BSM and DM result summary at the LHC

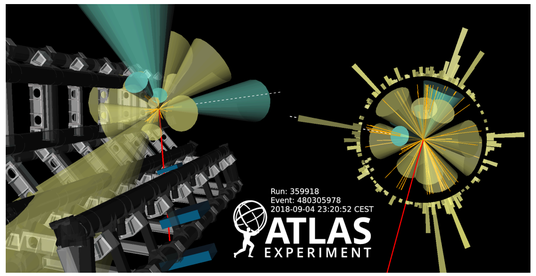
Javier Montejo Berlingen

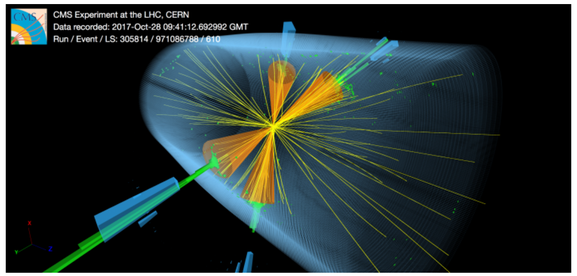
Institut de Física d'Altes Energies

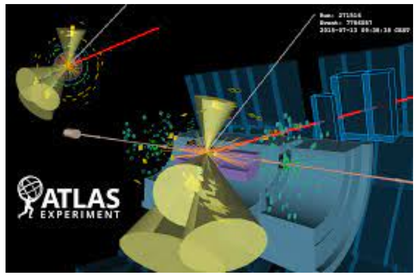
DMNet International Symposium

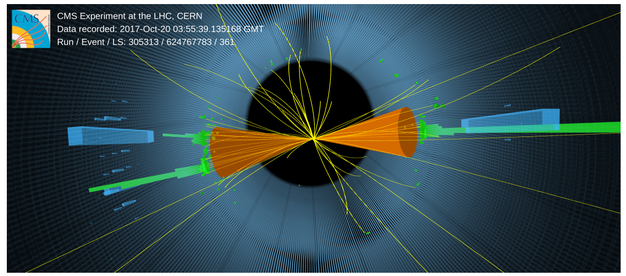
Introduction

The LHC is an incredible machine that allows us to explore the TeV scale for the first time:

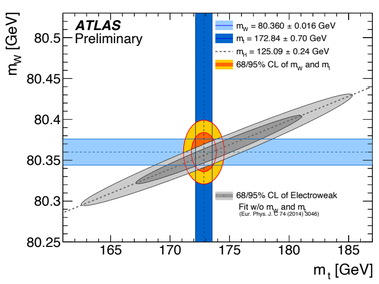


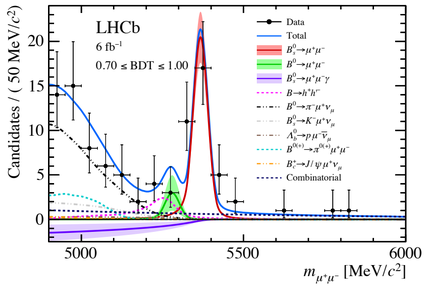


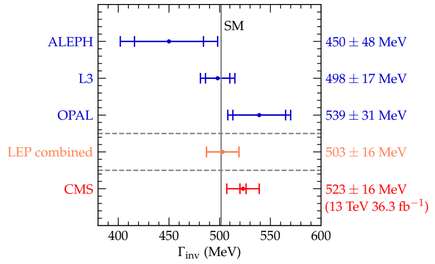


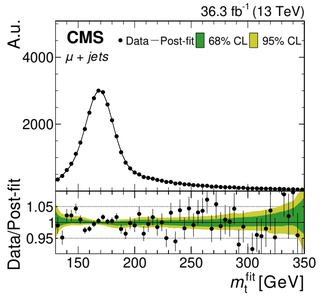


And allows us to scrutinize the electroweak scale with incredible precision:









In both cases we spend years analysing data not for the sake of it, but because we want to get insight into the **big physics questions**

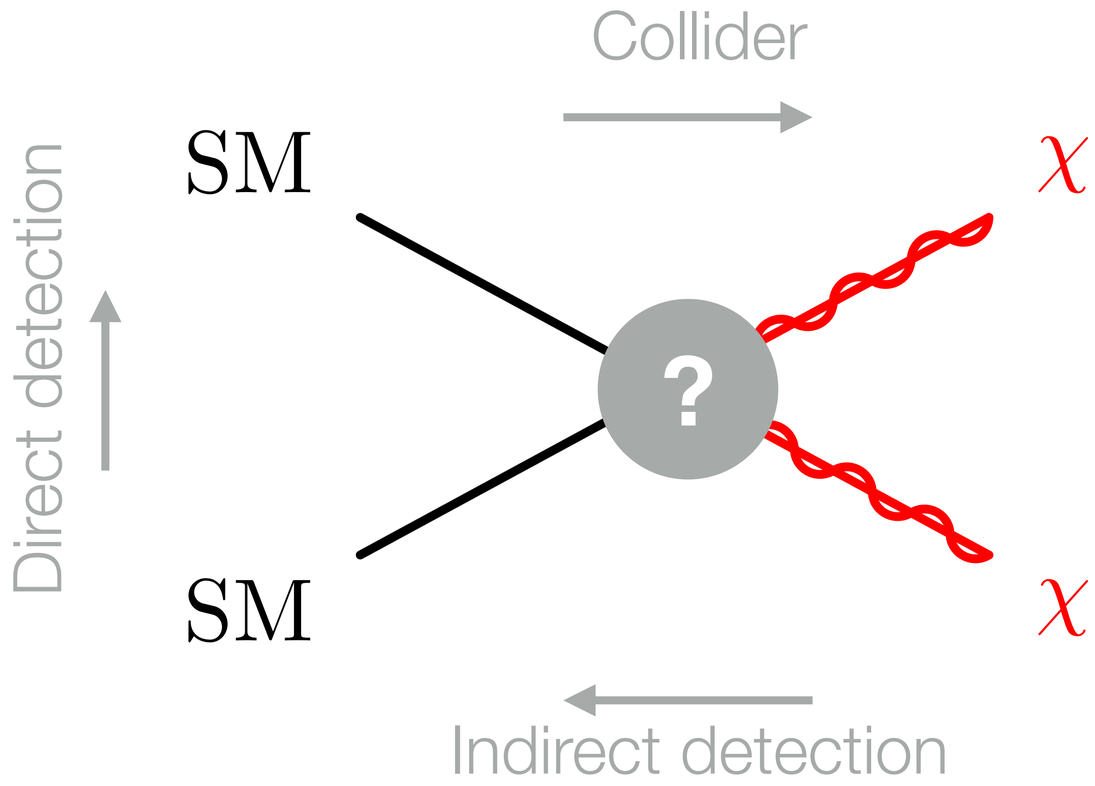
- *Why is the higgs so light? why is there so little antimatter? where do neutrino masses come from?* ***what is dark matter?***

All these questions can not be addressed within the Standard Model and require new physics

Introduction

The whole dark matter program revolves around finding possible signatures for interactions in the grey circle

- But we need to be very careful when extrapolating from one area to the other, no guarantee that the same interaction is in action



Introduction

The whole dark matter program revolves around finding possible signatures for interactions in the grey circle

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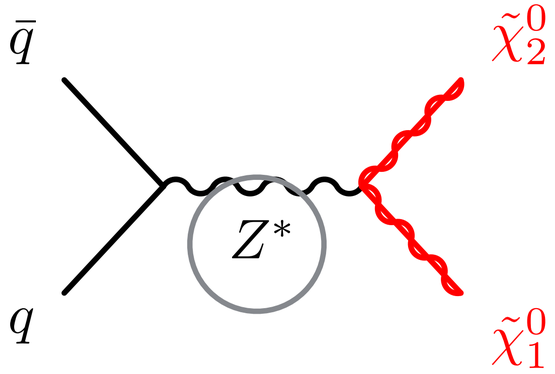
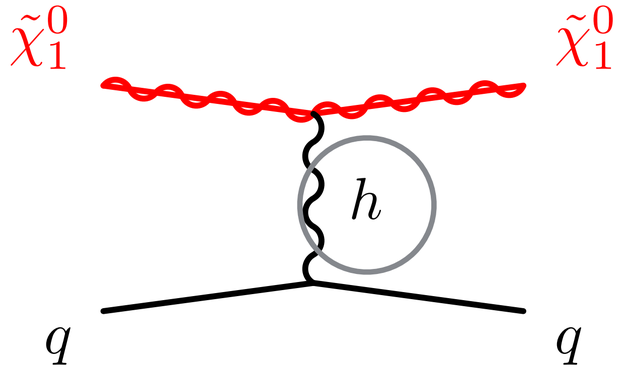
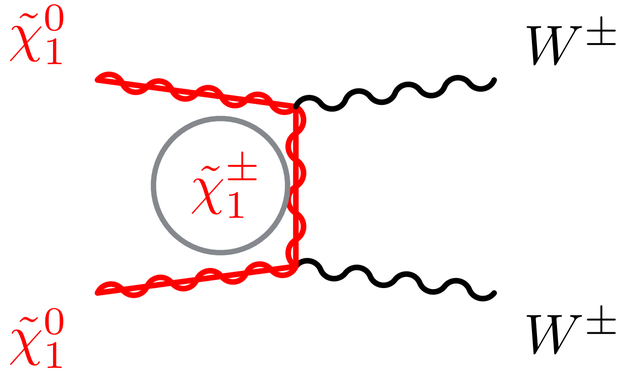
Collider



Direct detection



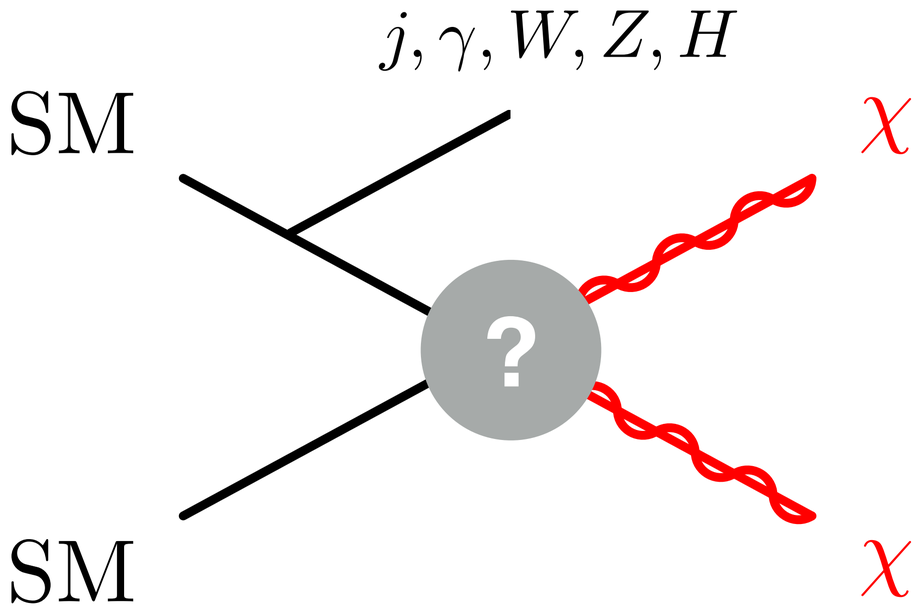
Indirect detection



Introduction

How we can detect DM at LHC?

- Dark Matter particles have no strong or EW interactions… they are undetectable for collider detectors! large missing transverse energy (MET) in the detector
- But we need a “visible” object to tag event → Search for DM events in association with a SM particle



In the following I'll try to give a quick glimpse at the LHC DM search programme, with a focus on ATLAS

and biased

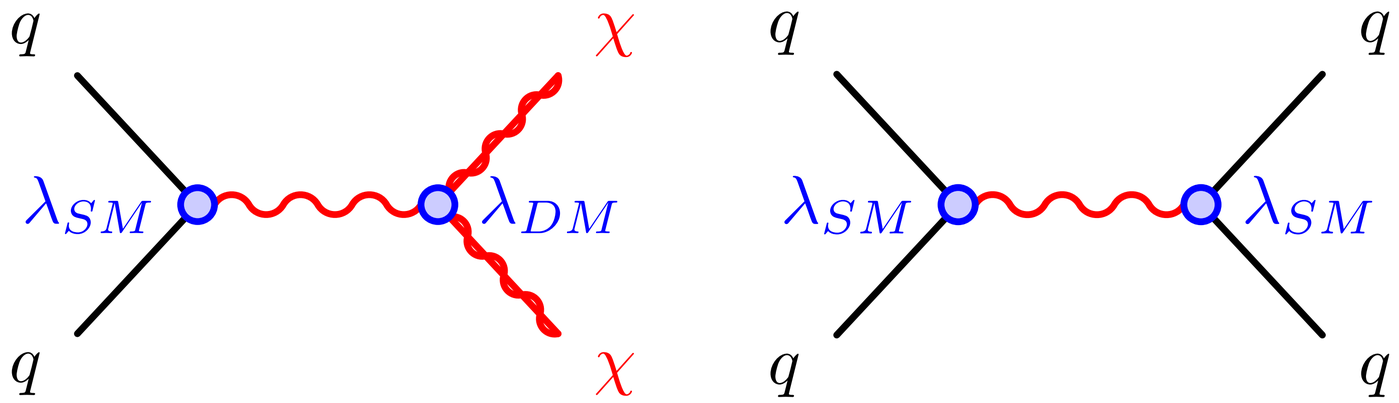
and supersymmetry

DM simplified models

Introduce a mediator of any kind for the interaction: scalar, pseudoscalar, vector or axial vector

- 4 parameters: DM and mediator masses, DM and SM couplings

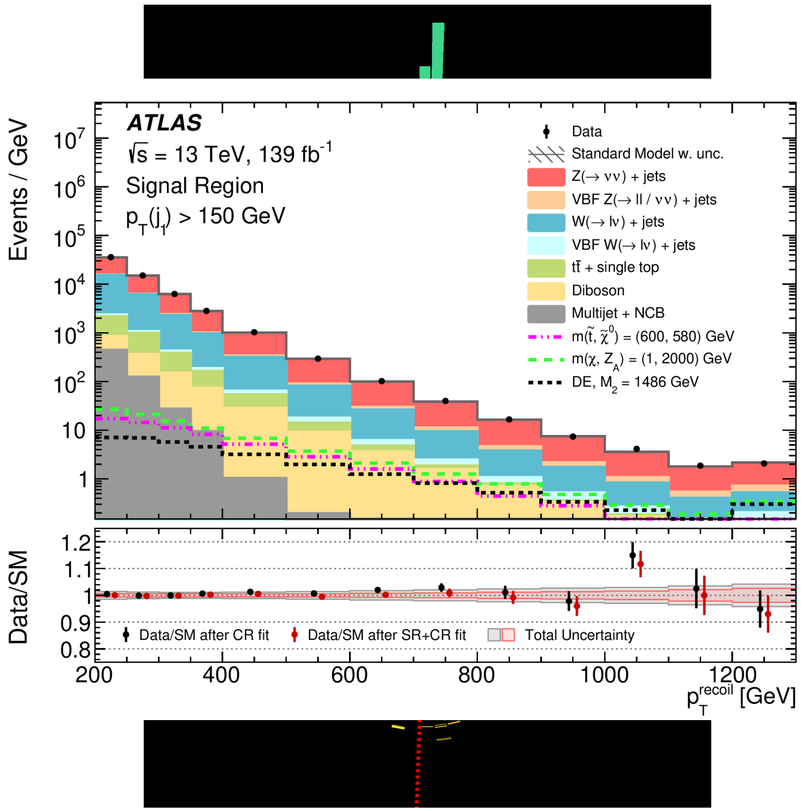
Two complementary approaches: direct and mediator searches

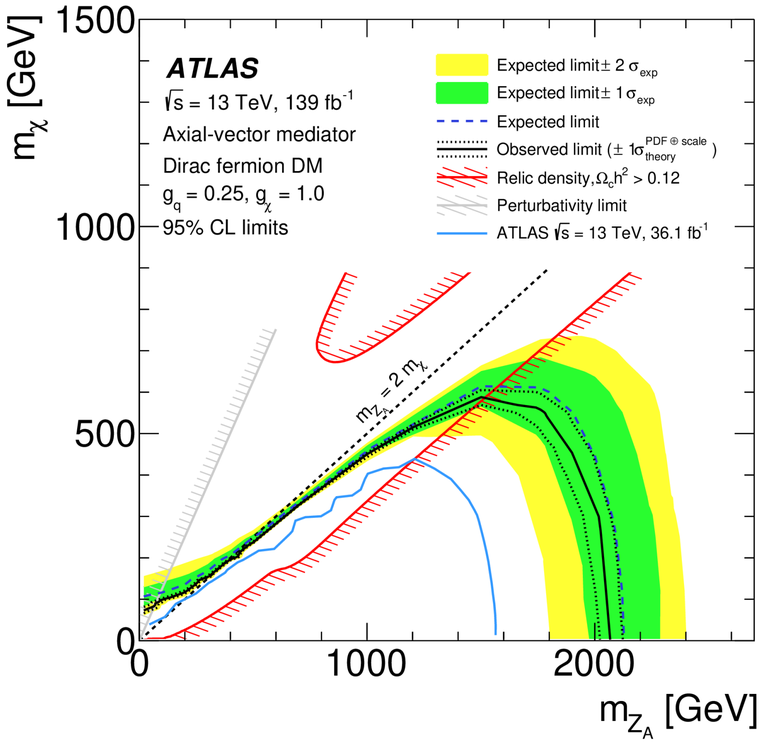


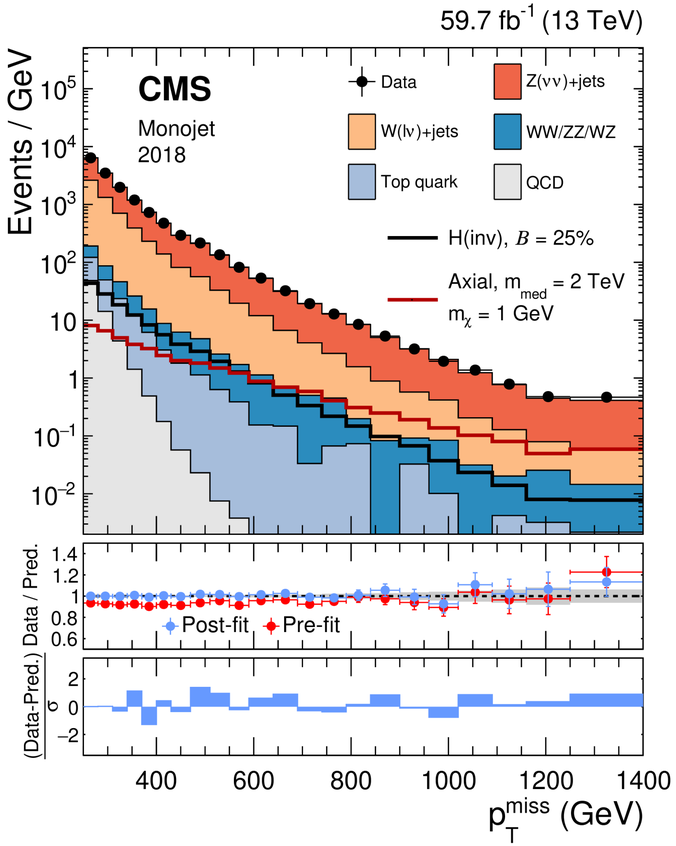
Direct searches: mono-jet

Introduce a spin-1 mediator decaying to DM particles: EXOT-2018-06

- Final state is large missing energy recoiling against a hard ISR jet
- Precise modelling of V+jets through fit of Z(ℓℓ)+jets and extrapolation with NNLO prediction





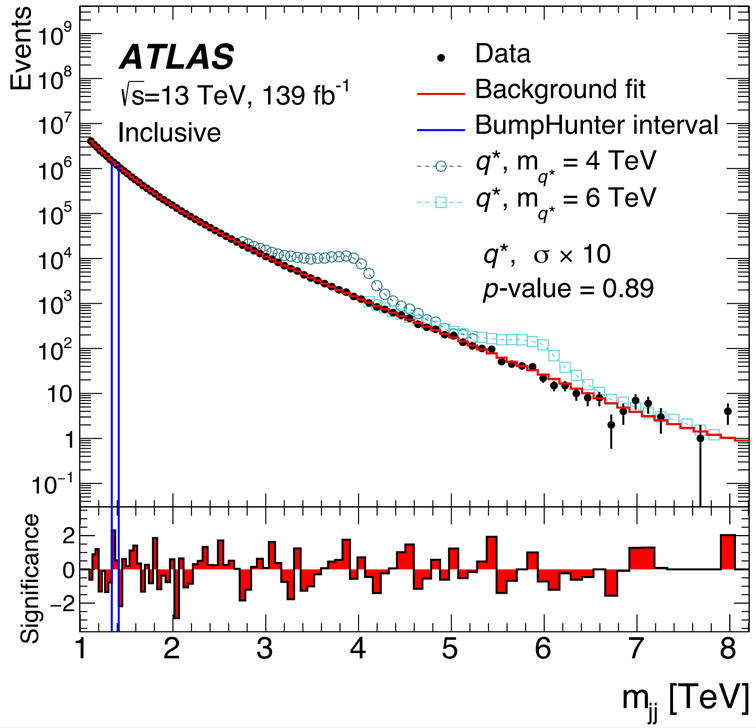


Mediator searches: di-jet

If the mediator is produced from SM particles it can also decay back to SM particles: EXOT-2019-03

- Not directly a DM search but puts constraints on the SM couplings allowed for the mediator to DM

Search for a bump in the di-jet final state

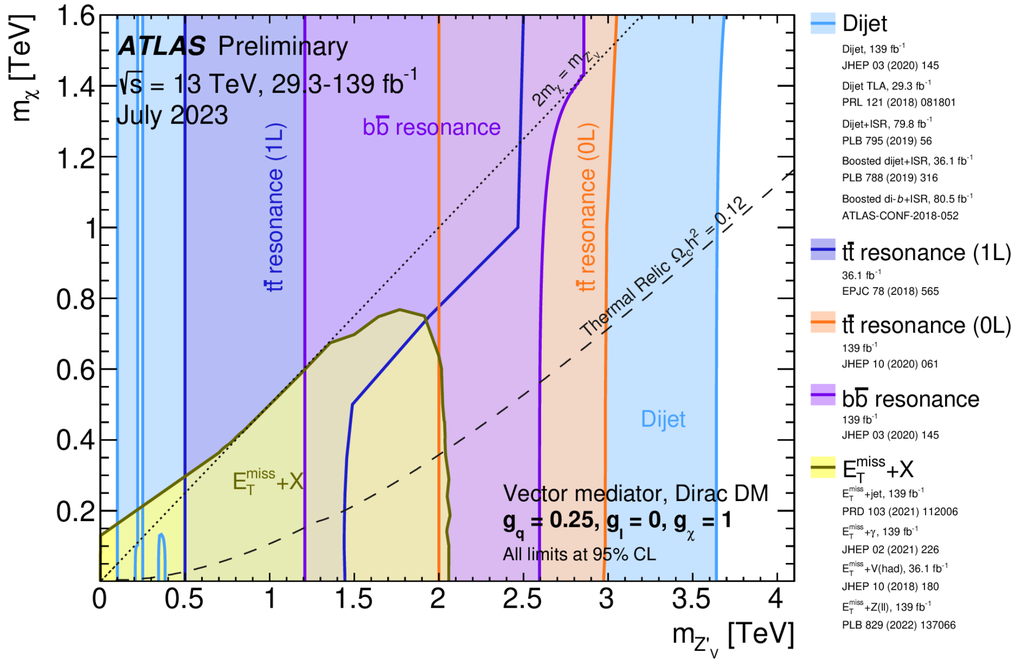


Direct vs mediator searches

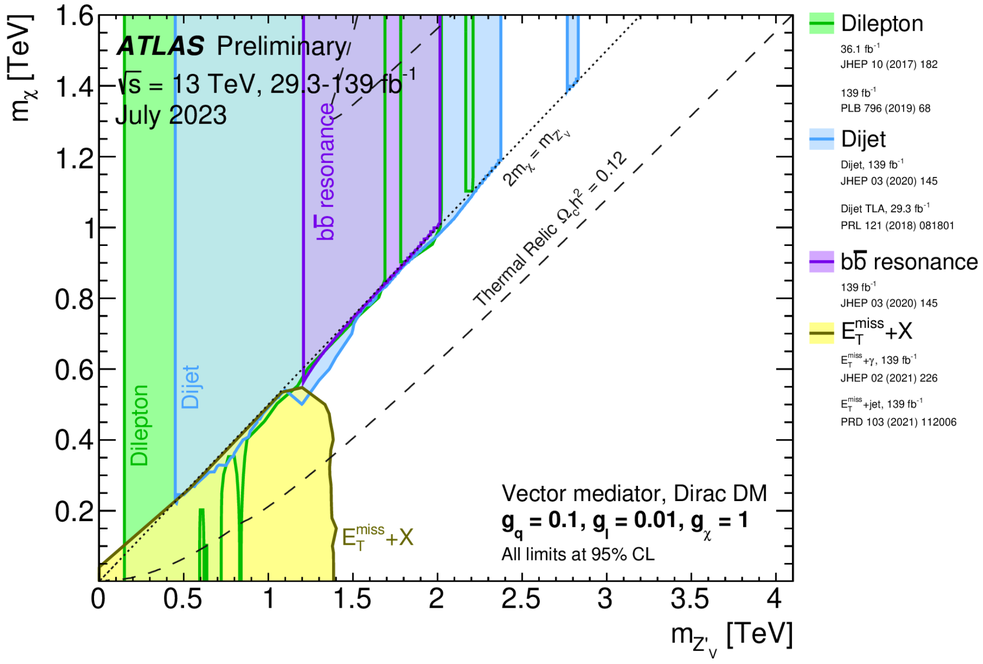
Both approaches can be put in context by testing different choices for the couplings ATL-PHYS-PUB-2023-018

- Plots here for vector mediator and some choice of couplings. Also interpretations for axial-vector mediator

g_q=0.25, g_ℓ=0, g_χ=1



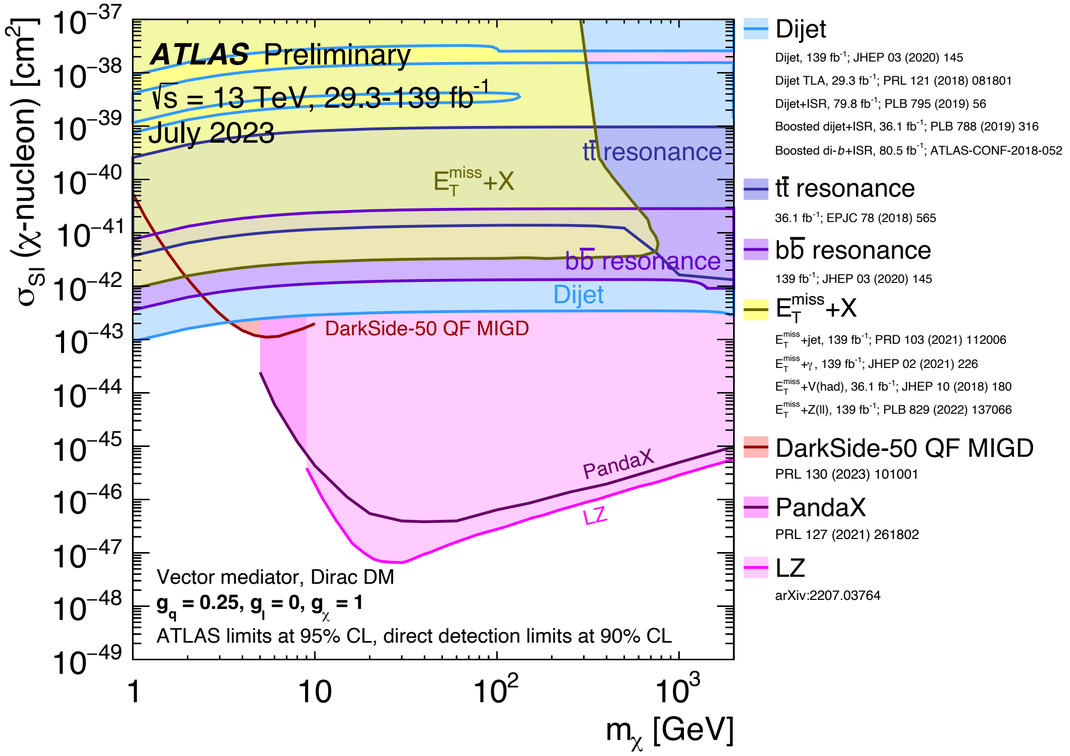
g_q=0.1, g_ℓ=0.01, g_χ=1

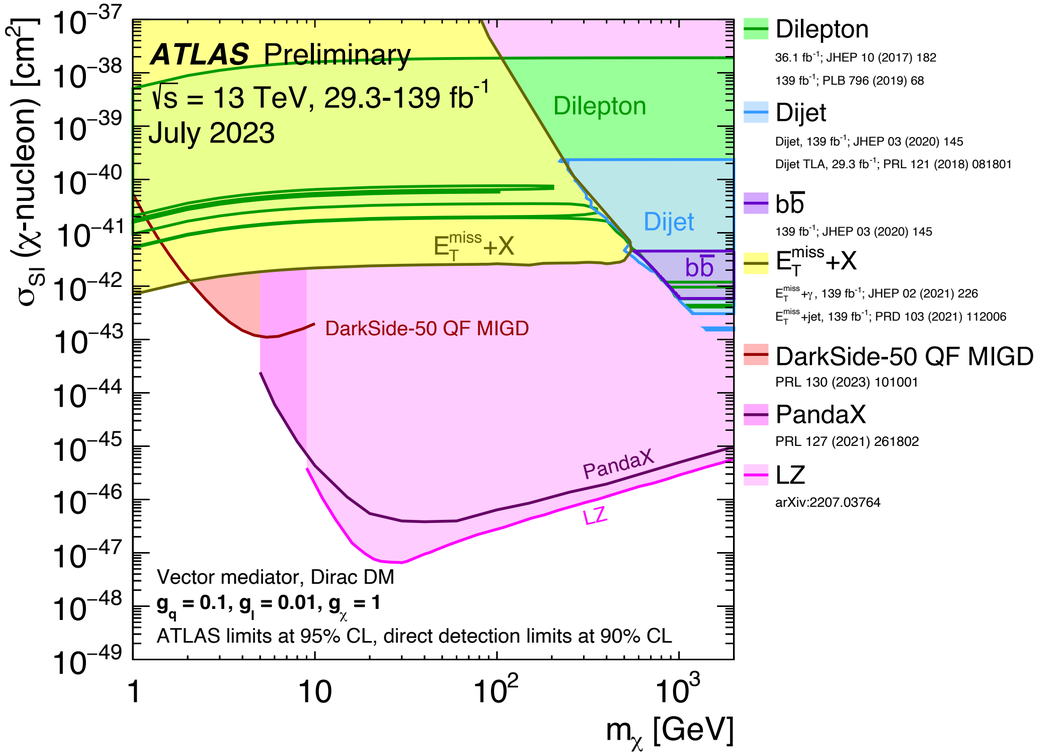


Direct vs mediator searches

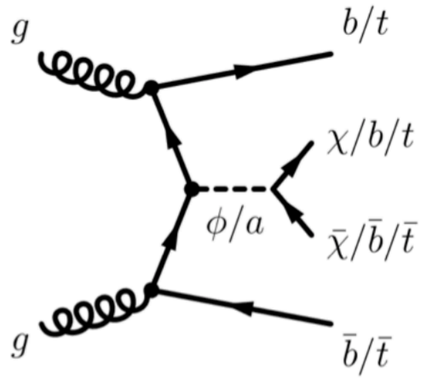
Both approaches can be put in context by testing different choices for the couplings ATL-PHYS-PUB-2023-018

- Plots here for vector mediator and some choice of couplings. Also interpretations for axial-vector mediator
- Can also be compared to sensitivity from direct detection experiments, complementary at low DM masses



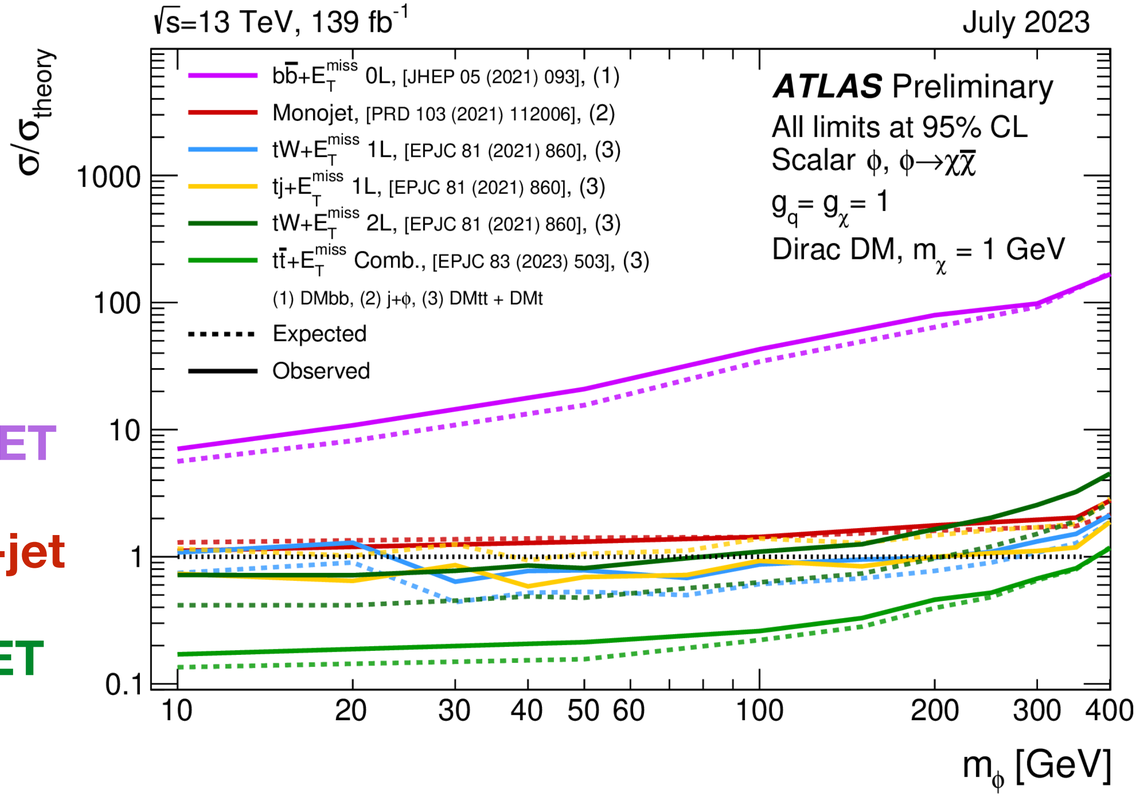


Direct searches: tt+MET



Introduce a spin-0 mediator with yukawa-like couplings

Leading production mode is in association with a top-quark pair



bb+MET

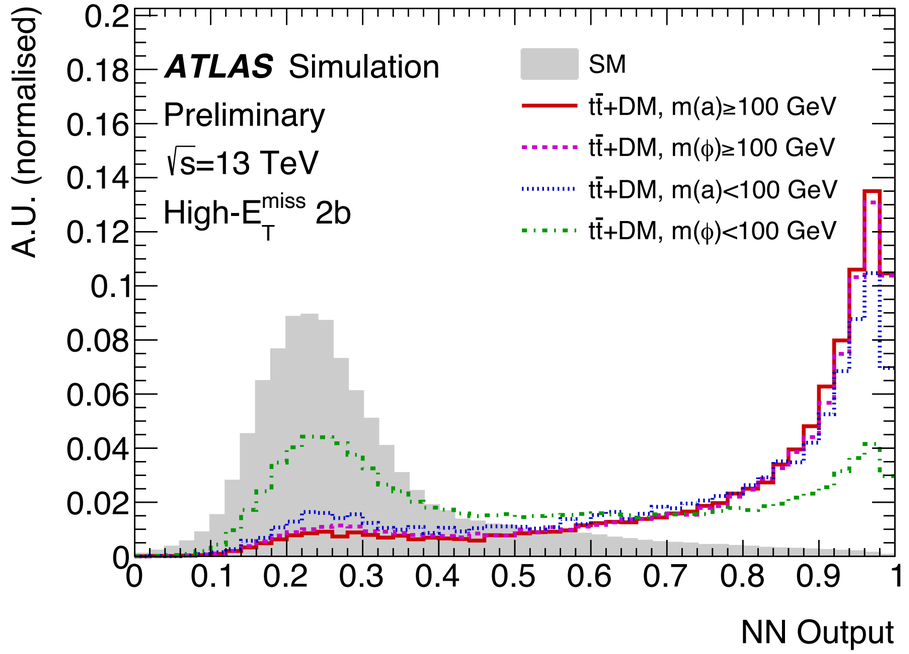
mono-jet

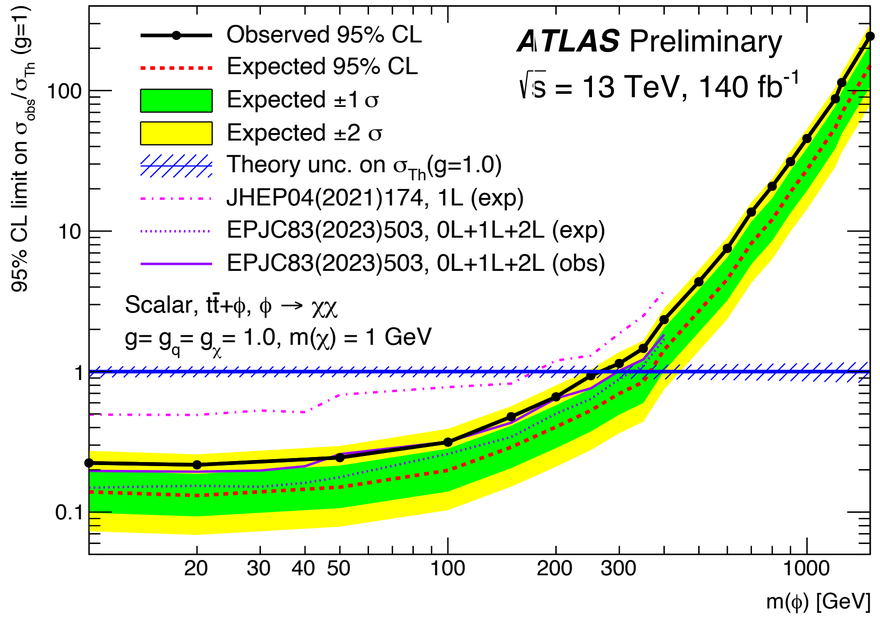
tt+MET

Direct searches: tt+MET

Recent re-analysis of the 1-lepton final state, massively improved sensitivity: ATLAS-CONF-2023-043

- Use neural networks to separate signal and background
- Include single-lepton triggers to access events with lower missing energy
- Expected limit better than previous full combination of 0/1/2-lepton final states



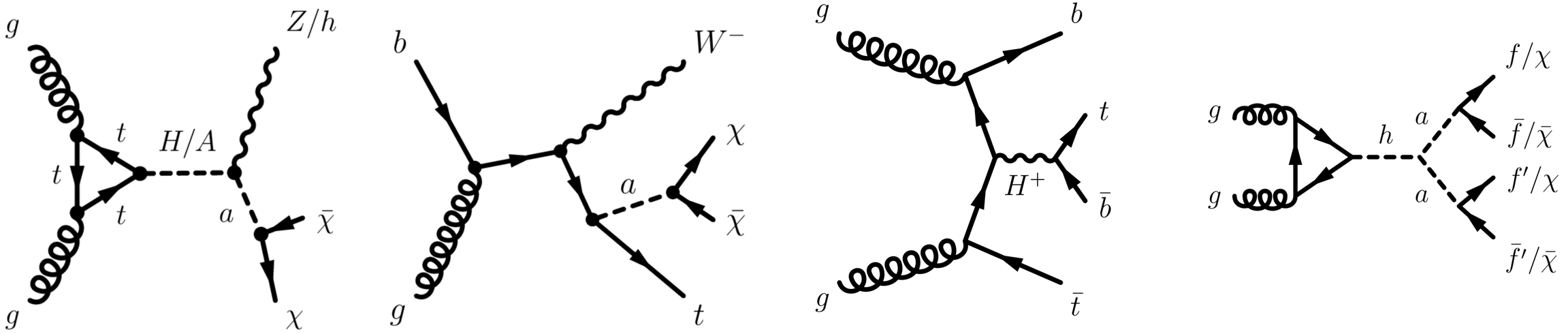


Towards more complete models

Explore the phenomenology of a 2HDM+a model, which has a feasible UV completion: EXOT-2018-64

Additional interesting signatures:

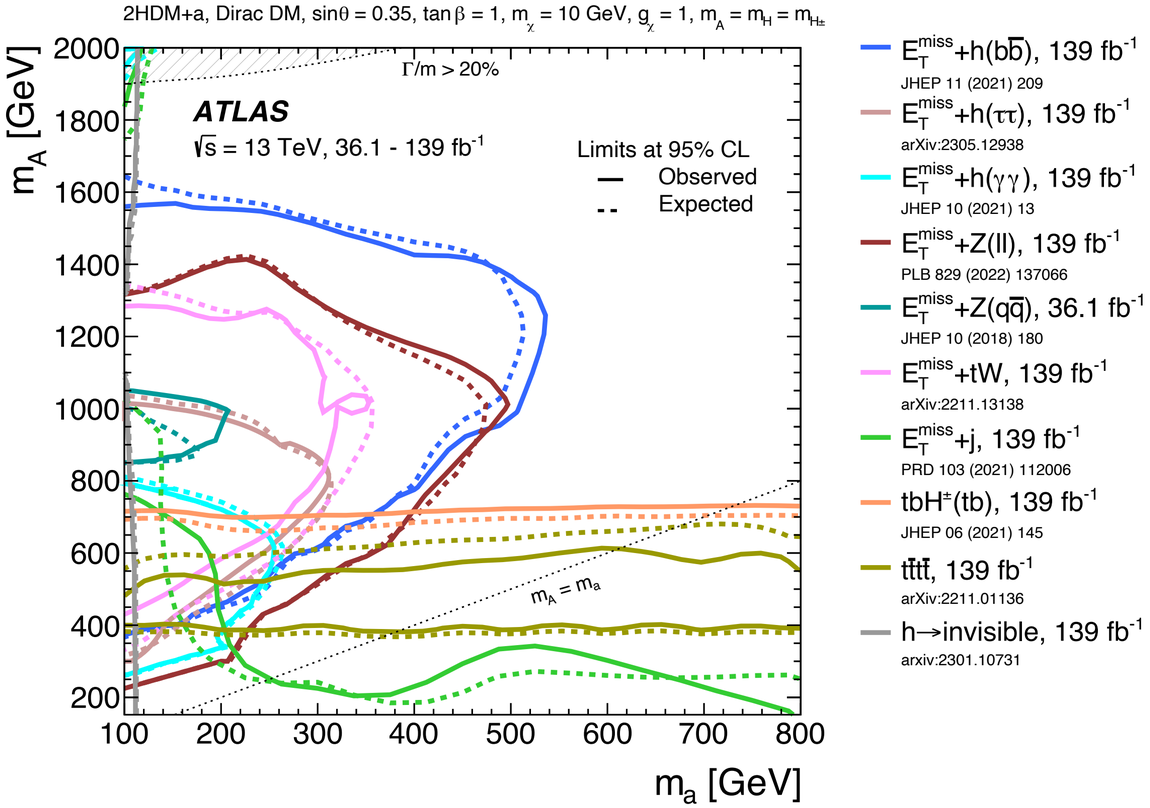
- DM based: mono-Z, mono-h, tW+MET, h→aa→ff+MET
- Mediator based: tbH$^+$, h→aa→ff+f'f'

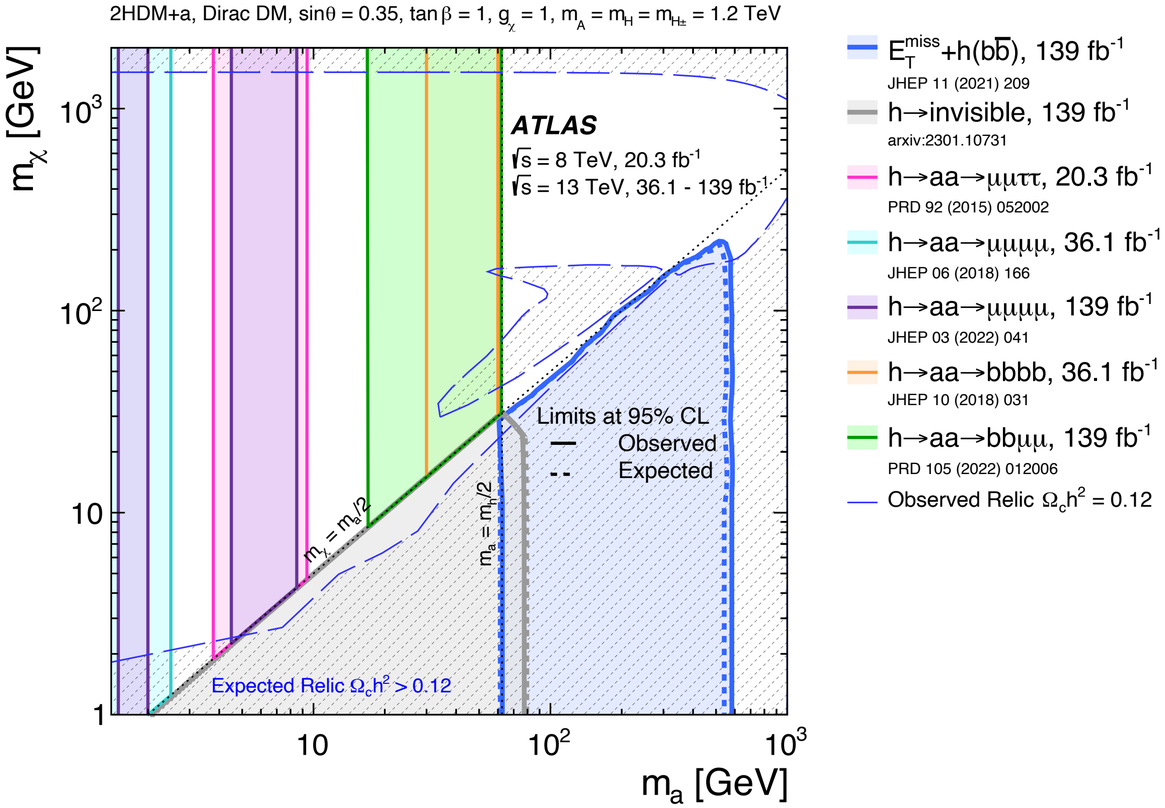


Towards more complete models

Complex interplay of the 5-dimensional model space ($m_{A/H/H^+}$, m_a, m_χ, sin θ, tan β)

- Sensitivity driven by mono-H(bb), mono-Z(ℓℓ), tbH+



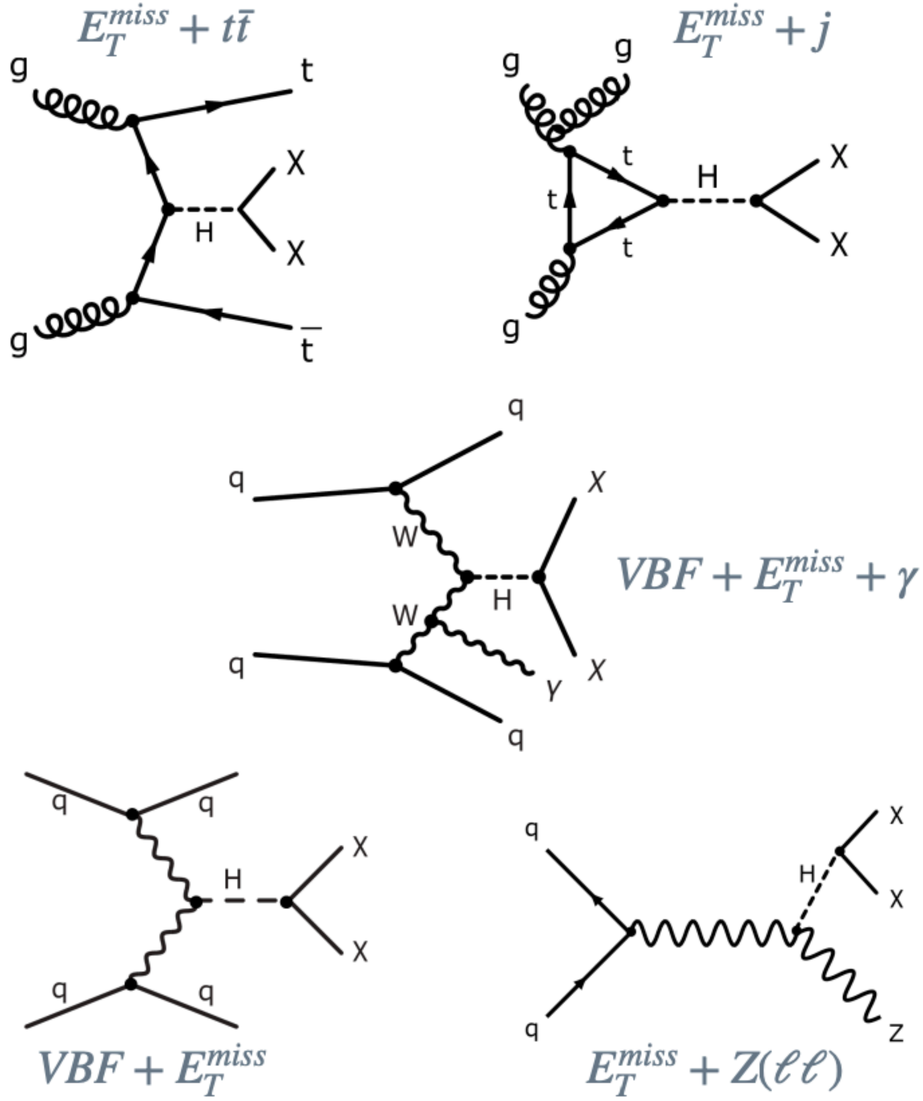


Higgs as a portal to DM

The SM higgs boson could couple to fermionic DM with yukawa-like couplings: HIGG-2021-05

For low masses ($\leq m_H/2$) the Higgs boson could decay to DM → invisible decays

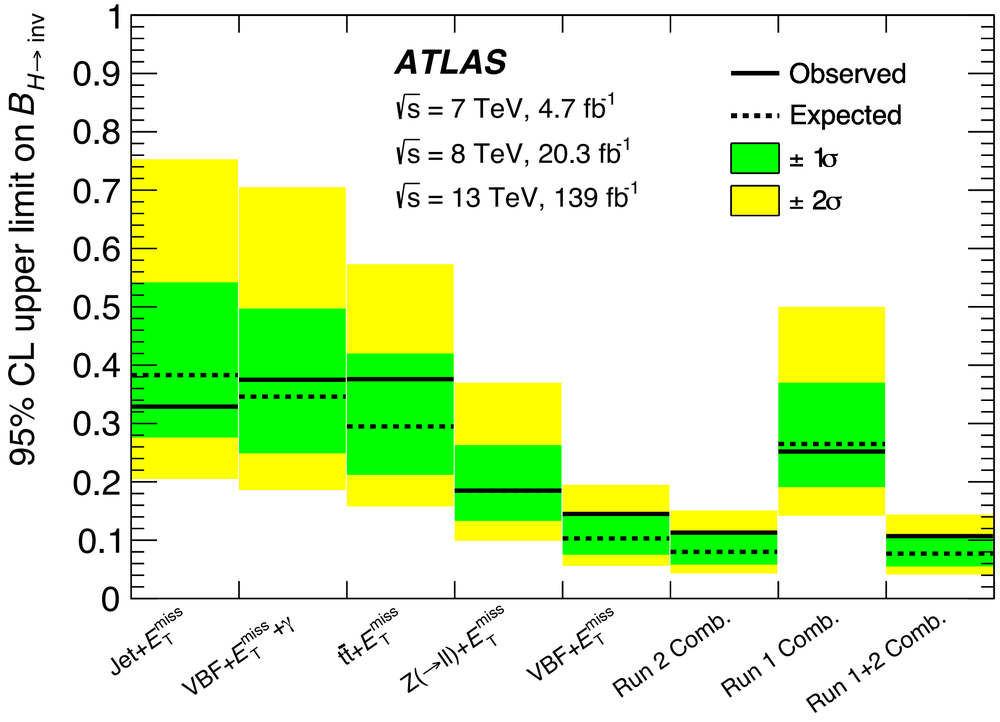
- Can exploit all of the higgs production modes
- Sensitivity dominated by VBF+MET

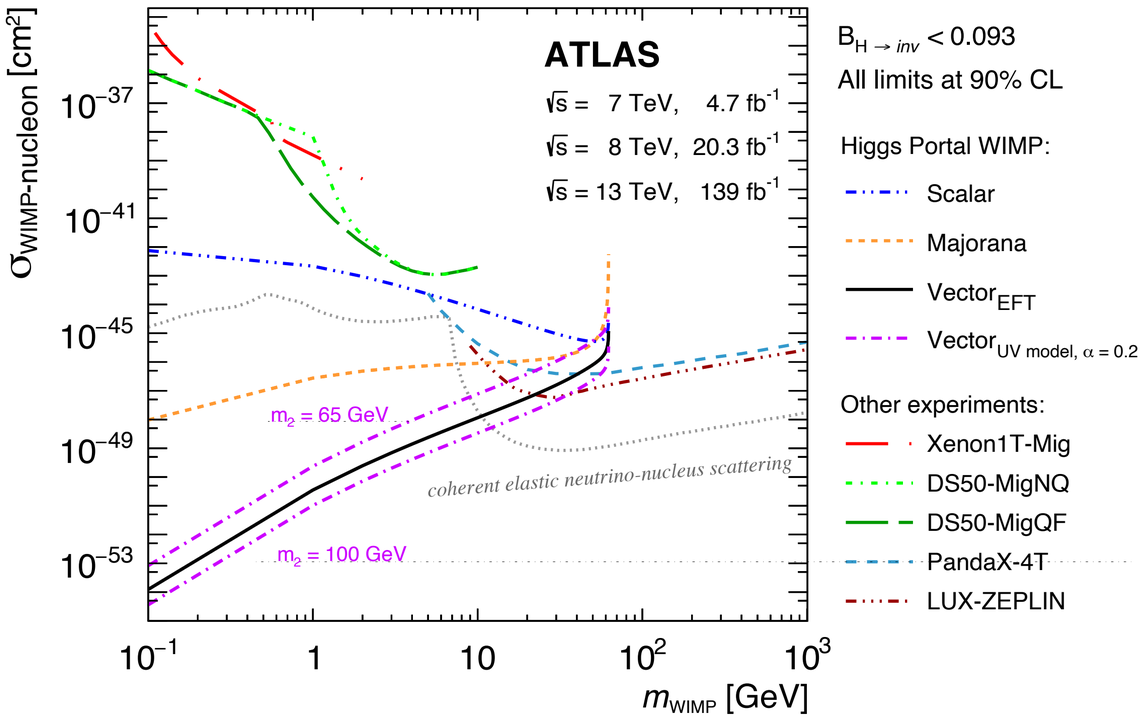


Higgs as a portal to DM

Statistical combination of 5 production modes across Run-1 and Run 2 datasets

Already probing BR(H→ χχ) at the 10% level





Supersymmetry

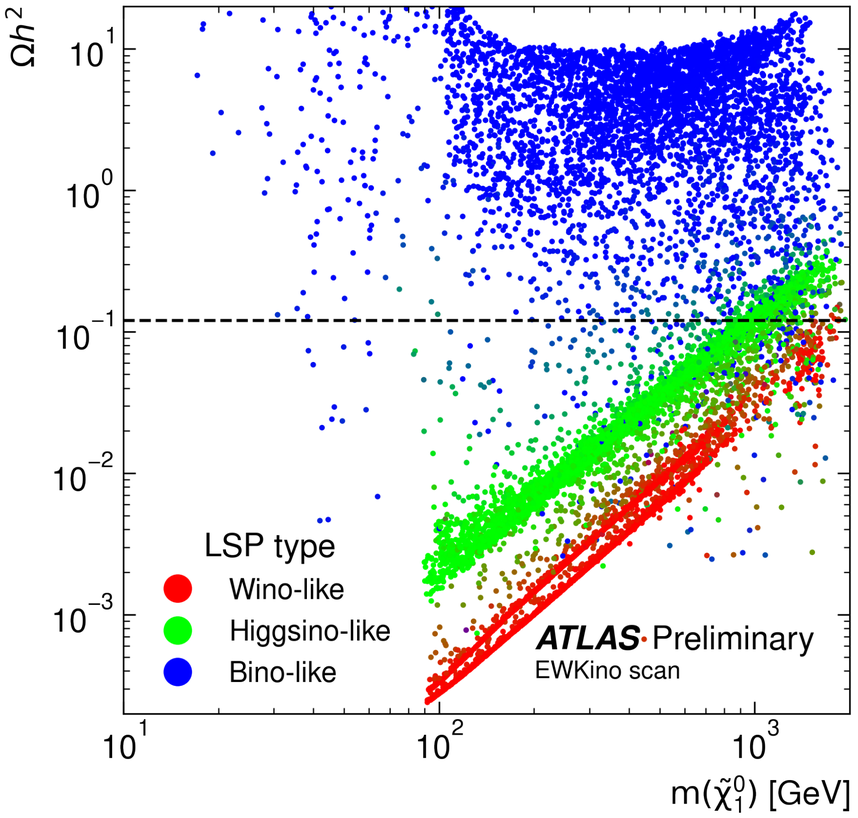
Supersymmetry provides solutions to many problems simultaneously: hierarchy problem, **dark matter**, gauge coupling unification

Highly dimensional parameter space (105 in MSSM) which we reduce to down to a few in our simplified models

- Take all statements from simplified models with a grain of salt

The electroweak superpartners are the bino, wino and higgsinos, depending on which one is the lightest supersymmetric particle (LSP) the phenomenology changes dramatically, especially for DM:

- **Bino**: no direct production, over-abundant relic density → add more nearby sparticles for effective co-annihilation
- **Wino**: small direct production, under-abundant relic density → assume other DM component
- **Higgsino**: very small direct production, under-abundant relic density → assume other DM component



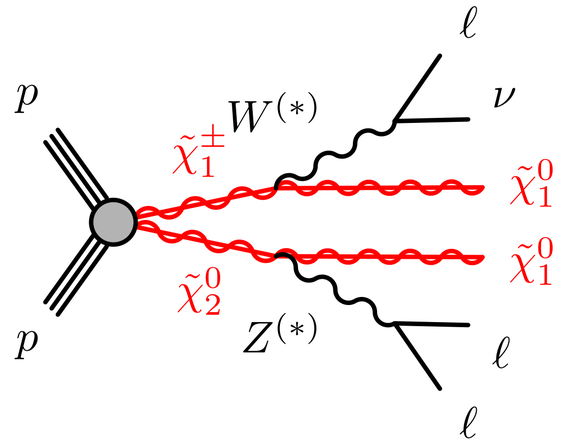
Supersymmetry

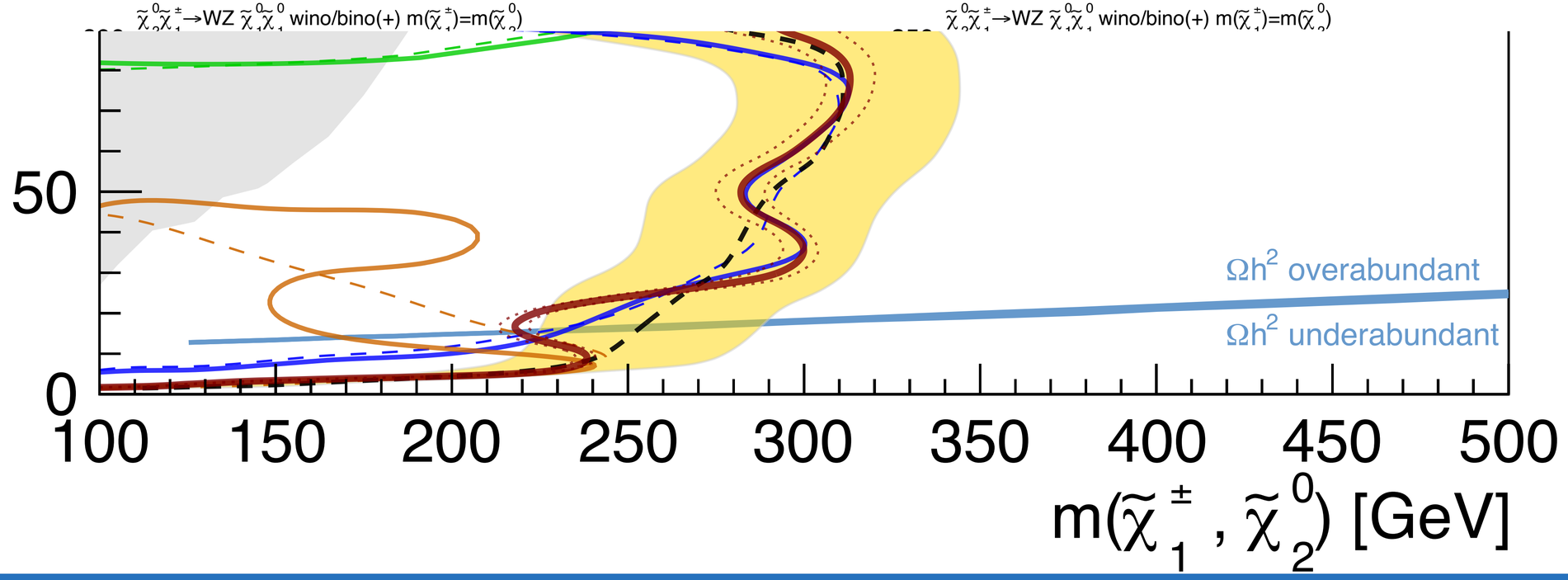
Example, search for wino production decaying to bino LSP: SUSY-2019-09

- Two/three-lepton plus missing energy final state

Set limits on the 2D plane of wino mass $m(\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0)$ vs bino mass $m(\tilde{\chi}_1^0)$

- Only a very small region where the mass splitting is small gives the right relic density





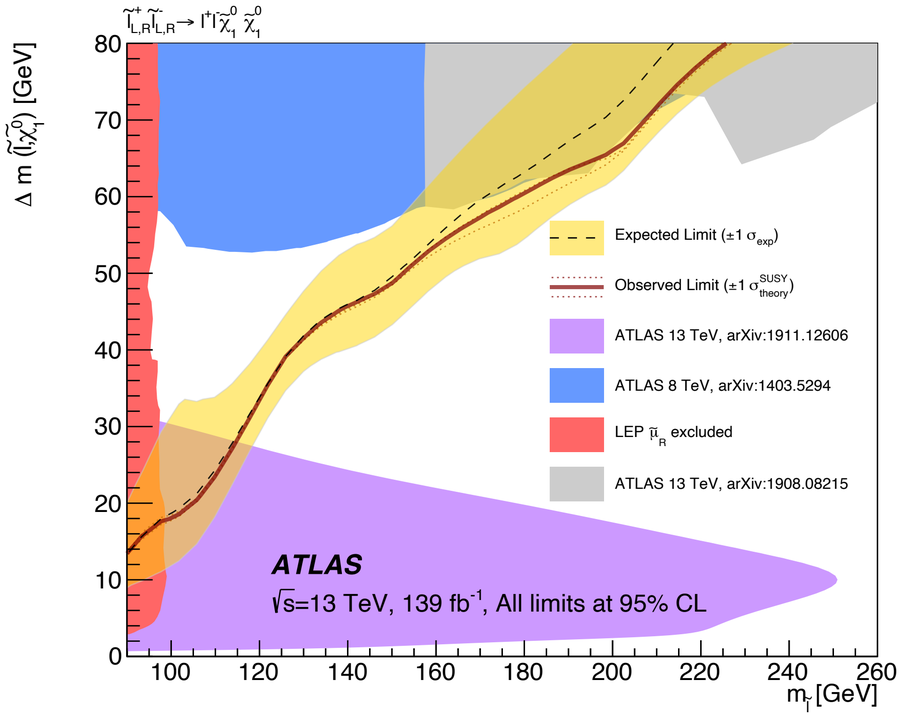
Supersymmetry

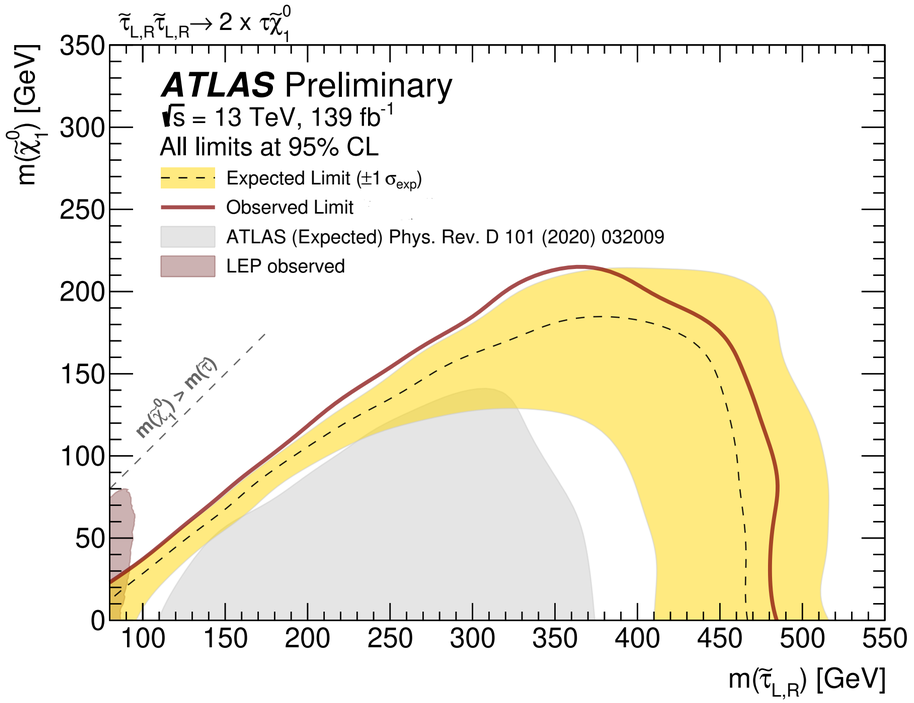
The bino LSP could also co-annihilate with sleptons to get the right relic density

- Needs a mass splitting of 20-30 GeV

Search for light slepton or stau production, 2L + MET: SUSY-2019-02 or 2τ + MET: ATLAS-CONF-2023-029

- The interesting region for DM is exactly the one that we are not able to cover yet





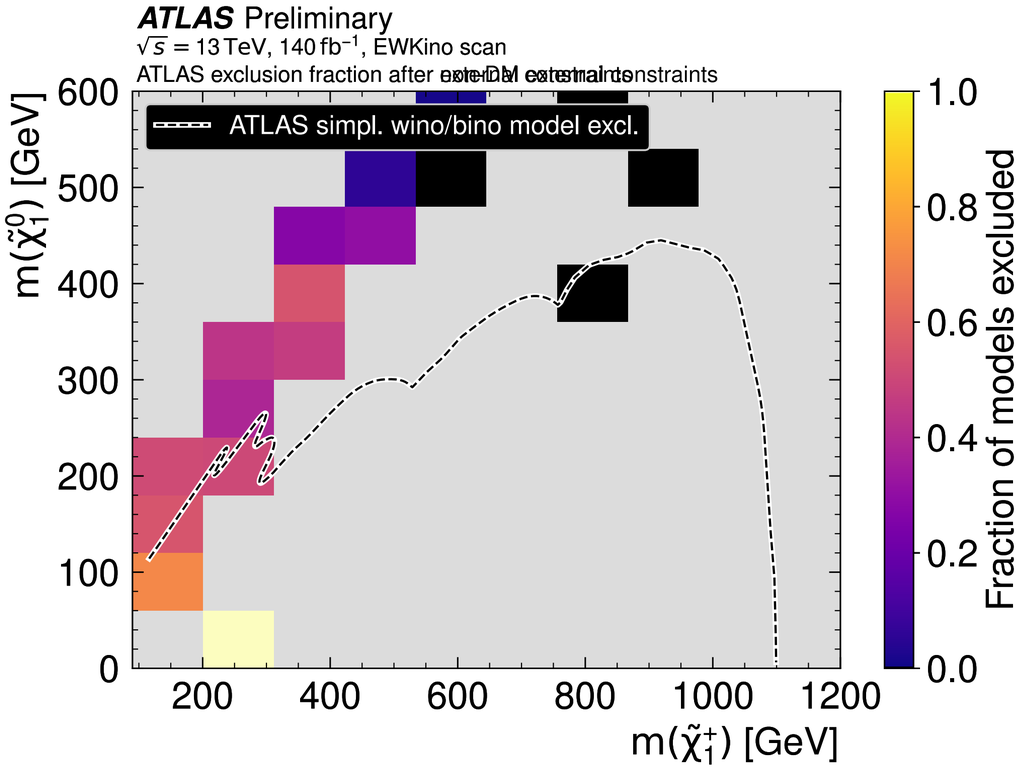
Supersymmetry

Going beyond simplified models, there is a very complex interplay between SUSY particle spectra, collider signatures and DM constraints

Perform a scan of the electroweak sector in the pMSSM: ATLAS-CONF-2023-055

Observations:

- Real limits are way weaker than what we show with our simplified models
- Most of the parameter space wasn't compatible with DM experiments to start with

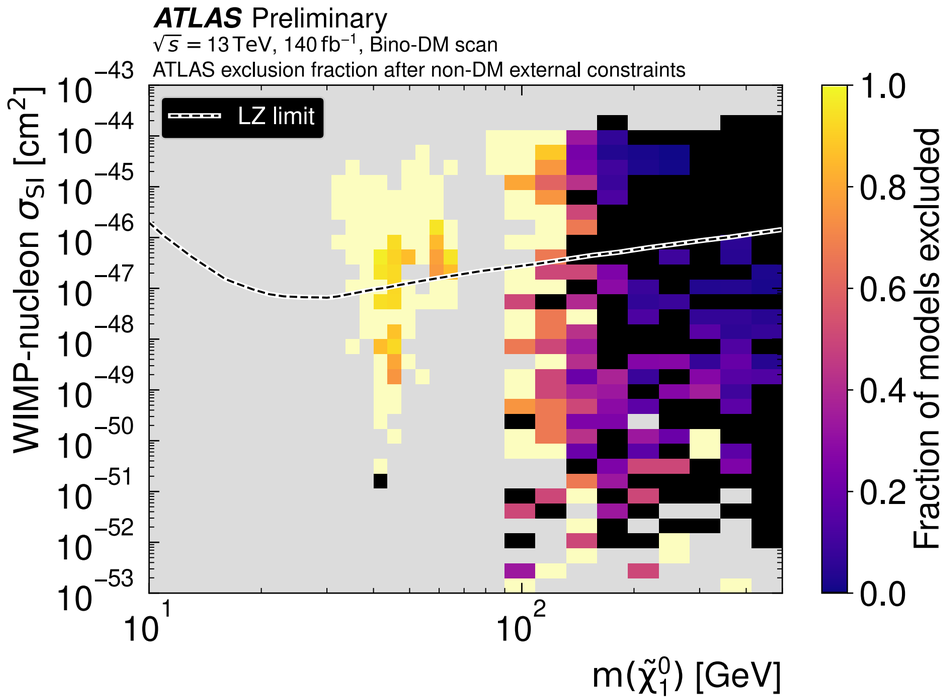


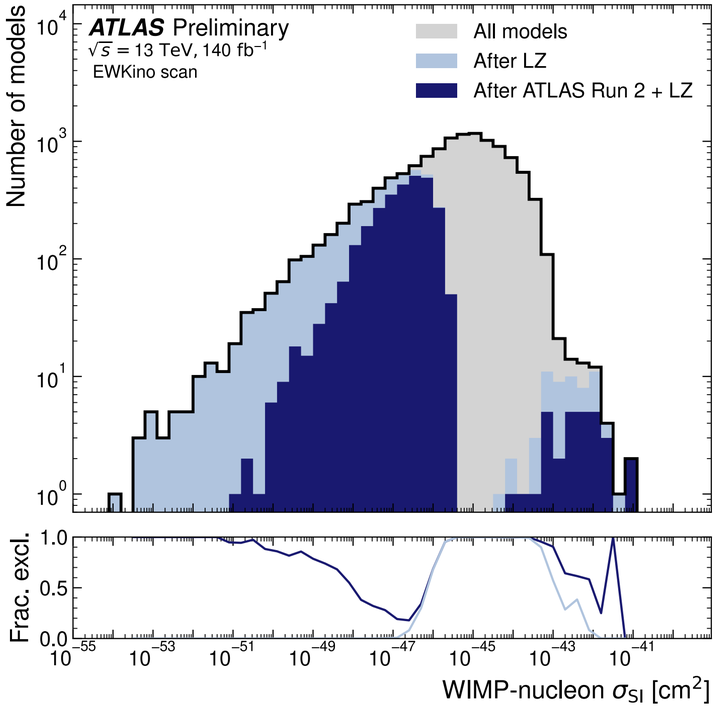
Supersymmetry

Collider searches and direct detection searches are strongly complementary

Strongest sensitivity form collider searches at:

- low neutralino mass
- tiny WIMP-nucleon cross-section



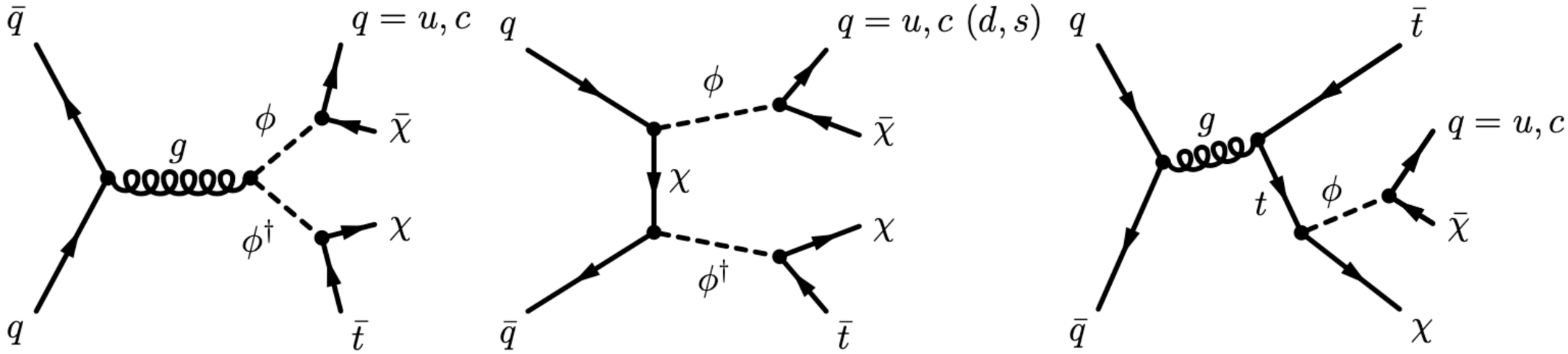


Flavoured dark matter

Additional interesting possibilities for non-minimal dark matter, e.g. flavoured DM 2010.10530

Leads to mono-top or top+charm+MET final states at colliders

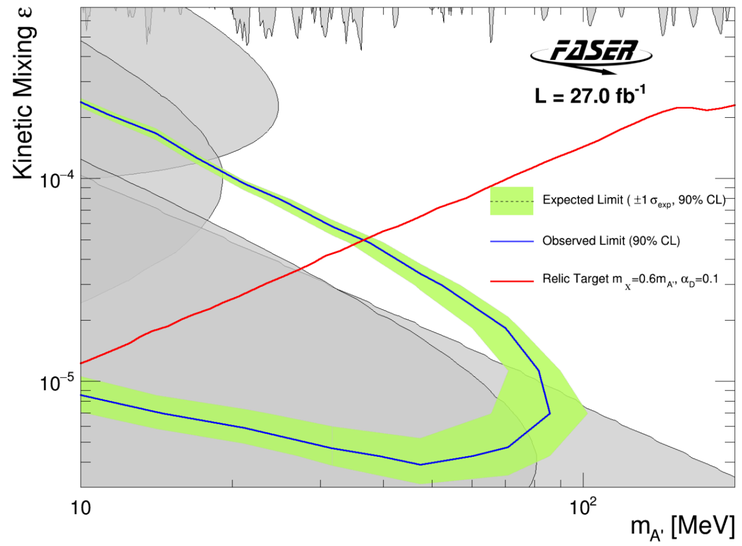
- We are starting to explore these less common signatures: tc+MET ATLAS-CONF-2023-058



Searches at the LHC and beyond

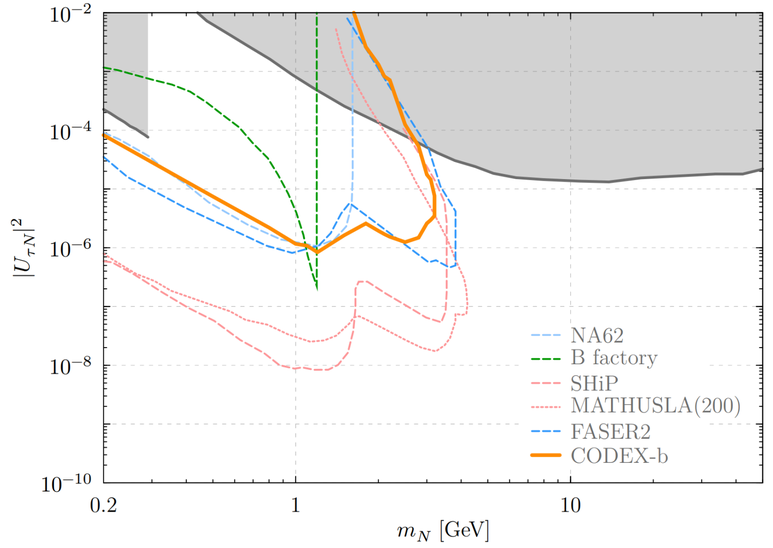
We tend to identify LHC searches = ATLAS/CMS searches (sometimes LHCb), but there is much more!

- FASER is producing first results on dark photons
- Many LLP experiments have been proposed, and some have already prototypes installed
  - ANUBIS, CODEX-b, MATHUSLA



And going slightly beyond scope, there are other (proposed) searches and **physics beyond colliders**

- E.g. NA64, HIKE, SHADOWS, SHIP, MilliQan and experiments at FPF



Conclusions

There is a vibrant and exciting program of searches for DM at the LHC

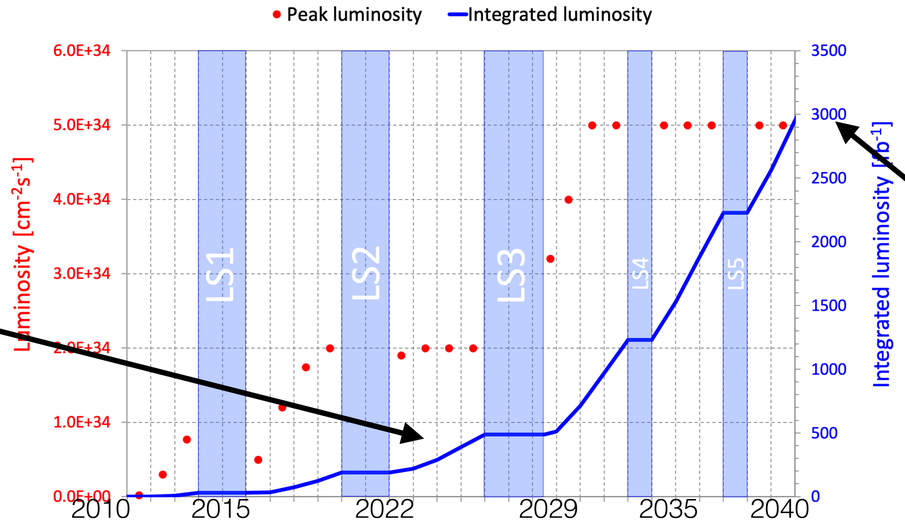
Strong complementarity between programs, both are needed!

- direct/indirect DM searches may prove DM but not identify DM particle
- collider searches can identify particle from the accompanying event and couplings, but cannot prove that's DM

Exciting times ahead with Run 3 dataset and upcoming HL-LHC runs

- Let's do our part and **leave no stone unturned**

And remember, we are here



and we are heading here
(see Caterina's talk)

lots of fun and challenges ahead!