SEARCH FOR THE STANDARD MODEL HIGGS BOSON DECAYING INTO $B\bar{B}$ AND PRODUCED IN ASSOCIATION WITH A TOP QUARK PAIR IN THE ATLAS EXPERIMENT

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Pheniics Days

E. Le Quilleuc, supervisors H. Bachacou, F. Déliot - CEA Saclay

OUTLINE

Intro : LHC, ATLAS experiment overview

I. $t\bar{t}H$ analysis

- Higgs boson production modes
- $t\bar{t}H$ decay modes accessible by the ATLAS detector
- Standard/boosted signatures

II. *b*-tagging in ATLAS

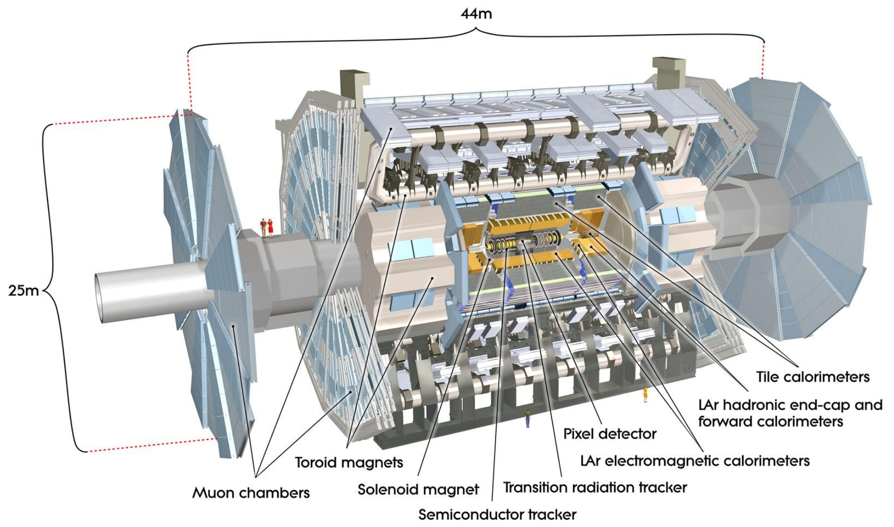
- Introduction
- Secondary vertex tagger
- Show somes studies/improvements

LHC AND ATLAS EXPERIMENTS

- LHC (Large Hadron Collider)
  - circular hadron collider located at Cern (27km circumference)
  - designed proton-proton (pp) center of mass energy **CME = 14 TeV**
  - designed luminosity **L ~10^{34} cm^{-2}s^{-1}**

- Operations
  - *2011* CME = 7 TeV, ∫ L dt ~ 7 fb^{-1}
  - *2012* CME = 8 TeV, ∫ L dt ~ 20 fb^{-1}
  - *2015* CME = 13 TeV, ∫ L dt ~ 3 fb^{-1}

- ATLAS : **a multi-purpose detector** which probes a range of high energy processes.
- **Purpose of the experiment:**
  - precise SM measurements, like Higgs boson properties
  - Discover new physics with very energetic particles in the final state

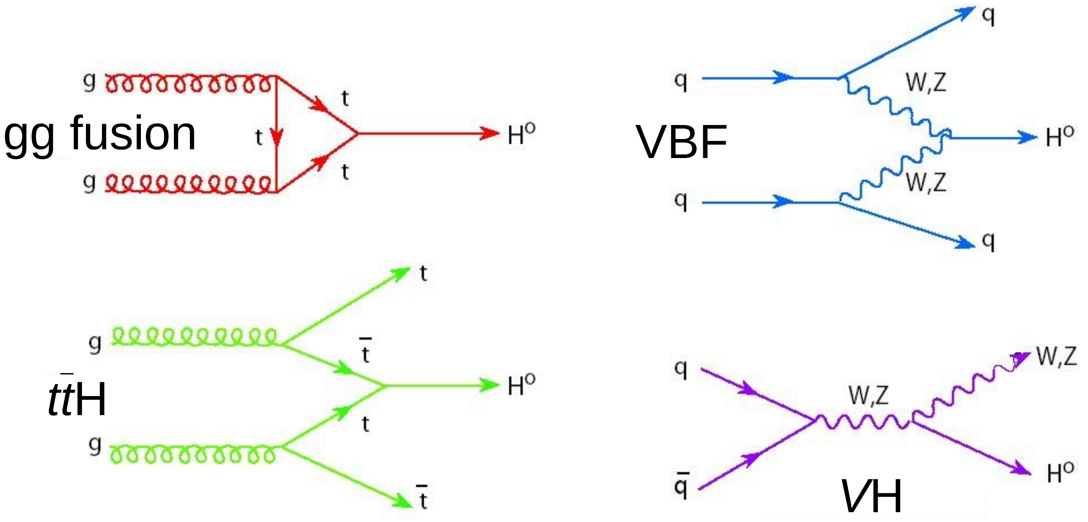


ATLAS detector

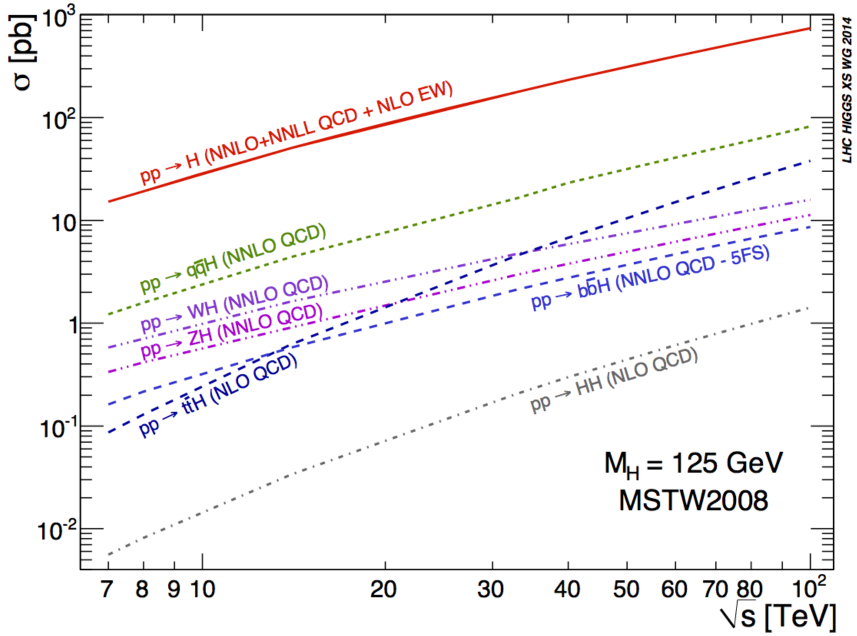
I. TTH ANALYSIS IN ATLAS

HIGGS PRODUCTIONS AT THE LHC

- Higgs production Feynman diagrams at the LHC :



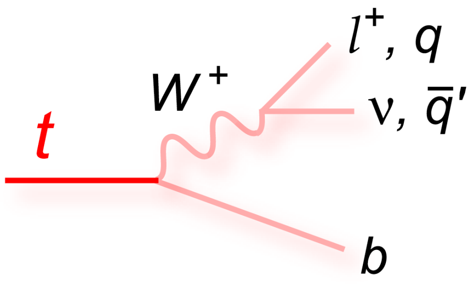
- Higgs production cross sections with CME



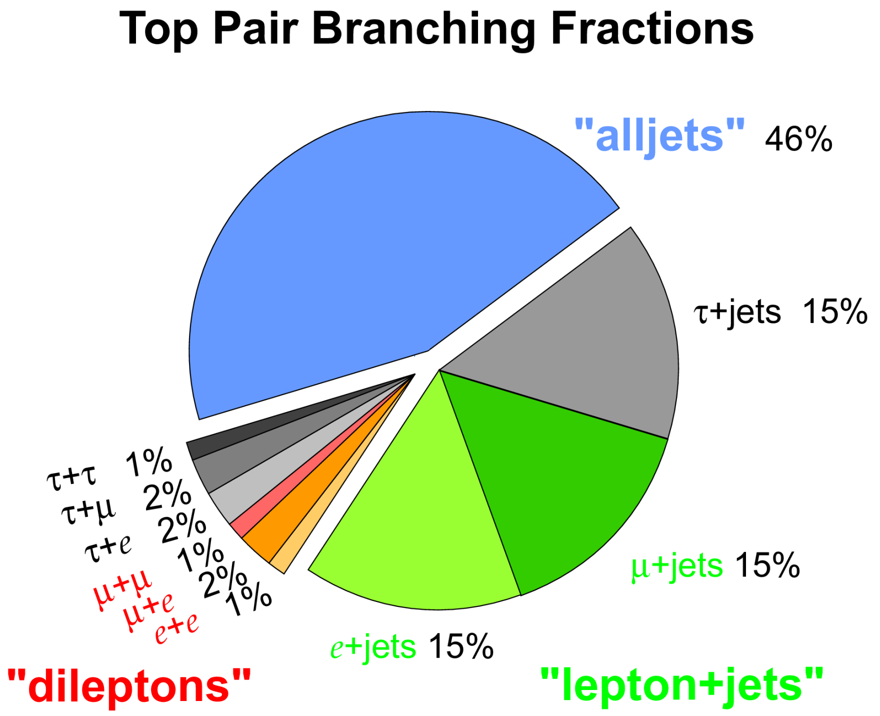
- In 2012, Higgs boson discovery by ATLAS and CMS (gg fusion largest cross section)
- 8 TeV → 13 TeV, factor ~2 increase of gg fusion, VBF & VH cross sections, while ~4 $t\bar{t}H$ cross section (opening of the phase space)
- The $t\bar{t}H$ cross section prop. to the (top Yukawa coupling)^2 → its precise measurement is essential in order to constrain the Higgs mechanism of the SM (Yukawa couplings prop fermion masses) and BSM theories

TTH DECAY MODES

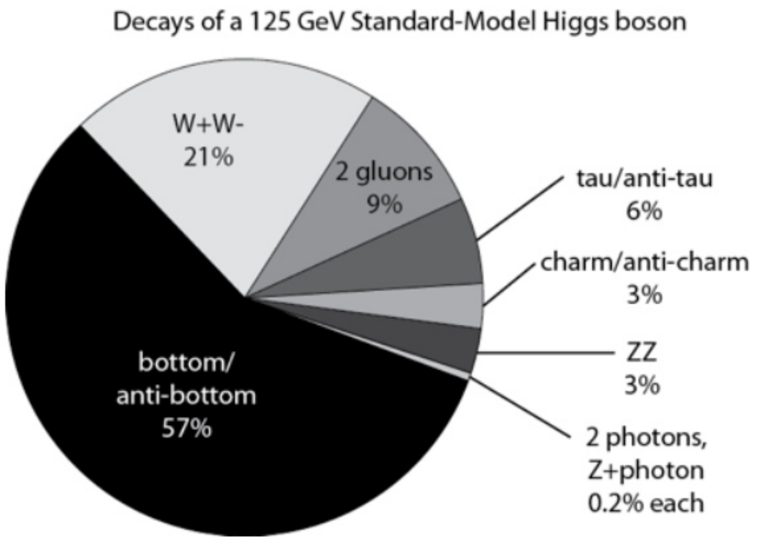
- *t*-quark decay → Wb



- Note : lepton = electron or muon



- Higgs boson branching ratios :



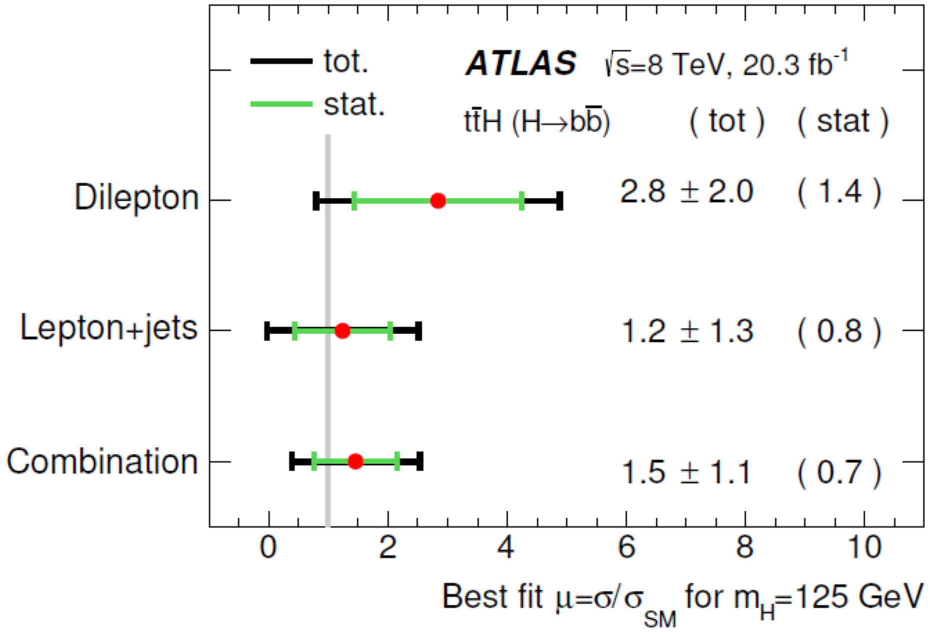
- $t\bar{t}$ → **dileptons** : very clean signature but low statistics
- $t\bar{t}$ → **lepton+jets** : compromise between clean signature and fair statistics
- H → $b\bar{b}$: highest branching ratio of the SM

TTH 8 TEV RESULTS

Signatures in the signal region (resolved)

- **Lepton + jets** : 1 charged lepton, >= 6 jets, >= 4 b-tags
- **dilepton** : 2 charged leptons, >= 4 b-tags

- Main background : $t\bar{t}$ + jets



Signal strength for individual channels and their combination

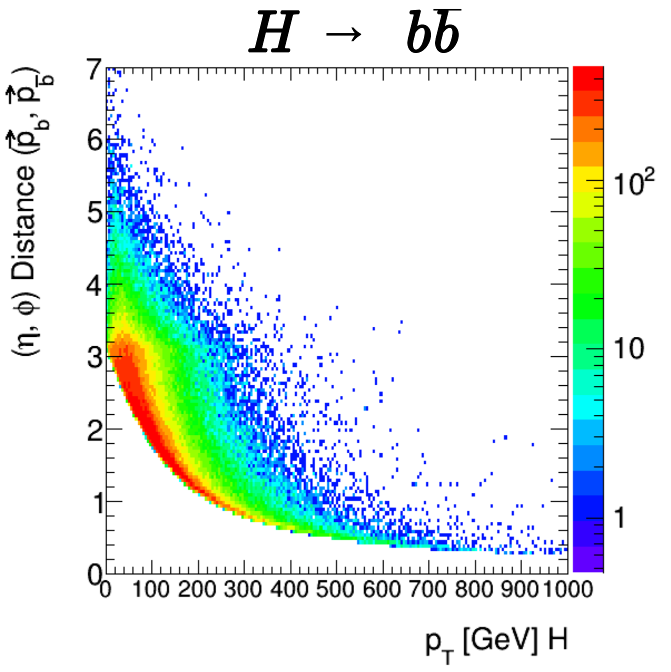
BOOSTED TTH ANALYSIS

- **Boosted ttH analysis** : top/Higgs are produced at high momenta
    - decay products are well separated
    - can be merged into large radius jets

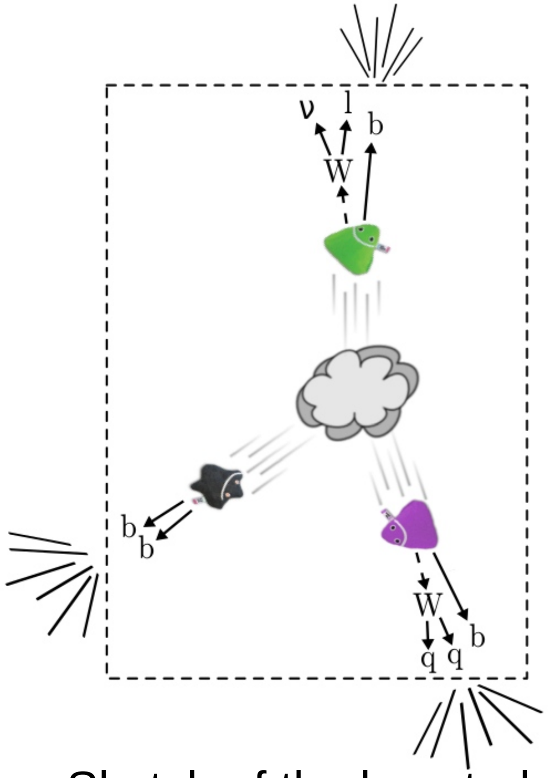
- **Signature** : 1 charged lepton,
  1 large-R jet that contains hadronic top
  1 large radius jet that contains Higgs boson

- Suffers from very low statistics

- Currently working on the selection results will be shown with 2016 data



Distribution $\Delta R_{b\bar{b}}$ vs $p_{T,\ Higgs}$



Sketch of the boosted $t\bar{t}$H signature

II. B-TAGGING IN ATLAS

B-TAGGING IN SHORT

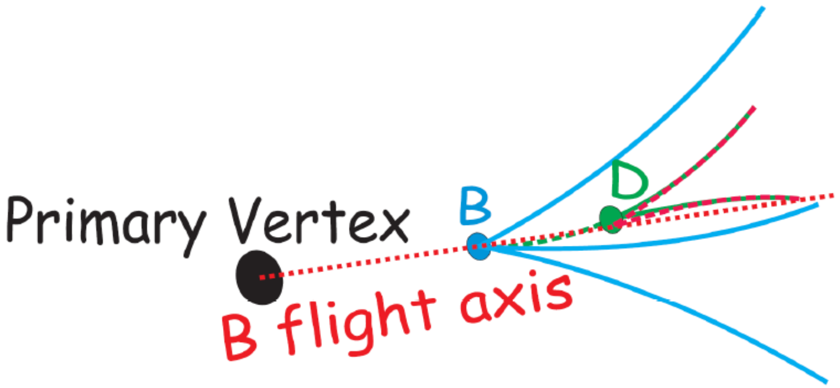
- *b*-tagging ≡ identification of jets coming from the hadronization of *b*-quarks
- Motivation :
  - Many interesting physics processes contain b-quarks in the final state (t-quark and Higgs boson)
  - QCD background processes mainly produce *light*-jets (from *u*, *d*, *s*-quarks or gluons)
- b-hadrons have a relatively large lifetime = O(ps)

→ experimentally tracks from b-hadron decays

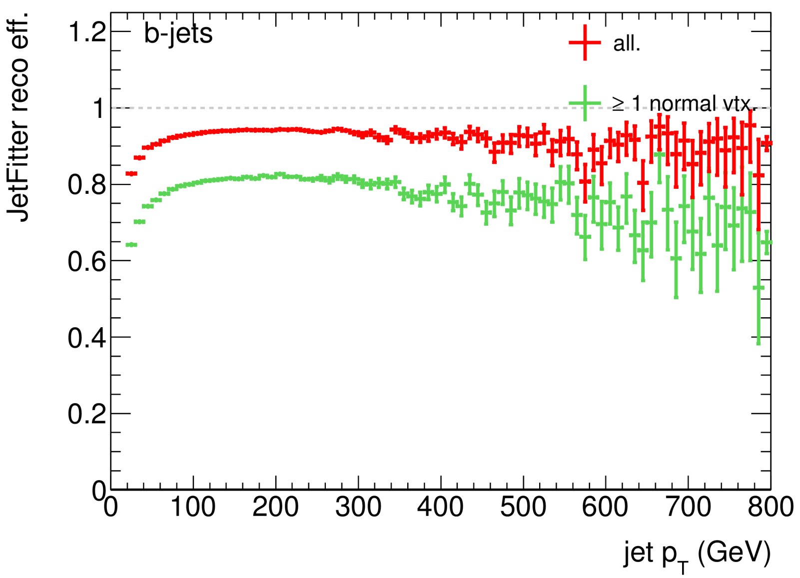
  - do not point to the hard pp collision, called primary vertex (PV)
  - cross each other into a single geometrical point called Secondary Vertex (SV)
- Main background of b-tagging :
  - light (*u*)-jets (fake b-hadron vertices like V0 decays, material hadronic interaction, γ → e+e-, detector resolution effects
  - *c*-jets (from hadronisation of *c*-quarks)

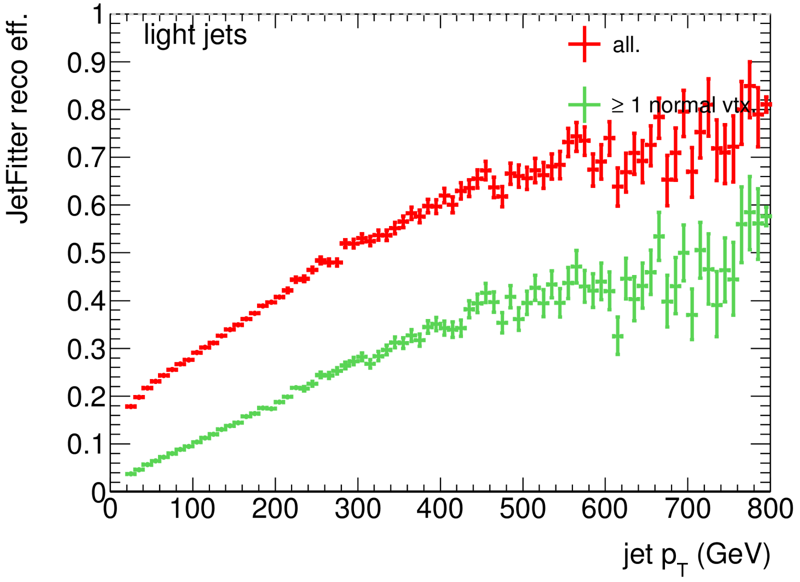
SV BASED ALGORITHM

- *b*-hadron almost always decays into **c-hadron** with lifetime O(ps)
- **JetFitter (JF)** : reconstruct vertices from *b*-hadron and *c*-hadron decays along the same *b* flight axis
    - Tries to contrain jet tracks to intersect the *b* flight axis (= the jet direction for the first fit iteration)
    - Fit vertices and the *b* flight axis and keep vertices high significance (1-track or multi-track vertices)



Decay chain B → D + X





"Reco" efficiency = Z / Y

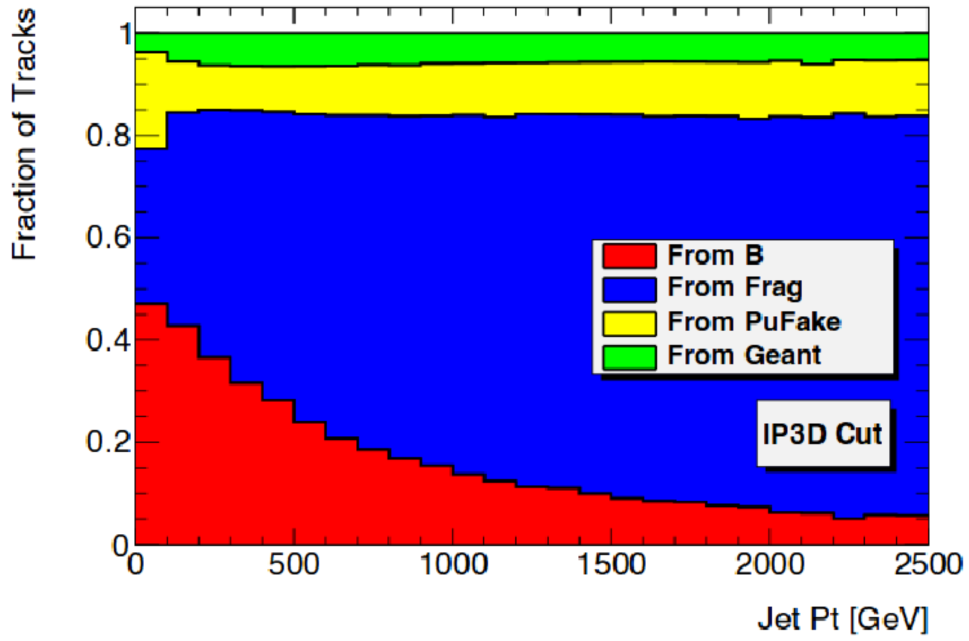
Z = specific vertex reconstructed (no llr cut)

Y = all b-jets

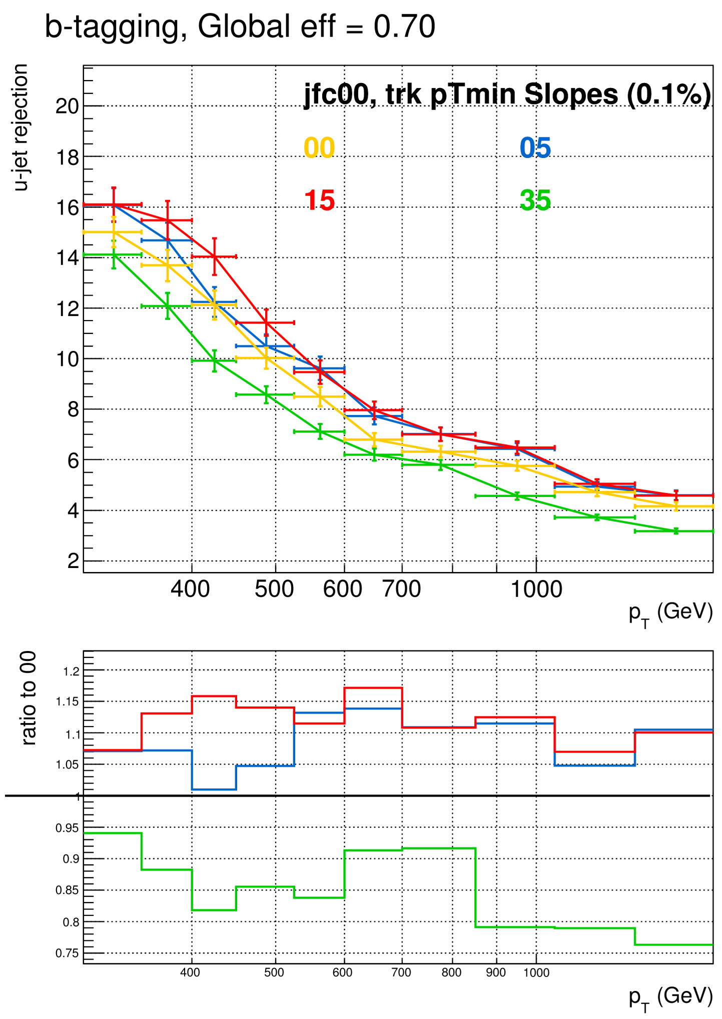
- JetFitter reco eff. increases linearly with jet pT for *u*-jets

JF TRACK PT SELECTION, HIGH PT

- **Explanation** : number of fragmentation tracks (ie from hadronisation) increases with jet pT, more collimated tracks



Origin of track fraction in a b-jet
as function of jet pT



- **Select tracks for vertex reconstruction with higher pT** : cut proportional to the ~ sum of tracks pT

example : track pT > 1.5 % * sum track pT → 15 % improvement of the rejection of *u*-jets

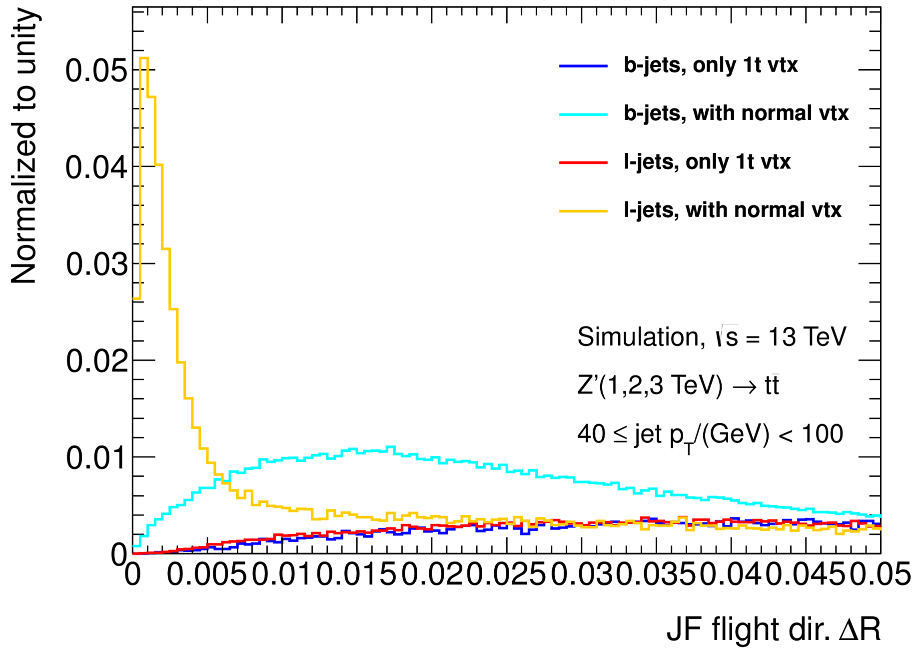
JF FLIGHT DIRECTION DR

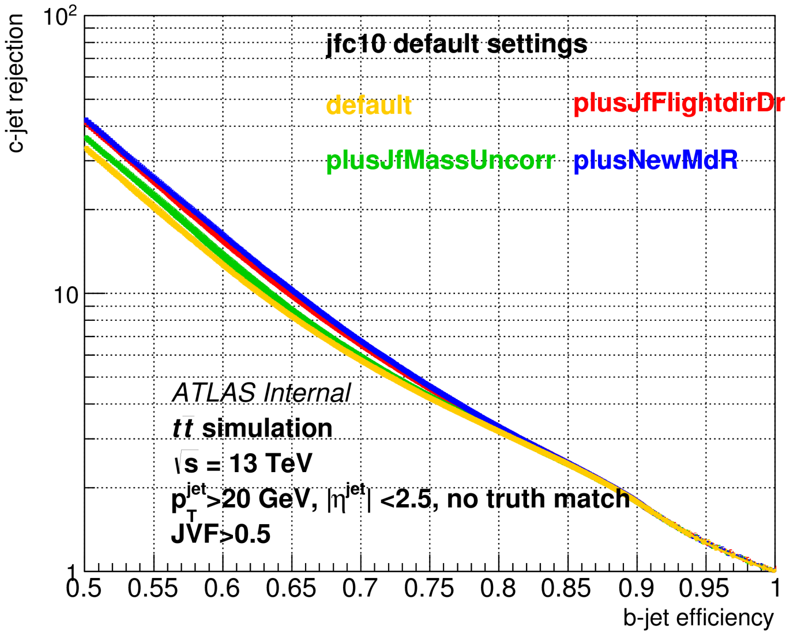
- **The vertices mass, decay length** ect can be exploited to separate *b*-jets from *u*-jets
- **flight dir. DR** : pseudo-angle between $\bar{p}_{vtx}$ and the *b*-flight axis

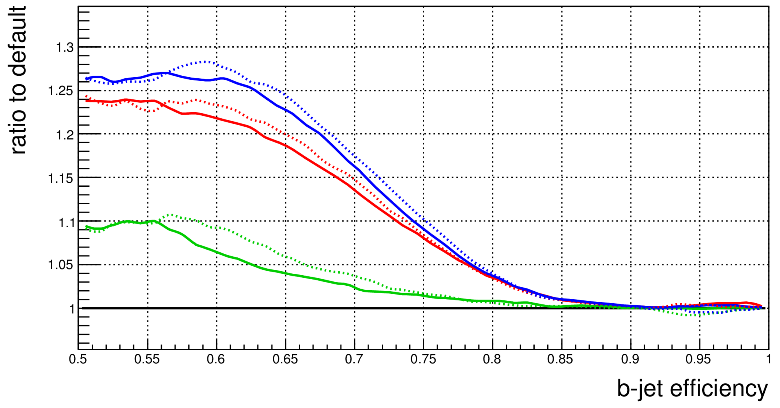
u-jets : peak near 0 for u-jets due to V0s decays (into 2 charged particles)

b-jets : larger tail because the B-hadron decays into charged and neutral particles

Low pT







- **Adding fligh dir. DR** improves the JetFitter c-jet rejection by 20% at a 65% b-jet effiency

CONCLUSION

- **$t\bar{t}$H cross section measurement** can be improved by the boosted analysis with 13 TeV data
- **Boosted channel is under study with optimization of the selection**
- ***b*-tagging** is an important feature for search of interesting processes at the LHC
- We improved the secondary vertex reconstruction
  - At high jet pT, with a tighter selection on tracks pT
  - By adding new information to *b*-tagging final discriminant

BACK UP

JETFITTER TRACK SELECTION @ HIGH JET PT

BDT STUDIES

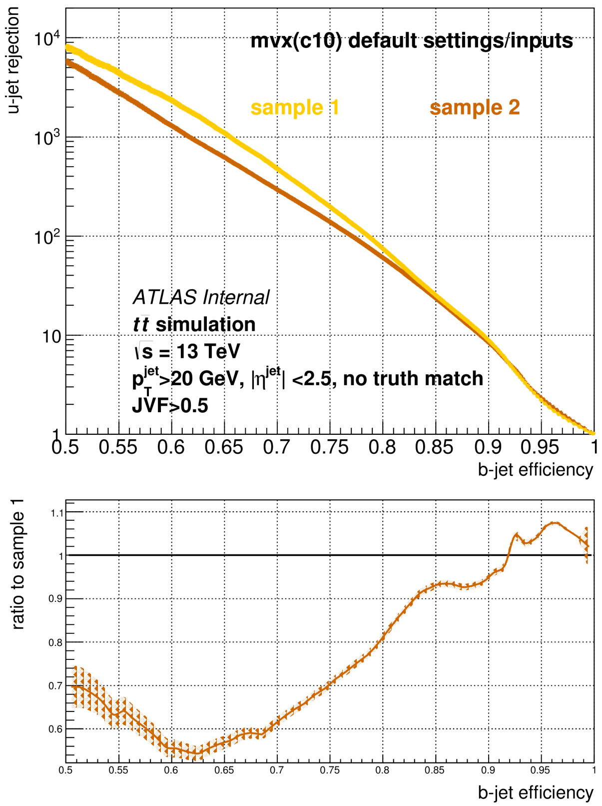
MV2 DEFAULT : 2 TRAININGS

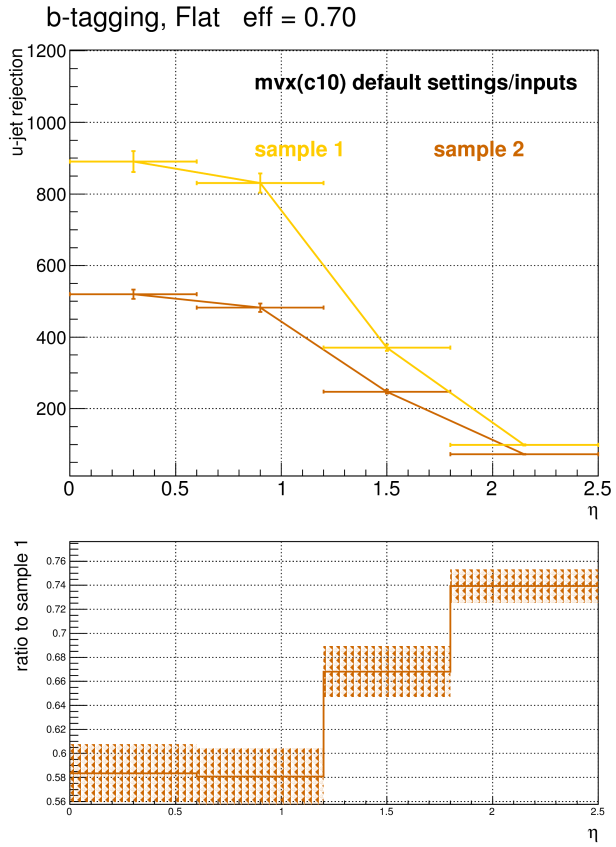
10% c-jet

- 2 mv2 obtained with same training settings but with 2 statistically independent training samples → we evaluate their performances

Significantly large discrepancy between the evaluation of the 2 trainings

(!= overtraining here)





- Issue origin : in training, jets with SV1 and JF vertices (good jets) are treated differently than jets without these reconstructed vertices (bad jets)

- Bad jets are reweighted with factor 10e-6

BDT WEIGHT

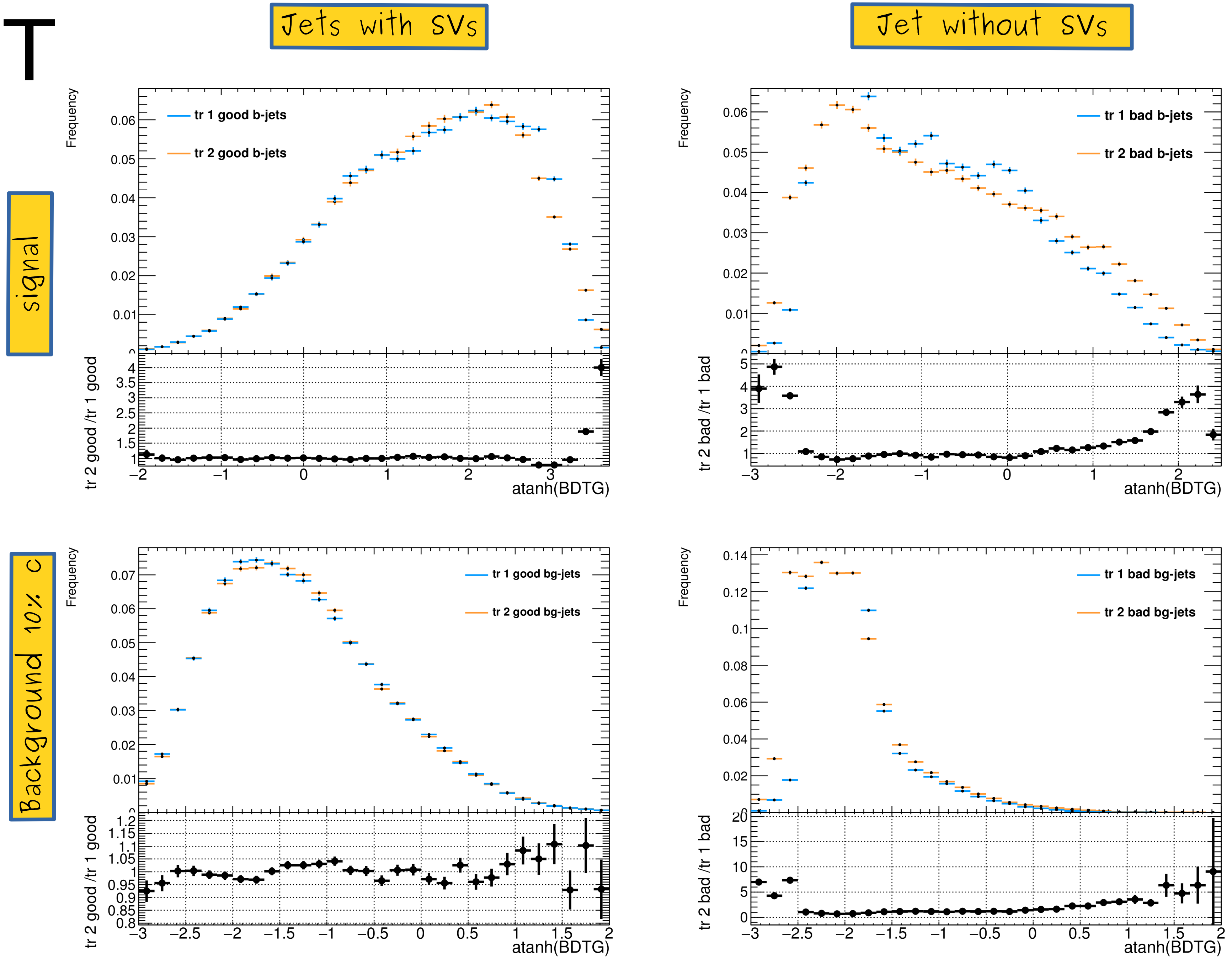
- Comparison of BDT weight obtained from 2 statistically independent trainings

  for good/bad , signal(b) and background

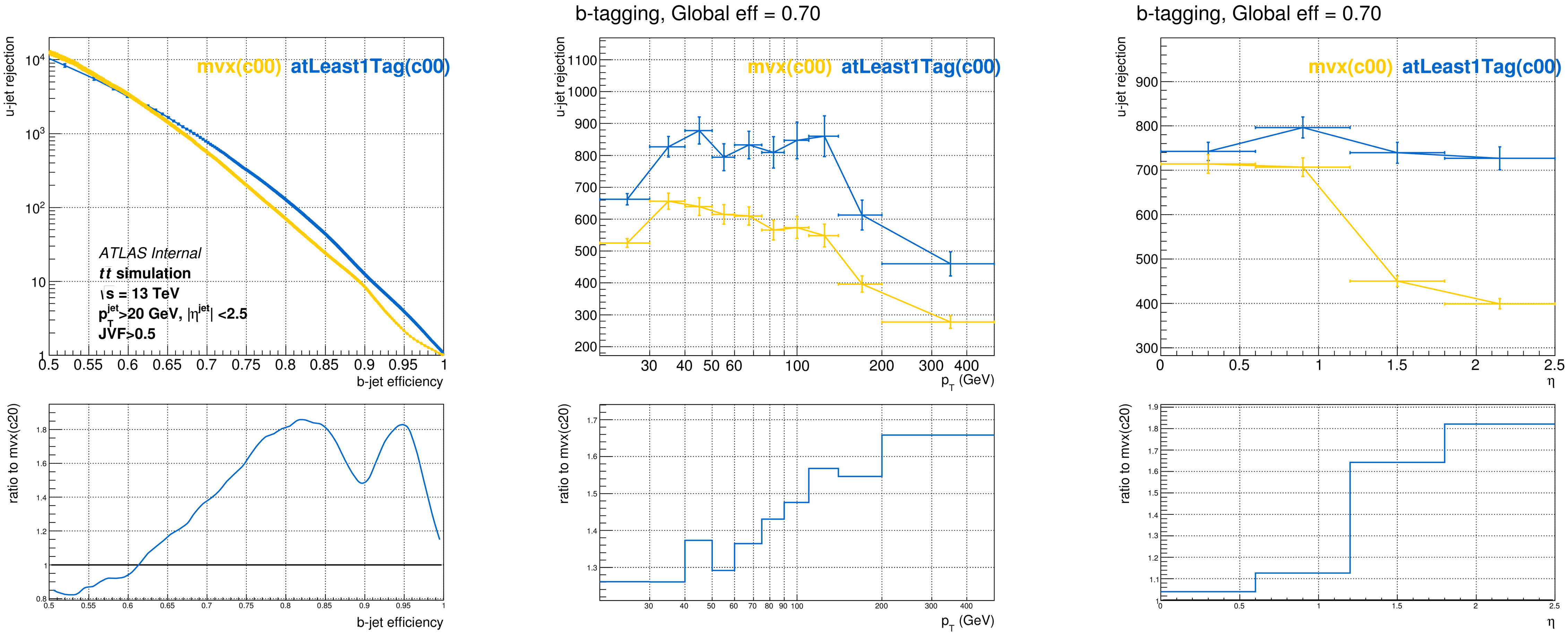
- ~ good agreement of 2 BDT weights for good jets

- Large differences on the tails of BDT dist. for bad jets

- **Key point** : most u-jets in ttbar (98%) are bad jets. The discrepancy at low BDT for bad u-jets leads to huge differences in the evaluation since bad-jets are not down weighted



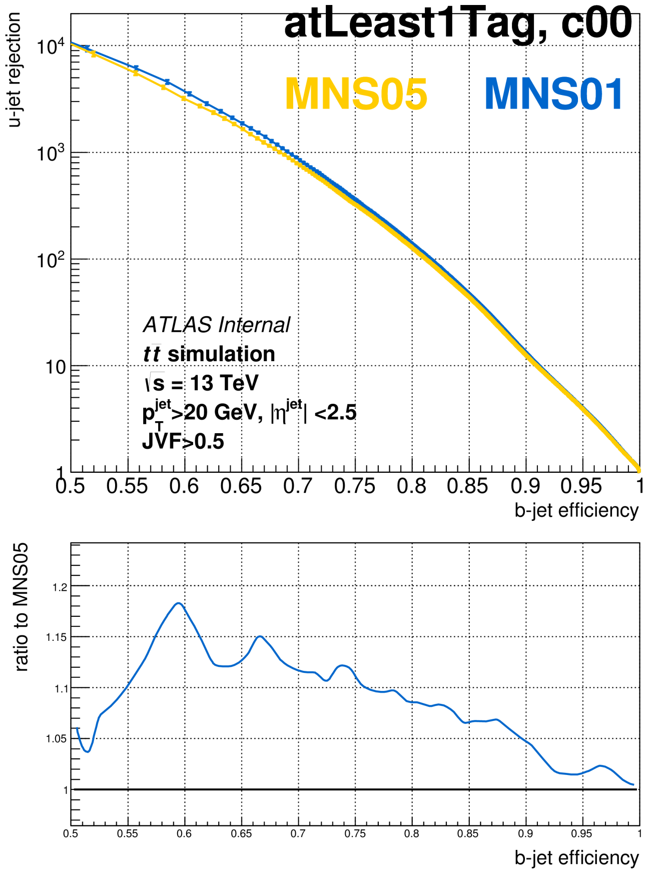
FAIR COMPARISON C00

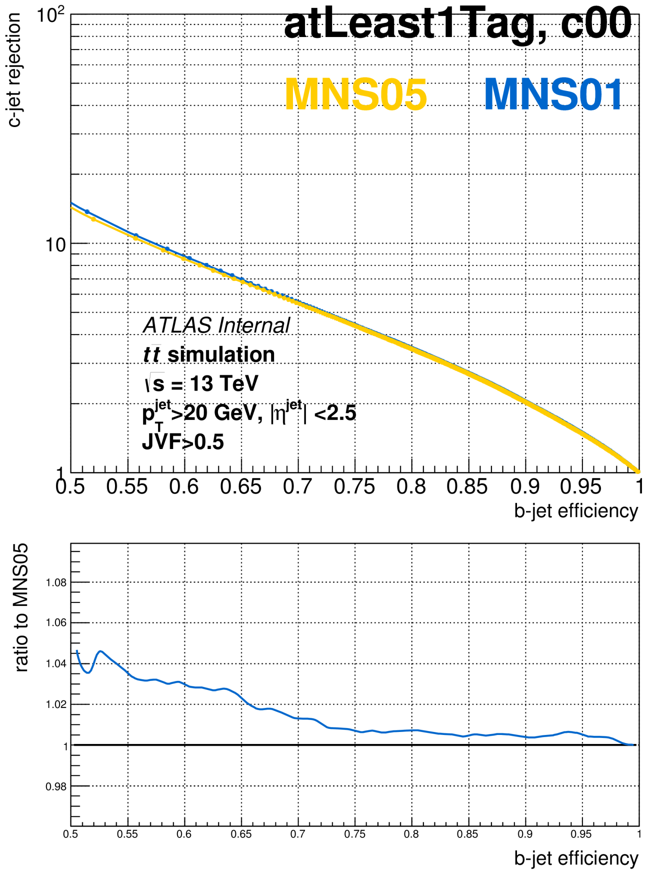


- Comparison
  - **AtLest1Tag : slightly different new good jet definition** = at least 1 of the 3 taggers IP, SV1, JF is defined (~ very similar to IP only since IP is very inclusive)
  - **mvx(c00)** : retraining with default mv2c00 settings
- C-fraction issue forced us to consider the case c00 = "no charm in the background" → fair comparison with new training

SOME OPTIMIZATIONS

- **Minimum Node Size** (MSN) : minimum fraction of events contained in a leaf during training : # jets in leaf / total # jets in training
- The new training takes more jets because it is more inclusive → more events in fraction denominator → must reduce the Minimum Node Size
- Default value : 0.5%, new value : 0.1%

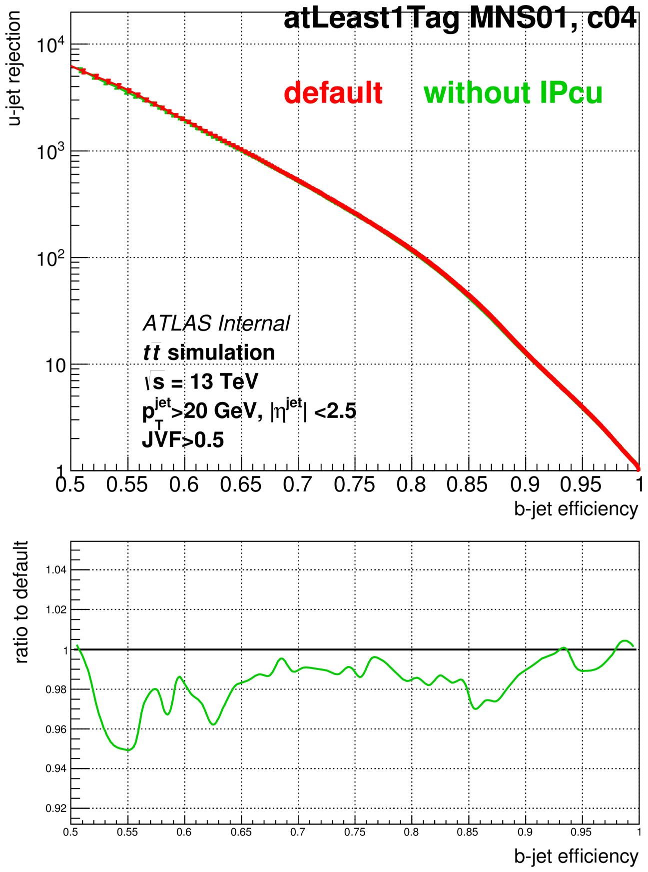




- For both IpxD, 3 discriminant variables
  - Llr_IP = likelihood(IPb) - likelihood(IPu)
  - Llr_IP_c = likelihood(IPb) - likelihood(IPc)
  - Llr_IP_cu = likelihood(IPc) - likelihood(IPu)

only 2 are linearly independent , ex:

Llr_IP_cu = Llr_IP - Llr_IP_c



JF TRACK PT SELECTION, HIGH PT

- **Cut on JF track pT** proportional to Scalar sum of pT over selected tracks
- **With a slope a = 0.5%, 1.5%, 3.5%**
- **Sample : last MC15 Z' → ttbar , mass = {0.4, 1, 3, 4 } TeV**
- **Kinematic selection** (jet) : pT > 300 GeV & | eta | < 2.5
- **Pile-up removal** : JVF > 0.5
- **Training** with only JF variables