Searches for additional Higgs bosons in the ATLAS detector

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On behalf of
the ATLAS Collaboration

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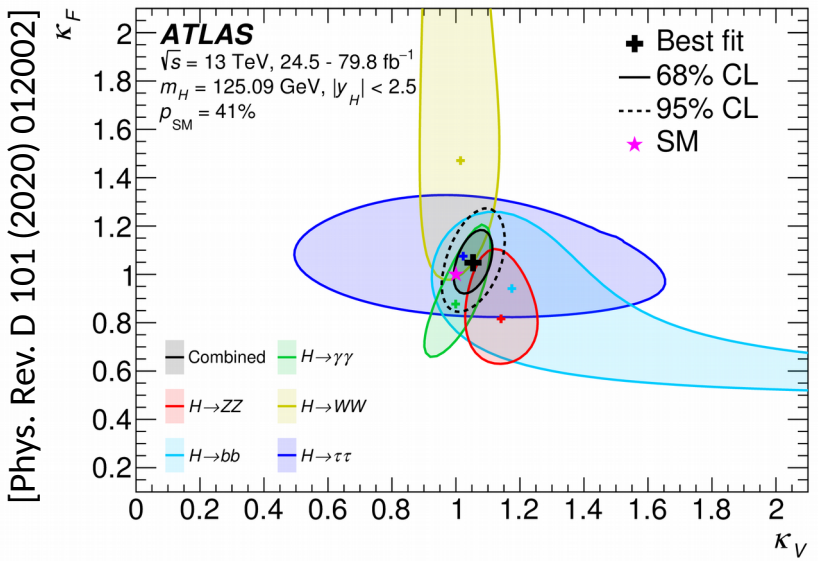
More Higgs bosons?



So far excellent agreement of measurements with predictions from Standard Model (SM) Higgs boson assumptions.

→ *e.g. coupling measurements.*

The SM is not the ultimate theory of nature – serious short-comings:

- No Dark Matter (DM) candidate,
- No explanation for matter-anti-matter asymmetry,
- Neutrino masses not included,
- …

Many extensions of the Standard Model predict more than one Higgs boson:

- E.g. Two-Higgs-Doublet models (2HDM) predict 5 Higgs bosons: two neutral CP even (h, H), one CP odd (A) and two charged Higgs bosons (H^{+-}).

  → *Supersymmetry is an example for a 2HDM.*

Search program

- Indirect searches:

  → Precision measurements of SM Higgs couplings and reinterpretations in BSM extensions.

  → E.g. searches for DM, and interpretation in models with extended Higgs sector.

- Direct searches:

  → Searches for additional neutral Higgs bosons in all possible decay modes (ZZ, WW, Zγ, γγ, Zh, hh, ττ, tt, bb)

  e.g. *H/A → ττ (Phys. Rev. Lett. 125 (2020) 051801)*
  H → γγ (ATLAS-CONF-2020-037)
  H → ZZ (ATLAS-CONF-2020-032)

  → Searches for charged Higgs bosons,

  e.g. *H^+ → tb (ATLAS-CONF-2020-039)*

  → Searches for double-charged Higgs bosons.

See also posters by Adrian, Janina and Yufeng!

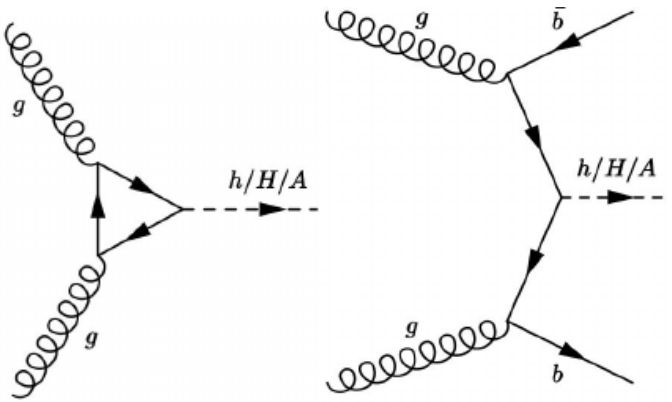
A/H → ττ

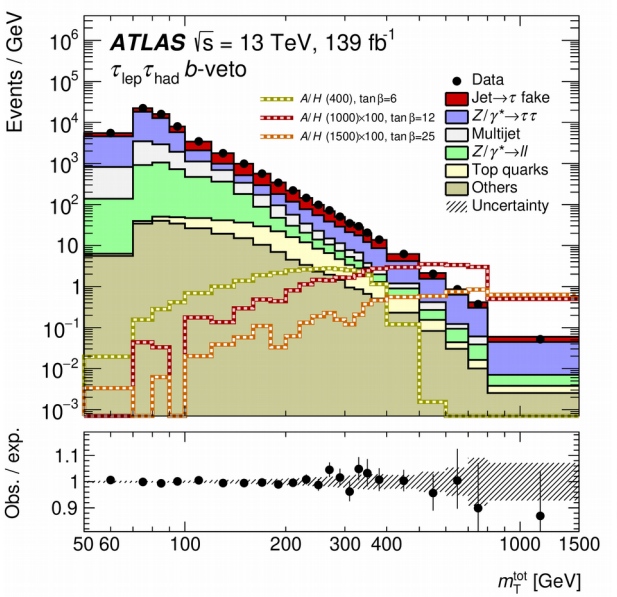
[Phys. Rev. Lett. 125 (2020) 051801]

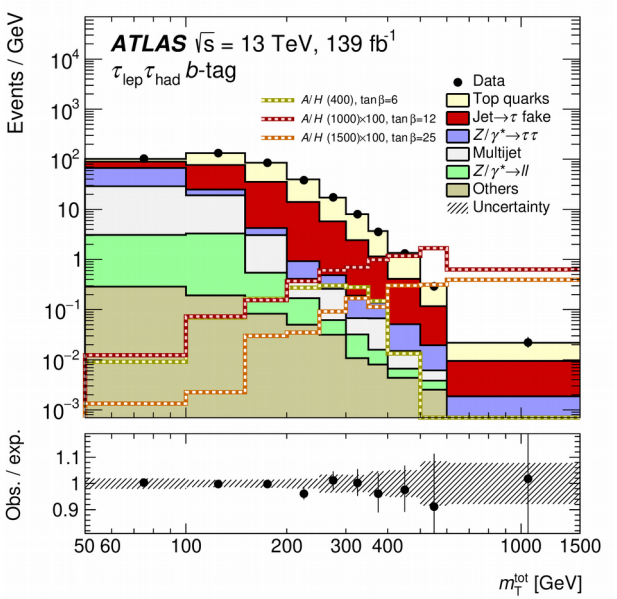
→ *Searching for a new heavy (pseudo)scalar.*

- Decays to di-tau final states possibly enhanced wrt other decay modes in a type-II 2HDM, especially at large tan(β) values.
- Consider final states with leptonically decaying tau + hadronically decaying tau ($\tau_{lep}\tau_{had}$) or both taus decaying hadronically ($\tau_{had}\tau_{had}$)

Identified by a BDT







- Search categories in **b-tag** for b-associated and **b-veto** for ggF production.
- Reconstruction of di-tau mass via:

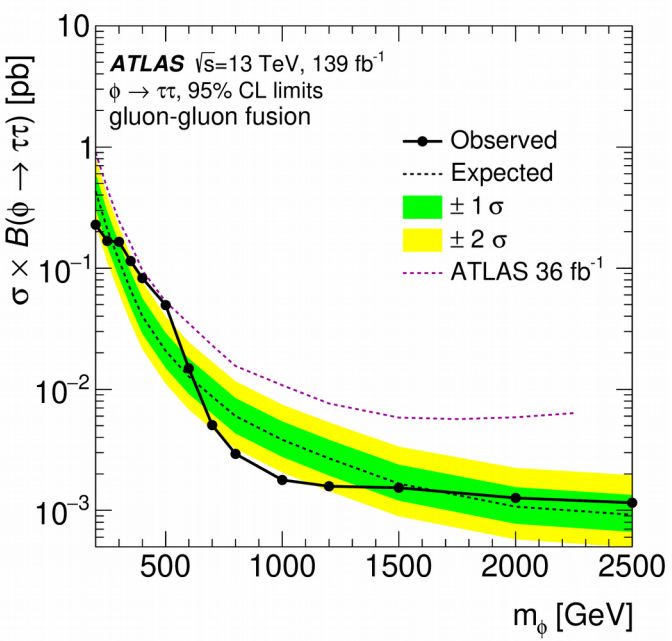
$$m_T^{tot} = \sqrt{(p_T^{\tau_1} + p_T^{\tau_2} + E_T^{miss})^2 - (\mathbf{p}_T^{\tau_1} + \mathbf{p}_T^{\tau_2} + \mathbf{E}_T^{miss})^2}$$

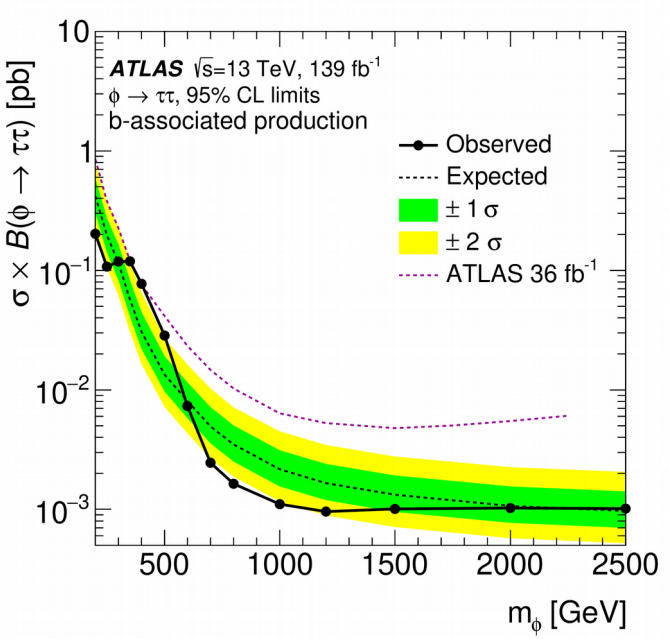
- Dominant backgrounds ($t\bar{t}$, W+jets, and multi-jet) estimated via a data-driven method.

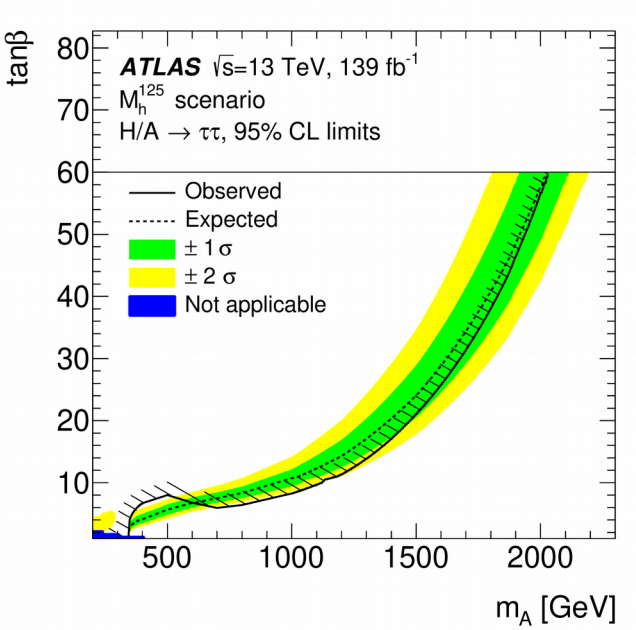
A/H → ττ

[Phys. Rev. Lett. 125 (2020) 051801]

- No significant excess in data wrt background expectations.
- Interpretations in different 2HDM/M_h^{125} variants.
- E.g. exclude tan(β) > 21 for m_A = 1.5 TeV in M_h^{125}



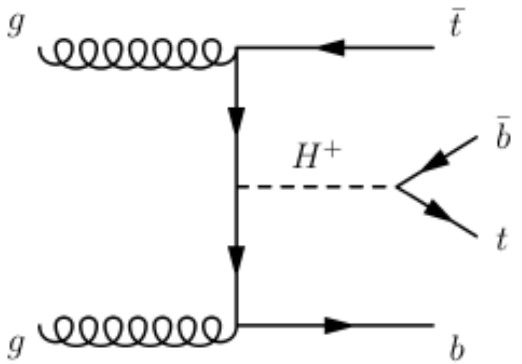


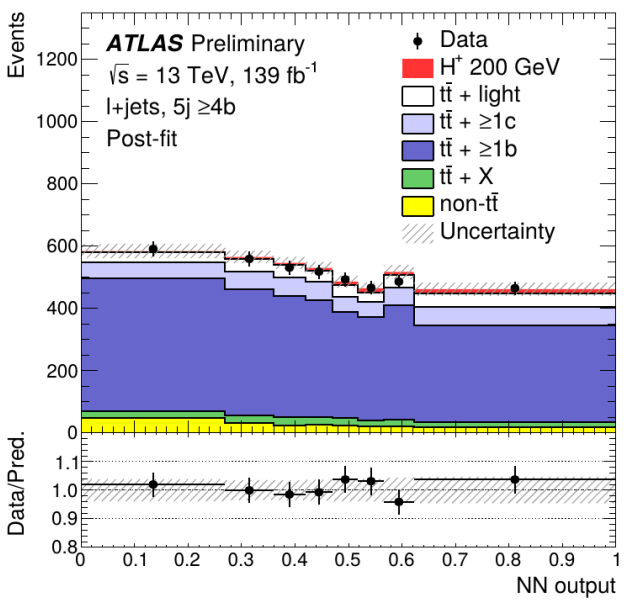


$H^+ \rightarrow tb$

New

[ATLAS-CONF-2020-039]





Charged Higgs boson predicted in many BSM scenarios.

In 2HDM with $\cos(\beta-\alpha)\sim 0$ dominant decay $H^+ \rightarrow tb$ for $m(H^+)>200$ GeV.

→ Search for H^+ produced in association with top and bottom quarks in final states with an electron or a muon.

→ Split into categories with different multiplicities of jets and b-tagged jets (5 jets + 3 or ≥ 4 b-jet, ≥ 6 jets + 3 or ≥ 4 b-jets) .

As simulated-based modeling of top-related backgrounds not matching data → **reweighting procedure** based on jet multiplicity and H_T distributions.

Neural network trained on parameters related to (transverse) momentum, energies, mass and separations of jets, including different H^+ masses.

$H^+ \rightarrow tb$

New

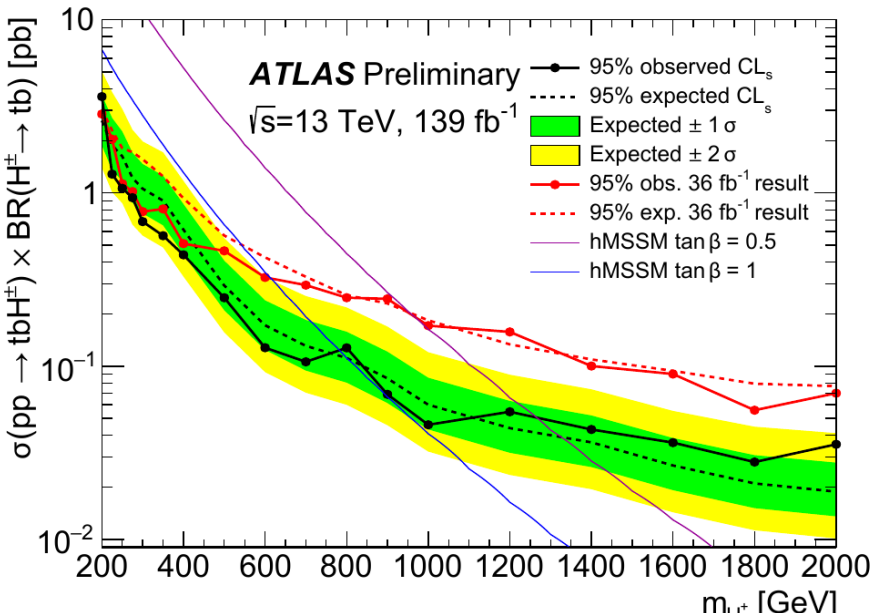
[ATLAS-CONF-2020-039]

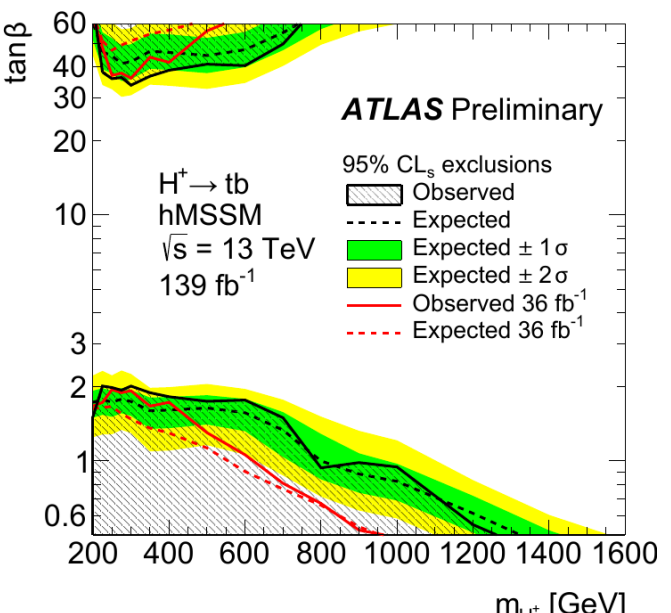
No significant excess above SM expectations observed.

Upper limits:

- σ x BR = 3.6 pb for m_{H+} = 200 GeV
- σ x BR = 0.035 pb for m_{H+} = 2 TeV

Interpretation in hMSSM and different M_h^{125} variants.





Searches for resonances decaying to photon pairs

New

[ATLAS-CONF-2020-037]

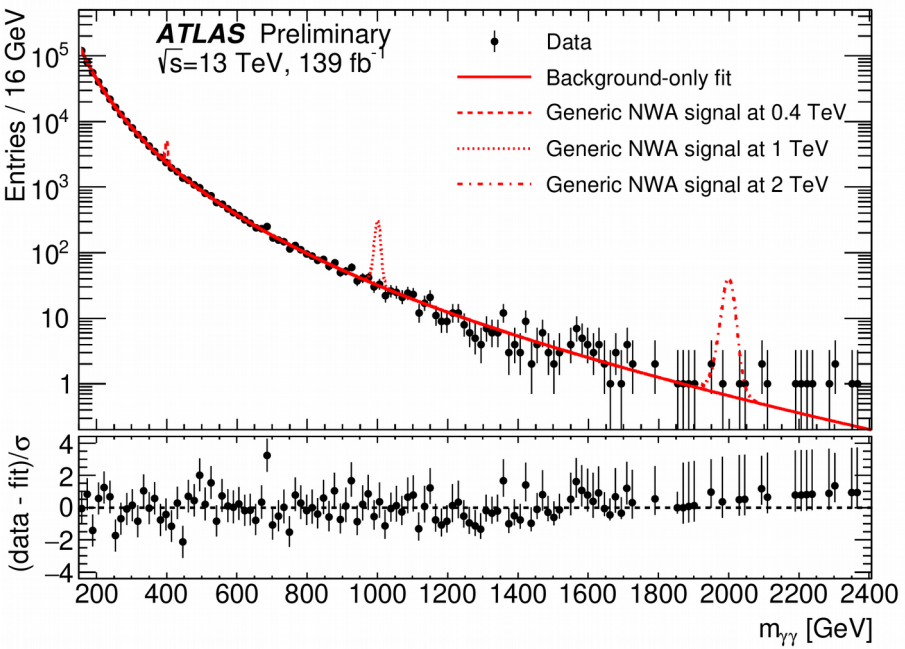
→ Search for high-mass resonances > 160 GeV.

→ Using invariant mass of photon pair due to **excellent resolution**.

- Spin 0 and spin 2 possibilities considered, narrow and large width assumptions for spin 0
  – up to $\Gamma_X / m_X = 10\%$;
- Randall-Sundrum gravition model for spin 2

- Common event selection for both cases; **improved photon reconstruction and identification**.

- Background/signal shapes modeled by **functional forms**
  → Double-sided Crystal Ball function for narrow-width assumption, ⊗ relativistic Breit-Wigner function for large width.
  → Functional form for backgrounds from templates built from simulation for γγ events, and from a data control region for γ +jet events.

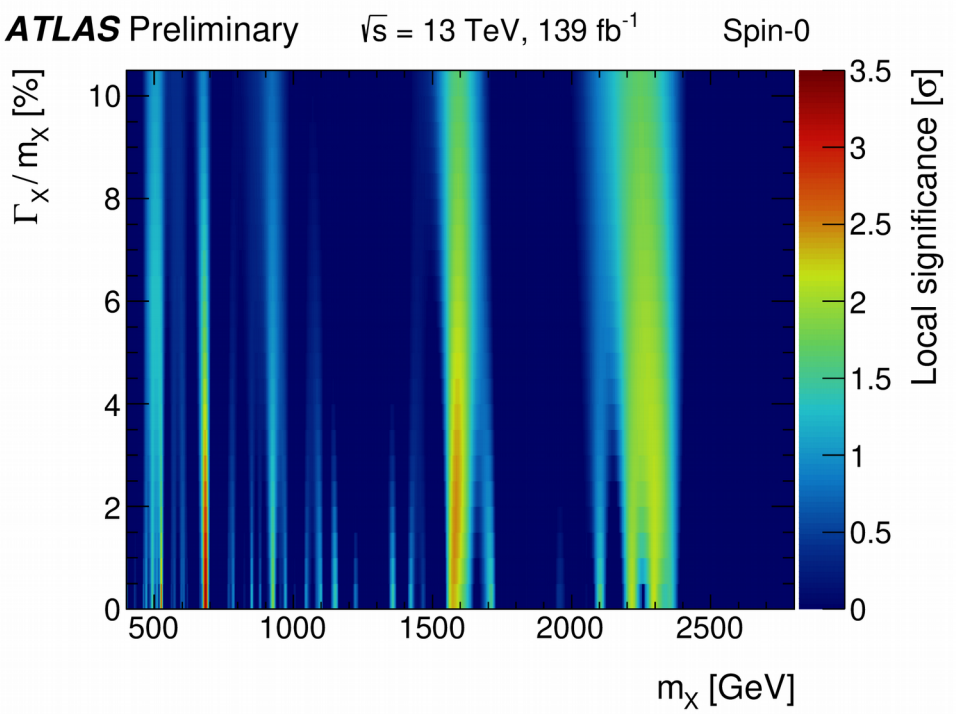


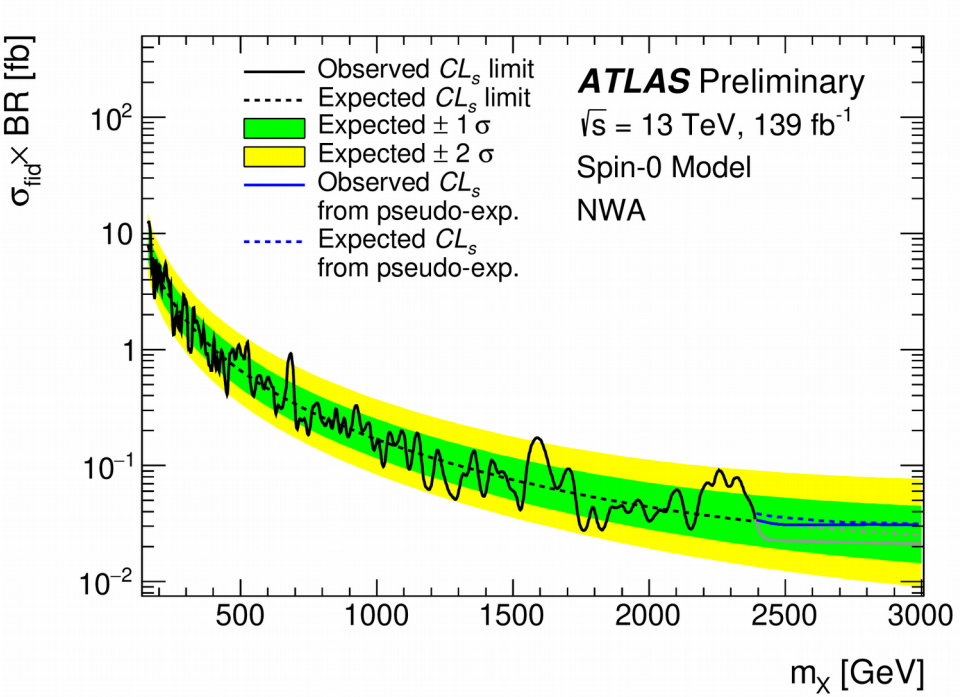
Searches for resonances decaying to photon pairs

New

[ATLAS-CONF-2020-037]

- Largest deviation: 3.29σ (local), 1.3σ (global) at m_X =684 GeV
- Upper limits for the narrow-width assumption: 12.5 fb (162 GeV) to 0.03 fb (3 TeV).





Search for a resonance in ZZ → $l^+l^-l^+l^-$ or ZZ → $l^+l^-\nu\nu$

New

[ATLAS-CONF-2020-032]

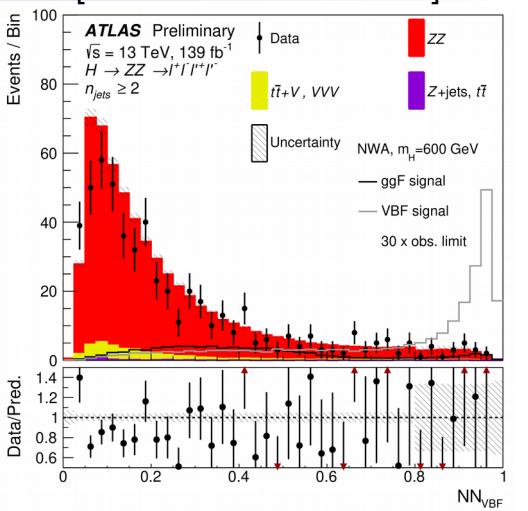
→ Search for heavy spin 0 resonance (e.g. heavy Higgs) or spin 2 gravition, mass range 200 GeV – 2 TeV.

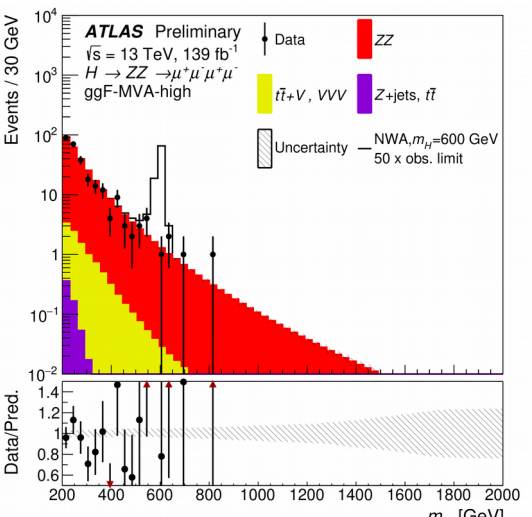
Combination of $l^+l^-l^+l^-$ and $l^+l^-\nu\nu$ channels to benefit from mass resolution in 4l case and larger branching ratio in $l^+l^-\nu\nu$ case.

$l^+l^-l^+l^-$:

- 2 opposite-sign lepton pairs,
- Improvements wrt previous results due to improved lepton reconstruction/isolation and use of PFlow jets; improved event selection,
- Background to signal separation by a sequence of recurrent networks and multilayer perceptrons → one classifier for ggF and one for VBF

  → Depending on score and lepton flavour 5 categories,
- Final discrimination in invariant mass of 4-lepton system.
- Main background ZZ, modeled by empirical functions, normalization allowed to vary freely in fit.





Search for a resonance in ZZ → $l^+l^-l^+l^-$ or ZZ → $l^+l^-\nu\bar{\nu}$

New

[ATLAS-CONF-2020-032]

$l^+l^-\nu\bar{\nu}$:

- Two close opposite-sign same-flavour leptons.
- Full mass cannot be reconstructed, thus use of transverse mass:

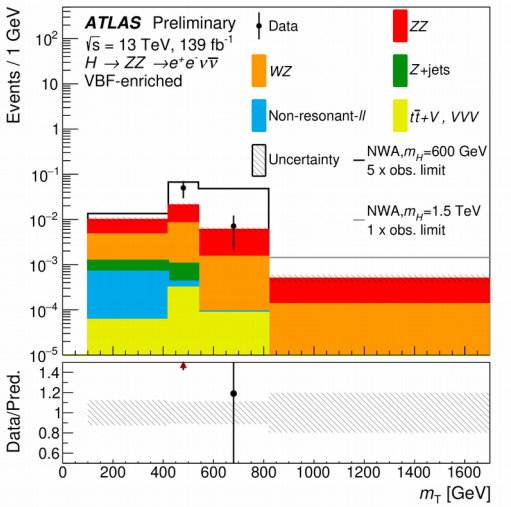
$$m_{\mathrm{T}} \equiv \sqrt{\left[\sqrt{m_Z^2 + \left(p_{\mathrm{T}}^{\ell\ell}\right)^2} + \sqrt{m_Z^2 + \left(E_{\mathrm{T}}^{\mathrm{miss}}\right)^2}\right]^2 - \left|\vec{p}_{\mathrm{T}}^{\,\ell\ell} + \vec{E}_{\mathrm{T}}^{\mathrm{miss}}\right|^2}$$

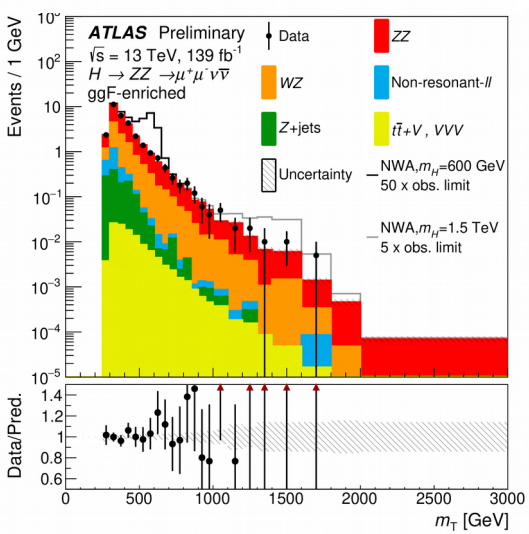
- Cut-based analysis relying on high E_T^{miss} and E_T^{miss} significance; E_T^{miss} in opposite direction to leptons.

- Dominant backgrounds ZZ and WZ

  → WZ estimated with help of a 3-lepton control region.

  → ZZ from simulation, with normalization allowed to vary freely.



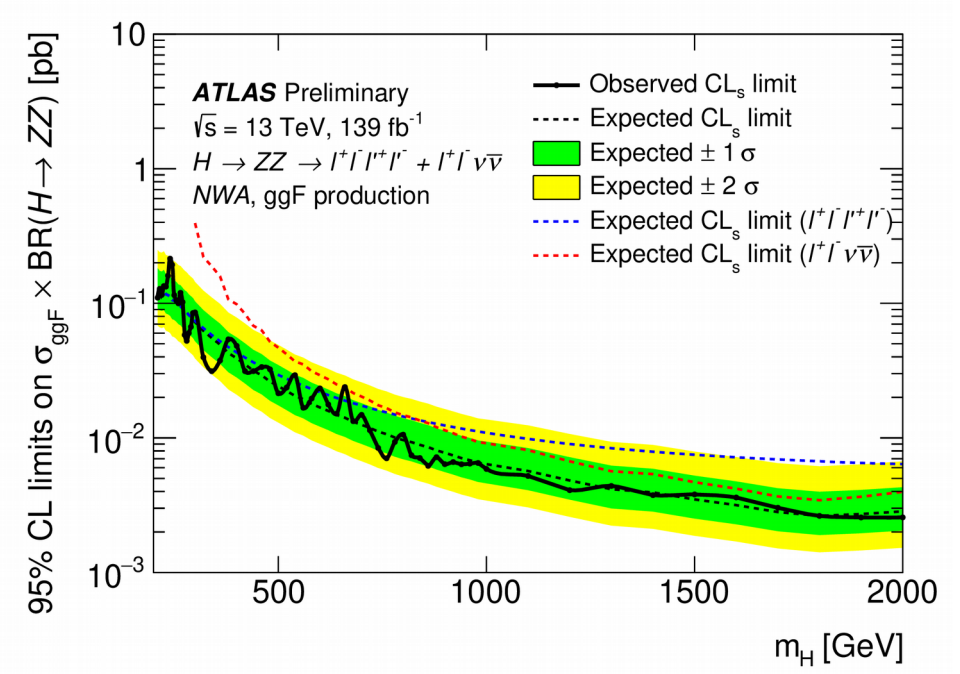


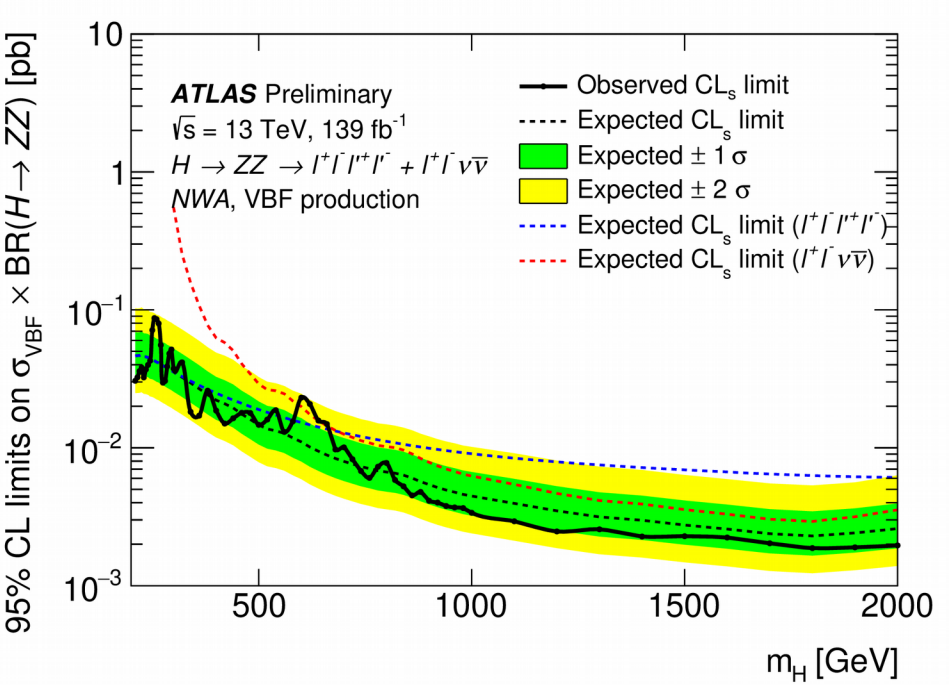
Search for heavy Higgs in ZZ → $l^+l^-l^+l^-$ or ZZ → $l^+l^-\nu\nu$

New

[ATLAS-CONF-2020-032]

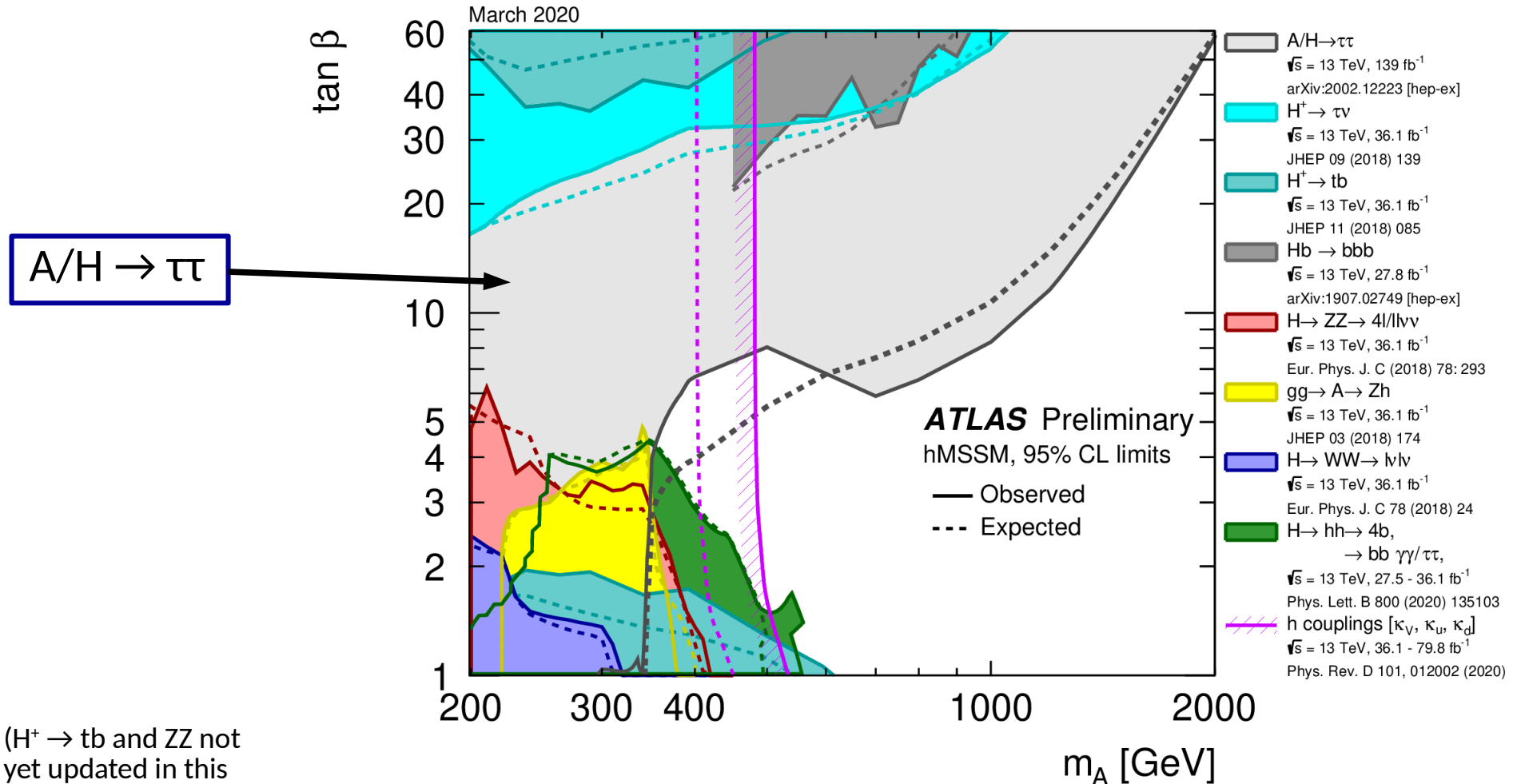
- Combination of both channels → no significant excess seen.
- In case of NWA approximation, fits for ggF and VBF processes done separately (with the respective other process profiled) to not assume a certain fraction.
- In LWA cases, interference effects between heavy and light Higgs and Higgs – gg → ZZ considered.
- Interpretations also in 2HDM models and for a Randall-Sundrum graviton.





Summary in hMSSM

[Reference]



A/H → ττ

(H⁺ → tb and ZZ not yet updated in this plot)

Summary

Presented selected searches for additional heavy (charged) Higgs bosons.

Sophisticated techniques in use:

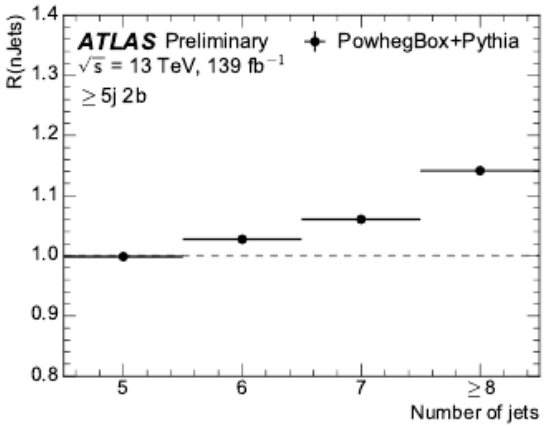
- Hadronic tau identification via BDT,
- Jet multiplicity and jet H_T based reweighting to correct for mismodeling in simulation,
- Improved object reconstruction,
- Functional forms to model backgrounds,
- Sequences of (deep) neural networks to better discriminate signals from backgrounds.

No significant excess in data seen yet, but only part of the full dataset analyzed already. Significant update of constraints on 2HDM models.

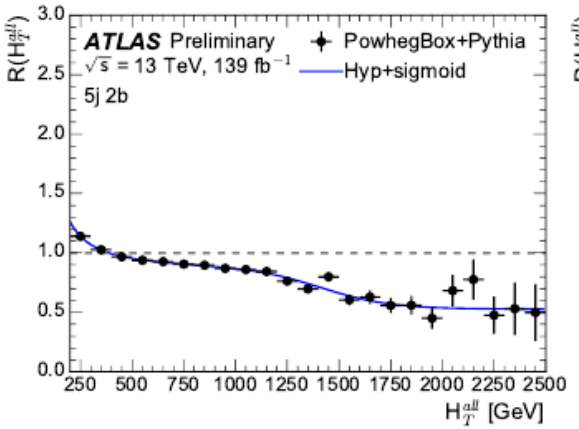
Backup

$H^+ \rightarrow tb$ – reweighting procedure for top related backgrounds

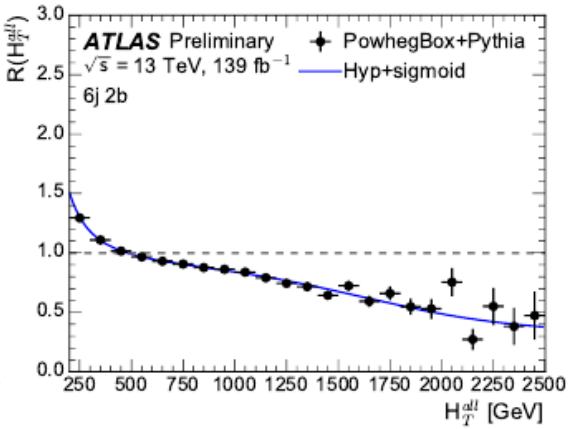
[ATLAS-CONF-2020-039]



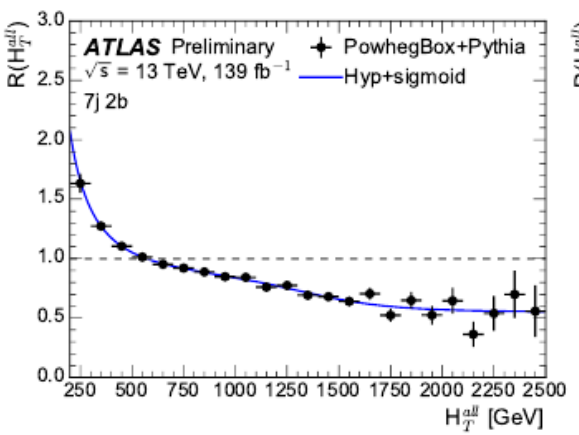
(a) ≥5j2b



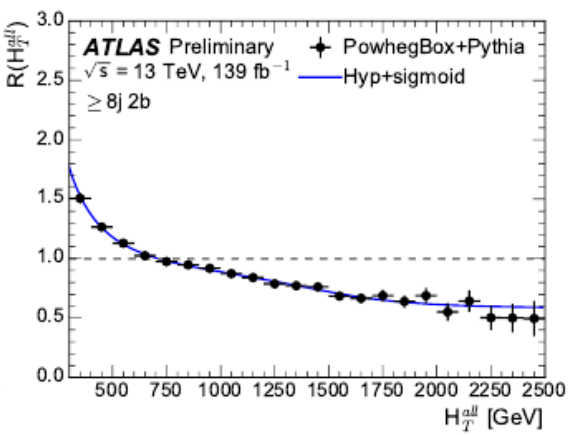
(b) 5j2b



(c) 6j2b



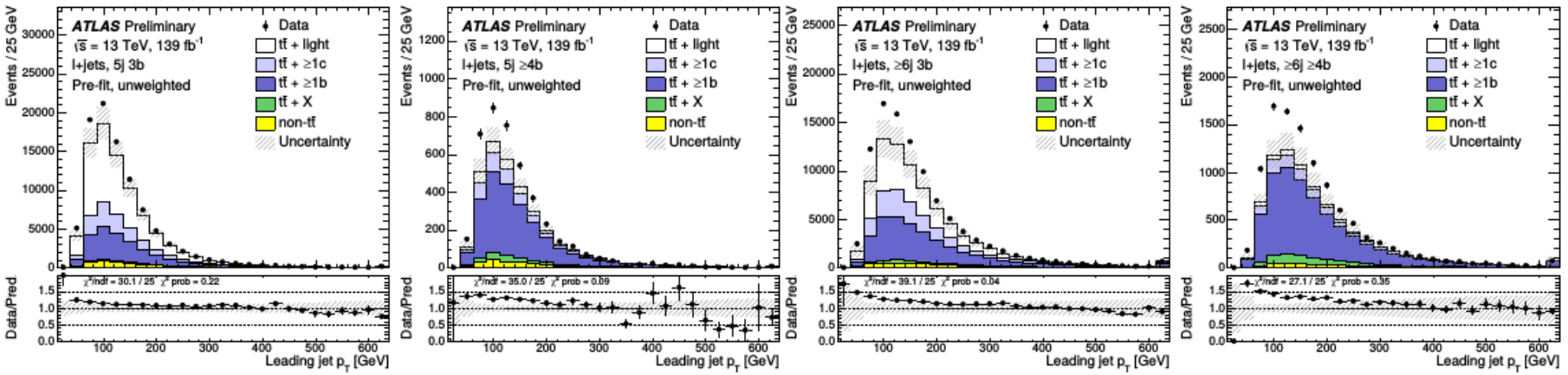
(d) 7j2b



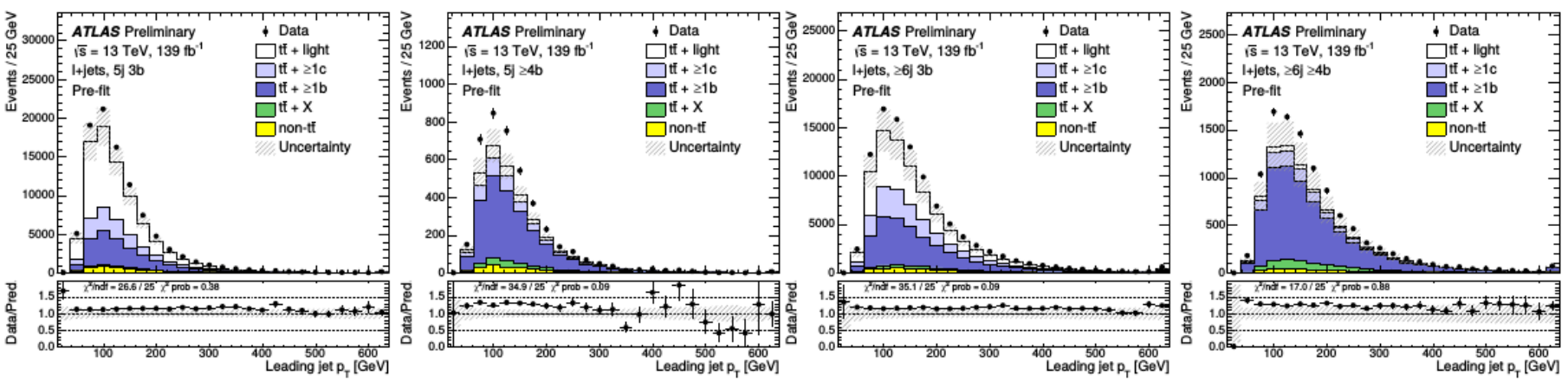
(e) ≥8j2b

$H^+ \rightarrow tb$ – reweighting procedure for top related backgrounds

[ATLAS-CONF-2020-039]



(a) 5j3b, unweighted (b) 5j≥4b, unweighted (c) ≥6j3b, unweighted (d) ≥6j≥4b, unweighted



(e) 5j3b, reweighted (f) 5j≥4b, reweighted (g) ≥6j3b, reweighted (h) ≥6j≥4b, reweighted