Multilepton and multiphoton signatures of supersymmetry at the LHC

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Chalmers University of Technology

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Multileptons based on:

J. D'Hondt, K. De Causmaecker, B. Fuks, A. Mariotti, K. Mawatari, C.P., D. Redigolo

arXiv:1310.0018 [hep-ph] (Physics Letters B)

Multiphotons based on:

G. Ferretti, A. Mariotti, K. Mawatari, C.P.

arXiv:1312.1698 [hep-ph] (JHEP)

What is the current feeling among BSM theorists?

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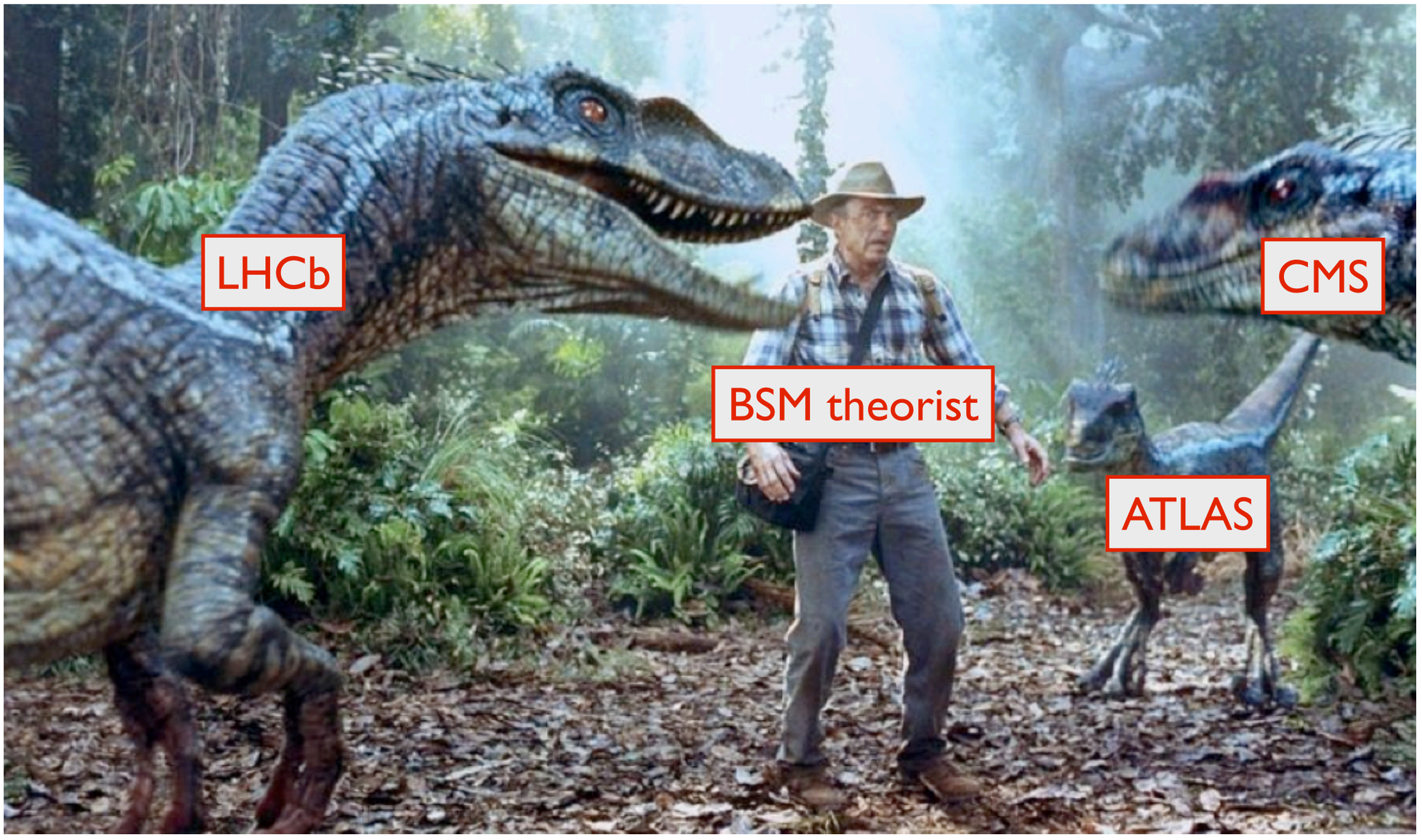
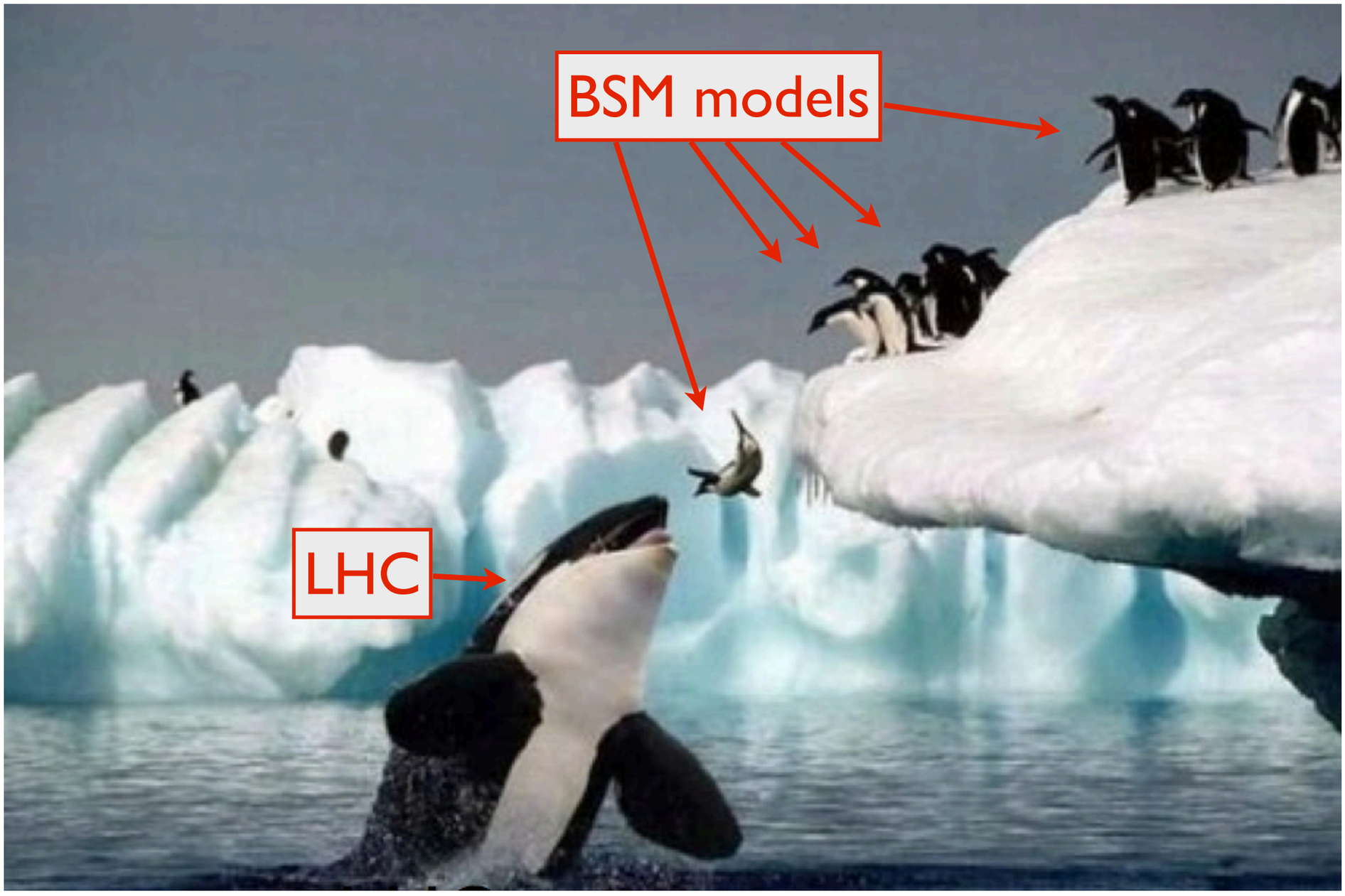


Credit: Hitoshi Murayama

What is the current feeling among BSM theorists?



Credit: Stephen Martin

What is the current feeling among BSM theorists?

Credit: Nathaniel Craig

However...

- ... so far the LHC has mainly probed colored production

- ... so far LHC searches has mainly been aimed at minimal BSM scenarios

However...

- ... so far the LHC has mainly probed colored production
- ... so far LHC searches has mainly been aimed at minimal BSM scenarios

This motivates:

- Non-minimal models
- Non-standard signatures at the LHC
- New LHC searches and strategies

Outline and results

Part I

Exercise: Explain a small excess in multi-lepton events observed last year by CMS with BSM physics.

Result: It is possible with a simple GMSB model, which, in addition, gives rise to non-standard signatures that could be searched for at the LHC.

Outline and results

Part I

Exercise: Explain a small excess in multi-lepton events observed last year by CMS with BSM physics.

Result: It is possible with a simple GMSB model, which, in addition, gives rise to non-standard signatures that could be searched for at the LHC.

Part II

Exercise: Study how the standard phenomenology of GMSB is modified if SUSY is broken in more than one hidden sector.

Result: Softer final state spectrum, but with additional photons.
Existing LHC searches are poorly sensitive.
However, these models can be probed with new, dedicated, searches.

Part I

Multilepton signatures

CMS SUS-13-002

$19.5\,\mathrm{fb}^{-1}$ at $\sqrt{s} = 8\,\mathrm{TeV}$

Search for events with three or more leptons

Selection 4 Lepton Results		E_T^{miss}	$N(\tau_h)=0$, $N_{b-jets}=0$ obs	exp	$N(\tau_h)=1$, $N_{b-jets}=0$ obs	exp	$N(\tau_h)=0$, $N_{b-jets}\geq 1$ obs	exp	$N(\tau_h)=1$, $N_{b-jets}\geq 1$ obs	exp
OSSF0 $H_T < 200$	NA	(100,∞)	0	0.11 ± 0.08	0	0.17 ± 0.1	0	0.03 ± 0.04	0	0.04 ± 0.04
OSSF0 $H_T < 200$	NA	(50,100)	0	0.01 ± 0.03	2	0.7 ± 0.33	0	0 ± 0.02	0	0.28 ± 0.16
OSSF0 $H_T < 200$	NA	(0,50)	0	0.01 ± 0.02	1	0.7 ± 0.3	0	0.001 ± 0.02	0	0.13 ± 0.08
OSSF1 $H_T < 200$	off-Z	(100,∞)	0	0.06 ± 0.04	3	0.6 ± 0.24	0	0.02 ± 0.04	0	0.32 ± 0.2
OSSF1 $H_T < 200$	on-Z	(100,∞)	1	0.5 ± 0.18	2	2.5 ± 0.5	1	0.38 ± 0.2	0	0.21 ± 0.1
OSSF1 $H_T < 200$	off-Z	(50,100)	0	0.18 ± 0.06	4	2.1 ± 0.5	0	0.16 ± 0.08	1	0.45 ± 0.24
OSSF1 $H_T < 200$	on-Z	(50,100)	2	1.2 ± 0.34	9	9.6 ± 1.6	2	0.42 ± 0.23	0	0.5 ± 0.16
OSSF1 $H_T < 200$	off-Z	(0,50)	2	0.46 ± 0.18	15	7.5 ± 2	0	0.09 ± 0.06	0	0.7 ± 0.31
OSSF1 $H_T < 200$	on-Z	(0,50)	4	3 ± 0.8	41	40 ± 10	1	0.31 ± 0.15	2	1.5 ± 0.47
OSSF2 $H_T < 200$	off-Z	(100,∞)	0	0.04 ± 0.03	-	-	0	0.05 ± 0.04	-	-
OSSF2 $H_T < 200$	on-Z	(100,∞)	0	0.34 ± 0.15	-	-	0	0.46 ± 0.25	-	-
OSSF2 $H_T < 200$	off-Z	(50,100)	2	0.18 ± 0.13	-	-	0	0.02 ± 0.03	-	-
OSSF2 $H_T < 200$	on-Z	(50,100)	4	3.9 ± 2.5	-	-	0	0.5 ± 0.21	-	-
OSSF2 $H_T < 200$	off-Z	(0,50)	7	8.9 ± 2.4	-	-	1	0.23 ± 0.09	-	-
OSSF2 $H_T < 200$	on-Z	(0,50)	*156	159 ± 34	-	-	4	2.9 ± 0.8	-	-

In the category: - 4 leptons with one hadronic tau

- One OSSF lepton pair, off-Z
- Low hadronic activity, $H_T < 200$ GeV, no b-jets

Observed: 22

Expected: 10.2 ± 2.4

Slide from presentation by Andrea Gozzelino (CMS) at the conference "SUSY 2013", August 26

Origin & significance of discrepancy

CMS-SUS-13-002

Categorie:

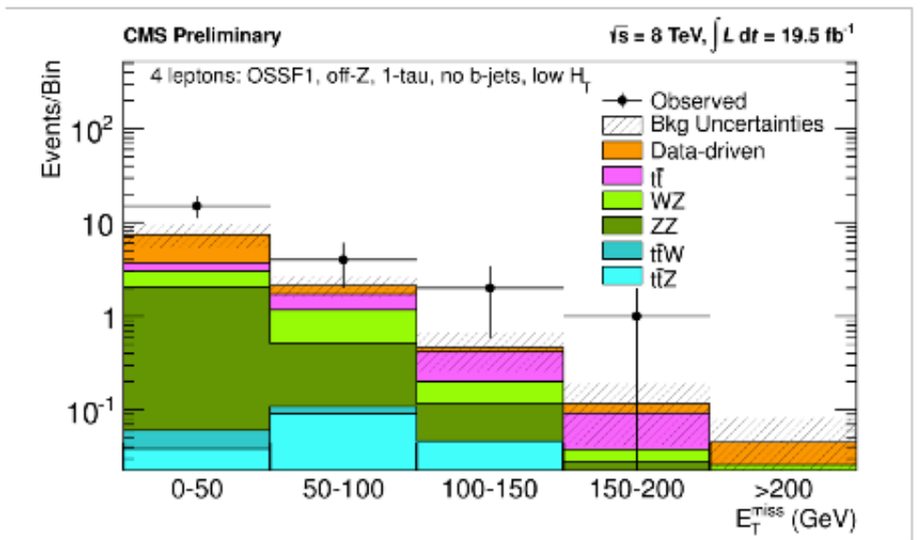
4 leptons, OSSF1, off-Z,

including 1 τ,

no b-tags, HT< 200 GeV

Observe = 22 events

Expected = 10 ± 2.4 events



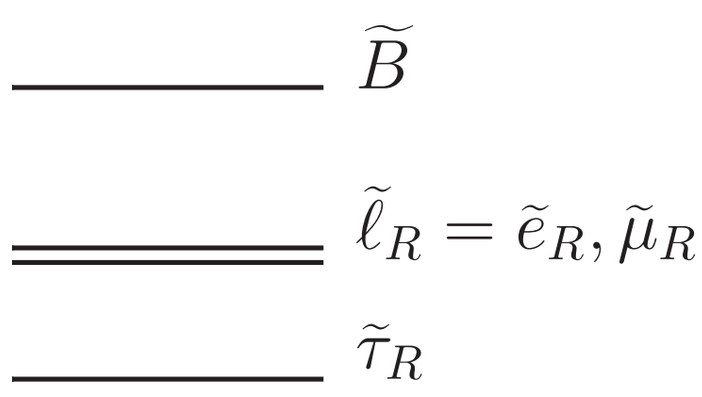
Probability for 1 out of 64 categories to have as large a fluctuation ≈ 50 %

Probability for all bins in 1 out of 64 categories to have as large a fluctuation ≈ 5 %

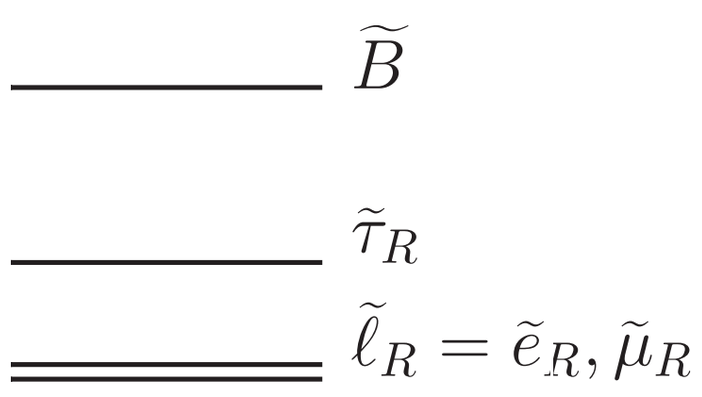
Given that we search for new physics in 64 different categories of multi-lepton events, it is not surprising that we find one category with a large deviation between observed yield and expected SM background.

Simplified models of GMSB

M.I



M.II



[CMS SUS-13-002]

Simplified models of GMSB

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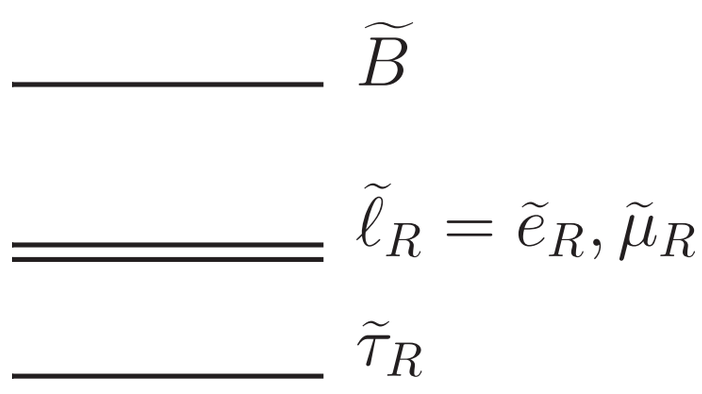
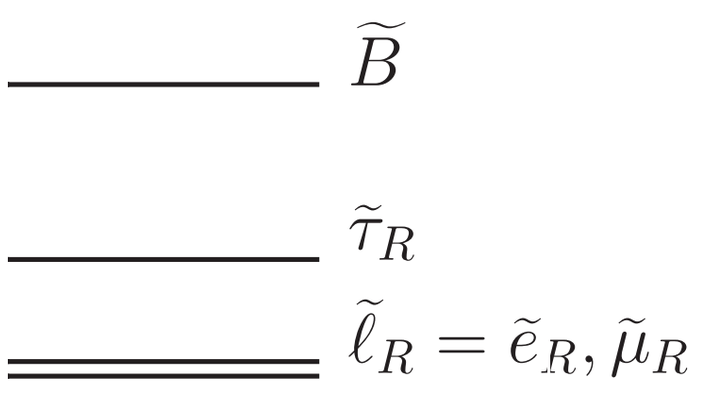


M.II



$\tilde{\tau}_R \to \tau\tilde{G}$

$\tilde{\ell}_R \to \ell\tilde{G}$

Simplified models of GMSB

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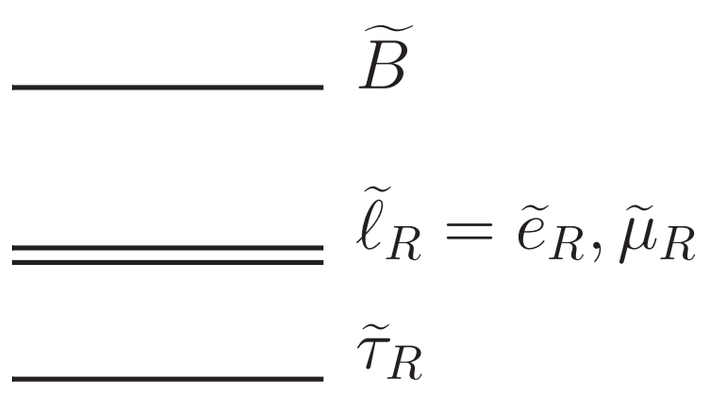

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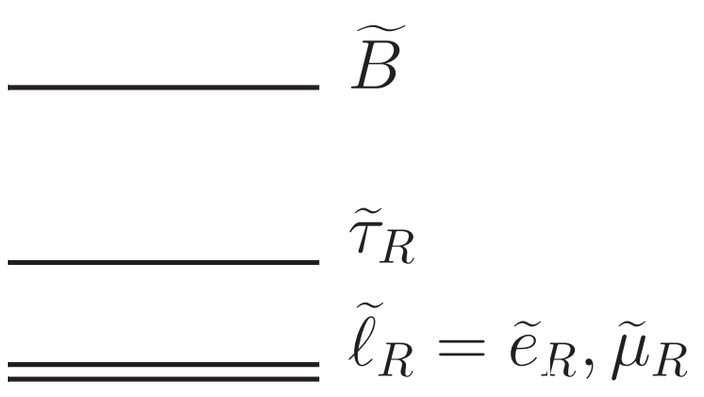

Simplified models of GMSB

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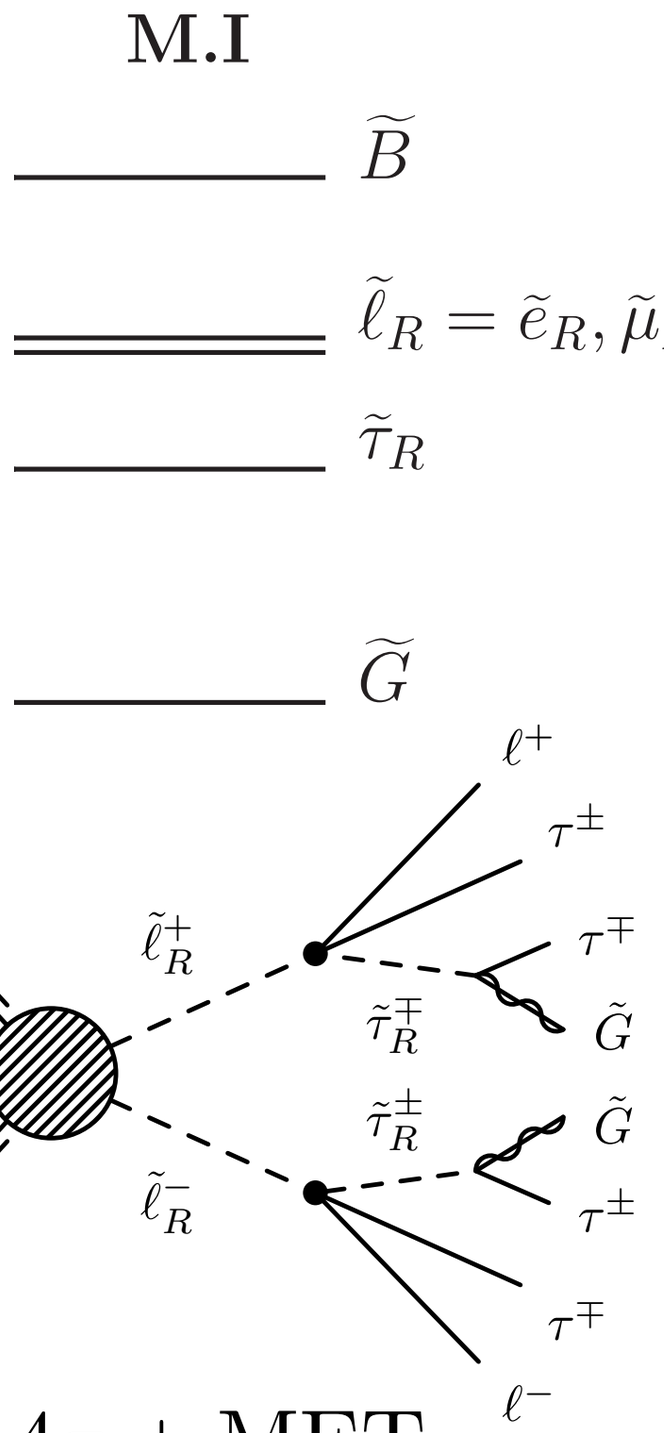
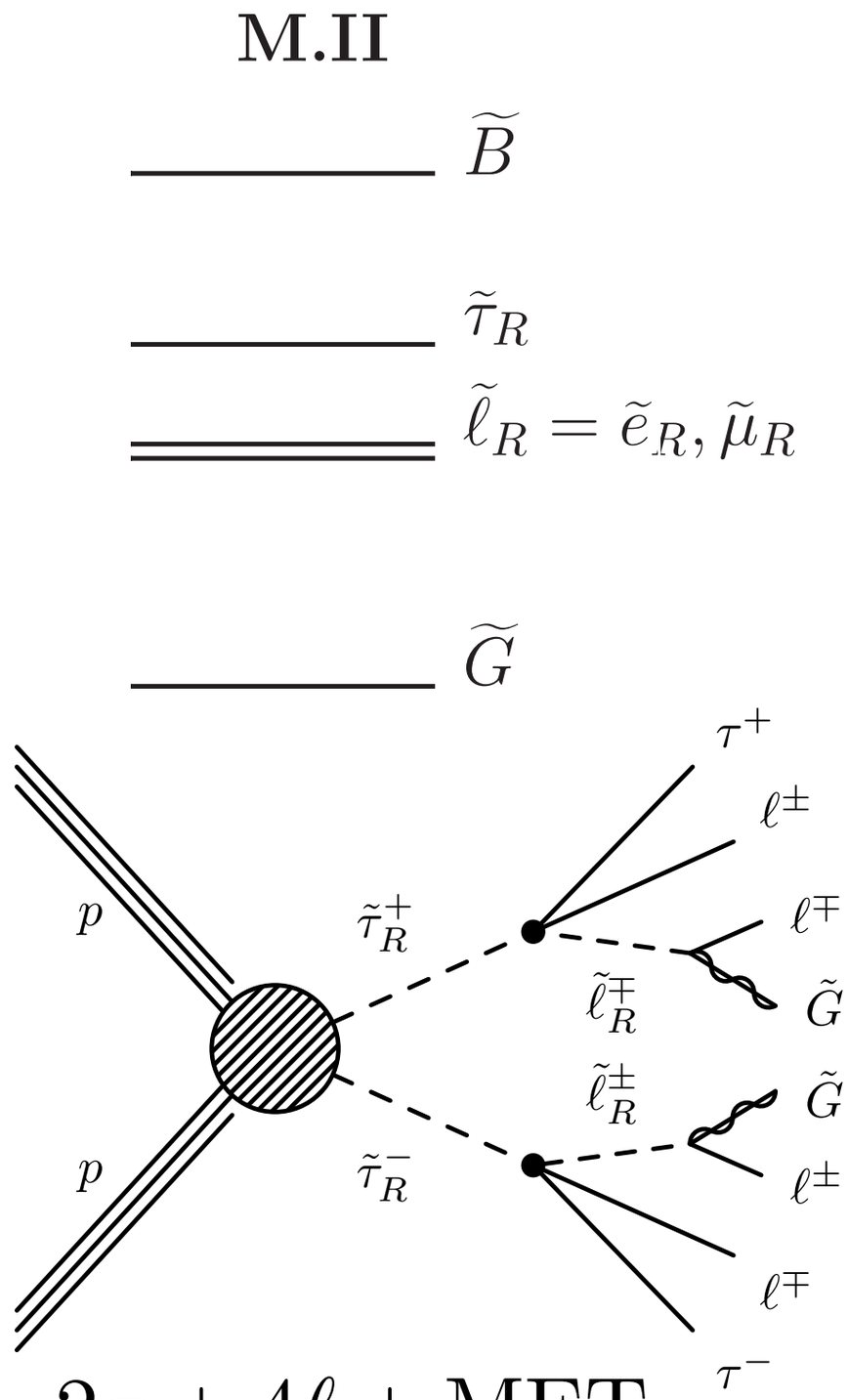


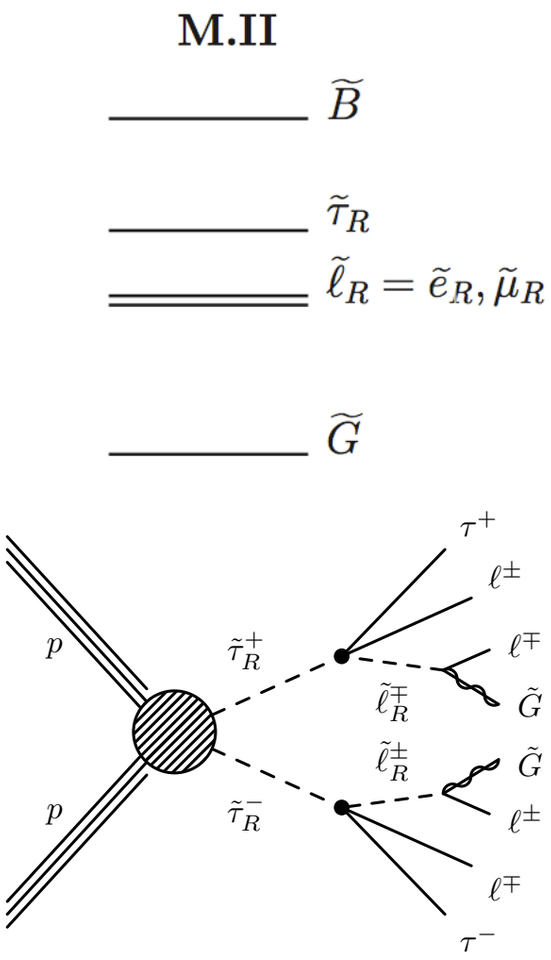
$2\ell + 4\tau + \mathrm{MET}$

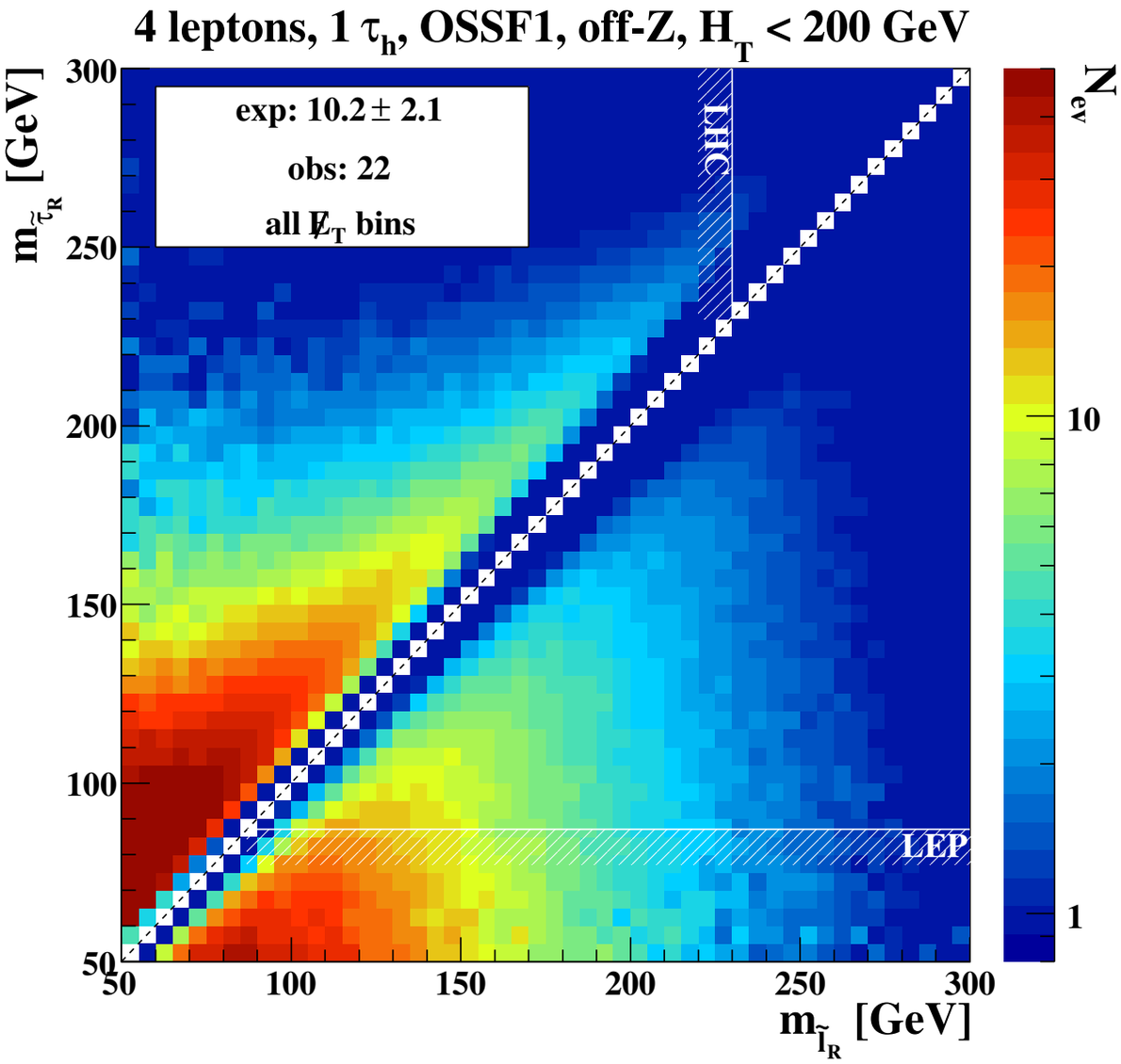
M.II

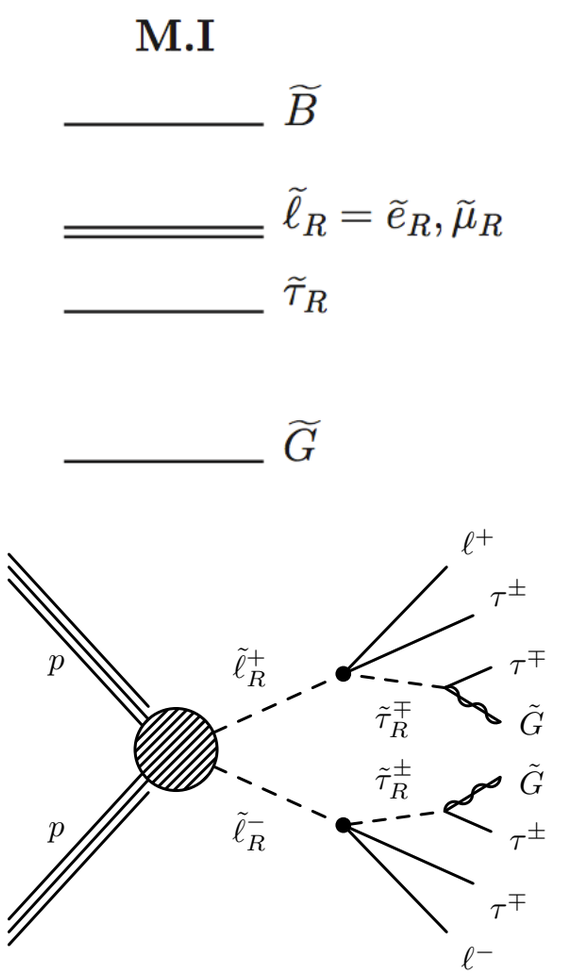


$2\tau + 4\ell + \mathrm{MET}$

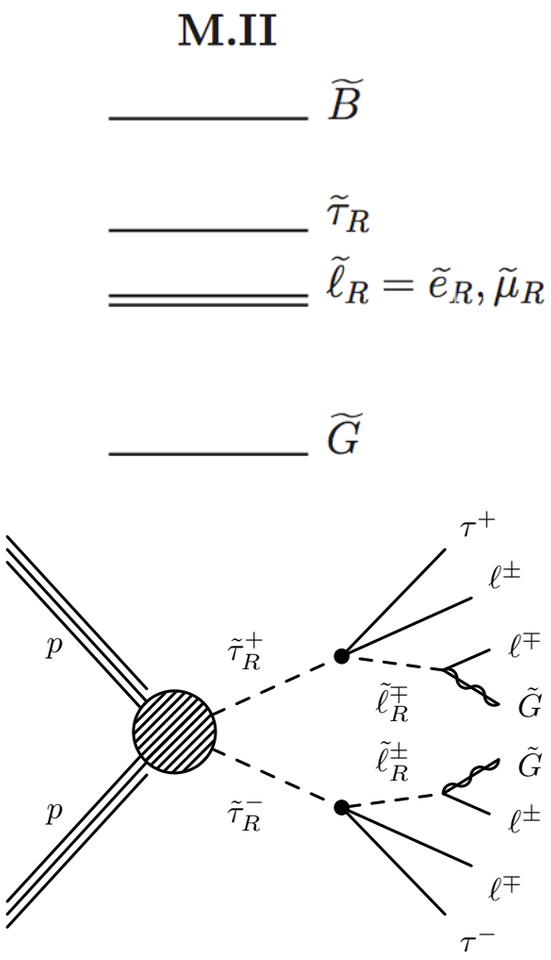
Comparison with CMS search

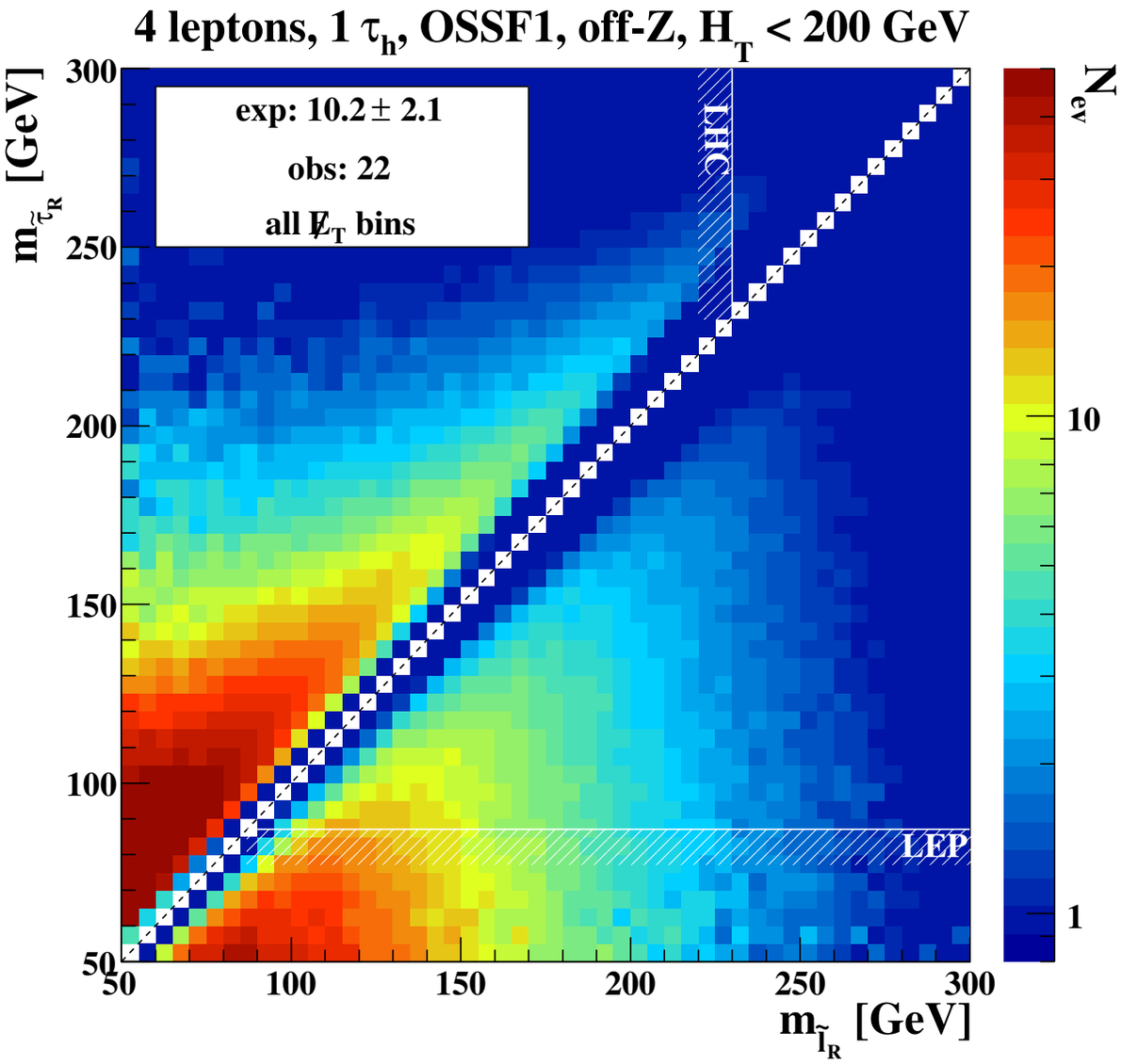


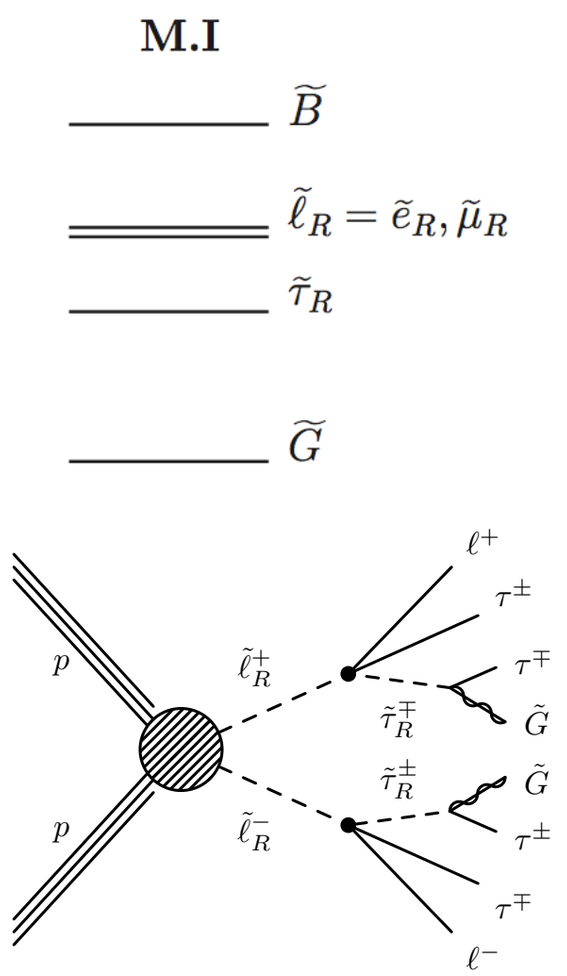




Comparison with CMS search







NLSP pair production sets bounds on these models

Comparison with CMS search

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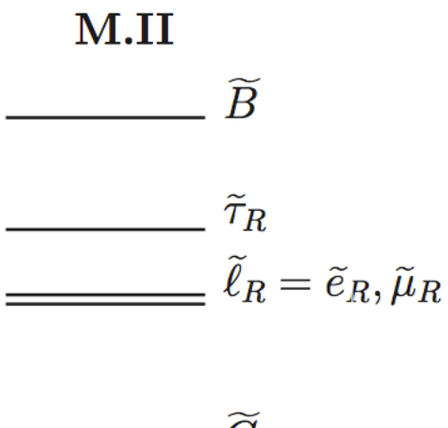
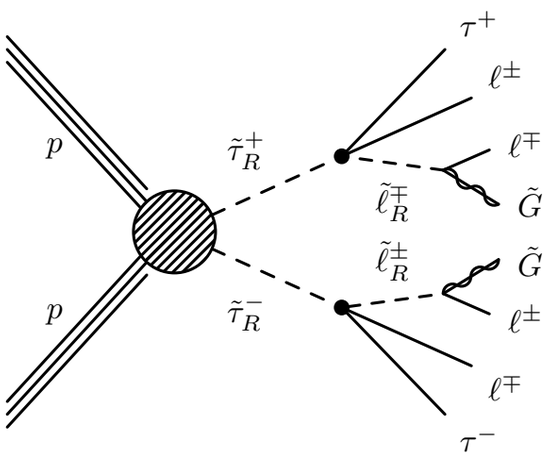
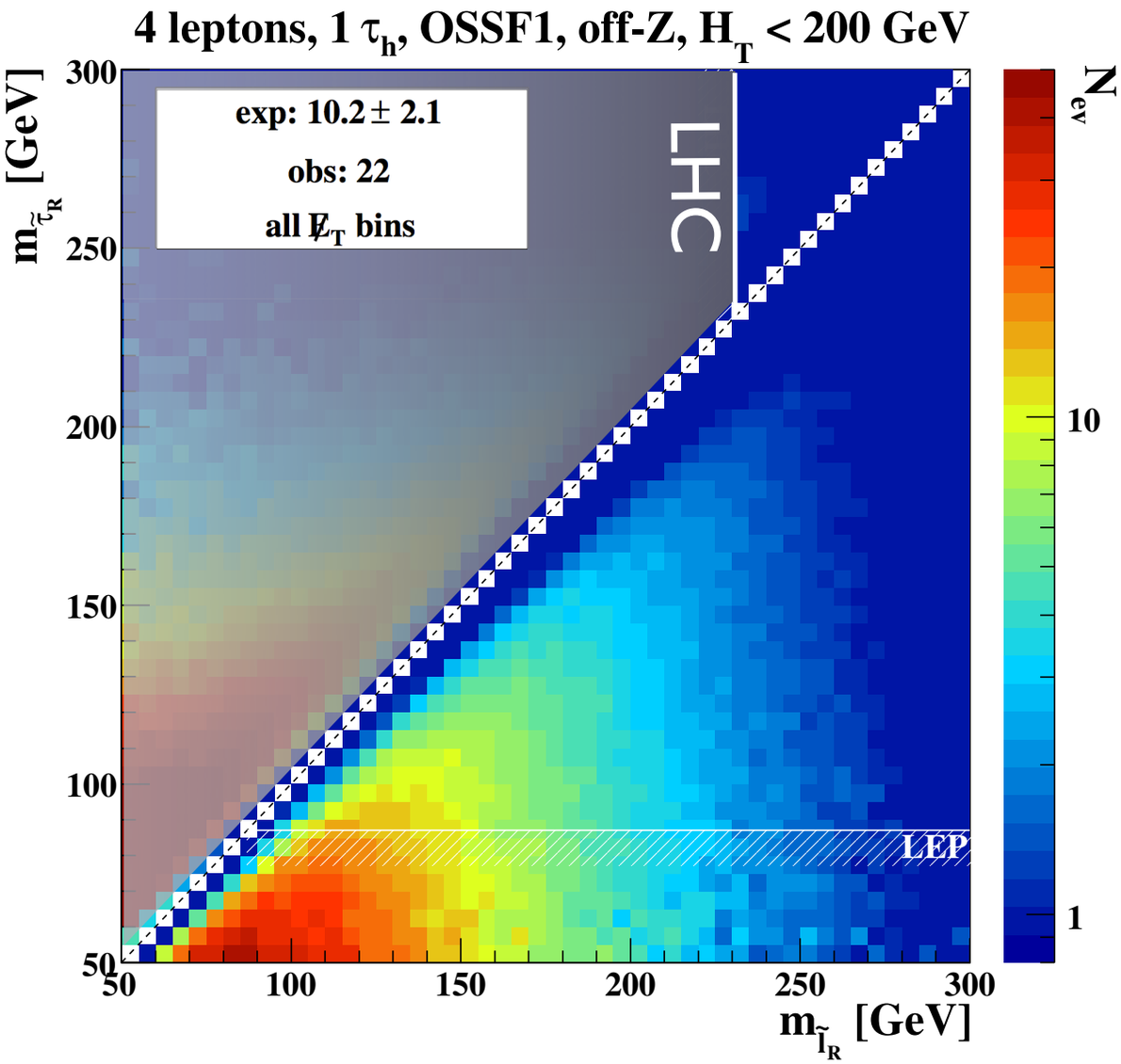
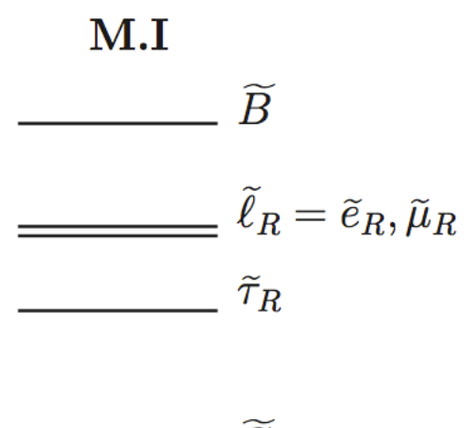
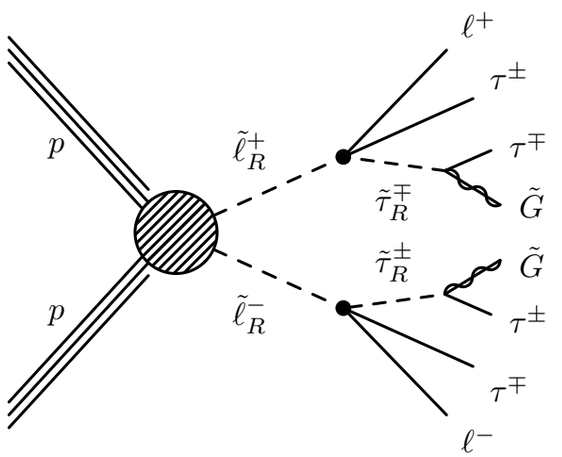






M.I





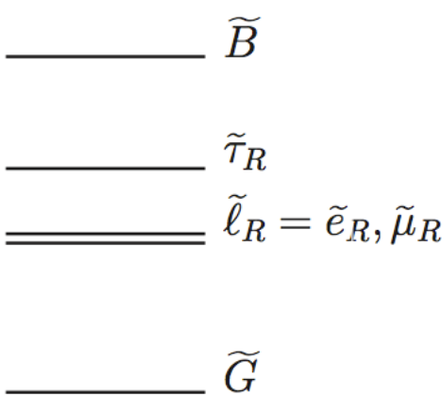
NLSP pair production sets bounds on these models

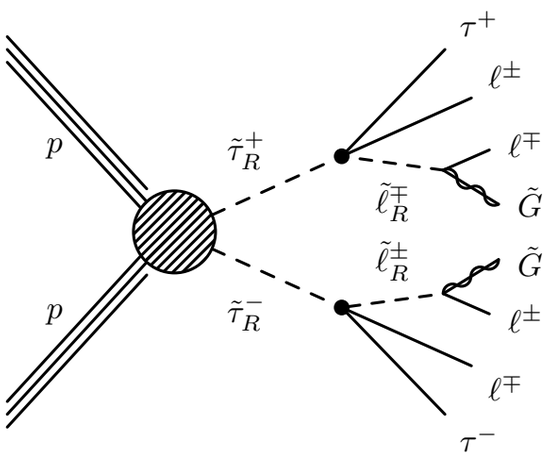
$$\text{M.II}: \quad pp \to \tilde{\ell}_R \tilde{\ell}_R \quad , \quad \tilde{\ell}_R \to \ell \tilde{G} \quad \Rightarrow \quad \ell^+\ell^- + \text{MET}$$

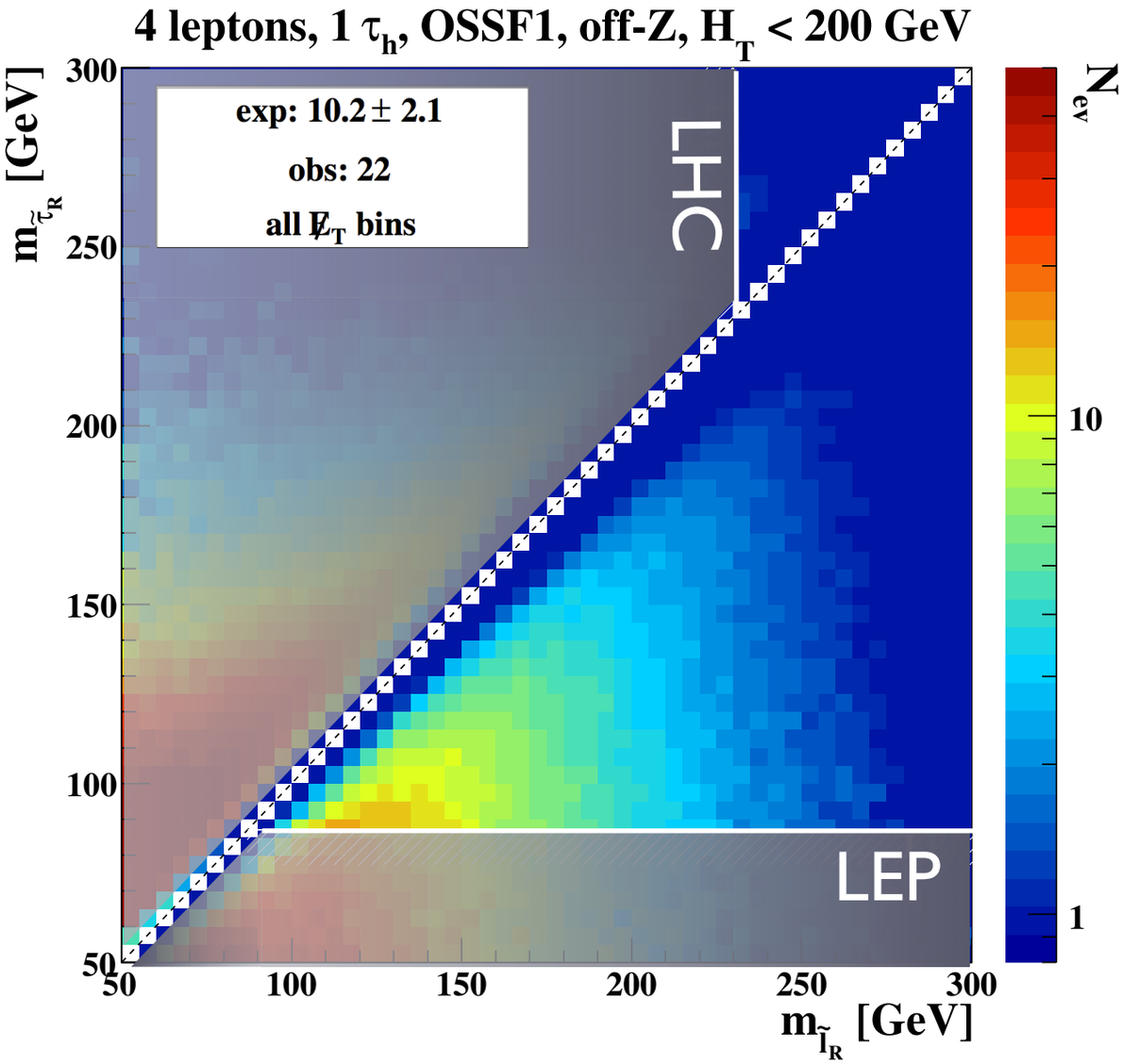
$$\Rightarrow \quad m_{\tilde{\ell}_R} > 230\,\text{GeV} \text{ [ATLAS-CONF-2013-049,CMS-PAS-SUS-13-006]}$$

Comparison with CMS search

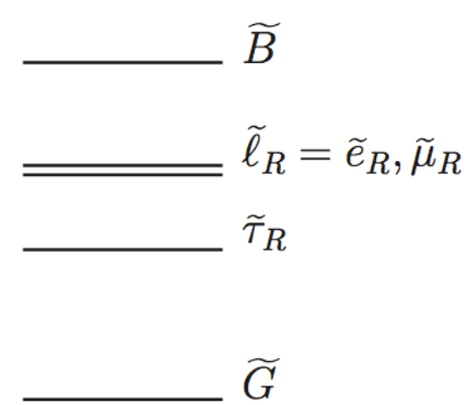
M.II

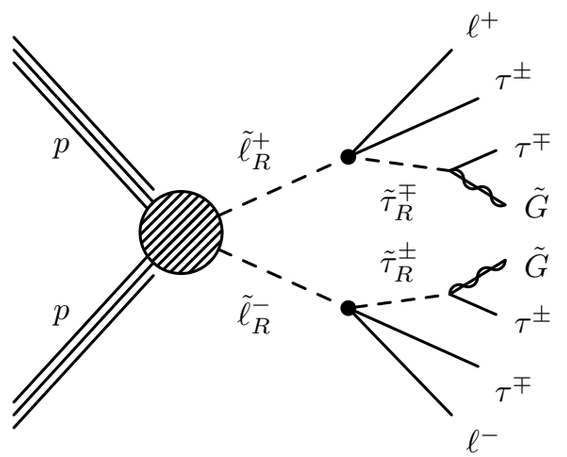






M.I



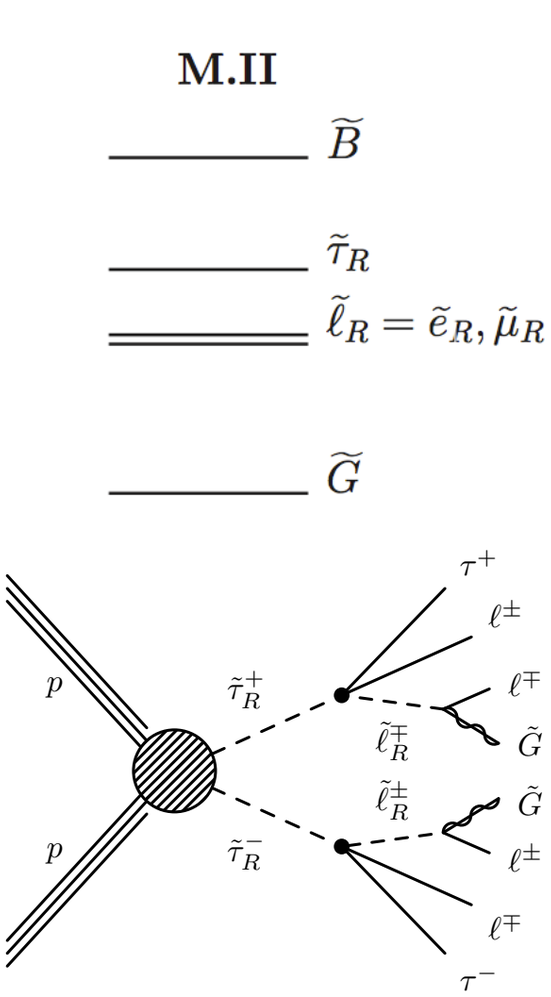


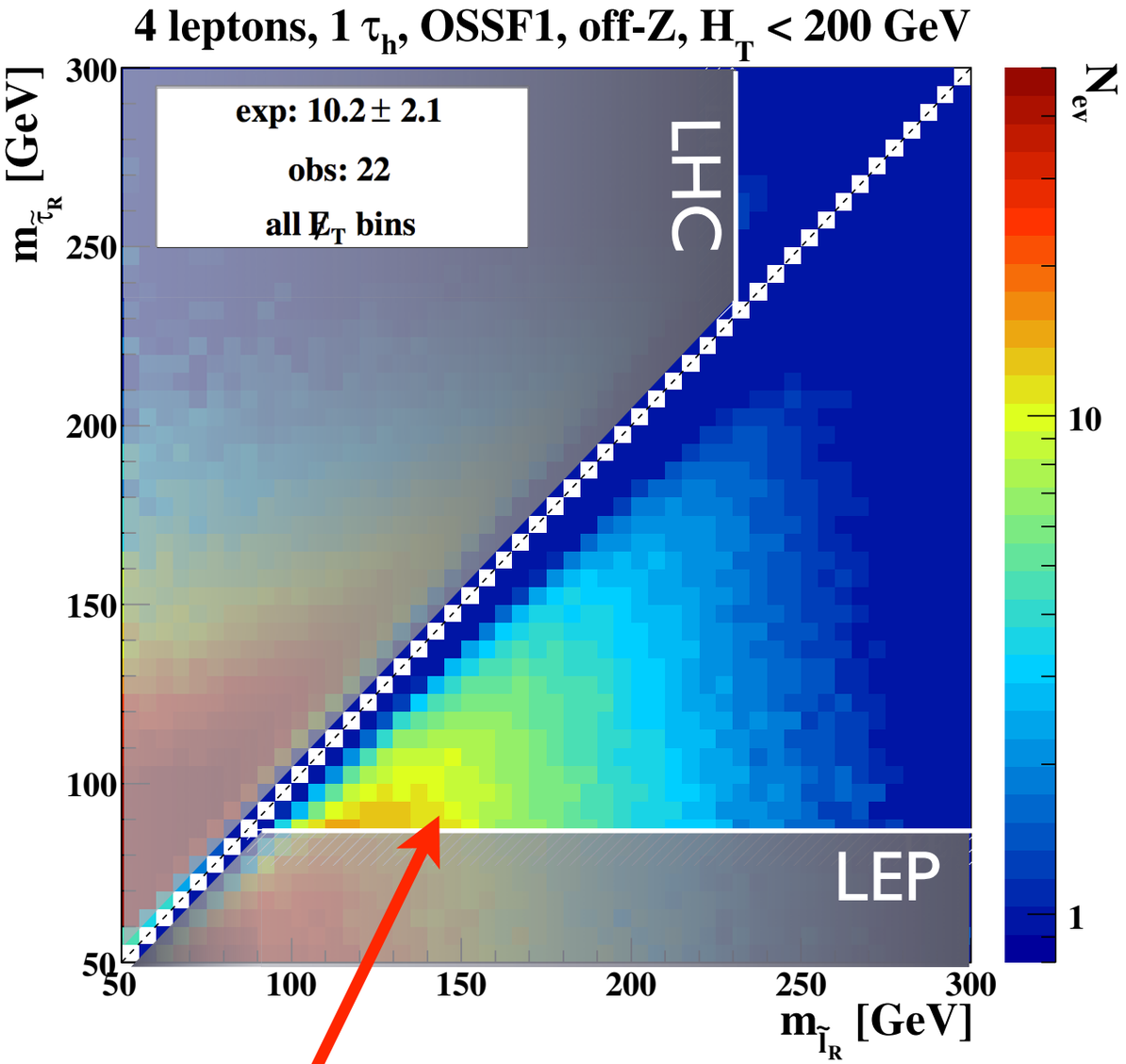
NLSP pair production sets bounds on these models

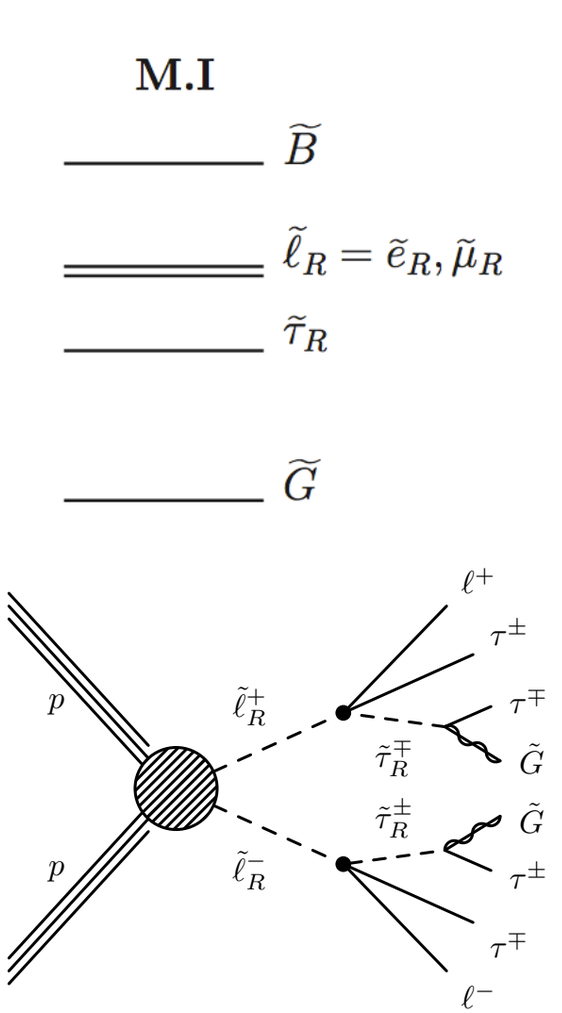
$$\text{M.I}: \; pp \to \tilde{\tau}_R \tilde{\tau}_R \;\; , \;\; \tilde{\tau}_R \to \tau \tilde{G} \;\; \rightarrow \;\; \tau\tau + \text{MET}$$

$$\rightarrow \; m_{\tilde{\tau}_R} > 87\,\text{GeV} \;\; \text{[LEP]}$$

Comparison with CMS search

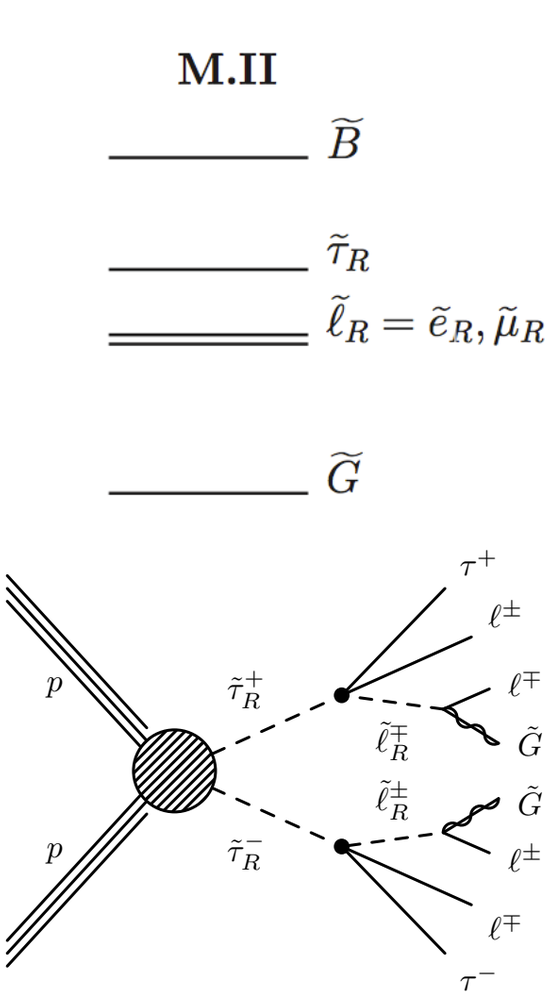


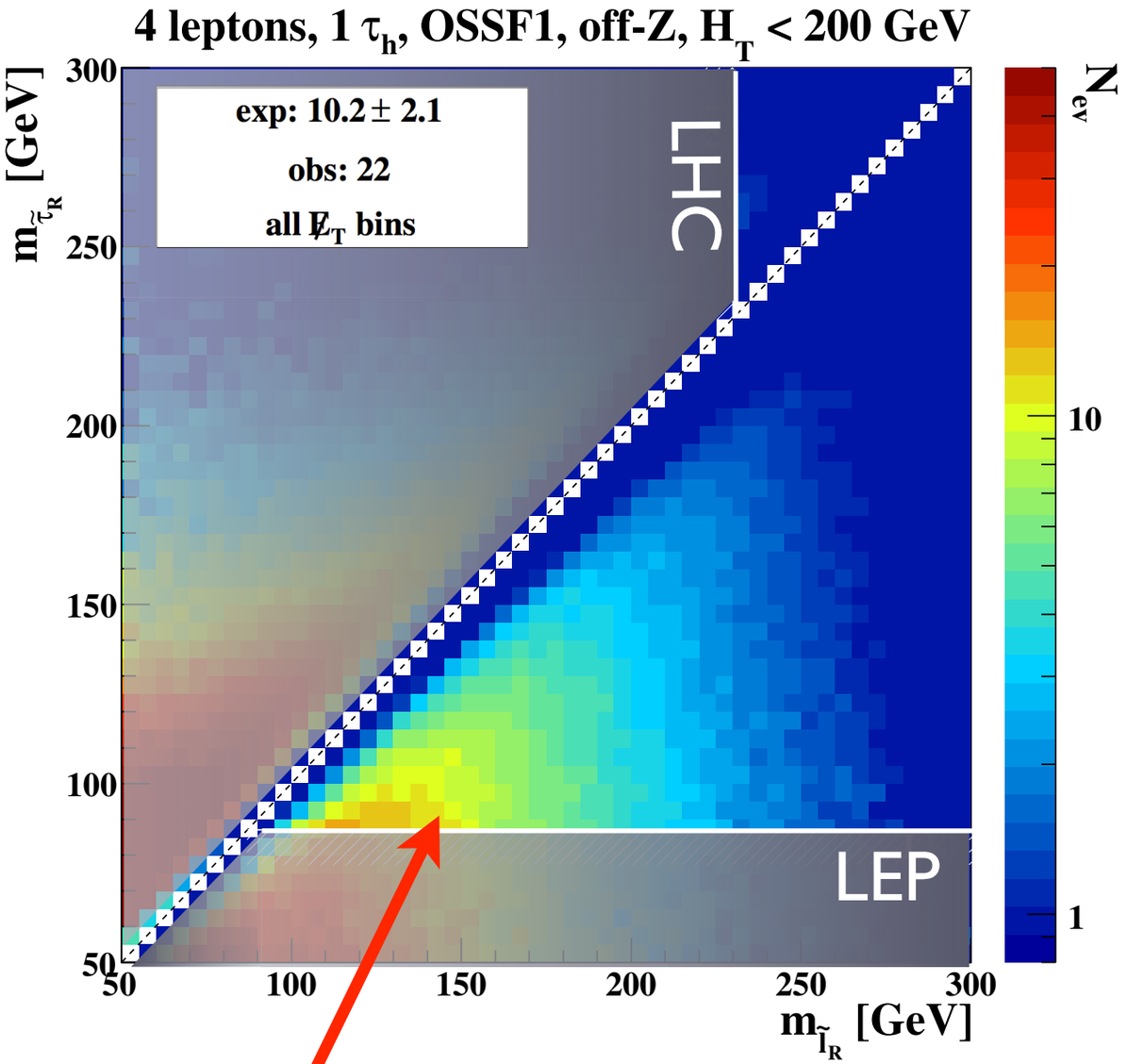


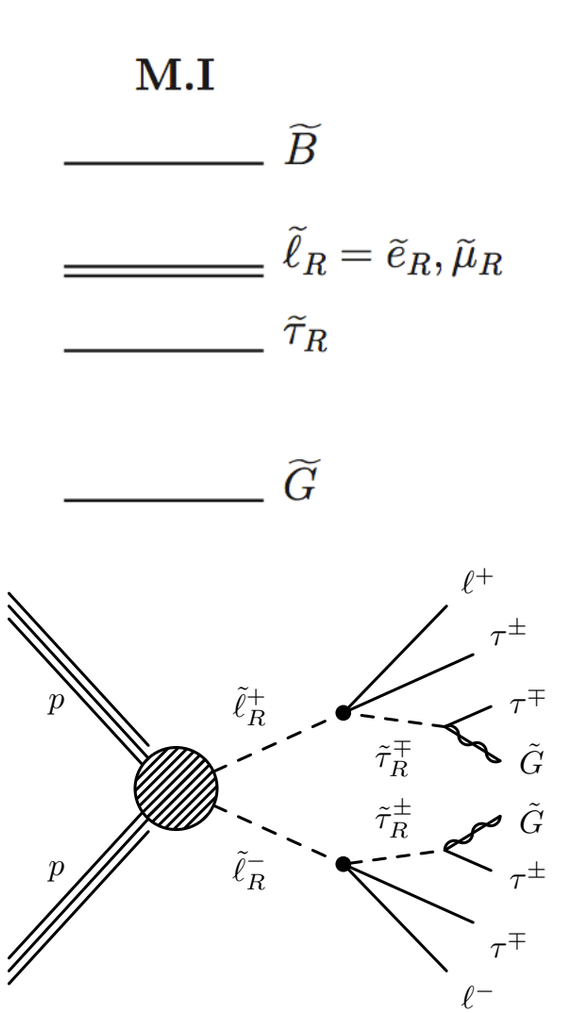


Preferred region: $m_{\tilde{\ell}_R} \sim 145\,\mathrm{GeV}$, $m_{\tilde{\tau}_R} \sim 90\,\mathrm{GeV}$

Comparison with CMS search

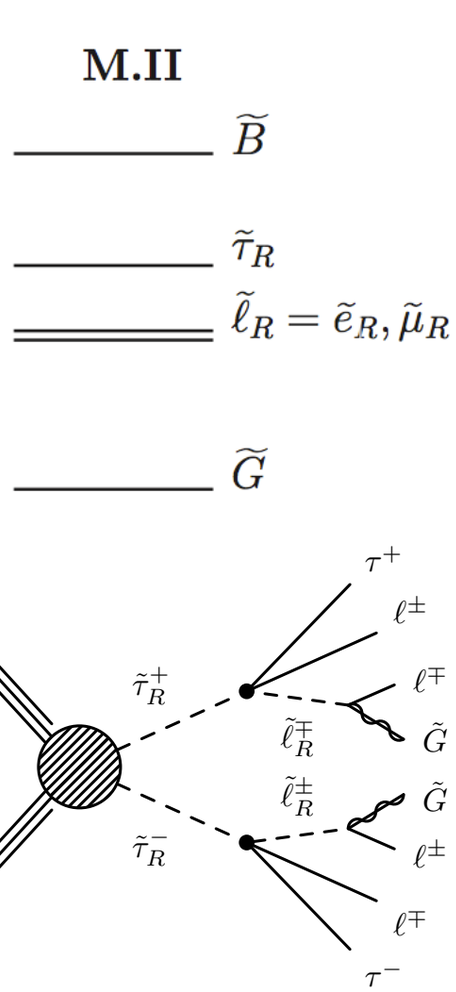


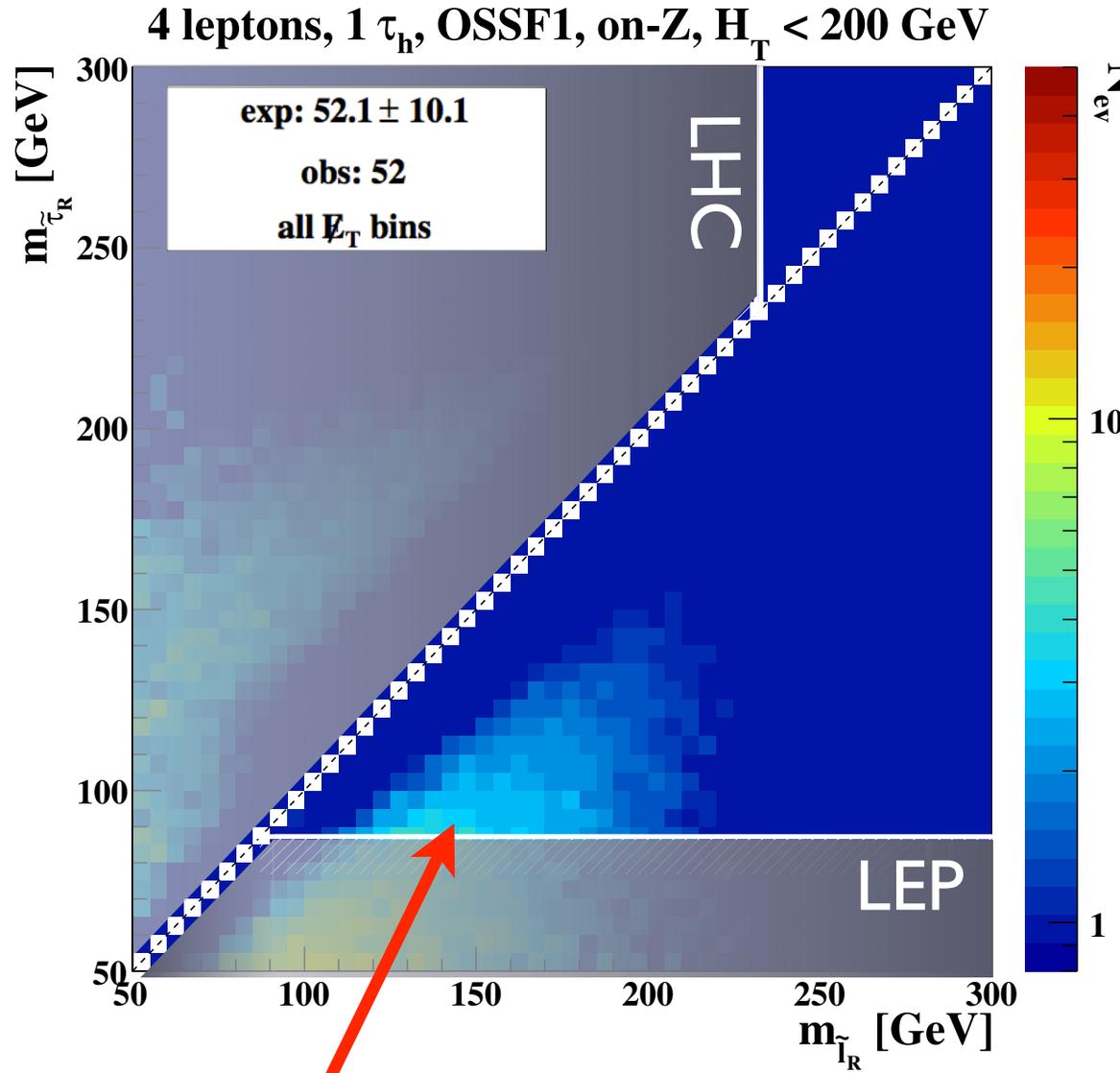


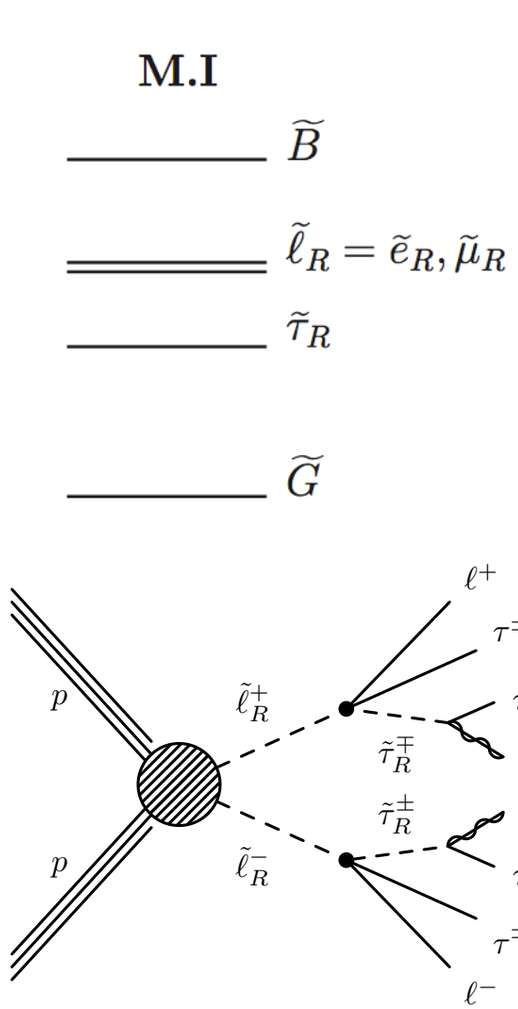


Preferred region: $m_{\tilde{\ell}_R} \sim 145\,\mathrm{GeV}$, $m_{\tilde{\tau}_R} \sim 90\,\mathrm{GeV}$

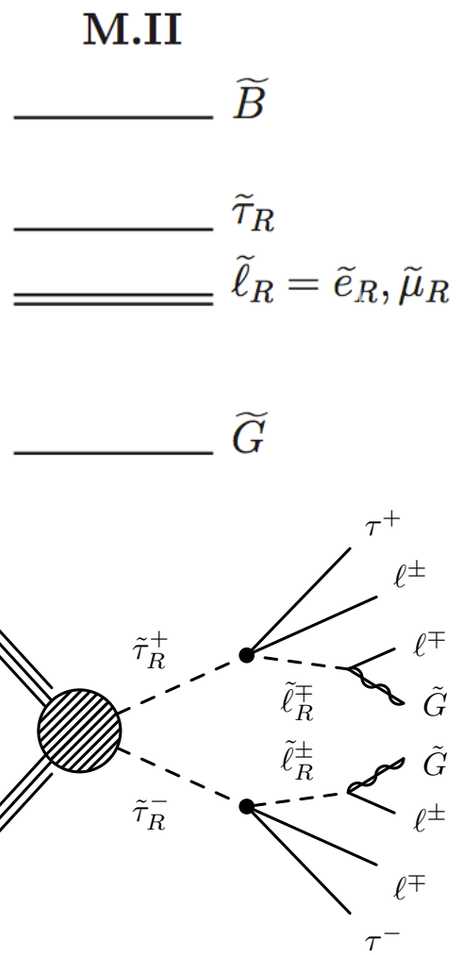
Same category, but on-Z

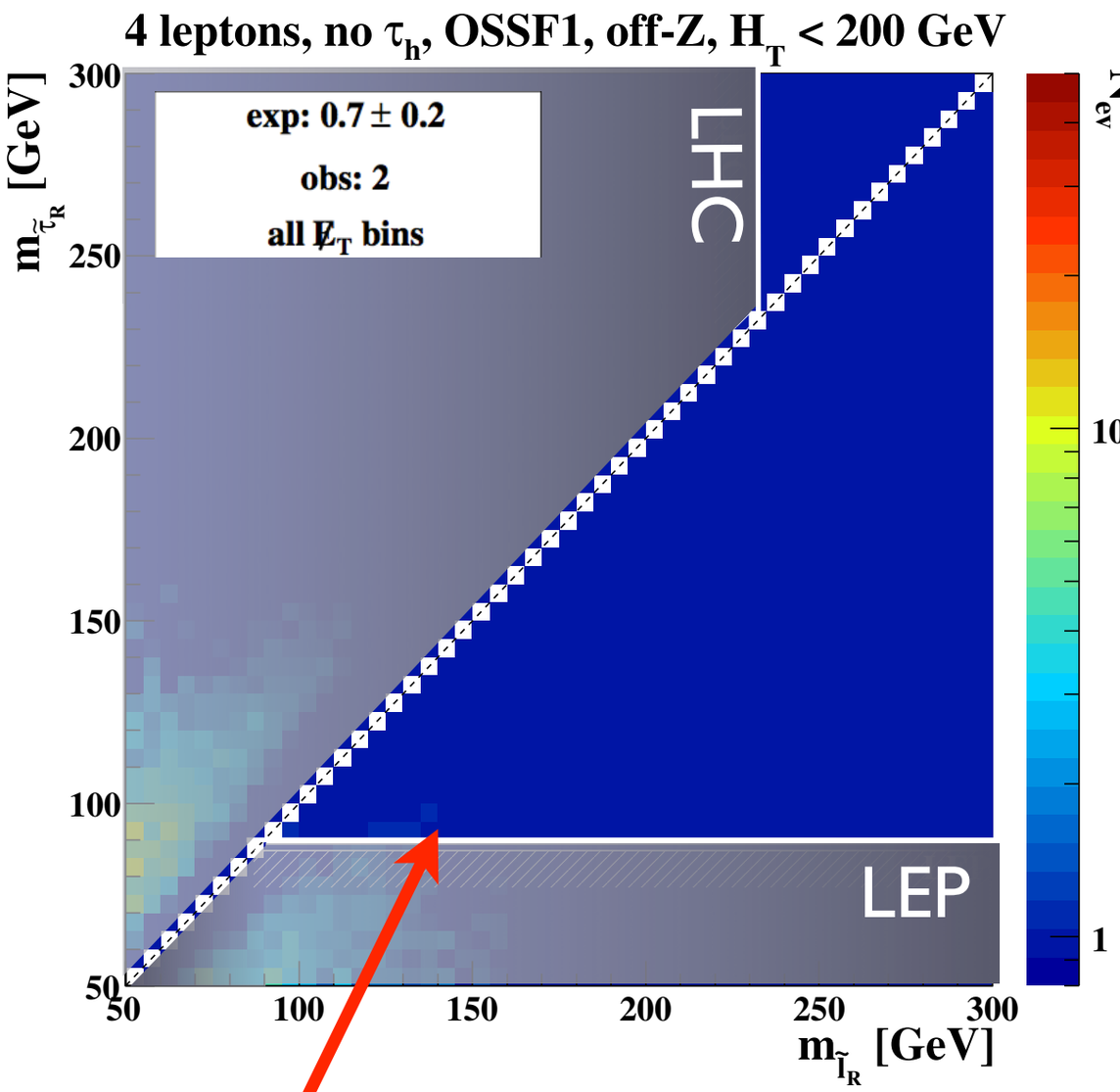


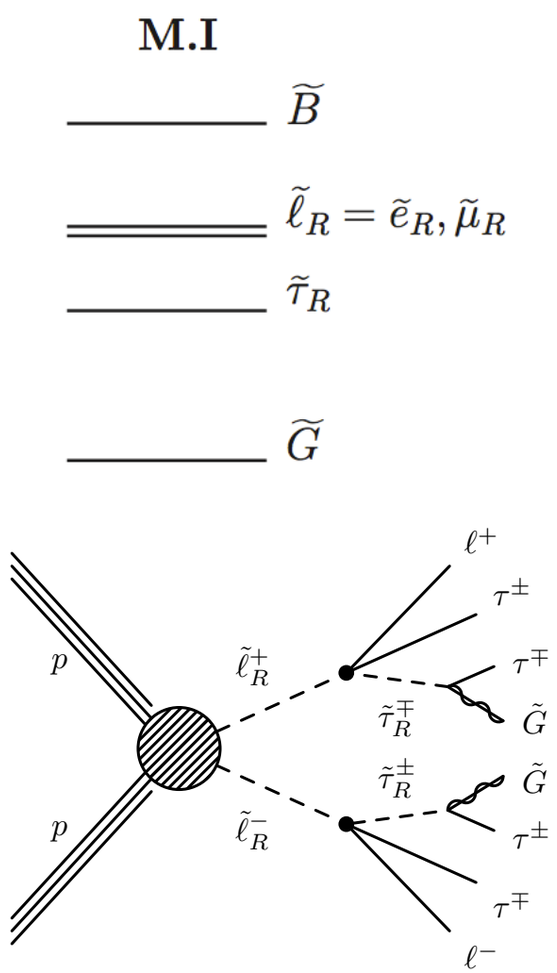




4 leptons, no hadronic tau







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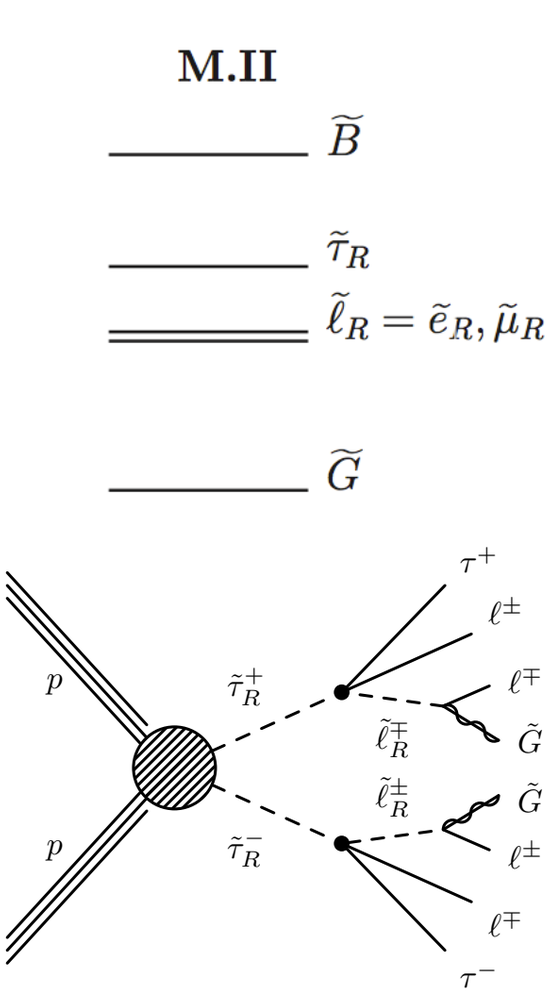
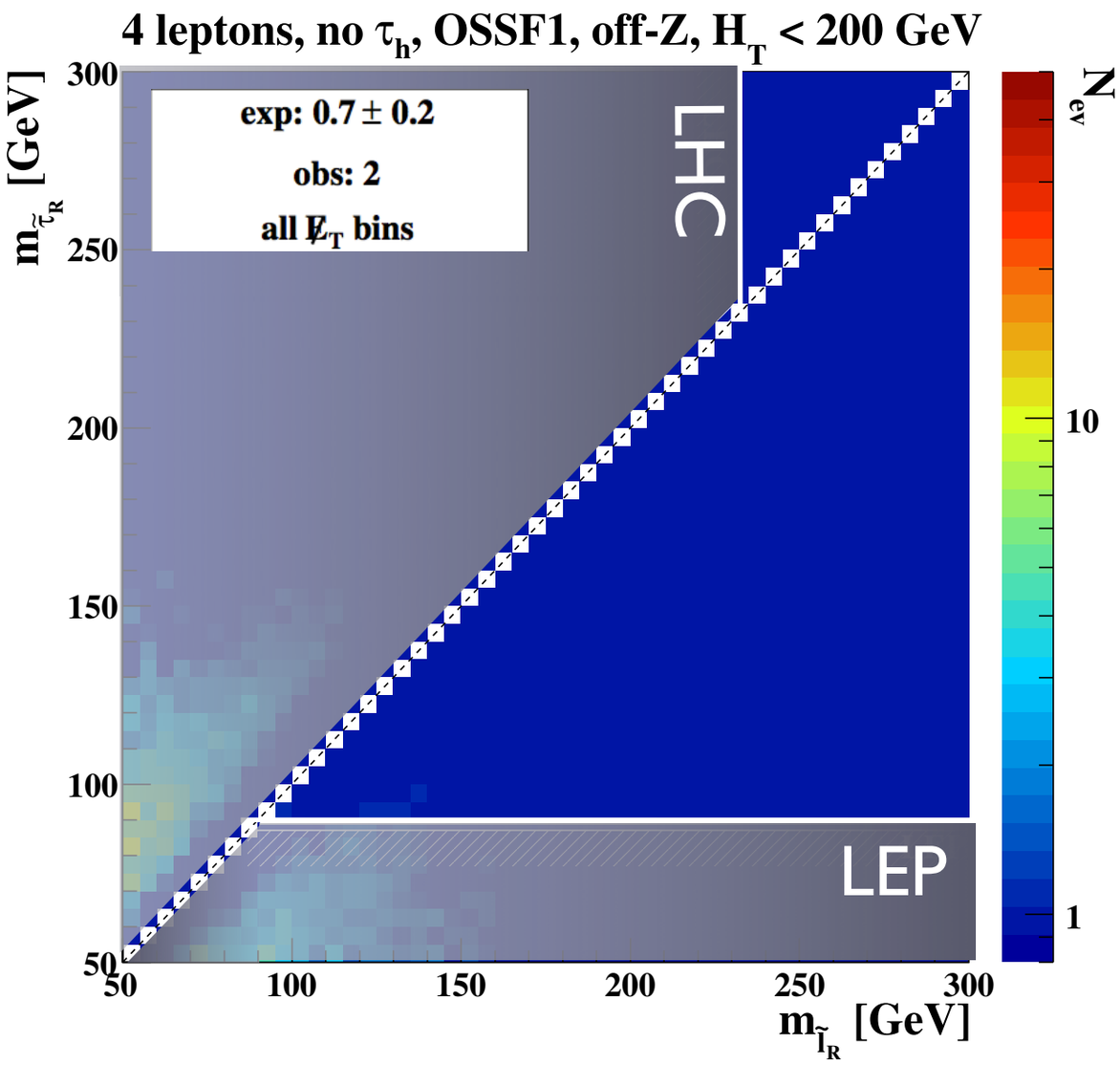
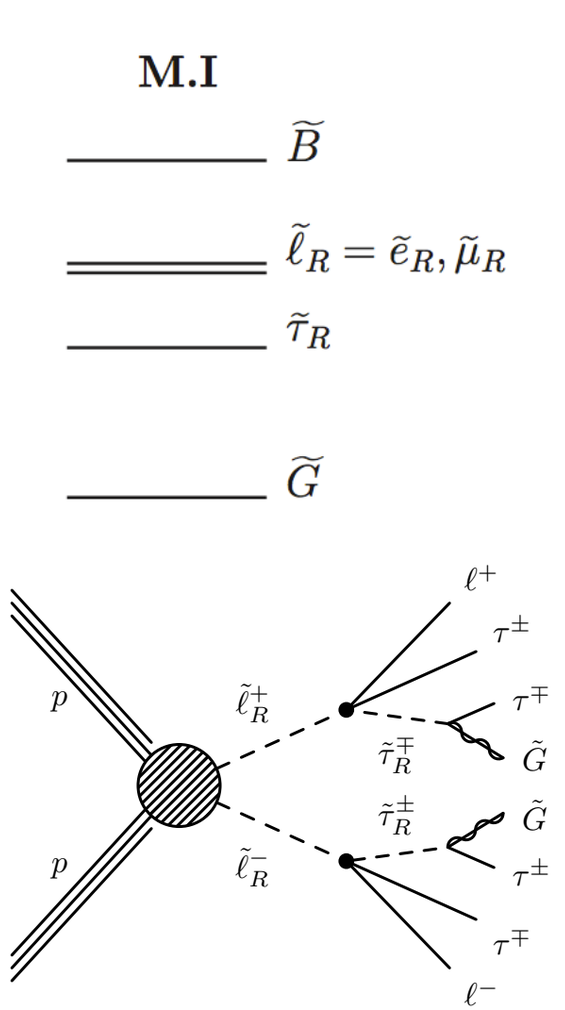


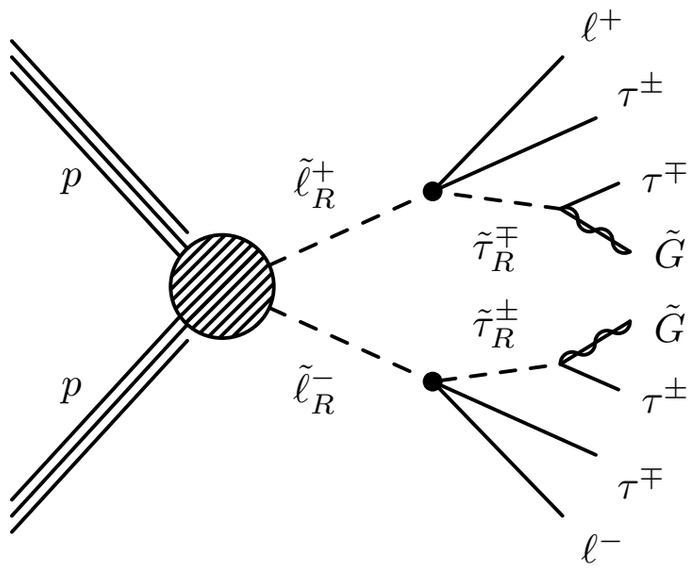




In all the 3 lepton categories, the backgrounds are larger and the signal yield is always in agreement with the expectations.

Comparison with other LHC searches

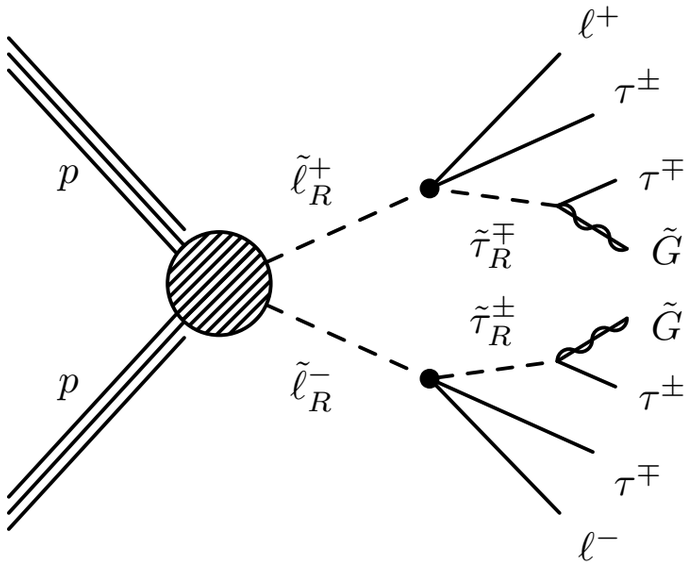
- CMS RPV multi-lepton search, CMS-PAS-SUS-13-010
- ATLAS di-tau+MET search, ATLAS-CONF-2013-028
- ATLAS 3-lepton search, arXiv:1402.7029
- ATLAS multi-lepton search, ATLAS-CONF-2013-036



$$m_{\tilde{\ell}_R} = 145\,\mathrm{GeV}$$

$$m_{\tilde{\tau}_R} = 90\,\mathrm{GeV}$$

Prospects

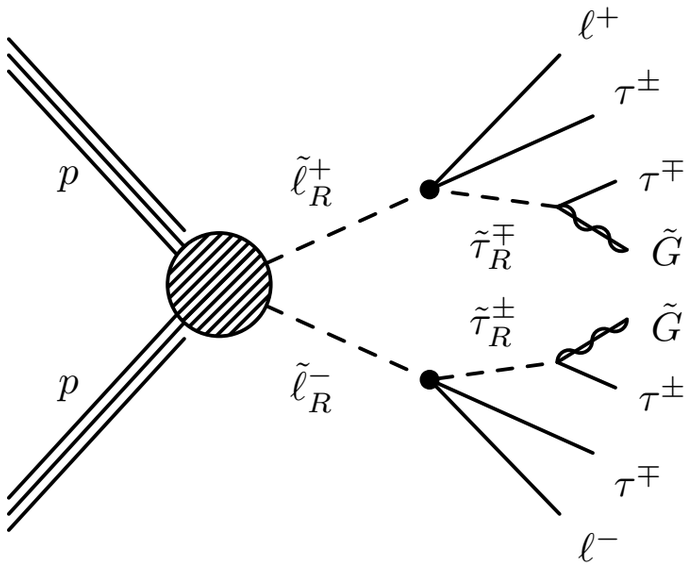


$$m_{\tilde{\ell}_R} = 145\,\mathrm{GeV}$$

$$m_{\tilde{\tau}_R} = 90\,\mathrm{GeV}$$

		$19.5\,\mathrm{fb}^{-1}$	$100\,\mathrm{fb}^{-1}$
$N(\ell)$	$N(\tau_h)$	$N_{\mathrm{events}}(8\ \mathrm{TeV})$	$N_{\mathrm{events}}(13\ \mathrm{TeV})$
4	2	22.5	223
5	0	0.074	0.79
5	1	1.7	14.7
5	2	7.4	76.1
6	0	0	0
6	1	0.075	0.66
6	2	1.0	7.89
>6	0	0.038	13.9

Prospects



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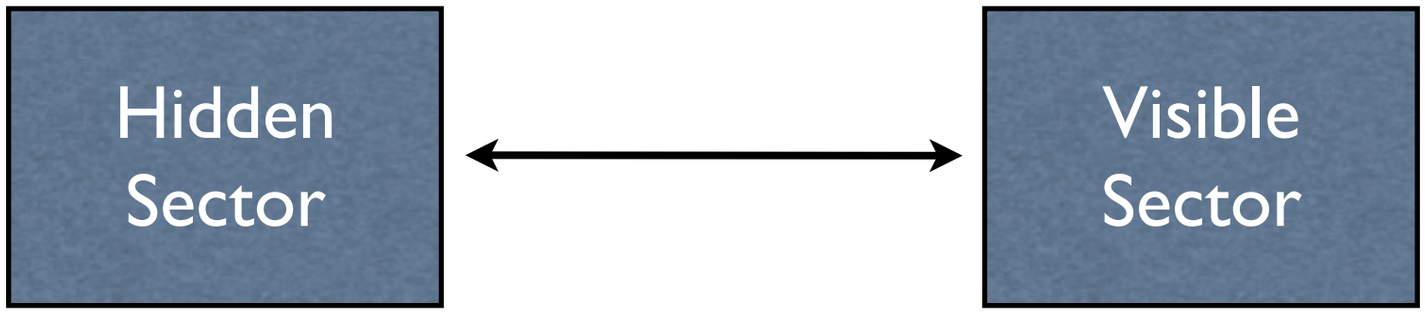
Proposed LHC search: $2\tau_h + (2/3)\ell + \mathrm{MET}$

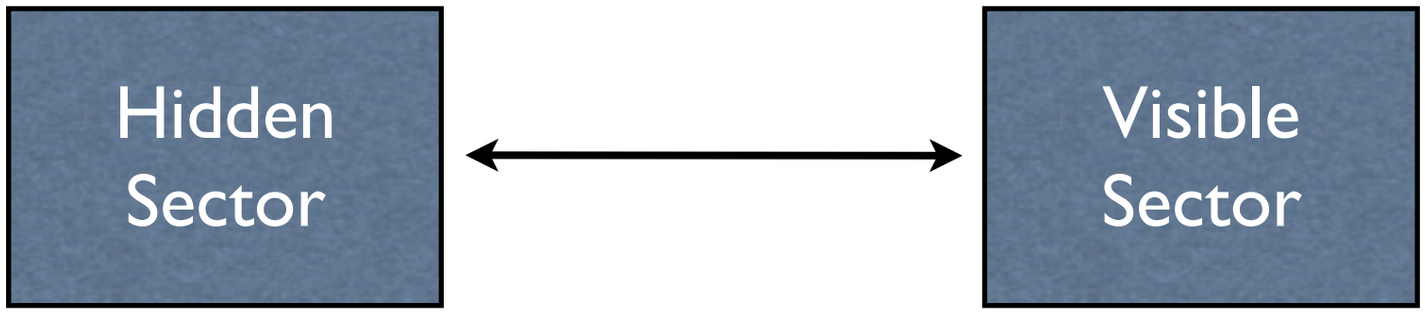
Part II

Multiphoton signatures

Supersymmetry breaking

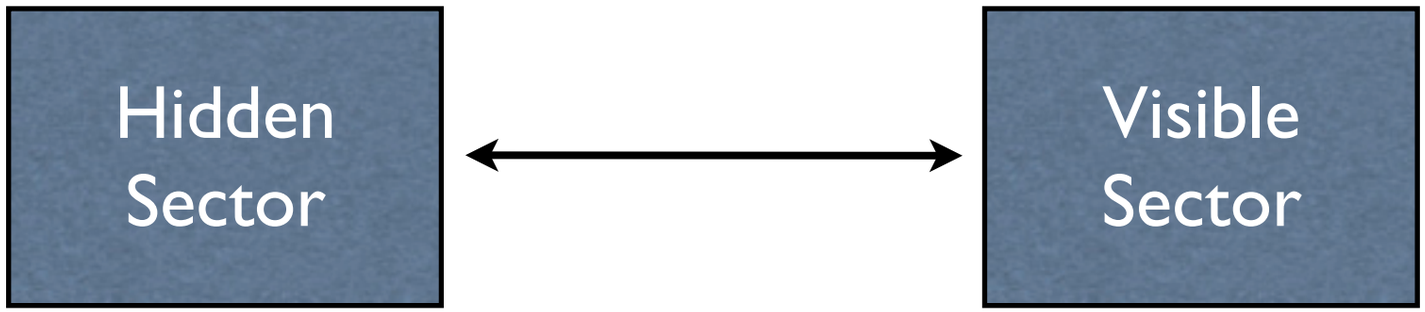


Supersymmetry breaking



f is the VEV that breaks supersymmetry
(cf. $\langle H \rangle = v$ that breaks EW symmetry in the SM)

Supersymmetry breaking



SUSY Breaking

MSSM

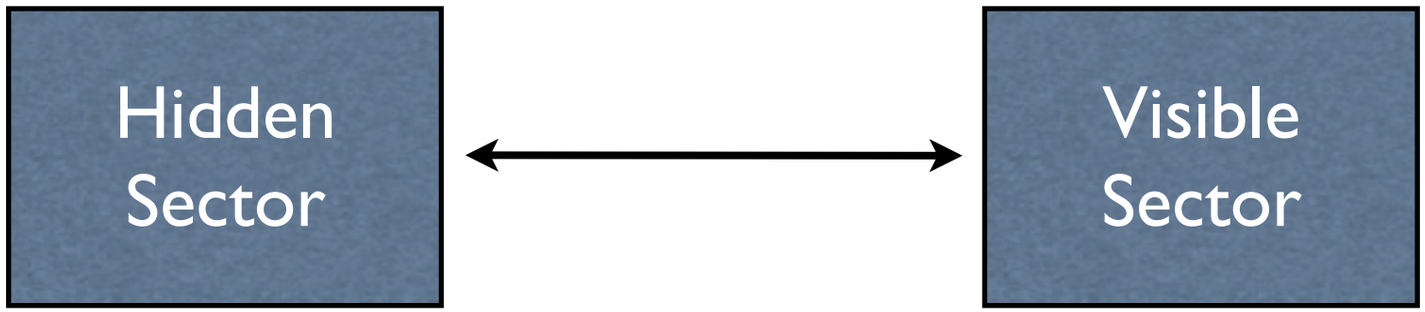
$X \supset \theta^2 f + \sqrt{2}\theta\,\tilde{\eta}$

Goldstino, eaten by gravitino, $m_{3/2} = (1/\sqrt{3}M_P)\,f$

(cf. EW Goldstone bosons, eaten by W/Z, $m_W = (g/2)\,v$)

f is the VEV that breaks supersymmetry

(cf. $\langle H \rangle = v$ that breaks EW symmetry in the SM)



SUSY Breaking

$X \supset \theta^2 f + \sqrt{2}\theta\,\tilde{\eta}$

MSSM

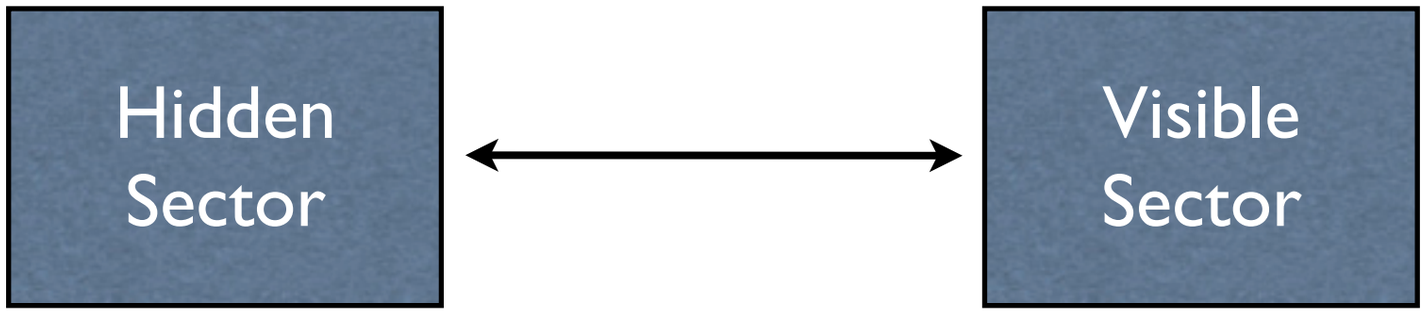
What happens if SUSY is broken in more than one hidden sector?

Previous studies of multiple hidden sector models in the context of gravity mediation:

[Benakli,Moura] [Cheung,Nomura,Thaler] [Craig,March-Russell,McCullough] [Izawa,Nakai,Shimomura] [Thaler,Thomas] [Cheung,D'Eramo,Thaler] [Cheng,Huang,Low,Menon][Bertolini,Rehermann,Thaler]

Multiple hidden sector models in the context of gauge mediation:

[Argurio,Komargodski,Mariotti] [Argurio,De Causmaecker,Ferretti,Mariotti,Mawatari,Takaesu] [Liu,Wang,Yang]



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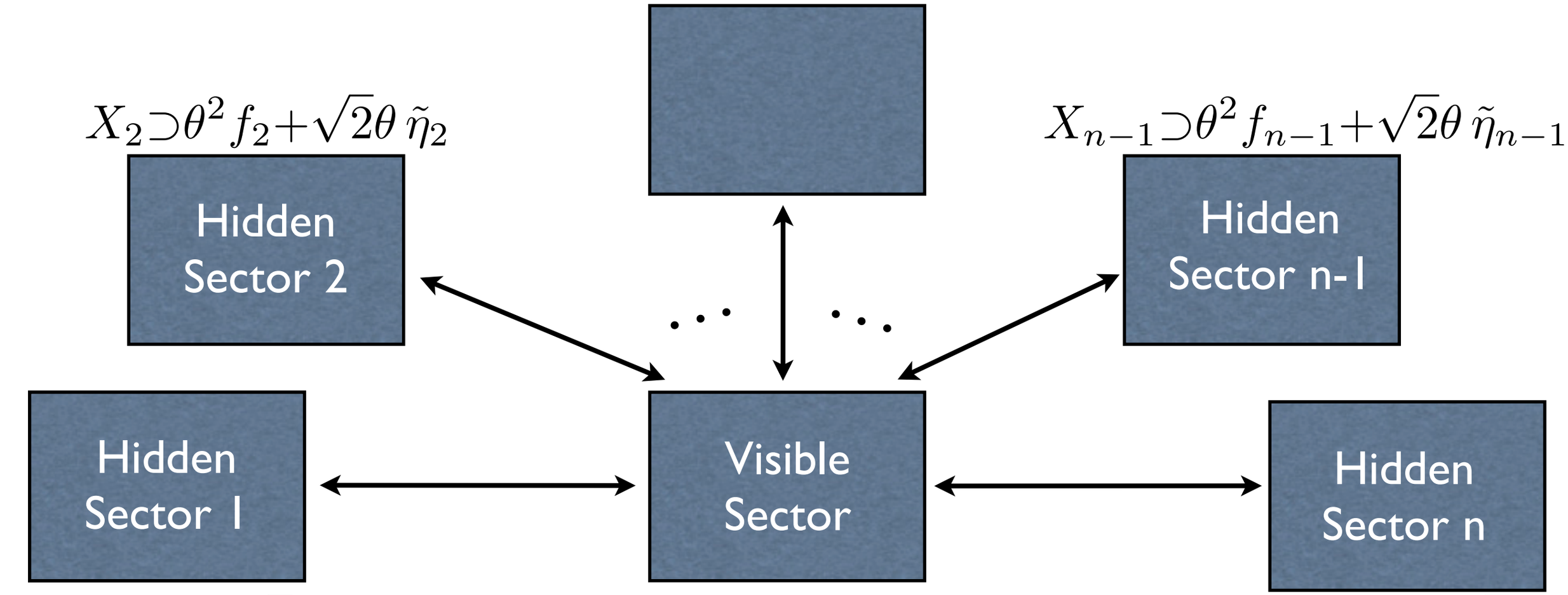
What happens if SUSY is broken in more than one hidden sector?

(cf. EW symmetry is broken in the SM both by the scalar sector and the QCD sector)



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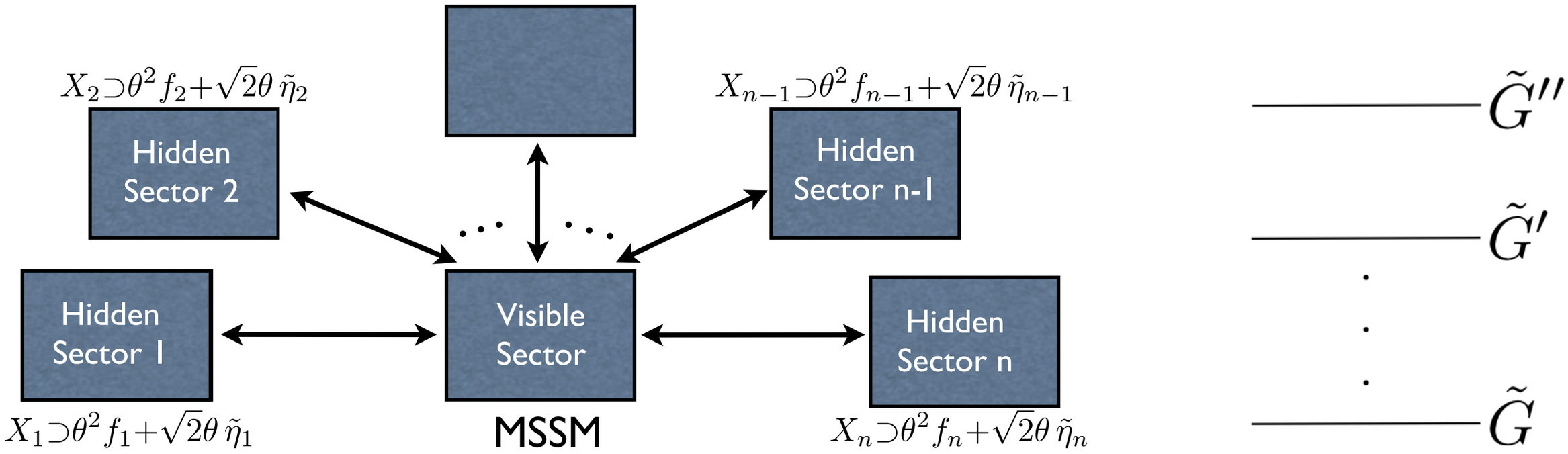
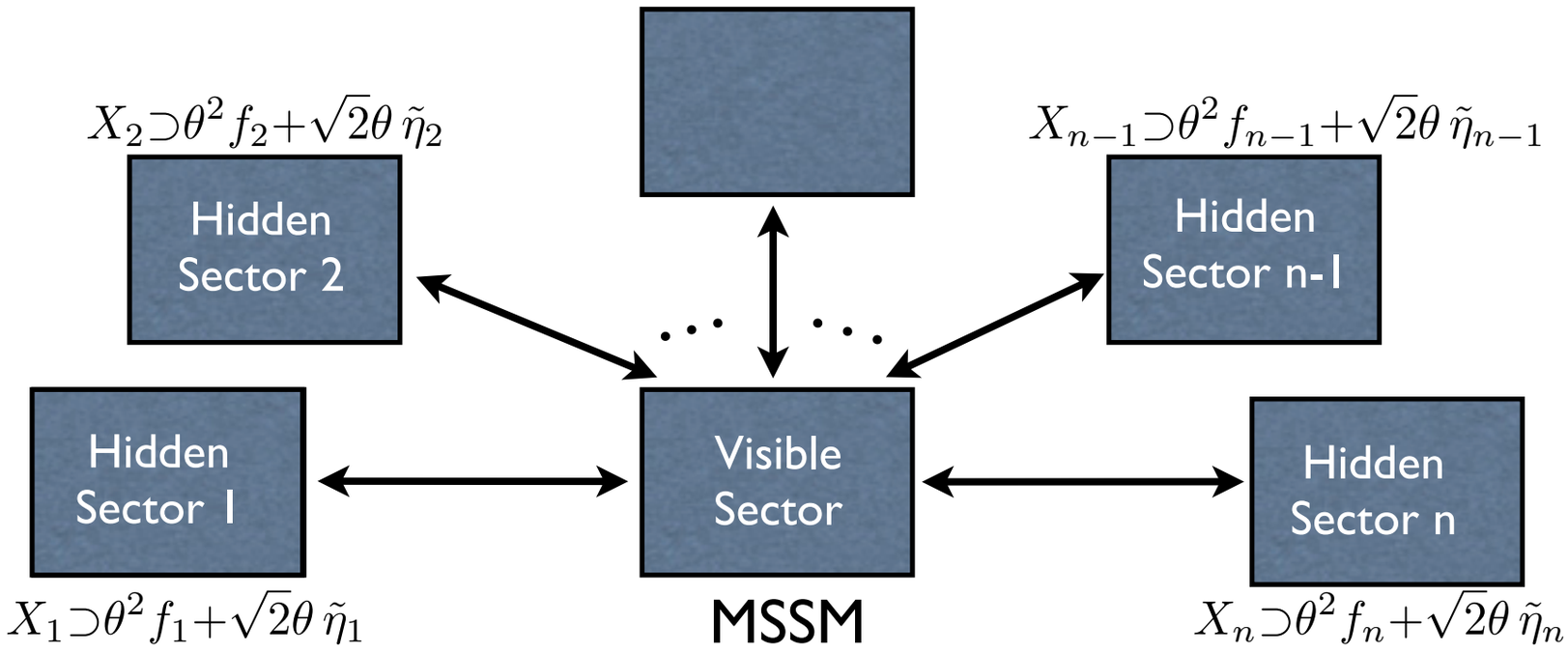
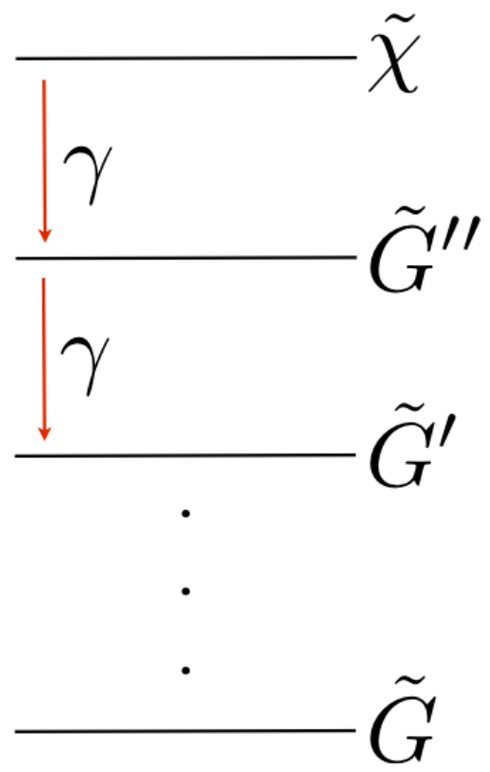


- The true goldstino $\tilde{G}$ (eaten by the gravitino) is given by one linear combination $\tilde{G} = (f_1\tilde{\eta}_1 + \cdots + f_n\tilde{\eta}_n)/f$

- All the other n-1 linear combinations $\tilde{G}', \tilde{G}'', \ldots$ are pseudo-goldstini, and they acquire masses at the tree and radiative level





- If the lightest MSSM superpartner is a Bino-like neutralino, it dominantly decays to a photon and the heaviest pseudo-goldstini

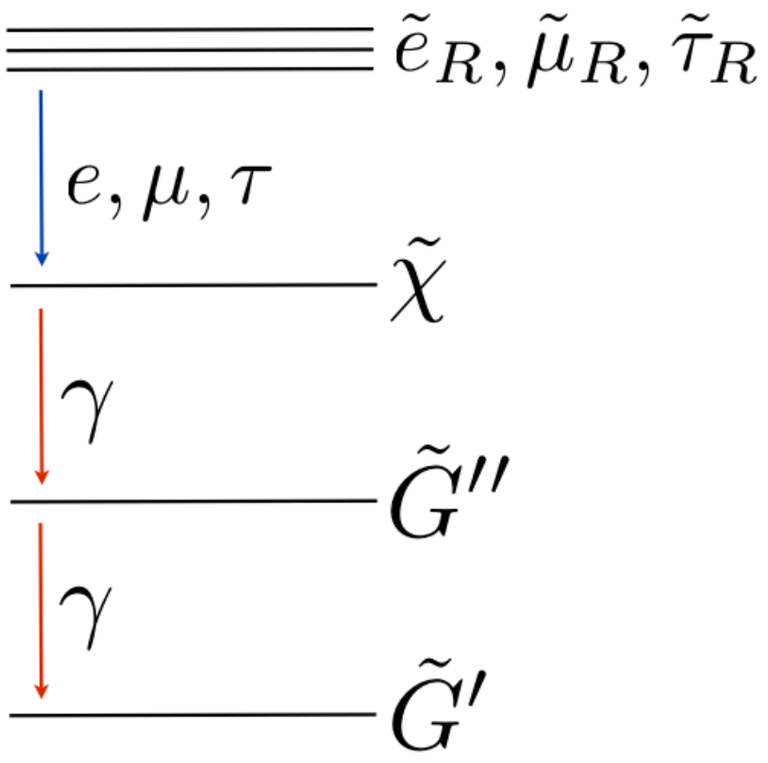
  → Softer final state spectrum

- If there are more than 2 hidden sectors, the pseudo-goldstino can decay to a photon and a lighter pseudo-goldstino

  → Additional (soft) photons in the final state

Simplified model of GMSB with goldstini

3 Sector Model



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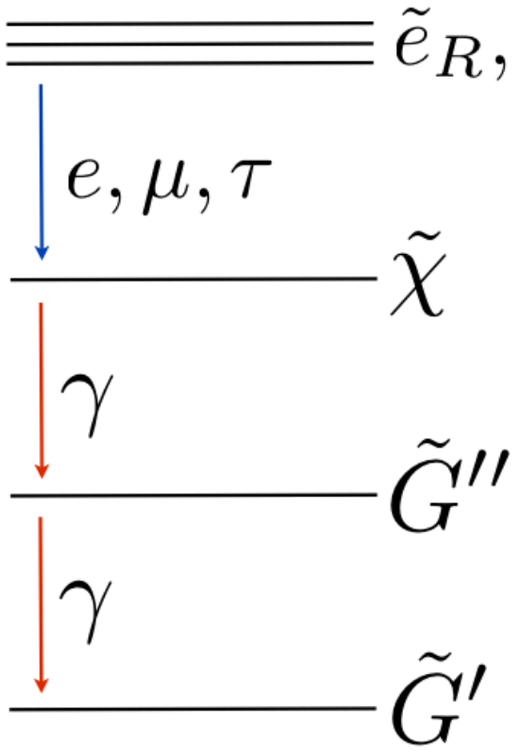
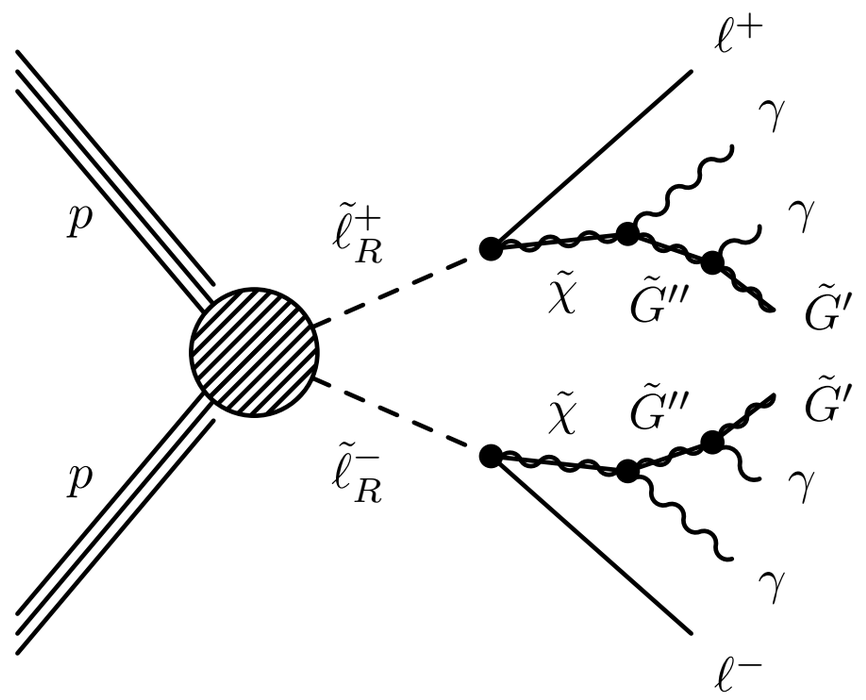
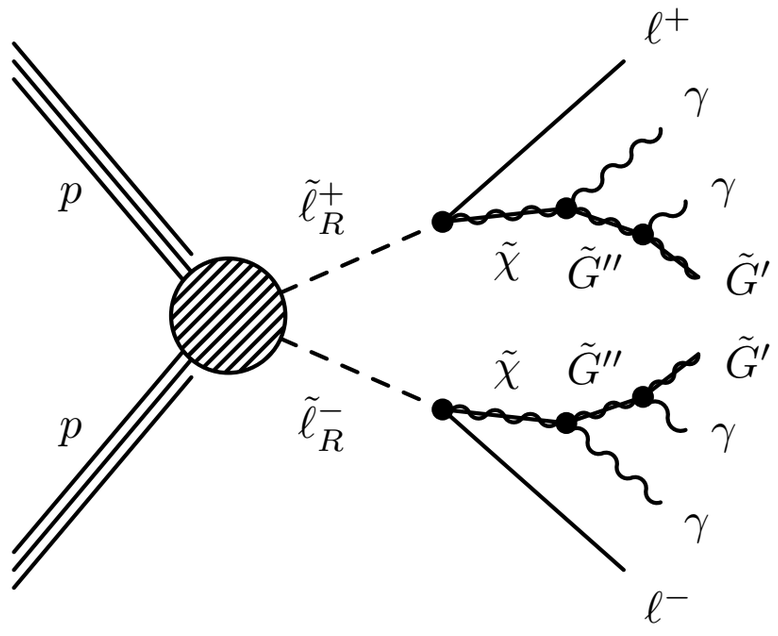




$$\ell^+\ell^- + 4\gamma + \text{MET}$$

Comparing with existing LHC searches

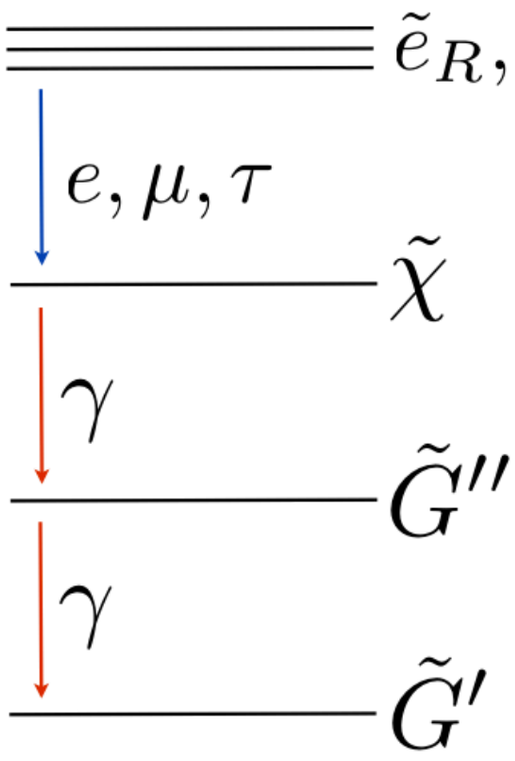
- CMS diphoton+MET search, CMS-PAS-SUS-12-018 (jet requirement)
- ATLAS lepton+photon+MET search, ATLAS-CONF-2012-144 (tight cuts)
- Dileptons+MET searches have too large backgrounds
- The most relevant search is the inclusive ATLAS diphoton+MET search, [arXiv:1209.0753 [hep-ex]]
- Updated diphoton+MET search in ATLAS-CONF-2014-001 (however, less sensitive due to tighter cuts)



3 Sector Model

- The most relevant search is the inclusive ATLAS diphoton+MET search [arXiv:1209.0753 [hep-ex]] $4.8\,\mathrm{fb}^{-1}$ at $\sqrt{s} = 7\,\mathrm{TeV}$

$$p_T^{\gamma_{1,2}} > 50\,\mathrm{GeV}\ ,\ \mathrm{MET} > 125\,\mathrm{GeV}$$



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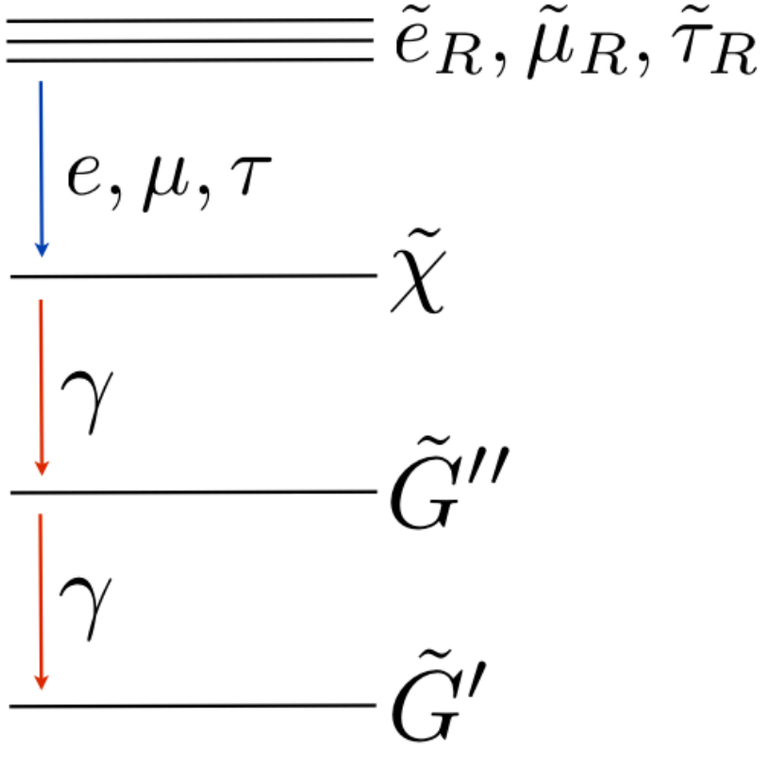

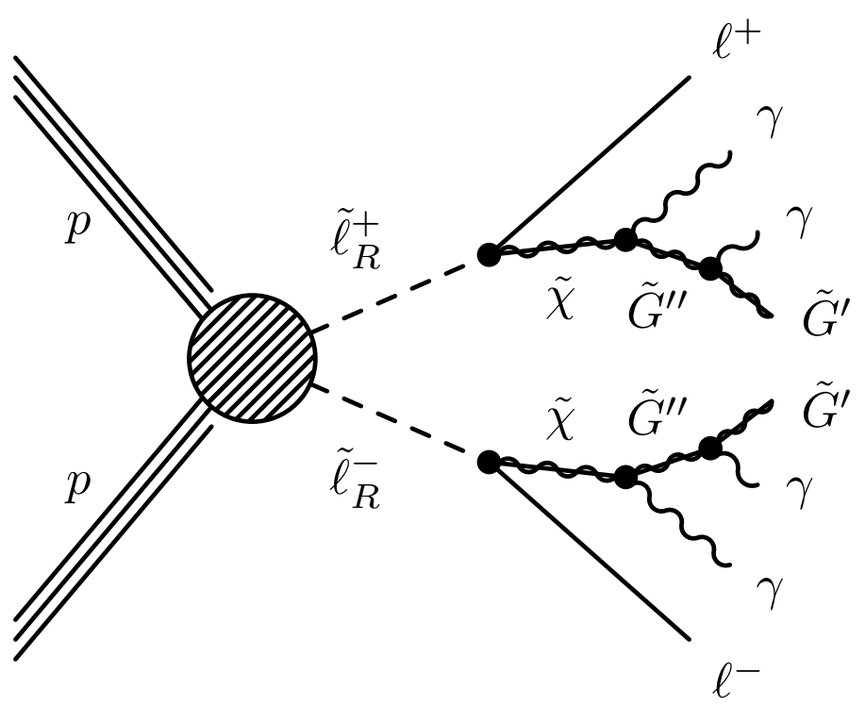

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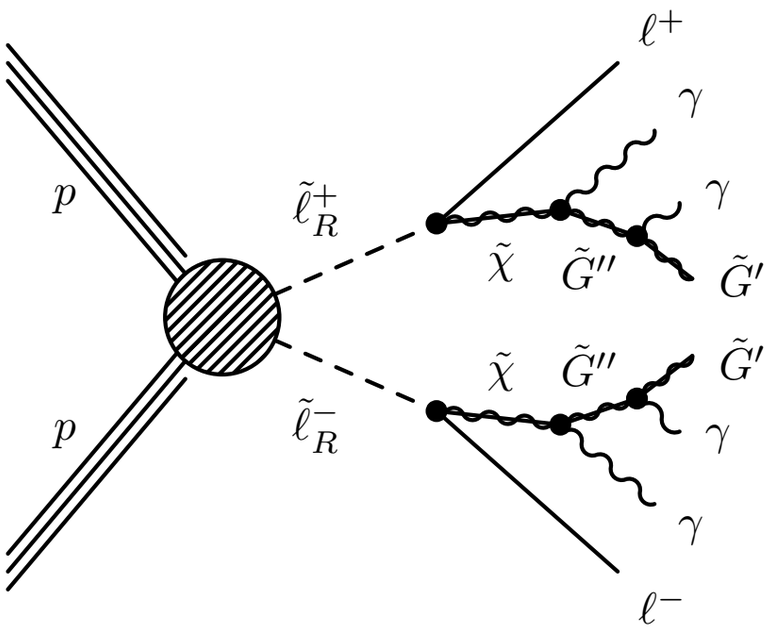
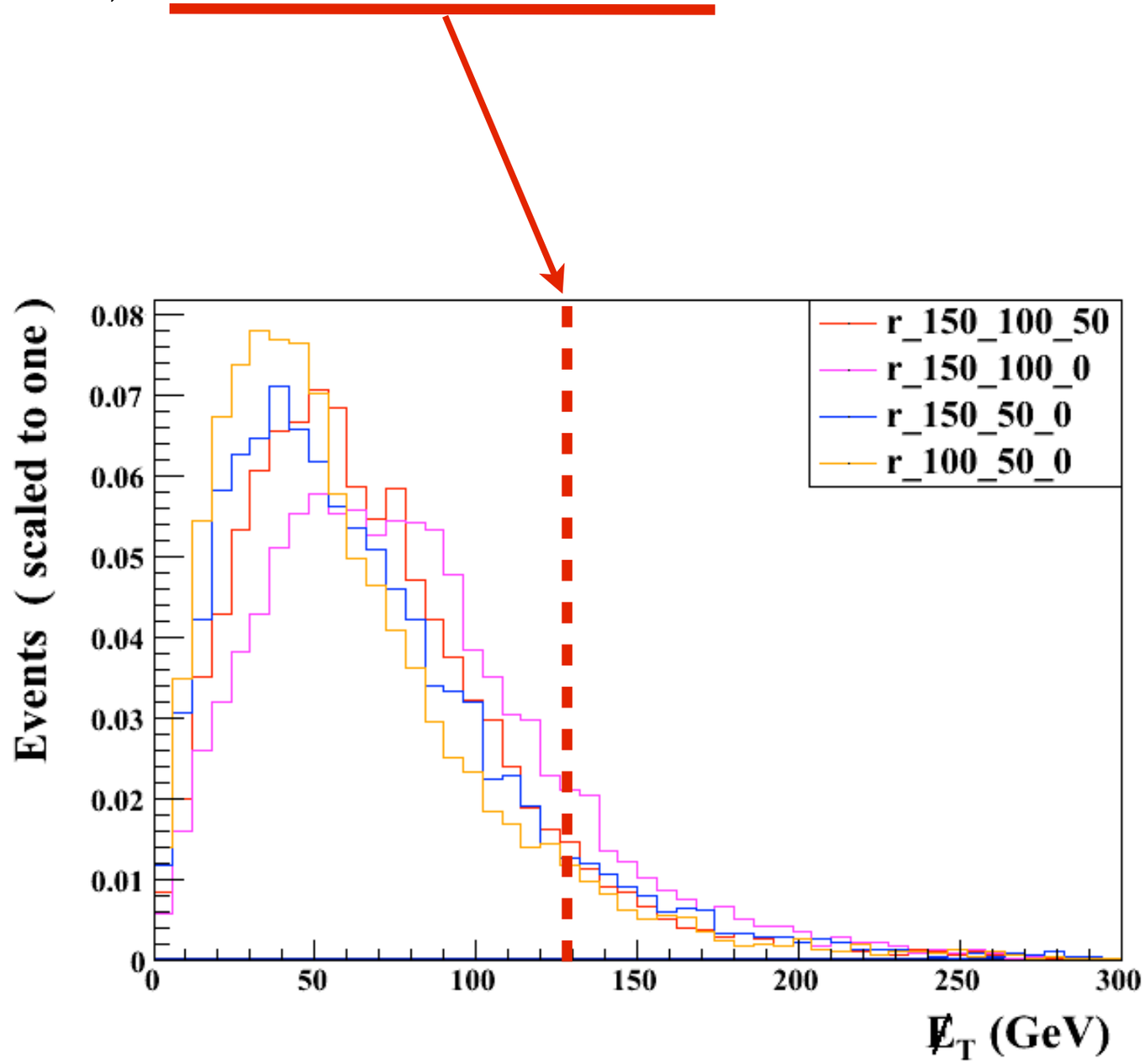


M_{ℓ_R}	M_χ	$M_{G''}$	$M_{G'}$
200	150	100	50
200	150	100	0
200	150	50	0
200	100	50	0

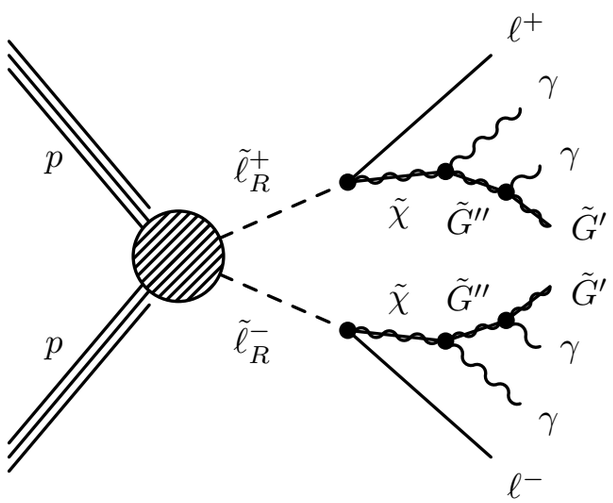


3 Sector Model

Number of signal events with 20 fb^{-1} of data at LHC-8TeV

final state	MET	150-100-50	150-100-0	150-50-0	100-50-0
3γ	(0-50)	32	25	39	43
	(50-100)	34	37	32	27
	(100-∞)	11	19	14	9

final state	MET	150-100-50	150-100-0	150-50-0	100-50-0
4γ	(0-50)	16	13	19	18
	(50-100)	15	19	13	9
	(100-∞)	3.4	8.3	5.6	3.0



$$p_T > 20 \text{ GeV} \ , \ |\eta| < 2.5 \ , \ \Delta R > 0.4$$

M_{ℓ_R}	M_χ	$M_{G''}$	$M_{G'}$
200	150	100	50
200	150	100	0
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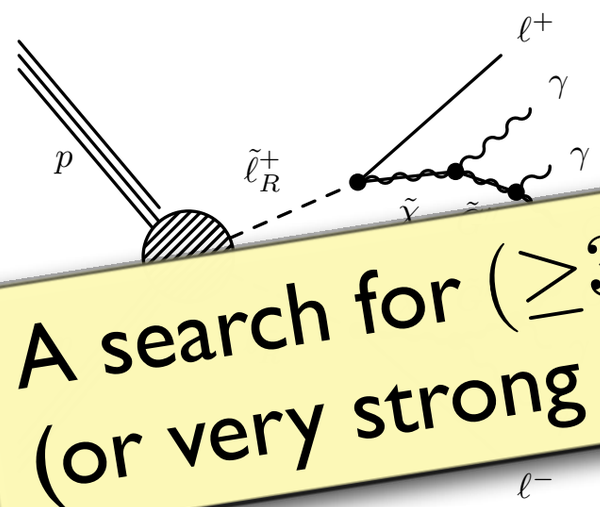


			50
200	150	100	0
200	150	50	0
200	100	50	0

$\Delta R > 0.4$

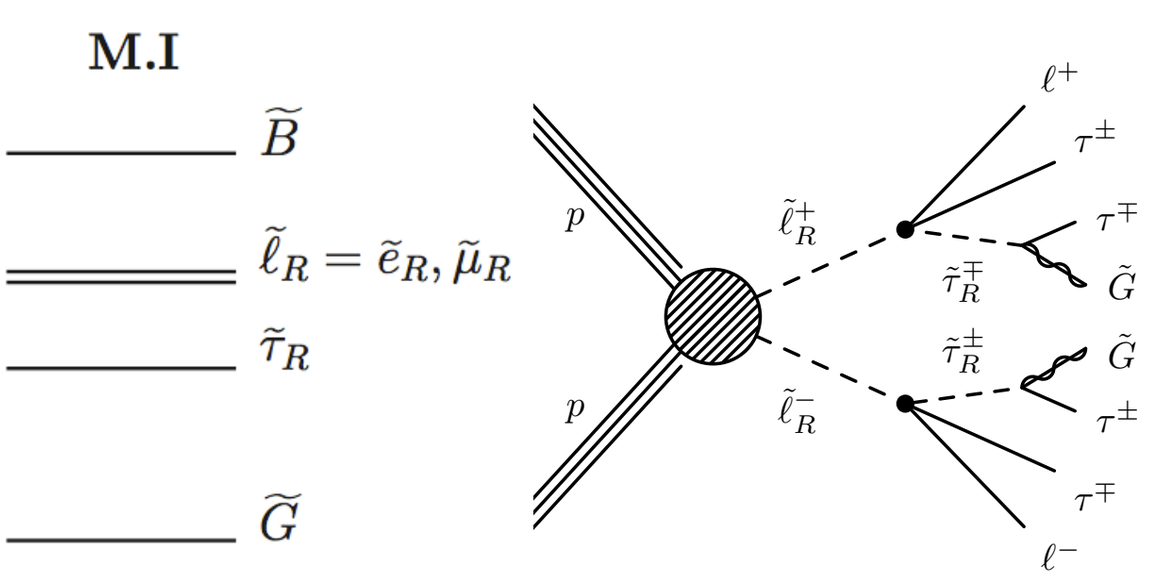
A search for $(\geq 3)\gamma + \mathrm{MET}$ could lead to a discovery (or very strong constraints) already with the existing LHC data set!

Conclusions

Part I

The simplified GMSB model can explain the small CMS excess without being excluded by any other LHC searches.

The best fit to the data was obtained for $m_{\tilde{\ell}_R} = 145\,\mathrm{GeV}$, $m_{\tilde{\tau}_R} = 90\,\mathrm{GeV}$
Would be excluded with a stronger bound on the stau mass.



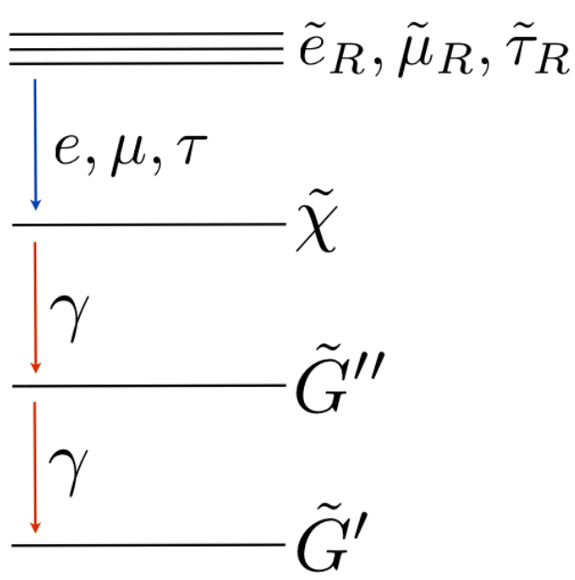
Proposed search: $2\tau_h + (2/3)\ell + \mathrm{MET}$

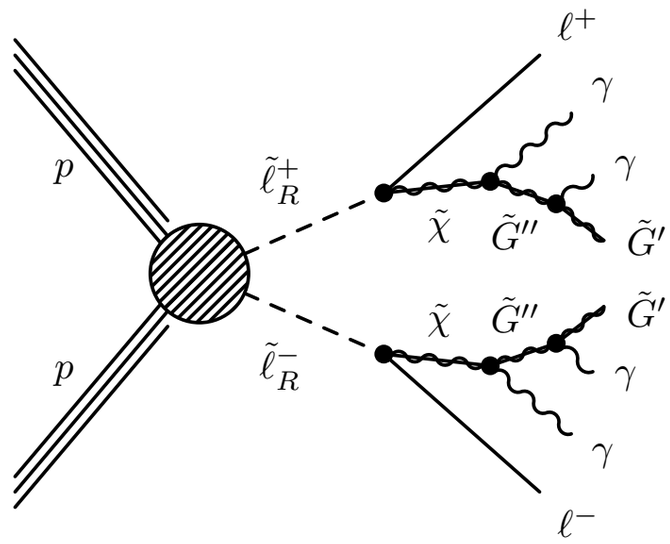
Conclusions

Part II

In GMSB models with multiple hidden sectors, the presence of pseudo-goldstini implies final state spectra which are soft but involve additional photons.

Focused on slepton pair production, one could consider other production modes





Proposed searches:

$$(\geqslant 3)\gamma + \mathrm{MET}$$

$$\ell^+\ell^- + (\geqslant 2)\gamma + \mathrm{MET}$$

Thank you!