Multilepton and multiphoton signatures of GMSB at the LHC

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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]

Multiphotons based on:

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

arXiv:1312.1698 [hep-ph]

Motivations

- So far the LHC has not seen any clear signal of BSM physics
- However, so far the LHC has mainly probed colored production
- Also, so far it has mainly probed minimal BSM scenarios

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

Plan of the talk and results

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Part I

Exercise: Explain a small excess in multi-lepton events observed recently by CMS with BSM physics (without being excluded by other data).

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.

Plan of the talk and results

Part I

Exercise: Explain a small excess in multi-lepton events observed recently by CMS with BSM physics (without being excluded by other data).

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Part II

Exercise: Study how the standard phenomenology of GMSB is modified by the non-minimal assumption that SUSY is broken in more than one hidden sector.

Result: Also these models give rise to non-standard signatures, with 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

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(τ_h)=0, N_{b-jets}=0 obs	exp	N(τ_h)=1, N_{b-jets}=0 obs	exp	N(τ_h)=0, $N_{b-jets}\geq$1 obs	exp	N(τ_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:

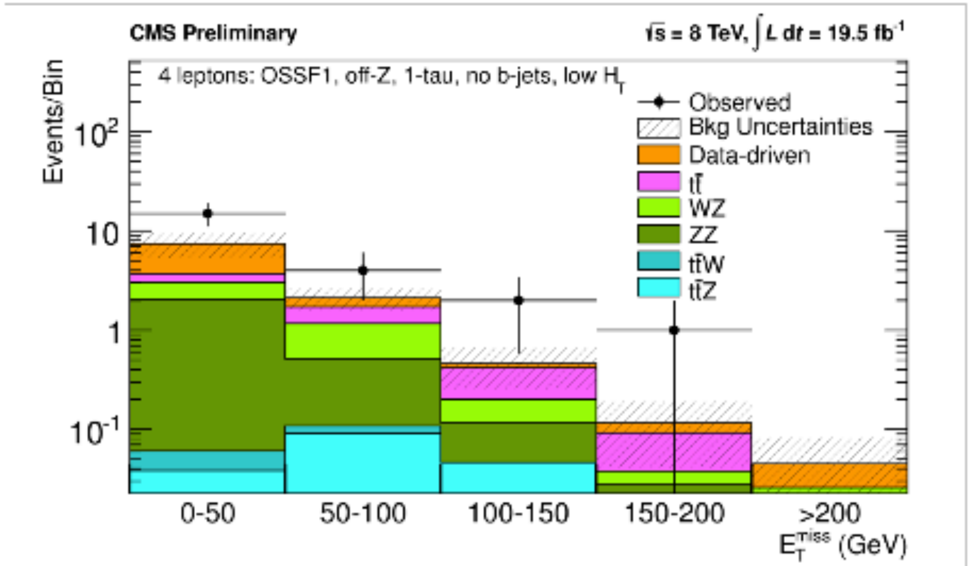
4 leptons, OSSF1, off-Z,

including 1 τ,

no b-tags, HT< 200 GeV

Observe = 22 events

Expected = 10 ± 2.4 events



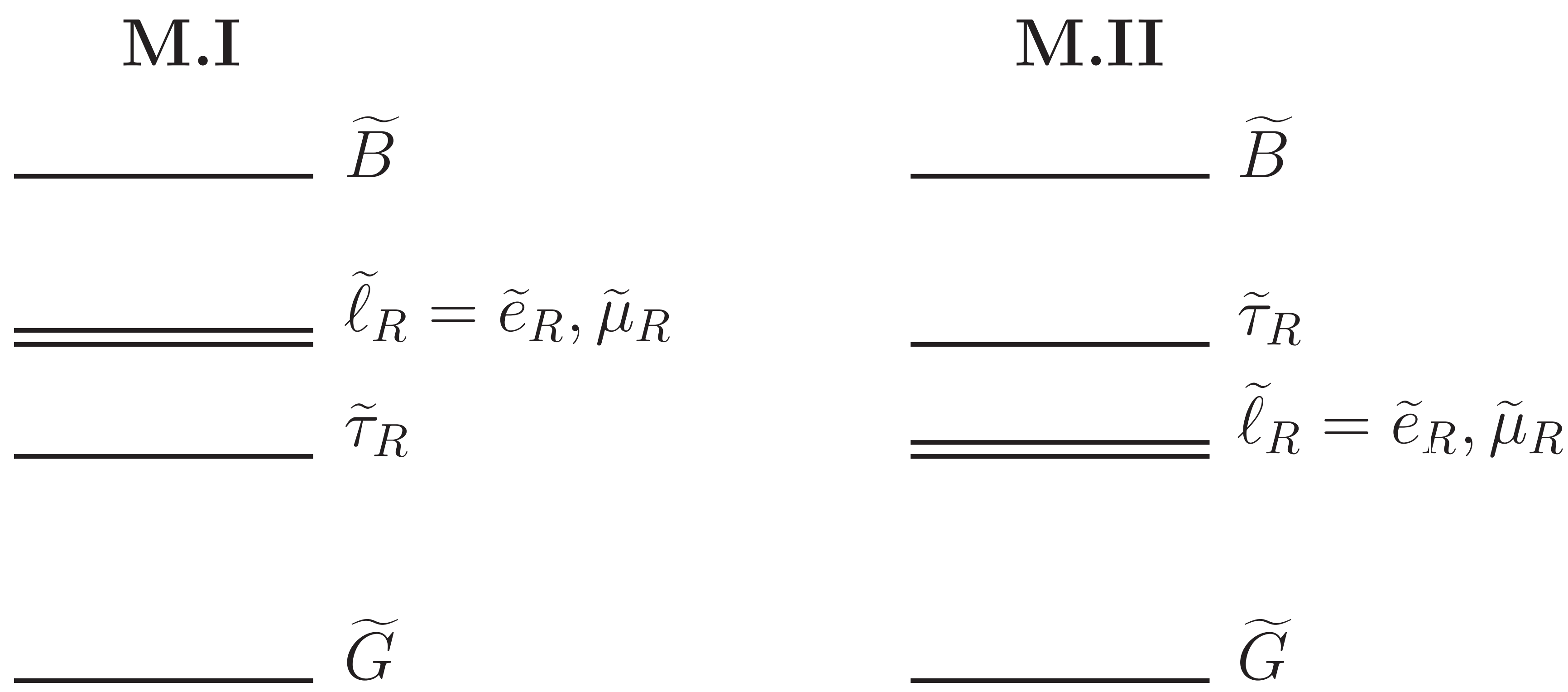
Probability for 1 out of 64 categories to have as large a fluctuation ≈ 50 %

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.

Trieste, August 26th 2013 Andrea Gozzelino - CMS 13

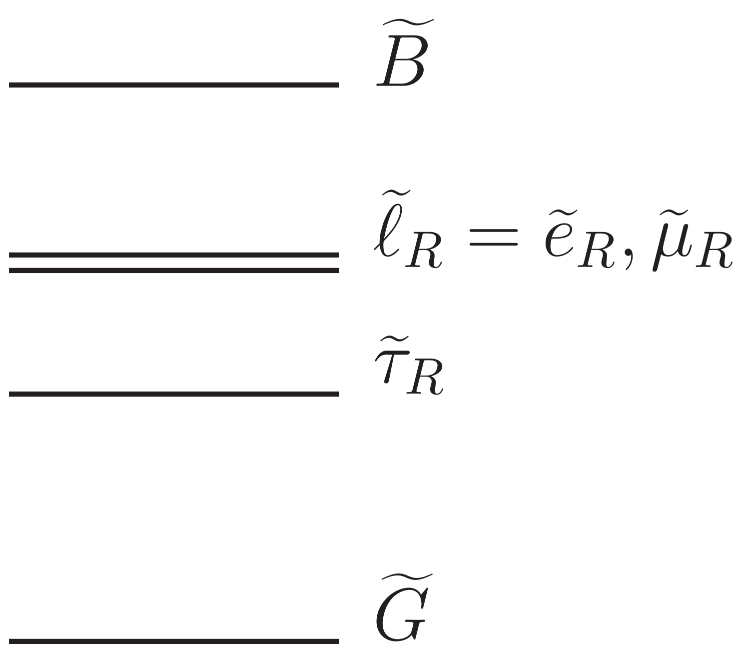
Simplified models of GMSB



[CMS SUS-13-002]

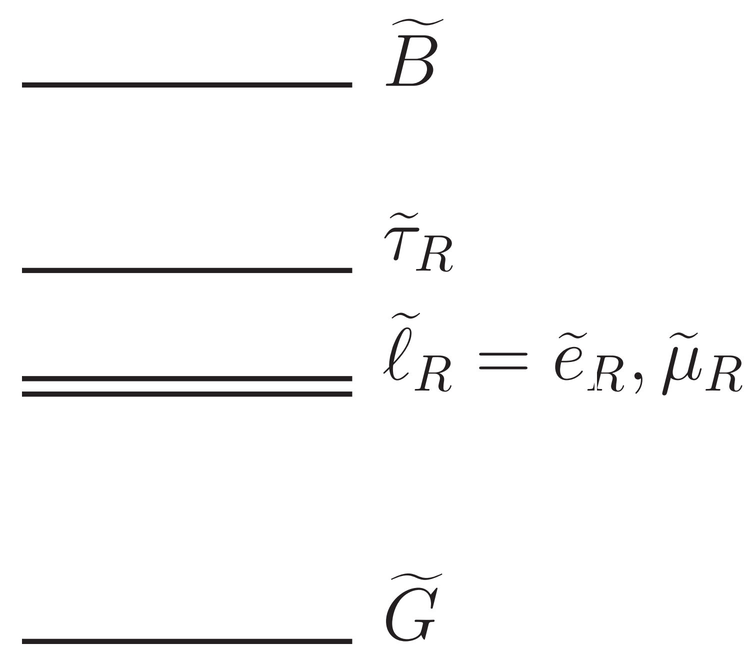
Simplified models of GMSB

M.I



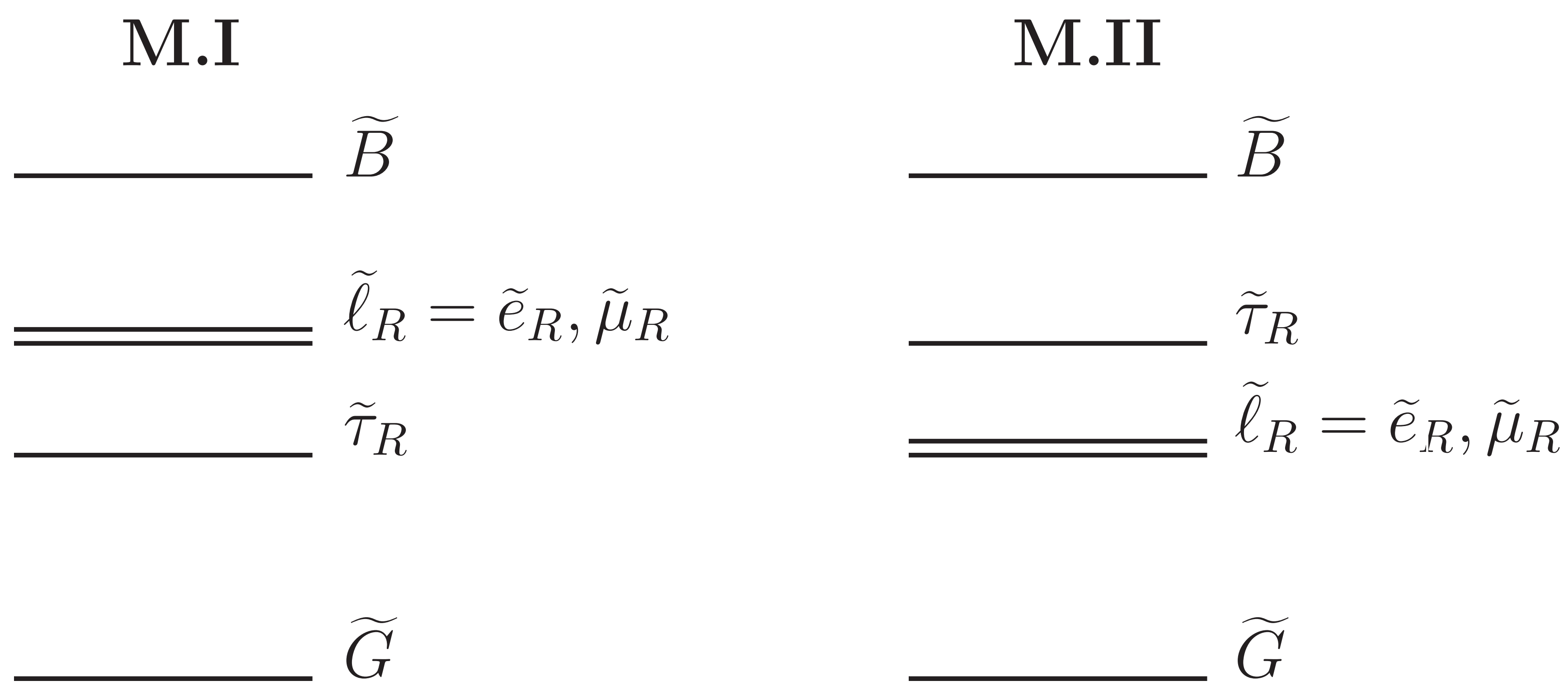
$$\tilde{\tau}_R \to \tau \tilde{G}$$

M.II



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

Simplified models of GMSB



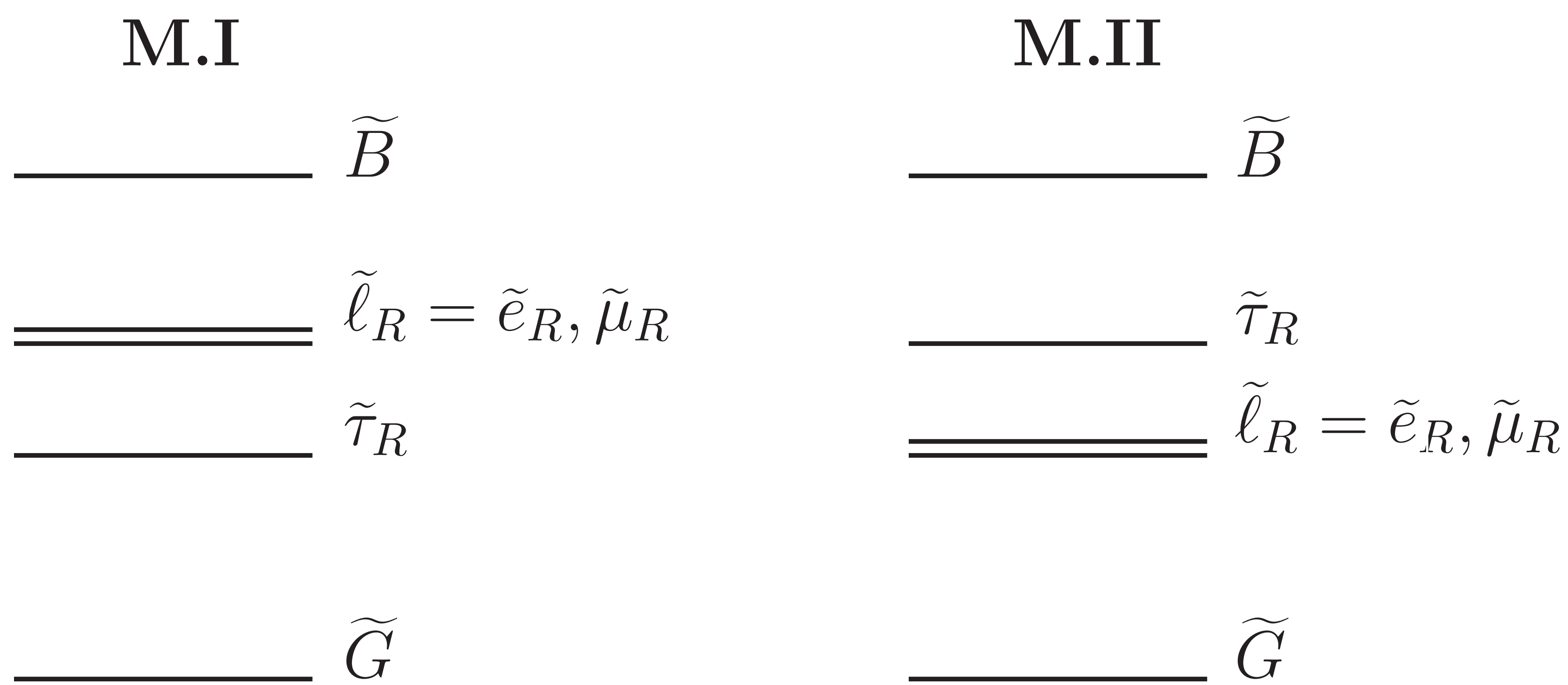
$$\tilde{\tau}_R \to \tau \tilde{G}$$

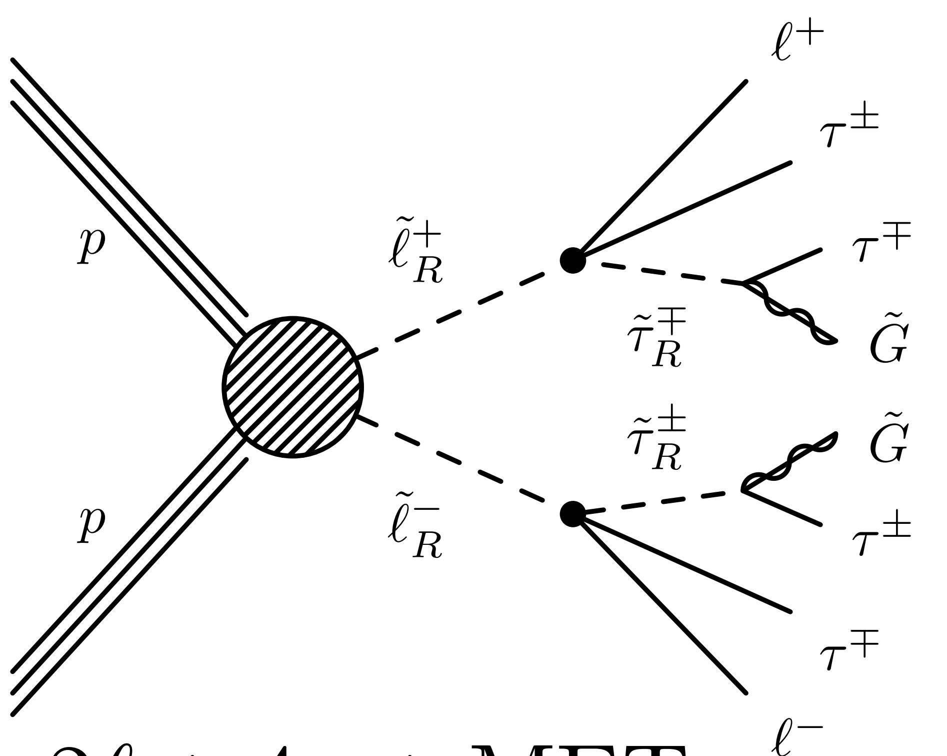
$$\tilde{\ell}_R \to \ell \tau \tilde{\tau}_R$$

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

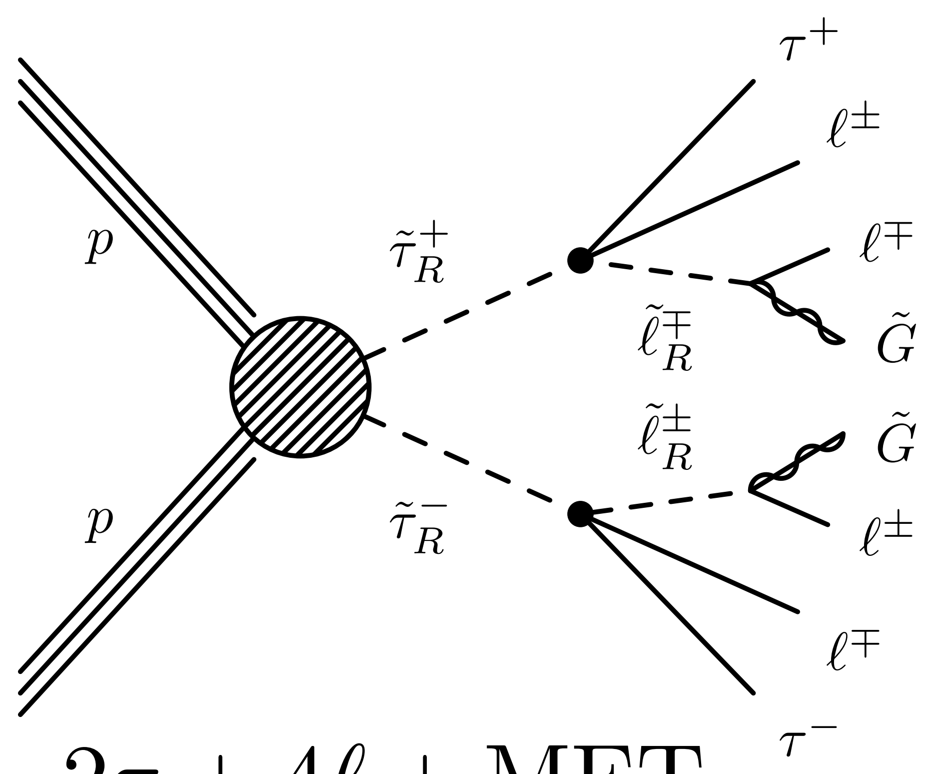
$$\tilde{\tau}_R \to \tau \ell \tilde{\ell}_R$$

Simplified models of GMSB





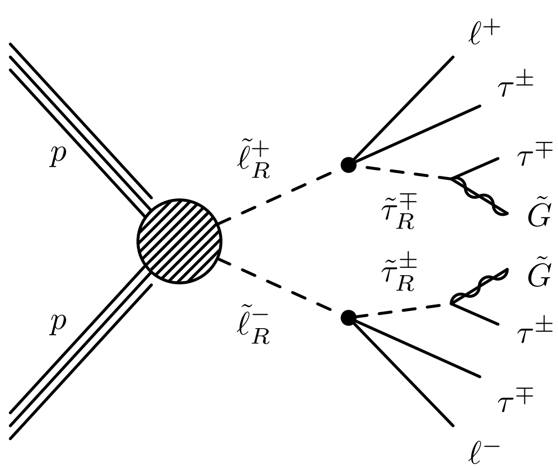
$2\ell + 4\tau + \mathrm{MET}$

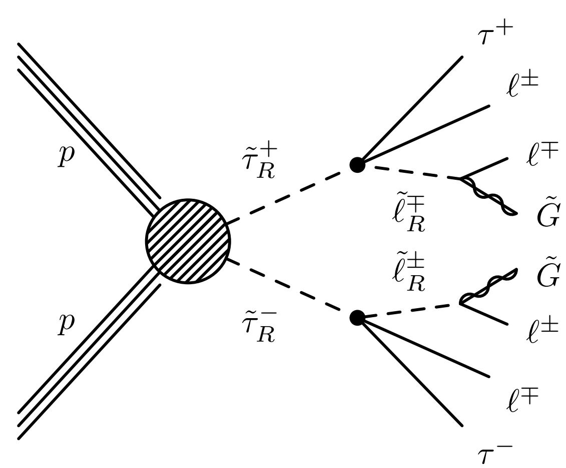


$2\tau + 4\ell + \mathrm{MET}$

Comparison with CMS search

- Fix $m_{3/2} = 1\,\mathrm{eV}, m_{\tilde{B}} = 500\,\mathrm{GeV}$
- Consider slepton/stau masses in the range 50-300 GeV
- Simulate the following two processes at LHC-8TeV

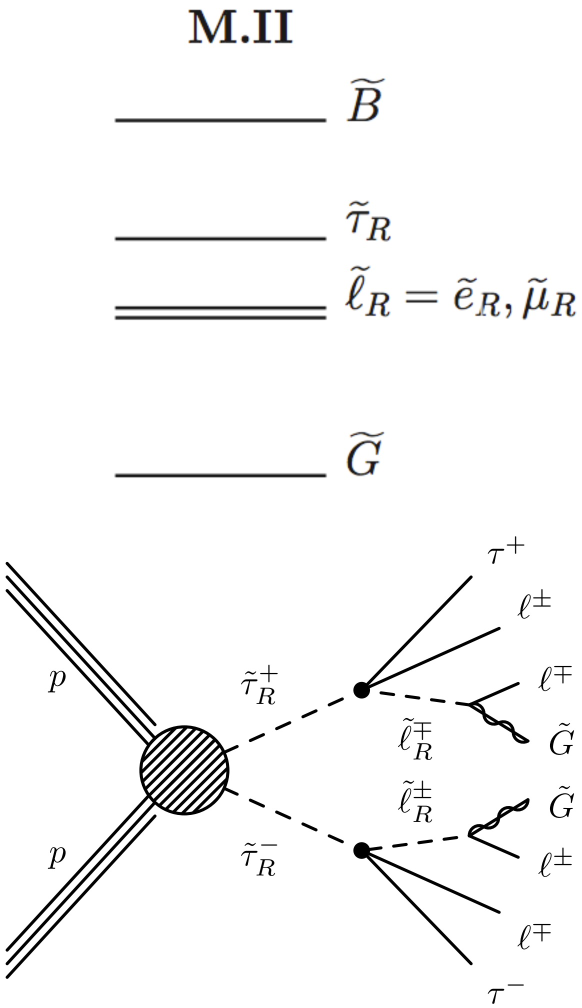


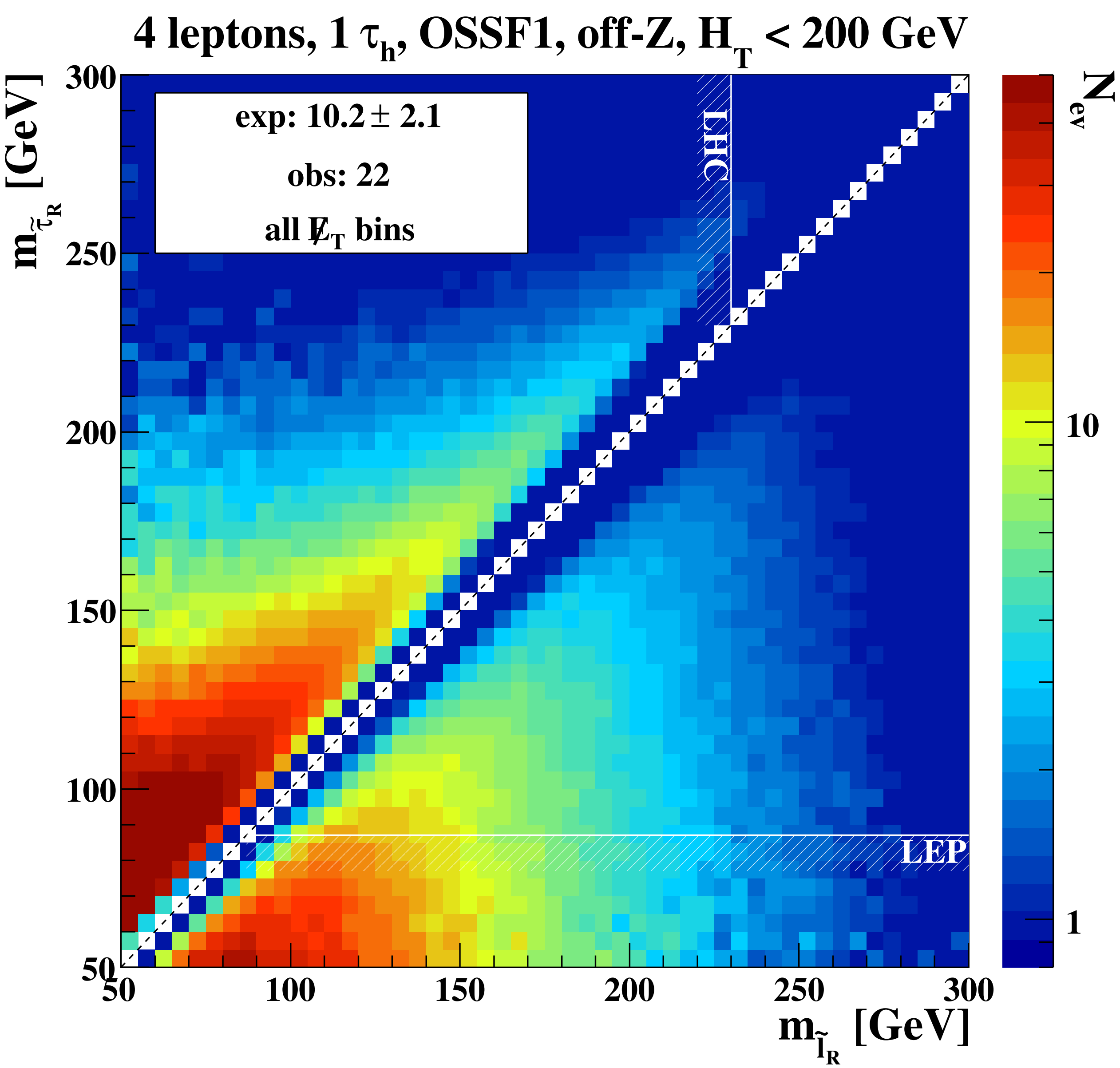


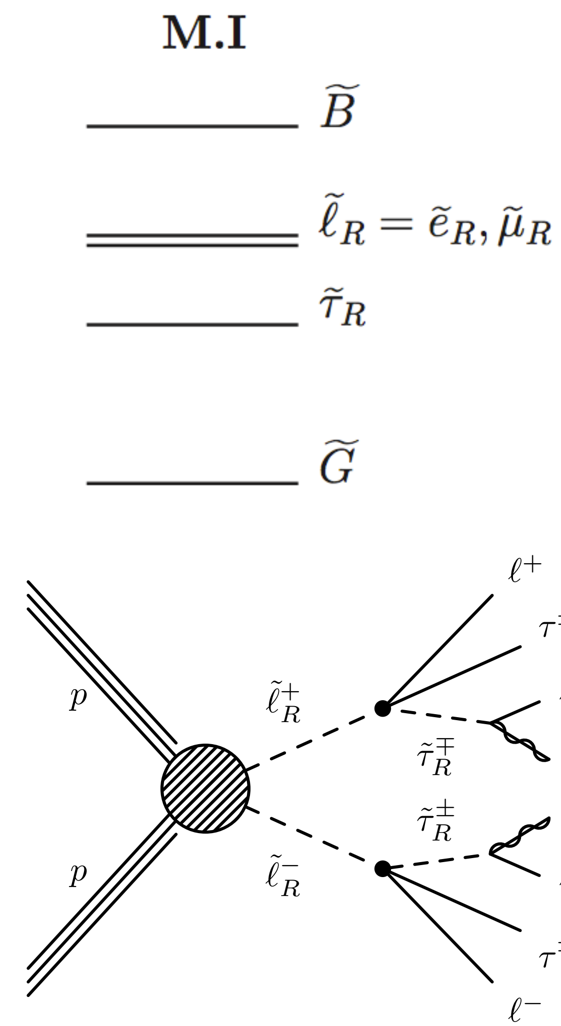
Simulations/analysis done with:

FeynRules	[Christensen,Duhr,Fuks]
MadGraph 5	[Alwall,Herquet,Maltoni,Mattelaer,Stelzer]
Pythia	[Sjöstrand,Mrenna,Skands]
Delphes	[Ovyn,Rouby,Lemaitre]
MadAnalysis 5	[Conte,Fuks,Serret]

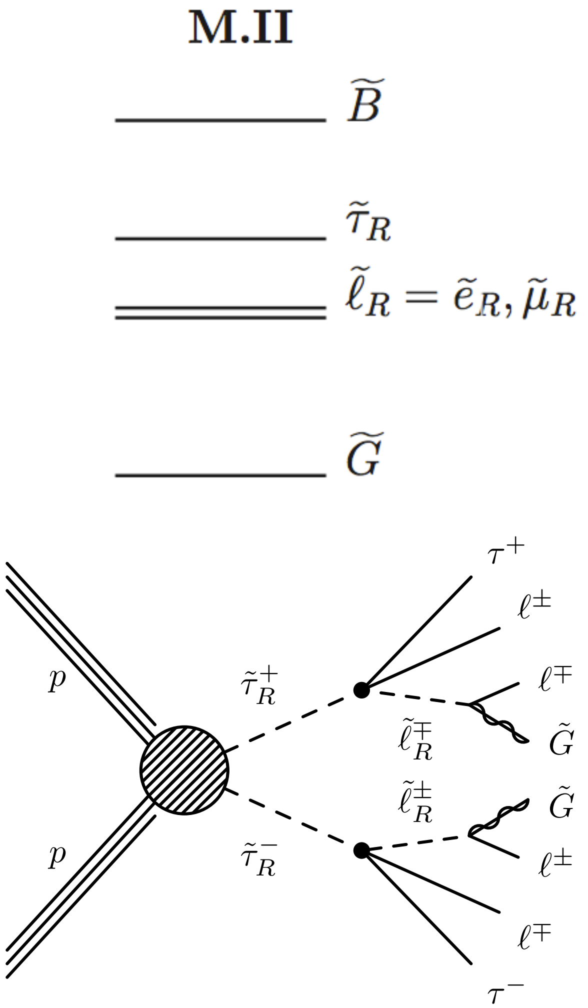
Comparison with CMS search

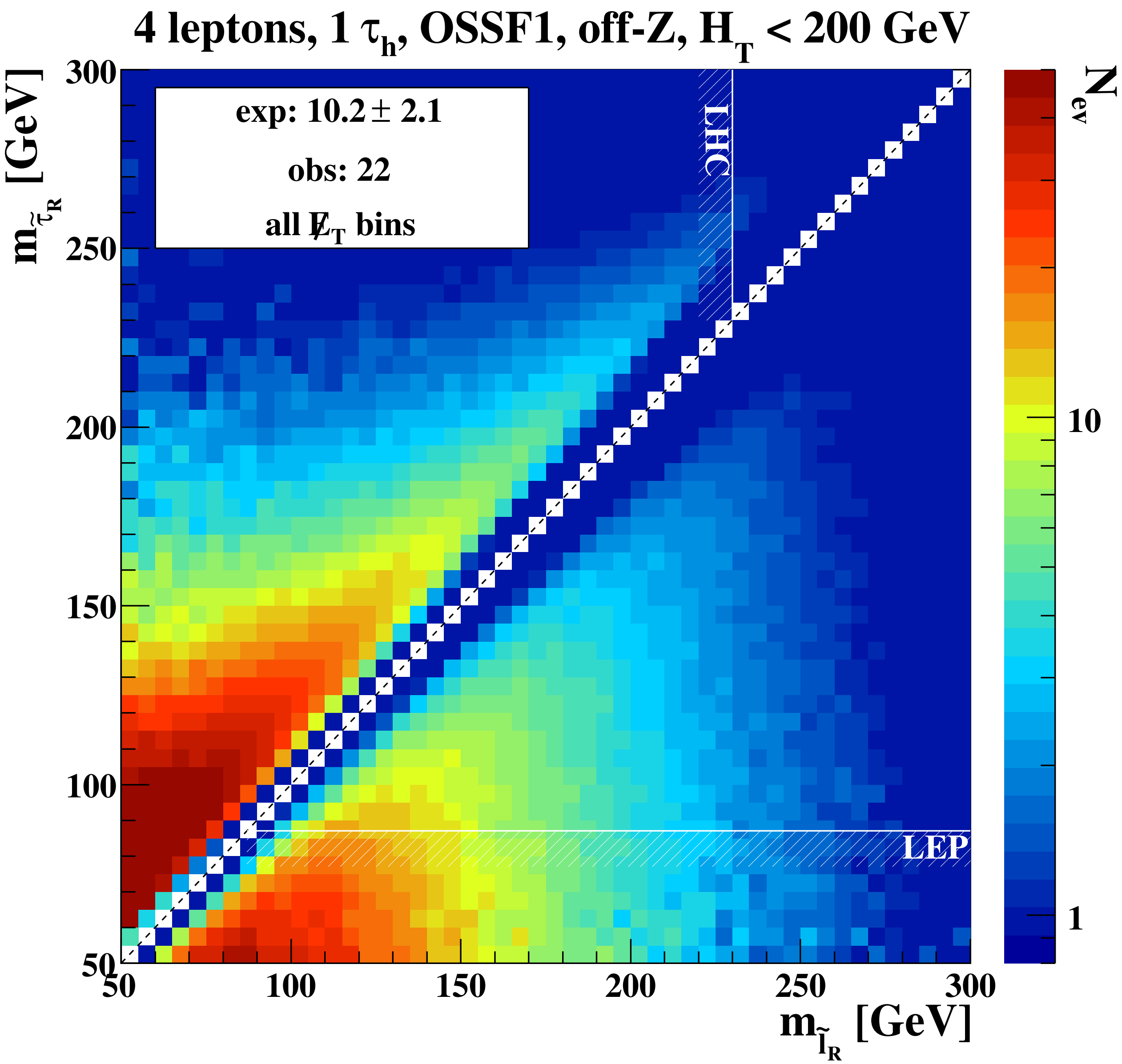


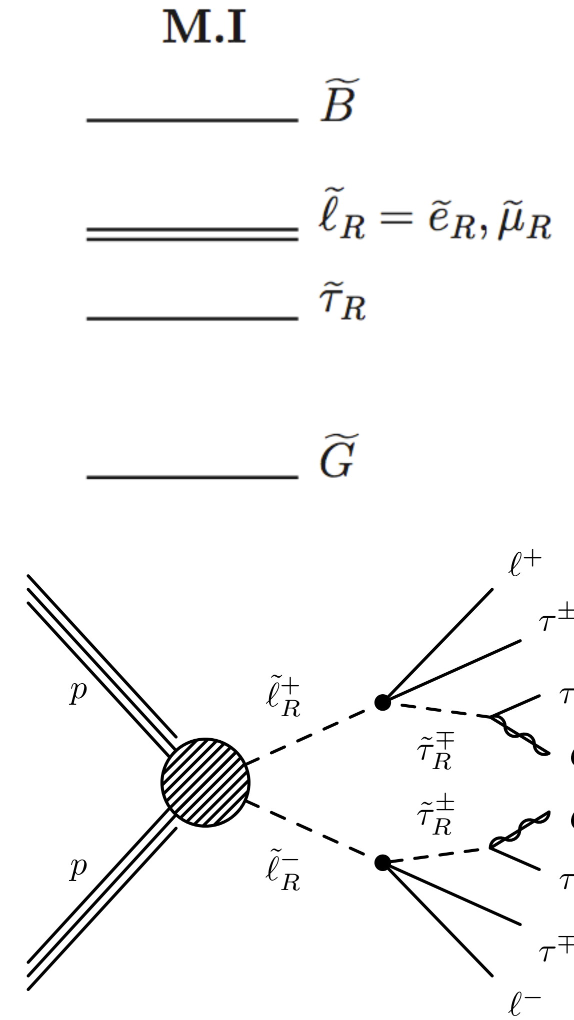




Comparison with CMS search

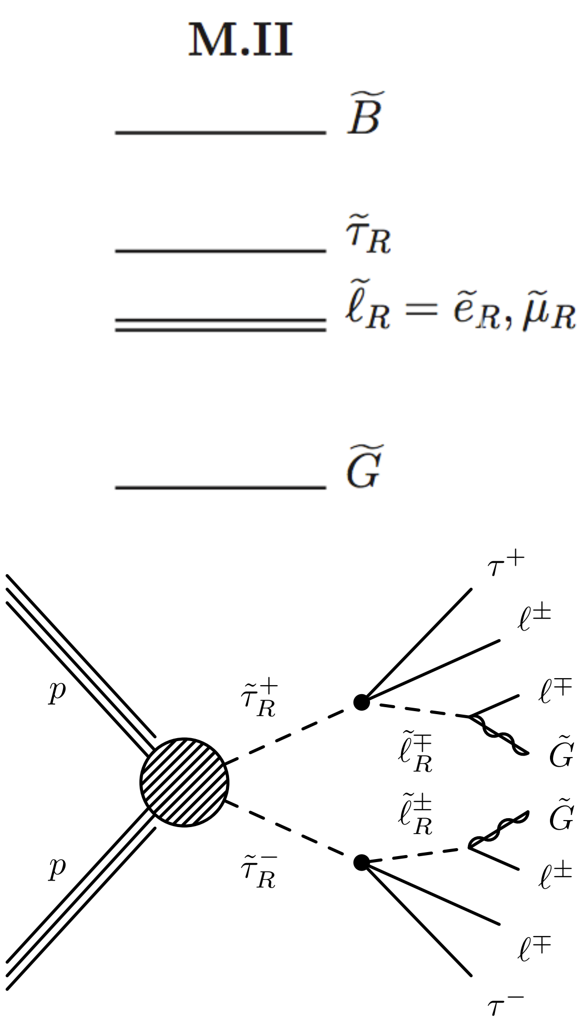


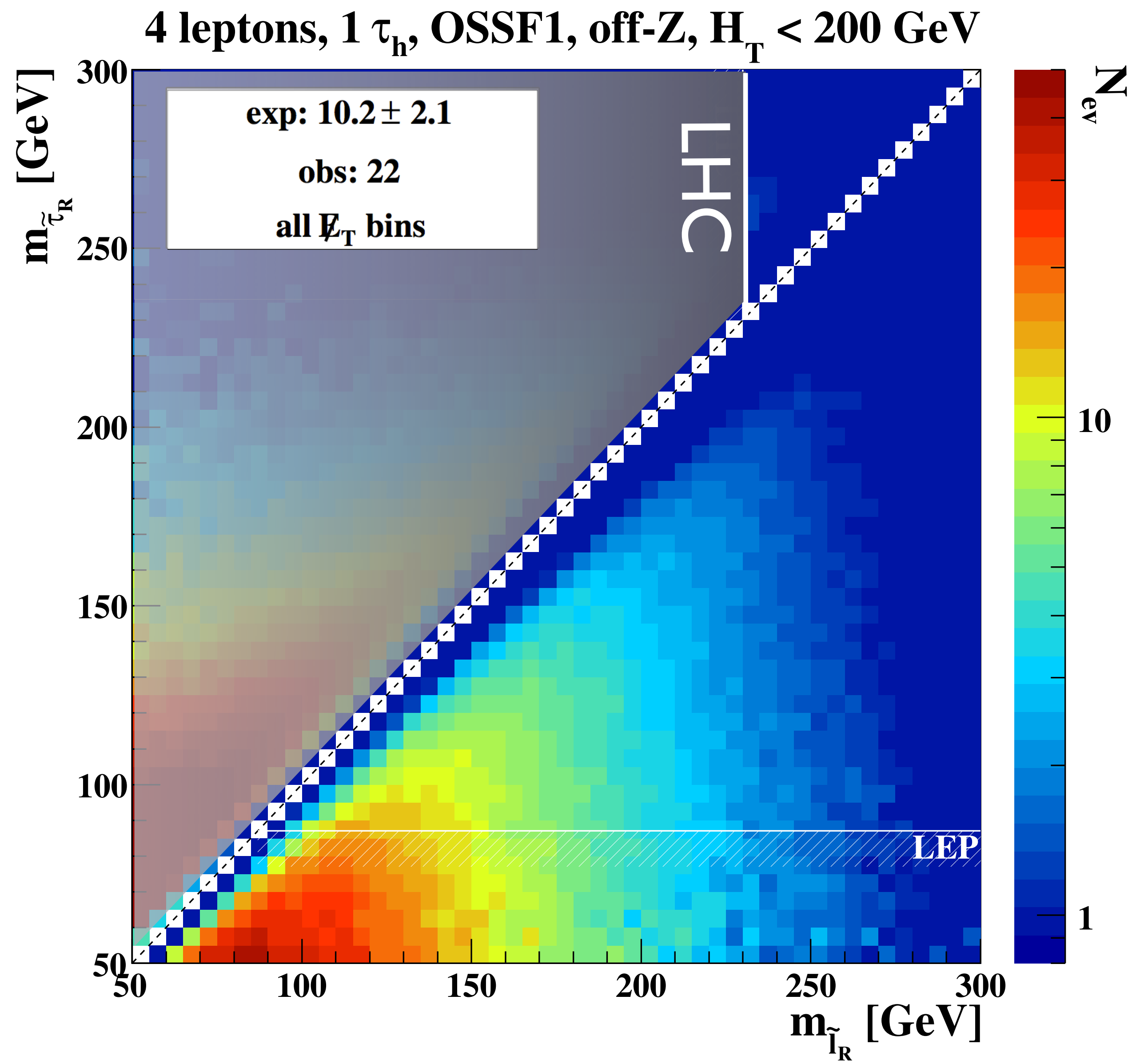


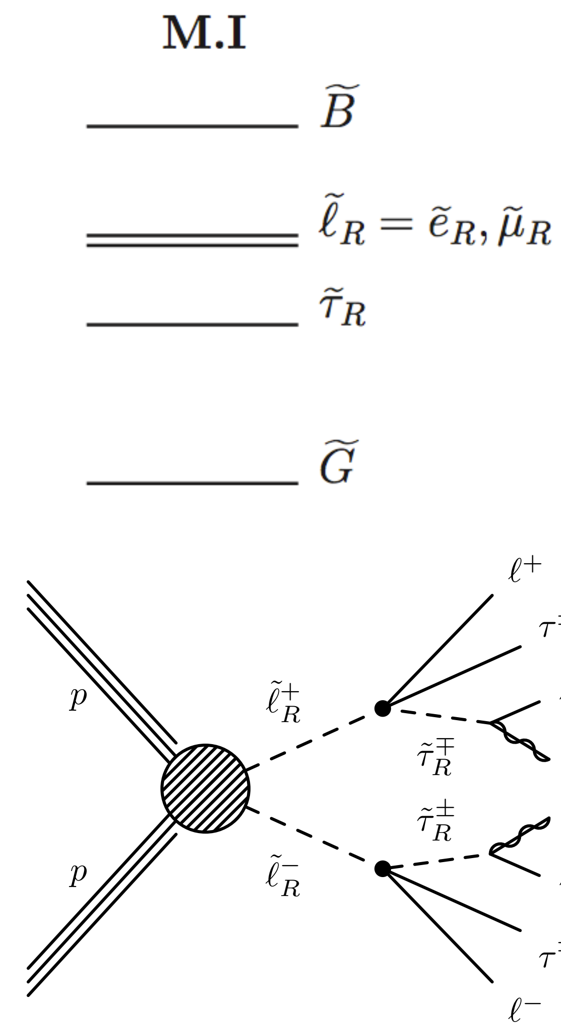


NLSP pair production sets bounds on these models

Comparison with CMS search





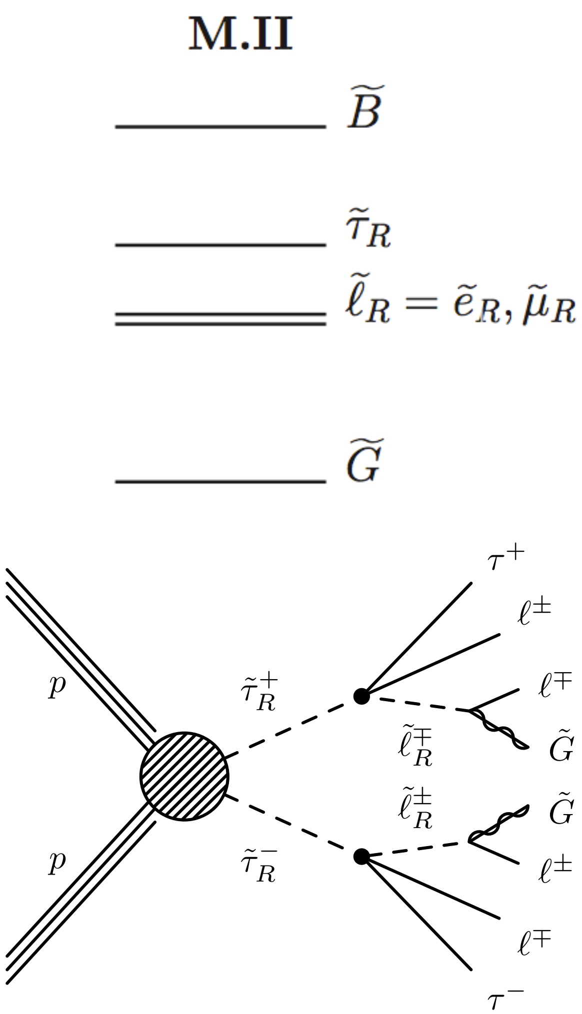


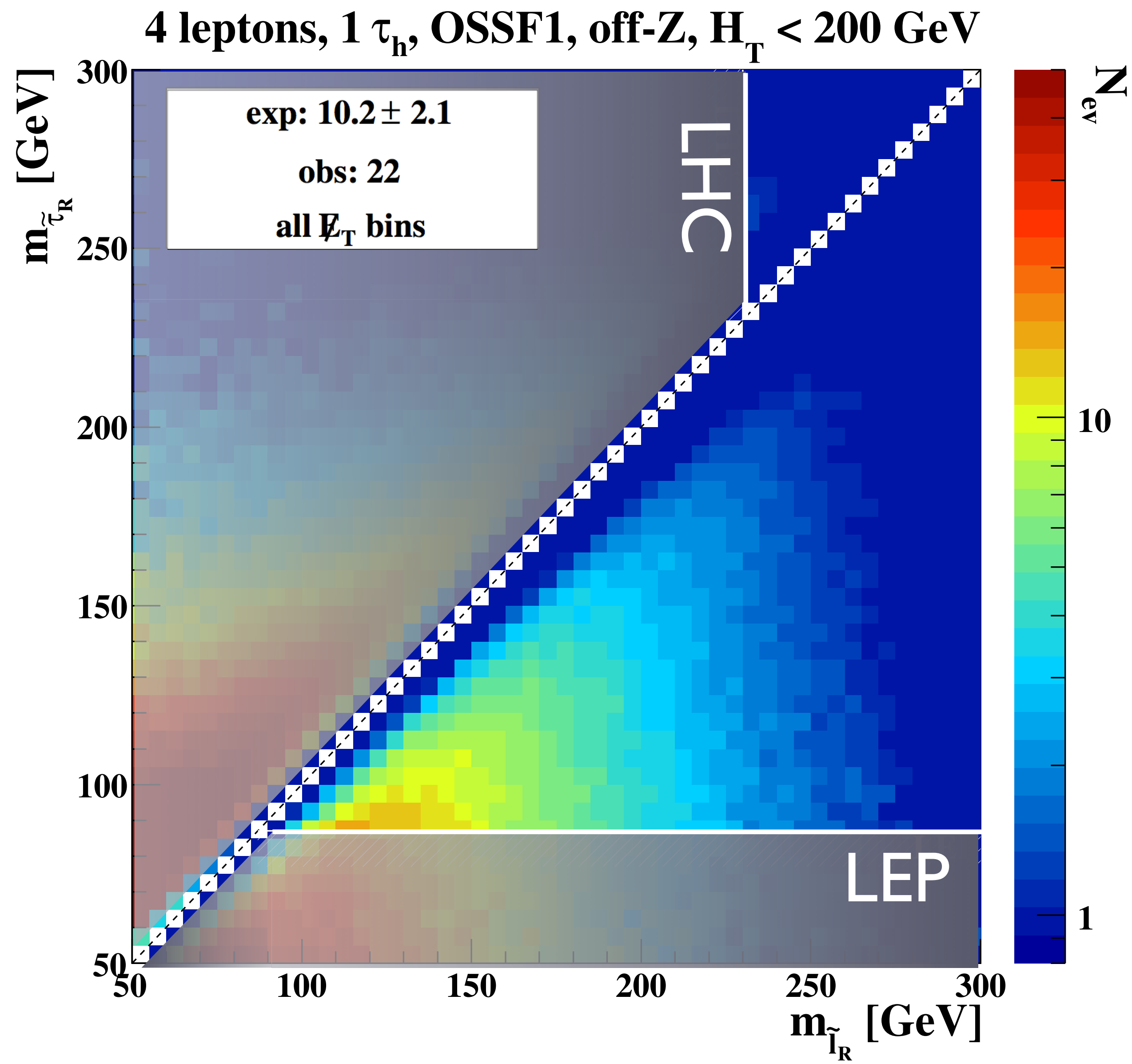
NLSP pair production sets bounds on these models

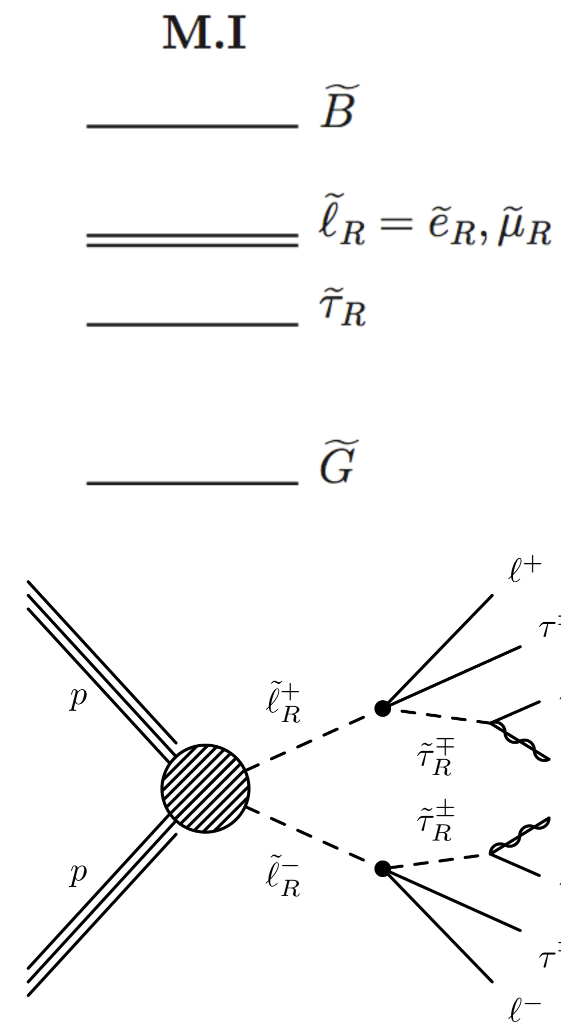
$$\text{M.II}: \; pp \to \tilde{\ell}_R \tilde{\ell}_R \;, \; \tilde{\ell}_R \to \ell \tilde{G} \; \rightarrow \; \ell^+ \ell^- + \text{MET}$$

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

Comparison with CMS search





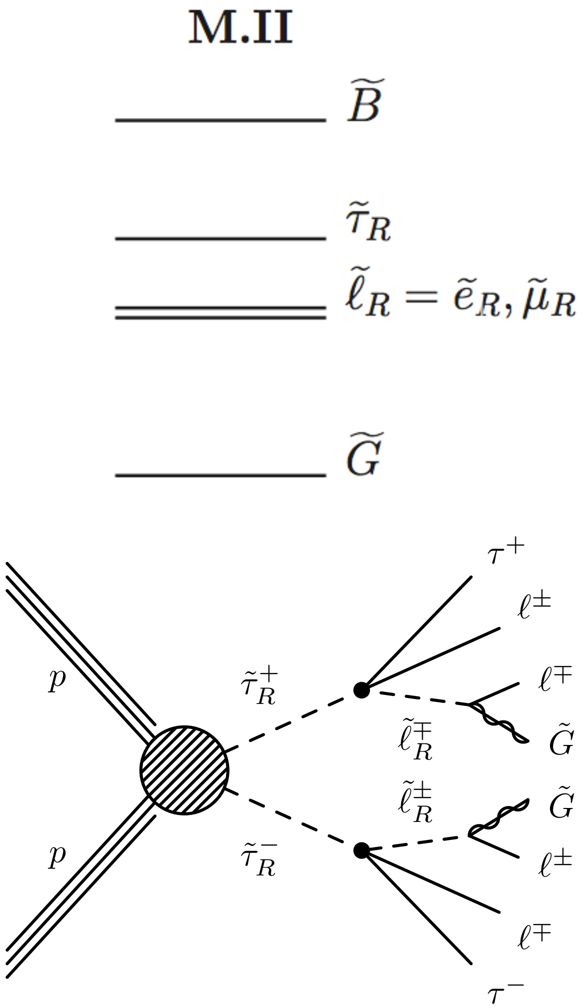


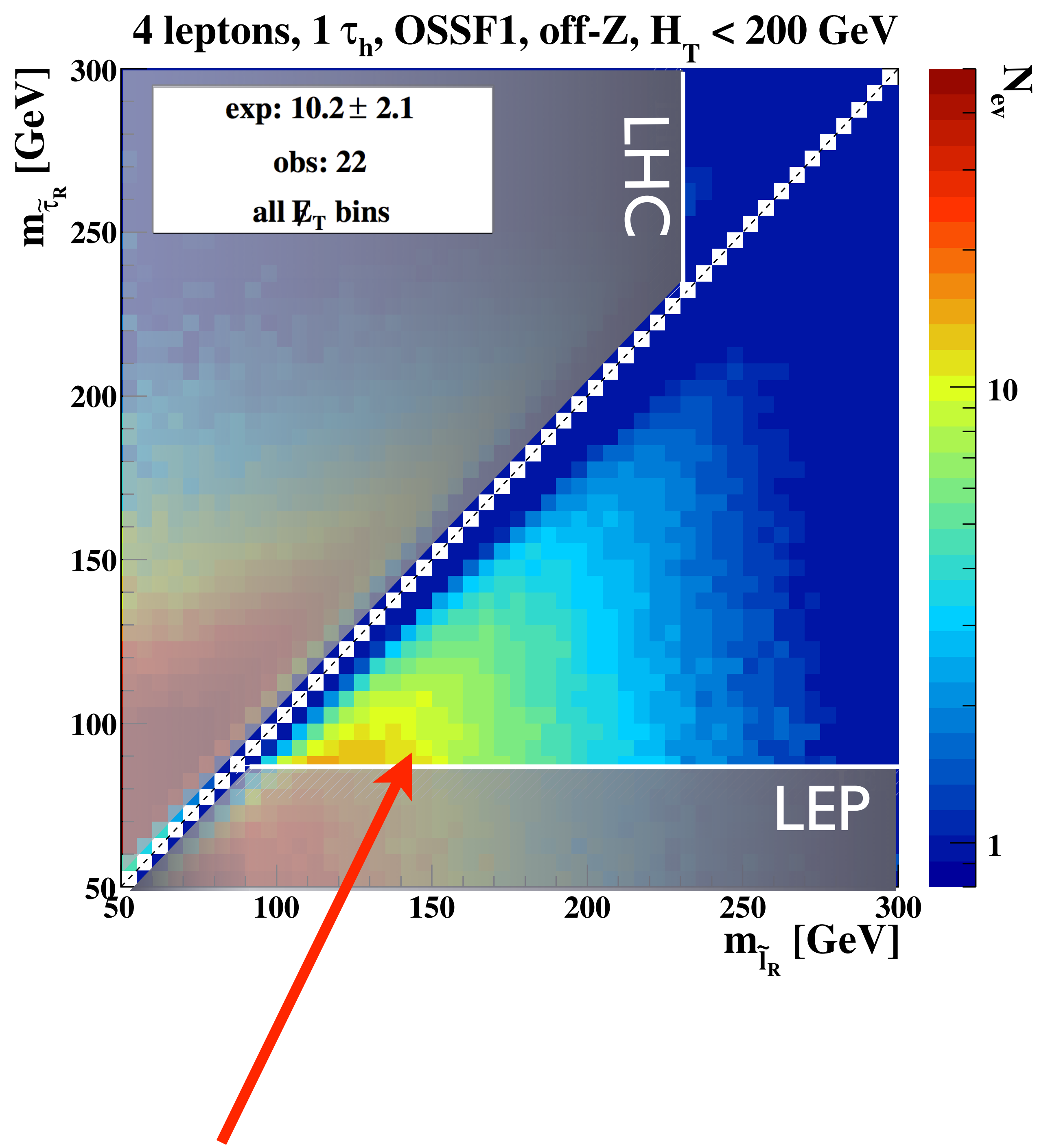
NLSP pair production sets bounds on these models

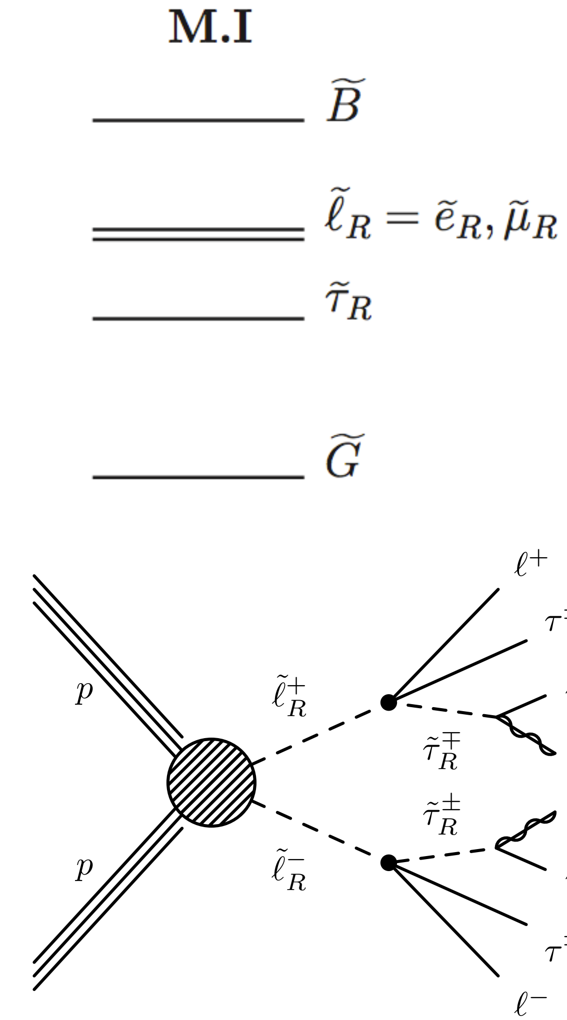
$$\text{M.I}: \; pp \to \tilde{\tau}_R \tilde{\tau}_R \;\; , \;\; \tilde{\tau}_R \to \tau \tilde{G} \;\; \Rightarrow \;\; \tau\tau + \text{MET}$$

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

Comparison with CMS search

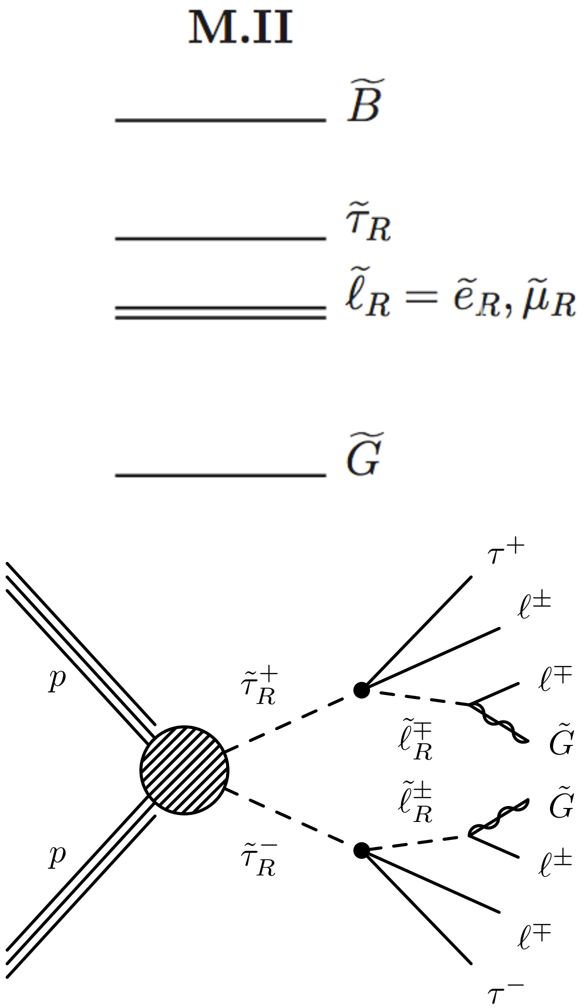


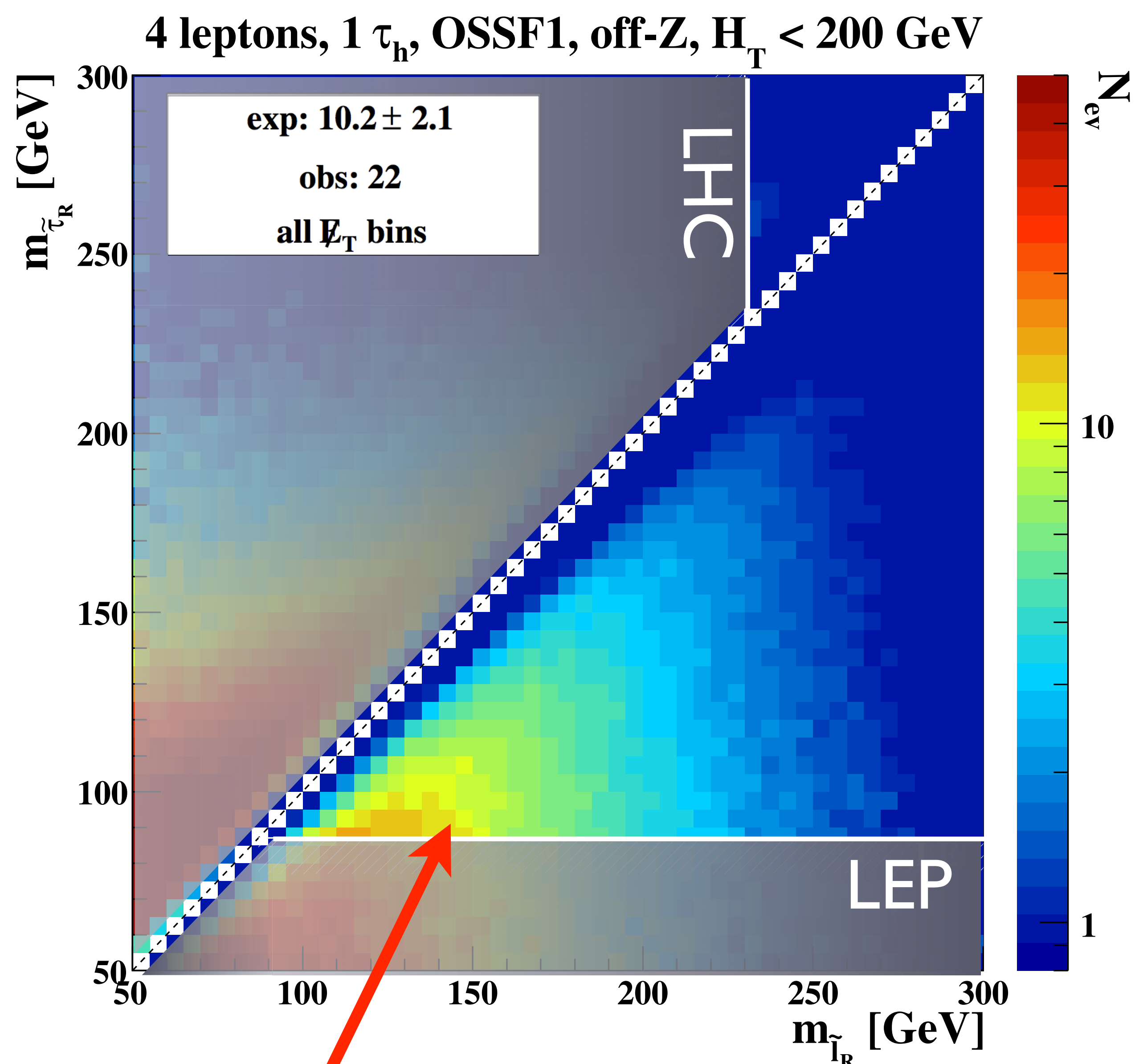


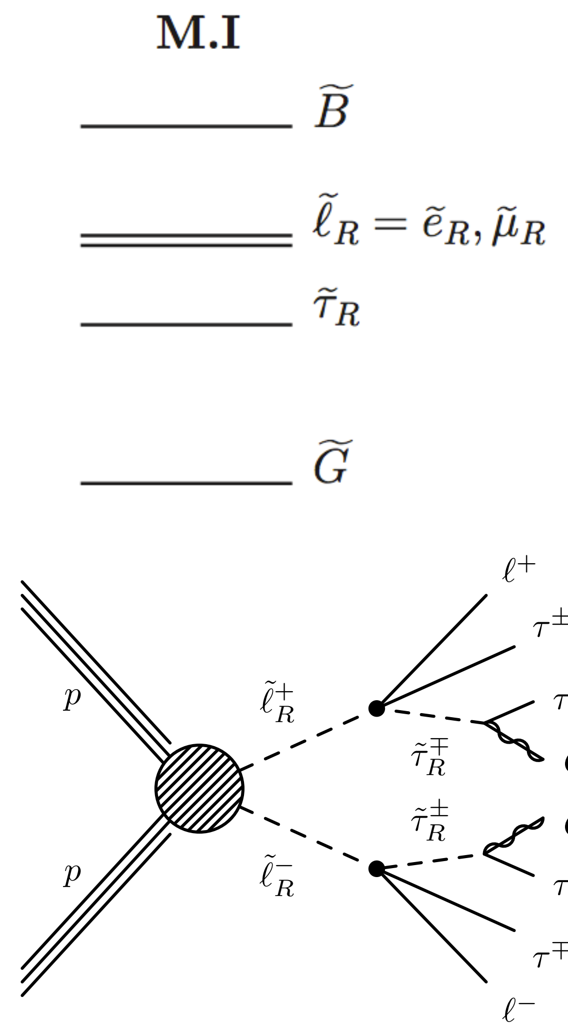


Preferred region: $m_{\tilde{\ell}_R} \sim 145\,\mathrm{GeV}\ ,\ m_{\tilde{\tau}_R} \sim 90\,\mathrm{GeV}$

Comparison with CMS search

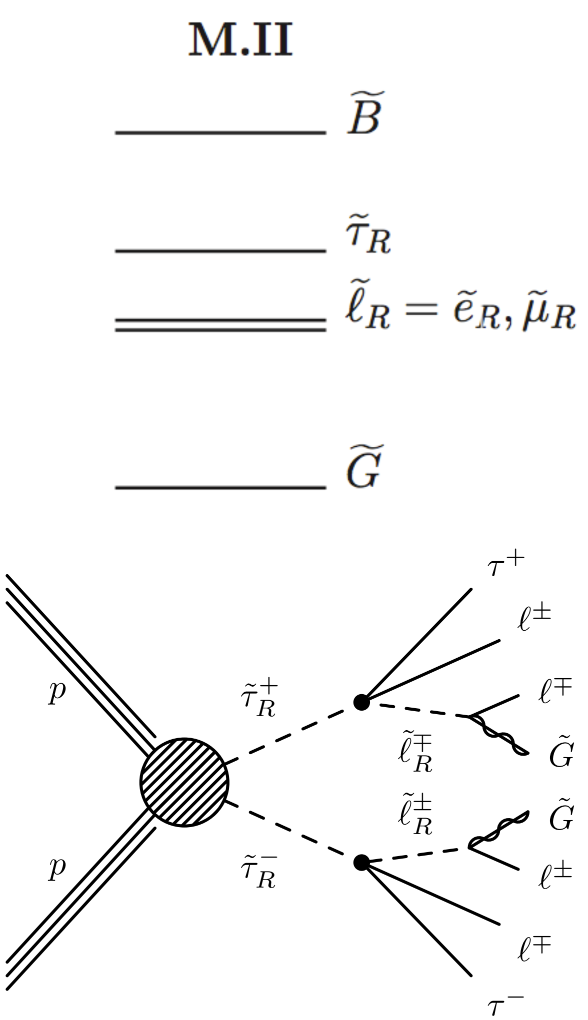


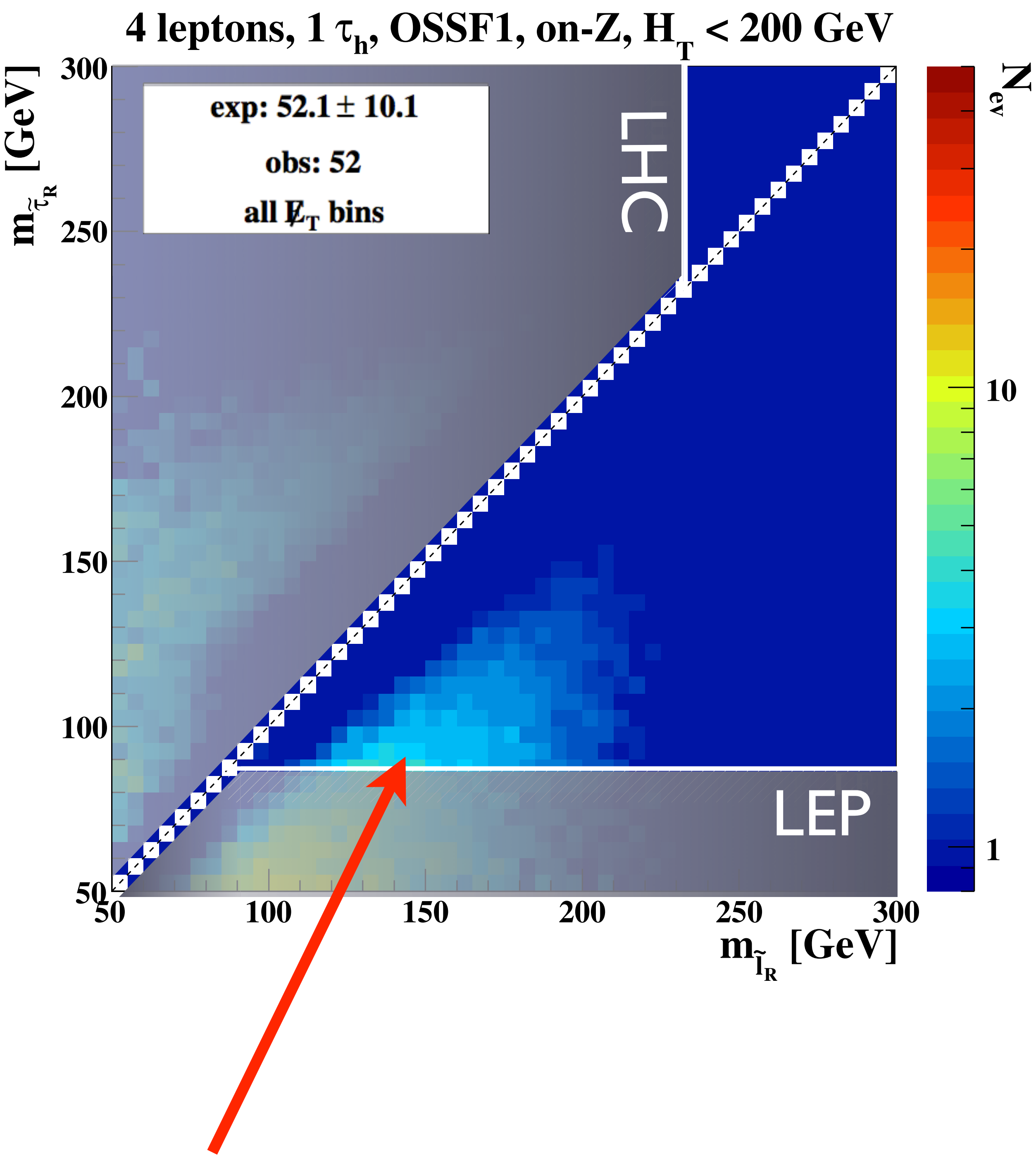


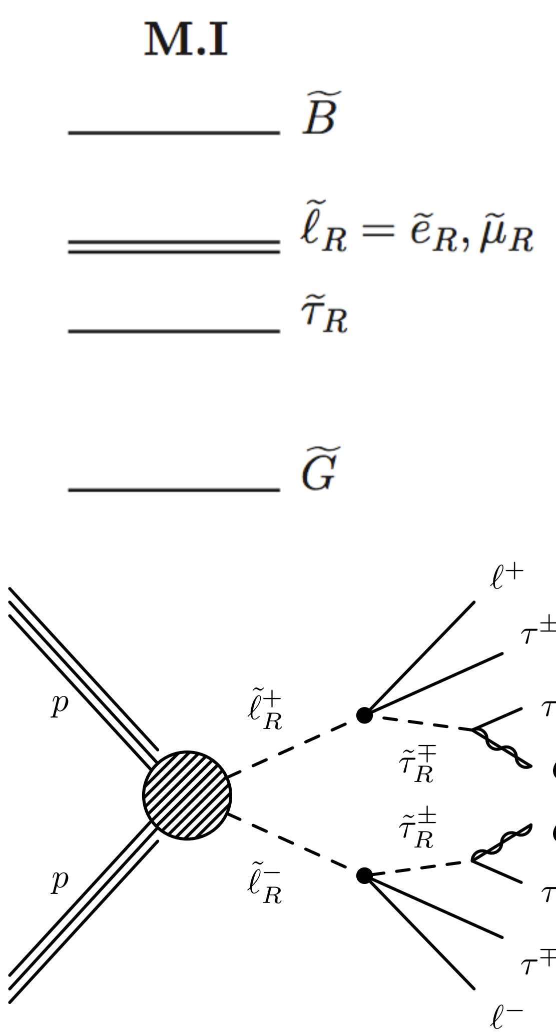


Preferred region: $m_{\tilde{\ell}_R} \sim 145\,\mathrm{GeV}$, $m_{\tilde{\tau}_R} \sim 90\,\mathrm{GeV}$

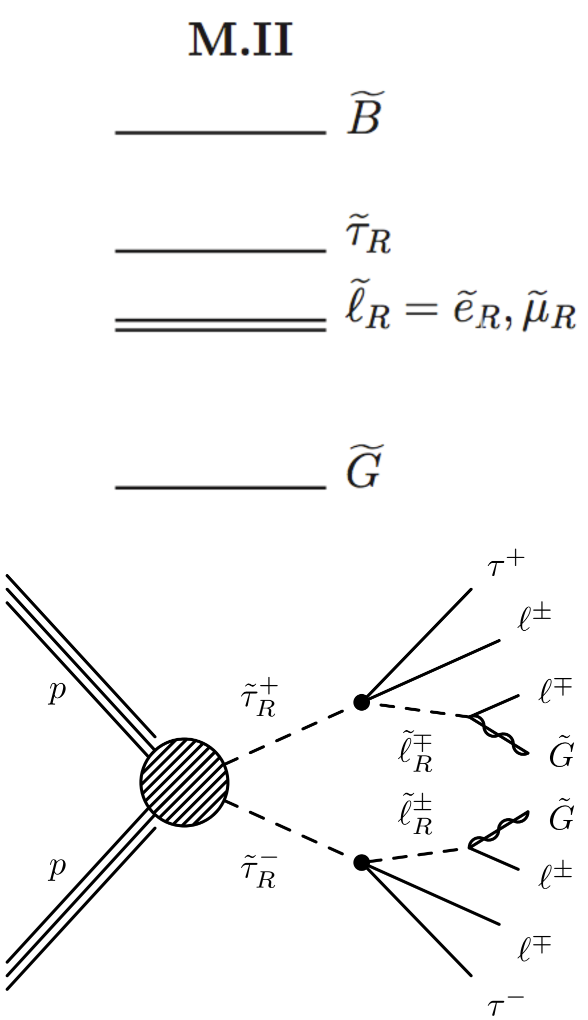
Same category, but on-Z

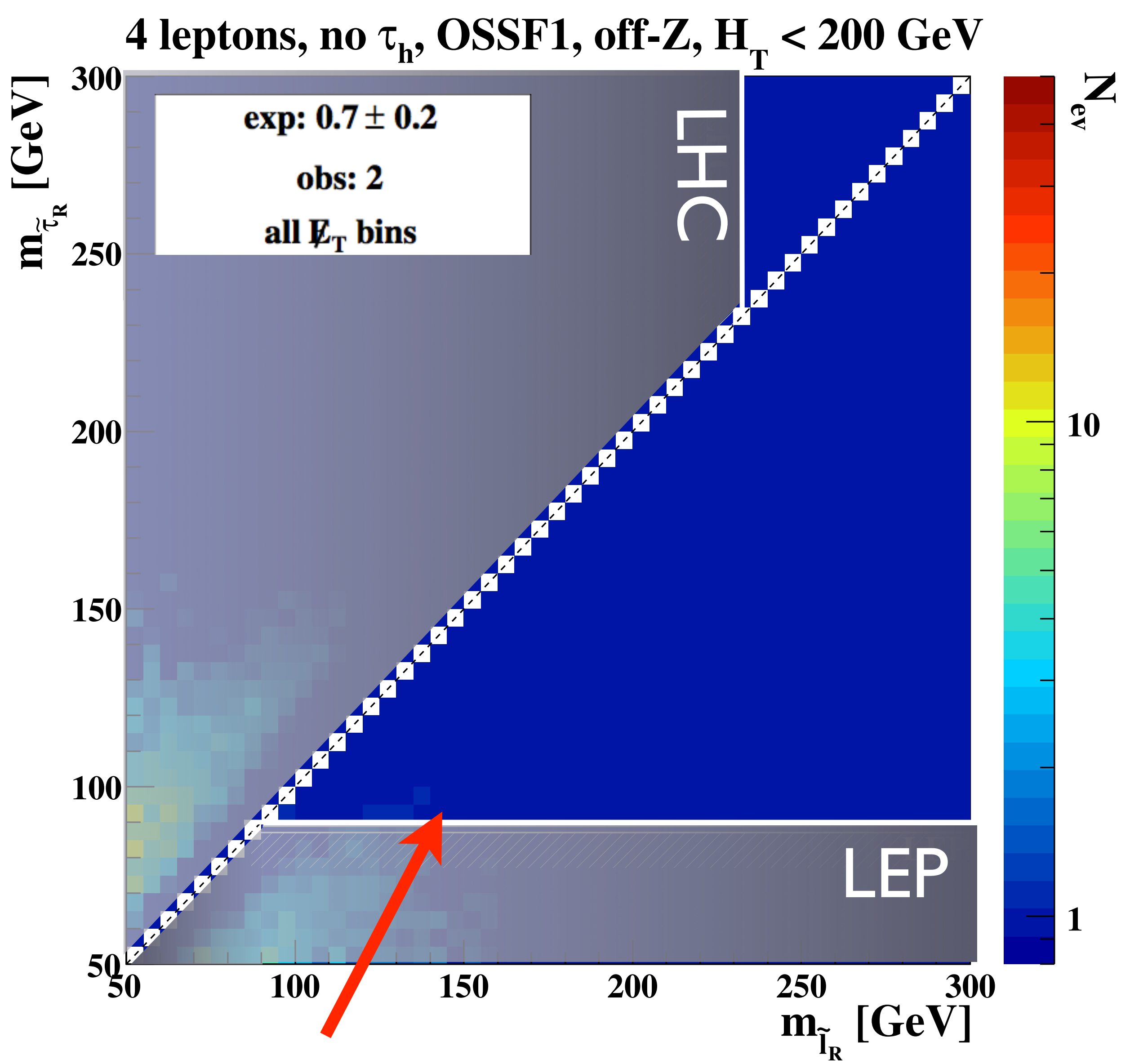


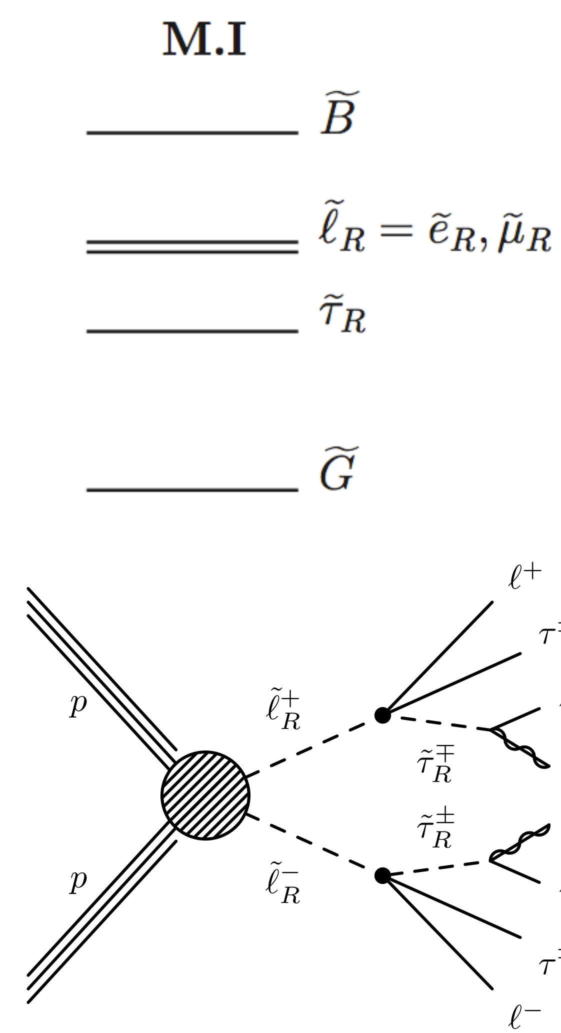




4 leptons, no hadronic tau







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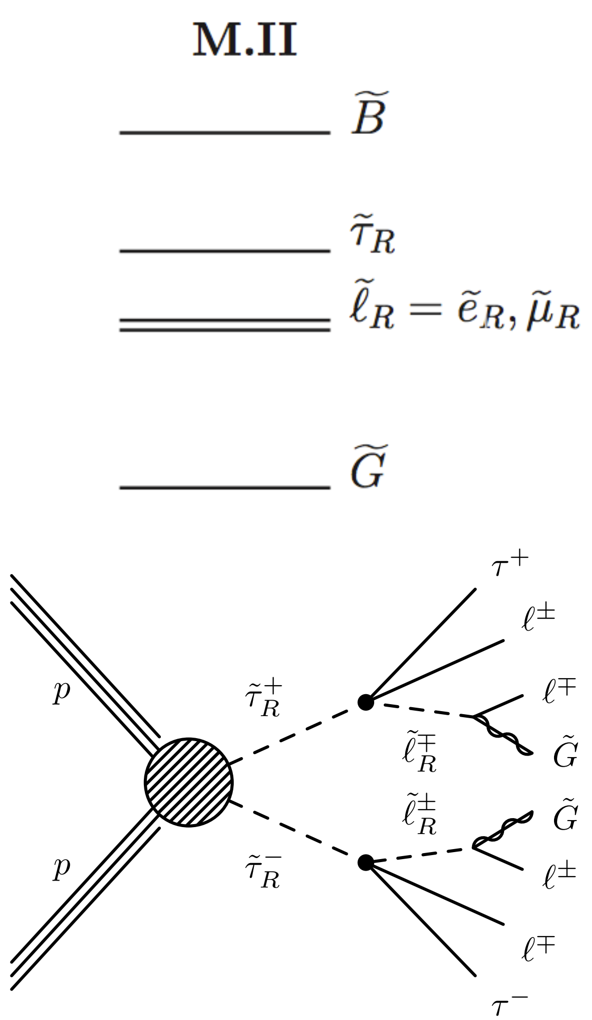
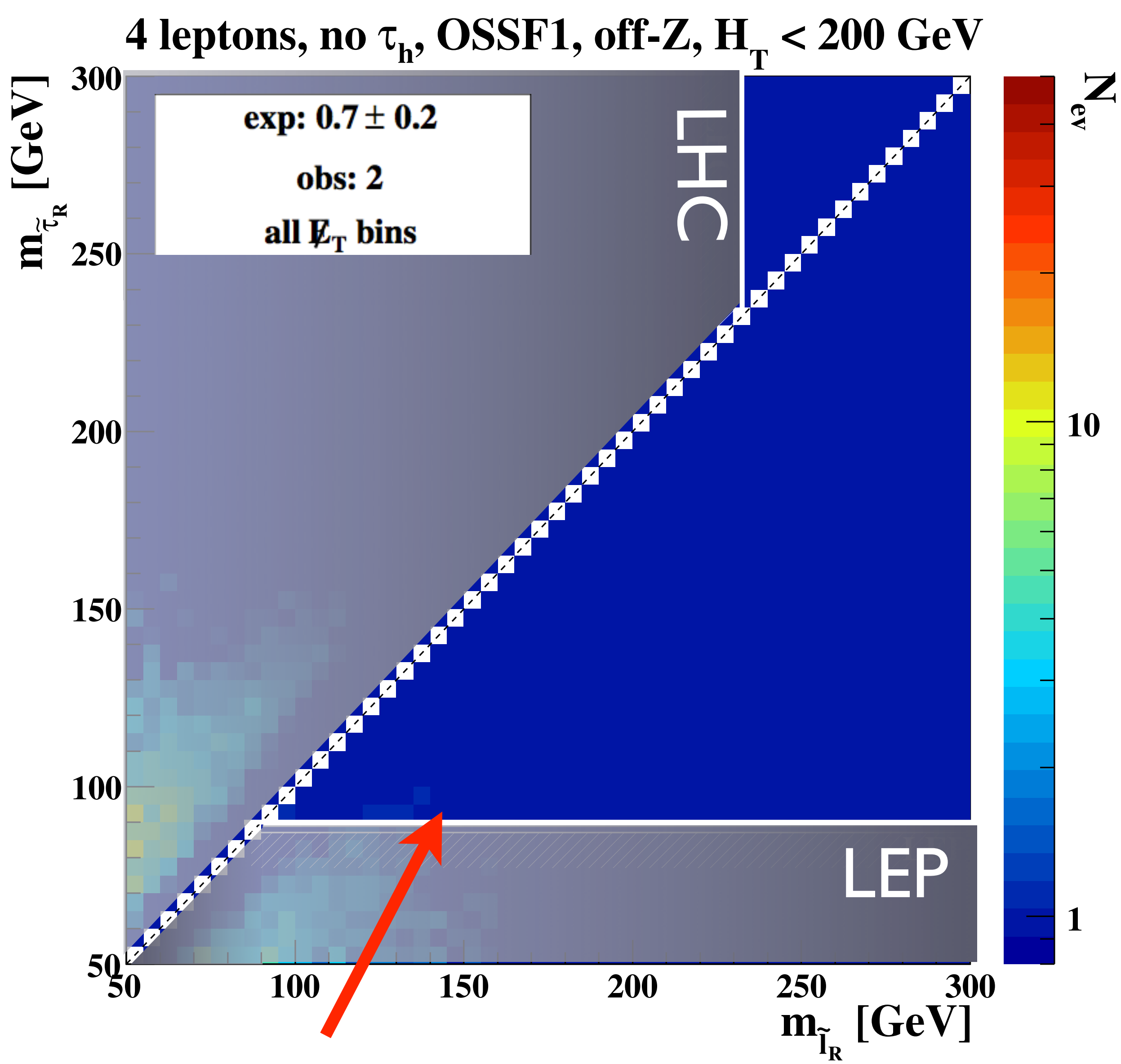
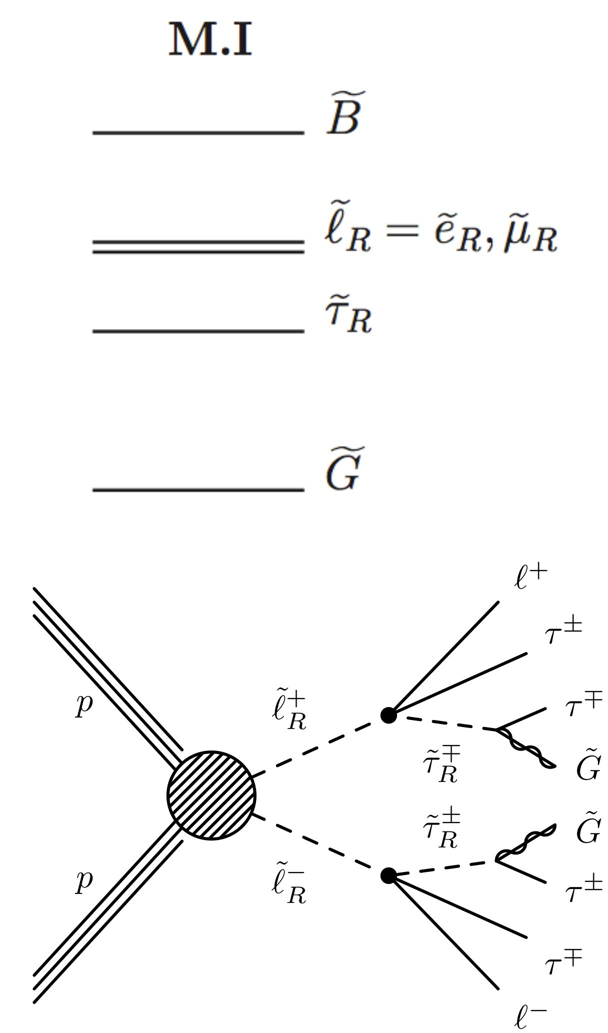


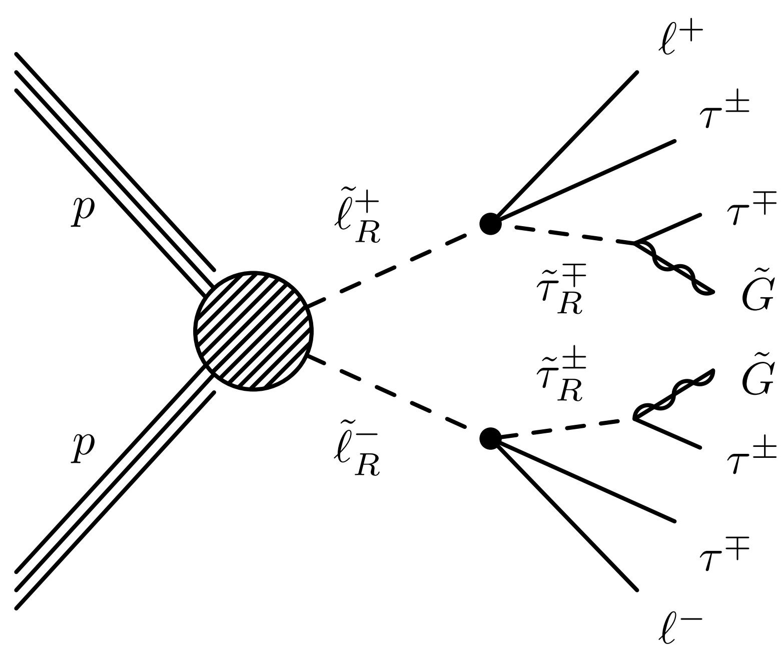




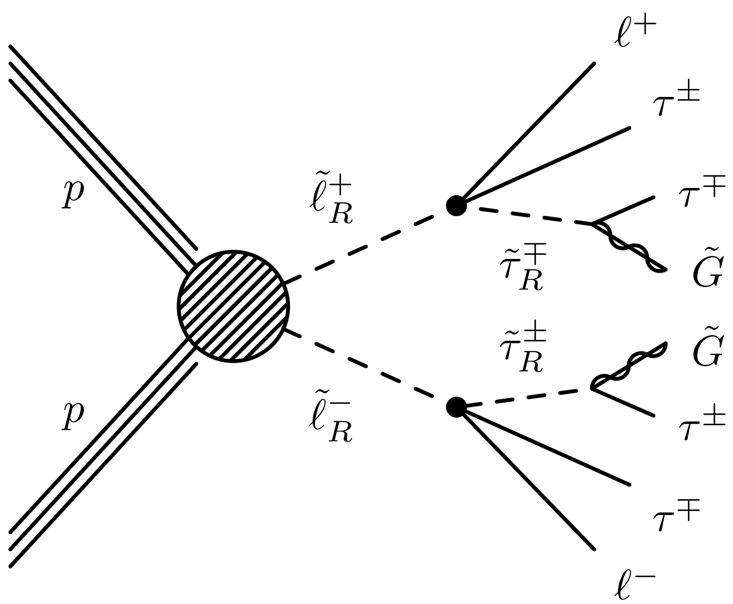
Note that in all the 3 lepton categories, the backgrounds are so large, that the signal yield is always in agreement with the expectations.

Comparison with other searches

- CMS multi-lepton search CMS SUS-13-010 (requires 4 electrons or muons)
- ATLAS multi-lepton search (requires MET>100 GeV)
- ATLAS di-tau+MET search (lepton veto)



Prospects

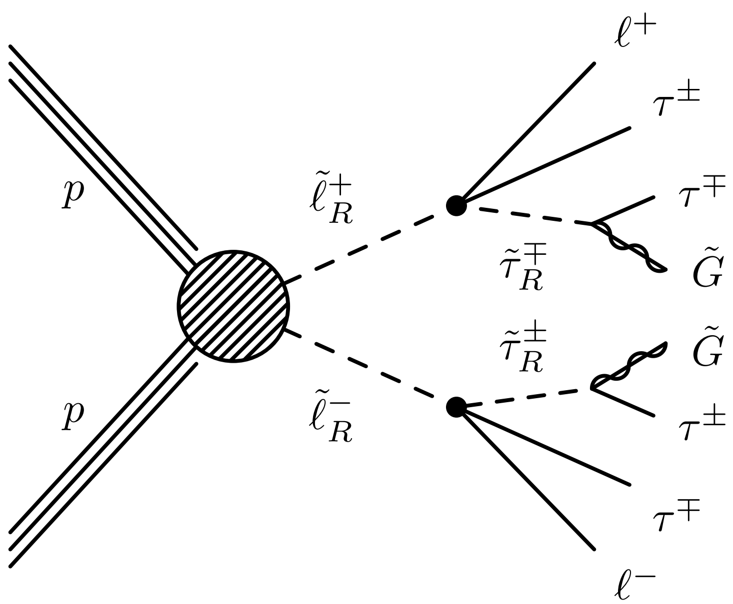


$$m_{\tilde{\ell}_R} = 145\,\mathrm{GeV}$$

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

		$19.5\,\mathrm{fb}^{-1}$	$100\,\mathrm{fb}^{-1}$
$N(\ell)$	$N(\tau_h)$	N_{events}(8 TeV)	N_{events}(13 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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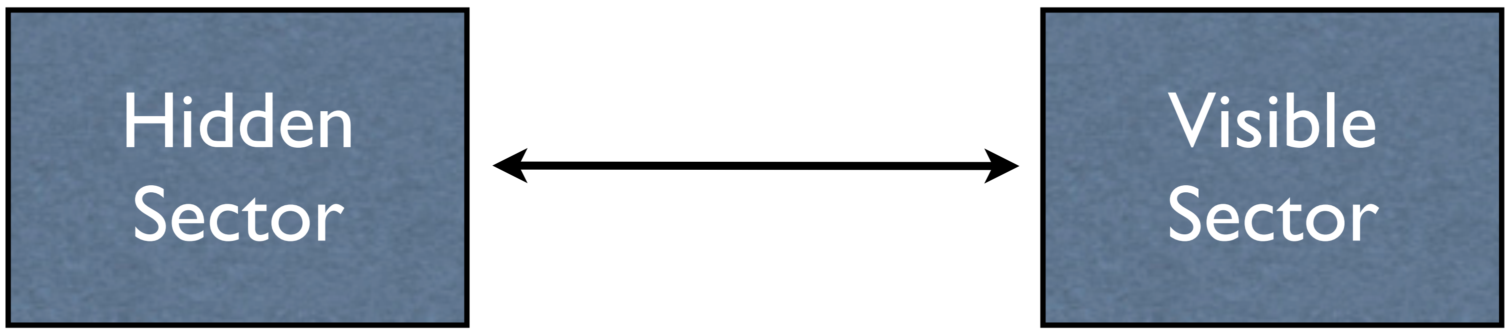
Proposed LHC search: $2\tau_h + (2/3)\ell + \mathrm{MET}$

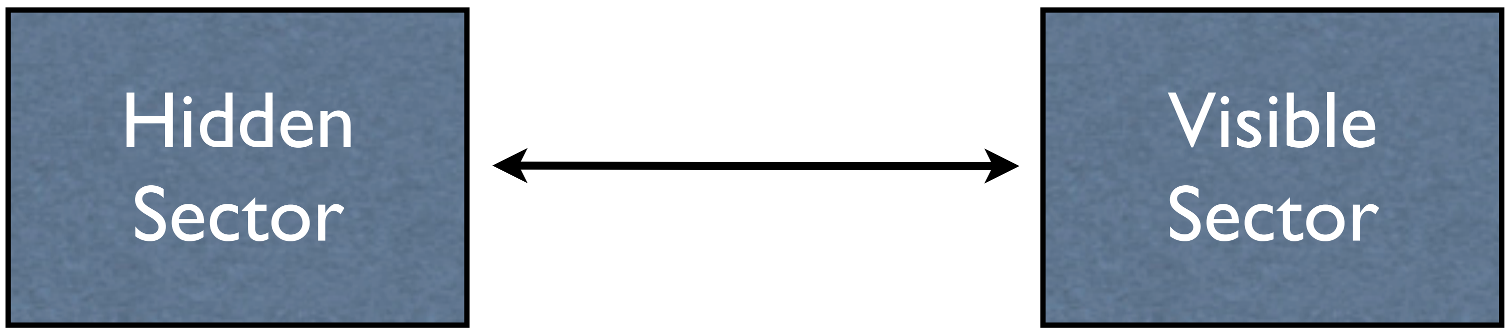
Part II



SUSY Breaking

MSSM

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

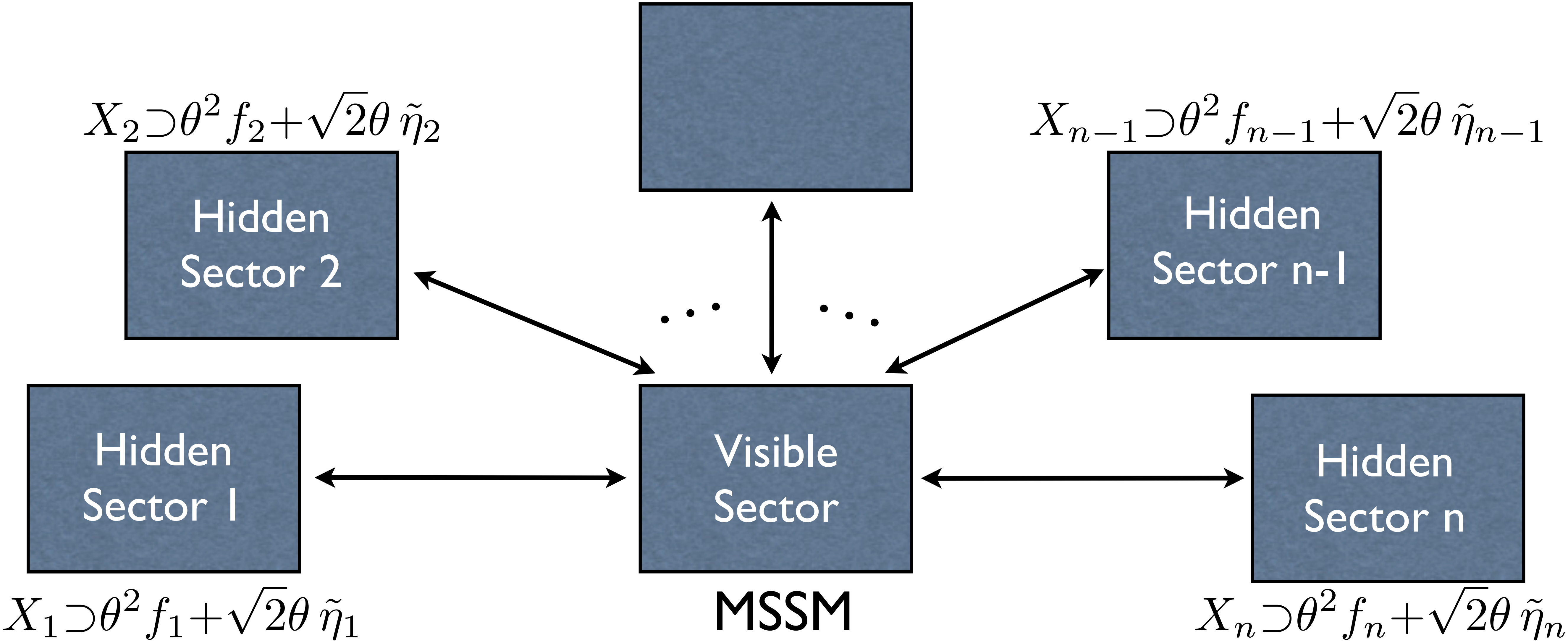


SUSY Breaking

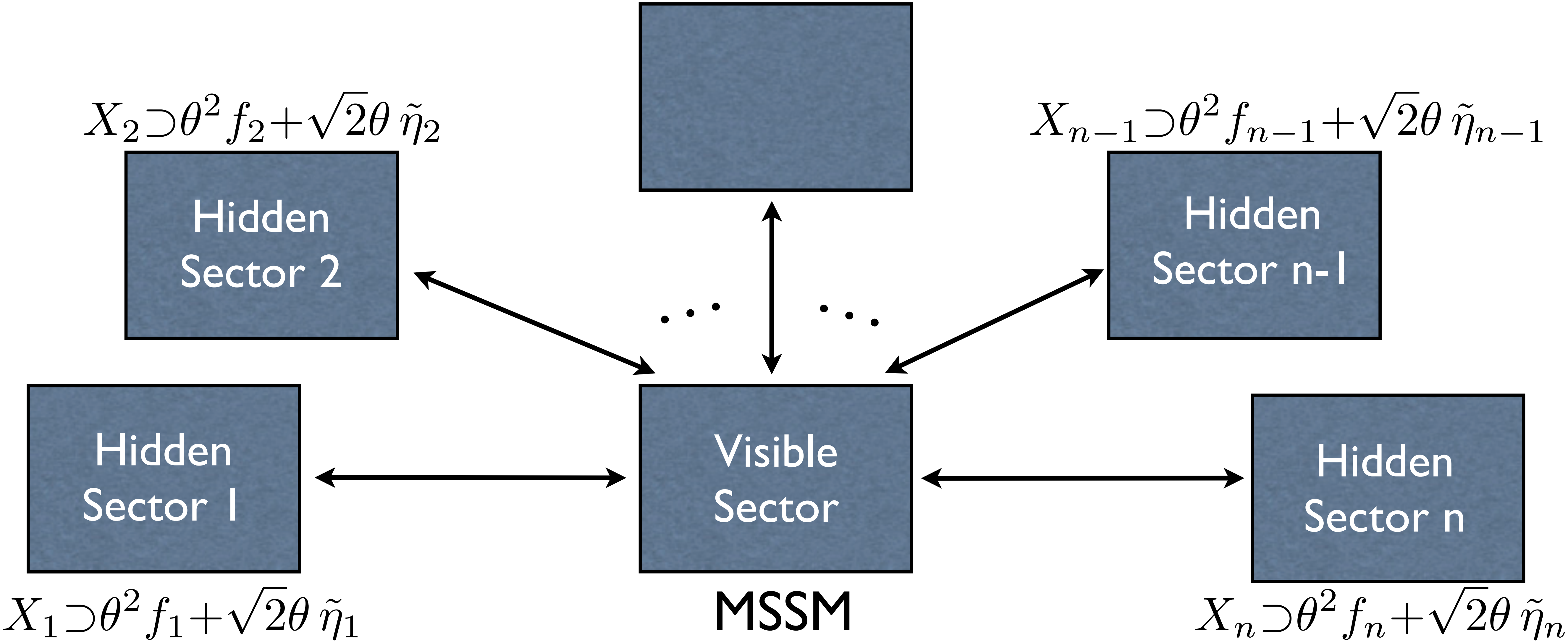
MSSM

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

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



$X_2 \supset \theta^2 f_2 + \sqrt{2}\theta\, \tilde{\eta}_2$
Hidden Sector 2
$X_{n-1} \supset \theta^2 f_{n-1} + \sqrt{2}\theta\, \tilde{\eta}_{n-1}$
Hidden Sector n-1
Hidden Sector 1
Visible Sector
Hidden Sector n
$X_1 \supset \theta^2 f_1 + \sqrt{2}\theta\, \tilde{\eta}_1$
MSSM
$X_n \supset \theta^2 f_n + \sqrt{2}\theta\, \tilde{\eta}_n$



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]

GMSB with multiple hidden sectors

- The n additional neutral fermions extend the 4 by 4 MSSM neutralino mass matrix to an (4+n) by (4+n) matrix
- The true goldstino is given by the linear combination
$$\tilde{G} = \frac{1}{f}(f_1\tilde{\eta}_1 + \cdots + f_n\tilde{\eta}_n)$$
- All the other n-1 linear combination are pseudo-goldstini $\tilde{G}', \tilde{G}'', \ldots$ and they acquire masses at the tree and radiative level
- If the Lightest Ordinary SUSY Particle (LOSP) is a Bino-like neutralino, it dominantly decays to a photon and the heaviest pseudo-goldstini

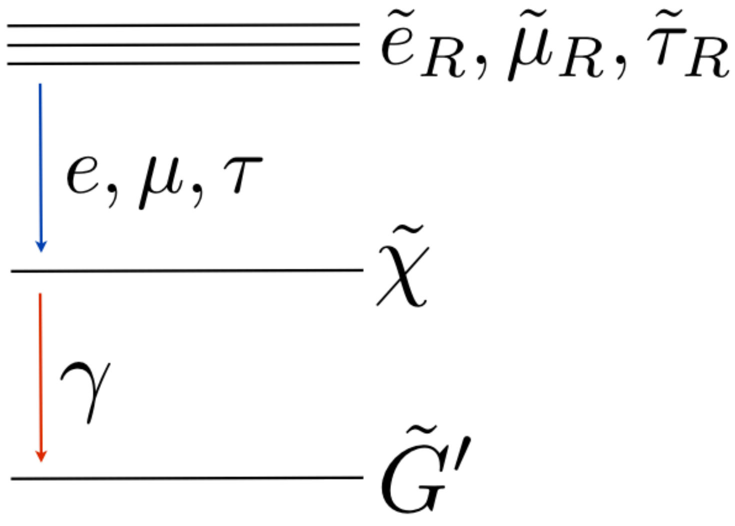
  → Softer final state spectrum

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

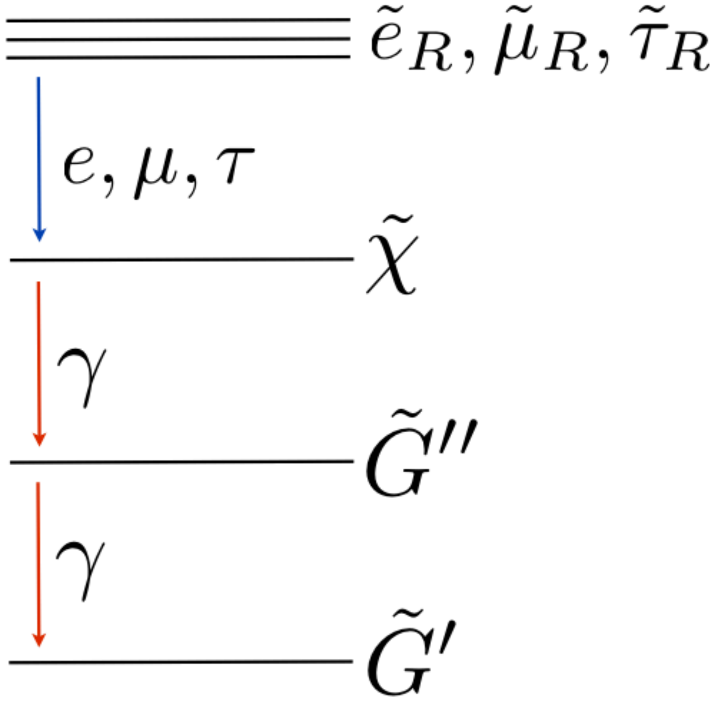
  → Additional (soft) photons in the final state

Simplified models of GMSB with goldstini

2 Sector Model

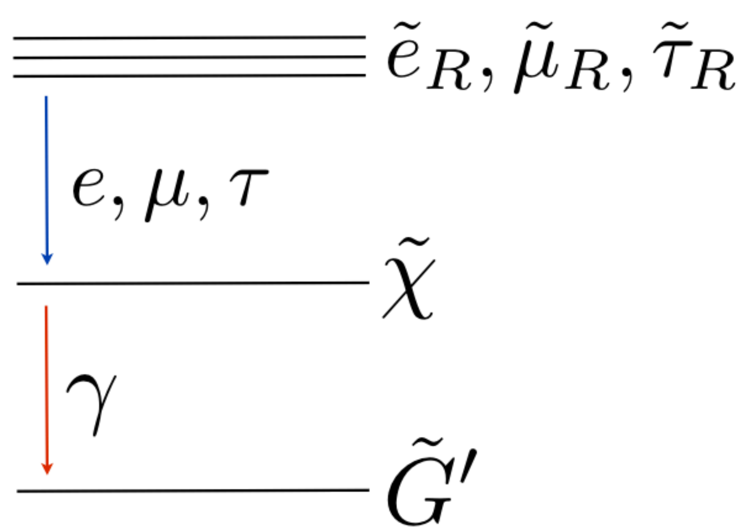


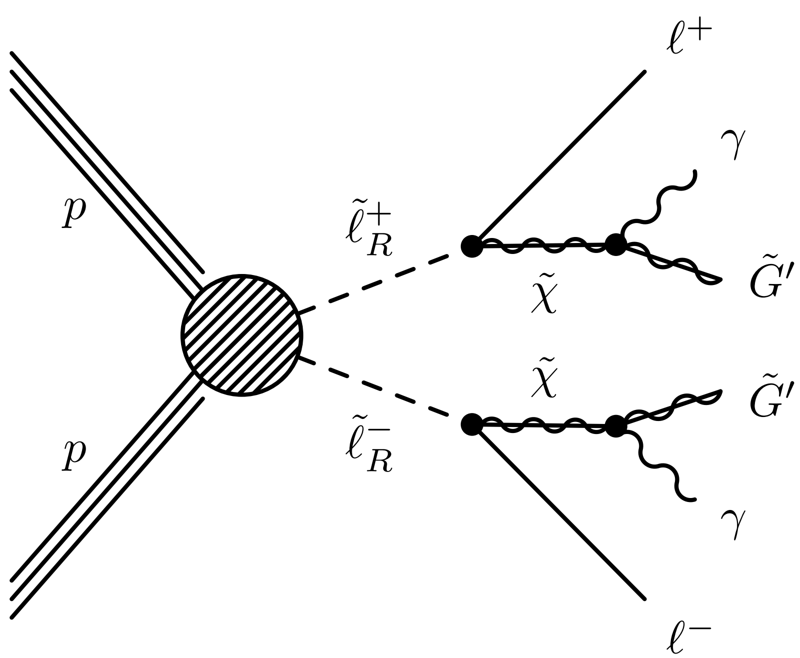
3 Sector Model



Simplified models of GMSB with goldstini

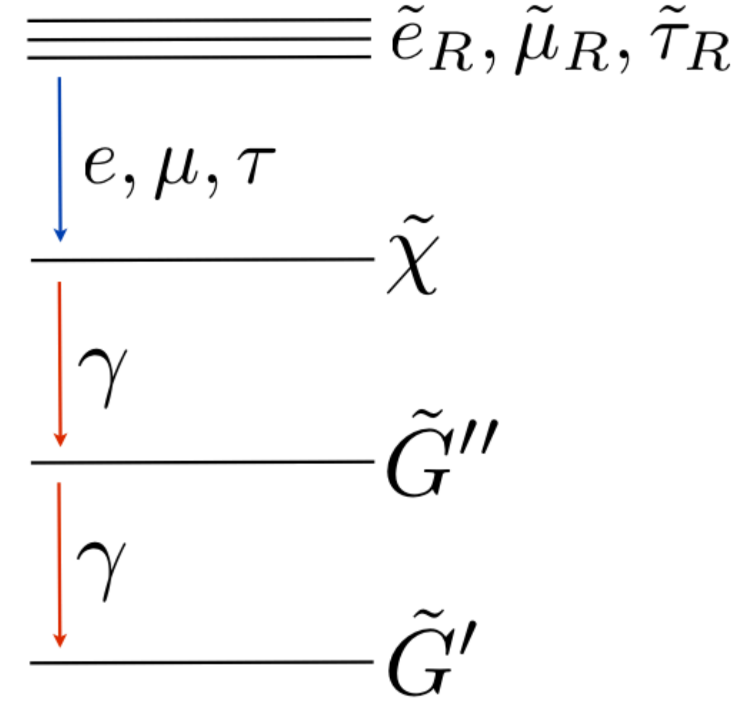
2 Sector Model

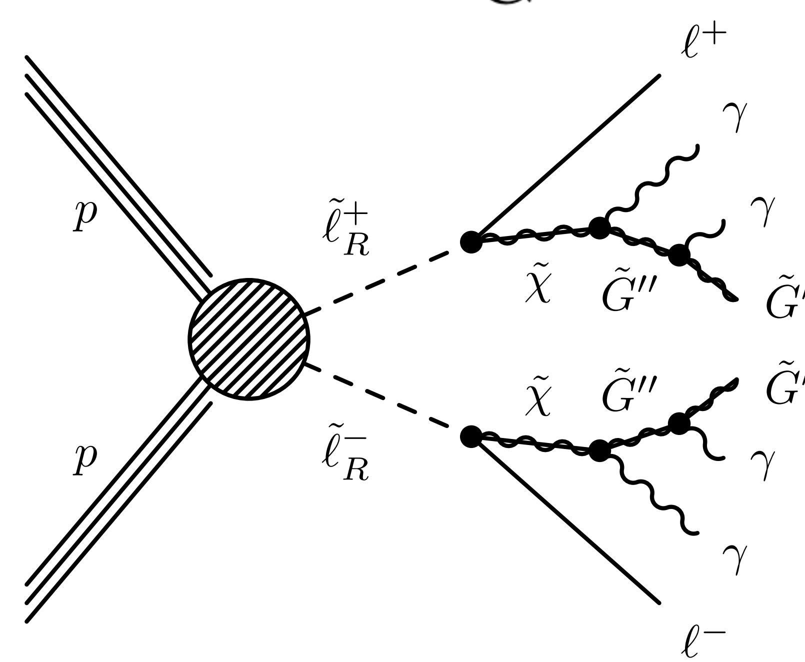




$$\ell^+\ell^- + 2\gamma + \mathrm{MET}$$

3 Sector Model

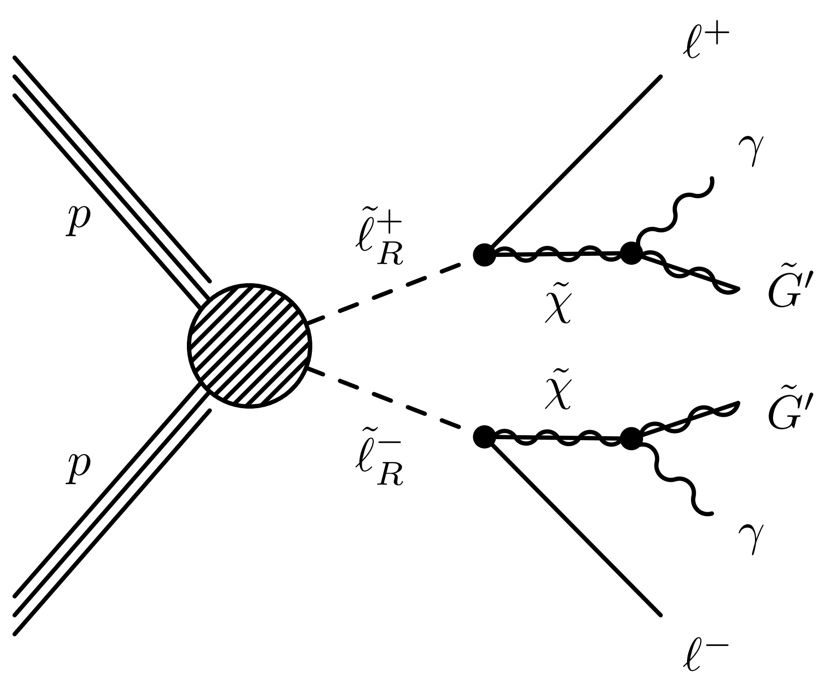


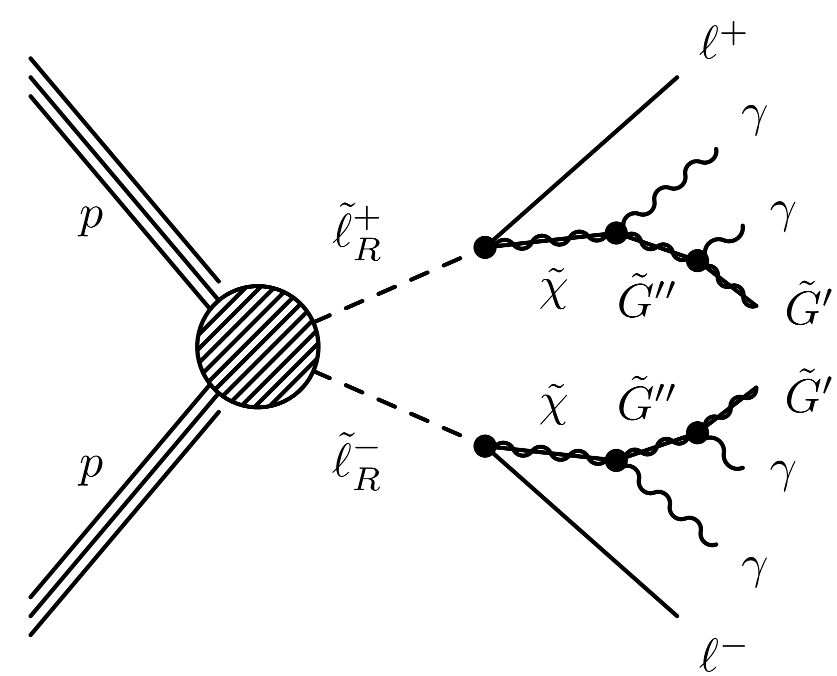


$$\ell^+\ell^- + 4\gamma + \mathrm{MET}$$

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]]

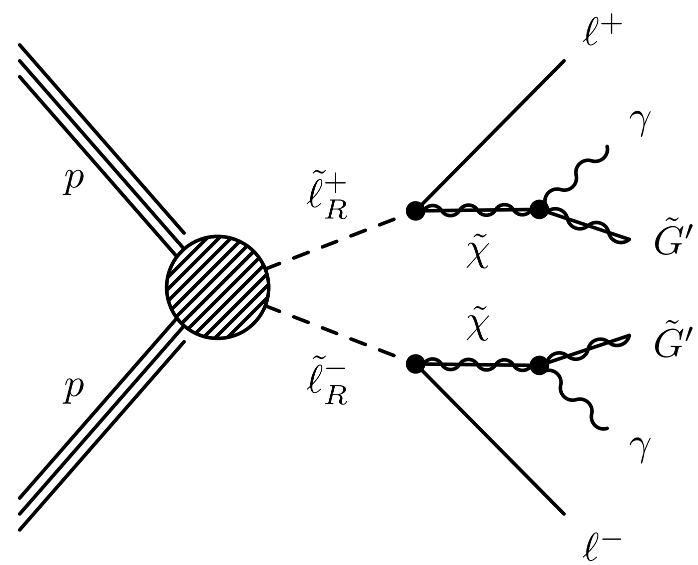




2 Sector Model

- The most relevant search is the inclusive ATLAS diphoton+MET search [arXiv:1209.0753 [hep-ex]]

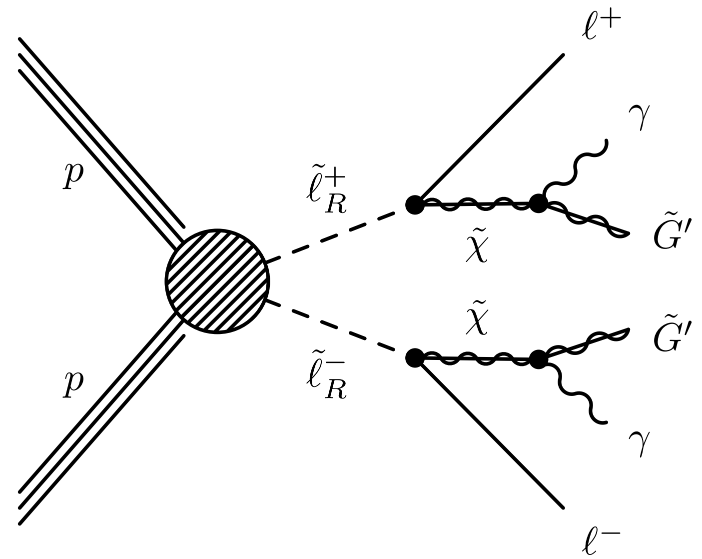
$$p_T^{\gamma_{1,2}} > 50\,\mathrm{GeV}\ ,\ \mathrm{MET} > 125\,\mathrm{GeV}$$

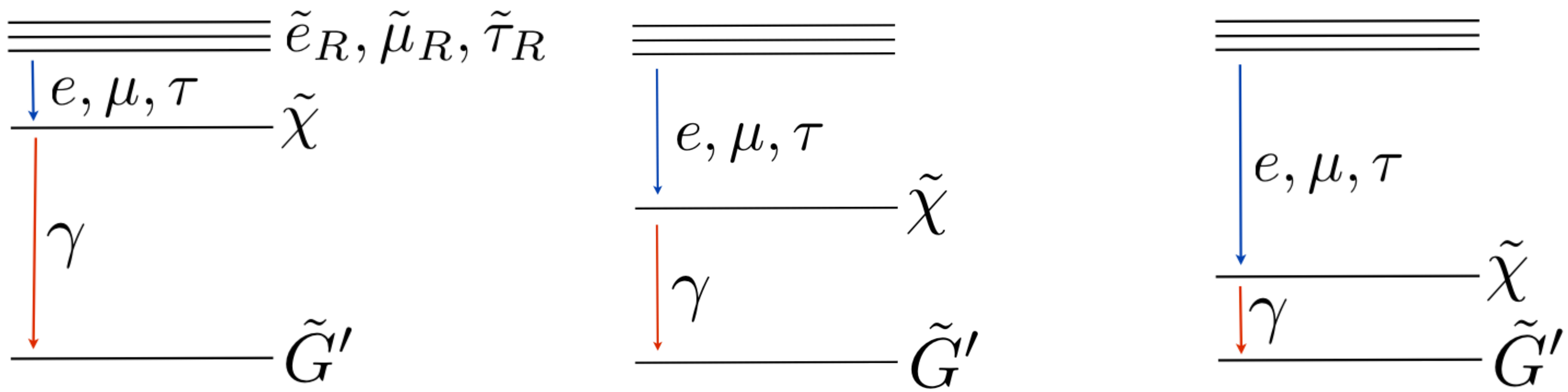


2 Sector Model

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

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





$$2\gamma + \mathrm{MET}$$

2 Sector Model

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

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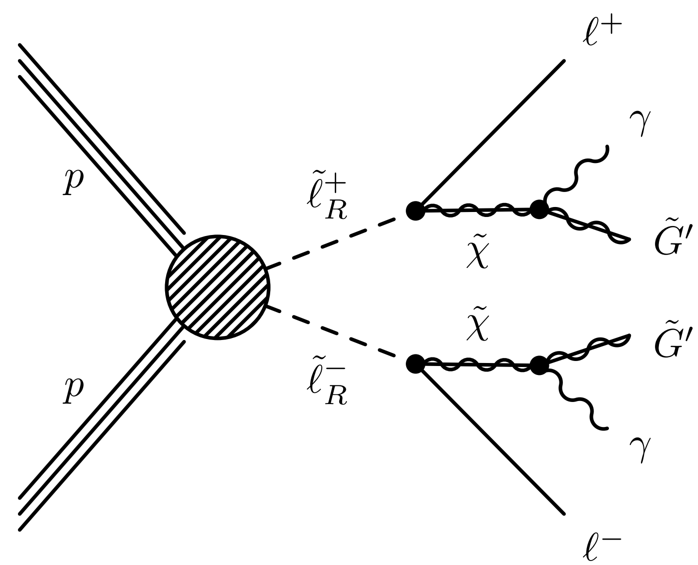

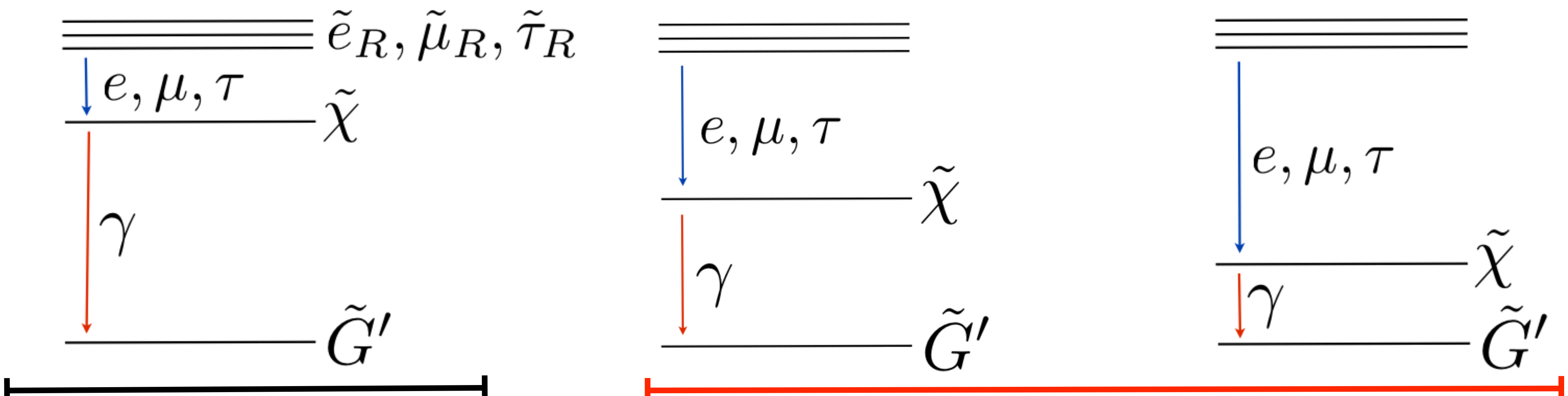

$2\gamma + \mathrm{MET}$ $\quad$ $\ell^+\ell^- + 2\gamma + \mathrm{MET}$

2 Sector Model

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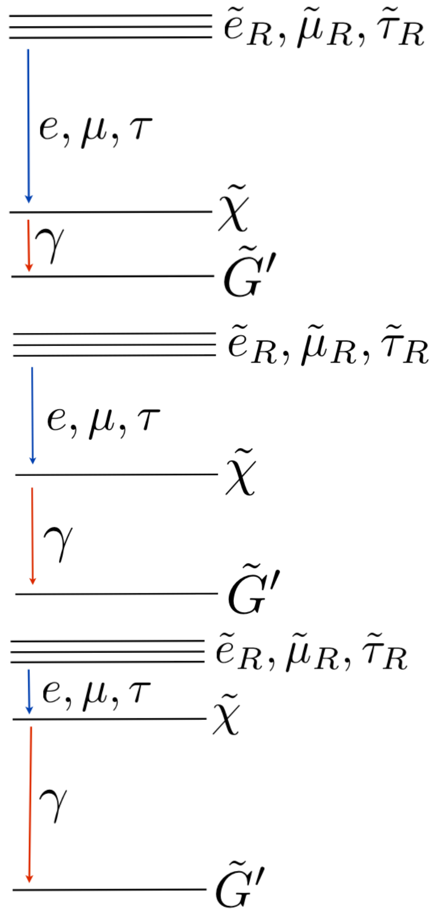


	$M_{\ell_R} = 200$ GeV $(K_{G'}, x, M_{G'})$	$2\gamma + \not{E}_T$	$2\ell + 2\gamma + \not{E}_T$
A'	$(100, 0.1, 0)$	7	20
	$(100, 0.1, 75)$	1	8
	$(100, 0.1, 150)$	2	2
B'	$(100, 0.5, 0)$	10	27
	$(100, 0.5, 75)$	5	20
	$(100, 0.5, 150)$	0	2
C'	$(100, 0.9, 0)$	29	8
	$(100, 0.9, 75)$	19	3
	$(100, 0.9, 150)$	1	0

$p_T^{\ell} > 20$ GeV
$p_T^{\gamma} > 20$ GeV
MET > 50 GeV

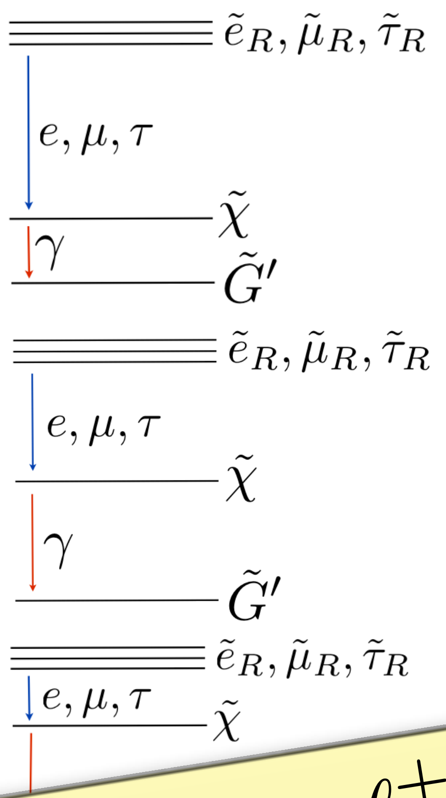
$$M_\chi = x M_{\ell_R} + (1-x) M_{G'}$$

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

2 Sector Model

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

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



	$M_{\ell_R} = 200$ GeV $(K_{G'}, x, M_{G'})$	$2\gamma + \not{E}_T$	$2\ell + 2\gamma + \not{E}_T$
A'	$(100, 0.1, 0)$	7	20
	$(100, 0.1, 75)$	1	8
	$(100, 0.1, 150)$	2	2
B'	$(100, 0.5, 0)$	10	27
	$(100, 0.5, 75)$	5	20
	$(100, 0.5, 150)$	0	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]
	[illegible]	1	0

$p_T^{\ell} > 20$ GeV
$p_T^{\gamma} > 20$ GeV
$\mathrm{MET} > 50\,\mathrm{GeV}$

$M_{\chi} = x M_{\ell_R} + (1-x) M_{G'}$

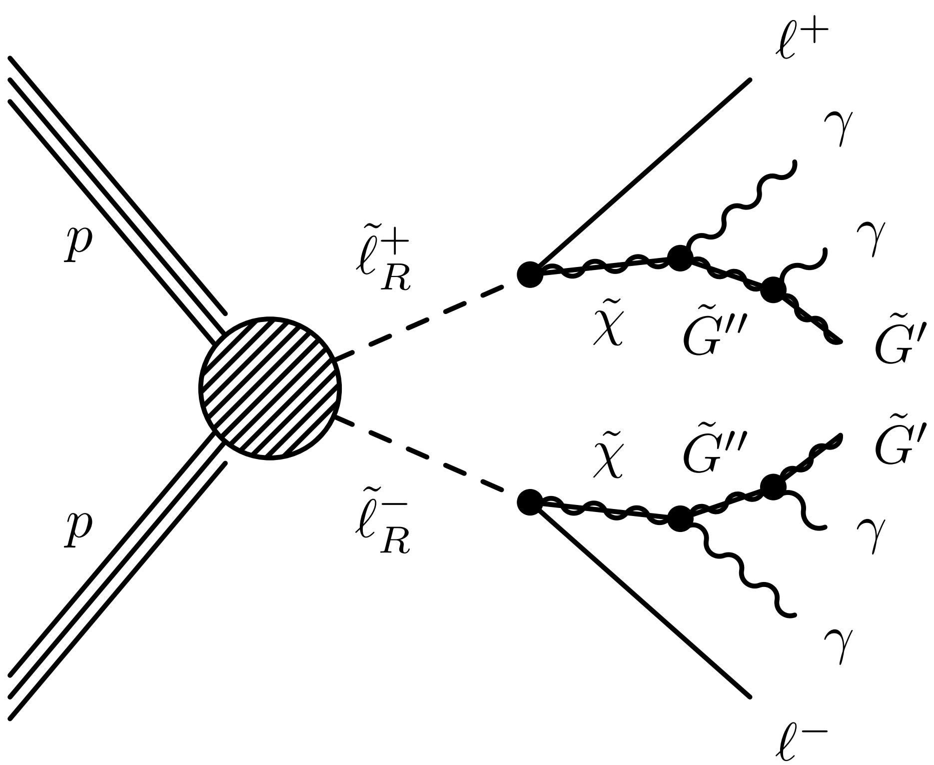
Number of expected events with 20 fb^{-1} of data at LHC-8TeV

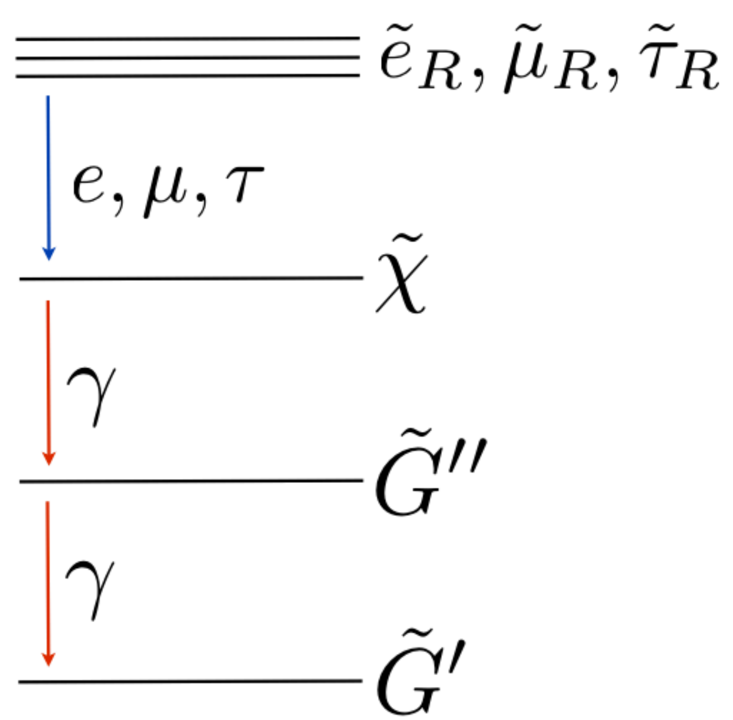
A search for $\ell^+\ell^- + (\geq 2)\gamma + \mathrm{MET}$ could lead to a discovery (or very strong constraints) already with the existing LHC data set!

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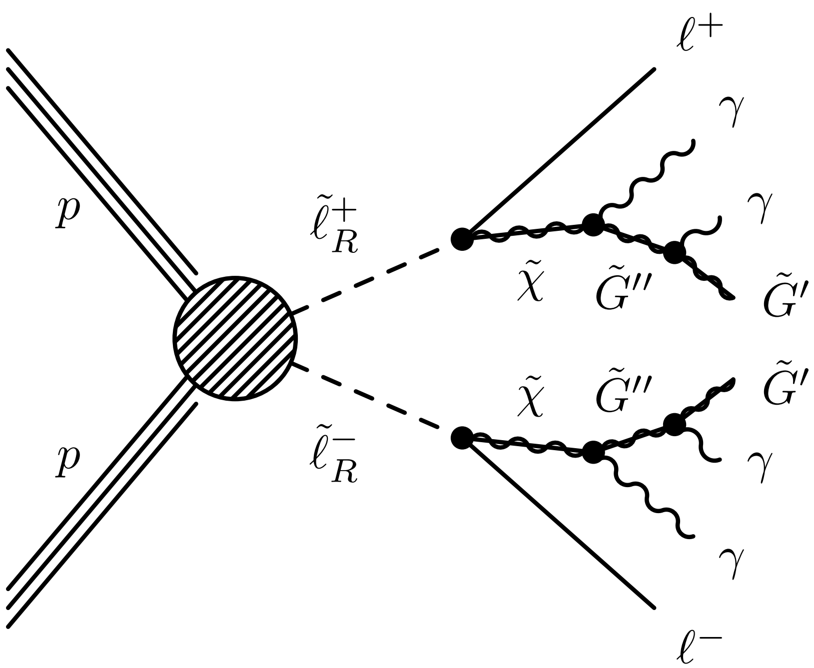
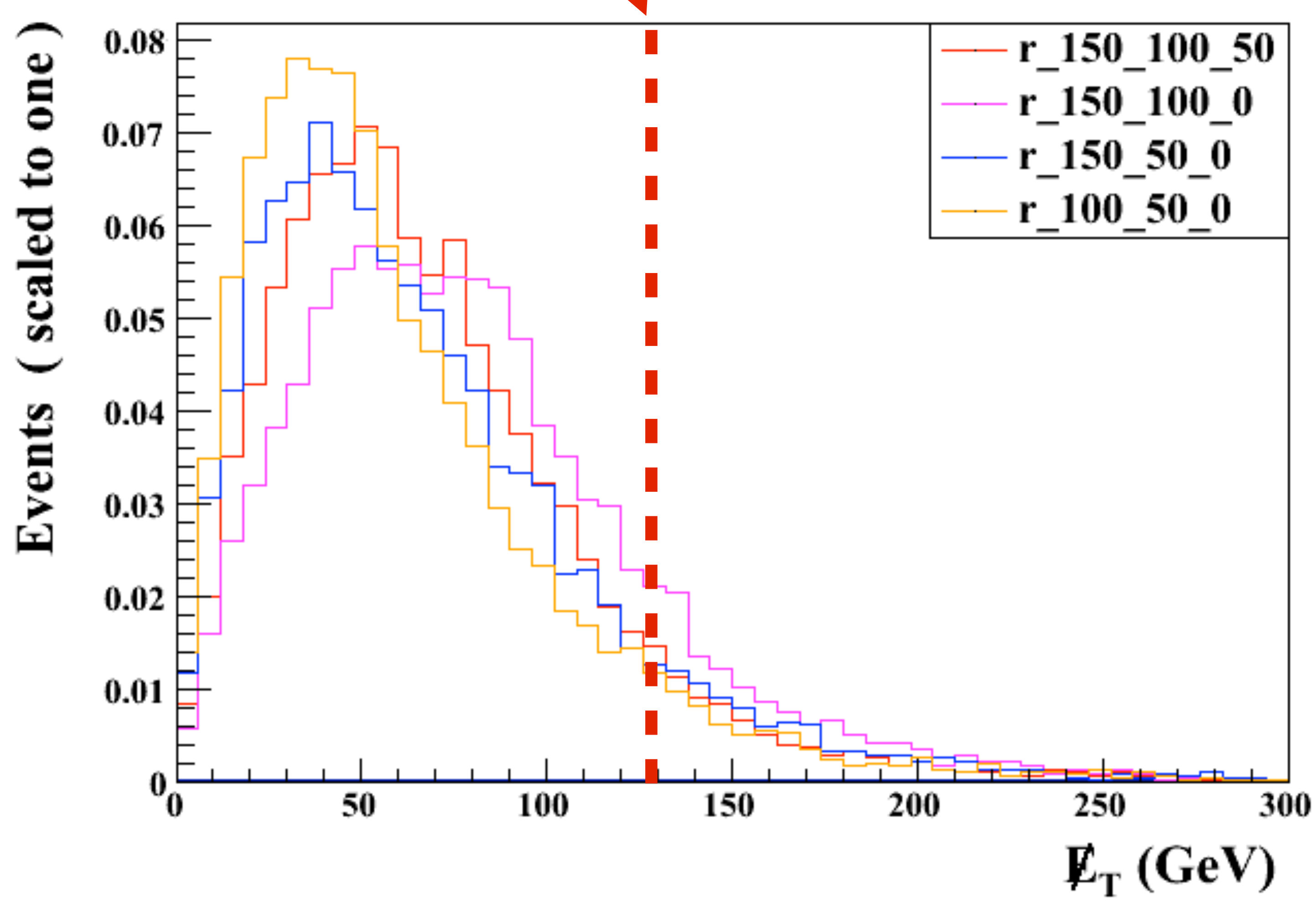
$$p_T^{\gamma_{1,2}} > 50\,\mathrm{GeV}\ ,\ \underline{\mathrm{MET} > 125\,\mathrm{GeV}}$$



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

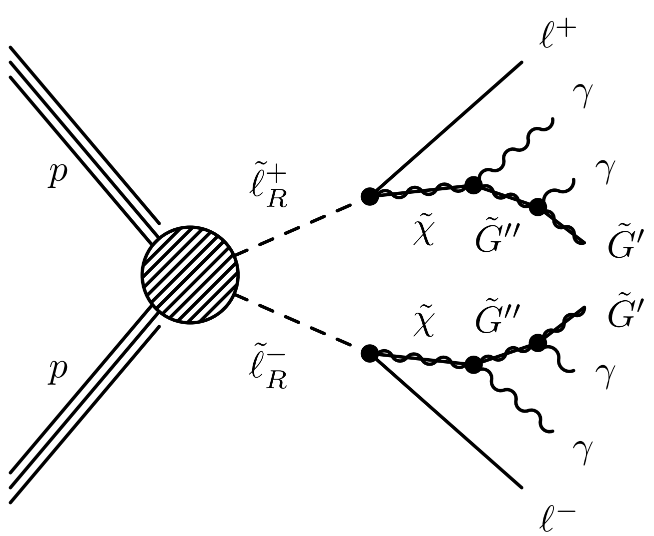


3 Sector Model

Number of expected 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
200	150	50	0
200	100	50	0

3 Sector Model

Number of expected 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
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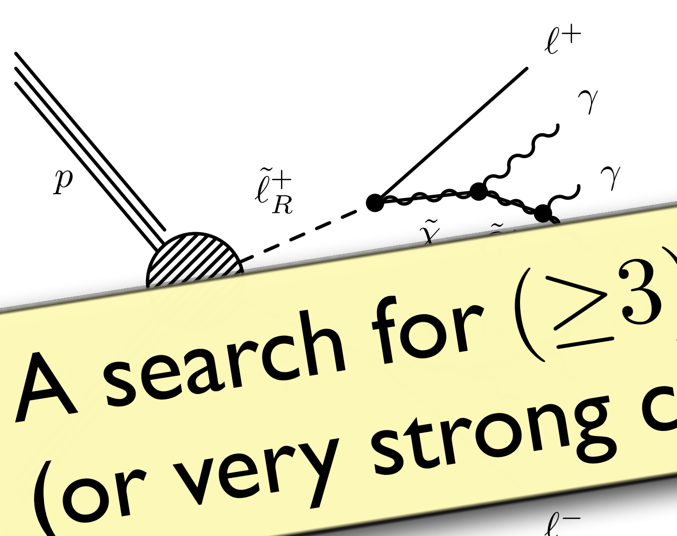
	(100-∞)	3.4	8.3	5.6	3.0



> 0.4

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

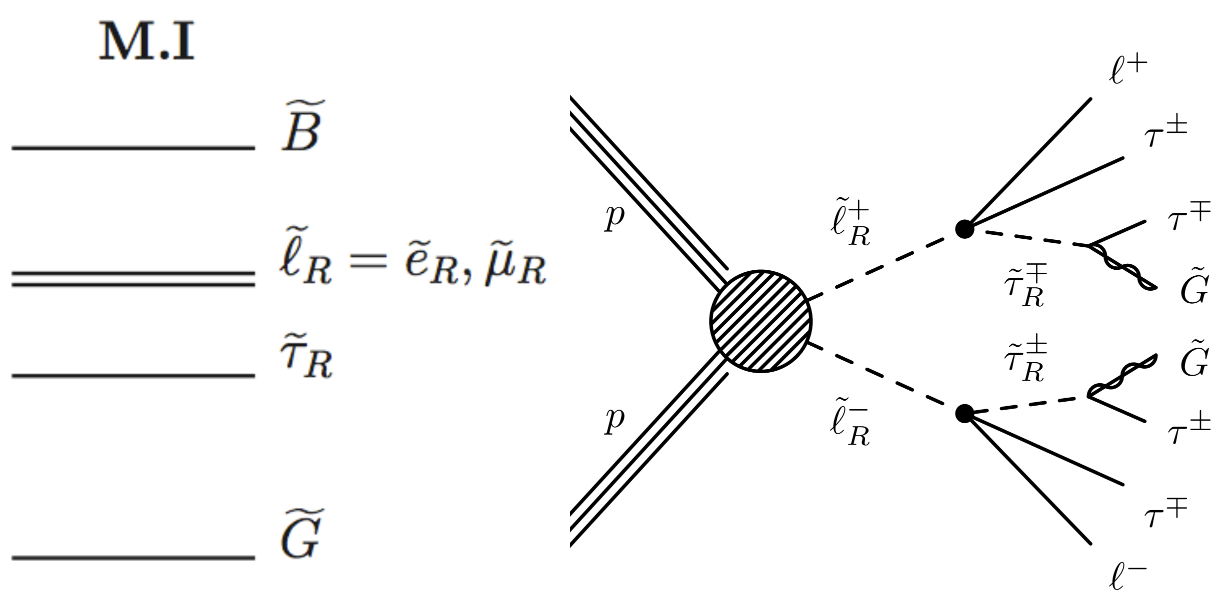
A search for $(\geq 3)\gamma + \mathrm{MET}$ could lead to a discovery (or very strong constraints) already with the existing LHC data set!

Conclusions

Part I

The simplified GMSB model can both explain the small CMS excess and explain why no sign of new physics has been seen in 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.



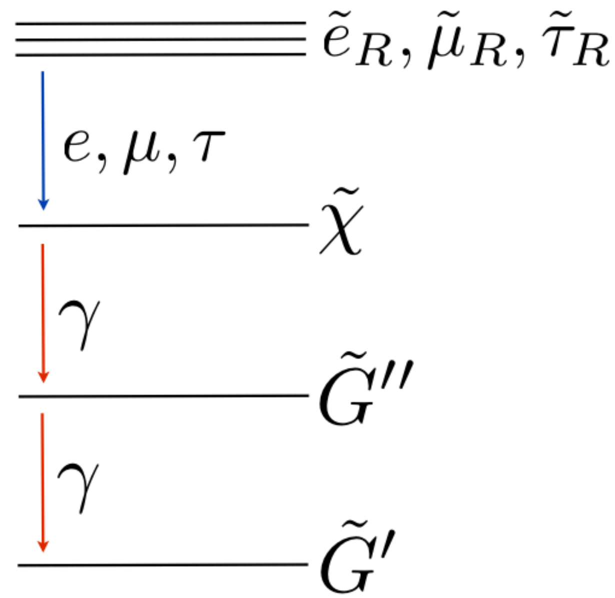
Proposed search: $2\tau_h + (2/3)\ell + \mathrm{MET}$

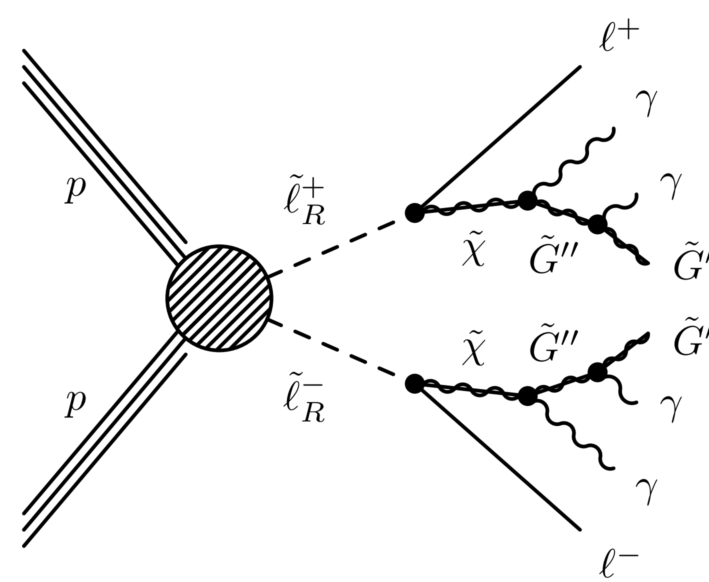
Conclusions

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:

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

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

Thank you!