Applications of Jet substructure-1

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Overview

- Kaluza Klein resonance
- Top partners decay
- Identifying the new physics

Outline

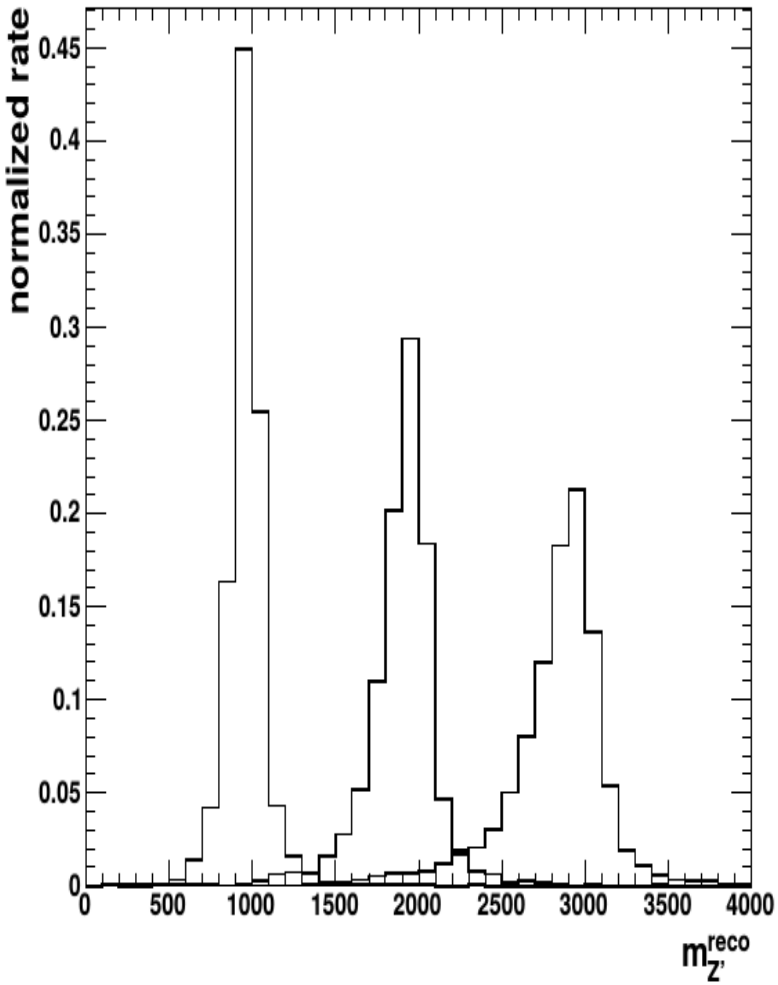
Kaluza Klein Gauge bosons

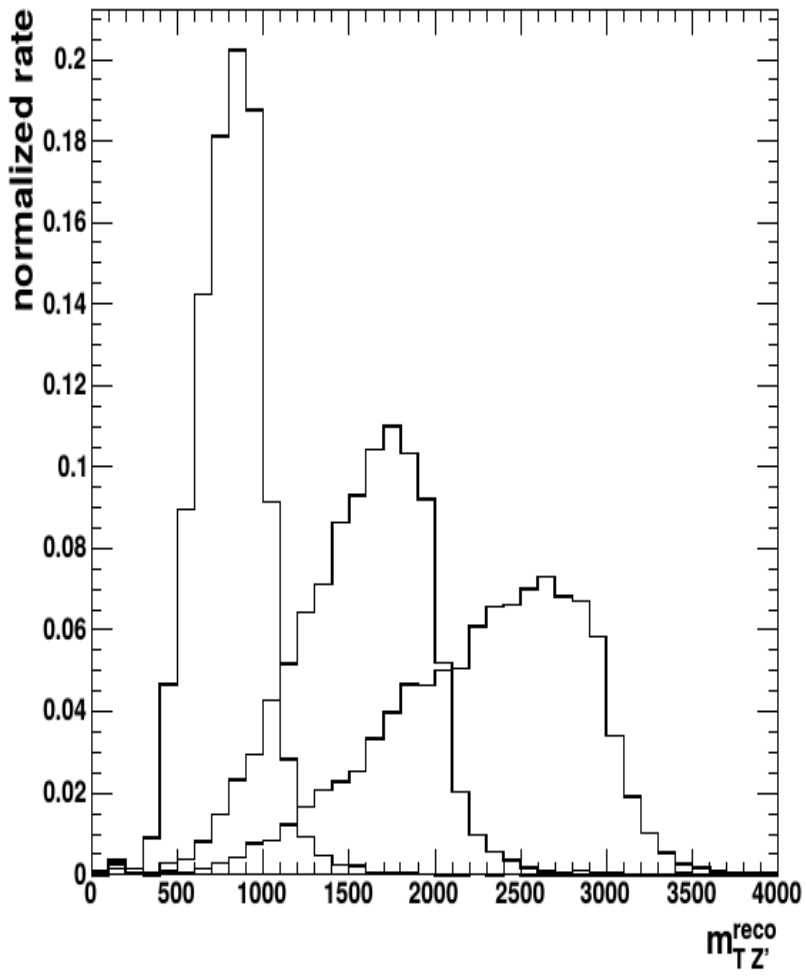
- first KK mode of photon, Z and W lie in the range if 2 - 3 TeV -hep-ph/0709.0007, Agashe, Davoudiasl, Gopalakrishna, Han, Huang, Perez, Si, Soni
- $A_1, Z_1 \rightarrow t\bar{t}$, the two tops are boosted and can be tagged using a suitable toptagger.
- $A_1, Z_1 \rightarrow WW$, two W's will be boosted and BDRS technique can be used to tag the W.
- $Z_1 \rightarrow Z\ h$, one of the cleanest signature is $Z \rightarrow l^+l^-$ and $h \rightarrow b\bar{b}$.

Analysis

- Three possible channels are considered - hep-ph/1010.5253, Katz, Son, Tweedie
  - $Z' \rightarrow W^+W^- \rightarrow lvq\bar{q}'$
    - One isolated lepton opposite to the hadronic W
    - Assuming boosted leptonic W, $\eta_W \sim \eta_l$, reconstruct complete missing energy vector
    - Hadronic W has been tagged using BDRS technique. $pT^W_{tagged} > m_Z/3$ to control W+jets.
  - $Z' \rightarrow Zh \rightarrow l^+l^-b\bar{b}$ - Similarly, two isolated leptons and double b tagged BDRS higgs-leptonic Z will be boosted, instead of two isolated leptons one can consider leptonic jet
  - $Z' \rightarrow Zh \rightarrow \nu\bar{\nu}b\bar{b}$ - single TeV scale jet with no other activity. The jet has been tagged as Higgs using variant of BDRS

Reconstructed Z'





$W^{'}$

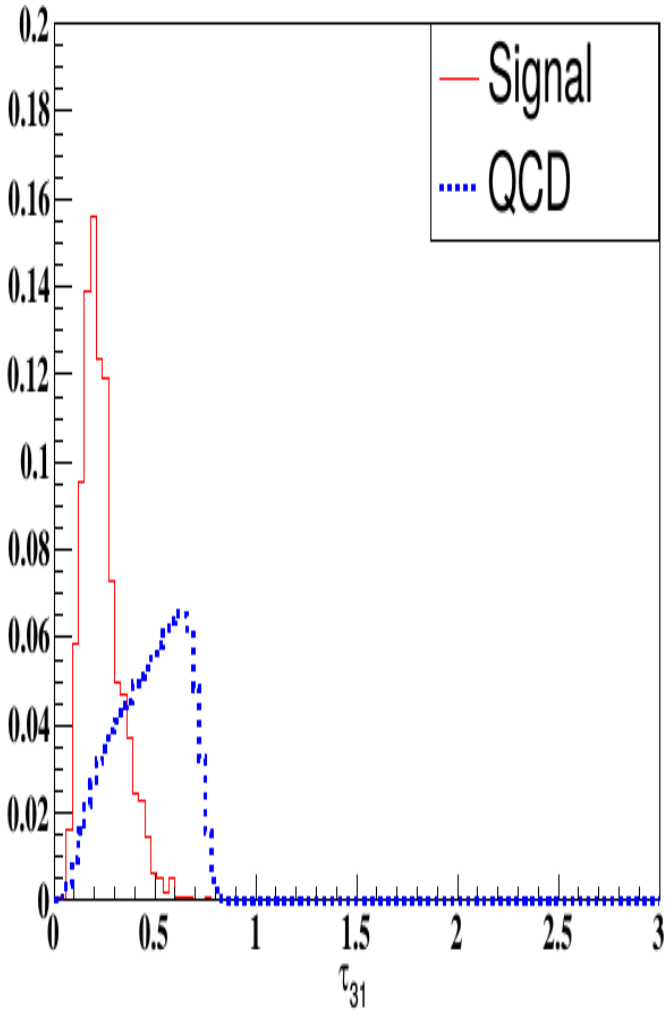
- Possible decay mode $W^{'} \rightarrow tb$ -hep-ph/0810.1497-Agashe, Gopalakrishna, Han, Huang, Soni
  - $p_T^q > 1$ TeV - suitable top tagger can be used
  - Once the top is tagged one can look for a b-jet outside the top-tagged jet.
  - Reconstruct $W^{'}$ using top and b.
- Other possible channels $W^{'} \rightarrow Wh,\ ZW$
  - $W^{'} \rightarrow Wh,\ h \rightarrow b\bar{b}$ can be tagged using higgs tagger
  - $W^{'} \rightarrow ZW,\ Z \rightarrow b\bar{b}$ and W decaying leptonically.

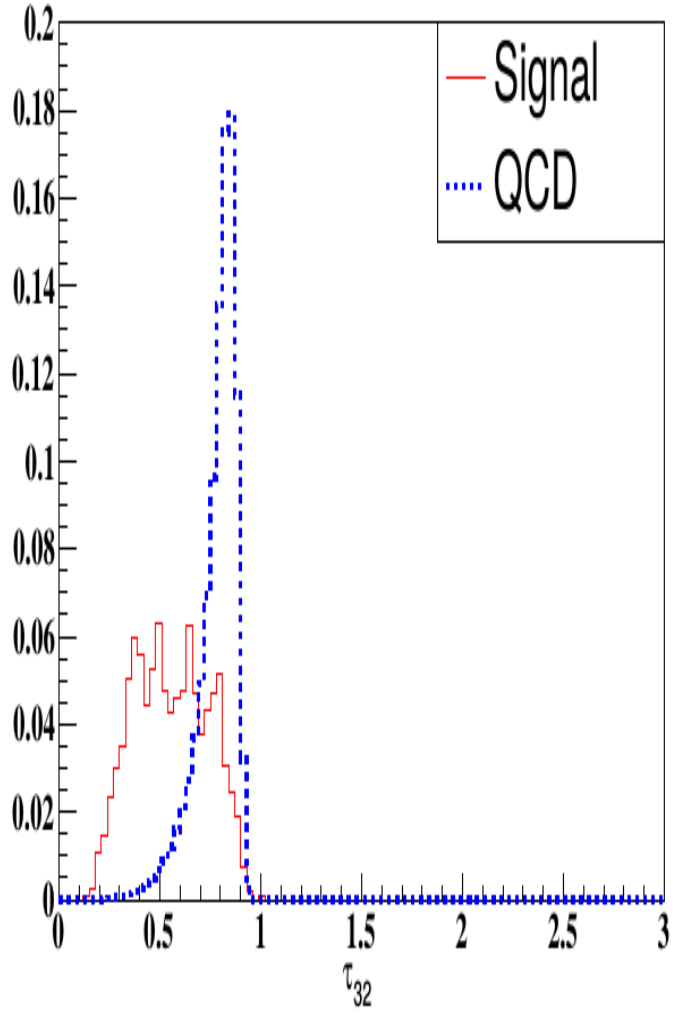
Kaluza Klein Gluon-usual decays

- KK states of SM particles are heavy and lie in the range of TeV.
- KK particles decay mainly to top, gauge bosons and Higgs which are boosted.
- $G^1 \to t\bar{t}$
  - m_{G_1} = 2-3 TeV
  - Produced via quark initiated process, $qq \to G^1 \to t\bar{t}$
  - high p_T top jets can be tagged using suitable top tagger to control background-hep-ph/0612015, Agashe, Belayev, Krupovnickas, Perez, Virzi; hep-ph/07061166, Randall, Lillie, Tao Wang

Analysis

- One can consider production of KK gluon in association with light jets. -hep-ph/1601.02033, Iyer, Sridhar, Mahmoudi, Mangalani
- 3-5 anti-Kt jets with R = 0.4
- Events with $p_T^{leading} > 1.1$ TeV and with $\tau_{31} < 0.3$ and $\tau_{32} < 0.35$
- The sub leading jet has $\tau_{21} < 0.6$
- Three leading jets reconstruct mass of KK gluon


Signal
QCD
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
0.5
1
1.5
2
2.5
3
τ_{31}


Signal
QCD
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
0.5
1
1.5
2
2.5
3
τ_{32}

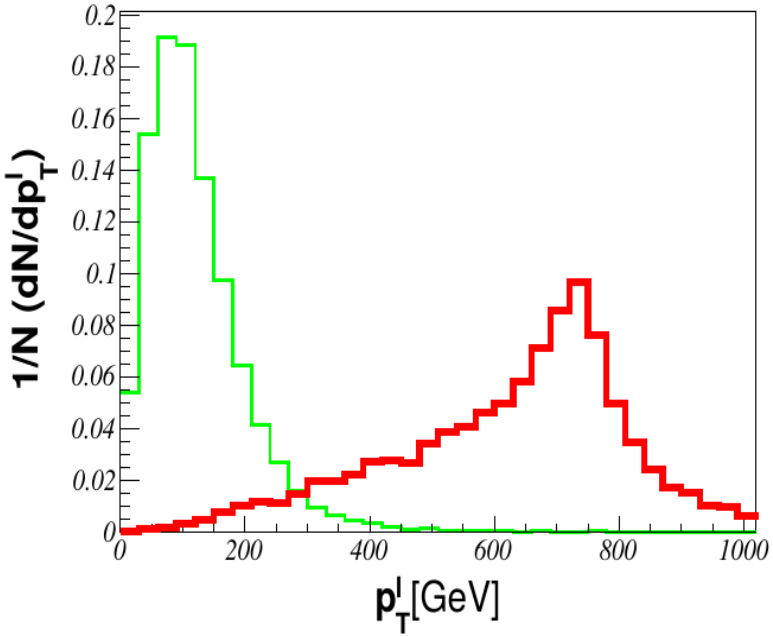
Other decays

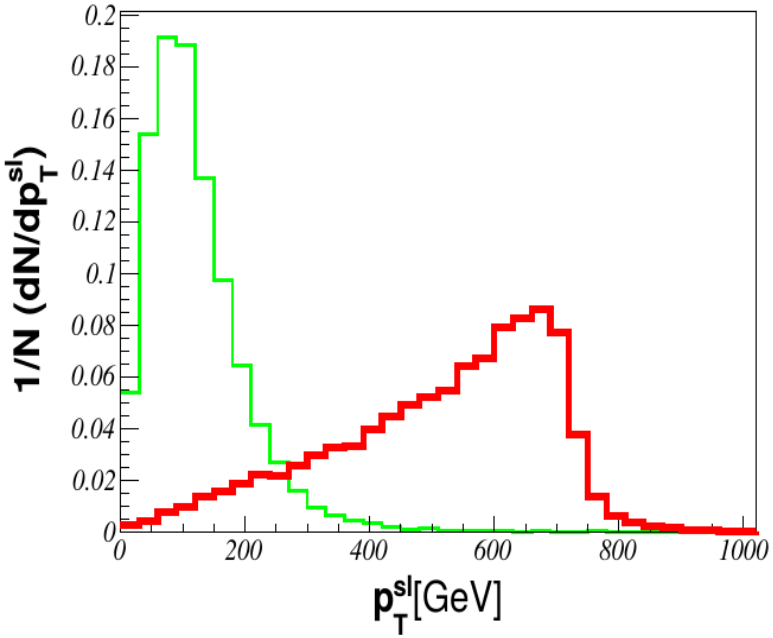
- KK fermions are lighter than KK gluon$\sim$ TeV
- $G^1 \rightarrow \Psi\ q$ where q = t, b - hep-ph/1110.6058, Bini, Contino, Vignaroli
- Possible decays of T,
  - $T \rightarrow tZ$ -hep-ph/1610.08810, Backovic, Flacke, Jain, Lee
    - Two same flavor opposite sign isolated leptons reconstruct Z
    - Two fat jet (R = 1.5 and p_T > 400(300) GeV)
    - Both the fat jets has been tagged as top using TopTagger
    - In addition, one of the top and Z has been used to reconstruct the mass of top partner and two tops along with Z has been used to reconstruct KK gluon

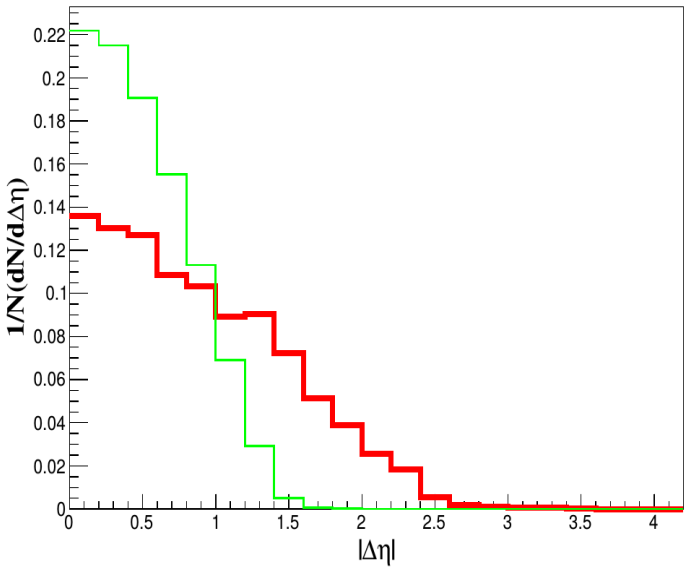
KK Higgs

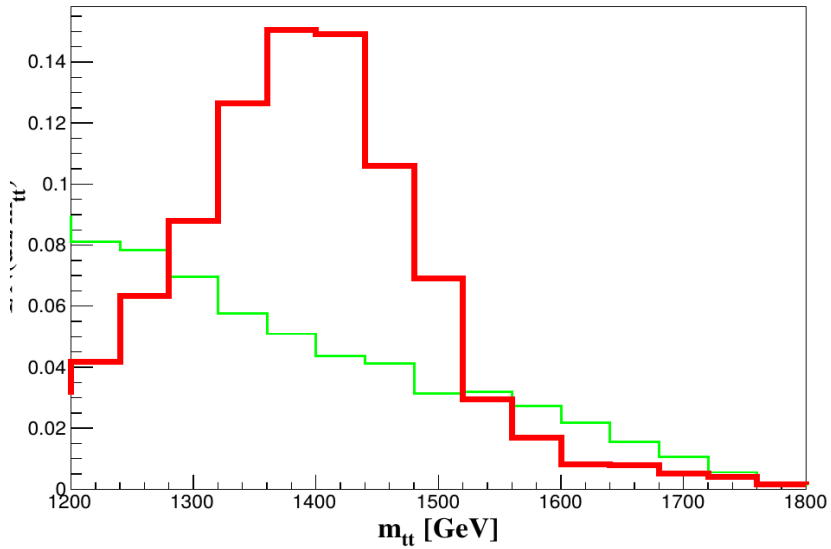
- $H^1 \rightarrow t\bar{t}$ has been considered -hep-ph/1608.07407- Mahmoudi, Maitra, Manglani, Sridhar
- m_{H^1} $1-2$ TeV
- p_T^t lies in the range of 300-800 GeV - tag both the tops using Toptagger
- Both the tops will have large angular separation.
- Reconstruct H_1 using two top-tagged jets

Reconstructed H'







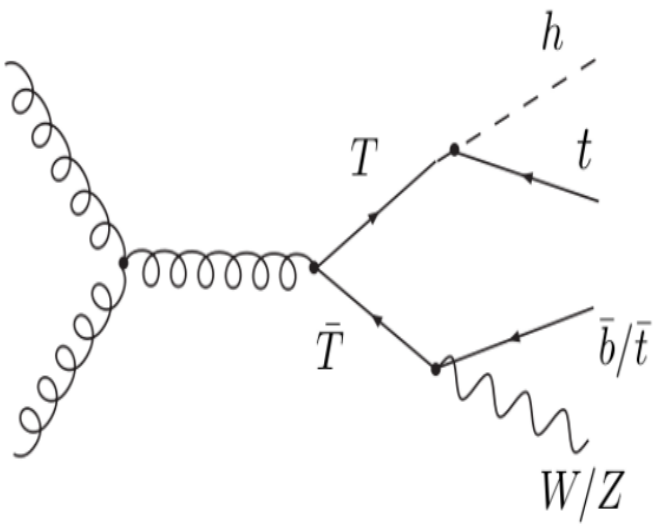


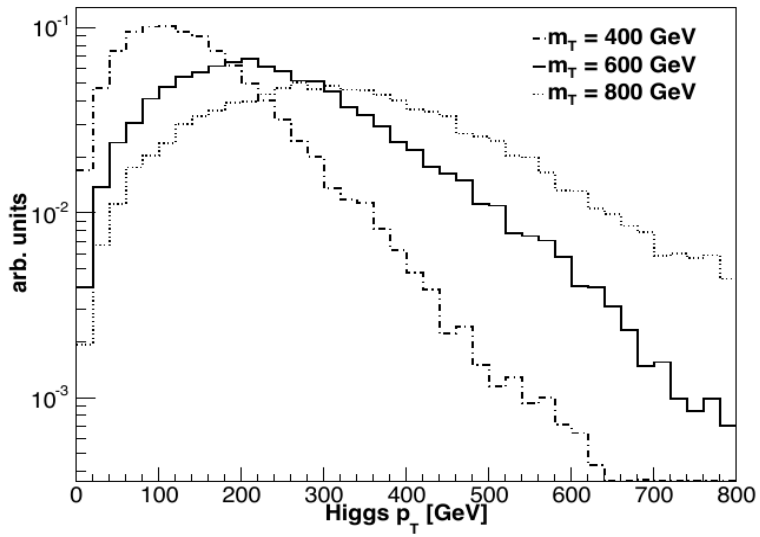
Outline

Higgs from a top partner

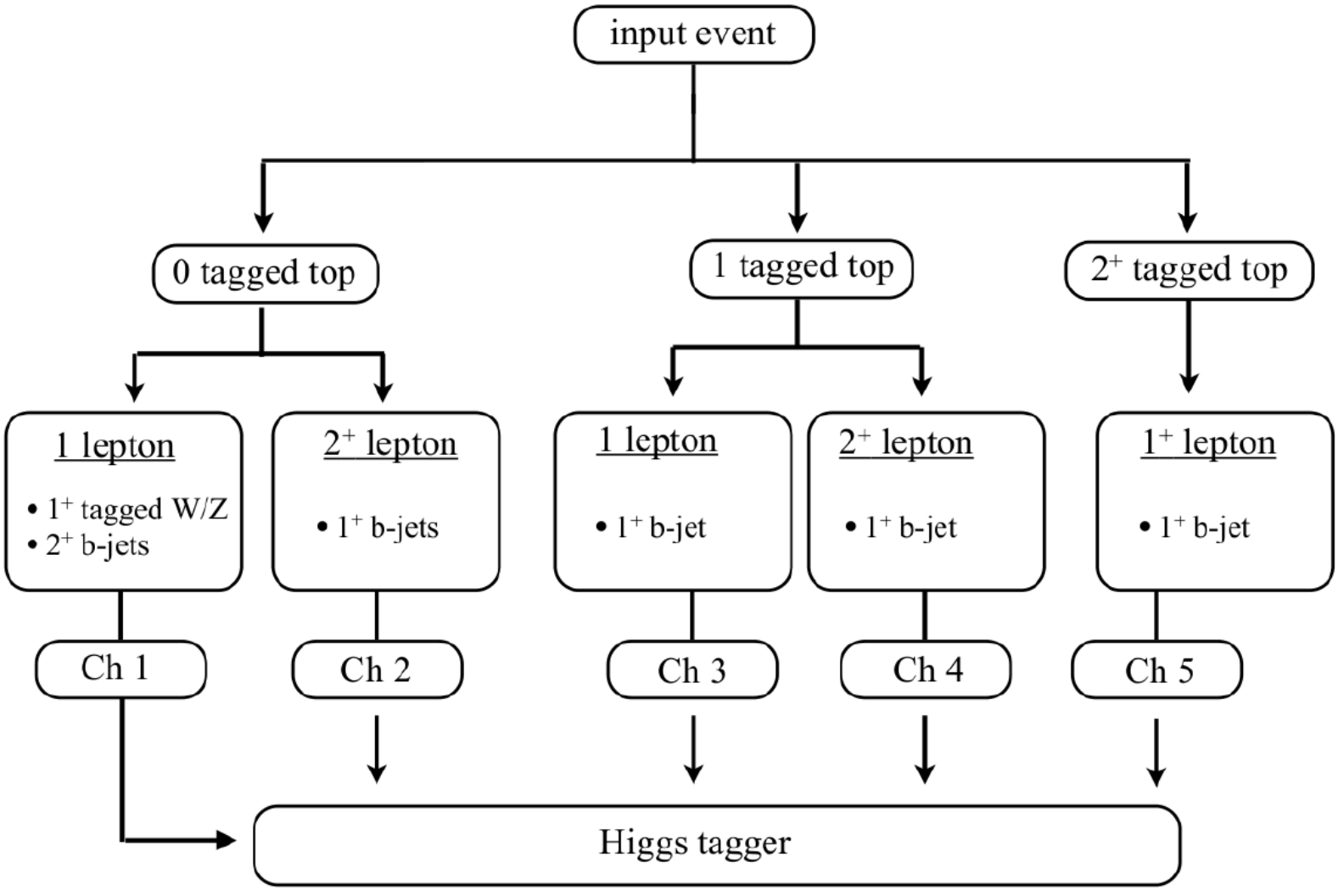
- Three possible decay channel exist for th, bW, tZ
- Top partner produces highly boosted higgs
  -hep-ph/1012.2866-Kribs, Martin, Roy

- Light Higgs boson can be discovered in their dominant $b\bar{b}$ mode





Analysis


input event
0 tagged top
1 tagged top
2+ tagged top
1 lepton
• 1+ tagged W/Z
• 2+ b-jets
2+ lepton
• 1+ b-jets
1 lepton
• 1+ b-jet
2+ lepton
• 1+ b-jet
1+ lepton
• 1+ b-jet
Ch 1
Ch 2
Ch 3
Ch 4
Ch 5
Higgs tagger

Hadronic final state

- $pp \rightarrow TT \rightarrow thth$ -hep-ph/1405.2677-Endo, Hamaguchi, Ishikawa, Stoll

- Both the tops and Higgs are reconstructed.
  - Out of these four fat jets, one has to identify the correct pair that reconstruct top partner.

  - Choose the pair having $\min[|M(t_1,h_1)-M(t_2,h_2)|,|M(t_1,h_2)-M(t_2,h_1)|]$

- Scenario-2: Either one of the top (higgs) is reconstructed along with two higgs (top)
  - Assuming no source of missing energy (fully hadronic state), p_T of the fourth particle is reconstructed.
  - p_z can be solved demanding that both the tops and higgs reconstruct the top partner.

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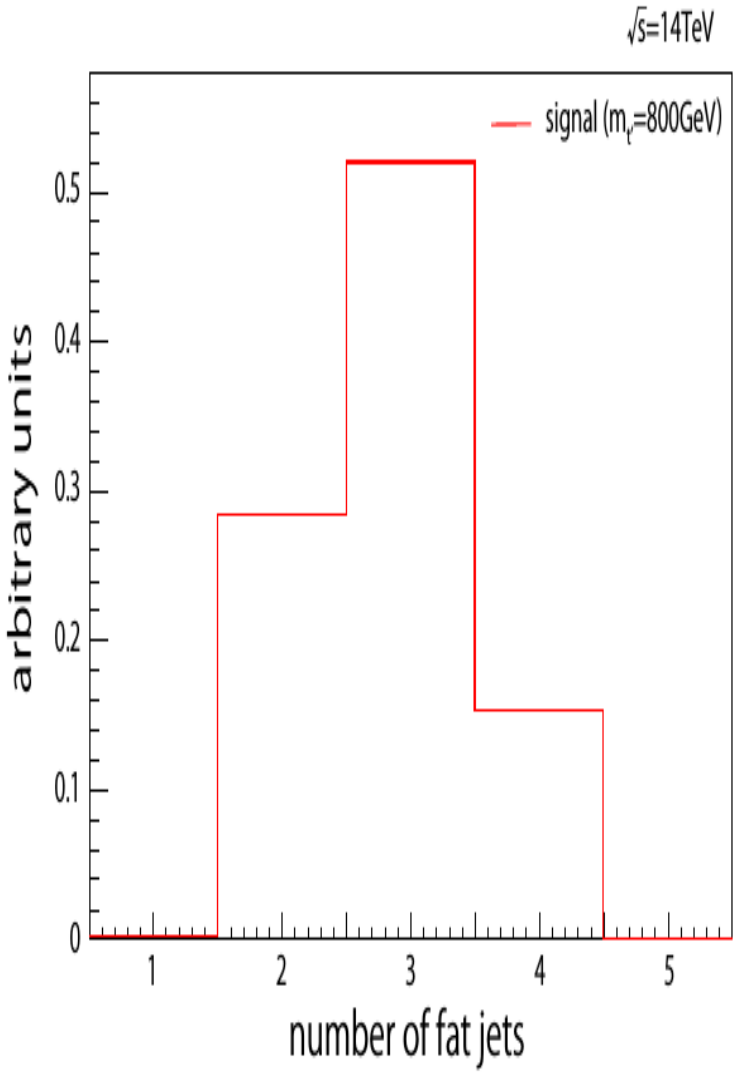
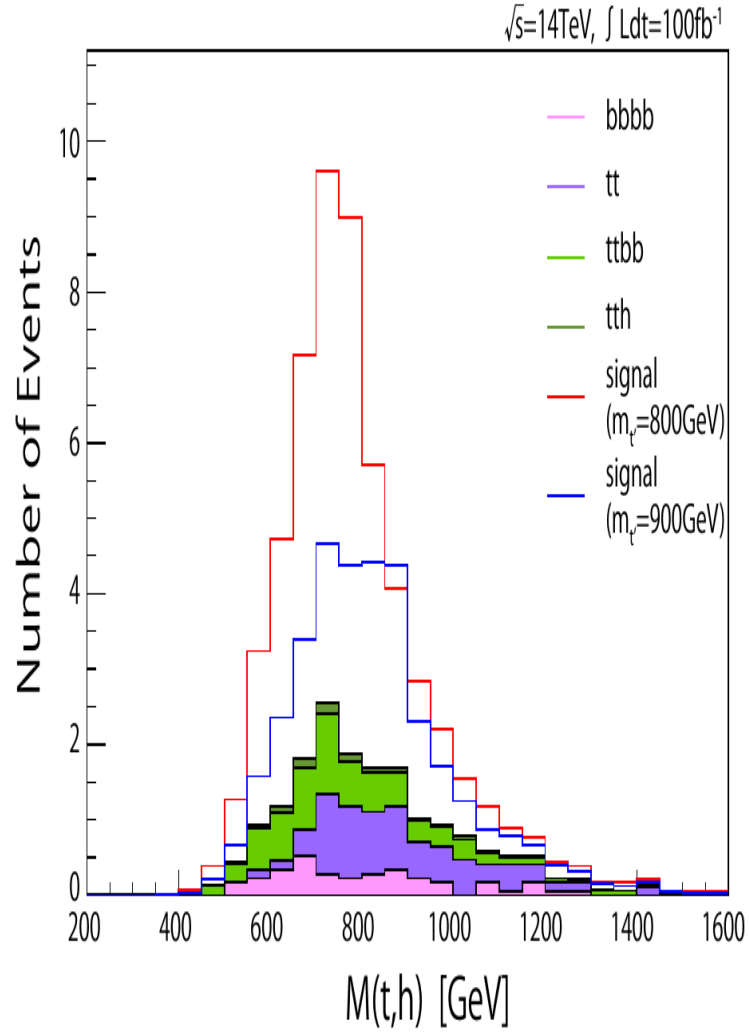
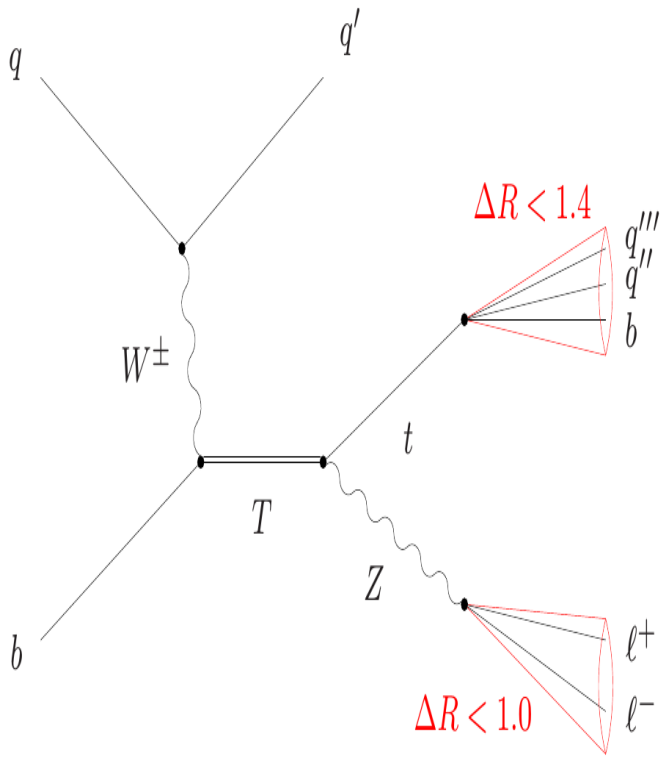

√s=14TeV
signal (m_t=800GeV)
arbitrary units
number of fat jets
0
0.1
0.2
0.3
0.4
0.5
1
2
3
4
5

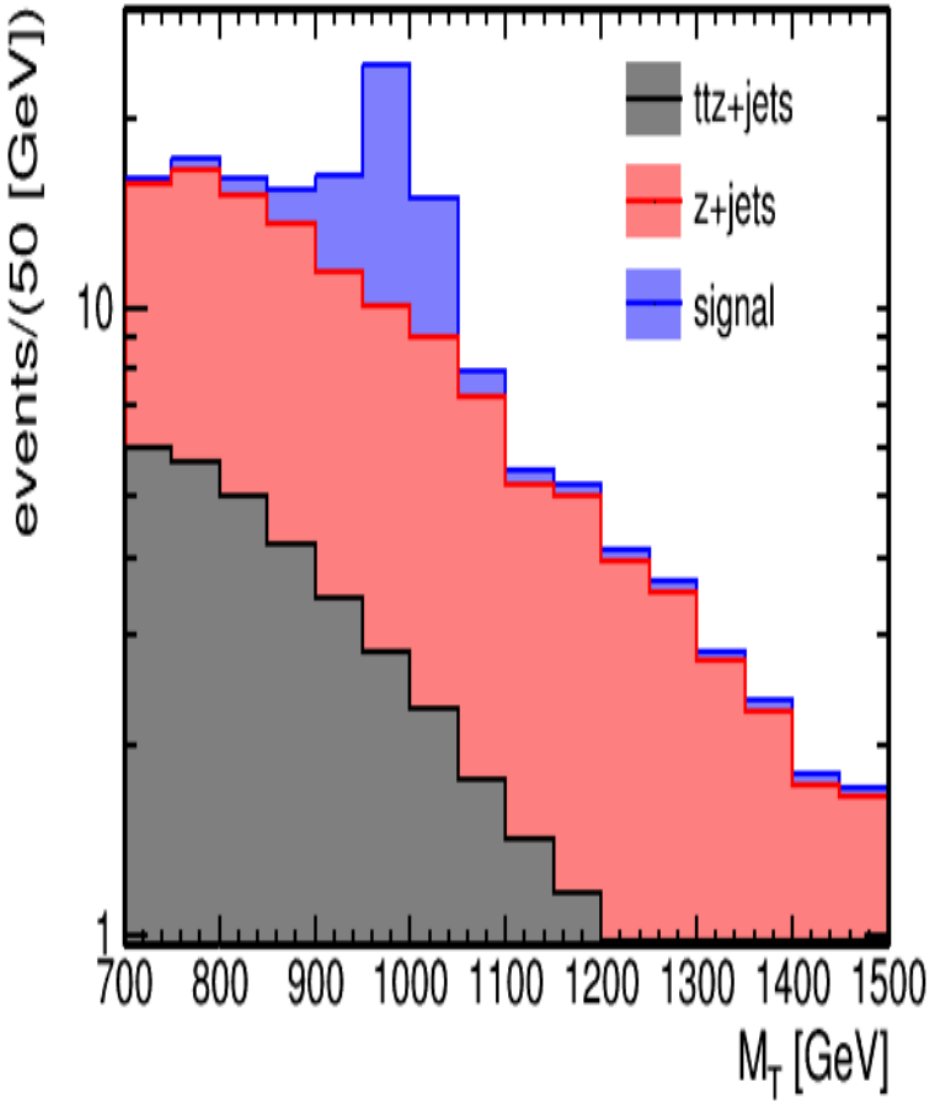

√s=14TeV, ∫ Ldt=100fb⁻¹
bbbb
tt
ttbb
tth
signal (m_t=800GeV)
signal (m_t=900GeV)
Number of Events
M(t,h) [GeV]
0
2
4
6
8
10
200
400
600
800
1000
1200
1400
1600

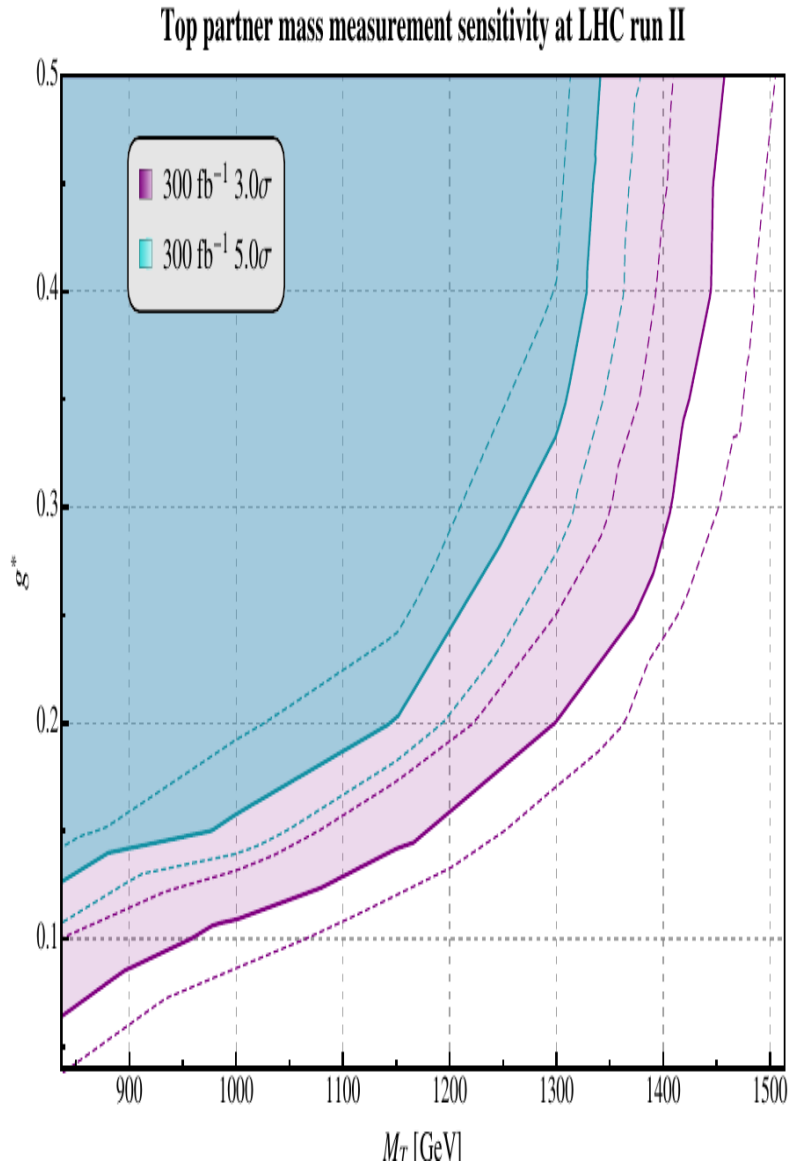
$T \rightarrow t\,Z$



hep-ph/1409.6962-Reuter, Tonini

- Two isolated lepton reconstructing Z.
- $p_T^Z > 200GeV$ and $\Delta R(l+, l-) < 1.0$
- $H_T > 400$ GeV, $n_b >= 1$ and $\mathrm{p_T^b} > 40$ GeV.
- Tag the fat jet as top and the b inside it.

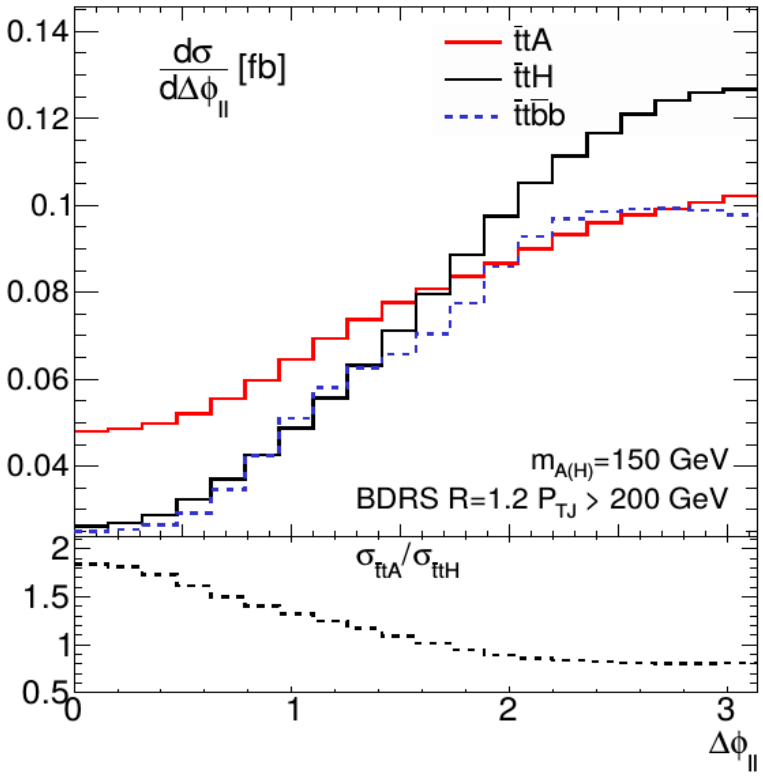




Detailed discussion for single production of T and all possible decay mode-hep-ph/1507.06568-Backovic, Flacke, Kim, Lee

Outline

CP measurement



- Dileptonic top pair with boosted Higgs hep-ph/1507.07926 -Buckley, Goncalves
- $\Delta\Phi_{ll}$ can be used to measure the CP properties. The variable works best for boosted Higgs.
- Higgs decaying to $b\bar{b}$ has been tagged using BDRS method.
- The technique has been used to differentiate ttA from ttH in type-1 2HDM-hep-ph/1607.086141-Goncalves, Lopez-Val

Spin identification

- $pp \to X, X \to V_1 V_2 \to 4q$ hep-ph/1604.06096-Buschmann, Yu
- The intermediate gauge boson masses, resonance masses and five angles (Cabibbo - Maksymowicz-Dell Aquila - Nelson angles) are sufficient to describe decay kinematics.

$$\cos\theta_{p_1} = -\hat{p}_{p_1} \cdot \hat{p}_{V_2} \ , \qquad \Phi_{V_1} = \frac{\vec{p}_{V_1} \cdot \left(\hat{n}_1 \times \hat{n}_{\rm sc}\right)}{\left|\vec{p}_{V_1} \cdot \left(\hat{n}_1 \times \hat{n}_{\rm sc}\right)\right|} \arccos\left(\hat{n}_1 \cdot \hat{n}_{\rm sc}\right) \ ,$$

$$\cos\theta_{p_3} = -\hat{p}_{p_3} \cdot \hat{p}_{V_1} \ , \qquad \Phi = \frac{\vec{p}_{V_1} \cdot \left(\hat{n}_1 \times \hat{n}_2\right)}{\left|\vec{p}_{V_1} \cdot \left(\hat{n}_1 \times \hat{n}_2\right)\right|} \arccos\left(-\hat{n}_1 \cdot \hat{n}_2\right) \ ,$$

$$\cos\theta^* = \hat{p}_{V_1} \cdot \hat{z}_{\rm beam} \ ,$$

$$\hat{n}_1 = \frac{\vec{p}_{p_1} \times \vec{p}_{p_2}}{\left|\vec{p}_{p_1} \times \vec{p}_{p_2}\right|} \ , \quad \hat{n}_2 = \frac{\vec{p}_{p_3} \times \vec{p}_{p_4}}{\left|\vec{p}_{p_3} \times \vec{p}_{p_4}\right|} \ , \text{ and } \hat{n}_{\rm sc} = \frac{\hat{z}_{\rm beam} \times \vec{p}_{p_1}}{\left|\hat{z}_{\rm beam} \times \vec{p}_{p_1}\right|}$$

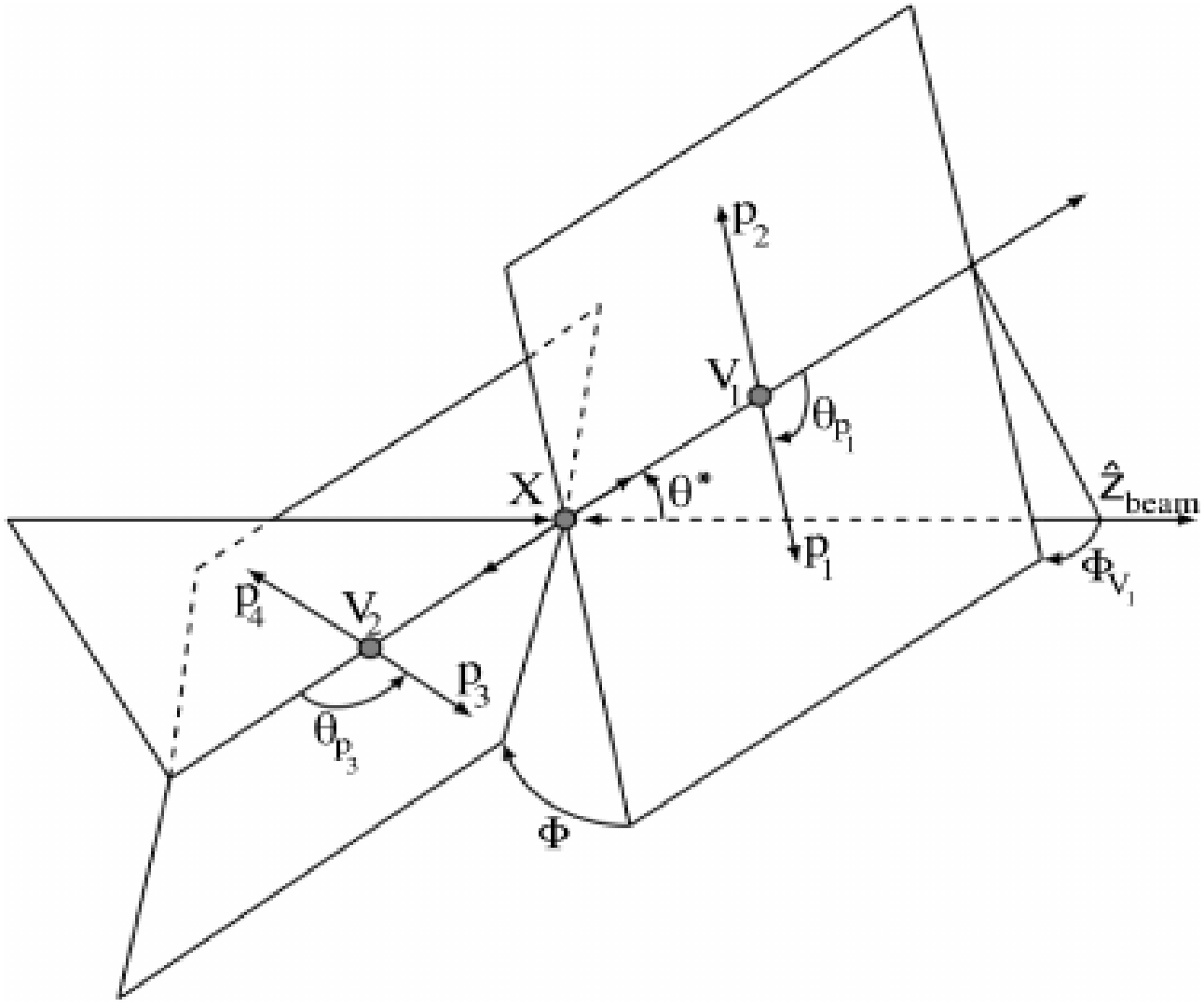
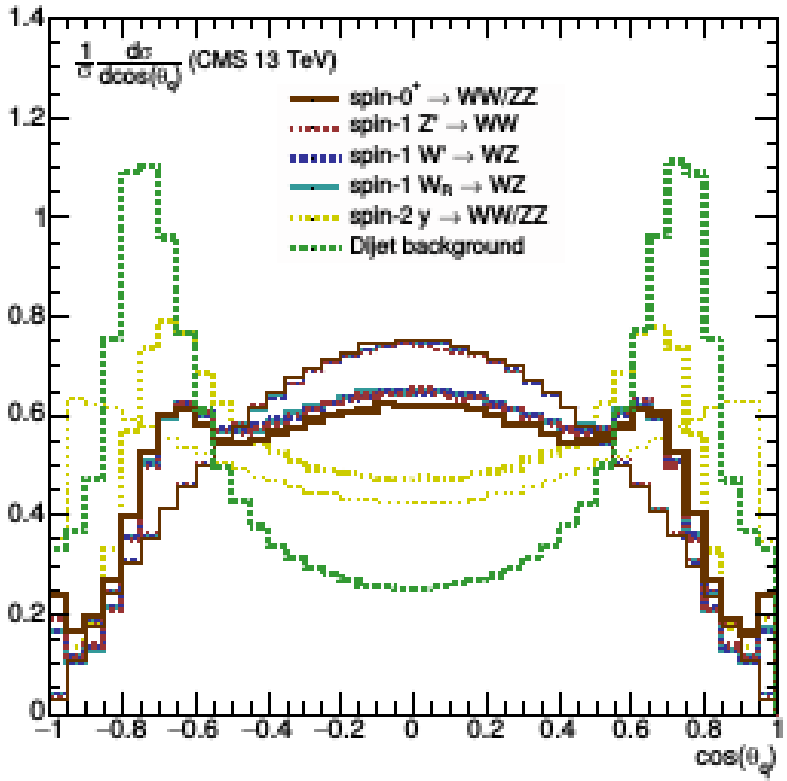


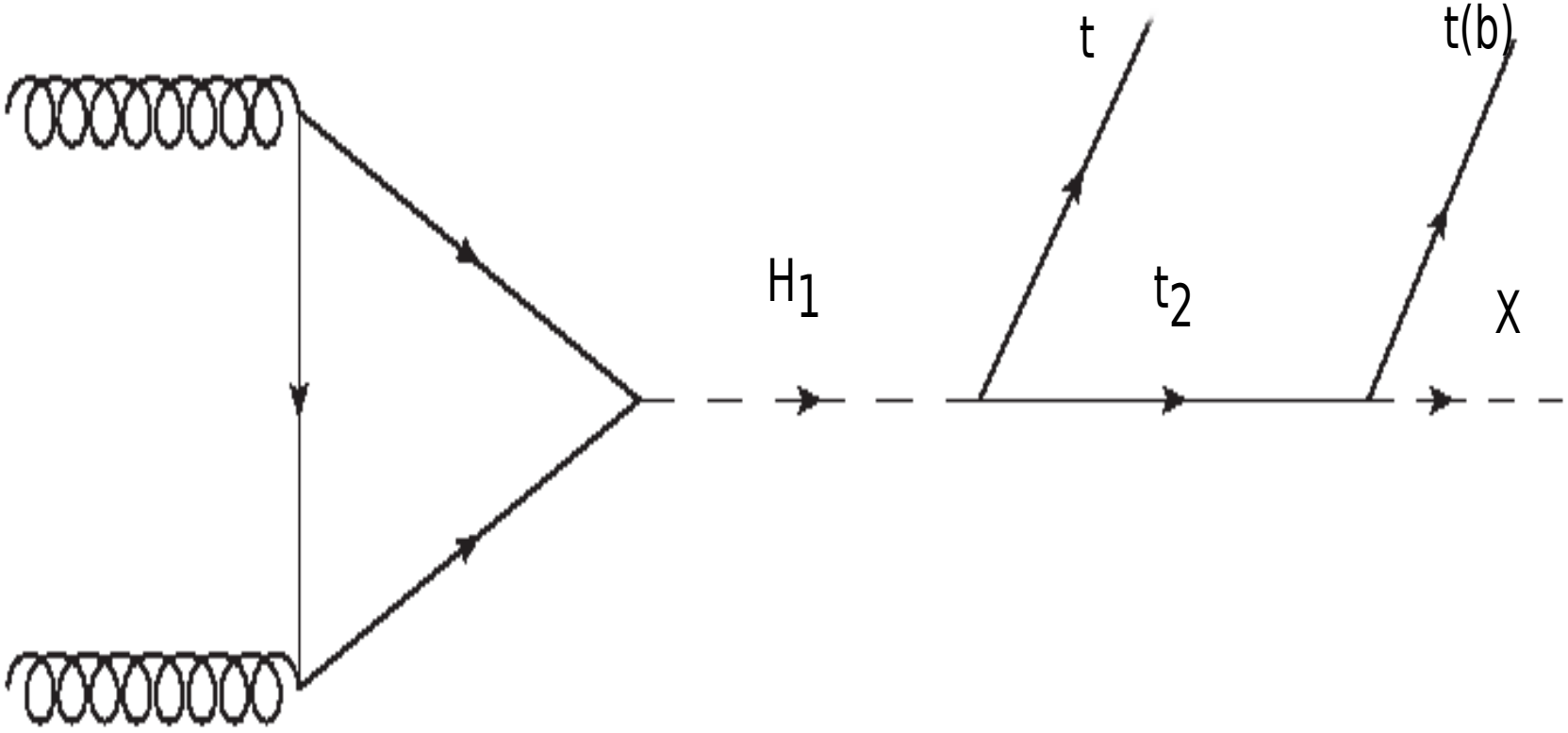
FIG. 1. Representation of the Nelson angles defined in Eq. 1

Analysis and Result



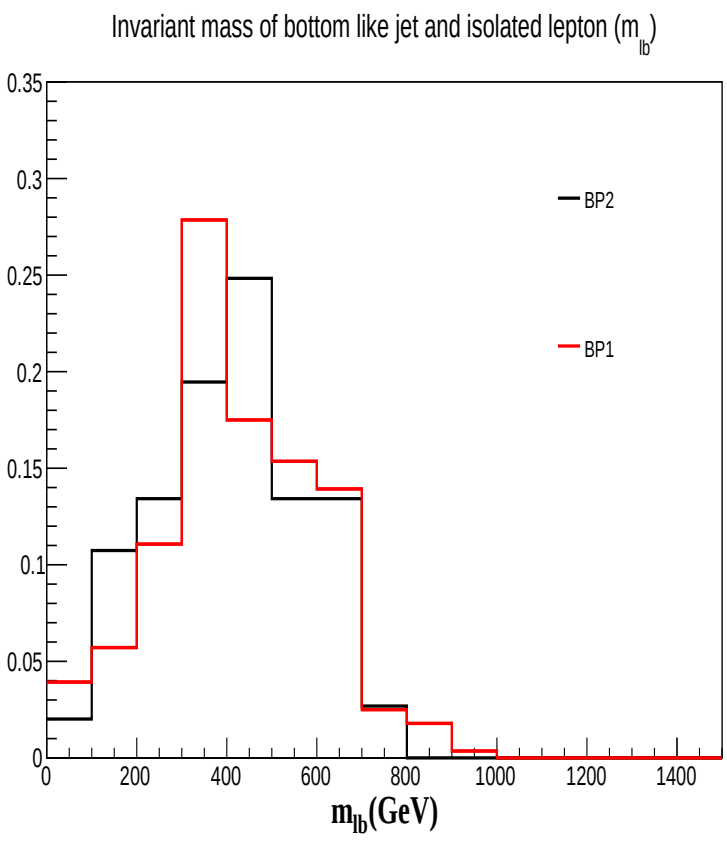
- Two anti-kT, R = 0.8 jets with $p_T > 30$ GeV
- $m_{JJ} > 1$ TeV
- $\tau_{21} < 0.45$ to tag W (Z)
- Identify the subjets as p_i

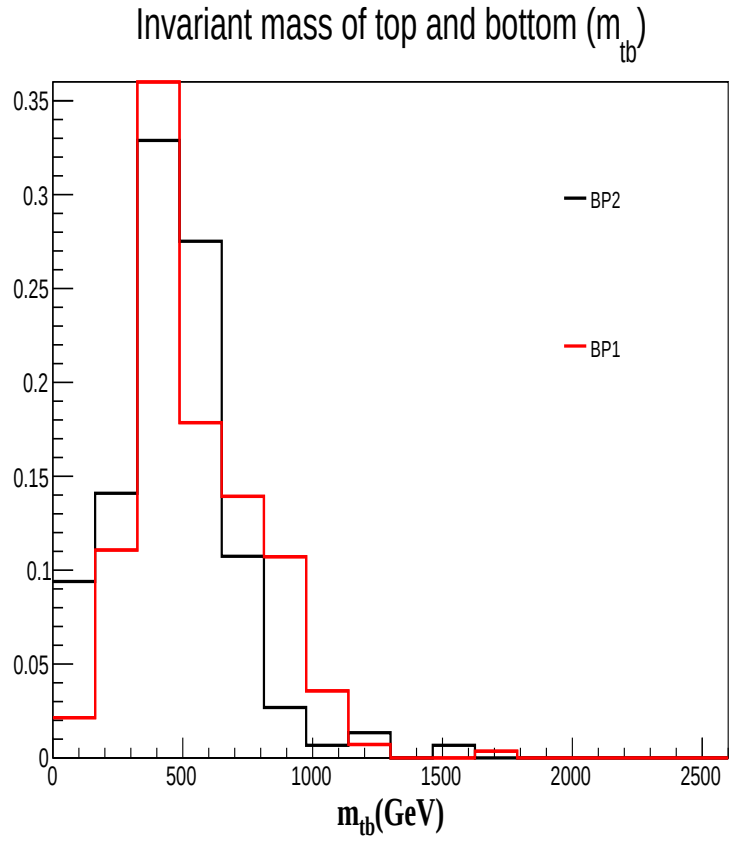
New physics using edges



- Look into the cascade decay of $H_1 \rightarrow tT \rightarrow tbW$
- Look for the kinematic edge in m_{bl} and m_{tb}
- We tag the top using toptagger.
- In addition we consider two more fatjets with different θ_J
- Identify the fatjet with low θ_J as lepton and the other one as b.

Edge





hep-ph/1609.06502-Iyer, Maitra