NP searches
Summary & Highlights

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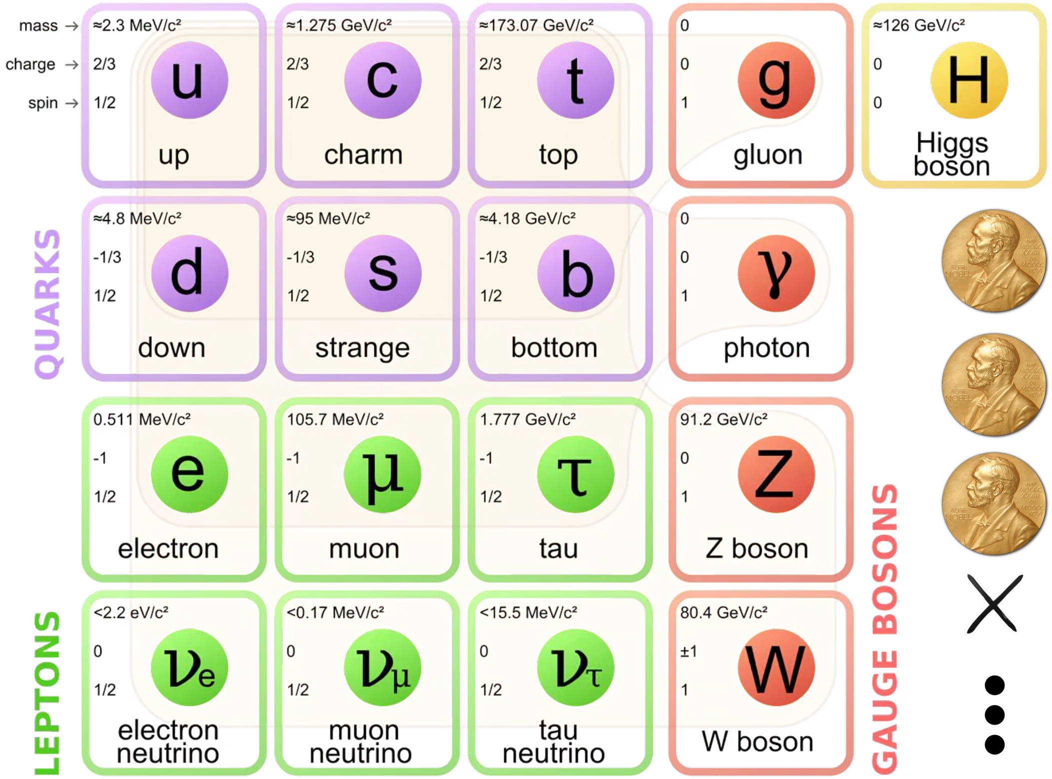
Why new physics:

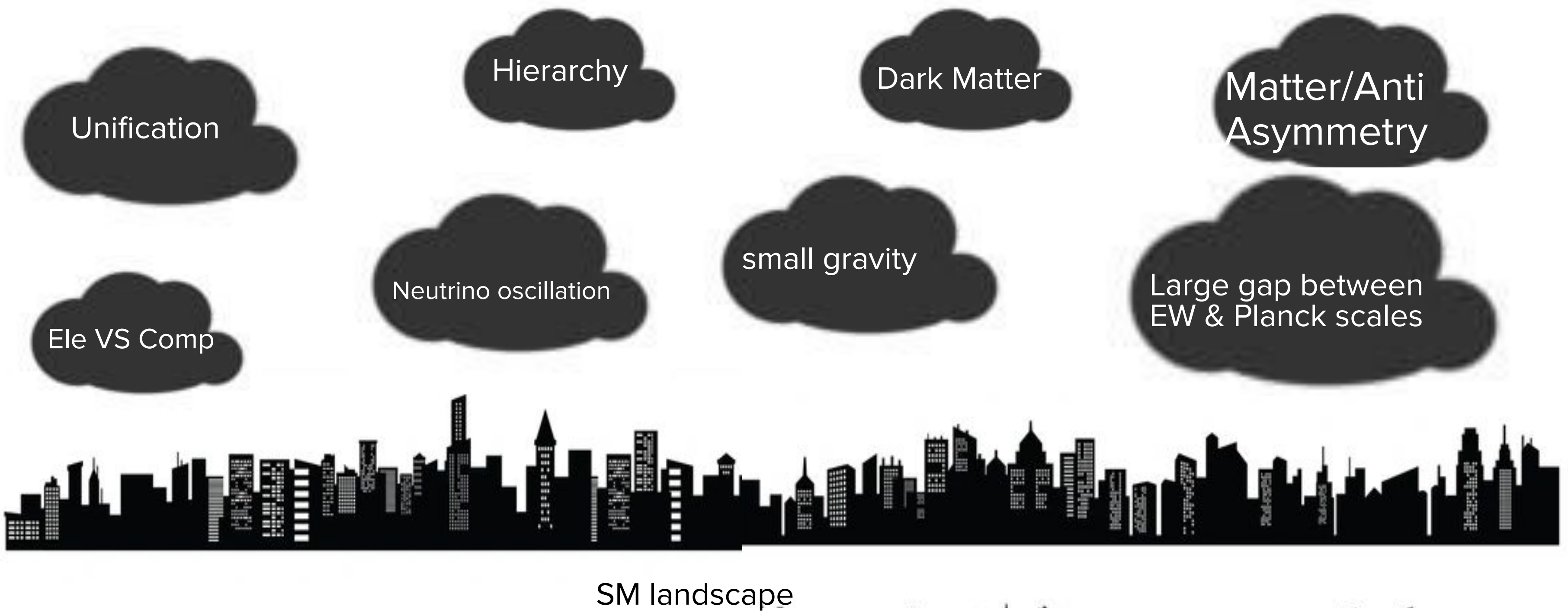
Today

20th century

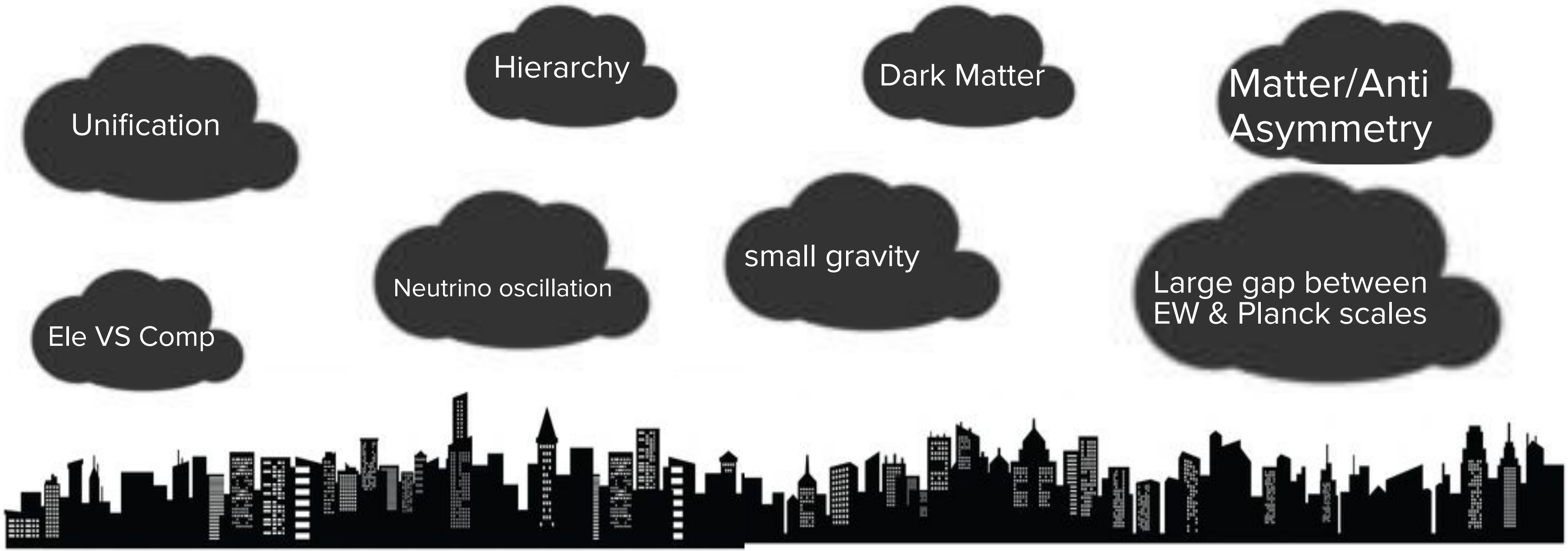
Classical landscape



Why new physics:



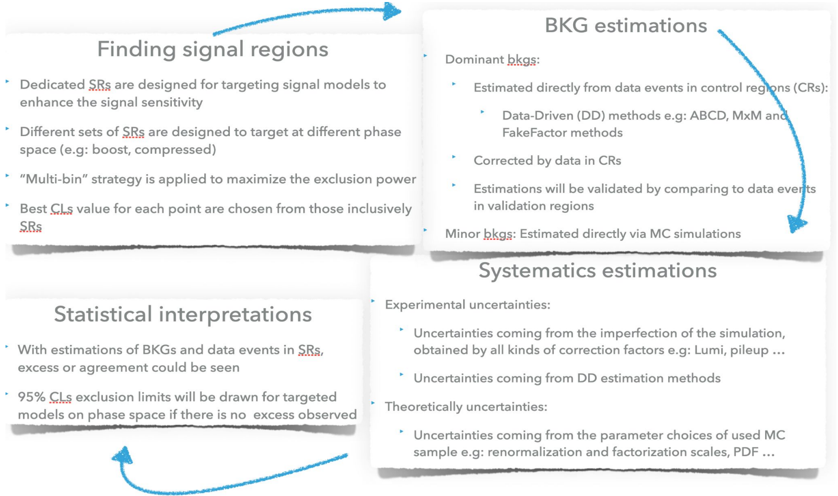
Why new physics:

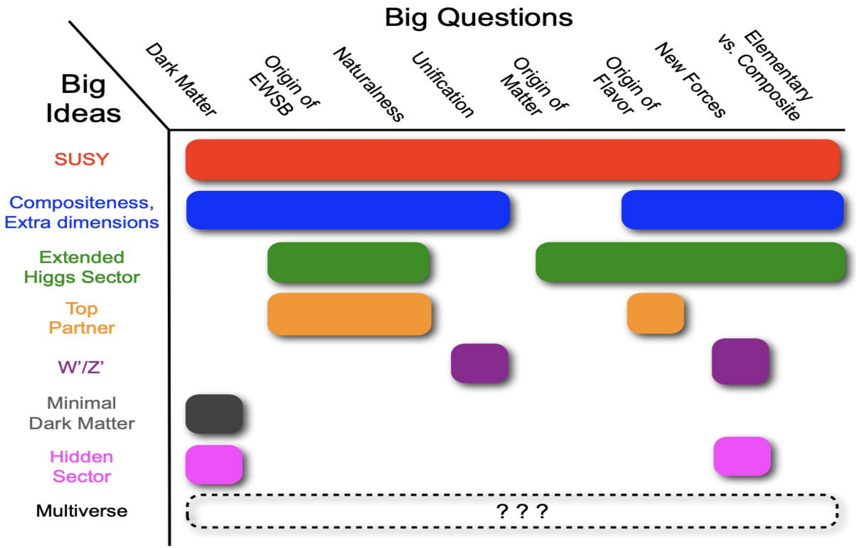


Golden age for revolutionary discovery!

Overview of NP searches @ LHC:

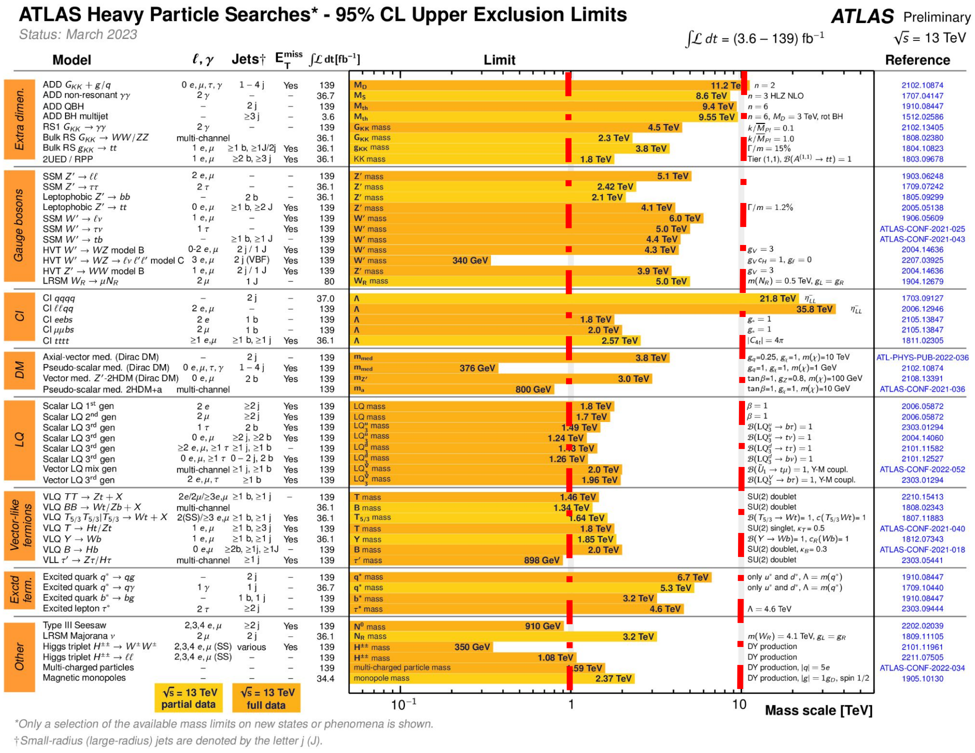
- LHC is world’s most powerful facilities to push the limits of our understanding of the universe at high energy frontier
- Searches covering most appealing directions of the new physics:
    - HBSM: see talk from Jin Wang
    - **Exotics**: see more details from 昊许, TianaoWang, 齐斌刘, 桐彬赵, YifanYang,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

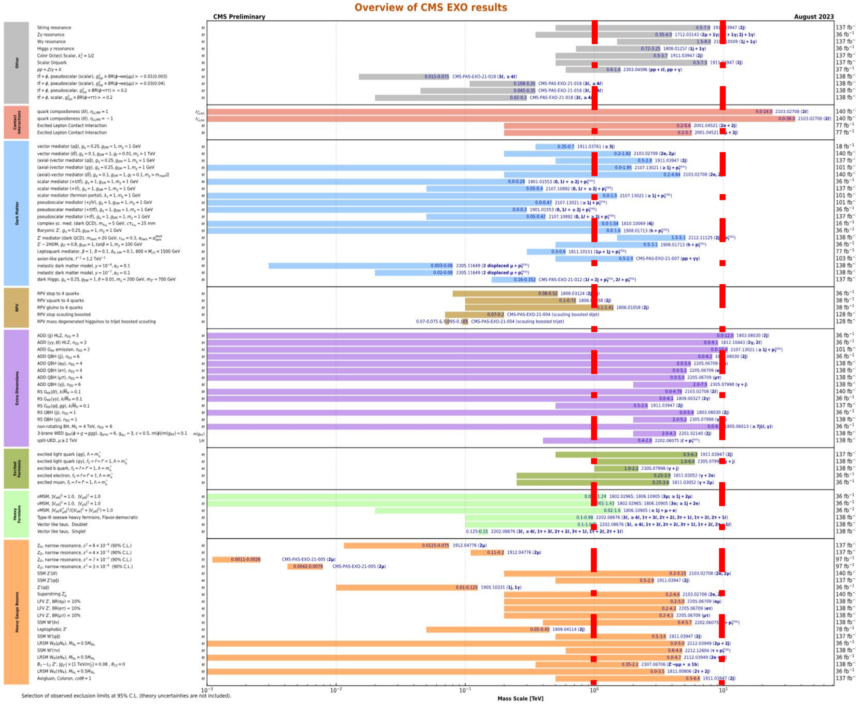




Exostic searches

Exotic summary:





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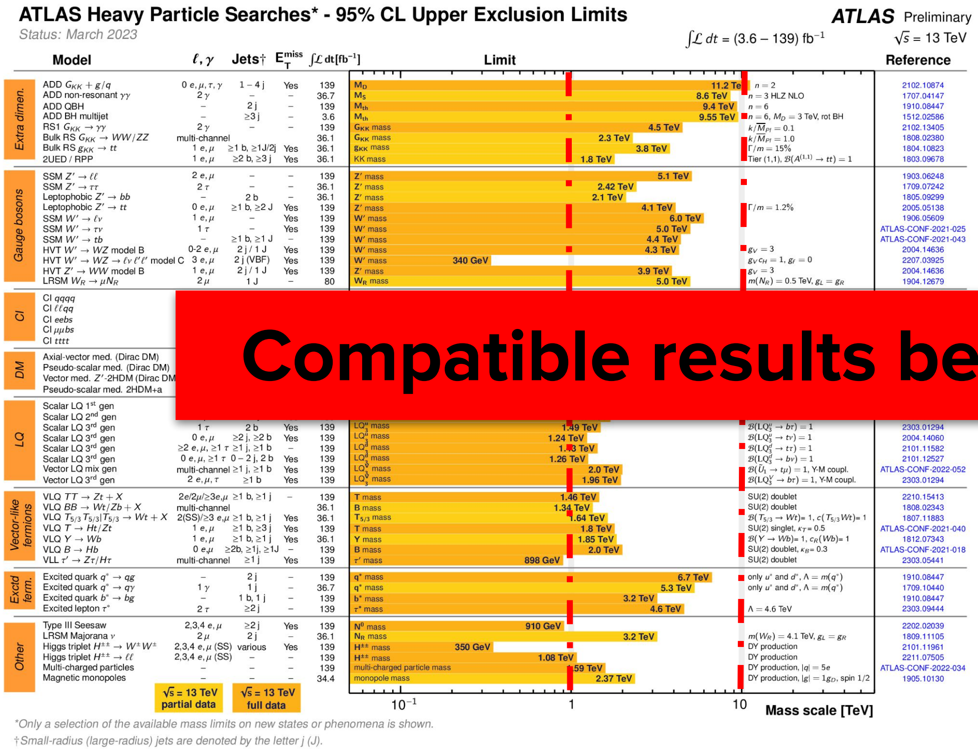
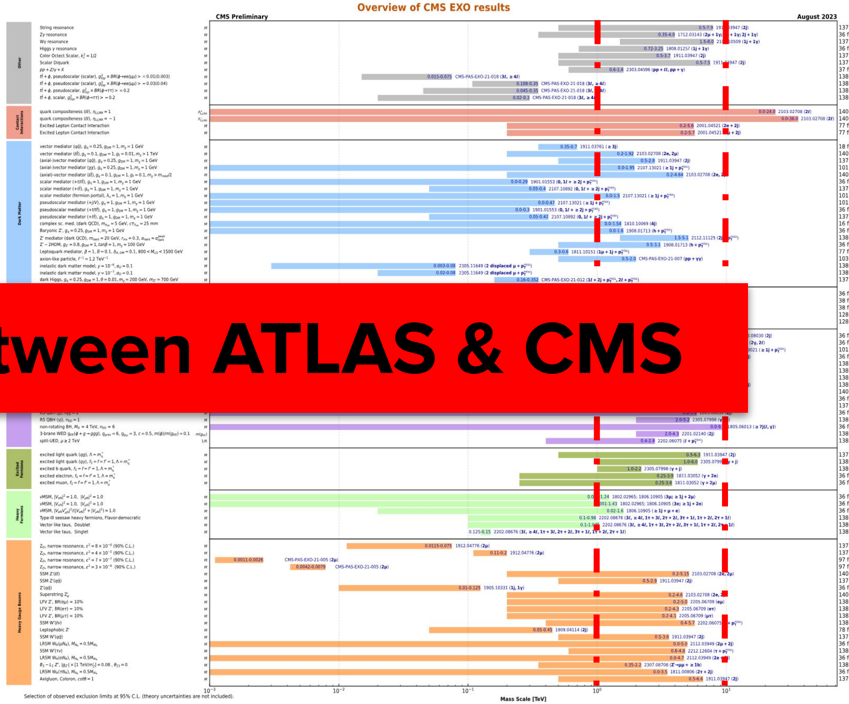


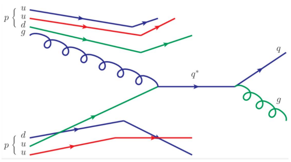


Compatible results between ATLAS & CMS

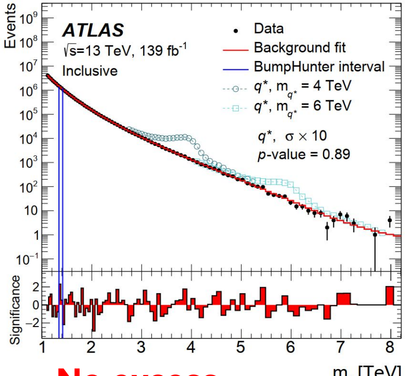
Compositeness searches:

Ele VS Comp

- 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



No excess

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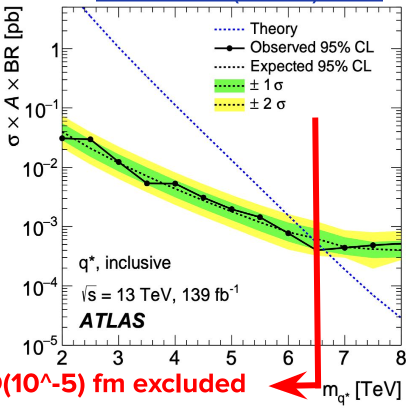
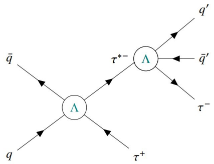


O(10^-5) fm excluded



Excited leptons

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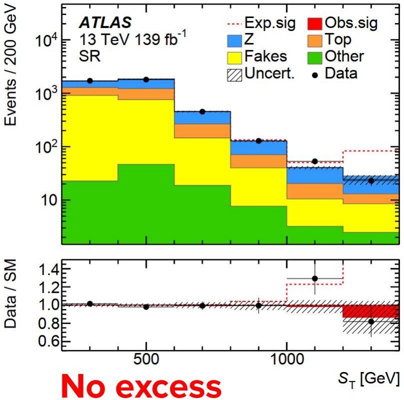
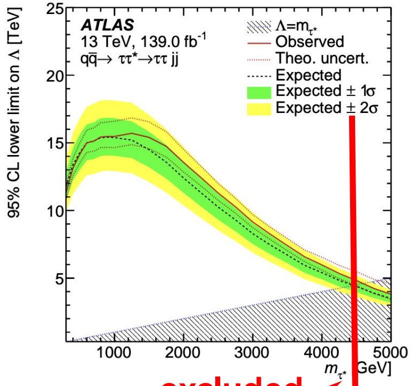


No excess



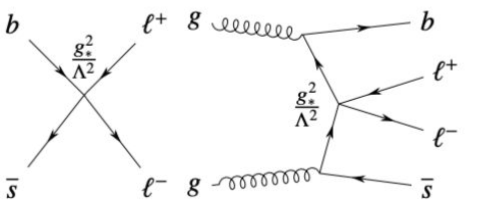
excluded

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, lν, 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
	$e\nu+\mu\nu$	6.0
	$\tau\nu$	5.0
Z'_{ψ}	$ee+\mu\mu$	4.5
Z'_{TC2}	$t\bar{t}$	3.9
Z'_{LUV}	$b\bar{b}b\bar{b}$	1.45
$W'_R(g'/g=1.0)$	tb	4.6
W'_{HVT} (model A)	$WZ\to XXqq$	3.9
W'_{HVT} (model B)	$WZ\to XXqq$	4.3
W'_{HVT} (model C)	$WZ\to\ell\nu\ell\ell$	3.4
Z'_{HVT} (model A)	$WW\to\ell\nu qq$	3.5
Z'_{HVT} (model B)	$WW\to\ell\nu qq$	3.9

Contact interaction

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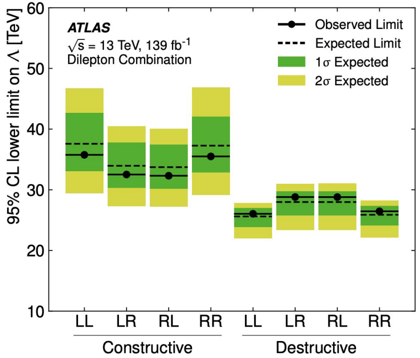
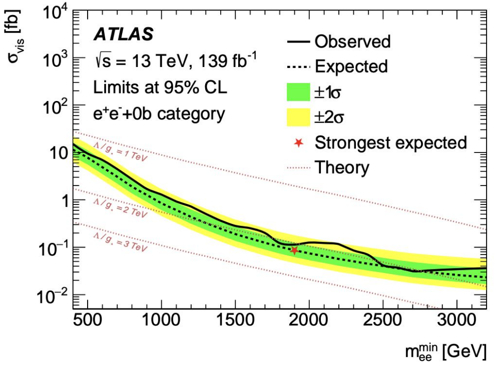


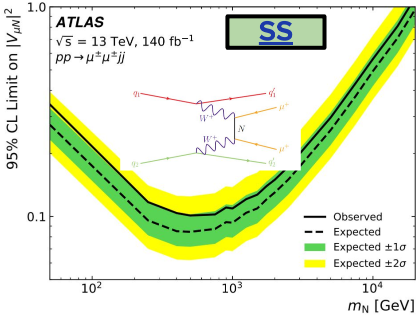


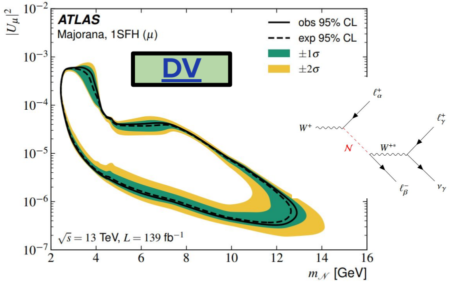
Additional lepton searches:

Neutrino oscillation

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

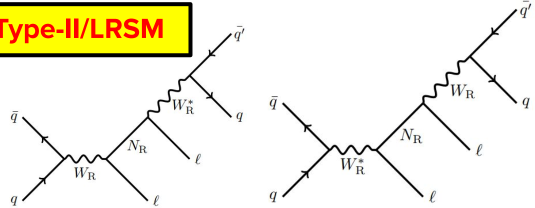
Type-I

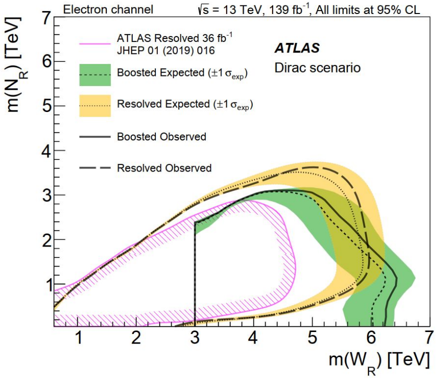




Type-II/LRSM

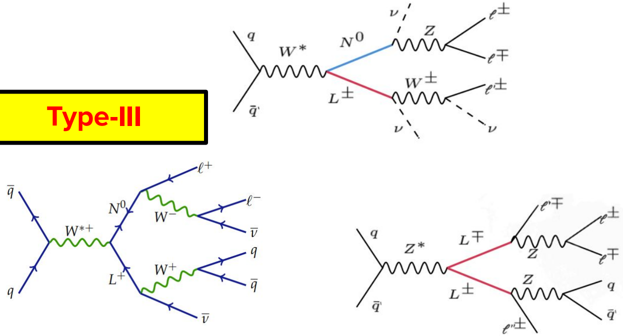
[2304.09553]

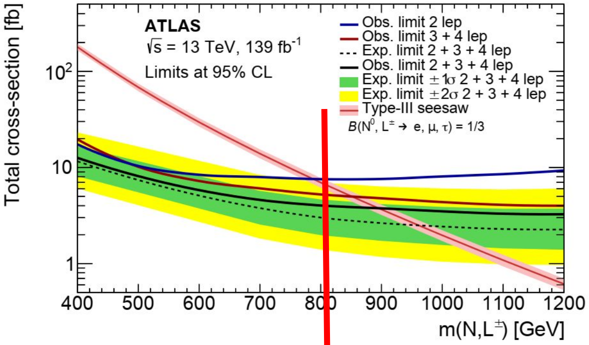




Type-III

[2304.09553]





excluded

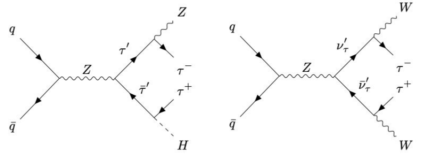
Vector-like lepton and quarks:

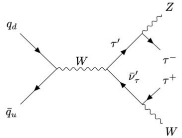
Large gap between EW & Planck scales

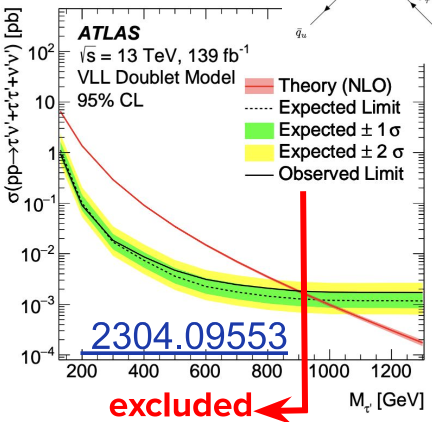
Hierarchy

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

VLL

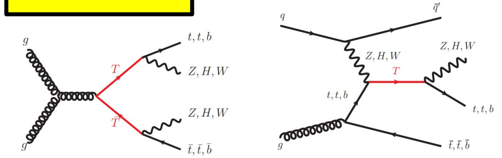




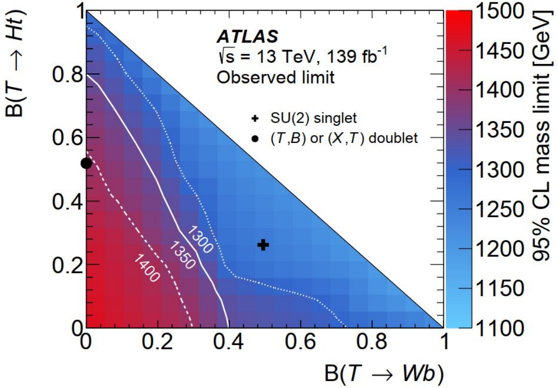


[2304.09553](https://arxiv.org/abs/2304.09553)

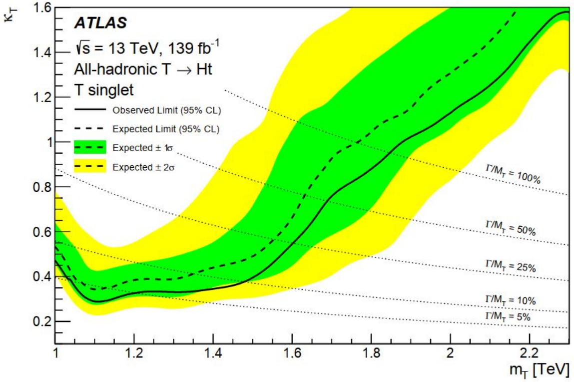
VLQ



[2210.15413](https://arxiv.org/abs/2210.15413)



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

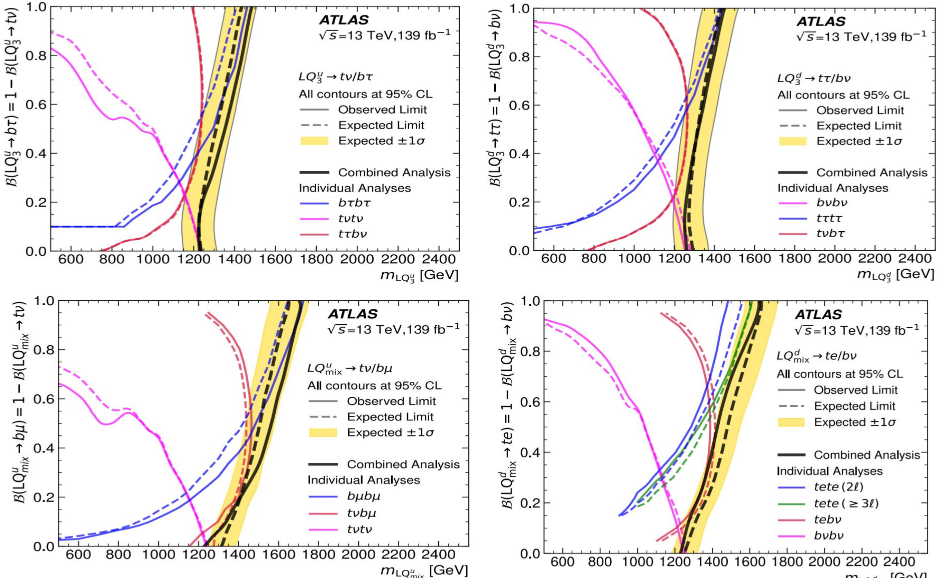


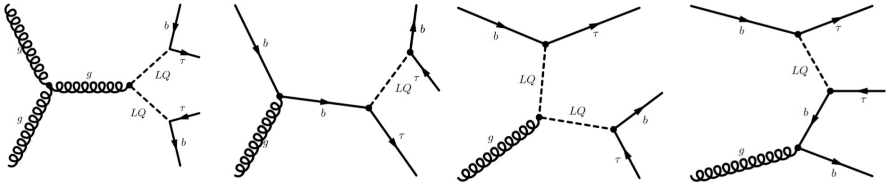
Unification

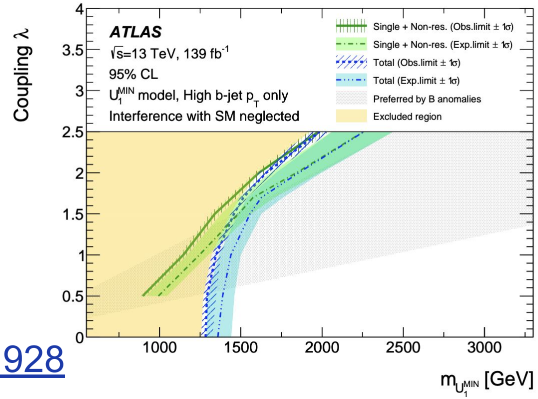
Ele VS Comp

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

Lepton Flavour Violation:

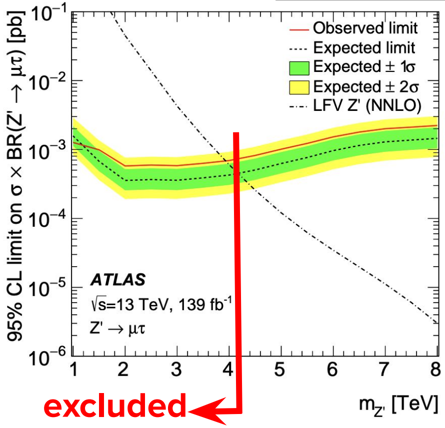
Neutrino oscillation

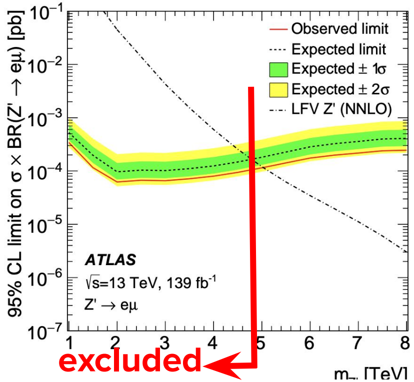
- Measuring the LFV precisely can probe the BSM (N and Z')
- Z/Z'->LFV (HLFV will be covered by another talk)
  - Z to emu, Z to etau, and Z to mutau with τ_had and τ_lep

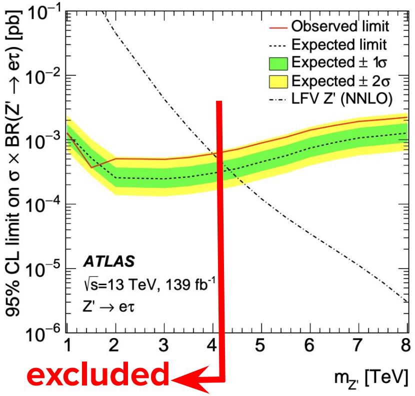
ZLFV

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

Z'LFV







2307.08567

Hidden(dark) sector searches:

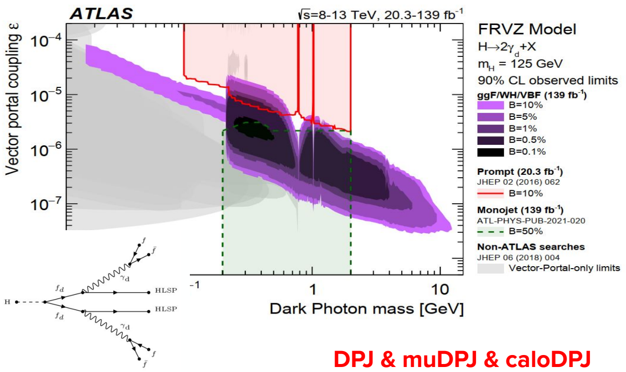
Hierarchy

Dark Matter

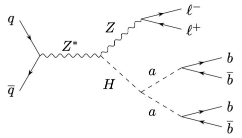
- Predicted by many BSM theories
- Particles in hidden sectors can only interact with SM particles via a mediator:
  - Could be Higgs, new scalar, pseudoscalar, vector or axial-vector particle
  - With small couplings leading to LLPs giving **DPJ**, **muDPJ**, **caloDPJ**, **DV**, and **muDV**

Dark photon through H portal

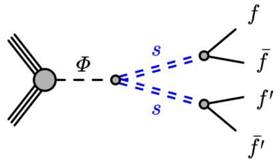
2107.06092

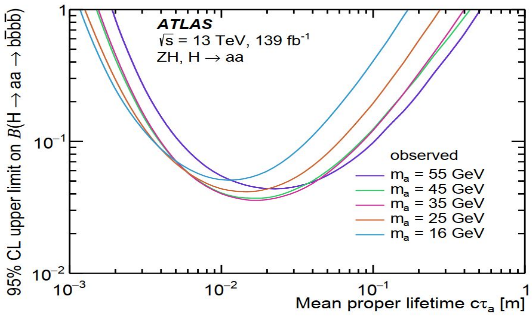


DPJ & muDPJ & caloDPJ

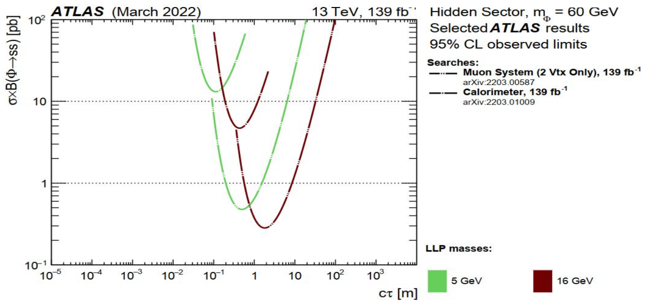


a and Φ searches





2107.06092 DV

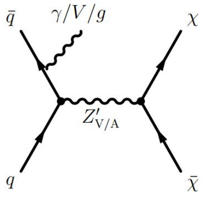


muDV & caloDPJ 2203.00587

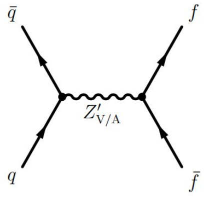
Dark Matter

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

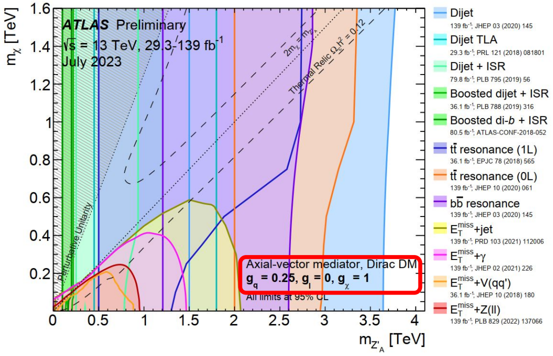


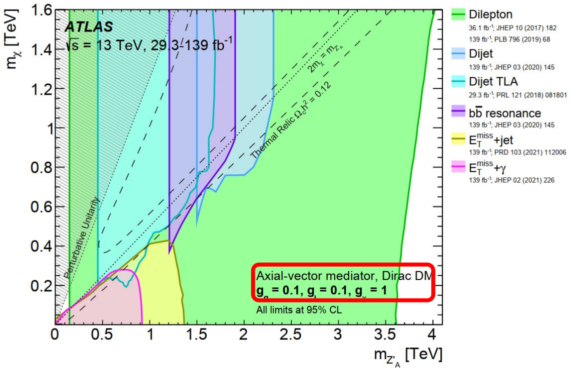
X+MET

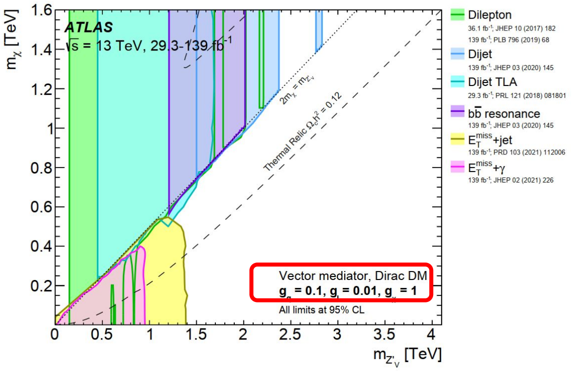


resonant

Vector or Axial vector portal







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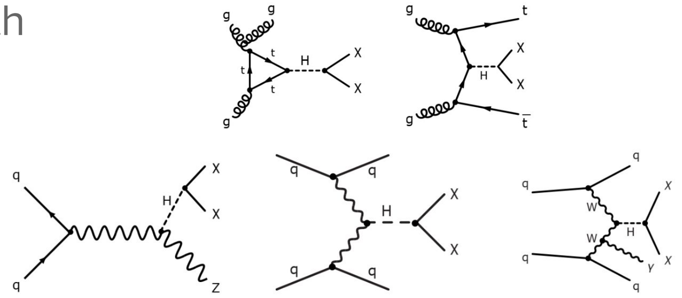
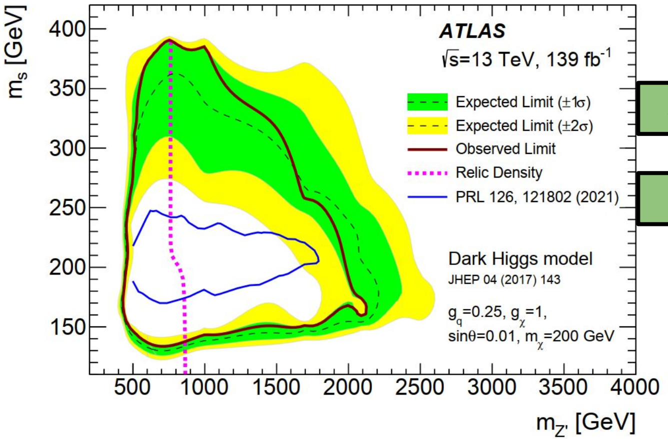
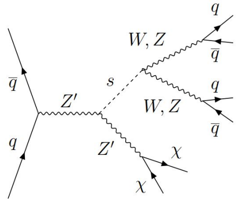


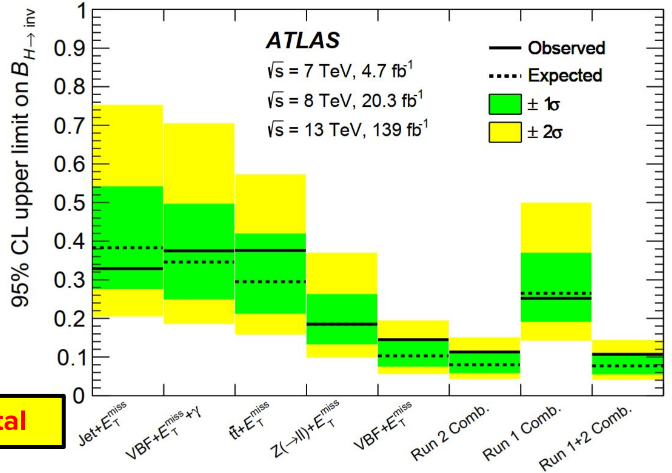
Vector portal with a dark Higgs boson (s)





SemiLep

FullHad



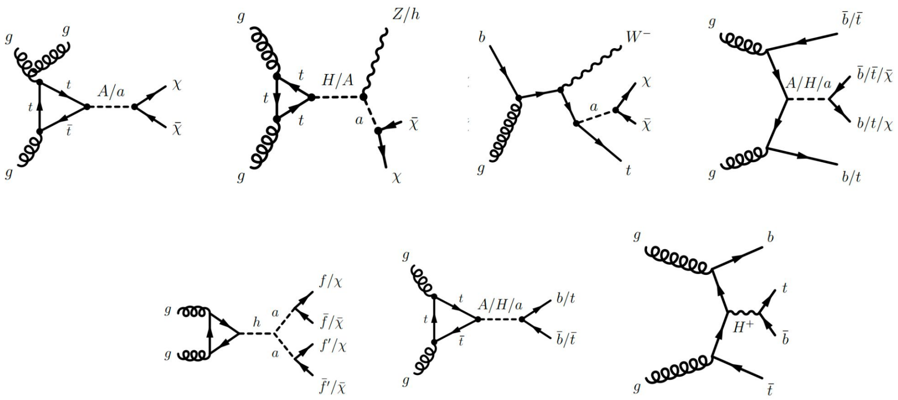
Higgs portal

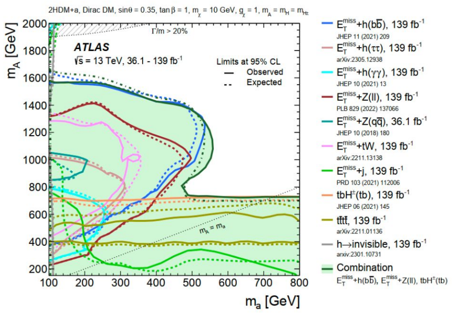
Dark Matter

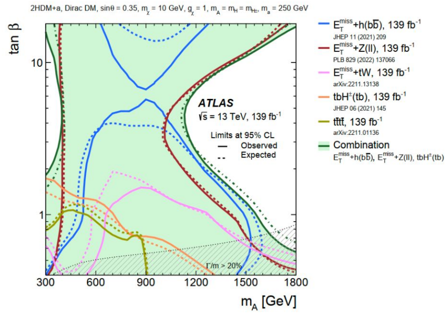
Dark matter searches:

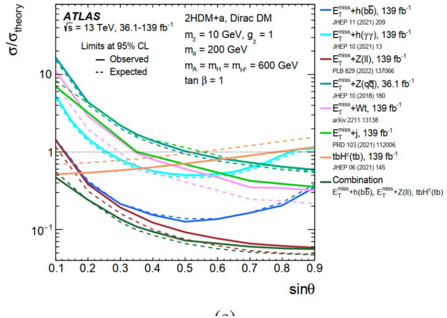
- WIMP mass close to the electroweak scale and an interaction strength with SM particles of the order of the weak interaction's strength
- Can be produced at LHC
- Simplified DM models are used:
  - Through a vector, axial vector, pseudoscalar or Higgs portal
  - Composite stable particles coupled with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

Pseudoscalar portal



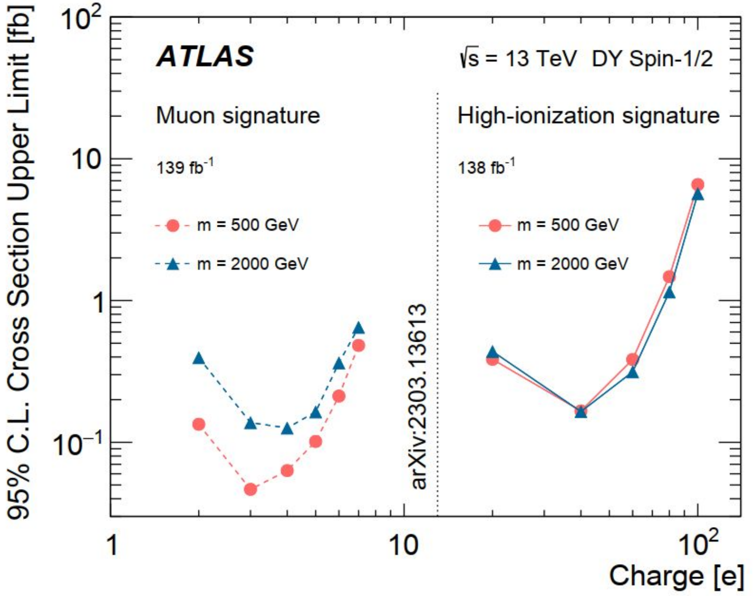






Charged LLPs:

- 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



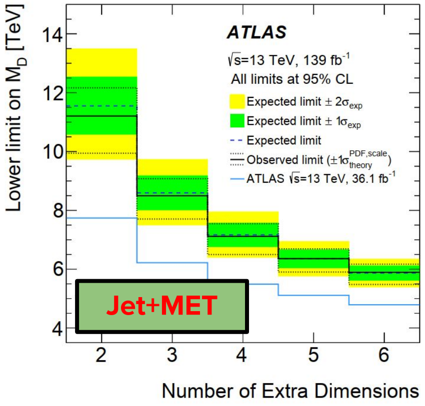
- For MCP:
    - Models with 500 GeV masses are strongly excluded
    - At 2 TeV, none of the MCP models are excluded

Gravitons:

small gravity

- 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

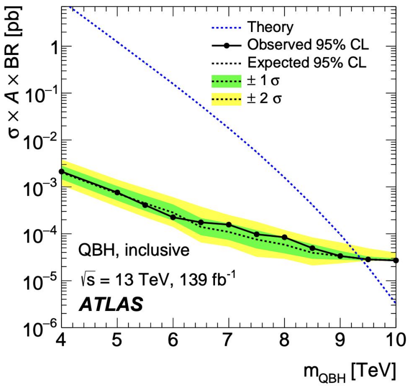
Analysis final state	Model	k/M_{Planck}	Excluded mass range for $m_{G_{KK}}$ [TeV]
bb	RS1	0.2	< 2.8
$\gamma\gamma$	RS1	0.1	< 4.5
Semileptonic $t\bar{t}$ (36.1 fb^{-1})	bulk RS	1.0	0.45–0.65
$HH \to bbbb$	bulk RS	1.0	0.298–1.46
$WW/ZZ \to qqqq$	bulk RS	1.0	1.3–1.8
$WW \to \ell\nu qq + ZZ \to \ell\ell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

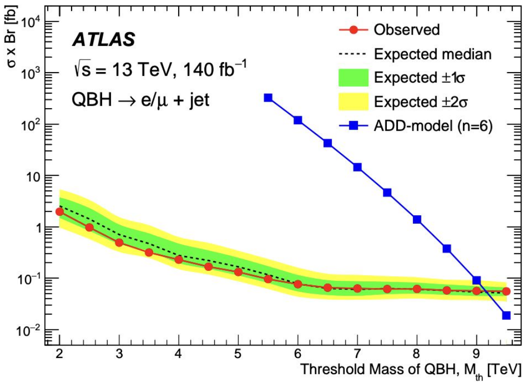
small gravity

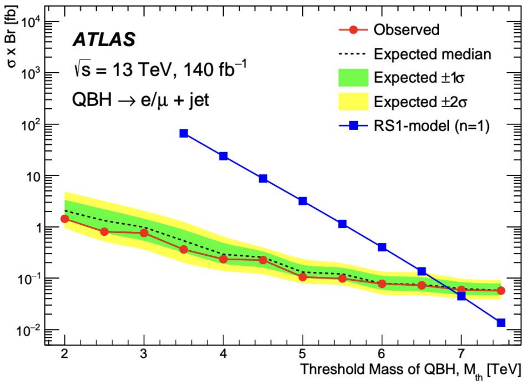
Quantum black hole:

- 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 MD, decay into two-particle final states

Dijet resonant





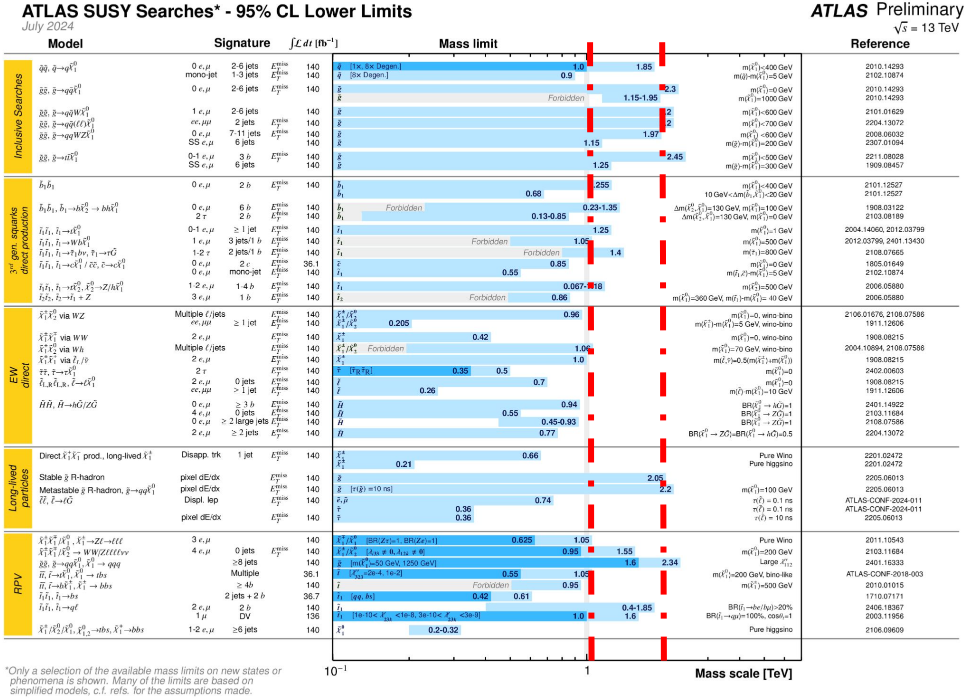


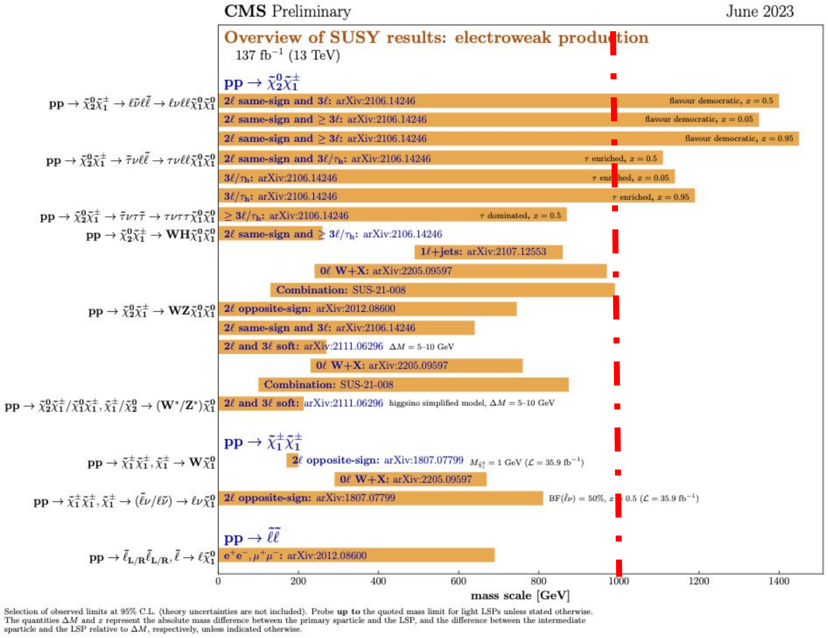
SUSY searches

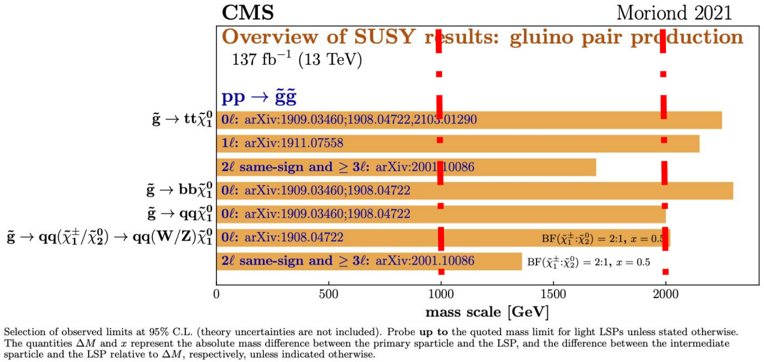
Why SUSY:

- "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

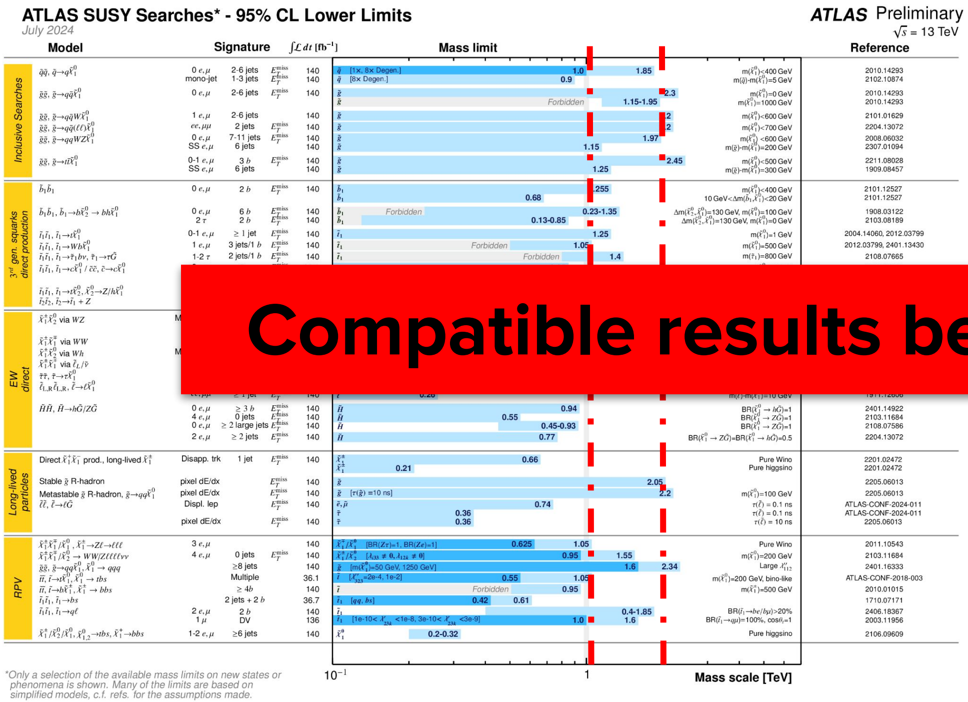
SUSY summary:

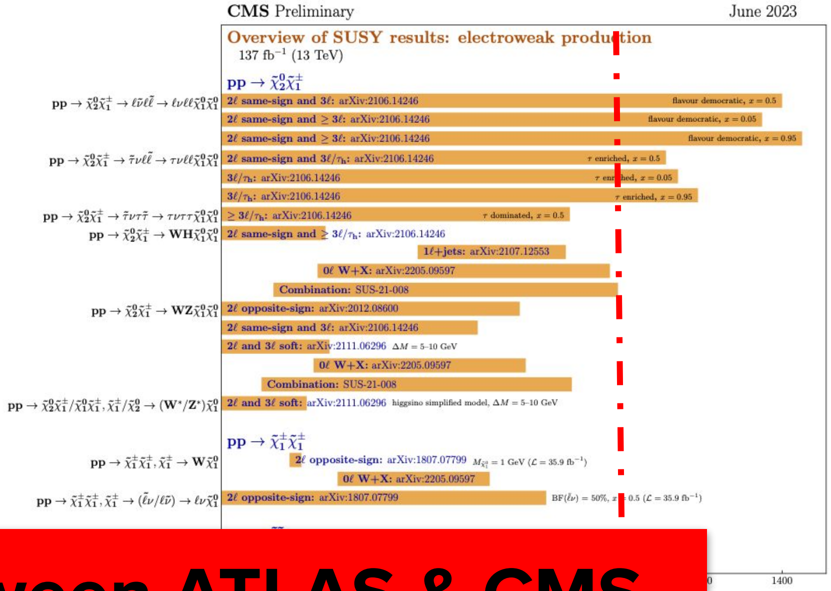




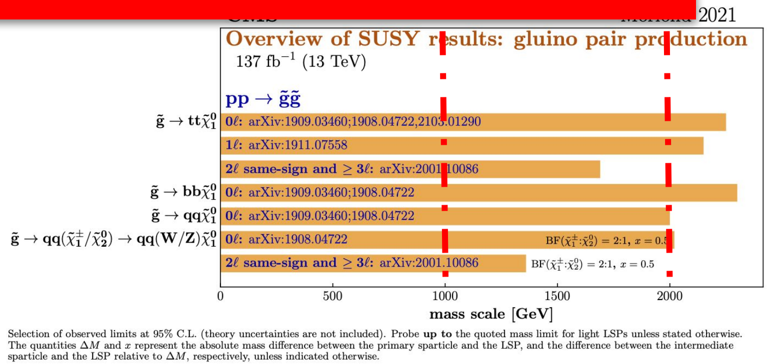


SUSY summary:

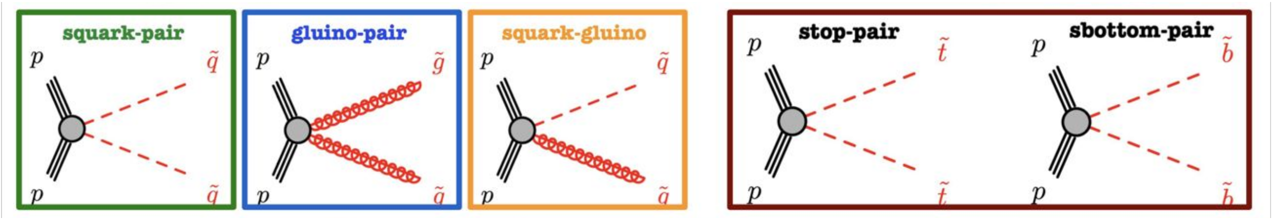


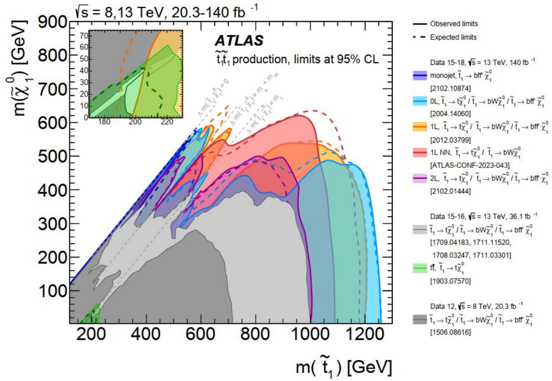


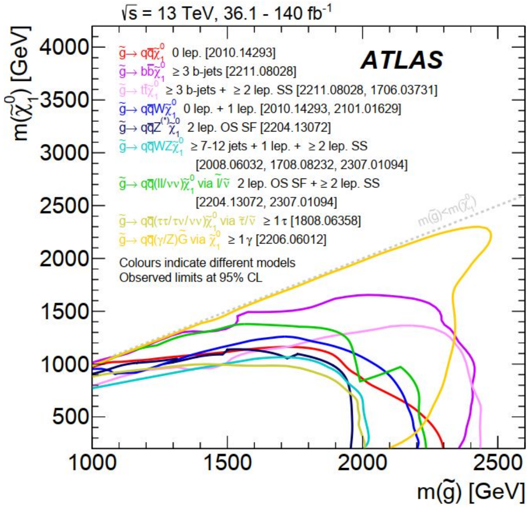
Compatible results between ATLAS & CMS

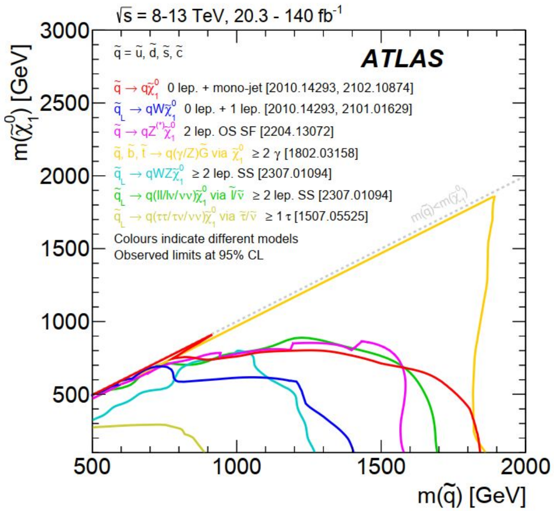


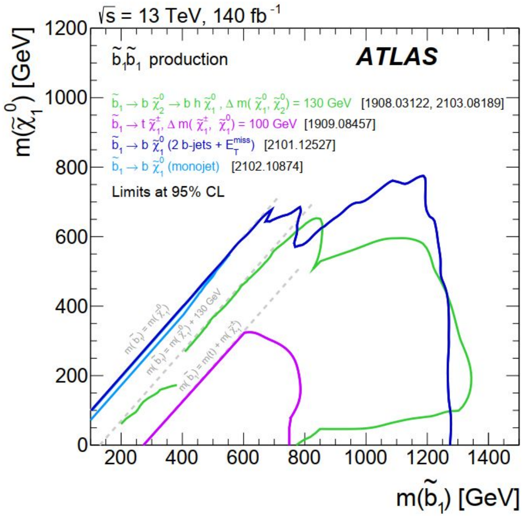
Strongly produced SUSY:



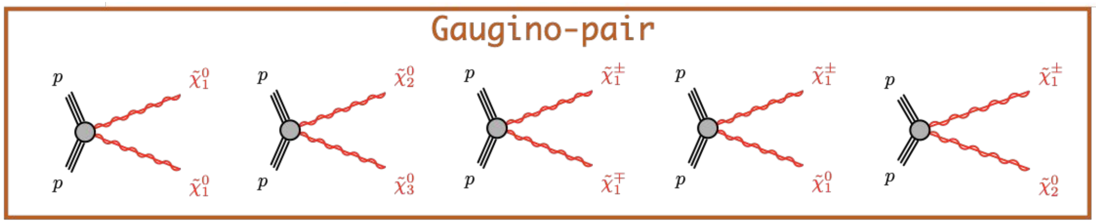


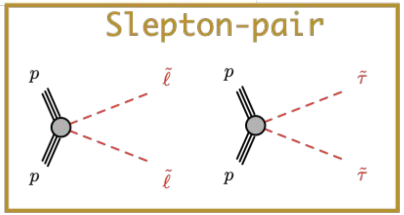


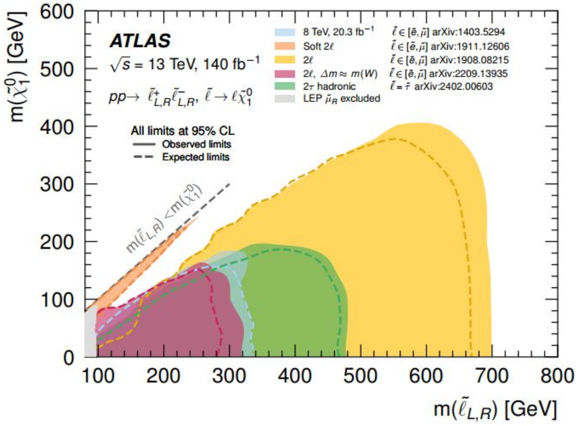


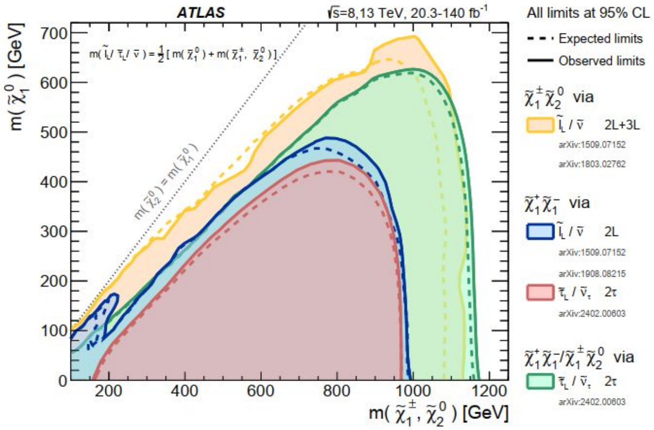


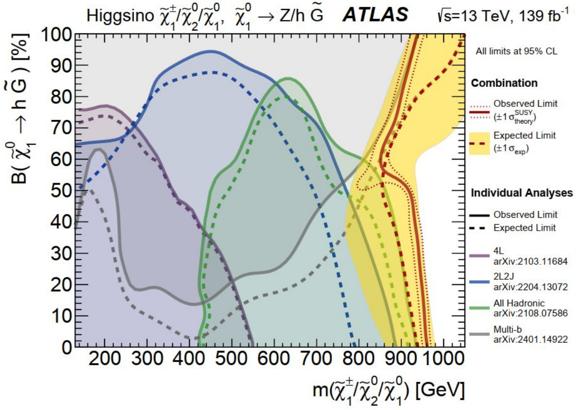
EWKly produced SUSY:





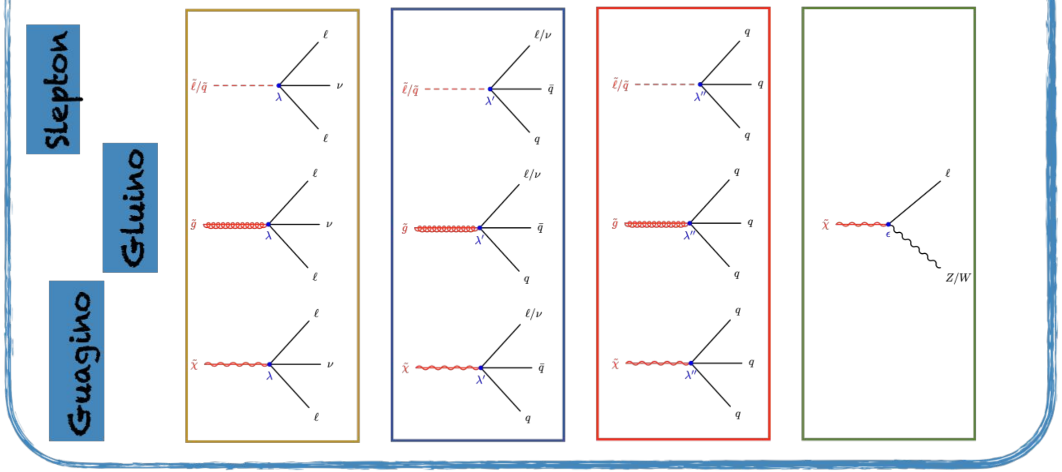


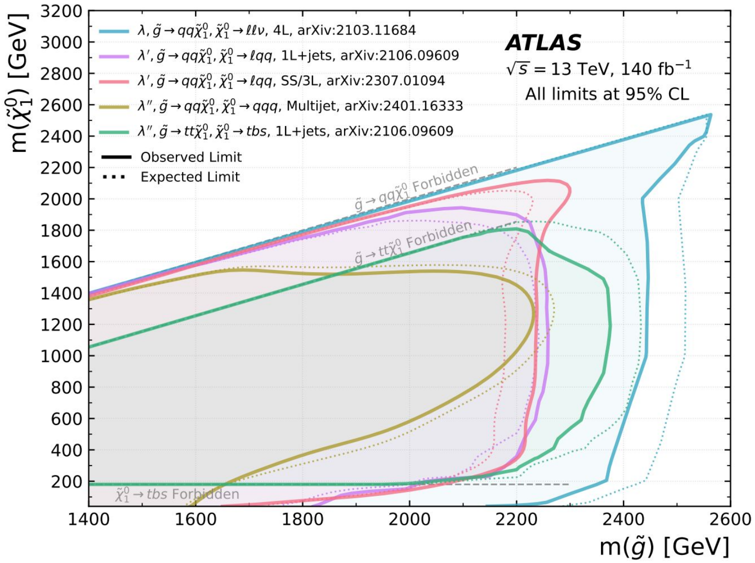




RPV case: (prompt)

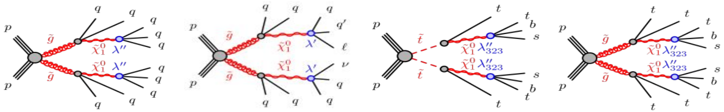
$$W = W_{MSSM} + W_R;\ W_R = \frac{1}{2}\lambda_{ijk}L_iL_j\bar{E}_k + \lambda'_{ijk}L_iQ_j\bar{D}_k + \frac{1}{2}\lambda''_{ijk}\bar{U}_i\bar{D}_j\bar{D}_k + \kappa_i L_i H_2$$



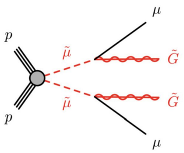


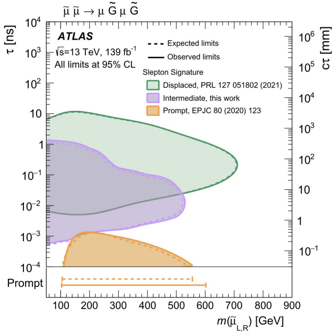
RPC-RPV:

- Using published results to fill the gap between the RPC and RPV scenarios
- Stau+EWKinos LLE case got published: [ATL-PHYS-PUB-2024-007]
- Gluino & Squarks with LQD and UDD are ongoing

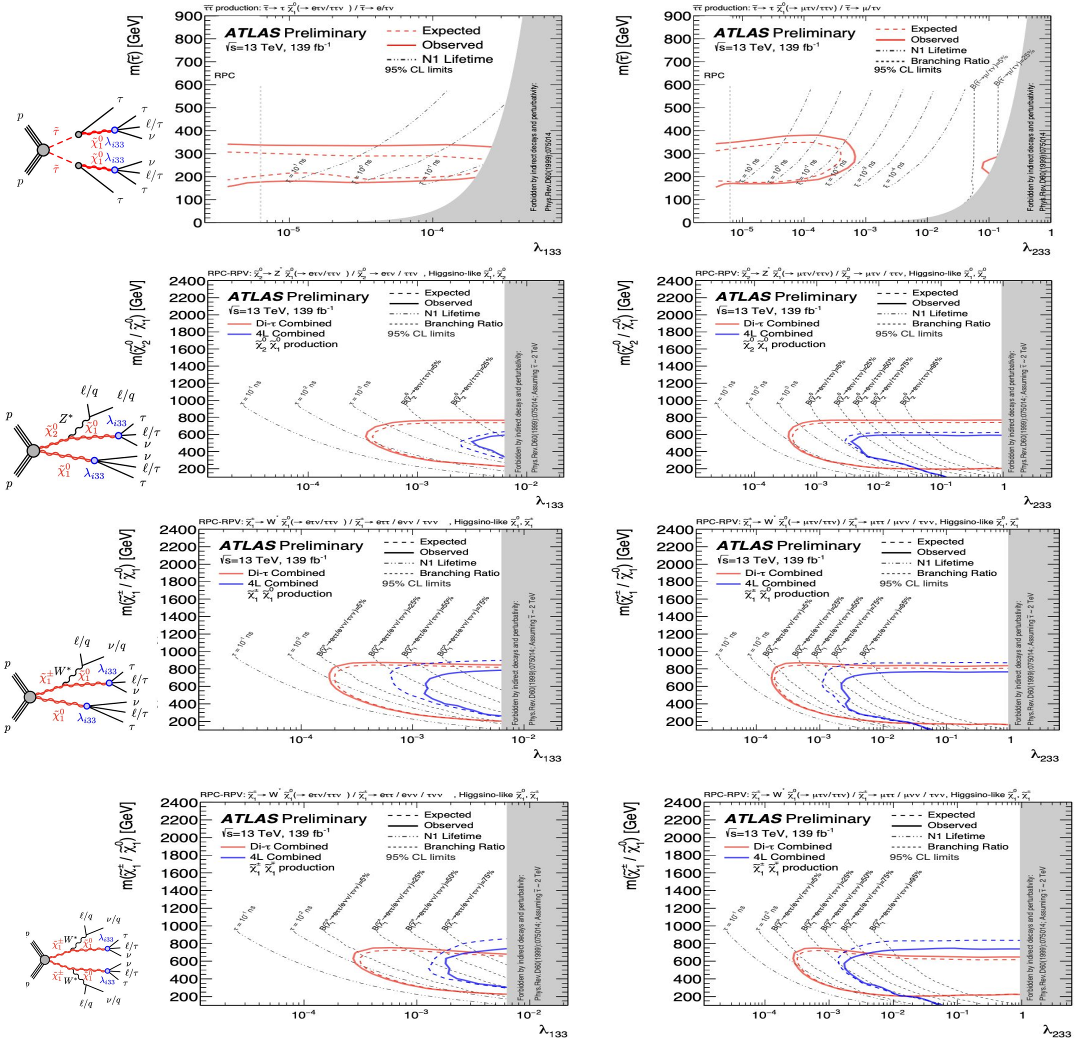


- Published results can also be used to fill the gap between Long-Lived with prompt

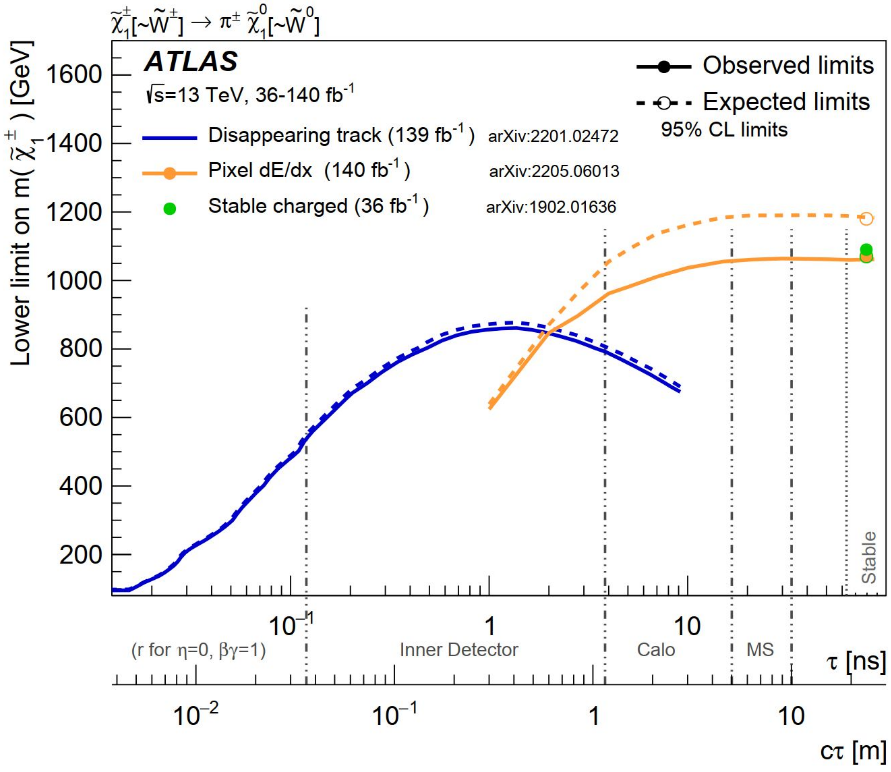


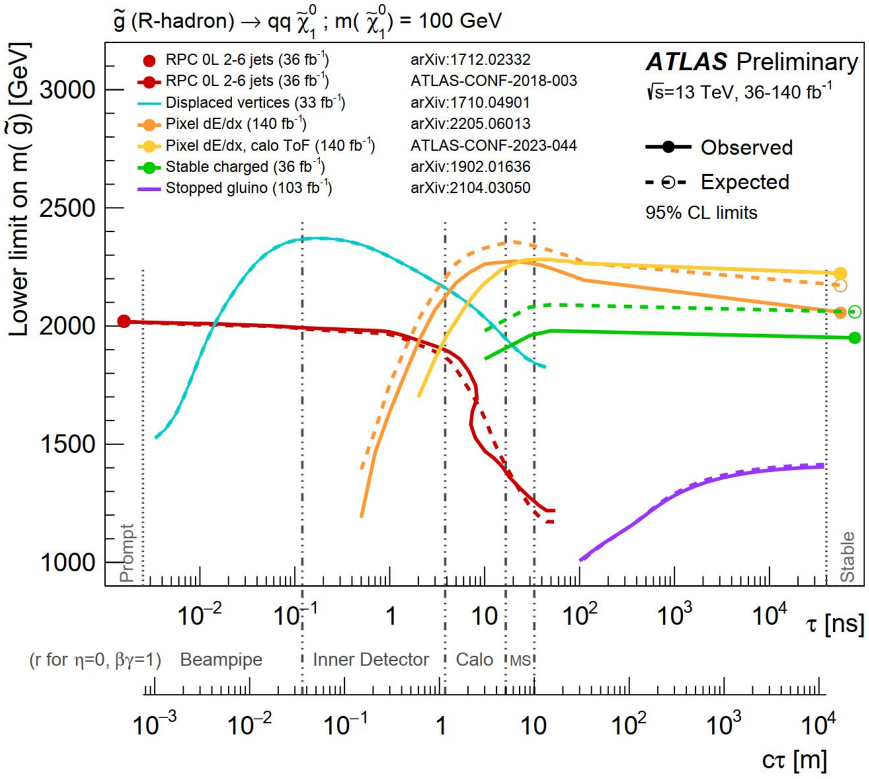


[PLB 846 (2023) 138172]



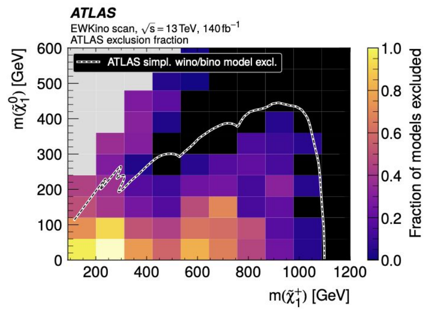
Long-Lived SUSY:

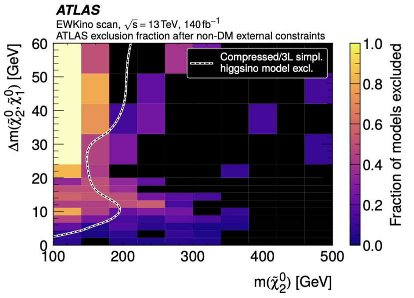


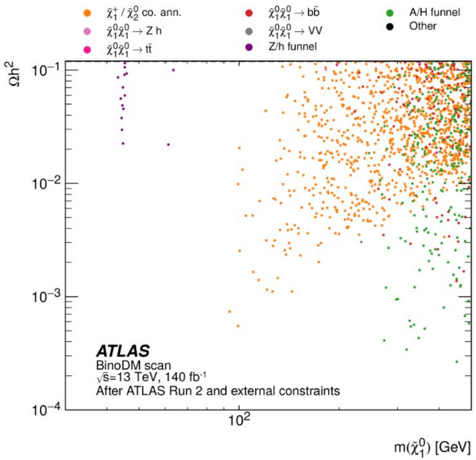


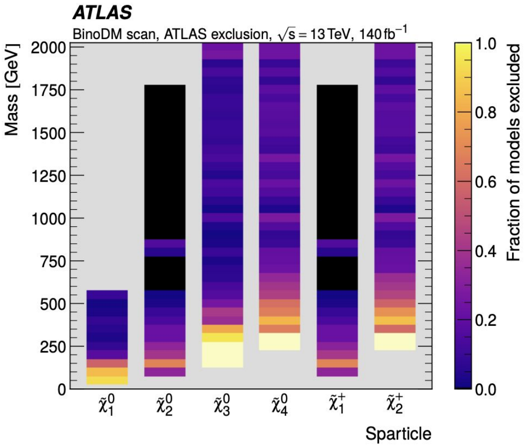
Beyond simplified model:

- 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