Search for pair production of squarks or gluinos decaying to sleptons or WZ bosons with two same-sign or three leptons final states using 139 fb^{-1} ATLAS data

Shiyi Liang, on behalf of ATLAS Collaboration

Institute of High Energy Physics, Chinese Academy of Sciences

30 March 2023

DIS2023: Deep-Inelastic Scattering and Related Subjects

Outline

Introduction of Super-symmetry

$\tilde{q}/\tilde{g}$ search in SS/3L final states

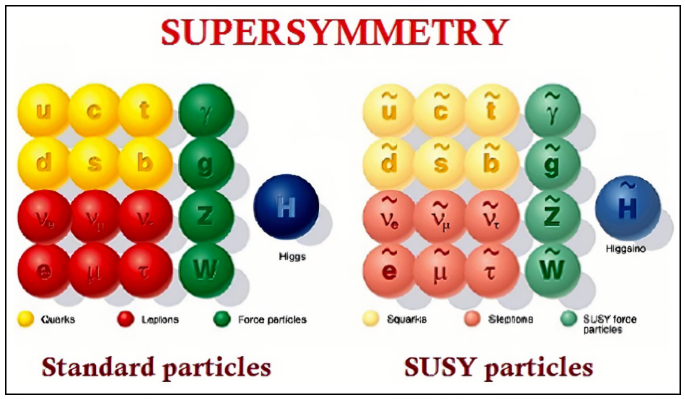
Summary

Introduction of Super-symmetry

Introduction of Super-symmetry

Super-symmetry(SUSY): fermion–boson symmetry

Minimal Super-symmetric Standard Model



Names	Spin	P_R	Gauge Eigenstates	Mass Eigenstates
Higgs bosons	0	+1	$H_u^0\ H_d^0\ H_u^+\ H_d^-$	$h^0\ H^0\ A^0\ H^\pm$
squarks	0	−1	$\tilde{u}_L\ \tilde{u}_R\ \tilde{d}_L\ \tilde{d}_R$ $\tilde{s}_L\ \tilde{s}_R\ \tilde{c}_L\ \tilde{c}_R$ $\tilde{t}_L\ \tilde{t}_R\ \tilde{b}_L\ \tilde{b}_R$	(same) (same) $\tilde{t}_1\ \tilde{t}_2\ \tilde{b}_1\ \tilde{b}_2$
sleptons	0	−1	$\tilde{e}_L\ \tilde{e}_R\ \tilde{\nu}_e$ $\tilde{\mu}_L\ \tilde{\mu}_R\ \tilde{\nu}_\mu$ $\tilde{\tau}_L\ \tilde{\tau}_R\ \tilde{\nu}_\tau$	(same) (same) $\tilde{\tau}_1\ \tilde{\tau}_2\ \tilde{\nu}_\tau$
neutralinos	1/2	−1	$\tilde{B}^0\ \tilde{W}^0\ \tilde{H}_u^0\ \tilde{H}_d^0$	$\tilde{N}_1\ \tilde{N}_2\ \tilde{N}_3\ \tilde{N}_4$
charginos	1/2	−1	$\tilde{W}^\pm\ \tilde{H}_u^+\ \tilde{H}_d^-$	$\tilde{C}_1^\pm\ \tilde{C}_2^\pm$
gluino	1/2	−1	$\tilde{g}$	(same)
goldstino (gravitino)	1/2 (3/2)	−1	$\tilde{G}$	(same)

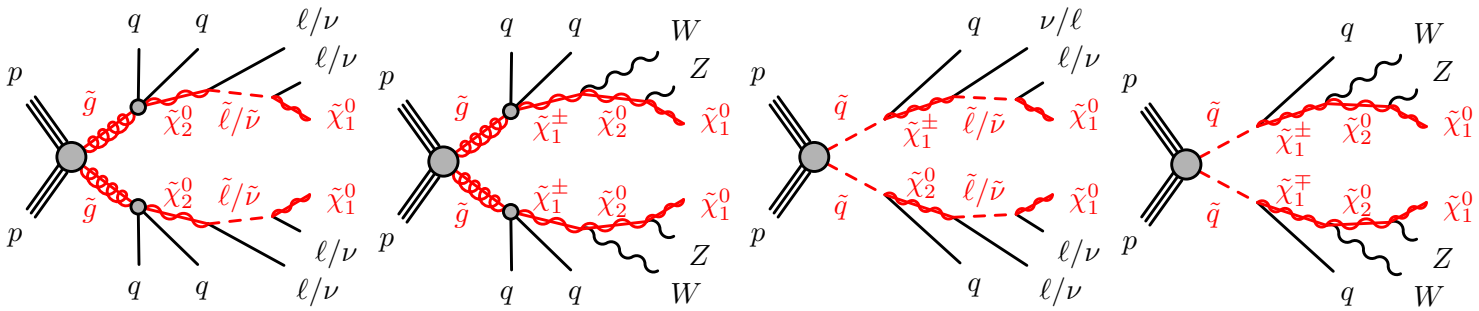
R-parity: $P_R = (-1)^{3(B-L)+2S}$
SUSY particles $\rightarrow$ odd R-parity; SM-particles $\rightarrow$ even R-parity

R-parity conserved(RPC):
SUSY particles produced in pairs, Lightest SUSY particle(LSP/$\tilde{\chi}_1^0$) is stable

$\tilde{q}/\tilde{g}$ search in SS/3L final states

Search for $\tilde{q}/\tilde{g}$ in SS/3L final states

- Target process: pair production of $\tilde{q}$ or $\tilde{g}$ decaying to sleptons or WZ bosons.
- Low SM backgrounds in two same-sign or three leptons final state increase sensitivity for Beyond-Standard-Model(BSM) processes with this final states.
- Consider four RPC signal models:



(a) GG 2-step sleptons (b) GG 2-step WZ (c) SS 2-step sleptons (d) SS 2-step WZ

Analysis strategy

Input: full run2 data of 139 fb^{-1} from ATLAS detector of LHC.

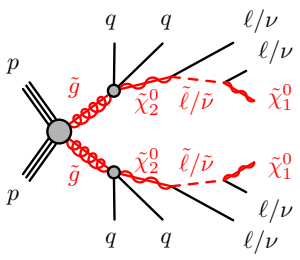
Background estimation

- Prompt (irreducible) backgrounds:
  - WZ+jets: normalized to data in a dedicated CR.
  - Others: estimated with MC samples
- Detector (reducible) backgrounds:
  - Charge-flip background, Fake/non-prompt lepton: data-driven method

Strategy

- Search for excesses of data over predicted SM processes in signal regions. If no significant excess is found, draw exclusion limit on $\tilde{g}/\tilde{q}$-$\tilde{\chi}_1^0$ mass plane.
  - For each signal model, design several signal regions targeting benchmark points in different region on the $\tilde{g}/\tilde{q}$-$\tilde{\chi}_1^0$ mass plane.
  - For each signal grid, use exclusion fit result from signal region providing lowest expected CLs(modified confidence level).
  - Multiple kinematic variables as well as the ratio of these variables are used in signal region definition.

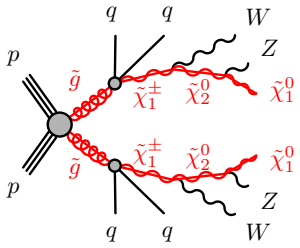
Event selection of $\tilde{g}$ production model



SR name	$n_{\mathrm{Sig}}(\ell)$	$n_{b\text{-jets}}$	n_{jets}	$p_{\mathrm{T}}^{\mathrm{jet}}$[GeV]	$E_{\mathrm{T}}^{\mathrm{miss}}$[GeV]	$E_{\mathrm{T}}^{\mathrm{miss}}/\sum p_{\mathrm{T}}^{\mathrm{jet}}$	$p_{\mathrm{T}}^{\ell 2}$[GeV]	other
SRGGSlep-L	$\geq 3^{\dagger}$	0	≥ 4	≥ 40	–	> 0.4	> 30	$E_{\mathrm{T}}^{\mathrm{miss}}/\sum p_{\mathrm{T}}^{\ell} > 1.4$
SRGGSlep-M					> 150	> 0.3	> 70	$\Delta\phi(\ell 1\ell 2, \mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}) > 0.7$
SRGGSlep-H					> 100	–	–	$\sum p_{\mathrm{T}}^{\mathrm{jet}} > 1200\,GeV$

†: SFOS pairs with $81 < m_{\mathrm{SFOS}} < 101\,GeV$ are not allowed

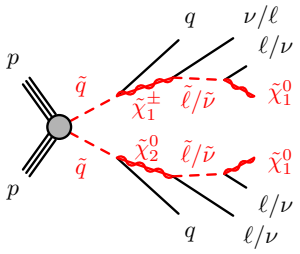
Table: Signal regions of RPC GG 2-step slepton model



SR name	$n_{\mathrm{Sig}}(\ell)(n_{\mathrm{BL}}(\ell))$	$n_{b\text{-jets}}$	n_{jets}	$p_{\mathrm{T}}^{\mathrm{jet}}$ [GeV]	$E_{\mathrm{T}}^{\mathrm{miss}}$[GeV]	m_{eff}[GeV]	$\Delta\phi(\ell 1\ell 2, \mathbf{p}_{\mathrm{T}}^{\mathrm{miss}})$	$\mathrm{Sig}(E_{\mathrm{T}}^{\mathrm{miss}})$
SRGGWZ-L	≥ 2 (≥ 3)	0	≥ 6	> 25	> 200	$> 8 \times \sum p_{\mathrm{T}}^{\ell}$	> 0.2	> 6
SRGGWZ-M	≥ 2 (–)		≥ 6	> 40	> 190	> 1300	> 0.8	–
SRGGWZ-H	≥ 2 (–)		≥ 6	> 40	> 150	> 2100	–	–

Table: Signal regions of RPC GG 2-step WZ model

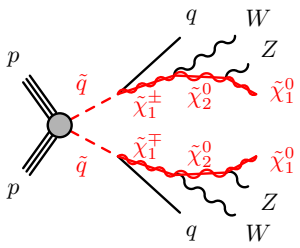
Event selection of $\tilde{q}$ production model



SR name	$n_{\mathrm{Sig}}(\ell)$	$^{\ell}$ [GeV]	$n_{b\text{-jets}}$	n_{jets}	$p_{\mathrm{T}}^{\mathrm{jet}}$ [GeV]	$E_{\mathrm{T}}^{\mathrm{miss}}$[GeV]	m_{eff}[GeV]	$\Delta\phi(\ell 1\ell 2, \mathbf{p}_{\mathrm{T}}^{\mathrm{miss}})$
	other requirements							
SRSSSlep-L	3*	< 60	0	≥ 3	$> 60, 60, 25$	> 100	> 600	> 1.4
	$\sum p_{\mathrm{T}}^{\ell} / \sum p_{\mathrm{T}}^{\mathrm{jet}} < 0.6$							
SRSSSlep-ML	3*	> 30	0	≥ 3	$> 60, 60, 25$	> 100	> 700	> 1.4
	$E_{\mathrm{T}}^{\mathrm{miss}} / \sum p_{\mathrm{T}}^{\ell} > 0.7, \quad \sum p_{\mathrm{T}}^{\ell} / \sum p_{\mathrm{T}}^{\mathrm{jet}} < 0.6$							
SRSSSlep-MH	3*	> 40	0	≥ 2	> 60	> 200	> 1000	> 0.5
	$E_{\mathrm{T}}^{\mathrm{miss}} / \sum p_{\mathrm{T}}^{\ell} > 0.7, \quad \Delta R(\ell 1, \ell 2) > 0.2$							
SRSSSlep-H	3*	> 40	0	≥ 2	> 60	> 200	> 2000	> 0.3
	$\Delta R(\ell 1, \ell 2) > 0.5$							
SRSSSlep-H (loose)	3*	> 40	0	≥ 2	> 60	> 200	> 1000	> 0.3
	$\Delta R(\ell 1, \ell 2) > 0.5$							

*: additional baseline leptons are not allowed, nor SFOS pairs with $81 < m_{\mathrm{SFOS}} < 101\,GeV$

Table: Signal regions of RPC SS 2-step slepton model



SR name	$n_{\mathrm{Sig}}(\ell)$	$n_{b\text{-jets}}$	n_{jets}	$p_{\mathrm{T}}^{\mathrm{jet}}$ [GeV]	$E_{\mathrm{T}}^{\mathrm{miss}}$[GeV]	m_{eff}[GeV]	$E_{\mathrm{T}}^{\mathrm{miss}} / \sum p_{\mathrm{T}}^{\ell}$	$\sum p_{\mathrm{T}}^{\ell} / \sum p_{\mathrm{T}}^{\mathrm{jet}}$	$n_{Z\to\ell^+\ell^-}$
SRSSWZ-L	≥ 3	0	≥ 4	> 25	$> 0.2 \times m_{\mathrm{eff}}$	–	–	< 0.2	$0^{\dagger}$
SRSSWZ-ML			≥ 6	> 25	> 150	> 800	> 1.2	< 0.3	$\geq 1^{\dagger}$
SRSSWZ-MH			≥ 5	> 40	> 200	> 900	> 1.1	< 0.4	$\geq 1^{\dagger}$
SRSSWZ-H			≥ 5	> 40	> 250	> 1500	> 0.3	< 0.7	–

†: based on number of SFOS pairs with $81 < m_{\mathrm{SFOS}} < 101\,GeV$

Table: Signal regions of RPC SS 2-step WZ model

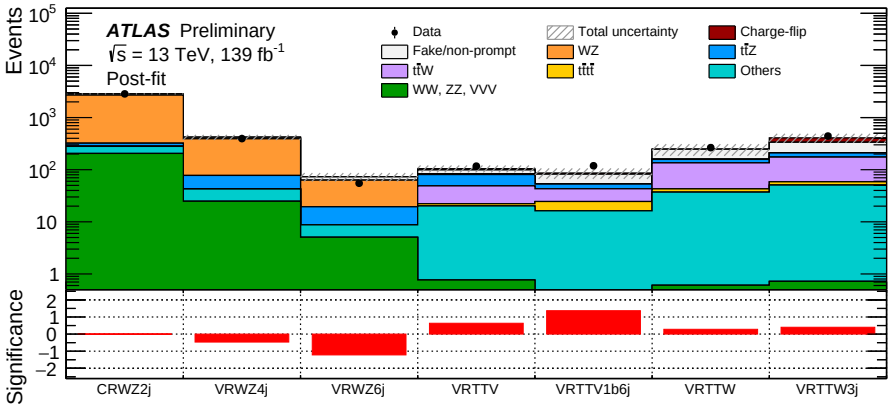
Background estimation validation

Dominant background: WZ+jets

	$n_{\mathrm{Sig}}(\ell)$	$n_{b\text{-jets}}$	n_{jets}	$p_{\mathrm{T}}^{\mathrm{jet}}$ [GeV]	m_{eff} [GeV]	$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]
	other requirements					
VRWZ4j	3*	0	≥ 4	> 25	$[600, 1500]$	$[30, 250]$
	$E_{\mathrm{T}}^{\mathrm{miss}}/m_{\mathrm{eff}} < 0.2$, $81 < m_{\mathrm{SFOS}} < 101\,GeV$					
VRWZ6j	3*	0	≥ 6	> 25	$[400, 1500]$	$[30, 250]$
	$E_{\mathrm{T}}^{\mathrm{miss}}/m_{\mathrm{eff}} < 0.15$, $81 < m_{\mathrm{SFOS}} < 101\,GeV$					
VRTTV	≥ 2	≥ 1	≥ 3	> 40	$[600, 1500]$	$[30, 250]$
	$> 30\,GeV$ for the two leading-same-sign leptons, $\Delta R > 1.1$ between the leading-lepton and any jet, $\sum p_{\mathrm{T}}^{b-\mathrm{jet}}/\sum p_{\mathrm{T}}^{\mathrm{jet}} > 0.4$, $E_{\mathrm{T}}^{\mathrm{miss}}/m_{\mathrm{eff}} > 0.1$					
VRTTV1b6j	≥ 2	≥ 1	≥ 6	> 40	< 1500	$[30, 250]$
	$> 30\,GeV$ for the two leading-same-sign leptons, $E_{\mathrm{T}}^{\mathrm{miss}}/m_{\mathrm{eff}} < 0.15$					
VRTTW	2* ($\mu^{\pm}\mu^{\pm}$)	≥ 2	≥ 2	> 25	< 1500	$[30, 250]$
	both leptons with $> 25\,GeV$, one with $> 40\,GeV$					
VRTTW3j	2* ($e^{\pm}\mu^{\pm}$)	≥ 2	≥ 3	> 25	< 1500	$[30, 250]$
	both leptons with $> 25\,GeV$					

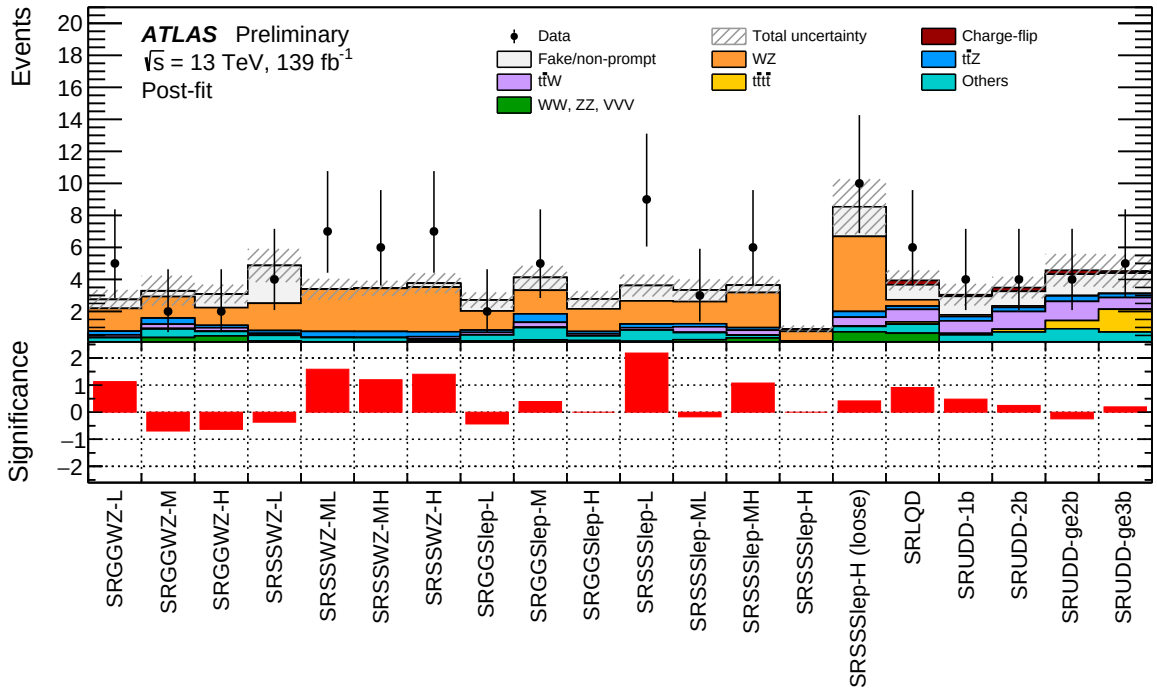
*: additional baseline leptons are not allowed

Table: Validation region definition



(e) Data and SM background comparison in CR and VRs

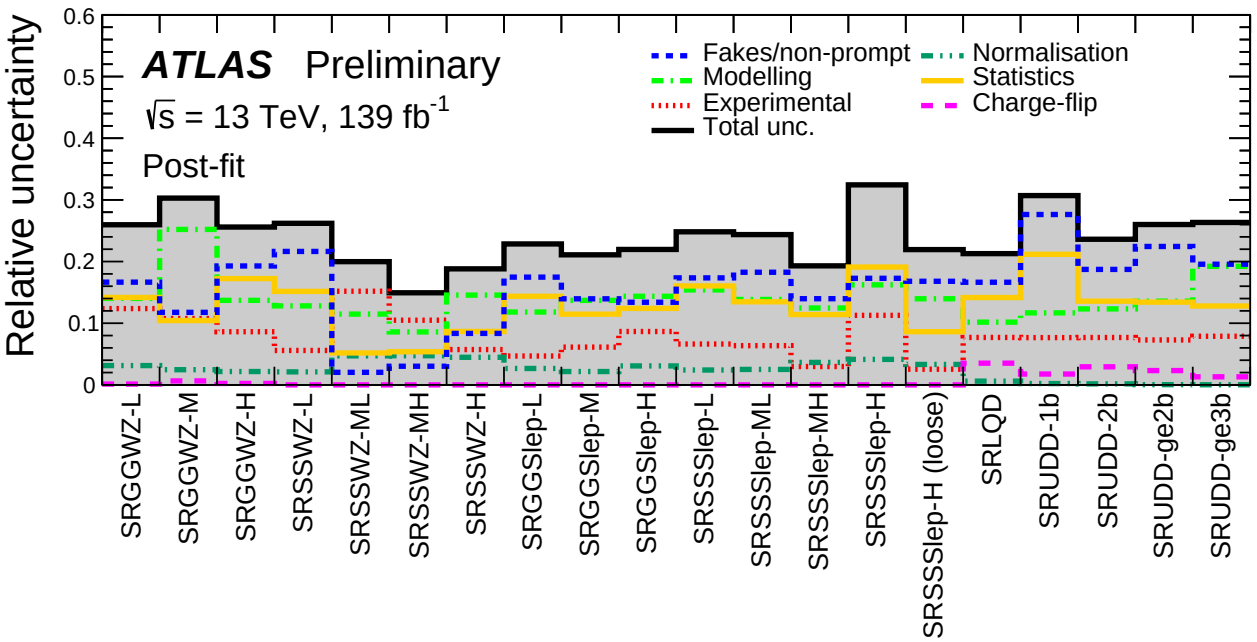
Results



(f) Data and SM background in SRs

- No significant excess above the SM expectation is observed.
- We see small excesses in SRSSWZ-ML/MH/H. SRSSSlep-L is with the most significant excess, but still not reach to 3σ.

Results: systematic

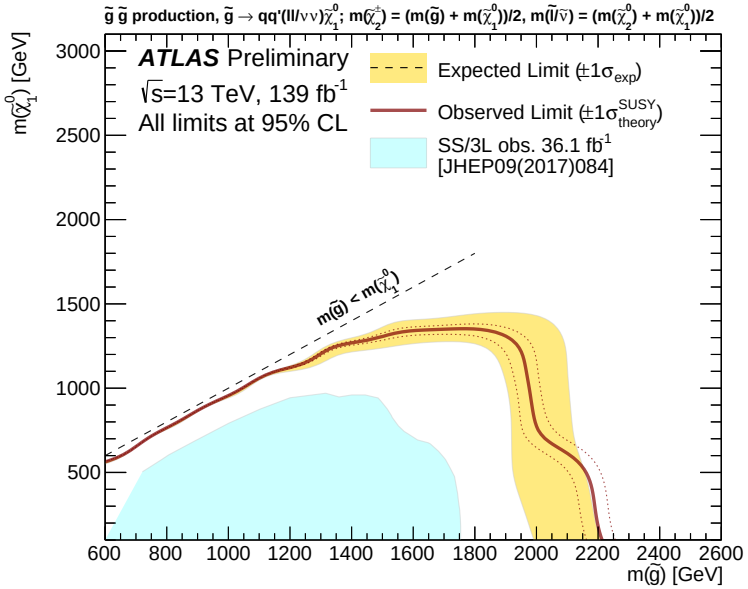


(g) Relative uncertainties

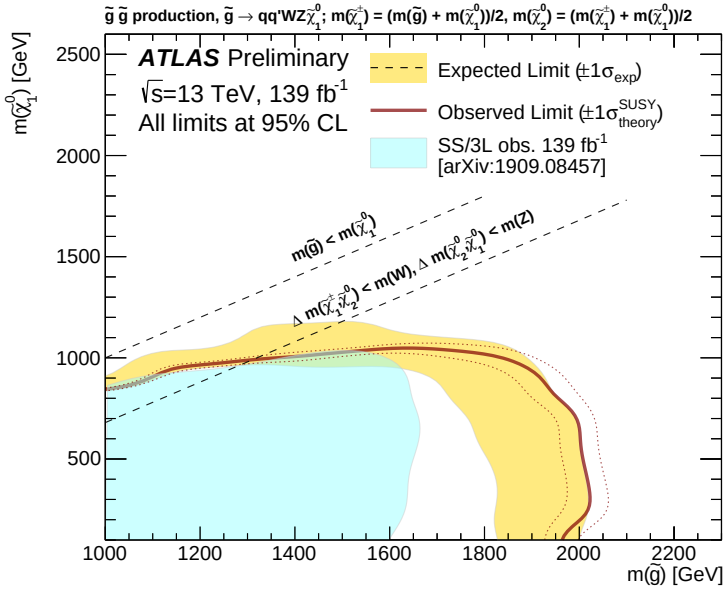
The main systematic is from estimation of Fake/non-prompt lepton.

Interpretation

Exclusion limits on $\tilde{g}$-$\tilde{\chi}_1^0$ mass plane



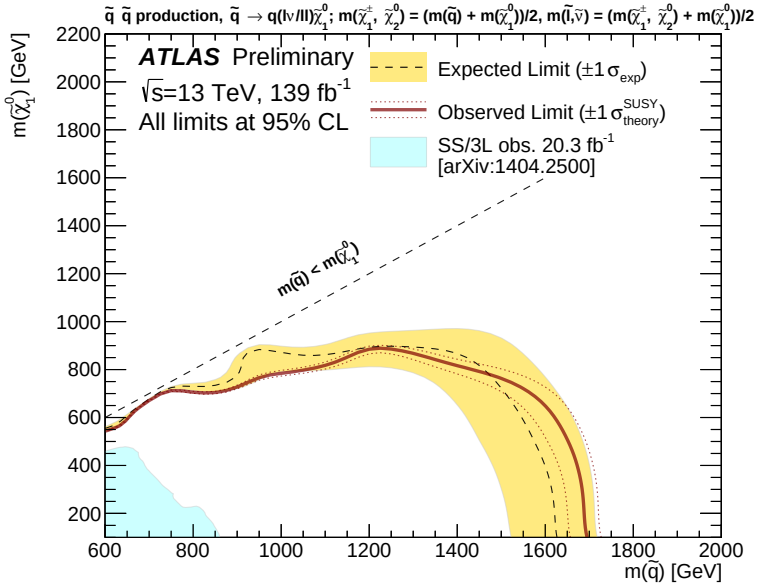
(h) GG 2-step slepton



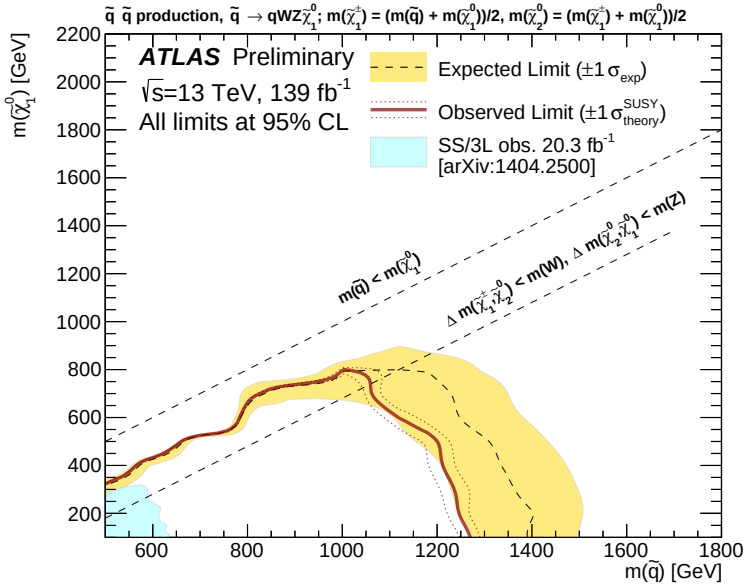
(i) GG 2-step WZ

Interpretation

Exclusion limits on $\tilde{q}$-$\tilde{\chi}_1^0$ mass plane



(j) SS 2-step slepton



(k) SS 2-step WZ

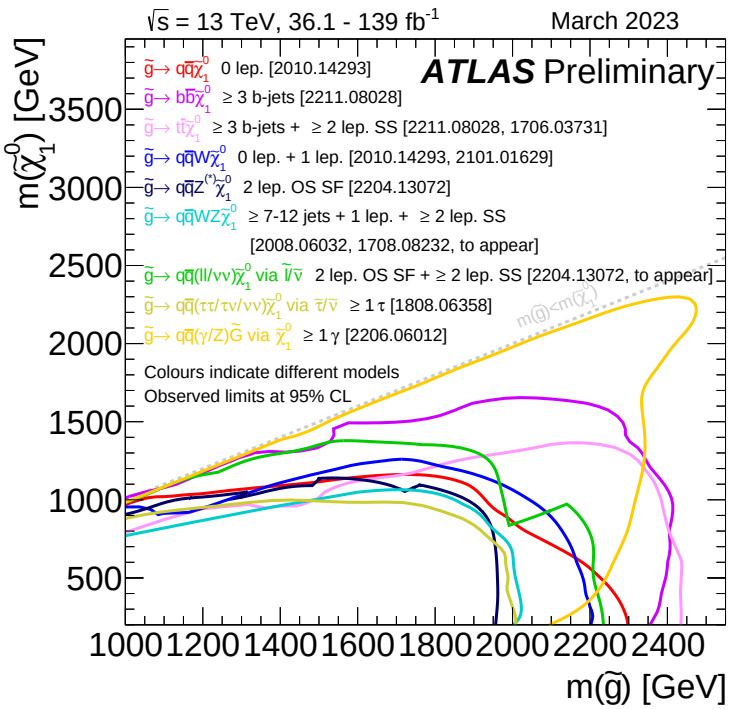
Summary

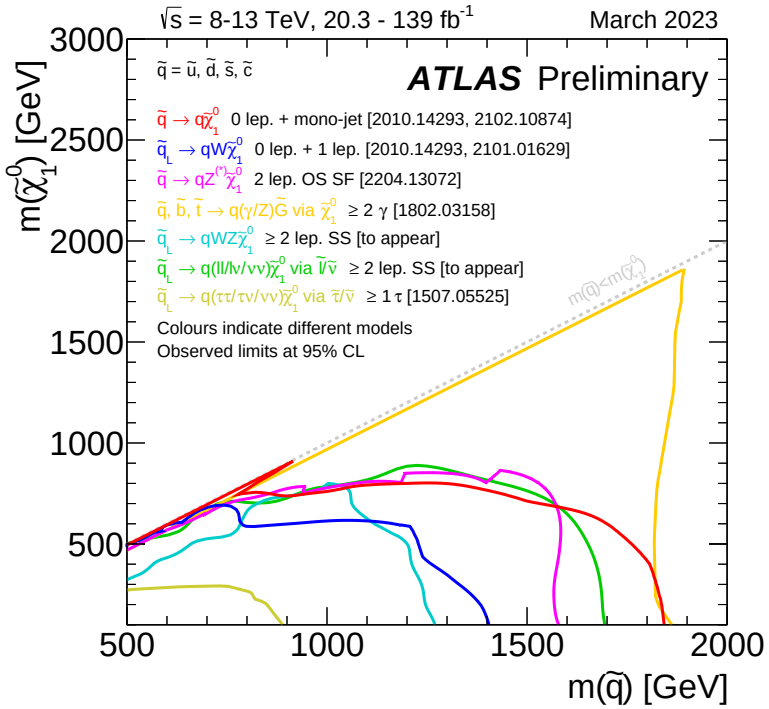
Summary: $\tilde{q}/\tilde{g}$ search in SS/3L

- No significant excess above the SM expectation is observed in all SRs.
- Lower limits on particle masses reach up to 2200 GeV for $\tilde{g}$ and 1700 GeV for $\tilde{q}$ at 95% CL.

ATLAS-CONF-2023-017

Summary: $\tilde{q}/\tilde{g}$ search in ATLAS





More results will come out soon from Run3 data.

Thanks for your attention!

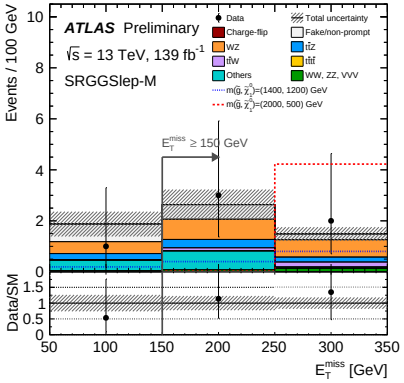
Backup

Observed data and expected background contributions

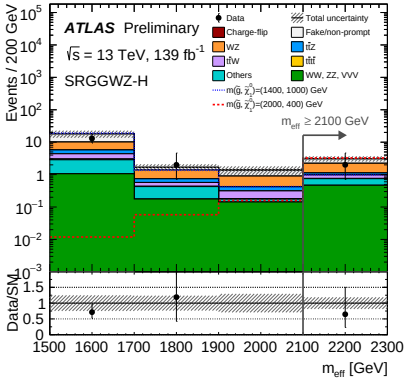
	SRGGWZ-L	SRGGWZ-M	SRGGWZ-H	SRSSWZ-L	SRSSWZ-ML	SRSSWZ-MH	SRSSWZ-H
Observed	5	2	2	4	7	6	7
Total background	3.0 ± 0.7	3.5 ± 1.1	3.3 ± 0.6	5.2 ± 1.1	3.8 ± 0.8	3.9 ± 0.6	4.2 ± 0.7
ZZ, $W^{\pm}W^{\pm}$, VVV	0.09 ± 0.05	0.37 ± 0.15	0.47 ± 0.18	0.14 ± 0.07	0.09 ± 0.05	0.11 ± 0.05	0.15 ± 0.07
WZ	1.7 ± 0.5	1.6 ± 0.9	1.3 ± 0.5	2.0 ± 0.7	3.1 ± 0.7	3.1 ± 0.5	3.2 ± 0.7
$t\bar{t}W$	0.15 ± 0.09	0.26 ± 0.12	0.22 ± 0.07	0.12 ± 0.07	< 0.05	< 0.05	0.14 ± 0.03
$t\bar{t}Z$	0.24 ± 0.08	0.38 ± 0.22	0.15 ± 0.10	0.18 ± 0.10	0.38 ± 0.12	0.38 ± 0.11	0.31 ± 0.10
$t\bar{t}t\bar{t}$	0.02 ± 0.01	0.04 ± 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Other SM processes	0.26 ± 0.17	0.53 ± 0.27	0.28 ± 0.15	0.36 ± 0.20	0.28 ± 0.15	0.25 ± 0.13	0.12 ± 0.07
Fake/non-prompt	0.56 ± 0.29	0.34 ± 0.24	0.85 ± 0.29	2.4 ± 0.8	< 0.3	< 0.3	0.24 ± 0.16
Charge-flip	< 0.02	0.03 ± 0.01	< 0.02	–	–	–	–

	SRGGSlep-L	SRGGSlep-M	SRGGSlep-H	SRSSSlep-L	SRSSSlep-ML	SRSSSlep-MH	SRSSSlep-H	SRSSSlep-H (loose)
Observed	2	5	0	9	3	6	0	10
Total background	2.9 ± 0.5	4.4 ± 0.8	3.0 ± 0.6	3.9 ± 0.8	3.6 ± 0.7	4.0 ± 0.6	0.99 ± 0.26	9.3 ± 1.9
WZ	1.39 ± 0.32	1.7 ± 0.4	1.6 ± 0.5	1.7 ± 0.5	1.6 ± 0.5	2.6 ± 0.5	0.71 ± 0.20	5.5 ± 1.3
ZZ, $W^{\pm}W^{\pm}$, VVV	0.14 ± 0.08	0.21 ± 0.11	0.18 ± 0.09	0.13 ± 0.07	0.23 ± 0.12	0.34 ± 0.17	0.04 ± 0.02	0.7 ± 0.4
$t\bar{t}W$	0.15 ± 0.08	0.31 ± 0.09	0.11 ± 0.05	0.14 ± 0.08	0.35 ± 0.07	0.30 ± 0.07	< 0.05	0.55 ± 0.29
$t\bar{t}Z$	0.15 ± 0.08	0.53 ± 0.18	0.15 ± 0.09	0.23 ± 0.14	0.19 ± 0.08	0.16 ± 0.09	0.05 ± 0.03	0.36 ± 0.22
$t\bar{t}t\bar{t}$	< 0.02	0.02 ± 0.01	0.02 ± 0.01	< 0.02	< 0.02	< 0.02	< 0.02	0.02 ± 0.01
Other SM processes	0.39 ± 0.23	0.8 ± 0.4	0.29 ± 0.18	0.7 ± 0.4	0.44 ± 0.25	0.17 ± 0.09	0.02 ± 0.03	0.34 ± 0.18
Fake/non-prompt	0.68 ± 0.32	0.8 ± 0.4	0.61 ± 0.19	0.96 ± 0.30	0.7 ± 0.4	0.46 ± 0.33	0.14 ± 0.14	1.9 ± 1.3
Charge-flip	–	–	–	–	–	–	–	–

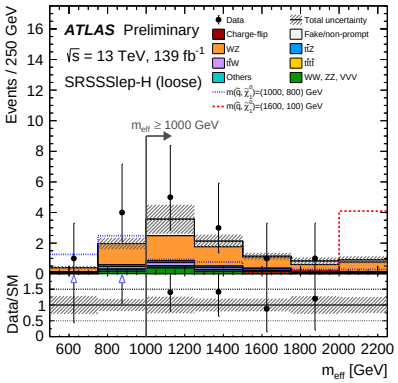
Distribution



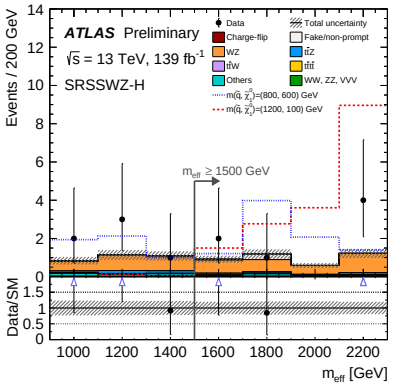
(l) SRGGSlep-M



(m) SRGGWZ-H



(n) SRSSSlep-H (loose)

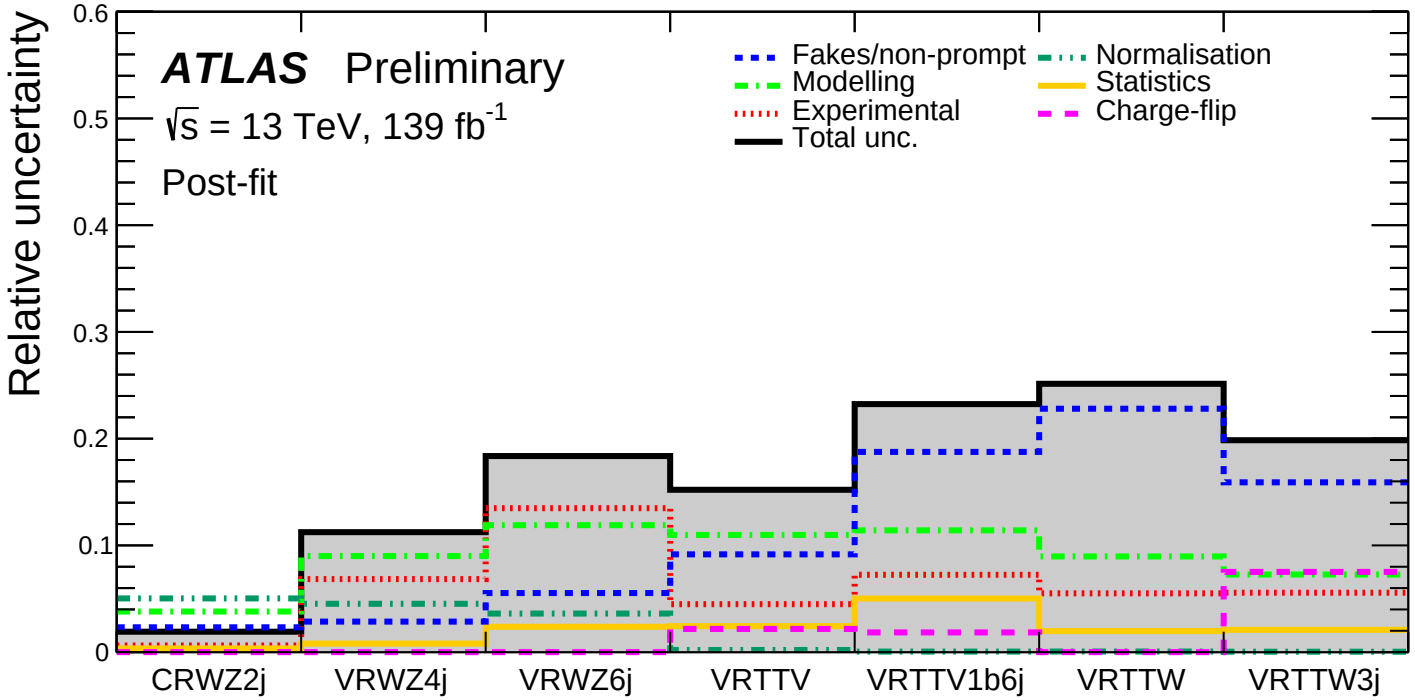


(o) SRSSWZ-H

Interpretation: model-independent fit

SR	σ_{vis}[fb]	S^{95}_{obs}	S^{95}_{exp}	CL_b	$p(s=0)$ (Z)
SRGGWZ-L	0.06	8.1	$5.2^{+2.2}_{-1.1}$	0.91	0.05 (1.64)
SRGGWZ-M	0.03	4.5	$5.2^{+2.1}_{-1.3}$	0.32	0.50 (0.00)
SRGGWZ-H	0.03	3.9	$5.0^{+2.0}_{-1.4}$	0.23	0.50 (0.00)
SRSSWZ-L	0.04	5.7	$6.1^{+2.3}_{-1.6}$	0.41	0.50 (0.00)
SRSSWZ-ML	0.07	10.4	$6.5^{+2.3}_{-1.5}$	0.94	0.02 (2.04)
SRSSWZ-MH	0.06	8.6	$5.3^{+2.0}_{-1.4}$	0.93	0.04 (1.74)
SRSSWZ-H	0.06	8.6	$5.4^{+2.5}_{-1.1}$	0.91	0.09 (1.32)
SRGGSlep-L	0.03	4.0	$4.7^{+2.0}_{-1.2}$	0.33	0.50 (0.00)
SRGGSlep-M	0.04	6.2	$5.8^{+2.2}_{-1.7}$	0.60	0.43 (0.17)
SRGGSlep-H	0.02	2.9	$4.7^{+2.0}_{-1.1}$	0.00	0.35 (0.39)
SRSSSlep-L	0.08	11.7	$5.6^{+2.4}_{-1.3}$	0.99	0.01 (2.33)
SRSSSlep-ML	0.03	4.8	$5.1^{+2.2}_{-1.3}$	0.43	0.50 (0.00)
SRSSSlep-MH	0.06	7.9	$5.4^{+2.3}_{-1.4}$	0.85	0.15 (1.06)
SRSSSlep-H	0.02	2.9	$3.5^{+1.3}_{-0.5}$	0.04	0.36 (0.35)
SRSSSlep-H (loose)	0.07	9.9	$8.1^{+3.3}_{-2.0}$	0.70	0.32 (0.46)

CR, VR systematic



(p) Relative uncertainties

Charge-flip background estimation

If one of the secondary electron tracks is subsequently preferred to the original track in the reconstruction of the electron candidate, the charge assigned to the electron might be incorrect.

$$\xi_{\mathrm{Data}} = \xi_{\mathrm{True}} \times SF; \qquad (SF = \frac{\xi_{\mathrm{Data}}}{\xi_{\mathrm{MC}}})$$

$$\xi_{\mathrm{True}} = \frac{N_{\mathrm{GoodEleWrongQ}}}{N_{\mathrm{GoodEle}}}$$

ξ_{True} is measured in $t\bar{t}$ and Z+jets MC simulations.
scale factors (SF) are released by the Egamma TP sub-group.

Fake/non-prompt lepton estimations

Non-prompt leptons arising from hadron decays or photon conversions, as well as hadrons misreconstructed as electrons.

$$\begin{pmatrix} n_{\text{signal}} \\ n_{\text{all}} \end{pmatrix} = \begin{pmatrix} 1 & 1 \\ \frac{1}{\varepsilon} & \frac{1}{\zeta} \end{pmatrix} \cdot \begin{pmatrix} n_{\text{signal, prompt}} \\ n_{\text{signal, F/NP}} \end{pmatrix} \tag{1}$$

ε: probabilities for prompt leptons, calculated with simulated $t\bar{t}$ decays to leptons.
ζ: probabilities fake/non-prompt leptons, measured in the range 10GeV$<$ pt $<$75GeV in dedicated regions in data enriched predominantly in $t\bar{t}$ events with one or two prompt leptons and one F/NP lepton forming a same-sign pair.