Tagging Tops in Leptonic Decay

Suman Chatterjee
Tata Institute of Fundamental Research
Mumbai, India

Collaborators : Tuhin S Roy (TIFR Mumbai)
Rohini Godbole (IISc Bengaluru)

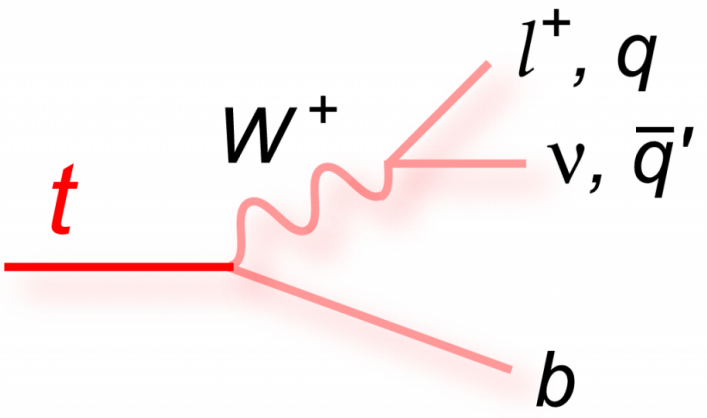
EPS-HEP 2019
Ghent, Belgium

12th July 2019

Leptonic Decay of Boosted Top

- Searches for new physics push the limits to higher ends of energy
- Heavy 'new particles' => SM decay products are boosted
- Boosted top => Products within a fat jet
- Hadronic Decay => Full reconstruction of decay products => many taggers

  HEP top tagger, CMS top tagger, Shower deconstruction, ..



- Leptonic decay =>

  muon : Energetic track with isolation criteria within a narrow cone [hep-ph :007.2221]

  electron : Challenging for shower shape measurements in ECAL due to hadronic neighbourhood

- Background :

  b jets (either at matrix element level / parton shower)

  hadronically decaying top

  (b decays semileptonically / quark jet fakes as lepton)

  QCD (pion faking as electron / muon)

Event Generation & Detector Simulation

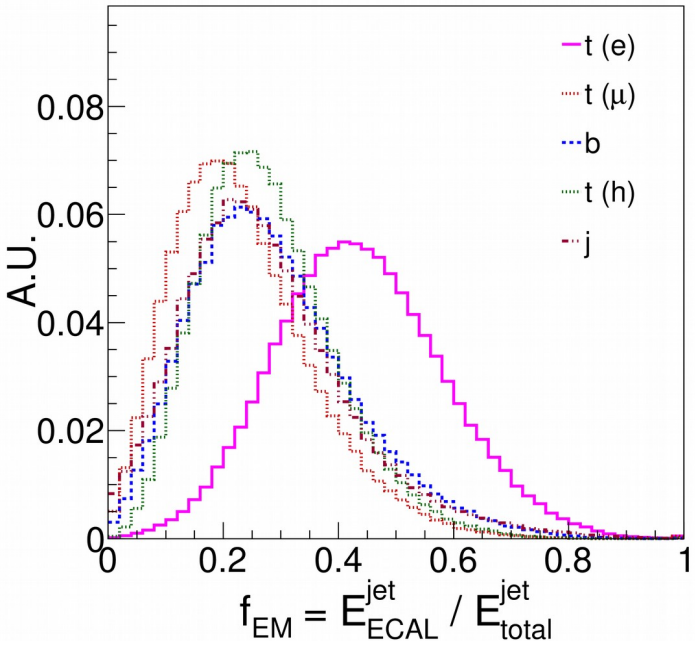
- Generator : Madgraph
- Parton shower + Hadronization + MPI : Pythia8
- Detector simulation : Delphes (CMS geometry)

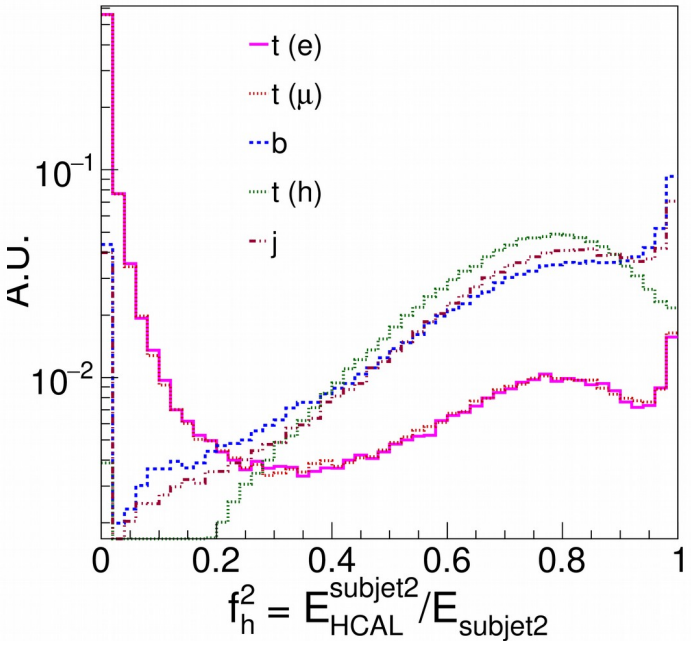
Object Reconstruction & Selection

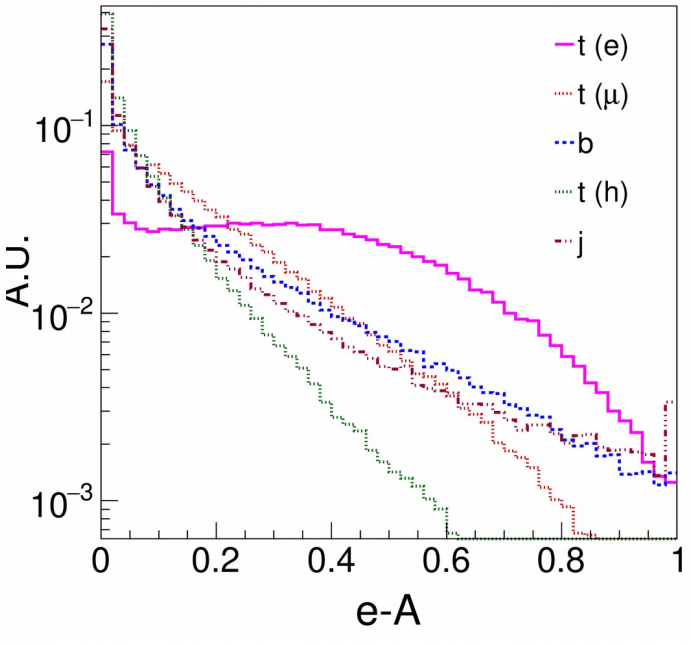
- Jet reconstruction using anti-k_T algorithm with R = 0.8
  Inputs : all the particle-flow candidates
- Only the leading jet (p_T > 500 GeV) is studied for the tagging

Weapons : Energy Fractions of Jet and Subjets

- Top (e) : electron final state => large energy deposit in ECAL
- Also use subjets after soft-drop grooming [hep-ph : 1402.2657]
- For electron final state : one subjet EM rich & other Hadron rich
- e-A : $f^{ECAL}_1 - f^{ECAL}_2 / (f^{ECAL}_1 + f^{ECAL}_2)$ where $f_i^{ECAL} = E_i^{ECAL} / E$ (1,2 => subjets)
- Lepton mostly ends up in sub-leading subjet



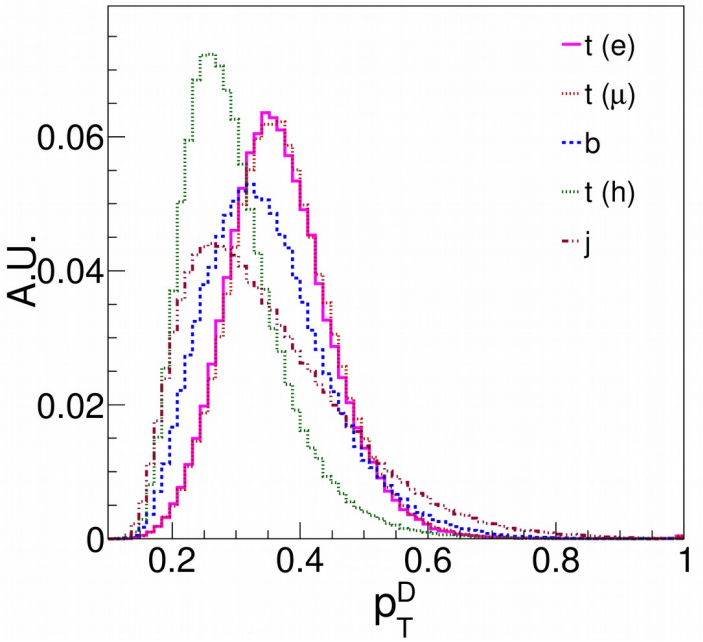


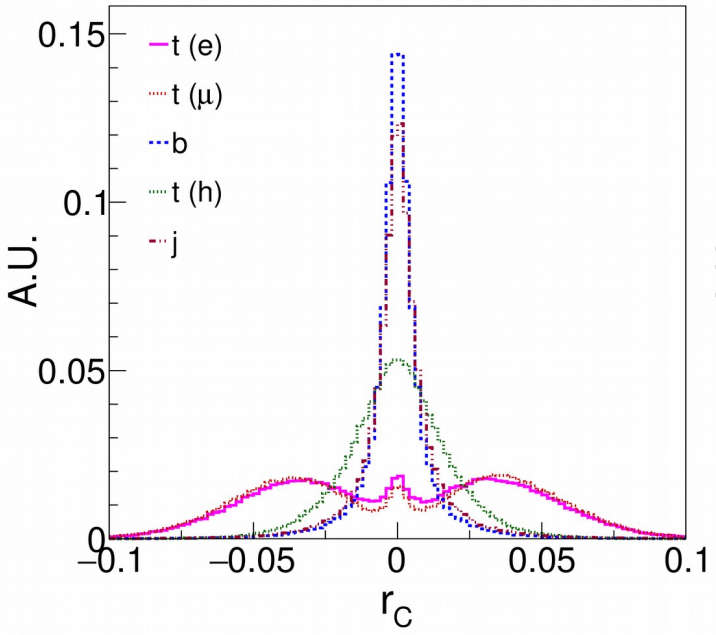


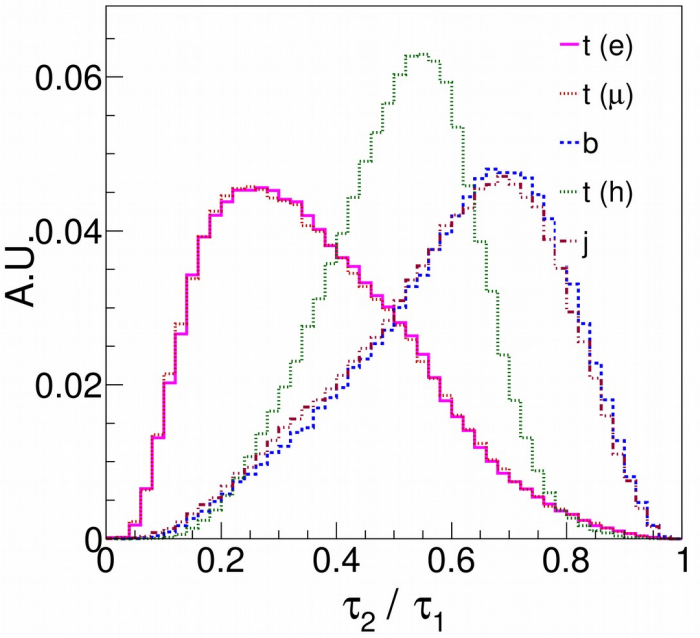
e-A => quantification of asymmetry of energy deposits in ECAL by two subjets

Weapons : Structure inside Jet

- Use constituents of AK8 jet
- Democracy in momentum distribution within jet : $p_T^D = \frac{\sqrt{\sum_i (p_T^i)^2}}{\sum_i p_T^i}$
  Hard prongs inside jet => larger value of p_T^D
- Charge radius : $r_C = \frac{\sum_i q^i \Delta R_{i,jet} p_T^i}{\sum_i p_T^i}$ Hard charged particles => larger value of charge radius
- 2 hard prongs in leptonic top => τ_{21} is a natural discriminator





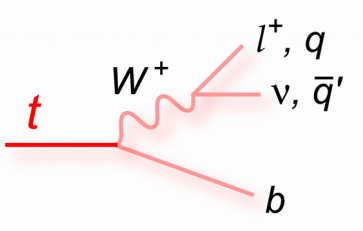


- Also used soft-drop mass (peaks in between W and top mass)

ν Sensitive New Observables

- Aim to construct observables sensitive to neutrino momentum in top decay => Sensitive to the difference between top and new particles decaying to similar final states
(e.g. : $t^{\sim}$ -> b l ν χ_0 => in detector : lepton + b-jet + MET)

- Follow top decay chain using relativistic kinematics



$$S_{lb} = \frac{E_l}{E_b}\frac{(m_t^2 - m_b^2 - m_W^2 - 2p_b.p_l)}{m_W^2 - m_l^2} \xrightarrow{\text{physically}} \frac{1 - cos\theta_{b\nu}}{1 - cos\theta_{l\nu}}$$

- Another handle => $p_\nu{}^{\perp}/p_\nu{}^{\parallel} = R$: ratio of neutrino momentum perpendicular to and along with lepton direction

- Using masslessness of neutrino : $E_\nu = \frac{m_W^2\sqrt{1+R^2}}{2p_l(\sqrt{1+R^2}-1)}$

- Asuming 'small R' $f_{bW} = E_b/(E_l + E_\nu)$

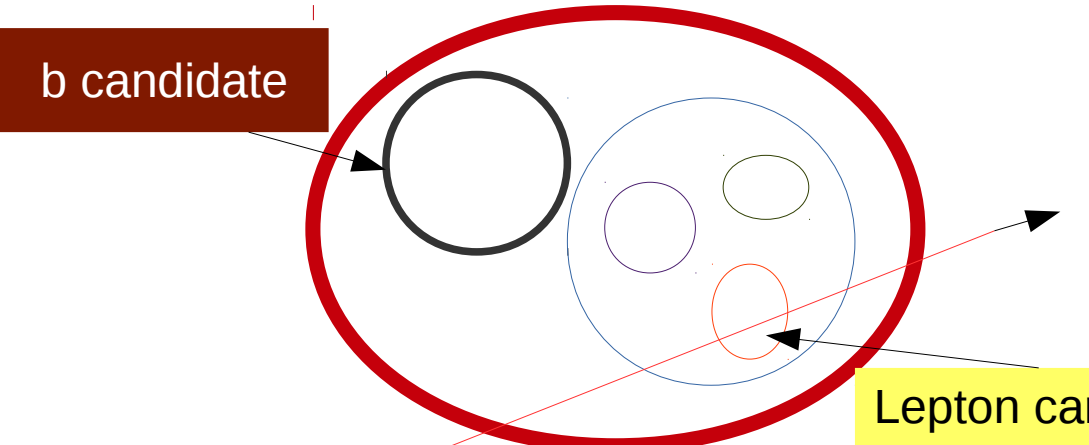
$$R = \sqrt{\frac{2m_W^2}{E_l}\cdot\frac{(E_b - \vec{p_b}.\hat{p_l})}{m_t^2 - m_b^2 - m_W^2 - 2p_b.p_l}}$$

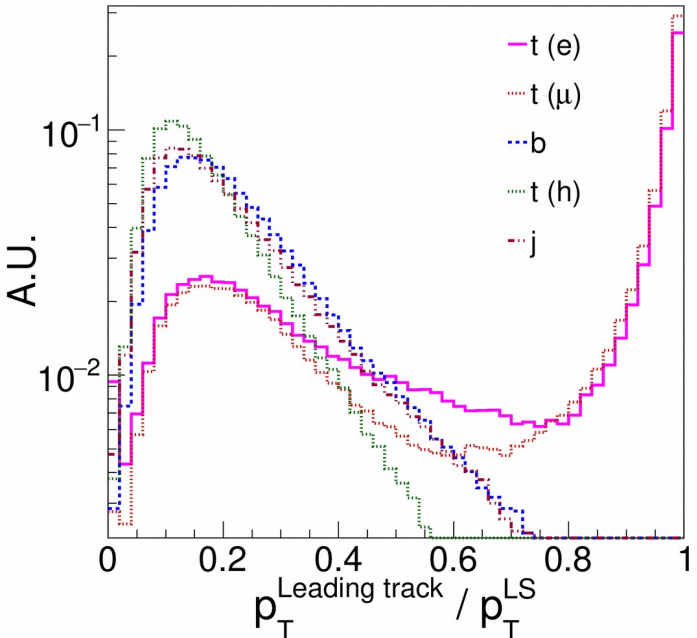
Calculation is based on :

i) 4-momentum conservation in top decay
ii) neutrino is massless
iii) R is small (for the last part)

Lepton Candidate in Fat Jet

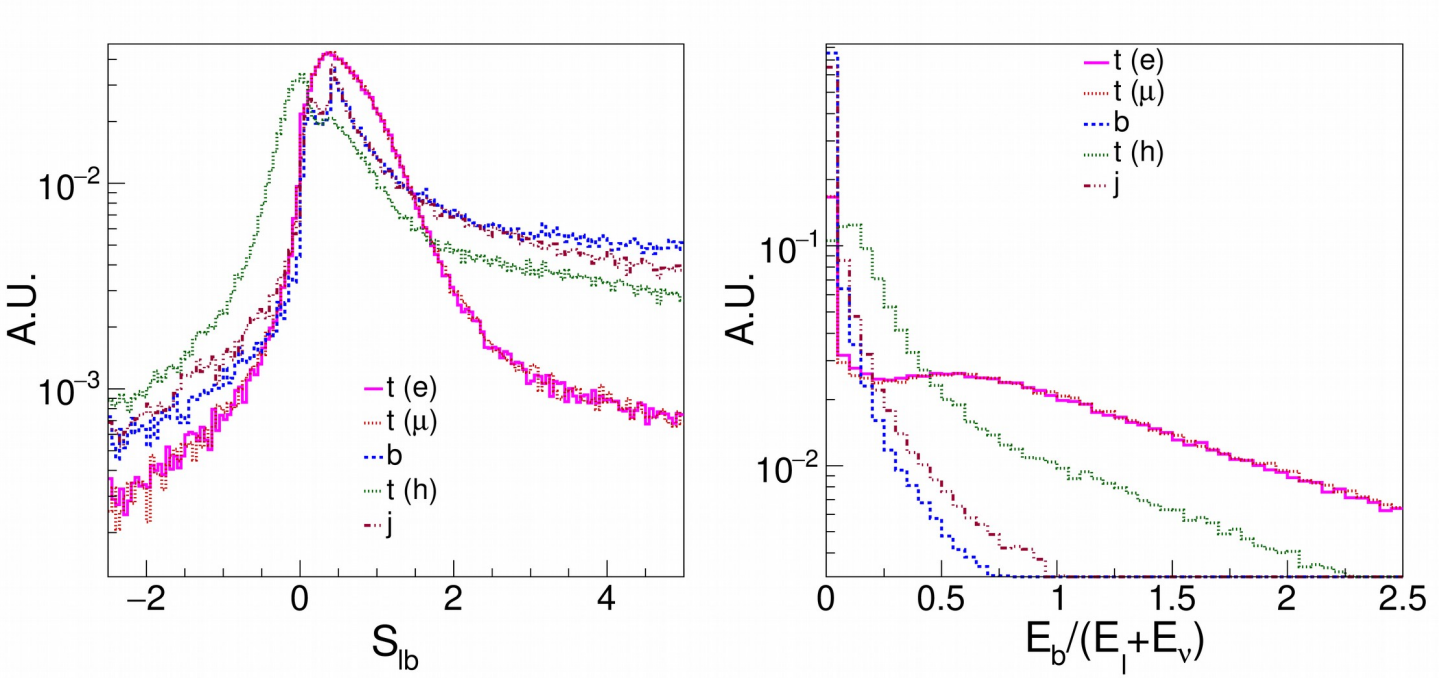
- Need lepton candidate to use in observables mentioned earlier
- Rely on excellent track reconstruction algorithms and jet substurcture
- Start with a AK8 jet => Perform soft-drop grooming
- Subjet with less hadron energy fraction => Lepton subjet (LS)
  Subjet with more hadron energy fraction => Hadron subjet (HS)
- 3 exclusive k_T subjets of LS => exclusive subjet which contains the leading track => lepton candidate
- HS => b candidate





Weapons : ν sensitive new observables

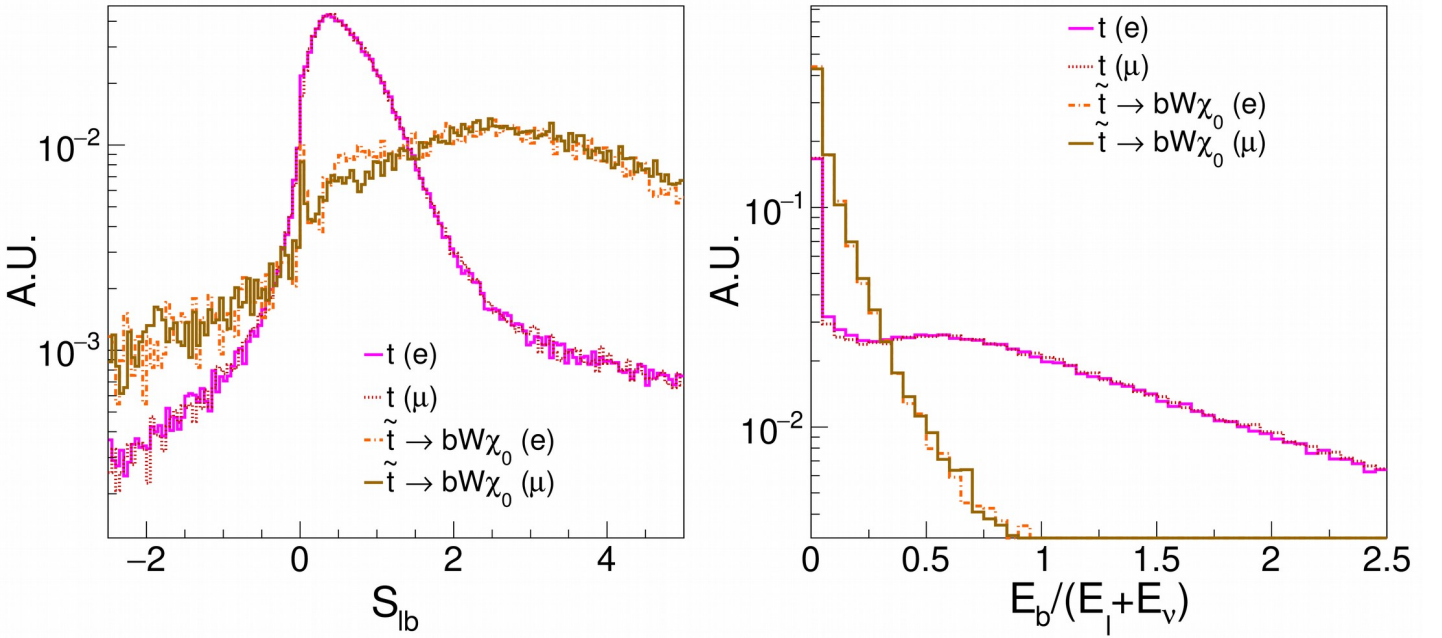
- Distribution in simulated samples : top signal, SM bkg, BSM bkg



Variables discriminate top from both SM bkg and stop particles

Both e and μ final states result very similar distributions

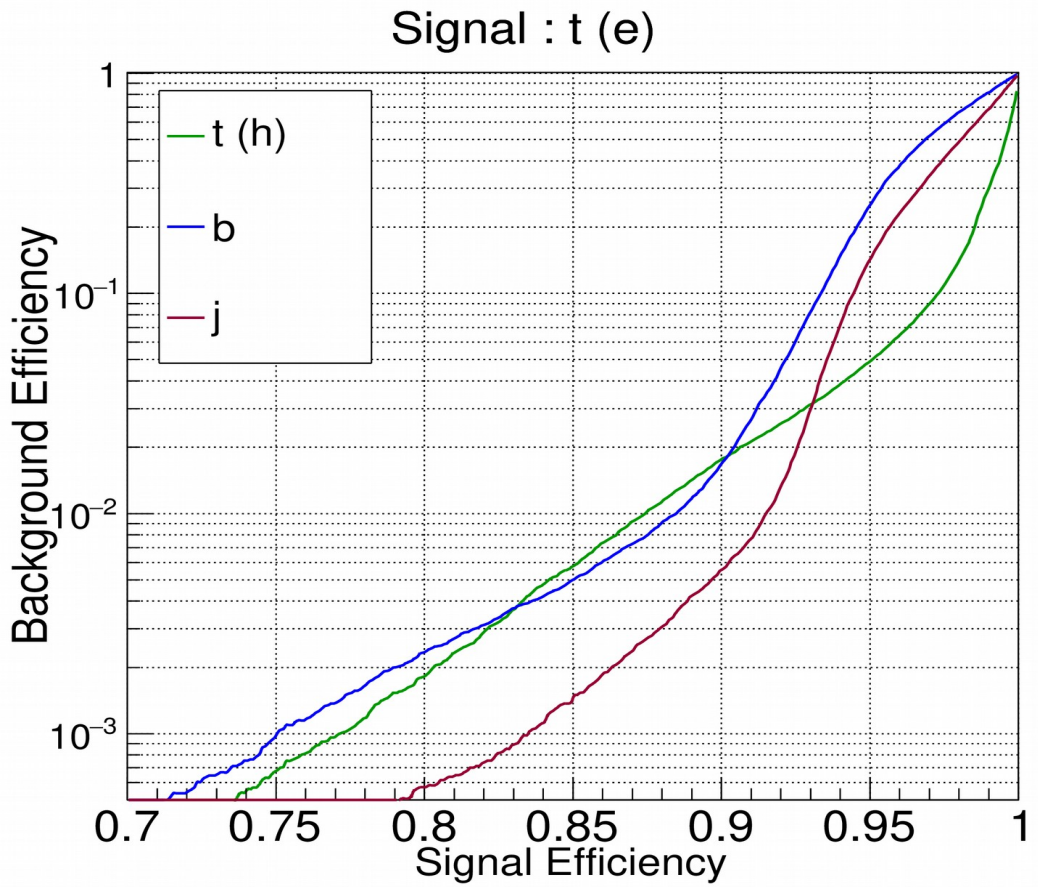
(generic leptonic top tagger variables)

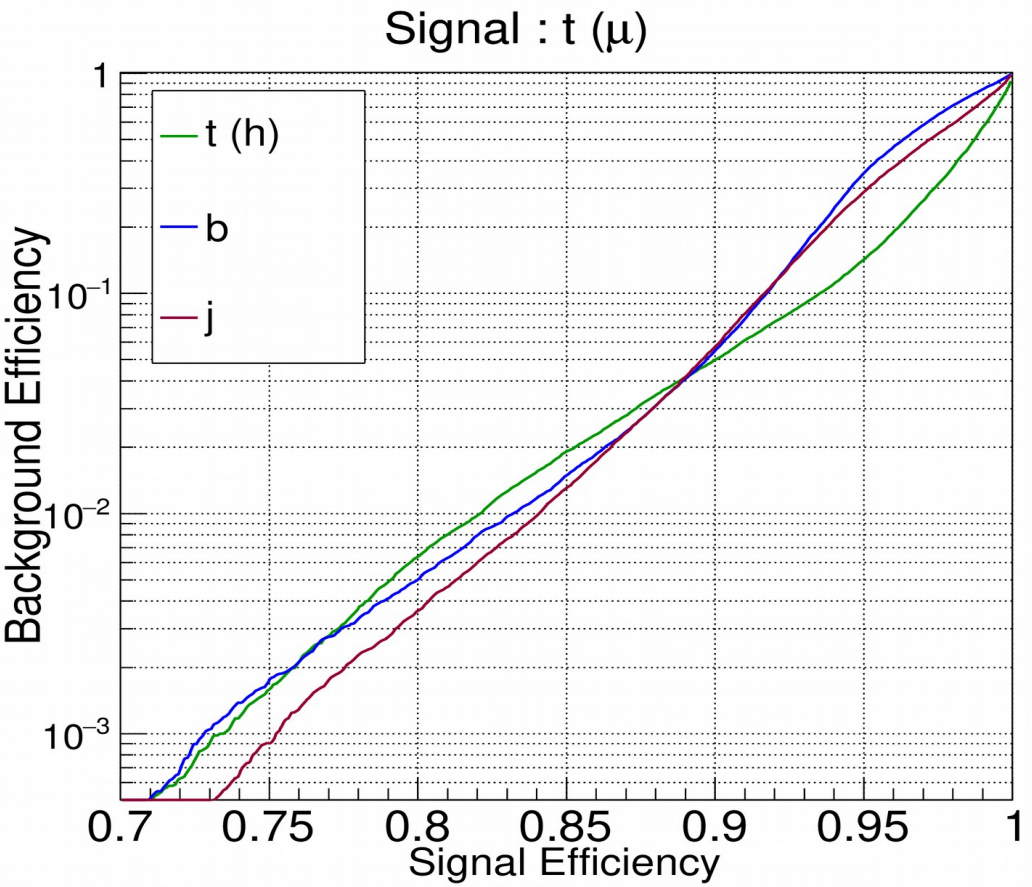


$M(\tilde{t}) = 200$ GeV
$M(\chi_0) = 100$ GeV

Performance

- Multi-variate analysis with BDT classifier
- Variables chosen targetting electronic final state (neutrino sensitive observables are not used here)

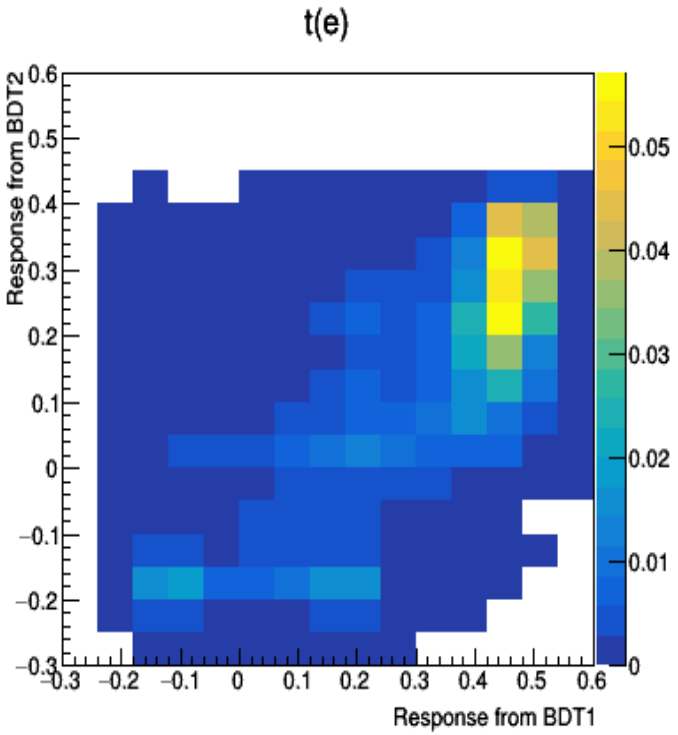


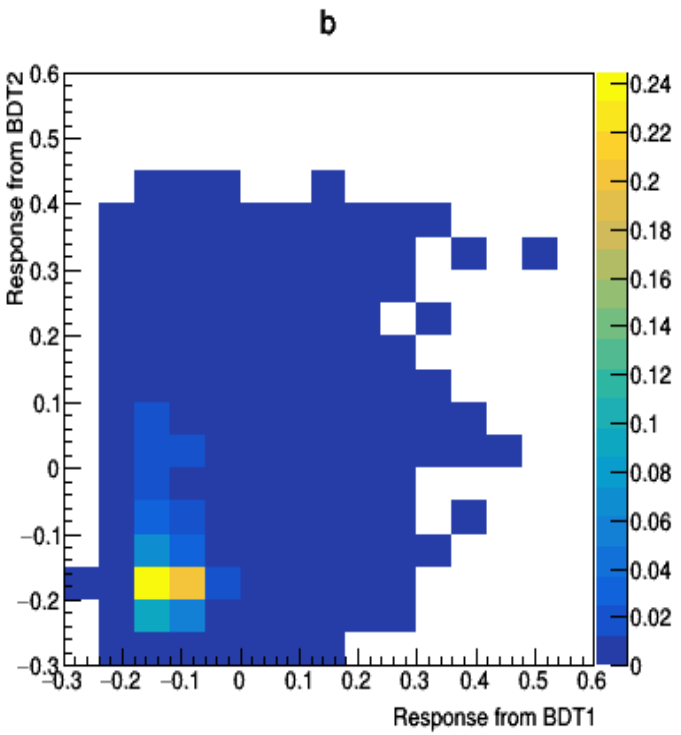


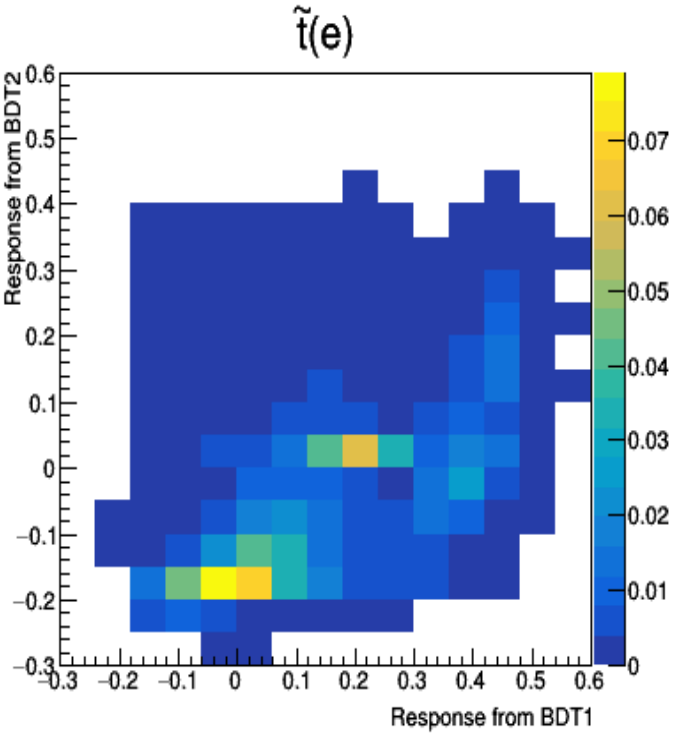
- Excellent performance!

Performance

- Exploit neutrino sensitive variables using BDT
- BDT 1 : t(e) signal and b jet bkg using all variables except neutrino sensitive ones
- BDT 2 : t(e) signal and b jet bkg using only two neutrino sensitive variables







- Different samples lie on different regions of the plane

Summary

- Exploited different energy components of the jet and jet substructure to tag top quark in leptonic decay mode
- Developed observables sensitive to neutrino momentum to distinguish top quark from SM bkg and BSM signal (stop for example)
- More exiciting time for tagging business at LHC Run 3 at higher COM energy and also to analyze humongous amount of Run 2 data already available!

This work is soon to appear in arXiv

Correlation Map