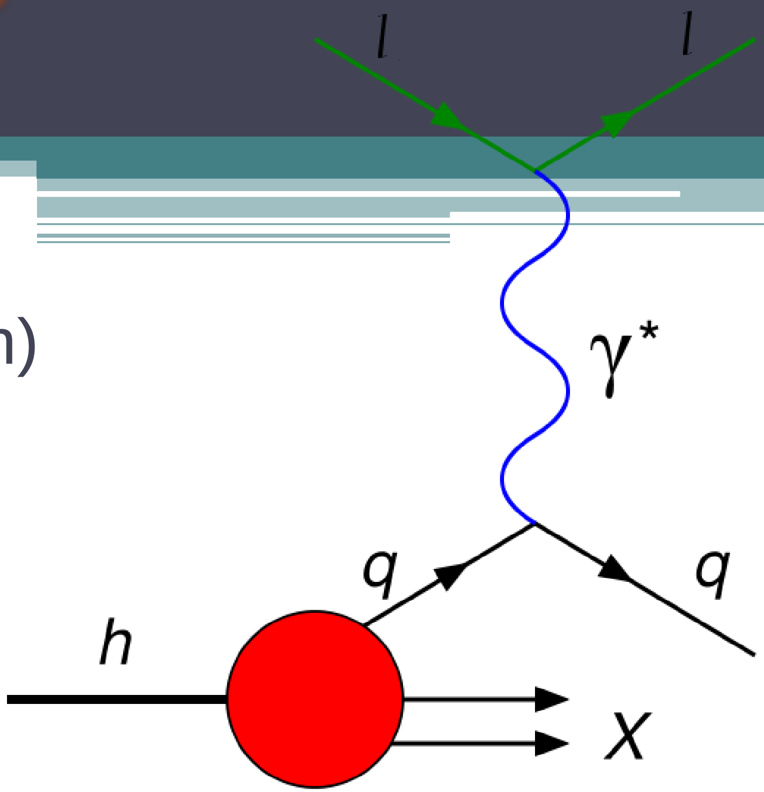
Measurement of the jet production cross-section at 7 TeV

Accepted by JHEP: arXiv:1312.3524 [hep-ex]



Gagik Vardanyan
(on behalf of ATLAS collaboration)

DIS XXII, 28 April – 02 May 2014, Warsaw

OUTLINE

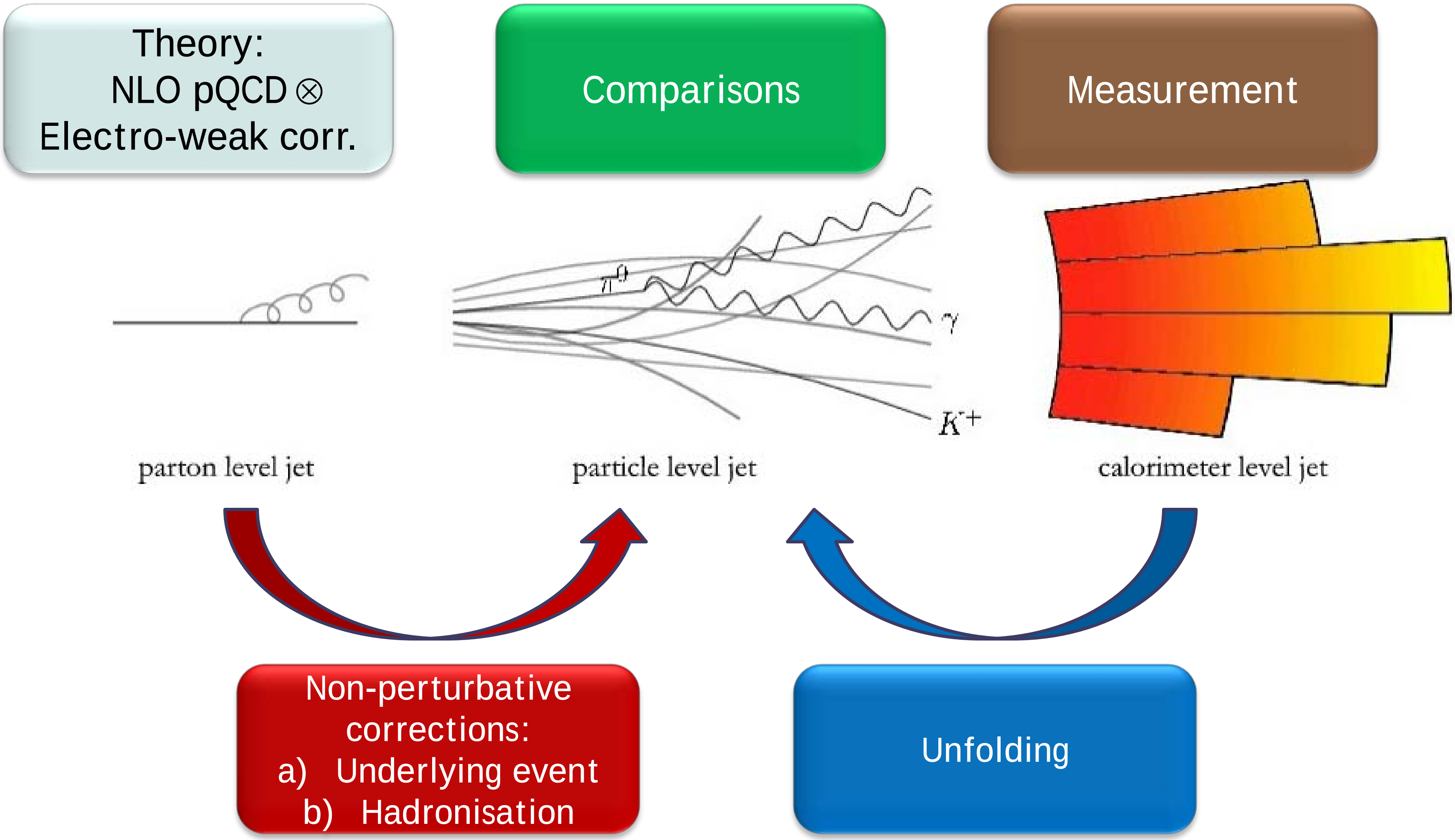
- **Introduction**
- **Experimental measurement**
- **Theoretical predictions**
- **Data/theory comparisons**
- **Conclusions**

INTRODUCTION

Differential di-jet cross-sections are

- **sensitive to:**
  - Parton Distribution Functions and α_s
    - especially to gluon densities with high momentum fraction
  - resonances and new interactions
    - thus, can be employed in searches beyond the Standard Model
- **defined as:** $\frac{d^2\sigma}{dm_{12}dy^*}$ **, where**
  - m_{12} is the invariant mass of the two leading jets in the event
  - y^* is the half of the absolute rapidity separation between those: $y^* = |y_1 - y_2|/2$
- **measured:**
  - for anti-kt jets with R=0.4 and R=0.6
    - probing different regimes of the interplay of perturbative and non-perturbative QCD
  - in proton-proton collisions at $\sqrt{s} = 7$ TeV, L= 4.5 fb^{-1}
  - up to 5 TeV in di-jet mass and 3.0 in y*

STRATEGY

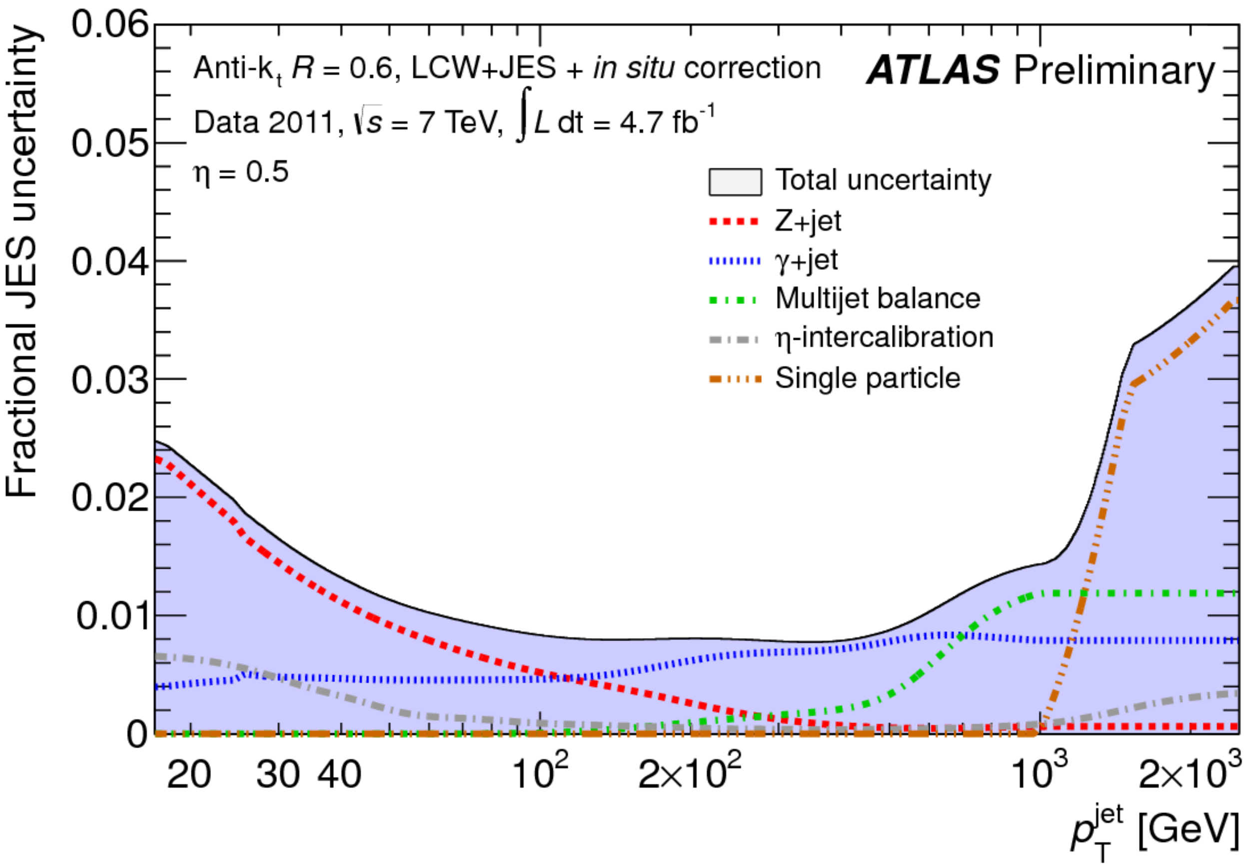

Theory:
NLO pQCD ⊗
Electro-weak corr.
Comparisons
Measurement
π^0
γ
K^+
parton level jet
particle level jet
calorimeter level jet
Non-perturbative
corrections:
a) Underlying event
b) Hadronisation
Unfolding

EXPERIMENT SIDE : *trigger, jet reconstruction, MC samples*

trigger	a combination of fully efficient 3-level single jet triggers
jet reconstruction	anti-kt algorithm with R=0.4 and R=0.6 built from 3D topological clusters of energy depositions in calorimeters
jet cleaning	a complex of criteria was employed to reject fake jets rising from non-collision background
event selection	at least two good jets with |y|<3.0 and pT > 100 GeV for the leading one, pT > 50 GeV for the subleading one
Monte Carlo	PYTHIA 6 with AUET2B for jet energy calibration and data unfolding (GEANT 4 for derector simulation)

EXPERIMENT SIDE : *jet energy scale and uncertainties*

Pile-up Correction → Origin Correction → Absolute JES → Residual in-situ JES



- JES uncertainties are derived with several *in-situ* techniques using pT balance between jets and well measured reference objects.
- Thorough studies of the stability of the measurement under high pile-up conditions.

EXPERIMENT SIDE : *unfolding, uncertainties*

unfolding

- ***Iterative, Dynamically Stabilised***
- Iterative improvement of transfer matrix
- Data-driven closure test

$$N_i^{part} = \sum_j N_j^{reco} \varepsilon_j^{reco} A_{ij} / \varepsilon_i^{part}$$

statistical uncertainties

- ***Bootstrap method***
- 10000 pseudo-experiments with random poisson-distributed weights
- Allows to keep track of the statistical correlations with other measurements based on the same data sample.

systematic uncertainties

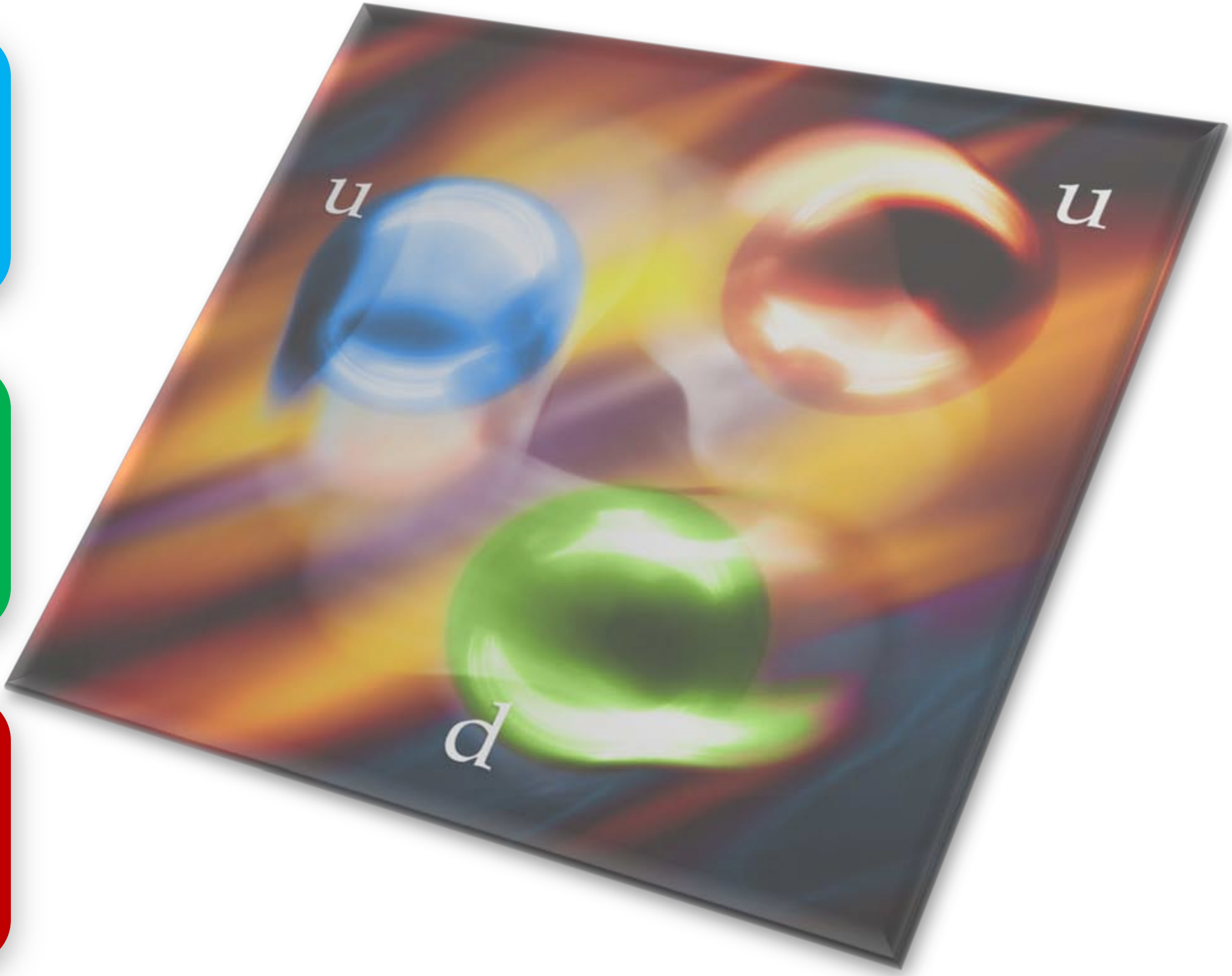
- ***jet energy scale (the dominant uncertainty)***, jet energy resolution, jet angular resolution, cleaning efficiency, unfolding closure
- luminosity uncertainty: 1.8 % fully correlated between all data points

THEORETICAL PREDICTIONS

NLO pQCD (NLOJet++)

Electro-weak (EW) corrections

Non-perturbative (NP) corrections



THEORY PREDICTIONS: *Next-to-leading order pQCD*

- The fixed-order $O(\alpha_s^3)$ QCD calculations are performed with the NLOJet++ program interfaced with APPLGRID for the following PDFs:
  - CT10
  - HERAPDF1.5
  - epATLJet13
  - MSTW 2008
  - NNPDF2.1
  - NNPDF2.3
  - ABM11
- Nominal scale choice:

$$\mu = \mu_R = \mu_F = p_T^{\max} e^{0.3y^*}$$

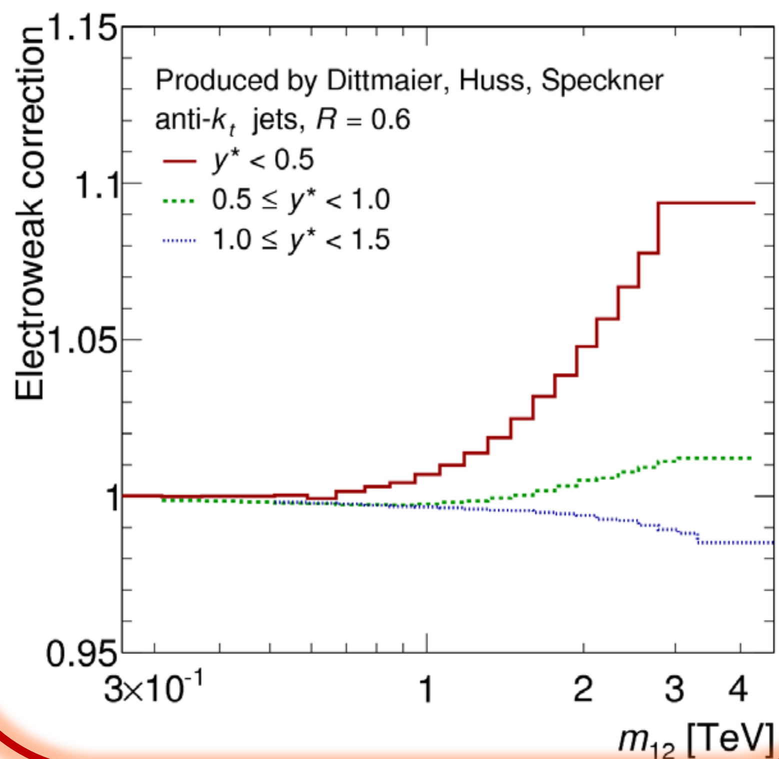
- *POWHEG predictions were computed employing NLO matrix element calculation interfaced with PYTHIA (with AUET2B and Perugia 2011 tunes) using the CT10 PDF (both scales are set equal to the default value of* p_T^{Born}*)*

Theoretical uncertainties:

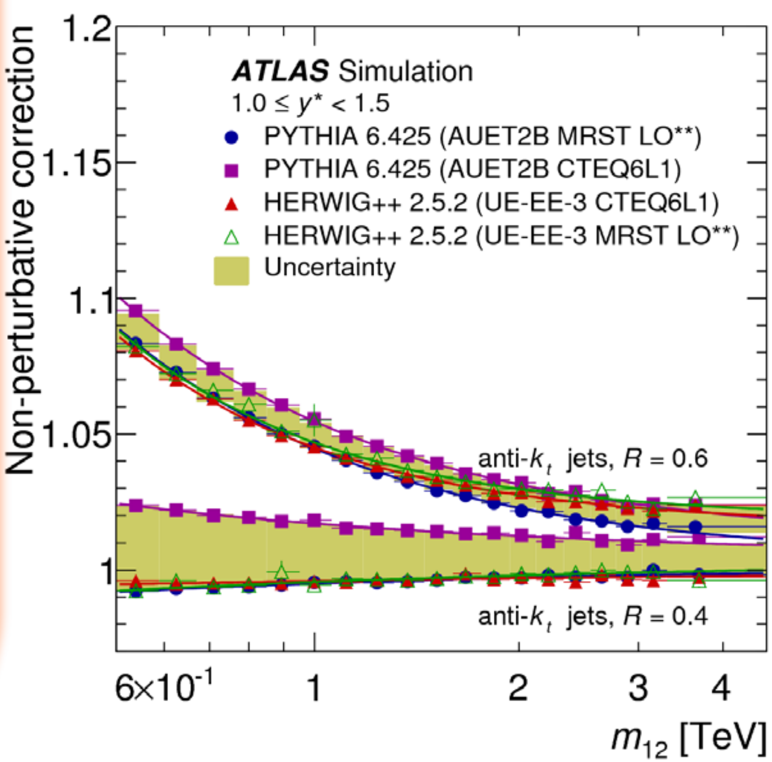
- PDF parametrisation
- Scale choice
- α_s

THEORY PREDICTIONS: *Electro-weak and non-perturbative corrections*

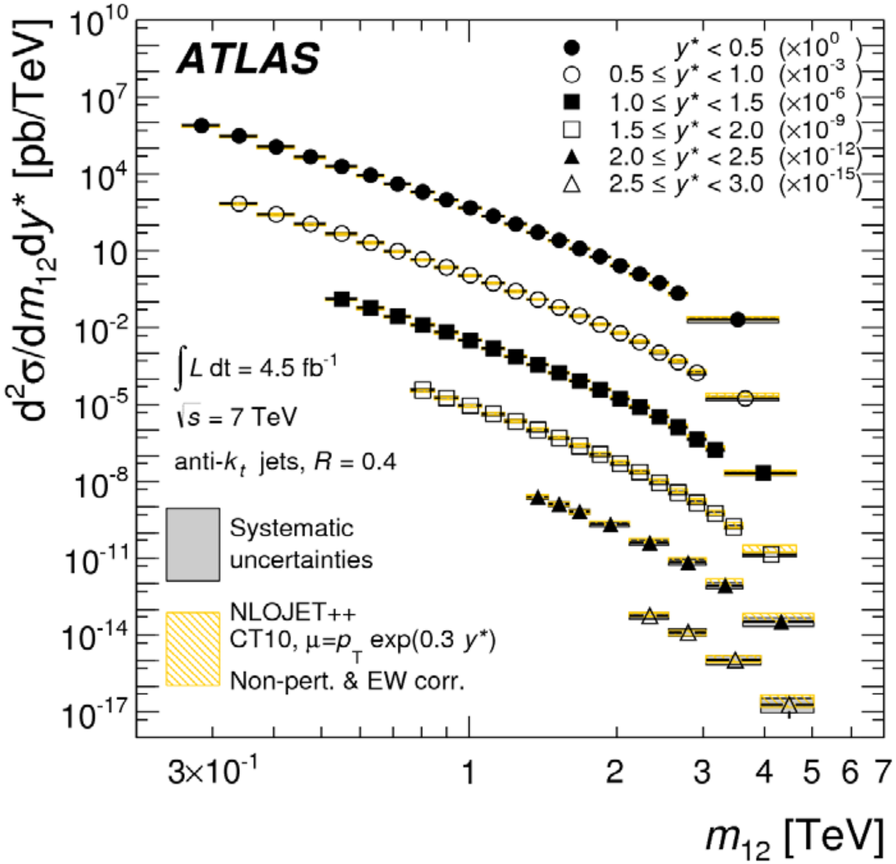
Electroweak tree-level effects of $O(\alpha\alpha_s, \alpha^2)$ and loop effects of $O(\alpha\alpha_s^2)$ are derived for NLO electroweak processes on a LO QCD.

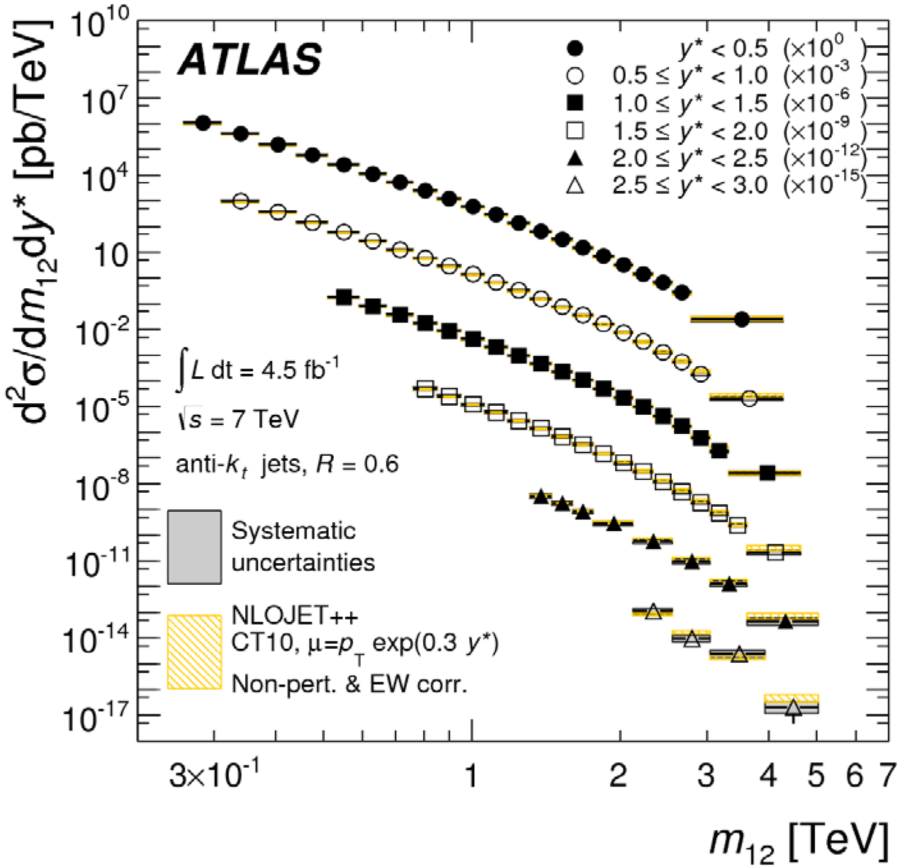


Non-perturbative corrections are assessed using leading-logarithmic parton shower Monte Carlos as binwise ratios of cross-section at the particle level including hadronisation and underlying event effects, over that at the parton level.



CROSS-SECTION RESULTS





Measured cross-sections and NLO pQCD predictions for CT10 PDF set corrected for electroweak and non-perturbative effects for R=0.4 (left) and R=0.6 (right) .

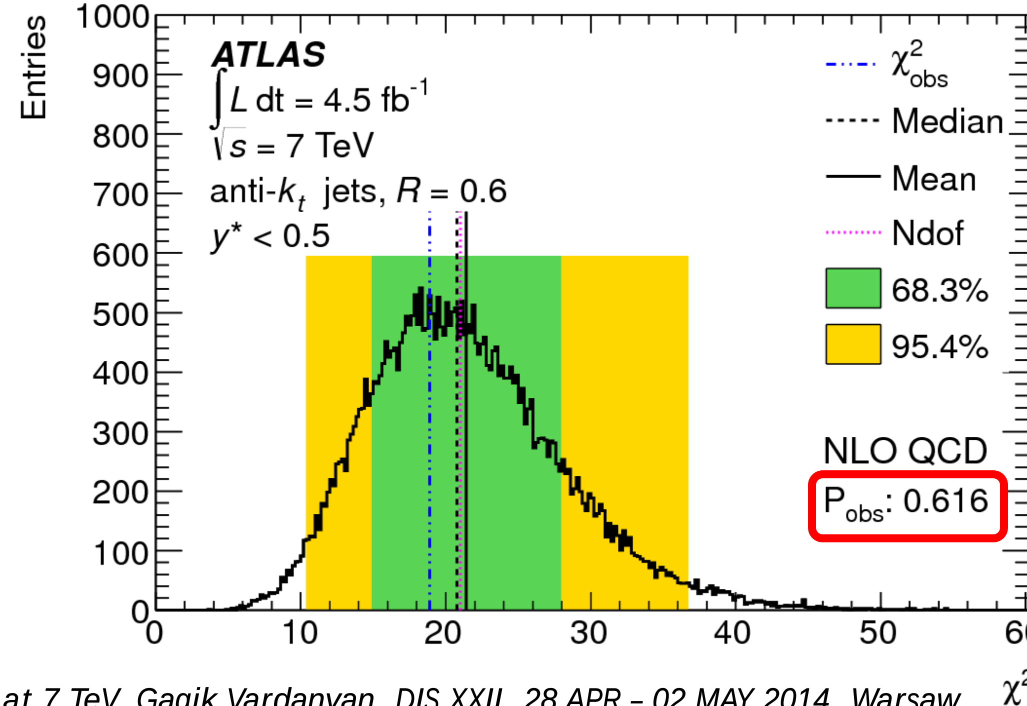
No major deviation of the data from the theoretical predictions is observed over the full kinematic range, covering almost 8 orders of magnitude in measured cross-section values.

QUANTITATIVE COMPARISONS: *test statistic, the frequentist method*

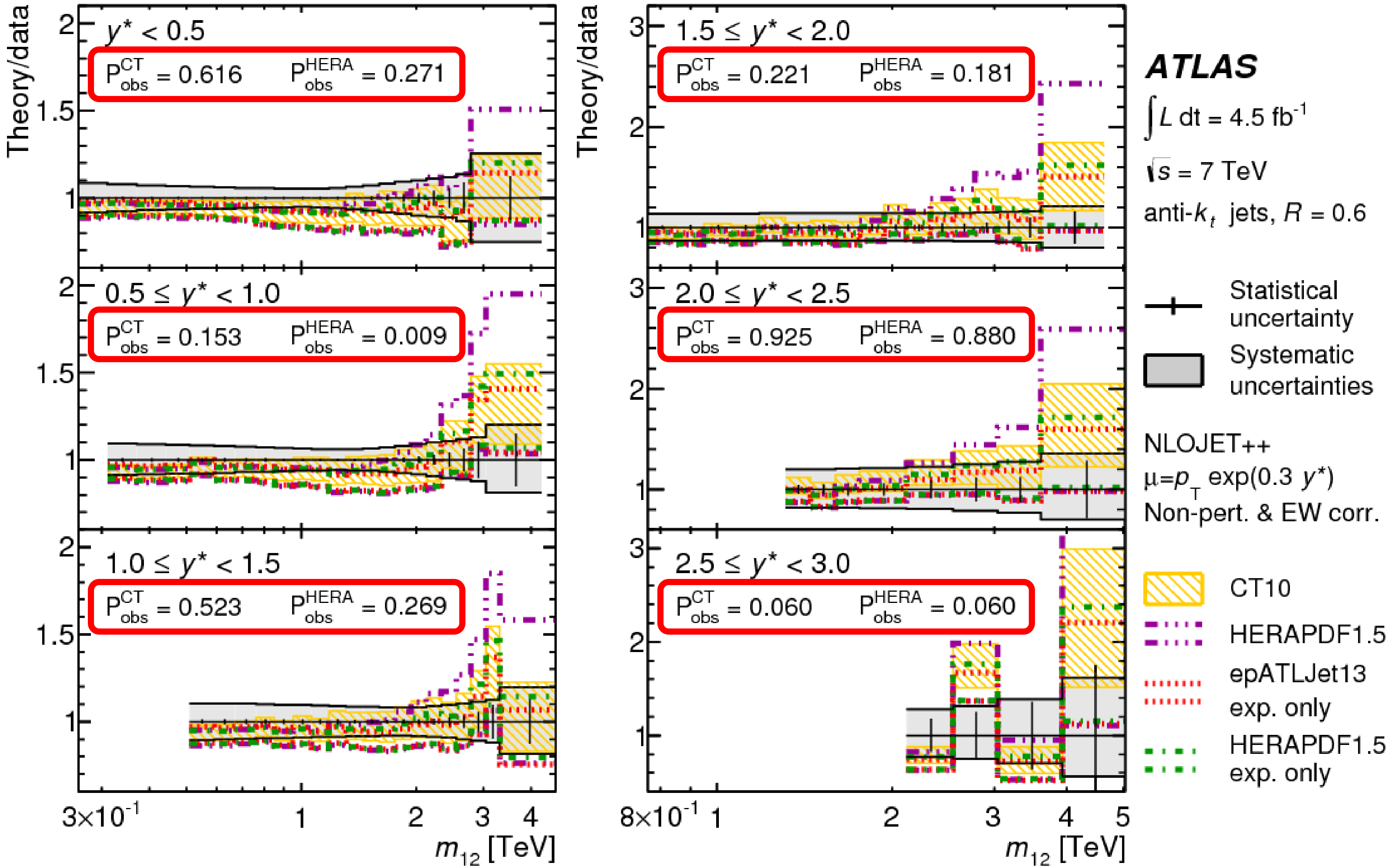
A generalised χ^2 definition to account for asymmetric uncertainties and correlations:

$$\chi^2(\mathbf{d};\mathbf{t}) = \sum_{i,j}\left[d_i - \left(1+\sum_a \beta_a\cdot\left(\boldsymbol{\epsilon}_a^{\pm}(\beta_a)\right)_i\right)t_i\right]\cdot\left[C_{\mathrm{su}}^{-1}(\mathbf{t})\right]_{ij} \cdot\left[d_j - \left(1+\sum_a \beta_a\cdot\left(\boldsymbol{\epsilon}_a^{\pm}(\beta_a)\right)_j\right)t_j\right] + \sum_a \beta_a^2$$

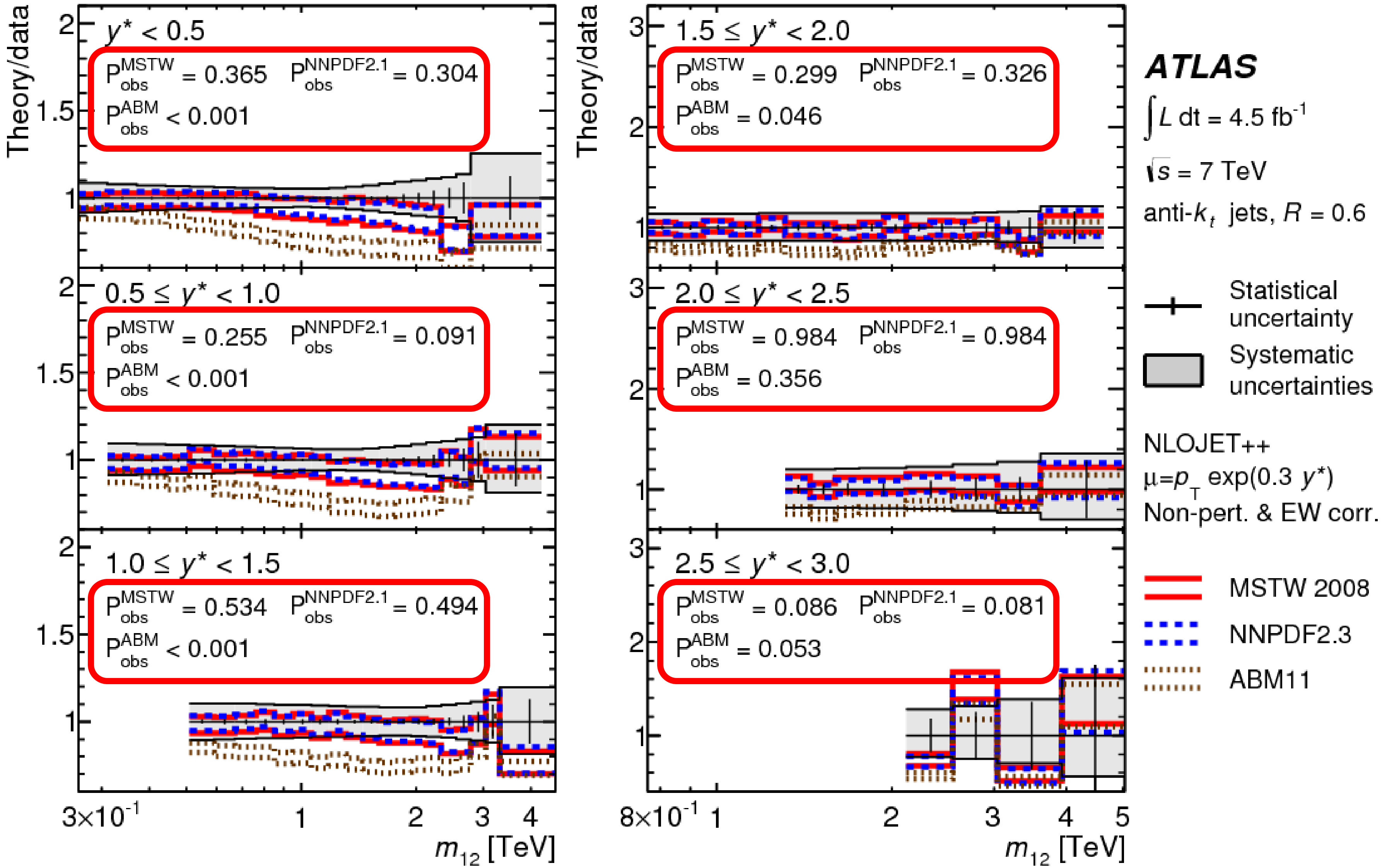
- ➢ A frequentist method is used to build the distribution of the test statistic
- ➢ *observed probability* is the fraction of the pseudo-data having a χ^2 value larger, than that observed in the data



COMPARISONS: *Data to theoretical predictions with CT10, HERAPDF1.5*



COMPARISONS: *Data to theory with MSTW 2008, NNPDF2.3, ABM11*

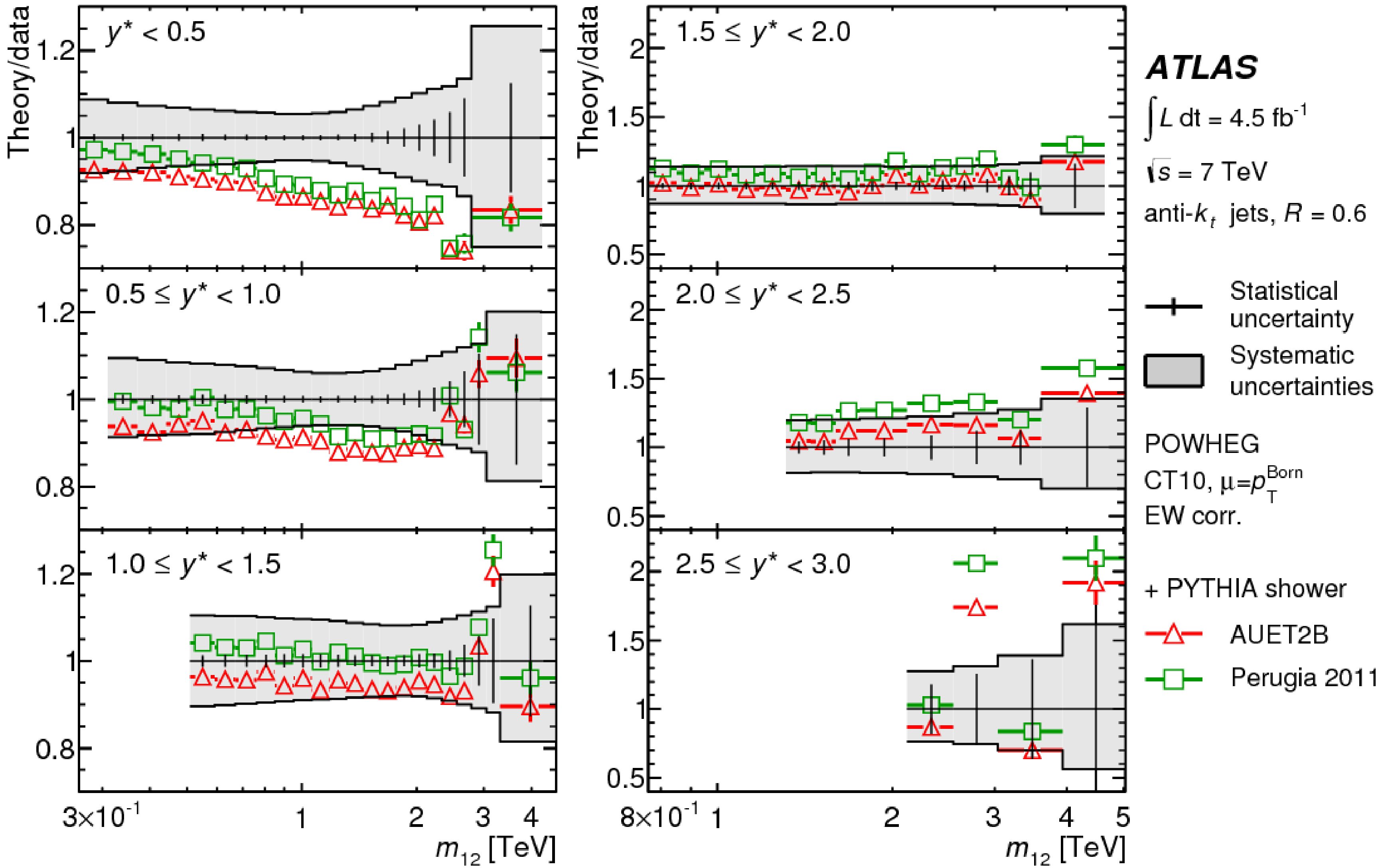


QUANTITATIVE COMPARISONS: *summary*

PDF set	y^* ranges	mass range (full/high)	P_{obs} $R = 0.4$	P_{obs} $R = 0.6$
CT10	$y^* < 0.5$	high	0.742	0.785
	$y^* < 1.5$	high	0.080	0.066
	$y^* < 1.5$	full	0.324	0.168
HERAPDF1.5	$y^* < 0.5$	high	0.688	0.504
	$y^* < 1.5$	high	0.025	0.007
	$y^* < 1.5$	full	0.137	0.025
MSTW 2008	$y^* < 0.5$	high	0.328	0.533
	$y^* < 1.5$	high	0.167	0.183
	$y^* < 1.5$	full	0.470	0.352
NNPDF2.1	$y^* < 0.5$	high	0.405	0.568
	$y^* < 1.5$	high	0.151	0.125
	$y^* < 1.5$	full	0.431	0.242
ABM11	$y^* < 0.5$	high	0.024	$< 10^{-3}$
	$y^* < 1.5$	high	$< 10^{-3}$	$< 10^{-3}$
	$y^* < 1.5$	full	$< 10^{-3}$	$< 10^{-3}$

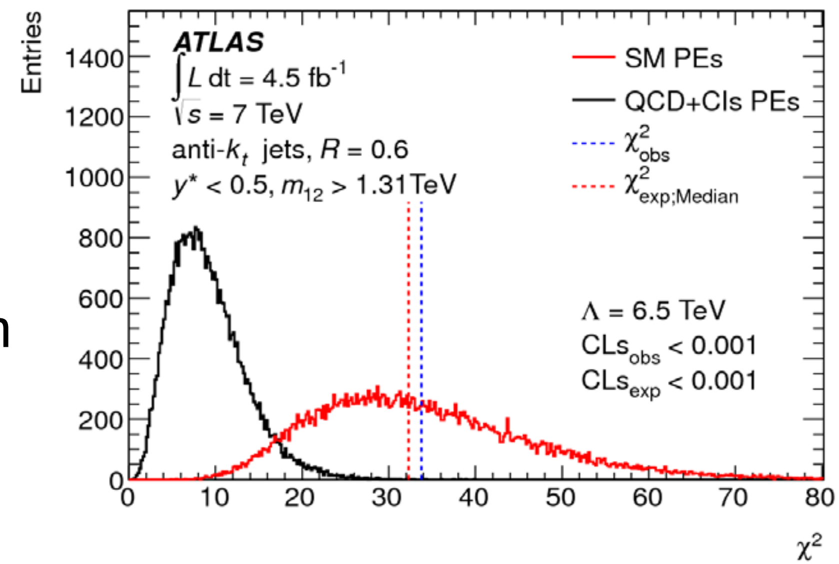
Measurement is sensitive to PDFs. Good general agreement with CT10, MSTW 2008 and NNPDF2.1.

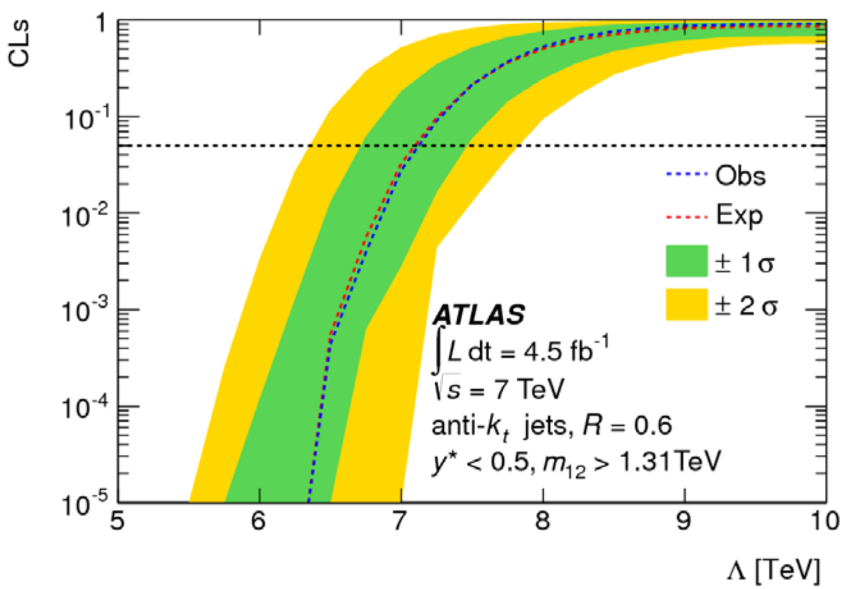
COMPARISONS : *Data to POWHEG (NLO QCD) + PYTHIA (qualitative)*



SEARCH FOR CONTACT INTERACTIONS (CIs)

- To illustrate sensitivity of the measurement to physics beyond SM, an example of the model of QCD+Contact Interactions is considered
- High di-jet mass sub-sample
- No EW and NP corrections for CI portion
- 95% CL lower limit on Λ compositeness scale of CIs





PDF set	Λ [TeV]			
	$R = 0.4$		$R = 0.6$	
	Exp	Obs	Exp	Obs
CT10	7.3	7.2	7.1	7.1
HERAPDF1.5	7.5	7.7	7.3	7.7
MSTW 2008	7.3	7.0	7.1	6.9
NNPDF2.1	7.3	7.2	7.2	7.0

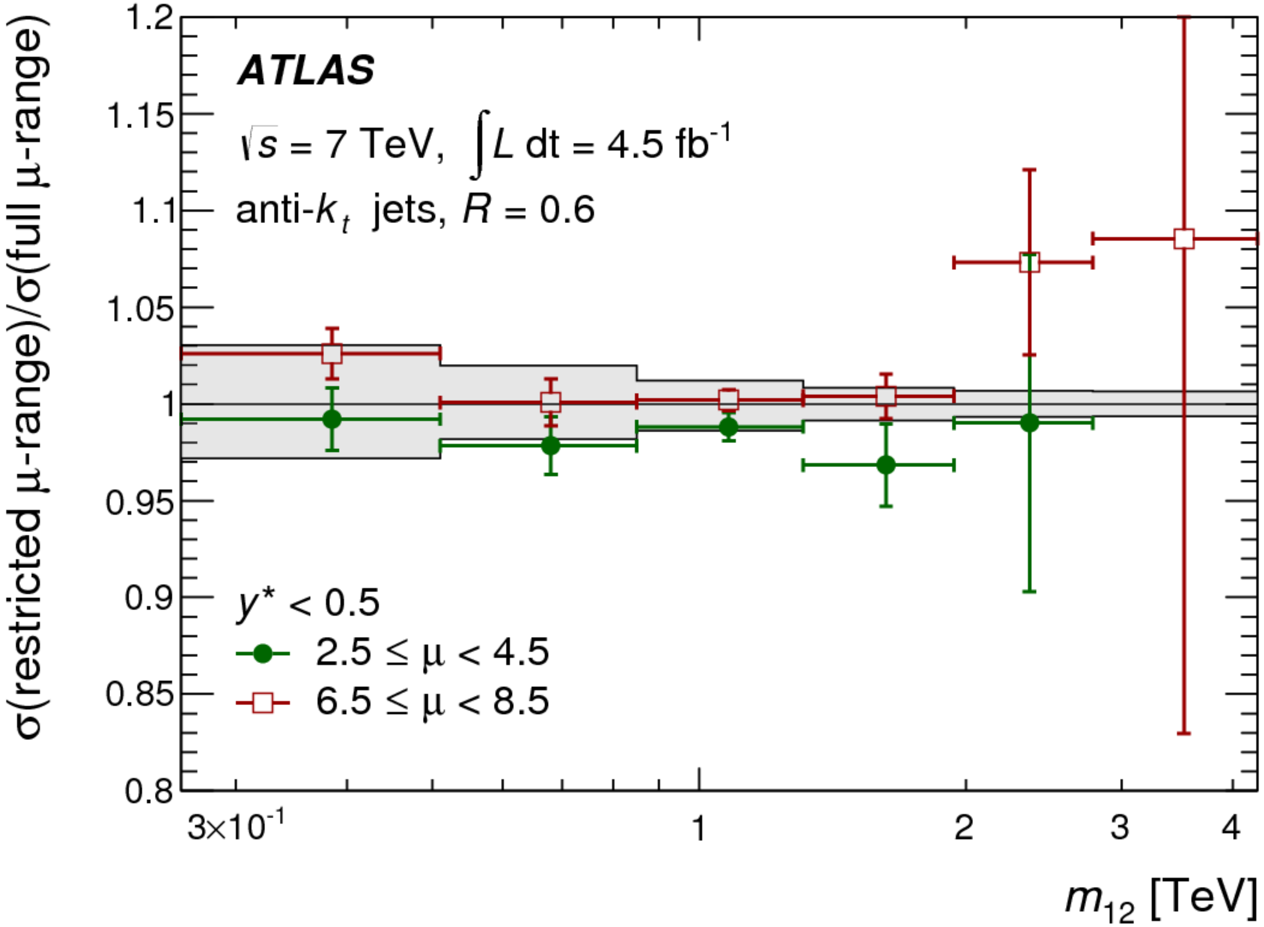
CONCLUSIONS

- Double differential di-jet cross-sections are measured:
  - for anti-kt jets with R=0.4 and R=0.6
  - in proton-proton collisions at $\sqrt{s} = 7$ TeV, L= 4.5 fb^{-1}
  - up to 5 TeV in di-jet mass and 3.0 in y*
- Smaller uncertainties wrt previous ATLAS measurements of di-jet production:
  - high mass region can be potentially used to constrain PDFs at high momentum fraction
- Quantitative comparisons of data with NLO pQCD predictions corrected for electro-weak and non-perturbative effects
  - good agreement with CT10, MSTW 2008, and NNPDF2.1
- Exploration and exclusion of contact interactions
  - exclusion of compositeness scales Λ < 6.9 – 7.7 TeV is achieved, depending on the PDF set
- All the information about uncertainties and correlations are provided in the paper allowing to perform PDF fits as well as to confront any model beyond SM with the data.

BACKUP SLIDES

BACKUP: *pile-up stability*

Spread of the cross-sections measured for different sub-samples of data corresponding to high/low μ values is within the pile-up component of the jet energy scale uncertainty .



BACKUP: *jet energy scale (expanded)*

Pile-up Correction → **Origin Correction** → **Absolute JES** → **Residual in-situ JES**

Pile-up Correction

Average offset subtraction based on the number of reconstructed primary vertices and the number of additional interactions per bunch crossing.

Origin Correction

Correction of the jet direction to be originated from the hardest-scattered primary vertex instead of the geometrical centre of ATLAS.

Absolute JES

Main Monte Carlo based calibration aiming to restore reconstructed jet energy to the particle level. Corrects for calorimeter non-compensation, dead material, leakage.

Residual in-situ JES

Residual calibration to correct for remaining differences between data and Monte Carlo using di-jet, photon+jet, Z+jet and multi-jet events.