



SEARCHES FOR DARK MATTER WITH THE ATLAS EXPERIMENT AT THE LHC

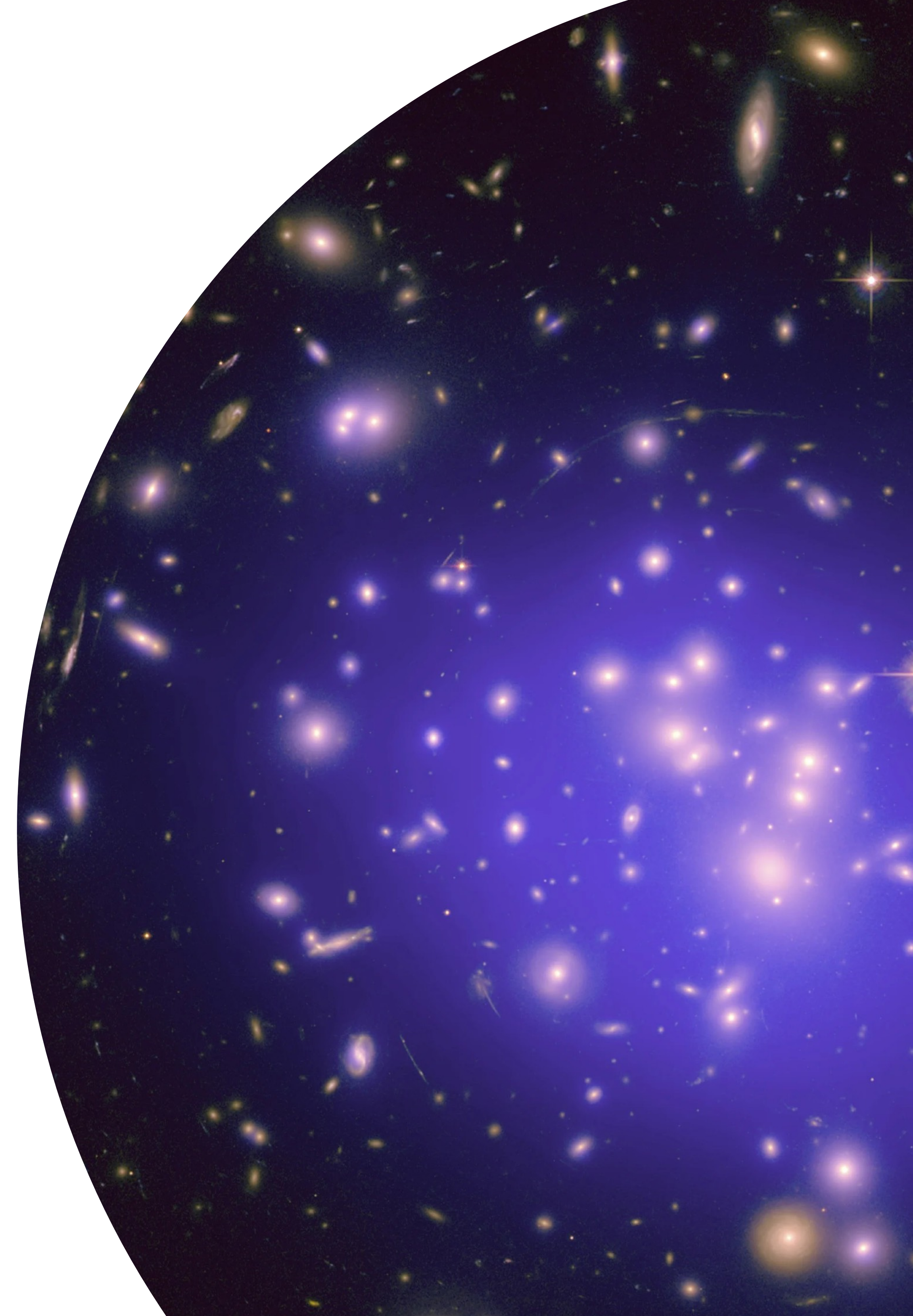
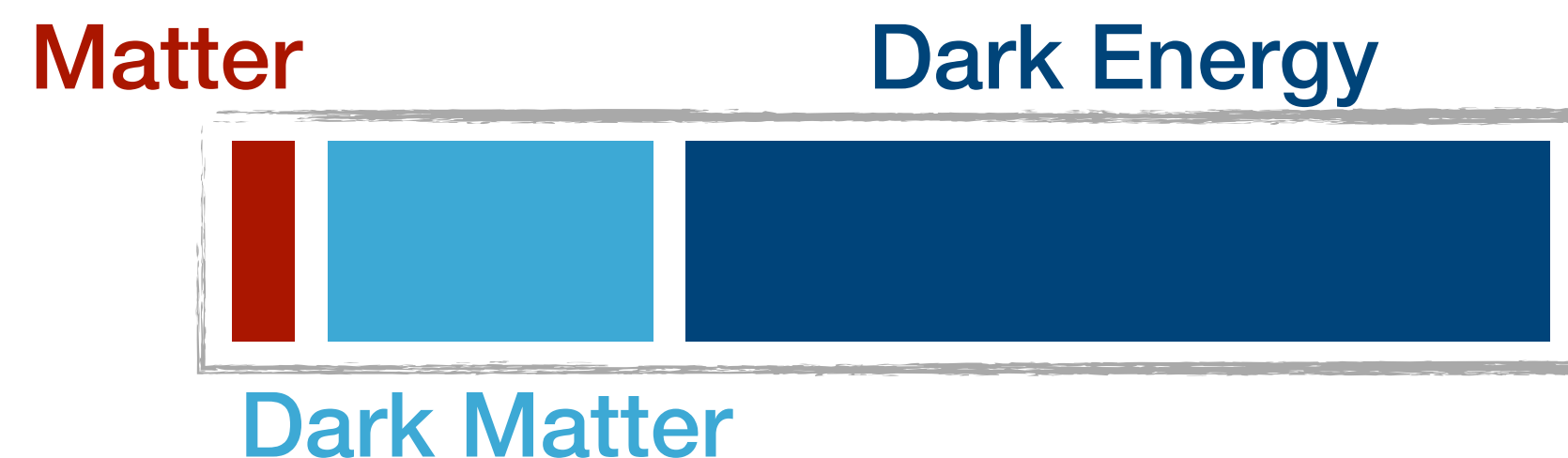
M. Bauce, *on behalf of the ATLAS Collaboration*
Lake Louise Winter Institute, February 18-24 2024

DARK MATTER AT COLLIDERS

- Dark Matter existence has been confirmed by many Astronomical observations
- Plenty of models trying to describe its behaviour though yet not clear
- At colliders, most DM searches are driven by a crucial assumption:
 - DM is a **Weakly Interacting Massive Particle**



These searches are complementary to those of Direct and Indirect Detection experiments

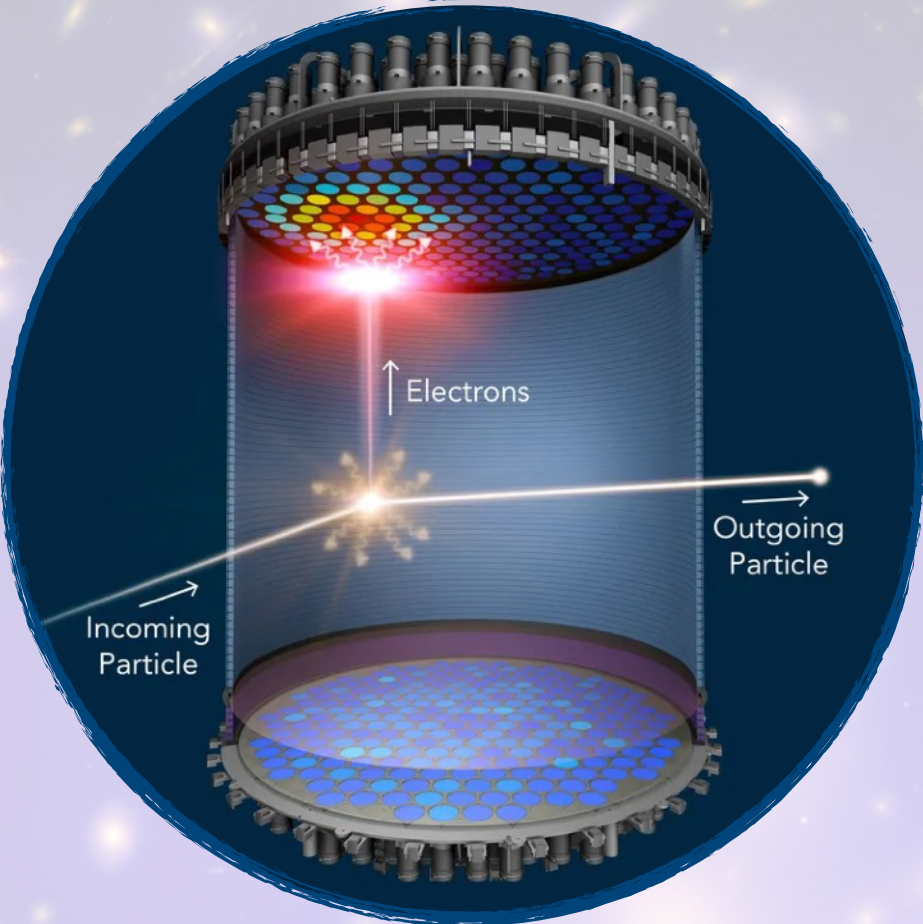
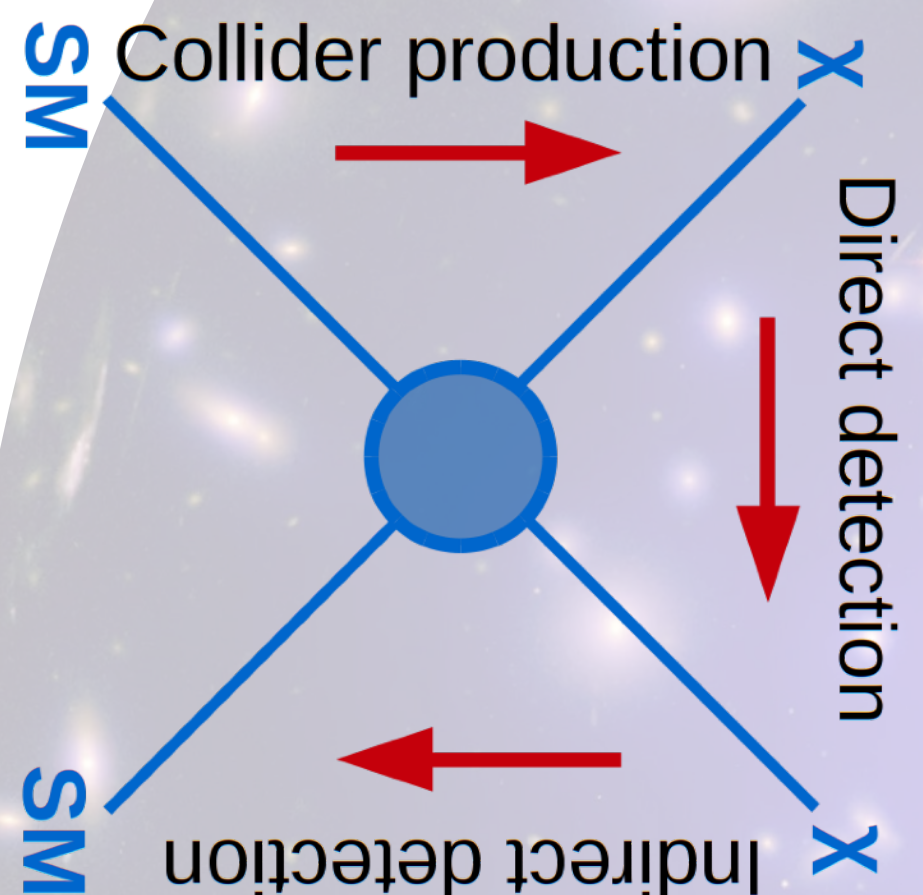
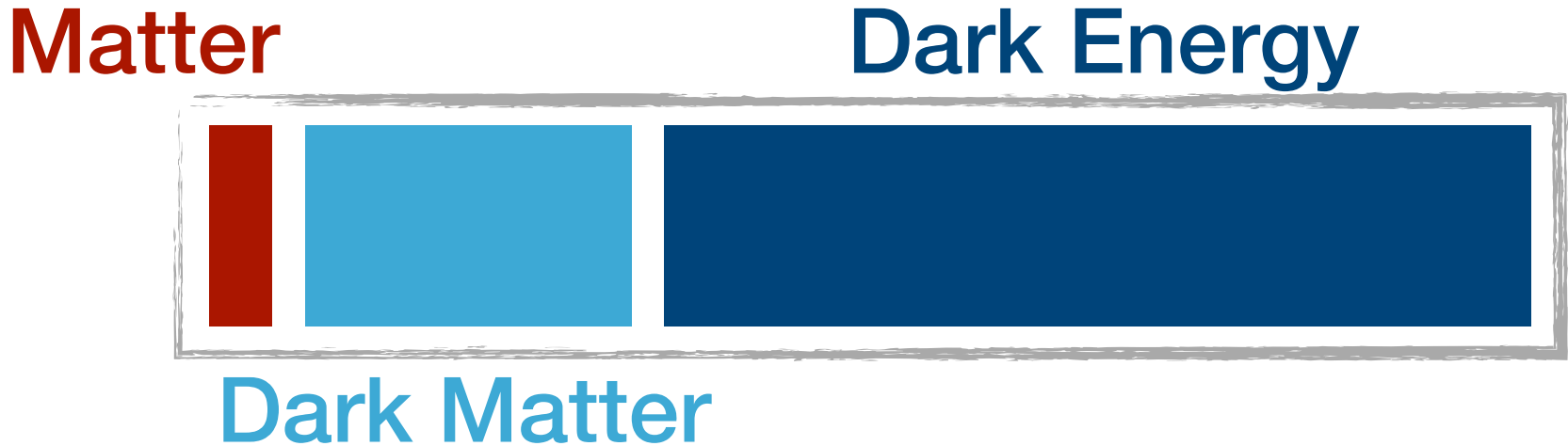


DARK MATTER AT COLLIDERS

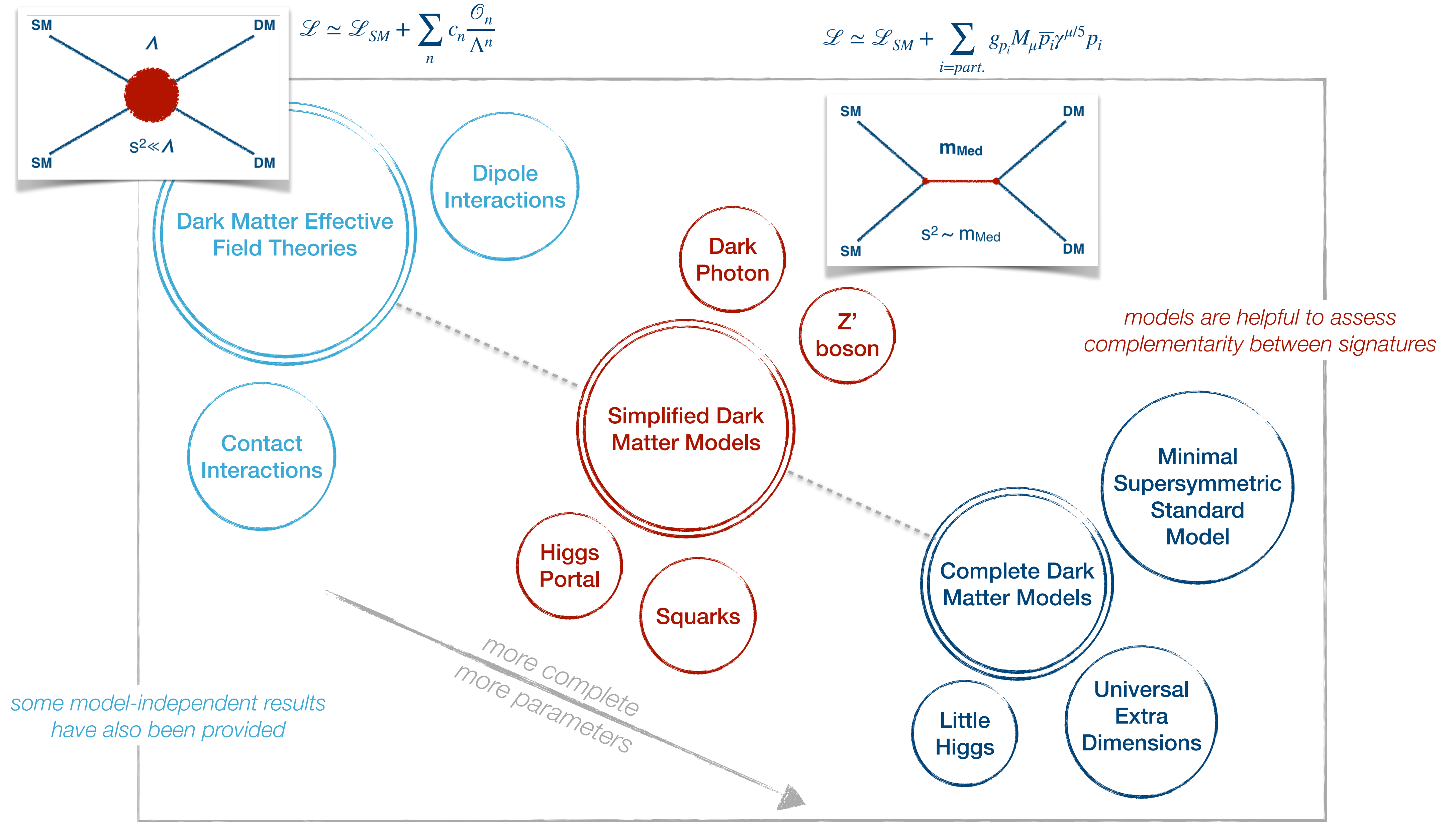
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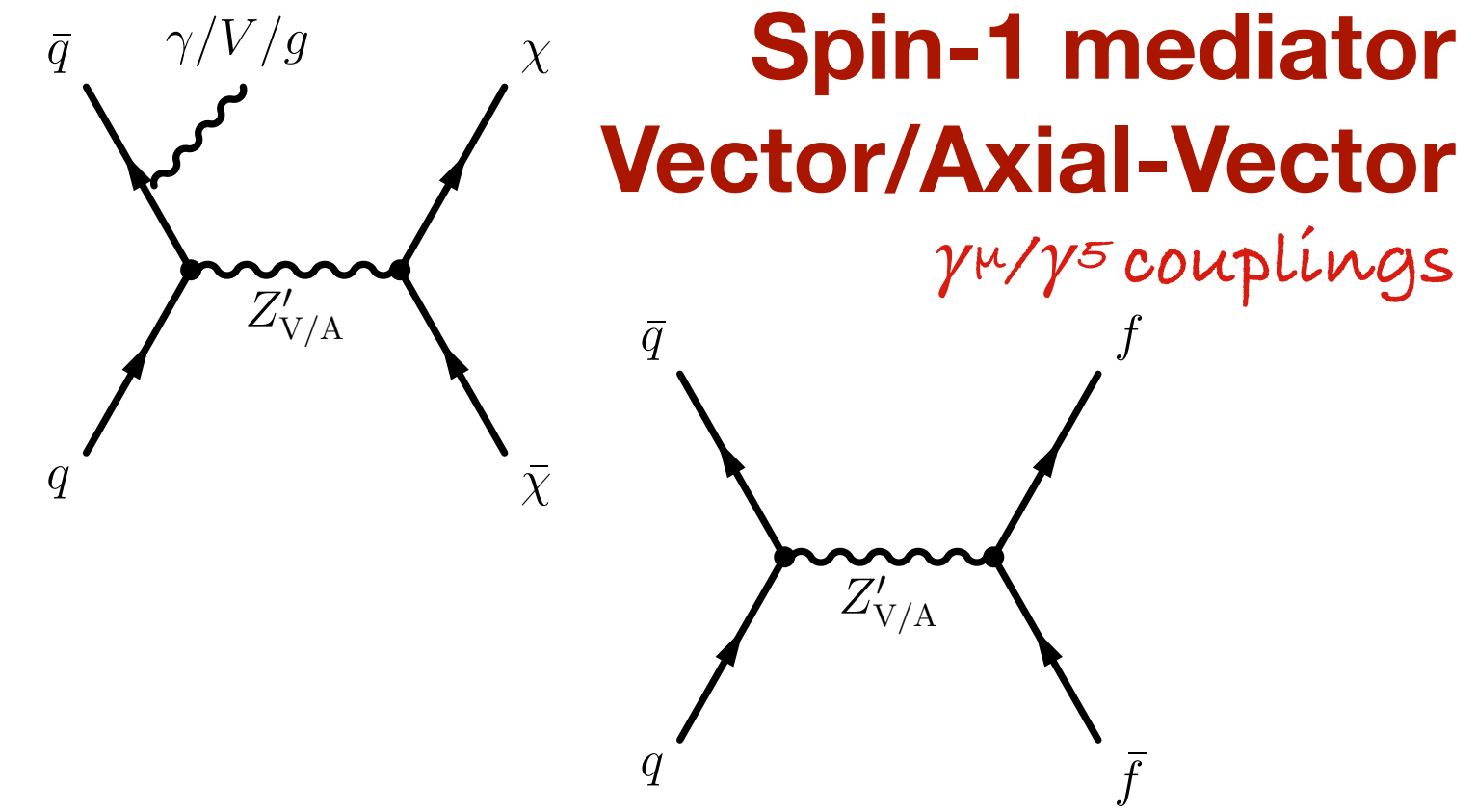
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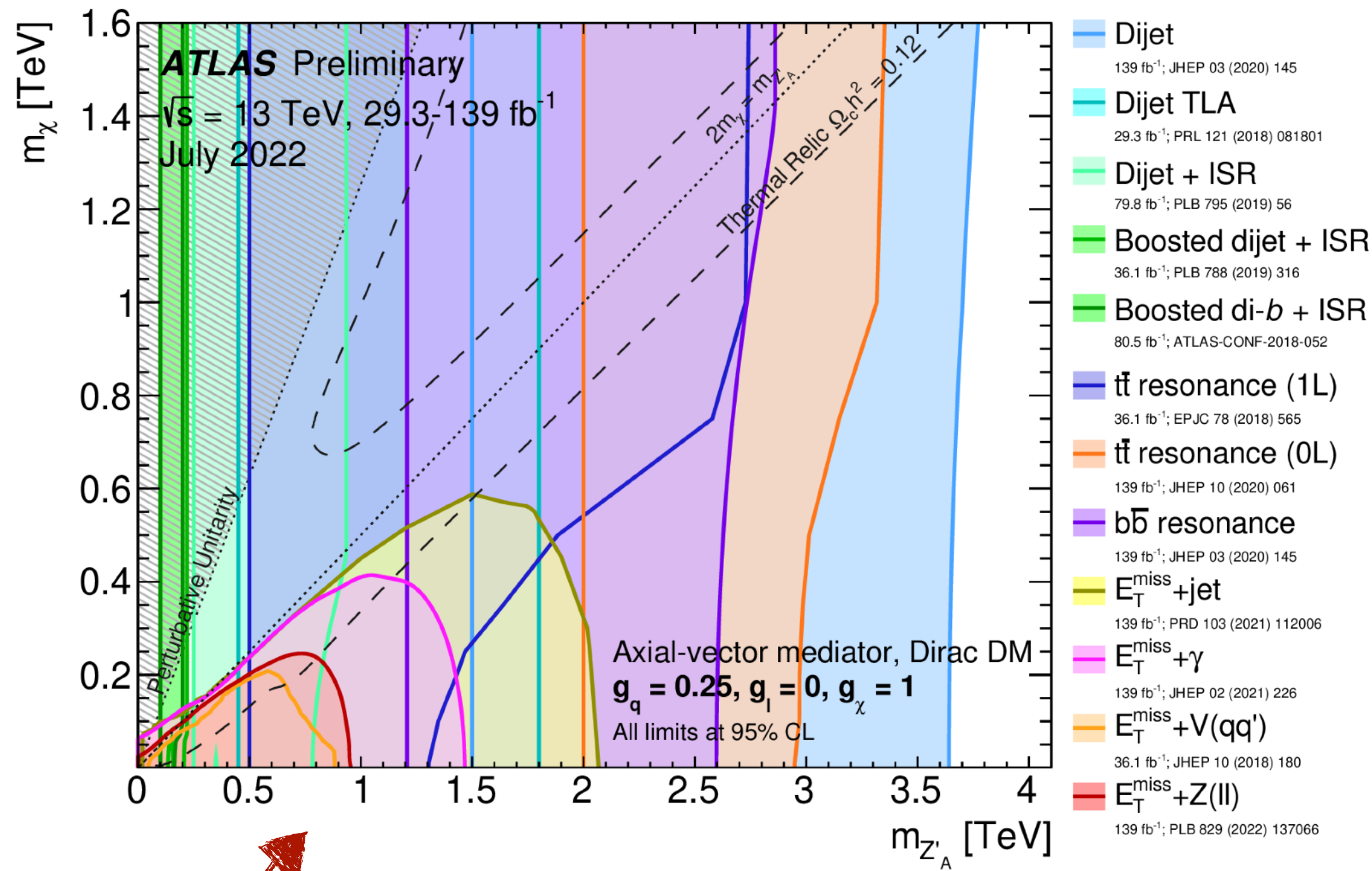
DARK MATTER BENCHMARK MODELS



SIMPLIFIED MODELS - (AXIAL)VECTOR

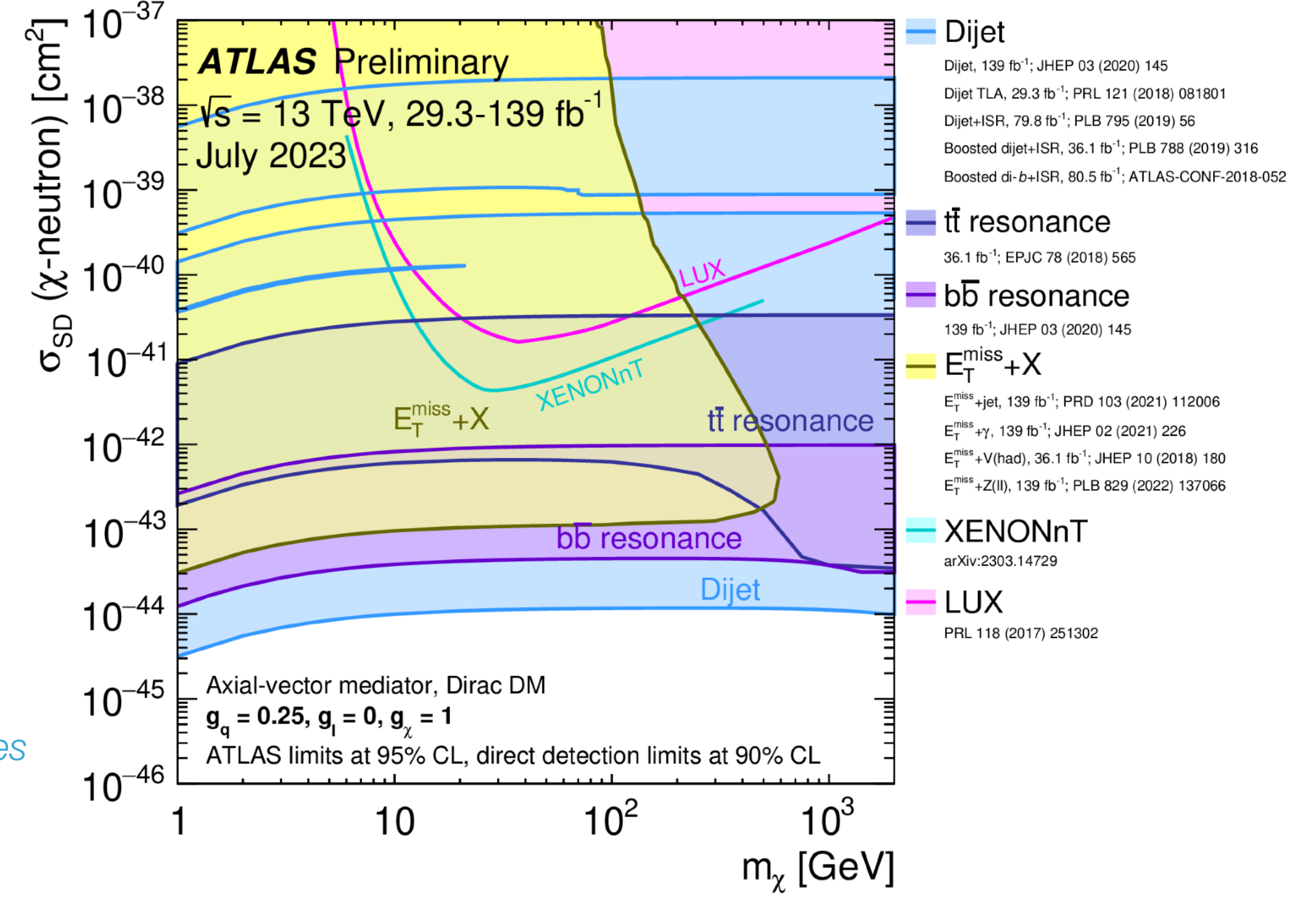


Resonance searches

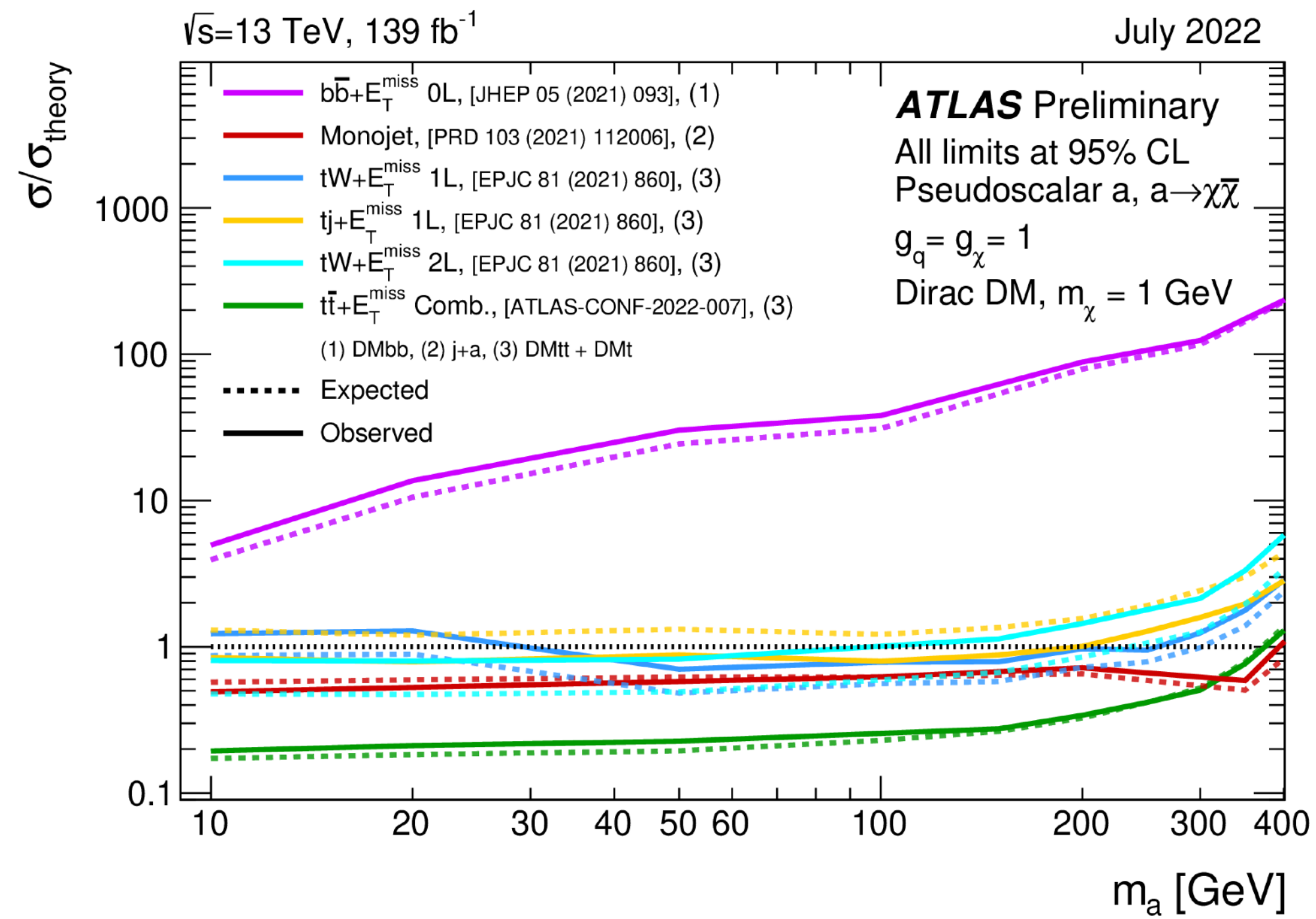


$E_T^{\text{miss}} + X$ searches

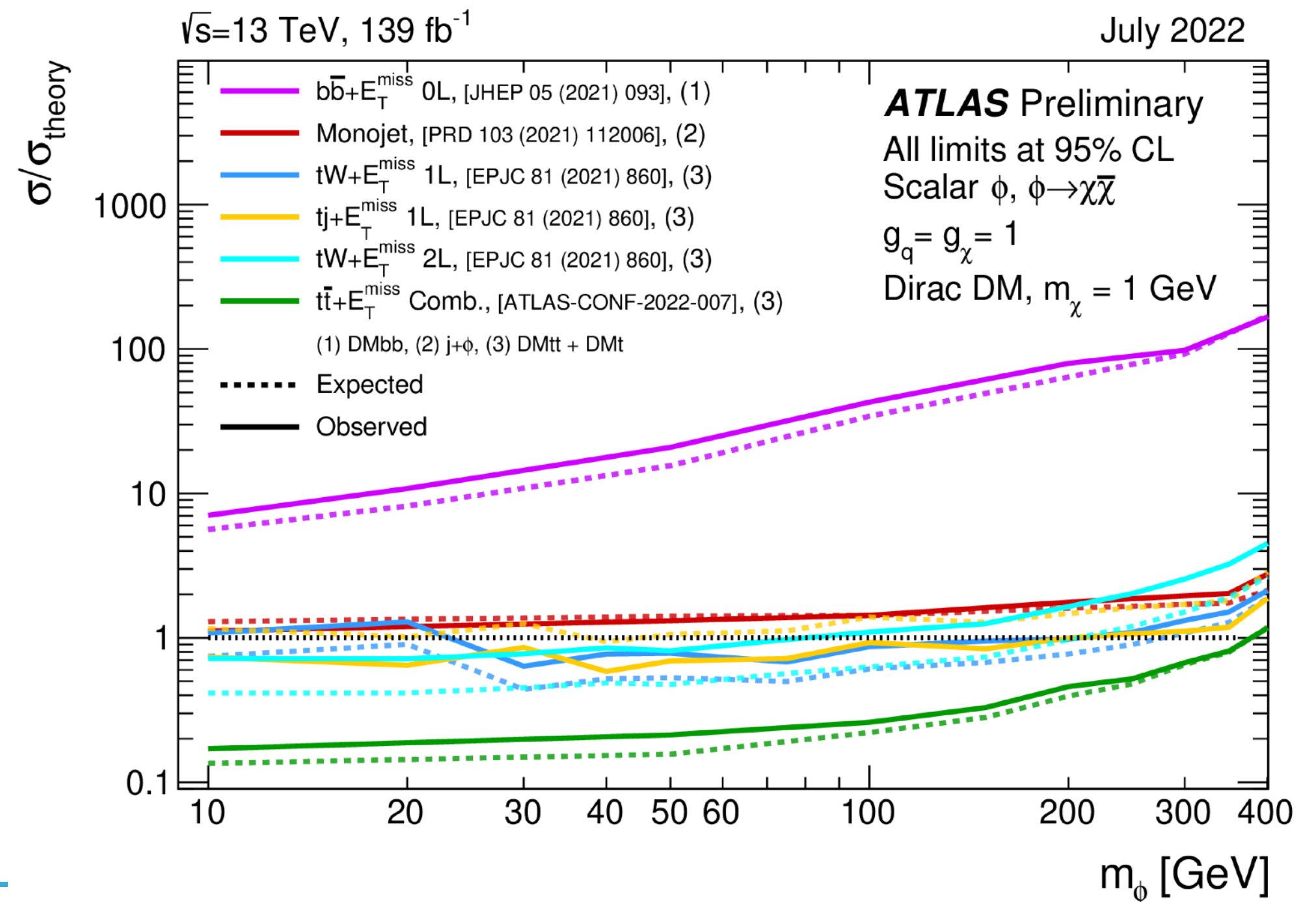
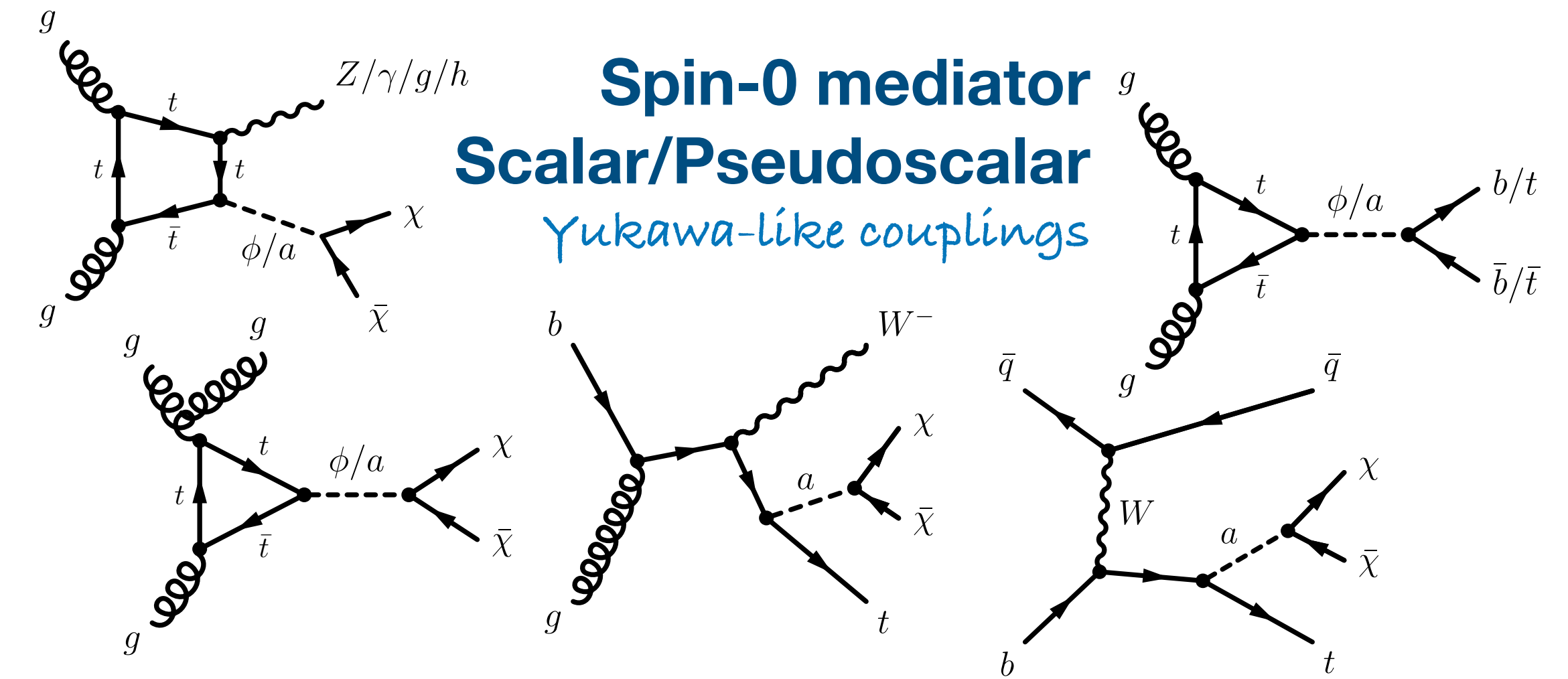
results depending on coupling choices



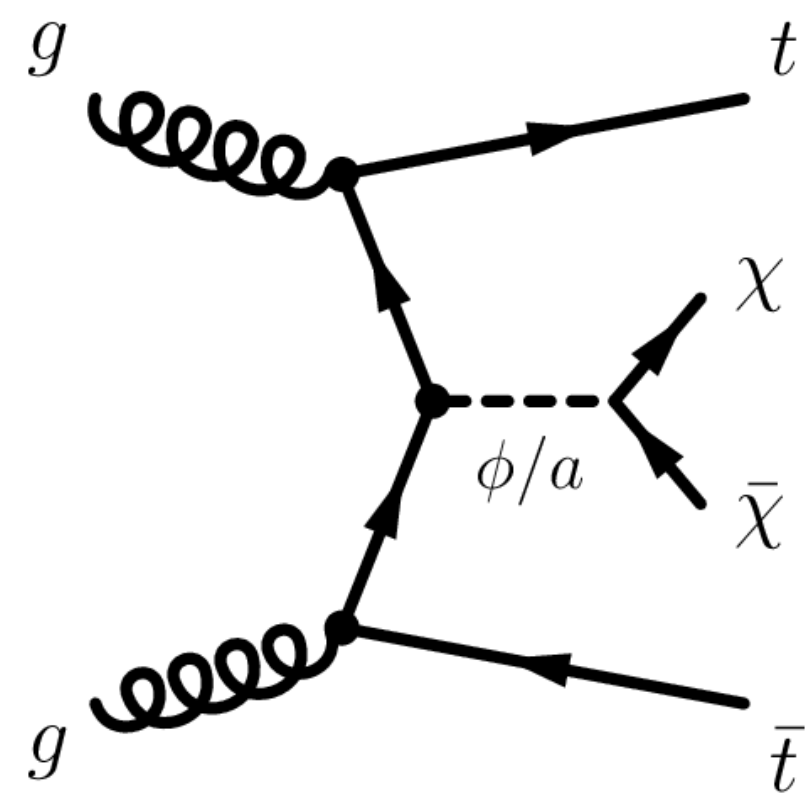
SIMPLIFIED MODELS – (PSEUDO)SCALAR



Signatures dominated by heavy flavour quarks + E_T^{miss}

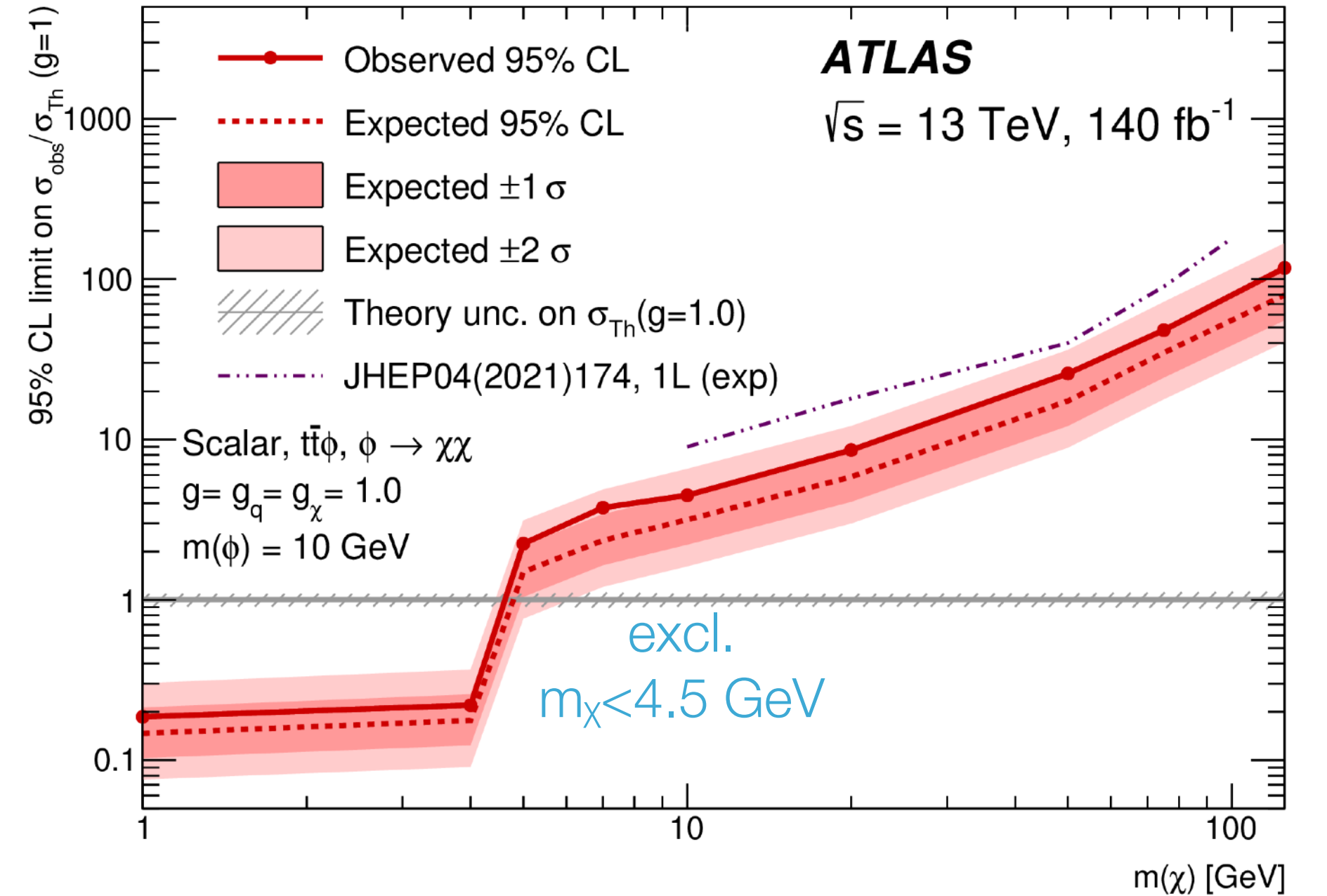
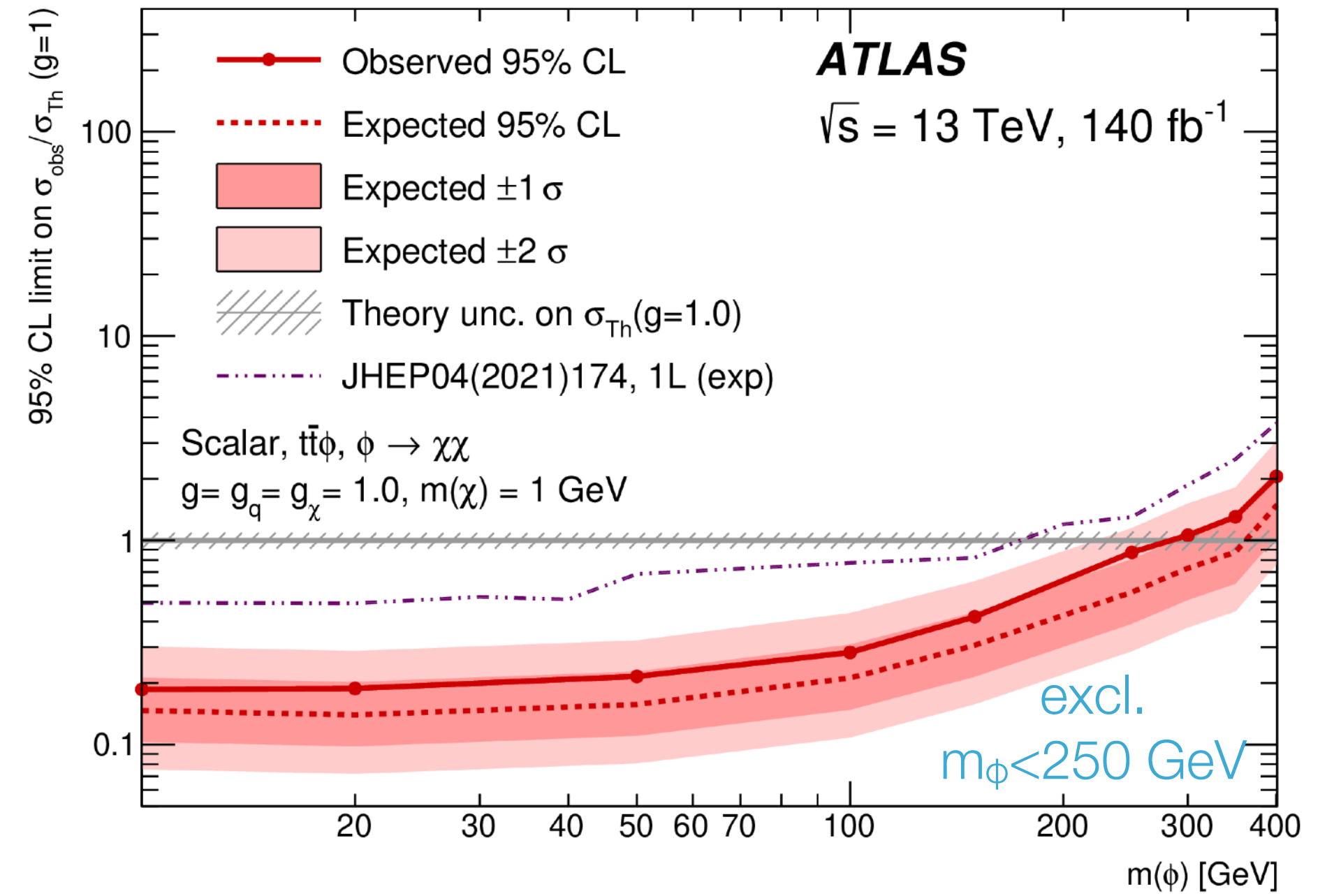
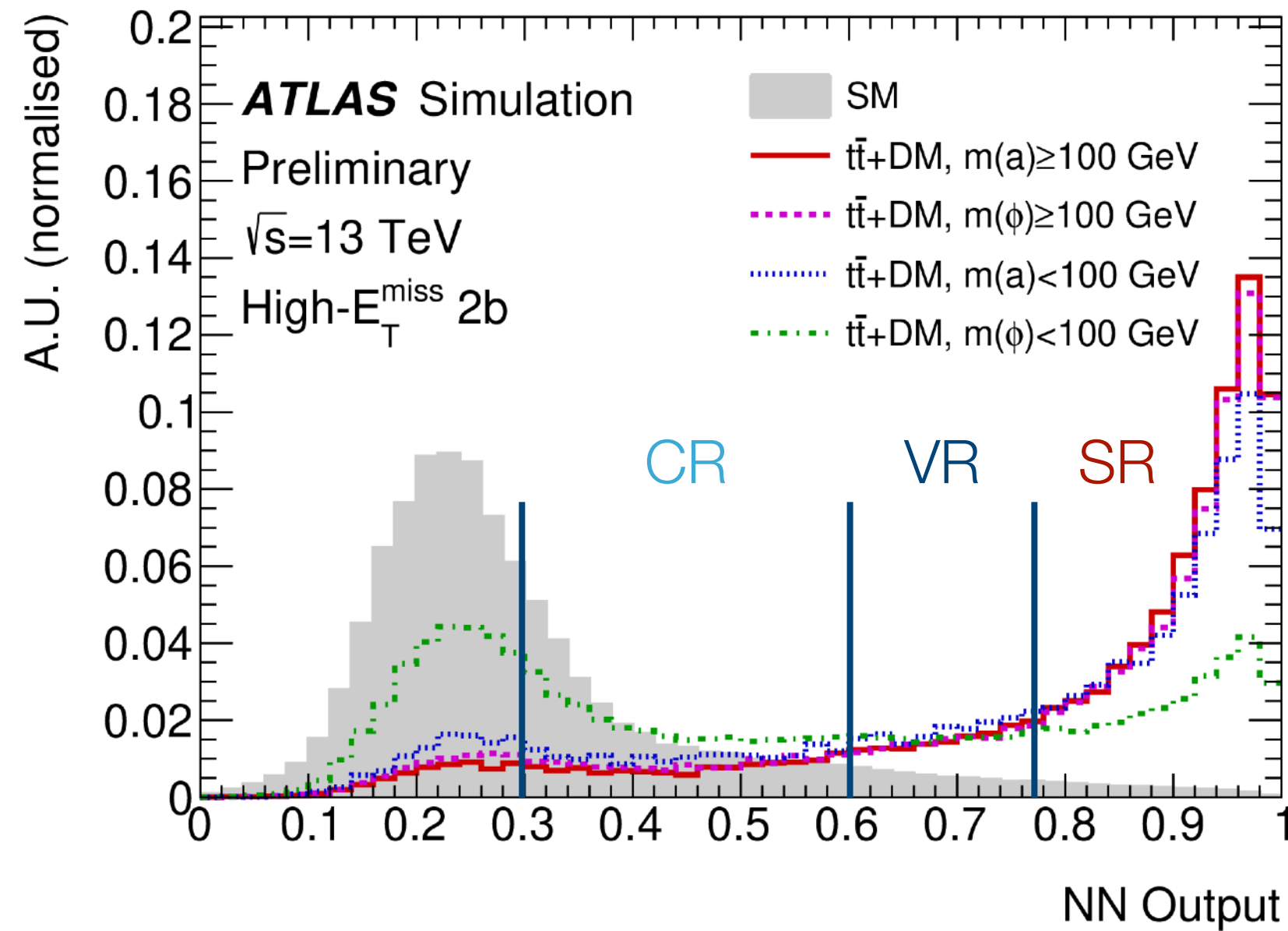


DARK MATTER + TT



$E_T^{miss} > 230 \text{ GeV}$
 1 lepton
 1, ≥ 2 b-jets
 $\geq 2, \geq 1$ jets
 top-tagged jet multiplet

NN exploited for signal events separation

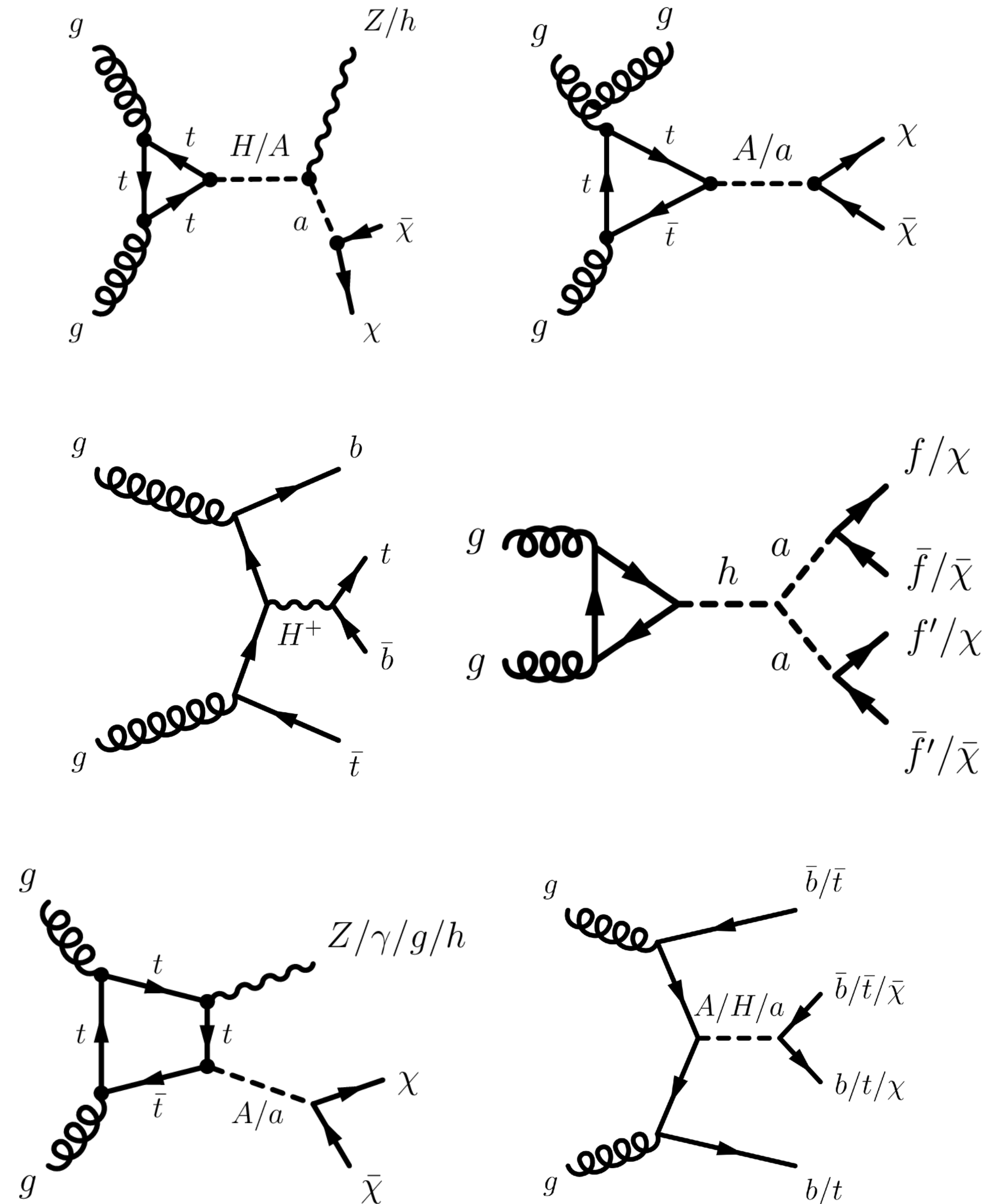


EXTENDED HIGGS SECTOR – 2HDM+a

The simplest UV-complete benchmark model with a pseudoscalar mediator:

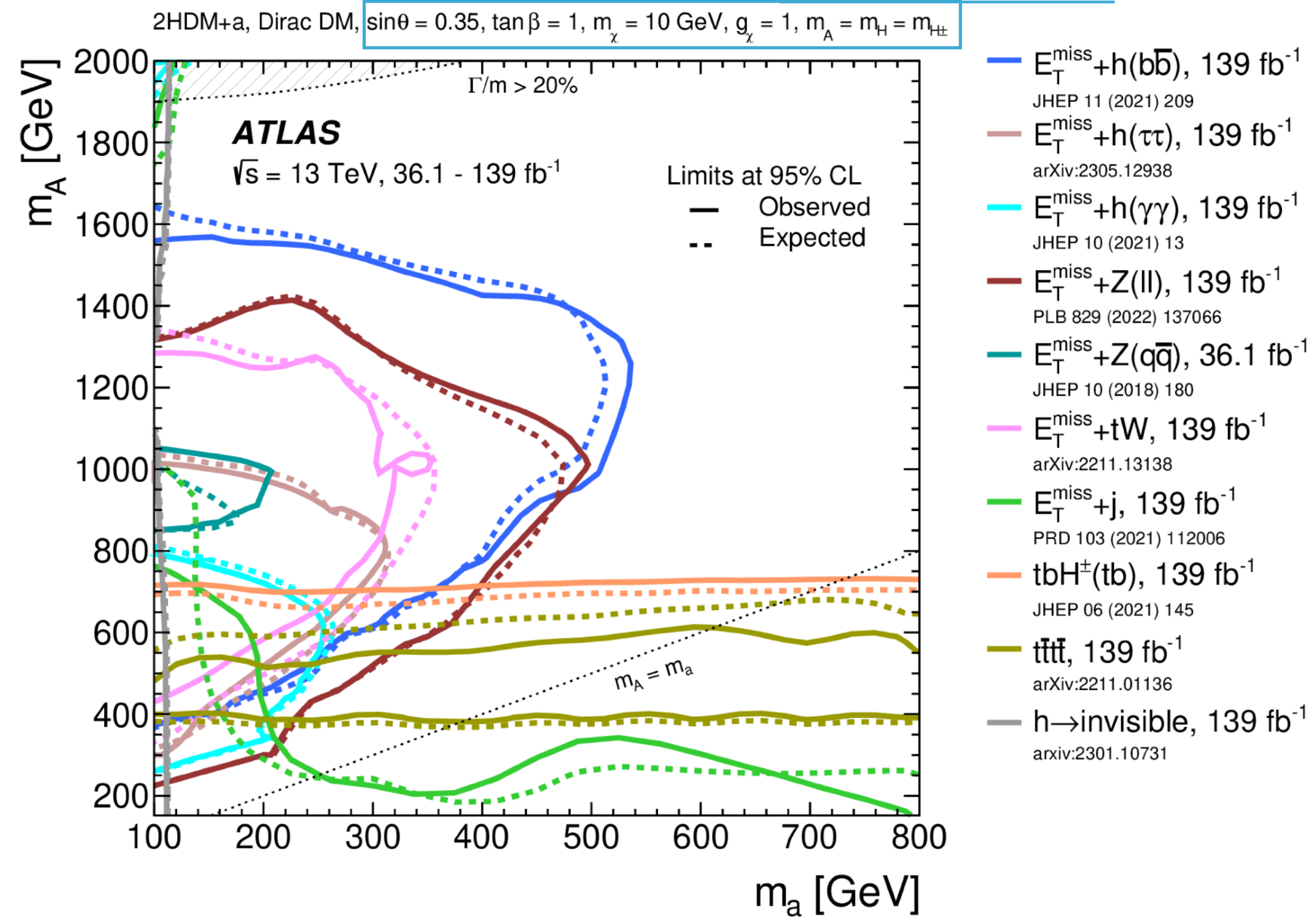
2 Higgs Doublet Model + pseudoscalar a

- extend Higgs sector by an additional complex doublet
 - 5 Higgs bosons: CP-even h , CP-even H , CP-odd A , and two charged bosons H_{\pm}
 - 15 parameters, reduced to 5 in 6 scenarios
- PS mediator a couples to fermionic Dirac DM candidate χ and mixes with the pseudoscalar A
 - less constraints from direct-detection experiments
- Wide range of signatures at collider, complex interplay across parameter space (A - a mixing)
- Includes signatures not predicted in the commonly used simplified models



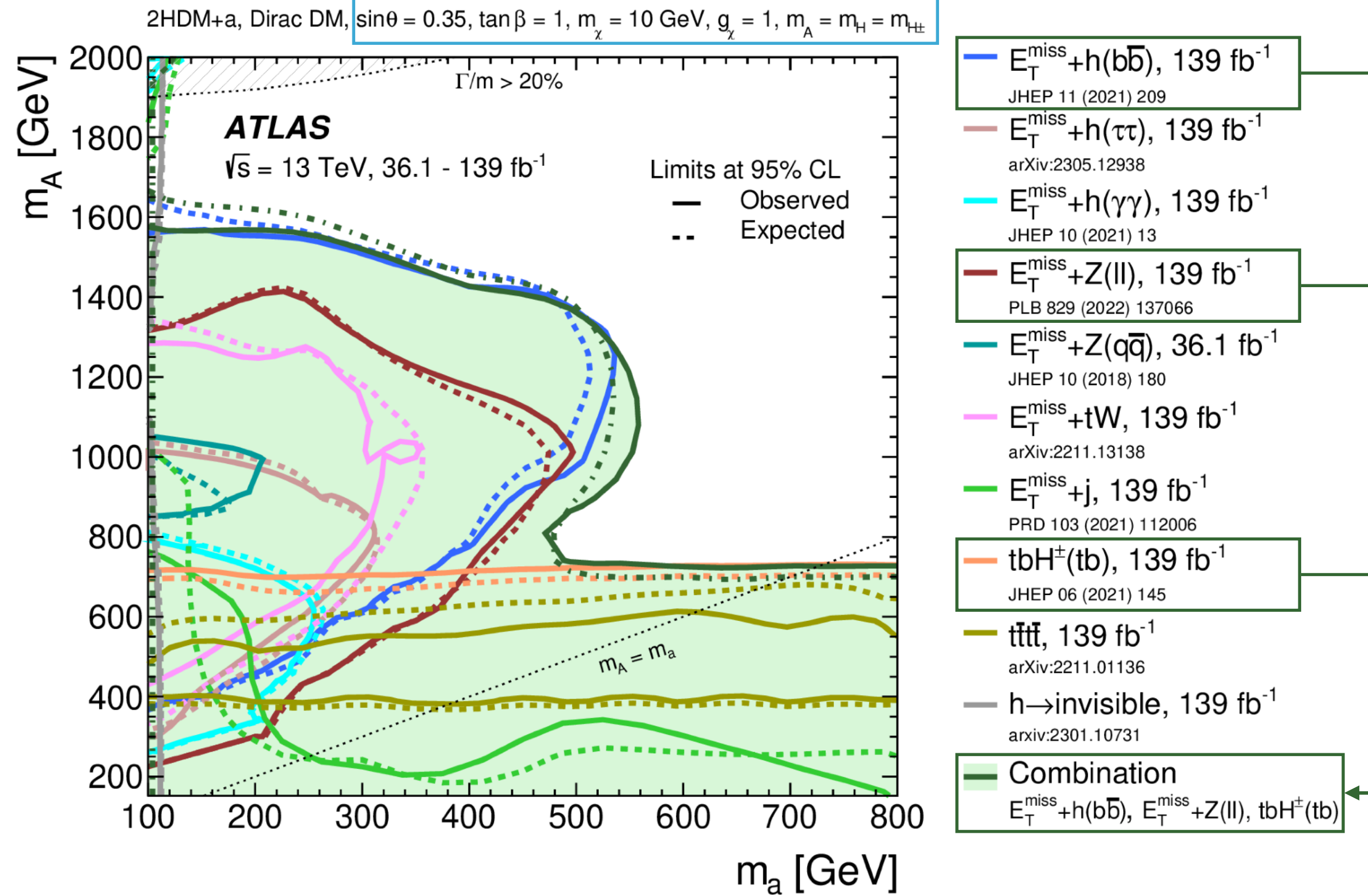
EXTENDED HIGGS SECTOR – 2HDM+a

 Benchmark



EXTENDED HIGGS SECTOR - 2HDM+a

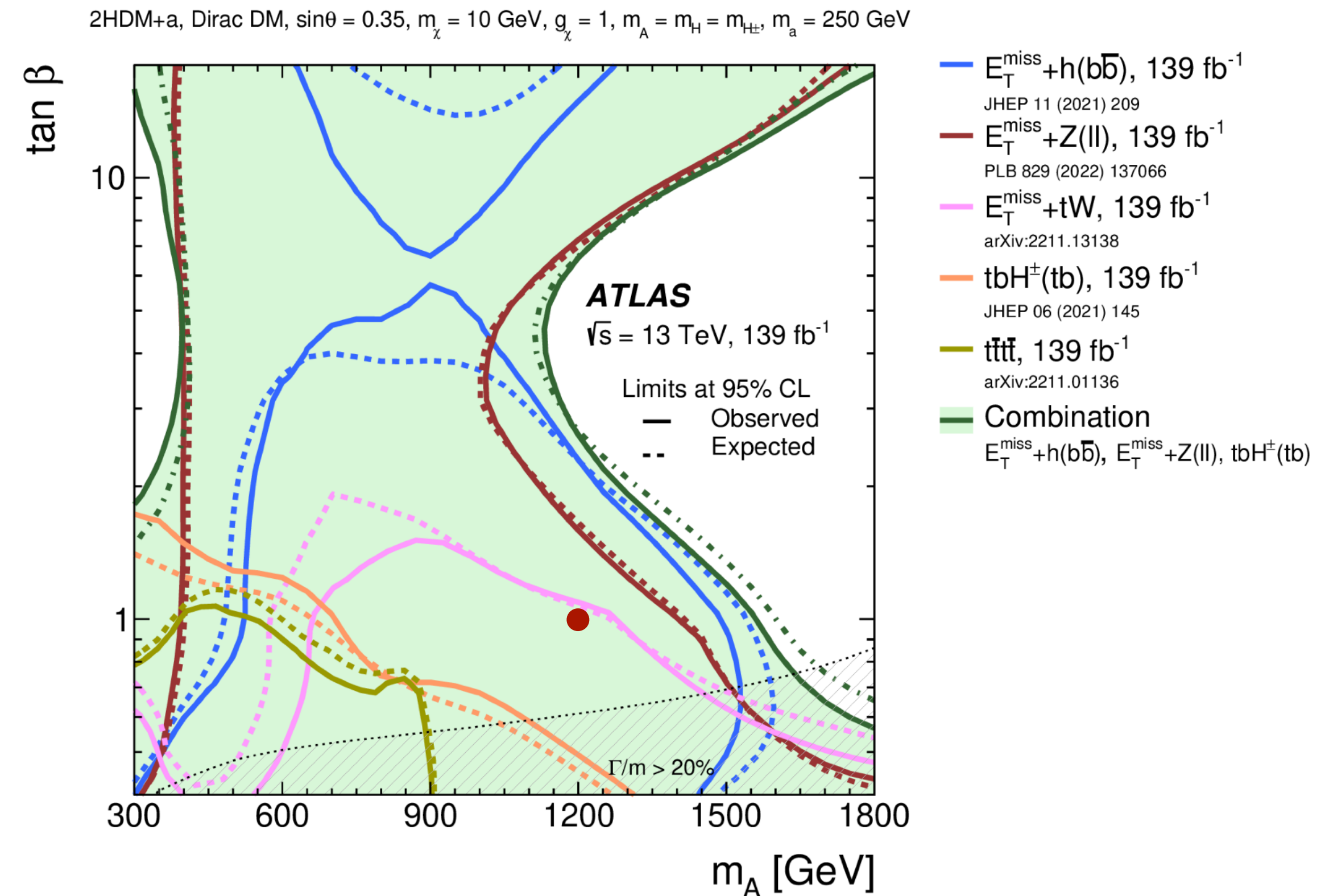
Benchmark



Combination of the most sensitive channels
 $E_T^{\text{miss}} + h(b\bar{b}), E_T^{\text{miss}} + Z(\ell\ell), tb + H^\pm \rightarrow tb$

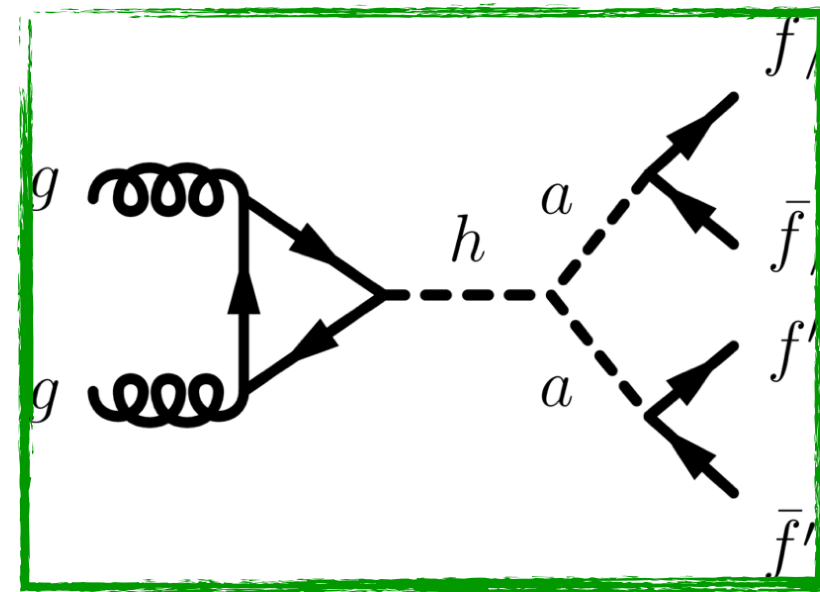
Sensitivity in m_A reduced when changing value of parameters, e.g. $\tan(\beta) > 1$

2D scan as a function of different model parameters highlight the yet uncovered regions of this model.



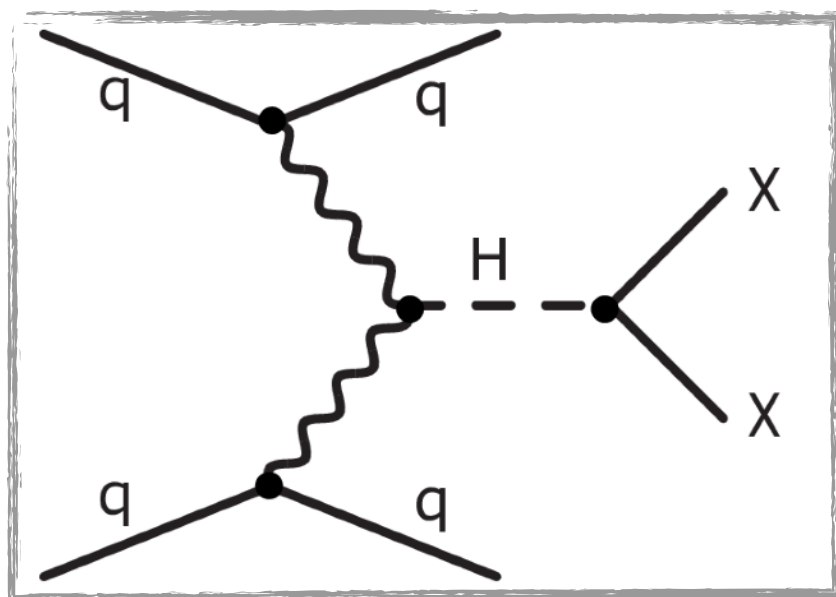
EXTENDED HIGGS SECTOR - 2HDM+a

Benchmark

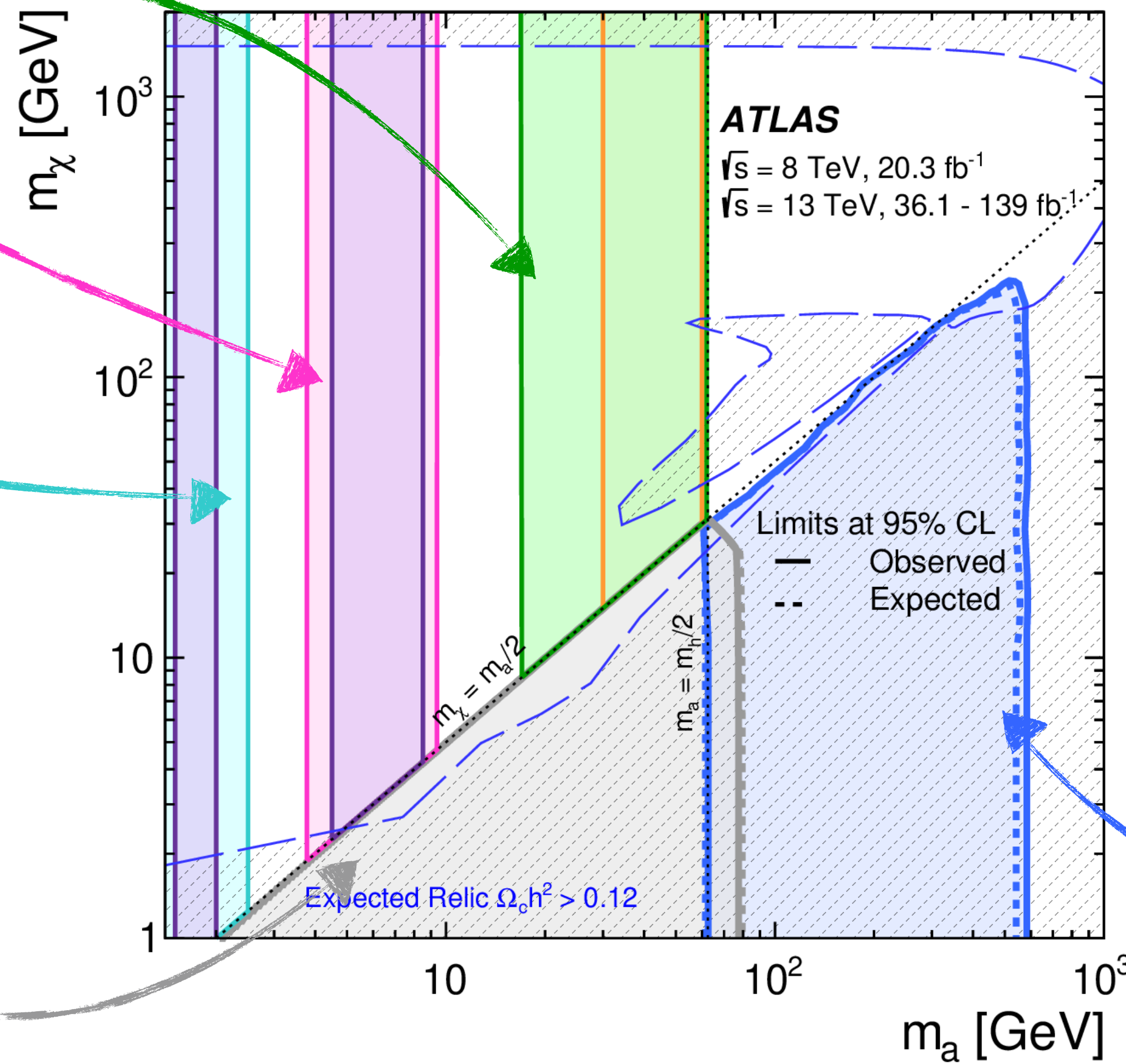


$h \rightarrow aa \rightarrow ffff$ sensitive when $a \leftrightarrow \chi\chi$ also for very light resonances

Invisible Higgs signatures covering low DM masses

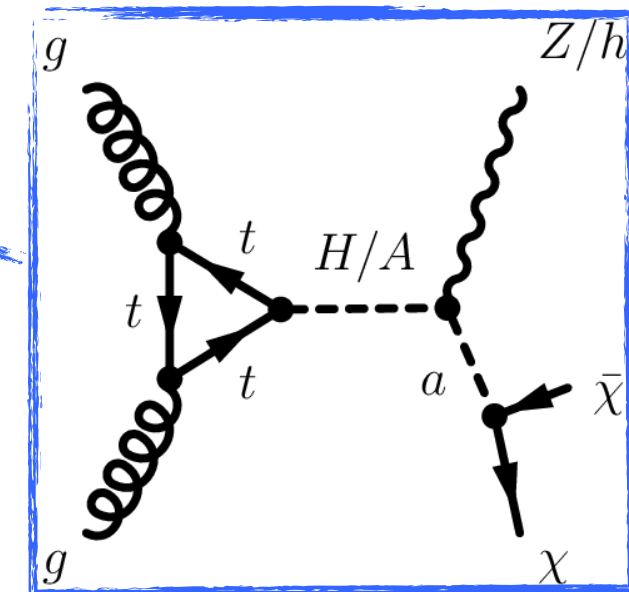


2HDM+a, Dirac DM, $\sin\theta = 0.35, \tan\beta = 1, g_\chi = 1, m_A = m_H = m_{H\pm} = 1.2 \text{ TeV}$



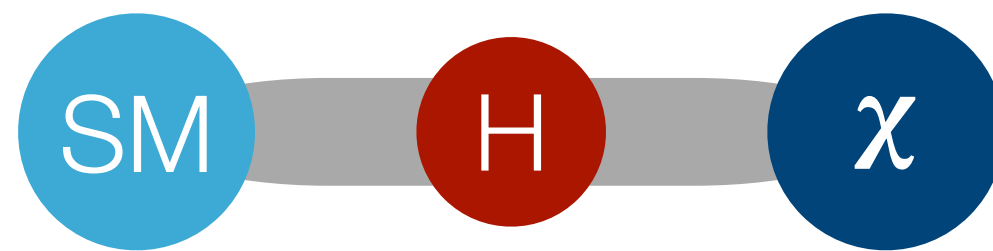
- $E_T^{\text{miss}} + h(b\bar{b}), 139 \text{ fb}^{-1}$
JHEP 11 (2021) 209
- $h \rightarrow \text{invisible}, 139 \text{ fb}^{-1}$
arxiv:2301.10731
- $h \rightarrow aa \rightarrow \mu\mu\tau\tau, 20.3 \text{ fb}^{-1}$
PRD 92 (2015) 052002
- $h \rightarrow aa \rightarrow \mu\mu\mu\mu, 36.1 \text{ fb}^{-1}$
JHEP 06 (2018) 166
- $h \rightarrow aa \rightarrow \mu\mu\mu\mu, 139 \text{ fb}^{-1}$
JHEP 03 (2022) 041
- $h \rightarrow aa \rightarrow bbbb, 36.1 \text{ fb}^{-1}$
JHEP 10 (2018) 031
- $h \rightarrow aa \rightarrow bb\mu\mu, 139 \text{ fb}^{-1}$
PRD 105 (2022) 012006
- Observed Relic $\Omega_c h^2 = 0.12$

$E_T^{\text{miss}} + h(b\bar{b})$ dominating at high m_a

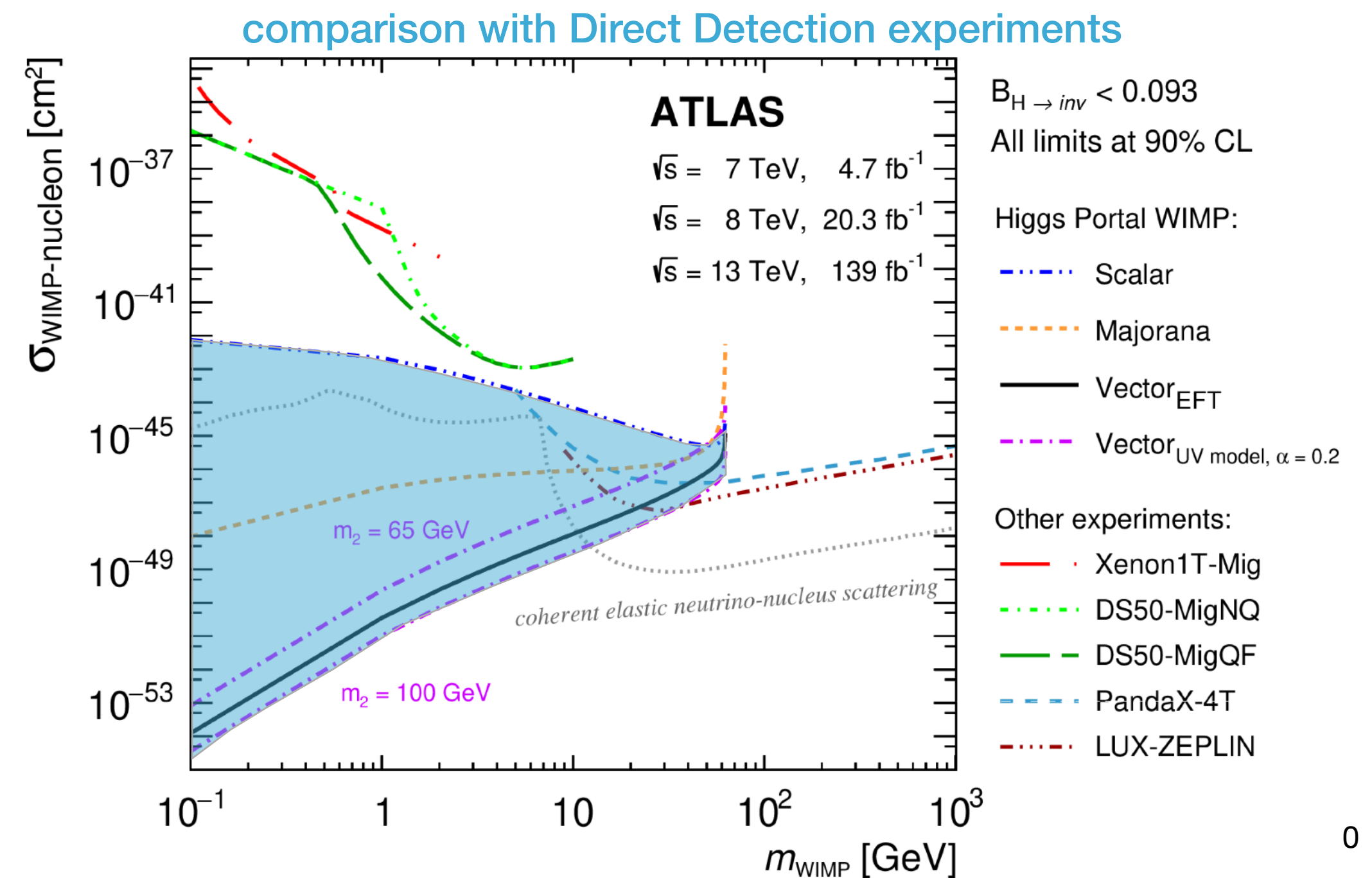
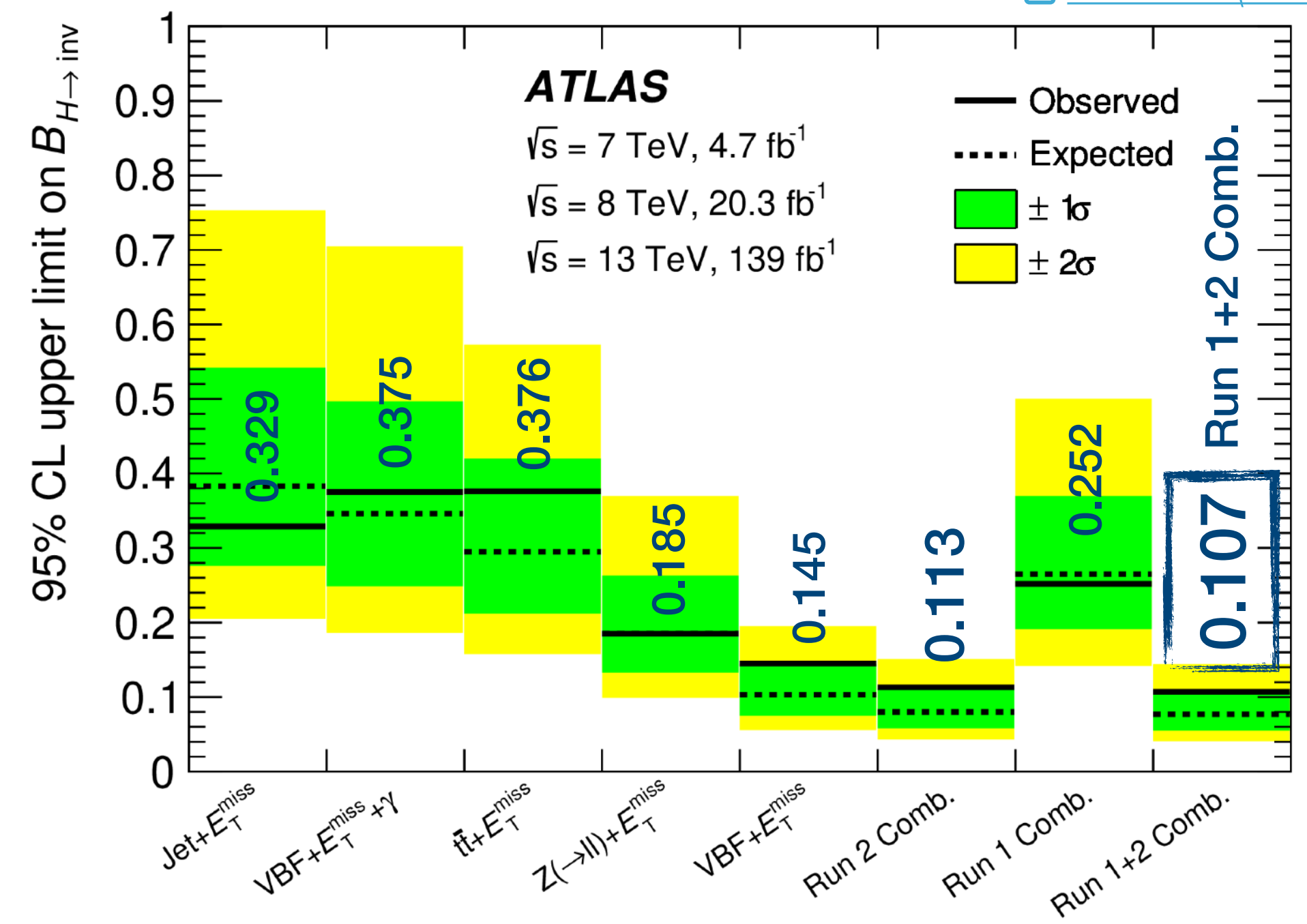
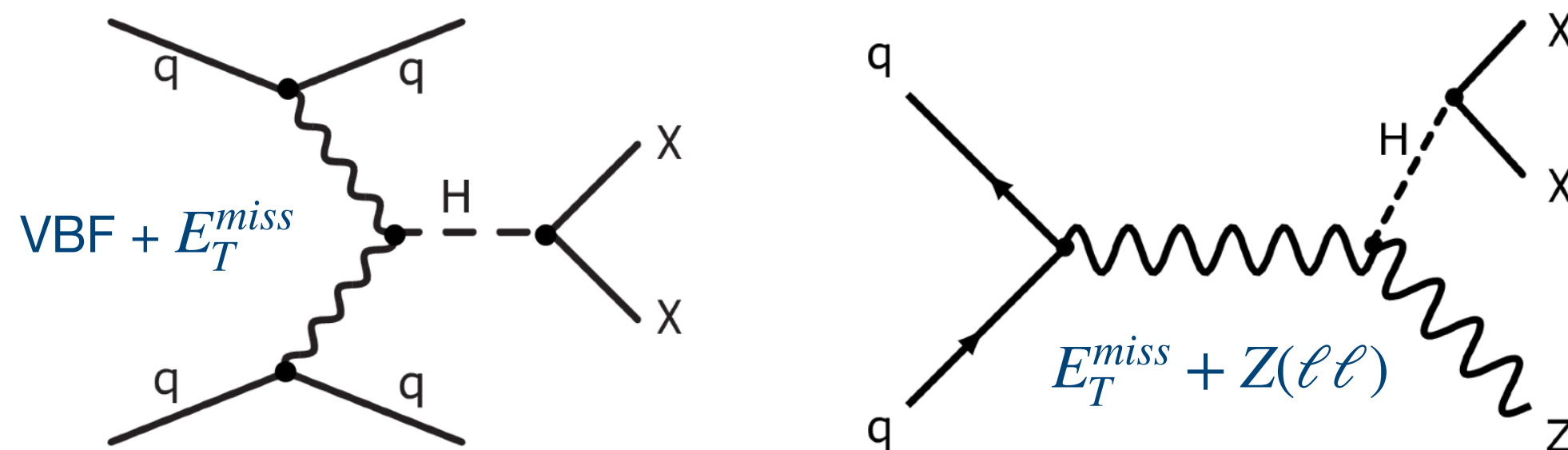


THE HIGGS SECTOR AS A PORTAL

Higgs boson acting as portal connecting the dark sector and the SM sector:

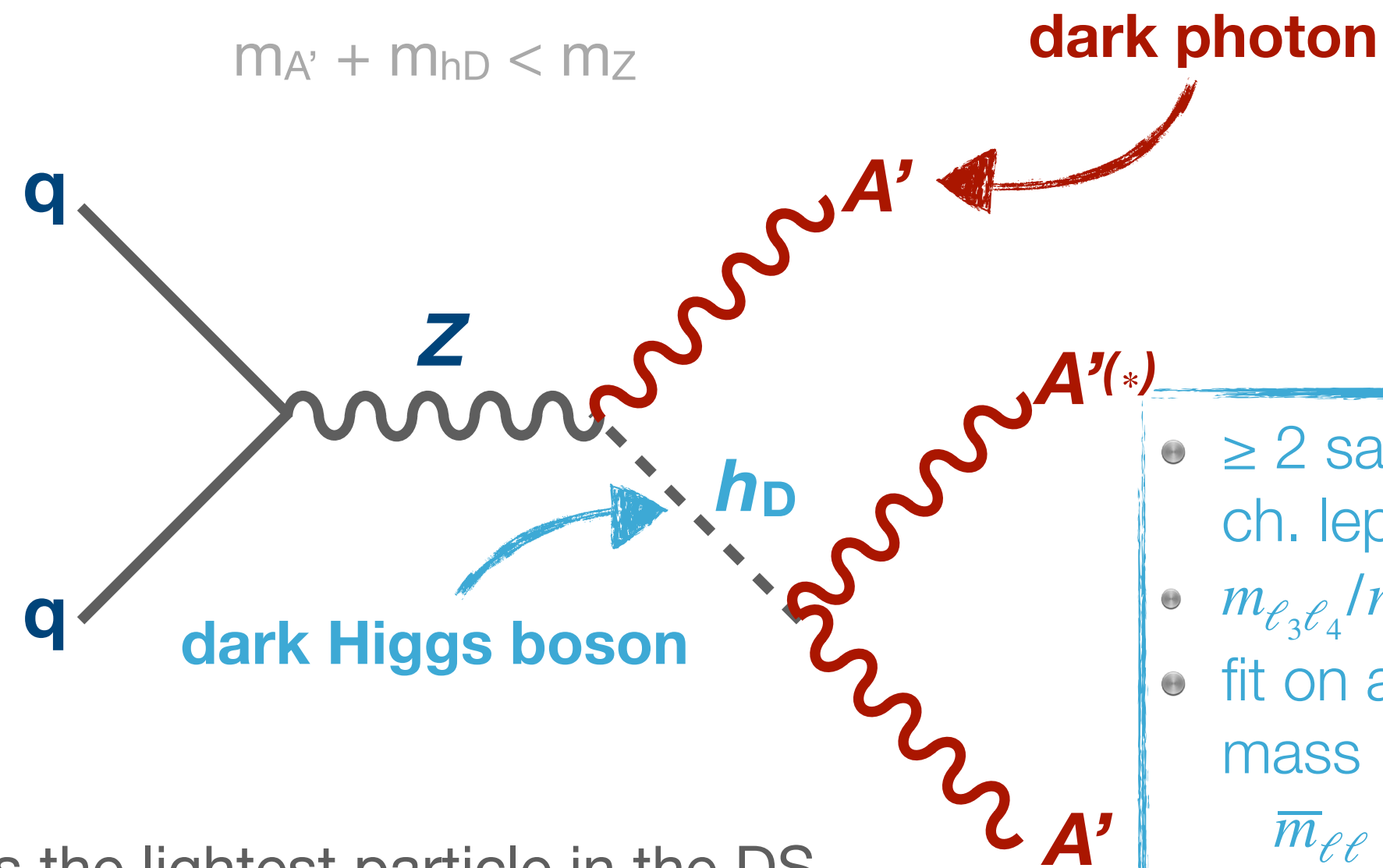


- DM can be produced via the Higgs boson decay
- Look for anomalous decays of the Higgs boson (SM BR(H → inv.) = 0.12%)
- Signatures characterised by $E_T^{miss} + X$ for different Higgs production modes



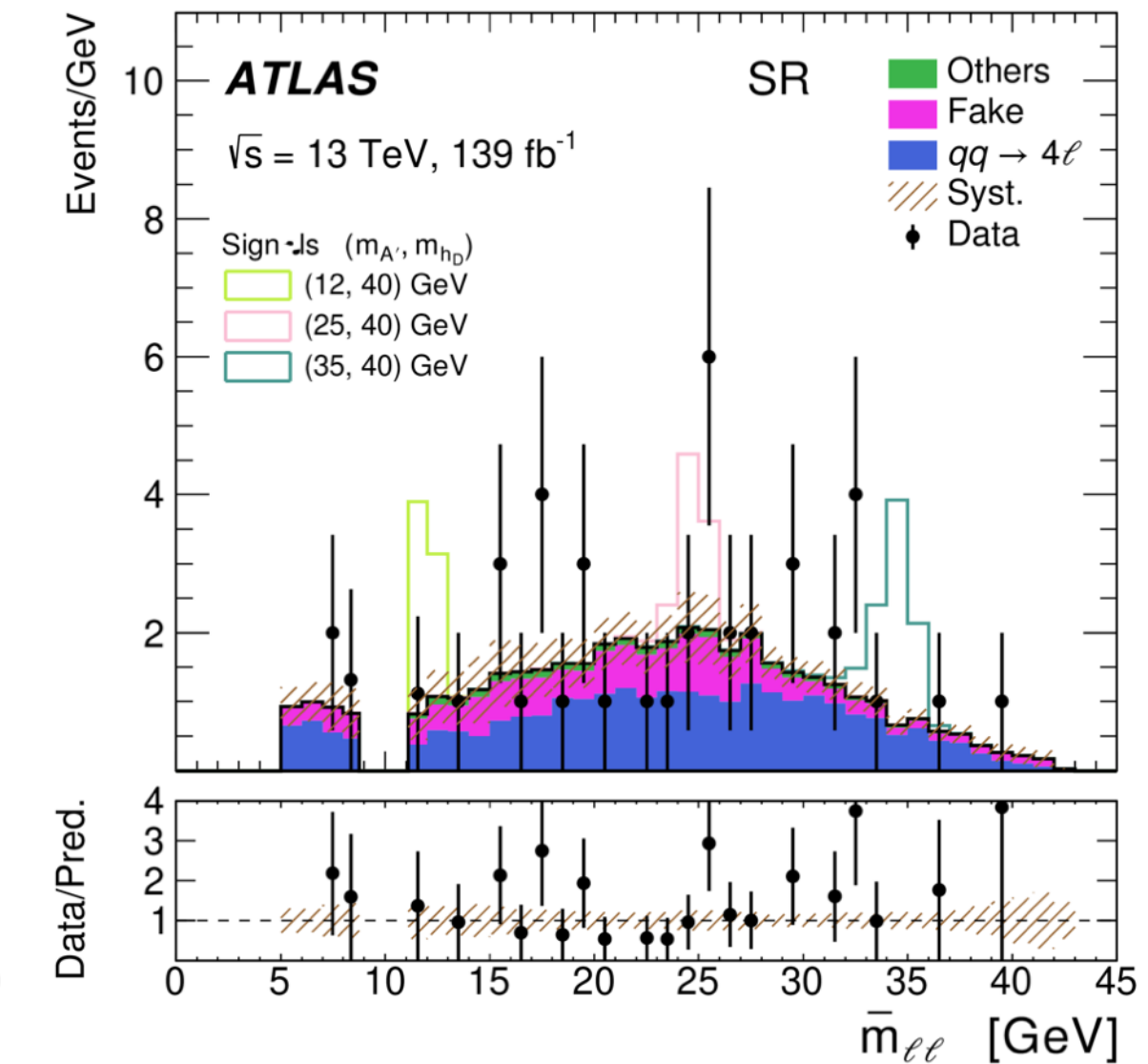
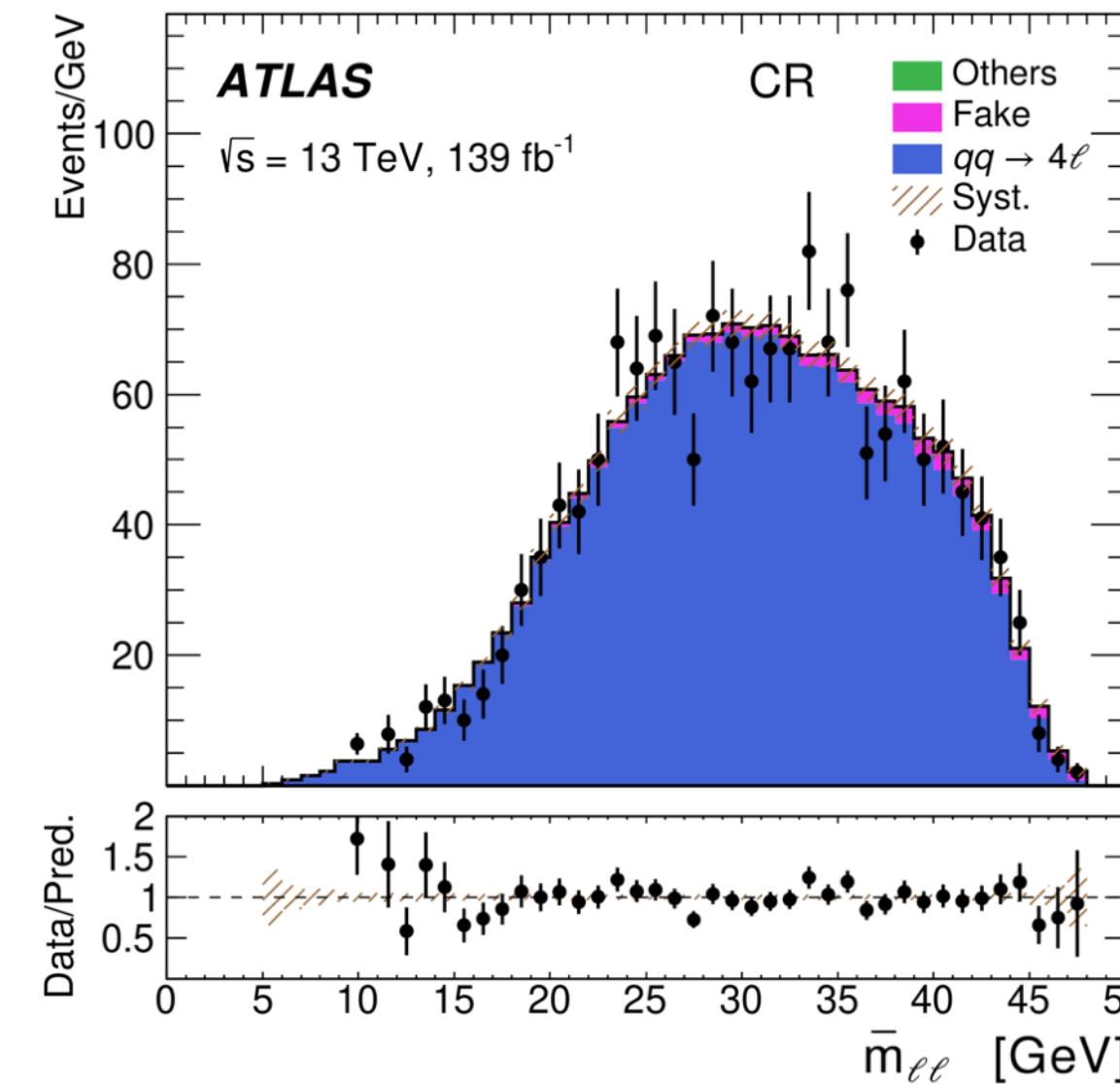
HIGGS AND DARK PHOTONS

dark Abelian Higgs scenario - broken $U(1)_D$

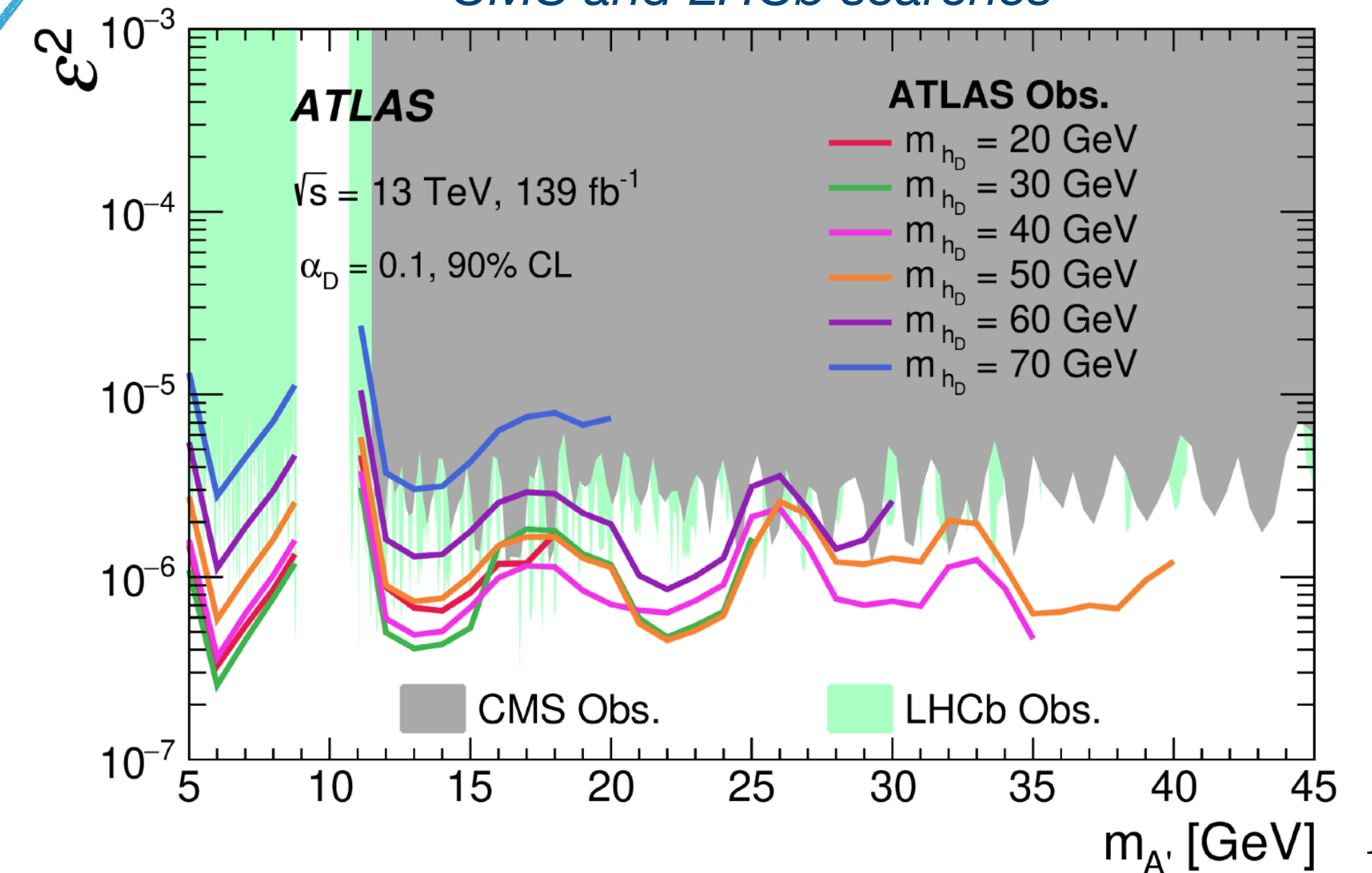


- ≥ 2 same-fl. & opposite-ch. lepton pairs
 - $m_{\ell_3\ell_4}/m_{\ell_1\ell_2} > 0.85$
 - fit on average dilepton mass
- $$\bar{m}_{\ell\ell} = (m_{\ell_1\ell_2} + m_{\ell_3\ell_4})/2$$

A' is the lightest particle in the DS and invisible DS decays are kinematically forbidden $A' \rightarrow \ell^+\ell^-$



limits on kinetic mixing comparable with CMS and LHCb searches



NOT THE USUAL JETS

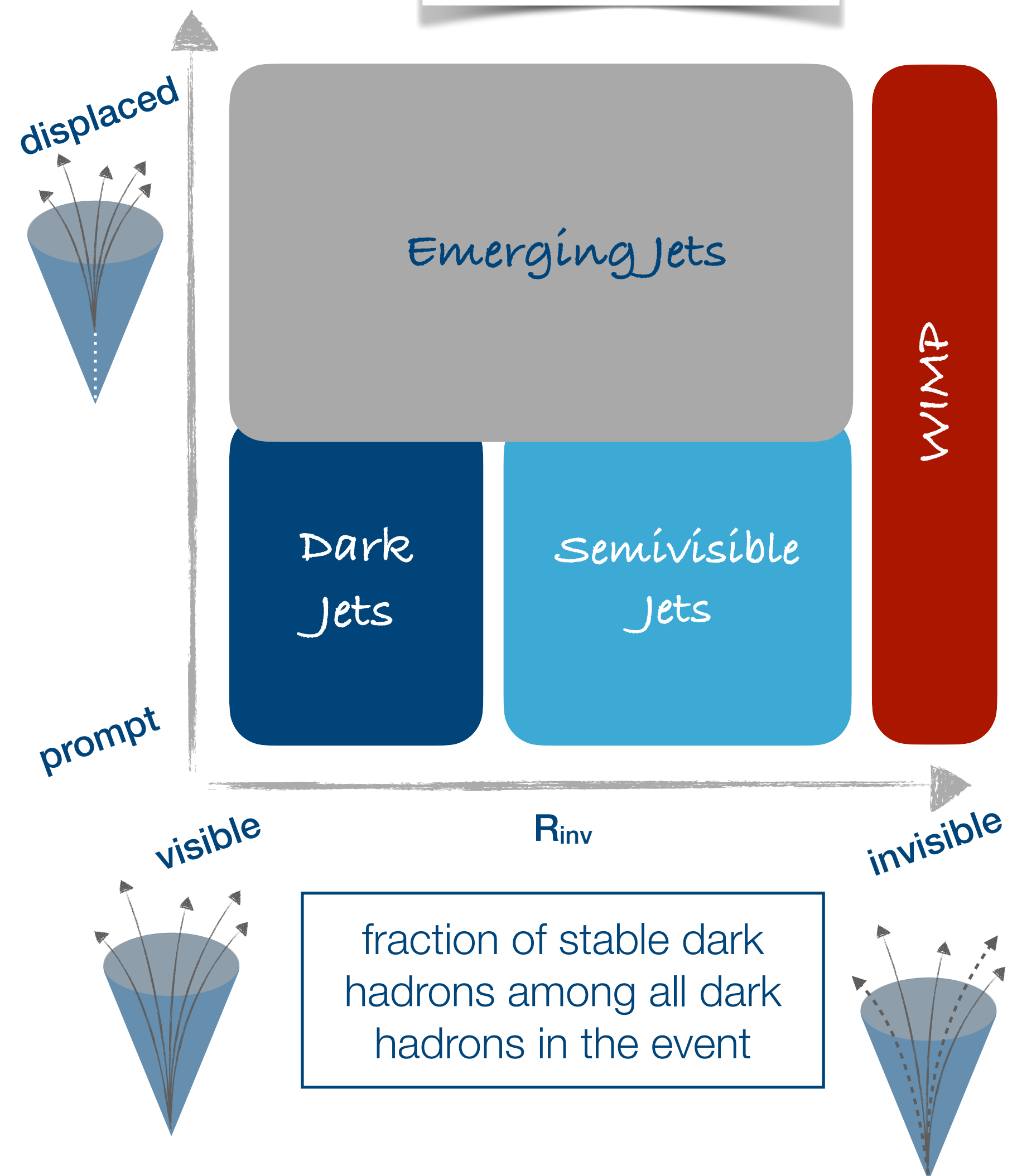
Some models predict the existence of a hidden sector, composed of particles not going through the SM gauge interactions

- connection with the SM through mediators, which could be **DM candidates** or **portals to DM**

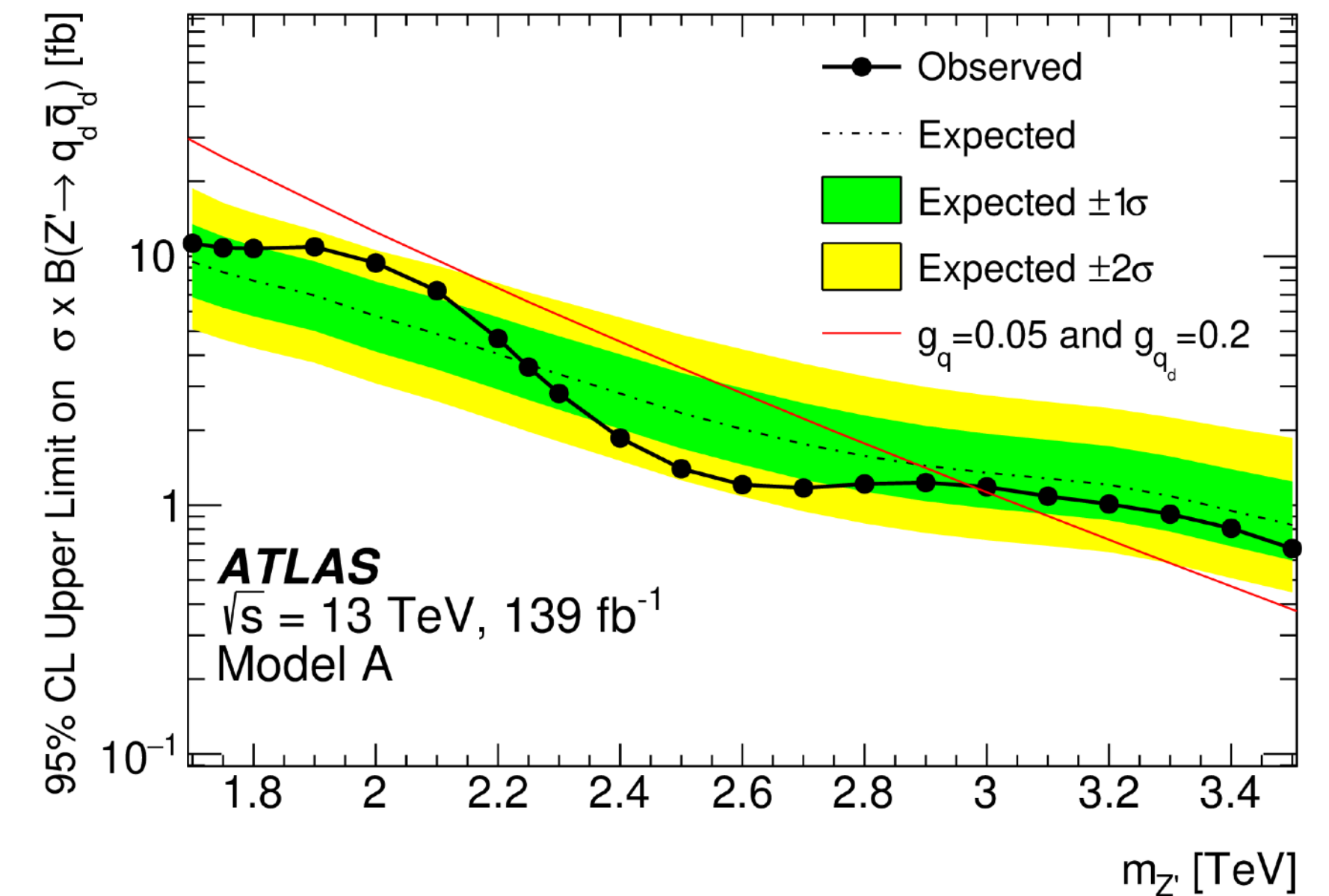
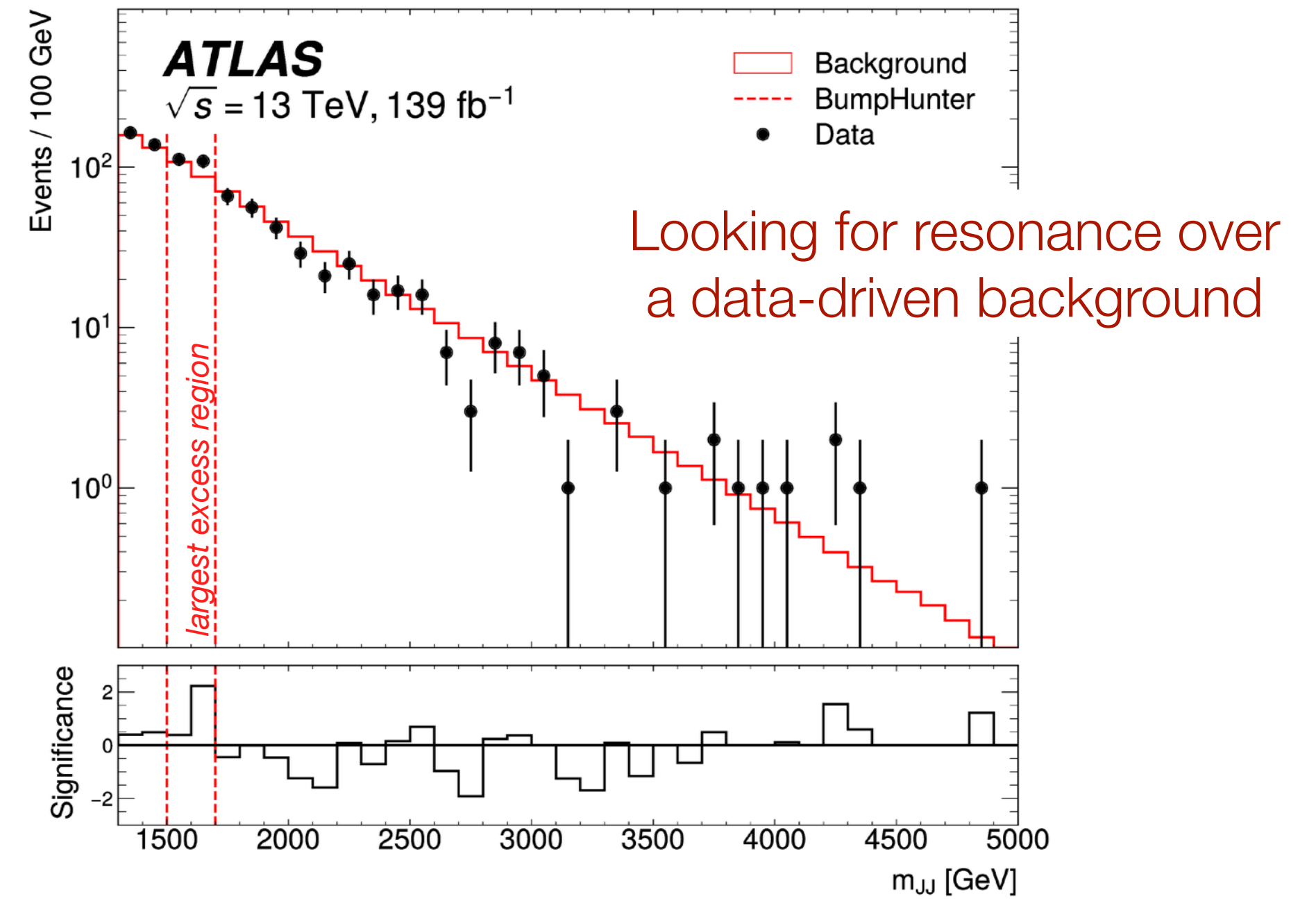
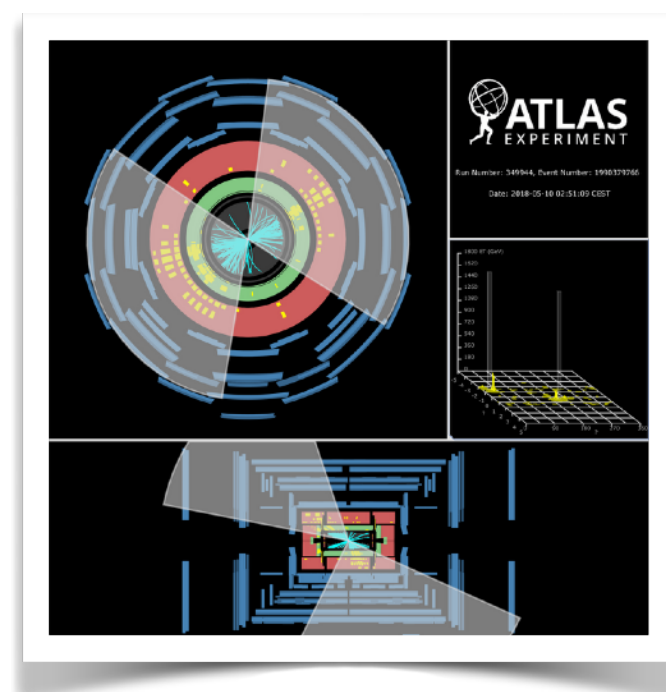
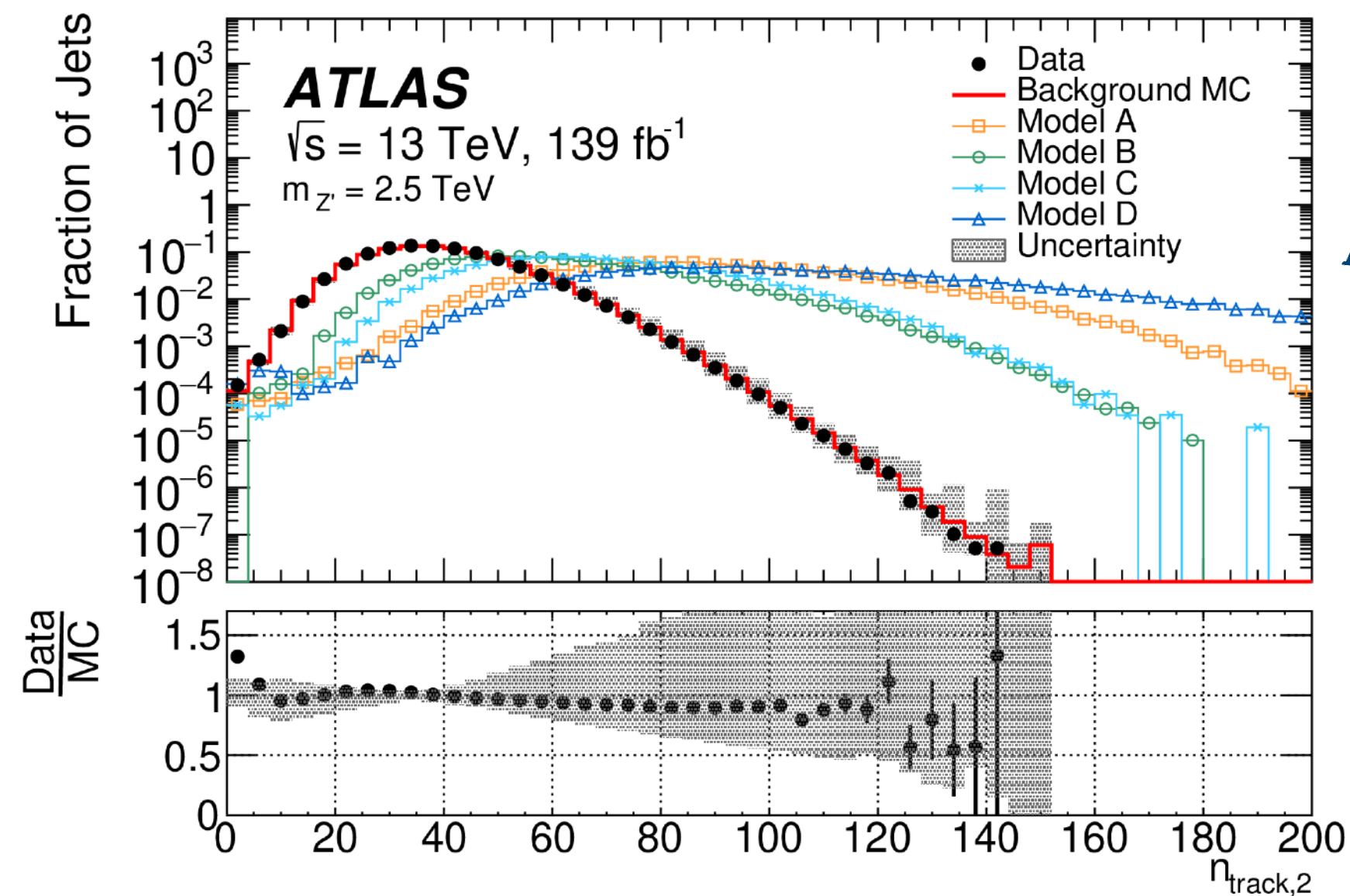
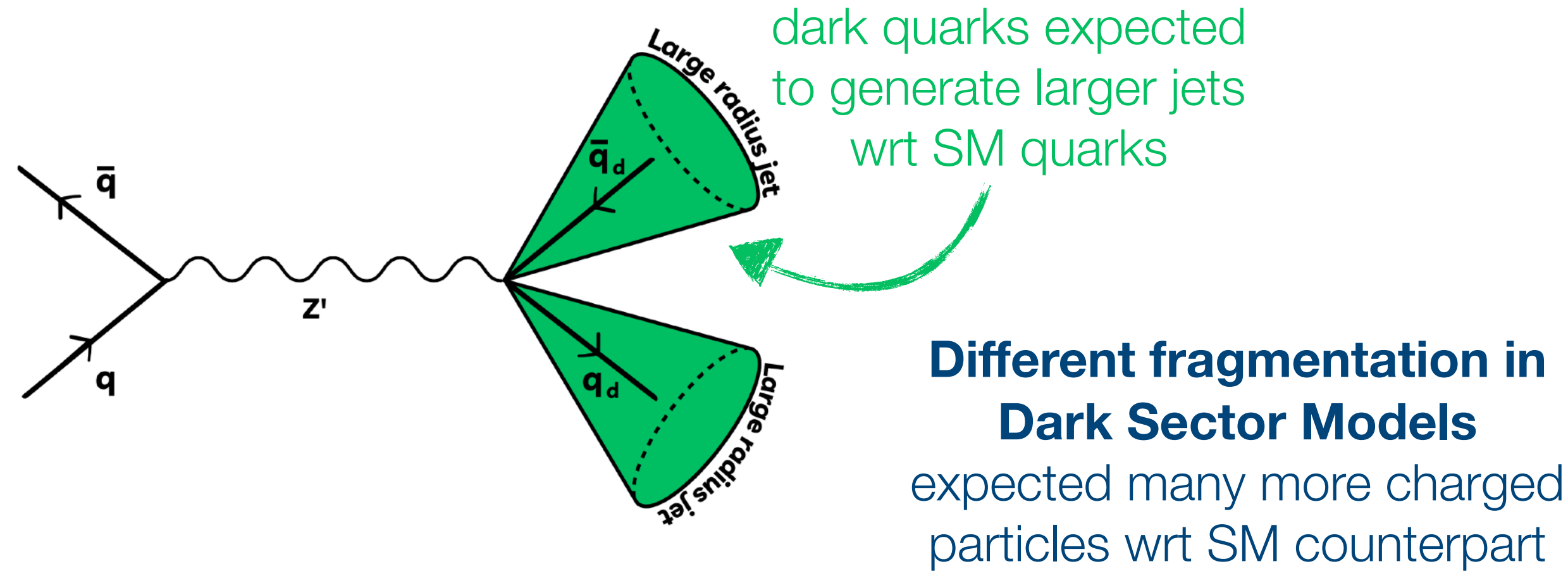
Also possible to have **strongly interacting dark sectors**

- stable dark hadrons can be DM candidates
- dark quarks form bound dark hadron states
- unstable dark hadrons can decay to SM quarks, or cross detector with no interaction

A very wide range of unusual-jet signatures to explore 



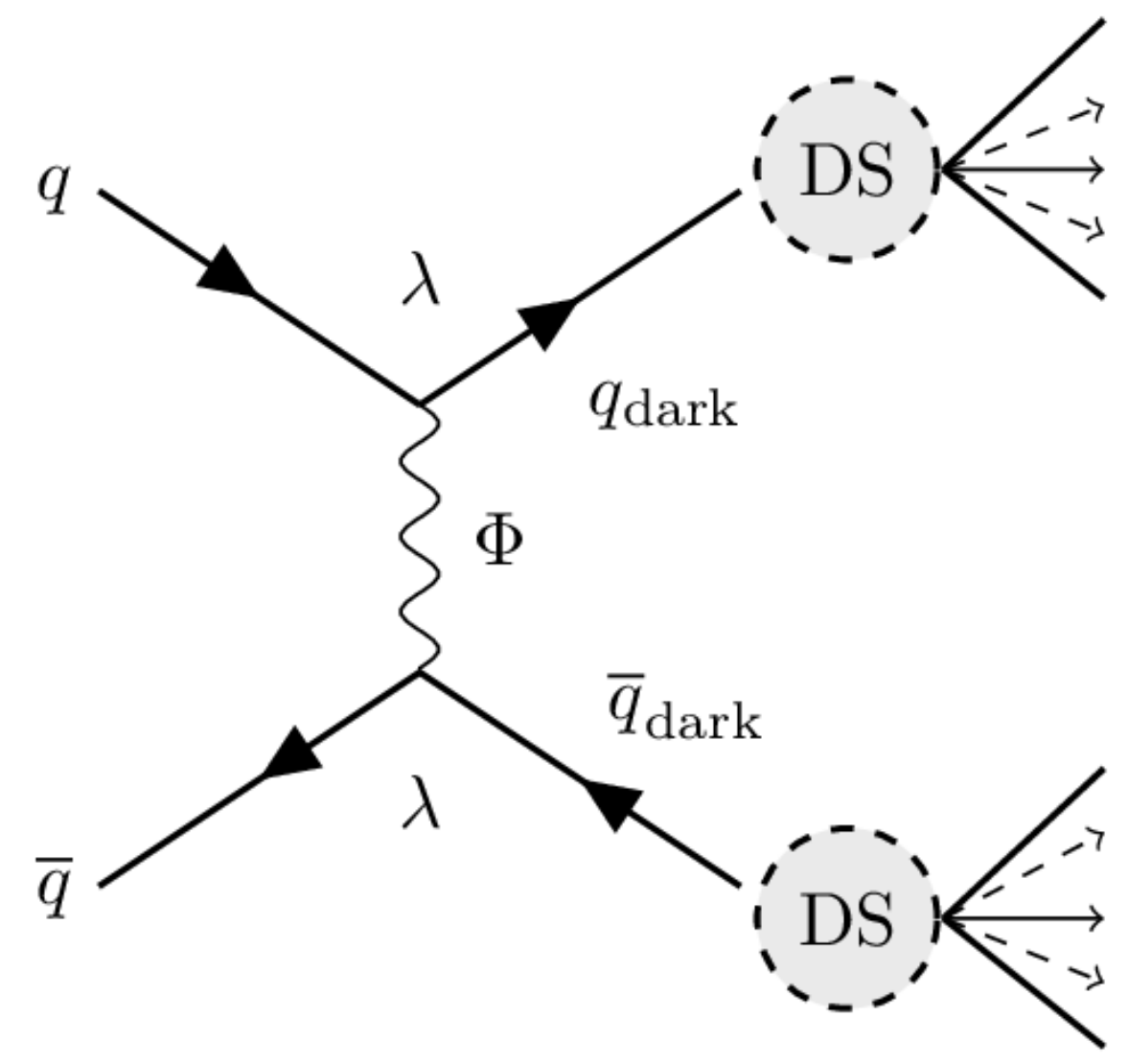
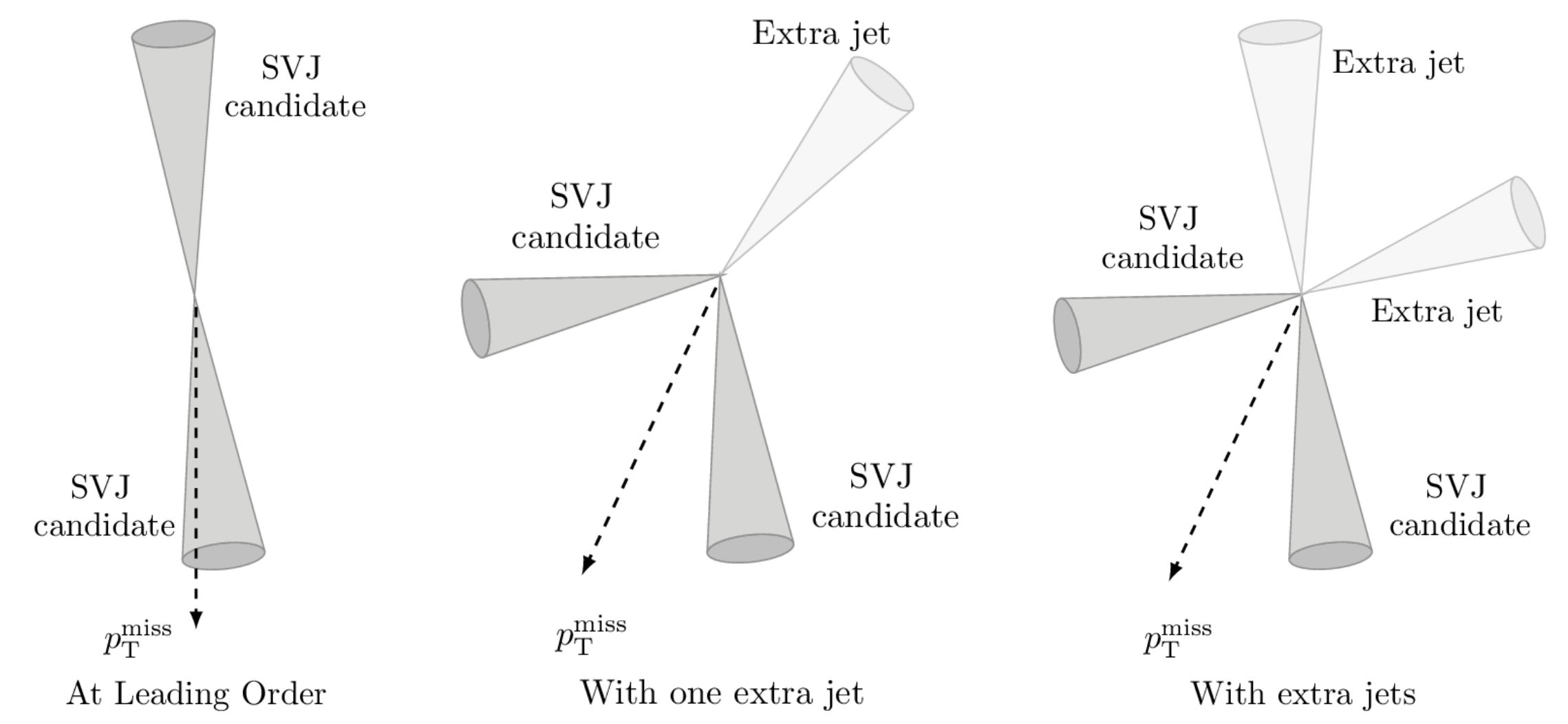
DARK JETS RESONANCE



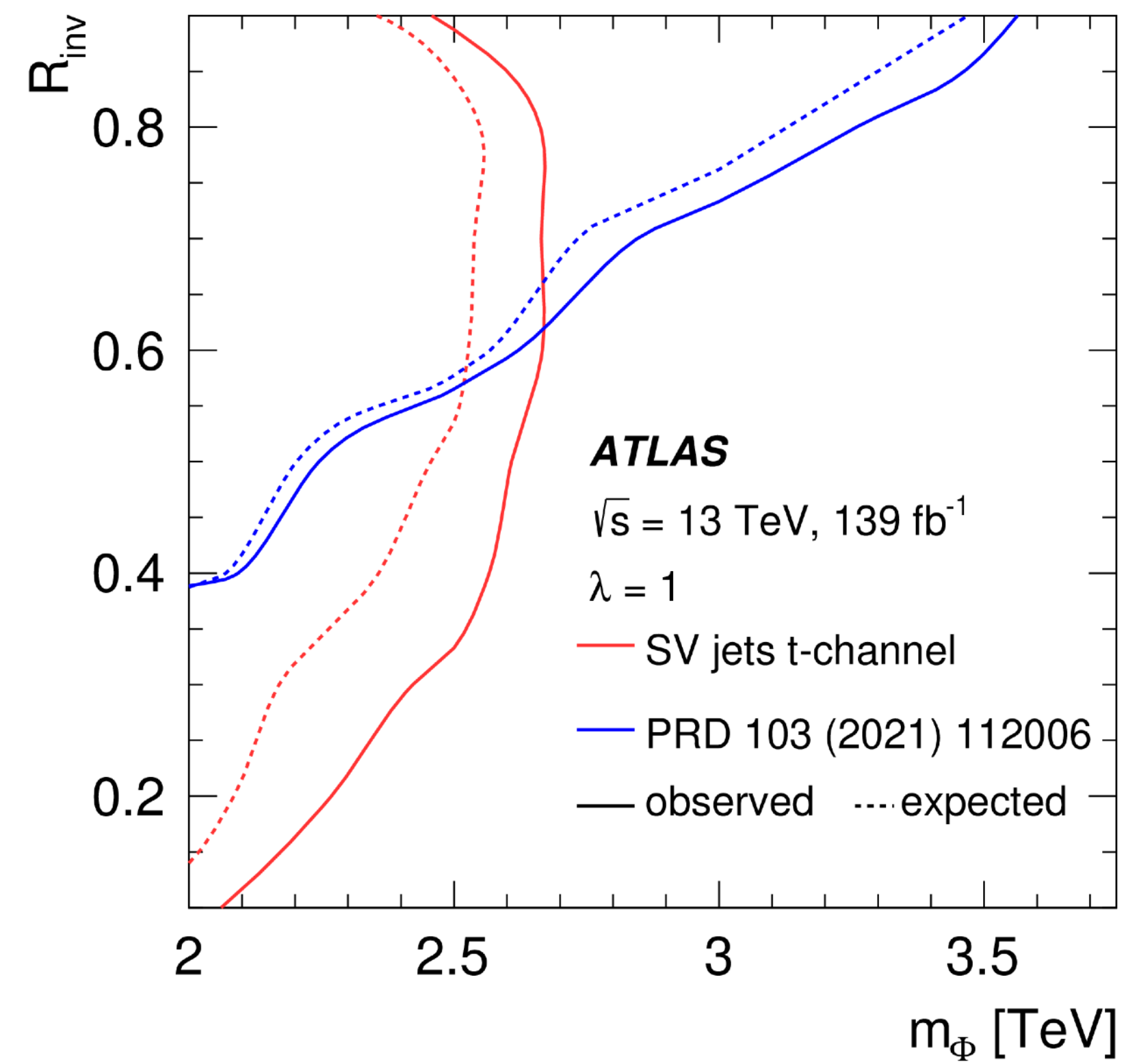
SEMIVISIBLE JETS

If DM particles are produced inside a jet of SM particles we obtain objects called **Semivisible Jets** (R_V)

- significant contribution to event's p_T^{miss} , can arise in strongly interacting dark sectors
- Final state with one of the jets aligned with p_T^{miss} direction



search for **semivisible jets (SVJ) produced via t-channel mediator ϕ exchange** - coupling λ unknown



CONCLUSIONS

- Still a **lot of things to understand** about Dark Matter
- Wide **variety of models** considered as benchmarks and guiding lights: many experimental signatures
- Searches at colliders are **complementary** to non-collider searches
- **Broad analyses programs** in ATLAS:
 - profit from any signature, combine them
 - best analyses techniques put in place
 - still some results expected from Run 2 dataset
 - Run 3 is providing a new consistent dataset to be analysed soon!

Matter

Dark Energy



Dark Matter



BACKUP

You never know what you might need