Tracking, Vertexing & b-Tagging Performance in ATLAS

Mark Tibbetts  LBNL
on behalf of the ATLAS Collaboration

- Physics Motivation
- ATLAS Inner Detector
- Track & vertex reconstruction (2011/12)
- b-Tagging Calibration (2011)
- Summary

The Eye of ATLAS: Hadronic interaction vertices
Physics Motivation

- pp interactions at ATLAS result in hundreds of primary & secondary charged stable particles ($\tau > 3 \times 10^{-11}$s)
- Precise measurement of their kinematics is essential to all physics analyses
  - Important for lepton ID, isolation and missing $E_T$
- Requires high precision and well understood tracking detectors
- Vertex reconstruction important to identify primary interactions
  - Also displaced particle decays and material interactions
- b-Tagging algorithms identify jets and reduce backgrounds for physics signatures with heavy flavour:
  - From decays: $t \rightarrow Wb; H \rightarrow b\bar{b}; b' \rightarrow Zb; \tilde{b} \rightarrow b\tilde{\chi}$
  - Production cross-sections: $Wb(b); Zb(b)$
ATLAS Inner Detector

- **3 detector sub-layers:**
  - Pixel and SCT (microstrips) both silicon based detectors
  - TRT drift tube based detector
- All layers comprise barrel and 2 endcaps
- $|\eta|<2.5$
- 2T axial solenoid field for momentum measurement

<table>
<thead>
<tr>
<th>Subdetector</th>
<th>Element size</th>
<th>Resolution $[\mu m]$</th>
<th>Hits/track in the barrel</th>
<th>radii of the barrel layers $[mm]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pixel</td>
<td>$50 \mu m \times 400 \mu m$</td>
<td>$10 \times 115$</td>
<td>3</td>
<td>50.5, 88.5 &amp; 122.5</td>
</tr>
<tr>
<td>SCT</td>
<td>$80 \mu m$</td>
<td>17</td>
<td>8</td>
<td>299, 371, 443 &amp; 514</td>
</tr>
<tr>
<td>TRT</td>
<td>4 mm</td>
<td>130</td>
<td>$\sim 30$</td>
<td>from 554 to 1082</td>
</tr>
</tbody>
</table>
Track & Vertex Reconstruction

Track Reconstruction

- Algorithms based on pattern recognition
  - **Inside out**
    - Silicon seeds extended out to TRT
    - Reconstructs most primary tracks
  - **Back-tracking**:
    - TRT seeded with inward extension
    - Recovers secondary tracks (conversions, hadronic interactions, V0 decays)

Primary Vertex (PV) Reconstruction

- Iteratively fit tracks consistent with interaction region
- Choose physics PV based on $\Sigma(pT^2)$
  - Becomes reference PV for b-tagging
  - Physics object association is also used

**PV resolution** in data from 'split vertex' method: well modelled in 2011 & 2012
Impact of Pileup

- Current challenge at LHC is impact of high pileup
- Significant effort to understand and mitigate this impact wrt tracking and PV reconstruction
- In 2012 define more robust track selection for PV reconstruction
  - Moderate drop in primary efficiency (~2-5%) for significant reduction in fake track fraction (30%+ → <10%)
  - Negligible fake PV probability
Neural Network (NN) Clustering

- High density of charged particles presents clustering challenge
  - Different charged particles can contribute to single cluster for pixels
- Pattern recognition from NN can identify and separate each sub-cluster
  - Input is information from 7x7 pixel array & tracking information where available
- NN clustering is now the default in ATLAS reconstruction
- Also improves pixel hit resolution resulting in **excellent impact parameter measurement**
Detector Alignment

• Tracking residuals used for alignment
  - Different levels: Whole ID, barrel vs. endcaps, layer by layer, individual modules
• However misalignment 'weak modes' exist which cannot be constrained by track residuals
  - Measure through biases in well known invariant masses (Ks & J/ψ)
• Improved alignment description in reconstruction significantly impacts Z mass resolution in data
B-Tagging Algorithms

- Algorithms to identify heavy flavour content in reconstructed jets
  - Impact parameter of tracks in jet
    - **IP3D** uses track weights based on longitudinal and transverse IP significance
  - Displaced secondary vertex
    - **SV1** reconstructs inclusive displaced vertex
    - **JetFitter** reconstructs multiple vertices along implied b-hadron line of flight
  - Cascade decay topologies
  - Advanced NN based algorithms
    - **JetFitterCombNN**: IP3D+JetFitter
    - **MV1**: IP3D+JetFitterCombNN+SV1

MC calibration results illustrated with **MV1 @ 70% b-jet efficiency**
b-Jet Efficiency from Muon Jets

- b-jet tag efficiencies measured in data from jets containing muons
- Two complementary methods:
  - **pTrel**: Likelihood fits of muon pT relative to jet axis pre & post tag
  - **System8**: Define 3 independent selection criteria (muon tag, lifetime tag under study & opposite side jet tag); event counts extract b efficiency
- **Results combined for increased precision, excellent agreement!**
- **Systematics <20%**
  - Dominant contribution at low pT from muon jets → inclusive b-jets extrapolation

Analyses correct MC with Scale factor = data eff. / MC eff.
b-Jet Efficiency from Top

- $t \rightarrow Wb$: b-jet control sample; high purity for single- & di-lepton channel candidate events

- 3 complementary methods
  - **Tag counting**: multiplicity of tagged jets gives efficiency as expect 2 b-jets (modulo acceptance, $g \rightarrow bb$, etc.)
  - **Kinematic selection**: measure tag rate for lead jets in ttbar candidate events
  - **Kinematic fit**: fits of ttbar event topology derive pure b-jet weight distributions

- Methods agree very well & compatible within uncertainty to muon based results

- Dominant systematics from jet uncertainties & flavour composition modelling (ISR/FSR)
c-Jet Efficiency from D^*+ Decays

- Tag c-jets with exclusive D^{*+} → D^{0}(K\pi)\pi reconstruction
- Background subtracted fit of pseudo proper D^{0} time to extract B → D^{*}X contribution
- Systematics < 25%
  - Dominant contribution from extrapolating to inclusive c-jets
Mistag Rates from Multi-Jets

- Rate of non-heavy flavour jets passing tag criteria measured in dijet data

- Two complimentary methods
  - **Negative tag**: mistag from resolution effects; correct for long lived hadrons & material interactions

  - **SV0 mass**: Likelihood fit of SV invariant mass

- Methods agree well; systematics up to 100% depending on method & jet kinematics
Summary

- **ATLAS** is maintaining excellent performance with tracking, vertexing & b-tagging in the large datasets already collected in 2011 & 2012
- Impact of tracking and PV reconstruction with high pileup well understood
- Advanced clustering to disentangle high density tracking in high pT jets
- Measurements of tracking detector alignment weak modes used to improve resolution in data
- **Multivariate b-tagging algorithms significantly improve mistag rates**
- Performance of b-tagging algorithms calibrated with full 2011 dataset
  - **First calibrations from top events in 2011 for ICHEP2012**
    - ATLAS-CONF-2012-097
  - Initial calibrations for 2012 data under way
BACK UP
Inner Detector Material

![Graphs showing radiation length and interaction length for different materials such as Services, TRT, SCT, Pixel, and Beam-pipe.](image-url)
Track Reconstruction Algorithms
Impact of High Pileup

- Higher pileup means higher charged particle multiplicity
- More inner detector hits
- Higher probability of fake tracks and hence fake PVs
- Decrease in PV reconstruction efficiency
- Robust tracks: $\geq 9$ Si hits, 0 pixel holes

Robust track reconstruction cuts shown to significantly reduce impact of pileup for moderate efficiency loss
Track Multiplicity in High pT Jets

ATLAS Preliminary Simulation

Jet $p_T$ [GeV] vs. $\langle\text{Min Track Separation}\rangle$ [mm]

$Z_{\min}$

$\rho_{\min}$
Detector Alignment

- Tracking residuals used for alignment
- However 'weak modes' can exist which don't impact helical shape
  - e.g., B-field
- Weak modes bias track parameters (pT, etc.)
- Determine their presence and correct with e.g., Ks reconstruction

- Charge asymmetric momentum bias measurement from $Z \rightarrow \mu\mu$ improves with new alignment
  \[ q/p \rightarrow q/p(1 + q\mu T \delta_{\text{sagitta}}) \]
- Correction derived from electron E/p
Alignment Evolution

Level 1 alignment

ATLAS preliminary
April - May 2011

Global X translation [μm]

Run number

6th July 2012  Mark Tibbetts (LBNL)  ICHEP 2012, Melbourne
Impact Parameter Resolution

- Impact parameter \((d_0, z_0)\) significance measures whether track comes from given PV
- Critical component of many b-tagging algorithms
- Track IP resolution in data dependent on PV resolution, needs to be unfolded
  \[
  \sigma^2(d_0) = \sigma^2(d_0^{\text{track}}) + \sigma^2(\text{PV})
  \]
- Good agreement between data and MC for range of track pT
- Resolution worse in forward region due to multiple scattering
References

- **Papers:**
  - “A measurement of the material in the ATLAS inner detector using secondary hadronic interactions”
    arXiv:1110.6191

- **CONF Notes:**
  - “Measuring the b-tag efficiency using top-pair events with 4.7 fb$^{-1}$ at the ATLAS detector”
    ATLAS-CONF-2012-097
  - “Measurement of the b-tag Efficiency in a Sample of Jets Containing Muons with 5 fb$^{-1}$ of Data from the ATLAS Detector”
    ATLAS-CONF-2012-043
  - “Performance of the ATLAS Inner Detector Track and Vertex Reconstruction in the High Pile-Up LHC Environment”
    ATLAS-CONF-2012-042
  - “Measurement of the Mistag Rate of $b$-tagging algorithms with 5 fb$^{-1}$ of Data Collected by the ATLAS Detector”
    ATLAS-CONF-2012-040
  - “b-jet tagging calibration on c-jets containing D* mesons”
    ATLAS-CONF-2012-039
  - “Alignment of the ATLAS Inner Detector Tracking System with 2010 LHC proton-proton collisions at sqrt(s) = 7 TeV”
    ATLAS-CONF-2011-012