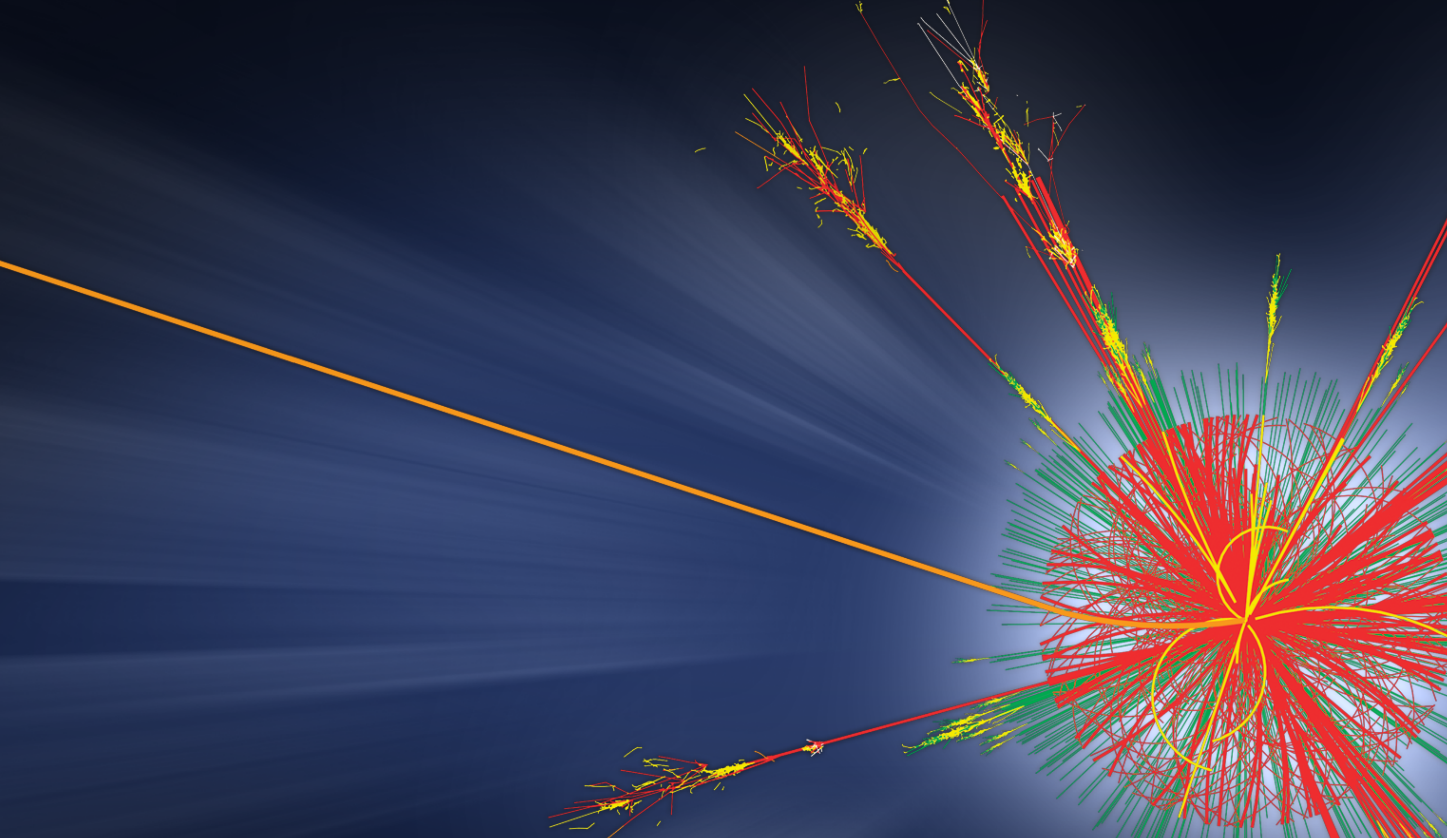


Searches for new physics at ATLAS

Kate Pachal
Simon Fraser University
on behalf of the ATLAS Collaboration

Introduction

- ATLAS has been collecting data since 2010, now nearing end of Run 2
- Searches for new physics have been a primary motivator for LHC physics program
- We haven't found anything yet
- Should we despair? …

(Spoiler: no!)

Problems!

Dark matter

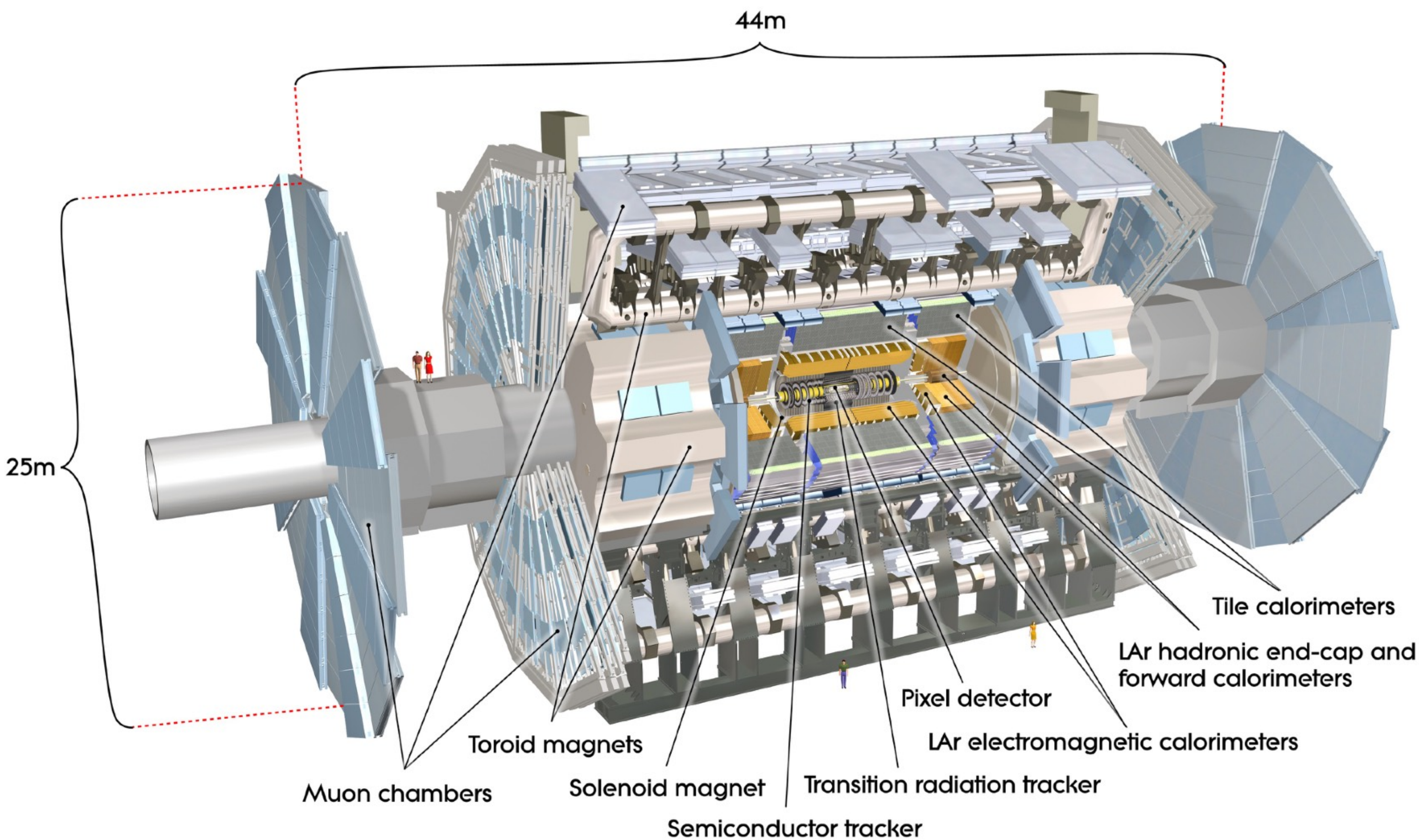
Hierarchy problem

Gauge unification

Higgs fine-tuning

….

Obligatory ATLAS experiment slide



Using simplified models, summaries, and scans to identify research directions

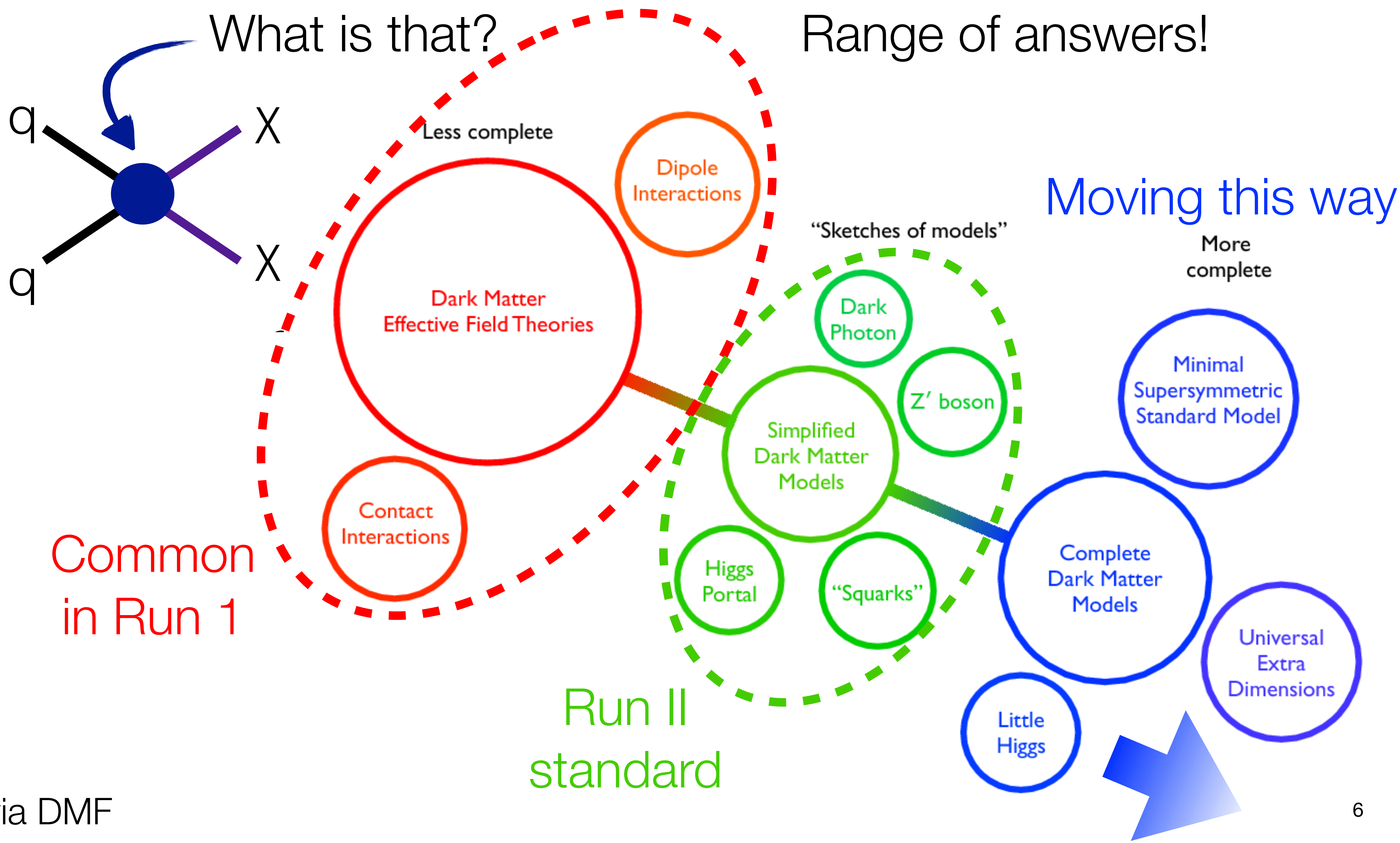
How should we interpret search results so far?

Most important statement in any search:
did we find **evidence of new physics**?

- If no, set limits! With limits, analyses prioritise making generalised statements which are as easy as possible to reinterpret in different frameworks
- Simplified models are just spherical cows but give us a framework to understand how our results relate to one another
- Summaries in context of various models help us find holes and plan next steps for search program

All models, and therefore all limits, should be taken with a grain of salt!
But they are important to let us **contextualise** our zeros.

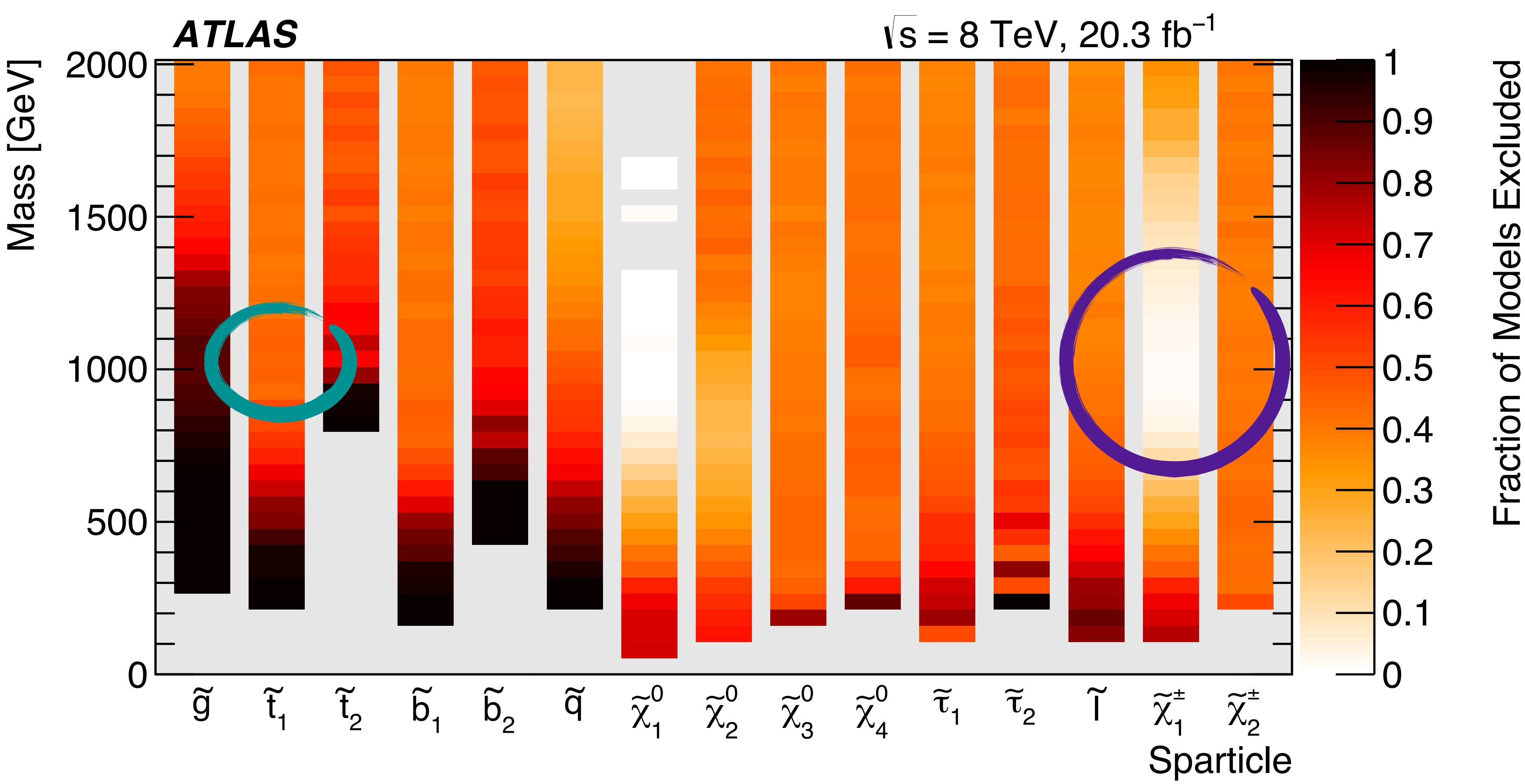
Example: simplified dark matter models at ATLAS



via DMF

Example: PMSSM scan

- Use simplified "phenomenological" MSSM as a model generator
  - Throw toy universes with different parameters and check exclusion with analyses
  - Results reported as fraction of models excluded
- Advantages: help us find holes! Disadvantages: difficult to make meaningful statements given sparse sampling of the parameter space



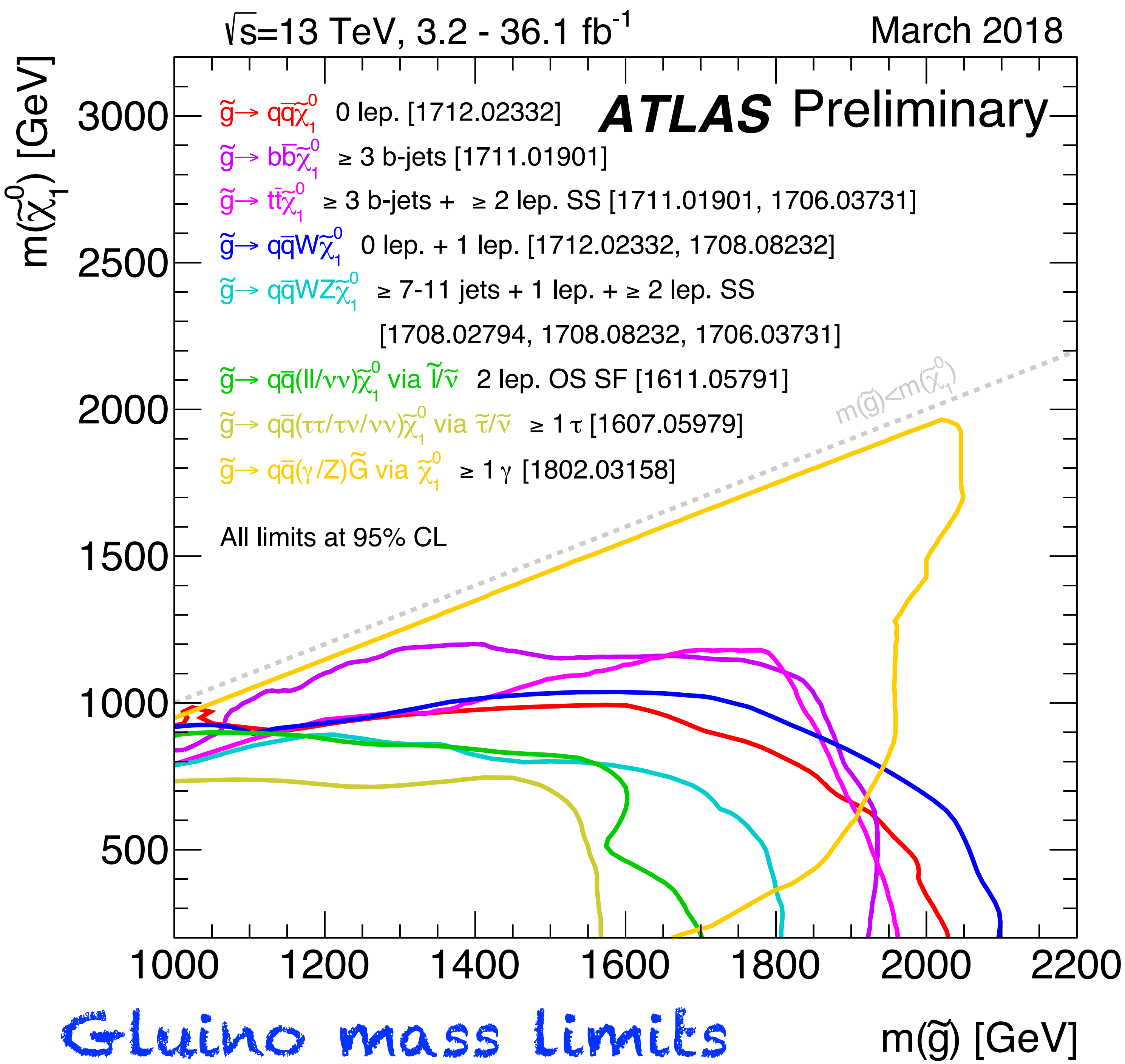
(8 TeV plot)

Highlighting under-covered spots

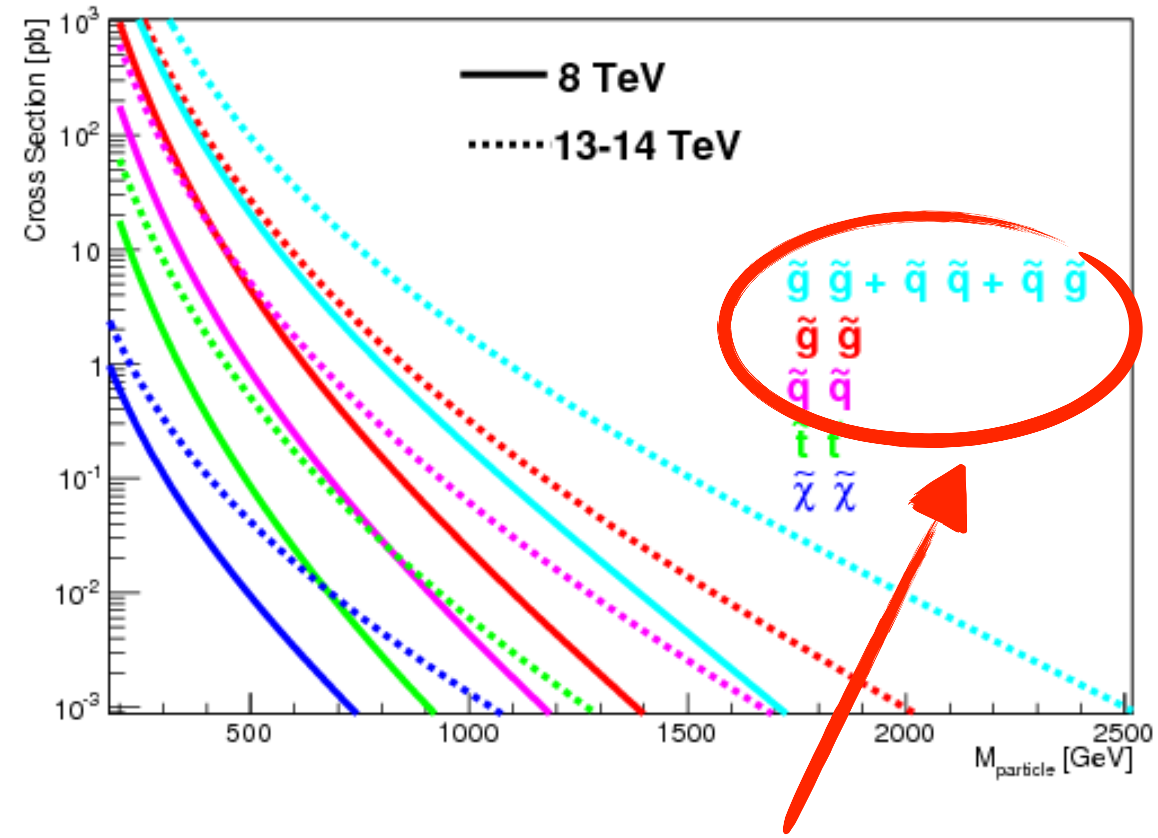
Best limits exclude 1 TeV stop, but not in all models

Current results in SUSY

SUSY strong production

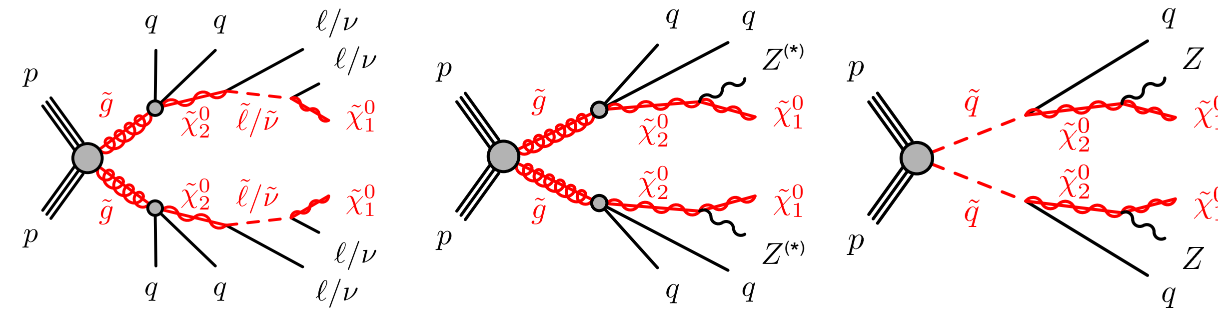


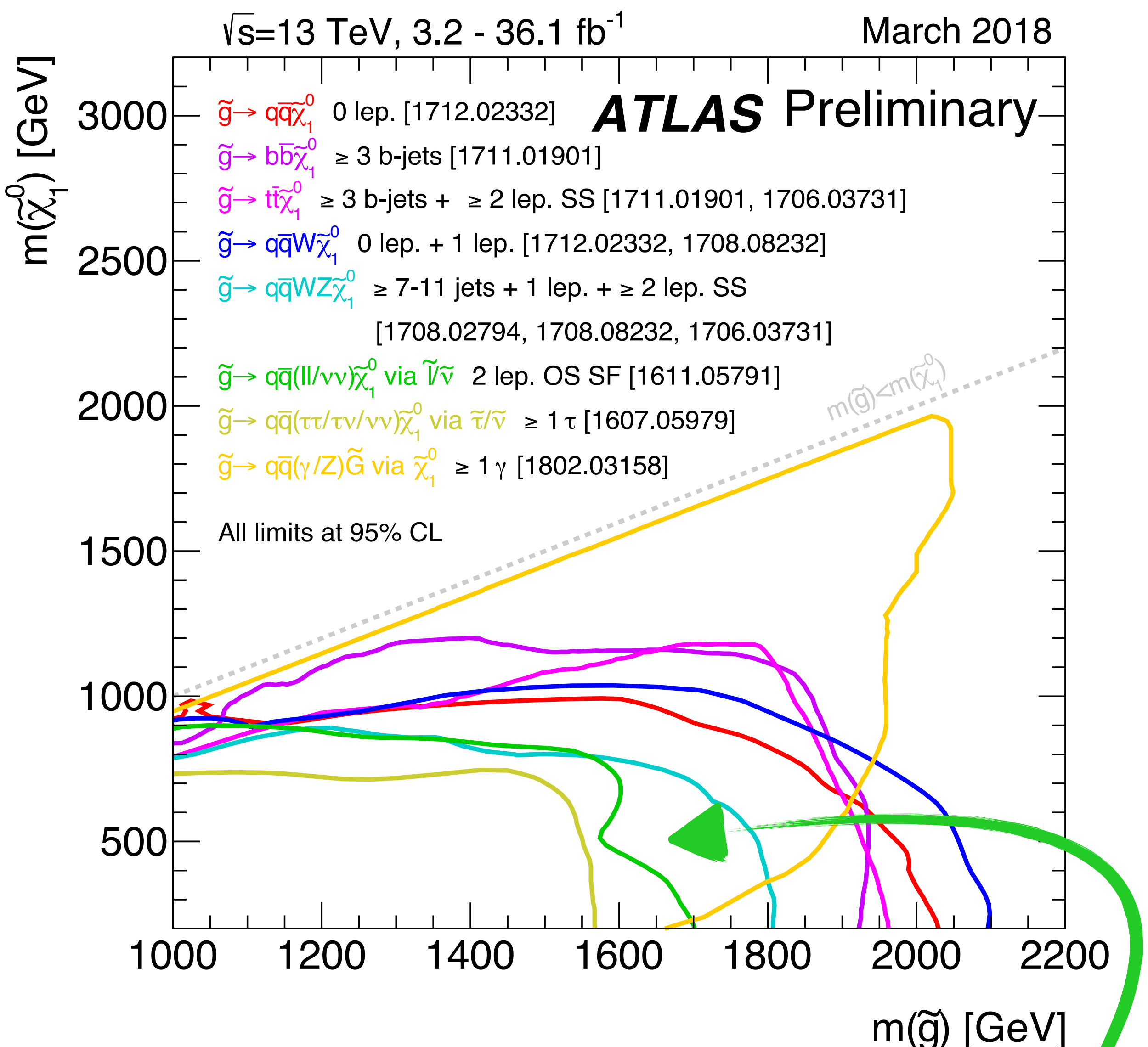
Gluino mass limits up to ~2 TeV!

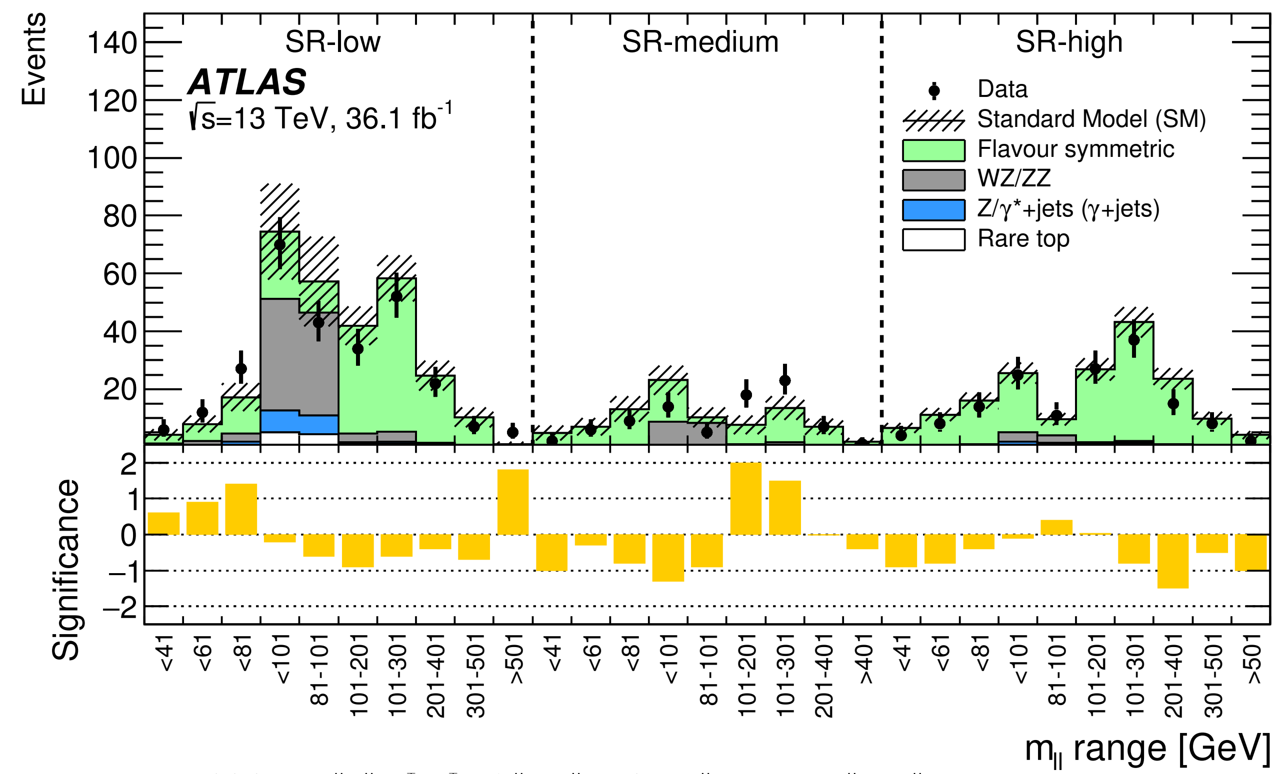


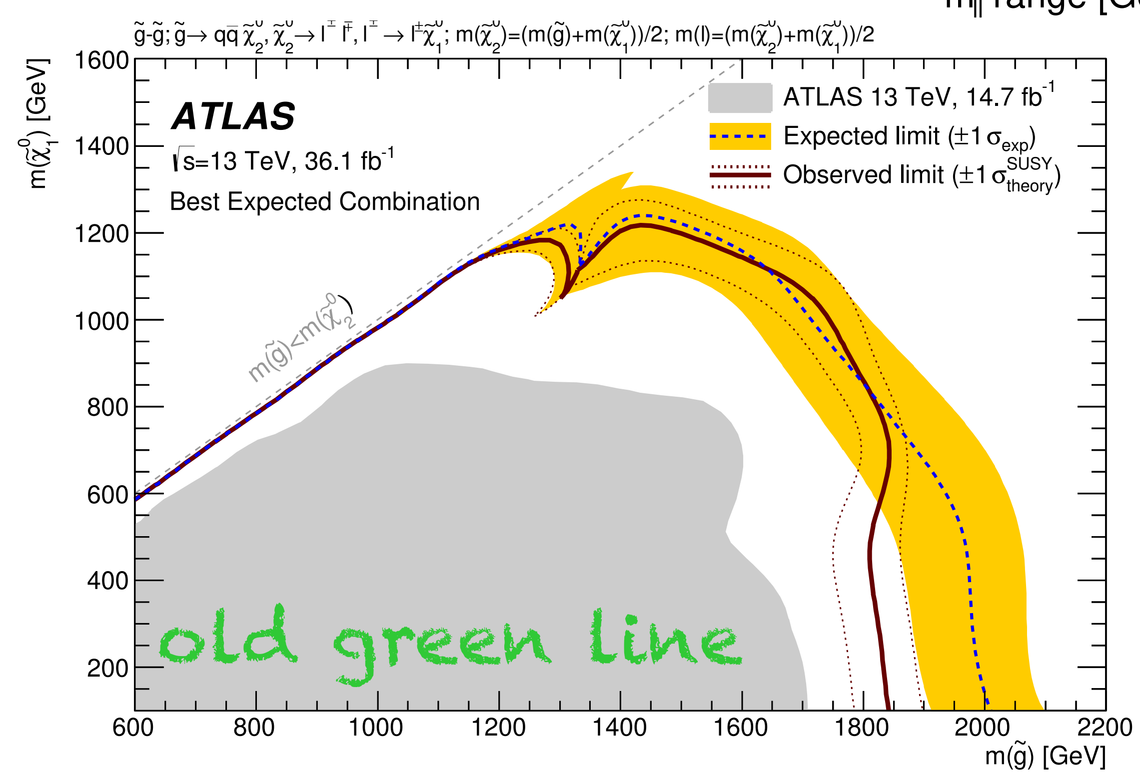
- High production σ with boost from 13 TeV -> strong motivation for early run II searches!
- Squark & gluino production gives final states with lots of hadronic activity + MET
- Strong limits with 36/fb!

Recent highlights: SUSY strong production







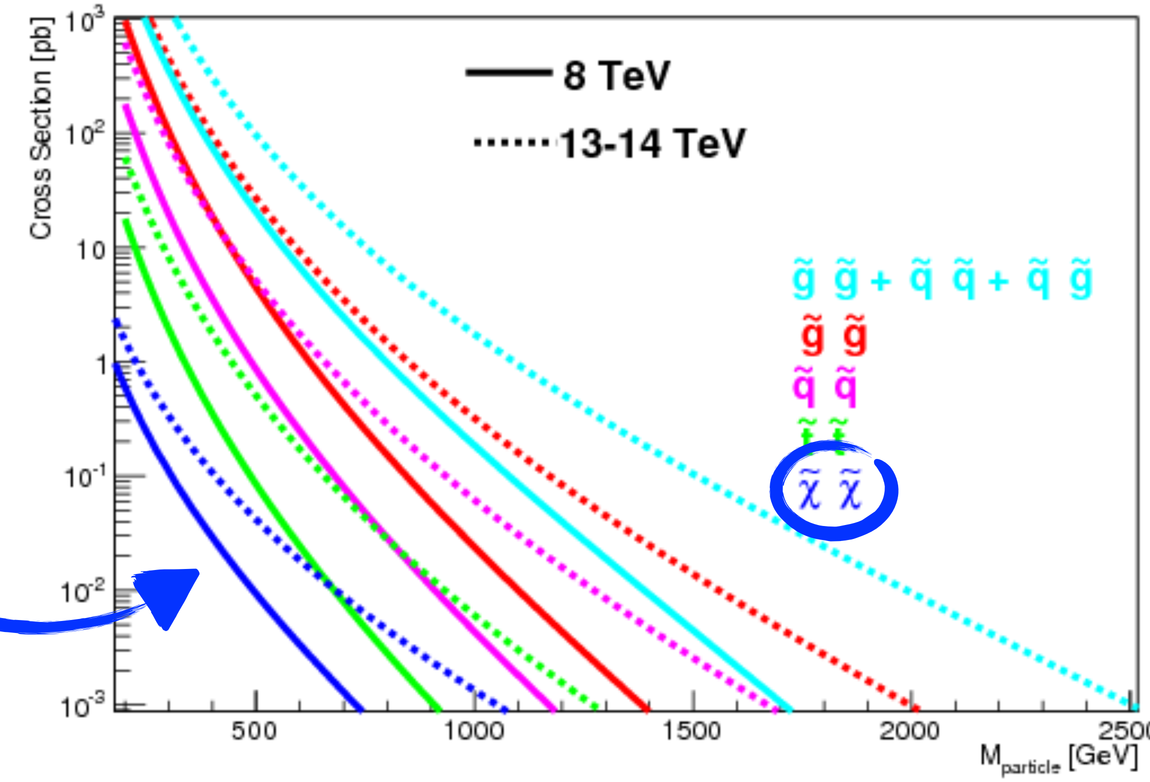


Highlight: OS-dilepton update!

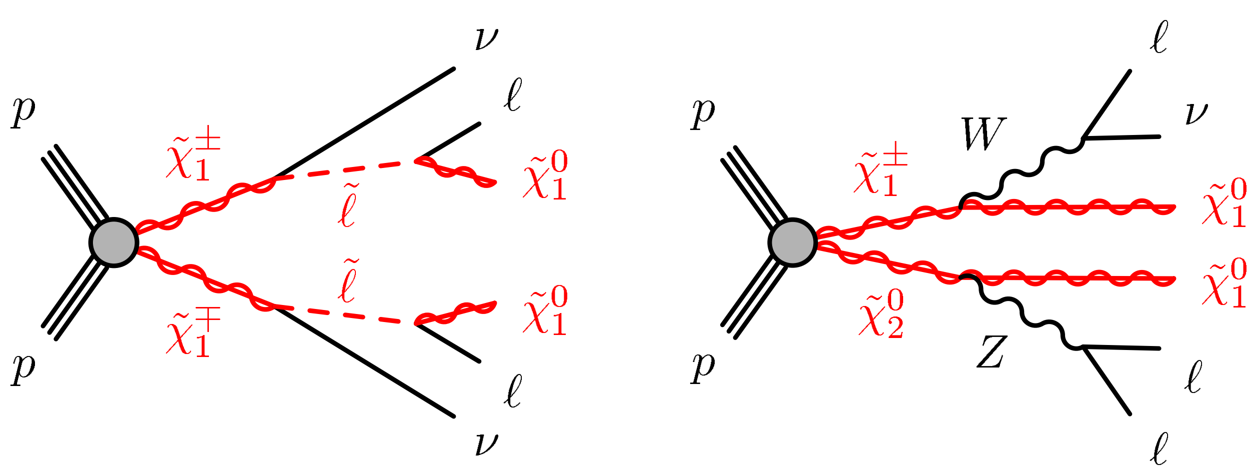
arXiv:1805.11381

Recent highlights: EW SUSY

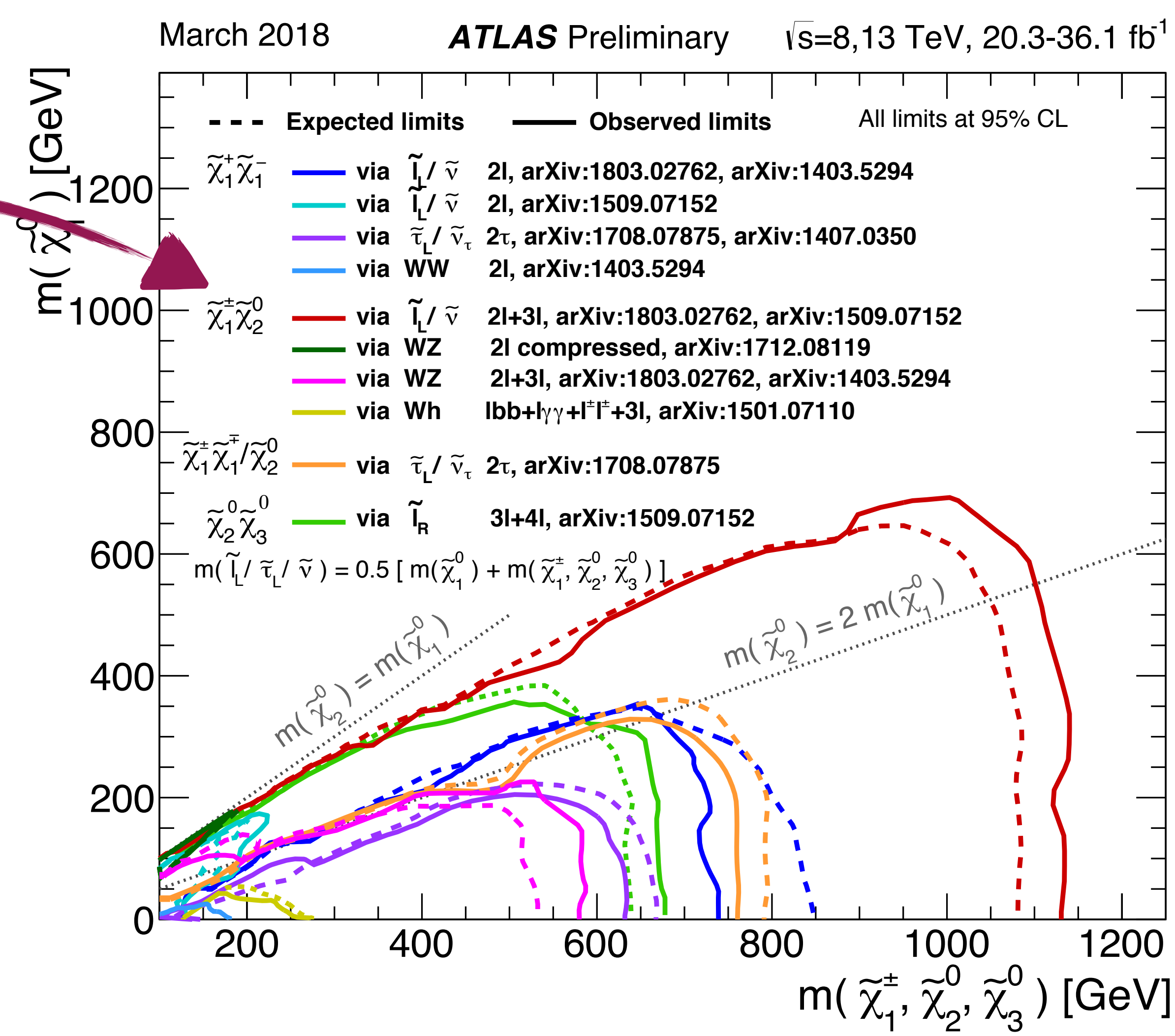
- Production σ for EW smaller; benefited less from CME jump
- Signature: leptons/gauge bosons+MET. Clean; main bkgs from diboson, ttbar



Highlight:2/3L



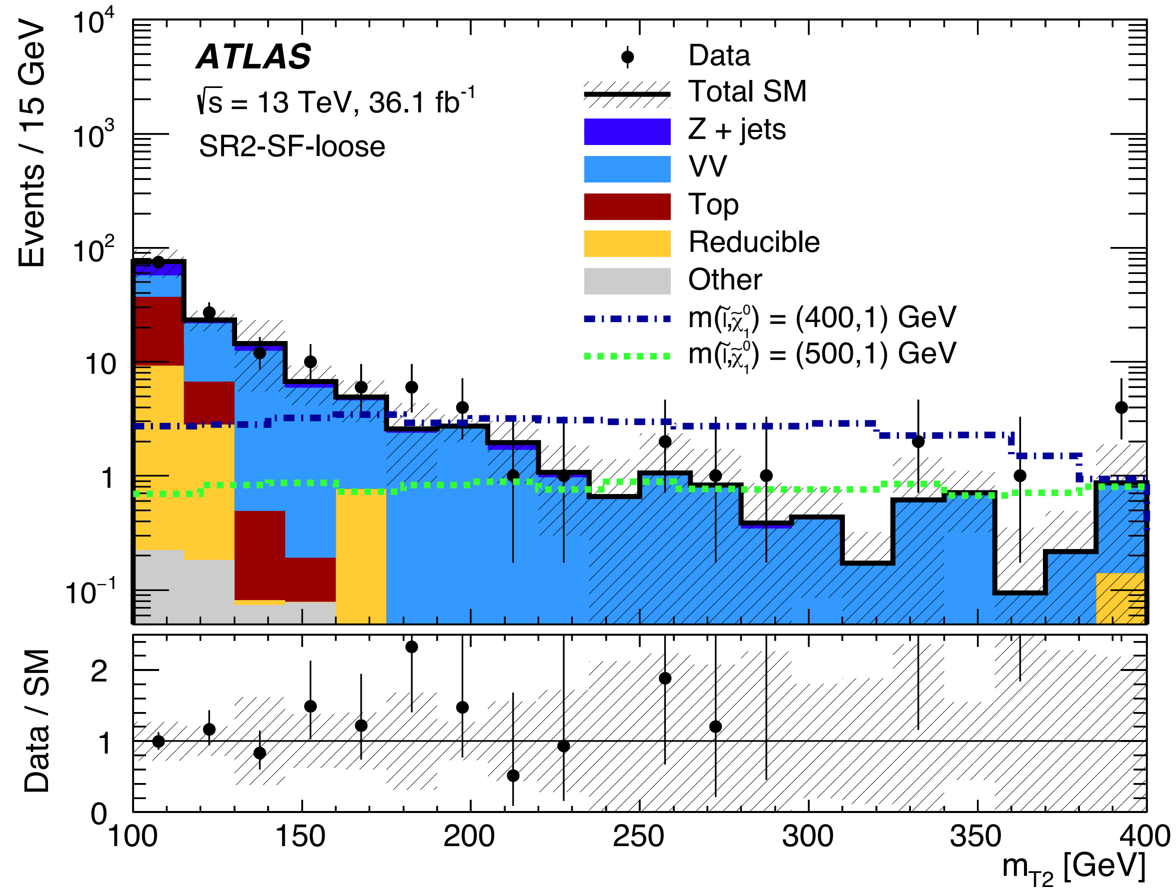
arXiv:1803.02762



+ arXiv:1806.02293 (New!)

Recent highlights: EW SUSY

Highlight:2/3L

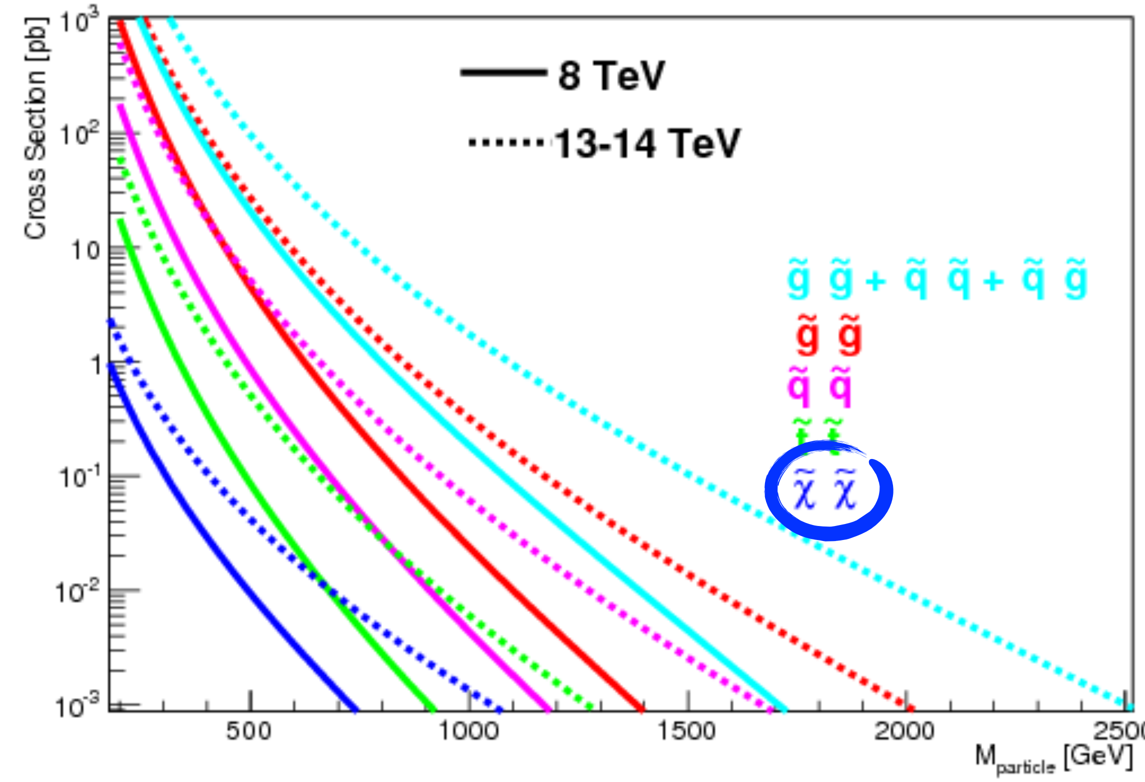


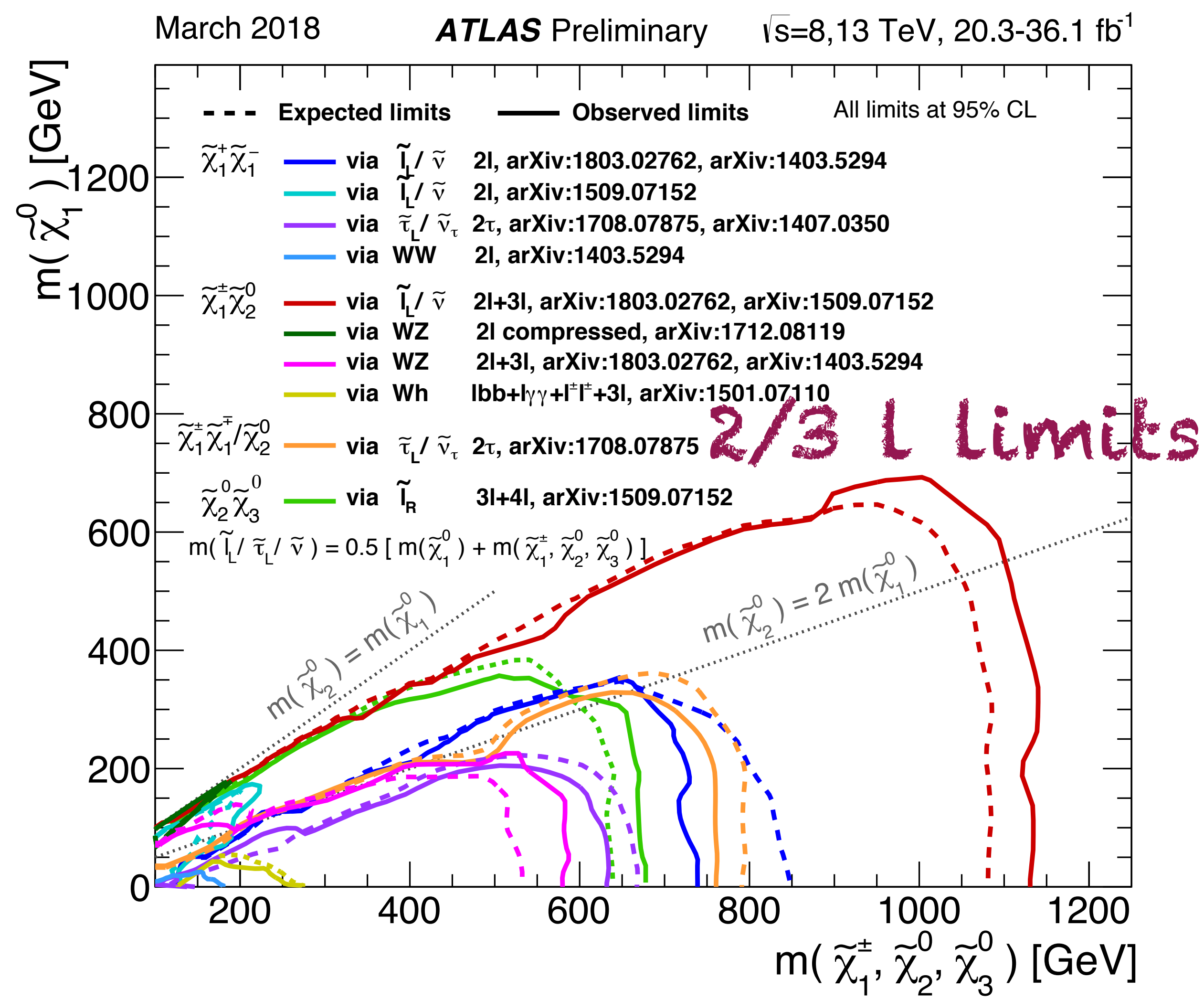
$$m_{T2} = \min_{\mathbf{q}_T}\left[\max\left(m_T(\mathbf{p}_T^{\ell 1}, \mathbf{q}_T), m_T(\mathbf{p}_T^{\ell 2}, \mathbf{p}_T^{\text{miss}} - \mathbf{q}_T)\right)\right]$$

Use E_T^{miss}, m_{T2}, etc to gain info where lots of unmeasured particles

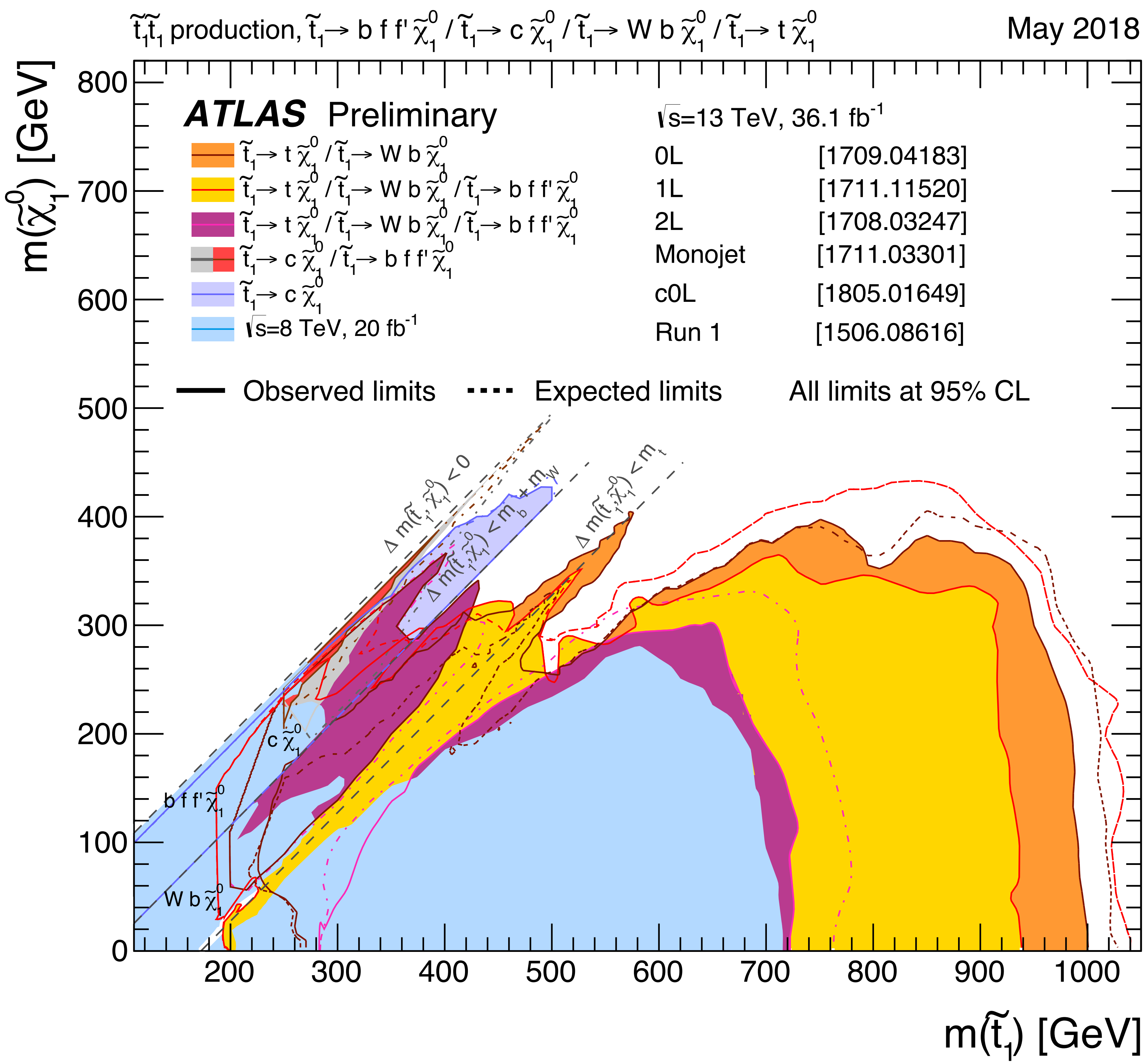
arXiv:1803.02762

+ arXiv:1806.02293 (New!)

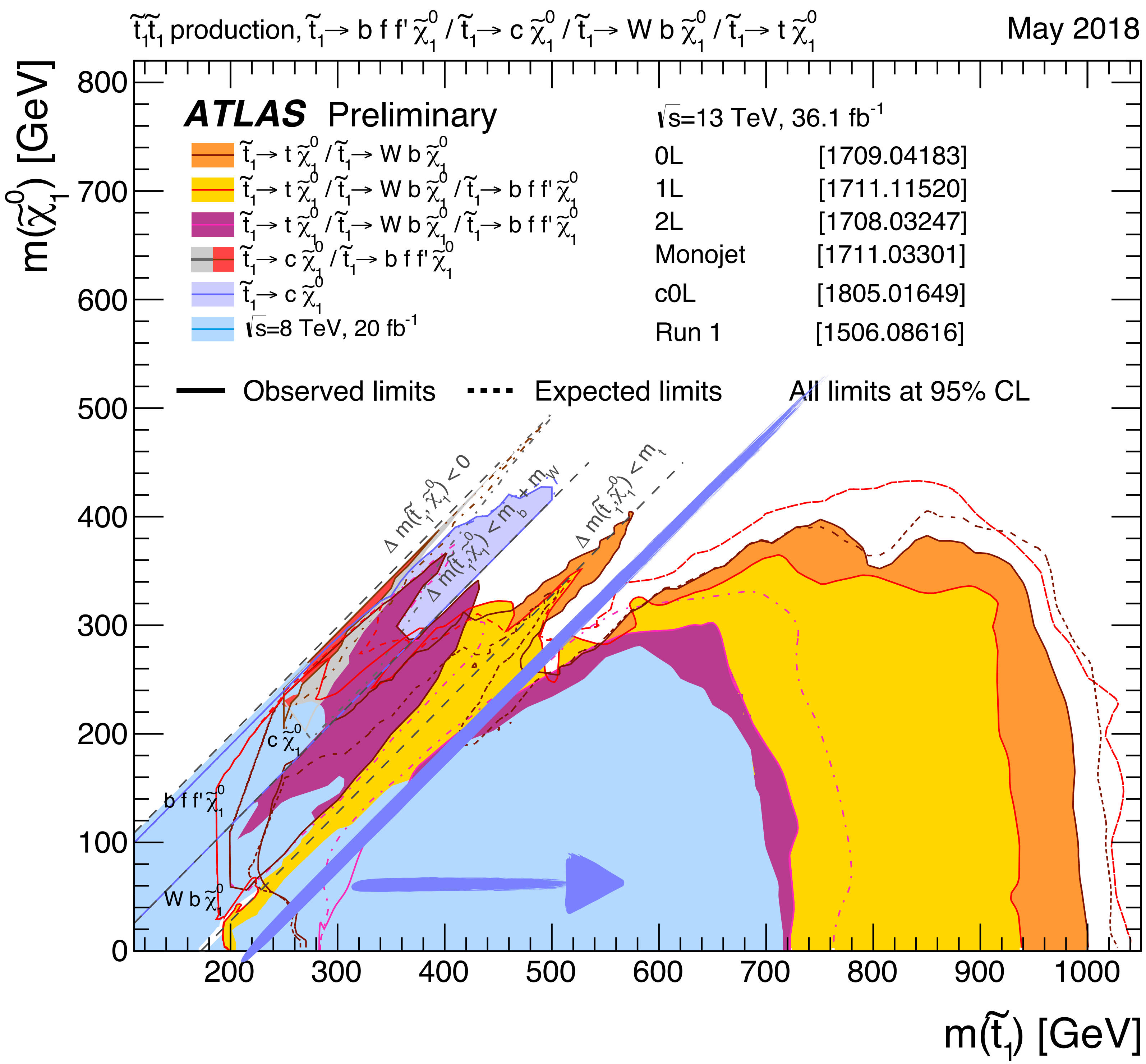




Compressed spectra in SUSY

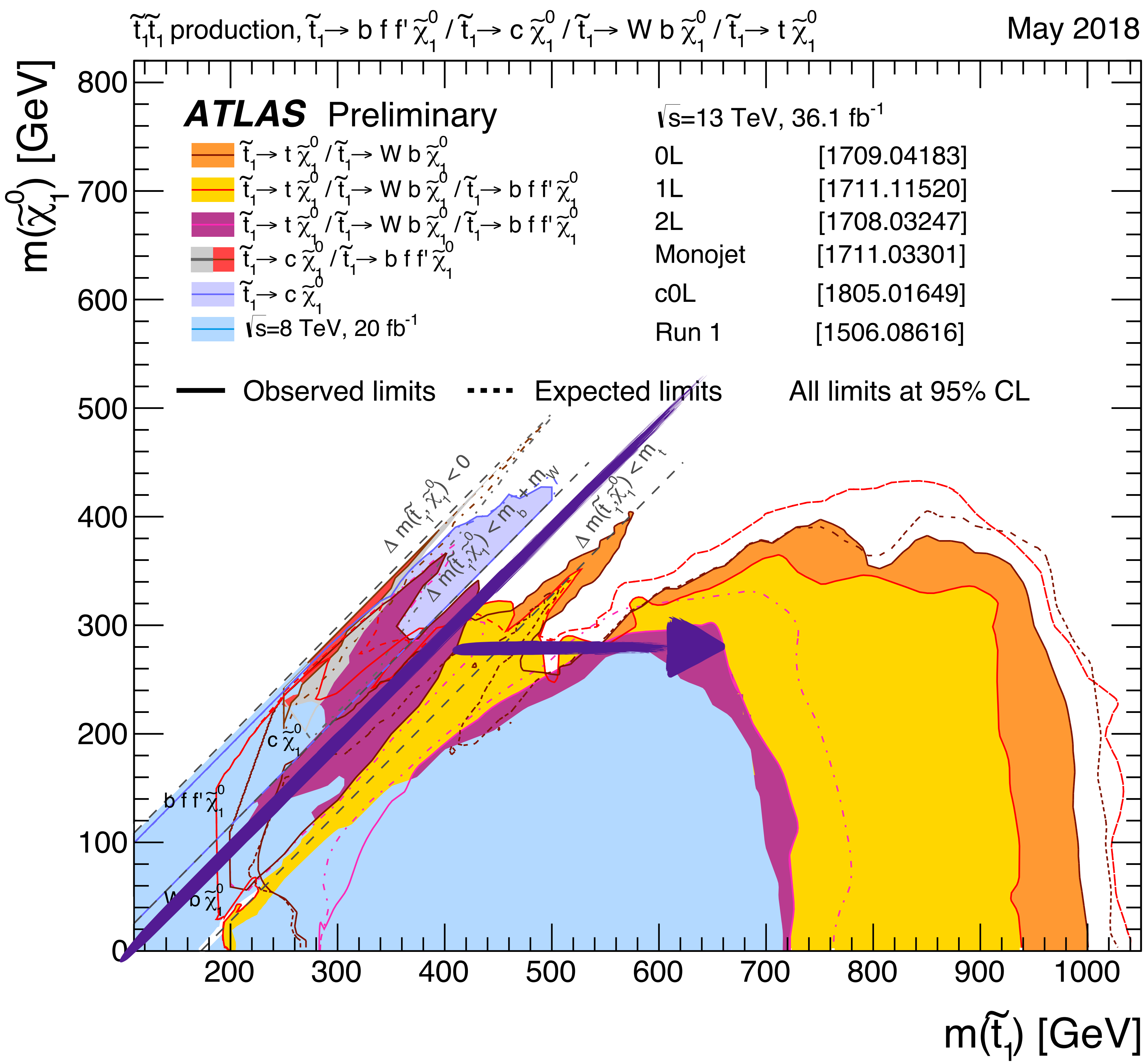


Compressed spectra in SUSY



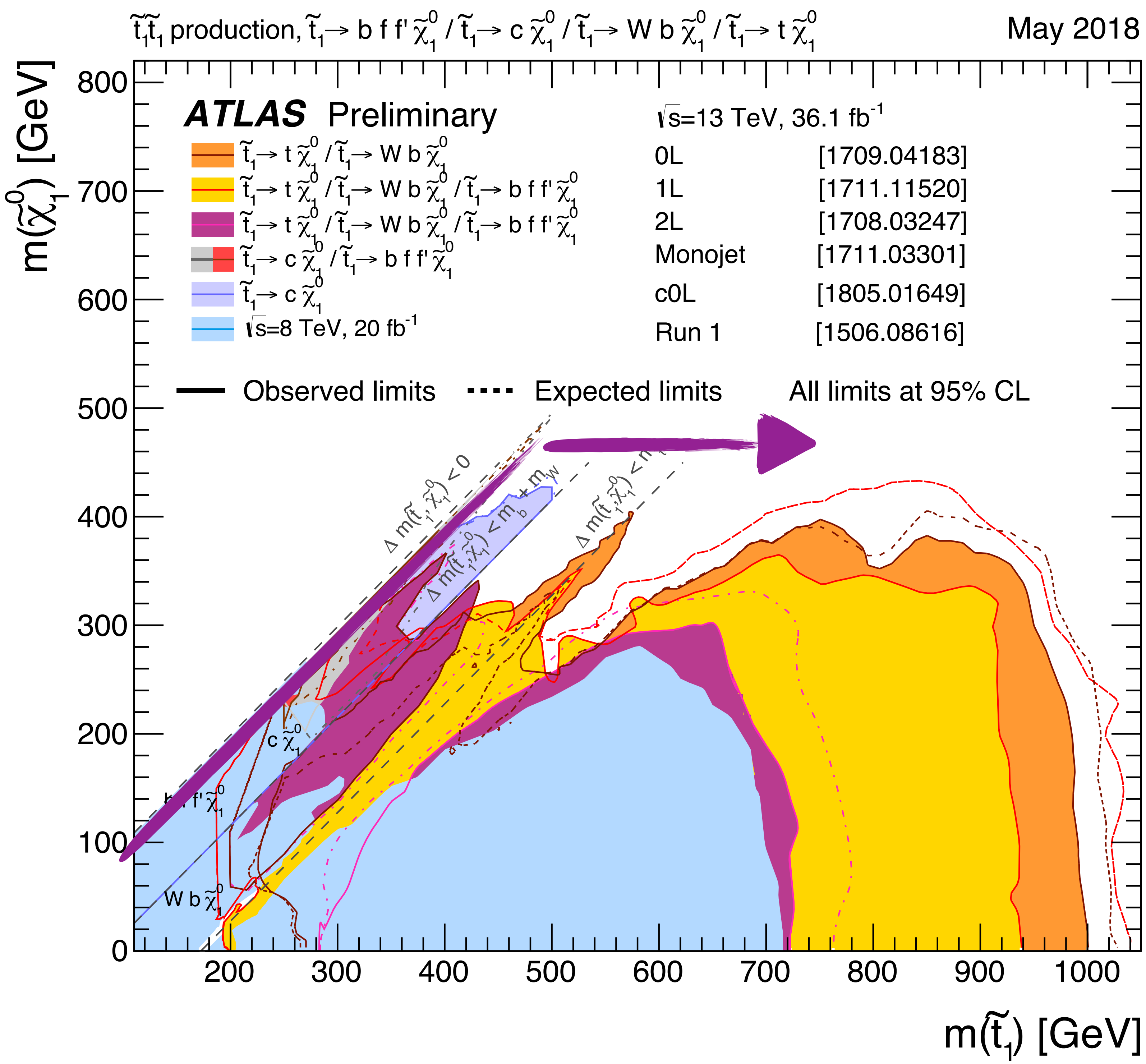
LSP a lot lighter than stop: nice easy signatures, maybe even boosted

Compressed spectra in SUSY



Mass splitting smaller than top mass: decays suppressed

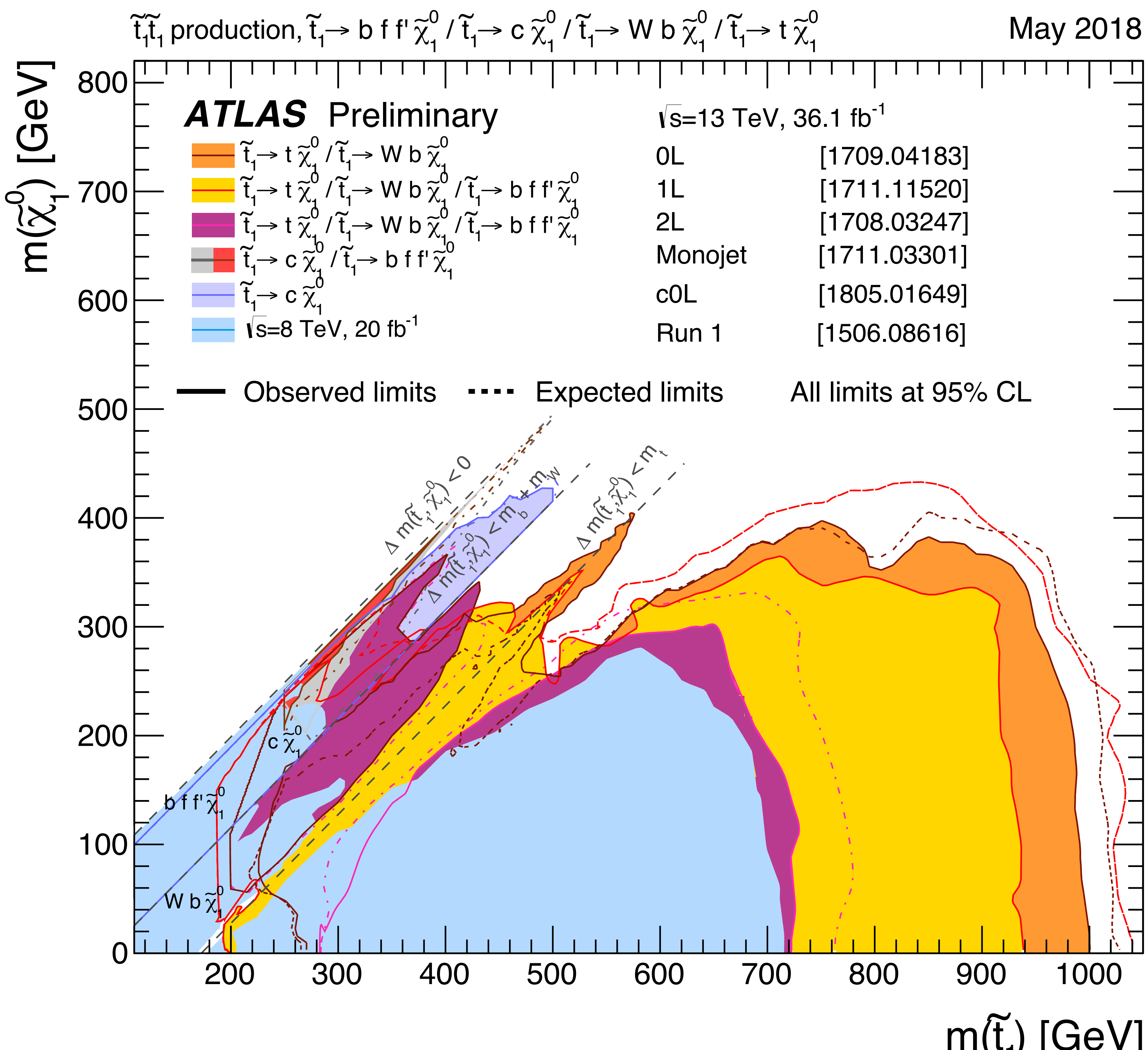
Compressed spectra in SUSY

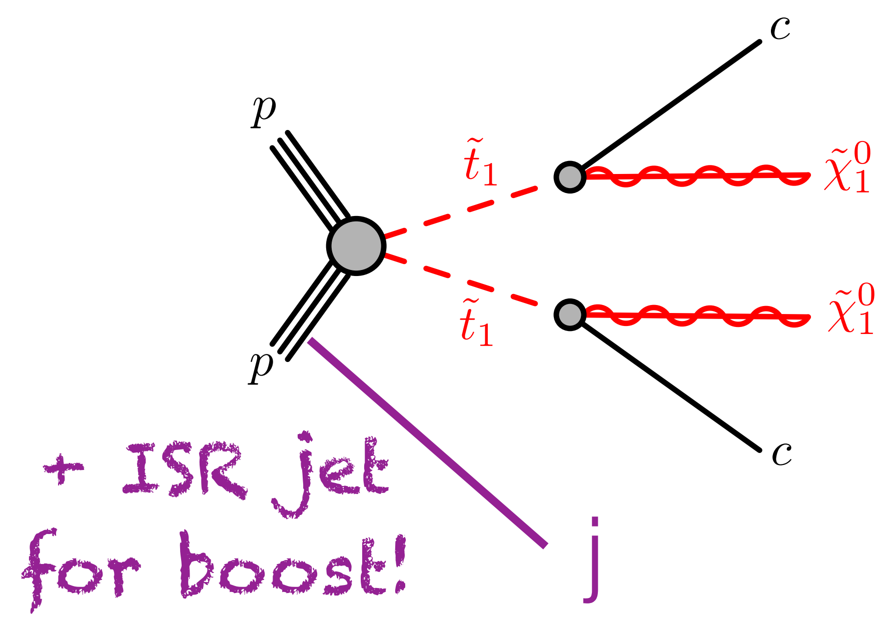


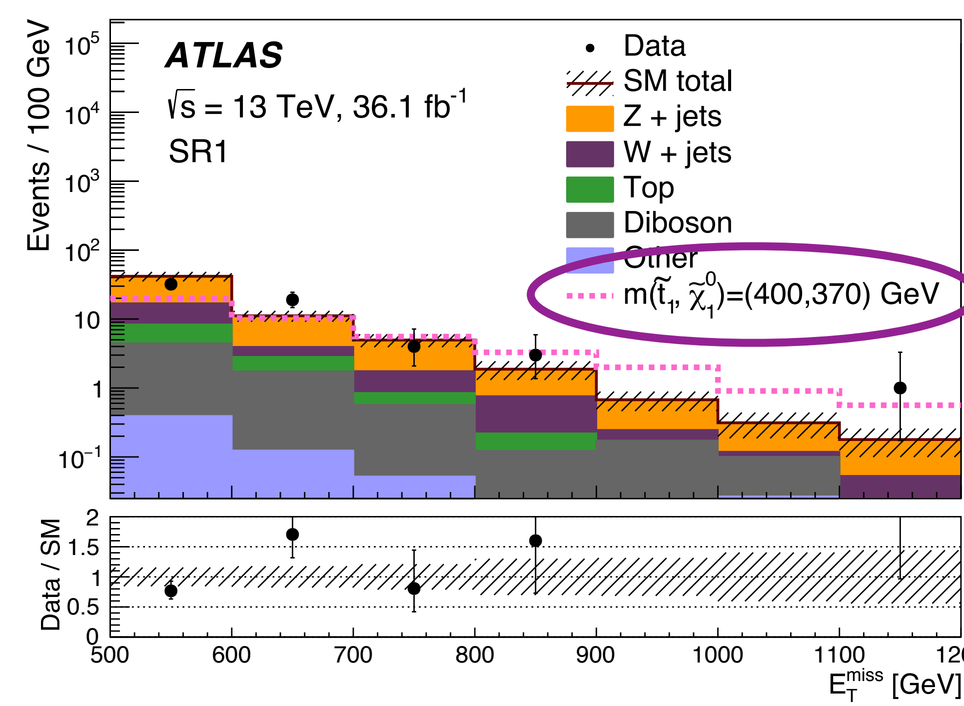
Mass splitting really small: “compressed”. SM particles so soft they are hard to detect

Compressed spectra in SUSY

[arXiv:1708.08232](https://arxiv.org/abs/1708.08232)

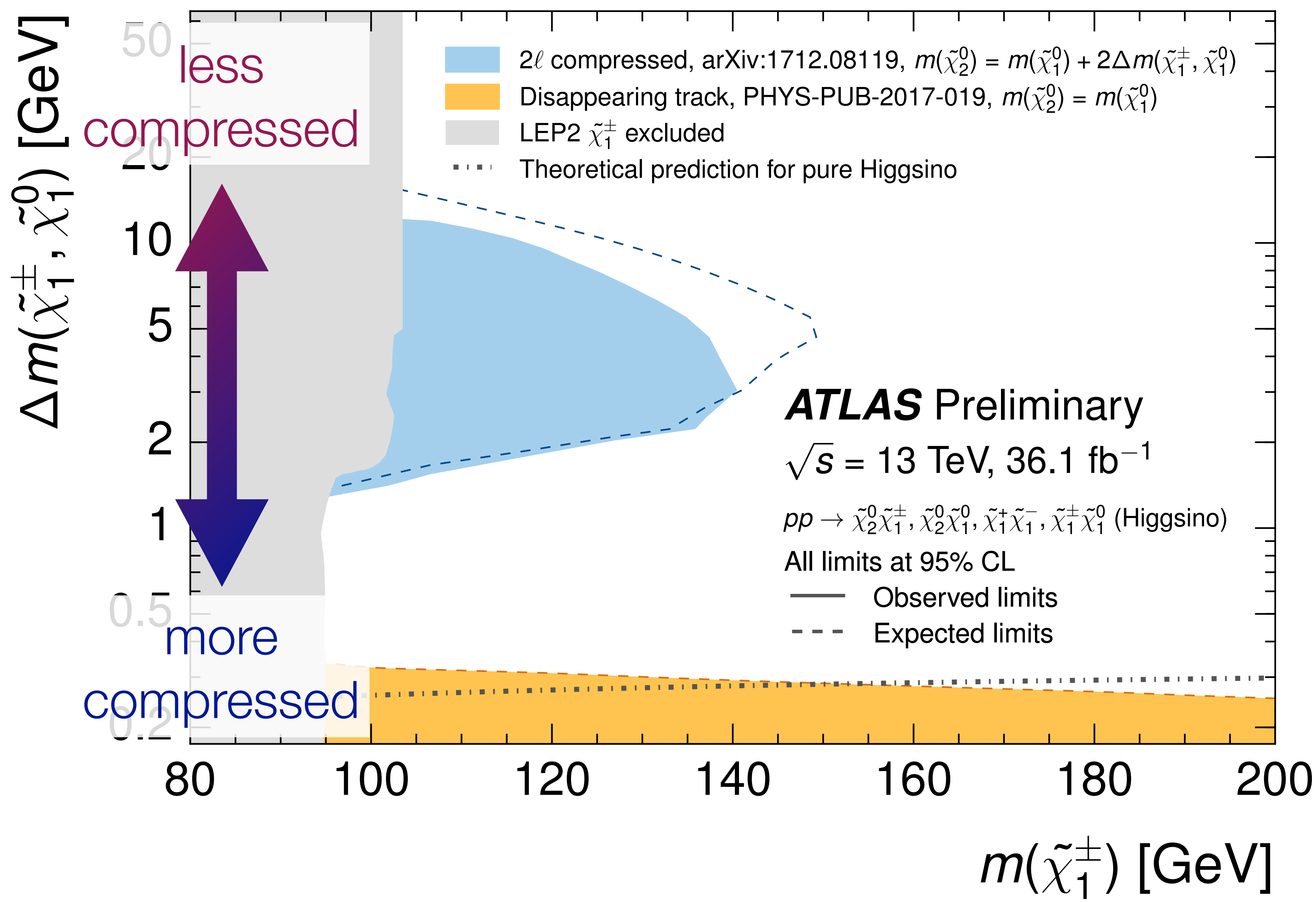






A challenging corner: Higgsinos

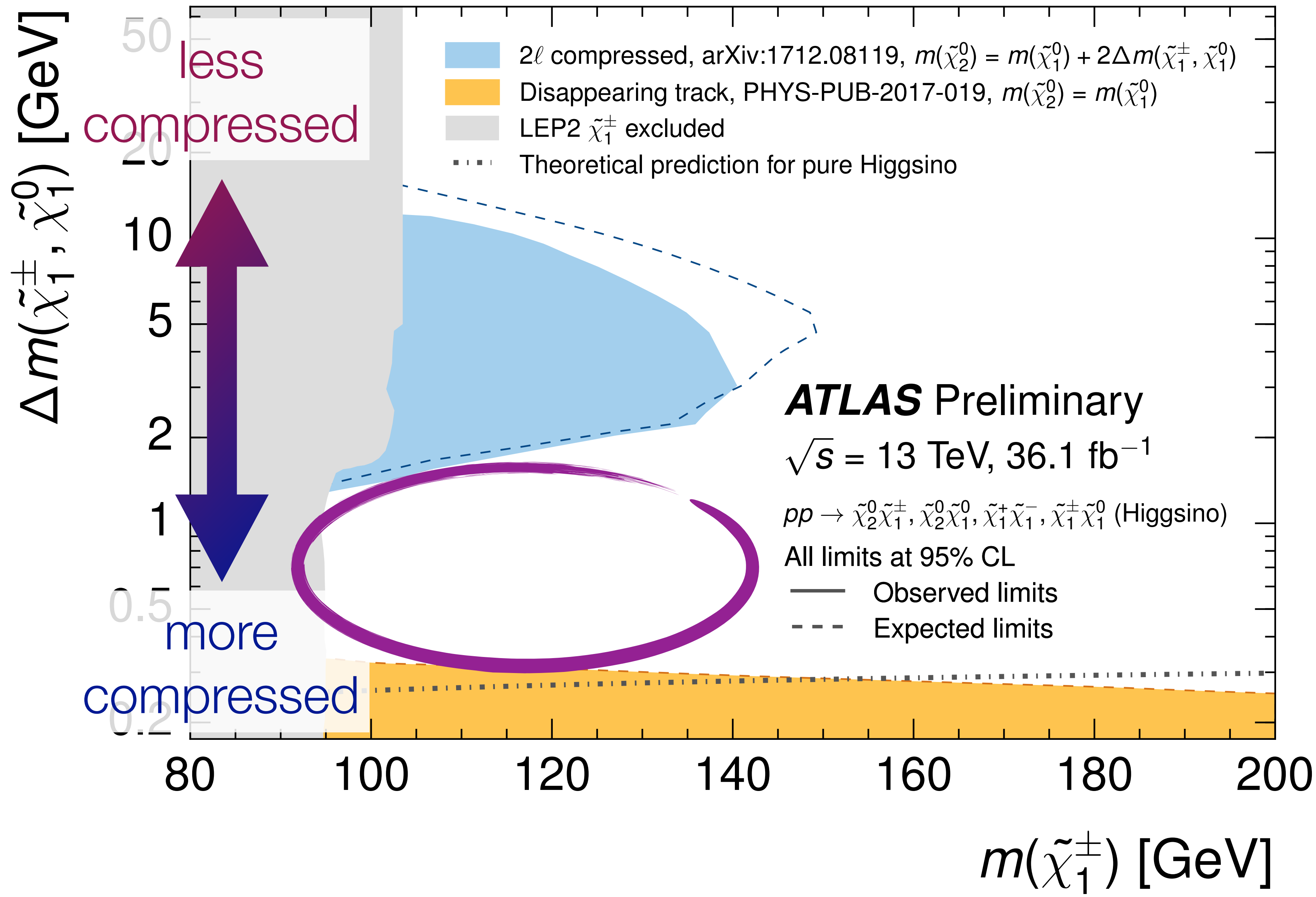
Dedicated search for **compressed EW scenarios** (arxiv:1712.08119) handles mid-range



When sufficiently compressed, decays suppressed and Higgsino becomes long-lived: search via **disappearing tracks** (arxiv:1712.02118)

A challenging corner: Higgsinos

Dedicated search for **compressed EW scenarios** (arxiv:1712.08119) handles mid-range

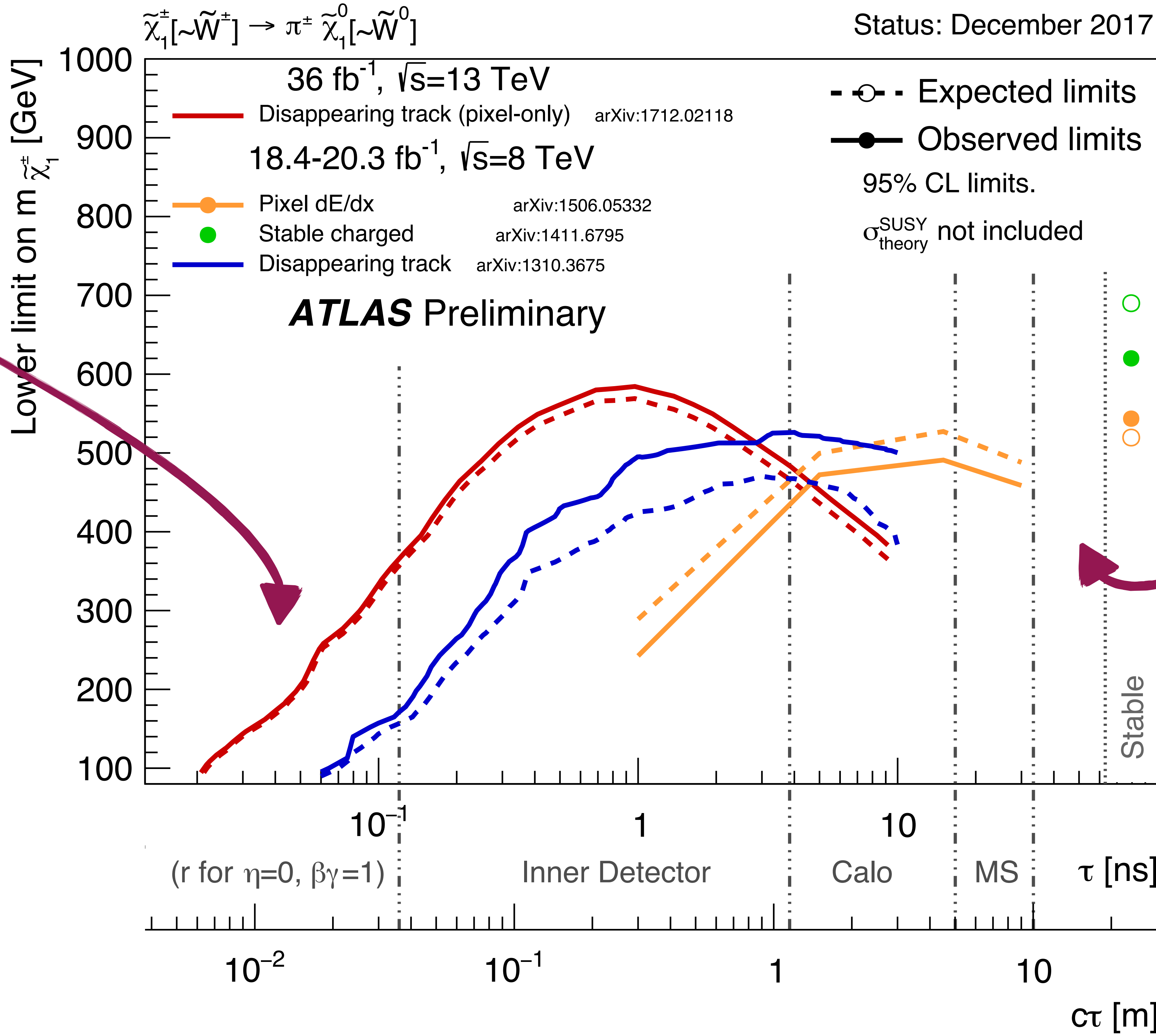


Not currently accessed!

When sufficiently compressed, decays suppressed and Higgsino becomes long-lived: search via **disappearing tracks** (arxiv:1712.02118)

RPC meets RPV: Long-lived charginos

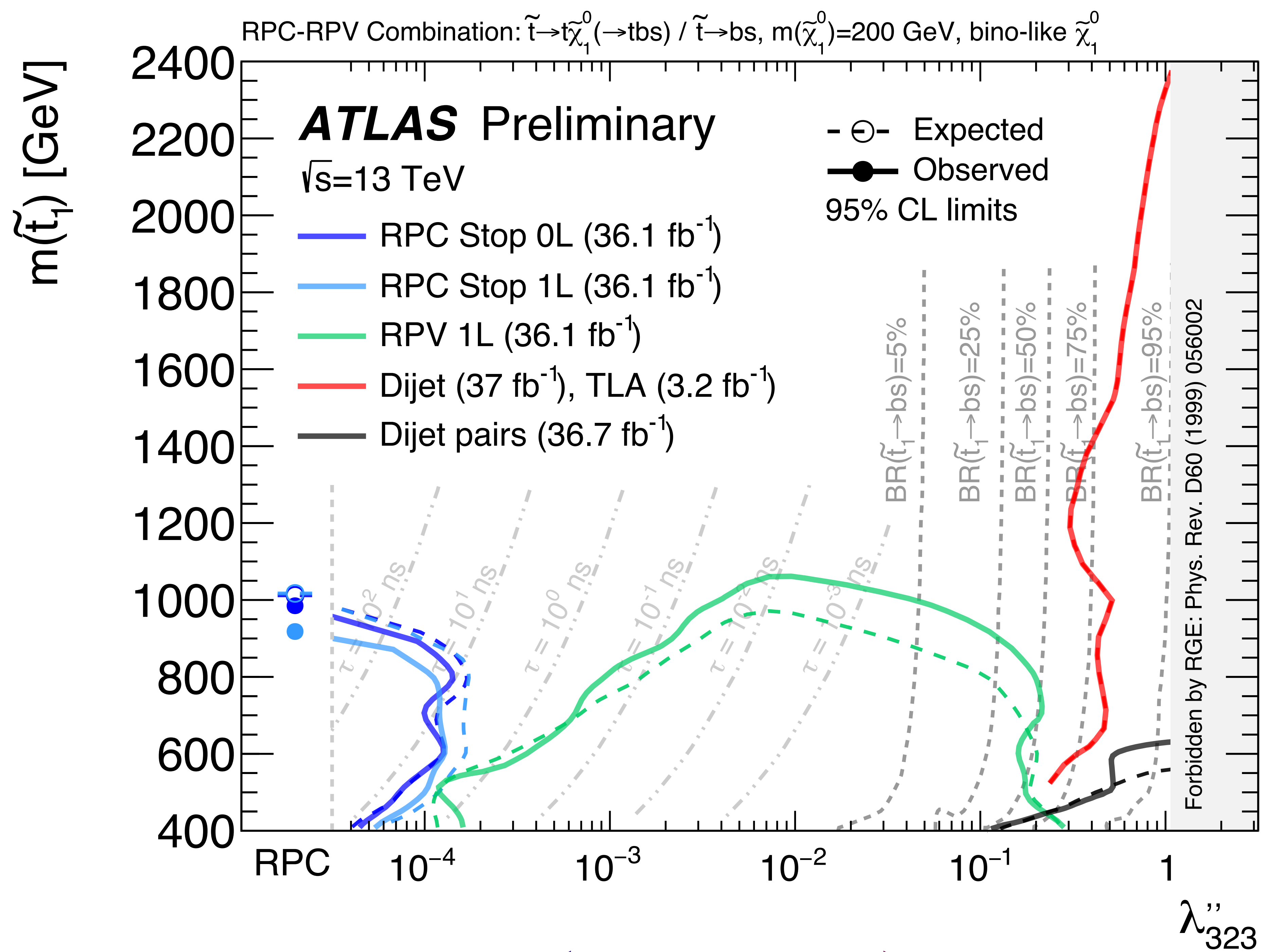
Short lifetimes are more difficult



Decay lengths outside the detector = stable for us

ATLAS-CONF-2018-003

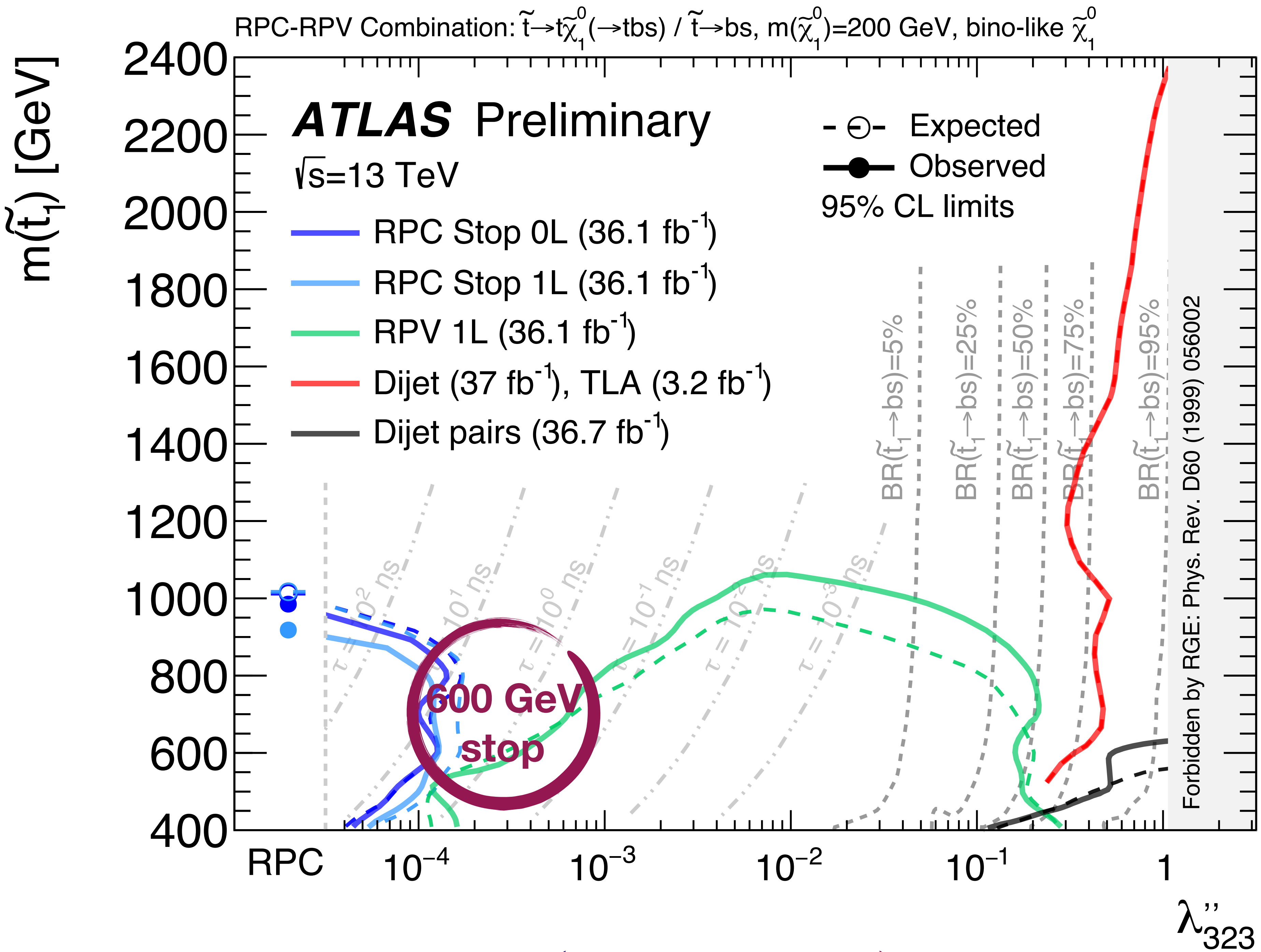
RPC meets RPV: Stops



ATLAS-CONF-2018-003

More RPC-like ⟷ More RPV-like

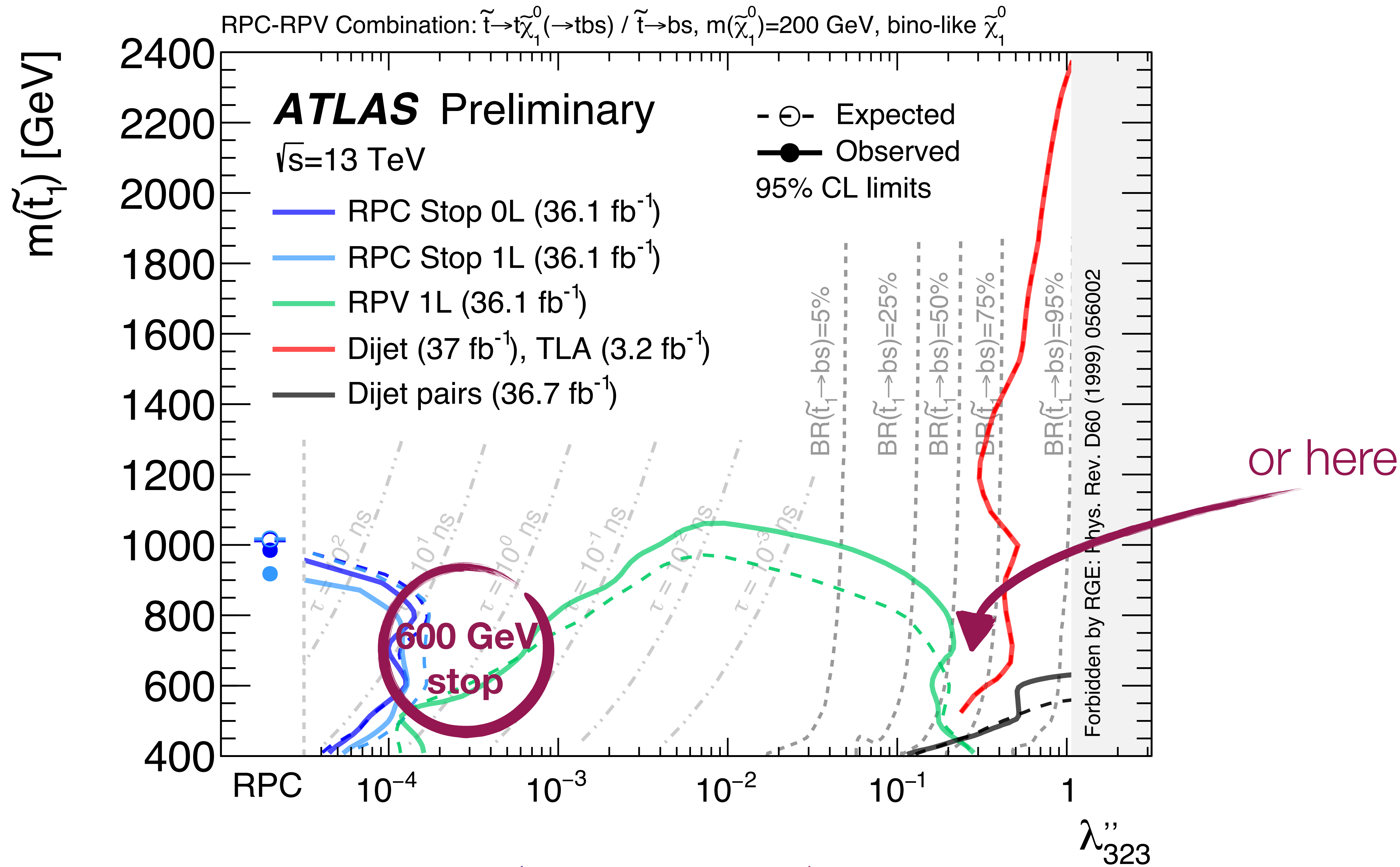
RPC meets RPV: Stops



More RPC-like ⟷ More RPV-like

ATLAS-CONF-2018-003

RPC meets RPV: Stops



More RPC-like ⟷ More RPV-like

ATLAS-CONF-2018-003

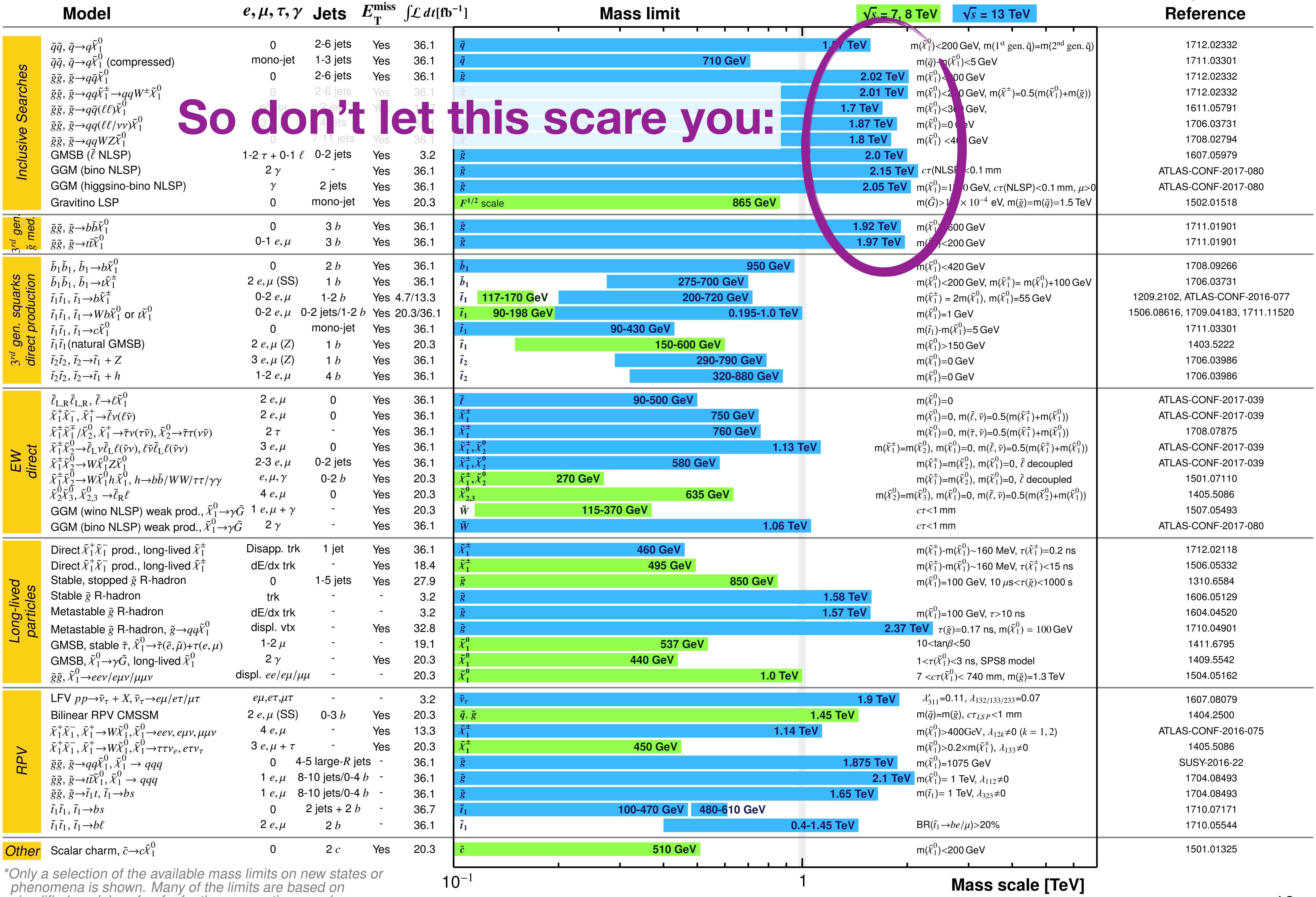
ATLAS SUSY Searches* - 95% CL Lower Limits

December 2017

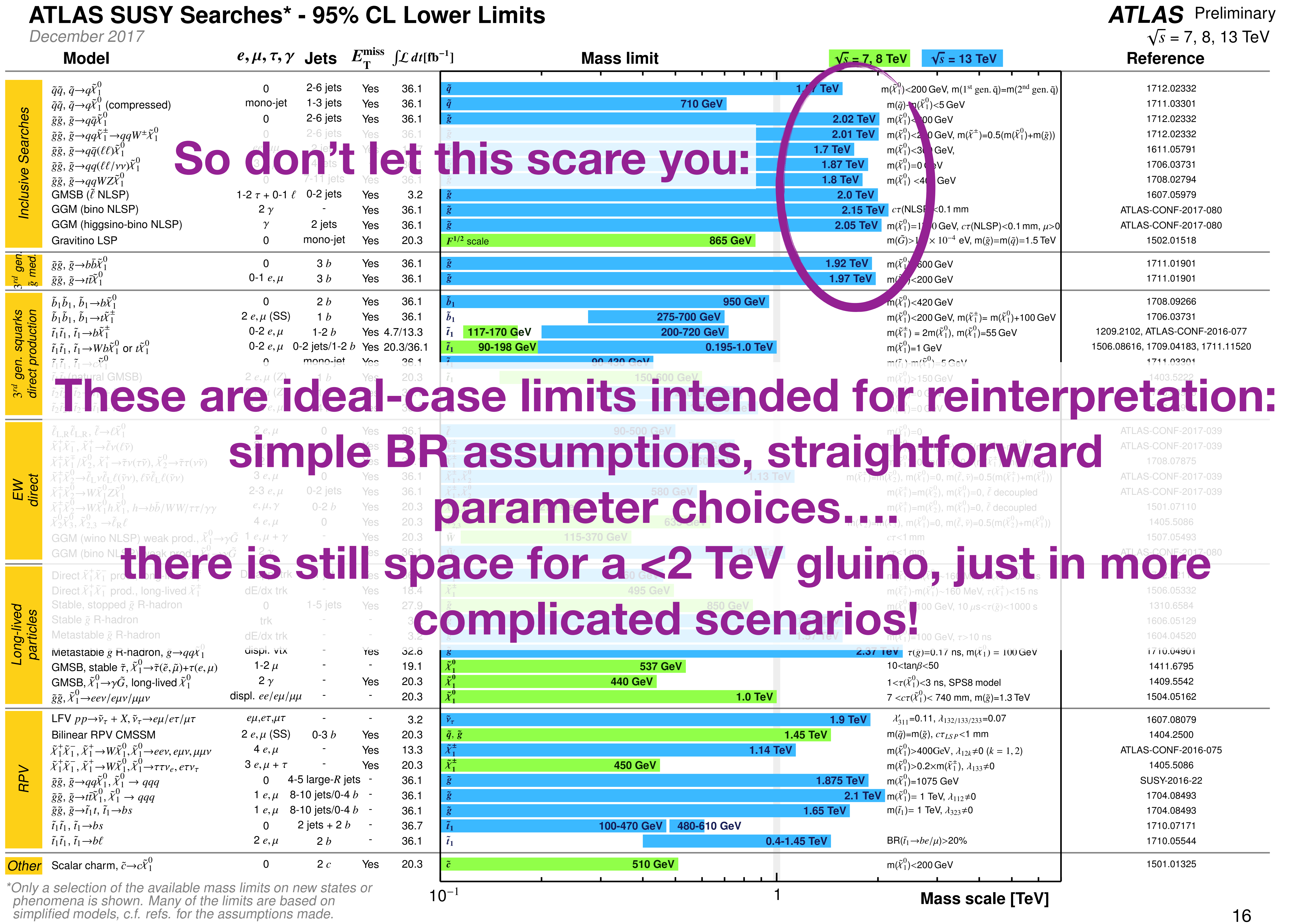
ATLAS Preliminary

$\sqrt{s}$ = 7, 8, 13 TeV

So don't let this scare you:



*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.



So don't let this scare you:

These are ideal-case limits intended for reinterpretation: simple BR assumptions, straightforward parameter choices….

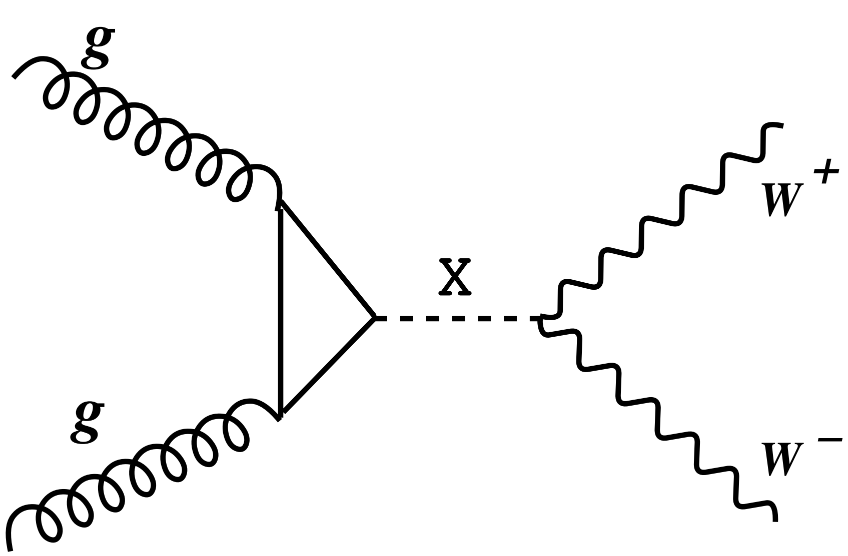
there is still space for a <2 TeV gluino, just in more complicated scenarios!

BSM Higgs

The BSM Higgs program

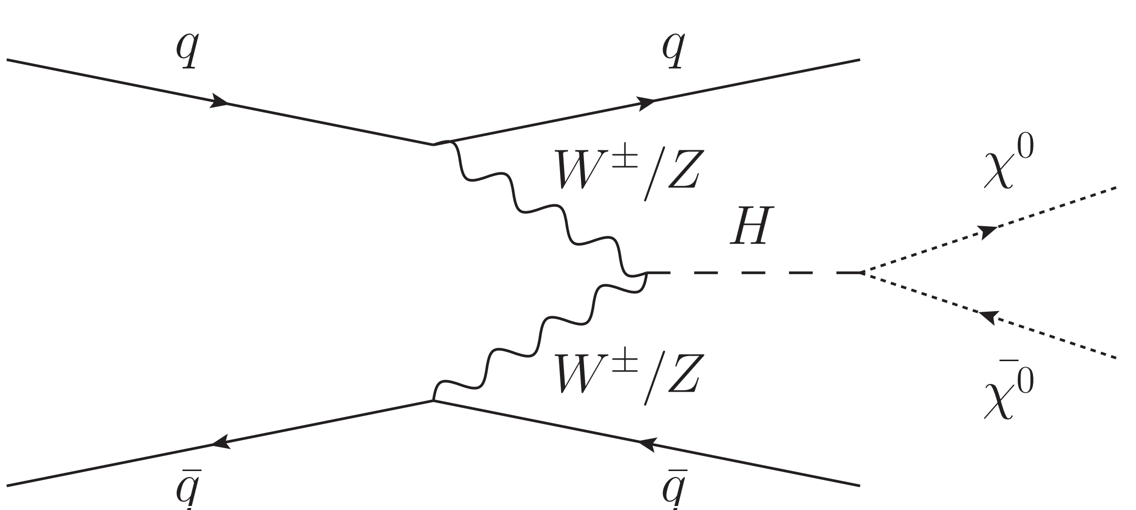
Additional Higgses

- Many models (incl. 2HDM) postulate additional Higgs bosons
- Charged higgses or heavier equivalents of SM Higgs



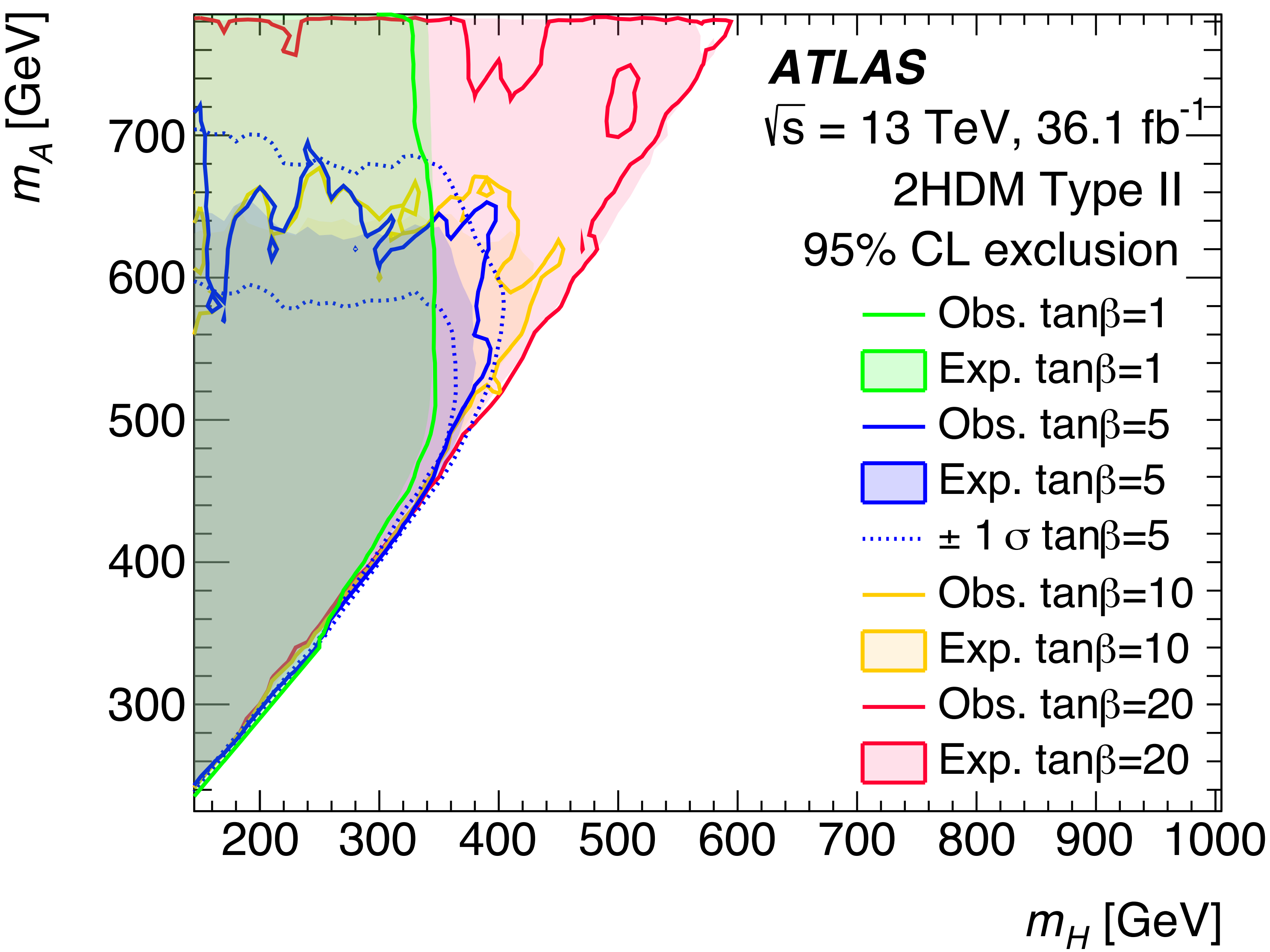
Higgs to Invisible

- Look for production of DM particles by decays of SM Higgs
- Uncertainty on SM Higgs production σ is ~30%, so sufficient "wiggle room" to allow this

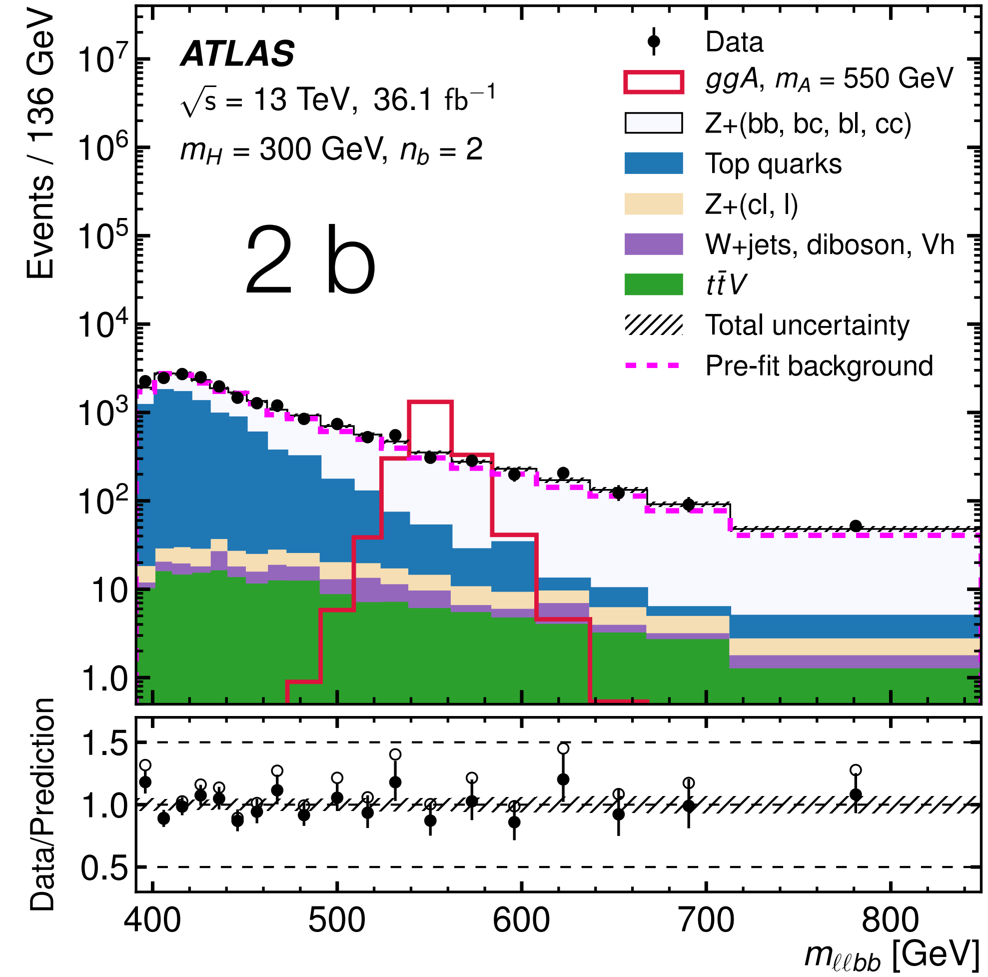


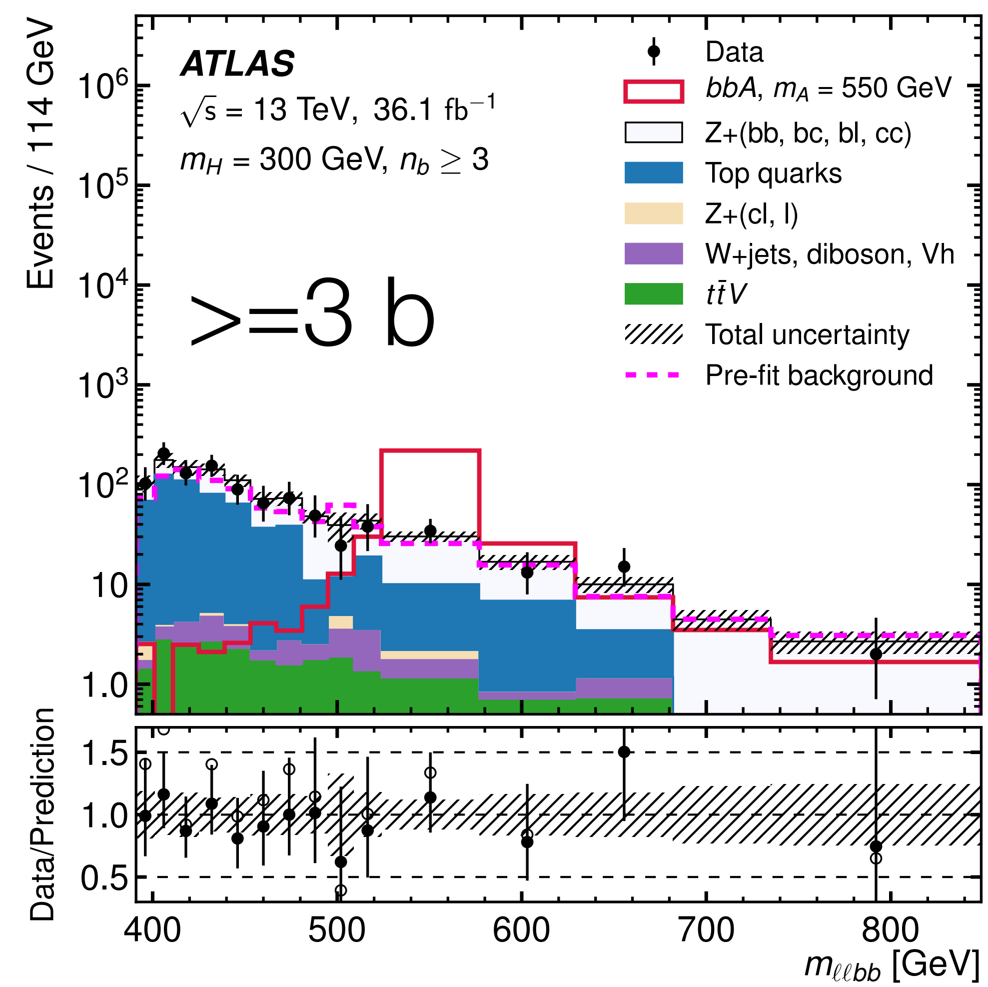
Recent highlights: Heavy Higgs to ZH

- Search in Z→ll, (another non-SM) H→bb. Possible additional b-jets in association with A.
- Results framed in 2HDM model with various parameter choices for generality



CERN-EP-2018-030





(Other) exotics searches

Exotics search methodology

- Largely signature driven
- Each signature open to range of BSM models
- Various dedicated summary or combination efforts in Run II

Diboson

MET+X

Jet pairs

Heavy flavour

Exotics search methodology

- Largely signature driven
- Each signature open to range of BSM models
- Various dedicated summary or combination efforts in Run II

Diboson

Heavy scalars

New (spin-1 or 2) bosons

MET+X

Black holes

Dark matter

Jet pairs

Compositeness

Heavy flavour

Exotics search methodology

- Largely signature driven
- Each signature open to range of BSM models
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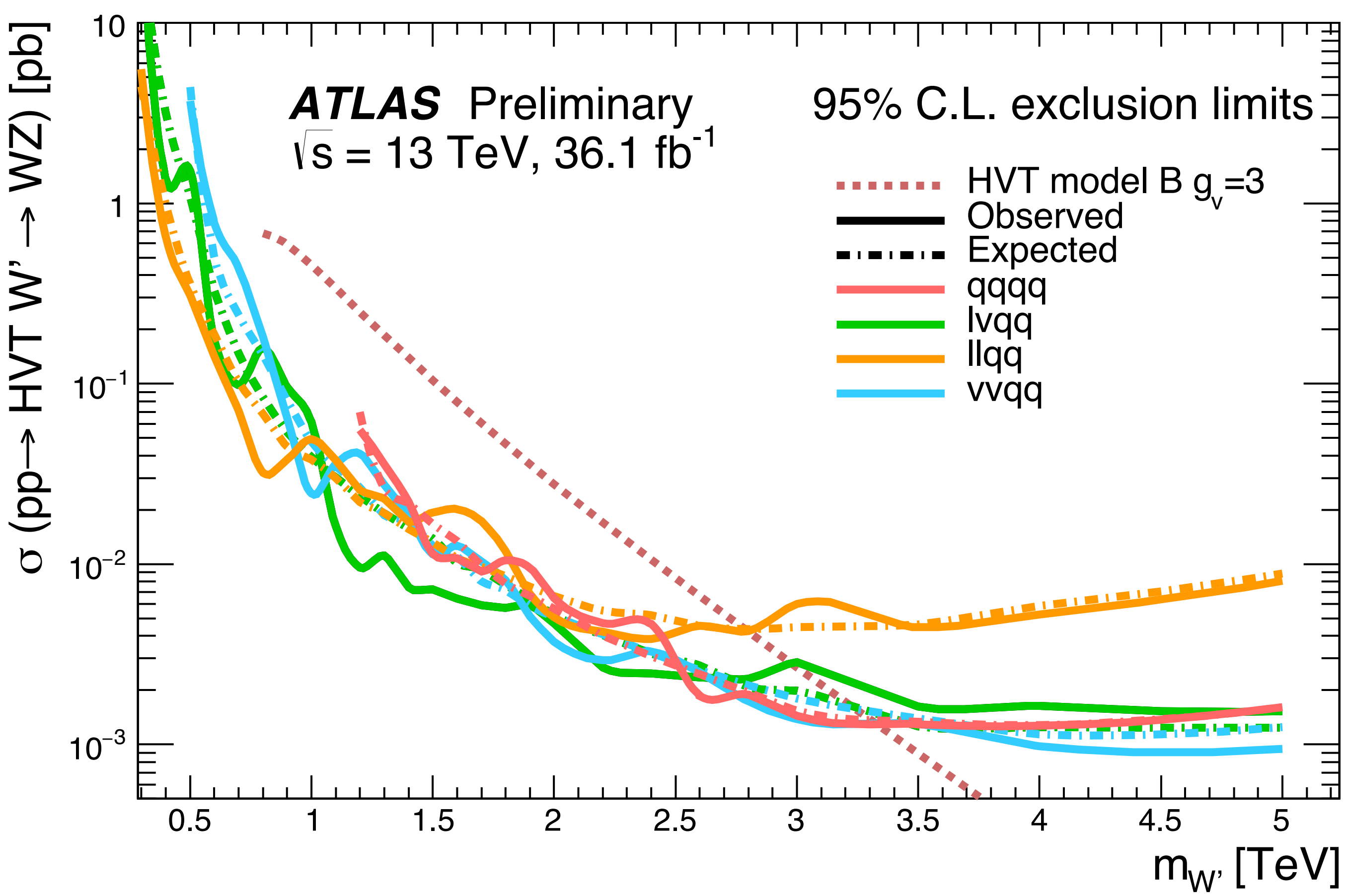


Diboson

Heavy scalars

New (spin-1 or 2) bosons

MET+X

Black holes

Dark matter

Jet pairs

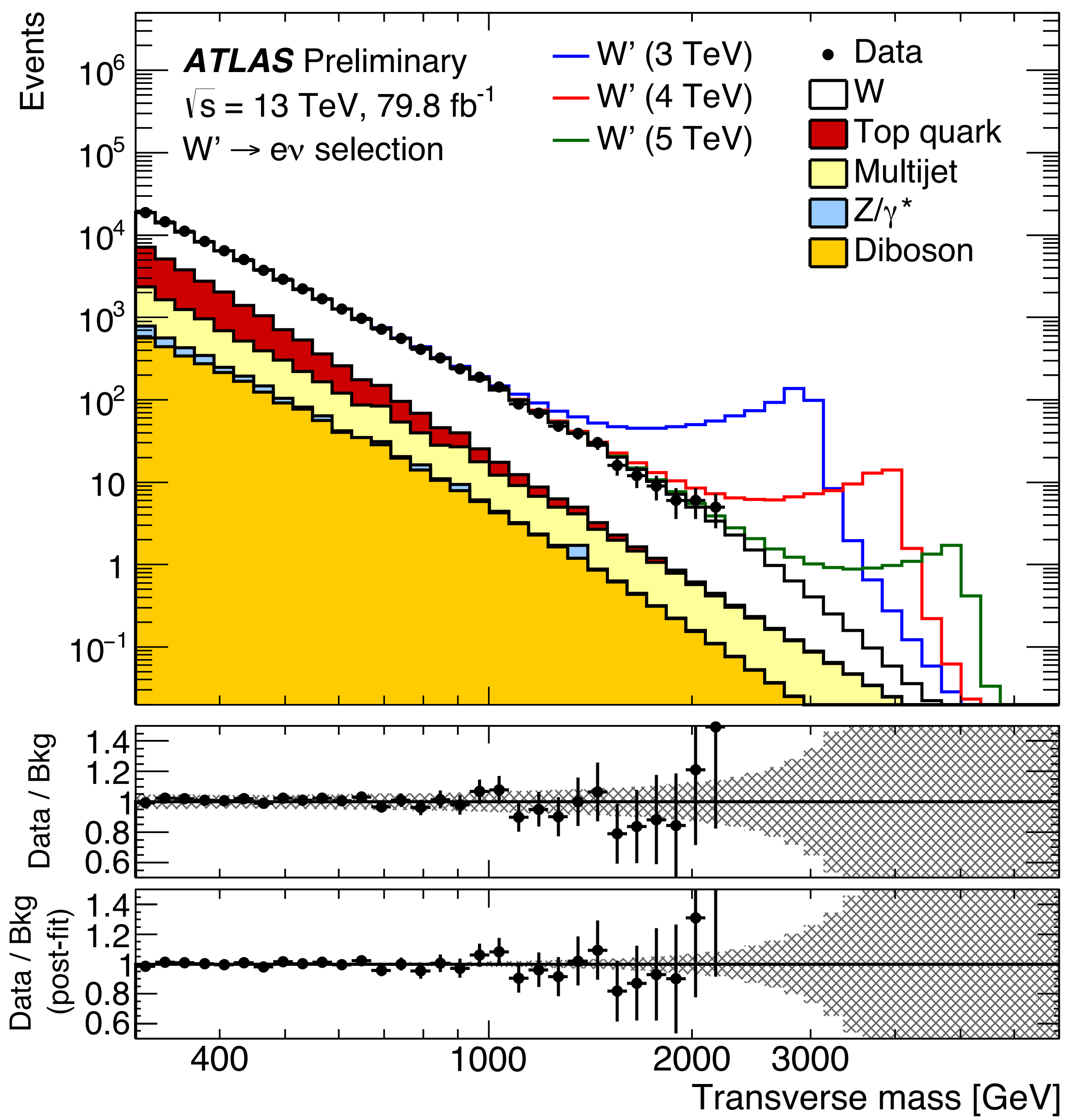
Compositeness

Heavy flavour

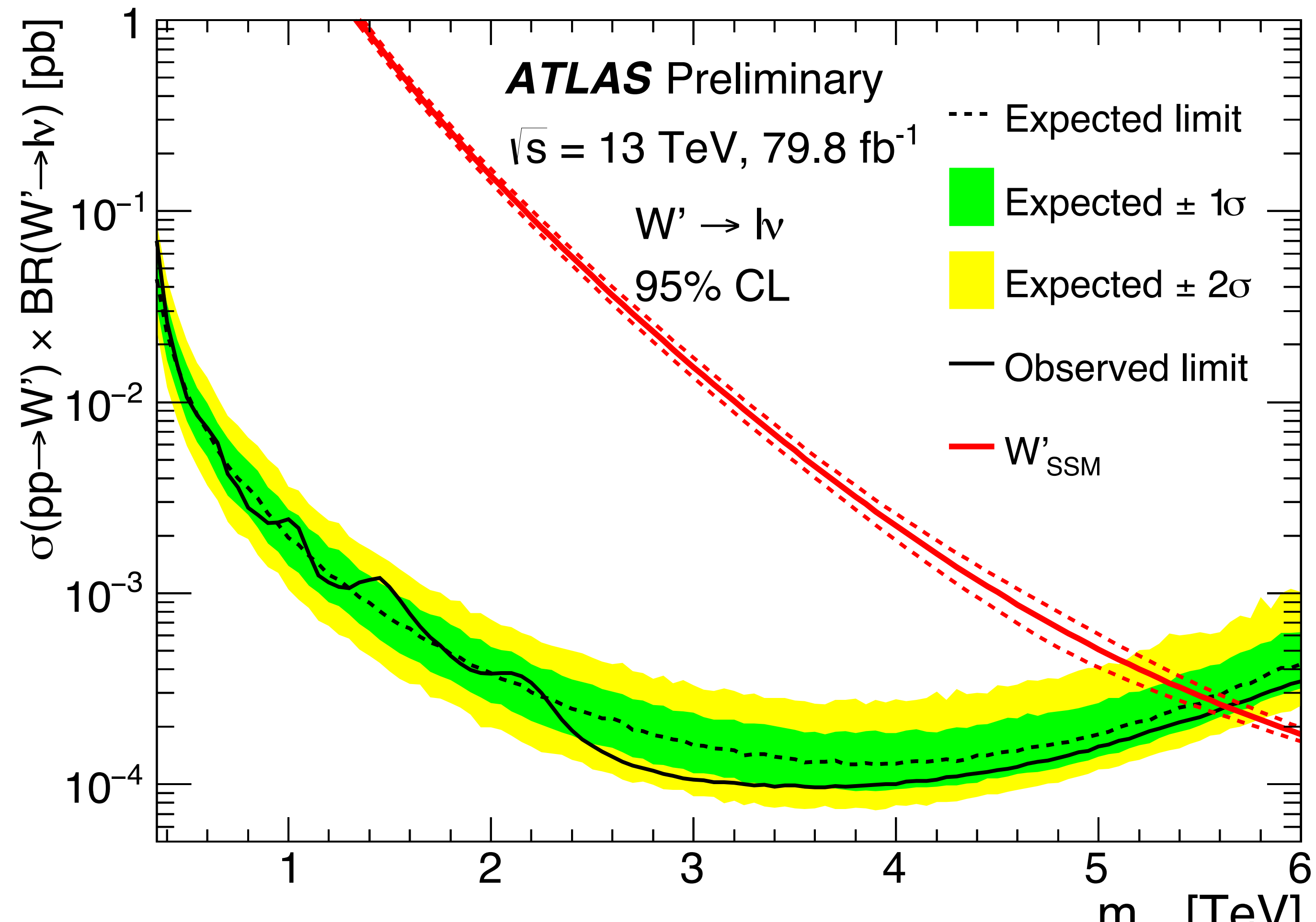
Recent highlights: lepton+MET

ATLAS-CONF-2018-017

$$m_T = \sqrt{2 p_T E_T^{\text{miss}} (1 - \cos \phi_{\ell\nu})}$$



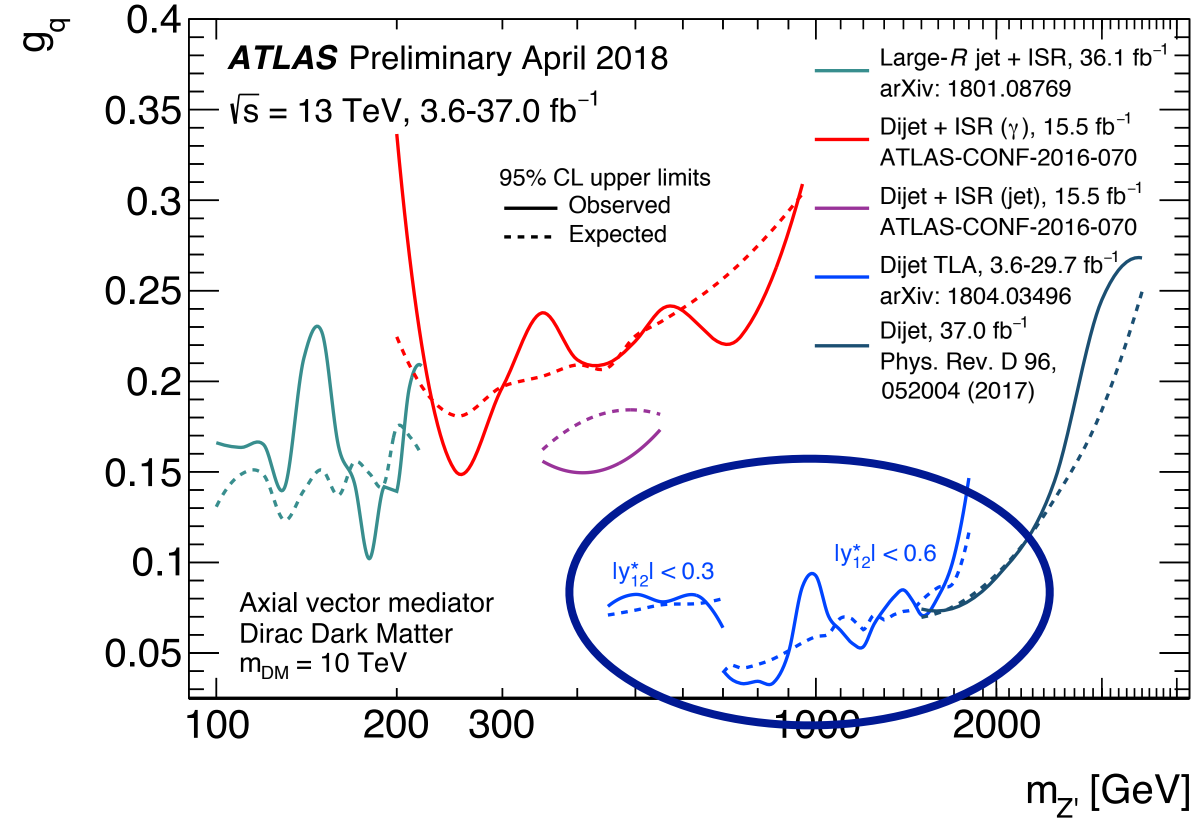
- Search for heavy resonances decaying to e/μ + ν
- W' boson used as benchmark model to define limits
- One of first 80/fb "intermediate" ATLAS results

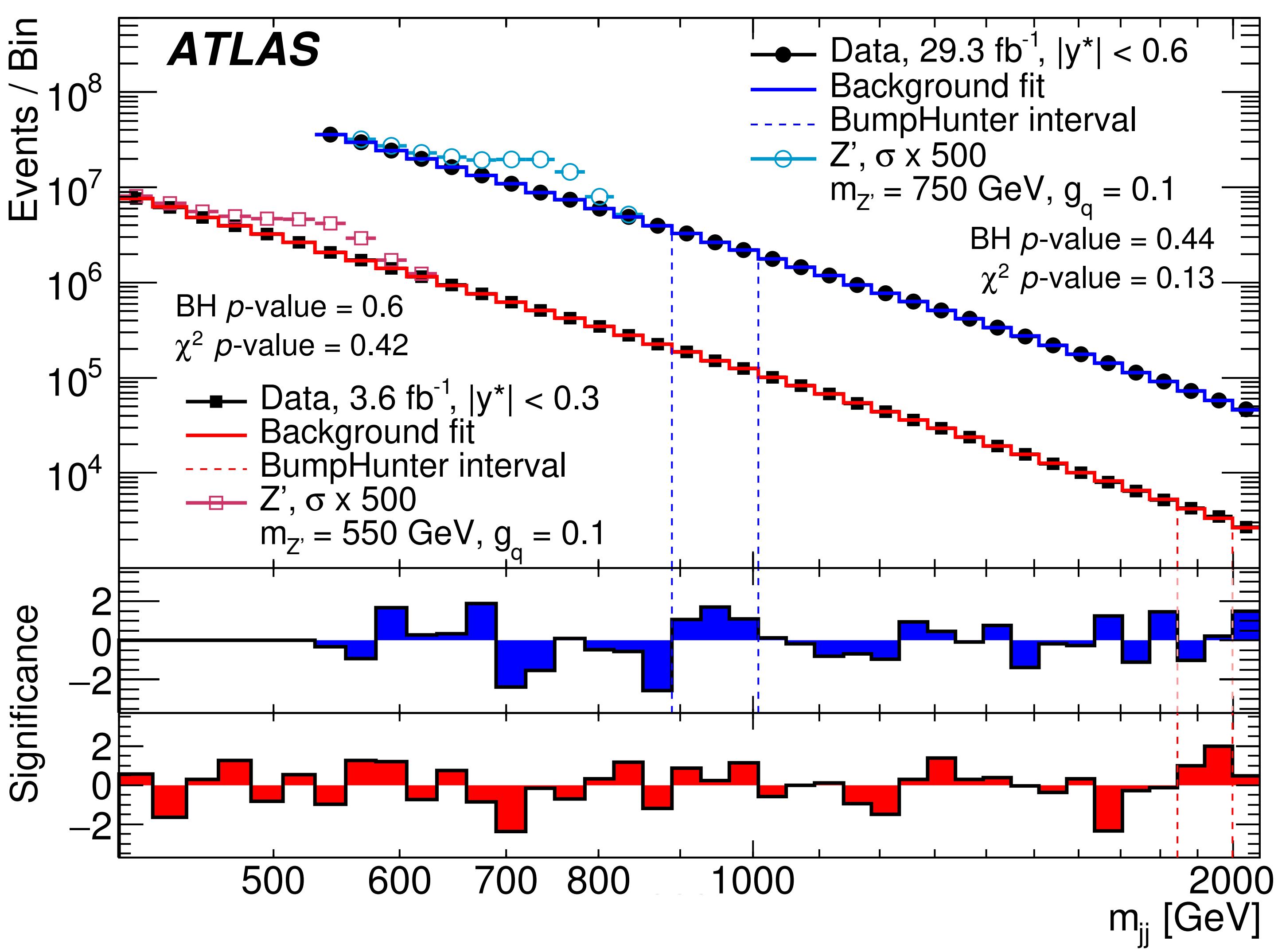


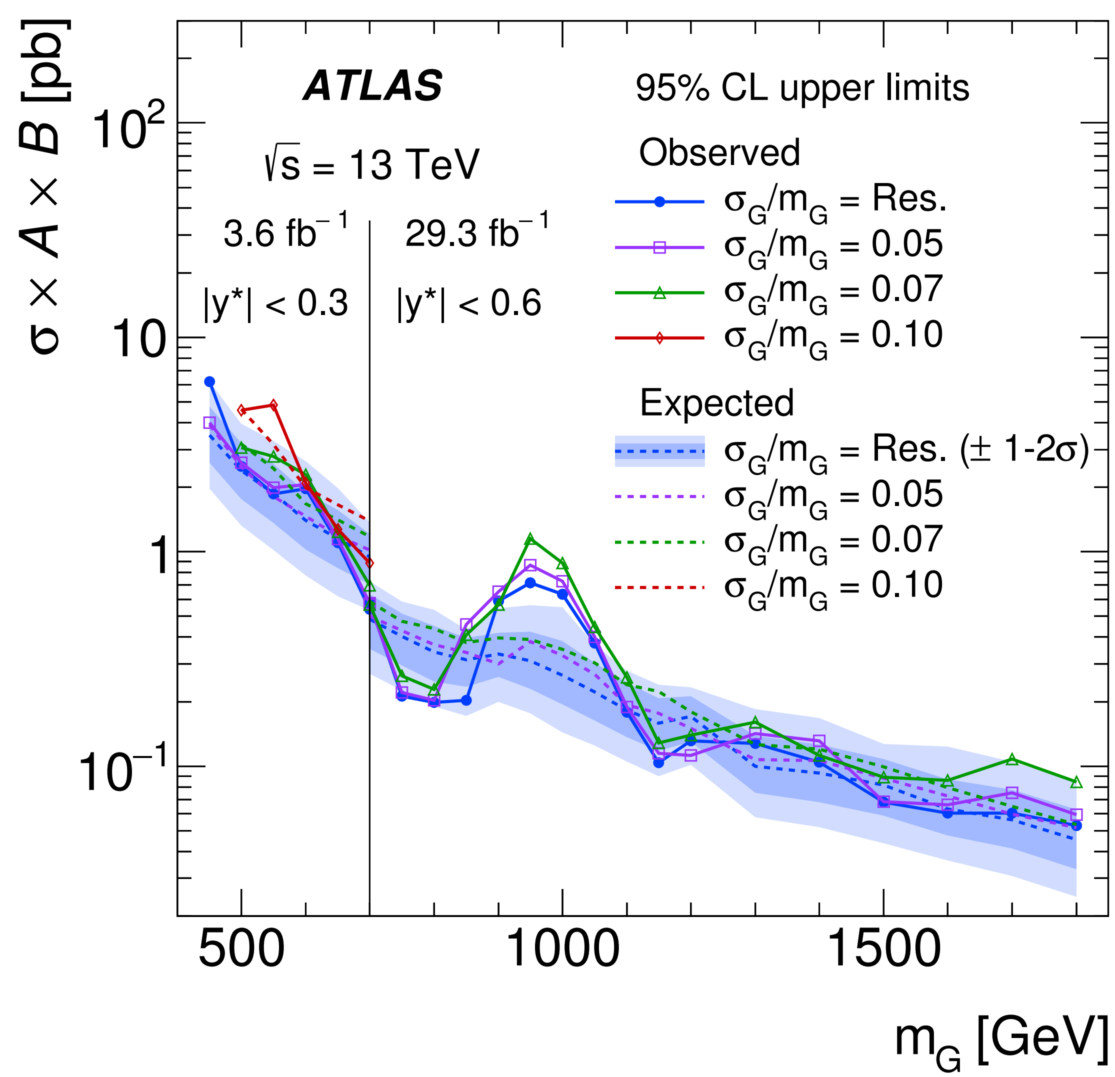
arxiv:1804.03496

Recent highlights: TLA

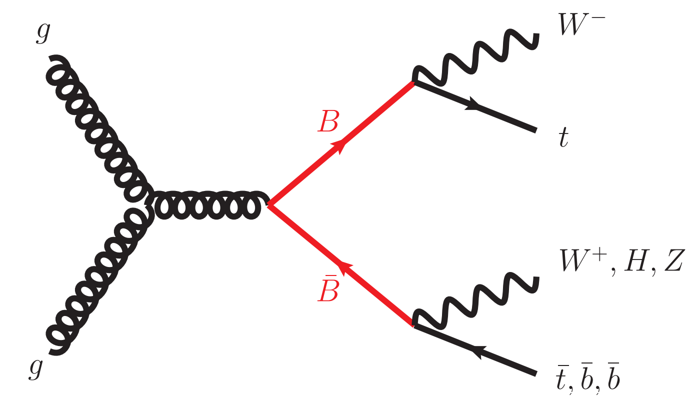
- Dijet final state open to many models. Here, look for Z' mediator
- Use jets at trigger level to access low cross section, low mass signals

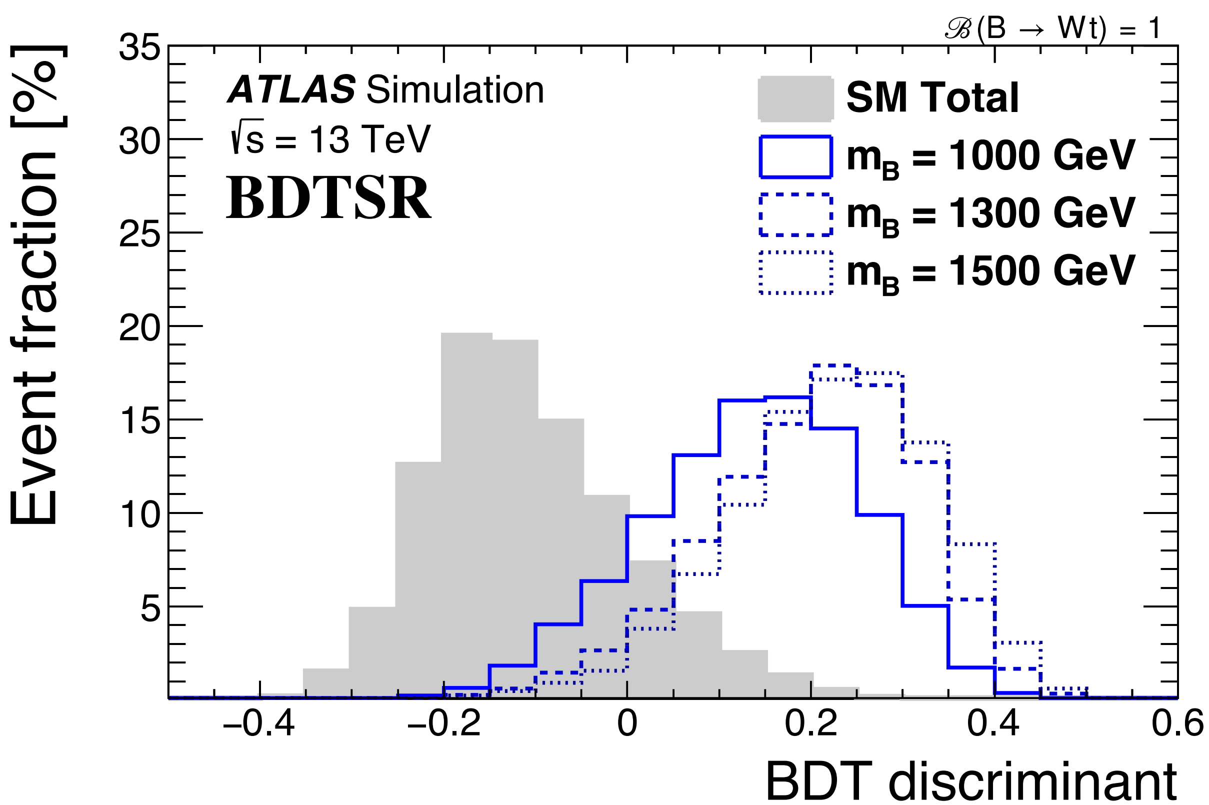






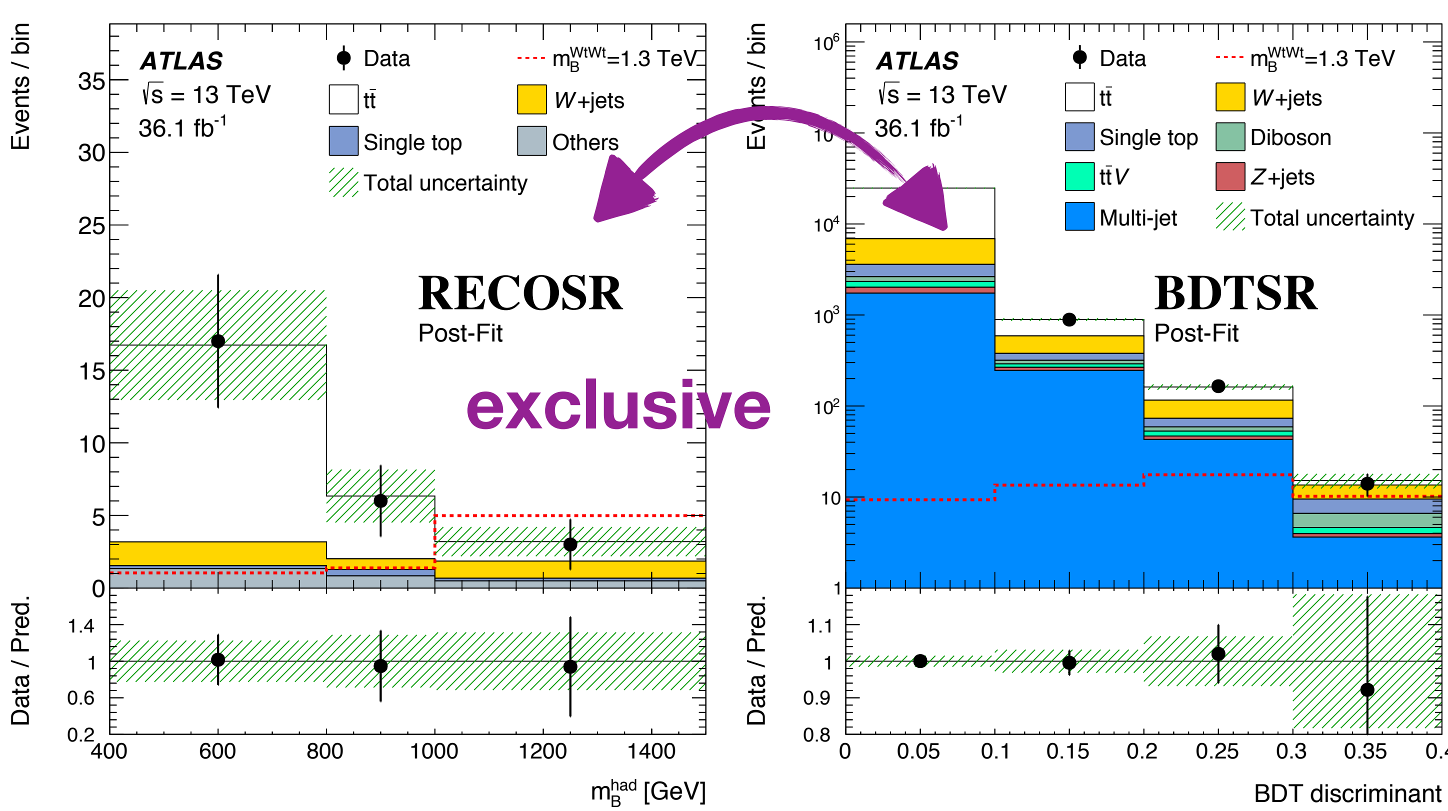
Recent highlights: vector-like quarks

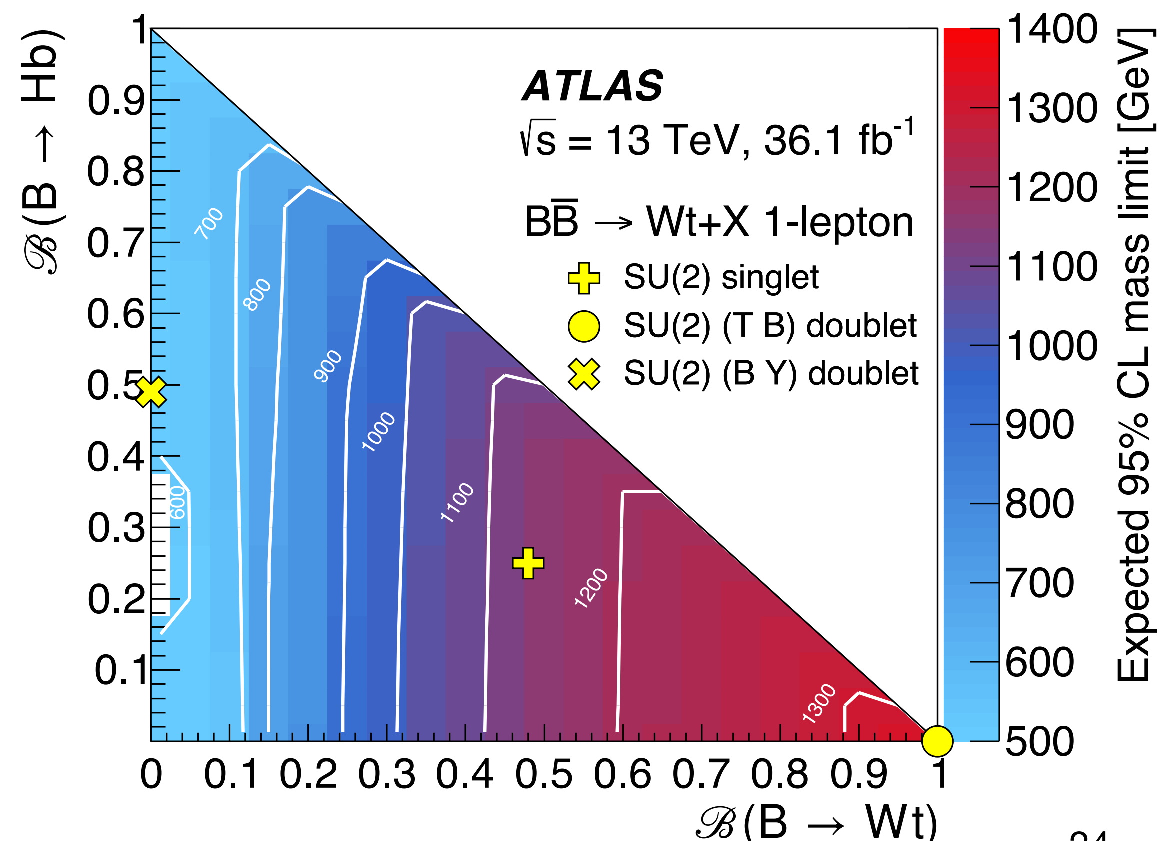




- Example of increasing usage of machine learning in ATLAS: one signal region defined via a BDT!
- Only events not in traditional SR considered in BDT selection

arxiv:1806.01762

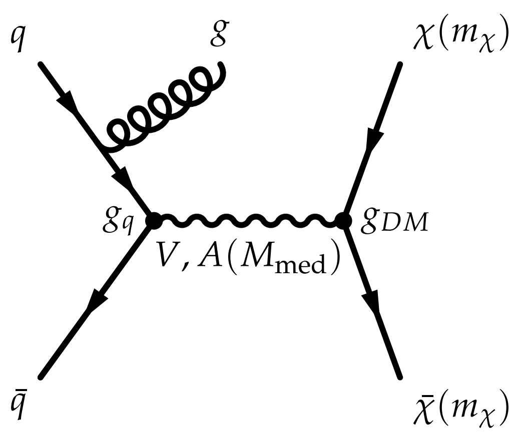




Exotics constraints on dark matter

Z′ simplified model

- Assume vector or axial-vector mediator

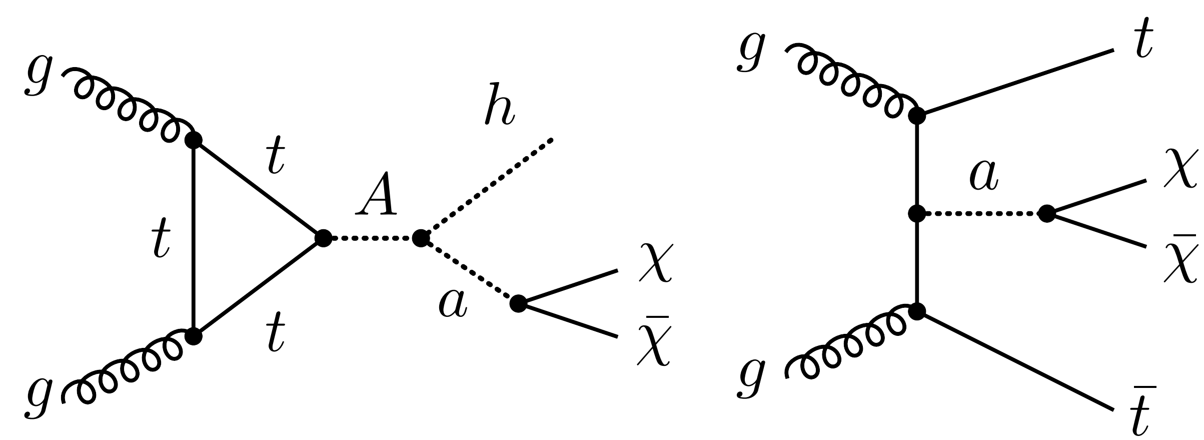


- Strong constraints from mono-X, dijet(+X), dilepton analysis families
- Public plots out now, see next page!

arxiv:1507.00966

2-Higgs doublet model

- More realistic benchmark
- Still simplified, but UV-complete

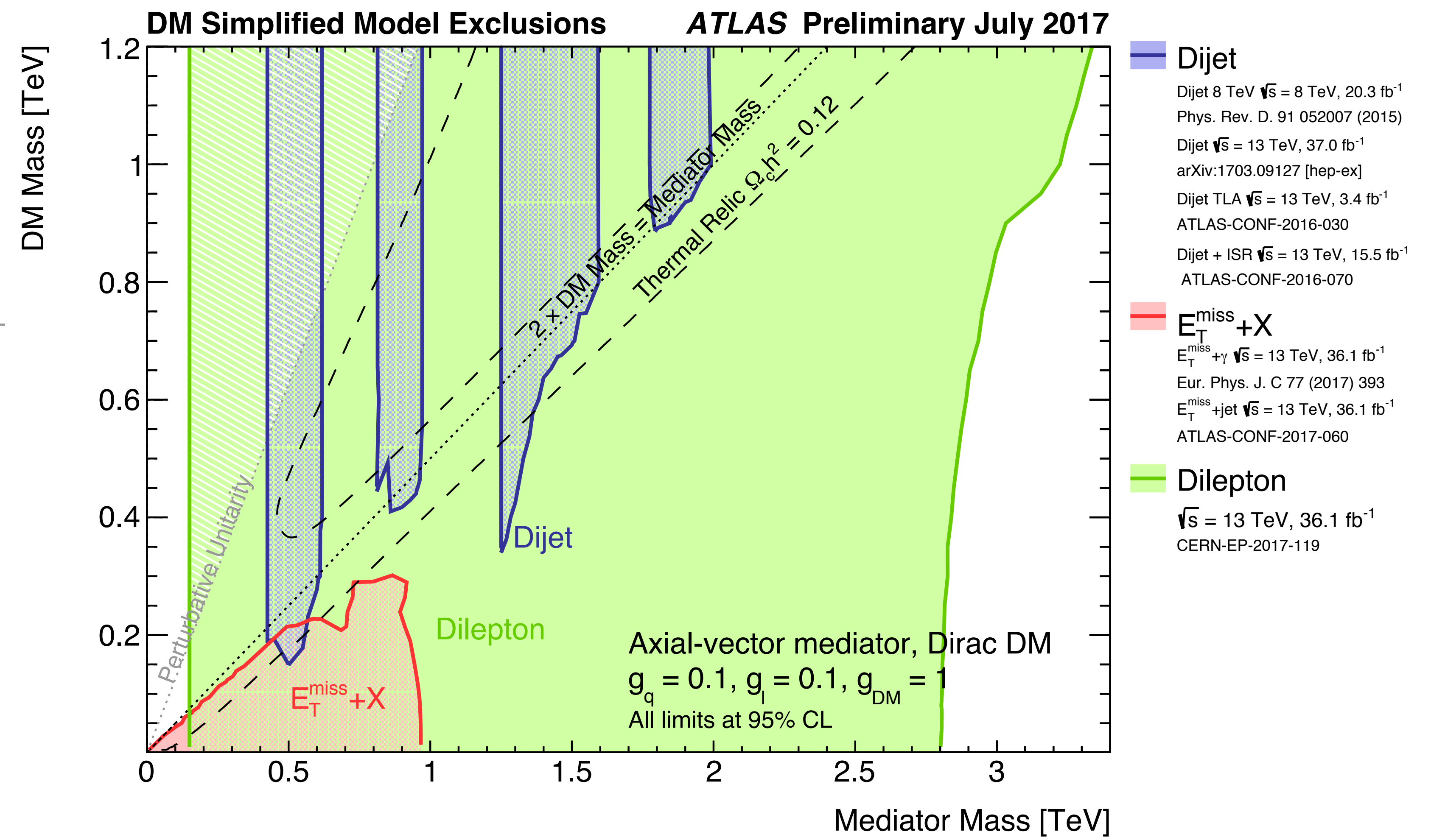


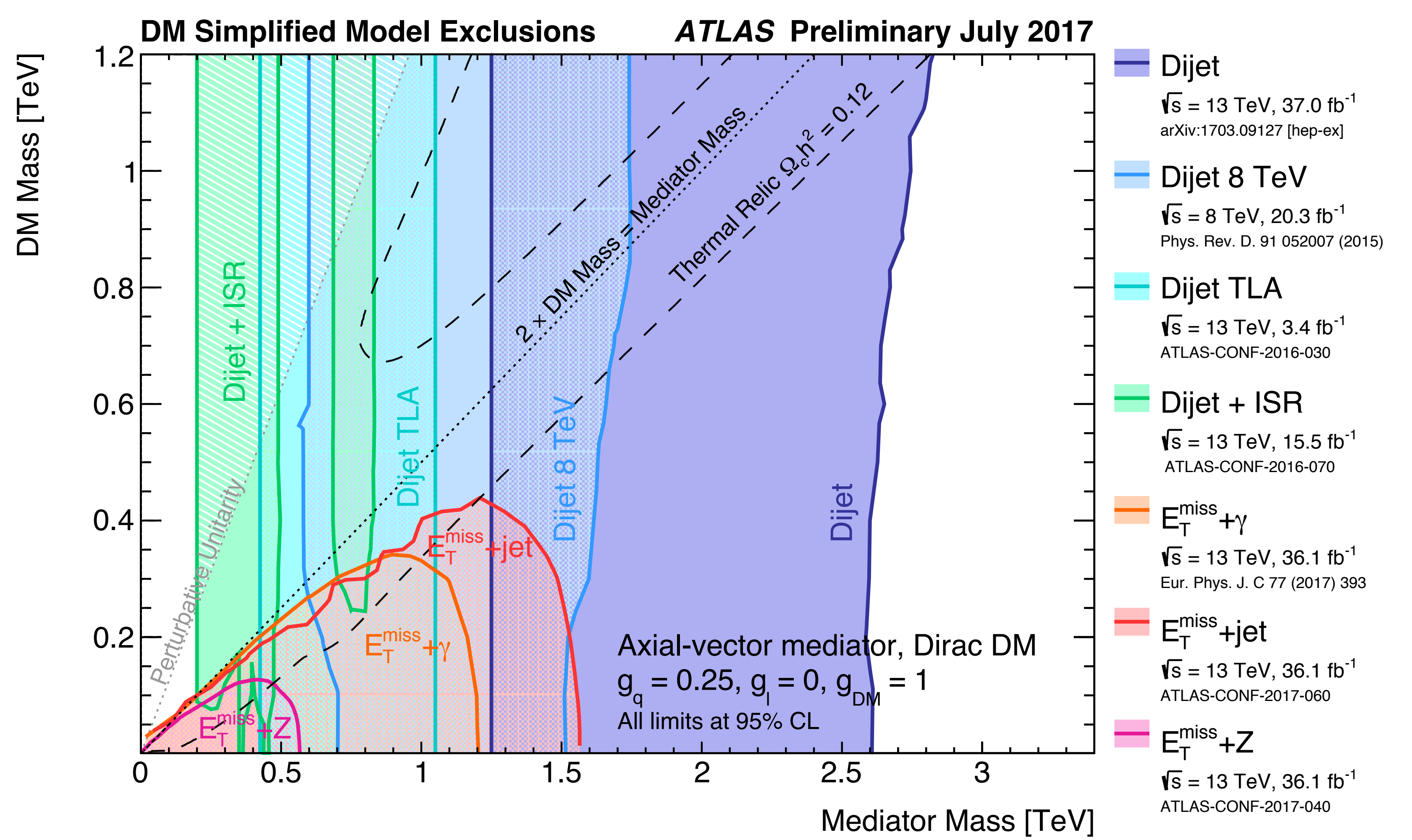
- Strong constraints from mono-X, heavy flavour analyses
- Summary in whitepaper

arxiv:1701.07427

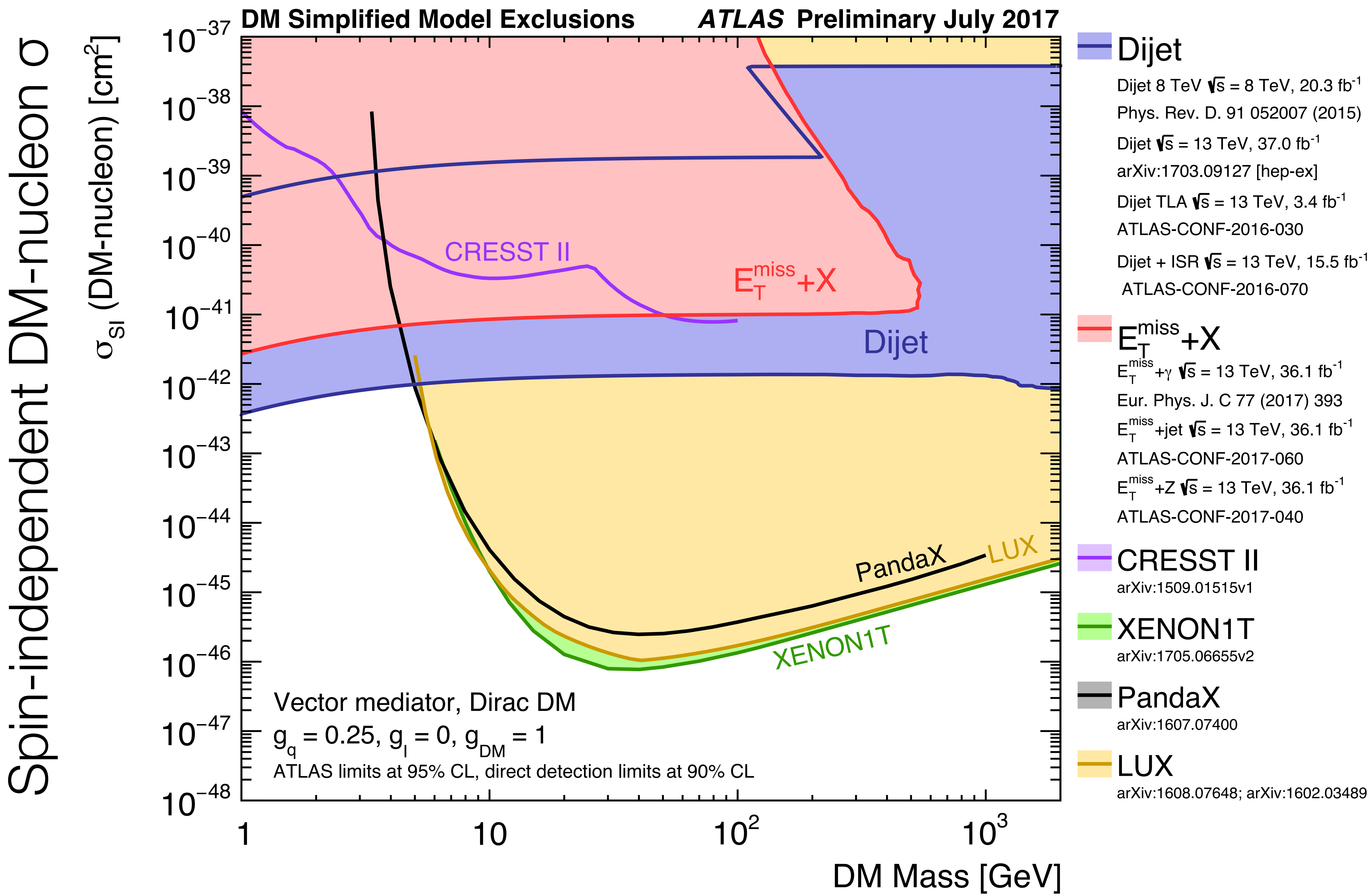
Dark matter: Z' mediator summary

- Results still depend a lot on the assumptions we make, even with just 5 free parameters!
- Plots: axial-vector mediator (vector mediator in backup)
- Top: $g_L = 0.1$, $g_q = 0.1$
- Bottom: $g_L = 0$, $g_q = 0.25$

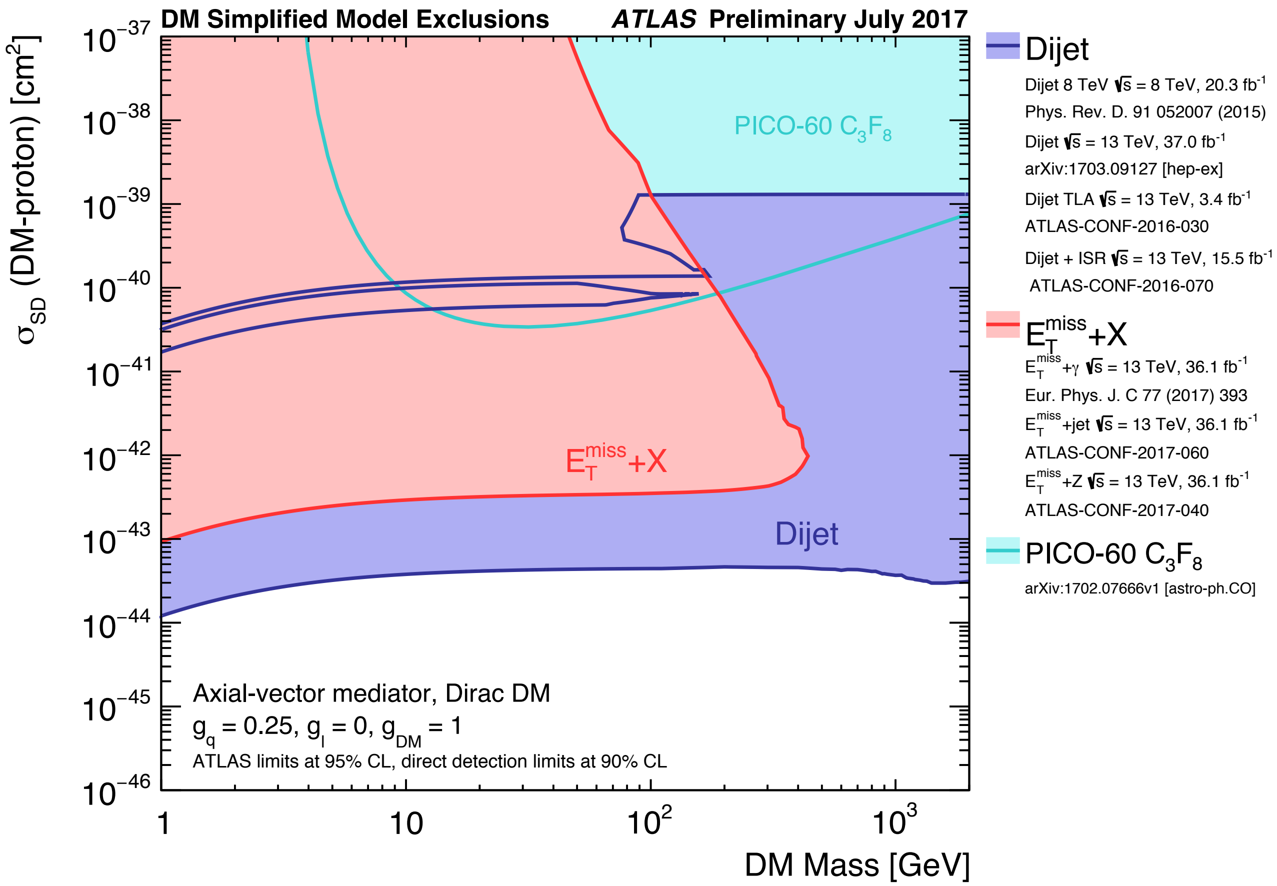


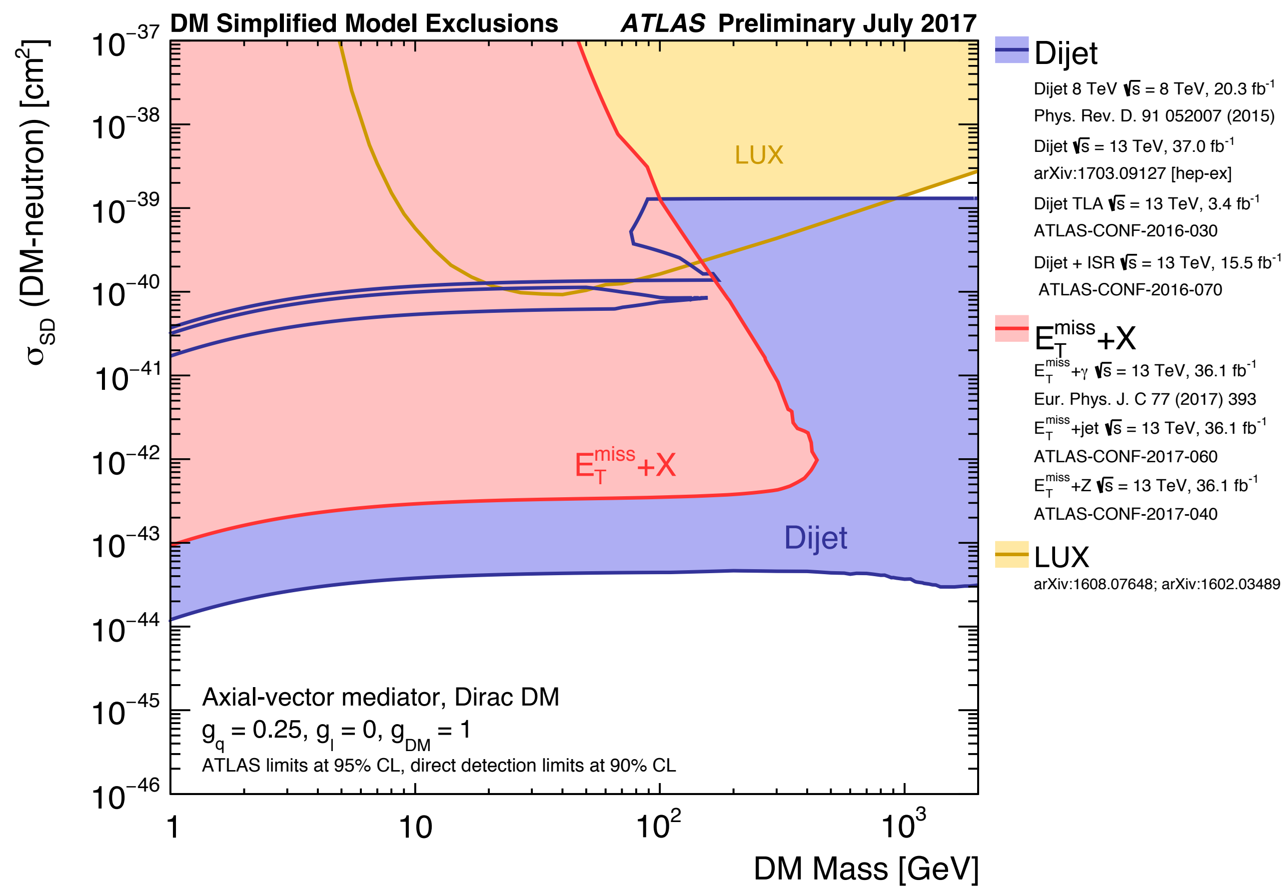


Comparing collider DM limits to the rest of the field



Comparing collider DM limits to the rest of the field





- Axial vector mediators, spin dependent limits
- Left: DM-proton cross section. Right: DM-neutron cross section.

Important to place collider results in wider context!

Now what?

Up and out

Search program in early Run II focused on low-hanging fruit: strongly produced signatures, simple final states, simple detector needs

Up and out

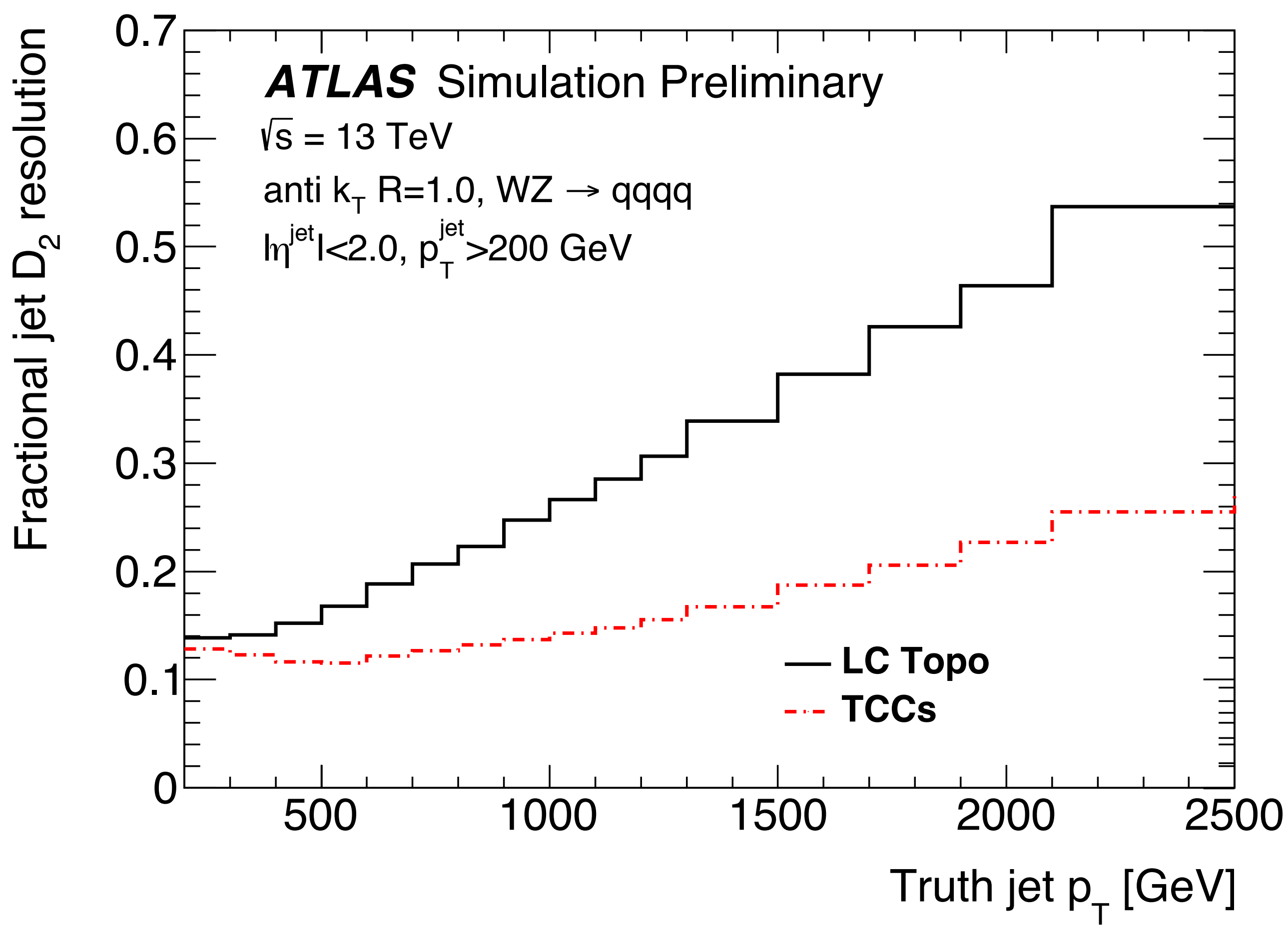
Now working up the tree:
EW SUSY, low mass or low cross section signals are still benefitting from increasing luminosity

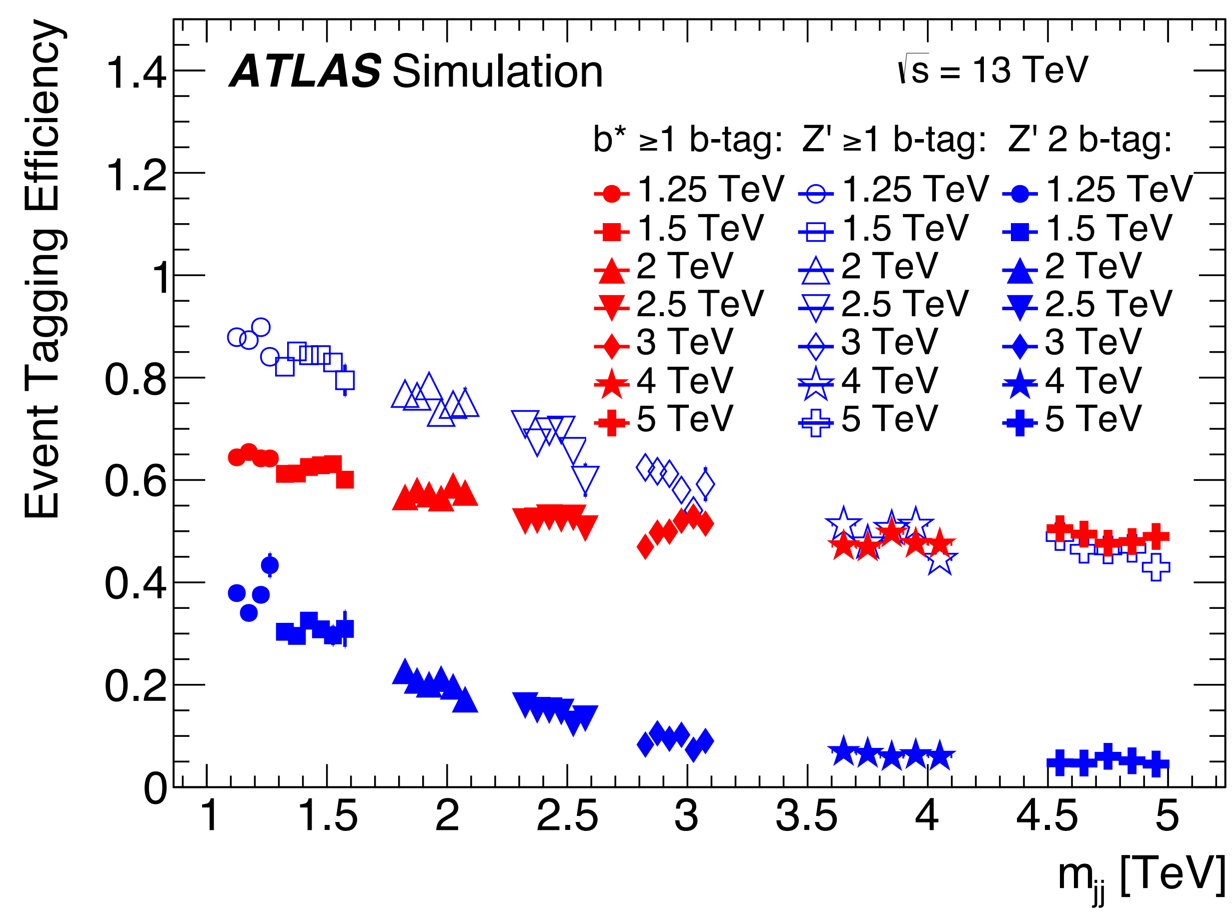
Up and out

Lots left to do which is hard to see or hard to access! Really compressed states, long lived particles, signatures with interference…

Improving performance improves analyses!

- Instead of sitting and waiting for a slow accumulation of luminosity, push performance improvements and analysis reach improves.

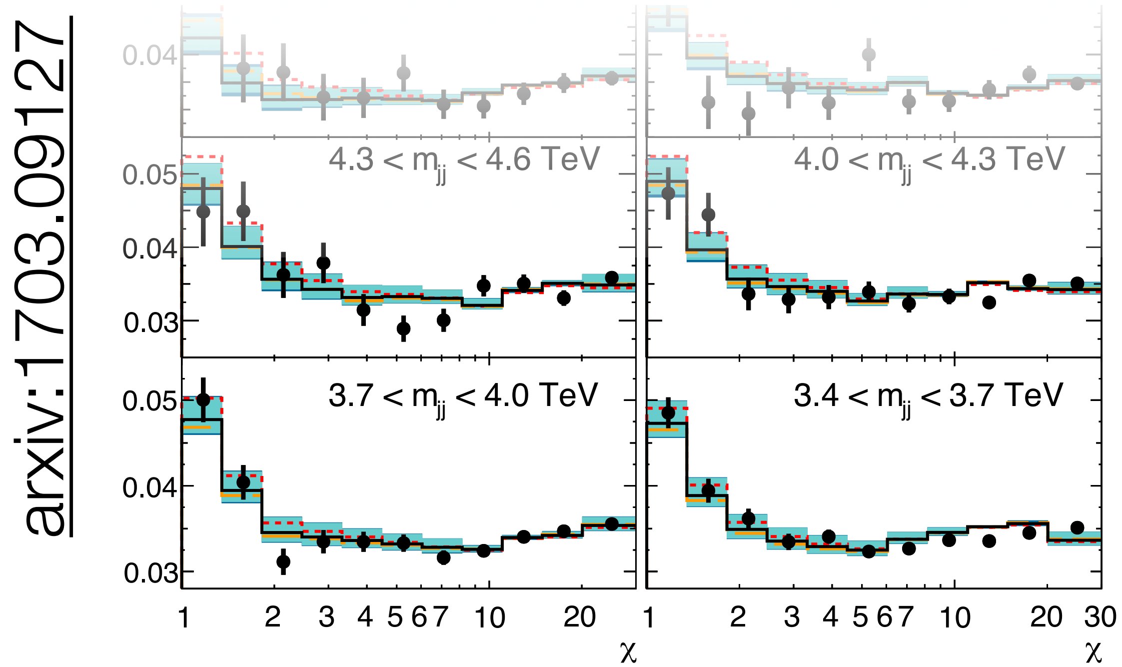


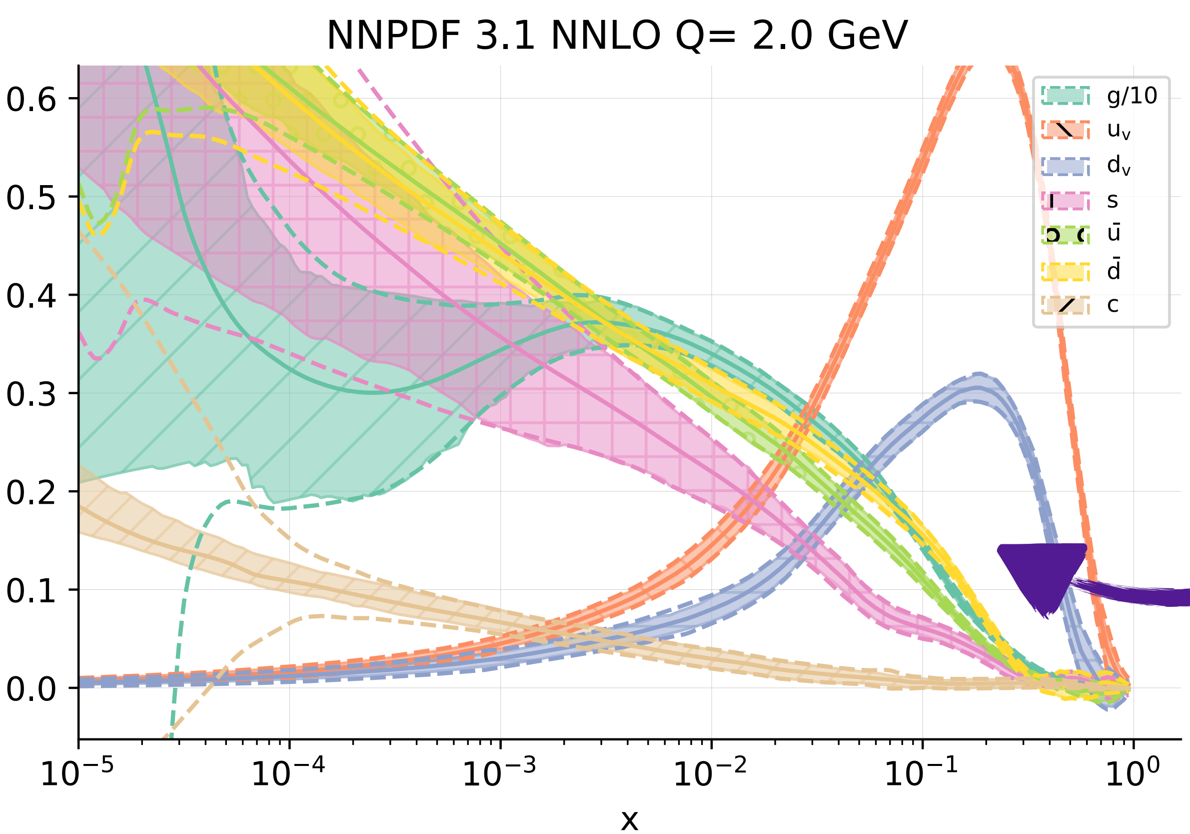


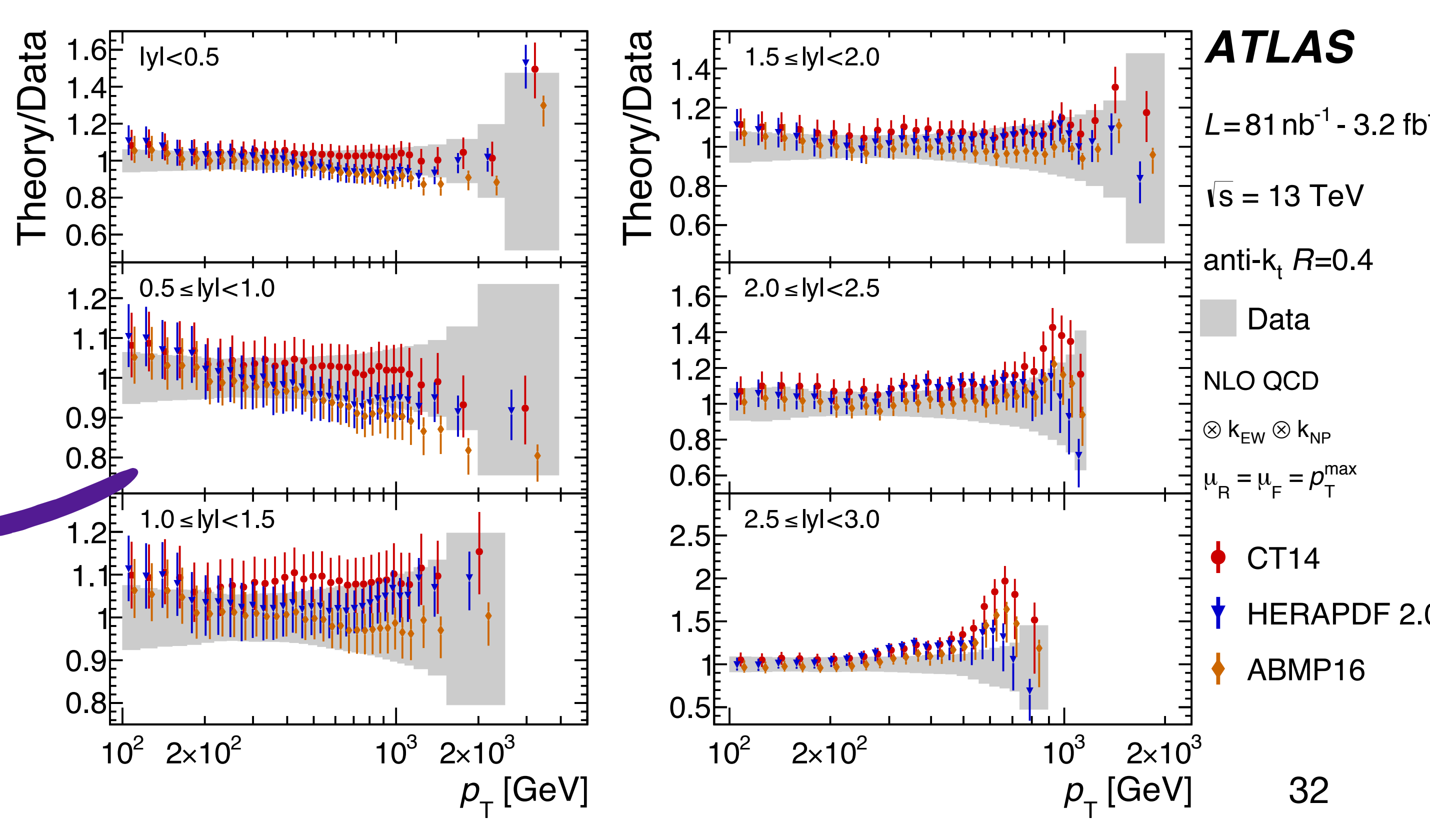
Example: new jet inputs in VVJJ improve resolution!

Example: improving b-tagging efficiency would benefit searches!

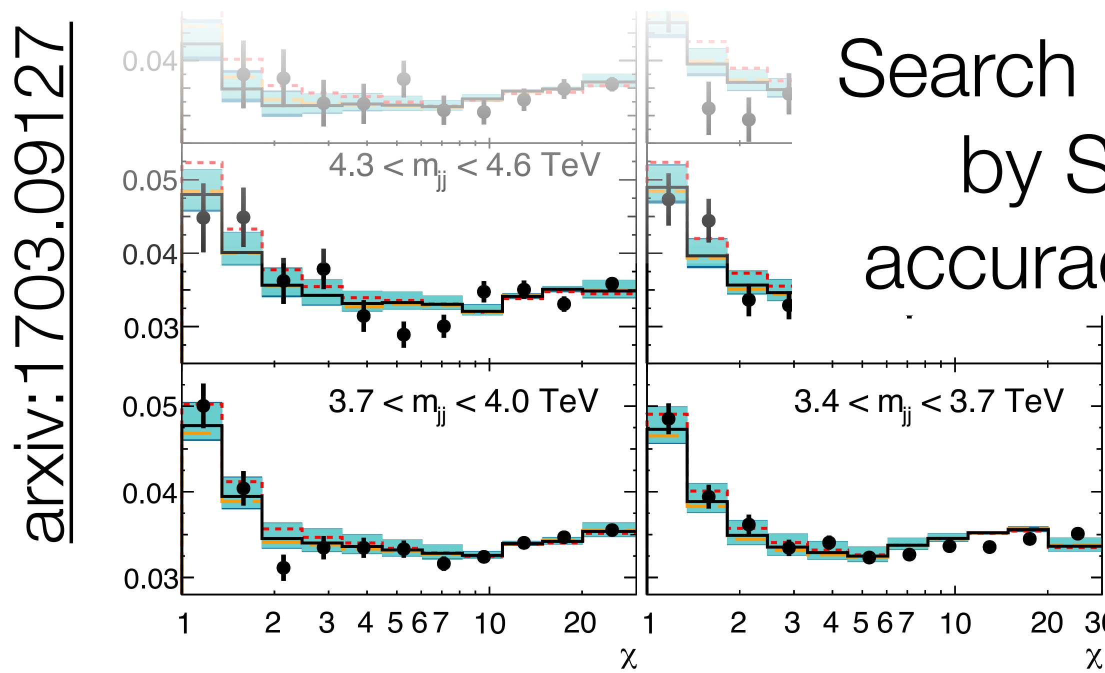
The search and measurement lifecycle



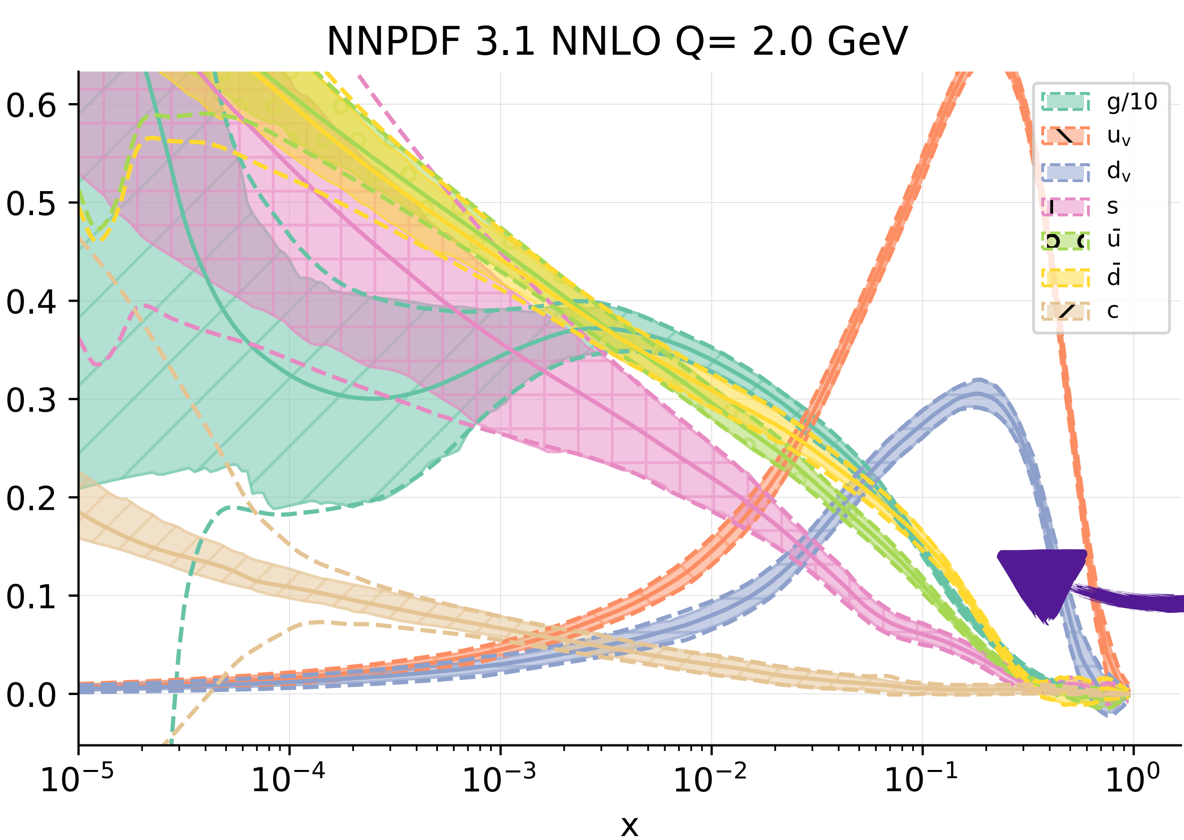


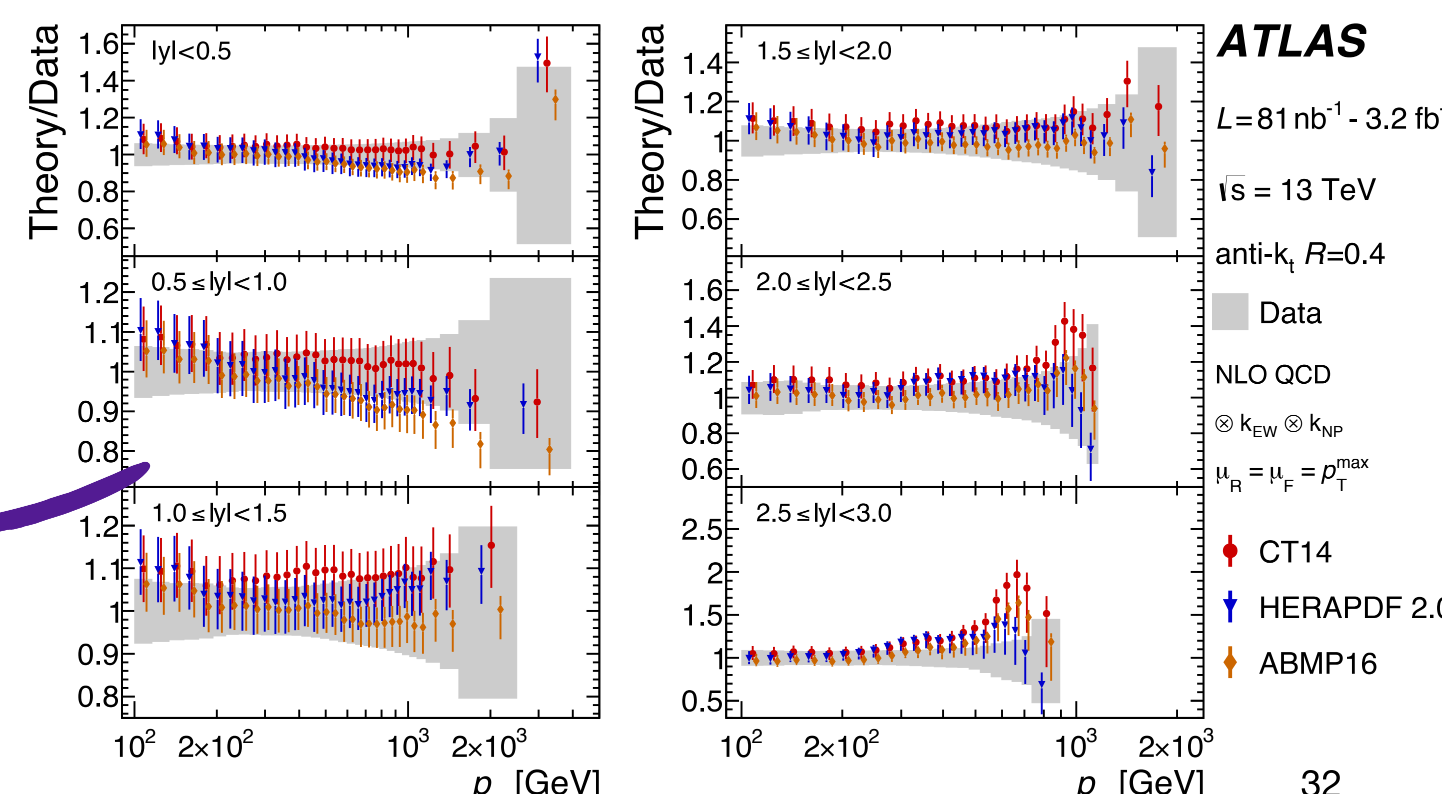


The search and measurement lifecycle

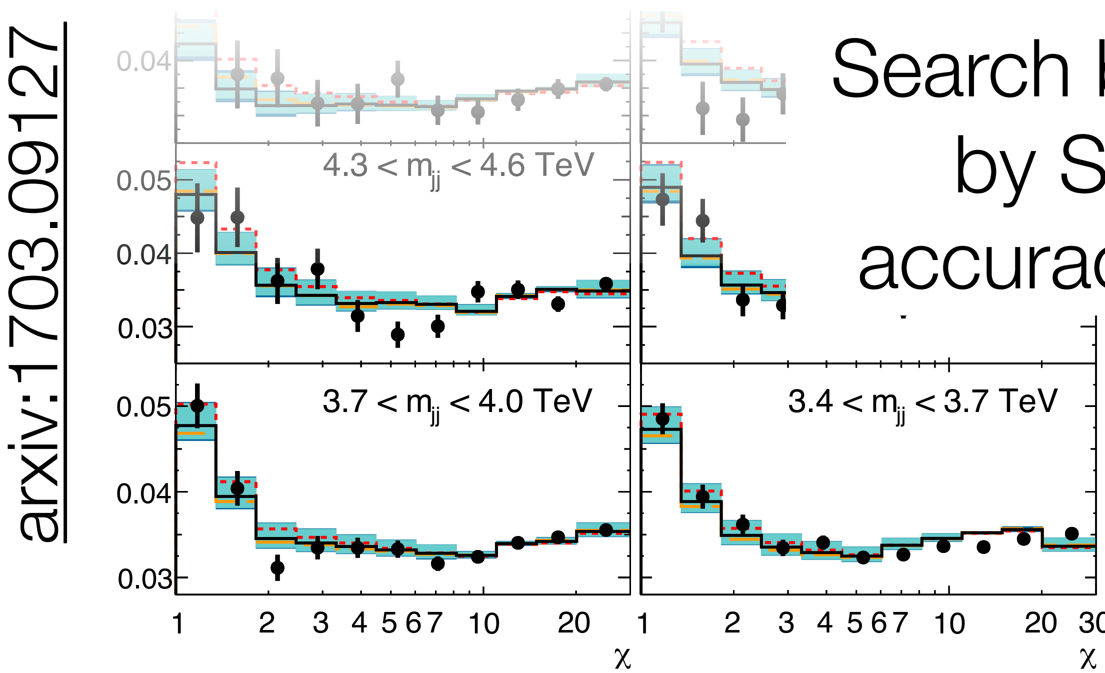


Search becomes limited by SM prediction accuracy/uncertainties



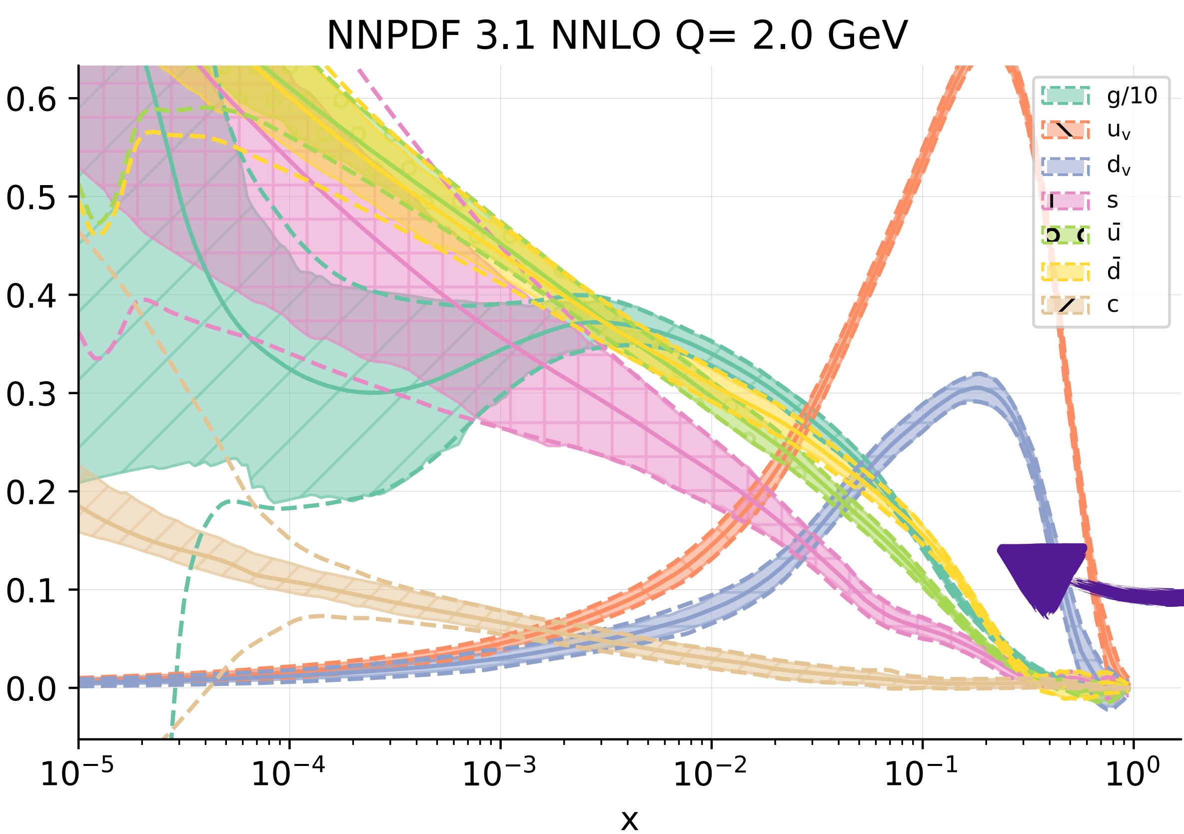


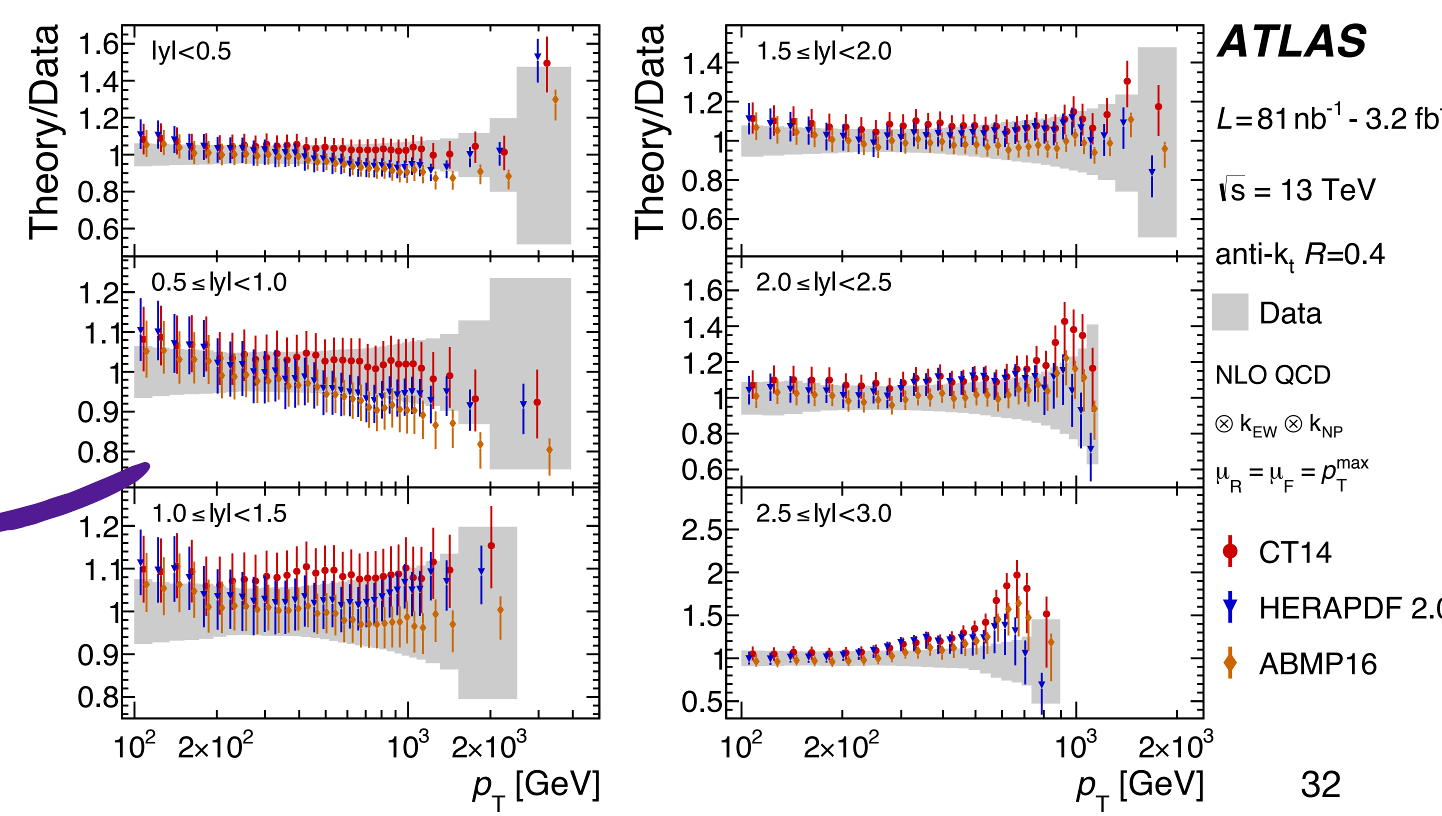
The search and measurement lifecycle



Search becomes limited by SM prediction accuracy/uncertainties

Measurement provides new input for theory predictions

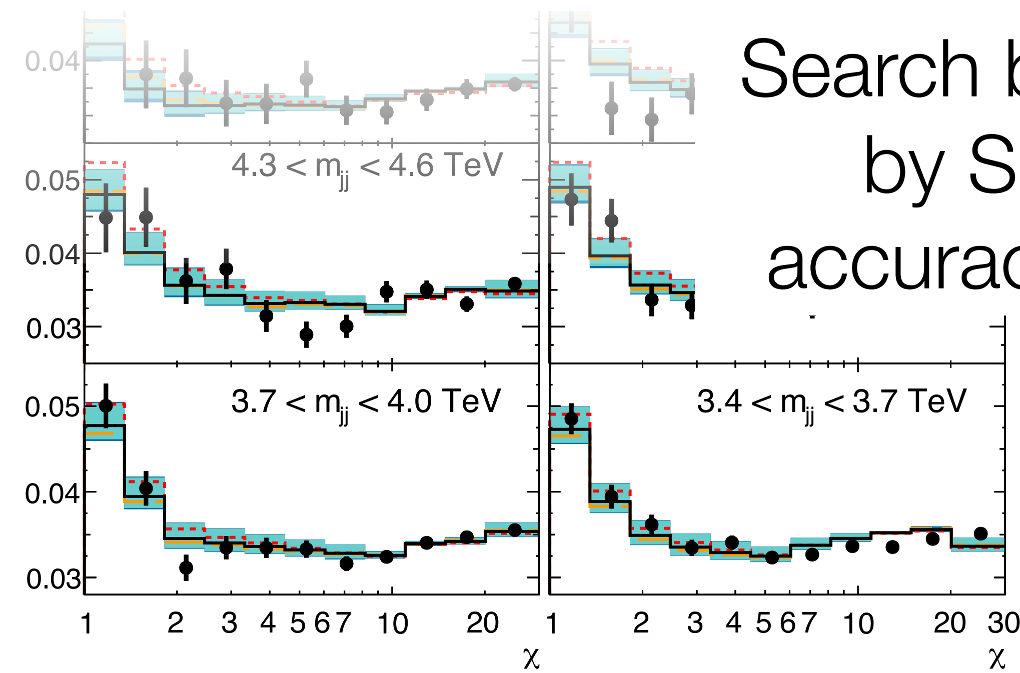




The search and measurement lifecycle

Predictions improve

arxiv:1703.09127



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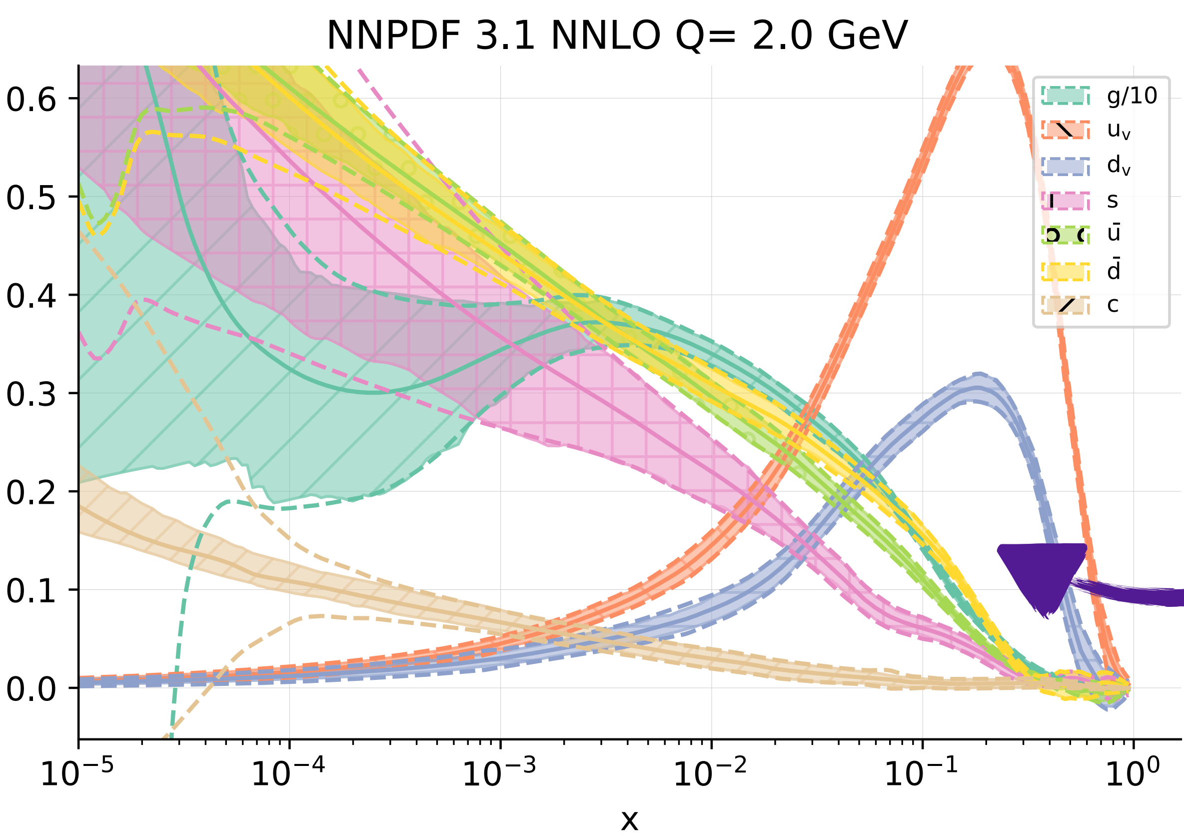
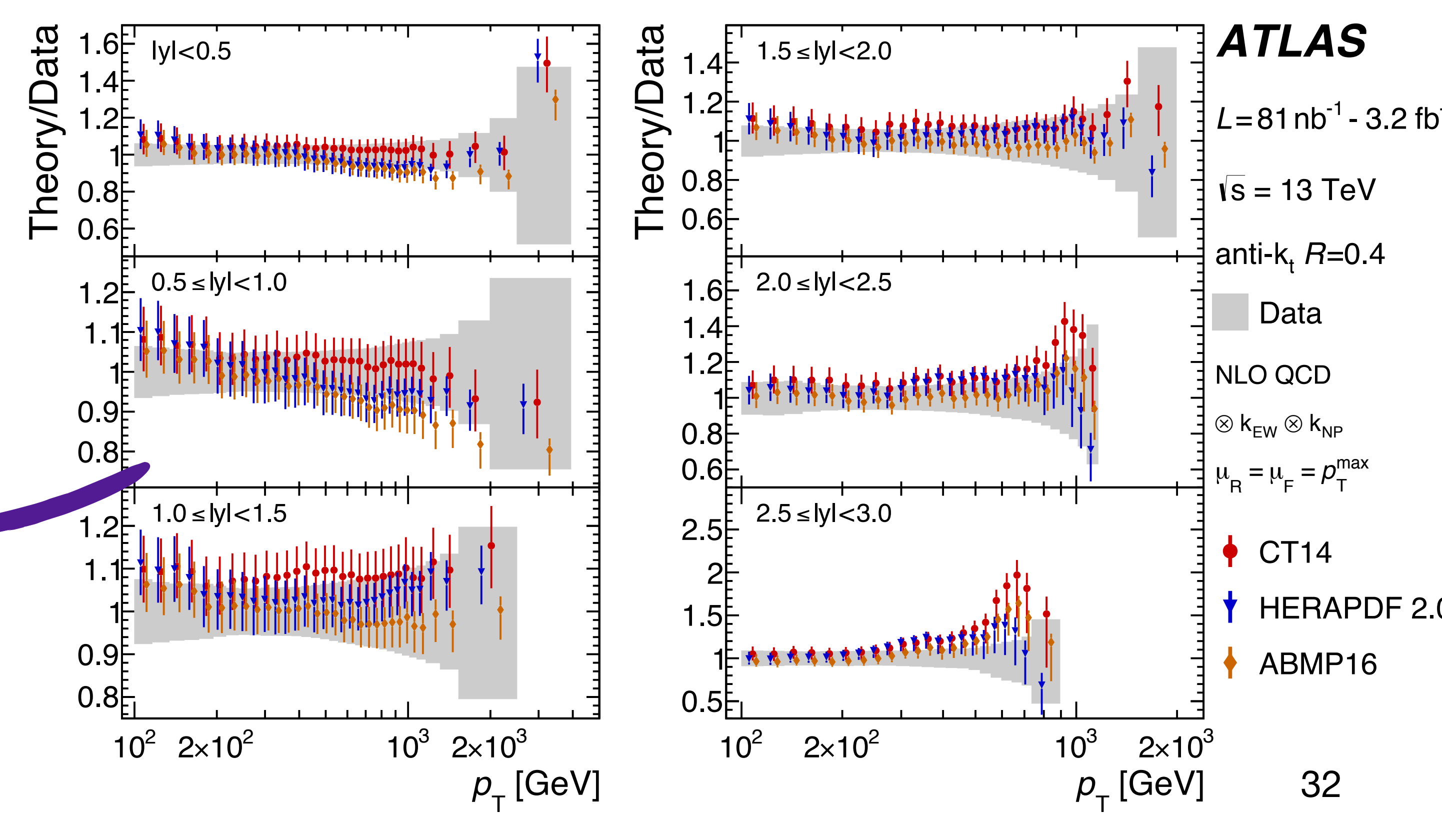




The BSM landscape at 13 TeV

Looked under most of the obvious rocks …

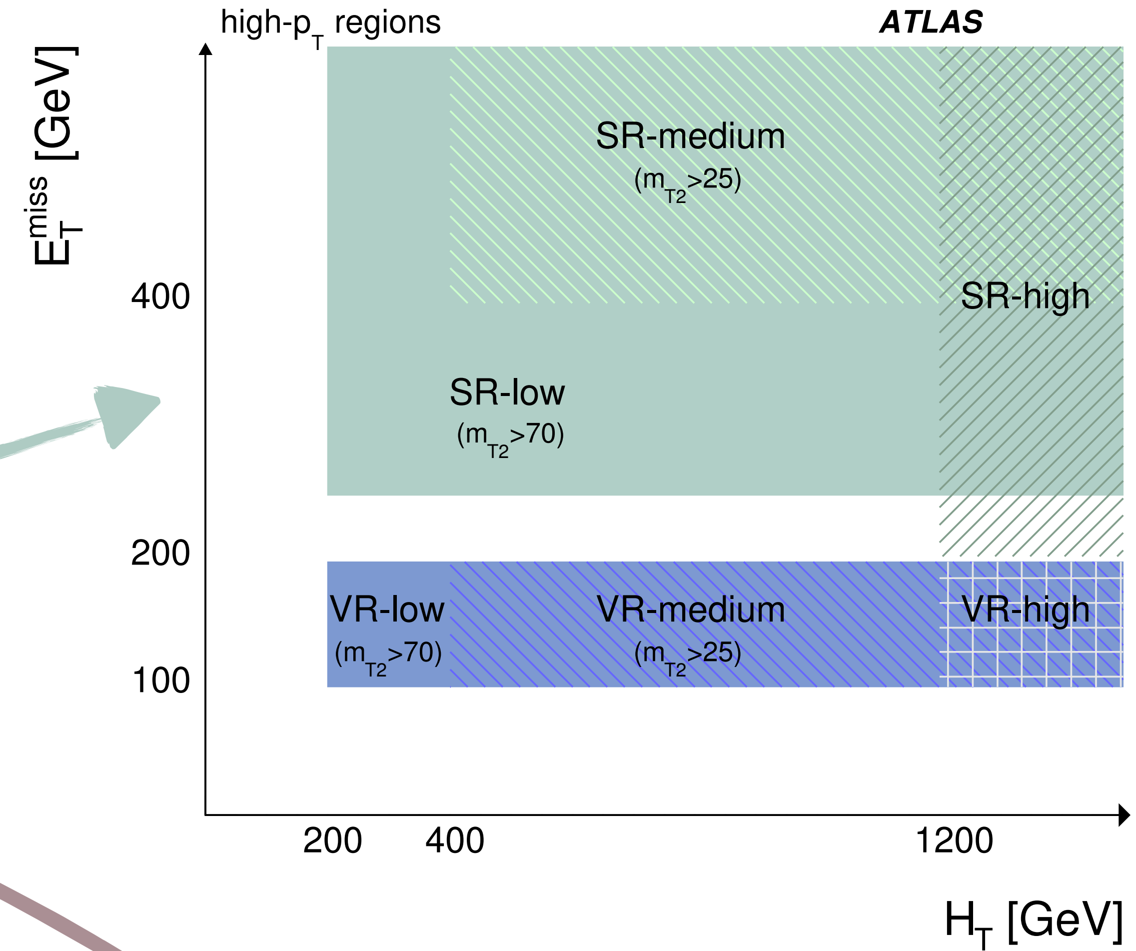
… time to start getting more complex!

Thanks! Any questions?

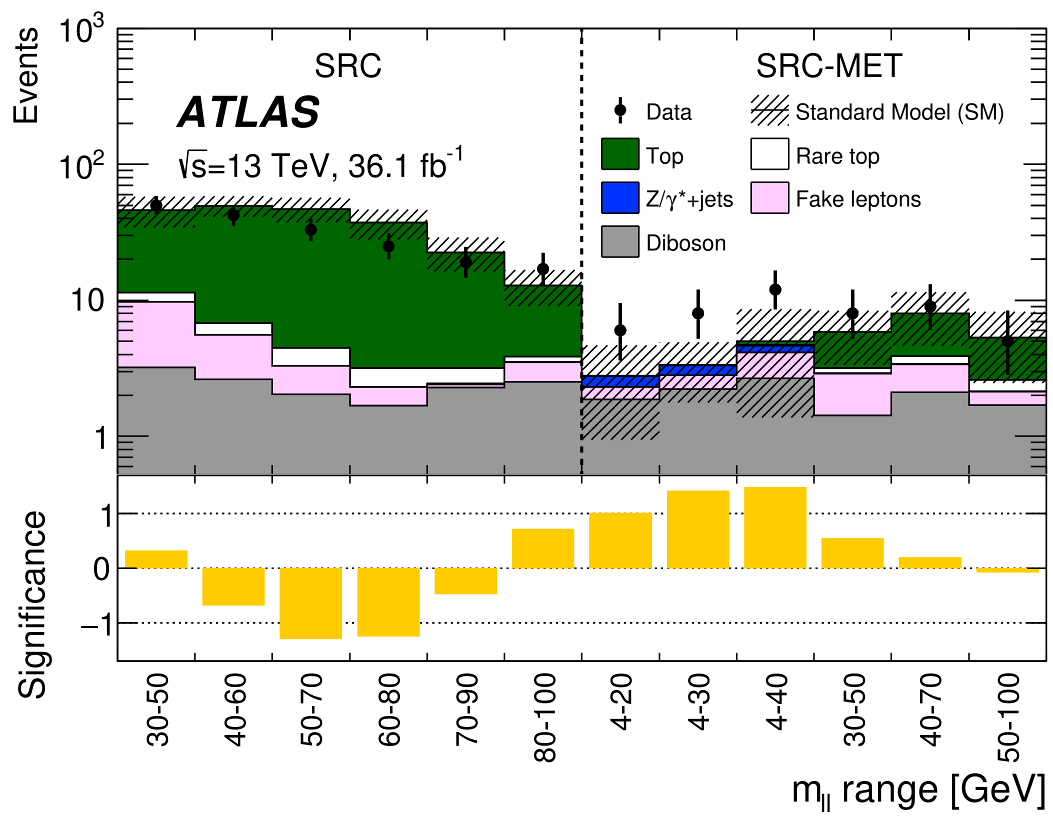
Backup

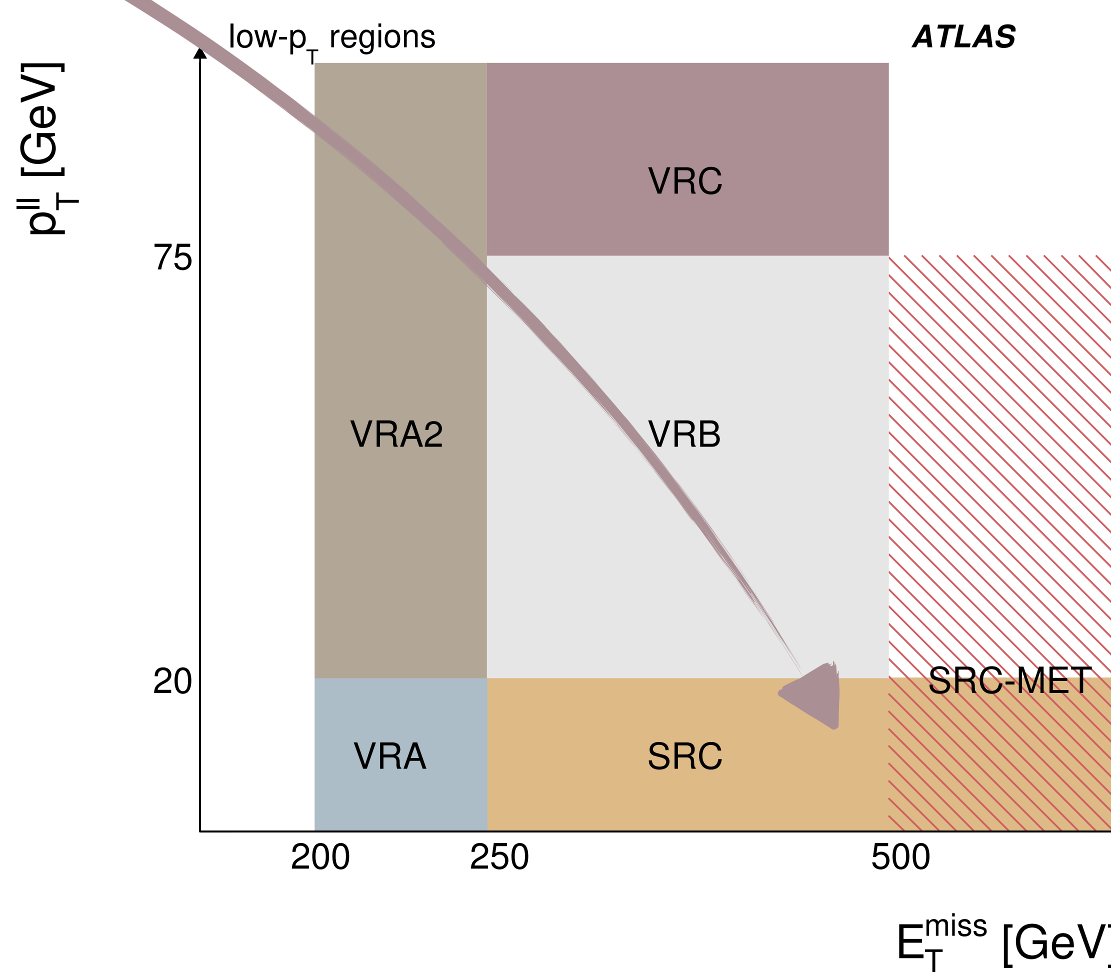
Additional info: SUSY opposite sign dilepton

- “High-p_T lepton search” addresses non-compressed cases where kinematic edge near the Z peak
- “Low-p_T lepton search” addresses small Δm between two lightest neutralinos: compressed scenario
- Simplified model: set masses of all not-relevant particles very high so they decouple
- Key backgrounds: Z/γ^* + jets, fake leptons, diboson and rare top processes



Low-pT signal region yields





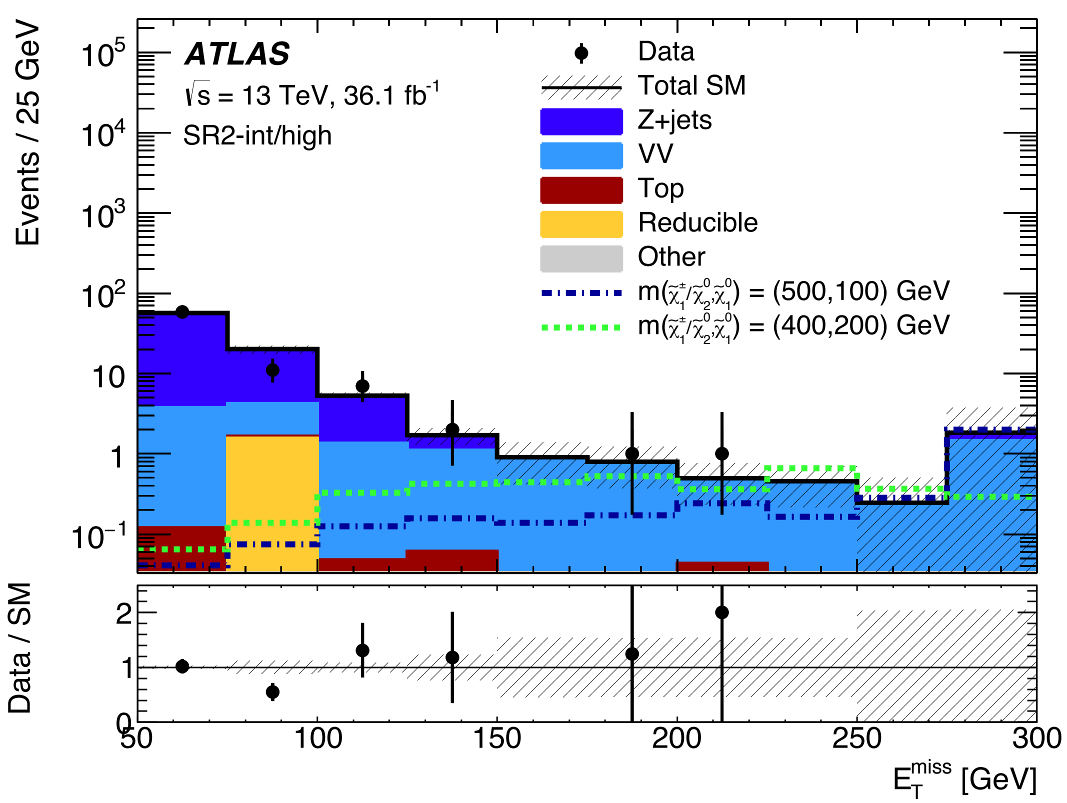
2l + no jets shown in main body!

Additional info: SUSY 2/3 lepton EW search

- The idea: if squarks & gluinos are a lot heavier than sleptons/ charginos/neutralinos, then higher cross sections doesn't benefit them in search

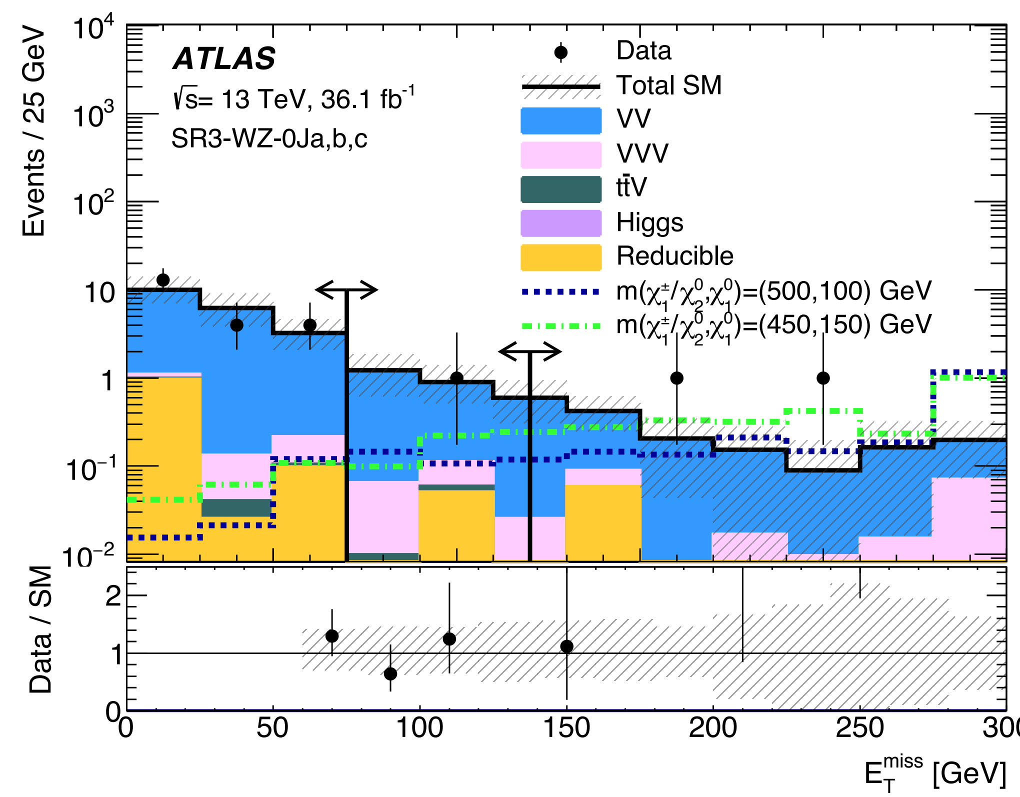
And go look up the RJR analysis!

- Simplified model: take mass-degenerate, pure wino chargino1 & neutralino2; mass-degenerate sleptons
- Many individual signal regions defined by m_{ll}, m_{T2}, number of jets, MET, … Just a few sample distributions shown here!

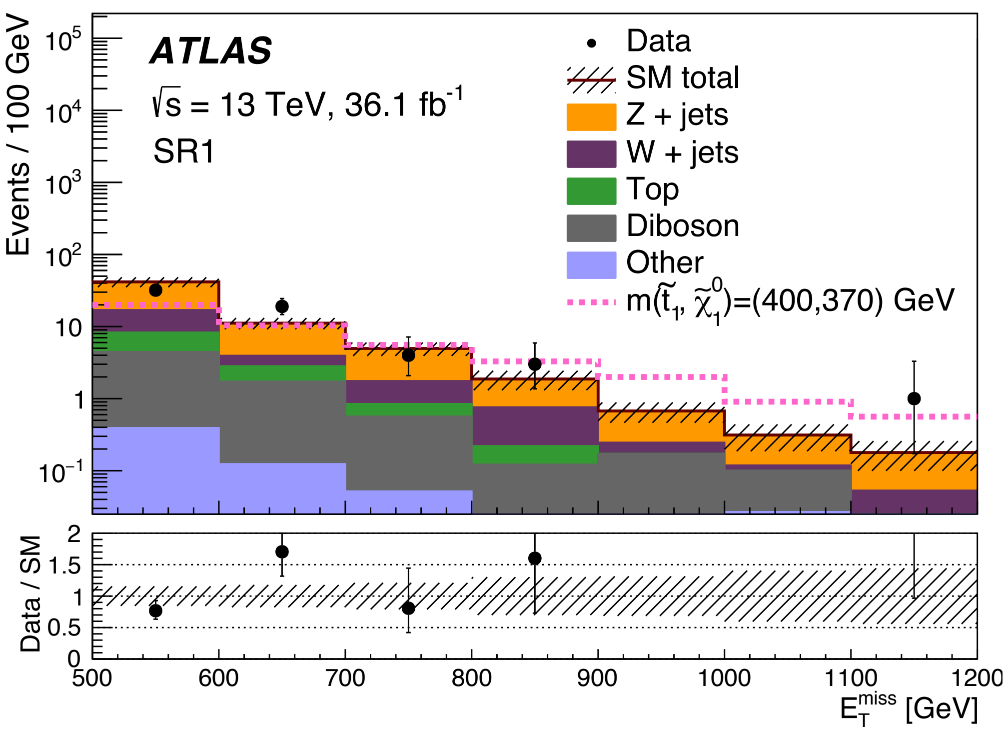


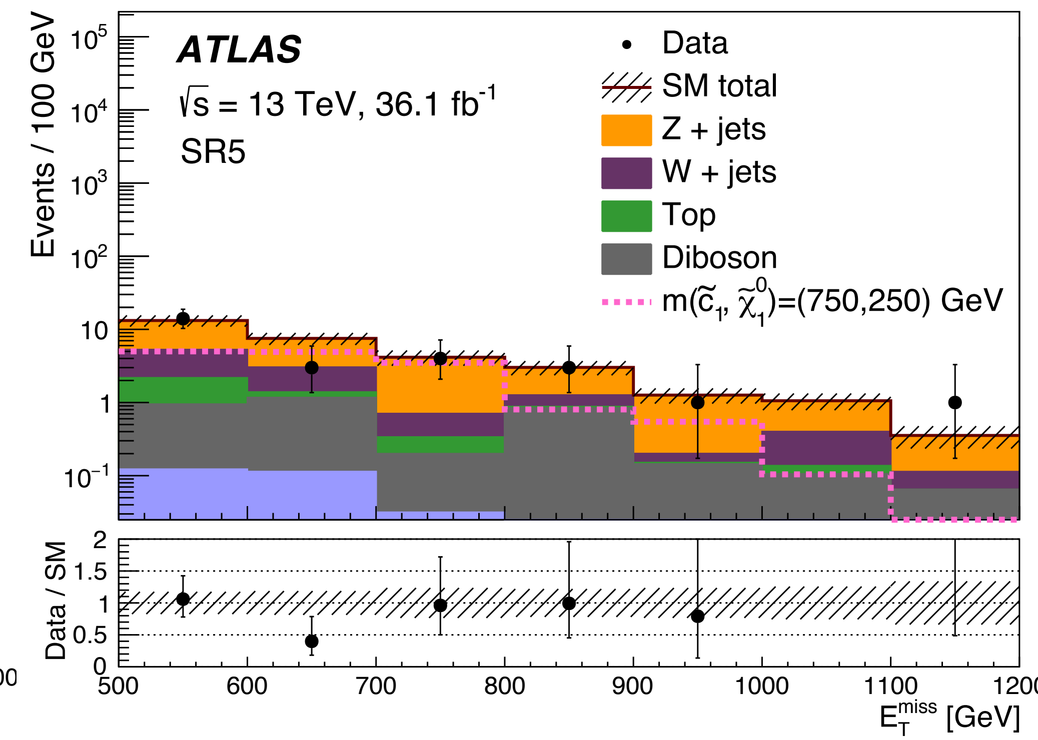
2l + jets

3 leptons



Additional info: SUSY stop to charm



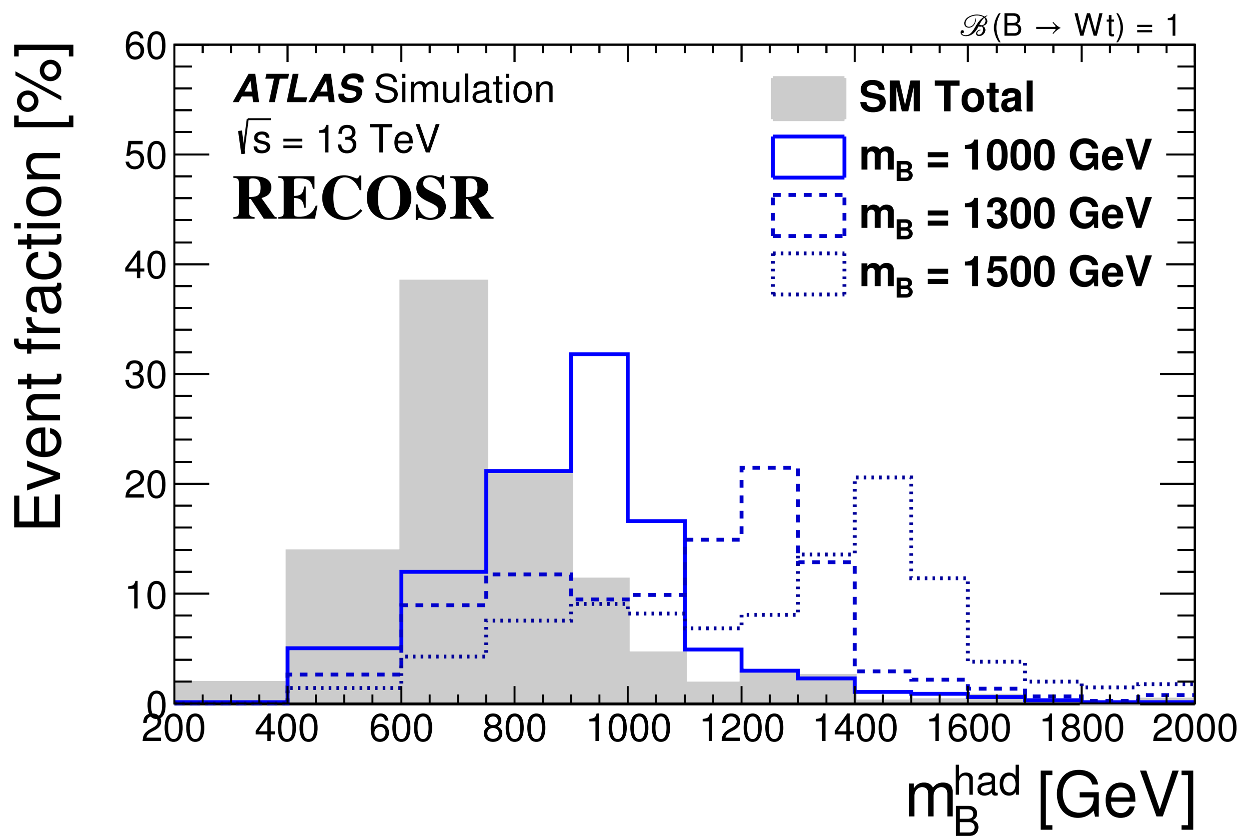


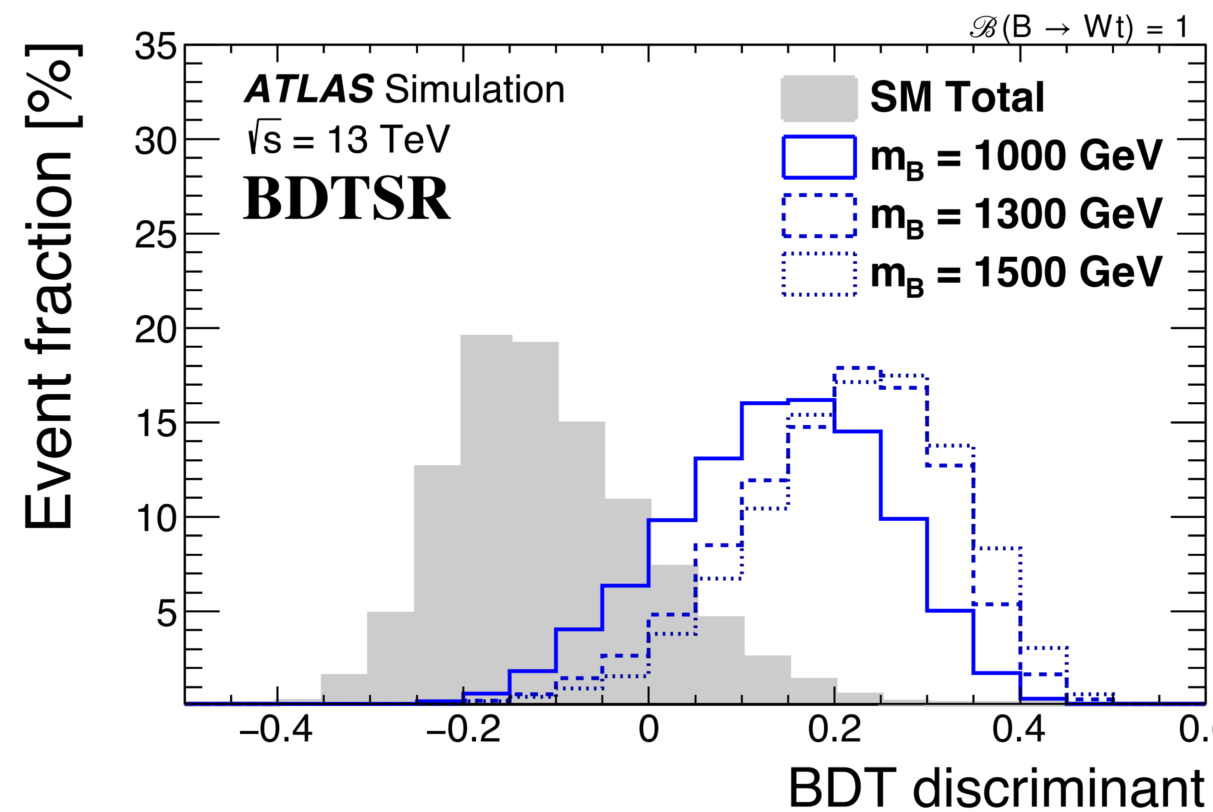
Main background: Z(νν)+jets
Other: W(τν)+jets, diboson, ttbar, …

- Model: stop pair production with flavour violation, allowing decay to charm + LSP, or flavour-conserving charm squark pair production. Assume 100% BR to c+LSP in both.
- Require 2j, >= 1 c-tagged jets, MET, lepton veto. SR's further cut on cjet+MET transverse mass to reduce τ contamination
- Separate signal regions with softer/harder, more/fewer jets for various levels of compression

Additional info: Exotics VLQs

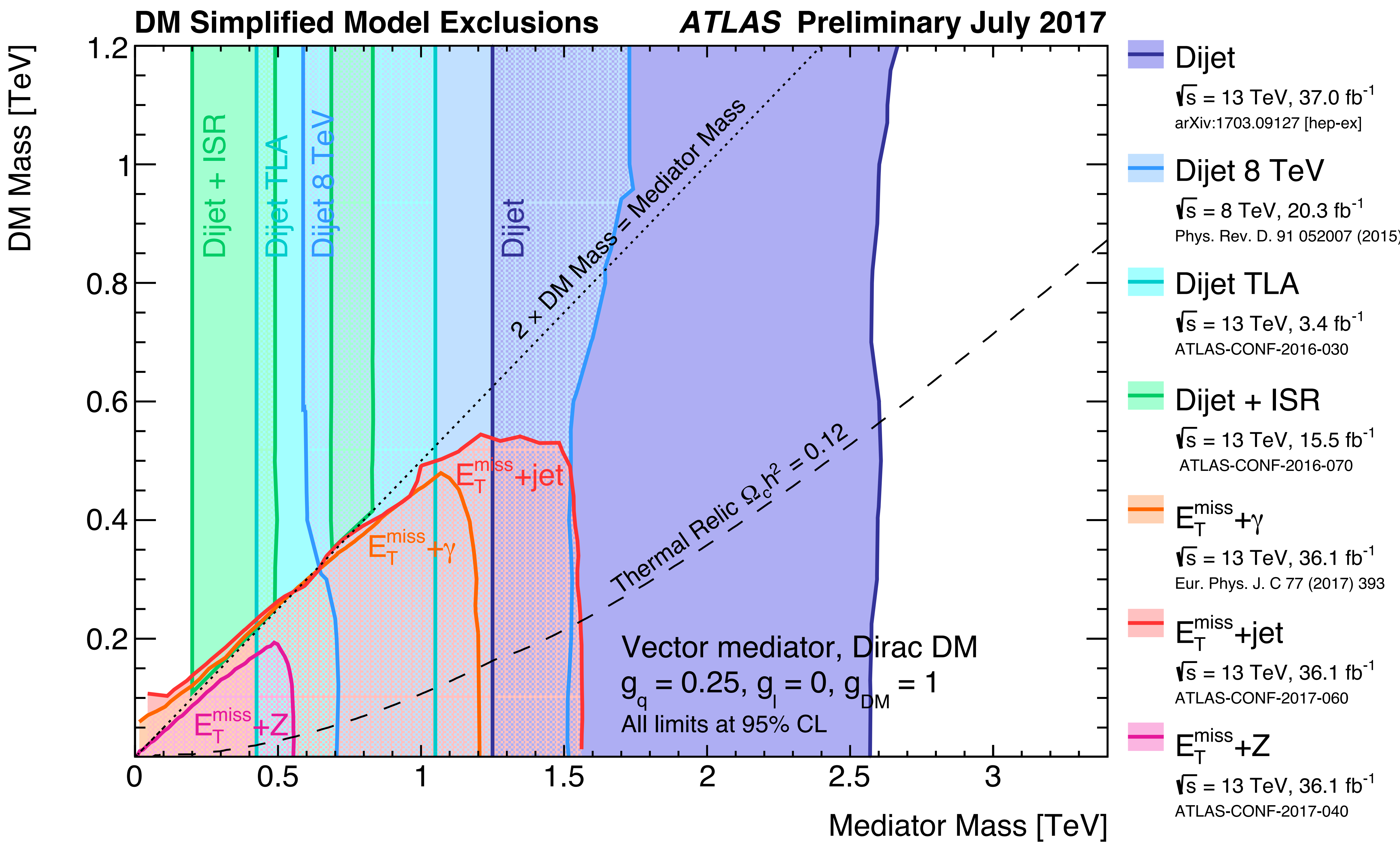
S_T, large-R jet mass
best BDT variables





- Vector-like quarks couple preferentially to 3rd generation and allow flavour-changing neutral currents as well as regular quark-like charged current decays
  - E.g. T VLQ can give T-> (Wb, Zt, Ht)
- Classify events by number of jets, b-jets, leptons.
- RECOSR: 3 large-R jets, one W-tagged. b-jet not near lepton. S_T (scalar sum of MET, lepton, small-R jet pTs) must be large. BDTSR: trained and used on events which do not pass RECOSR.

Vector mediator DM summary plots: leptophobic



Vector mediator DM summary plots: leptophilic