Search for top-quark-associated production of heavy scalar or pseudoscalar in pp collisions at 13 TeV

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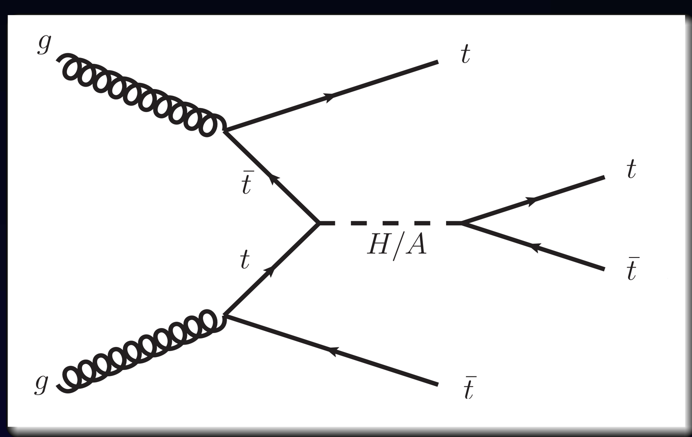
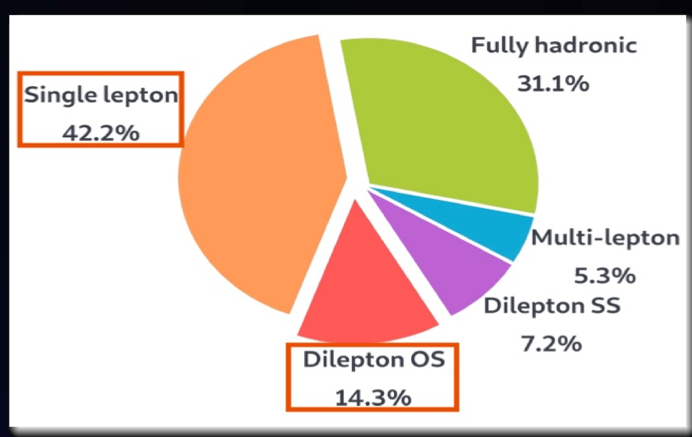
1. MOTIVATION & OBJECTIVES





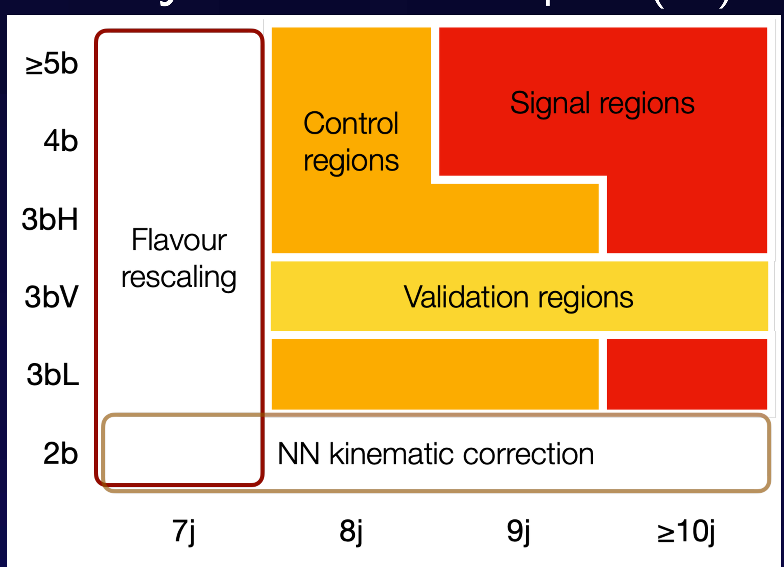
1. Feynaman diagram for production of scalar/pseudoscalar Higgs [1], decay channels for four-top-quarks process

- All plots are available here [1]

- Inconsistencies between theoretical and experimental Standard Model (SM) $t\bar{t}t\bar{t}$ process:
  - Prediction [2] of $t\bar{t}t\bar{t}$ production from the SM : $13.37^{+1.04}_{-1.78}$ fb
  - Measurement [3] of the $t\bar{t}t\bar{t}$ production: $22.5^{+6.6}_{-5.5}$ fb
- Analysis targets:
  - Search for Two-Higgs-Doublet-Model [4] (2HDM) type-II signal
    - Signal: $t\bar{t}H/A \to t\bar{t}t\bar{t}$
  - Interpretation for low $tan\beta$ region in the alignment limit, $sin(\beta - \alpha) \to 1$ where h couplings are similar to the SM Higgs boson and $tan\beta$ is the ratio of the vacuum-expectation-values of the two Higgs doublets.
  - Reinterpretation of results in sgluon Model [5].
    - Signal: $S_8S_8 \to t\bar{t}t\bar{t}$
- Similar search published in multi-lepton channel [6].

2. OBJECT & EVENT PRESELECTION

- **Decay Channel**: one lepton (1L) and di-lepton opposite sign channel (2LOS)



2. Schematic view of event categorisation for 1L [1]

Name	$N_b^{60\%}$	$N_b^{70\%}$	$N_b^{85\%}$
2b	-	= 2	-
3bL	≤ 2	= 3	-
3bH	= 3	= 3	> 3
3bV	= 3	= 3	= 3
≥4b (2LOS)	-	≥ 4	-
4b (1L)	-	= 4	-
≥5b (1L)	-	≥ 5	-

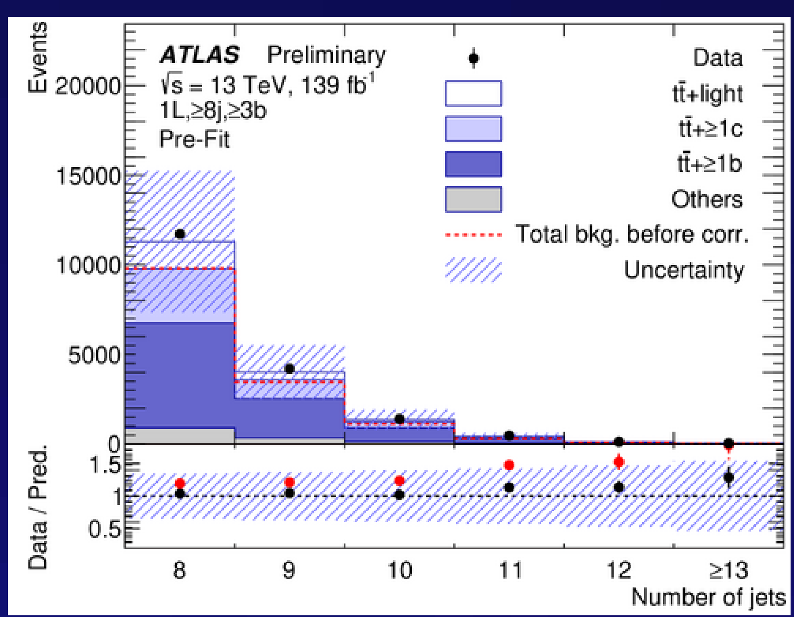
3. Summary of b-tagging requirements [1]

3. BACKGROUNDS PROCESSES

- **Major Background**: $t\bar{t}$+jets ($t\bar{t}+\geq 1b$, $t\bar{t}+\geq 1c$, $t\bar{t}$+light), SM $t\bar{t}t\bar{t}$
- **Minor Background**: $t\bar{t}$H, $t\bar{t}$W,$t\bar{t}$Z, single top quark, V(=W,Z)+jets, (less than 1% - $t\bar{t}t$, $t\bar{t}$WW, $t\bar{t}$WZ, tZ)

- Mismodelling in $t\bar{t}$+jets estimation corrected by data driven factors in two steps:
  - Heavy Flavor (HF) normalisation factors
  - Neural Network (NN)-based kinematic reweighting factors [7]

    $w(\mathbf{x}) = e^{o(\mathbf{x})}$



4. Data/MC comparison before and after data-driven corrections [1]

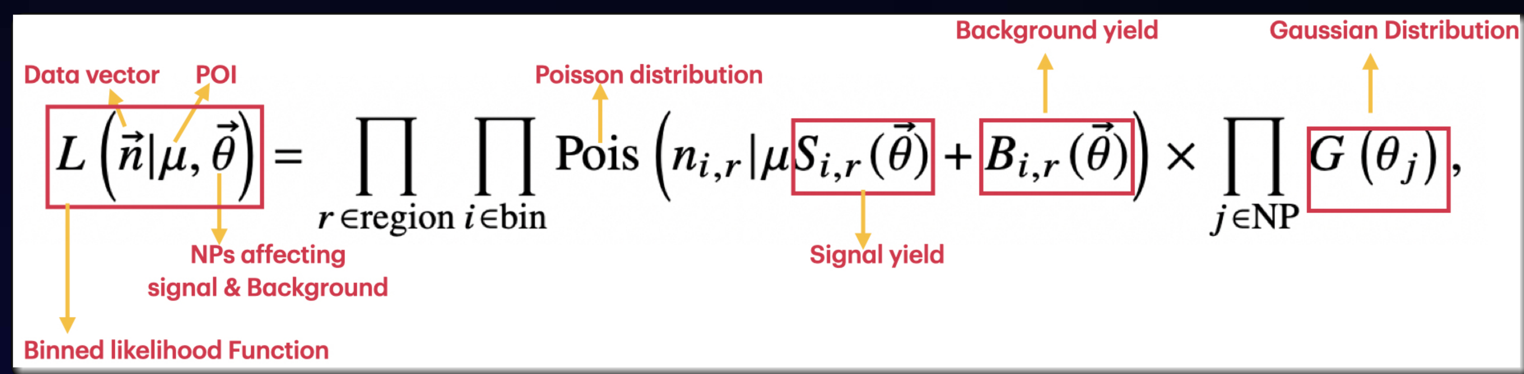
$$o(\mathbf{x}) = P(data|\mathbf{x}) = \frac{\alpha_{data}P_{data}(\mathbf{x})}{\alpha_{data}P_{data}(\mathbf{x}) + \alpha_{MC}P_{MC}(\mathbf{x})}$$

4. SIGNAL-BACKGROUND DISCRIMINATION

- A mass parameterized message passing graph neural network (GNN).
- GNN input variables :

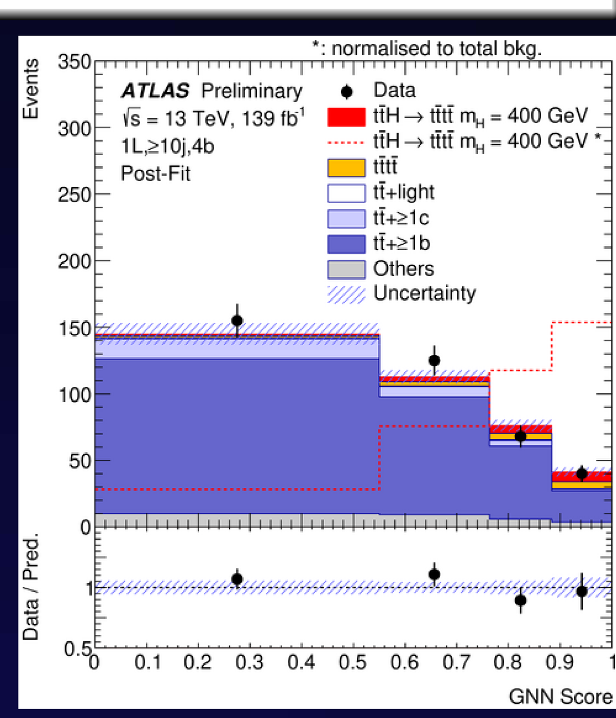
Node	Edge	Global
Object p_T, η, E, b-tagging score, Object type encoding number	$\Delta\eta$, $\Delta\phi$, ΔR between pairs of objects	H_T, m_{ll} for 2LOS and m_T for 1L,, N_{jets}, $NRCjets_{m>100}$, M_{bbb}^{avg}, ΔR_{bb}^{min}, ΔR_{bl}^{min}, $\frac{\sum_i p_{Ti}}{\sum_i E_i}$, Sum of pcb for the first 6 jets $\sum_{i<6} pcb_i$, $\sum d_{12}$, $\sum d_{23}$, $\frac{\sum_{i=0}^{3} p_{Ti}}{\sum_{i\geq 4} p_{Ti}}$

5. STATISTICAL ANALYSIS



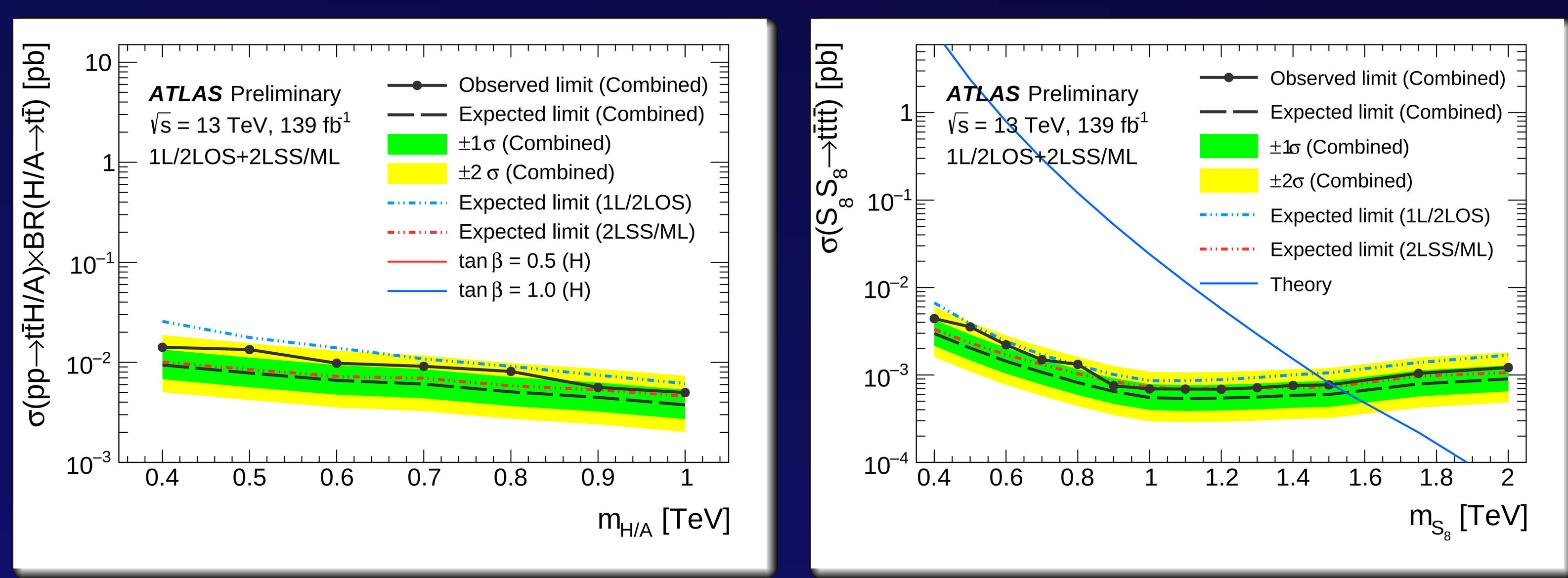
$$L(\vec{n}|\mu,\vec{\theta}) = \prod_{r\in region}\prod_{i\in bin} \text{Pois}\left(n_{i,r}|\mu S_{i,r}(\vec{\theta}) + B_{i,r}(\vec{\theta})\right) \times \prod_{j\in NP} G(\theta_j),$$

- A binned profile likelihood fit performed including all SRs and CRs of both channels.
- $t\bar{t}$ modelling systematic uncertainties dominate the results.
- Jet Energy Scale (JES) and Jet Energy Resolution (JER) have highest contribution from experimental systematics.



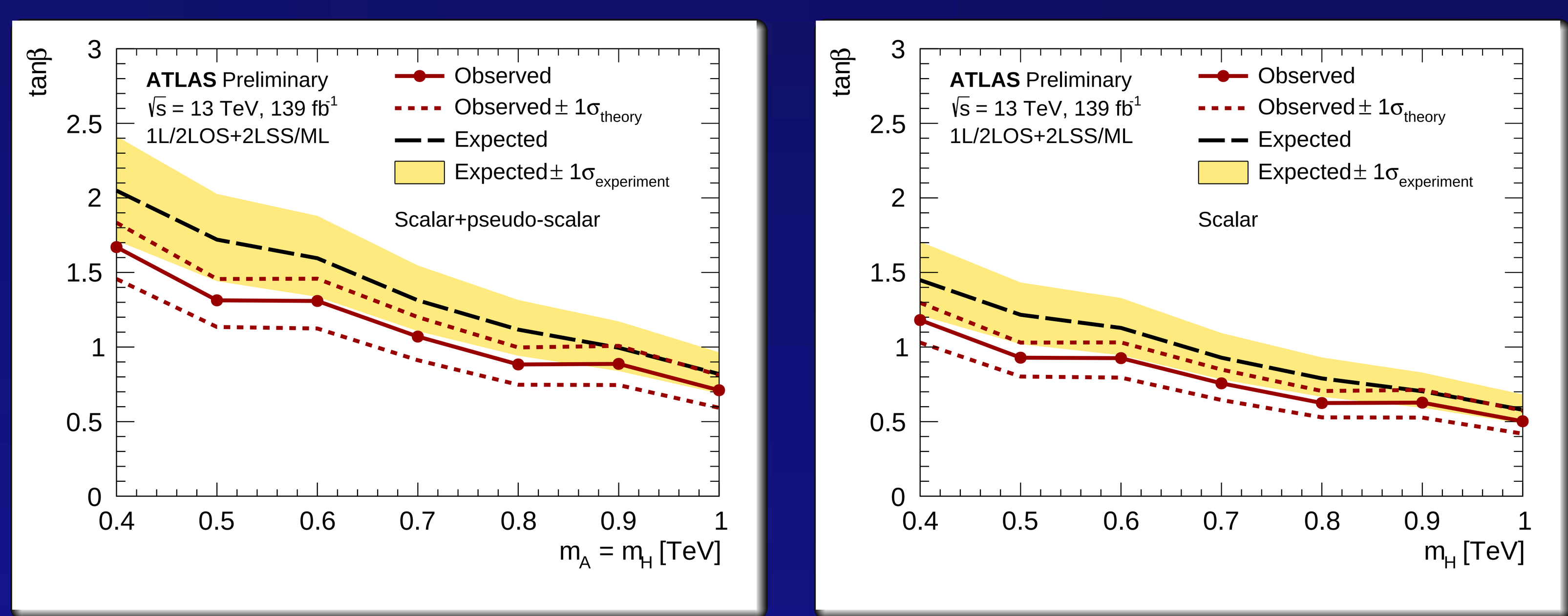
5. Post-fit distribution of the GNN Score [1]

- 95% CL upper limits on the cross section of the production estimated.



6. Expected and observed 95% CL upper limits on the cross-section times branching fraction [1]

- 95% CL lower limits on the values of $tan\beta$ as a function of mass of Higgs.



7. Expected and observed 95% CL lower limits on tanβ as a function of $m_{H/A}$ [1]

6. CONCLUSION

- A search for heavy scalar or pseudoscalar Higgs in $t\bar{t}H/A \to t\bar{t}t\bar{t}$ in 1LOS channel performed. Excluded $tan\beta$ values at 0.4(1.0) TeV below
  - 1.7(0.7) when scalar and pseudoscalar both contribute
  - 1.2(0.5) when scalar or pseudoscalar contribute
- Reinterpretation of results in the context of sgluon model
  - Mass signals $m_{s_8} < 1500$ GeV excluded.

REFERENCES

[1] ATLAS collaboration. (2024). ATLAS-CONF-2024-002.

[2] M. van Beekveld et al. (2022). arXiv: 2212.03259.

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[5] L. Darmé et al. *JHEP* 09 (2021).

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