

NP searches

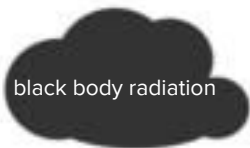
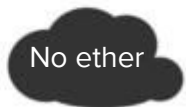
Summary & Highlights

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Why new physics:

20th century



Classical landscape

Today

	mass → $\approx 2.3 \text{ MeV}/c^2$ charge → $2/3$ spin → $1/2$ u up	mass → $\approx 1.275 \text{ GeV}/c^2$ charge → $2/3$ spin → $1/2$ c charm	mass → $\approx 173.07 \text{ GeV}/c^2$ charge → $2/3$ spin → $1/2$ t top	mass → 0 charge → 0 spin → 1 g gluon	mass → $\approx 126 \text{ GeV}/c^2$ charge → 0 spin → 0 H Higgs boson
QUARKS	mass → $\approx 4.8 \text{ MeV}/c^2$ charge → $-1/3$ spin → $1/2$ d down	mass → $\approx 95 \text{ MeV}/c^2$ charge → $-1/3$ spin → $1/2$ s strange	mass → $\approx 4.18 \text{ GeV}/c^2$ charge → $-1/3$ spin → $1/2$ b bottom	mass → 0 charge → 0 spin → 1 γ photon	
	mass → $0.511 \text{ MeV}/c^2$ charge → -1 spin → $1/2$ e electron	mass → $105.7 \text{ MeV}/c^2$ charge → -1 spin → $1/2$ μ muon	mass → $1.777 \text{ GeV}/c^2$ charge → -1 spin → $1/2$ τ tau	mass → $91.2 \text{ GeV}/c^2$ charge → 0 spin → 1 Z Z boson	
LEPTONS	mass → $< 2.2 \text{ eV}/c^2$ charge → 0 spin → $1/2$ ν_e electron neutrino	mass → $< 0.17 \text{ MeV}/c^2$ charge → 0 spin → $1/2$ ν_μ muon neutrino	mass → $< 15.5 \text{ MeV}/c^2$ charge → 0 spin → $1/2$ ν_τ tau neutrino	mass → $80.4 \text{ GeV}/c^2$ charge → ± 1 spin → 1 W W boson	GAUGE BOSONS

Why new physics:

Unification

Hierarchy

Dark Matter

Matter/Anti
Asymmetry

Ele VS Comp

Neutrino oscillation

small gravity

Large gap between
EW & Planck scales



SM landscape

Why new physics:

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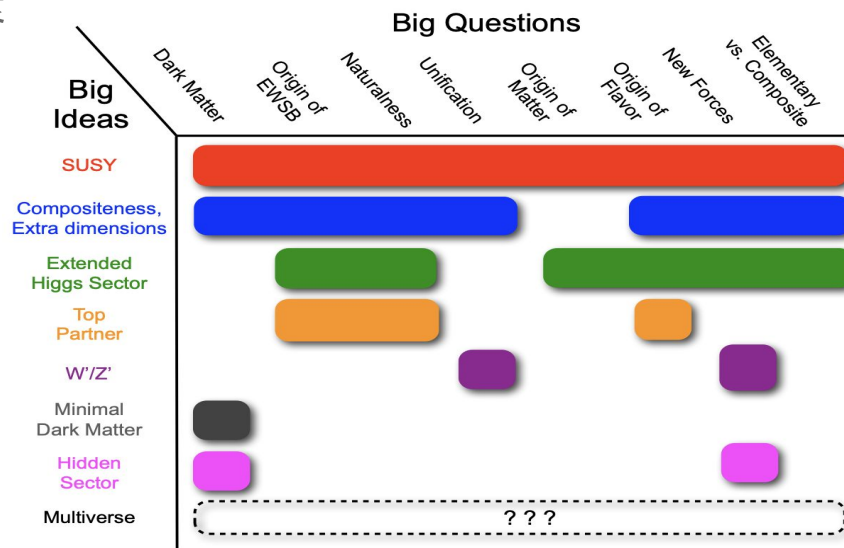
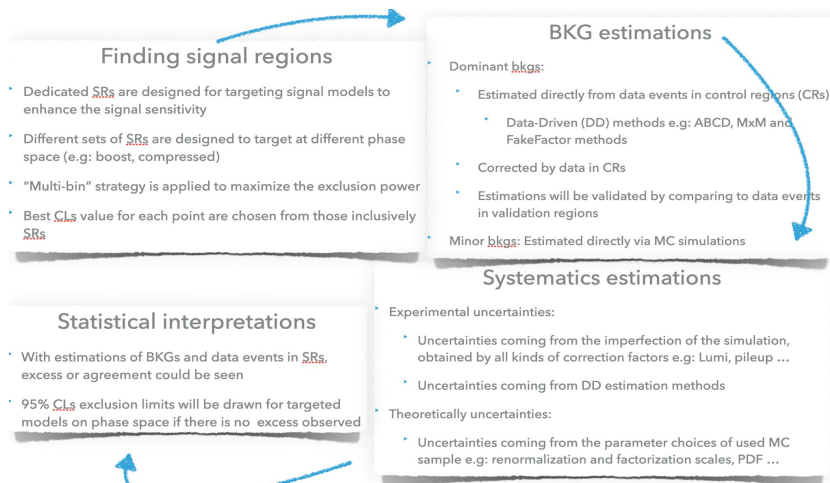
Large gap between
EW & Planck scales



Golden age for revolutionary discovery!

Overview of NP searches @ LHC:

- LHC is world's most powerful facilities to push the limits of our understanding of the universe at high energy frontier
- Searches covering most appealing directions of the new physics:
 - HBSM: see talk from Jin Wang
 - **Exotics**: see more details from 昊许, TianaoWang, 齐斌刘, 桐彬赵, YifanYang, 丹宁刘, 睿袁
 - **SUSY**: see more details from 诗怡梁, 家荣袁



Exostic searches

Exotic summary:

ATLAS Heavy Particle Searches* - 95% CL Upper Exclusion Limits

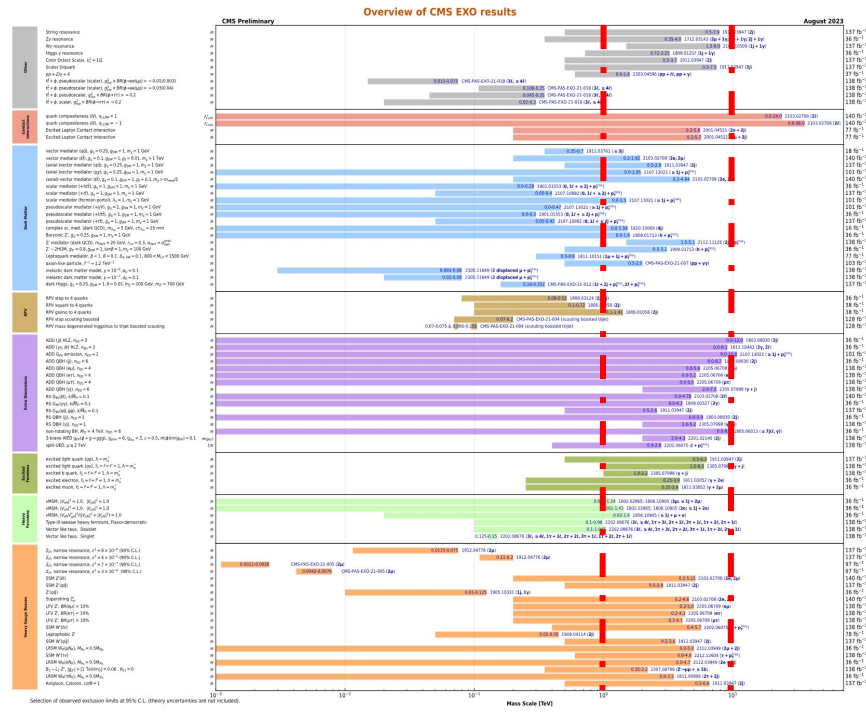
Status: March 2023

Model	f, γ	Jets [†]	$m_{\text{excl}}^{\text{min}} [TeV]$	Limit	$\int \mathcal{L} dt = (3.6 - 139) fb^{-1}$	Reference
Extra dimen.	ADD $G_{\mu\nu} / g$	$0, e, \mu, \tau, \gamma$	1-4	Yes	139	2102.10074
	ADD non-resonant $\gamma\gamma$	2γ	-	Yes	36.7	1910.04147
	ADD $\mathcal{O}BH$	-	$2j$	-	139	1910.08447
	ADD BH multilet	-	$\geq 3j$	-	3.6	1512.02586
	RSI $G_{\mu\nu} \rightarrow \gamma\gamma$	2γ	-	Yes	139	2102.13405
	Bulk RS $G_{\mu\nu} \rightarrow WW/ZZ$	multi-channel	-	Yes	36.1	1908.02390
Gauge bosons	Bulk RS $g_{\mu\nu} \rightarrow tt$	$1, e, \mu$	$\geq 1b, \geq 1t, \geq 2j$	Yes	36.1	1904.10023
	ZUED/RSF	$1, e, \mu$	$\geq 2b, \geq 3j$	Yes	36.1	1903.09070
	Z mass	-	-	Yes	139	1903.09248
CI	SSM $Z' \rightarrow ff$	$2, e, \mu$	-	Yes	139	1709.07242
	SSM $Z' \rightarrow \tau\tau$	$2, \tau$	-	Yes	36.1	1605.09299
	Leptophobic $Z' \rightarrow bb$	-	$2b$	-	36.1	2005.01338
	Leptophobic $Z' \rightarrow \tau\tau$	$0, e, \mu, \tau$	$\geq 1b, \geq 2j$	Yes	139	1906.05659
	SSM $W' \rightarrow \tau\nu$	$1, e, \mu, \tau$	-	Yes	139	1906.05659
	SSM $W' \rightarrow \nu\nu$	$1, \tau$	-	Yes	139	2004.14636
	HVT $W' \rightarrow WZ$ model B	$0-2, e, \mu, \tau$	$\geq 1b, \geq 1j$	Yes	139	2007.02925
	HVT $W' \rightarrow WZ \rightarrow \ell\nu$ ($\ell = e, \mu, \tau$) model C	$3, e, \mu, \tau$	$2j$ (VBF)	Yes	139	2004.14636
	HVT $Z' \rightarrow WW$ model B	$1, e, \mu, \tau$	$2j$ (1j)	Yes	139	1904.12679
	LRSM $W_R \rightarrow \mu N_R$	$2, \mu$	$1j$	-	80	1703.09127
DM	Cl $q\bar{q}q$	-	$2j$	-	37.0	2006.12946
	Cl $t\bar{t}q$	$2, e, \mu, \tau$	-	Yes	139	2105.13847
	Cl $e\bar{e}b$	$2, e, \mu$	$1b$	-	139	2105.13847
	Cl $\mu\bar{\mu}b$	$2, \mu$	$1b$	-	139	1811.02295
LO	Cl $t\bar{t}t$	$\geq 1, e, \mu, \tau$	$\geq 1b, 1j$	Yes	36.1	1703.09127
	Axial-vector med. (Dirac DM)	-	$2j$	-	139	2006.12946
	Pseudo-scalar med. (Dirac DM)	$0, e, \mu, \tau, \gamma$	$1, 4j$	Yes	139	2105.13847
	Vector med. Z'-2HDM (Dirac DM)	$0, e, \mu, \tau$	$2b$	Yes	139	2105.13847
	Pseudo-scalar med. 2HDM-a	multi-channel	-	Yes	139	2105.13847
	Scalar LO 1^{st} gen	$2, e$	$\geq 2j$	Yes	139	2105.13847
	Scalar LO 2^{nd} gen	$2, \mu, \tau$	$\geq 2j$	Yes	139	2105.13847
	Scalar LO 3^{rd} gen	$1, \tau$	$2b$	Yes	139	2105.13847
	Scalar LO 1^{st} gen	$0, e, \mu, \tau$	$\geq 2b, \geq 2j$	Yes	139	2105.13847
	Scalar LO 2^{nd} gen	$\geq 2, e, \mu, \tau$	$\geq 1, \tau, \geq 1j, \geq 1b$	Yes	139	2105.13847
Vector-like fermions	Scalar LO 3^{rd} gen	$0, e, \mu, \tau$	$\geq 1, 2b$	Yes	139	2105.13847
	Vector LO 1^{st} gen	$2, e, \mu, \tau$	$\geq 1b$	Yes	139	2105.13847
	Vector LO 2^{nd} gen	$2, e, \mu, \tau$	$\geq 1b$	Yes	139	2105.13847
	VLQ $TT \rightarrow Zt + X$	$2e, 2\mu, 2e, \mu, \tau, 1b, \geq 1j$	-	Yes	139	2105.13847
	VLQ $BB \rightarrow WtZb + X$	multi-channel	-	Yes	36.1	2105.13847
	VLQ $T_{3/2} T_{3/2} \rightarrow Wt + X$	$2(S)3, 3, 2, 1, b, \geq 1j, \geq 1b$	-	Yes	36.1	2105.13847
	VLQ $T \rightarrow FtZ$	$1, e, \mu, \tau$	$\geq 1b, \geq 3j$	Yes	36.1	2105.13847
	VLQ $Y \rightarrow Wb$	$1, e, \mu, \tau$	$\geq 1b, \geq 1j$	Yes	36.1	2105.13847
	VLQ $B \rightarrow Hb$	$0, e, \mu, \tau$	$\geq 2b, \geq 1j, \geq 1b$	Yes	139	2105.13847
	VLQ $U' \rightarrow ZtH$	multi-channel $\geq 1j$	Yes	139	2105.13847	
Exotic fermions	Excited quark $q^* \rightarrow qg$	q^* mass	$2j$	Yes	139	1910.08447
	Excited quark $q^* \rightarrow q\gamma$	q^* mass	$1j$	Yes	36.7	1709.10440
	Excited quark $q^* \rightarrow b\bar{g}$	b^* mass	$1b, 1j$	Yes	139	1910.08447
	Excited lepton τ^*	τ^* mass	$\geq 2j$	Yes	139	2003.09444
Other	Type III Seesaw	$2.3-4, e, \mu$	$\geq 2j$	Yes	139	2202.02029
	LRSM Majorana ν	$2, \mu$	$\geq 1j$	Yes	36.1	1909.11105
	Higgs triplet $H^{\pm\pm} \rightarrow W^{\pm}W^{\pm}$	$2.3-4, e, \mu$ (SS)	various	Yes	139	2101.1981
	Higgs triplet $H^{\pm\pm} \rightarrow ZZ$	$2.3-4, e, \mu$ (SS)	-	Yes	139	2021.07505
	Multi-charged particles	-	-	Yes	139	DY production, $1g \rightarrow 5e$
	Magnetic monopoles	-	-	Yes	34.4	DY production, $1g \rightarrow 1g, \text{spin } 1/2$

*Only a selection of the available mass limits on new states or phenomena is shown.

† Small-radius (large-radius) jets are denoted by the letter j (J).

ATLAS Preliminary
 $\int \mathcal{L} dt = (3.6 - 139) fb^{-1}$
 $\sqrt{s} = 13 TeV$



Selection of observed exclusion limits at 95% CL. Theory uncertainties are not included.

Exotic summary:

ATLAS Heavy Particle Searches* - 95% CL Upper Exclusion Limits

Status: March 2023

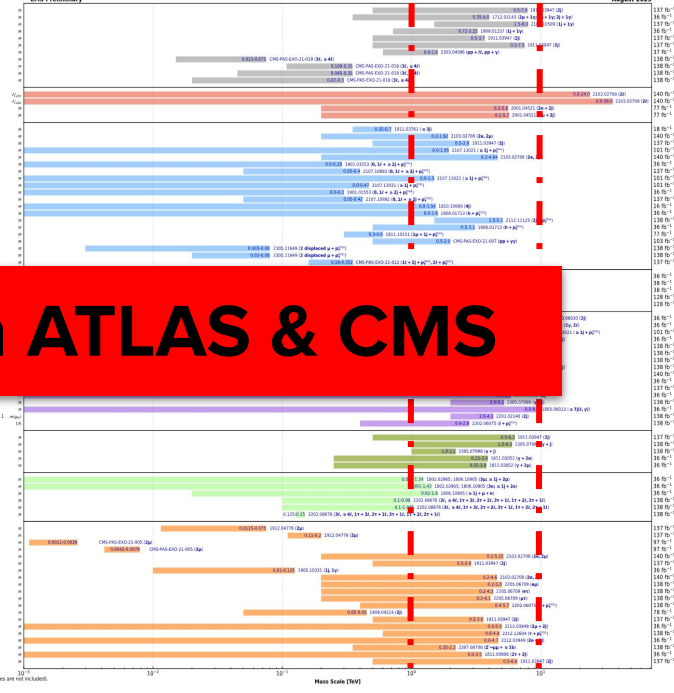
Model	f, γ	Jets [†]	$m_{\text{miss}}^{\text{min}}$	$\sqrt{s} \mathcal{L} dt [fb^{-1}]$	Limit	Reference
Extra dimen.	ADD $G_{\mu\nu} / g$	$0, e, \mu, \tau, \gamma$	1-4	Yes	139	2102.10074
ADD non-resonant $\gamma\gamma$	2γ	-	-	-	36.7	1707.94147
ADD $Q\bar{Q}H$	-	$2j$	-	-	139	1910.08447
ADD BH mujet	-	$\geq 3j$	-	-	3.6	1512.02596
RS1 $G_{\mu\nu} \rightarrow \mu\mu$	2γ	-	-	-	139	2102.13405
Bulk RS $G_{\mu\nu} \rightarrow WW/ZZ$	multi-channel	-	-	-	36.1	1808.02890
Bulk RS $g\bar{g} \rightarrow t\bar{t}$	$1, e, \mu$	$\geq 1b, \geq 1t, \geq 2j$	-	-	36.1	1804.10023
ZUED/RSF	$1, e, \mu$	$\geq 2b, \geq 3j$	-	-	36.1	1803.09070
Gauge bosons	SSM $Z' \rightarrow f\bar{f}$	$2, e, \mu$	-	-	139	1903.06248
SSM $Z' \rightarrow \tau\bar{\tau}$	$2, \tau$	-	-	-	36.1	1709.07242
Leptophobic $Z' \rightarrow b\bar{b}$	-	$2b$	-	-	36.1	1805.09299
Leptophobic $Z' \rightarrow \pi\pi$	$0, e, \mu, \tau$	$\geq 1b, \geq 2j$	-	-	Yes	139
SSM $W' \rightarrow e\bar{e}$	$1, e, \mu, \tau$	-	-	-	Yes	139
SSM $W' \rightarrow \tau\nu$	$1, \tau$	-	-	-	Yes	139
SSM $W' \rightarrow e\bar{\nu}$	$1, e, \mu, \tau$	$\geq 1b, \geq 1j$	-	-	Yes	139
HVT $W' \rightarrow WZ$ model B	$0-2, e, \mu, \tau$	$2j, 1j$	-	-	Yes	139
HVT $W' \rightarrow WZ \rightarrow \ell\nu(\ell'f)$ model C	$3, e, \mu, \tau$	$2j(\text{VBF})$	-	-	Yes	139
HVT $Z' \rightarrow WW$ model B	$1, e, \mu, \tau$	$2j, 1j$	-	-	Yes	139
LRSM $W_R \rightarrow \mu N_R$	$2, \mu$	$1j$	-	-	80	2004.14636
CI	CI $qqqq$	-	-	-	-	1904.12679
CI $f\bar{f}q\bar{q}$	-	-	-	-	-	-
CI $e\bar{e}bb$	-	-	-	-	-	-
CI $\mu\bar{\mu}bb$	-	-	-	-	-	-
CI $t\bar{t}tt$	-	-	-	-	-	-
DM	Axial-vector med. (Dirac DM)	-	-	-	-	-
Pseudo-scalar med. (Dirac DM)	-	-	-	-	-	-
Vector med. Z'-2HDM (Dirac DM)	-	-	-	-	-	-
Pseudo-scalar med. 2HDM-a	-	-	-	-	-	-
LO	Scalar LQ 2 nd gen	$1, \tau$	$2b$	Yes	139	2303.01294
Scalar LQ 3 rd gen	$0, e, \mu, \tau$	$\geq 2, \geq 2b$	-	-	Yes	139
Scalar LQ 3 rd gen	$\geq 2, e, \mu, \tau$	$\geq 1, \geq 1b, \geq 1j$	-	-	Yes	139
Scalar LQ 3 rd gen	$0, e, \mu, \tau$	$\geq 1, \geq 0-2j, \geq 2b$	-	-	Yes	139
Vector LQ 3 rd gen	$2, e, \mu, \tau$	$\geq 1, \geq 1b$	-	-	Yes	139
Vector LQ 3 rd gen	$2, e, \mu, \tau$	$\geq 1b$	-	-	Yes	139
Vector-like fermions	VLO $TT \rightarrow Z\ell + X$	$2e, 2\mu, 2e, \mu$	$\geq 1b, \geq 1j$	-	-	139
VLO $BB \rightarrow WZ/Zb + X$	multi-channel	-	-	-	36.1	1808.02343
VLO $T_{3/2} T_{3/2} \rightarrow Wt + X$	$2(S\bar{S})/3, 3, 3$	$\geq 1b, \geq 1j$	-	-	36.1	1807.1883
VLO $T \rightarrow HtZ$	$1, e, \mu, \tau$	$\geq 1b, \geq 3j$	-	-	Yes	139
VLO $Y \rightarrow Wb$	$1, e, \mu, \tau$	$\geq 1b, \geq 1j$	-	-	Yes	139
VLO $B \rightarrow Hb$	$0, e, \mu, \tau$	$\geq 2b, \geq 1j$	-	-	Yes	139
VLO $U \rightarrow Z'HH$	multi-channel $\geq 1j$	-	-	-	Yes	139
Exotic fermions	Excited quark $q^* \rightarrow qg$	q^* mass	-	-	139	1910.08447
Excited quark $q^* \rightarrow q\gamma$	$1, \gamma$	$1j$	-	-	36.7	1709.10440
Excited quark $q^* \rightarrow b\bar{g}$	-	$1b, 1j$	-	-	139	1910.08447
Excited lepton $\ell^* \rightarrow \ell\gamma$	$2, \tau$	$\geq 2j$	-	-	139	2303.09444
Other	Type III Seesaw	$2.3-4, e, \mu$	$\geq 2j$	Yes	139	2302.00339
LRSM Majorana ν	$1, e, \mu, \tau$	$2j$	-	-	36.1	1809.11105
Higgs triplet $H^{\pm\pm} \rightarrow W^{\pm}W^{\pm}$	$2.3-4, e, \mu$ (SS)	various	-	-	Yes	2101.1981
Higgs triplet $H^{\pm\pm} \rightarrow Z\bar{Z}$	$2.3-4, e, \mu$ (SS)	-	-	-	Yes	2211.07505
Multi-charged particles	-	-	-	-	139	ATLAS-CONF-2022-034
Magnetic monopoles	-	-	-	-	34.4	1905.10330

$\sqrt{s} \mathcal{L} dt = (3.6 - 139) \text{ fb}^{-1}$

ATLAS Preliminary

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

Overview of CMS EXO results



Compatible results between ATLAS & CMS

*Only a selection of the available mass limits on new states or phenomena is shown.

† Small-radius (large-radius) jets are denoted by the letter j (J).

$\sqrt{s} = 13 \text{ TeV}$
partial data

$\sqrt{s} = 13 \text{ TeV}$
full data

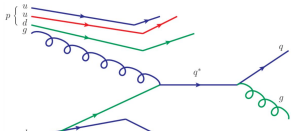
Mass scale [TeV]

Selection of observed exclusion limits at 95% CL. Theory uncertainties are not included.

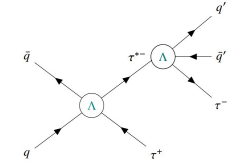
Mass Scale [TeV]

Compositeness searches:

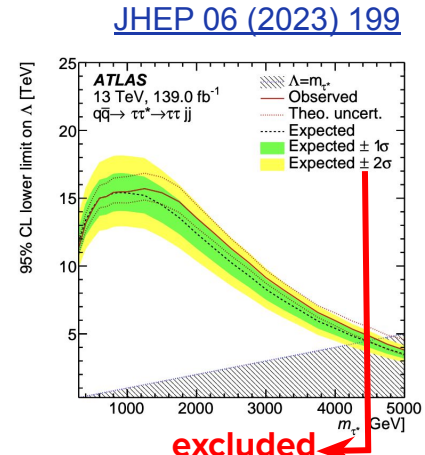
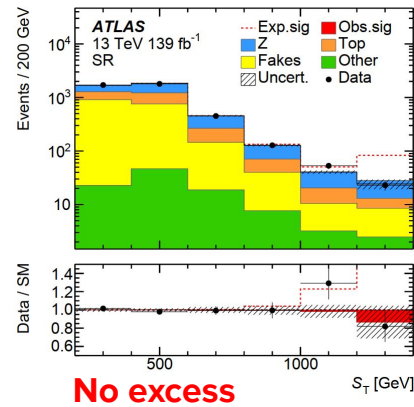
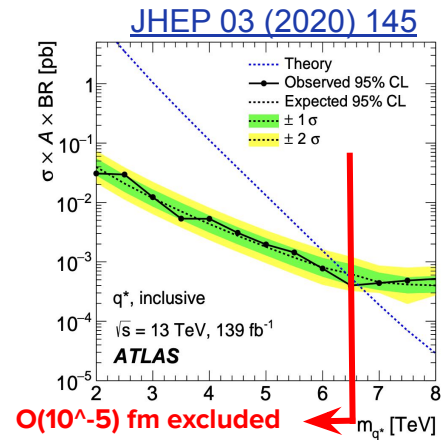
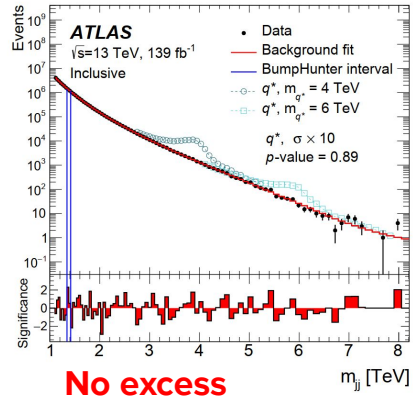
- Explain if the current quarks or leptons are elementary or compositeness
- Search for excited states of quarks (q^*) and leptons (l^*)
- Excited states could be produced by Gauge Interactions (GI) or contact interaction (CI)



Excited quarks



Excited leptons



Additional vector boson searches:

Unification

Hierarchy

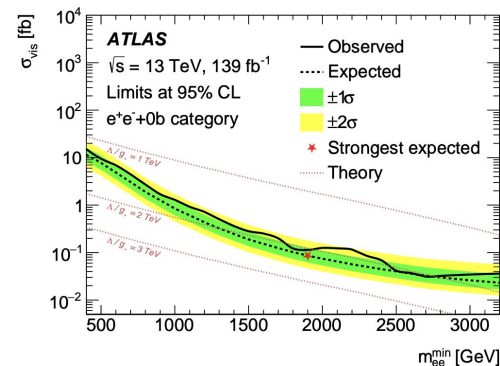
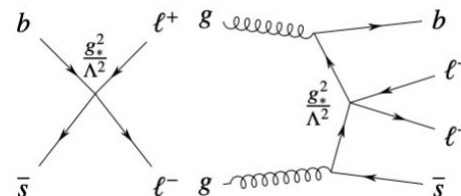
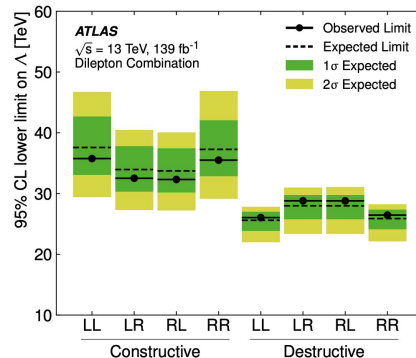
- Motivated by many BSM theories:
 - Sequential Standard Model (SSM), GUT, topcolour-assisted-technicolour (TC2), heavy vector triplet (HVT)
- Rich phenomena behind according to different models
- LHC search for them by using resonant & excesses in the tails
 - Two-body final states with quarks or leptons: dijet, ll, lv, and with τ
 - Diboson final states: VV, VH in FullHad, Lep+Jets
 - Final states with heavy quarks: Z' to tt, W' to tb, and ttZ' to tttt
 - CI: bsll final state

resonant

V'	Analysis final state	Observed lower limit on $m_{V'}$ [TeV]
Z'_{SSM}	bb	2.7
	ee + $\mu\mu$	5.1
W'_{SSM}	qq	4.0
	e ν + $\mu\nu$	6.0
	$\tau\nu$	5.0
Z'_{\psi}	ee + $\mu\mu$	4.5
Z'_{TC2}	t \bar{t}	3.9
Z'_{LUV}	b $\bar{b}b\bar{b}$	1.45
W'_{R}(g'/g = 1.0)	t b	4.6
W'_{HVT} (model A)	WZ \rightarrow XXqq	3.9
W'_{HVT} (model B)	WZ \rightarrow XXqq	4.3
W'_{HVT} (model C)	WZ \rightarrow $\ell\nu\ell\ell$	3.4
Z'_{HVT} (model A)	WW \rightarrow $\ell\nu qq$	3.5
Z'_{HVT} (model B)	WW \rightarrow $\ell\nu qq$	3.9

Contact interaction

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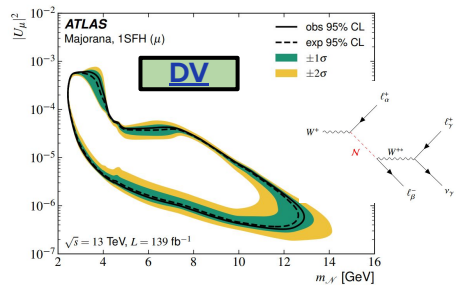
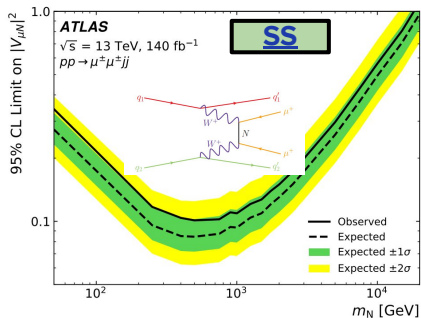


Additional lepton searches:

Neutrino oscillation

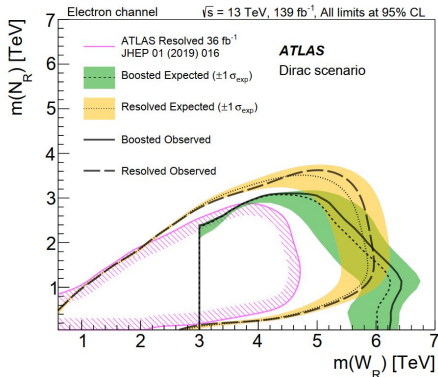
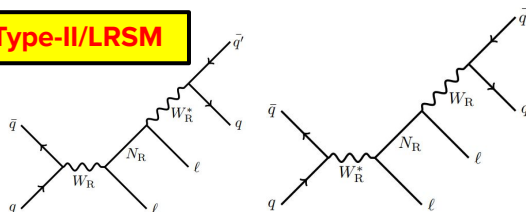
- Motivated by seesaw theories:
 - Type-I with right-handed neutrinos
 - Type-II with a scalar triplet
 - Type-III with fermion triplets

Type-I



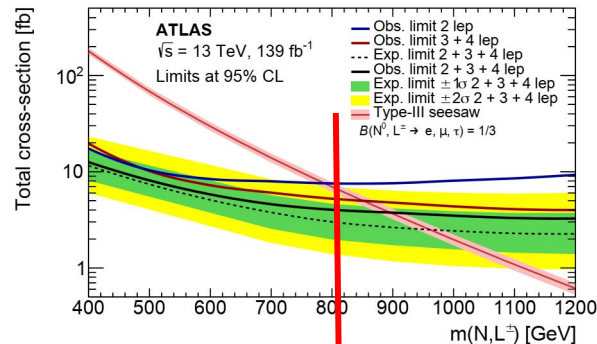
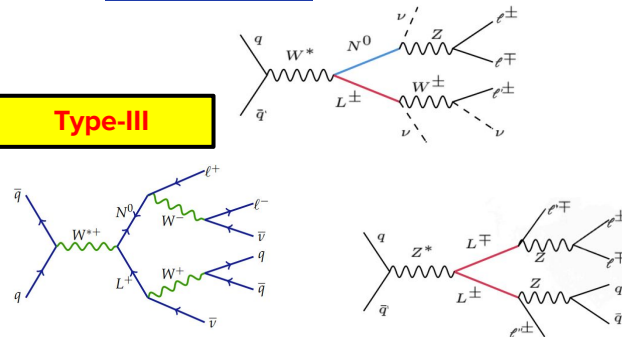
2304.09553

Type-II/LRSM



2304.09553

Type-III



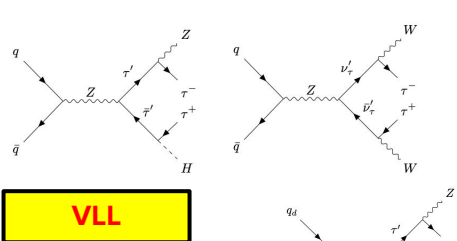
excluded

Vector-like lepton and quarks:

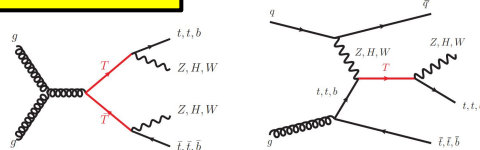
Large gap between
EW & Planck scales

- VLQ: motivated from many composite Higgs models
- VLL: motivated from string theory, large extra D ...

Hierarchy

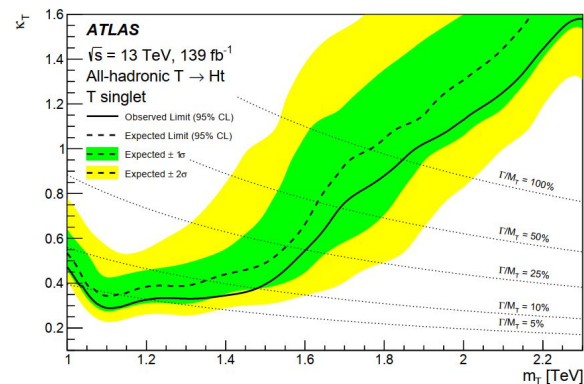
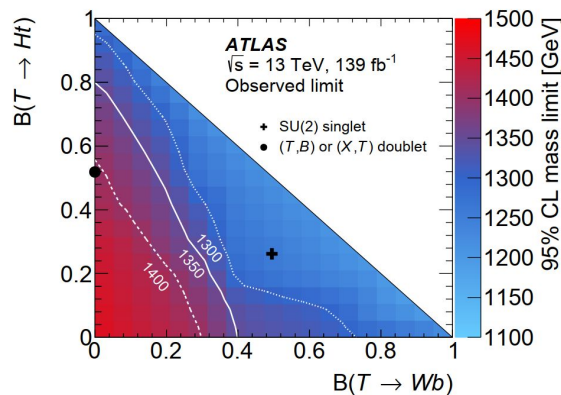
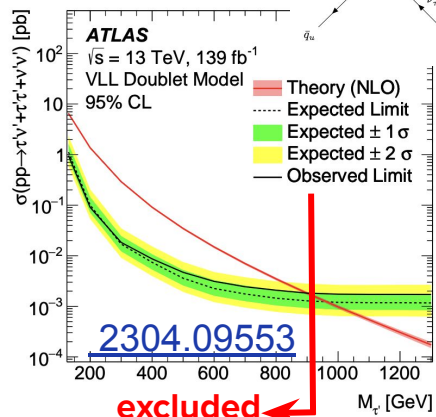


VLQ



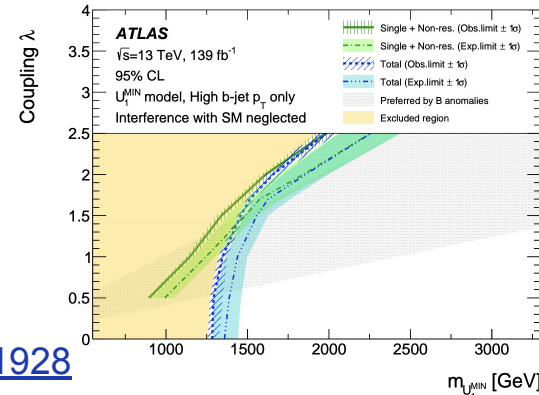
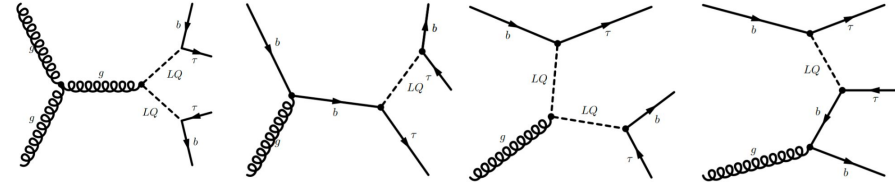
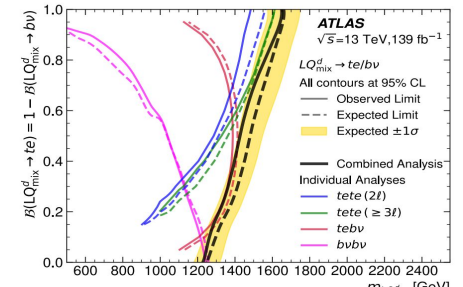
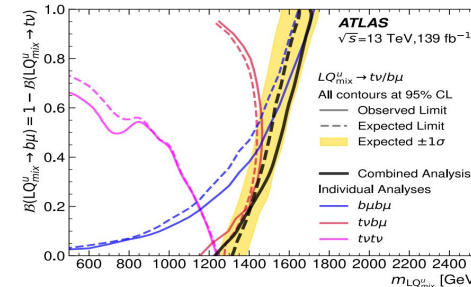
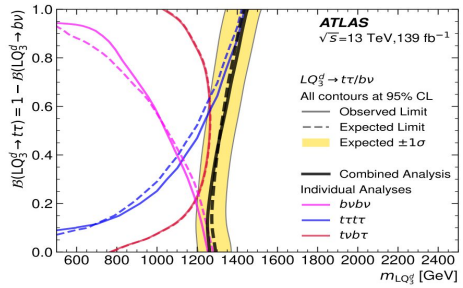
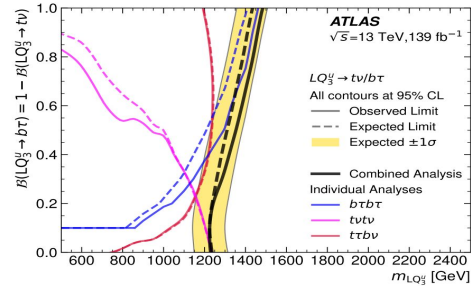
[2210.15413](#)

Search	Production mode	Decay channel
Hadronic T search [136]	Single	$T \rightarrow Ht$
Hadronic B search [135]	Single	$B \rightarrow Hb$
Multilepton (single) [137]	Single	$T \rightarrow Zt$
Multilepton (pair) [138]	Pair	$TT \rightarrow ZtVt, BB \rightarrow ZbVb, V = W, Z, H$
High E_T^{miss} [139]	Pair	$T \rightarrow Vt$ or $B \rightarrow Vb, V = W, Z, H$
Lepton and jets [140]	Single	$T \rightarrow Ht, T \rightarrow Zt$



Leptoquarks:

- Could explain the similarity of the lepton and quark structure
- Motivated by many BSM:
 - GUT, composite fermions, and SUSY
 - Explain the B anomalies and mu g-2
- Up and down type LQ searches separately



[2401.11928](https://arxiv.org/abs/2401.11928)

Lepton Flavour Violation:

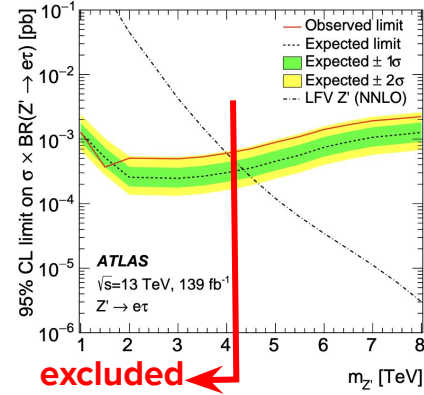
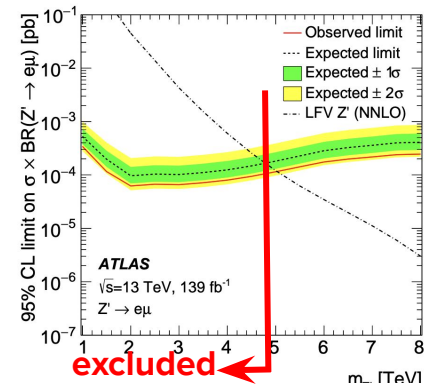
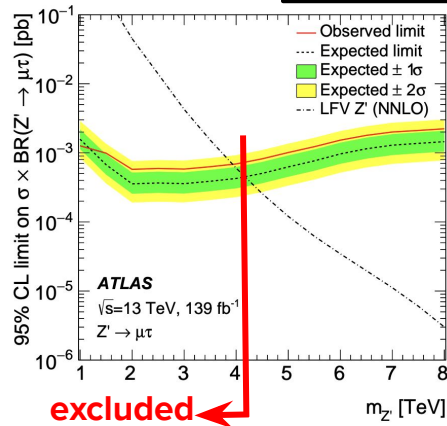


- Measuring the LFV precisely can probe the BSM (N and Z')
- Z/Z' → LFV (HLFV will be covered by another talk)
 - Z to eμ, Z to eτ, and Z to μτ with τ_{had} and τ_{lep}

ZLFV

Channel	Upper limit on $\mathcal{B}(Z \rightarrow \ell\ell')$
$e\mu$	2.62×10^{-7}
$e\tau$ (τ_{had} and τ_{lep} channels combined)	5.0×10^{-6}
$\mu\tau$ (τ_{had} and τ_{lep} channels combined)	6.5×10^{-6}

Z'LFV



[2307.08567](https://arxiv.org/abs/2307.08567)

Hierarchy

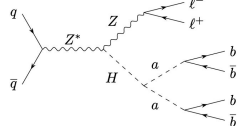
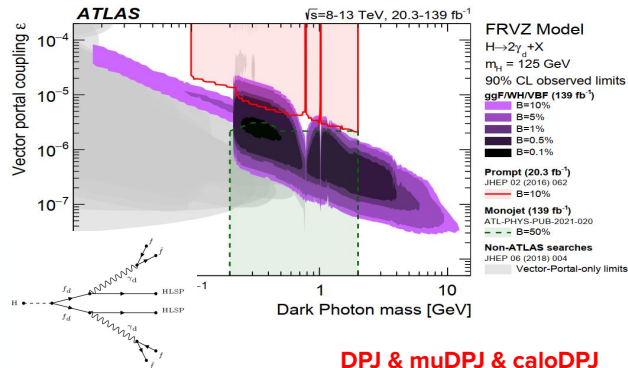
Dark Matter

Hidden(dark) sector searches:

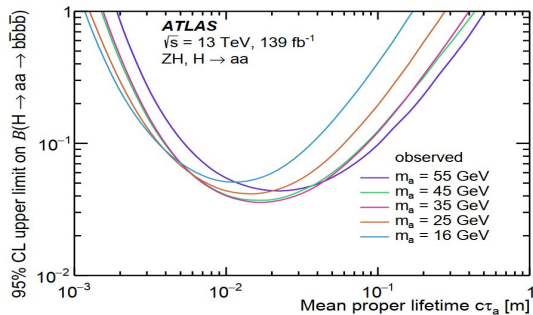
- Predicted by many BSM theories
- Particles in hidden sectors can only interact with SM particles via a mediator:
 - Could be Higgs, new scalar, pseudoscalar, vector or axial-vector particle
 - With small couplings leading to LLPs giving **DPJ**, **muDPJ**, **caloDPJ**, **DV**, and **muDV**

Dark photon through H portal

[2107.06092](#)

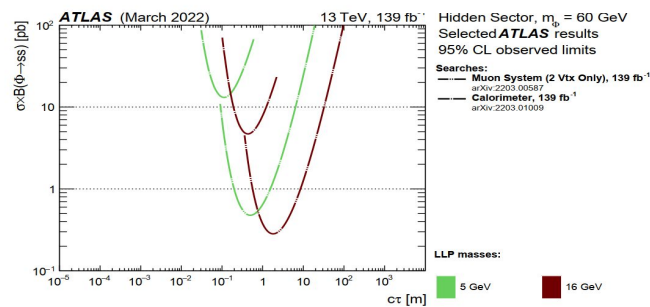
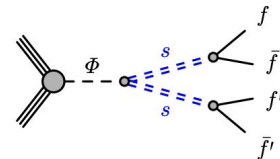


a and Φ searches



[2107.06092](#)

DV



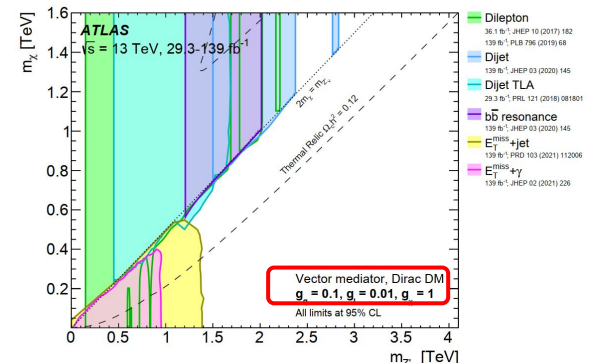
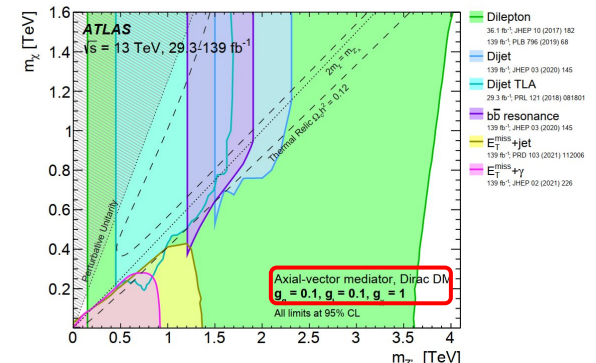
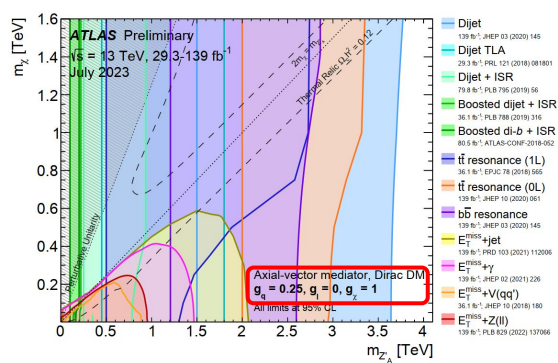
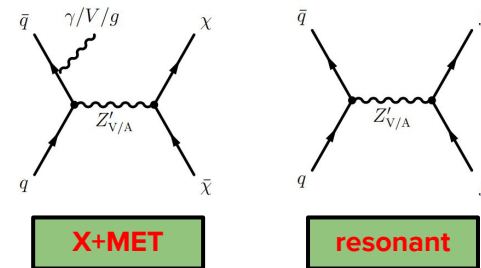
muDV & caloDPJ

[2203.00587](#)

Dark matter searches:

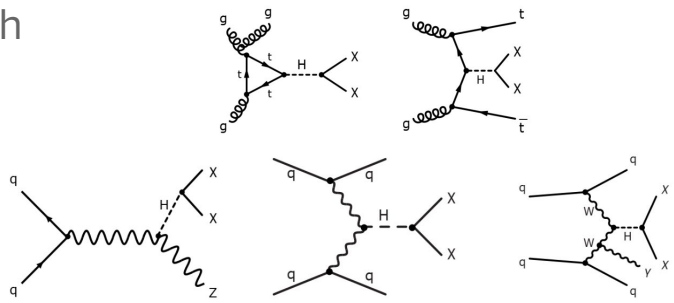
- WIMP mass close to the electroweak scale and an interaction strength with SM particles of the order of the weak interaction's strength
- Can be produced at LHC
- Simplified DM models are used:
 - Through a vector, axial vector, pseudoscalar or Higgs portal
 - Composite stable particles coupled with hidden sector

Vector or Axial vector portal

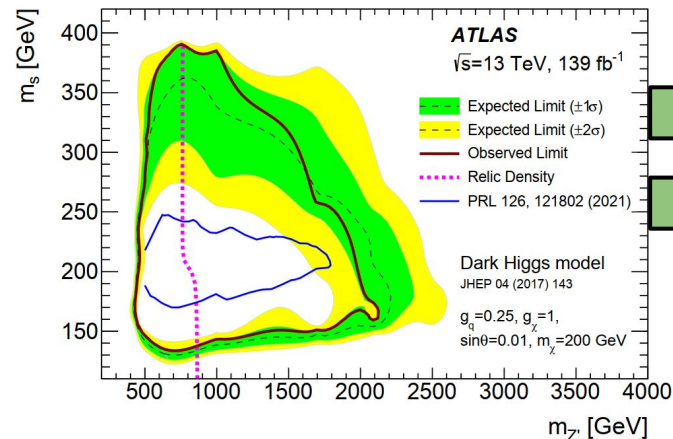
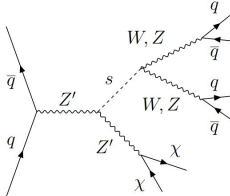


Dark matter searches:

- WIMP mass close to the electroweak scale and an interaction strength with SM particles of the order of the weak interaction's strength
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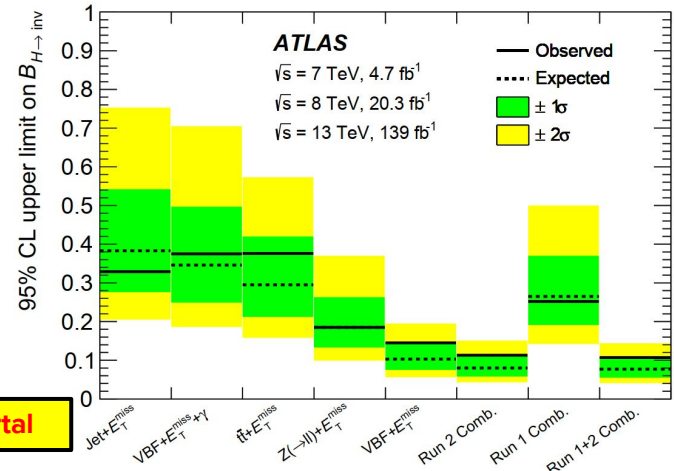
Vector portal with a dark Higgs boson (s)



SemiLep

FullHad

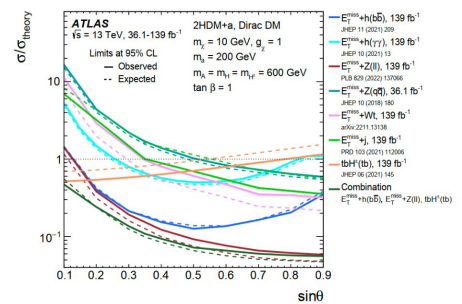
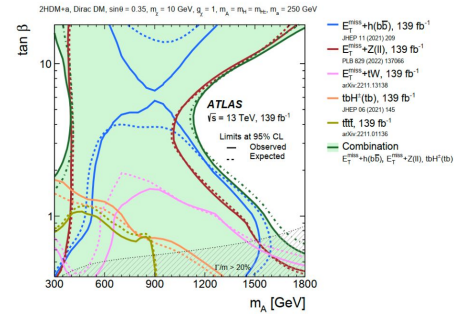
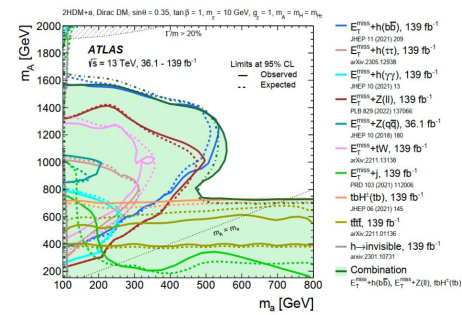
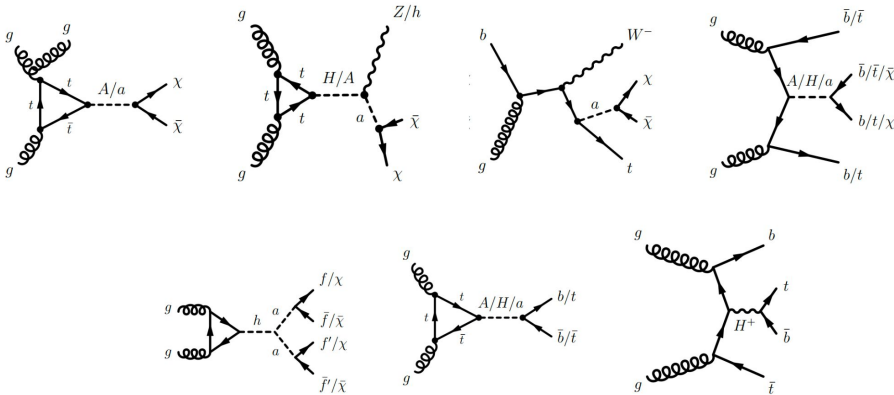
Higgs portal



Dark matter searches:

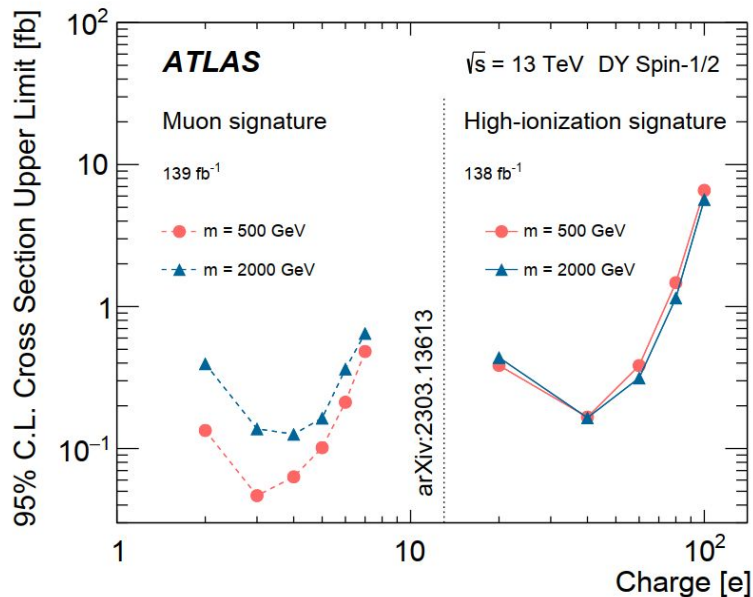
- WIMP mass close to the electroweak scale and an interaction strength with SM particles of the order of the weak interaction's strength
- Can be produced at LHC
- Simplified DM models are used:
 - Through a vector, axial vector, pseudoscalar or Higgs portal
 - Composite stable particles coupled with hidden sector

Pseudoscalar portal



Charged LLPs:

- Motivated from many BSM theories
- Can have varied charge multiplicity $|z|$:
 - Multi-charged particles (MCPs): $2 < |z| < 7$:
 - Two doubly charged fermions, table multi-charged technibaryons, long-lived doubly charged Higgs bosons
 - Like heavy muons with a higher specific energy loss dE/dx in the pixel, TRT and MDT
 - Highly ionizing particles (HIPs): $20 < |z| < 100$
 - Strange matter, Q-ball, Dirac magnetic monopoles
 - HI hit in TRT and custom HIP trigger together with specific reco alg

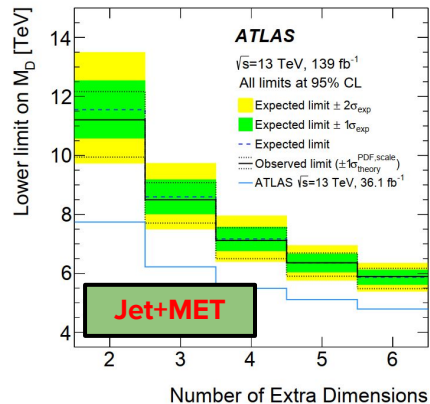


- For MCP:
 - Models with 500 GeV masses are strongly excluded
 - At 2 TeV, none of the MCP models are excluded

Gravitons:

- Motivated from extra dimensions:
 - Arkani-Hamed, Dimopoulos and Dvali (ADD) model
 - Randall–Sundrum (RS) model
- If produced in the pp collisions, the KK graviton (G_{KK}) escapes into the EDs

ADD GKK

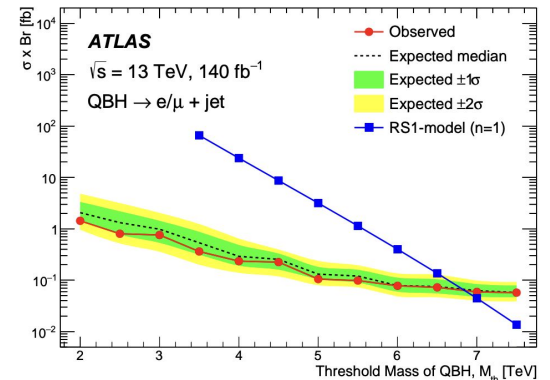
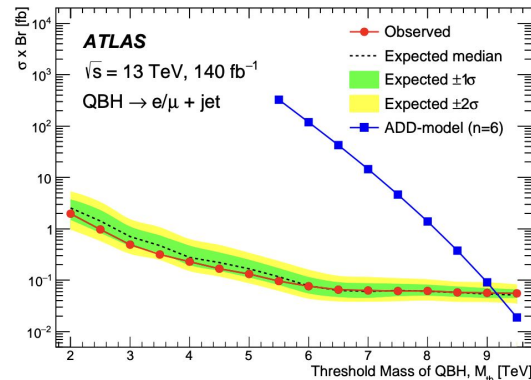
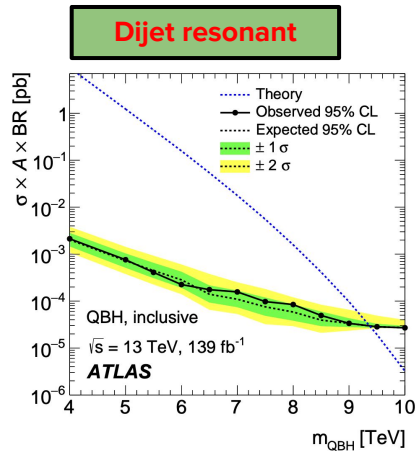


RS GKK

Analysis final state	Model	k/M_{Planck}	Excluded mass range for $m_{G_{KK}}$ [TeV]
bb	RS1	0.2	< 2.8
$\gamma\gamma$	RS1	0.1	< 4.5
Semileptonic $t\bar{t}$ (36.1 fb^{-1})	bulk RS	1.0	0.45–0.65
$HH \rightarrow bbbb$	bulk RS	1.0	0.298–1.46
$WW/ZZ \rightarrow qq\bar{q}\bar{q}$	bulk RS	1.0	1.3–1.8
$WW \rightarrow \ell\nu q\bar{q} + ZZ \rightarrow \ell\ell q\bar{q}$	bulk RS	1.0	
ggF production	bulk RS	1.0	< 2.0
VBF production	bulk RS	1.0	< 0.76
$ZZ \rightarrow \ell\ell\ell\ell + ZZ \rightarrow \ell\ell\nu\nu$	bulk RS	1.0	< 1.83

Quantum black hole:

- Motivated from extra dimensions:
 - Arkani-Hamed, Dimopoulos and Dvali (ADD) model
 - Randall–Sundrum (RS) model
- QBH could potentially be produced at the LHC if the energy is above the fundamental Planck scale M_D , decay into two-particle final states



SUSY searches

Why SUSY:

- “SUSY is the most complete microscopic theory conceived so far to go beyond the SM”:
 - Can be used to compute any* observable quantity
 - Contains the ingredients to deal with all/most issues that the SM cannot address
 - “Supersymmetric models are extremely compelling theoretically”
- “SUSY is the most complete “LHC” of experimental signals conceived so far to go beyond the SM”:
 - Hard to find an experimental signature that can be attained in another model and cannot be attained in SUSY
 - Comes with “some” way to judge how likely it is the particular signal at hand
 - Allows to derive the experimental implications of observing such signal
- Being “complete” in the theory and experimental sense:
 - Can use it to stress-test the capability of your present (or future) accelerator+experiment
 - Create a solid ground for exchange about reinterpretation/preservation of the searches

SUSY summary:

ATLAS SUSY Searches* - 95% CL Lower Limits

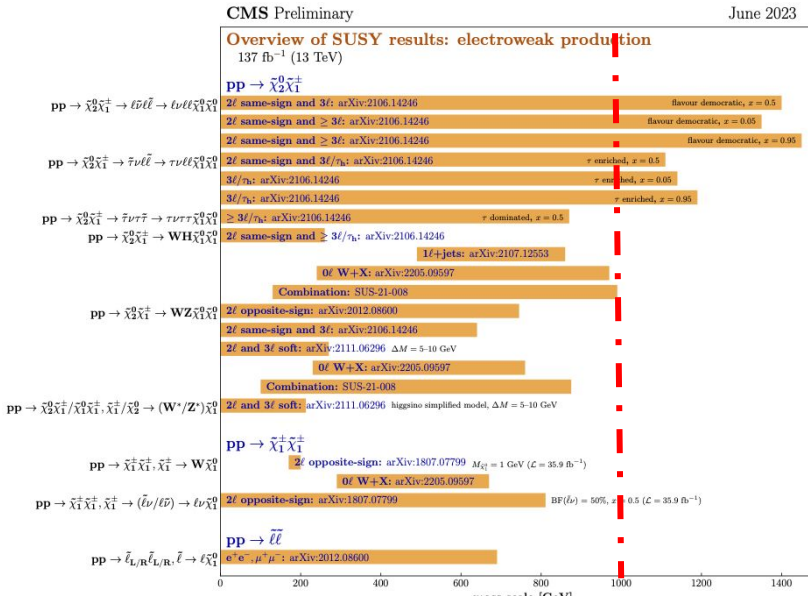
July 2024

Model	Signature	\sqrt{s} [TeV]	Mass limit	Reference		
Inclusive Searches	$0.1 \epsilon, \mu$ mono jet	E_{miss}^{140}	140	$m(\tilde{t}_1) > 400$ GeV		
	$2-6$ jets	E_{miss}^{140}	140	$m(\tilde{t}_1) > 400$ GeV		
	$1-3$ jets	E_{miss}^{140}	140	$m(\tilde{t}_1) > 400$ GeV		
	$2-6$ jets	E_{miss}^{140}	140	$m(\tilde{t}_1) > 400$ GeV		
1 st gms. squares direct production	$h_1 h_1$	$0.1 \epsilon, \mu$	E_{miss}^{140}	140	$m(\tilde{t}_1) > 400$ GeV	
	$h_1 h_1, h_1 \rightarrow h_1^0 h_2^0 \rightarrow hh h_1^0$	$0.1 \epsilon, \mu$	E_{miss}^{140}	140	$m(\tilde{t}_1) > 400$ GeV	
	$h_1 h_1, h_1 \rightarrow h_1^0 h_2^0$	$0.1 \epsilon, \mu$	E_{miss}^{140}	140	$m(\tilde{t}_1) > 400$ GeV	
	$h_1 h_1, h_1 \rightarrow h_1^0 h_2^0$	$0.1 \epsilon, \mu$	E_{miss}^{140}	140	$m(\tilde{t}_1) > 400$ GeV	
	$h_1 h_1, h_1 \rightarrow h_1^0 h_2^0$	$0.1 \epsilon, \mu$	E_{miss}^{140}	140	$m(\tilde{t}_1) > 400$ GeV	
	$h_1 h_1, h_1 \rightarrow h_1^0 h_2^0$	$0.1 \epsilon, \mu$	E_{miss}^{140}	140	$m(\tilde{t}_1) > 400$ GeV	
	$h_1 h_1, h_1 \rightarrow h_1^0 h_2^0$	$0.1 \epsilon, \mu$	E_{miss}^{140}	140	$m(\tilde{t}_1) > 400$ GeV	
	$h_1 h_1, h_1 \rightarrow h_1^0 h_2^0$	$0.1 \epsilon, \mu$	E_{miss}^{140}	140	$m(\tilde{t}_1) > 400$ GeV	
	$h_1 h_1, h_1 \rightarrow h_1^0 h_2^0$	$0.1 \epsilon, \mu$	E_{miss}^{140}	140	$m(\tilde{t}_1) > 400$ GeV	
	$h_1 h_1, h_1 \rightarrow h_1^0 h_2^0$	$0.1 \epsilon, \mu$	E_{miss}^{140}	140	$m(\tilde{t}_1) > 400$ GeV	
EW direct	$\tilde{t}_1 \tilde{t}_1^* \rightarrow W Z$	$0.1 \epsilon, \mu$	E_{miss}^{140}	140	$m(\tilde{t}_1) > 400$ GeV	
	$\tilde{t}_1 \tilde{t}_1^* \rightarrow W W$	$0.1 \epsilon, \mu$	E_{miss}^{140}	140	$m(\tilde{t}_1) > 400$ GeV	
	$\tilde{t}_1 \tilde{t}_1^* \rightarrow W W$	$0.1 \epsilon, \mu$	E_{miss}^{140}	140	$m(\tilde{t}_1) > 400$ GeV	
	$\tilde{t}_1 \tilde{t}_1^* \rightarrow W W$	$0.1 \epsilon, \mu$	E_{miss}^{140}	140	$m(\tilde{t}_1) > 400$ GeV	
	$\tilde{t}_1 \tilde{t}_1^* \rightarrow W W$	$0.1 \epsilon, \mu$	E_{miss}^{140}	140	$m(\tilde{t}_1) > 400$ GeV	
	$\tilde{t}_1 \tilde{t}_1^* \rightarrow W W$	$0.1 \epsilon, \mu$	E_{miss}^{140}	140	$m(\tilde{t}_1) > 400$ GeV	
	$\tilde{t}_1 \tilde{t}_1^* \rightarrow W W$	$0.1 \epsilon, \mu$	E_{miss}^{140}	140	$m(\tilde{t}_1) > 400$ GeV	
	$\tilde{t}_1 \tilde{t}_1^* \rightarrow W W$	$0.1 \epsilon, \mu$	E_{miss}^{140}	140	$m(\tilde{t}_1) > 400$ GeV	
	$\tilde{t}_1 \tilde{t}_1^* \rightarrow W W$	$0.1 \epsilon, \mu$	E_{miss}^{140}	140	$m(\tilde{t}_1) > 400$ GeV	
	$\tilde{t}_1 \tilde{t}_1^* \rightarrow W W$	$0.1 \epsilon, \mu$	E_{miss}^{140}	140	$m(\tilde{t}_1) > 400$ GeV	
Long-lived particles	Direct $\tilde{t}_1 \tilde{t}_1^*$ prod., long-lived \tilde{t}_1^*	Disapp. trk	1 jet	E_{miss}^{140}	140	$m(\tilde{t}_1) > 400$ GeV
	Stable β R-hadron	pixel dE/dx		E_{miss}^{140}	140	$m(\tilde{t}_1) > 400$ GeV
	Metastable β R-hadron, $\beta \rightarrow \nu \tilde{t}_1^*$	pixel dE/dx		E_{miss}^{140}	140	$m(\tilde{t}_1) > 400$ GeV
	$\tilde{H}, \tilde{L} \rightarrow G$	Displ. lep		E_{miss}^{140}	140	$m(\tilde{t}_1) > 400$ GeV
		pixel dE/dx		E_{miss}^{140}	140	$m(\tilde{t}_1) > 400$ GeV
	RPV	$\tilde{t}_1 \tilde{t}_1^* \rightarrow W Z$	$3 \epsilon, \mu$	E_{miss}^{140}	140	$m(\tilde{t}_1) > 400$ GeV
		$\tilde{t}_1 \tilde{t}_1^* \rightarrow W W$	$4 \epsilon, \mu$	E_{miss}^{140}	140	$m(\tilde{t}_1) > 400$ GeV
		$\tilde{t}_1 \tilde{t}_1^* \rightarrow W W$	≥ 3 jets	E_{miss}^{140}	140	$m(\tilde{t}_1) > 400$ GeV
		$\tilde{t}_1 \tilde{t}_1^* \rightarrow W W$	Multiple	E_{miss}^{140}	140	$m(\tilde{t}_1) > 400$ GeV
		$\tilde{t}_1 \tilde{t}_1^* \rightarrow W W$	$\geq 4b$	E_{miss}^{140}	140	$m(\tilde{t}_1) > 400$ GeV
$\tilde{t}_1 \tilde{t}_1^* \rightarrow W W$		2 jets + $2b$	E_{miss}^{140}	140	$m(\tilde{t}_1) > 400$ GeV	
$\tilde{t}_1 \tilde{t}_1^* \rightarrow W W$		$2b$	E_{miss}^{140}	140	$m(\tilde{t}_1) > 400$ GeV	
$\tilde{t}_1 \tilde{t}_1^* \rightarrow W W$		DV	E_{miss}^{140}	140	$m(\tilde{t}_1) > 400$ GeV	
$\tilde{t}_1 \tilde{t}_1^* \rightarrow W W$		$2b$	E_{miss}^{140}	140	$m(\tilde{t}_1) > 400$ GeV	
$\tilde{t}_1 \tilde{t}_1^* \rightarrow W W$		$2b$	E_{miss}^{140}	140	$m(\tilde{t}_1) > 400$ GeV	

*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.

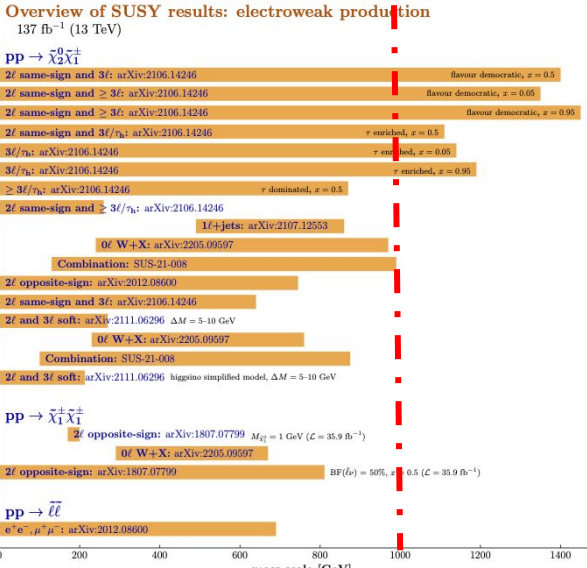
ATLAS Preliminary

$\sqrt{s} = 13$ TeV



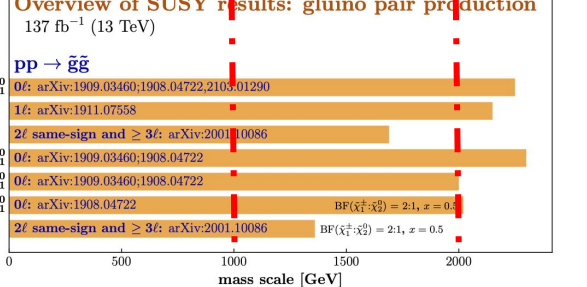
Selection of observed limits at 95% C.L. (theory uncertainties are not included). Probe up to the quoted mass limit for light LSPs unless stated otherwise. The quantities ΔM and x represent the absolute mass difference between the primary sparticle and the LSP, and the difference between the intermediate sparticle and the LSP relative to ΔM , respectively, unless indicated otherwise.

CMS Preliminary



Selection of observed limits at 95% C.L. (theory uncertainties are not included). Probe up to the quoted mass limit for light LSPs unless stated otherwise. The quantities ΔM and x represent the absolute mass difference between the primary sparticle and the LSP, and the difference between the intermediate sparticle and the LSP relative to ΔM , respectively, unless indicated otherwise.

CMS Moriond 2021

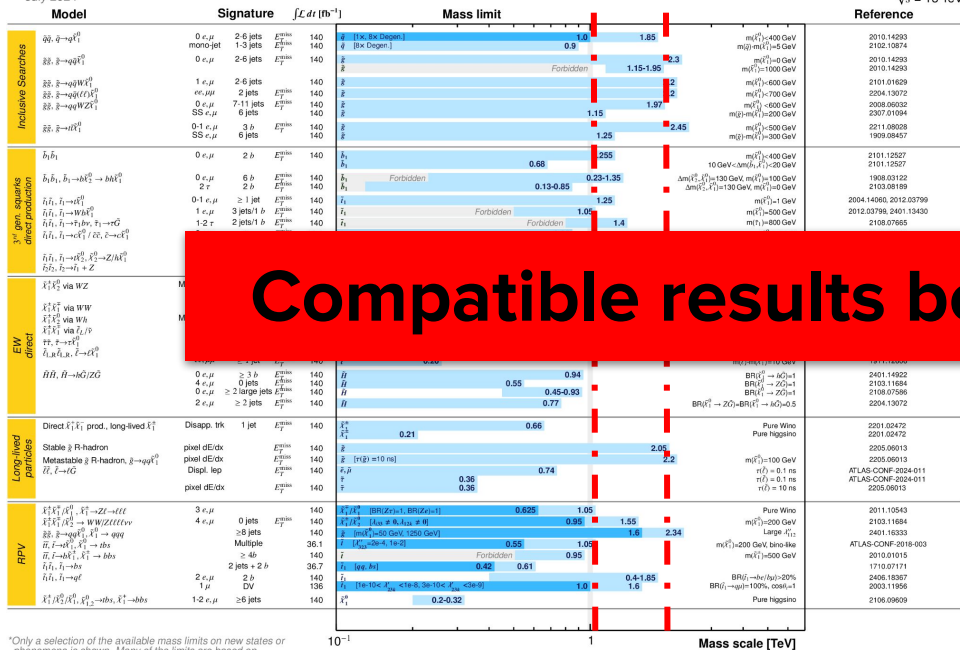


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SUSY summary:

ATLAS SUSY Searches* - 95% CL Lower Limits

July 2024



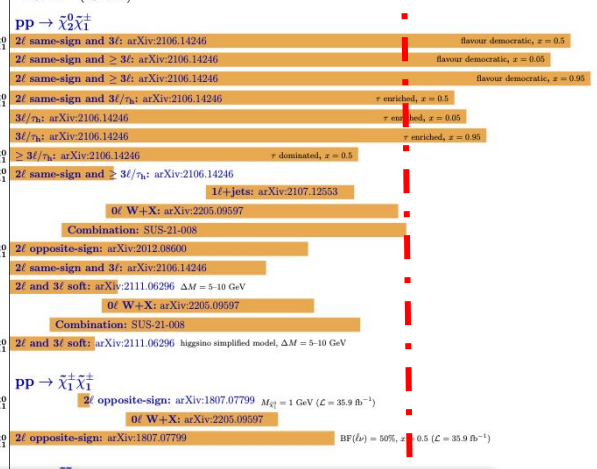
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ATLAS Preliminary

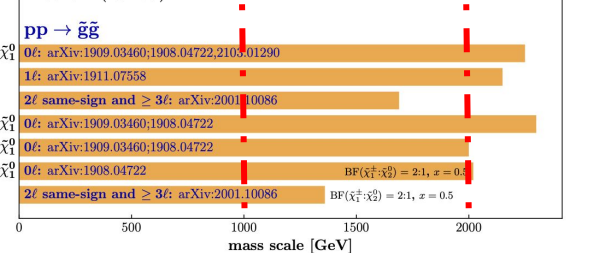
$\sqrt{s} = 13$ TeV

CMS Preliminary

Overview of SUSY results: electroweak production

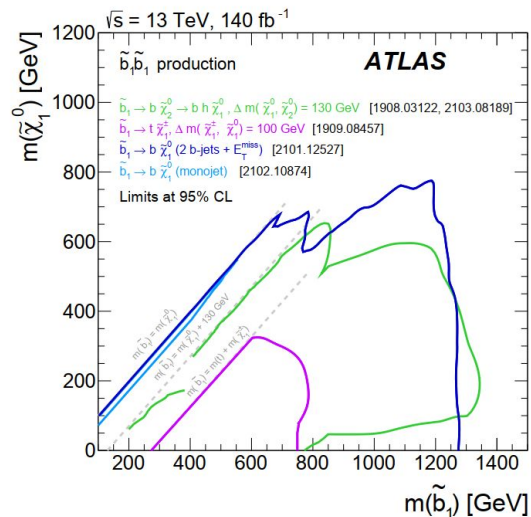
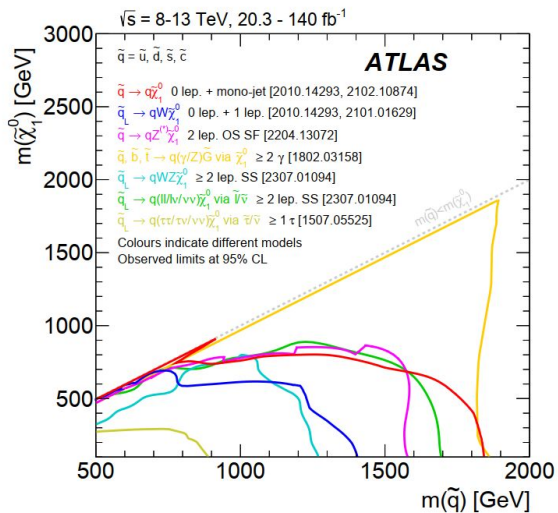
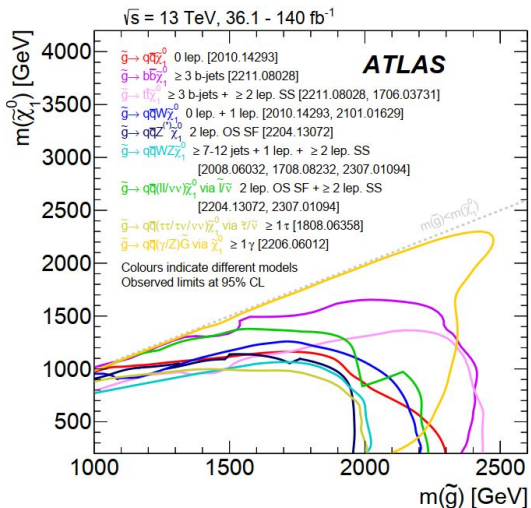
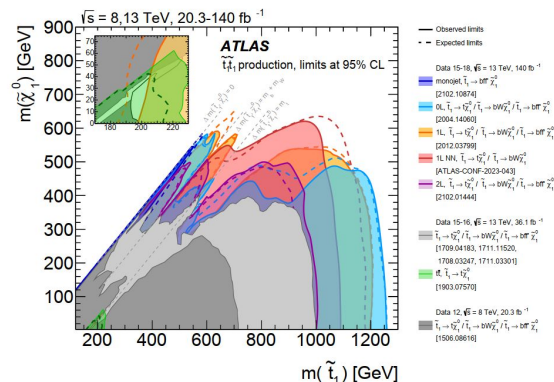
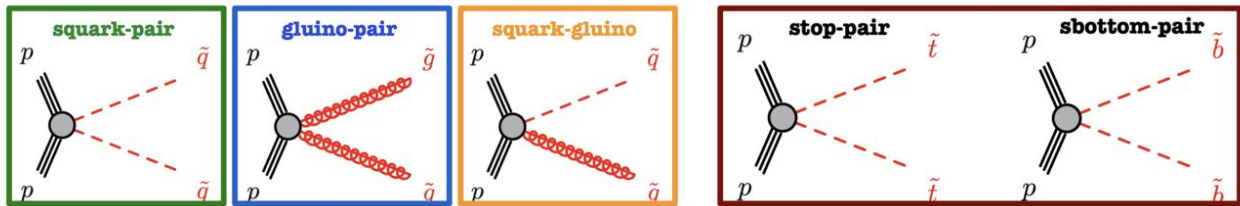


Overview of SUSY results: gluino pair production

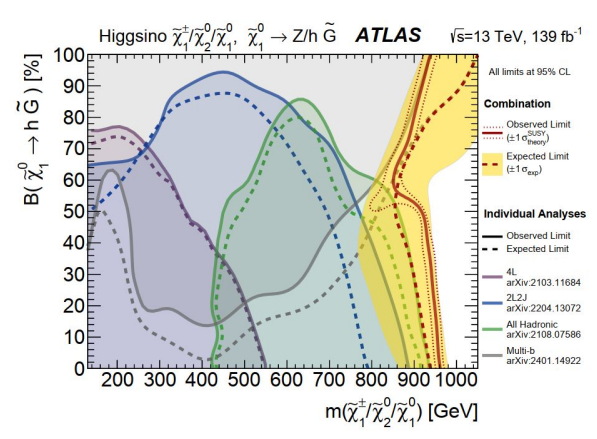
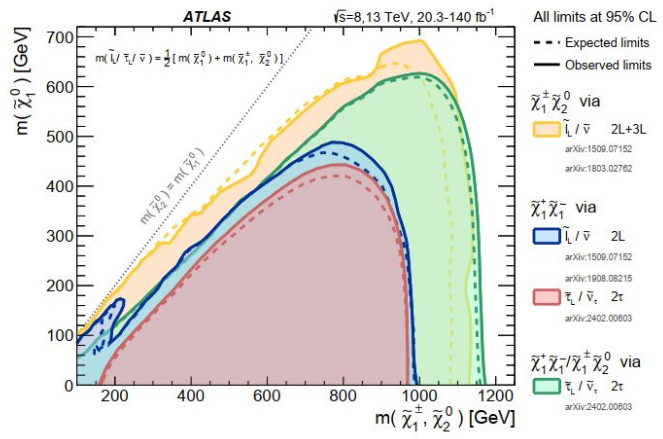
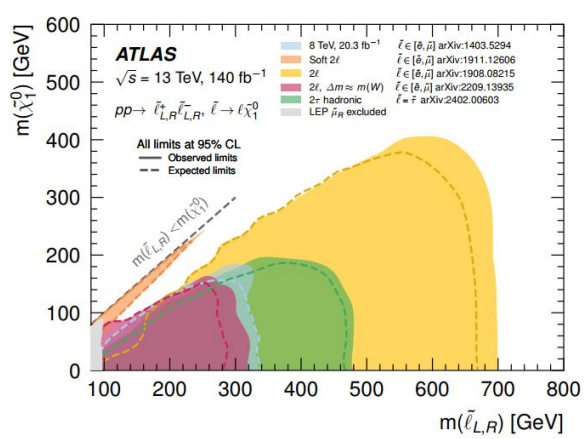
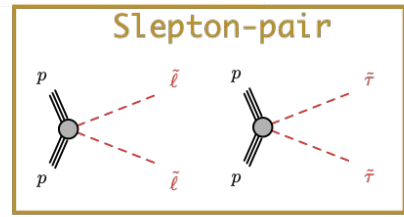
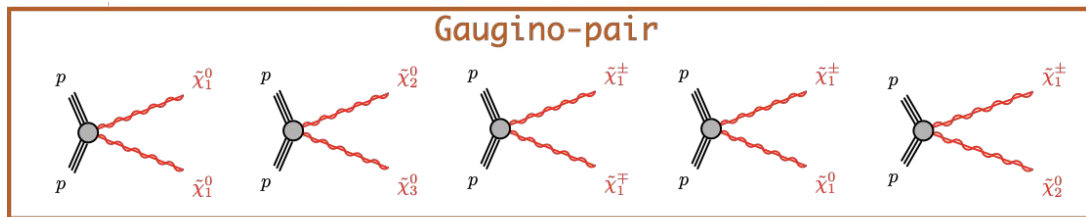


Selection of observed limits at 95% C.L. (theory uncertainties are not included). Probe up to the quoted mass limit for light LSPs unless stated otherwise. The quantities ΔM and α represent the absolute mass difference between the primary sparticle and the LSP, and the difference between the intermediate sparticle and the LSP relative to ΔM , respectively, unless indicated otherwise.

Strongly produced SUSY:



EWKly produced SUSY:



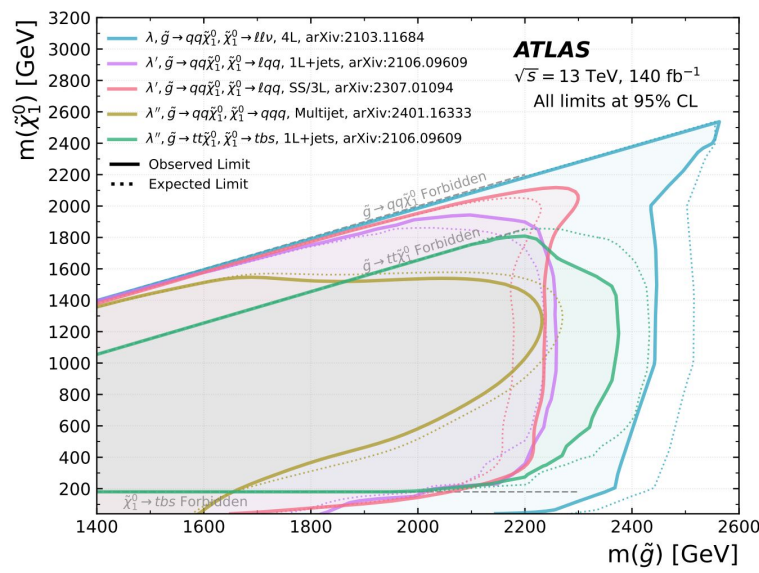
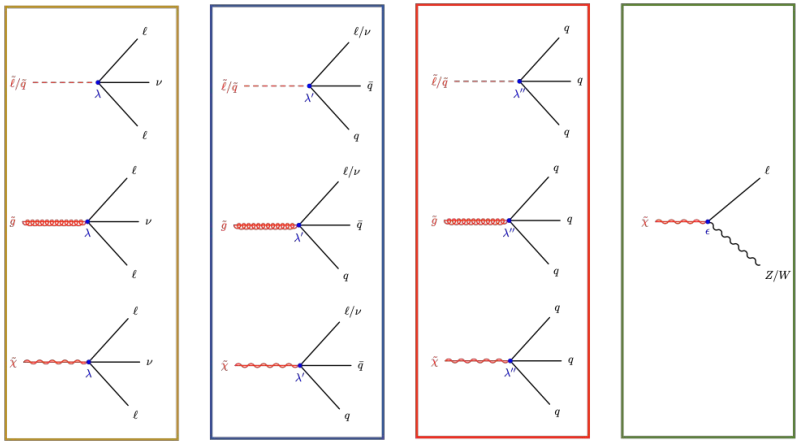
RPV case: (prompt)

$$W = W_{MSSM} + W_R; \quad W_R = \frac{1}{2} \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \frac{1}{2} \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k + \kappa_i L_i H_2$$

Slepton

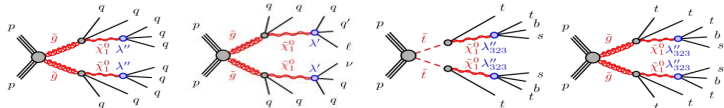
Gluino

Gauginos

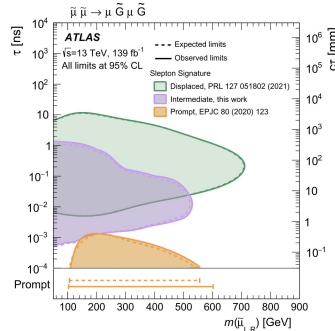
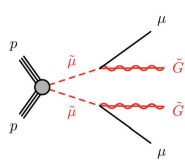


RPC-RPV:

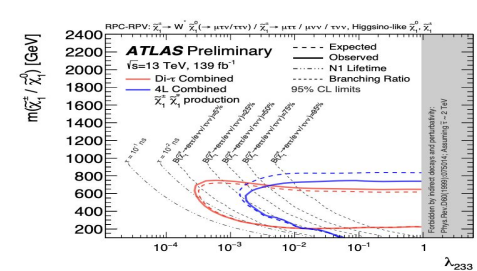
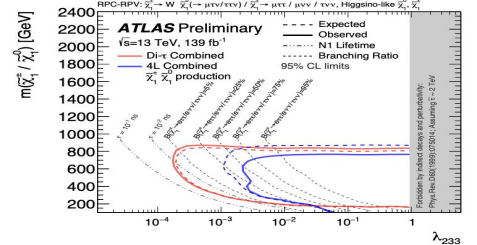
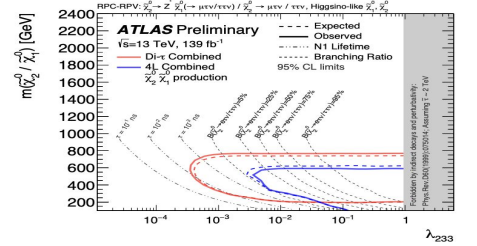
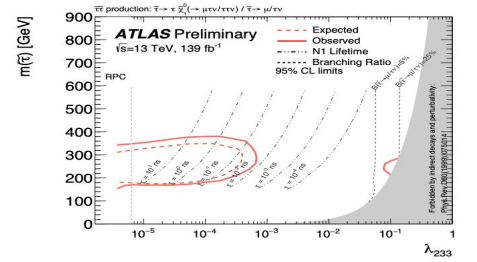
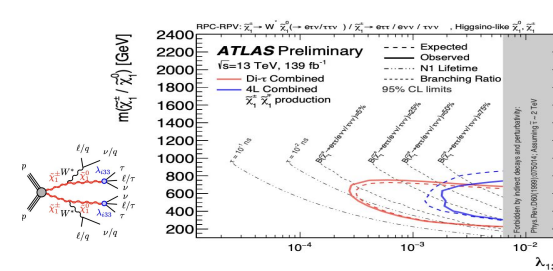
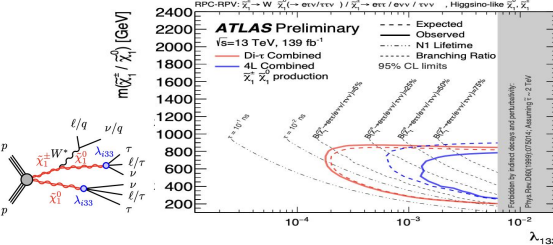
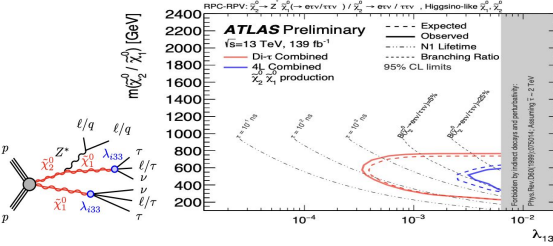
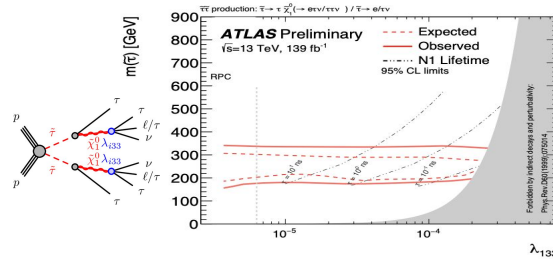
- Using published results to fill the gap between the RPC and RPV scenarios
- Stau+EWKinos LLE case got published: [ATL-PHYS-PUB-2024-007](https://arxiv.org/abs/2407.13817)
- Glauino & Squarks with LQD and UDD are ongoing



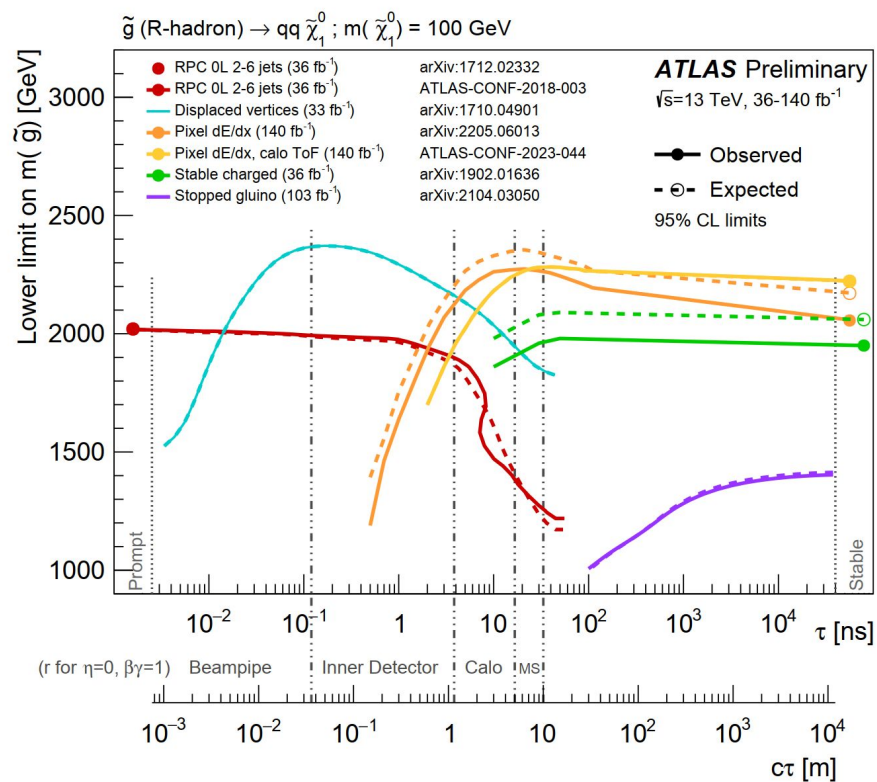
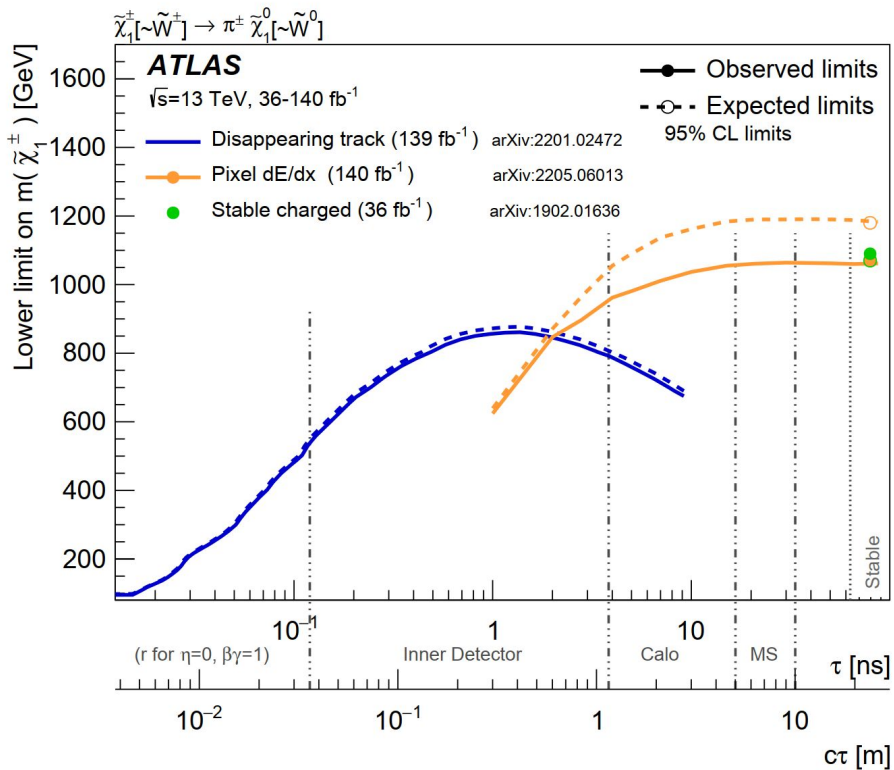
- Published results can also be used to fill the gap between Long-Lived with prompt



[PLB 846 \(2023\) 138172](https://arxiv.org/abs/2312.13817)

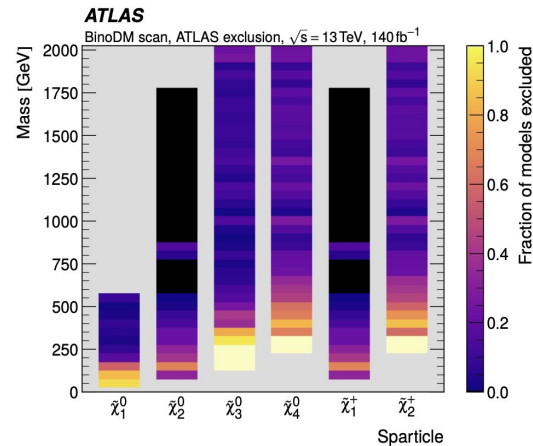
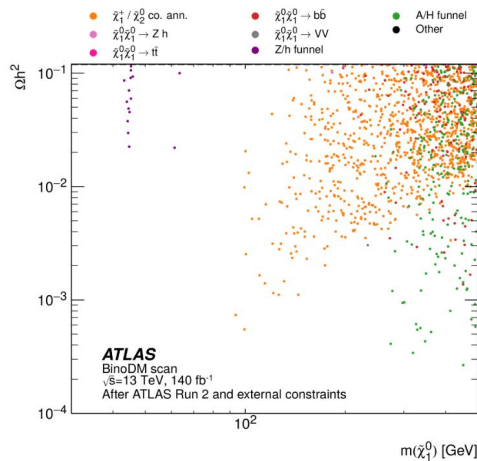
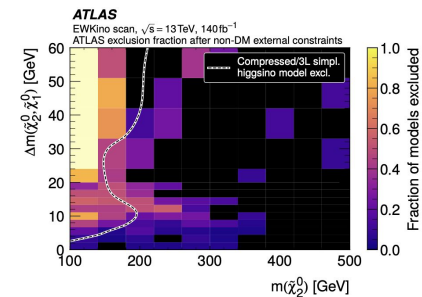
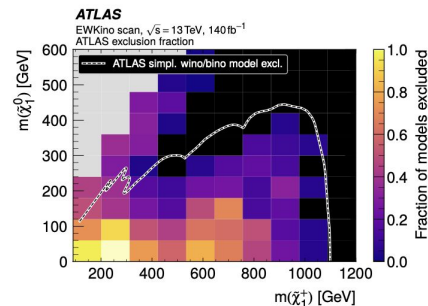


Long-Lived SUSY:



Beyond simplified model:

- pMSSM-19 scannings
- GMSB scannings
- Plenty of information can be extracted from the scanning:
 - Presented in function of mass(EWKino), DM related observables
 - Complementary constraints from collider and non-collider measurements
 - Z/h 'funnel regions' got completed exclusion
 - ...



Summary & Outlook:

- Summary:
 - The Run 2 data have offered an unprecedented opportunity to search for answers to many of the fundamental questions still open today in high-energy physics
 - No significant excess of events in data observed
 - Putting more stringent constraints on the phase space of models with applications of most cutting edge techs and methods
 - “Theorists are happy with our current search strategies”
 - Targeting at specific final states and interpreting as wider as we can
- Outlook:
 - “Leave no stone unturned”
 - Followed the “tiny trace” we saw
 - Go beyond simplified models
 - Reinterpretation & Preservation are the keys to the future:
 - Build a bridge between experimentalists and theorists
 - Necessary step for (Q)AI4Science
 - A tool might change the search pattern for the future