Measurement of double-differential inclusive jet cross section @ energy $\sqrt{s}$=13TeV with CMS

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- Measurements
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CMS Detector

Technical Details:

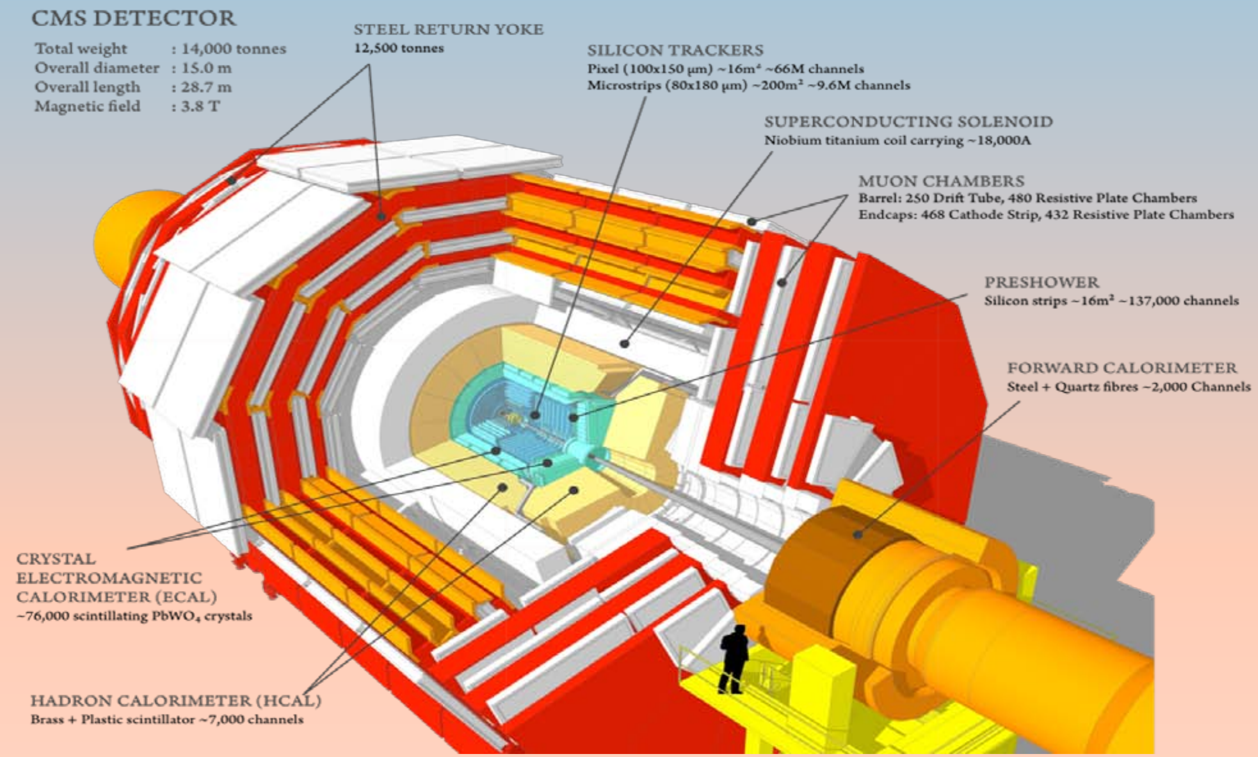
Magnetic Field: 3.8T

Tracker: |η|<2.5

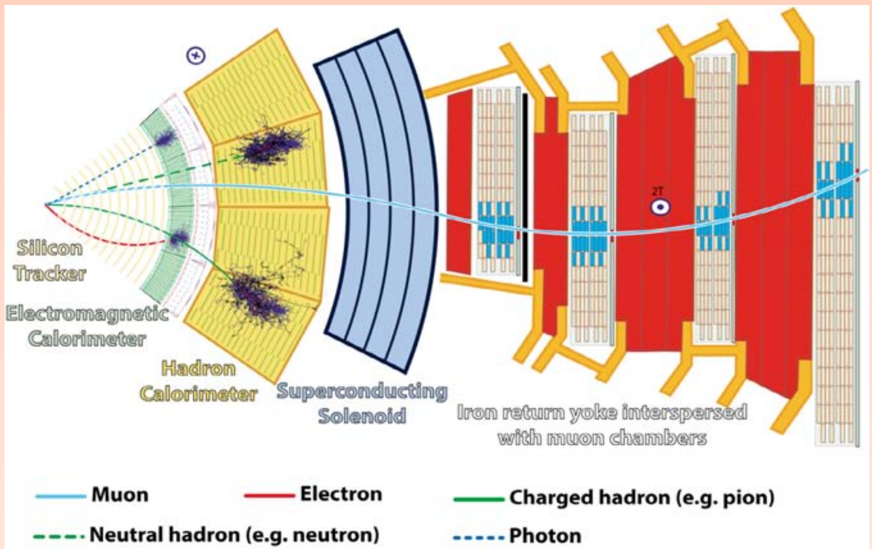
Central Calorimeter: |η|<3

Forward Calorimeter: 3<|η|<5

$$\eta \equiv -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$$



Graphical Depiction of CMS detector (Compact Muon Solenoid)



CMS Trigger

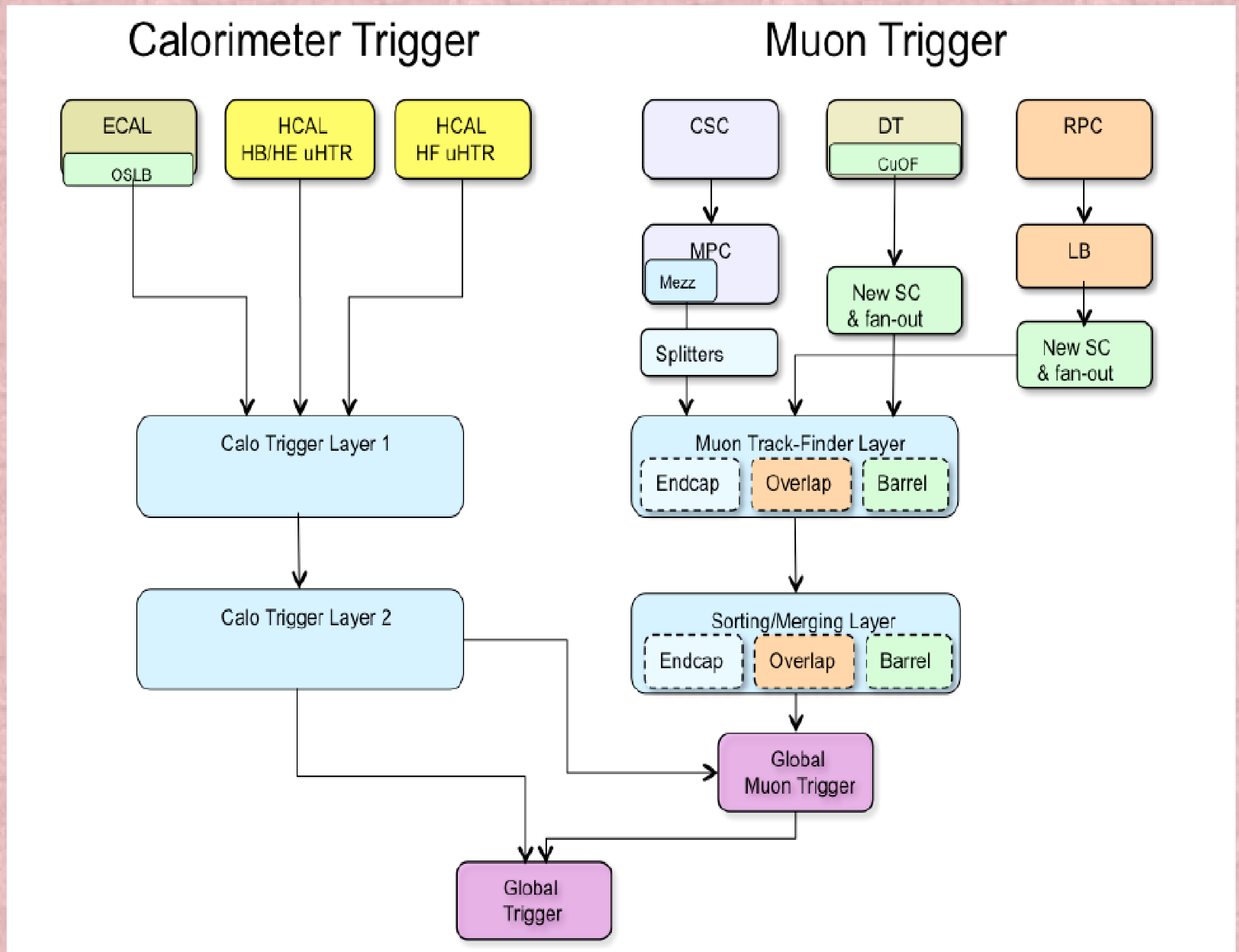
- LHC collides protons in each 25ns. (40 MHz, 10^9 events/s)
- Demanding the quick selecton of the interesting events

Level-1 Trigger (L1T)

40 MHz → 100 kHz

High Level Trigger (HLT)

100 kHz → 100 Hz



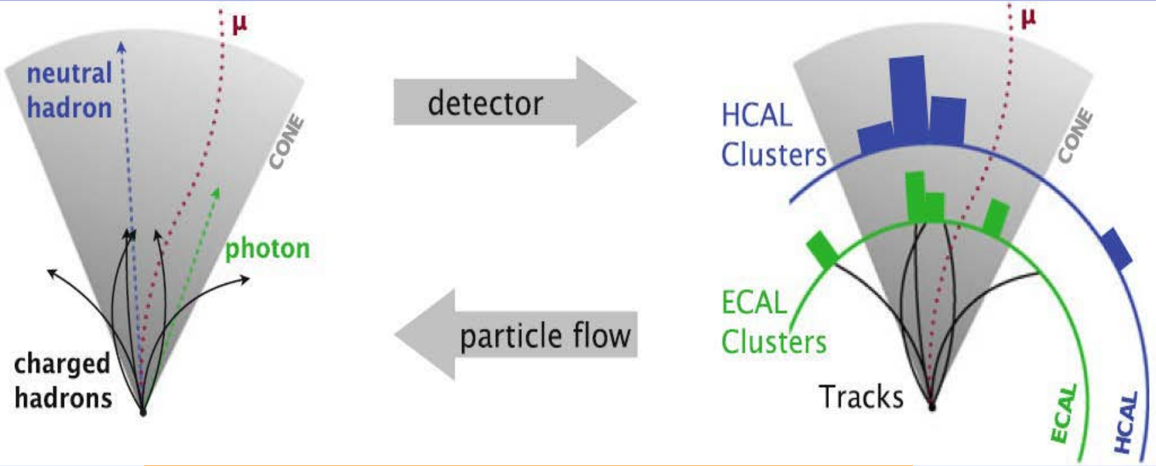
Jet Reconstruction

At CMS experiment,
the Particle Flow algorithm is used, which both handles and implements the information from all of the sub-detectors' systems as a result of the reconstruction and identification of particles.

After that,

the 4-vector momentum of the particles are introduced to the **anti-kt** algorithm which combines the particles into jets.

Particle Flow Algorithm (PF)



Anti-kt Algorithm : p=-1

diB=$k^{2p}_{T,i}$

$$d_{ij} = \min\left(k_{T,i}^{2p}, k_{T,j}^{2p}\right)\frac{\Delta R_{ij}^2}{R^2}$$

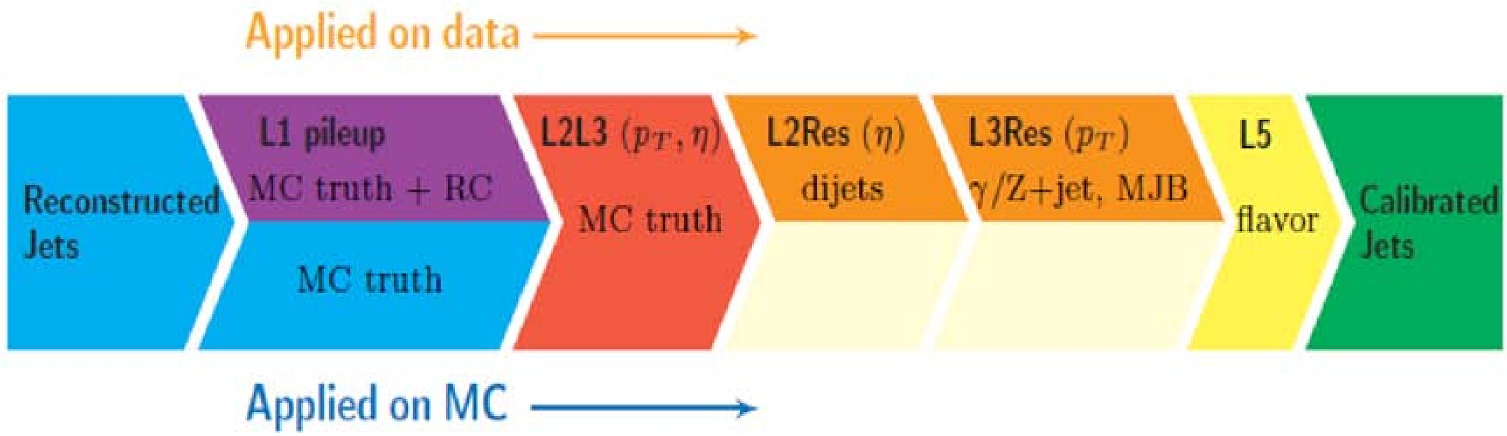
Jet Energy Correction

By the completion of the jets identification it is vital to correct their energy.

This correction is important due to the fact that :

The calorimeters have non-linear and non-uniform response in energy deposits by particles.

Jet Energy Correction (JEC) at CMS



Data for Analysis

- The data for the following analysis collected with the CMS at 2016 in 25ns @ √s=13TeV

$$\frac{d^2\sigma}{dp_T dy} = \frac{1}{\varepsilon \cdot L} \frac{N_{jets}}{\Delta p_T (2 \cdot \Delta |y|)}$$

- Total integrated luminosity L = 30.1 fb^{-1}
- Demanding one good primary vertex, tight JetID and jet p_T>113 GeV
- Jets up to p_T 3 TeV and |y|<2.0 in four different rapidity regions with step at 0.5

Trigger Studies

➢ **High Level single Jet Triggers:**

$$eff_{HLT\_AK8PFJetX} = \frac{Incl\,RecoJet\_O\left(trig_{ref} + L1Obj\_p_T > Z + HLTObj\_p_T > Y\right)}{Incl\,RecoJet\_O\left(trig_{ref}\right)}$$

HLT Triggers	Lumi (pb^{-1})	Turn-on(GeV)	Phase Division(p_T)
HLT_AK8PFJet40	0.043978	-	74-114
HLT_AK8PFJet80	0.851458	114.47	114-196
HLT_AK8PFJet140	8.54722	186.92	196-272
HLT_AK8PFJet200	70.6187	260.31	272-330
HLT_AK8PFJet260	442.356	330.34	330-395
HLT_AK8PFJet320	1310.37	381.33	395-468
HLT_AK8PFJet400	3924.74	461.54	468-548
HLT_AK8PFJet450	29464.1	501.76	>548

Unfolding

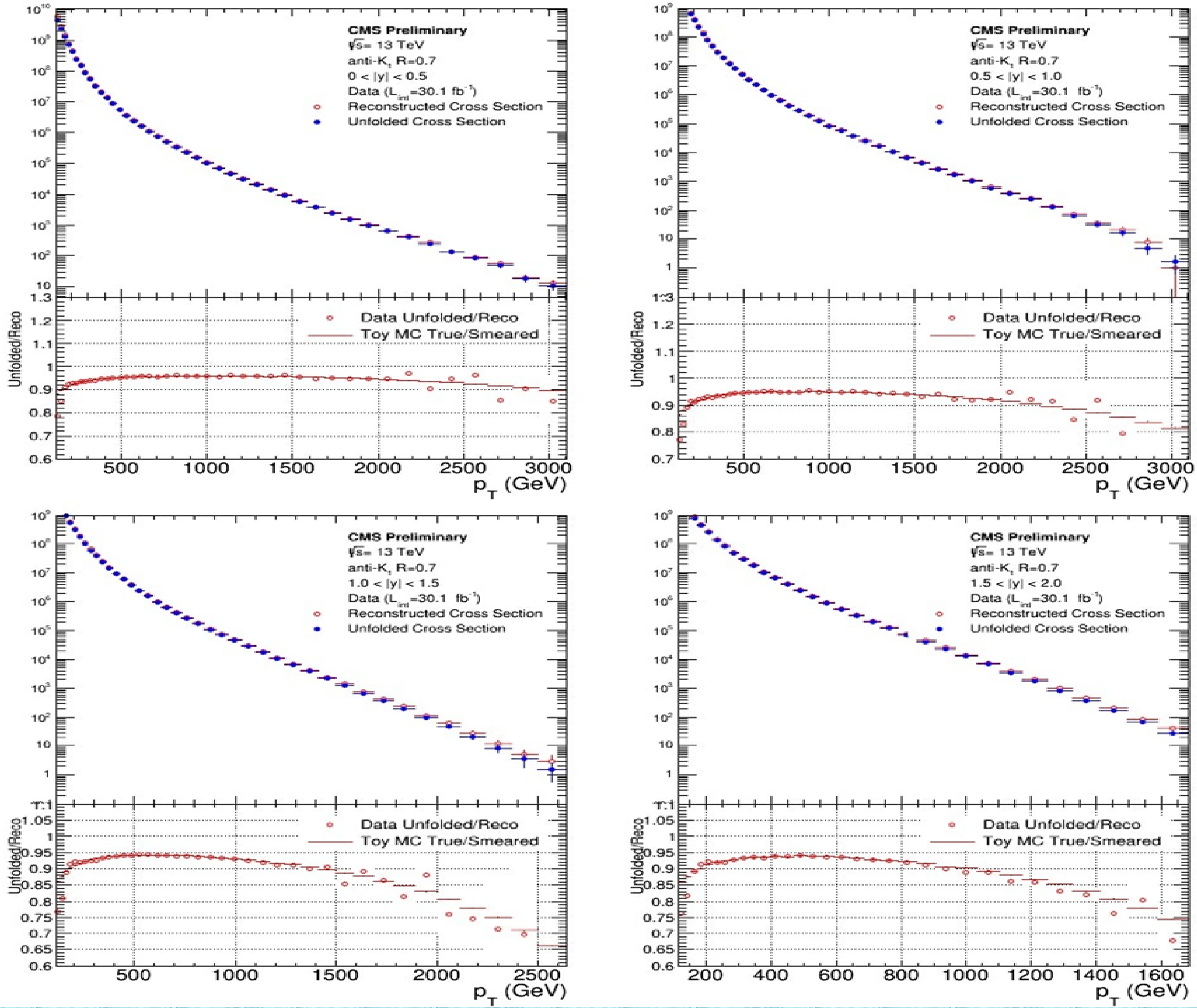
- Unfolding is a way to pass from the detector level to the stable-parton level :

DETECTOR LEVEL UNFOLDING → **PARTICLE LEVEL**

- This method is used owning to the fact that there is no "perfect" detector due to mainly finite precision and limited efficiency in the measurement procedure of events, like the measurement of energy.
- Iterative D'Agostini Bayesian with ROOUnfold Software package
- Construction of the Response Matrices:
  1. Events are generated with flat spectrum with regard to p_T
  2. These events are then weighted by the theoretical cross sections obtained from NLOJet++(FASTNLO) using CT14 PDF set and corrected for non-perturbative effects. In this way the Toy MC constructs the true p_T cross section.
  3. The measured cross sections are generated by smearing the true cross sections with the resolution obtaining from JetMET group.
  4. Construction of the Response Matrices using the Toy MC a total of 100M events are generated for each rapidity bin.

Unfolding - Data

Data Results :
reconstructed
and unfolded are now
being presented for
our observable for the
four different regions
of rapidity.
The correction after
the unfolding is 5-20%



Systematic Uncertainties

Experimental Systematic Uncertainties Studies :

1. Uncertainties due to jet energy scale (JES) ,
   $p_T = p_T(1 \pm 1\sigma)$
2. Uncertainties due to jet energy resolution (JER)
3. Uncertainties due to trigger efficiency curves (trigger efficiency corrections) and jet ID ~ 1 %
4. Uncertainties due to luminosity of 2016 data ~ 2.6%

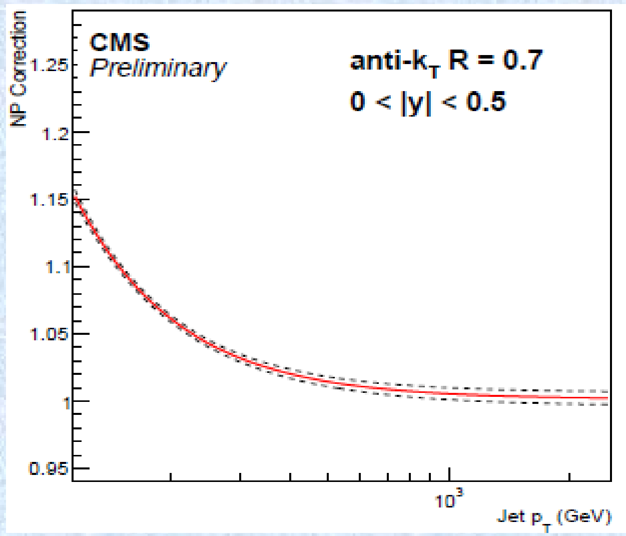
$$\sigma_{sys+} = \frac{|JES\_up|}{JES\_normal}$$

$$\sigma_{JER+} = \frac{JER\_up}{JER\_nominal}$$

Theoretical Systematic Uncertainties Studies :

1. Scale uncertainties ~ 1-8 %
2. PDF uncertainties ~ 1-12 %
3. NP uncertainties

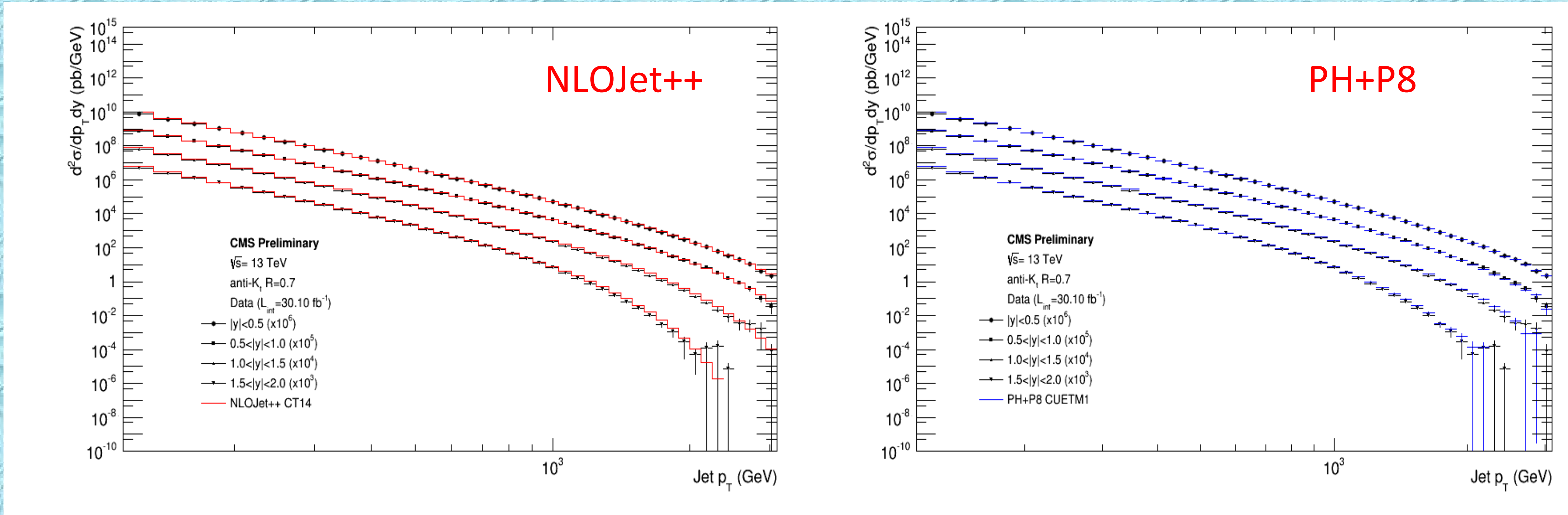
$$C_0^{NP} = \frac{N_{LO(NLO)}^{PS+HAD+MPI}}{N_{LO(NLO)}^{PS}}$$



Systematic Uncertainties

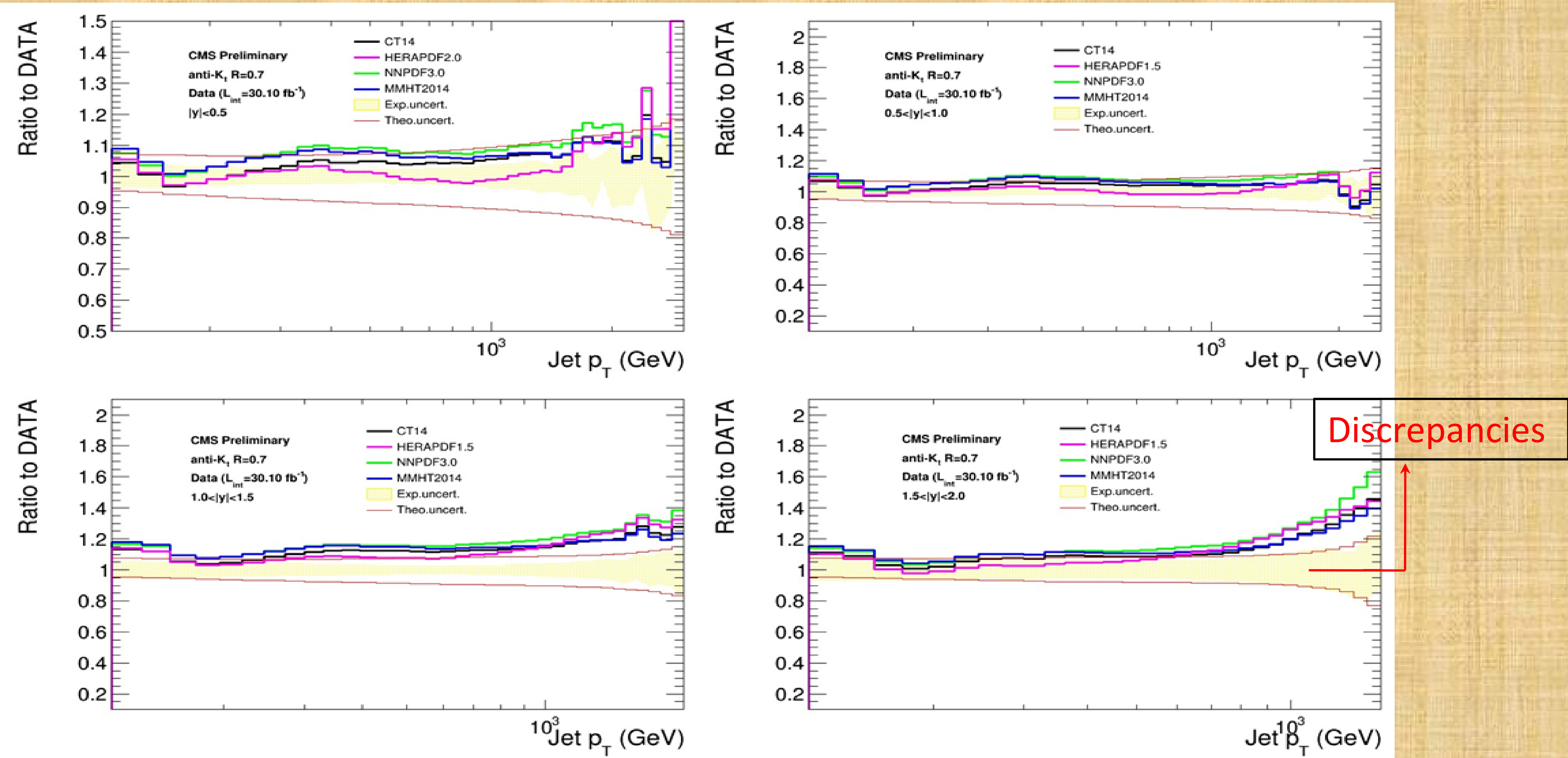
Systematic Effect	AK7 Jet Measurement
JES	8-65 %
JER	1-2 %
Luminosity	2.6 %
Trigger Efficiency	1 %
Pile-Up	-
PDF	1-8 %
Scale	1-12 %
NP Corrections	1 %
TOTAL	10 – 65 %

Cross Section - Unfolded Level - Final Results



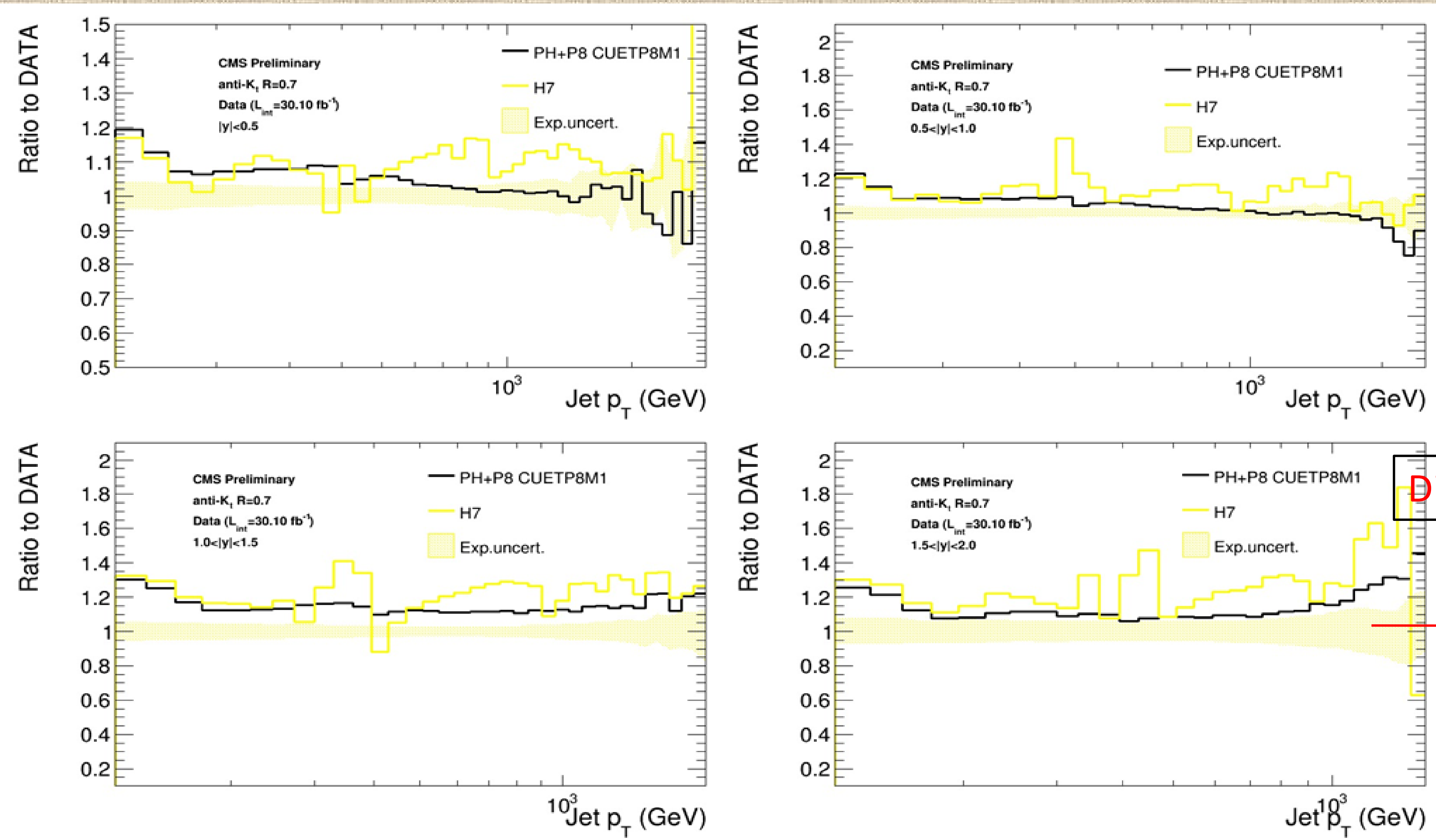
- The results at the stable-particle level (unfolded spectra) for the large cone (AK7 R=0.7) for four different ranges of rapidity with step 0.5. are presented here.
- The final results are compared with theoretical predictions at 2nd order perturbation theory (NLO) QCD.
- At the left plot, the observable are compared with the software computing package NLOJet++ and at the right plot with the Monte Carlo Event Generator POWHEG+Pythia8 tune CUETM1.

Cross Section - Unfolded Level - Final Results



Satisfactory adjustment with the different PDF+NLOJet++ for the barrel region of detector.

Cross Section - Unfolded Level - Final Results



Discrepancies

Sufficient description for the event generator PH+P8 for the barrel region of the detector..

Summary

- ➢ Measurement of the double differential cross section for inclusive jet at energy 13 TeV.
  - The data belongs to the 2016 statistics (30.1 fb-1)
  - The observable is calculated
  - Unfolding using Toy MC
  - Systematic Uncertainties: JES, JER, NP corrections
- ➢ Comparison at a stable-parton level with :
  - NLOJet++ combining with different PDFs
  - Monte Carlo Event Generators (NLO)
- ➢ Sufficient description of the final results in the barrel region (|y|<1.5).
- ➢ Discepancies in outer rapidity regions. From my point of view, it is not easy to say that H7 is promising. It fluctuates a lot. We need more MC statistics.

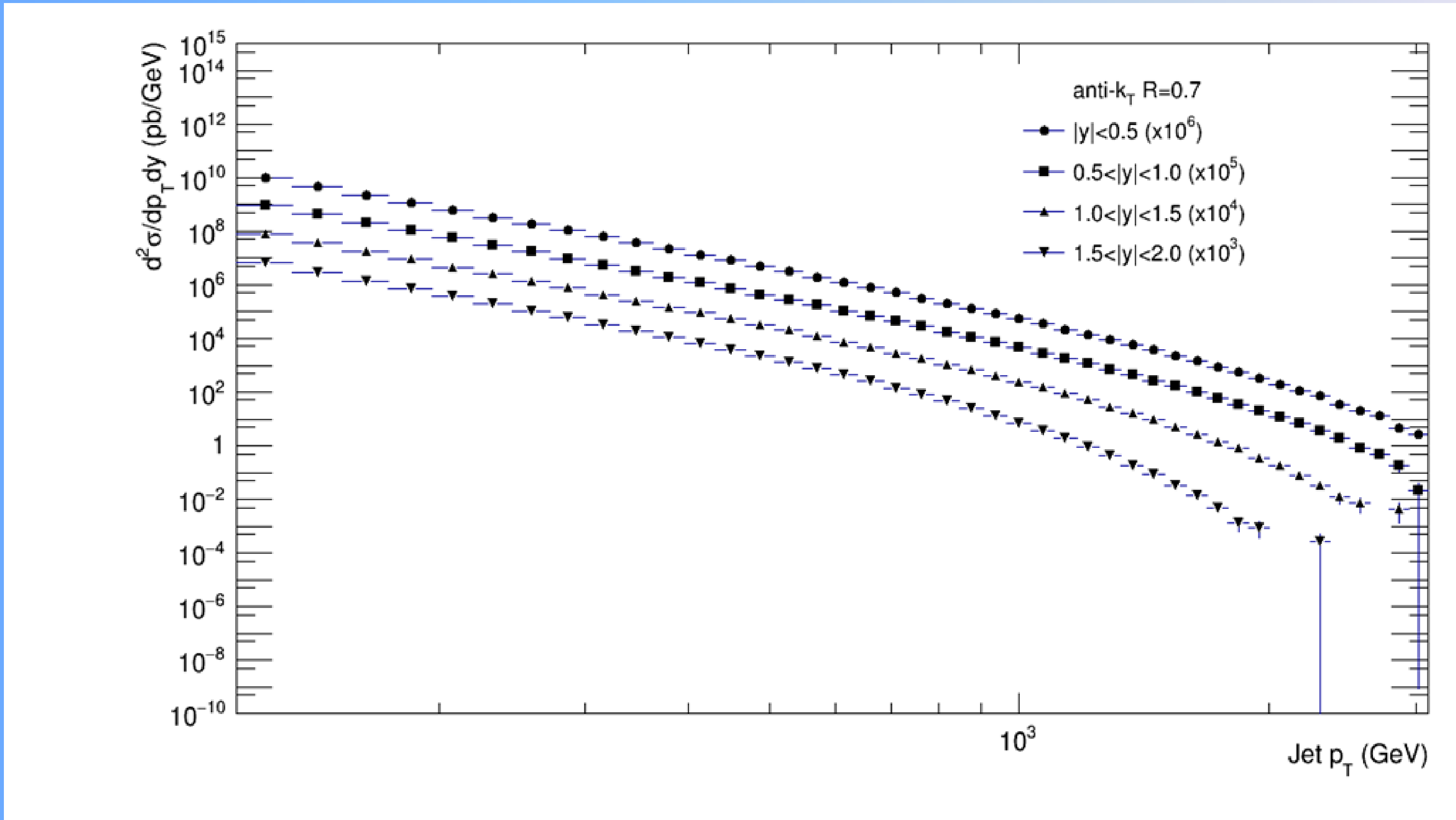
Thank you all both for your patience and attention

SPARE SLIDES

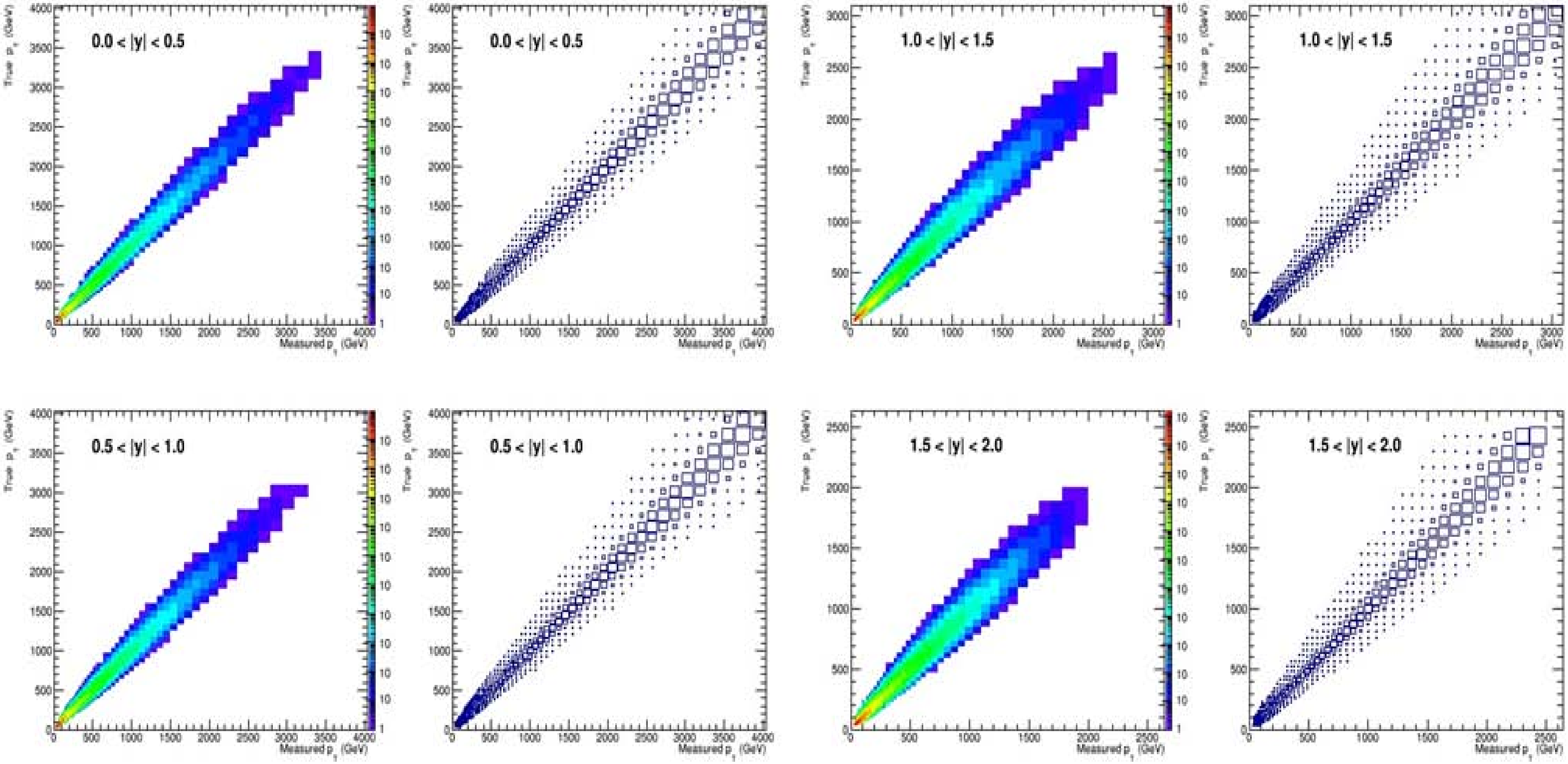
Cross Section - Detector Level

- Measurement of the double differential inclusive jet cross section.

$$\frac{d^2\sigma}{dp_T dy} = \frac{1}{\varepsilon \cdot L} \frac{N_{jets}}{\Delta p_T (2 \cdot \Delta |y|)}$$



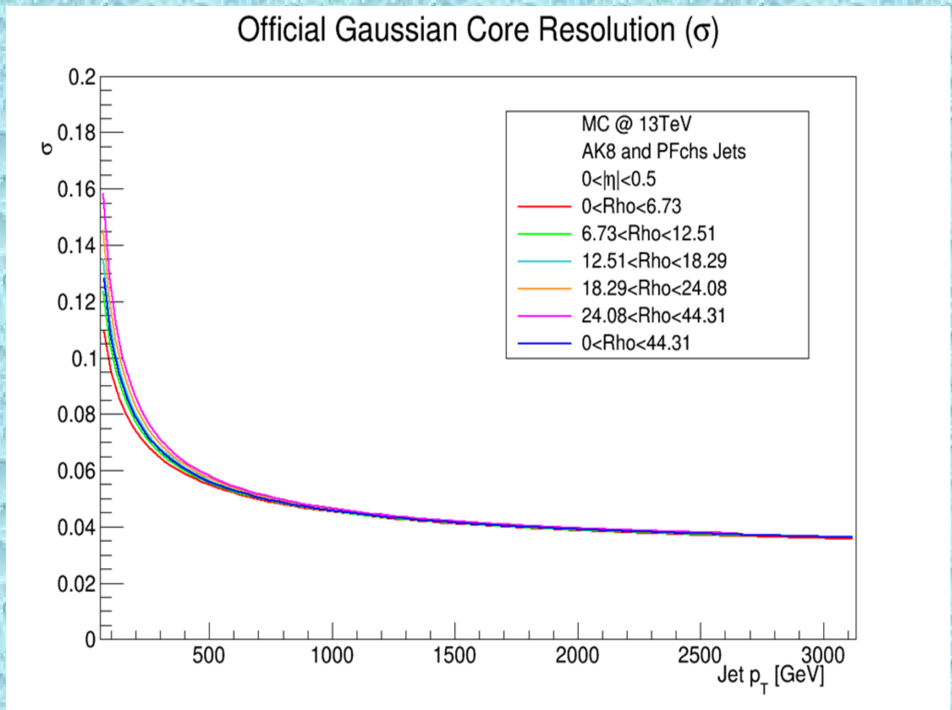
Unfolding - Response Matrices



Systematic Experimental Uncertainties

2. Systematic Uncertainties due to Jet Energy Resolution (JER)

- ➢ JER: the migrations of the events between the different bins inside the histogram
  Scale Factors from JetMET
- ➢ The transverse momentum resolution is estimated by the «official» p_T Resolution by JetMET for 12 different regions of rapidity and 5 bins of Rho



Trigger	Rho: 0-6.73	Rho:6.73-12.51	Rho:12.51-18.29	Rho:18.29-24.08	Rho:24.08-44.31
HLT_ AK8PFJetall	0.07858	0.42870	0.36185	0.11092	0.01995
HLT_ AK8PFJet40	0.06880	0.39839	0.38256	0.12838	0.02188
HLT_ AK8PFJet60	0.08431	0.44050	0.35125	0.10463	0.01931
HLT_ AK8PFJet80	0.09000	0.44824	0.34463	0.09934	0.01779
HLT_ AK8PFJet140	0.08829	0.44709	0.34703	0.09982	0.01777
HLT_ AK8PFJet200	0.08770	0.44753	0.34781	0.09956	0.01740
HLT_ AK8PFJet260	0.09406	0.44932	0.34150	0.09808	0.01704
HLT_ AK8PFJet320	0.08444	0.44427	0.35177	0.10186	0.01765
HLT_ AK8PFJet400	0.09147	0.44820	0.34449	0.09881	0.01703
HLT_ AK8AK8PFJet450	0.06814	0.41302	0.37613	0.12030	0.02239

Systematic Experimental Uncertainties

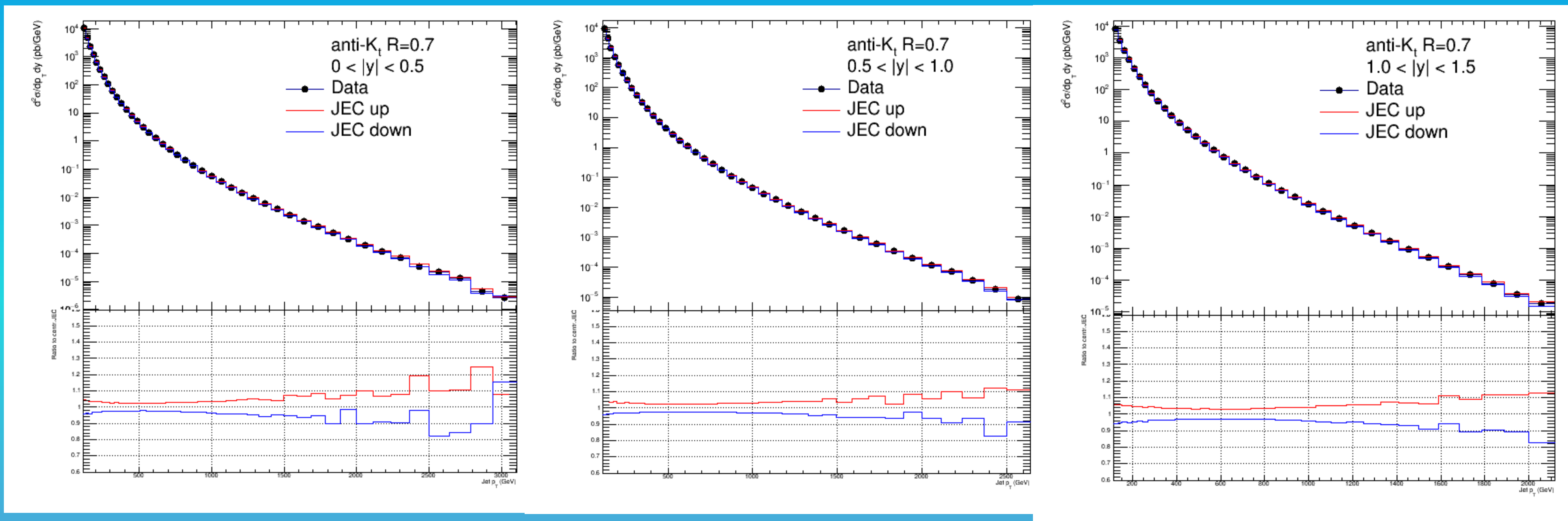
ystematic Uncertainties due to Jet Energy Scale (JES)

Varying up and down the transverse momentum p_T from all jets by the uncertainty : $p_T = p_T(1\pm1\sigma)$

The new observables are compared with the nominal distribution

Estimating the uncertainties due to Jet Energy Scale :

$$\sigma_{sys+} = \frac{|JES\_up|}{JES\_normal} \qquad \sigma_{sys-} = \frac{|JES\_down|}{JES\_normal}$$



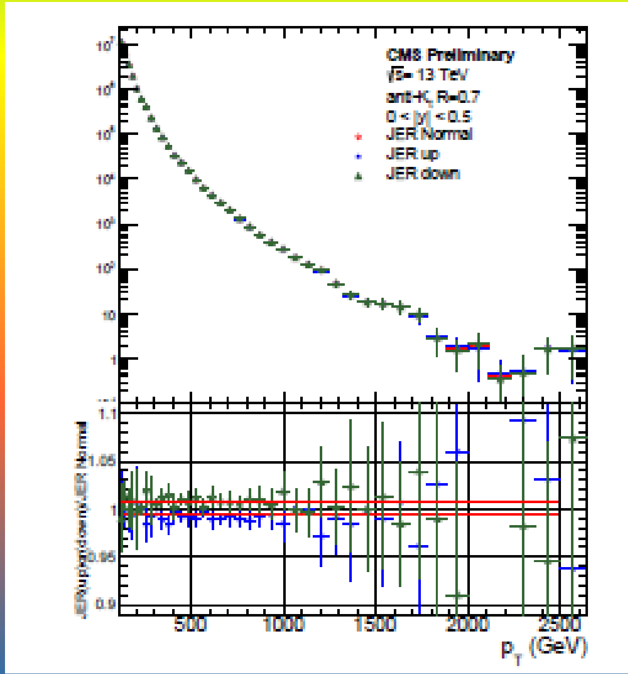
Systematic Experimental Uncertainties

- The uncertainty due to JER is as follows :

  Varying the values of the transverse momentum pT up and down by the scale factors which appeared at the table in the previous slide and comstructing three different curves (up,nominal,down) in the same plot. Finally, using the formulas at the middle of the slide, we calculate the JER uncertainties :

$$\sigma_{JER+} = \frac{JER\_up}{JER\_nominal} \qquad \sigma_{JER-} = \frac{JER\_down}{JER\_nominal}$$

0.0<|y|<0.5



|y|	AK7
0.0-0.5	**1%**
0.5-1.1	**1%**
1.1-1.7	**1%**
1.7-2.3	**1%**
2.3-2.8	**1.5%**
2.8-3.2	**2%**
3.2-5.0	**2%**

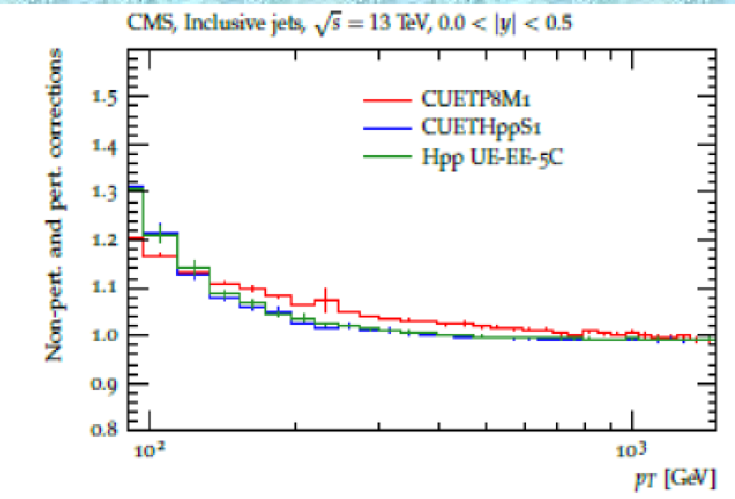
Non-Perturbative Corrections

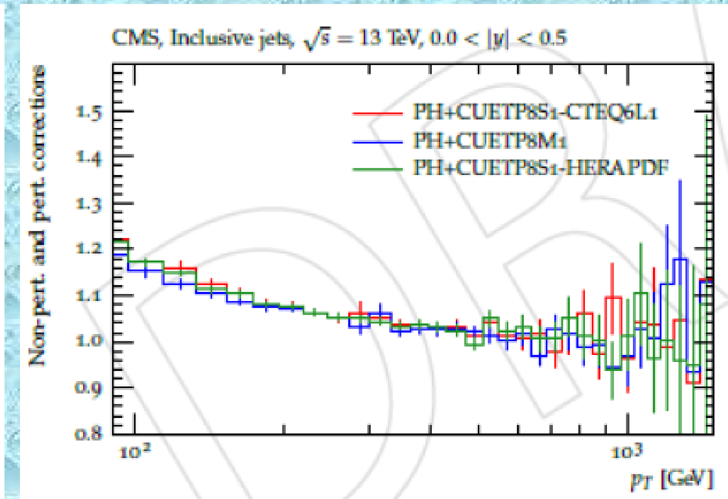
- Corrections due to model assumptions used at QCD (fixed-order predictions as used in fits of SM). The formula for these corrections is displayed at the top right hand corner of the slide:
- For this calculation of non-perturbative factors the following Monte Carlo event generators were used :

$$C_0^{NP} = \frac{N_{LO(NLO)}^{PS+HAD+MPI}}{N_{LO(NLO)}^{PS}}$$

- POWHEG (CT14nlo) + PYTHIA8 CUETP8M1
- POWHEG (CT14nlo) + PYTHIA8 CUETP8S1-CTEQ6L1
- POWHEG (HERAPDF2.0NLO) + PYTHIA8 CUETP8S1-HERAPDF
- PYTHIA8 CUETP8M1
- HERWIG++ UE-EE-5C
- HERWIG++ CUETHppS1

|y|<0.5

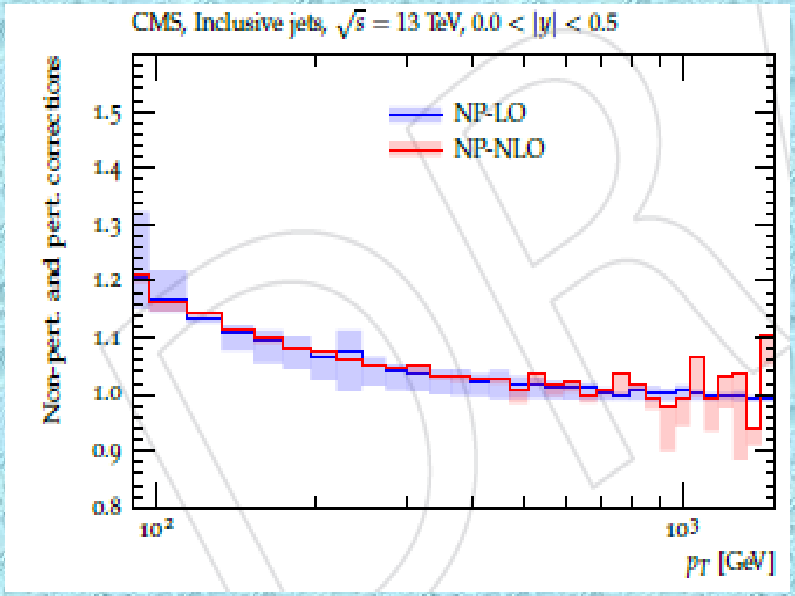


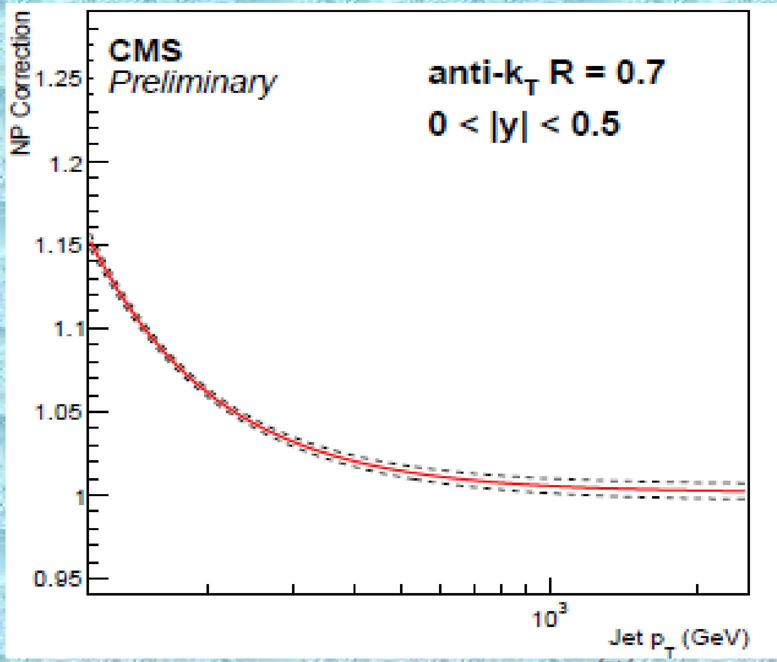


Non-Perturbative Corrections

- The envelopes from the plots according to LO and NLO MC event generators are presented only for the first rapidity bin.
- The previous corrections (previous slide) are estimated on average for the final correction
- For the procedure of fitting the relation $y=a+b*x^c$ was used, where a,b,c, are considered free parameters
- NPs are applied to the NLOJet++ predictions

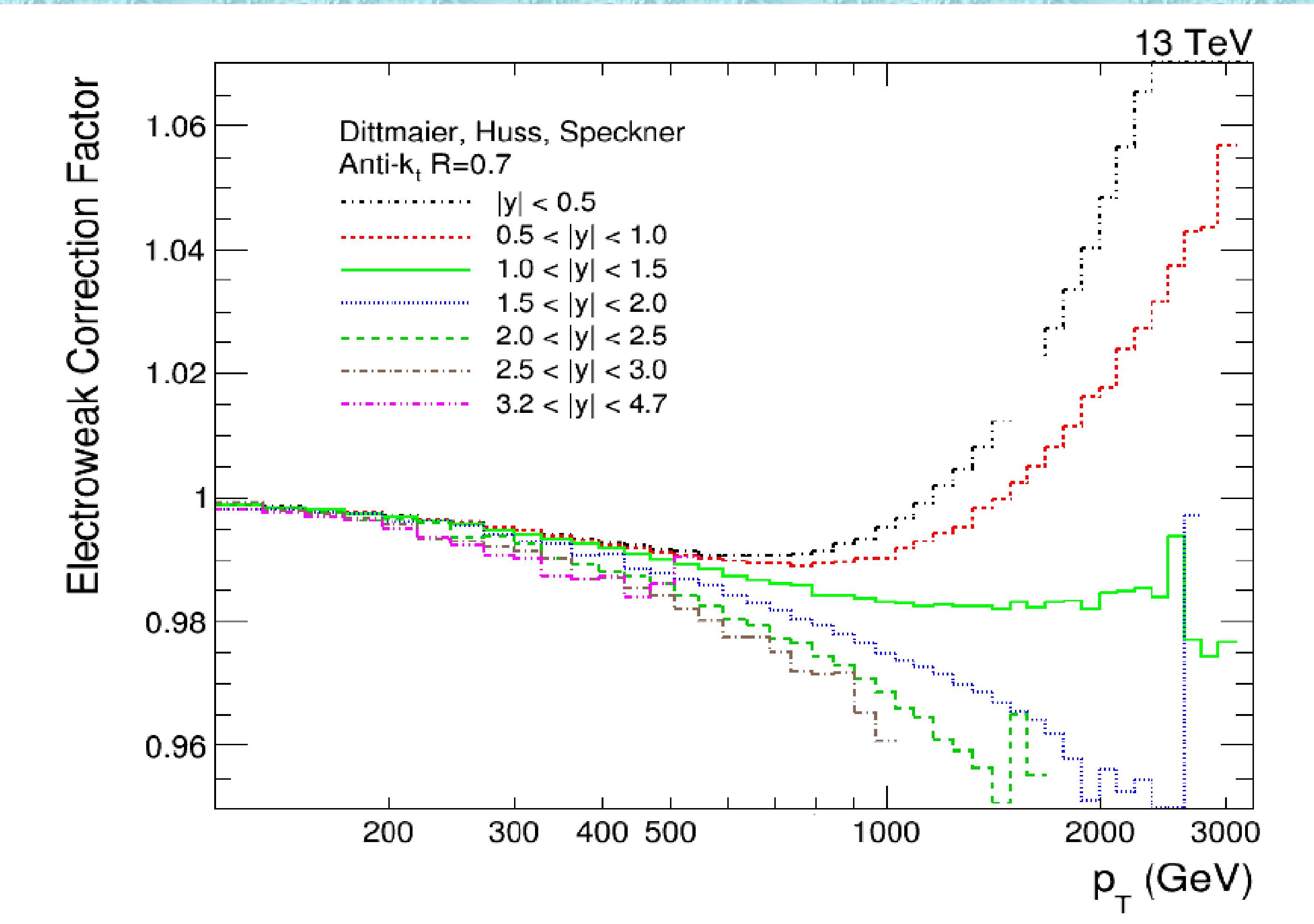
|y|<0.5





Electroweak Corrections

- Arising from the virtual exchanges of massive gauge W and Z
- Become sizeable at high jet transverse momentum p_T and central rapidity y.
- Electroweak corrctions are applied to the NLOJet++ predictions (like NP)



AK7 (R=0.7)
These corrections range between 0.96-1.05 depending on the jet

Transverse momentum and rapidity and are less 3% for p_T<1TeV.