Z' production at the LHC in an extended MSSM

Gennaro Corcella

INFN, Laboratori Nazionali di Frascati

1. Introduction
2. Z' production in U(1)$'$ and Sequential Standard Model
3. MSSM features including U(1)$'$
4. Z' branching ratios in SM and MSSM
5. Cross sections and event rates at the LHC
6. Conclusions

Work in progress

In collaboration with Simonetta Gentile (ATLAS - Università di Roma)

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

Sequential Standard Model (SM-like couplings), string-inspired U(1)', Kaluza–Klein gravitons

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

CMS: $\mathcal{L} = 4.9$ fb^{-1} (dileptons)

$m(Z'_{SSM}) > 2.32$ TeV , $m(Z'_{\psi}) > 2.00$ TeV, $m(Z'_{KK}) > 1.81 - 2.13$ TeV

ATLAS: $\mathcal{L}$=1.08 fb^{-1} (e^+e^-) and $\mathcal{L}$=1.21 fb^{-1} $(\mu^+\mu^-)$

$m(Z'_{SSM}) > 1.83$ TeV , $m(Z'_{U(1)'})$ >1.49-1.64 TeV , $m(Z'_{KK})$ >0.71-1.63 TeV

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

Z' mass constrains invariant masses; unexplored corners of phase space

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

T. Gherghetta et al., PRD57 (1998) 3178: pioneering work on Z' decays in the MSSM, but for $m_{Z'} = 700$ GeV and only one point in the parameter space

C.-F. Chang et al., JHEP09 (2011) 058: two sets of MSSM parameters and $m_{Z'}$=1-2 TeV, but treating sfermion, gaugino and Higgs masses as free parameters

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

$$E_6 \to SO(10) \times U(1)_\psi \quad , \quad SO(10) \to SU(5) \times U(1)_\chi \quad ; \quad E_6 \to \mathrm{SM} \times \mathrm{U}(1)_\eta$$

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

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	$\arctan(\sqrt{15}/9) - \pi/2$

	$2\sqrt{10}\, Q_\chi$	$2\sqrt{6}\, Q_\psi$	$2\sqrt{15}\, Q_\eta$
Q	-1	1	2
u^c	-1	1	2
d^c	3	1	-1
L	3	1	-1
ℓ^c	-1	1	2
ν^c_ℓ	-5	1	5
H	-2	-2	-1
H^c	2	-2	-4
S^c	0	4	5
D	2	-2	-4
D^c	-2	-2	-1

U(1)' coupling and charges:

$$g' = \sqrt{\frac{5}{3}} g_1 \quad ; \quad Q'(\Phi) = Q'_\psi(\Phi)\cos\theta - Q'_\chi(\Phi)\sin\theta$$

$$Q = (u \;\; d)_L \;, \quad L = (\ell \;\; \nu)_L \quad , \quad D \text{ exotic squarks} \;, \quad S \text{ singlet}$$

Minimal Supersymmetric Standard Model and U(1)'

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

Higgs sector: h, H, A, $H^{\pm}$ (MSSM) and a new scalar H'

Three vacuum expectation values $v_1 < v_2 < v_3 \quad \tan\beta = v_2/v_1$

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

Chargino sector is unchanged, as the Z' is neutral

New Z' decay modes besides the SM ones:

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

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, μ

Examples for pseudoscalar and charged Higgs and chargino masses:

$$m^2_{H^\pm} = \frac{2\sqrt{2}\mu A_f}{\sin 2\beta} + \left(1 - 4\frac{\mu^2}{g_2^2 v_3^2}\right) m^2_W \quad , \quad m^2_A = \frac{\sqrt{2}\mu A_f v_3}{\sin 2\beta}\left(1 + \frac{v_1^2 + v_2^2}{4v_3^2}\sin^2 2\beta\right)$$

$$m^2_{\tilde{\chi}^\pm_{1,2}} = \frac{1}{2}\left[|M_2|^2 + |\mu|^2 + 2m^2_W \mp \sqrt{(|M_2|^2 + |\mu|^2 + 2m^2_W)^2 - 4|\mu M_2 - m^2_W \sin 2\beta|^2}\right]$$

Sfermion masses m_a^2 get D-terms like (m_0 soft mass at the Z' scale):

$$V(\phi,\phi^*) \sim \frac{1}{2}\sum_a g_a^2(\phi^* T^a \phi)^2 \quad ; \quad m^2 = m_0^2 + \Delta m_D^2$$

First contribution (electroweak symmetry breaking):

$$\Delta\tilde{m}_a^2 = (T_{3,a}g_1^2 - Y_a g_2^2)(v_1^2 - v_2^2) = (T_{3,a} - Q_a \sin^2\theta_W) m_Z^2 \cos 2\beta$$

Second contribution driven by the new U(1)' symmetry:

$$\Delta\tilde{m}_a'^2 = \frac{g'^2}{2}(Q_1' v_1^2 + Q_2' v_2^2 + Q_3' v_3^2)$$

$$\mathcal{M}_{\tilde{f}}^2 = \begin{pmatrix} (M_{\rm LL}^{\tilde{f}})^2 & (M_{\rm LR}^{\tilde{f}})^2 \\ (M_{\rm LR}^{\tilde{f}})^2 & (M_{\rm RR}^{\tilde{f}})^2 \end{pmatrix}$$

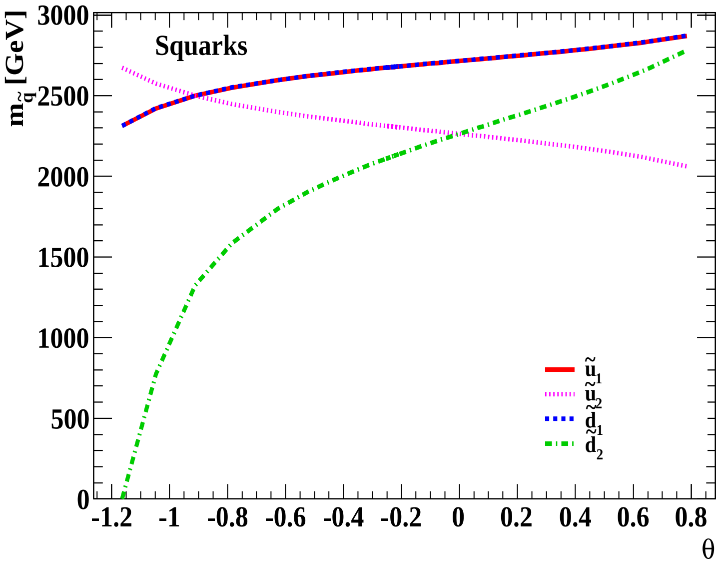
$$\begin{aligned}
(M_{\rm LL}^{\tilde{u}})^2 &= (m_{\tilde{u}_{\rm L}}^0)^2 + m_u^2 + \left(\frac{1}{2} - \frac{2}{3}x_w\right) m_Z^2 \cos 2\beta + Q_{\tilde{u}_{\rm L}}' \Delta\tilde{m}_{\tilde{u}_L}'^2 \\
(M_{\rm RR}^{\tilde{u}})^2 &= (m_{\tilde{u}_R}^0)^2 + m_u^2 + \left(\frac{1}{2} - \frac{2}{3}x_w\right) m_Z^2 \cos 2\beta + Q_{\tilde{u}_R}' \Delta\tilde{m}_{\tilde{u}_R}'^2 \\
(M_{\rm LR}^{\tilde{u}})^2 &= m_u \left(A_u - \mu \cot\beta\right).
\end{aligned}$$

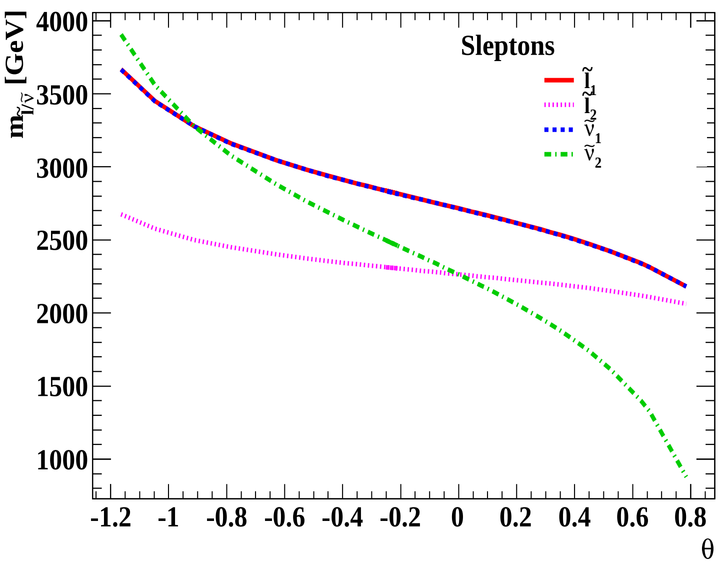
Mass eigenstates $\tilde{u}_{1,2}$, $\tilde{d}_{1,2}$ $\tilde{\ell}_{1,2}$, $\tilde{\nu}_{1,2}$ – mixing term relevant only for stop quarks

Representative Point:

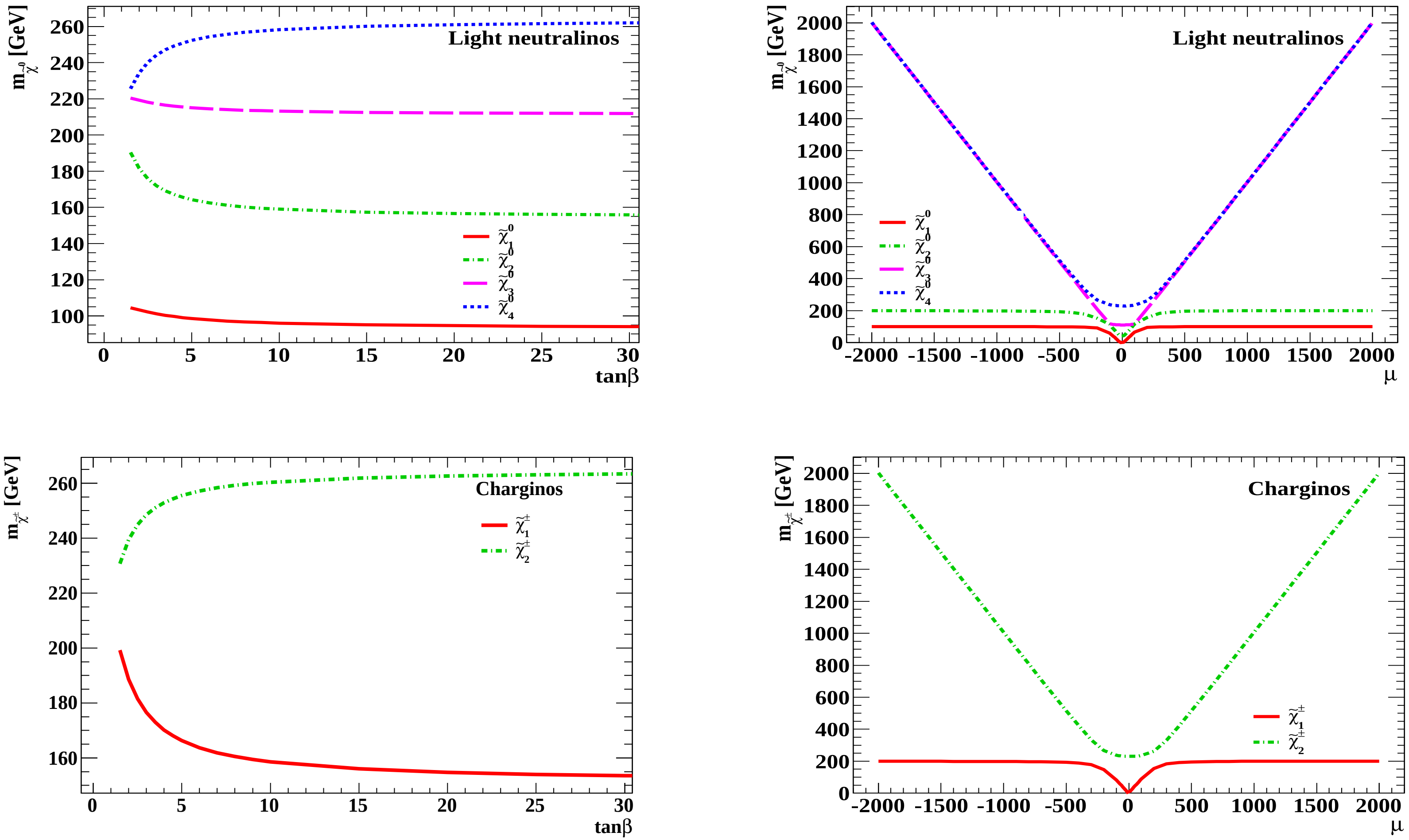
$$m_{Z'} = 3 \text{ TeV} \ , \ \theta = \theta_I = \arccos\sqrt{\frac{5}{8}} - \frac{\pi}{2}$$
$$\mu = 200 \ , \ \tan\beta = 20 \ , \ A_q = A_\ell = A_f = 500 \text{ GeV}$$
$$m^0_{\tilde{q}_L} = m^0_{\tilde{q}_R} = m^0_{\tilde{\ell}_L} = m^0_{\tilde{\ell}_R} = m^0_{\tilde{\nu}_L} = m_{\tilde{\nu}_R} = 2.5 \text{ TeV}$$
$$M_1 = 100 \text{ GeV} \ , \ M_2 = 200 \text{ GeV} \ , \ M' = 1 \text{ TeV}$$

$m_{\tilde{u}_1}$	$m_{\tilde{u}_2}$	$m_{\tilde{d}_1}$	$m_{\tilde{d}_2}$	$m_{\tilde{\ell}_1}$	$m_{\tilde{\ell}_2}$	$m_{\tilde{\nu}_1}$	$m_{\tilde{\nu}_2}$
2499.4	2499.7	2500.7	1323.1	3279.0	2500.4	3278.1	3279.1
$m_{\tilde{\chi}^0_1}$	$m_{\tilde{\chi}^0_2}$	$m_{\tilde{\chi}^0_3}$	$m_{\tilde{\chi}^0_4}$	$m_{\tilde{\chi}^0_5}$	$m_{\tilde{\chi}^0_6}$	$m_{\tilde{\chi}^\pm_1}$	$m_{\tilde{\chi}^\mp_2}$
94.6	156.5	212.2	260.9	2541.4	3541.4	154.8	262.1
m_h	m_A	m_H	$m_{H'}$	$m_{H^\pm}$			
90.7	1190.7	1190.7	3000.0	1193.4			





Dependence of neutralino and chargino spectra on MSSM parameters



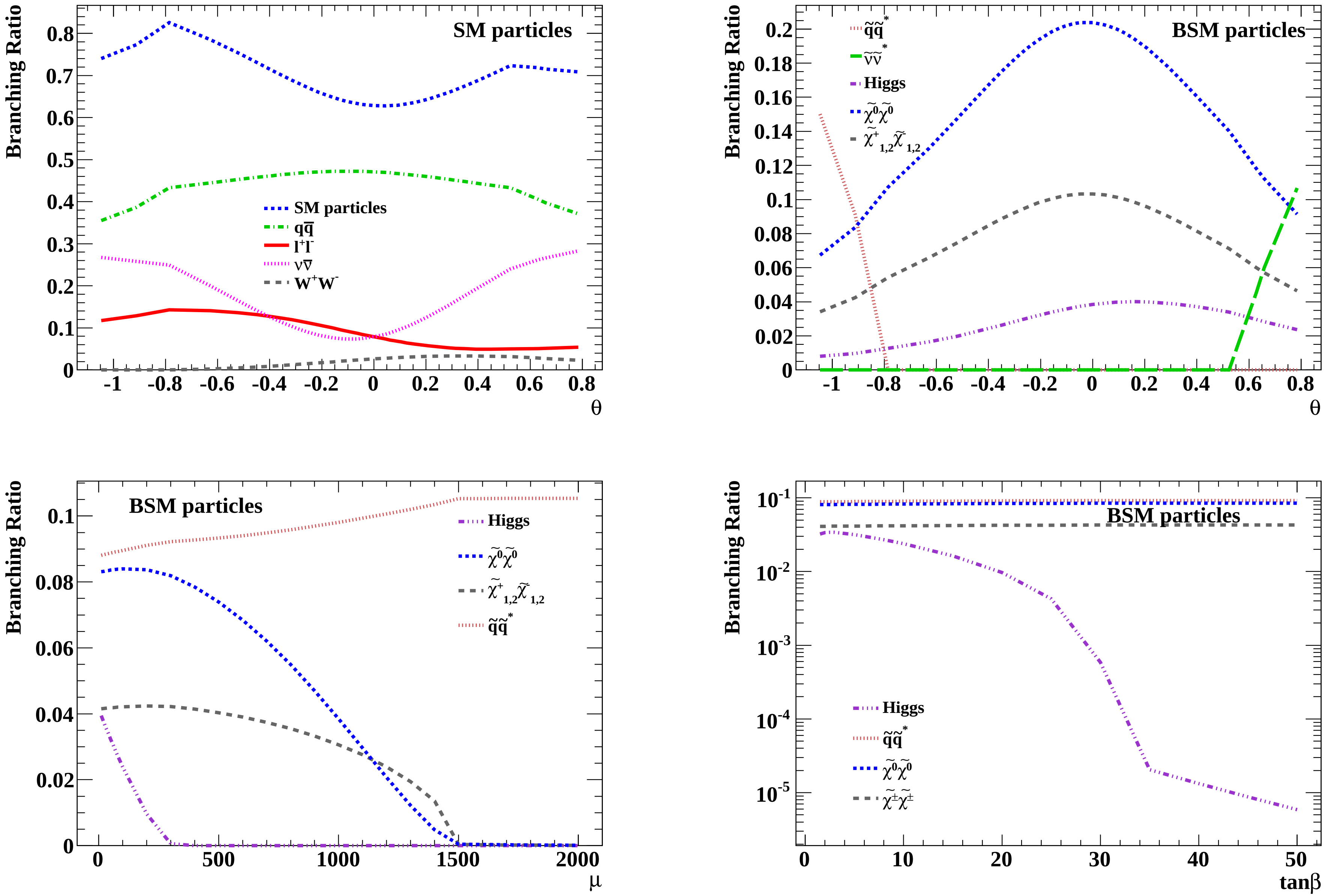
Comparison with ISAJET: good agreement for Representative Point

Model	$m_{\tilde{\chi}_1^0}$	$m_{\tilde{\chi}_2^0}$	$m_{\tilde{\chi}_3^0}$	$m_{\tilde{\chi}_4^0}$	m_h	m_H	m_A	$m_{H^\pm}$	$m_{\tilde{\chi}_1^\pm}$	$m_{\tilde{\chi}_2^\pm}$
U(1)'/MSSM	94.6	156.6	212.2	261.0	90.7	1190.0	1190.0	1190.0	155.0	263.0
MSSM	91.3	152.2	210.2	266.7	114.1	1190.0	1197.9	1200.7	147.5	266.8

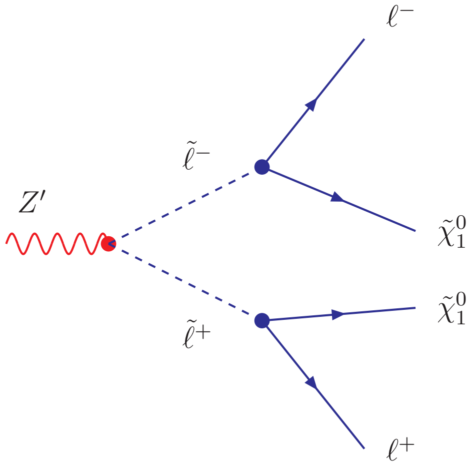
Branching ratios in the Representative Point

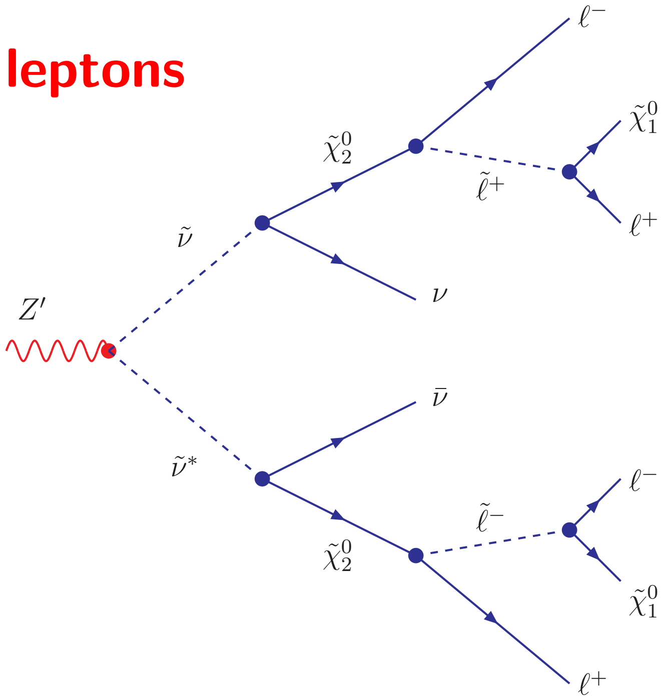
Final state	BR (%)	Final State	BR (%)
$\sum_i u_i \bar{u}_i$	0.00	$\tilde{\chi}_1^0 \tilde{\chi}_1^0$	0.07
$\sum_i d_i \bar{d}_i$	40.67	$\tilde{\chi}_1^0 \tilde{\chi}_2^0$	0.43
$\sum_i \ell_i^+ \ell_i^-$	13.56	$\tilde{\chi}_1^0 \tilde{\chi}_3^0$	0.71
$\sum_i \nu_i \bar{\nu}_i$	27.11	$\tilde{\chi}_1^0 \tilde{\chi}_4^0$	0.27
$\sum_{i,j} \tilde{u}_i \tilde{u}_j^*$	0.00	$\tilde{\chi}_1^0 \tilde{\chi}_5^0$	$\sim 10^{-6}$
$\sum_{i,j} \tilde{d}_i \tilde{d}_j^*$	9.58	$\tilde{\chi}_2^0 \tilde{\chi}_2^0$	0.65
$\sum_{i,j} \tilde{\ell}_i \tilde{\ell}_j^*$	0.00	$\tilde{\chi}_2^0 \tilde{\chi}_3^0$	2.13
$\sum_{i,j} \tilde{\nu}_i \tilde{\nu}_j^*$	0.00	$\tilde{\chi}_2^0 \tilde{\chi}_4^0$	0.80
$H^+ H^-$	0.50	$\tilde{\chi}_3^0 \tilde{\chi}_3^0$	1.75
hA	$\sim 10^{-3}$	$\tilde{\chi}_3^0 \tilde{\chi}_4^0$	1.31
HA	0.51	$\tilde{\chi}_3^0 \tilde{\chi}_5^0$	$\sim 10^{-6}$
ZH	$\sim 10^{-3}$	$\tilde{\chi}_4^0 \tilde{\chi}_4^0$	0.25
ZH'	0.00	$\tilde{\chi}_1^\pm \tilde{\chi}_2^\mp$	1.95
$H'A$	0.00	$\tilde{\chi}_2^\pm \tilde{\chi}_2^\mp$	0.54
$W^\pm H^\mp$	$\sim 10^{-3}$	$\tilde{\chi}_1^\pm \tilde{\chi}_1^\mp$	1.76

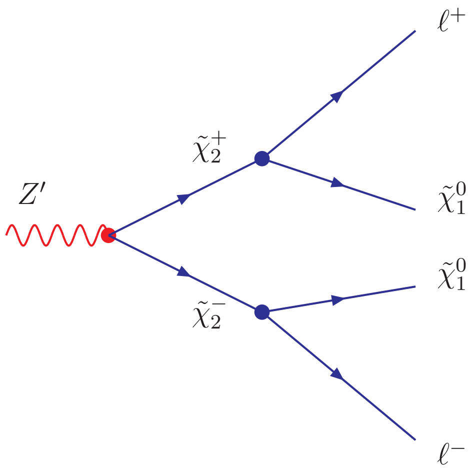
Branching ratios as a function of the U(1)′ and MSSM parameters

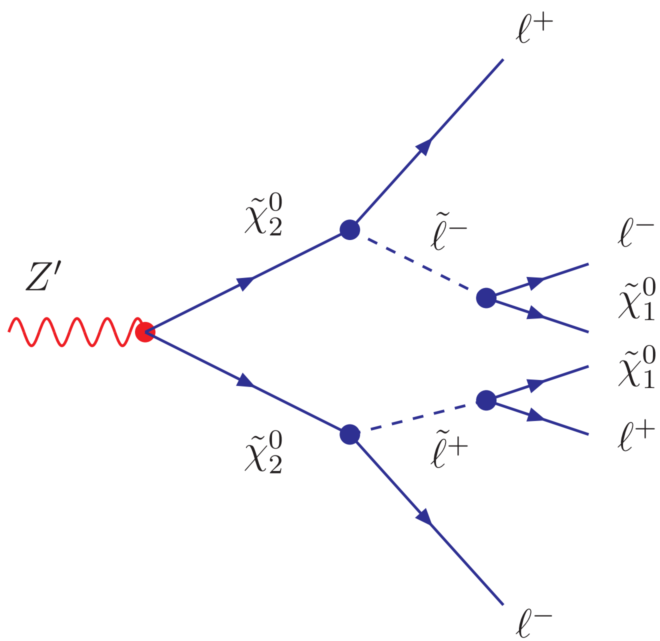


Z' decays into final states with leptons









Lagrangian for Z' coupling with fermions

$$\mathcal{L}_f = g' \bar{f} \gamma^\mu (v_f - a_f \gamma_5) f Z'_\mu$$

$$v_f = \frac{1}{2}\left[Q'(f_L) + Q'(f_R)\right] = \frac{1}{2}\left[(Q'_\psi(f_L) + Q'_\psi(f_R))\cos\theta - (Q'_\chi(f_L) + Q'_\chi(f_R))\sin\theta\right]$$

$$a_f = \frac{1}{2}\left[Q'(f_L) - Q'(f_R)\right] = \frac{1}{2}\left[(Q'_\psi(f_L) - Q'_\psi(f_R))\cos\theta - (Q'_\chi(f_L) - Q'_\chi(f_R))\sin\theta\right]$$

Z' rate into fermions:

$$\Gamma(Z' \to f\bar{f}) = C_f \frac{g'^2}{12\pi} m_{Z'} \left[v_f^2 \left(1 + 2\frac{m_f^2}{m_{Z'}^2}\right) + a_f^2 \left(1 - 4\frac{m_f^2}{m_{Z'}^2}\right)\right] \left(1 - 4\frac{m_f^2}{m_{Z'}^2}\right)^{1/2}$$

Lagrangian for Z' coupling with sfermions

$$\mathcal{L}_{\tilde{f}} = g'(v_f \pm a_f)[\tilde{f}^*_{L,R}(\partial_\mu \tilde{f}_{L,R}) - (\partial_\mu \tilde{f}^*_{L,R})\tilde{f}_{L,R}] Z'^\mu$$

Z' rate into sfermions:

$$\Gamma(Z' \to \tilde{f}_{L,R}\tilde{f}^*_{L,R}) = C_f \frac{g'^2}{48\pi} m_{Z'} (v_f \pm a_f)^2 \left(1 - 4\frac{m_{\tilde{f}}^2}{m_{Z'}^2}\right)^{1/2}$$

Zero rates into sfermions if $v_f = \pm a_f$, e.g. Z'_N and Z'_I couplings to $\tilde{f}_R \tilde{f}^*_R$

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

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

Z'_η ($\theta \simeq 0.66$):

$m_{Z'}$	$m^0_{\tilde{\ell}}$	$m_{\tilde{\ell}_1}$	$m_{\tilde{\ell}_2}$	$m_{\tilde{\nu}_1}$	$m_{\tilde{\nu}_2}$
1000	800	736.9	665.9	732.6	379.3
1000	900	844.4	783.2	840.6	560.2
1500	1100	994.0	873.8	990.8	298.0
1500	1300	1211.6	1115.1	1209.0	754.2
2000	1500	1361.2	1205.6	1358.9	503.8
2000	1800	1686.1	1563.1	1684.2	1115.3
2500	1800	1618.0	1411.9	1616.1	344.7
2500	2200	2053.8	1895.6	2052.2	1311.0
3000	2200	1985.7	1744.6	1984.1	586.4
3000	2600	2421.4	2227.9	2420.0	1504.6
3500	2500	2242.3	1950.2	2240.9	358.9
3500	3100	2896.2	2676.5	2895.1	1867.8
4000	2900	2610.2	2283.3	2608.9	643.3
4000	3500	3263.9	3008.9	3262.9	2062.5

$m_{Z'}$	$m^0_{\tilde{\ell}}$	$B_{q\bar{q}}$	$B_{\ell\ell}$	$B_{\nu\nu}$	B_{WW}	B_{ZH}	$B_{\tilde{\chi}^\pm\tilde{\chi}^\mp}$	$B_{\tilde{\chi}^0\tilde{\chi}^0}$	$B_{\tilde{\nu}\tilde{\nu}^*}$	$B_{\rm SM}$	$B_{\rm BSM}$
1.0	0.8	39.45	5.24	27.26	3.01	2.91	4.92	8.64	8.54	71.96	28.04
1.5	1.1	37.82	4.93	25.63	2.71	2.67	5.16	9.76	11.31	68.39	31.61
2.0	1.5	37.97	4.91	25.54	2.66	2.64	5.33	10.33	10.61	68.42	31.58
2.5	1.8	37.46	4.83	25.12	2.60	2.59	5.33	10.44	11.61	67.42	32.58
3.0	2.2	37.60	4.84	25.17	2.59	2.59	5.38	10.61	11.14	67.60	32.40
3.5	2.5	37.30	4.80	24.94	2.56	2.56	5.36	10.61	11.73	67.03	32.97
4.0	2.9	37.41	4.81	25.00	2.56	2.56	5.39	10.70	11.38	67.22	32.78

$Z'_\psi \ (\theta = 0)$:

$m_{Z'}$	$m^0_{\tilde{\ell}}$	$m_{\tilde{\ell}_1}$	$m_{\tilde{\ell}_2}$	$m_{\tilde{\nu}_1}$	$m_{\tilde{\nu}_2}$
1000	400	535.2	194.2	529.2	189.2
1000	700	785.1	606.4	781.0	604.8
1500	600	801.7	285.4	797.7	282.0
1500	1000	1132.6	849.4	112.7	848.3
2000	800	1068.4	377.8	1065.4	375.2
2000	1300	1480.3	1092.1	1478.2	1091.2
2500	1000	1335.2	470.6	1333.8	468.6
2500	1600	1828.3	1334.7	1826.6	1334.0
3000	1100	1528.5	296.2	1526.4	292.9
3000	1900	2176.3	1577.2	2174.9	1576.6
3500	1300	1795.2	401.8	1793.4	399.4
3500	2200	2524.4	1819.7	2523.2	1819.2
4000	1500	2061.9	502.7	2060.4	500.8
4000	2500	2872.5	2062.2	2871.4	2061.7
5000	1800	2523.2	343.1	2521.9	340.3
5000	3100	3568.8	2547.1	3567.9	2546.7

$m_{Z'}$	$m^0_{\tilde{\ell}}$	$\mathrm{B}_{q\bar{q}}$	$\mathrm{B}_{\ell\ell}$	$\mathrm{B}_{\nu\nu}$	B_{WW}	B_{ZH}	$\mathrm{B}_{\tilde{\chi}^\pm\tilde{\chi}^\mp}$	$\mathrm{B}_{\tilde{\chi}^0\tilde{\chi}^0}$	$\mathrm{B}_{\tilde{\nu}\tilde{\nu}^*}$	$\mathrm{B}_{\tilde{\ell}\tilde{\ell}^*}$	B_{SM}	$\mathrm{B}_{\mathrm{BSM}}$
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
1.5	0.6	46.78	7.90	7.90	2.71	2.69	9.73	18.64	1.83	1.83	62.57	37.43
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
2.5	1.0	46.01	7.70	7.70	2.58	2.59	9.99	19.68	1.79	1.78	61.42	38.58
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
3.5	1.3	44.91	7.50	7.50	2.49	2.51	9.86	19.58	1.83	1.83	59.92	40.08
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
4.5	1.6	44.32	7.40	7.40	2.45	2.47	9.78	19.47	1.84	1.84	59.11	40.89
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

Z'_N ($\theta \simeq -0.25$):

$m_{Z'}$	$m^0_{\tilde{\ell}}$	$m_{\tilde{\ell}_1}$	$m_{\tilde{\ell}_2}$	$m_{\tilde{\nu}_1}$	$m_{\tilde{\nu}_2}$
1000	400	601.1	249.7	595.8	400.0
1000	600	749.2	512.2	745.0	600.0
1500	500	837.4	165.4	833.6	500.0
1500	900	1123.1	766.4	1120.2	900.0
2000	700	1136.4	303.9	1133.6	700.0
2000	1200	1497.1	1021.0	1495.0	1200.0
2500	800	1375.8	131.8	1372.9	800.0
2500	1500	1871.2	1275.7	1869.5	1500.0
3000	1000	1673.7	319.9	1671.8	1000.0
3000	1800	2245.3	1530.4	2243.9	1800.0
3500	1200	1972.6	466.2	1971.0	1200.0
3500	2100	2619.4	1785.3	2618.2	2100.0
4000	1300	2211.6	303.9	2210.2	1300.0
4000	2400	2993.6	2040.2	2992.5	2400.0
5000	1600	2749.8	249.7	2748.6	1600.0
5000	3100	3822.5	2666.9	3821.6	3100.0

$m_{Z'}$	$m^0_{\tilde{\ell}}$	$B_{q\bar{q}}$	$B_{\ell\ell}$	$B_{\nu\nu}$	B_{WW}	B_{ZH}	$B_{\tilde{\chi}^{\pm}\tilde{\chi}^{\mp}}$	$B_{\tilde{\chi}^0\tilde{\chi}^0}$	$B_{\tilde{\ell}\tilde{\ell}}$	$B_{\rm SM}$	$B_{\rm BSM}$
1.0	0.4	49.51	11.98	9.59	1.71	1.68	8.71	15.78	1.04	71.08	28.92
1.5	0.5	47.99	11.51	9.21	1.57	1.57	9.26	17.76	1.12	68.71	31.29
2.0	0.7	47.50	11.36	9.08	1.53	1.54	9.44	18.46	1.08	67.94	32.06
2.5	0.8	47.16	11.26	9.01	1.50	1.52	9.50	18.73	1.12	67.42	32.58
2.5	1.5	47.69	11.38	9.11	1.52	1.53	9.61	18.94	0.00	68.18	31.82
3.0	1.0	46.43	11.30	8.86	1.47	1.49	9.43	18.66	1.08	66.36	33.64
3.5	1.2	45.85	10.93	8.74	1.45	1.47	9.35	18.56	1.05	65.53	34.47
4.0	1.3	45.42	10.83	8.66	1.43	1.45	9.29	18.47	1.07	64.91	35.09
4.5	1.5	45.13	10.75	8.60	1.42	1.44	9.24	18.41	1.05	64.48	35.52
5.0	1.6	44.90	10.70	8.56	1.41	1.43	9.21	18.35	1.06	64.15	35.85

Z'_I $(\theta \simeq -0.91)$:

$m_{Z'}$	$m^0_{\tilde{\ell}}$	$m_{\tilde{\ell}_1}$	$m_{\tilde{\ell}_2}$	$m_{\tilde{\nu}_1}$	$m_{\tilde{\nu}_2}$
1000	200	736.3	204.7	732.0	734.8
1000	1000	1226.6	1001.0	1223.0	1224.7
1500	200	1080.4	204.7	1077.4	1079.3
1500	1000	1458.5	1001.0	1456.3	1457.7
2000	200	1429.1	204.7	1426.8	1428.3
2000	1000	1732.7	1001.0	1730.8	1732.0
2500	200	1779.7	204.7	1777.9	1779.0
2500	3000	3482.4	3000.3	3481.5	3482.1
3000	200	2131.5	204.7	2129.7	2130.7
3000	3000	3674.5	3000.3	3673.7	3674.2
3500	200	2483.4	204.7	2482.1	2482.9
3500	3000	3889.4	3000.3	3888.5	3889.1
4000	200	2836.9	204.7	2834.8	2835.5
4000	3000	4123.4	3000.3	4122.6	4123.1
5000	200	3541.5	204.7	3540.6	3541.2
5000	3000	4637.0	3000.3	4636.4	4636.8

$m_{Z'}$	$m^0_{\tilde{\ell}}$	$B_{q\bar{q}}$	$B_{\ell\ell}$	$B_{\nu\nu}$	$B_{H^+H^-}$	B_{WH}	B_{HA}	$B_{\tilde{\chi}^\pm\tilde{\chi}^\mp}$	$B_{\tilde{\chi}^0\tilde{\chi}^0}$	$B_{\rm SM}$	$B_{\rm BSM}$
1.0	1.0	44.06	14.69	29.37	0.00	$\sim 10^{-3}$	$\sim 10^{-4}$	4.31	7.58	88.11	11.89
1.5	1.0	43.39	14.46	28.93	0.00	$\sim 10^{-4}$	$\sim 10^{-4}$	4.56	8.65	86.78	13.22
2.0	1.0	43.16	14.38	28.77	0.00	$\sim 10^{-4}$	$\sim 10^{-3}$	4.65	9.03	86.31	13.69
2.5	1.0	42.99	14.33	28.66	0.06	$\sim 10^{-3}$	0.07	4.68	9.19	85.98	14.02
3.0	1.0	42.53	14.18	28.36	0.53	$\sim 10^{-3}$	0.53	4.66	9.20	85.07	14.93
3.5	1.0	42.16	14.05	28.11	0.91	$\sim 10^{-3}$	0.92	4.64	9.19	84.33	15.67
4.0	1.0	41.90	13.96	27.93	1.20	$\sim 10^{-3}$	1.21	4.62	9.17	83.79	16.21
4.5	1.0	41.70	13.90	27.80	1.40	$\sim 10^{-3}$	1.41	4.61	9.16	83.40	16.60
5.0	1.0	41.56	13.85	27.71	1.56	0.01	1.57	4.60	9.15	83.12	16.88

$Z'_S \ (\theta \simeq -1.16)$:

$m_{Z'}$	$m^0_{\tilde{\ell}}$	$m_{\tilde{\ell}_1}$	$m_{\tilde{\ell}_2}$	$m_{\tilde{\nu}_1}$	$m_{\tilde{\nu}_2}$
1000	200	917.9	376.8	914.4	1020.0
1000	1000	1342.6	1049.7	1340.2	1414.3
1500	200	1357.4	516.7	1355.0	1513.4
1500	1000	1674.1	1107.7	1672.2	1802.9
2000	200	1800.7	664.8	1798.9	2010.0
2000	1000	2050.0	1184.0	2048.4	2236.1
2500	200	2245.5	816.7	2244.1	2508.0
2500	3000	3742.0	3102.7	3741.1	3905.2
3000	200	2691.2	970.5	2690.0	3006.7
3000	3000	4025.2	3146.7	4024.4	4242.7
3500	200	3137.3	1125.6	3136.3	3505.7
3500	3000	4336.2	3198.0	4335.4	4609.8
4000	200	3583.6	1281.4	3582.7	4005.0
4000	3000	4669.3	3256.1	4668.6	5000.0
5000	200	4476.9	1594.3	4476.2	5004.0
5000	3000	5385.4	3391.4	5384.8	5831.0

$m_{Z'}$	$m^0_{\tilde{\ell}}$	$B_{q\bar{q}}$	$B_{\ell\ell}$	$B_{\nu\nu}$	B_{WW}	B_{ZH}	$B_{\tilde{\chi}^{\pm}\tilde{\chi}^{\mp}}$	$B_{\tilde{\chi}^0\tilde{\chi}^0}$	$B_{\tilde{\ell}\tilde{\ell}^*}$	$B_{\tilde{q}\tilde{q}^*}$	$B_{\rm SM}$	$B_{\rm BSM}$
1.0	0.2	42.29	13.70	34.57	0.15	0.14	3.33	5.75	0.07	0.00	90.56	9.44
1.5	0.2	41.84	13.54	34.16	0.15	0.14	3.51	6.59	0.07	0.00	89.54	10.46
2.0	0.2	41.67	13.48	34.02	0.14	0.14	3.57	6.90	0.08	0.00	89.17	10.82
2.5	0.2	41.56	13.44	33.91	0.14	0.14	3.59	7.03	0.08	0.00	88.92	11.08
3.0	0.2	41.25	13.34	33.66	0.14	0.14	3.58	7.06	0.08	0.00	88.25	11.75
3.5	0.2	40.99	13.26	33.45	0.14	0.14	3.57	7.07	0.08	0.00	87.70	12.30
4.0	0.2	40.81	13.20	33.30	0.14	0.14	3.56	7.07	0.08	0.00	87.30	12.70
4.5	0.2	40.67	13.15	33.19	0.14	0.14	3.56	7.07	0.08	0.00	87.01	12.99
5.0	0.2	37.34	12.07	30.46	0.13	0.13	3.27	6.50	0.07	7.97	79.87	20.12

Z'_χ ($\theta \simeq -1.57$): (unphysical sfermion spectrum)

$m_{Z'}$	$B_{q\bar{q}}$	$B_{\ell\ell}$	$B_{\nu\nu}$	B_{WW}	$B_{H^+H^-}$	B_{ZH}	B_{HA}	B_{SM}	B_{BSM}
1.0	44.35	12.44	42.29	0.90	0.00	0.02	$\sim 10^{-3}$	99.08	0.92
2.0	44.32	12.34	41.96	0.84	0.00	0.28	0.26	98.62	1.38
3.0	44.03	12.24	41.63	0.82	0.24	0.53	0.52	97.89	2.11
4.0	43.84	12.18	41.43	0.82	0.46	0.64	0.63	97.45	2.55
5.0	43.74	12.15	41.33	0.81	0.58	0.70	0.69	97.22	2.78

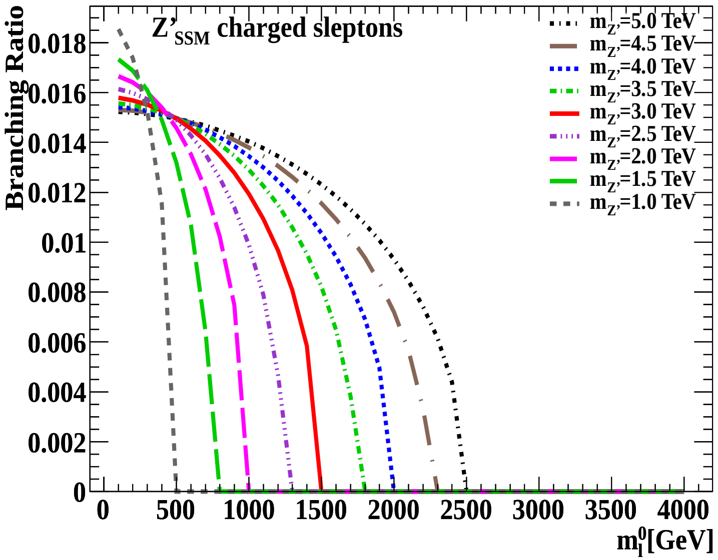
$Z'_{\rm SSM}$:

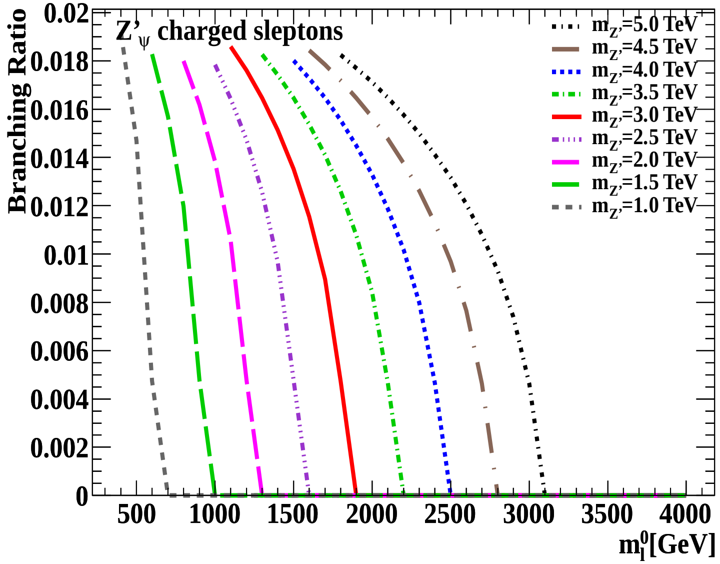
$m_{Z'}$	$m^0_{\tilde{\ell}}$	$m_{\tilde{\ell}_1}$	$m_{\tilde{\ell}_2}$	$m_{\tilde{\nu}_1}$	$m_{\tilde{\nu}_2}$
1000	100	110.6	109.1	76.6	100.0
1000	500	502.2	501.9	495.8	500
1500	100	110.6	109.1	76.6	100.0
1500	750	751.5	751.3	747.2	750.0
2000	100	110.6	109.1	76.6	100.0
2000	1000	1001.1	1000.9	997.9	1000.0
2500	100	110.6	109.1	76.6	100.0
2500	1250	1250.9	1250.8	1248.3	1250.0
3000	100	110.6	109.1	76.6	100.0
3000	1500	1001.1	1000.9	997.9	1000.0
3500	100	110.6	109.1	76.6	100.0
3500	1750	1750.6	1750.6	1748.8	1750.0
4000	100	110.6	109.1	76.6	100.0
4000	2000	2000.6	2000.5	1999.0	2000.0
4500	100	110.6	109.1	76.6	100.0
4500	2250	2250.5	2250.4	2249.1	2250.0
5000	100	110.6	109.1	76.6	100.0
5000	2500	2500.4	2500.4	2499.2	2500.0

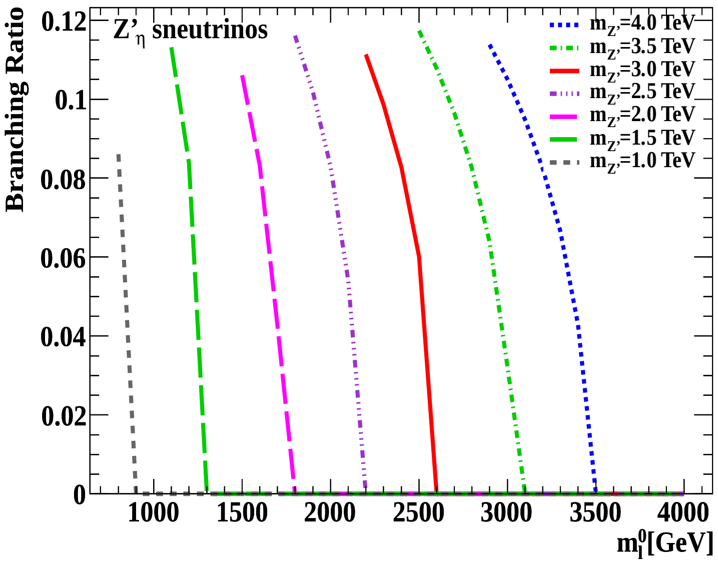
$Z'_{\rm SSM}$ branching ratios:

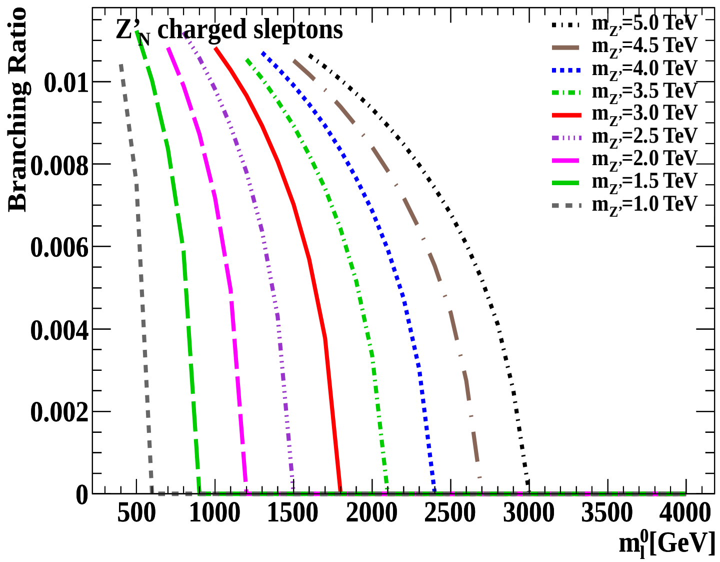
$m_{Z'}$	$m^0_{\tilde{\ell}}$	B_q	B_ℓ	B_ν	B_{WW}	B_{HH}	B_{Zh}	B_{hA}	B_{ch}	B_{neu}	$B_{\tilde{\ell}}$	$B_{\tilde{\nu}}$	$B_{\rm SM}$	$B_{\rm BSM}$
1.0	0.1	29.6	3.9	7.7	5.6	0.0	0.0	0.0	18.3	29.3	1.9	3.8	41.2	58.8
1.0	0.5	31.4	4.1	8.2	5.9	0.0	0.0	0.0	19.4	31.1	0.0	0.0	43.6	56.4
1.5	0.1	27.4	3.5	7.0	4.9	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

Dependence of branching ratios on Z' and slepton masses

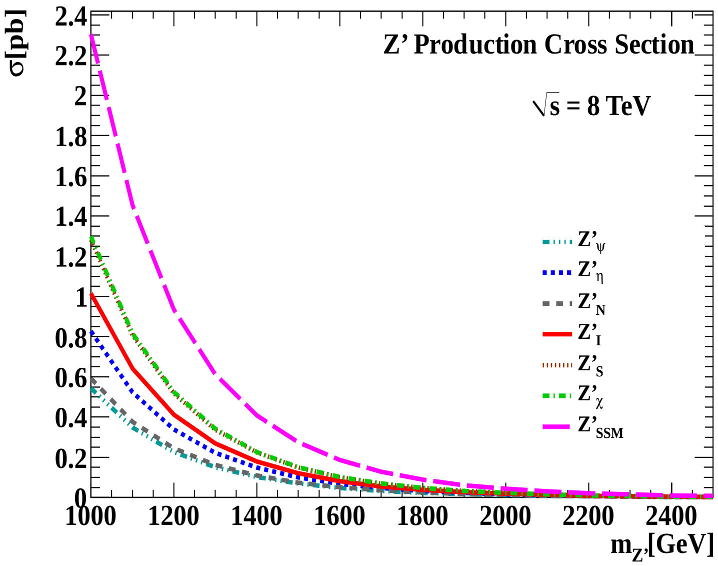


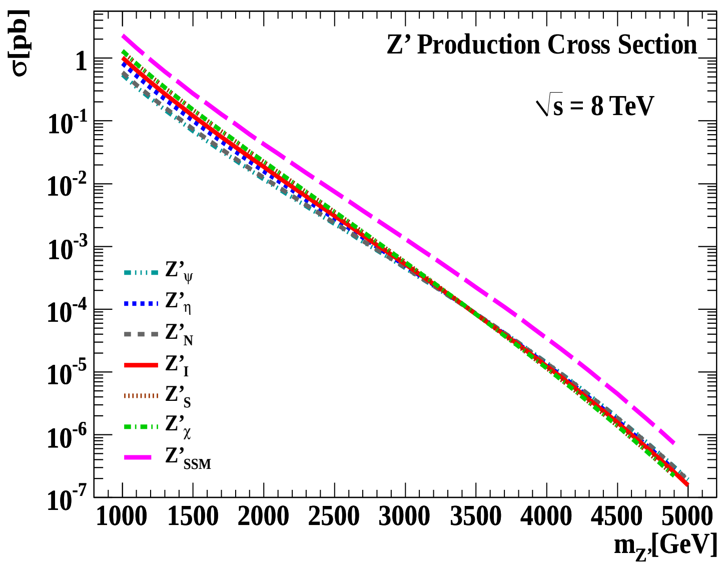


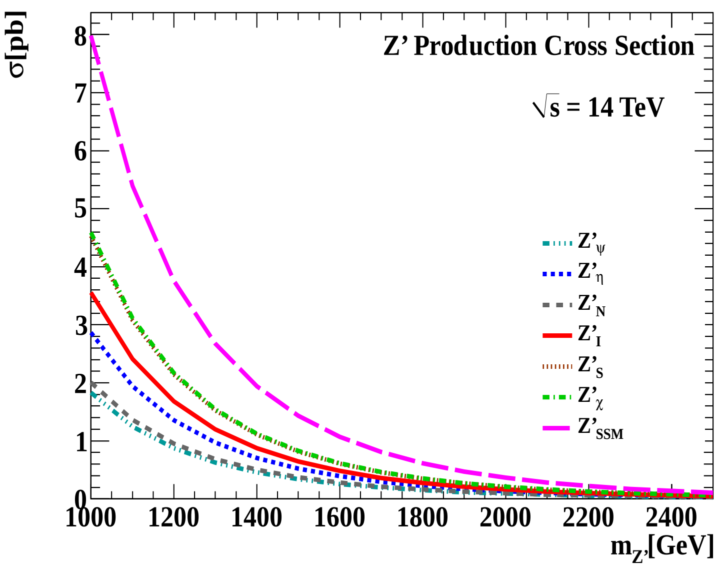


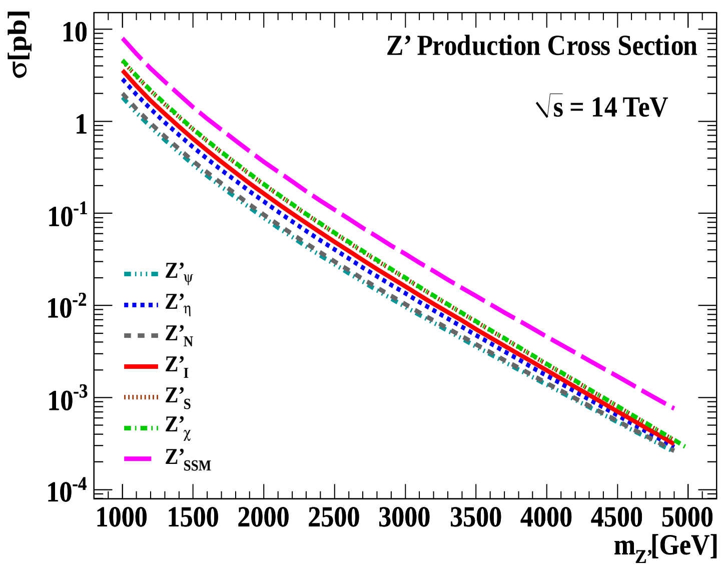


Production cross sections in pp collisions $q\bar{q} \to Z'$, LO pdf CTEQ6L









Expected event numbers (narrow width approximation):

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

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

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

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

Model	$m_{Z'}$ (TeV)	$\mathrm{N}_{\mathrm{casc}}$	$\mathrm{N}_{\mathrm{slep}}$
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

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

Model	$m_{Z'}$ (TeV)	$\mathrm{N}_{\mathrm{casc}}$	$\mathrm{N}_{\mathrm{slep}}$
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	19570	606

Conclusions and outlook

Work in progress on Z' phenomenology in supersymmetry at the LHC

BSM modes decrease the SM rates and the Z' may set a constrain on sparticle invariant masses

Marrying U(1)' and MSSM: two extra neutralinos, one new neutral scalar Higgs, D-term contribution to sfermion masses

Studies of mass spectra, Z' branching ratios and production cross sections spanning the parameter space

BSM branching ratios 10-30% for U(1)' groups 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

In progress:

Release of the paper and documentation of the calculations

Implementation of the U(1)'/MSSM models in Monte Carlo codes: parton showers, Z' width effects, hadronization and acceptance cuts on jets and leptons

Revisiting the limits on the Z' mass