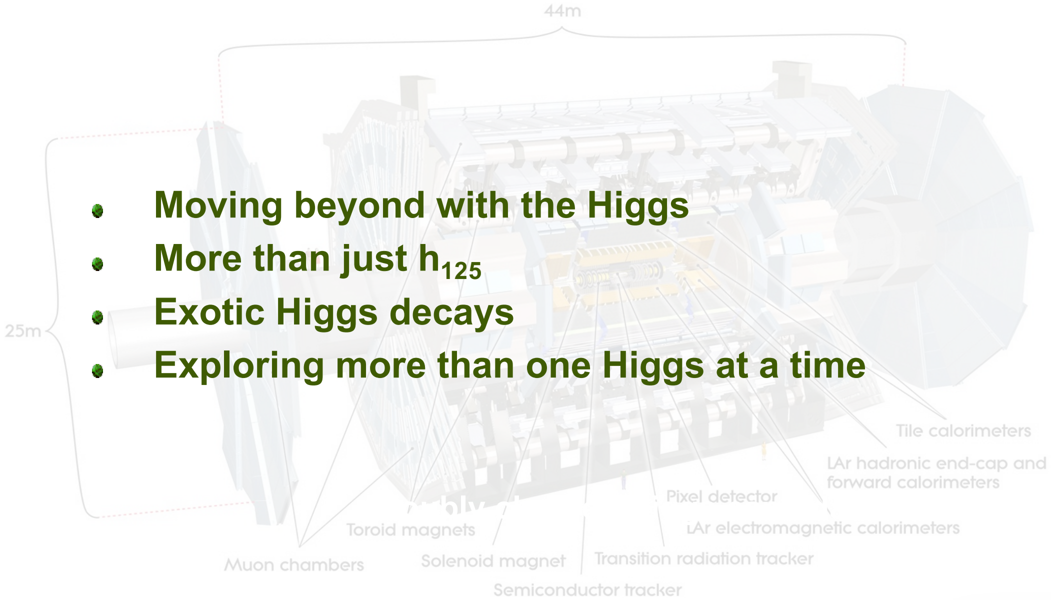
Searches for new physics in the Higgs sector with the ATLAS detector

- Moving beyond with the Higgs
- More than just h_{125}
- Exotic Higgs decays
- Exploring more than one Higgs at a time



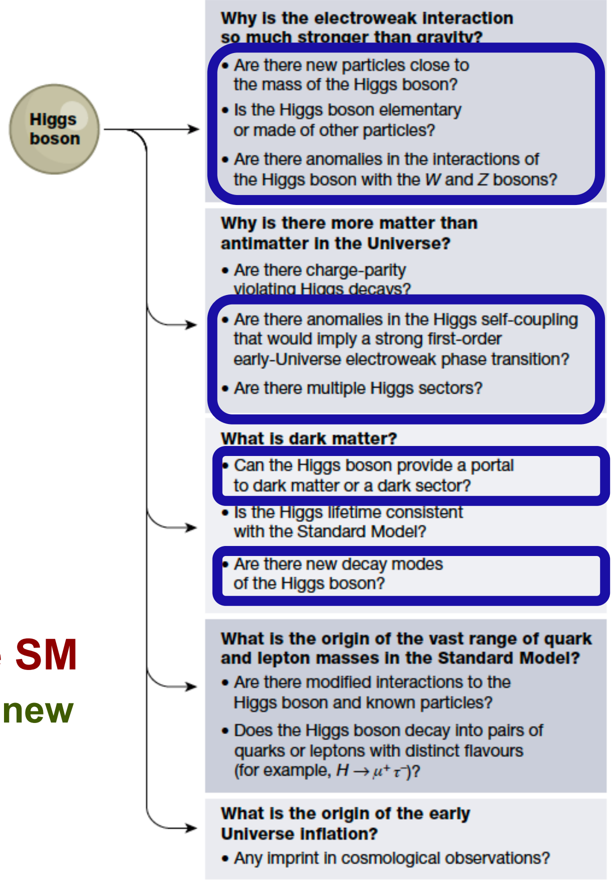
Gustavo Otero y Garzón – On Behalf of the ATLAS Collaboration
University of Buenos Aires, Argentina

TeVPA 2023

A paradigm of new Physics

- **11 years after discovery, that scalar looks pretty much like the SM Higgs boson**
  - **Major branching fractions observed**
  - **Properties do not show obvious anomalies**

- **Yet, important phenomena are not described by the SM**
  - **Exotic decays and extended Higgs sector could reveal new physics**
  - **Still, Br($H \rightarrow$inv) < 10%!**

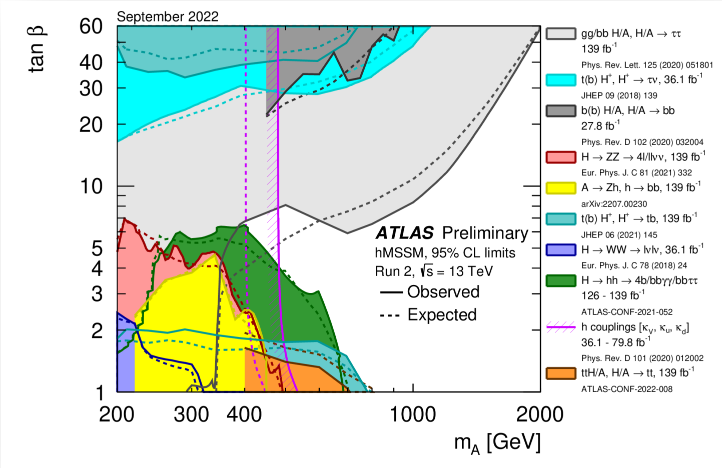


Nature 607, 41–47 (2022)

Making more of the Higgs

- **Why only one h_{125}? Many extensions of the SM predict additional Higgs bosons**
  - **Electroweak singlets: *H***
  - **Two Higgs Doublet Models (2HDM): *h*, *H* (CP-even), *A* (CP-odd), $H^{\pm}$**
  - **Three Higgs Doublet Models (3HDM): 3 CP-even, 2 CP-odd neutral bosons, 2 charged ones**
  - **Georgi-Machacek model (GM): *H*, triplet and quintet**

ATL-PHYS-PUB-2022-043



- **Exotic decays could reveal new physics**
  - **Portal to dark/hidden sectors**

- **Main single-Higgs production channels do not give the full picture**
  - **Di-Higgs production predicted, unique sensitivity to anomalous couplings**

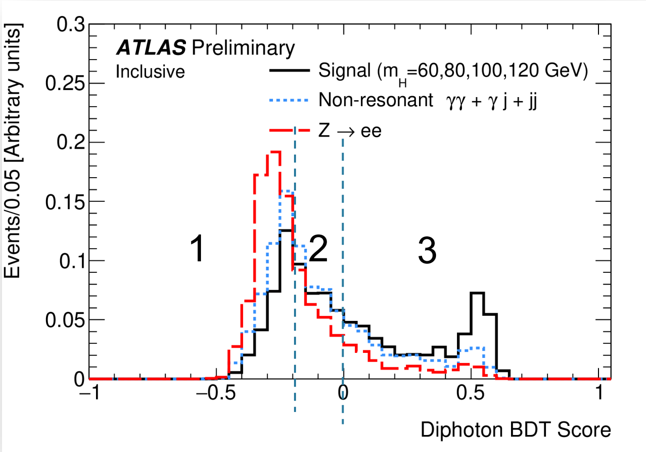
Will highlight a small set of recent results indicating the directions of experimental exploration

Neutral BSM Higgs boson searches

Low-mass $X \to \gamma\gamma$

ATLAS-CONF-2023-035

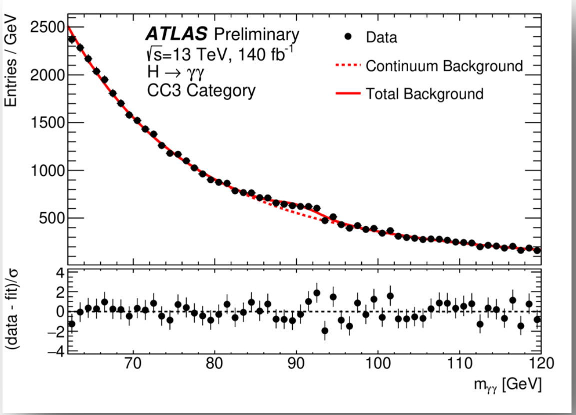
- **Search for light scalar $X \to \gamma\gamma$ (m_H<125 GeV)**
  - **2.9σ excess at 95 GeV reported by CMS (CMS PAS HIG-20-002)**
- **Several categories defined based on photon conversion status for a model-independent search**
  - **CC: two converted photons**
  - **UU: two unconverted photons**
  - **UC: One converted photon**
- **Additional Boosted Decision Tree(BDT) discrimination to separate signal in a model-dependent search using SM-like Higgs boson as benchmark (to compare to CMS)**

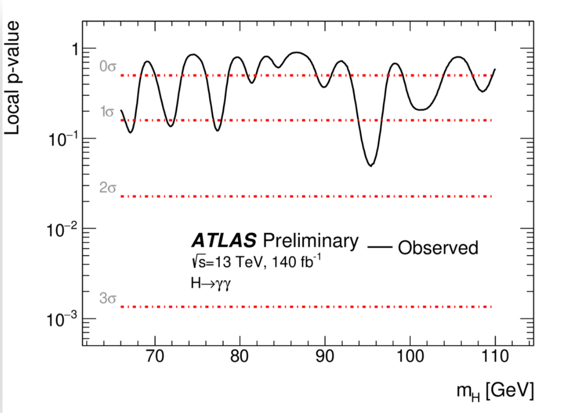


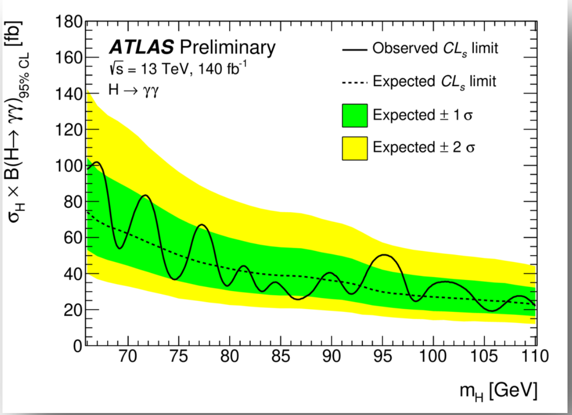
Low-mass $X \to \gamma\gamma$

ATLAS-CONF-2023-035

- **Fit diphoton invariant mass**
  - **Double sided crystal ball for Drell-Yan, exponentiated polynomials for non-resonant background**
  - **Search dominated by non-resonant background modeling uncertainties**







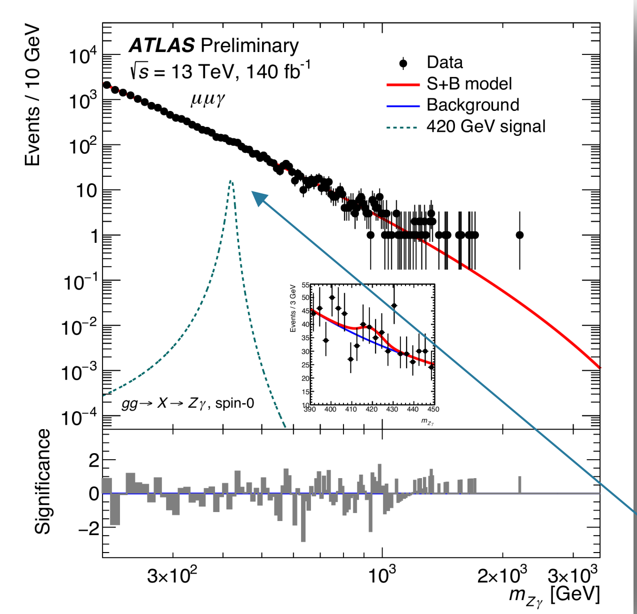
Model dependent results

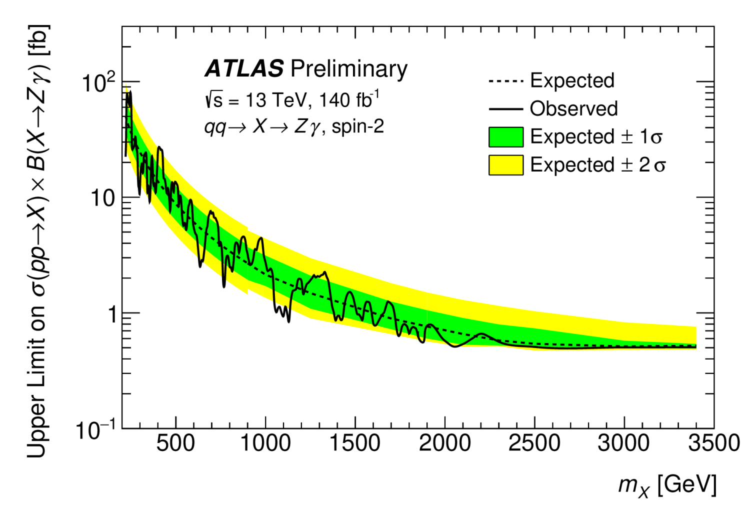
- **No significant excess observed**
  - **Local 1.7σ excess at 95 GeV in the model dependent search**
  - **Local 2.2σ excess at 72 GeV in the model independent search**

High-mass $X \rightarrow Z\gamma$

ATLAS-CONF-2023-030

- **Search for heavy narrow resonances (220 GeV < m_X < 3.4 TeV)**
  - **$Z \rightarrow ee / \mu\mu$**
  - **Spin 0: ggF, spin 2: ggF and $qq \rightarrow X$**
  - **Dominant background: non-resonant $Z\gamma$ and Z+jets modeled with analytical functions**
  - **Custom BDT based electron ID**





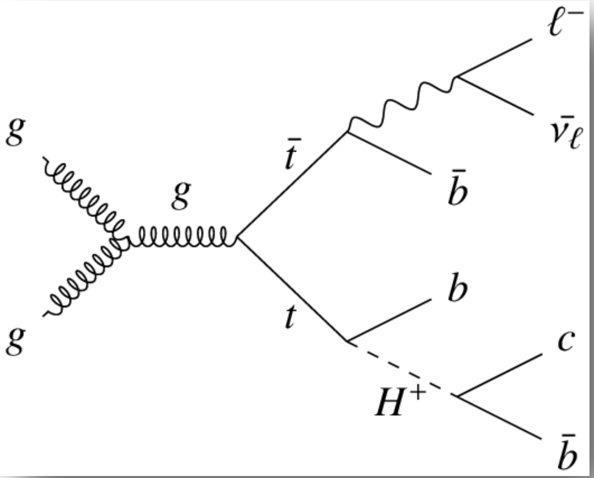
2.3σ local excess at m_X = 420 GeV

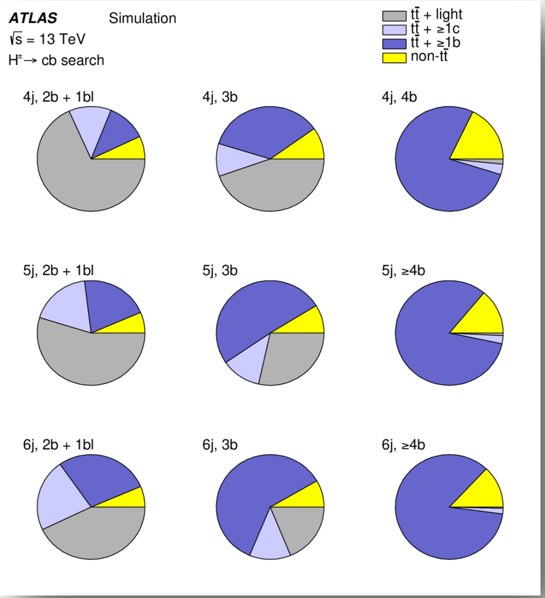
Charged Higgs searches

Charged Higgs search $H^{\pm} \rightarrow cb$

arXiv:2302.11739 (accepted by JHEP)

- **3HDM predicts 2 charged Higgs bosons**
  - Lightest one lighter than the top quark (m(H±) 60 - 160 GeV)



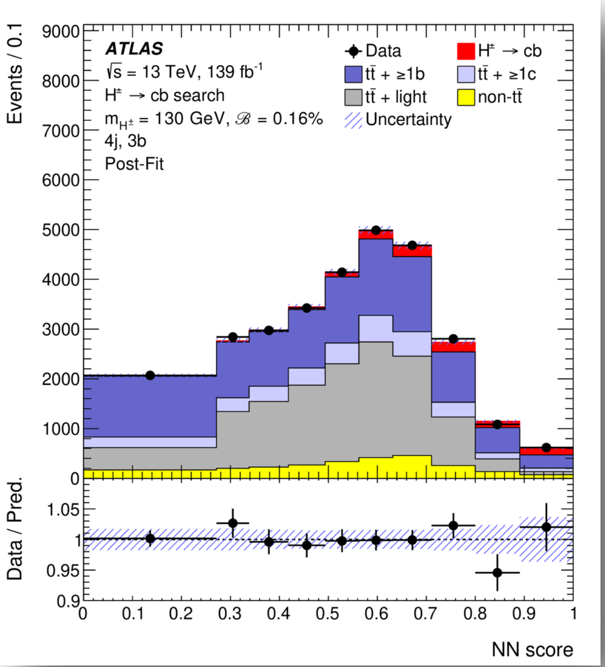


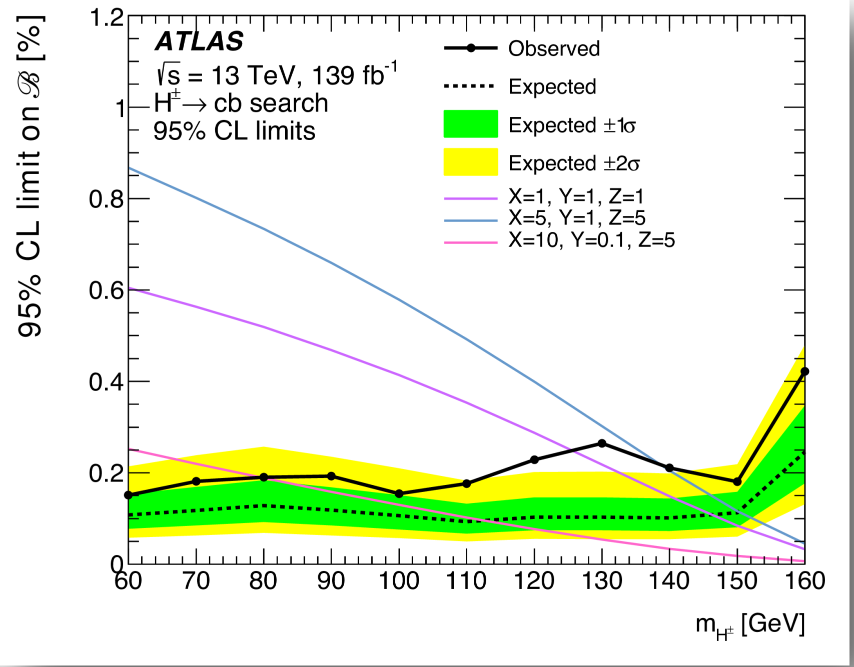
- Categories based on number of jets and b-jets
- Use mass parametrized NN (29 inputs)
- Fit NN scores in SRs and total yields in CRs

Charged Higgs search $H^{\pm} \rightarrow cb$

arXiv:2302.11739 (accepted by JHEP)

- **No significant excess observed**
  - Upper limits on BR of 15 – 42% in $60<m_{H\pm}<160$ compared to 3HDM predictions
  - 3σ local (2.5σ global) excess at $m_{H\pm}$= 130 GeV
  - x5 improvement in sensitivity compared to only existing CMS result before this

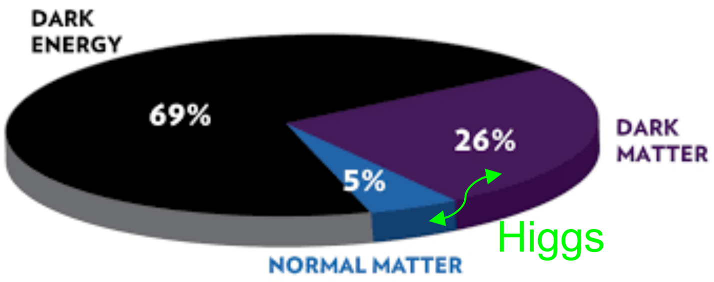


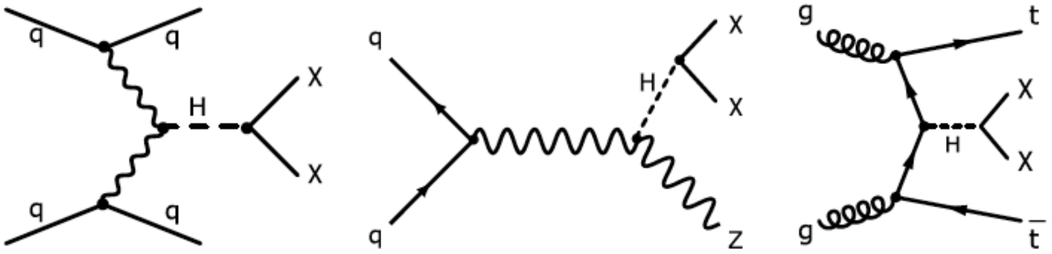


Invisible Higgs decays

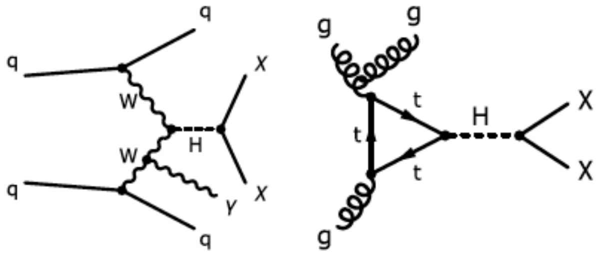
Invisible Higgs decays

- **Within the SM the BR($H\rightarrow$inv) = 0.1% ($H \rightarrow ZZ^* \rightarrow 4\nu$)**
- **Higgs portal is a benchmark Dark Matter model**
  - **Dark matter may acquire mass through interaction with the SM Higgs**
  - **Decays to DM are invisible at the LHC**





(a) VBF topology (b) $Z+H$ topology (c) $t\bar{t}H$ topology



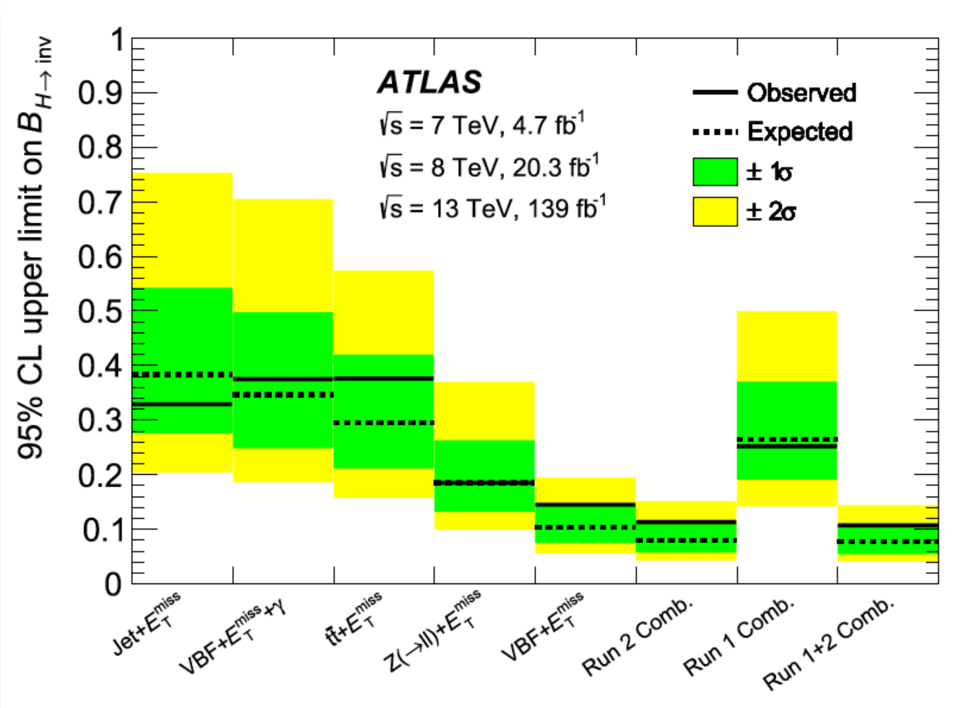
(d) VBF + photon topology (e) H+jet topology

Combination of invisible Higgs searches

Phys. Lett. B 842 (2023) 137963

- **Channels entering the combination**
  - ggF: jet + E_T^{miss} PRD 103 (2021) 112006
  - VBF: VBF + E_T^{miss} JHEP 08 (2022) 104
  - VBF+γ: VBF + E_t^{miss}+γ EPJC 82 (2022) 105
  - ZH: Z(→*ll*) + E_T^{miss} PLB 829 (2022) 137066
  - ttH: tt + E_T^{miss} EPJC 83 (2023) 503
  - Run 1 Combination PRD 92 (2015) 92004

95% CL Obs (Exp) limit Br (*H*→inv) < 10.7 (7.7)%

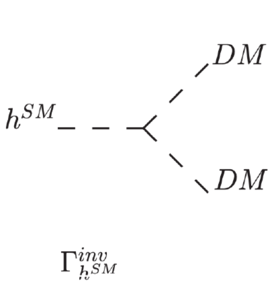


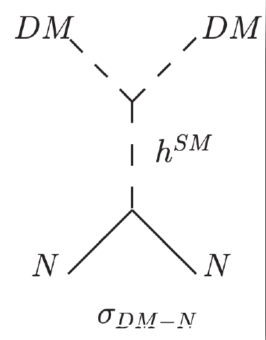
Higgs portal to Dark Matter

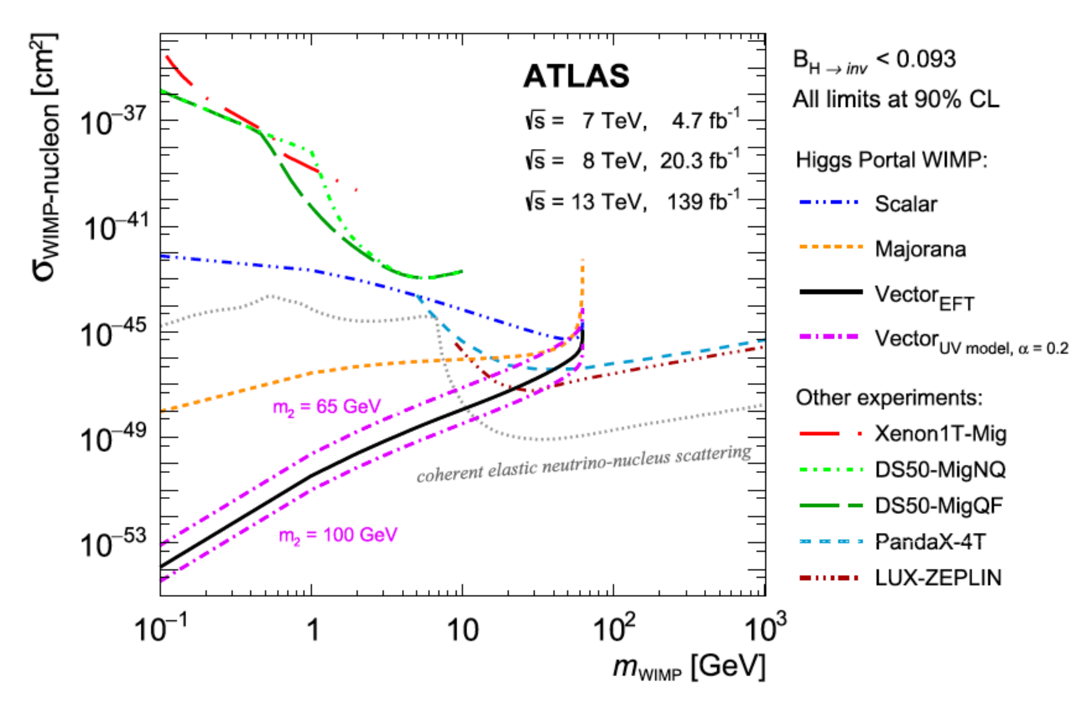
Phys. Lett. B 842 (2023) 137963

Convert observed Br($H\to$inv) limit into a limit on spin independent $\sigma_{\text{WIMP-nucleon}}$

- **Complementary sensitivity between direct detection experiments and collider searches**



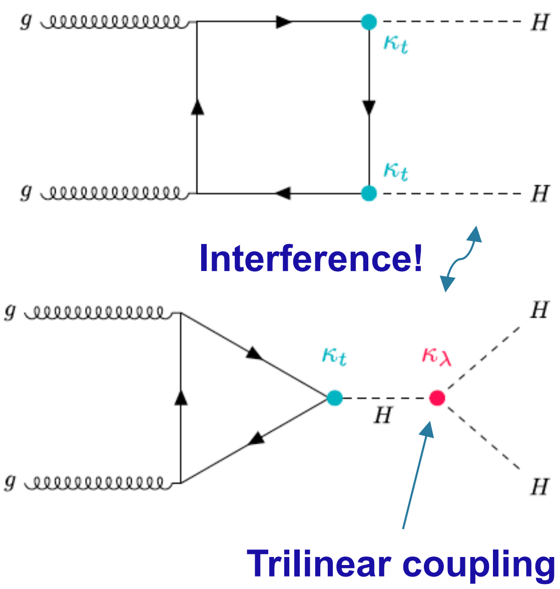


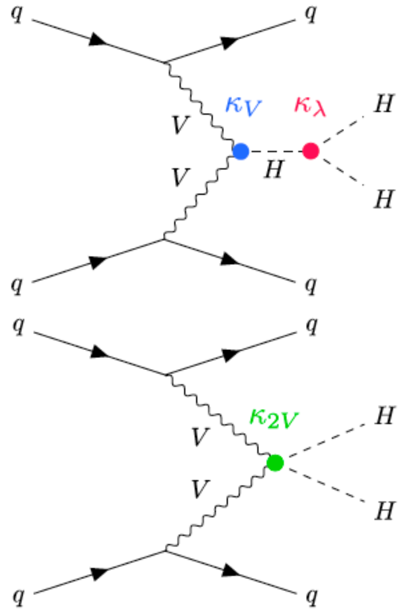


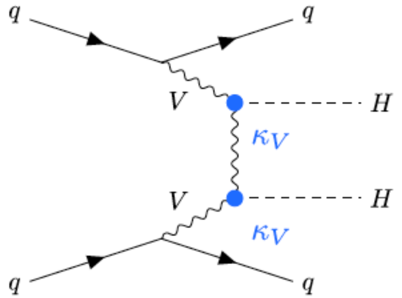
Search for hh production

Two Higgs are better than one

- **In the SM, Higgs pair production is driven by its self coupling λ_{HHH} which plays a crucial role in EWSB**
  - **Predicted σ_{HH} much smaller than single Higgs production**
  - **New physics can produce resonant Higgs pair production and/or enhance DiHiggs rates**
  - **Main production processes are ggF and VBF, dominant final states: bb+bb/ττ/γγ**

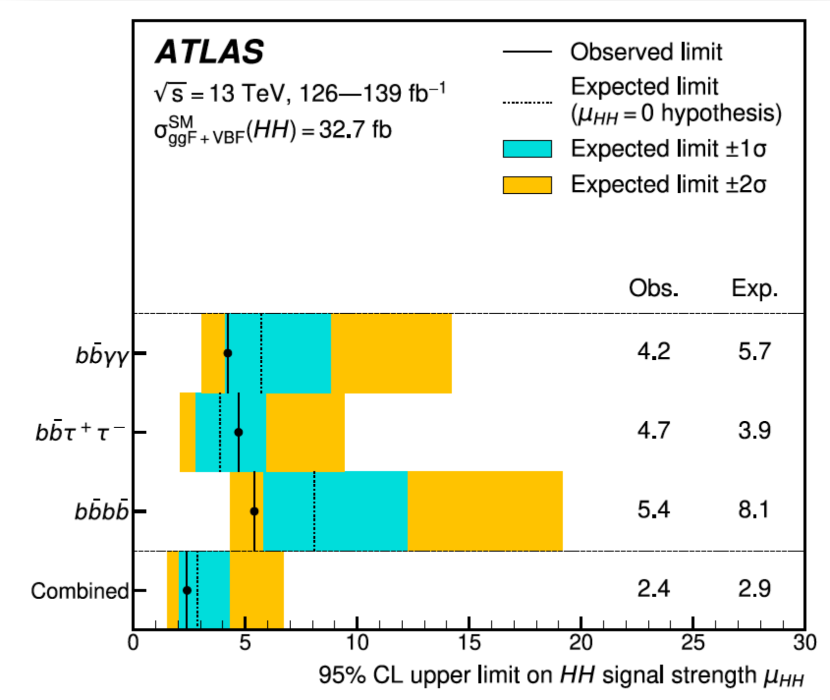


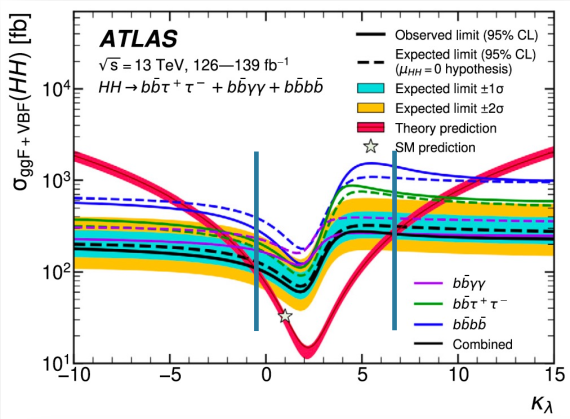


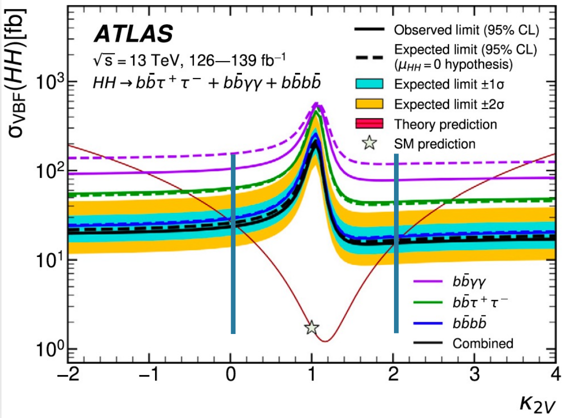


hh combination

Phys.Lett.B 843 (2023) 137745





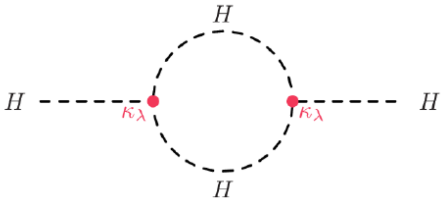


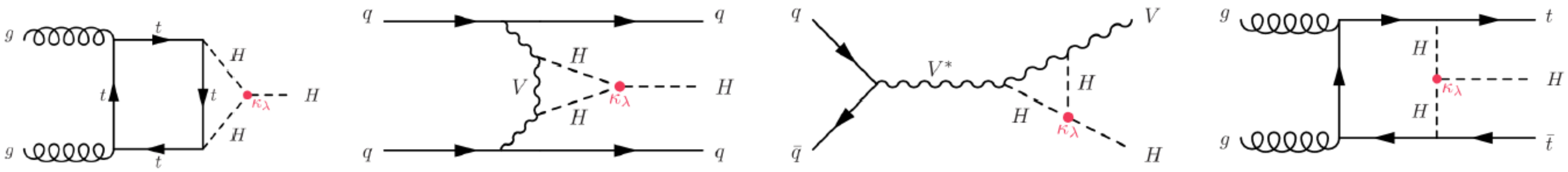
Getting closer to SM cross section

h+hh combination

Phys.Lett.B 843 (2023) 137745

- **Single Higgs processes are sensitive to κ_λ via NLO EW corrections**
  - Universal correction $O(\kappa_\lambda^2)$
  - $O(\kappa_\lambda)$: both process and kinematics dependent





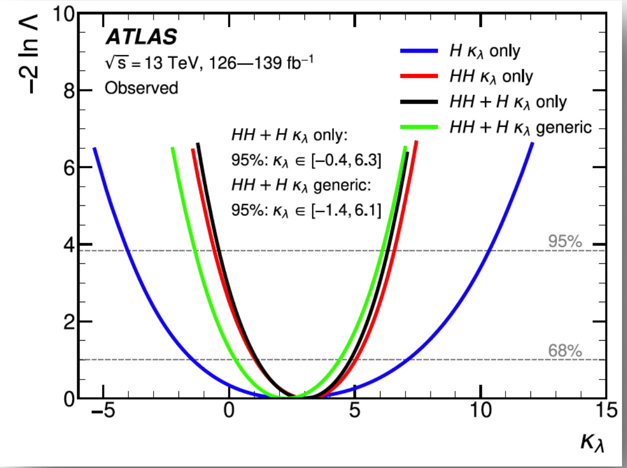
- **Simplified template cross section results are parametrized as a function of (κ_λ, κ_m) with κ_m the other coupling modifier (κ_V, κ_t, κ_b, κ_τ)**

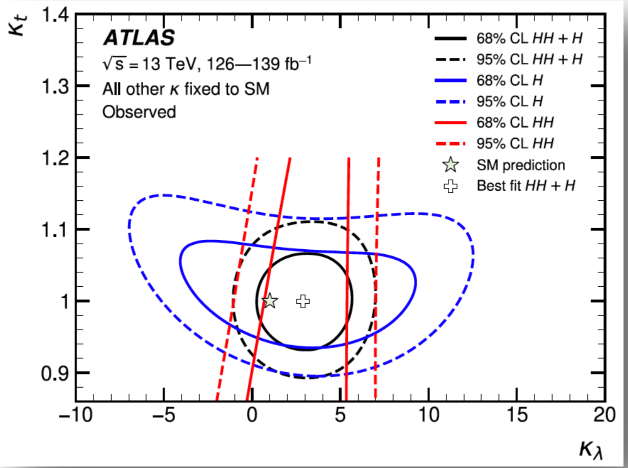
$$n_{i,f}^{\text{signal}}(\kappa_\lambda, \kappa_m) \propto \underbrace{\mu_i(\kappa_\lambda, \kappa_m)}_{\text{production}} \times \underbrace{\mu_f(\kappa_\lambda, \kappa_m)}_{\text{decay}} \times \sigma_{\text{SM},i} \times \text{BR}_{\text{SM},f} \times (\epsilon \times A)_{if}$$

h+hh combination

Phys.Lett.B 843 (2023) 137745

- **Combination provides the strongest constraints to date on κ_λ**
  - More sensitive and less model-dependent results
  - Single Higgs and HH combination produce stronger constraints (κ_λ, κ_t) plane
  - κ_λ limits obtained in a variety of combination assumptions





Combination assumption	Obs. 95% CL	Exp. 95% CL	Obs. value$^{+1\sigma}_{-1\sigma}$
HH combination	$-0.6 < \kappa_\lambda < 6.6$	$-2.1 < \kappa_\lambda < 7.8$	$\kappa_\lambda = 3.1^{+1.9}_{-2.0}$
Single-H combination	$-4.0 < \kappa_\lambda < 10.3$	$-5.2 < \kappa_\lambda < 11.5$	$\kappa_\lambda = 2.5^{+4.6}_{-3.9}$
HH+H combination	$-0.4 < \kappa_\lambda < 6.3$	$-1.9 < \kappa_\lambda < 7.6$	$\kappa_\lambda = 3.0^{+1.8}_{-1.9}$
HH+H combination, κ_t floating	$-0.4 < \kappa_\lambda < 6.3$	$-1.9 < \kappa_\lambda < 7.6$	$\kappa_\lambda = 3.0^{+1.8}_{-1.9}$
HH+H combination, κ_t, κ_V, κ_b, κ_τ floating	$-1.4 < \kappa_\lambda < 6.1$	$-2.2 < \kappa_\lambda < 7.7$	$\kappa_\lambda = 2.3^{+2.1}_{-2.0}$

In conclusion

- **Have shown selected highlights of ATLAS BSM Higgs searches**
  - Many more results in https://twiki.cern.ch/twiki/bin/view/AtlasPublic
  - Extensive search program with full Run 2 data, Run 3 coming

- **Pushing the limits of our understanding of possible BSM in the Higgs sector**
  - Large diversity of new ideas and techniques developed for these searches
  - No sign of new physics yet
  - Strong limits set on a large variety of final states
  - Local excesses seen need to be investigated

Back Up