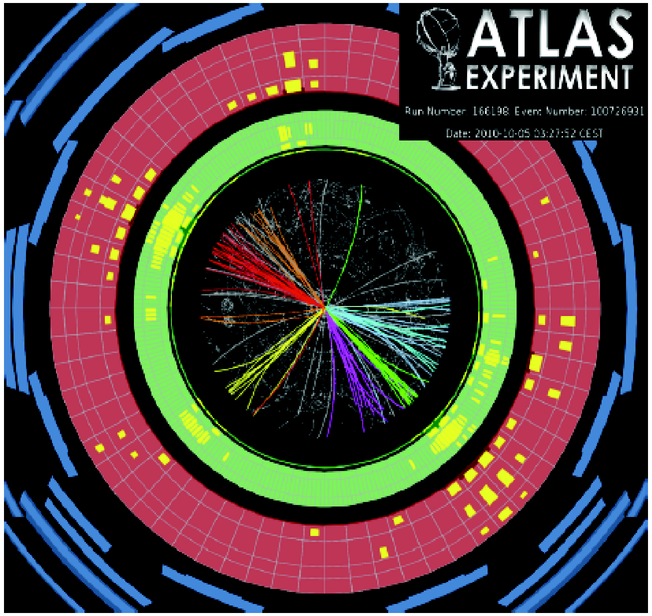
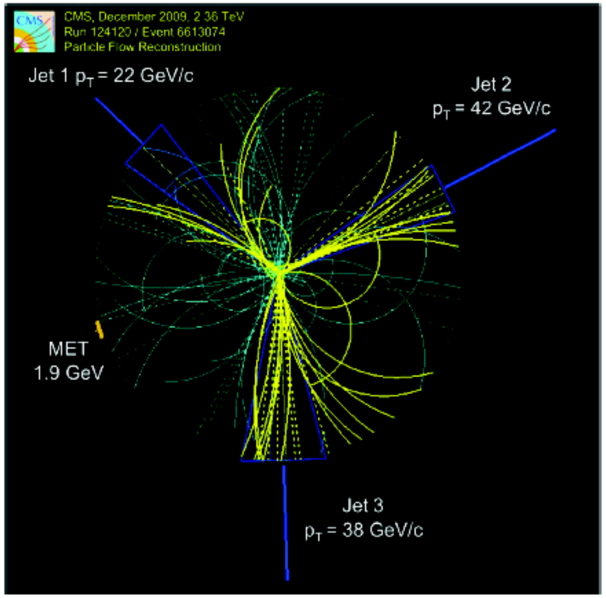
Towards defining JES correlations between ATLAS and CMS

Disclaimer: This is my personal view

Tancredi.Carli@cern.ch





Jet energy scale uncertainties are usually among largest experimental uncertainties

Need to clarify the role of correlations among experiments in top combinations

Aim is to identify sources that are correlated/uncorrelated across experiments

Two discussions among ATLAS/CMS experts happened

The way how the JES uncertainties are evaluated in the two experiments
are quite different and more work is needed to arrive at concrete recommendations

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

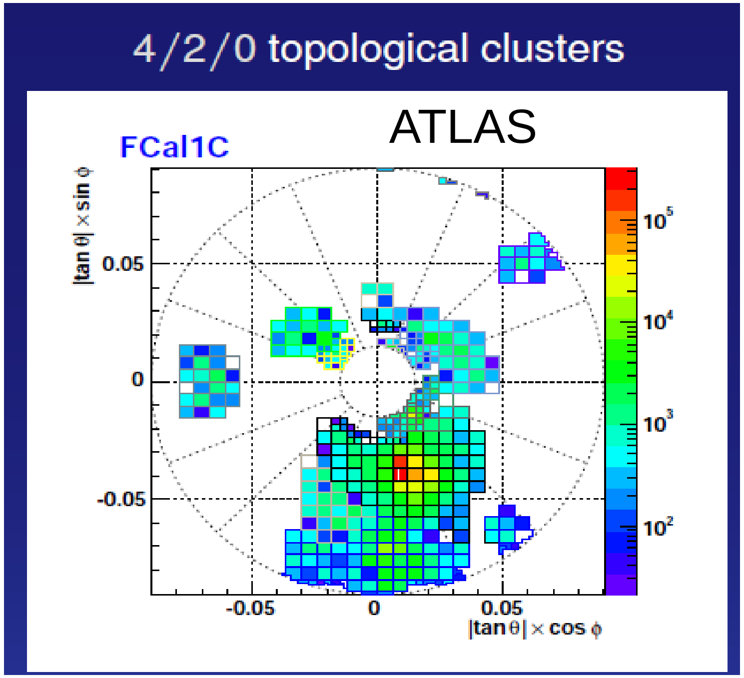
(historic development → aim to converge in shutdown)

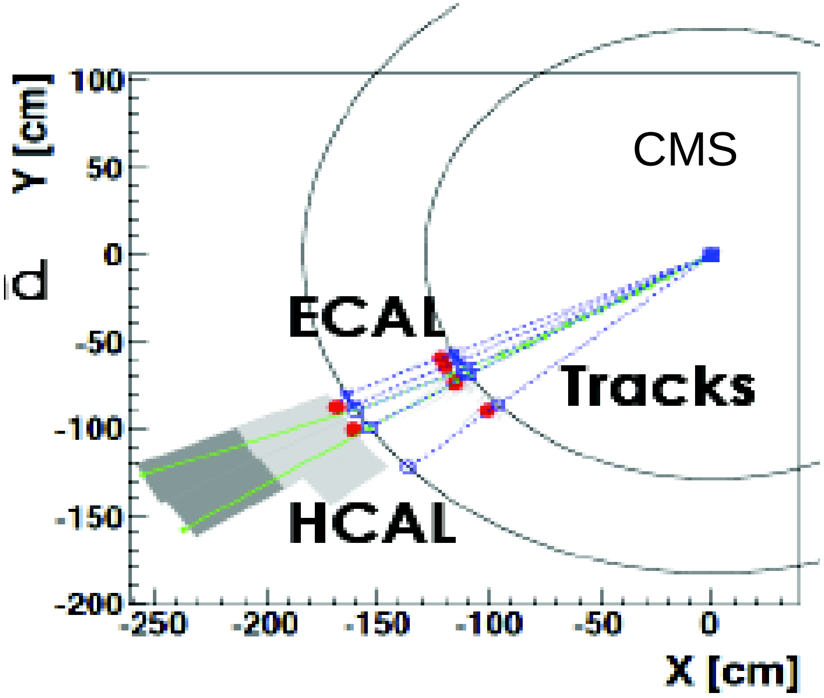
Both collaborations also use other algorithms large-R Akt, C/A for substructure techniques...

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)



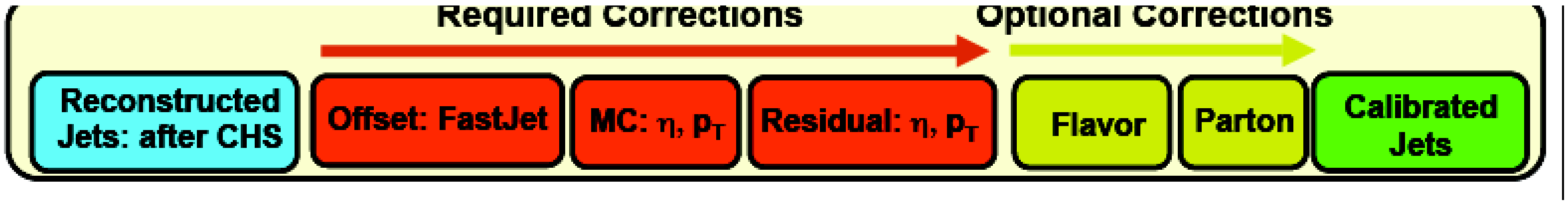


Different technique to reconstruct jets are not a problem to evaluate the correlations between the experiments

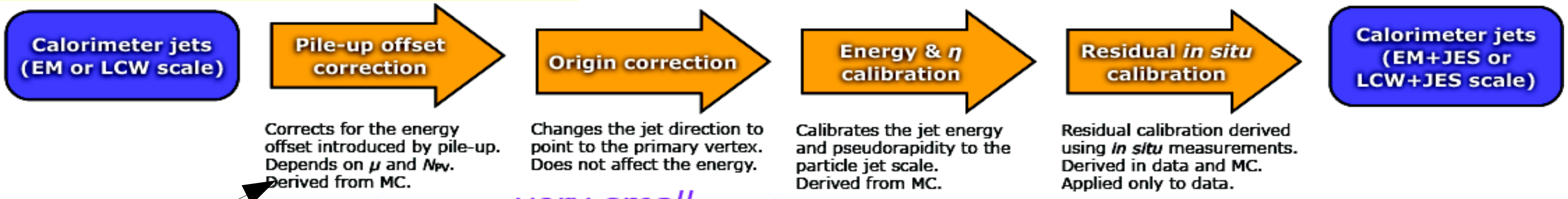
Both experiments use in situ method for uncertainty

Jet calibration strategy

CMS calibration strategy



ATLAS calibration strategy



Corrects for the energy offset introduced by pile-up. Depends on μ and N_{PV}. Derived from MC.

Changes the jet direction to point to the primary vertex. Does not affect the energy.

Calibrates the jet energy and pseudorapidity to the particle jet scale. Derived from MC.

Residual calibration derived using *in situ* measurements. Derived in data and MC. Applied only to data.

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

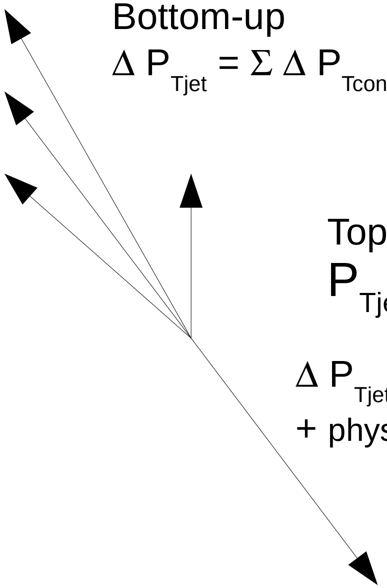
Jet calibration done with respect to the inclusive jet sample (using MC)
ATLAS and CMS quote JES uncertainties with respect to MC

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)



Bottom-up
$\Delta P_{Tjet} = \Sigma \Delta P_{Tconst}$

Top-down:
$P_{Tjet} = P_{Tref}$

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

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)

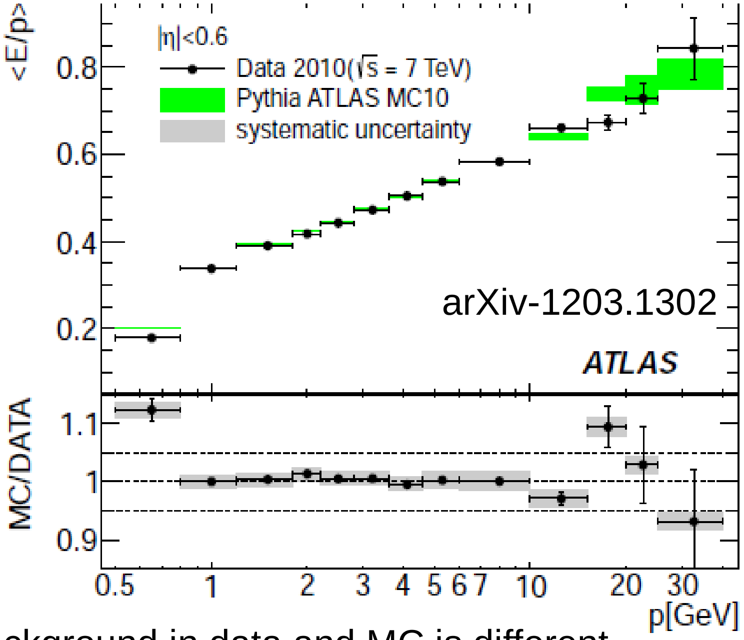
CMS:
Measurements from in situ pt-balance techniques (gamma/Z-jet balance)
plus extrapolations to low and high-pt using jet constituents uncertainties
complemented by fragmentation modeling uncertainties (mixed approach)

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

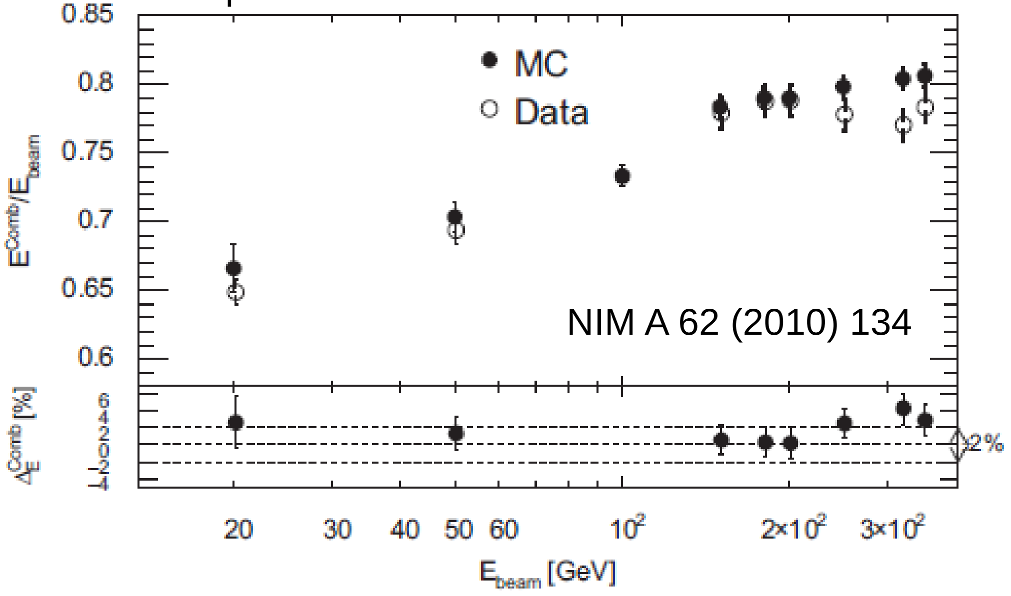
Uncertainties depending on event samples:
ATLAS/CMS: Parton flavour (gluon/light-quark/heavy-quark)
ATLAS/CMS: Pile-up (Nvtx)
ATLAS only: Close-by jets (dR_{JJ})

ATLAS calorimeter response uncertainty from single hadron response

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

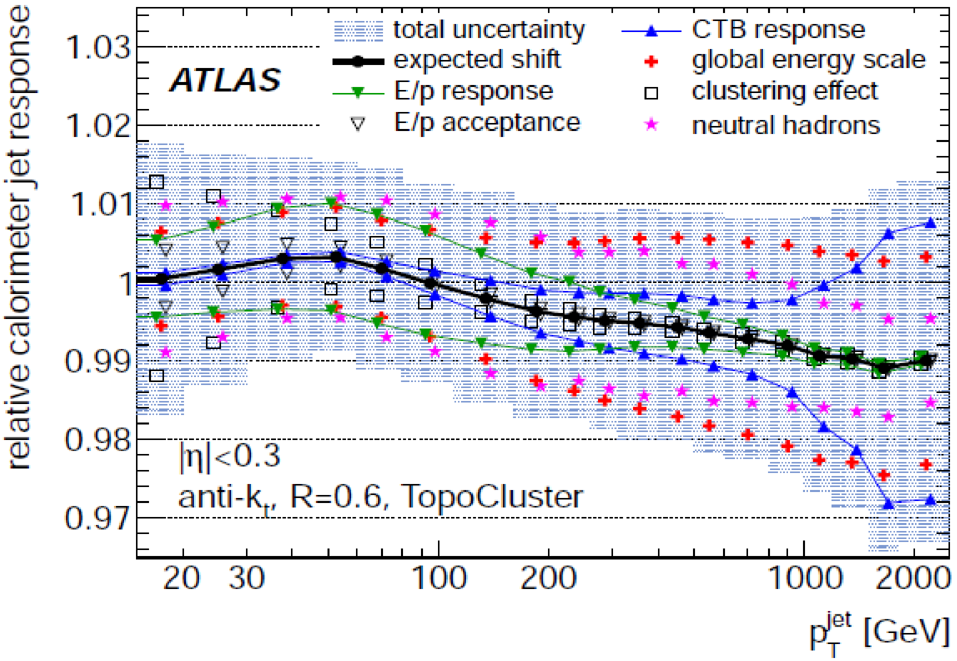


20<p<350 GeV from combined ATLAS test beam

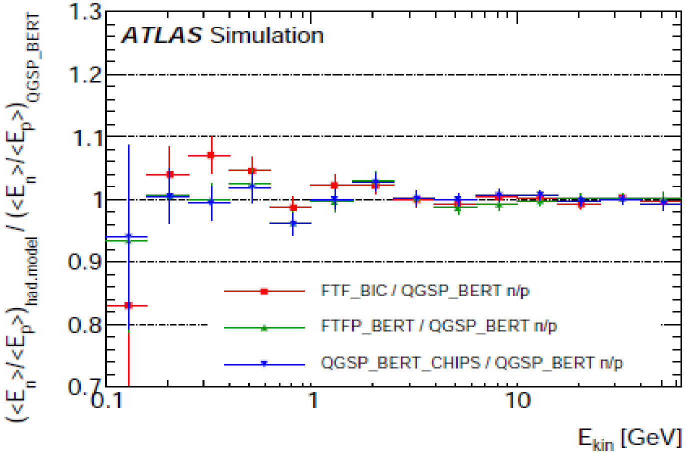


Background in data and MC is different
-> subtract measured background in data and MC
Also: measured pions, proton and anti-protons from Kaon/Lambda decays

Calorimeter response uncertainty



Uncertainty on neutral hadrons from MC

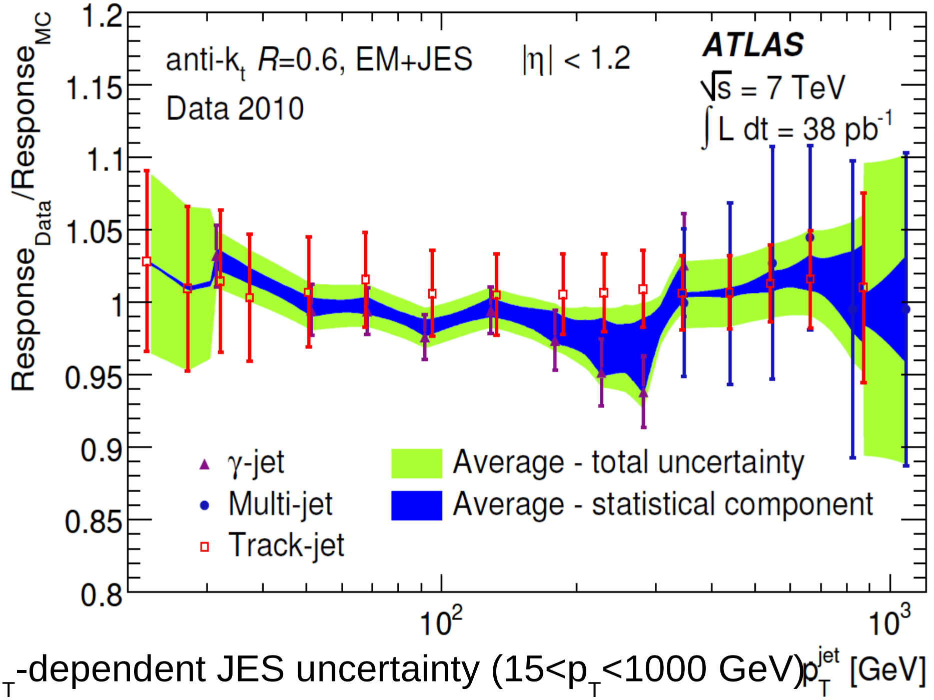


(a)

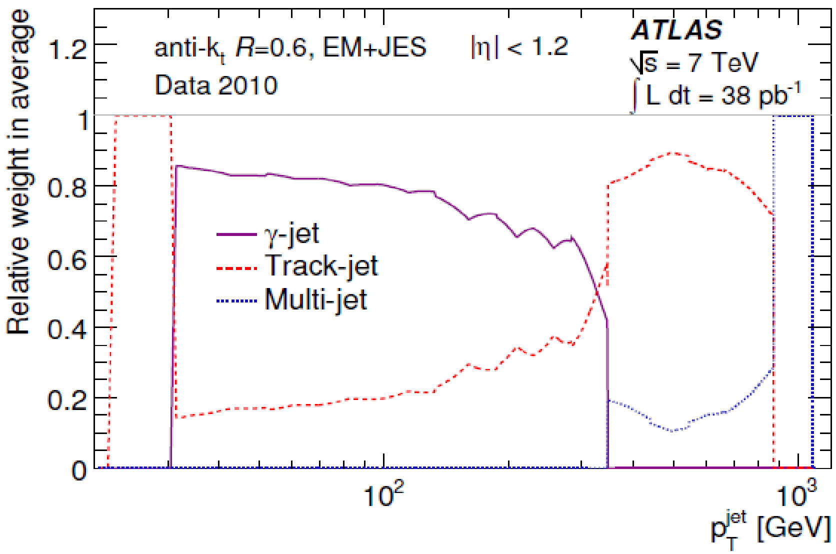
JES uncertainty =calorimeter uncertainty+fragmentation modeling

ATLAS JES uncertainty 2010 results

Combination of in situ measurement



Combination weights



P_T-dependent JES uncertainty ($15<p_T<1000$ GeV)

Weighted average in pt bins + smoothing (preserving all correlations)

Increase uncertainty by sqrt(Chi2/dof), if methods inconsistent

2010:

By default no correction for data/MC difference

Single hadron response default and only marginal improvement

Statistical uncertainty would need to be propagated

Correlations from single particles

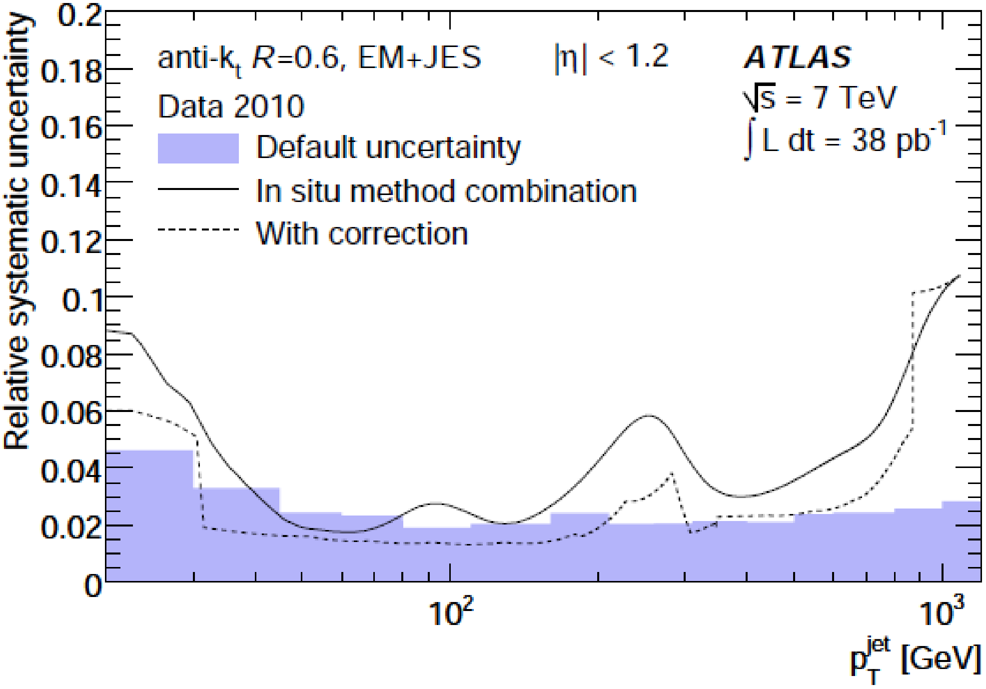
low-pt in situ high-pt test-beam

2011:

Correction for data/MC (about -2%)

Evaluation in situ technique validation

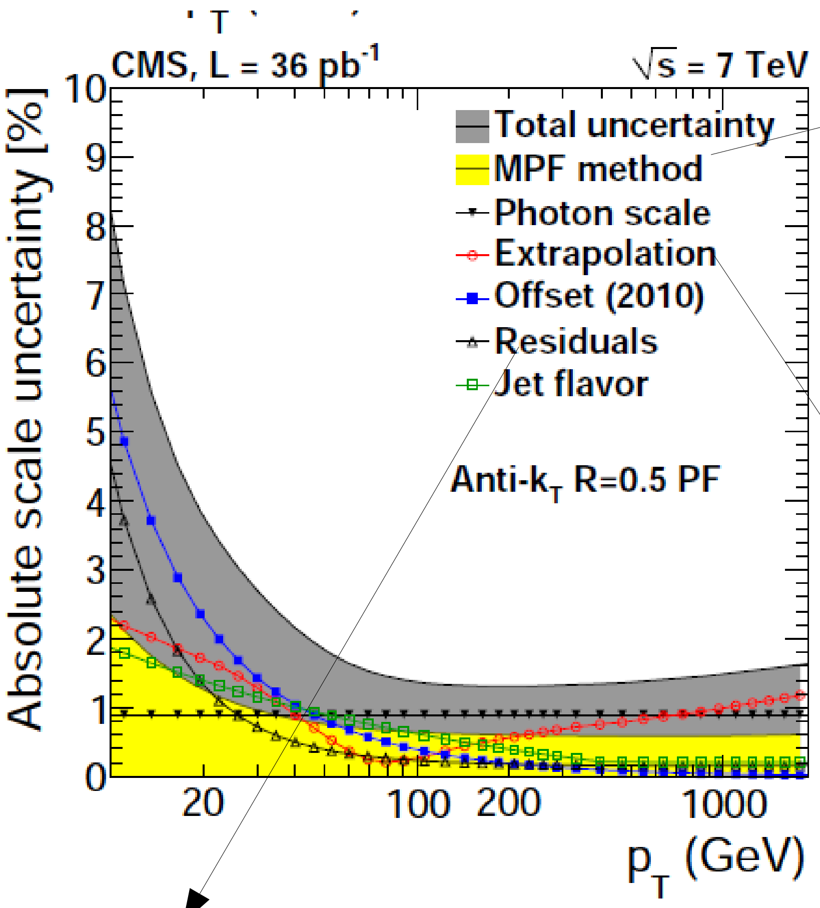
Correlations from in situ uncertainties



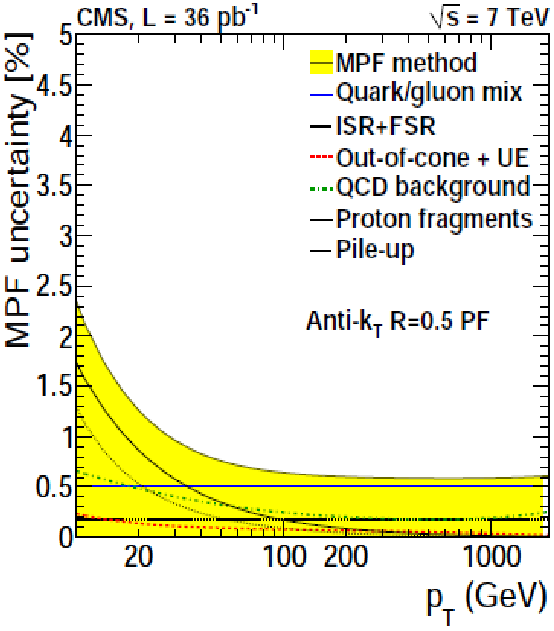
CMS JES in central region 2010 results

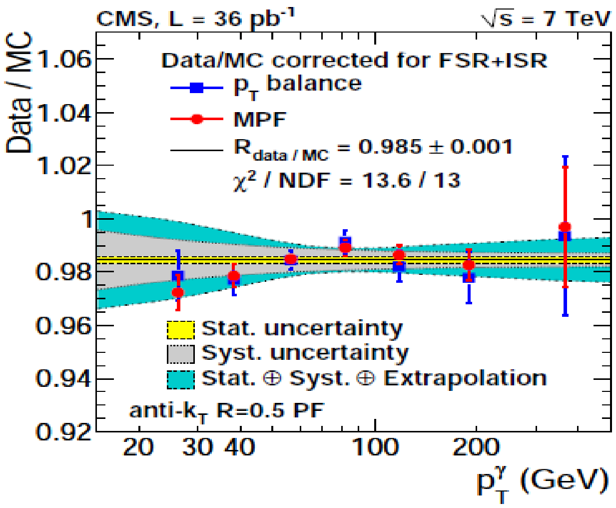
Uncertainty related to in situ methods

JINST 6 (2011) 11002

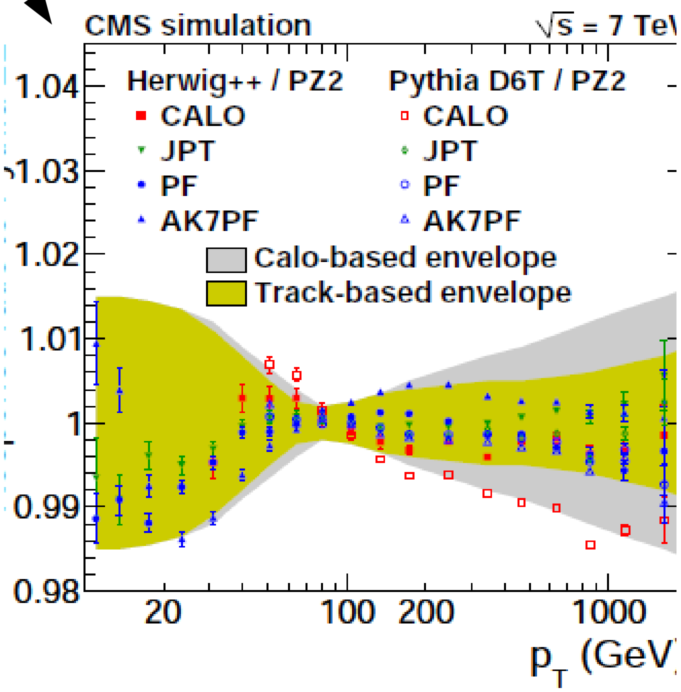


quark/gluon respnse difference in Pythia/Herwig





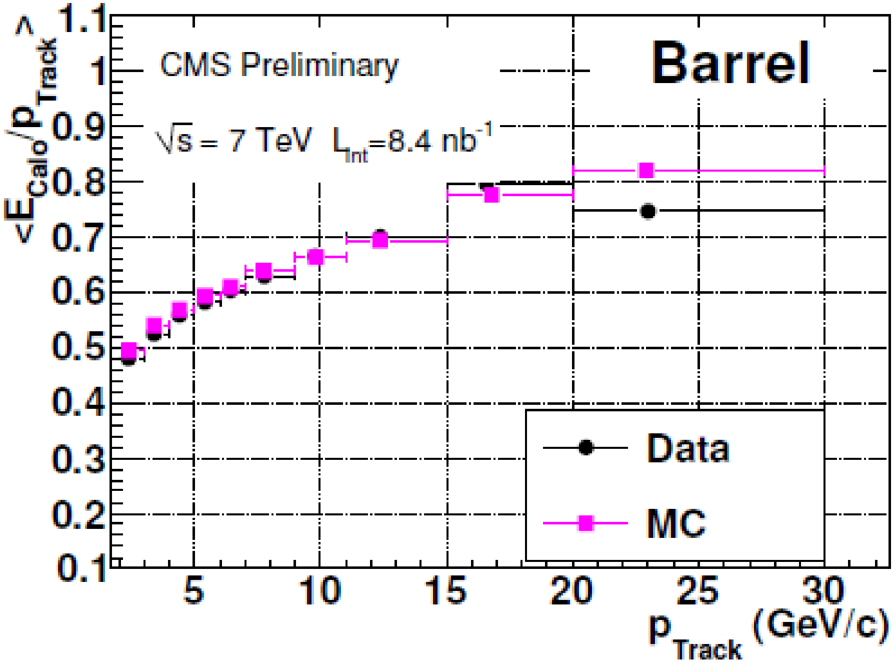
Constant response correction 1.015

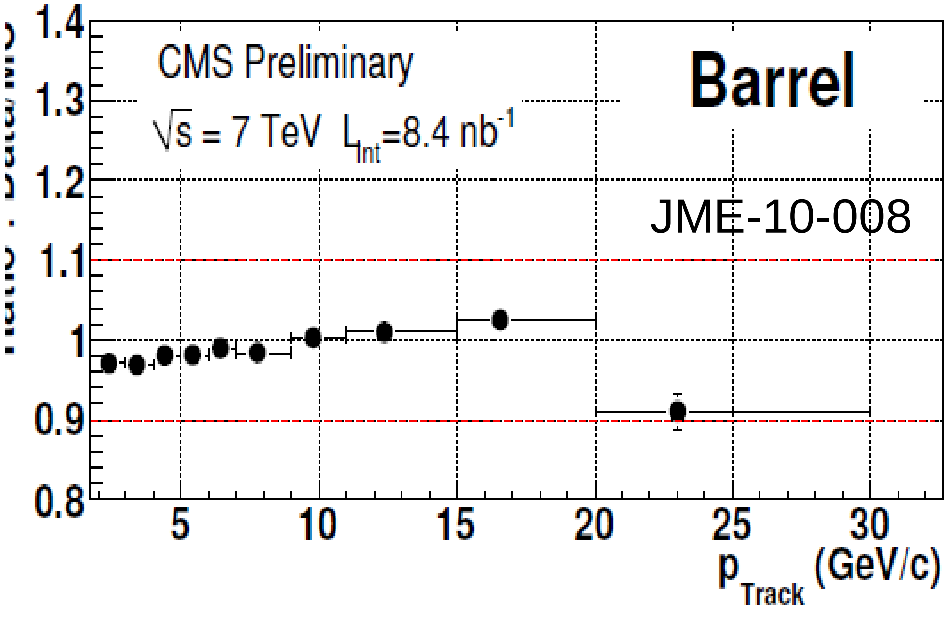


Extrapolation based on single hadron response for calorimeter objects objects with constrains in region where in situ methods available+uncertainty from fragmentation modeling

CMS isolated hadron response measurements

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





JME-10-008

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%

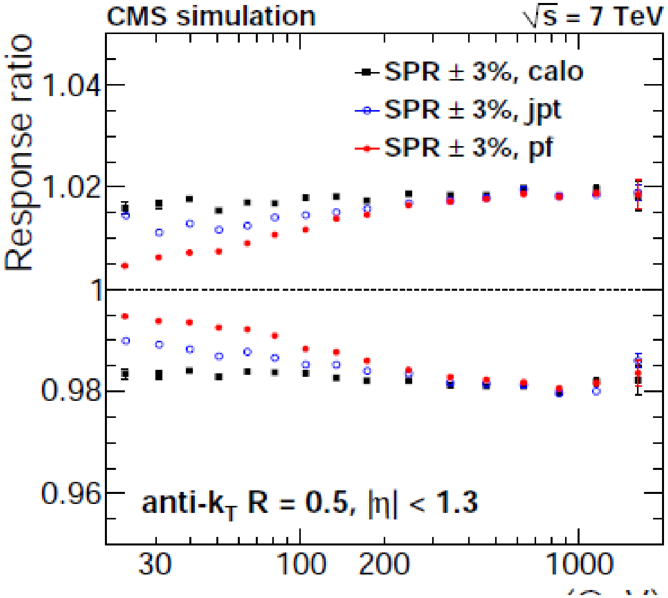
Extrapolation based on jets constituents

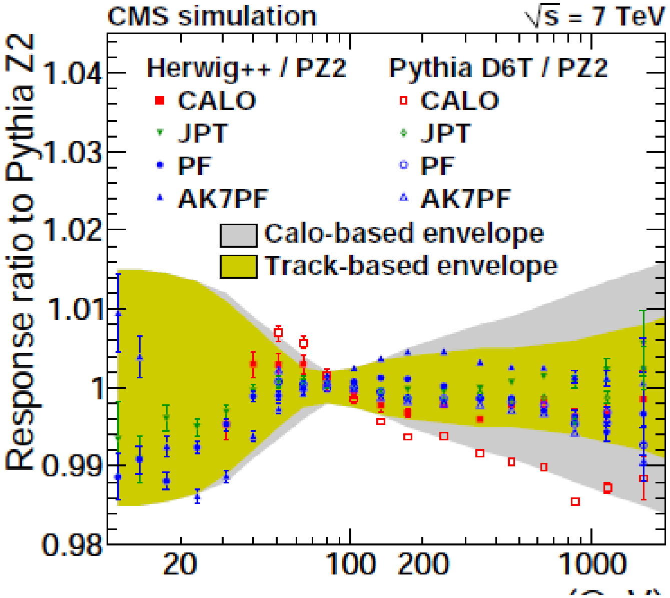
Calorimeter objects from single hadron response measurements

Track momentum and track efficiency measurement gives no uncertainty

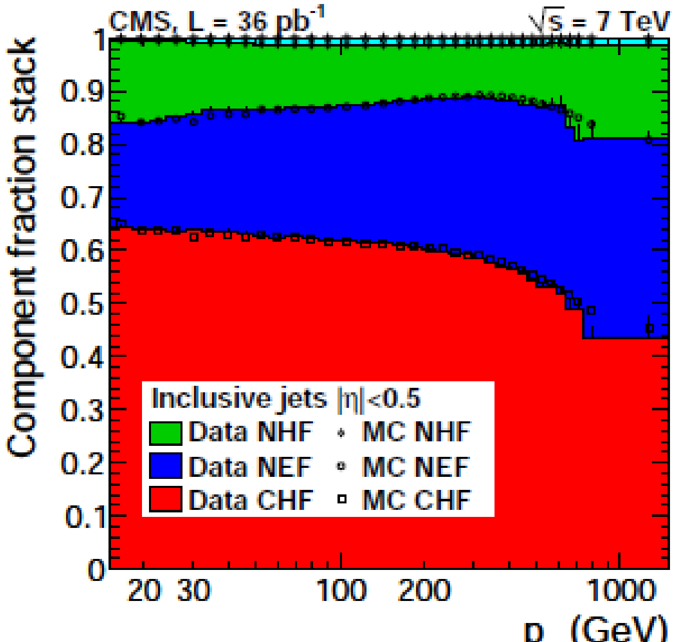
+ constraint in region where in situ methods are precise (around 100 GeV)

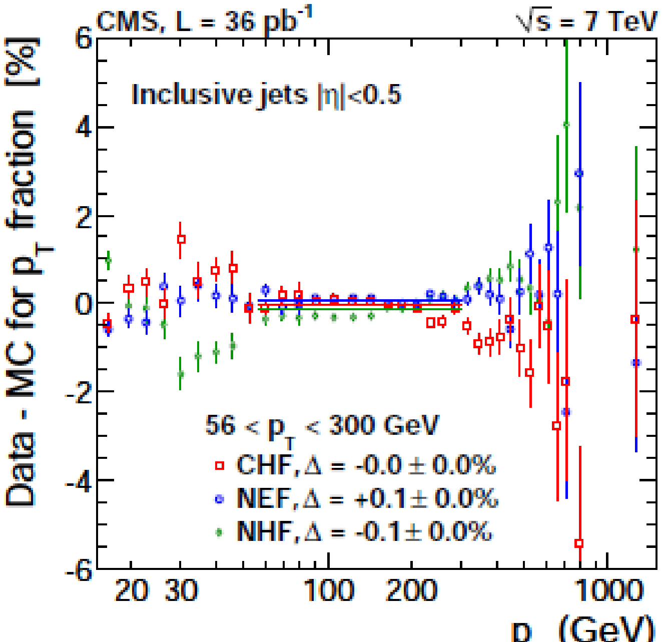
+ Uncertainty related to fragmentation modeling: Response ratio Pythia6 (Z2 and D6T tune) and Herwig++





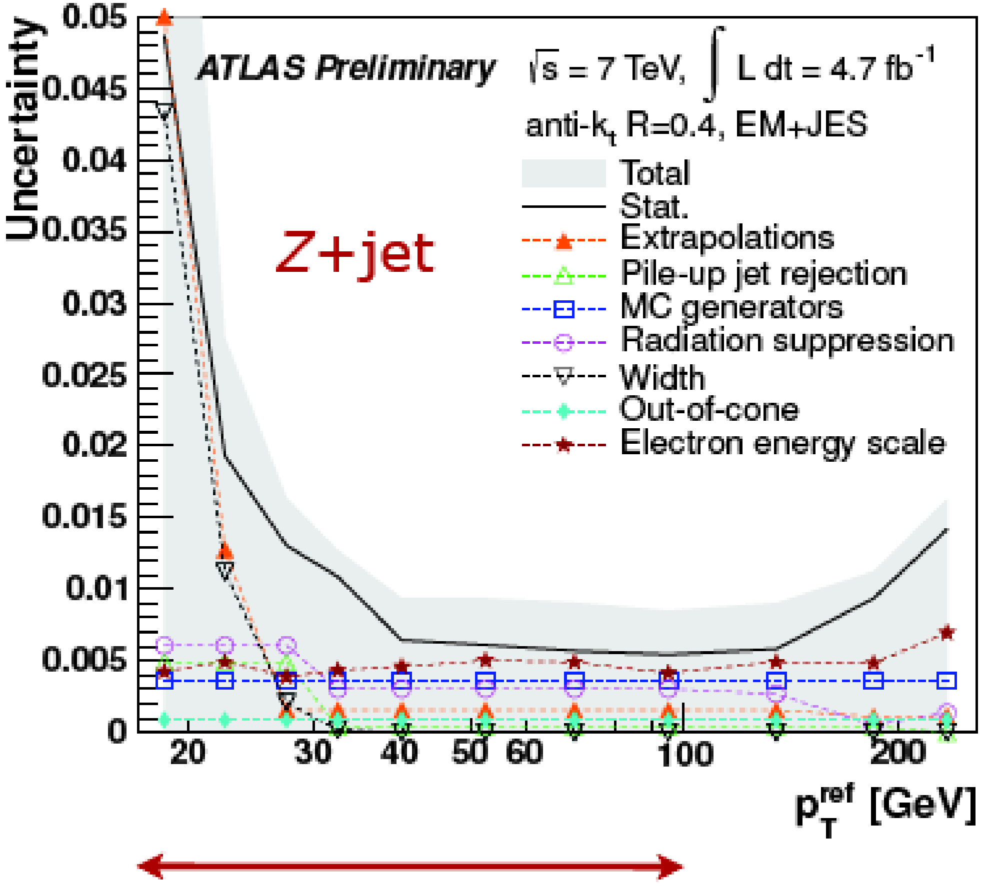
For particle flow show that jet composition of particle flow objects is well described by MC



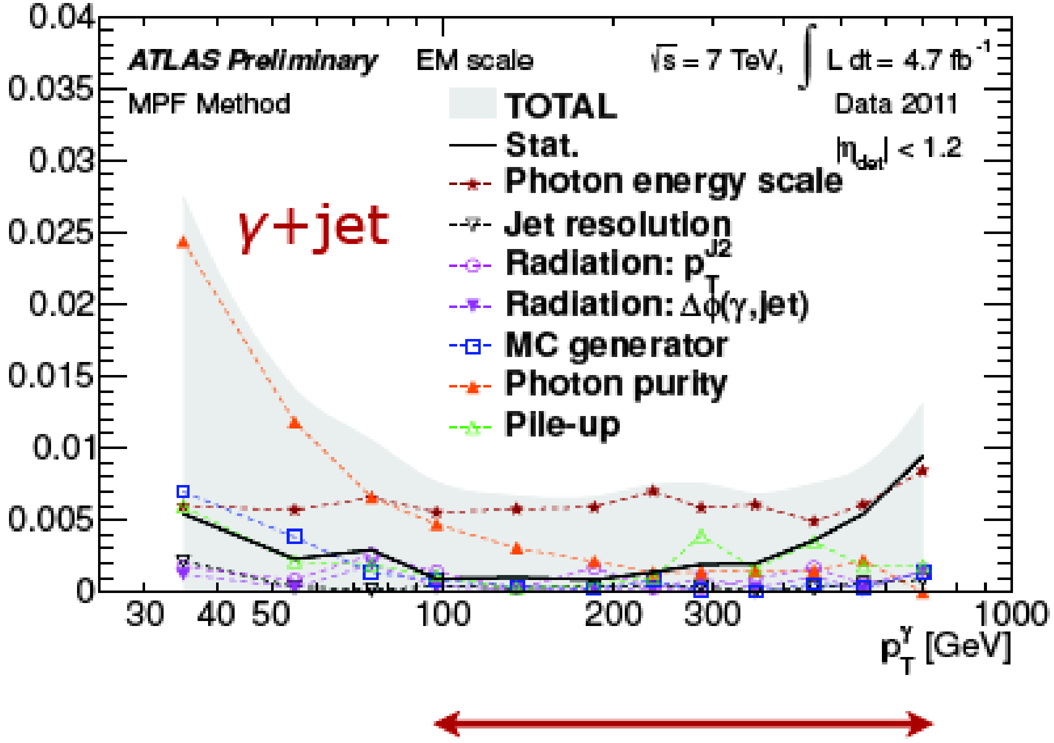


Recent ATLAS 2011 in situ measurement results

Pt balance between jet and reference object



17-100



100-800

In 2011 ATLAS JES uncertainties will be based on in situ measurements:
Gamma/Z+jet, multijet balance for 15<pt<1000 GeV.
For p>1000 GeV single hadron response measurements
Correlations are derived from systematic uncertainties of in situ measurement on reference object and physics effects

ATLAS JES uncertainty sources

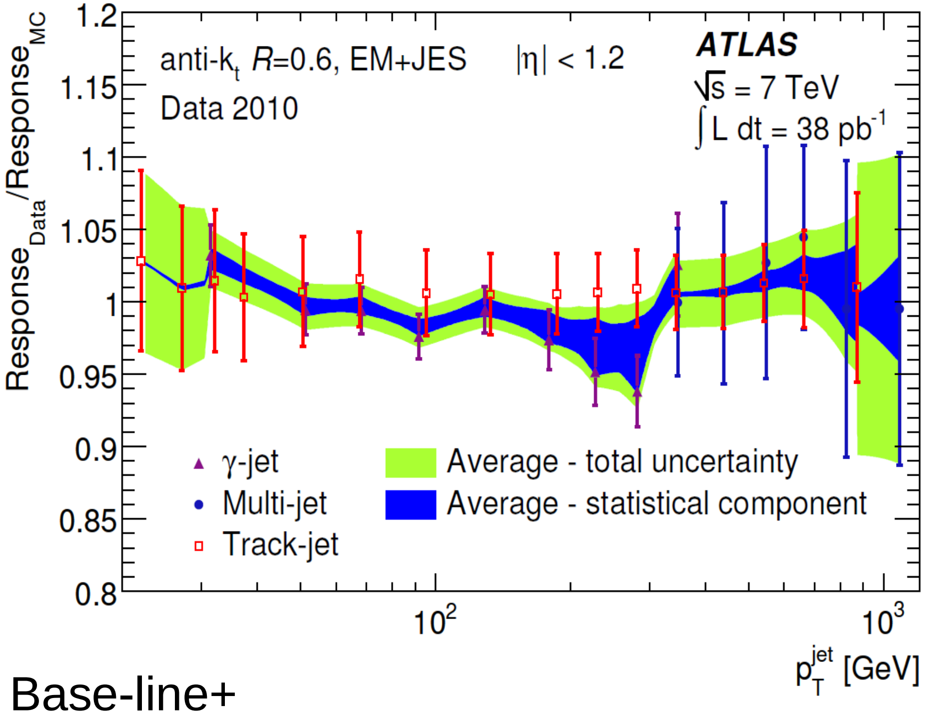
Uncertainties measured in reference samples: Z+jet, gamma+jet (mainly quark jets)

- 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)		**6+11**	
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		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)		**6+12**	
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		model
Statistical components	statistical uncertainty for each of the 12 bins		stat./meth.
Multijet p_T balance		**8+10**	
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		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.

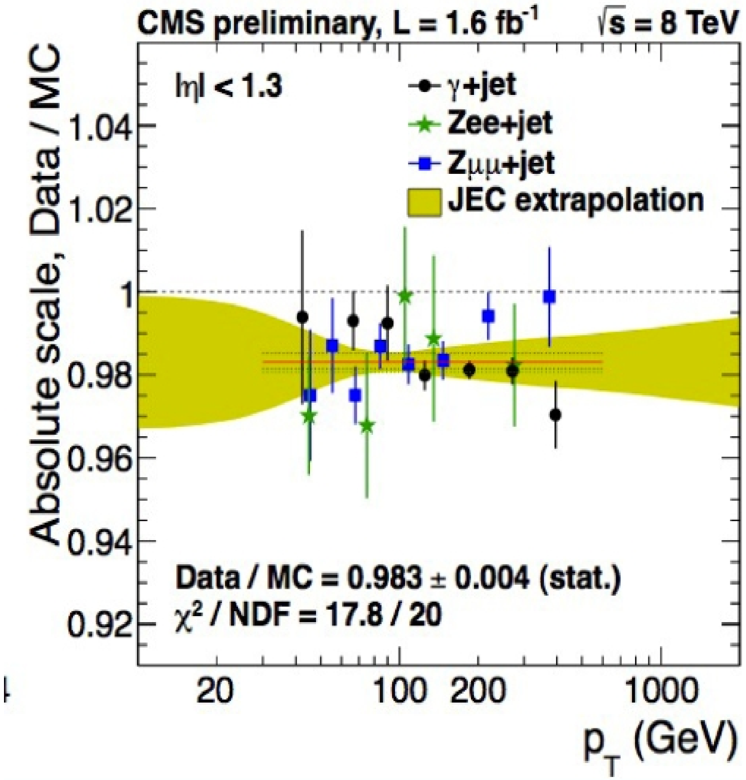
In 2011 ATLAS uses combination of in situ techniques. Pt-dependence: weighted average in pt bins + smoothing

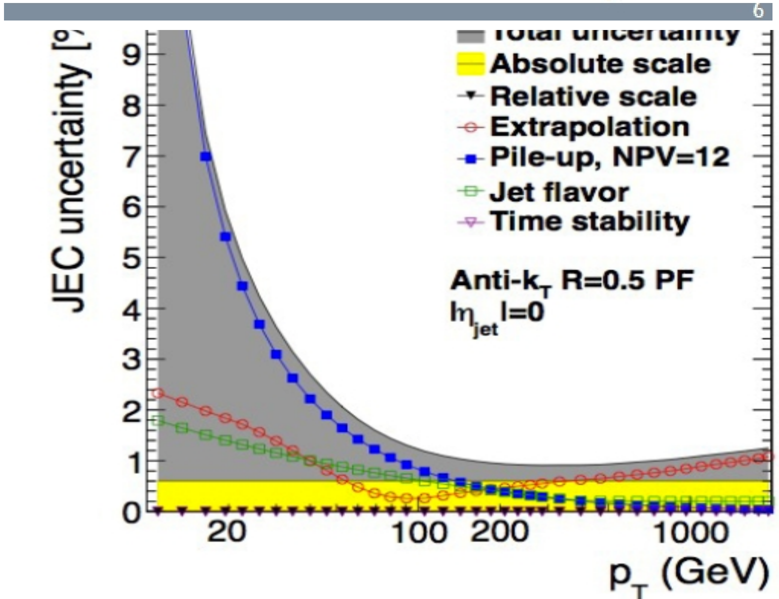


Base-line+
Event sample dependent uncertainties

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

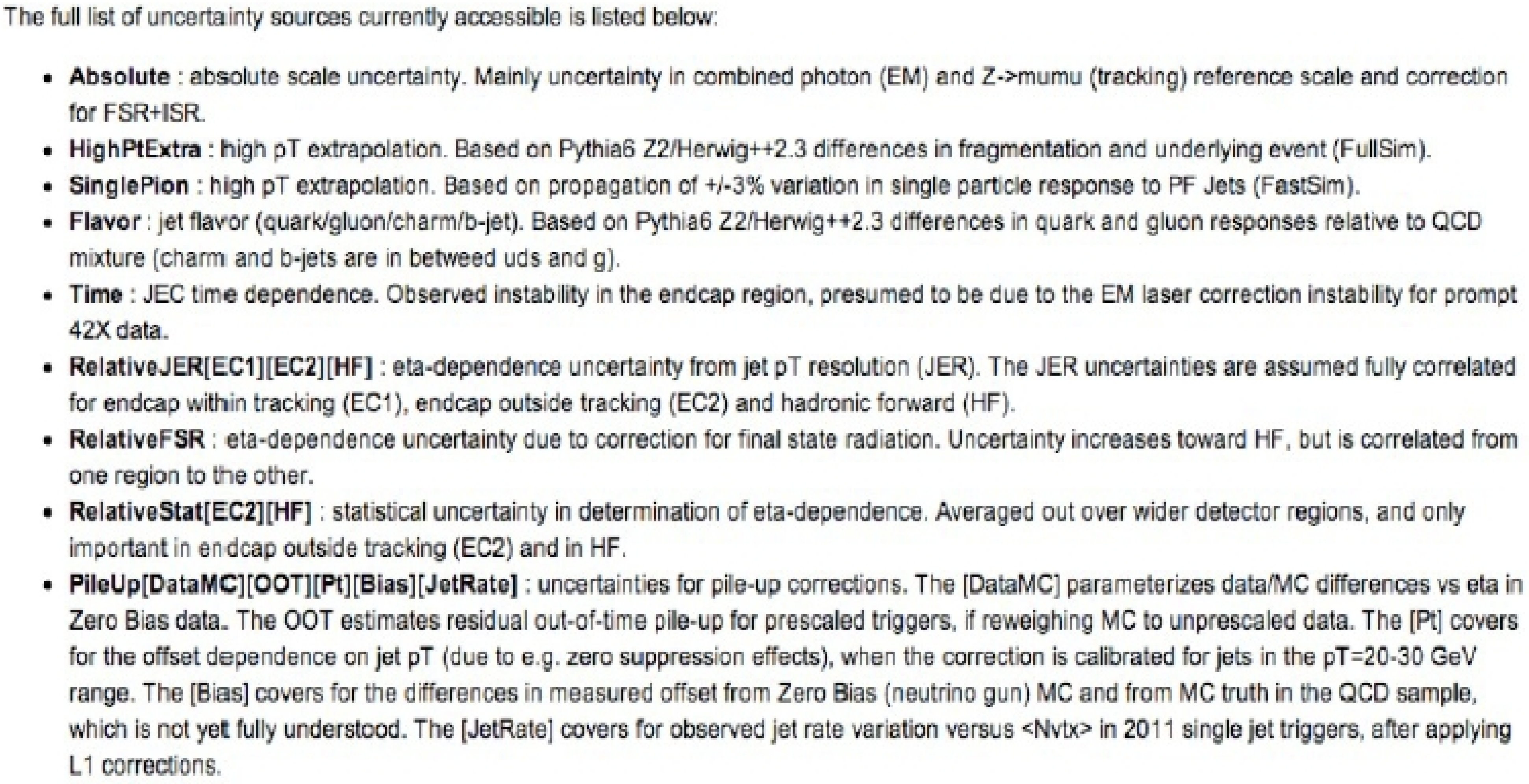
CMS uses in situ techniques in regions 100-200 GeV Pt-dependence from extrapolation to low and high-pt varying particle flow objects





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:



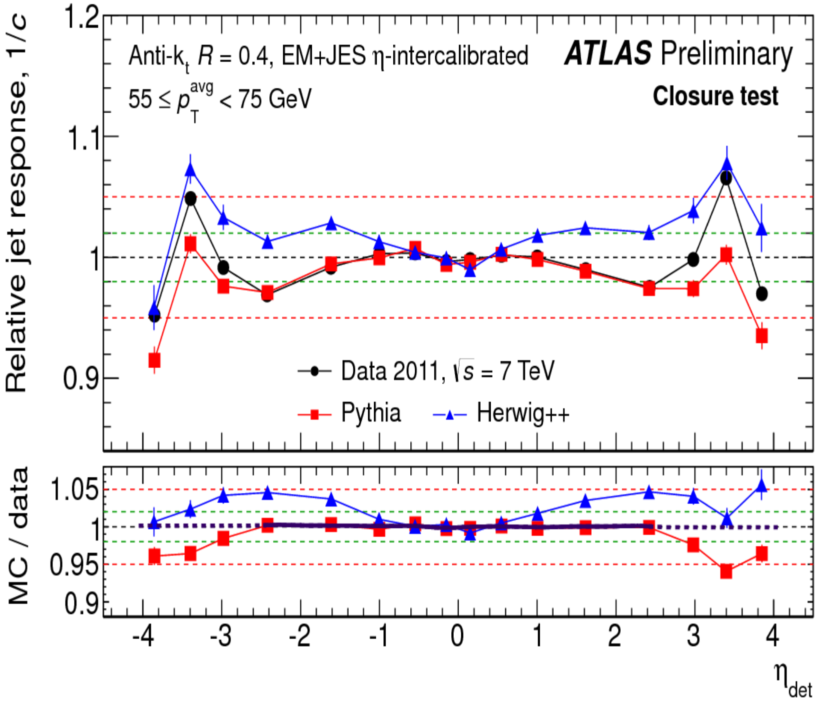
The full list of uncertainty sources currently accessible is listed below:

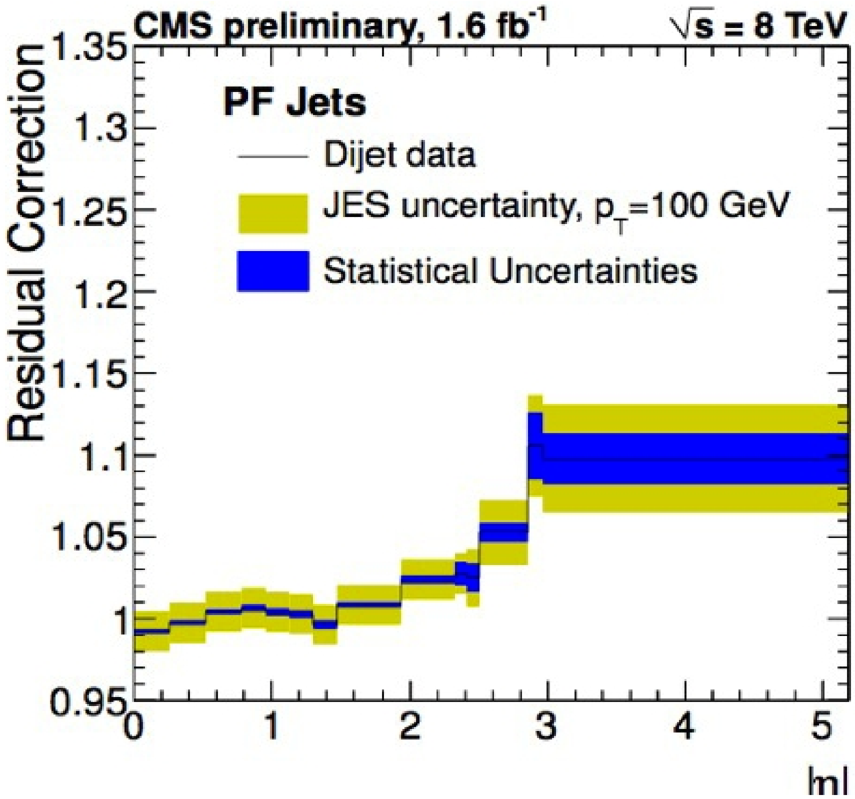
- **Absolute** : absolute scale uncertainty. Mainly uncertainty in combined photon (EM) and Z->mumu (tracking) reference scale and correction for FSR+ISR.
- **HighPtExtra** : high pT extrapolation. Based on Pythia6 Z2/Herwig++2.3 differences in fragmentation and underlying event (FullSim).
- **SinglePion** : 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%

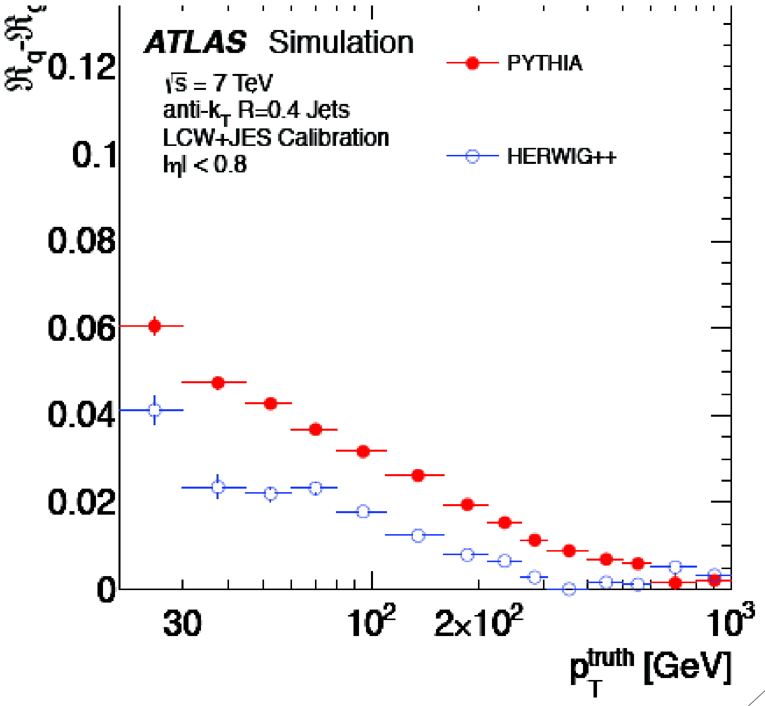
CMS use Pythia to derive a correction
correction below 2.5% for |eta|<2.4
up to 10% in forward region
Uncertainty at eta=4 for p_T=100 GeV 3%

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

JES flavour dependence

ATLAS had detailed studies using purified samples

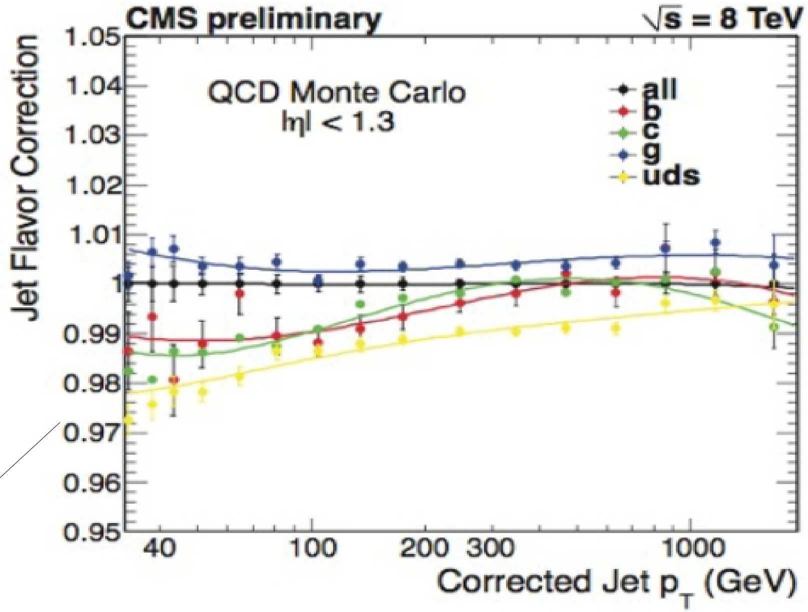
See ATLAS-CONF-2012-138



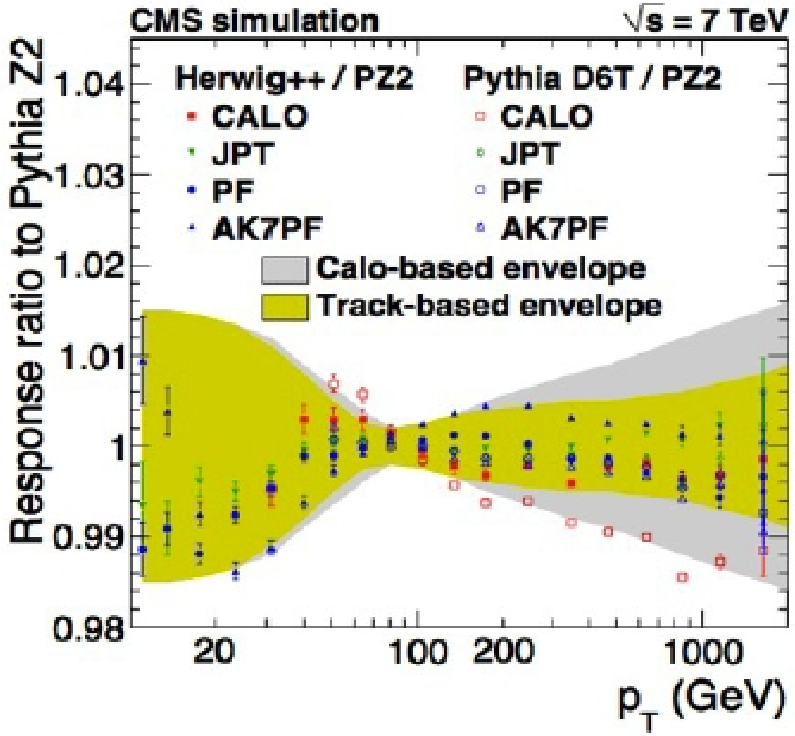
CMS

Δf_g =100%

Flavour corrections



Jet flavour uncertainty



Sample dependent!

flavour composition uncertainty

flavour response uncertainty

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

quark-gluon jet response difference

uncertainty on gluon jet response (from MC)

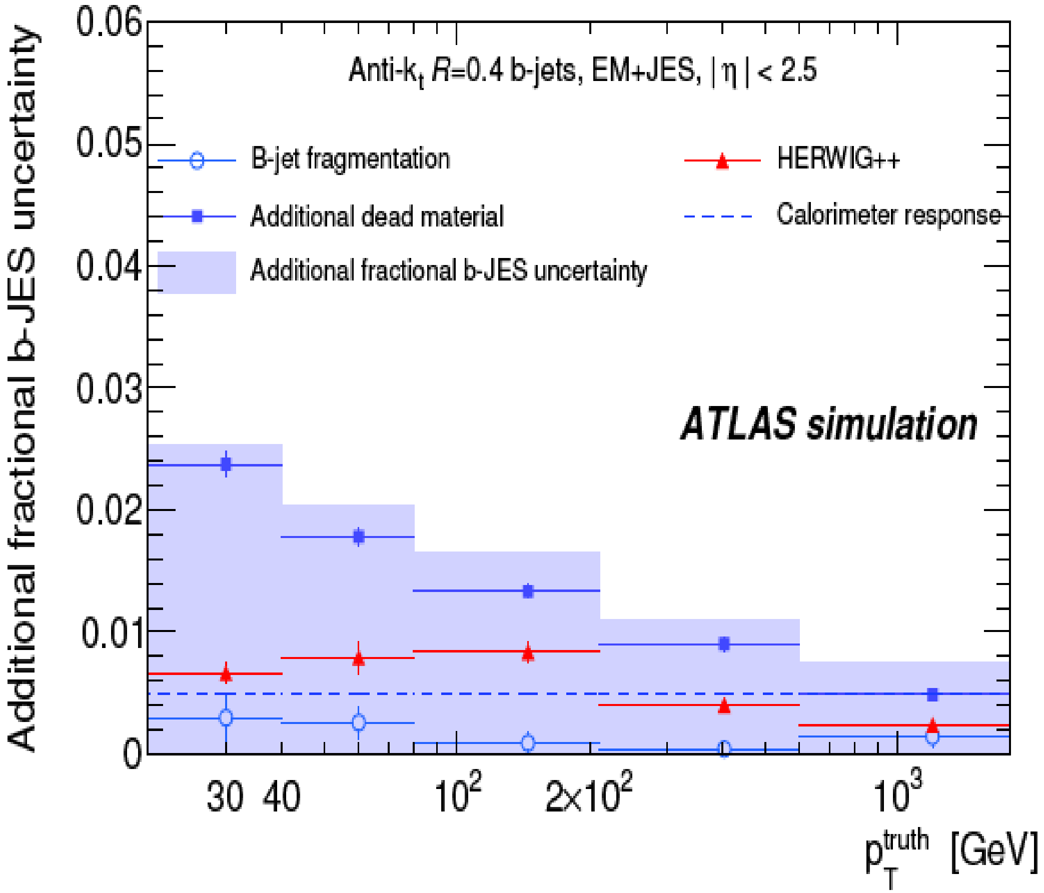
uncertainty on gluon fraction

fraction of gluon jets in sample

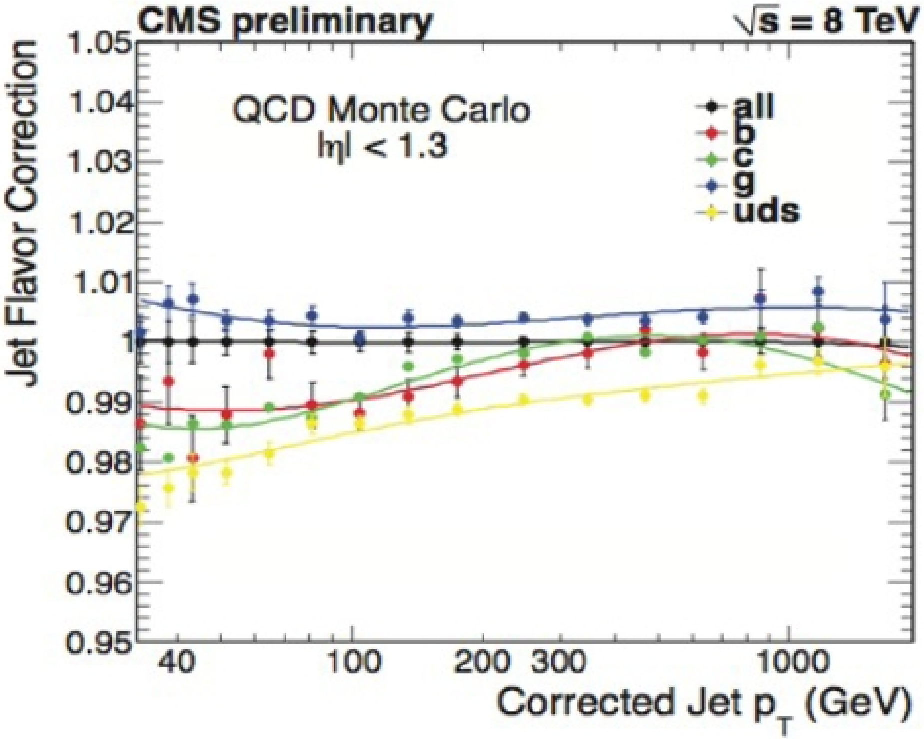
ATLAS estimated
From MC

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

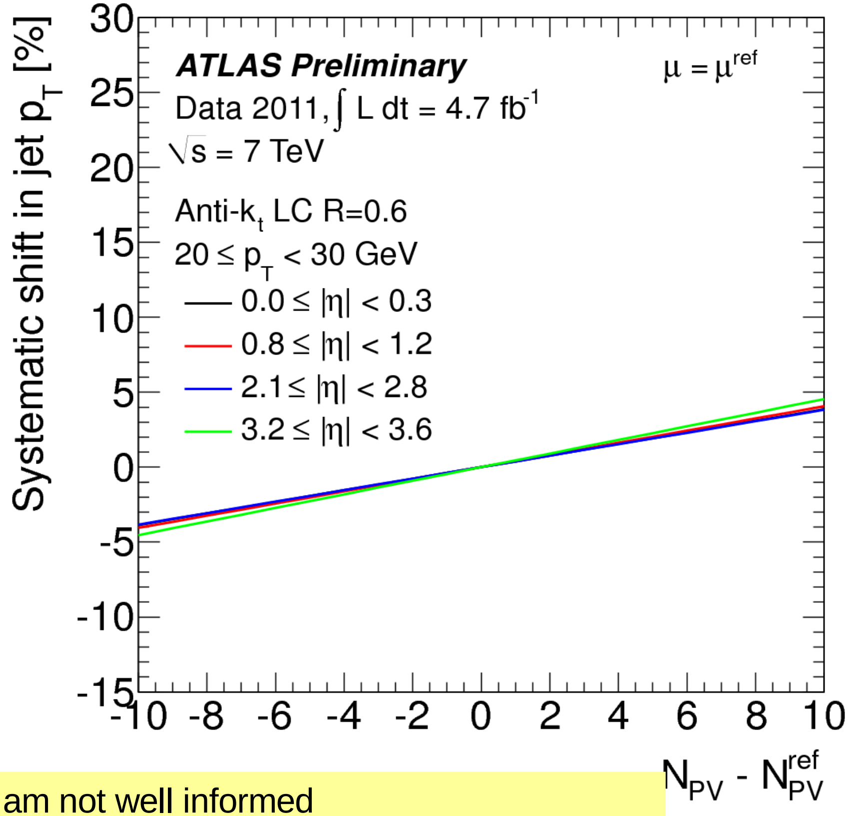
Pile-up corrections

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

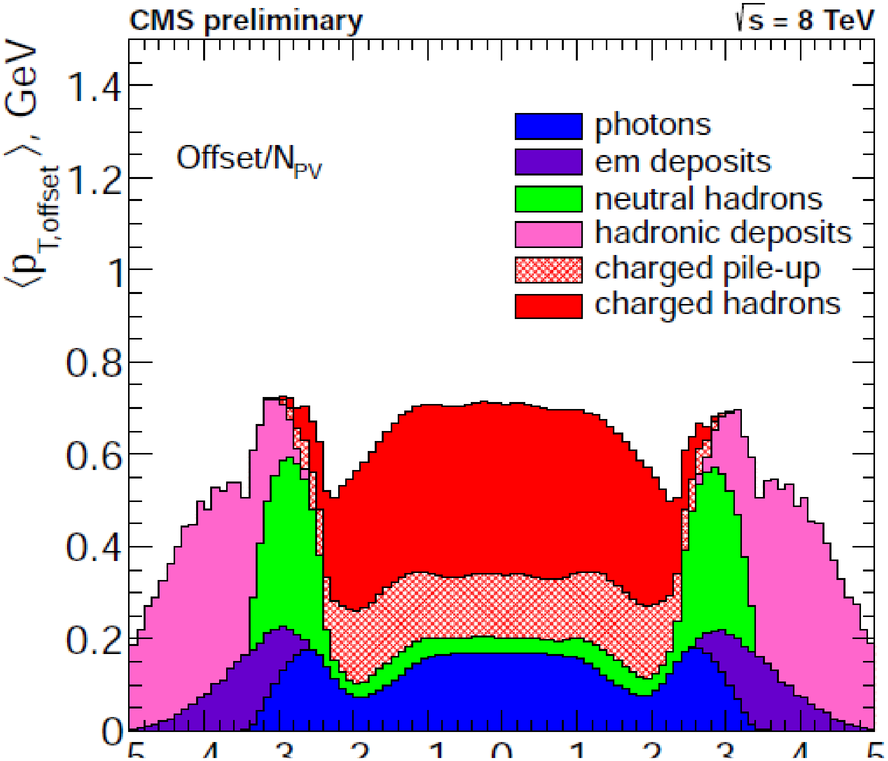
CMS uses jet area technique (Cacciari/Salam)

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



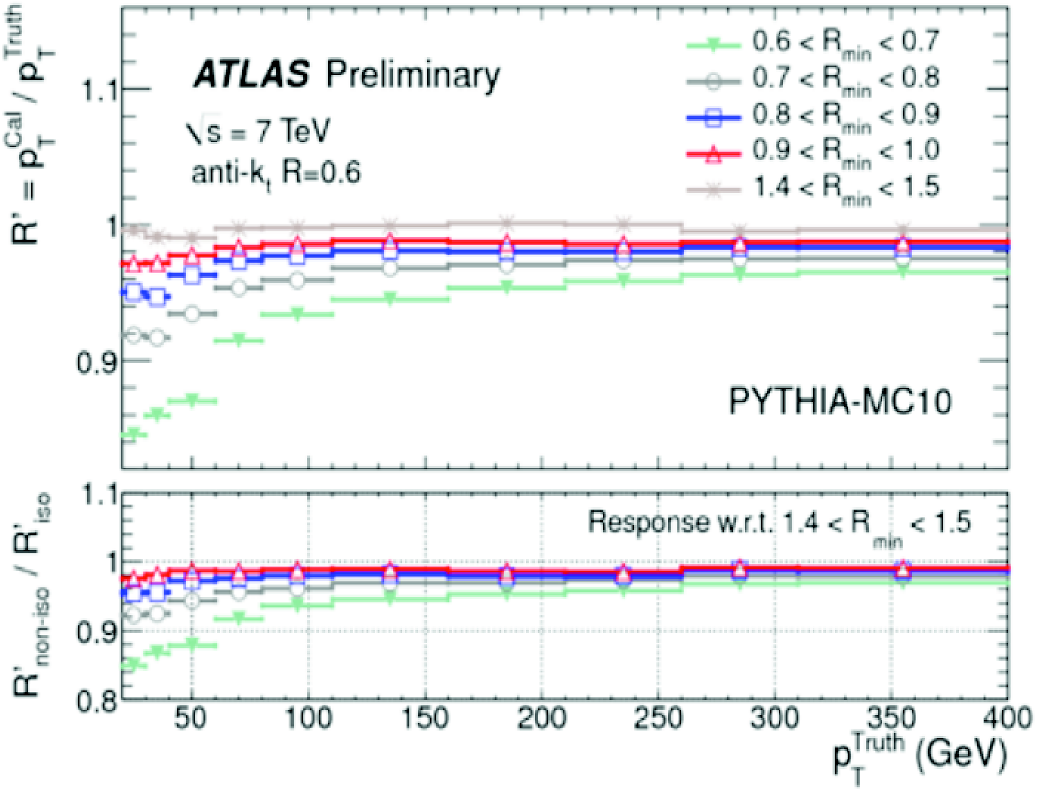
I am not well informed
About CMS pile-up corrections!



- 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

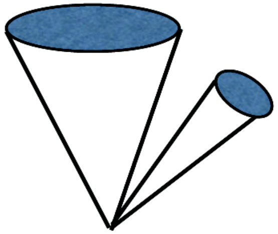
JES uncertainty due to close-by jets

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

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

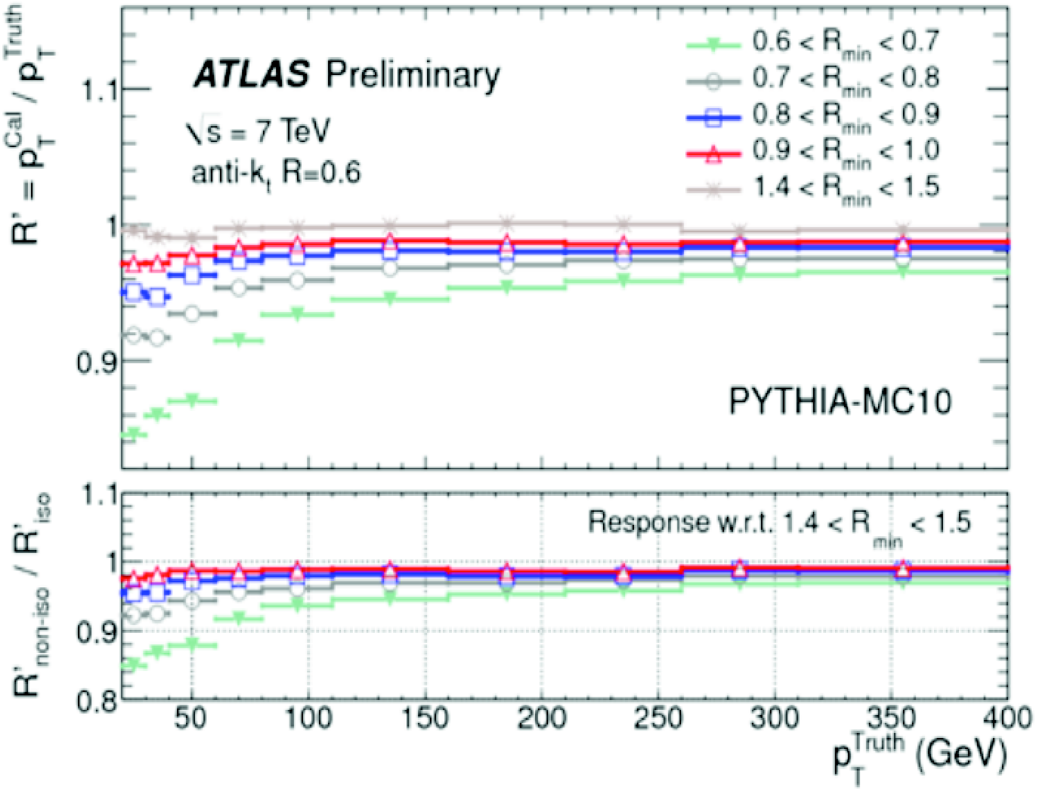


DeltaRmin
smallest DR to closest jet

CMS will look in the
size of the effect.

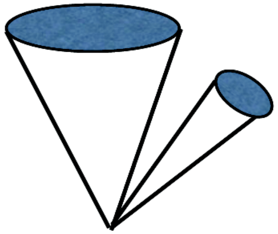
JES uncertainty due to close-by jets

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

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



DeltaRmin
smallest DR to closest jet

CMS will look in the size of the effect.

Conclusion

Need to clarify JES uncertainty evaluation procedure in ATLAS and CMS

Biggest problem related to (baseline/absolute) JES uncertainty in central region

Need more detailed break-down from the CMS side

Aim is to quote uncertainties related to detector and modeling separately

General problem: ATLAS and CMS performance documentation is behind physics analysis

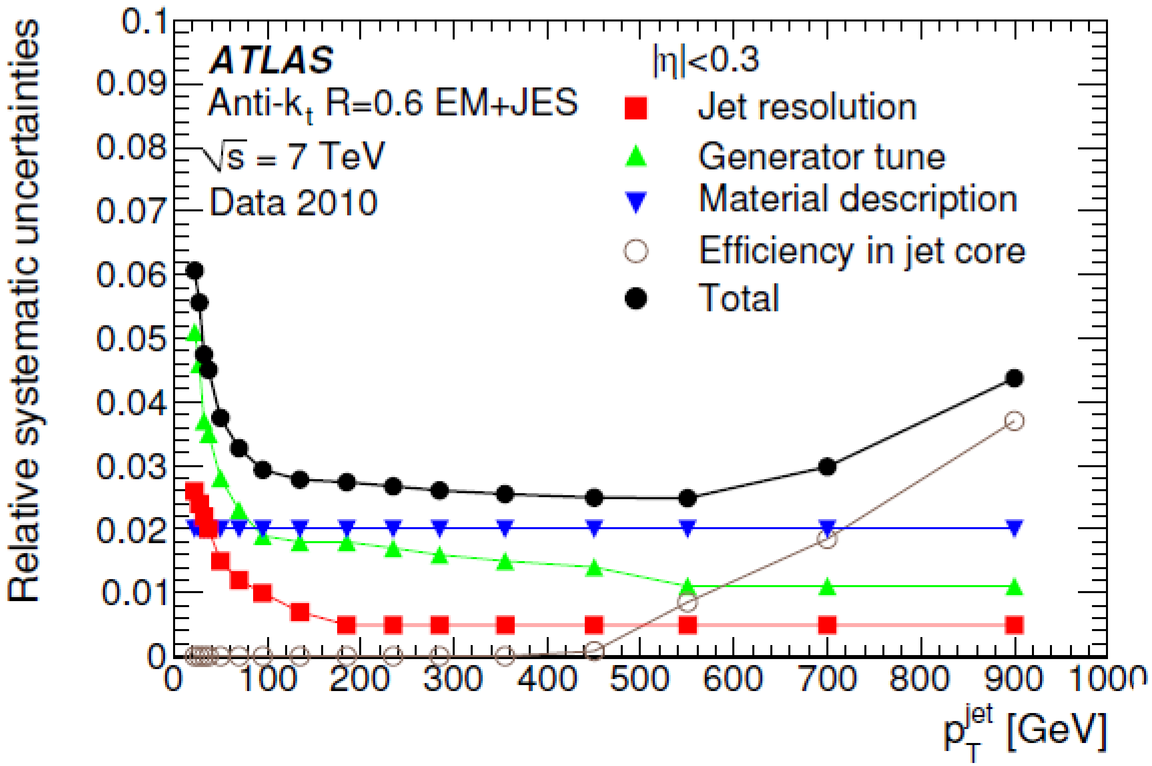
Need to continue dialogue

Better understanding might avoid double counting of uncertainties

Detailed list of points to clarify exchanged between ATLAS/CMS

Back-up

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:

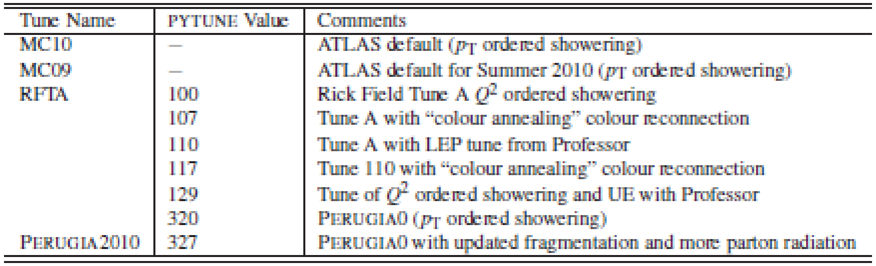
Rate of fake tracks <0.1%

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

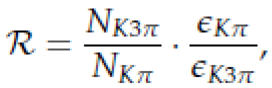
CMS tracking studies

Studies I know in CMS

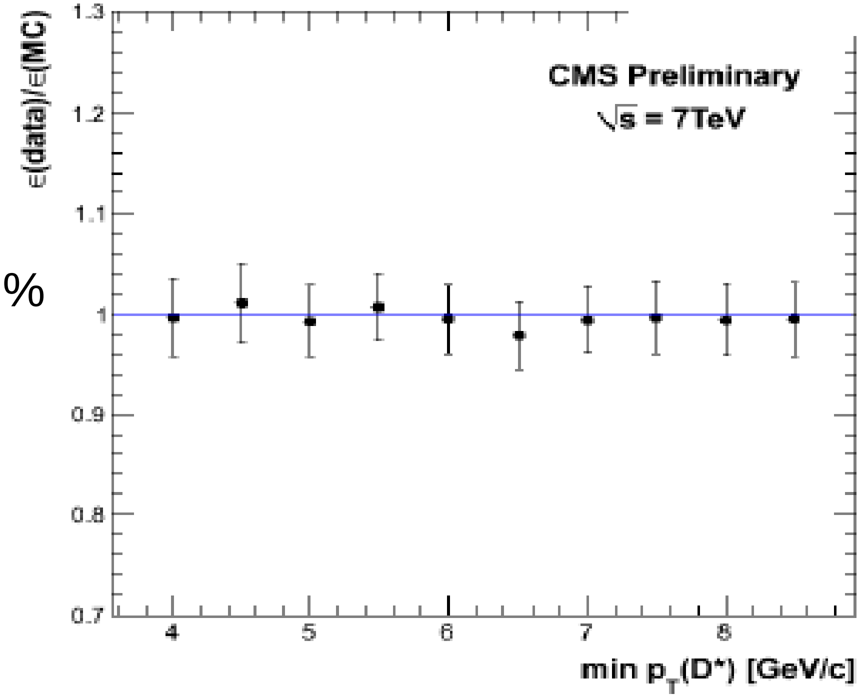
CMS PAS TRK-10-002

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%

Using D-mesons for pions

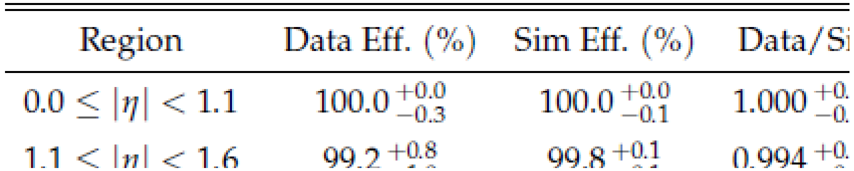


$\mathcal{R} = \frac{N_{K3\pi}}{N_{K\pi}} \cdot \frac{\epsilon_{K\pi}}{\epsilon_{K3\pi}},$



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

For isolated muons:



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

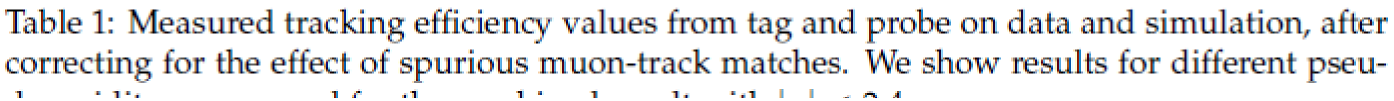
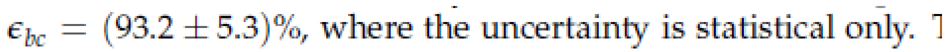
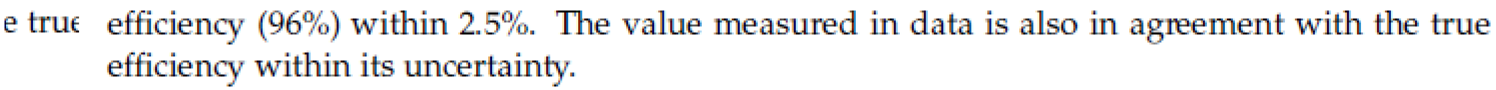


Table 1: Measured tracking efficiency values from tag and probe on data and simulation, after correcting for the effect of spurious muon-track matches. We show results for different pseu-

For non-isolated muons:

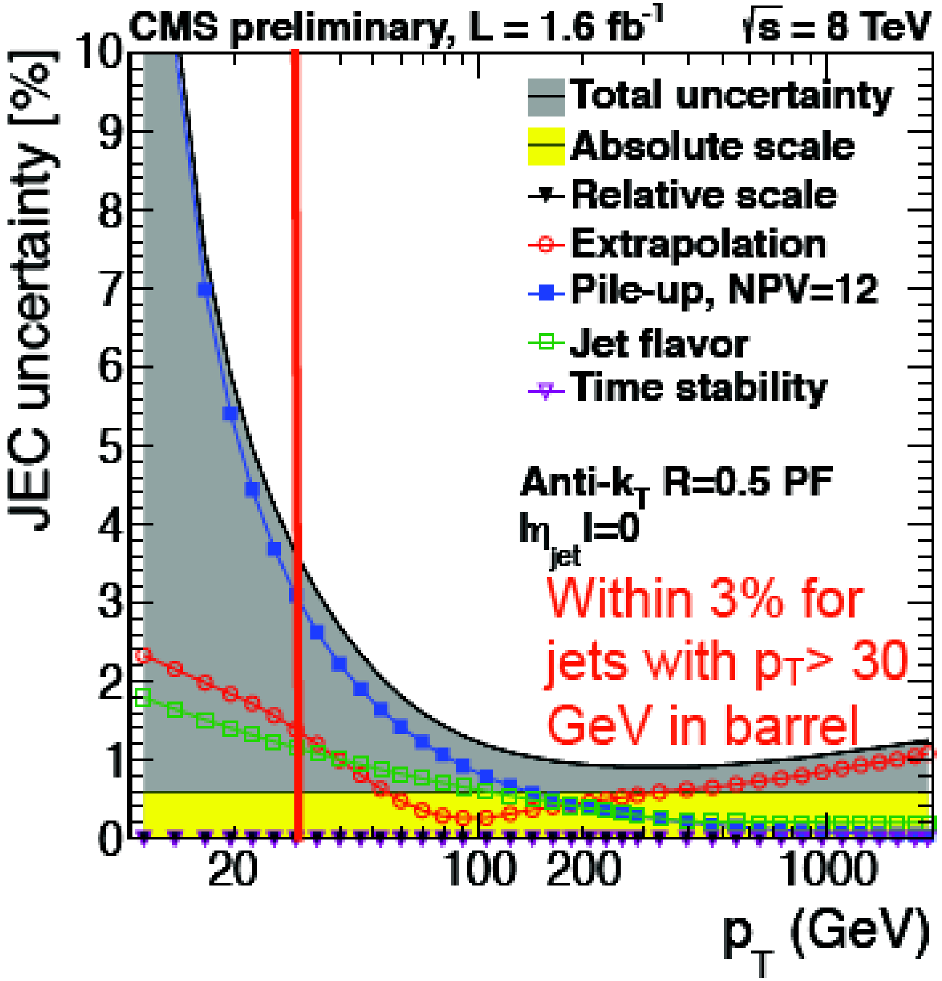


$\epsilon_{bc} = (93.2 \pm 5.3)\%$, where the uncertainty is statistical only.

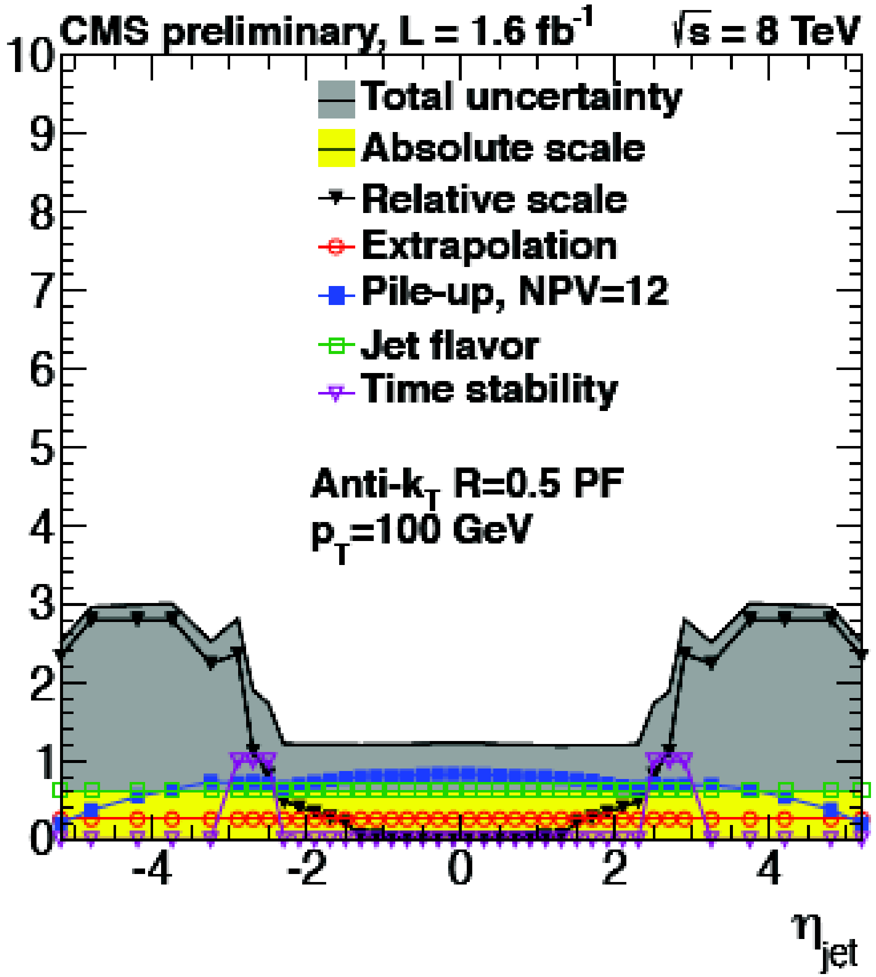


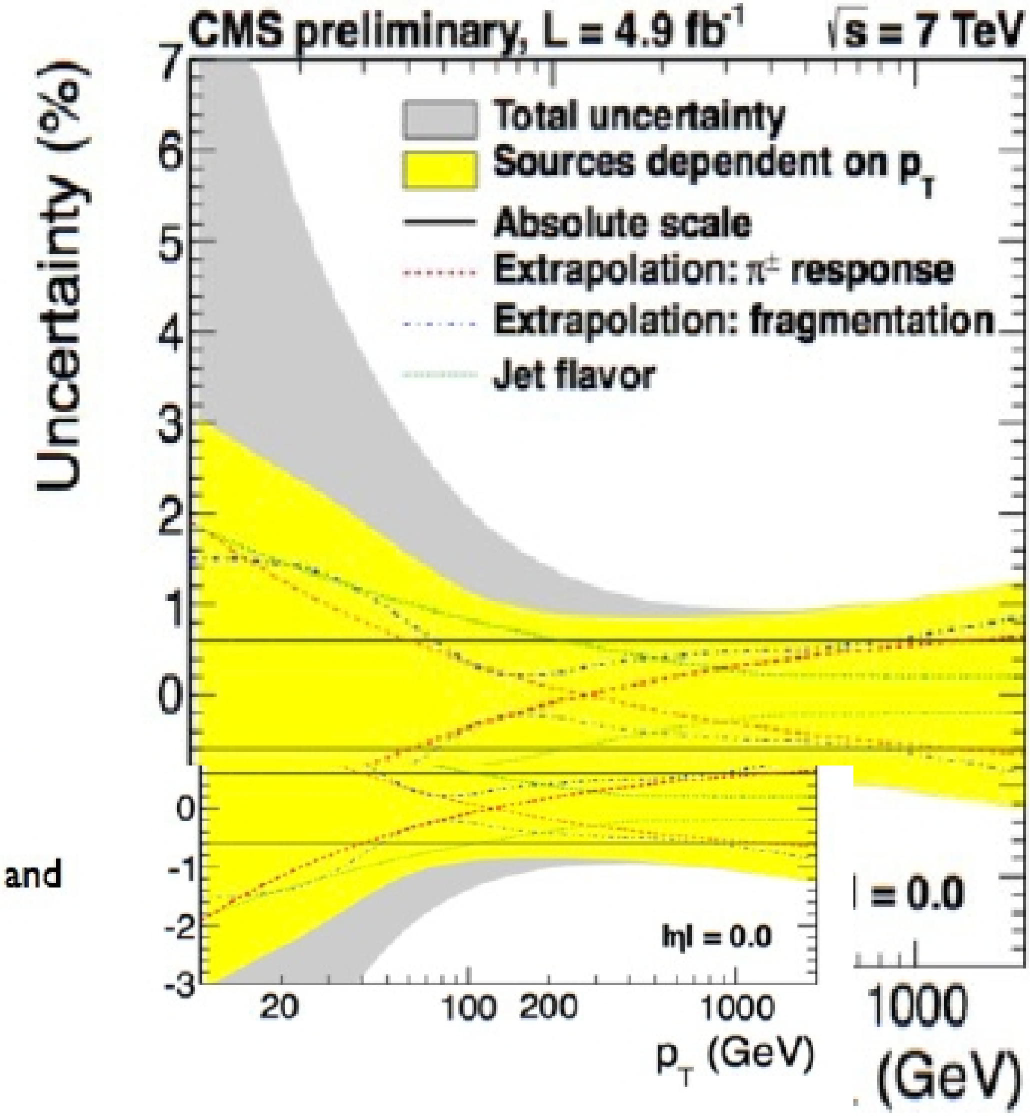
e true efficiency (96%) within 2.5%. The value measured in data is also in agreement with the true efficiency within its uncertainty.

- ◆ Uncertainties in 2012 data comparable to 2010, 2011.
  - Pileup uncertainties increasing due to higher average pileup.



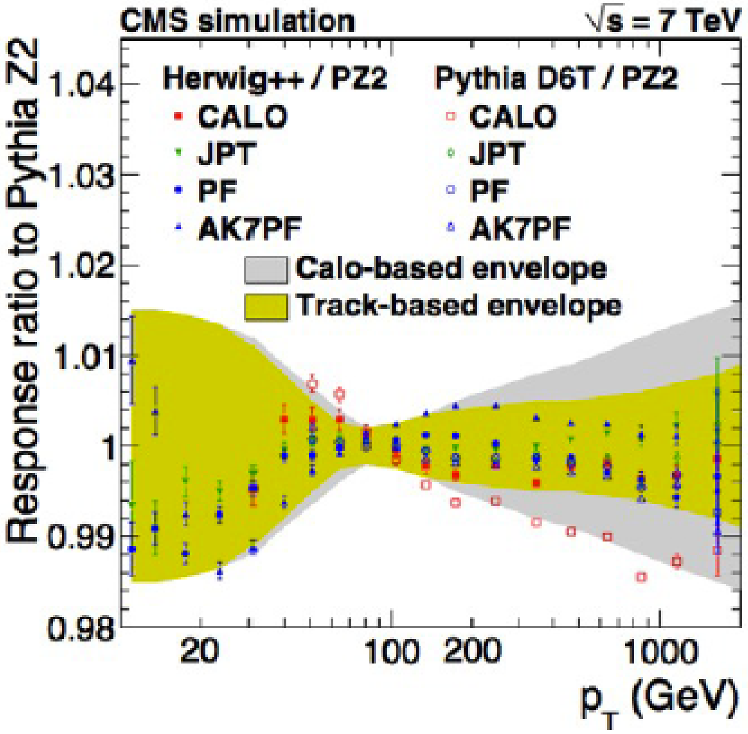
Within 3% for jets with p_T> 30 GeV in barrel

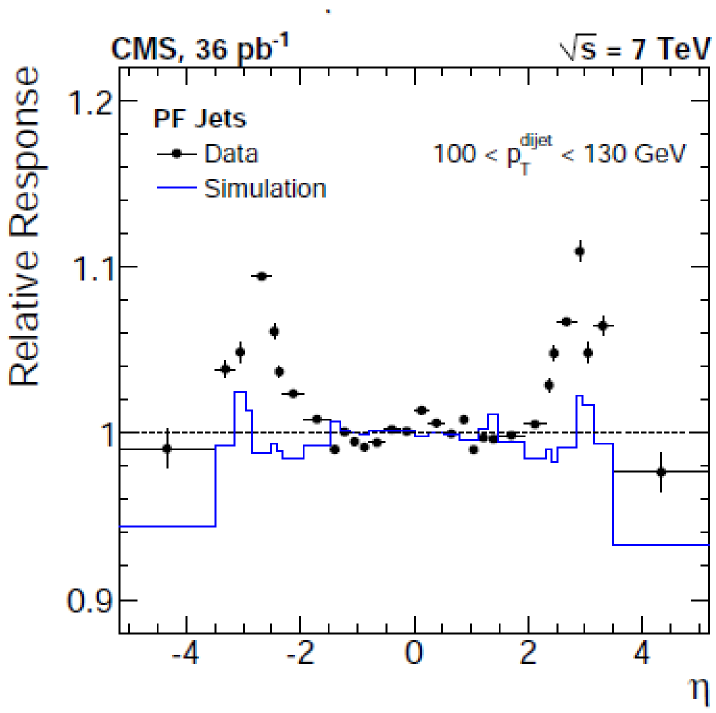


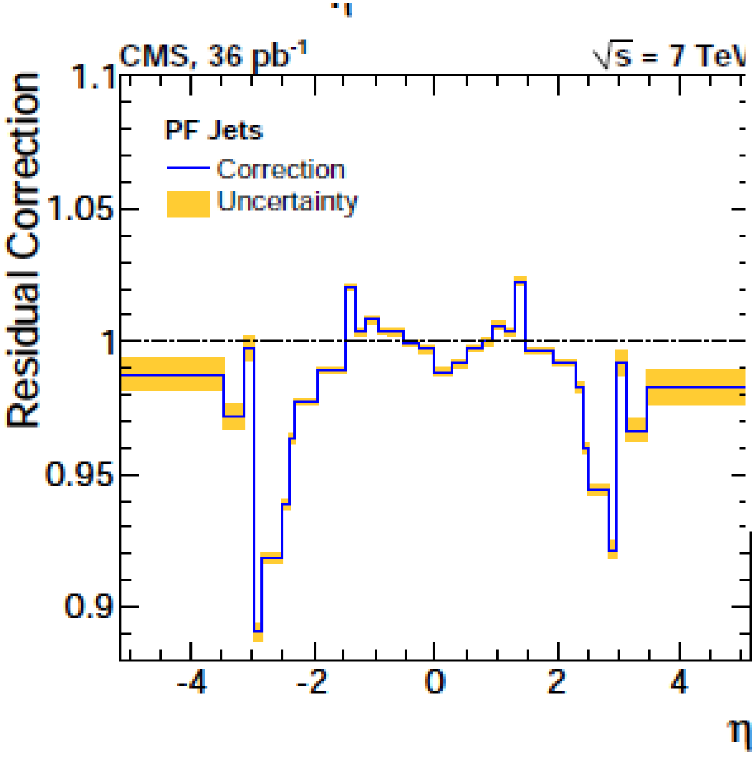


- Top mass: effect of JEC on template shapes
- In the example, extrapolation uncertainty broken into **correlated** (fragmentation) and **anti-correlated** parts (pion response)
- Important feature: sources can cross zero to produce anti-correlation
- Allowed JEC shapes obtained as linear combinations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

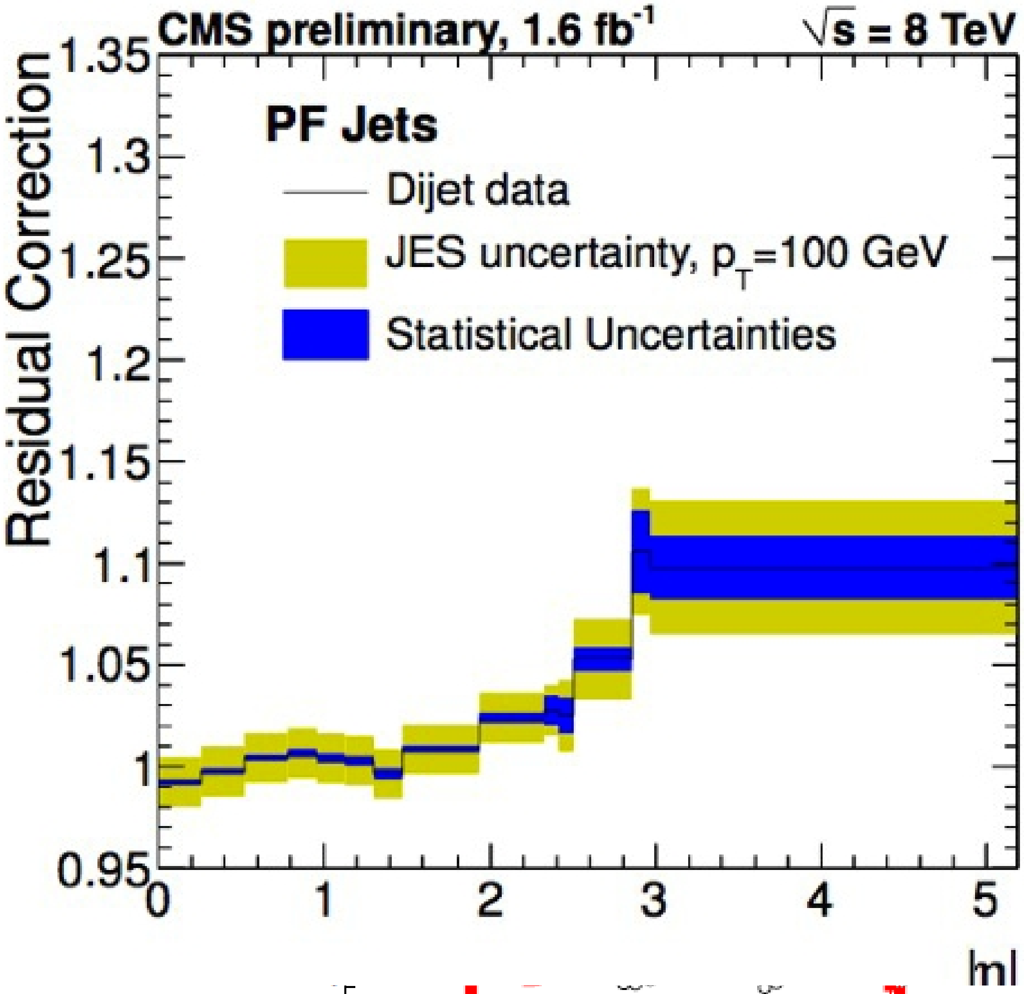
- MC truth jet response extracted for Calo, JPT, (AK5)PF, AK7PF with Pythia D6T, Herwig++ and Pythia Z2 (default tune)
- Scaled results to be the same at roughly pT=100 GeV.
  - absolute residual correction (data/MC) are extracted in that pt region
- Difference in shape between pythia and Herwig++ extrapolated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

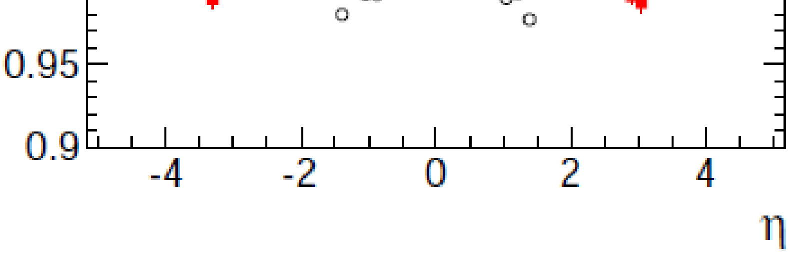




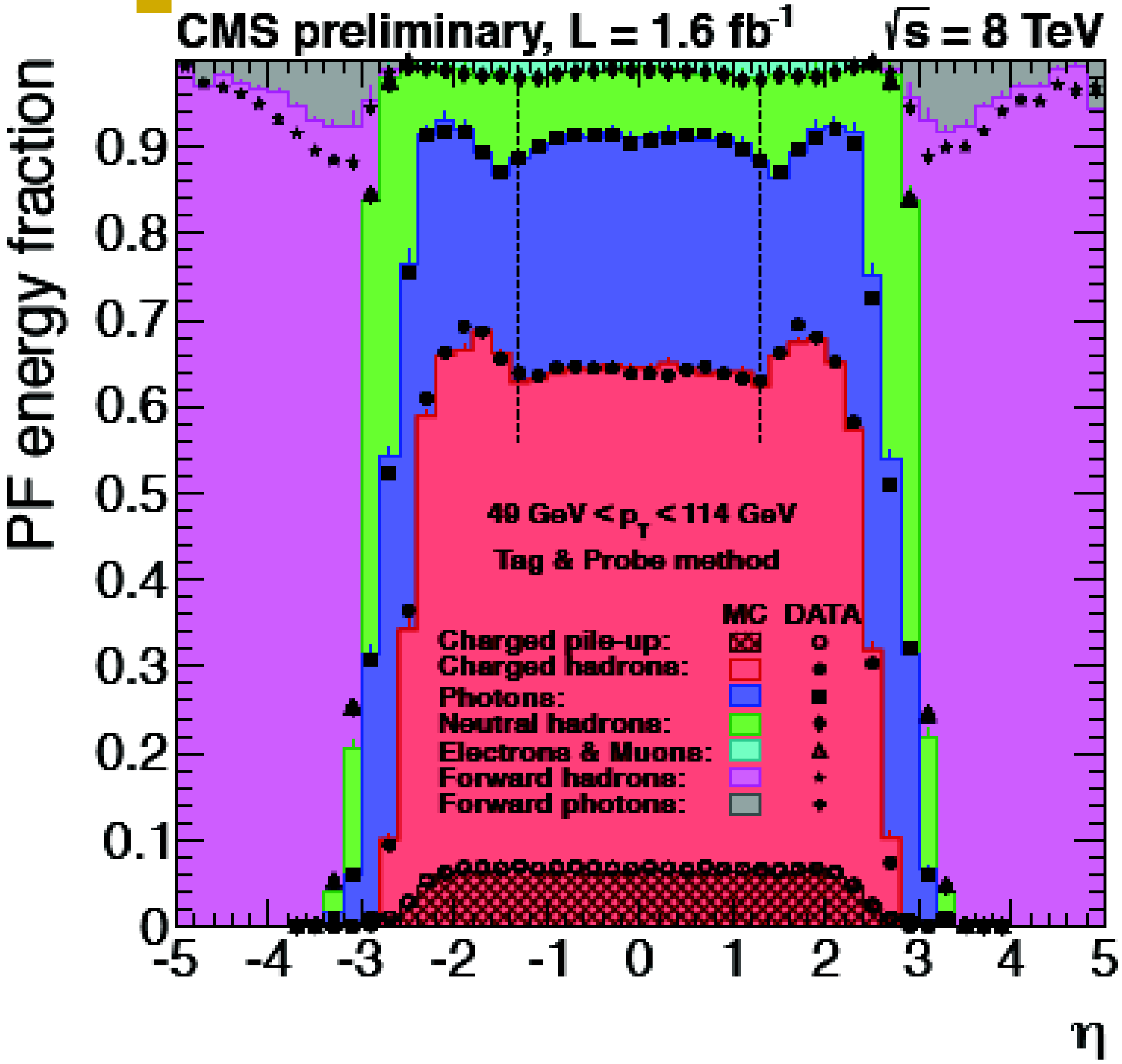


Slide not finished
Talk here about forward JES

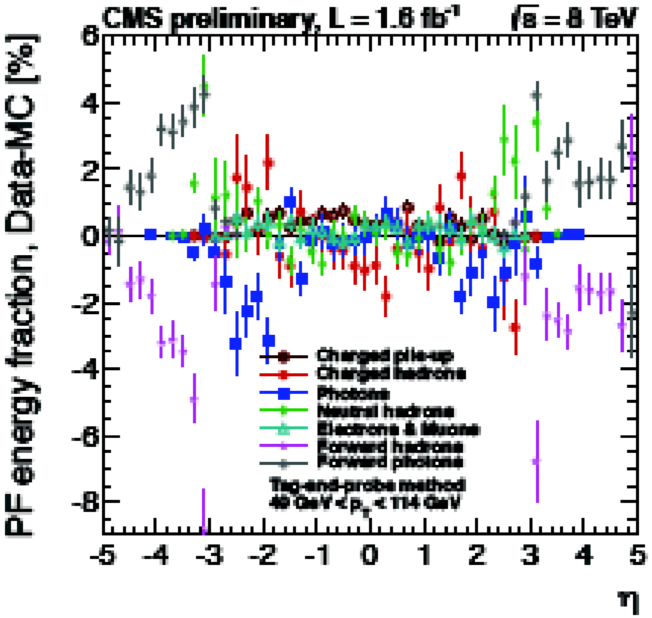




Jet composition vs η



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



Flavour mapping