

Searches for Supersymmetry with the ATLAS detector

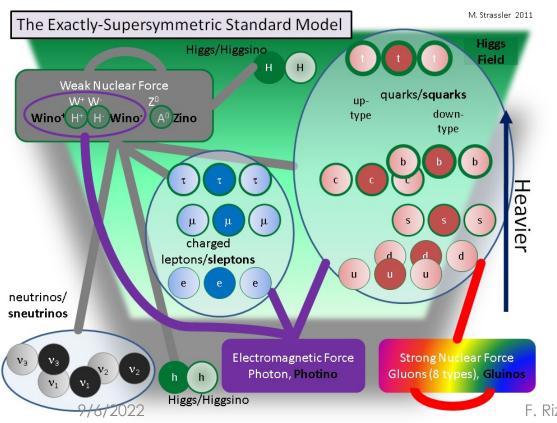
FLERA RIZATDINOVA ON BEHALF OF THE ATLAS COLLABORATION

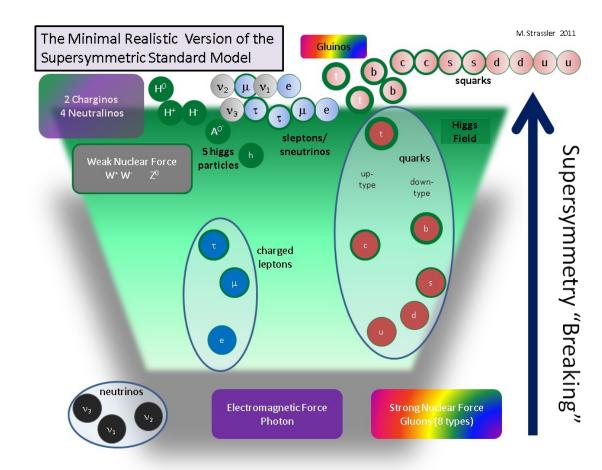
Introduction

- Supersymmetry: a set of theories that predict existence of boson (fermion) partners for existing fermion (boson) particles of the Standard Model
 - offers a mechanism to stabilize the Higgs boson mass
- Several Higgs bosons in the theory in addition to the SM boson, both neutral and charged
 - neutral higgsinos and neutral EW gauginos mix to form neutralinos
 - charged higgsinos and charged EW gauginos mix to form charginos
- If R-parity R=(-1)^{3(B-L)+2S} is conserved, the lightest neutral SUSY particle (LSP) can't decay, making it a dark matter candidate

SUSY in a nutshell

• If the world were exactly supersymmetric, every particle known would have superpartners with the same interactions and the same mass





 For supersymmetry to be consistent with data, it must be hidden or "spontaneously broken," pushing the SUSY masses beyond existing experimental limits

Simplified SUSY models

- Too many model parameters (124 in MSSM) what to search for?
- The approach: make assumptions to reduce the parameter space (down to 3 4 parameters) and focus on specific decay chains
 - Pro: easier to make searches orthogonal, to combine, and to re-interpret
 - Con: almost guaranteed not to be what is realized in nature
- Boosted vs compressed modes
 - boosted: larger difference between decaying sparticles and resulting particles, more energy per object
 - compressed: smaller difference, less energy per object

Ways to look for SUSY signals

• Kinematics of events

- large missing momentum: sensitive to RPC scenarios with LSP in the final state that escape detection
- large event energy scale
- characteristic event energy structure (invariant masses, angles)
- Specific event features
 - multiple heavy flavor jets in the final state
 - long-lived objects (in RPV scenarios)

A snapshot of SUSY results at ATLAS

ATLAS SUSY Searches* - 95% CL Lower Limits March 2022

ATLAS Preliminary $\sqrt{s} = 13 \text{ TeV}$

March 2022			\sqrt{s} = 13 TeV
Model	Signature ∫⊥ dt [fb ⁻¹	Mass limit	Reference
$\tilde{q}\tilde{q}, \tilde{q} \rightarrow q \tilde{\chi}_1^0$	$\begin{array}{ccc} 0 \ e, \mu & ext{ 2-6 jets } E_T^{ ext{miss}} & ext{139} \\ ext{mono-jet} & ext{1-3 jets } E_T^{ ext{miss}} & ext{139} \end{array}$	q 1.0 1.85 q [8x Degen.] 0.9	$\begin{array}{c} m(\tilde{x}_1^0)\!$
$\begin{array}{c} \tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}\tilde{\chi}_{1}^{0} \\ \tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}\tilde{\chi}_{1}^{0} \\ \tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}W\tilde{\chi}_{1}^{0} \\ \tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}(U)\tilde{\chi}_{1}^{0} \\ \tilde{g}\tilde{g}, \tilde{g} \rightarrow qqWZ\tilde{\chi}_{1}^{0} \\ \tilde{g}\tilde{g}, \tilde{g} \rightarrow qWZ\tilde{\chi}_{1}^{0} \end{array}$	0 e, μ 2-6 jets E_T^{miss} 139	ğ 2.3 ğ Forbidden 1.15-1.95	$m(\xi_1^0)=0 \text{ GeV}$ 2010.14293 $m(\tilde{\xi}_1^0)=1000 \text{ GeV}$ 2010.14293
$\widetilde{\mathcal{S}}$ $\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\bar{q}W\tilde{\chi}_{1}^{0}$	1 <i>e</i> , <i>µ</i> 2-6 jets 139	<i>ğ</i> 2.2	m($\tilde{\chi}_1^0$)<600 GeV 2101.01629
$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\bar{q}(\ell\ell)\tilde{\chi}_1^0$	$ee, \mu\mu$ 2 jets E_T^{miss} 139	ĝ 2.2	m(ζ_1^0)<700 GeV CERN-EP-2022-014
$\tilde{g}\tilde{g}, \tilde{g} \rightarrow qqWZ\tilde{\chi}_1^0$	$\begin{array}{cccc} 0 \ e, \mu & \ 7 \ -11 \ { m jets} & \ E_T^{ m miss} & \ 139 \ { m SS} \ e, \mu & \ 6 \ { m jets} & \ 139 \end{array}$	ž 1.97 ž 1.15	m(ℓ_1^0)<660 GeV 2008.06032 m(g)-m(ℓ_1^0)=200 GeV 1909.08457
$\Xi \tilde{g}\tilde{g}, \tilde{g} \rightarrow t \tilde{t} \tilde{\chi}_1^0$	$\begin{array}{cccccc} 0{-}1 & e, \mu & 3 & b & E_T^{\rm miss} & 79.8 \\ {\rm SS} & e, \mu & 6 & {\rm jets} & 139 \end{array}$	ŝ ŝ 1.25	m(\$\vec{k}') < 200 GeV ATLAS-CONF-2018-041 m(\vec{k}')-m(\vec{k}')=300 GeV 1909.08457
$ ilde{b}_1 ilde{b}_1$	$0 e, \mu$ $2 b E_T^{miss}$ 139	δ ₁ 1.255 δ ₁ 0.68	m(K ¹)<400 GeV 2101.12527 10 GeV<∆m(J ₁ ,X ¹)>20 GeV 2101.12527
$\tilde{b}_1 \tilde{b}_1, \tilde{b}_1 \rightarrow b \tilde{\chi}_2^0 \rightarrow b h \tilde{\chi}_1^0$	$\begin{array}{cccc} 0 \ e, \mu & 6 \ b & E_T^{\rm miss} & 139 \\ 2 \ \tau & 2 \ b & E_T^{\rm miss} & 139 \end{array}$	$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	⁰)=130 GeV, m(ζ ⁰)=100 GeV 1908.03122 , ζ ⁰)=130 GeV, m(ζ ⁰)=0 GeV 2103.08189
$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow t \tilde{\chi}_1^0$	0-1 $e, \mu \ge 1$ jet E_T^{miss} 139	ĩ ₁ 1.25	m($\tilde{\chi}_{1}^{0}$)=1 GeV 2004.14060,2012.03799
$\begin{array}{c} \begin{array}{c} \bullet \\ \bullet $	1 e, μ 3 jets/1 b E_T^{miss} 139 1-2 τ 2 jets/1 b E_T^{miss} 139	<i>i</i> ₁ Forbidden 0.65 <i>i</i> ₁ Forbidden 1.4	m($\tilde{\chi}_1^0$)=500 GeV 2012.03799 m($\tilde{\tau}_1$)=800 GeV 2108.07665
$ \begin{array}{c} \mathbf{\tilde{h}}_{1}\mathbf{\tilde{h}}_{1}, \mathbf{\tilde{h}}_{1} \rightarrow \mathbf{\tilde{t}}_{1}\mathbf{\tilde{b}}_{1}, \mathbf{\tilde{t}}_{1} \rightarrow \mathbf{\tilde{t}}_{1}\mathbf{\tilde{b}}_{1}, \mathbf{\tilde{t}}_{1} \rightarrow \mathbf{\tilde{t}}_{1}\mathbf{\tilde{t}}_{1} \end{array} \\ \mathbf{\tilde{t}}_{1}\mathbf{\tilde{t}}_{1}, \mathbf{\tilde{t}}_{1} \rightarrow \mathbf{\tilde{t}}_{1}\mathbf{\tilde{t}}_{1}^{0} / \mathbf{\tilde{c}}\mathbf{\tilde{c}}, \mathbf{\tilde{c}} \rightarrow \mathbf{\tilde{c}}\mathbf{\tilde{t}}_{1}^{0} \end{array} $		τ ₁ <i>Porbidden</i> 1.4 č 0.85	$m(\chi^0_1) = 0$ GeV 1805.01649
<u> </u>	$0 e, \mu$ mono-jet E_T^{fniss} 139	Ĩ ₁ 0.55	$m(\tilde{t}_1,\tilde{c})-m(\tilde{x}_1^0)=5$ GeV 2102.10874
$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow t \tilde{\chi}_2^0, \tilde{\chi}_2^0 \rightarrow Z/h \tilde{\chi}_1^0$	$1-2 \ e, \mu$ $1-4 \ b \ E_T^{\text{miss}}$ 139	<i>ĩ</i> ₁ 0.067-1.18	$m(\tilde{k}_2^0) = 500 \text{ GeV}$ 2006.05880
$\tilde{t}_2 \tilde{t}_2, \tilde{t}_2 \rightarrow \tilde{t}_1 + Z$	$3 e, \mu$ $1 b E_T^{\text{miss}}$ 139		30 GeV, m(ĩ₁)-m(X̃₁)= 40 GeV 2006.05880
$ ilde{\chi}_1^{\pm} ilde{\chi}_2^0$ via WZ	$\begin{array}{llllllllllllllllllllllllllllllllllll$	$egin{array}{cccc} & \chi_1^{\pm}/\tilde{\chi}_2^0 & & 0.96 \ & \chi_1^{\pm}/\tilde{\chi}_2^0 & & 0.205 \end{array}$	$m(\tilde{\chi}_1^0)=0$, wino-bino 2106.01676, 2108.07586 $(\tilde{\chi}_1^0)-m(\tilde{\chi}_1^0)=5$ GeV, wino-bino 1911.12606
$\tilde{\chi}_1^{\pm} \tilde{\chi}_1^{\mp}$ via WW	$2 e, \mu$ E_T^{miss} 139	$\tilde{\chi}_{1}^{\pm}$ 0.42	m($\tilde{\chi}_1^0$)=0, wino-bino 1908.08215
$\tilde{\chi}_{1}^{\pm}\tilde{\chi}_{2}^{0}$ via Wh	Multiple ℓ /jets E_T^{miss} 139	$\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0$ Forbidden 1.06	m($\tilde{\chi}_1^0$)=70 GeV, wino-bino 2004.10894, 2108.07586
$\begin{array}{c} \overleftarrow{\mathbf{x}}_{1}^{\pm} \widetilde{\mathbf{x}}_{1}^{\mp} \operatorname{via} \widetilde{\ell}_{L} / \widetilde{\mathbf{v}} \\ \overrightarrow{\mathbf{x}}_{1}^{\pm} \widetilde{\tau}_{1}, \widetilde{\tau}_{-} \tau \widetilde{\mathbf{x}}_{1}^{0} \\ \overrightarrow{\tau} \widetilde{\tau}, \widetilde{\tau}_{-} \tau \widetilde{\mathbf{x}}_{1}^{0} \end{array}$	$\begin{array}{ccc} 2 \ e, \mu & E_T^{\text{miss}} & 139 \\ 2 \ \tau & E_T^{\text{miss}} & 139 \end{array}$	$\tilde{\chi}_{1}^{+}$ 1.0 $\tilde{\tau}$ [$\tilde{\tau}_{L}, \tilde{\tau}_{R,L}$] 0.16-0.3 0.12-0.39	$\begin{array}{ccc} m(\tilde{\ell}, \tilde{\nu}) = 0.5(m(\tilde{\ell}_1^+) + m(\tilde{\ell}_1^0)) & 1908.08215 \\ m(\tilde{\ell}_1^0) = 0 & 1911.06660 \end{array}$
$\begin{array}{c} \blacksquare \overleftarrow{\eth} & \stackrel{\tau\tau, \tau \to \tau \chi_1}{\tilde{\ell}_{L,R} \tilde{\ell}_{L,R}, \tilde{\ell} \to \ell \tilde{\chi}_1^0} \end{array}$		<i>t</i> (L, K, L) 0.10-0.3 0.12-0.39	$m(\chi_1)=0$ 1911.0000 $m(\chi_1^0)=0$ 1908.08215
		<i>ī</i> 0.256	m(ℓ)-m(ℓ1)=10 GeV 1911.12606
$\tilde{H}\tilde{H}, \tilde{H} \rightarrow h\tilde{G}/Z\tilde{G}$	$\begin{array}{llllllllllllllllllllllllllllllllllll$	H 0.13-0.23 0.29-0.88 H 0.55	$\begin{array}{ccc} BR(\lambda_1^0 \to h\tilde{C}) = 1 & 1806.04030 \\ BR(\lambda_1^0 \to Z\tilde{C}) = 1 & 2103.11684 \end{array}$
	$0 e, \mu \ge 2$ large jets E_T 139	й 0.45-0.93	$\begin{array}{c c} BR(\vec{X}_1^0 \to Z\vec{O}) = 1 & 2103.11684 \\ BR(\vec{X}_1^0 \to Z\vec{O}) = 1 & 2108.07586 \end{array}$
Direct $\tilde{\chi}_1^+ \tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^+$	^e Disapp. trk 1 jet E_T^{miss} 139	$ \tilde{\chi}^{\pm}_{1} = 0.66 $ $ \tilde{\chi}^{\pm}_{1} = 0.21 $	Pure Wino 2201.02472 Pure higgsino 2201.02472
Stable g R-hadron	pixel dE/dx E_T^{miss} 139	ğ 2.05	CERN-EP-2022-029
		\tilde{g} [r(\tilde{g}) =10 ns] 2.2	$m(\tilde{\chi}_1^0)$ =100 GeV CERN-EP-2022-029
Metastable g R-hadron, $g \rightarrow qqk$ $\tilde{\ell}\tilde{\ell}, \tilde{\ell} \rightarrow \ell\tilde{G}$	Displ. lep E_T^{miss} 139	ē, µ 0.7	$\tau(\tilde{\ell}) = 0.1 \text{ns}$ 2011.07812
	pixel dE/dx E_T^{miss} 139	τ 0.34 τ 0.36	$\tau(\tilde{\ell}) = 0.1 \text{ ns}$ 2011.07812 $\tau(\tilde{\ell}) = 10 \text{ ns}$ CERN-EP-2022-029
$\tilde{\chi}_1^{\pm} \tilde{\chi}_1^{\mp} / \tilde{\chi}_1^0, \tilde{\chi}_1^{\pm} \rightarrow Z \ell \rightarrow \ell \ell \ell$	3 <i>e</i> , <i>µ</i> 139	$\tilde{\chi}_{1}^{\mp}/\tilde{\chi}_{1}^{0}$ [BR($Z\tau$)=1, BR(Ze)=1] 0.625 1.05	Pure Wino 2011.10543
$\tilde{\chi}_1^{\pm} \tilde{\chi}_1^{\mp} / \tilde{\chi}_2^0 \rightarrow WW/Z\ell\ell\ell\ell\nu\nu$	4 e, μ 0 jets E_T^{miss} 139 4-5 large jets 36.1	$\tilde{\lambda}_{1}^{\pm}/\tilde{\lambda}_{2}^{0}$ [$\lambda_{t33} \neq 0, \lambda_{12k} \neq 0$] 0.95 1.55 $\tilde{\rho}$ [m($\tilde{\lambda}_{1}^{0}$)=200 GeV 1100 GeV] 1.3 1.9	m(\tilde{k}_1^0)=200 GeV 2103.11684 Large $\mathcal{X}_{112}^{\prime}$ 1804.03568
$\widetilde{g}\widetilde{g}, \widetilde{g} \to qq\widetilde{\chi}_1^0, \widetilde{\chi}_1^0 \to qqq$ $\widetilde{t}, \widetilde{t} \to t\widetilde{\chi}_1^0, \widetilde{\chi}_1^0 \to tbs$	4-5 large jets 36.1 Multiple 36.1	$\tilde{g} \ [m(\tilde{k}_1^0)=200 \text{ GeV}, 1100 \text{ GeV}]$ 1.3 1.9 $\tilde{t} \ [l_{1,3}^{\prime}=2e\cdot4, 1e\cdot2]$ 0.55 1.05	$m(\tilde{\chi}_1^0)=200 \text{ GeV, bino-like}$ ATLAS-CONF-2018-003
$\begin{array}{l} \overbrace{i}^{\widetilde{t}}, \overbrace{i}^{\widetilde{t}} \rightarrow t \chi_{1}^{\widetilde{t}}, \chi_{1}^{\widetilde{t}} \rightarrow t b s \\ \overbrace{i}^{\widetilde{t}}, \overbrace{i} \rightarrow b \widetilde{\chi}_{1}^{\pm}, \widetilde{\chi}_{1}^{\pm} \rightarrow b b s \end{array}$	$\geq 4b$ 139	i Forbidden 0.95	$m(\tilde{\chi}_1^+)=200 \text{ GeV}$ 2010.01015
$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow bs$	2 jets + 2 b 36.7	$\tilde{t}_1 [qq, bs]$ 0.42 0.61	
$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow q\ell$	$\begin{array}{cccc} 2 \ e, \mu & 2 \ b & 36.1 \\ 1 \ \mu & \text{DV} & 136 \end{array}$	$\frac{\tilde{t}_1}{\tilde{t}_1} = \frac{0.4-1.45}{1.0}$	BR(i,-+b(p))>20% BR(i,-+g(p)=100%, cos(),=1 BR(i,g(p)=100%, cos(),=1 BR(i,g(p)=100%, cos(),=1
$\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0/\tilde{\chi}_1^0, \tilde{\chi}_{1,2}^0 \rightarrow tbs, \tilde{\chi}_1^+ \rightarrow bbs$	$1-2 \ e, \mu \ge 6 \ jets$ 139	\tilde{x}_1^0 0.2-0.32	Pure higgsino 2106.09609
			6
*Only a selection of the available		0 ⁻¹ 1 N	lass scale [TeV]

9/6/2022

*Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.

Latest ATLAS SUSY results

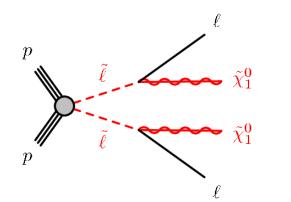
• Reviewed in this presentation:

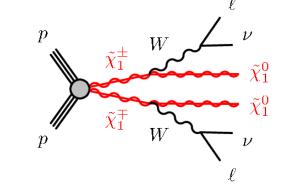
- sleptons/charginos in 2I+0j
- charginos/neutralinos in 2I+2j
- squarks/gluinos in 2l+2j
- charginos/neutralinos in all hadronic
- LLP: disappearing track
- LLP: dE/dx

• Many more results are published or are coming soon!

*EW*²*l*+0*j*

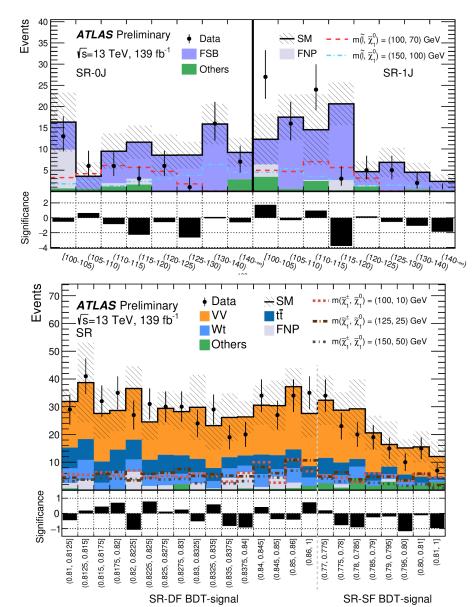
- Searching for EW production of charginos and sleptons in events with two OS leptons and MET using BDT
- Searches are targeting the phase space, where mass difference between sleptons and charginos is close to the mass of W. Light smuons can provide an explanation for the muon g-2 anomaly.





• Main backgrounds: tt, Wt, VV

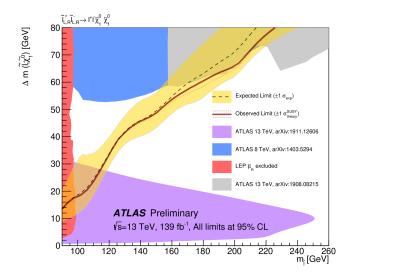
ATLAS-CONF-2022-006

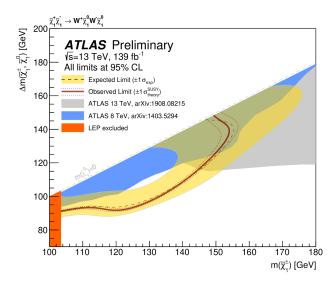


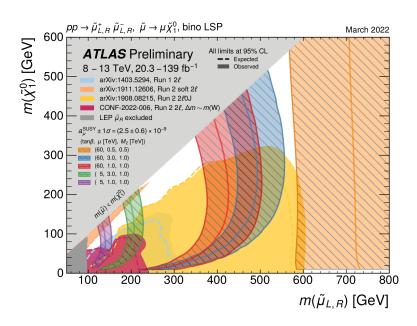
9/6/2022

EW²l+0j: results

- Sleptons with masses up to 150 GeV are excluded for the mass splitting between slepton and LSP of 50 GeV.
- Chargino masses up to 135 GeV are excluded for the mass splitting between chargino and LSP up to 100 GeV
- Smuons exclusion limit still have some regions compatible with results of g-2 experiment

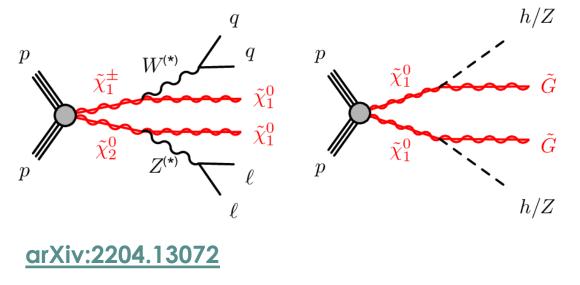


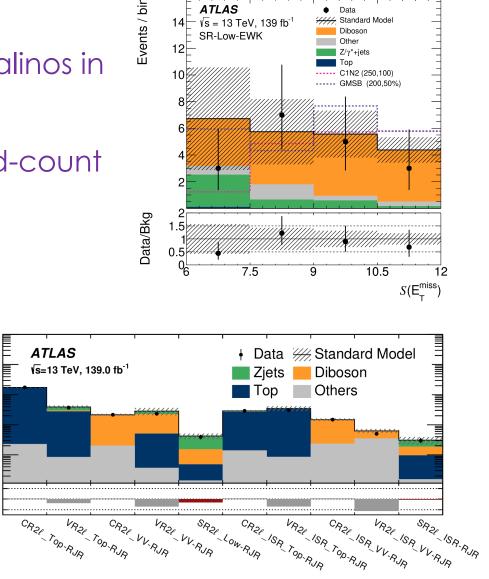




EW 2*l*+2*j*

- Searching for EW production of charginos / neutralinos in events with two OS leptons, ≥2 jets and MET
- 139/fb, recursive-jigsaw reconstruction or cut-and-count
- Models: C1N2, GMSB
- Backgrounds: VV, tt, Drell-Yan





Events

Significance

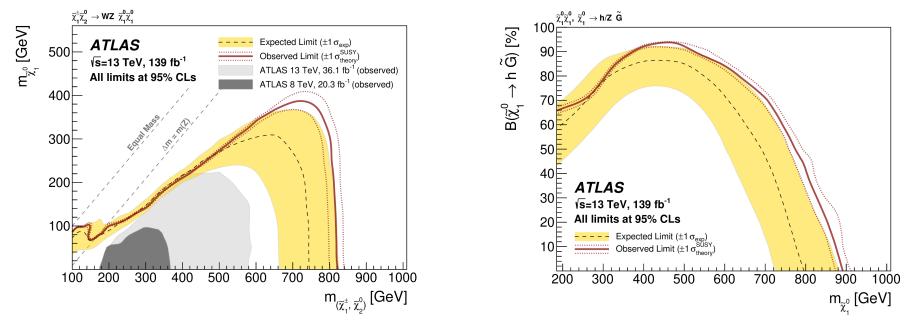
 10^{3}

10²

10

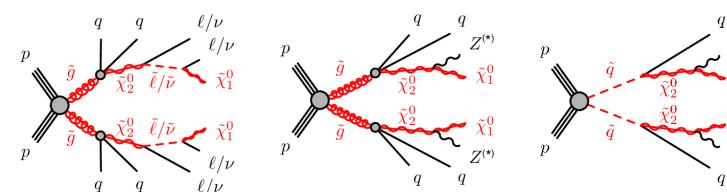
EW 2l+2j: results

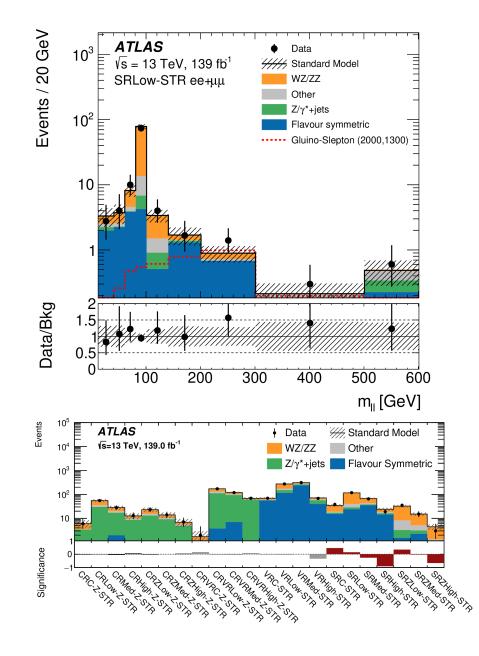
- RJR: model-independent search, a follow-up on the 36/fb 2l2j excess of 2.0σ (ISR region) / 1.4σ (low-mass region)
 - no excess in any of signal regions
- Cut-and-count search: exclude electroweakinos up to 900 GeV



Strong 2l+2j

- Searching for production of squarks / gluinos in events with two OS leptons, ≥2 jets and MET
- 139/fb, cut-and-count
- Models: gluino-slepton, gluino-Z(*), squark-Z(*)
- Backgrounds: VV, tt, Drell-Yan, instrumental

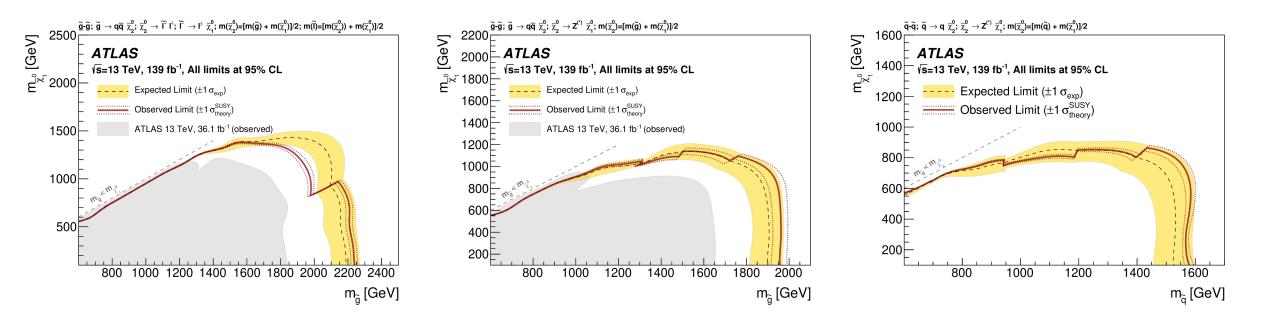




arXiv:2204.13072

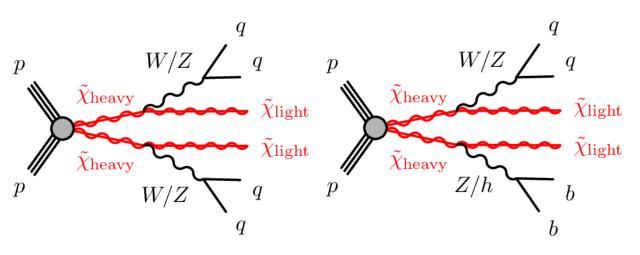
Strong 21+2j: results

• Exclude masses up to 1550 GeV for squarks and 2250 GeV for gluinos

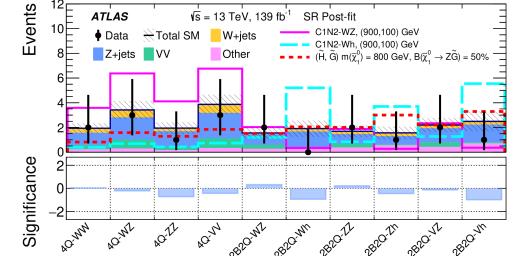


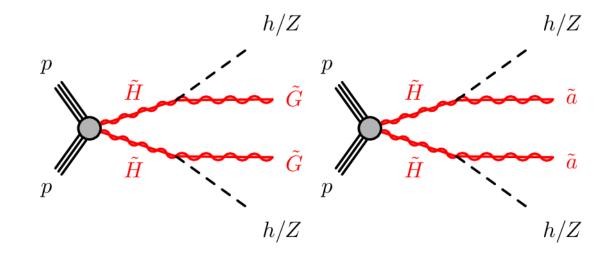
EW all hadronic

- Searching for EW production of charginos / neutralinos in events with two boosted hadronically decaying bosons and MET
- Models: baseline MSSM, GGM / naturalness-driven gravitino LSP, naturalness-driven axino LSP
- Main BG: $Z(\rightarrow vv)$ +jets semi-data-driven estimation



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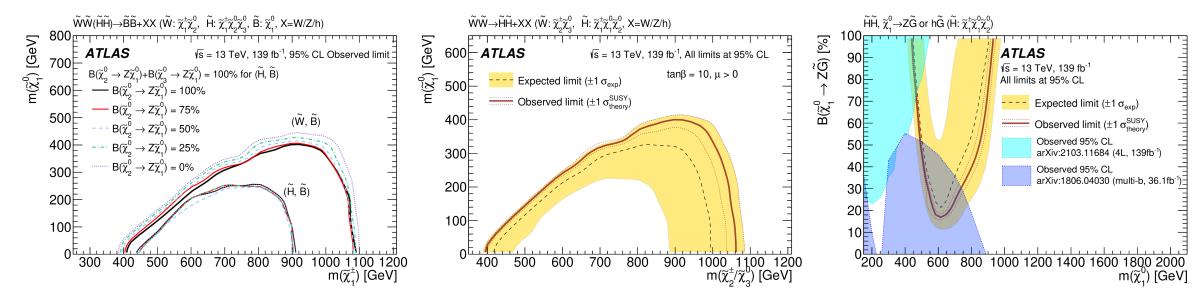




14

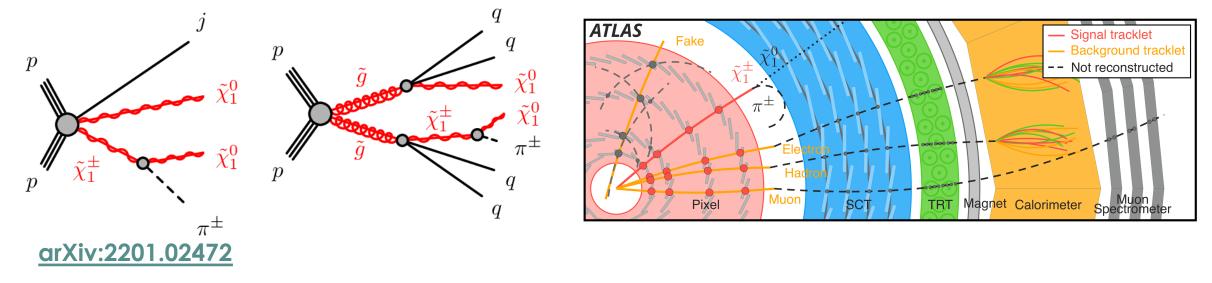
EW all hadronic: results

- Exclude wino (higgsino) up to 1060 (900) GeV when LSP mass is below 400 (240) GeV and mass splitting is larger than 400 (450) GeV
- Examples of exclusion plots for $(\widetilde{W}, \widetilde{B})/(\widetilde{H}, \widetilde{B})$, $(\widetilde{W}, \widetilde{H})$ and $(\widetilde{H}, \widetilde{G})$ models



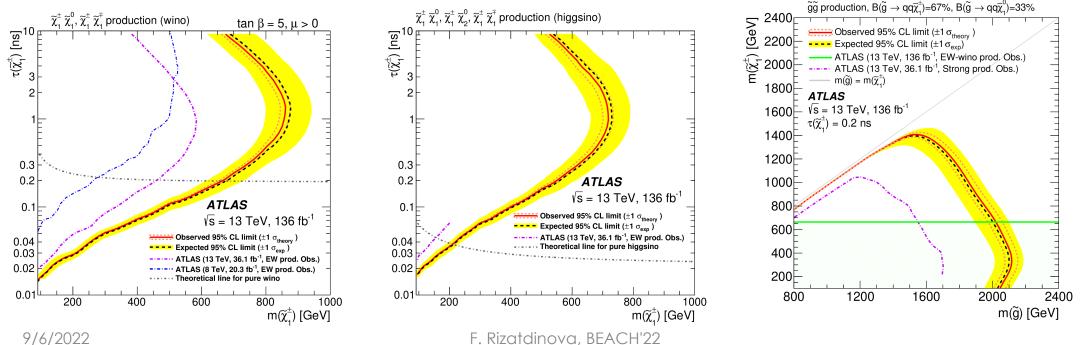
Disappearing track

- Searching for EW or strong production of long-lived charginos decaying into LSP and a low momentum π + (due to small mass difference between chargino and neutralino)
- Signature: MET + a track that crosses pixel layers and then disappears
- Background is dominated by fake tracklets and it is estimated using a template method in the CR



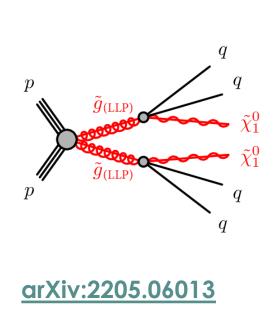
Disappearing track: results

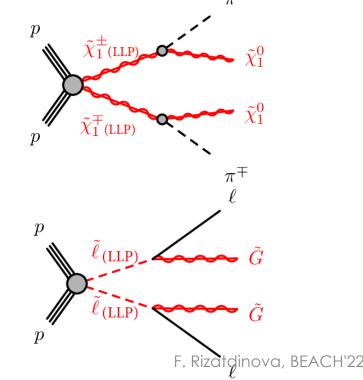
- Chargino masses excluded up to 660 (210) GeV when chargino is pure wino (higgsino)
- For charginos from gluino cascade decays, gluinos up to 2.1 TeV are excluded for charginos of 300 GeV and a lifetime of 0.2 ns



dE/dx in the pixel detector

- Searching for EW or strong production of heavy, longlived R-hadrons / charginos / sleptons
- Signature: a track with large specific ionization losses in the pixel detector + MET
- 139/fb, cut-and-count



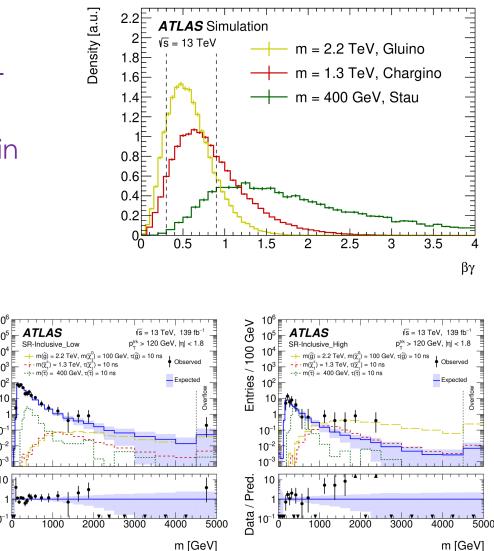


GeV

8

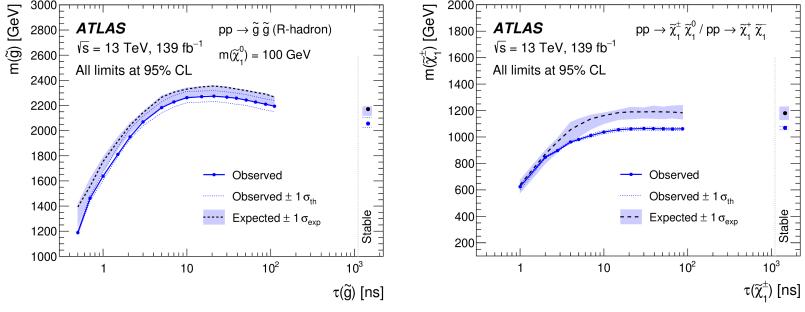
Entries

Data / Pred



dE/dx: results

- Maximum sensitivity achieved for LLPs with lifetimes τ of 10 30 ns
- Exclude masses up to 2.27 TeV for gluino R-hadrons with τ =20 ns and an LSP mass of 100 GeV, up to 1.07 TeV for charginos with τ =30 ns



Conclusion

- ATLAS has an extensive SUSY search program
 - various original analyses
 - expanding coverage thanks to reinterpretation of existing results
- Identifying uncovered areas and looking for new ways to explore the SUSY parameter space
- A lot of interesting results are obtained with Run 2 data, more to come
- Looking forward to taking more data with Run 3 that recently started





Thank you!

And special thanks to:



DOE for supporting this research

The ATLAS Collaboration

