Search for production of a Higgs boson and a single top quark in multilepton final states at 13 TeV

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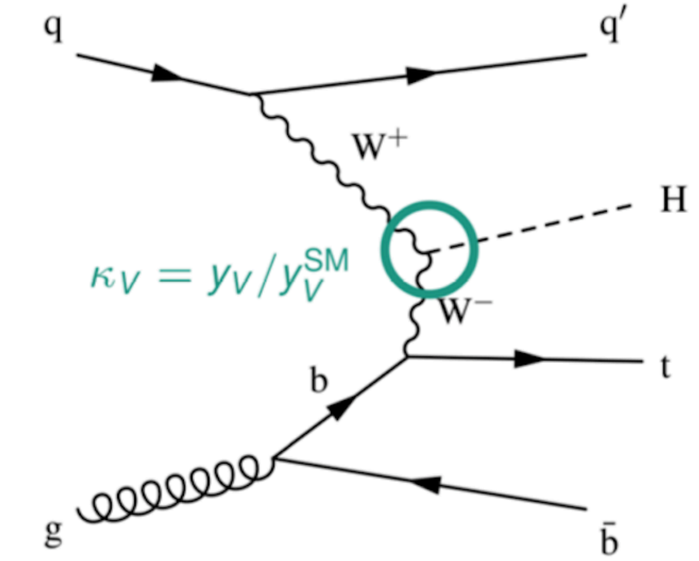
Introduction

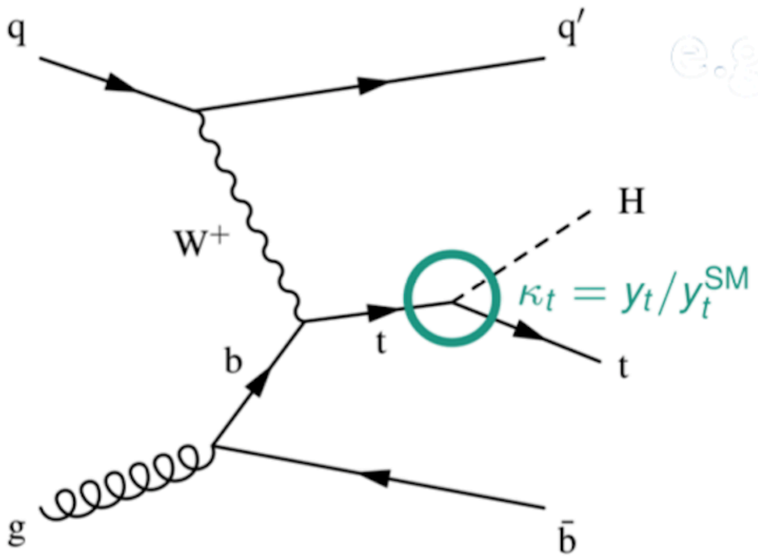
- Current luminosity and centre-of-mass energy at LHC motivate the search for rare SM single top-quark processes, such as the production of a single top quark in association with a Higgs boson (tHq)
- Challenging process

$$\sigma(tHq) \approx 74\ fb$$ arXiv:1610.07922

$\sigma(tH)$ is 7 times smaller than $\sigma(ttH)$

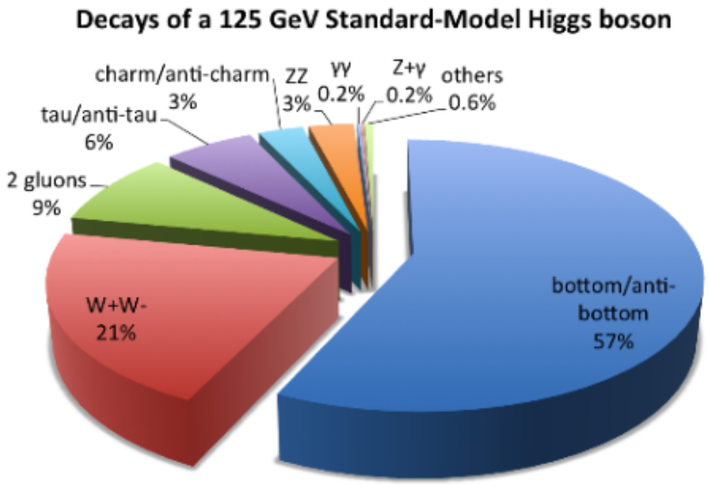
- A deviation from the SM prediction could be an indication of new physics.
- Test the SM accuracy and presence the new physics
- Final state: Higgs boson + top quark + forward light jet + b-jet.



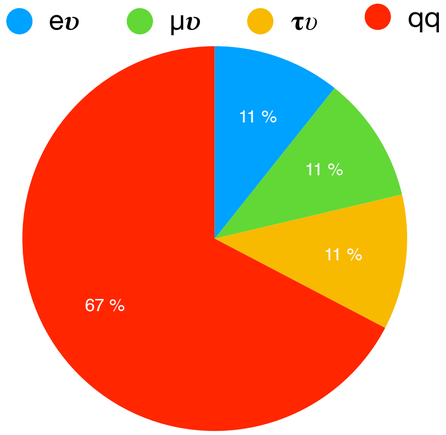


Introduction

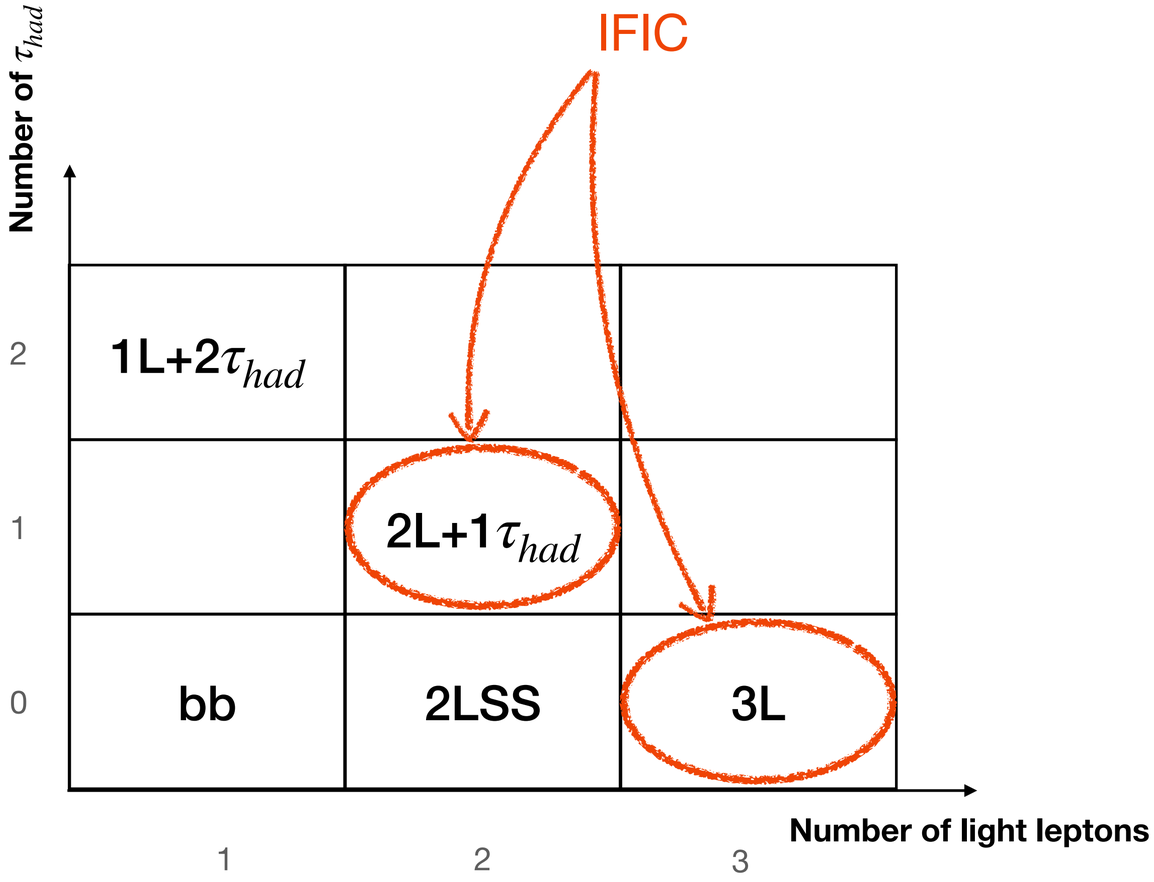
- Higgs decay channels:



- Top decay channels:
  - t -> Wb



- Channels split according to multiplicity of final state leptons



- Channels considered:
  - H -> bb
  - H -> WW*/ZZ* (multilepton)
  - H -> $\tau\tau$ (τ_{had} or τ_{lep})

Motivations

- tHq vertex is sensitive to the magnitude and the sign of Higgs-top-Yukawa coupling (y_t)

- Standard Model: $y_t = 1 \rightarrow \sigma_{SM}(tH) \approx 74\ fb$

- Inverted coupling: $y_t = -1 \rightarrow \sigma(tH) \approx 10 \times \sigma_{SM}(tH)$

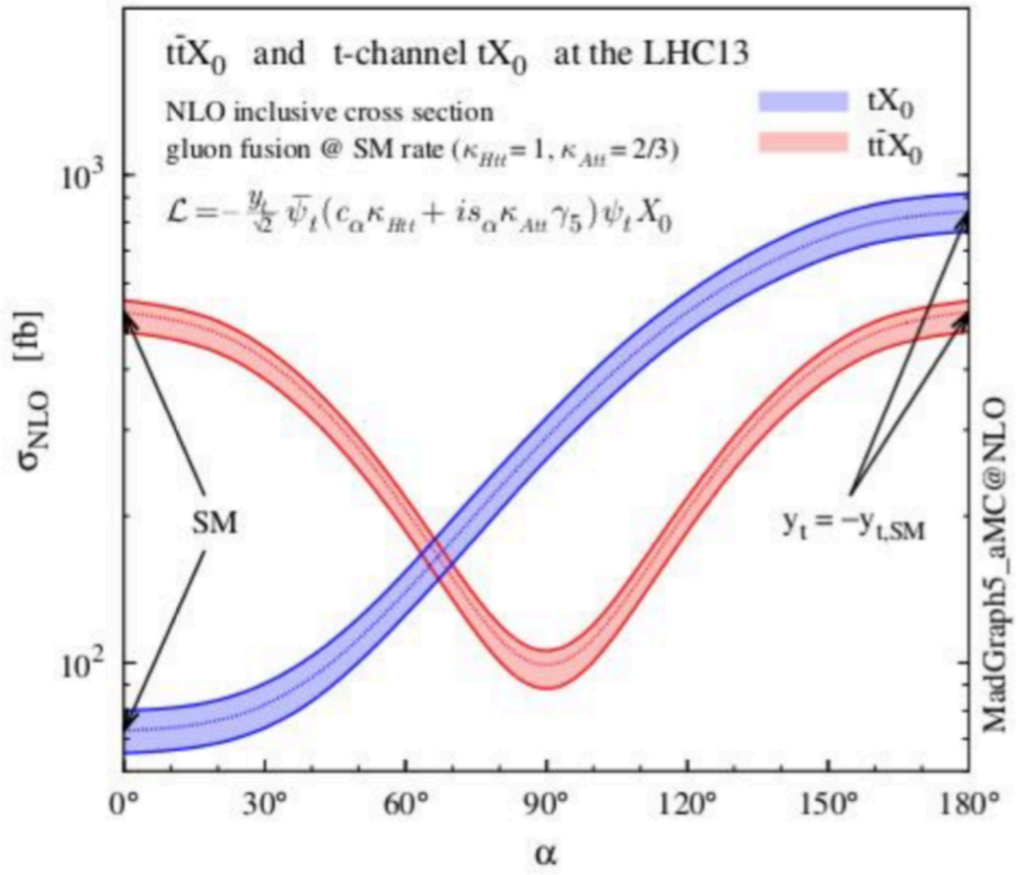
  - Current limit CMS-PAS-HIG-19-008:

    -0.7 < y_t < -0.9 or 0.7 < y_t < 1.1 (@ 95 % CL)

- ATLAS goals at $139\ fb^{-1}$:

  - Search for production of tHq process:

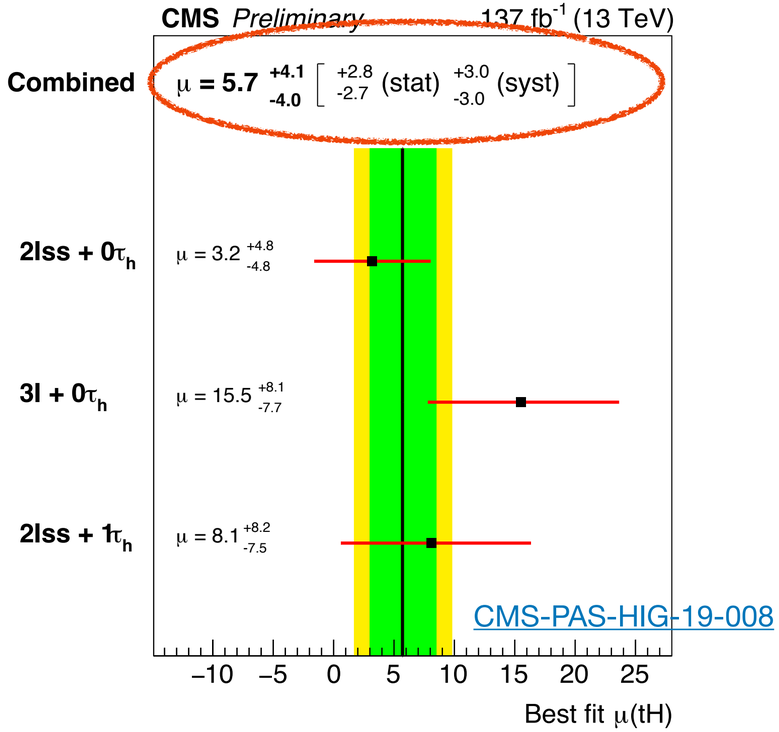
    - Improve current cross-section production limit (μ_{tH})
    - *Possible: Exclusion of inverted hypothesis* $y_t = -1$



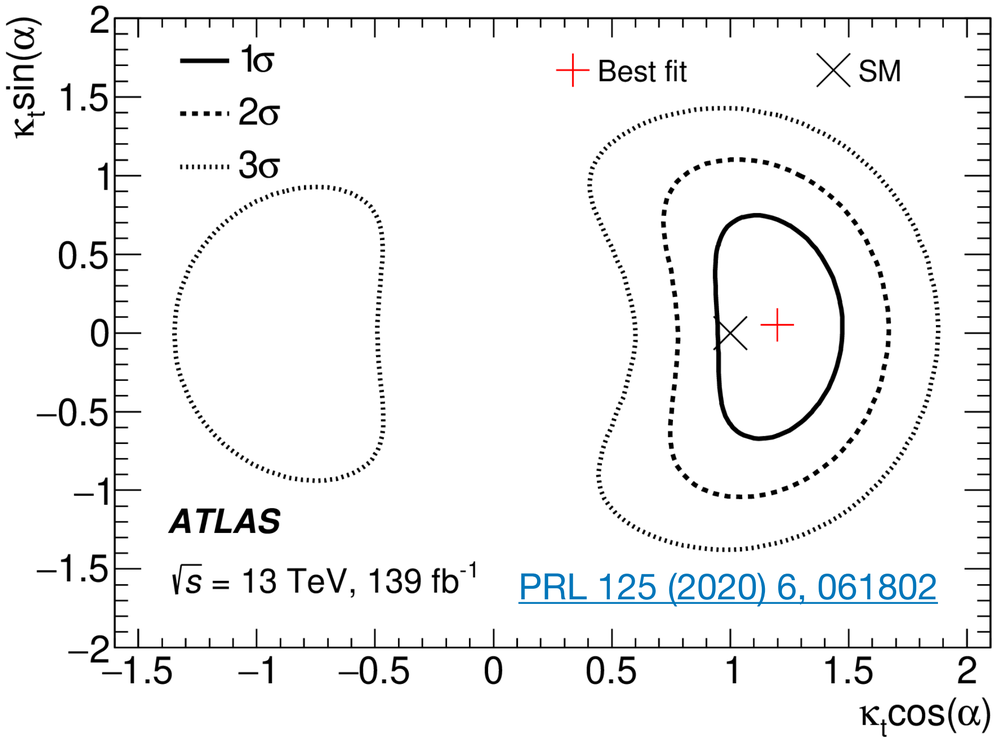
[1] arXiv:1504.00611

Benchmarks

- Latest results from CMS:
  - ttH / tH multilepton ($137\ fb^{-1}$) CMS-PAS-HIG-19-008
    - $-0.7 < y_t < -0.9$ or $0.7 < y_t < 1.1$ (@ 95 % CL)
  - tH ($36\ fb^{-1}$) CMS PAS HIG-18-009:
    - $\sigma(tH) < 14 \times \sigma_{SM}(tH)$ (@ 95% CL)

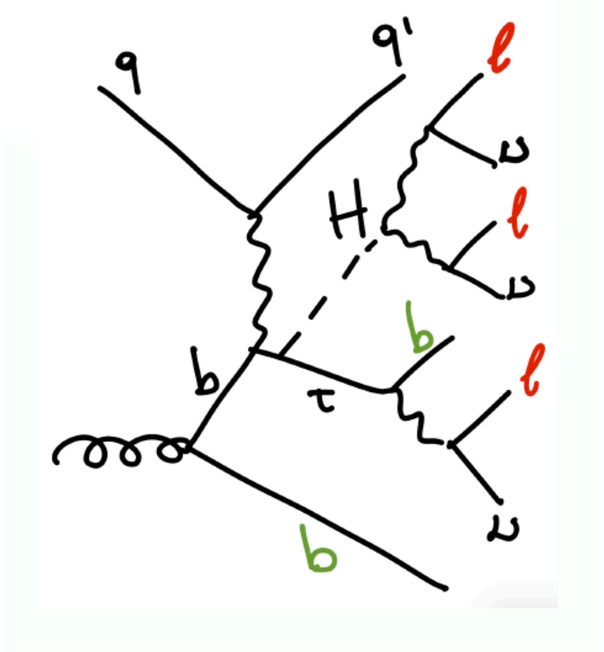


- Latest results from ATLAS
  - H -> $\gamma\gamma$ ($139\ fb^{-1}$) ATLAS-CONF-2020-026
    - $\sigma(tH) < 8 \times \sigma_{SM}(tH)$ (@ 95% CL)
  - ttH/ tH ($139\ fb^{-1}$) PRL 125 (2020) 6, 061802
    - $\sigma(tH) < 12 \times \sigma_{SM}(tH)$ (@ 95% CL)



- The tHq process has not yet been observed and only the upper limits are set

3L channel

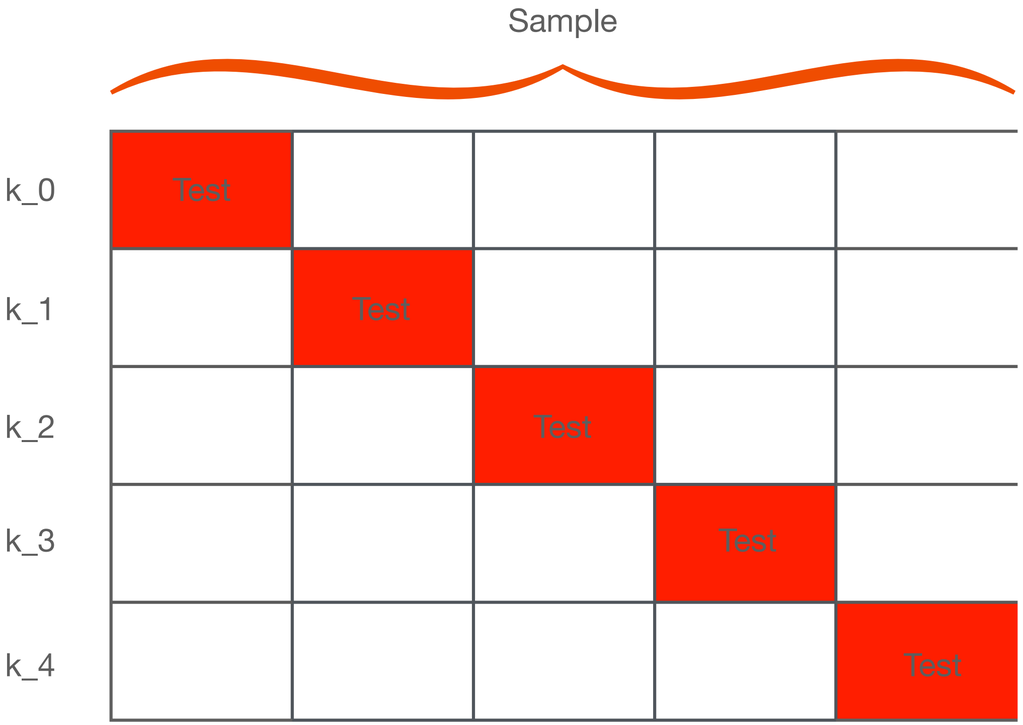


- Preselection (topology based):
  - Exactly 3 light lepton (e / μ) and 0 τ_{had}
    - Ordered by pt: pt > 27/20/10 GeV
  - Total lepton charge = ± 1
  - Number of jets = 0 - 6
    - Jet pt: pt > 20 GeV
  - Number of Bjets = 0 - 4

- Analysis strategy:
  - Study event signature (reconstruction information) to discriminate signal from SM background
  - Explore advance MVA techniques:
    - K-folding (cross-validation / increase statistic)
    - BDT from XGBoost package employed
    - Define features for BDT
    - Study the impact of negative weights
    - Optimize features and hyperparameters
    - Define several BDT for different processes
  - Define signal, control and validation regions
  - Lepton fake studies
    - Probing variables which are discriminant on the origin of misidentify leptons
  - Fit strategy

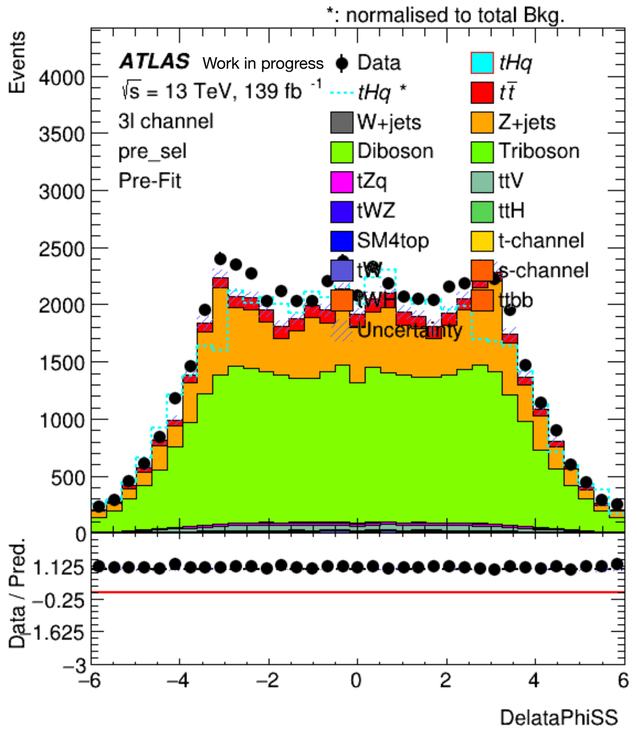
3L channel

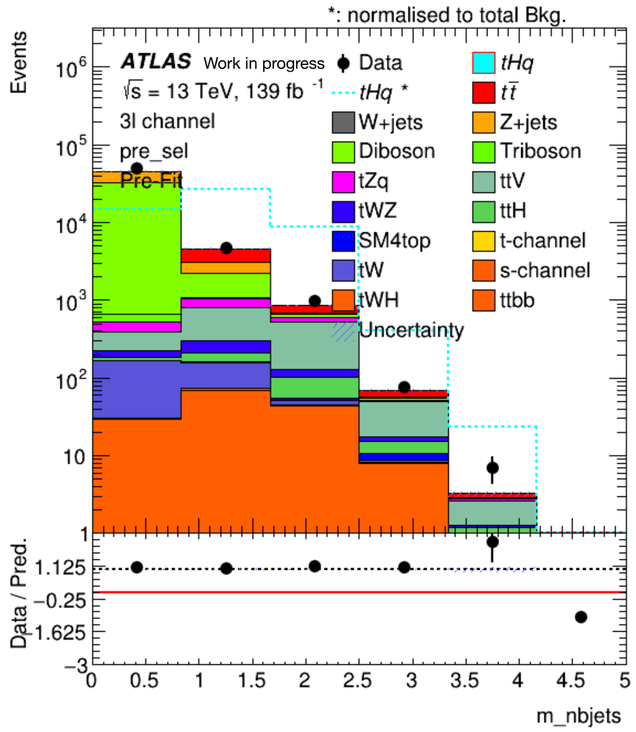
- K folding:
  - Shuffle the events randomly
  - Split the sample in k groups
  - Use 1 group for testing and the others for training the BDT
  - Retain the predictions and discard the model



- Features for BDT
  - Explore the most discriminant variables:
    - At this moment, 37 variables as input for the BDT

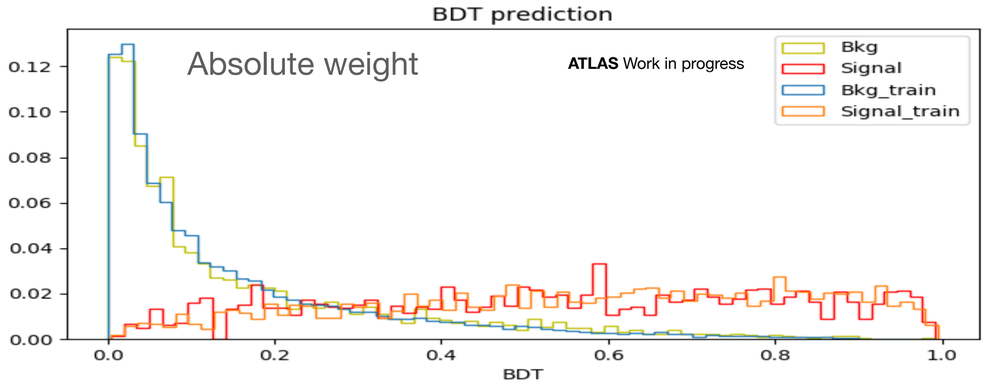
Preselection region

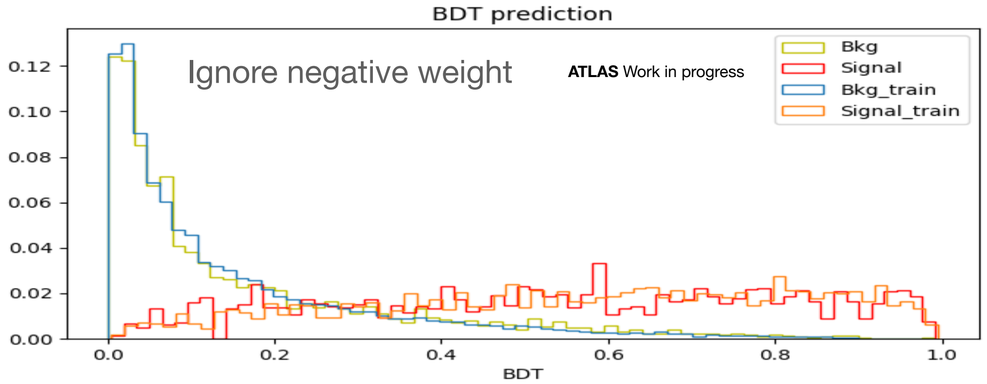




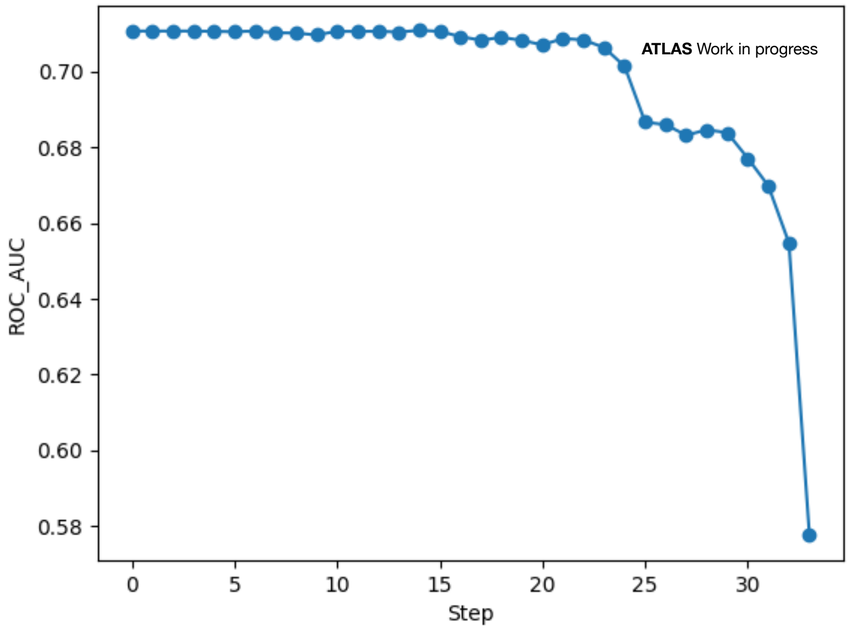
3L channel

- Study the impact of negative weights :
  - 35% of negative weight in the signal sample (NLO)
  - Study several approaches
  - Negligible performance differences

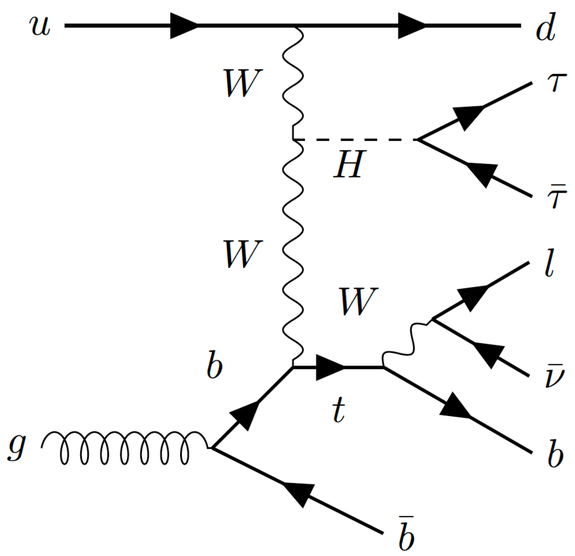




- Features optimization
  - Rank the features for the BDT
  - Remove the last feature and restart the BDT
  - Several skills could be measured to check the goodness of the performance



2L+1τ_{had} channel



- Preselection:
  - Exactly 2 light leptons (e / μ) and 1τ_{had}
  - Absolute value of total charge $< \pm 1$
  - Number of jets = 0 - 6

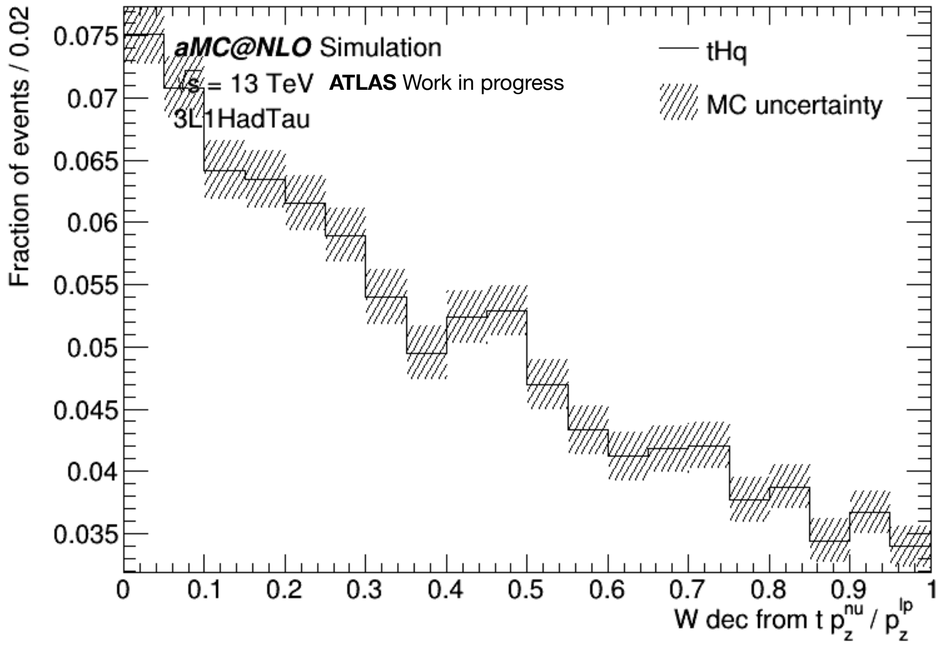
- Analysis strategy:
  - Study event reconstruction information to discriminate signal from SM background
  - Reconstruction of the tHq with τ_{had} :
    - Top reconstruction
    - Higgs reconstruction:
      - Collinear approximation
      - Missing mass calculator (MMC)
      - Kinematic Likelihood Fitter
      - Recursive Jigsaw Reconstruction
  - Define signal, control and validation regions
  - Fit strategy

2L+1τ_{had} channel

- Top reconstruction
  - W mass and top mass used as constraints
  - Collinear constrain: the z-component of the neutrino momentum is proportional to the z-component of the light lepton

$$p_\nu^z = \alpha \cdot p_l^z$$

  - Neutrinos and light leptons are assumed to be massless



- At this moment, this hypothesis just works for a subset of signal events
- Other options are being explored:
  - Neural network as a linear regressor
  - Improve the top requirement inspired in parton level reconstruction information

2L+1τ_{had} channel

- Higgs reconstruction
  - **Approach 1 : Collinear approximation**:
    - The τ_{lep} and its decays are collinear
    - The source of E^T_{miss} is only due to the neutrinos
  - This approximation is only valid for boosted $\tau\tau$
  - This approximation becomes applicable in tHq due to the extra numbers of b-jet
  - Disadvantages: the collinear approximation is very sensitive to the resolution of E^T_{miss}

- Higgs reconstruction
  - **Approach 2 : Kinematic Likelihood (KL) Fitter**:
    - Library for kinematic fitting using a likelihood approach (complete info: KLFitter)
  - Developed for events with top quark to reconstruction
  - Input requirements: top mass, Higgs Mass and τ
  - Extra requirements should be added, example:
    - Collinear requirement

Summary

- The tHq is an excellent process to test the SM and search new physics.
- The goals of the analyses is searching for tHq production and try to improve the current measurement.
  - Possible goal: exclude the inverse hypothesis of Higgs-top-Yukawa coupling (y_t)
- The contribution of the Valencia team to the tHq analyses in the multilepton channel in ATLAS has been presented
- Status of the analysis:
  - Basic strategies defined
  - Study different tools to reconstruct the process
  - Study to enhance the signal VS background discrimination.