Measuring the top Higgs couplings CP-nature in ttH(H→bb) dilepton events

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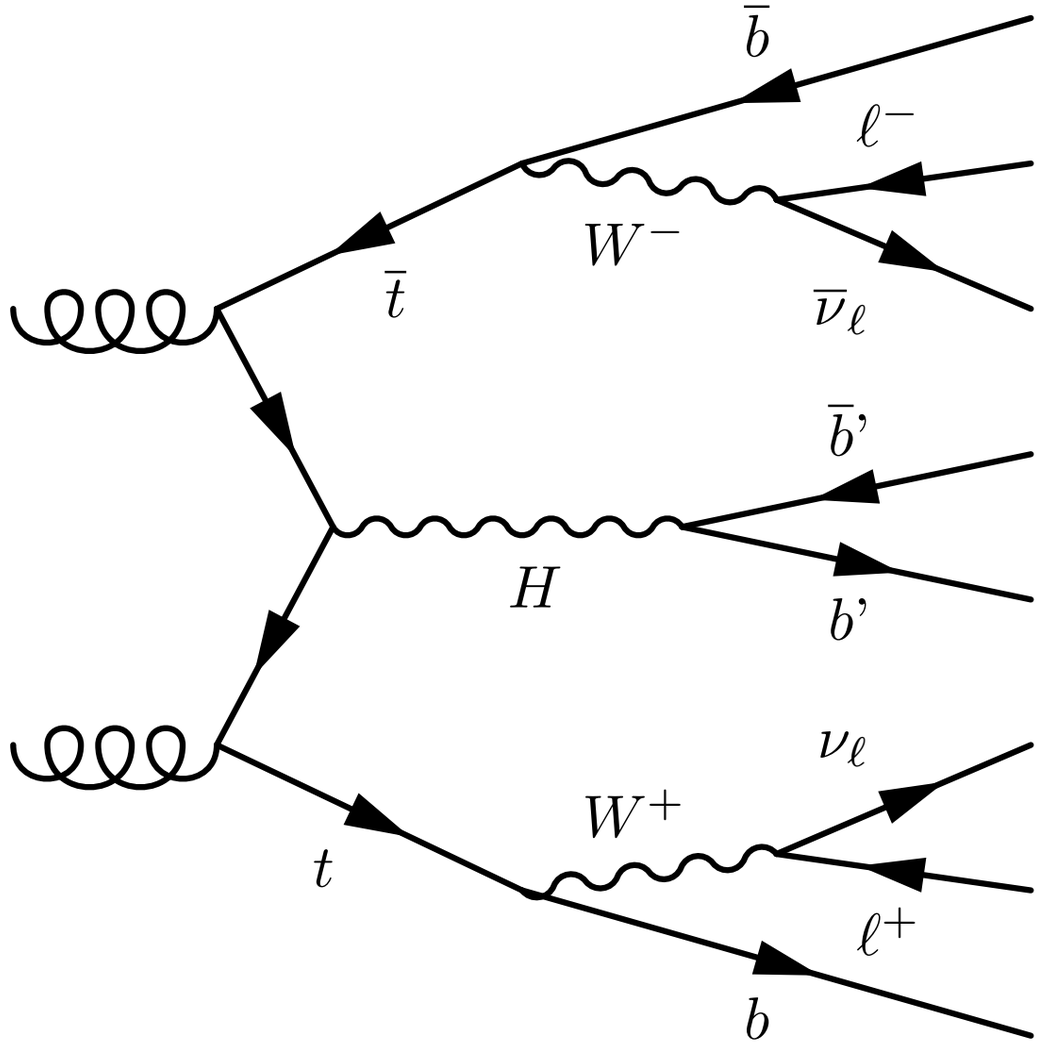
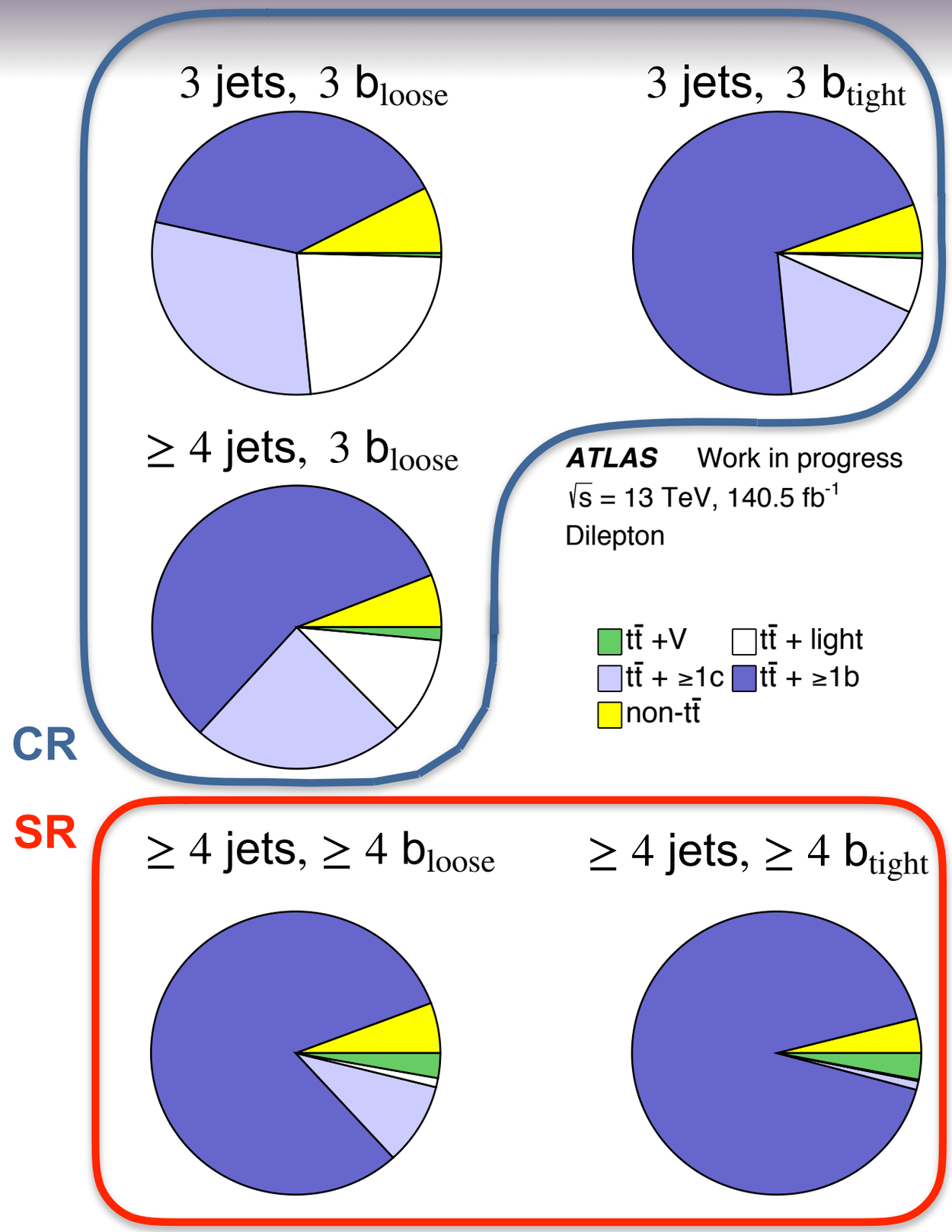
Motivation

- **ttH in Atlas**
  - ttH(bb) Paper: *Phys. Rev. D. 97 (2018) 072016*
  - ttH observation: *Phys. Lett. B 784 (2018) 173*
- **Following discovery, what is next for ttH?**
  - More precise signal strength measurement with full Run 2 data
  - Directly test the top Yukawa coupling (y_t) and its CP-structure



SM analysis outline

- **ttH(bb) analysis channels:**
  - All hadronic
  - lepton+jets
  - dilepton
- **Different Control (CR) and Signal (SR) regions**
  - **CR**: Constrain different background contributions
  - **SR**: Extract ttH signal
  - Regions defined on:
    - number of jets
    - numbers of b-tagged jets

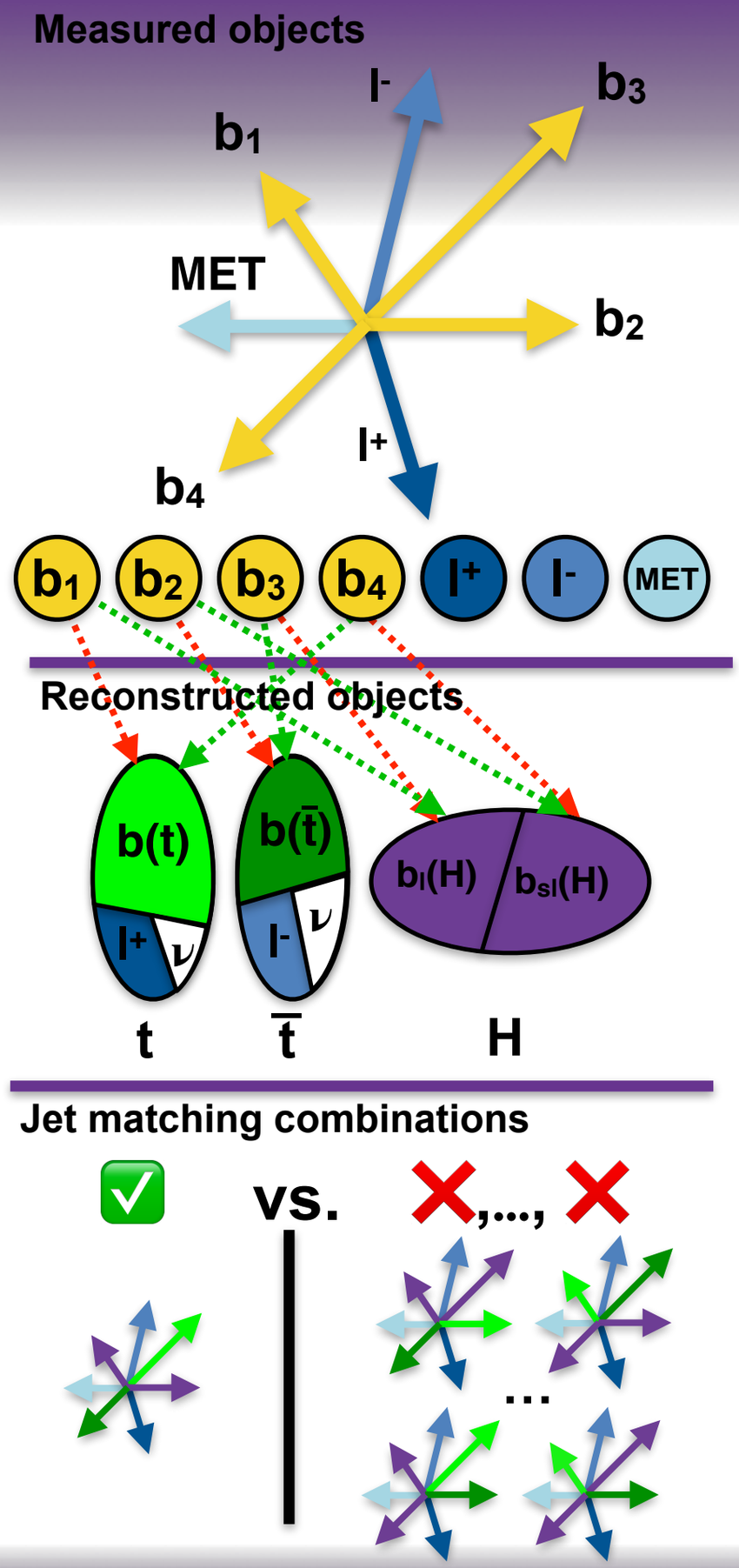


Higgs reconstruction

- **Higgs kinematics:**
  - improve signal-background separation, need to reconstruct Higgs.

- **Measured objects:**
  - 4 b-jets, 2 leptons and MET

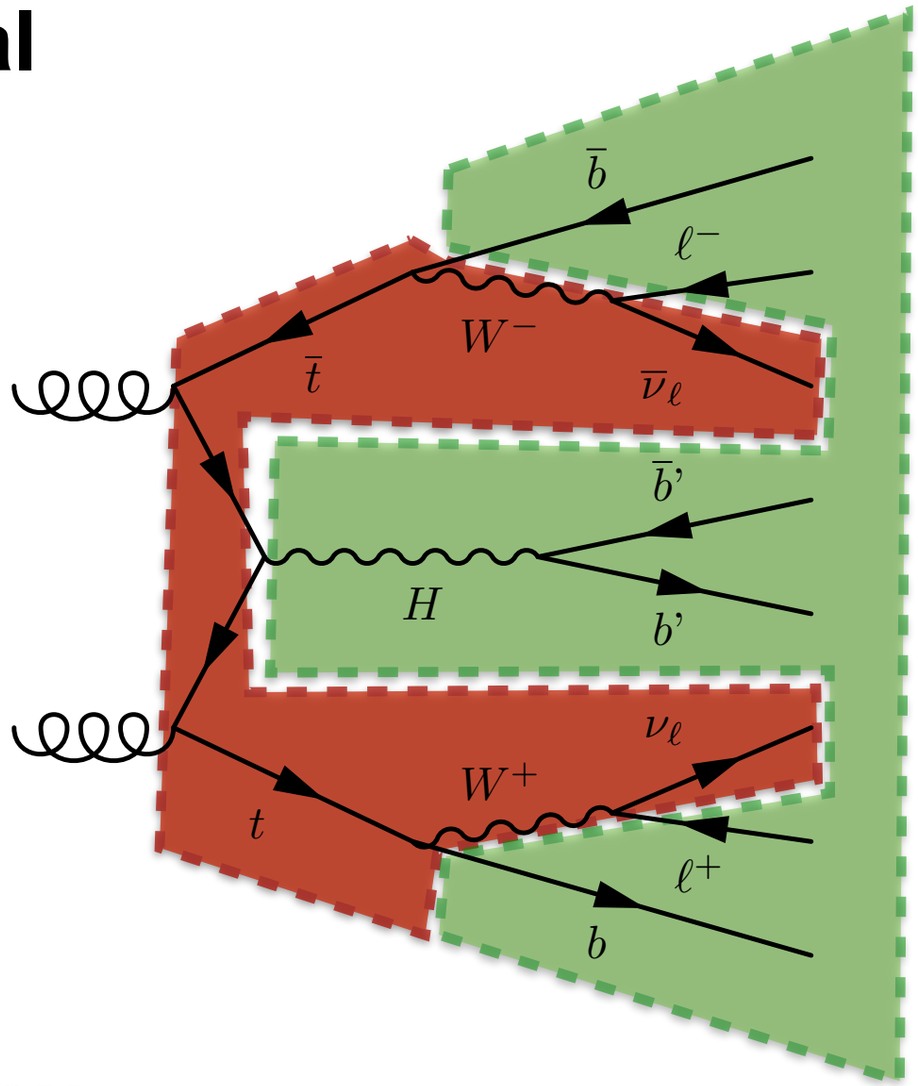
- **Reconstructed objects:**
  - $H = b_i + b_j$
  - $t\bar{t} = b_{k/m} + \bar{l}/l$ (+ $MET_{1/2}$) *with i,j,k,m=1…4*
- **Jet assignments:**
  - Assign a jet to all 4 b's (b from t, b from $\bar{t}$, leading b_l, sub-leading b_{sl} from H)
  - Train ***"Reco-BDT"*** with correct matched events vs. all wrong matched possibilities



Top reconstruction — Neutrino weighting

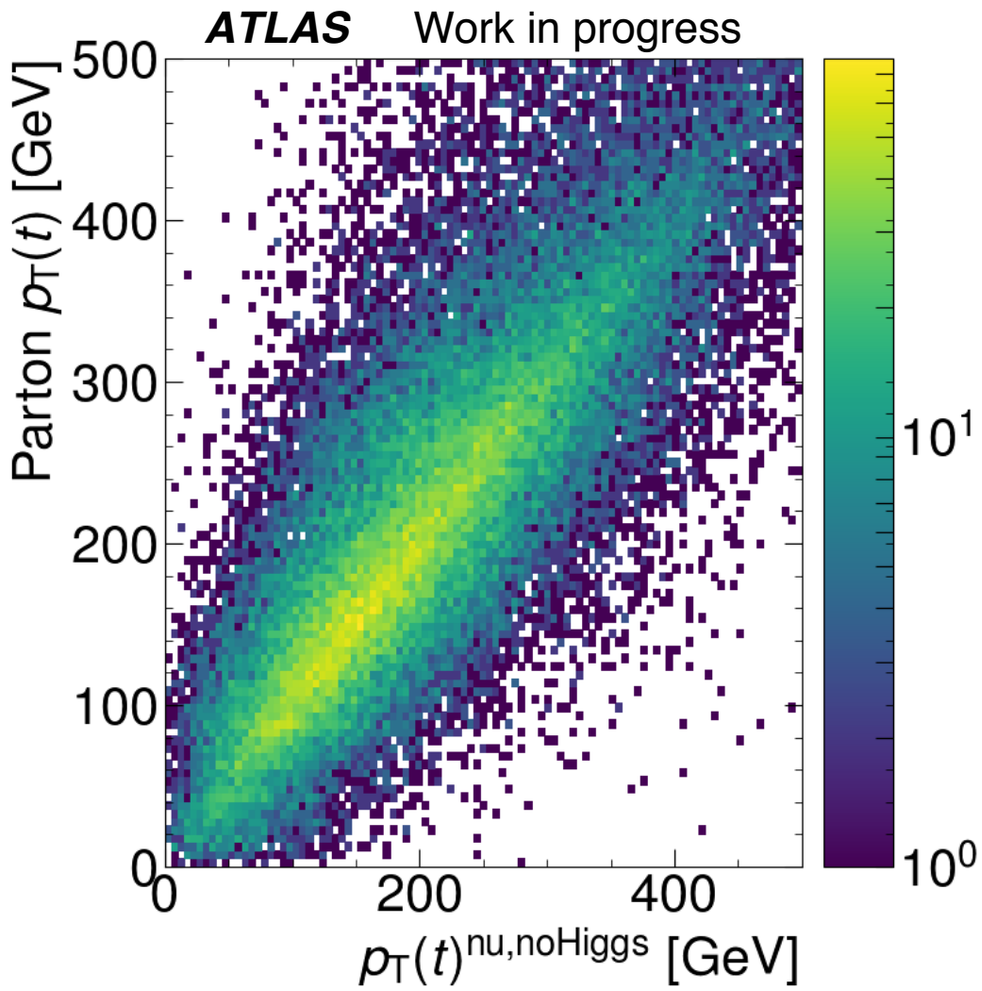
- **$t\bar{t}$ kinematics improve selection and sensitive to y_t CP.**
- **2 neutrinos in final state, need special reconstruction:**
  - Constraints from: m_{top}, m_W
  - Sampling on $\eta(\nu/\bar{\nu})$
- **In $t\bar{t}$: ν-weighting has been successfully used:** https://arxiv.org/abs/1612.05220
- **In ttH:**
  - Challenging due to high-multiplicity final state

➡ **never before used in such a complex system**



Performance of neutrino weighting in ttH

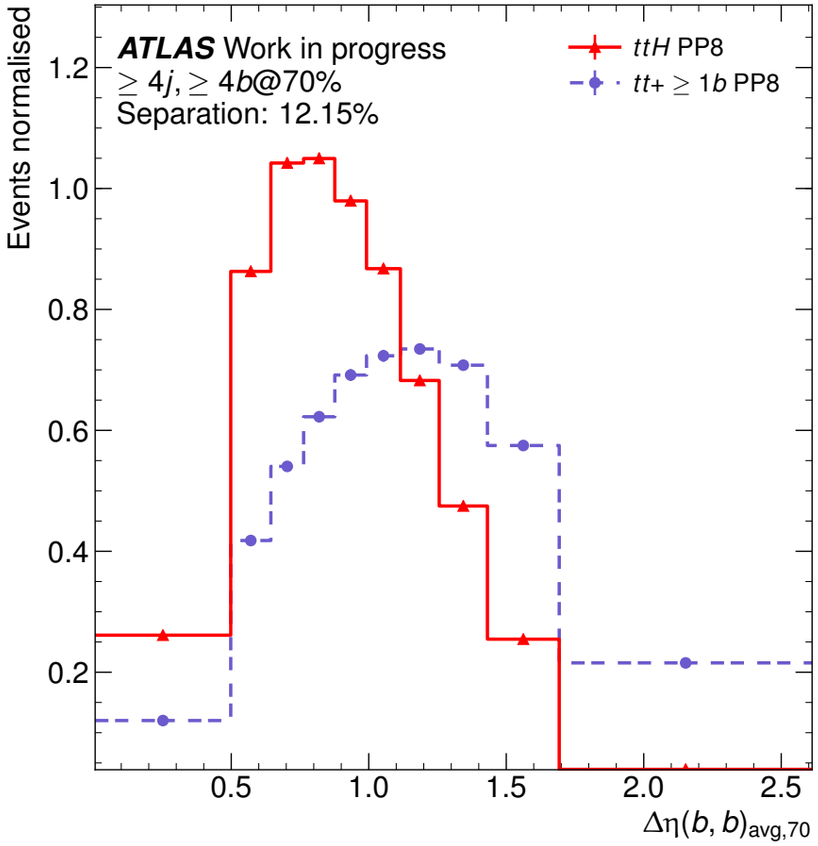
- **$t\bar{t}$-system reconstructed for each jet-combination:**
  - Reconstructed $p_T(t)$ has high agreement with truth $p_T(t)$

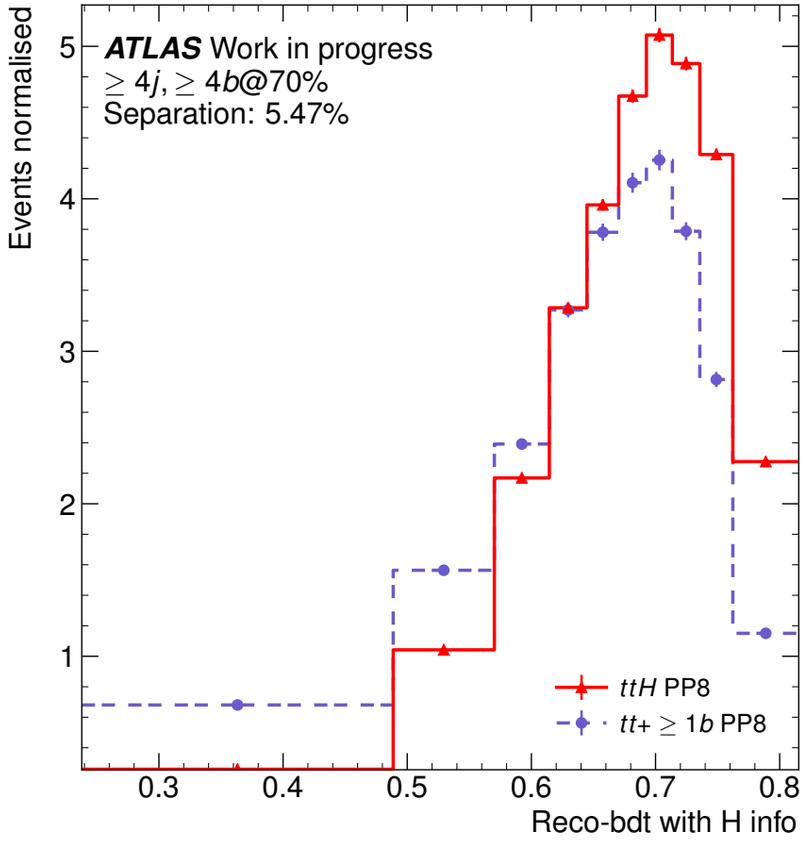


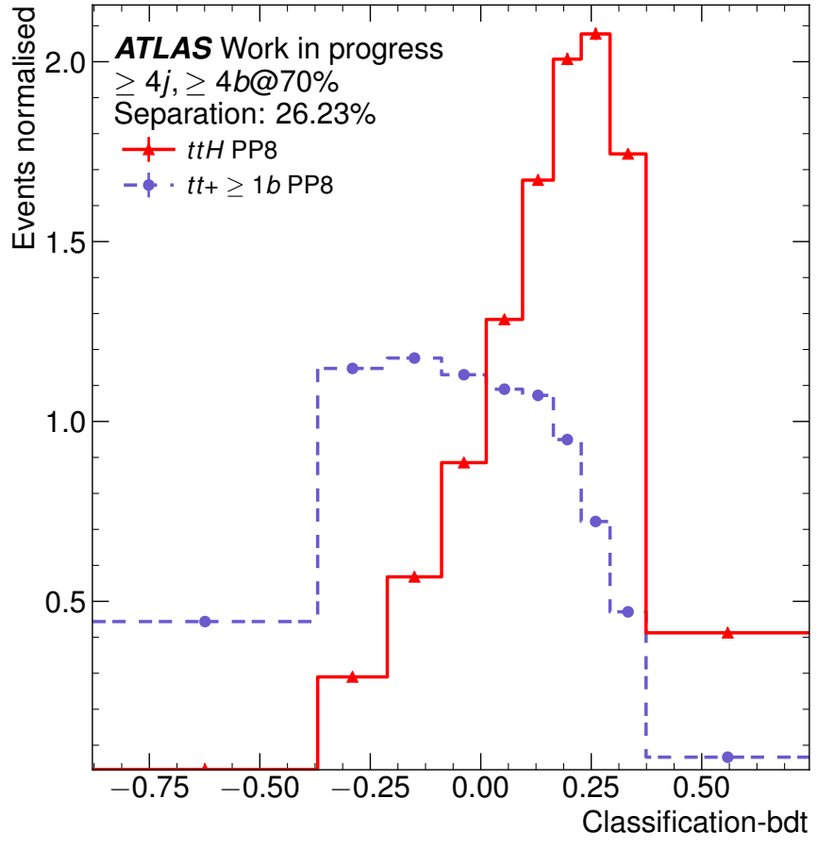
- **Jet matching efficiency for all Jets matched to the correct object:**
  - $\varepsilon_{random}(all) \cong 6\%$
  - $\varepsilon_{no\text{-}higgs,info}(all)=25.8\%$
  - $\varepsilon_{no\text{-}higgs,info+v\text{-}weighting}(all)=27.0\%$
  - $\varepsilon_{higgs,info}(all)=38.0\%$
  - $\varepsilon_{higgs,info+v\text{-}weighting}(all)=39.0\%$

Extracting ttH signal from $t\bar{t}$+b and other backgrounds

- **Many observables show separation between ttH and tt+≥1b events**
- **Combined into "*Classification BDT*"**

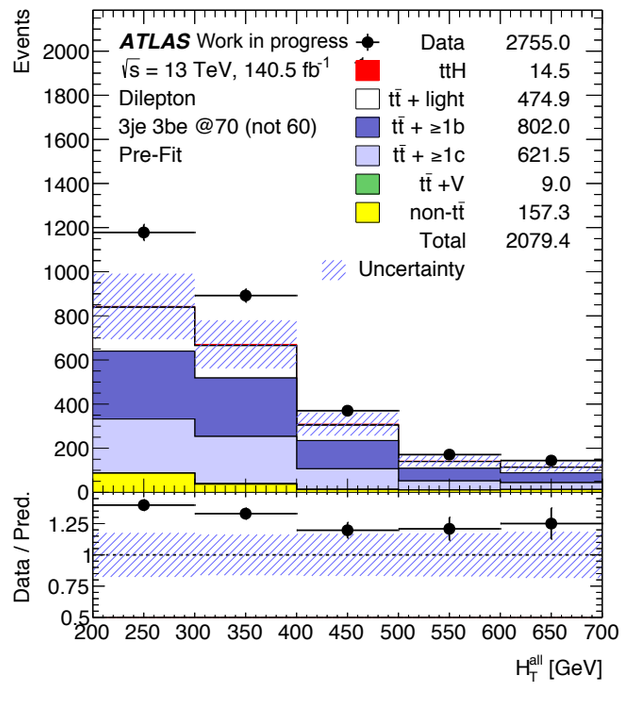


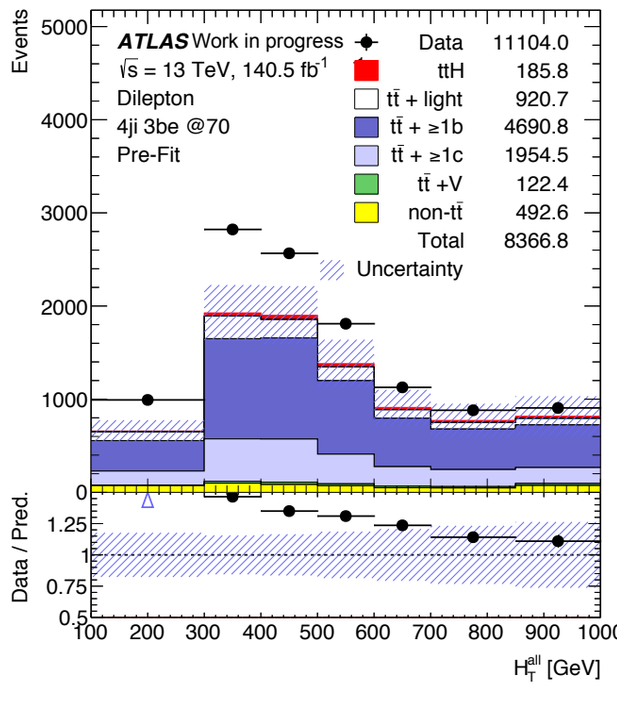




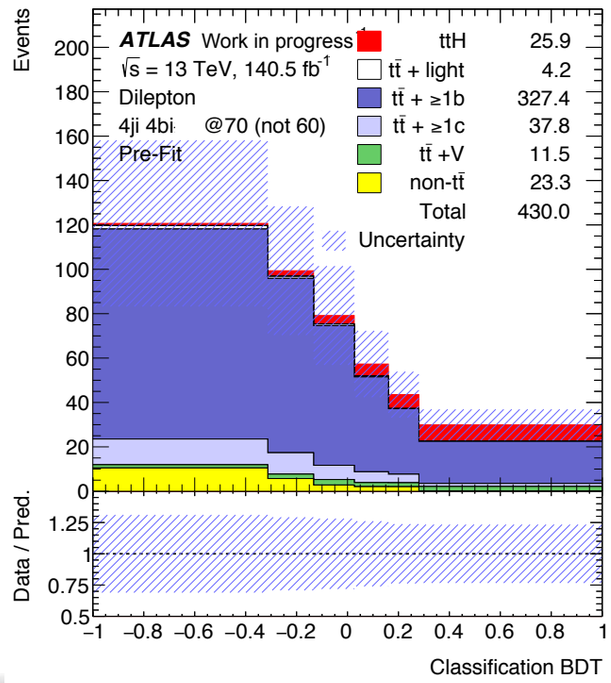
ttH fit inputs

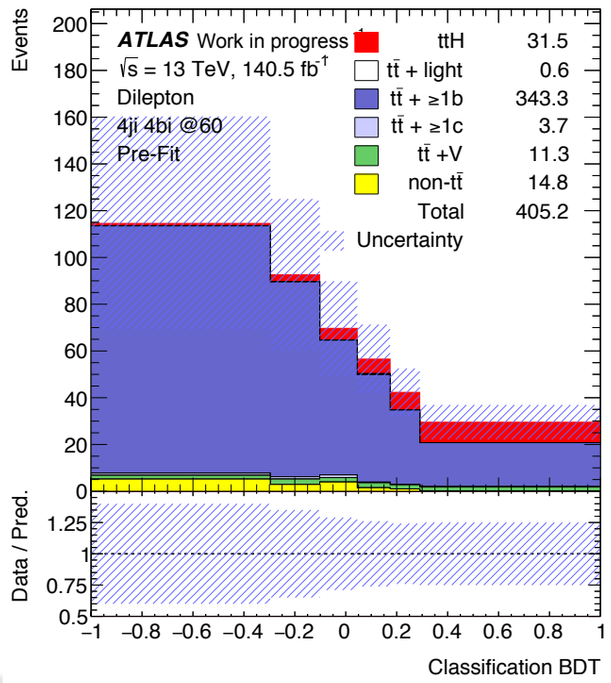
- **CR:** $H_T^{all} = \sum_{jets,leptons} |p_T|$
  - Constrain different background contributions





- **SR: Classification BDT**
  - High S/B ratio to improve sensitivity





ttH(bb) CP analysis overview

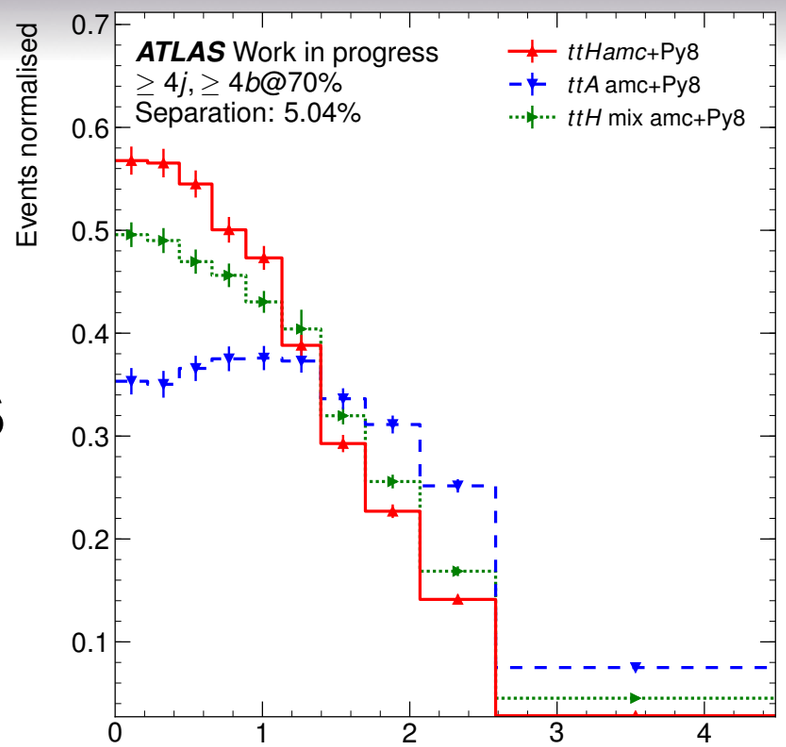
- **y_t expected to be CP-even in SM**
- **CP-odd or CP-mixed coupling scenarios vastly discussed in theory:**

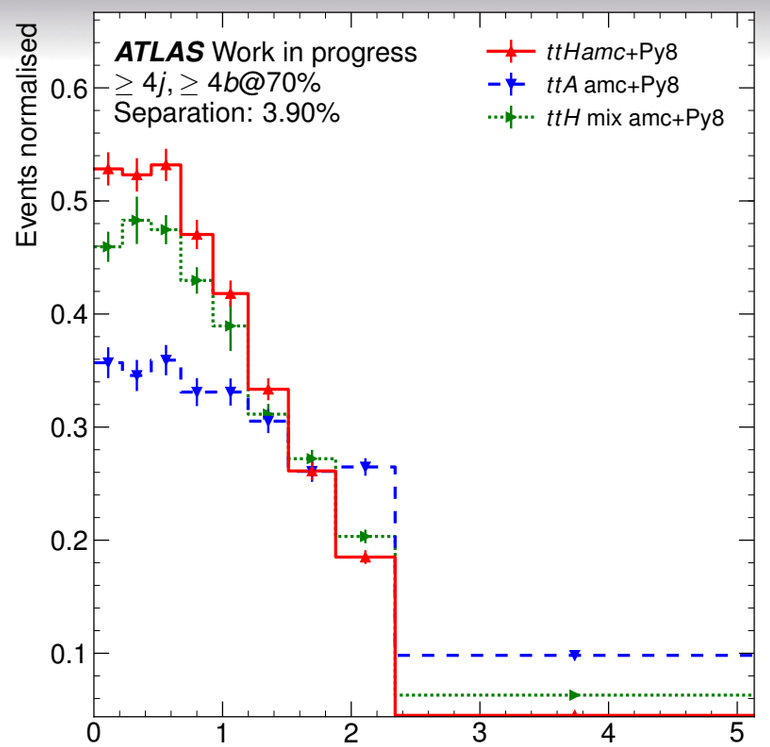
$$\mathcal{L}_{ttH} = y_t \kappa \bar{t}(\cos\alpha + i \sin\alpha\gamma_5)th$$

- **Testing different signal hypothesis:**
  - ttH: cos α=0, CP-even
  - ttA: cos α=1, CP-Odd
- **ttH(bb) CP analysis channels:**
  - lepton+jets
  - dilepton

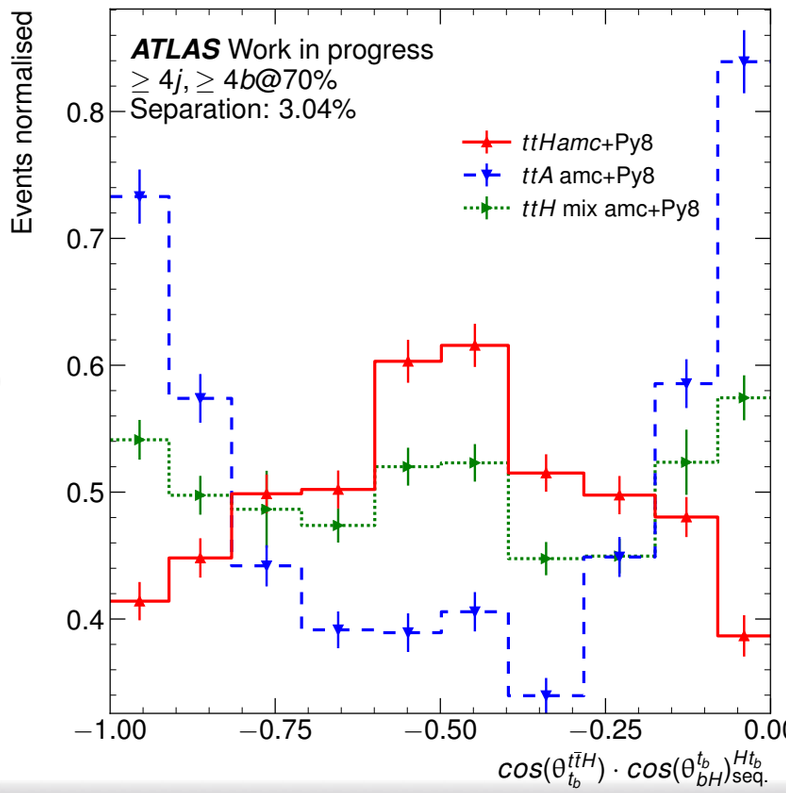
CP sensitive observables

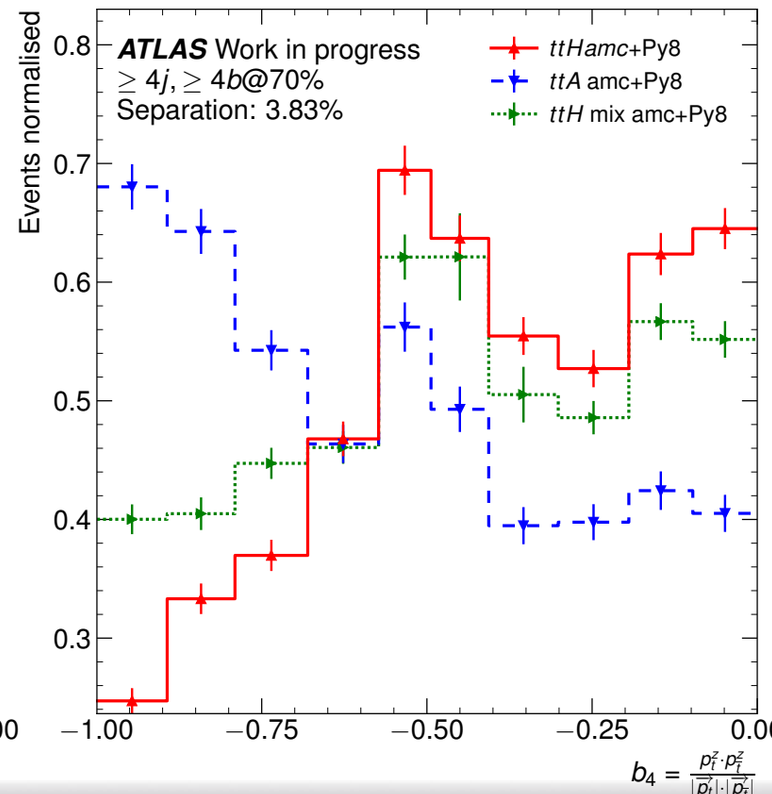
- **“Simple” kinematics**





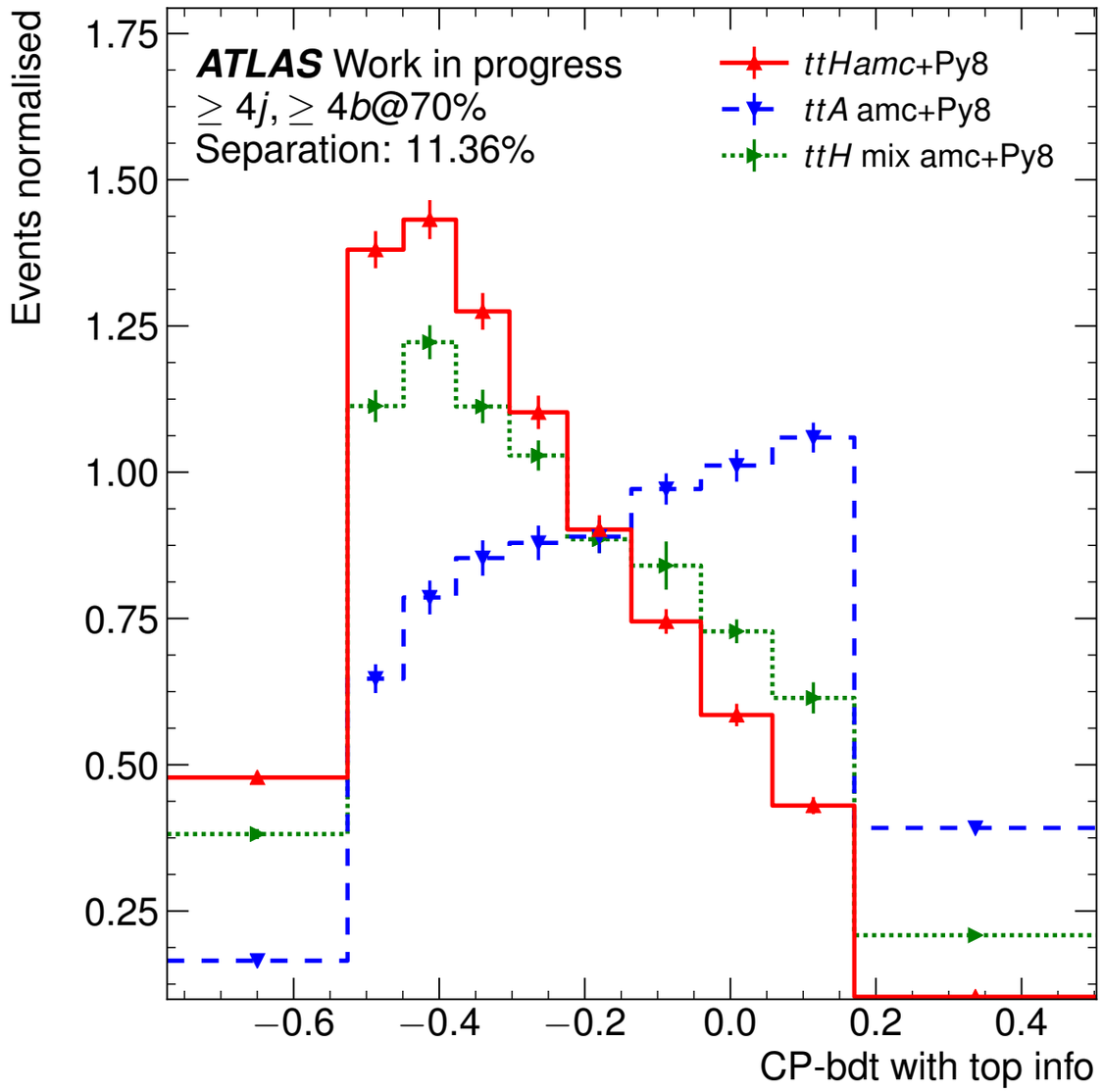
- **More complex angular observables**



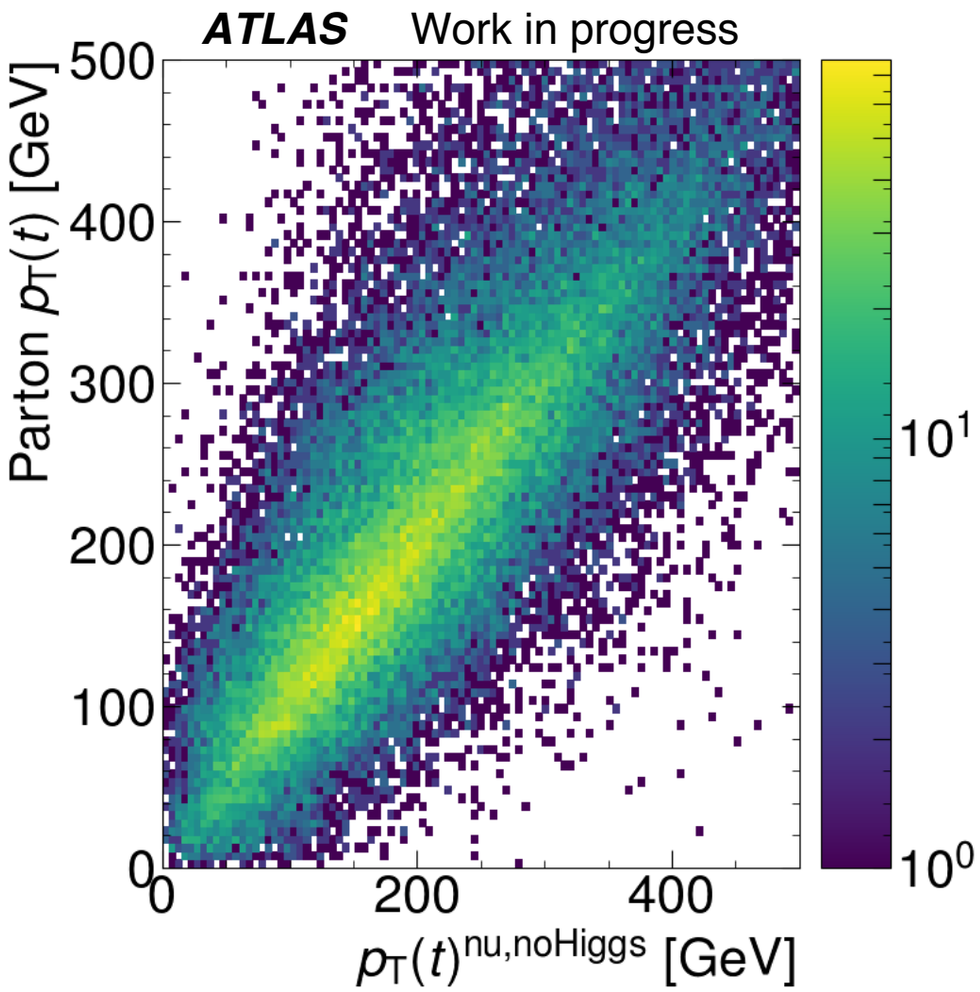


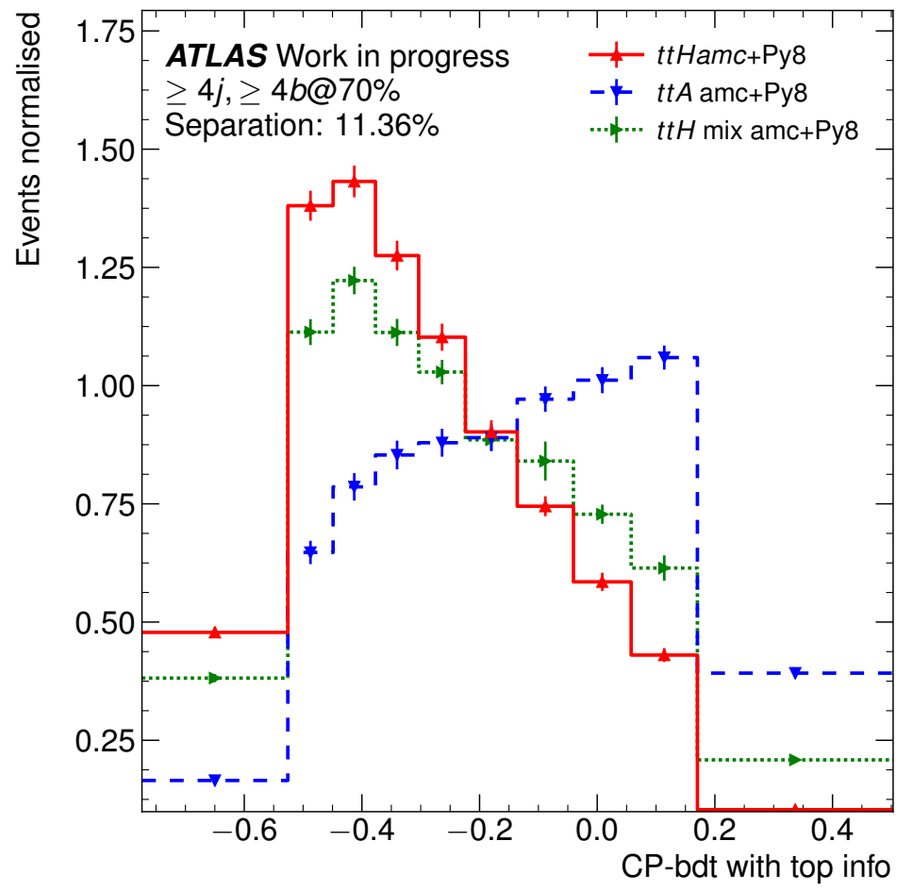
ttH CP signal extraction

- **Separation between different CP scenarios with “*CP-BDT*”**
- **Final fit inputs:**
  - CR: H_T^{all}
  - SR split in regions of classification BDT:
    - Bins with high S/B ratio to **extract signal**
    - CP-BDT: discriminating different CP samples



Summary





- We will use new techniques to measure the CP-nature of y_t for the first time in $t\bar{t}H$ events!