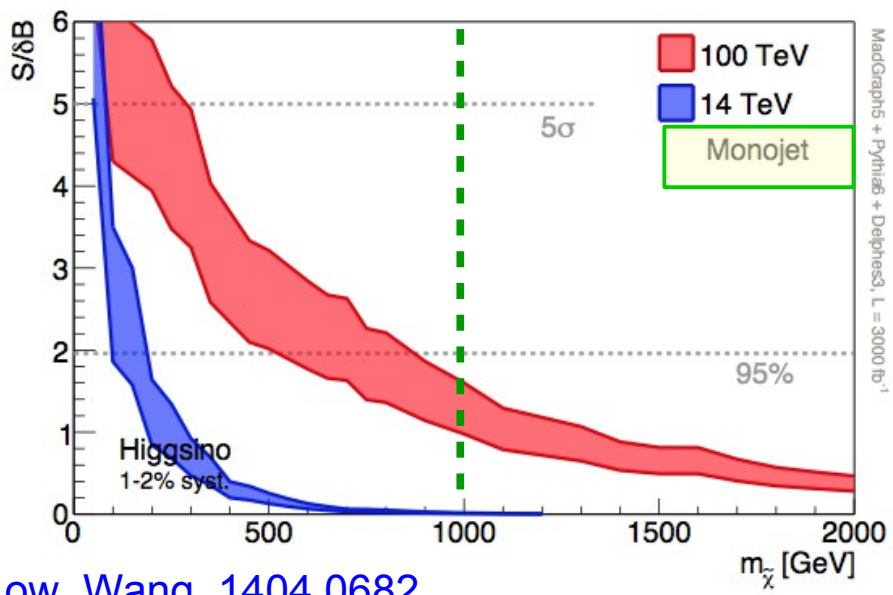

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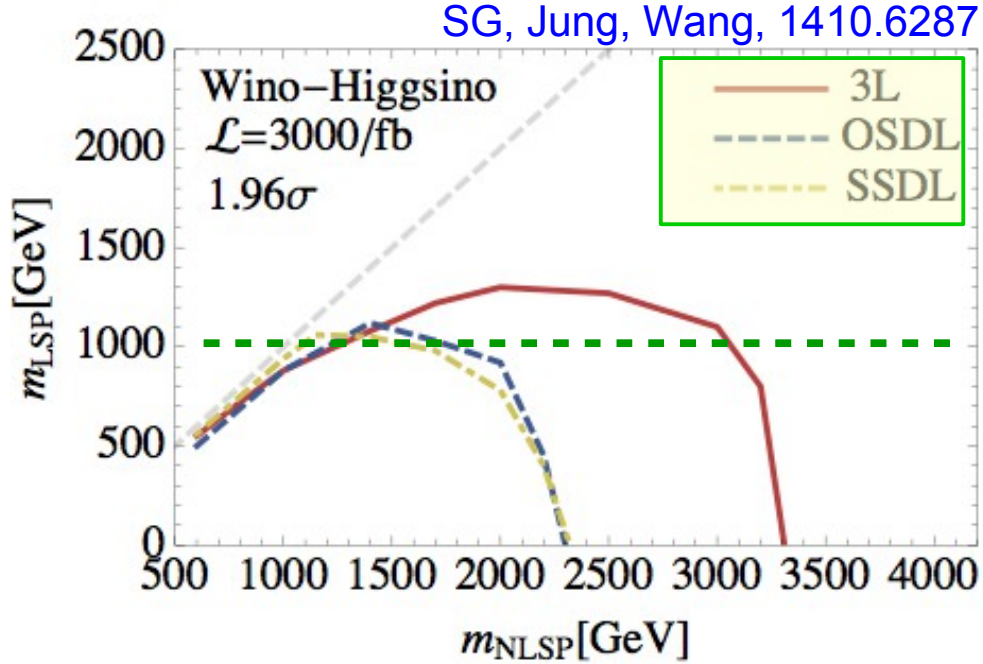


Conclusions/discussion

- Several DM SUSY scenarios are <u>only weakly constrained</u> by the present (direct/indirect detection and collider) experiments.

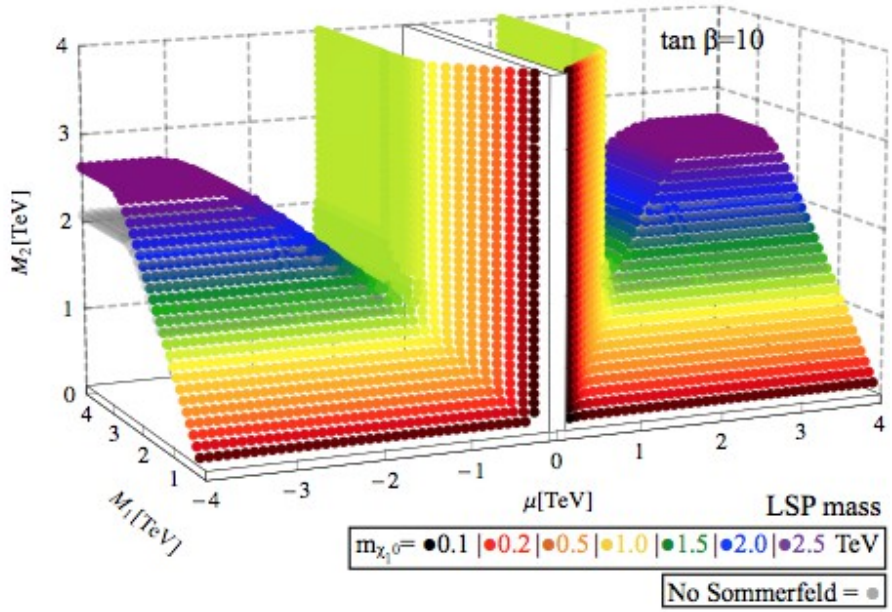
  Particularly, some scenarios are not constrained beyond the LEP bound

- Wish list for the LHC: Mono-X + something and VBF + something search strategies

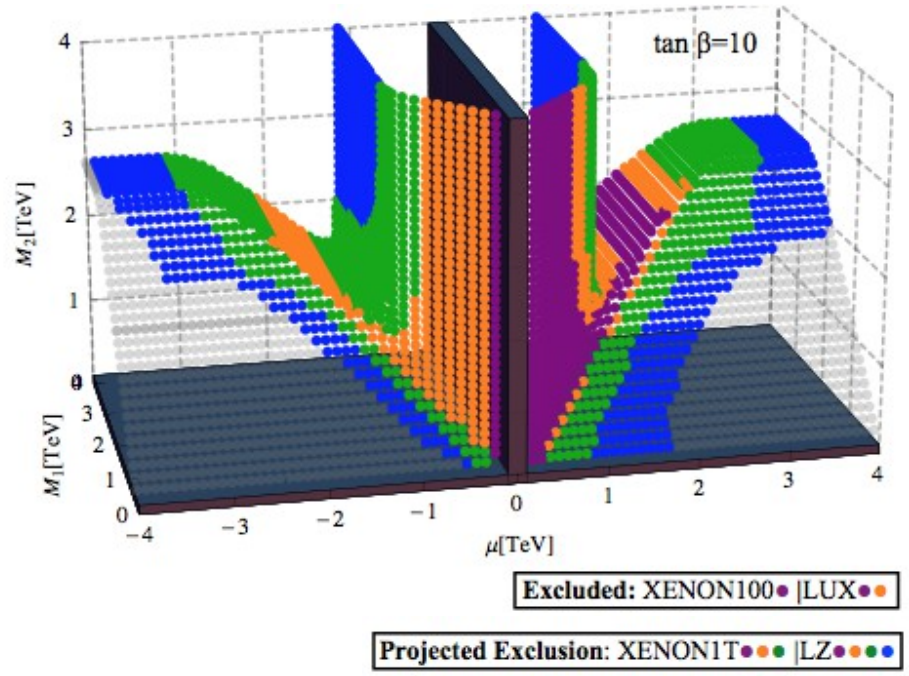
- Wino DM pure state can be tested by <u>disappearing track searches.</u>

- Higgsino DM pure state is the most challenging scenario.

SUSY constraints and blind spots



"Well tempered" neutralinos are (and will be) well probed by our direct detection experimental program



Bramante, et al. 1510.03460

Combinations of neutralino mass parameters M_1, M_2, μ that produce the correct relic abundance

How to probe generalized blind spots for which the tree-level contribution from the light Higgs exchange cancels the contribution from the heavy Higgs?

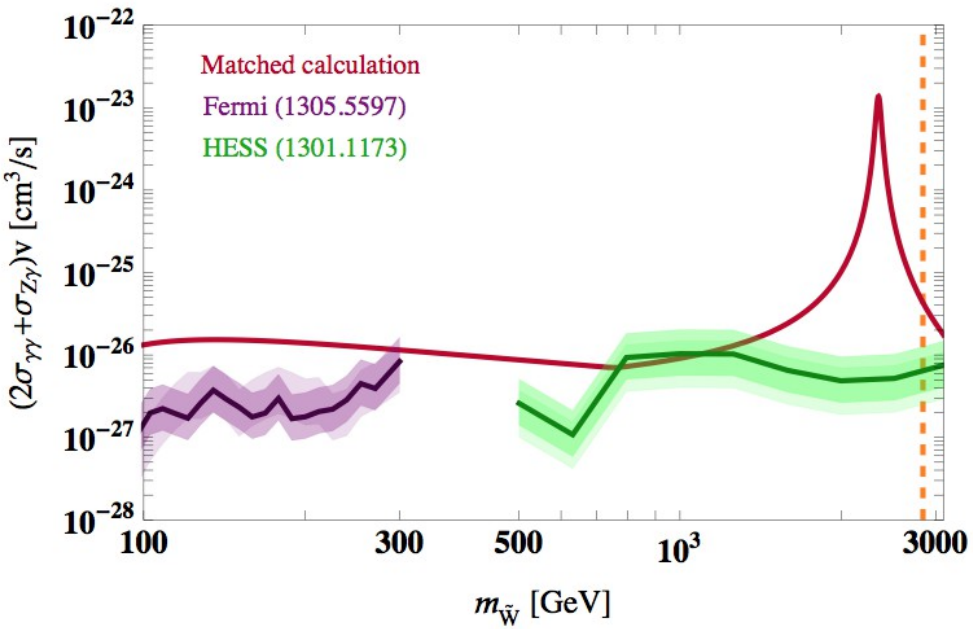
Huang, Wagner, 1404.0392

SUSY DM pure state (Wino)

Thermal scenario with mass at about **2.8 TeV**

See also
Beneke et al., 1601.04718

Indirect detection



Fan, Reece, 1307.4400

Constraint on Wino annihilation into photon(s)

See also
Cohen et al., 1307.4082
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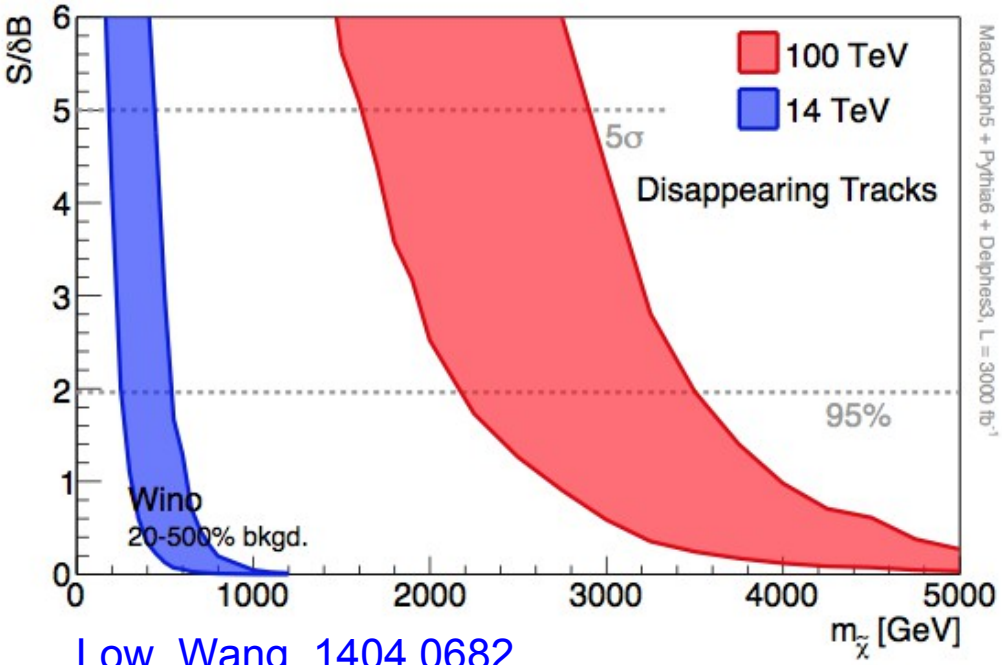
(Future) colliders



Low, Wang, 1404.0682

Constraints from disappearing tracks searches

The challenge comes from the fact that we have a squeezed spectrum