Higgs and Dark Matter (Part 1).

An ATLAS perspective within QU-II.

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QU Attract.Workshop

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HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

CLUSTER OF EXCELLENCE
QUANTUM UNIVERSE

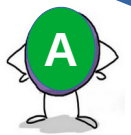
ATLAS EXPERIMENT

DESY.

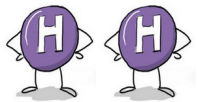
In a nutshell

- Higgs and DM searches closely linked in many areas + close links also to SMART area (ML tools)
- Benefit from strong ties between ATLAS, CMS, and Theory groups in QU-II

Higgs properties



BSM Higgs

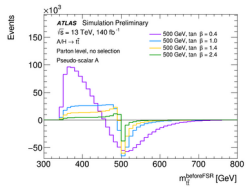


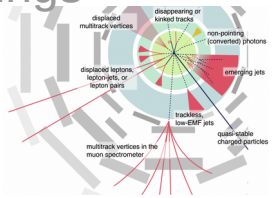
Higgs potential

(BSM) Higgs portal

Prompt signatures Long-lived particles

ALP couplings





Principal Investigators in ATLAS Higgs + DM

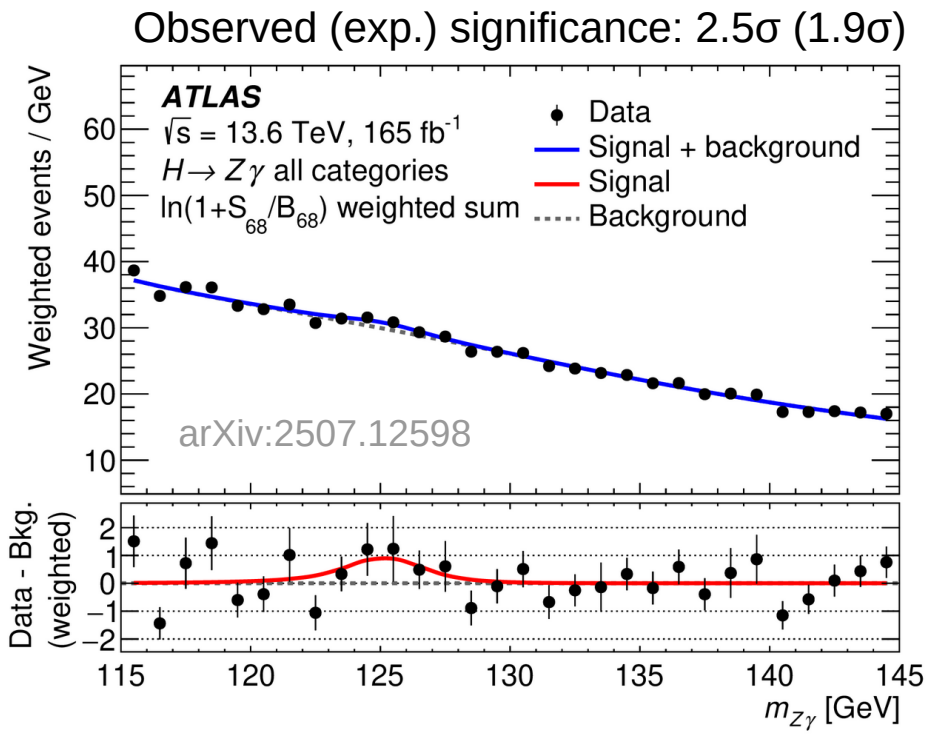
Kerstin Tackmann

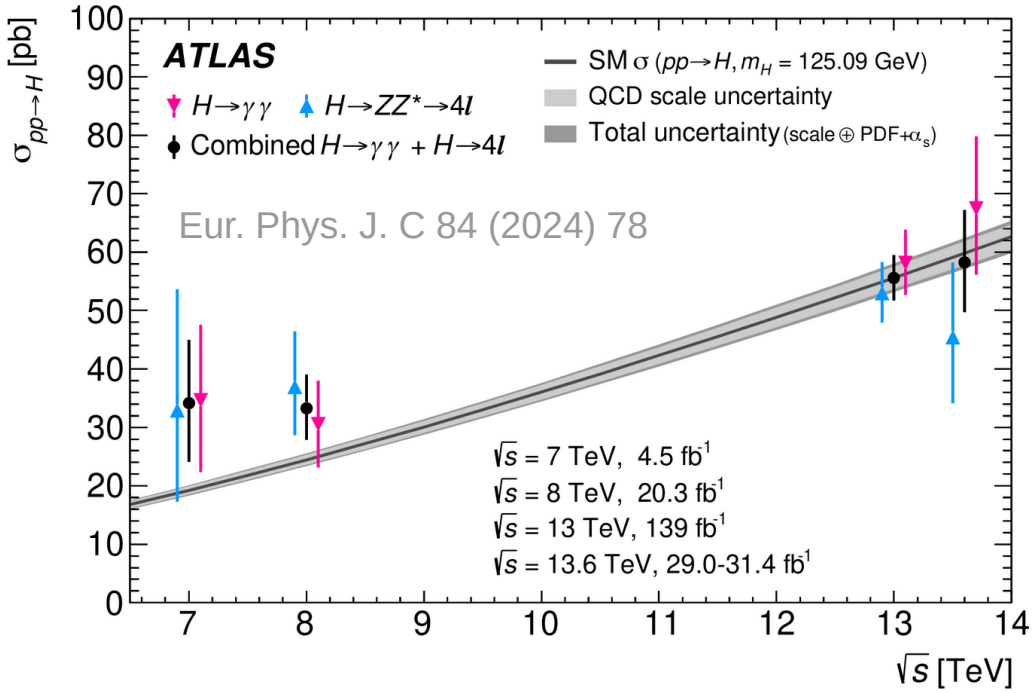
Sarah Heim

Katharina Behr

Measurement of Higgs-boson properties

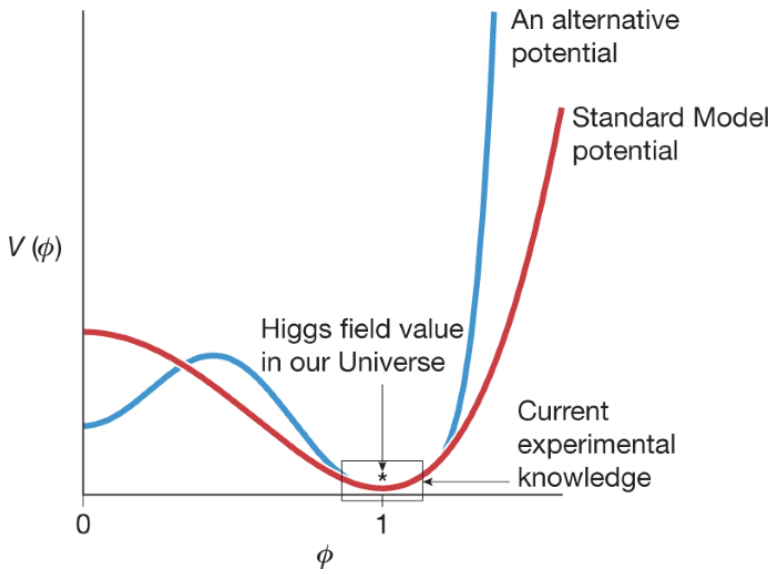
- Leading role in analyses targeting signatures with photons and leptons
  - Cross-section and coupling measurements in the “golden” channels yy and 4ℓ
  - Searches for rare decays like Zγ
- Benefitting from exchange with QU-II Theory for signal predictions

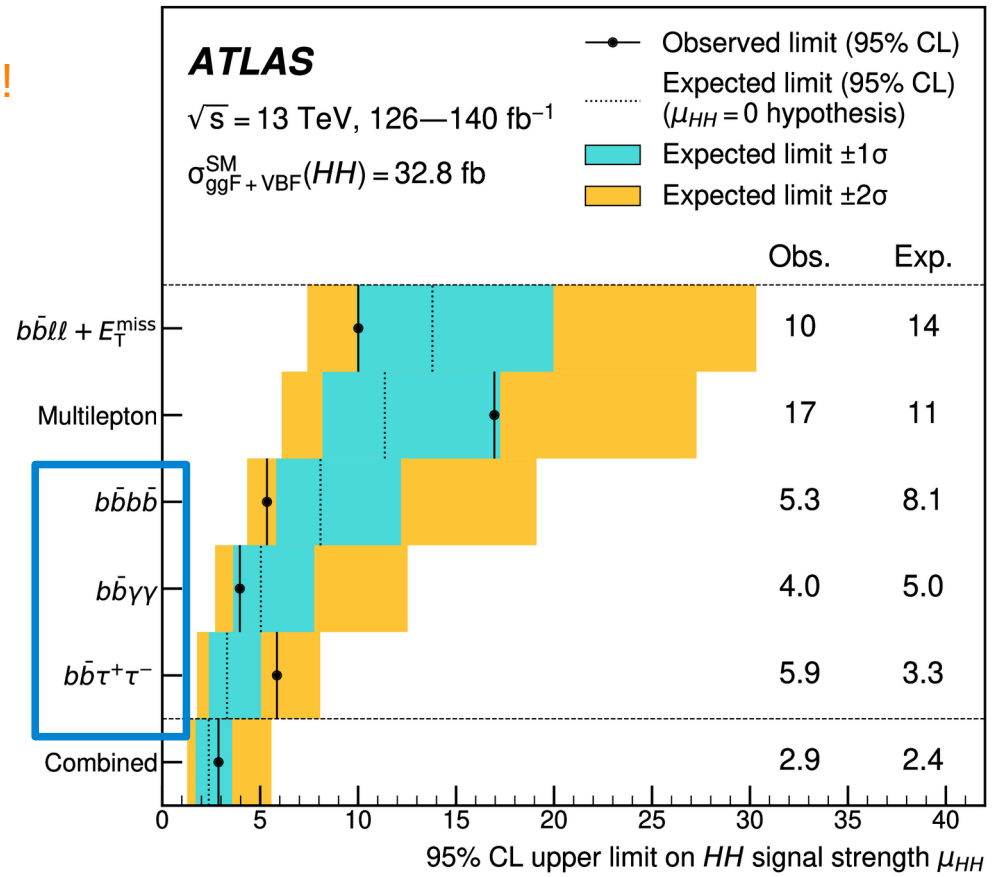




Searches for Higgs-boson pair production

- Unique access to Higgs trilinear coupling → full shape of Higgs potential!
- Our group is currently involved in Run-3 searches in all three “golden” HH channels.
- Contributed to ATLAS Run-2 legacy combination and (on-going) ATLAS+CMS HH combination.
- Unique situation here in QU-II:
  both local ATLAS and CMS groups, plus strong Theory group!

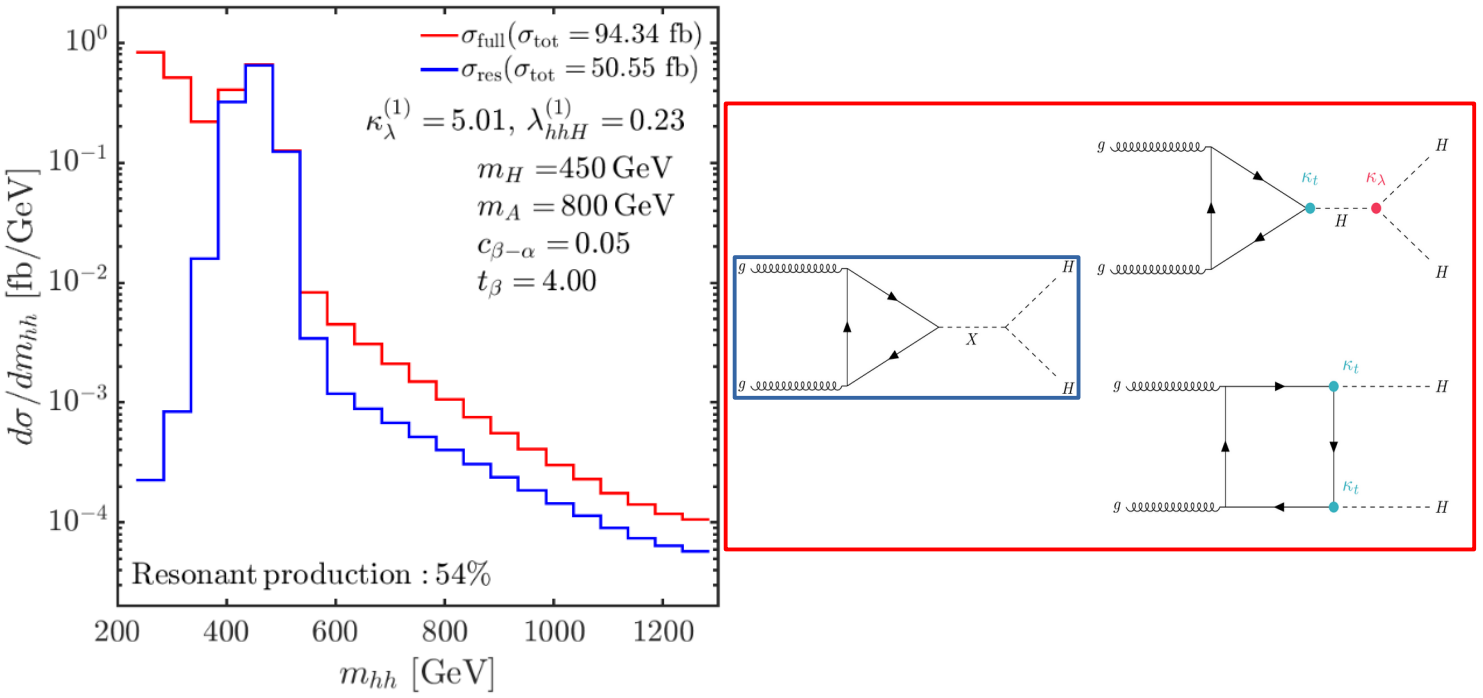




Examples of cooperations with QU-II Theory

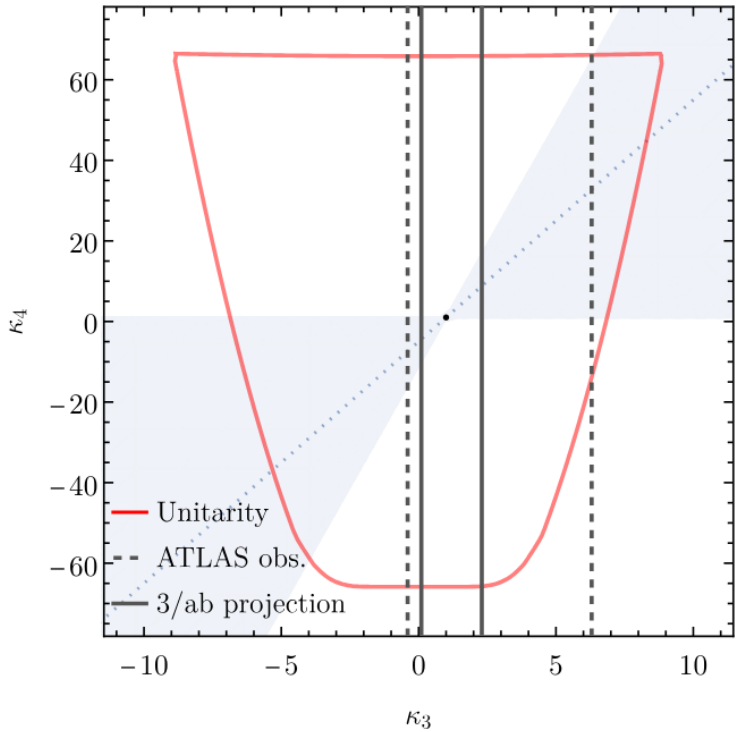
- Interference between resonant and non-resonant HH production
- Not included in current searches, relevant for Run-3 HH programme

K. Rachenko, G. Weiglein et al.
Eur. Phys. J. C. 85 (2025) 437



- Relevance of triple-Higgs production to constrain the quartic self-coupling
- Inspired several triple-Higgs searches in ATLAS and CMS with leading QU-II contributions

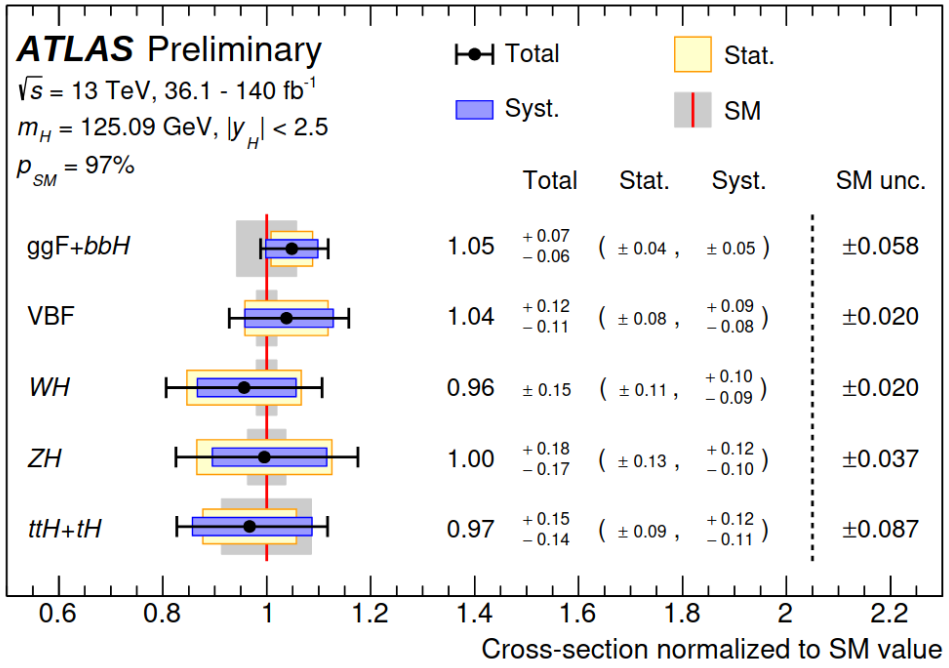
P. Stylianou, G. Weiglein
Eur.Phys.J.C 84 (2024) 4, 366



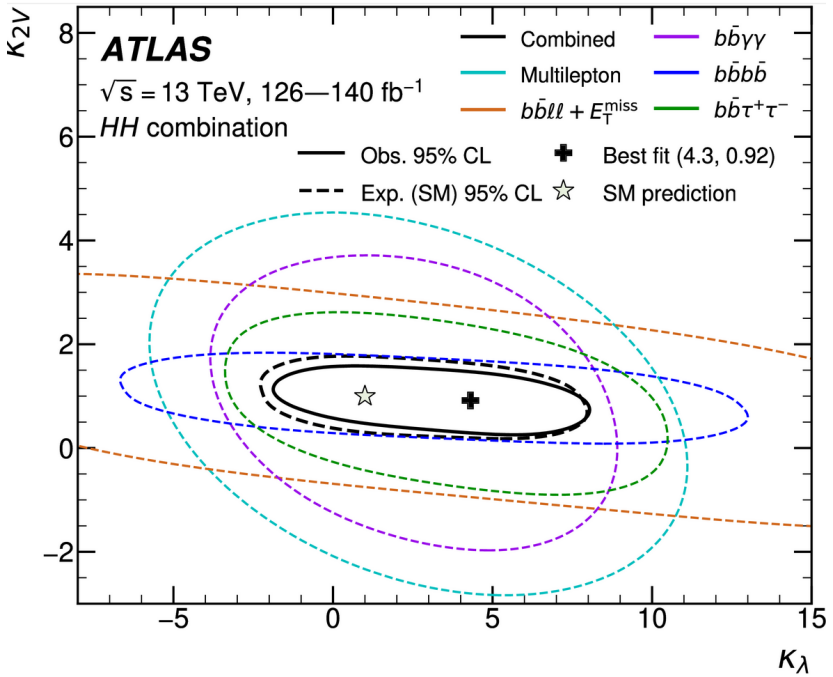
Global fits

- Most precise measurements obtained from combining independent measurements
  - Combine different production modes and decay channels, combine H and HH measurements
- Better sensitivity to Higgs couplings to other particles and self-coupling, EFT, BSM models, …
- Again, benefitting from QU-II for future ATLAS+CMS combinations

ATLAS-CONF-2025-006

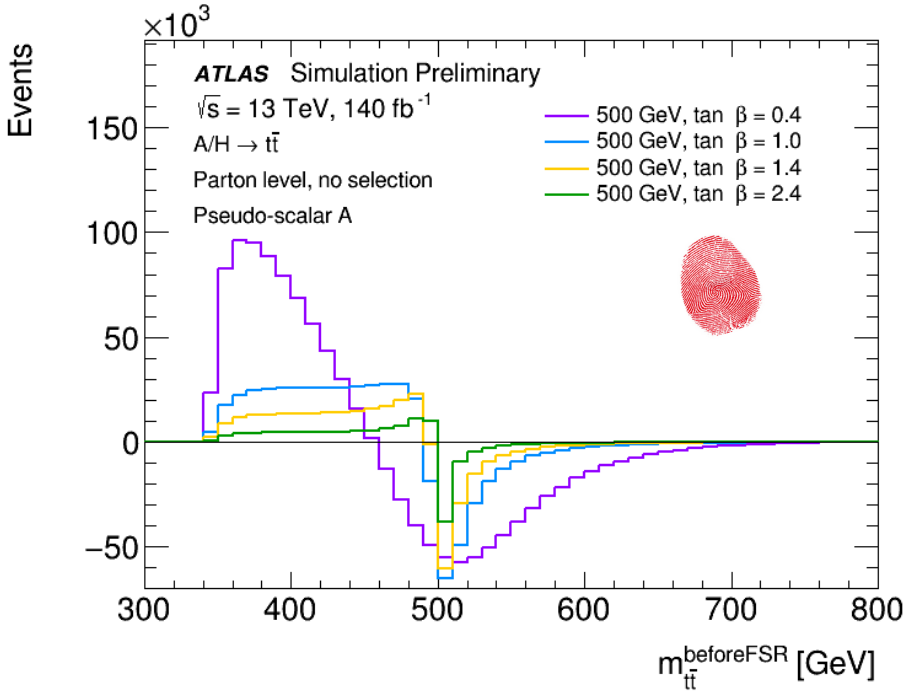


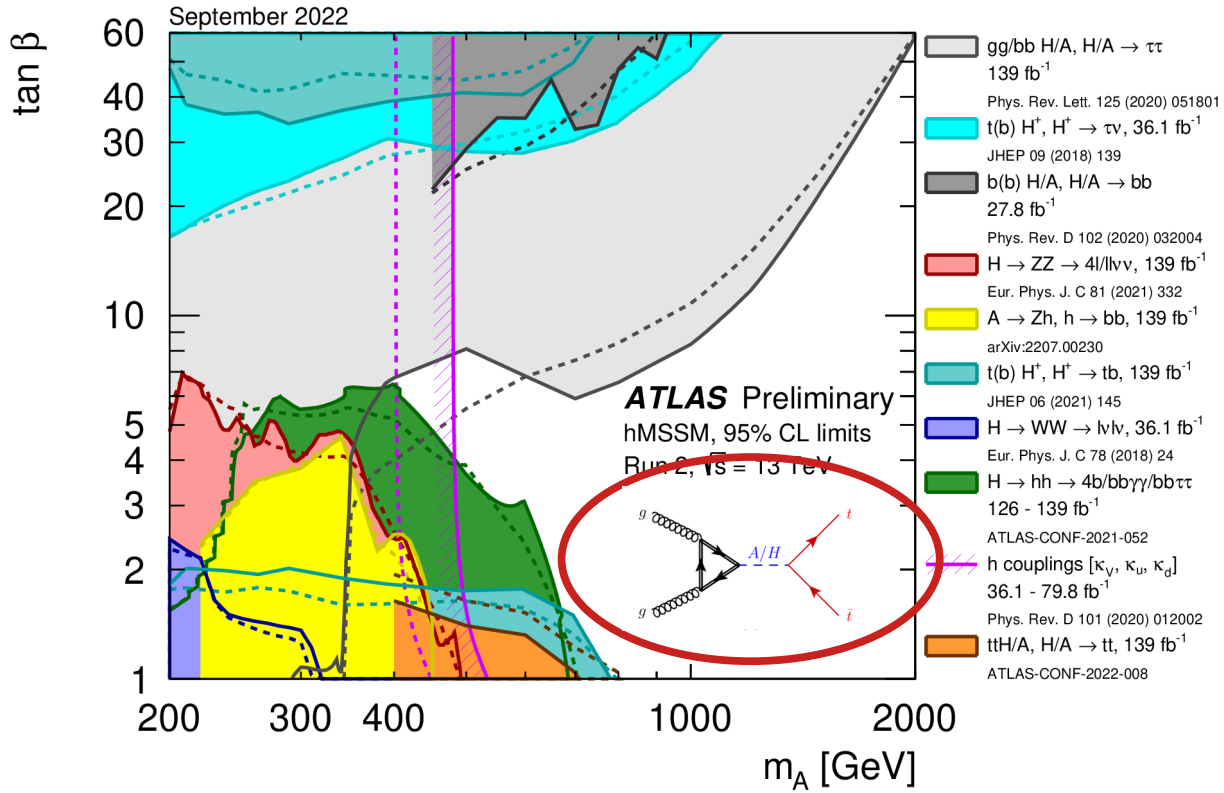
Phys. Rev. Lett. 133 (2024) 101801



Fingerprints of heavy neutral Higgs bosons A/H

- (Pseudo)scalar decays to a top-antitop quark pair provide access to unprobed regions of parameter space
  - E.g. high-mass, low-tanβ region of type-II 2HDMs; various DM models
- Key challenge: signal-background interference
- Pushing the limits of conventional searches (reconstruction, spin information, statistical analysis, …)!



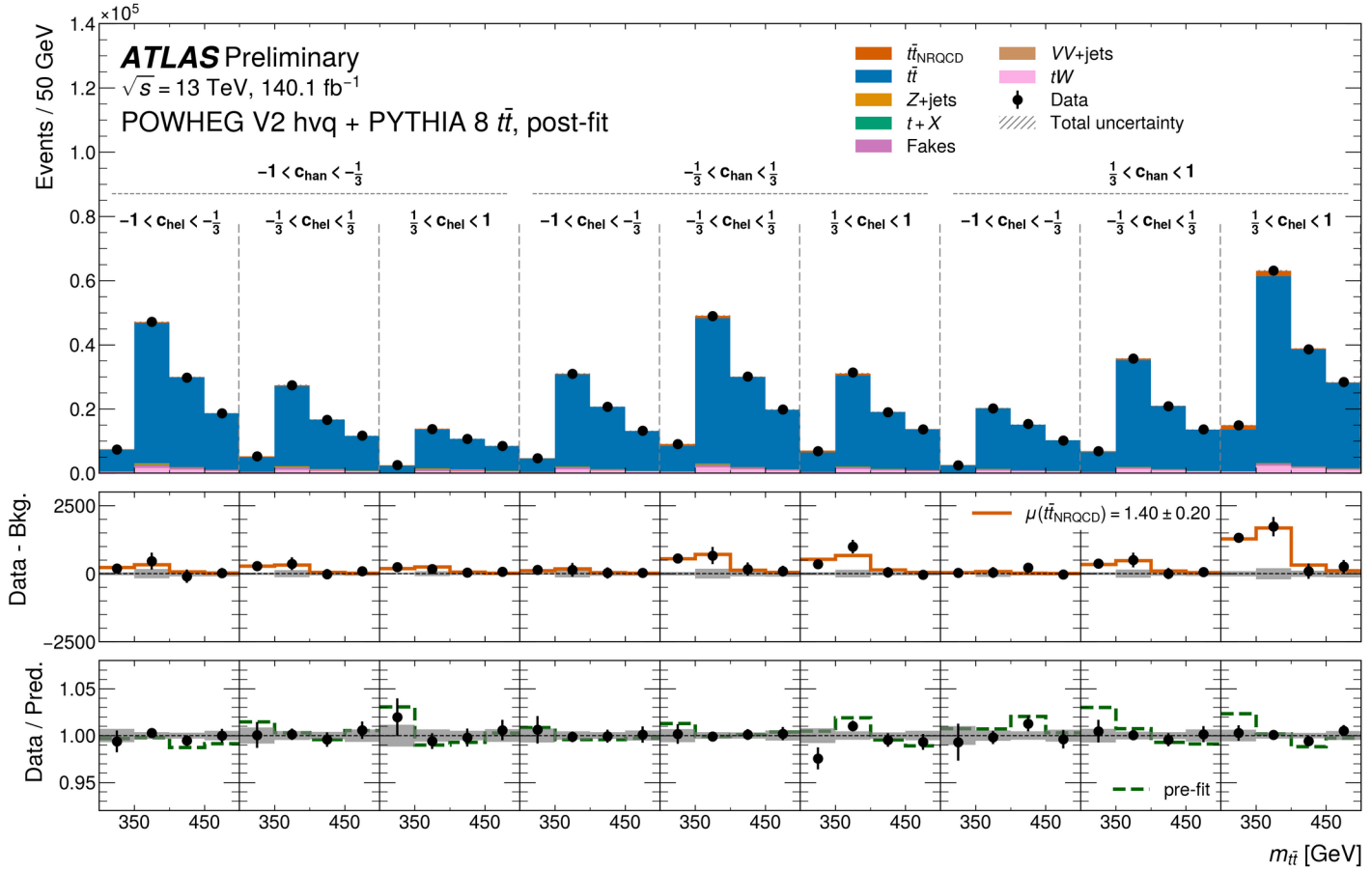


Observation of an excess at the ttbar threshold

- Consistent with formation of ttbar quasi-bound-state (“toponium”)
- Need to characterise excess! Any room left for BSM physics?
- Discovery with leading contributions from QU-II ATLAS, CMS and Theory!

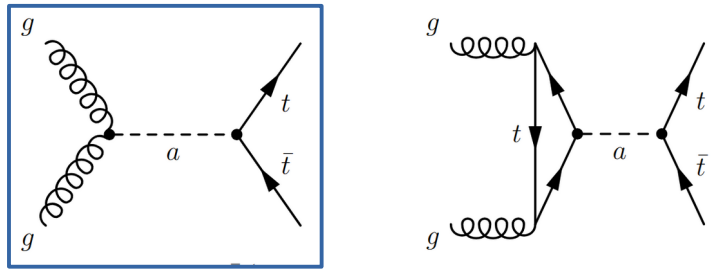
$\sigma_{toponium}$ = 9.0 ± 1.2 (stat) ± 0.6 (syst) pb

Theory: 6.4 pb

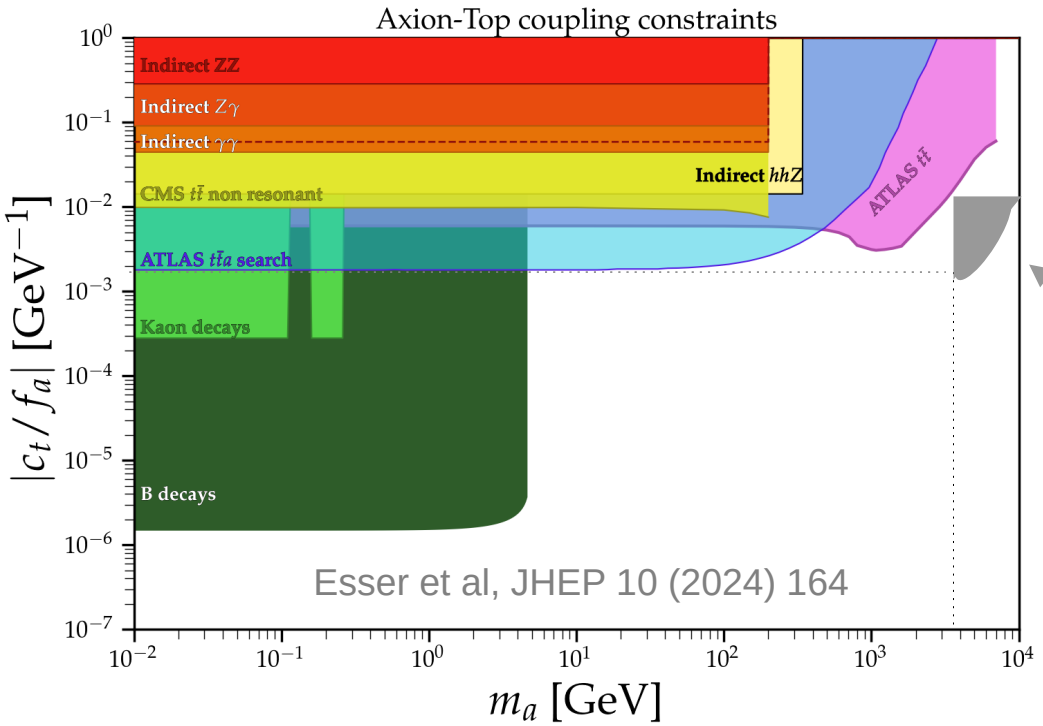


Interference searches for heavy ALP → ttbar

- ALP Yukawa couplings to fermions → decays to top quarks!
- Key difference to BSM Higgs: direct gluon coupling
- Interference pattern may allow to distinguish ALP from BSM Higgs
- Unique sensitivity to large ALP masses and low couplings



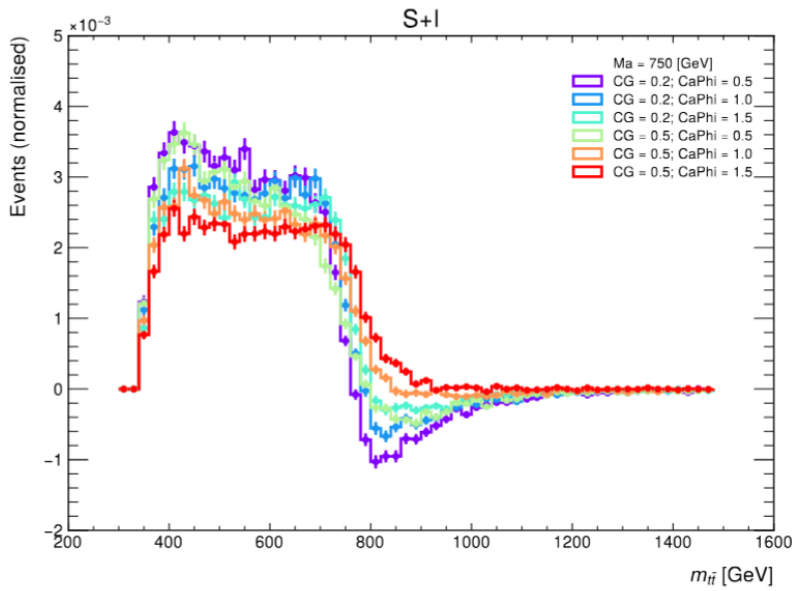
Unique for ALPs!



Esser et al, JHEP 10 (2024) 164

Sensitivity projection from Run-2 A/H → ttbar search assuming $c_g = 0$.

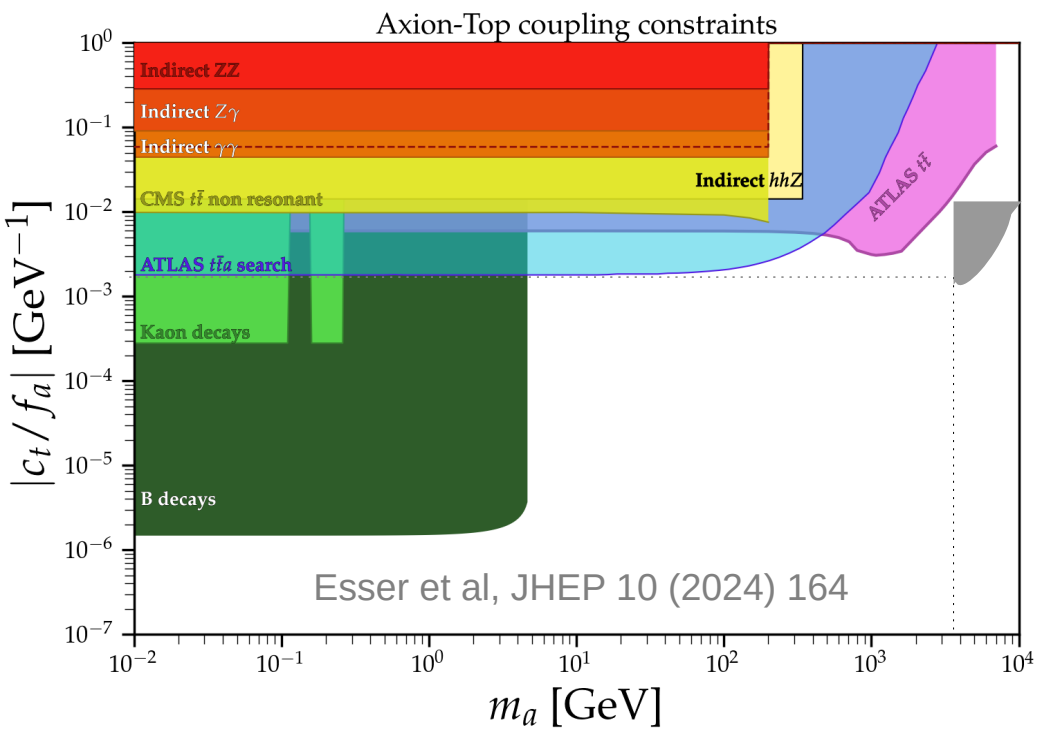
M. Rodrigues, KB



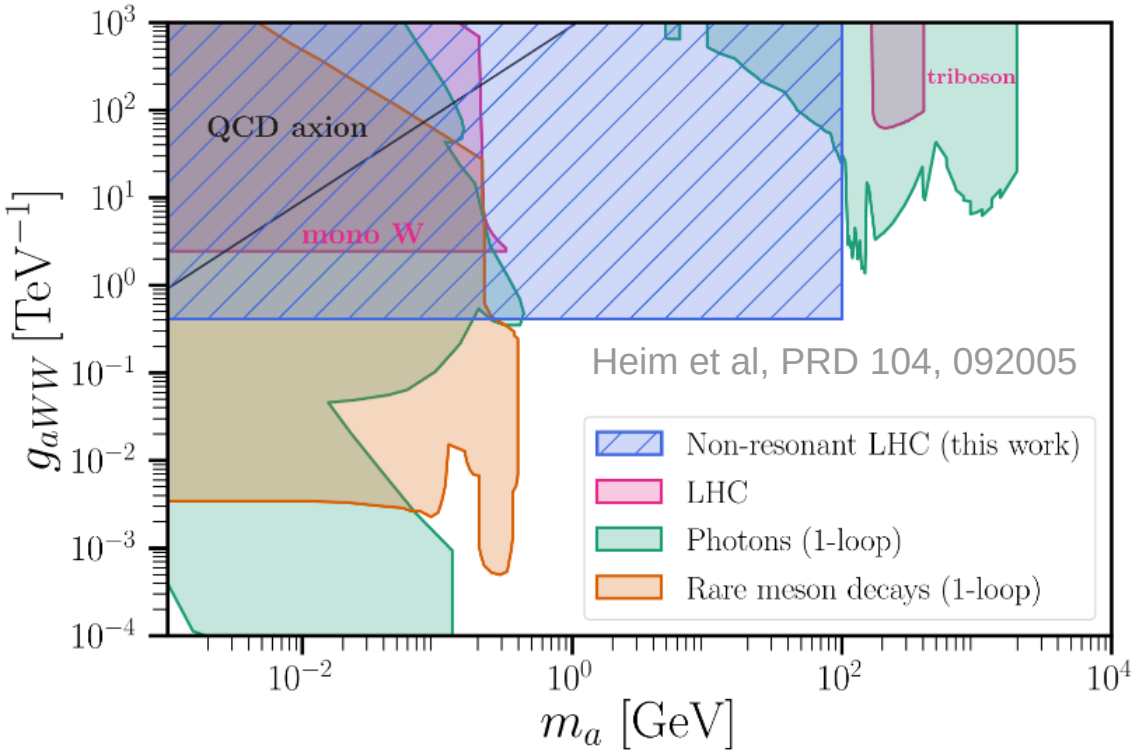
Global ALP coupling analysis

- Joint analysis of ALP couplings to gluons, tops, bosons, ...
- Based on heavy ALP searches at colliders
- Combine QU-II expertise of ATLAS, CMS, and Theory!

ALP-top



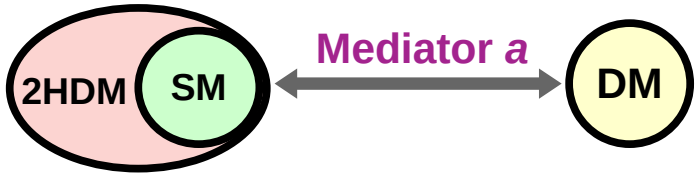
ALP-W



(BSM) Higgs Portal

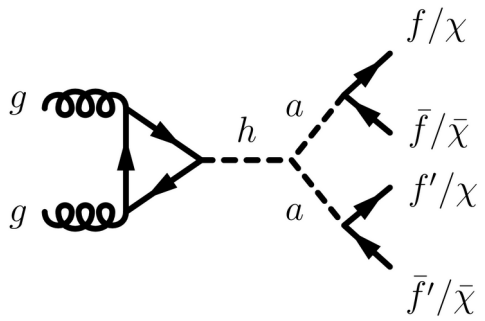
> Dark sector may communicate with SM sector in different ways:

- Higgs boson as portal → invisible Higgs decays
- Extra (pseudo)scalars
  - → invisible Higgs decays
  - → Exotics Higgs decays
  - → Extra Higgs searches



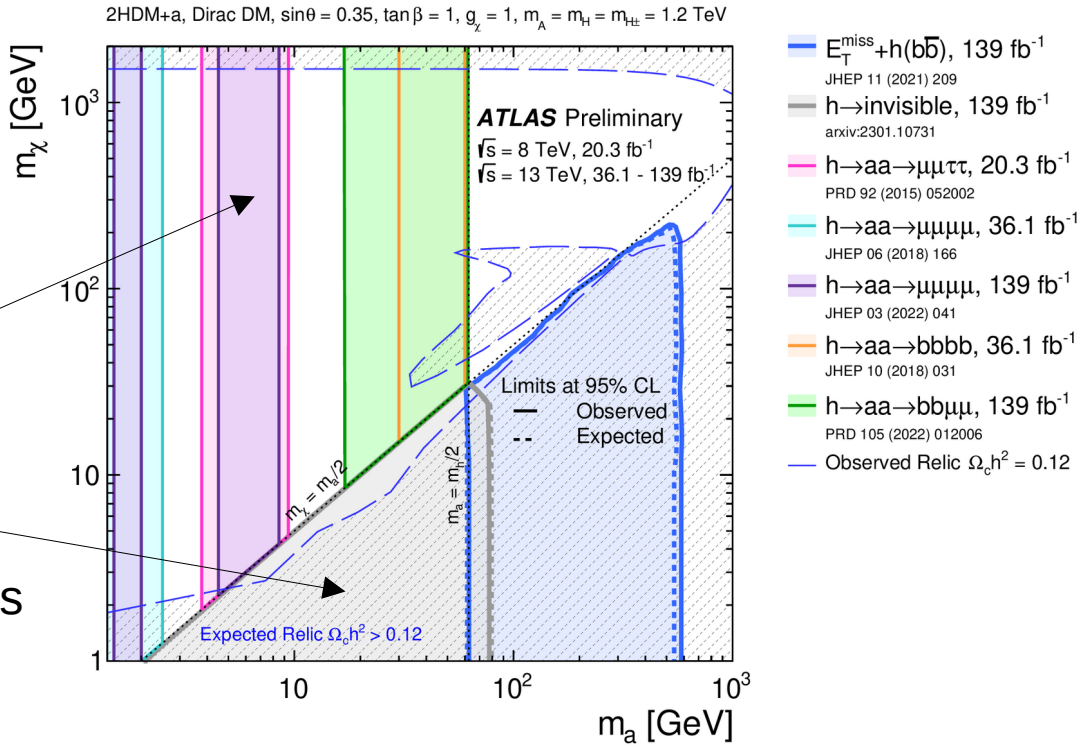
> Leading QU-II contributions to model building and a large variety of searches

Extended Higgs sector + pseudoscalar mediator: 2HDM+*a*



Exotic Higgs decays

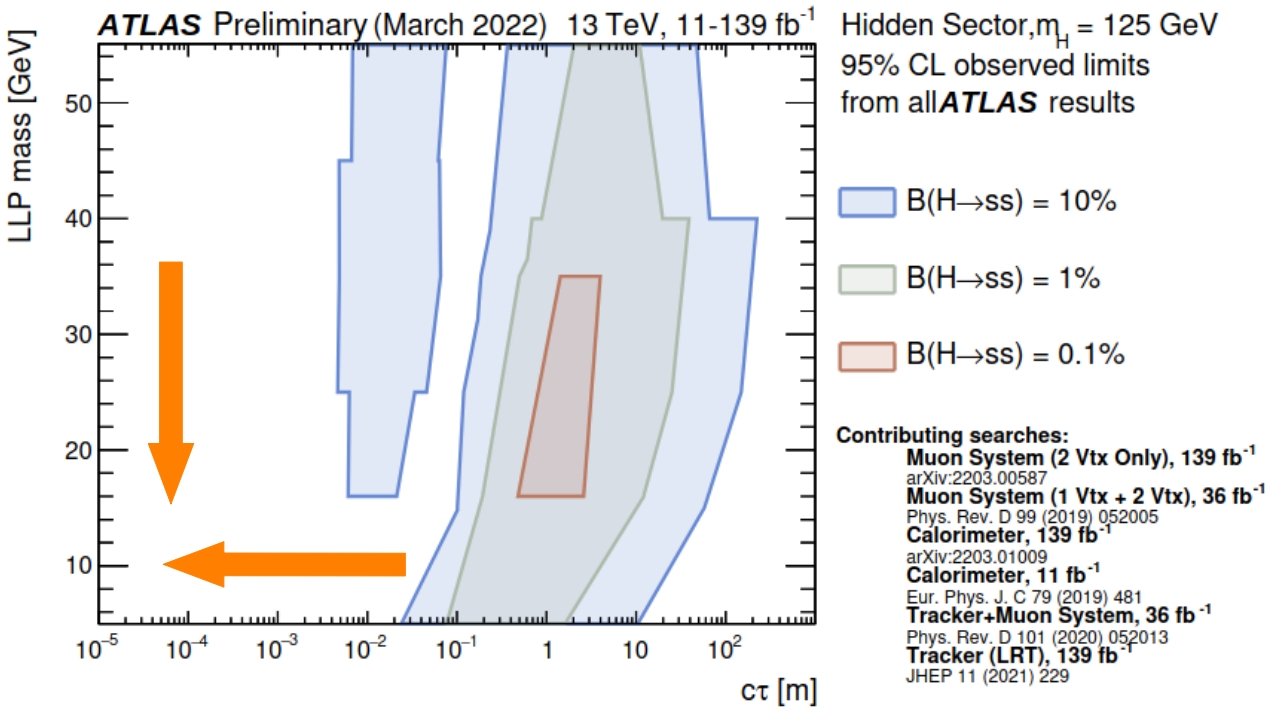
Invisible Higgs decays

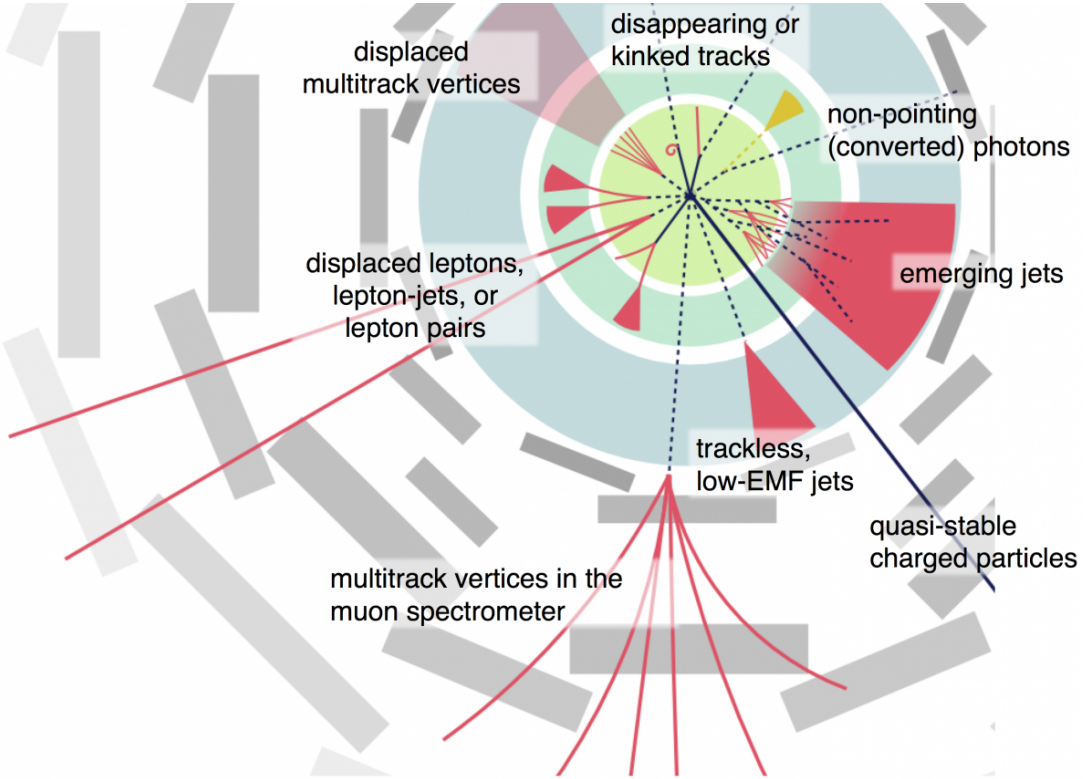


Non-prompt searches

- Broad and leading involvement in searches for non-standard signatures
- Novel ML techniques to open up new phase space → QU-II links with CMS and Theory via SMART
- E.g. use of autoencoders for low-mass displaced vertices
  → unique sensitivity to light, short-lived particles

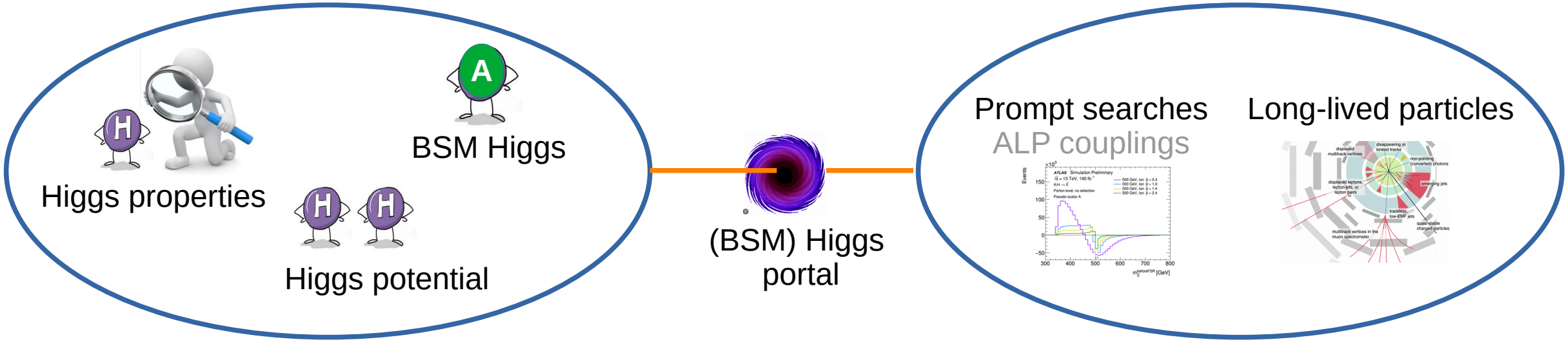
ATL-PHYS-PUB-2022-007





Summary

- Diverse range of Higgs and DM searches in QU-II ATLAS
- Very happy to take questions and discuss during the day!



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Extra Material