ATLAS results and prospects with focus on BSM

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on behalf of the ATLAS collaboration

7th workshop on Theory, Phenomenology and Experiments in Flavour Physics and the future of BSM physics
Capri, 9/06/18

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PRISMA

Caveat

- Impossible to cover all ATLAS results relevant for BSM searches (strictly speaking all SM measurements are indirect BSM searches too)
- Focus on a choice of direct searches and measurements interpreted as BSM limits and for which prospects are available
- Aim is to present experimental challenges and expectations
- Will NOT list all models being considered, but discuss interpretation restrictions where relevant

Outline

- Introduction
- Direct BSM searches
  - SUSY → 3rd generation squarks, EW, long-lived particles
  - All the rest → resonances, dark matter
- Indirect BSM searches
  - Very rare decays → limits on anomalous couplings
  - Higgs and top couplings → EFT interpretations
- Conclusion

Introduction

BSM: why and how?

- Open questions in the SM
  - Nature of Dark Matter
  - Hierarchy problem
  - Matter/antimatter asymmetry
  - ...
- Experimental strategies at LHC
  - High energy → sensitivity to heavy new particles
  - High luminosity → sensitivity to rare processes
  - Mostly model-independent searches with possibility to recast results

BSM theories and models provide answers!

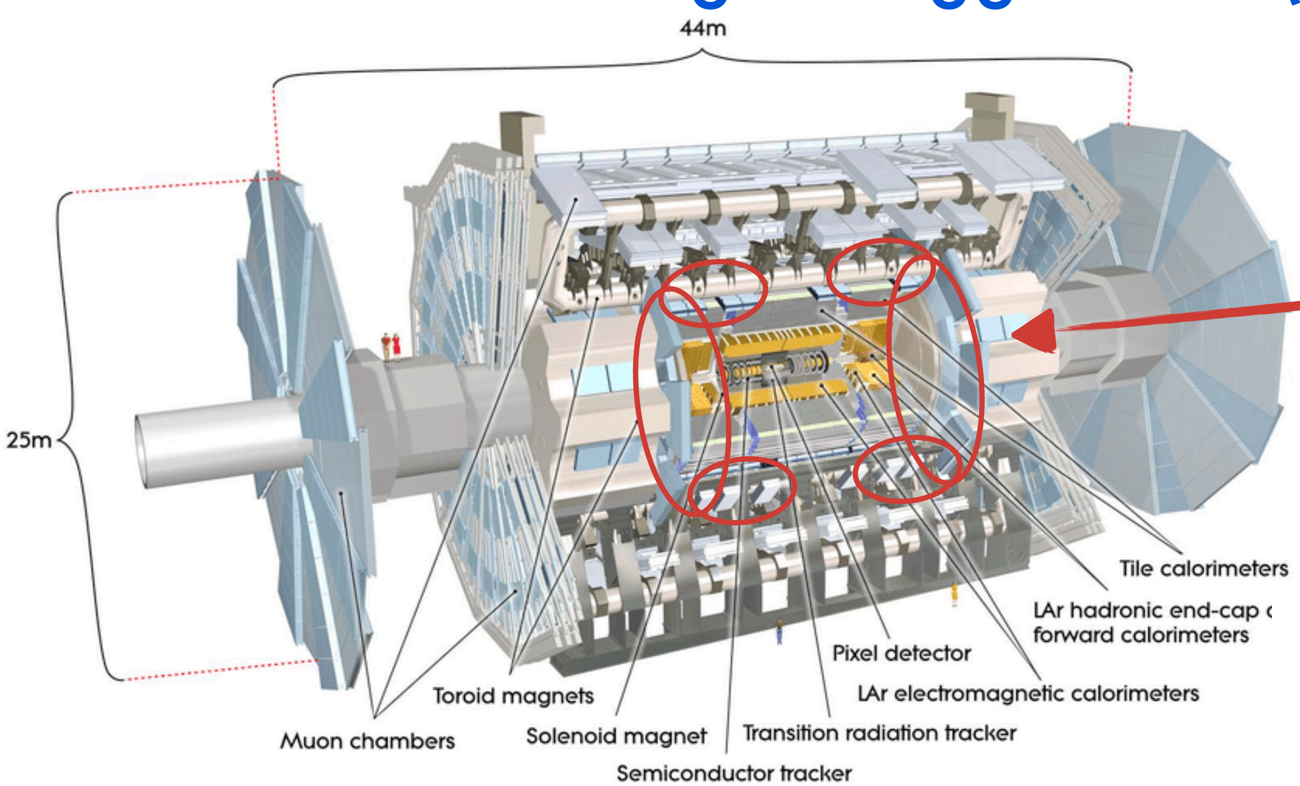
From LHC to HL-LHC

- Run 2
  - integrated luminosity so far >100/fb
  - results with up to 36/fb of data
- Run 3
  - instantaneous luminosity $>2.5\times10^{34}cm^{-2}s^{-1}$
  - integrated luminosity 300/fb
- Run 4
  - instantaneous luminosity $>5\times10^{34}cm^{-2}s^{-1}$
  - integrated luminosity 3000/fb

HL-LHC Webpage

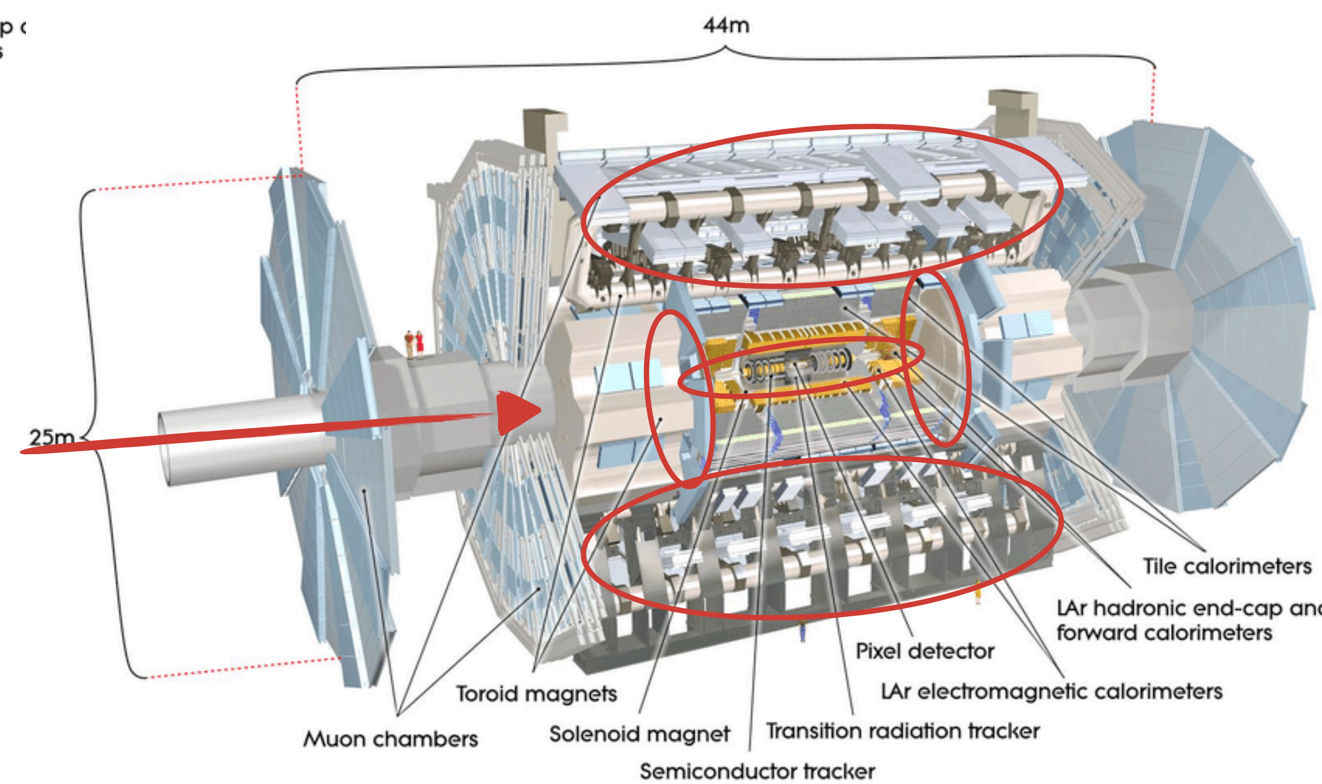
ATLAS upgrades

Main challenges: trigger rate (runs 3 and 4) and pile-up (run 4)



- Run 3
  - reduce muon fakes and improve trigger coverage
  - faster trigger off-detector electronics and tracking at trigger level

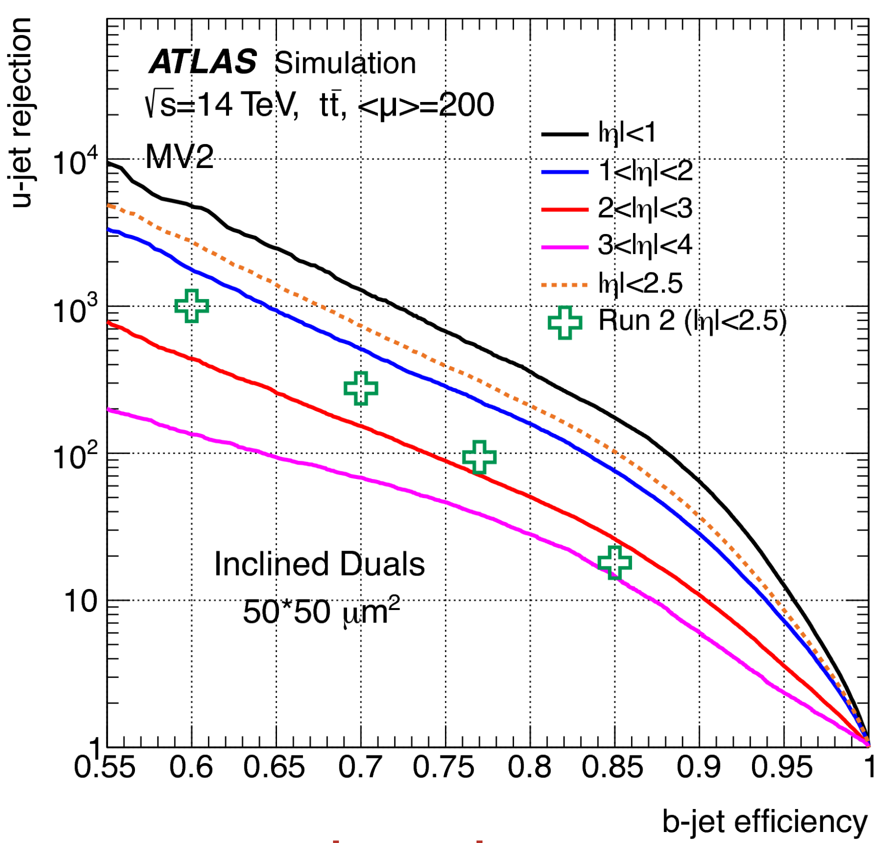
- Run 4
  - silicon tracker up to |η|<4.0
  - new barrel muon chambers
  - timing information in endcaps
  - improved calorimeter readout
  - new trigger electronics



Performance

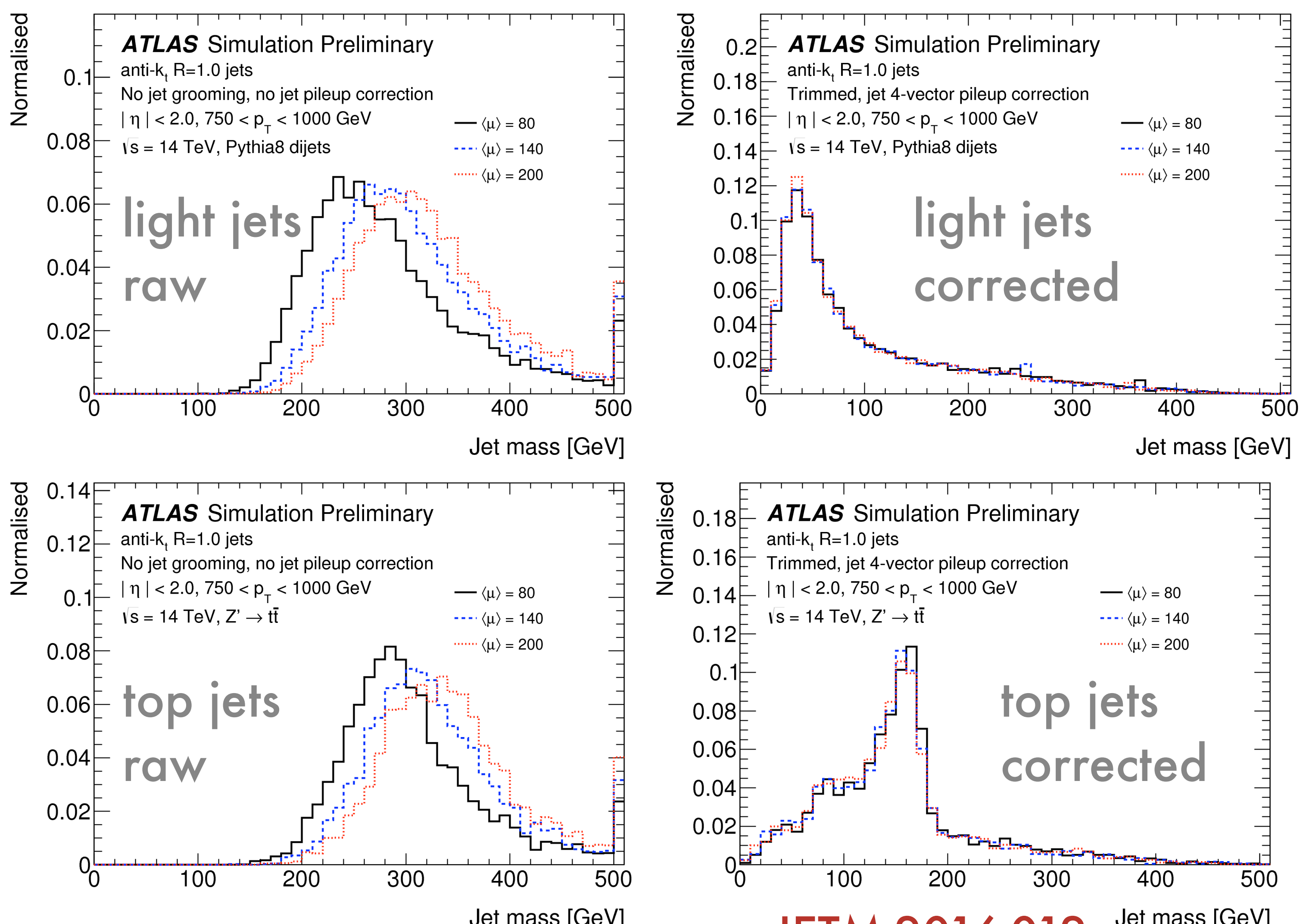
New hardware and new reconstruction techniques allow to recover or improve on run 2 performance in spite of much higher pile-up level

Example: b-tagging Driven by tracking



ITk Pixel TDR

Example: jet mass - Driven by techniques

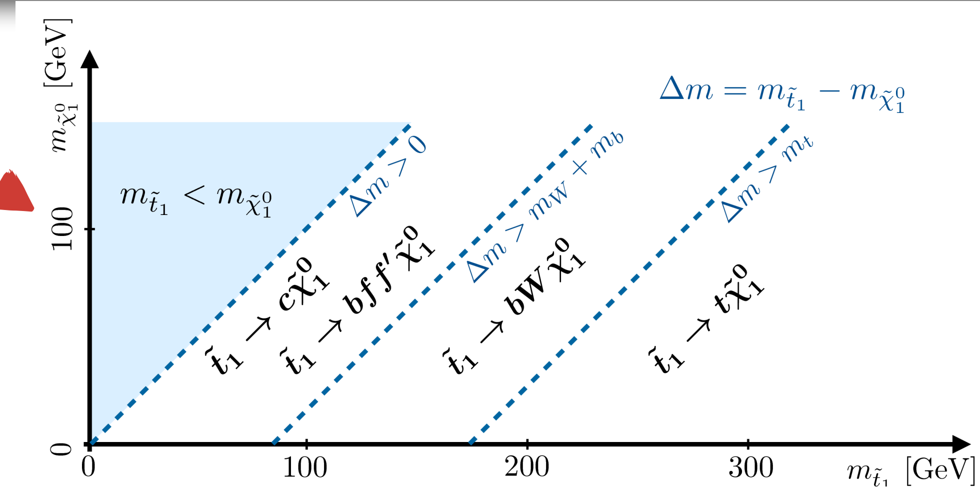


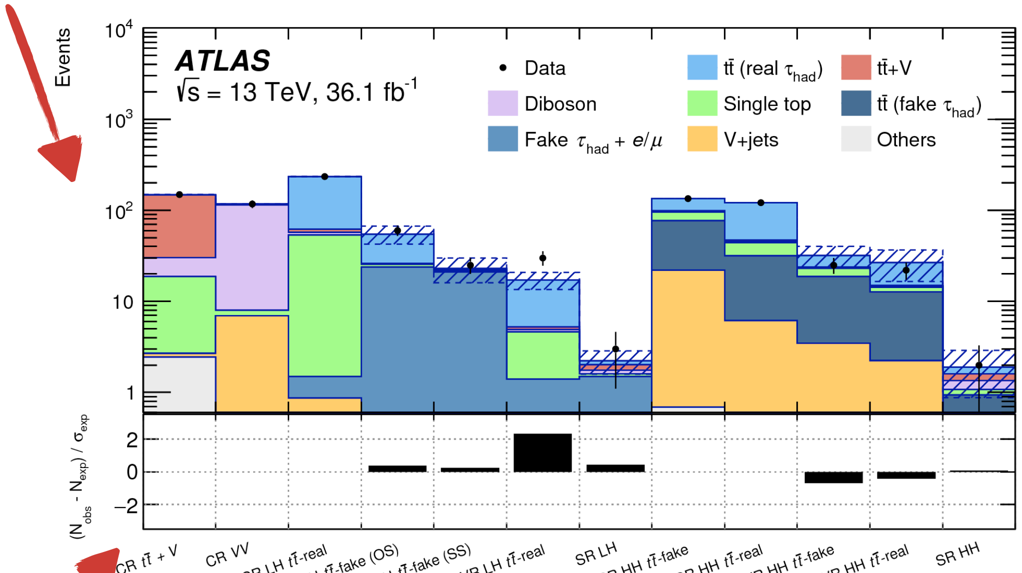
JETM-2016-012

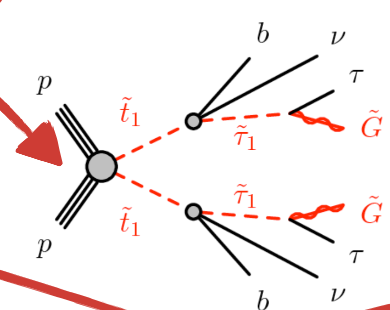
Direct BSM searches

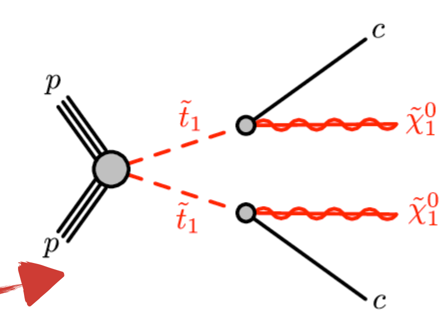
SUSY 3rd gen squarks

- Many searches for stop pair production. Decay topology depends on masses of SUSY particles
- General strategy
  - Dedicated signal regions for different scenarios
  - Background estimate in control regions
  - Model-independent limits on number of events
  - Model-dependent mass limits (next slide)
- Limiting factors
  - Most signal regions limited by statistics
  - Background modelling uncertainties O(20%)
- Examples of recent results and techniques
  - stop to stau: BDT for hadronic tau ID [1803.10178]
  - stop to charm: c-jet tagging [1805.01649]
  - RPV stop to jets: $\Delta R_{jets} \propto m_{stop}$ [1710.07171]

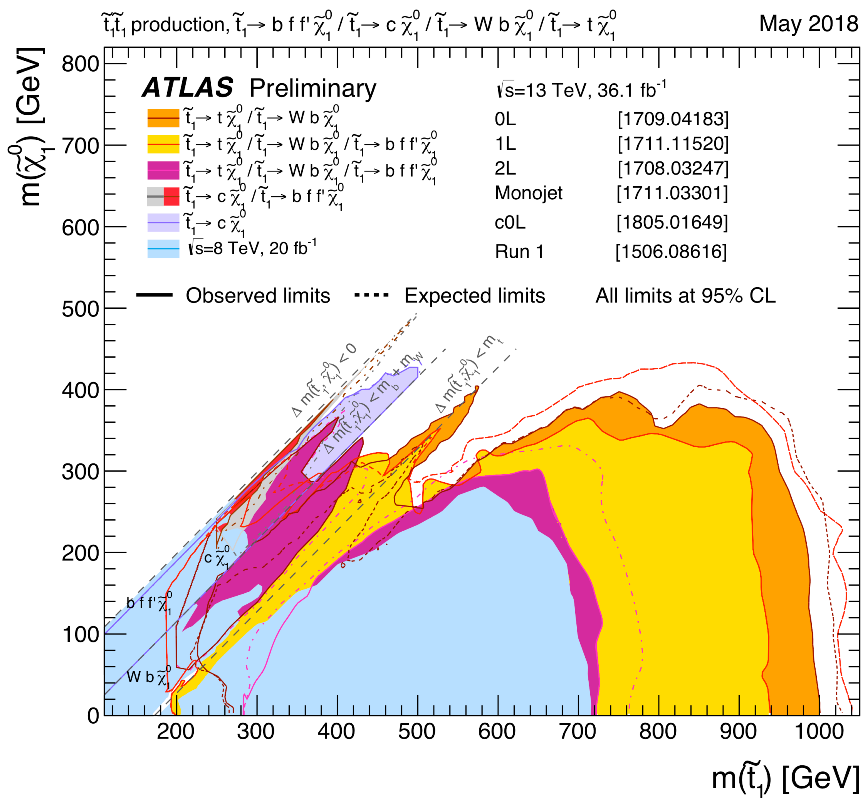


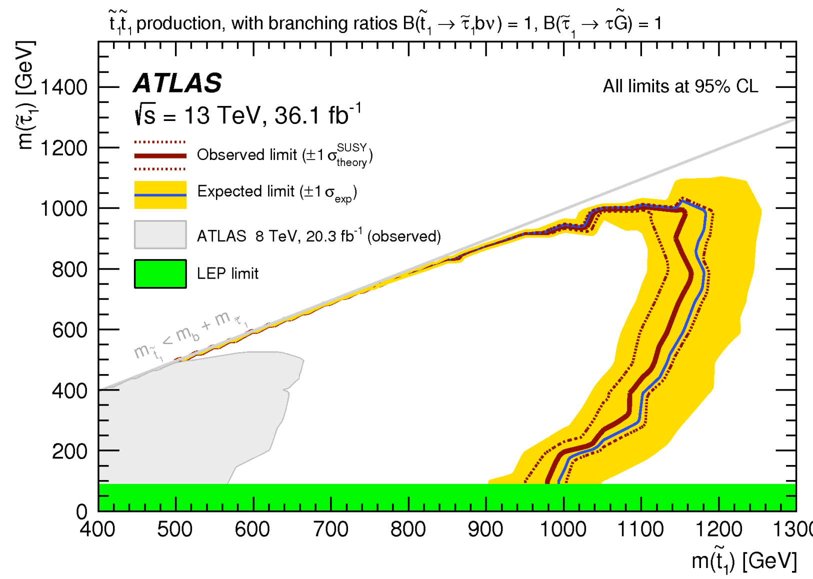




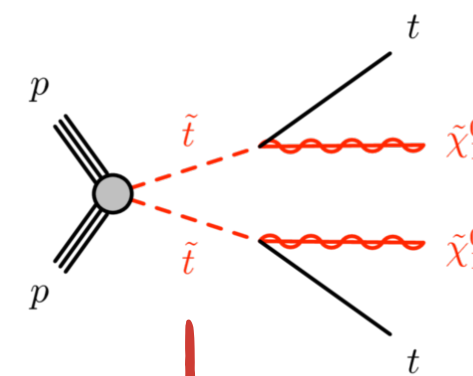


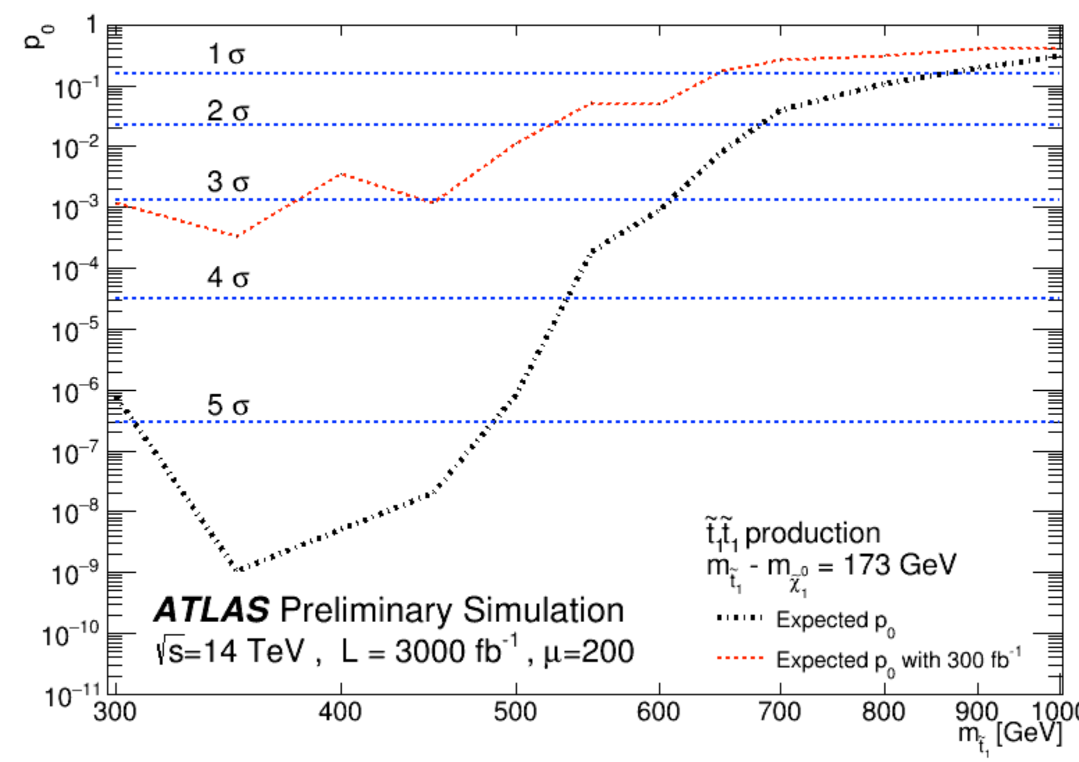
SUSY 3rd gen squarks





[1803.10178](1803.10178)





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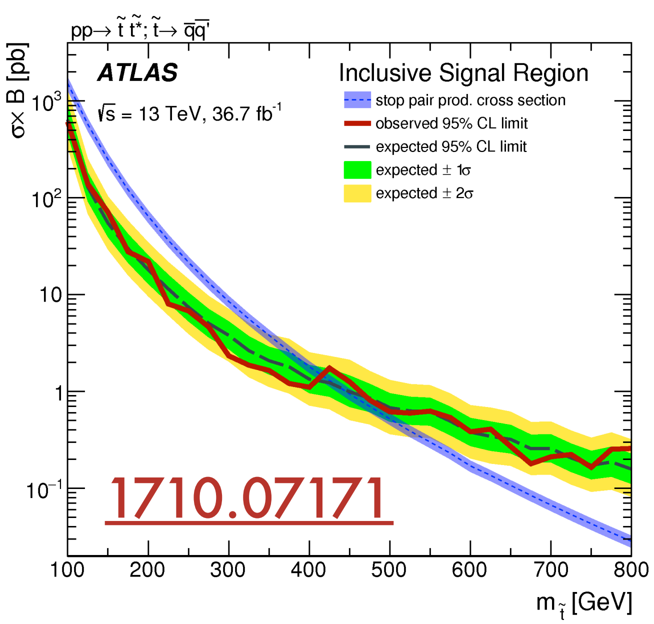
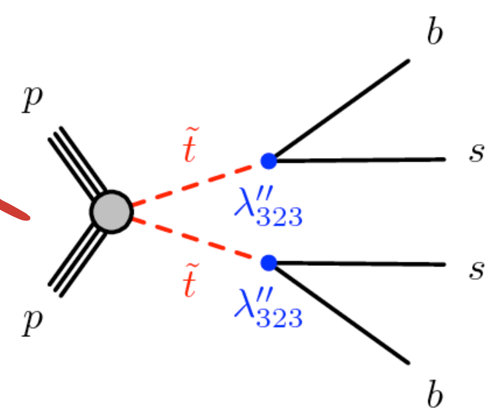
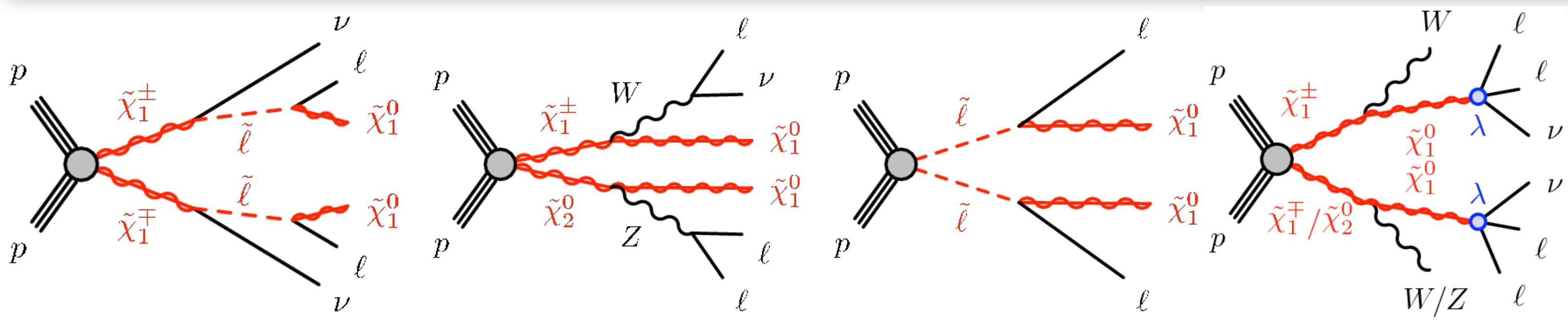


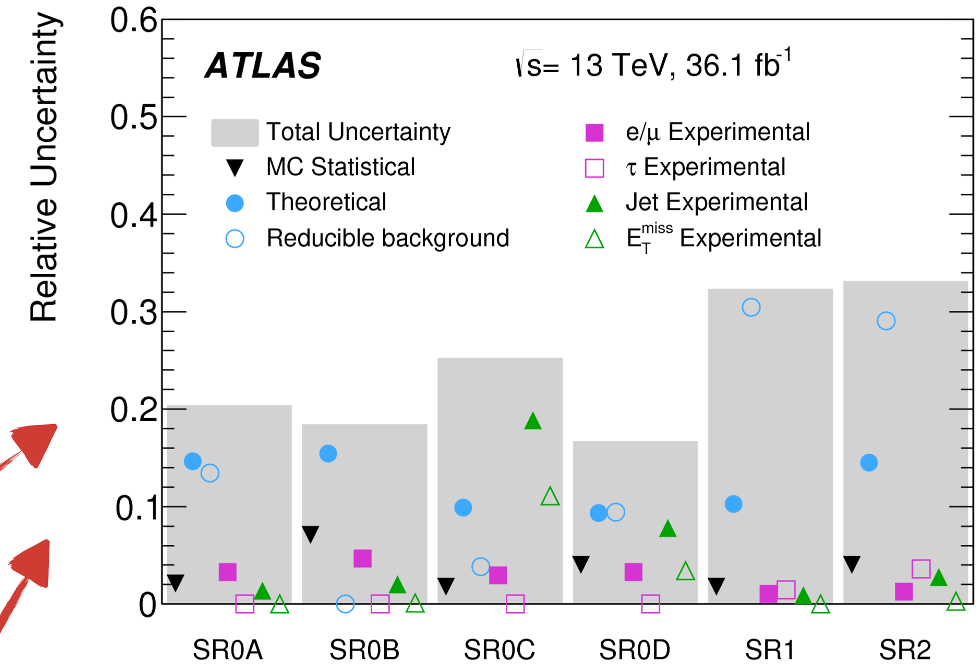
[1710.07171](1710.07171)

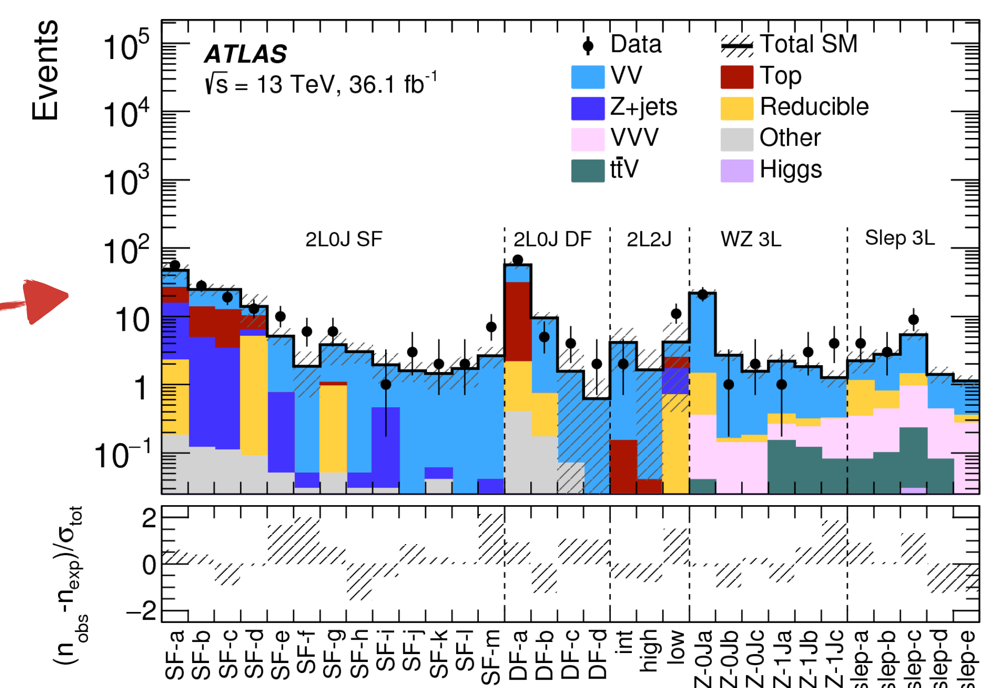


SUSY electroweak

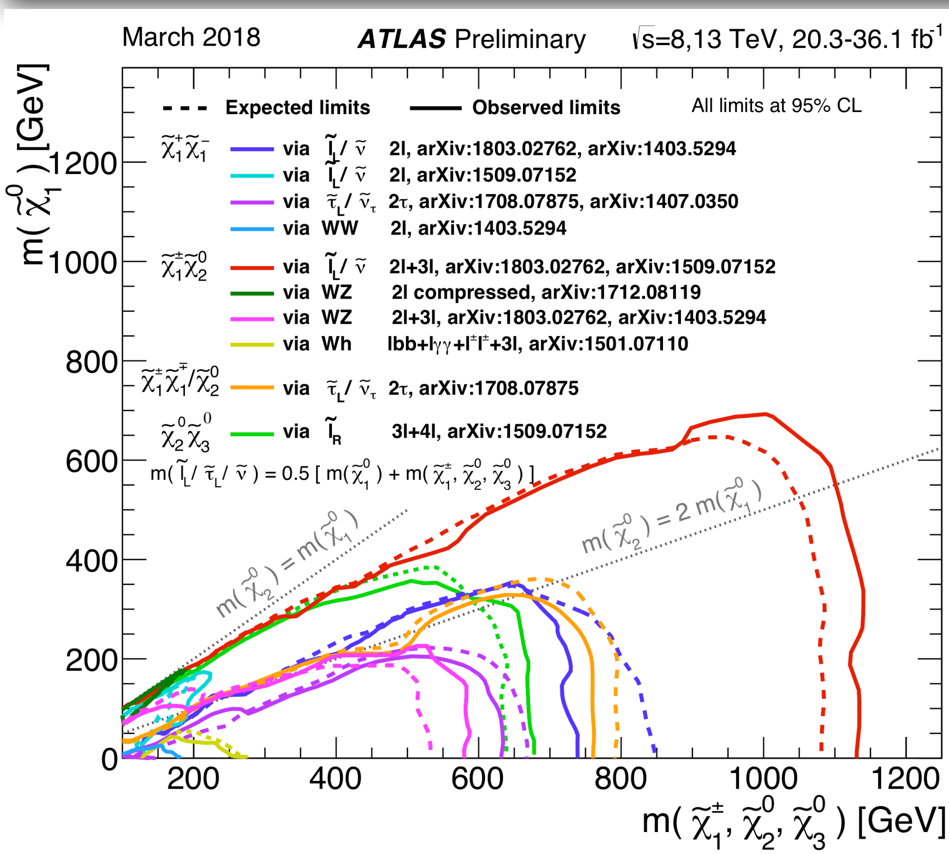


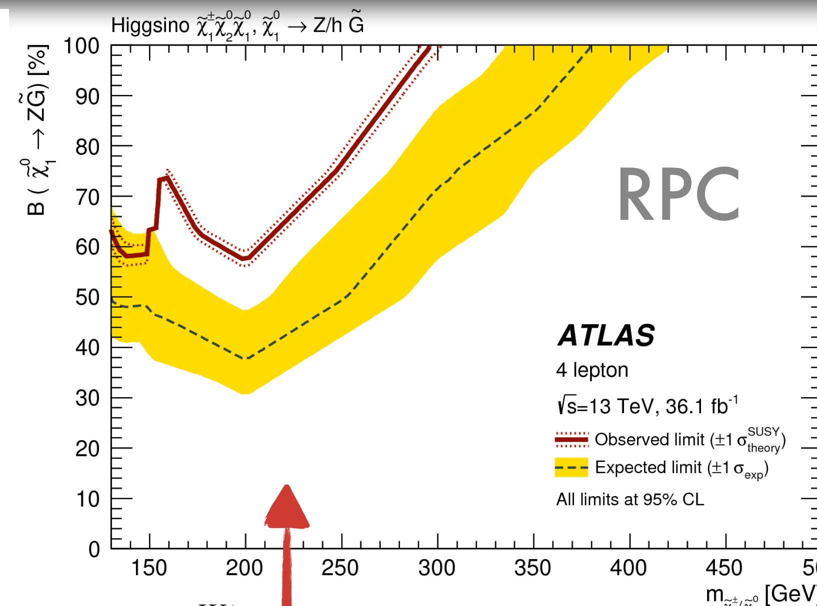
- Very different processes with similar final states
- General strategy as for squark searches
- Limiting factors
  - Background estimate: statistics in control regions, data-driven estimates, diboson modelling
- Examples of recent results and techniques
  - 2l and 3l (RPC): Z+jets background with high MET in 2l+jets regions estimated with γ+jets template [1803.02762]
  - 4l (RPV and RPC): includes taus, fake lepton bkg estimate with “fake factors” [1804.03602]

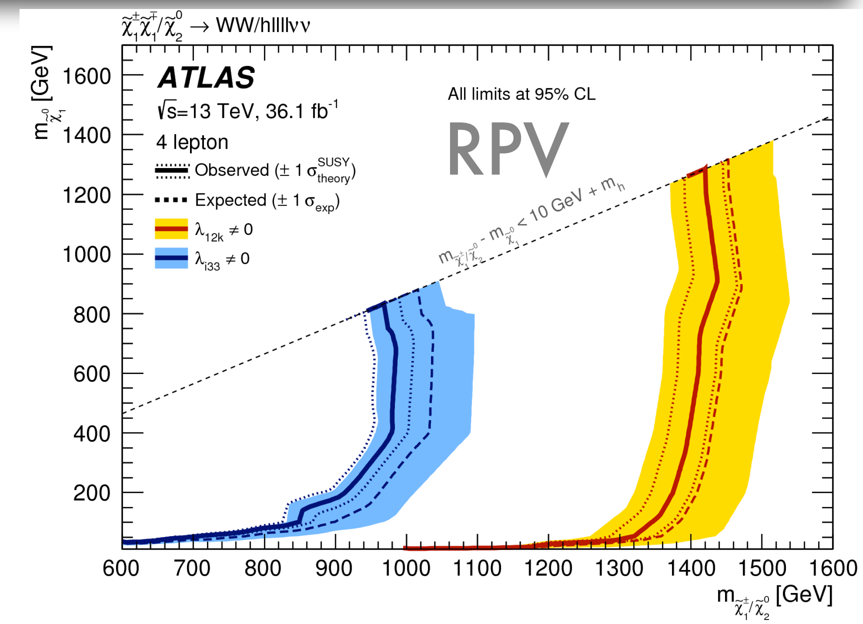


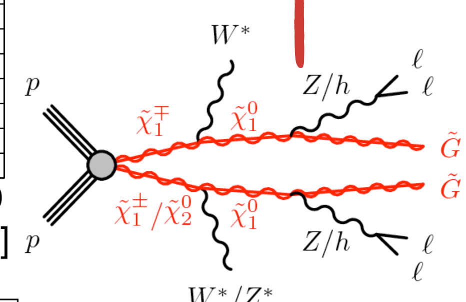


SUSY electroweak

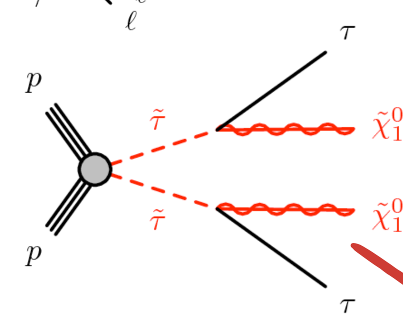


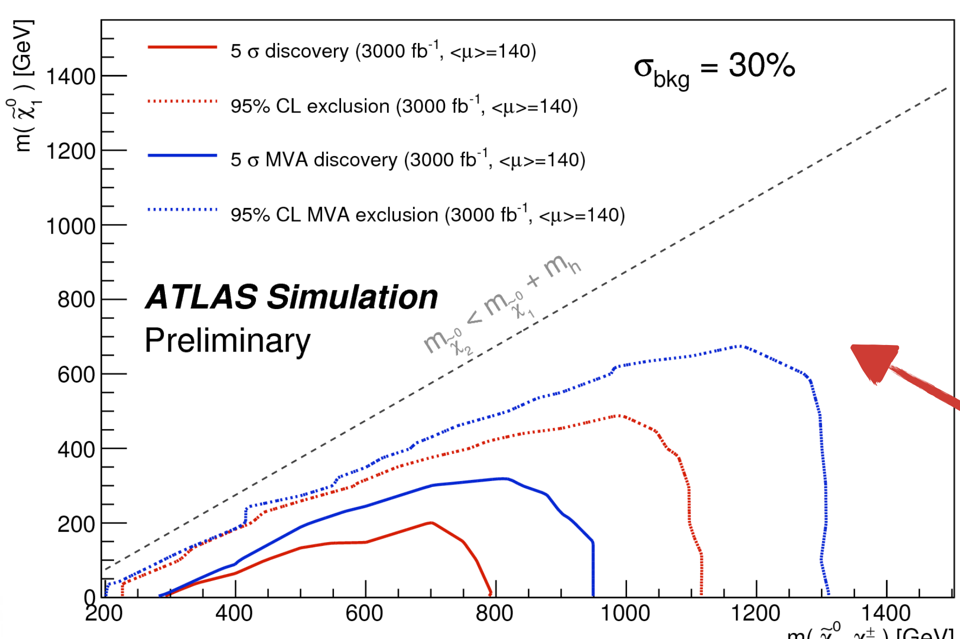


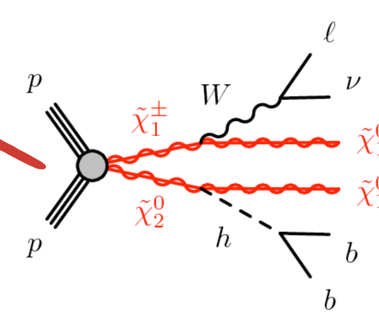


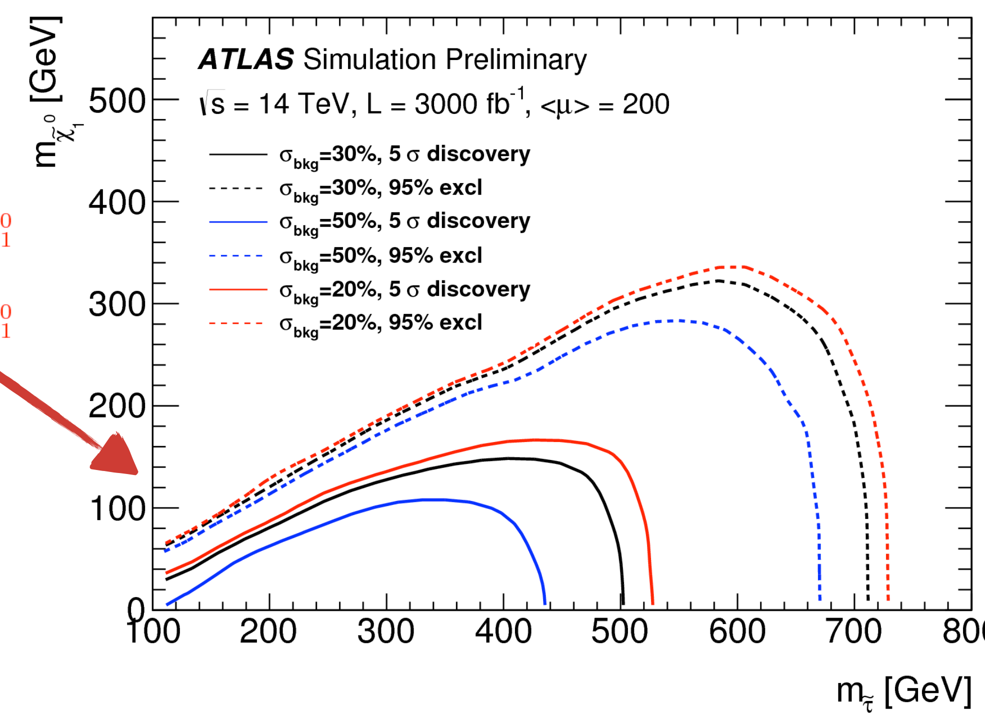


1804.03602









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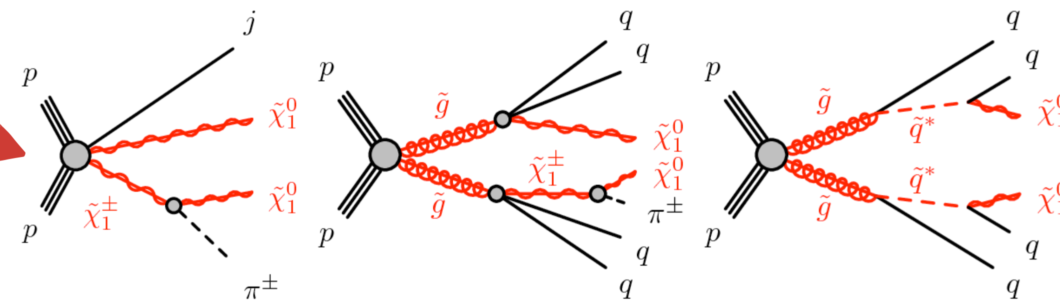
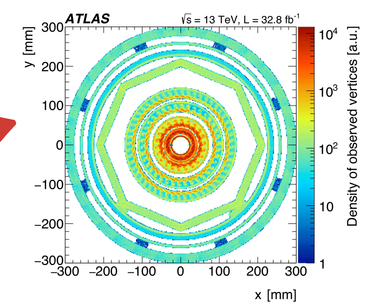
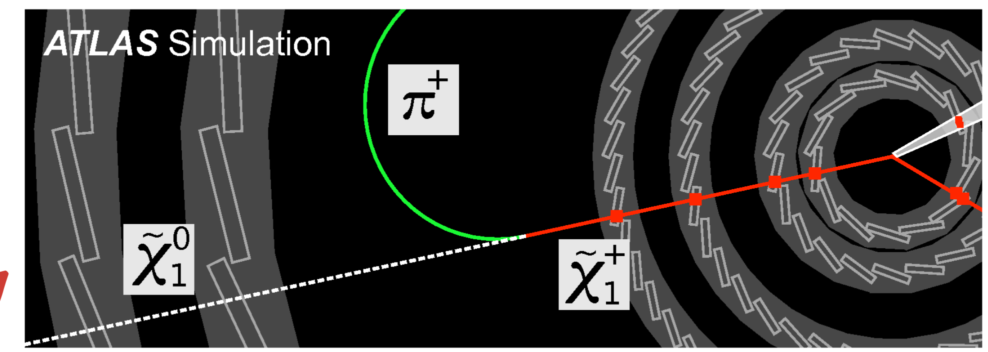
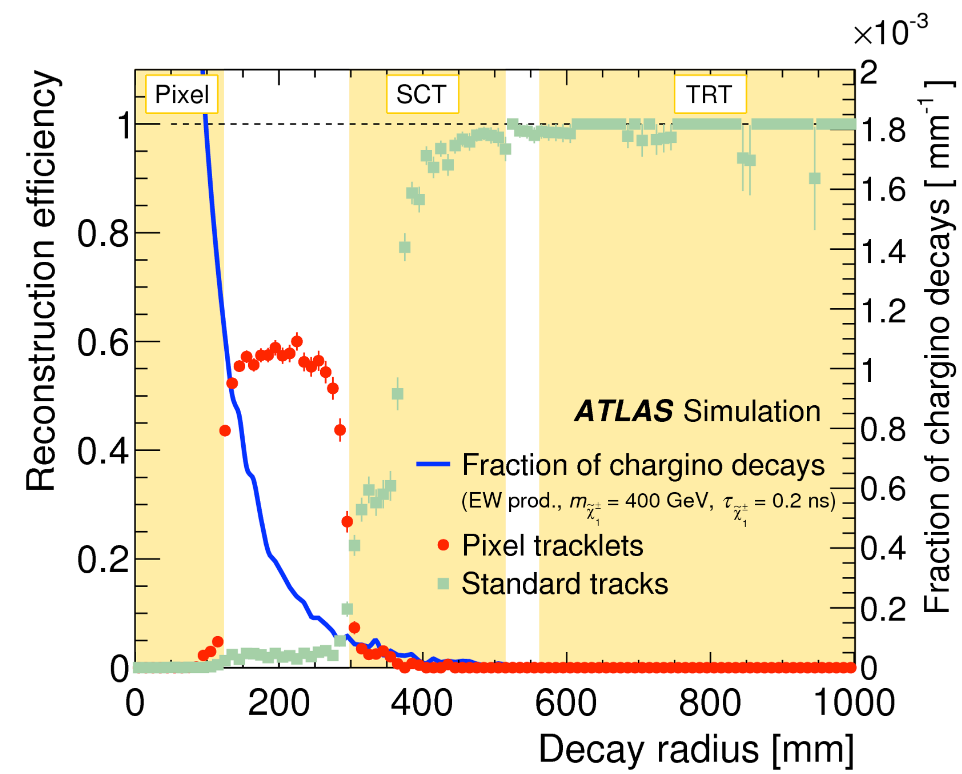
Long-lived particles

- Appear e.g. for mass-degenerate spectra, small couplings or highly virtual intermediate states
- Specific strategies
  - Dedicated reconstruction techniques
  - Limits on cross section vs. lifetime or only model-dependent
- Limiting factors
  - Statistics, background estimate
- Examples of recent results and techniques
  - Disappearing track: pixel-only tracklets [1712.02118]
  - Displaced vertex: large-radius tracking algorithm [1710.04901]
  - Reinterpretation: b-jet multiplicity correlation with lifetime [ATLAS-CONF-2018-003]

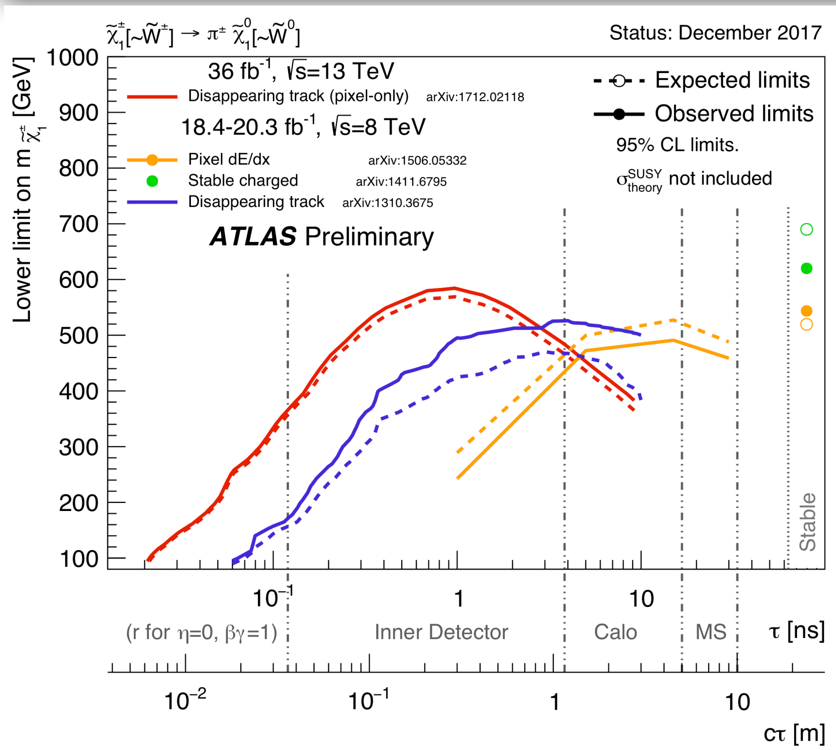


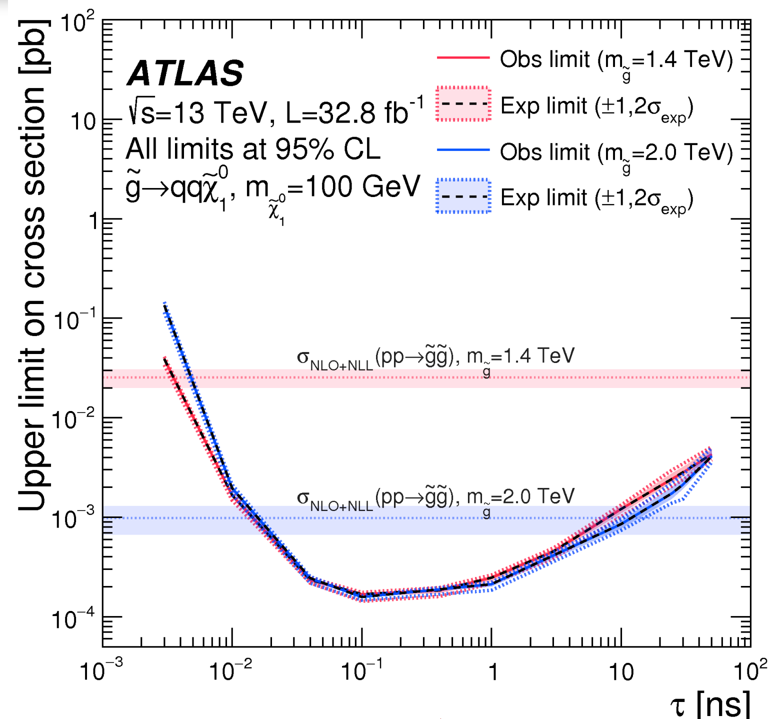


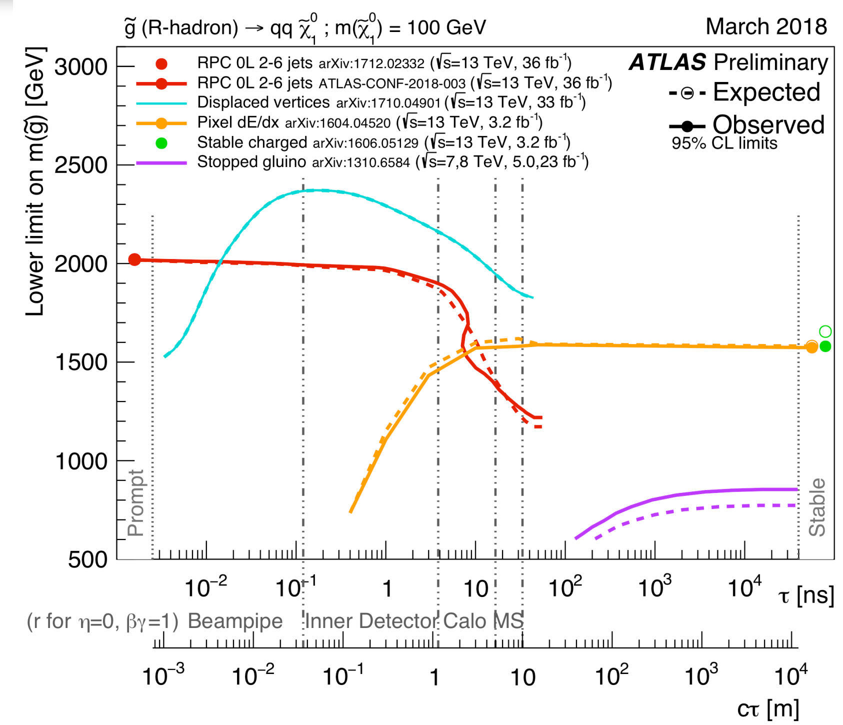




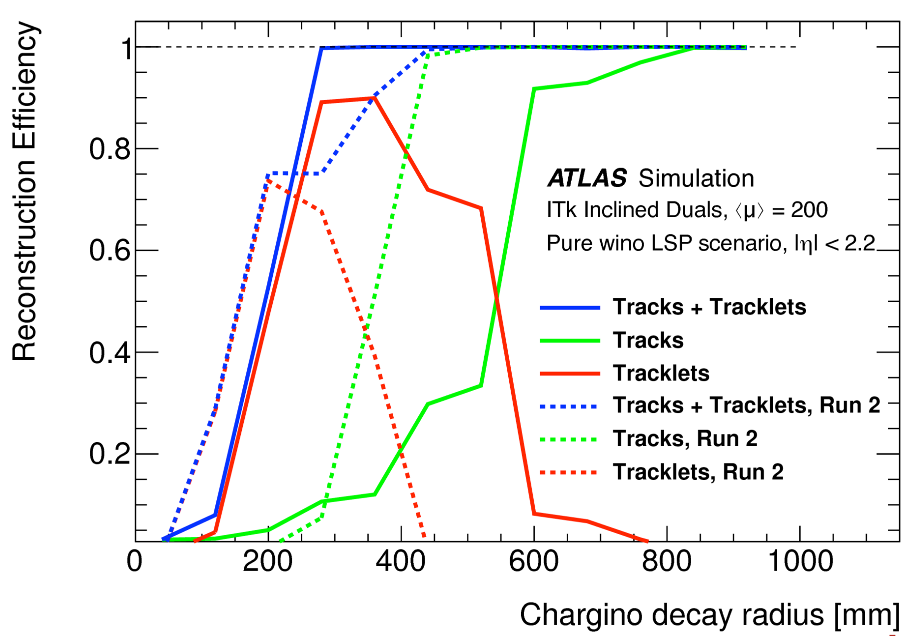
Long-lived particles

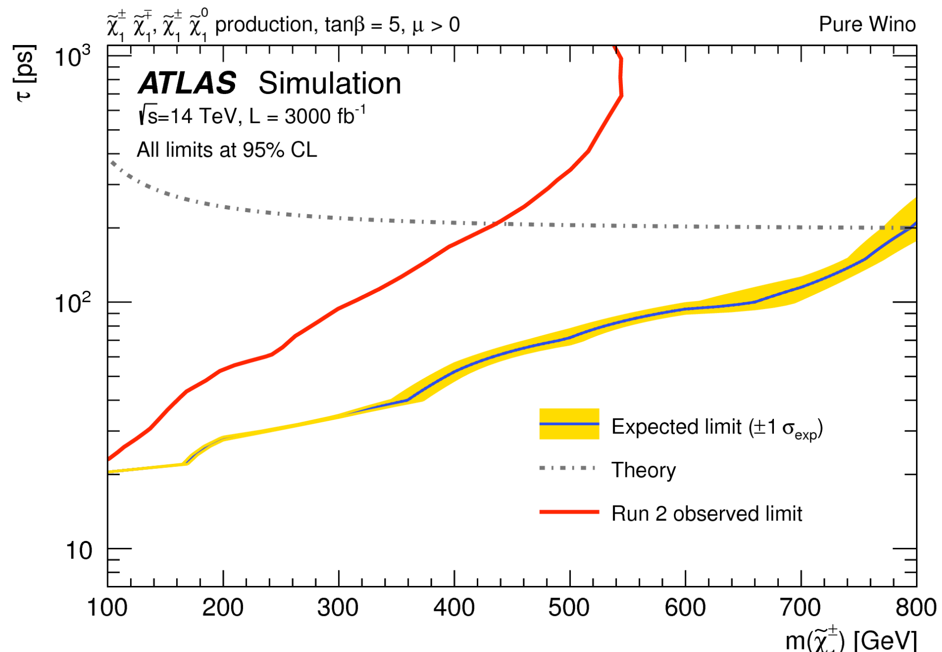






1710.04901





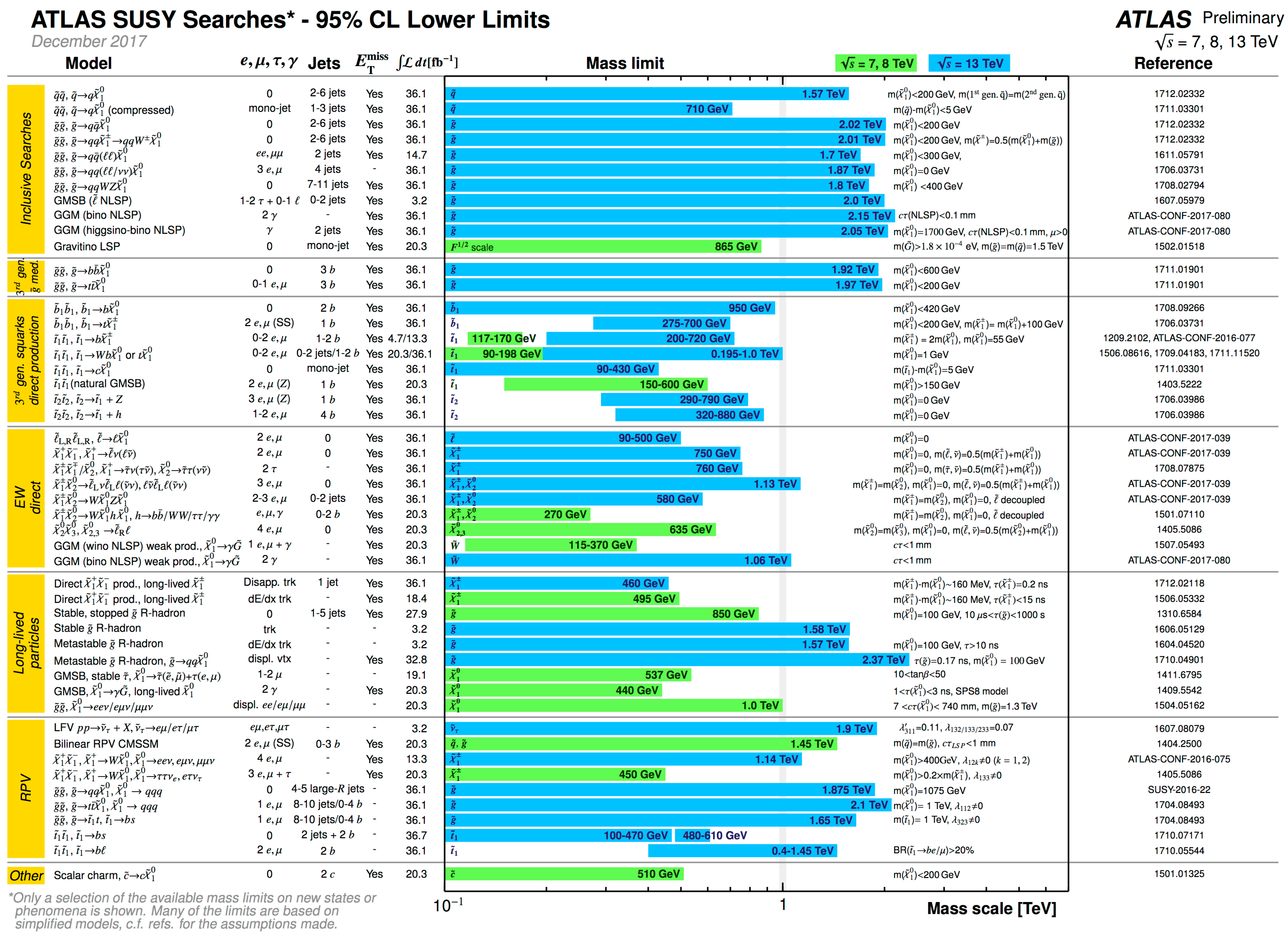
ITk Pixel TDR

SUSY summary

ATLAS EXPERIMENT

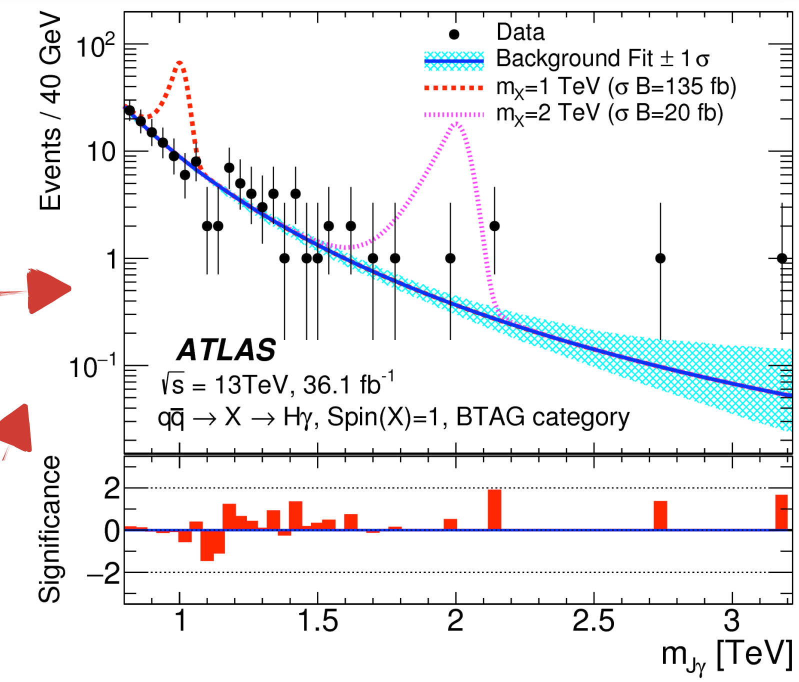
Many more searches have excluded SUSY particles up to the given masses and with the given assumptions

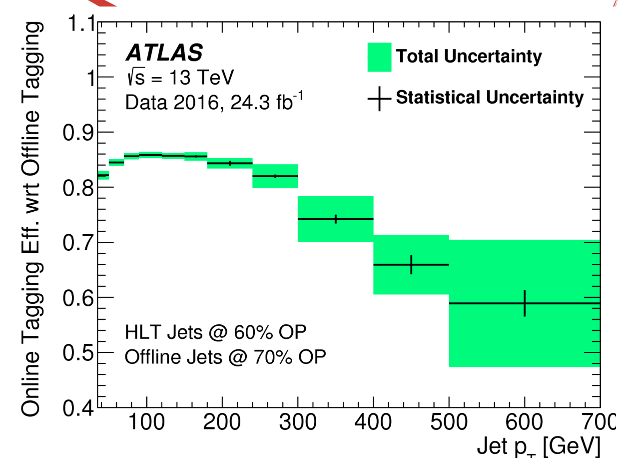
Only a selection is shown here

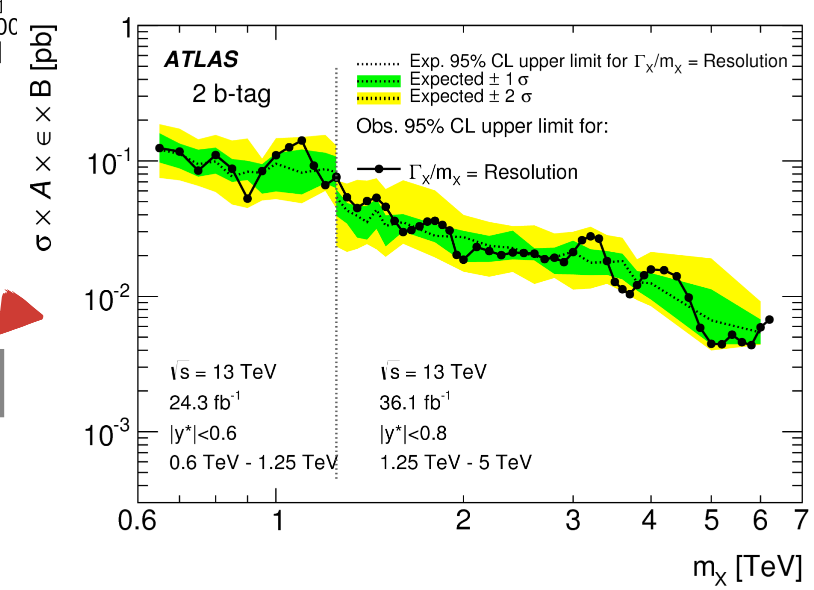


Resonances

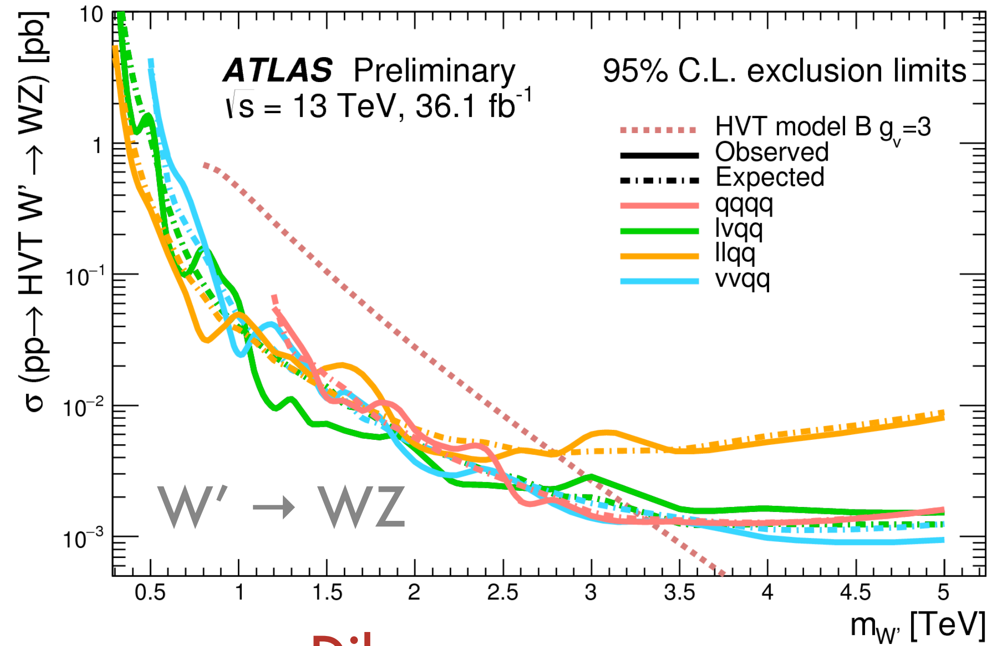
- Signature based searches for BSM resonances
- General strategy
  - Data/MC comparison in mass spectrum
  - σ*BR limit (almost) model-independent
  - Model-dependent limit on mass
- Limiting factors
  - Background modelling at low mass
  - Statistics at high mass
- Examples of recent results and techniques
  - W/Z/hγ: boosted W/Z/h decays [1805.01908]
  - bb or bg: b-jet trigger for low mass [1805.09299]
  - ZH: data driven background normalisation [1804.01126]
  - low mass dijet: analysis at trigger level [1804.03496]



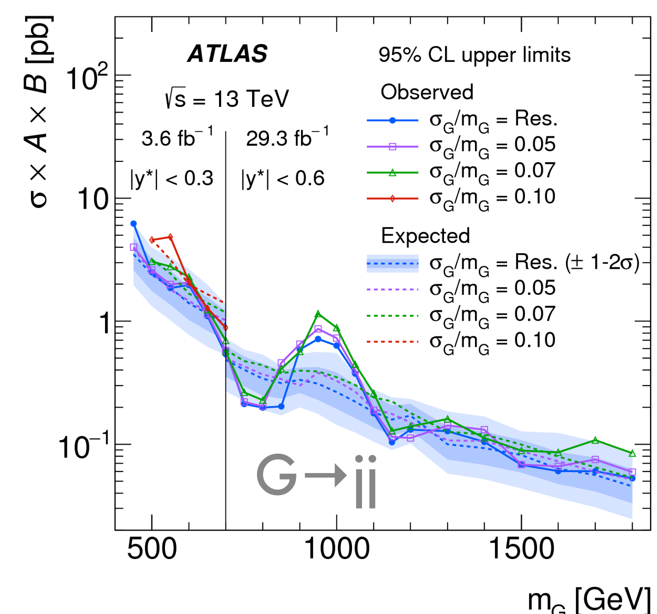




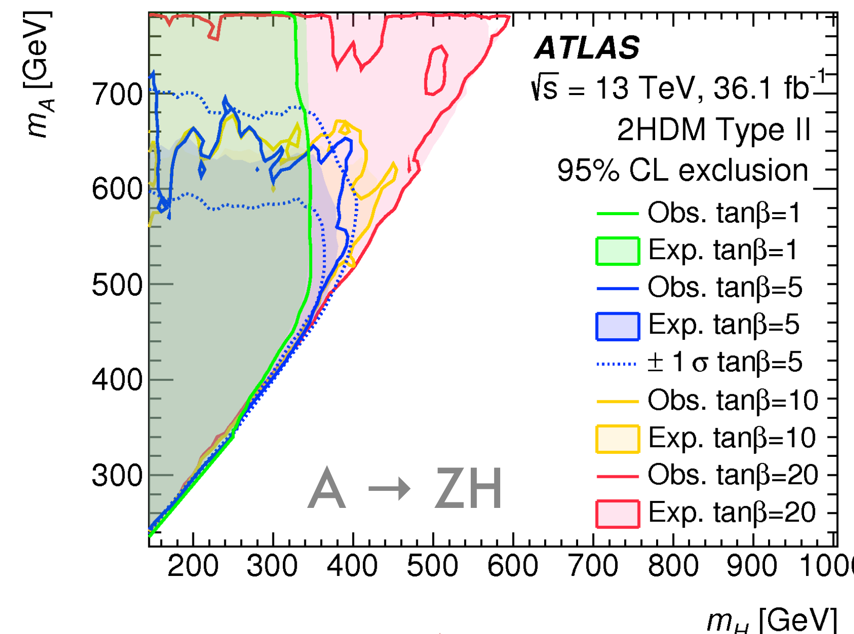
Resonances



Diboson summary



1804.03496



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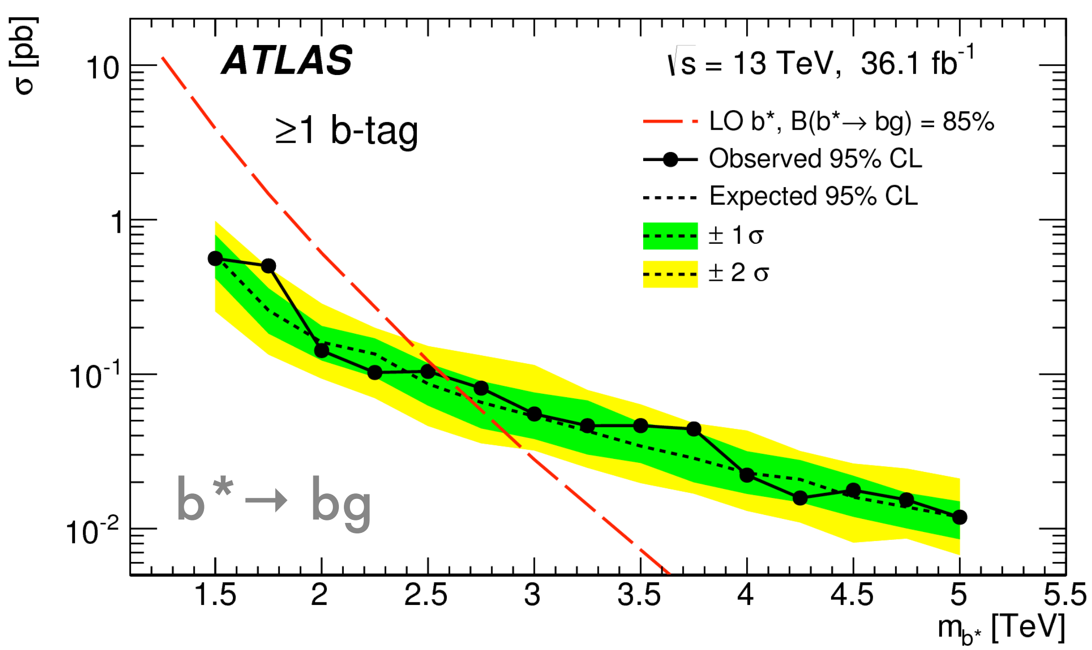
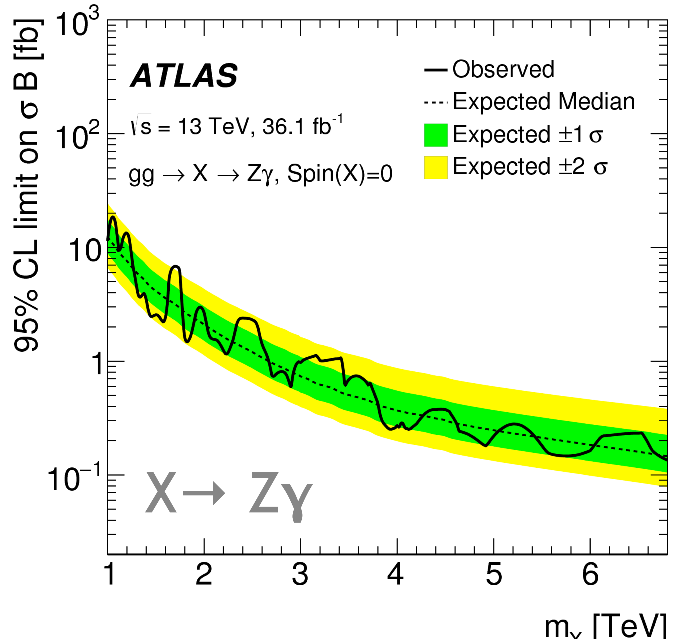
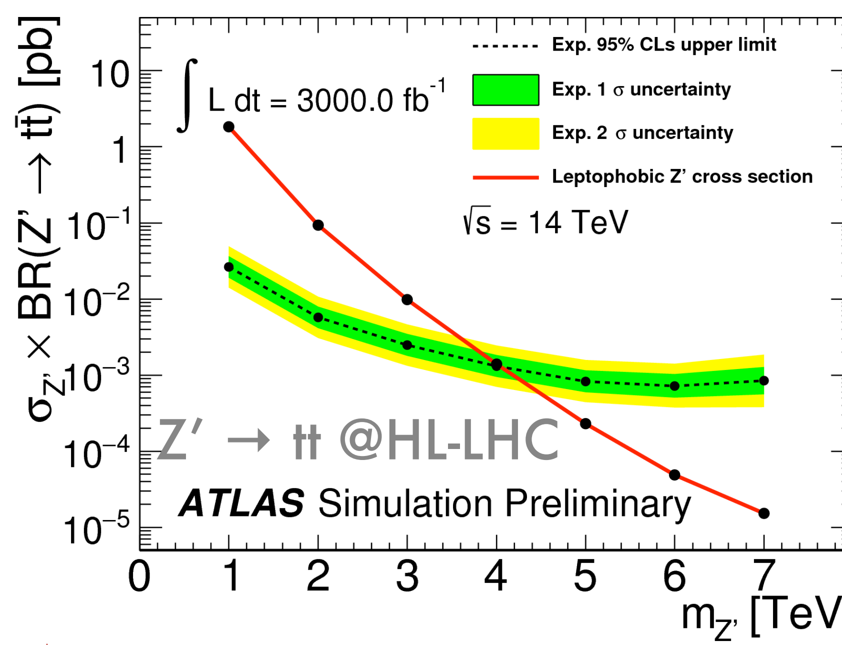


1805.09299



1805.01908



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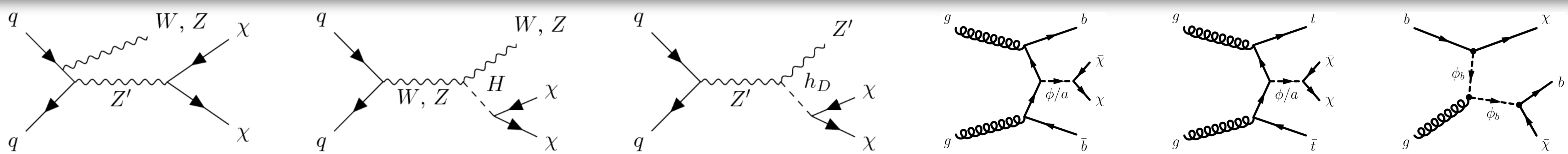
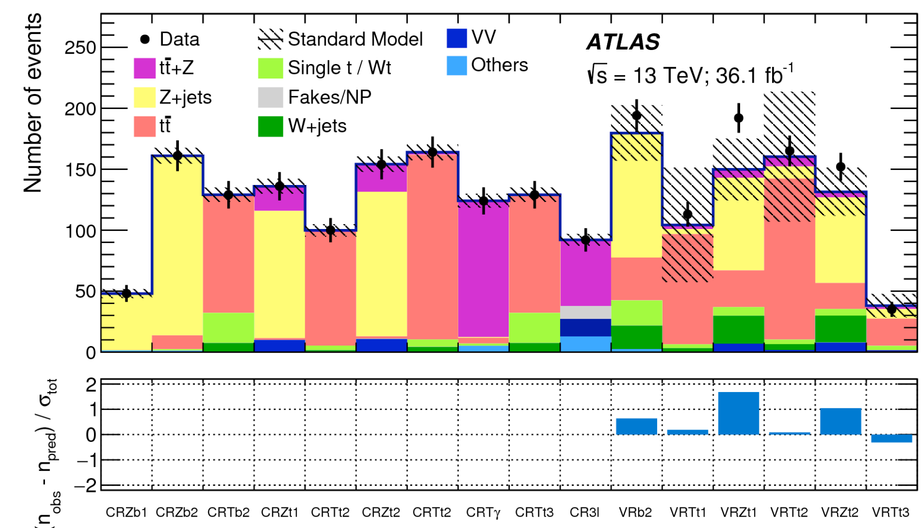
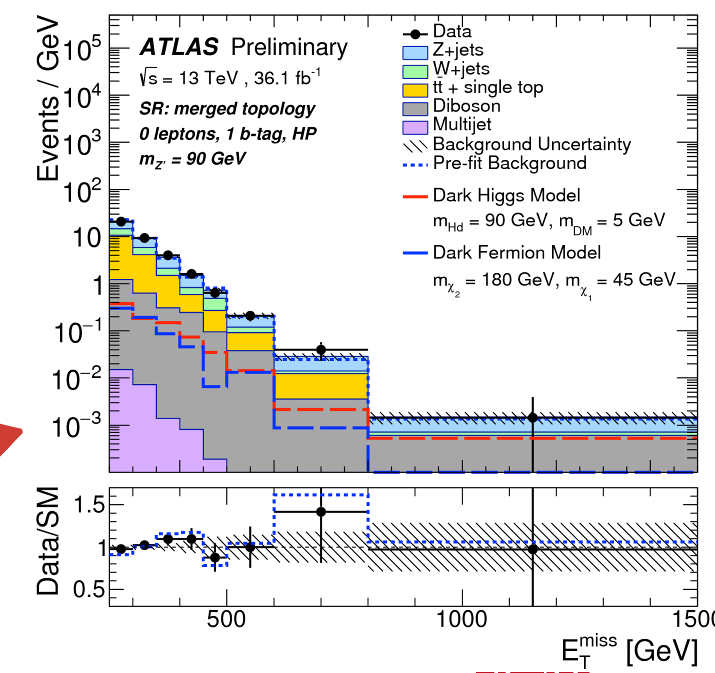
DM searches

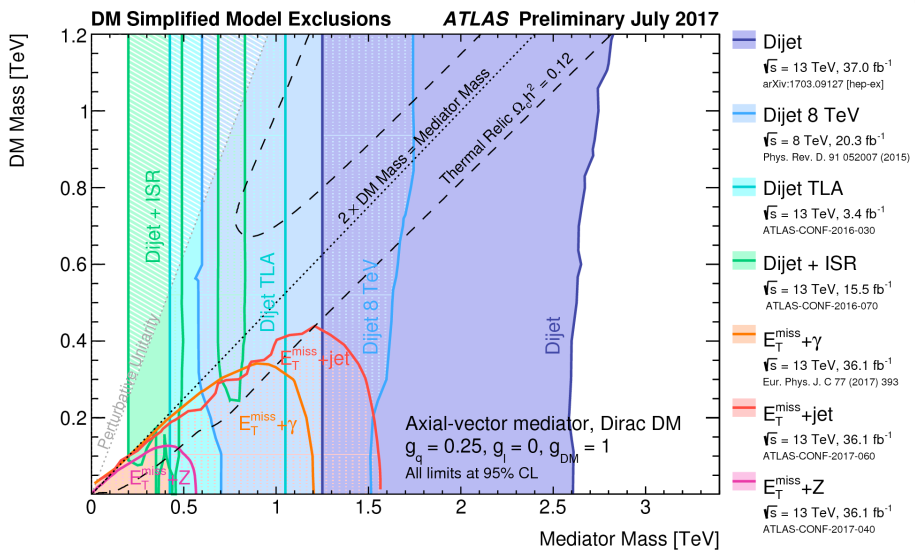


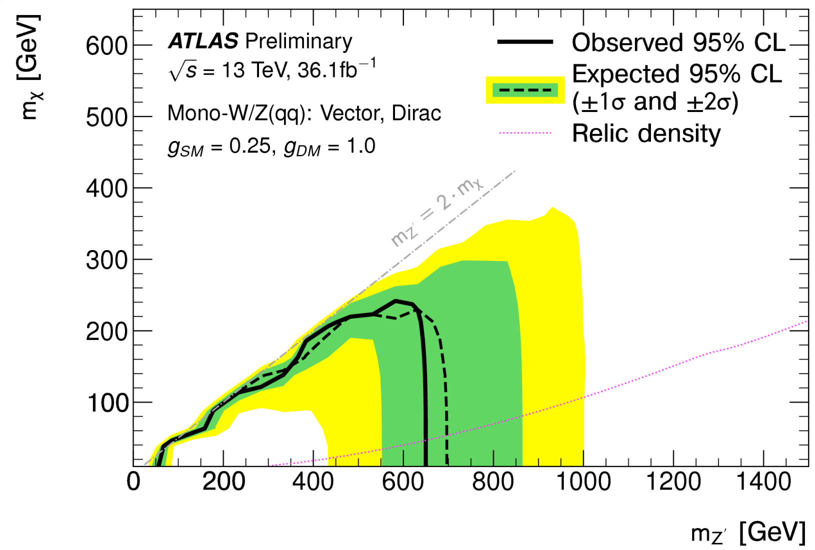
- Searches for DM candidates and mediators
- All RPC SUSY searches are also DM searches
- **General strategy**
  - DM candidates → high MET signature
  - Mediators → reinterpretation of resonance searches
- **Limiting factor**
  - Very strong model dependence in the interpretation
- **Examples of recent results and techniques**
  - t/b+MET: signal regions optimised for each model, similar strategy to SUSY searches [1710.11412]
  - W/Z/Z′+MET: resolved or boosted W/Z/Z′ decay to hadrons, large irreducible background, sensitivity limited by systematics [ATLAS-CONF-2018-005]



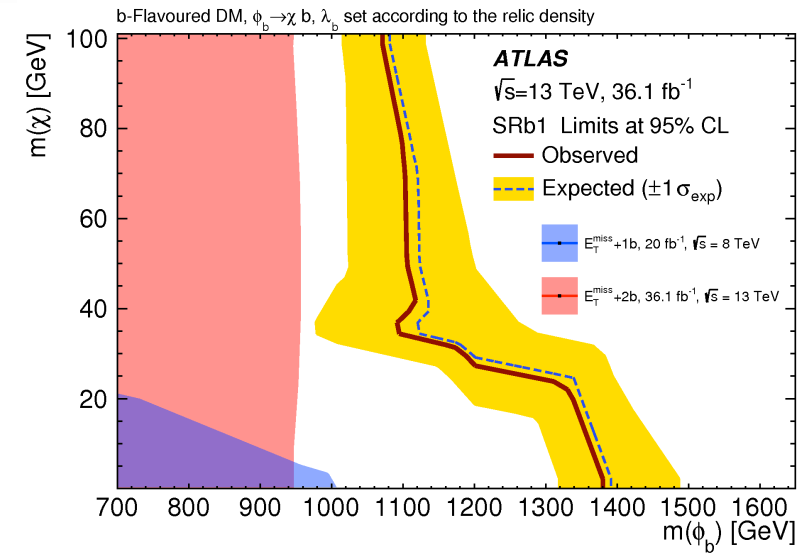


DM searches





[1710.11412](https://arxiv.org/abs/1710.11412)



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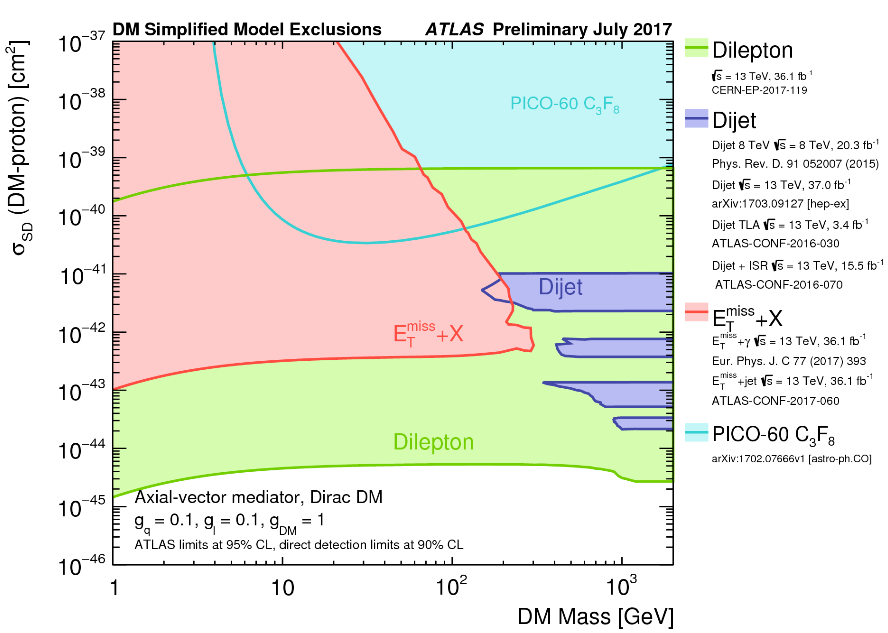

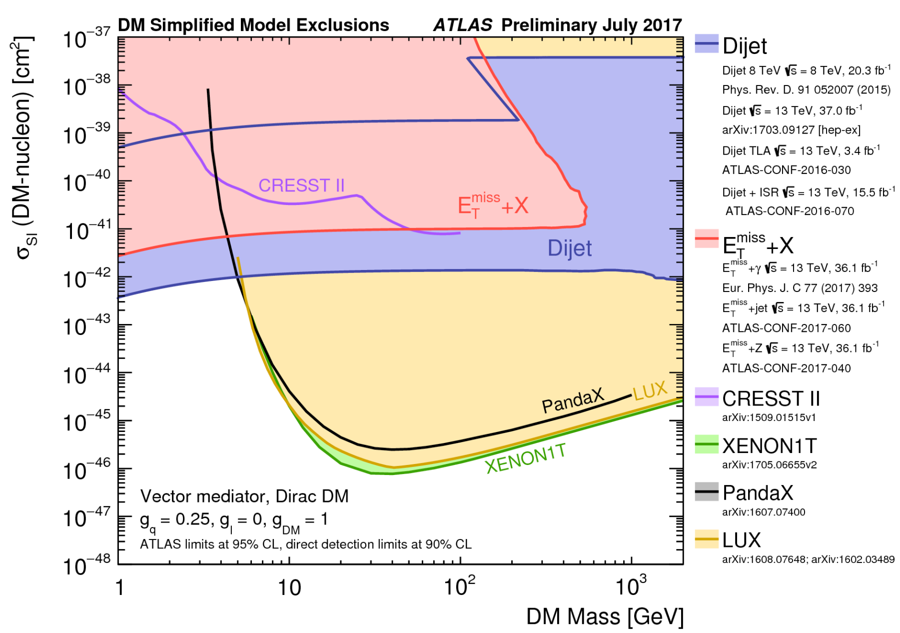

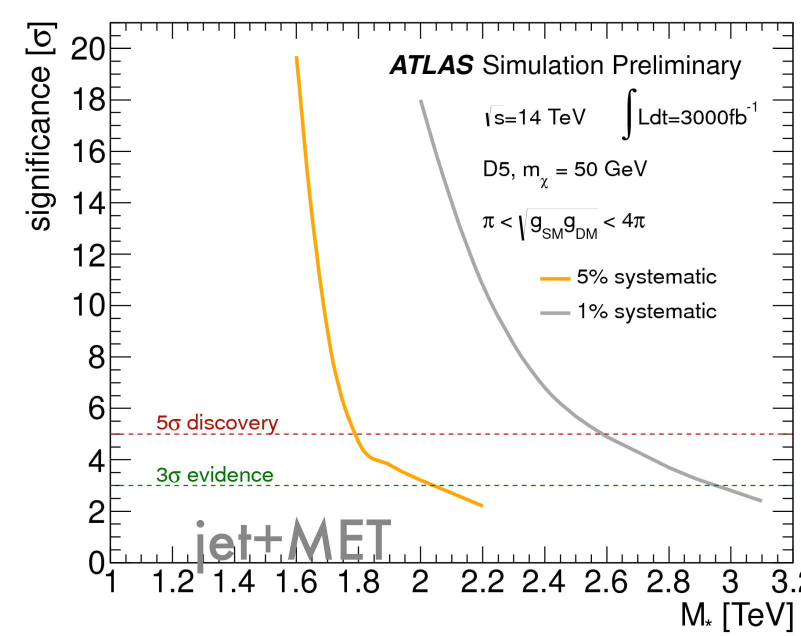

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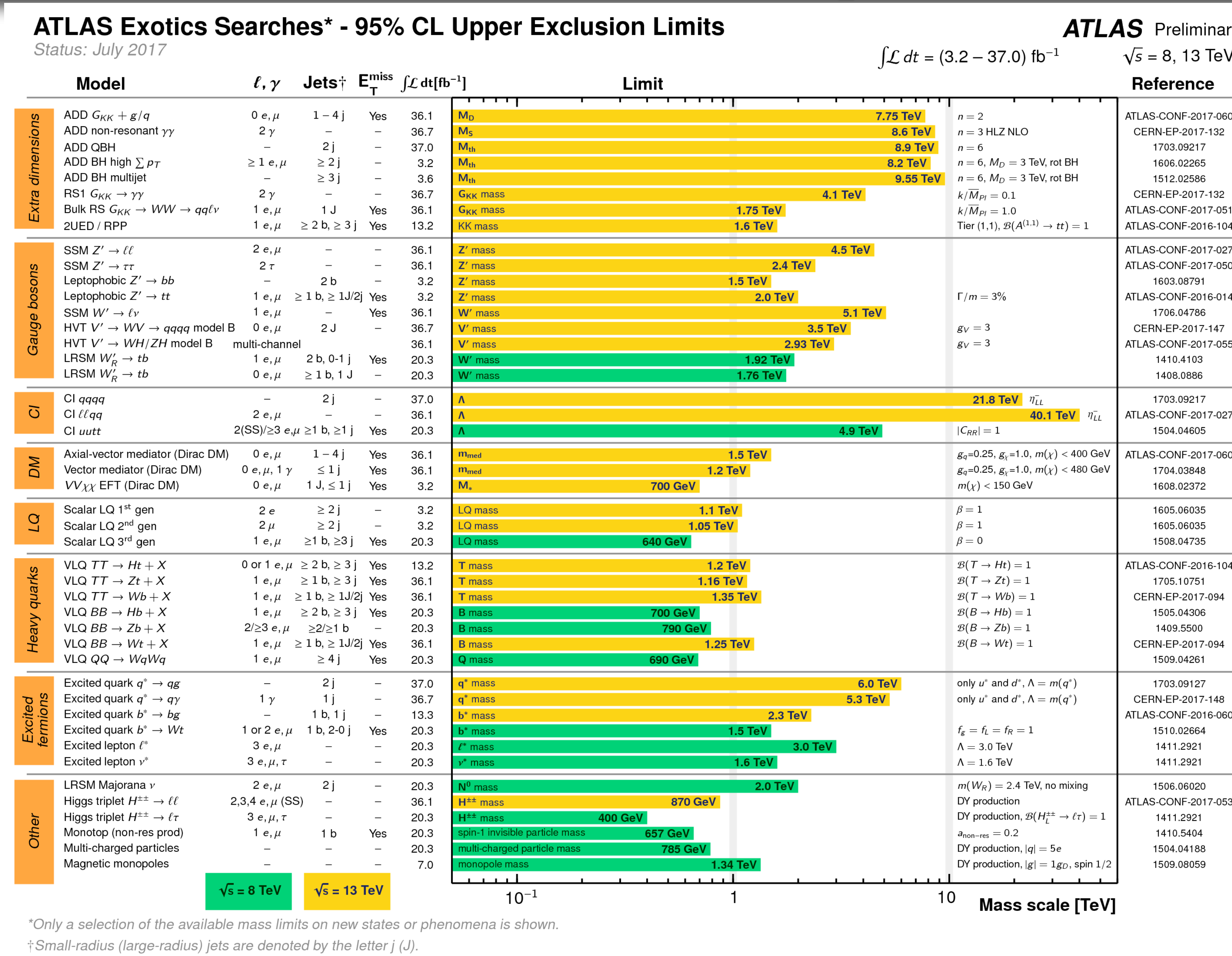
Exotics summary

Many more searches have excluded exotic particles up to the given masses and with the given assumptions

Only a selection is shown here



PRISMA Cluster of Excellence

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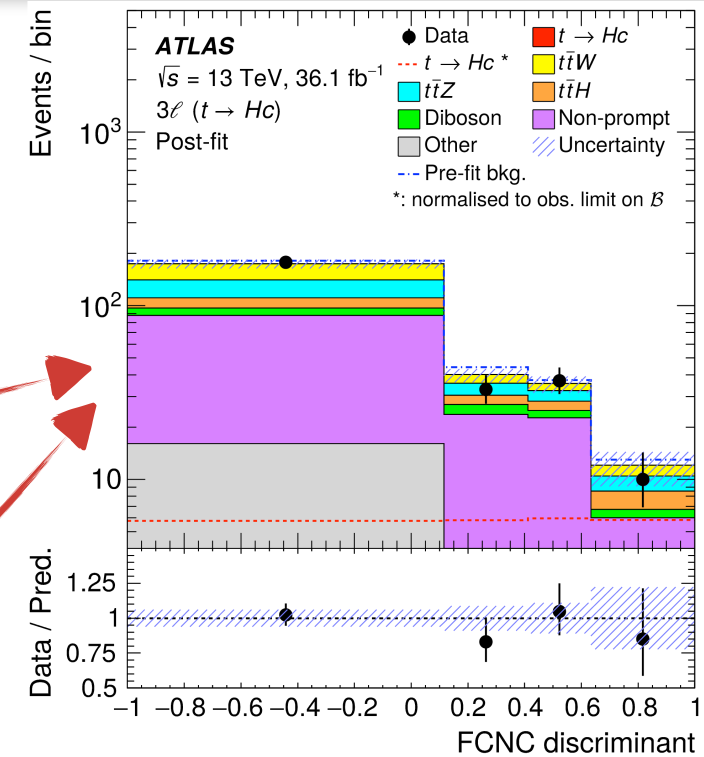
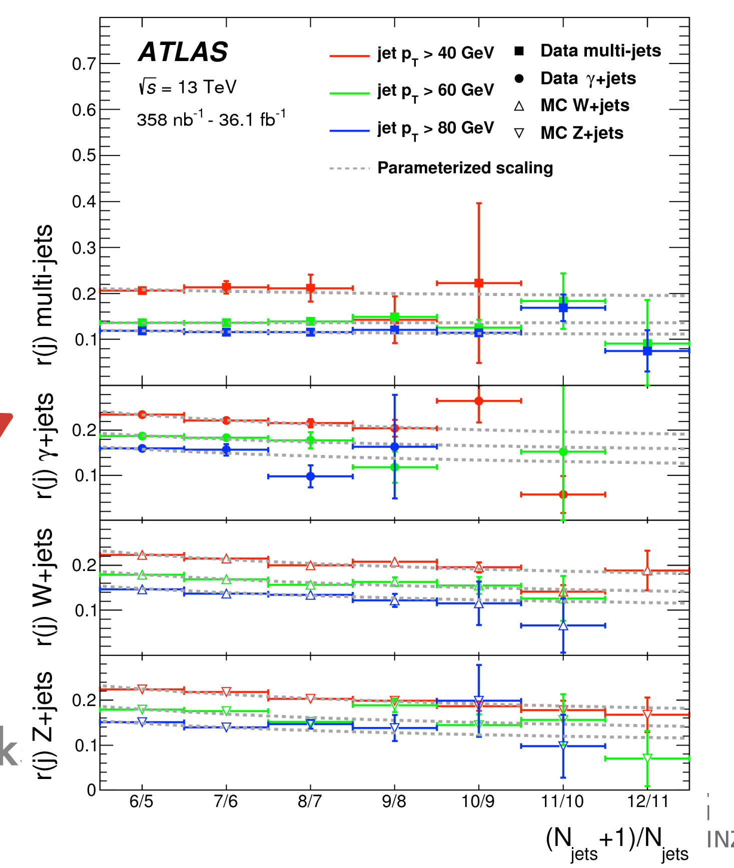
Indirect BSM searches

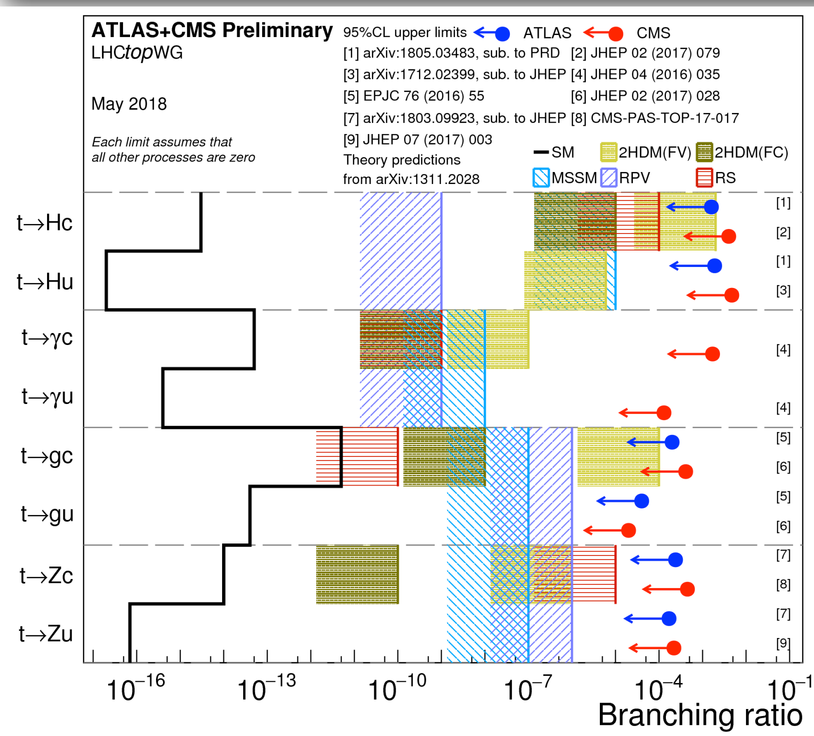
Very rare processes

- Processes expected in the SM with very low probability, well beyond sensitivity
- Searches for enhancement as predicted by many BSM models
- **Strategies**
  - Template fit of discriminant distribution
- **Limiting factor:** Statistics
- **Examples of latest results and techniques**
  - FCNC t→Hq: 2 same-sign or 3 leptons, boosted decision trees for background suppression [1805.03483]
  - hh→bbγγ: data-driven continuum diphoton background fit [paper in preparation]
  - tttt: high multiplicity jet and b-jet signal regions, jet-scaling parametrisation [1704.08493]





Very rare processes

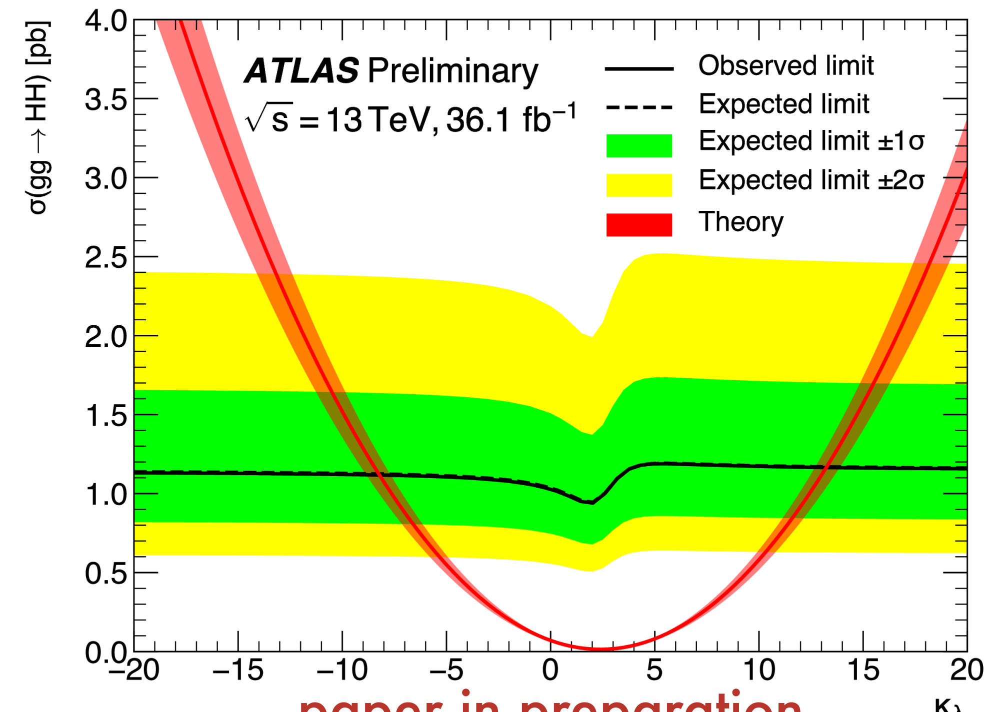


σ(tttt) < 60 (84) fb

μ < 6.5

@ 95% CL

1704.08493

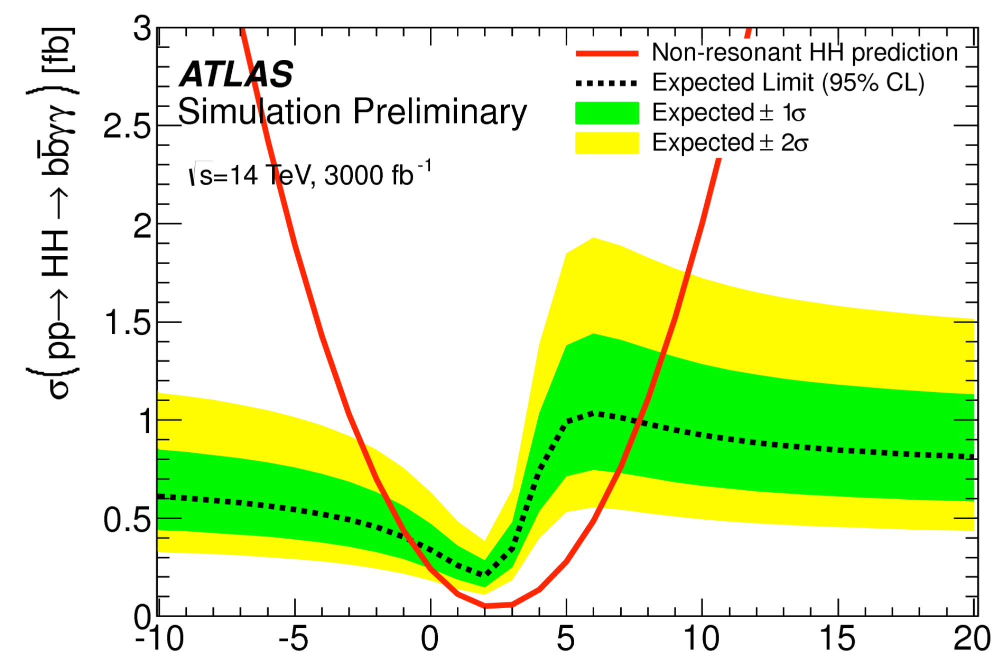


paper in preparation

HL-LHC 3/ab stat only

	$t \to Hu$	$t \to Hc$	$t \to Hu + Hc$
Reference scenario	$1.2 \cdot 10^{-4}$	$1.0 \cdot 10^{-4}$	$0.55 \cdot 10^{-4}$
Middle scenario	$1.2 \cdot 10^{-4}$	$1.1 \cdot 10^{-4}$	$0.58 \cdot 10^{-4}$
Low scenario	$1.4 \cdot 10^{-4}$	$1.2 \cdot 10^{-4}$	$0.66 \cdot 10^{-4}$

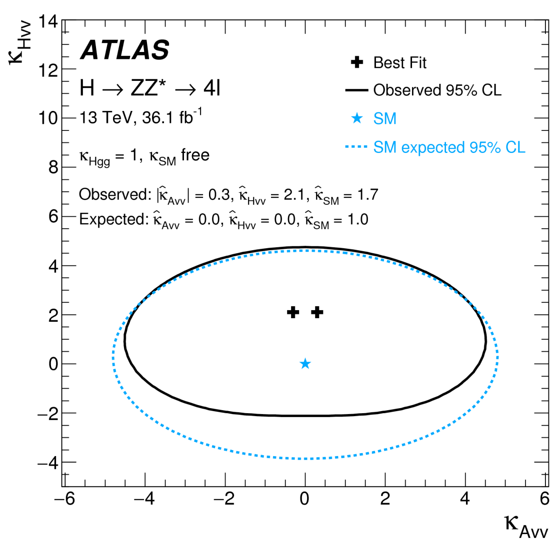
ATL-PHYS-PUB-2016-019



ATL-PHYS-PUB-2017-001

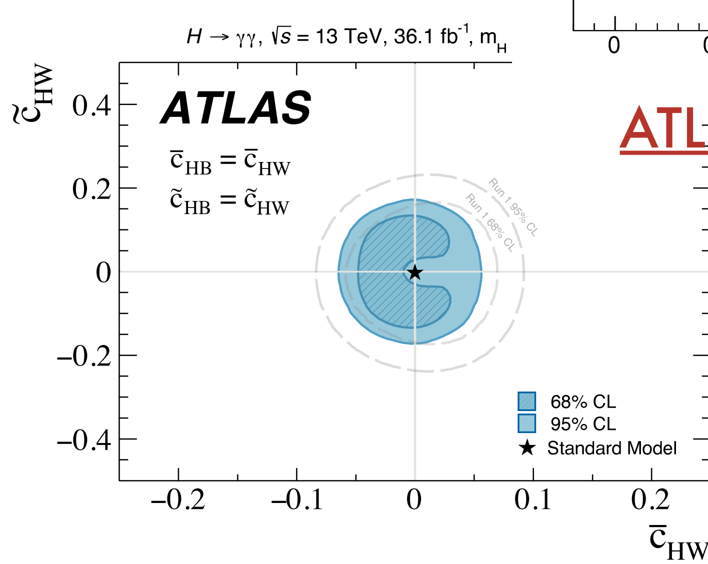
Higgs couplings

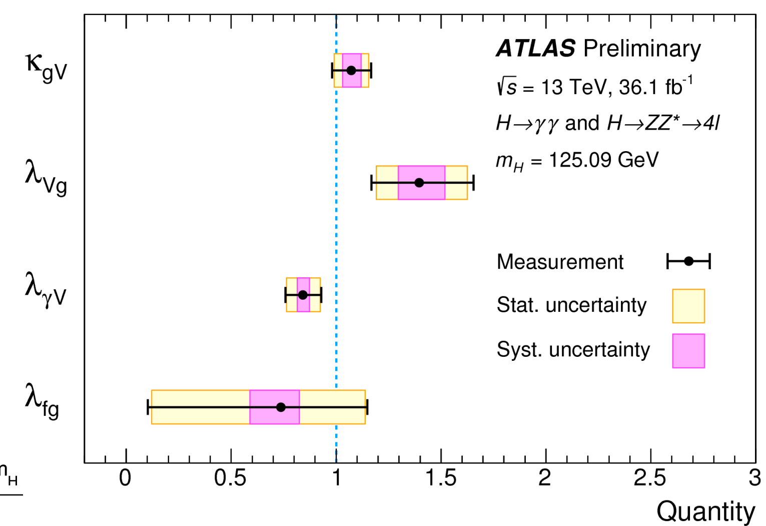
- **First EFT interpretations** of SM Higgs boson cross section measurements (inclusive and differential)
  → limits on anomalous couplings
- **Kappa framework** used in the past
  → fit of couplings from several decay and production channels (model-dependent)



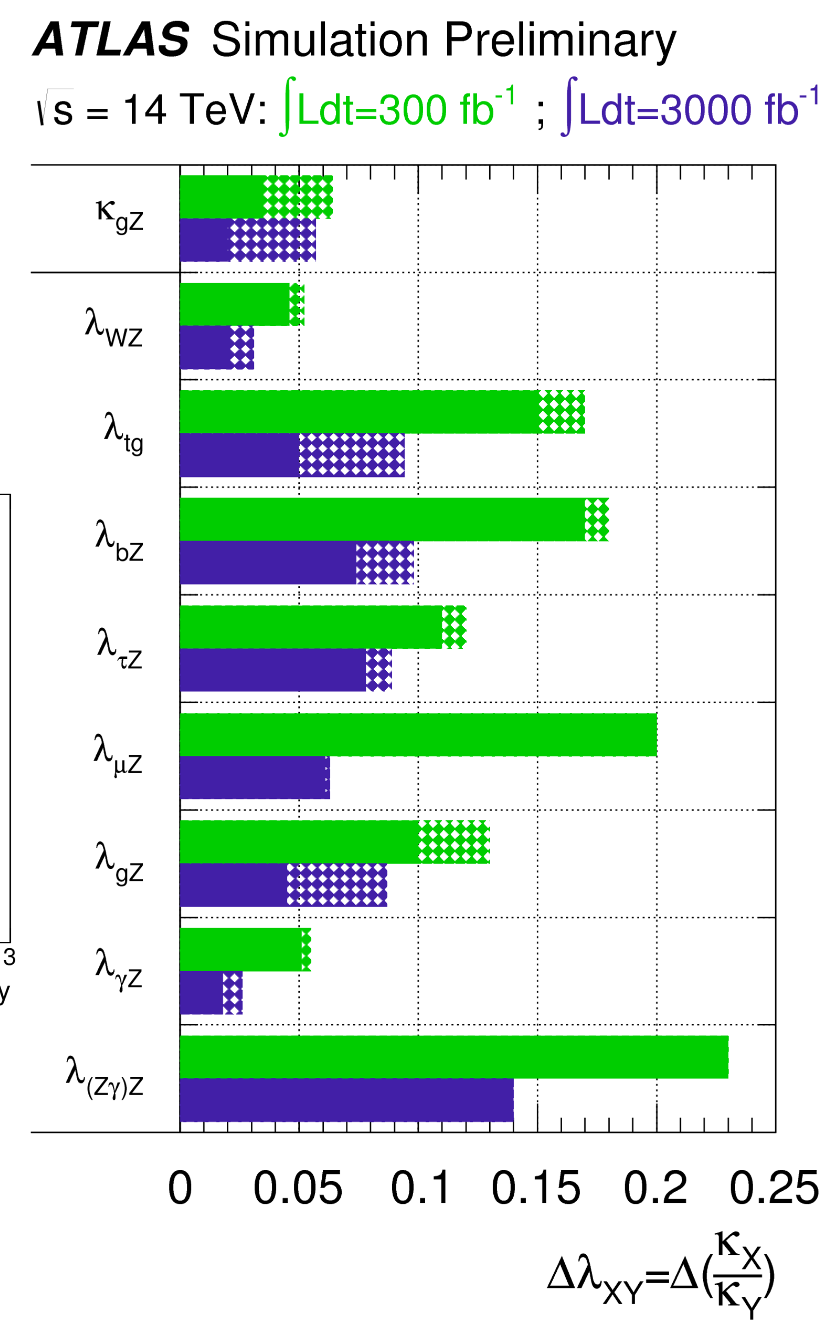
1712.02304

1802.04146





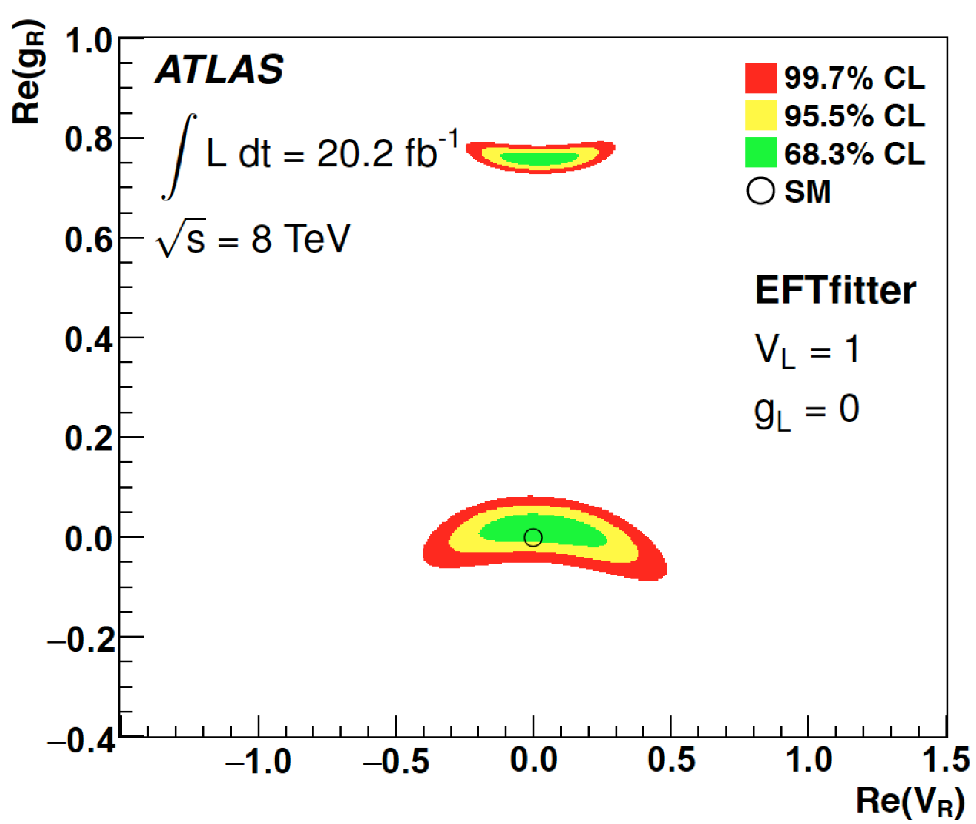
ATLAS-CONF-2017-047



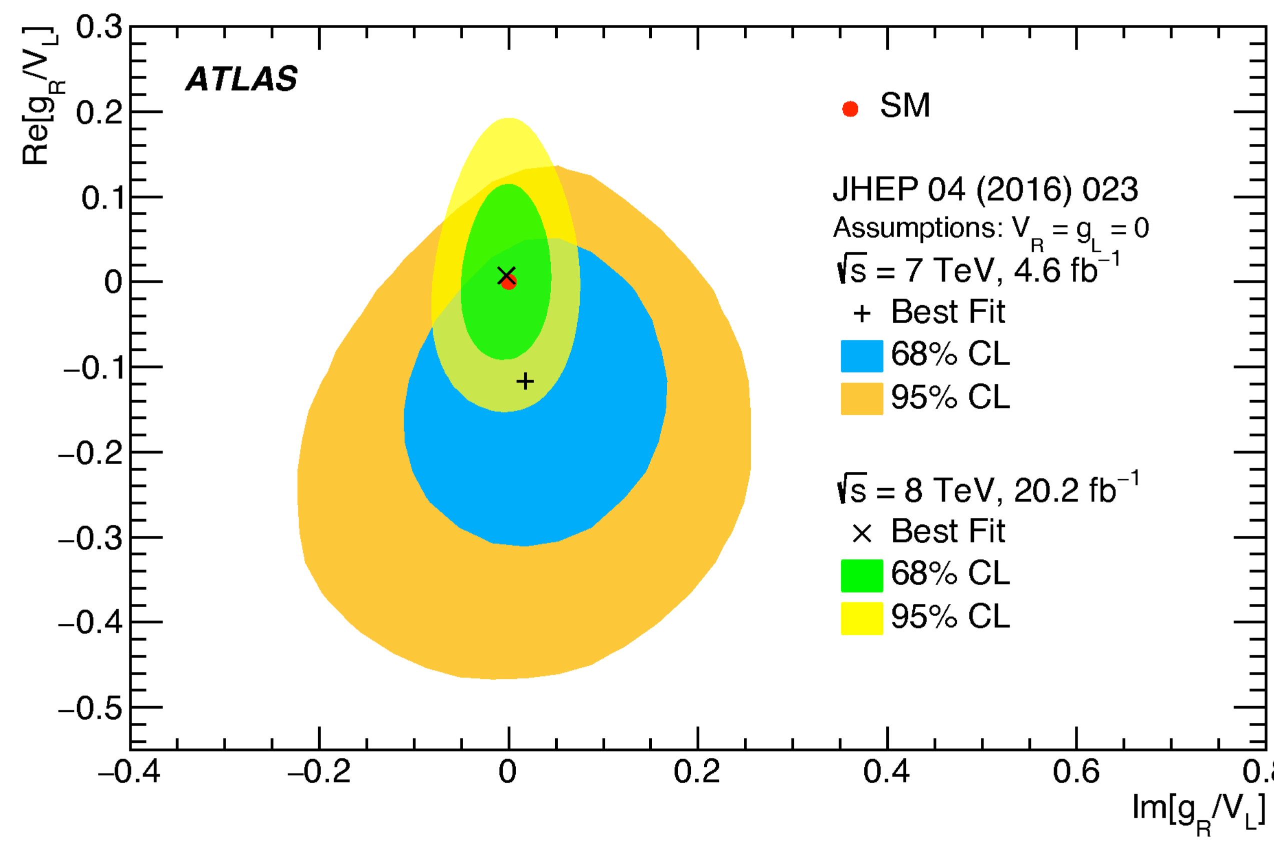
ATL-PHYS-PUB-2013-014

Top couplings

- Some 8 TeV results interpreted in EFT
  - Wtb from single top production
  - W helicity in top pair production
- More expected in the future, e.g. from associated production with Z or γ



[1612.02577](1612.02577)



[1707.05393](1707.05393)

Conclusion

Summary

- Extensive programme of direct BSM searches carried out at ATLAS
  - Large variety of strategies
  - Many ingenuous analysis methods
  - See full list of results for SUSY and exotics
- More and more SM measurements being interpreted as limits on anomalous couplings
  - Very rare processes being searched for long before sensitivity at SM level is reached
  - Higgs and top cross section and property measurements interpreted in EFT

Outlook

- Strongly improved detector, slightly higher energy and 3/ab of data expected at HL-LHC
  - Big improvement for all statistically limited searches
  - Background estimate can profit from more populated control regions, better measurements and calculations
- Much higher pile-up requires improved analysis techniques
  - Non-trivial reconstruction e.g. of boosted W/Z/h and top decays used extensively in searches for heavy particles
  - Lots of very promising ideas in collaboration between experimentalists and theorists

Backup