

b-tagging in ATLAS

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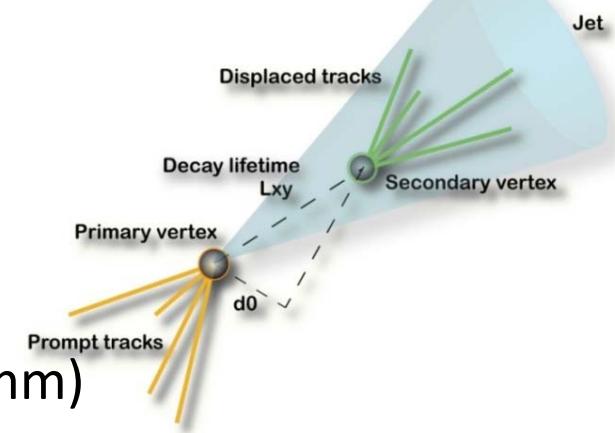
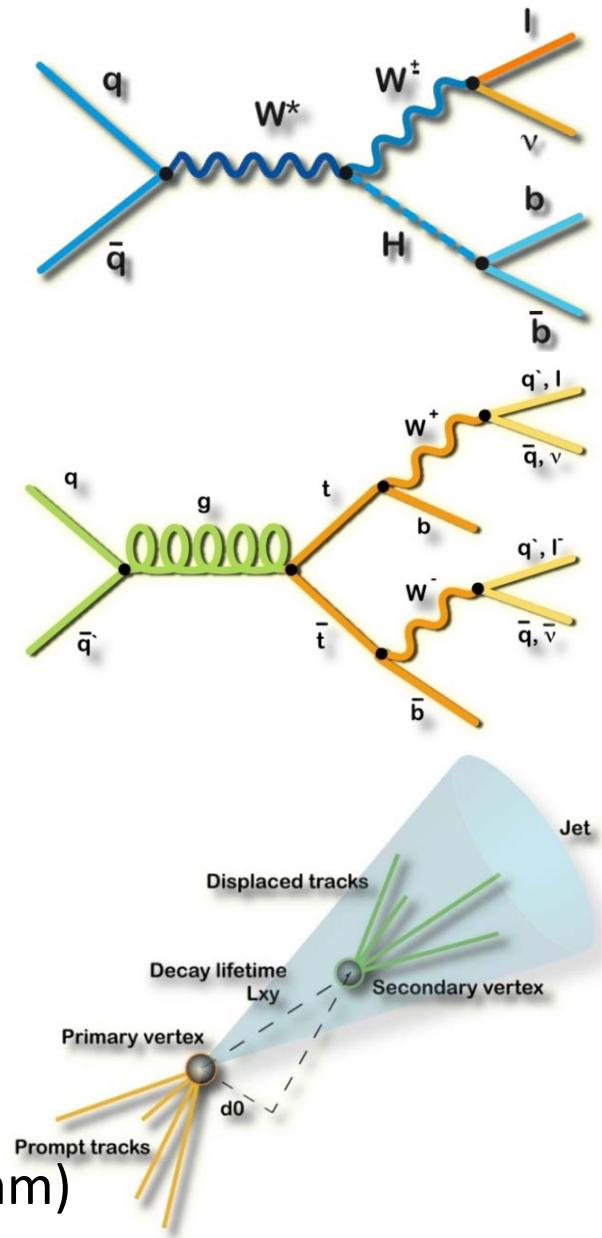


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Introduction

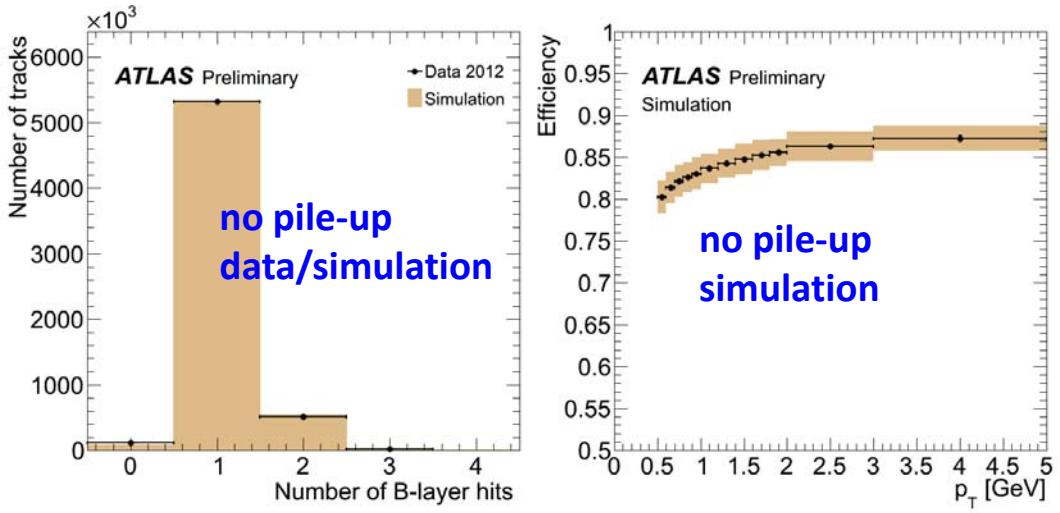
- B-tagging is an essential tool for the physics that includes high- p_T b-jets in there final state
 - e.g., Higgs search ($H \rightarrow bb$), top physics ($t \rightarrow Wb$), new physics search ($\tilde{b} \rightarrow b\tilde{\chi}$, etc...)
 - Also used to veto background ($H \rightarrow WW$ analysis to veto top backgrounds)
→ b-jet efficiency and purity is very important
- Each analysis has different optimized operation point in terms of “b-jet efficiency vs fake b-tagged jet rejection”
- B-jet tagging rely on B-hadron properties
 - Displaced vertex (secondary vertex) from primary vertex due to its long life time (typically travel a few mm)
 - Large B-hadron mass
 - Large impact parameter (d_0)
 - Semi-leptonic e/μ decay of B-hadron (~40% including $b \rightarrow c \rightarrow l\nu X$ decay)



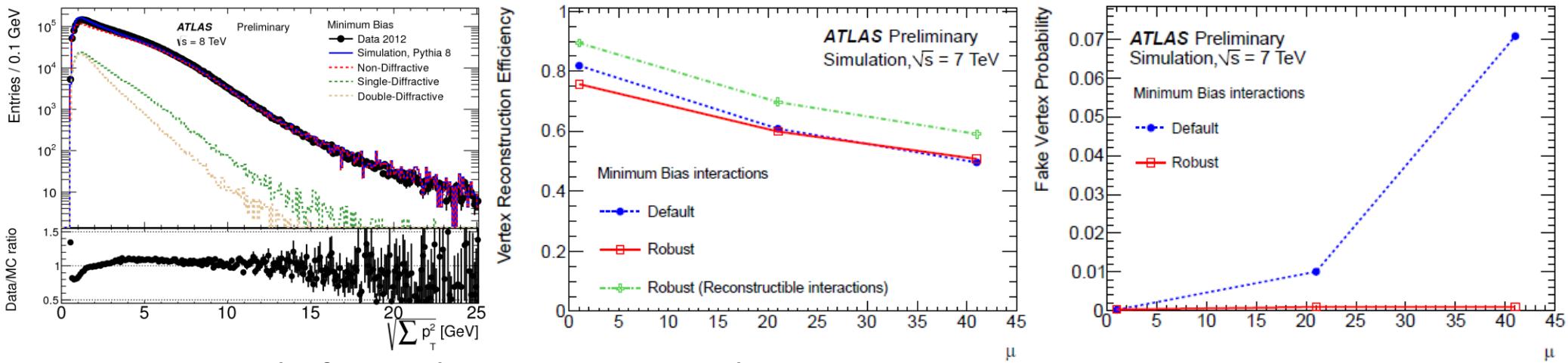
Tracking, vertexing, and impact of pileup

- Track reconstruction

- Inside-out tracking
 - Silicon seeds → extrapolate to TRT
 - Primary tracking
- Outside-in tracking
 - TRT seeds → extrapolate to silicon
 - Secondary tracking to recover conversions, V0 decays



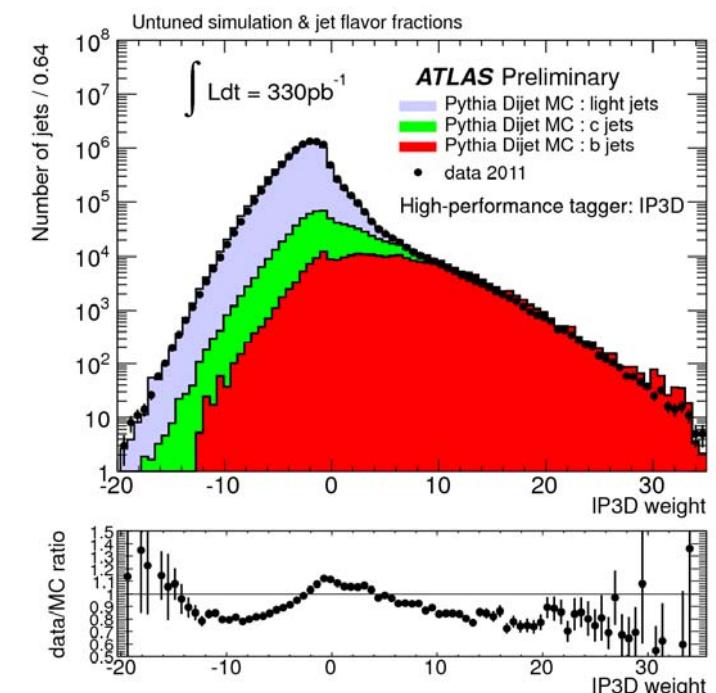
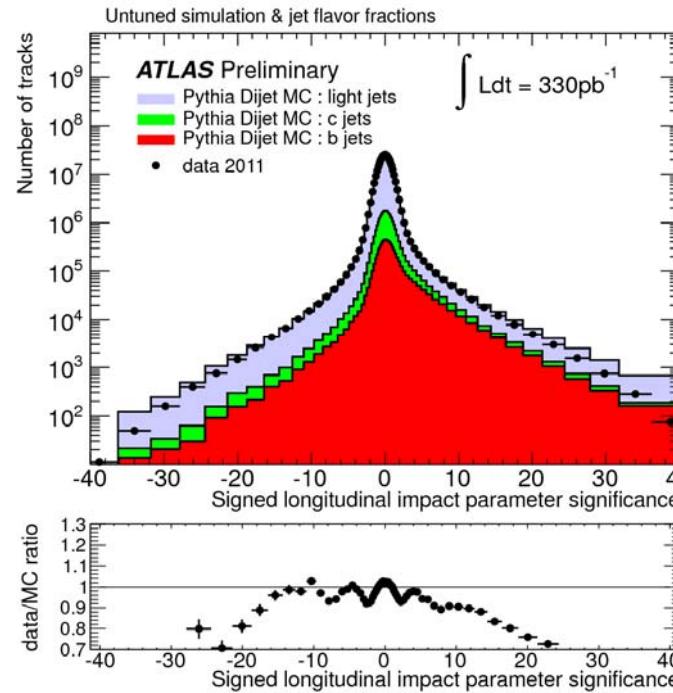
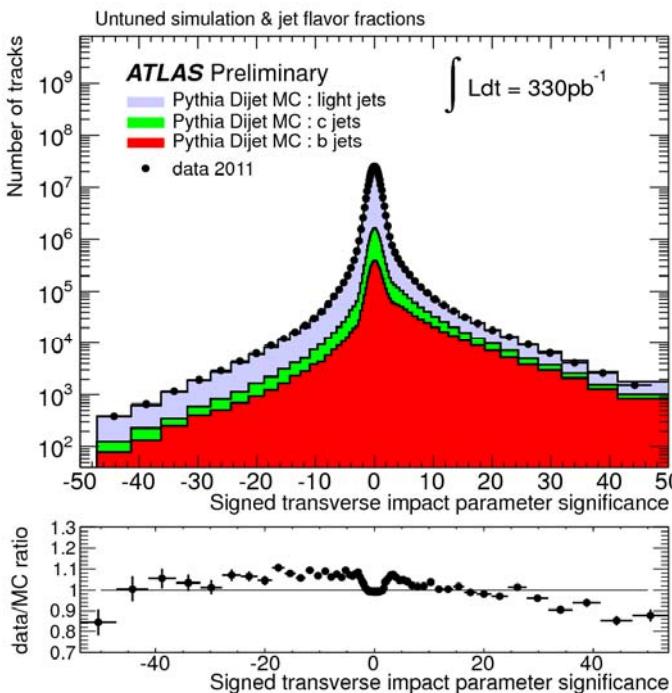
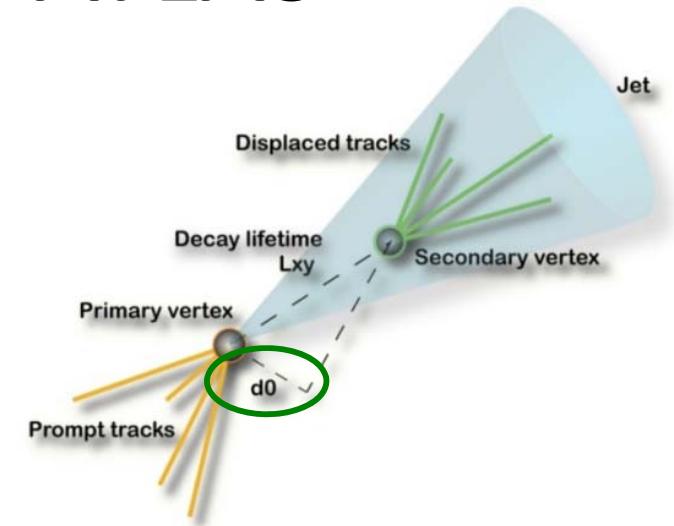
- Vertex reconstruction performance at high pileup



- Iteratively fit tracks consistent with interaction position
- Choose highest $\Sigma(p_T^2)$ as the physics primary vertex
 - This position becomes reference for the b-tagging

B-tagging algorithm in ATLAS

- Impact parameter (IP) base
 - IP3D: Log-likelihood base algorithm
 - Use transverse and longitudinal IP significance as the PDFs
 - $w_{\text{track}} = p_b/p_l$
 - $w_{\text{jet}} = \sum_{\text{track}} \log(w_{\text{track}})$

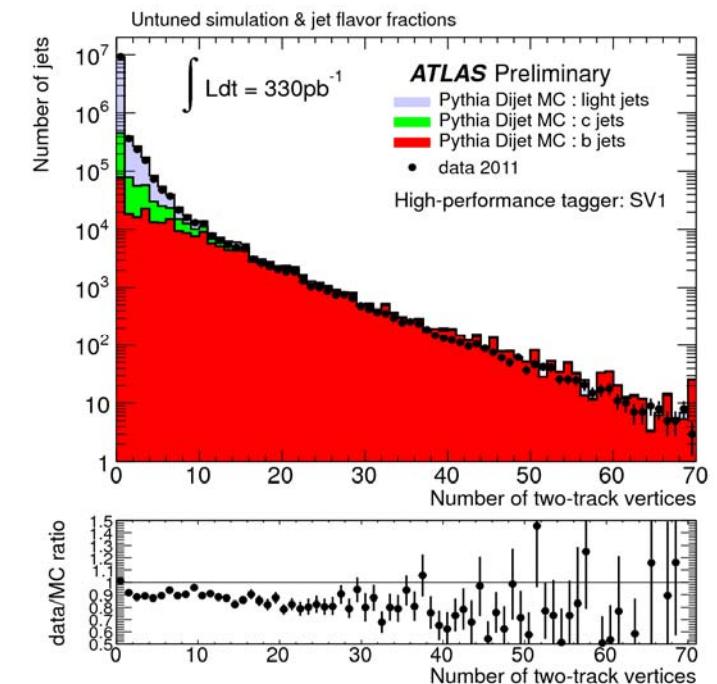
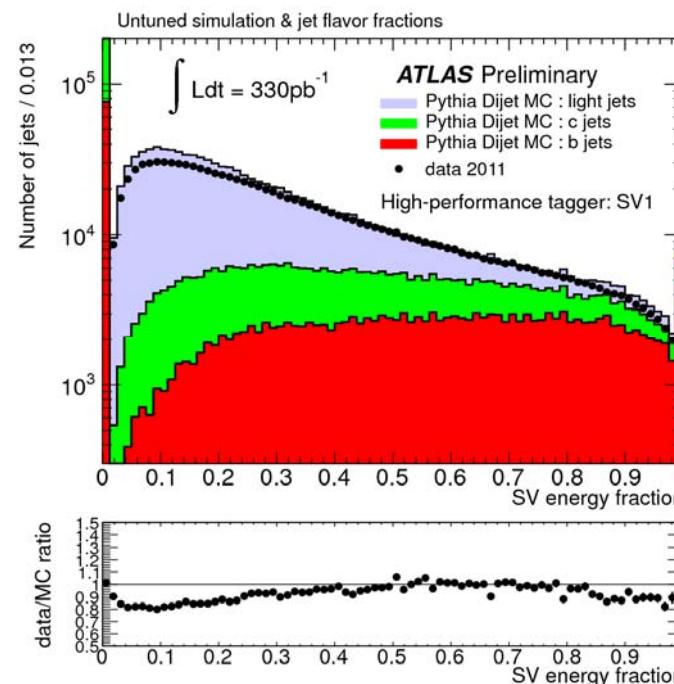
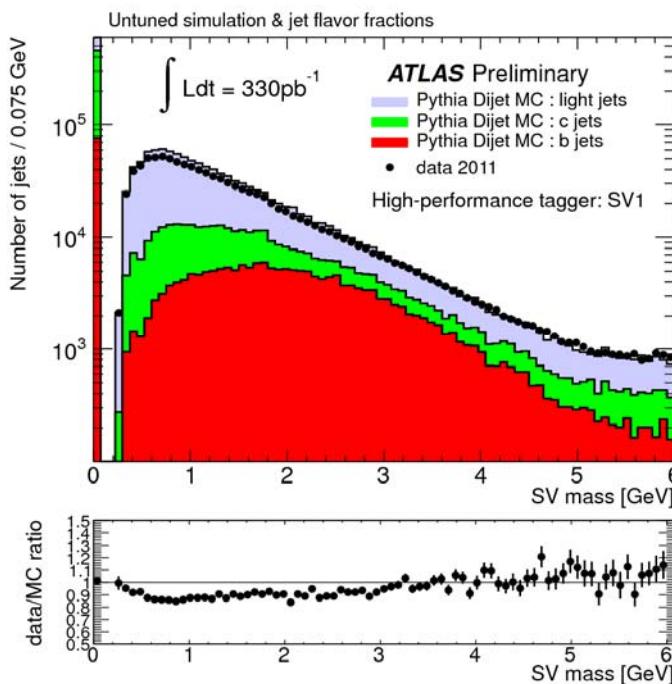
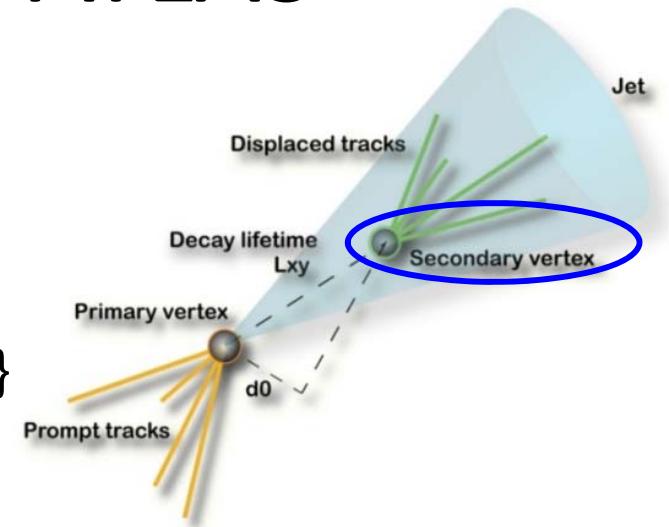


B-tagging algorithm in ATLAS

- Secondary vertex (SV) base

SV1: Log-likelihood base algorithm

- reconstruct SV and take likelihood ratio of:
 - 2D { SV mass, $\Sigma(P_T \text{ SV track})/\Sigma(P_T \text{ all track in jet})$ }
 - 1D number of two-track vertices
 - dR (jet-direction, PV \rightarrow SV direction)

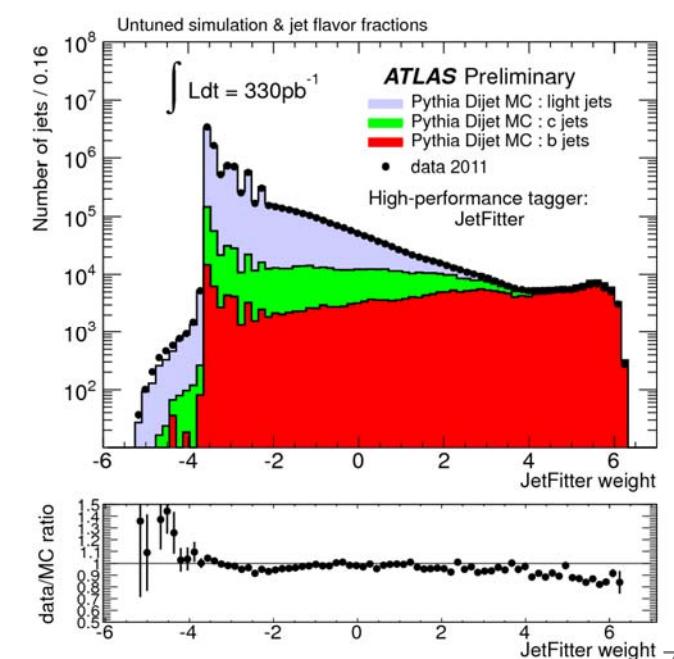
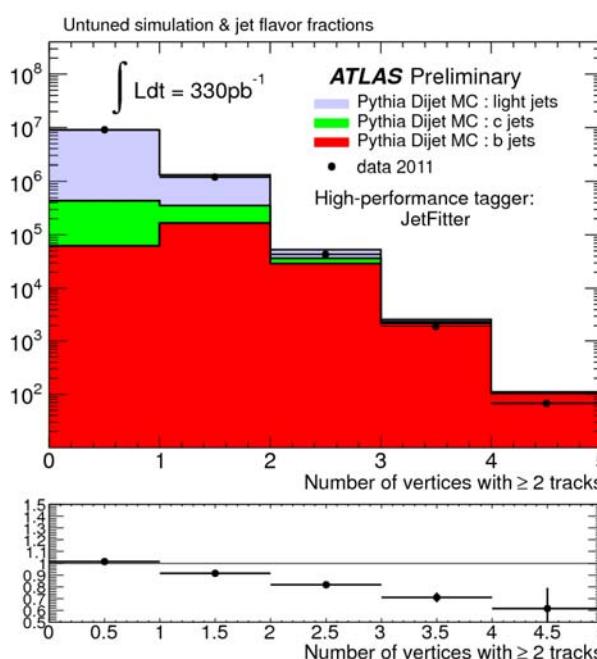
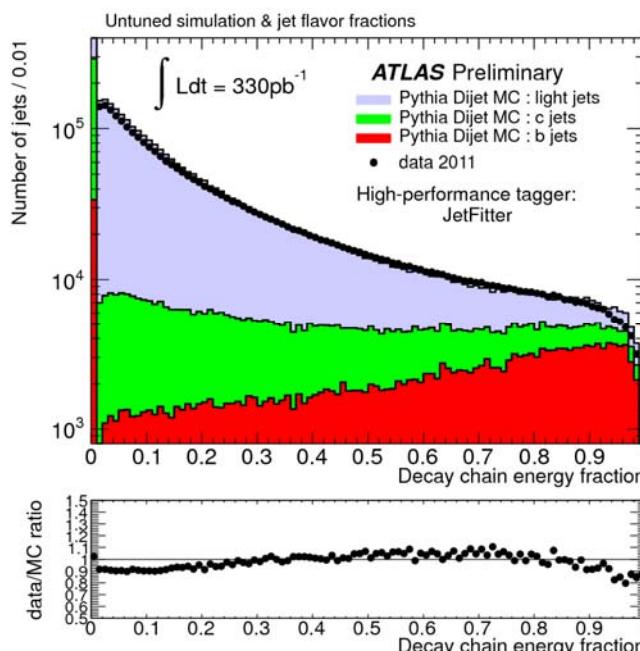
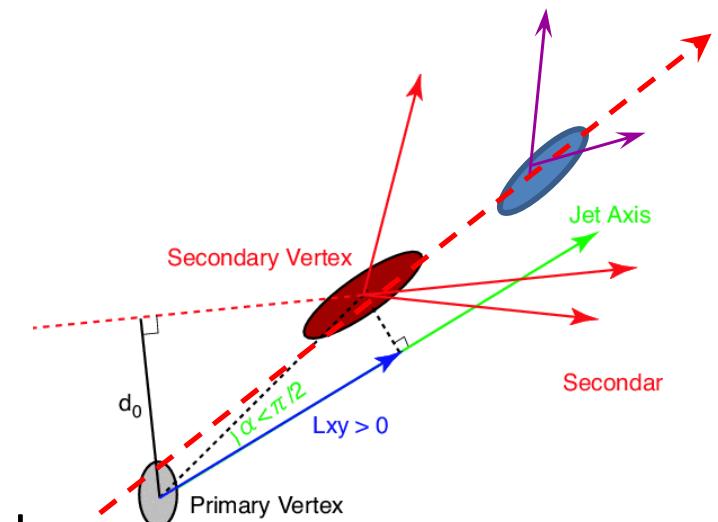


B-tagging algorithm in ATLAS

- Secondary vertex (SV) base

JetFitter: Special algorithm

- Exploit the topology of weak B/C-hadron decay chain ($b \rightarrow c \rightarrow X$) inside jets
- Use Kalman filter to find **a common line** on $PV \rightarrow b$ vertex $\rightarrow c$ vertex decay chain
- Discrimination of b/c/light-jets based on likelihood similarly as SV1.



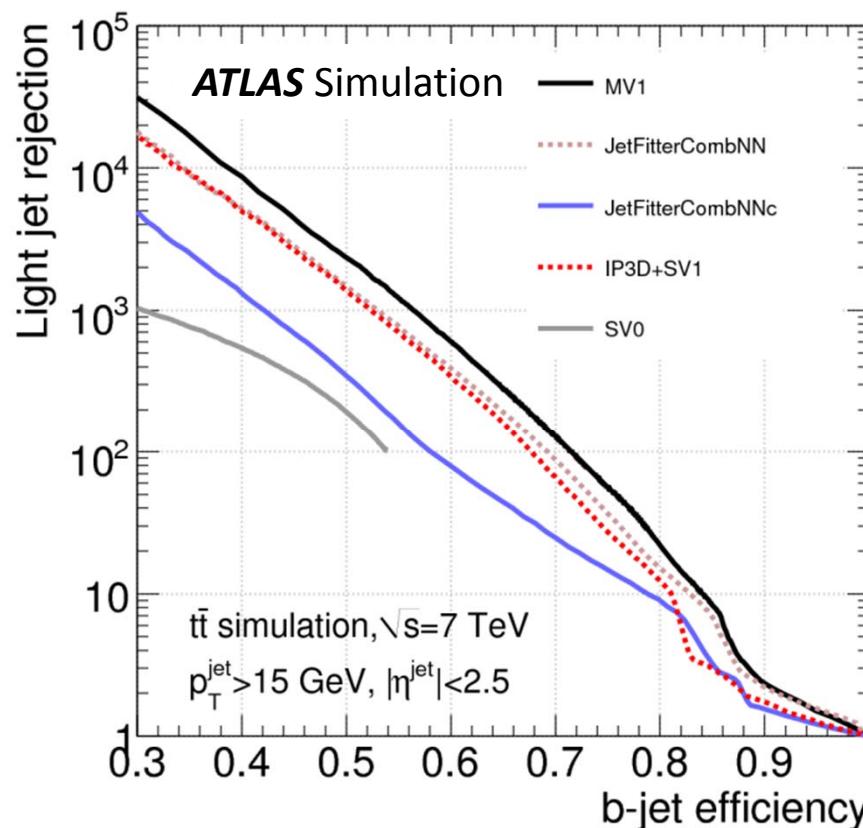
B-tagging algorithm in ATLAS

- Advanced algorithm based on multivariate technique

MV1: a Neural network base tagger that is combined

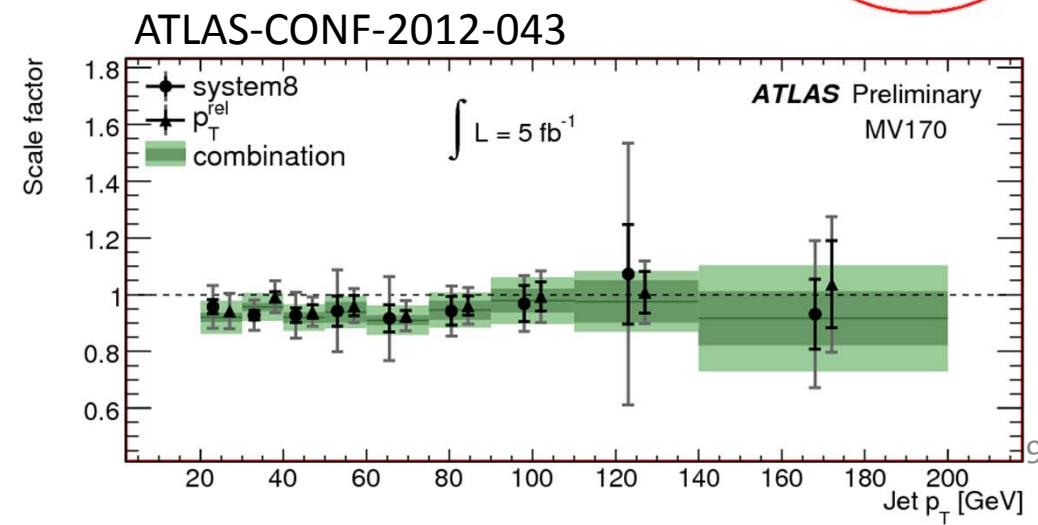
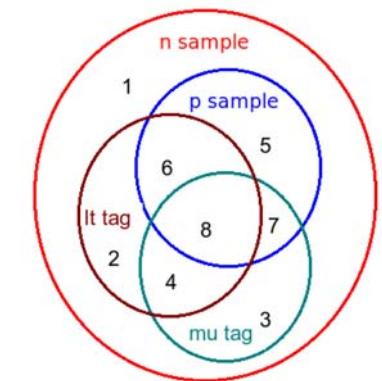
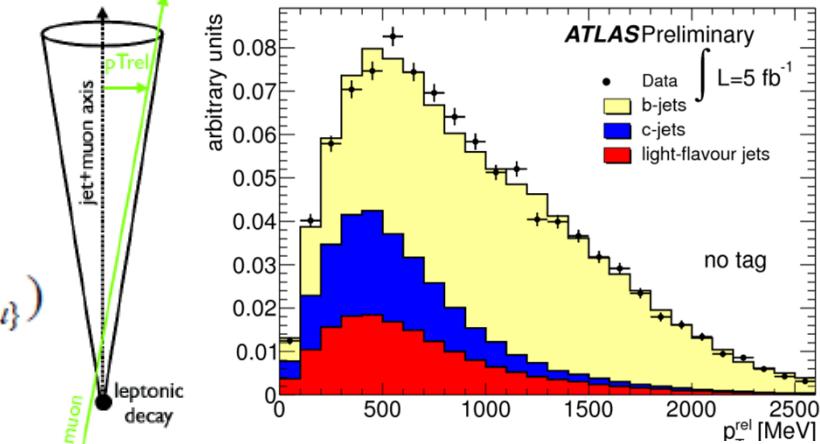
IP3D/SV1/JetFitter information as input variables

→ b-tag efficiency 70% (MV1) with 0.7% light-flavor (20% charm-jet)



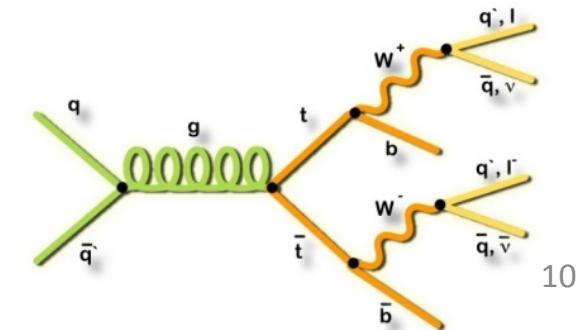
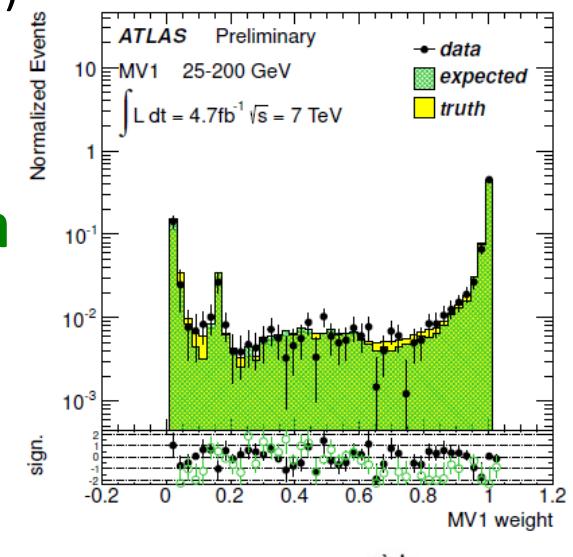
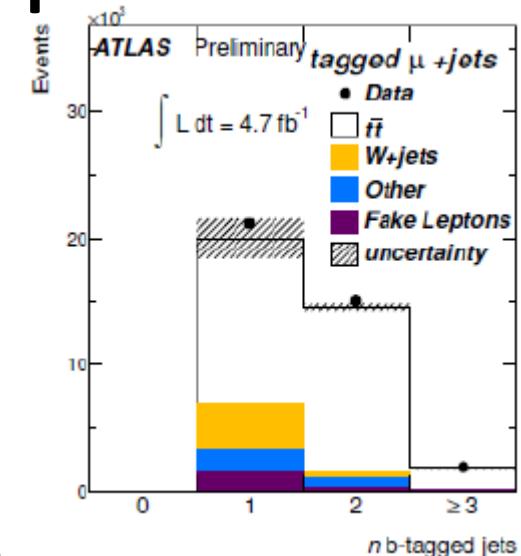
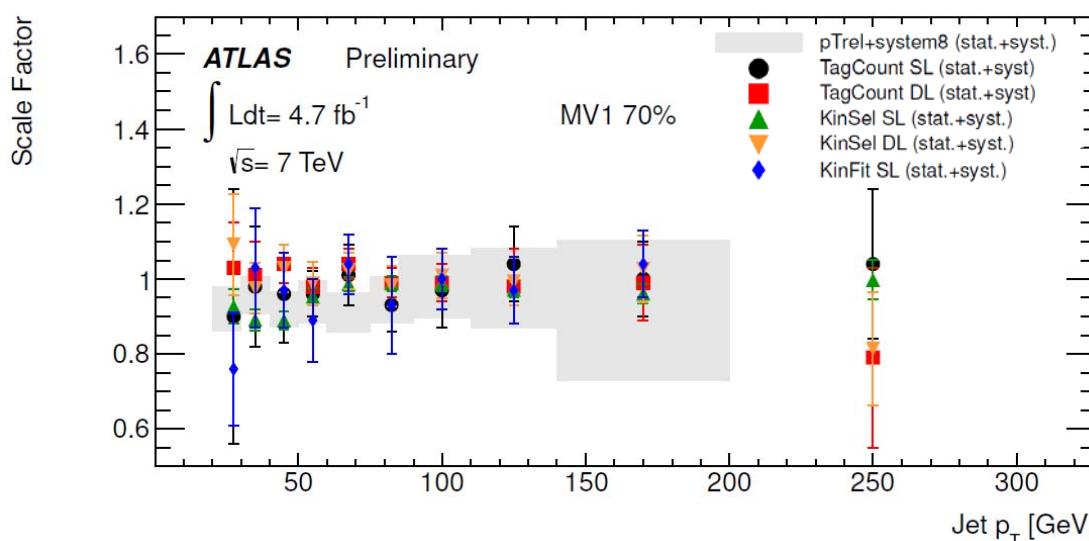
B-tagging Calibrations with Muon jets

- B-tagging efficiency measurement in data with jets containing muon
 - **p_T^{rel}**: Template fit of muon p_T respect to jet axis (p_T^{rel}) to get flavor fraction before and after b-tagging $\varepsilon_b = \frac{N_b^{\text{tagged}}}{N_b}$
 - **System8**: Define 3 independent jet selection criteria to construct 8 samples.
Use event counts to solve for b-tagging efficiency.
(muon tag, life time tag, opposite side tag)
- Results combined to improve scale factor precision
 - Very good agreement b/w two methods
 - Total uncertainty is 5-19 %
- **For high-p_T range, these calibration methods are taken over by ttbar method** (next page)



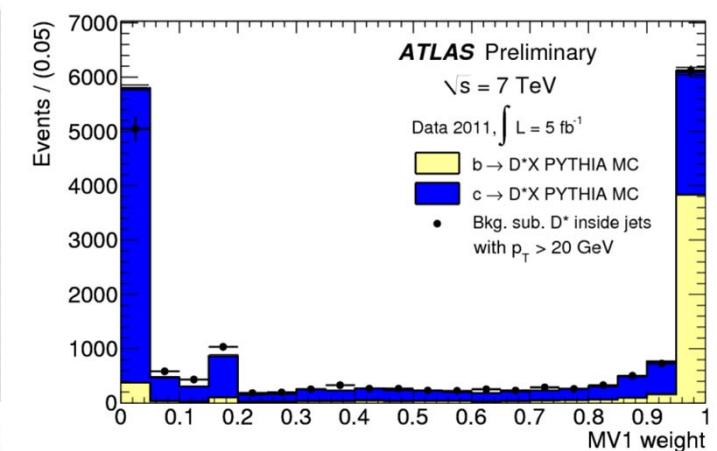
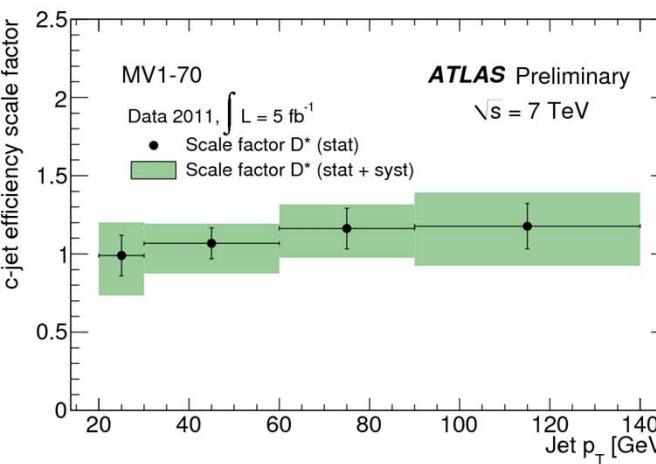
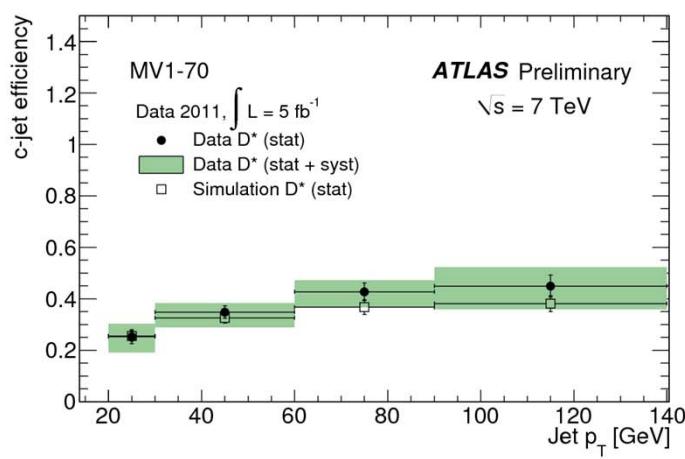
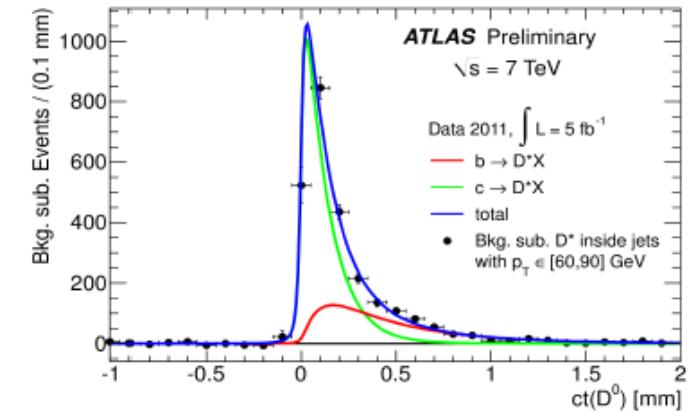
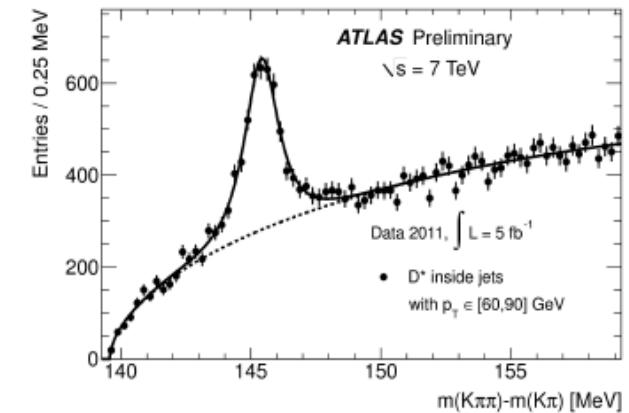
B-tagging Calibrations with top events

- Top events are nice calibration source due to its signature ($t \rightarrow W b$)
- Calibration with di-lepton & single lepton channel
 - **Tag counting**: Use multiplicity of b-tagged jets
 - **Kinematic selection**: Measure tag rate for jets
 - **Kinematic fit**: Fit top-pair event topology
to derive b-jet weight distribution (only l+jets)
- **Very good agreement among various method**
- **Also consistent result with muon-jet method**
- **Accuracy of ttbar calibration is ~2% for 2012 data**



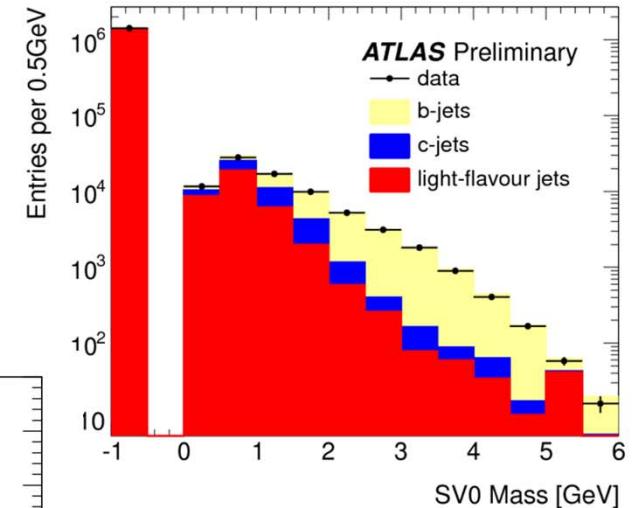
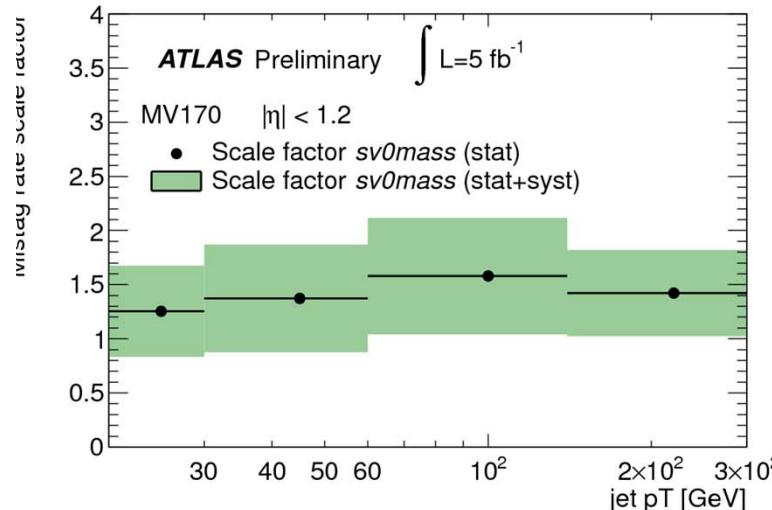
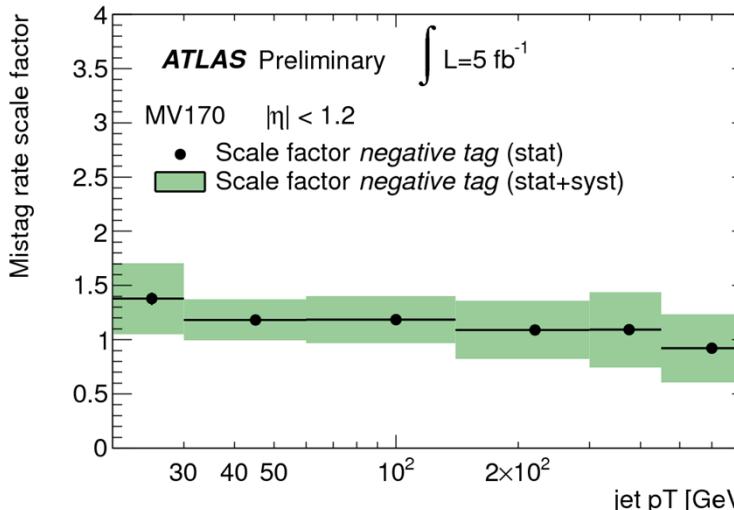
C-tagging Calibrations with D^{*+} decays

- Significant fraction of c-jets are “b-tagged”
- Calibration by reconstructing $D^{*+} \rightarrow \pi^+ D^0 (\rightarrow K^- \pi^+)$ decay chain
- Fit with the background-subtracted data for D^0 pseudo-proper time distribution to extract $b \rightarrow D^* X$ contribution
- In general, very good agreement for data/MC
- Systematic uncertainty ranges 12-25%



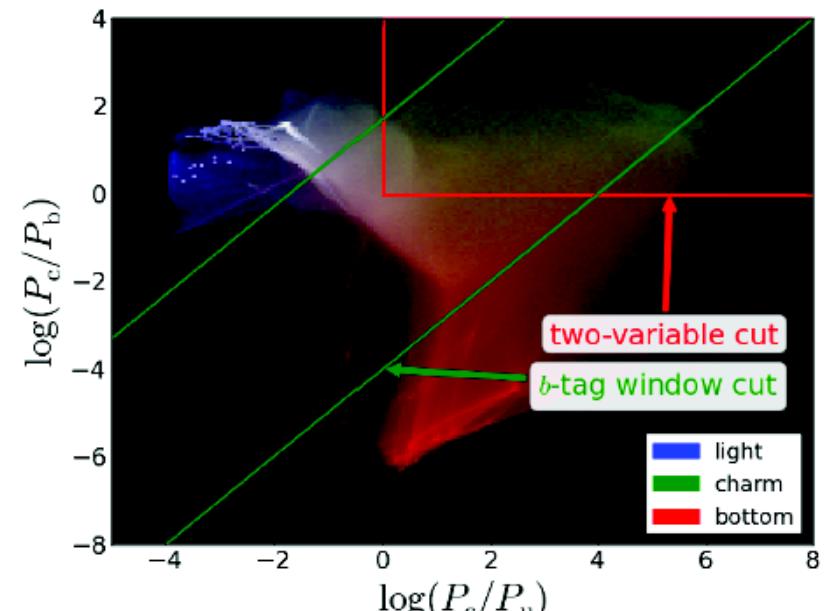
Mistag rate Calibrations

- Small fraction of light flavor jets are also “b-tagged” due to the detector resolution limitation, long-lived particles, and material interaction
- Calibrate with di-jet data
 - **Negative Tag method:** mistag from resolution effects
 - **SV0 mass method:** fits invariant mass of secondary vertex
- Good agreement between two methods
- Total uncertainties: 10-100%



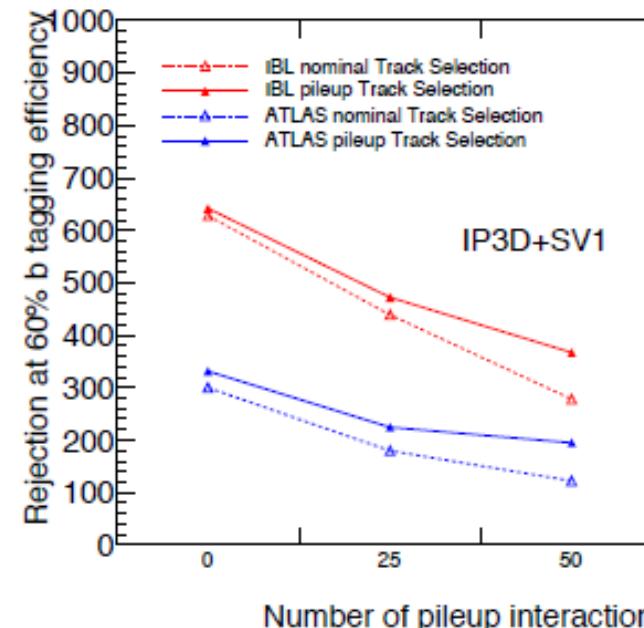
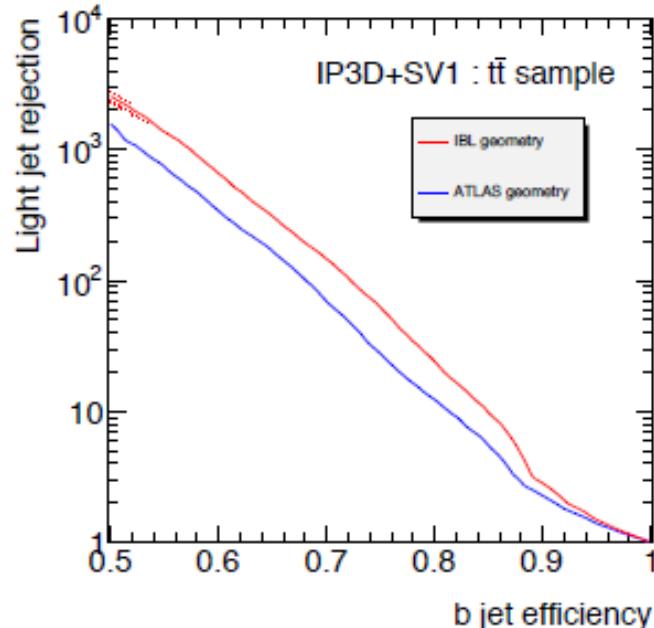
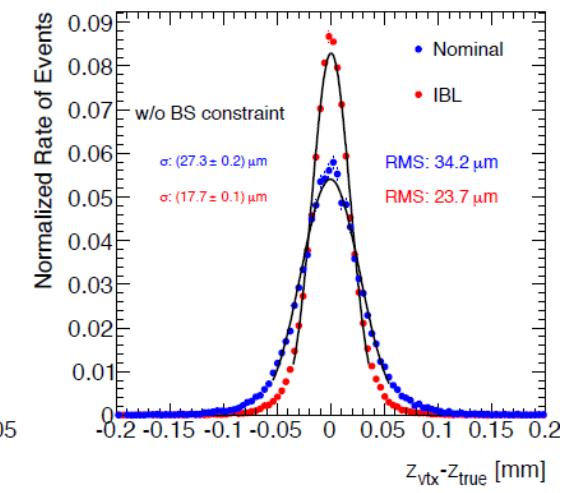
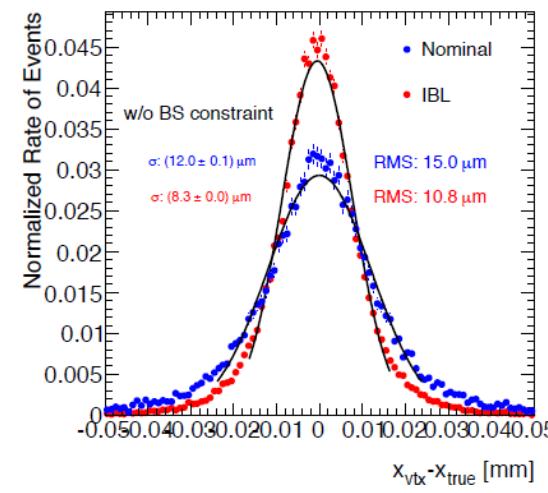
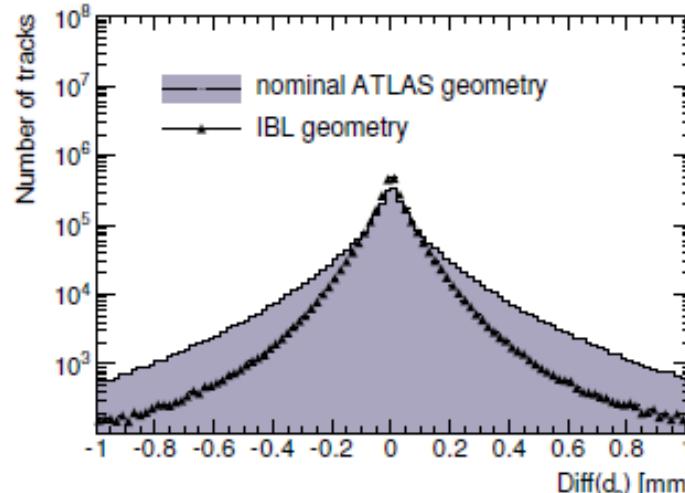
Future Prospects

- High p_T jet calibration ($p_T > 300$ GeV)
 - Work in progress to extend b-jet calibration up to $p_T = 1$ TeV
- More sophisticated multivariate-base b-tagging
 - Combine many b-tagging information using multivariate technique
- Improve c-jets rejection
 - Current b-tagging algorithm also identify significant amount of charm-jets
 - Work in progress to reject c-jet contribution by employing 2-D separation of (b-jets vs light-jets) and (b-jets vs c-jets)



Future Prospects (cont.)

- Post-shutdown b-tagging performance
 - IBL (Insertable B-Layer, 4th layer of PIXEL detector) will be inserted during long shutdown
 - Pileup robust B-tagging optimization study ongoing



Plots from IBL TDR

Summary

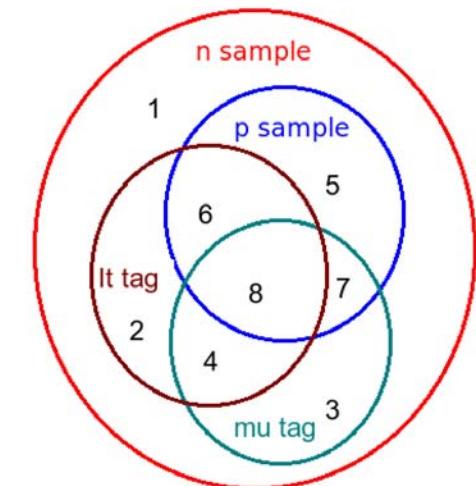
- Excellent performance achieved for tracking/vertexing and b-tagging with ATLAS inner detector
- Track/vertex properties are well modeled by MC simulation.
- We successfully commissioned sophisticated b-tagging algorithm and achieved high b-tagging performance
 - **70% b-tagging efficiency with 0.7% mistag rate**
- We developed several methods to calibrate b-tagging performance
 - **B-tagging calibration with muon-jets & ttbar method**
 - **C-tagging calibration with D* method**
 - **Mistag calibration with negative tag/SV mass method**
- We plan to improve b-tagging performance
 - **B-tagging with combining b-tagging input variables**
 - **C-jet rejection by employing 2-D separation of b/c/light jets**
- B-tagging performance after shutdown will be improved thanks to IBL
 - **Significant improvement expected**
 - **Pileup robust optimization study ongoing**

backup

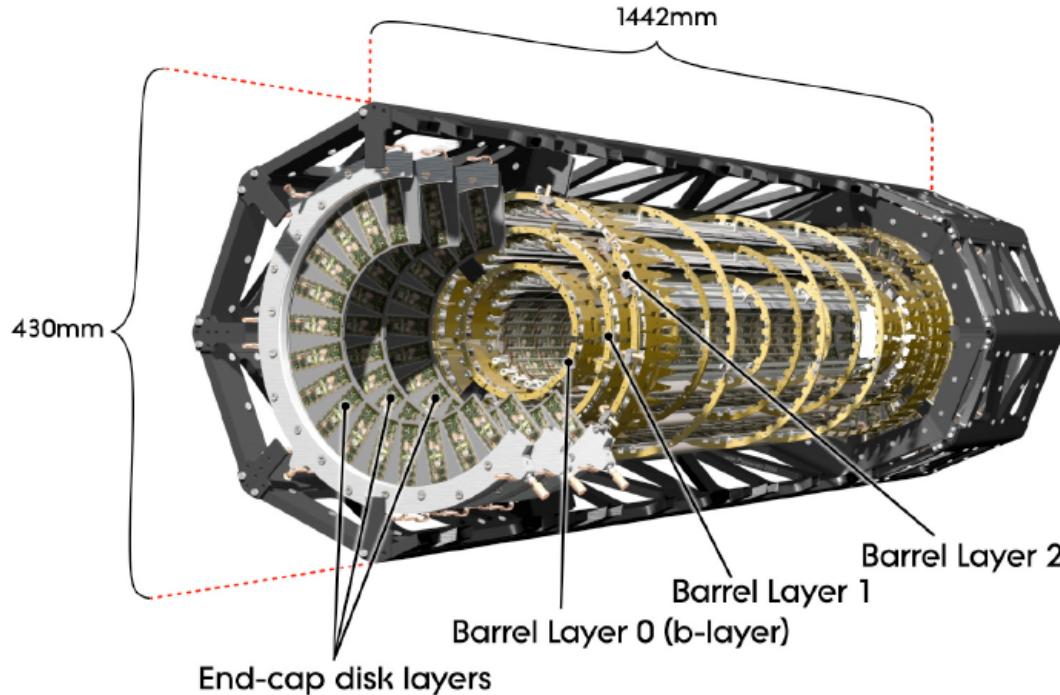
System8

- Form 2 samples that have different flavor composition
(for example, muon-jets sample as n, and muon-jets + life-time b-tagged sample as p)
- Apply 2 un-correlated b-tagging algorithms (muon-base & specific algorithm to be calibrated)
- Designed to use less simulation input
- Alpha parameters are correlation coefficients
- Solve 8 unknowns with 8 equations by χ^2 minimization

$$\begin{aligned}
 n &= n_b + n_{cl} \\
 p &= p_b + p_{cl} \\
 n^{LT} &= \epsilon_b^{LT} n_b + \epsilon_{cl}^{LT} n_{cl} \\
 p^{LT} &= \alpha_6 \epsilon_b^{LT} p_b + \alpha_4 \epsilon_{cl}^{LT} p_{cl} \\
 n^{MT} &= \epsilon_b^{MT} n_b + \epsilon_{cl}^{MT} n_{cl} \\
 p^{MT} &= \alpha_5 \epsilon_b^{MT} p_b + \alpha_3 \epsilon_{cl}^{MT} p_{cl} \\
 n^{LT,MT} &= \alpha_1 \epsilon_b^{LT} \epsilon_b^{MT} n_b + \alpha_2 \epsilon_{cl}^{LT} \epsilon_{cl}^{MT} n_{cl} \\
 p^{LT,MT} &= \alpha_7 \alpha_6 \alpha_5 \epsilon_b^{LT} \epsilon_b^{MT} p_b + \alpha_8 \alpha_4 \alpha_3 \epsilon_{cl}^{LT} \epsilon_{cl}^{MT} p_{cl}
 \end{aligned}$$



Inner detector & IBL



| Item | Radial Extension [mm] | Length [mm] | Staves / Sectors | Modules | Pixels ($\times 10^6$) |
|----------------------|--------------------------|---------------------------|---------------------|--------------|-----------------------------|
| Beam pipe (today) | $29 < R < 36$ | | | | |
| Beam pipe (with IBL) | $25 < R < 29$ | | | | |
| IBL | Envelope | $31.0 < R < 40.0$ | | | |
| | Sensitive | $< R > = 25.7$ | $ Z < 332$ | 14 | 224 |
| | | | | | 6.02 |
| Pixel | Envelope | $45.5 < R < 241.0$ | $ Z < 3092$ | | |
| B-layer | Sensitive | $< R > = 50.5$ | $ Z < 400.5$ | 22 | 286 |
| Layer 1 | Sensitive | $< R > = 88.5$ | $ Z < 400.5$ | 38 | 494 |
| Layer 2 | Sensitive | $< R > = 122.5$ | $ Z < 400.5$ | 52 | 676 |
| Disk 1 | Sensitive | $88.8 < R < 149.6 = 88.5$ | $< Z > = 495$ | 8×2 | 48×2 |
| Disk 1 | Sensitive | $88.8 < R < 149.6 = 88.5$ | $< Z > = 580$ | 8×2 | 48×2 |
| Disk 1 | Sensitive | $88.8 < R < 149.6 = 88.5$ | $< Z > = 650$ | 8×2 | 48×2 |
| | | | | | <i>Pixel Total</i> |
| | | | | | 80.4 |