Signatures of compressed SUSY

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- Introduction
- Signal I: Photons from well-tempered neutralinos
- Signal II: Compressed gluinos
- Conclusions

Worked based on:

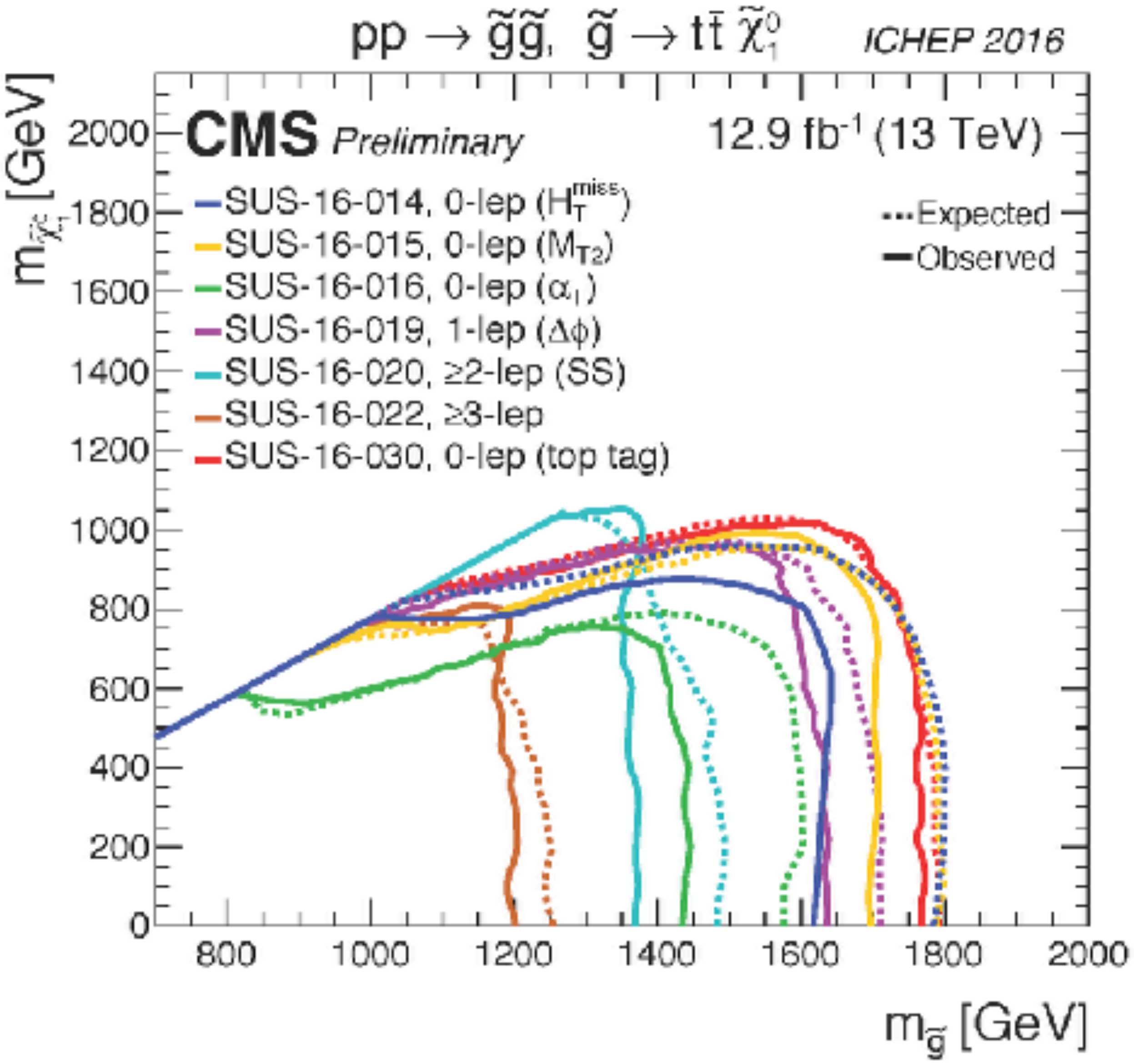
J. Bramante, AD, F. Elahi, A. Martin and B. Ostdiek PRD90(2014)095008

AD, A. Martin, Nirmal Raj arXiv:1605.06479

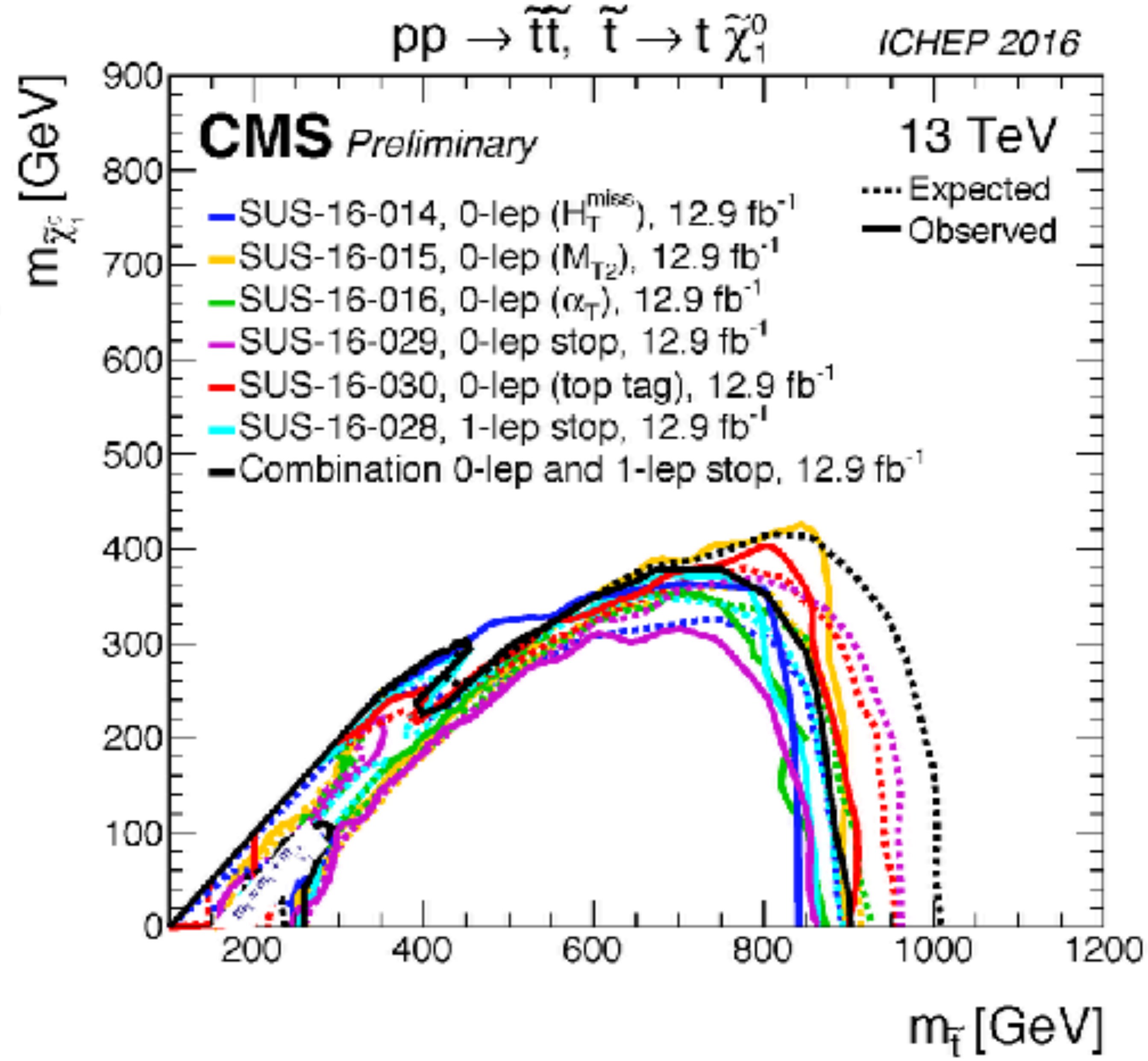
Introduction

- With the discovery of the Higgs the SM is now a complete description for particle physics (forgetting DM).
- On the other hand that same discovery by itself makes the theory fine-tuned.
- The lack of any other experimental evidence makes us believe that either the SM is the only theory above the Fermi scale or....

- Any model aiming to explain the hierarchy problem has to remain ‘natural’
- One possibility for SUSY models to escape the bounds on superparners is to suppose that the spectrum is compressed.



$pp \rightarrow \tilde{g}\tilde{g},\ \tilde{g} \rightarrow t\bar{t}\,\tilde{\chi}^0_1$
ICHEP 2016
CMS Preliminary
12.9 fb^{-1} (13 TeV)
SUS-16-014, 0-lep (H_T^{miss})
SUS-16-015, 0-lep (M_{T2})
SUS-16-016, 0-lep (α_T)
SUS-16-019, 1-lep ($\Delta\phi$)
SUS-16-020, ≥2-lep (SS)
SUS-16-022, ≥3-lep
SUS-16-030, 0-lep (top tag)
Expected
Observed
$m_{\tilde{\chi}^0_1}$ [GeV]
$m_{\tilde{g}}$ [GeV]



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SUS-16-016, 0-lep (α_T), 12.9 fb^{-1}
SUS-16-029, 0-lep stop, 12.9 fb^{-1}
SUS-16-030, 0-lep (top tag), 12.9 fb^{-1}
SUS-16-028, 1-lep stop, 12.9 fb^{-1}
Combination 0-lep and 1-lep stop, 12.9 fb^{-1}
Expected
Observed
$m_{\tilde{\chi}^0_1}$ [GeV]
$m_{\tilde{t}}$ [GeV]

- In the first part of the talk I will study an alternative signal to discover electroweakinos in compressed spectra.

- These scenarios are a possibility in order to explain the observed DM relic density through a non-trivial mixing among the different neutralinos, since a pure Bino tends to overclose the universe and a pure Higgsino or Wino will co-annihilate to fast.

Arkani-Hamed, AD, Giudice

- In the second part I will study another compressed scenario also based on DM.
- In this case it will be a situation where the mass of the gluino is only around O(100 GeV) larger than the one of the LSP.
- DM is then obtained via co-annihilation

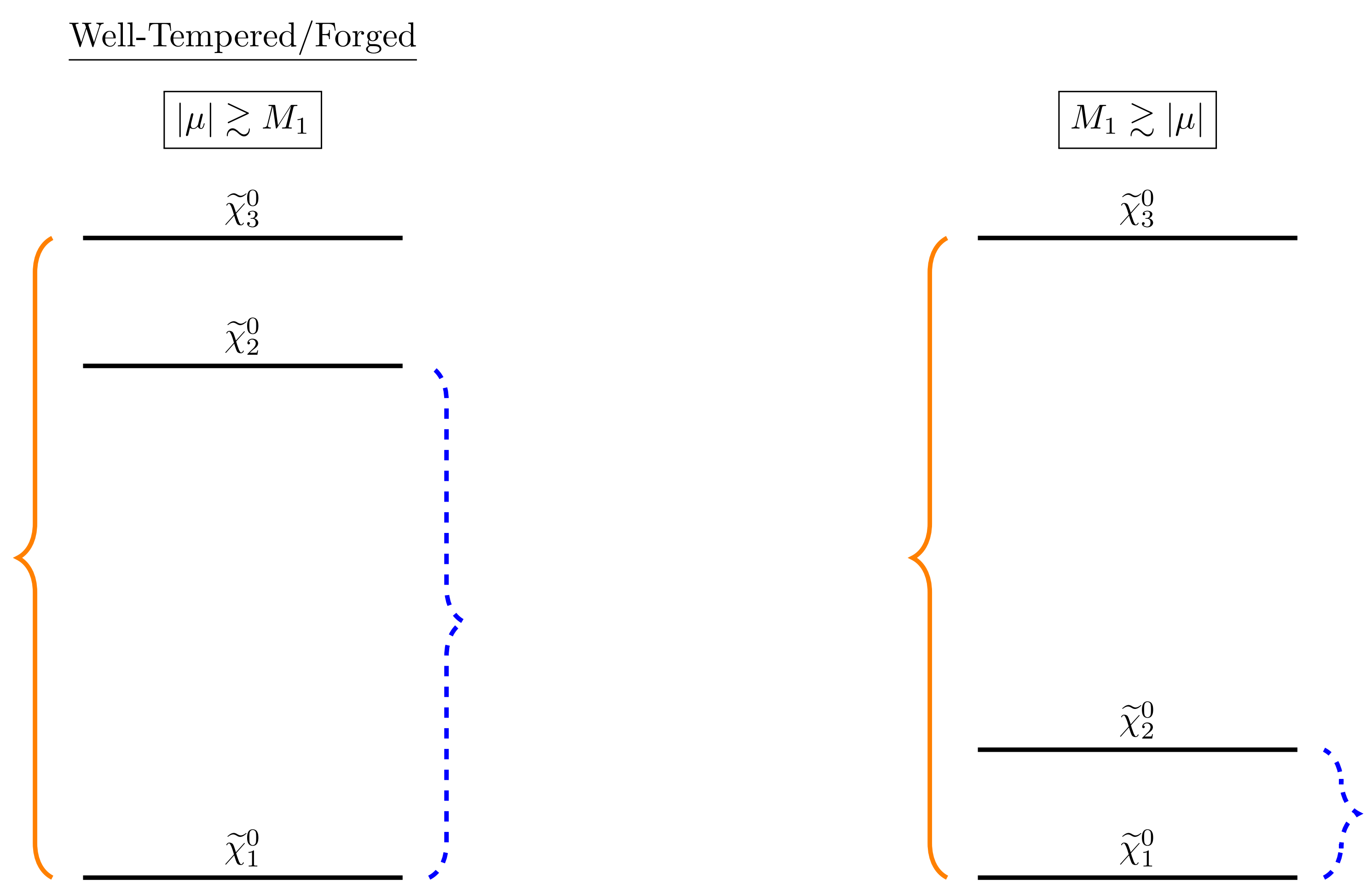
Photons from well-tempered neutralinos

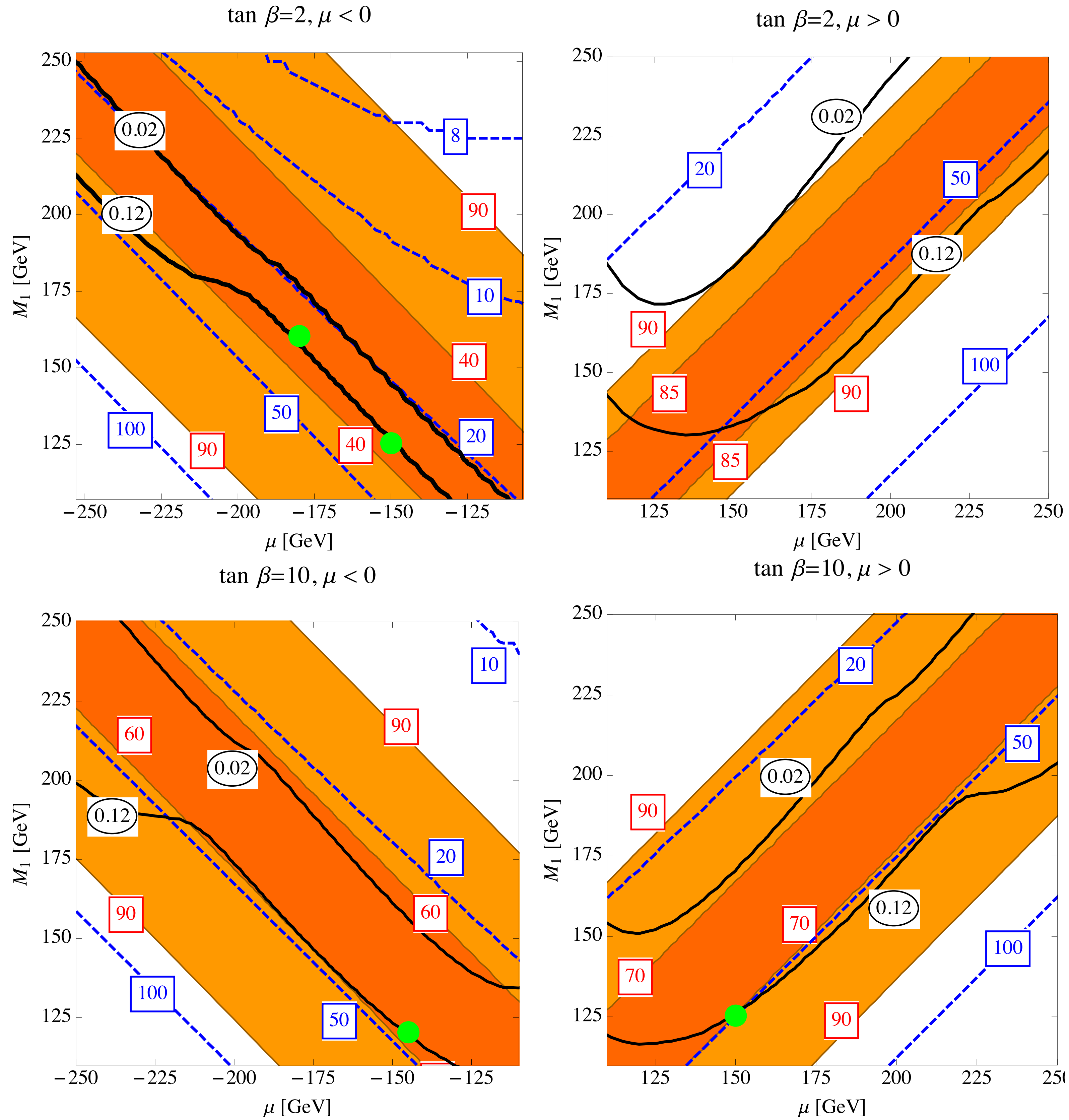
- DM relic abundance can be accommodated within the MSSM with just neutralinos in the following cases:
  - Bino very light with mass $m_z/2$ or $m_h/2$
  - Higgsino around 1 TeV
  - Wino around 2 TeV
  - Non-trivial admixture of Bino-Higgsino or Bino-Wino

- The non-trivial Bino-Higgsino admixture could have implications for the LHC
- It can also be obtained in models of minimal sugra using the focus point scenario.
- μ is small due to the cancellation of the soft mass of the Higgs and M_1 is small due to the running.
- One possible natural SUSY scenario.

- Standard trilepton searches for electrowikinos can be problematic for compressed spectra. These scenarios are motivated by DM.

splittings of ~40 GeV

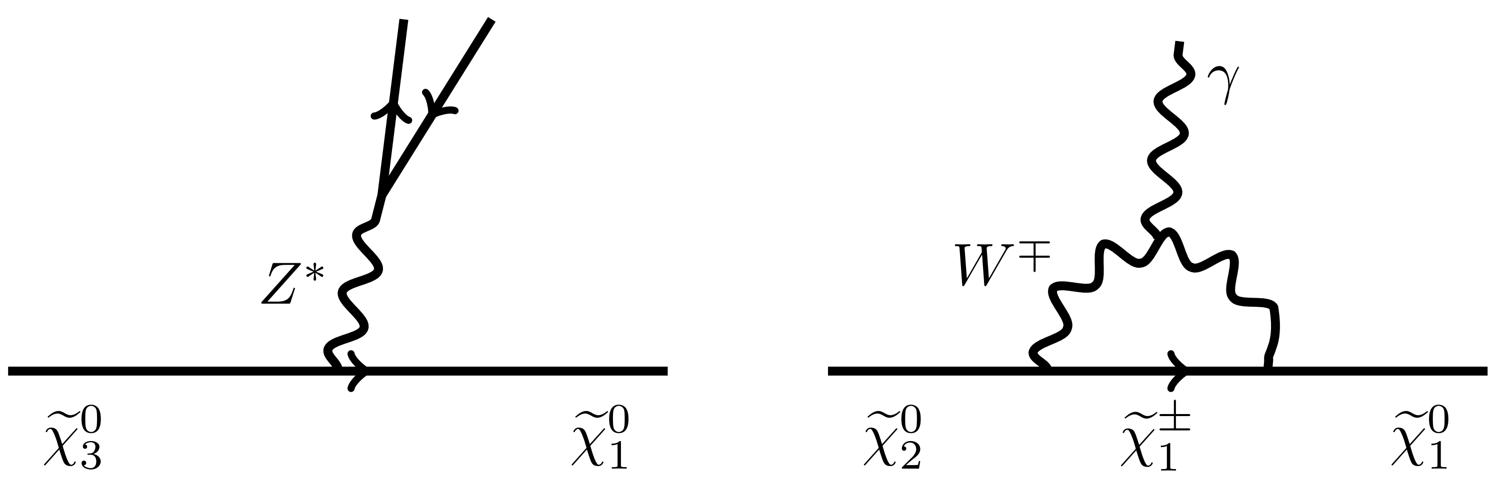


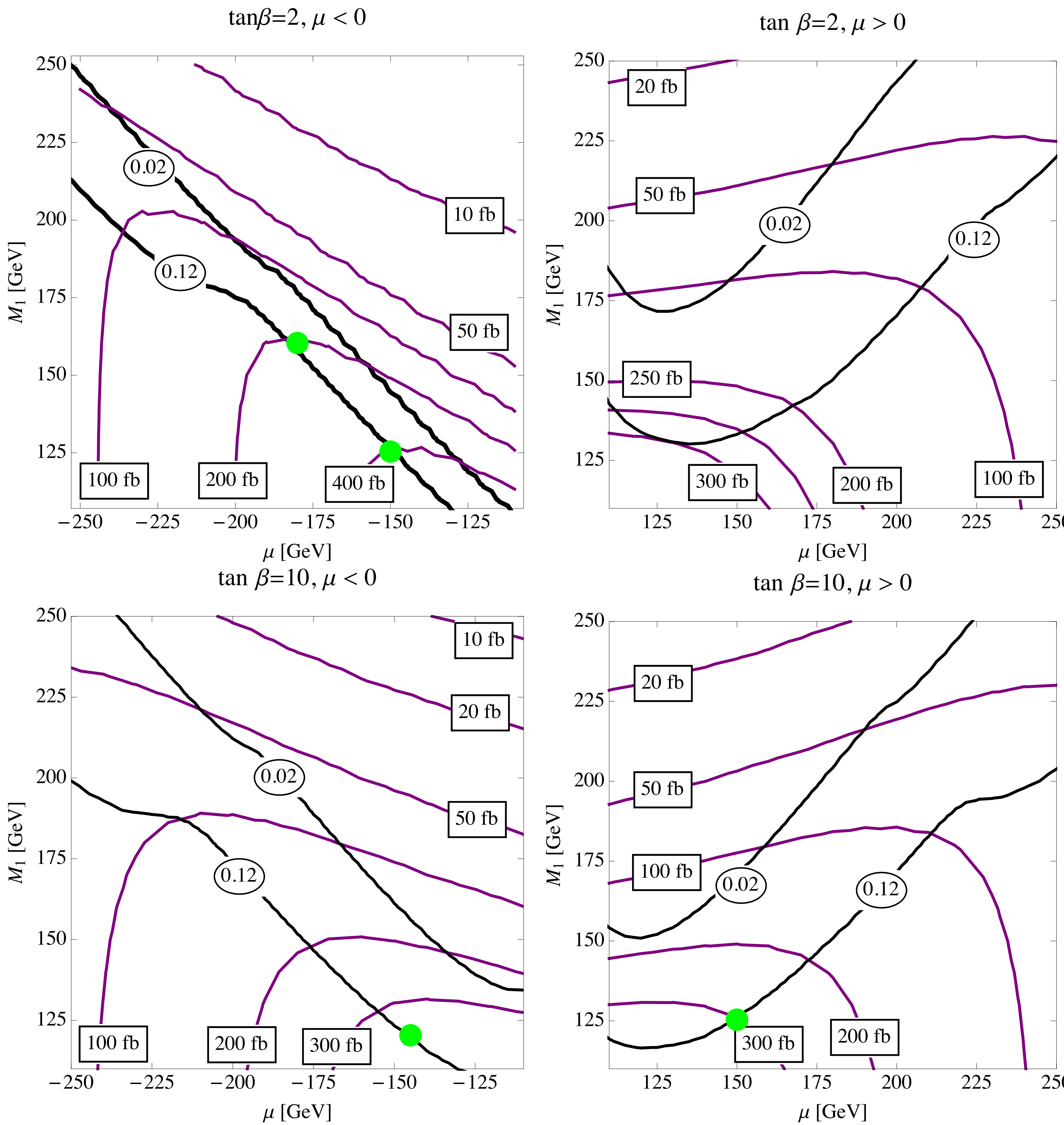


Masses, splitting and Ωh^2

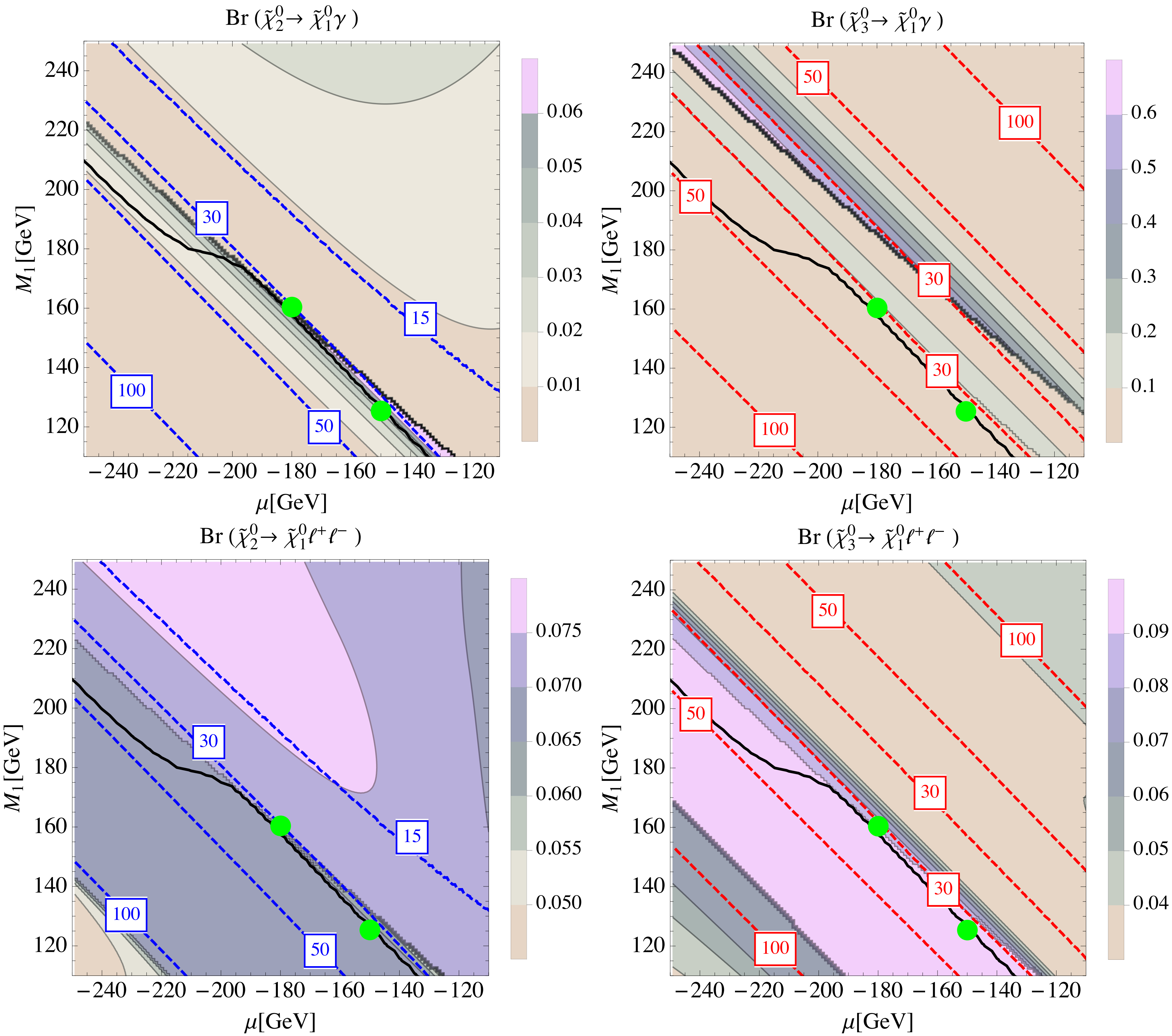
- Since the splittings are quite small I am going to propose a different way of discovering this kind of spectra:

$$pp \to \chi_2\chi_3 \to \ell^+\ell^-\gamma + \chi_1\chi_1$$





Total cross-section of $pp \to \chi_2\chi_3$



Splittings and BR's

- The following benchmark points are going to be simulated with SuSpect, SUSY-HIT, MG5@NCLO and Pythia and we trigger on the leptons:

Benchmark points	Point A	Point B	Point C	Point D
μ	-150 GeV	-180 GeV	-145 GeV	150 GeV
M_1	125 GeV	160 GeV	120 GeV	125 GeV
$\tan\beta$	2	2	10	10
$m_{\widetilde{\chi}_1^0}$	124.0 GeV	157 GeV	105 GeV	103 GeV
$m_{\widetilde{\chi}_2^0}$	156.9 GeV	186 GeV	150 GeV	153 GeV
$m_{\widetilde{\chi}_3^0}$	157.4 GeV	188 GeV	163 GeV	173 GeV
$\sigma(pp \to \widetilde{\chi}_2^0\widetilde{\chi}_3^0)$	394 fb	200 fb	345 fb	287 fb
$BR(\widetilde{\chi}_2^0 \to \widetilde{\chi}_1^0\gamma)$	0.0441	0.0028	0.0017	0.0014
$BR(\widetilde{\chi}_2^0 \to \widetilde{\chi}_1^0\ell^+\ell^-)$	0.0671	0.0712	0.0702	0.0700
$BR(\widetilde{\chi}_3^0 \to \widetilde{\chi}_1^0\gamma)$	0.0024	0.0767	0.0115	0.0102
$BR(\widetilde{\chi}_3^0 \to \widetilde{\chi}_1^0\ell^+\ell^-)$	0.0714	0.0613	0.0447	0.0304
$\sigma(pp \to \widetilde{\chi}_2^0\widetilde{\chi}_3^0 \to \gamma\ell^+\ell^-\widetilde{\chi}_1^0\widetilde{\chi}_1^0)$	1.297 fb	1.125 fb	0.279 fb	0.205 fb

- Main backgrounds:

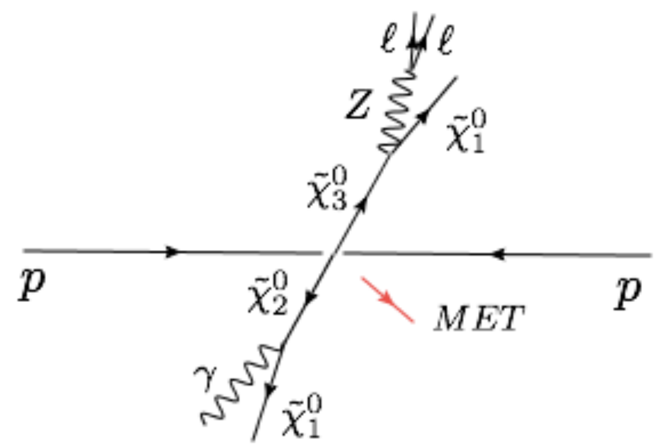
$$pp \to t\bar{t}\ \gamma\big|_{\text{dilepton decay}}$$

$$pp \to \gamma^*/Z(\tau^+\tau^-)\ \gamma\big|_{\text{dilepton decay}}$$

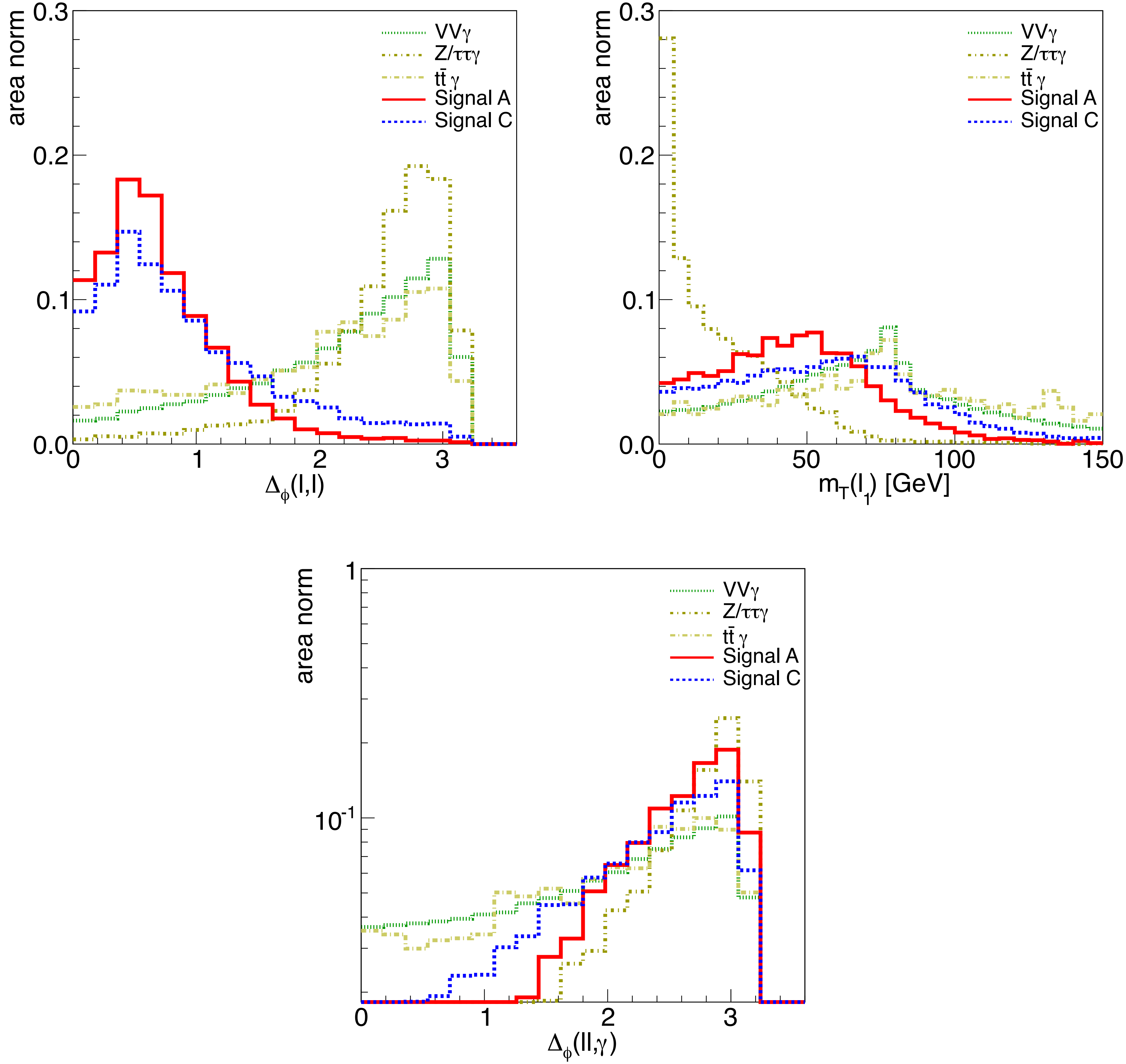
$$pp \to VV\ \gamma\big|_{\text{dilepton decay}}$$

- Fakes coming from jets faking a lepton are under control assuming the following rate:

$$\epsilon_{j\to\ell} = 0.01\%$$



- p_t cuts: $p_{T,\ell_1} > 20$ GeV $\quad p_{T,\ell_2} > 8$ GeV $\quad p_{T,\gamma} > 20$ GeV
- Jet-veto
- Azimutal angle between leptons $<\pi/2$
- 10 GeV $<M_T(\text{leptons})<m_W$
- Azimutal angle between lepton pair and γ
- $m_{ll} << m_W$


area norm
VVγ
Z/ττγ
tt̄ γ
Signal A
Signal C
Δϕ(l,l)
mT(l1) [GeV]
Δϕ(ll,γ)
0.0
0.1
0.2
0.3
0
1
2
3
50
100
150
10^-1

'small mass splitting' cuts	Cross section [ab]					Significance
Cut	Signal A	Signal B	$VV\gamma$	$t\bar{t}\gamma$	$Z/\tau\tau\gamma$	S/B
0) Basic Selection	281	169	5830	18900	24500	5.7×10^{-3} (3.4×10^{-3})
1) $N_{jets} = 0$	181	108	4820	1220	21400	6.6×10^{-3} (3.9×10^{-3})
2) $\lvert\Delta\phi_{\ell_1,\ell_2}\rvert < 1.0$	118	79.5	580	201	567	8.8×10^{-2} (5.9×10^{-2})
3) $\left.\begin{array}{c}15\text{ GeV} < m_T(\ell_2) < 50\text{ GeV}\\ m_T(\ell_1) < 60\text{ GeV}\end{array}\right\}$	52.4	38.2	93.3	32.8	92.2	0.24 (0.17)
4) $\lvert\Delta\phi_{\ell\ell-\gamma}\rvert > 1.45$	49.9	37.0	65.2	25.0	67.8	0.32 (0.23)
5) 30 GeV $< p_{T,\gamma} <$ 100 GeV	36.9	28.2	36.6	17.2	19.0	0.51 (0.39)
6) $\not{E}_T$ cuts	26.8	20.2	24.6	3.90	0.00	0.94 (0.71)
7) $m_{\ell\ell} <$ 24 GeV	23.3	19.3	9.29	0.00	0.00	2.5 (2.1)

Luminosity needed: A 430 fb^{-1} B 620 fb^{-1} C 4300 fb^{-1} D 1900 fb^{-1}

'large mass splitting' cuts	Cross section [ab]					Significance
Cut	Signal C	Signal D	$VV\gamma$	$t\bar{t}\gamma$	$Z/\tau\tau\gamma$	S/B
0) Basic Selection	256	411	5830	18900	24500	5.2×10^{-3} (8.3×10^{-3})
1) $N_{jets} = 0$	157	227	4820	1220	21400	5.7×10^{-3} (8.3×10^{-3})
2) $\lvert\Delta\phi_{\ell_1,\ell_2}\rvert < 1.05$	68.3	109	618	208	608	4.8×10^{-2} (7.6×10^{-2})
3) $\left.\begin{array}{c}10\text{ GeV} < m_T(\ell_1) < 100\text{ GeV}\\ 10\text{ GeV} < m_T(\ell_2) < 95\text{ GeV}\end{array}\right\}$	47.9	72.2	389	127	117	7.5×10^{-2} (0.11)
4) 8 GeV $< \not{E}_T <$ 95 GeV	45.8	69.4	375	116	84.1	7.9×10^{-2} (0.12)
5) $m_{\ell\ell} <$ 39 GeV	42.8	64.0	228	35.9	51.5	0.14 (0.20)

- In general the bigger the splitting the more difficult to use this signal
- Also the bigger the splitting the bigger chance not to lose one of the leptons in the usual tri-lepton searches
- Other photons signals with charginos were analyzed but the significance was smaller.

Compressed Gluinos

- Another way of achieving the relic abundance in the MSSM is when the LSP is the Bino which interacts very weakly and there is another particle almost degenerate in mass whose co-annihilations could reproduce the right value for Ωh^2.

- In this scenarios the splitting between the LSP and the NLSP is the one that sets the relic abundance.
- Of all the possible superparners the one with larger interactions are the gluinos.
- Larger interactions means that the splitting will be also larger.

- For the case of the gluino, the splitting needed to correctly explained the relic abundance is:

$$\Delta M \simeq 100 \ \mathrm{GeV}$$

- One may wonder in which UV theories that can be achieved, it requieres non-universal gaugino masses but that is all I will talk about this…..

- In order to present the analysis I am going to decouple the rest of the supersymmetric spectrum.

- Therefore the process to study is:

$$p\,p \to \widetilde{g}\,\widetilde{g} \to 2(\widetilde{q})^{*} + 2j \to 2\widetilde{\chi}_1^0 + 4j$$

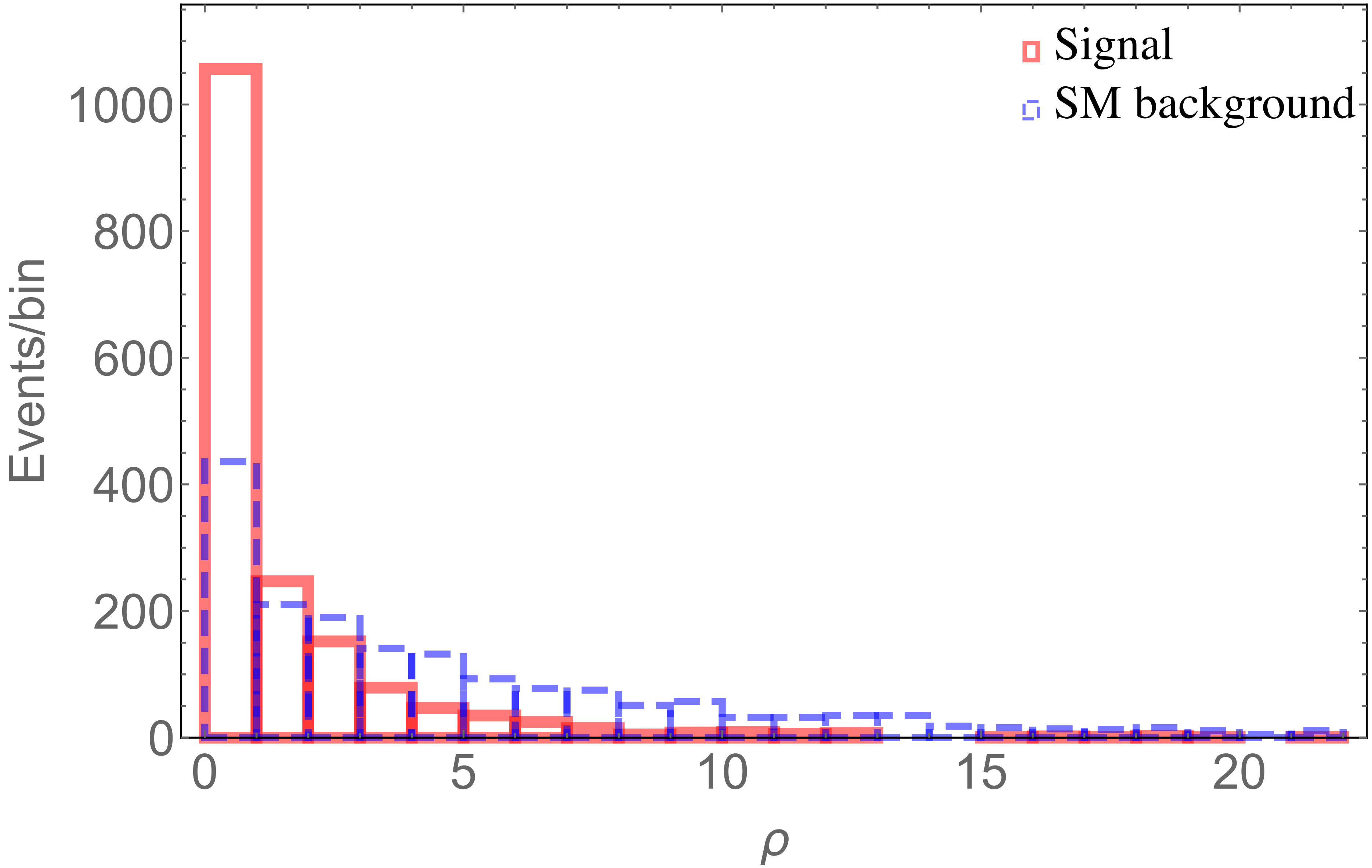
- Since the mass difference between the gluino and the neutralino is small then:
  - Jets coming from the gluinos are soft.
  - There is not a lot of MET since the gluinos are produced almost at rest and both neutralinos are almost back to back.

- Of course there will also be ISR jets in our events.
- We will distinguish ISR-jets from jets coming from gluinos (honest jets) by the energy.
- $E_{jet} > \Delta M$ ISR, $E_{jet} < \Delta M$ honest
- We expect $N_{ISR} < N_{honest}$

- Main backgrounds that can be calculated are:
    - Z+4j
    - Lost leptons: W+4j, t-tbar, single top
- There is a multijet QCD background with missmeasured MET that we relay on the experimentalists to calculate.
- We will trigger in MET:
    - EF trigger with MET>60 (90) GeV, L2>40 GeV, L1>35 GeV for 8 (13) TeV

- Event are generated using Madgraph demanding the following:
  - MET> 60 (90) GeV for 8 (13) TeV
  - p_T>40 GeV $|\eta|$<2.5
  - b-veto (50% efficient)

- We implement the following cuts:
  - $N_{\text{honest}} > 4$
  - Angle: $||\Delta\phi(\not{E}_T, j_{\text{ISR,max}})| - \pi| \leq 1.5$
  - Energy: $\rho \equiv \frac{\sum_{i=0}^{N_{\text{ISR}}} E^i_{\text{ISR}}}{\not{E}_T} \frac{N_{\text{ISR}}}{N_{\text{honest}}} \leq k(\sqrt{s}, m_{\tilde{g}})$



Values of ρ for the signal and background

Cut	Signal cross-section (fb)	$Z + 4j$ cross-section (fb)	"Lost leptons" cross-section (fb)
Basic cut + trigger	5.77 ± 0.06	1390 ± 13	2282 ± 46
Cut I	3.05 ± 0.04 (53%)	393 ± 7 (28%)	544 ± 22 (24%)
Cut II	2.72 ± 0.04 (47%)	288 ± 6 (21%)	393 ± 18 (17%)
Cut III	2.24 ± 0.04 (39%)	145 ± 4 (10%)	242 ± 15 (10%)

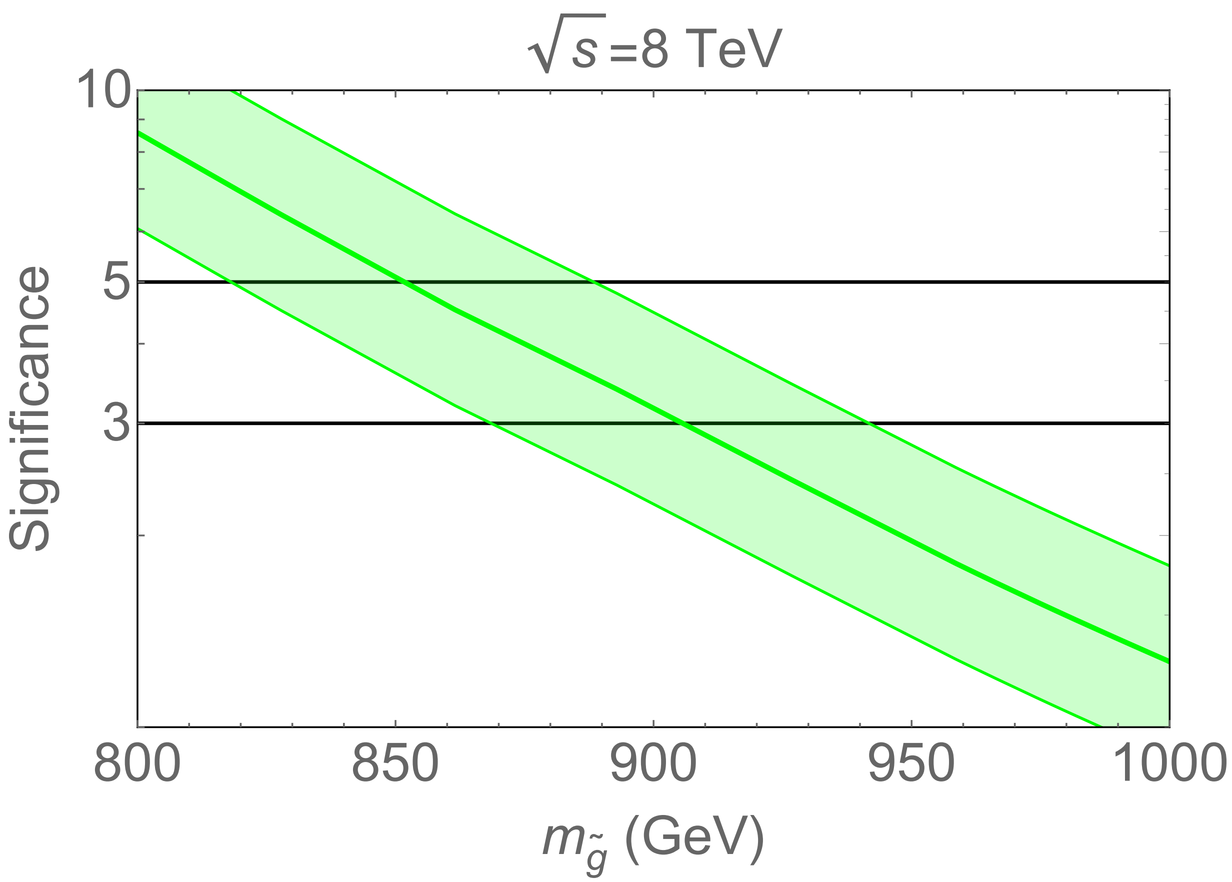
Cut flow for m_g=1 TeV MET-cut=60 GeV at 8 TeV

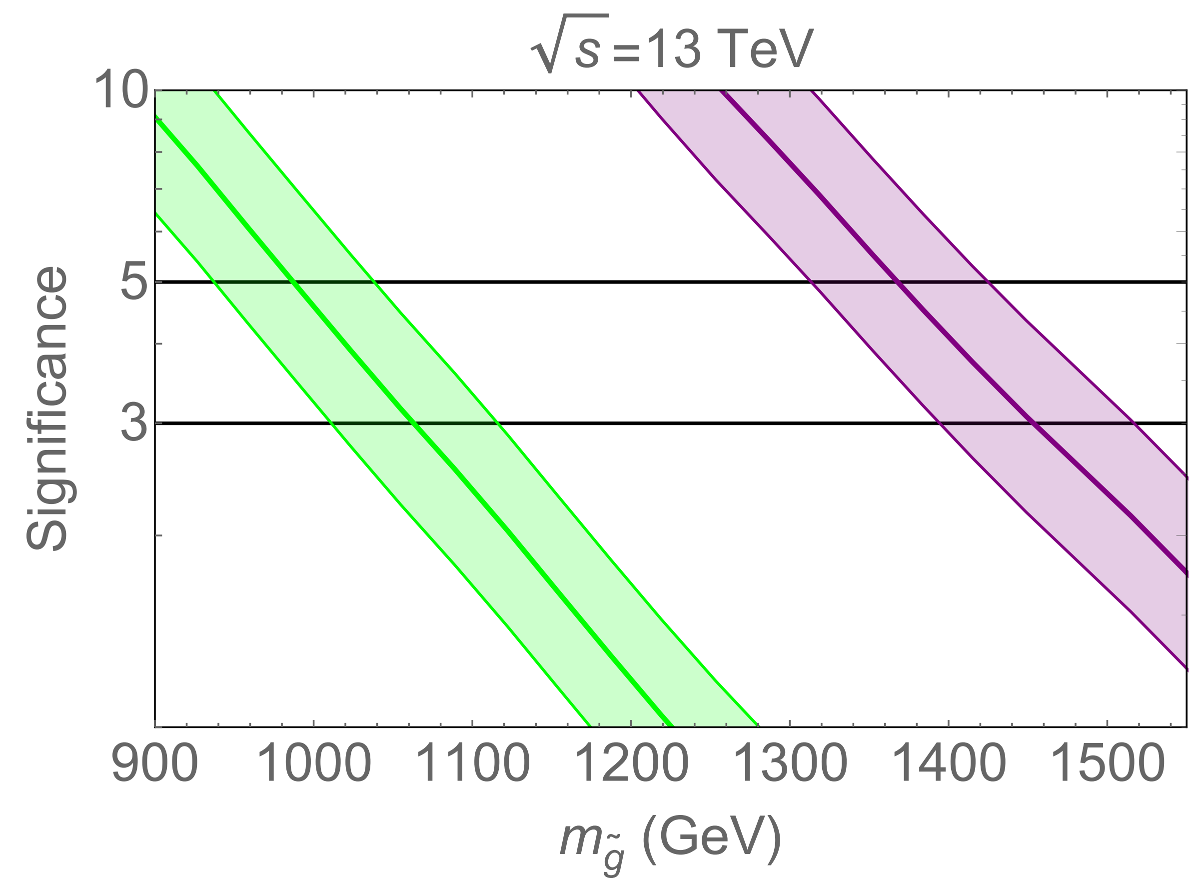
$\sqrt{s} = 8$ TeV, $\mathcal{L} = 20$ fb^{-1}		
$\not{E}_{T,8}^{\rm cut}$	3σ	5σ
60 GeV	900 GeV	850 GeV
100 GeV	890 GeV	840 GeV
140 GeV	880 GeV	825 GeV

$\sqrt{s} = 13$ TeV, 5σ reach		
$\not{E}_{T,13}^{\rm cut}$	$\mathcal{L} = 20$ fb^{-1}	$\mathcal{L} = 3$ ab^{-1}
90 GeV	990 GeV	1370 GeV
180 GeV	980 GeV	1360 GeV

Results for 8 TeV and 13 TeV

(reminder the reach with usual search for 8 TeV is around 650 GeV)





The band accounts for a systematic error of around 75%

- We are able to put bounds of around 900 GeV for 8 TeV which is better than ~700 GeV that you get with the usual technique.
- As before the larger the splitting the less efficient our analysis is.
- For 13 TeV one can get to 1.5 TeV masses.

Conclusions

- In this talk I have analyzed two different channels to discover compressed SUSY.

- In the first part of my talk I have studied the possibility of an alternative way of discovering eletroweakinos with compressed spectrum motivated by DM

- Production of two heavier neutralinos with a subsequent decay into two leptons and a photon may provide the handle for mass differences around 40 GeV.

- In the second part of the talk I have studied the possibility of an alternative way of discovering gluinos with compressed spectrum motivated by DM

- Production of two gluinos with a subsequent decay into two jets and a MET using angular and energy variables may provide the handle for mass differences around 100 GeV.

- This kind of studies may be very important for a future hadron collider.