

Recent results on light mediators searches in ATLAS

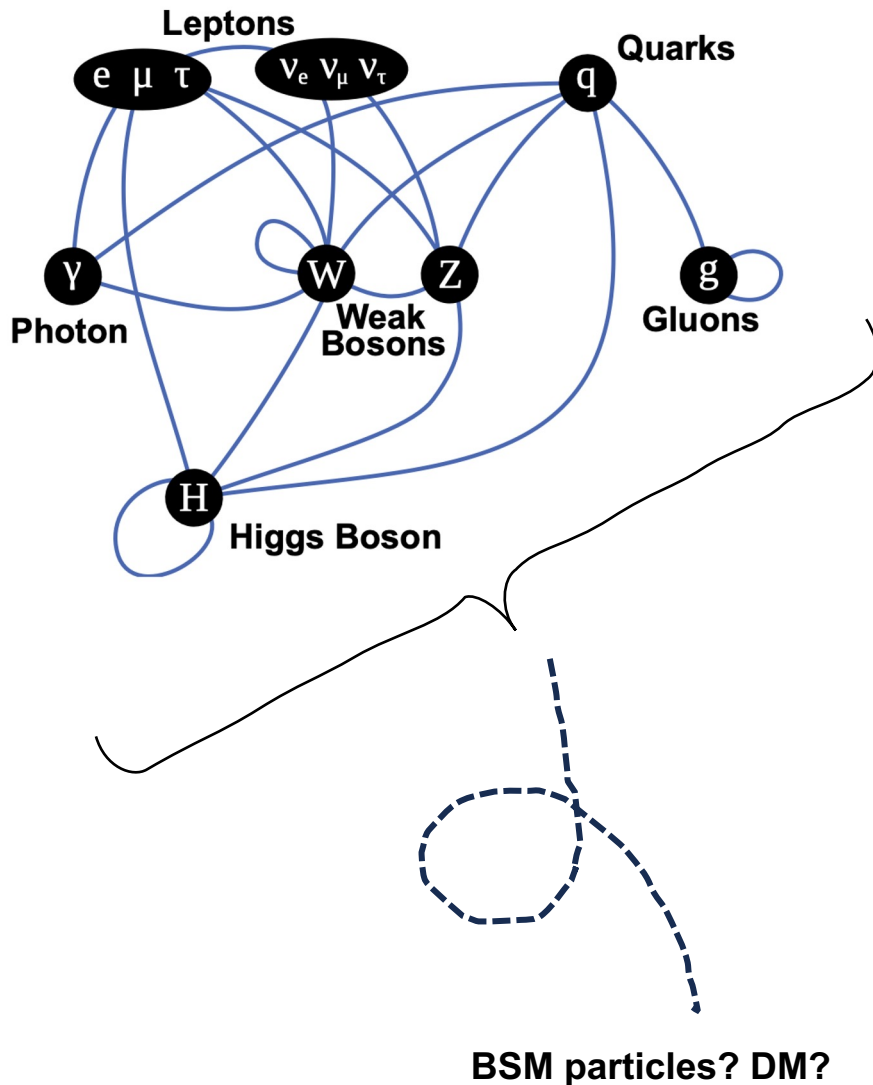
LHCP 2024

Zirui Wang (University of Michigan)

On behalf of the ATLAS Collaboration

3 June 2024, Boston, USA





The discovery of Higgs boson completed the last piece of the SM particle content.



But **SM cannot explain:**

- What is the nature of dark matter and dark energy?
- How do neutrinos obtain their mass?
- How to include gravity in the SM ?
- ...



Many **new physics with light BSM mediators** aim to address those fundamental questions.



The Discovery of new particles would **probe new physics!**

Recent ATLAS searches on light BSM mediators:

- **Light Scalar or Pseudoscalar mediator search:**
 - **DM-motivated:**
 - Dark Higgs: mono- $s(bb)$ [ATLAS-CONF-2024-004](#)
 - 2HDM+ a light pseudo scalar search: mono- $V(\text{had})$ [CERN-EP-2024-128] and summary [arXiv:2306.00641](#)
 - **Axion-like Particles (ALPs):**
 - $H \rightarrow aa \rightarrow 4\gamma$ [arXiv:2312.03306](#)
 - $H \rightarrow Za, a \rightarrow \gamma\gamma$ [PLB 848 \(2024\) 138536](#)
- **Dark Photons (A'):**
 - Dark photon in the rare Z decay [PRL, 131, 251801](#)

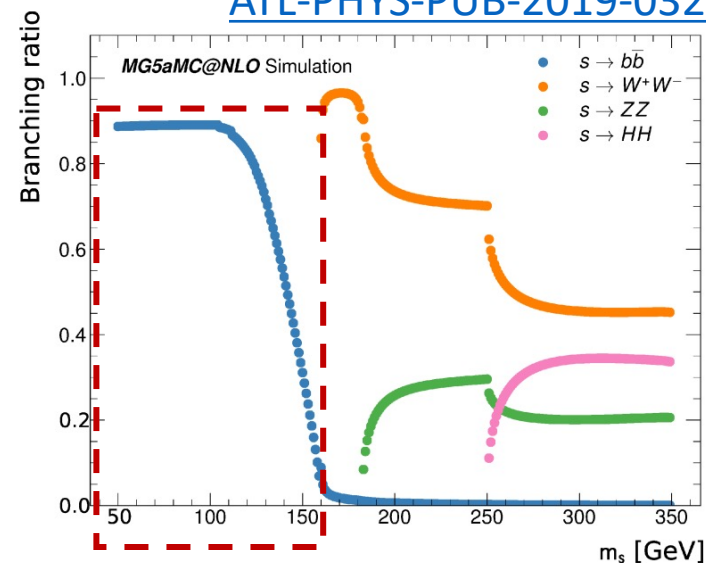
Caveats:

- A personal selection of topics.
- Other new ATLAS results in this Feeble Interaction session:
 - Monday: [Nicola's talk](#) on prompt searches
 - Thursday: [Sebastien's talk](#) on dark sector results
 - Friday: [Gareth's talk](#) on HNLs, [Ismet's](#) and [Cristiano's talks](#) on LLP searches.
- Check out the ATLAS public [web page](#) for a more comprehensive overview

- **Dark sector model with a scalar s (dark Higgs)**
- Mediator Z' coupling to DM g_χ floating in different benchmarks.



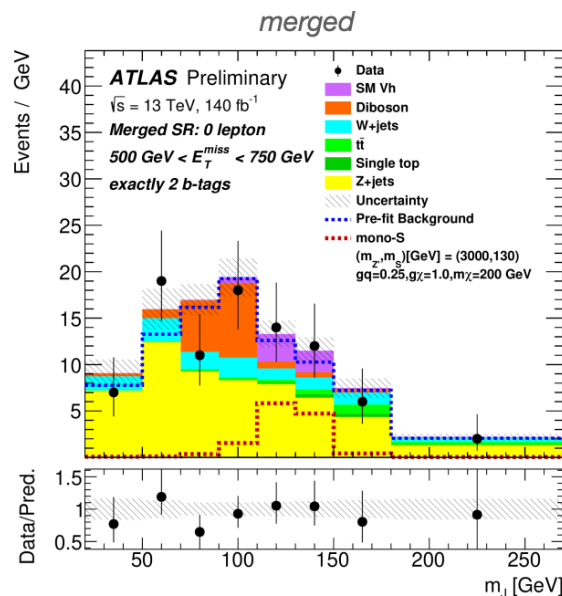
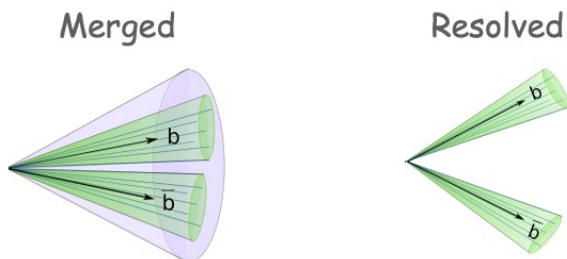
ATL-PHYS-PUB-2019-032



Dark Higgs mono- $s(bb)$ search

[ATLAS-CONF-2024-004](#)

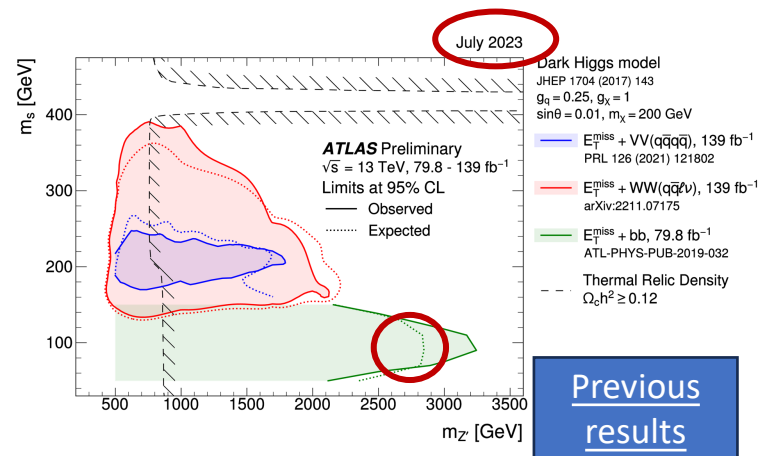
- Final state: MET + bb
- Dominating low mass (< 150 GeV).
- Signal topologies:



Novel X- \rightarrow bb mass-agnostic tagger ([link](#)):
 Developed for merged topologies \rightarrow delivered major sensitivities

ATLAS-CONF-2024-004

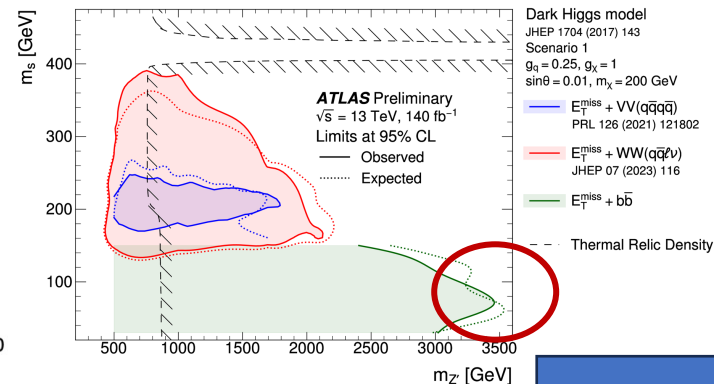
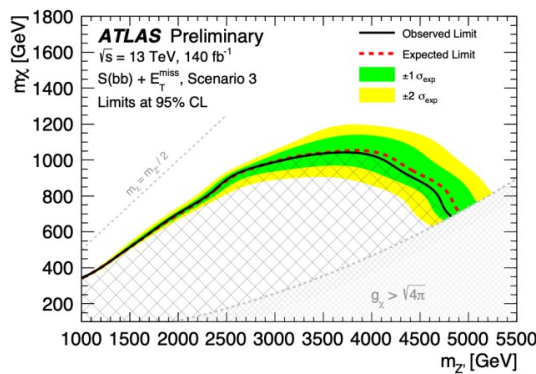
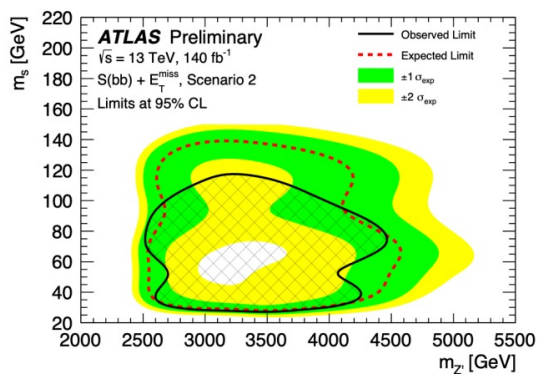
- **Complementary sensitivity** to high-mass dark Higgs searches in $s(VV)$ channels.
- **Large improved sensitivity** to the previous re-interpretation results.
- **First exploration** of parameter space more **compatible with the cosmological relic-density observation**.



$\sin\theta = 0.01, m_x = 900$ GeV, $g_q = 0.25,$
 g_x constrained by relic density

$\sin\theta = 0.01, m_s = 70$ GeV, $g_q = 0.25,$
 g_x constrained by relic density

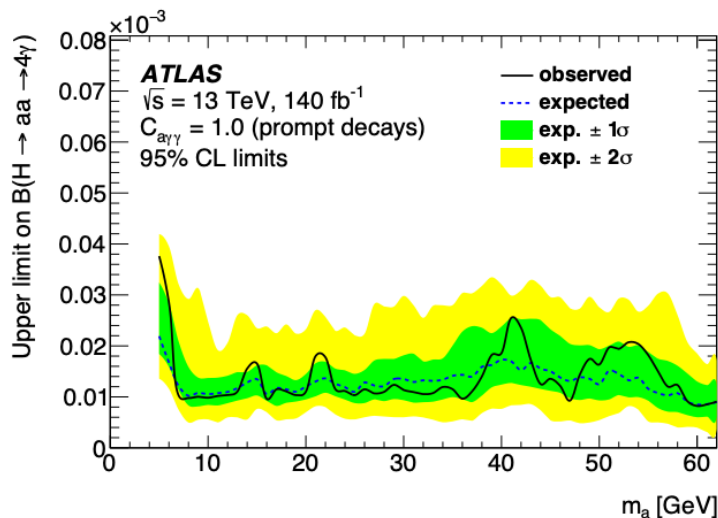
$\sin\theta = 0.01, m_x = 200$ GeV, $g_q = 0.25, g_x = 1.0$



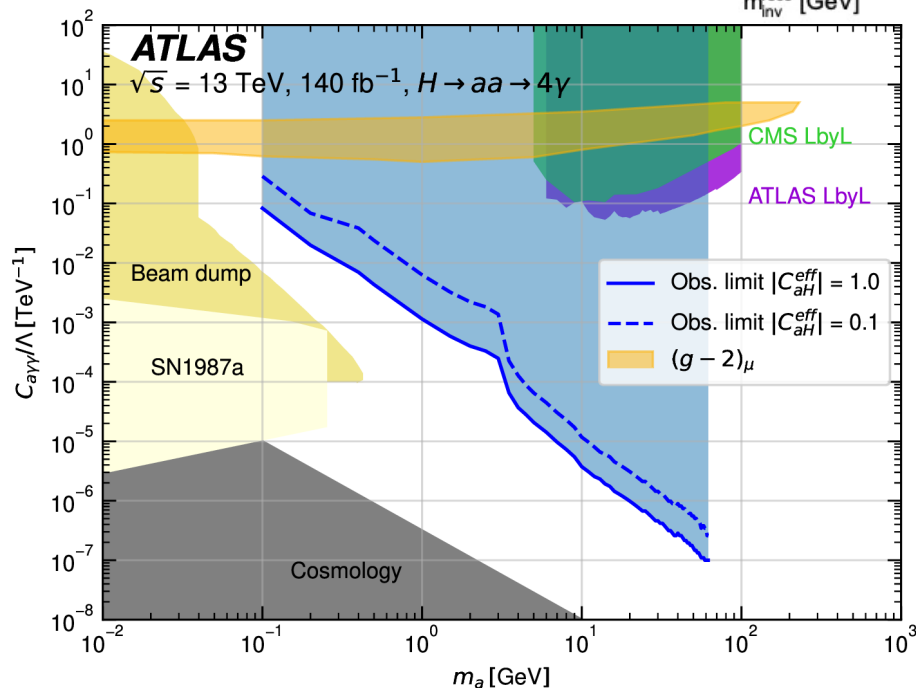
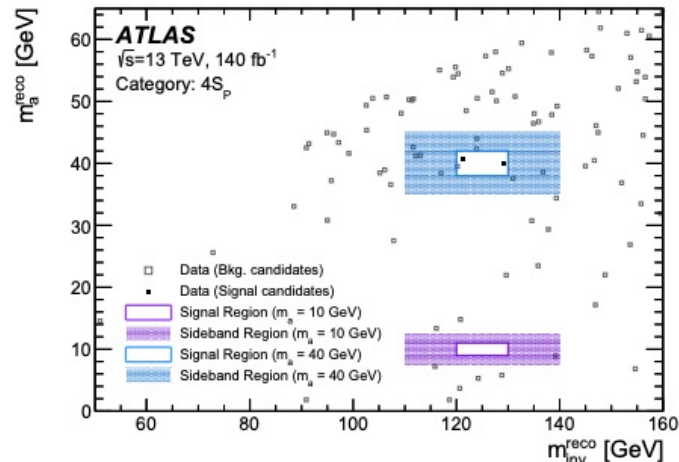
ALP mass range probed: $0.1 < m_a < 60$ GeV

[arXiv:2312.03306](https://arxiv.org/abs/2312.03306)

- **Collimated signature:** identified as single object when $m_a < 3.5$ GeV
- Both **Prompt (major sensitivity)** and **long-lived** signatures included



- **First time coverage of the full mass range** between 100 MeV and 62 GeV
- **Most stringent limits to date.**

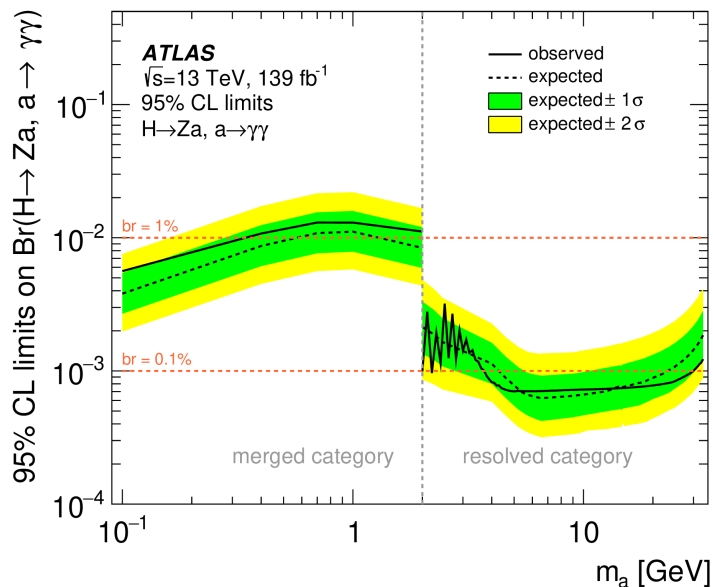
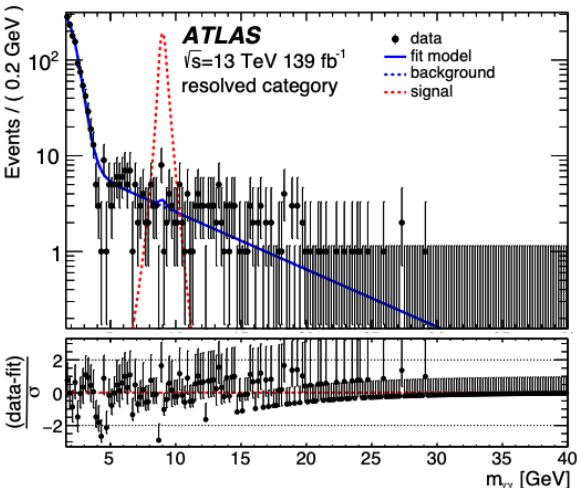


Limits on the ALP mass and coupling to photons at 95% CL, assuming $|C_{aH}^{eff}|/\Lambda^2 = 1 \text{ TeV}^{-2}$ (solid line) and $|C_{aH}^{eff}|/\Lambda^2 = 0.1 \text{ TeV}^{-2}$ (dashed line)

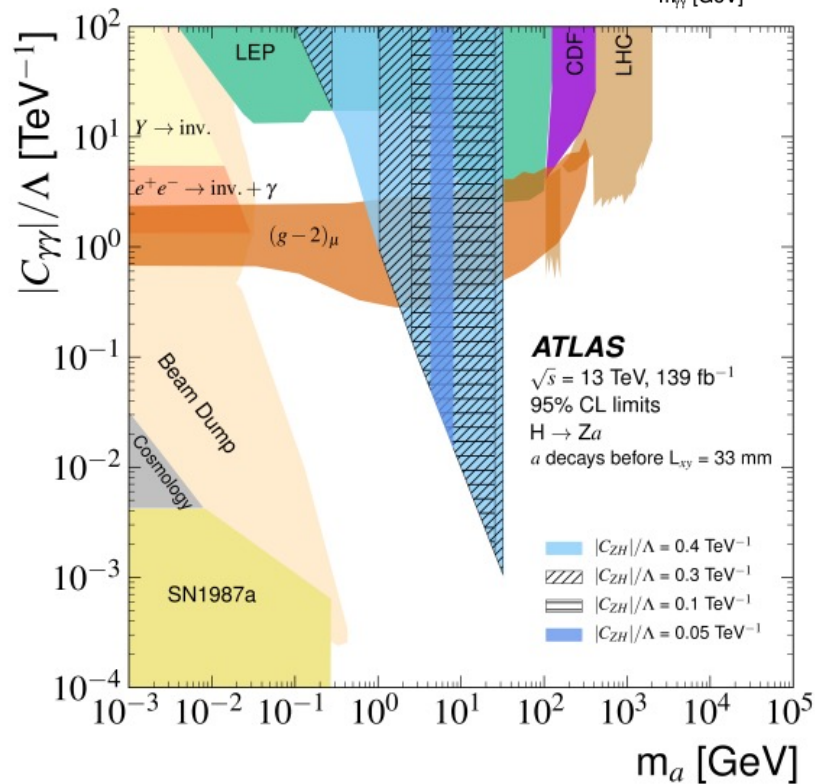
ALP mass range probed: $0.1 < m_a < 33$ GeV

[Phys. Lett. B 848 \(2024\) 138536](#)

- **Collimated signature:** identified as single object when $m_a < 2$ GeV
- Final state contains a lepton pair from Z decay and one (merged) or two (resolved) photons from a



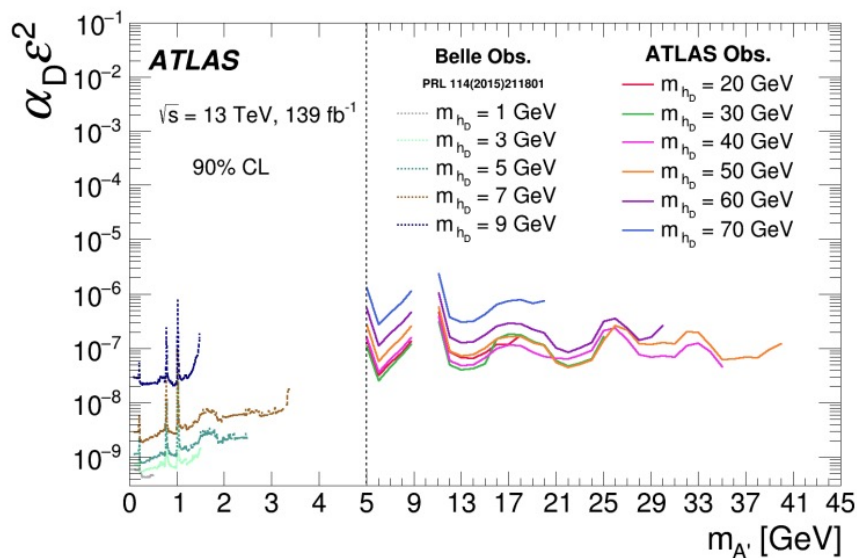
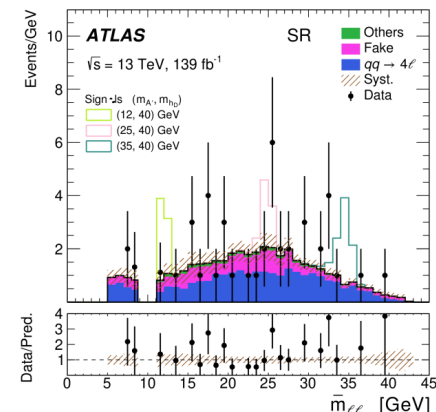
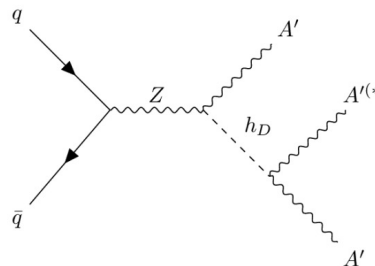
Complementary sensitivities between merged and resolved categories



[Phys. Rev. Lett. 131, 251801](#)

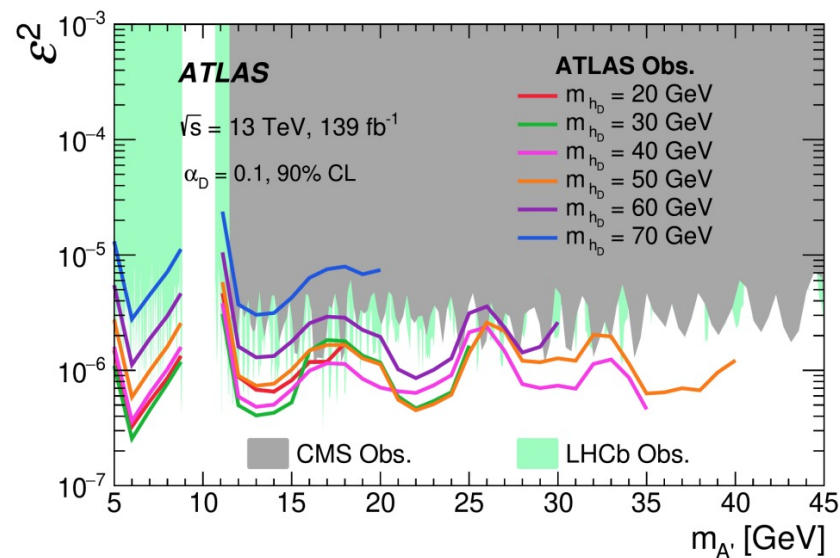
Search for **dark photon A'** from BSM rare Z decay: $Z \rightarrow A' h_D$ (h_D is the dark Higgs)

- Final state: ≥ 2 SFOS lepton pairs
- **New mass region for exploring dark sector couplings**



Limit on $\alpha_D \epsilon^2$:

- **Significant extend the probing range to 40 GeV**



Limit on ϵ^2 (assuming $\alpha_D=0.1$):

- **Competitive sensitivity with other LHC results**

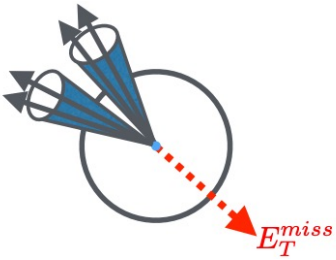
Signature: hadronically decaying W or Z boson and large missing transverse momentum.

- Include both resolved and merged topologies.

New for LHCP:
CERN-EP-2024-128

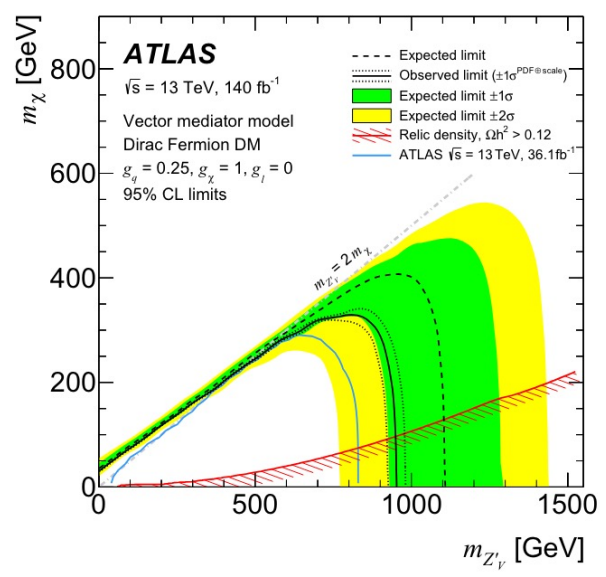
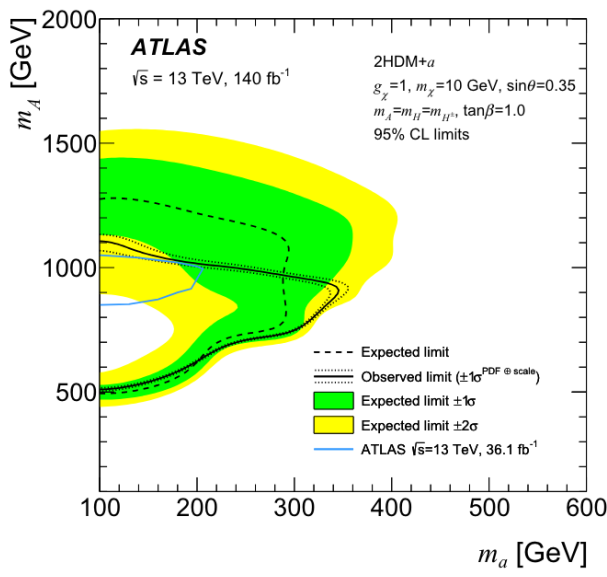
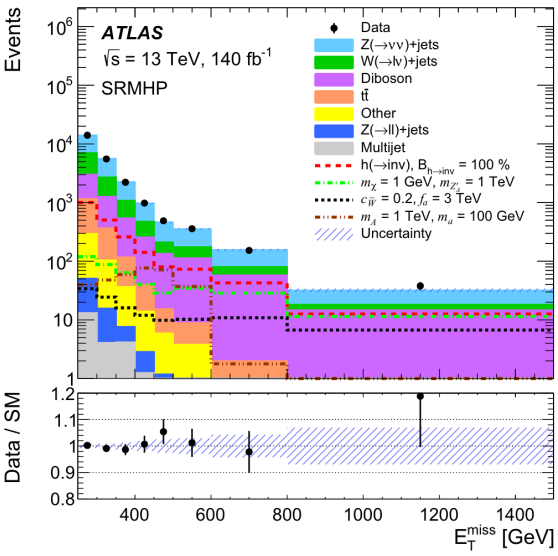
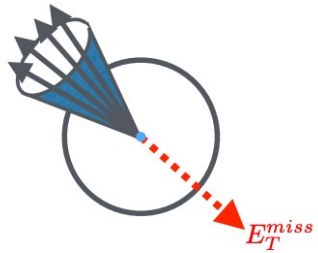
Resolved topology:

2 small jets with $R = 0.4$
& $E_T^{miss} > 200$ GeV



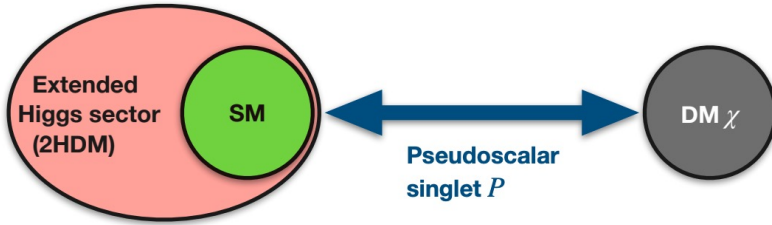
Merged topology:

Large jet with $R = 1.0$
& $E_T^{miss} > 250$ GeV



Dark matter interpretations:

- $BR(H \rightarrow \text{inv}) < 34\%$ (31%) obs (exp)
- 2HDM+a Exclusion on pseudoscalar mediator a up to 350 GeV
- Z' Vector DM mediator Improved exclusion sensitivity



- 2HDM+ a model provides access to DM-SM interaction, via

MET+X (mediator \rightarrow invisible)

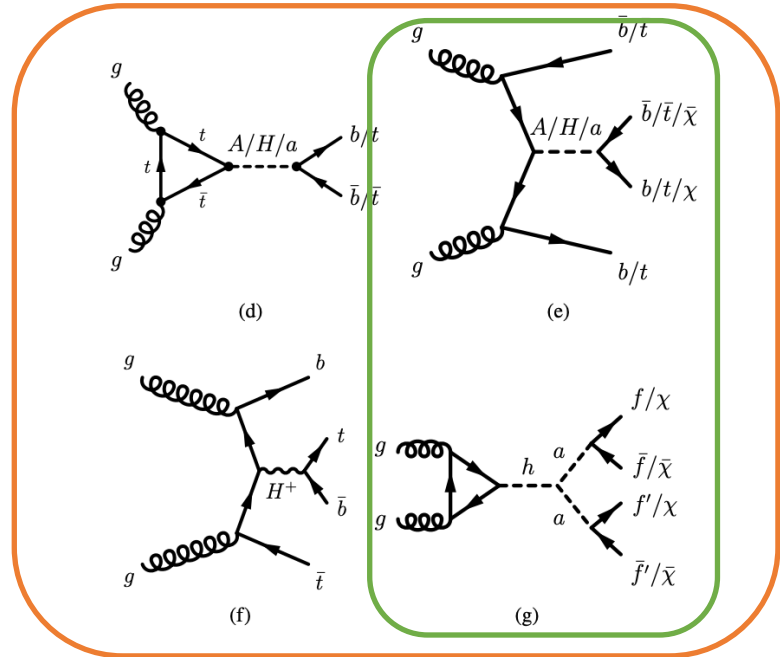
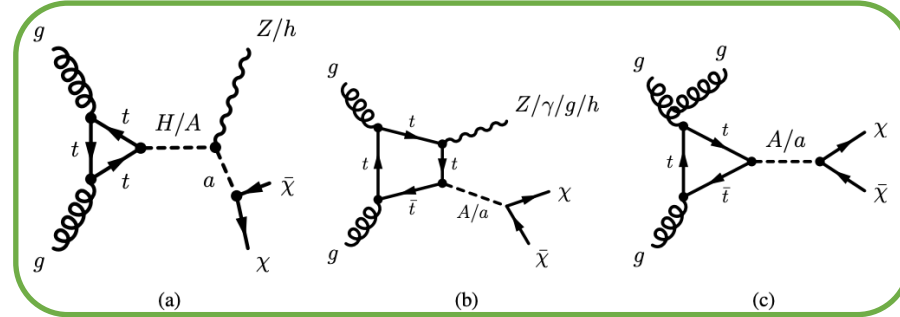
Resonance/ decay product reconstruction (mediator \rightarrow visible)

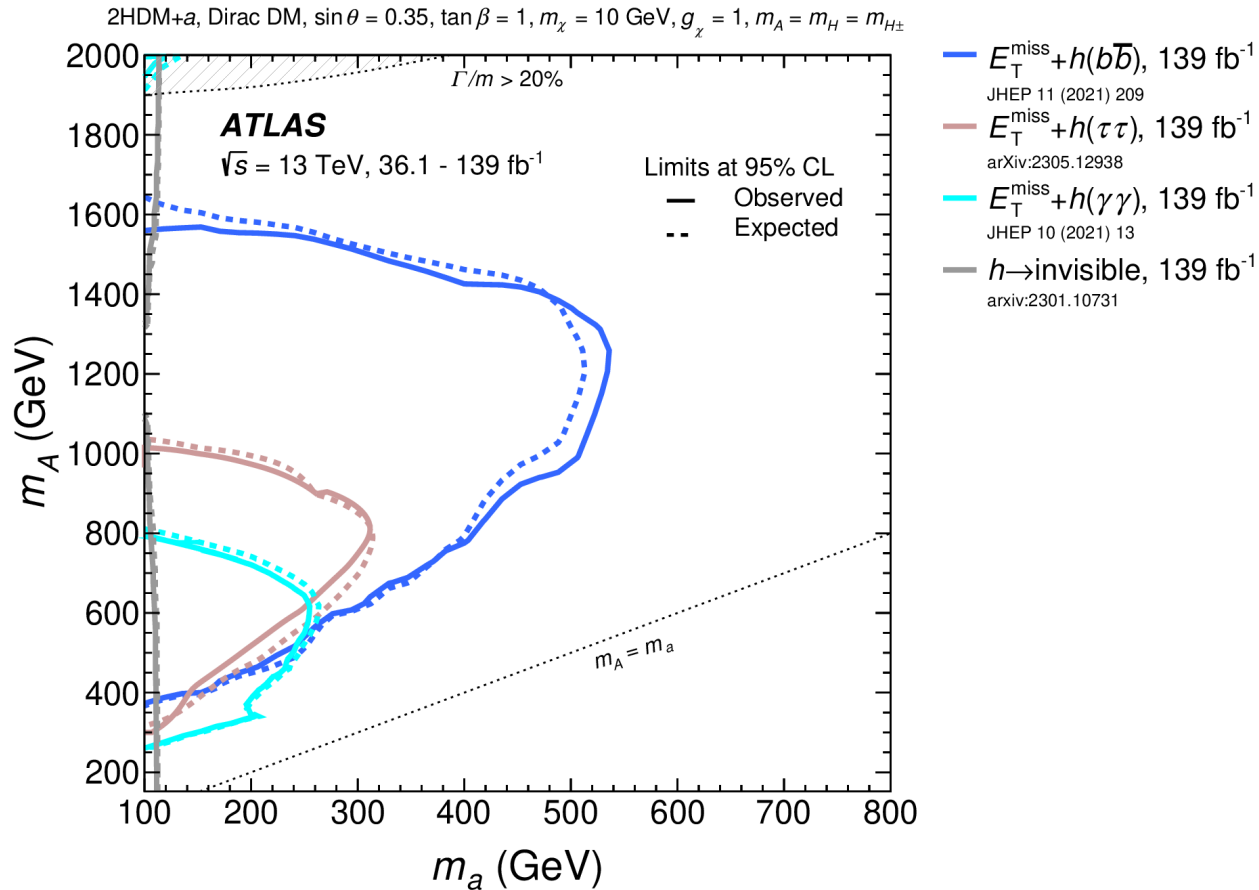
- Fully defined by 14 parameters but reduced to 5 unconstrained parameters.

$m_A = m_H = m_{H^\pm}$	masses of additional heavy Higgs
m_a	mass of pseudo-scalar mediator
m_χ	DM mass
$\sin \theta$	mixing angle between the pseudo-scalars
$\tan \beta$	ratio of 2 Higgs doublet VEVs

- The importance of the model and the multitude of signatures involved \rightarrow one of the most extensive search projects in ATLAS.

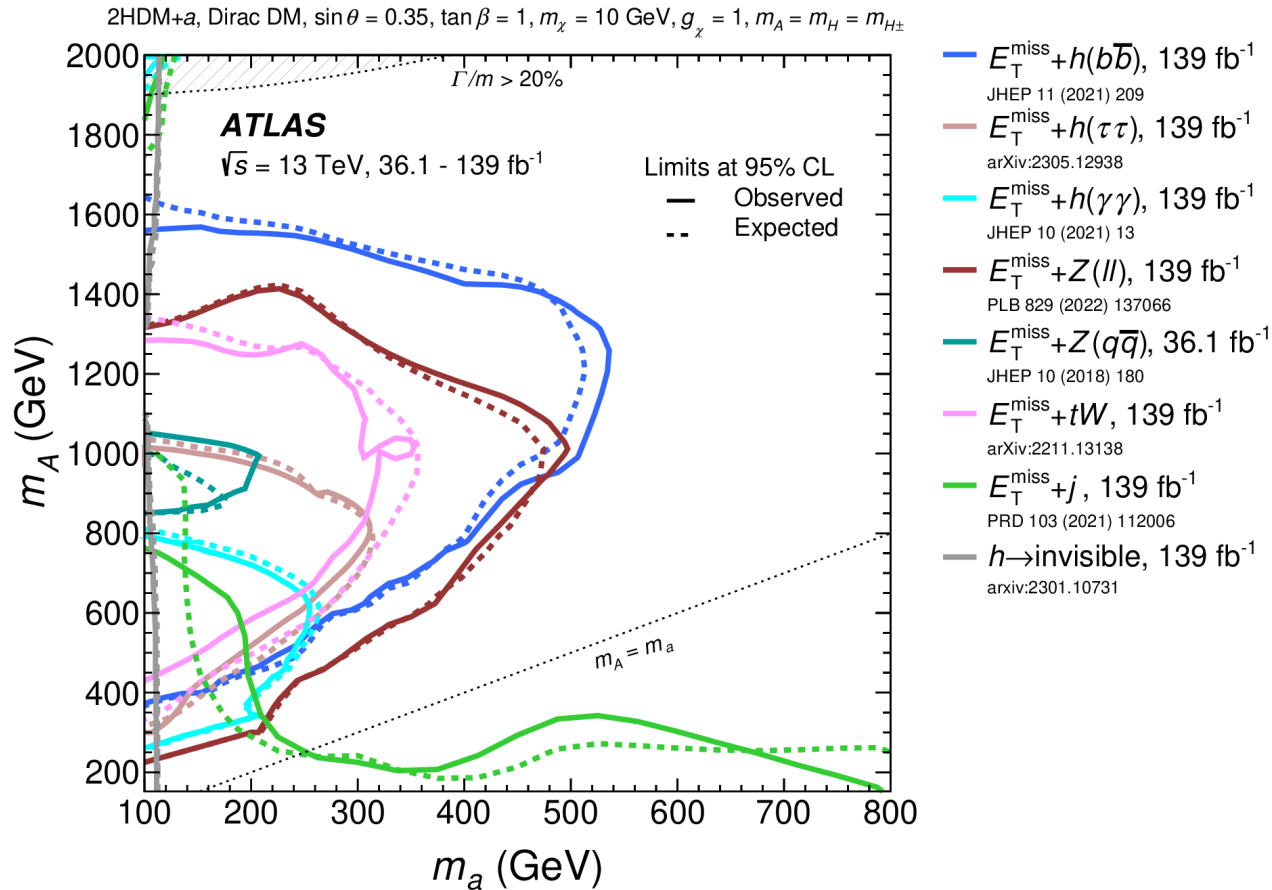
2HDM+ a : A pillar model with a light pseudoscalar mediator in LHC DM searches





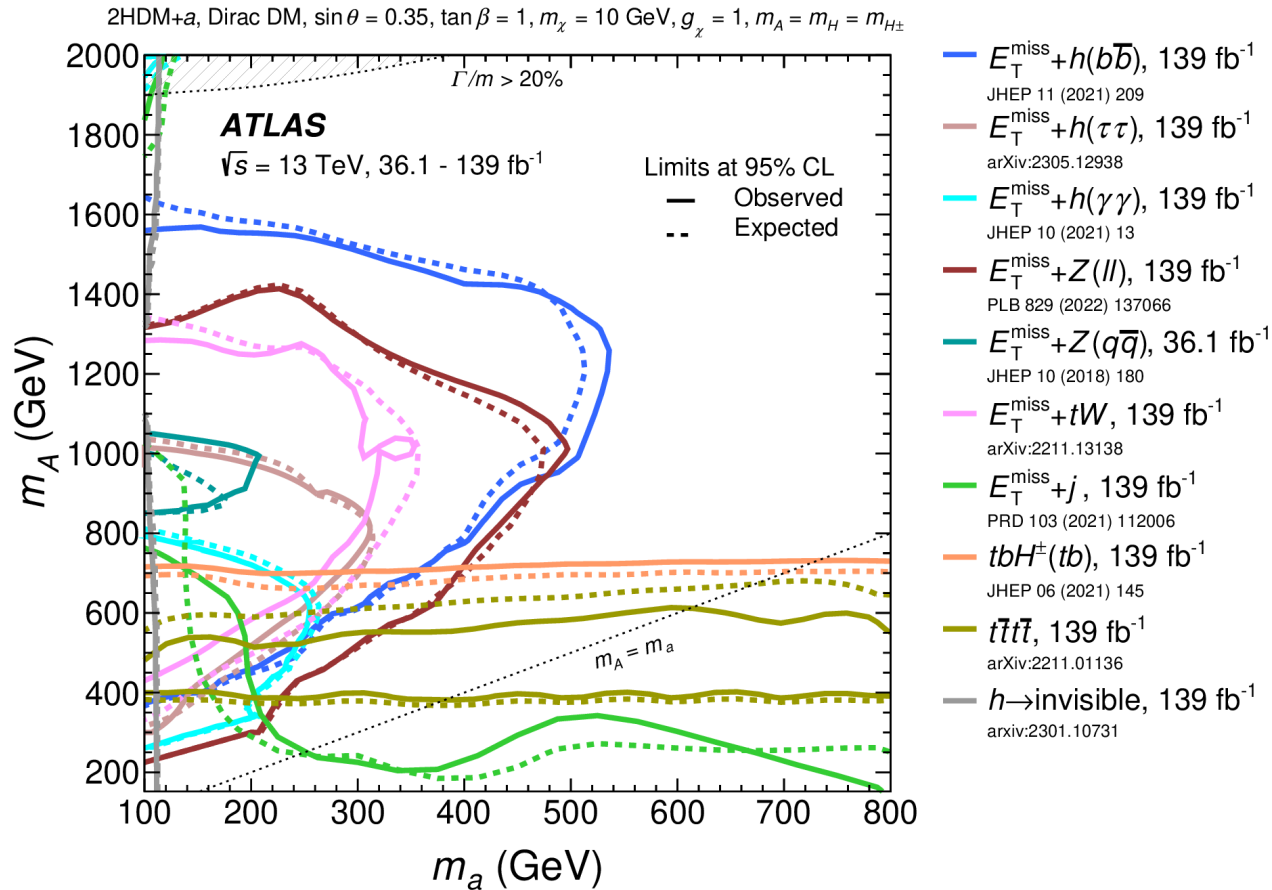
Higgs + DM signatures

DM appears in the final state together with Higgs



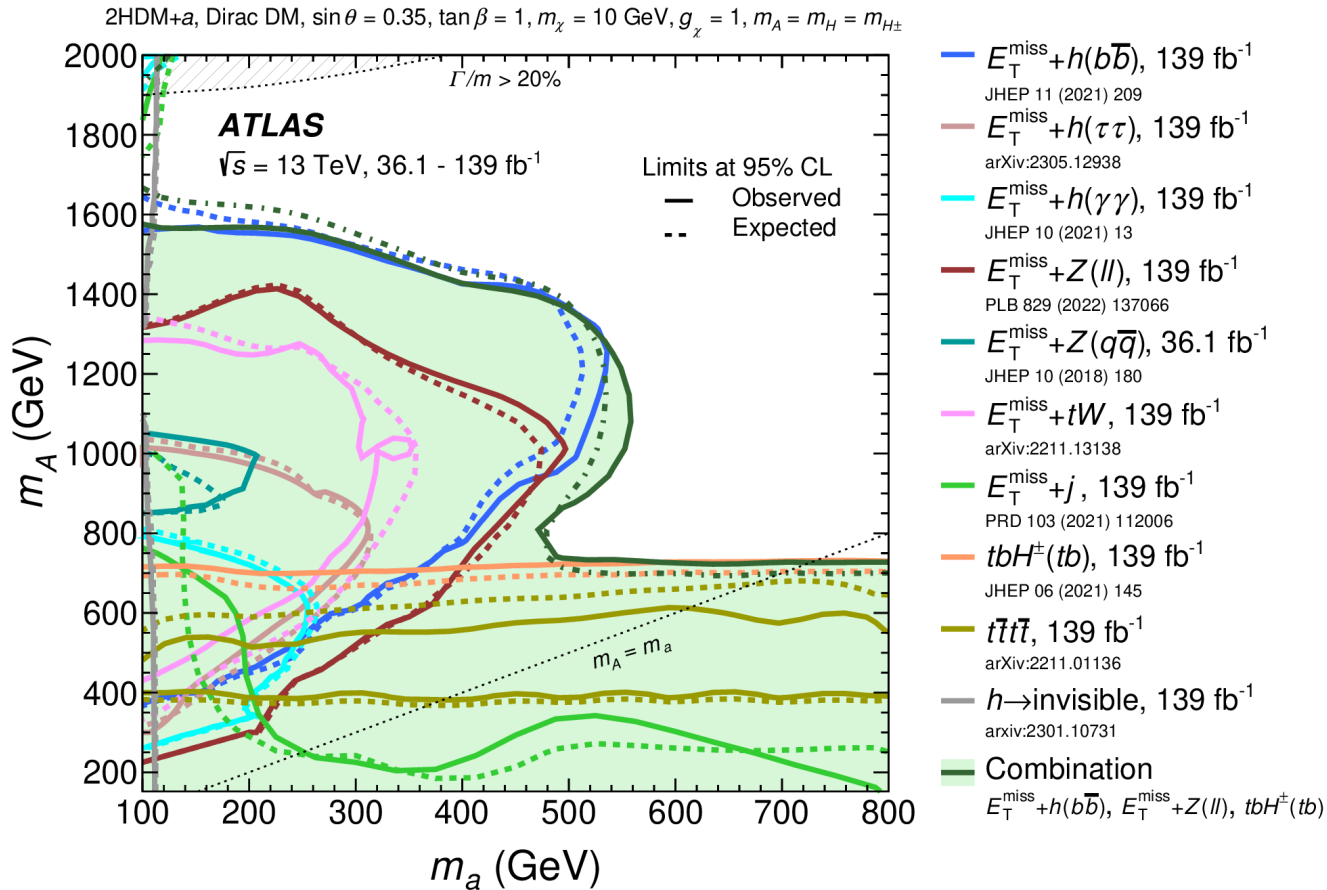
Add X + DM signatures, sensitivities largely improved at lower $m_{A/H}$

DM appears in the final state together with other SM particles



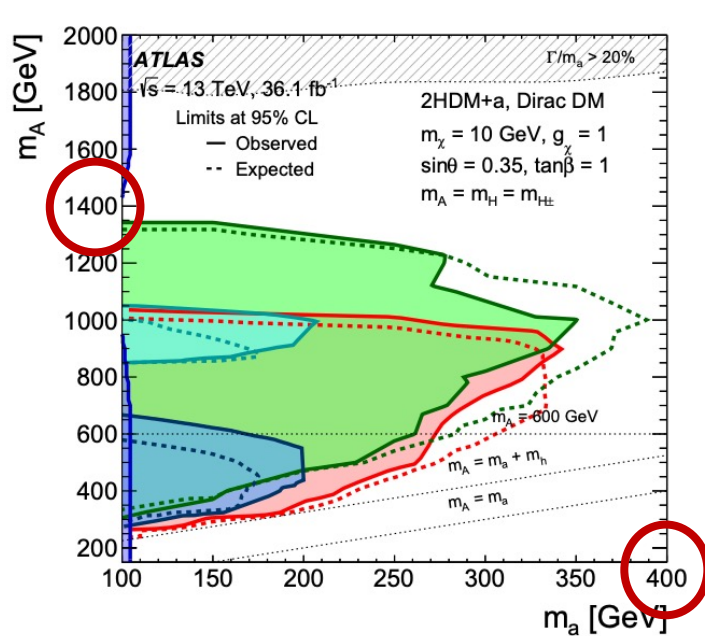
Add exotic Higgs boson signatures, complementarity obtained from resonant signatures.

DM doesn't need to appear in the final state

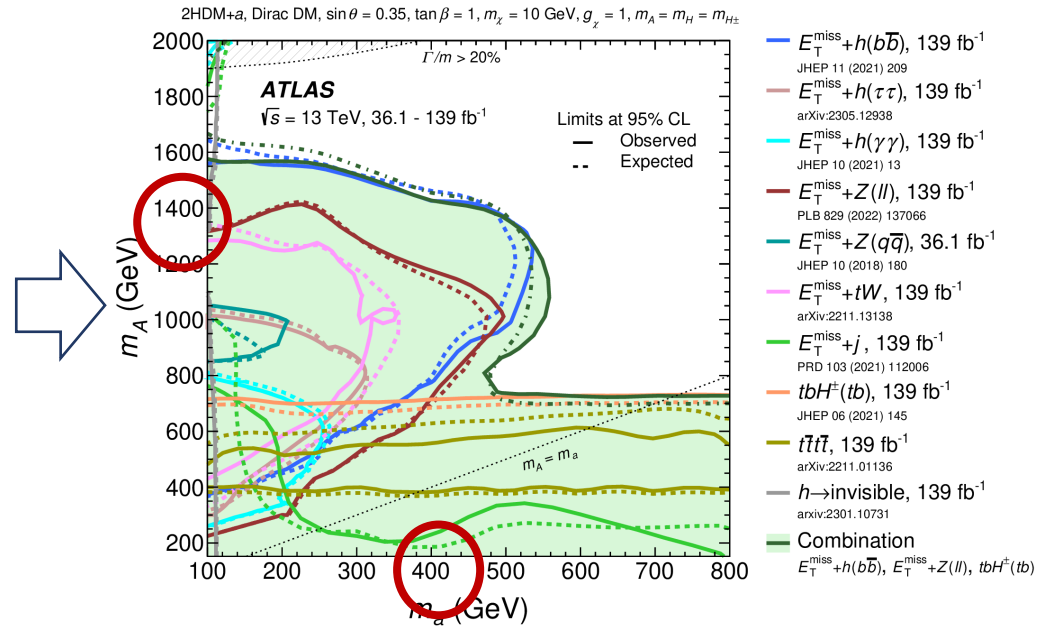


Combine analyses – reaching the best sensitivity!

Having three most sensitive channels combined



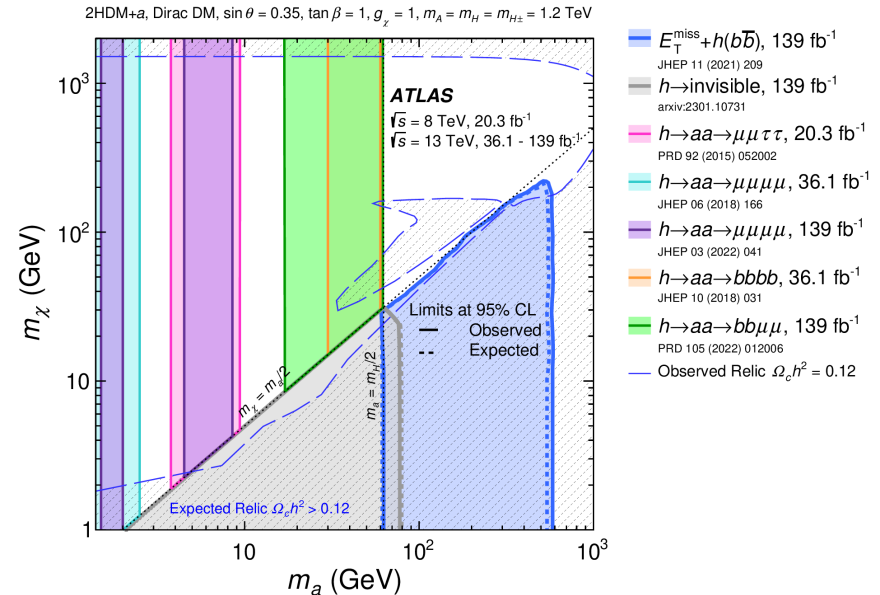
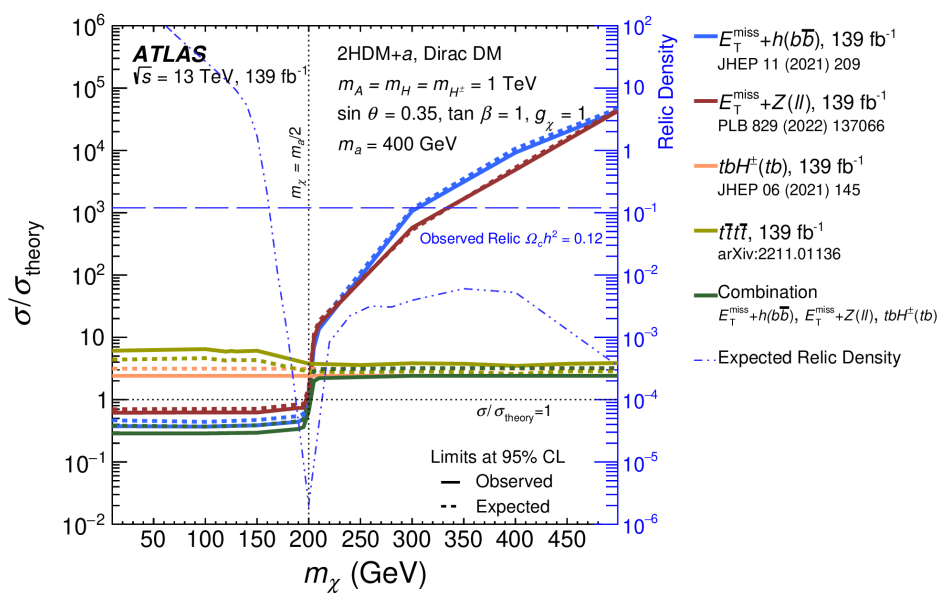
Results in 2016



Most recent summary

- The **best LHC result on 2HDM+a** to date with impressive large improvements
- We largely narrow down the space of possibilities for light pseudo scalar mediator + dark matter!

Full Run 2 2HDM+a summary paper has been accepted by **Science Bulletin**
[arXiv:2306.00641](https://arxiv.org/abs/2306.00641)



Exclusions in a DM mass scan – connection with relic density constraints

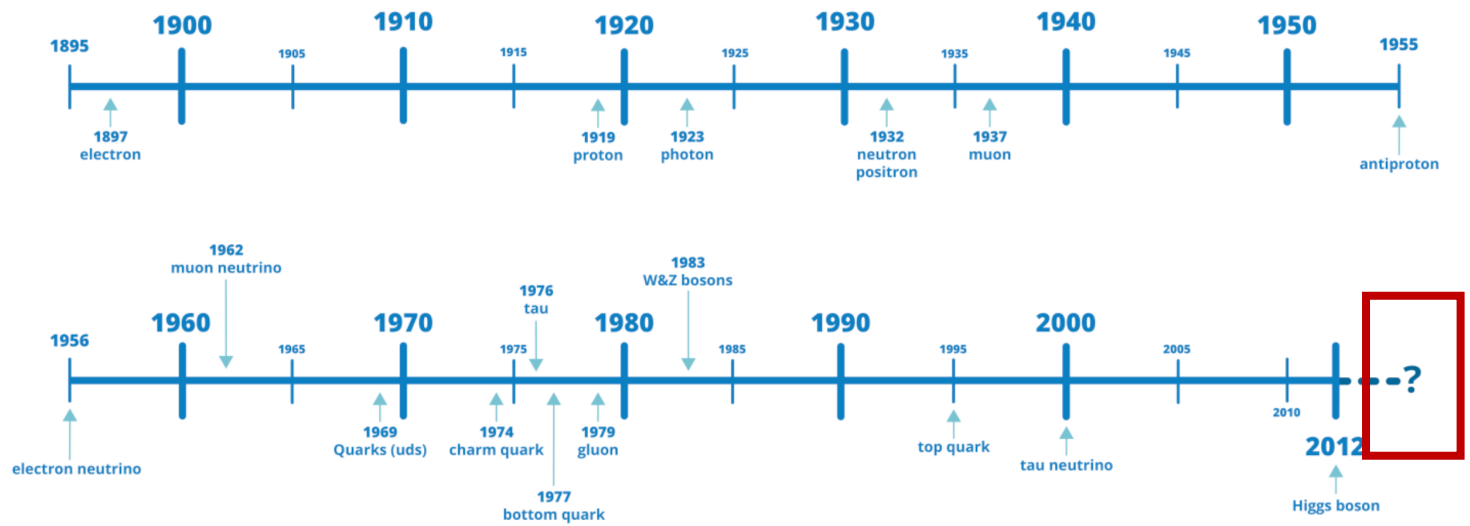
Contribution from **dedicated light mediator $h \rightarrow aa \rightarrow 4f$ searches** constrains the DM-mediator mass plane

- The **most comprehensive set of results** to date.
- Shed light on the future DM model development and search projects.

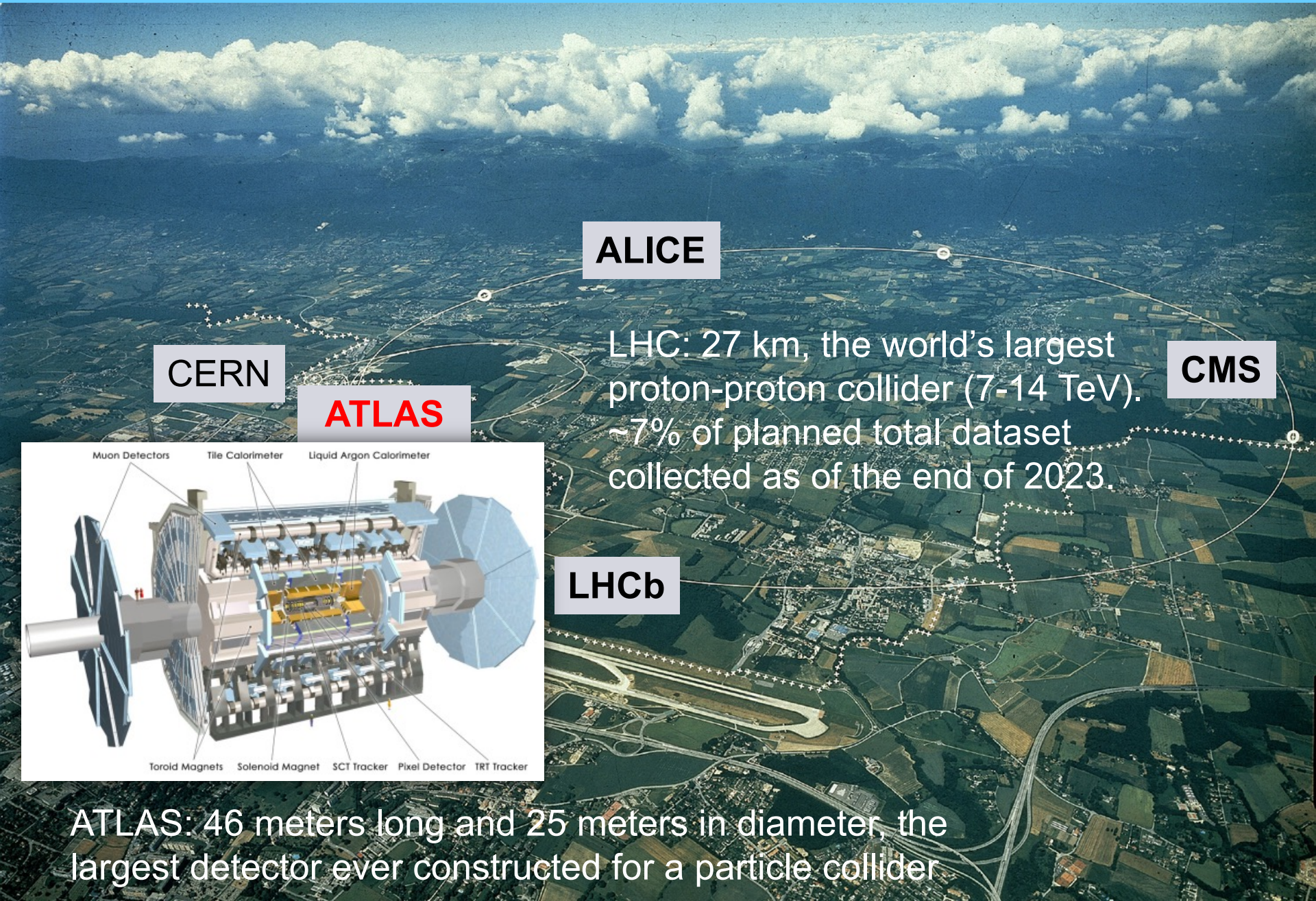
- Many theories, of various degrees of complexity, contain light BSM mediators.
- It is important to **cover all this ground** and also **prepare for unexpected, not-yet-theorised discoveries**.
- **No stone must be left unturned till probing the New Physics!**



Key particle discoveries



Backup



ALICE

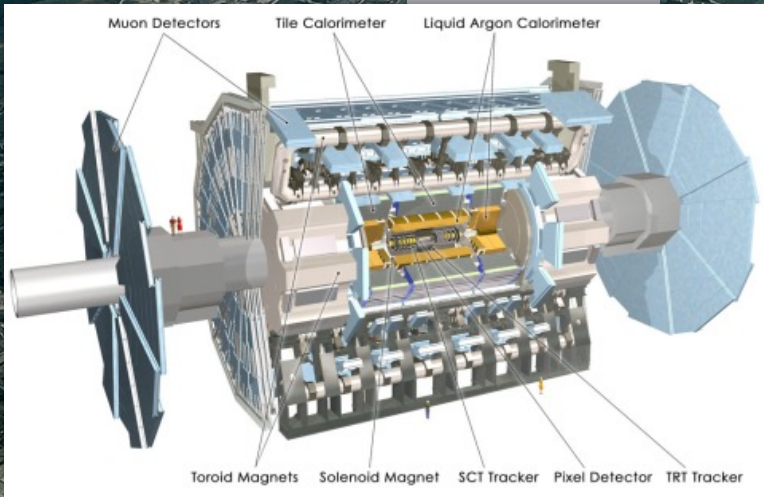
LHC: 27 km, the world's largest proton-proton collider (7-14 TeV).
~7% of planned total dataset collected as of the end of 2023.

CMS

CERN

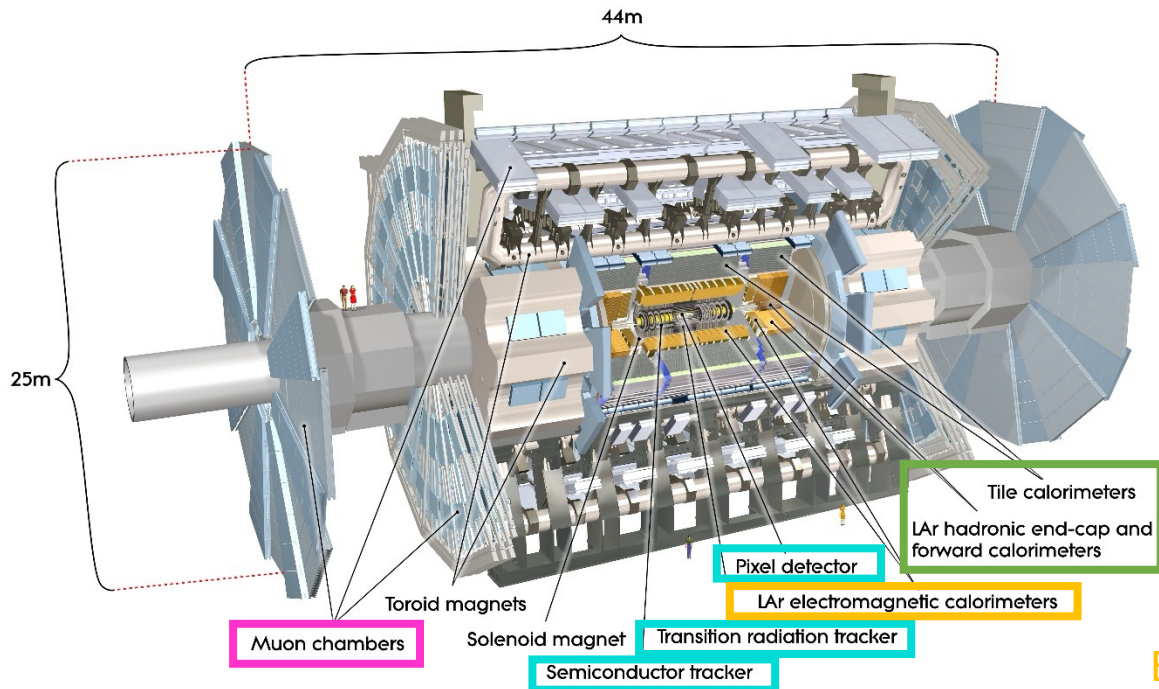
ATLAS

LHCb



ATLAS: 46 meters long and 25 meters in diameter, the largest detector ever constructed for a particle collider

The **largest detector** ever constructed for a particle collider.



Hadronic calorimeter

Trigger and measurement of jets and E_T^{miss} .

EM calorimeter

e/ γ trigger, identification and measurement.

Muon Spectrometer:

Muon trigger and tracking.

Inner detector

Precise tracking and vertexing, e/ π separation.

- Solenoid Magnet: 2T
- Toroid Magnets: 0.5-1T

Theoretical benchmarks: sharpen the regions of interest.

