



University
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BSM physics in ATLAS and CMS

LHC Days, Split, 2024
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Introduction and Overview

There are good reasons to think physics beyond the SM exists:

- Dark Matter, Hierarchy problem, CP-violation (i.e. matter over anti-matter), ++

I'll be focussing on BSM results from SUSY and exotics:

- I've tried to find examples where the experiments have looked at similar models:
 - VLQ Combinations
 - Low-mass resonances
 - pMSSM scans
- Quite a lot of combinations:
 - Reflects the tail of Run-2 - combinations of searches naturally come after the searches.
- Still loads of really interesting results I can't include: see public results pages – [CMS susy](#), [CMS exotica](#), [CMS B2G](#), [ATLAS susy](#), [ATLAS exotics](#)

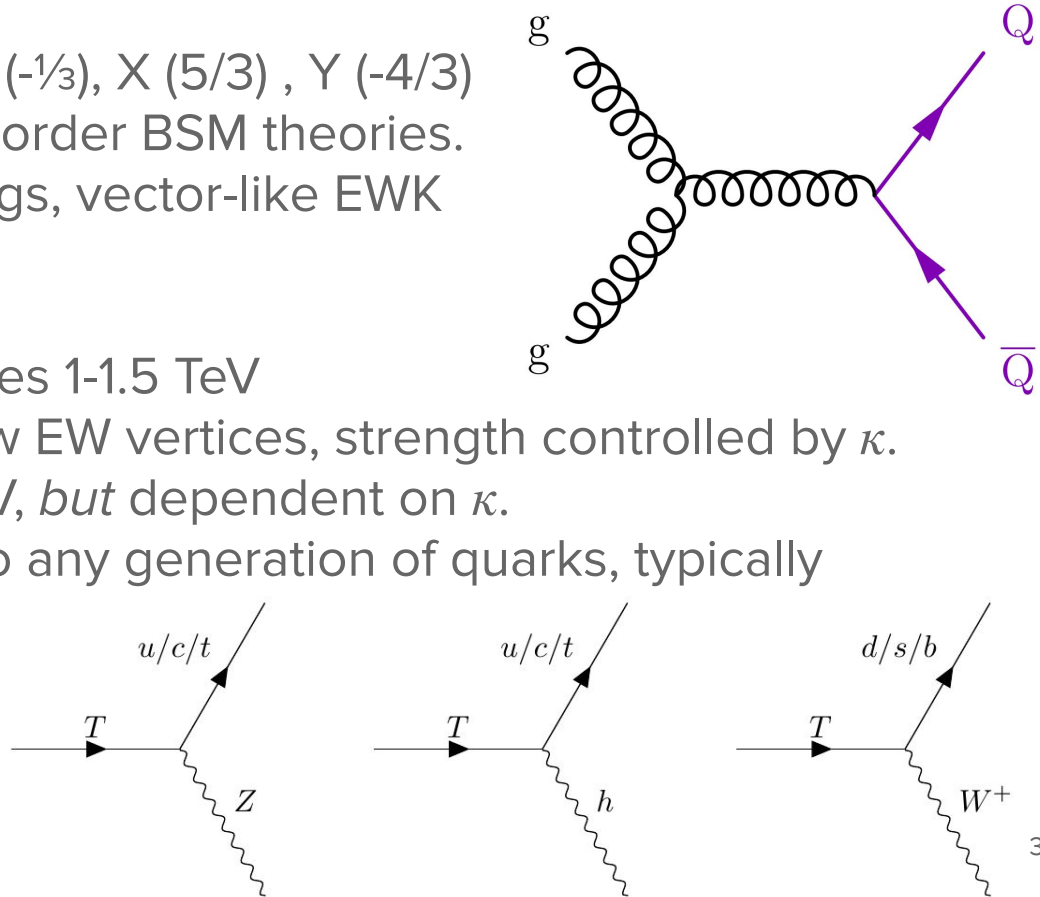
“BSM” covers a very wide range of physics, and I've only got 15 minutes. So I'm not covering:

- LLPs (see next talk!)
- BSM Higgs (see discussion yesterday)

Vector-like quarks: CMS review/ATLAS combination

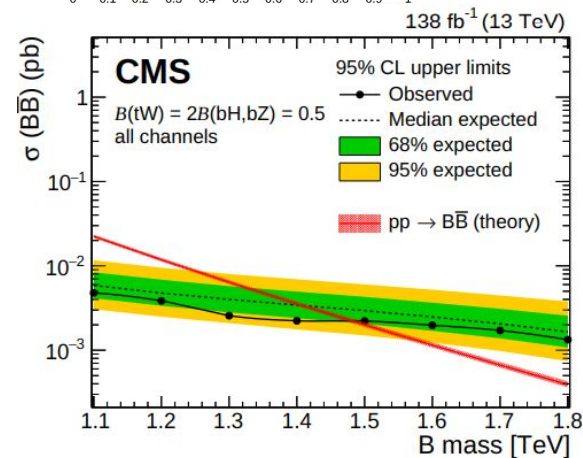
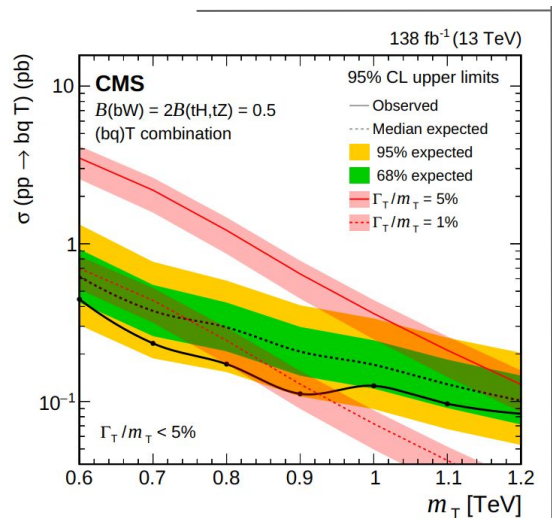
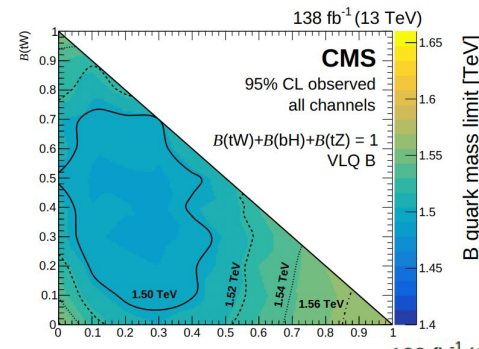
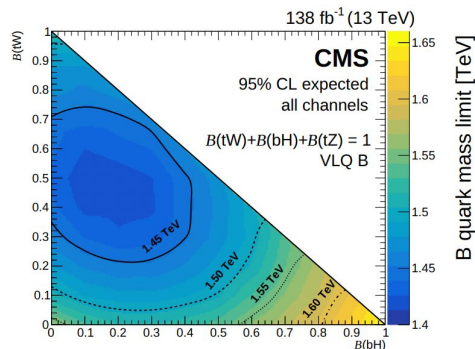
- Vector-like quarks - T ($2/3$), B ($-1/3$), X ($5/3$), Y ($-4/3$)
 - Occur in several higher-order BSM theories.
 - Quark-like QCD couplings, vector-like EWK couplings.
 - QCD pair produced:
 - Mass range of studies 1-1.5 TeV
 - Single produced via new EW vertices, strength controlled by κ .
 - Studies up to 2.1 TeV, *but* dependent on κ .
 - In principle can decay to any generation of quarks, typically searches prioritise 3rd.
 - Mass not from Higgs Mechanism!

(evades most 4th gen. Constraints from Higgs XS)



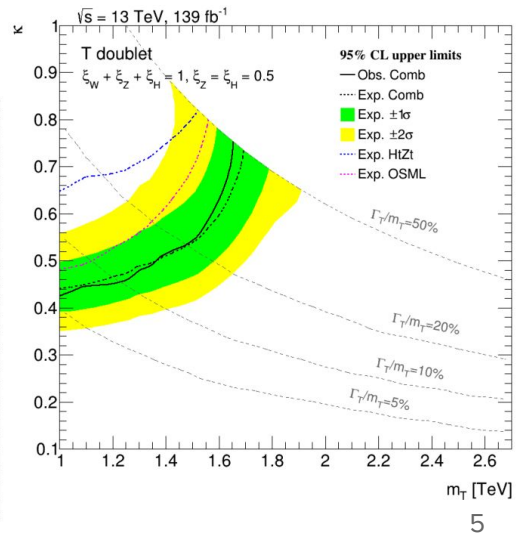
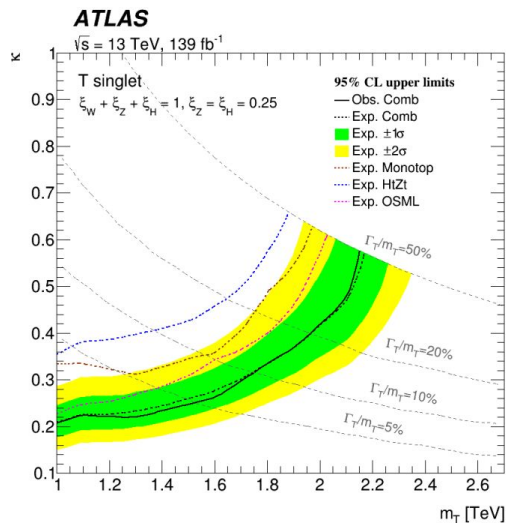
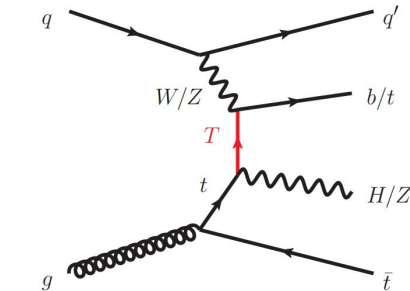
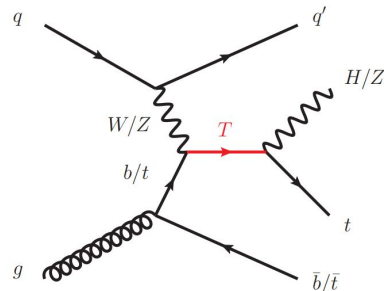
Vector-like quarks: CMS review/ATLAS combination

- [arXiv:2405.17605](https://arxiv.org/abs/2405.17605)
- Includes 2 combinations:
- BB pair production:
 - 2 searches ([1](#) & [2](#)), includes all-had, 1-lep and multi-lep channels.
 - (c.f. ATLAS 36.1 fb⁻¹ TT and BB [combination](#))
- single-T production:
 - 3 searches for T → (H/Z)t: (Z/H) → bb, H → γγ; Z → νν



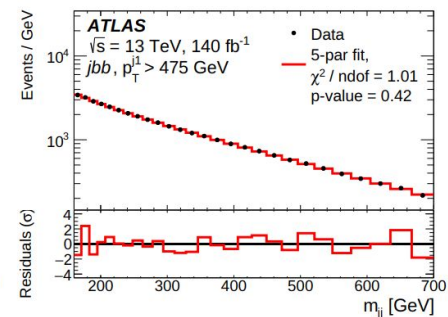
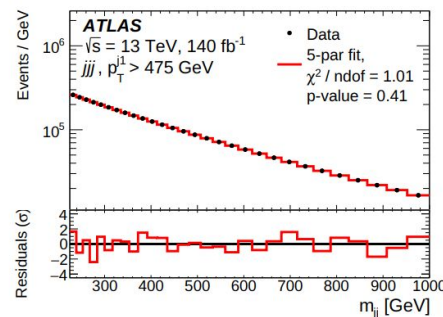
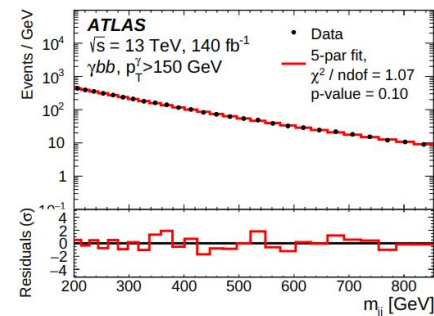
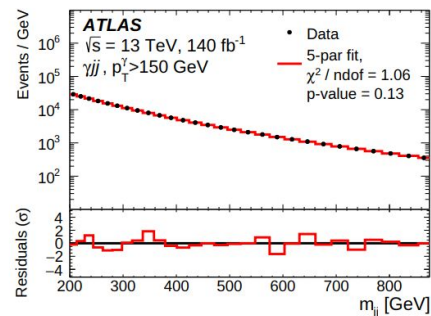
Vector-like quarks: CMS review/ATLAS combination

- [arxiv:2408.08789](https://arxiv.org/abs/2408.08789)
- Full statistical combination of three searches targeting $T \rightarrow (H/Z)t$
 - [Mono-top](#), [OSML](#), [HT/ZT](#)
 - I.e. focussing on hadronic top decay, leptonic Z/h decay, leptonic top decay
- Best limit on singlet-T mass - outperforms all individual searches:
 - $\kappa=0.5$, $M < 2.1$ TeV



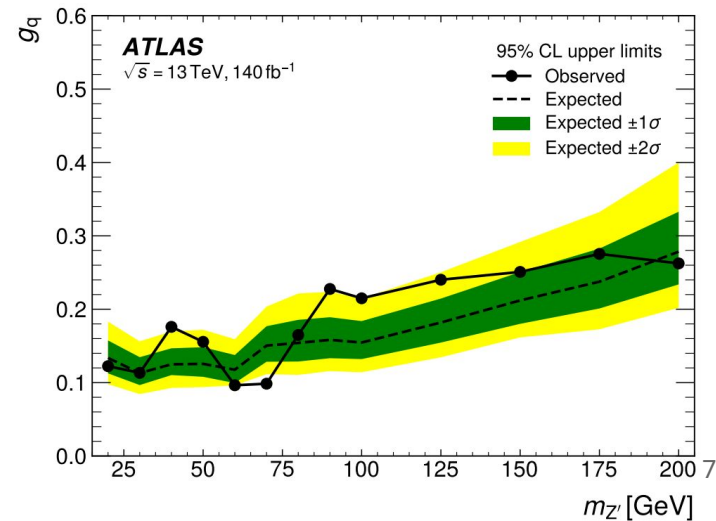
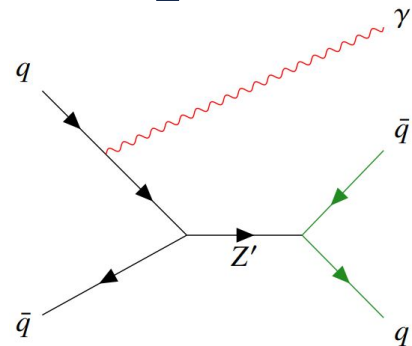
ATLAS: low mass-dijet resonances search (Phys. Rev. D 110, 032002)

- Search for new physics decaying to dijets + (jet or MET)
- Dijet invariant mass 200-650GeV
 - Extends existing ATLAS coverage
- Also considers di-bjet case.
- No significant excesses.
- Limits placed on Z'
- Also provides model-independent limits for Gaussian resonances.



ATLAS: low mass hadronic resonances + photon search (arxiv: [2408.00049](https://arxiv.org/abs/2408.00049))

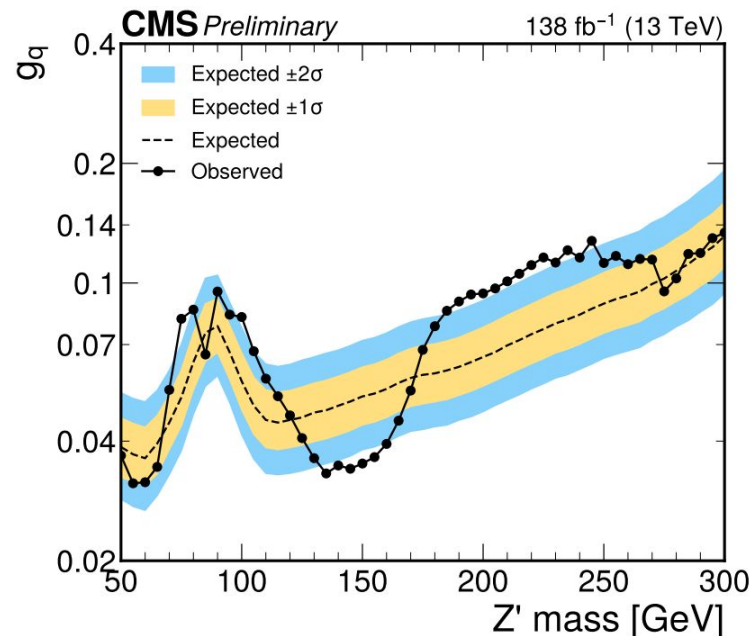
- Even lighter than previous study - just 20 - 100 GeV
 - First coverage of this mass range by ATLAS
 - CMS 36 fb⁻¹: ([Phys. Rev. Lett. 123 \(2019\) 231803](https://arxiv.org/abs/1903.01543))
- ISR photon is used for trigger
 - Otherwise jet trigger p_T cuts restrict mass range
- Uses [TAR](#) jets – better performance at low mass.
- Resonance inside a single, two-pronged large-R jet (using D₂).
- No evidence of new resonances
- g_q couplings are excluded down to 0.1 for a DM + Z' mediator model – lowest couplings explored for the very low mass range.



CMS: low mass vector and scalar resonances

(CMS-PAS-EXO-24-007)

- 50 - 300 GeV - roughly inbetween the two ATLAS analyses.
- Large quark/gluon ISR required:
 - Again otherwise jet p_T triggers make the mass range inaccessible.
- ParticleNet algorithm used to tag SM vs BSM jets.
- Also used soft-drop mass (decorrelated from NN output).
- For Z' models, g_q couplings in 50-80 GeV range go even lower than previous search.



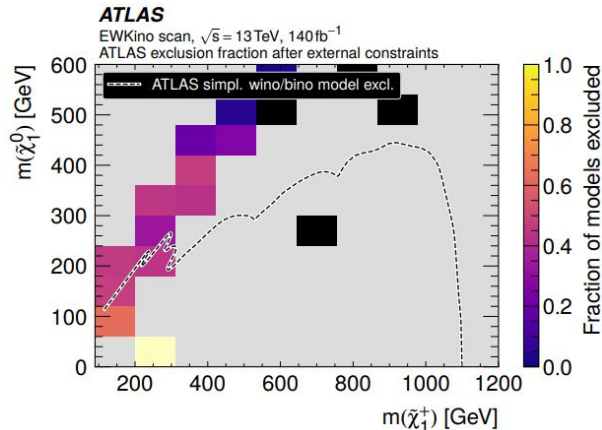
Scanning the pMSSM

- 105-dimensional MSSM – too computationally complex to scan (even for phenomenologists)
- LHC searches typically use simplified models: 2-4 free parameters.
- In the full-SUSY space, constraints from other areas of physics matter:
 - DM relic density
 - LEP constraints (e.g. $Z \rightarrow$ invisible)
 - Flavour constraints
- Recent ATLAS ([JHEP 05\(2024\)106](#)) and CMS ([CMS-PAS-SUS-24-004](#)) scans.
- Not your usual combinations:
 - Somewhere between an experimental paper and a pheno scan (c.f. e.g. [Gambit](#), [Mastercode](#))
 - (Re)use of public and internal reinterpretation tools (e.g. [pyhf](#))

ATLAS EWK pMSSM scan ([JHEP 05\(2024\)106](https://arxiv.org/abs/2403.02455))

EWkino scan

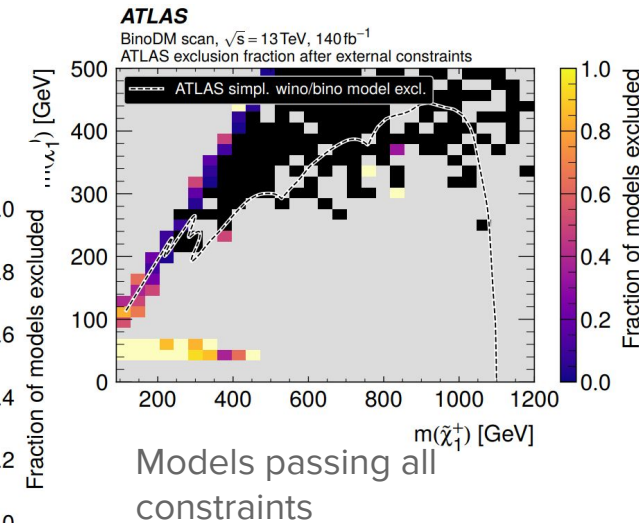
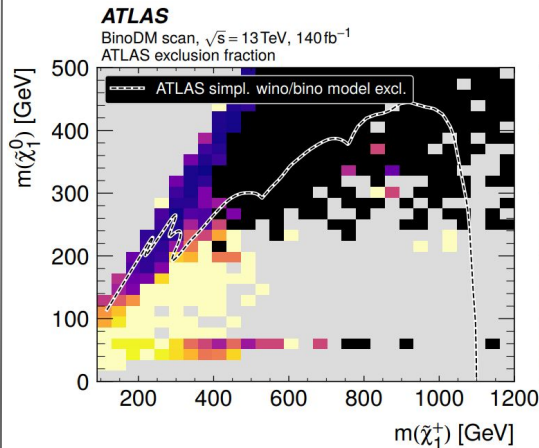
- 20000 points
- Neutralino LSP



- Compressed scenarios survive!
- C.f. recent ATLAS search for this scenario ([Phys. Rev. Lett. 132, 221801](https://arxiv.org/abs/2308.14849))

Bino-DM scan

- 437500 points
- Bino-like neutralino LSP (achieved by oversampling)
- Extra DM relic density constraints (before event generation)



All Models

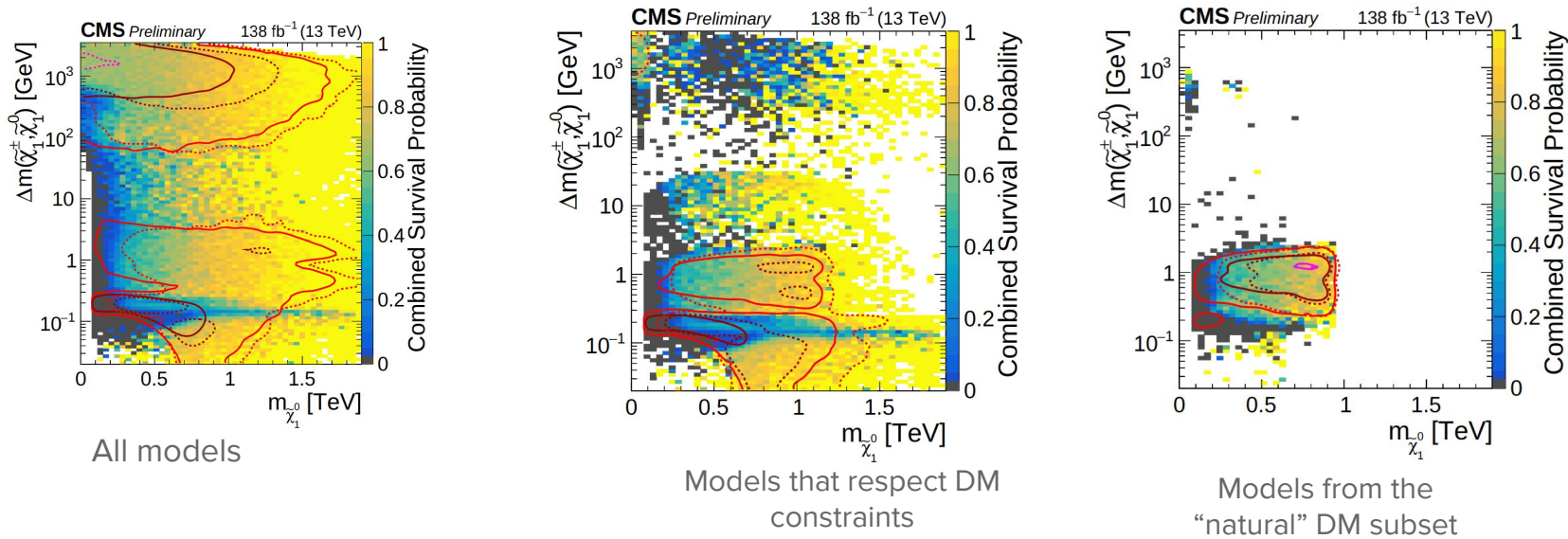
CMS pMSSM scan (CMS-PAS-SUS-24-004)

- EWK and Strong (phase space is about 50:50)
- MCMC scan: 24 million points *without* CMS likelihoods
 - Use LEP, flavour, and EW constraints
- Of those, choose 500k at random for event generation.
- Pythia 8.2+FastSim
- Run analyses, get likelihoods
 - Where necessary, simplified likelihoods, were used instead of unavailable full-likelihood – again reusing public reinterpretation material internally.

CMS pMSSM scan (CMS-PAS-SUS-24-004)

- Squarks below 1 TeV - strongly excluded.
- Lots of unexcluded parameter space that resolves hierarchy problem *or* DM relic density – but not much that does *both*.
 - Higgsino-like DM dominates space that does both

Adapted from Fig. 4



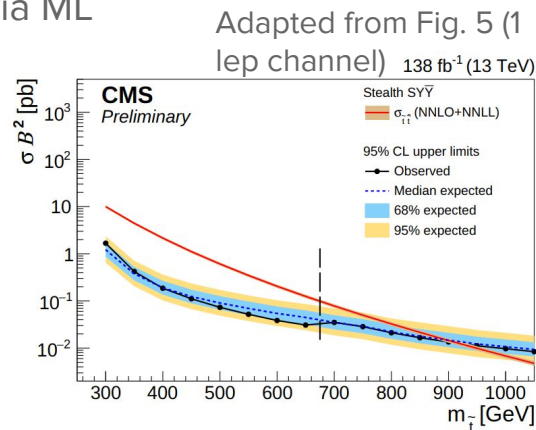
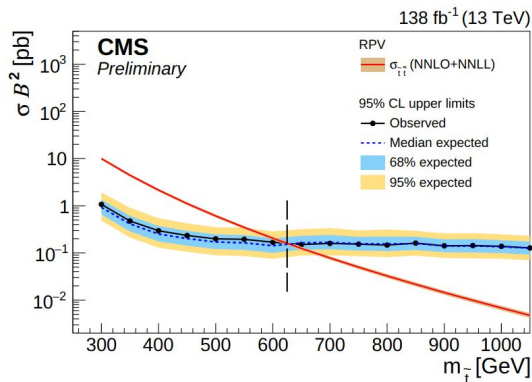
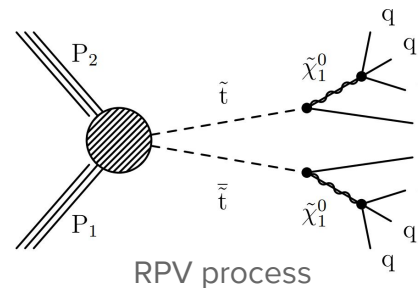
Conclusion

- ATLAS and CMS are still producing very interesting “traditional” searches for new physics.
- Resonance searches still exploring new territory.
- First single-VLQ combinations provide new limits.
- EWK pMSSM scans do leave some areas uncovered:
 - Particularly compressed regions/higgsino LSP.
- Looking forward to seeing some Run 3 searches soon, too!

BONUS

CMS Search for top squarks in final states with many light flavor jets and 0, 1, or 2 leptons

- [CMS-PAS-SUS-23-001](#)
- Search for RPV/Stealth SUSY
 - (Earlier CMS squark search saw 2.8σ local significance)
- New “ABCDisCoTEC” method for background estimation:
 - Start with ABCD method
 - [ABCDisCO](#): Better choice of variables that define ABCD via ML
 - Variables that define ABCD made orthogonal
 - “ABCDisCoTEC” - new loss term, better treatment of non-closure.
- No deviation from SM.



ATLAS EWK pMSSM scan strategy

- includes *many* EWK ATLAS susy analyses.
- Uniform scan of pMSSM (19 dimensions)
 - Veto otherwise excluded points before event generation.
- Makes extensive use of internal & public reinterpretation tools ([SimpleAnalysis](#), [RECAST](#), *Fastsim*, [pyhf](#)) - reusability helps the experiments themselves!
- Includes beyond-collider constraints.
- FastSim+RECAST is what takes this way beyond what pheno can do alone.

