Top Modelling Systematic Uncertainty in Top Mass Measurements

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- MC generator systematics
- Additional radiation from ttbar system
- Parton Density function in ME
- Parton shower and fragmentation
- b-fragmentation

Recent measurements

CMS 2012

l+jets JHEP 12 (2012) 105

kinematic fit to reconstruct M_{top}

ideogram method:
Likelihood function to test compatibility of event kinematics with top decay hypothesis
all good permutations are used

2d fit M_{top} and JSF

dilepton EPJ C 72 (2012) 220

matrix element weighting techniques to reconstruct M_{top}

probablility the ttbar kinematics fulfils given mass hypothesis
best mass hypothesis is taken

fully hadronic EPJ C74 (2012) 2758

1d ideogram method Mtop and JSF

CMS 2014

l+jets TOP-14-001

Following closely techniques in CMS 2012 l+jets

ATLAS 2013

l+jets ATLAS-CONF-2013-046

kin. fit to reconstructed M_{top}

template method
2d fit M_{top}, JSF exploiting Mw constrain
3d fit M_{top}, JSF and bJSF
(relative b-to-light JSF)

dilepton ATLAS-CONF-2013-077

kinematic fit to reconstruct mass between lepton and b-quark from one top
1d template M_{lb}

Evaluation of Ttbar modelling systematics

CMS

- Radiation
  Renormalisation and factorisation scale changed by factor of 2 in Madgraph+Pythia

  ME-PS matching threshold in Madgraph varied from from default 20 GeV by factor of 2

- MC generator
  Dilepton: MadGraph vs Powheg

  For 2014 l+jets:
  - MadGraph vs Powheg
  - p_{Ttop} reweighting

- PDF
  Based on CTEQ6,6
  For 2014 measurement: PDF4LHC prescription

- Choice parton shower model and fragmentation
  Included in jet response uncertainty
  b-fragmentation modelling varied

ATLAS

- Radiation
  ISR/FSR PS starting scale changed by factor of 2 in ACERMC+Pythia

  Radiation systematics based on ALPGEN not yet used in top mass analysis

- MC generator
  MC@NLO+Herwig vs Powheg+Herwig
  (very different jet multiplicities,
  Alpgen does not contain top width)

- PDF
  based on CT10

- Choice parton shower model and fragmentation
  Also included in jet response uncertainty,
  but would like to cover other effects (parton->jet)
  evaluate, e.g. Powheg+Pythia vs Powheg+Herwig

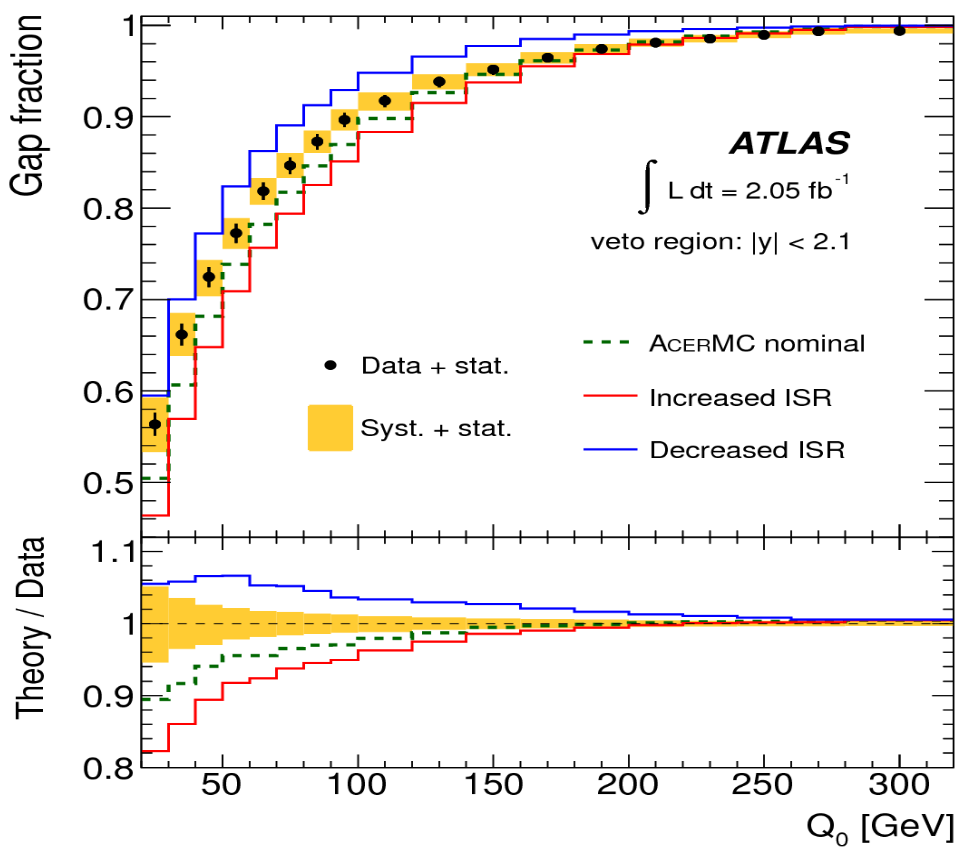
Constrains on additional radiation systematics in ATLAS

Take pragmatic approach: tune MCs to measured observables sensitive to radiations

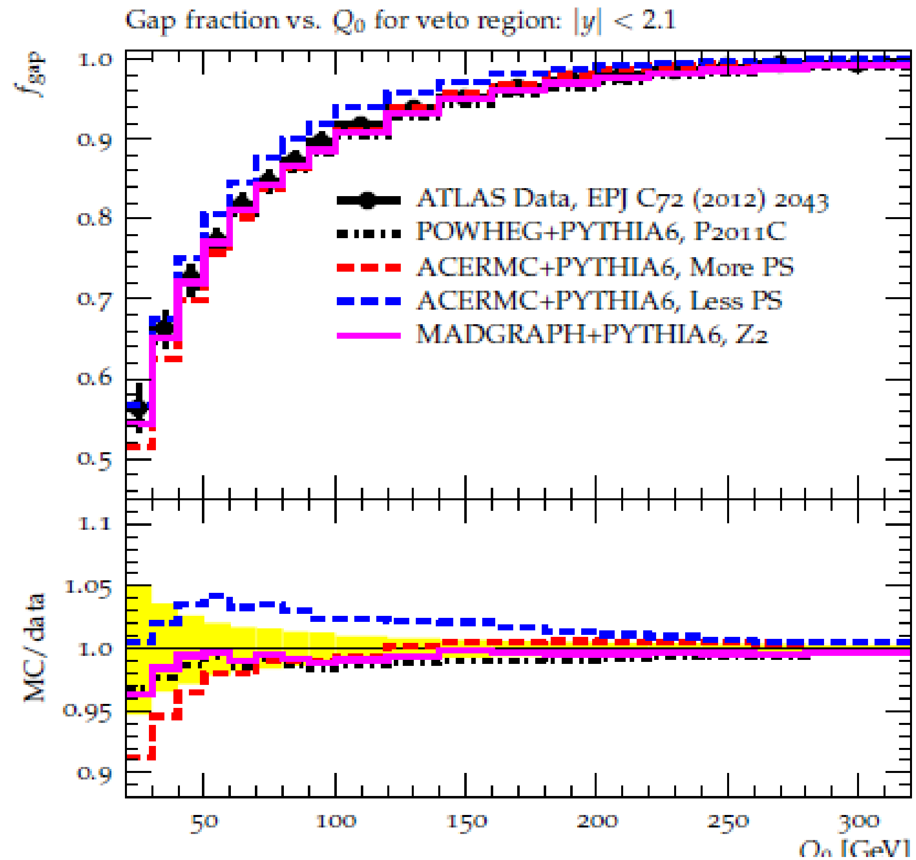
Jet gap fraction measurement ATLAS EPJ C72 (2012) 2043
Dilepton channel with two b-tags
Fraction of events that do not have
additional central jet above a pt-cut

See more details i ′ Liza Mijovic
ATLAS-PHYS-PUB-2014-005

Settings estimated before measurement



After tuning

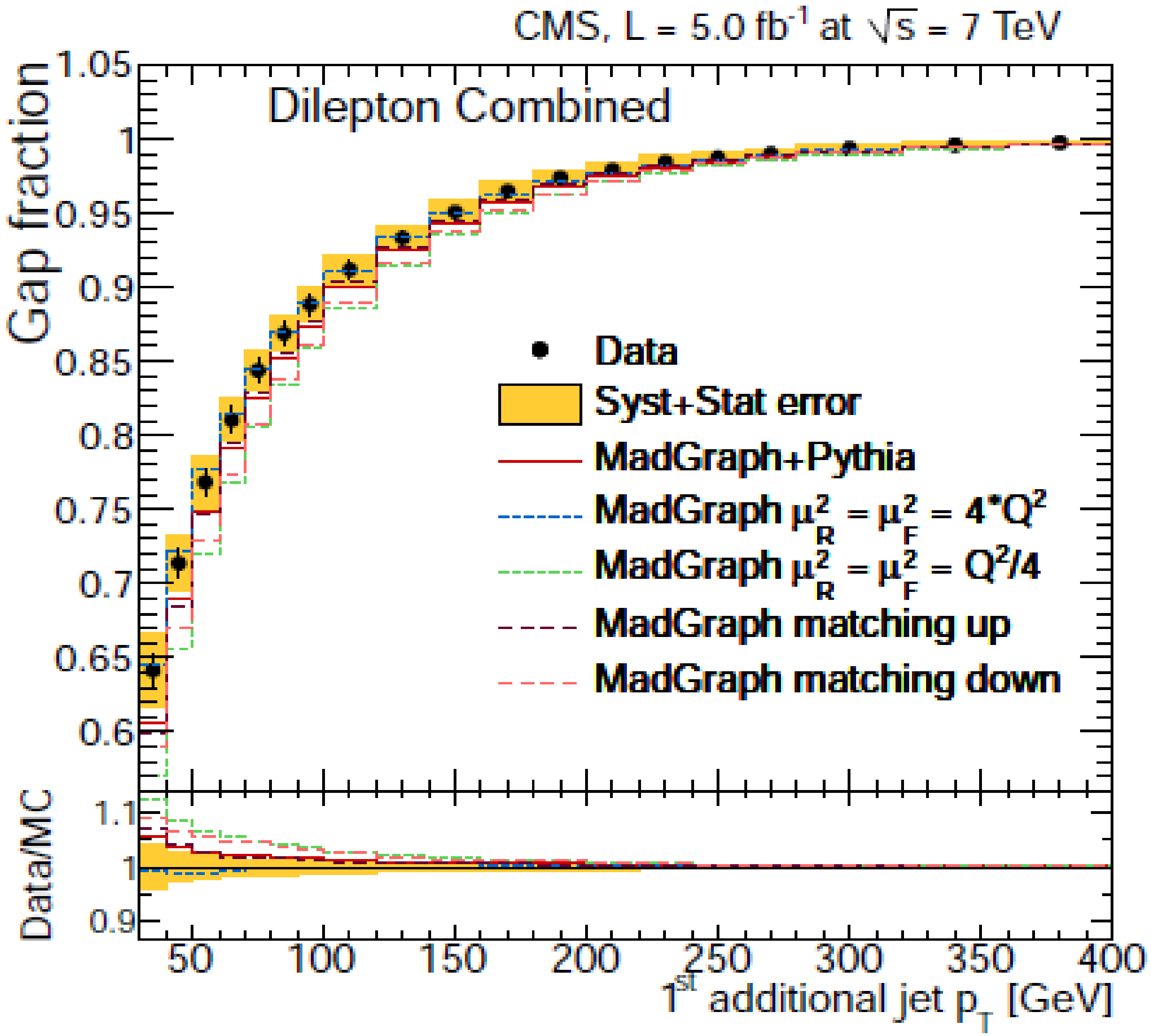


Reduction of systematics by tuning ISR/FSR parameter in ACERMC (see back-up for details)
Central CMS MC Madgraph+Pythia+Z2 tune describes ATLAS data well

Constrains on additional radiation systematics in CMS

Variation inspired by theory, show a posteriori consistency with data (arXiv:1404.3171)

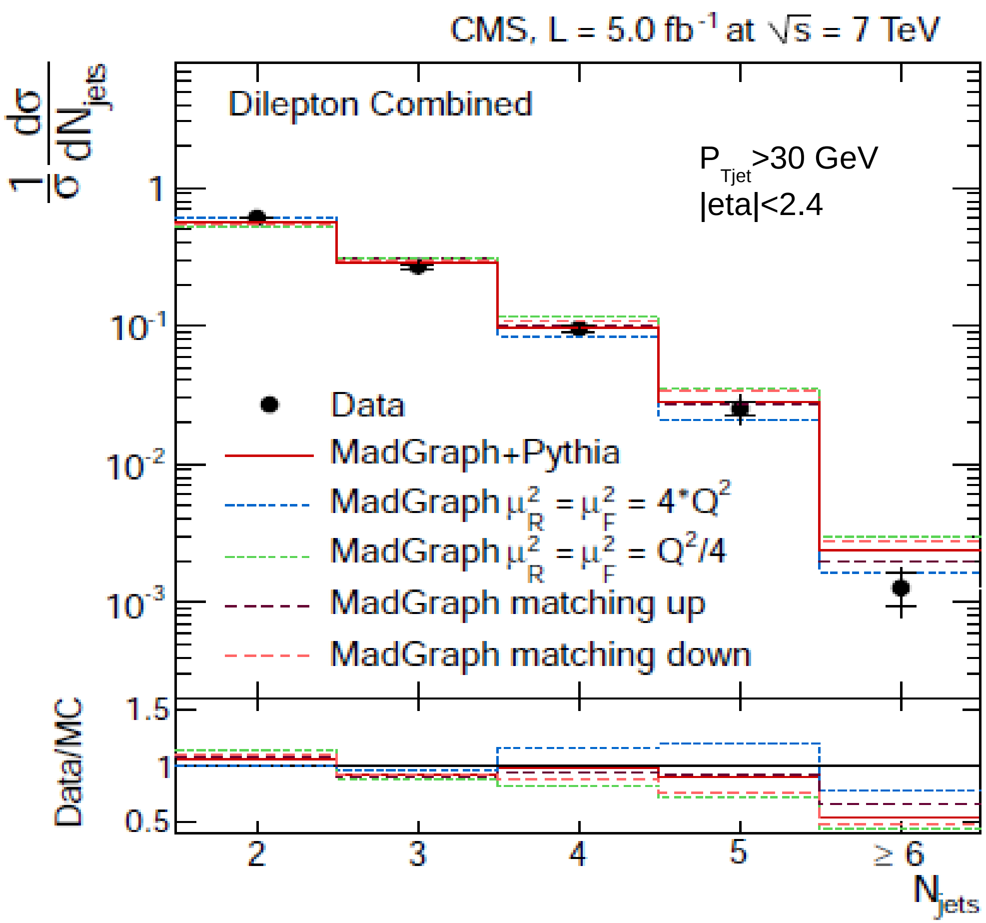
Renormalisation and factorisation scale changed by factor of 2 in Madgraph (LO multi-leg)
ME-PS matching threshold in Madgraph varied from from default 20 GeV by factor of 2

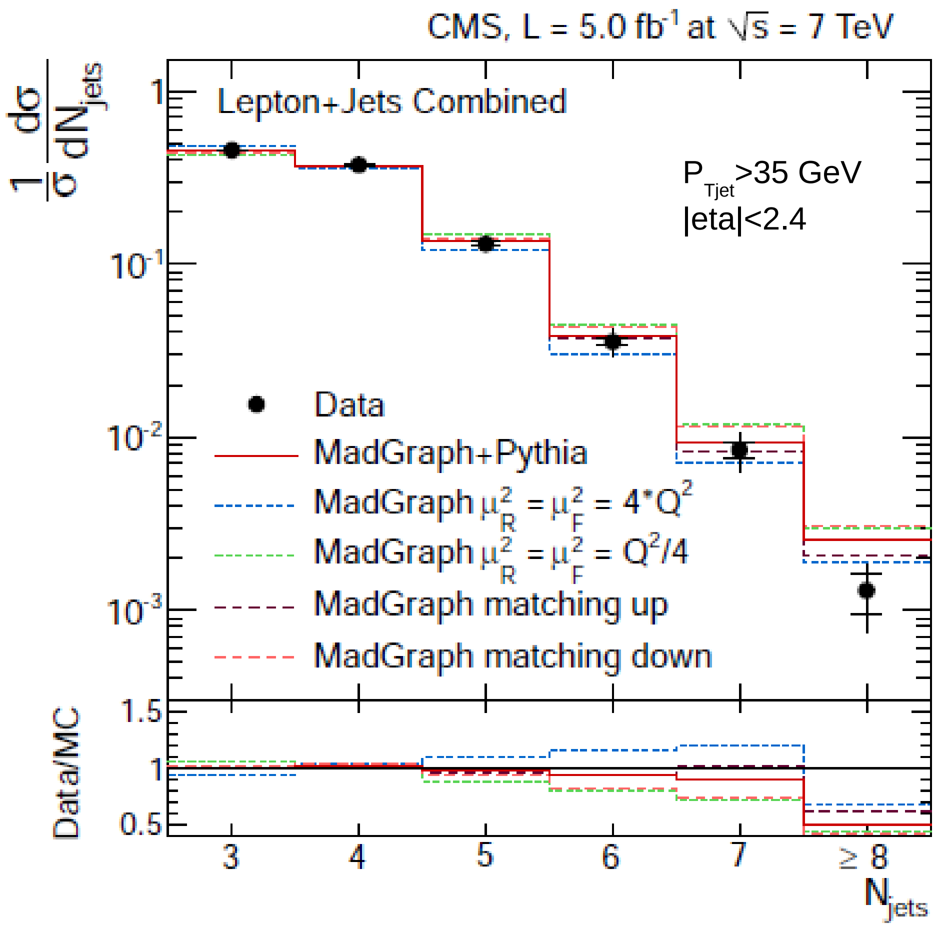


Note, inverted ratio with respect to figures on previous slide

Constrains on radiation systematics – Jet multiplicity

Jet multiplicity in dilepton and l+jet events (arXiv:1404.3171)





Data covered by systematics variations in MadGraph

Similar measurement in ATLAS-CONF-2012-155

Rivet routine in preparation

Radiation systematics

Uncertainties in MeV
Number in () provided for combination

Channel/Method	CMS 2012 standard	CMS 2014 standard	ATLAS 2013 standard	ATLAS 2013 3D
l+jets				
PDF	70	90	90	170
μ_r and μ_{fac}	240	120 ± 130		
ME-PS Matching	180	150 ± 130		
AcerMC ISR/FSR			960	450
ME-generator	(20)	230 ± 140	360	190

According to measurement sensitive to radiation, ATLAS and CMS variation should have similar effect
Effect on top mass can depend on measurement techniques

ACERMC variations make much larger effect in ATLAS 2D measurement than CMS 2D

ATLAS 3D measurement gives reduced radiation systematics

Large reduction of radiation systematics in new CMS measurement
(reduced statistical uncertainties ?)

Large statistical uncertainties in systematics uncertainty (as evaluated by new CMS)

Radiation systematics

Uncertainties in MeV
Number is () provided for combination
Number with * not included (max taken)

Channel/Method	CMS 2012 standard	CMS 2014 standard	ATLAS 2013 standard	ATLAS 2013 3D
l+jets				
PDF	70	90	90	170
μ_r and μ_{fac}	240	120 ± 130		
ME-PS Matching	180	150 ± 130		
AcerMC ISR/FSR			960	450
ME-generator	(20)	230 ± 140	360	190
dilepton				
PDF	90		120	
μ_r and μ_{fac}	550		200*	
ME-PS Matching	190			
ME-generator	40		140	
AcerMC ISR/FSR			370	
hadronic				
PDF	60			
μ_r and μ_{fac}	220 ± 340			
ME-PS Matching	240 ± 340			
ME-generator	(190)			
AcerMC ISR/FSR				

Quoted is 1d method as in combination

Treatment of statistical uncertainties in systematics evaluations

From CMS, EPJ C74 (2014) 2758

Table 2: Overview of systematic uncertainties. The total is defined by adding in quadrature the contributions from all sources, by choosing for each the larger of the estimated shift or its statistical uncertainty, as indicated by the bold script.

	1D analysis	2D analysis	
	δ_{m_t} (GeV)	δ_{m_t} (GeV)	δ_{JES}
Fit calibration	**0.13**	**0.14**	**0.001**
Jet energy scale	**0.97** ± 0.06	0.09 ± **0.10**	**0.002** ± 0.001
b-JES	**0.49** ± 0.06	**0.52** ± 0.10	**0.001** ± 0.001
Jet energy resolution	**0.15** ± 0.06	**0.13** ± 0.10	**0.003** ± 0.001
b tagging	0.05 ± **0.06**	0.04 ± **0.10**	**0.001** ± 0.001
Trigger	**0.24** ± 0.06	**0.26** ± 0.10	**0.006** ± 0.001
Pileup	0.05 ± **0.06**	0.09 ± **0.10**	**0.001** ± 0.001
Parton distribution functions	0.03 ± **0.06**	0.07 ± **0.10**	**0.001** ± 0.001
Renormalization and factorization scale	0.08 ± **0.22**	0.31 ± **0.34**	**0.005** ± 0.003
ME-PS matching threshold	**0.24** ± 0.22	0.29 ± **0.34**	0.001 ± **0.003**
Underlying event	**0.20** ± 0.12	**0.42** ± 0.20	**0.004** ± 0.002
Color reconnection effects	0.04 ± **0.15**	**0.58** ± 0.25	**0.006** ± 0.002
Multijet background	**0.13** ± 0.06	**0.60** ± 0.10	**0.006** ± 0.001
Total	1.21	1.23	0.013

Need to increase MC statistics for systematics variation samples, if possible
Need to learn how to reduce statistical fluctuations on systematics uncertainties
Taking maximum of statistical uncertainty and mean not the only possibility

Hadronisation systematics

CMS 2011

b-JES:
b-jet response in between light-quark/gluon response
Therefore take Pythia/Herwig++ for light quark/gluons as b-jet uncertainty

CMS 2014

b-JES
Compare Pythia/Herwig++ for each jet flavour
For light-quarks, gluons and b-quark uncertainty is evaluated separately and added in quadrature

b-fragmentation
Bowler-Lund fragmentation re-tuned to ALEPH and DELPHI data
Difference between this retune and Pythia Z2 tune is uncertainty

Semi-leptonic B hadron decays
Semi-leptonic branching varied by -0.45 and +0.77% for B^0 and B^{+-} Hadrons (from PDG)

Quoted separately and not included in final result
MC@NLO+Herwig vs Powheg+Pythia Z2 tune

→ approach avoids possible double counting when changing pythia/herwig
- detector response on particle jet
- b-fragmenation
- p_{Ttop} modelling

ATLAS

b-JES
- Dedicated b-JES based on MC Pythia/Herwig
  b-fragmentation function
  Pythia nominal/tuned Bowler-Lund (tuned to LEP data)
- Validation with data in situ (limited precision)

Parton shower and fragmentation effects on Ttbar event topology
exchange Pythia/Herwig to cover:
- -choice of parton shower
- -hadronisation effect (string vs cluster)
- -underlying event
- -b-fragmentation
- -B-Hadron decay tables

→ possible double counting with other systematics:
- effect of detector response on particle jet -> detector jet
- underlying event
- b-fragmentation

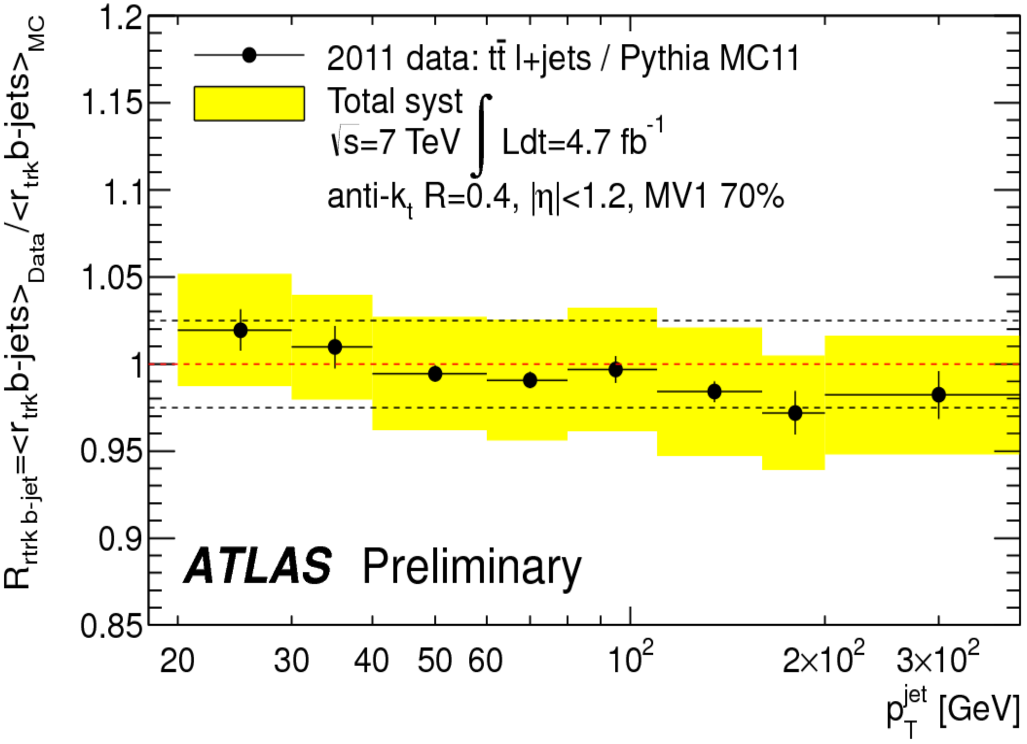
b-Jet response validation in ATLAS data

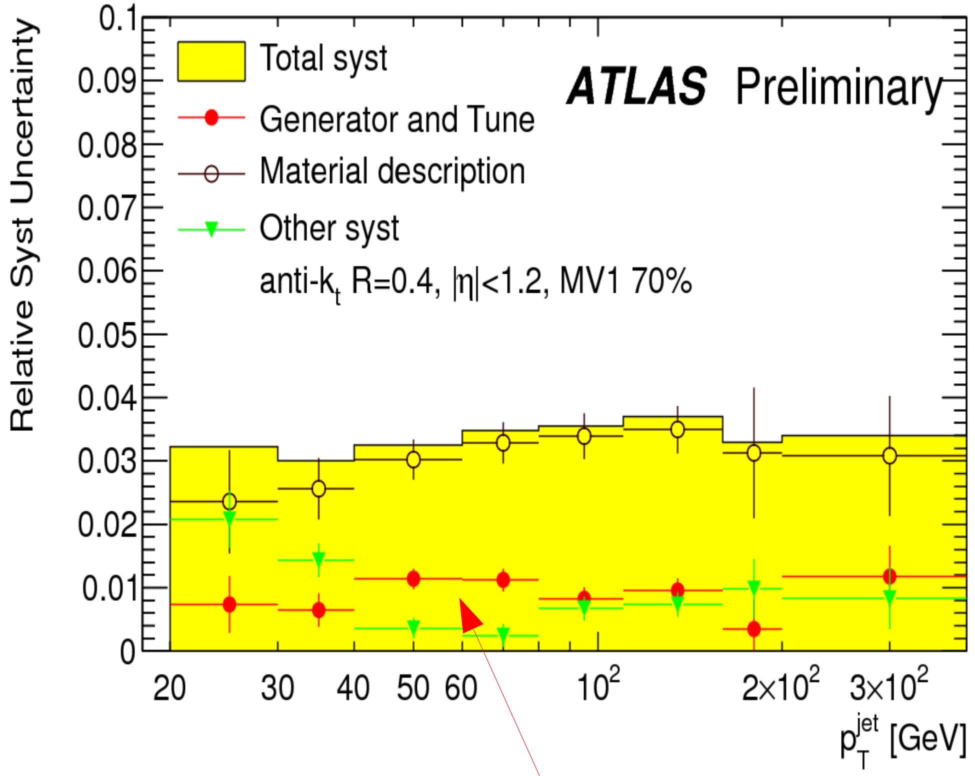
Study jet response comparing calorimeter to track jets in ttbar events

$$r_{\mathrm{trk}} = \frac{\sum \vec{p}_{\mathrm{T}}^{\,\mathrm{track}}}{p_{\mathrm{T}}^{\mathrm{jet}}}.$$

compare data to MC

Uncertainty then given by
Calo-to-track response in Data/MC
for systematic variations





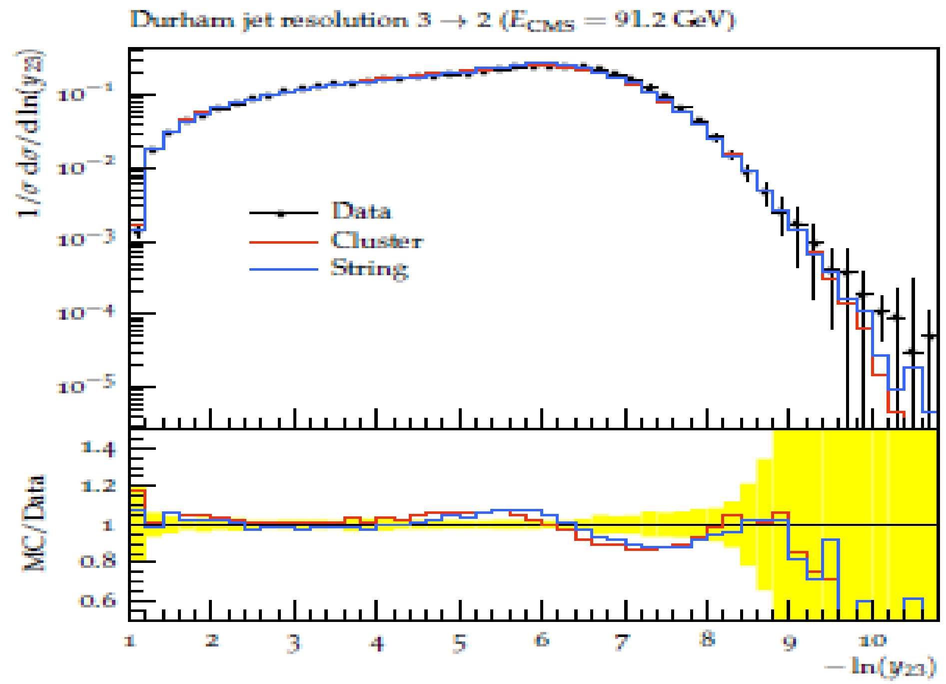
Generator and tune
Powheg+Herwig vs MC@NLO+Herwig
Powheg+Herwig vs Powheg+Pythia

Calo-to-track response ratio well described by Powheg+Pythia
Difference due to generator and Pythia/Herwig is small !

Study of cluster vs string fragmentation in Sherpa

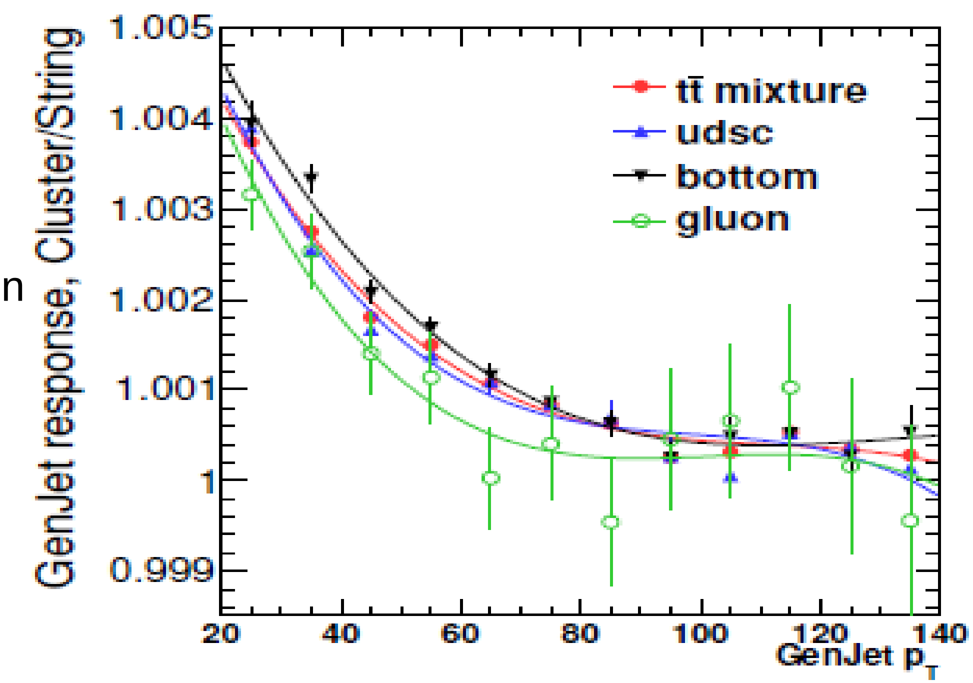
Particle-level study using Sherpa 2.1:

- use same pT-ordered parton shower (CSShower++)
- exchange
  - in-built sherpa cluster fragmentation (AHADIC++, Hadrons++)
  - Pythia 6.4.18 for lund string fragmenation



Validate set-up in e^+e^- data
Shown are differential jet rate at 91.2 GeV
(other variables similar quality)

Look at particle jet response with respect to
Selected parton for string and cluster fragmentation



Difference between cluster/string model
and jet flavours on jet response
Are very small

Jet shape

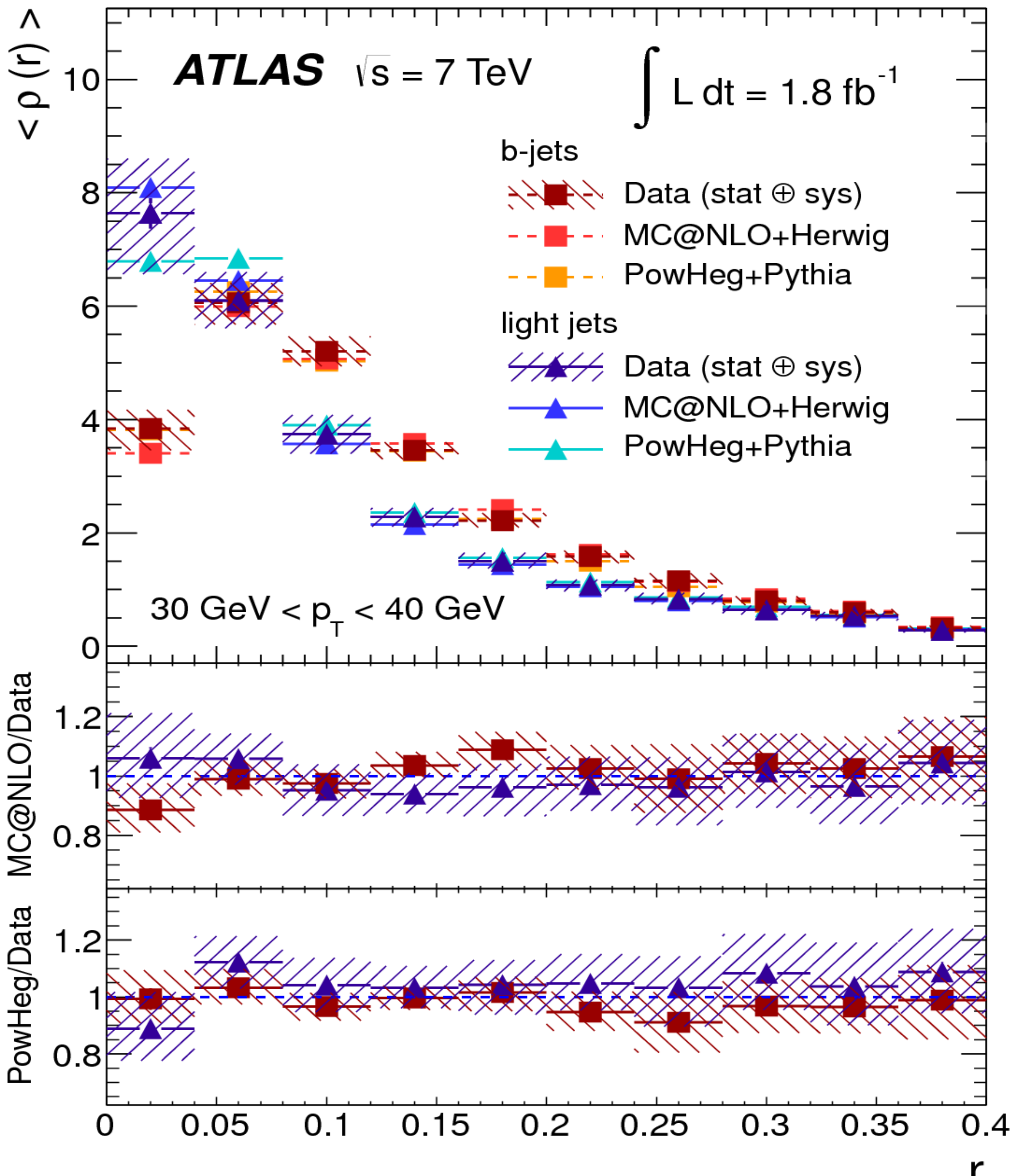
Measurement of
differential jet shape in ttbar events
(EPJ C73 (2013) 2676)

Jet shape:
Transverse energy in annulus
around jet axis

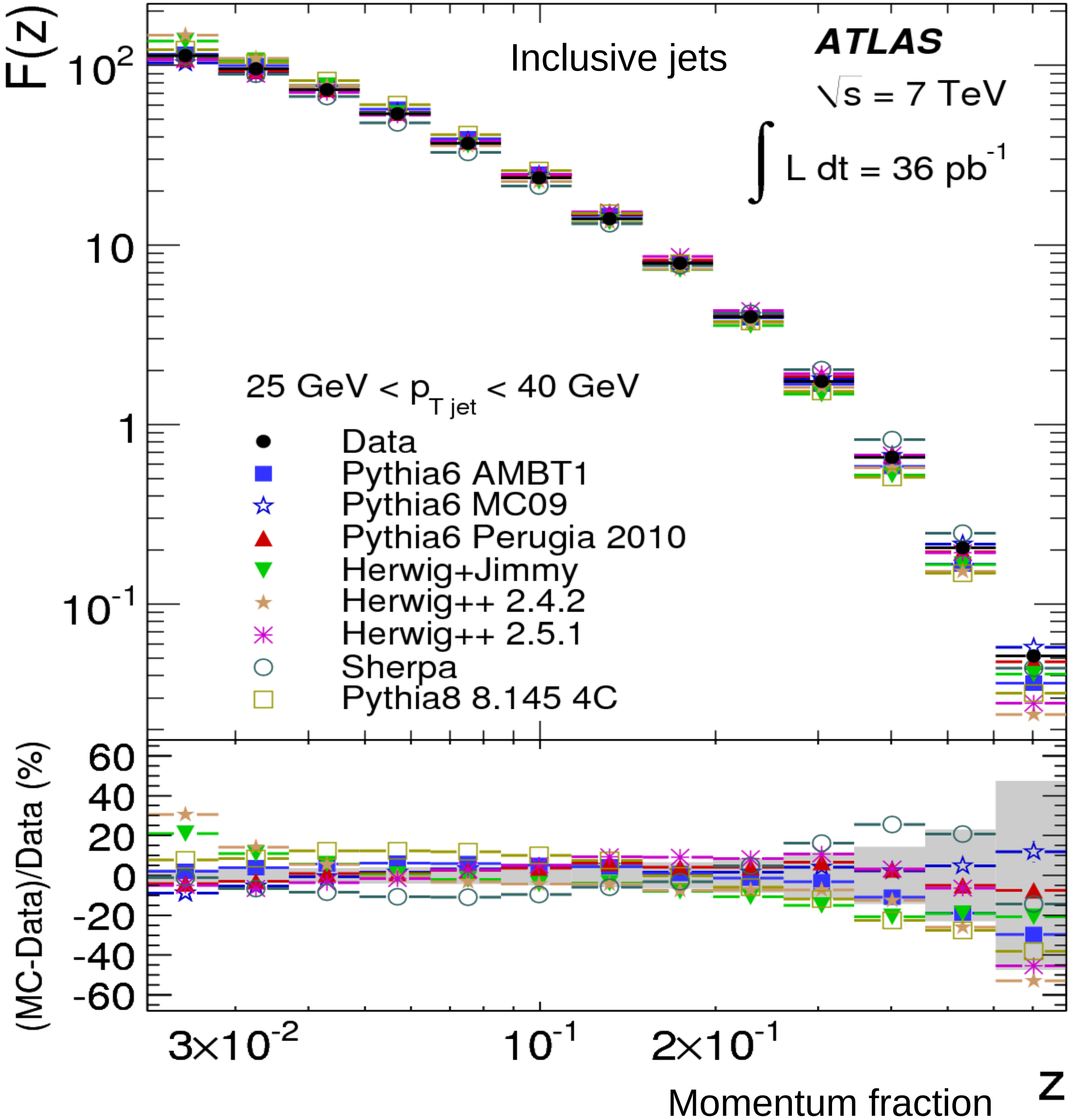
$$\rho(r) = \frac{1}{\Delta r} \frac{p_{\mathrm{T}}(r - \Delta r/2, r + \Delta r/2)}{p_{\mathrm{T}}(0,R)}$$

B-jets are wider than
light-quark jets from W-decay

Both Powheg+Pythia
and MC@NLO+Herwig
describe data
for light jets from W-decay
and b-jets



Jet fragmentation



Fragmentation function

$$F(z, p_{\mathrm{T\,jet}}) \equiv \frac{1}{N_{\mathrm{jet}}} \frac{dN_{ch}}{dz},$$

Charged particle
Momentum fraction

$$z = \frac{p_{\mathrm{jet}} \cdot p_{ch}}{|p_{\mathrm{jet}}|^2},$$

Within measurement precision present MCs describe data

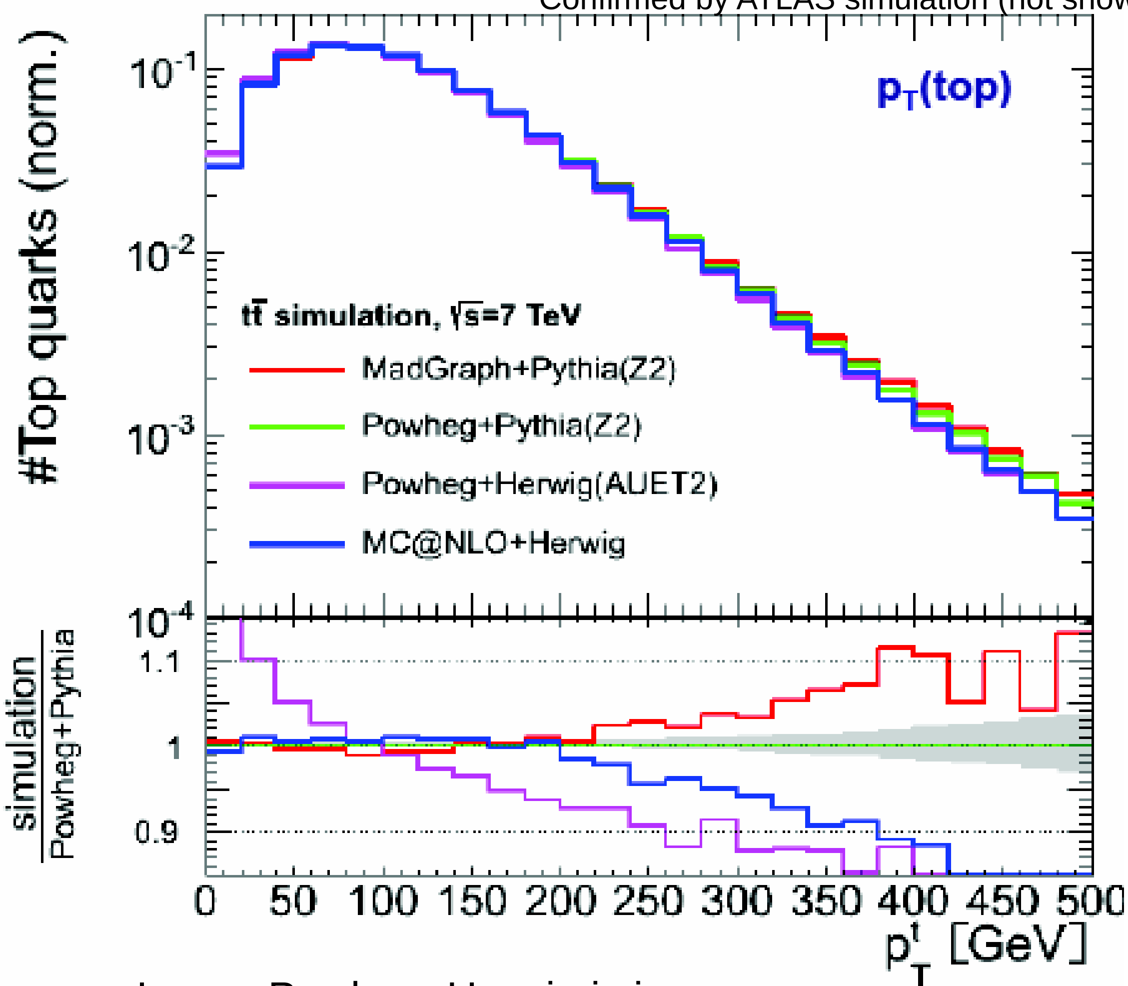
Herwig is worse, but still ok

-> would be interesting to have this measurement for b-jets

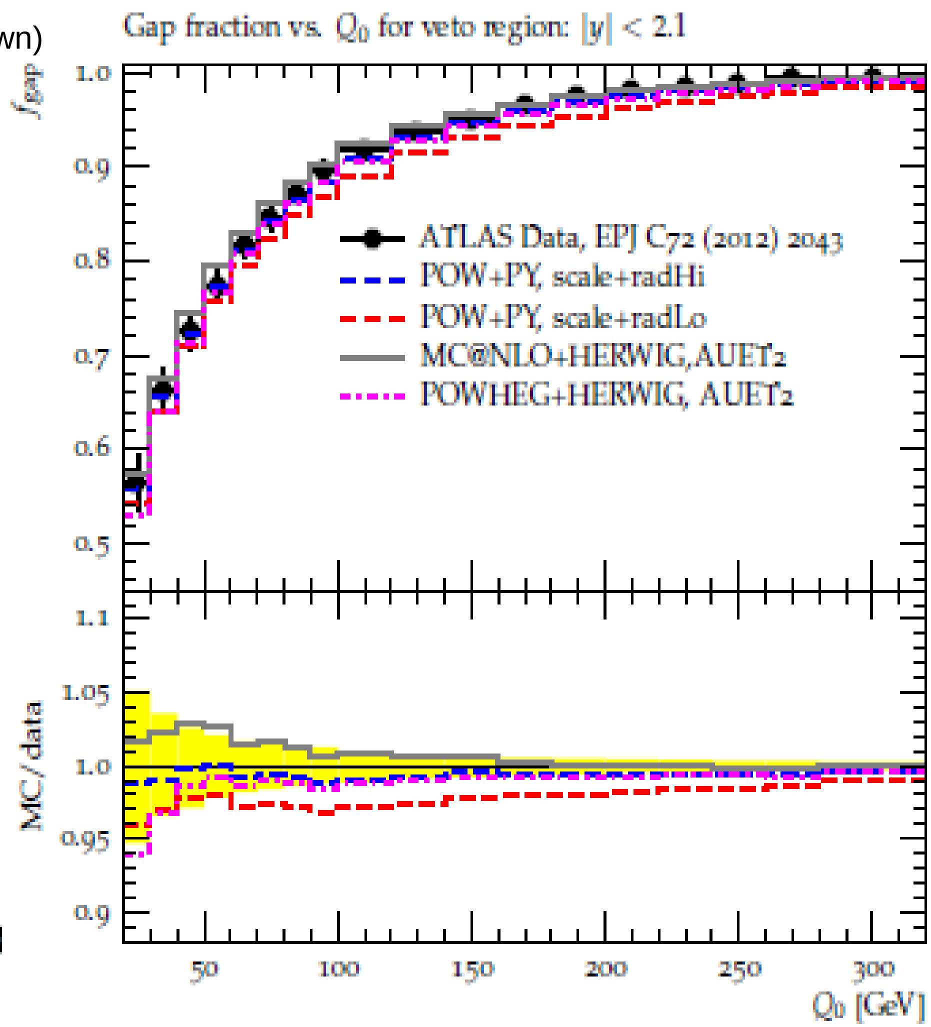
Ttbar event topology for Pythia Herwig parton showers

When switching from Pythia to Herwig in Powheg, changes in the ttbar event kinematics are observed e.g. shown by M. Aldaya/F. Spano in last TopLHC meeting

CMS simulation, $\sqrt{s}$ = 7 TeV
Confirmed by ATLAS simulation (not shown)



In p_{Ttop} Powheg+Herwig is in better agreement with data (not shown)



Powheg+Herwig describes additional radiation

Overview of hadronisation systematics

Uncertainties in MeV
Number with () provided for combination, not included in main result
* not included in main result

	CMS		ATLAS	
	2011	2014	2012	2012
Channel/Method	standard	standard	standard	3D
l+jets	(580)	330*	1300	270
dilepton	(760)	-	440	
hadronic	(930)	-	-	-

ATLAS 2D method has large uncertainty due to Pythia/Herwig (1.3 GeV !)
Reduced by 3D method fitting b-JSF relative to light-quark JSF
(at the cost of increasing detector uncertainty since sensitive to pt-dependence of uncertainties)

2011 CMS uncertainties from ATLAS/CMS top mass combination note
Hadronisation uncertainty is sizeable compared to total systematics
(50-90% of total uncertainty depending on channel)

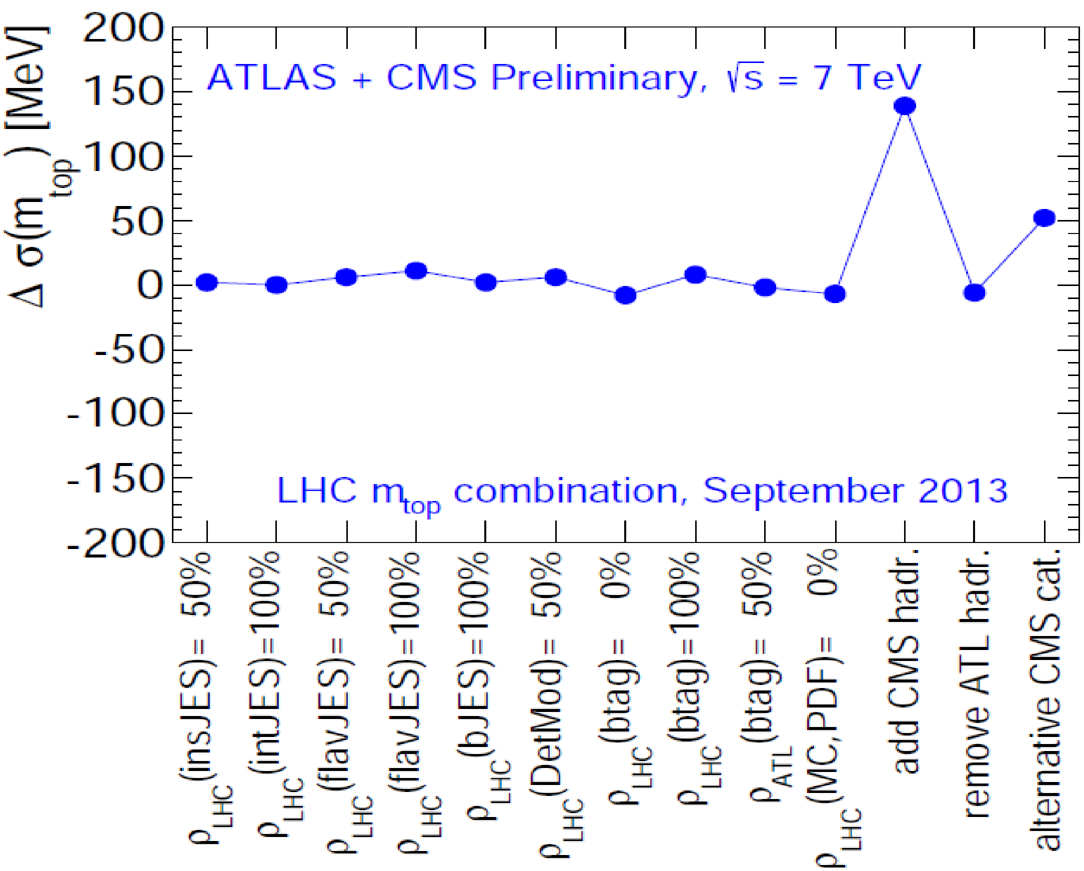
New CMS measurement reduced uncertainty, but still about 50% of total uncertainty

Agreed last year to evaluate double counting between Pythia/Herwig with other systematics,
e.g. by re-calibrating jets with Herwig (instead of Pythia) → still ongoing

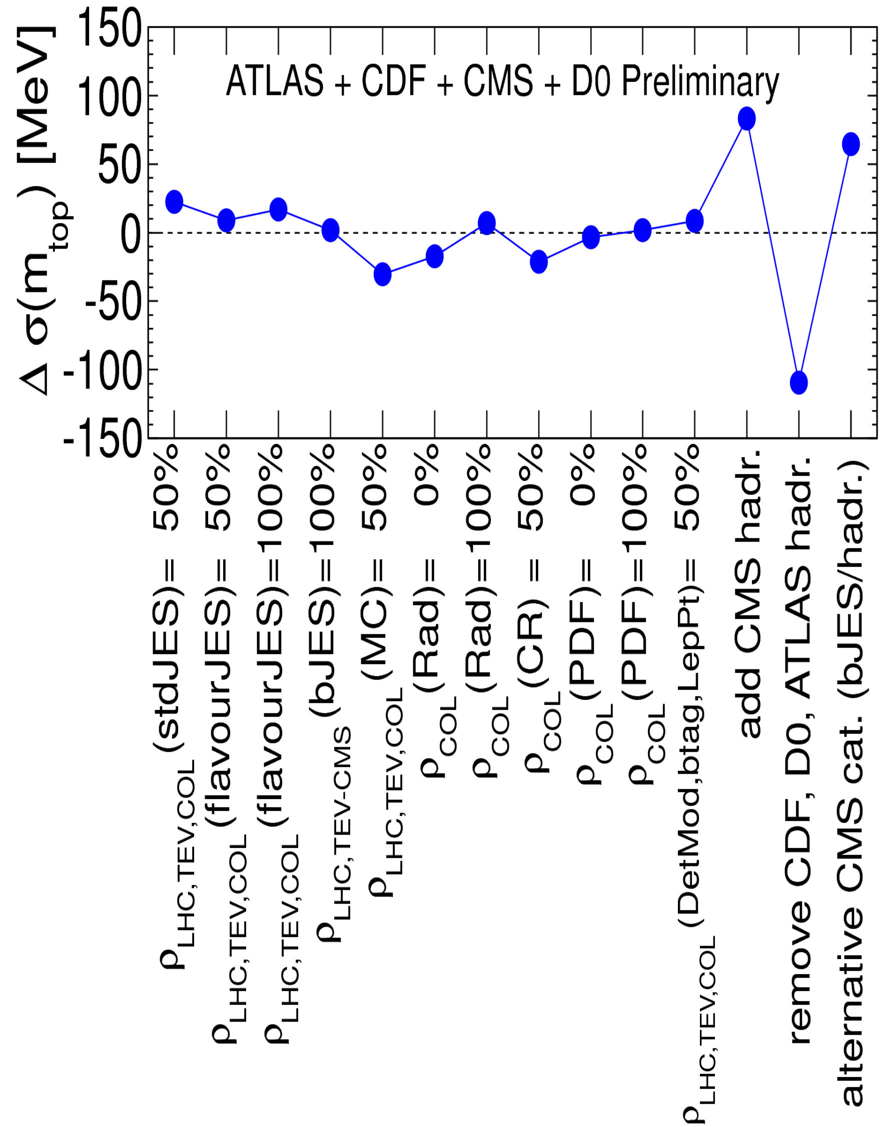
Effect of hadronisation systematics treatment in combinations

Influcence of hadronisation systematics treatment in combinations:

ATLAS/CMS combination ATLAS-CONF-2013-102

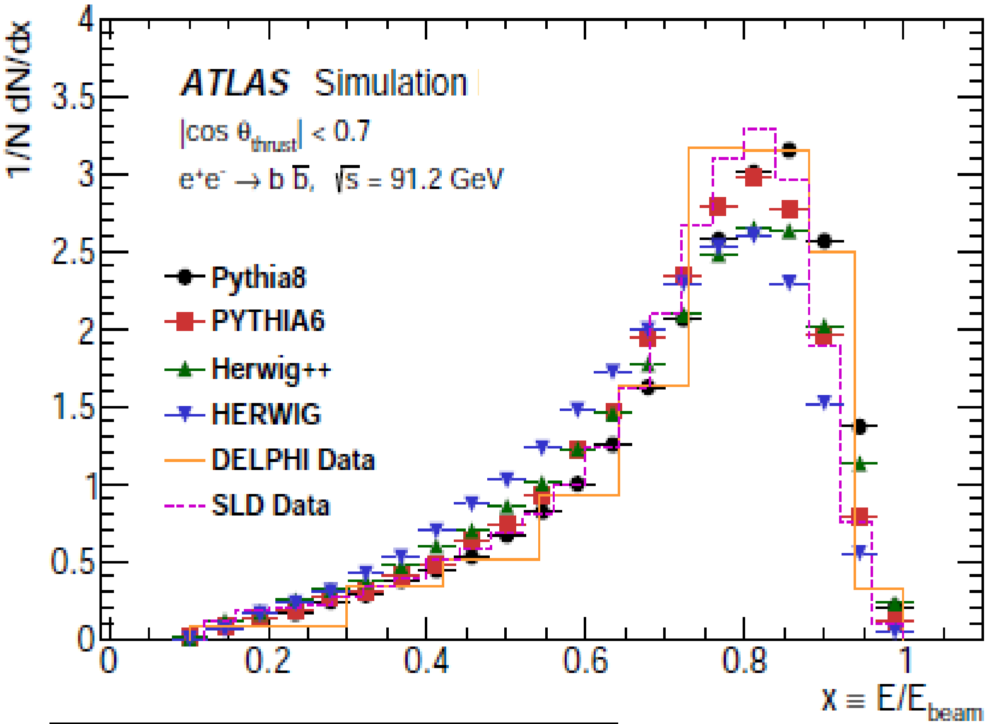


World combination ATLAS-CONF-2014-008



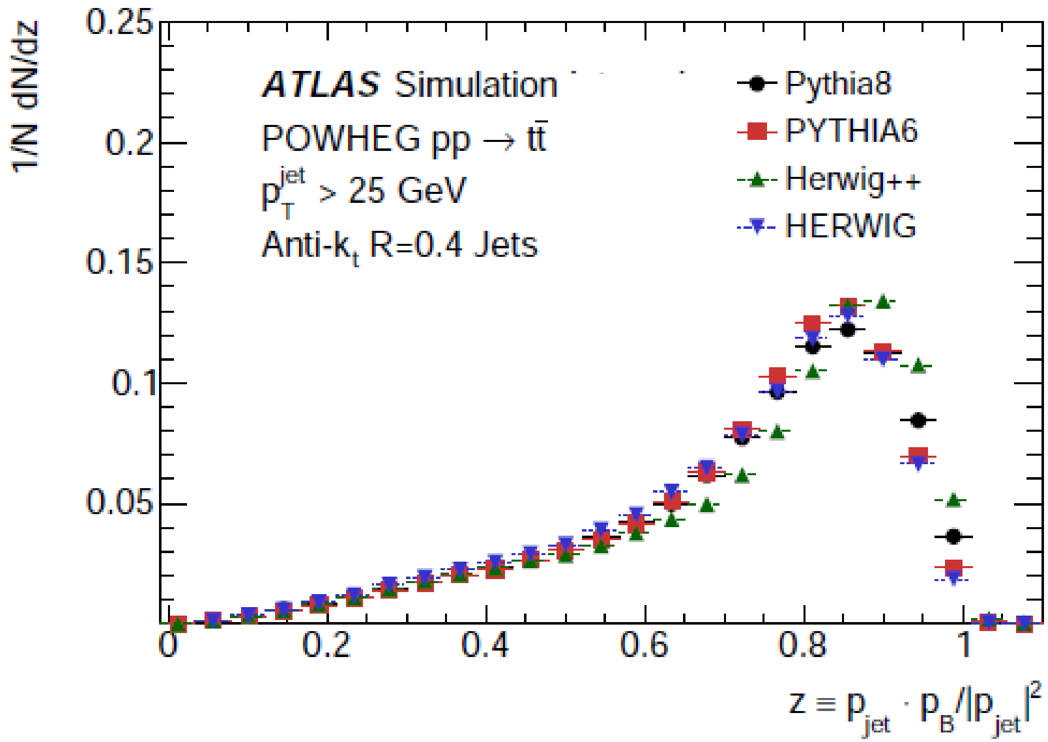
B-fragmentation

Electron-positron collisions



mean E_B/E_{beam}	
Pythia8	0.7303 ± 0.0005
PYTHIA6	0.7090 ± 0.0005
Herwig++	0.7012 ± 0.0006
HERWIG	0.6782 ± 0.0005
Delphi Data	0.699 ± 0.011
SLD Data	0.709 ± 0.005

Proton-proton ttbar events



Fragmentation function with respect to anti-kt jet R=0.4 |eta|<2.4 Containing B-hadron with pt>5 GeV

Herwig++ has harder fragmentation

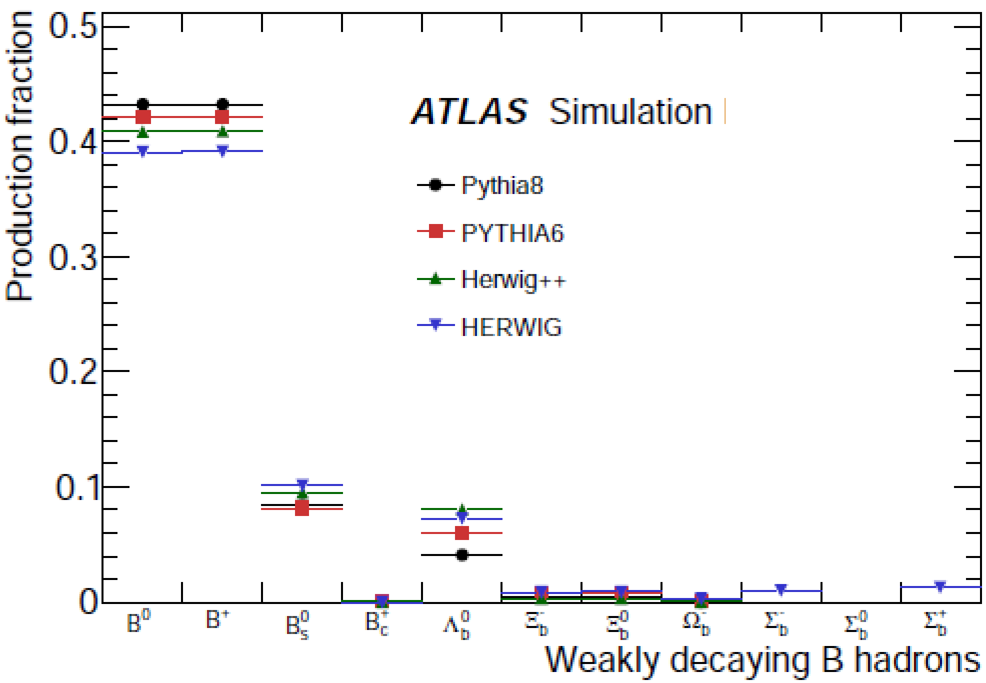
Herwig softer fragmenation in e^+e^-, but similar to other MCs in proton-proton

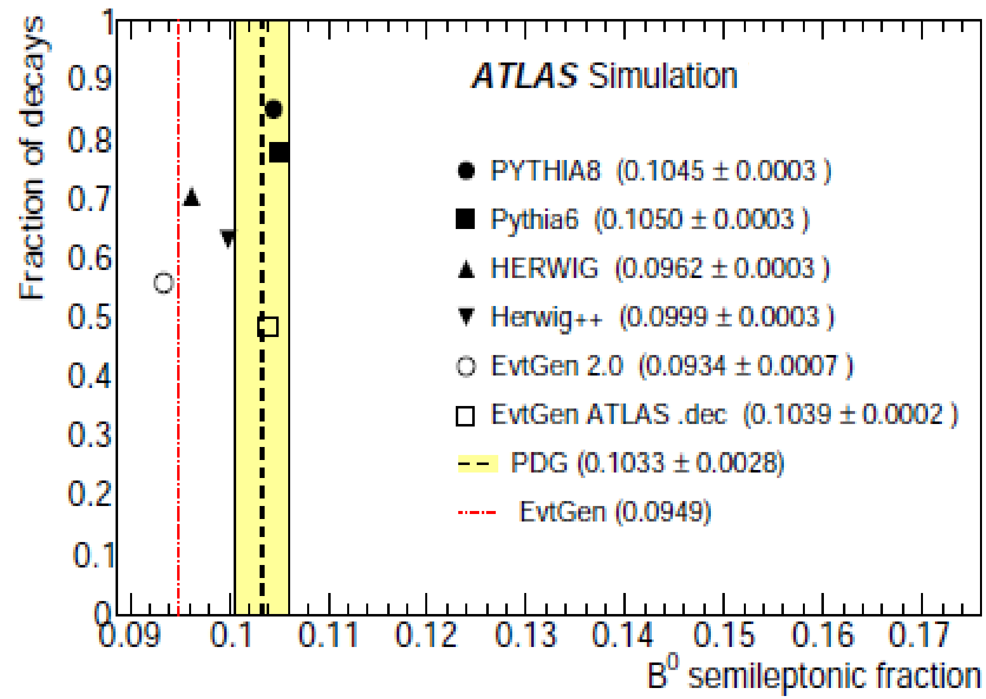
B-hadron multiplicities and decays

ATLAS started to systematically compare b-fragmentation, B-hadron multiplicities and B-hadron decays (lifetimes, semi-leptonic branching, charged multiplicities) in various MC generators
Similar CMS effort presented by M Seidel in November TopLHC meeting

Match any B-Hadrons with pt>5 GeV to jets and study B-hadron species:

Semi-leptonic decay fractions





Species	Pythia8	PYTHIA6	Herwig++	HERWIG	Referenc PDG
B^+	43.2	42.1	40.9	39.1	40.2 ± 0.7
B^0	43.2	42.2	40.9	39.1	40.2 ± 0.7
B_s^0	8.4	8.2	9.5	10.1	10.4 ± 0.6
Baryons	5.1	7.3	8.6	11.7	9.3 ± 1.5

EVTGen commissioning ongoing allows to use same b-fragmentation properties in all MCs and to define dedicated uncertainty

All MCs in reasonable agreement, Pythia8 has low Baryon fraction

Conclusion

Radiation systematics can be constraint by dedicated measurement
(jet multiplicities and fraction of events with additional jet activity)

The variations chosen by ATLAS (ACERMC ISR/FSR or ALPGEN ren&fac scale)
by CMS (Madgraph ren&fac scale)
Have similar effect on these measurements

The effect on the top mass measurements depends on the techniques

No consensus on treatment of hadronisation systematics

CMS treats this as cross-checks and claims all effects are included in
jet energy scale uncertainty and b-fragmentation

ATLAS can not exclude effects on overall event topology (e.g. p_{Ttop})
and would like to keep effect on ME+PS merging

Good news is that all numbers are meanwhile available.

The possible double counting on many modelling effects is hard to evaluate
In my view, all uncertainties should be evaluated
However, it is not clear, if added in quadrature or taking maximum of
various effects is better (also given the large statistical uncertainties)

B-fragmentation needs more attention. Measurements are needed !

Back-up

Settings and Samples

ATLAS settings for radiation systematics

AcerMC + Pythia6 AUET2B LessPS and MorePS	AcerMC 3.8	Pythia6 v6.426	$Q = 2mt$	CTEQ6l1	AUET2B
	+ PARP(67), PARP(64), PARP(72), PARJ(82) variations				
Alpgen + Pythia6, P2011	Alpgen v2.14	Pythia6 v6.425	$Q = \sqrt{\sum m_T^2}$, with $m_T^2 = m^2 + p_T^2$	CTEQ5L	Perugia 2011
Alpgen as_down,radHi	same settings as Alpgen + Pythia6, P2011 but with ren. scale in ME and PS varied simultaneously by factor 0.5 and UE retune				Perugia 2011 radHi
Alpgen as_down,radLo	same settings as Alpgen + Pythia6, P2011 but with ren. scale in ME and PS varied simultaneously by factor 2.0 and UE retune				Perugia 2011 radLo

CMS settings for radiation systematics

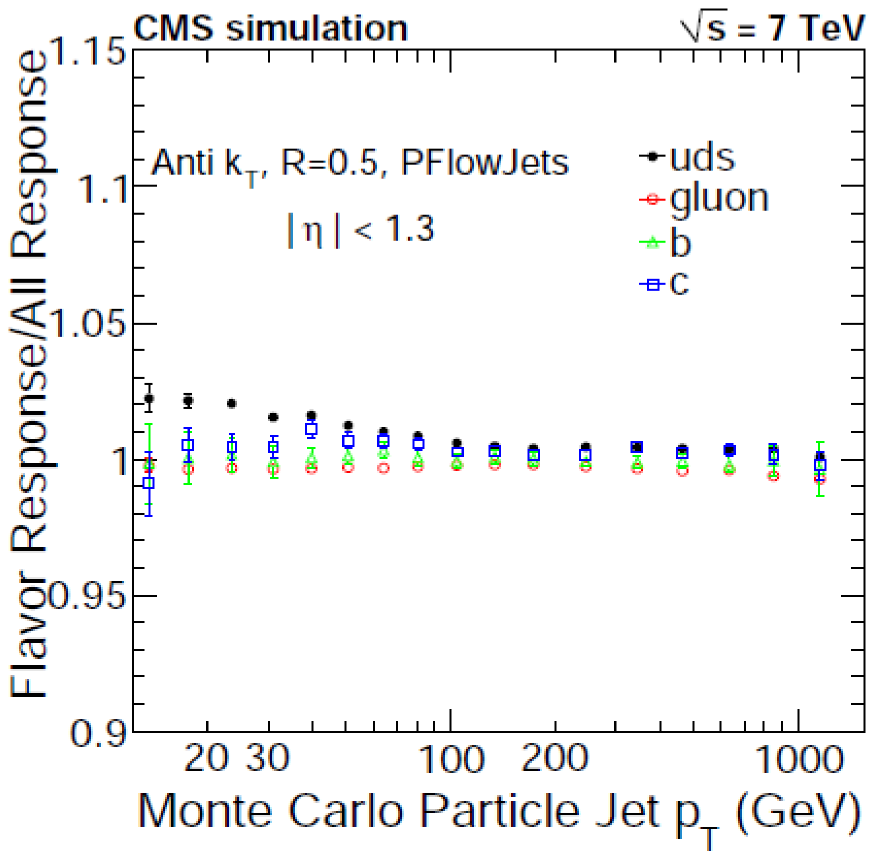
MadGraph + Pythia6, Z2 (used in 7 TeVanalyses)	MadGraph v5.1.1.0	Pythia6 v6.424	$Q = \sqrt{m_t^2 + \sum p_T^2(jet)}$	CTEQ6l	Z2

	CMS MadGraph +Pythia6	ATLAS Alpgen +Pythia6	ATLAS AcerMC +Pythia6 7 TeV (8 TeV)
nominal sample settings			
FSR: PARP(72)	0.25 GeV	0.26 GeV	0.26 (0.527) GeV
ISR: PARP(64)	1.0	1.0	1.0 (0.68)
PARP(61)	0.25 GeV	0.26 GeV	0.26 (0.192) GeV
ME: alpsfact/ktfac	1.0	1.0	-
Less PS (as_down,radLo) sample settings			
FSR: PARP(72)	0.125 GeV	0.13 GeV	0.11 (0.150) GeV
ISR: PARP(64)	4.0	-	3.50 (4.08)
PARP(61)	-	0.13 GeV	same as nominal
ME: alpsfact/ktfac	2.0	2.0	-
More PS (as_up,radHi) sample settings			
FSR: PARP(72)	0.50 GeV	0.52 GeV	0.37 (0.425) GeV
ISR: PARP(64)	0.25	-	0.90 (1.02)
PARP(61)	-	0.52 GeV	same as nominal
ME: alpsfact/ktfac	0.5	0.5	-

Detector response to jets in CMS simulation

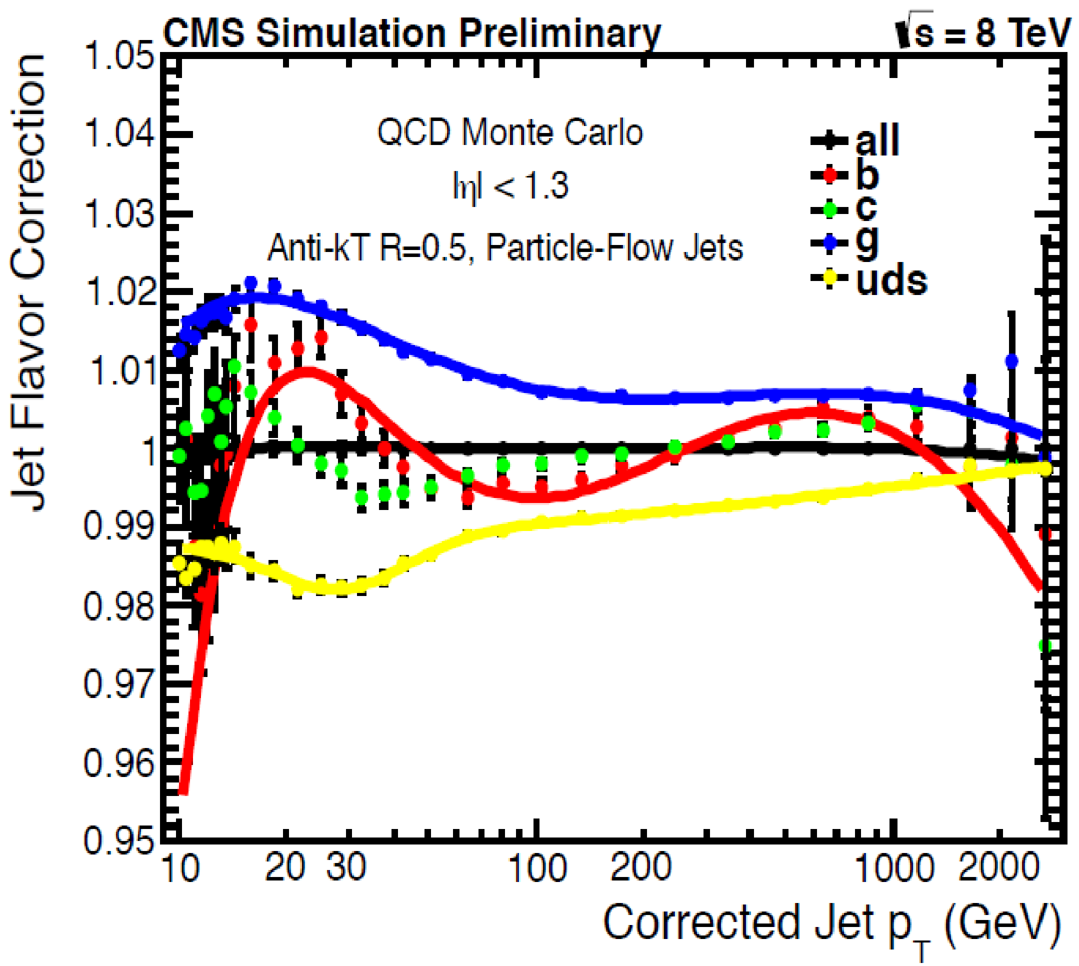
B-JES: CMS 2011

b-jet response in between light-quark/gluon response taken Pythia/Herwig++ for light quark/gluons as b-jet uncertainty



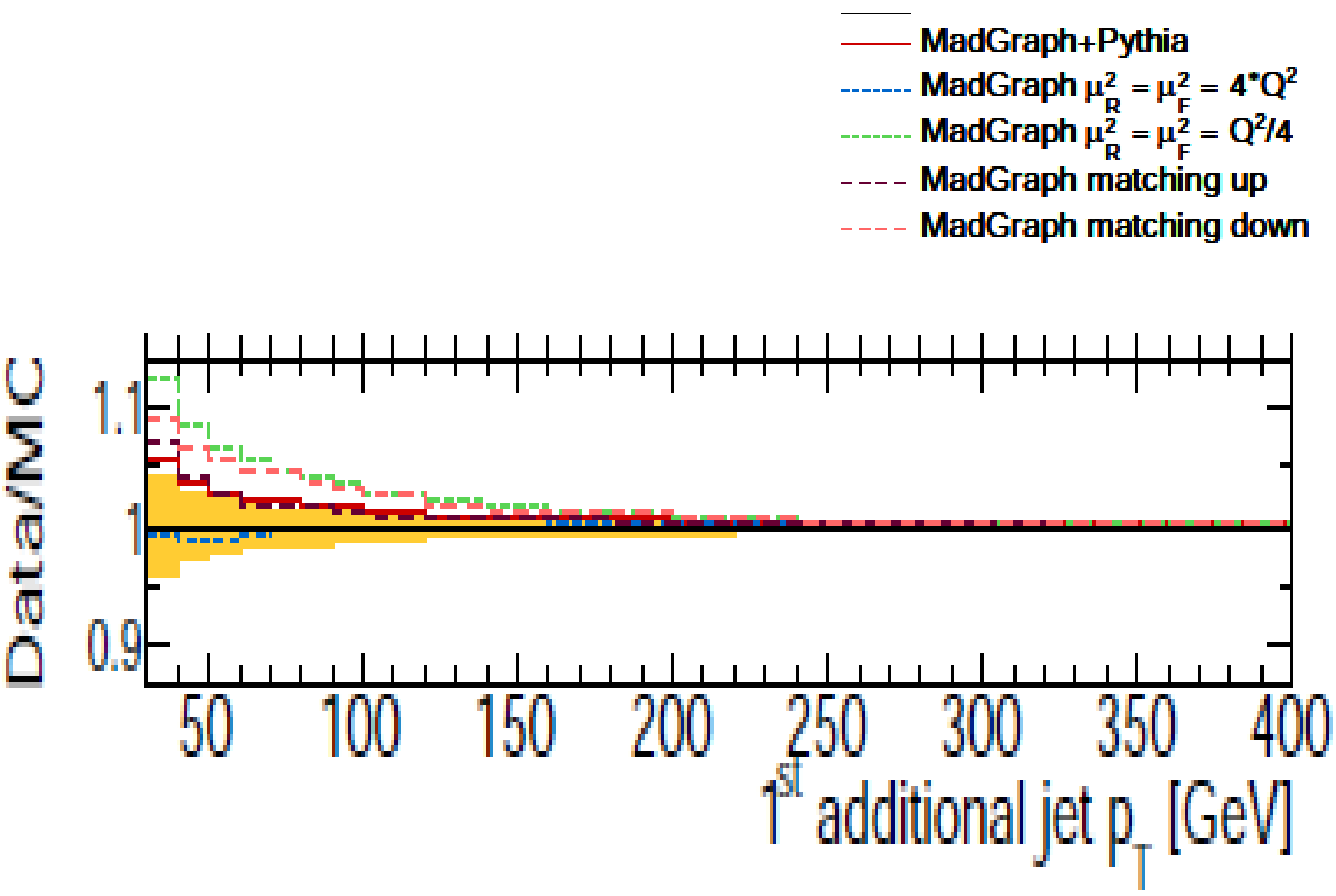
B-JES CMS 2014

Compare Pythia/Herwig++ for each jet flavour
For light-quarks, gluons and b-quark uncertainty is evaluated separately and added in quadrature



These results are based on Herwig++
-> CMS and ATLAS need to move to ttbar MC with Herwig++ (work ongoing)

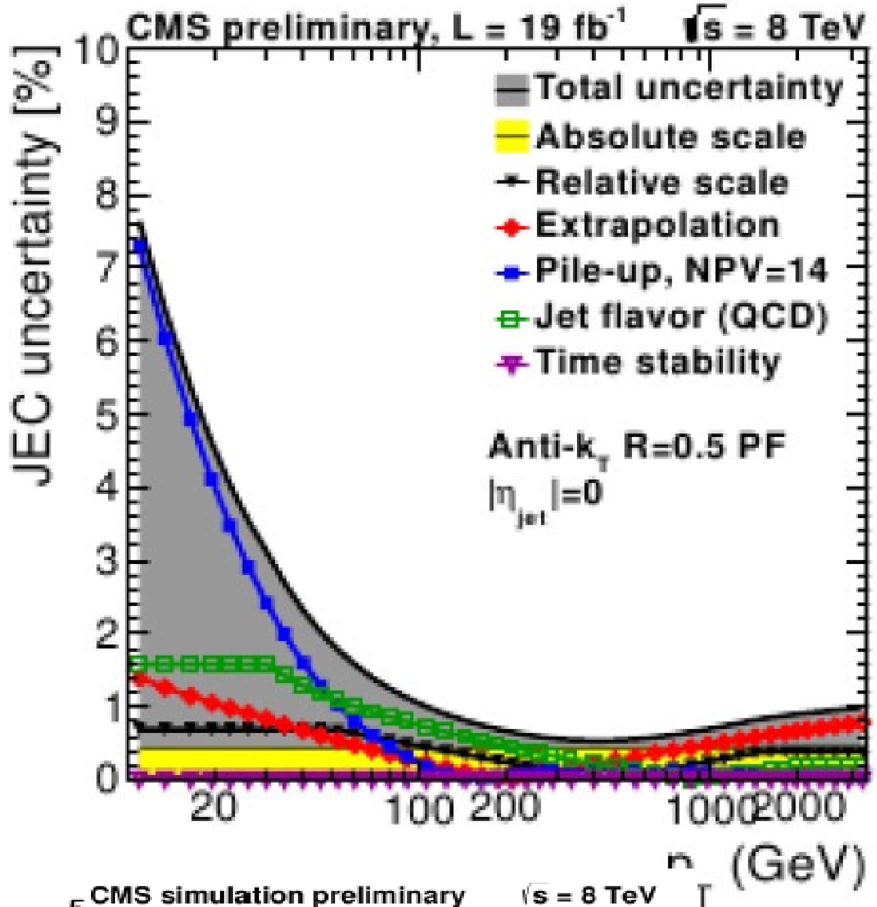
Additional Radiation Systematics CMS

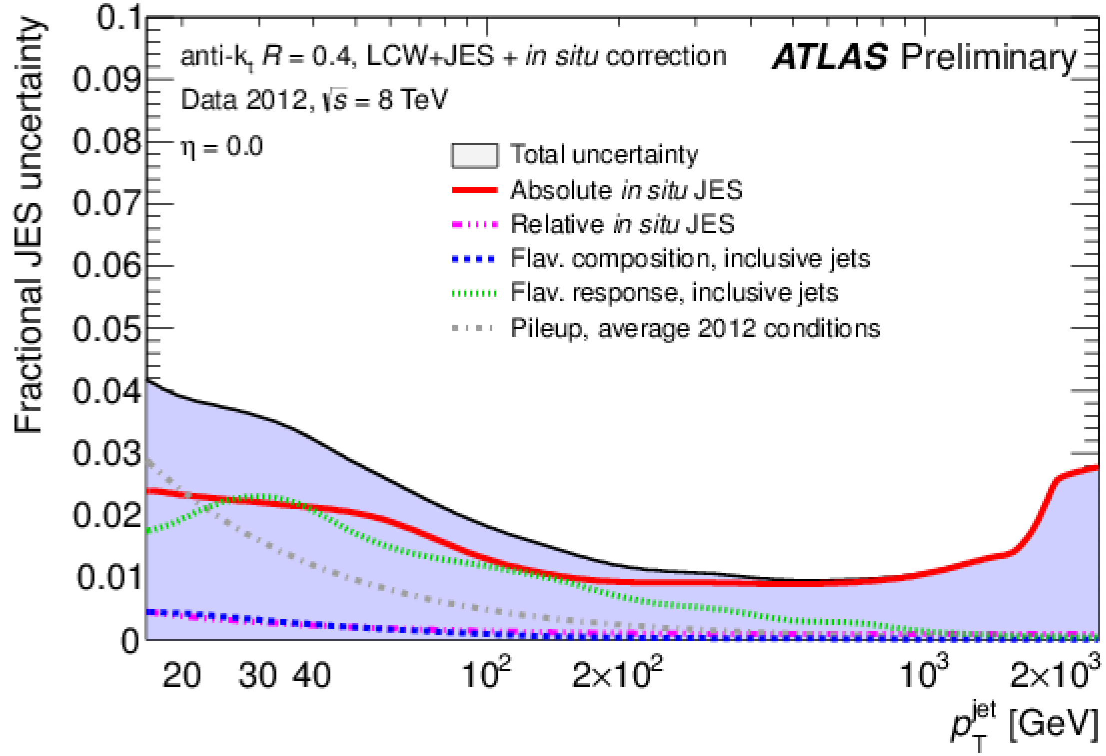


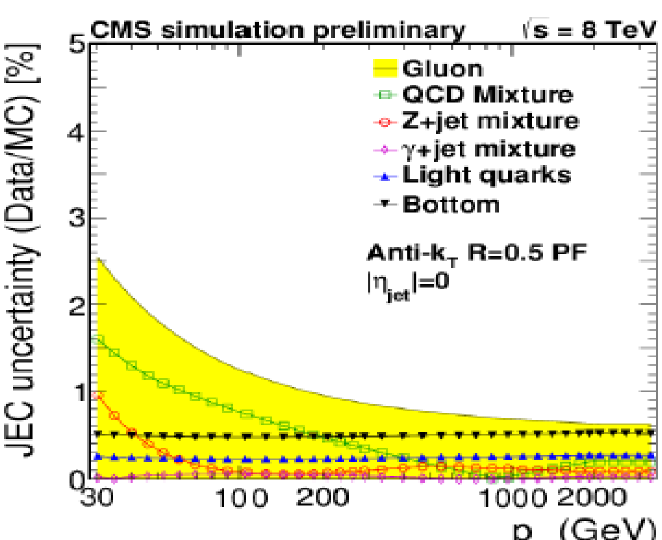
JES – 8 TeV

CMS – DB-2013/033
(set of slides)

ATLAS 2012 - figures







	CMS			ATLAS		
JES	20	50	100	20	50	100
pile-up	2%	1%	0.4%	1.5%	1%	0.1%
flavour	1.5%	1%	0.8%	2%	1.5%	1.2%
total	3%	2%	1.2	4%	3%	1.8%