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# Update on search W'→WH with lepton + boosted jet final state


**Jennifer Ngadiuba**

Andreas Hinzmann, Clemens Lange, Benjamin Kilminster (UZH)
Mengmeng Wang, Qiang Li (Peking University)


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# Introduction

- Last report on April 16th
  - https://indico.cern.ch/event/313936/
- Today's report focuses on main background ttbar (~85%)
  - Understand of the topology
  - Estimate potential separation power
  - Propose new selections

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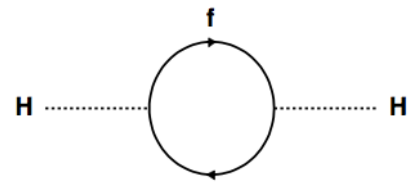
# Theoretical motivations

- **The Higgs mass hierarchy problem**

  - The Higgs mass gains quantum corrections from fermion loops




$M_H^2$ (125 GeV) = $M_0^2 + \delta M_H^2$

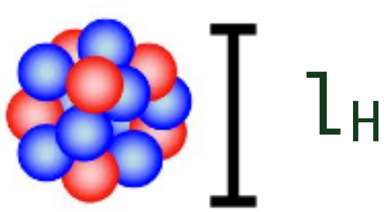
$$\delta M_H^2 = -2\frac{|\lambda_f|^2}{16\pi^2}\Lambda^2 + \dots$$

**fine tuning:** $\Lambda$ ~ gravitational scale ~ $M_{Planck}$ ~ $10^{18}$ GeV

  - If new physics at the TeV scale exists the cut-off scale $\Lambda$ is set by the scale of the new dynamics ... $\Lambda$ ~ 1 TeV

## The composite Higgs model

Higgs as a composite state of a new strong interaction



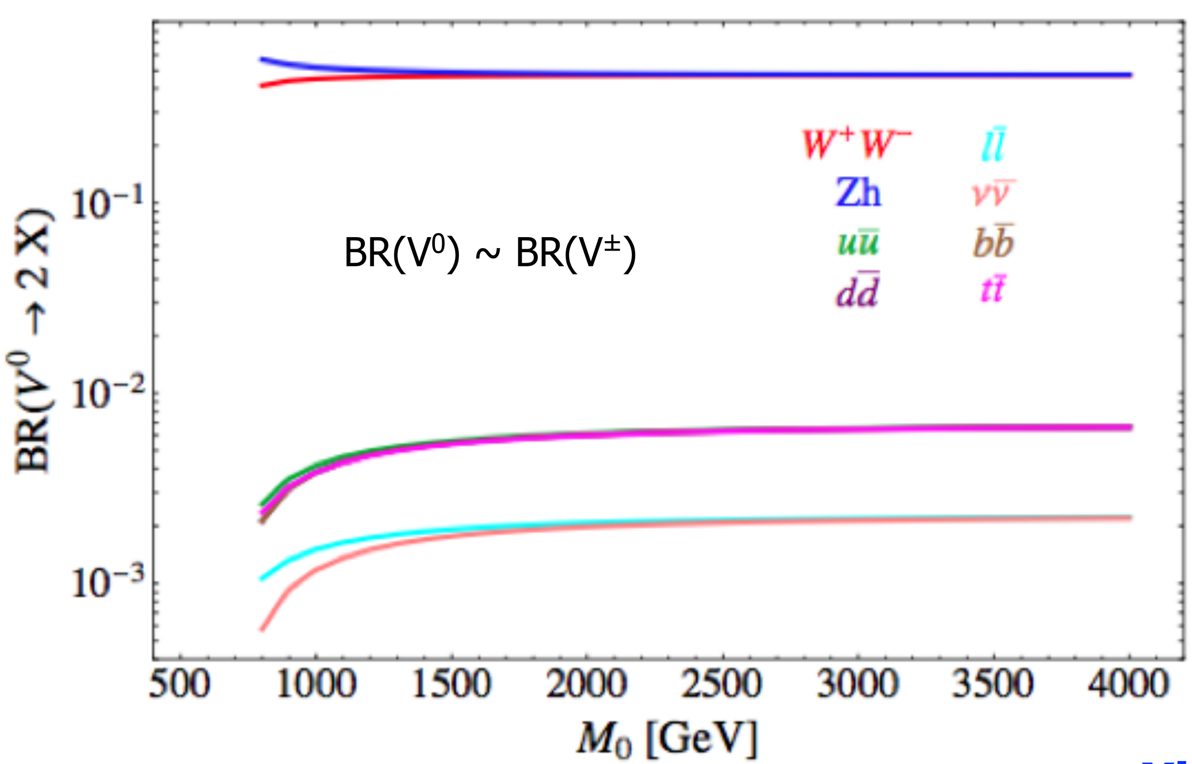

The hierarchy problem is solved:

- corrections to $m_H$ screened at $1/l_H$

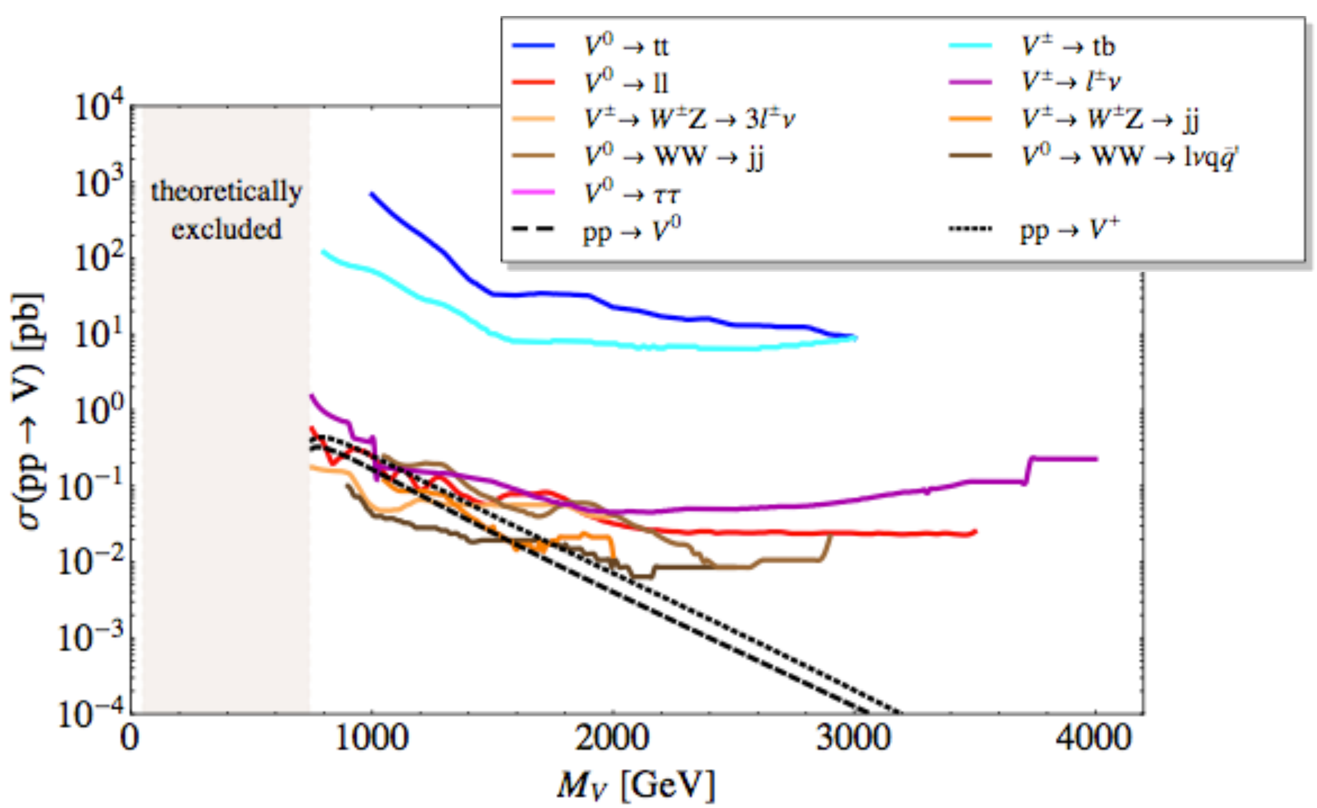
# Data & Bounds

- The composite Higgs boson couples to the SM particles and to new heavier gauge bosons, such as **Z′** and **W′**, with masses in the TeV region
  - in this scenario the neutral ($V^0$) and the charged ($V^\pm$) heavy resonances decay primarly to SM vector bosons (W,Z,Higgs)

**Branching Ratios for the two body decays of the neutral vector $V^0$ (Z′)**




**Bounds on the production cross sections**




arXiv:1402.4431

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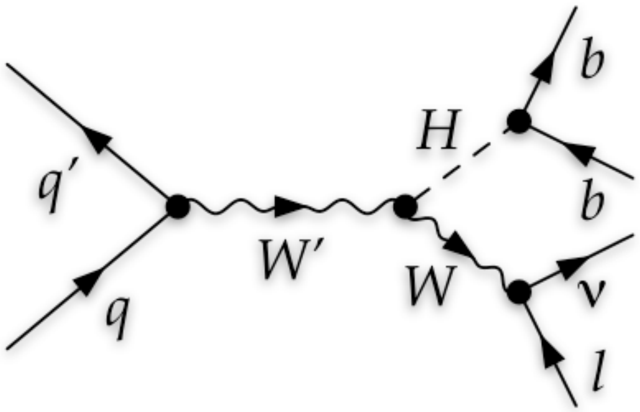
# W′ signal: **W′ → WH → bbℓν**

## Signature:

- high $p_T$ isolated lepton --> High Pt muon ID, HEEP electron ID
- large missing transverse energy
- merged Higgs jets --> Cambridge-Aachen jet with R=0.8 and CHS




## Selections:

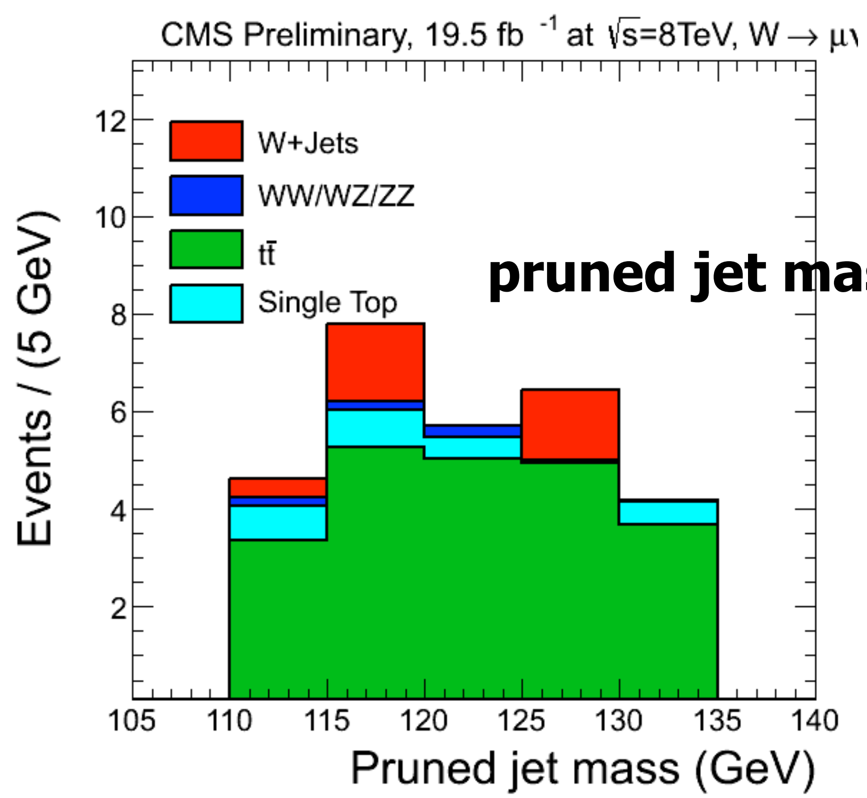
**ttbar main background**

- Higgs-jet $p_T$ > 200 GeV
- leptonic W $p_T$ > 200 GeV
- **2 b-tagged subjets @ CSVL**
- **veto b-tagged additional jets**

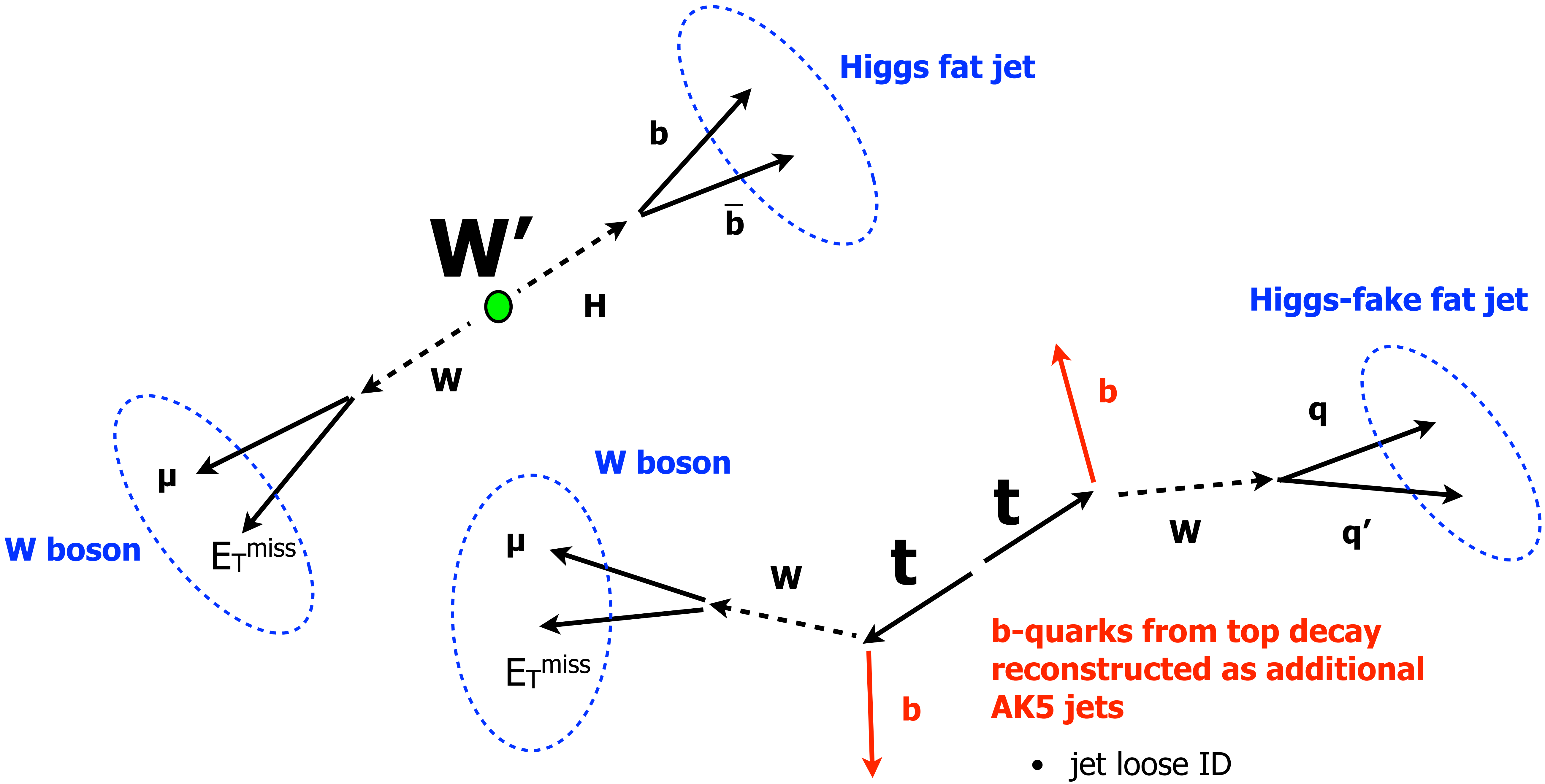
back-to-back topology {

- $\Delta R(\text{jet}^{CA8}, \mu) > \pi/2$
- $\Delta\Phi(\text{MET}, \text{jet}^{CA8}) > 2$
- $\Delta\Phi(\text{jet}^{CA8}, W) > 2$

- **110 < pruned jet mass < 135 GeV**



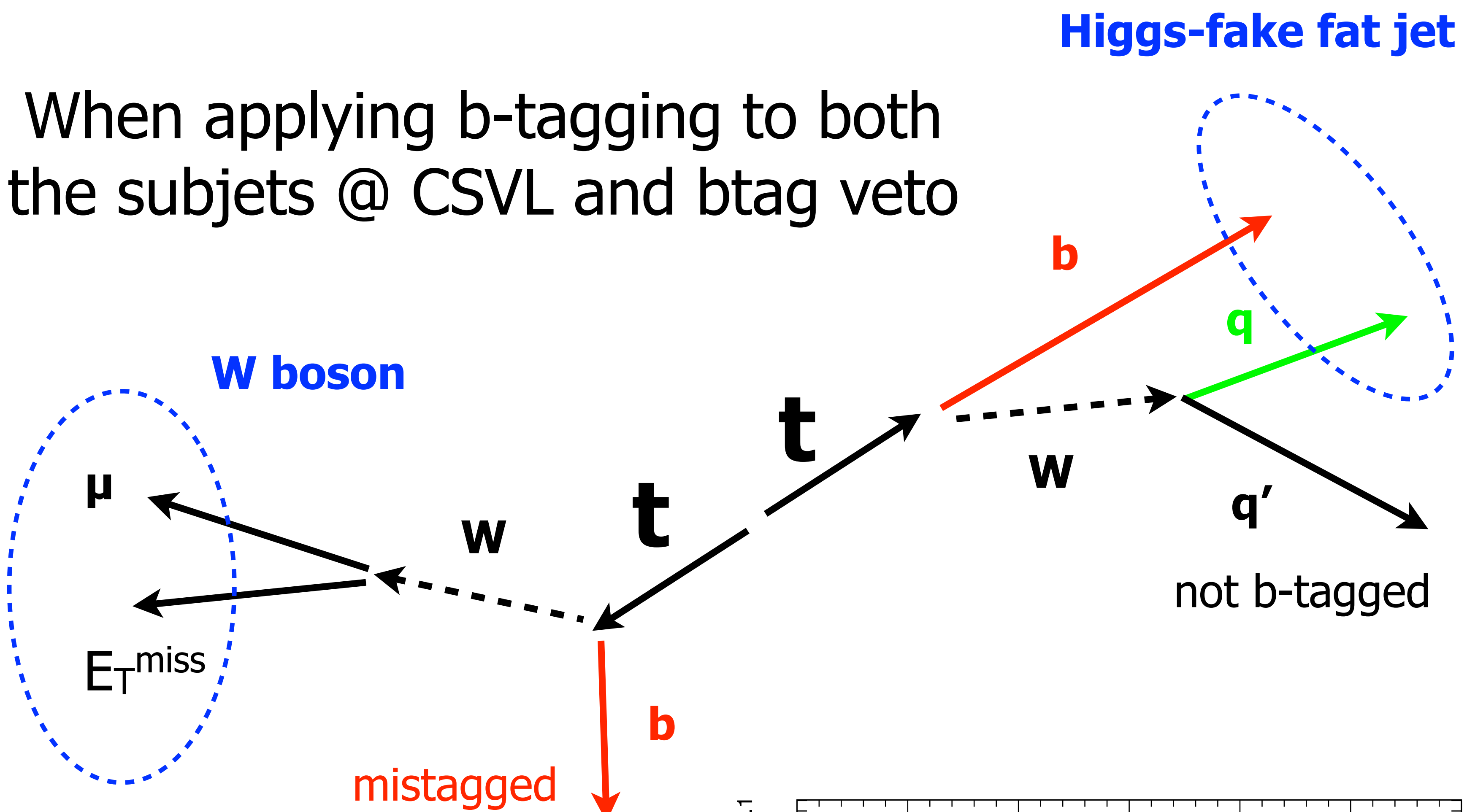
# ttbar vs W’



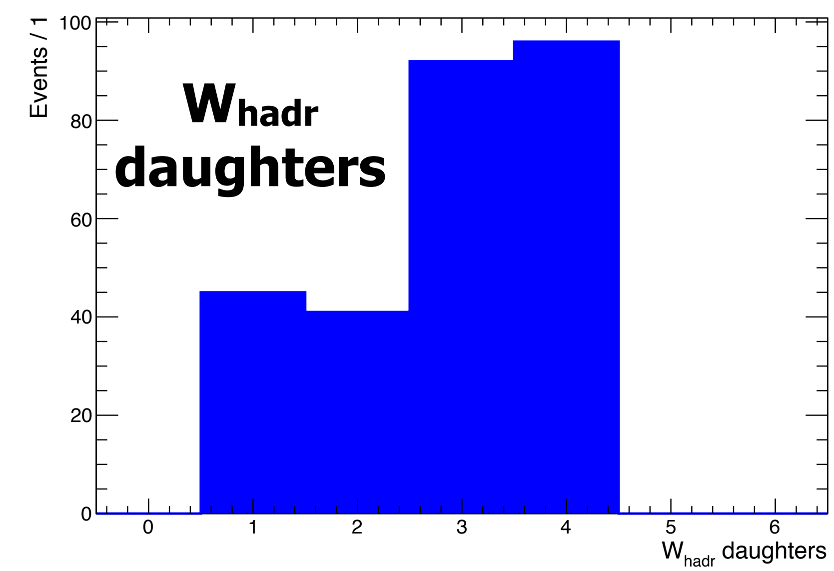

- jet loose ID
- $p_T$ > 30 GeV, |η| < 2.4
- ΔR(μ,ak5) > 0.3
- ΔR(ca8,ak5) > 0.8

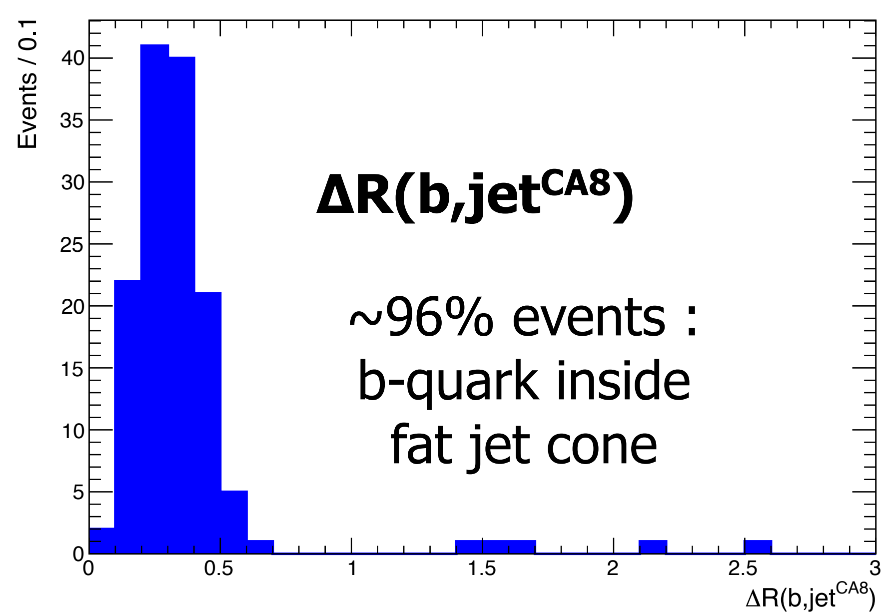
# ttbar vs W'

When applying b-tagging to both the subjets @ CSVL and btag veto




~70% events
**q = c-quark**
higher mistagging probability

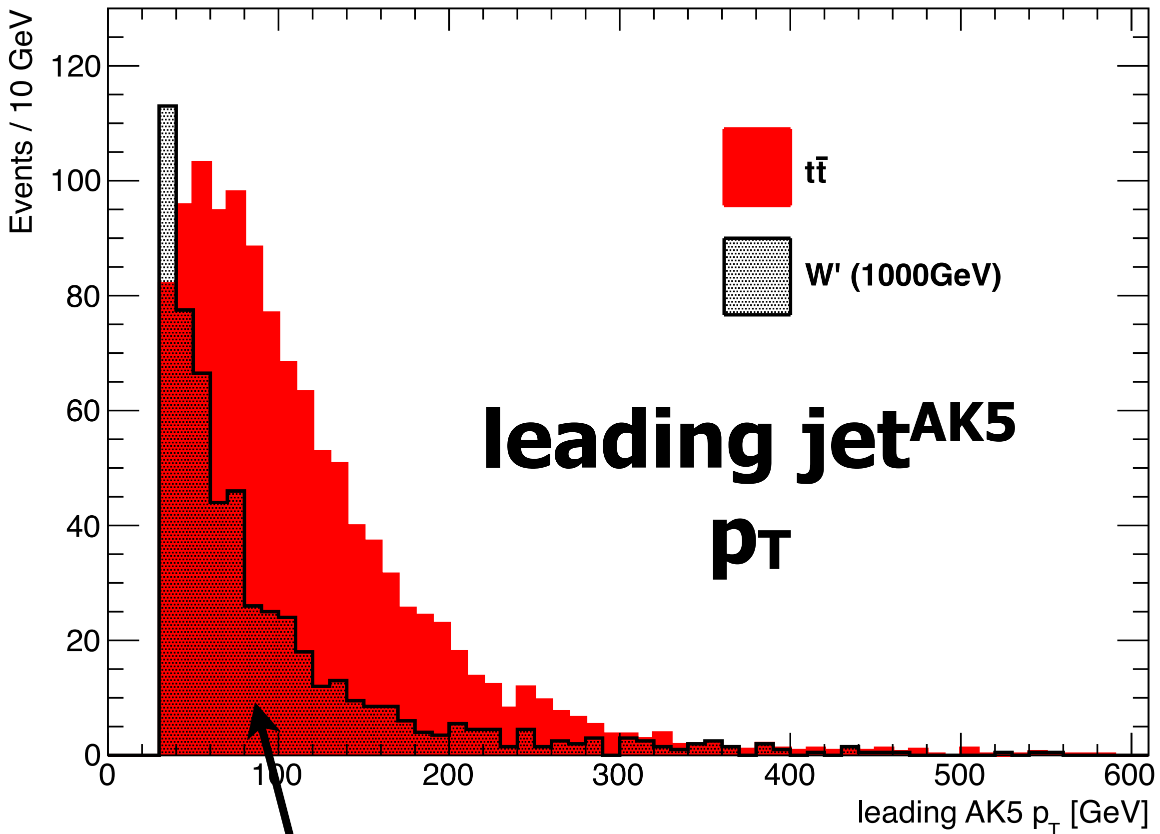


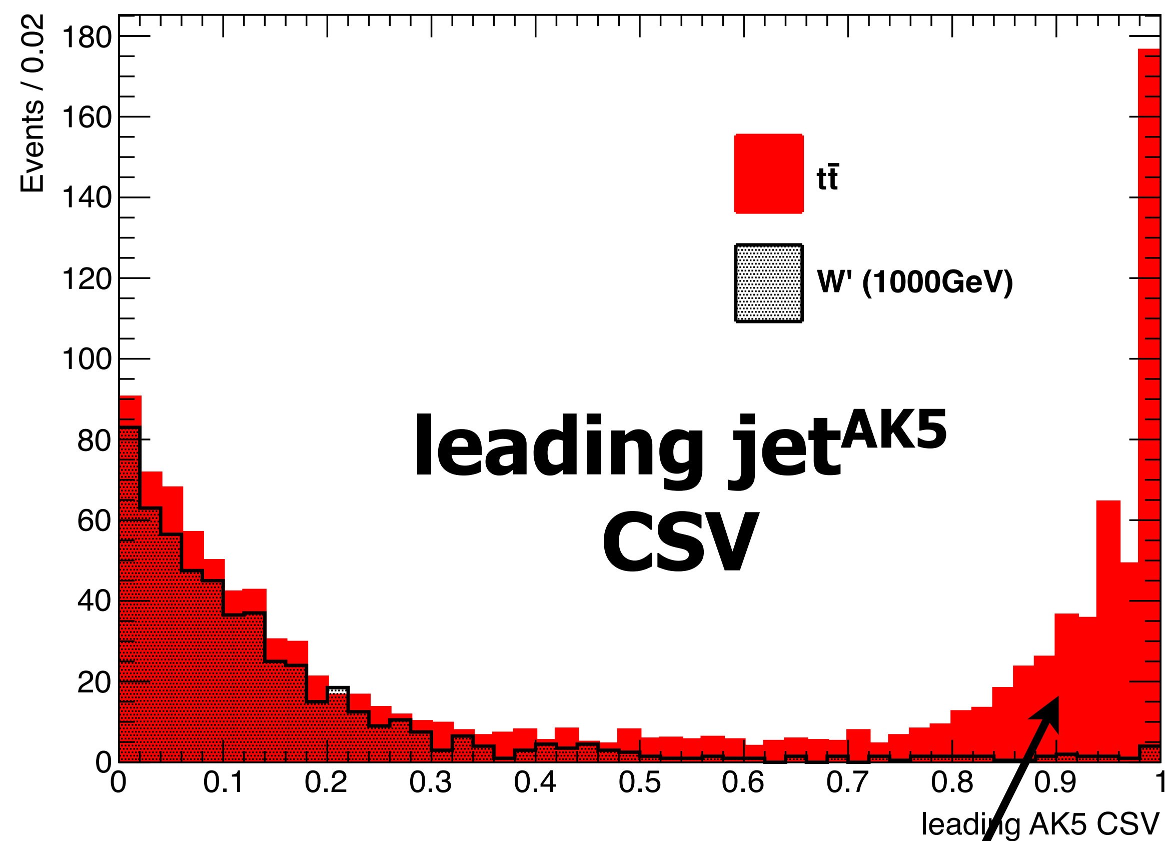



# BDT analysis

- In order to take into account many variables and the correlations between them 2000 **Boosted Decision Trees** are trained with all the selections excluding
  - b-tag veto
  - subjets b-tagging
- In order to gain more statistics a pruned jet mass region between **110-150 GeV** is considered where the ttbar background is larger compared to the W+jets
- **Only events with at least one additional AK5 jet** are used for the training

# BDT input variables



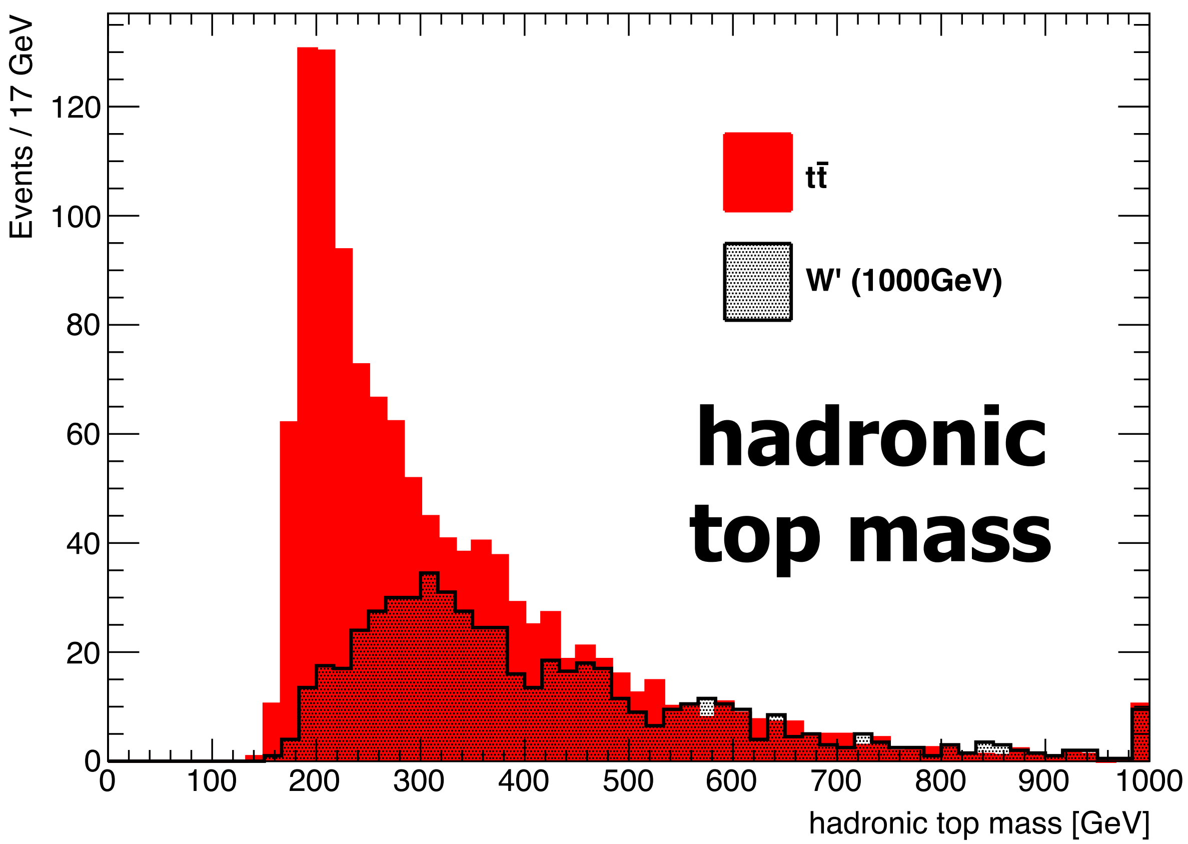



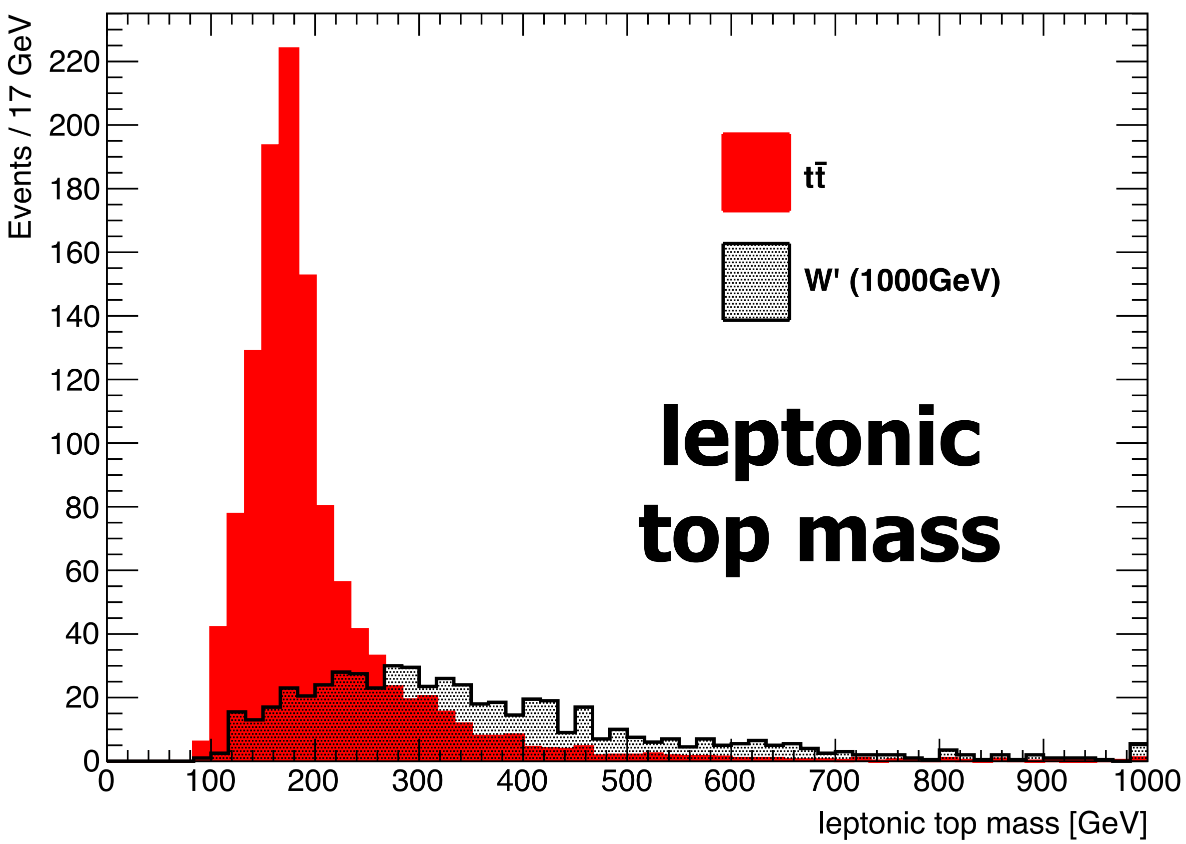

**Signal:** low $p_T$ spectrum

**ttbar:** b-tagged AK5 jets

# BDT input variables

Found the best resolution on the top mass when computing it respect to the closest AK5 jet



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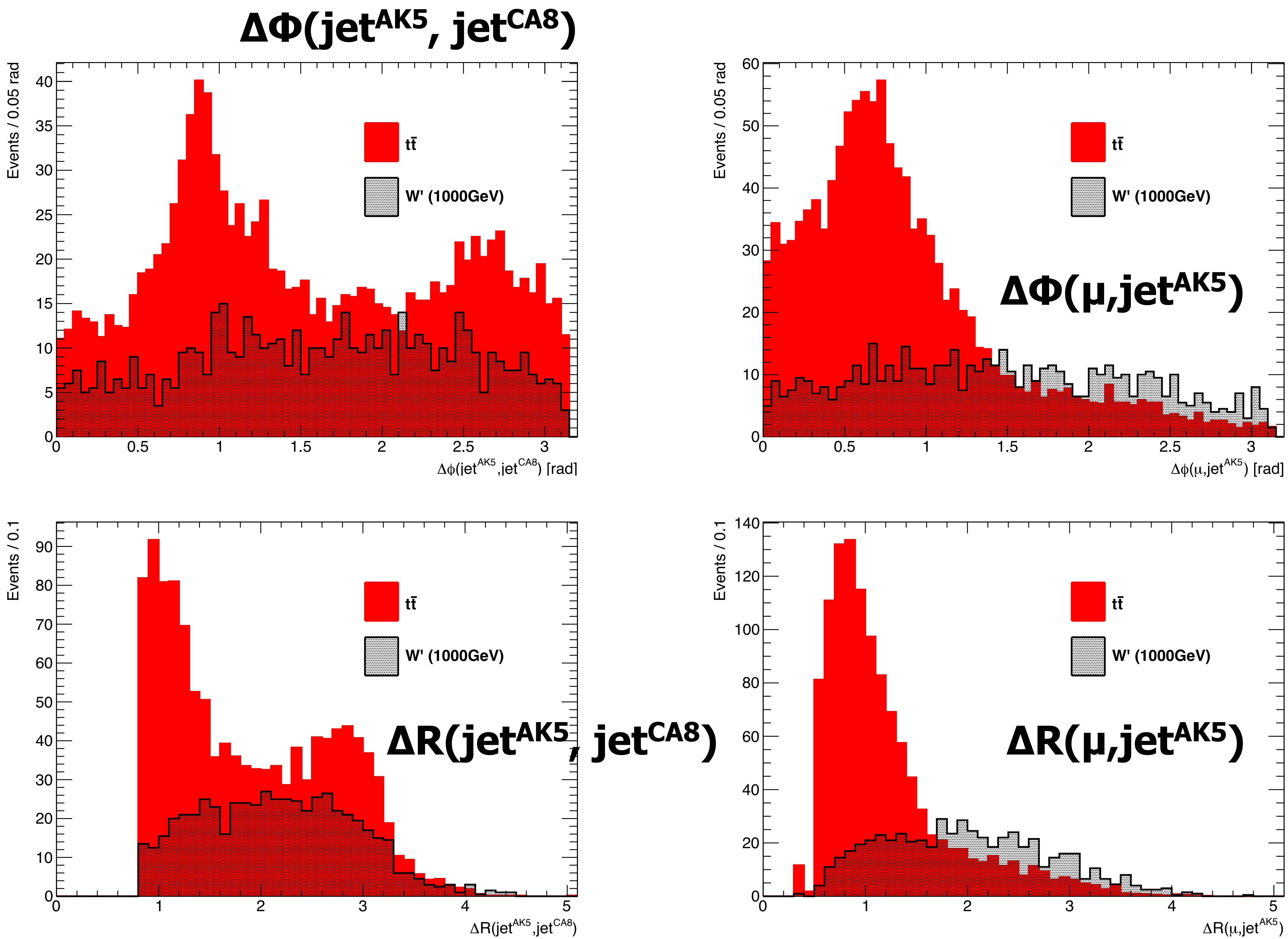
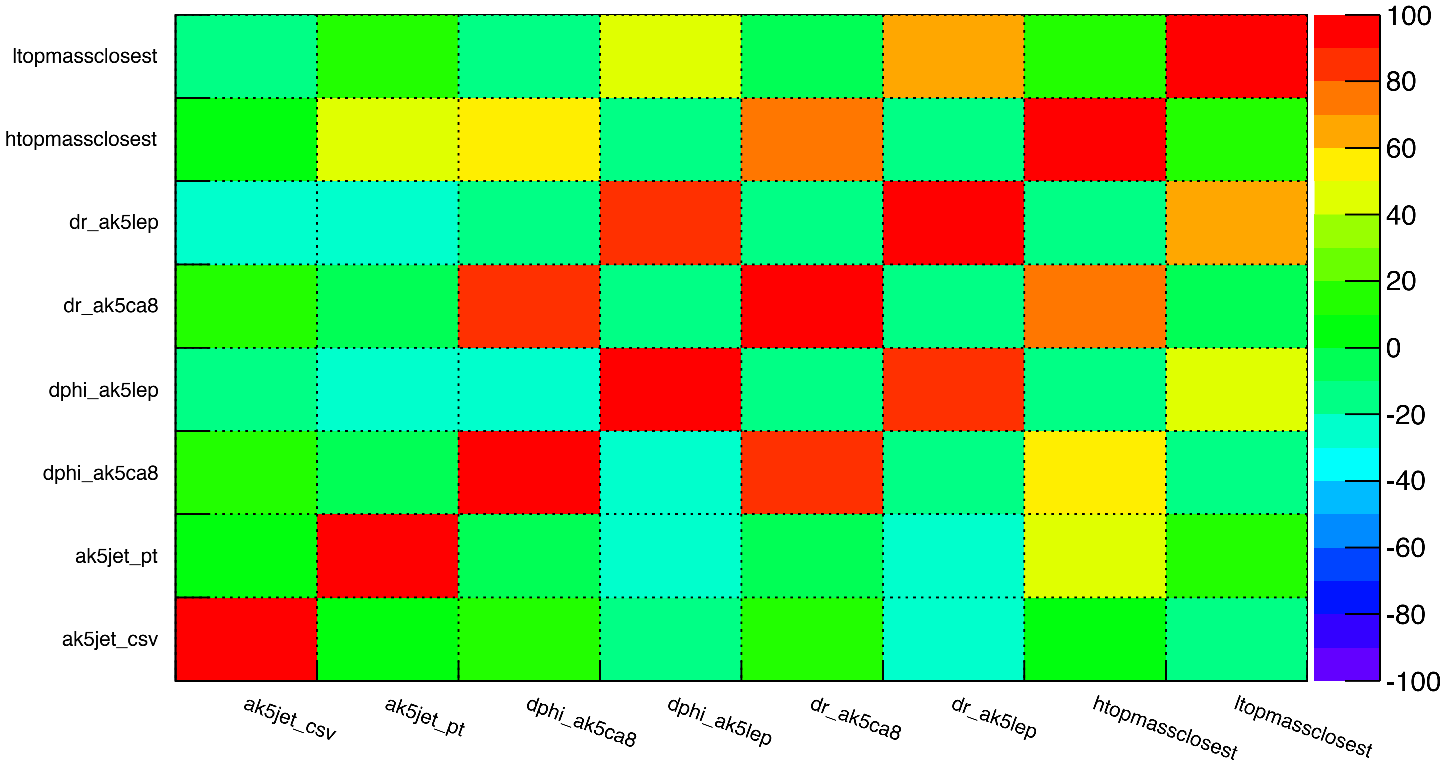
# Input variables

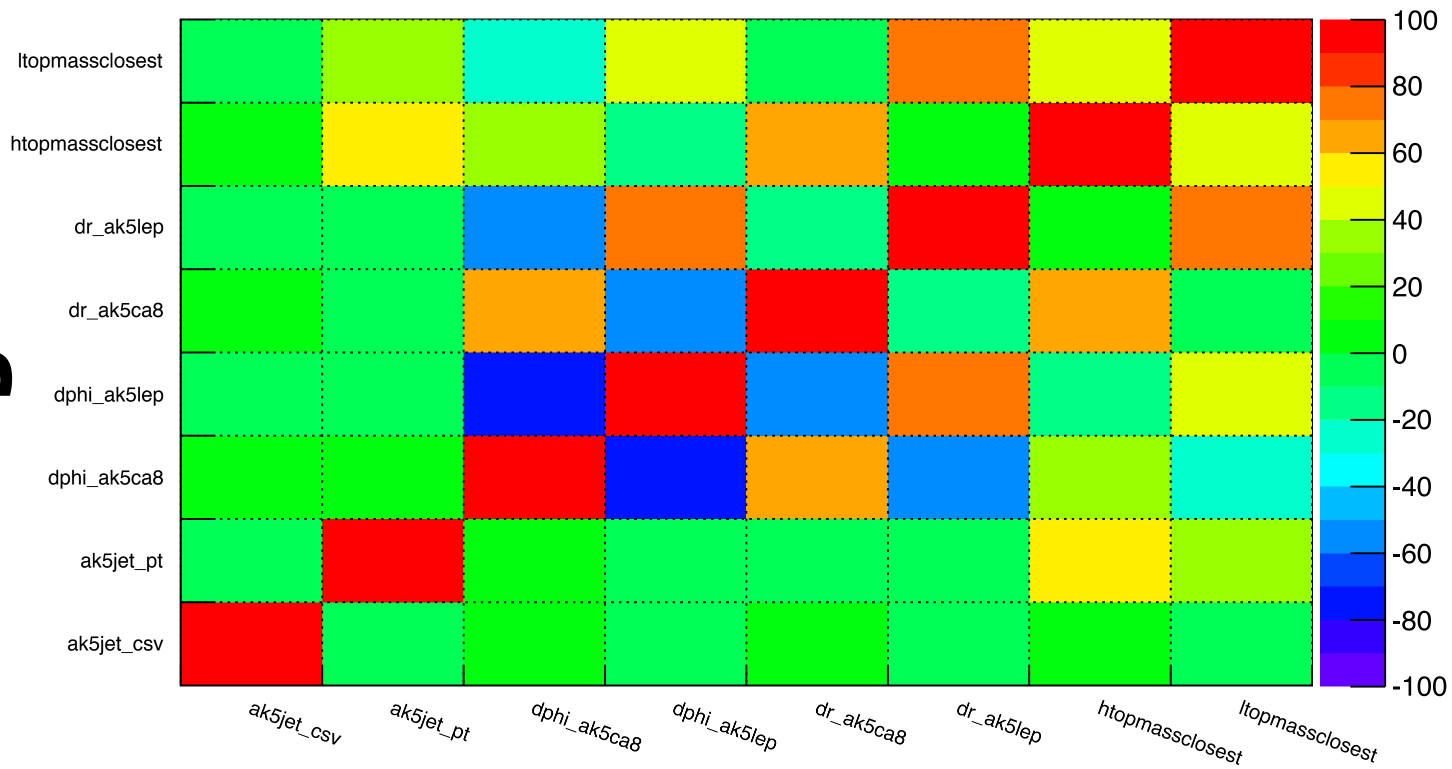


# Correlation Matrix

ttbar




signal

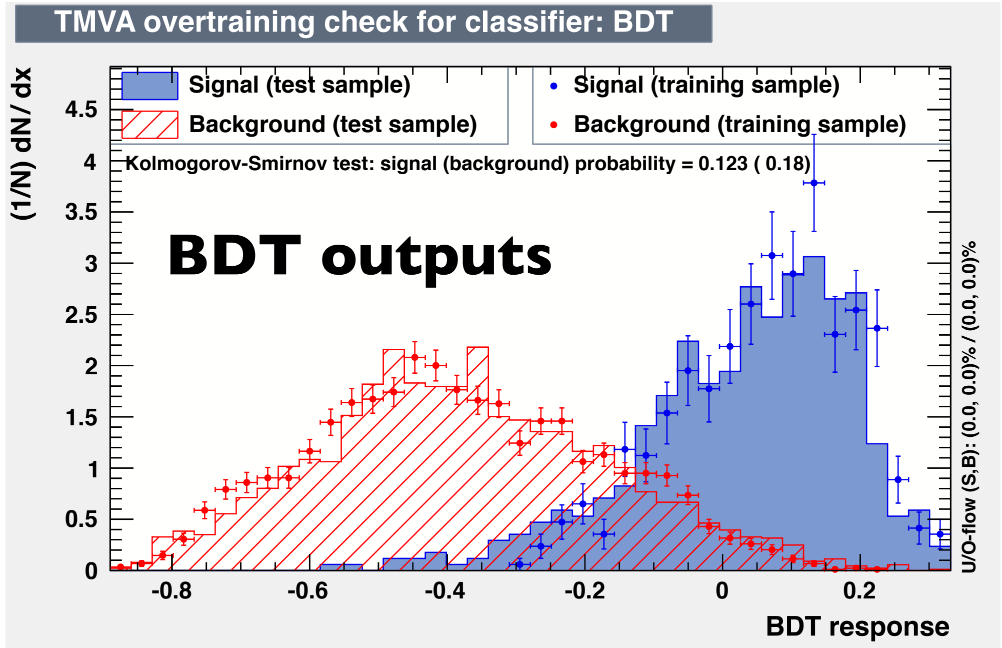



## Strongest correlations:

- leptonic top mass vs $\Delta R(\mu, jet^{AK5})$
- leptonic top mass vs $\Delta\Phi(\mu, jet^{AK5})$
- hadronic top mass vs $\Delta R(jet^{CA8}, jet^{AK5})$
- hadronic top mass vs $\Delta\Phi(jet^{CA8}, jet^{AK5})$
- hadronic top mass vs $jet^{AK5}$ $p_T$

## Ranking:

1. $p_T$ $jet^{AK5}$
2. CSV $jet^{AK5}$
3. leptonic top mass
4. hadronic top mass
5. $\Delta R(\mu, jet^{AK5})$
6. $\Delta R(jet^{CA8}, jet^{AK5})$
7. $\Delta\Phi(jet^{CA8}, jet^{AK5})$
8. $\Delta\Phi(\mu, jet^{AK5})$

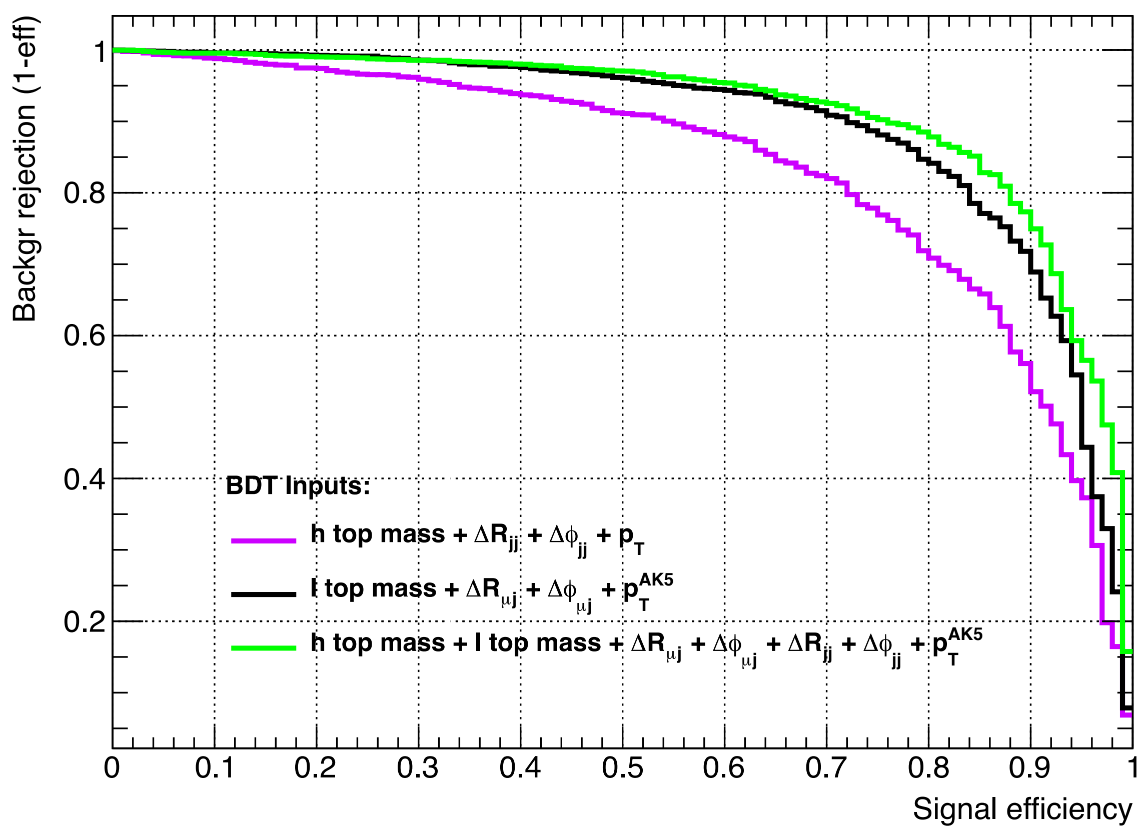


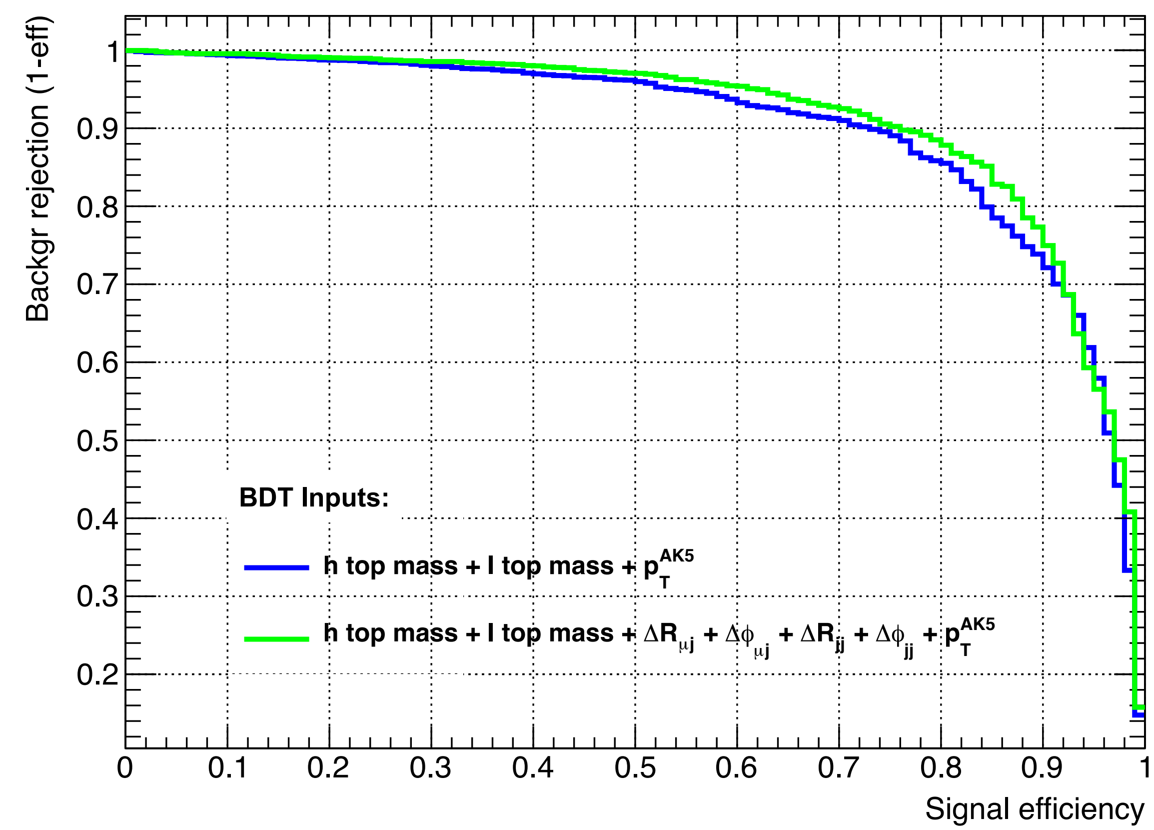
# ROC curves

## Comparison between different sets of BDT input variables

A better performance is achieved when:

- combining hadronic and leptonic top mass together with the related kinematical variables ( $\Delta R(jet^{AK5},jet^{CA8})$, $\Delta R(\mu,jet^{AK5})$ ... )
- adding the kinematical variables in addition to the jet $p_T$




ttbar rejection at signal efficiency = 0.8

- **0.709**
- **0.841**
- **0.878**

**~ 4%-24% improvement**

ttbar rejection at signal efficiency = 0.8

- **0.855**
- **0.878**

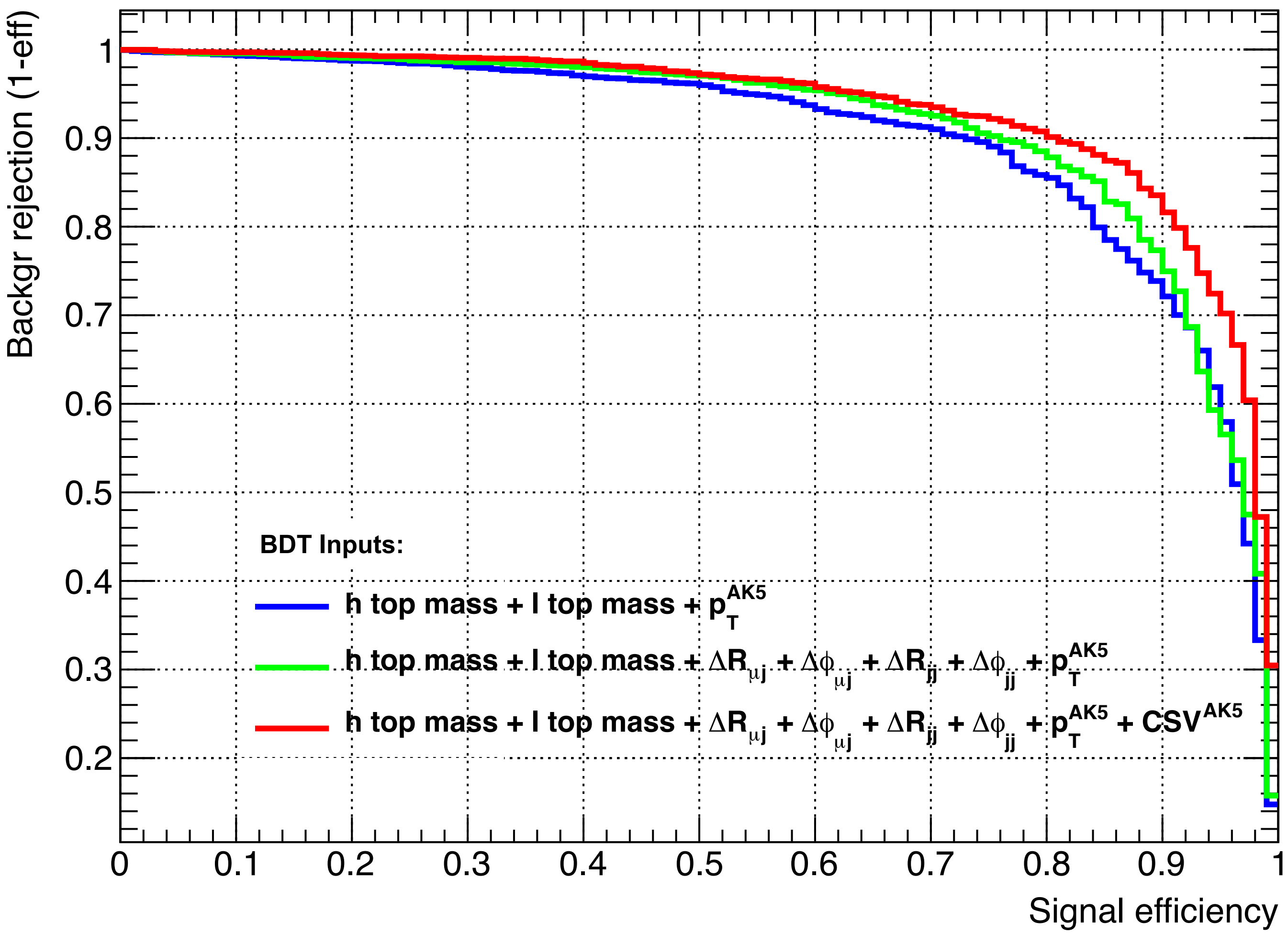
**~3% improvement**

# ROC curves

## Comparison between different sets of BDT input variables

A better performance is achieved when:

- combining hadronic and leptonic top mass together with the related kinematical variables ( $\Delta R(jet^{AK5}, jet^{CA8})$, $\Delta R(\mu, jet^{AK5})$ ... )
- adding the kinematical variables in addition to the jet $p_T$
- adding the AK5 jet CSV in addition to the jet $p_T$ and kinematical variables




ttbar rejection at signal efficiency = 0.8

- **0.901**
- **0.878**
- **0.855**

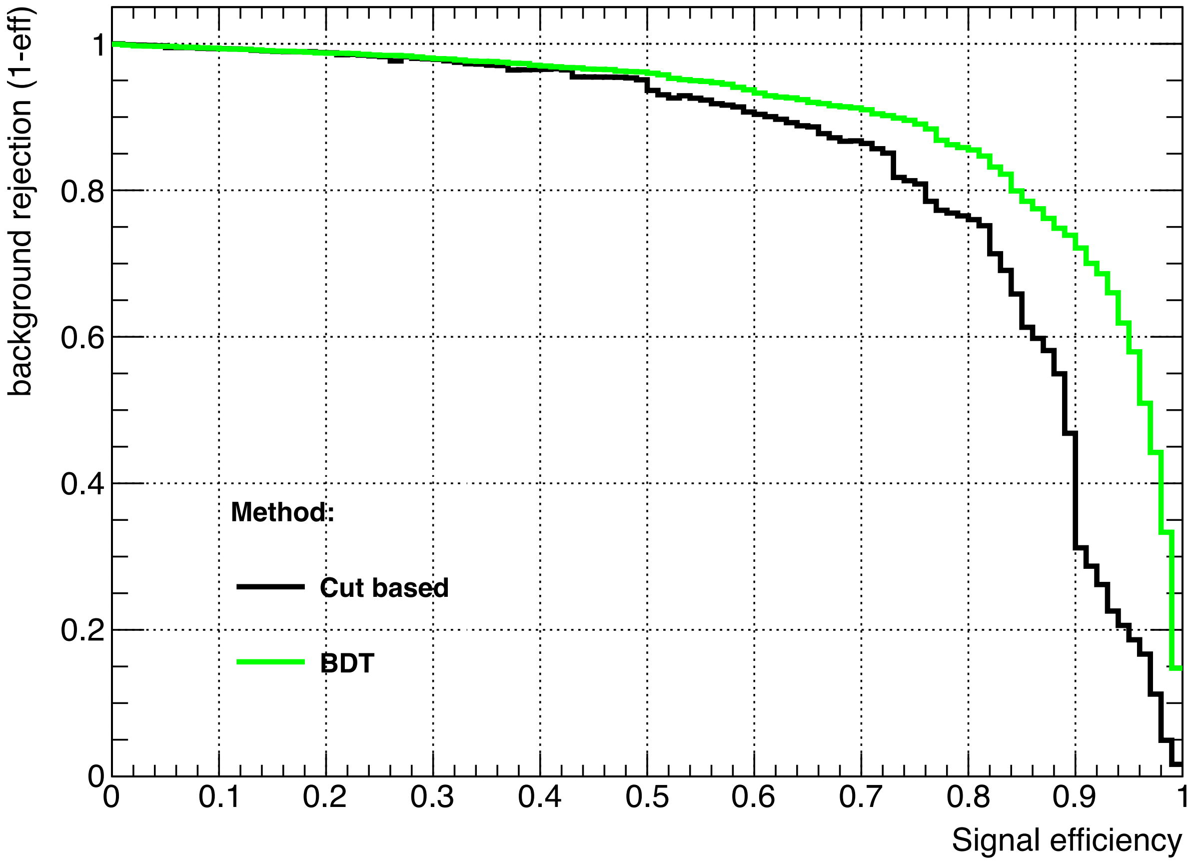
**~5% improvement**

- studied the possibility to exclude the jet CSV as input variable (see next slides)

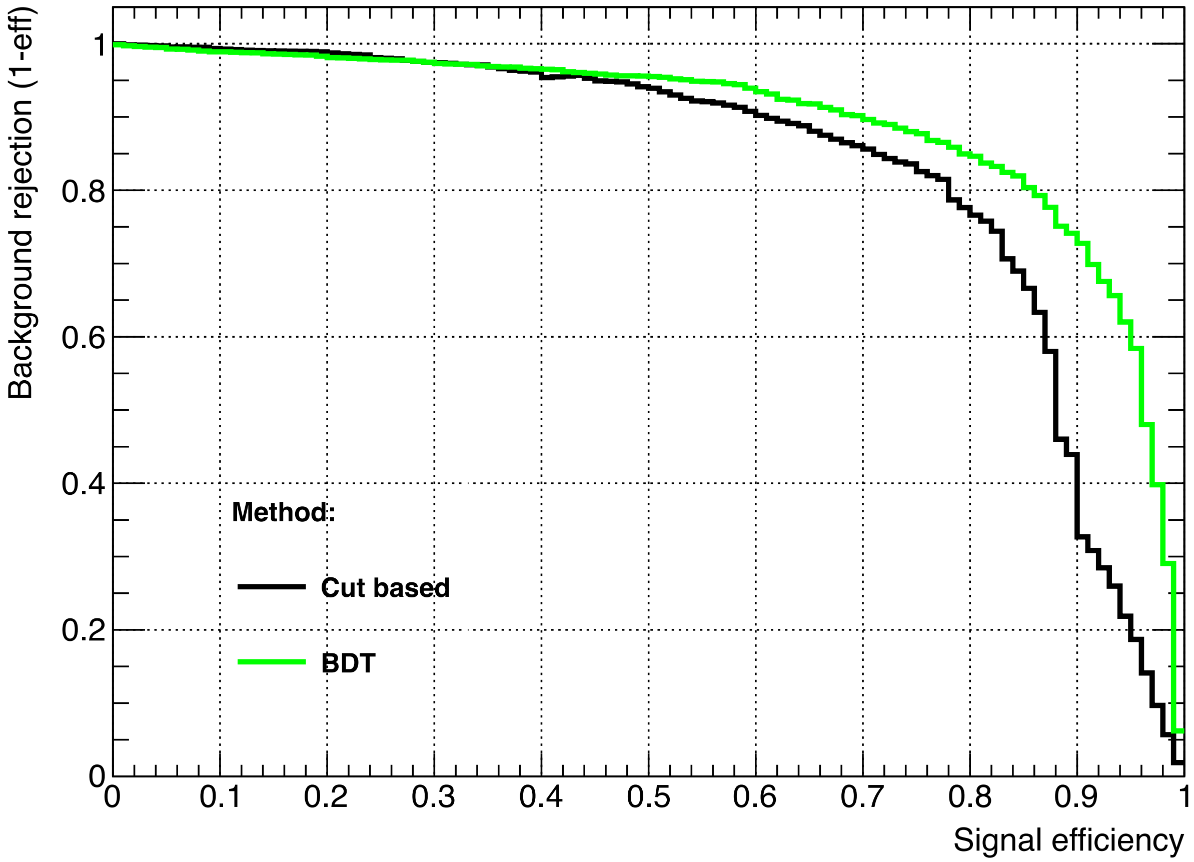
# Cuts vs BDT

## Comparison between cuts and BDT for same set of input vairables

hadronic top mass +
leptonic top mass + $jet^{AK5}$ $p_T$




leptonic top mass +
hadronic top mass/$jet^{AK5}$ $p_T$




ttbar rejection at signal efficiency = 0.8

- **0.855**
- **0.760**

**~13% improvement**

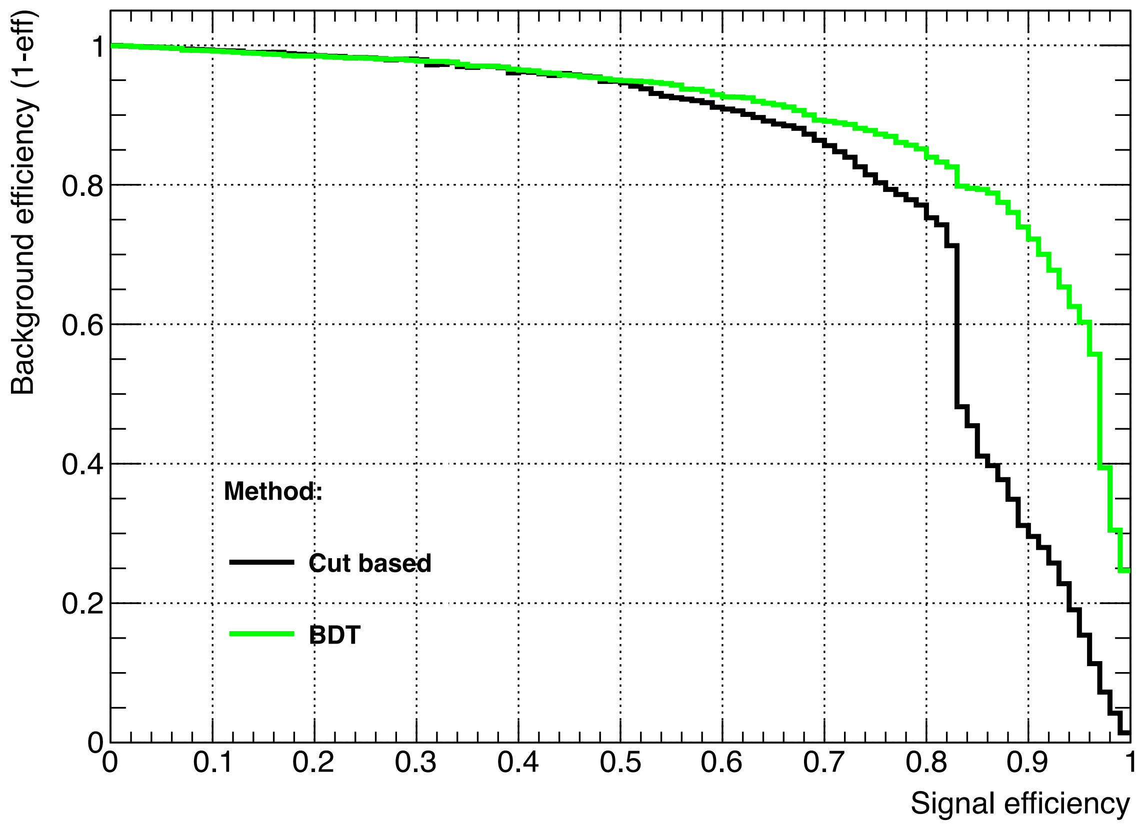
ttbar rejection at signal efficiency = 0.8

- **0.846**
- **0.766**

# Cuts vs BDT

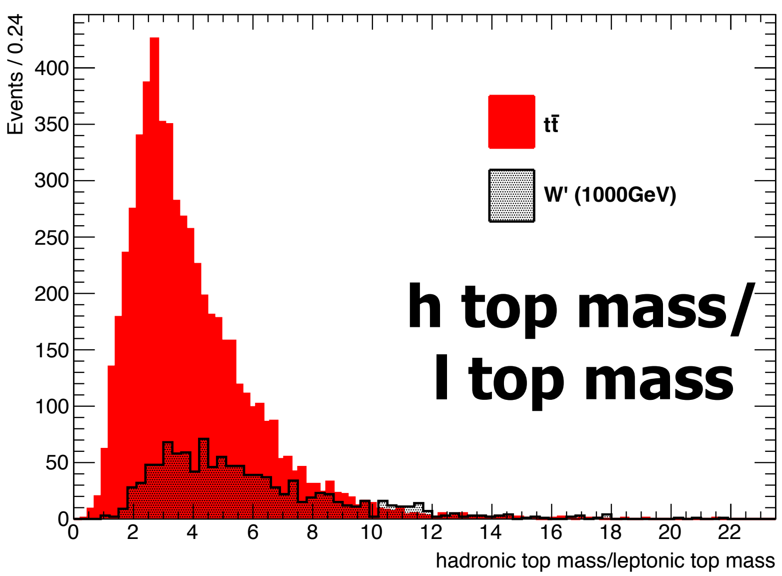
## Comparison between cuts and BDT for same set of input vairables

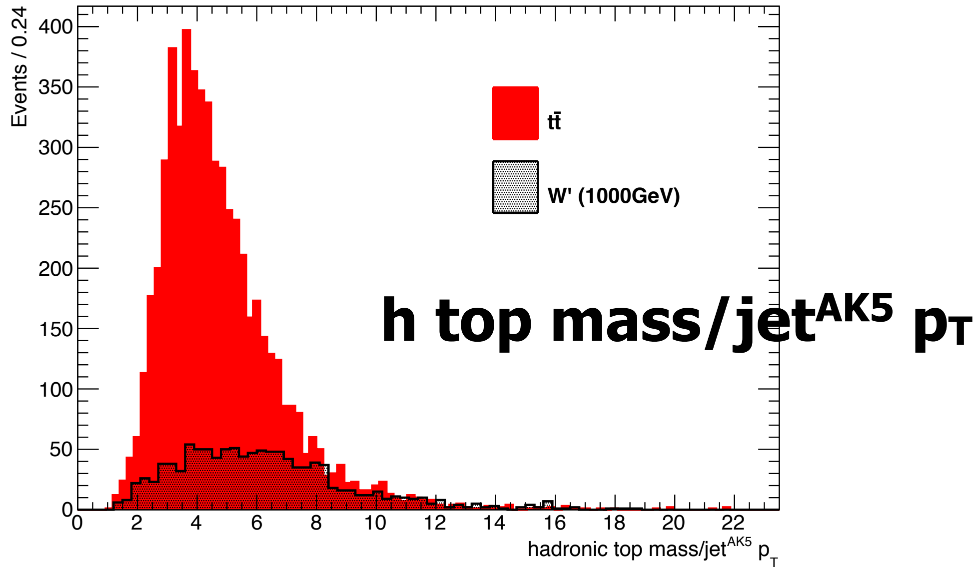
hadronic top mass + leptonic top mass
+ h top mass/l top mass
+ $jet^{AK5}$ $p_T$




ttbar rejection at
signal efficiency = 0.8

- **0.840**
- **0.753**




The variable shapes for background and signal is not a powerful discriminant, hence:

- BDT takes into account correlations between the variables
- better performance of BDT

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# Cuts efficiencies

| veto | W' (1TeV) | TTbar | $\varepsilon_S/(1+\sqrt{B})$ |
|---|---|---|---|
| **btag veto** | 0.199 (896) | 5.74e-5 (31.93) | 0.0299 |
| **veto additional AK5 jets** | 0.140 (630) | 1.47e-5 (8.19) | 0.0363 |
| **# AK5 jets > 1** | 0.194 (871) | 5.71e-5 (31.72) | 0.0293 |
| **# AK5 jets > 1 +<br>150 < leptonic top mass < 200 GeV** | 0.187 (839) | 3.79e-5 (21.08) | 0.0334 |
| **btag veto +<br>150 < (leptonic top mass \|\| hadronic top mass) < 200 GeV** | 0.189 (850) | 3.83e-5 (21.29) | 0.0337 |
| **btag veto +<br>150 < leptonic top mass < 200 GeV** | 0.191 (860) | 4.38e-5 (24.36) | 0.0322 |
| **btag veto +<br>150 < hadronic top mass < 200 GeV** | 0.197 (885) | 5.04e-5 (28.04) | 0.0313 |
| **btag veto +<br>150 < leptonic top mass < 220 GeV** | 0.187 (842) | 4.05e-5 (22.51) | 0.0326 |
| **btag veto +<br>150 < hadronic top mass < 300 GeV** | 0.182 (818) | 3.20e-5 (17.81) | 0.0349 |
| **btag veto +<br>(150 < leptonic top mass < 220 GeV \|\|<br>(150 < hadronic top mass < 300 GeV)** | 0.174 (781) | 2.69e-5 (12.89) | 0.0379 |
| **(150 < leptonic top mass < 220 GeV \|\|<br>(150 < hadronic top mass < 300 GeV)** | 0.181 (811) | 3.57e-5 (19.85) | 0.0332 |

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# BDT efficiencies

| veto | W′ (1TeV) | TTbar | $\varepsilon_S/(1+\sqrt{B})$ |
|---|---|---|---|
| **BDT < 0** | 0.183 (822) | 1.80e-5 (10.03) | 0.0439 |
| **BDT < -0.1** | 0.201 (903) | 2.69e-5 (14.94) | 0.0413 |
| **BDT < -0.2** | 0.208 (936) | 4.42e-5 (24.56) | 0.0349 |

## btag veto + kinematics-only BDT

| veto | W′ (1TeV) | TTbar | $\varepsilon_S/(1+\sqrt{B})$ |
|---|---|---|---|
| **btag veto** | 0.199 (896) | 5.74e-5 (31.93) | 0.0299 |
| **BDT < 0** | 0.183 (820) | 1.62e-5 (9.01) | 0.0457 |
| **BDT < -0.1** | 0.197 (883) | 3.57e-5 (19.85) | 0.0361 |
| **BDT < -0.2** | 0.199 (895) | 5.45e-5 (30.29) | 0.0306 |

# Conclusions

- The ttbar background topology has been fully understood
  - b-quark from top decay inside the Higgs-fake jet cone
- Different options have been implemented and studied to reject it
- The BDT gives the best sensitivity in terms of signal efficiency and background rejection
  - in addition to the a simple b-tag veto, **cuts on top masses** can improve the significance or xsec-limit of **~26%**
  - in addition to the a simple b-tag veto, **cut on kinematic-only BDT** can improve the significance or xsec-limit of **~53%**
- **Next steps:** test and validate BDT performance with data and with background of varying composition defining control regions that have different kinematics that favor backgrounds
  - varying pruned jet mass window and subjets b-tag requirements (0/1/2 CSVL)

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# Ongoing work

- **Benchmark models**
  - Use current narrow-width W' samples for the following benchmark models
    - Composite Higgs W'
    - Little Higgs W'
    - SSM W'
    - Model B with simplified phenomenological Lagrangian W'
- **W+jets background**
  - Check impact of new selection presented today
  - Method A: Derive scale factor in sideband and use MC shape in signal region (good closure confirmed)
  - Method B: Alpha ratio method with enlarged sideband 40-110 GeV (need to check if sufficient statistics)
- **Higgs tagging**
  - Use CSVL subjet b-tagging if subjet dR>0.3 otherwise CSV b-tagging on fatjet (because subjet b-tagging for subjet dR<0.3 not supported)
  - Derive uncertainty for using N-subjettiness tau21 for H->bb in addition to systematics used for tau21 on W->qq
- **Complete AN-14-121**

# Backup

| veto | W' (1TeV) | TTbar | $\varepsilon_S/(1+\sqrt{B})$ |
|---|---|---|---|
| **veto additional AK5 jets pt > 50** | 0.165 (741) | 3.20e-5 (17.81) | 0.0316 |
| **veto additional AK5 jets pt > 100** | 0.193 (865) | 8.61e-5 (47.89) | 0.0244 |
| **# AK5 jets > 1 pt > 50** | 0.205 (921) | 9.57e-5 (53.21) | 0.0247 |
| **# AK5 jets > 1 pt > 100** | 0.211 (950) | 13.14e-5 (73.07) | 0.0221 |
| **# AK5 jets > 1 pt > 50 + 150 < leptonic top mass < 220 GeV** | 0.199 (896) | 6.51e-5 (36.23) | 0.0284 |
| **# AK5 jets > 1 pt > 50 + 150 < hadronic top mass < 300 GeV** | 0.199 (892) | 8.69e-5 (48.30) | 0.0250 |
| **# AK5 jets > 1 pt > 100 + 150 < leptonic top mass < 220 GeV** | 0.210 (944) | 11.30e-5 (62.83) | 0.0235 |
| **# AK5 jets > 1 pt > 100 + 150 < hadronic top mass < 300 GeV** | 0.211 (946) | 13.07e-5 (72.66) | 0.0222 |
| **# AK5 jets > 1 pt > 50 + (150 < leptonic top mass < 220 GeV \|\| (150 < hadronic top mass < 300 GeV)** | 0.193(867) | 5.85e-5 (32.54) | 0.0288 |
| **# AK5 jets > 1 pt > 100 + (150 < leptonic top mass < 220 GeV \|\| (150 < hadronic top mass < 300 GeV)** | 0.209 (940) | 11.23e-5 (62.42) | 0.0235 |