Performance of tracking and b-tagging in ATLAS and CMS with first Run-2 data

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Physics Motivation

- Tracking and b-tagging crucial for physics analyses at LHC

- Tracking
  - Vertex detectors for precise measurement of trajectories of charged particles and estimation of track parameters
  - Event reconstruction and particle identification

- B-tagging builds on top of an excellent tracking performance
  - Exploits the b lifetime ($c\tau = 450\mu m$), looking for tracks with impact parameter significance and displaced secondary vertices
  - Needs tracking, vertexing, secondary vertexing

- Many analyses with b-jet final states
  - H physics - $H\rightarrow bb$
  - Top and SM
  - Exotics and SUSY
  - Both selection and veto
  - Important also for the online selection in the trigger systems
ATLAS Inner Detector

- **Pixel + double-sided Si strip + transition radiation tracker**
  - Innermost pixel layer (IBL) added before Run-2
    - Track precision
      - Closer to the beamline (3.3cm), smaller dimensions along z
      - Impact parameters important for b-tagging
    - Reconstruction robustness
      - wrt higher pileup, detector failures, aging

- In an axial magnetic field from a solenoid of 2T
  - $|\eta| < 2.5$

<table>
<thead>
<tr>
<th></th>
<th>channel</th>
<th>dimensions</th>
<th>&lt;hits on track&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>IBL+</td>
<td>12M+80M</td>
<td>50µmx250µm, 50µmx400µm</td>
<td>1+ 3</td>
</tr>
<tr>
<td>Pixel</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCT</td>
<td>3.5M</td>
<td>~80µm</td>
<td>8</td>
</tr>
<tr>
<td>TRT</td>
<td>350k</td>
<td>straws R=2mm</td>
<td>~33</td>
</tr>
</tbody>
</table>
Improvements due to IBL in Run-2

- More precise estimation of impact parameters important for b-tagging
- Detailed analyses of the material distribution in the tracker lead to improved description → improvements in the tracking performance and data/MC comparisons

![Graphs showing improvements in tracking performance and data/MC comparisons](image-url)
IBL and alignment

Calibration, alignment of the detector and determination of the beamspot position important ingredients for optimal tracking/b-tagging

- Irradiation of front-ends in 2015 → an increased current in the course of a run and correspondingly an increased temperature of staves leading to thermal bowing of the IBL staves
- 2015: time-dependent alignment introduced to mitigate the effect
- 2016: automated alignment procedure accounting for in-run changes, automatic corrections each ~2h
- Poster of Giulia Ripellino on the ATLAS ID alignment

IDTR-2015-011

IDTR-2016-002
CMS Tracker

Pixel (100μm x 150μm)
- 3 barrel layers (R = 4.4cm – 10.2cm)
- 2 endcap disks
- 66M channels

Strip tracker (~100μm strip pitch)
- 10 barrel layers (R = 25.5cm-110cm)
- 12 endcap disks
- single sided and double sided layers
- 10M channels

|η| < 2.5
typically ~16 hits on track

3.8T solenoidal field
with 200m² of sensitive area the largest silicon tracker

Upgrade of the pixel detector in 2016-2017 shutdown
- Reduction of material
- Additional layer In barrel and EC
- B-tagging will benefit
Track reconstruction

- **ATLAS**
  - Using seeds (triplets) from different layers of the detector
  - Higher purity seeds used first
  - Combinatorial track finding
  - Track scoring and ambiguity resolving
    - With NN pixel clustering and identification of clusters from multiple tracks
  - TRT extensions

- **CMS**
  - Iterative tracking
    - To reduce CPU time
    - Start from higher pT, beamline compatible seeds
    - Loosen requirements in next iterations and mask hits used in previous stages
Tracking in dense environment / ATLAS

- Tracking in the dense environment such as core of jets with nearby tracks sharing clusters challenging

- AmbiguitySolver reoptimised to deal with clusters originating from multiple tracks
  - Merged clusters identified by NN clustering
  - Track information (incident angle), charge collection pattern used in the NN
  - Optimised scoring for such clusters, an increase of tracking efficiency
  - Poster of P.E. Sidebo on the robustness of NN pixel clustering
Tracking in dense environment /CMS

- JetCore tracking - another stage of the iterative tracking to obtain
  - Increase the number of seeds from pix, 2 TIB layers with high pT and beamline compatibility in the jet core
  - Pixel cluster splitter to deal with merged pixel clusters – jet direction and expected charge/shape of the cluster
B-tagging

characteristics of B hadrons in bjet
- tracks with large positive IP
- Presence of secondary vertices
- 40% of jets with e,\(\mu\)

- Variety of taggers exploiting these features (and their combinations)

- **ATLAS**
  - IP2D, IP3D
  - SV
  - JetFitter
  - MV2cxx

- **CMS**
  - JP
  - CSVv2
  - SoftElectron, SoftMuon
  - cMVAv2
B-tagging performance/ ATLAS

- **Light/c rejection 2015 vs Run1**
  - MV2(BDT) vs MV1(NN) + tracking + IBL

- **Further improvements for 2016**
  - IP taggers
    - Hit pattern requirements for tracks used in the IP tagger adjusted to recover highly boosted decays
  - SV taggers
    - only tracks with higher pT considered in pT>300GeV to reduce fake vtx, tracks from fragmentation
    - Pileup tracks reduced by removing low transverse IP and high longitudinal IP significance
  - MVA
    - MVA training procedure improved between 2015 and 2016
    - Significant improvement (+40%) c-jet rejection at 77% b-jet efficiency MV2c10
      - Poster of A. Calandri on developments for 2016
B-tagging performance / ATLAS

- Data-MC comparison of the MV2C10 output
  - $e-\mu\bar{t}t$ selection of events for b-jet rich sample

- Discriminators on the input of the MV2C10

- First data of 2016 (4pb$^{-1}$)

more in the backup
B-tagging performance /CMS

- **CSVv2**
  - Combined SV algorithm (real vtx/ pseudo vtx/ no vtx cases)
  - an improved performance wrt Run-1
    - Upgraded to multilayer perceptron to use more input variables (nSV, $\alpha$(SV,jet),...)
  - CSVv2 8% better efficiency wrt CSV @1% mistag for light jets

- **cMVAv2**
  - outperforms CSVv2 by 4% in efficiency for the same mistag probability of light partons

- **CSVv2** discriminator for AK4 jets— data 2016/MC comparison in multijet (left) and $t\bar{t}$ $e\mu$ events (right)
B-tagging scale factors (2015)/ CMS

- Data/Simulation scale factors of CVSv2 and cMVAv2 for b-efficiency (left) and misidentification probability cMVAv2M (right)
  - Scale factors from μ+jet compared with t̅t̅ events for CSVv2
    - TagCount andReweight methods
    - Loose, Medium, Tight working points compared
Summary and outlook

- Commissioning of tracking for 2016 proceeding well
  - Improved performance due to IBL
  - Tracking developments for better $b$-tagging
    - Nearby tracks / tracking in dense environment for an improved track reconstruction efficiency/precision in the core of jets
    - Alignment / beamspot / detector calibration – important role for precise track parameter estimation and reconstruction of $b$-decays

- $B$-tagging will benefit from improvements wrt Run-1 and early Run-2 performance
  - Optimisation of $b$-tagging discriminators
  - Multivariate techniques refined for 2016 data
  - Robust methods to calibrate $b$-tagging performance

- Excellent performance of the LHC
  - By now the integrated lumi of 2016 almost reached the total of 2015
  - Look forward to new results from Run-2
Backup slides
B-tagging scale factors / ATLAS

Data2015/MC comparison in $e\mu+2\text{jet}$ events and b-tagging efficiency and SF for MV2c20 @85% working point

FTAG-2016-002
## Tracking efficiency/ ATLAS

<table>
<thead>
<tr>
<th>Track Quality Selection</th>
<th>Loose</th>
<th>Tight Primary</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>η Range</strong></td>
<td>$</td>
<td>\eta</td>
</tr>
<tr>
<td>Track Reconstruction Efficiency</td>
<td>91%</td>
<td>73%</td>
</tr>
<tr>
<td>Sys$_{+5% Extra}$</td>
<td>0.4%</td>
<td>0.9%</td>
</tr>
<tr>
<td>Sys$_{PixServExtra}$</td>
<td>—</td>
<td>2.0%</td>
</tr>
<tr>
<td>Sys$_{+30% IBLExtra}$</td>
<td>0.2%</td>
<td>0.5%</td>
</tr>
<tr>
<td>Total Systematic Uncertainty</td>
<td>0.4%</td>
<td>2.2%</td>
</tr>
</tbody>
</table>

- Tracking efficiencies for $0.4 \text{GeV} < p_T < 20 \text{ GeV}$ and Loose & Tight Primary selection in regions with the smallest/largest systematic uncertainties

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Scale factors CSVv2 / CMS

- Data / simulation scale factors b-tagging efficiency for CSVv2