

Searching for supersymmetry in Z' decays

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2. Z' bosons in $U(1)'$ and Sequential Standard Model
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G.C. and S. Gentile, Nucl. Phys. B 886 (2013) 293 and work in progress

Searches for heavy gauge bosons Z' among the main objectives of LHC

GUT-inspired $U(1)'$, Sequential Standard Model, Kaluza–Klein models

LHC analyses focus on SM decays, e.g. high-mass dilepton resonances

CMS: $\mathcal{L} = 20 \text{ fb}^{-1} \Rightarrow m(Z'_{\text{SSM}}) > 2.96 \text{ TeV}$, $m(Z'_{\text{GUT}}) > 2.6 \text{ TeV}$

ATLAS: $\mathcal{L} = 20 \text{ fb}^{-1} \Rightarrow m(Z'_{\text{SSM}}) > 2.86 \text{ TeV}$, $m(Z'_{\text{GUT}}) > 2.38\text{--}2.54 \text{ TeV}$

In BSM analyses, why not BSM Z' decays, e.g. both SM and MSSM modes

Lower SM branching ratios with BSM decays \Rightarrow lower Z' mass exclusion limits

Z' standard decays still useful for searches, BSM modes for supersymmetry

Z' constrains sparticle invariant masses, e.g. $Z' \rightarrow \tilde{\ell}^+ \tilde{\ell}^- \Rightarrow m_{Z'} = m_{\tilde{\ell}^+ \tilde{\ell}^-}$

Supersymmetric Z' decays allow study of unexplored phase space

Decays $Z' \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0$: monojet events and Dark Matter candidates

Related work on supersymmetric Z' decays:

Gherghetta et al (98), Kang & Langacker (05), Baumgart et al (07), Chang et al (11)

U(1)' gauge groups in GUT-inspired models:

$$E_6 \rightarrow SO(10) \times U(1)'_\psi \quad , \quad SO(10) \rightarrow SU(5) \times U(1)'_\chi$$

$$Z'(\theta) = Z'_\psi \cos \theta - Z'_\chi \sin \theta$$

$$E_6 \rightarrow SM \times U(1)'_\eta \quad \theta = \arccos \sqrt{5/8} \Rightarrow Z'_\eta$$

Orthogonal combination to Z'_η : $\theta = \arccos \sqrt{5/8} - \pi/2 \Rightarrow Z'_I$

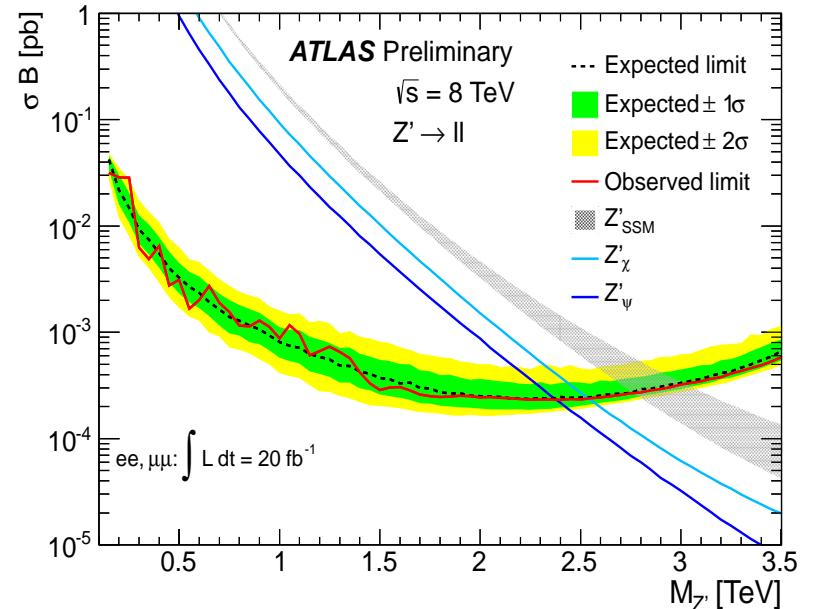
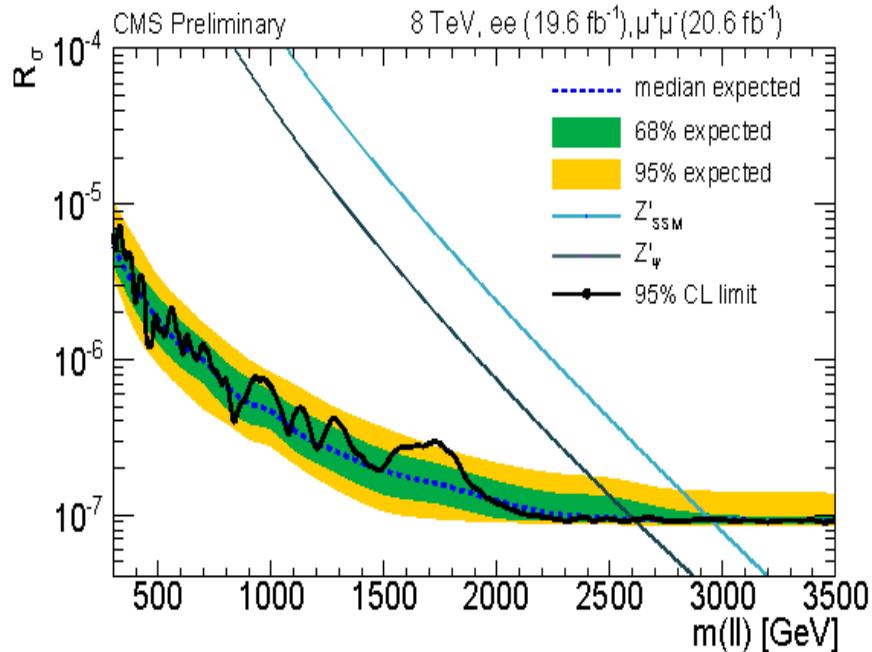
Secluded model (singlet S): $\theta = \arctan(\sqrt{15}/9) - \pi/2 \Rightarrow Z'_S$

Model Z'_N : equivalent to Z'_χ with ‘unconventional’ SO(10) representations

Model	θ
Z'_χ	$-\pi/2$
Z'_ψ	0
Z'_η	$\arccos \sqrt{5/8}$
Z'_I	$\arccos \sqrt{5/8} - \pi/2$
Z'_N	$\arctan \sqrt{15} - \pi/2$
Z'_S	$\arctan(\sqrt{15}/9) - \pi/2$

Product $\sigma \times \text{BR}$ to obtain the Z' mass exclusion limits

$$\text{BR} = \text{BR}(\mu^+\mu^-) + \text{BR}(e^+e^-) \quad R_\sigma = (\sigma \times \text{BR})_{Z'}/(\sigma \times \text{BR})_Z$$



Intersection of 1σ and 2σ bands with the theory curves yields the exclusion limits

Right: ATLAS $\Rightarrow m(Z'_{\text{SSM}}) > 2.86 \text{ TeV}, m(Z'_{\text{GUT}}) > 2.38-2.54 \text{ TeV}$

Left: CMS $\Rightarrow m(Z'_{\text{SSM}}) > 2.96 \text{ TeV}, m(Z'_{\text{GUT}}) > 2.6 \text{ TeV}$

Minimal Supersymmetric Standard Model and $U(1)'$ (i.e. UMSSM)

The extra Z' requires a singlet Higgs to break $U(1)'$ and get mass

$$\Phi_1 = \begin{pmatrix} \phi_1^0 \\ \phi_1^- \end{pmatrix}, \quad \Phi_2 = \begin{pmatrix} \phi_2^+ \\ \phi_2^0 \end{pmatrix}, \quad \Phi_3 = \phi_3^0, \quad Q'_i = Q'(\Phi_i)$$

Higgs sector after EWSB: h, H, A, H^\pm (MSSM) and a new scalar H'

Three vacuum expectation values $v_i = \sqrt{2} \langle \phi_i^0 \rangle$ $v_1 < v_2 < v_3$ $\tan \beta = v_2/v_1$

Gauginos: new \tilde{Z}' and \tilde{H}' lead to two new neutralinos, i.e. $\tilde{\chi}_1^0, \dots, \tilde{\chi}_6^0$

Chargino sector is unchanged, as the Z' is neutral

Tree-level gaugino masses are obtained after diagonalizing the mass matrices in terms of the MSSM parameters $M_1, M_2, M', \tan \beta, A_f, \mu$

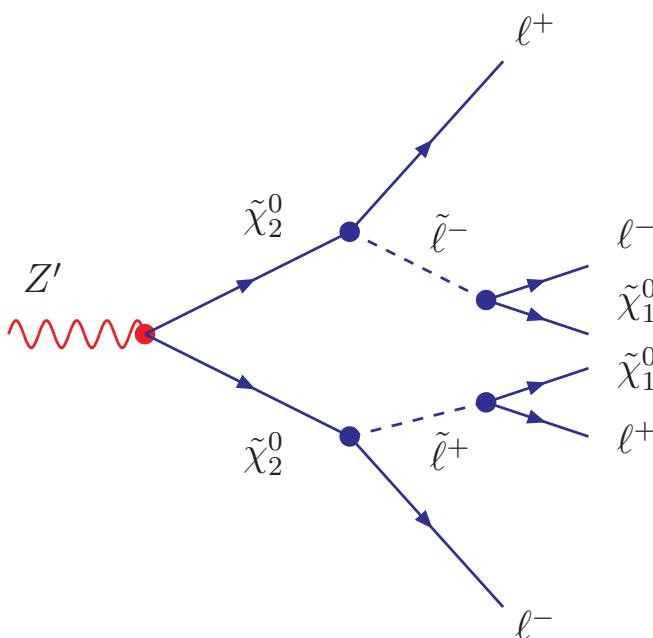
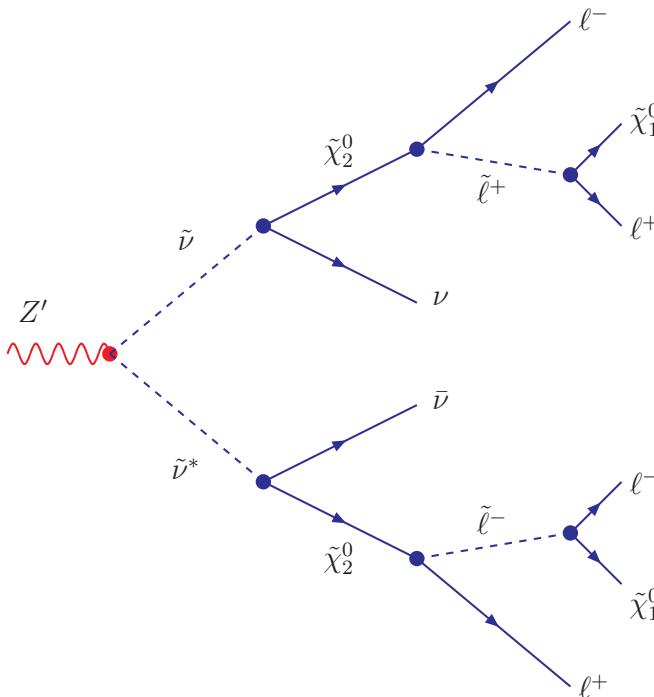
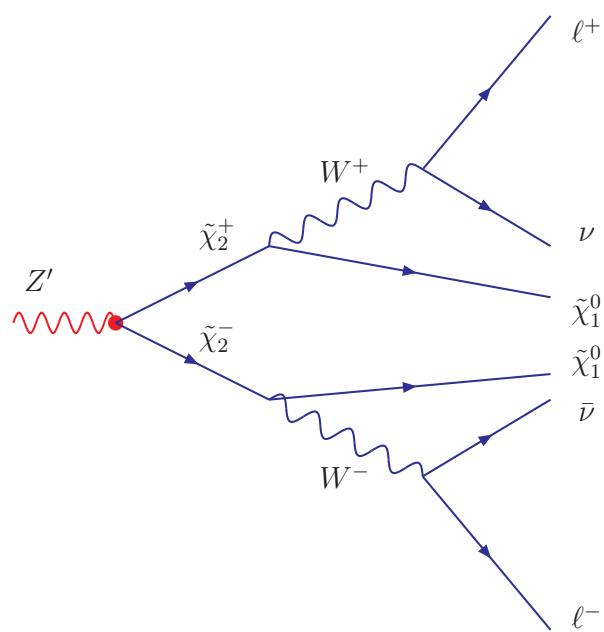
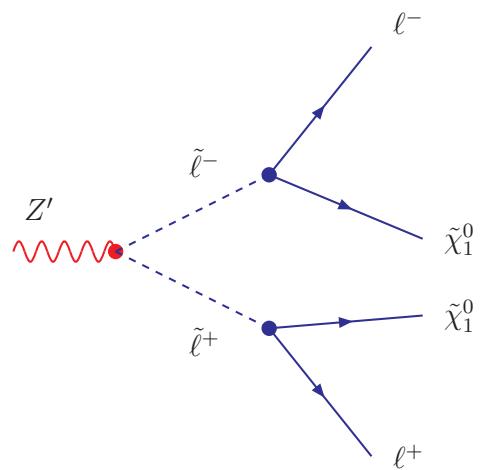
Sfermion masses get extra D-term contribution: $\tilde{m}^2 = \tilde{m}_0^2 + \Delta \tilde{m}^2$

$$\Delta \tilde{m}_a^2 = g'^2 Q'_a (Q'_1 v_1^2 + Q'_2 v_2^2 + Q'_3 v_3^2)/2$$

New Z' decay modes besides the SM ones:

$$Z' \rightarrow \tilde{q}\tilde{q}^*, \tilde{\ell}^+\tilde{\ell}^-, \tilde{\nu}\tilde{\nu}^*, \tilde{\chi}_i^0\tilde{\chi}_j^0, \tilde{\chi}_{1,2}^+\tilde{\chi}_{1,2}^-, ZH, Zh, ZA, H^+H^-, hA, HA, WW$$

Supersymmetry in Z' decays



Branching ratios into SM and BSM particles varying the Z' and slepton masses

$\mu = 200 \text{ GeV}$, $\tan \beta = 20$, $A_q = A_\ell = 500 \text{ GeV}$, $m_{\tilde{q}}^0 = 5 \text{ TeV}$, $M_1 = 150 \text{ GeV}$, $M_2 = 300 \text{ GeV}$, $M' = 1 \text{ TeV}$

Z'_η ($\theta \simeq 0.66$):

$m_{Z'}$	$m_{\tilde{\ell}}^0$	$B_{q\bar{q}}$	$B_{\ell\ell}$	$B_{\nu\nu}$	B_{WW}	B_{ZH}	$B_{\tilde{\chi}^+ \tilde{\chi}^-}$	$B_{\tilde{\chi}^0 \tilde{\chi}^0}$	$B_{\tilde{\nu}\tilde{\nu}^*}$	B_{SM}	B_{BSM}
1.0	0.8	39.45	5.24	27.26	3.01	2.91	4.92	8.64	8.54	71.96	28.04
1.0	0.9	43.14	5.73	29.81	3.30	3.18	5.38	9.45	0.00	78.68	21.32
2.0	1.5	37.97	4.91	25.54	2.66	2.64	5.33	10.33	10.61	68.42	31.58
2.0	1.8	42.47	5.49	28.57	2.98	2.95	5.96	11.56	0.00	76.54	23.46
3.0	2.2	37.60	4.84	25.17	2.59	2.59	5.38	10.61	11.14	67.60	32.40
3.0	2.6	42.31	5.45	28.32	2.92	2.91	6.06	11.94	0.00	76.08	23.92
4.0	2.9	37.41	4.81	25.00	2.56	2.56	5.39	10.70	11.38	67.22	32.78
4.0	3.5	42.22	5.43	28.21	2.89	2.89	6.08	12.07	0.00	75.85	24.15

Z'_ψ ($\theta = 0$) :

$m_{Z'}$	$m_{\tilde{\ell}}^0$	$B_{q\bar{q}}$	$B_{\ell\ell}$	$B_{\nu\nu}$	B_{WW}	B_{ZH}	$B_{\tilde{\chi}^+ \tilde{\chi}^-}$	$B_{\tilde{\chi}^0 \tilde{\chi}^0}$	$B_{\tilde{\nu}\tilde{\nu}^*}$	$B_{\tilde{\ell}\tilde{\ell}^*}$	B_{SM}	B_{BSM}
1.0	0.4	48.16	8.26	8.26	3.00	2.89	9.13	16.53	1.91	1.90	64.69	35.31
1.0	0.7	50.07	8.59	8.59	3.08	2.99	9.49	17.18	0.00	0.00	67.25	32.75
2.0	0.8	46.30	7.77	7.77	2.62	2.62	9.92	19.37	1.80	1.80	61.85	38.15
2.0	1.3	48.03	8.06	8.06	2.72	2.72	10.29	20.10	0.00	0.00	64.16	35.84
3.0	1.1	45.35	7.58	7.58	2.53	2.54	9.92	19.63	1.86	1.86	60.51	39.49
3.0	1.9	47.10	7.88	7.88	2.62	2.64	10.30	20.39	0.00	0.00	62.85	37.15
4.0	1.5	44.60	7.45	7.45	2.47	2.49	9.82	19.53	1.80	1.80	59.49	40.51
4.0	2.5	46.26	7.72	7.72	2.56	2.58	10.19	20.26	0.00	0.00	61.71	38.29
5.0	1.8	44.16	7.37	7.37	2.44	2.46	9.76	19.44	1.82	1.82	58.89	41.11
5.0	3.1	45.83	7.65	7.65	2.53	2.55	10.13	20.18	0.00	0.00	61.12	38.88

$$Z'_{\text{SSM}}: \quad g' = g_2/(2 \cos \theta_W)$$

$m_{Z'}$	$m_{\tilde{\ell}}^0$	B_q	B_ℓ	B_ν	B_{WW}	B_{HH}	B_{Zh}	B_{hA}	B_{χ^\pm}	B_{χ^0}	$B_{\tilde{\ell}}$	$B_{\tilde{\nu}}$	B_{SM}	B_{BSM}
1.0	0.1	29.6	3.9	7.7	5.6	0.0	0.0	0.0	18.3	29.3	1.9	3.8	41.2	58.8
1.0	0.5	31.4	4.1	8.2	5.9	0.0	0.0	0.0	19.4	31.1	0.0	0.0	43.6	56.4
1.5	0.1	27.4	3.5	7.0	4.9	0.9	0.9	0.8	17.8	32.5	1.7	3.5	37.9	62.1
1.5	0.7	28.9	3.7	7.4	5.1	0.0	0.9	0.8	18.8	34.3	0.0	0.0	40.0	60.0
2.0	0.1	26.2	3.4	6.7	4.6	0.0	1.9	1.8	17.4	33.0	1.7	3.3	36.3	63.7
2.0	1.0	27.6	3.5	7.0	4.8	0.0	2.0	1.9	18.3	34.7	0.0	0.0	38.2	61.8
2.5	0.1	25.4	3.3	6.5	4.4	0.9	2.6	2.5	16.9	32.8	1.6	3.2	35.1	64.9
2.5	1.2	26.6	3.4	6.8	4.6	0.9	2.7	2.7	17.8	34.4	0.0	0.0	36.8	63.2
3.0	0.1	24.8	3.2	6.3	4.2	1.7	3.0	2.9	16.6	32.5	1.6	3.1	34.3	65.7
3.0	1.5	26.0	1.7	6.6	4.5	1.8	3.1	3.1	17.4	34.1	0.0	0.0	36.0	64.0
3.5	0.1	24.4	3.1	6.2	4.2	2.3	3.2	3.2	16.4	32.3	1.6	3.1	33.7	66.2
3.5	1.7	25.6	1.4	6.5	4.4	2.4	3.4	3.3	17.2	33.9	0.0	0.0	35.4	64.6
4.0	0.1	24.2	3.1	6.1	4.1	2.6	3.4	3.4	16.3	32.2	1.5	3.1	33.4	66.6
4.0	2.0	25.3	1.2	6.4	4.3	2.8	3.6	3.5	17.1	33.7	0.0	0.0	35.0	65.0
4.5	0.1	24.0	3.1	6.1	4.1	2.9	3.5	3.5	16.2	32.1	1.5	3.0	33.2	66.8
4.5	2.2	25.1	1.1	6.4	4.3	3.0	3.7	3.7	17.0	33.6	0.0	0.0	34.8	65.2
5.0	0.1	23.9	3.0	6.1	4.1	3.1	3.6	3.6	16.1	32.0	1.5	3.0	33.0	67.0
5.0	2.5	25.0	1.0	6.4	4.2	3.3	3.8	3.7	16.9	33.5	0.0	0.0	34.6	65.4

Expected event numbers (narrow width approximation):

$$\sigma(pp \rightarrow Z' \rightarrow f_1 f_2) \simeq \sigma(pp \rightarrow Z') \times \text{BR}(Z' \rightarrow f_1 f_2) ; N = \mathcal{L} \sigma$$

Cascade events: $N_{\text{casc}} = N(\tilde{\ell}^+ \tilde{\ell}^-) + N(\tilde{\nu} \tilde{\nu}^*) + N(\tilde{\chi}^+ \tilde{\chi}^-) + N(\tilde{\chi}^0 \tilde{\chi}^0)$

Charged-slepton events: $N_{\text{slep}} = N(\tilde{\ell}^+ \tilde{\ell}^-)$

$\sqrt{s} = 8 \text{ TeV}$ $\mathcal{L} = 20 \text{ fb}^{-1}$

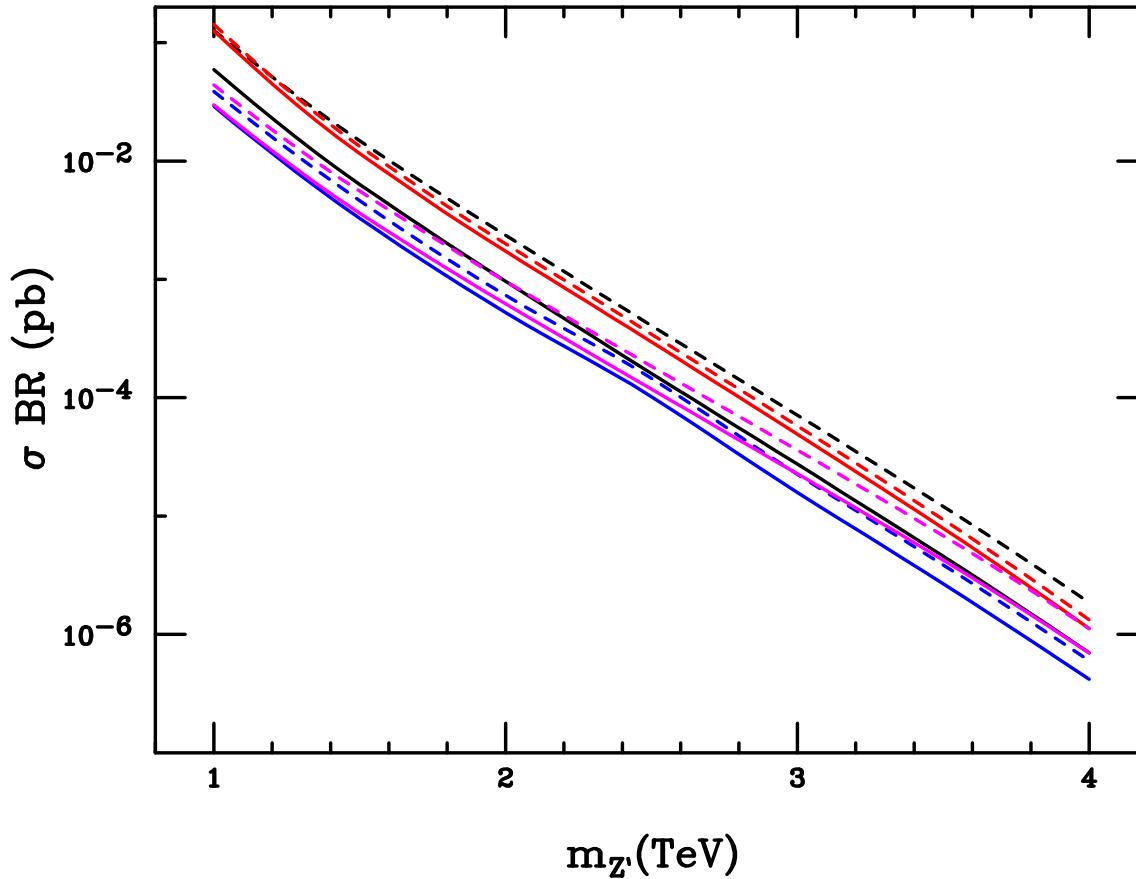
$\sqrt{s} = 14 \text{ TeV}$ $\mathcal{L} = 100 \text{ fb}^{-1}$

Model	$m_{Z'} \text{ (TeV)}$	N_{casc}	N_{slep}
Z'_η	1.5	523	–
Z'_η	2.0	55	–
Z'_ψ	1.5	599	36
Z'_ψ	2.0	73	4
Z'_N	1.5	400	17
Z'_N	2.0	70	3
Z'_I	1.5	317	–
Z'_I	2.0	50	–
Z'_S	1.5	30	–
Z'_S	2.0	46	–
Z'_{SSM}	1.5	2968	95
Z'_{SSM}	2.0	462	14

Model	$m_{Z'} \text{ (TeV)}$	N_{casc}	N_{slep}
Z'_η	1.5	13650	–
Z'_η	2.0	2344	–
Z'_ψ	1.5	10241	622
Z'_ψ	2.0	2784	162
Z'_N	1.5	9979	414
Z'_N	2.0	2705	104
Z'_I	1.5	8507	–
Z'_I	2.0	2230	–
Z'_S	1.5	8242	65
Z'_S	2.0	2146	16
Z'_{SSM}	1.5	775715	24774
Z'_{SSM}	2.0	19570	606

Impact of BSM decays on the σ BR product

G.C., arXiv:1207.5424, Proceedings of Blois2012

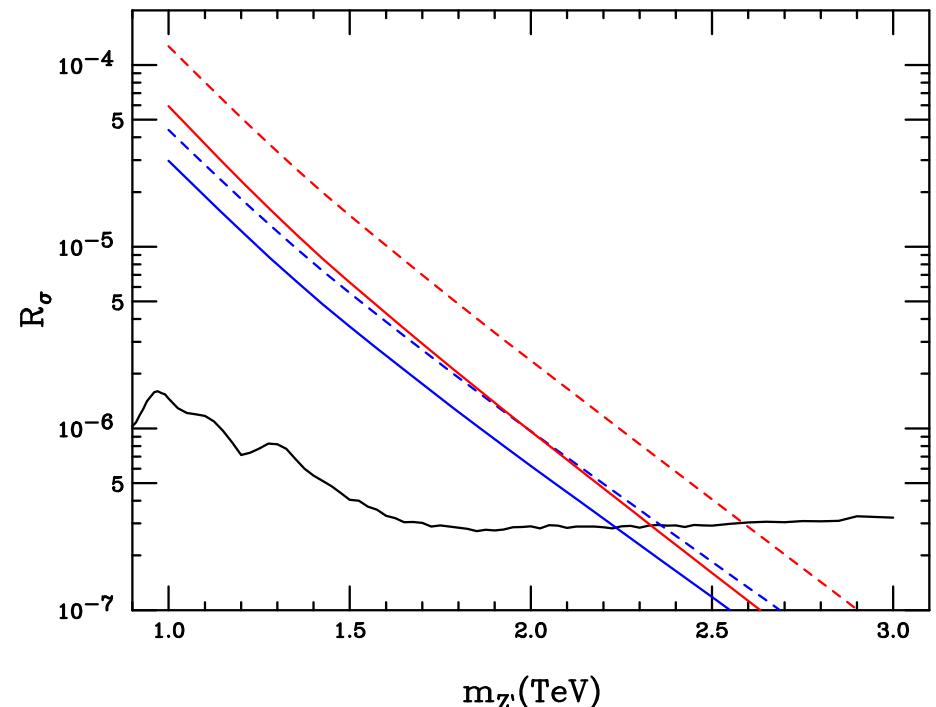
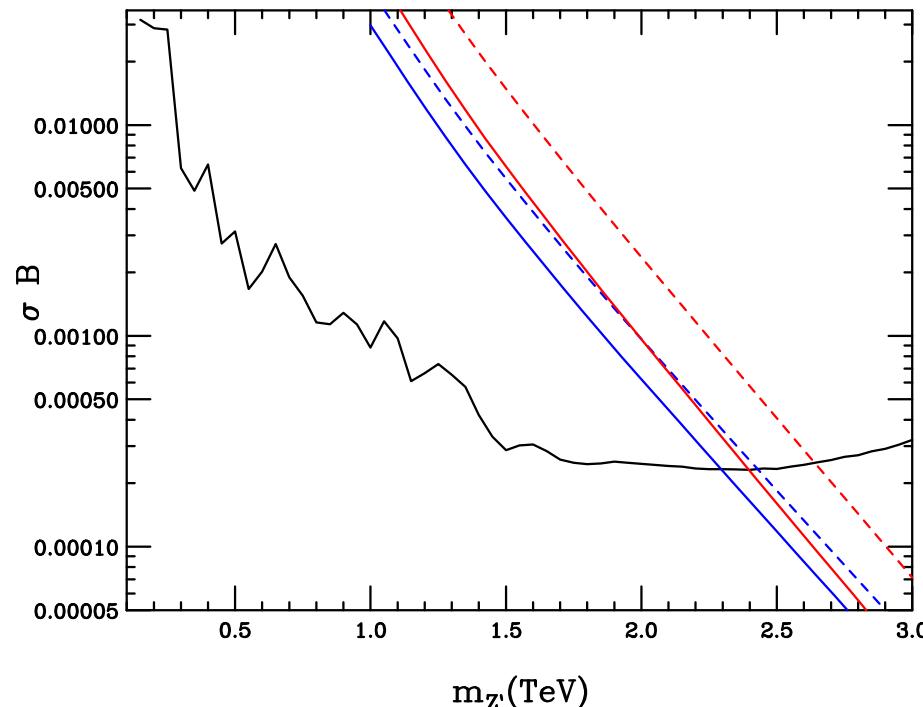


Solid: SM+BSM decays ; Dashes: only SM decays

Black: Z'_SSM ; Blue: Z'_η ; Red: Z'_I ; Magenta: Z'_ψ

Impact of inclusion of SUSY decays: Z'_SSM 60%; Z'_η : 30% ; Z'_I : 13% ; Z'_ψ : 40%

Preliminary results on mass exclusion limits in the SUSY reference point



Solid: SM+BSM decays ; Dashes: only SM decays

Black: CMS (right) and ATLAS (left) 95% C.L. limits; Red: Z'_{SSM} ; Blue: Z'_{ψ}

Excluded-mass shift: Z'_{SSM} : $\Delta m \simeq 300 \text{ GeV}$; Z'_{ψ} : $\Delta m \simeq 150 \text{ GeV}$

Conclusions and outlook

Novel investigation on Z' phenomenology in supersymmetry at the LHC
BSM modes decrease SM rates; the Z' constrains sparticle invariant masses
BSM branching ratios 10-30% in $U(1)'$ models and up to 60% for SSM
Up to $\mathcal{O}(10^5)$ supersymmetric events with sleptons and gauginos in the high-luminosity phase of the LHC, especially for SSM
 $(\Delta m_{Z'})_{\min} \approx 150\text{-}300 \text{ GeV}$ for a reference point in the parameter space

In progress:

MC implementation (SPheno/MadGraph/HERWIG): showers, width effects, hadronization, acceptance cuts

Background estimation and exclusive final-state analysis

Optimal choice of the SUSY/ $U(1)'$ points

Possible scenarios wherein the Z' decays mostly in supersymmetry

Revisiting the Z' -mass exclusion limits (ongoing CMS analysis)