What’s new with light scalars!

Searches for Beyond Standard Model Higgs boson decays
(including low mass resonances)

Judith Höfer – IFIC Valencia
on behalf of the ATLAS collaboration

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Overview

'a' or 'A' is the new light (pseudo-)scalar

Motivation

New analyses

$gg \to A$, tta

$H \to Za$, $H \to aa$

References

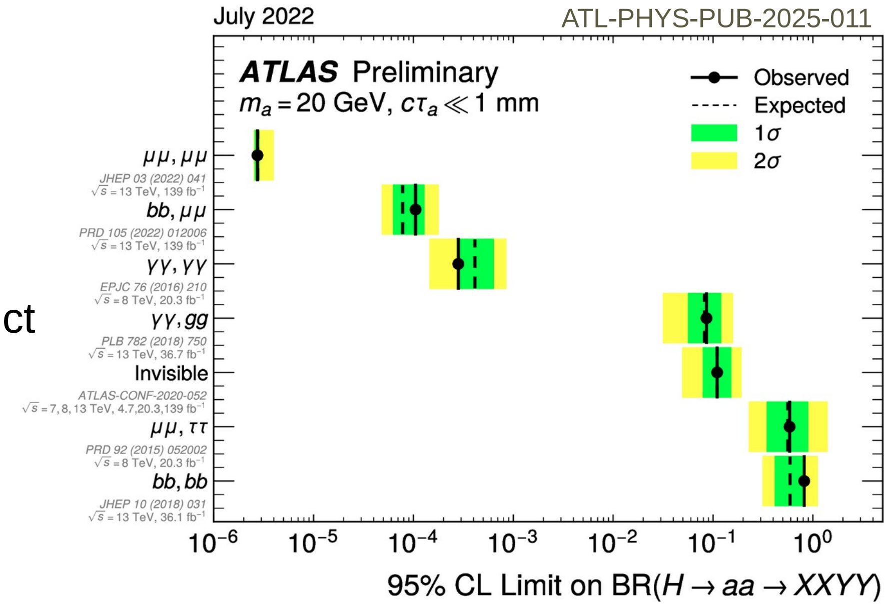
Direct & associate production

$gg \to A \to \tau\tau$	JHEP 12 (2024) 126
tta, $a \to bb$	arXiv:2503.17254

Higgs portal

$H \to Za \to ll$+jets	arXiv:2411.16361
$H \to aa \to 4\tau$ (merged)	arXiv:2503.05463
$H \to aa \to 2\gamma 2\tau$	JHEP 03 (2025) 190
$H \to aa \to 4b$, $6b$	arXiv:2507.01165

Light Scalar Searches



Motivation & models

- Many BSM models addressing the shortcomings of the SM have extended Higgs sectors and can predict light (pseudo-)scalars ‘a’

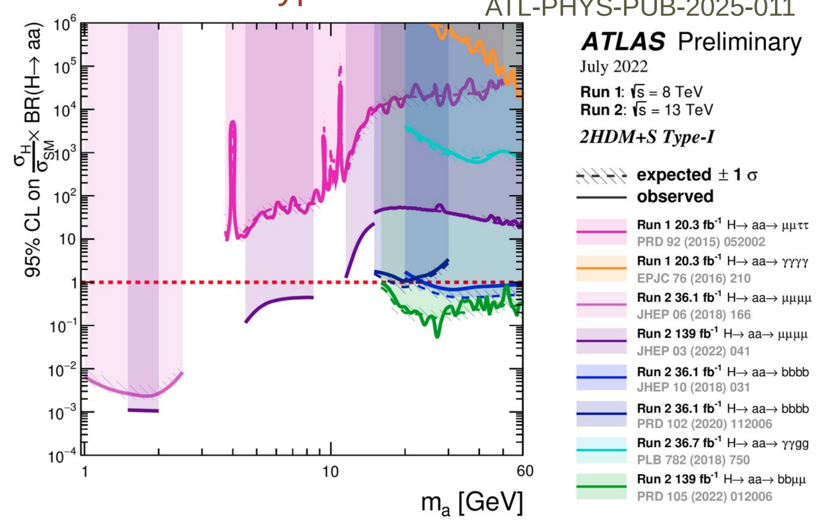
  e.g. 2HDM, 2HDM+a, TRSM, portals to hidden sectors

- In many models light scalars have **Yukawa-like couplings** inherited from mixing with the SM Higgs boson

- Extensive search program at the LHC for different production mechanisms and in different final states

  e.g. ATLAS searches for H → aa

2HDM+S Type-I



Motivation

Comments on experimental methods

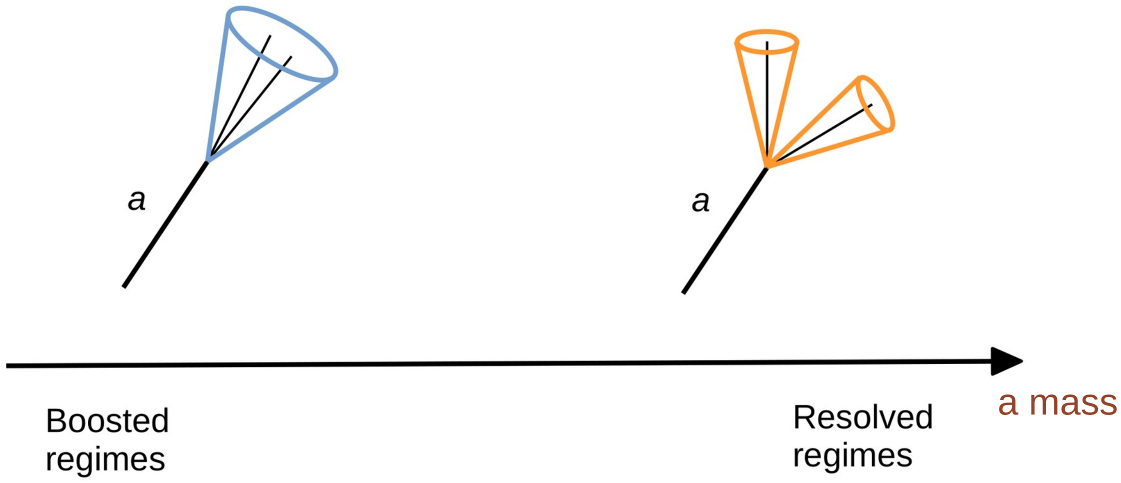
[1] DeXTer: Deep Sets based Neural Networks for Low-pT $X \to bb$ Identification in ATLAS, ATL-PHYS-PUB-2022-042

[2] Improved reconstruction of highly boosted τ-lepton pairs in the $\tau\tau \to (\mu\nu_\mu\nu_\tau)$(hadrons + ν_τ) decay channels, 2412.14937

[3] Reconstruction and identification of pairs of collimated τ-leptons decaying hadronically, 2411.09357

Merged vs. resolved

- At lower mass of the light scalar, it will be produced with a significant Lorentz boost
  - the decay products are collimated and merge
  - motivates dedicated experimental techniques like double-b-taggers [1], merged $\mu\tau_{had}$ objects [2] or boosted di-τ objects [3]



Overview

Motivation

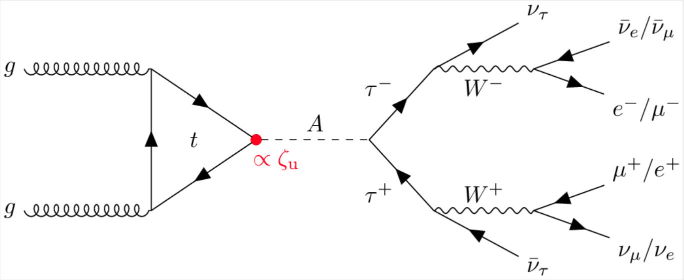
New analyses

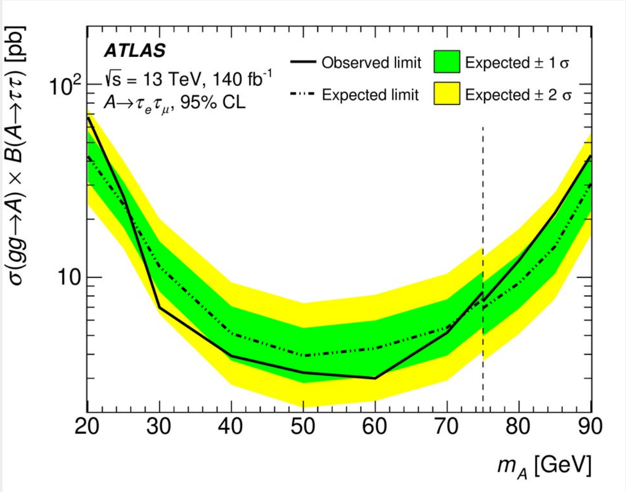
- $gg \rightarrow A$, tta
- $H \rightarrow Za$, $H \rightarrow aa$

gg → A → ττ

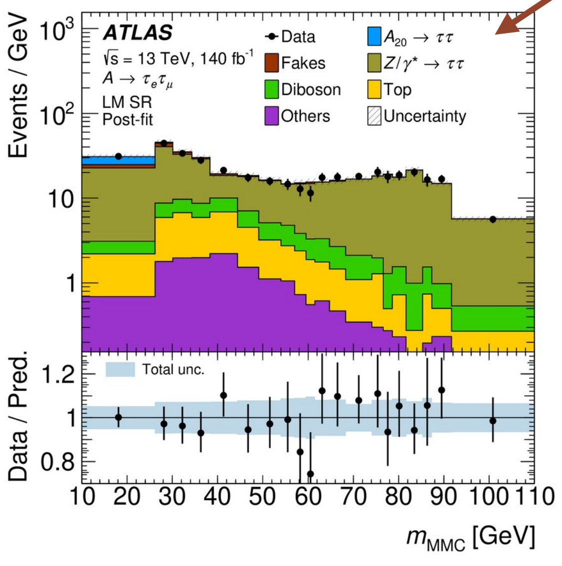
JHEP 12 (2024) 126

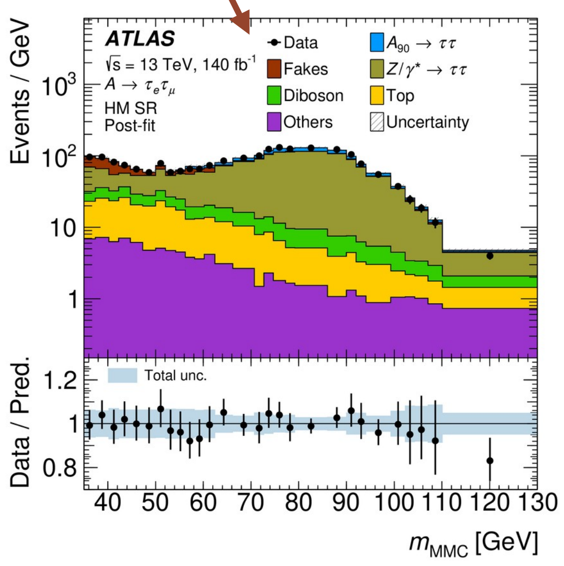
- Search for CP-odd scalar A, m = 20 – 90 GeV
- gg → A → ττ, → **eμ**4ν final state
- Select =1e, =1μ (opposite charge) events
- Main background: Z → ττ
- Main observable: m_{MMC}, a likelihood-based estimator of invariant di-τ mass
- Two signal regions: low mass and high mass





Largest local excess: 1.8 σ (m_A = 20 GeV)



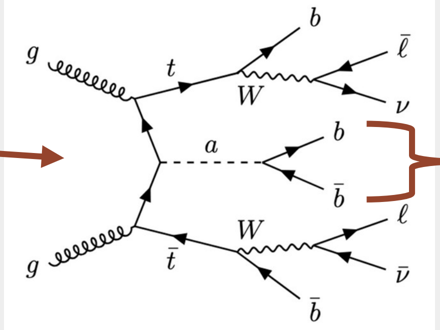


gg → A, H → Za, tta

tta, a → bb

arXiv:2503.17254

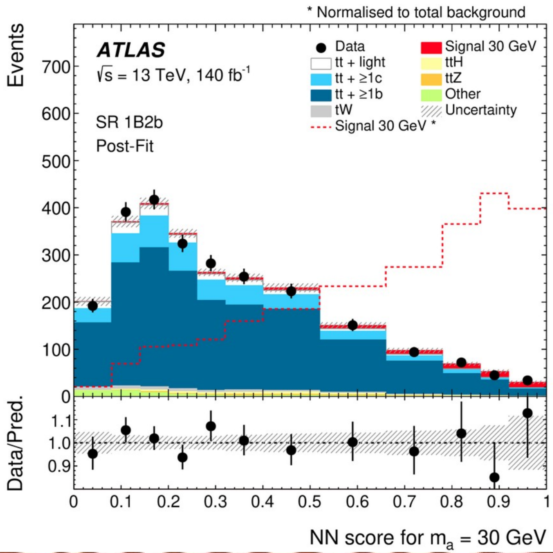
- Search for light scalar a, m = 12 – 100 GeV
- tta production, a → bb decay (merged or resolved)
- Select events with two leptons from tt and ≥ 3 jet
- Main background: tt+jets, especially tt+bb
    - Derive re-weighting to improve modelling
- Main observables: number of b-tagged and double-b-tagged jets, lepton-jet- and jet-jet-pairing BDT scores, discrimination NN score

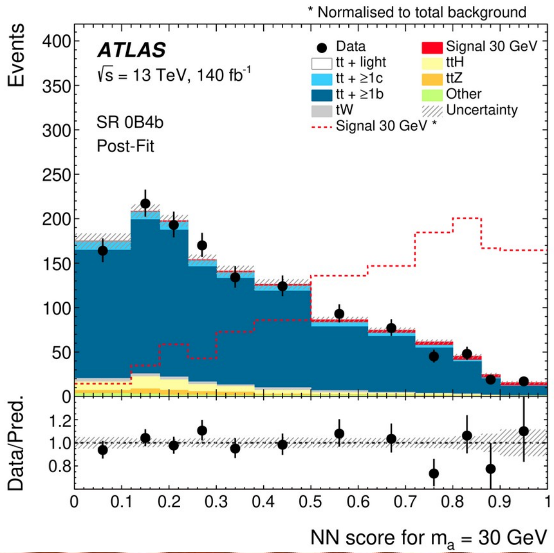


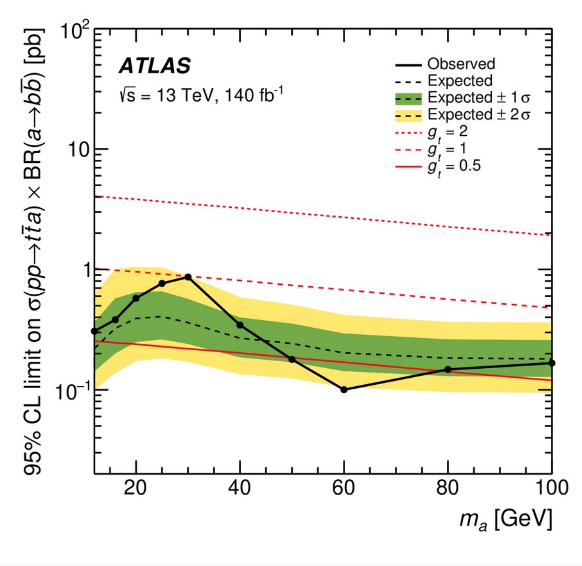
2 b-jets (DL1r)

or

1 double-b-jet (DeXTer)







Largest local excess: 2.0 σ (m_a = 30 GeV)

Overview

Motivation

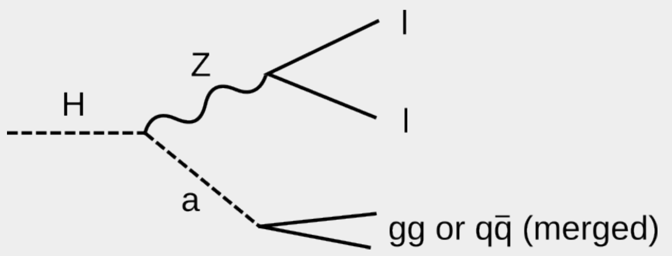
New analyses

- $gg \rightarrow A, tta$
- $H \rightarrow Za$, $H \rightarrow aa$

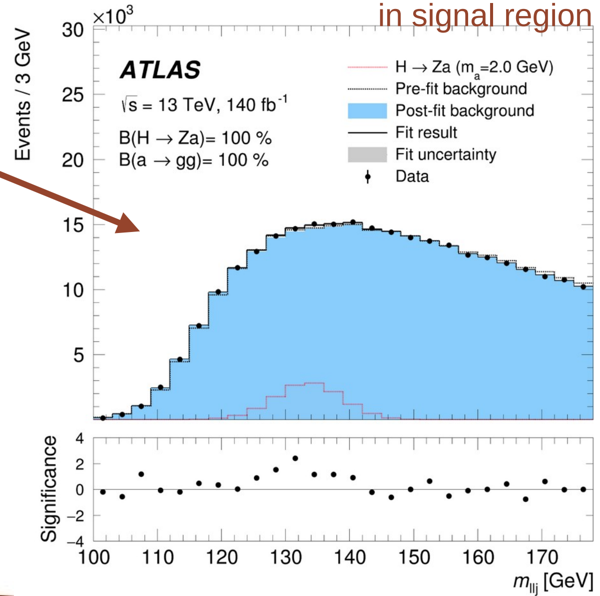
H → Za → ll+jets

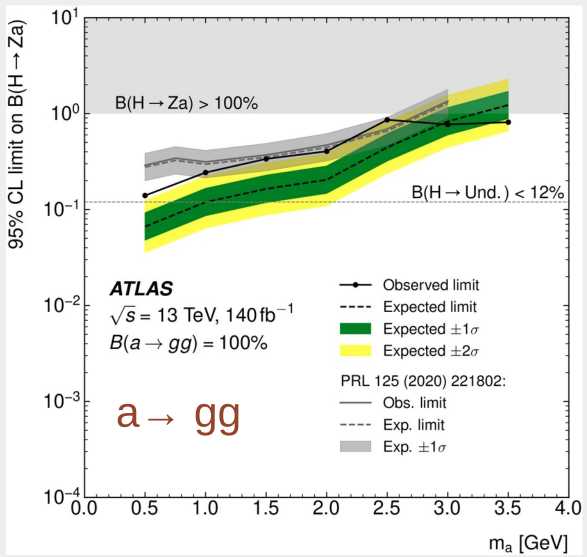
arXiv:2411.16361

- Search for light scalar a, m = 0.5 – 3.5 GeV
- H → Za production, a → gg or qq decay (merged)
- Select events with two leptons from Z and ≥ 1 jet
- Main background: Z+jets
  - Derive NN-based re-weighting to improve modelling
- Main observables: lepton-lepton-jet invariant mass m_{llj}, NN-based a mass estimation from jet observables, classification NN score



in signal region





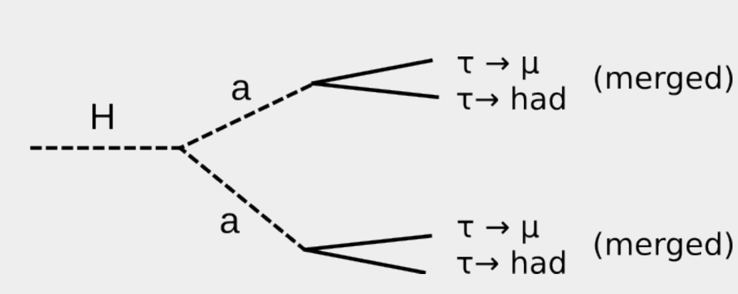
see paper for a → qq limit plot

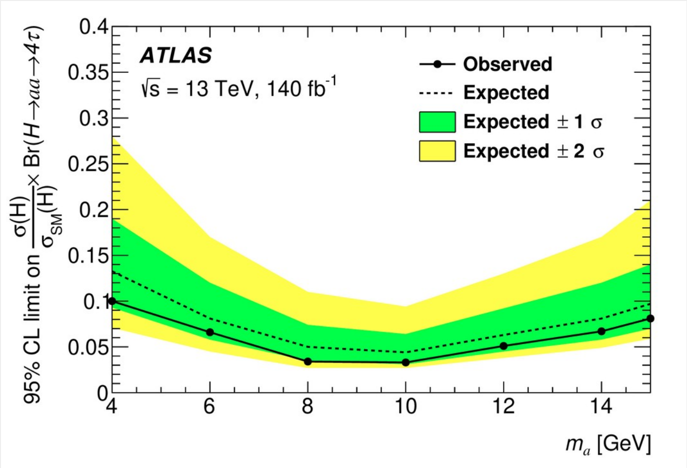
Largest local excess: 1.5 σ (m_a = 0.5 GeV, a → gg)

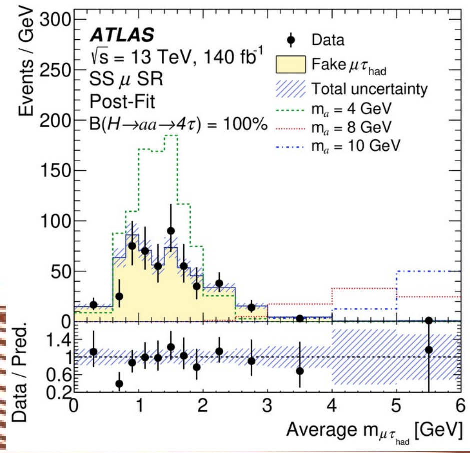
H → aa → ττττ

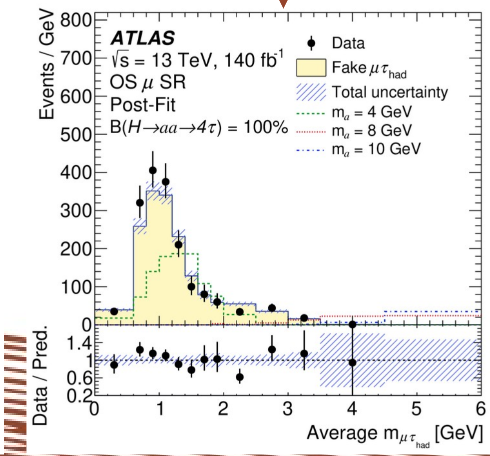
arXiv:2503.05463

- Search for light scalar a, m = 4 – 15 GeV
- H → aa production, a → ττ → μ, had decay (merged)
- Select events with exactly two $\mu\tau_{had}$ objects (hadronic τ with opposite-charge μ inside) with mass < 15 GeV, and combined invariant mass slightly below Higgs mass (missing neutrinos)
- Main background: events with fake τ_{had} with non-prompt μ from hadron decays
  - Estimate with tight-to-loose data-driven method
- Main observable: (corrected) average mass of $\mu\tau_{had}$ objects







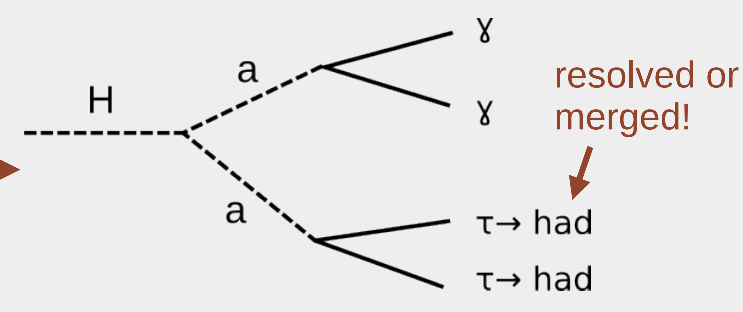


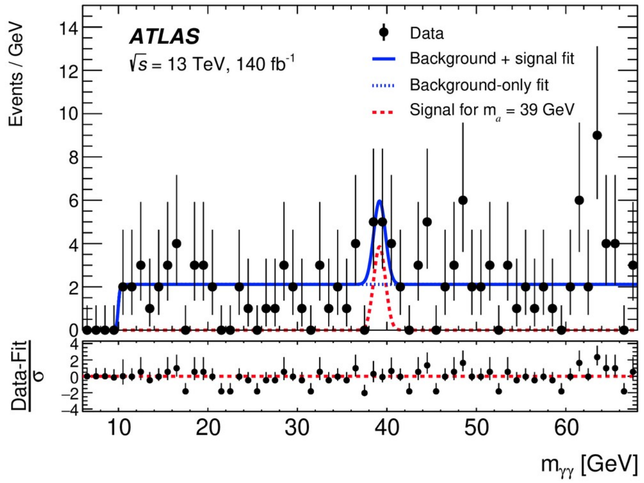
No excess observed

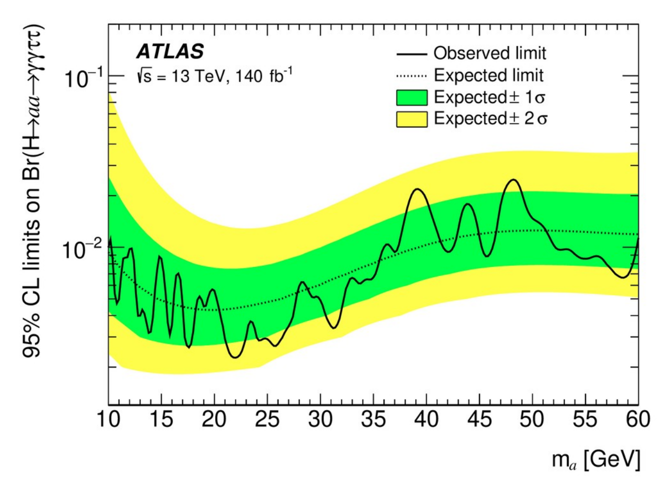
H → aa → $\gamma\gamma\tau_{had}\tau_{had}$

JHEP 03 (2025) 190

- Search for light scalar a, m = 10 – 60 GeV
- H → aa production, a → $\gamma\gamma$, a → $\tau_{had}\tau_{had}$ decay (resolved or merged)
- Select events with 2 photons and either one boosted di-τ candidate or two resolved τ-leptons
- Main background: continuum $\gamma\gamma$, γ jet and jet jet events, with jets misidentified as photons or τ_{had}
  - Estimate data-driven by parametrising continuum shape by an analytical function
- Main observable: invariant photon mass $m_{\gamma\gamma}$







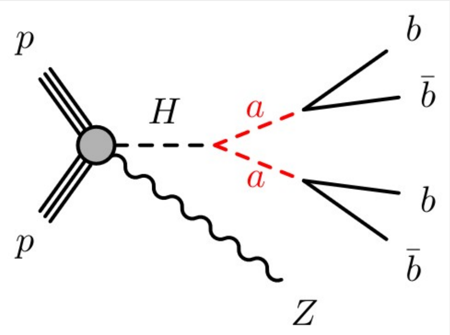
Largest local excess: 2.2 σ (m_a = 39 GeV)
2.1 σ (m_a = 48 GeV)

ZH, H → aa → 4b

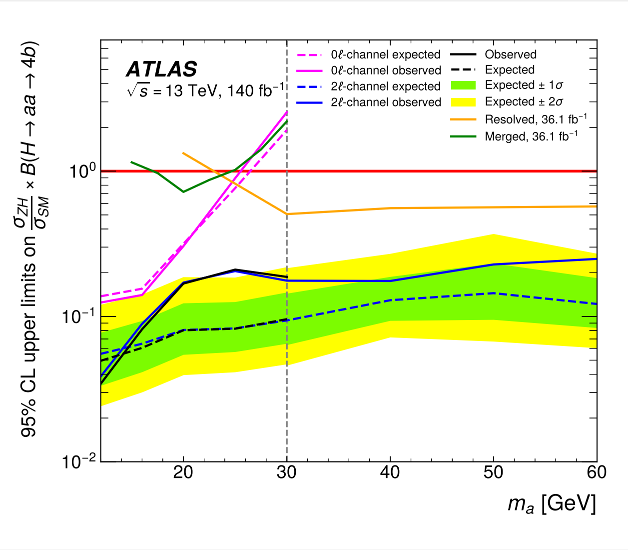
NEW!

arXiv:2507.01165

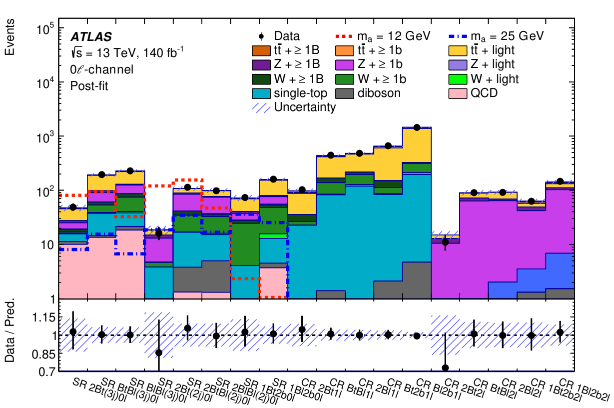
- Search for light scalar a, m = 12 – 60 GeV
- ZH, H → aa production, a → bb decay (resolved or merged)
- Select events with 2 leptons or E_T^{miss} (2ν) from the Z decay and at least 3 b-objects: b-tagged jets, double-b-tagged jets or displaced vertices outside of jets
- Main background: Z+jets, tt
  - Derive re-weighting to improve modelling
- Main observables: number of b-objects, NN-based quadruplet selection (object pairing), discrimination BDT score

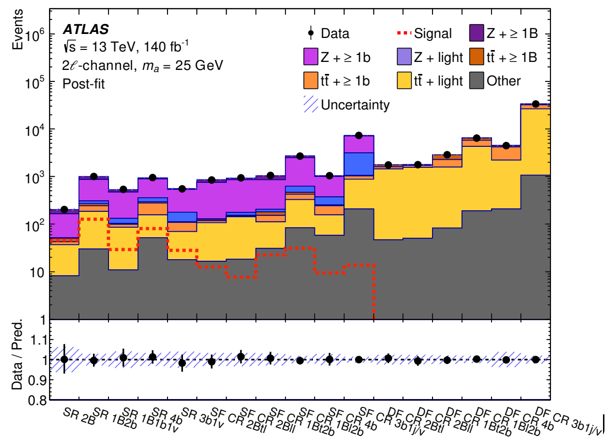


resolved (DL1r) or merged (DeXTer)!



Largest local excess: 2.83 σ (m_a = 25 GeV)
2.04 σ global





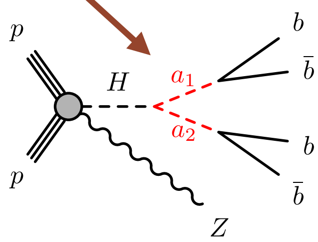
ZH, H → a_1a_2 → 4b / 6b

NEW!

arXiv:2507.01165

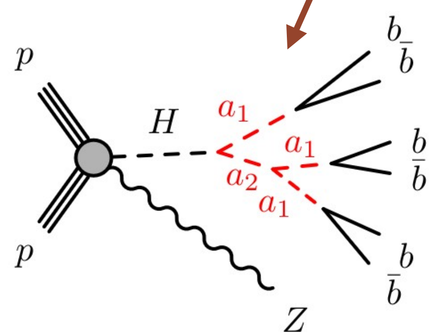
- Same analysis did also search for decays to two scalars of **different mass** H → a_1a_2 → 4b

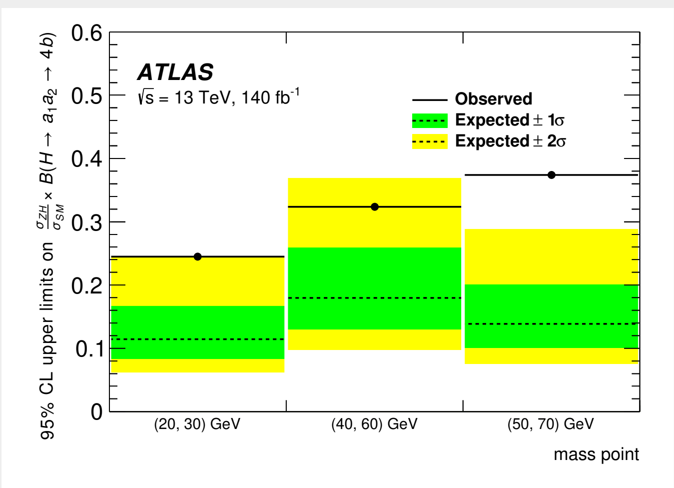
  → same analysis strategy



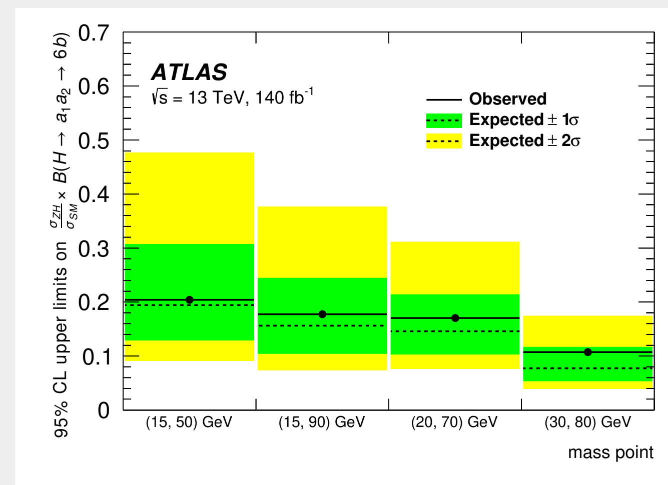
- And even **cascade** decays H → a_1a_2 → $3a_1$ → 6b (a_2 → a_1a_1)

  → slightly different analysis strategy: no explicit pairing of b-objects, just discrimination BDT score





All a_1 → bb resolved or merged!



Largest local excess: 3.28 σ ($m_{a1,a2}$ = 50, 70 GeV)
2.57 σ global

First ever search for H → a_1a_2!

Largest local excess: ~1 σ ($m_{a1,a2}$ = 30, 80 GeV)

Conclusion

- Many new exciting results for light scalar searches!

Thank you for your attention.

And compliments to all the analysis teams
for their great analyses!

IFIC INSTITUT DE FÍSICA CORPUSCULAR
Judith Höfer
judith.hoefer@ific.uv.es

Backup

Interpretation as long-lived ALPs!

Axion-Like Particles

Both plots assume the ALPs exclusively decay to photons.

ATL-PHYS-PUB-2025-007

- Searches for light scalars can also be sensitive to ALPs, particularly when a → γγ
- Two existing searches (with an interpretation for ALPs or being a search for ALPs) ...
  - H → Za, a → γγ, m_a = 2 – 33 GeV Phys. Lett. B 850 (2024) 138536
  - H → aa → 4γ, m_a = 0.1 – 62 GeV Eur. Phys. J. C 84 (2024) 742
- … have been re-interpreted:
  - for longer lifetimes → sensitive to smaller couplings
  - for smaller masses m_a = 0.01 - 0.1 GeV