Mistag Rate Measurements for b-tagging using Negative Tags

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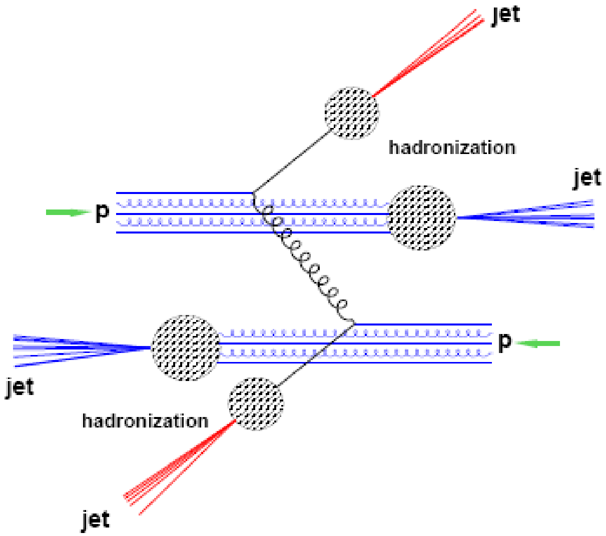
Introduction

- Over View
- b-tagging
  - Motivation for the b-tagging
  - General b-tagging techniques
- Mistag rate
  - Definition
  - Measuring a mistag rate
- Summary

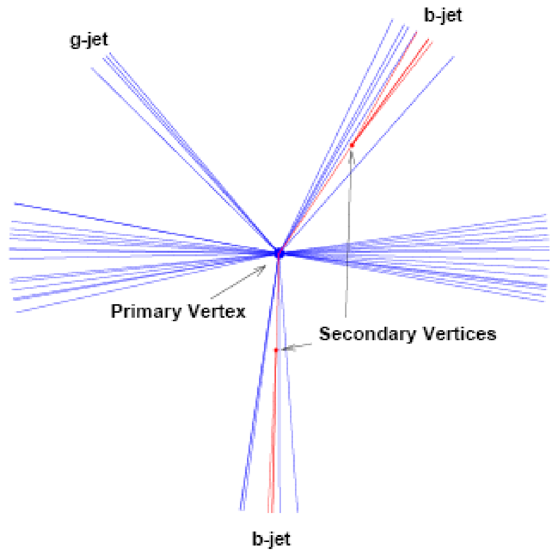
Overview (I)

- At the LHC (during pp collision), two strongly interacting (hard scattered) partons hadronize into jets of particles
- Particles inside jets further decay into quasi-stable particles which produce hits in the detector.
- Collision with the soft scattering of 2 partons dominates the production cross-section a.k.a minimum bias events.
- Mostly, all of the interesting physics are in hard scattering events.
- All hadronization occurs at one space point called primary vertex.



Overview (II)

- Some particle (e.g; b-,c-hadrons) can travel considerable distance from their point of origin (primary vertex, or PV) before they decay. Particles from these decays form a secondary vertex (SV)
- Primary and secondary vertices can be distinguished using pixel detector and silicon detector information and can be used to perform a b-, c- jet identification.
- We call a jet as a b-jet if it originates from b-quark, c-jet if it originated from c-quarks and light jet if it originated from light quarks (u, d, s) or gluon.
- The largest challenge of the jet identification at the LHC is a huge background of light jets and pile-up events (up to 23 events at high luminosity LHC run).
- Most of these pile-up events are minimum-bias and can be separated from hard scattering processes by requiring the high P particle in the primary vertex.

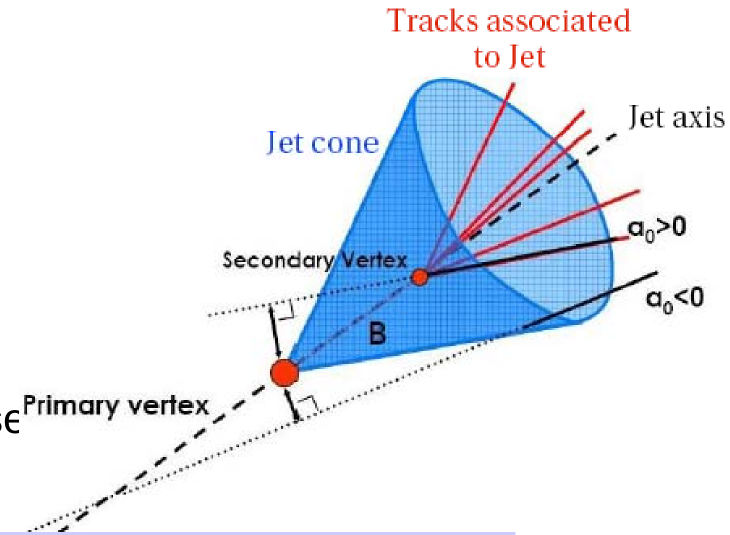


b-tagging: motivation

- In Atlas b-tagging is important for high P physics program which includes:
  - Searches for Higgs boson (both Standard Model Higgs and non-Standard Model Higgs bosons)
  - Precision measurements of the top quark properties
  - Searches for SUSY particles
- In most cases simple kinematic cuts are not enough to separate the background from the signal. B-tagging (heavy flavor tagging) is an extra powerful tool which is being used the by hadron colliders collaborations for years.
- Definition: Identify a jets which contain a b quark.
  - b-quarks hadronize into B-hadrons, which then decays in cascades into lighter hadrons (**recognized as b jets**).
  - To identify these jets one takes advantage of several properties of B-hadrons which helps to distinguish them from lighter quark jets (**known as b-tagging**)

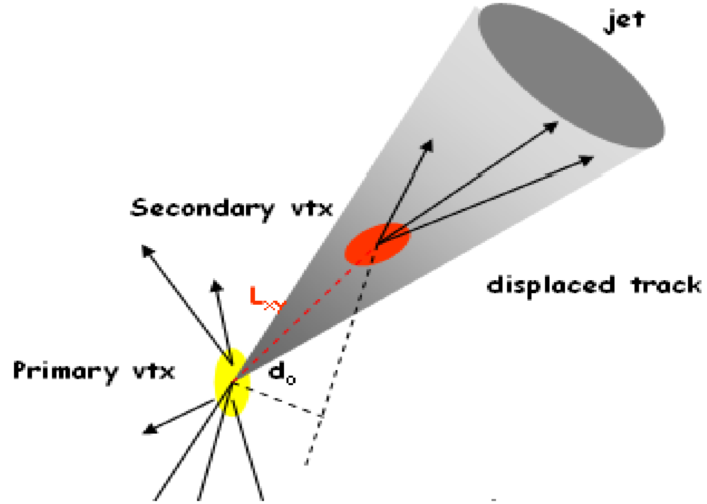
b-tagging overview (I)

- ATLAS b-tagging algorithms are based on using the long lifetime, large mass and large momentum fraction of b-hadrons produced in b-quark jets, as well as on the presence of soft leptons from semi-leptonic b-decays.
  - **B-tagging methods used (most developed in Atlas):**
    - Lifetime taggers (impact parameters (IP) tag)
    - Secondary Vertex taggers
    - Combination of the above taggers
  - **Definition of Signed I.P.**
    - Distance of closest approach to the primary Vertex (P.V.)
    - a_0 and z_0: track impact parameter in transverse (r-ϕ) and in longitudinal (r-z) plane.
    - $S(IP) = IP/\sigma(IP)$



Note : IP is a signed quantity w.r.t to jet axis (so is S(IP)) :
- positive if $\theta < \pi/2$
- negative if $\theta > \pi/2$

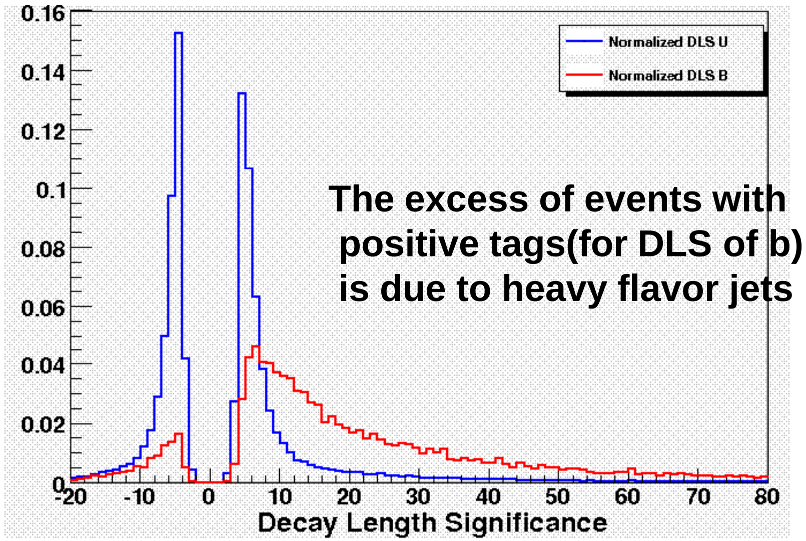
b-tagging overview (II)



- Build up track-based jets and fit their tracks to a secondary vertex
- Select tracks with **high IP** to build secondary vertices.
- Tracks with high IP will form vertices with high **decay length significance** :

  $$S(Lxy) = Lxy/\sigma(Lxy).$$

  (Like S(IP), S(Lxy) is a signed quantity)
- Jet are then tagged by requiring a dR < 0.4 matching between the jet axis and the secondary vertex.



Requirements to tag a jet positively :

- match a secondary vertex with S(Lxy) > cut

Requirements to tag a jet negatively :

- match a secondary vertex with S(Lxy) < -cut

SV1 tagger

- Currently we are developing the method of the mistag measurement for the SV1 algorithm
- Among the selected tracks (tracks associated to jet), find and remove the tracks from $\Lambda(K^o)$ decay, γ conversion and material interaction.
- Remaining tracks are combined and try to fit them into one Sec. Vtx., If the fit to χ^2 is not acceptable, remove the tracks with highest contribution until χ^2 is acceptable.
- Variables such as:

  (not to co-relate with the track impact parameter: e.g; distance between PV and SV are highly co-related, so use some other variables)
  - N: No. of good 2 tracks vertices in the jet
  - M: invariant mass of all particles in the secondary vertex
  - F: Energy Fraction (E svx /E jet).

IP3 b-tagging algorithm

- Mistag rate measurement method is also under development based on the IP3D taggers.
- Select the tracks based on pre-defined track grade (called good tracks).
- For each good charge track:
  - Obtain signed impact parameter (a^0 or $\mathbb{Z}^0$)
  - Obtain the significance: $S = a^0/\sigma(a^0)$ and $\mathbb{Z}^0/\sigma(\mathbb{Z}^0)$
  - Calculate the track weight $W_{track} = b(S)/u(S)$; b(S) and u(S) are PDF's for b-quark and u-qurak jet respectively.
  - PDF:probability density function for a jet to be a of type (b or light).
  - Jet weight:
    - $W^{IP}_{Jet} = \sum_{i=1} \ln(W_{track\_i})$

Mistag rate overview (I)

- TAGGING EFFICIENCY:
  - For a jet of a given flavor (light, c, b quark gluon), the **tagging efficiency** is the ratio of the tagged jets to the number of jets of this particular flavor.
- MISTAGGING RATE:
  - a ratio of the number of tagged light jets to the total number of light jets in a sample.
- Tracks with negative impact parameters can be used to evaluate the tagging efficiency from light(uds) quark and gluon(g) jets.
- For jets of any other flavor, using the negative I.P. tracks, the tagging efficiency is called NEGATIVE TAG RATE.

Mistag rate overview (II)

- Major sources that lead to tagging of the light jets:
  - finite resolution of the reconstructed track/vertex parameters
  - Tracks/vertices from the long-lived particles that decay in jets
- We cannot measure the mistagging rate directly on data because of the presence of b, c jets in an inclusive jet sample
- Assuming that the resolution of the track impact parameter significance or secondary vertex significance is perfectly symmetric, and that the contribution from long-lived particles can be effectively suppressed, the “negative” tagging rate should be close to the “positive” tagging rate.

Mistag Rate: The Main Idea (I)

- Instead of measuring the positive tagging rate ε_l, try to measure the negative tagging rate ($\overline{\varepsilon}_{incl}$)
- There are two issues:
  - Presence of the tracks from long-lived particles (due to residual inefficiency of the V0-filter).
  - Presence of the tracks from b, c-hadrons in the negative tails in addition to the resolution.
- Tevatron: use MC to find correction factors and apply to data. In both cases the correction factors are close to 1.
- The mistagging rate is calculated as :

$$\varepsilon_l = \overline{\varepsilon}_{incl} \times k_{ll} \times k_{hf}$$

(From MC)
For method to be Reliable
We need: $K_{ll} \sim 1$; $K_{hf} \sim 1$

Mistag Rate: The Main Idea (II)

- Negative tagging rate:
  - SV1: use vertices with negative normalized distance *D*;
  - IP3 : use tracks with negative IP, and inverting their IP sign;
- Correction factors:
  - Correction factor due to the presence of decay products of long-lived particles in light jets:

$$k_{ll} = \varepsilon_l / \bar{\varepsilon}_l$$

  - Correction factor due to the presence of an additional tail on negative side from *b, c* hadron decays

$$k_{hf} = \frac{\bar{\varepsilon}_l}{\bar{\varepsilon}_{incl}}$$

Data samples

- We used the following data samples:
  - J2 : ~198 K events
    - Energy range: 35 – 70 GeV
    - Reconstruction Version: 13.0.30.2
  - J3 : ~586K events
    - Energy range: 70 – 140 GeV
    - Reconstruction Version: 13.0.30.2
  - J4 : ~300K events
    - Energy range: 140 – 280 GeV
    - Reconstruction Version: 13.0.30.2

SV1 Tagger: Negative tags (I)

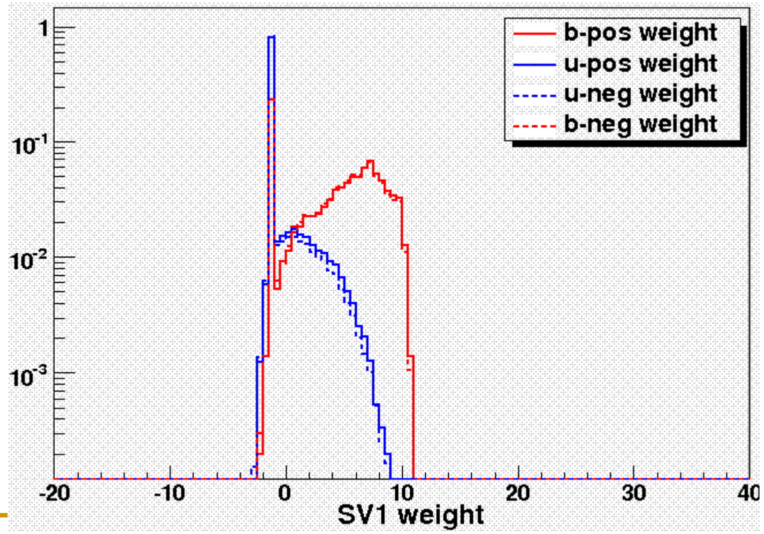
- Event Selection Criteria:
  - Used Release: 13.0.40
  - Dijet Sample :J2,J3, J4 (as described in the previous slide)
  - Jet P_T > 20 GeV ; |Jet eta| < 2.0 ;
  - Require 2 leading jets with $\Delta\phi>2$ (back-to-back).
  - Label b, c, light jets by matching jets with partons after FSR:
    - **b jet**: a b-quark (Pt > 5 GeV) found in a cone of 0.4 arround the jet axis
    - **c jet** : a c quark
    - **light jet** : left jets plus purification (Δr > 0.8 from the nearest b, c jets)

Graph:

Sec. Vtx Weights for Pos. and Neg.Tails.

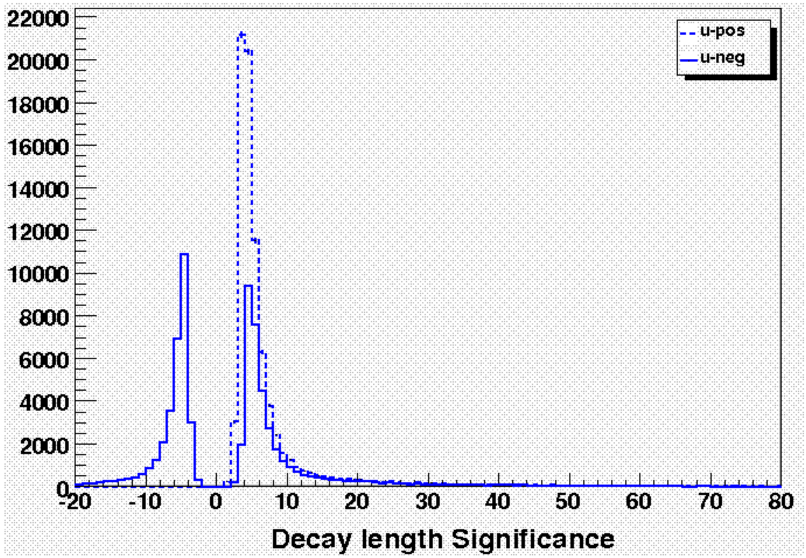
Peak weight= -1, corresponds to jets

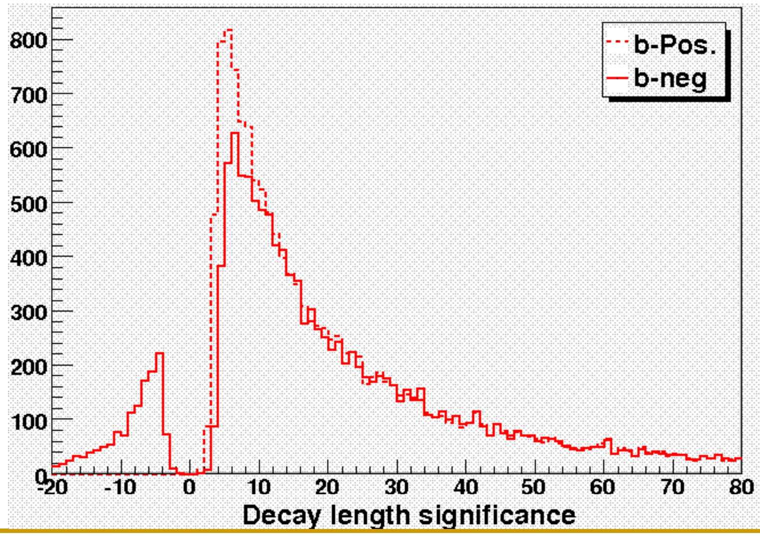
Without Sec. Vtx.



SV1 Tagger: Negative tags (II)

- We need to estimate the probability to tag b and light jets with "negative" tagger
- Negative tagging is obtained with *BTagVrtSec.getNegativeTail=True* (this option is available in the standard reco code)

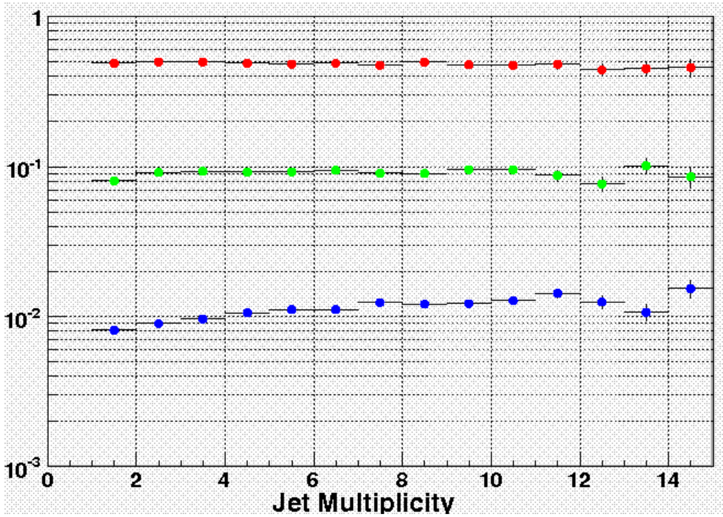


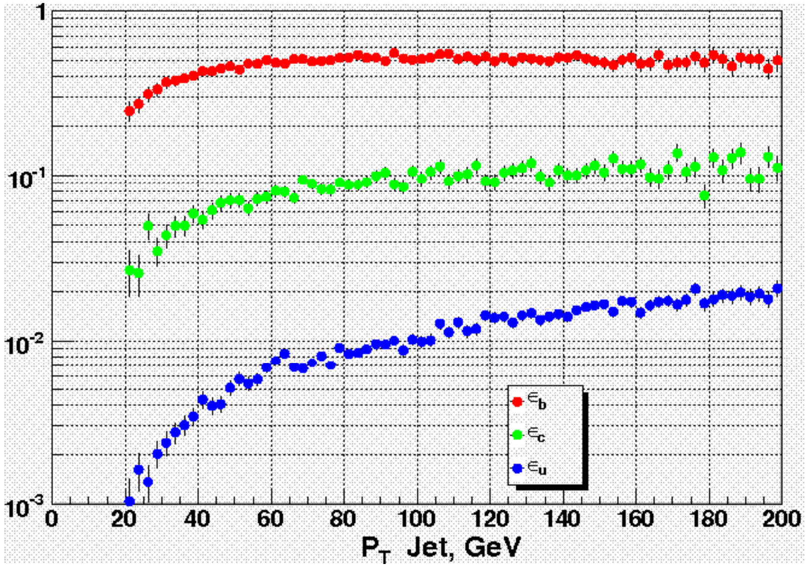


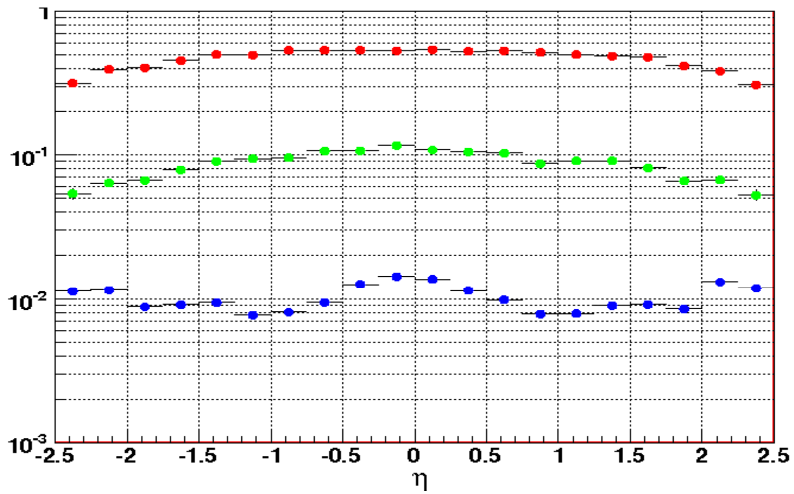
SV1 Conventional Efficicency

- Efficiencies shown for *weight* > 4
- Definition of efficiency:

$$\varepsilon_{b/c/u} = \frac{No.\ of\ Jets\ of\ flavor\ q\ tagged\ as\ (b/c/light)}{No.\ of\ Jets\ of\ flavor\ q}$$







SV1: Correction Factor K_{LL}

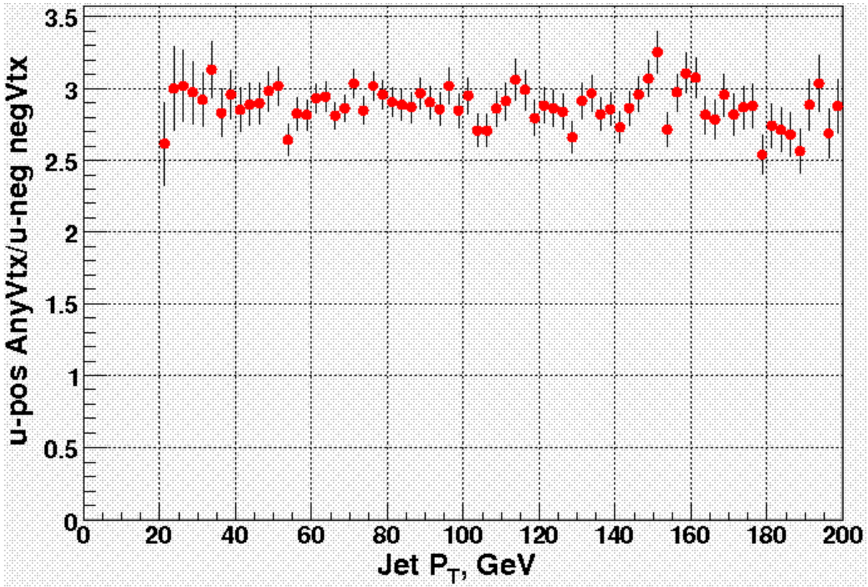
- The tagging probability can be split into two factors: probability to find a SV in a jet and probability to tag a jet with a SV

$$k_{ll} = \frac{\varepsilon_l}{\bar{\varepsilon}_l} = \underbrace{\frac{f_l^{SV}}{\bar{f}_l^{SV}}}_{\text{First term}} \times \underbrace{\frac{\varepsilon_l^{SV}}{\bar{\varepsilon}_l^{SV}}}_{\text{2nd term}}$$

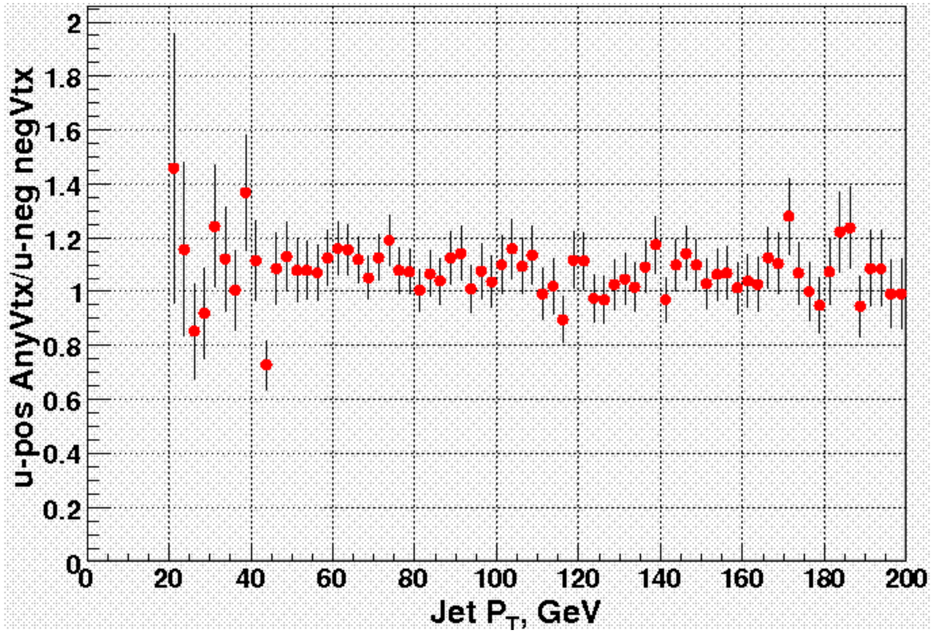
- the first term accounts for the difference between negative and positive tags, it is large, of the order of 3
- the second term is close to 1 – can be derived from MC

Correction Factor K_{LL}

Ratio of probabilities to find a SV: 2--3

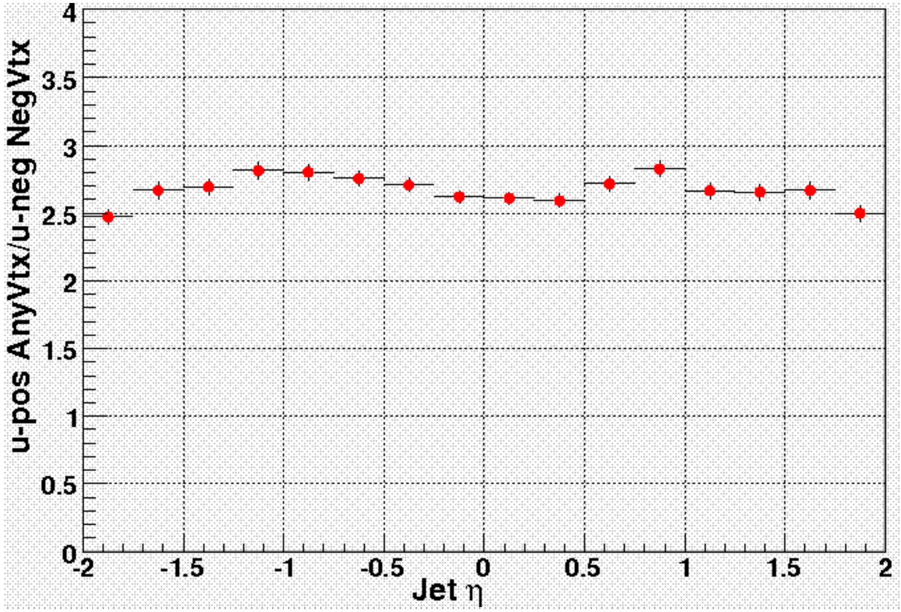


Ratio of tagging rates in jets with SV: ~1

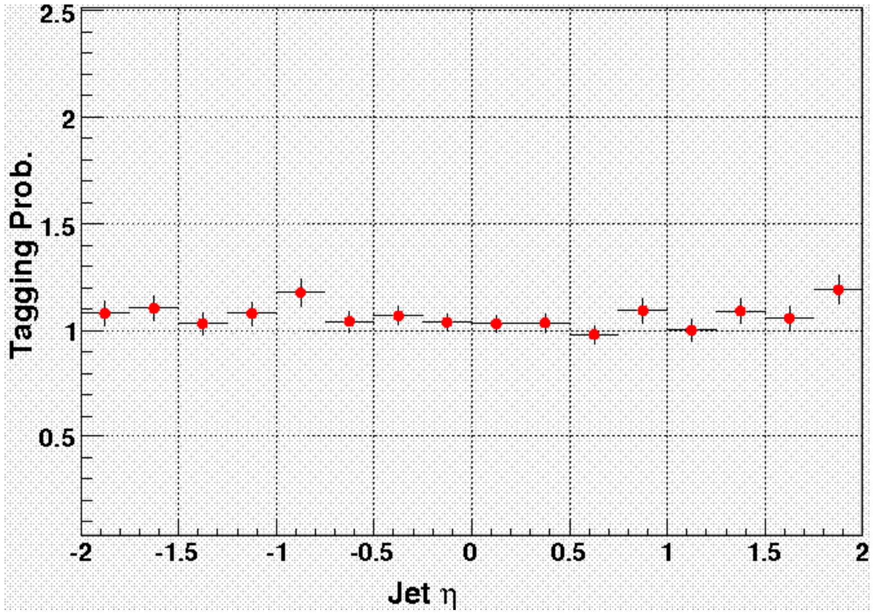


Correction Factor K_{LL}

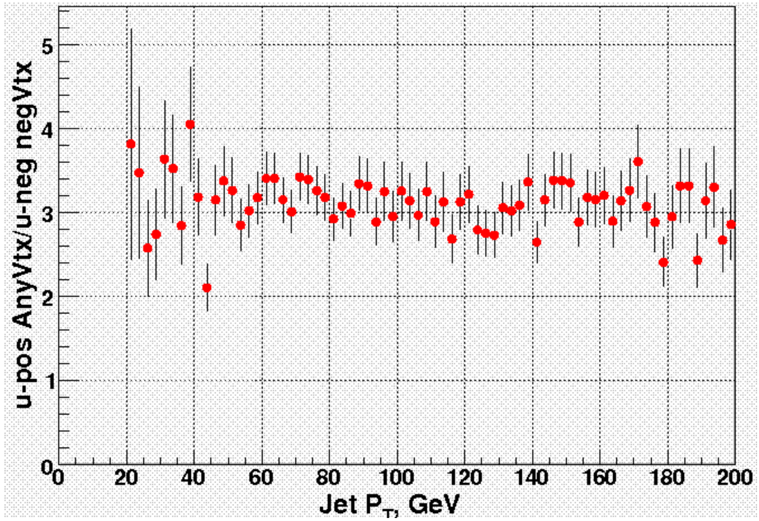
Ratio of probabilities to find a SV: 2--3

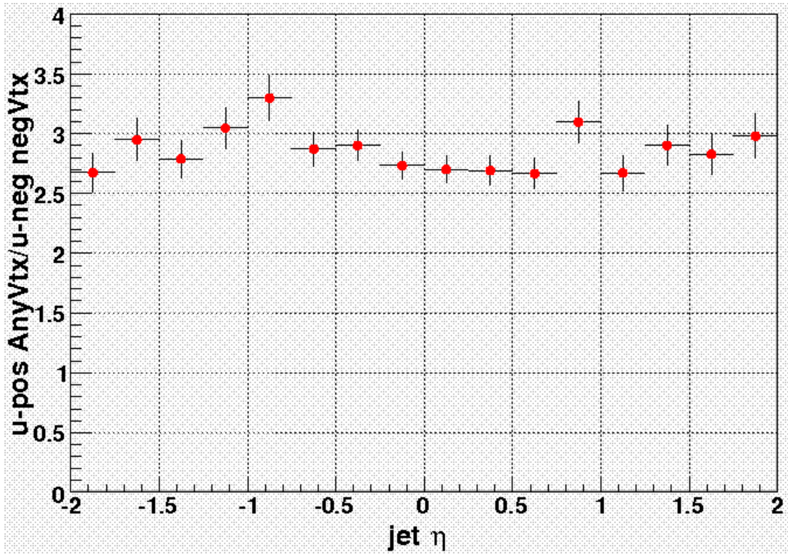


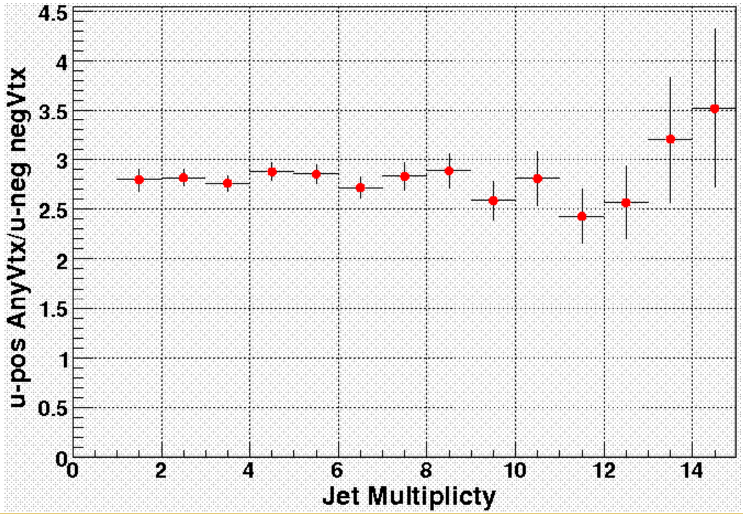
Ratio of tagging rates in jets with SV: ~1



K_{LL} : as function of P_T, η and, Jet Multiplicity







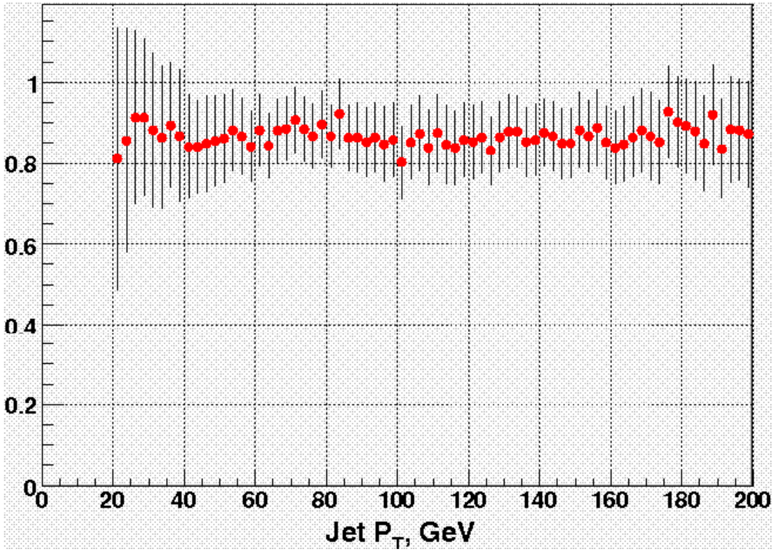
Weight > 4

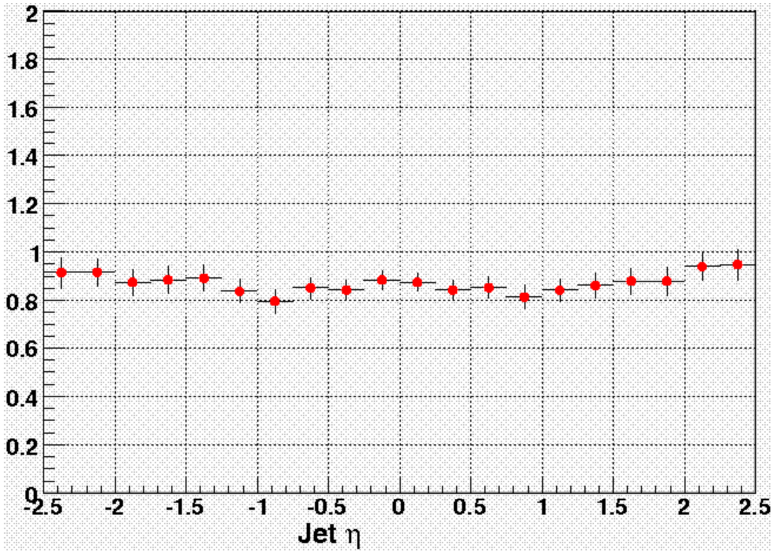
- ***K_{ll}* seems to be decreasing at looser weight cuts.**
- **we believe we can measure this on data, with systematic ~ 10 % (roughly)**

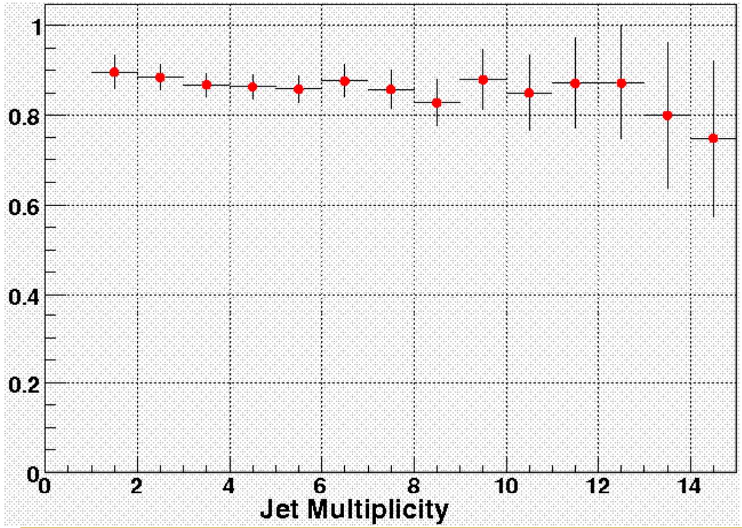
More on K_{LL}

- K_{LL} is closer to 1, as we go to looser operating points, can be taken from MC (needs more tunning).
- K_{LL} does not seem to depend on the physics process (seems to be stable as a function of jet multiplicity).

Correction Factor K_{hf}







Weight > 4

- K_{HF} is closer to 1 for looser.
  (can be taken from MC)

More on K_{hf}

- K_{hf} is reasonably closer to 1, can be taken from MC
- K_{hf} does not seem to depend on the physics process (seems to be stable as a function of jet multiplicity).
- Also does not depend on the operating points.

More on SV1: Mistag rate study

- The preliminary study shows that the suggested method – measurement of the negative tagging rate with applying the correction factors, k_{hf} and k_{ll} from MC– should work well.
- k_{hf}, k_{ll} are close to 1, and do not depend on physics process and operating point of the tagger.

Mistag Rate for SV1 tagger: (I)

- We performed the closure test as:
  - From our definition of Mistag rate:

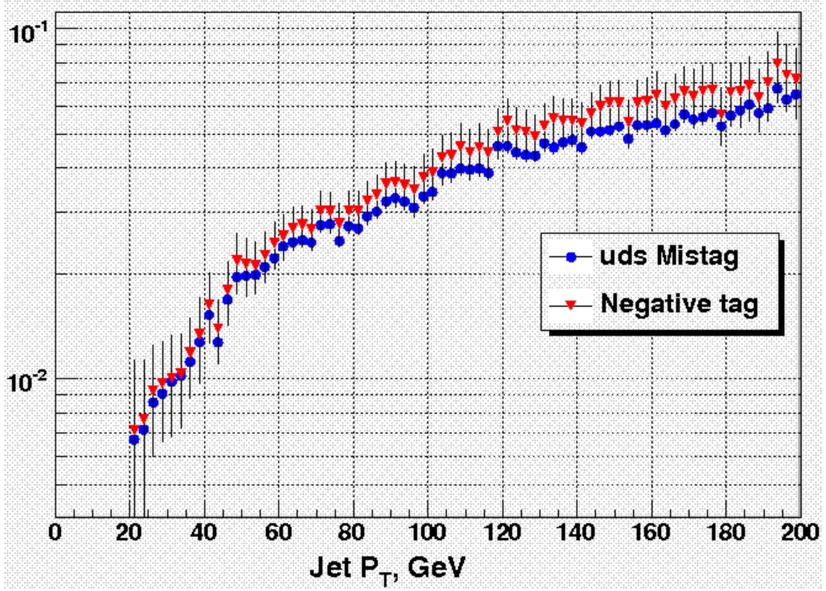
$$\varepsilon_l = \bar{\varepsilon}_{incl} \times k_{ll} \times k_{hf}$$

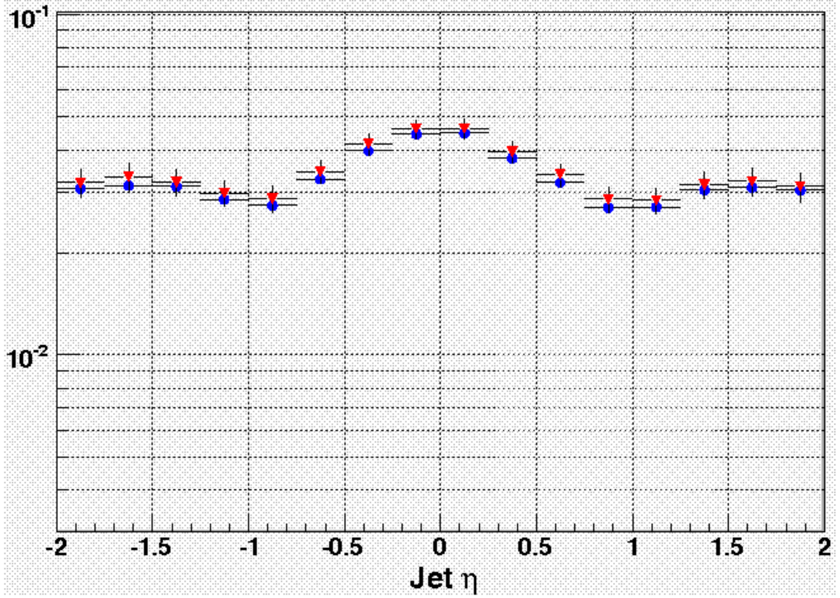
Light jet Mistag Rate (ε_l)

Negative Tag rate ($\bar{\varepsilon}_{incl}$)

Mistag Rate for SV1 tagger: (II)

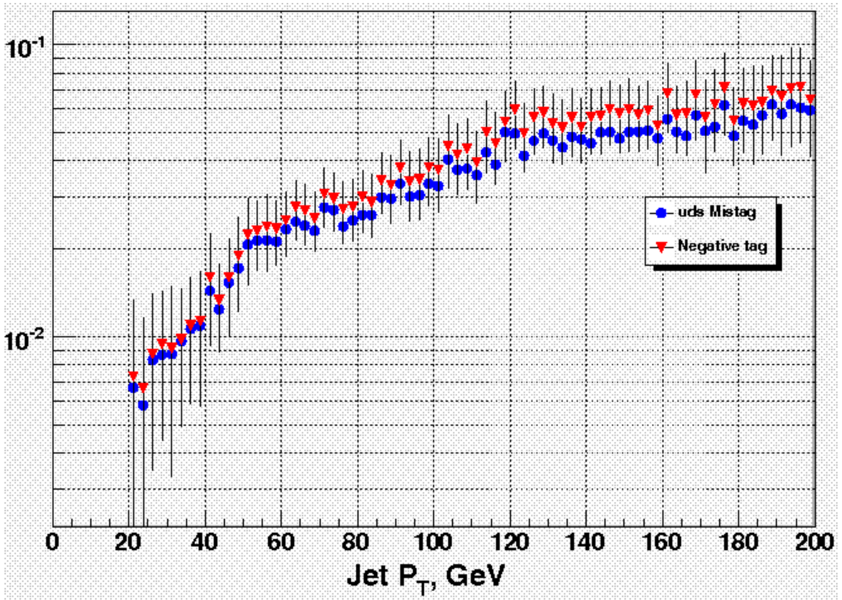
Comparison of the measured mistag rate (red triangles) to the actual mistag rate (blue dots) known from Monte Carlo. Measured mistag rate is slightly higher. This small discrepancy is under investigation.





Mistag Rate for SV1 tagger: (III)

Comparison of the measured mistag rate (red triangles) to the actual mistag rate (blue dots) known from Monte Carlo.

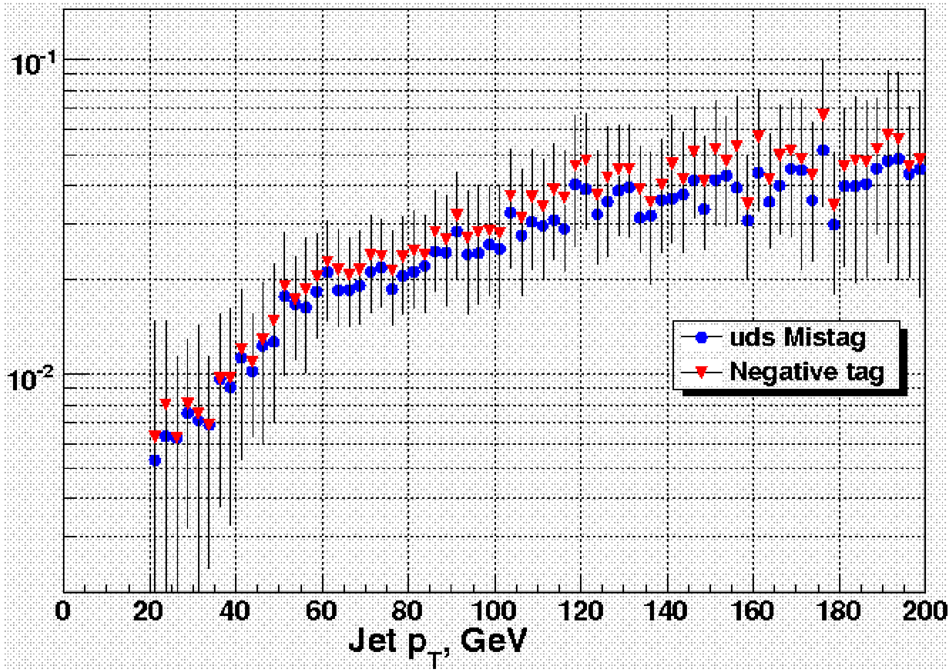


Graph: when we remove the tracks with $\Delta\phi$ > 0.01.

- Already see a good agreement between the measured and true mistag rates.
- Track and jet resolution will not be measured very well in the early data.
- Measure the $\Delta\phi$ between the jet and tracks (associated to jet).
- Tracks with small $\Delta\phi$ are essentially parallel to jet axis and sign of IP (SIP) for these tracks is random value.
- Main source of admixture of tracks from b-decays to the negative SIP tail.
- Remove these tracks with $\Delta\phi$ > 0.01 (jet angular resolution).

Mistag Rate for SV1 tagger: (IV)

- Check that if the presence of more than one primary vertex in a jet can increase the mistag rate for this taggers.
- Do not see a major difference in the measurement of mistag rate by requiring only 1 primary vertex (as is shown here) and having more than 1 P.V. (as shown on previous slides for the mistag rate measurement using SV1 tagger).



Summary on SV1 Mistag Rate Study:

- We have demonstrated the mistag rate study using the SV1 tagger.
- Results are stable and have no depnadence on Jet Pt, Jet eta, Jet Multiplicity, No. of Primary Vtx.
- Closure test is performed which looks good.
- Our study shows that the method adopted to find the mistag rates using SV1 taggers is valid.
- These results will be tested on different operating points and will be compiled in a Atlas note.
- Mistag rate study for the IP3D taggers is under way.

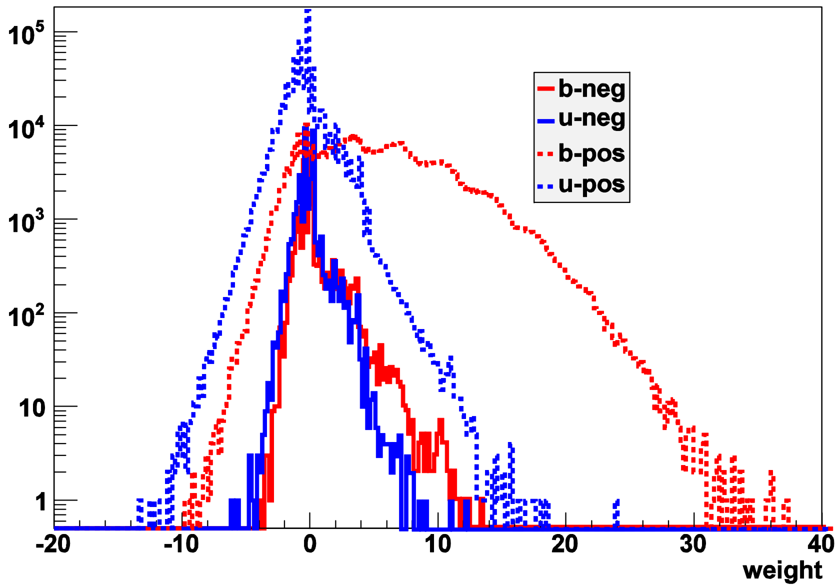
IP3 Tagger:

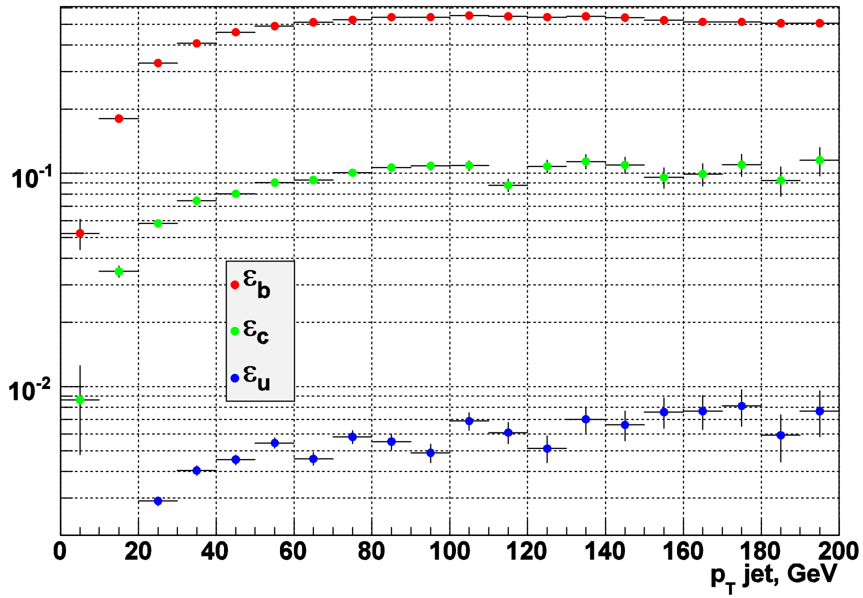
- For IP3 negative tagging we use tracks with negative IP, and invert their IP sign. Standard IP3 tagger uses tracks with ANY impact parameter signs.
  - If one uses all tracks for negative tags, then the negative tagging rate for b-jets is too high (k_{hf}>>1), try to avoid.
  - If one uses only tracks with IP < 0, then k_{hf} is close to 1, but k_{ll} increases.
  - The latter option provides the better modeling of the light jet mistagging rate, but need to think how to deal with large k_{ll}

IP3 Conventional Efficiency

- Used Release: 13.0.40 (preliminary result)
- Dijet Sample :J4 (available in Release 13 ~ 300 K events)
- Used 2 leading jets back-to-back ($\Delta\phi$>2).
- Tracks are associated with a jets (within a cone of 0.4)

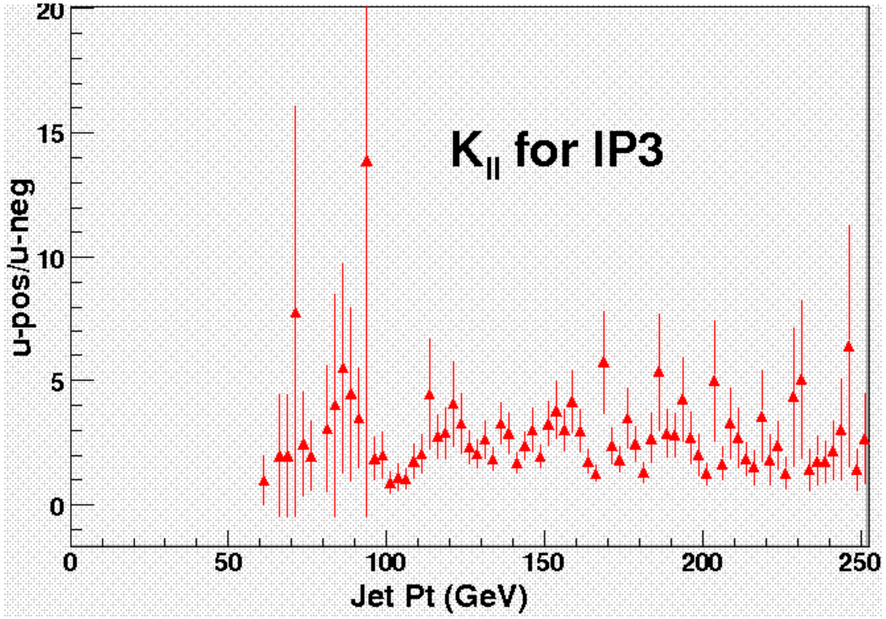
- Efficiencies shown for *weight* > 5





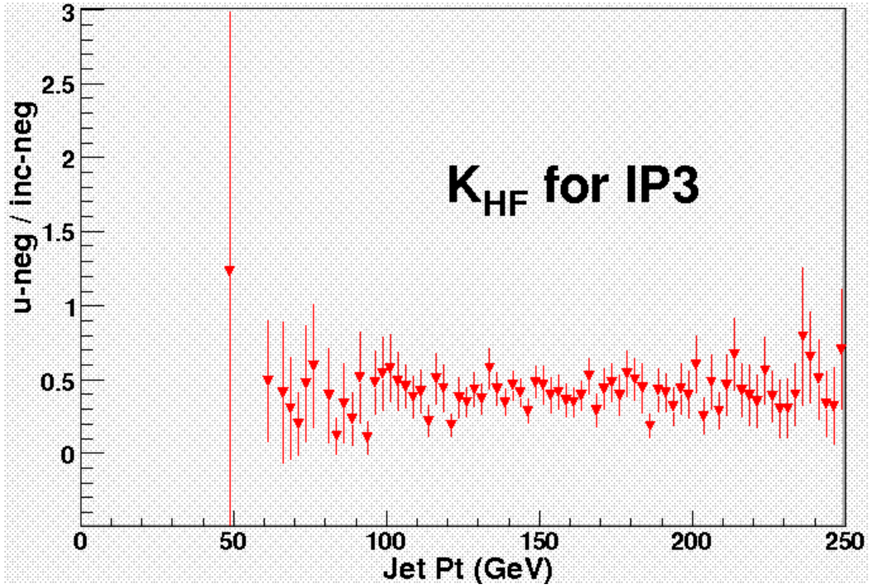
IP3 Correction factor K_{LL}

- It is larger little than 1 ~2 (for IP3).
- *weight* > 5
- (preliminary result)



IP3 Correction factor K_{hf}

- *Use weight* > 5
- *khf* looks good (<< 1), for IP3.
- This is preliminary study for the IP3 tagger and we are working on this.



Summary:

- We suggested the method to measure the mistag rate on dijet data which is expected to have a huge statistics
- The method is Monte Carlo dependent, i.e. some correction factors should be extracted from Monte Carlo.
- Nevertheless, corrections are expected to be small and will not introduce too large systematic uncertainty
- The method works well for **SV1 tagger**
- Preliminary study of the negative tagging rate with correction factors for **IP taggers** is also encouraging.
- Some additional modifications are needed for IP based taggers.
- This is work in progress – if you have got interested in this topic please join us!

The End

$f_l^{SV} / \bar{f}_l^{SV}$ Ratio

- Want to measure this factor on data, but can measure only the ratio for inclusive sample, which is sum of light, *b* and *c* jets.
- It turned out that the ratio strongly depends on the flavor of the jet.
- This ratio can be approximated from data using upper cut on normalized distance $L(xy)_{max}$:

$$\frac{f_l^{SV}}{\bar{f}_l^{SV}} = k_{SV} \times \frac{f_{incl}^{SV}}{\bar{f}_{incl}^{SV}}$$

- For light jets, ratio is relatively flat with *Dmax* cut, for heavy flavor jets this ratio quickly goes down as $L(xy)_{max}$ decreases, and $kSV \rightarrow 1$

$f^{SV} / \bar{f}^{SV}$ Vs Cut on Normalized Distance

light jets: the ratio flat vs $L(xy)_{max}$ cut
b/c-jets: the ratio goes down as $L(xy)_{max}$ decreases

assume f_b=0.03, f_c=0.07 (from di-jet MC)