Mini-Review: Physics with Electroweakinos

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Motivation I: Susy and Naturalness

Why light electroweak (EW) particles?

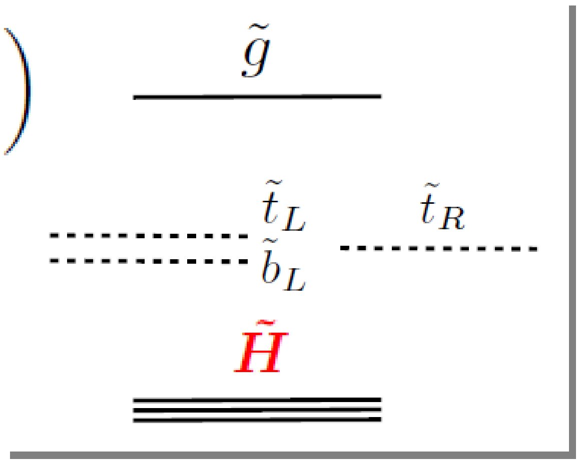
SUSY cancels the quadratic sensitivity of the Higgs mass to some New Physics (NP) scale, but ...

$$\frac{m^2_{\rm Higgs}}{2} = -|\mu|^2 + \cdots + \delta m^2_H$$

Mass scale for Higgsinos

$$\delta m^2_{H_u}|_{\rm stop} \propto \frac{1}{16\pi^2} y_t^2 \left(m^2_{Q_3} + m^2_{u_3} + |A_t|^2 \right) \log\left(\frac{\Lambda}{\rm TeV}\right)$$

$$\delta m^2_{H_u}|_{\rm gluino} \propto \frac{1}{16\pi^2} y_t^2 \left(\frac{\alpha_s}{\pi}\right) |M_3|^2 \log^2\left(\frac{\Lambda}{\rm TeV}\right)$$



Papucci, Ruderman, Weiler, 1110.6926

Valid also beyond the Minimal Supersymmetric Standard Model (MSSM)

- Typically, SUSY breaking mediation schemes predict $m_{\tilde{W}}, m_{\tilde{B}} < m_{\tilde{g}}$

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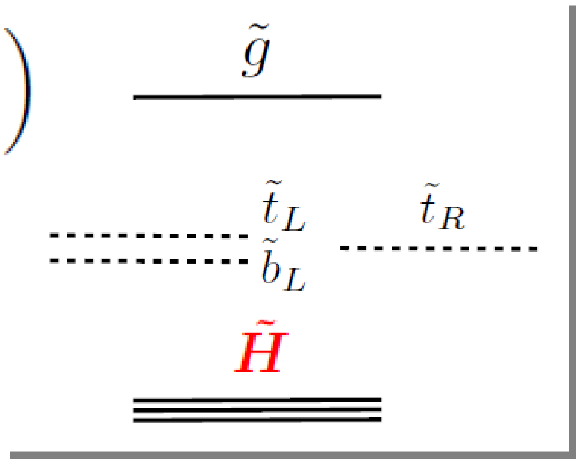

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Conclusion.

Naturalness ➡ EW particles generically at the bottom of the SUSY spectrum

Motivation II: Susy and Un-Naturalness

- A "simply un-natural Susy spectrum": gauginos quite lighter than sfermions

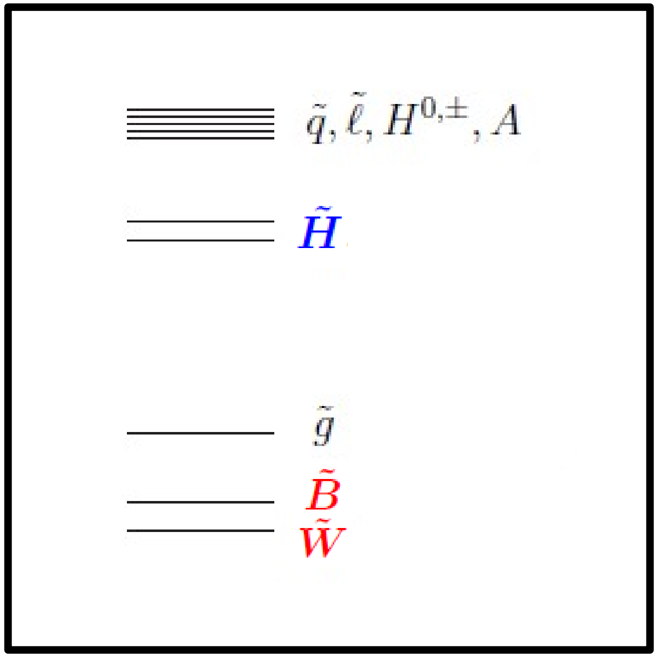
Hall, Nomura '11
Arvanitaki et al. '12
Arkani-Hamed et al. '12 ...

Split Susy inspired models

$$\mathcal{L}_{\rm SB} \supset \frac{1}{M_*^2}\int d^4\theta (X^\dagger X)(\Phi^\dagger\Phi + H_u H_d)$$

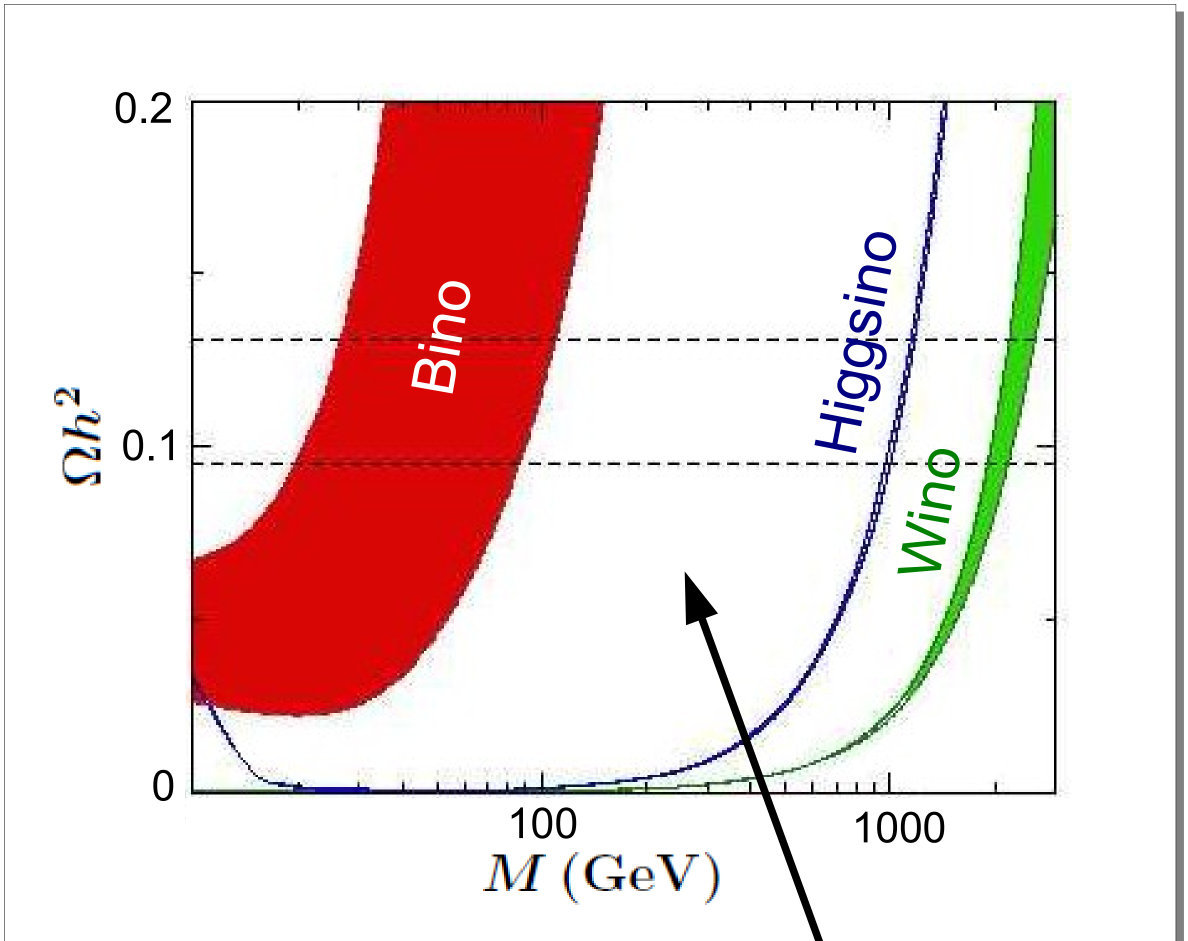
$$-\frac{\alpha_i b_i}{4\pi}\frac{m_{3/2}}{2}\lambda_i\lambda_i - \frac{m_{3/2}}{2}\tilde{G}\tilde{G} + \int d^4\theta (H_u H_d)$$

- scalar masses of order $F_X/M_* \gtrsim F_X/M_{\rm Pl} = m_{3/2}$
- Higgsino mass model dependent: could be order gravitino mass or additionally suppressed
- gaugino masses 1-loop factor below the gravitino mass



Motivation III: Susy and Dark Matter

Supersymmetry has a "natural" DM candidate, once the R-parity is imposed: the lightest SUSY particle (LSP)



Arkani-Hamed, Delgado, Giudice, 0601041

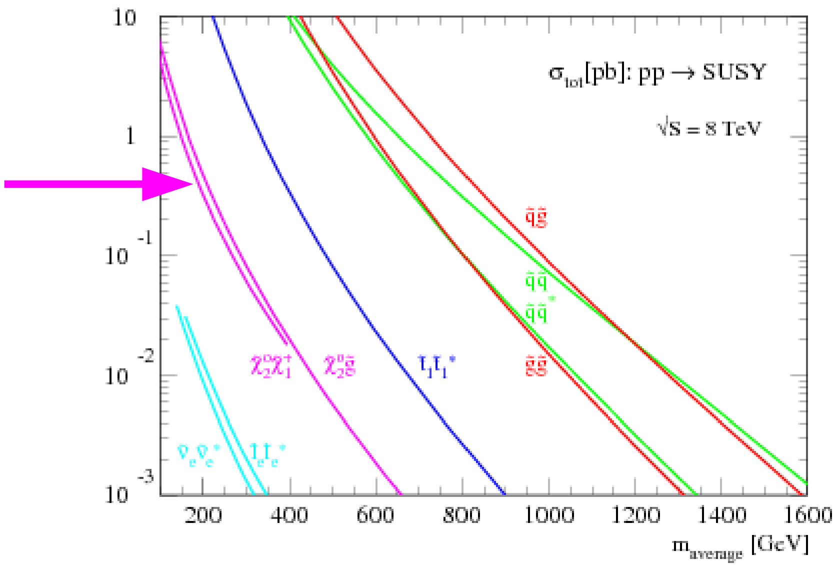
"Well tempered Neutralino"

Higgsino, Binos, Winos can be DM

They can even account for the measured relic density.

Two scales to aim for
Higgsino: ~1TeV
Wino: ~2.5TeV

Present status of EW-ino searches



At 400 GeV:

$$\sigma(\tilde{g}\tilde{g}) \sim 20\,\mathrm{pb}$$
$$\sigma(\tilde{\chi}^{\pm}\tilde{\chi}^{\pm}) \sim 0.02\,\mathrm{pb}$$

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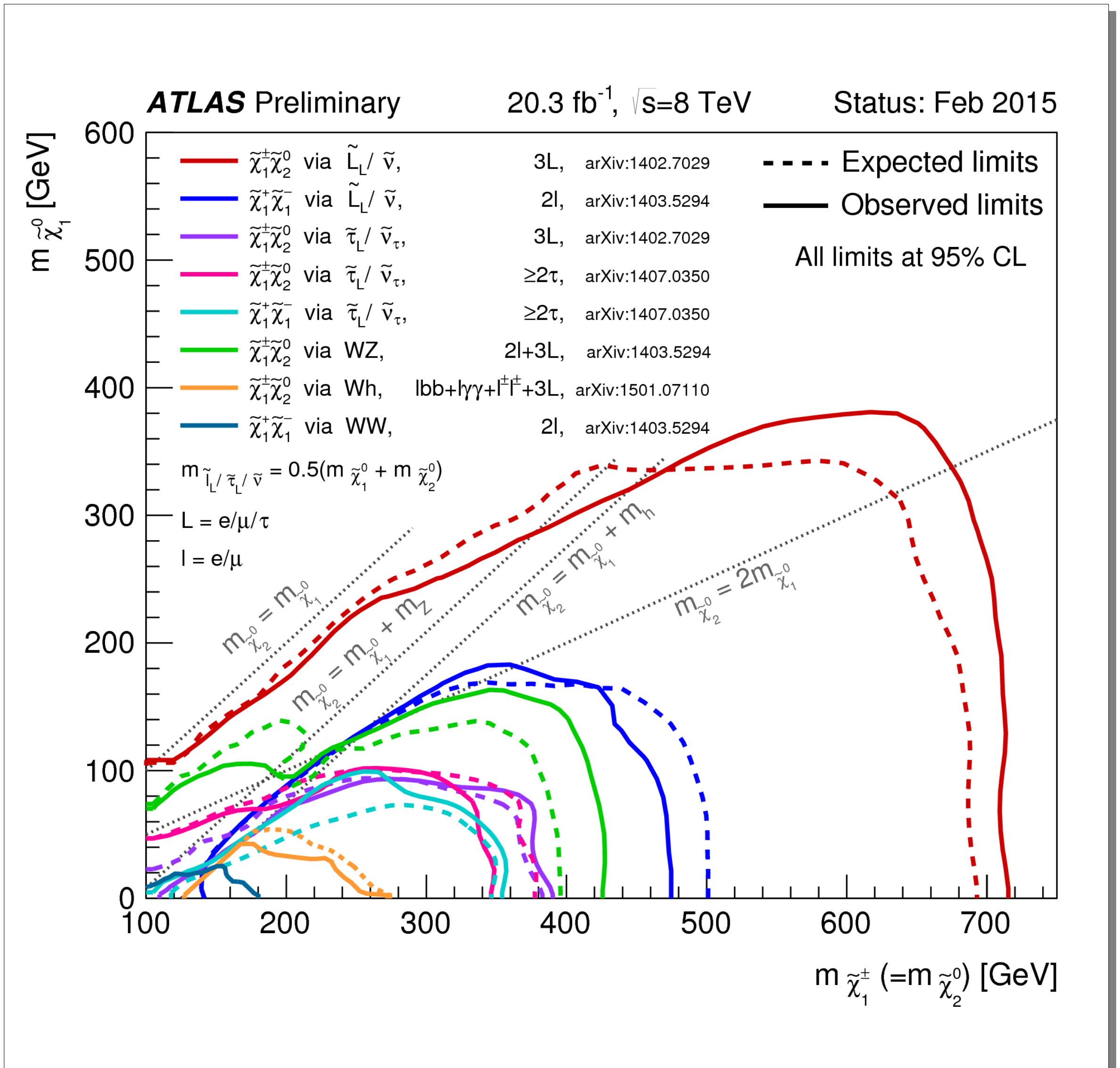

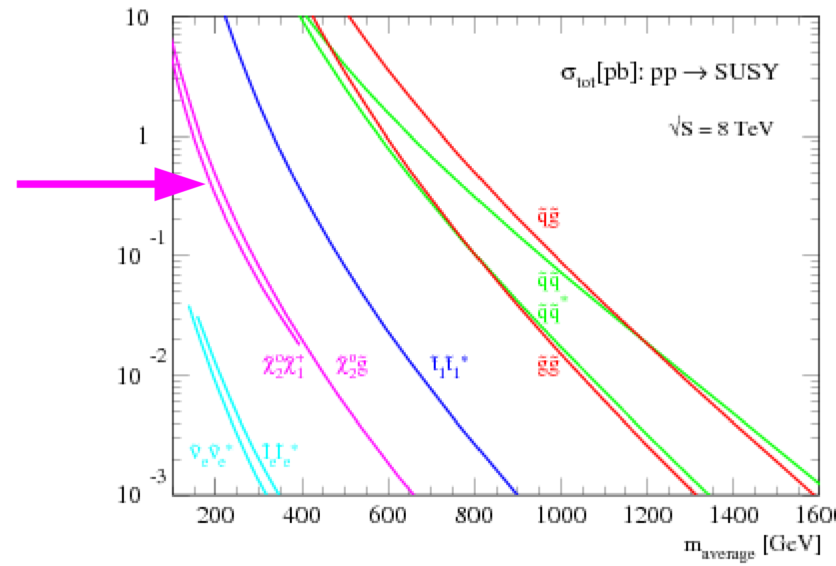

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 S.Gori

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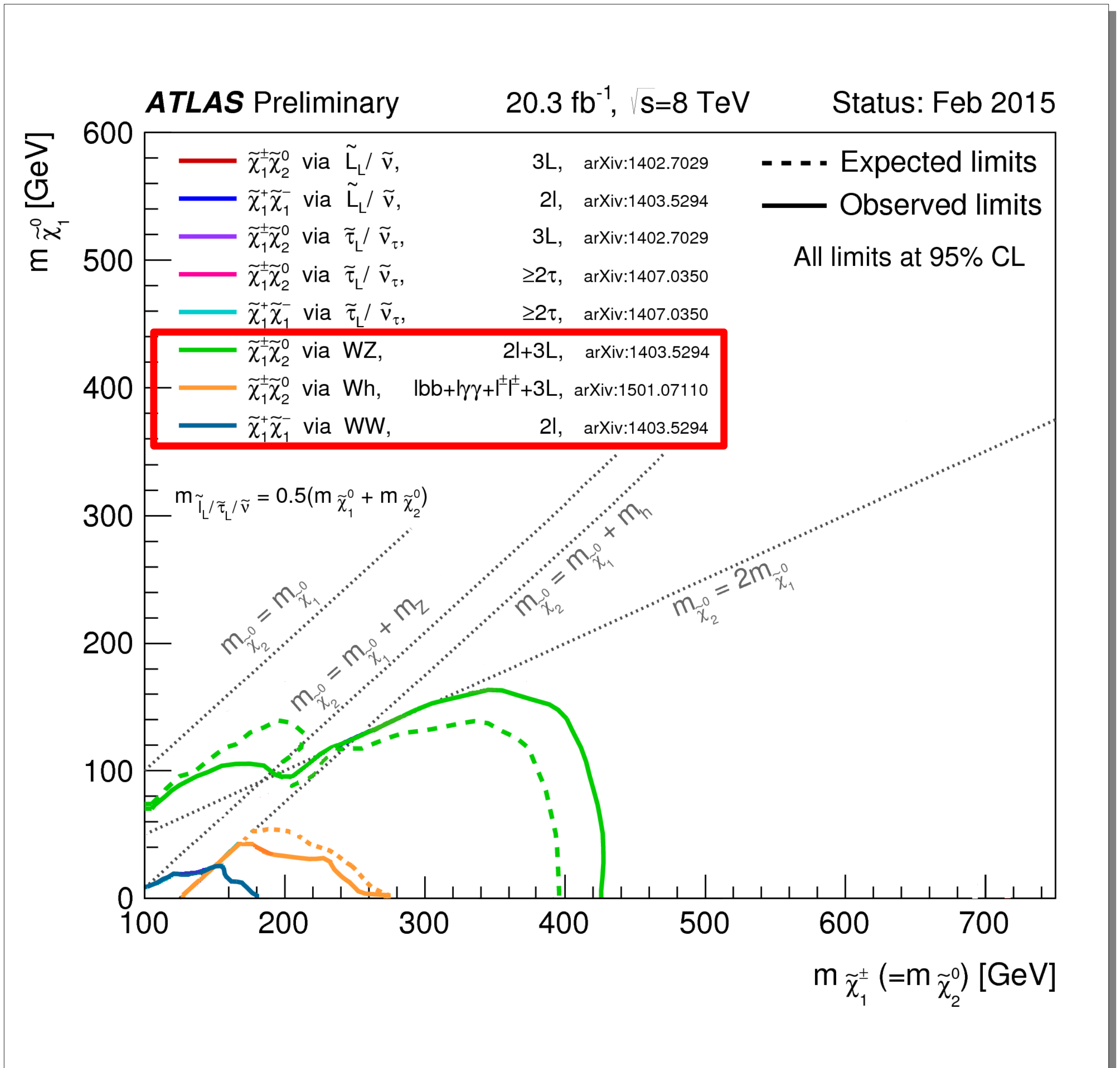

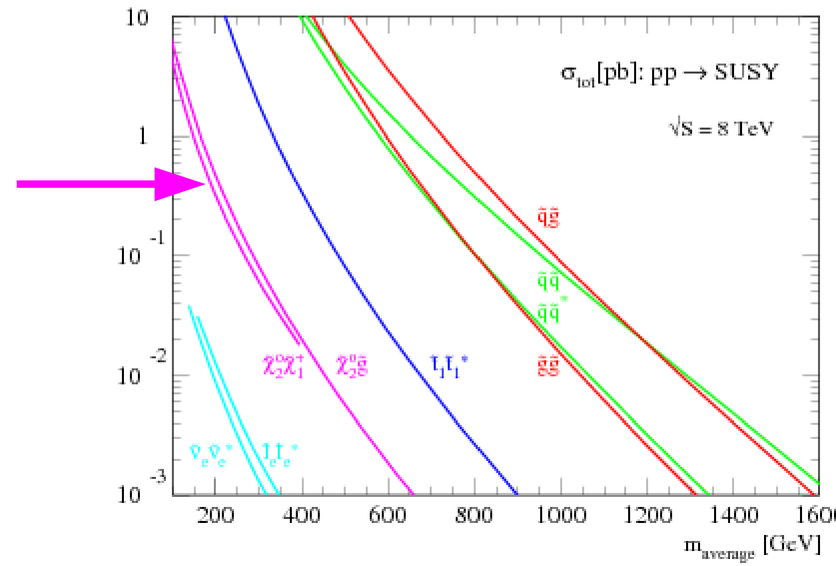

$$\begin{cases} \chi_1^{\pm} \rightarrow W^{(*)}\chi_1^0 \rightarrow (\ell\nu, qq)\chi_1^0, \\ \chi_2^0 \rightarrow Z^{(*)}\chi_1^0 \rightarrow \ell\ell\chi_1^0 \end{cases}$$

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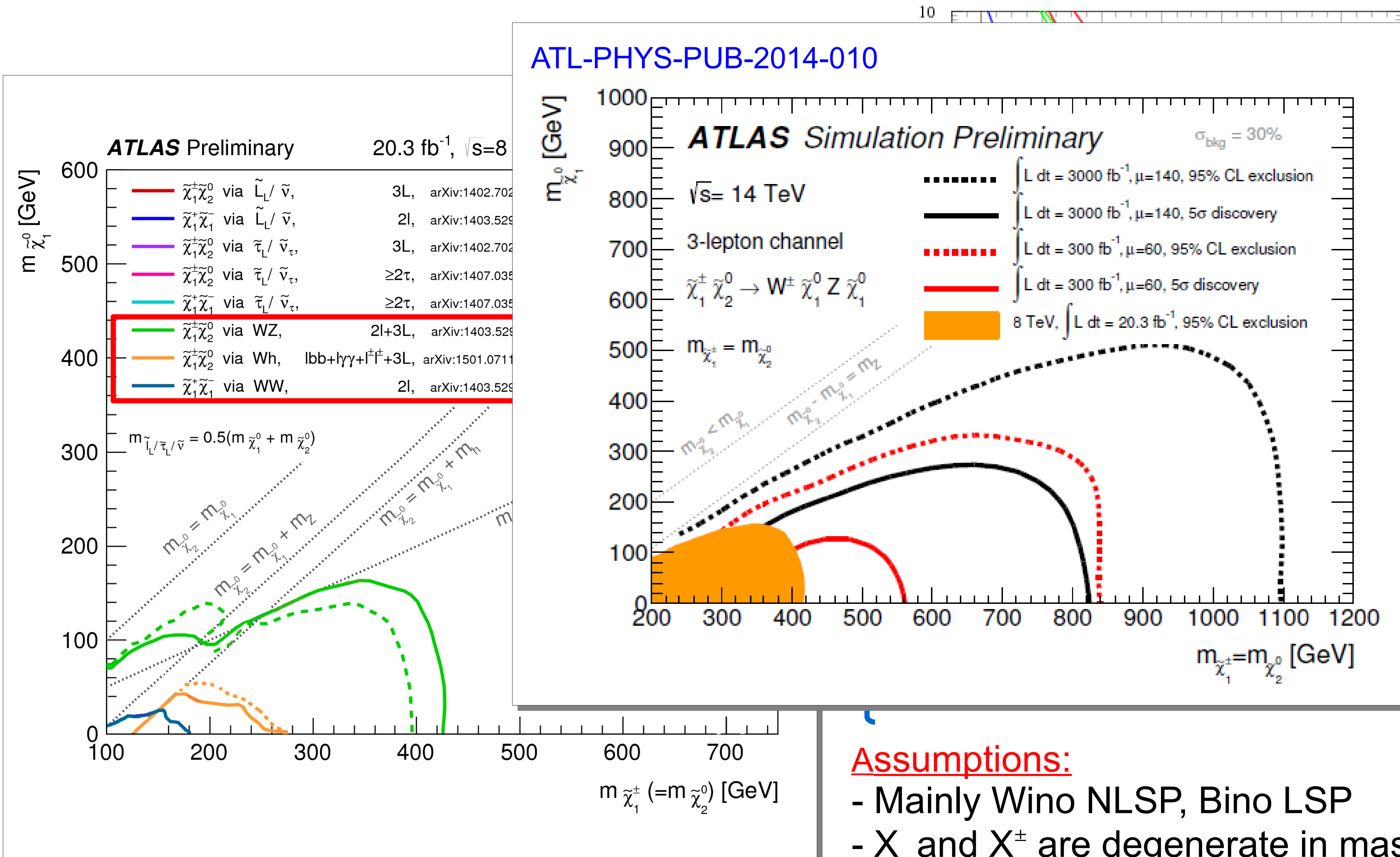
$$\left\{ \chi_1^{\pm} \rightarrow W^{(*)}\chi_1^0 \rightarrow \ell\nu\chi_1^0 \right.$$

Assumptions:

- Mainly Wino NLSP, Bino LSP
- X_2 and $X^{\pm}$ are degenerate in mass
- 100% branching ratios

Projections of EW-ino searches



Assumptions:

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"EW questions" for the next few years

14 TeV LHC vs. 7-8 TeV LHC

- Production cross sections increase by a factor of ~2 (for ~400GeV ew-inos)
- Much more luminosity achievable (3000 fb^{-1} vs. ~25 fb^{-1})
- Cross sections of subleading production modes become relevant:
  VBF production of ~200GeV charginos at the level of O(10fb)

- Can additional production modes play an important role?
- How can we probe the squeezed region?
- What can the Higgs tell us?
- Will we be able to have access to a pure Higgsino or Wino state DM?
  If not, what energy do we need?

Squeezed region

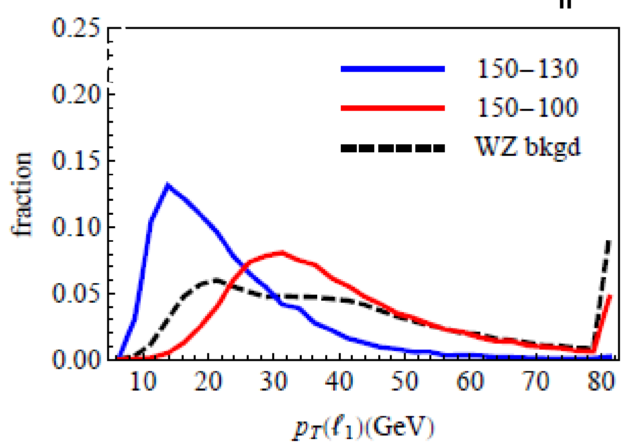
- Why is it difficult?

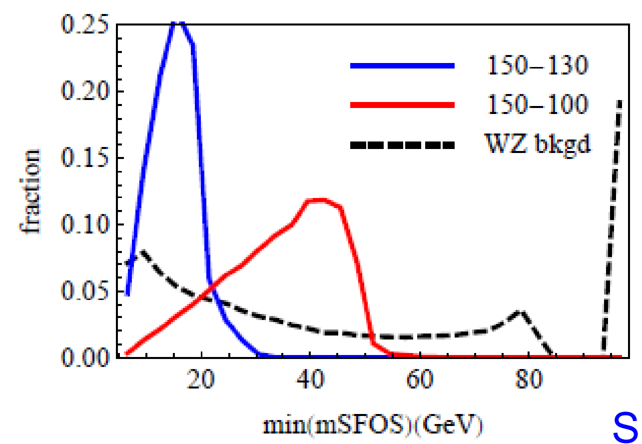
$$\chi_2^0 \rightarrow Z^{(*)}\chi_1^0 \rightarrow \ell\ell + \mathrm{MET}$$
$$\chi_1^\pm \rightarrow W^{(*)}\chi_1^0 \rightarrow \ell + \mathrm{MET}$$

- Small lepton p_T and small MET.
- Small invariant mass of opposite sign same flavor leptons (OSSF) m_{ll}

Present multi-lepton searches ask for

- Single or di-lepton trigger (~ 10 GeV - 20 GeV)
- m_{ll} > 12 GeV





SG, Jung, Wang, 1307.5952

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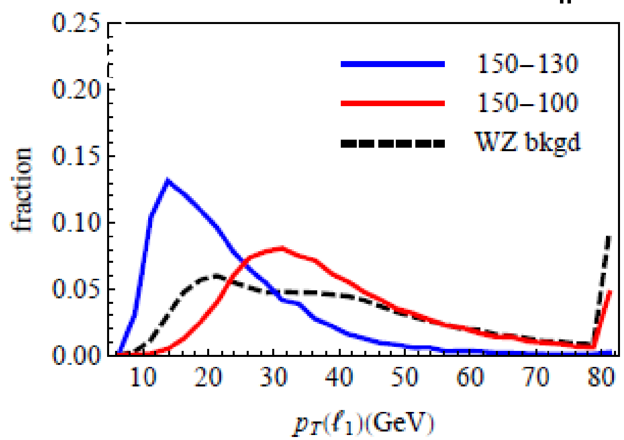

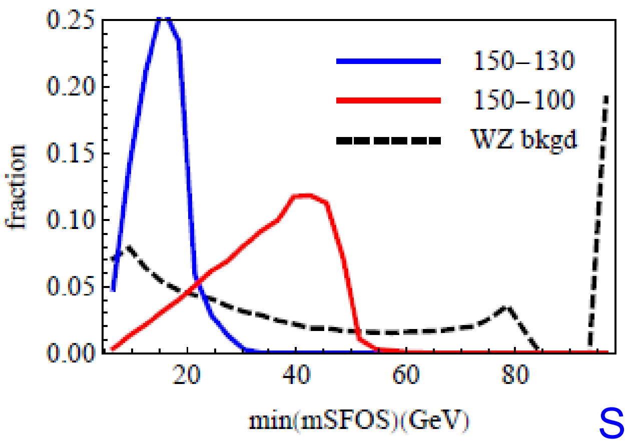

SG, Jung, Wang, 1307.5952

- How to do better?

Production of ew-inos in association with something

- VBF production (VBF trigger?) see for example Giudice, Han, Wang, Wang, 1004.4902
- EW-inos produced in association with one jet/photon/Z

Mono-something trigger or trigger on the decay products of the EW-inos?

Proposed search: ISR jet+3 (soft) leptons

SG, Jung, Wang,1307.5952

$$pp \to \chi_2^0 \chi_1^\pm + j$$

$$\chi_2^0 \to Z^{(*)} \chi_1^0 \to \ell\ell + \mathrm{MET}$$
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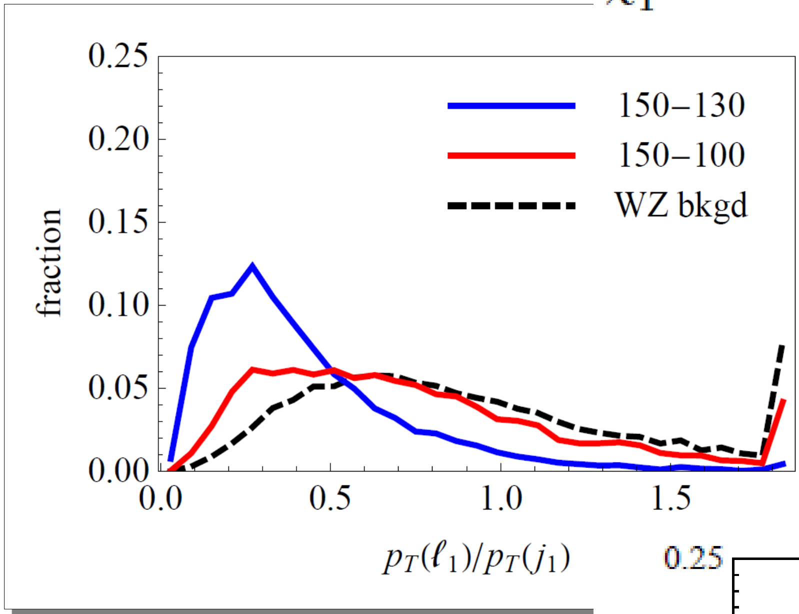
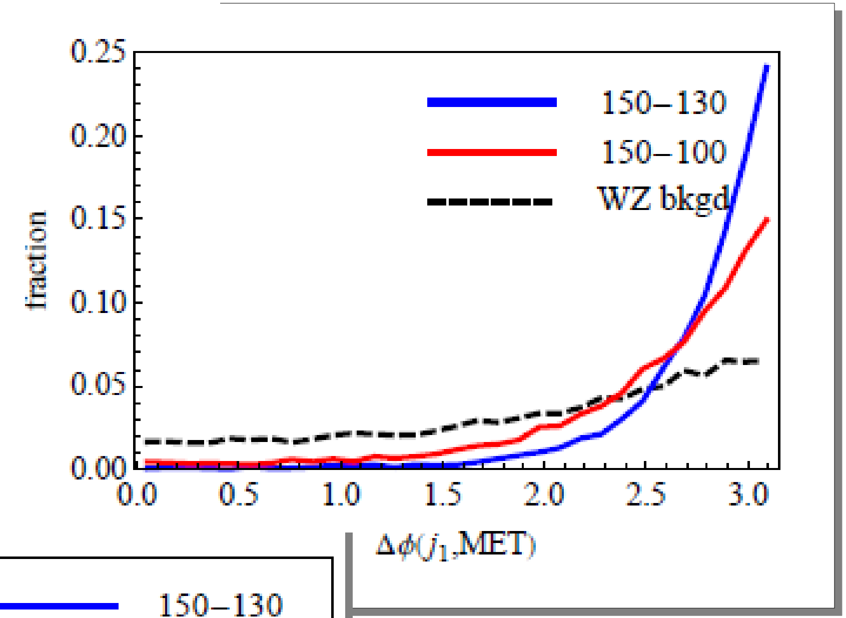
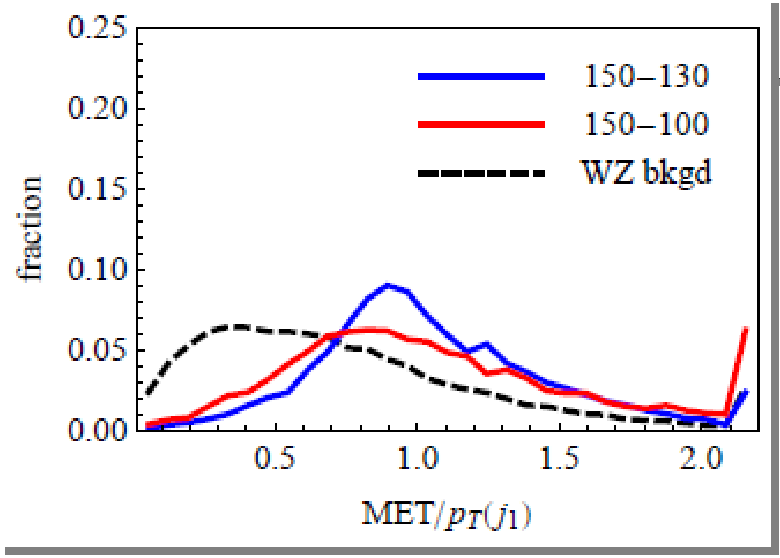




$$-\vec{E}_T^{\mathrm{miss}} = \vec{p}_T(j_1) + \sum \vec{p}_T(\ell),$$

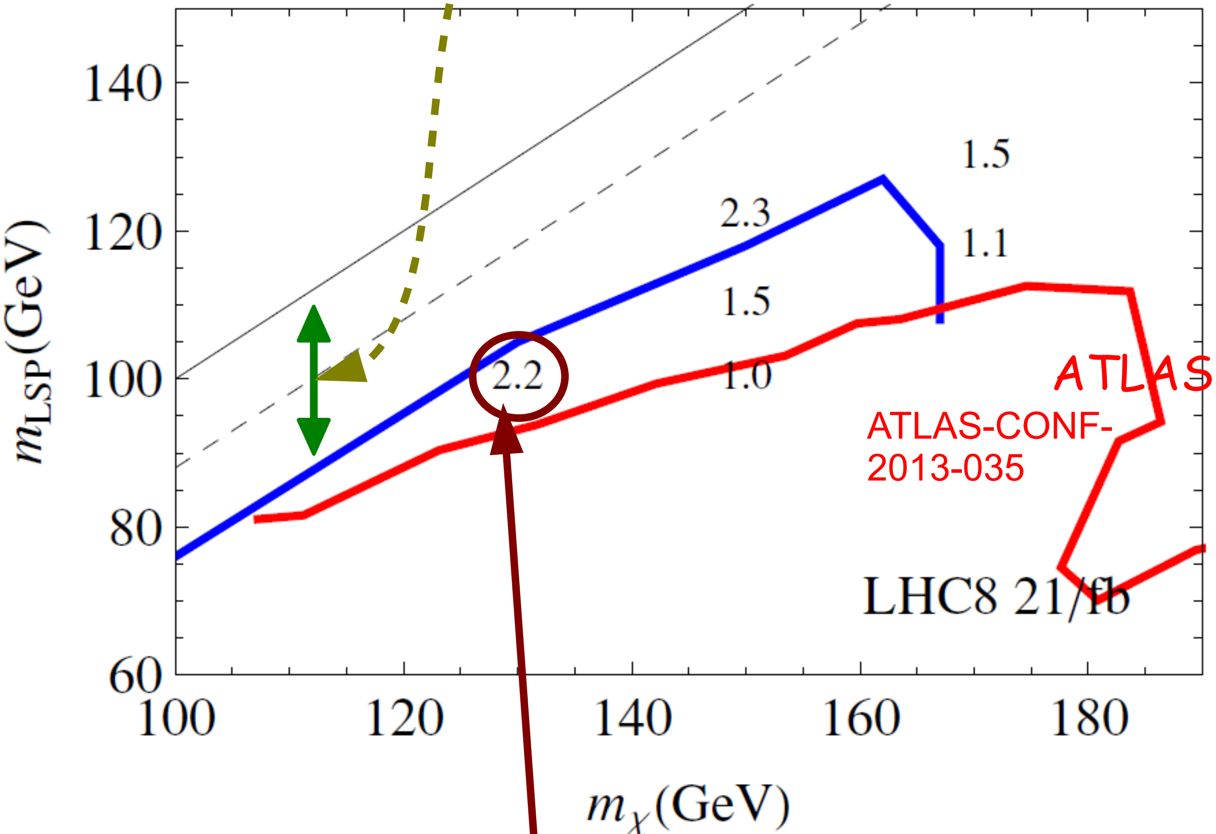
$$|\vec{p}_T(\ell)| \sim \gamma E_\ell^0$$



Estimation the reach at Run I

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

Call for experimentalists!



SG, Jung, Wang,1307.5952

Improvement on $S/\sqrt{B+(0.15\cdot B)^2}$ in comparison with the ATLAS search

Estimation the reach at Run II

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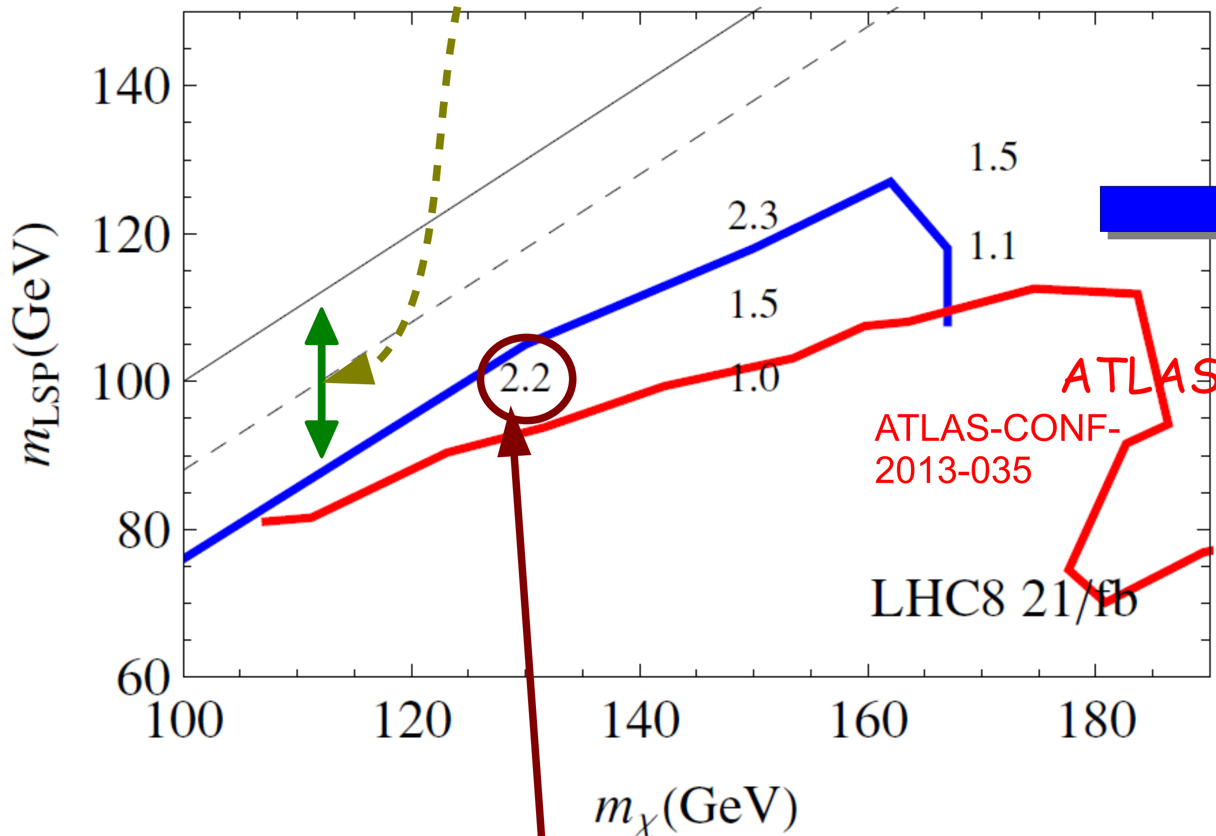

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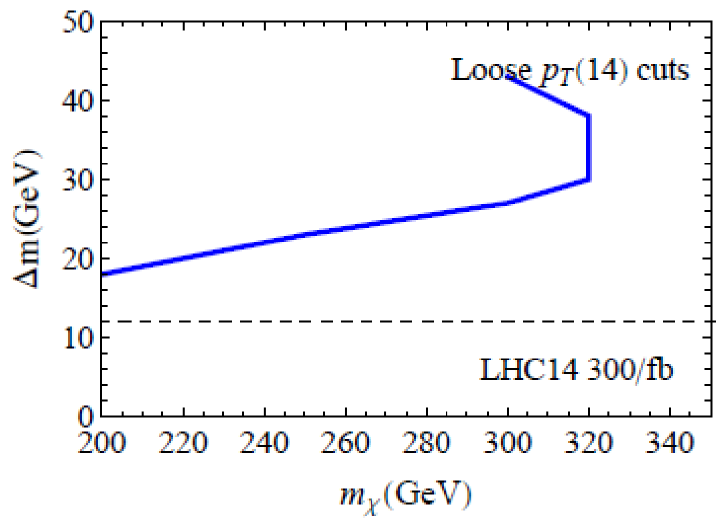
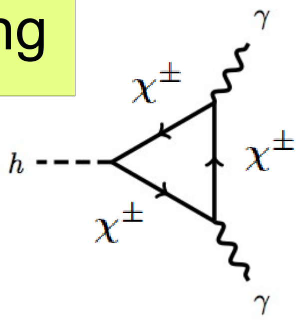
How can we improve on this at Run II?



Improvement on $S/\sqrt{B+(0.15\cdot B)^2}$ in comparison with the ATLAS search

An independent probe: the Higgs

Charginos can be probed by the measurement of the Higgs di-photon coupling



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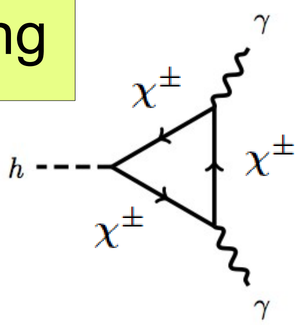

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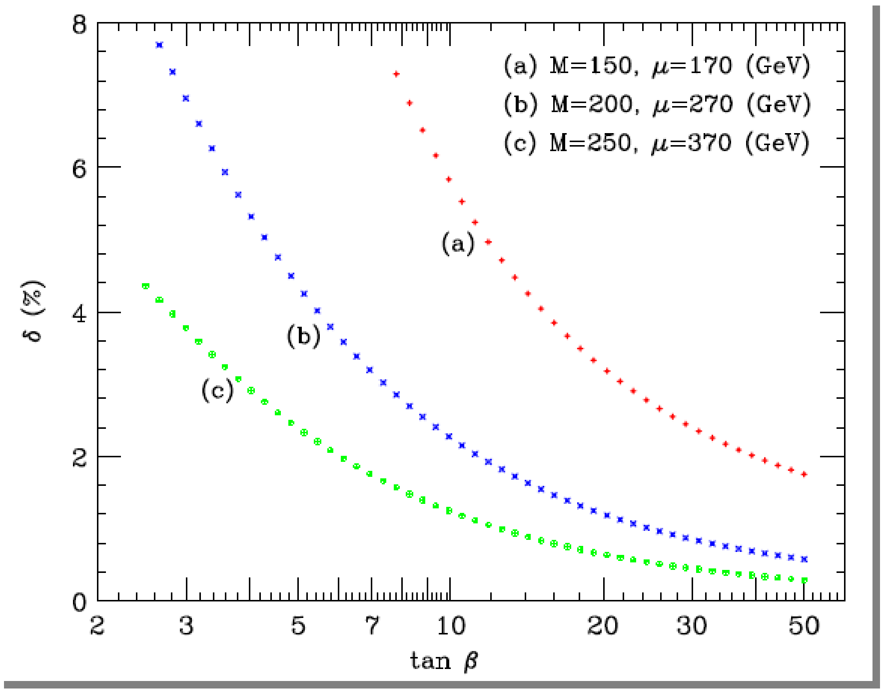
Diaz, Perez, 0412066



$$\frac{\Delta}{(4\pi^2)^2}\frac{h}{v}F_{\mu\nu}F^{\mu\nu}\frac{\partial \log \det(M(v))}{\partial \log v}$$

$$\Rightarrow \Delta A_{\gamma\gamma} \propto -\frac{m_W^2 s_\beta c_\beta}{M_2 \mu}$$

The NP effects are typically small,
but could be accessible in the future

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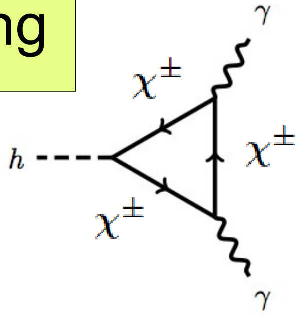

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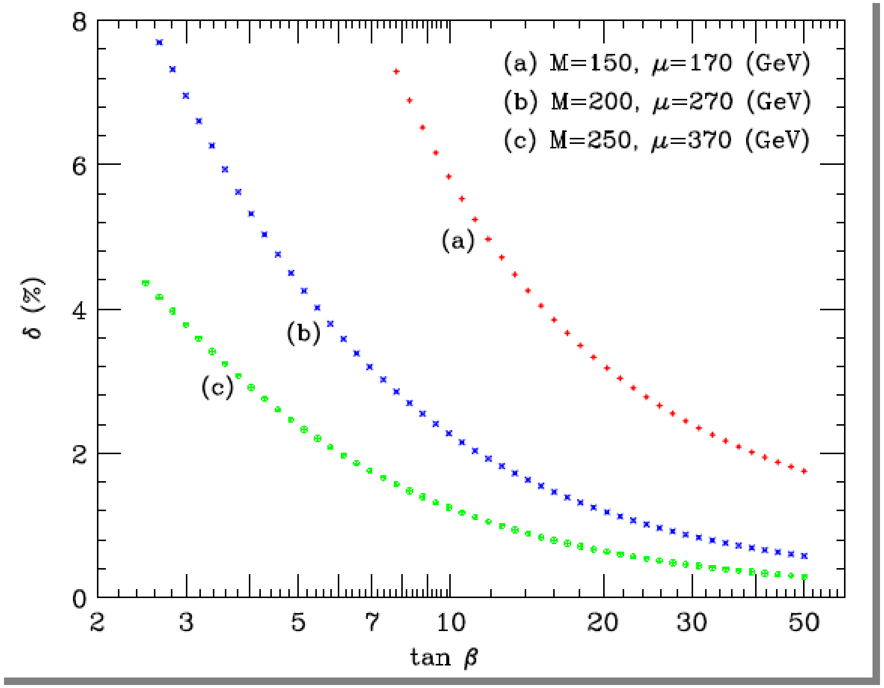

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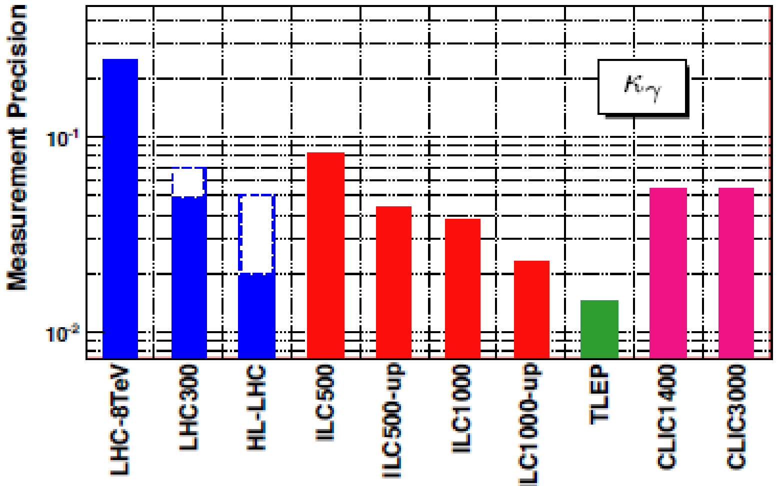

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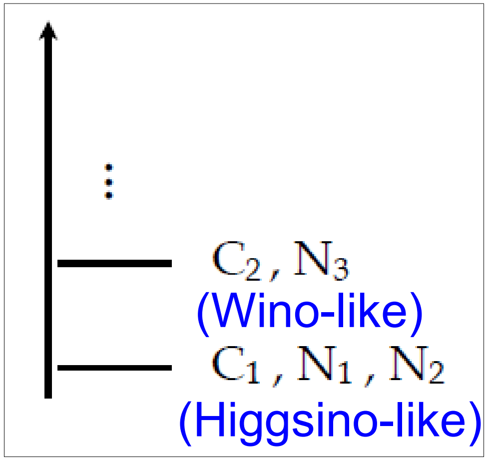
1401.6081 Snowmass

"EW questions": testing DM models

- How much are higher energies going to buy us in the reach for EW particles?
- Can we have access to pure Higgsino (or Wino) states, as possible DM candidates?

1. Wino-Higgsino scenario
   NLSP - LSP



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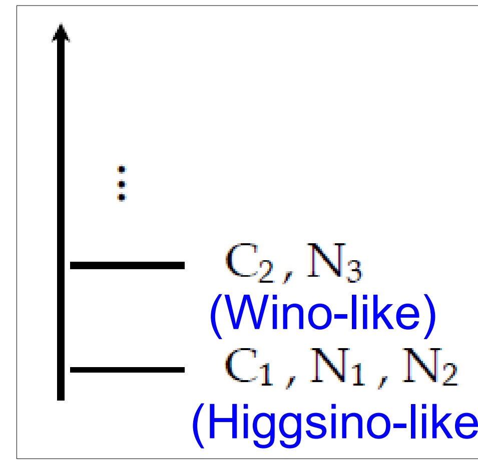

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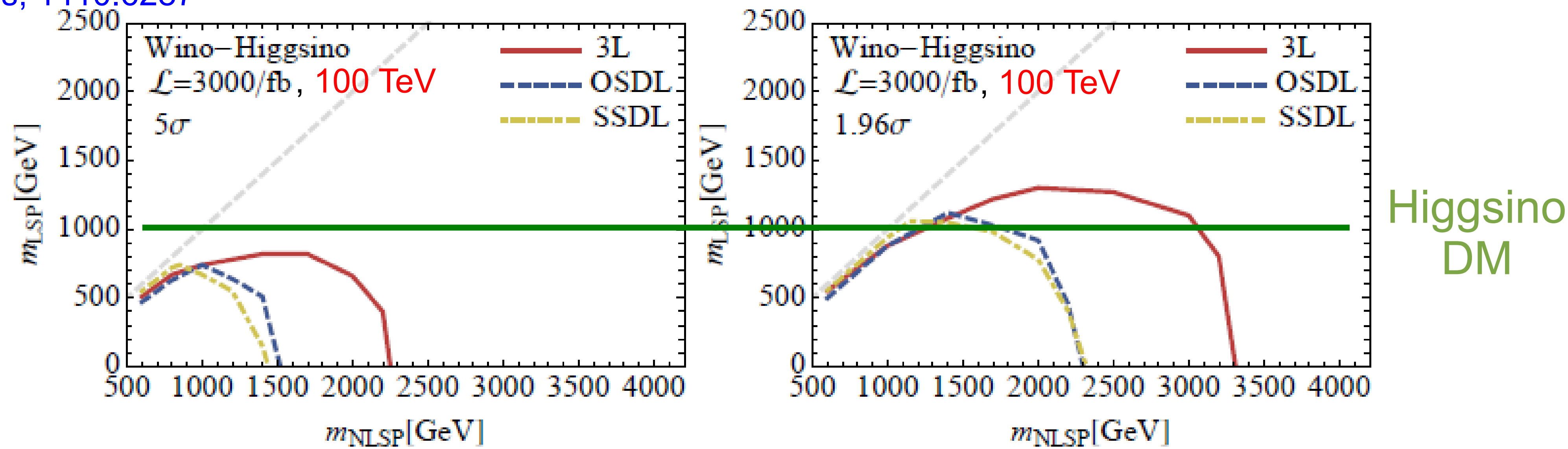
NLSP - LSP

Because of the Goldstone equivalence theorem:
BR(NLSP ⟶LSP Z) = BR(NLSP⟶LSP h) ~ 1/4

Jung, 1404.2691

SG,Jung,Wang, Wells, 1410.6287



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2. Higgsino-Wino scenario

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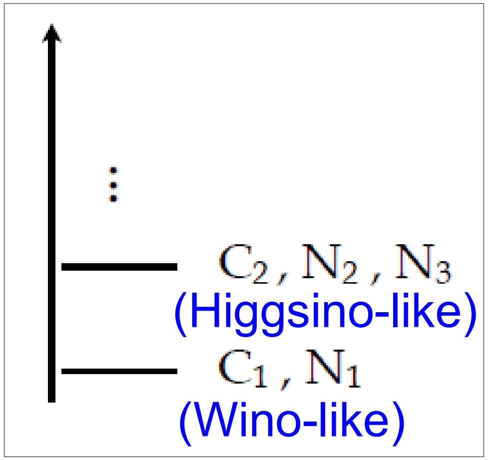

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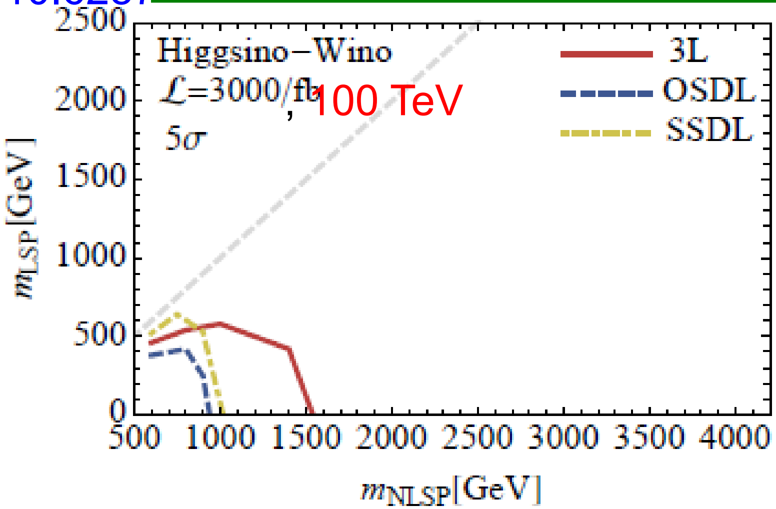
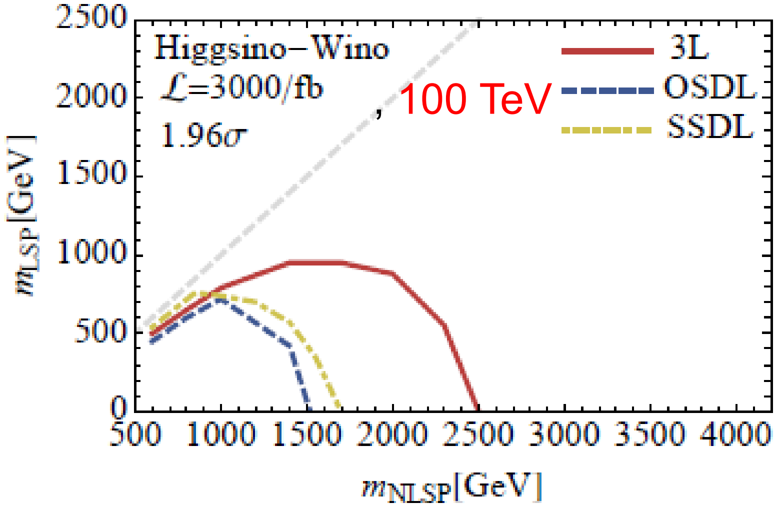
Wino DM





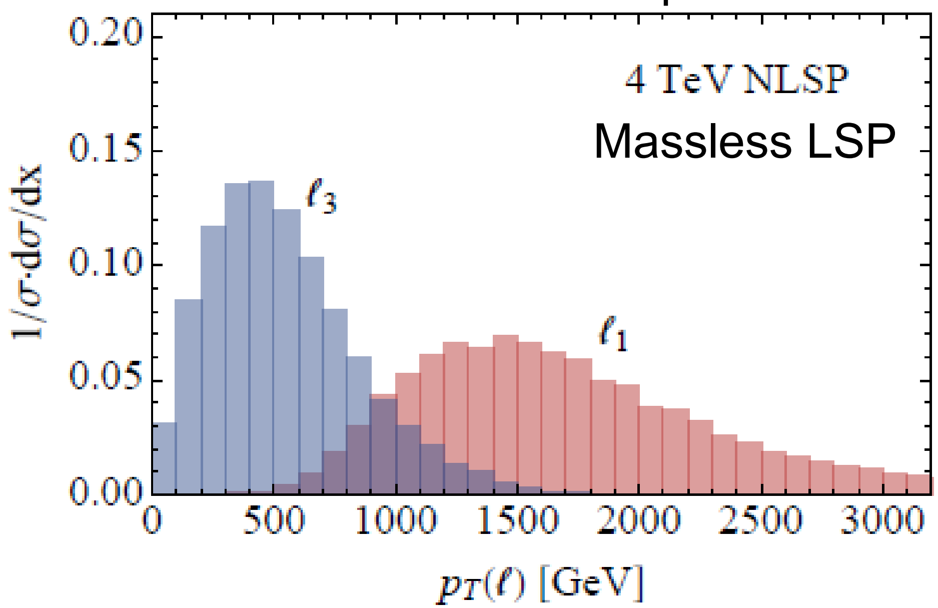
Disappearing track searches could be the route. Low, Wang, 1404.0682

A brand new collider!

Issues and opportunities

Identification of very boosted leptons.
Measurement of their flavor and charge

Distributions for the 3 lepton channel



The SSDL channel can be particularly affected by this issue

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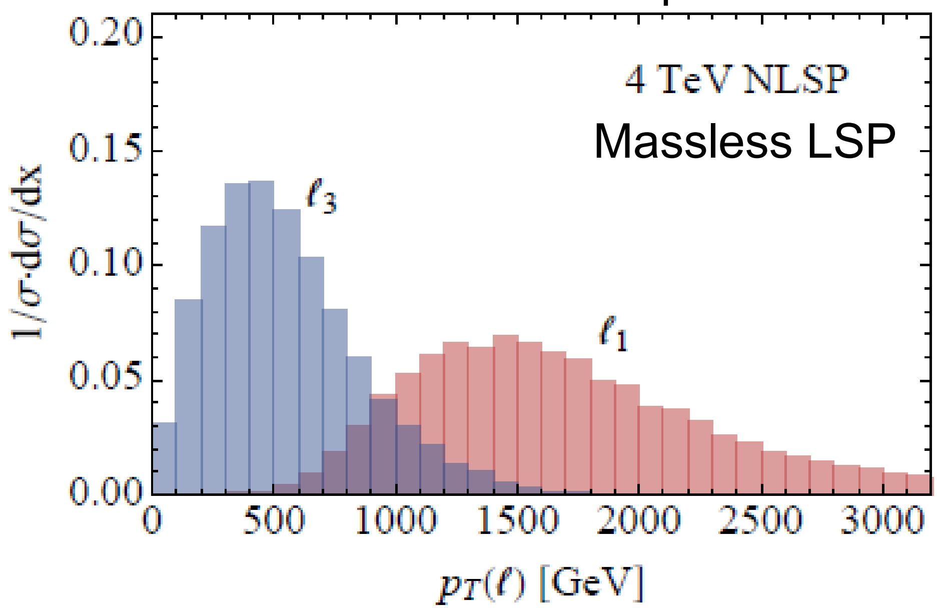

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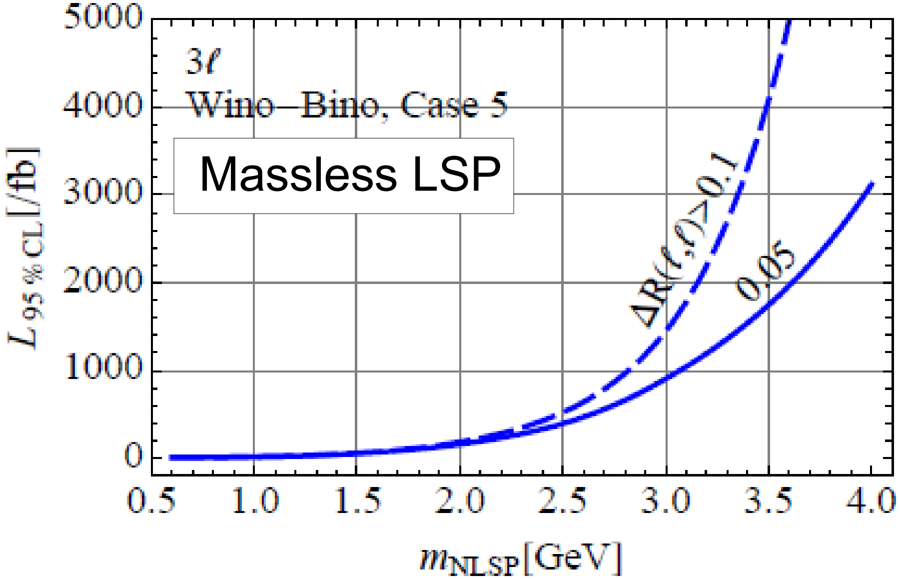
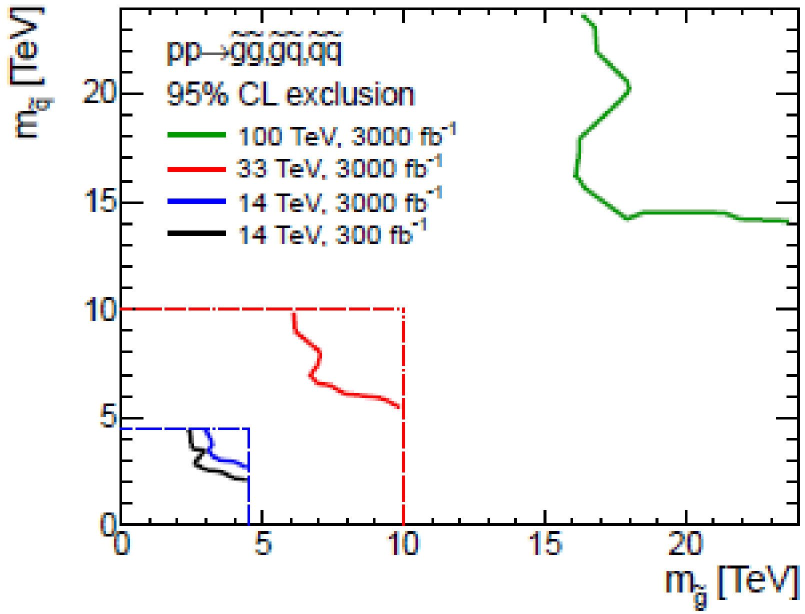
Lepton separation criterion will affect a lot the reach of the 3 lepton channel



Comparison with the gluino reach

Split Susy also implies not too heavy gluinos.
How does the reach compare?

From Cohen et al. 1311.6480



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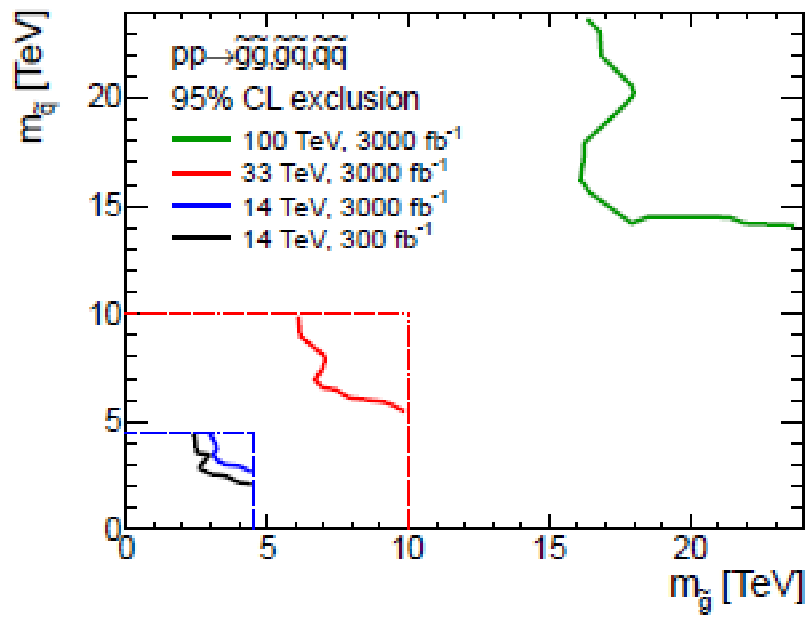


Similar argument for the LHC
~3 TeV reach for gluinos

In mSUGRA:
$M_1 : M_2 : M_3 \sim 1:2:6$
➡ $M_1 \geq 2.5$ TeV, $M_2 \geq 5$ TeV

Independently on the Higgsino mass, we cannot probe such heavy Binos, Winos

In AMSB:
$M_1 : M_2 : M_3 \sim 3:1:8$
➡ $M_1 \geq 5.5$ TeV, $M_2 \geq 2$ TeV

This scenario can be probed by the 3 lepton signature if Higgsinos are lighter than ~1.2 TeV
(Wino-Higgsino scenario)

Conclusions & remarks

Electroweakinos play a special role in natural and un-natural SUSY theories

- Great prospects for probing "difficult regions" in the coming years: squeezed spectra!

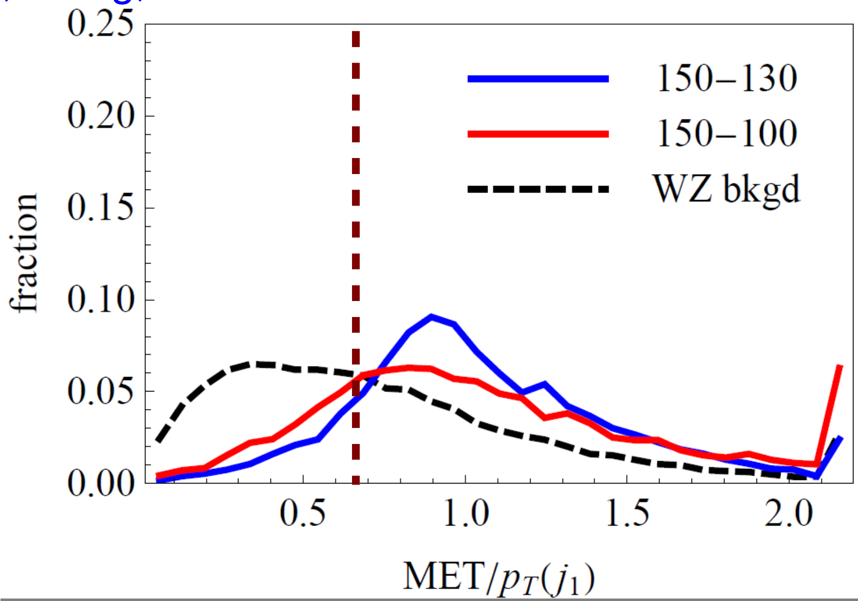
- Looking more forward: the role of future colliders

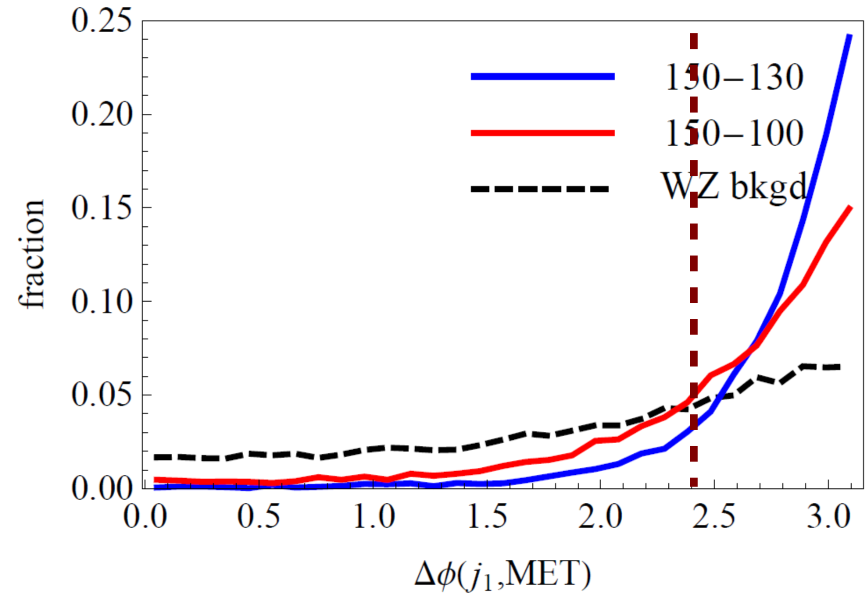
- Higgs coupling measurements can play an important role

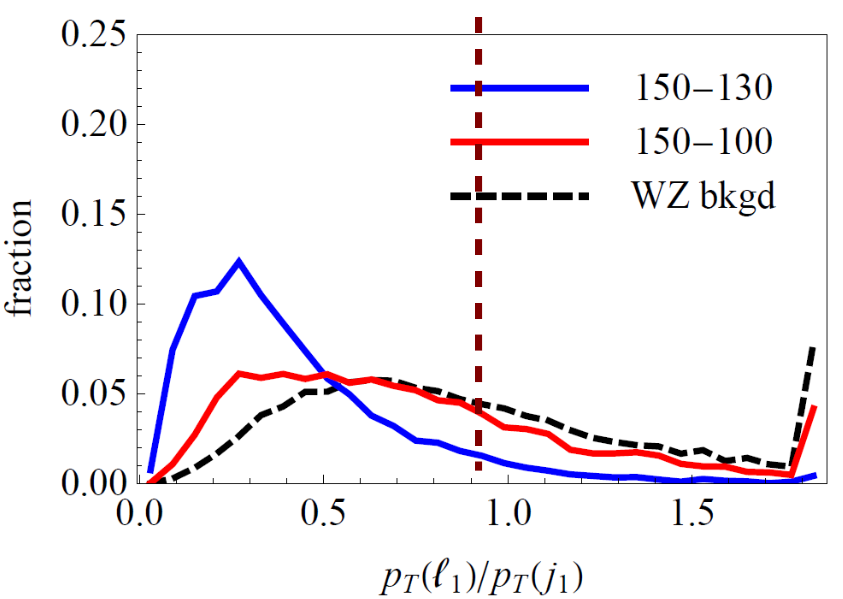
- A 100 TeV pp collider with 3000 fb^{-1} data could probe Higgsino Dark Matter, if Winos are not too heavy

Proposed search: correlation variables

SG, Jung, Wang,1307.5952







Some kinematics:

$$-\vec{E}_T^{\mathrm{miss}} = \vec{p}_T(j_1) + \sum \vec{p}_T(\ell), \qquad |\vec{p}_T(\ell)| \sim \gamma E_\ell^0$$

$$(E_\ell^0)_{\mathrm{sig}} \sim \Delta,\ \Delta \equiv m_{\chi_2} - m_{\mathrm{LSP}} \ll m_{\chi_2}$$

$$(E_\ell^0)_{\mathrm{bkgd}} \sim m_{W,Z}/2$$

$$\gamma \sim \frac{\sqrt{p_T^2(j_1)/4 + M^2}}{M}$$

$$M_{\mathrm{sig}} \sim m(\chi_2),\ M_{\mathrm{bkgd}} = m_{\mathrm{W,Z}}$$