Radius Scan for Inclusive Jets in CMS Experiment at $\sqrt{s}$ = 13 TeV

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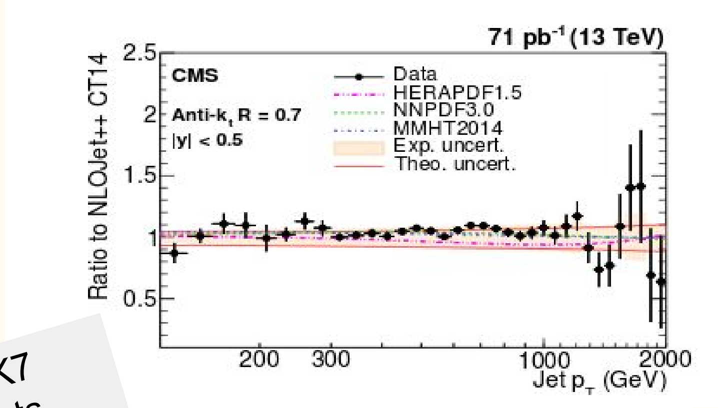
CMS

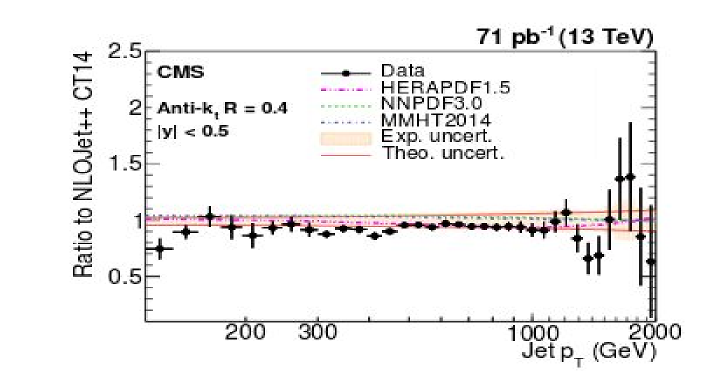
Inclusive Jets

- p p -> jets + X
- Inclusive Jets are benchmark tools to probe QCD@LHC
- Small uncertainties => Higher orders in perturbative series are important
- Used to constrain PDF, determine α_s, look closely on color structure of hadrons
- Estimates QCD background for BSM searches

X-section of Inclusive Jets : Measured by CMS

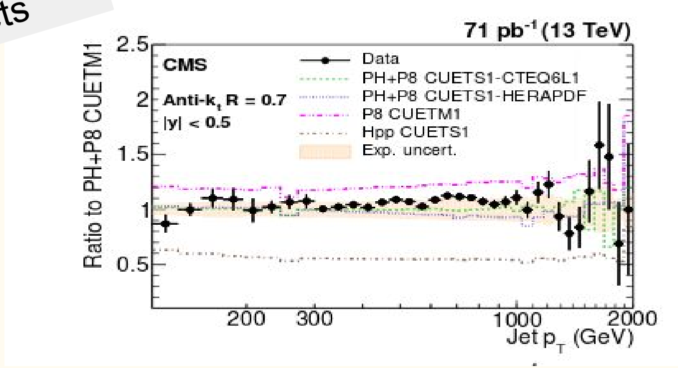
(arXiv:1605.04436)

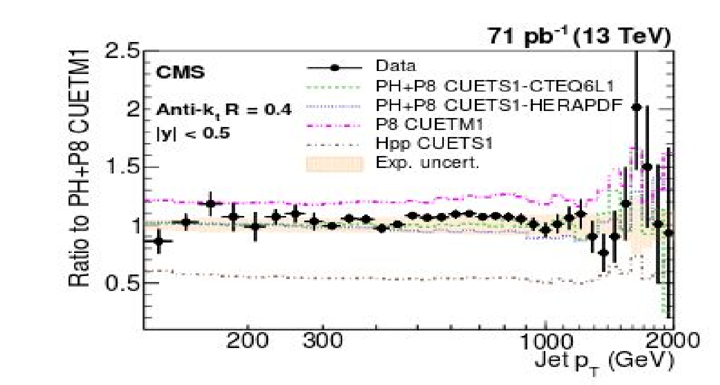




AK7 Jets

AK4 Jets



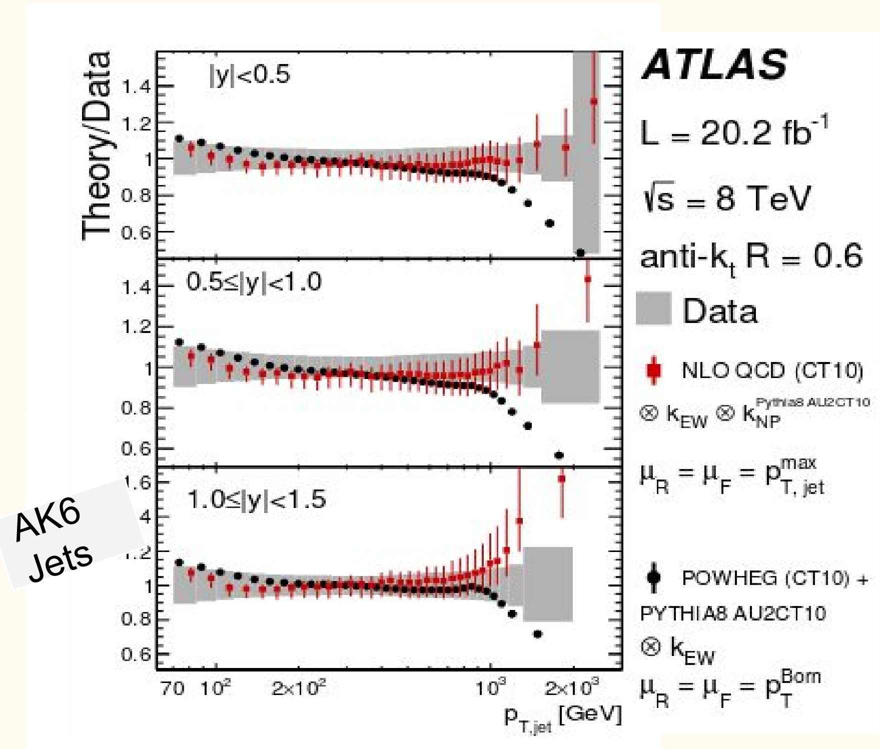


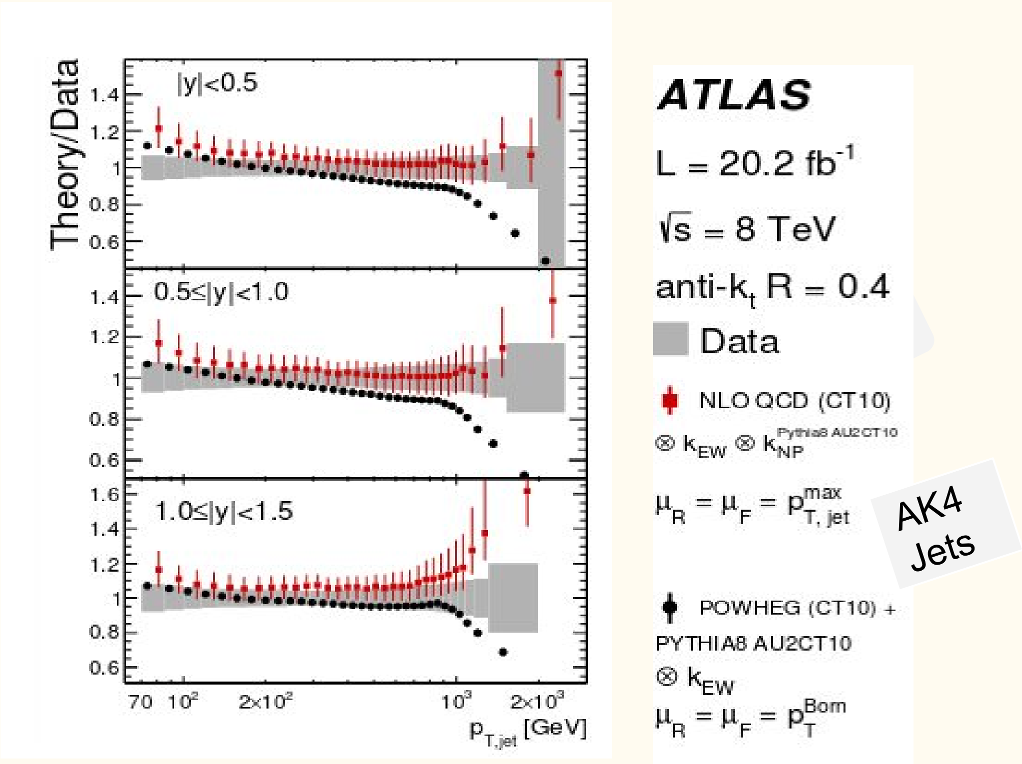
➡ Different jet sizes show different trends when compared to prediction

(Fixed order calculation vs NLO+Parton Shower)

X-section of Inclusive Jets : Measured by ATLAS

(arXiv:1706.03192)





- Different experiments show different trends when compared to prediction
- Recent results from ATLAS (@13 TeV) for AK4 jets are similar (arXiv: 1711.02692)

Radius Scan for Inclusive Jets

Aim to measure inclusive jet cross section for 12 jet radii : R= 0.1,0.2,....,1.2

Compare with prediction from Monte Carlo generator for the variable :
'inclusive jet x-section for radius R / inclusive jet x-section for AK4 jets'

Calibration Used :

Standard Jet Energy Corrections for AK4 Jets are used for AK1,...,AK6 jets

Standard Jet Energy Corrections for AK8 Jets are used for AK7,...,AK12 jets

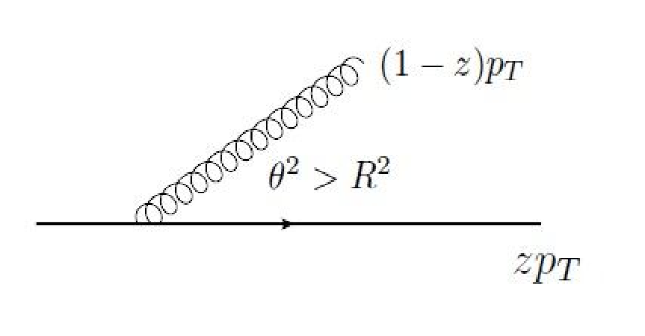
Standard jet energy resolution / smearing factors for AK4 jets are used AK1,...,AK6 jets and smearing factors for AK8 jets are used AK7,...,AK12 jets

Size Matters for Jet

Fragmentation

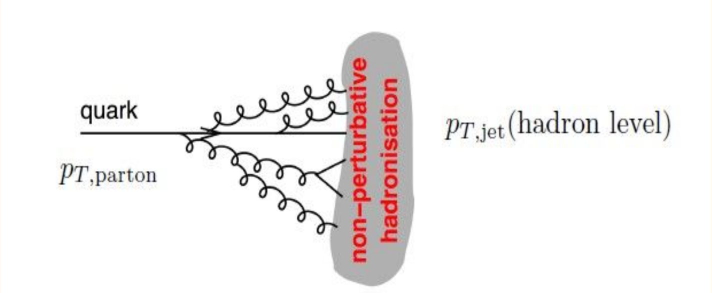
$$\langle \delta p_t \rangle_{\text{pert}} = \int \frac{d\theta^2}{\theta^2} \int dz \, \underbrace{p_t\left(\max[z, 1-z] - 1\right)}_{\delta p_t} \frac{\alpha_s(\theta\,(1-z)\,p_t)}{2\pi} P_{qq}(z)\,\Theta(\theta - f_{\text{alg}}(z)R) \,,$$

$$\langle \delta p_t \rangle_q = -C_F \frac{\alpha_s}{\pi} p_t \ln \frac{1}{R} \left(2 \ln 2 - \frac{3}{8} \right)$$



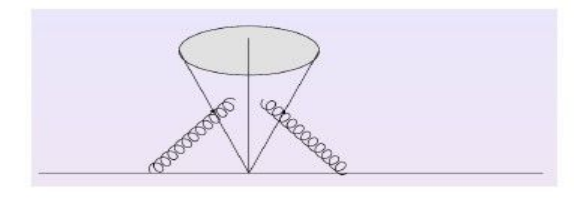
Hadronisation

$$\langle \delta p_t \rangle_q = -\frac{2C_F}{\pi} \int_0^{\mu_I} \alpha_s(k_t)\, dk_t \times \frac{1}{R}$$



Underlying Event

$$\delta p_t = \frac{1}{2} \Lambda_{UE} R^2$$



Data Samples Used

Experimental Data : 35.9 fb-1 data collected by CMS in 2016

Monte Carlo Generators :

Pythia8 (Matrix Elements for 2->2 processes → pt ordered Parton Shower → Lund String Hadronisation) with Tune CUETP8M1

Herwig++ (Matrix Elements for 2->2 processes → angle ordered Parton Shower Color Cluster Hadronisation) with Tune CUETHS1

Madgraph (LO Matrix Element for 2->2, 2->3,2->4 processes Pythia8 PS+Had)

Powheg+Pythia8 (CUETP8M1 & CP5 tunes) : NLO+LL

Powheg+Herwig++(EE5C tune) : NLO+LL

NLOJet++ for fixed order prediction @NLO ⊗ Non-perturbative correction

Event Selection in Experimental Data

Triggers : Single Jet HLT triggers for AK8 Jets with thresholds (40,60,80,140,200,260,320,400,450,500 GeV)

⟵ At least one of the triggers has to fire

Events failing data quality criteria are rejected

Pile-up Mitigation : Charged Hadron Subtraction & Area Subtraction

Quality criteria for identification (Tight ID) to remove detector noise : efficiency $> 99\%$

Cut on MET/ Total Energy in event to reject non-QCD contribution (W+jets, Z+jets) and reconstruction inefficiency

Trigger Efficiency

Determined using "tag & probe" method

➡ If there is a jet within $\Delta R = 0.5$, call it a tag jet & look in opposite hemisphere & whether there is a jet within $\Delta R = 0.2$ around trigger object

Figure from data

Figure from data

The triggers are used in the region where they are $> 99\%$ efficient

Phase Space Division by Triggers

Lowest prescaled triggers are used to select jets to use statistical power of data

Figure from data

Comparison of Characteristic Variables for Jets

Figure from data

Figure from data

Because of tracker dynamic inefficiency in early part of 2016 data, comparison to MC does not lead to very good agreement

- but agreement is better for later part of 2016 data

Comparison of Cross Section @ Detector Level

Figure from data

Figure from data

Pythia8 describes the shape of spectra best

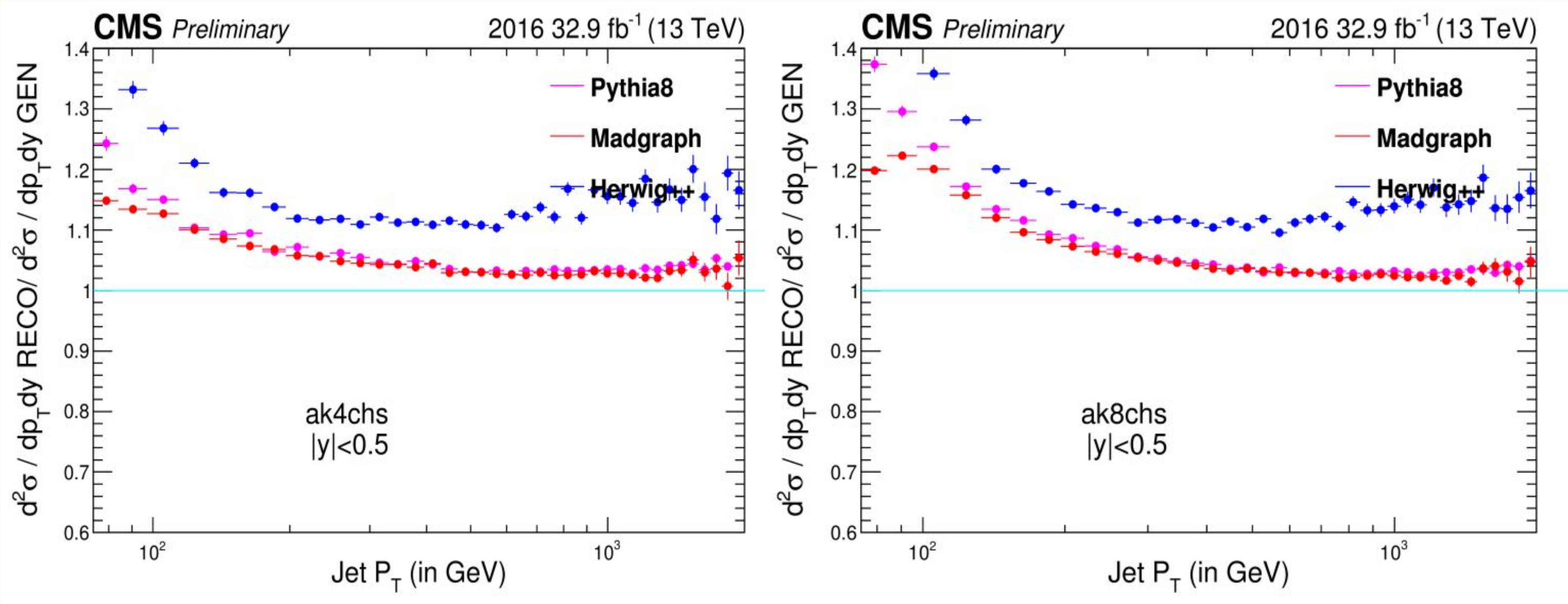
Comparison of Cross Section @ Detector Level

Figure from data

Figure from data

All the MCs do good job to describe cross-section ratio

Do MCs Behave Similarly?

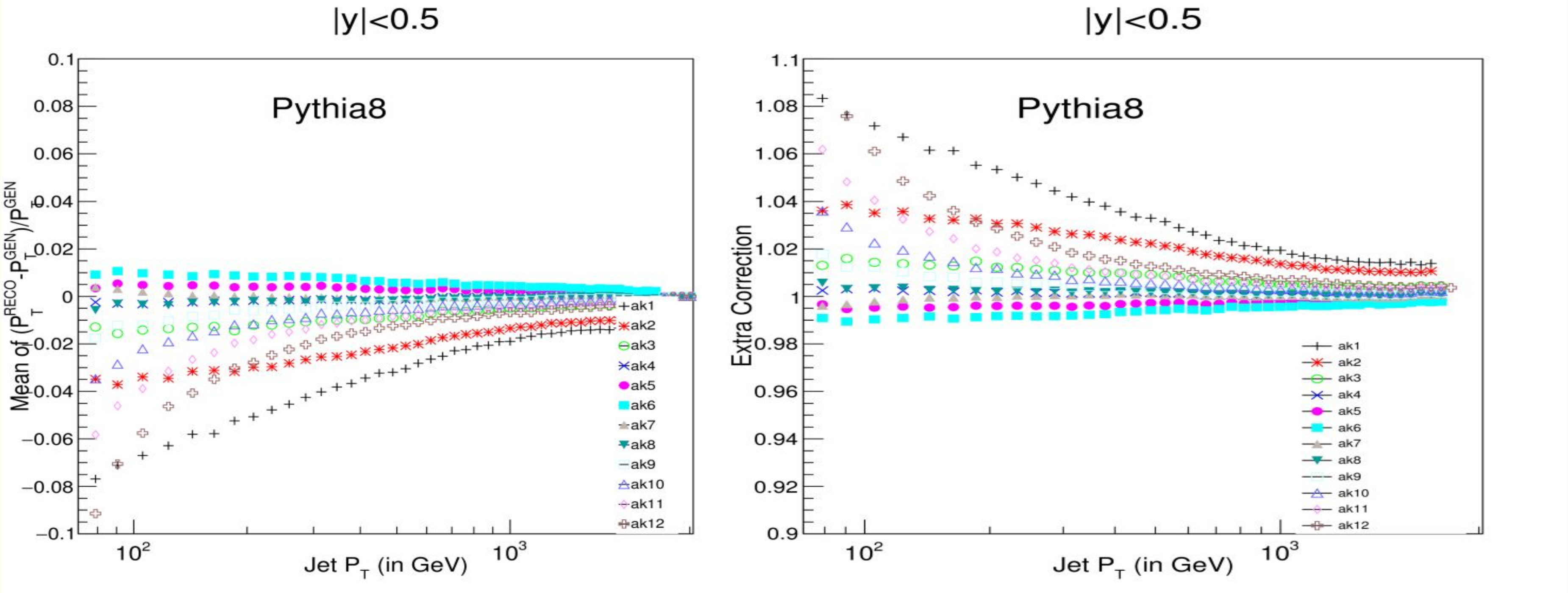


Pythia8 & MC are quite close

Jet Energy Scale is different for Herwig++

Extra Correction Factor!

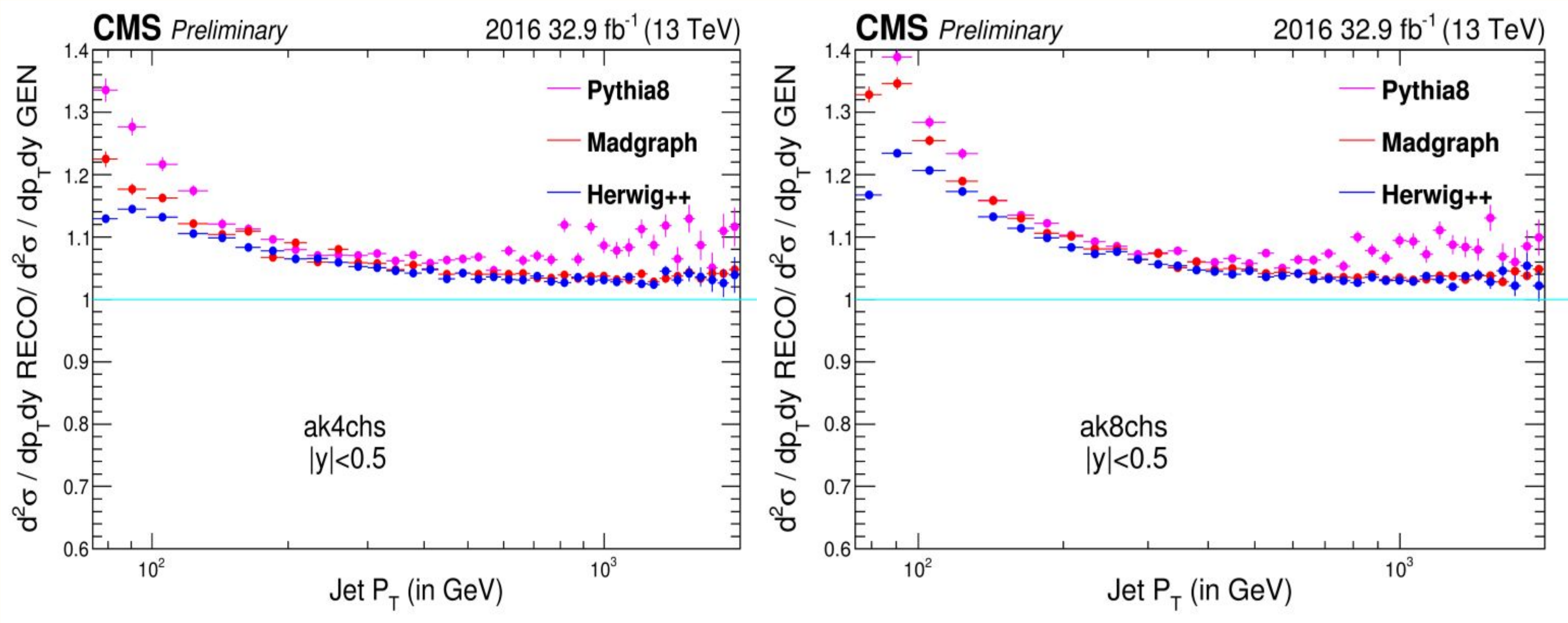
Left Plot : Jet Energy Scale (JES) - 1   Right Plot : Extra Correction to make JES 1



AK4 & AK8 jets are quite well calibrated (expected)

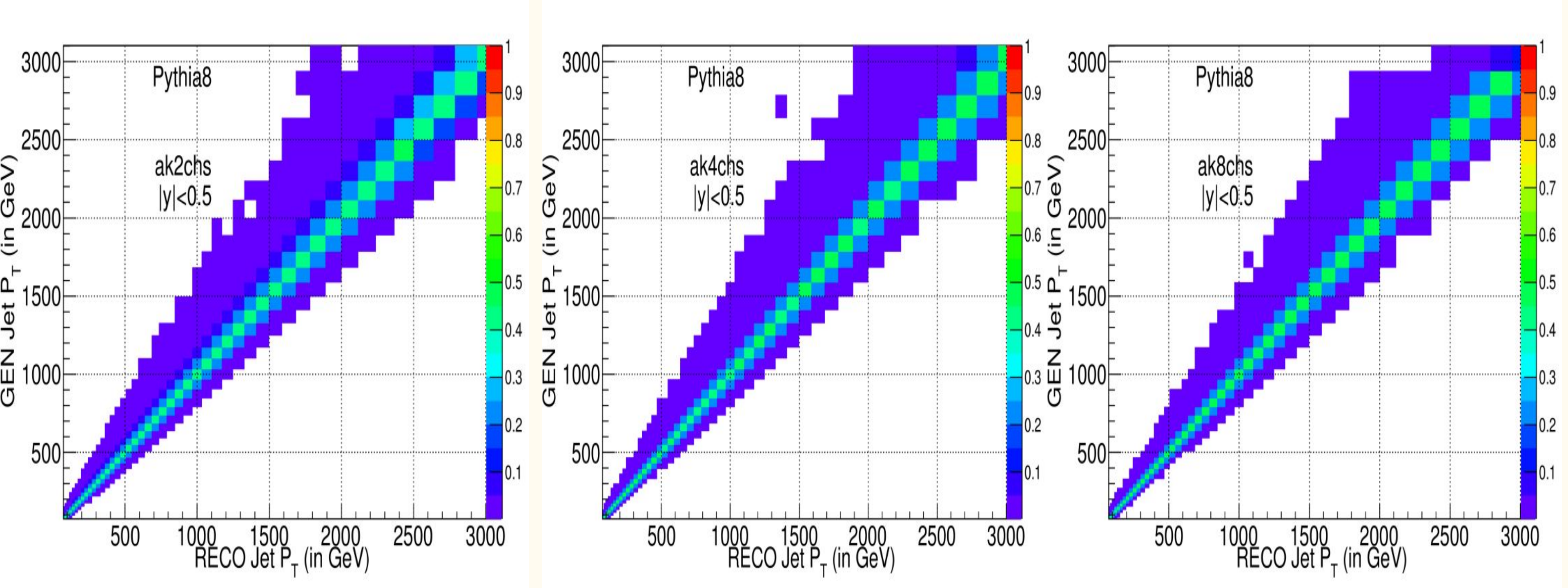
correction is significant for very narrow or very fat jets

After Effect of Extra Correction (MC)



Madgraph & Herwig++ are very close after extra correction; Pythia8 is also close-by

Detector to Particle Level : Unfolding



Detector effects are incorporated in simulation and correlation matrices are used to undo detector effects & bring back the data to particle level

Trial on Pythia8

Closure Test for Unfolding

Trial on Herwig++

Figure from data

Figure from data

Detector level spectra is brought back to generator level perfectly by unfolding for particular model for simulation

Uncertainties : Statistical

Variation of response matrix by 10% of the whole sample size =>
take the standard deviation as statistical uncertainty (delete 10% Jackknife method)

For x-section

Figure from data

For x-section ratio w.r.t AK4

Figure from data

Statistical uncertainty is quite small both for x-section & x-section ratio

Uncertainties : Experimental Systematics (Jet Energy Scale)

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Figure from data

Flavour uncertainty is one of the major contributors in systematics coming from jet energy calibration

Uncertainties : Experimental Systematics (Total)

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Jet Energy Scale & Unfolding techniques contribute maximally in systematics for x-section

While taking the ratio, most of the systematics cancel out!

Uncertainties : Experimental Systematics (Total)

Figure from data

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Jet Energy Scale & Unfolding techniques contribute maximally in systematics for x-section

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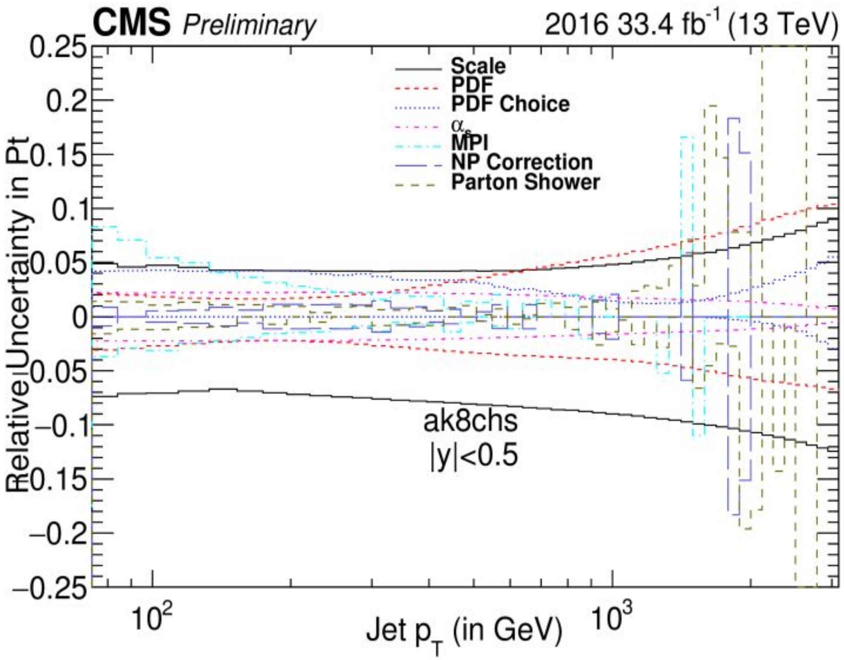
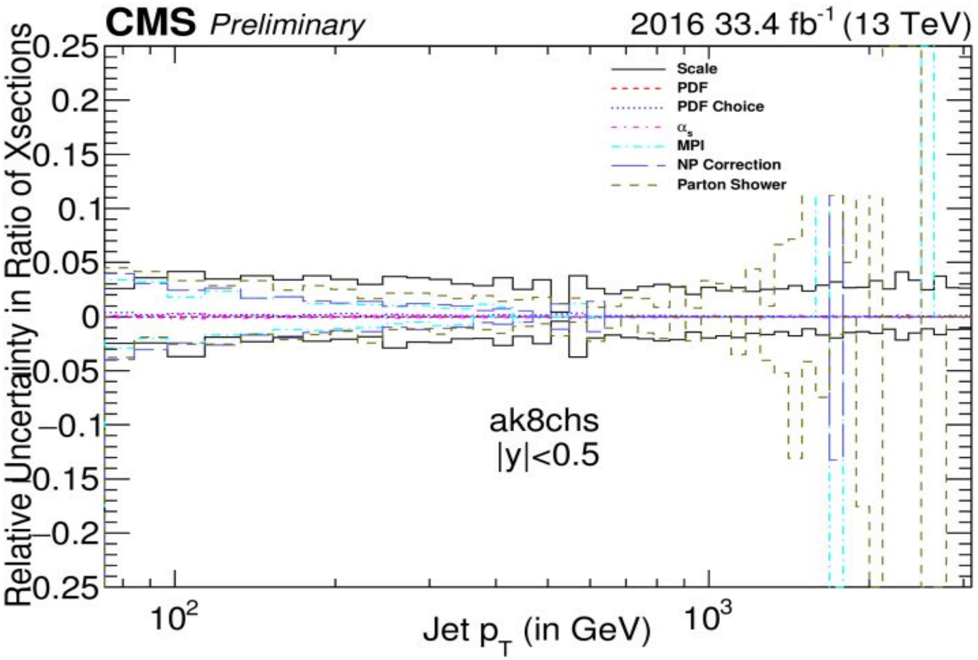
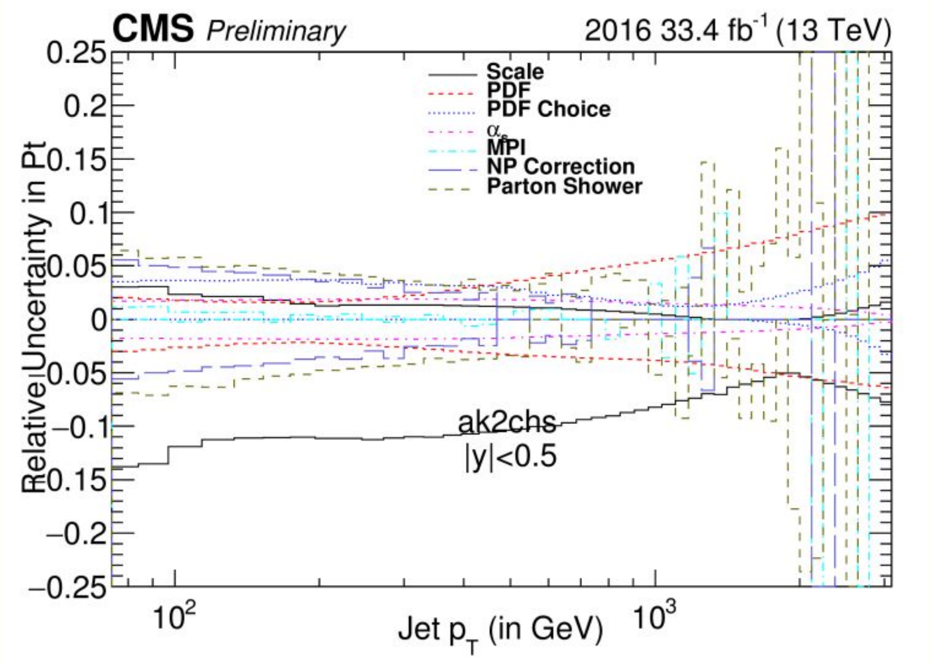
Uncertainties : Theoretical Systematics (Total)

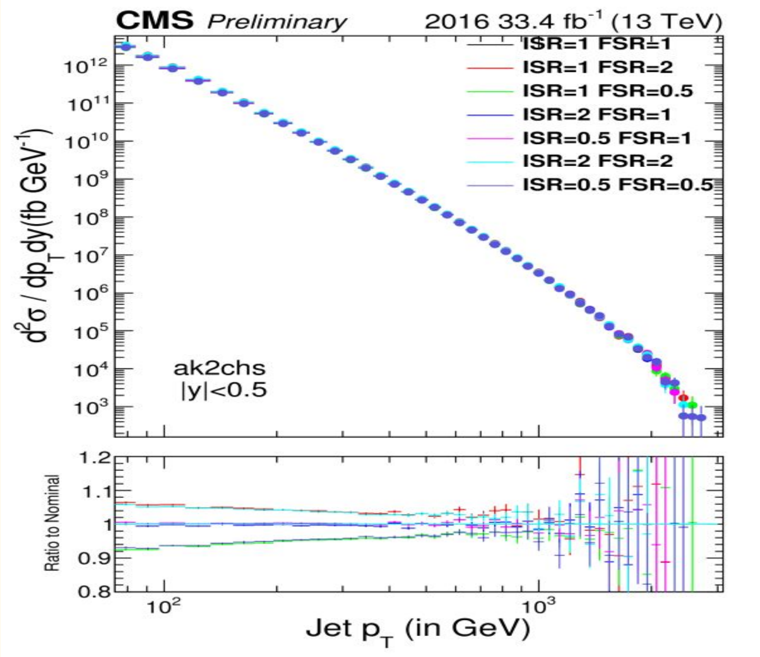




Choice of scales in generation process (renormalization & factorization scales) and in parton shower evolution dominate in systematics

Uncertainties : Theoretical Systematics (Exclusively Scale Choice part)





Choice of scales in generation process (renormalization & factorization scales) and in parton shower evolution dominate in systematics

Data-MC Comparison : Particle Level

Figure from data

Figure from data

Powheg+P8 can describe data reasonably well both at low and high jet radii

fixed order calculation match with data at high radius but can not model narrow jets

Data-MC Comparison : Particle Level

Figure from data

Figure from data

Pythia8 parton shower combined with Powheg generator can describe jets of sizes, from small to medium, quite better than Herwig++ parton shower

Data-MC Comparison : Trend with Jet Size

Figure from data

Figure from data

(MC generator + Parton Shower) combination can describe the trend better than fixed order calculation

Powheg+Pythia8 seems to be the best both in low & high pt region

Summary & Outlook

- Radius Scan for inclusive jets is being performed for the first time in CMS experiment
- Will be useful to control theory uncertainties in different (perturbative/non-perturbative) regimes
- Is useful to provide the importance of resummation effect in MCs as compared to fixed order calculation
- Can also compare with ATLAS results on inclusive jets (R=0.4 & 0.6) directly

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THANK YOU!

BACK UP