# B-tagging Algorithms At Atlas


**M. Saleem**

University of Oklahoma, USA

saleem@mail.cern.ch



Signaling the Arrival of LHC Era

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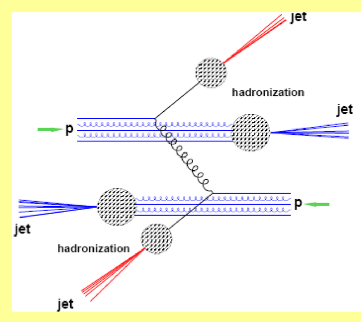
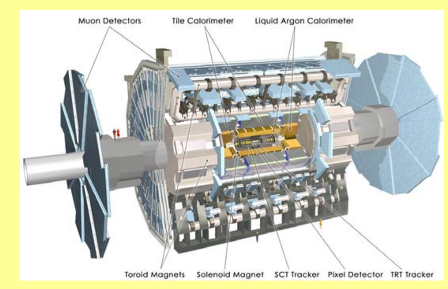
## Overview (I)

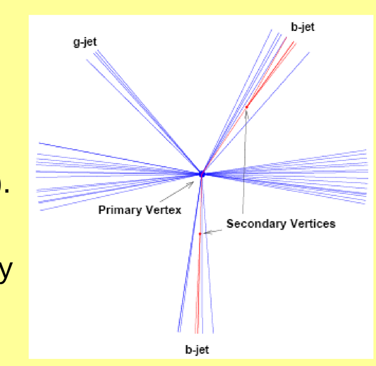
- At the LHC (during pp collision), two strongly interacting (hard scattered) partons hadronize into jets of particles
- Particles inside jets further decay into quasi-stable particles which produce hits in the detector.
- Collision with the soft scattering of 2 partons dominates the production cross-section 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 (PV).
- Some particle (e.g; b-,c-hadrons) can travel considerable distance from their point of origin (PV) before they decay. Particles from these decays form a secondary vertex (SV)




## Overview (II)



- 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 is originated from c-quarks and light jet if it is 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 PT particle in the primary vertex.




## b-tagging: motivations

- **In Atlas b-tagging is important for high PT physics program which includes:**
  - o Precision measurements of the top quark properties
  - o Large Cross-section, moderate $\varepsilon_b$ >50% (will be good)
    - Help reducing the combinatoric background w+jets
    - S/B ~ 2 x (4 x) if require one (two) b-tagged jet(s).
- **Searches for Higgs boson (both Standard Model Higgs and non-Standard Model Higgs bosons)**
  - o H->bb , ttH(->bb) with 4 b-jets. (comaparitve low cross-section, require high $\varepsilon_b$ ~ 70%)
  - o SUSY Higgs (H+ ->tb)
- **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 collider collaborations for years.

## b-tagging Over View

- **Definition: Identify a jets which contain a b quark.**
- b-quarks from B-hadrons, which consequently decays into lighter hadrons (**recognized as b jets**).
- To identify these jets one takes advantage of several properties of B-hadrons (long lifetime $c\tau$= 450 $\mu$m, travels order of few mm, large mass and momentum fraction of b-hadrons in b-quark jets) which helps to distinguish them from lighter quark jets (**known as b-tagging**).
- **B-tagging methods used (mostly used in Atlas)**
  - o Spatial taggers
    - Impact Parameter (IPn Based Tagger) ; n=2,3
  - o Secondary Vertex (SV) based taggers.
    - SV1 , SV2 Taggers.
  - o Soft Lepton Tagger - which use the fact that 20% of b-quarks decay semi-leptonically b to c / $\nu$.

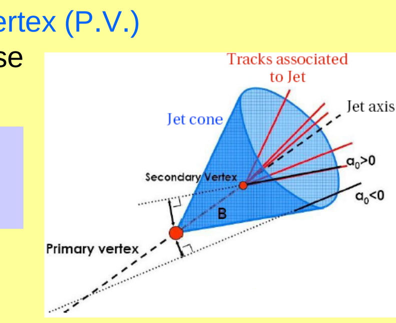
## IP Based b-tagging algorithm (I)

- **Definition of Signed I.P.**

  Distance of closest approach to the primary Vertex (P.V.)

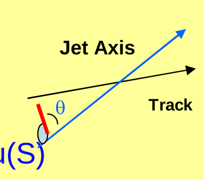
  d0 and Z0: track impact parameter in transverse ($r$- $\phi$) and in longitudinal (r-z) plane.

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



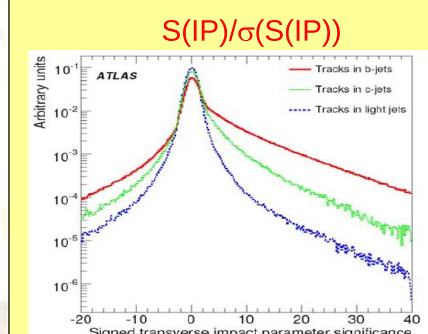

- Select the tracks based on pre-defined track grade (called good tracks).
- **For each good charged track:**
  - Obtain signed impact parameter (d0 or Z0)
  - Obtain the significance: S = d0/$\sigma$(d0) and Z0/$\sigma$(z0)
  - Calculate the track weight $W_{track}$ = b(S)/u(S) ; b(S) and u(S) are PDF's 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: $W_{IPJet} = \sum_{i=1} \ln(W_{track\_i})$ ; $W_{track\_i} = b(S_i)/u(S_i)$.



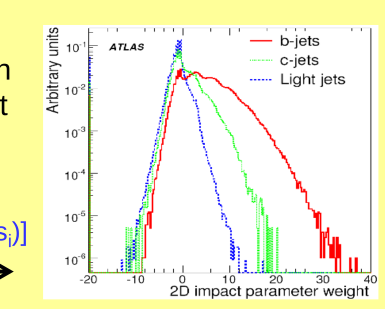

## IP Based b-tagging algorithm (II)

S(IP)/$\sigma$(S(IP))




Noramlized distribution Feed to PDF's for b-jet b(s) and light jet u(s)

$W_{IPJet} = \sum_{i=1}^{Ntrack} \ln[b(s_i)/u(s_i)]$




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

- Algorithm's based on IP Taggers:
- IPxD (x=1,2,3)
- **Jet Prob**: $d_0/\sigma(d_0)$ of each track compared to the resolution func. Of the prompt track obtained from data using negative side of SIP.

  Rejection = $1/\varepsilon_{light}$ = 30 @ $\varepsilon_b$ = 60 %
- IP2D ($d_0$):

  Rejection = $1/\varepsilon_{light}$ = 46 @ $\varepsilon_b$ = 60 %
- IP3D ($d_0$ + $Z_0$ : 2D Pdf):

  Rejection = $1/\varepsilon_{light}$ = 67 @ $\varepsilon_b$ = 60 %

## Secondary Vertex (SV) tagger (I)

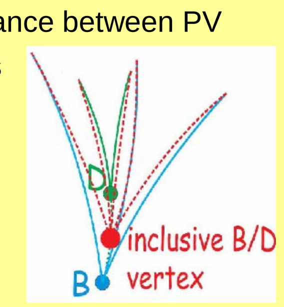
- Among the selected tracks (tracks associated to jet), find and remove the tracks from $\Lambda$(Ko) decay, $\gamma$ conversion and material interaction.
- Remaining tracks are combined and try to fit them into one Sec. Vtx., If the fit to $\chi^2$ is not acceptable, remove the tracks with highest contribution until $\chi^2$ 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

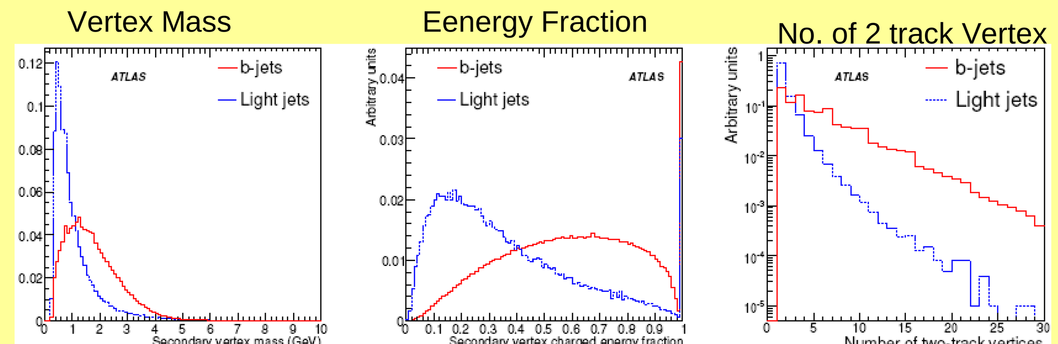
  N: No. of good 2 tracks vertices in the jet

  M: invariant mass of all particles in the secondary vertex

  F: Energy Fraction (E svx /E jet).




## Secondary Vertex (SV) tagger (II)




$W_{vertex}$ = log[b(…)/u(…)] ; one or more dimensional variable

Efficiency of secondary vertex is limited by the efficiency of second vertex.

Combination of IP3D and SV has better performance/

Combined with IP3D : "IP3D + SV1" : Rejection = $1/\varepsilon_{light}$ = 154 @ $\varepsilon_b$ = 60 %

## Topological Sec Vertex ("Jet Fitter")

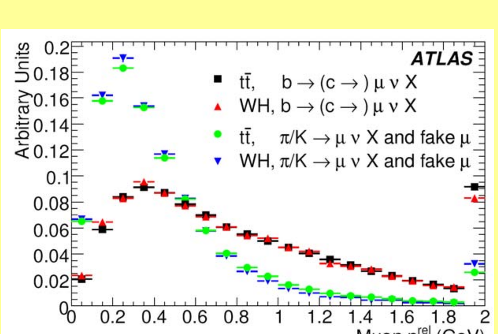
- Reconstruct the complete topology of decay chain based on the assumption that primary vertex b and c decays are on the same line (along the b-hadron flight direction).
  - Vertex Fitter uses the Kalman Filter approach (finds a common line on which PV, b, c hadron vertices lie).
- With this approach b-, c- vertices are not merged even when single track is attached to them.
- Vertex variables used in liklihood are:
  - Vertex mass,
  - Energy fraction,
  - Flight length significance
- Discrimination between b-, c-, and light jet is based on the liklihood using above variables.
  - 20% improvement in light jet rejection than other methods.
  - Promising for b/c seperation

## Soft lepton Based Tagging Algorithm

- Efficiency is a-priori limited by semi-leptonic Branching ratio:
  - Br(b -> $l$ x) ~ 11 % ; Br(b -> c -> $l$ x) ~ 10 % ($l = e$ , $\mu$)
- Low co-relation with the "spatial" algorithms.
  - Perfect for obtaining b-tag efficiency from data.
- Both algorithms make use of $P_T$rel (relative $P_T$ of lepton w.r.t. Jet axis).
- For Soft-muon taggers:
  - Rejection: 300 @ $\varepsilon_b$ = 10 %
- For Soft-electron taggers:
  - Low $P_T$ electron ID in dense jet environment is very challenging-which at 80% electron effieceincy gives:

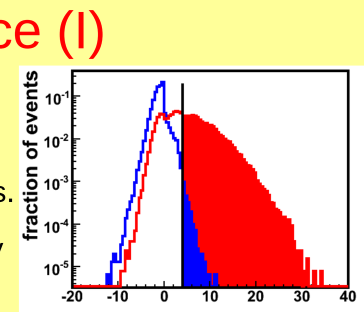
    Rejection ~200 against charged pions

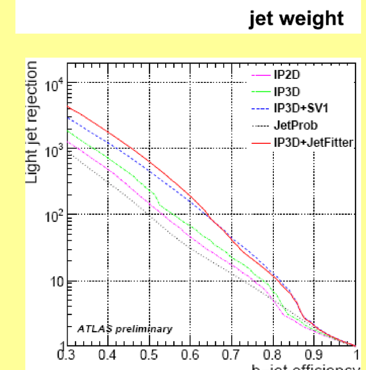
    Rejection ~2-3 against Conversion
  - Rejection:~100 @ $\varepsilon_b$ = 7 %




## B-tagging performance (I)

- Performance of the b-tagging methods is given by $\varepsilon_b$ along with rejection of tau/charm/light jets, which is inverse of mis-tag rates.
- These quantities are estimated from MC samples by cutting on the jet weights of the respective taggers.
- For a given $\varepsilon_b$ expected Rejection
  - Startup: Rejection = 1/ $\varepsilon_{light}$ = 30 @ 60%
  - upto 200 for the highend taggers (JetFitter).
  - Soft muon: Rejection = 300 @ 10%
  - Soft electron: Rejection=100 @ 8%
  - Charm: Rejection 5-7 @ 60%, 20 with JetFitter




## B-tagging performance (II)

- This depends on Jet PT , $\eta$
  - Degraded performance at :
    - Low PT (due to more material inner detector)
    - High PT(Higher track density)
    - High $\eta$ (low detector acceptance)