Almost invisible electroweakinos

Stefania Gori

Perimeter Institute

TRIUMF theory workshop on
Cosmology at Colliders

Vancouver,
December 9th 2013

Outline

1. **Introduction:**
   Status of the LHC searches for electroweakinos

2. **Difficult searches:**
   electroweakinos in a squeezed spectrum

   Review of the possible searches to close the gap

   - VBF production
   - ISR jet
     - Monojet
     - Jet+soft leptons

Light Electroweakinos

- Naturalness wants Higgsino to be light.

  since the μ parameter enters the Higgs potential at tree level

$$\frac{m_Z^2}{2} = -|\mu|^2 - \frac{m_{H_u}^2 \tan^2\beta - m_{H_d}^2}{\tan^2\beta - 1}$$

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

Split Susy inspired models
Hall, Nomura '11
Arvanitaki et al. '12
Arkani-Hamed et al. '12 ...

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

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

★ scalar masses of order
$F_X/M_* \gtrsim F_X/M_{\rm Pl} = m_{3/2}$

★ gaugino masses from anomaly mediation,
1-loop factor below the gravitino mass

★ Higgsino mass model dependent:
could be order gravitino mass
or additionally suppressed

Wolfgang's talk

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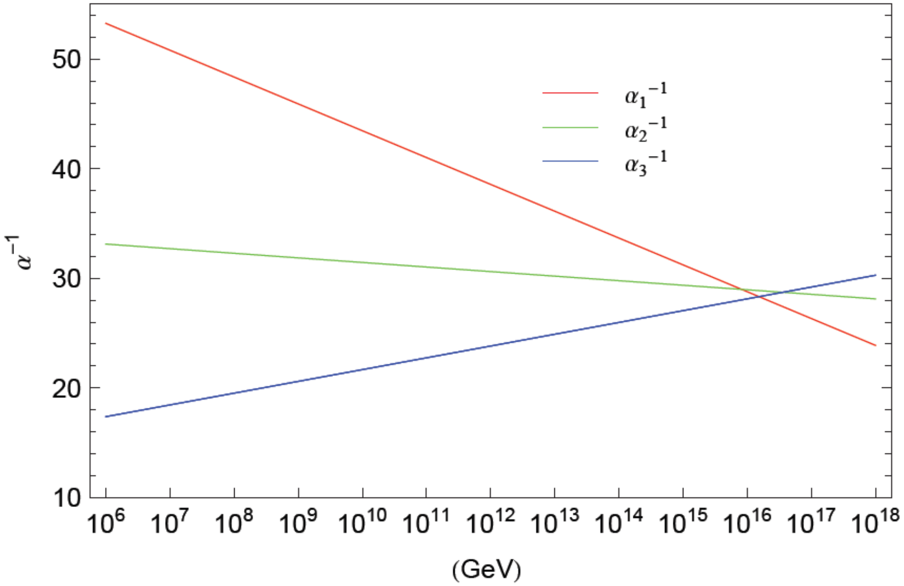
- Light gauginos alone can preserve gauge coupling unification



Scalar and Higgsino masses fixed at 10^3 TeV, gluino at ~15 TeV, wino at ~2 TeV

From Arkani-Hamed et al. 1212.6971

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- Light gauginos alone can preserve gauge coupling unification

- EWKino masses get less renormalized than the gluino mass.

$$\beta_{M_i} \propto \frac{g_i^2}{16\pi^2} M_i$$

Even starting from universal conditions at GUT, at the ew scale the gluino is quite heavier than the ew gauginos

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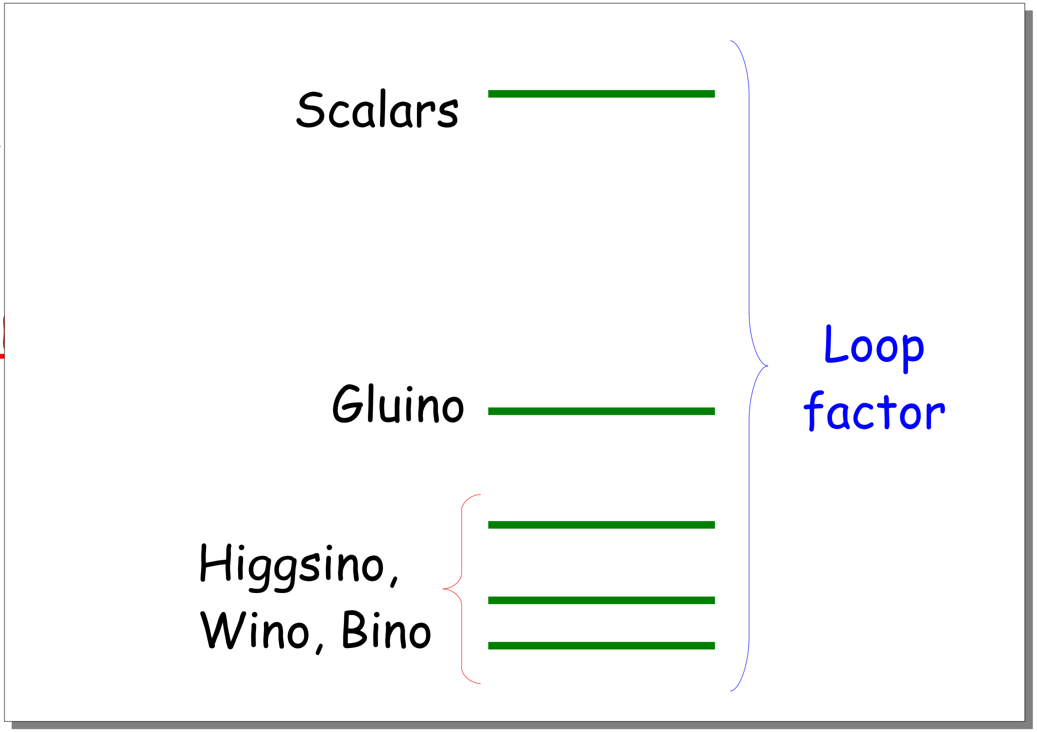


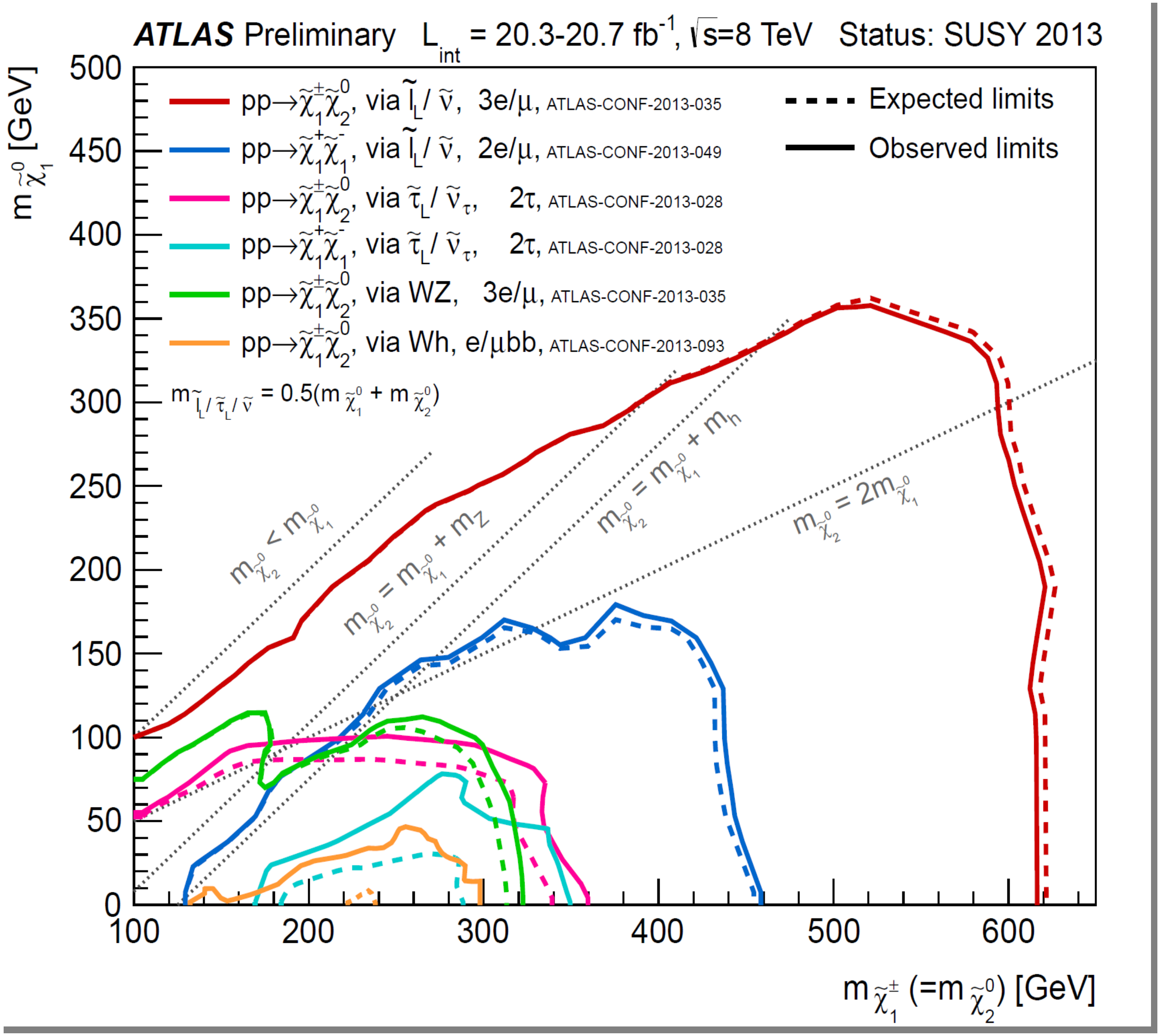
Scalars

Gluino

Higgsino,
Wino, Bino

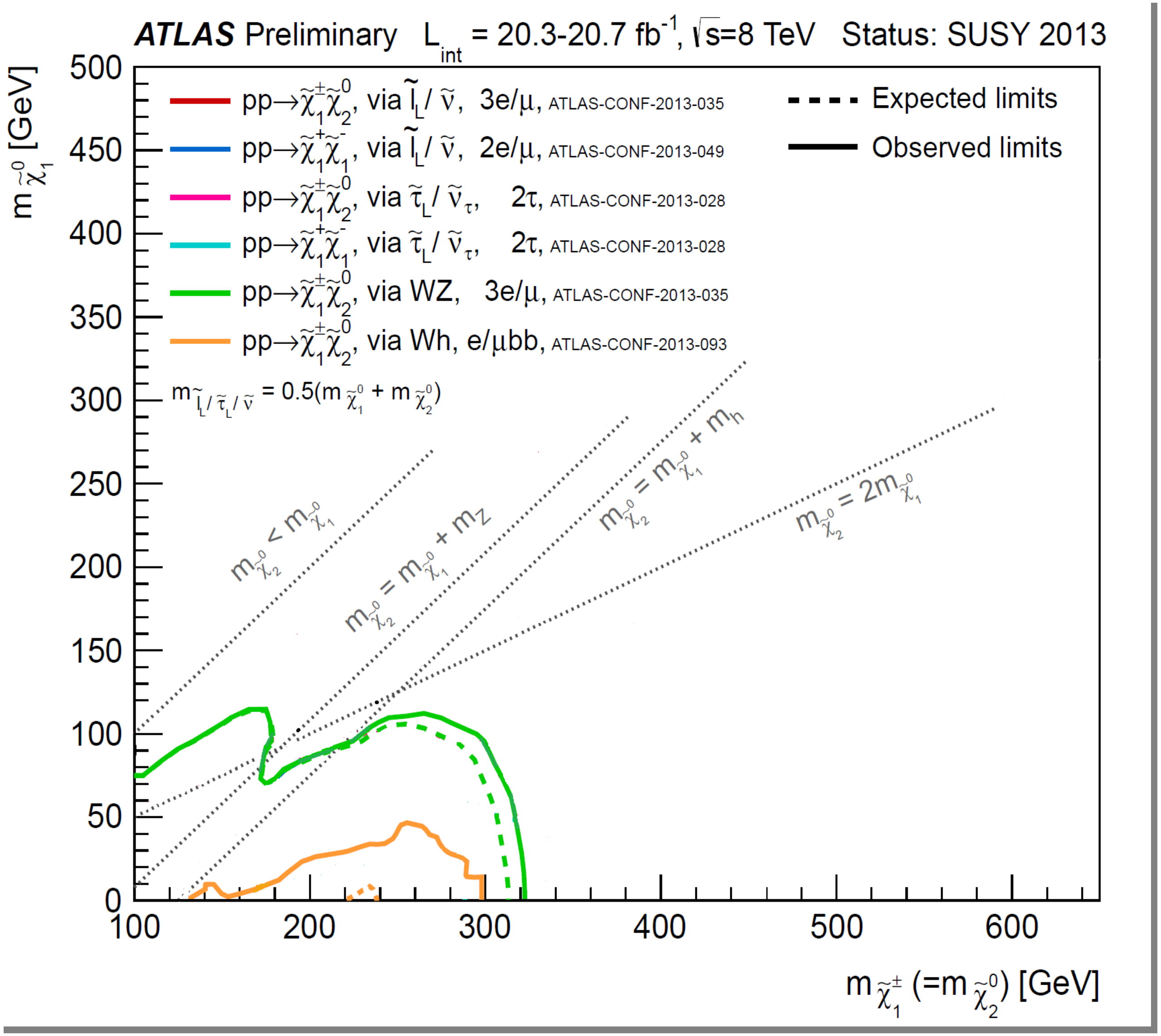
Loop
factor

Electroweakino searches...up to now



See also CMS: SUS-13-006 and SUS-13-017

Electroweakino searches...up to now



$$pp \to \chi_2\chi^\pm$$

$$\begin{cases} \chi_1^\pm \to W^{(*)}\chi_1^0 \to \ell\nu\chi_1^0, \quad (\ell = e,\mu) \\ \chi_2^0 \to Z^{(*)}\chi_1^0 \to \ell\ell\chi_1^0 \end{cases}$$

$$\begin{cases} \chi_1^\pm \to W^{(*)}\chi_1^0 \to \ell\nu\chi_1^0, \quad (\ell = e,\mu) \\ \chi_2^0 \to h\chi_1^0 \to b\bar{b}\chi_1^0 \end{cases}$$

Assumptions:

- Mainly wino NLSP, bino LSP
- X_2 and $X^\pm$ are degenerate in mass
- 100% branching ratios

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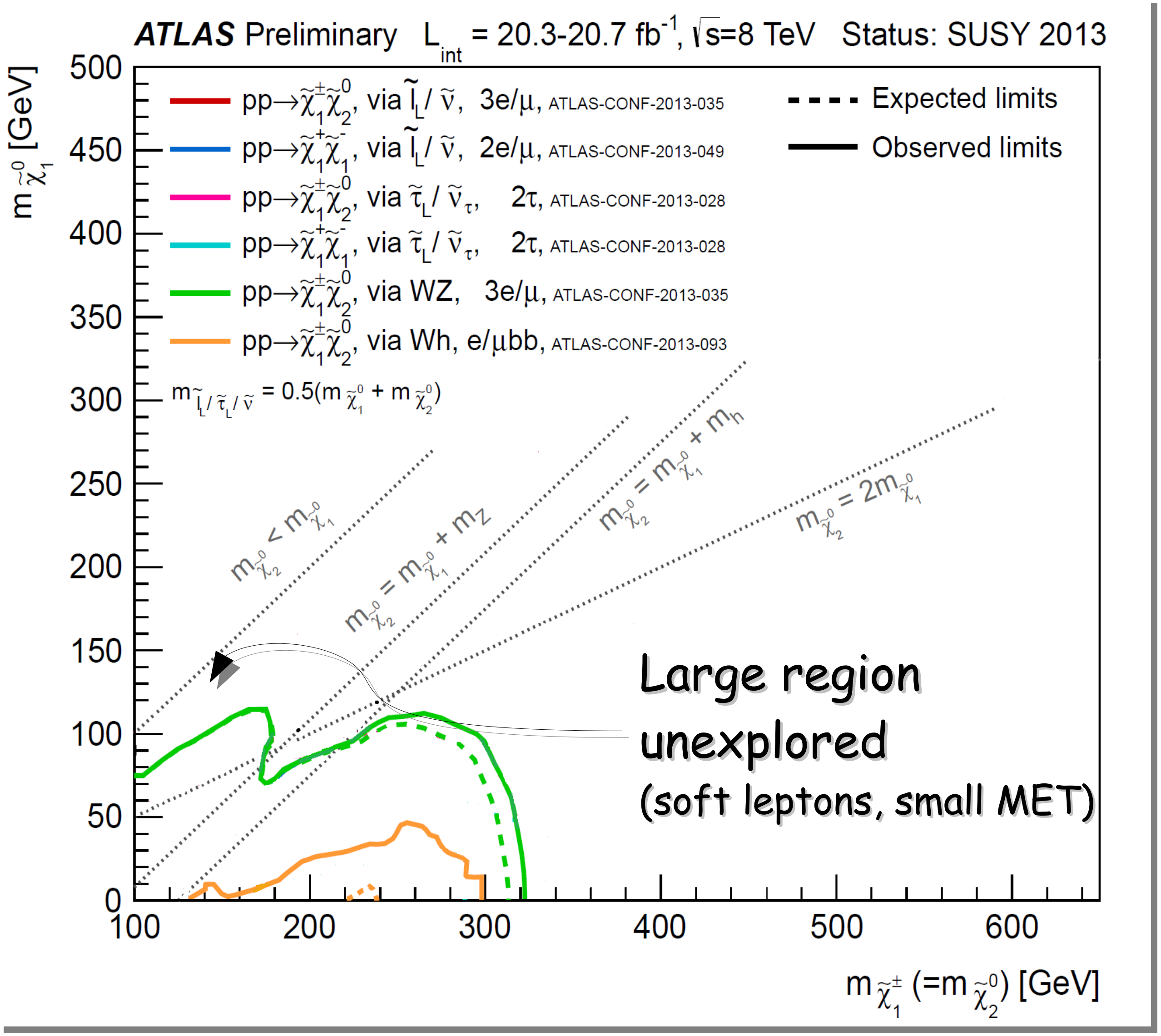

Large region unexplored

(soft leptons, small MET)

$$pp \to \chi_2 \chi^\pm$$

$$\left\{\begin{array}{lll} \chi_1^\pm & \to & W^{(*)}\chi_1^0 \to \ell\nu\chi_1^0, \quad (\ell = e,\mu) \\ \chi_2^0 & \to & Z^{(*)}\chi_1^0 \to \ell\ell\chi_1^0 \end{array}\right.$$

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Window to dark matter?

Some motivations for compression

Well tempered neutralino: Arkani-Hamed, Delgado, Giudice 0601041

Efficient annihilation → no significant mass splitting

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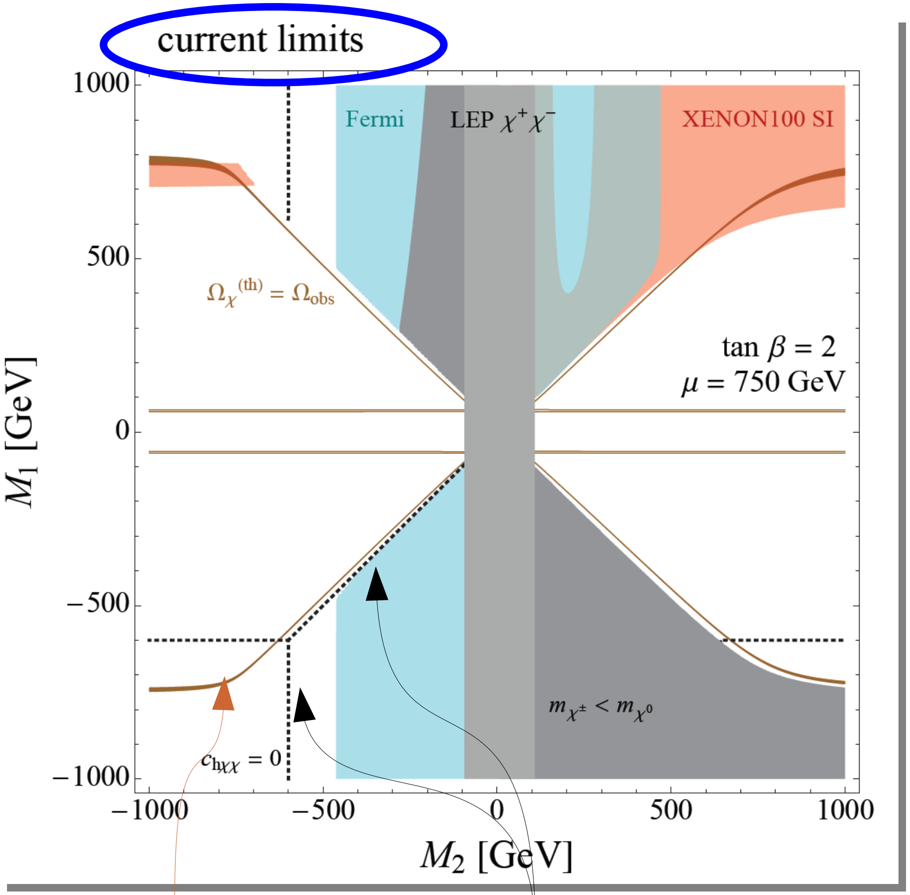

Thermal DM

Blind spots

Cheung, Hall, Pinner, Ruderman, 1211.4873

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

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

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

Well-tempered neutralinos can be „blind spots“ for DM direct searches

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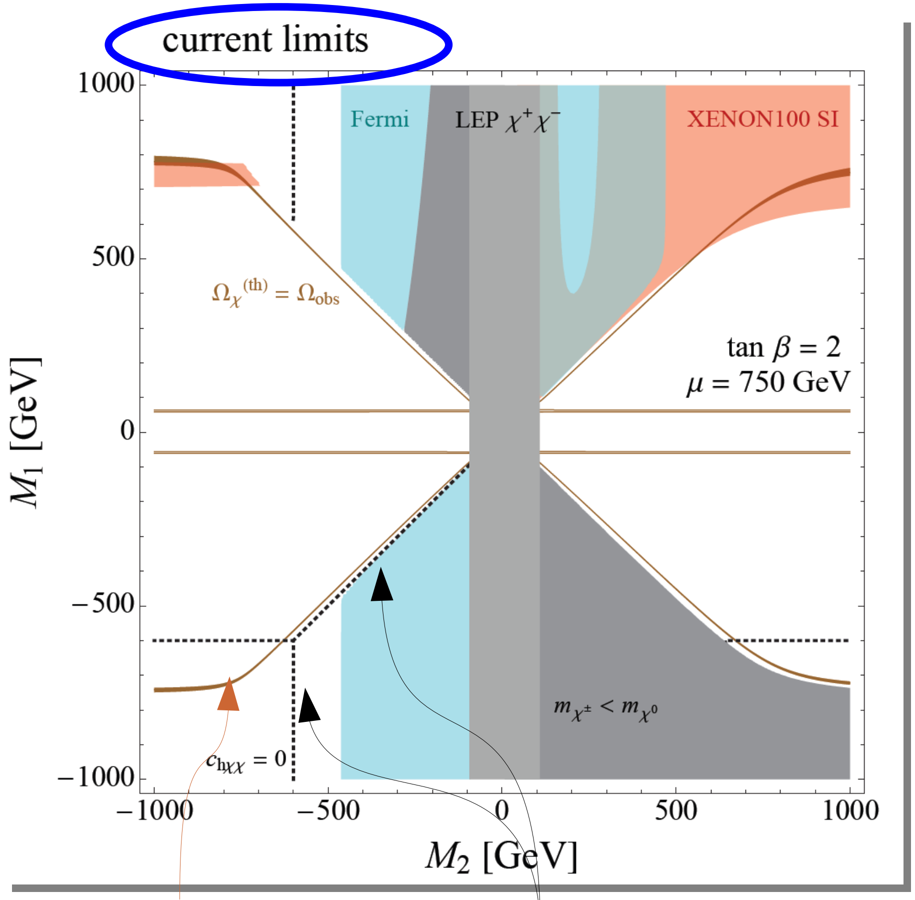

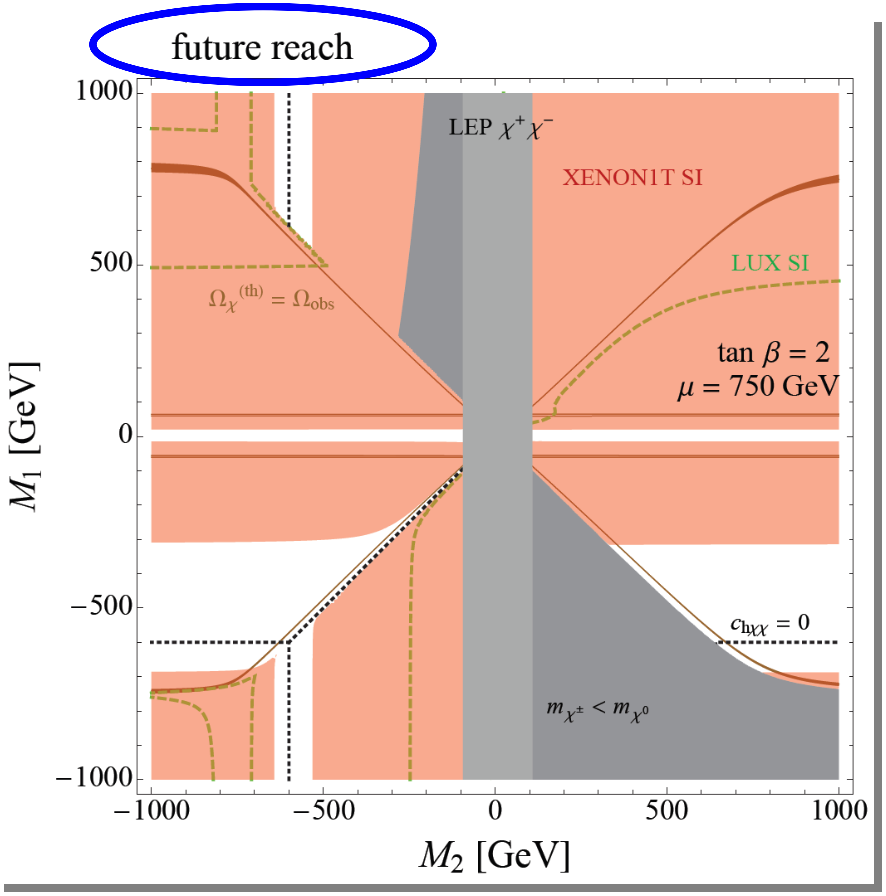

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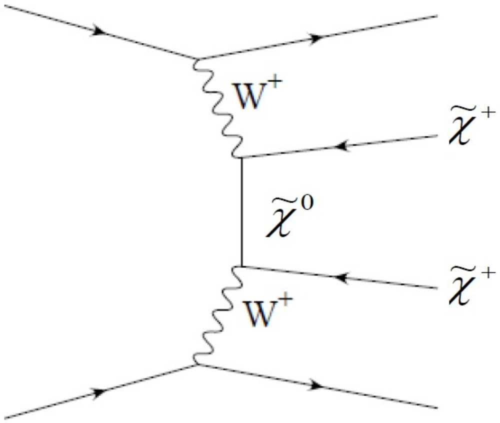
Well-tempered neutralinos can be „blind spots“ for DM direct searches

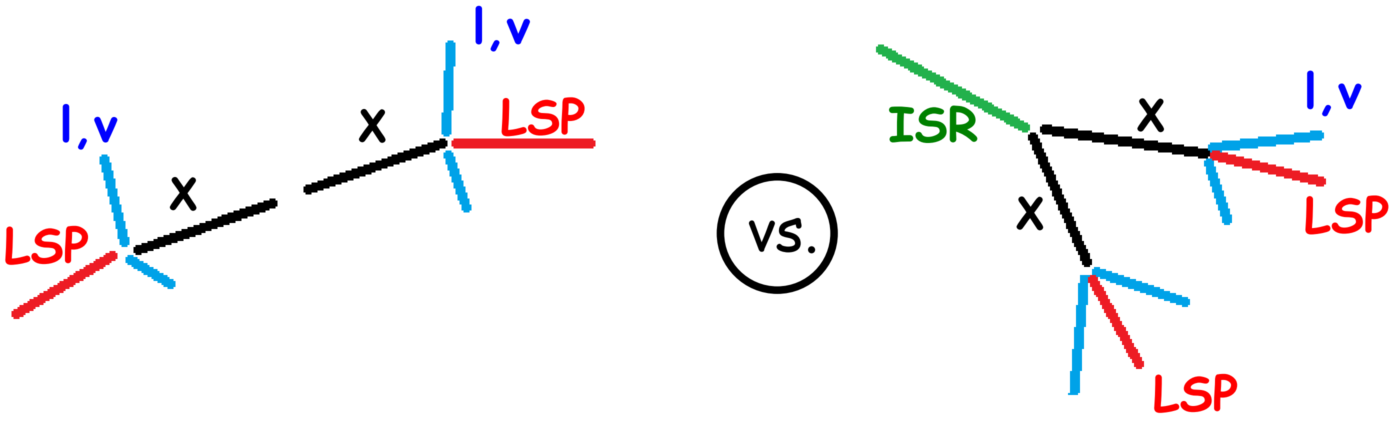
How to probe ew squeezed spectra?

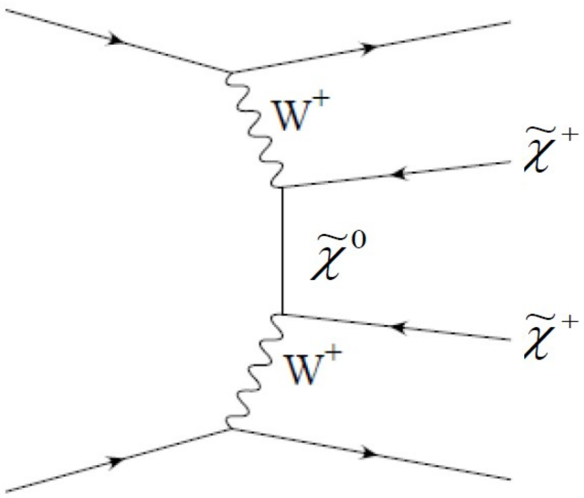
- VBF production:

exploit the kinematic of 2 forward jets



- ISR jet:





VBF production

VBF production (1)

14 TeV LHC

Giudice, Han, Wang, Wang, 1004.4902

See also:
Datta et al. 0111012
Cho et al. 0601063
Dutta et al. 1210.0964
Delannoy et al. 1304.7779
Delannoy et al. 1308.0355

- Two boosted jets in the forward direction, in the opposite hemispheres

$$p_T^j > 60\,\mathrm{GeV}$$

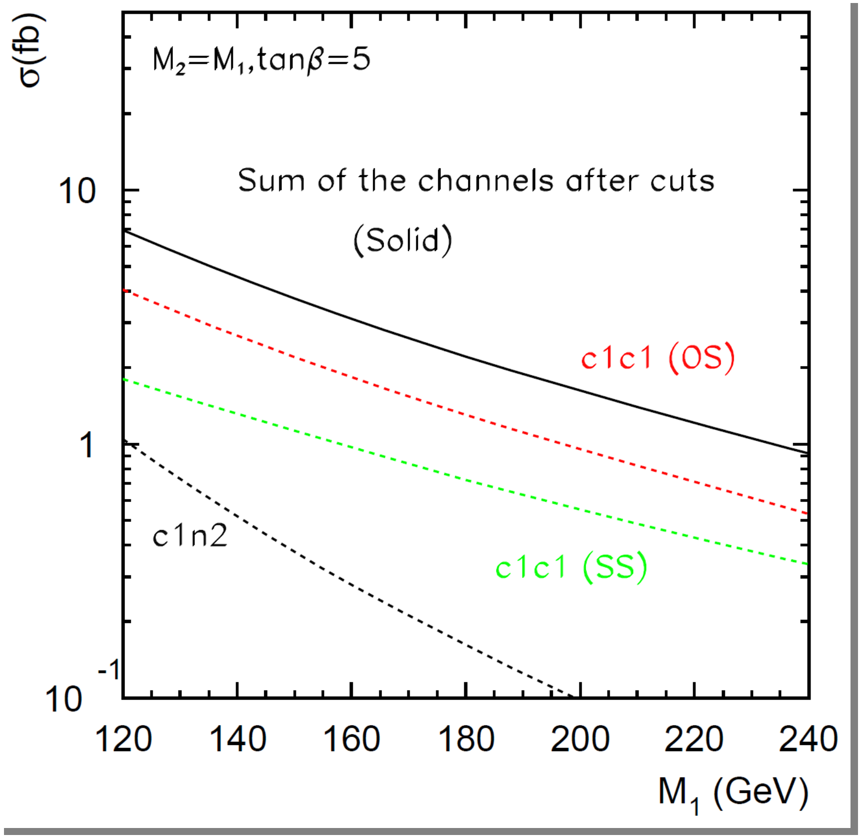
$$\eta_{j_1} \cdot \eta_{j_2} < 0,\ |\eta_{j_1} - \eta_{j_2}| > 4.4$$

- Large invariant mass of the di-jet system

$$M_{jj} > 1200\,\mathrm{GeV}$$

- Large missing energy from the missing gaugino pair

$$\mathrm{E_T^{miss}} > 100\,\mathrm{GeV}$$



Main backgrounds: Z+jets, W+jets

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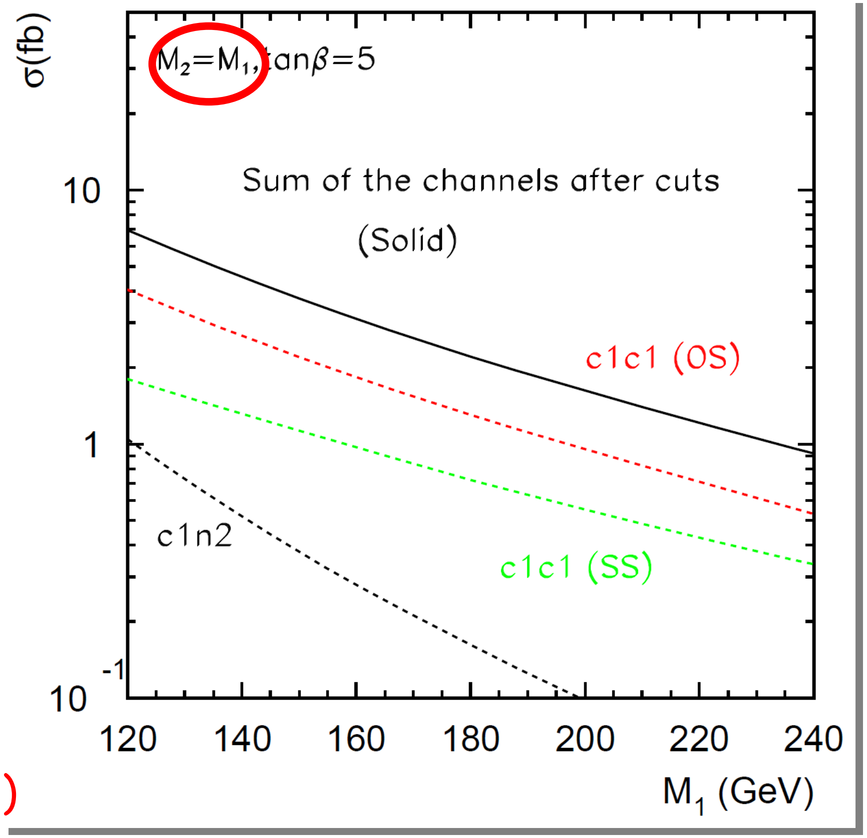
- Veto visible leptons

(acceptance goes down quickly, increasing the splitting)



Main backgrounds: Z+jets, W+jets

VBF production (2)

14 TeV LHC

Giudice, Han, Wang, Wang, 1004.4902

See also:
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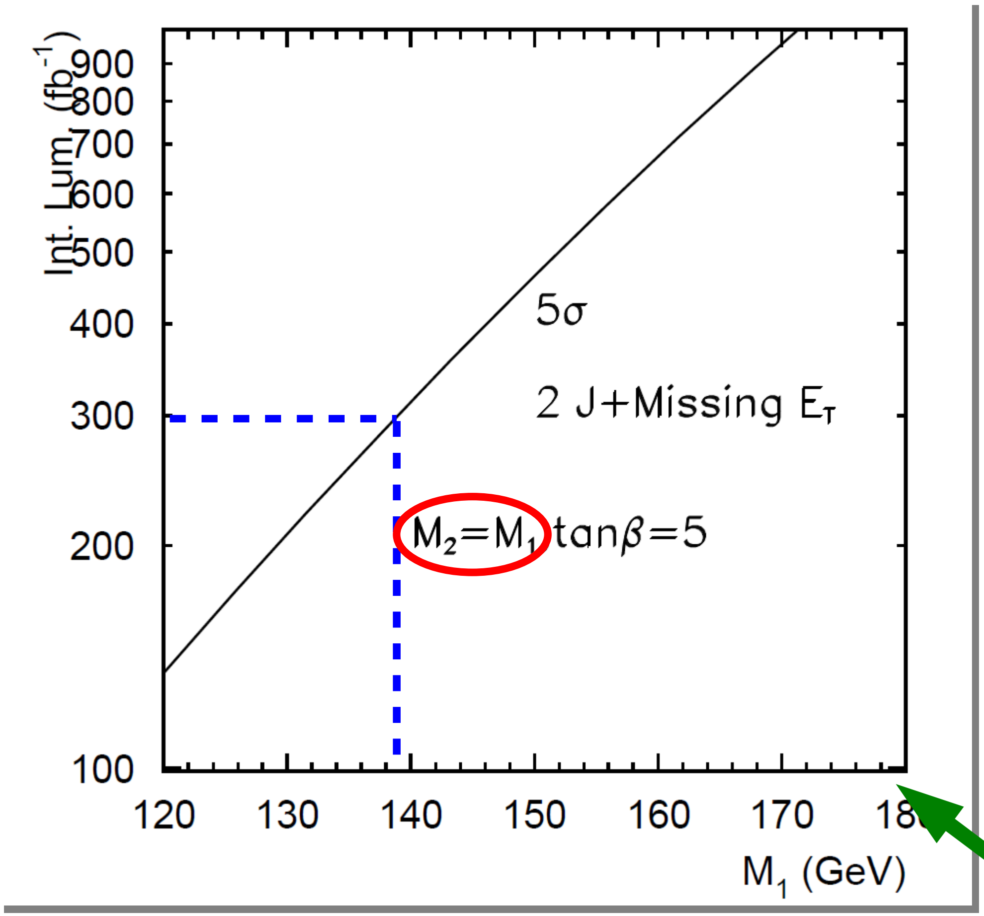
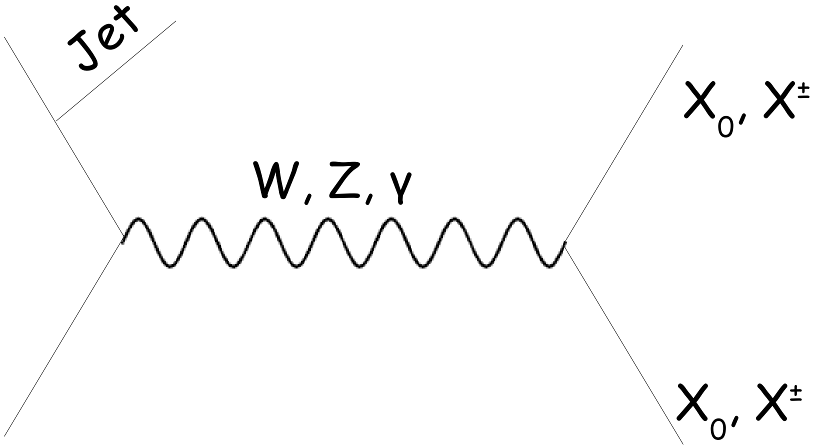


- Need good control of systematics $S/B \sim (2\text{-}3)\%$

- Requiring a soft lepton (muon) might help
(for a bit <u>less squeezed</u> benchmarks)

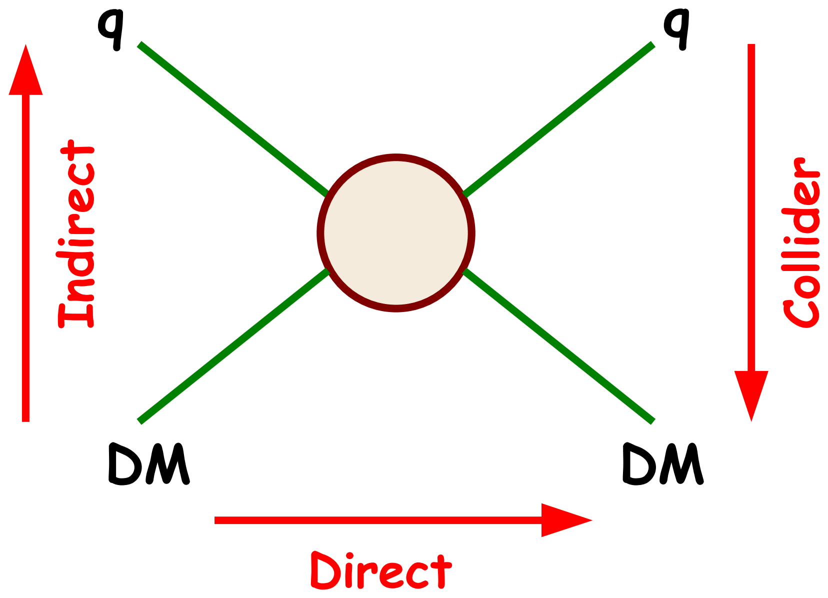
The reach depends on the neutralino/chargino composition

No reach beyond LEP at the 8 TeV LHC



Drell-Yan production with ISR jet

Monojet (1)



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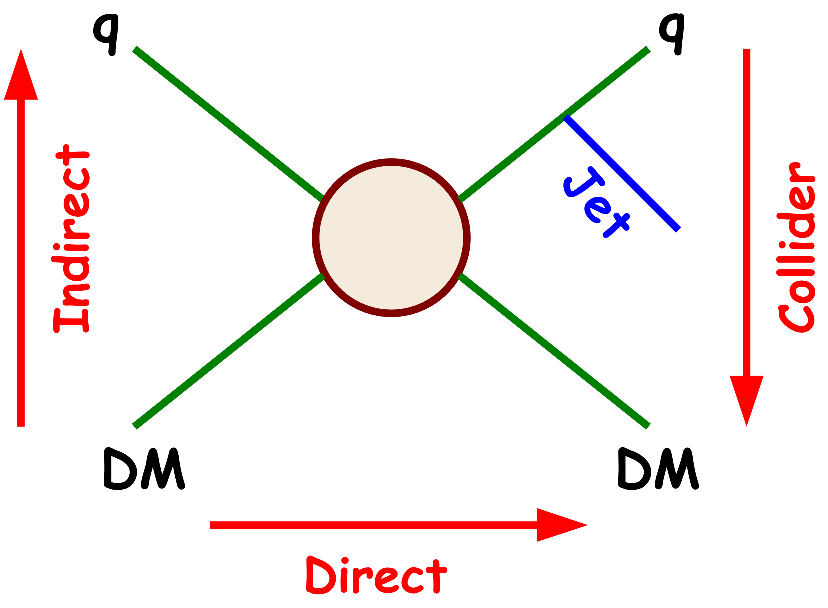


DM searches with mono-jet

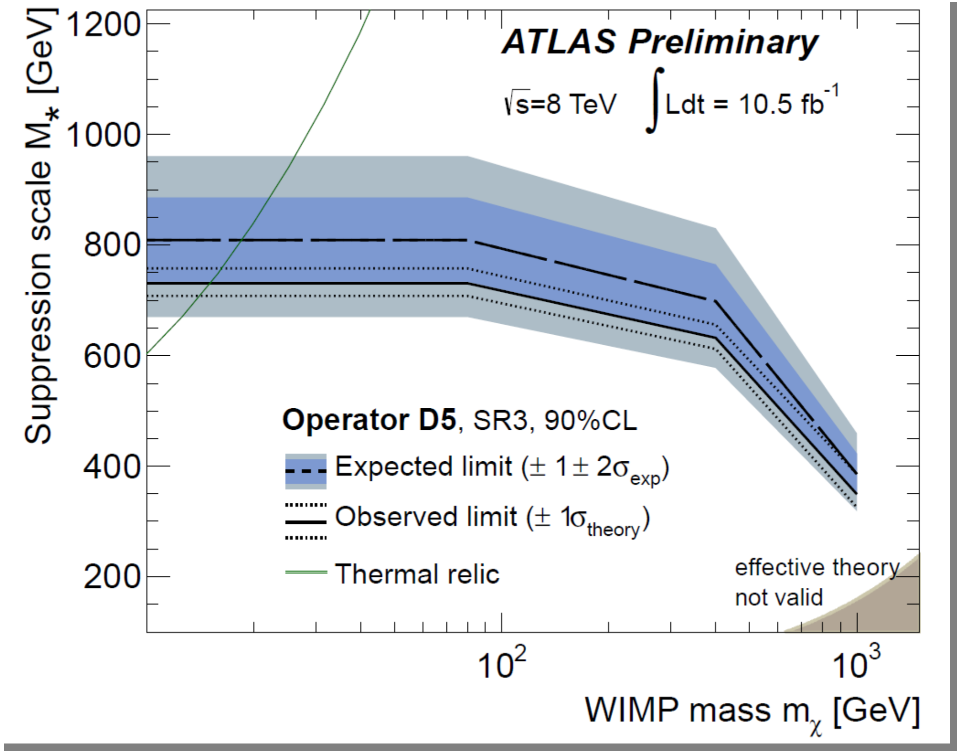
For early works:

Beltran et al. 1002.4137
Goodman et al. 1005.1286, 1008.1783
Bai et al. 1005.3797
Rajaran et al. 1108.1196
Fox et al. 1109.4398

Example:

$$\frac{1}{M_*^2}(\bar{\chi}\gamma_\mu\chi)(\bar{q}\gamma^\mu q)$$

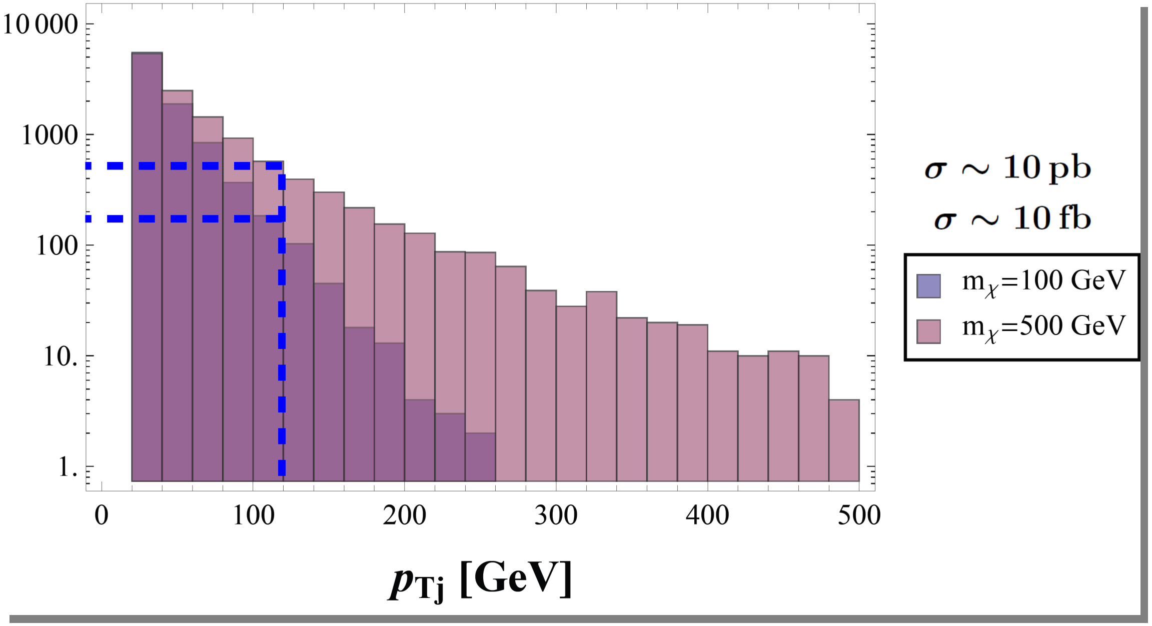
ATLAS-CONF-2012-147



Monojet (2)

ISR jet + $\chi_1^+\chi_1^-$, $\chi_1^\pm\chi_2^0$, ... $\to E_T^{miss}$

Present 8 TeV Monojet searches are not sensitive beyond the LEP bound



ATLAS-CONF-2012-147
$10 fb^{-1}$, 8 TeV

In particular,
the most significant
signal region:

SR1:

$$p_T(j) > 120 \text{ GeV},$$
$$E_T^{miss} > 120 \text{ GeV}$$

Veto visible leptons
(and a third jet above 30 GeV)

Exclusion: 2.8pb

Extrapolating to the 14 TeV LHC,
maybe some reach beyond LEP
Giudice, Han, Wang, Wang, 1004.4902

An intermediate regime

$\Delta \equiv m_{X2} - m_{LSP} \sim (10\text{-}40)$ GeV

Pretty (but not extremely) squeezed scenarios

„traditional" method (monojet) suffers from low efficiency.

ISR jet + soft visible leptons + some MET signature

3l+MET+ISR jet

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

The ATLAS analysis ATLAS-CONF-2013-035 is the one that gets closest in probing ew squeezed spectra. Still, below $\Delta \sim 30$ GeV, the entire parameter space is open

To better compare with the ATLAS reach, we will make the same set of assumptions (wino like NLSP, degenerate X_2 and $X^{\pm}$, 100% branching ratio)

An intermediate regime

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2l+MET+ISR jet

Han, Kribs, Martin, Menon,
in preparation

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Signal region for more squeezed spectra

3lepton+MET signature

ATLAS-CONF-2013-035

Selection	SRnoZa	SRnoZb	SRnoZc	SRZa	SRZb	SRZc
Tri-boson	1.7 ± 1.7					
ZZ	14 ± 8					
$t\bar{t}V$	0.23 ± 0.23					
WZ	50 ± 9					
Σ SM irreducible	65 ± 12					
SM reducible	31 ± 14					
Σ SM	**96 ± 19**					
Data	**101**					
p_0-value	0.41					
N_{signal} excluded (exp)	39.3					
N_{signal} excluded (obs)	41.8					
$\sigma_{\mathrm{visible}}$ excluded (exp) [fb]	1.90					
$\sigma_{\mathrm{visible}}$ excluded (obs) [fb]	2.02					

- Single or di-lepton trigger
- Third lepton with pT >10 GeV
- $\mathrm{E_T^{miss}} > 50\,\mathrm{GeV}$
- $\mathrm{mSFOS} < 60\,\mathrm{GeV},\ \min(\mathrm{mSFOS}) > 12\,\mathrm{GeV}$

  (Z-veto) (to avoid low mass QCD resonances)
- Either $\mathrm{E_T^{miss}} < 75\,\mathrm{GeV}$

  or $m_T(W) < 110\,\mathrm{GeV}$

  or $p_T(\ell_3) < 30\,\mathrm{GeV}$

Signal region for more squeezed spectra

3lepton+MET signature

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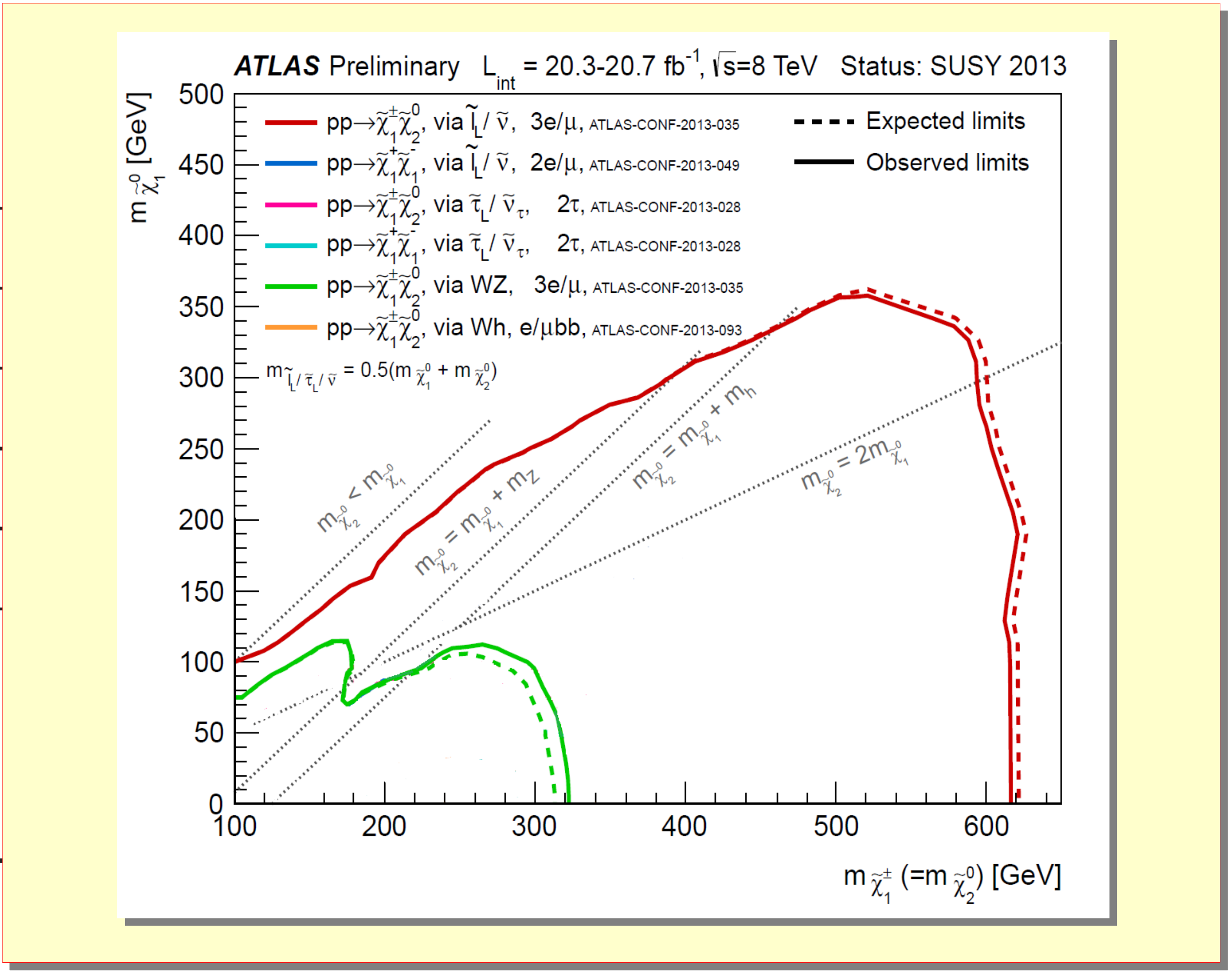
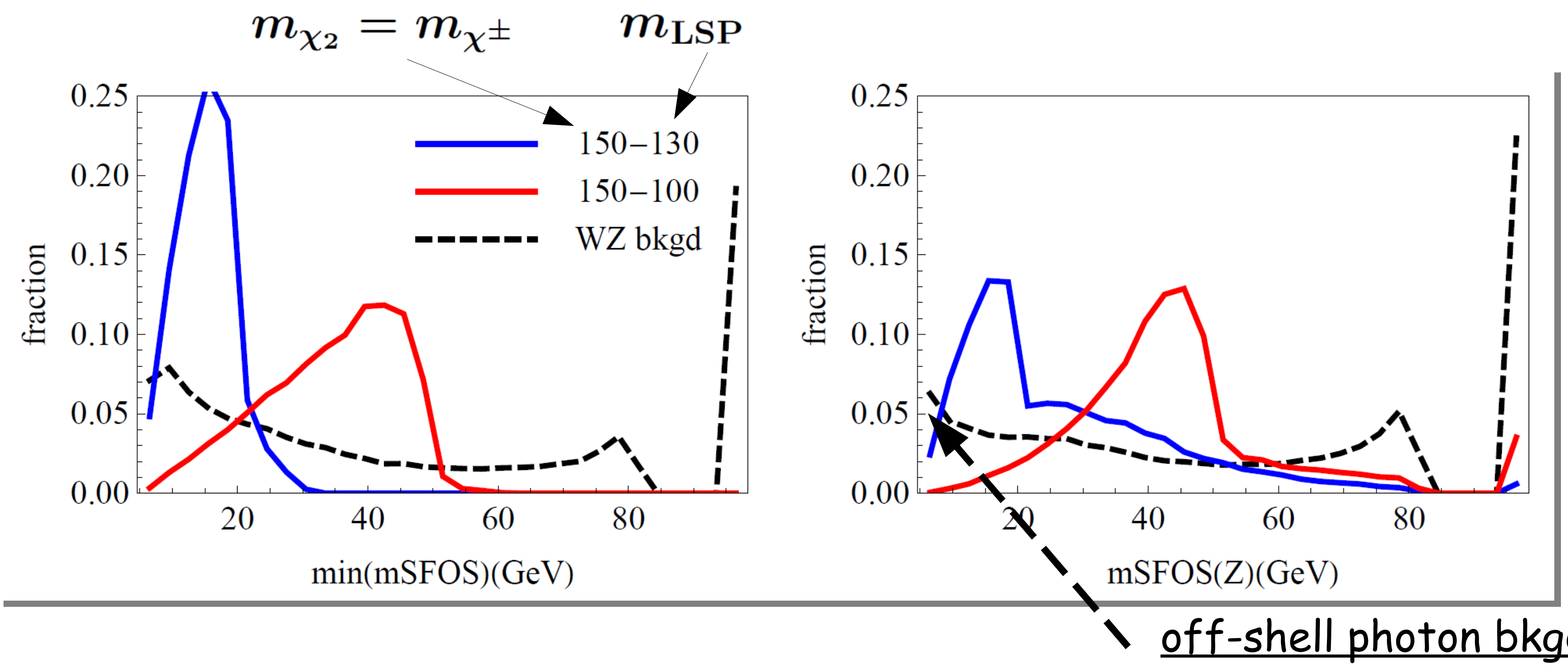


Lepton invariant masses



off-shell photon bkgd

mSFOS>12GeV

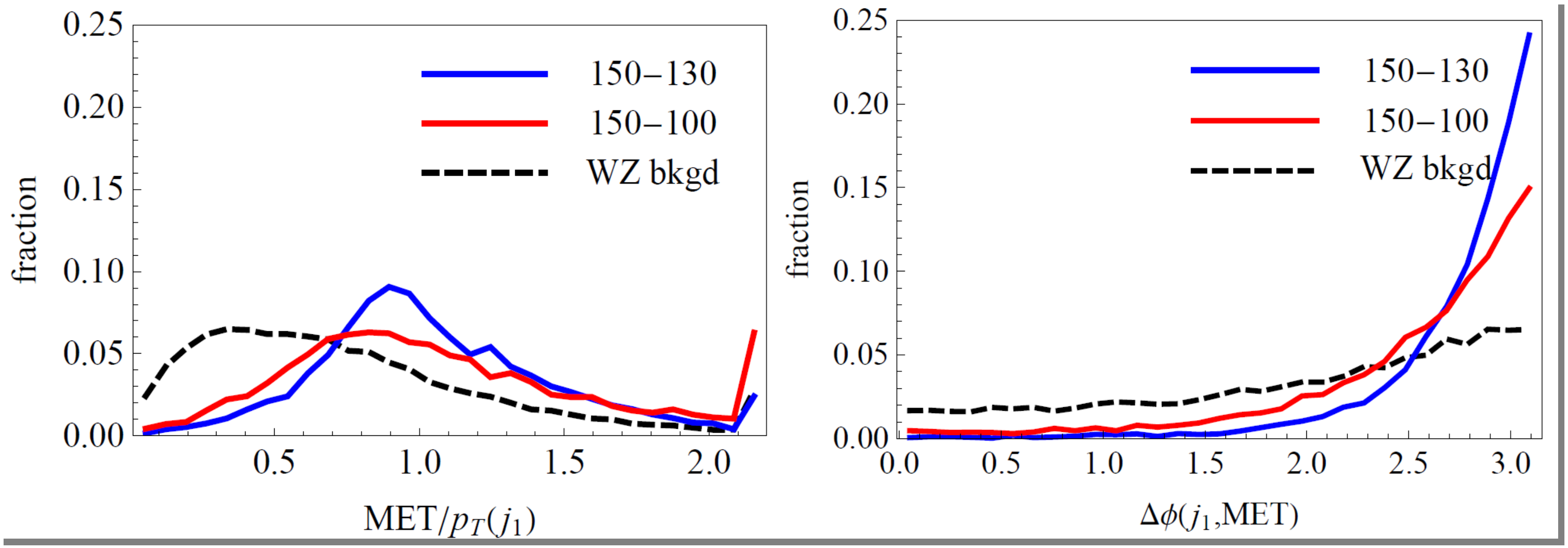
(low mass QCD resonances)

- Edge at mSFOS~$\Delta \equiv m_{\chi_2} - m_{LSP}$
- Experimental collaborations use mSFOS(Z), however, the minimum of all possible SFOS invariant masses min(mSFOS) has a clearer edge

$$\begin{aligned} \chi_1^\pm &\rightarrow W^{(*)}\chi_1^0 \rightarrow \ell\nu\chi_1^0, \quad (\ell = e, \mu) \\ \chi_2^0 &\rightarrow Z^{(*)}\chi_1^0 \rightarrow \ell\ell\chi_1^0 \end{aligned}$$

➡ Lower and upper bounds on the values of mSFOS

ISR and correlation variables



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

- Sizable MET in the signal arises only from a hard ISR (the two LSPs are not anymore back to back)

$$(E_\ell^0)_{\mathrm{sig}} \sim \Delta,$$

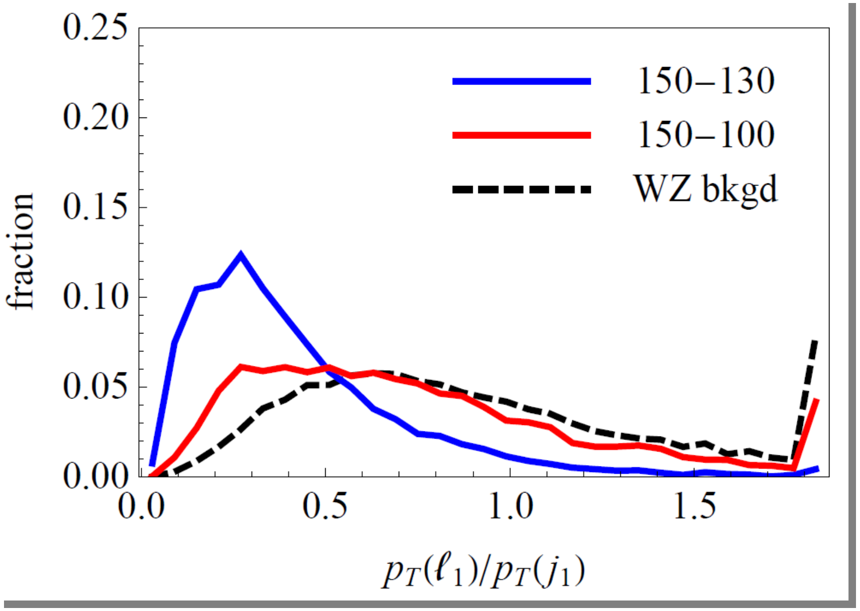
$$\Delta \equiv m_{\chi_2} - m_{\mathrm{LSP}} \ll m_{\chi_2}$$

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

Correlations are more and more pronounced going to more and more squeezed spectra

ISR and correlation variables

<u>Weaker correlation</u> between the pT of the leptons and the pT of the ISR jet



$p_T(j_1) > 30\,\mathrm{GeV}$

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

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

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

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

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

Stronger correlation going to harder ISR jets

It can be a <u>more useful variable at the 14 TeV</u> LHC with <u>high luminosity</u>

Summary of the variables

Intermediate p_T for the ISR jet: (30-60) GeV

- Soft leptons
- Small SFOS lepton invariant masses
- Correlation between MET and p_T of the ISR jet
- (weaker) correlation between p_T of the leptons and p_T of the ISR jet

How to trigger on these events?

Trigger

In principle,
three muon trigger with
pT > 6 GeV

ATLAS-CONF-2013-035 trigger:

- Single electron or single muon: pT > 25 GeV
- Symmetric di-muon trigger: pT > 14 GeV
- Asymmetric di-muon trigger: pT > 18, 10 GeV
- Symmetric di-electron trigger: pT > 14 GeV
- Asymmetric di-electron trigger: pT > 25, 10 GeV
- Electron-muon trigger:
  one electron with pT > 14 (10) GeV, one muon with pT > 10 (18) GeV

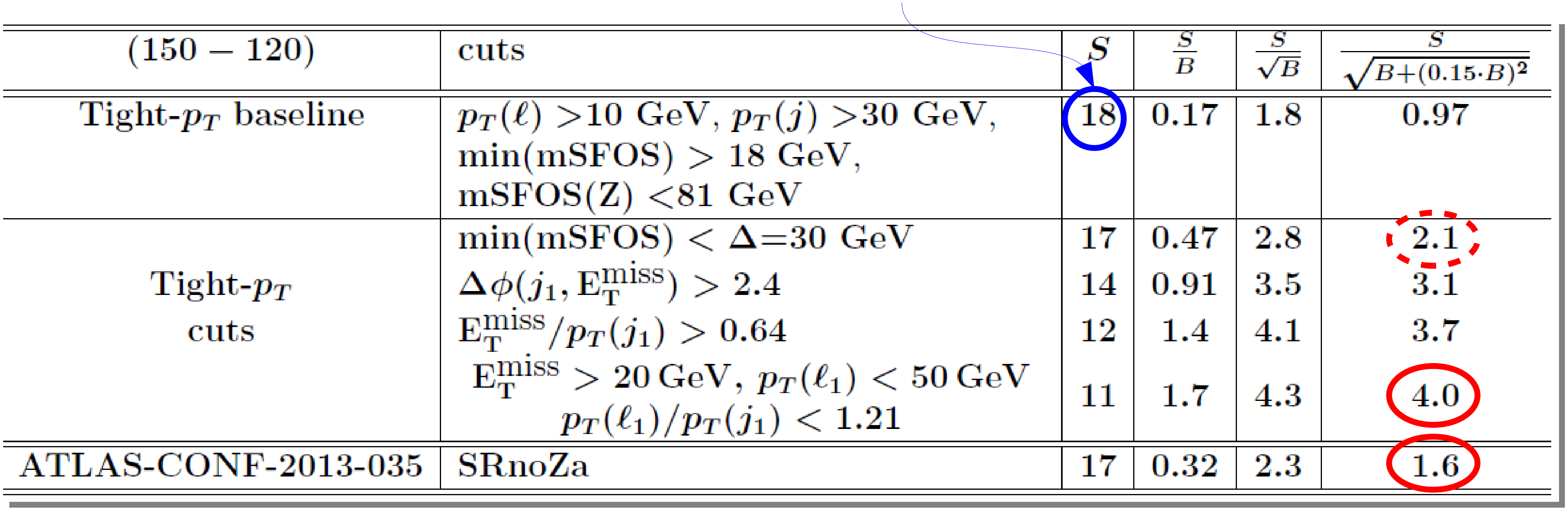
Check of the rates:

150-120 benchmark

	Trigger $+ p_T^j > 30\,\mathrm{GeV}$	Trigger$+ p_T^j > 50\,\mathrm{GeV}$
Acceptance	10%	6%
N. Events ($21\,\mathrm{fb}^{-1}$)	70	40

Example of optimization of the cuts

The request of a third lepton above 10 GeV reduces the signal by a factor of ~ 4



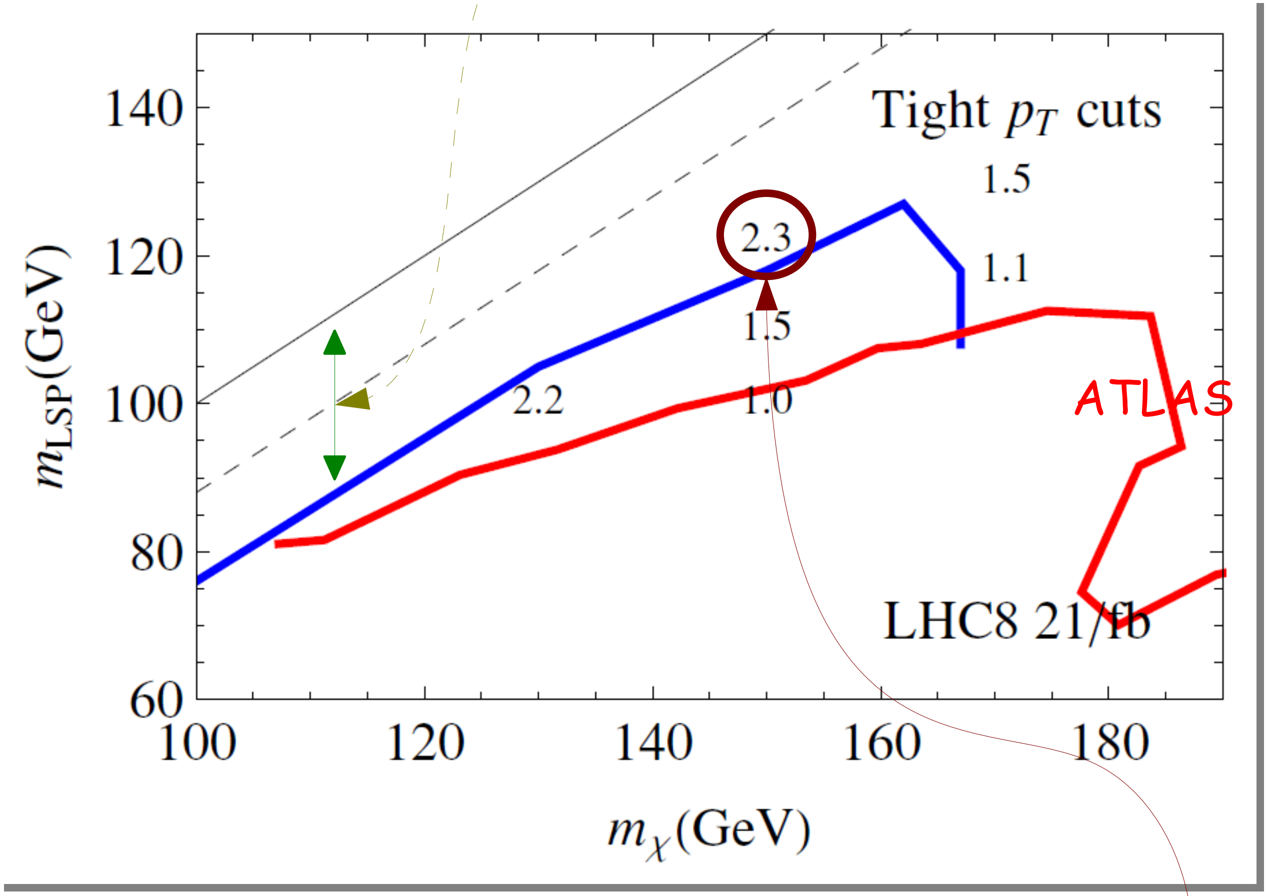
(150 – 120)	cuts	S	$\frac{S}{B}$	$\frac{S}{\sqrt{B}}$	$\frac{S}{\sqrt{B+(0.15\cdot B)^2}}$
Tight-p_T baseline	$p_T(\ell)>10$ GeV, $p_T(j)>30$ GeV, min(mSFOS) >18 GeV, mSFOS(Z) <81 GeV	18	0.17	1.8	0.97
Tight-p_T cuts	min(mSFOS) $<\Delta=30$ GeV	17	0.47	2.8	2.1
	$\Delta\phi(j_1, E_T^{miss}) > 2.4$	14	0.91	3.5	3.1
	$E_T^{miss}/p_T(j_1) > 0.64$	12	1.4	4.1	3.7
	$E_T^{miss} > 20$ GeV, $p_T(\ell_1) < 50$ GeV $p_T(\ell_1)/p_T(j_1) < 1.21$	11	1.7	4.3	4.0
ATLAS-CONF-2013-035	SRnoZa	17	0.32	2.3	1.6

Notes:

- Imposing $E_T^{miss} > 50\,\mathrm{GeV}$ would change the significance by only ~10%
- The cut on min(mSFOS) alone is already able to reach the significance obtained by the ATLAS analysis

Estimation of the reach

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



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

Parenthesis: lighter sleptons

ATLAS and CMS collaborations present also bounds for the decay chain

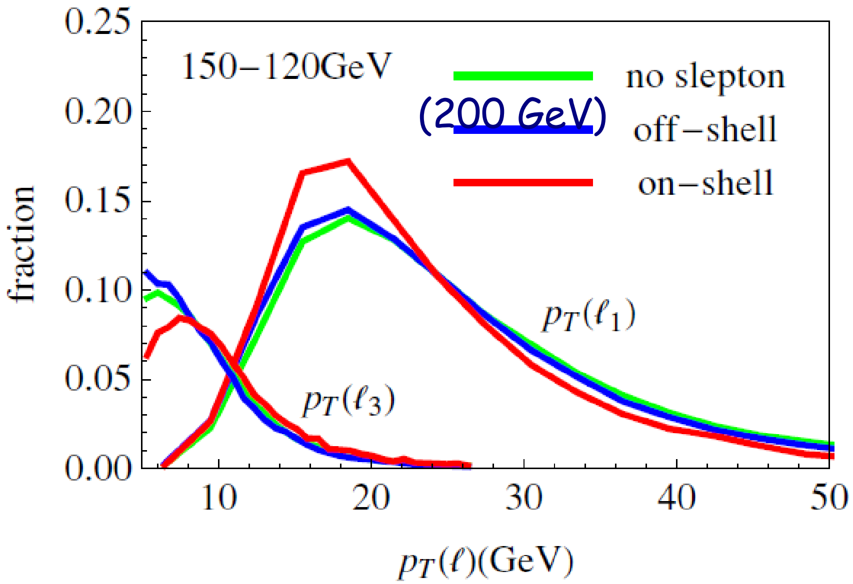
$$\begin{cases} \chi_1^\pm \to \tilde{\ell}\nu,\ \tilde{\nu}\ell \to \ell\nu\chi_1^0, \\ \chi_2^0 \to \tilde{\ell}\ell \to \ell\ell\chi_1^0 \end{cases}$$

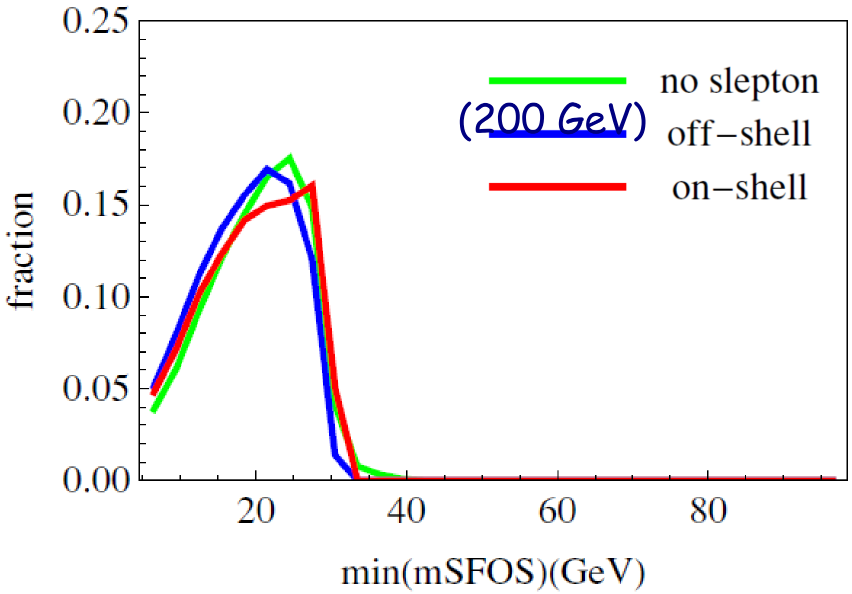
in the case of light sleptons in the spectrum

$$m_{\tilde{\nu}} = m_{\tilde{\ell}_L} = (m_{\chi_2} - m_{\rm LSP})/2$$

Assumptions:

- Degenerate sneutrino and left handed sleptons
- Right handed sleptons are heavy





The distributions for our kinematic variables are not sizably affected

⇨ We can apply similar cuts to the case of heavy sleptons („no slepton" in the plot)

Parenthesis: lighter sleptons

ATLAS and CMS collaborations present also bounds for the decay chain

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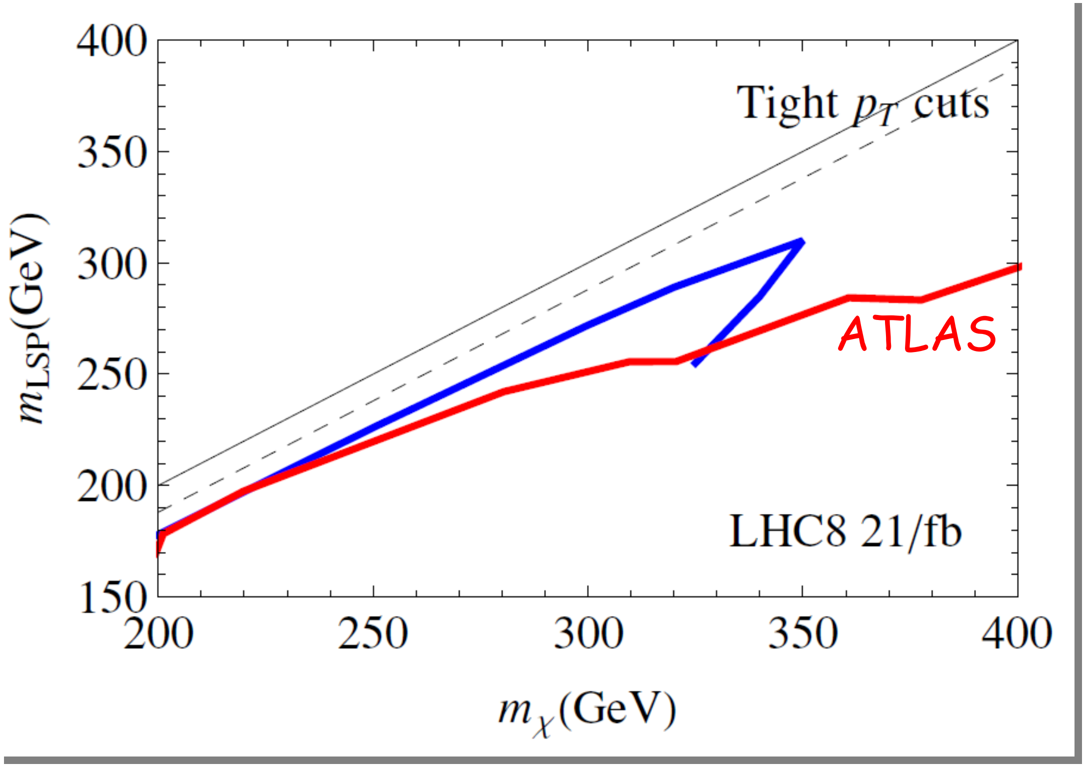
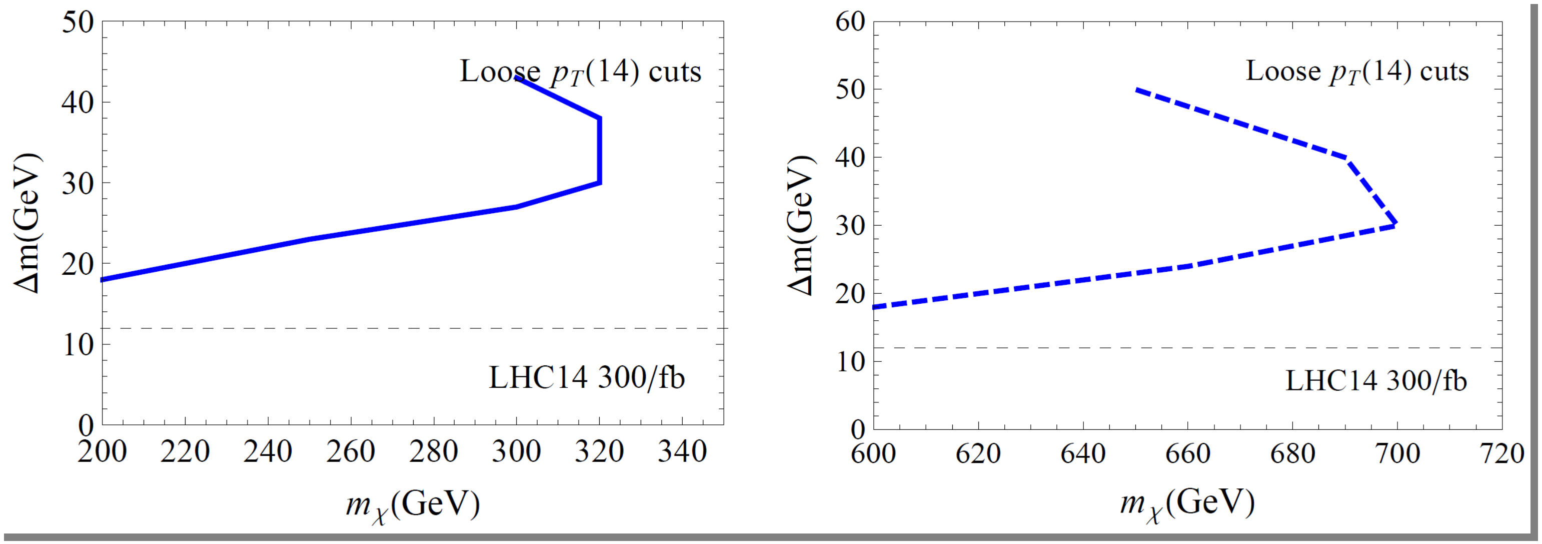


Prospects for the 14TeV LHC

With 300 fb^{-1} data

300 – 280	cuts	S	$\frac{S}{B}$	$\frac{S}{\sqrt{B}}$	$\frac{S}{\sqrt{B+(0.15 \cdot B)^2}}$
Loose-p_T baseline	$p_T(\ell) > 7$ GeV, $p_T(j) > 30$ GeV, min(mSFOS) > 12 GeV, mSFOS(Z) < 81 GeV	56	0.018	1.0	0.12
Loose-p_T (14) cuts	min(mSFOS) $< \Delta = 20$ GeV	50	0.049	1.6	0.32
	$E_T^{miss} > 60$ GeV $p_T(\ell_1) < 50$ GeV	32	0.21	2.6	0.78
	$p_T(\ell_1)/p_T(j_1) < 0.2$	17	0.64	3.3	2.59
	$E_T^{miss}/p_T(j_1) > 0.9$	13	1.2	3.9	3.44



Heavy sleptons

Light sleptons

2 (soft) leptons+ISR jet (1)

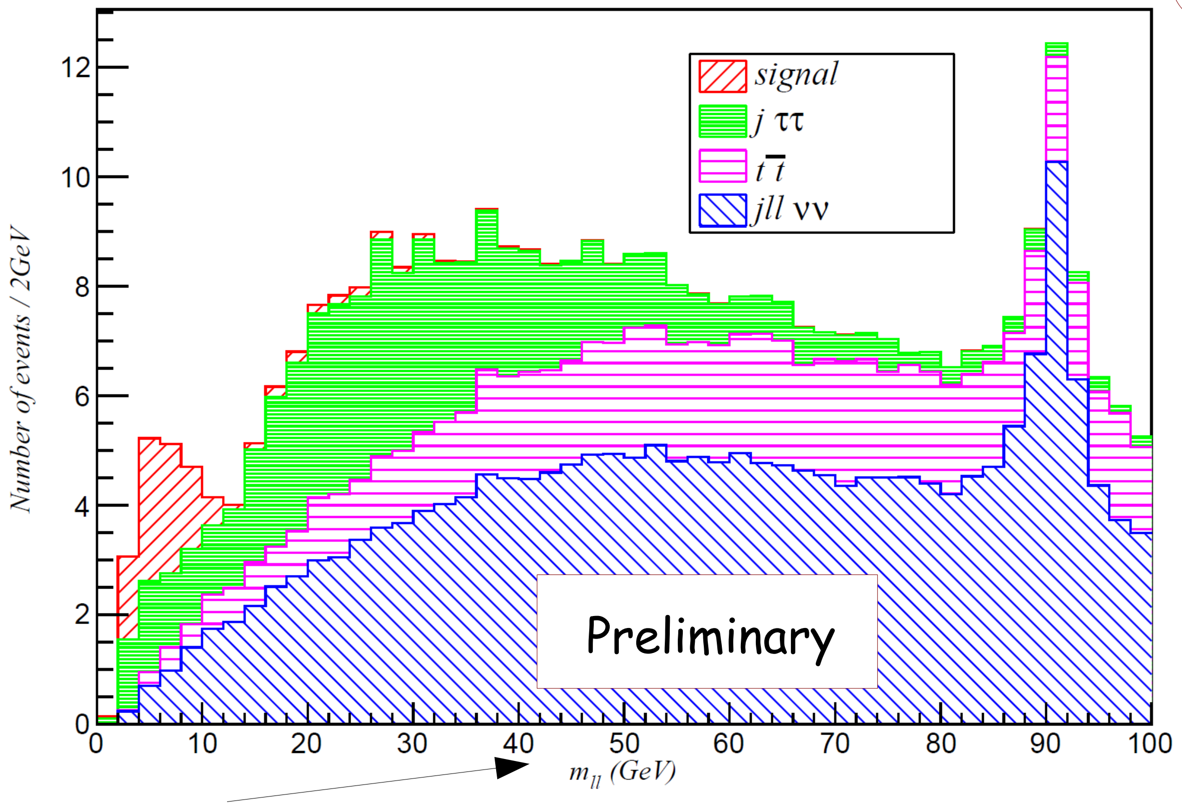
Some preview of the work in progress: Han, Kribs, Martin, Menon

$$pp \to \chi_1^+\chi_1^-,\ \chi_1^\pm\chi_2^0,\ \ldots \to 2\ell + \mathrm{E}_\mathrm{T}^{\mathrm{miss}}$$

Example scenario:

M1=350, M2=1000, μ=110, tanβ=10

ISR jet asked to be above 100 GeV



$M_{\chi 1}$~100 GeV,

$M_{\chi 2}$~115 GeV,

M_{chargino}~110 GeV

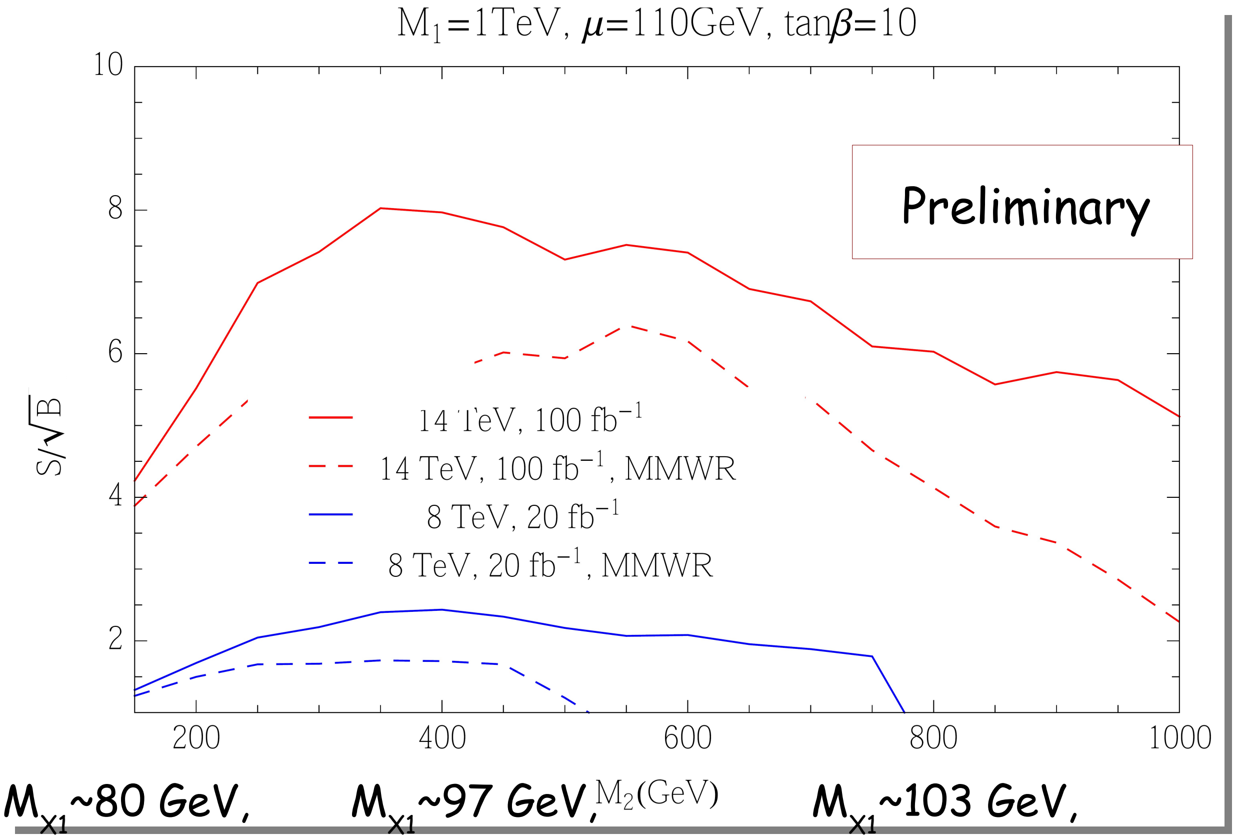
Not necessarily SFOS

Thanks to Adam Martin!

2 (soft) leptons+ISR jet (2)

Some preview of the work in progress: Han, Kribs, Martin, Menon

$$pp \to \chi_1^+\chi_1^-,\ \chi_1^\pm\chi_2^0,\ \ldots \to 2\ell + \mathrm{E_T^{miss}}$$



M_{χ_1}~80 GeV,	M_{χ_1}~97 GeV,	M_{χ_1}~103 GeV,
M_{χ_2}~120 GeV,	M_{χ_2}~116 GeV,	M_{χ_2}~114 GeV,
$M_{\chi_\pm}$~90 GeV	$M_{\chi_\pm}$~102 GeV	$M_{\chi_\pm}$~107 GeV

ISR jet asked to be above 100 GeV

Fake background from W+jets found to be (5-10)%

Thanks to Adam Martin!

Conclusions and outlook

- Squeezed and light electroweak spectra are an interesting theoretical possibility

- Experimental searches are known to be more difficult
  - VBF production seems challenging
  - The presence of a relatively boosted ISR jet looks more promising (delicate interplay between the pT of the jet and the other kinematic variables)

Possible improvements for the 3leptons+MET+ISR jet signature

- Weaker lower bound on min(mSFOS)
- Lower thresholds for leptons. Requiring 1-2 muons might help

Outlook for experimentalists

Production through Higgs decay

What if very light ewinos?

Generically electroweak particles will couple to the 125 GeV Higgs.

This feature has been recently exploited in the search:

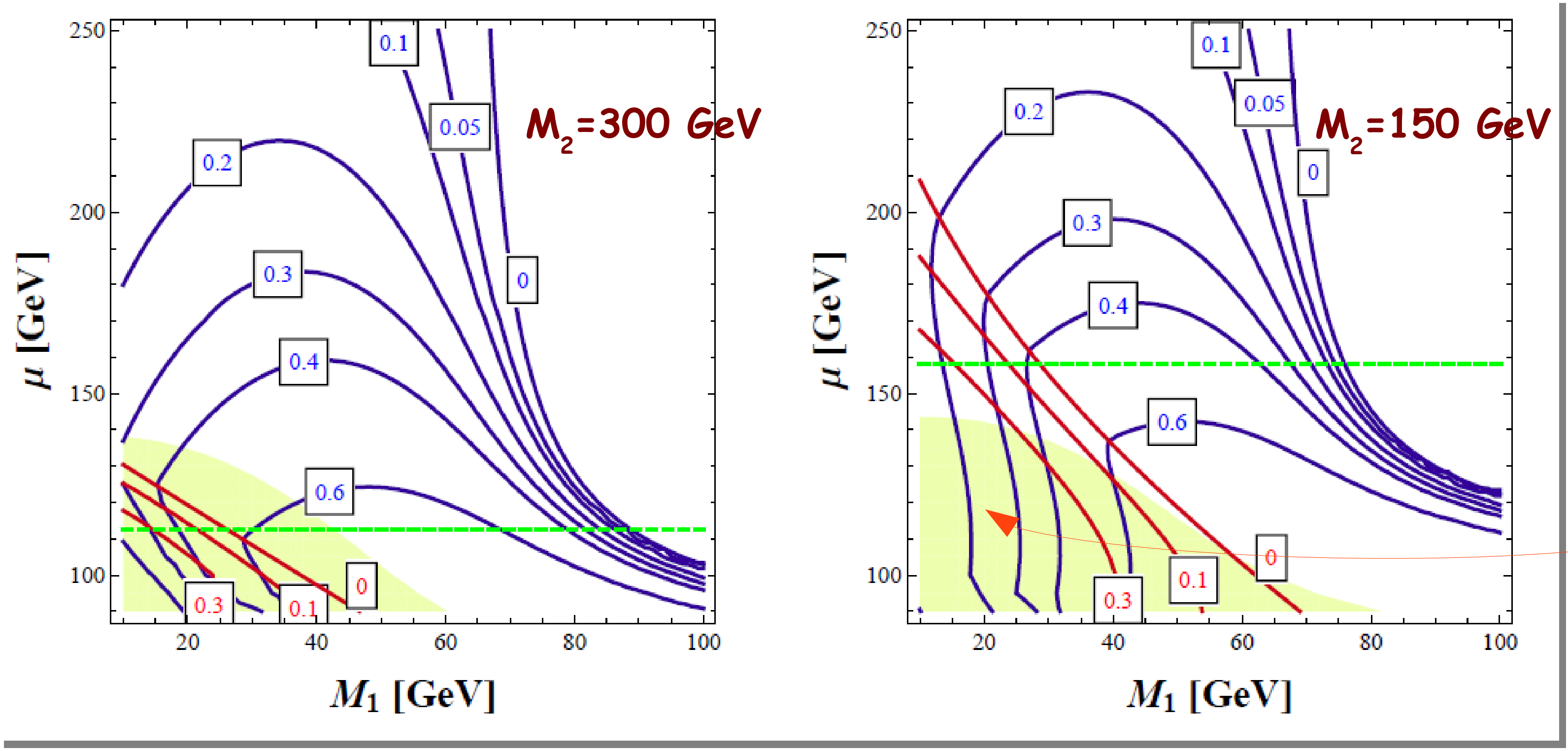
$$\begin{aligned}\chi_1^\pm &\to W^{(*)}\chi_1^0 \to \ell\nu\chi_1^0, \quad (\ell = e, \mu)\\ \chi_2^0 &\to h\chi_1^0 \to b\bar{b}\chi_1^0\end{aligned}$$

ATLAS-CONF-2013-093, CMS-PAS-SUS-13-017

Room for very light ewinos produced in Higgs decay ?

- In the MSSM not anymore

SG, J.Shelton, in preparation



LEP measurement of the Z invisible and total widths

$h \to \chi_1\chi_1$

$h \to \chi_1\chi_2$

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ATLAS-CONF-2013-093, CMS-PAS-SUS-13-017

Room for very light ewinos produced in Higgs decay ?

SG, J.Shelton, in preparation

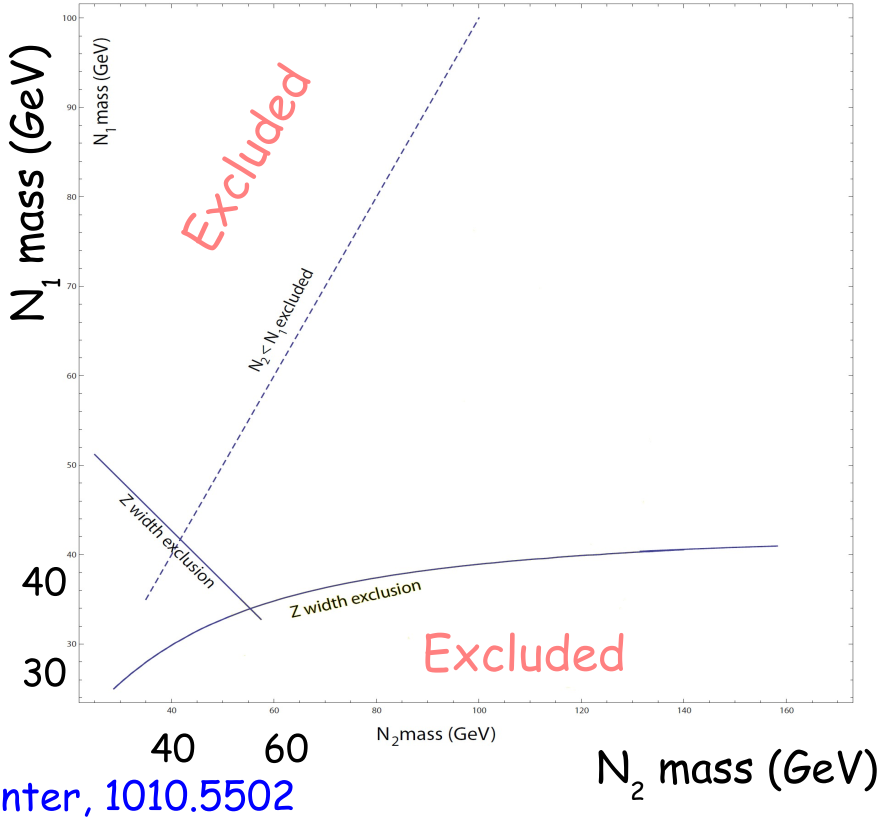
- In the NMSSM a bit more freedom thanks to the $\lambda H_u \tilde{S} \tilde{H}_d$ coupling

- Models with extra neutrinos:

  Carpenter, 1010.5502
  Keung, Schwaller, 1103.3765

$$L' = \begin{pmatrix} \chi_\nu \\ \chi_\ell \end{pmatrix}, \quad \eta_\nu$$

$$\mathcal{L} \supset Y_n H L' \eta_\nu + \frac{M}{2}\eta_\nu\eta_\nu + \text{h.c.}$$



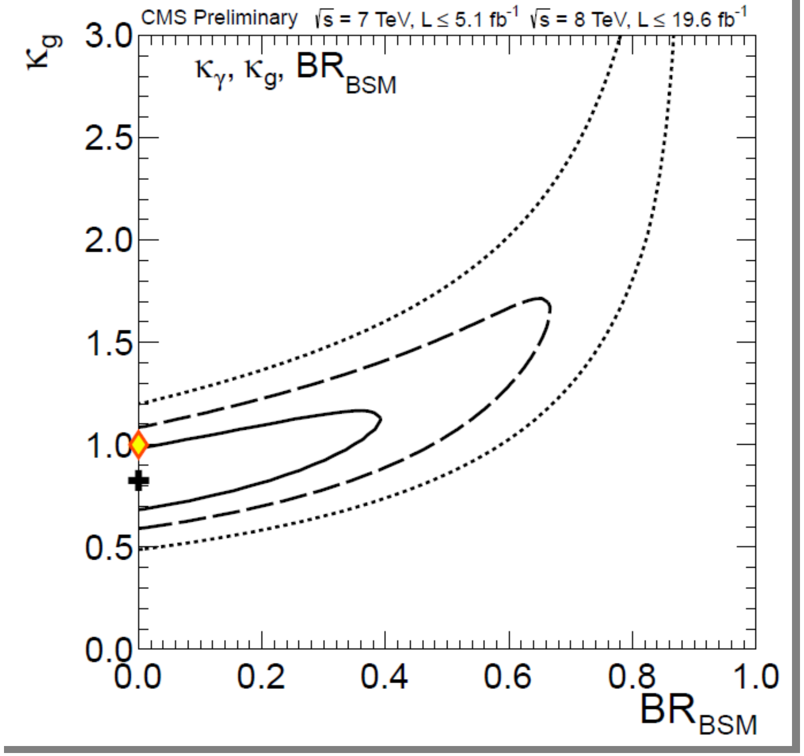
Carpenter, 1010.5502

Higgs exotic decays

- Indirect „measurement“ of the Higgs invisible (or exotic) width, through the measurement of the Higgs SM couplings
  - A lot of theory work on extracting the Higgs invisible width

    See for example: Belanger et al. '13
    Giardino et al. '13
    Ellis, You '13
    Djouadi, Moreau '13
  - Lately indirect bounds given by the experimental collaborations

CMS PAS HIG-13-005



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  - Lately indirect bounds given by the experimental collaborations

- Direct measurement of the Higgs invisible width from

$$Zh \to \ell\ell \mathrm{E}_{\mathrm{T}}^{\mathrm{miss}},\ Zh \to bb\mathrm{E}_{\mathrm{T}}^{\mathrm{miss}},\ \mathrm{VBF\ Higgs}$$

ATLAS-CONF-2013-011
CMS PAS HIG-13-018

CMS PAS HIG-13-028

CMS PAS HIG-13-013

→ Most stringent limit: BR(invisible) < 65% @ 95% C.L.

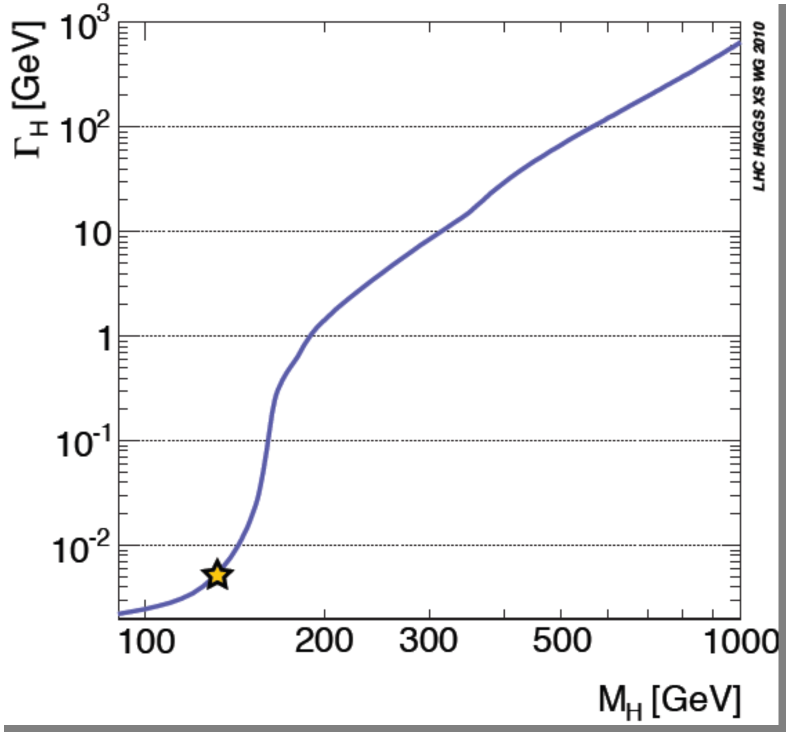
Higgs exotic decays (1)

- Prospect at the 14 TeV LHC with 300 fb^{-1}

Klute et al., 1205.2699
Peskin, 1207.2516
CMS collaboration, 1307.7135.
ATLAS collaboration, 1307.7292.

BR(invisible) < (5-10)%

- Theoretically to get a ~10% branching fraction is very easy!



$$\Gamma_h(125\ \text{GeV}) = 4.1\ \text{MeV}$$

Very many new signatures experimentalists could look for

Review work:

Exotic Decays of the 125 GeV Higgs Boson

D.Curtin, R.Essig, SG, P.Jaiswal, A.Katz, T.Liu, Z.Liu, D.McKeen, J.Shelton, M.Strassler, Z.Surujon, B.Tweedie and Y.Zhong, 1312.xxxx

A (soft) multilepton + MET signature

SG, J.Shelton, in preparation

- Models with RH neutrinos, easily produce a sizable branching ratio for

$$h \to N_2 N_2 \quad \text{followed by} \quad N_2 \to Z^{(*)} N_1$$

- From a signature-based prospective,

which are the present bounds on the 4 leptons+MET signature?

✭ Higgs produced in gg fusion and in VBF

CMS-PAS-SUS-13-010

CMS constrains better the decay topology (no requirement on MET)

Very inclusive analysis:
4 iso-leptons with $p_T(l_1) > 20$ GeV and $p_T(l_i) > 10$ GeV
at least one SFOS lepton pair

- Events classified according to the value of the lepton pair invariant masses (m_1 and m_2)

Only bin populated: $m_1 < 75$ GeV, $m_2 < 75$ GeV

✭ Wh associated production

Events populate the signal region SRNOZa
ATLAS-CONF-2013-035

Pro: lower p_T thresholds,

Contra: higher requirement on MET

Summary and bounds

		CMS-PAS-SUS-13-010	ATLAS-CONF-2013-035
Model	Mode	CMS bin Prediction	ATLAS bin Prediction
“Optimistic” ($M_1 = 20$ GeV, $M_2 = 55$ GeV)	gluon fusion	50.4	2.4
	VBF	56.2	7.6
	Wh	2.1	14
	total	108	24
“Pessimistic” ($M_1 = 35$ GeV, $M_2 = 55$ GeV)	gluon fusion	–	0.6
	VBF	2.15	2.9
	Wh	0.21	3.6
	total	2.37	7

*Numbers obtained having fixed

$$\mathrm{BR}(h \to N_2 N_2) = 1$$

12 events are excluded at 95% C.L.

41.8 events are excluded at 95% C.L.

Summary and bounds

CMS-PAS-SUS-13-010 ATLAS-CONF-2013-035

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*Numbers obtained having fixed

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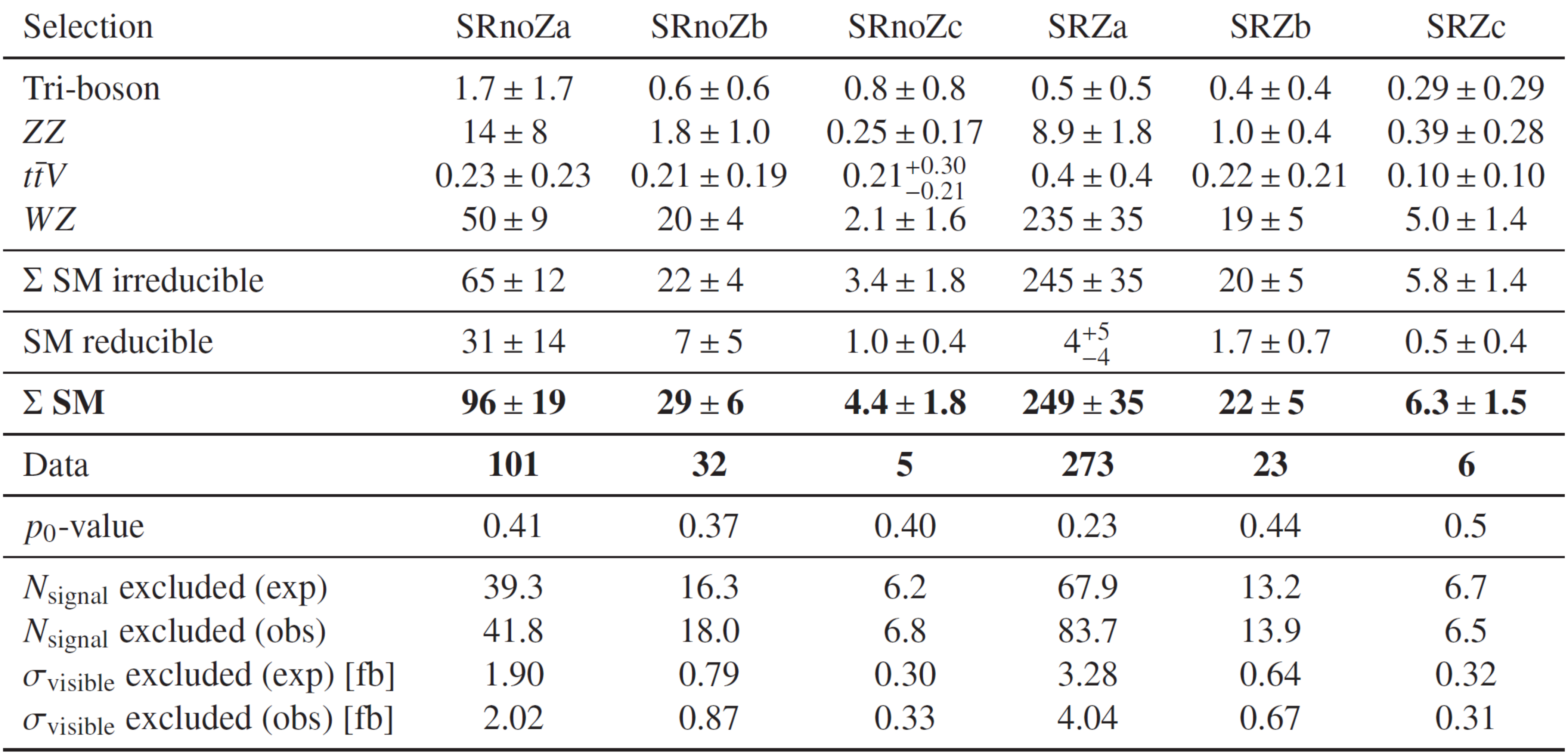
12 events are excluded at 95% C.L.

41.8 events are excluded at 95% C.L.

$$\mathrm{BR}(h \to N_2 N_2) < 11\% \ @\, 95\%\ \mathrm{C.L.}$$

ATLAS 3l search

ATLAS-CONF-2013-035



Selection	SRnoZa	SRnoZb	SRnoZc	SRZa	SRZb	SRZc
Tri-boson	1.7 ± 1.7	0.6 ± 0.6	0.8 ± 0.8	0.5 ± 0.5	0.4 ± 0.4	0.29 ± 0.29
ZZ	14 ± 8	1.8 ± 1.0	0.25 ± 0.17	8.9 ± 1.8	1.0 ± 0.4	0.39 ± 0.28
$t\bar{t}V$	0.23 ± 0.23	0.21 ± 0.19	$0.21^{+0.30}_{-0.21}$	0.4 ± 0.4	0.22 ± 0.21	0.10 ± 0.10
WZ	50 ± 9	20 ± 4	2.1 ± 1.6	235 ± 35	19 ± 5	5.0 ± 1.4
Σ SM irreducible	65 ± 12	22 ± 4	3.4 ± 1.8	245 ± 35	20 ± 5	5.8 ± 1.4
SM reducible	31 ± 14	7 ± 5	1.0 ± 0.4	4^{+5}_{-4}	1.7 ± 0.7	0.5 ± 0.4
Σ SM	**96 ± 19**	**29 ± 6**	**4.4 ± 1.8**	**249 ± 35**	**22 ± 5**	**6.3 ± 1.5**
Data	**101**	**32**	**5**	**273**	**23**	**6**
p_0-value	0.41	0.37	0.40	0.23	0.44	0.5
N_{signal} excluded (exp)	39.3	16.3	6.2	67.9	13.2	6.7
N_{signal} excluded (obs)	41.8	18.0	6.8	83.7	13.9	6.5
$\sigma_{\mathrm{visible}}$ excluded (exp) [fb]	1.90	0.79	0.30	3.28	0.64	0.32
$\sigma_{\mathrm{visible}}$ excluded (obs) [fb]	2.02	0.87	0.33	4.04	0.67	0.31

SRnoZa

$\mathrm{mSFOS} < 60\,\mathrm{GeV}$, $\min(\mathrm{mSFOS}) > 12\,\mathrm{GeV}$, $\mathrm{E}_{\mathrm{T}}^{\mathrm{miss}} > 50\,\mathrm{GeV}$ and

either $\mathrm{E}_{\mathrm{T}}^{\mathrm{miss}} < 75\,\mathrm{GeV}$ or $m_T(W) < 110\,\mathrm{GeV}$ or $p_T(\ell_3) < 30\,\mathrm{GeV}$