Four top quark production in the Standard Model at CMS experiment

IOP conference 23rd March 2016

Lana Beck[1,2], on behalf of the CMS collaboration

[1]University of Bristol

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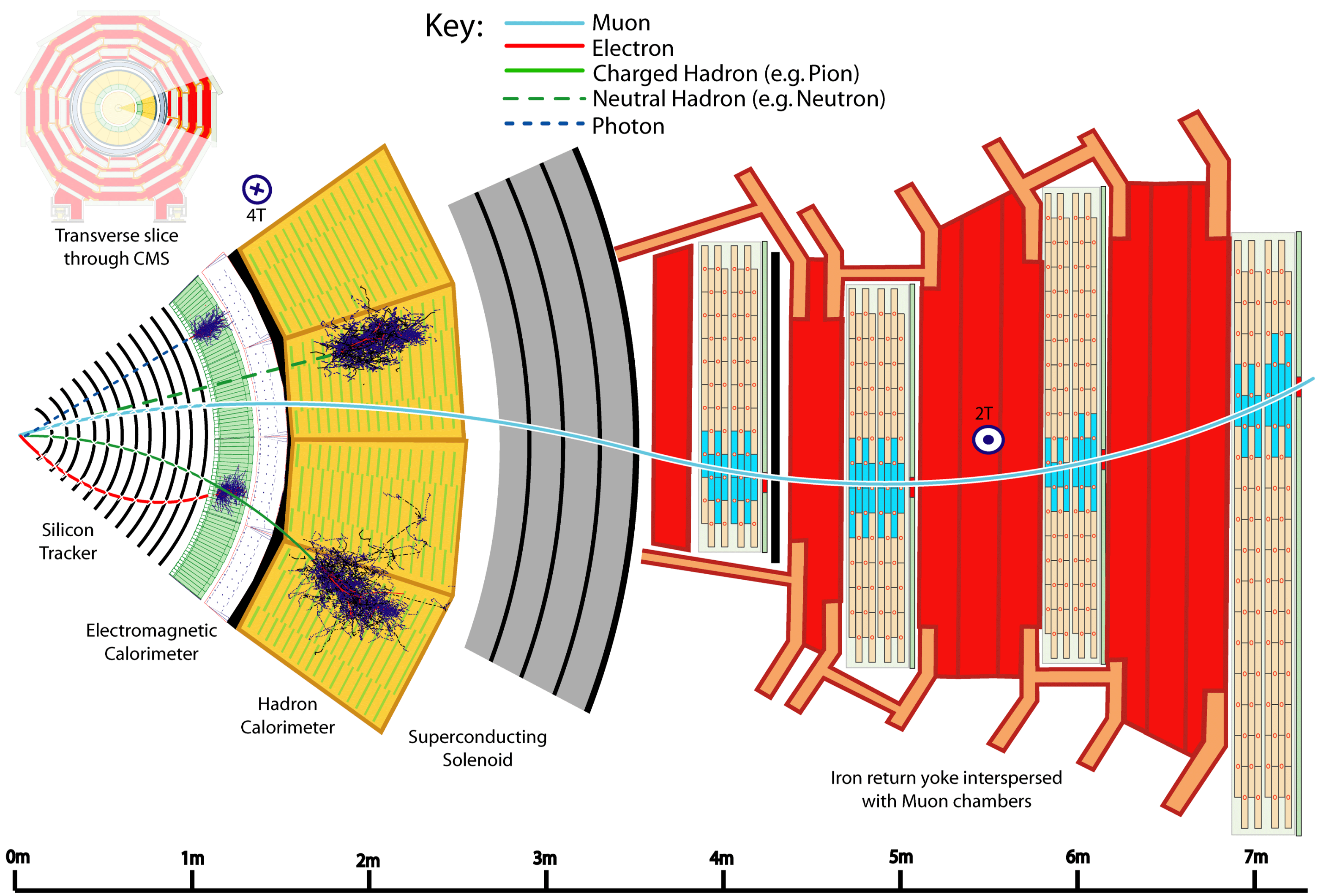
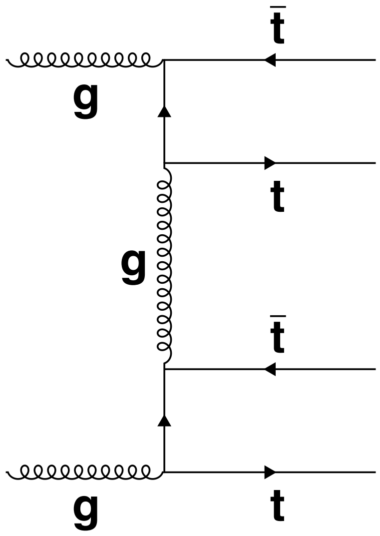
CMS detector



Motivation for four top search

- It is an extremely rare SM process
- Cross section of ≈ 1 fb at 8 TeV*
- Cross section is enhanced in many BSM models



*1 fb ≈ 1 event in 10^{14} proton-proton collisions

Motivation for four top search

- It is an extremely rare SM process
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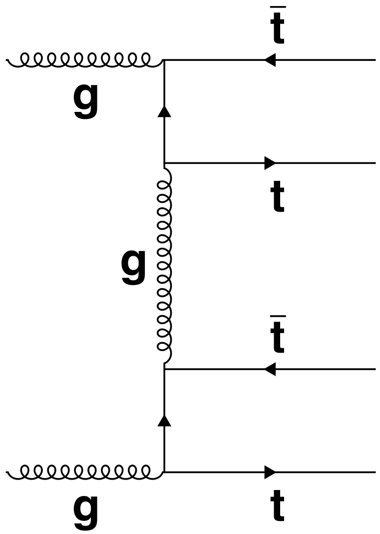
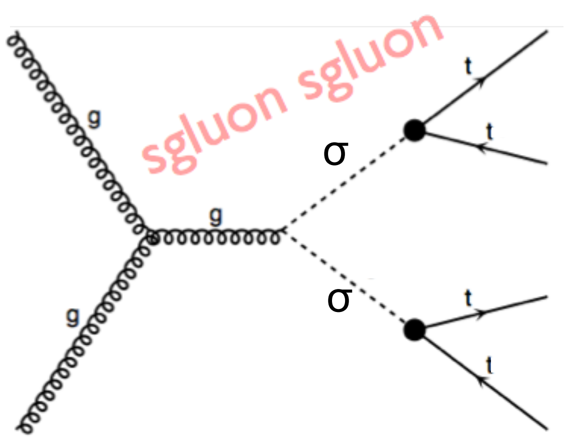
  Models with tttt signatures include:
  - Supersymmetry
  - New gauge forces
  - Higgs boson or top quark compositeness
  - Extra dimensions



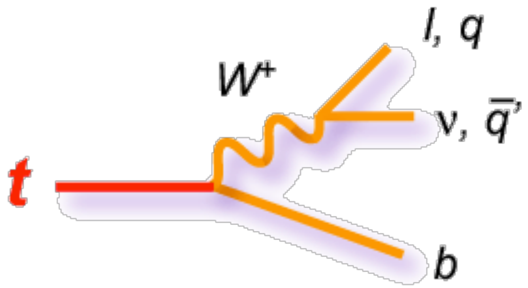


- Cross sections up to 10,000 times that of SM tttt production

*1 fb ≈ 1 event in 10^{14} proton-proton collisions

Top Quark

- Only quark to decay before it hadronises
- ~100% branching ratio to b quarks in standard model



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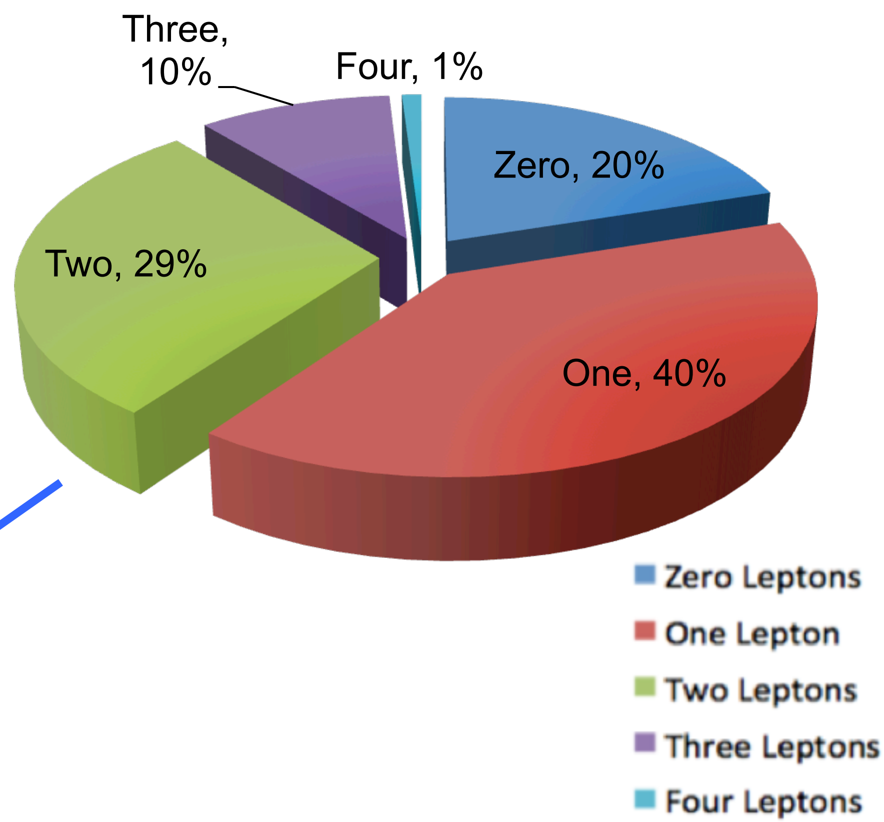
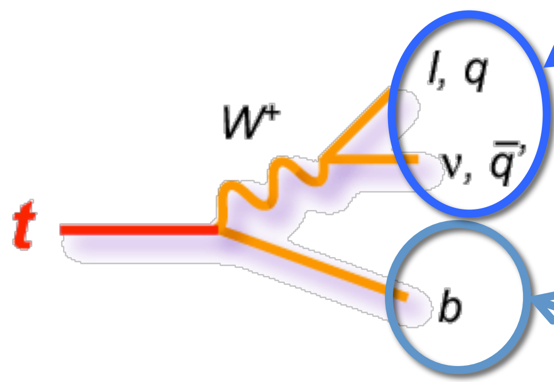
Four Top decay channels





b-quark identification is integral to top quark reconstruction

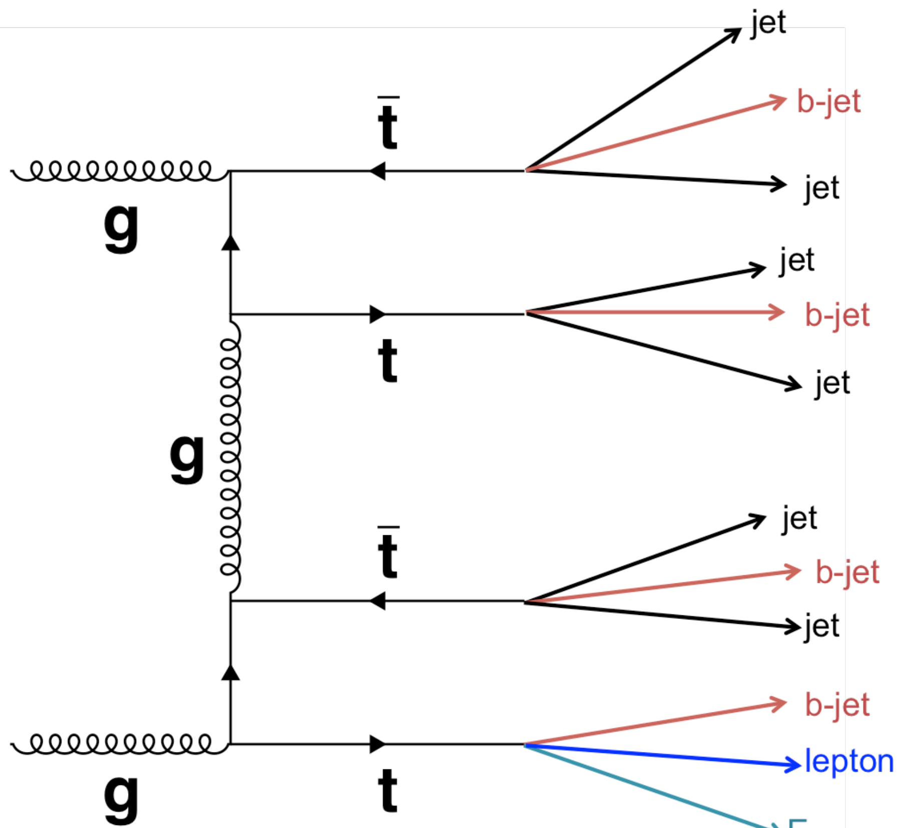
Single lepton channel

Single lepton channel (μ/e) which has ~40% BR

10 jets
4 b-jets
1 lepton
E_{Tmiss}

Selection

- Exactly 1 tight mu/e
- Additional lepton veto
- ≥ 6 jets
- ≥ 2 b-tagged jets



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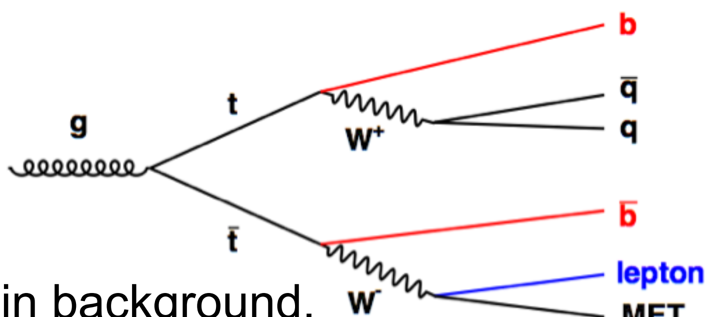
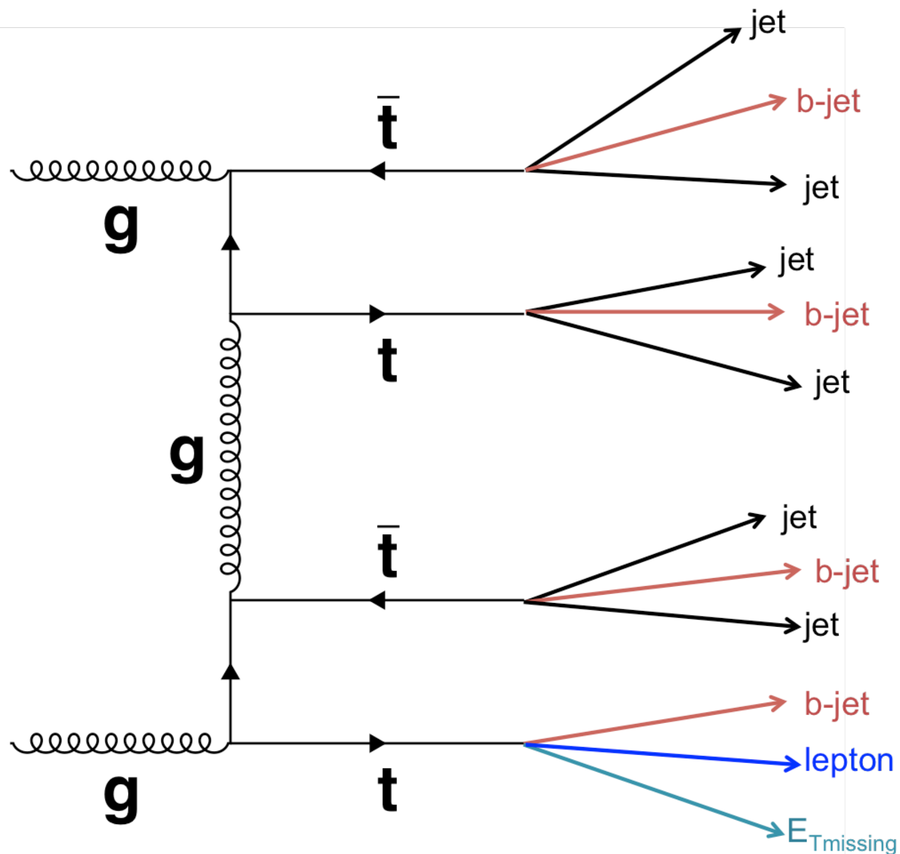


Main background, ttbar production



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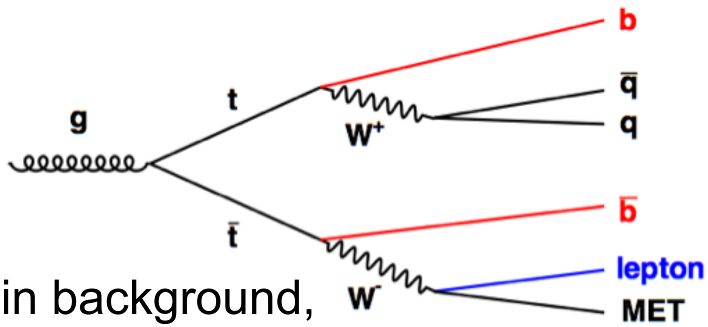

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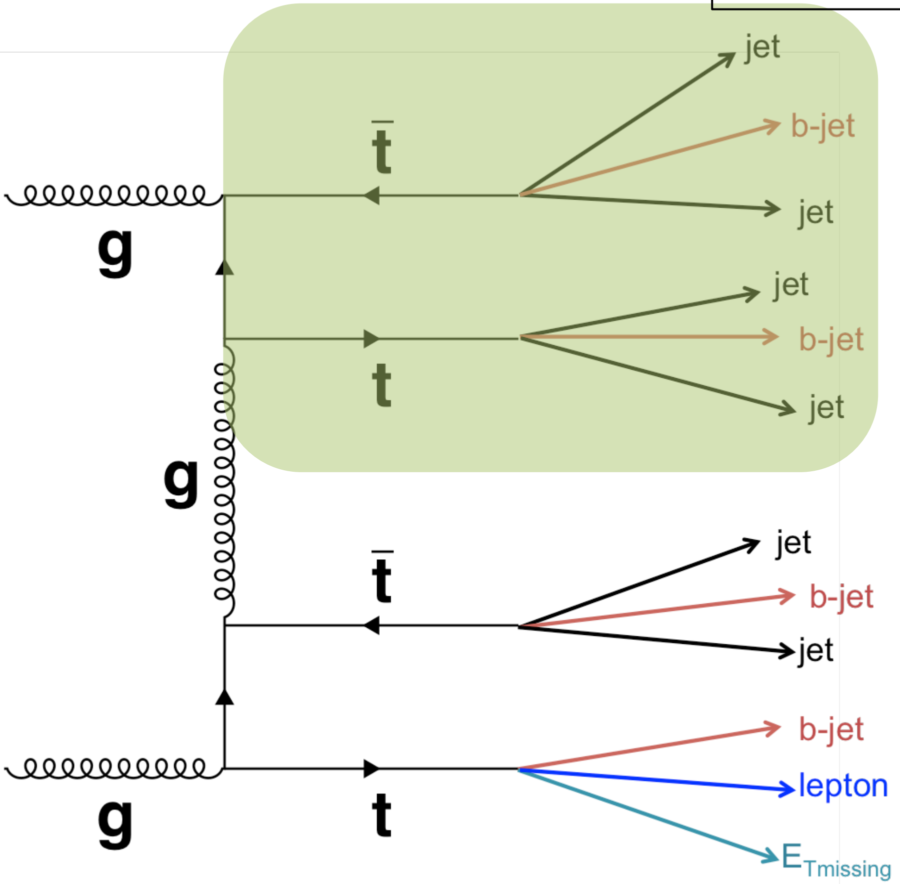
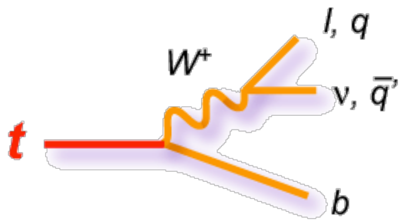
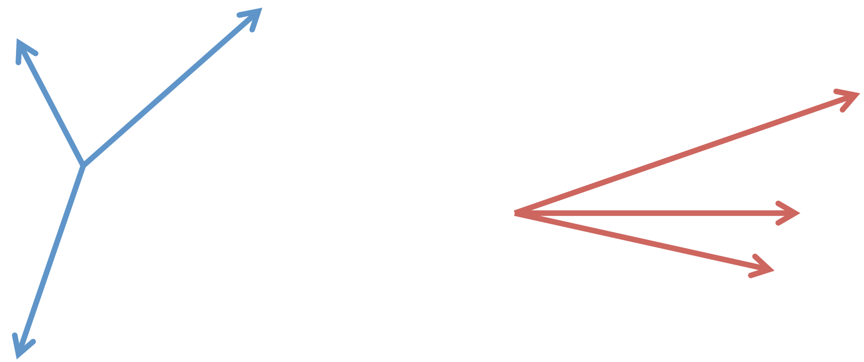


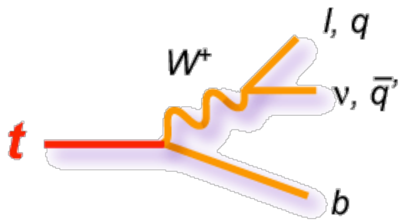
Should be possible to reconstruct more than one hadronically decaying top quark in signal events but not in background

Reconstruction of top quarks



Look at every combination of jets in the event





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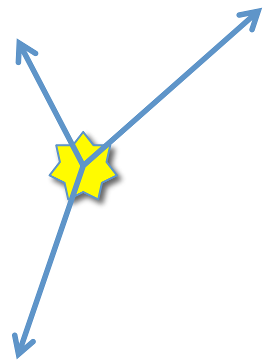
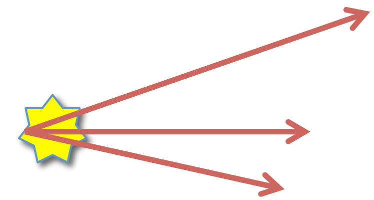
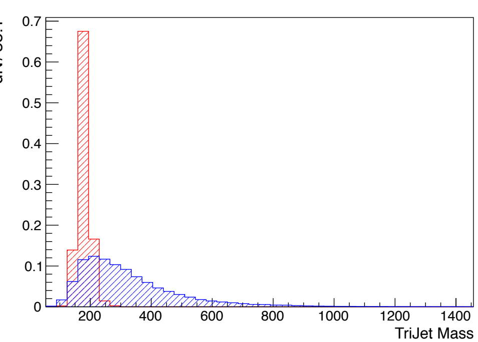
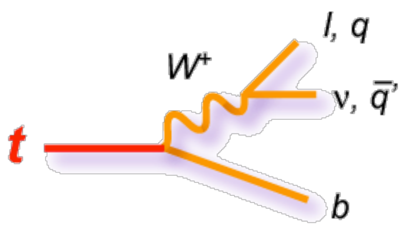




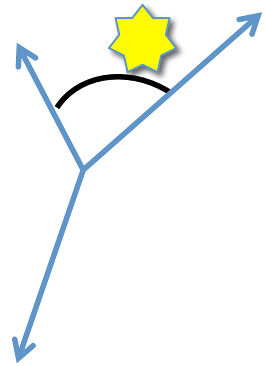
	Bad	Good
Invariant Mass of 3 jets	Not close to top	Close to top mass

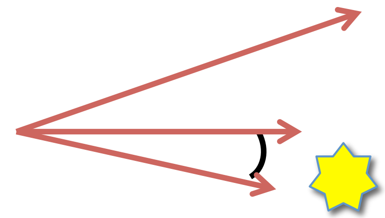




Reconstruction of top quarks

Look at every combination of jets in the event





	Bad	Good
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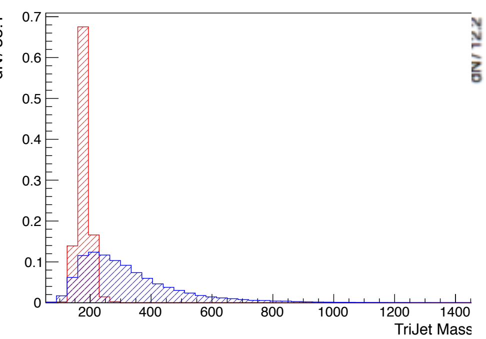
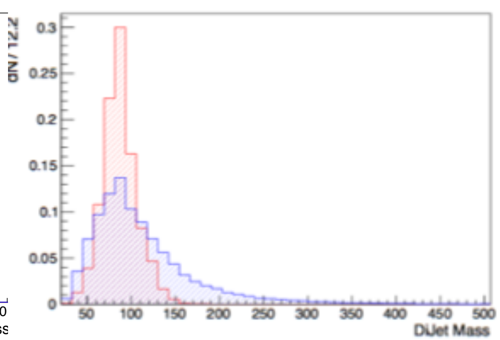
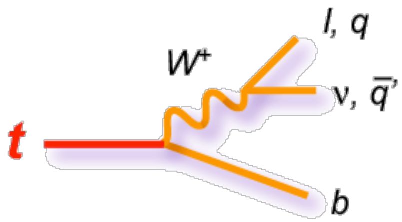
Inv. Mass of 2 closest jets	Not close to W	Close to W mass

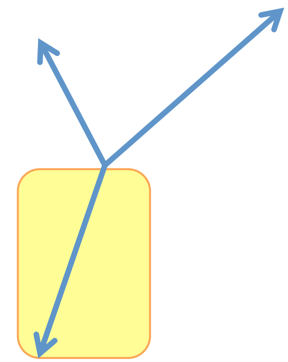


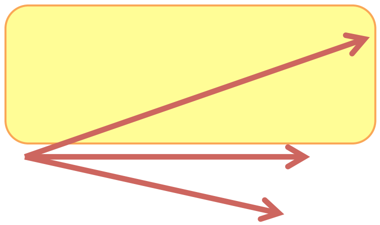




Reconstruction of top quarks

Look at every combination of jets in the event





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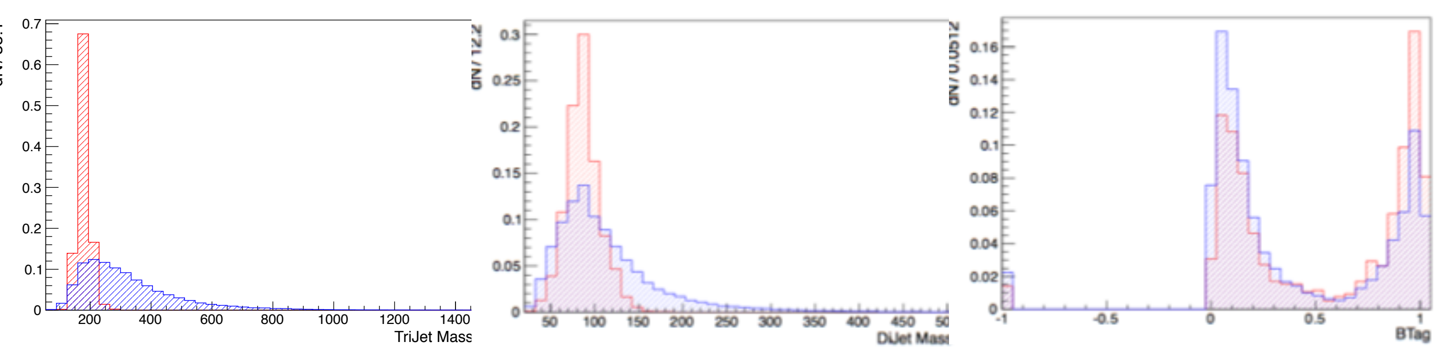
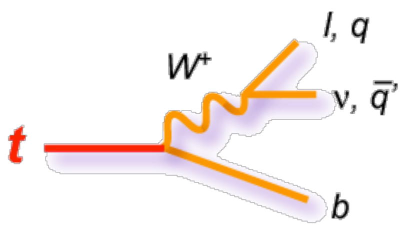
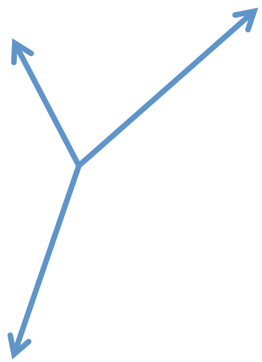
3rd jet b tagged?	No	Yes

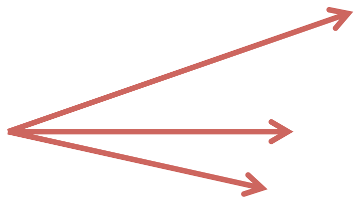




Reconstruction of top quarks

Look at every combination of jets in the event





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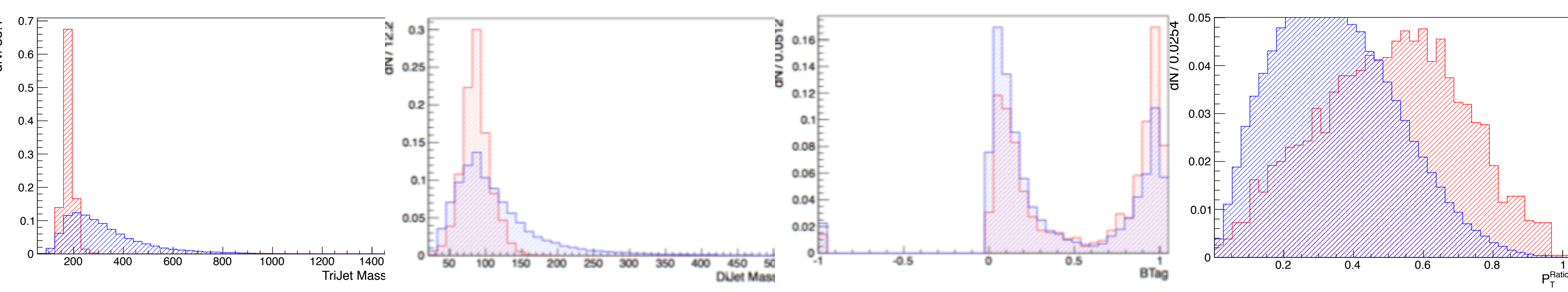
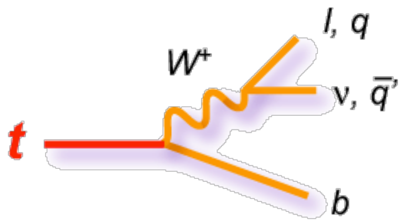
$\Sigma\overrightarrow{p_T}/\Sigma p_T$	0.1	0.9



Reconstruction of top quarks



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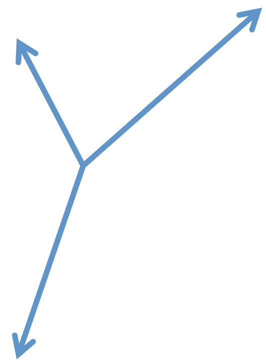

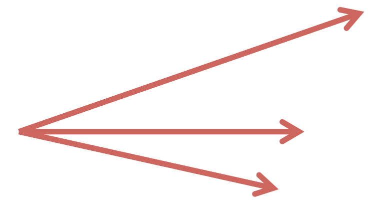

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Boosted Decision Tree

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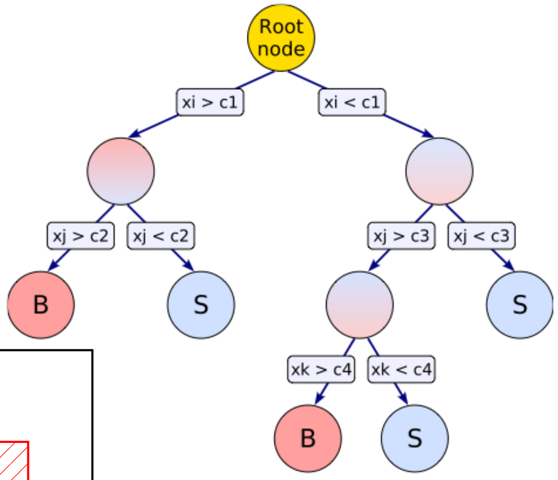
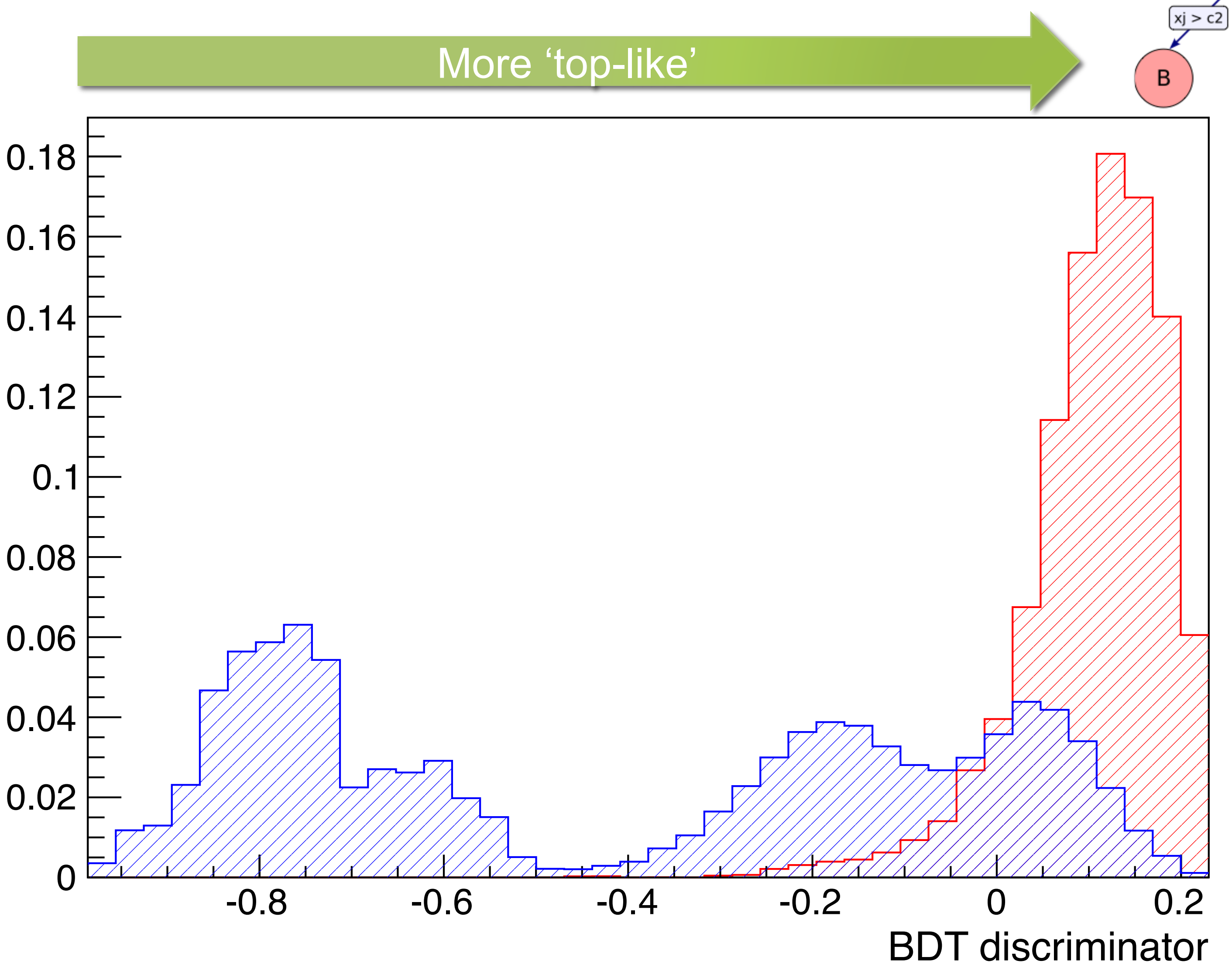
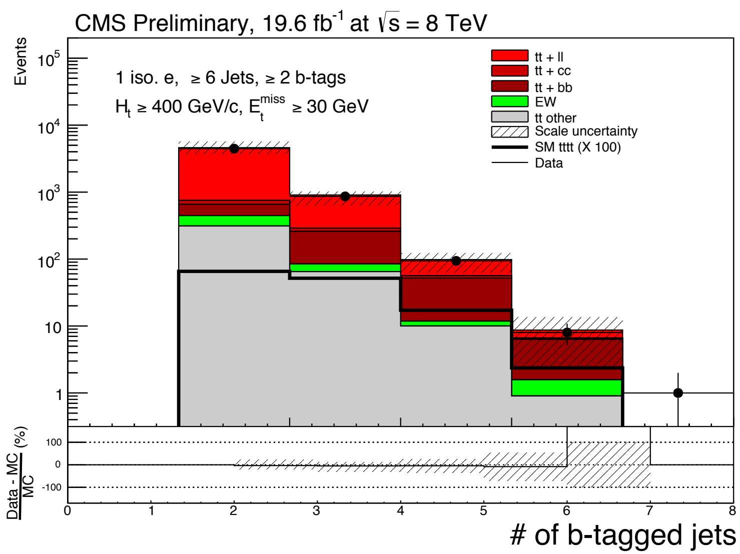
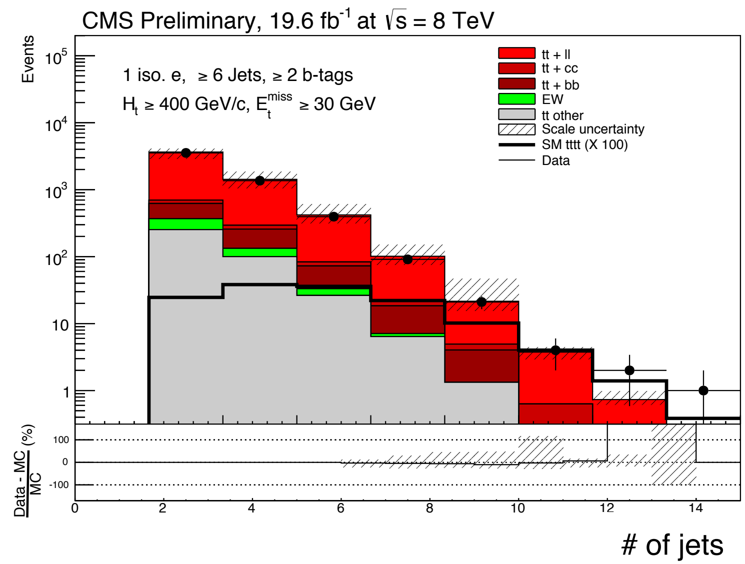
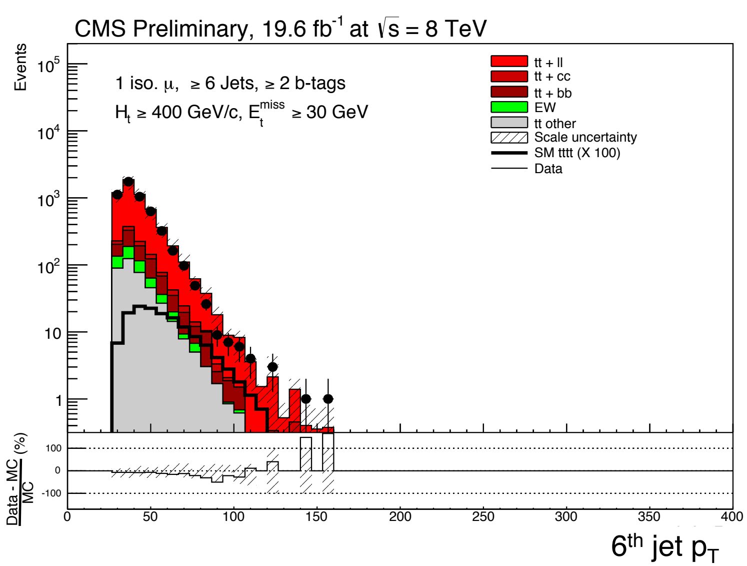


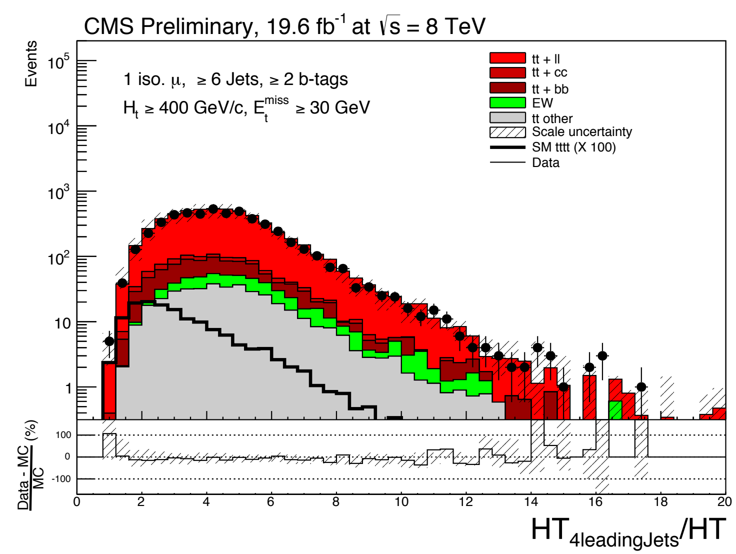


Finding discriminating variables

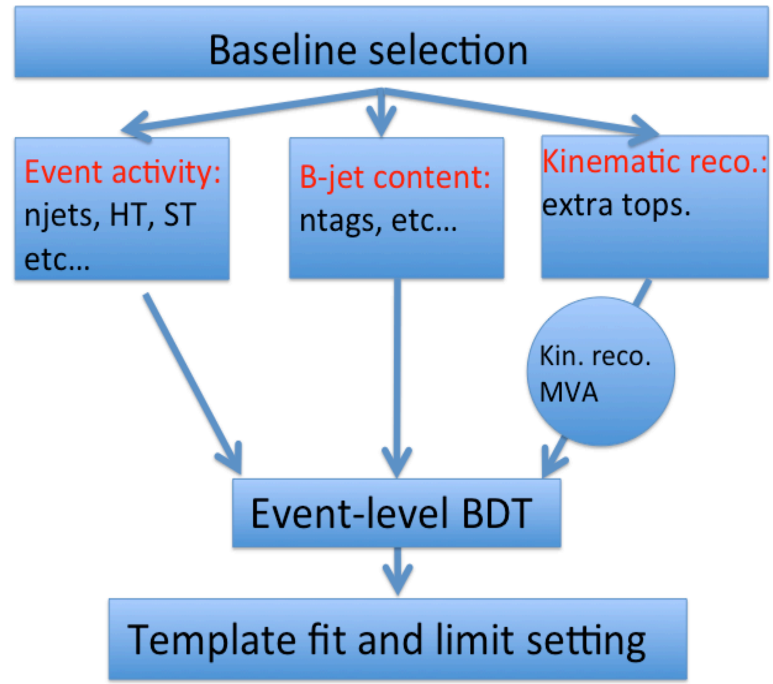




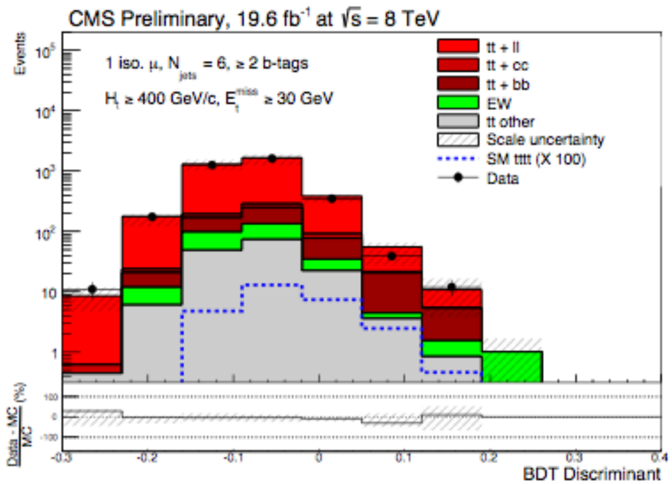




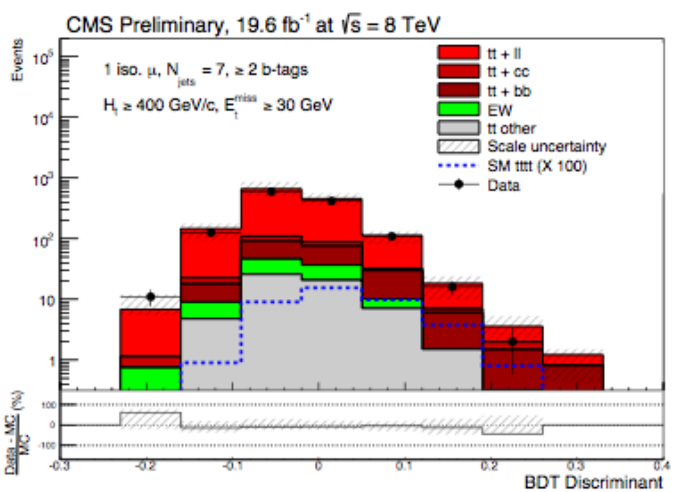
Analysis flow and BDT output distributions

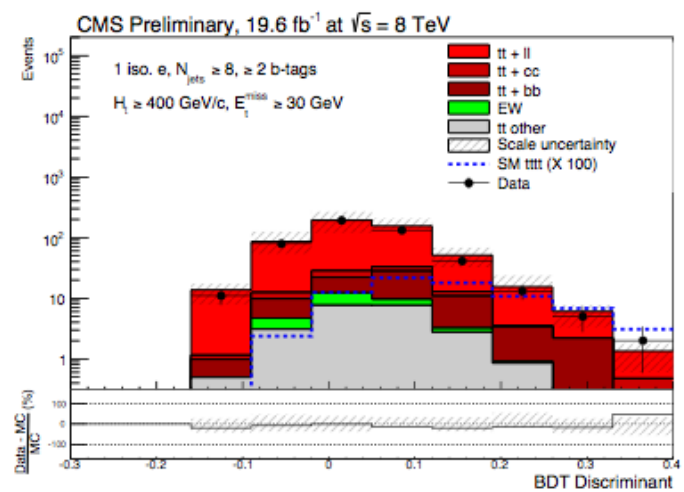


6jets



7jets





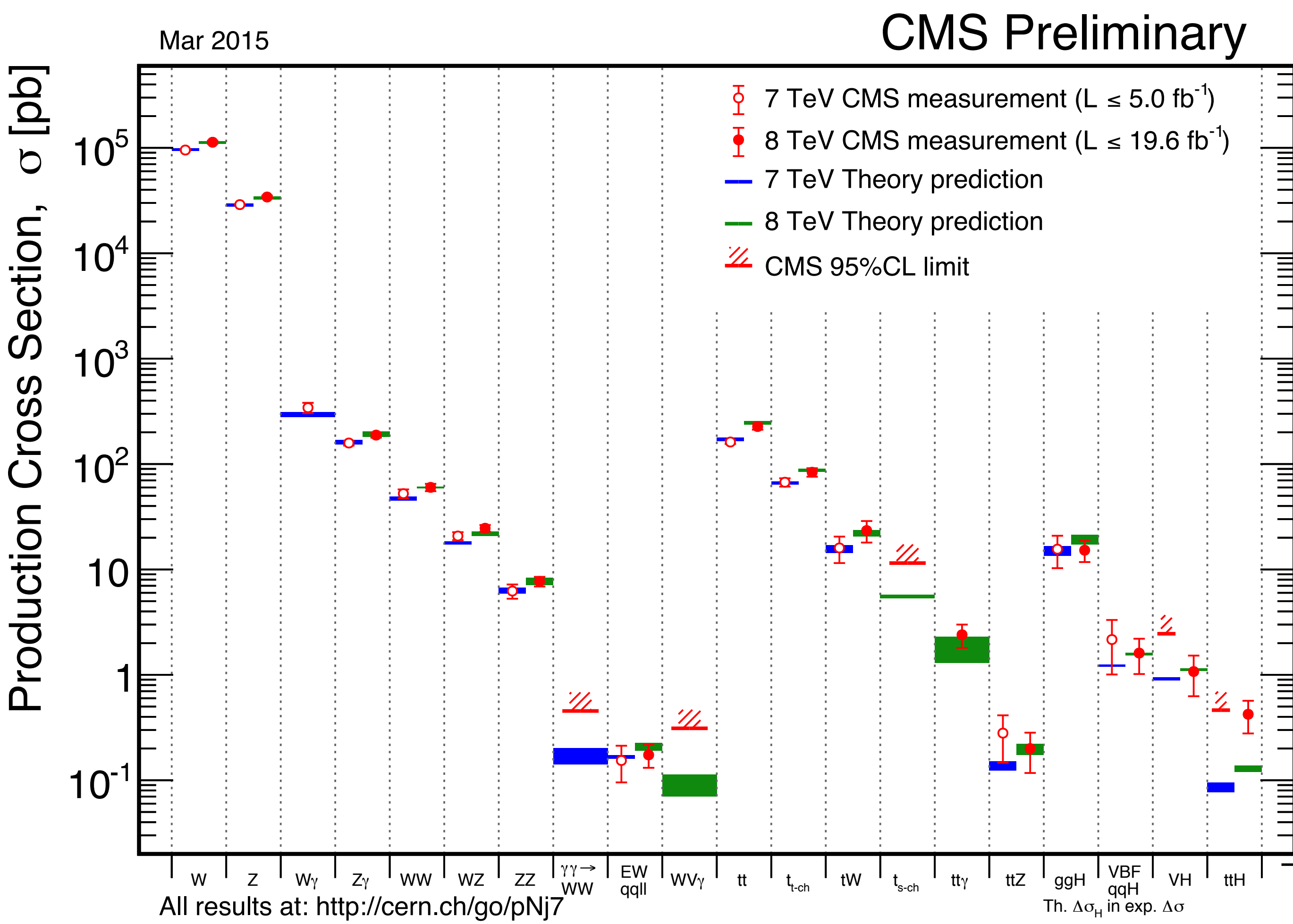
>8jets

More signal like

Four top signal scaled by 100

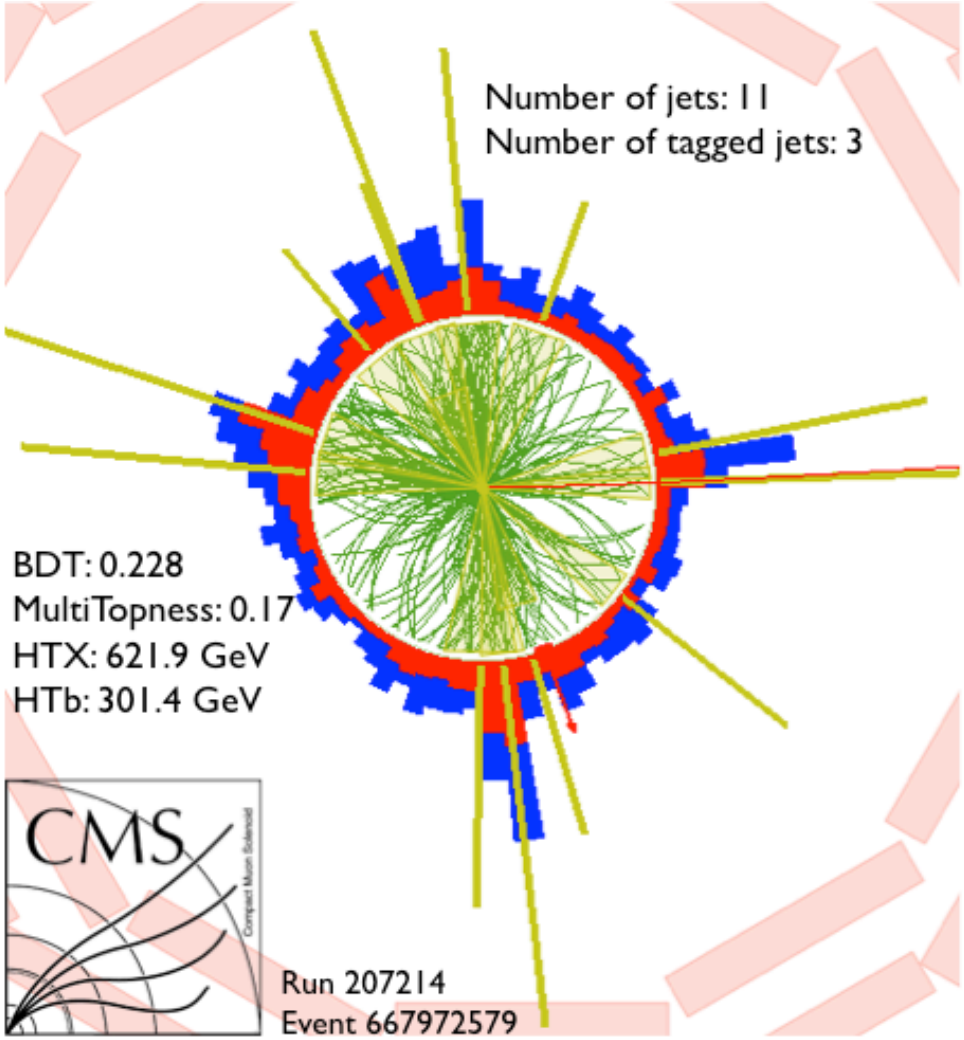
Standard model cross sections

A limit of 25 times the standard model cross section was set on four top quark production



95% CL on σ_{tttt} of 32 fb observed (32 fb expected)

Four top quark production candidate



What does Run2 @ 13TeV mean for my analysis?

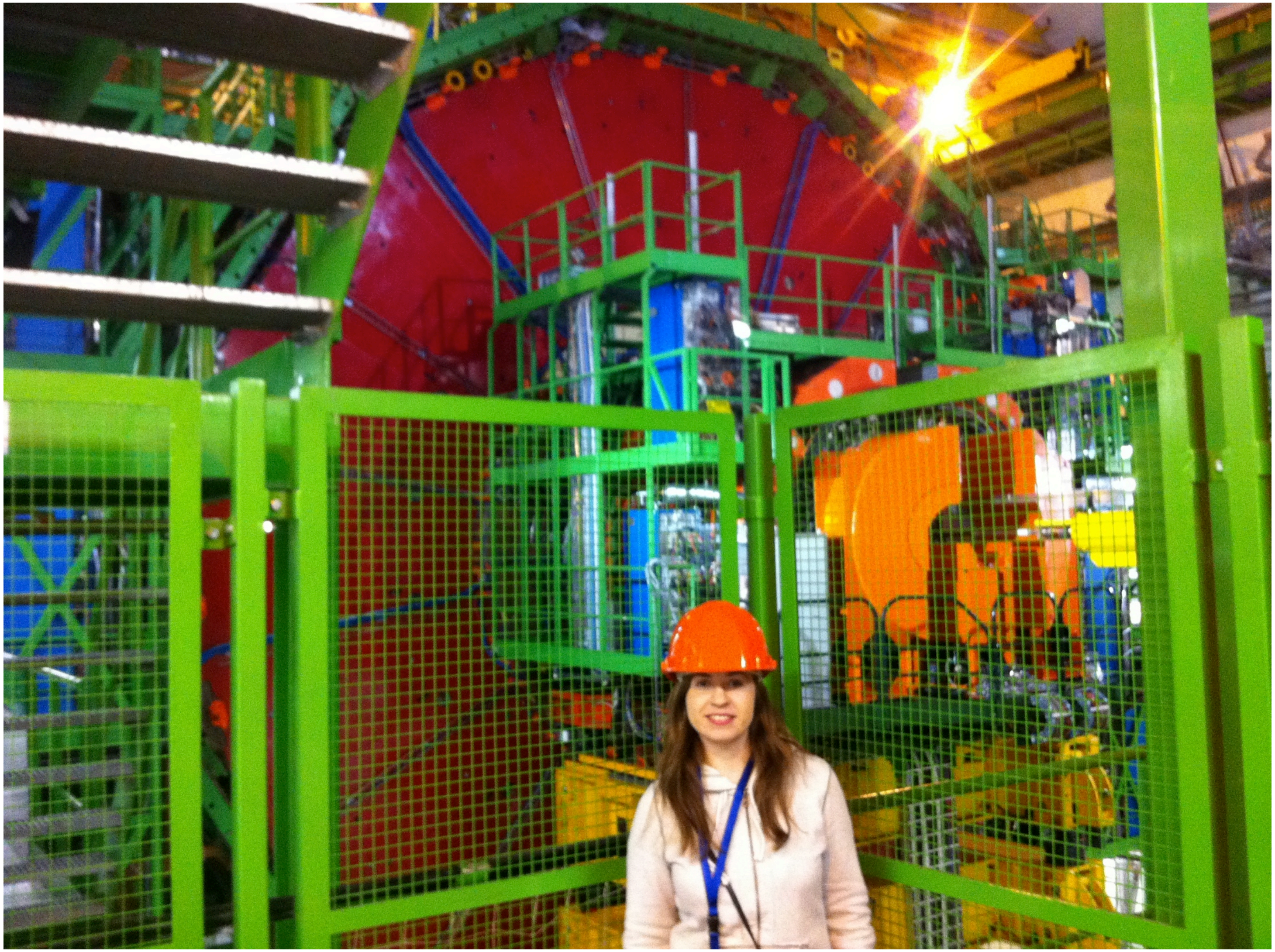
- 9 x increase in tttt cross section, 4 x increase in tt background
- Upgrades to detector and simulation
- Larger significance by combining more decay channels
- More discriminating variables found so far
- Possible observation of tttt production or a tighter cross section limit

Conclusions

- Four top production is a rare standard model process
- Some BSM models can enhance the tttt cross section
- Identifying b-quarks & reconstructing top quarks is key to this analysis
- Boosted Decision Trees used to separate signal and background
- At 8 TeV: set a limit of 25 x the standard model cross section
  - our paper doi: 10.1007/JHEP11(2014)154
  - phenomenological interpretation in the context of a sgluon model

  doi: 10.1016/j.physletb.2015.04.043
- We have high hopes for 13 TeV results

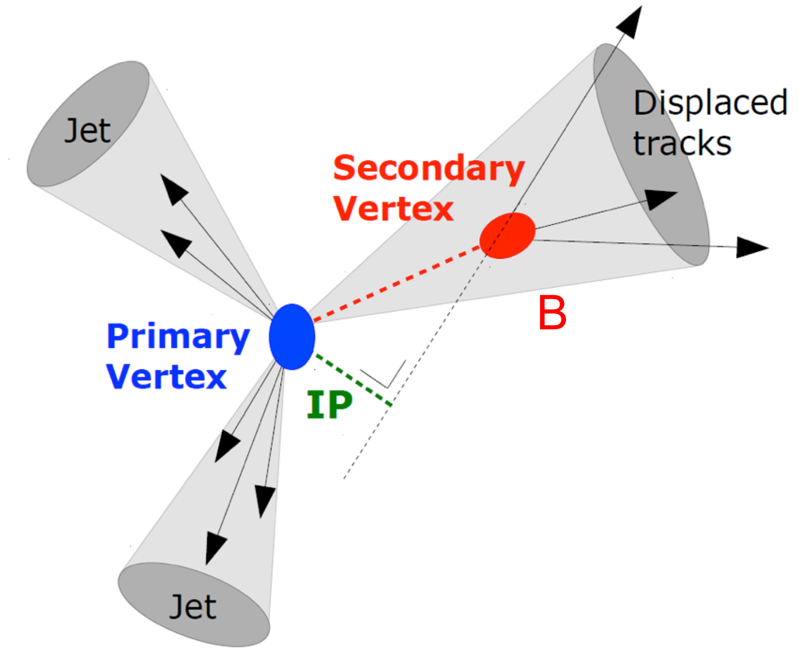
Thanks for listening

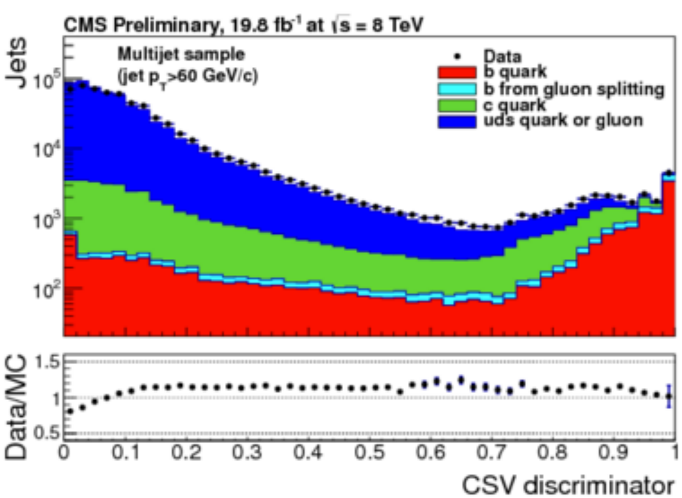


BACKUP

b-quark identification

- b-quarks travel a short distance before decaying
- Displaced tracks in the detector -> secondary vertex
- b-jets are often wider and have more constituent particles
- b-tagging associates a single, real number - a discriminator - with each jet, which is higher for more b-quark-like jets

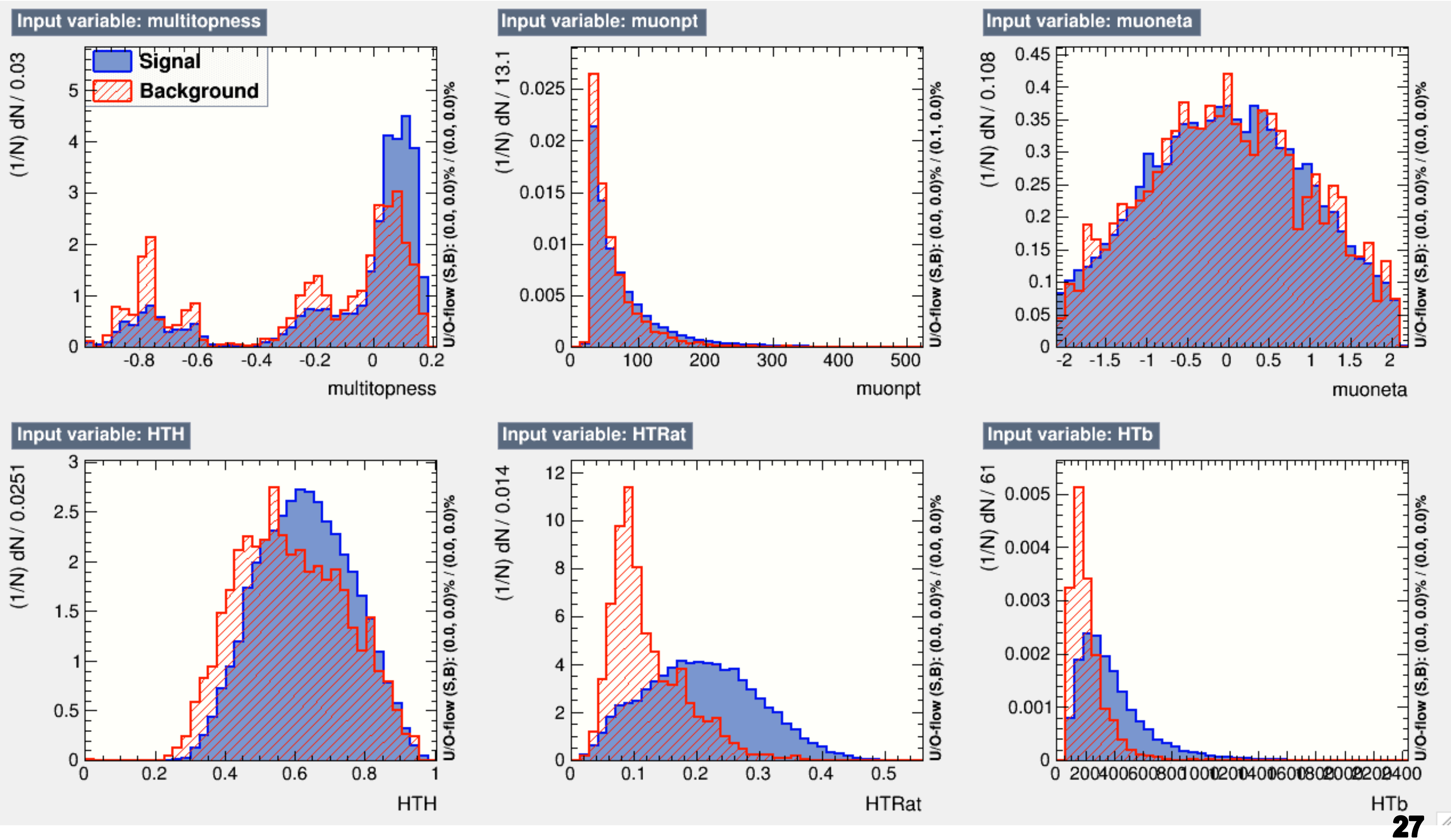




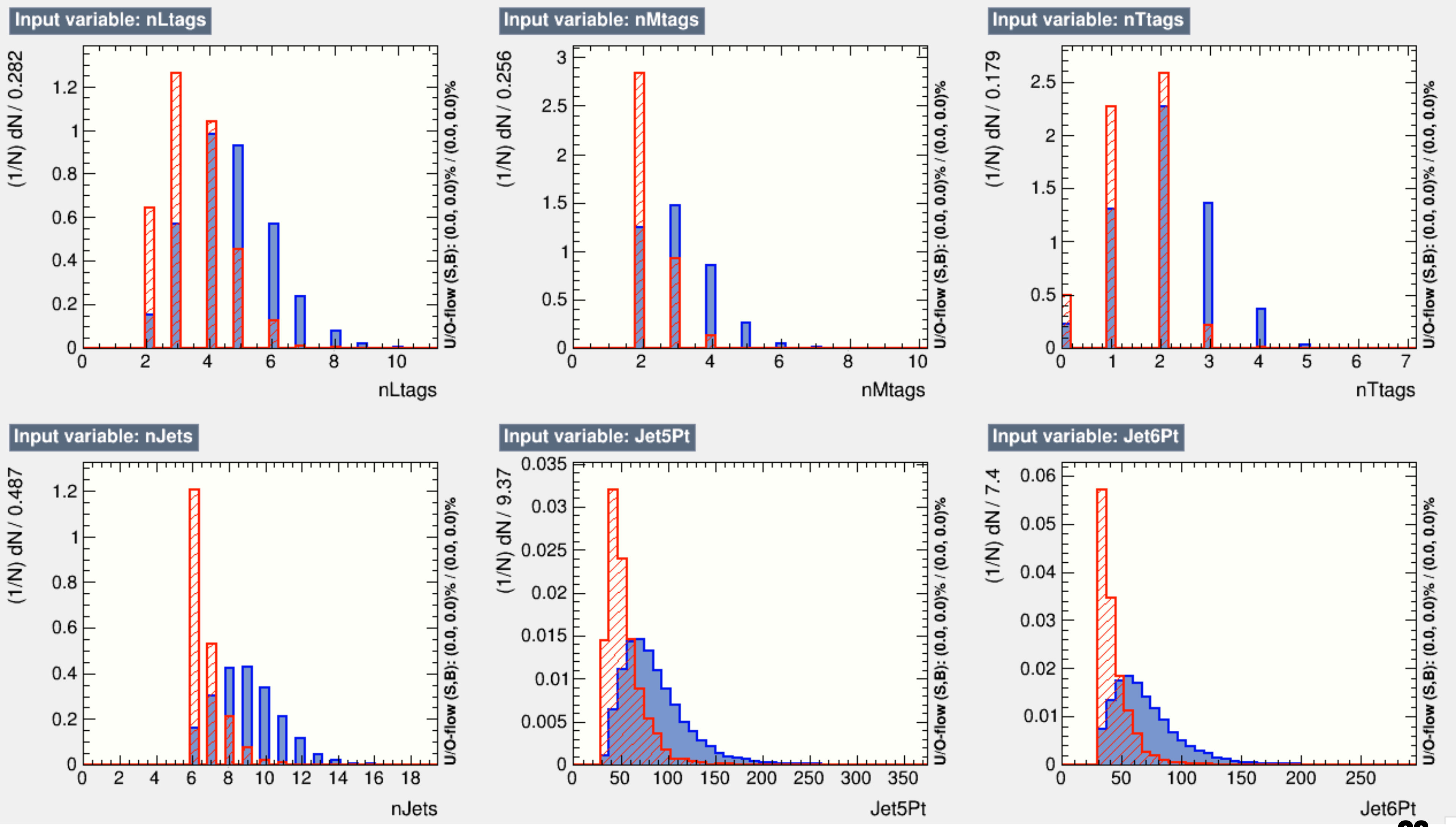
Event Level BDT

- Input variables
  - Multitopness
  - Lepton pT
  - Lepton eta
  - HTH = HT/H
  - HTRat = HT_{4 leading jets} / HT
  - HTb = HT of CSVM b jets
  - Number of CSVL, CSVM, CSVT b tags
  - nJets
  - 5^{th} Jet pT
  - 6^{th} Jet pT

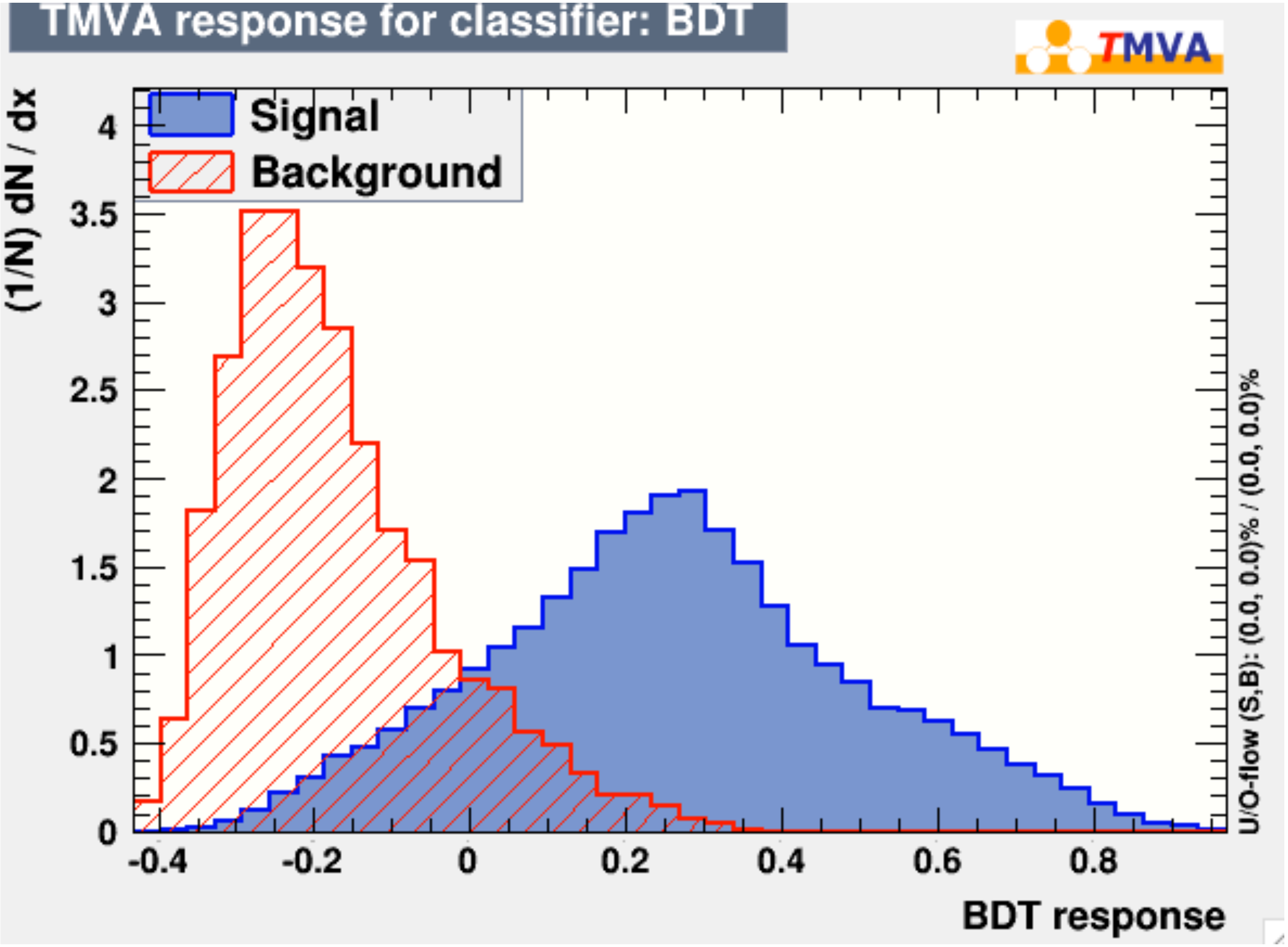
BDT input variables – training (I)



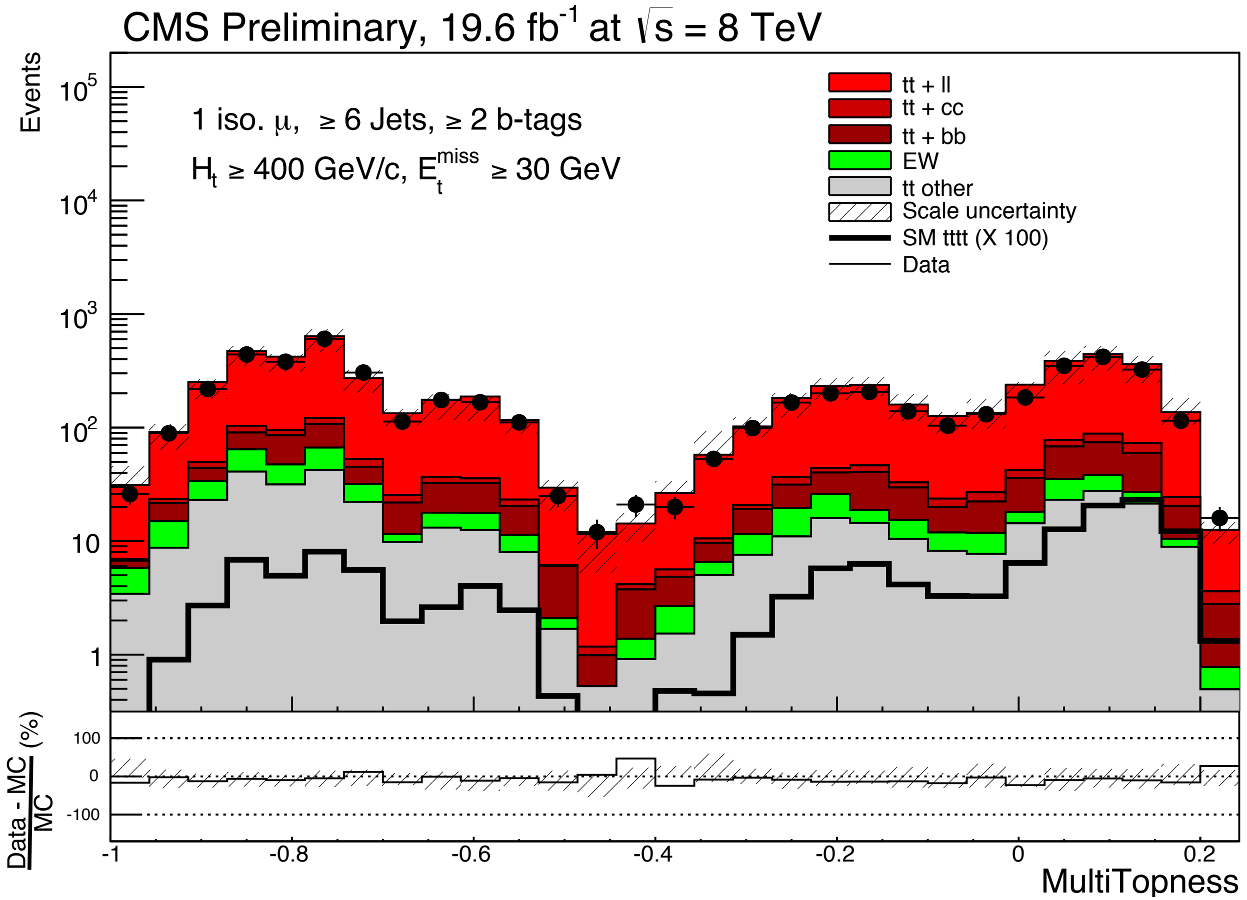
BDT input variables - training (II)



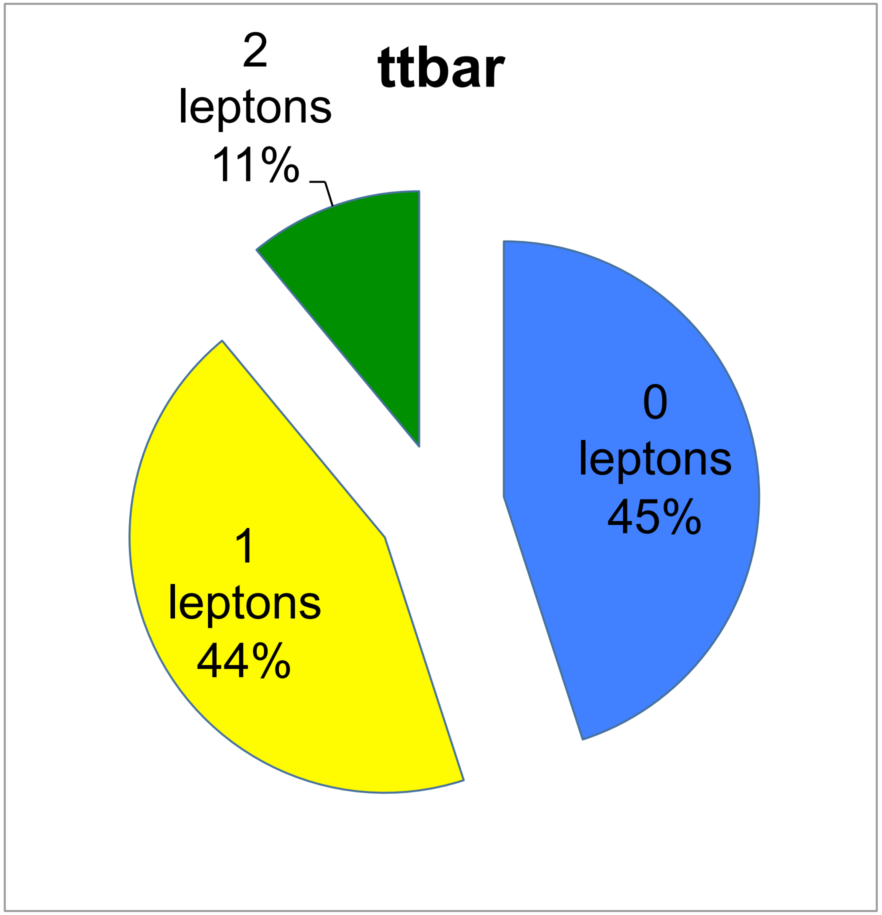
BDT output - training

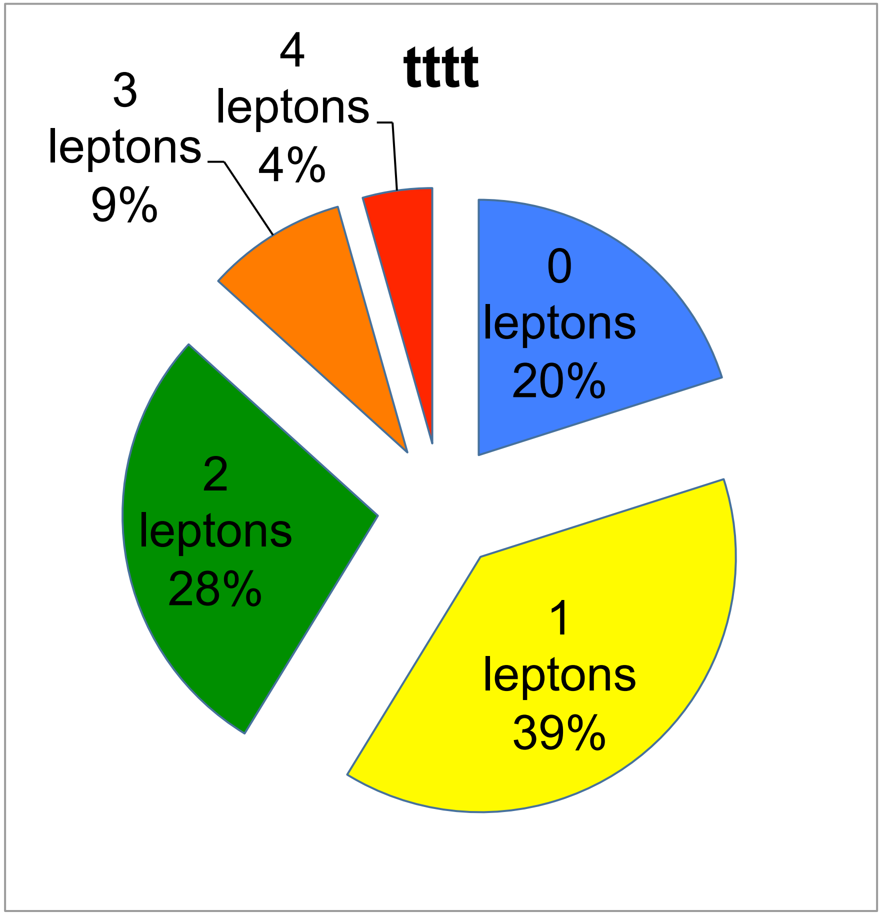


Multitopness

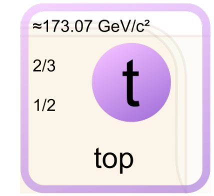


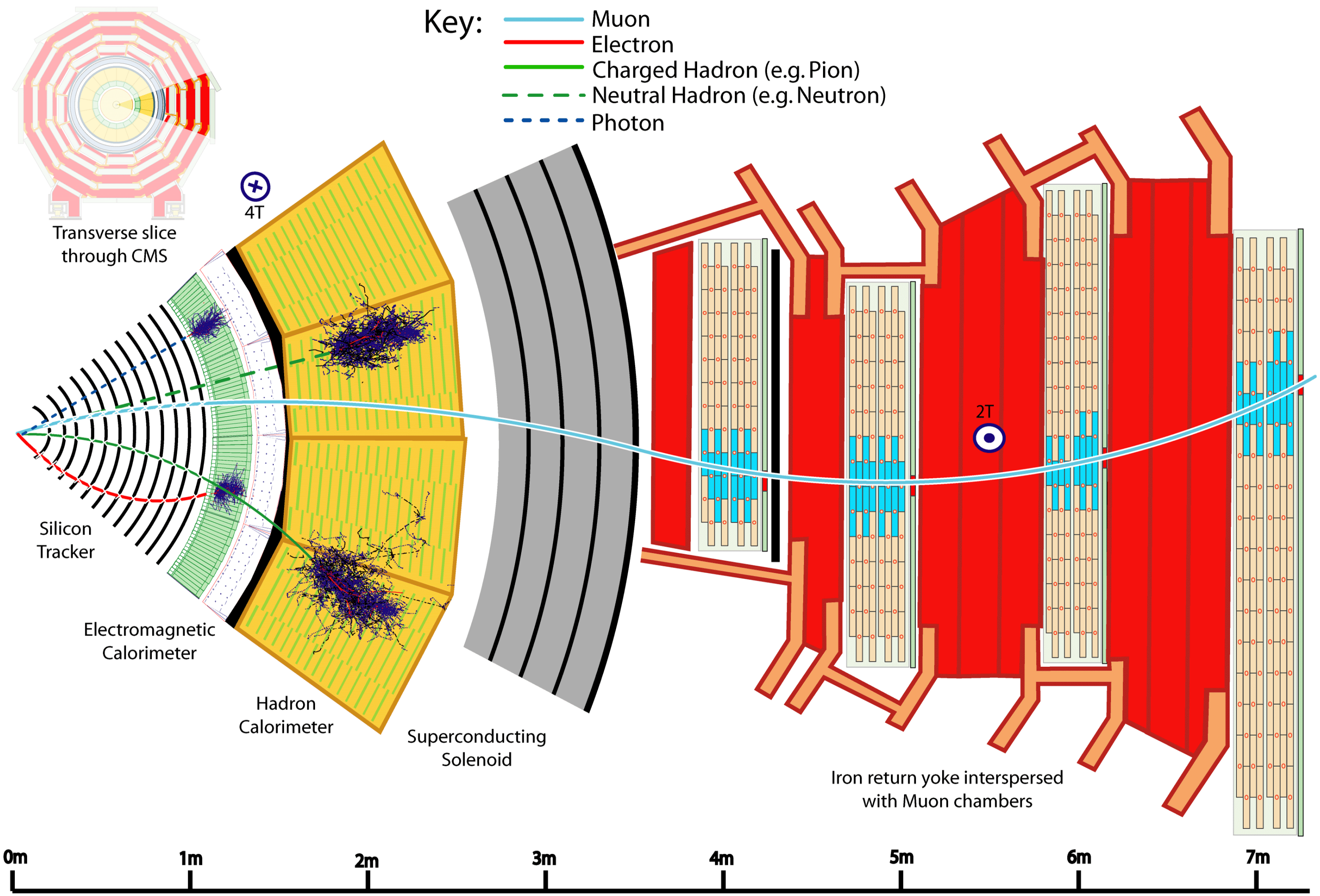
Multi-top production





CMS detector





CMS paper

Phenomenology study

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Search for standard model production of four top quarks in the lepton + jets channel in pp collisions at $\sqrt{s} = 8$ TeV

JHEP11(2014)154

The CMS collaboration

E-mail: cms-publication-committee-chair@cern.ch

Abstract: A search is presented for standard model (SM) production of four top quarks ($t\bar{t}t\bar{t}$) in pp collisions in the lepton + jets channel. The data correspond to an integrated luminosity of 19.6 fb^{-1} recorded at a centre-of-mass energy of 8 TeV with the CMS detector at the CERN LHC. The expected cross section for SM $t\bar{t}t\bar{t}$ production is $\sigma^{\rm SM}_{t\bar{t}t\bar{t}} \approx 1$ fb. A combination of kinematic reconstruction and multivariate techniques is used to distinguish between the small signal and large background. The data are consistent with expectations of the SM, and an upper limit of 32 fb is set at a 95% confidence level on the cross section for producing four top quarks in the SM, where a limit of 32 ± 17 fb is expected.

Keywords: Hadron-Hadron Scattering, Top physics

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doi:10.1007/JHEP11(2014)154

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ELSEVIER

Probing top-philic sgluons with LHC Run I data

Lana Beck [a,b,c], Freya Blekman [b,c], Didar Dobur [c,d,e], Benjamin Fuks [f], James Keaveney [b,c], Kentarou Mawatari [b,c,g,*]

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ABSTRACT

Many theories beyond the Standard Model predict the existence of colored scalar states, known as sgluons, lying in the adjoint representation of the QCD gauge group. In scenarios where they are top-philic, sgluons are expected to be copiously pair-produced at the LHC via strong interactions with decays into pairs of top quarks or gluons. Consequently, sgluons can be sought in multijet and multitop events at the LHC. We revisit two LHC Run I analyses in which events featuring either the same-sign dileptonic decay of a four-top-quark system or its single leptonic decay are probed. Adopting a simplified model approach, we show how this reinterpretation allows us to extract simultaneous bounds on the sgluon mass and couplings.

1. Introduction

Despite its success in describing all experimental high-energy physics data, the Standard Model (SM) of particle physics leaves many important and conceptual issues unanswered. As a consequence, many theoretical frameworks extending it have been developed over the last decades, and new phenomena have been searched for experimentally. Weak scale supersymmetry, and in particular its minimal realization known as the Minimal Supersymmetric Standard Model (MSSM) [1,2], is one of the most studied of those beyond the SM setups. It is however more and more constrained by data, and especially by the recent results of the LHC experiments [3,4]. There are nevertheless large varieties of alternative non-minimal supersymmetric models that deserve to be investigated and whose signatures may be different from the expectations of the minimal choice.

Along these lines, we focus on $N = 1/N = 2$ hybrid [5,6] and R-symmetric [7–9] supersymmetric theories that both predict extra scalar partners to the SM gauge bosons. These additional degrees of freedom lie in the adjoint representation of the gauge group and are indeed not present in the MSSM. Among the new particles, the colored states commonly dubbed sgluons have received special attention as they are expected to be copiously produced at hadron colliders [10–18]. Those fields however appear not only in supersymmetry but also in vector-like confining theories [19] and extra-dimensional models [20]. Motivated by typical sgluon signatures that are similar in all these models, we adopt a simplified model approach describing the dynamics of a scalar field lying in the octet representation of $SU(3)_c$ and interacting with the SM [21,17]. This subsequently allows both for a model-independent approach and a simplification of the non-minimal supersymmetric parameter spaces that in general contain hundreds of free parameters.

This simplified approach has been used experimentally in order to search for hints of sgluons in LHC collision data at center-of-mass energies of 7 TeV and 8 TeV. As a consequence of null results, limits on the sgluon mass, m_S, have been extracted after probing the production of a sgluon pair that decays into either a four top-quark system yielding a same-sign dilepton final state [22], or a four-jet final state [23]. In the former case, m_S is

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CMS paper	Phenomenology study

CMS paper

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Search for standard model production of four top quarks in the lepton + jets channel in pp collisions at $\sqrt{s} = 8$ TeV

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The CMS collaboration

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ABSTRACT: A search is presented for standard model (SM) production of four top quarks ($t\bar{t}t\bar{t}$) in pp collisions in the lepton + jets channel. The data correspond to an integrated luminosity of 19.6 fb^{-1} recorded at a centre-of-mass energy of 8 TeV with the CMS detector at the CERN LHC. The expected cross section for SM $t\bar{t}t\bar{t}$ production is $\sigma^{SM}_{t\bar{t}t\bar{t}} \approx 1$ fb. A combination of kinematic reconstruction and multivariate techniques is used to distinguish between the small signal and large background. The data are consistent with expectations of the SM, and an upper limit of 32 fb is set at a 95% confidence level on the cross section for producing four top quarks in the SM, where a limit of 32 ± 17 fb is expected.

KEYWORDS: Hadron-Hadron Scattering, Top physics

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Phenomenology study

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Probing top-philic sgluons with LHC Run I data

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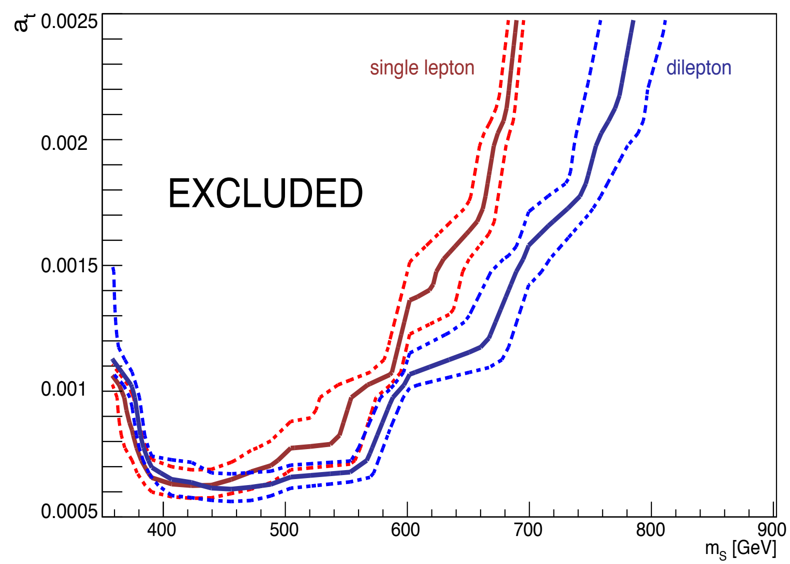
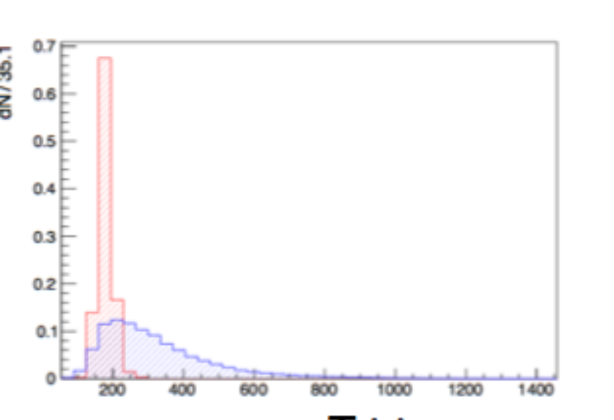


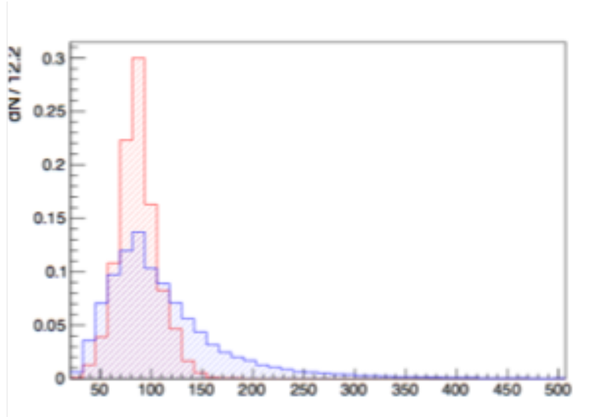
Distinguishing variables between good and bad tri-jet combinations

Good tri-jet defined as all 3 jets originating from a top quark and bad tri-jet being any other combination

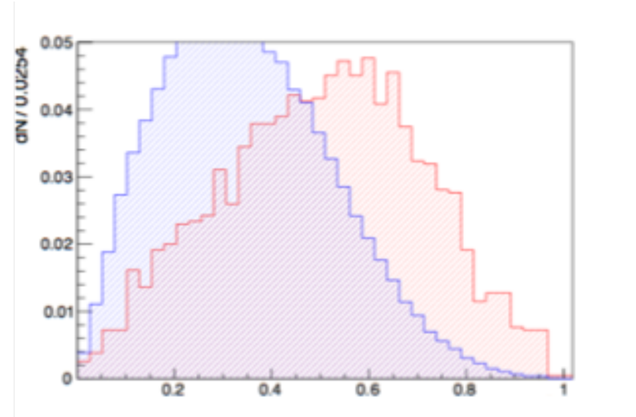
Tri-jet invariant mass	good tri-jets should have an invariant mass close to top mass
Di-jet invariant mass	formed from two jets with smallest ΔR separation and should have mass close to the W mass
$\Sigma p_T / \Sigma p_T$	ratio of vectorial p_T to the scalar sum of the p_T of the jets in the tri-jet
$\Delta\phi_{T\text{-}W}$	$\Delta\phi$ between tri-jet and di-jet system used in invariant mass variable
$\Delta\phi_{T\text{-}b}$	$\Delta\phi$ between tri-jet and jet not included in di-jet system
CSV_j	CSV b-tagging discriminator for jet not used in di-jet



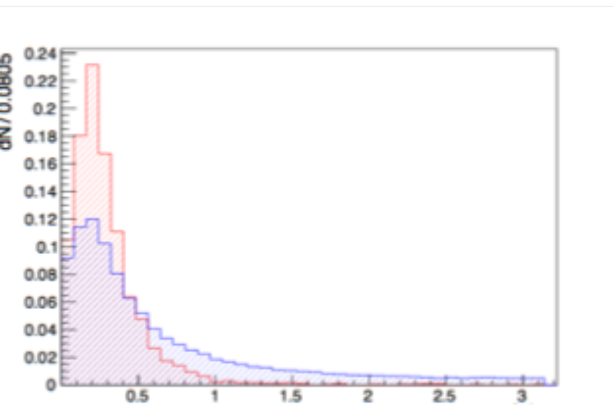
Tri-jet mass



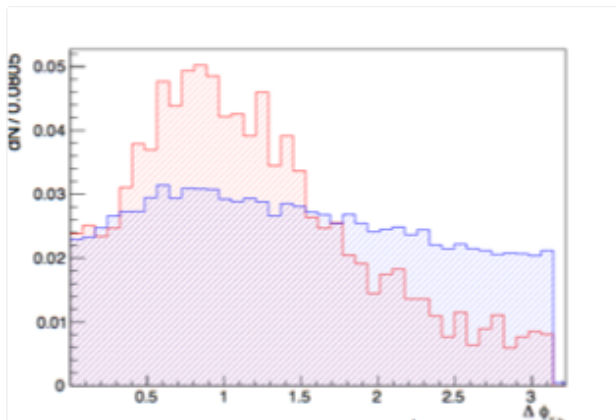
Di-jet mass



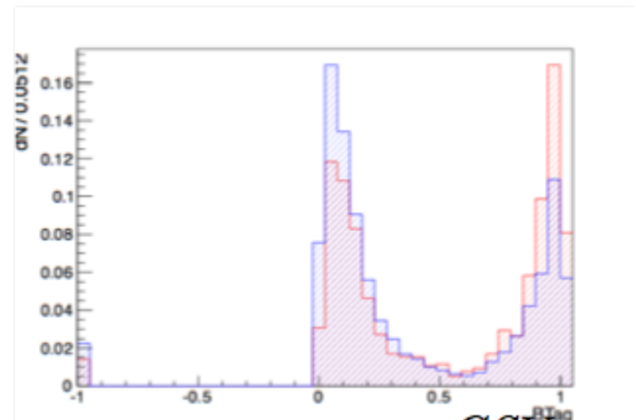
$\Sigma\vec{p}_T/\Sigma p_T$



$\Delta\phi_{T\text{-}W}$



$\Delta\phi_{T-b}$



CSV_j

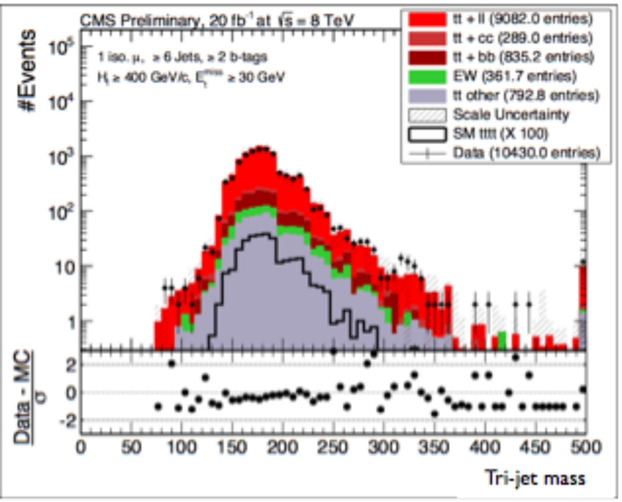
Blue - Bad combinations

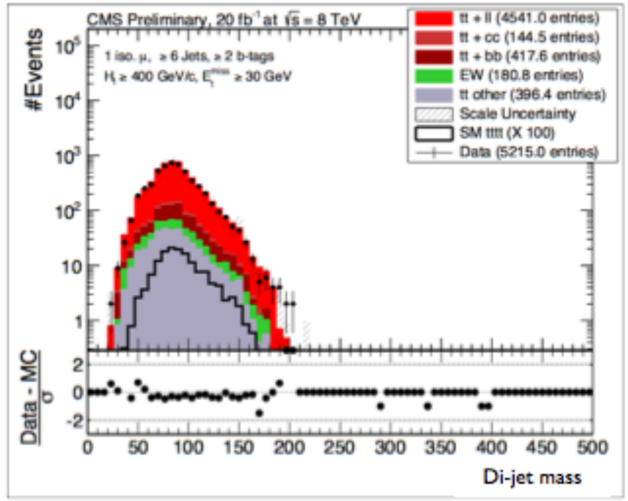
Red - Good combinations

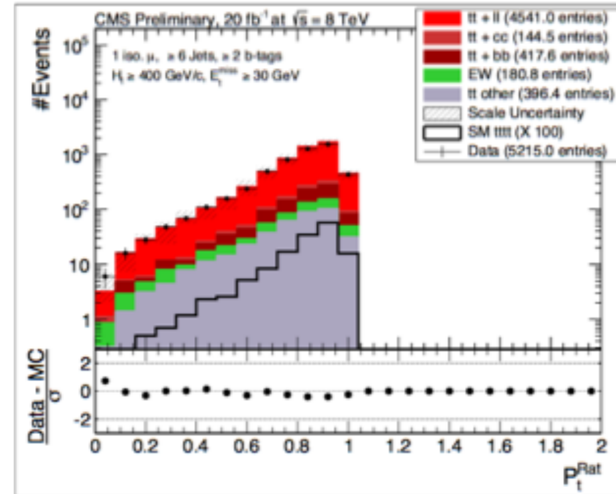
After baseline selection

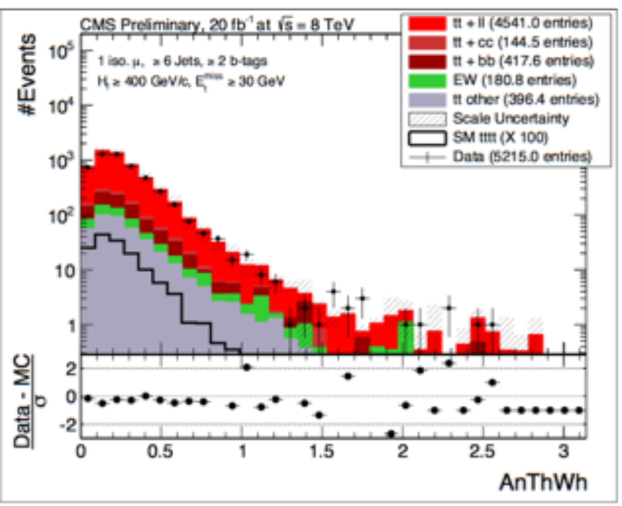
Version 4.1.2. of TMVA package used to combine variables

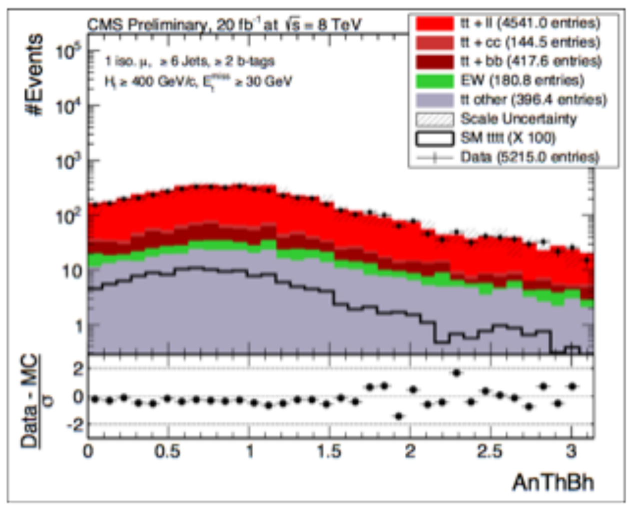
Data simulation comparison for highest ranked tri-jet

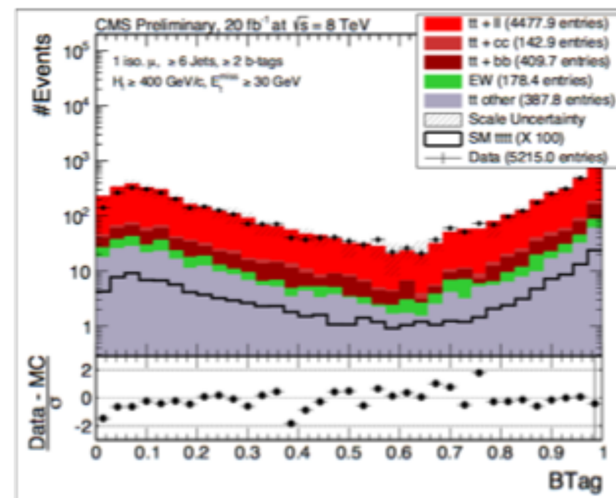








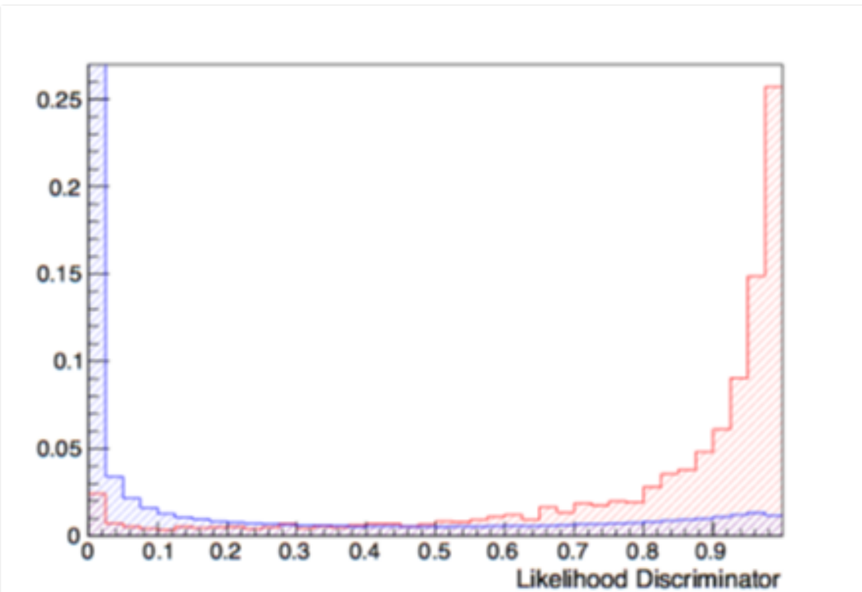


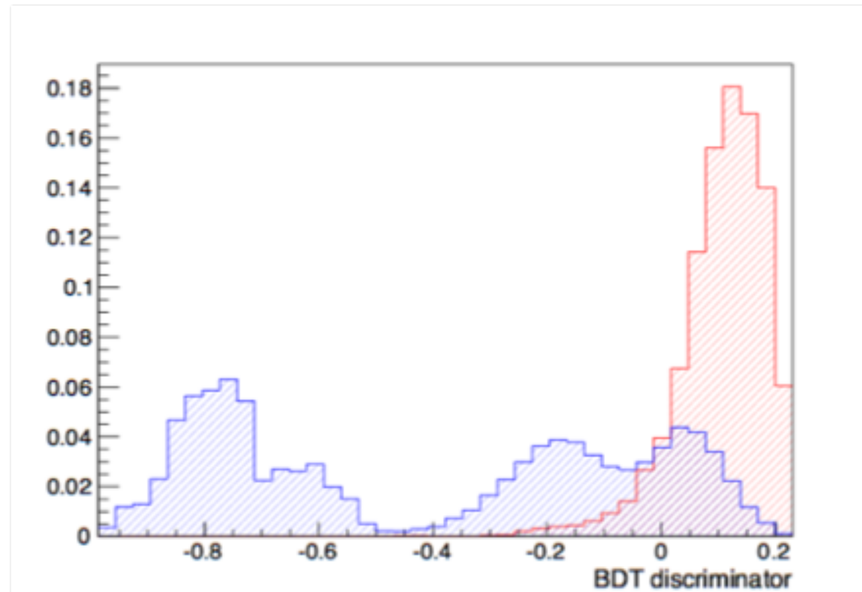


Good agreement observed

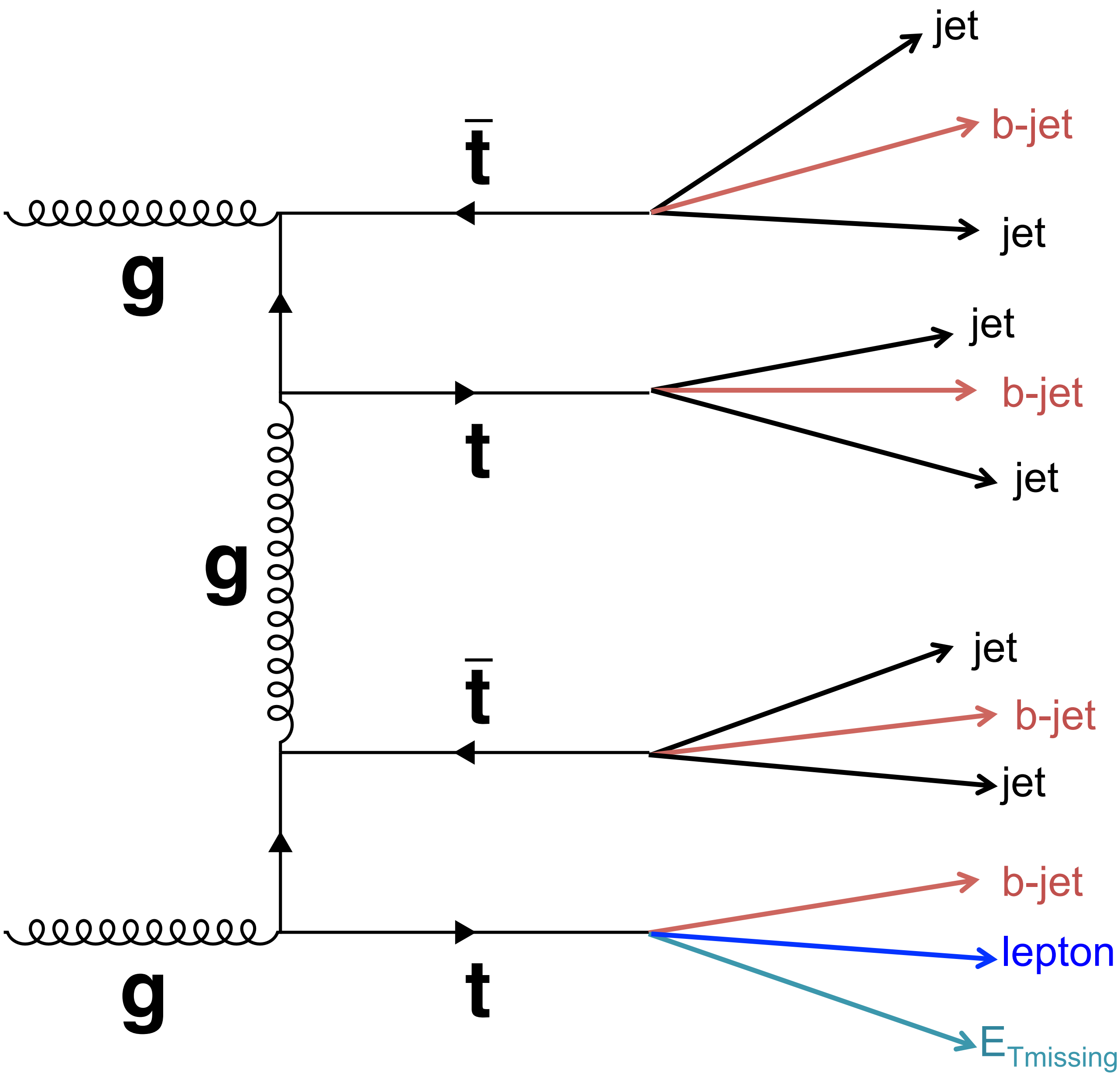
Resulting discriminators

MVA trained on 200K ttbar events providing a large sample of data for good and bad tri-jets

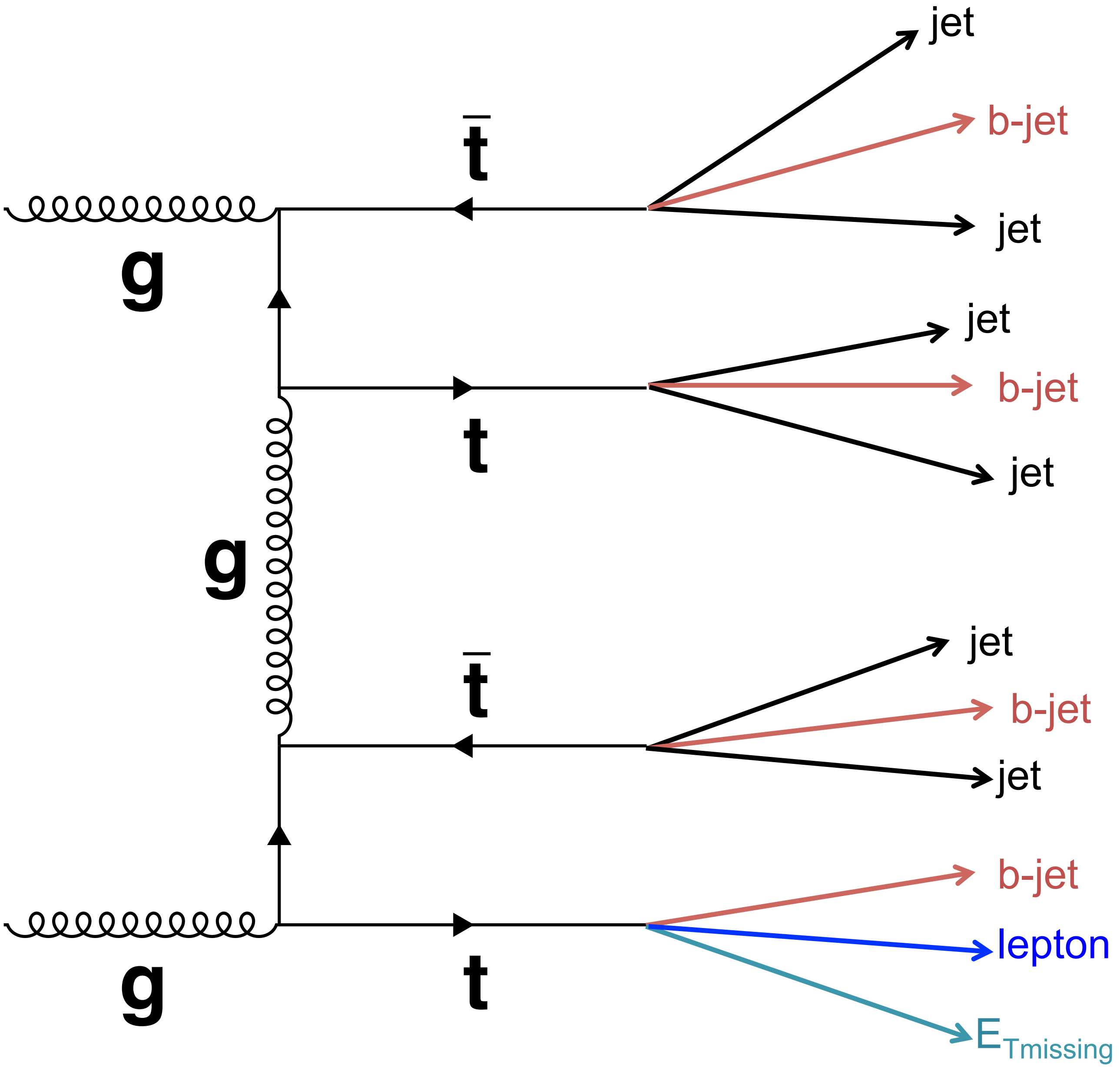




	Simplicity	Transparent?	Computation	Correlated variables
Likelihood	Simple	Yes	Not intensive	Less effective
BDT	Complex	No	More Intensive	Works well



10 jets
4 b-jets
1 lepton
E_{Tmiss}



10 jets
4 b-jets
1 lepton
E_{Tmiss}

CMS Detector