Searching for new symmetries in the Higgs sector at ATLAS

Phenomenology 2023 Symposium
University of Pittsburgh
8-10th May 2023

UNIVERSITY OF BIRMINGHAM

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On behalf of the ATLAS collaboration

Introduction

- Discovery of the Higgs boson (H) with m_H=125 GeV confirms mass generation mechanism via spontaneous electroweak symmetry breaking (EWSB)
- The Standard Model (SM) is consistent with many experimental measurements but cannot describe e.g. dark energy/matter, matter asymmetry and gravity
- Many extensions Beyond the Standard Model (BSM) predict additional scalar fields for EWSB and extra Higgs-like bosons. These may be, depending on the model:
  - CP-even scalars h and H
  - CP-odd pseudoscalars a and A
  - charged scalars H^+ and H^-
  - Described using mixing parameters and Higgs-doublet vacuum expectation values

- Here, highlight recent searches for additional (low- or high-mass) Higgs bosons, and decays of H(125 GeV) to new light scalar particles

Related ATLAS talks in this session

- "Searches for BSM resonances in ATLAS", Blaz Leban
- "Searches for Dark Matter with the ATLAS Experiment at the LHC", Jia Jian Teoh

ATLAS Results

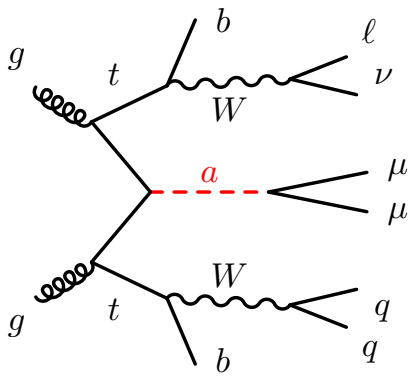
There are many searches, focus on the most recent preliminary and final ATLAS results

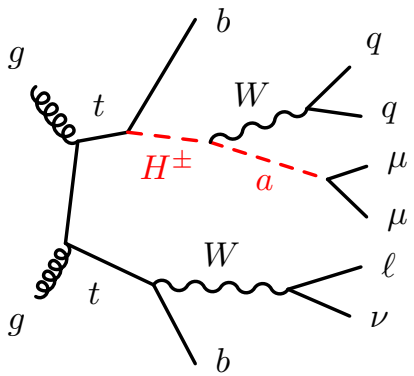
- Search for a new light pseudoscalar decaying into a pair of muons in events with a top-quark pair arXiv:2304.14247 (Submitted to Phys. Rev. D)
- Search for heavy Higgs bosons in multilepton plus b-jets final states ATLAS-CONF-2022-039 (preliminary result)
- Charged Higgs search arXiv:2302.11739 (submitted to JHEP)
- Dark matter searches with $H \to \tau\tau$ decays ATLAS-CONF-2022-069 (preliminary result)

- Analyses use full Run 2 data sample ($\sqrt{s} = 13$ TeV p–p collisions) with integrated luminosity of 139 fb^{-1}
- Use the excellent resolution of the ATLAS detector for searching for signatures of BSM physics e.g. lepton reconstruction, b-jet identification etc..

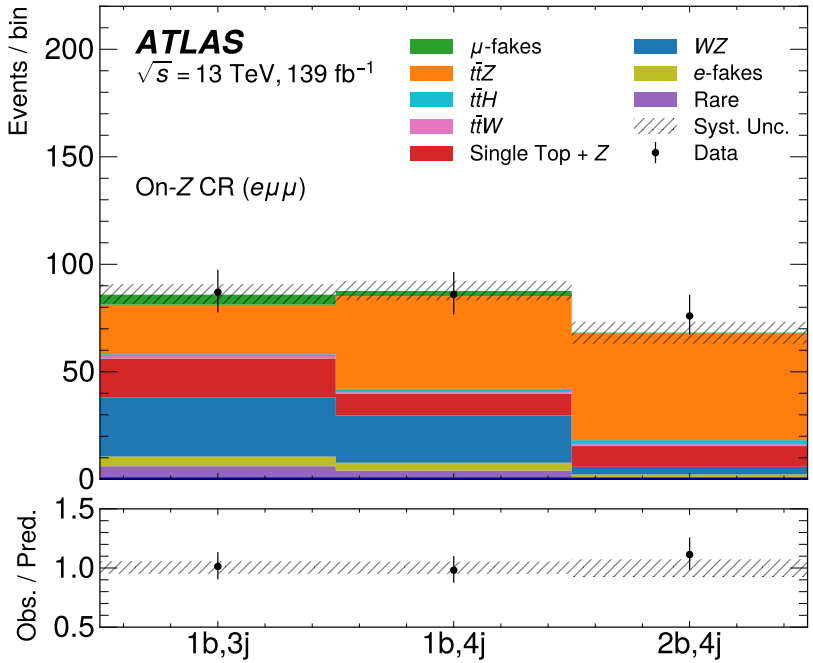
Search for $a \to \mu\mu$ in $t\bar{t}$ events arXiv:2304.14247 (Sub. to Phys. Rev. D)

- New light pseudoscalars mix with fields in an extended Higgs sector, may include additional heavy neutral and charged scalars, inheriting the Yukawa couplings to fermions.
- Large coupling to top quarks suggests to search in events with a top-quark pair
- Two scenarios $pp \to t\bar{t}a$ and $pp \to t\bar{t}$ with $t \to H^{\pm}b, H^{\pm} \to W^{\pm}a$ using $a \to \mu\mu$ for high mass resolution



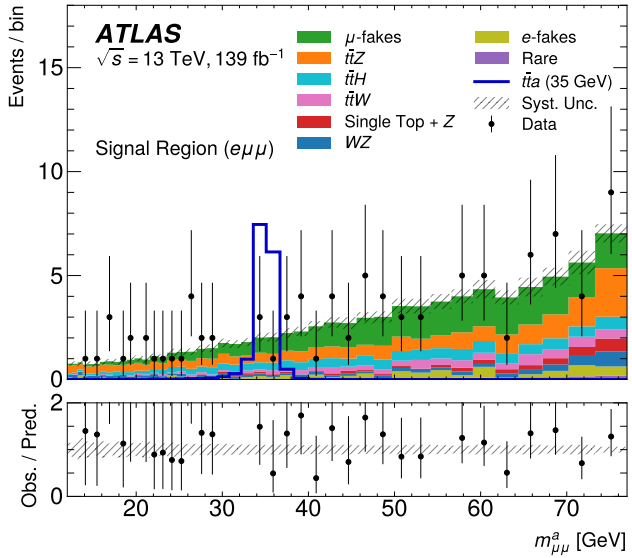


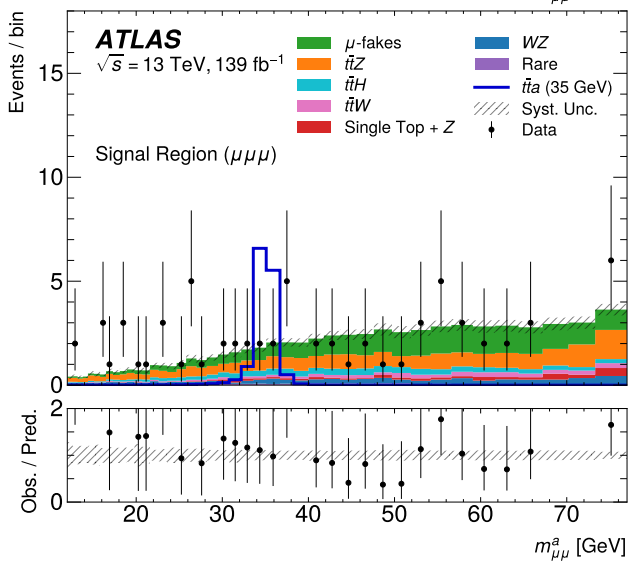
- Search in range $15 < m_a < 72$ GeV and $120 \leq m_{H^{\pm}} \leq 160$ GeV
- One leptonic top decay: 3 lepton signature $e\mu\mu$ and $\mu\mu\mu$
- Define "On-Z"control regions ($n_{b-\text{jets}}$, n_{jets})
- $t\bar{t}$ control region ($p_T^{\mu,\text{fake}}$)

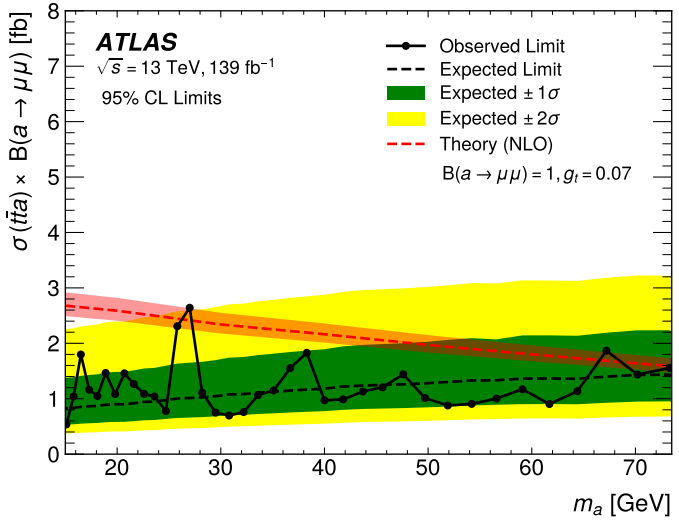


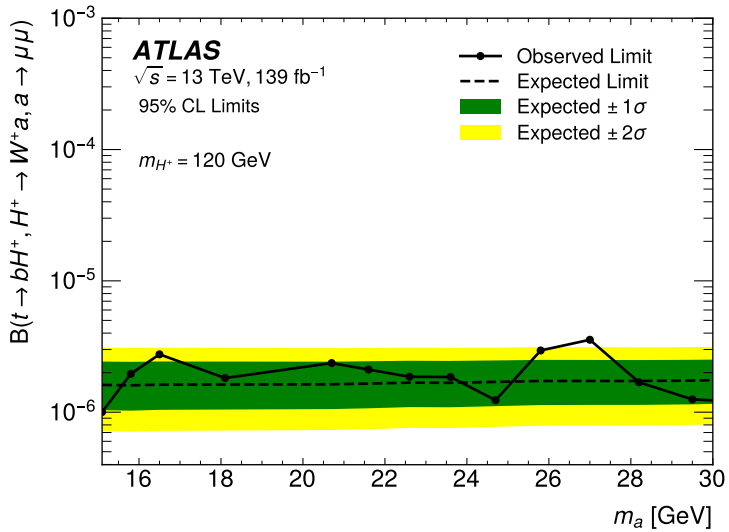
Search for $a \to \mu\mu$ in $t\bar{t}$ events arXiv:2304.14247 (Sub. to Phys. Rev. D)

Signal region plots for hypothesis $m_a = 35$ GeV (parameterised width of double crystal ball vs m_a)
Upper limits at 95% confidence level on $\sigma(t\bar{t}a) \times \mathcal{B}$ and $\mathcal{B}\ (t \to H^{\pm} b, H^{\pm} \to W^{\pm} a, a \to \mu\mu)$ vs m_a for various m_{H^+}. Results largely dominated by statistical uncertainties





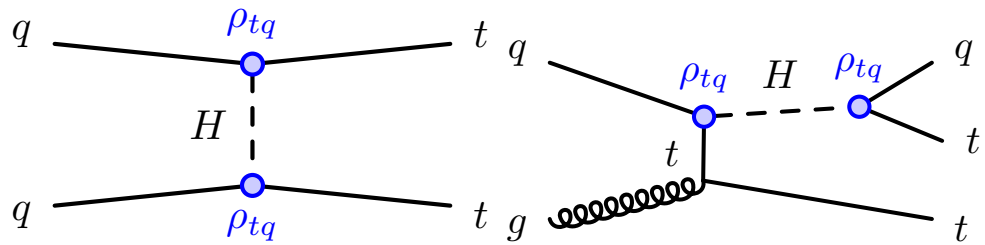




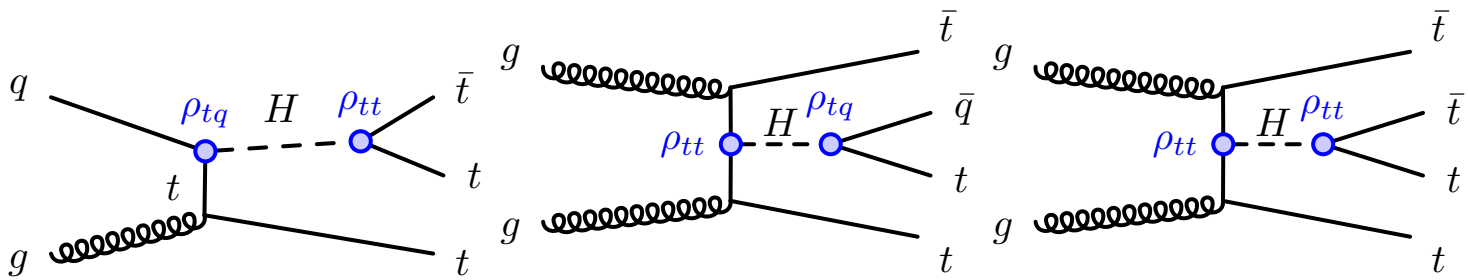
Heavy Higgs boson in multilepton plus b-jets final states
ATLAS-CONF-2022-039

- Results are interpreted in the general two Higgs doublet model (g2HDM) allowing flavour changing neutral Higgs (FCNH) couplings
- Additional heavy (sub-TeV) bosons: consider three couplings involving top quarks to up-type quarks ρ_{tu}, ρ_{tc} and ρ_{tt} (ρ_{tc} and ρ_{tt} can explain generation of baryon asymmetry)
- Benchmark values e.g. $\rho_{tt} = 0.4$, $\rho_{tq} = 0.2$
- Analysis targets 5 production modes
- First BSM search for three top-quark production (sensitivity to new physics)

same sign tt (sstt), ttq

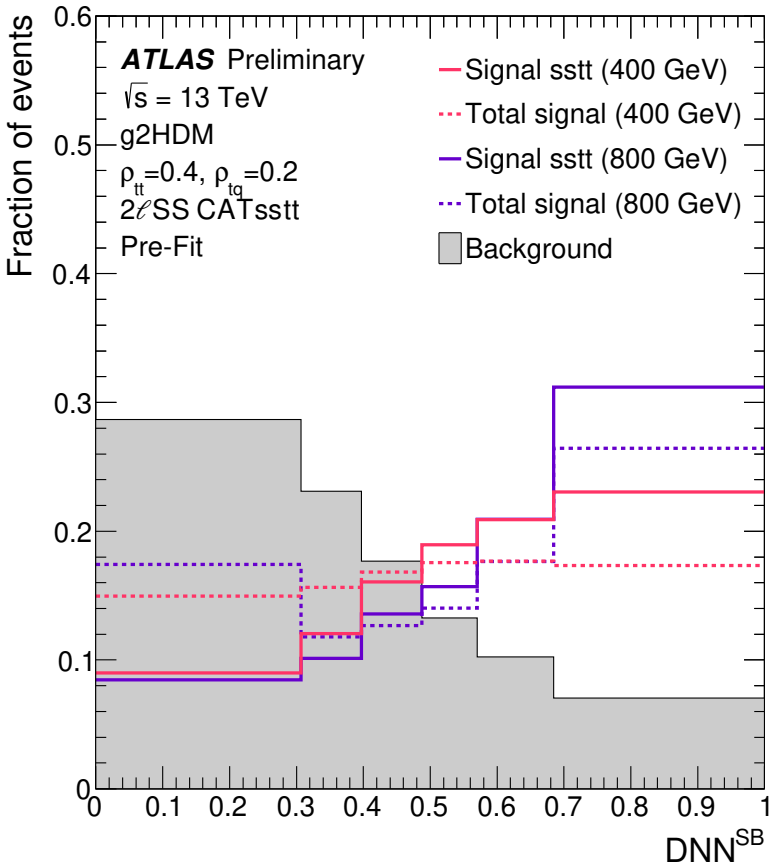


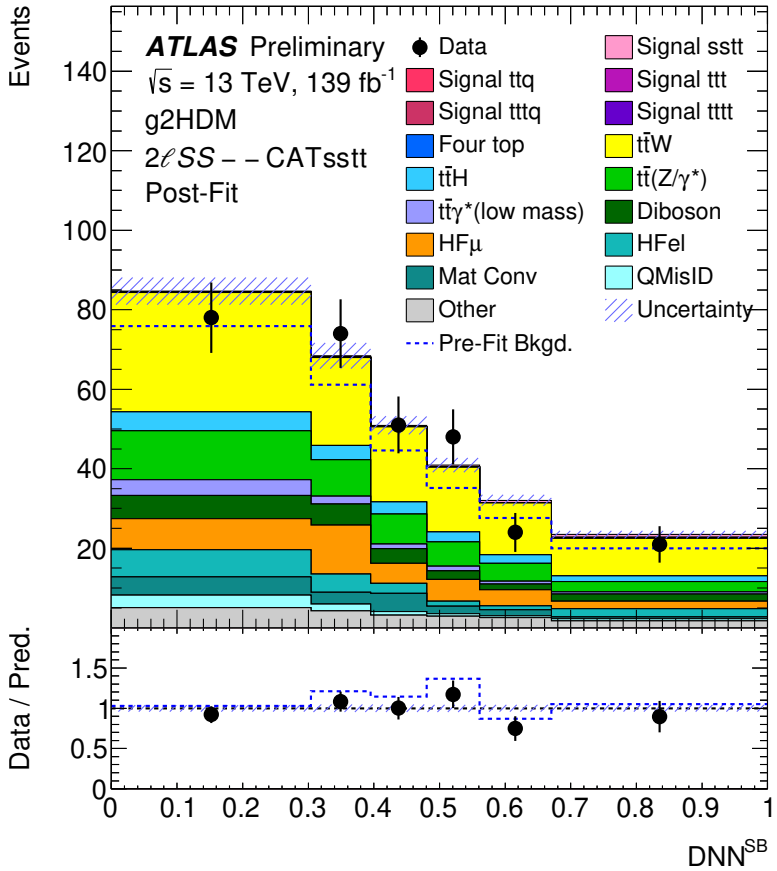
ttt,$tttq$,$tttt$



Heavy Higgs boson in multilepton plus b-jets final states
ATLAS-CONF-2022-039

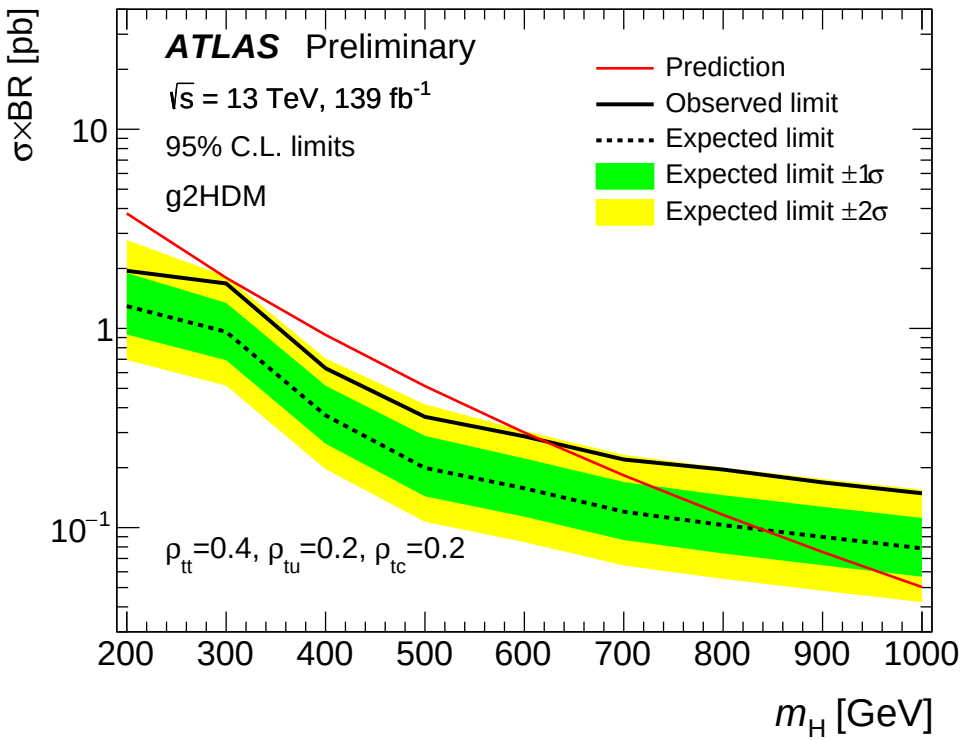
- Event categorisation based on lepton multiplicity and charge: $2l$ same-sign, $3l$, and $4l$
- Further split based on output of the multi-category deep neural network (DNN^{cat}), using 12 input variables, targeting the 5 BSM signals
- Split further according to lepton charge of any same-sign pair "++" or "- -"
- Second DNN^{SB} in each category to suppress SM background (and act as discriminant)
- Control regions to constrain main backgrounds: WZ, ttZ, converted and HF leptons

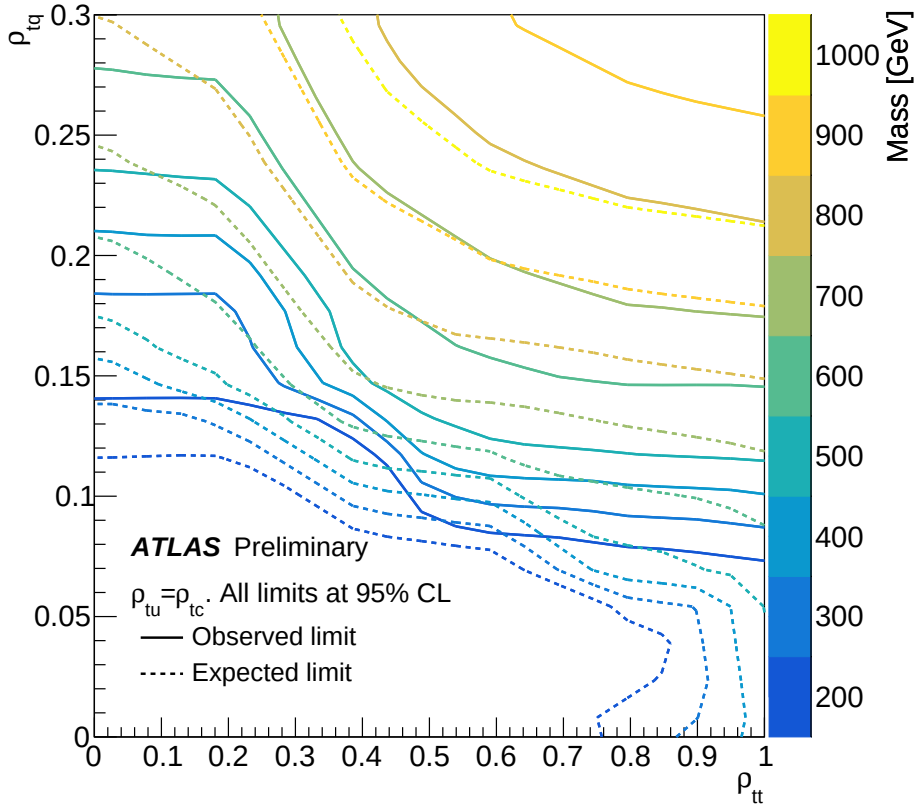




Heavy Higgs boson in multilepton plus b-jets final states
ATLAS-CONF-2022-039

- 95% CL upper limits on the $\sigma \times BR$ for all the 2HDM signals together
- A mild excess observed over the SM expectation at $m_H = 1000$ GeV for a local significance of 2.81σ
- Limits on m_H were set for different coupling choices
- Excluded masses as a function of two couplings



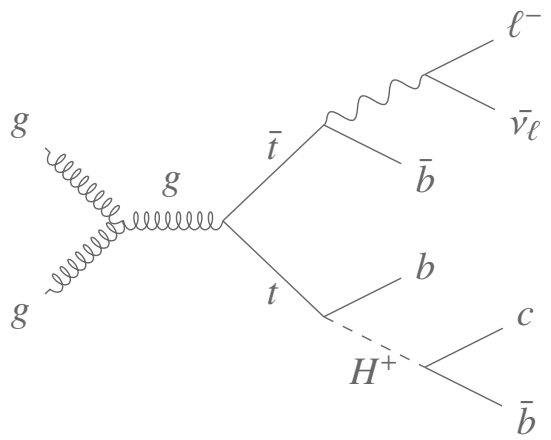


Charged Higgs Search $H^{\pm} \to cb$ arXiv:2302.11739 (submitted to JHEP)

Three Higgs doublet model (3HDM)

- 3 CP-even plus 2 CP-odd neutral Higgs bosons and 2 charged Higgs bosons
- Lightest $H^{\pm}$ can be lighter than top quark
- Decays to $\tau\nu$, cb or cs

Search for $H^{\pm} \to cb$ in top-quark decays
(SM background $W^{\pm} \to cb$ CKM suppressed)



- Experimental signature: single-lepton, ≥ 4 jets, ≥ 3 b-jets.
- Dominant tt+jets backgrd: $2b + 1b$ loose CR, derive $t\bar{t}$ MC correction (H_T)
- Mass parameterised NN (29 inputs). Simultaneous fit of 6 regions
- 10 bins for $3b$-jet distributions, 1 bin for $\geq 4b$-jet

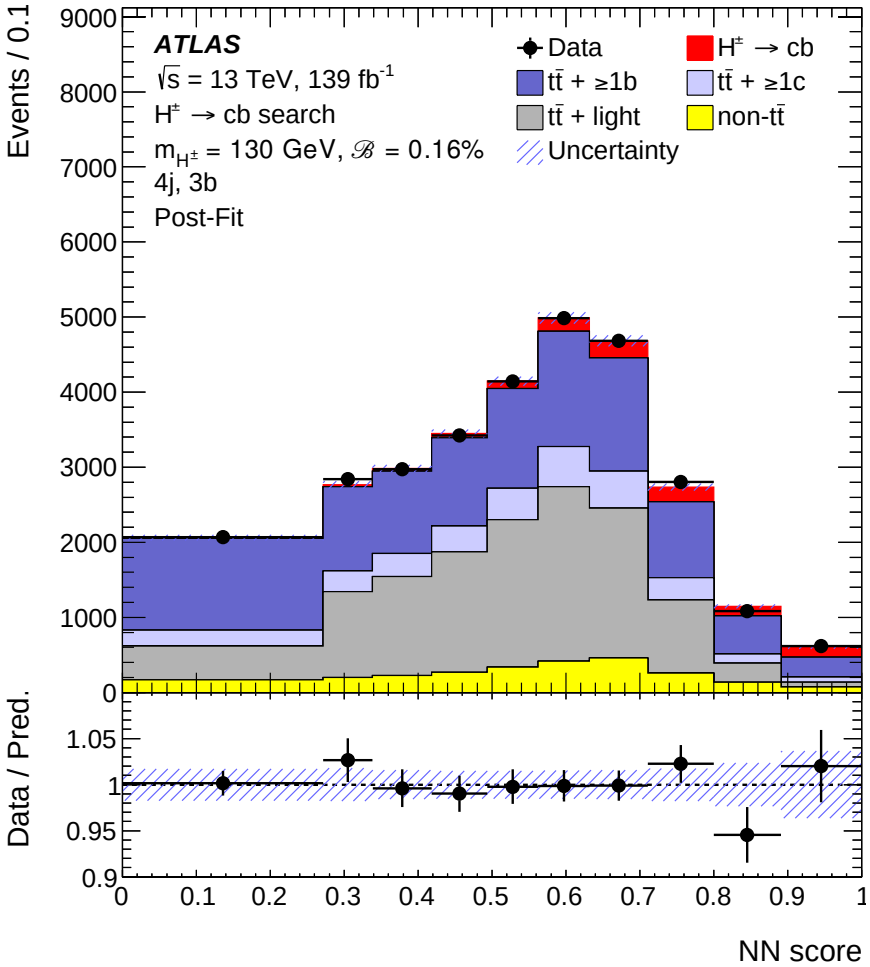
N_j \ N_b	**2b + 1bl:** exactly two b-tagged jets (60% OP) plus one loose b- tagged jet (70% OP)	**3b:** exactly three b-tagged jets (60% OP)	**≥4b:** at least four b-tagged jets (60% OP)
4j: exactly four jets	**4j, 2b + 1bl** (data-based $t\bar{t}$ corrections, 10 bins)	**4j, 3b** (signal region, 10 bins)	**4j, 4b** ($t\bar{t}$ + ≥ 1b background control region and large S/B region, 1 bin)
5j: exactly five jets	**5j, 2b + 1bl** (data-based $t\bar{t}$ corrections, 10 bins)	**5j, 3b** (signal region, 10 bins)	**5j,≥ 4b** ($t\bar{t}$ + ≥ 1b background control region and large S/B region, 1 bin)
6j: exactly six jets	**6j, 2b + 1bl** (data-based $t\bar{t}$ corrections, 10 bins)	**6j, 3b** (signal region, shape correction for the NN discriminant in low S/B bins, 10 bins)	**6j,≥ 4b** ($t\bar{t}$ + ≥ 1b background control region, 1 bin)

Regions used to derive $t\bar{t}$ correction **Regions for NN training and fit**

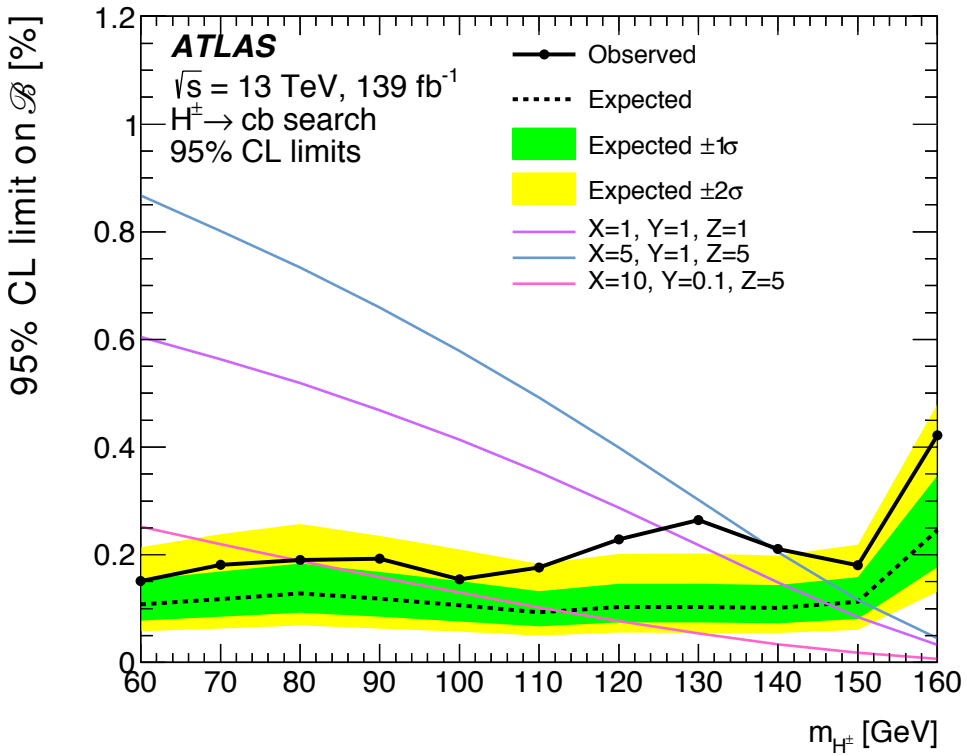
Results: Charged Higgs Search $H^{\pm} \to cb$

arXiv:2302.11739

- Example below of NN score for 4-jet, 3b-jet category (best-fit branching fraction of 0.16%)
- 3σ local (2.5σ global) excess at $m_{H^{\pm}} = 130$ GeV



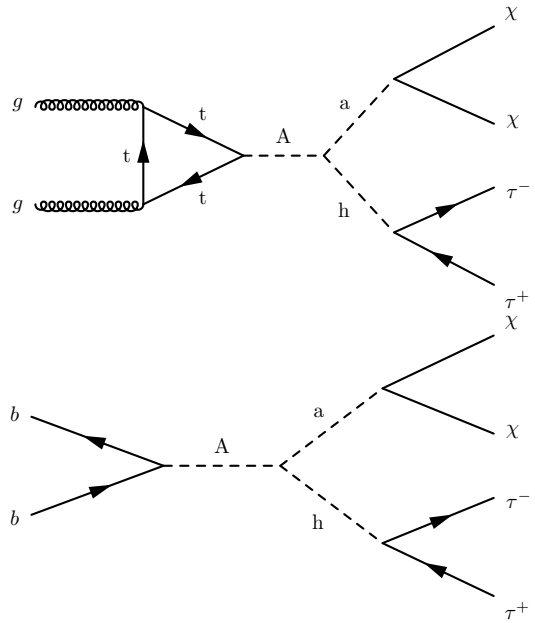
Benchmark 3HDM signals from Phys. Rev. D 98, 115024 (2018) and arXiv:1605.05881 [hep-ph]



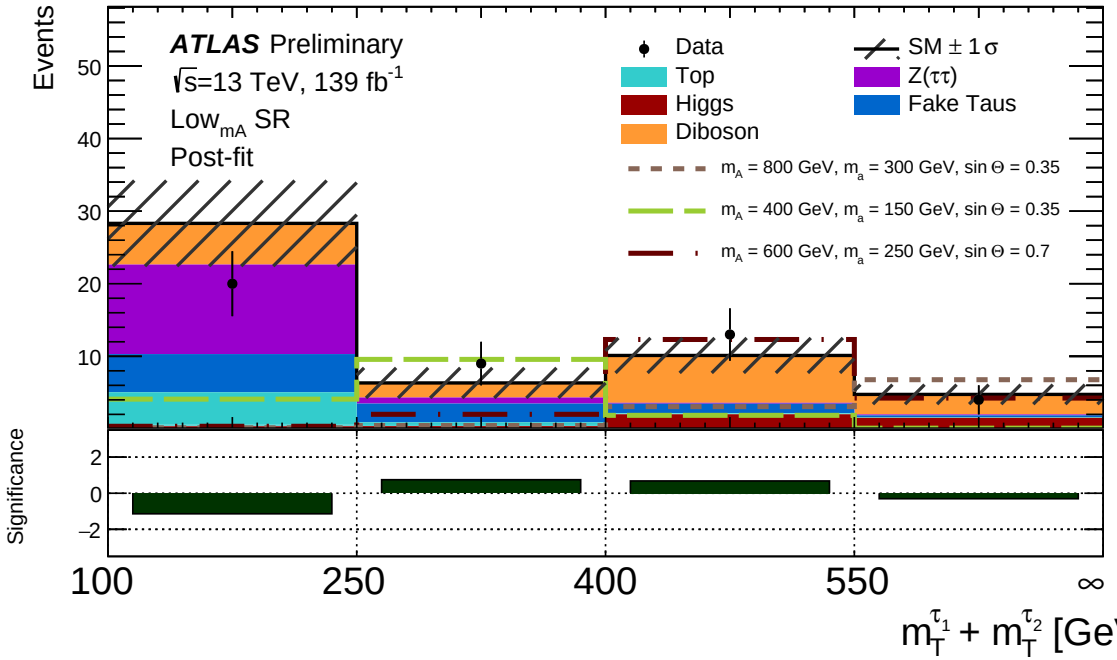
Improvement of factor 5 in sensitivity and extension in $m_{H^{\pm}}$ compared to previous results

Search for Dark Matter $H \to \tau\tau$ plus Missing E_T ATLAS-CONF-2022-069

- Complementary to mono-$H(125) \to bb$, $\gamma\gamma$ searches
- Probes structure of BSM physics responsible for dark matter production
- Interpretation in 2HDM+a model:
- Adds new pseudoscalar singlet, a, that couples to baseline 2HDM. Fermionic DM particle χ with mass 10 GeV



- Signature: 2 hadronic taus + missing E_T
- 2 cut-based signal regions targeting low/high m_A signatures
- $Z \to \tau\tau$, top-quark processes: fitted to data in CRs
- Fake taus ($W \to \tau\nu$, multi-jet): fake-factor method
- Diboson: Normalisation studied in data validation region

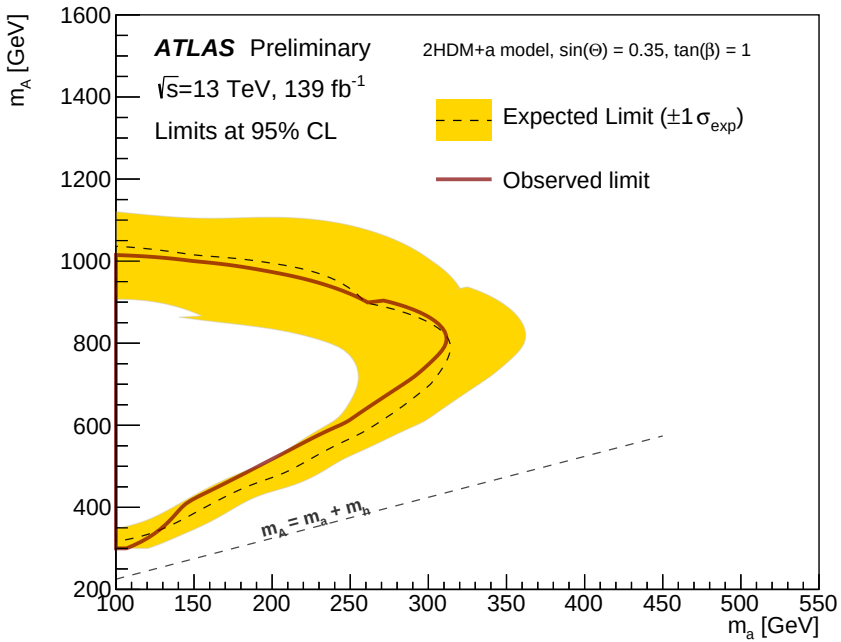


Results: Search for Dark Matter $H \to \tau\tau$ plus Missing E_T

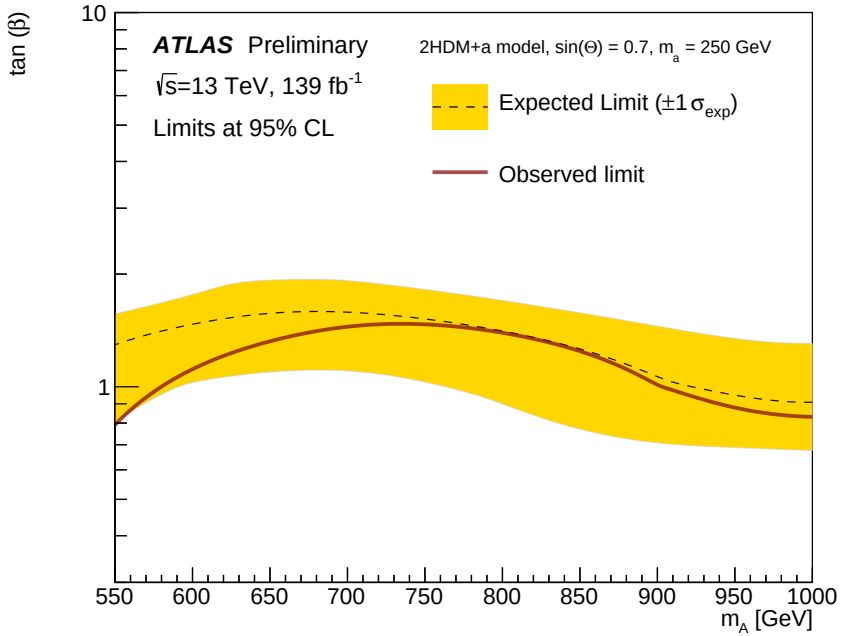
ATLAS-CONF-2022-069

Observed and expected exclusion contours at 95% CL

- As a function of m_a and m_A with $\sin\Theta = 0.35$ (mixing angle between the two pseudoscalars) and $\tan\beta = 1$
- The excluded area is to the left of the solid line



- As a function of m_A and $\tan\beta$ with $\sin\Theta = 0.7$ and $m_a = 250$ GeV
- The excluded area is below the solid line.



Summary

- Searches for additional Higgs bosons at ATLAS have yielded results that are still compatible with the Standard Model
- These searches push the limits of our understanding of BSM and provide an opportunity to discover new physics . . .
- ATLAS continues to search for them and has started the Run 3 programme at a centre-of-mass energy of 13.6 TeV

Backup

Results: Charged Higgs Search $H^{\pm} \to cb$

arXiv:2302.11739

- Broad excess across all regions
- consistent with $m_{H^{\pm}}$ resolution (degraded by ambiguity in choosing correct b-jet pair)