Inclusive jet measurements in CMS

in 2016 pp collisions at 13 TeV

Patrick L.S. Connor
on behalf of the CMS Collaboration

Universität Hamburg

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Bundesministerium für Bildung und Forschung

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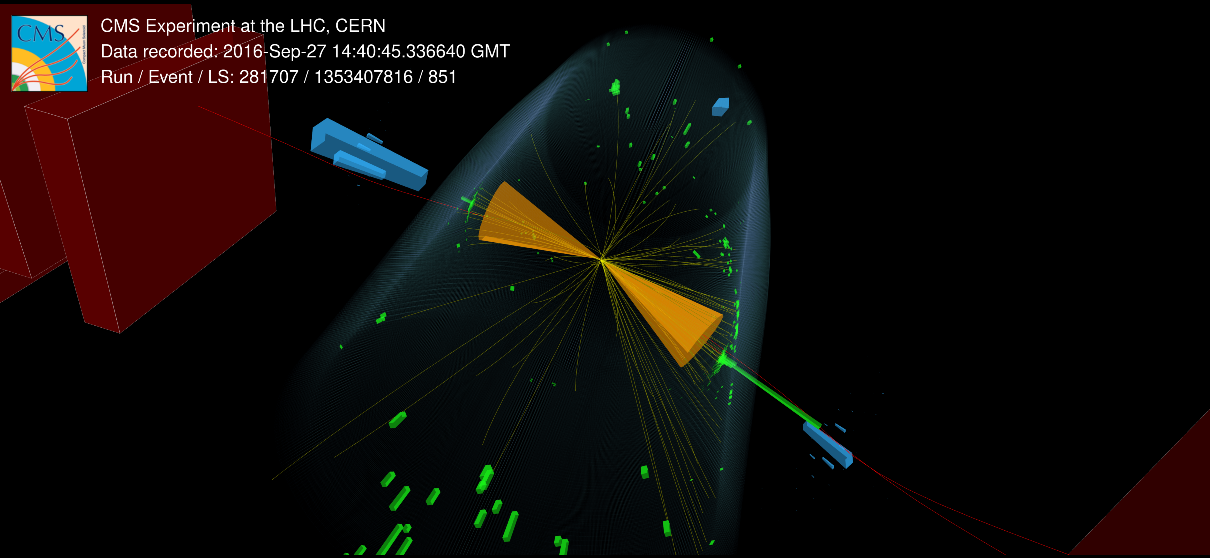
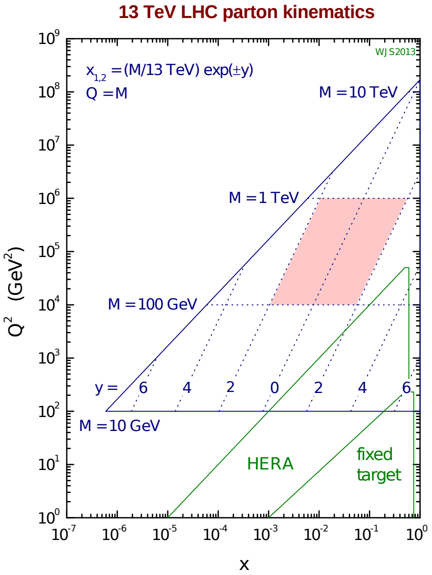
IN NATURAL SCIENCES

Introduction


CMS Experiment at the LHC, CERN
Data recorded: 2016-Sep-27 14:40:45.336640 GMT
Run / Event / LS: 281707 / 1353407816 / 851

Ref. [1]

Outline



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Goals

- Test state-of-the-art predictions.
- Provide additional constraints on PDFs at high x and on α_S.
- Test possible 4-quark c.i.

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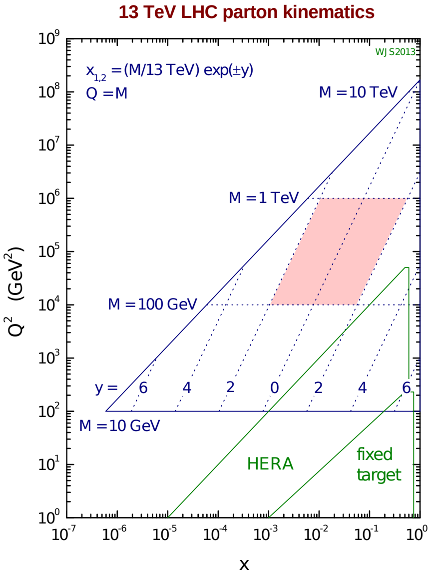

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Today

Two 13 TeV measurements (anti-k_t, $R = 0.4 - 0.7$) with $36.3 - 33.5\,\mathrm{fb}^{-1}$:

- Data reduction and improvements w.r.t. analysis at 8 TeV in this presentation.
- QCD interpretation in the directly following presentation by Katerina.

Motivation

Factorisation [3]

$$\underbrace{\sigma_{pp\to\text{jet}+X}}_{\text{experimental data}} = \sum_{ij\in gq\bar{q}} \overbrace{f_i(x_i,\mu_F^2)\otimes f_j(x_j,\mu_F^2)}^{\text{PDFs}}$$

$$\otimes \underbrace{\hat{\sigma}_{ij\to\text{jet}+X}\left(x_i, x_j, \frac{Q^2}{\mu_F^2}, \frac{Q^2}{\mu_R^2}, \alpha_S(\mu_R^2)\right)}_{\text{SM(EFT)}}$$

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Predictions

- $\hat{\sigma}$ NNLO & NLO+NLL
- f Various global PDF sets

$\longrightarrow$ NP & EW corrections also included to the predictions in our comparisons.

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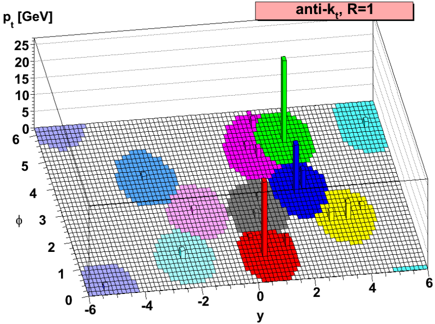
Observable definition

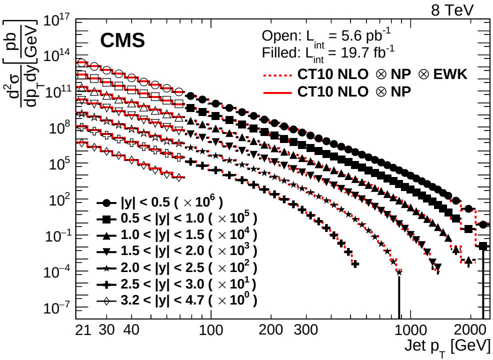
At hadron level, using anti-k_T clustering algorithm [4, 5] ($R = 0.4, 0.7$):

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}p_\mathrm{T}\,\mathrm{d}y} = \frac{1}{\mathcal{L}}\frac{N_\text{jets}^\text{eff}}{\Delta p_\mathrm{T}\,\Delta y}$$

with $p_\mathrm{T} > 97\,\text{GeV}$ and $|y| < 2.0$



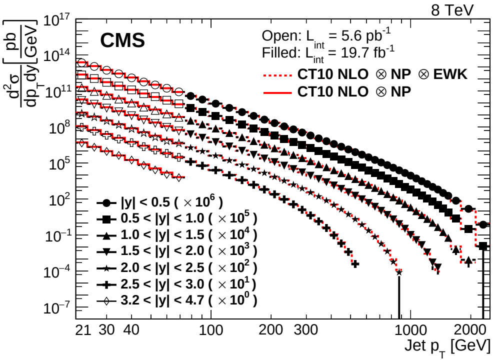
History

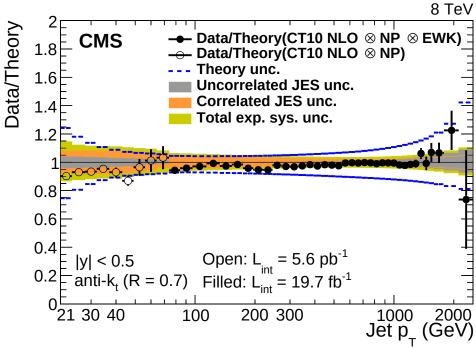


Former measurements at LHC

$\sqrt{s}$	ATLAS	CMS
2.76 TeV	0.0002 fb^{-1} [6]	0.0054 fb^{-1} [7]
7 TeV	4.5 fb^{-1} [8]	5.0 fb^{-1} [9, 10]
8 TeV	20 fb^{-1} [11]	20 fb^{-1} [12]
13 TeV	3.2 fb^{-1} [13]	0.071 fb^{-1} [14]

$\longrightarrow$ in particular, the measurement with 8 TeV has been successfully included in several global PDF fits [15, 16, 17].





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A precision measurement in log scale

« Logarithmic scale can hide monsters. »

- 1% bin-to-bin uncorrelated systematic uncertainties to cover residual effects.
- At medium p_{T}, much larger than statistical uncertainty.

Data reduction

Data set

Counting

Jet energy calibration

Pile-up corrections

Unfolding

Data set

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Multicount observable, i.e. several jets per event:

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- "Good" events (PV, MET, ...).

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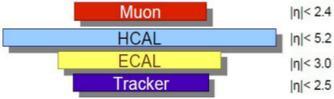

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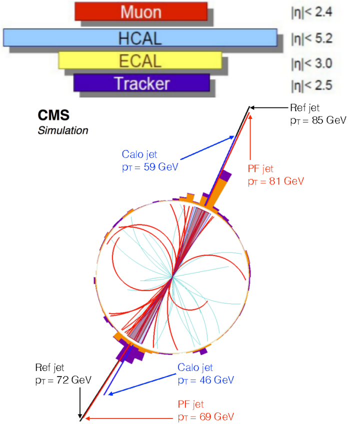

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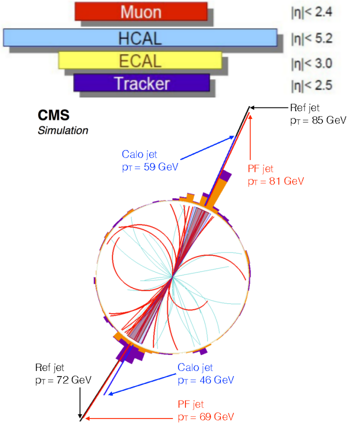

Simulated data

generator	PDF	ME	tune [18]
PYTHIA 8 (230) [19]	NNPDF 2.3 [20]	LO $2 \to 2$	CUETP8M1
MADGRAPH5_aMC@NLO (2.4.3) [21, 22]	NNPDF 2.3 [20]	LO $2 \to 2, 3, 4$	CUETP8M1
HERWIG++ (2.7.1) [23]	CTEQ6L1 [24]	LO $2 \to 2$	CUETHppS1

Counting

Trigger strategy

- In 2016, bunches cross every $25\,$ns at CMS
  $\longrightarrow$ production rate too large to record all jets.
- Record jets with $\neq$ rates w.r.t. their energy
  $\longrightarrow$ multiply by event-based prescale factor in count of jets.
- Identify jets on the fly with fast reconstruction [25]
  $\longrightarrow$ Use only regions of 99.5% of efficiency in every y bin
  ($+$ residual inefficiency corrected).

$\longrightarrow$ Different w.r.t. former measurement, where every single jet was passing a trigger selection & trigger contributions were normalised w.r.t. their respective $\mathcal{L}_{\text{eff}}$

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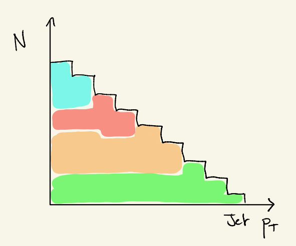

	$p_{\mathrm{T}}^{\mathrm{HLT}}$ (GeV)	40	60	80	140	200	260	320	400	450
AK4	$p_{\mathrm{T}}^{\mathrm{PF}}$ (GeV)	74–97	97–133	133–196	196–272	272–362	362–430	430–548	548–592	$>$592
	$\mathcal{L}_{\text{eff}}$ (pb^{-1})	0.267	0.726	2.76	24.2	103	594	1770	5190	36300
AK7	$p_{\mathrm{T}}^{\mathrm{PF}}$ (GeV)	74–97	97–114	114–196	196–272	272–330	330–395	395–507	507–592	$>$592
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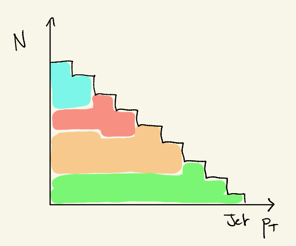

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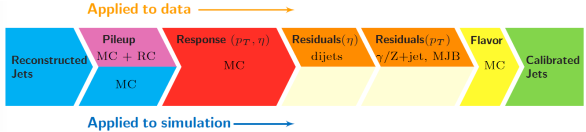
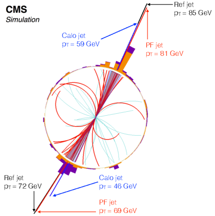
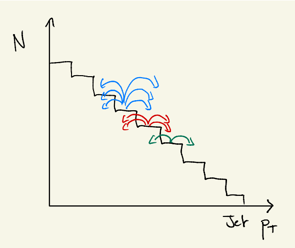
Uncertainties

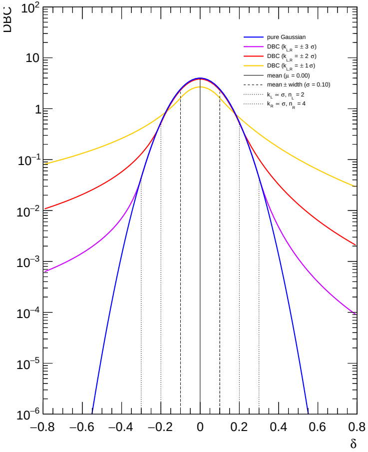
- Statistical correlations
- Luminosity $\mathcal{L}$ (correlated 1.2%)
- Trigger uncertainty (uncorrelated 0.2%)
- Inefficiencies (*e.g.* ECAL prefiring)

Jet energy calibration









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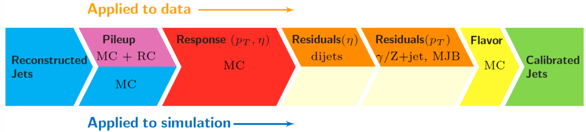
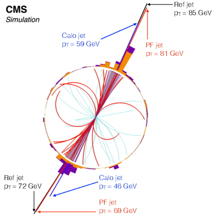
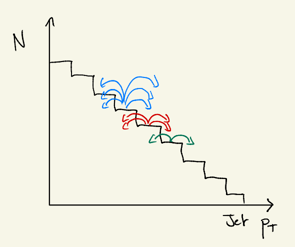






Corrections [26, 27]

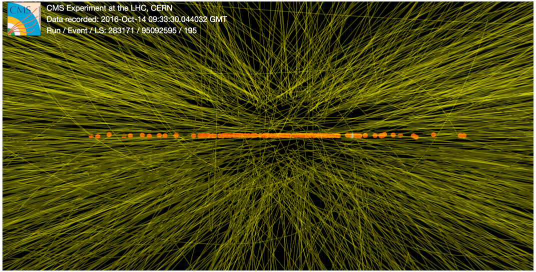
Scale $\langle p_T^{\mathrm{Ref}} \rangle \approx \langle p_T^{\mathrm{PF}} \rangle$ both in real and simulated data

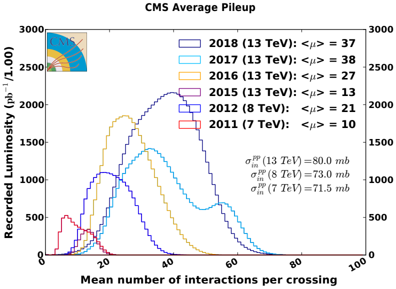
$\longrightarrow$ Many sources of uncertainties related to various effects (e.g. PU).

Resolution smearing rate from true level to detector level corrected in simulated data to resemble real data

$\longrightarrow$ Global uncertainty from SFs.

Pile-up corrections



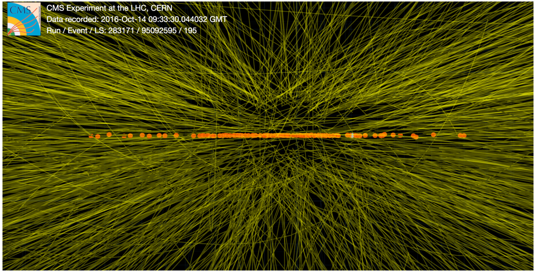


Context

Several pp collisions at each bunch crossing:

Pros higher chances for rare events (high p_{T}).

Cons
- distinctions among collisions more difficult (multiplicity);
- additional contribution to jets (scale offset & worse resolution).



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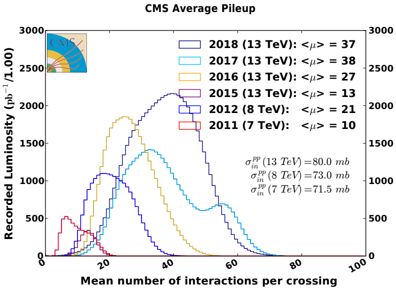
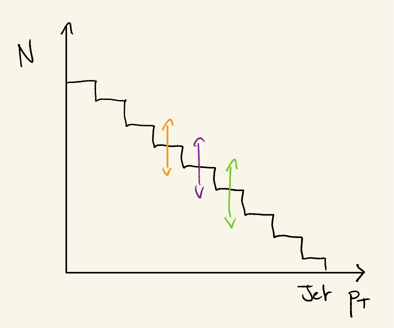
PU profile correction

Correct the profile of simulated data to profile in real data by event reweighting

$\longrightarrow$ additional uncertainty from MB cross section.



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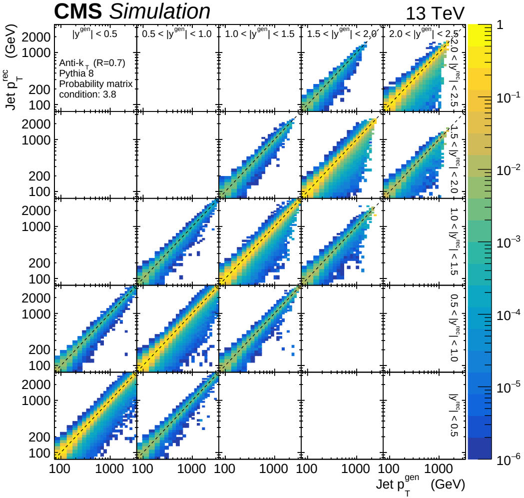


Unfolding

Matrix inversion

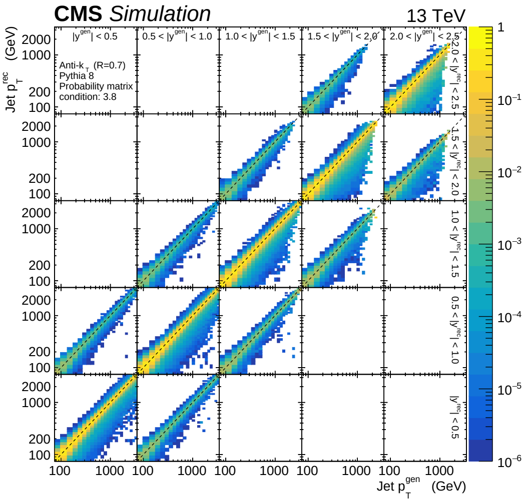
For binned data:

$$\mathbf{A}\mathbf{x} + \mathbf{b} = \mathbf{y} \qquad (1)$$

- $\mathbf{x}$ data distribution at particle level
- $\mathbf{y}$ data distribution at detector level
- $\mathbf{b}$ background spectrum at detector level
- $\mathbf{A}$ probability matrix (figure)

$\longrightarrow$ instable...

Unfolding



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Least-square minimisation [28, 29]

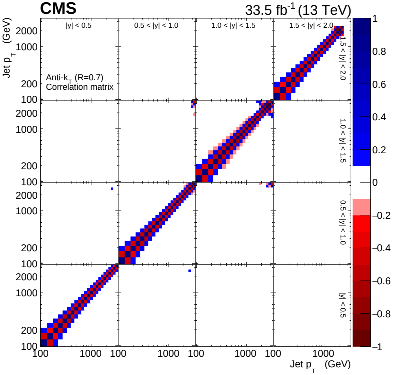
with #detector-level bins $= 2 \times$ #particle-level bins (but **no** Tikhonov regularisation)

$$\chi^2 = \min_{\mathbf{x}} \left[(\mathbf{A}\mathbf{x} + \mathbf{b} - \mathbf{y})^\intercal \, \mathbf{V}^{-1} \, (\mathbf{A}\mathbf{x} + \mathbf{b} - \mathbf{y}) \right] \qquad (2)$$

- $\mathbf{V}$ covariance matrix accounting for partial correlations

(at 8 TeV, we used D'Agostini [30, 31] unfolding in each y bin separately with toy RM)

Unfolding



Uncertainties

- The limited statistics of the simulated data contributes as an extra uncertainty.
- Additional contributions from migrations across the edges of the phase space are included.

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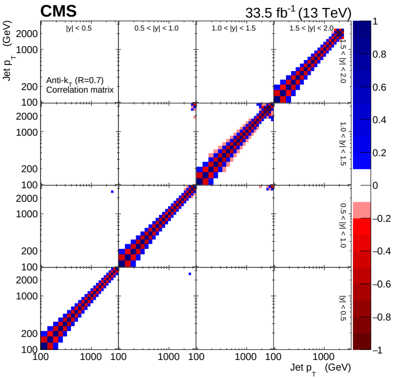
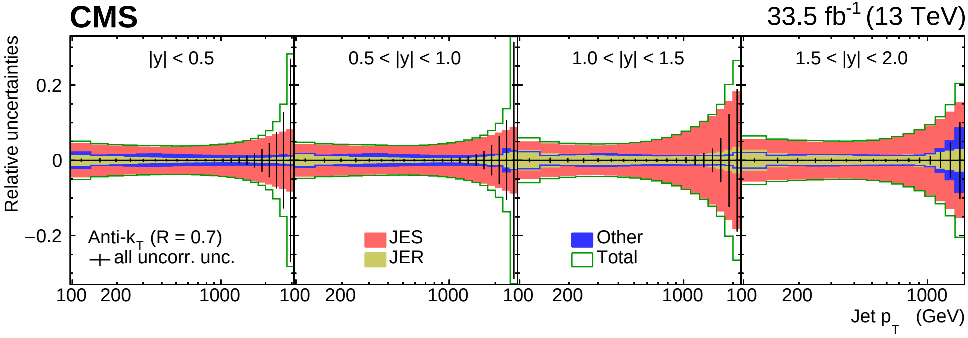


Uncertainties

- The limited statistics of the simulated data contributes as an extra uncertainty.
- Additional contributions from migrations across the edges of the phase space are included.
- All systematic uncertainties are inferred to particle-level by applying the variations either in the input data or in the probability matrix (and smoothed).



Results

Overview

Comparison

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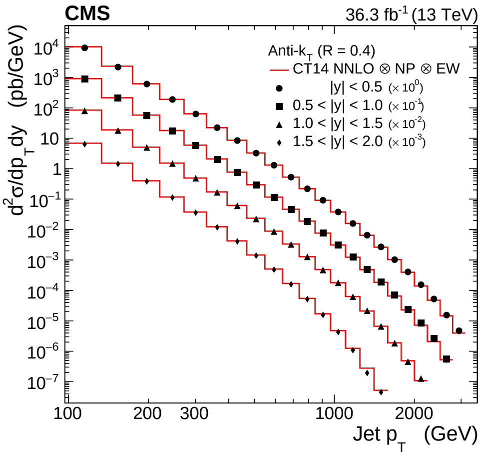
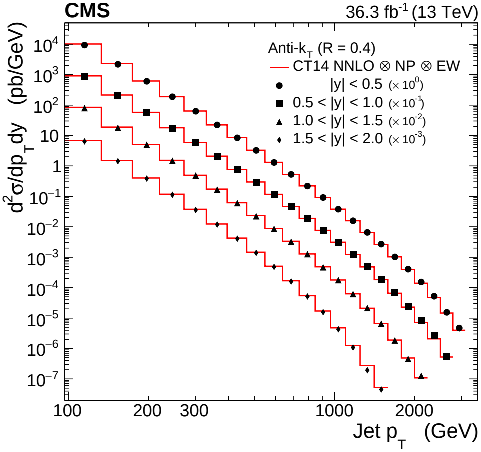


Result

- 4 y bins, from ~ 100 GeV to 3 TeV.
- Bin uncertainty uncertainty almost not visible in log scale.



Overview

Result

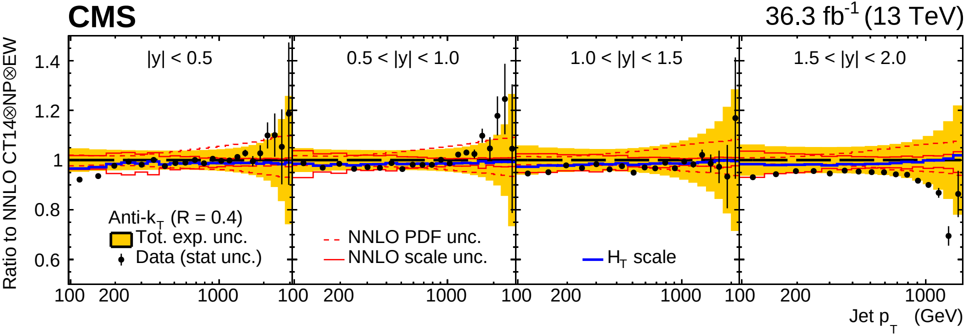
- 4 y bins, from ~ 100 GeV to 3 TeV.
- Bin uncertainty uncertainty almost not visible in log scale.
- So-called "tests of smoothness" have been performed to check the presence of steps or outliers in the final spectrum.

Tests of smoothness [32]

$$\chi^2_n = \min_{b_i} \left[(\mathbf{x} - \mathbf{y}_{b_i})^\intercal \, \mathbf{V}_\mathbf{x}^{-1} \, (\mathbf{x} - \mathbf{y}_{b_i}) \right] \quad \text{with} \quad y^j_{b_i} = \frac{1}{\Delta p^j_\mathrm{T}} \int_{p^j_\mathrm{T}} \exp\left(\sum_{i=0}^{n} b_i \, T_i \left(\log p_\mathrm{T} \right) \right) \mathrm{d}p_\mathrm{T}$$

$\longrightarrow \chi^2_6 \sim$ ndf in all y bins!

Comparison



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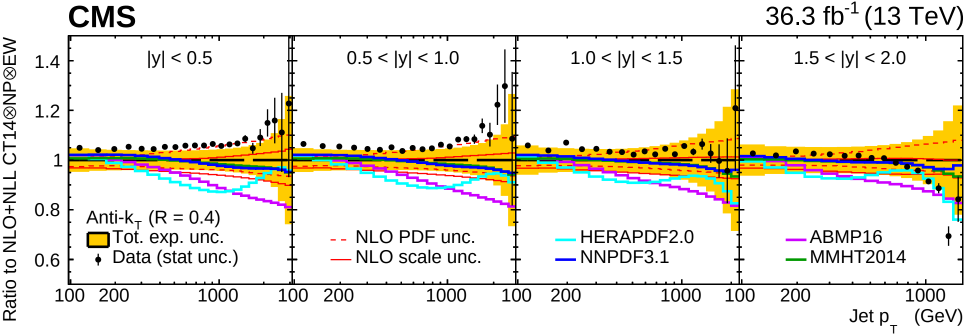

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- NLO+NLL [36] with various global PDF [37, 38, 39, 40, 41] sets.

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Grazie mille!

Stay in the room: the next talk is about the QCD interpretation...

Back-up

Acronyms I

AK4 anti k_T algorithm ($R = 0.4$). 16–18

AK7 anti k_T algorithm ($R = 0.7$). 16–18

ATLAS A Toroidal LHC ApparatuS. 9, 10

c.i. Contact Interactions. 4, 5

CHS Charged Hadron Subtraction. 12–15

CMS Compact Muon Solenoid. 9, 10, 16–18, 35–40

ECAL Electromagnetic CALorimeter. 12–18

EFT Effective Field Theory. 6–8

EW Electroweak. 6–8

FO fixed order. 35–40

LHC Large Hadron Collider. 9, 10

MB Minimum Bias. 21, 22

ME Matrix Element. 12–15

MET Missing Transverse Energy. 12–15

NLL Next to Leading Logarithm. 6–8, 32, 33, 35–40

NLO Next to Leading Order. 6–8, 32, 33, 35–40

NNLO Next to Next to Leading Order. 6–8, 32, 33, 35–40

NP Non-Perturbative. 6–8

PDF Parton Distribution Function. 4–10, 12–15, 32, 33

PF Particle-Flow. 12–15

PU pile-up. 12–15, 19–22

PV Primary Vertex. 12–15

QCD Quantum Chromodynamics. 4, 5, 35–40

RM Response Matrix. 25, 26

SF Scale Factor. 19, 20

SM Standard Model. 6–8

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Patrick L.S. Connor

patrick.connor@desy.de
Universität Hamburg
`https://www.desy.de/~connorpa`

MIN-Fakultät
Institut für Experimentalphysik
Tel.: +49 40 8998-82165
Geb.: DESY Campus 68/121

Center for Data and Computing
in natural Sciences
Tel.: +49 42838-6109
Geb.: Notkestraße 9