PROPOSAL FOR A TREATMENT OF THE B-TAGGING SYSTEMATICS IN TOP LHC COMBINATIONS

James Keaveney (Vrije Universiteit Brussel),
Luca Scodellaro (Instituto de Fisica de Cantabria - CSIC),
Martin zur Nedden (Humboldt-Universitaet zu Berlin)

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Introduction

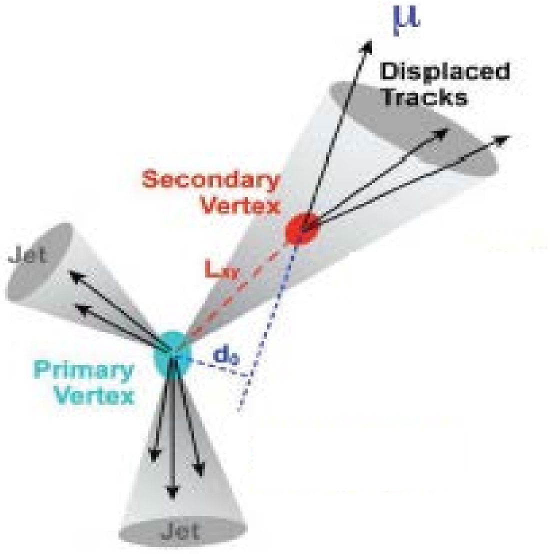
- Top physics at LHC has entered the realm of precision physics:
  - Correlations between analysis techniques, sources of uncertainty and procedures for their evaluation have to be taken into account
- b-jet identification (tagging) is a key ingredient of many analyses, but so far no correlation has been considered
- A team of b-tag experts studied this issue in the TopLHC WG:
  - Comparison of b-tagging techniques, samples and methods used to calibrate their performance on data, sources of systematics and their treatment
- Today, we present a proposal for the treatment of b-tagging correlations for future top physics combinations at LHC

Outline

- Overview of b-tagging in ATLAS and CMS:
  - b-tagging algorithms
  - Calibration of b-tagging performance on data
- Systematic uncertainties in b-tag calibrations:
  - Categorization and correlations between the systematics
  - Treatment of the correlated systematics in ATLAS and CMS
- Treatment of the correlations in top combination:
  - Proposed split of the systematic uncertainties for the coming 8 TeV top physics analyses
  - Documentation in Twiki

b-Tagging Algorithms

- ATLAS and CMS developed various algorithms to identify jets from b quarks exploiting two basic characteristics of B hadron decays

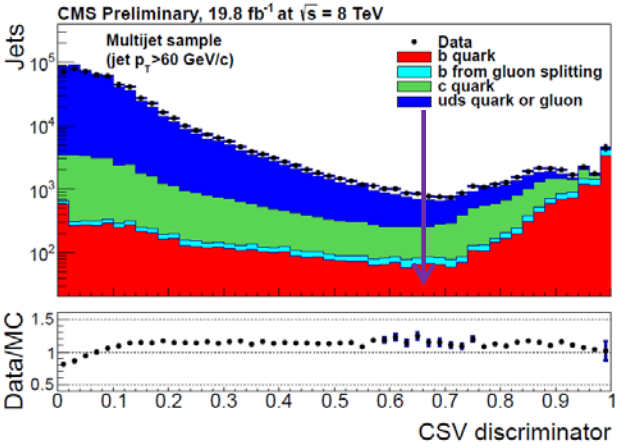


- Large lifetime leads to:
  - Tracks with large impact parameter with respect to the interaction primary vertex
  - Displaced secondary vertices

- High semi-leptonic decay branching ratio:
  - Presence of low momentum leptons inside the cone of the jet
  - Typical signatures from muon and electrons

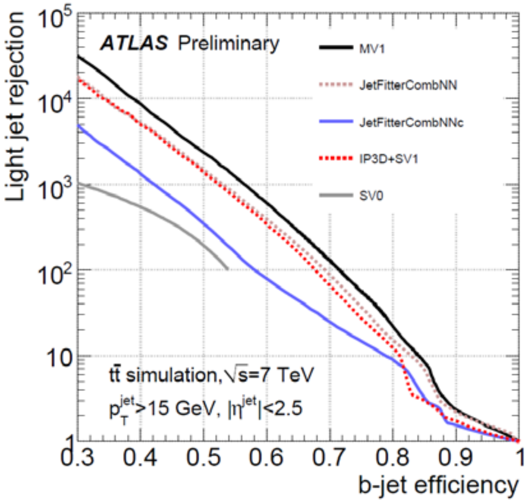
b-Tagging Algorithms

- Most performant algorithms use multivariate combinations of simplest information to provide a b-jet discriminator:
  - ATLAS: the MV1 algorithm combines the outputs of more simple algorithms through a multivariate approach
  - CMS: the combined secondary vertex (CSV) algorithm uses secondary vertices and track-based lifetime information to build a likelihood-based discriminator
- b-jets are identified by a selection on the b-tag discriminator:
  - Example: CSV>0.679 is the most used requirement in CMS



b-Tagging Algorithms

- Performance is studied as of b-tag efficiency vs light jet mis-identification curves:
  - Example: performance curve for the MV1 algorithm in ATLAS



- Both experiments define three working points (WP) for analyses:
  - ATLAS: using fixed b-jet efficiencies (usually 60, 70 and 80%)
  - CMS: fixing mis-identification rate for light jets at 0.1, 1 and 10%
    - Here comparing systematics for medium WP in 8 TeV analyses

b-Tagging Calibrations

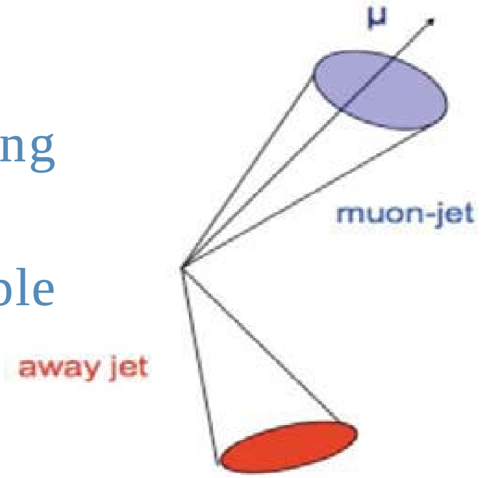
- Simulations do not predict perfectly the discriminator shapes:
  - Need to calibrate MC performance on data
- Calibrations expressed as data/MC scale factors for b-jet tagging efficiencies and for light jet mis-identification (*mistag*) rates:
  - b-tag efficiency SFs provided as a function of jet p_T (eta dependence also studied and found to be flat)
    - Focus on their measurement and uncertainty treatment
  - Mistag SFs provided as a function of the jet p_T and η
    - Measured on inclusive jet samples
    - Largest uncertainties from detector and reconstruction effects
  - ATLAS has independent c-jets calibration based on D*, CMS for the moment using b-jets calibration with larger uncertainties

References on b-Tagging

- ATLAS bibliography:
  - 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
  - Measuring the b-tag efficiency in a ttbar sample with 4.7 fb^{-1} of data from the ATLAS detector, ATLAS-CONF-2012-097
  - Calibration of b-tagging using dileptonic top pair events in a combinatorial likelihood approach with the ATLAS experiment, ATLAS-CONF-2014-004
  - b-jet tagging calibration on c-jets containing D* mesons, ATLAS-CONF-2012-039
  - Measurement of the Mistag Rate of b-tagging algorithms with 5 fb^{-1} of Data Collected by the ATLAS Detector, ATLAS-CONF-2012-040
- CMS bibliography:
  - Identification of b-quark jets with the CMS experiment, The CMS collaboration, 2013 *JINST* **8** P04013
  - Performance of b tagging at sqrt(s)=8 TeV in multijet, ttbar and boosted topology events, CMS-PAS-BTV-13-001

Efficiency Measurements

- The general idea is to measure b-jet content of a b-enriched jet sample before and after the b-tagging requirement
- Sample 1: jets with a soft muon
  - Exploiting the high semileptonic decay branching ratio of B hadrons
  - Often looking at the away jet to enrich the sample in content
- Advantage: allow to select a sample of b-jets independent from the top analysis datasets
- Limitation: muon requirement can have a (weak) bias on impact parameter based b-tagging algorithms



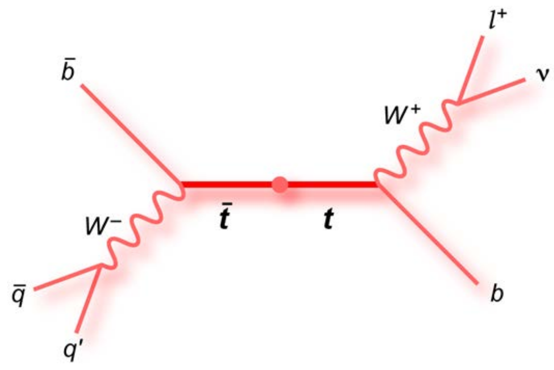
Measurements in Jets with a Soft Muon

- Measurements in ATLAS:
  - p_T^{rel}: template fit of the muon p_T w.r.t the jet axis
    - Only for 7 TeV data
  - System8: equations with 8 unknowns, using two samples (with different purities) and two weakly correlated taggers (the lifetime tagger under study and the muon p_T^{rel})

- Measurements in CMS:
  - Using p_T^{rel} and system8 method as well
  - Extending p_T^{rel} method up to 800 GeV looking at muon IP3D
  - Lifetime tagger (LT) method: template fit of a reference discriminator (usually JetProbability which is calibrated in data)

Efficiency Measurements

- Sample 2: jets from top quark decays
  - BR(t⟶Wb) ~100%
  - Isolated leptons from W decays to reduce the background contamination
  - Single lepton and dilepton decay channels providing two orthogonal datasets



- Advantage: very pure and well known b-jet sample
- Limitation: using the same datasets as in top physics measurements

Measurements in Jets from Top Decays

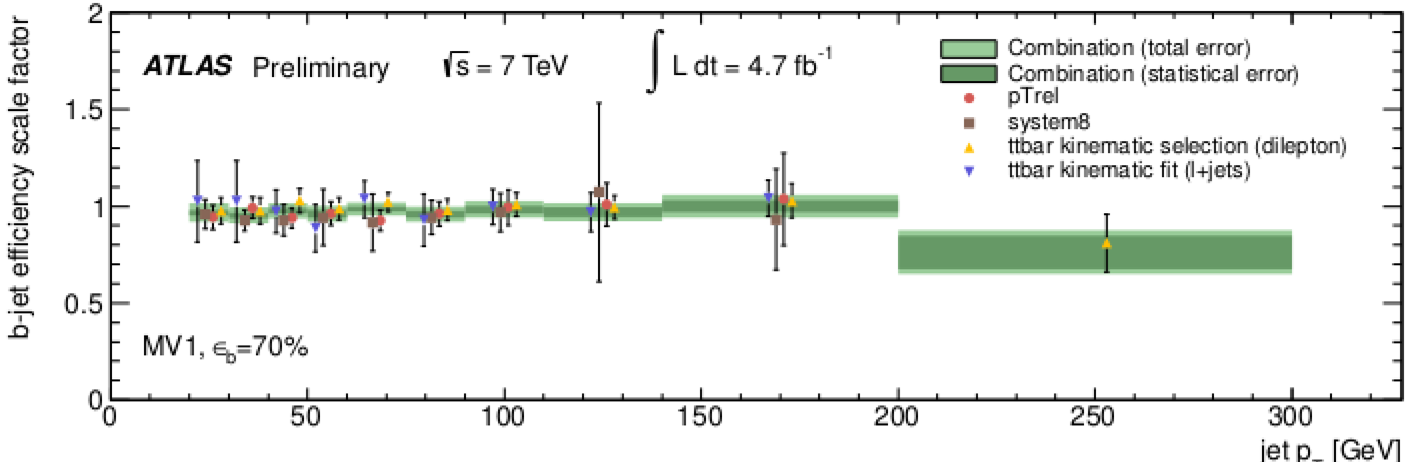
- Measurements in ATLAS:
  - Tag counting: fit b-jet efficiency on the number of tagged jets
    - Only for 7 TeV data
  - Kinematic selection: based on sample composition estimates
  - Kinematic fit: use a kinematic fit to reconstruct the final states and increase the purity of the sample

- Measurements on CMS:
  - Tag counting techniques
  - bSample method (kinematic based)
  - LT method on dilepton events
    - Only for 8 TeV data

(Tag counting techniques and bSample method:) Not yet as a function of p_T

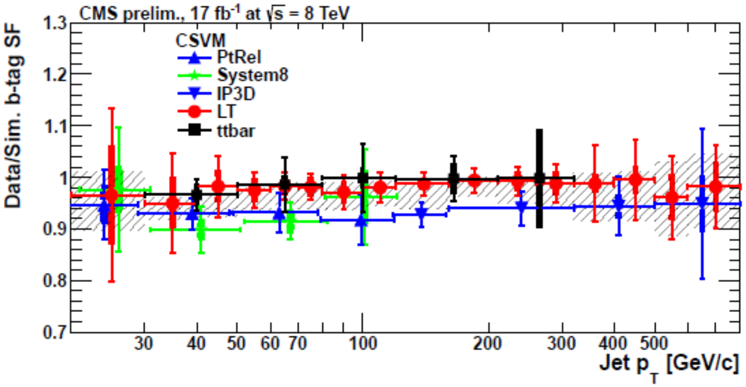
Combination of Efficiency Measurements

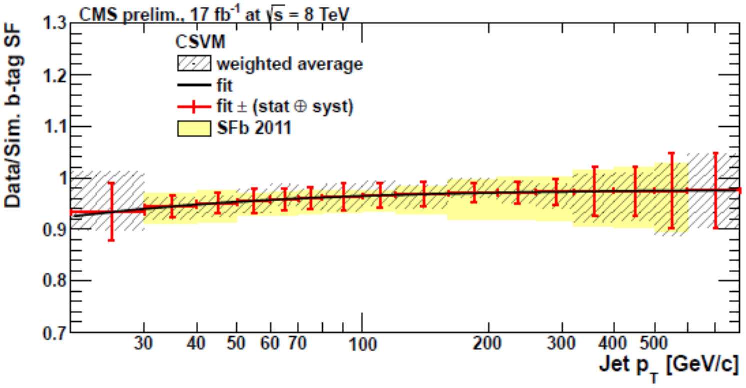
- Combination in ATLAS:
  - **Combine p_T^{rel}, system8 and two $t\bar{t}$ analyses (in different channels to avoid bias to physics analyses)**
  - Global fit with all systematic uncertainties as nuisance parameters which can shift the mean data/MC SF
  - Systematic uncertainties can be fully correlated or uncorrelated in each single kinematic bin or across kinematic bins



Combination of Efficiency Measurements

- Combination in CMS:
  - **Combining measurements on jets with a soft muon and top based LT analysis**
  - Also providing combination w/o top based measurements
  - Using the least squared BLUE method
  - Source of uncertainties common between two or more methods are taken as (anti-)correlated
  - Systematics considered correlated across the bins





Correlations between Systematics

- We considered two types of correlations for the systematic uncertainties on the measured b-tag scale factors (SFs):
  - Correlations with other parts of the top physics analysis:
    - These are sources of uncertainty on the b-tag performance measurements that are also considered in the general analysis
    - Typical example is the uncertainty on the jet energy scale in a measurement of the top quark mass
  - Correlations between the two experiments:
    - Common sources of uncertainty
    - Typically related to the general physics modelling of the calibration samples

Correlations between Systematics

- Correlations affecting different categories of systematics

Category of Systematic Uncertainty	Correlation with physics analysis	Correlation between exp.
General physics modelling (ISR/FSR, parton showering, etc.)	YES	YES
Specific physics modelling (p_T spectrum for soft muons, light/charm ratio, etc.)	NO	YES
Detector description (JES, pileup, etc.)	YES	NO
Method specific	NO	NO

Correlations between Systematics

- Systematics uncorrelated both between experiment and with other parts of the analyses:
  - Just a total systematic uncertainty to quote
- Systematics correlated with other parts of the physics analyses:
  - For now, do not account for this kind of correlations
    - Experiments should decide internally how to deal with them
- Systematics correlated between experiments:
  - Quote separately the main uncertainty on b-tag SFs
  - The others merged into one remaining correlated category
    - Focus on physics modelling systematics in the next slides

Physics Modelling Systematics

- Sources of uncertainty due to physics modelling of muon jets:
  - Production of b and c quarks (fraction of gluon splitting)
  - Decays of the B hadrons
  - b-quark fragmentation
  - Ratio of charm to light jets in the calibration sample
  - Simulation of the p_T spectrum of the muon
- Sources of uncertainty due to physics modelling of $t\bar{t}$ events:
  - Monte Carlo $t\bar{t}$ generator
  - Description of the parton showering
  - Initial and final state radiation
  - Effect of the underlying events

Physics Modelling Systematics

Source	Treatment in ATLAS	Treatment in CMS	Corr.
b/c production	b,c $\rightarrow$ gg scale by 50%	b,c $\rightarrow$ gg scale by 50%	Yes
B decay	Reweight according to BR	Neglected (small)	No
b quark frag.	Average B hadron energy fraction varied ±5%	Average B hadron energy fraction varied ±5%	Yes
c2l ratio	c/l ratio scaled by factor 2	l/c ratio scaled by ±20%	Yes
Muon p_T spectrum	p_T spectrum reweighting	Vary cut on muon p_T	Yes
$t\bar{t}$ generator	Compare MC@NLO to POWHEG (with Herwig)	Compare fit to templates from QCD events	No
Parton Showering	Compare Herwig to Pythia	Compare Herwig to Pythia	Yes
ISR and FSR	Using AcerMC+Pythia	Varying Q^2 scale and ME-PS threshold	Yes
Underlying events	Neglegible	Varying parameters	No

Split of the Systematics

- We identified five major correlated sources of uncertainty:
  - b/c production, muon p_T, charm-to-light ratio, b-frag., PS, IFSR
  - They contribute about at the same level of 0.2 - 1.3%
  - **We provide them as separate uncertainties**

source	size at ATLAS	size at CMS
b/c prod.	low pT: 0.1% - 0.2%, high ph: 1.2% - 2.0%	low pT: 0.1% - 0.3%, high ph: 0.5% - 1.3%
muon pT	low pT: 0.8% - 2.7%, high ph: 0.2% - 0.8%	low pT: 0.1% - 1.1%, high ph: 0.1 - 0.9%
c/l ratio	<0.1% - 0.2%	<0.1% - 0.2%
b-frag.	0.2% - 2.7%	0.2% - 0.8%
PS	0.1% - 4.1%	0.3% - 0.6%
IFSR	01.% - 4.1%	0.3% - 0.6%

Split of the Systematics

- Charm-to-light systematics is equally small for both experiments (up to 0.2%)
  - It is the only one remaining "small" uncertainty
  - **We do not consider it separately, adding to b-frag.**

source	size at ATLAS	size at CMS
b/c prod.	low pT: 0.1% - 0.2%, high ph: 1.2% - 2.0%	low pT: 0.1% - 0.3%, high ph: 0.5% - 1.3%
muon pT	low pT: 0.8% - 2.7%, high ph: 0.2% - 0.8%	low pT: 0.1% - 1.1%, high ph: 0.1 - 0.9%
c/l ratio	<0.1% - 0.2%	<0.1% - 0.2%
b-frag.	0.2% - 2.7%	0.2% - 0.8%
PS	0.1% - 4.1%	0.3% - 0.6%
IFSR	01.% - 4.1%	0.3% - 0.6%

Split of the Systematics

- Example of information provided for a specific algorithm:

pT bin	30-40	40-50	50-60	60-70	70-80	80-100	100-120	120-160	160-210	210-260	260-320	320-400	>400
Uncor.	1.8	1.7	1.9	1.7	1.7	2.1	2.0	2.1	1.5	2.1	2.2	4.6	4.6
b/c prod.	0.1	<0.1	0.2	0.3	0.1	0.4	0.5	0.6	1.0	0.7	1.3	0.9	1.0
muon pT	0.1	0.1	0.7	0.6	0.4	1.0	0.8	0.5	0.1	0.1	0.1	0.8	1.0
b-frag.	0.7	0.7	0.4	0.6	0.5	0.5	0.3	0.2	0.2	0.3	0.2	0.4	0.4
PS	0.4	0.4	0.5	0.4	0.5	0.6	0.5	0.4	0.3	0.3	0.3	0.3	0.3
IFSR	0.4	0.4	0.5	0.4	0.5	0.6	0.5	0.4	0.3	0.3	0.3	0.3	0.3

- Analysers should now propagate in their analyses all the six of sets of uncertainty:
  - Using the same technique as for the global uncertainty used so far
- Resulting uncertainties on the final results can be combined taking into account their correlations between the experiments

Documentation in Twiki

- The proposed splitting of the b-tagging systematics will be summarized in the TopLHC WG twiki:
  - https://twiki.cern.ch/twiki/bin/view/LHCPhysics/TopLHCWG

- Tables with the systematics breakdown and code snippets to use them will be provided for the most used taggers
  - Do not hesitate to let us know if you need the breakdown for a different b-tagging algorithm or working point

- Also considering different data taking and calibration periods
  - The size of the systematics depends on the calibration methods (and combination) used in each period

Conclusions

- Understanding of b-tagging correlations between ATLAS and CMS is crucial for combining precision measurements at LHC

- We analysed the different approaches the two collaborations have been taken regarding every aspect of b-jet identification:
  - b-tagging algorithms and working point definition
  - Calibrations samples and methods,
  - Combination strategy,
  - Source of systematics considered and their treatment

Conclusions

- The common sources of uncertainty have been identified:
  - The treatments of each uncertainty have been compared to establish how its effect is correlated in the measured b-tag SFs
    - We have sometimes agreed on using a common treatment
  - The size of the uncertainties has been found to be in reasonable agreement across the whole p_T spectrum of jets from top decays

- We agreed on a proposal on how to treat the correlations between systematic uncertainties used in physics analyses

- Splitting of b-tag systematics has been provided and documented in a twiki (well, not yet…):
  - Ready to be used in analyses aiming to future LHC combinations

BACKUP MATERIAL

Categorization of the Systematics

Category	Systematic Uncertainty Sources
Detector description	Pile up, track multipliciy description, jet energy scale and resolution, jet reconstruction efficiency, lepton energy resolution, scale and trigger, fake leptons
Physics modelling	Soft muon (b/c production, b fragmentation, B decays, muon spectrum, charm-to-light ratio) and ttbar production modelling (generator, parton shower, initial and final state radiation, underlying events)
Method specific	LT method (CMS), flavour composition (ATLAS)

Correlations between Systematics

- These categories of systematic uncertainties can be correlated in different way

	Systematic uncorraleted between the two experiments	Systematic correlated between the two experiments
Systematics uncorraleted with other parts of the top physics analyses	**Method specific**	**Specific physics modelling** (p_T spectrum for soft muons, light/charm ratio, etc.)
Systematics correlated with other parts of the top physics analyses	**Detector description** (JES, pileup, etc.)	**General physics modelling** (ISR/FSR, parton showering, etc.)

Physics Modelling Systematics

- Treatment of physics modeling systematics in ATLAS and CMS:

ATLAS

Systematic source	
Estimate of the uncertainty in ATLAS	Estimate of the uncertainty in CMS
Typical size of the uncertainty in ATLAS	Typical size of the uncertainty in CMS
Sign of the uncertainty on the SFs	Sign of the uncertainty on the SFs
Proposed treatment of the correlation	

c/b production modelling	
→, scaled by 50%	→, scaled by 50%
0.1-0.5%	0.1-0.8%
SFs decrease as GS increases	SFs decrease as GS increases
Fully correlated	

CMS

Physics Modelling Systematics

ATLAS

CMS

b decay modelling	
Reweight according to BR	Neglected
0.1-0.3%	
Correlation irrelevant	

b quark fragmentation	
Average B hadron energy fraction varied ±5%	Average B hadron energy fraction varied ±5%
0.1-2%	0.1-0.8%
SFs decrease as B hadron EF increases	SFs decrease as B hadron EF increases
Fully correlated	

Physics Modelling Systematics

ATLAS | CMS

Charm-to-light ratio	
c/l ratio scaled by a factor 2	l/c ratio scaled by ±20%
0.1-0.3%	0.1-0.2%
SFs decrease for higher l/c ratio	SFs decrease for higher l/c ratio
Fully correlated	

Muon spectrum modelling	
Muon p_T spectrum reweighting	Vary cut on muon p_T
0.1-1.3%	0.1-1.0%
SFs decrease for harder spectrum	SFs decrease for tighter cuts
Same SF behaviour as the muon p_T spectrum become harder: fully correlated	

Physics Modelling Systematics

ATLAS

Generator	
Compare MC@NLO+Herwig to POWHEG+Herwig	Comparing templates from QCD
0.4-1.1%	<0.1% (Neglected)
Correlation irrelevant	

Parton shower	
Compare Herwig to Pythia	Compare Herwig to Pythia
0.3-1.5%	0.2-1.5% (0.2-0.6% in combination)
SFs increase	SFs increase
Fully correlated	

CMS

Physics Modelling Systematics

ATLAS | CMS

Initial and final state radiation	
Using AcerMC+Pythia	Varying Q^2 scale and ME-PS threshold
0.6-1.4%	0.2-1.5% (0.3-0.6% in combination)
SFs increase if ISR/FSR increases	SFs increase if ISR/FSR increases
Same effect on SFs when varying the level of radiation: fully correlated	

Underlying events	
Neglected	Varying parameters for multi-parton int., color reconnection and collider tune
	<0.1%
Correlation irrelevant	

Measurement of Mistag Rates

- Both experiment measure the mis-identification rate for light jets measuring the tagging rate for negative taggers:
  - Measurements in inclusive jet data (dominated by light jets)
  - Correction factors derived by MC
- Systematic table still under discussion:

	Systematic uncorrelated between the two exp.	**Systematic correlated between the two exp.**
Systematics uncorrelated with the analyses	fake tracks, sign flip, sample and run dep.	b and c fraction in neg. tags
Systematics correlated with the analyses	pileup, track mult., γ conv. and nuclear inter., JES	g fraction, K^0_S and Λ, track multiplicity(?)