Jet energy measurement in the ATLAS detector

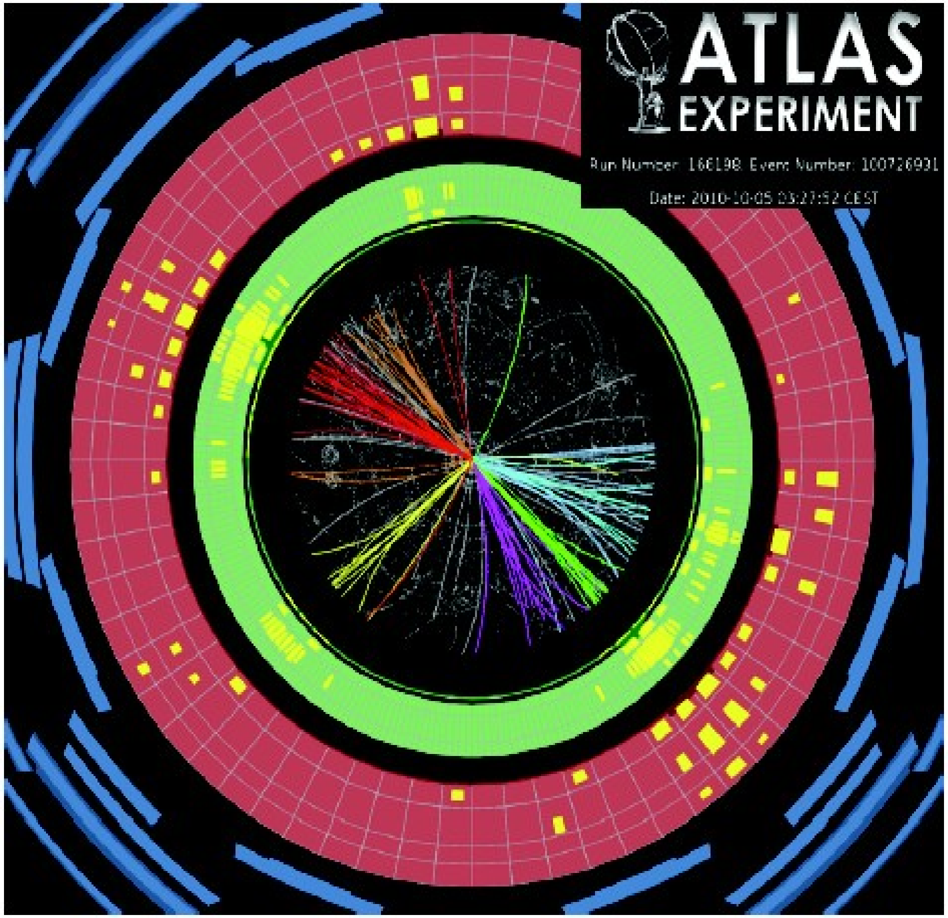
Jet energy scale uncertainties are usually among largest experimental uncertainties

Need precise jet energy measurements and provide
uncertainties and theit correlations to physics analysis

Need also to identify sources that are correlated/uncorrelated across experiments

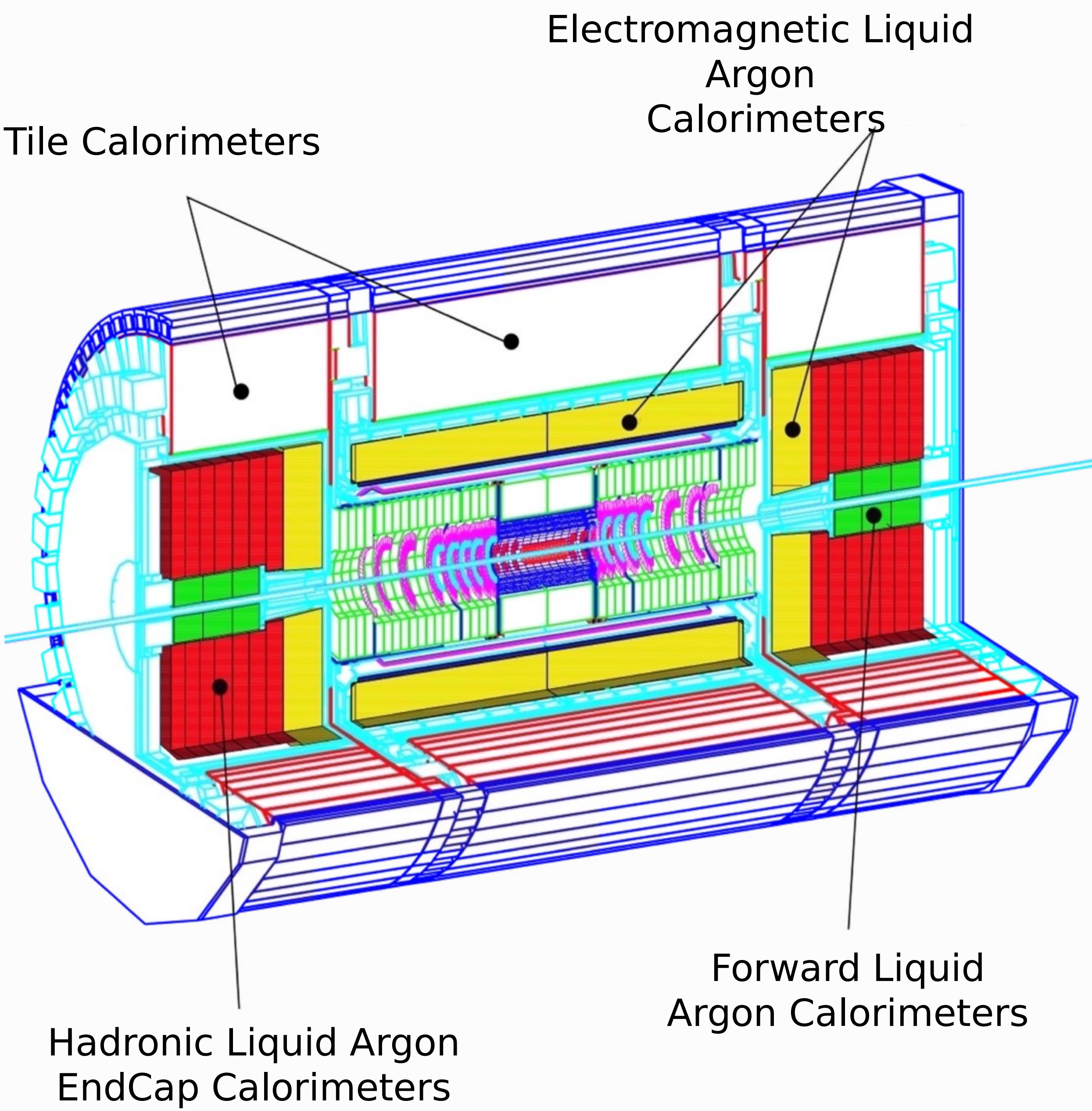
Outline:

- Jet calibration
- Single hadron response in ATLAS calorimeter
- Strategy to derive JES uncertainties
- Results for 2010, 2011 and 2012



Tancredi.Carli@cern.ch

ATLAS calorimeter



Electromagnetic Calorimeters:

* Liquid Argon/Pb accordion structure;
* highly granular readout (~170,000 channels);
* $0.0025 \leq \Delta\eta \leq 0.05$, $0.025 \leq \Delta\varphi \leq 0.1$;
* 2-3 longitudinal samplings;
* ~24-26 X_0 deep
* covers $|\eta|<3.2$, presampler up to $|\eta|<1.8$;

Central Hadronic Calorimeters

* Scintillator/Fe in tiled readout;
* $\Delta\eta \times \Delta\varphi = 0.1 \times 0.1$
* 3 longitudinal samplings,
* covers $|\eta|<1.7$;

EndCap Hadronic Calorimeters

* Liquid Argon/Cu parallel plate absorber structure;
* $\Delta\eta \times \Delta\varphi = 0.1 \times 0.1$ ($1.5<|\eta|<2.5$),
$\Delta\eta \times \Delta\varphi = 0.2 \times 0.2$ ($2.5<|\eta|<3.2$);
* 4 samplings;

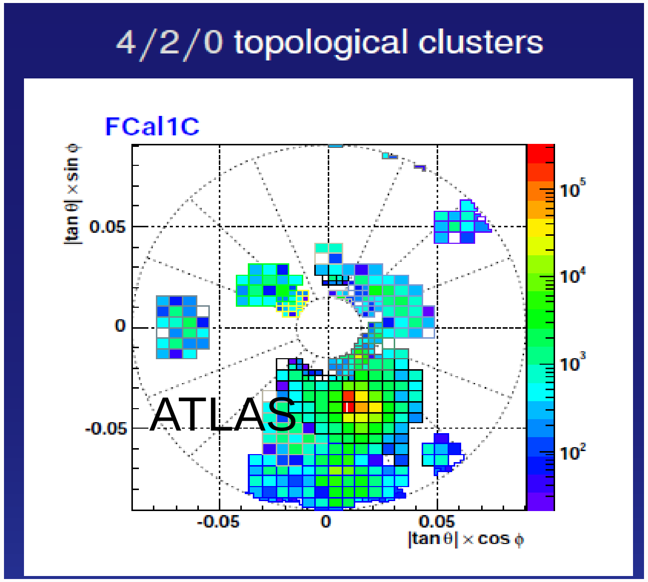
Forward Calorimeters

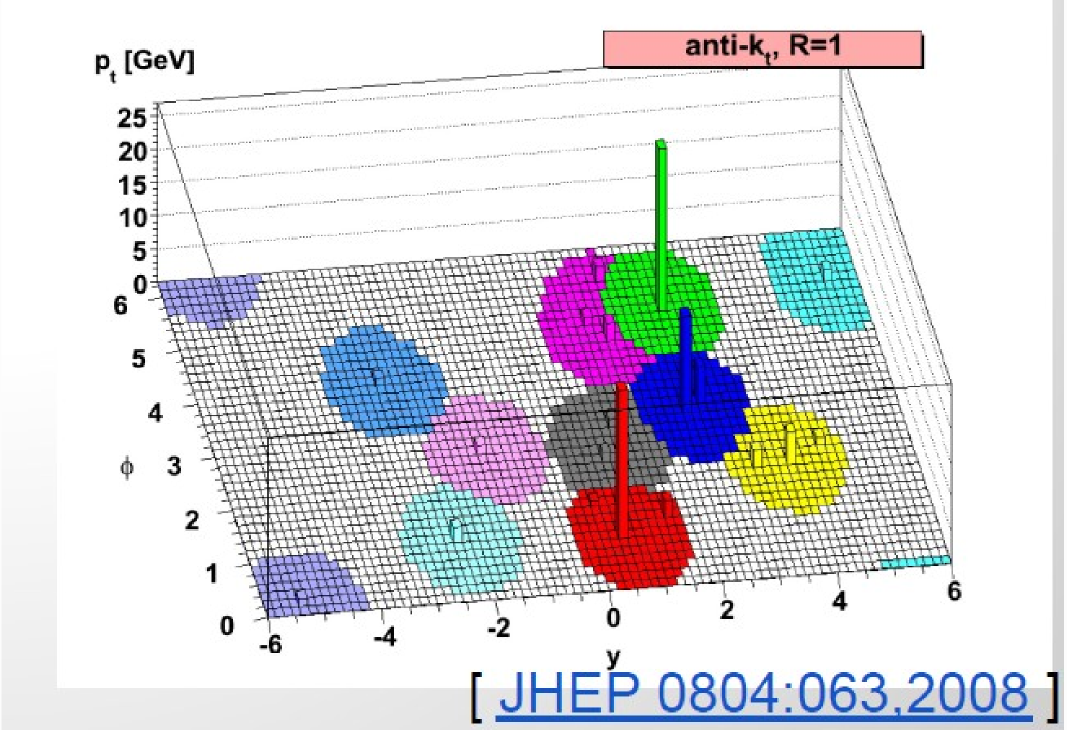
* Liquid Argon/Cu or W absorbers with tubular electrodes in non-projective geometry;
* $\Delta\eta \times \Delta\varphi \approx 0.2 \times 0.2$ ($3.2<|\eta|<4.9$)
* 3 samplings;

Jet Definitions

Jet algorithm:
ATLAS uses the anti-kt jet algorithm with R=0.4 and 0.6
Clustering algorithm starting from the hardest jet input.
Input: calorimeter clusters, tracks, particles, partons

Other algorithms in use:
Anti-kt with R=1.0,
Cambridge algo for substructure techniques...
.





[JHEP 0804:063,2008]

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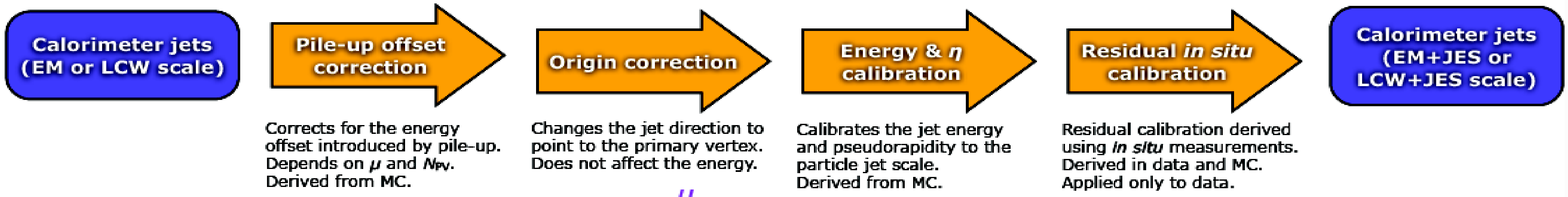
Jet inputs:
Topological calorimeter clusters starting from high S/B calo cells and adding neighbours
calibrated suing
• basic calorimeter scale (EM-scale)
• locally corrected for lower hadron response, dead material
  and out-of-cluster losses (LCW-scale). Calibration derived from single pion MC.
Track jets are used for systematic studies and special cases
 jet mass, b-JES, subjets JES, pile-up etc.

Jet calibration strategy



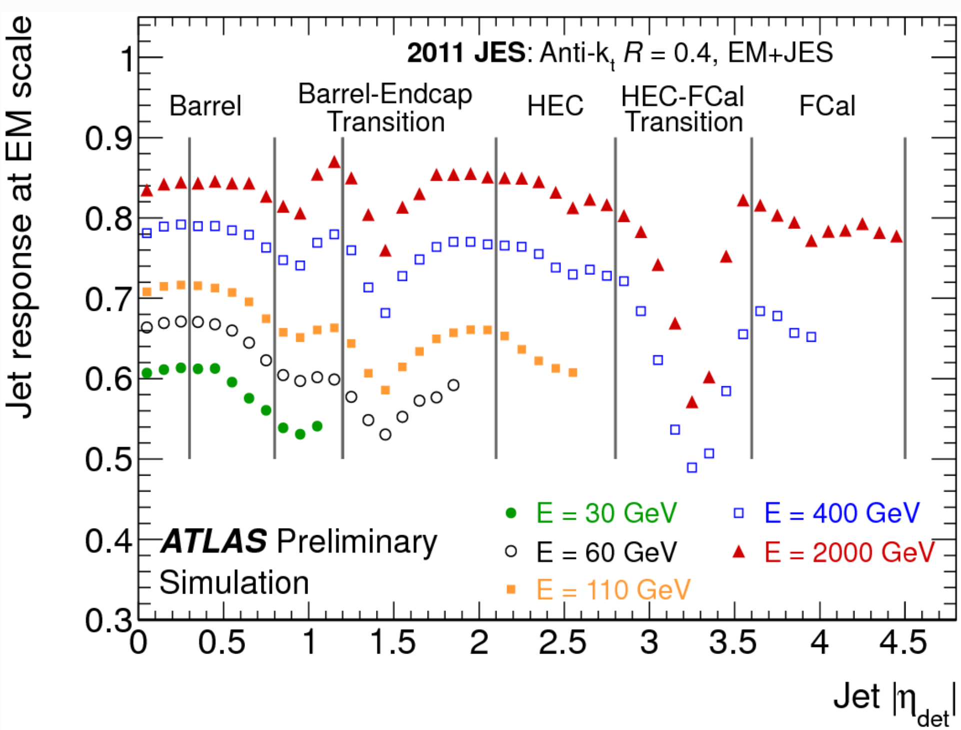
very small

Corrections derived from MC

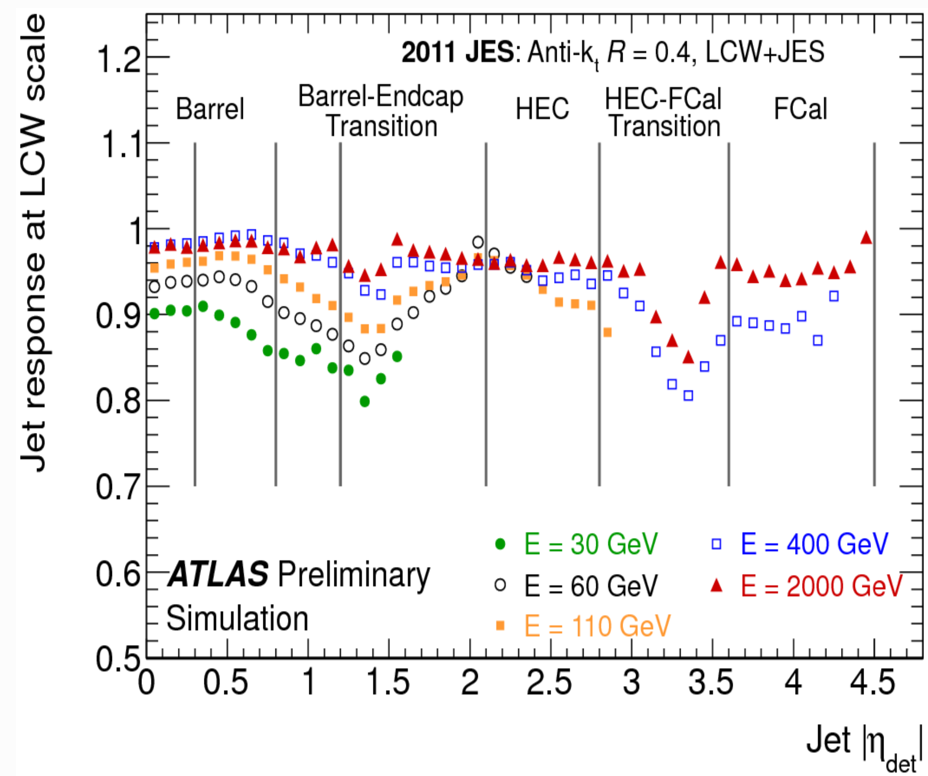
Residual calibration measured in data and MC (up to 2.5%)

Jet calibration done with respect to the inclusive jet sample (using MC)
ATLAS quotes JES uncertainties with respect to MC (not absolute)
Data corrected to MC particle jet reference

Basic cluster energy measurement (EM-scale)

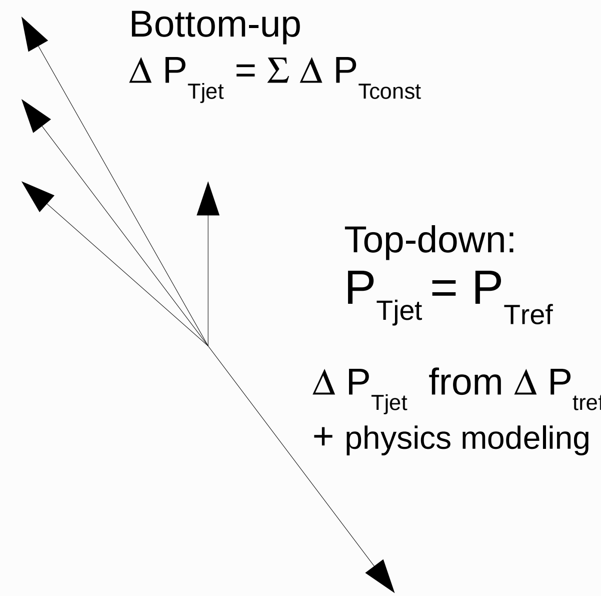


Local cluster calibration applied (LCW-scale)



Techniques to determine JES uncertainties

Jet calibration done with respect to the inclusive jet sample (using MC)
ATLAS quotes JES uncertainties with respect to MC
Evaluate how MC describes data



Bottom-up approach:

Evaluate measurement uncertainties of jet constituents complemented with modeling uncertainties on particle spectra impinging the detector

Top-down approach:

Use well measured reference object and do some physics assumption (e.g. on pt-balance of jet to reference object)

ATLAS:
2010: jet constituents uncertainties and in situ pt-balance methods as cross checks (bottom-up)
2011: in situ balance methods up to 1 TeV, jet constituents uncertainties above (top-down)

JES uncertainty in central region (baseline JES) using top-down or bottom up approach

Relative forward to central JES uncertainty from dijet balance

Uncertainties depending on event samples:
- Jet flavour: gluon/light-quark/heavy-quark (*)
- Pile-up depending on measured number of primary vertics and average number of expected pile-up events
- Presence of close-by jets (dR_{JJ})

(*) Definition of jet flavour is not easy. We adopt an operational definition. To be refined...

In the following I will talk

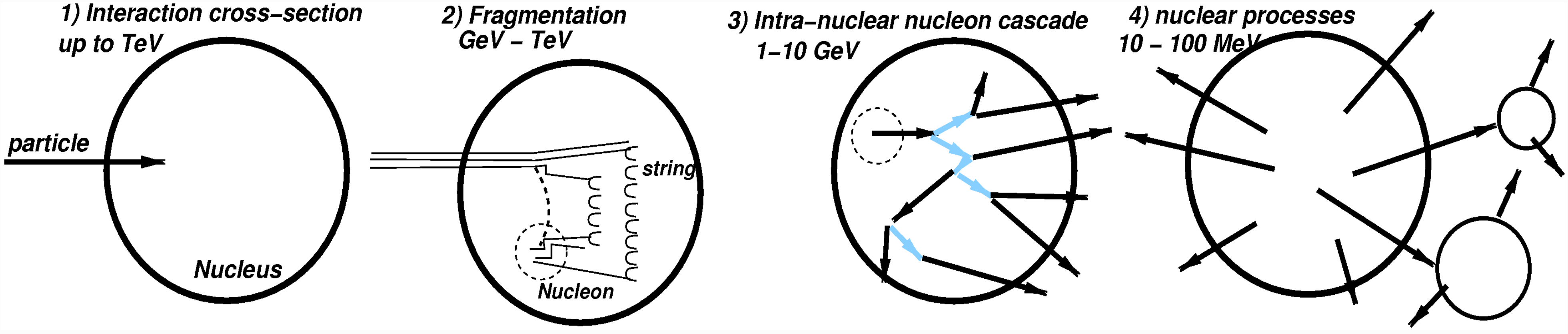
1) Understanding of the single hadron response in the ATLAS calorimeter
   - Test-beam measurements
   - in situ measurement in zero-bias proton proton collisions
   - derivation of the JES uncertainty

2) In situ techniques exploiting transverse momentum balance

3) Results on JES uncertainty

4) Examples for total JES uncertainty for given event topologies

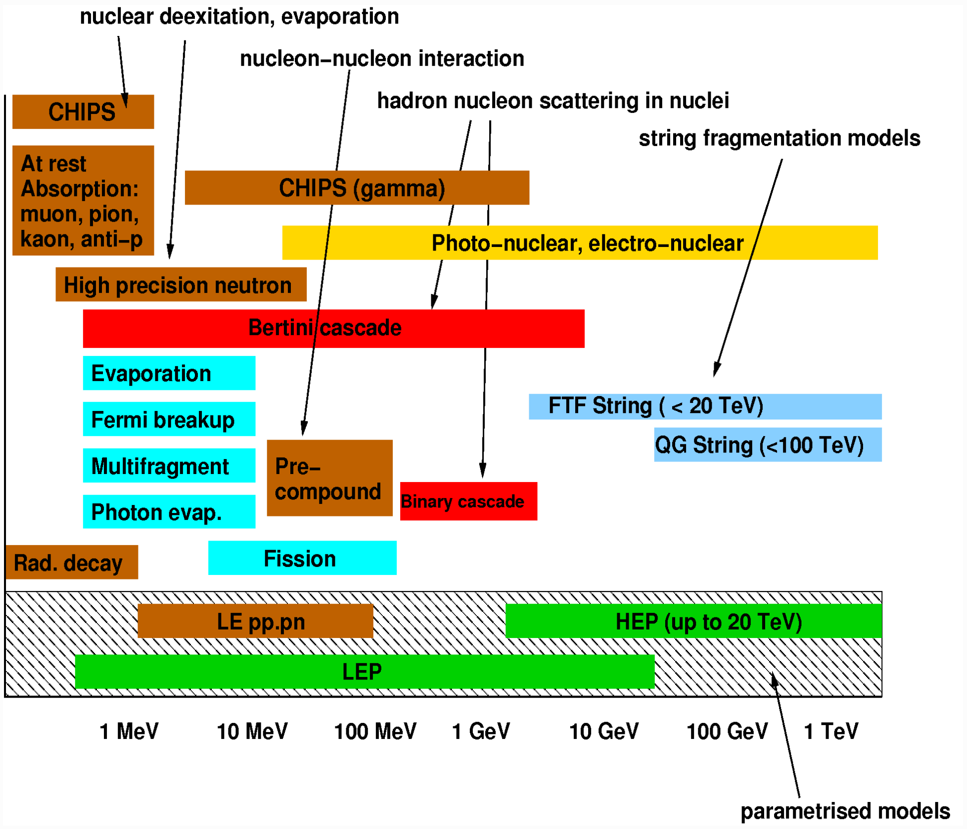
Geant4 Hadron shower models



G4 develop several models for hadron showers

LHEP: legacy from G3 parmeterisations based
QGSP: Quark/gluon string fragmentation
FTFP: Fritiof Lund model
BERT: Bertini model using nuclear cascade

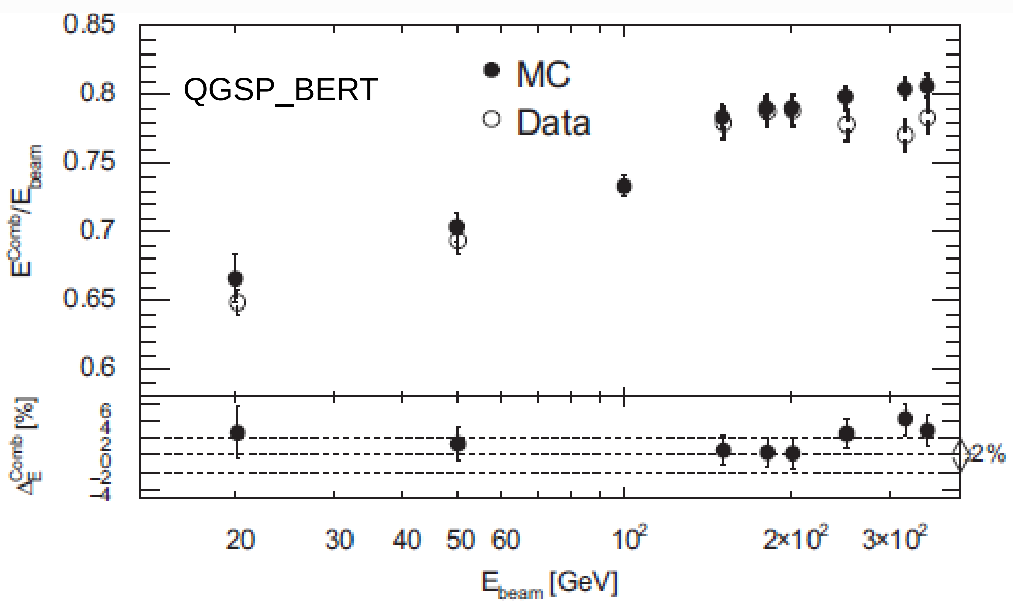
G3 used by Tevatron, Lep and Hera experiments
Early G4 default LHEP or QGSP
Based on test-beam work adapted QGSP_BERT
Might switch to FTFP_BERT in the future

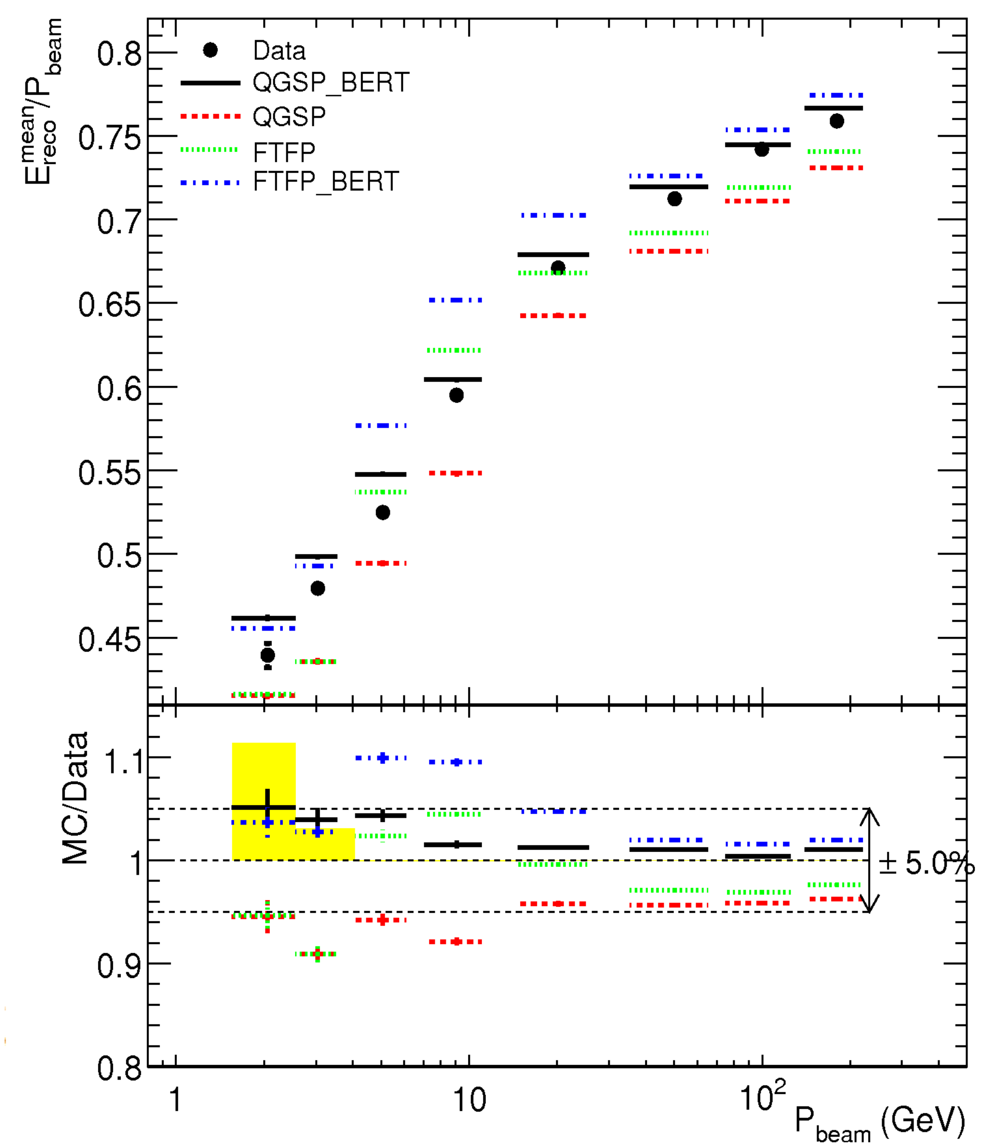


Examples of pion response measurements

ATLAS combined test-beam 2002
Barrel: tracker, Lar/Tile calorimeter
Full slice of the ATLAS detector
Reconstruction techniques as in ATLAS

QGSP_BERT describes pion response
within 2% for E>10 GeV
5% for E<10 GeV

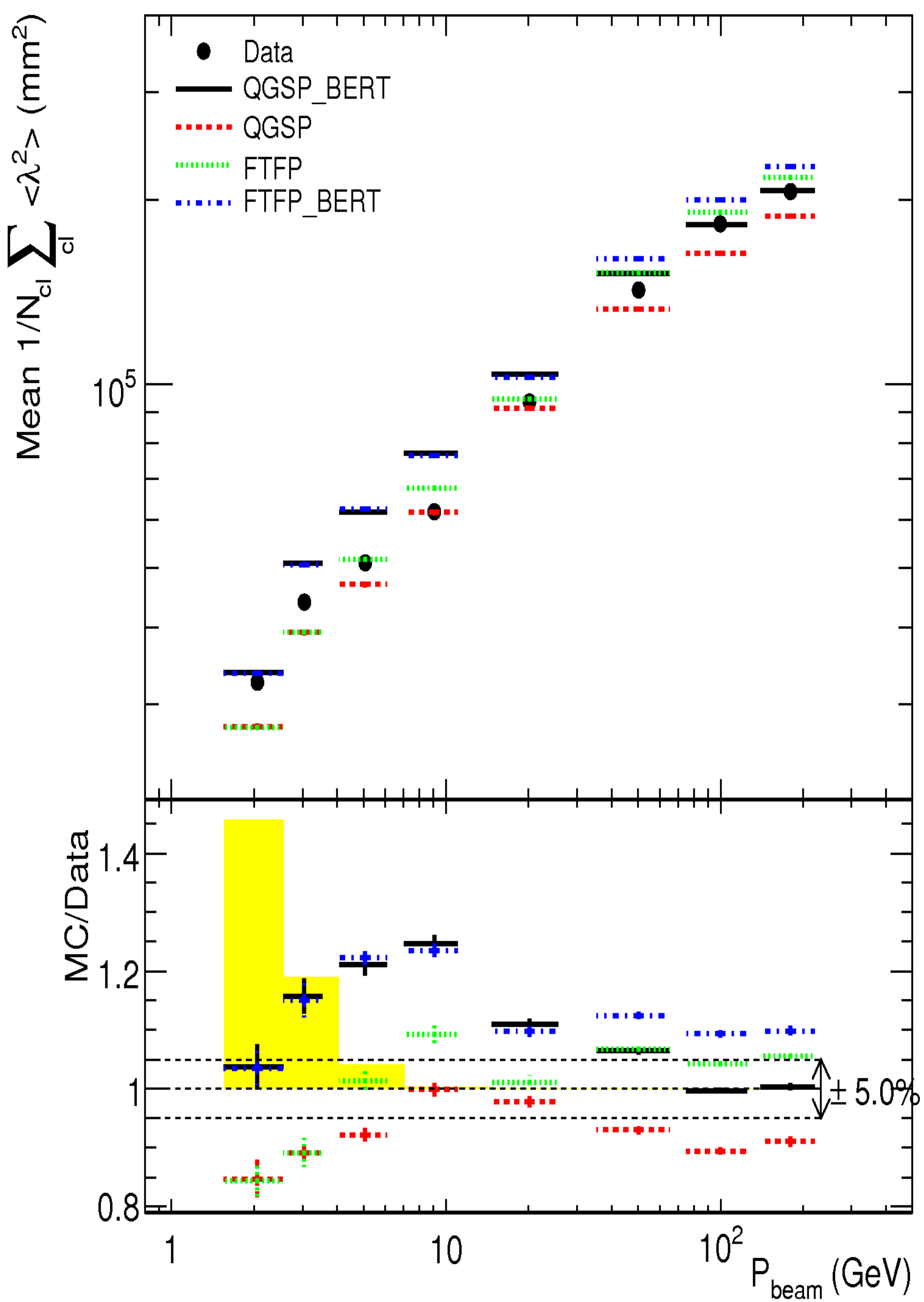


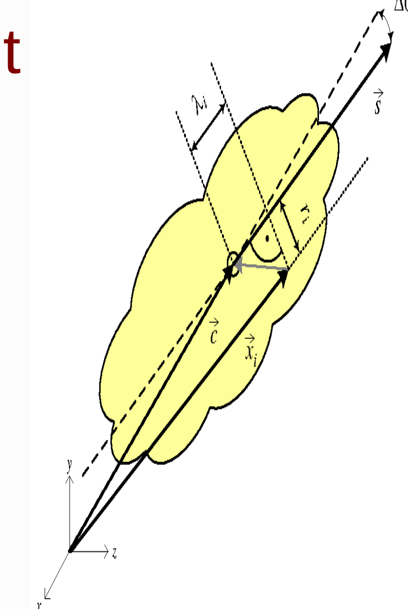


Data lower than QGSP_BERT simulation

Lateral and longitudinal shower development

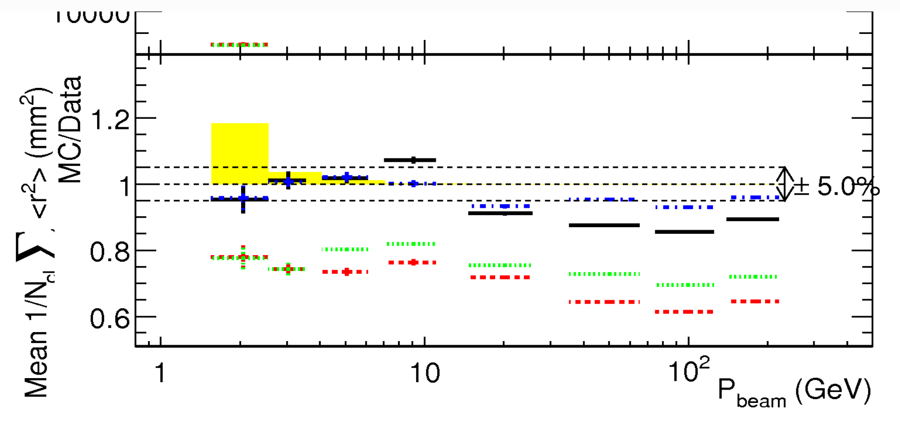
Longitudinal shower width





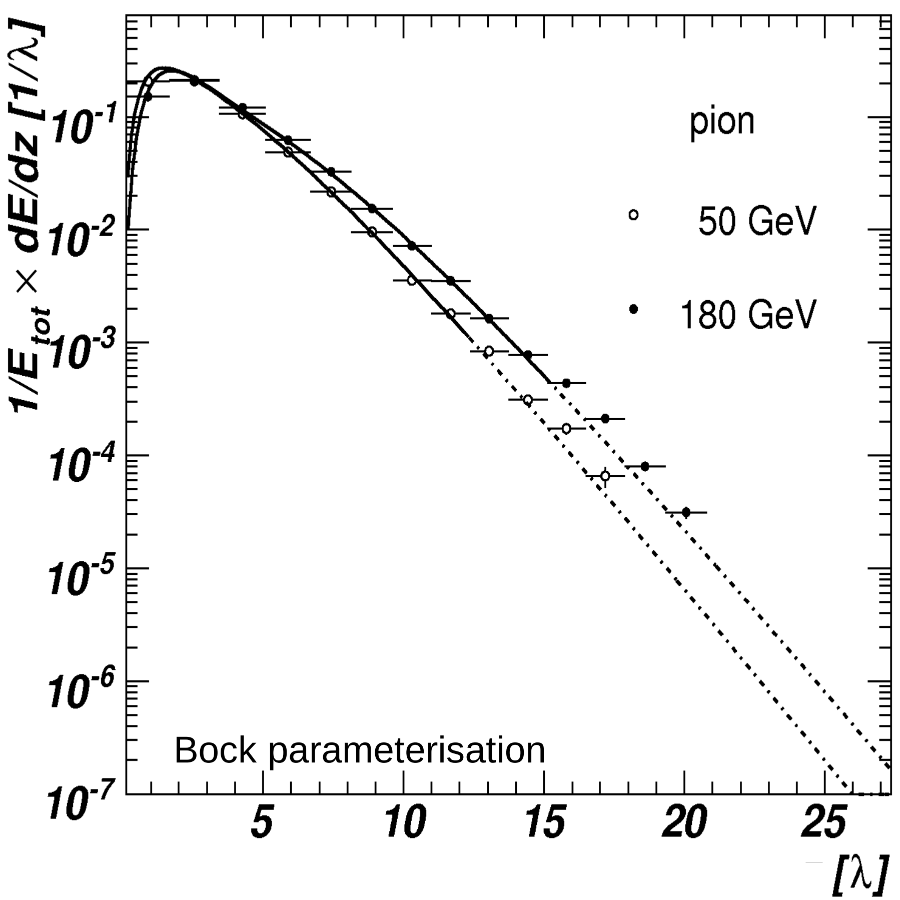
Bertini cascade widens hadronic shower longitudinally and laterally

Radial shower width

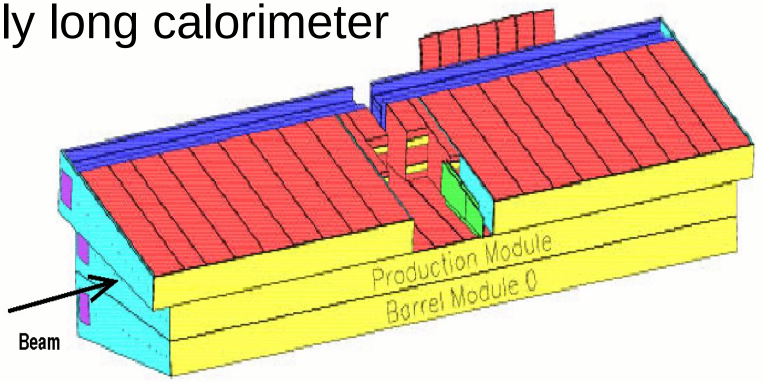


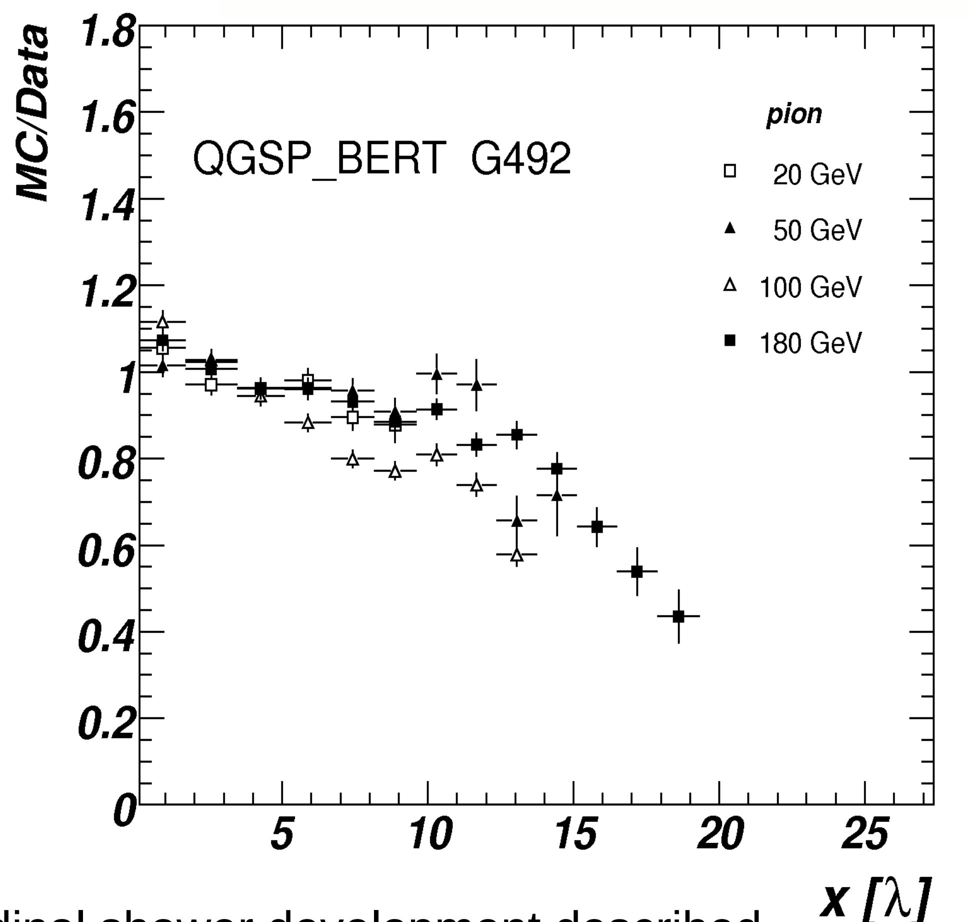
QGSP_BERT within 5% for E>10 GeV
20% for E<10 GeV
Showers still to narraow and short
Fritiof based showers too long

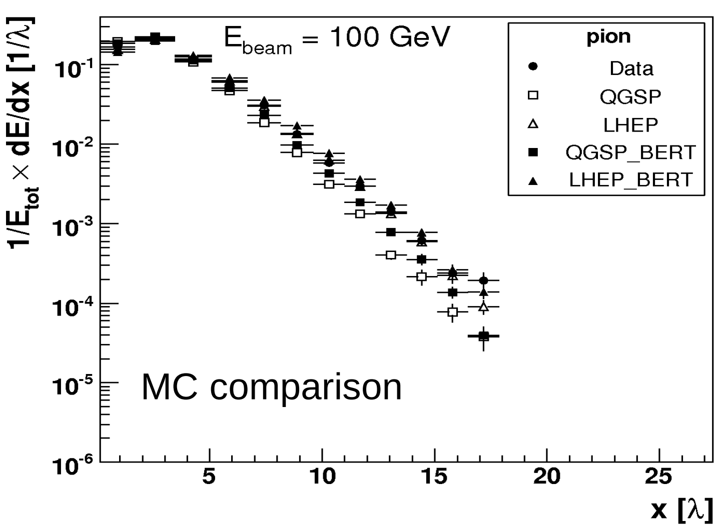
Tile calorimeter test-beam



TileCal rotated with respect to position in ATLAS
-> inifinitely long calorimeter







Longitudinal shower development described
Within ~10%. Still too short at low energies.

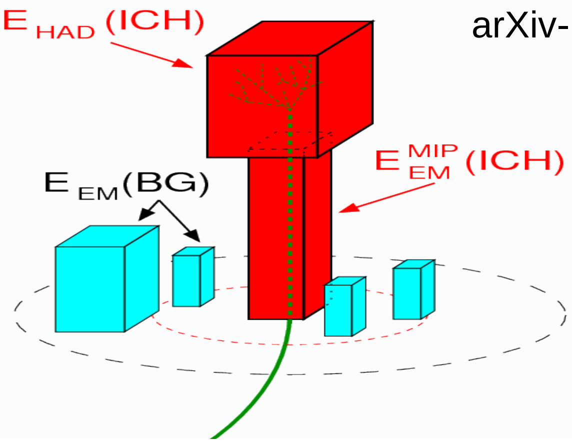
ATLAS calorimeter response uncertainty from single hadron response

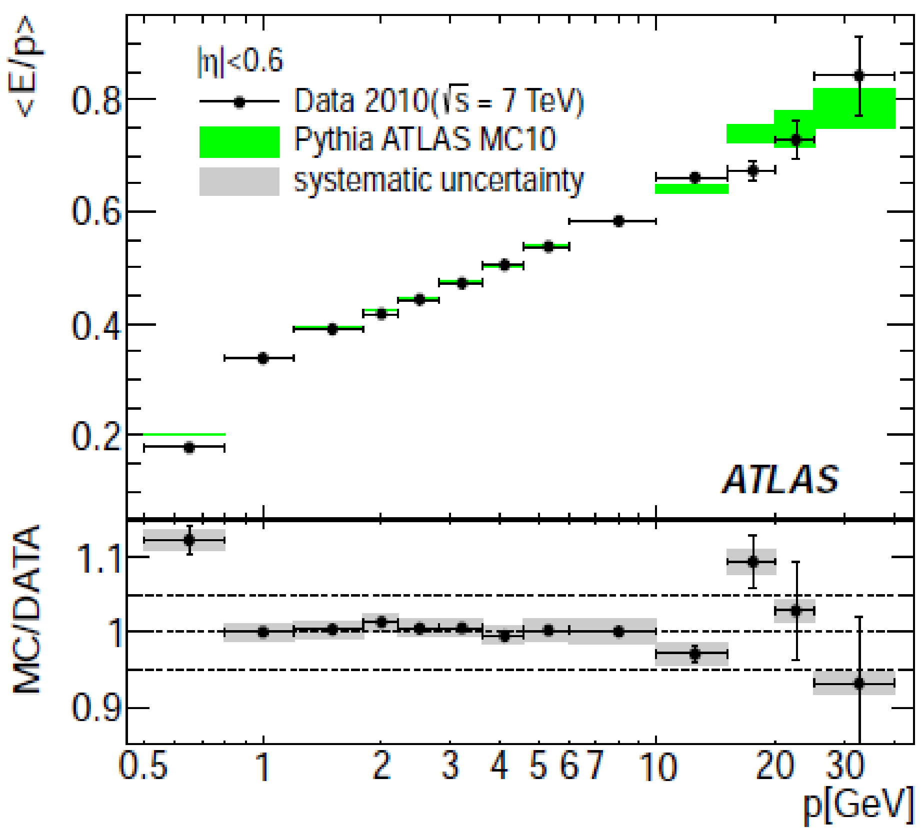
In situ single hadron response measurement
using isolated tracks in zero-bias proton proton collisions

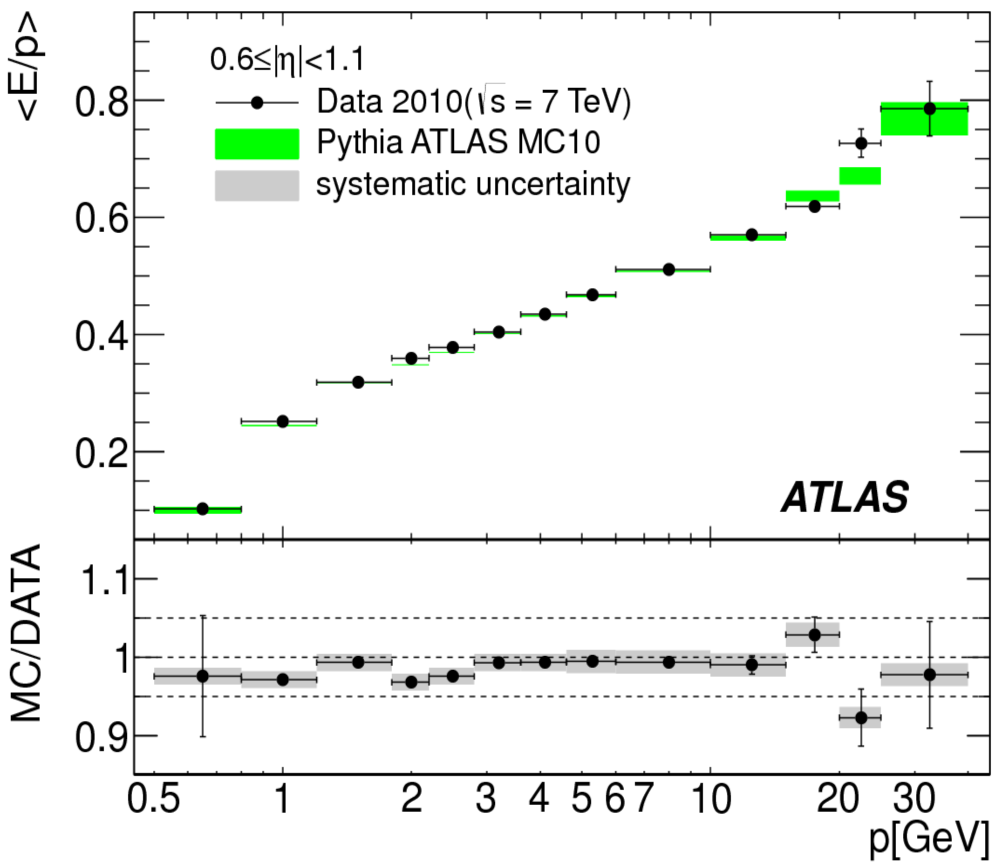
Background from neutral particles measured and subtracted
(difficult below 2 GeV)

Mix of hadrons (pion, proton, kaons). Special studies
Using identified hadron from kaon and Lambda decays

arXiv-1203.1302



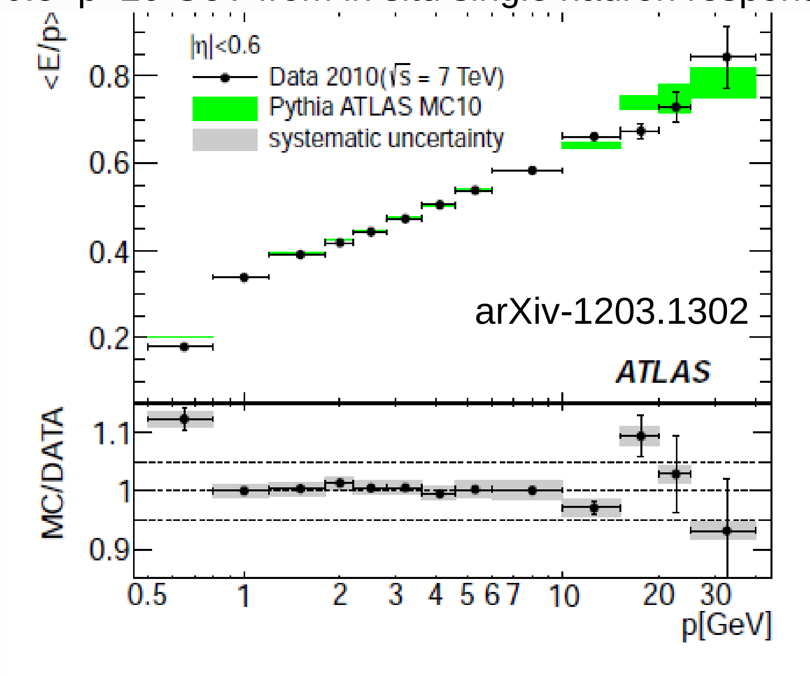




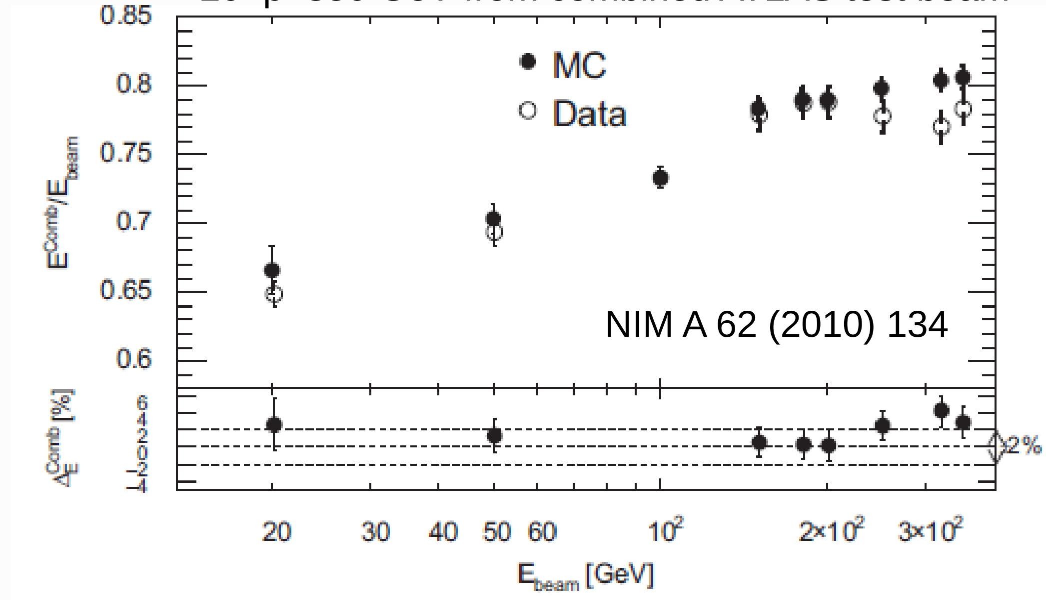
Surprise: better agreement in situ than in test beam (partly accidental, canceling effects)

ATLAS calorimeter response uncertainty from single hadron response

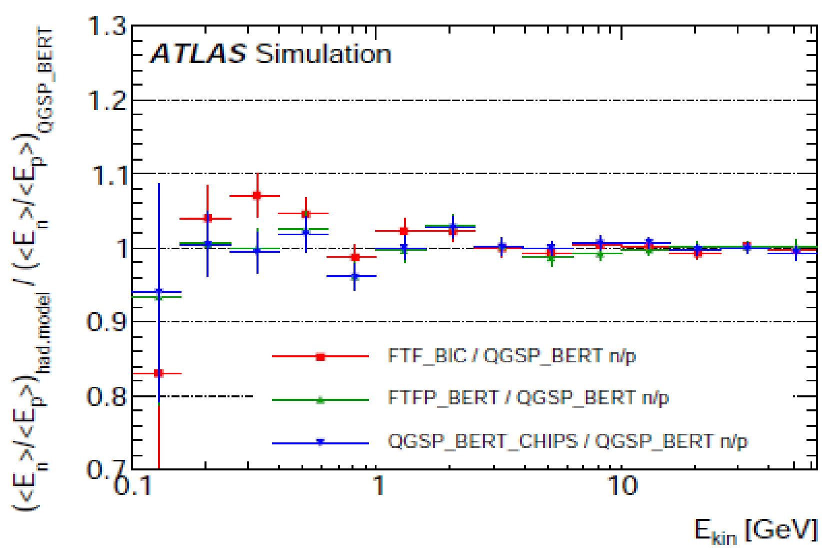
0.5<p<20 GeV from in situ single hadron response



20<p<350 GeV from combined ATLAS test beam

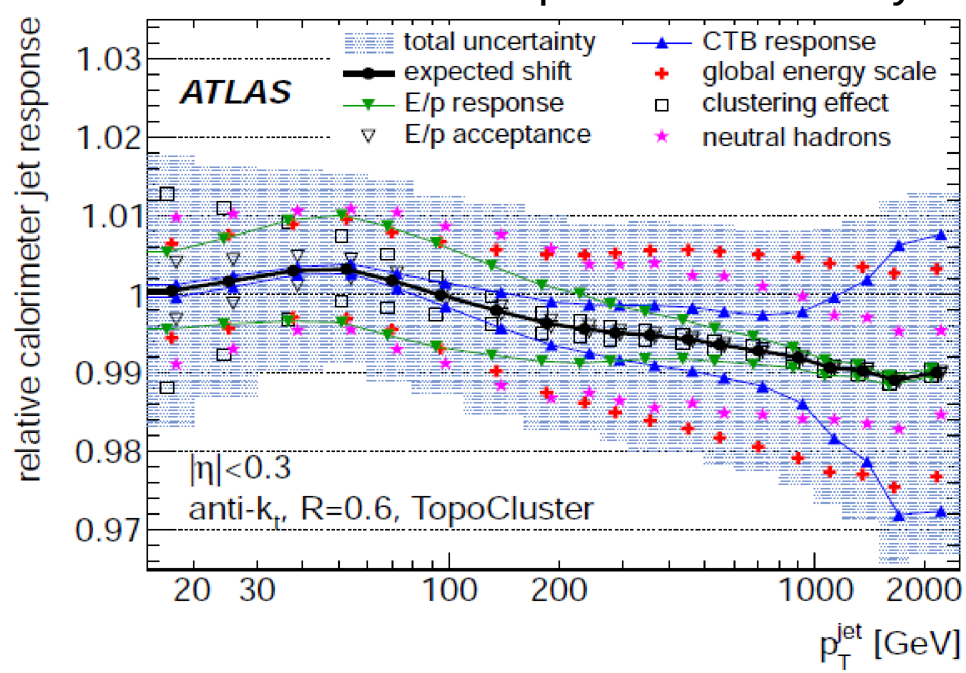


Uncertainty on neutral hadrons from MC



(a)

Calorimeter response uncertainty

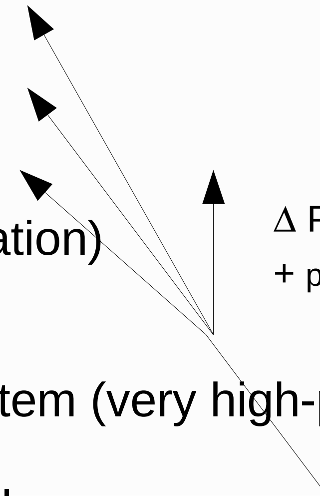


1-2%

JES uncertainty =calorimeter uncertainty+fragmentation modeling

Recent ATLAS 2011 in situ measurement results

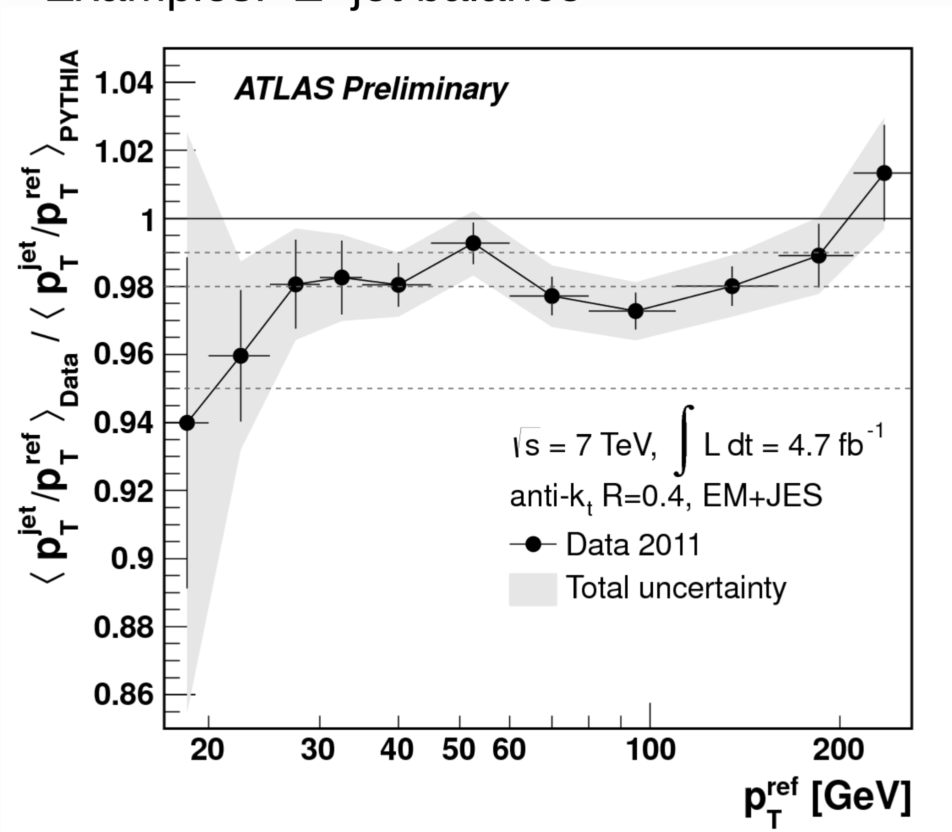
Exploit Pt balance between jet and reference object
 -> undersanding of calorimeter does not play a role
 -> need uncertainties on reference objects and physics effects (radiation)



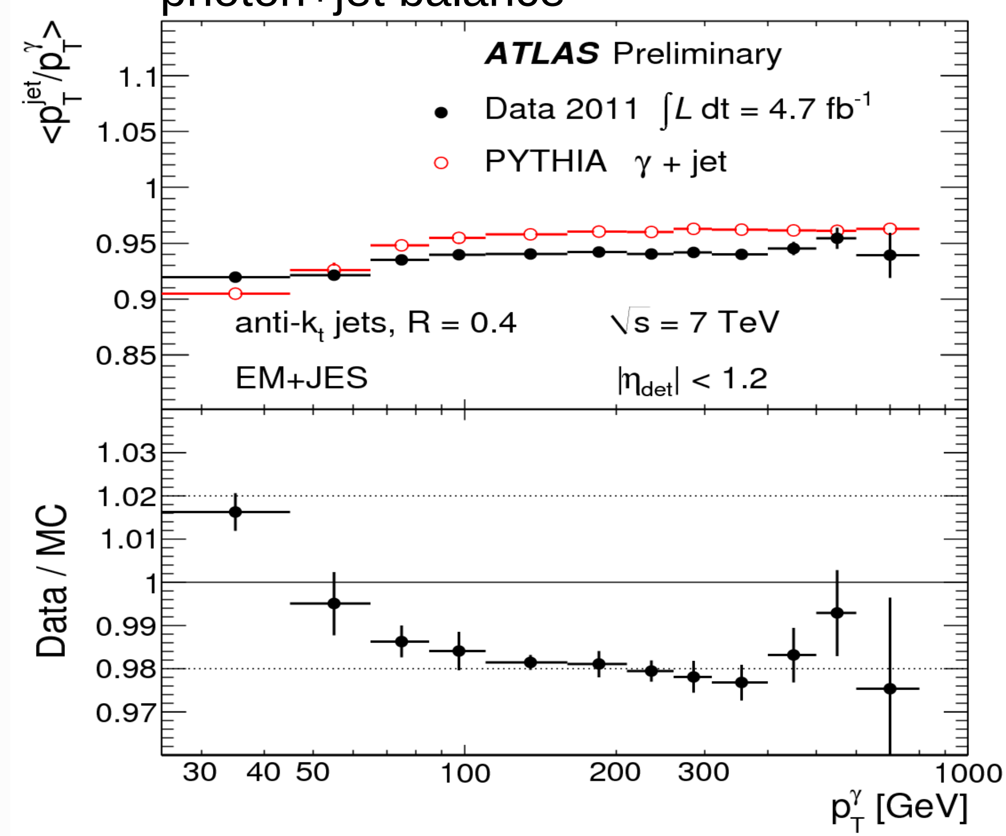
ΔP_{Tjet} from ΔP_{tref}
+ physics modeling

Reference objects:
1) Z-boson (low-pt), 2) Photon (medium and high pt) 2) Multijet system (very high-pt)

Examples: Z+jet balance



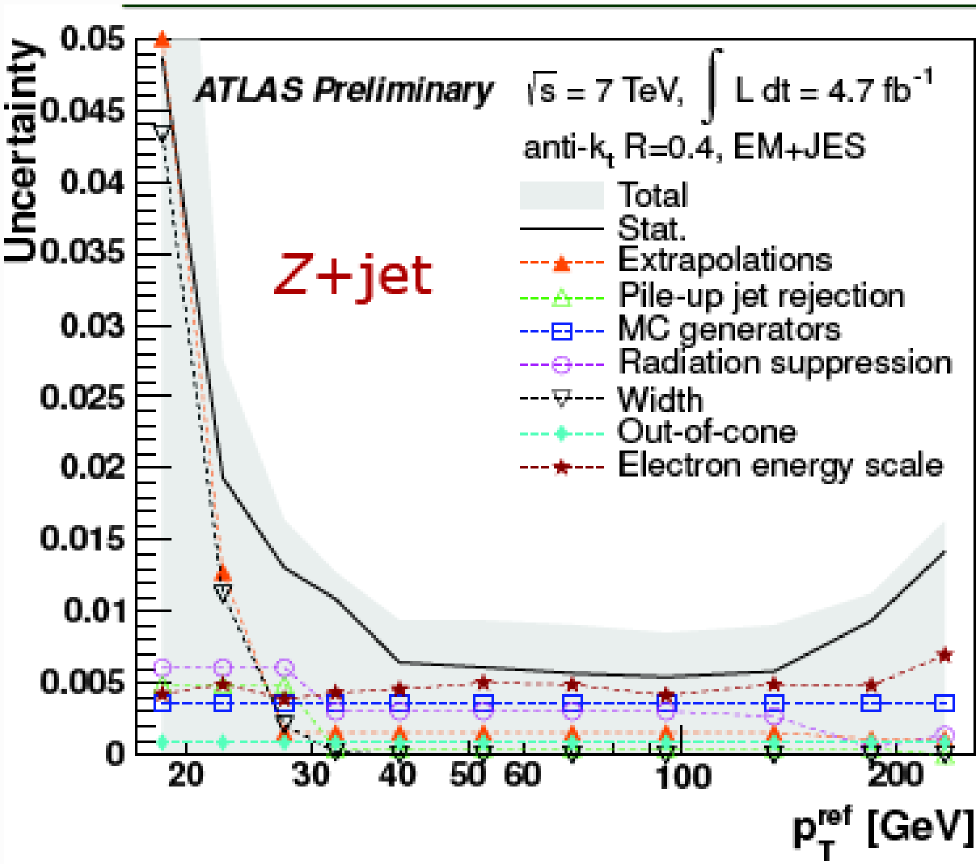
photon+jet balance

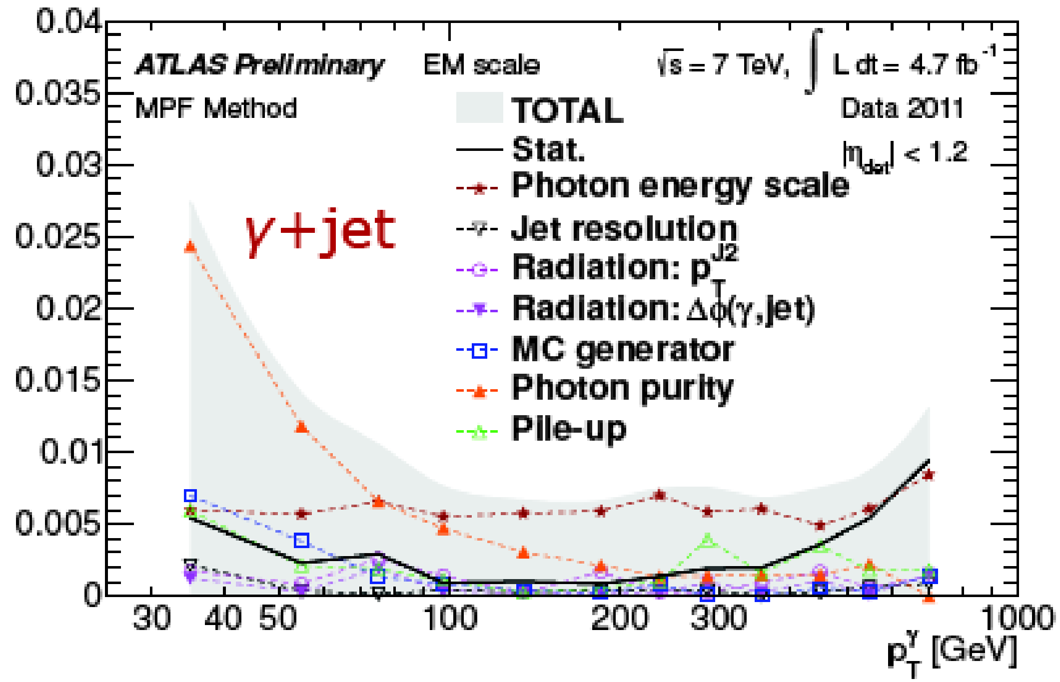


Reponse in data is about 2% lower than in MC -> can be corrected.
Correlations are derived from systematic uncertainties of in situ measurements on reference object and physics effects

Recent ATLAS 2011 in situ measurement results

Uncertainties from uncertainties on reference object (electron/photon scale)
and evaluation of physics effects (how well MC describes radiation, compare various models)





17-100

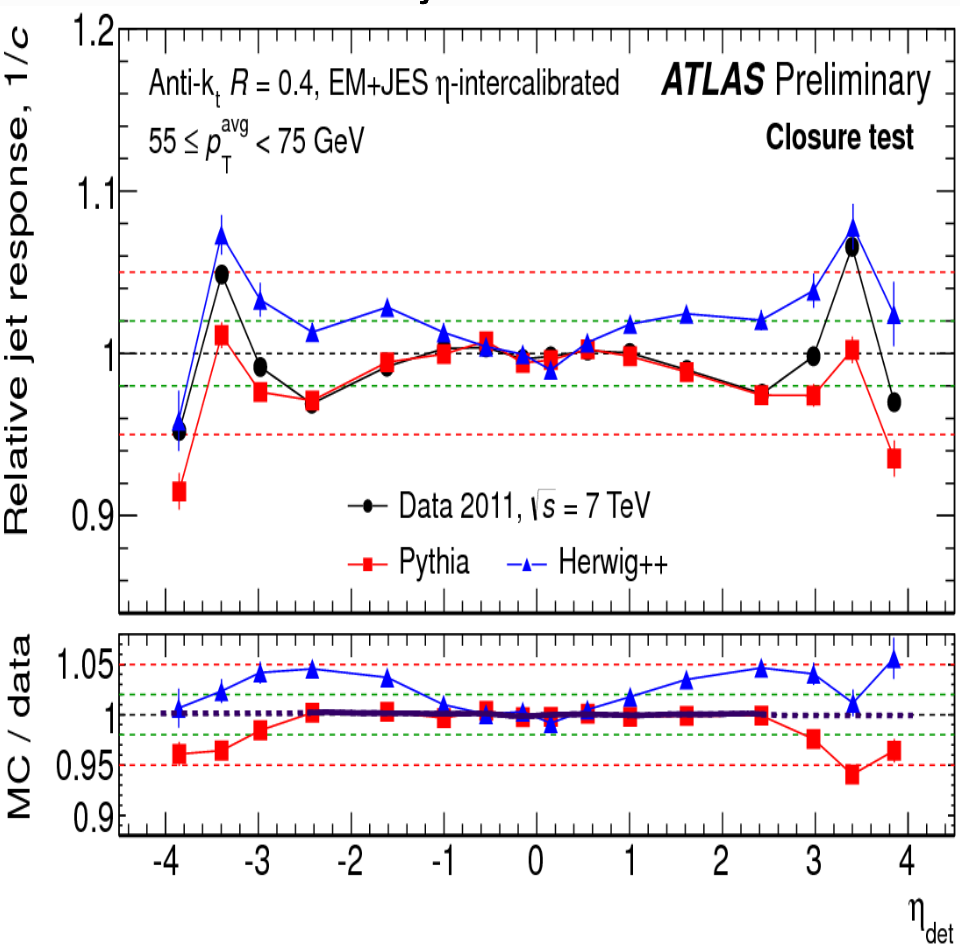
100-800

Correlations are derived from systematic uncertainties of in situ measurement
on reference object and physics effects, 1% uncertainty achieved

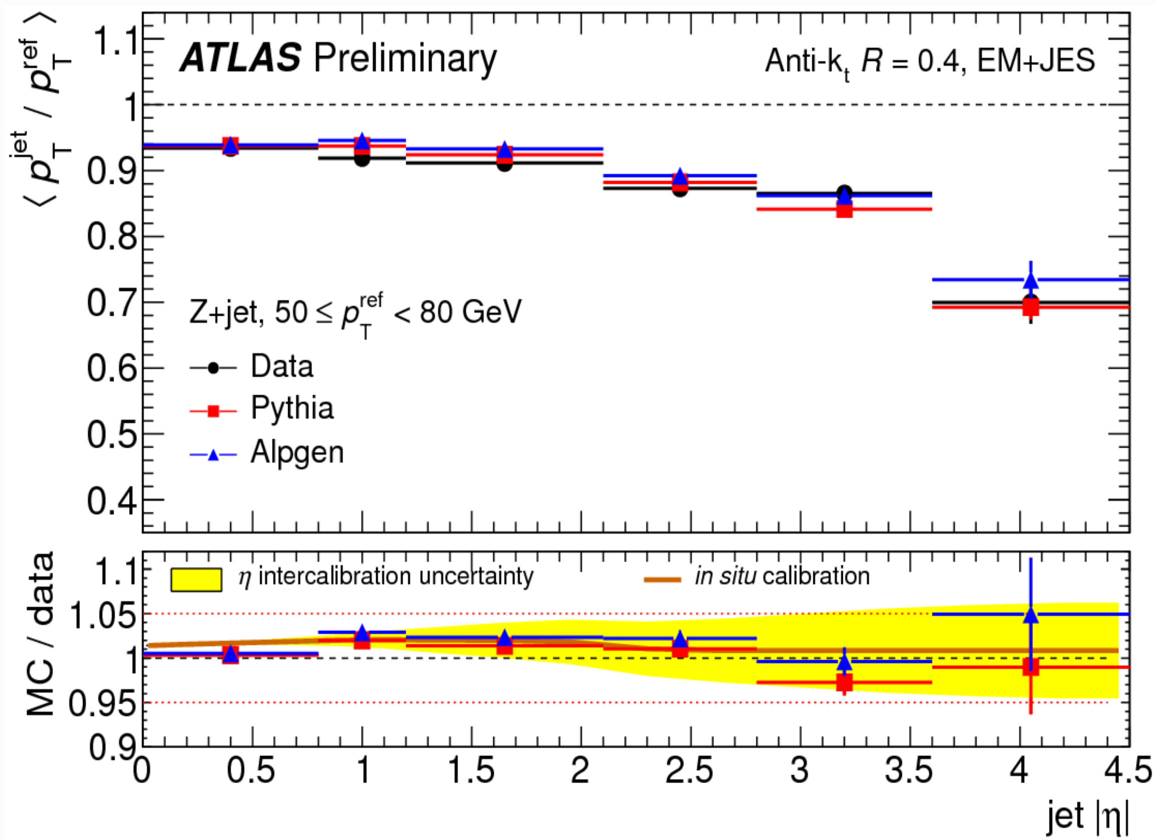
Forward JES from dijet balance between central and forward region

Forward energy scale is evaluated with respect to central region
Using assymetry (pt1-pt2)/(pt1+pt2) in events with dijet topology

Dijet balance



Z+jet balance



In forward region assign large uncertainties from parton shower model
Uncertainty validated using Z+jet balance

Jet energy uncertainties from in situ techniques

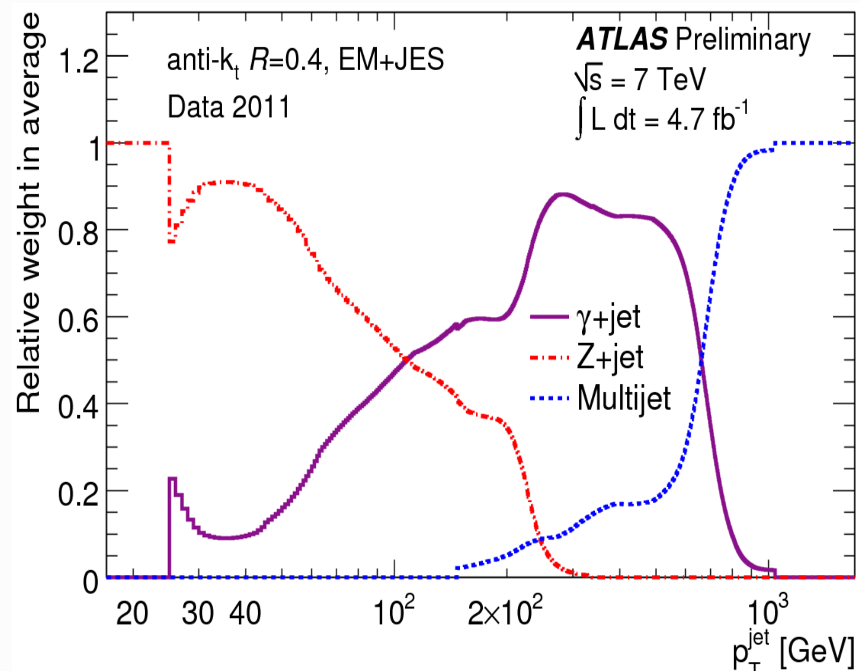
JES uncertainties derived from uncertainties of in pt-balance situ techniques

“Weighted mean” preserving correlations (using HVTOOLS)

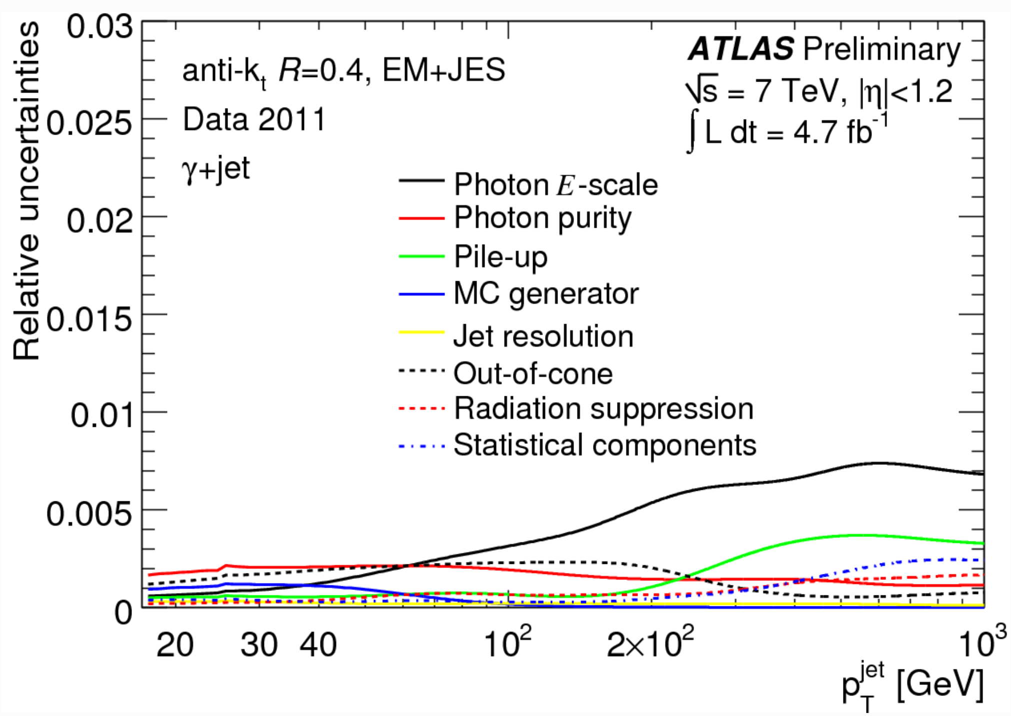
Individual uncertainty sources describe full correlation across pt and eta

Needed for fits and complex data analysis

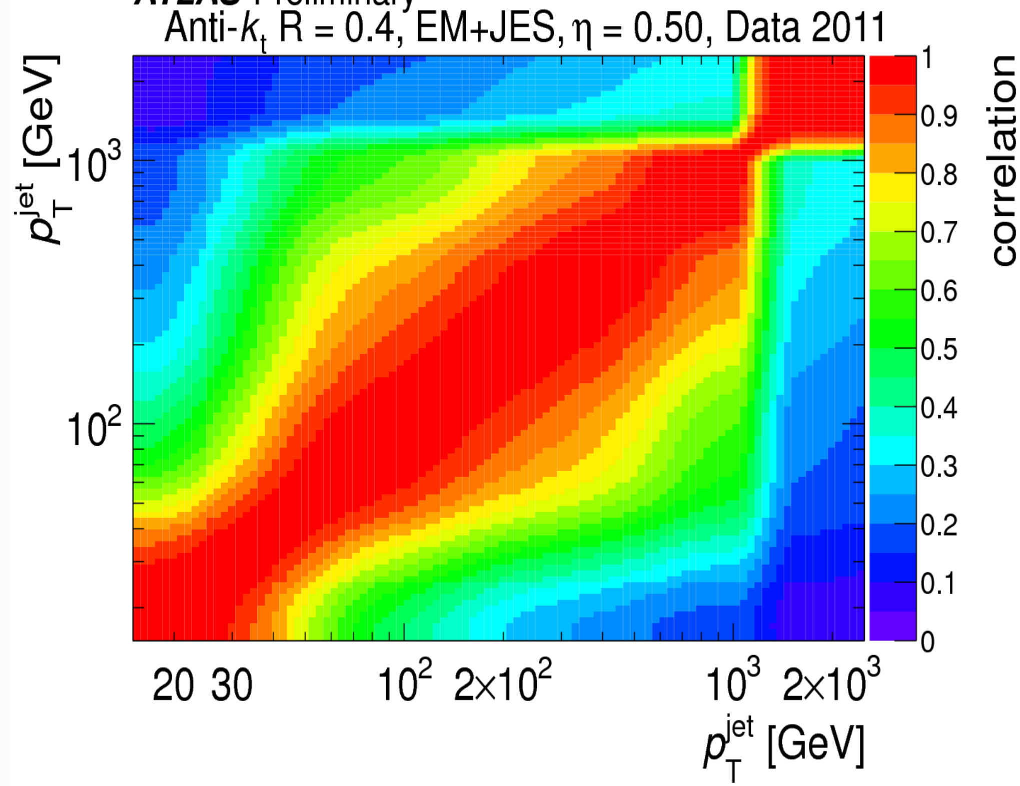
Combination weights



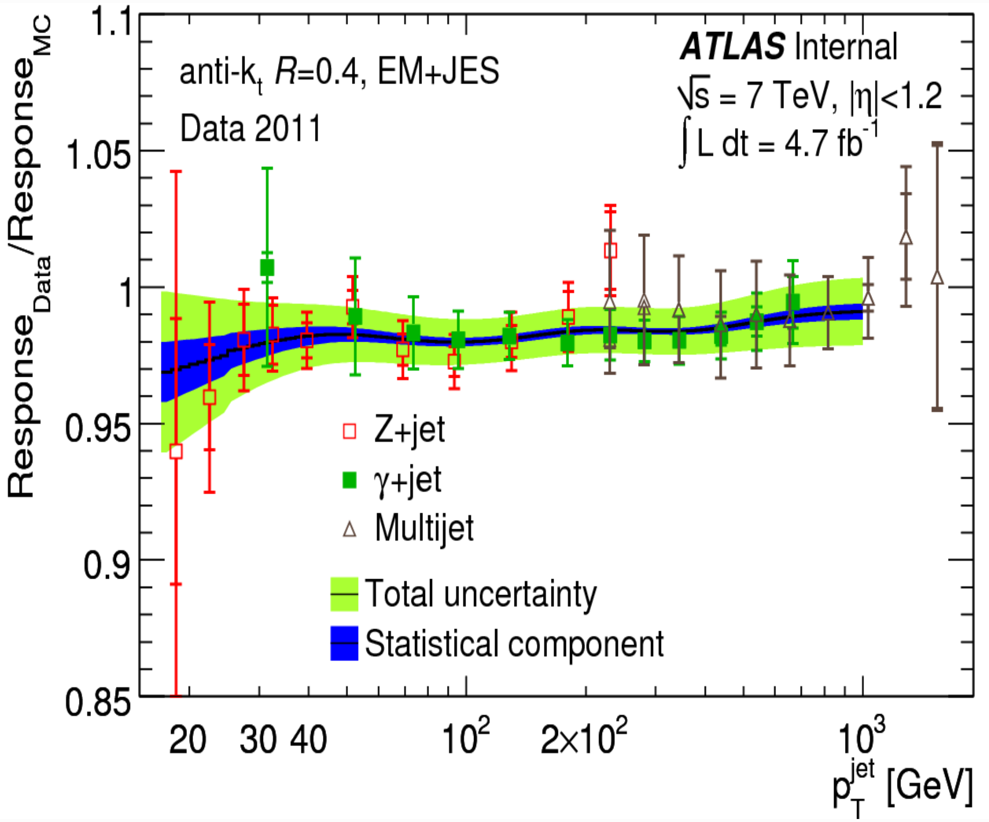
Uncertainty components in combination

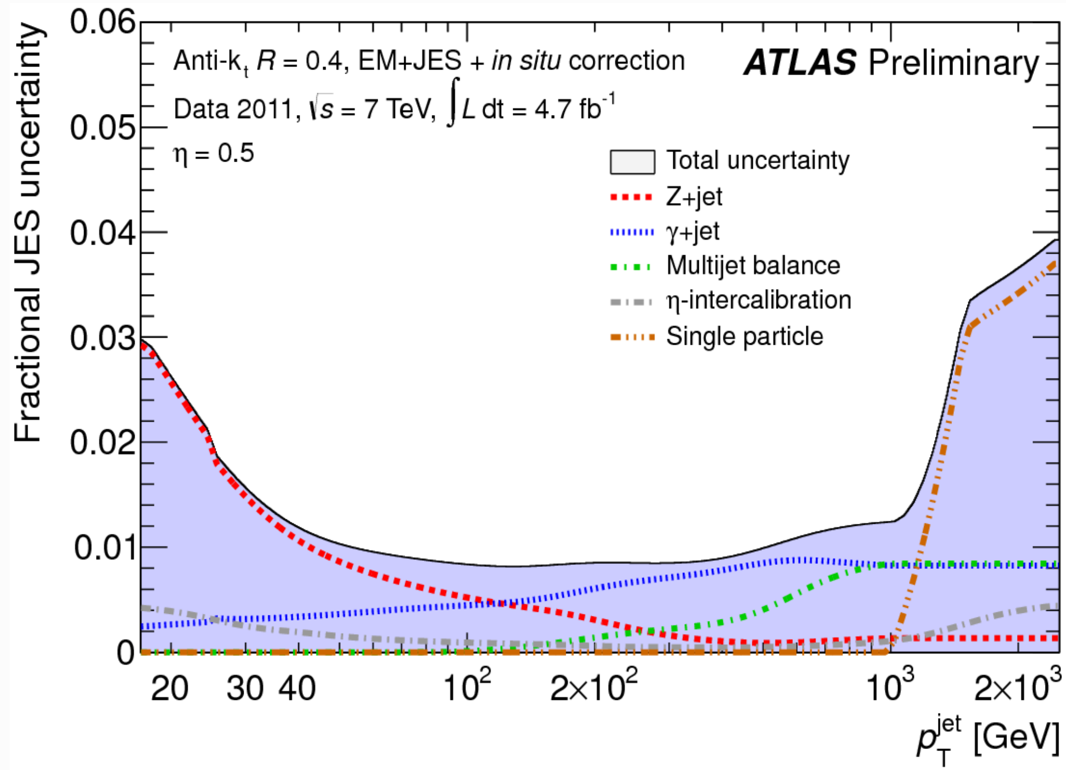


Correlation matrix



Result on baseline jet energy uncertainty from in situ techniques



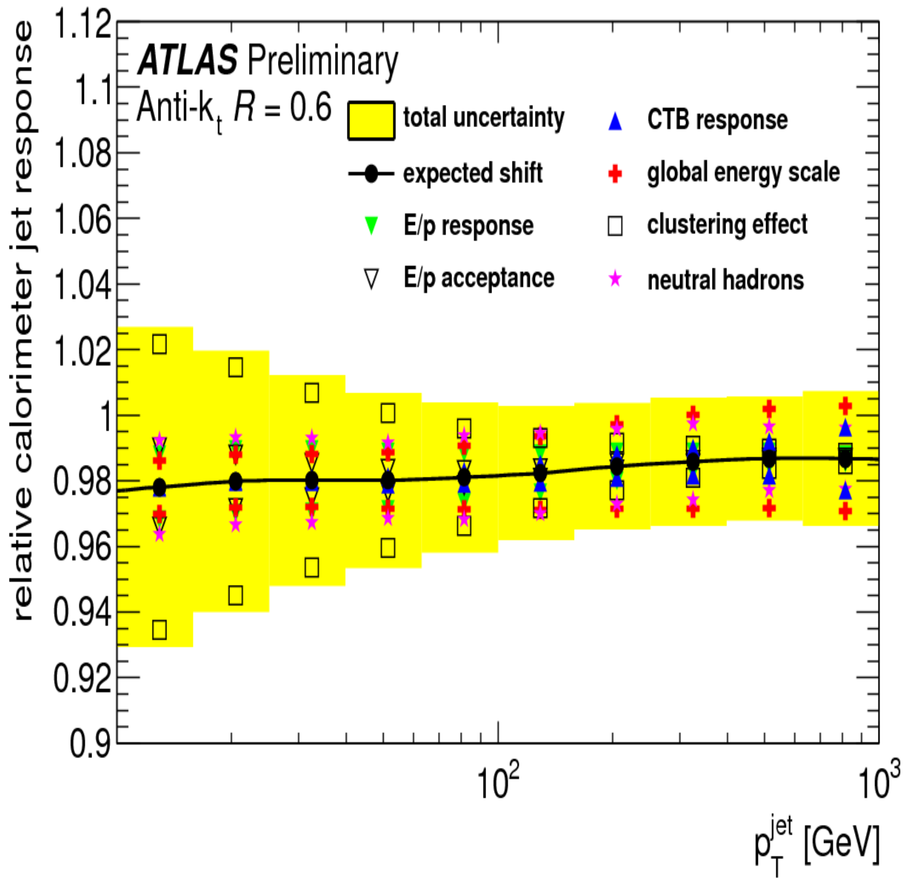


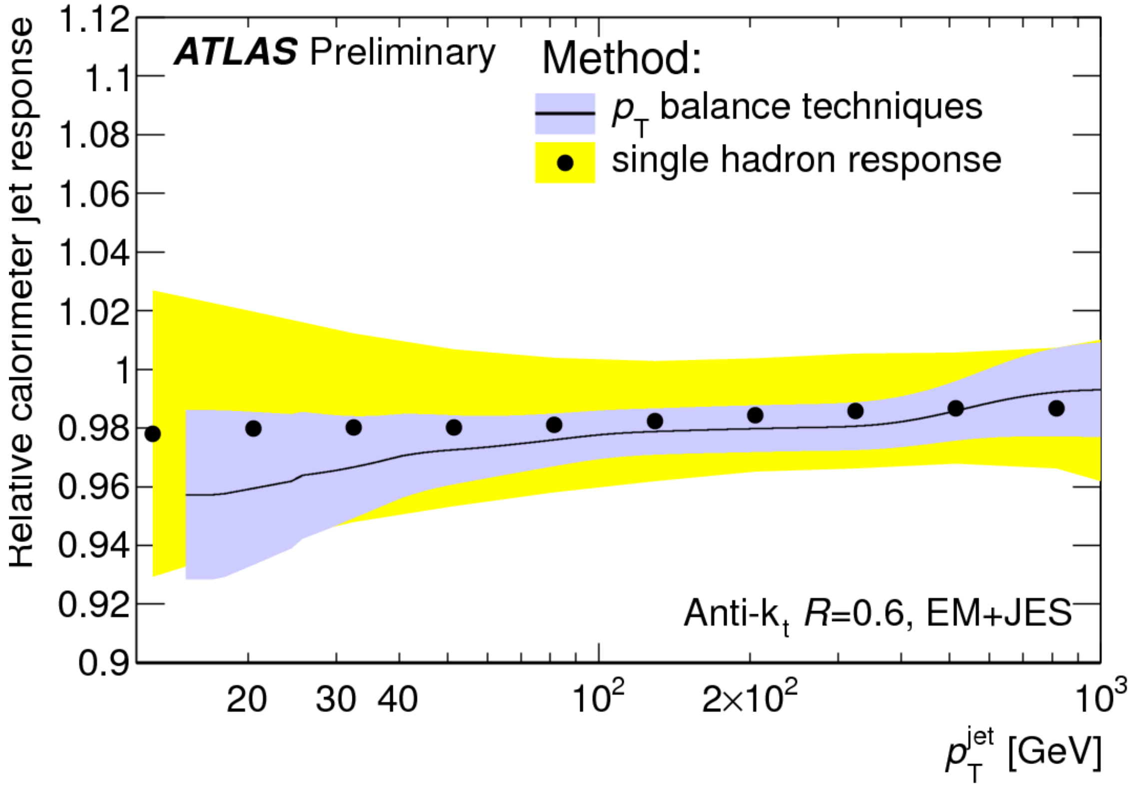
JES correction (black line)
JES uncertainty (bands)

At high-pt multijet balance
Beyond 1 TeV: uncertainty based on
Single hadron response

Comparison of JES uncertainty from Pt-balance in situ techniques and single hadron response

JES uncertainty based on
2011 single hadron response measurements (slightly different from 2010 I showed earlier)

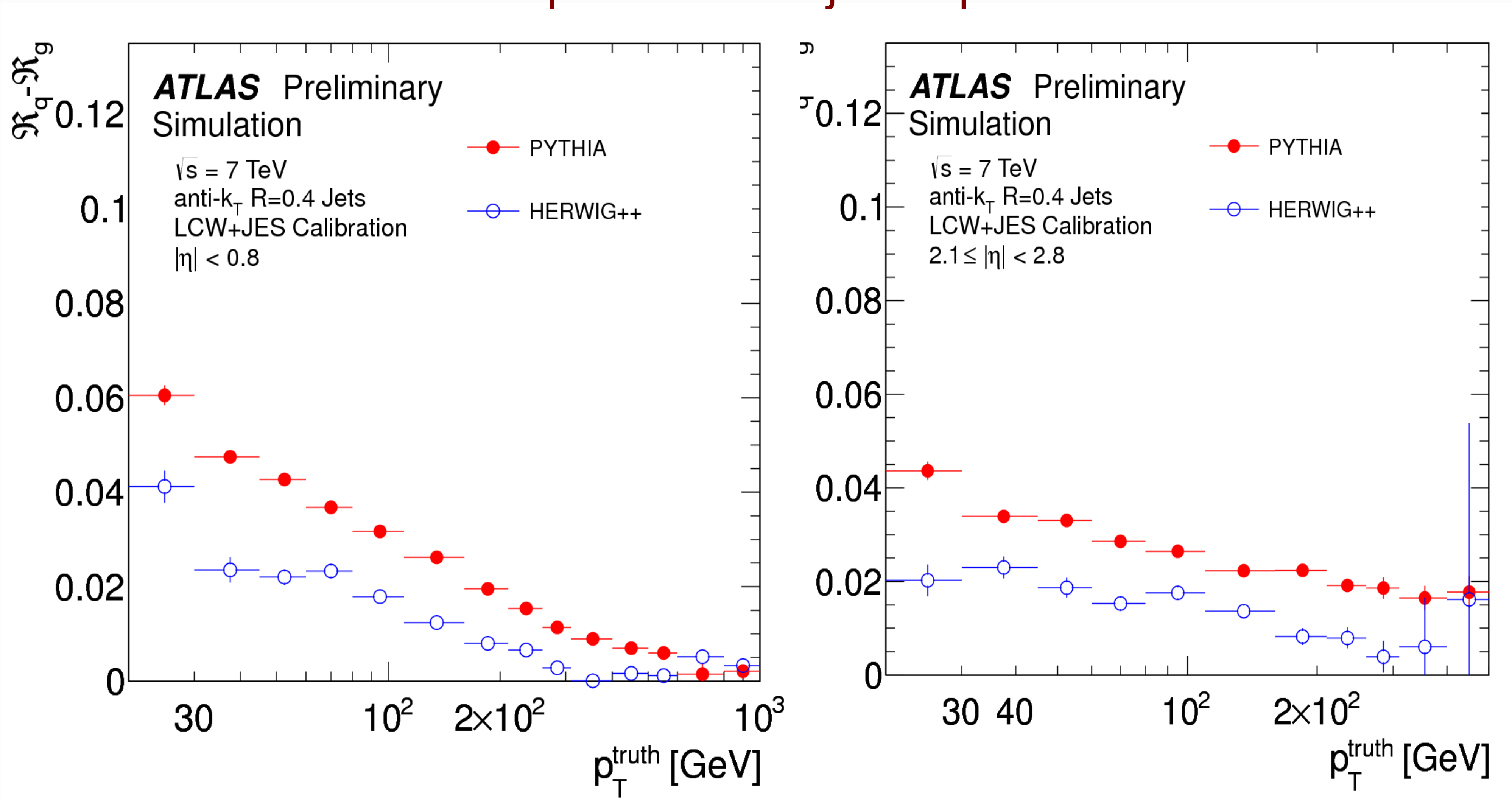




Nice agreement on JES corrections based on pt-balance in situ techniques and
Single hadron response measurement (*)
Uncertainties from pt-based in situ techniques are smaller

(*) Due to various small effects that single hadron response in data was lower than in MC

Flavour dependence of jet response



sample dependent!

flavour composition uncertainty | **flavour response uncertainty**

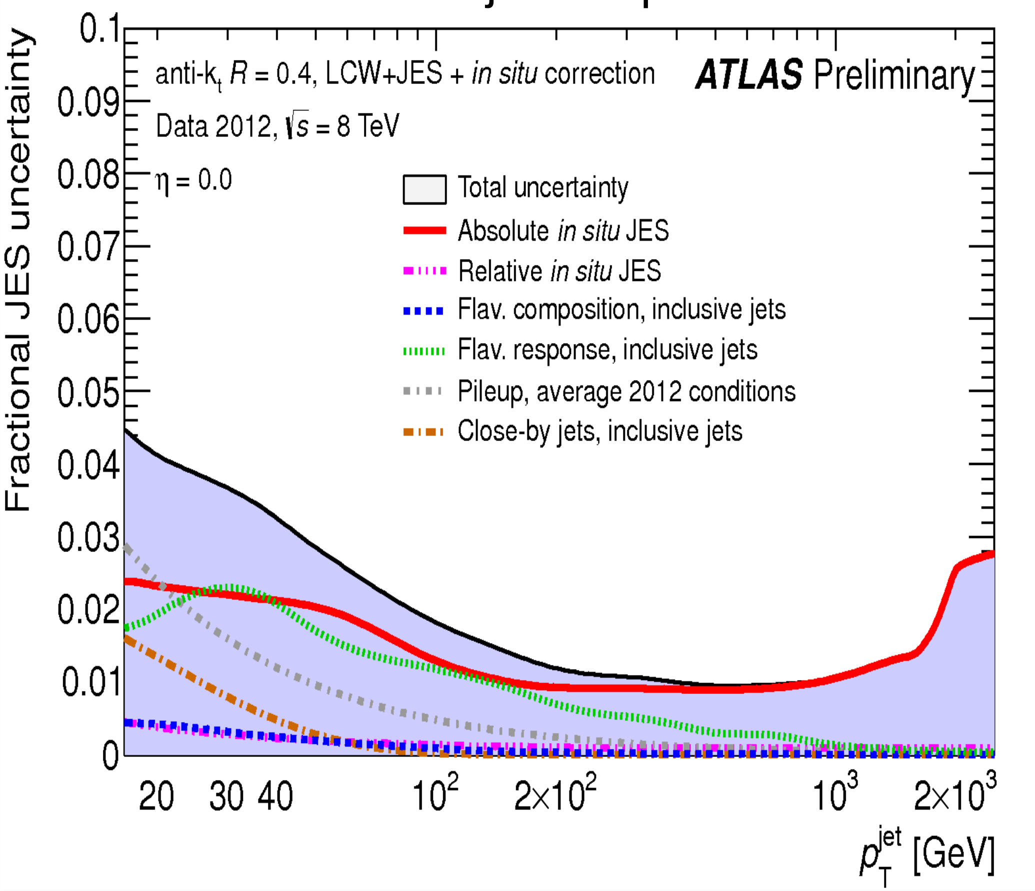
$$\Delta\mathfrak{R}_s = \Delta f_g \times (\mathfrak{R}_q - \mathfrak{R}_g) \oplus f_g \times \Delta\mathfrak{R}_g$$

uncertainty on gluon fraction | **quark-gluon jet response difference** | **fraction of gluon jets in sample** | **uncertainty on gluon jet response (from MC)**

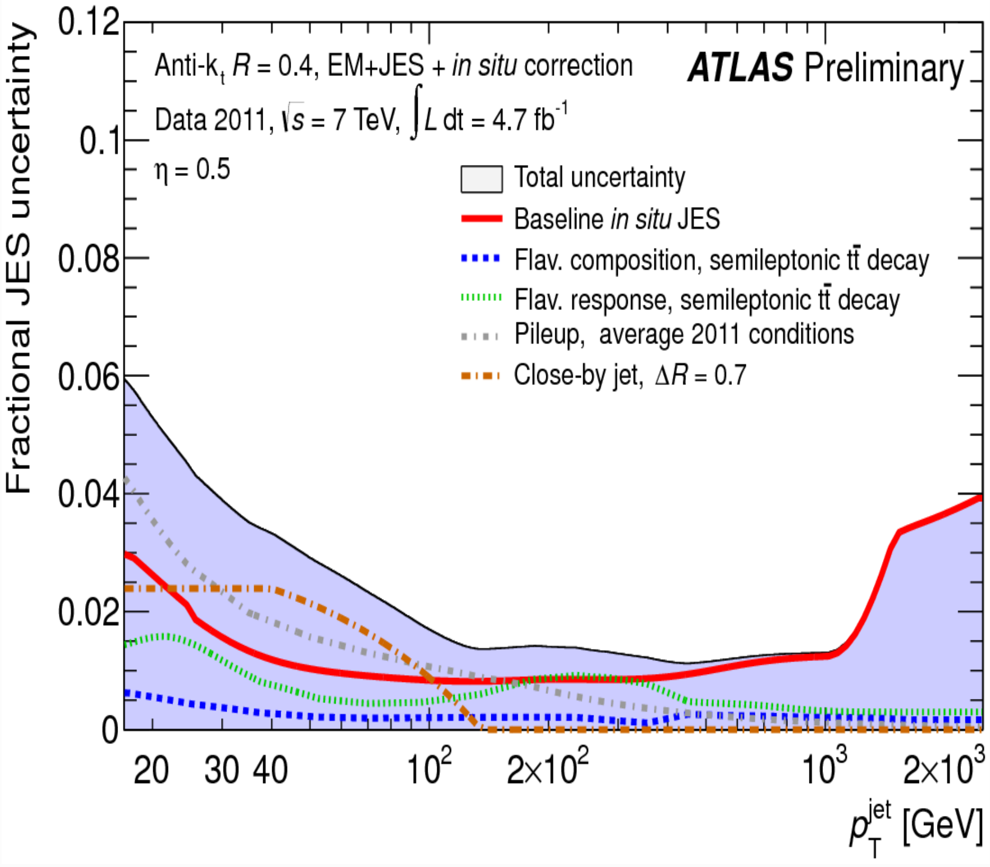
Example total JES uncertainty in an given analysis

For a given analysis uncertainties based on the even topology need to be added
1) jet fragmentation: jet flavour quark/gluon, heavy quarks
2) pile-up dependent on measured vertices and
expected average number of additional interactions
3) Effect on close-by jets parameterised on distance of two jets dRjj

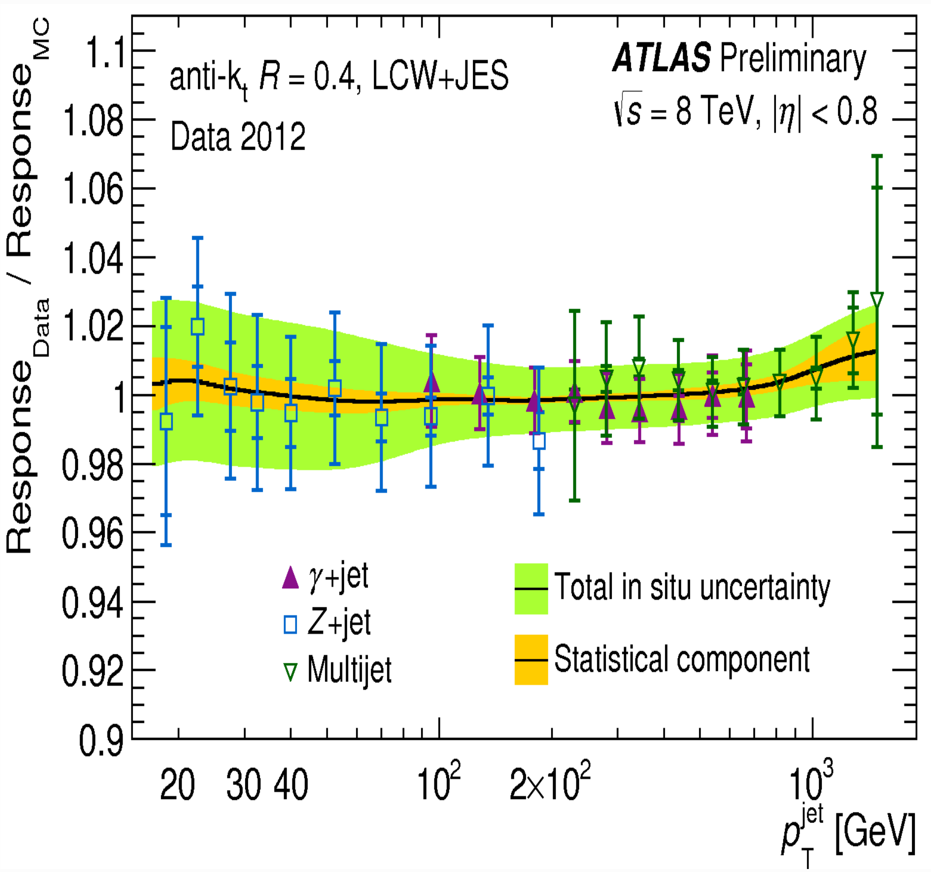
Inclusive jet sample

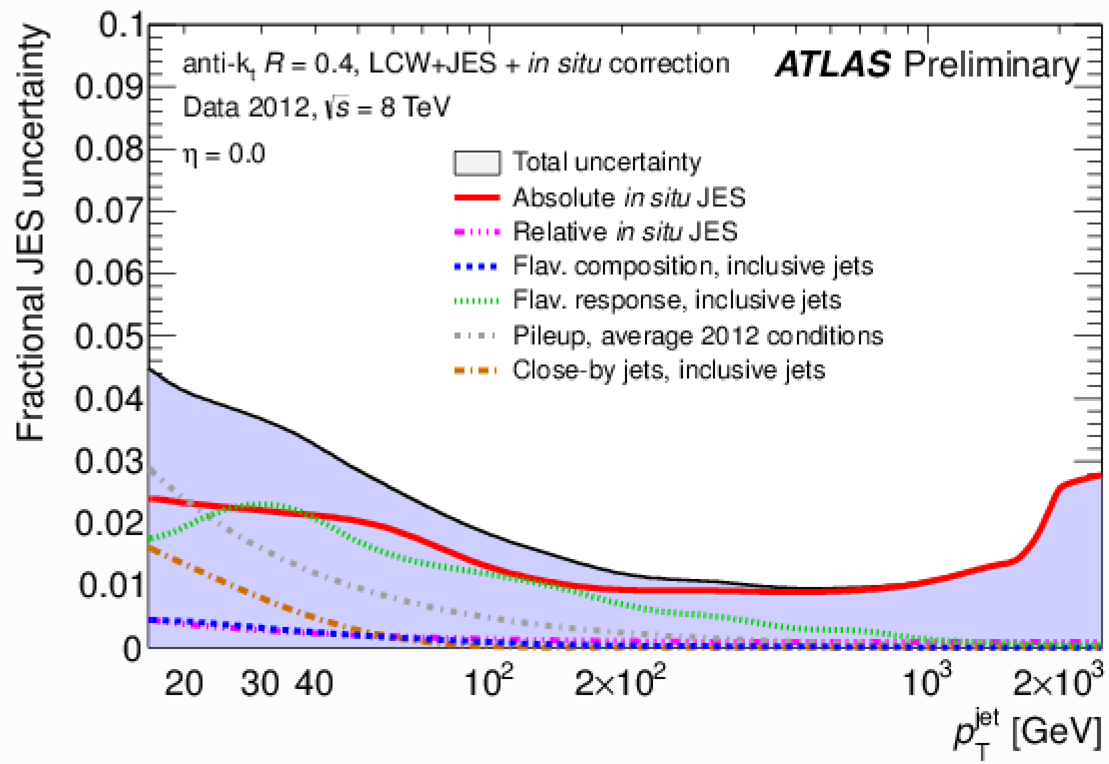


Semileptonic top sample



JES uncertainty in the 2012 data set





Conclusion

Response of ATLAS calorimeter is well described by simulation based on G4 thanks to detailed detector description and good progress in hadron shower simulations

In 2010 JES uncertainty was derived using single hadron response and systematic Monte Carlo variation for fragmenation uncertainties

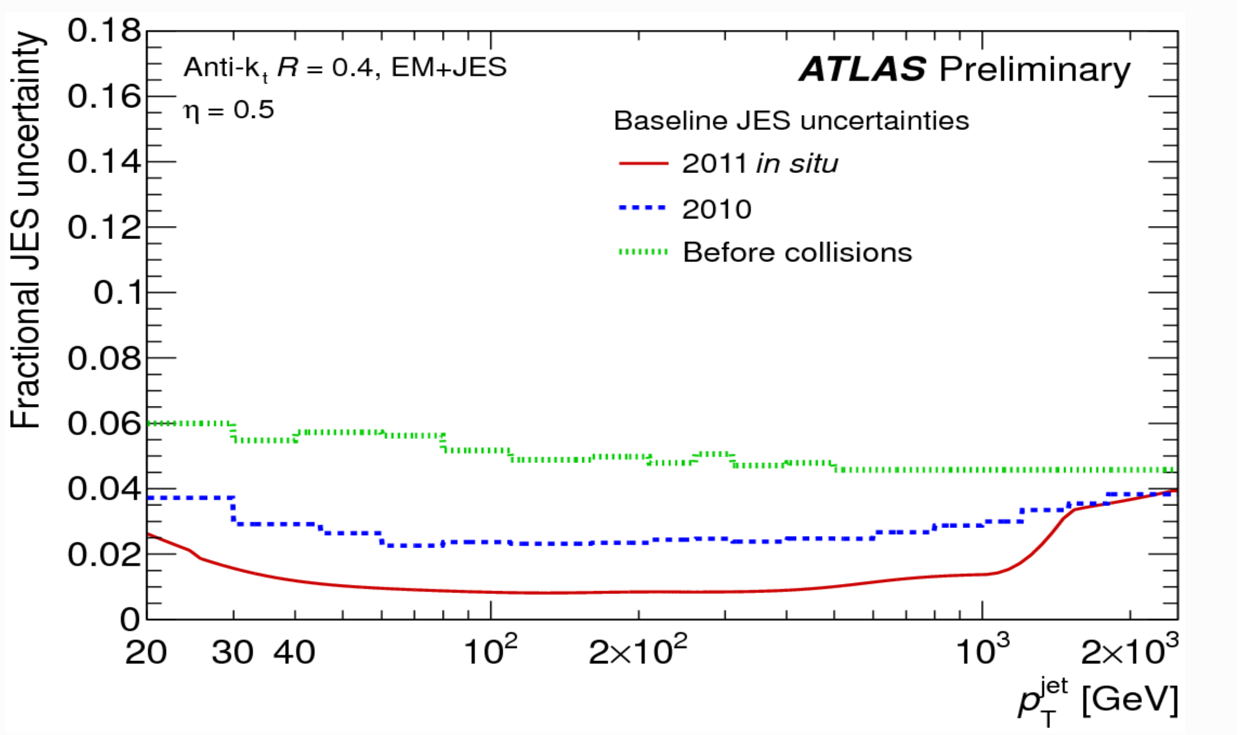
In 2011 JES uncertainty was derived using in situ techniques based on pt-balance

The baseline uncertainty in the barrel is 1-2%

Effect due to event topology (e.g. close-by) and jet flavour (quark/gluon) or Data sample (pile-up) are evaluated
Total uncertainty is 2-4%

Full correlation in pt and eta have (and their uncertainties) been derived. This is a solid basis for sophisticated analysis techniques (profile liklihood fits, Hessian PDF or alphas fits etc.)

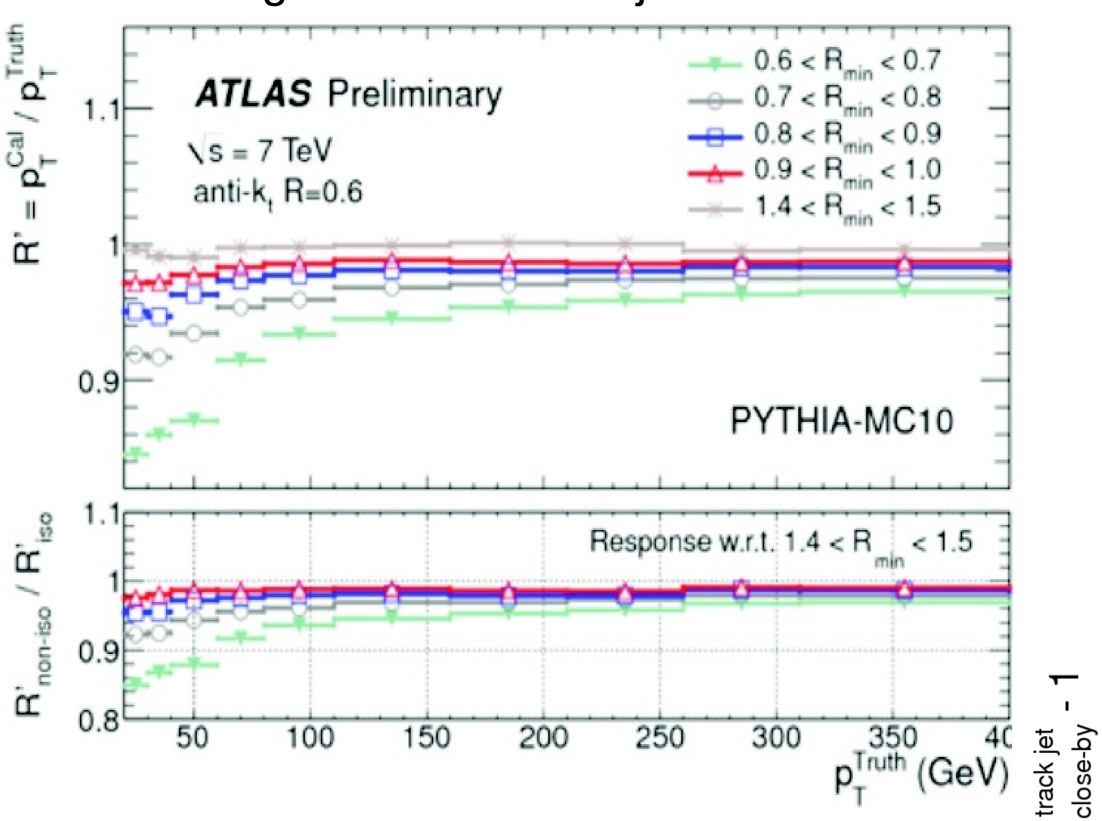
Many thanks to many young researchers working on all these issues with many innovative ideas !



Back-up material

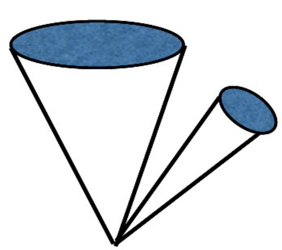
JES uncertainty due to close-by jets

Jet response depends on environment/event sample
Calibration given for isolated jets

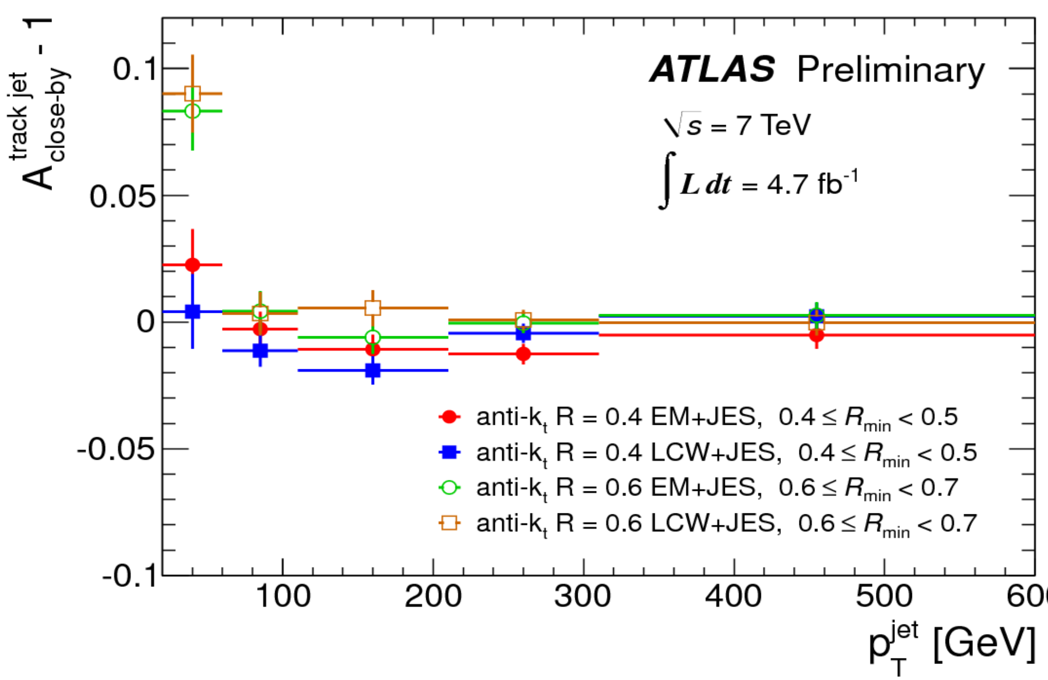


Uncertainty, i.e. how well the MC describes the response drop is evaluated using track jet that are more stable in dR

$$A_{close-by} = \left[r^{calo/track\ jet}_{non-iso/iso}\right]_{Data} \Big/ \left[r^{calo/track\ jet}_{non-iso/iso}\right]_{MC}$$

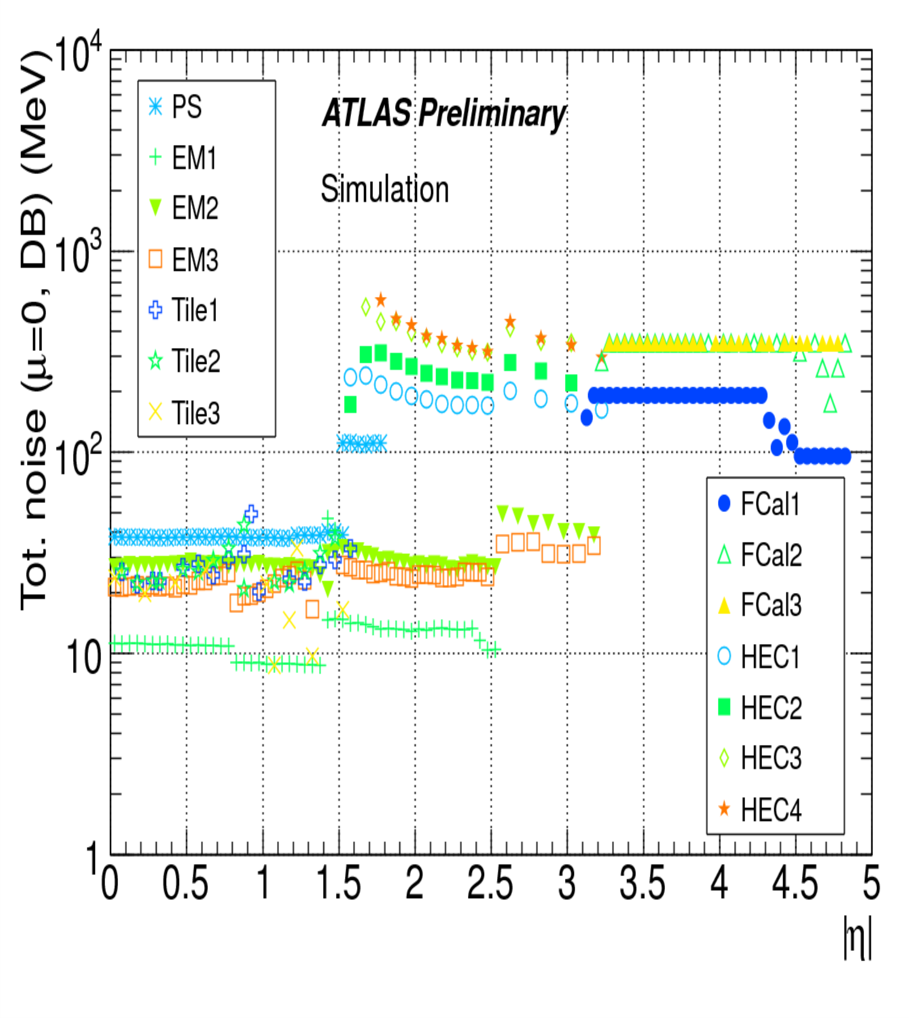


DeltaRmin
smallest DR to closest jet

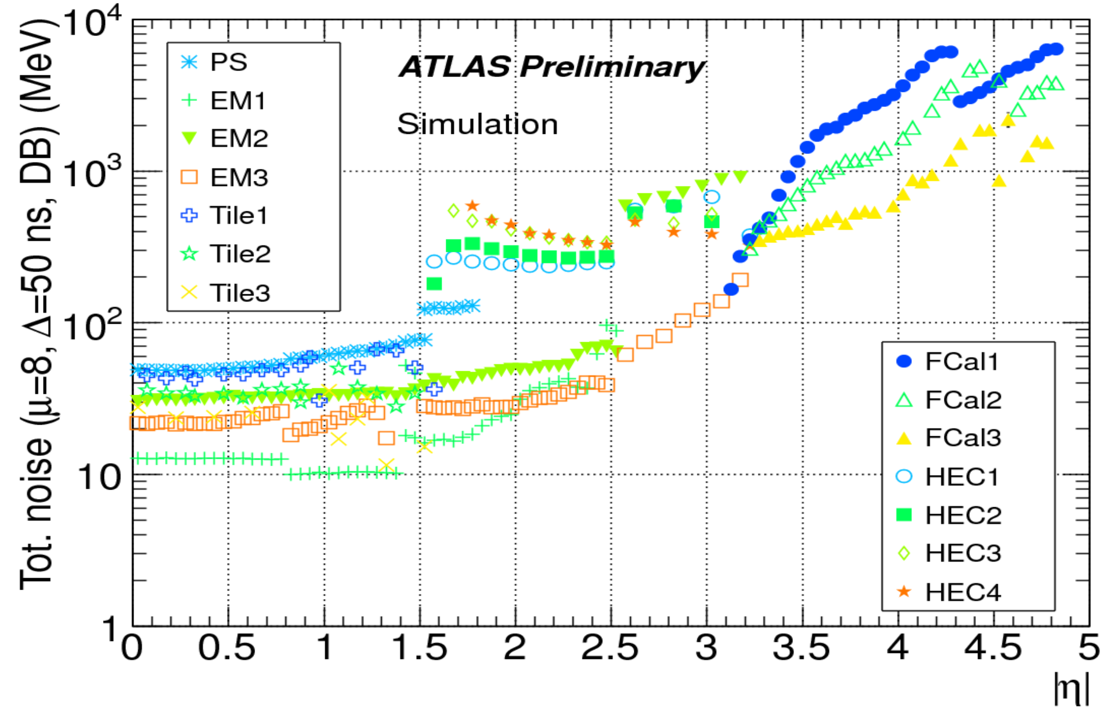


Cluster thresholds

Electronic noise ony



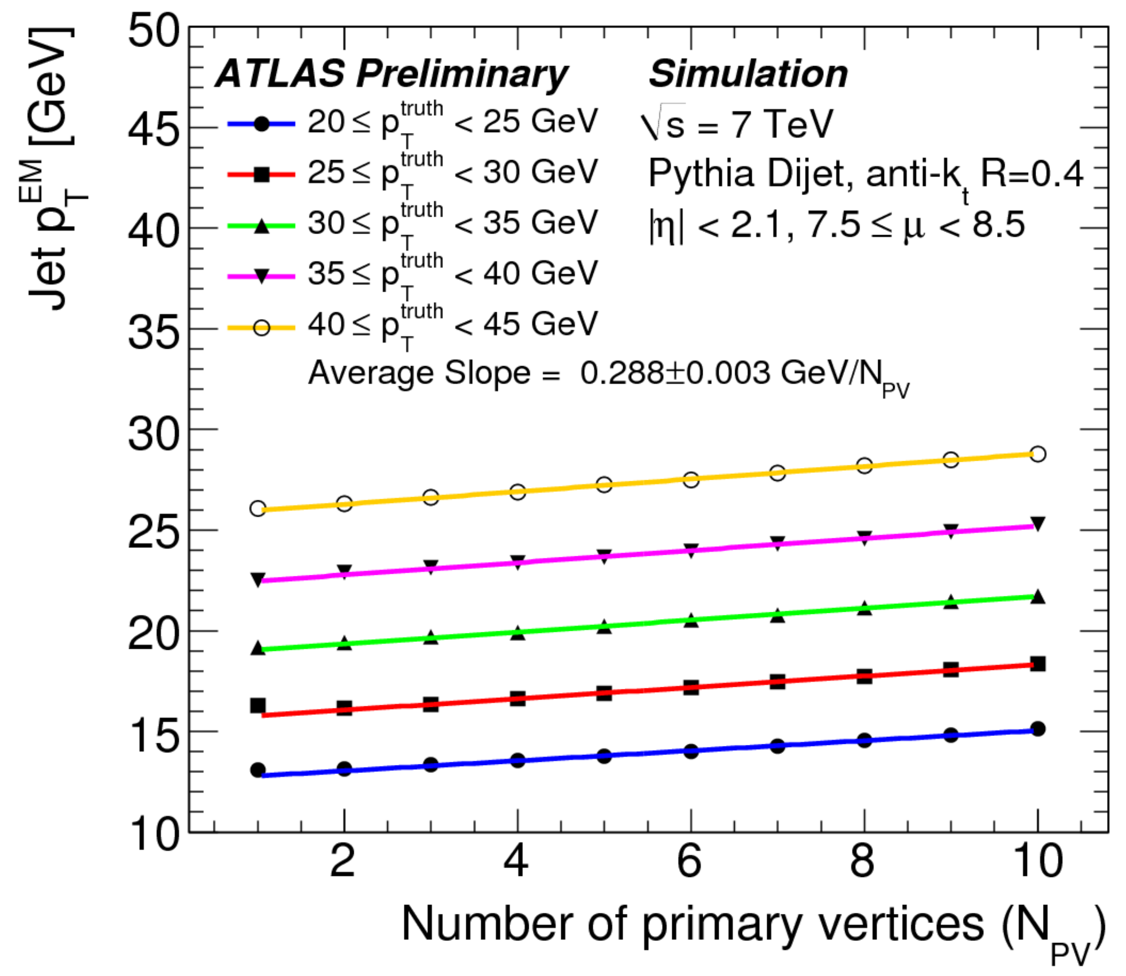
Electronic noise and pile-up noise



Corresponding to eight pile-up interactions

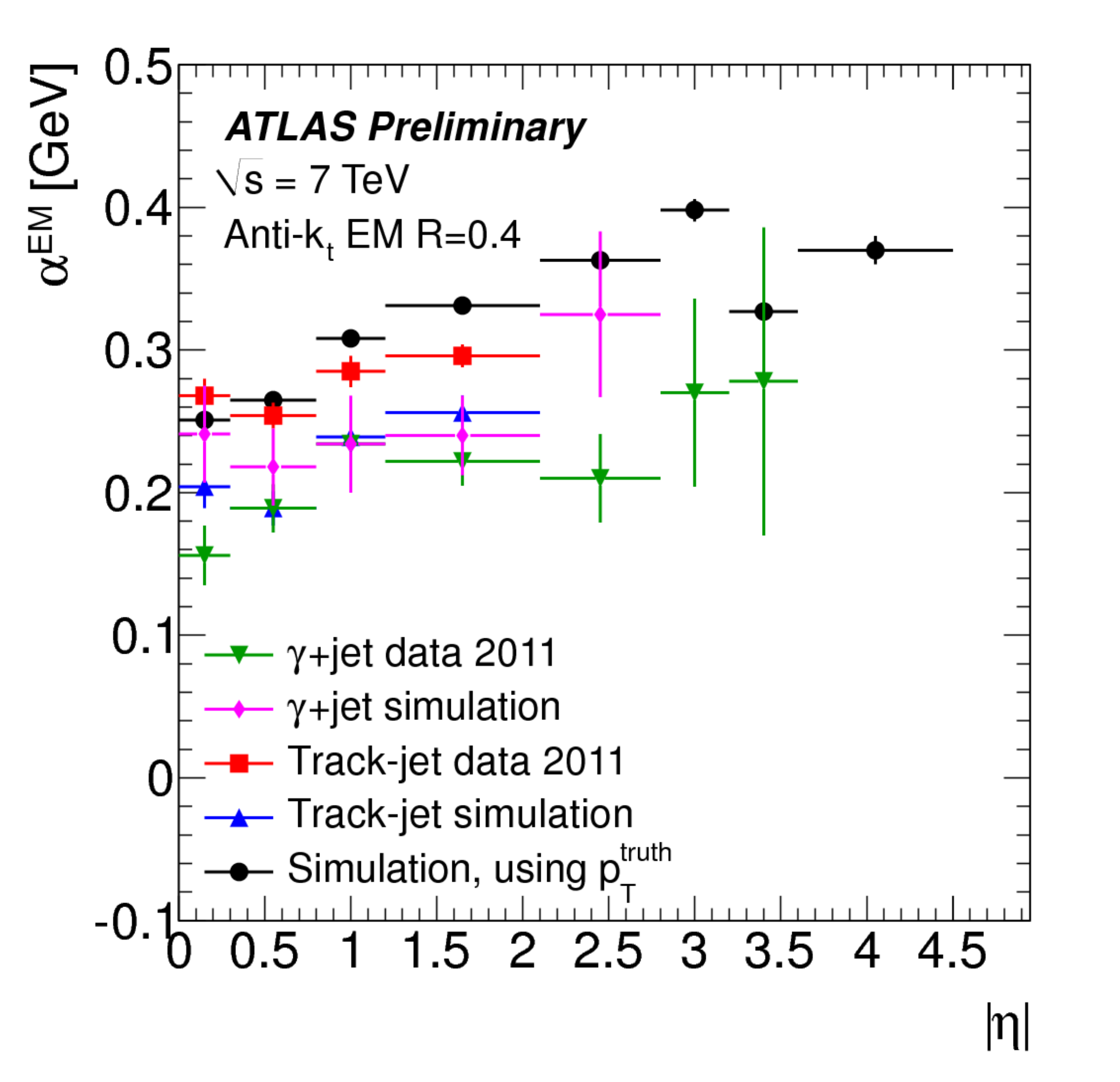
Derivation of pile-up correction

Look at jet respnse variation in bins of true pt in Monte Carlo simulation



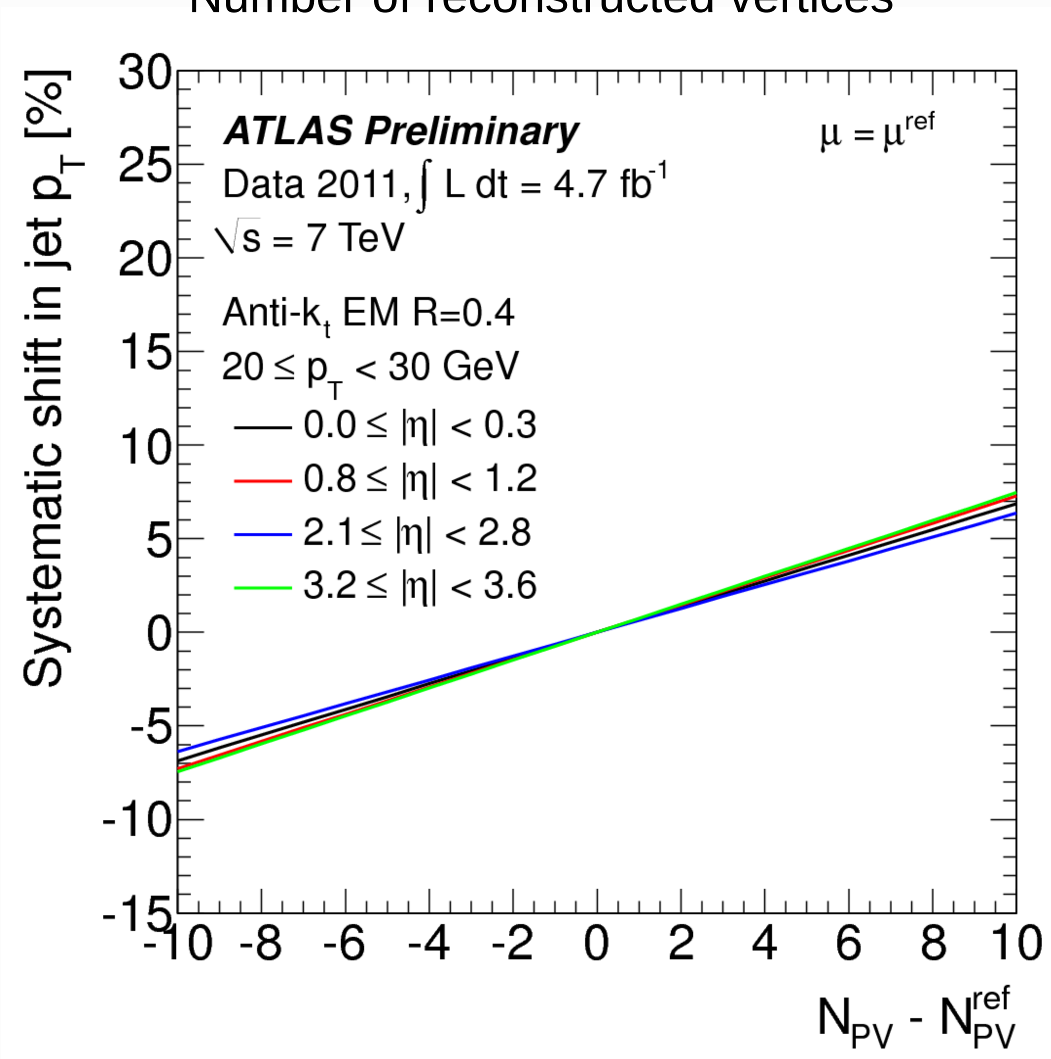
Validation of pile-up corrections

Look at jet response variation using stable reference:
gamma+jet balance, track-jet associated to primary vertex

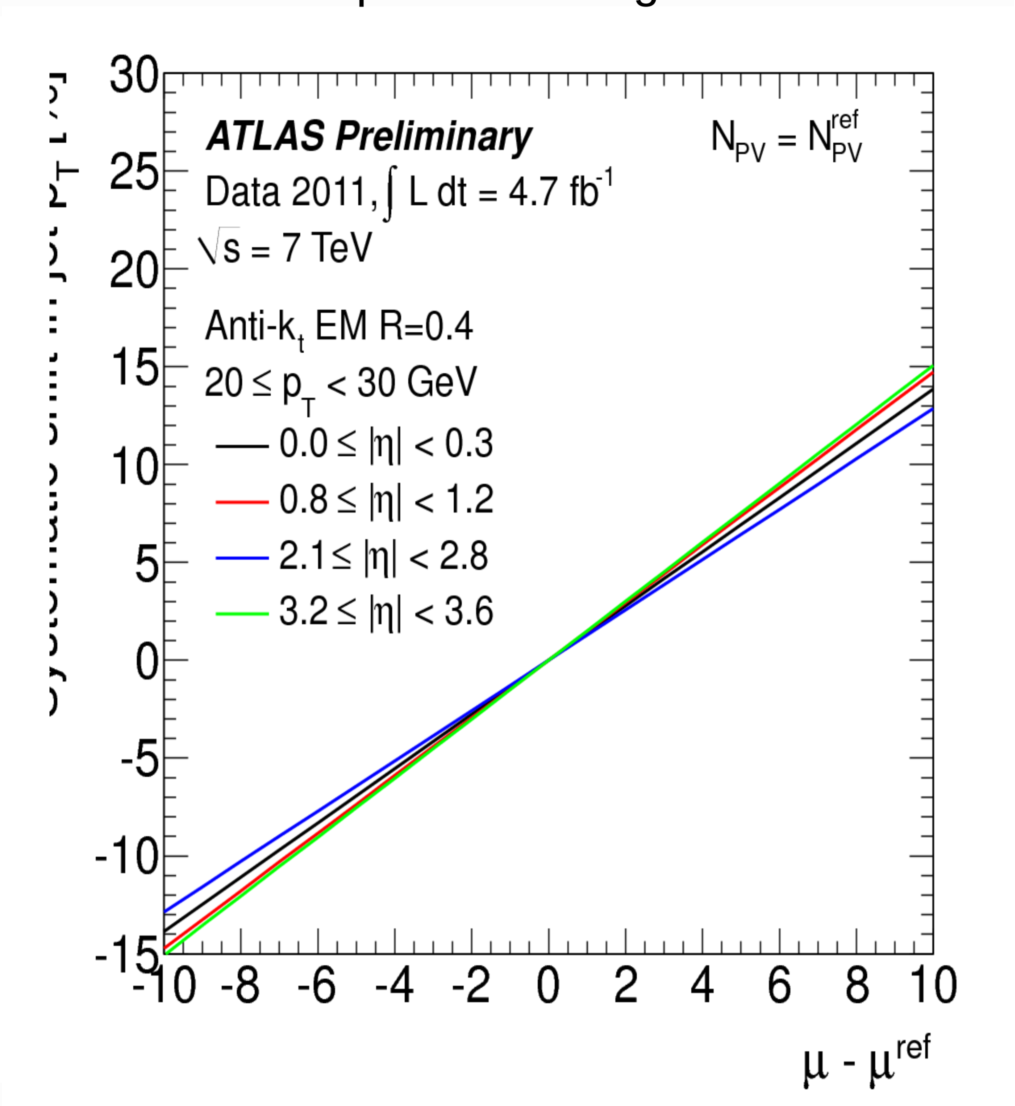


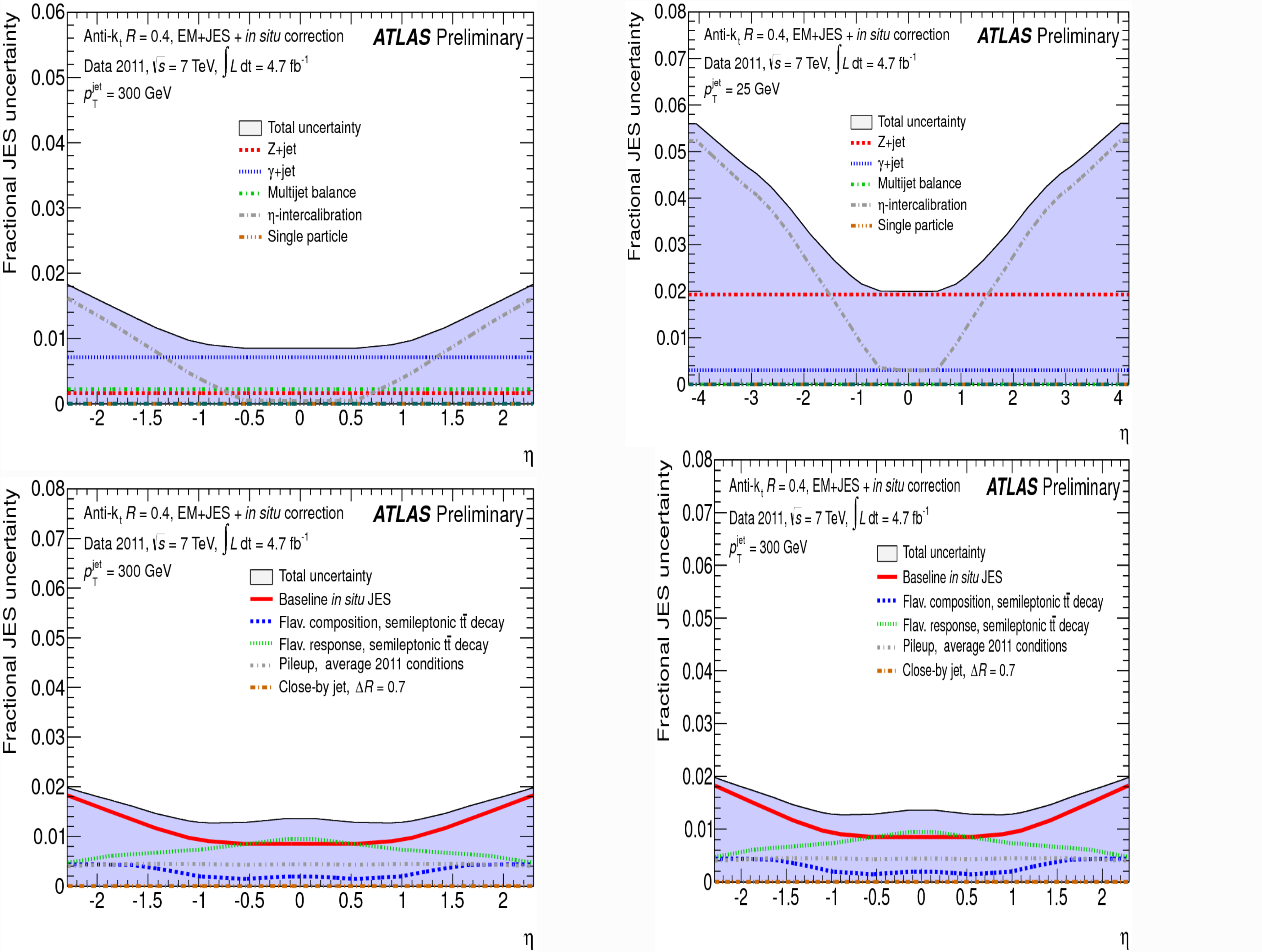
Pileup uncertainties

Number of reconstructed vertices

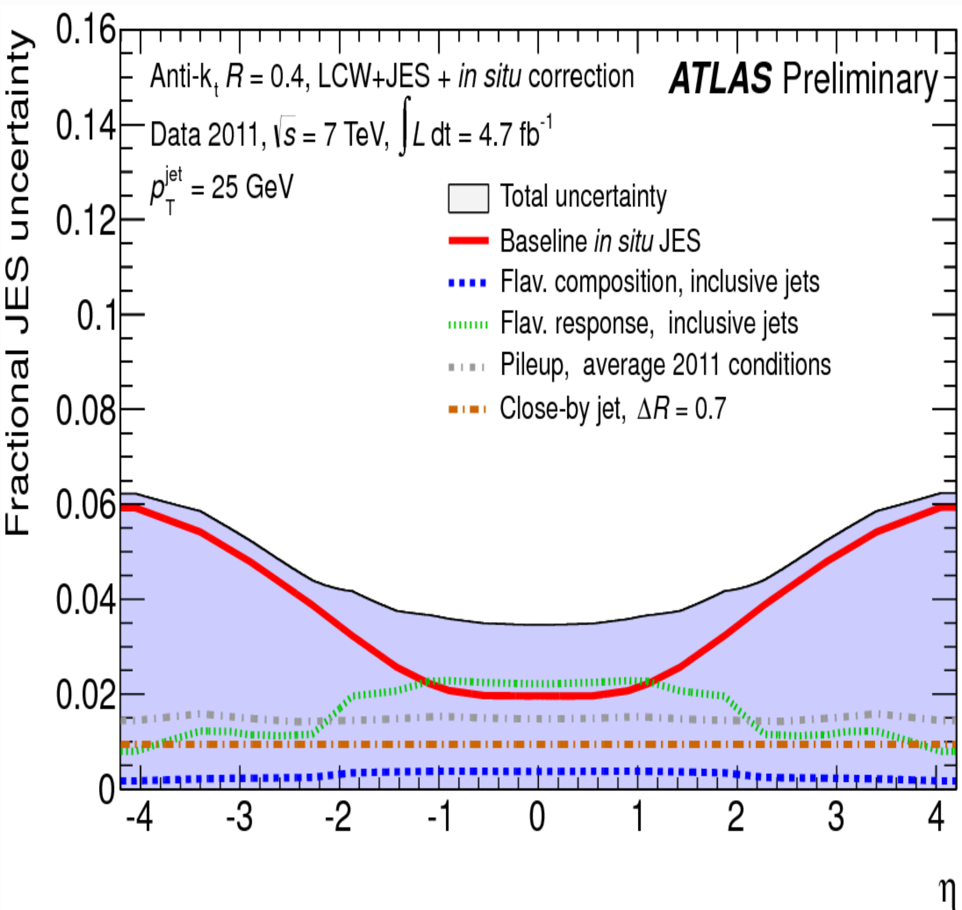


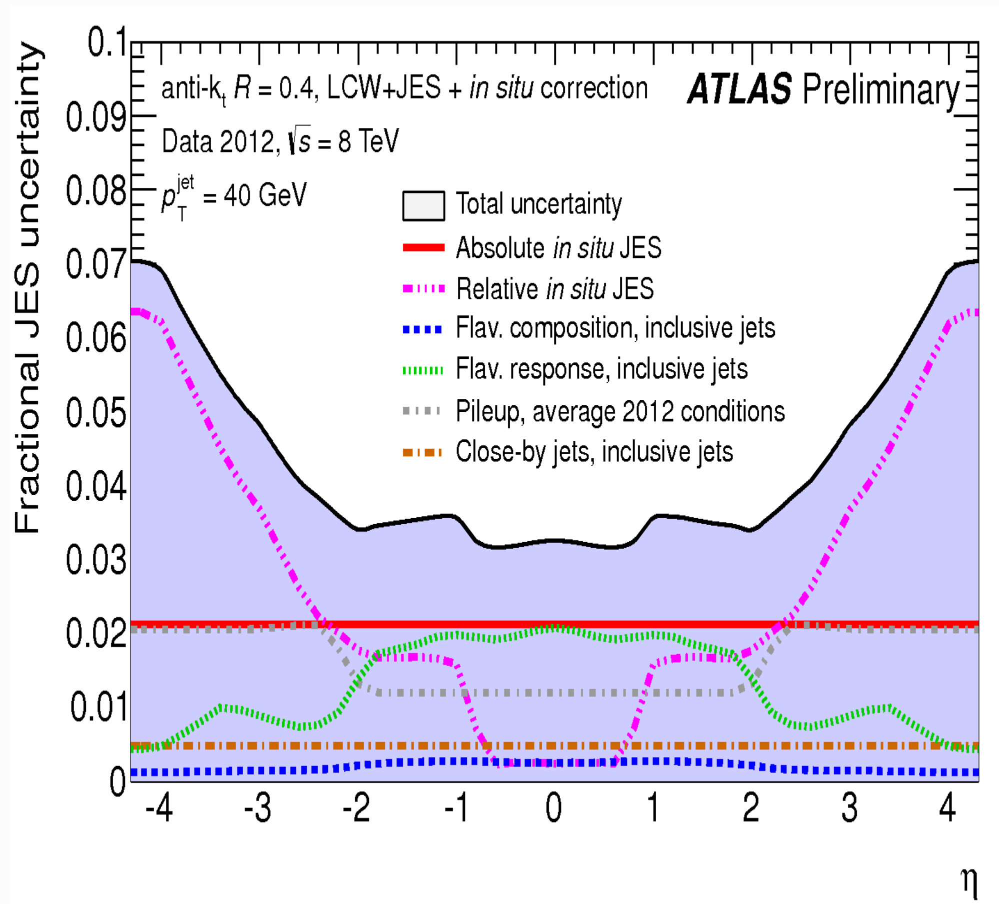
Number of expected average interactions



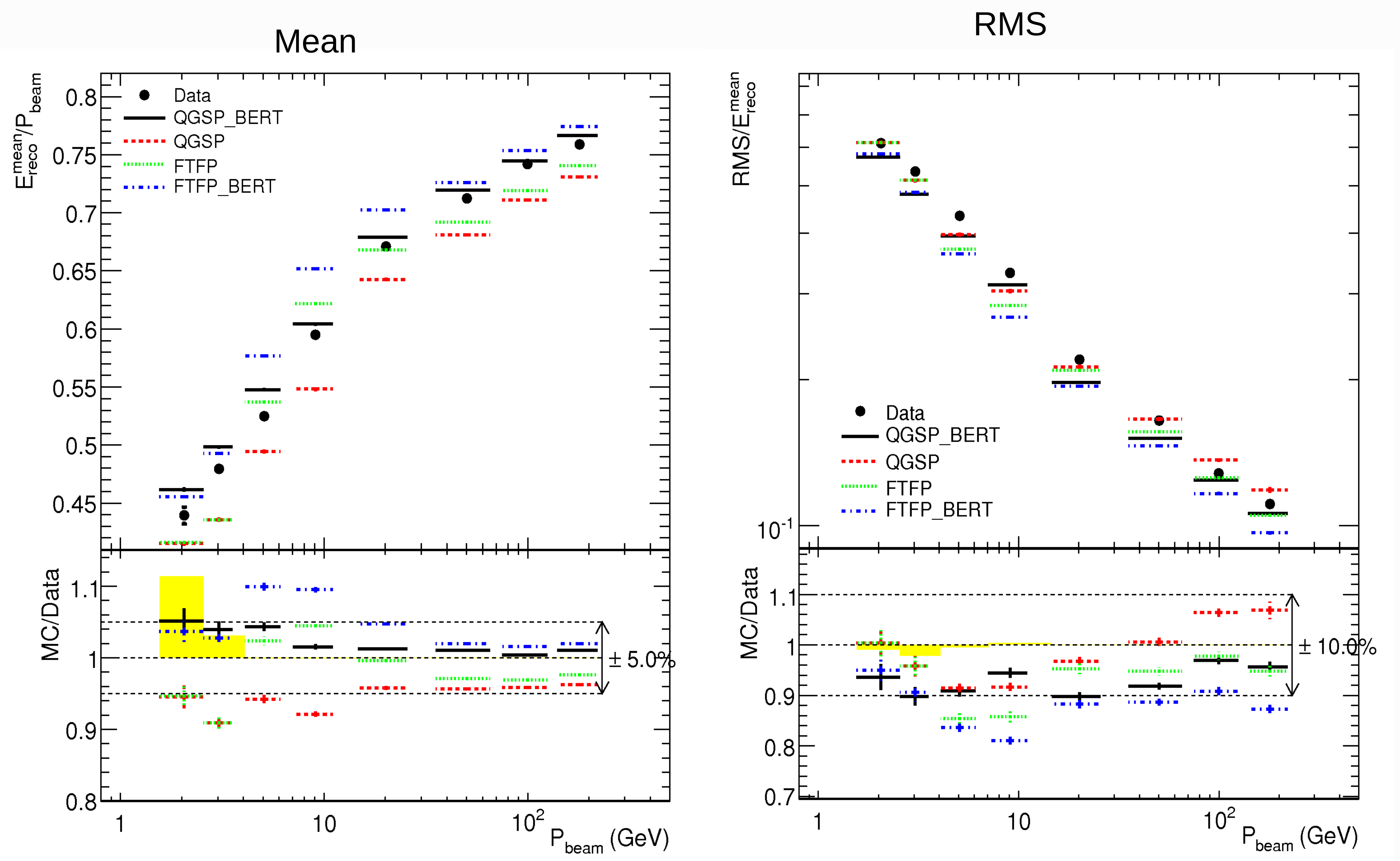


Anti-k$_t$ R = 0.4, EM+JES + *in situ* correction
ATLAS Preliminary
Data 2011, $\sqrt{s}$ = 7 TeV, $\int L\,dt$ = 4.7 fb^{-1}
p_T^{jet} = 300 GeV
Total uncertainty
Z+jet
γ+jet
Multijet balance
η-intercalibration
Single particle
Fractional JES uncertainty
η
0.06
0.05
0.04
0.03
0.02
0.01
0
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
Anti-k$_t$ R = 0.4, EM+JES + *in situ* correction
ATLAS Preliminary
Data 2011, $\sqrt{s}$ = 7 TeV, $\int L\,dt$ = 4.7 fb^{-1}
p_T^{jet} = 25 GeV
Total uncertainty
Z+jet
γ+jet
Multijet balance
η-intercalibration
Single particle
Fractional JES uncertainty
η
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
-4
-3
-2
-1
0
1
2
3
4
Anti-k$_t$ R = 0.4, EM+JES + *in situ* correction
ATLAS Preliminary
Data 2011, $\sqrt{s}$ = 7 TeV, $\int L\,dt$ = 4.7 fb^{-1}
p_T^{jet} = 300 GeV
Total uncertainty
Baseline *in situ* JES
Flav. composition, semileptonic $t\bar{t}$ decay
Flav. response, semileptonic $t\bar{t}$ decay
Pileup, average 2011 conditions
Close-by jet, ΔR = 0.7
Fractional JES uncertainty
η
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
Anti-k$_t$ R = 0.4, EM+JES + *in situ* correction
ATLAS Preliminary
Data 2011, $\sqrt{s}$ = 7 TeV, $\int L\,dt$ = 4.7 fb^{-1}
p_T^{jet} = 300 GeV
Total uncertainty
Baseline *in situ* JES
Flav. composition, semileptonic $t\bar{t}$ decay
Flav. response, semileptonic $t\bar{t}$ decay
Pileup, average 2011 conditions
Close-by jet, ΔR = 0.7
Fractional JES uncertainty
η
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2


Anti-k$_t$ R = 0.4, LCW+JES + in situ correction
ATLAS Preliminary
Data 2011, $\sqrt{s}$ = 7 TeV, $\int L\,dt$ = 4.7 fb^{-1}
p_T^{jet} = 25 GeV
Total uncertainty
Baseline in situ JES
Flav. composition, inclusive jets
Flav. response, inclusive jets
Pileup, average 2011 conditions
Close-by jet, ΔR = 0.7
Fractional JES uncertainty
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-4 -3 -2 -1 0 1 2 3 4
η


anti-k$_t$ R = 0.4, LCW+JES + in situ correction
ATLAS Preliminary
Data 2012, $\sqrt{s}$ = 8 TeV
p_T^{jet} = 40 GeV
Total uncertainty
Absolute in situ JES
Relative in situ JES
Flav. composition, inclusive jets
Flav. response, inclusive jets
Pileup, average 2012 conditions
Close-by jets, inclusive jets
Fractional JES uncertainty
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
-4 -3 -2 -1 0 1 2 3 4
η

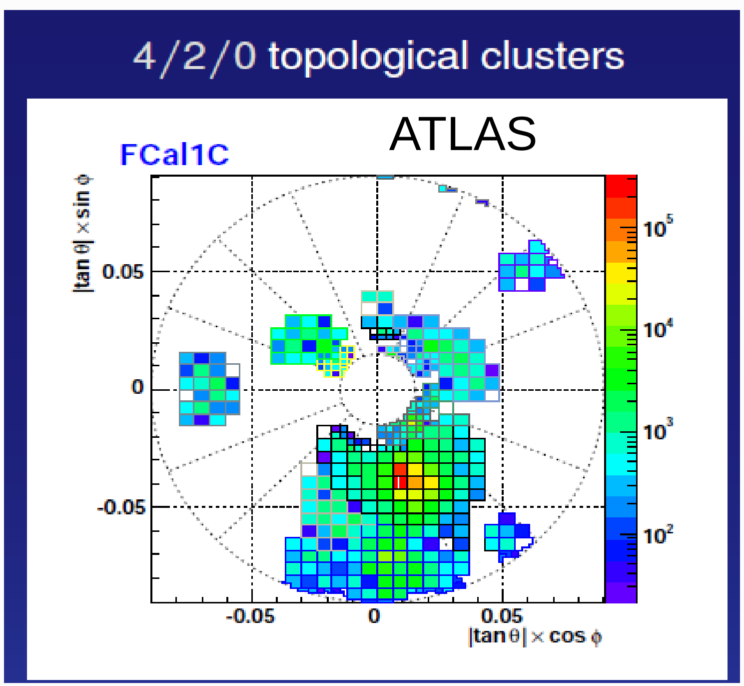
Single pion response in ATLAS combined test beam

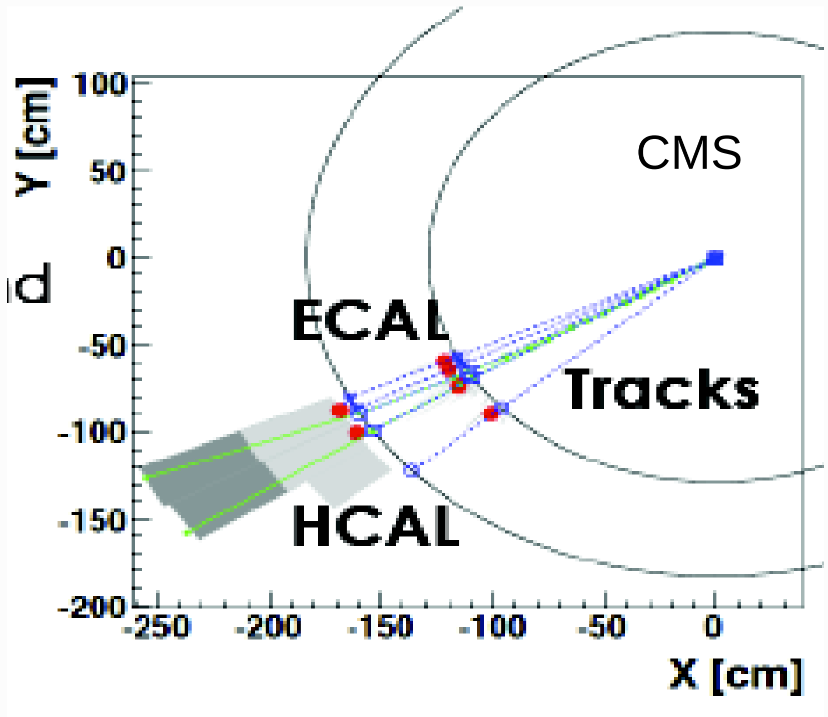


Jet Definitions

Jet algorithm:
ATLAS and CMS use the anti-kt jet algorithm
CMS: R=0.5 and R=0.7 ATLAS: R=0.4 and 0.6
(historic development → aim to converge in shutdown)
Both collaborations also use other algorithms large-R Akt, C/A for substructure techniques...

Jet inputs:
ATLAS: topological calorimeter clusters calibrated on basic calorimeter scale
(EM-scale) or locally corrected for lower hadron response and DM (LCW-scale)
Track jets are used for systematic studies (jet mass, b-JES, subjet JES), pile-up etc.
CMS: baseline are particle flow (PF) objects based on tracking and calorimetry
Also supported: calorimeter towers, or simple track cluster combination method (JPT)



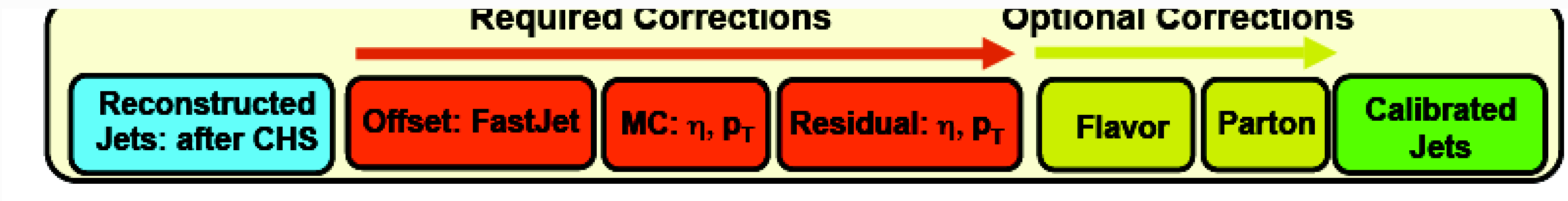


Different technique to reconstruct jets are not a problem to evaluate the correlations between the experiments

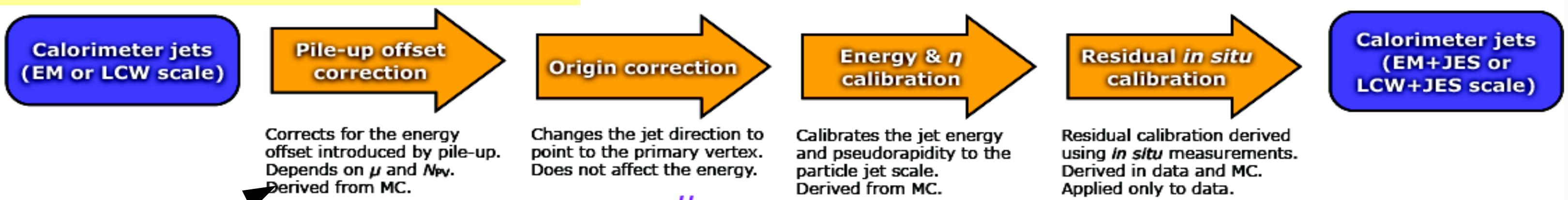
Both experiments use in situ method for uncertainty

Jet calibration strategy

CMS calibration strategy



ATLAS calibration strategy



very small

Corrections derived from MC

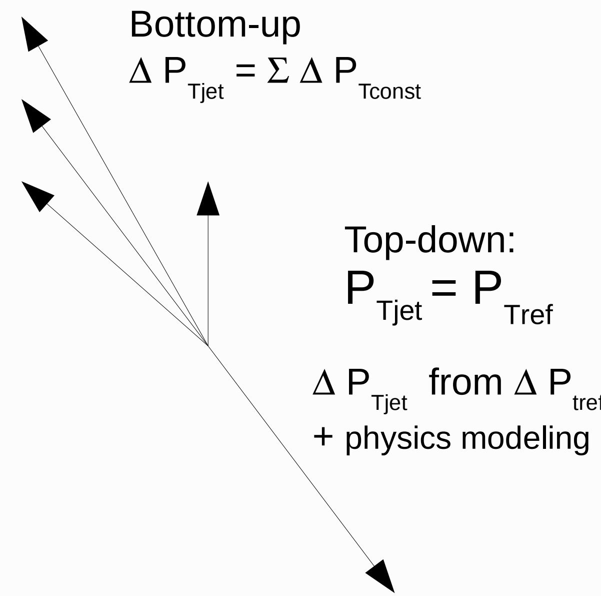
Residual calibration measured in data and MC (up to 2.5%)

ATLAS: simple offset
CMS: jet area

Similar calibration strategy in ATLAS and CMS
CMS also foresee higher level corrections e.g. for flavour or hadronisation

Jet calibration done with respect to the inclusive jet sample (using MC)
ATLAS and CMS quote JES uncertainties with respect to MC
Data corrected to MC particle jet reference

Technique to determine JES uncertainties



Jet calibration done with respect to the inclusive jet sample (using MC)
ATLAS and CMS quote JES uncertainties with respect to MC

Bottom-up approach:

Evaluate measurement uncertainties of jet constituents complemented with modeling uncertainties on particle spectra impinging the detector

Top-down approach:

Use well measured reference object and do some physics assumption (e.g. on pt-balance of jet to reference object)

ATLAS:
2010: jet constituents uncertainties and in situ pt-balance methods as cross checks (bottom-up)
2011: in situ balance methods up to 1 TeV, jet constituents uncertainties above (top-down)

CMS:
Measurements from in situ pt-balance techniques (gamma/Z-jet balance) plus extrapolations to low and high-pt using jet constituents uncertainties complemented by fragmentation modeling uncertainties (mixed approach)

JES uncertainty in central region ("Baseline" in ATLAS "Absolute" in CMS) using in situ techniques
Relative forward to central JES uncertainty from dijet balance

Uncertainties depending on event samples:
ATLAS/CMS: Parton flavour (gluon/light-quark/heavy-quark)
ATLAS/CMS: Pile-up (Nvtx)
ATLAS only: Close-by jets (dR_{JJ})

CMS JES in central region 2010 results

Uncertainty related to in situ methods

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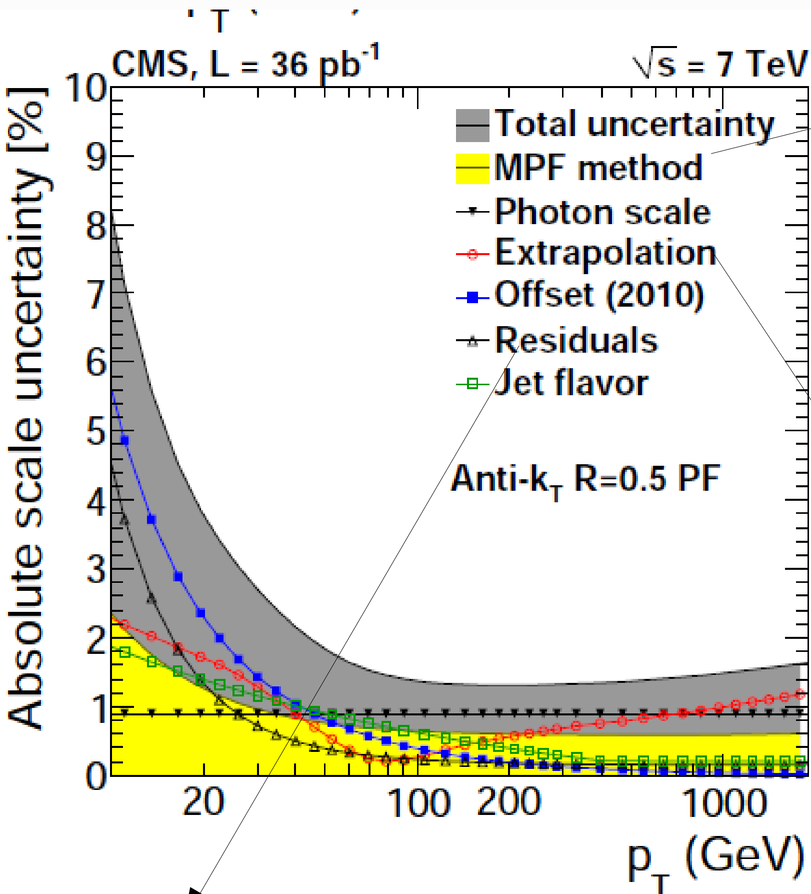
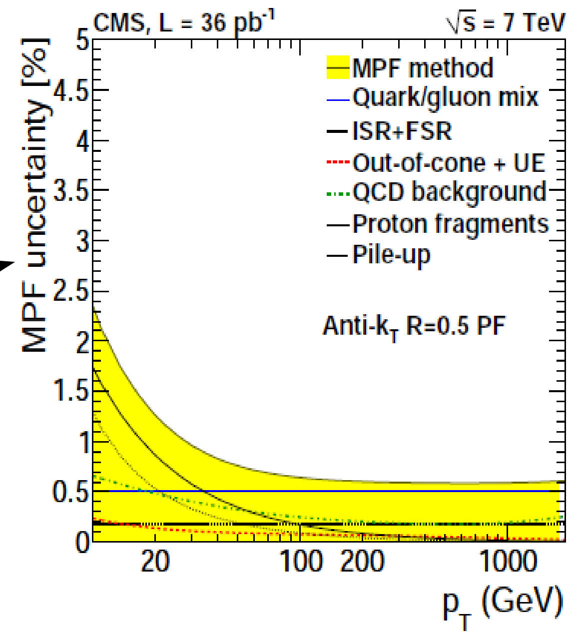
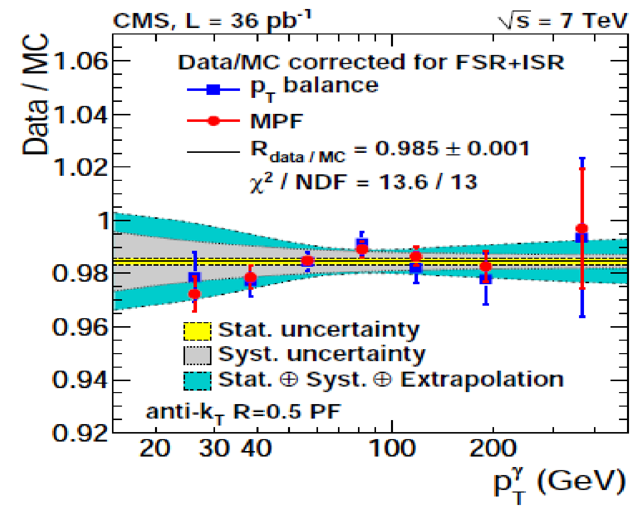
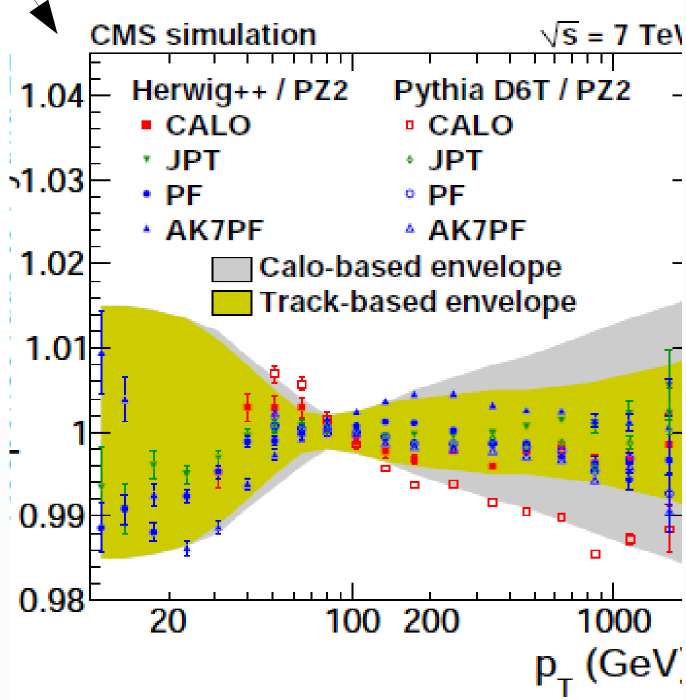






Constant response correction 1.015

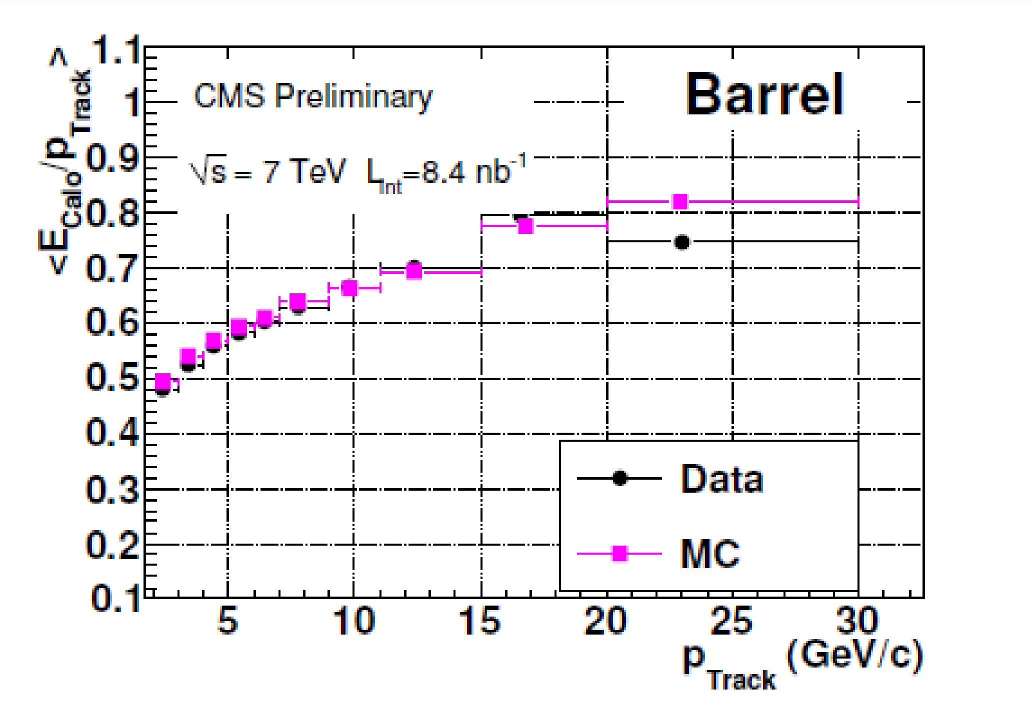


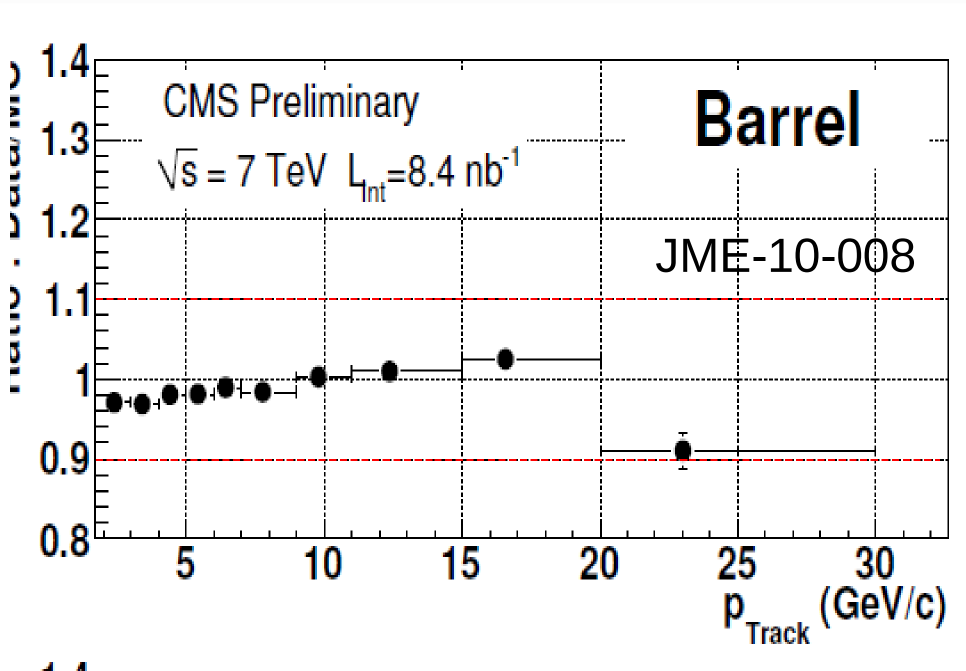
Extrapolation based on single hadron response for calorimeter objects objects with constrains in region where in situ methods available+uncertainty from fragmentation modeling

quark/gluon respnse difference in Pythia/Herwig

CMS isolated hadron response measurements

Single isolated hadron response measurements in CMS using 7 TeV minimum bias sample





$2 < p_{Track} < 20$ GeV

measurements up to eta<2.1 available

Direct probe of calorimeter response modeling by Geant4

Modelling uncertainty via neutral background contamination

Estimated via MC comparing isolated hadrons in minimum bias sample with single pion MC: <5%

Data in agreement with MC within 3%

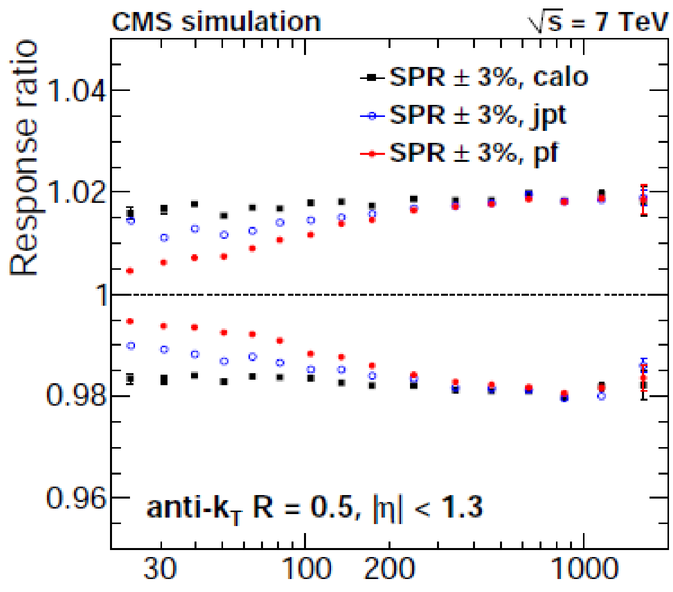
Extrapolation based on jets constituents

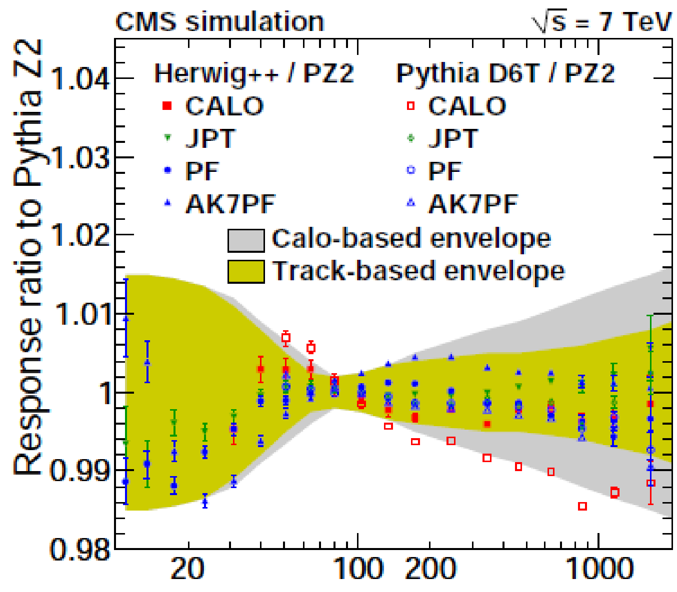
Calorimeter objects from single hadron response measurements

Track momentum and track efficiency measurement gives no uncertainty

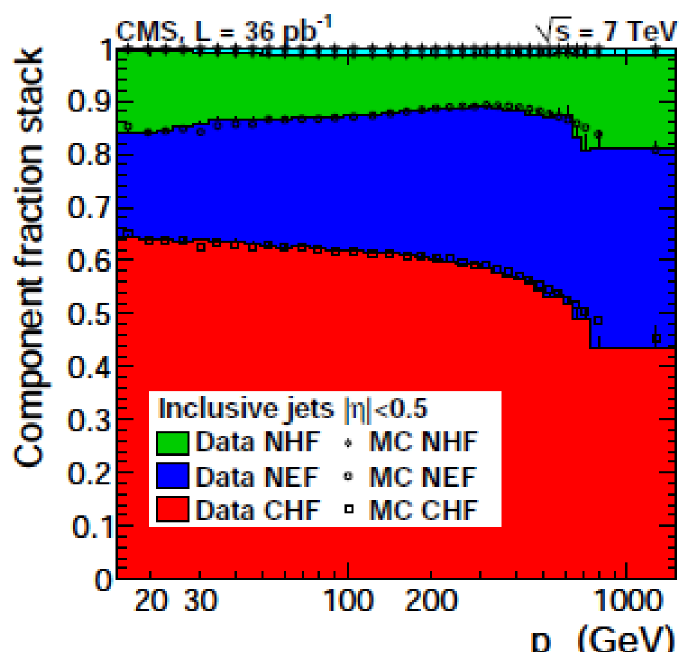
+ constraint in region where in situ methods are precise (around 100 GeV)

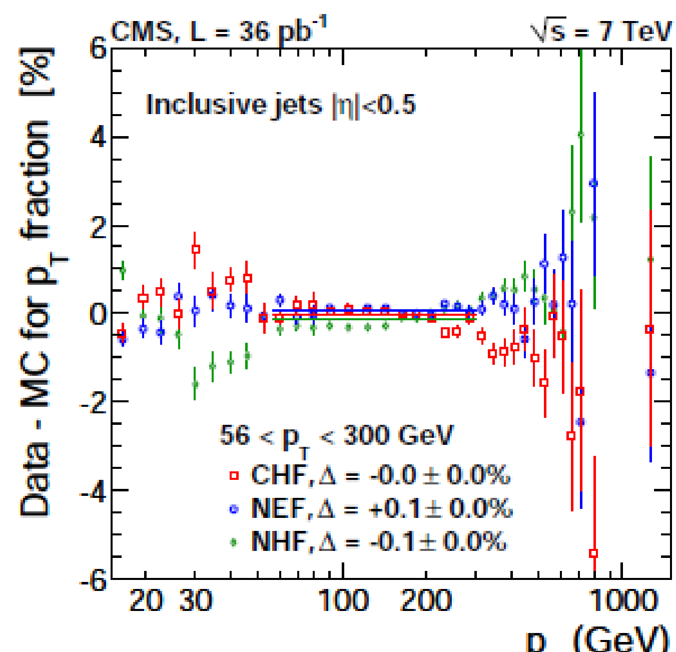
+ Uncertainty related to fragmentation modeling: Response ratio Pythia6 (Z2 and D6T tune) and Herwig++





For particle flow show that jet composition of particle flow objects is well described by MC





ATLAS JES uncertainty sources

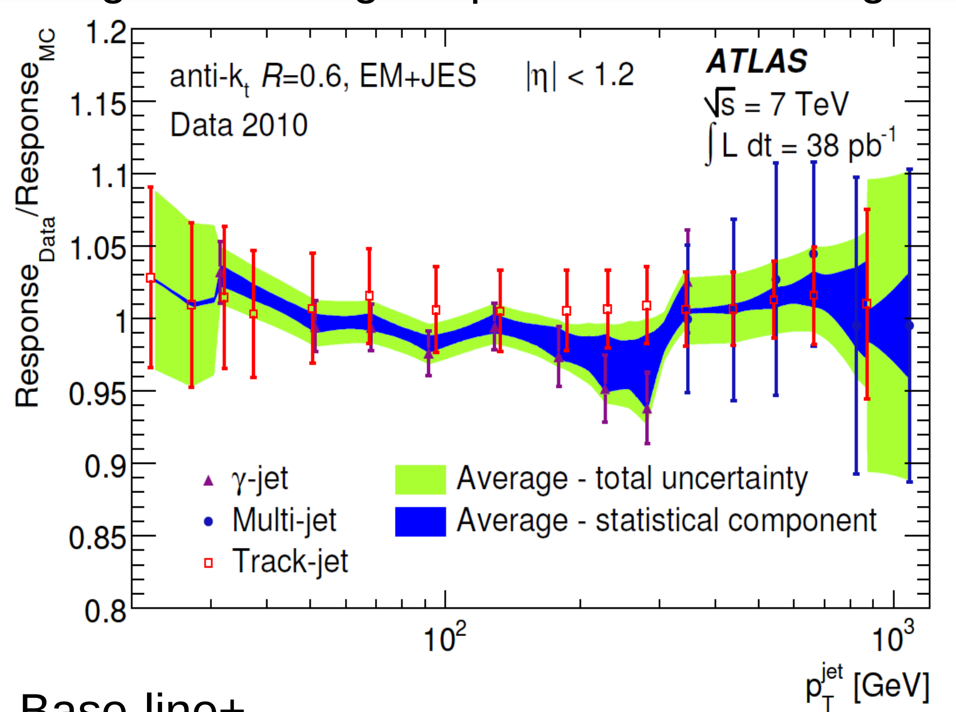
Uncertainties measured in reference samples: Z+jet, gamma+jet (mainly quark jets)

- forward JES
- pileup
- close-by
- flavour (q vs g)
- Heavy flavour

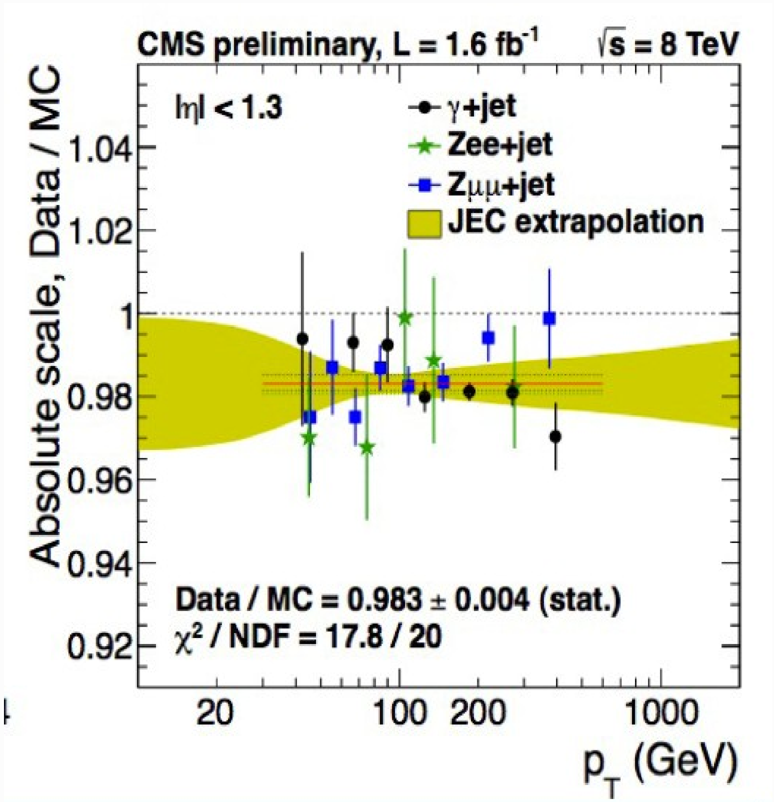
Configuration type	Reduction	N_{params}
All parameters	none	60
All parameters	global	11
All parameters	category	16

Name	Description	Number of components	Category
Common sources			
Electron/photon E scale	electron or photon energy scale	1	det.
Z+jet p_T balance (DB)			
MC generator	MC generator difference between ALPGEN/HERWIG and PYTHIA		model
Radiation suppression	radiation suppression due to second jet cut		model
Extrapolation	extrapolation in $\Delta\phi_{\text{jet-}Z}$ between jet and Z boson		model
Pile-up jet rejection	jet selection using jet vertex fraction		mixed
Out-of-cone	contribution of particles outside the jet cone	6+11	model
Width	width variation in Poisson fits to determine jet response		stat./meth.
Statistical components	statistical uncertainty for each of the 11 bins		stat./meth.
γ+jet p_T balance (MPF)			
MC Generator	MC generator difference HERWIG and PYTHIA		model
Radiation suppression	sensitivity to radiation suppression second jet cut		model
Jet resolution	variation of jet resolution within uncertainty		det.
Photon Purity	background response uncertainty and photon purity estimation		det.
Pile-up	sensitivity to pile-up interaction		mixed
Out-of-cone	contribution of particles outside the jet cone	6+12	model
Statistical components	statistical uncertainty for each of the 12 bins		stat./meth.
Multijet p_T balance			
α selection	angle between leading jet and recoil system		model
β selection	angle between leading jet and closest sub-leading jet		model
Dijet balance	dijet balance correction applied for $\|\eta\| < 2.8$		mixed
Close-by, recoil	JES uncertainty due to close-by jets in the recoil system		mixed
Fragmentation	jet fragmentation modelling uncertainty		mixed
Jet p_T threshold	jet p_T threshold	8+10	mixed
p_T asymmetry selection	p_T asymmetry selection between leading jet and sub-leading jet		model
UE,ISR/FSR	soft physics effects modelling: underlying event and soft radiation		mixed
Statistical components	statistical uncertainty for each of the 10 bins		stat./meth.

In 2011 ATLAS uses combination of in situ techniques. Pt-dependence: weighted average in pt bins + smoothing

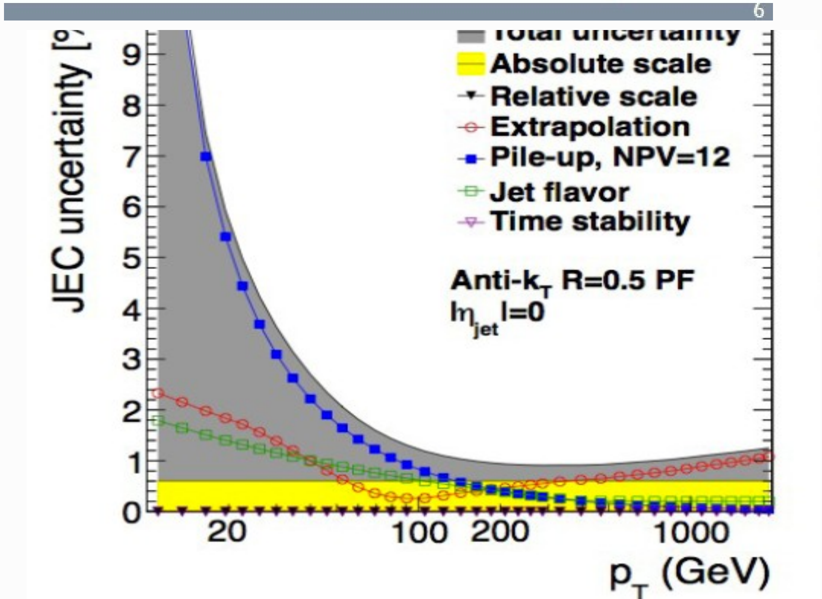


CMS uses in situ techniques in regions 100-200 GeV Pt-dependence from extrapolation to low and high-pt varying particle flow objects



Base-line+
Event sample dependent uncertainties

- pileup
- close-by
- flavour
  (q vs g)
- Heavy flavour



Main problem is that ATLAS considers 54 uncertainty source while CMS has only 1 for the absolute source from the fit of the in situ response data to MC ratio

ATLAS gives correlations from pt-dependent uncertainties of in situ techniques

CMS consider absolute scale constant in p_T. P_T dependence comes from extrapolation and extra effects (see below)

CMS uncertainty list:

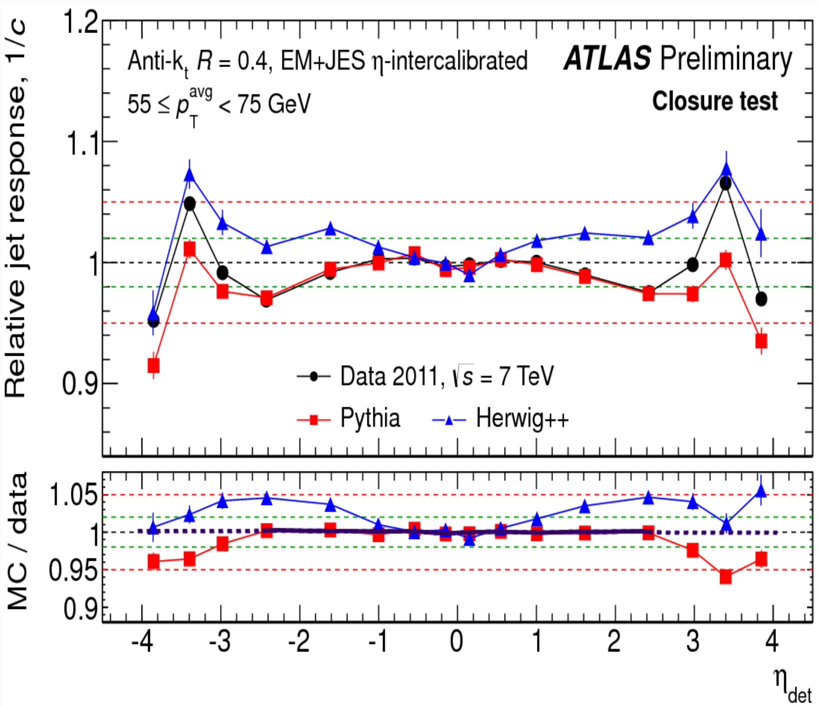
The full list of uncertainty sources currently accessible is listed below:

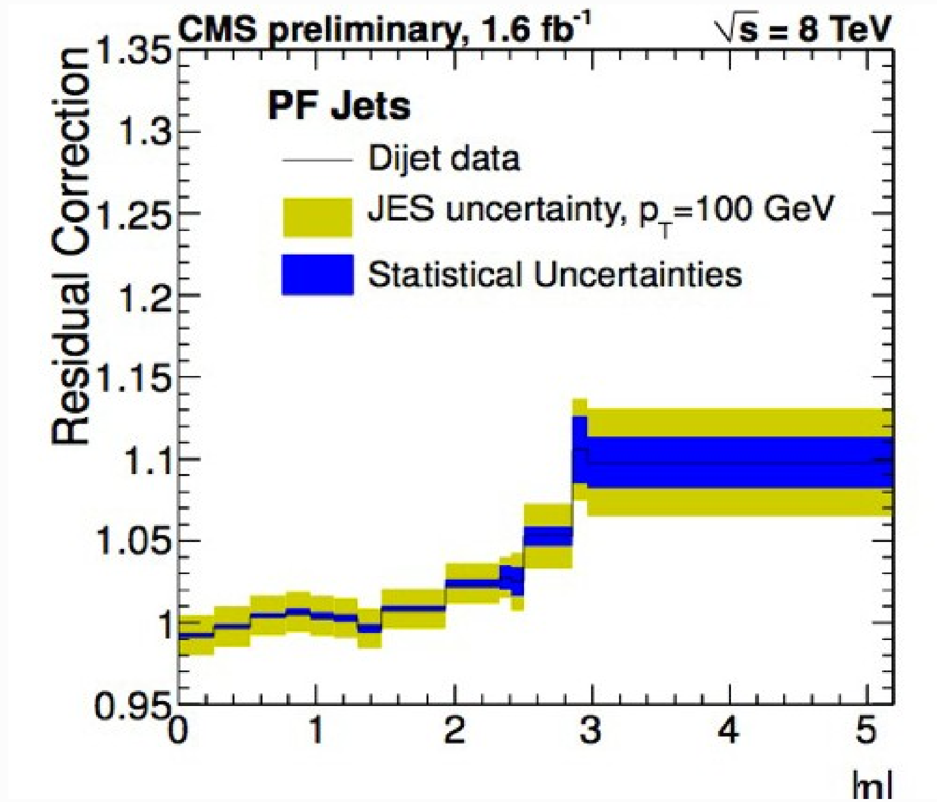
- **Absolute** : absolute scale uncertainty. Mainly uncertainty in combined photon (EM) and Z->mumu (tracking) reference scale and correction for FSR+ISR.
- **HighPtExtra** : high pT extrapolation. Based on Pythia6 Z2/Herwig++2.3 differences in fragmentation and underlying event (FullSim).
- **SinglePion** : high pT extrapolation. Based on propagation of +/-3% variation in single particle response to PF Jets (FastSim).
- **Flavor** : jet flavor (quark/gluon/charm/b-jet). Based on Pythia6 Z2/Herwig++2.3 differences in quark and gluon responses relative to QCD mixture (charm and b-jets are in betweed uds and g).
- **Time** : JEC time dependence. Observed instability in the endcap region, presumed to be due to the EM laser correction instability for prompt 42X data.
- **RelativeJER[EC1][EC2][HF]** : eta-dependence uncertainty from jet pT resolution (JER). The JER uncertainties are assumed fully correlated for endcap within tracking (EC1), endcap outside tracking (EC2) and hadronic forward (HF).
- **RelativeFSR** : eta-dependence uncertainty due to correction for final state radiation. Uncertainty increases toward HF, but is correlated from one region to the other.
- **RelativeStat[EC2][HF]** : statistical uncertainty in determination of eta-dependence. Averaged out over wider detector regions, and only important in endcap outside tracking (EC2) and in HF.
- **PileUp[DataMC][OOT][Pt][Bias][JetRate]** : uncertainties for pile-up corrections. The [DataMC] parameterizes data/MC differences vs eta in Zero Bias data. The OOT estimates residual out-of-time pile-up for prescaled triggers, if reweighing MC to unprescaled data. The [Pt] covers for the offset dependence on jet pT (due to e.g. zero suppression effects), when the correction is calibrated for jets in the pT=20-30 GeV range. The [Bias] covers for the differences in measured offset from Zero Bias (neutrino gun) MC and from MC truth in the QCD sample, which is not yet fully understood. The [JetRate] covers for observed jet rate variation versus <Nvtx> in 2011 single jet triggers, after applying L1 corrections.

Forward JES from dijet balance between central and forward region

In ATLAS and CMS forward energy scale is evaluated with respect to central region

Dijet balance after correction for |eta|<2.1





ATLAS uses Pythia to derive correction only for |eta|<2.1
Consider Pythia/Herwig difference as uncertainty
(Model dependence largest uncertainty)
Results cross-checked with Z+jet balance
Uncertainty at eta=4 for p_T=100 GeV: 5%

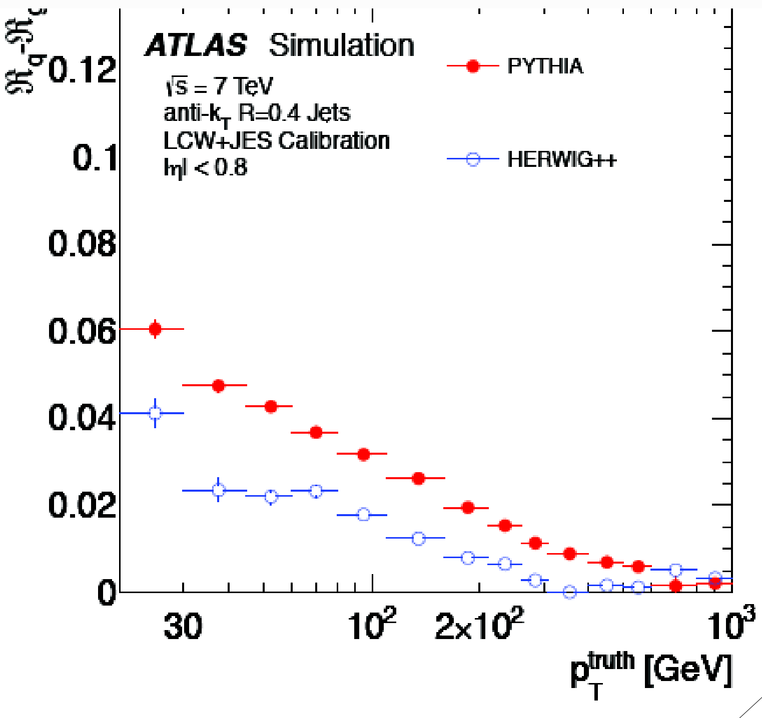
CMS use Pythia to derive a correction
correction below 2.5% for |eta|<2.4
up to 10% in forward region
Uncertainty at eta=4 for p_T=100 GeV 3%

Need to understand why Pythia/Herwig problem is not an issue for CMS

JES flavour dependence

ATLAS had detailed studies using purified samples

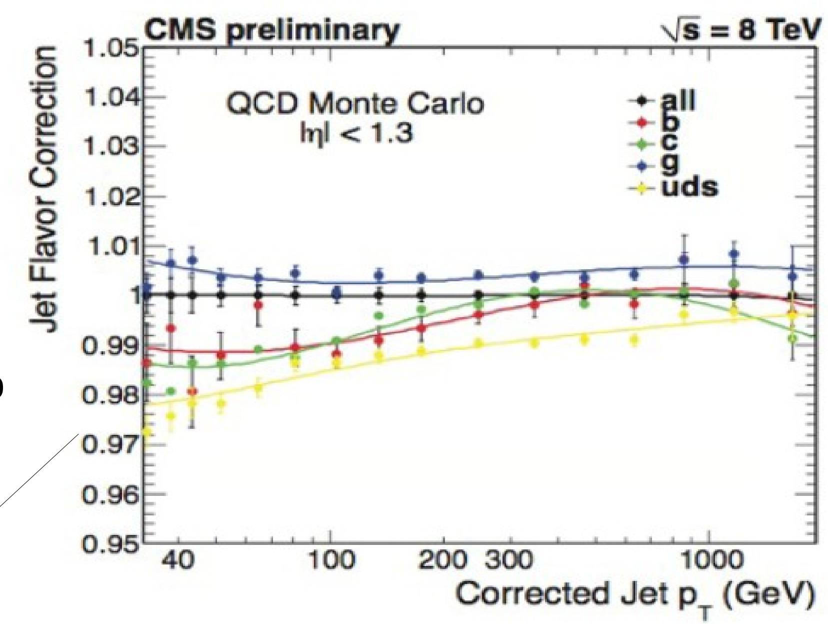
See ATLAS-CONF-2012-138



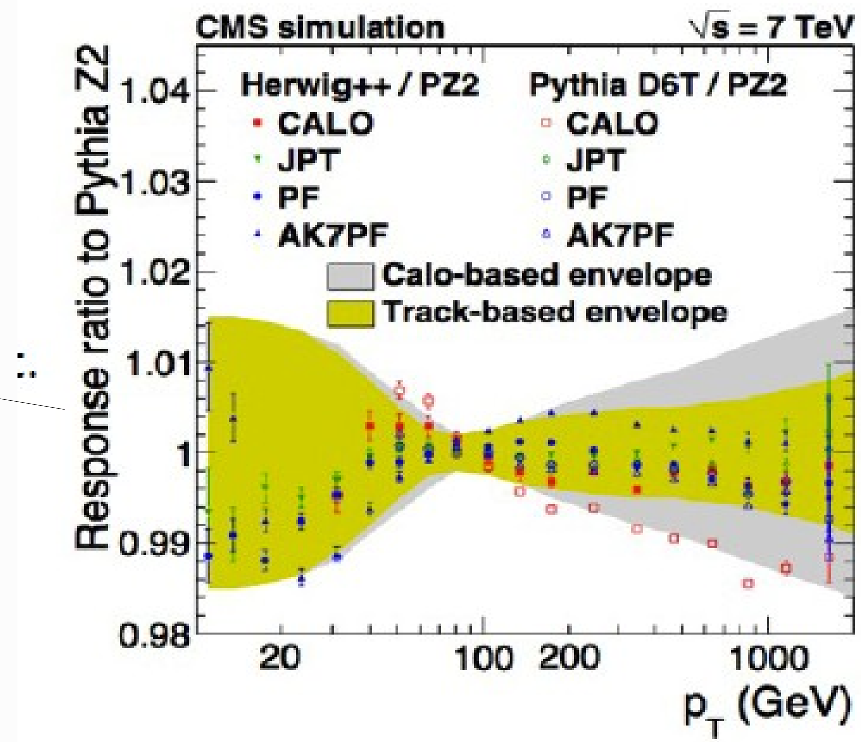
CMS

Δf_g =100%

Flavour corrections



Jet flavour uncertainty



Sample dependent!

flavour composition uncertainty

flavour response uncertainty

$$\Delta\mathfrak{R}_s = \Delta f_g \times (\mathfrak{R}_q - \mathfrak{R}_g) \oplus f_g \times \Delta\mathfrak{R}_g$$

uncertainty on gluon fraction

quark-gluon jet response difference

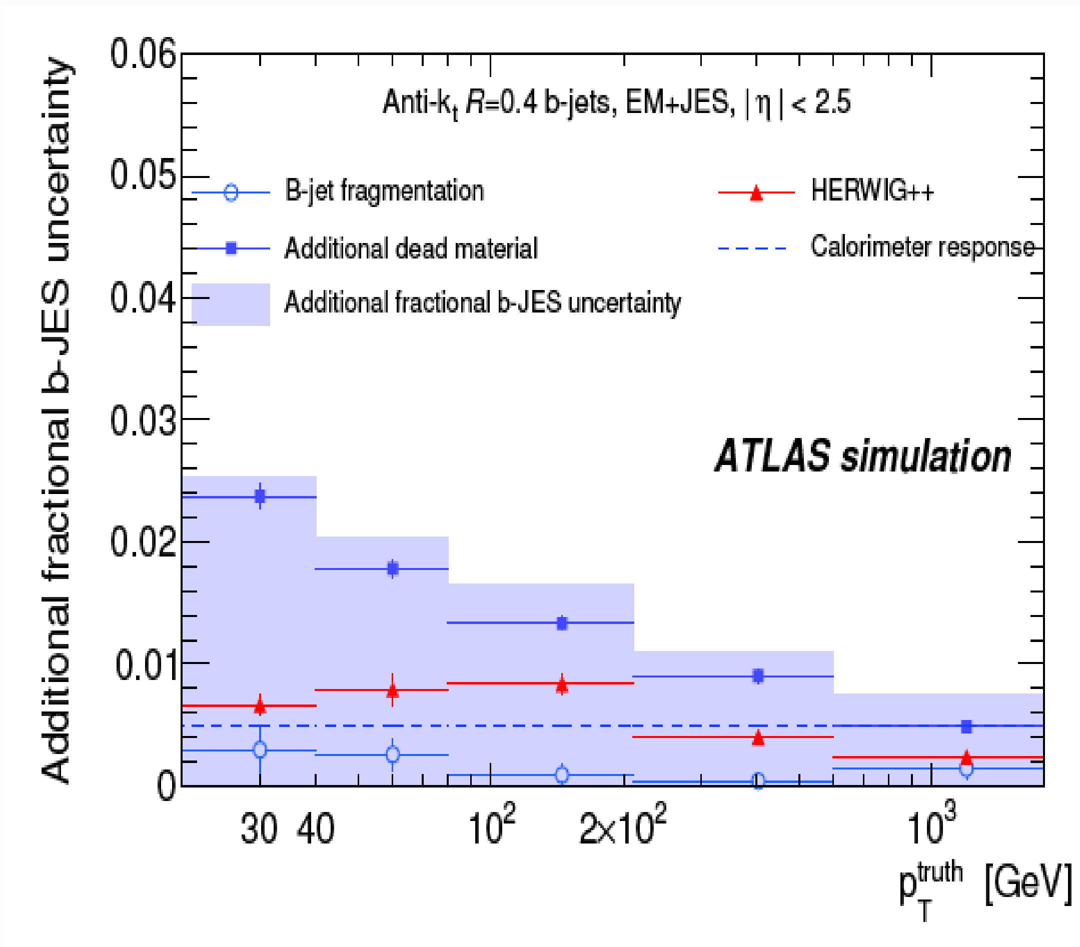
fraction of gluon jets in sample

uncertainty on gluon jet response (from MC)

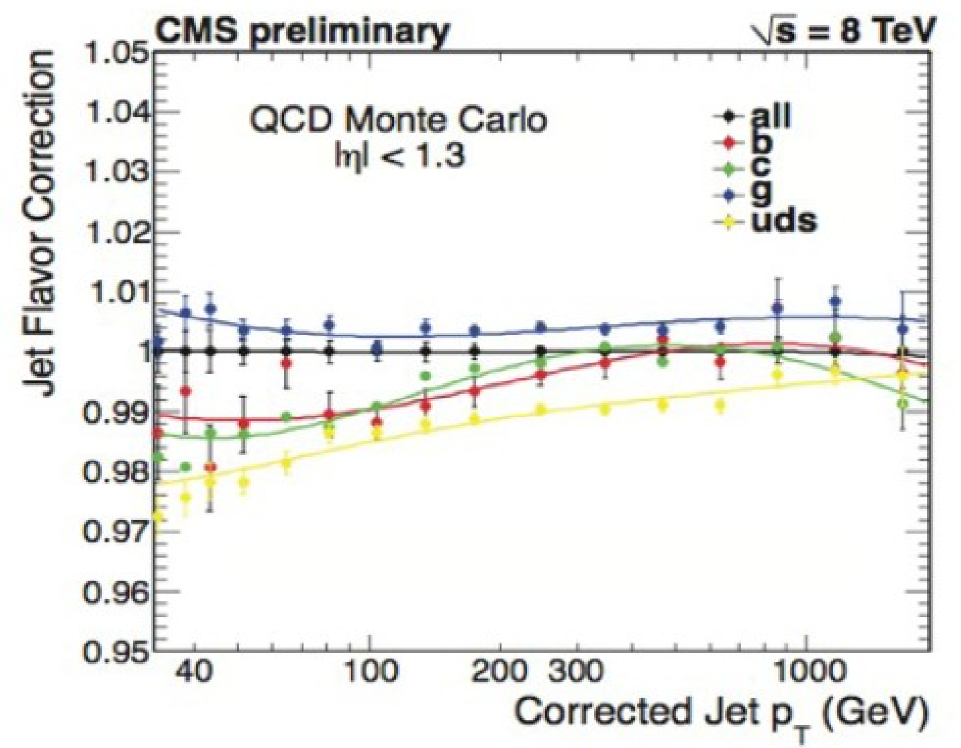
ATLAS estimated
From MC

JES for jets with b-quarks

ATLAS varies systematics effects in the MC
For b-jets and does in situ validation using tracking



CMS takes quark/gluon Pythia/Herwig
Difference as b-jet uncertainty



Since in 2011 the JES calibration is based on
In situ technique, ATLAS will only quote the
difference between b-jets and inclusive jets
for the dead material effect -> will drop

Open point:
Should we consider specific b-jet effects like
B-Hadron fragemenation function

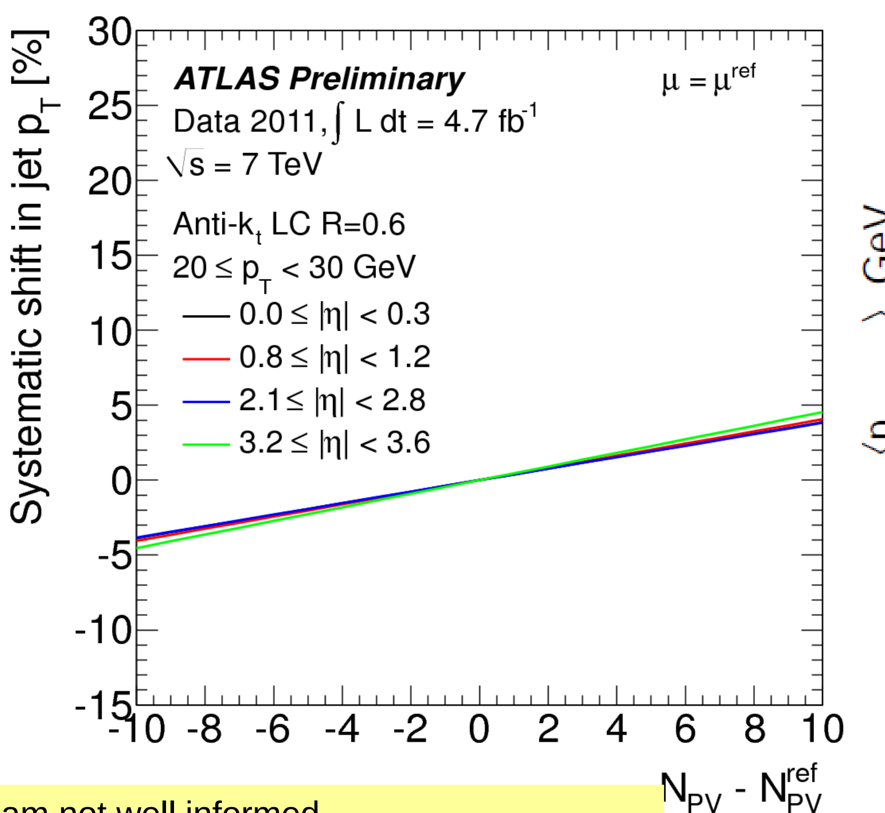
Pile-up corrections

ATLAS use simple offset correction
derived from MC (500-800 MeV/Nvtx)
Correction for in time and out-of-time pile-up
Validated with in situ (tracks, γ-jet)
Uncertainty with respect to mean Nvtx
in validation sample

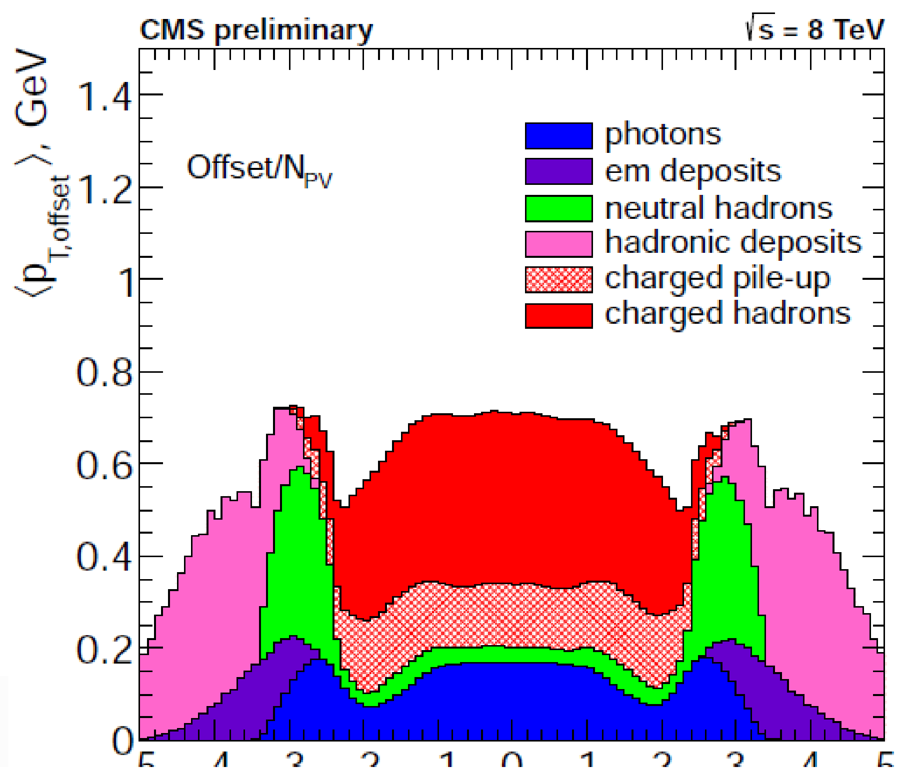
CMS uses jet area technique (Cacciari/Salam)

Advantage:
pile-up subtraction event-by-event
Data and MC differences do not matter
Better resolution
Largest uncertainty from non-closure
Use also off-set correction ?

- Part that remains as PU after this needs to be subtracted
  PU density x Effective area
  (FastJet-ρ)
- PU density depends on the # of primary vertex in the event

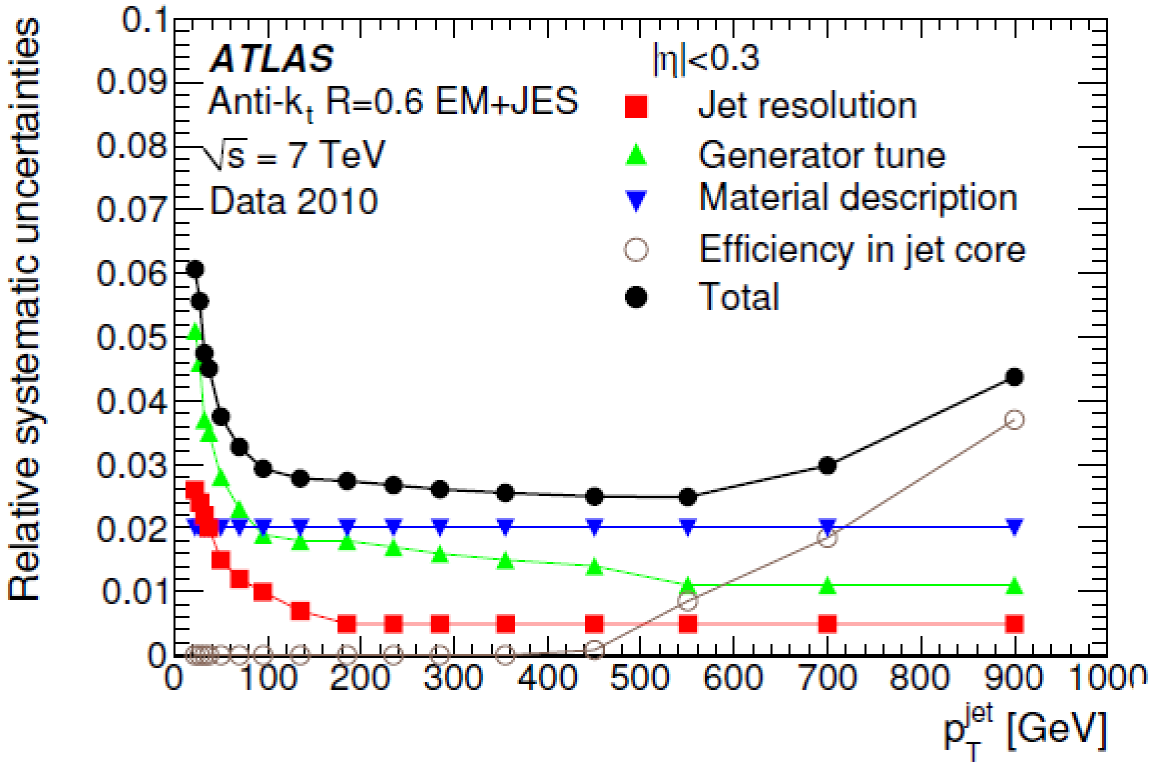


I am not well informed
About CMS pile-up corrections!



- Pile-up measured with Zero Bias data and MC, then calibrated to QCD MC offset.
  - Random cone method allows to separate contribution per subdetector
  - Most charged hadrons can be associated to pile-up vertices and removed

ATLAS systematic uncertainty from validation using associated tracks



Systematic uncertainty on material description

tracking efficiency uncertainty
2% for PTtrack>500 MeV
→ results in 2% uncertainty on JES

Tracking in jet core:

Rate of fake tracks <0.1%
Track losses in jet core
7.5% on Sum pttrack for 800<ptjet<1000 GeV

Generator tune:

Uncertainty on fragmentation

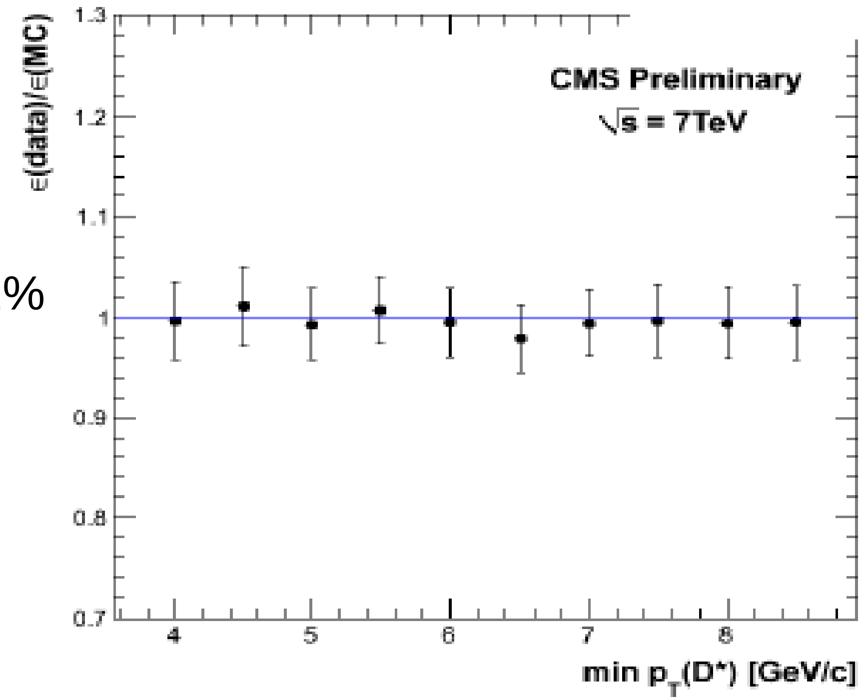
Tune Name	PYTUNE Value	Comments
MC10	–	ATLAS default (p_T ordered showering)
MC09	–	ATLAS default for Summer 2010 (p_T ordered showering)
RFTA	100	Rick Field Tune A Q^2 ordered showering
	107	Tune A with "colour annealing" colour reconnection
	110	Tune A with LEP tune from Professor
	117	Tune 110 with "colour annealing" colour reconnection
	129	Tune of Q^2 ordered showering and UE with Professor
	320	PERUGIA0 (p_T ordered showering)
PERUGIA2010	327	PERUGIA0 with updated fragmentation and more parton radiation

CMS tracking studies

Studies I know in CMS

CMS PAS TRK-10-002

Using D-mesons for pions $\mathcal{R} = \frac{N_{K3\pi}}{N_{K\pi}} \cdot \frac{\epsilon_{K\pi}}{\epsilon_{K3\pi}},$



The final result is $\epsilon(\text{data})/\epsilon(\text{MC}) = 1.007 \pm 0.034 \pm 0.014 \pm 0.012,$

Conclusions:
Track embedding method tracking efficiency is reproduced by MC within 1%
From J/Psi tag-and-probe isolated muon 1-2%
Non-isolated muons 5.3%
Pion tracking efficiency 3.9%

For isolated muons:

Region	Data Eff. (%)	Sim Eff. (%)	Data/Si
$0.0 \leq \lvert\eta\rvert < 1.1$	$100.0^{+0.0}_{-0.3}$	$100.0^{+0.0}_{-0.1}$	$1.000^{+0.}_{-0.}$
$1.1 < \lvert\eta\rvert < 1.6$	$99.2^{+0.8}$	$99.8^{+0.1}$	$0.994^{+0.}$

Table 1: Measured tracking efficiency values from tag and probe on data and simulation, after correcting for the effect of spurious muon-track matches. We show results for different pseu-

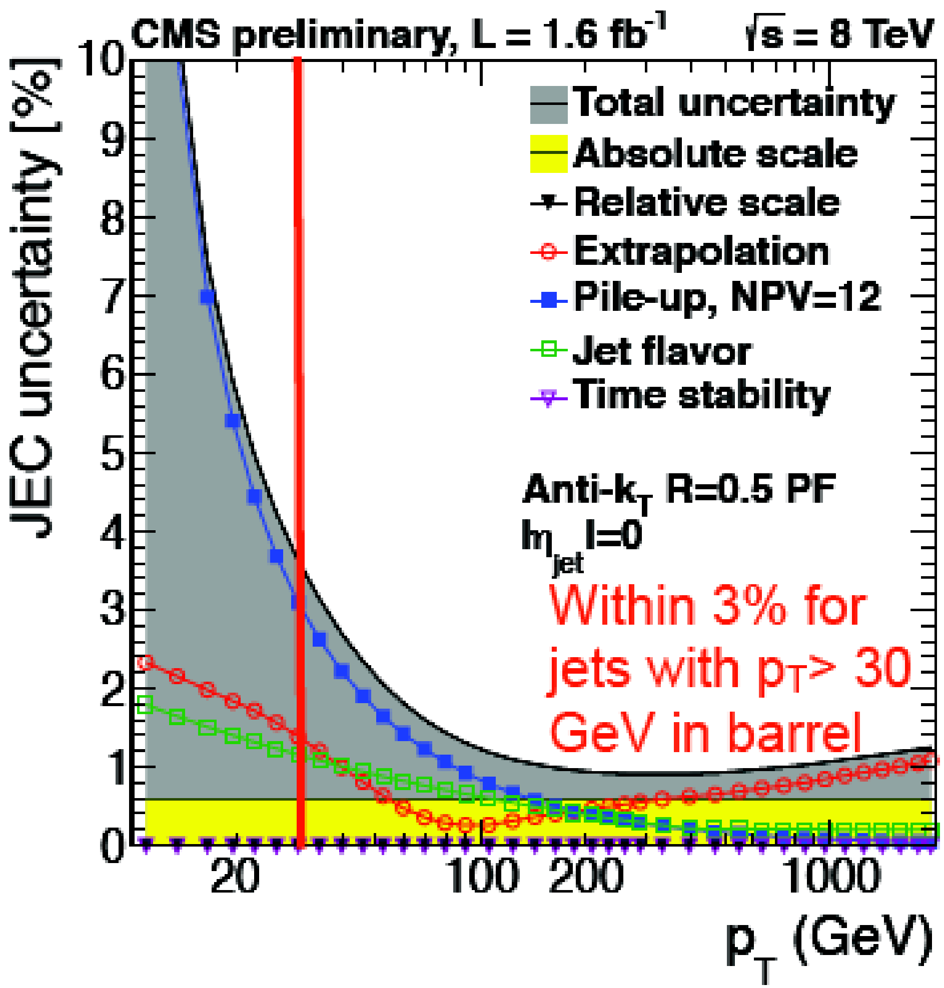
For non-isolated muons:

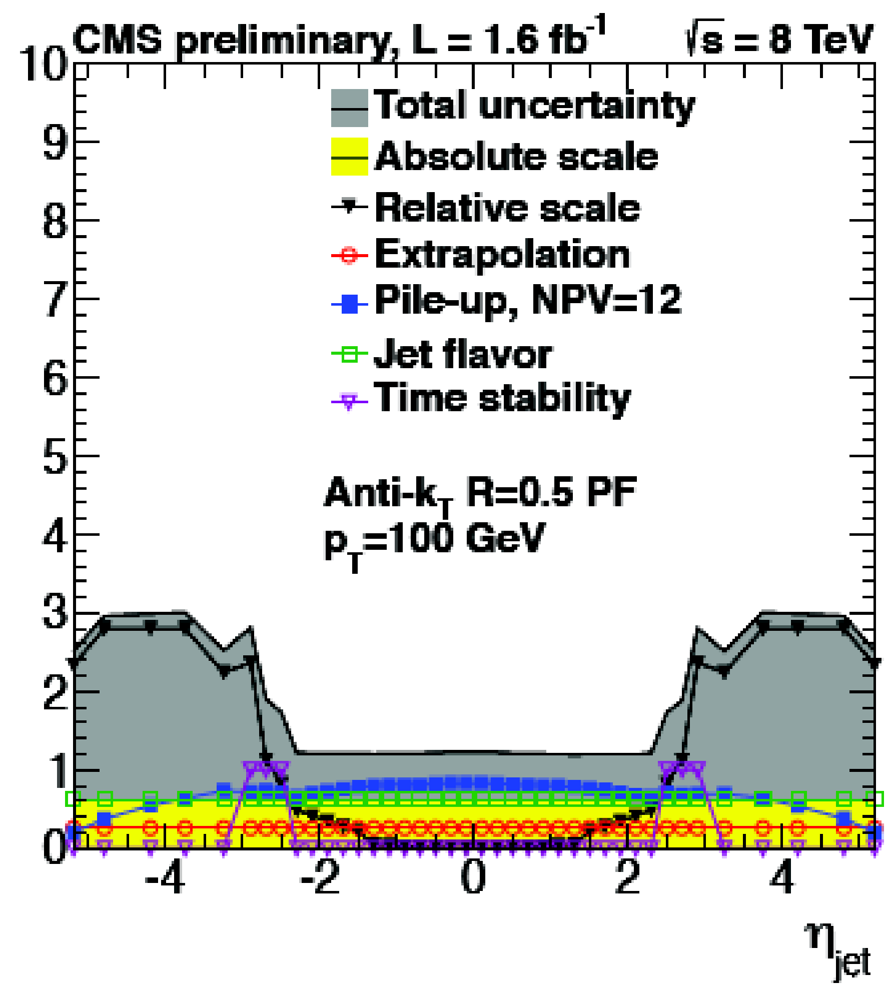
$\epsilon_{bc} = (93.2 \pm 5.3)\%$, where the uncertainty is statistical only. T

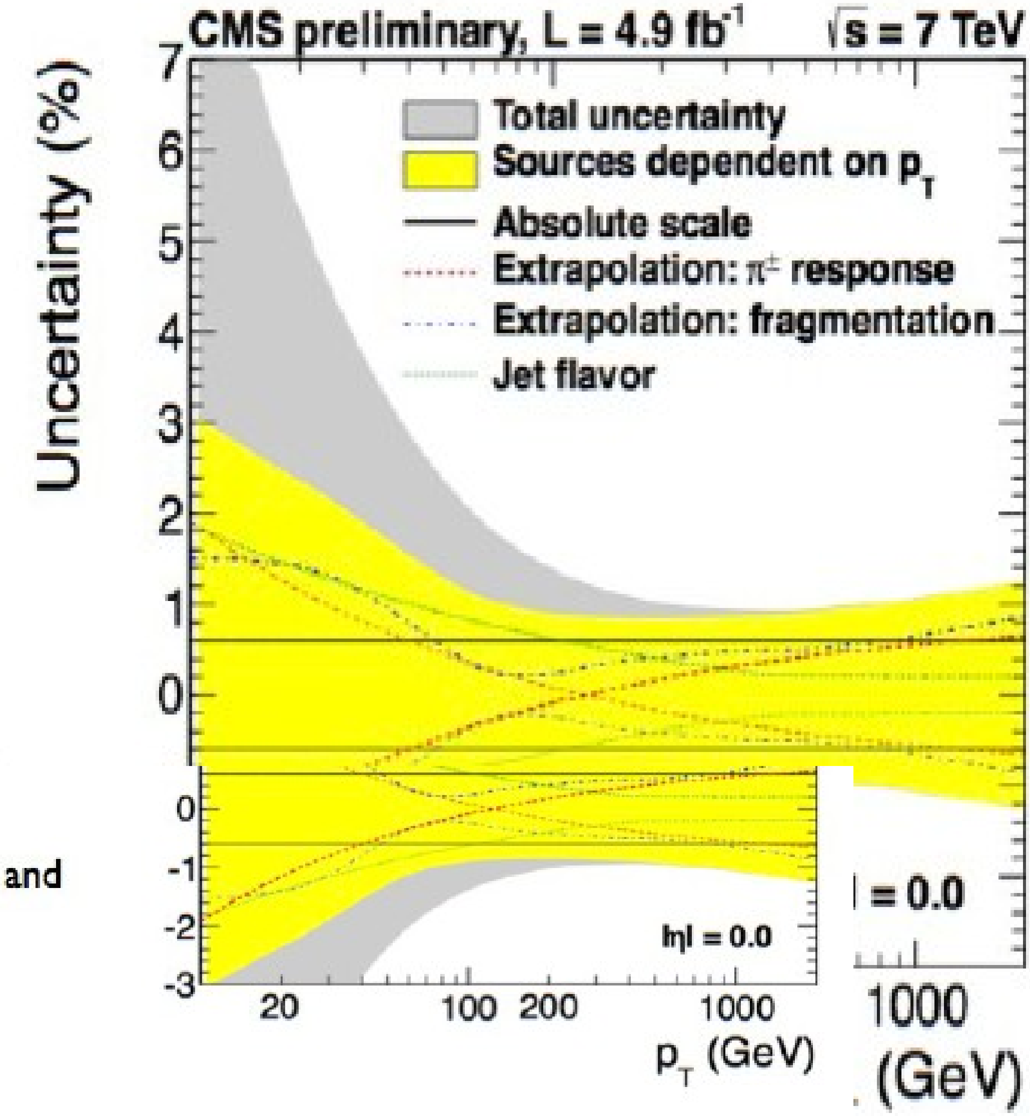
e true efficiency (96%) within 2.5%. The value measured in data is also in agreement with the true efficiency within its uncertainty.

◆Uncertainties in 2012 data comparable to 2010, 2011.

- Pileup uncertainties increasing due to higher average pileup.



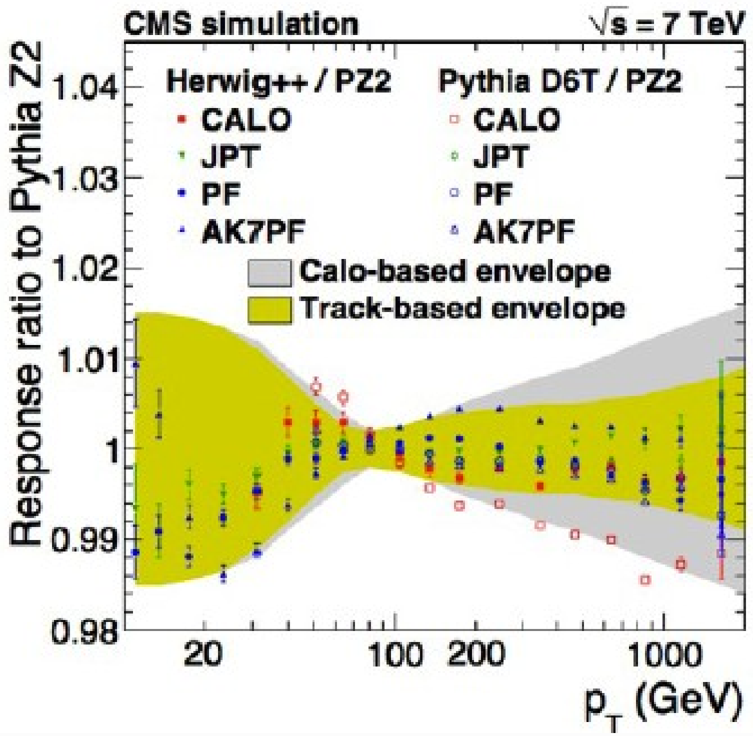


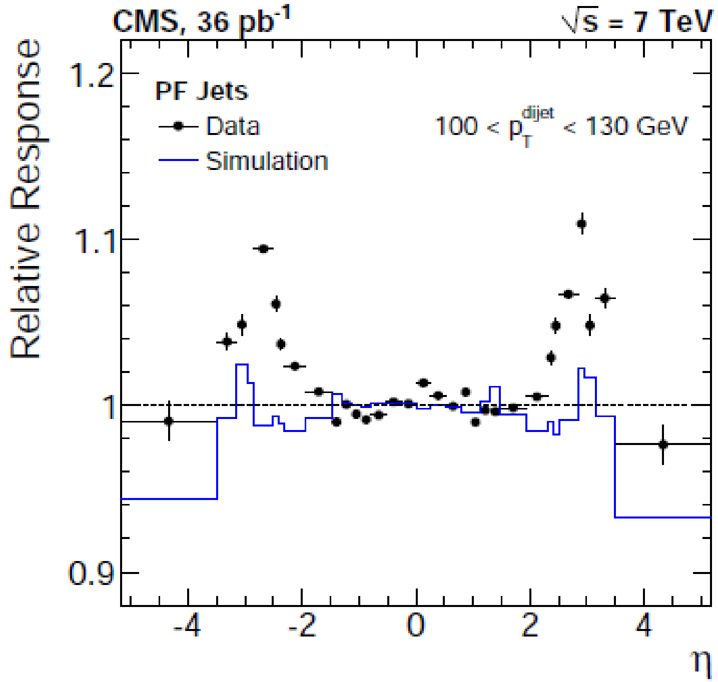


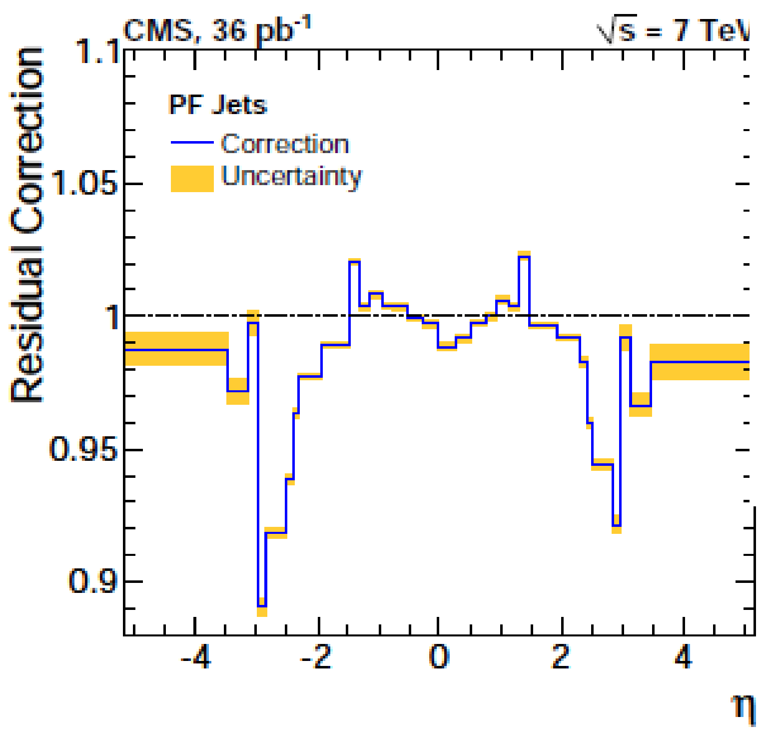
- Top mass: effect of JEC on template shapes
- In the example, extrapolation uncertainty broken into **correlated** (fragmentation) and **anti-correlated** parts (pion response)
- Important feature: sources can cross zero to produce anti-correlation
- Allowed JEC shapes obtained as linear combinations of sources

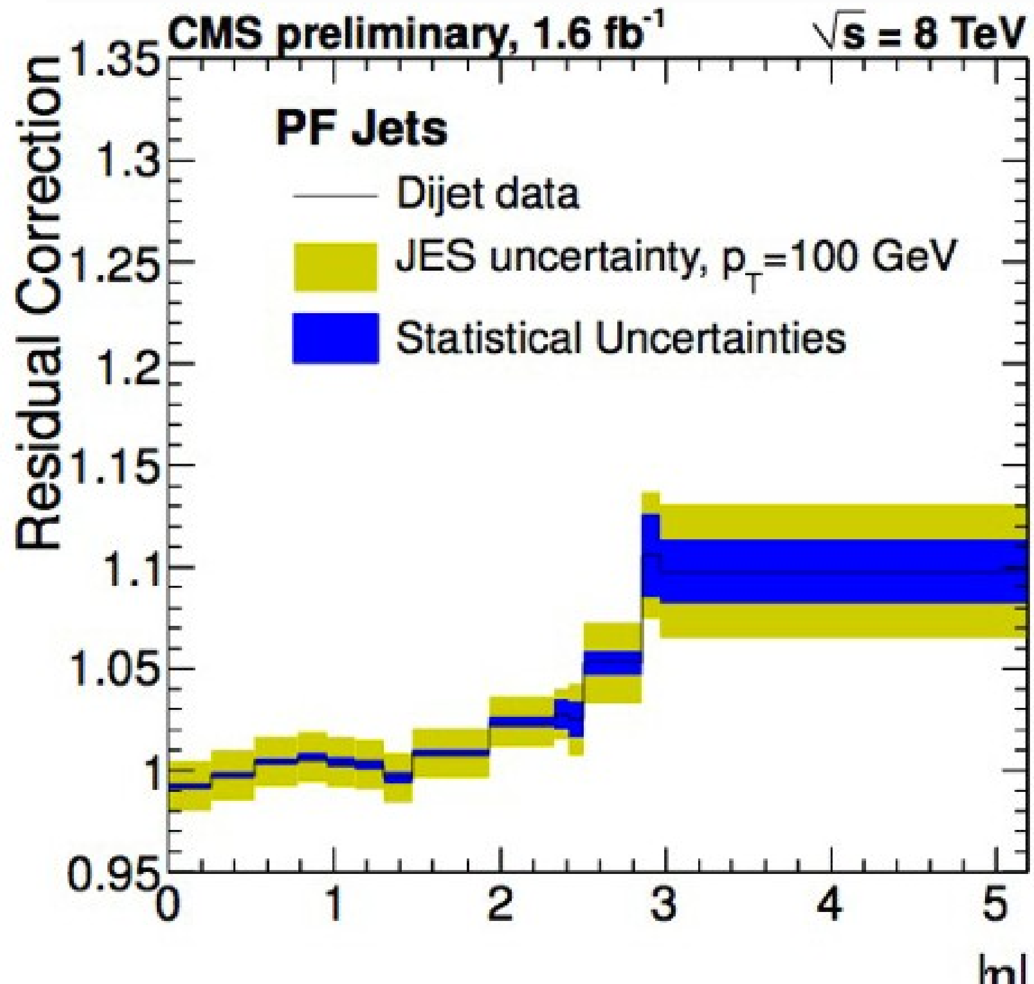
- Uncertainty correlations provided as 16 independent sources
  - sources mutually uncorrelated, and each represents 1σ uncertainty
  - sources categorize allowed shapes in JEC η_{jet} and p_T dependence
  - total uncertainty obtained by summing all sources in quadrature
- Sources have definite sign: "up" and "down"-type variations can each be positive or negative

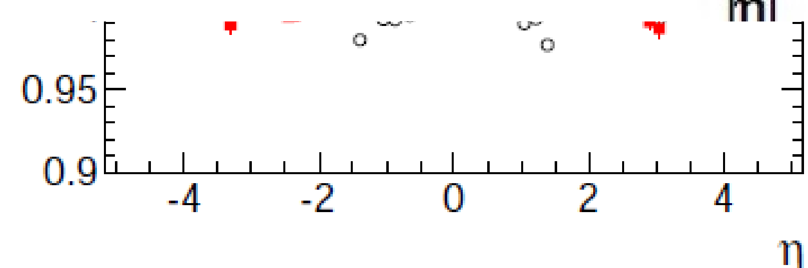
- MC truth jet response extracted for Calo, JPT, (AK5)PF, AK7PF with Pythia D6T, Herwig++ and Pythia Z2 (default tune)
- Scaled results to be the same at roughly pT=100 GeV.
  - absolute residual correction (data/MC) are extracted in that pt region
- Difference in shape between pythia and Herwig++ extrapolated in the full range
  - it matters only at low/very high pt.
- Difference within 1.5%



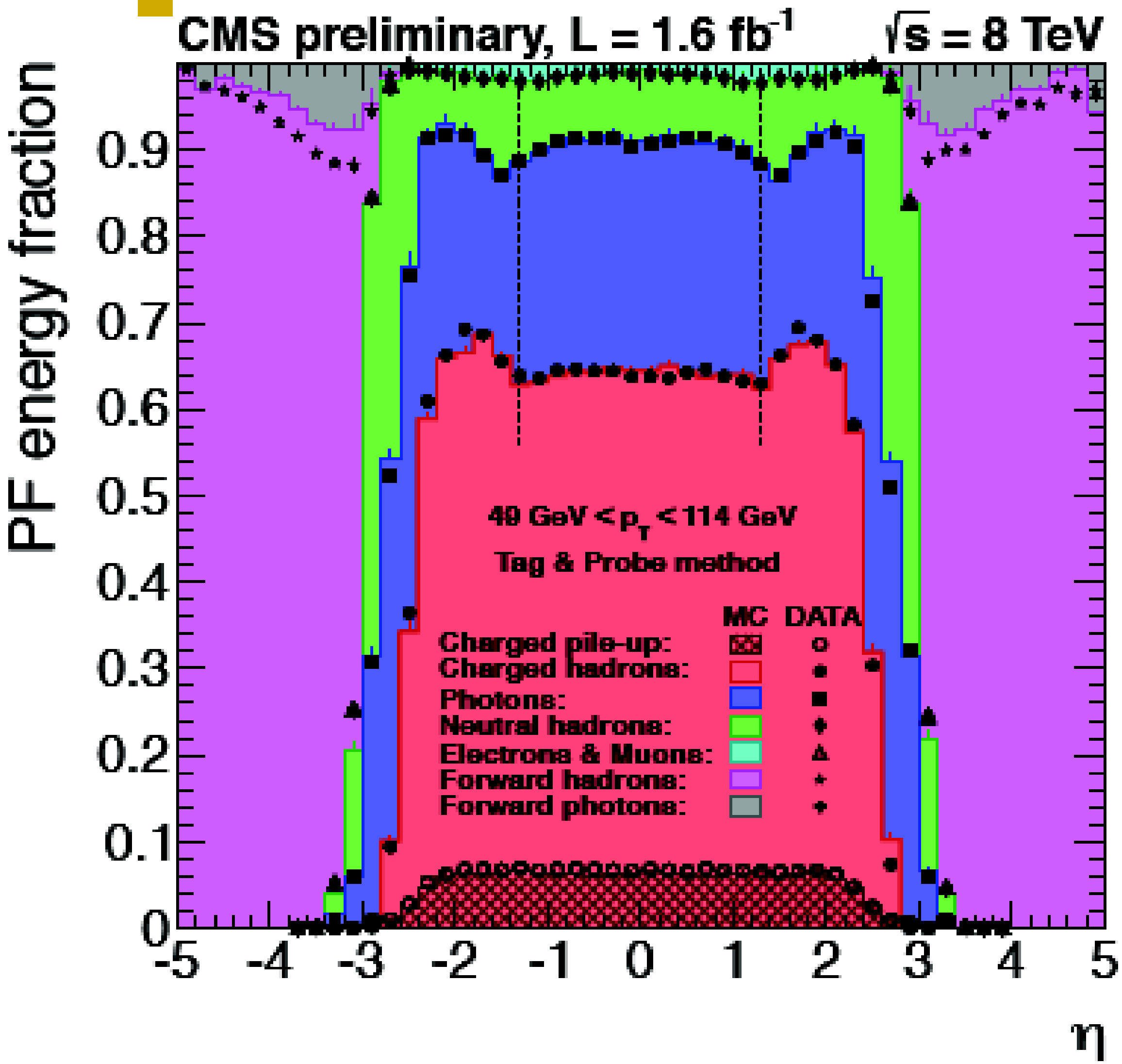

CMS, 36 pb-1
√s = 7 TeV
Relative Response
PF Jets
Data
Simulation
100 < p_T^dijet < 130 GeV
1.2
1.1
1
0.9
-4
-2
0
2
4
η


CMS, 36 pb-1
√s = 7 TeV
Residual Correction
PF Jets
Correction
Uncertainty
1.1
1.05
1
0.95
0.9
-4
-2
0
2
4
η

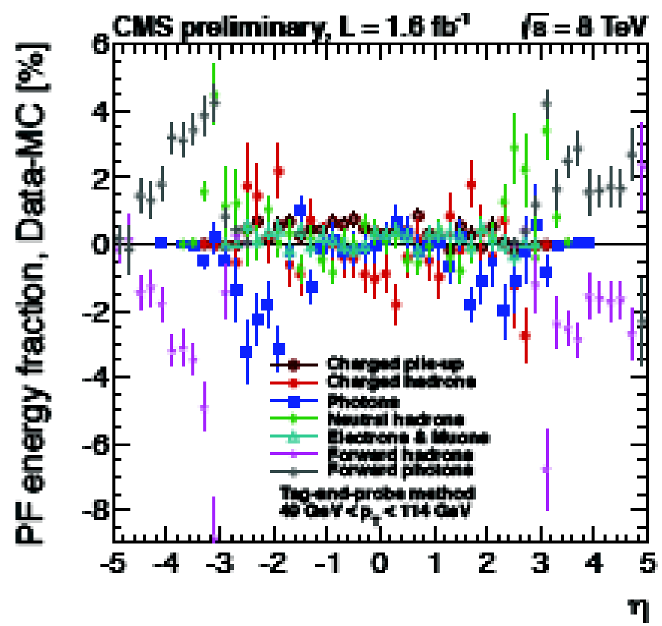

CMS preliminary, 1.6 fb-1
√s = 8 TeV
Residual Correction
PF Jets
Dijet data
JES uncertainty, p_T=100 GeV
Statistical Uncertainties
1.35
1.3
1.25
1.2
1.15
1.1
1.05
1
0.95
0
1
2
3
4
5
|η|


0.95
0.9
-4
-2
0
2
4
η

Jet composition vs η



- Jet composition shows increasing differences in the forward region
  - consistent with JEC at 2-13% level.



JES flavour dependence

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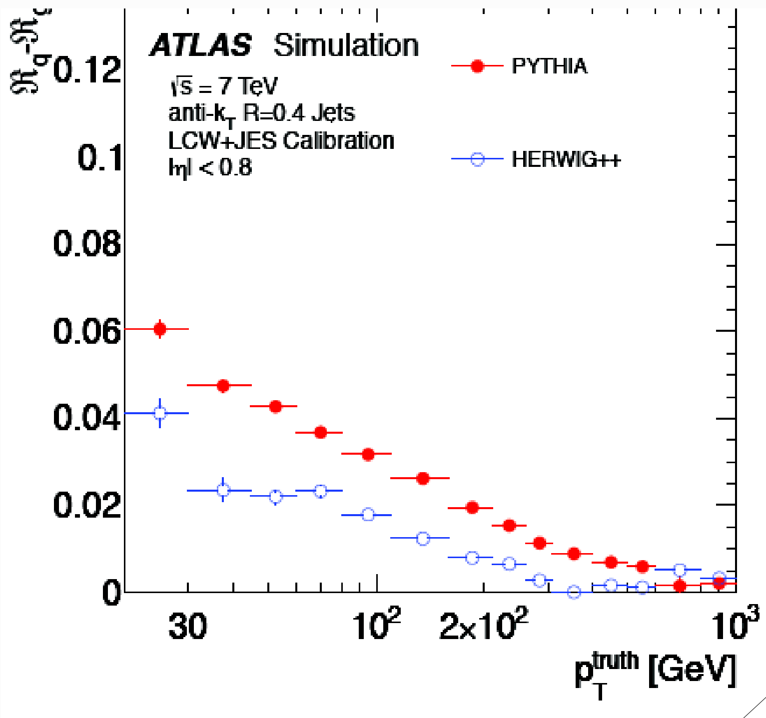
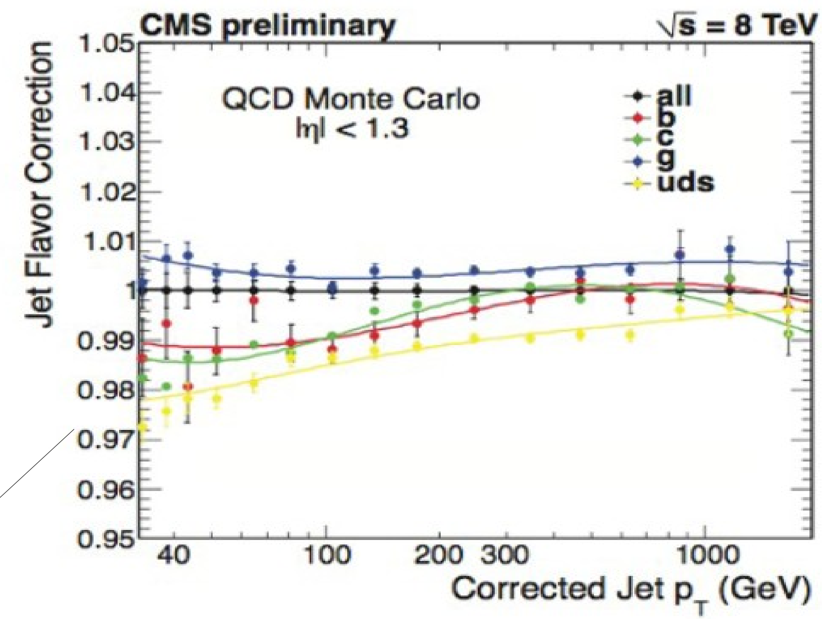


CMS

Δf_g =100%

Flavour corrections



Sample dependent!

flavour composition uncertainty

flavour response uncertainty

$$\Delta\mathfrak{R}_s = \Delta f_g \times (\mathfrak{R}_q - \mathfrak{R}_g) \oplus f_g \times \Delta\mathfrak{R}_g$$

quark-gluon jet response difference

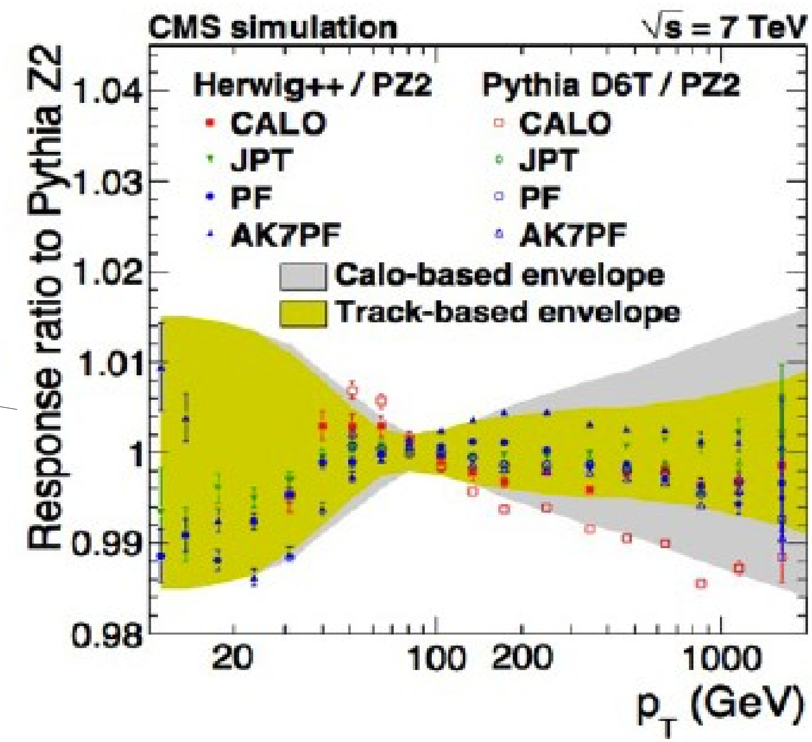
uncertainty on gluon jet response (from MC)

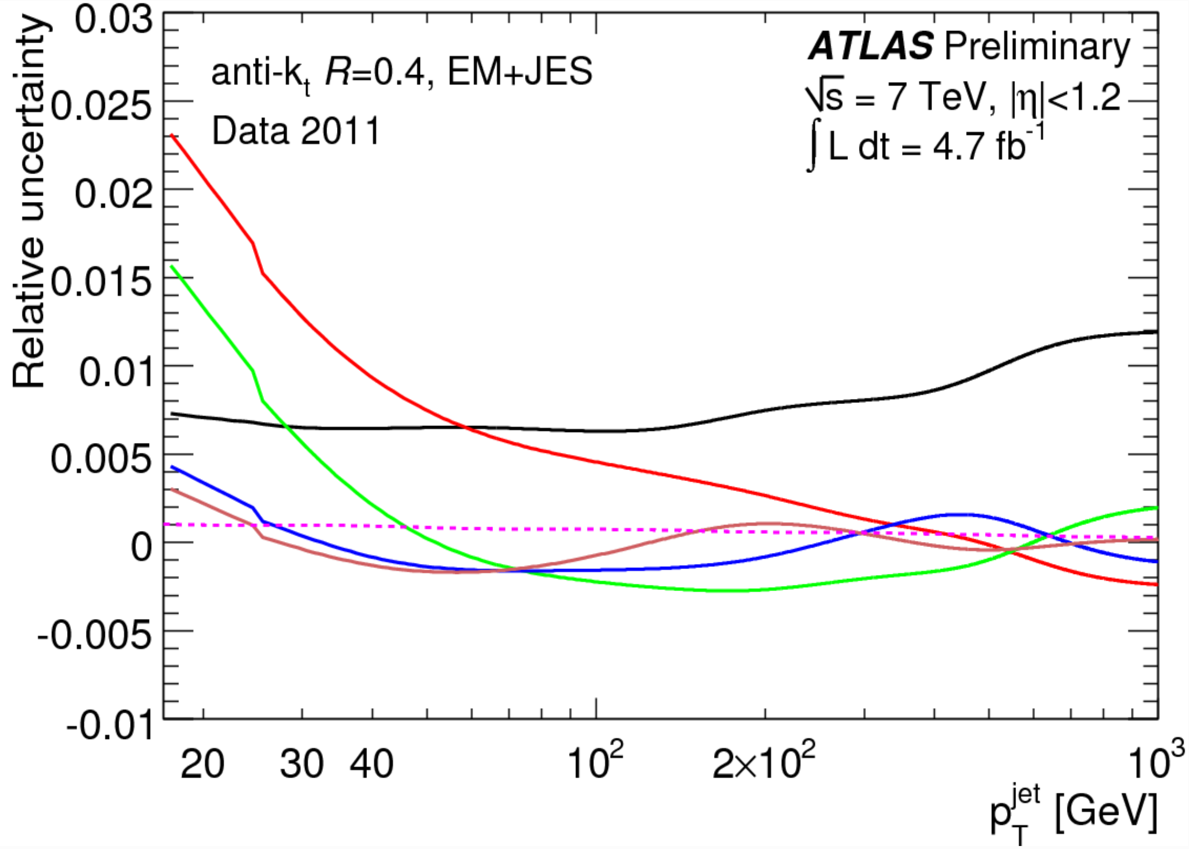
uncertainty on gluon fraction

fraction of gluon jets in sample

ATLAS estimated
From MC

Jet flavour uncertainty





ATLAS Preliminary
$\sqrt{s}$ = 7 TeV, |η|<1.2
∫ L dt = 4.7 fb^{-1}
anti-k$_t$ R=0.4, EM+JES
Data 2011
Relative uncertainty
0.03
0.025
0.02
0.015
0.01
0.005
0
-0.005
-0.01
20
30
40
10^2
2×10^2
10^3
p_T^{jet} [GeV]