Performance of b jet identification with the ATLAS detector at CERN

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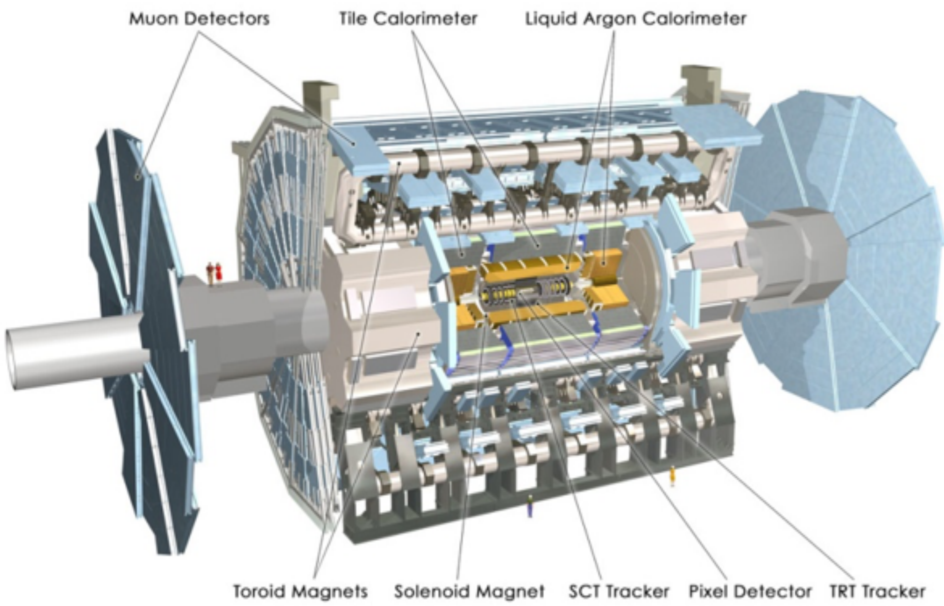
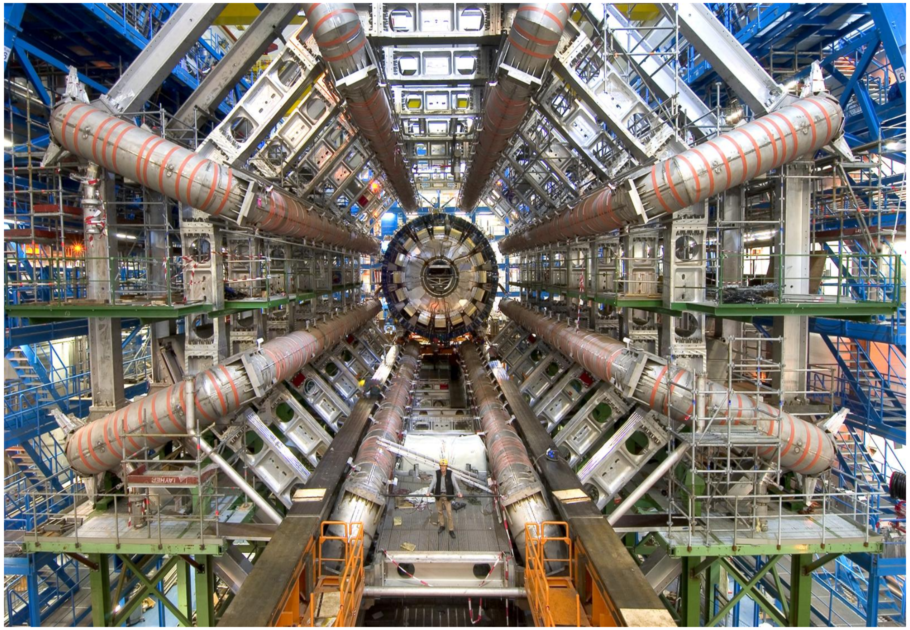
The ATLAS detector

- ATLAS (A Toroidal LHC ApparatuS) is one of the two general purpose detectors placed at one of the collision points of LHC ring at CERN.
- At 46 m long, 25 m high and 25 m wide, the 7000-tonne ATLAS detector is the largest volume particle detector ever constructed.
- It sits in a cavern 100 m below ground near the main CERN site, close to the village of Meyrin in Switzerland.





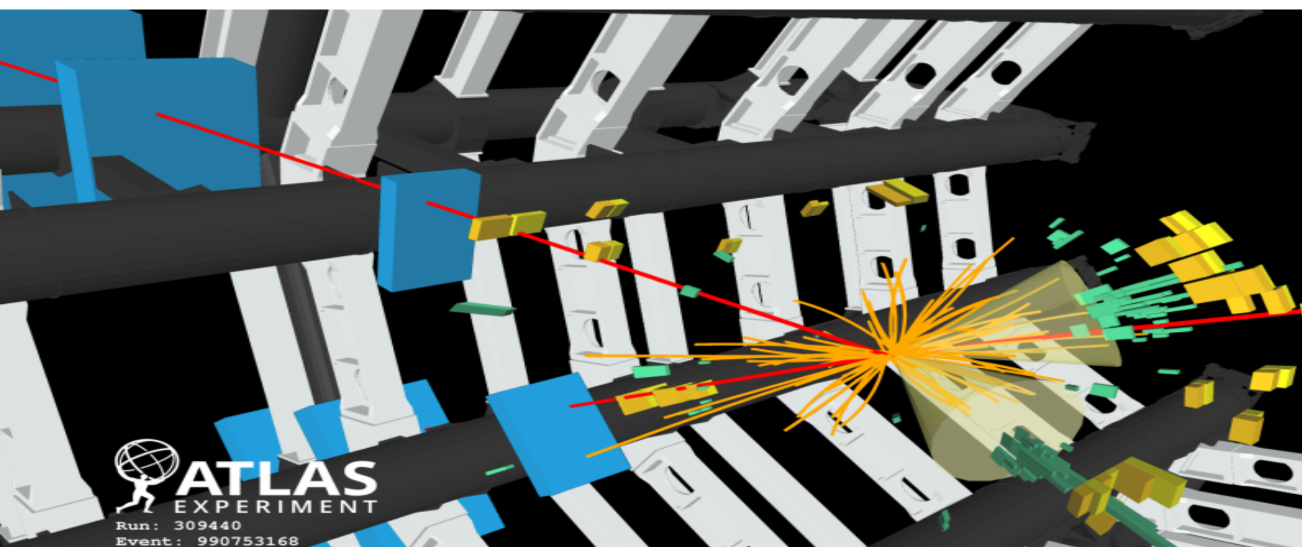
B-tagging

The identification of jets originating from B-hadrons (b-tagging) is crucial for many interesting physics signatures at the Large Hadron Collider (LHC):

- Top quarks decay into W bosons and b-quarks about 100% of the time
- The Standard Model Higgs boson predominantly decays into b-anti b-quark pairs
- Many searches for new physics, e.g. supersymmetry, involve final states with b-quarks

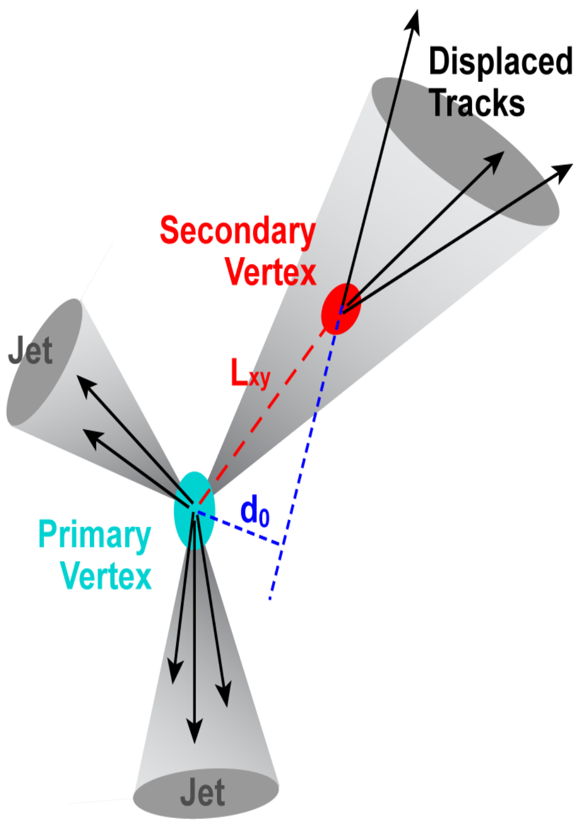
The b-tagging performance is characterized by b-tagging efficiency (the probability to correctly identify a b-jet) and mistag rate (the probability to misidentify a jet not originating from a B-hadron as a b-jet).

The b-tagging calibration : Connection of b-tagging efficiency & mistag rate for discrepancies between Monte Carlo simulation and data.



Event display of Higgs boson decayng to a b-anti b quark pair.

How B-tagging works



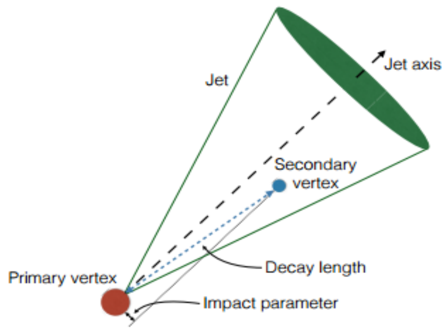
The long lifetime of hadrons with b-quarks (1.5 *10^-12 s), compared to other particles (e.g. Higgs boson lives for 10^-22 s) results in a typical decay topology with at least one vertex displaced from the primary vertex from the hard-scattering collision.

Identification of the b-quark jets is based on distinct strategies encoded in three basic algorithms:

- An impact parameter based algorithm (IP), an inclusive secondary vertex reconstruction algorithm (SV) and a decay chain multi-vertex reconstruction algorithm (JetFitter) !

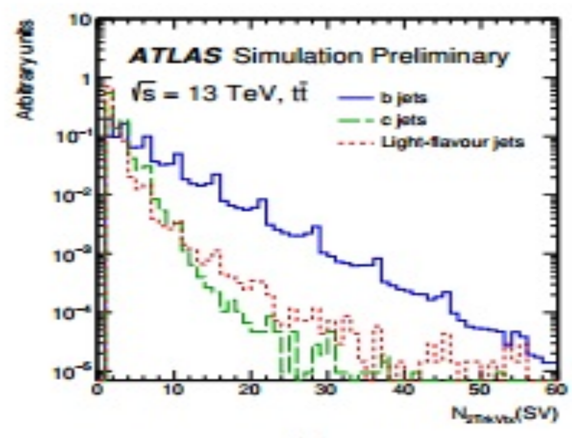
- The output of these algorithms are combined in a multivariate discriminant (MV2) which provides the best separation between the different jet flavors.

Basic B tagging algorithms



Secondary Vertex Finding Algorithm (SV) :

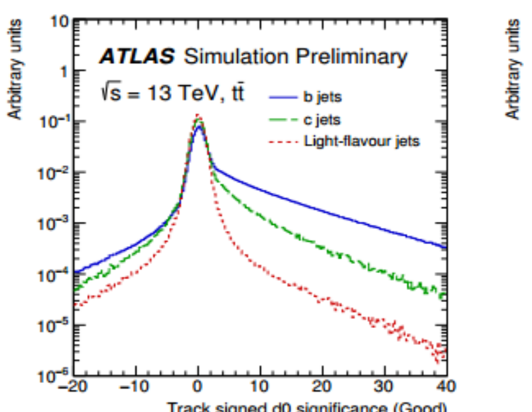
• Reconstructing an inclusive displaced secondary vertex within the jet • Single secondary vertex built by combining all track pairs except when compatible with conversion, V0 decays or material interactions



IP2D and IP3D: The Impact Parameter-based tagging Algorithms :

Input of IP2D/IP3D: transverse and longitudinal impact parameter significance of each track associated to the jet to form a per-track 2D template that takes correlations into account

•Log likelihood ratio (LLR) calculated and Reference histograms are separated in categories depending on the hit pattern of a given track



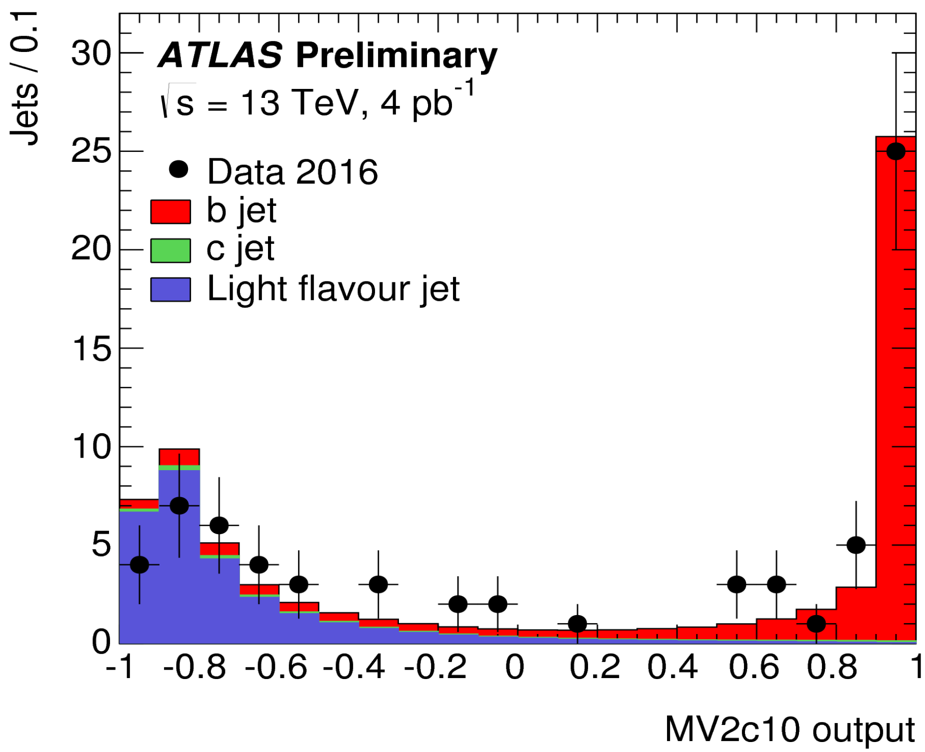
do significance

Decay Chain Multi-Vertex Algorithm (Jet Fitter) :

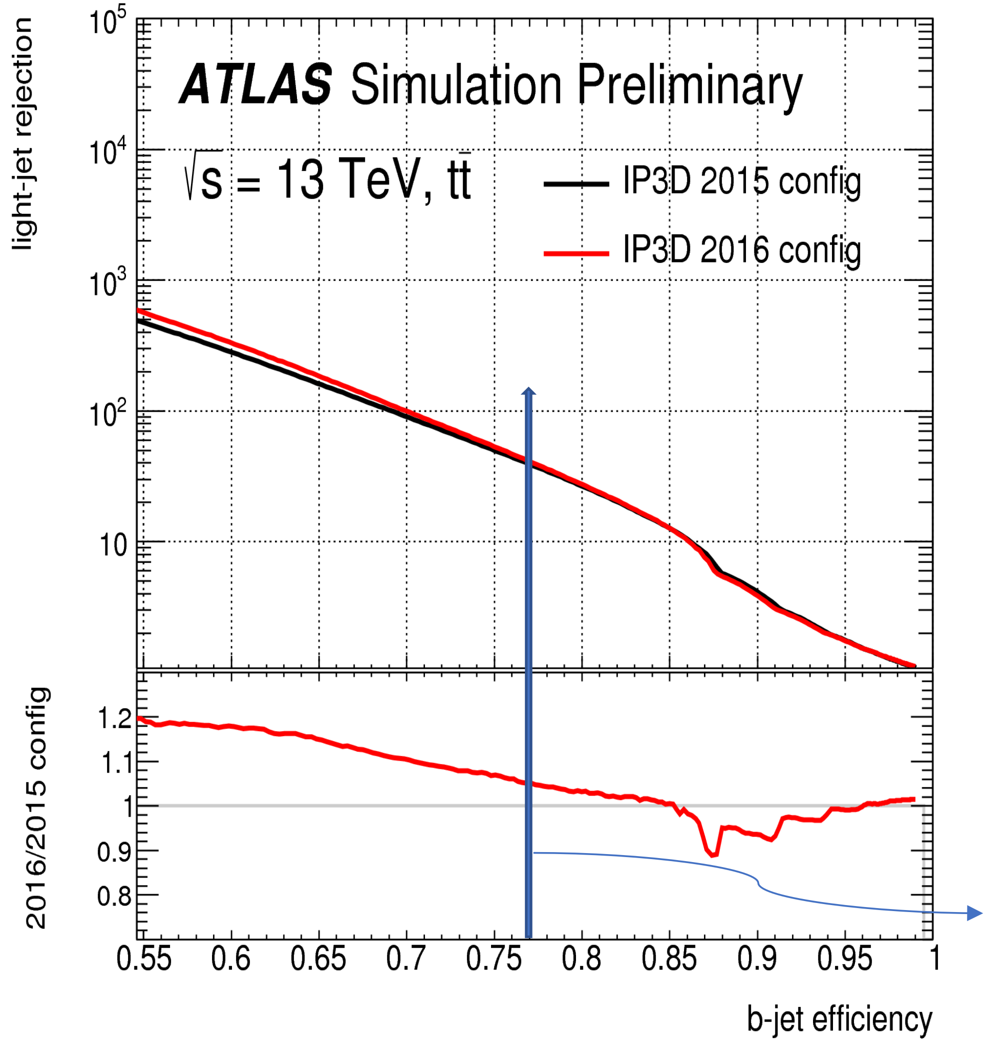
- Decay chain multi-vertex reconstruction algorithm exploiting the topology of b/c-hadron decays inside a jet
- Properties of the decay topology and secondary vertices reconstructed by the algorithm

Multivariate MV2 Algorithm and flavour-tagging performance

- MV2 attempts to combine the most relevant information about the origin of tracks based on low level b-taggers.
- Steps of this algorithm are the following :
  - Combining output of the three basic taggers (IP, SV, JF) with a Boosted Decision Tree (BDT) algorithm.
  - Training of the classifier performed on b, c and light-flavour jets from ttbar events.
  - Kinematic properties of the jets (pT/eta) included among the input variables → b, c and light flavour jets are reweighted to the same pt and eta spectrum.



B-tagging performance



ε_b = 0.77 operating point

To discriminate between b and light jets, we select the minimum values (cuts) for the output of the b-tagging algorithm ("Tag weight").

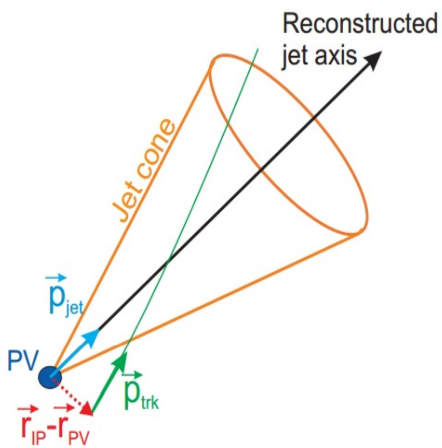
The value of tag weight cut defines the b-tagging efficiency and corresponds to mistag rate ("Operating point").

Mistag rate calibration

- Mistags occur as a result of finite detector resolution, presence of long-lived particles, and material interactions. As these effects can be different between the experimental data and simulation, it is important to measure the b-tagging performance in data and derive the correction factors for the simulation.

- The prevalent methods of mistag rate calibration include Negative tag method, MC based method and Direct tag method etc. Negative tag rate method has been the standard method so far for ATLAS collaboration.

Negative Tag method



- This is the default method used by ATLAS experiment.
- For tracks from fragmentation, positive and negative lifetime tracks are equally likely.
- The mistag rate is defined as : $\boldsymbol{\varepsilon_l = \varepsilon_{inc}^{neg} * k_{ll} * k_{hf}}$
  where, $\boldsymbol{K_{ll} = \varepsilon_l / \varepsilon_l^{neg}}$ &
  $\boldsymbol{k_{hf} = \varepsilon_l^{neg} / \varepsilon_{inc}^{neg}}$
- The term $\boldsymbol{K_{ll}}$ accounts for positive/negative asymmetry in light jets (due to secondaries and negative taggers themselves)
- And the term $\boldsymbol{k_{hf}}$ accounts for heavy flavor contamination in multi-jet events after tagging is applied.

- But the parameters $\boldsymbol{K_{ll}}$ and $\boldsymbol{k_{hf}}$ are derived on simulation using this method, hence it has systematic uncertainties.
- High negative/positive tag asymmetry observed ($\boldsymbol{k_{ll}}$ up to 10-15 already for ε_b=70%)
- Significant heavy flavor contamination has been observed ($\boldsymbol{k_{hf}}$ from 0.05 to 0.35)
- And when we don't know b & C jet fractions of data, uncertainties could be very large !

Why we need an alternative method

- Mistags are due to (1) Impact Parameter and Secondary Vertex resolution, and (2) long lived particles, fakes, interactions in material

- At loose working points, (1) prevails, at tight working points, (2) prevails

- Negative tag rate method can only directly measure (1) -> calibrate loose WPs, tight WPs are dominated by (2) -> MC driven systematic uncertainties

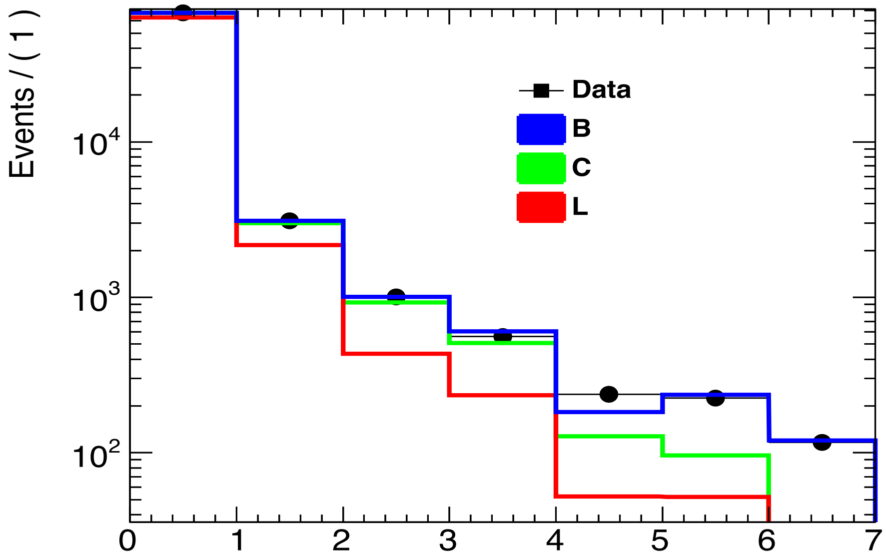
Alternative procedure: direct tag method

- Get b/c templates from MC

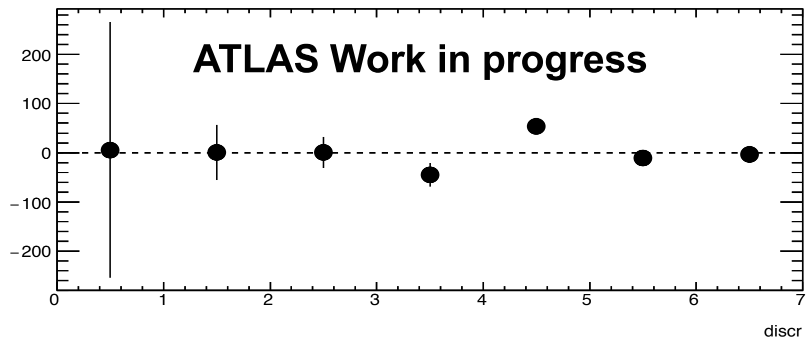
- For the start, get light template from MC and fix the last four bins (70-60,60-50, 50-30, 30-0)

- Let the first three bins (100-85, 85-77, 77-70) of the light template float in the fit, extract the fractions of b/c/light jets and calculate the mistag rate and data/MC scale factors

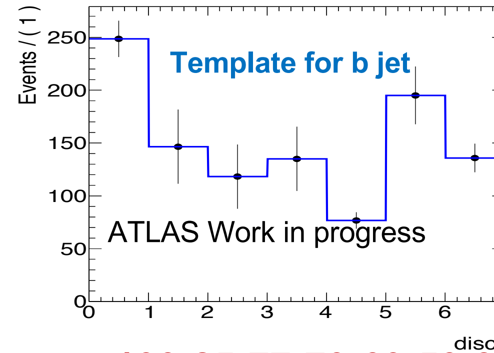
How template fit in Direct tag method works



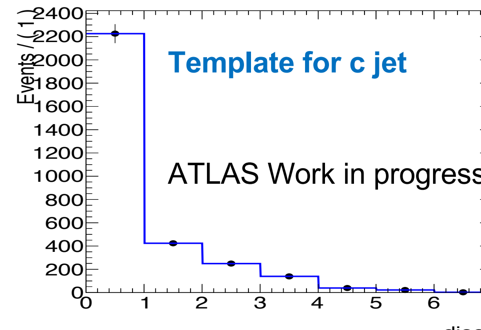
E_b : 100-85, 85-77, 77-70, 70-60, 60-50, 50-30,30-0



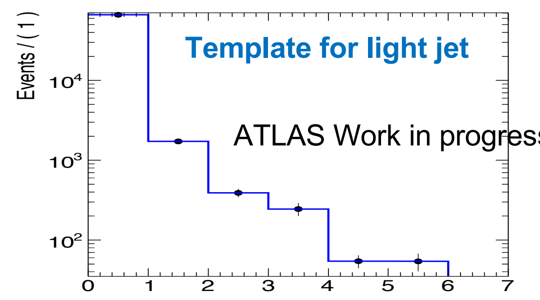
Template fit for pt bin 1 for central eta



E_b :100-85-77-70-60-50-30-0



E_b :100-85-77-70-60-50-30-0

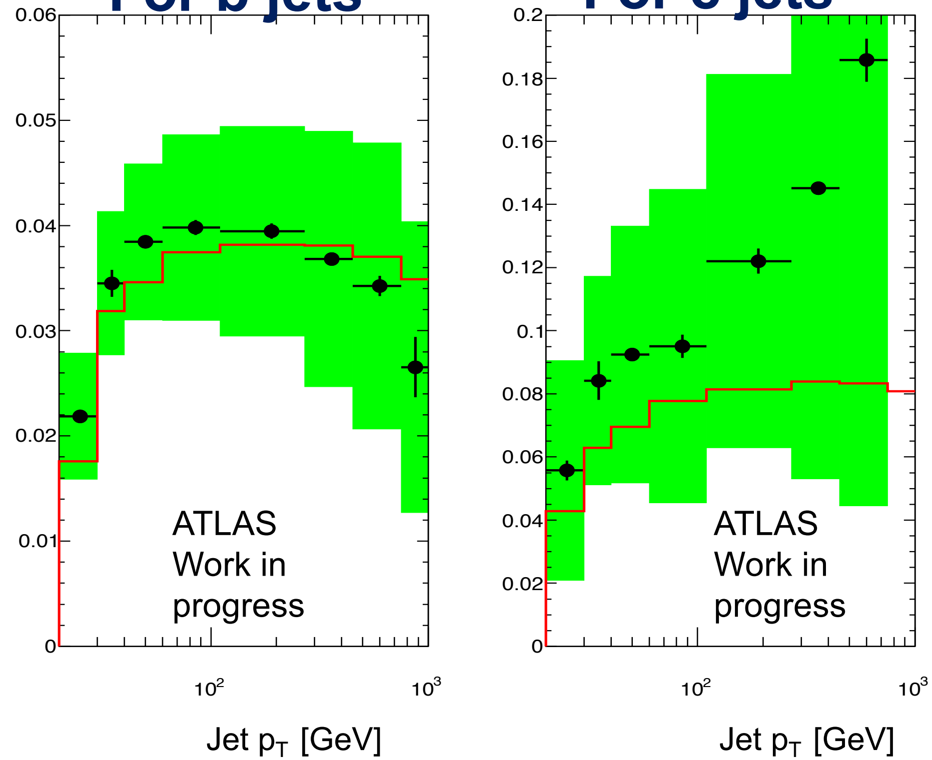


E_b :100-85-77-70-60-50-30-0

Direct tag plots : Flavor fractions

Using 2017 reconstruction

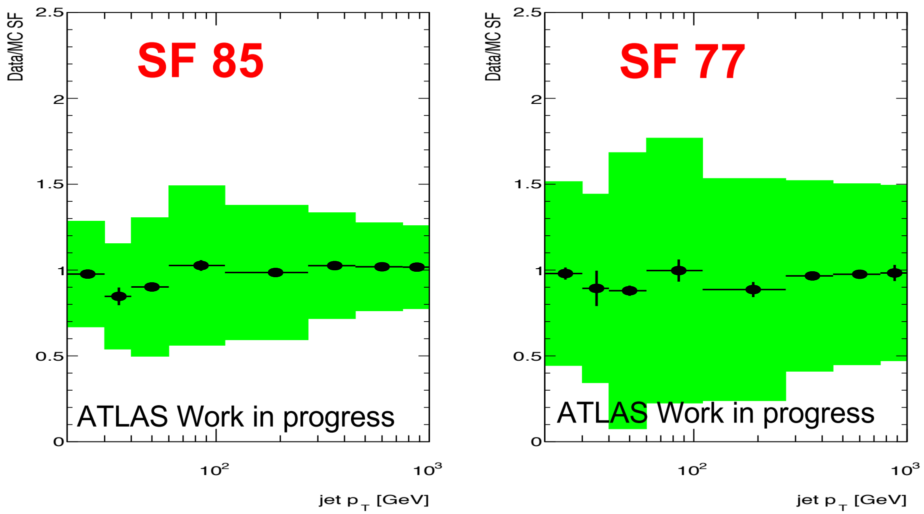
For b jets **For c jets**



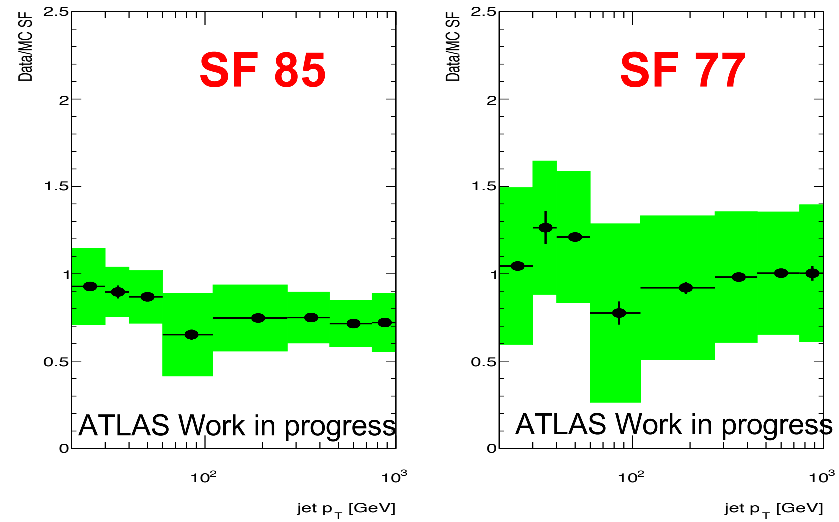
Flavor fraction for central eta

- **In the above plots : Red lines are MC, black points are Data, green color is representing systematic uncertainties.**

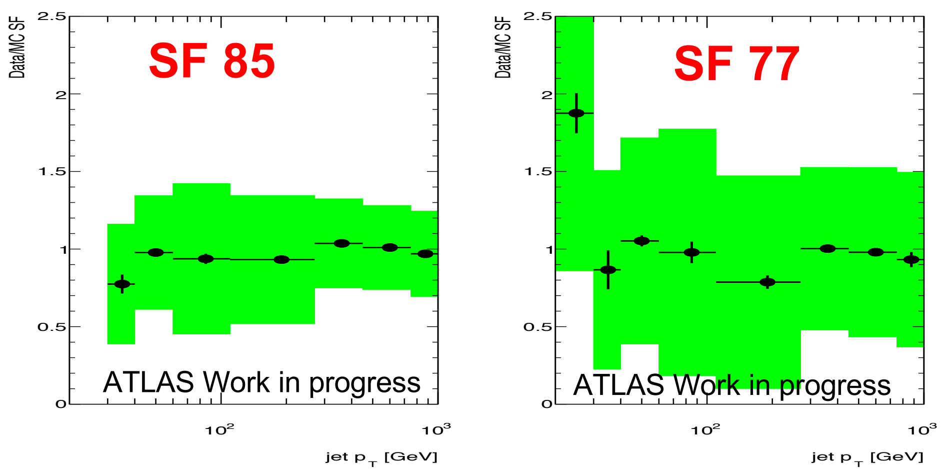
Scale Factors integrated using latest (2017) reconstruction



For Pythia



For SHERPA

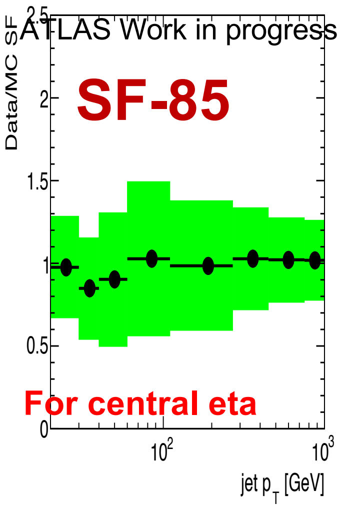


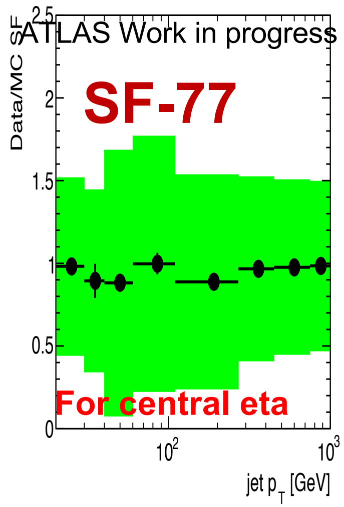
For HERWIG

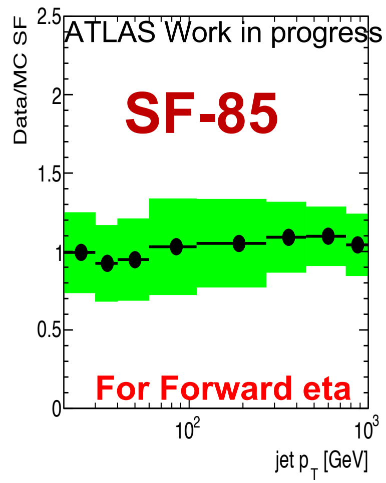
These results have been generated using added statistics and improved modeling of the new simulation (especially new digitization/simulation model in the pixels).

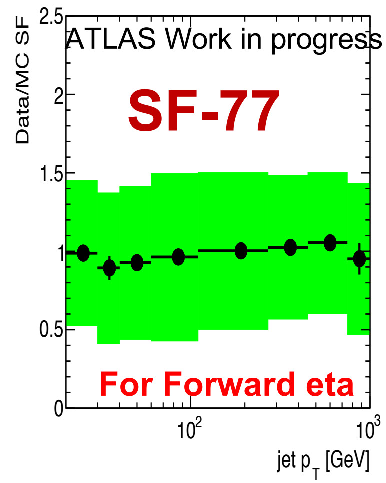
Comparison between Direct tag & Negative tag rate results for Pseudo Continuous b tagging

For Direct tag :

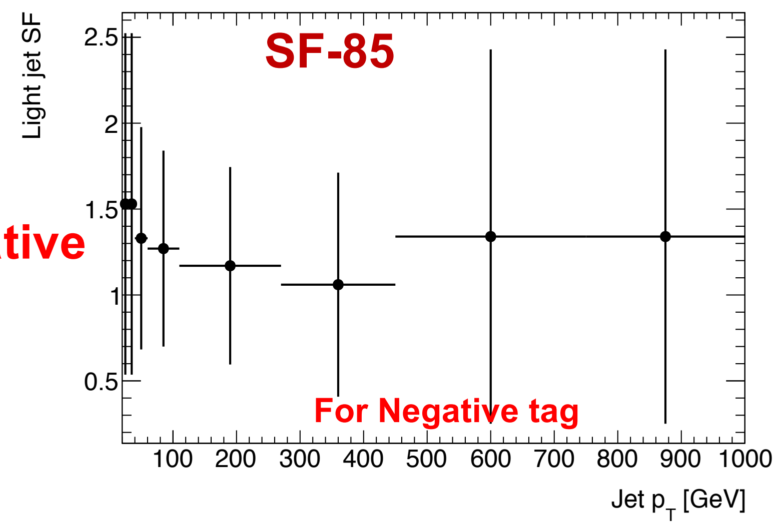


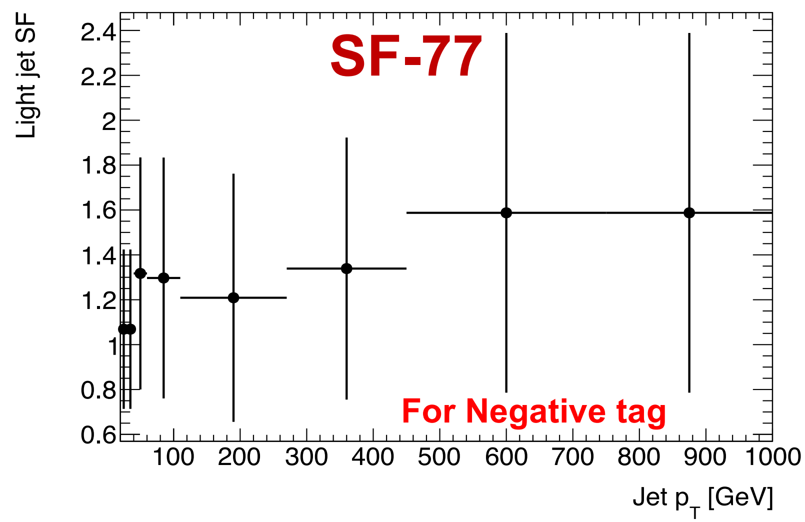






For Negative tag :





Conclusions

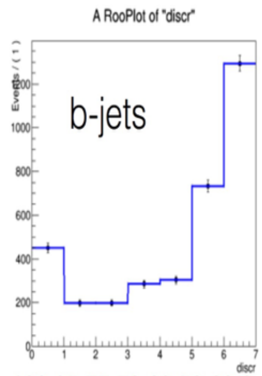
- B tagging is a very important task for many Physics results at the LHC.
- Newly developed Direct tag method is working very well for providing Light jet calibration.
- Flavor fractions for both b and c jets, which have been a major issues with previous release, are looking better.
- Results are compared to the results of standard/default (Negative tag) method. And they are looking comparable and sometimes better.
- Direct Tag method has the potential to stand as a complementary method for light jet calibration in ATLAS.
- We hope, Direct tag method will contribute to the official Physics results of ATLAS for providing better b-tagging performance soon.


Thank You!

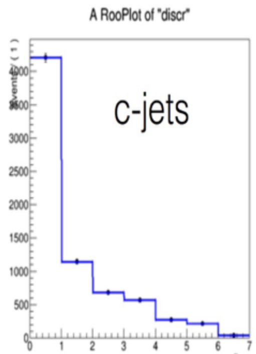
Backup slides

How Direct Tag method works

- Use directly MV2 distribution (not negative tag version)
- Procedure:
  - (1) Get b- and c-jet MV2 PDFs from MC



ε_b 100-85-77-70-60-50-30-0

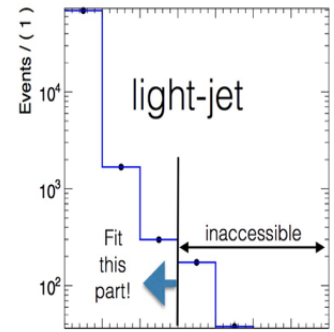


100-85-77-70-60-50-30-0

fix $PDF_b(\mathrm{MV2c})$

$PDF_c(\mathrm{MV2c})$

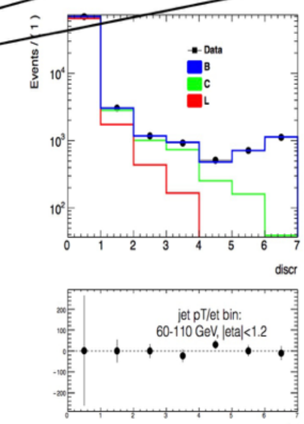
- (2) Fix the last four bins for the light-jet PDF from MC (right now 70-60-50-0%)



100-85-77-70-60-50-30- 0

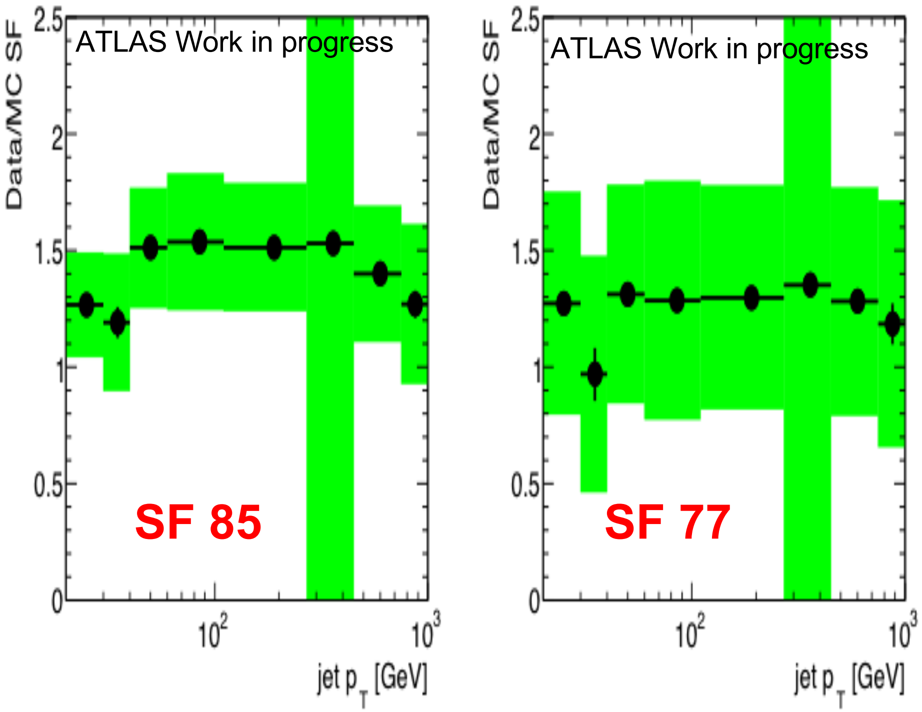
- (3) $\mathcal{L}(\mathrm{MV2c}, \vec{p}_l) = N_b PDF_b(\mathrm{MV2c}) + N_c PDF_c(\mathrm{MV2c}) + N_l PDF_l(\mathrm{MV2c}, \vec{p}_l)$

extract N_b, N_c, N_l and the 100-85%, 85-77%, 85-70% bins of the light jet PDF

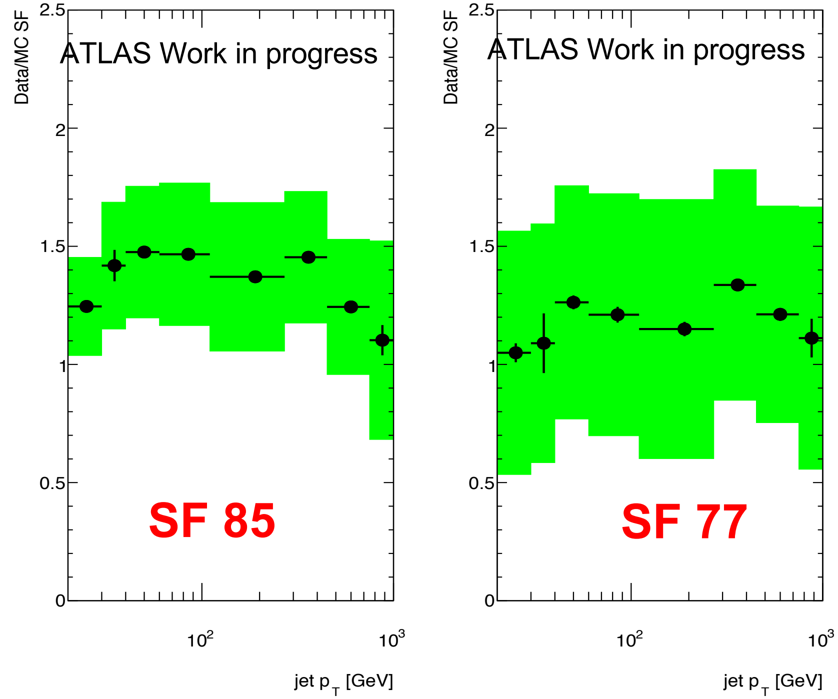


Documentation : https://cds.cern.ch/record/2309425/

Scale Factors integrated using 2016 reconstruction



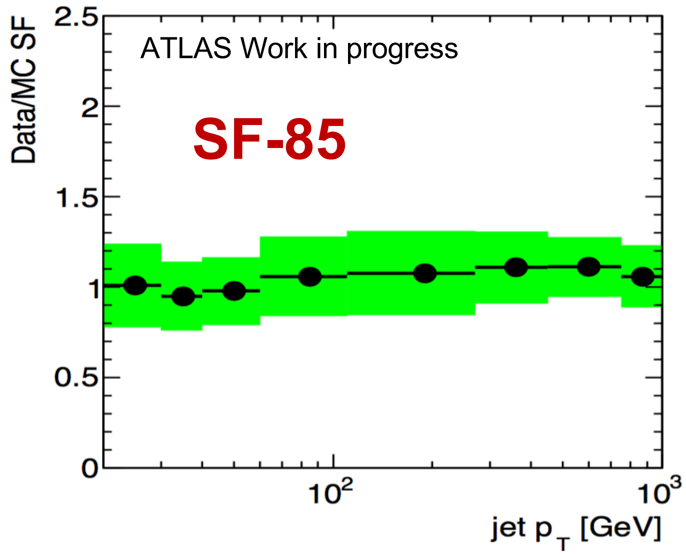
For Pythia

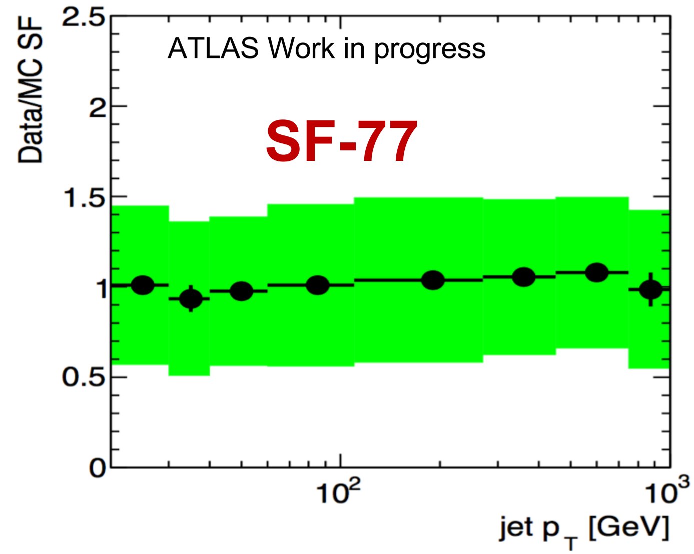


For HERWIG

Comparison between Direct tag & Negative tag rate results for Fixed Cut B Efficiencies

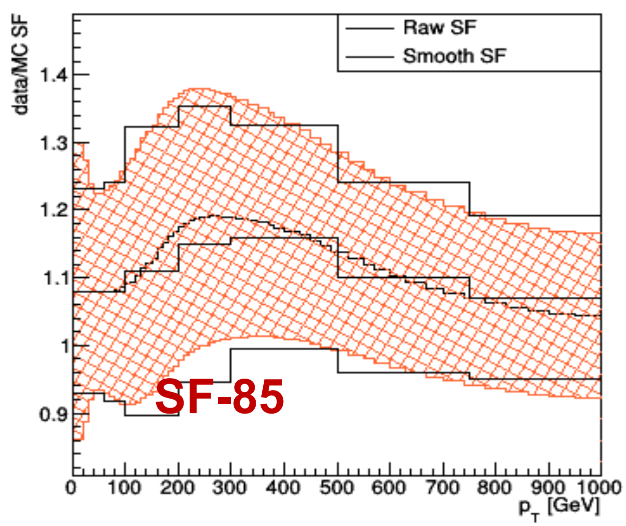
For Direct tag :





For Negative tag :

negative_tags Light



negative_tags Light