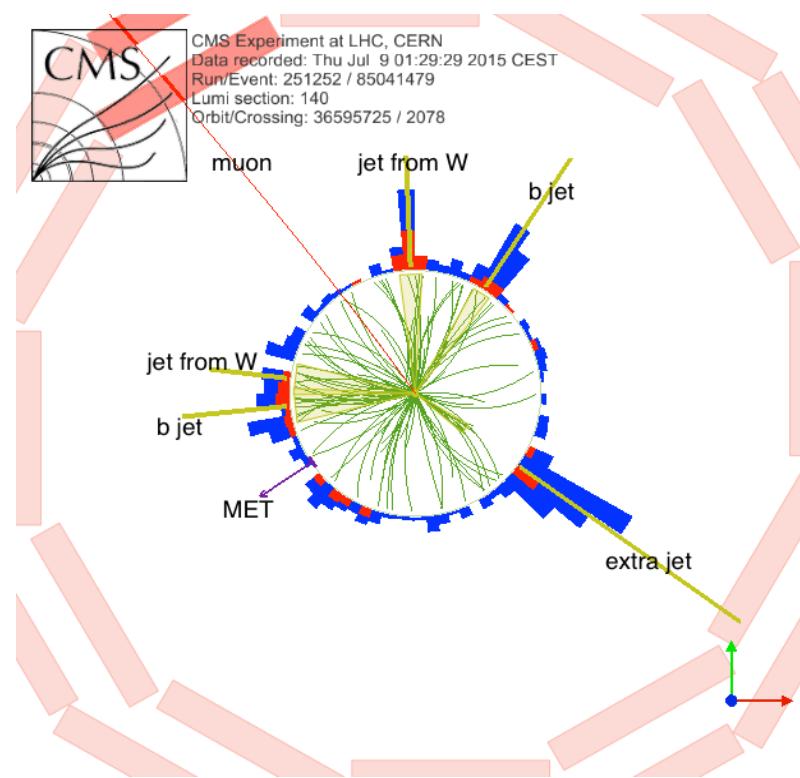
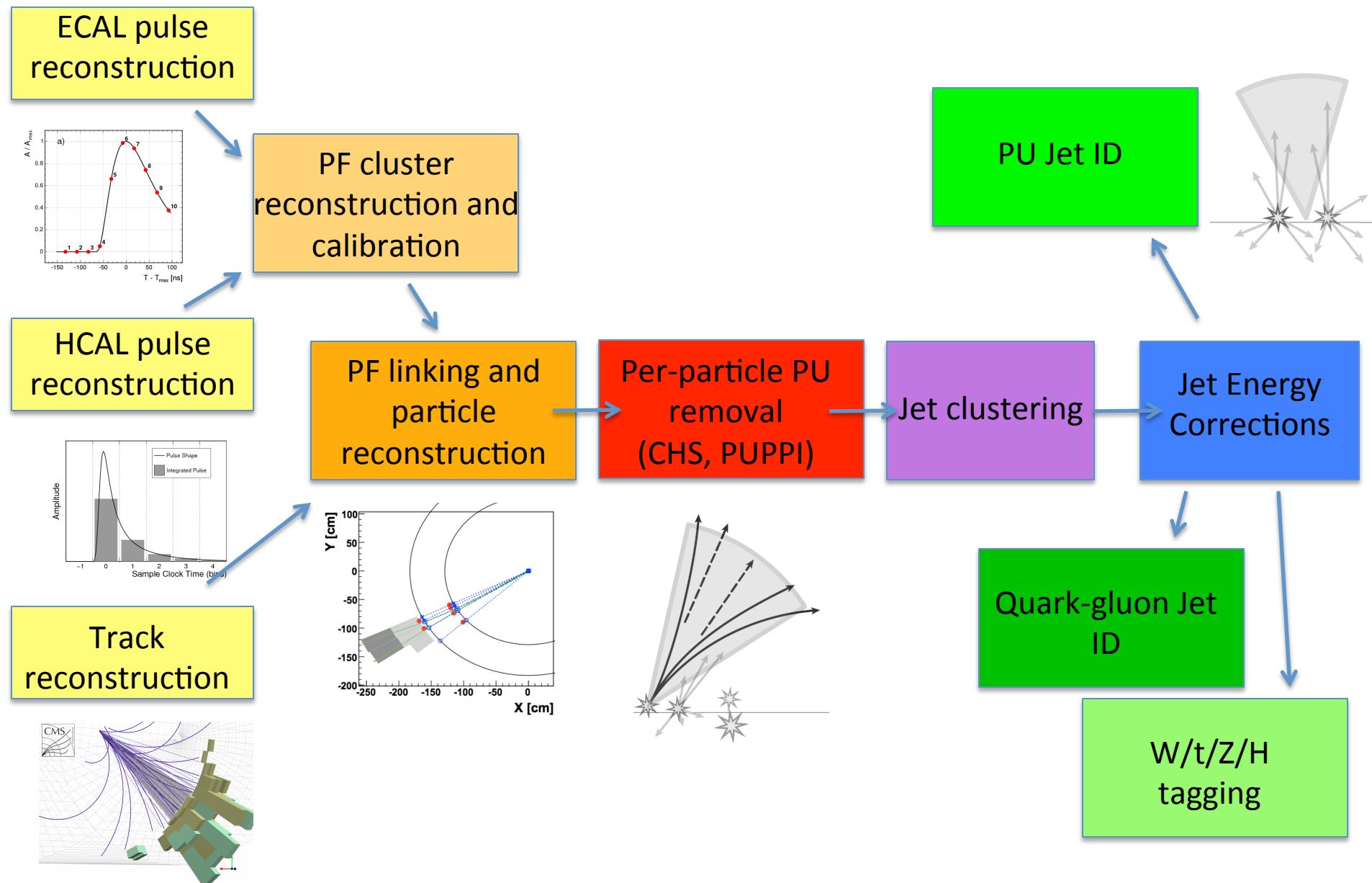


Jet Energy Corrections CMS overview

ipnl



CMS jets (and MET) reconstruction



Jet Energy Corrections - glossary

Particle-level jet (ptcl) : jet clustered from all stable particles in the event, excluding neutrinos.

PF jet : jet clustered from PF candidates.

CHS (charged hadron subtraction) : removal of all particles unambiguously associated to PU vertices before jet clustering, reduces IT PU.

Jet response : $p_{T,\text{reco}}/p_{T,\text{ptcl}}$

Note : I will mainly show public results from the 8TeV run

<http://cds.cern.ch/record/2052170>

<https://twiki.cern.ch/twiki/bin/view/CMSPublic/MultipleConeSizes14>

All public results in

<https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsJME>

Jet Energy Corrections and Resolution workflow

Pileup : $p_{T,\text{reco}}(\text{WithPU}) \rightarrow p_{T,\text{reco}}(\text{NoPU})$

Response : $p_{T,\text{reco}}(\text{NoPU}) \rightarrow p_{T,\text{ptcl}}$

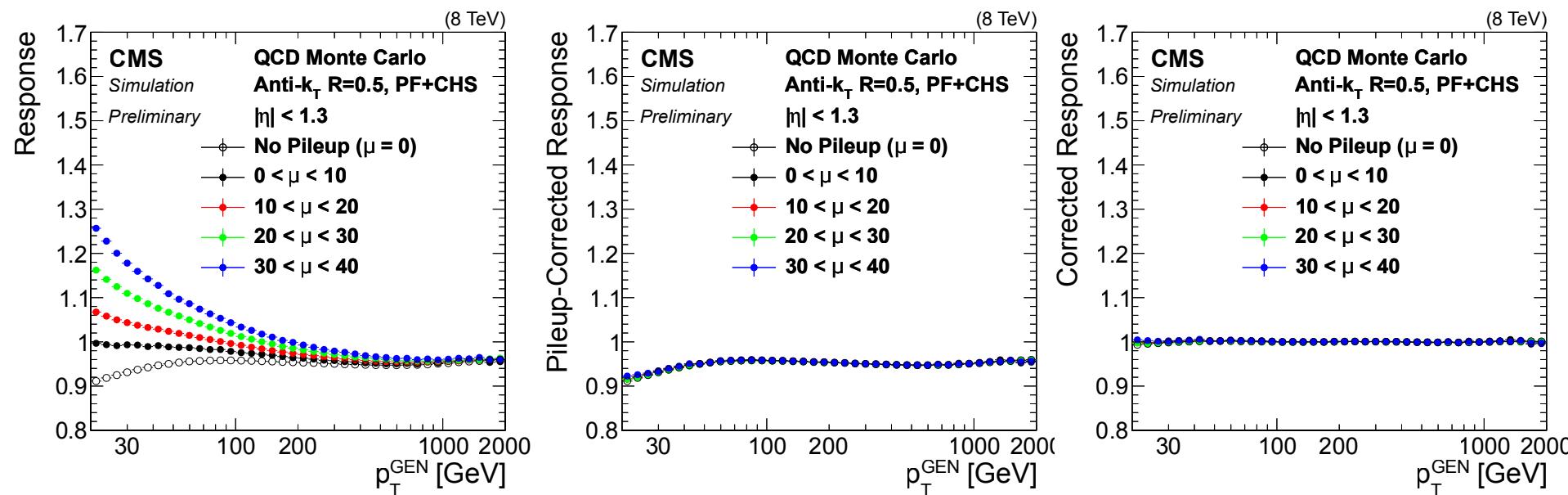
Data/MC residuals : $p_{T,\text{reco}}(\text{Data}) \rightarrow p_{T,\text{reco}}(\text{MC})$

Flavor (optional) : $p_T(\text{uds, c, b, g}) \rightarrow p_T(\text{QCD flavor mixture})$

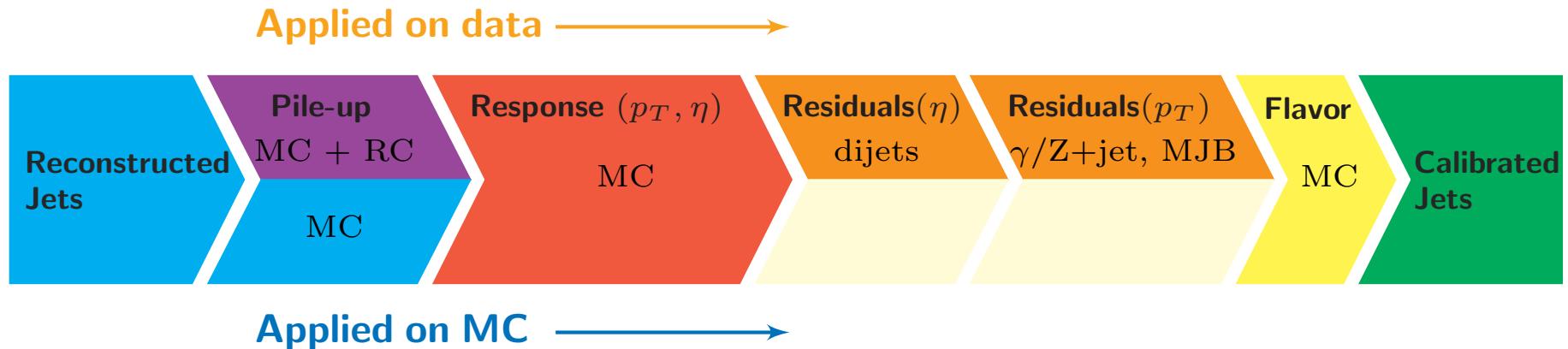
Applied on data



Applied on MC



Jet Energy Corrections and Resolution workflow



MC-truth corrections

Account for PU effects and simulated response

Extracted from Multijet QCD simulated sample with and without PU

Bulk of the corrections

Residual Data/MC corrections

PU residuals : Zero Bias

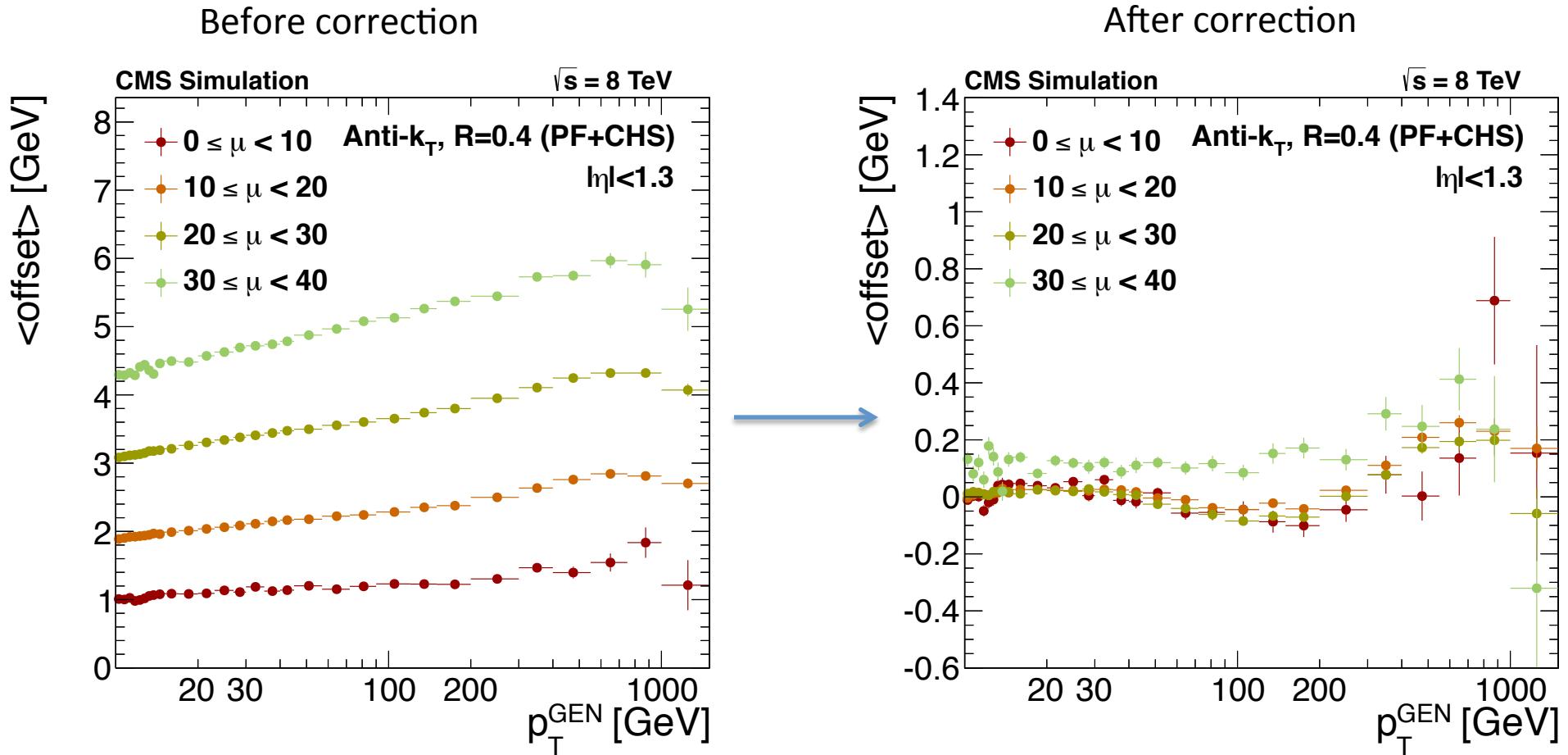
η -dependent residuals : dijet

p_T -dependent residuals : Z+jet, γ +jet, multijet

Small effect (~2% in the barrel)

Simulated PU corrections

Offset : p_T difference for a same jet in simulated events with and without PU
 As a function of $p_{T,\text{ptcl}}$, and in bins of true number of PU interactions (μ)



Leading uncertainty : offset p_T dependence from MC (propagated through in-situ measurements)

Simulated response corrections

Extracted from Multijet simulated sample

$$R_{\text{ptcl}}(\langle p_T \rangle, \eta) = \frac{\langle p_T \rangle}{\langle p_{T,\text{ptcl}} \rangle} [p_{T,\text{ptcl}}, \eta]$$

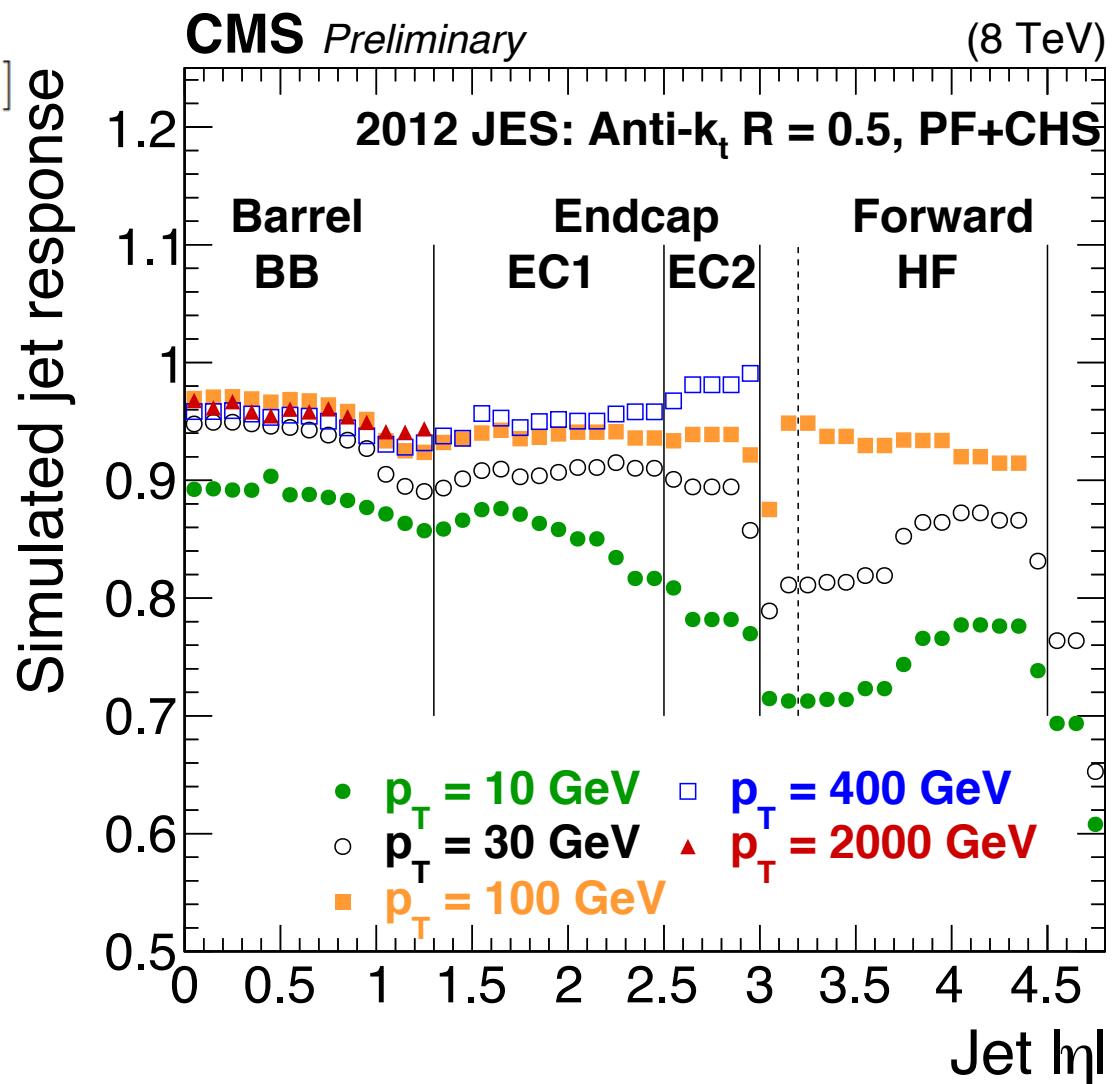
Stable response in barrel 0.95.
Related to ~ 0.6 response for
neutral hadrons (15% of p_T, ptcl)

at $p_T < 30$ GeV drop due to
HCAL acceptance (~ 3 GeV)

Lower response in endcaps and HF

Acceptance effects in transition
region $3 < |\eta| < 3.2$ and $|\eta| > 4.5$

Leading uncertainty: calorimeters
single pion response



Data/MC SF : offset correction with Random Cone

Residual data/MC scale factors for offset from Random Cone on ZeroBias events (random triggers in presence of beam crossing).

- p_T of Jet from PF candidates in randomly placed cone : average offset due to PU

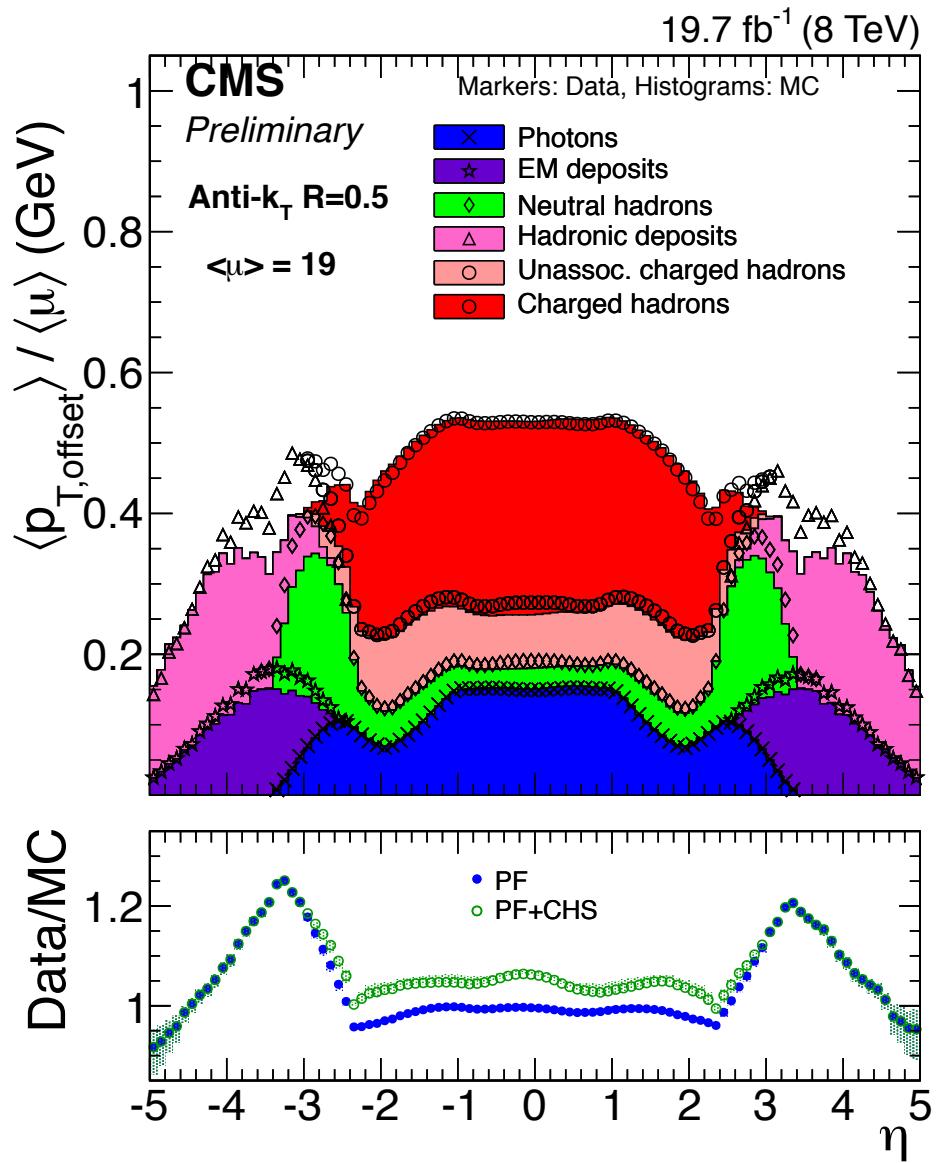
$$SF = \frac{\langle p_{T,\text{offset}} \rangle_{\text{data}}^{\text{RC}}(\eta, \langle \rho \rangle_{\text{data}})}{\langle p_{T,\text{offset}} \rangle_{\text{MC}}^{\text{RC}}(\eta, \langle \rho \rangle_{\text{MC}})}$$

Residual SF

- in tracker ~1 for PF, 1.05 for PF+CHS
- 0.9-1.25 in HF

Charged hadrons removed by CHS, reduces of ~50% offset (in the tracker coverage)

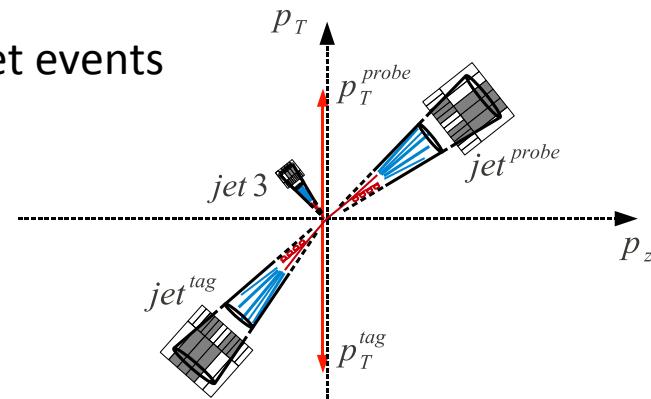
Leading uncertainty: $\langle \rho \rangle$ determination



Data/MC SF : relative (η -dependent) correction

Response uniformity vs η is checked on data vs MC with dijet events

- Tag jet in $|\eta| < 1/3$, probe jet eta unconstrained
- Analysis performed in bins of $p_{T,\text{Ave}} = 0.5 * (p_{T,\text{tag}} + p_{T,\text{probe}})$
- Correction for ISR/FSR (separately for p_T -balance and MPF methods)
- MPF method nominal (p_T -balance crosscheck)

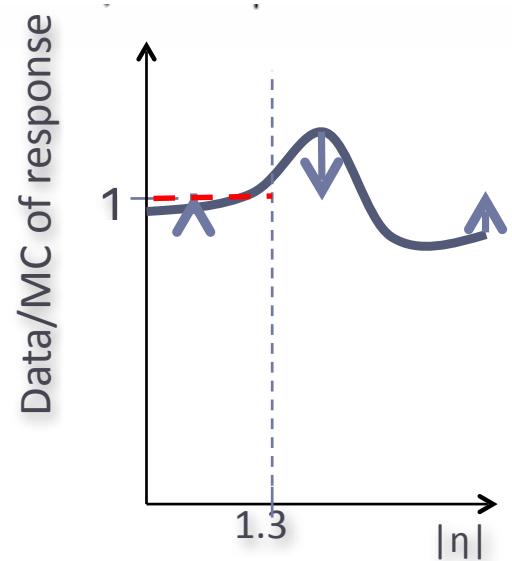


$$R_{\text{rel}}^{p_T} = \frac{1 + \langle \mathcal{A} \rangle}{1 - \langle \mathcal{A} \rangle}, \quad \text{where}$$

$$\mathcal{A} = \frac{p_{T,\text{probe}} - p_{T,\text{tag}}}{2p_{T,\text{ave}}}, \quad \text{and}$$

$$R_{\text{rel}}^{\text{MPF}} = \frac{1 + \langle \mathcal{B} \rangle}{1 - \langle \mathcal{B} \rangle}, \quad \text{where}$$

$$\mathcal{B} = \frac{\vec{p}_{\text{T}}^{\text{miss}} \cdot (\vec{p}_{T,\text{tag}} / p_{T,\text{tag}})}{2p_{T,\text{ave}}}.$$



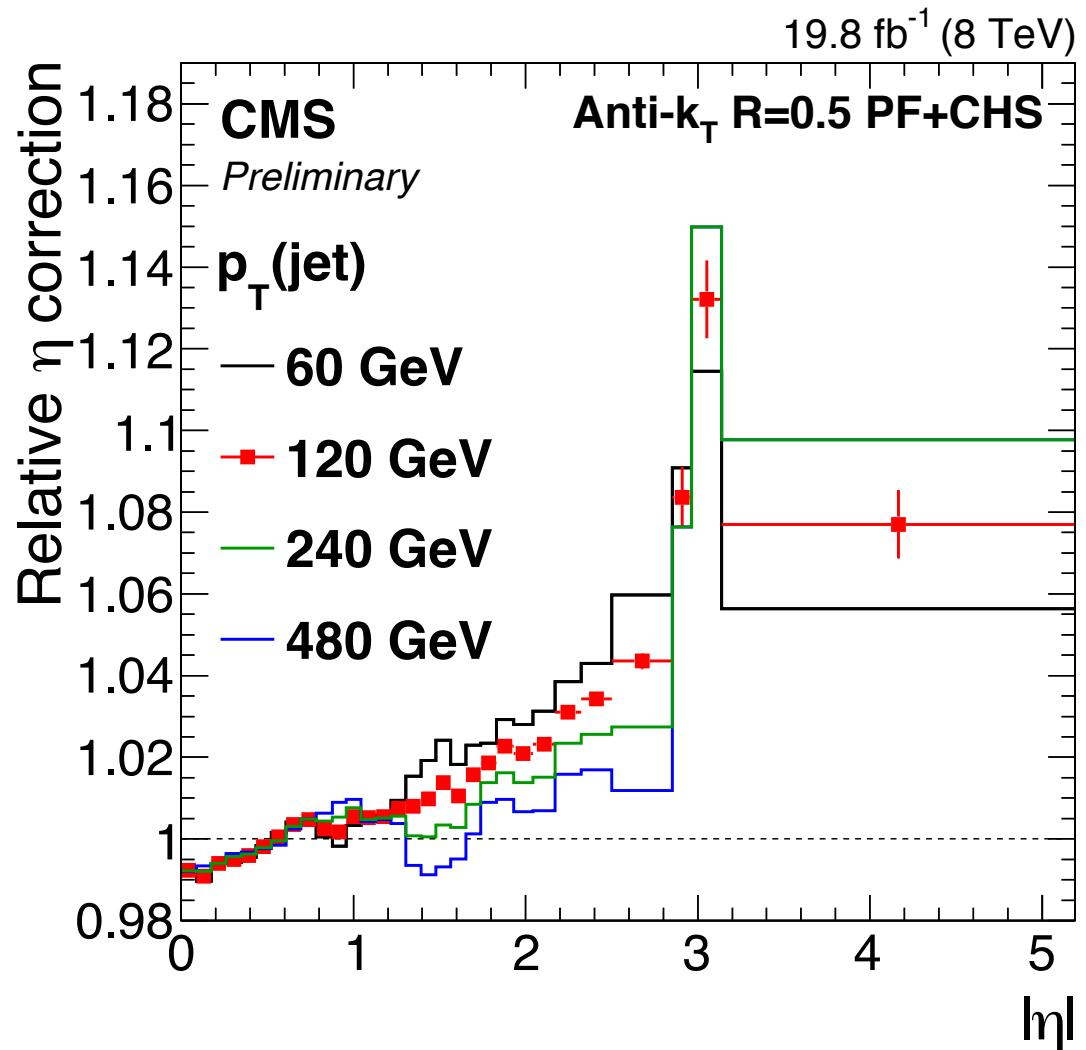
Data/MC SF : relative (η -dependent) correction

10

Data/MC SF from response ratio

- Correction higher at low p_T in endcaps
- p_T dependence (at least partly) due to barrel pt dependence
- Large residual in HF
- Lack of stat in fwd due to triggers (improved for 13TeV run)

Leading uncertainties: radiation, jet p_T resolution, low stat (HF), p_T dependence



Data/MC SF : absolute (p_T -dependent) correction

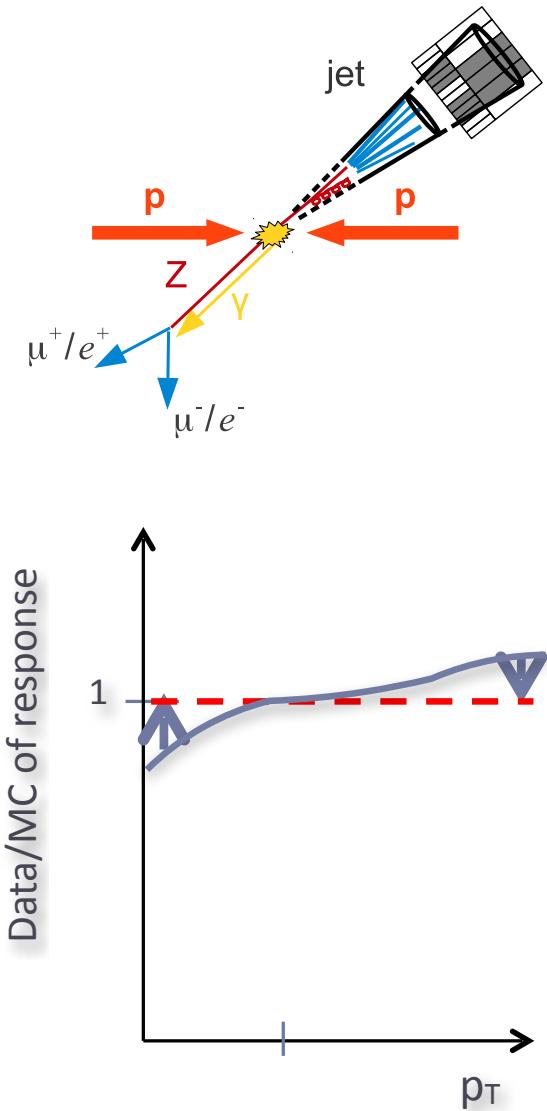
Response uniformity vs p_T (data vs MC) is evaluated using

- Z+j and $\gamma+j$ data , where the jet is calibrated vs a reference object (reasonable statistics for jets with p_T in [30,800])

$$R_{\text{jet},p_T} = \frac{p_{T,\text{jet}}}{p_{T,\text{ref}}},$$

$$R_{\text{jet,MPF}} = 1 + \frac{\vec{p}_{T,\text{miss}} \cdot \vec{p}_{T,\text{ref}}}{(p_{T,\text{ref}})^2}$$

- Multijet data ($p_T > 800$), where high p_T jet is calibrated vs a system of lower p_T jets (see next slide)



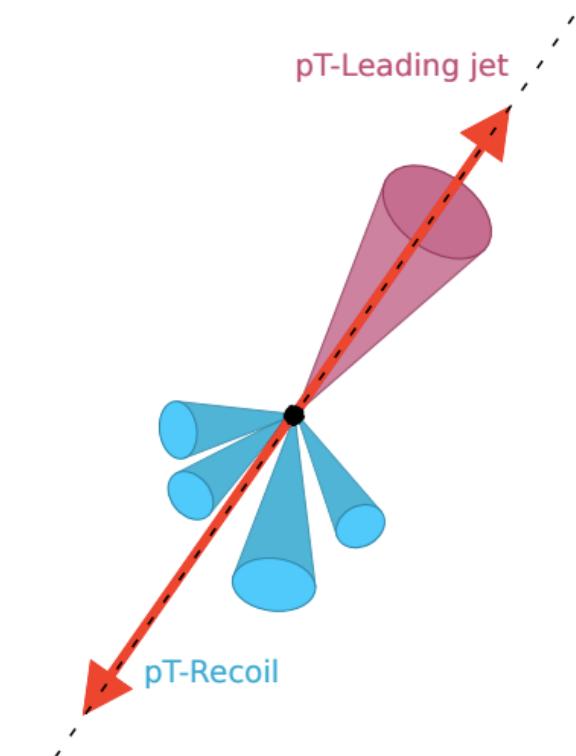
Data/MC SF : absolute (p_T -dependent) correction

Select events in which high p_T ($\sim 1\text{TeV}$) jets are balanced by a system of lower p_T jets (recoil).

$$MJB = \frac{|\vec{p}_T^{\text{Leading jet}}|}{|\vec{p}_T^{\text{Recoil}}|}$$

$$R_{\text{MPF}} = 1 + \frac{\vec{E}_t \cdot \vec{p}_T^{\text{Recoil}}}{(\vec{p}_T^{\text{Recoil}})^2}$$

$$\text{MJB} = \frac{\text{JES}(p_{T,\text{lead}}) p_{T,\text{lead}}}{\text{JES}(p_{T,\text{eff}}) p_{T,\text{recoil}}} \approx \frac{\text{JES}(p_T)}{\text{JES}(C_{\text{recoil}} \cdot p_T)}$$



MJB connects the high p_T JES to the JES of an effective lower p_T

C_{recoil} measures the level of arm of the MJB method in measuring p_T -dependence of JES

Data/MC SF : absolute (p_T -dependent) correction

Input from Z+j, γ +j, and multijet data is combined in a global fit

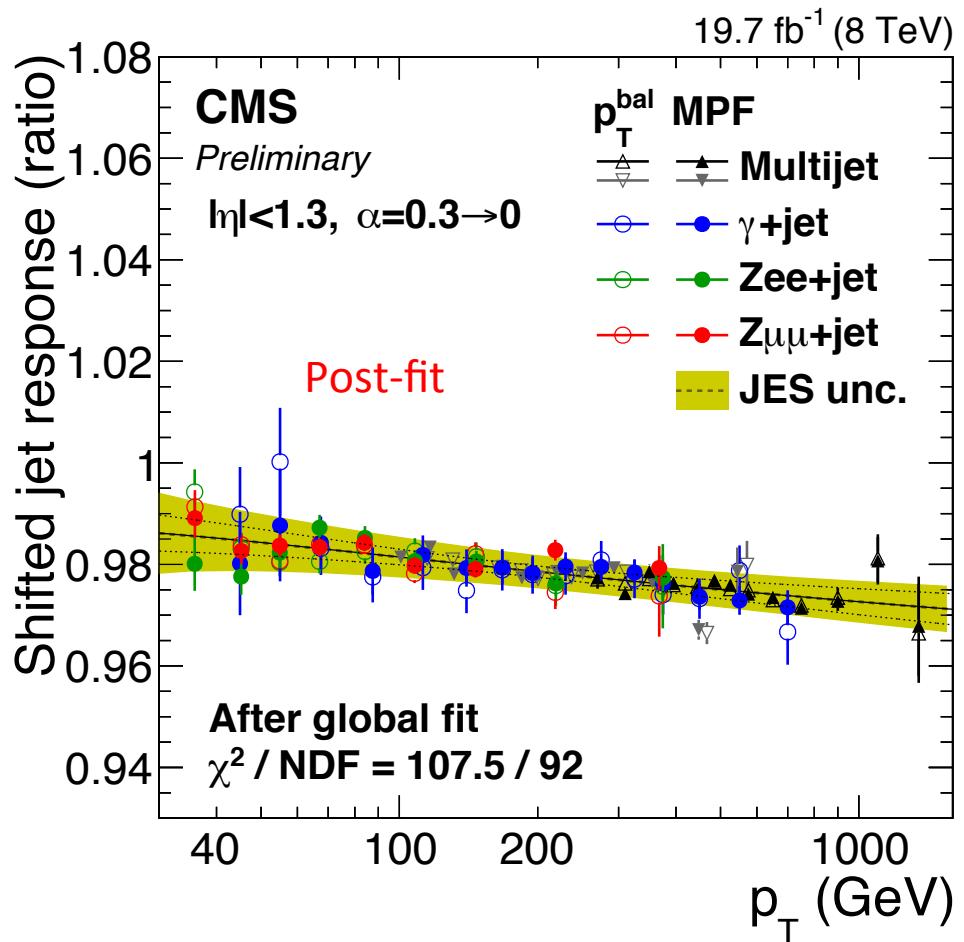
The fit accounts for absolute scale + linear dependence on p_T

Nuisance parameters in the fit

- Reference object scale
- Correction for ISR/FSR

After global fit all data in agreement
 $\text{Chi}^2 \sim 1$, no outliers for nuisance parameters

Leading uncertainties : reference objects scale, single pion response and fragmentation (from simulation)



Evolution of JEC Data/MC SF

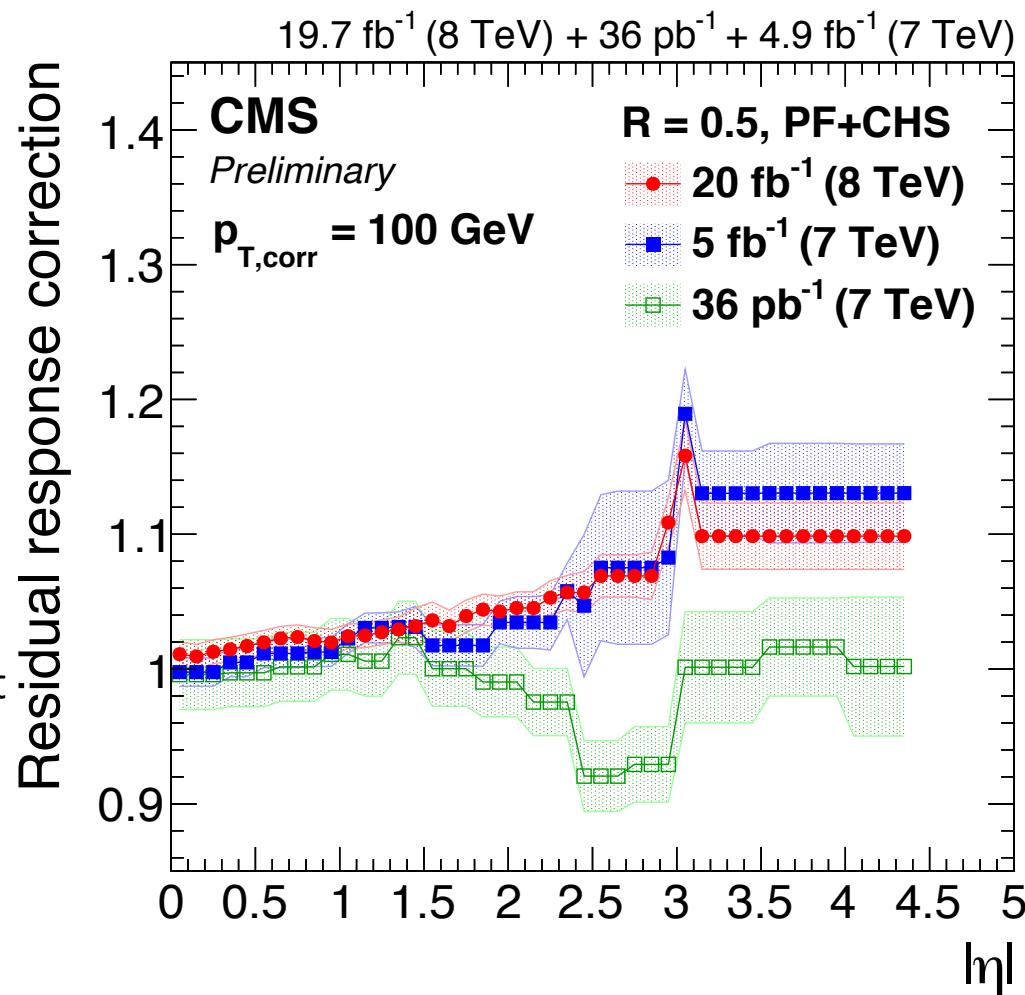
Residual jet energy corrections over the course of Run I have been stable, especially in barrel

2010 data: very first data

2011 data: calorimeter inter-calibration done based on data, HF readout fits improved

2012 data: corrections for radiation damage in the end caps kept performance at 2011 level

Continuous reduction of systematic uncertainties, despite increasing amount of pileup



Flavor response

Studied on simulated multijet events

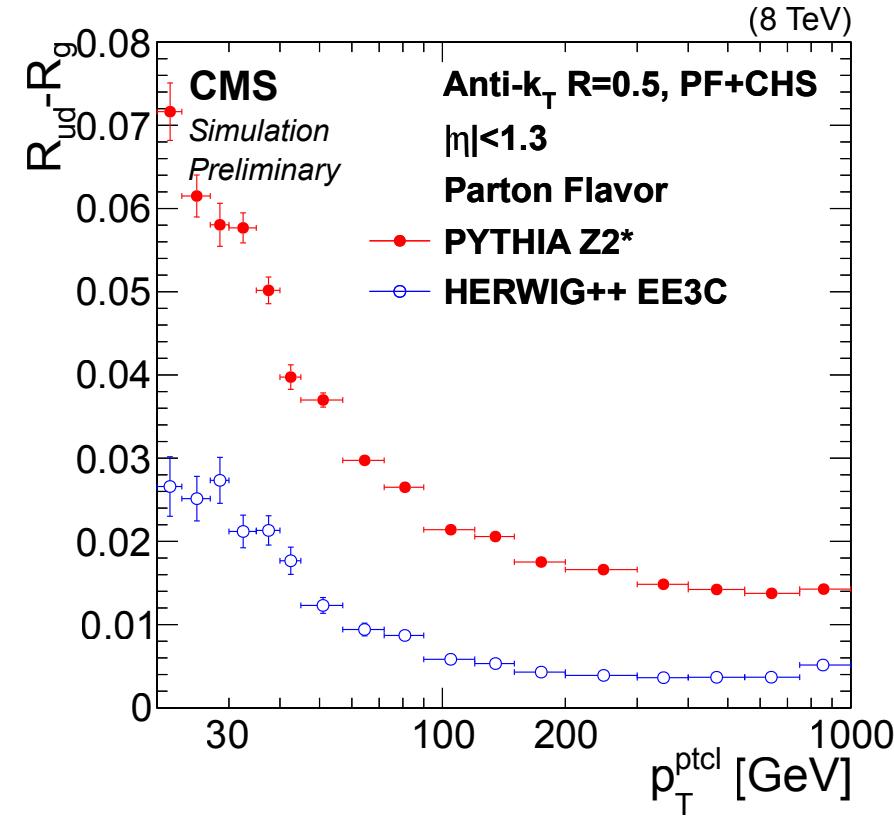
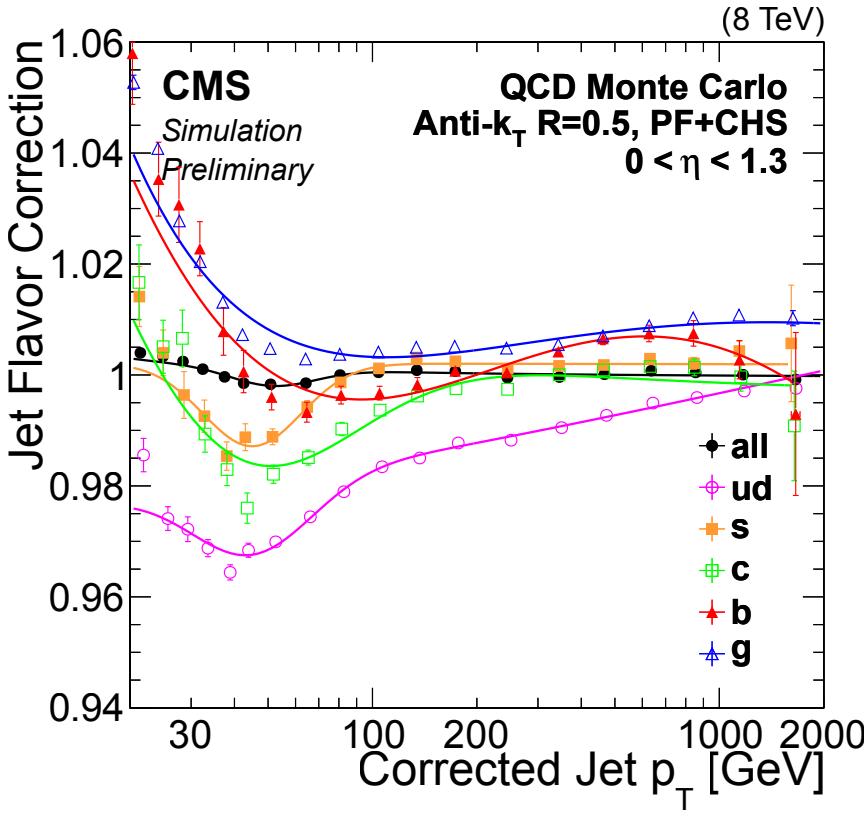
ud have highest response, gluons lowest, cbs in between

- g: large multiplicity, softer particles
- s: K_L inefficiently reconstructed by PF
- b: soft particles from heavy hadrons decays

Uncertainties from Pythia6 Z2* vs Herwig++ 2.3 EE3C per flavor (to propagate to any mixture)

Pythia6 / Herwig++ difference minimal for ud, maximal for gluons

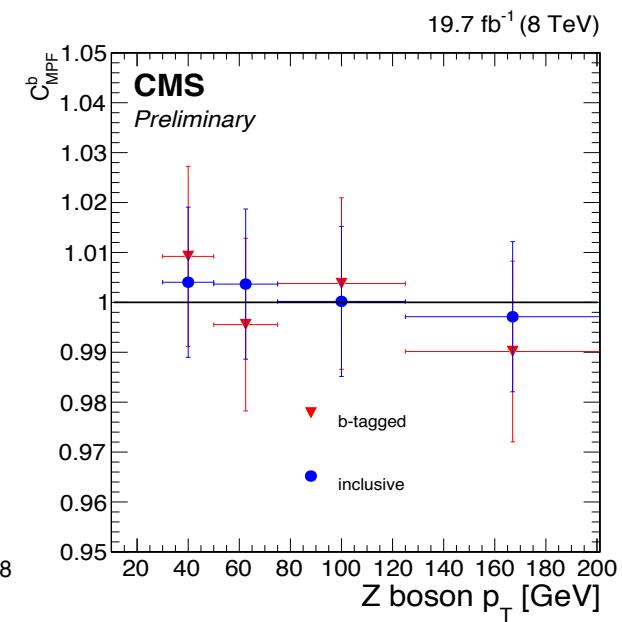
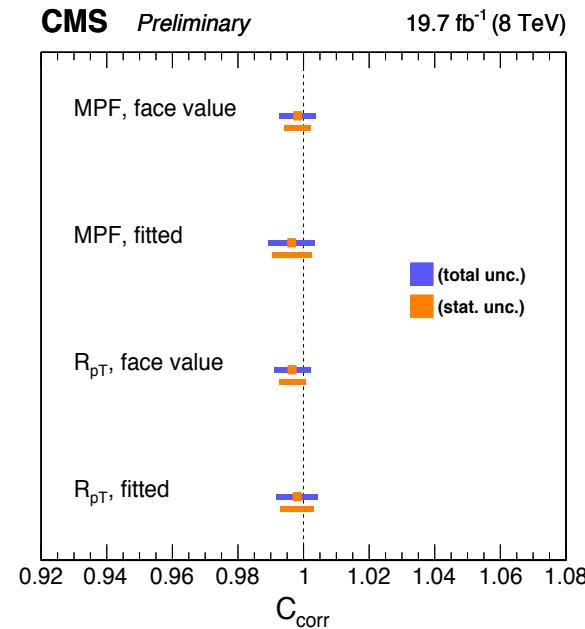
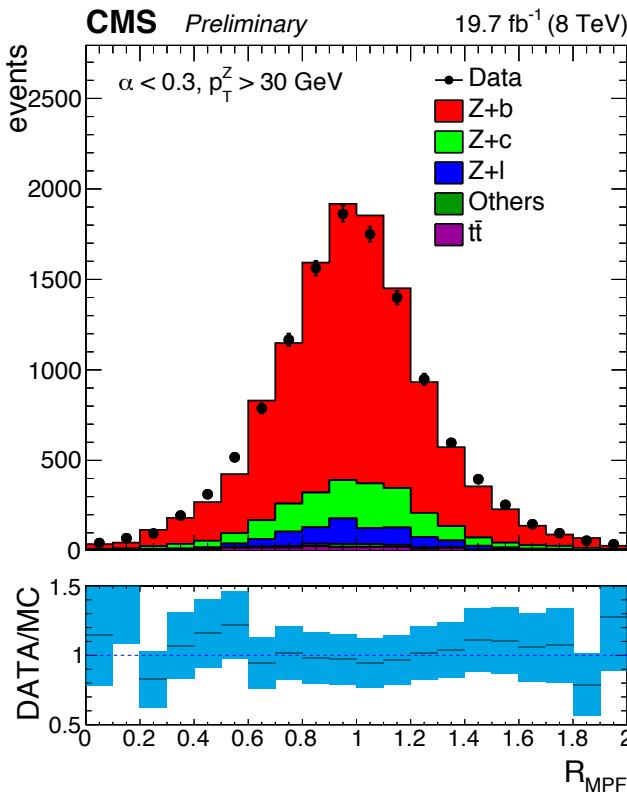
- in general, Herwig++ predicts smaller flavor response differences than Pythia



Flavor response : Z+b crosscheck

Flavor response crosschecked with Z+jet events where the jet is b-tagged (purity 70-80%)
 For the rest, same analysis as Z+j data/MC SF measurement

- Residual b-jet energy correction $C_{\text{corr}} = 0.998 + 0.004(\text{stat}) + 0.004(\text{syst})$, consistent with unity within b-jet flavor uncertainty of $\sim 0.5\%$
- No evidence for need of dedicated correction



JEC uncertainties

JetFlavorQCD dominant JEC uncertainty for inclusive jets (smaller for other analyses)

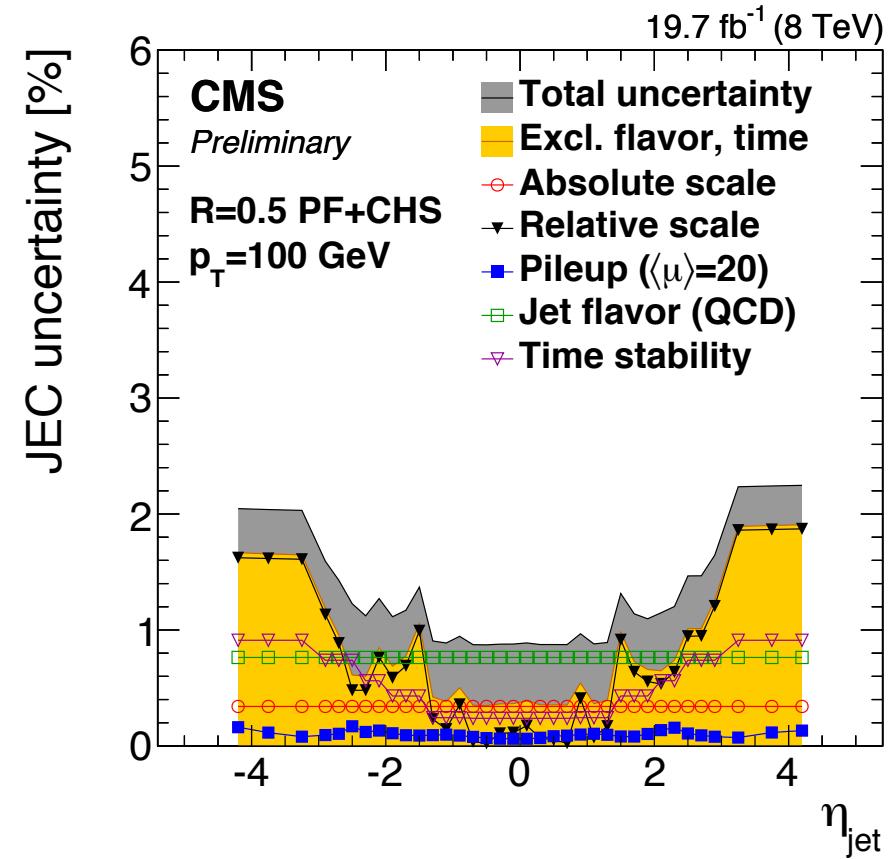
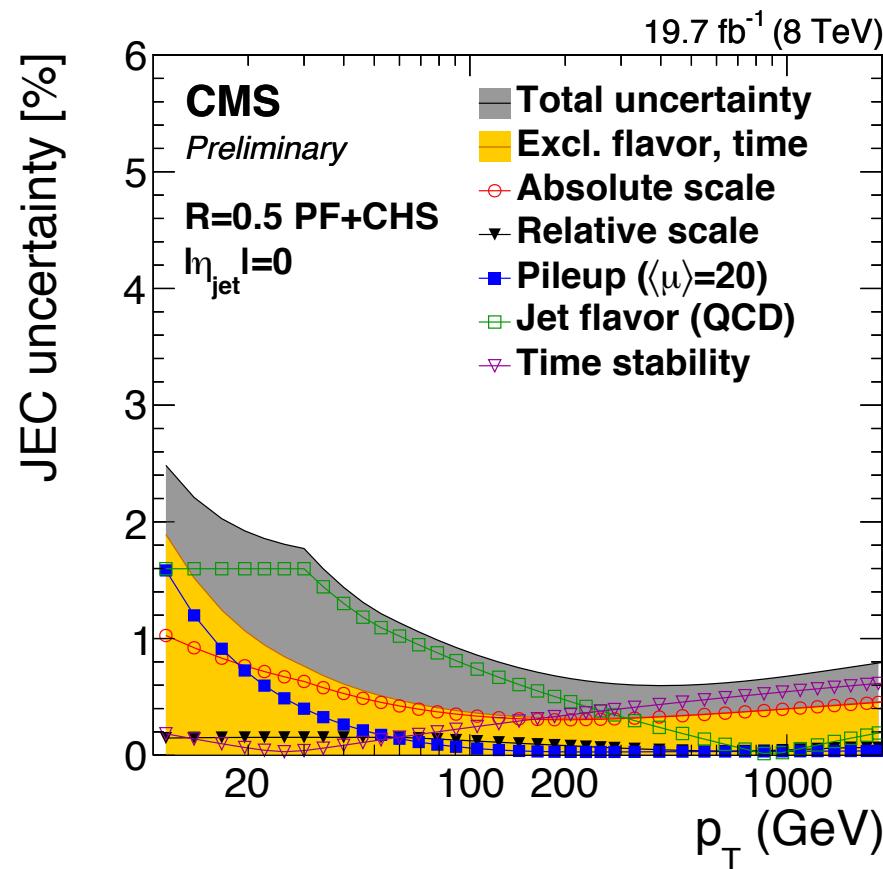
Time stability dominant at high pT (can be excluded for analysis on full 8 TeV data set)

Pileup uncertainty small (partially absorbed into residual $\eta + p_T$ corrections)

Other main uncertainties are **absolute scale** and **relative scale**

Minimum of 0.32% at pT=200 GeV and $|\eta|=0$, excluding optional flavor and time uncertainties

Minimum of 0.60% at pT=400 GeV and $|\eta|=0$, with default total uncertainty



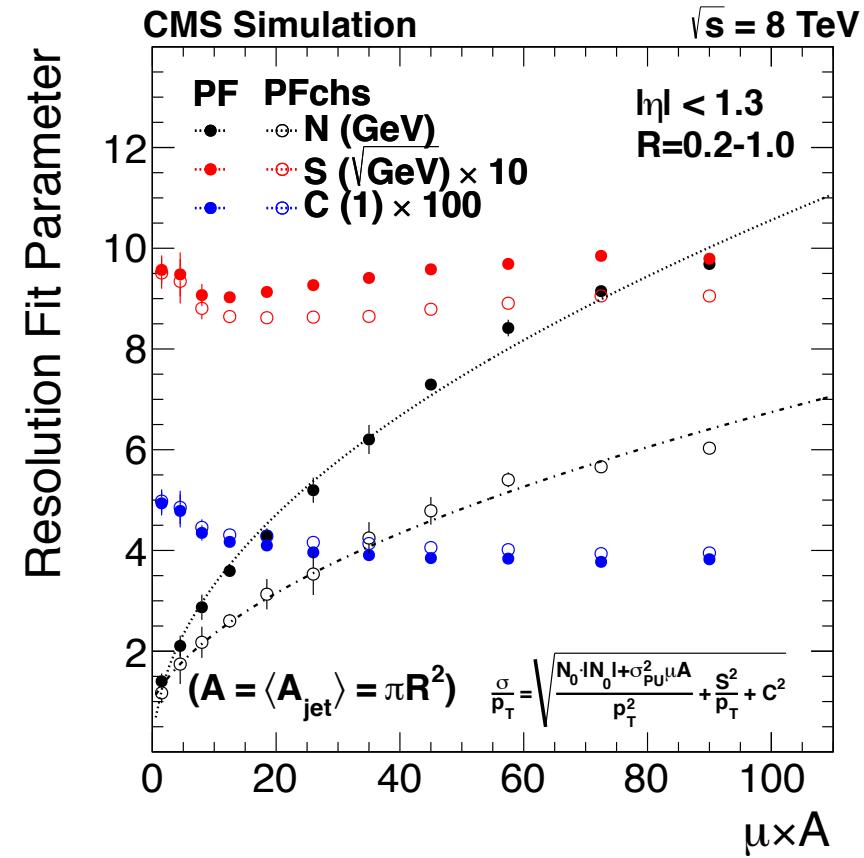
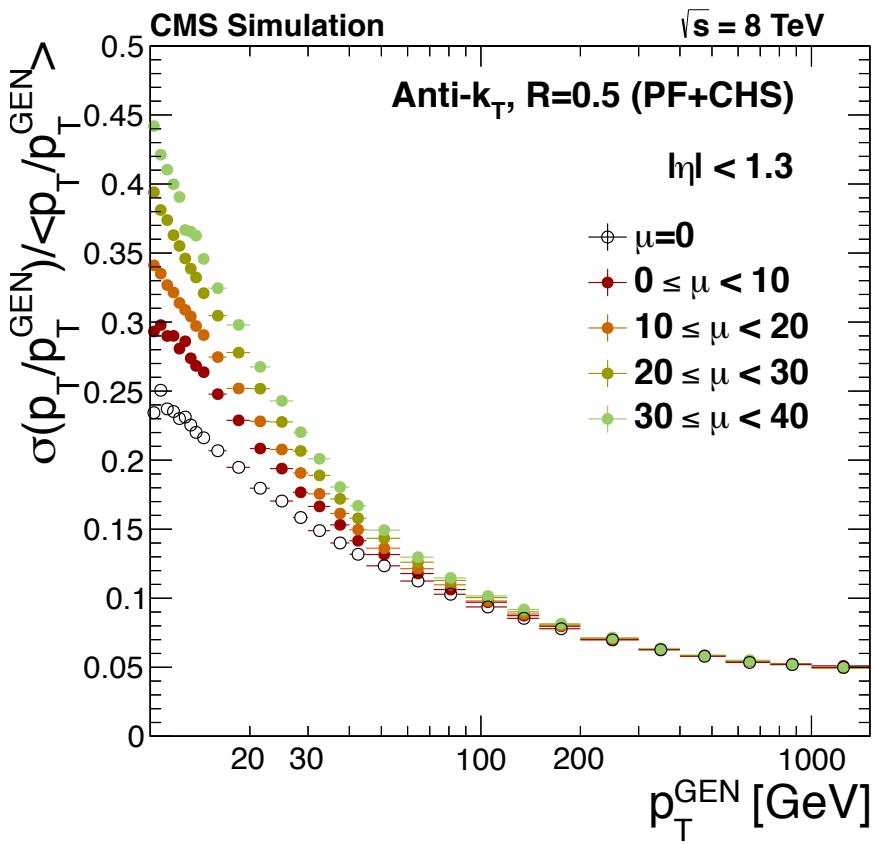
Jet Energy Resolution

Particle-level JER studied in simulated multijet events and parametrised with the NSC fit as for calo resolution

JER as a function of $p_{T,\text{ptcl}}$ for different R values

Parameters of the JER fit vs $\mu \times A$

JER data/MC SF are extracted using dijet and g+j events



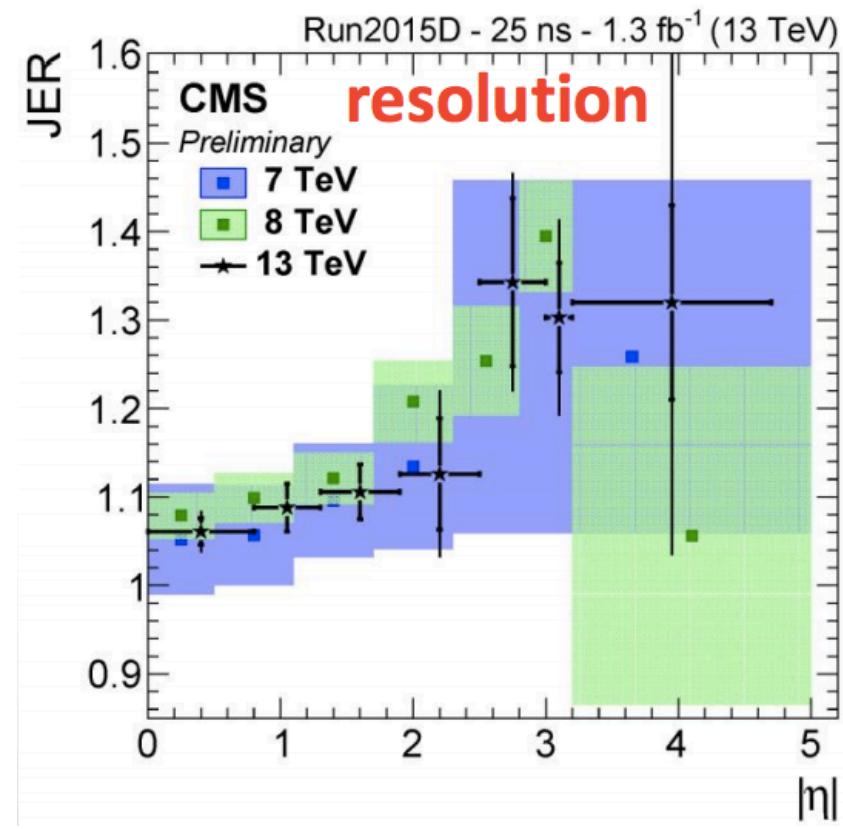
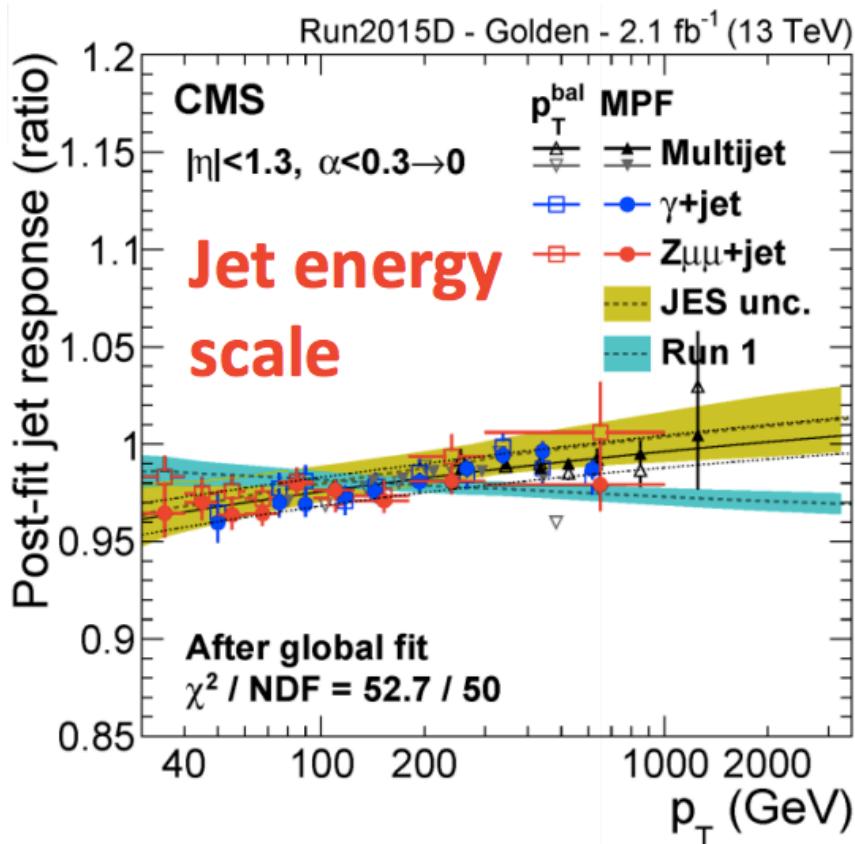
A look at 13TeV



VERY PRELIMINARY plots from December CMS seminar, things have changed since then...

Message to retain:

- Residual JEC show different behavior wrt Run1 but similar order of magnitude
- Resolution Data/MC SF in reasonable agreement within runs



Conclusion

Summary of CMS Jet Energy Corrections and Resolution (public) results

Only material from 8 TeV presented (paper in preparation), quick glimpse at preliminary 13TeV results.

Run1 data + careful simulation studies allowed for a deep understanding of JES
(→ reduction in systematics)

Run2 :

- baseline for summer conferences: Run1 methods are used for 13TeV data for the moment comparable performances
- more data and new methods will allow to constrain JES even more

good ATLAS-CMS communication on the subject (see e.g. work on uncertainties correlations within TOP LHC WG)

French groups involvement: mainly Lyon (Viola Sordini, Anne-Laure Pequegnot, Andrey Popov)

Also in preparation a paper on Particle Flow performances (strong contribution from Lyon – Colin Bernet)