Boosted Semi Leptonic Top Tagging With Tau

Amit Chakraborty[1], Amandip De[2], Rohini M Godbole[2], Monoranjan Guchait[3]

[1]SRM University AP, Amaravati,India

[2]Indian Institute of Science, Bangalore, India

[3]Tata Institute Of Fundamental Research, Mumbai, India

Motivation

- Top identification is of paramount interest; provides insight into models which address flavor hierarchies in SM fermions, naturalness problem etc.
- Any change to structure of the interaction → Change in polarization of produced top
- Hence the **polarization** of top quarks serves as a promising window for exploring the existence and nature of new physics.

  $\tilde{t}_1 \to t\tilde{\chi}_1^{\,0}$:

  $L \sim \tilde{\chi}_1^{\,0}[P_L g^{t\tilde{t}_{1L}} + P_R g^{t\tilde{t}_{1R}}]\tilde{t}_1 t$

  For example Higgsino like $\tilde{\chi}_0^1$: **Polarization** of t will be **opposite** to that of $\tilde{t}_1$ for small L-R mixing in $\tilde{t}_1$
- Heavy 'new particles' => SM decay products are **boosted**
- Boosted top, $p_T >> m_{Top}$ => Products are within a **fat jet**
- In semi-leptonic decay the angular distribution of lepton → identifier of top polarisation and τ being heavier then e/μ, its **coupling** to new physics processes could be **enhanced**.

Difficulties

- **Hadronic Decay** => Full reconstruction of decay products => many taggers - *HEP top tagger, CMS top tagger, Machine Learning based taggers*..[arXiv:1902.09914]
- **Leptonic Decay** =>
  - Muon: Energetic track with isolation criteria within a narrow cone [arXiv:1007.2221]
  - Electron: Challenging for shower shape measure in ECAL due to hadronic neighborhood [arXiv:1909.11041]
  - Tau: Tau decay; $B(\tau \to h\tau_\nu) \approx 64\%$ & leptonic $B(\tau \to l\nu_l\,\nu_\tau) \approx 36\%$

    1/3 prong objects are identified using final-state particles reconstructed in the tracker and in the calorimeters, both ECAL and HCAL. Suffers from large backgrounds from jet production.
- We propose a dedicated tagger for the top jets with tau.

Signal

p p > W′ > tb > τ ν b ; W′ mass = 1 TeV

$$\mathcal{L} = \frac{V_{ij}}{2\sqrt{2}}\bar{f}_i\gamma^\mu(g_R(1+\gamma_5)+g_L(1-\gamma_5))W'_\mu f_j + h.c.$$

$g_L = g_R = 0.5$ → produced top quark is unpolarized

Background

Dijet QCD: **p p > j j**
QCD requires multiple soft emissions & jet substructure depends on that. We have considered three pt bins: [200,300] [300,600] [600 – inf] whose cross section vary considerably.

Jet formation

Madgraph → Pythia8 → Delphes (CMS card)

- **Anti-K_T** jets of **radius 1.5** ; Jet $\mathbf{p_T}$ **> 200** GeV
- **Soft Drop** with $\mathbf{z_{cut}}$ **= 0.1 & β = 0.0** This helps to clean the jet for both soft and soft-colliner emissions:
- Cleaned jets constituents are again re-clustered to smaller subjets of size **R = 0.5** using **anti-K_T**

Tagging Algorithms

τ-tagging

- τ decay produces localized energy deposit in the EM and hadronic calorimeter in a ring around the core of the jet.

Charged tracks based algorithm

Collect tracks in $R_m = 0.1$ along jet axis with $p_T > 2$ GeV

↓

Leading track (tr_1) in R_m with $p_T > 6$ GeV; $|\eta| < 2.5$

↓

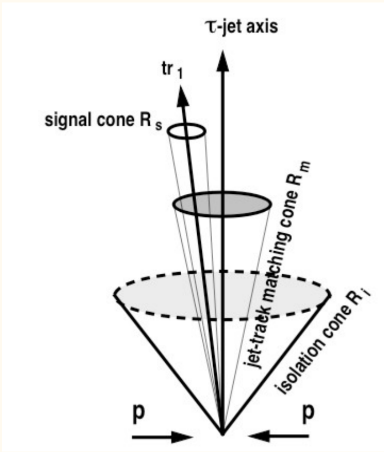
Signal tracks: any other tracks along tr_1 in R_s=0.07 & $|dz| < 2$ mm

↓

Isolation tracks: reconstructed tracks in $R_i = 0.45$ & $p_T > 1$ GeV

↓

Signal tracks = # Isolated tracks



- The **efficiency** of the algorithm is ~ 57%.

b-tagging

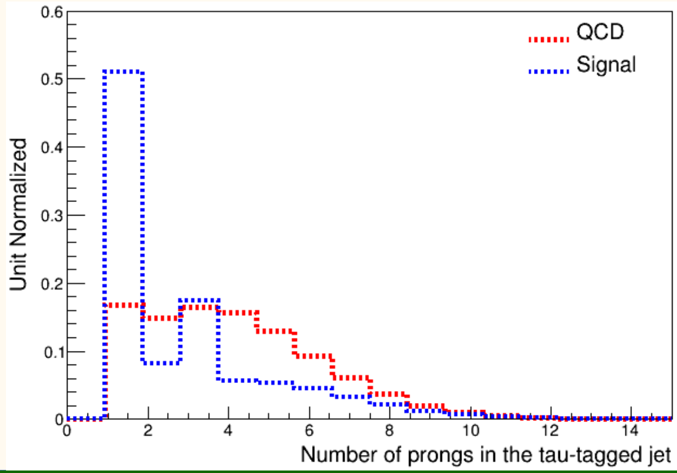
- b jets are identified on the basis of **hadronization** of heavy flavour quarks.
- A jet is tagged as a b-jet if the angular distance between the jet and the nearest B-hadron satisfy $\Delta R(jet, hadron) < 0.5$
- These hadrons for signal are coming from decay of W′ and top quark. And for QCD, fragmentation and radiation of the QCD partons.
- We use the following b-tagging efficiencies for different jet p_T [arXiv:1907.05120]

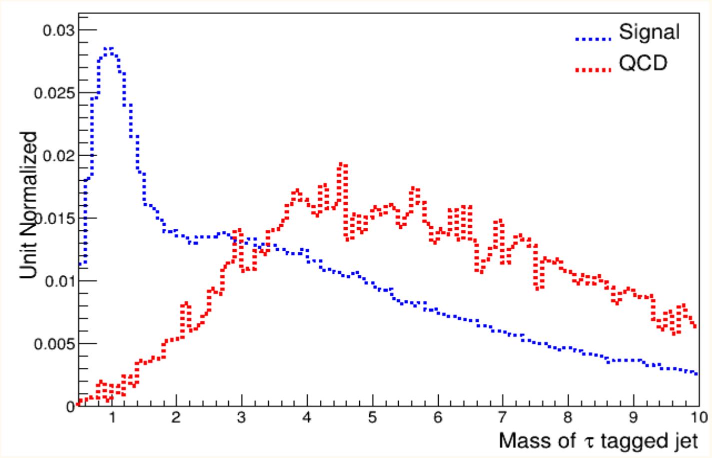
p_T of the b-jet (GeV)	b tagging Efficiency
upto 60	60 %
[60,200]	80 %
[200,400]	60 %
400-	50 %

Discriminators

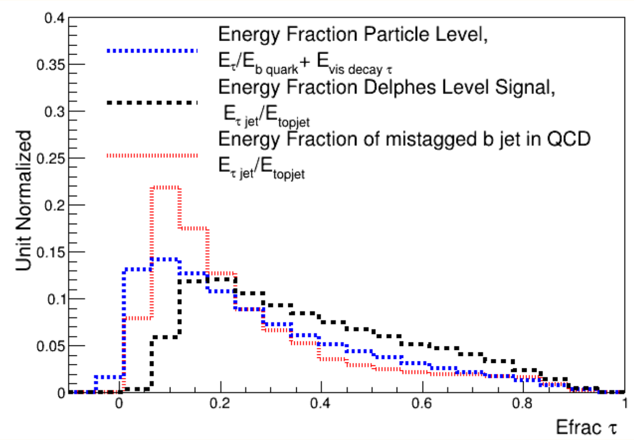
Tau prong & Mass

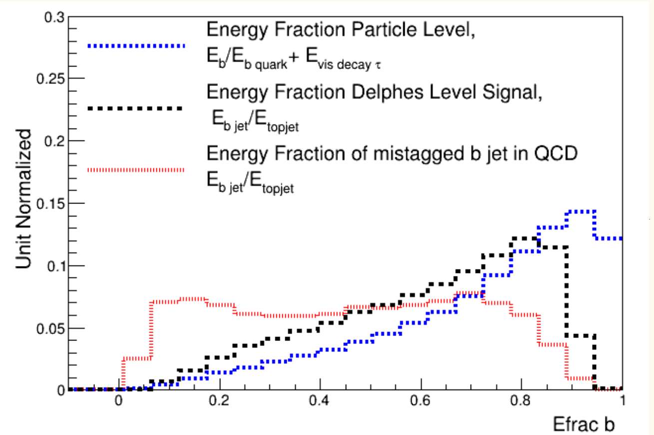
- The distribution of charged tracks → clear enhancement in 1 & 3 prong for signal.
- Mass reconstruction is performed using tracks and Ecal clusters. Due to multiple scatterings in QCD event, the mass shows a longer tail than signal.

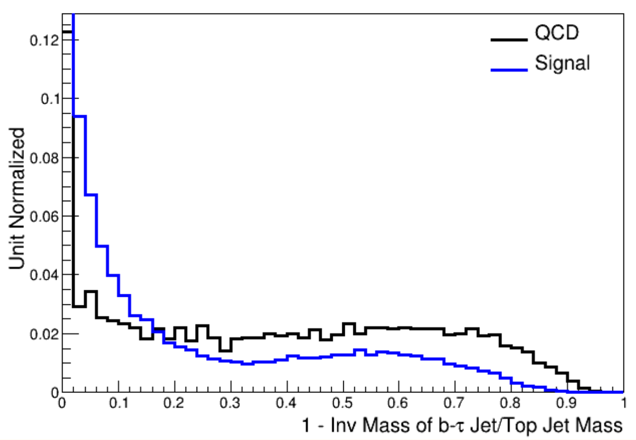




Energy Fractions







A lepton from a top decay is prompt & should carry a smaller energy fraction of the top system. Energy sharing for QCD in b is almost flat. QCD jet differs from the boosted top jet in the prompt shower where initial splitting is rather soft for QCD and relatively hard for top jet → large subjet multiplicity because of soft singularities in region with small E_b. A better estimator of energy flow would be ratio of jet masses: **1 – Invariant mass of b-tau jet/ Fatjet Mass**

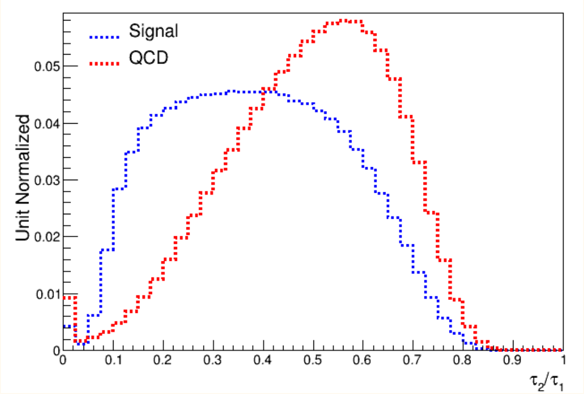
Subjettiness

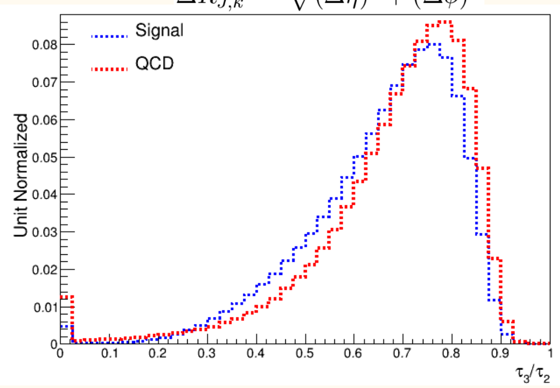
Advantage of different energy flow in decay pattern of top jets and q/g QCD jets, N-subjetiness:

$$\tau_N = \frac{1}{d_0} \sum_k p_{T,k} \min\{\Delta R_{1,k}, \Delta R_{2,k}, \cdots, \Delta R_{N,k}\}$$

$$d_0 = \sum_k p_{T,k} R_0$$

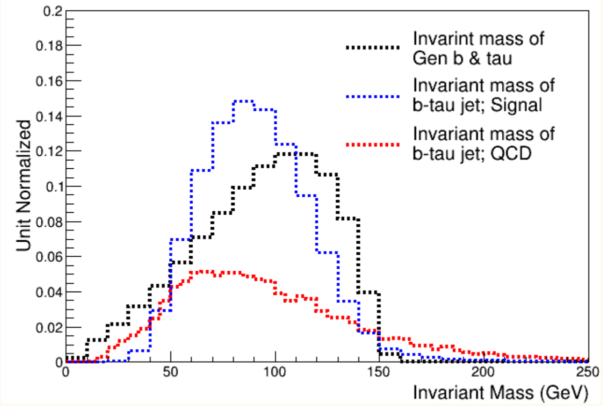
$$\Delta R_{J,k} = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$$





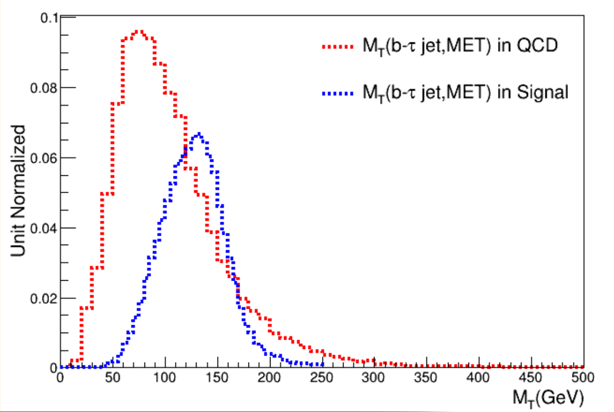
b-tau jet invariant mass

For a gen level b-tau system $m_{b\tau_{vis}} < \sqrt{m_t^2 - m_W^2}$ = 154.6 GeV. The interesting mass window is [60,150] GeV



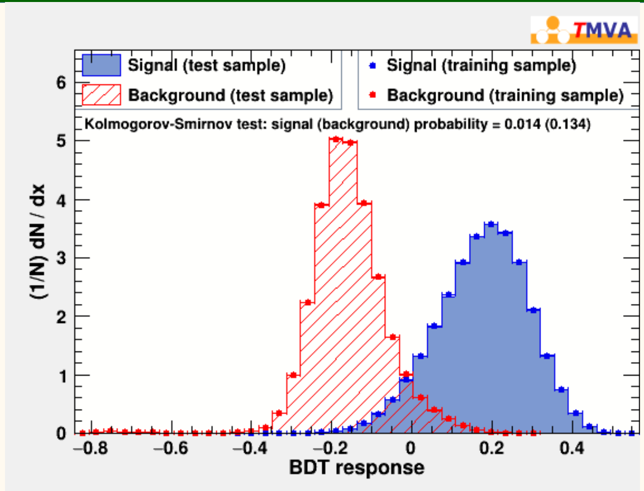
Transverse Mass

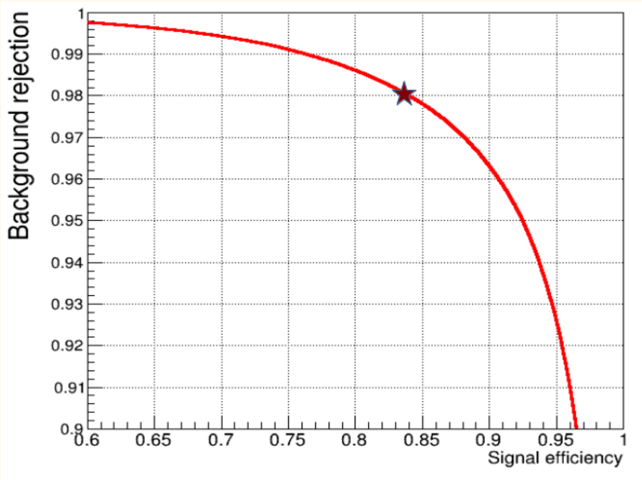
- Top transverse mass is defined as $\sqrt{m_{bl}^2 + 2(E_{bl}^T p_{nu}^T - p_{nu}^T p_{bl}^T cos\Delta\phi)}$
- Here two direct sources of neutrino from w and tau → difficult to configure MET. So traditional sTransverse mass observable will not provide the required information.
- The direction of MET is more co-linear to tau than b , since ν decays from a boosted W and a tau is expected to be inclined to tau decay plane. For QCD the Δφ(MET & τ) is random, as there is no intrinsic correlation between them.



Performance

- A **multivariate** analysis is performed in order to maximize signal efficiency and background rejection with the discriminators mentioned before.
- Sufficient samples have been generated for training and testing for luminosity of 10 fb^{-1}.
- For **comparison** tagging semi-leptonic decay of Top to electron [arxiv:1909.11014] projects Signal eff, > 75%, at 1% mistag rate.





Conclusion

- We summarized the boosted leptonic top tagging performance in tau decay and discussed a few important discriminators to reject QCD background.
- The efficiency is **at par** with the already established boosted leptonic top tagging methods with e/μ.
- The focus is on characteristics rather than reconstructing top mass so that it can be applied to other scenarios like ttbar.
- One more application could be identifying the **LEPTO-QUARKS** where a third generation leptoquark (mass ~ TeV) decays to b and tau. So in general a Fatjet with b & tau in it can have a fair probability of identification.