Measuring b-tagging efficiency at ATLAS using $p_{\mathrm{T}}^{\mathrm{rel}}$

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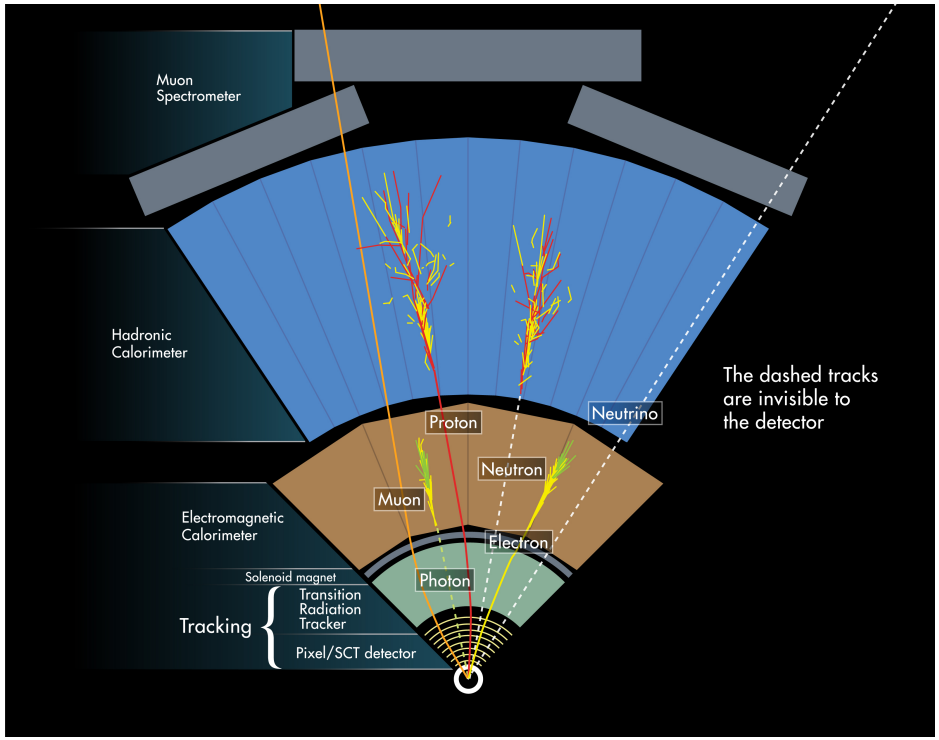
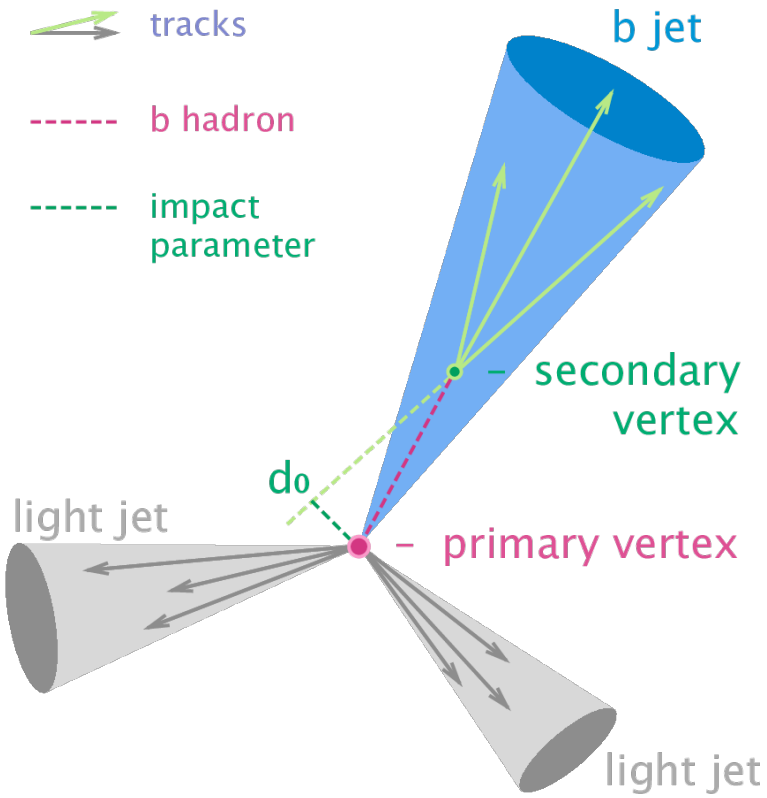
Flavor Tagging in ATLAS

- Directly tag heavy-flavor (b or c) objects
- Use tracks, secondary vertex, or associated leptons to tag jets as heavy- or light-flavor
- Important for top quark precision measurements, Higgs searches, and many BSM searches



b-hadron Properties for Tagging

- Most of the jet energy ($\sim$80%) goes into b-hadron
- Mass of $\sim$5 GeV
- Significant lifetime (1.5×10^{-12} s) compared to other particles (e.g. η: 5.0×10^{-19} s)
- High decay multiplicity (on avg: 5 charged particles)



MV2c10

- This calibration focuses on MV2c10, a gradient-boosted decision tree tagging algorithm (arxiv 152.01094 paper)
- Trained on $t\bar{t}$ events with b-jets for signal, mix of c- and light-jets for background
- Define four "working points", BDT cut values corresponding to 60%, 70%, 77%, and 85% b-tagging efficiency
  - Tighter selection $\rightarrow$ better bkg rejection $\rightarrow$ lower b-tagging efficiency/higher b-jet purity

Flavor-Tagging Calibration

- Need to calibrate MC-predicted tagging efficiency $\varepsilon_b^{\mathrm{MC}}$ to data $\varepsilon_b^{\mathrm{data}}$
- Plan: extract efficiency using N_b^{tag} and N_b^{untag}
- Results presented as data-to-MC scale factors κ_b

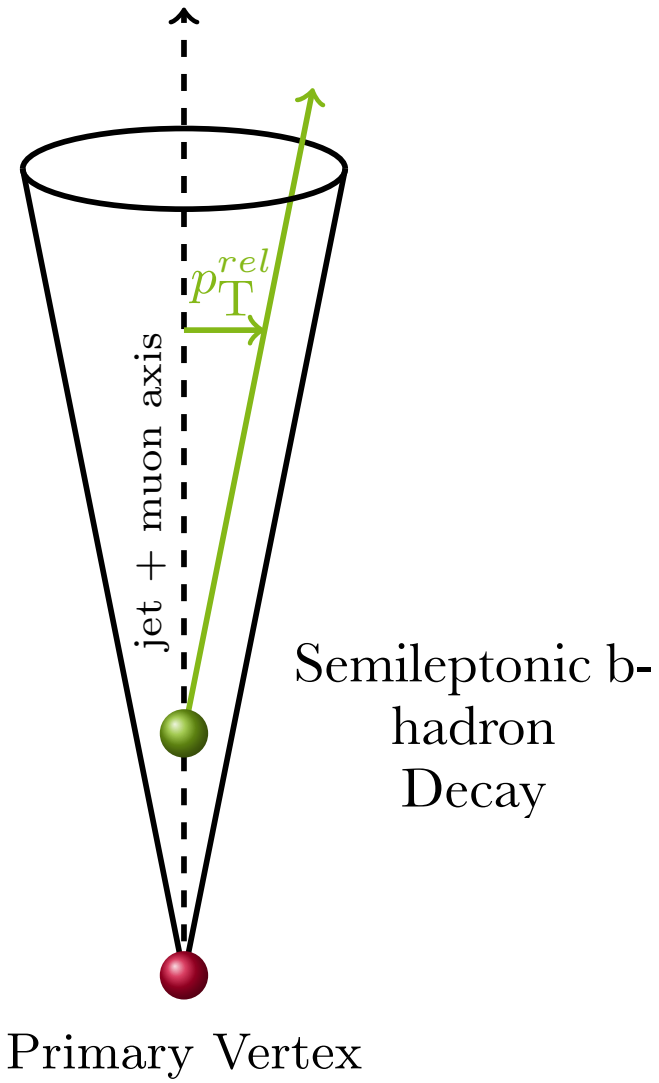
$$\varepsilon_b = \frac{N_b^{\mathrm{tagged}}}{N_b^{\mathrm{tagged}} + N_b^{\mathrm{untagged}}}$$

$$\kappa_b = \frac{\varepsilon_b^{\mathrm{data}}}{\varepsilon_b^{\mathrm{MC}}}$$

Introduction to $p_{\mathrm{T}}^{\mathrm{rel}}$

- In semi-leptonic decays of hadrons, measure $p_{\mathrm{T}}^{\mathrm{rel}}$ of muons relative to jet+muons axis
- $p_{\mathrm{T}}^{\mathrm{rel}}$ distribution is harder for heavy flavor decays than light flavor

$$p_{\mathrm{T}}^{\mathrm{rel}} = \sqrt{\vec{p}_{\mu}^{\,2} - \left(\frac{\vec{p}_{\mathrm{jet}} \cdot \vec{p}_{\mu}}{|\vec{p}_{\mathrm{jet}}|}\right)^2}$$



Other Calibrations

- Compared to $t\bar{t}$-based calibrations (likelihood-based, tag-and-probe, etc), $p_{\mathrm{T}}^{\mathrm{rel}}$ has larger cross section (but statistically limited in MC)
- $p_{\mathrm{T}}^{\mathrm{rel}}$ has different systematic uncertainties than $t\bar{t}$
- Currently working to implement $p_{\mathrm{T}}^{\mathrm{rel}}$ as a day-to-day b-tagging monitoring tool
  - TADA: fast physics monitoring framework (CDS)

Event/Object Selection

- First, select data using muon-in-jet triggers
- Apply kinematic cuts to muons and jets to cut down on pileup, fakes
- Require $\Delta R < 0.3$ match between muon and jet
- Require dijet/pair-production topology to enhance b-purity
  - Tag one jet as a b; because of pair production, remaining jets more likely to contain b
  - Jets failing pair-production selection are used to produce data-driven light template

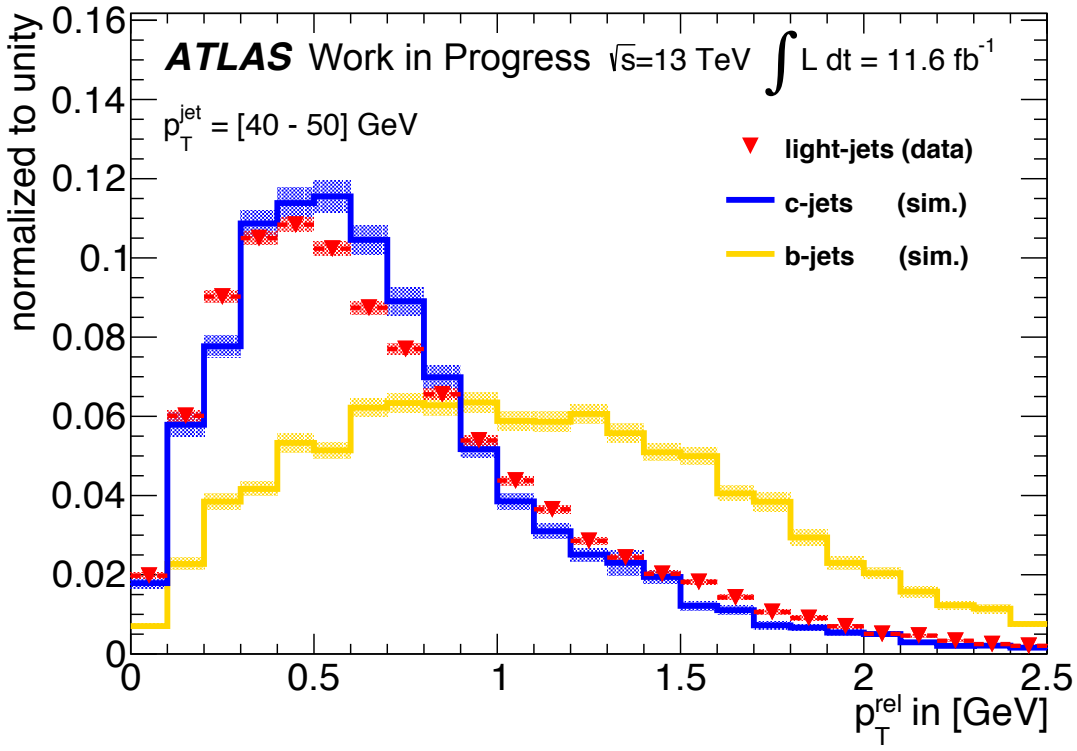
Calibration Strategy

- For each operating point:
  - Make $p_{\mathrm{T}}^{\mathrm{rel}}$ distributions for b, c (from MC with truth-level muon filter), light (from data)
  - Determine light-to-charm ratio using dijet MC (no muon filtering)
- Perform template fit to data for tagged and untagged $p_{\mathrm{T}}^{\mathrm{rel}}$ distributions
- Extract efficiency using N_b^{tag} and N_b^{untag} and calculate scale factors (κ_b):

$$\varepsilon_b = \frac{N_b^{\mathrm{tagged}}}{N_b^{\mathrm{tagged}} + N_b^{\mathrm{untagged}}}$$

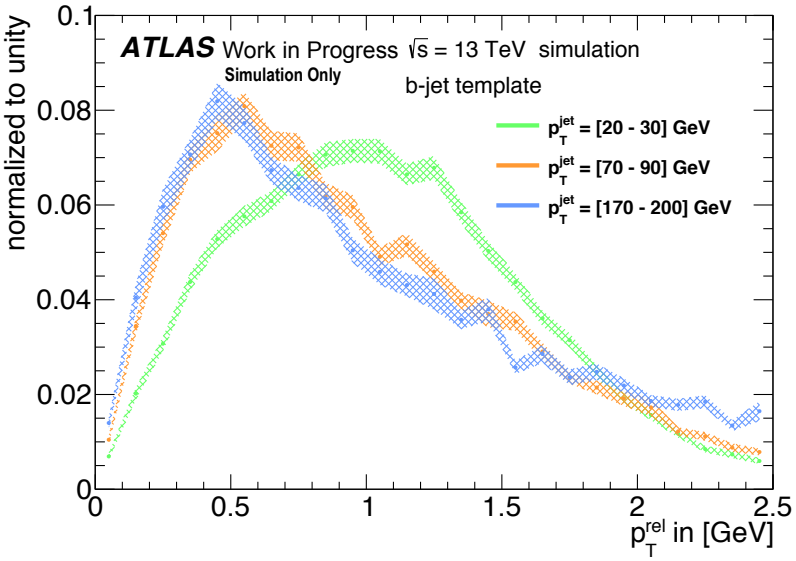
$$\kappa_b = \frac{\varepsilon_b^{\mathrm{data}}}{\varepsilon_b^{\mathrm{MC}}}$$

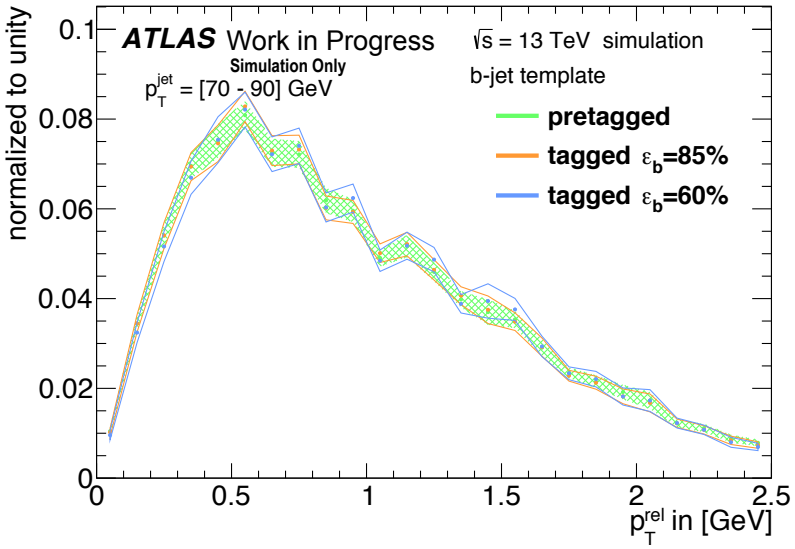
Template Shape Comparison



- Muon p_T^{rel} spectra for b-, c- and light-jet templates in yellow, blue and red, respectively
- Heavy flavor templates generated from muon-filtered MC
- Light template from data

Template Shape Dependence





- On left, *b*-jet template is shown for three different p_T^{jet}-bins in green, blue, and orange.
- On right, *b*-jet template is shown for untagged, loose (85%), and tight (60%) working points
- Can clearly see that p_T^{rel}-template shape depends on p_T^{jet} bin but not tagger decision

Systematic Uncertainties

- Include uncertainties from four major sources:
  - Detector and Calibration
  - Physics Modeling
  - MC Statistics
  - Template Selection
- Major sources to note:
  - Flat 4% semileptonic-to-inclusive extrapolation uncertainty (from Run 1, CONF Note)
  - Simulation statistical uncertainty larger at low $p_{\mathrm{T}}^{\mathrm{jet}}$
  - Light-to-charm ratio calculated using unfiltered MC (decay-in-flight and other light decays not produced as truth level) $\rightarrow$ major loss of statistics (especially at high $p_{\mathrm{T}}^{\mathrm{jet}}$)

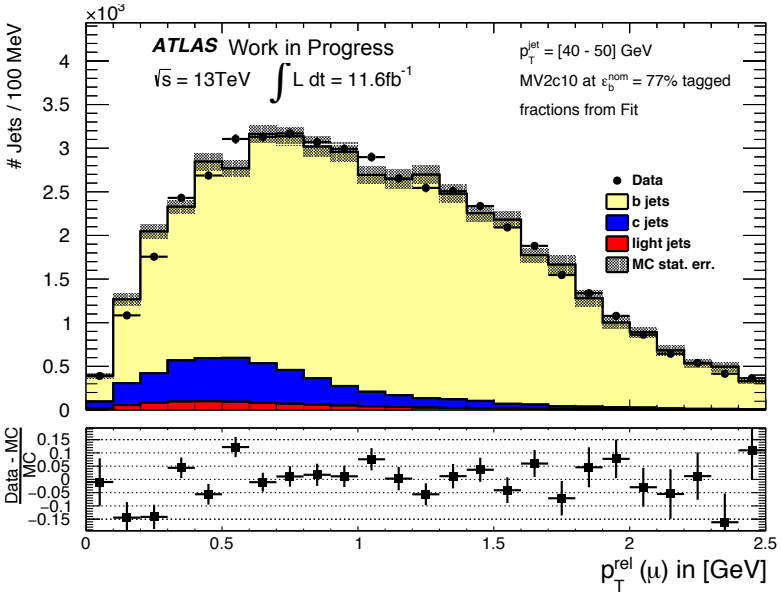
Systematics Example

Uncertainty Source	Systematic Uncertainty in $p_T^{jet}[GeV]$ Bins [%]								
	[20, 30]	[30, 40]	[40, 50]	[50, 70]	[70, 90]	[90, 110]	[110, 140]	[140, 170]	[170, 200]
Detector and Calibration	0.8	0.7	1.1	1.1	1.4	1.4	0.2	0.1	0.1
Physics Modeling	4.0	4.0	4.1	4.1	4.4	4.6	4.0	4.0	4.0
MC Statistical	8.0	8.3	3.0	2.5	4.1	2.6	1.4	1.5	1.3
Template Selection	1.7	3.5	1.1	1.0	5.7	2.5	9.2	11.0	12.2
Total Systematic Uncertainty	9.2	9.9	5.3	5.0	8.4	6.0	10.2	11.8	12.9
Data Statistical Uncertainty	0.5	0.5	0.6	0.8	0.7	1.4	0.3	0.4	0.4

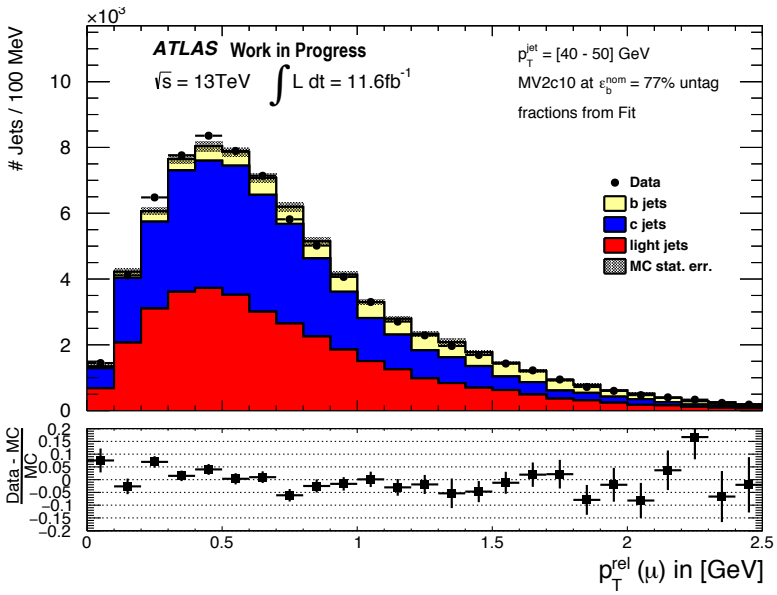
Systematic uncertainties for the MV2c10 tagging algorithm at 77% nominal b-tagging efficiency

- Red = semileptonic extrapolation
- Blue = simulation statistics
- Green = light-to-charm ratio statistics

p_T^{rel} Fit Examples



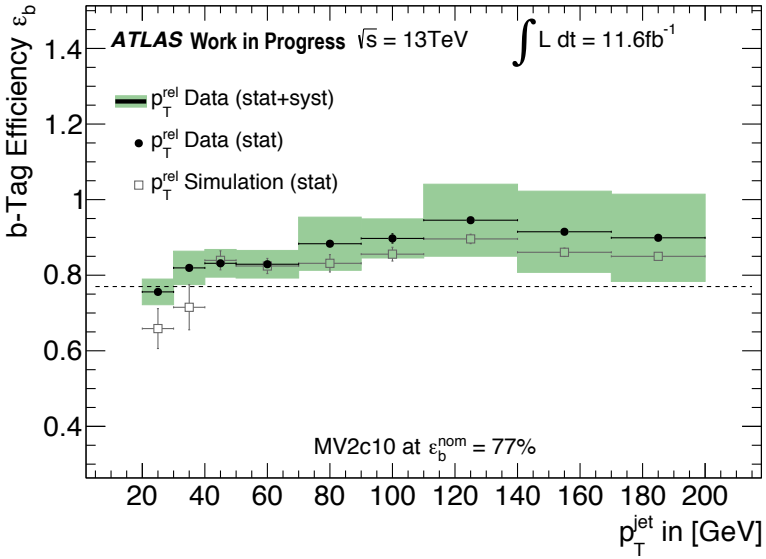
Tagged fit result

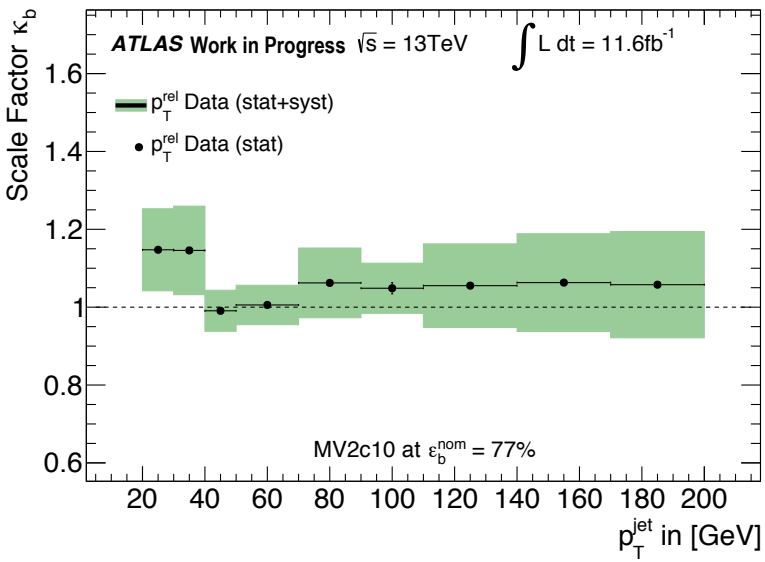


Untagged fit result

- Left distribution is tagged by MV2c10 at $\varepsilon_b^{nom} = 77\%$
- Right distribution is untagged
- Data shown in black dots, template in colored stack

Scale Factor Results, MV2c10 at 77%





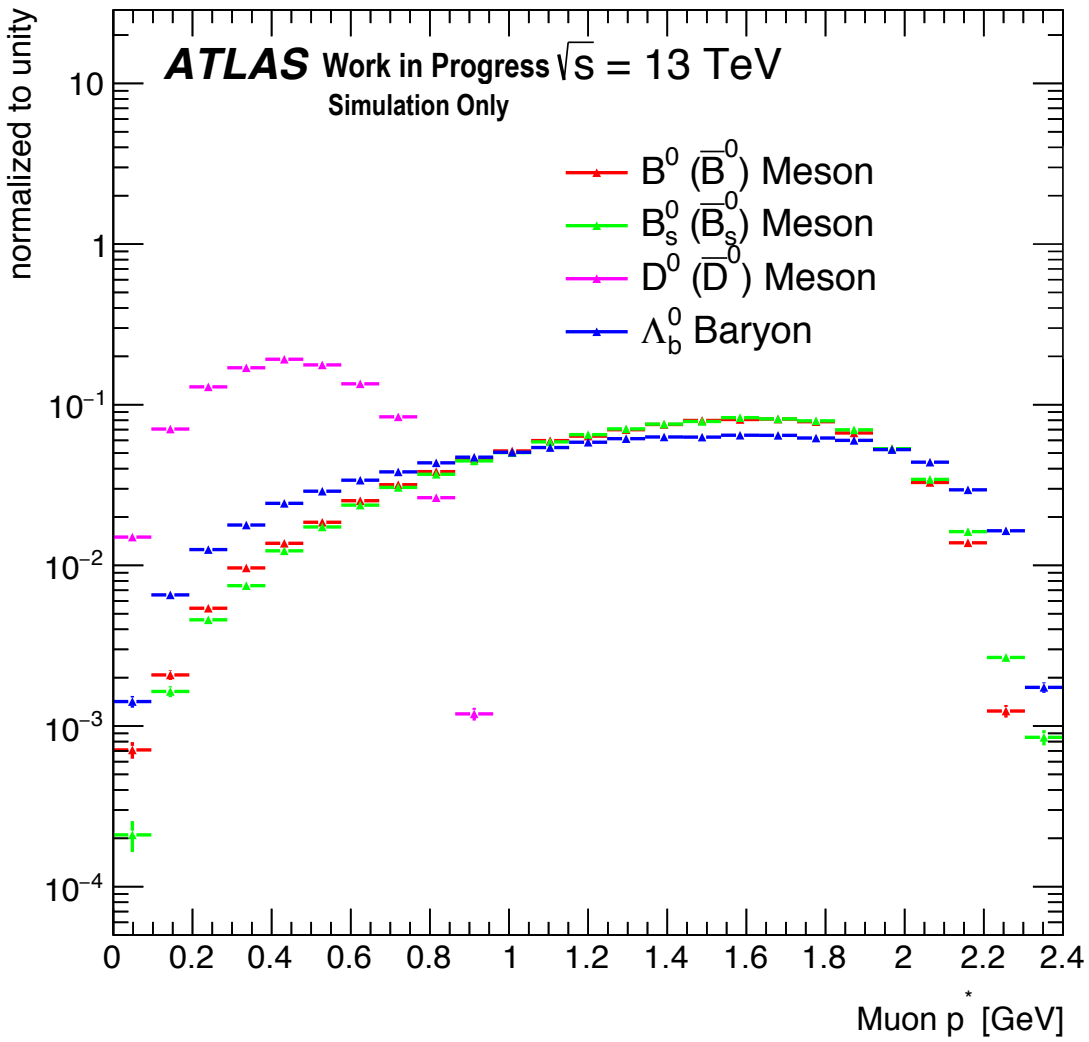
- p_T^{jet} dependent efficiencies (left) and scale factors (right) for MV2c10 at $\varepsilon_b^{nom} = 77\%$
- MC predictions shown in gray, data in black dots
- Uncertainty shown in green error bands

Conclusions

- Measured b-tagging efficiency of MV2c10 for four working points
- Results are presented in $p_{\mathrm{T}}^{\mathrm{jet}}$dependent scale factors
- Generally consistent with unity, larger scale factors in low/high p_{T} region
- Current working on internal/pub note approval

Backup Slides

p^* Distribution Comparison



Event Selection and Cuts

- Event Selection:
  - ≥ 2 Jets
  - ≥ 1 Muon
- Jet Cuts:
  - $p_T > 20$ GeV
  - $|\eta| \leq 2.5$
  - JVT Cut
- Muon Cuts:
  - $p_T > 4$ GeV
  - $|\eta| \leq 2.5$
  - $d_0 < 2$ mm
  - $|z_0 \cdot \sin(\theta)| < 4$ mm
  - Tight Quality Muons
- Muon-to-Jet Matching
  - Dynamic muon $p_T$cut:

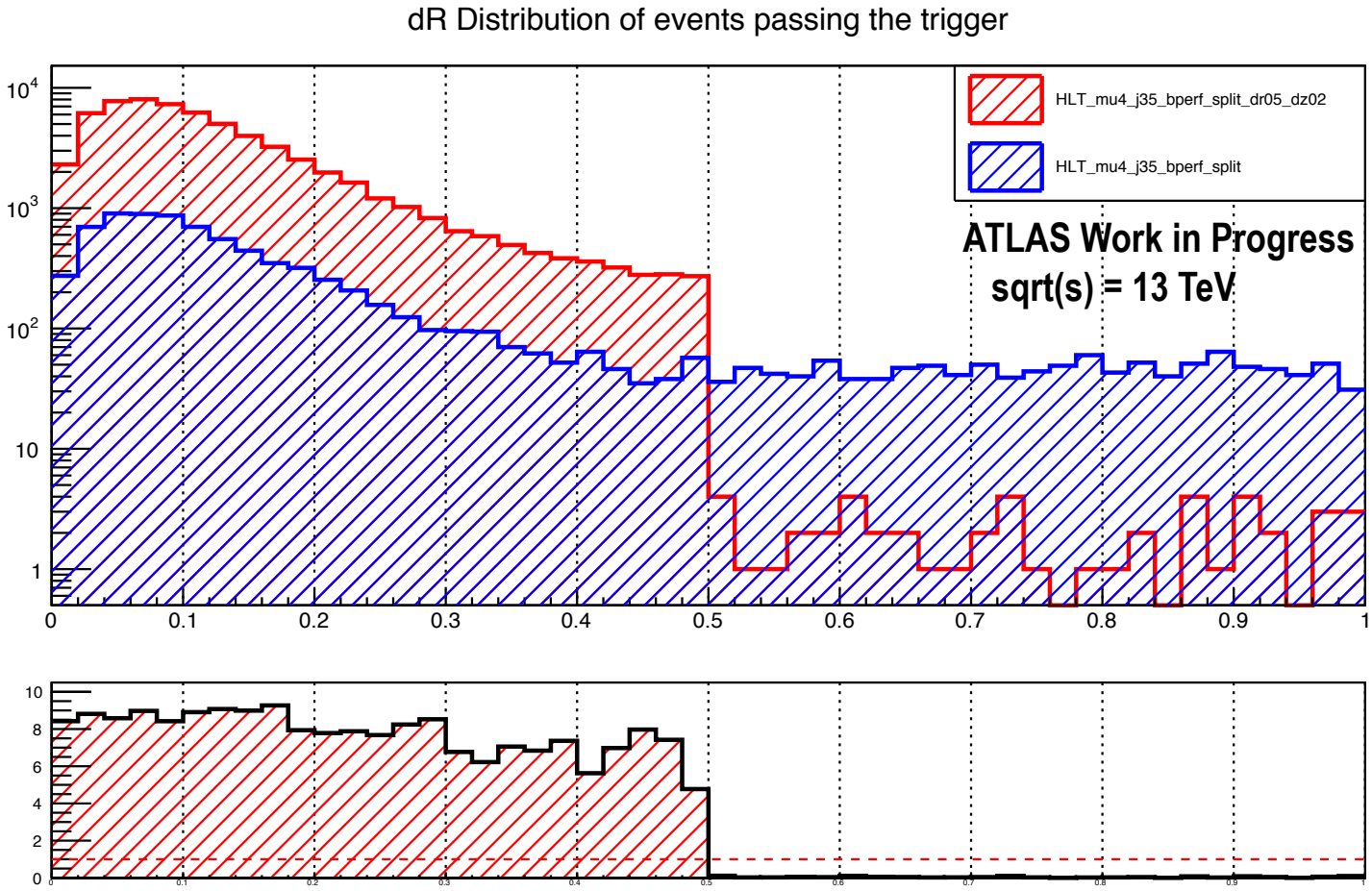
Jet pT	Muon pT
< 40 GeV	5 GeV
$40 - 90$ GeV	6 GeV
> 90 GeV	8 GeV

  - Tighter ΔR Cut: $\Delta R < 0.3$
- Backtag
  - Events must have at least one b-jet
  - Use SV1+IP3D to select backtag jet
  - Do not use BT jet in distributions to avoid bias

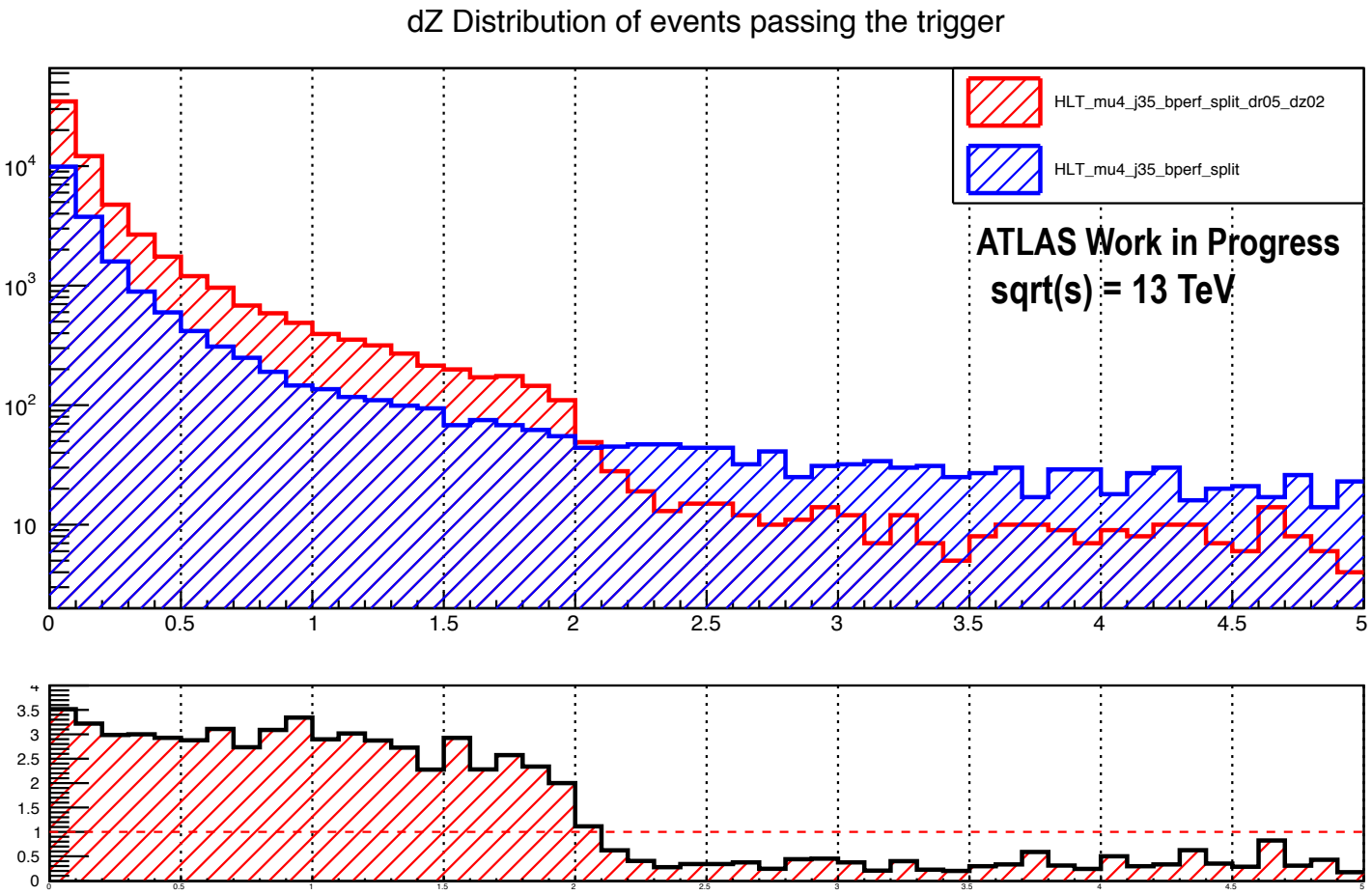
Trigger Studies

- Want to create templates in bins of $p_{\mathrm{T}}^{\mathrm{jet}}$
- Determine at which jet p_{T} each trigger is fully efficient to set binning
- Studied turn-on behavior using bootstrap method

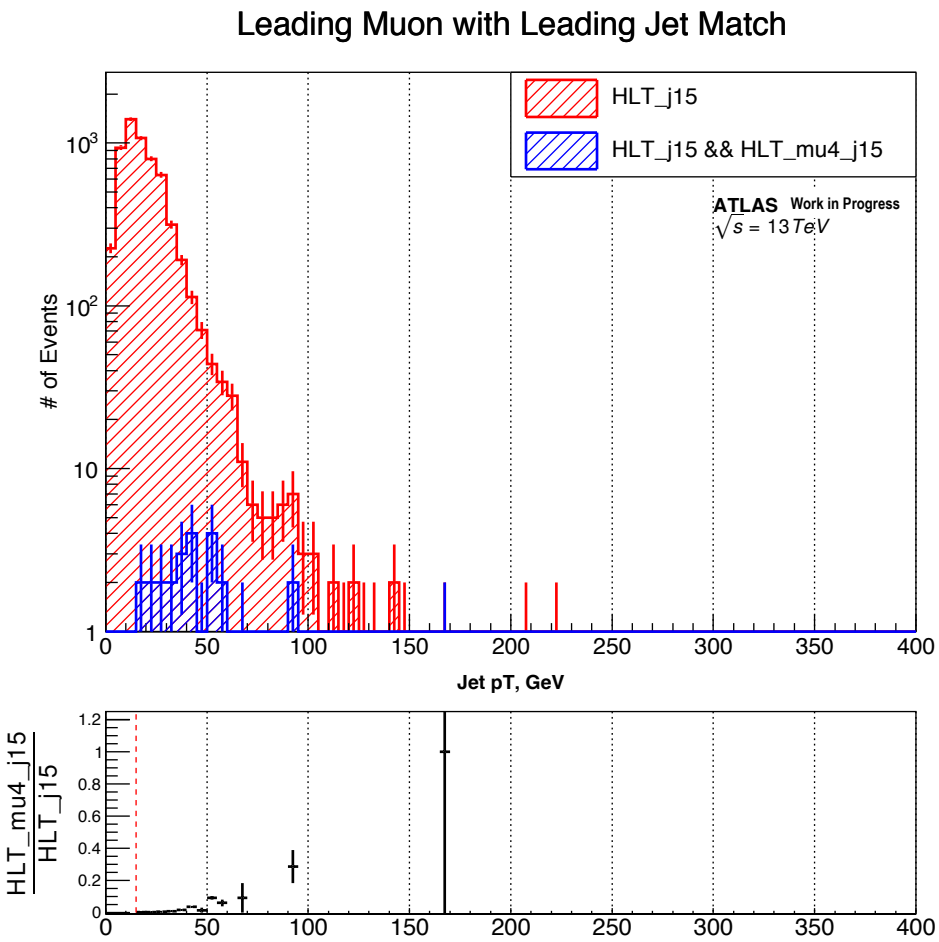
dR Trigger Turn-on Curve



dZ Trigger Turn-on Curve

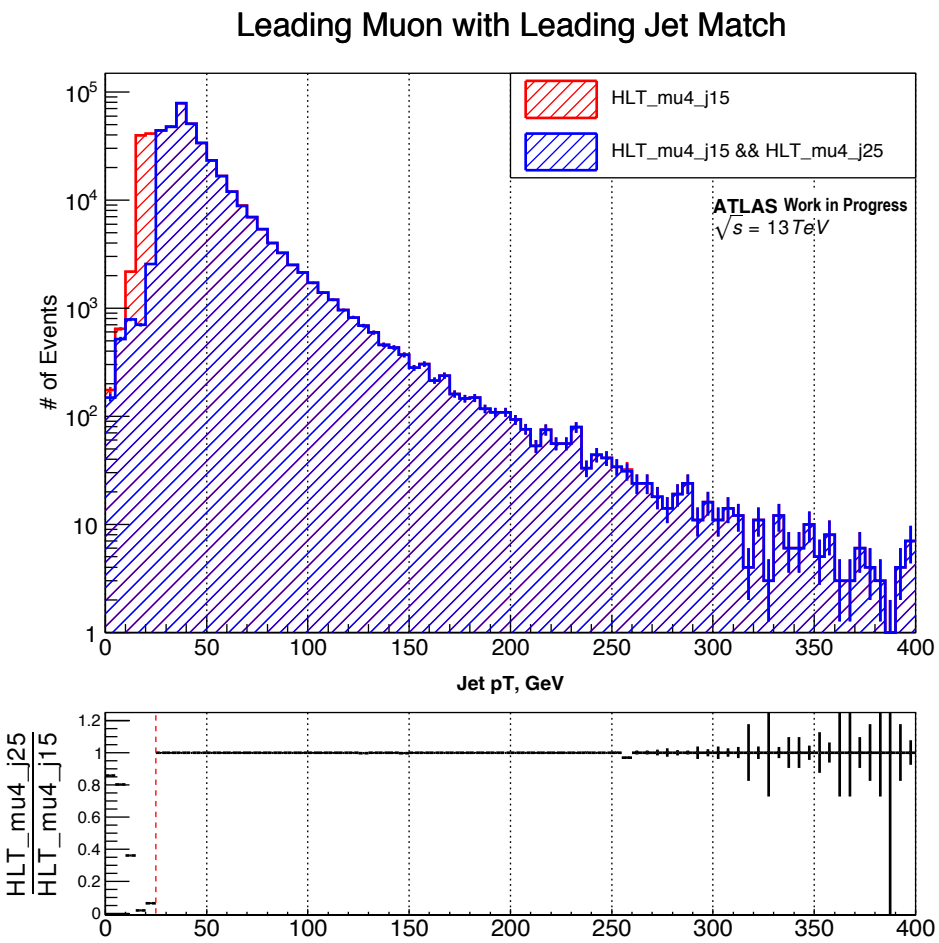


mu4_j15 jet p_T Turn-on Curve

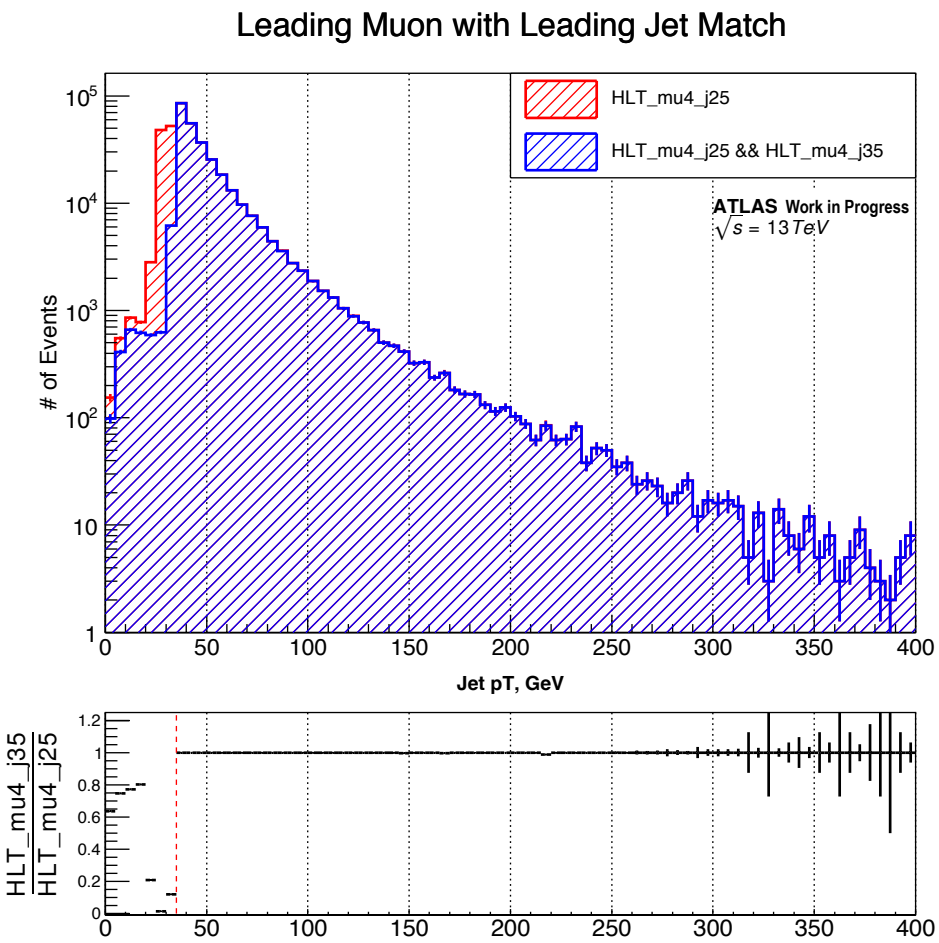


- Not enough data, but other triggers look fine, so we expect good performance
- This is lowest p_T muon-in-jet trigger, so need to use it at low p_T regardless

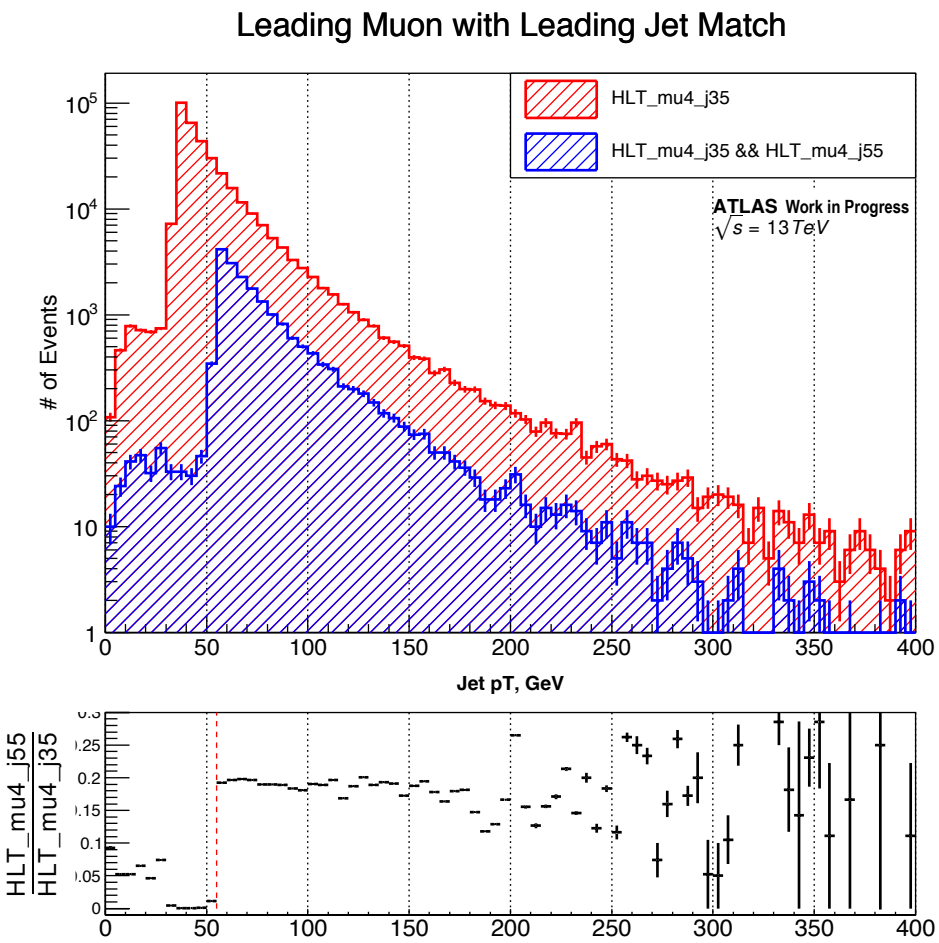
mu4_j25 jet p_T Turn-on Curve



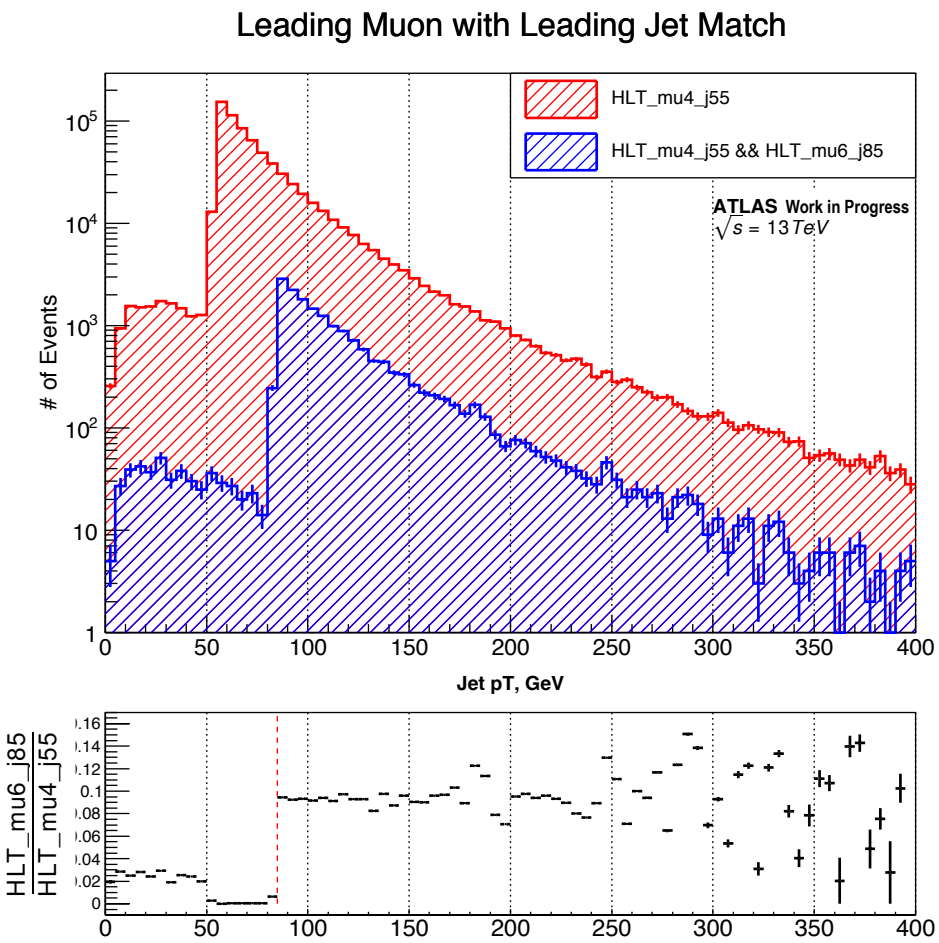
mu4_j35 jet p_T Turn-on Curve



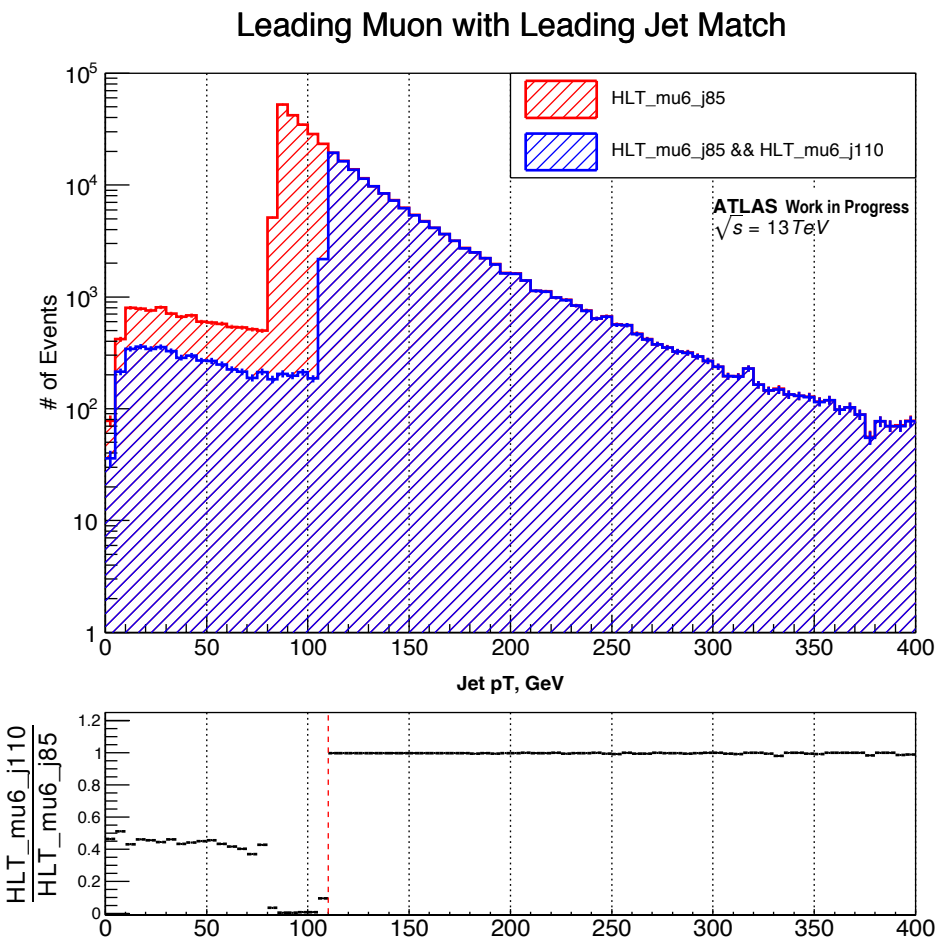
mu4_j55 jet p_T Turn-on Curve



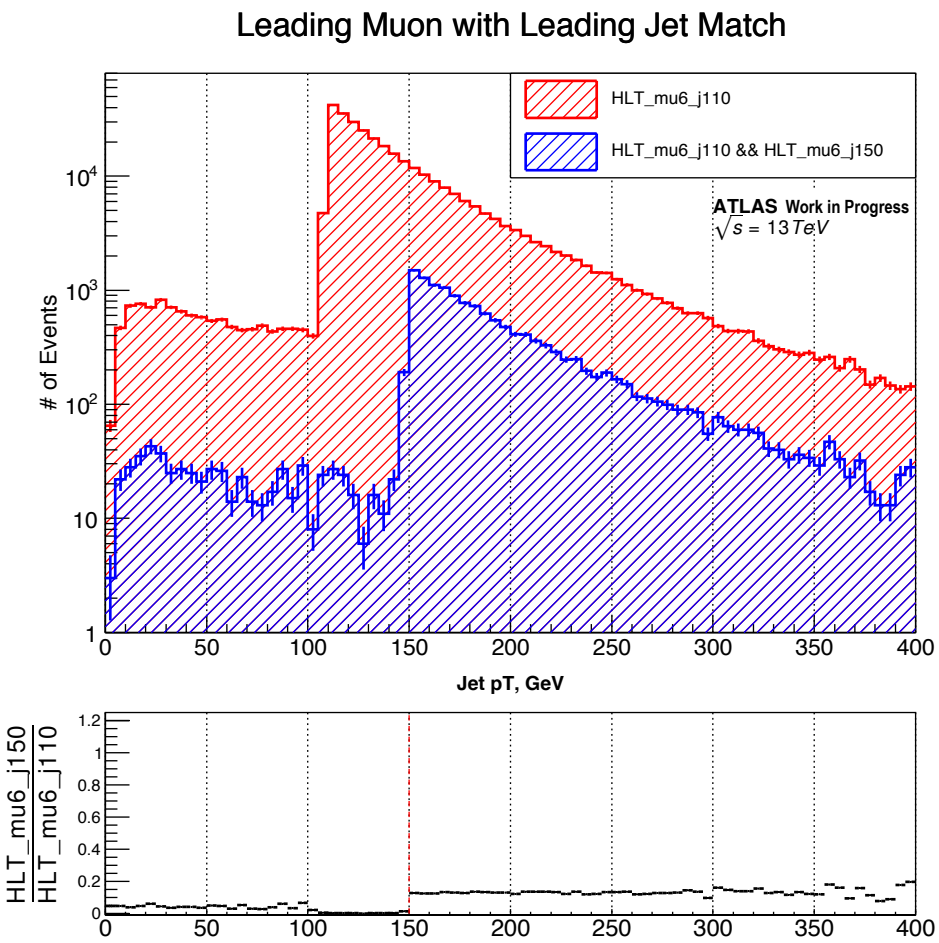
mu6_j85 jet p_T Turn-on Curve



mu6_j110 jet p_T Turn-on Curve



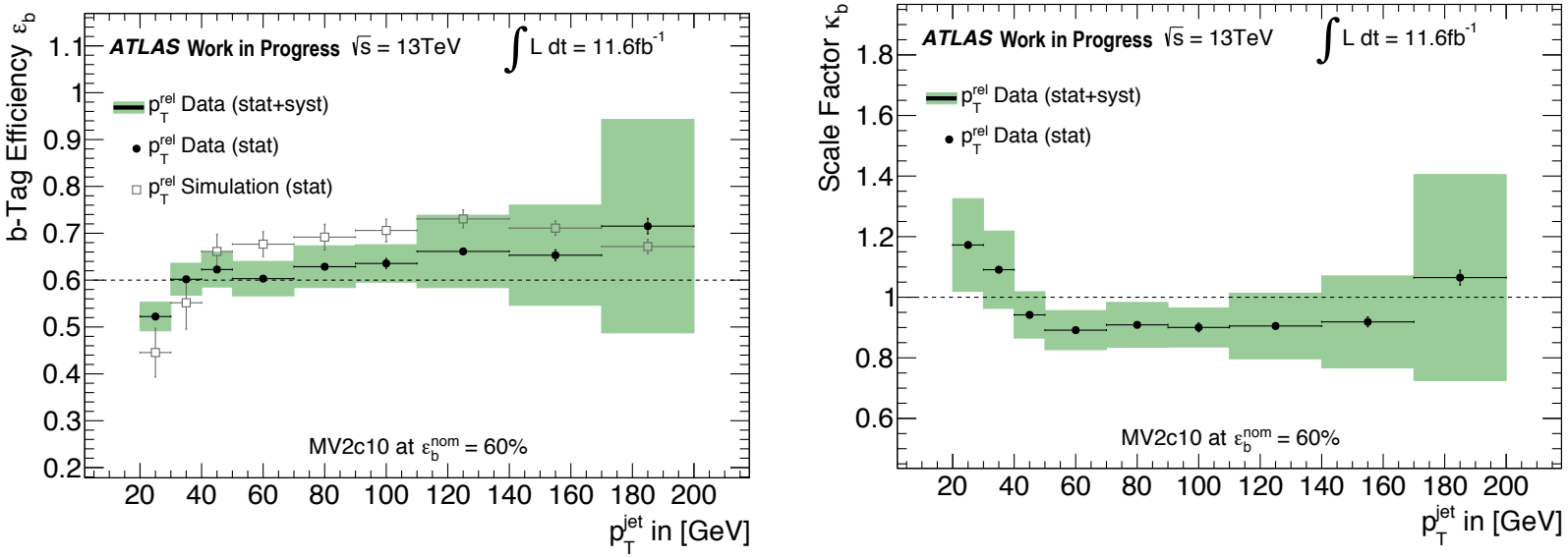
mu6_j150 jet p_T Turn-on Curve



Jet p_T Binning

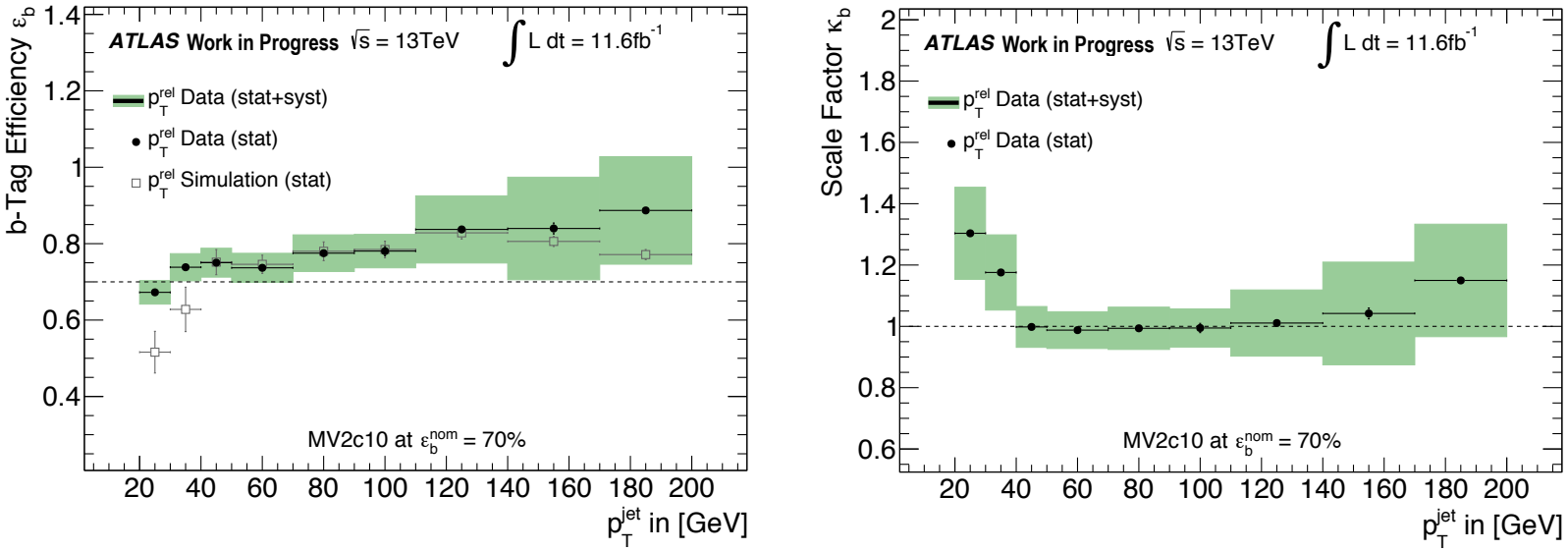
Jet p_T Bin	Jet p_T Threshold	Muon p_T Threshold	Effective Luminosity
[20 GeV, 30 GeV], [30 GeV, 40 GeV]	15 GeV	4 GeV	3.47 pb^{-1}
[40 GeV, 50 GeV]	25 GeV	4 GeV	3.85 pb^{-1}
[50 GeV, 70 GeV]	35 GeV	4 GeV	4.62 pb^{-1}
[70 GeV, 90 GeV], [90 GeV, 110 GeV]	55 GeV	4 GeV	32.52 pb^{-1}
[110 GeV, 140 GeV]	85 GeV	6 GeV	236.41 pb^{-1}
[140 GeV, 170 GeV]	110 GeV	6 GeV	361.19 pb^{-1}
[170 GeV, 200 GeV]	150 GeV	6 GeV	944.25 pb^{-1}

Scale Factor Results, MV2c10 at 60%



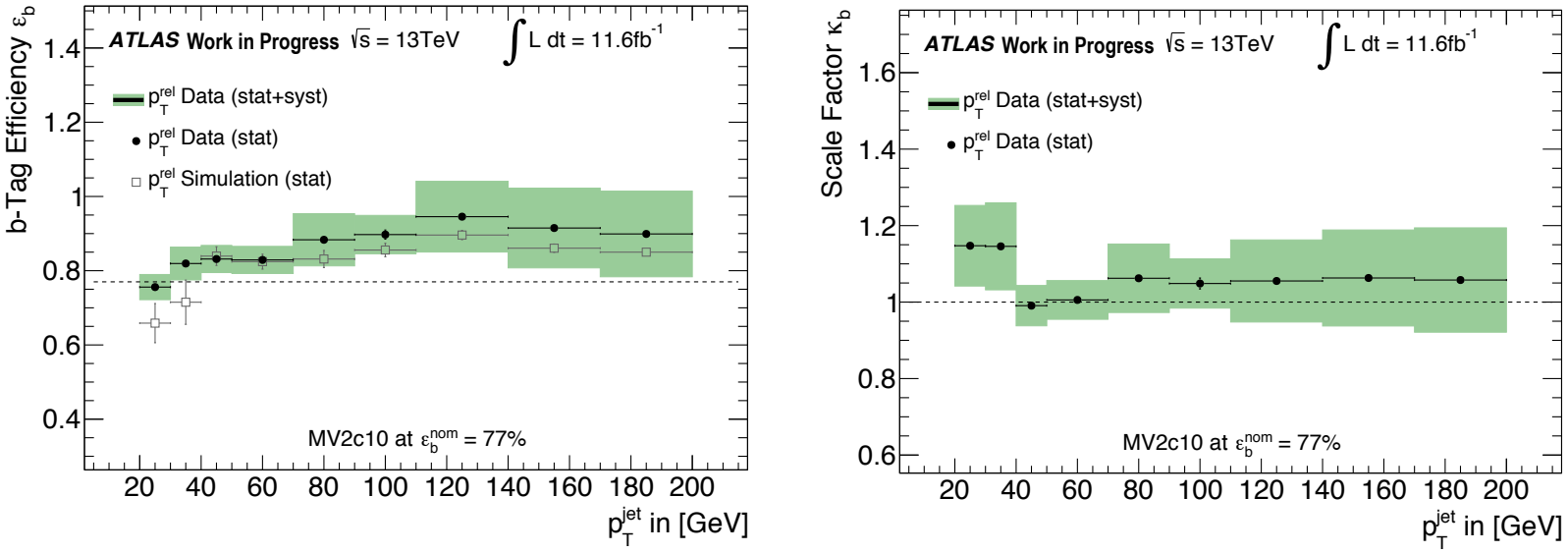
Jet p_T dependent efficiencies (left) and scale factors (right) measured by the p_T^{rel} method for the MV2c10 algorithm for the nominal efficiency of $\varepsilon_b^{nom} = 60\%$. MC predictions are shown in gray while the data is depicted in black dots. The statistic and systematic uncertainties are shown in the green error bands.

Scale Factor Results, MV2c10 at 70%



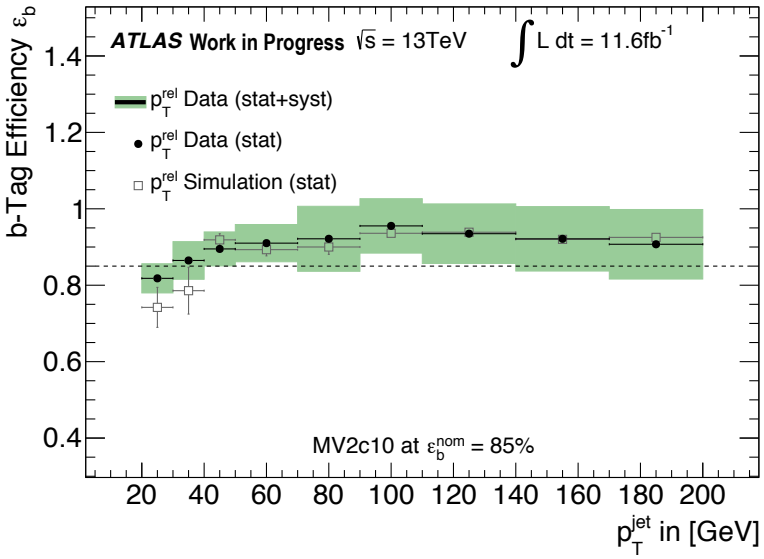
Jet p_T dependent efficiencies (left) and scale factors (right) measured by the p_T^{rel} method for the MV2c10 algorithm for the nominal efficiency of $\varepsilon_b^{nom} = 70\%$. MC predictions are shown in gray while the data is depicted in black dots. The statistic and systematic uncertainties are shown in the green error bands.

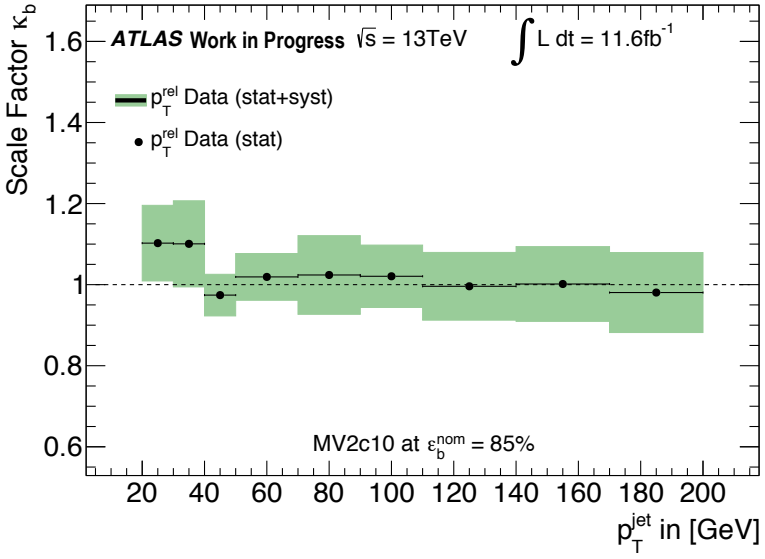
Scale Factor Results, MV2c10 at 77%



Jet p_T dependent efficiencies (left) and scale factors (right) measured by the p_T^{rel} method for the MV2c10 algorithm for the nominal efficiency of $\varepsilon_b^{nom} = 77\%$. MC predictions are shown in gray while the data is depicted in black dots. The statistic and systematic uncertainties are shown in the green error bands.

Scale Factor Results, MV2c10 at 85%





Jet p_T dependent efficiencies (left) and scale factors (right) measured by the p_T^{rel} method for the MV2c10 algorithm for the nominal efficiency of $\varepsilon_b^{nom} = 85\%$. MC predictions are shown in gray while the data is depicted in black dots. The statistic and systematic uncertainties are shown in the green error bands.

Systematic Uncertainty Summary, MV2c10 at 60%

Systematic Uncertainty Source	Systematic Uncertainty in $p_T^{jet}[GeV]$ Bins [%]								
	[20, 30]	[30, 40]	[40, 50]	[50, 70]	[70, 90]	[90, 110]	[110, 140]	[140, 170]	[170, 200]
Detector and Calibration Uncertainties	1.2	1.6	2.3	2.0	1.8	1.5	2.7	2.6	4.3
Modeling Uncertainties	5.4	5.2	5.1	5.3	6.0	5.9	9.3	10.5	14.9
MC Statistical Uncertainties	11.7	10.3	5.6	4.2	4.0	3.5	3.3	2.5	4.1
Template Selection Uncertainties	1.3	1.4	1.7	1.3	3.2	0.3	6.1	12.1	27.5
Total Systematic Uncertainty	13.0	11.7	8.1	7.2	8.1	7.0	11.9	16.4	31.8
Data Statistical Uncertainty	0.7	0.6	0.2	0.9	0.8	1.7	1.1	1.8	2.3

Systematic uncertainties for the MV2c10 tagging algorithm at 60% nominal *b*-tagging efficiency

Systematic Uncertainty Summary, MV2c10 at 70%

Systematic Uncertainty Source	Systematic Uncertainty in $p_T^{jet}[GeV]$ Bins [%]								
	[20, 30]	[30, 40]	[40, 50]	[50, 70]	[70, 90]	[90, 110]	[110, 140]	[140, 170]	[170, 200]
Detector and Calibration Uncertainties	1.1	0.9	1.4	1.6	1.6	1.6	3.0	2.7	0.2
Modeling Uncertainties	4.3	4.2	4.3	4.6	5.0	5.1	7.9	8.3	4.0
MC Statistical Uncertainties	10.6	9.3	4.6	3.3	3.2	2.9	2.0	4.6	1.7
Template Selection Uncertainties	0.6	2.1	1.7	1.2	3.1	0.6	6.2	12.6	15.3
Total Systematic Uncertainty	11.5	10.4	6.6	6.0	6.9	6.1	10.6	16.0	16.0
Data Statistical Uncertainty	0.6	0.5	0.7	0.8	0.8	1.5	1.1	1.7	0.5

Systematic uncertainties for the MV2c10 tagging algorithm at 70% nominal *b*-tagging efficiency

Systematic Uncertainty Summary, MV2c10 at 77%

Systematic Uncertainty Source	Systematic Uncertainty in $p_T^{jet}[GeV]$ Bins [%]								
	[20, 30]	[30, 40]	[40, 50]	[50, 70]	[70, 90]	[90, 110]	[110, 140]	[140, 170]	[170, 200]
Detector and Calibration Uncertainties	0.8	0.7	1.1	1.1	1.4	1.4	0.2	0.1	0.1
Modeling Uncertainties	4.0	4.0	4.1	4.1	4.4	4.6	4.0	4.0	4.0
MC Statistical Uncertainties	8.0	8.3	3.0	2.5	4.1	2.6	1.4	1.5	1.3
Template Selection Uncertainties	1.7	3.5	1.1	1.0	5.7	2.5	9.2	11.0	12.2
Total Systematic Uncertainty	9.2	9.9	5.3	5.0	8.4	6.0	10.2	11.8	12.9
Data Statistical Uncertainty	0.5	0.5	0.6	0.8	0.7	1.4	0.3	0.4	0.4

Systematic uncertainties for the MV2c10 tagging algorithm at 77% nominal *b*-tagging efficiency

Systematic Uncertainty Summary, MV2c10 at 85%

Systematic Uncertainty Source	Systematic Uncertainty in $p_T^{jet}[GeV]$ Bins [%]								
	[20, 30]	[30, 40]	[40, 50]	[50, 70]	[70, 90]	[90, 110]	[110, 140]	[140, 170]	[170, 200]
Detector and Calibration Uncertainties	0.2	0.2	0.7	0.5	0.2	0.1	0.1	0.0	0.1
Modeling Uncertainties	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
MC Statistical Uncertainties	7.1	7.8	1.9	2.1	2.2	1.2	0.9	1.0	0.8
Template Selection Uncertainties	2.4	4.0	2.7	3.3	8.3	6.3	7.3	8.2	9.2
Total Systematic Uncertainty	8.5	9.6	5.2	5.6	9.5	7.5	8.4	9.2	10.1
Data Statistical Uncertainty	0.3	0.3	0.6	0.7	0.2	0.4	0.2	0.3	0.3

Systematic uncertainties for the MV2c10 tagging algorithm at 85% nominal b-tagging efficiency

Full Uncertainties, MV2c10 at 60%

Systematic Uncertainty Source	Systematic Uncertainty in $p_T^{jet}[GeV]$ Bins [%]								
	[20, 30]	[30, 40]	[40, 50]	[50, 70]	[70, 90]	[90, 110]	[110, 140]	[140, 170]	[170, 200]
Detector and Calibration Uncertainties									
Pileup Offset Mu	< 0.1	0.3	0.4	0.4	-0.1	-0.1	0.1	< 0.1	1.1
Pileup Offset NPV	< 0.1	0.3	< 0.1	0.3	-0.2	-0.1	0.1	0.1	0.9
Pileup Pt Term	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.3	-0.1	-0.8
Pileup Rho Topology	0.2	0.3	0.7	0.3	-0.3	0.1	-0.1	0.7	1.6
B JES Response	< 0.1	0.2	0.4	0.5	0.3	< 0.1	0.2	-0.1	0.4
Flavour Composition	0.8	0.6	0.9	0.6	-1.4	-1.0	0.8	-0.7	1.7
Flavour Response	-0.2	-0.1	-0.4	-0.1	0.6	0.4	-0.1	-0.3	-0.4
Eta Intercalibration Modeling	0.3	0.5	0.7	0.4	-0.3	-0.7	0.7	-0.7	-0.1
Eta Intercalibration Total Stat	< 0.1	0.2	0.3	0.2	-0.1	< 0.1	< 0.1	0.1	0.9
Effective NP 1	0.7	1.2	1.5	1.0	-0.2	-0.3	0.8	-0.3	1.5
Effective NP 2	-0.1	< 0.1	< 0.1	0.1	0.1	< 0.1	0.7	-1.0	-0.3
Effective NP 3	< 0.1	< 0.1	-0.2	< 0.1	0.1	0.1	-0.4	0.1	-0.4
Effective NP 4	< 0.1	< 0.1	0.1	< 0.1	-0.1	0.3	< 0.1	0.3	-0.1
Effective NP 5	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.1	< 0.1	0.1	0.3
Effective NP Rest Term	< 0.1	< 0.1	0.2	0.1	-0.1	0.2	-0.1	0.2	0.3
JER Single NP	-0.2	0.5	0.7	1.4	0.5	-0.6	-2.0	1.9	-2.6
Muon ID	< 0.1	< 0.1	< 0.1	-0.1	0.2	0.1	-0.4	-0.1	< 0.1
Muon MS	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.1	0.3	-0.1	0.2
Muon Scale	-0.1	-0.1	< 0.1	< 0.1	-0.1	-0.1	-0.5	< 0.1	-0.4
Modeling Uncertainties									
Axis Smearing	0.4	0.7	0.8	0.7	2.4	2.3	7.3	8.0	12.5
BDecayFractions	0.5	0.6	0.7	0.9	1.2	1.1	1.2	1.2	1.3
B-Decay p* Spectrum	-3.5	-3.1	-2.8	-3.0	-2.5	-1.4	-0.8	-0.8	-1.1
Fake Muons	-0.5	-0.2	-0.1	0.6	-0.4	2.2	0.7	-0.7	-1.9
Gluon Splitting B	< 0.1	0.1	0.5	1.1	2.3	2.0	3.3	4.8	5.9
Gluon Splitting C	< 0.1	0.1	0.1	0.3	1.0	0.8	1.8	1.7	2.4
B Fragmentation Fractions	-0.3	-0.5	-0.7	-0.4	-0.3	-0.3	-0.5	-0.3	-0.2
B Fragmentation Function	0.4	-0.1	-0.4	-0.2	-0.3	-0.5	-0.7	-1.2	-1.8
SF to Inclusive	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
MC Statistical Uncertainties									
Template Statistics	1.2	0.8	-1.3	-1.6	-0.2	0.1	-2.0	1.3	-3.5
Simulation Statistics	11.7	10.2	5.5	3.9	4.0	3.4	2.6	2.2	2.3
Template Selection Uncertainties									
LC-Ratio	1.1	-1.4	1.5	0.9	-3.1	< 0.1	-6.0	-12.0	-27.5
Light Template Contamination	-0.5	-0.5	-0.4	-0.4	-0.4	-0.3	-0.4	-0.4	-0.6
JVT Efficiency	0.4	0.1	-0.8	-0.8	-0.7	< 0.1	-1.0	-1.2	-1.1
Data Statistical Uncertainty	0.7	0.6	0.2	0.9	0.8	1.7	1.1	1.8	2.3
Total Systematic Uncertainty	13.0	11.7	8.1	7.2	8.1	7.0	11.9	16.4	31.8

Full Uncertainties, MV2c10 at 70%

Systematic Uncertainty Source	Systematic Uncertainty in $p_T^{jet}[GeV]$ Bins [%]								
	[20, 30]	[30, 40]	[40, 50]	[50, 70]	[70, 90]	[90, 110]	[110, 140]	[140, 170]	[170, 200]
Detector and Calibration Uncertainties									
Pileup Offset Mu	< 0.1	0.1	0.3	0.3	-0.2	-0.1	0.1	< 0.1	< 0.1
Pileup Offset NPV	0.1	0.2	-0.1	0.3	-0.2	-0.1	0.1	0.1	< 0.1
Pileup Pt Term	< 0.1	< 0.1	-0.1	< 0.1	< 0.1	< 0.1	0.3	< 0.1	< 0.1
Pileup Rho Topology	0.2	0.1	0.4	0.2	-0.4	0.1	-0.1	0.7	0.1
B JES Response	< 0.1	< 0.1	< 0.1	0.3	0.1	< 0.1	0.1	< 0.1	< 0.1
Flavour Composition	0.7	0.4	0.8	0.5	-1.2	-1.0	0.7	-0.7	0.1
Flavour Response	-0.2	-0.1	-0.4	-0.1	0.6	0.4	-0.1	-0.3	< 0.1
Eta Intercalibration Modeling	0.1	0.2	0.4	0.3	-0.4	-0.7	0.6	-0.6	< 0.1
Eta Intercalibration Total Stat	0.1	< 0.1	0.2	0.1	-0.2	-0.1	< 0.1	0.1	< 0.1
Effective NP 1	0.7	0.5	0.7	0.7	-0.4	-0.4	0.6	-0.2	0.1
Effective NP 2	-0.1	< 0.1	< 0.1	0.1	< 0.1	-0.1	0.7	-0.8	< 0.1
Effective NP 3	< 0.1	< 0.1	-0.1	< 0.1	0.2	0.1	-0.4	< 0.1	< 0.1
Effective NP 4	< 0.1	< 0.1	< 0.1	< 0.1	-0.1	0.2	0.1	0.2	< 0.1
Effective NP 5	-0.1	< 0.1	< 0.1	0.1	< 0.1	0.1	< 0.1	0.1	< 0.1
Effective NP Rest Term	< 0.1	< 0.1	0.1	0.1	-0.1	0.1	< 0.1	0.2	< 0.1
JER Single NP	0.2	0.5	0.1	1.2	0.5	-0.6	-2.5	2.2	-0.1
Muon ID	< 0.1	< 0.1	-0.1	-0.1	0.1	0.1	-0.3	-0.1	< 0.1
Muon MS	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.3	-0.1	< 0.1
Muon Scale	< 0.1	-0.1	< 0.1	< 0.1	-0.1	-0.1	-0.5	< 0.1	< 0.1
Modeling Uncertainties									
Axis Smearing	0.3	0.5	0.8	0.5	2.0	2.0	6.4	6.9	0.3
BDecayFractions	< 0.1	< 0.1	< 0.1	0.6	0.6	0.6	0.5	0.4	< 0.1
B-Decay p* Spectrum	-1.4	-1.1	-1.2	-1.9	-1.3	-0.7	-0.1	-0.1	< 0.1
Fake Muons	-0.1	0.2	0.2	0.5	-0.4	1.8	0.2	-0.5	-0.2
Gluon Splitting B	< 0.1	< 0.1	< 0.1	0.7	1.3	1.0	1.1	1.5	0.2
Gluon Splitting C	< 0.1	0.1	0.1	0.3	0.9	0.7	1.7	1.6	0.1
B Fragmentation Fractions	0.1	-0.2	0.1	-0.3	-0.1	-0.2	-0.2	0.2	< 0.1
B Fragmentation Function	0.2	0.1	< 0.1	-0.1	-0.2	-0.3	-0.2	-0.4	-0.1
SF to Inclusive	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
MC Statistical Uncertainties									
Template Statistics	1.0	-0.2	1.4	-0.8	-0.6	-0.7	< 0.1	4.3	-0.3
Simulation Statistics	10.6	9.3	4.4	3.2	3.1	2.8	2.0	1.6	1.7
Template Selection Uncertainties									
LC-Ratio	-0.2	-2.0	1.4	0.9	-3.0	< 0.1	-6.1	-12.5	-15.3
Light Template Contamination	-0.6	-0.6	-0.6	-0.5	-0.6	-0.5	-0.8	-0.9	-1.5
JVT Efficiency	< 0.1	-0.1	-0.6	-0.7	-0.5	0.2	-0.8	-1.0	-0.1
Data Statistical Uncertainty	0.6	0.5	0.7	0.8	0.8	1.5	1.1	1.7	0.5
Total Systematic Uncertainty	11.5	10.4	6.6	6.0	6.9	6.1	10.6	16.0	16.0

Full Uncertainties, MV2c10 at 77%

Systematic Uncertainty Source	Systematic Uncertainty in $p_T^{jet}[GeV]$ Bins [%]								
	[20, 30]	[30, 40]	[40, 50]	[50, 70]	[70, 90]	[90, 110]	[110, 140]	[140, 170]	[170, 200]
Detector and Calibration Uncertainties									
Pileup Offset Mu	< 0.1	0.1	0.3	0.1	-0.2	-0.1	< 0.1	< 0.1	< 0.1
Pileup Offset NPV	< 0.1	0.2	-0.1	0.1	-0.2	-0.1	< 0.1	< 0.1	< 0.1
Pileup Pt Term	< 0.1	< 0.1	-0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Pileup Rho Topology	0.1	0.1	0.3	0.1	-0.3	< 0.1	< 0.1	< 0.1	< 0.1
B JES Response	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	-0.1	< 0.1	< 0.1	< 0.1
Flavour Composition	0.5	0.3	0.7	0.5	-1.0	-0.9	< 0.1	< 0.1	0.1
Flavour Response	-0.2	< 0.1	-0.3	-0.1	0.4	0.4	< 0.1	< 0.1	< 0.1
Eta Intercalibration Modeling	0.1	0.1	0.3	0.2	-0.4	-0.6	< 0.1	< 0.1	< 0.1
Eta Intercalibration Total Stat	0.1	< 0.1	0.2	< 0.1	-0.2	-0.2	< 0.1	< 0.1	< 0.1
Effective NP 1	0.5	0.3	0.6	0.3	-0.4	-0.4	< 0.1	< 0.1	0.1
Effective NP 2	-0.1	< 0.1	< 0.1	< 0.1	< 0.1	-0.1	< 0.1	< 0.1	< 0.1
Effective NP 3	< 0.1	< 0.1	< 0.1	< 0.1	0.2	0.1	< 0.1	< 0.1	< 0.1
Effective NP 4	< 0.1	< 0.1	< 0.1	-0.1	-0.1	0.1	< 0.1	< 0.1	< 0.1
Effective NP 5	< 0.1	< 0.1	< 0.1	0.1	< 0.1	0.1	< 0.1	< 0.1	< 0.1
Effective NP Rest Term	< 0.1	< 0.1	0.1	0.1	-0.1	0.1	< 0.1	< 0.1	< 0.1
JER Single NP	0.2	0.4	0.1	0.9	0.4	-0.4	-0.2	< 0.1	-0.1
Muon ID	< 0.1	< 0.1	< 0.1	-0.1	0.1	0.1	< 0.1	< 0.1	< 0.1
Muon MS	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Muon Scale	< 0.1	< 0.1	< 0.1	< 0.1	-0.1	-0.1	< 0.1	< 0.1	< 0.1
Modeling Uncertainties									
Axis Smearing	0.2	0.5	0.6	0.3	1.6	1.6	0.4	0.3	0.3
BDecayFractions	< 0.1	-0.1	< 0.1	-0.1	0.3	0.2	< 0.1	< 0.1	0.1
B-Decay p* Spectrum	-0.1	-0.2	< 0.1	-0.4	-0.4	< 0.1	< 0.1	< 0.1	-0.1
Fake Muons	< 0.1	0.2	0.2	0.4	-0.3	1.5	< 0.1	< 0.1	-0.1
Gluon Splitting B	< 0.1	< 0.1	< 0.1	< 0.1	0.5	0.2	< 0.1	0.1	0.3
Gluon Splitting C	< 0.1	0.1	0.1	0.3	0.8	0.6	0.1	0.1	< 0.1
B Fragmentation Fractions	0.1	-0.1	0.1	< 0.1	< 0.1	-0.1	< 0.1	< 0.1	< 0.1
B Fragmentation Function	0.1	< 0.1	< 0.1	< 0.1	-0.1	-0.1	< 0.1	< 0.1	-0.1
SF to Inclusive	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
MC Statistical Uncertainties									
Template Statistics	0.6	0.4	0.1	0.3	3.1	1.5	-0.3	0.8	-0.3
Simulation Statistics	8.0	8.3	3.0	2.4	2.8	2.1	1.4	1.3	1.3
Template Selection Uncertainties									
LC-Ratio	-1.6	-3.4	-0.7	-0.4	-5.5	-2.2	-9.0	-10.9	-12.1
Light Template Contamination	-0.7	-0.8	-0.7	-0.7	-1.1	-1.0	-2.2	-1.6	-1.4
JVT Efficiency	-0.1	-0.1	-0.5	-0.6	-0.3	0.4	< 0.1	-0.1	< 0.1
Data Statistical Uncertainty	0.5	0.5	0.6	0.8	0.7	1.4	0.3	0.4	0.4
Total Systematic Uncertainty	9.2	9.9	5.3	5.0	8.4	6.0	10.2	11.8	12.9

Full Uncertainties, MV2c10 at 85%

Systematic Uncertainty Source	Systematic Uncertainty in $p_T^{jet}[GeV]$ Bins [%]								
	[20, 30]	[30, 40]	[40, 50]	[50, 70]	[70, 90]	[90, 110]	[110, 140]	[140, 170]	[170, 200]
Detector and Calibration Uncertainties									
Pileup Offset Mu	< 0.1	< 0.1	0.2	0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Pileup Offset NPV	< 0.1	< 0.1	-0.1	0.1	-0.1	< 0.1	< 0.1	< 0.1	< 0.1
Pileup Pt Term	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Pileup Rho Topology	< 0.1	< 0.1	0.2	< 0.1	-0.1	< 0.1	< 0.1	< 0.1	< 0.1
B JES Response	< 0.1	< 0.1	-0.1	< 0.1	-0.1	< 0.1	< 0.1	< 0.1	< 0.1
Flavour Composition	< 0.1	< 0.1	0.4	0.2	-0.1	-0.1	< 0.1	< 0.1	< 0.1
Flavour Response	< 0.1	< 0.1	-0.2	-0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Eta Intercalibration Modeling	< 0.1	< 0.1	0.2	0.1	-0.1	-0.1	< 0.1	< 0.1	< 0.1
Eta Intercalibration Total Stat	< 0.1	< 0.1	0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Effective NP 1	0.1	< 0.1	0.3	0.1	-0.1	-0.1	< 0.1	< 0.1	< 0.1
Effective NP 2	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Effective NP 3	< 0.1	< 0.1	< 0.1	< 0.1	0.1	< 0.1	< 0.1	< 0.1	< 0.1
Effective NP 4	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Effective NP 5	< 0.1	< 0.1	< 0.1	0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Effective NP Rest Term	< 0.1	< 0.1	0.1	0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
JER Single NP	0.2	0.1	0.1	0.4	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Muon ID	< 0.1	< 0.1	< 0.1	-0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Muon MS	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Muon Scale	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Modeling Uncertainties									
Axis Smearing	< 0.1	0.1	0.3	0.2	0.1	0.1	0.2	0.2	0.2
BDecayFractions	-0.1	-0.1	-0.1	-0.1	-0.2	-0.1	0.1	0.1	0.1
B-Decay p* Spectrum	0.3	0.5	0.4	0.3	0.4	0.1	-0.1	-0.1	-0.1
Fake Muons	0.1	0.1	0.2	0.3	< 0.1	0.1	< 0.1	< 0.1	< 0.1
Gluon Splitting B	< 0.1	< 0.1	< 0.1	-0.1	-0.4	-0.2	< 0.1	< 0.1	-0.1
Gluon Splitting C	< 0.1	< 0.1	0.1	0.2	0.1	< 0.1	< 0.1	< 0.1	< 0.1
B Fragmentation Fractions	0.1	< 0.1	0.1	< 0.1	0.1	< 0.1	< 0.1	< 0.1	< 0.1
B Fragmentation Function	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	-0.1	-0.1
SF to Inclusive	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
MC Statistical Uncertainties									
Template Statistics	< 0.1	-0.2	-0.7	-0.9	-0.3	-0.3	< 0.1	0.4	-0.3
Simulation Statistics	7.1	7.8	1.8	1.8	2.1	1.1	0.9	1.0	0.8
Template Selection Uncertainties									
LC-Ratio	-2.3	-3.9	-2.4	-3.0	-8.2	-6.0	-7.2	-8.1	-9.1
Light Template Contamination	-0.7	-0.9	-1.0	-1.3	-1.4	-1.8	-1.4	-1.2	-1.1
JVT Efficiency	-0.1	< 0.1	-0.3	-0.4	< 0.1	0.1	< 0.1	< 0.1	< 0.1
Data Statistical Uncertainty	0.3	0.3	0.6	0.7	0.2	0.4	0.2	0.3	0.3
Total Systematic Uncertainty	8.5	9.6	5.2	5.6	9.5	7.5	8.4	9.2	10.1