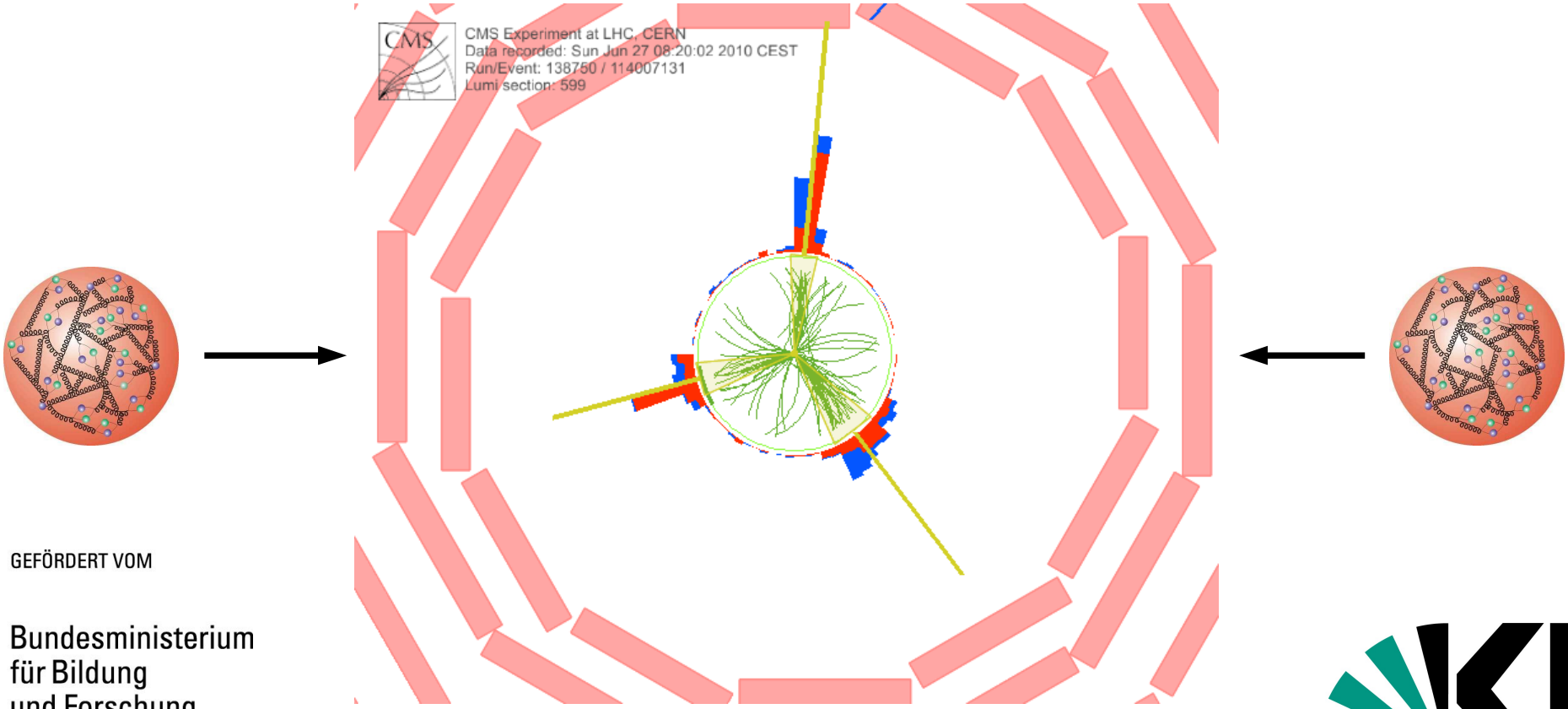
Jet Production at CMS and ATLAS



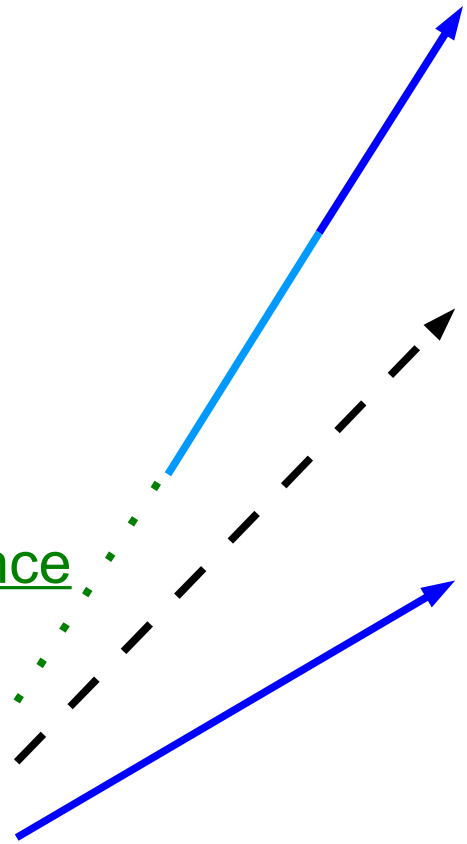
GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

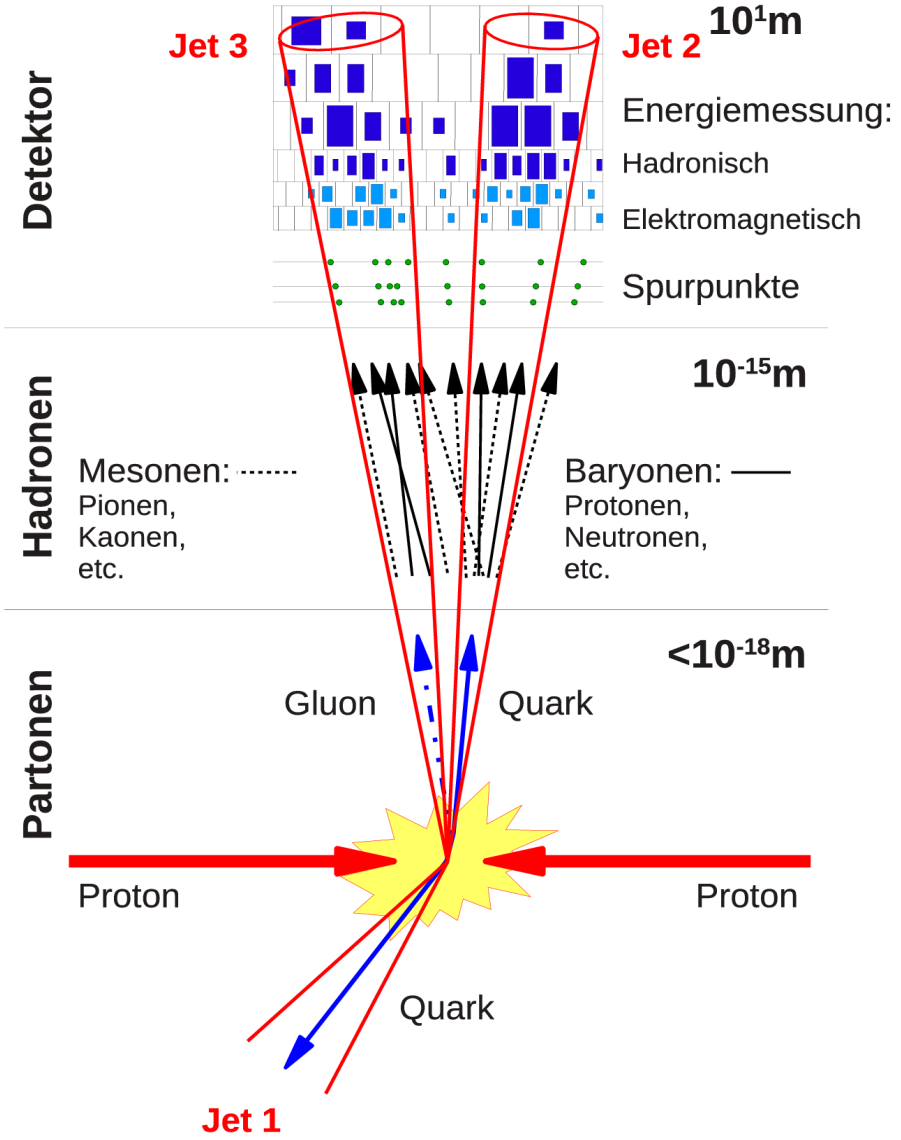
Klaus Rabbertz, KIT

Karlsruhe Institute of Technology

The "Jet" Menu

- Jet Algorithms
- Jet Uncertainties
- Inclusive Jet pT
- Di-Jet & 3-Jet Mass
- Photons
- Outlook





Jets establish correspondence between:
- detector measurements
- final state particles and
- hard partons

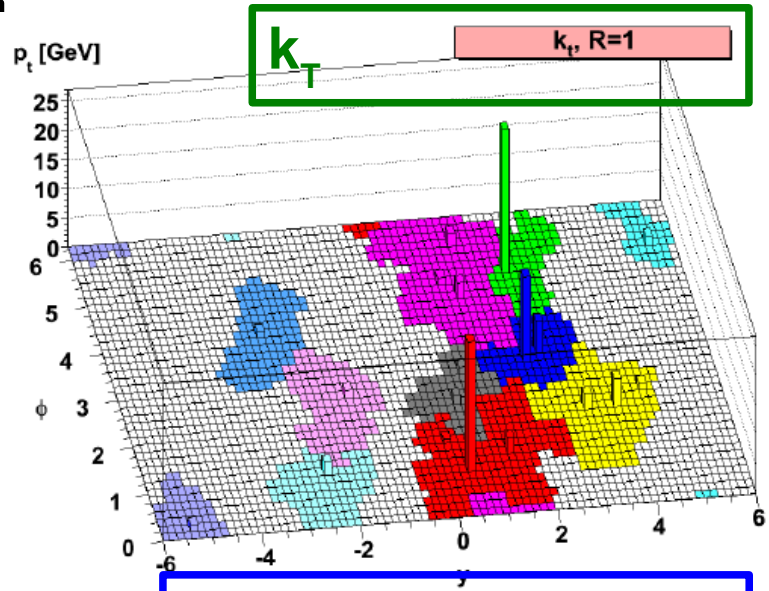
Jet Algorithms at LHC

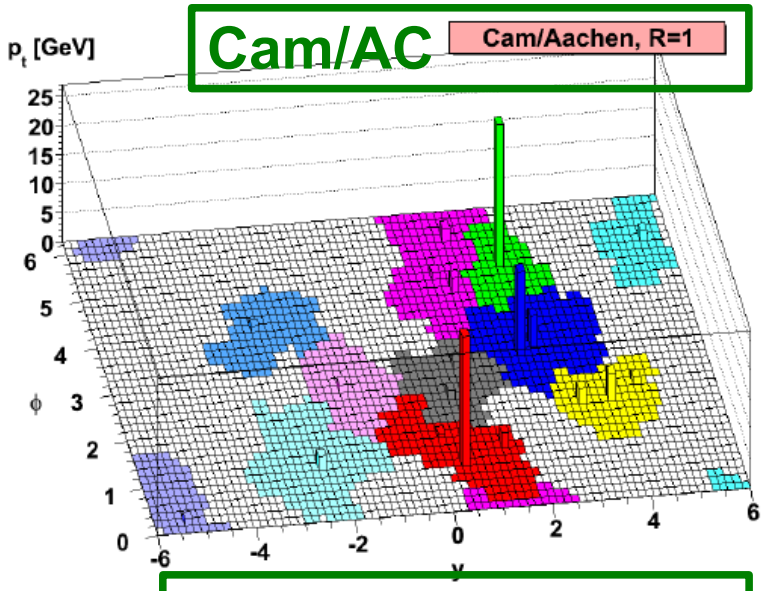
Primary algorithm at LHC:

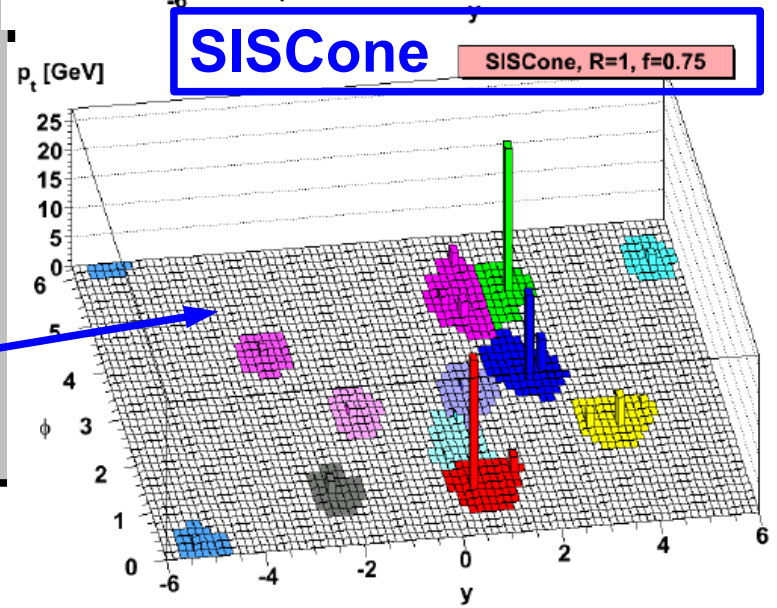
- **Anti-k_T:**
  ATLAS R = 0.4, 0.6
  CMS R = 0.5, 0.7
- k_T
- SISCone ("real" cone algo)
- Cambridge/Aachen
  used in jet substructure, for example in boosted top

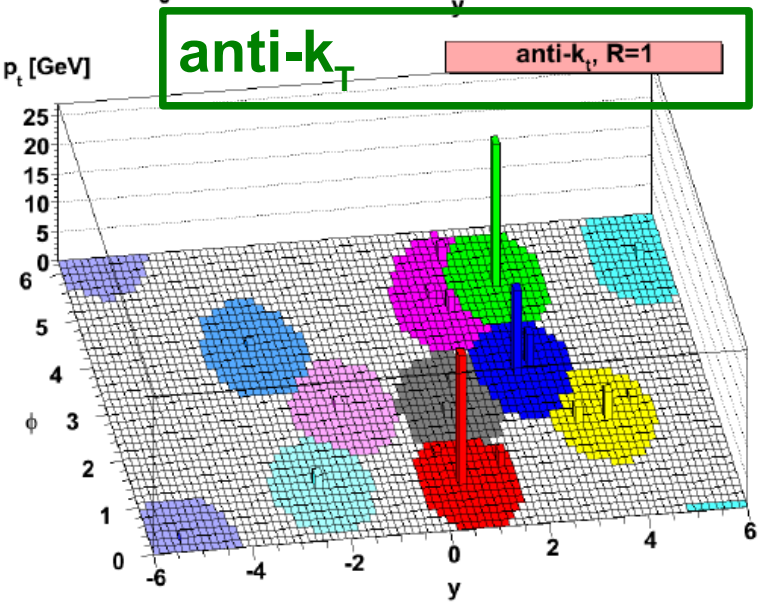
General interest to work with all four!

Only "real" cone algorithm!









Fast kT, Cacciari/Salam, PLB641, 2006
SISCone, Salam/Soyez, JHEP05, 2007
anti-kT, Cacciari et al., JHEP04, 2008

Jet Analysis Uncertainties

- **Experimental Uncertainties (~ in order of importance):**
  - Jet Energy Scale (JES)
    - Noise Treatment
    - Pile-Up Treatment
  - Luminosity: 3-5 % currently
  - Jet Energy Resolution (JER)
  - Trigger Efficiencies
  - Resolution in Rapidity
  - Resolution in Azimuth
  - Non-Collision Background
  - • • •

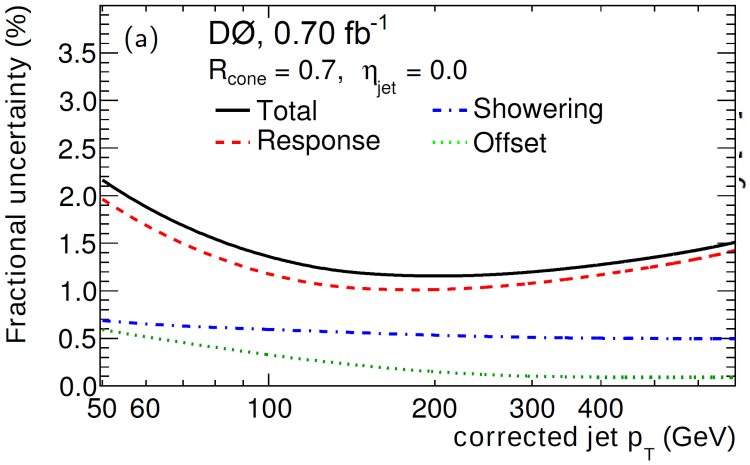
- **Theoretical Uncertainties:**
  - PDF Uncertainty
  - pQCD (Scale) Dependence
  - Non-perturbative Corrections
  - PDF Parameterization
  - NLO-NLL matching schemes
  - Electroweak Corrections
  - Knowledge of $\alpha_s(M_Z)$
  - • • •

There is a lot to learn here from Comparison to actual measurements!

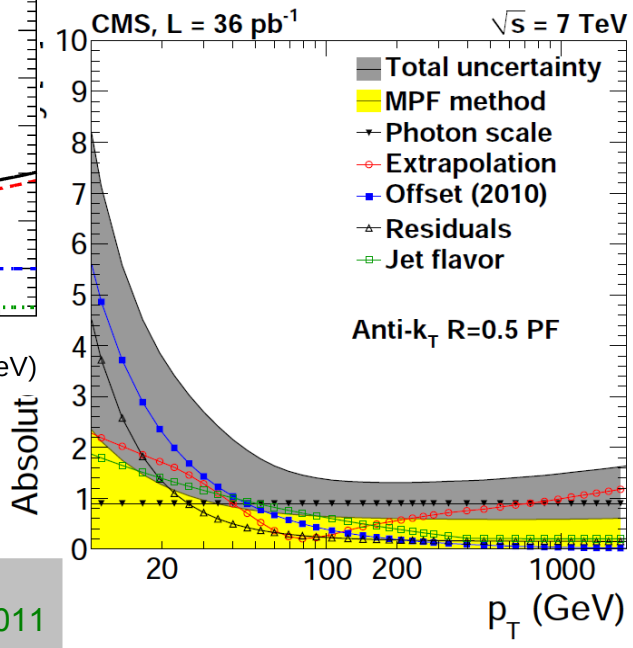
Jet Energy Scale

Dominant uncertainty for measurements of jet cross sections!
Enormous progress at Tevatron, and at LHC in just two years.
QCD at hadron colliders is becoming precision physics!

D0 from 0.7/fb (2011)

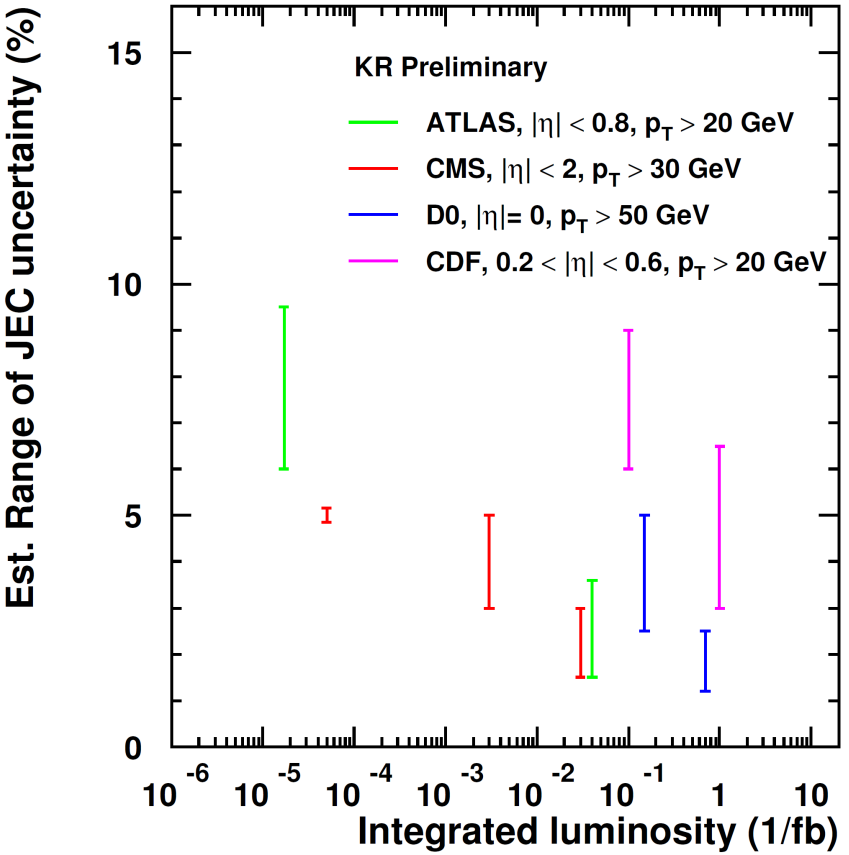


CMS from 36/pb (2010)

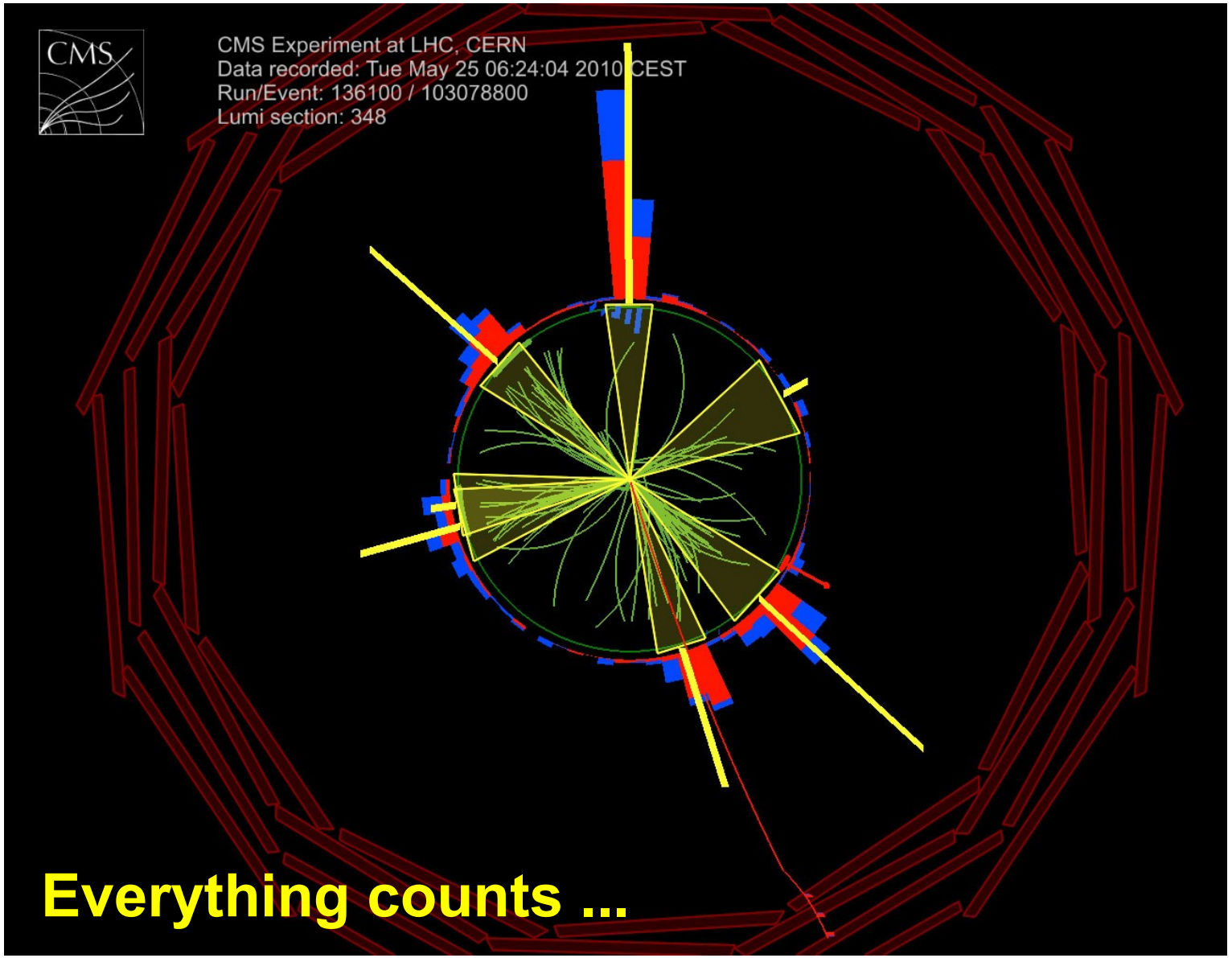


ATLAS, EPJC 71 2011; arXiv:1112.6297
CMS, JME-10-003; JME-10-010; JINST 6 2011
D0, arXiv:1110.3771; D0 prel. 2006

Development of JEC precision



All Inclusive



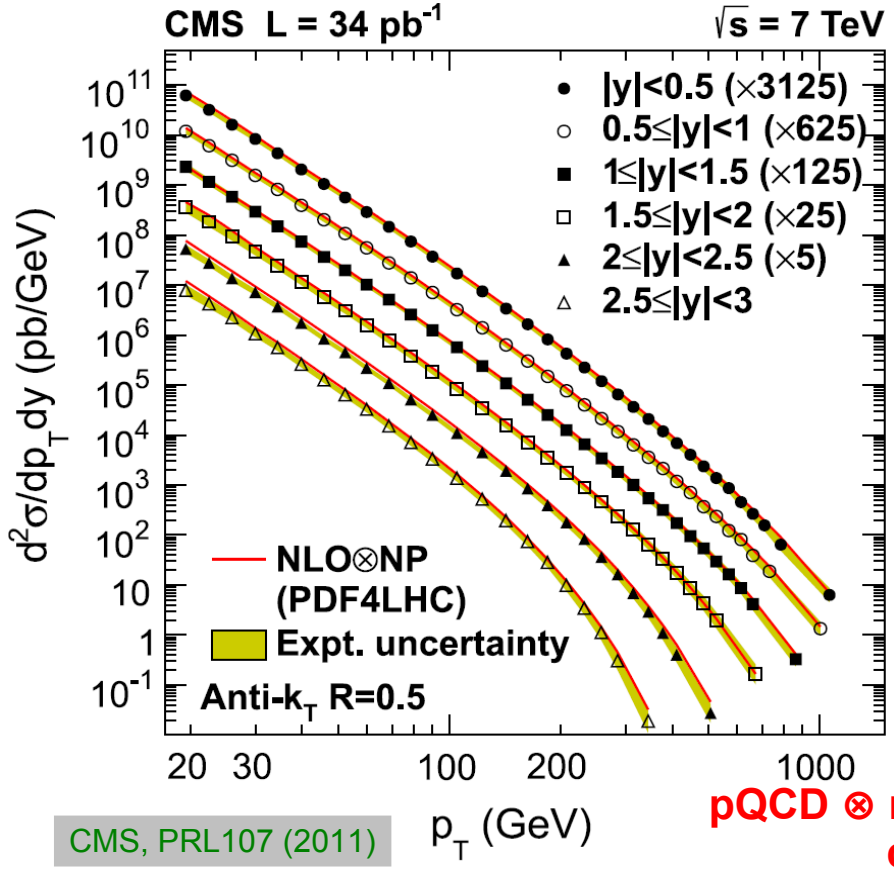
Inclusive Jets 2010

Roughly: Agreement with predictions of QCD

- up to rapities of about FIVE and over almost
- TWO orders of magnitude in jet p_T and
- TEN in jet cross section!

$$\frac{d^2\sigma}{dp_T dy} \propto \alpha_s^2$$

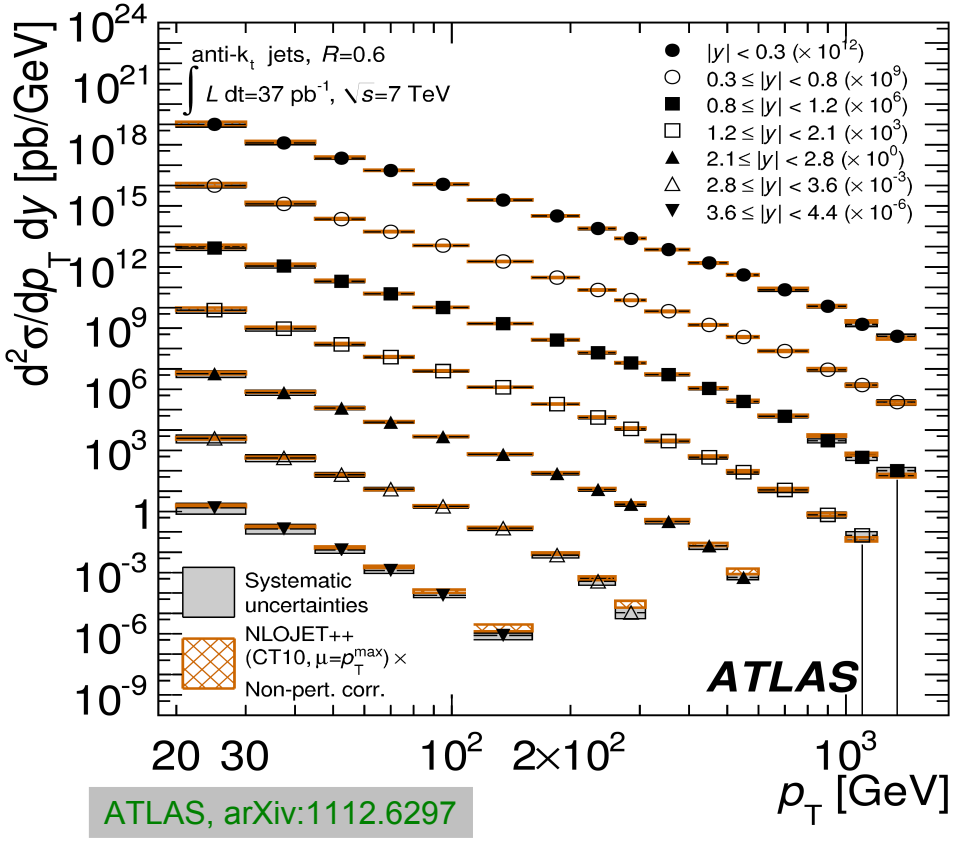
anti-kT, R=0.5



CMS, PRL107 (2011)

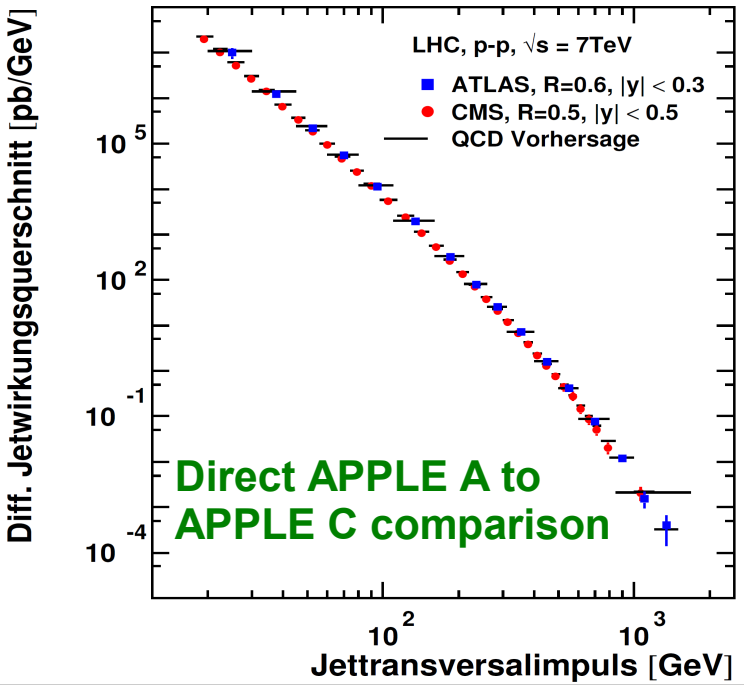
pQCD ⊗ non-perturbative corrections

anti-kT, R=0.6

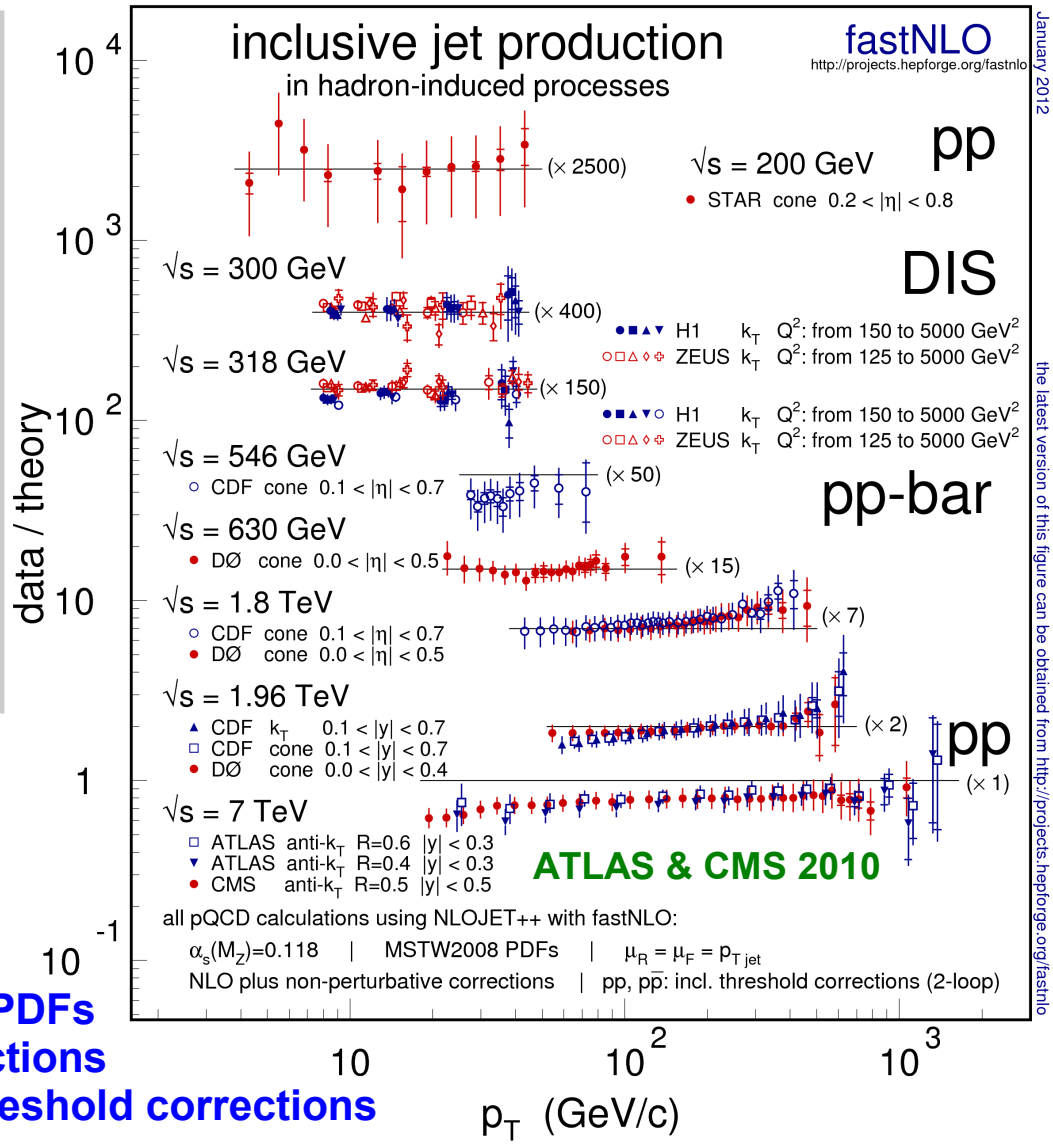


ATLAS, arXiv:1112.6297

Global Jet Comparison



ATLAS and CMS agree ... at least on a log scale :-)



- **Comparison of jet data from**
  - **STAR at RHIC**
  - **H1 and ZEUS at HERA**
  - **CDF and D0 at Tevatron**
  - **ATLAS and CMS at LHC**

MSTW2008 NLO PDFs
NLO ⊗ NP Corrections
Incl. Jets with threshold corrections

fastNLO, to be uploaded, arXiv:1109:1310v2, 2012

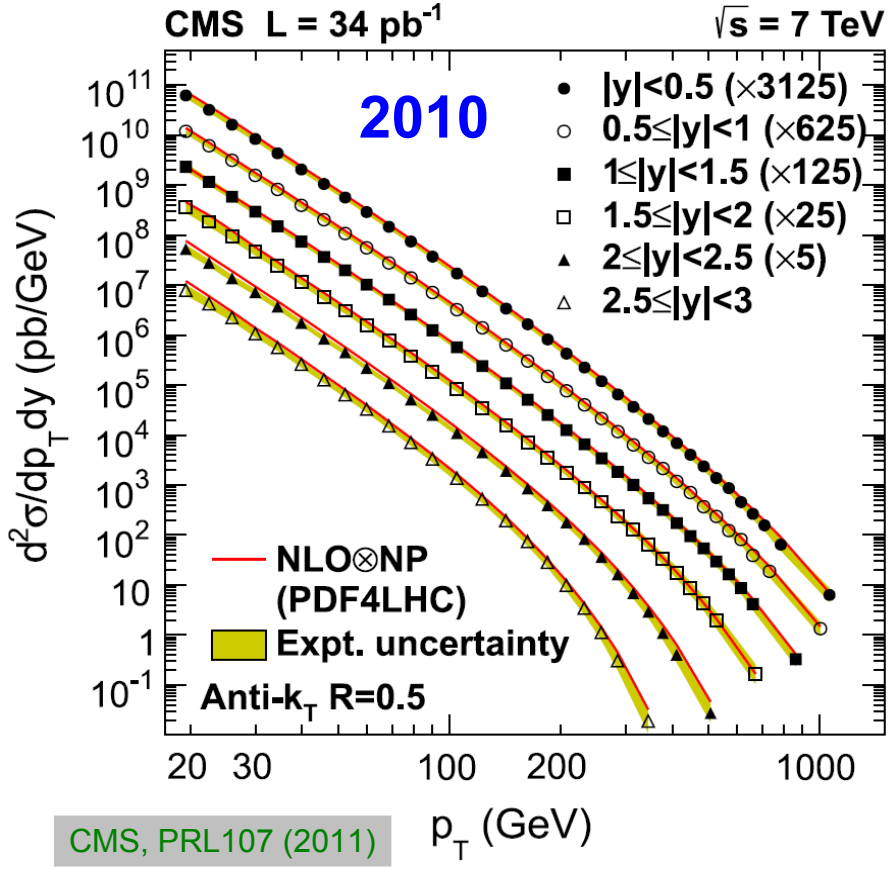
Inclusive Jets 2011

Brandnew: Preliminary results from CMS for 4.7 fb^{-1} of 2011

- **Jet p_T's up to 2 TeV**
- **Reduced jet energy scale uncertainty**
- **Correlations of uncertainties under study**

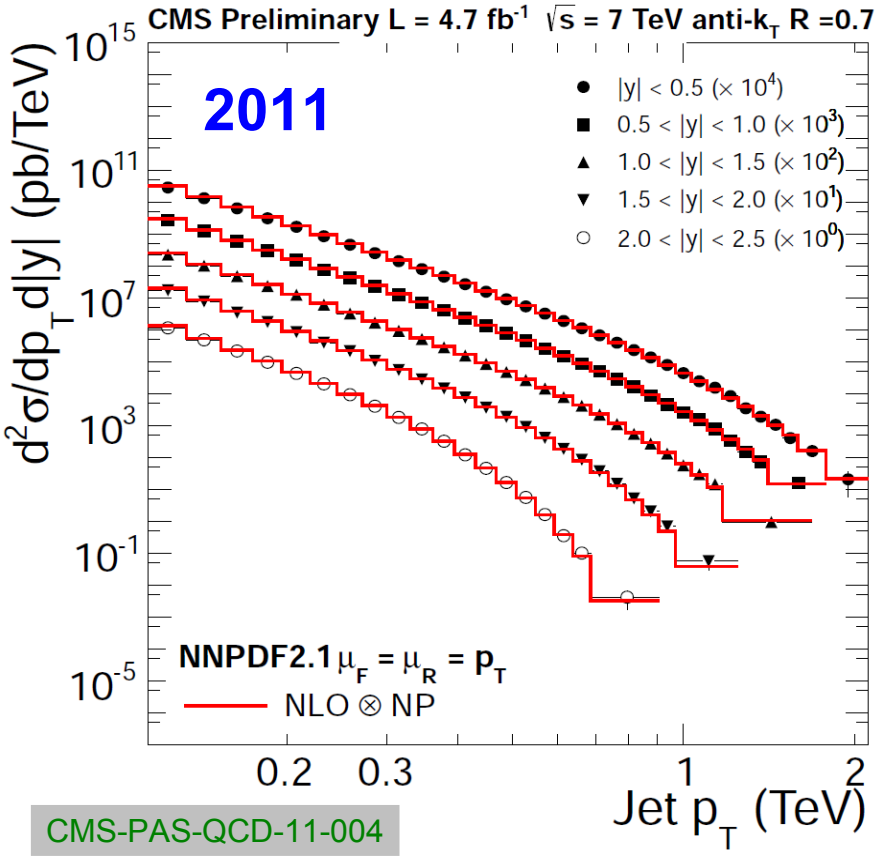
$$\frac{d^2\sigma}{dp_T dy} \propto \alpha_s^2$$

anti-kT, R=0.5



CMS, PRL107 (2011)

anti-kT, R=0.7



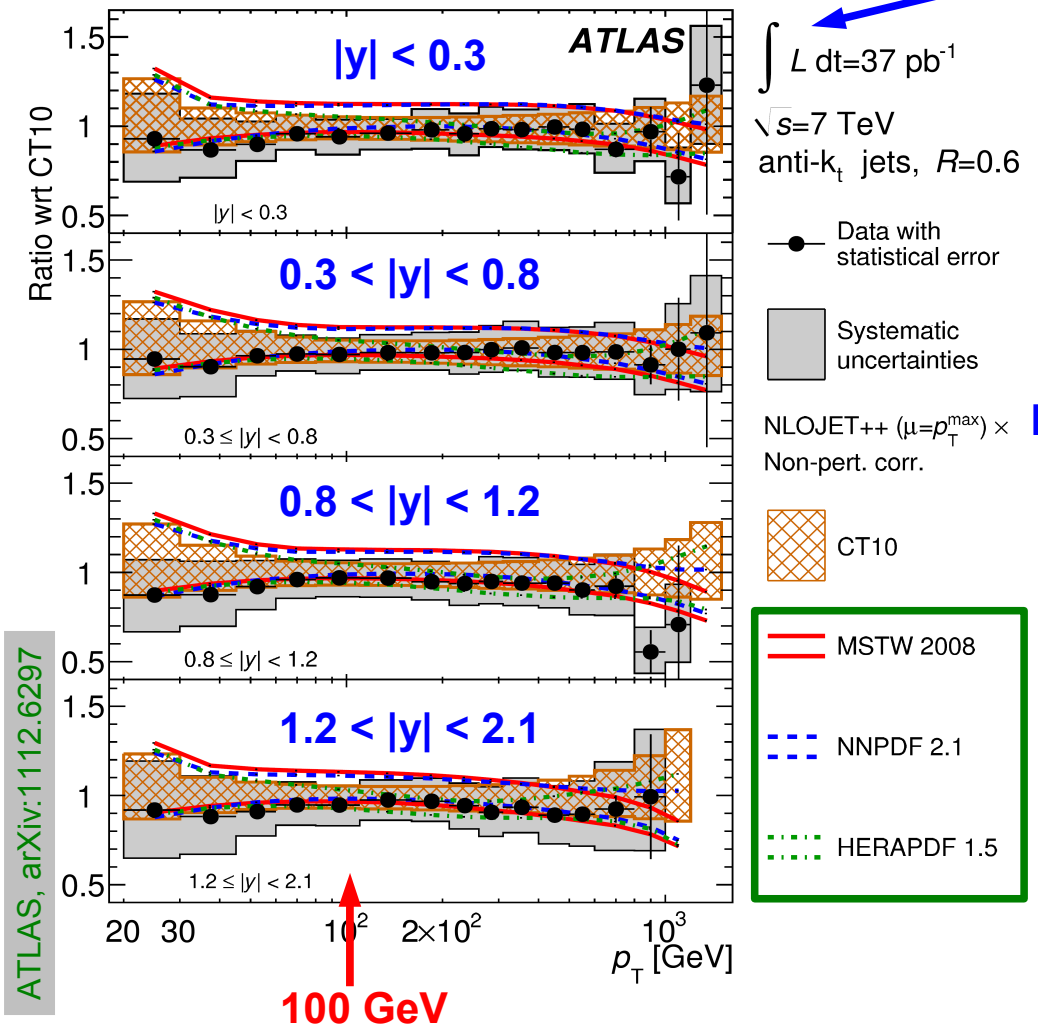
CMS-PAS-QCD-11-004

Detailed Comparison to PDFs

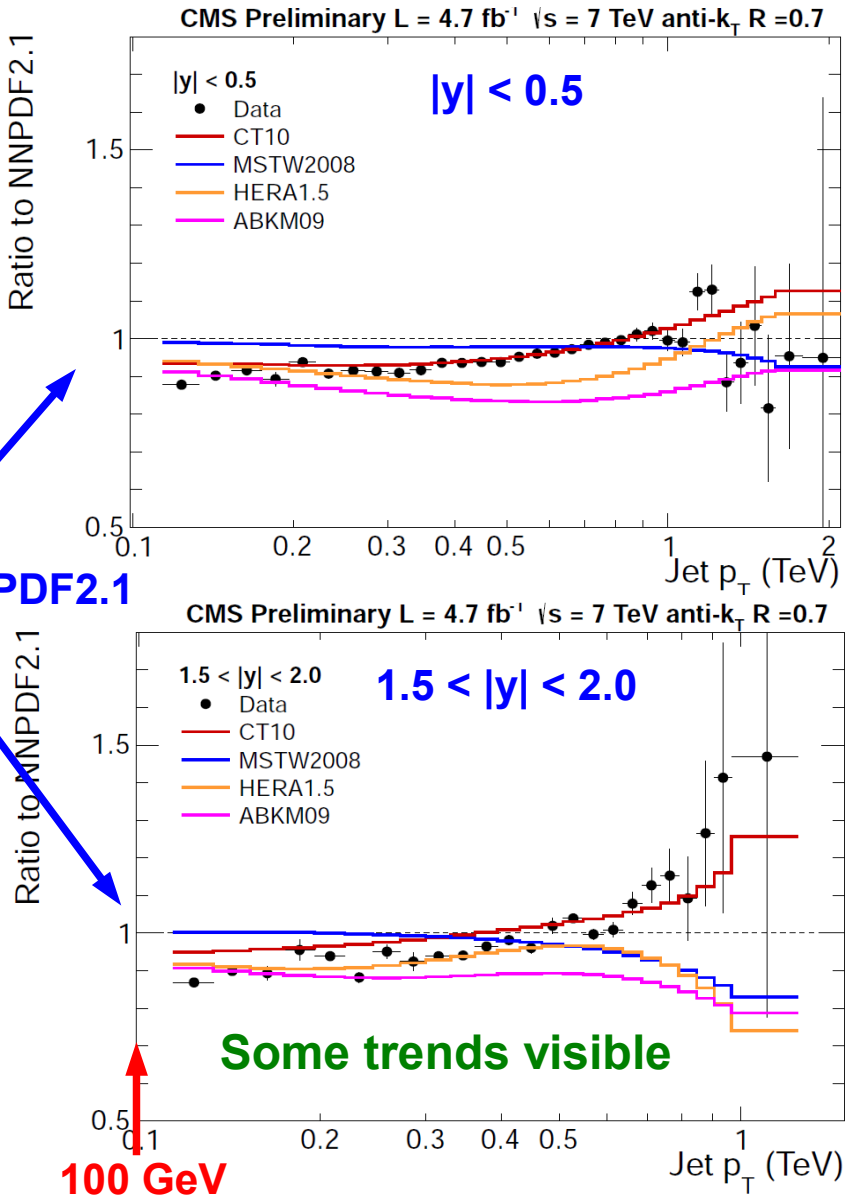
Compatibility with QCD using diverse PDFs

Ratio to CT10

R=0.6



Ratio to NNPDF2.1



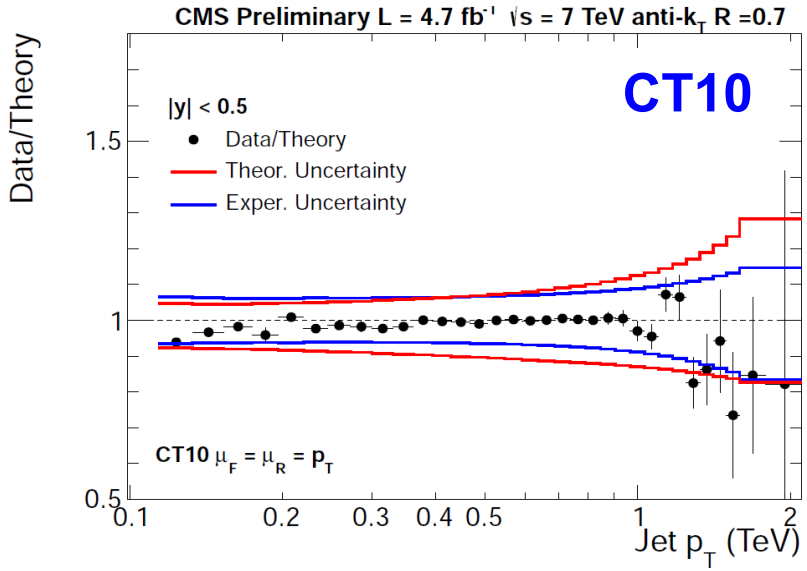
100 GeV

100 GeV

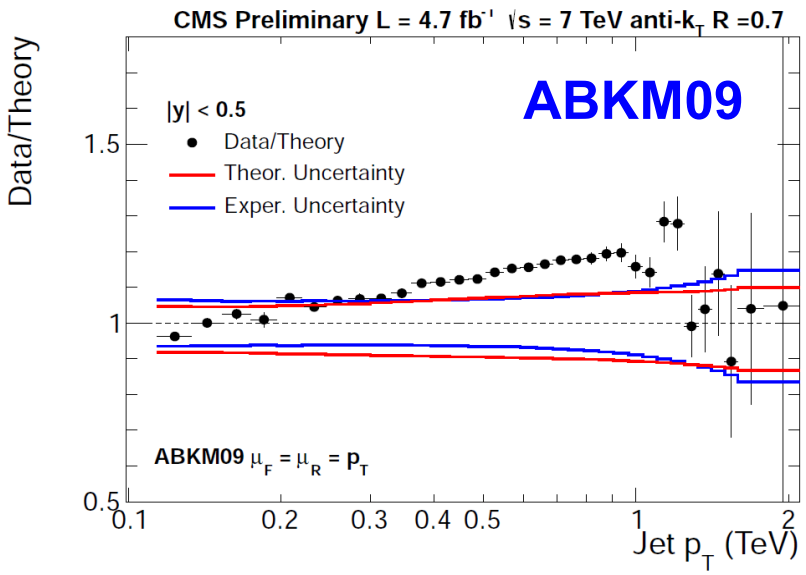
ATLAS, arXiv:1112.6297

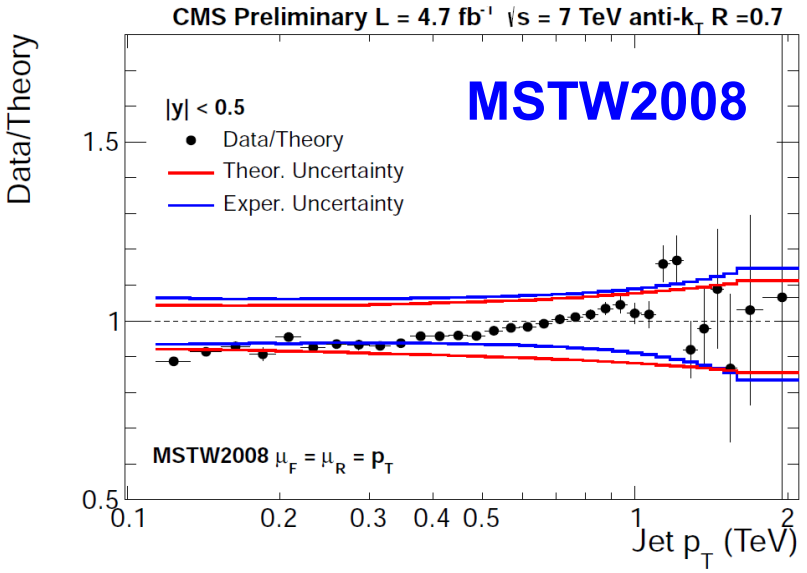
CMS-PAS-QCD-11-004

Comparison at |y| < 0.5



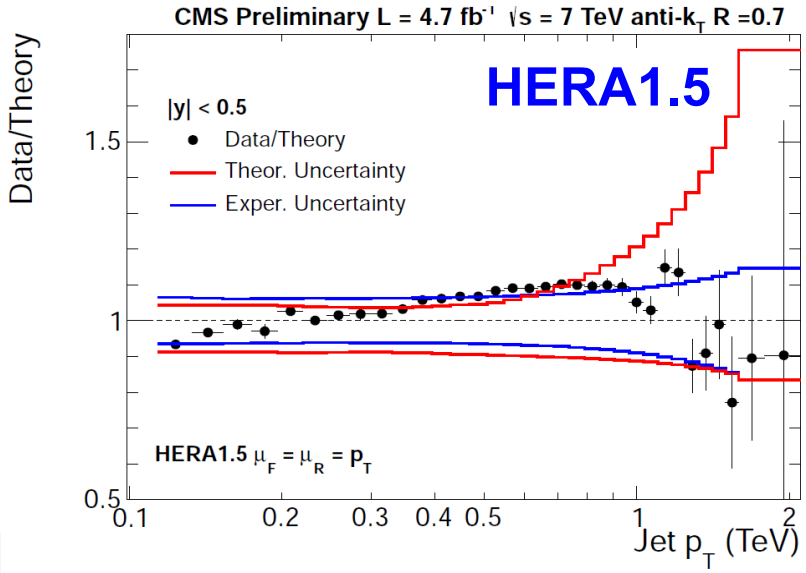
Inclusive Jets
|y| < 0.5





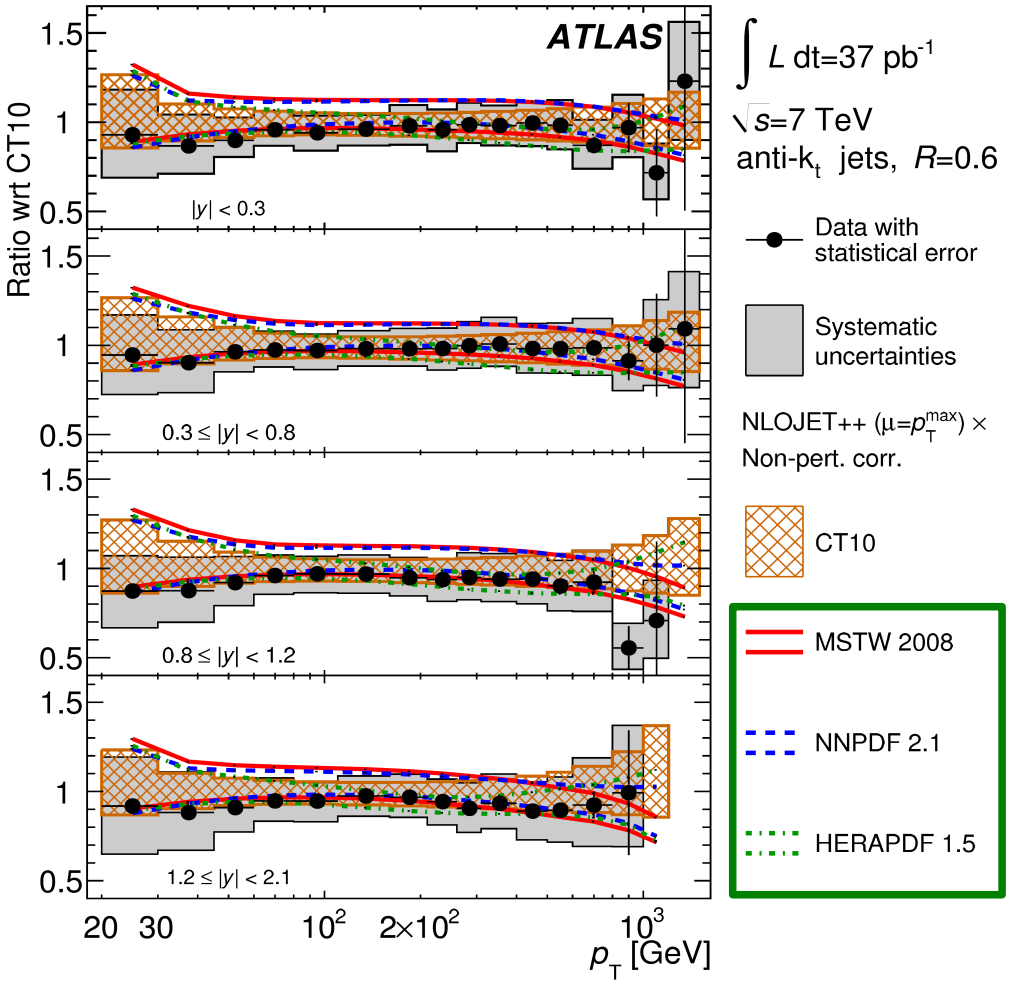
Backup Slide
1.5 < |y| < 2.0

CMS-PAS-QCD-11-004



PDFs and matched Showers

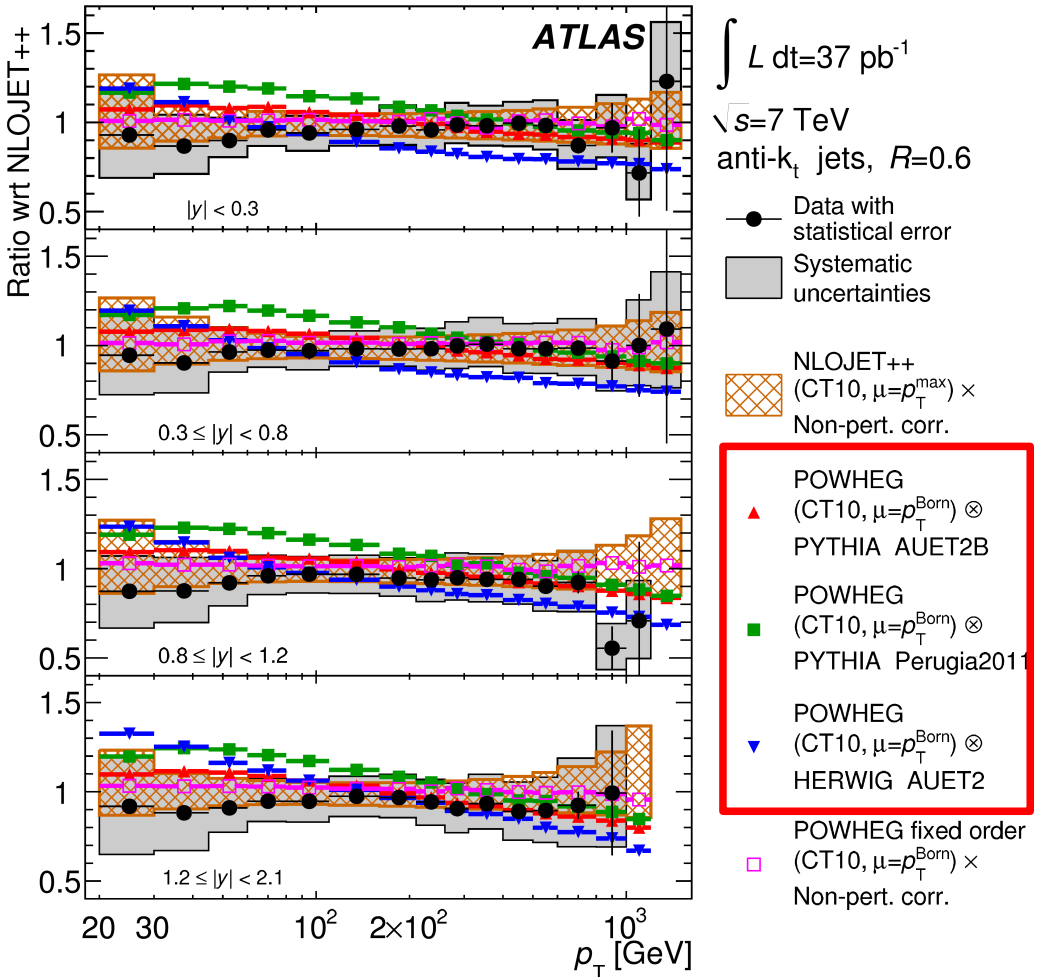
Compatibility with QCD using diverse PDFs



Agreement between NLO POWHEG vs. NLOJet++

POWHEG + matched parton showers ...

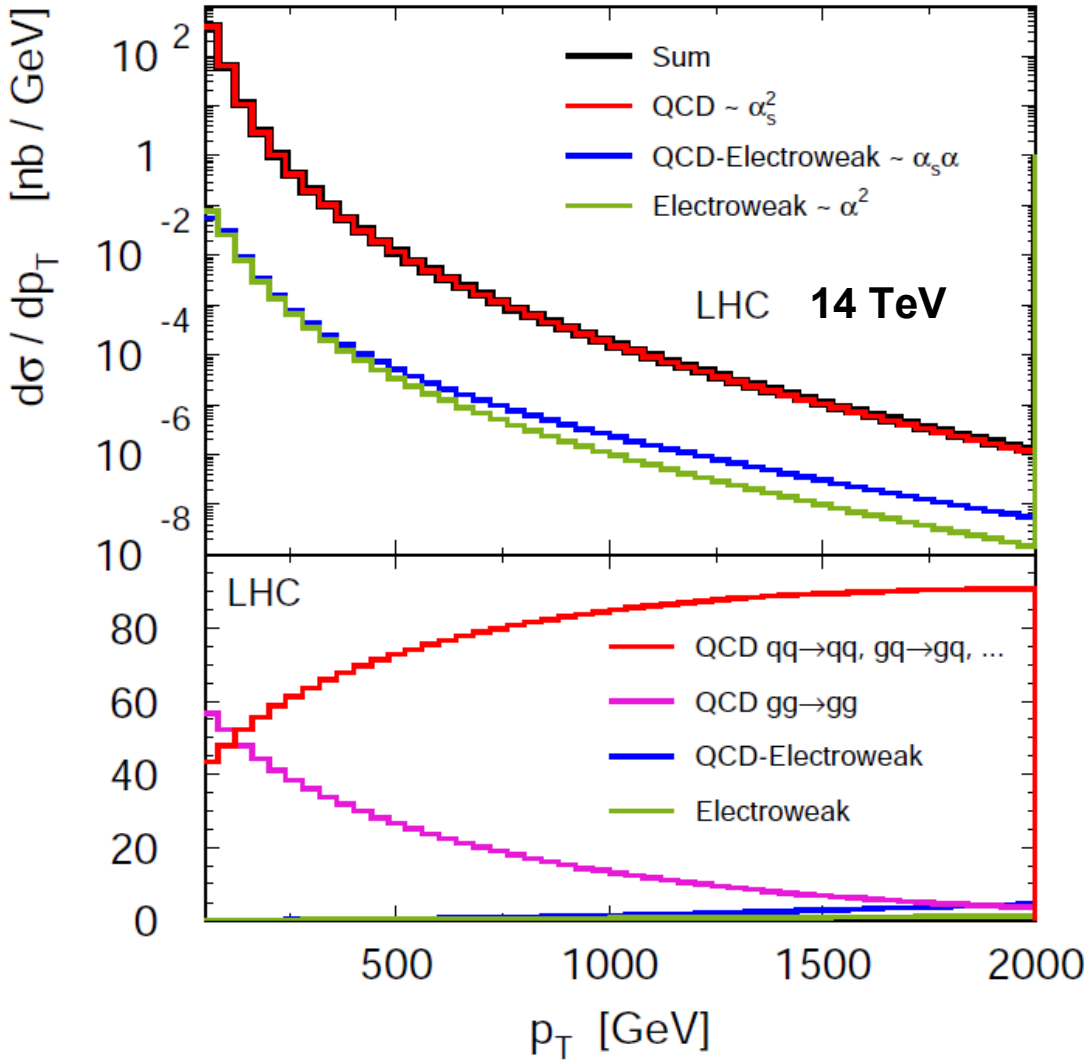
not a success story yet



POWHEG, S. Alioli et al., JHEP 1104 (2011)

Corrections at high pT ?

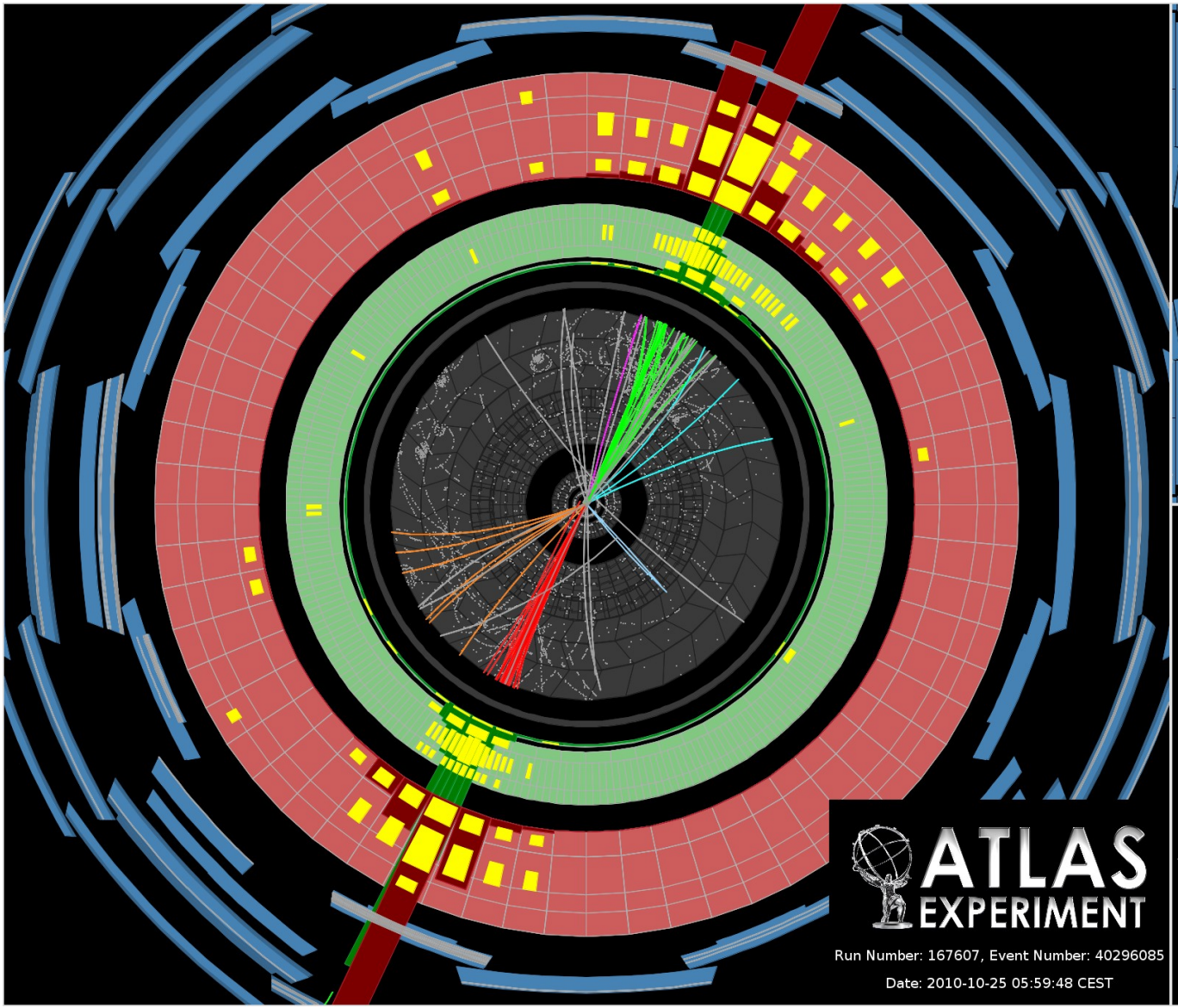
- More jet data to come from LHC at very high p_T
- Interesting comparisons to PDFs and extractions of αs to be made
- But need to think about
  - Electroweak corrections $\propto \alpha\alpha_s^2$ → effects up O(10%) ?
  - top as 6th flavour (NLOJet++ uses only 5)
  - Validity of evolution equations, could be modified by new physics

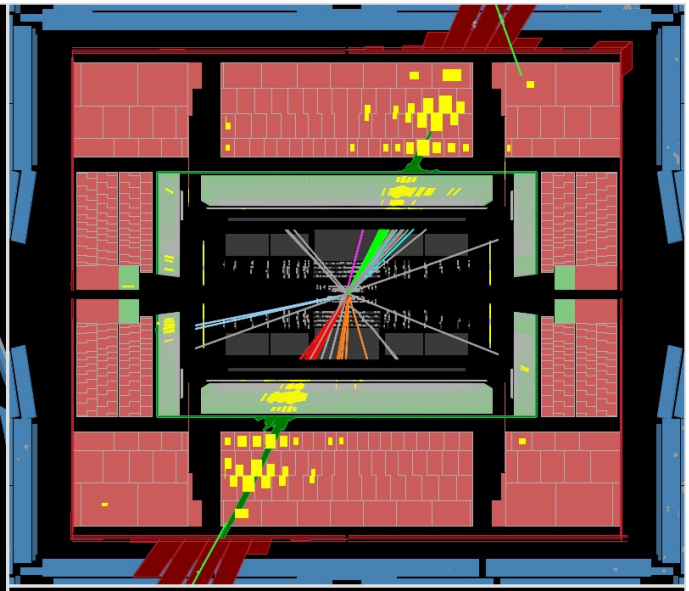


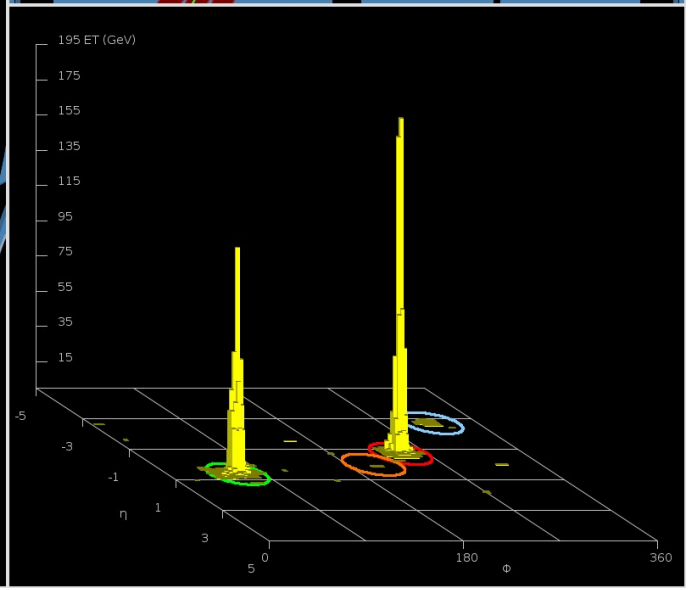
NLOJet++
Z.Nagy,
PRD68 2003
PRL88 2002

A. Scharf, arXiv:0910.0223

Just the two of us





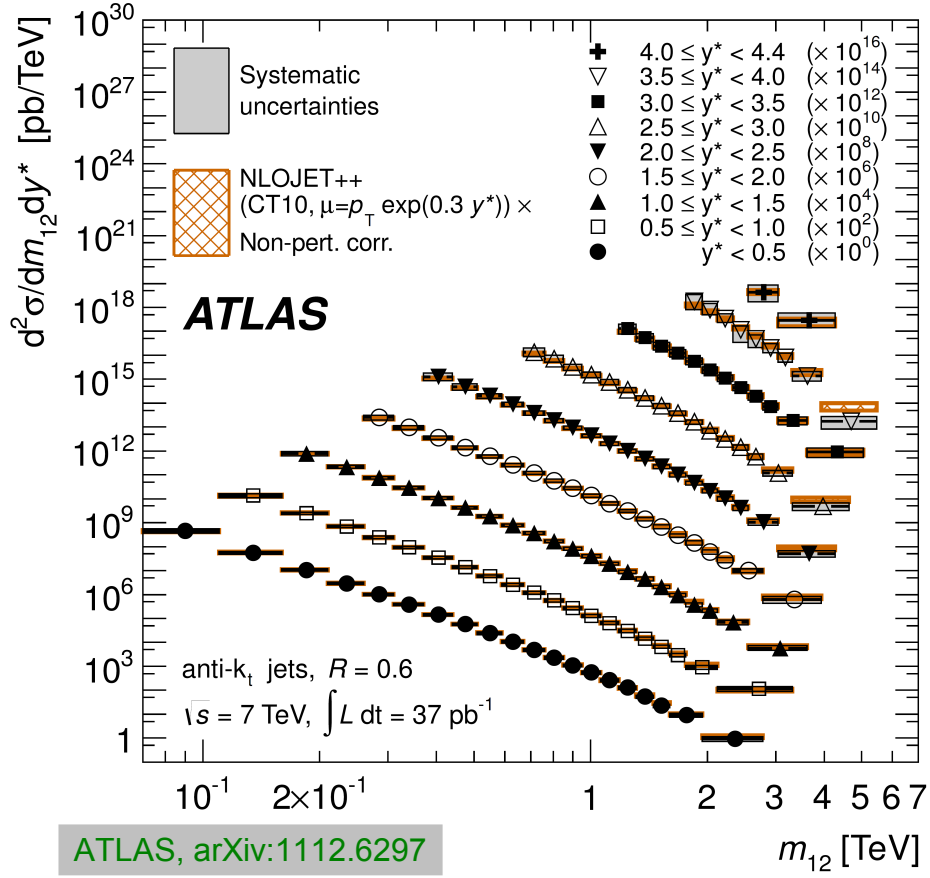


Dijet Mass 2010

Again: Agreement with predictions of QCD over many orders of magnitude in σ and M_{JJ}

$$\frac{d^2\sigma}{dM_{JJ}dy^*} \propto \alpha_s^2$$

anti-kT, R=0.6

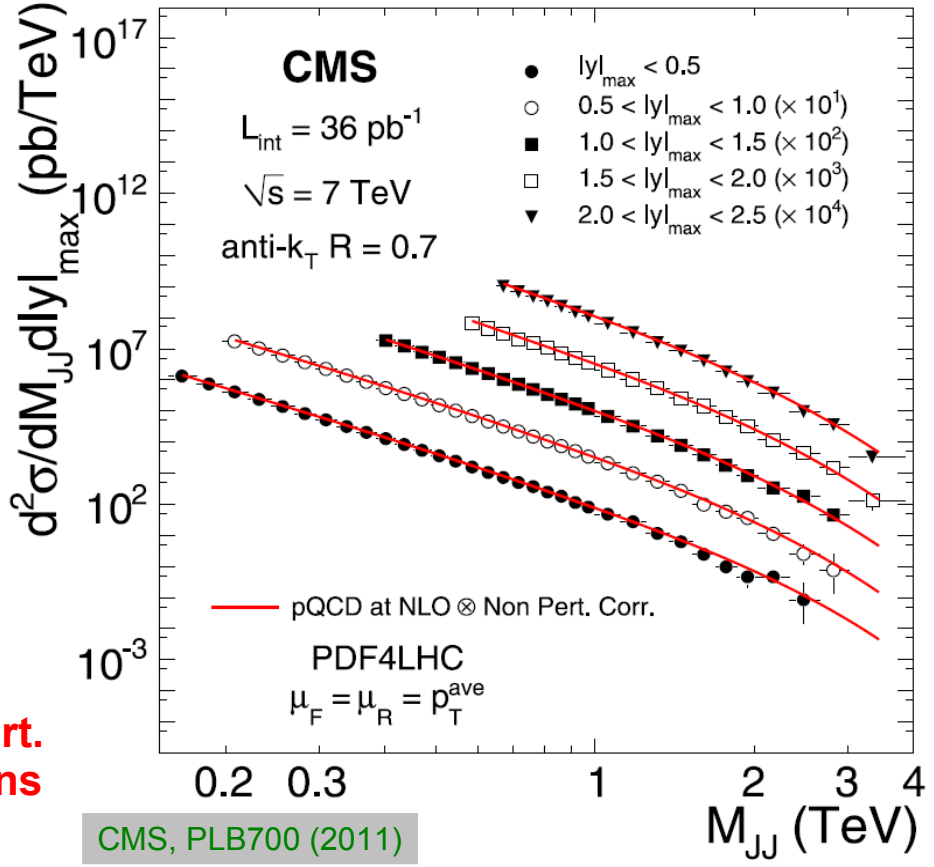


ATLAS, arXiv:1112.6297

pQCD ⊗ non-pert. corrections

$$\frac{d^2\sigma}{dM_{JJ}d|y_{max}|} \propto \alpha_s^2$$

anti-kT, R=0.7



CMS, PLB700 (2011)

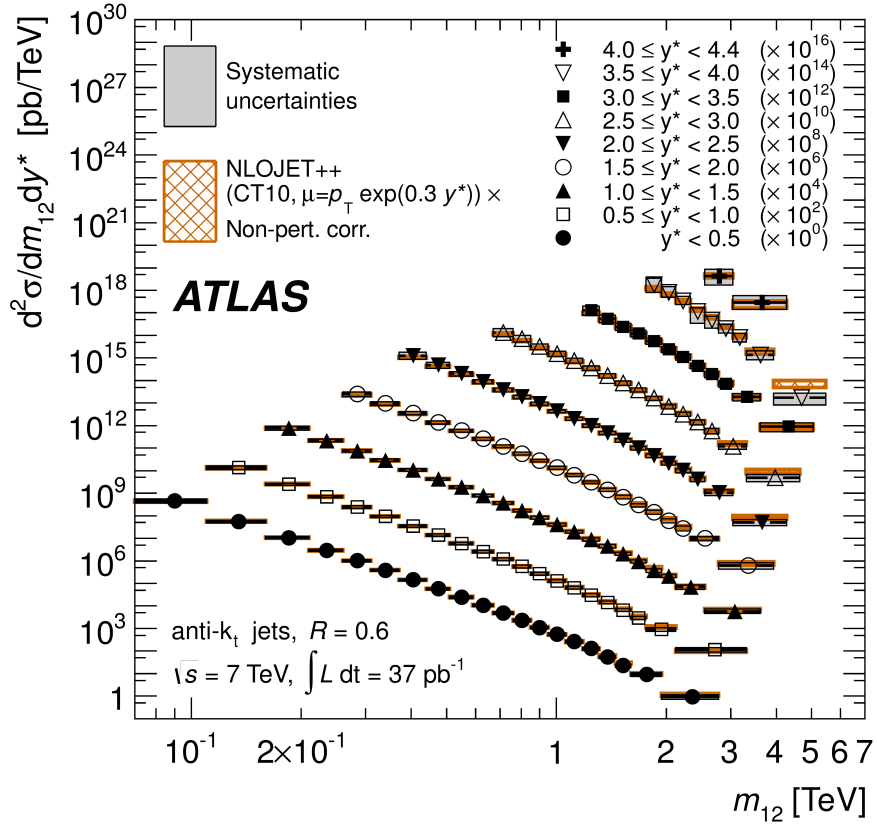
Dijet Mass ATLAS

$$\frac{d^2\sigma}{dM_{JJ}dy^*} \propto \alpha_s^2$$

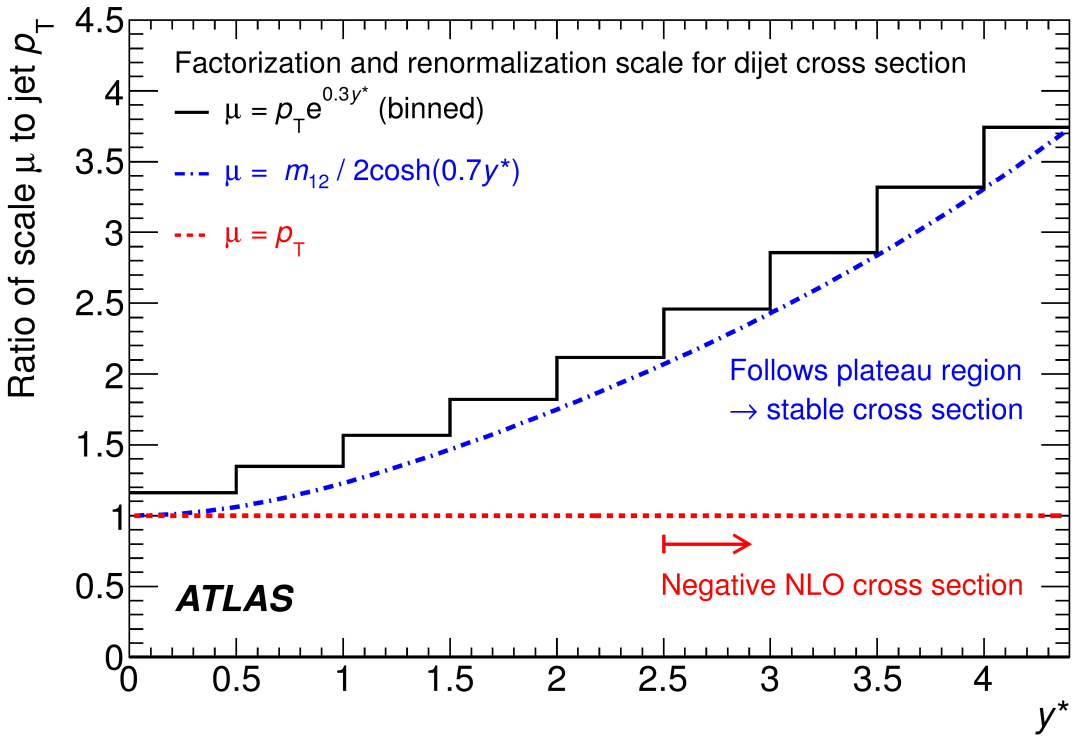
New choice for binning in rapidity by ATLAS
Also new choice for scale setting

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

$$y^* = \frac{1}{2}|y_1 - y_2| = \frac{1}{2}\ln\left(\frac{1+|\cos\Theta^*|}{1-|\cos\Theta^*|}\right)$$



Attention: Figure somewhat misleading ...
Negative NLO cross sections appear when checking scale uncertainties μ → μ/2

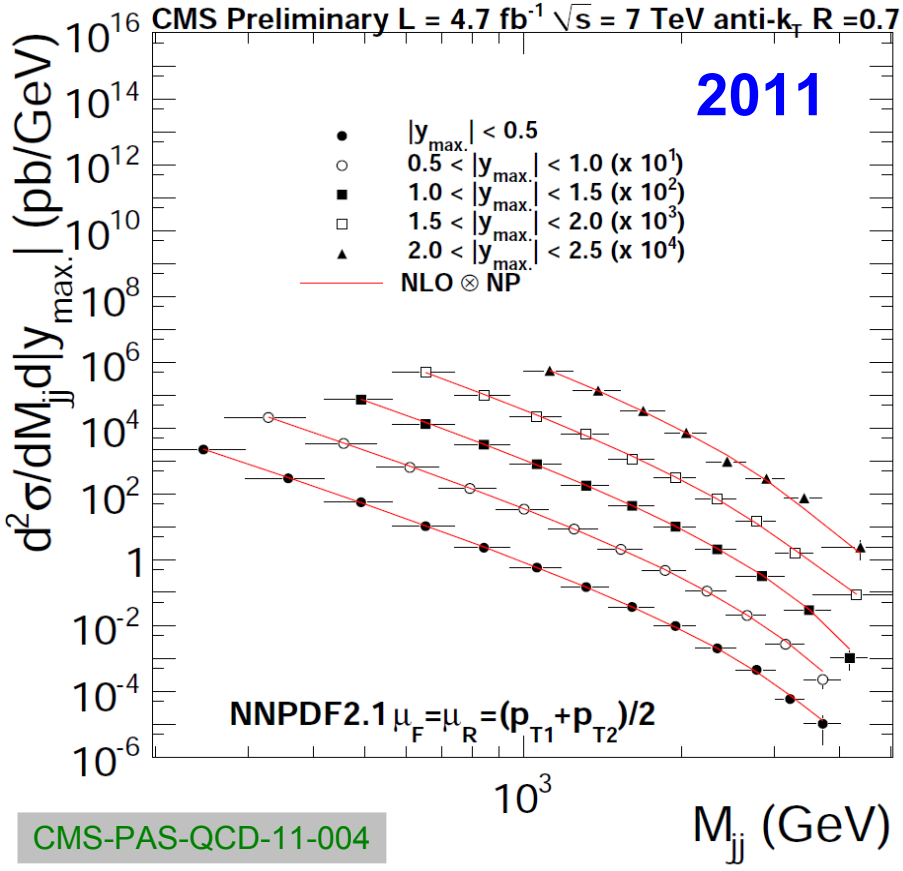


Dijet Mass 2011

Again new: Preliminary results from CMS for 4.7 fb^{-1} of 2011

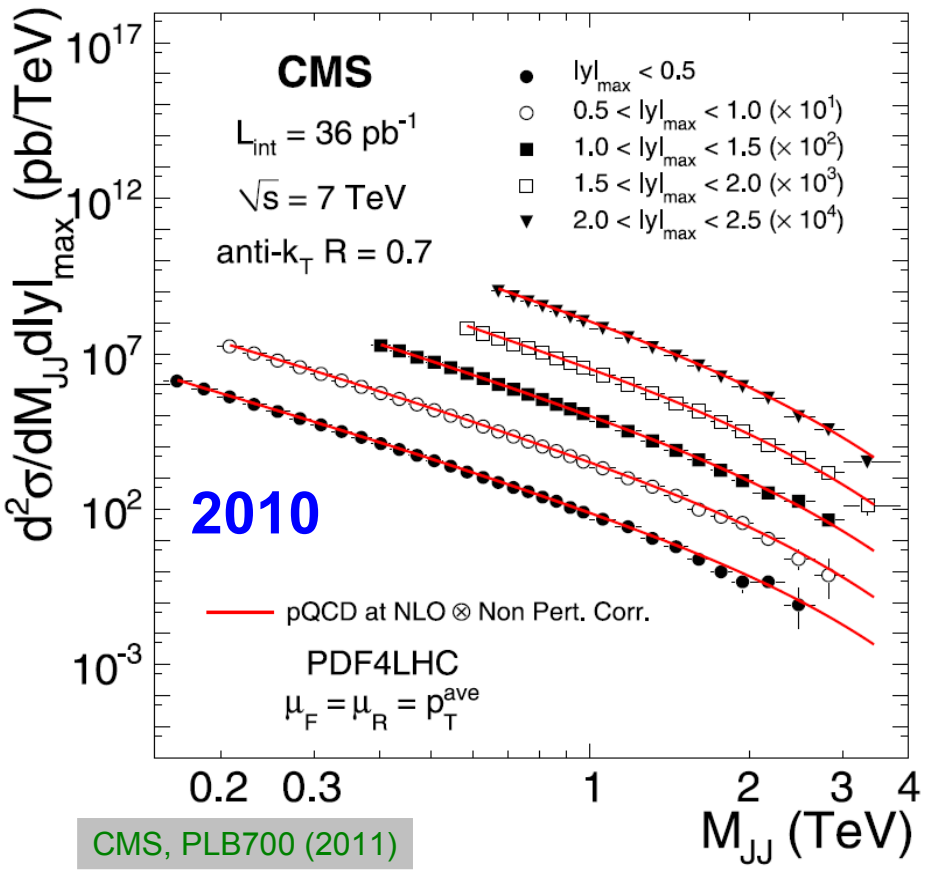
- Dijet masses up to 5 TeV
- Reduced jet energy scale uncertainty
- Correlations of uncertainties under study

anti-kT, R=0.7



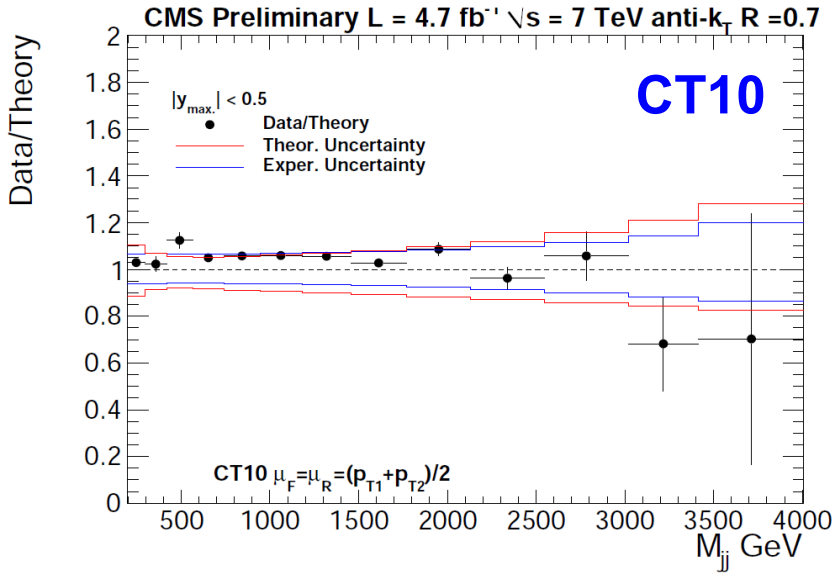
CMS-PAS-QCD-11-004

anti-kT, R=0.7

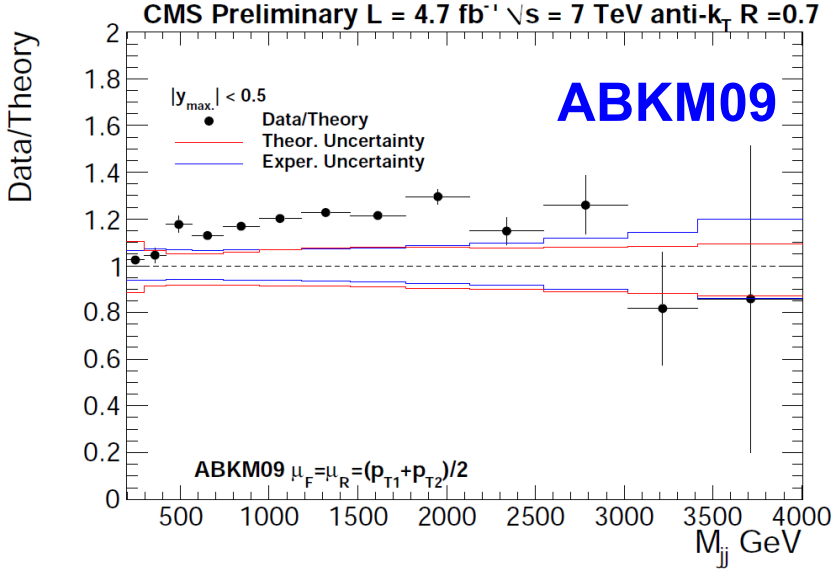


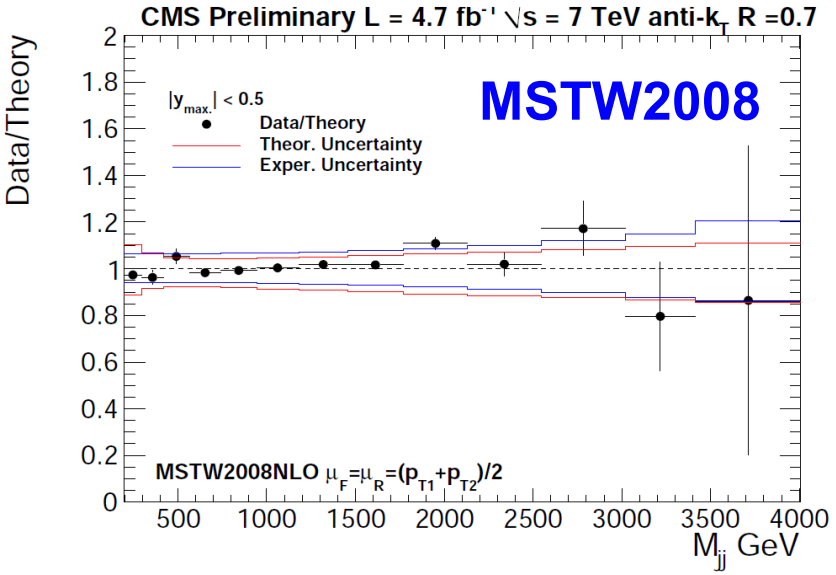
CMS, PLB700 (2011)

Comparison at $|y_{max}| < 0.5$

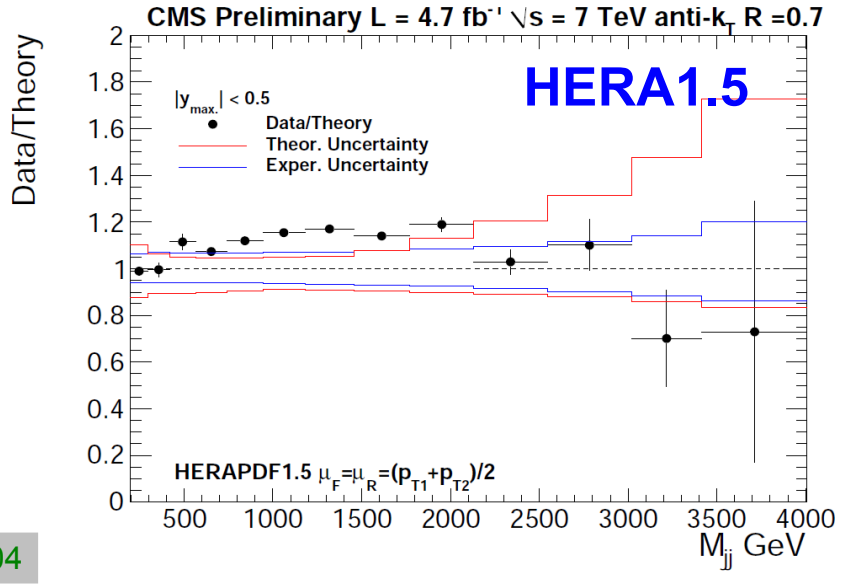


Dijet Mass
$|y_{max}| < 0.5$



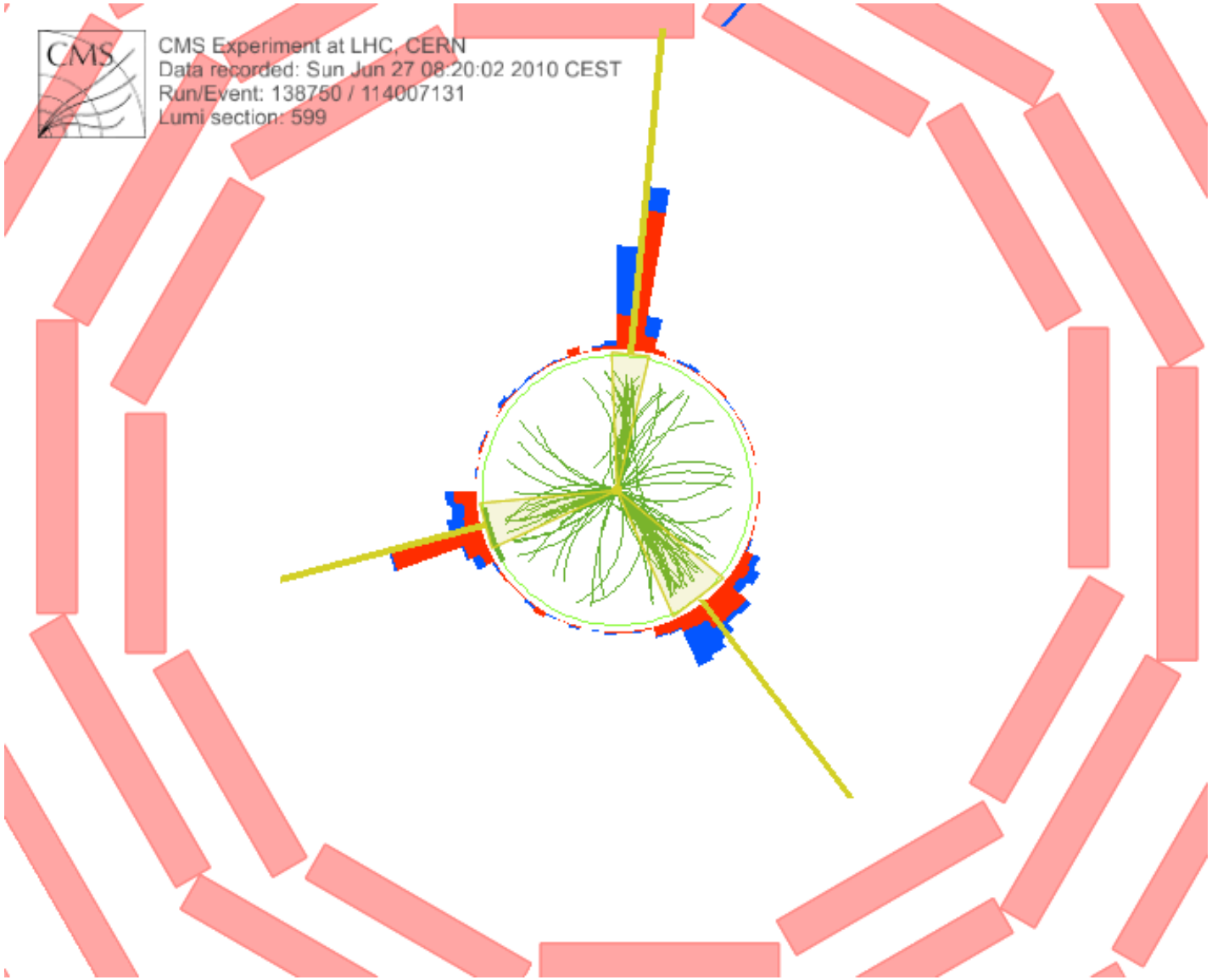


Dijet Mass
$|y_{max}| < 0.5$



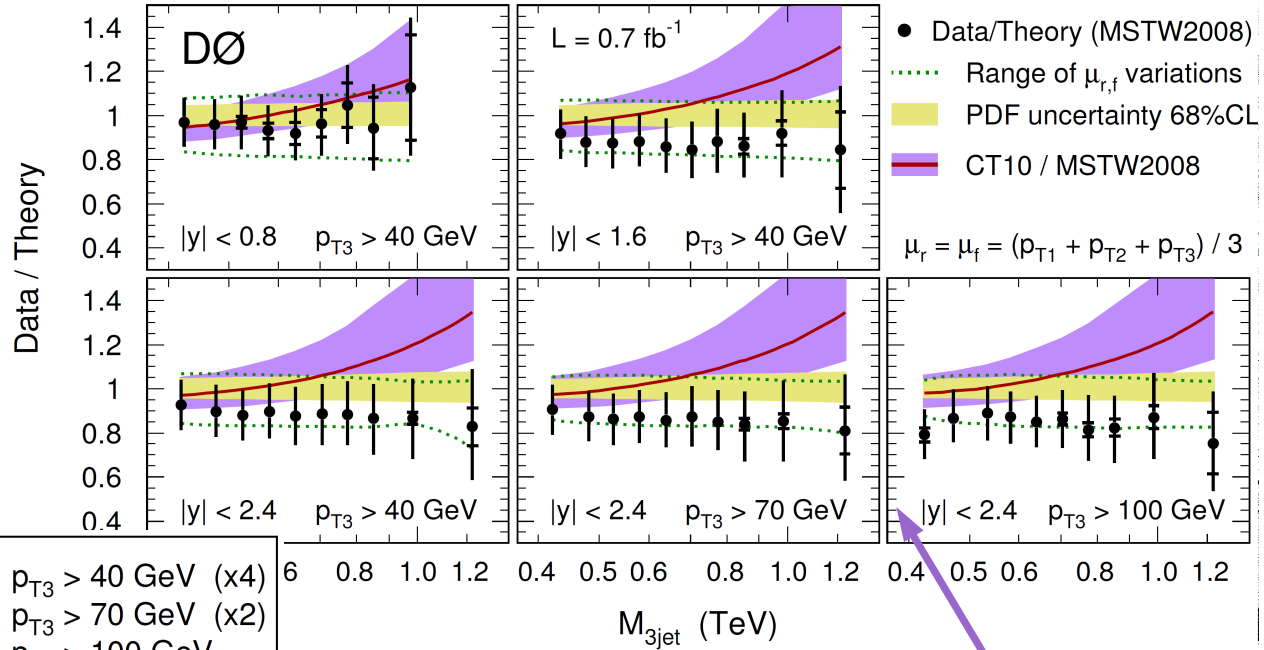
CMS-PAS-QCD-11-004

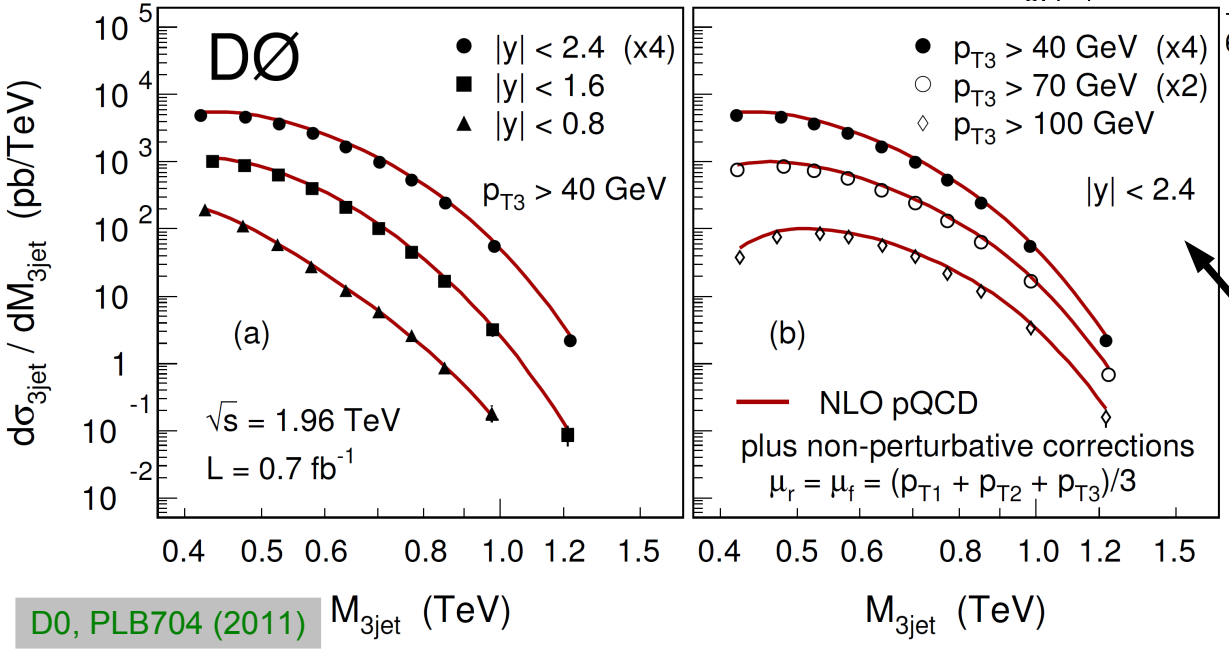
1 + 1 = 3


CMS
CMS Experiment at LHC, CERN
Data recorded: Sun Jun 27 08:20:02 2010 CEST
Run/Event: 138750 / 114007131
Lumi section: 599

3-Jet Mass - not from LHC yet

- Sensitive to α_s beyond 2→2 process
- Known at NLO (NLOJet++)
- Sensitive to PDFs
- Involves additional "scale" $p_{T,3}$





D0, PLB704 (2011)

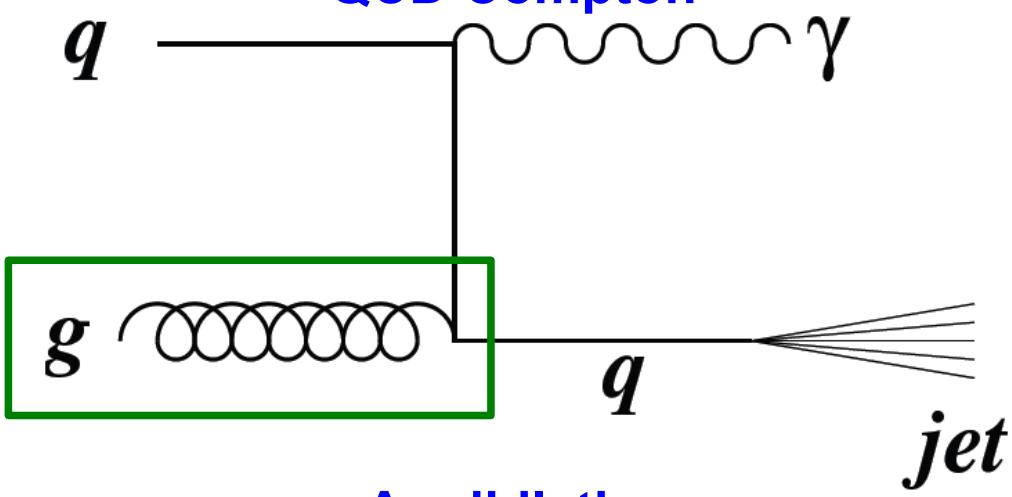
Most PDFs work ok, CT10 is off

D0 investigated 3 different lower pT thresholds $p_{T,3}$ and 3 max. rap. y

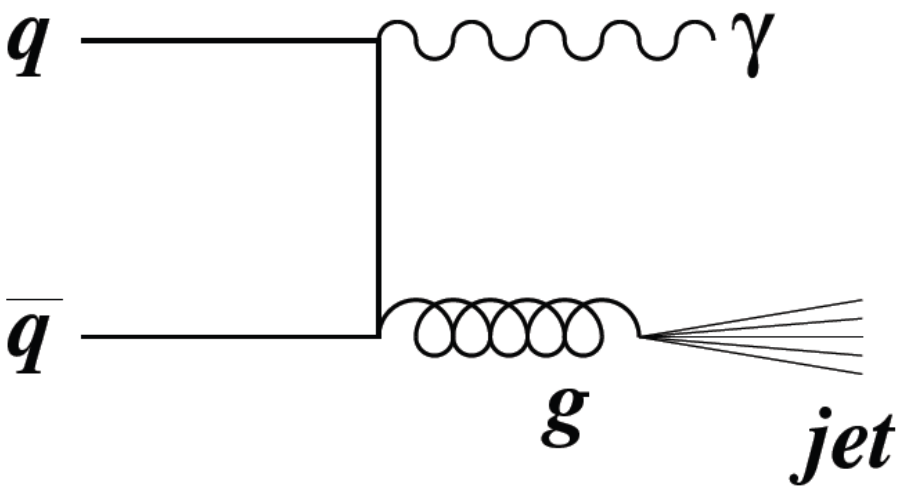
$$\frac{d\sigma_{3jet}}{dM_{3jet}} \propto \alpha_s^3$$

Isolated Prompt Photons

QCD Compton



Annihilation

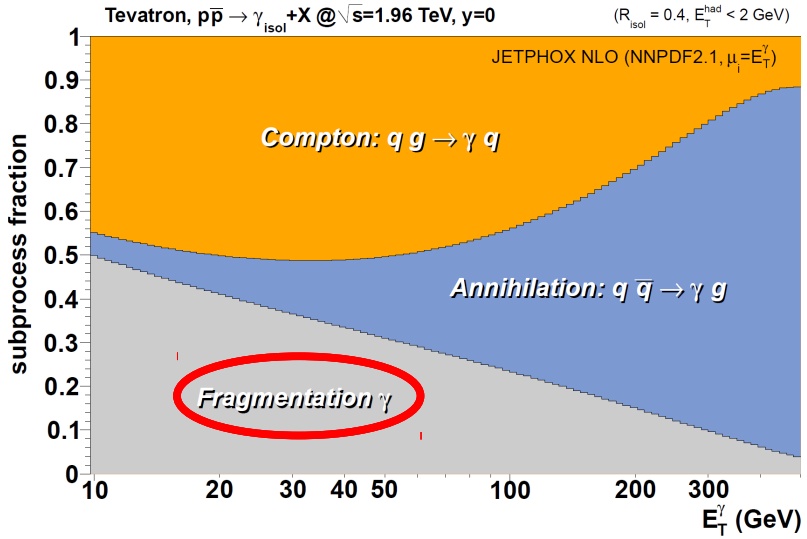


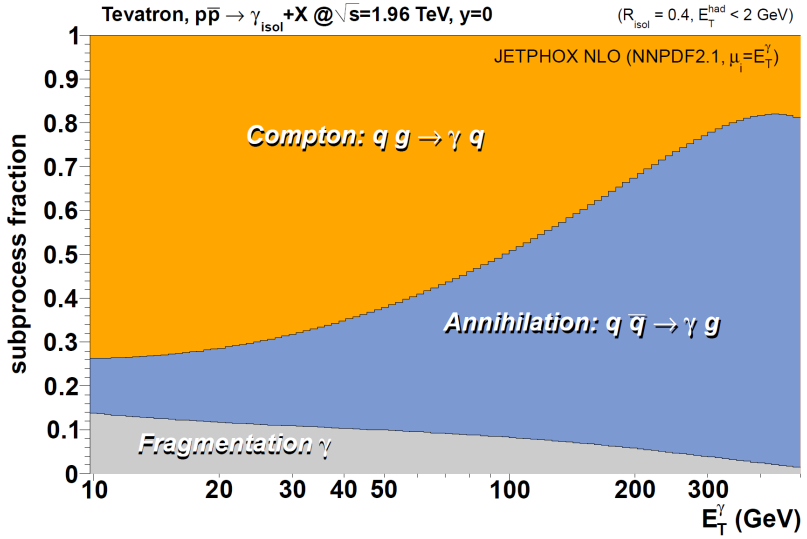
Signal Process Fractions

Inclusive

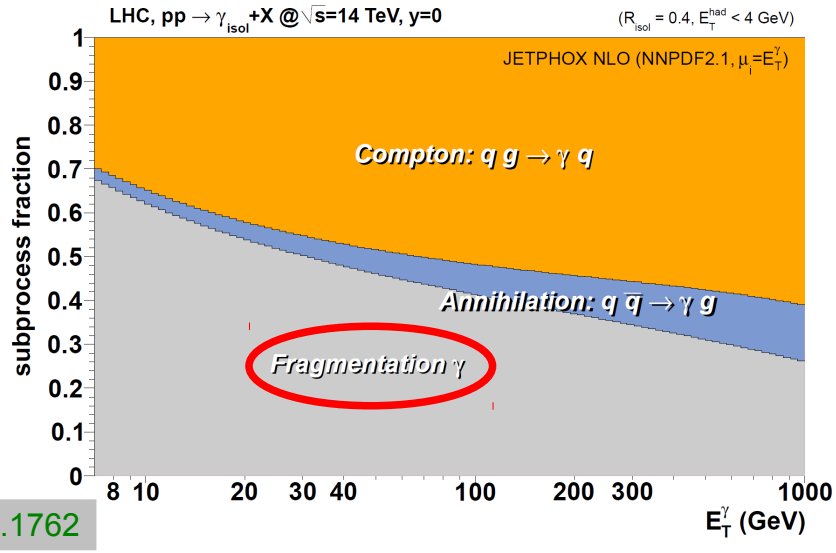
Isolated

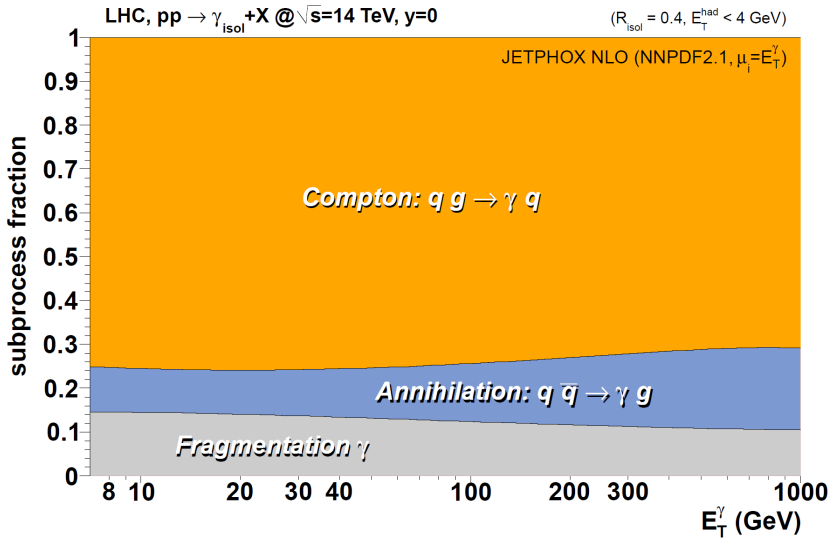
Tevatron





LHC 14 TeV





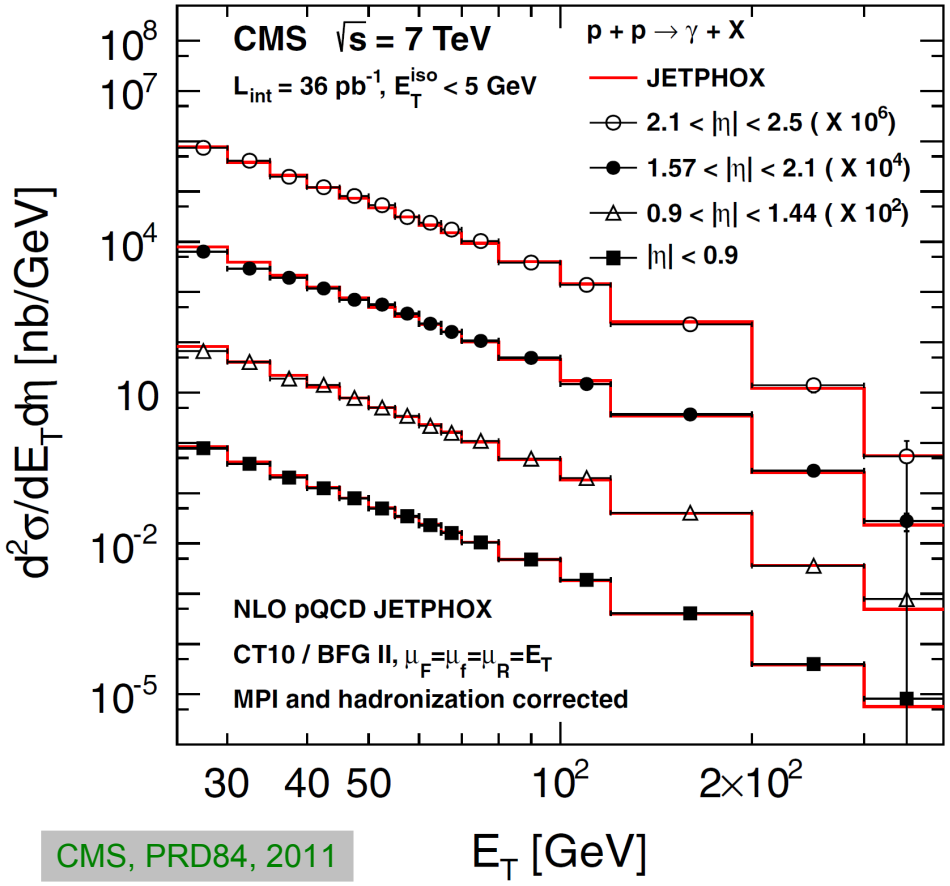
Background: Non-prompt Photons from Decays, e.g. π^0, η

d'Enterria, Rojo, arXiv:1202.1762

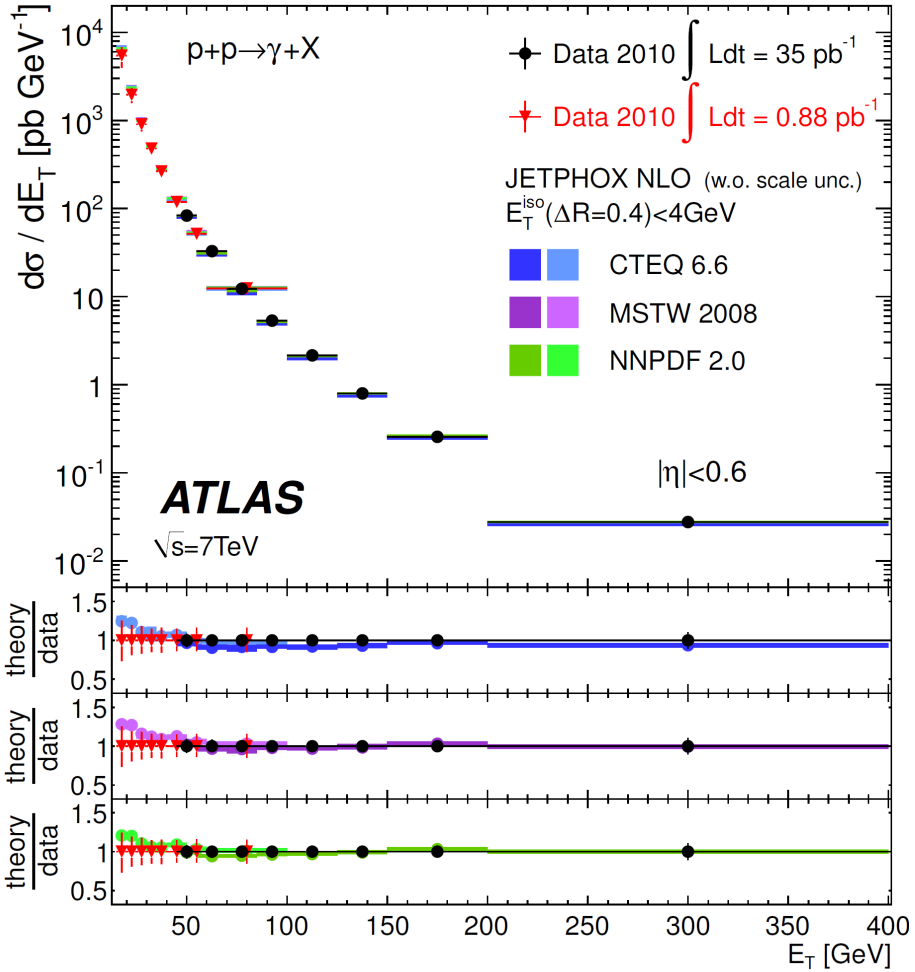
Isolated Prompt Photons

- Sensitive to the gluon density in the proton.
- In agreement with NLO (JetPhox) from ~25 up to 400 GeV, $|\eta| < 2.5$
- Limiting factor: Scale uncertainties in theory

JetPhox, Catani et al., JHEP05, 2002



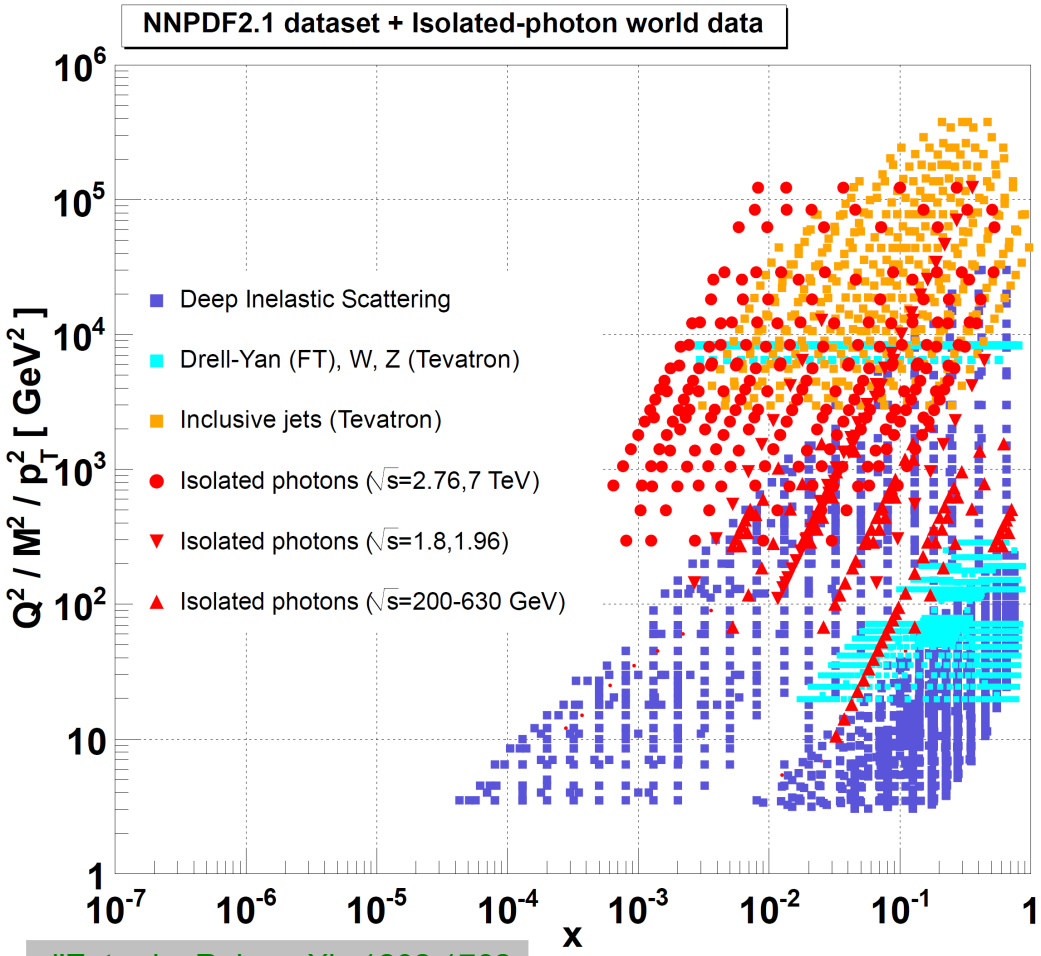
CMS, PRD84, 2011



ATLAS, PLB706, 2011:ATL-PHYS-PUB-2011-013

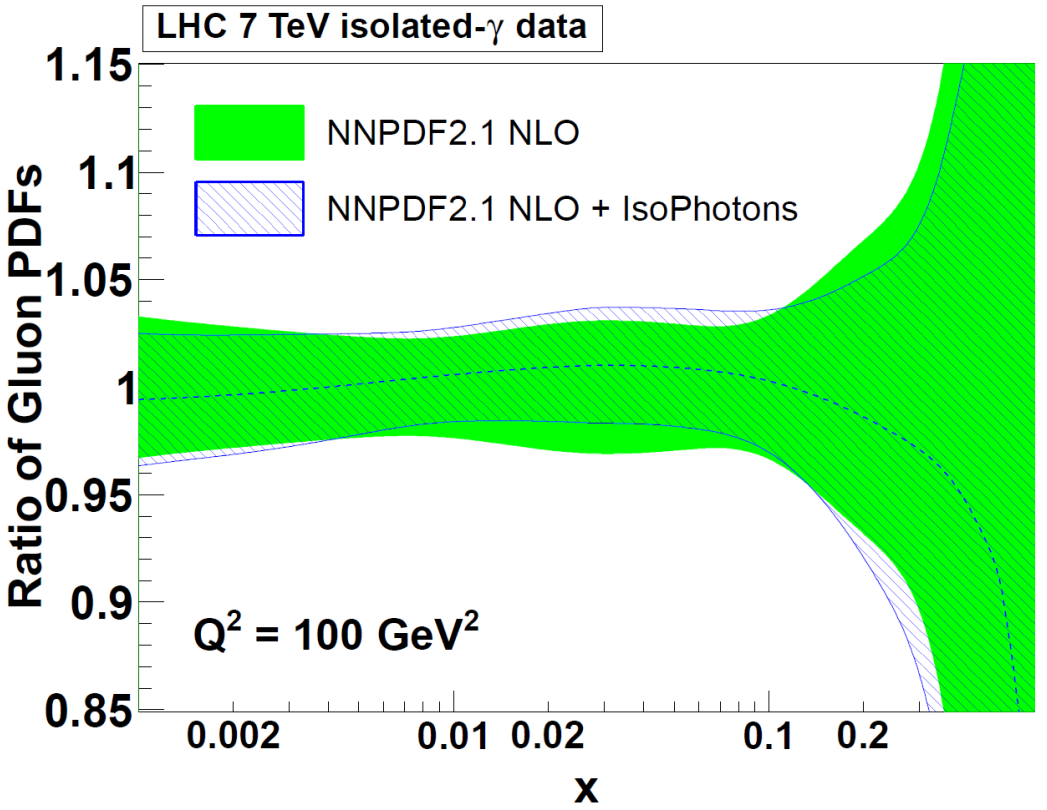
Photons and PDFs

Kinematic plane including photon data



d'Enterria, Rojo, arXiv:1202.1762

- Were abandoned for PDF fits due to discrepancies with fixed target experiments at E_{cms} of 20 – 40 GeV
- new investgation without inclusive data and At E_{CMS} > 200 GeV
- Moderate reduction in uncertainty of the gluon density at x around 0.02 by ~ 20%



Outlook

- Beautiful jet results from ATLAS and CMS start constraining PDFs
- Do not forget about photons for PDFs
- QCD at hadron colliders is becoming PRECISION PHYSICS
- Interplay between strong and electroweak interactions are important at the TeV scale
- Data quantity and quality at the LHC open up new regimes in phase space and precision to be exploited
- Differentiate carefully between “assumptions” and “established facts” in these new regimes to avoid missing something NEW
- Fresh results might show up for DIS2012 next week or later for the Summer Conferences. Stay tuned!

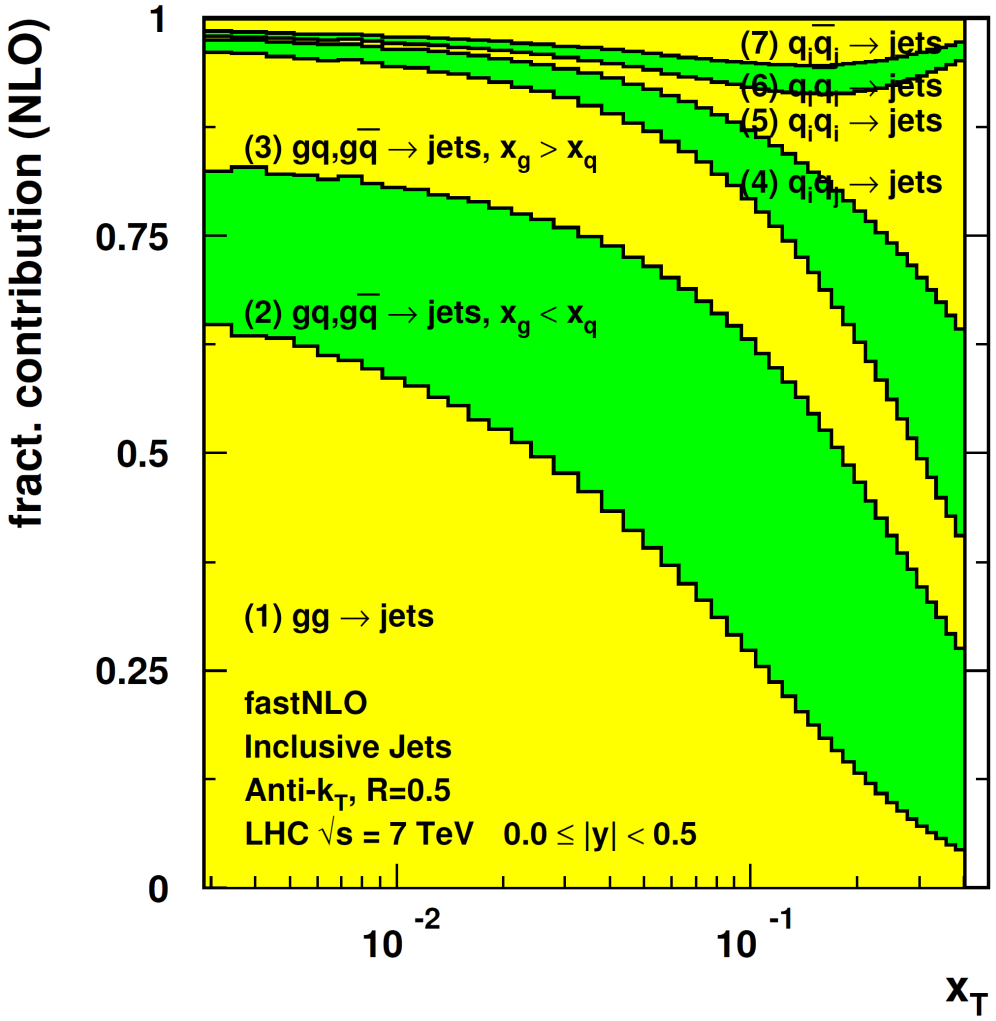
Thank you very much for your attention!

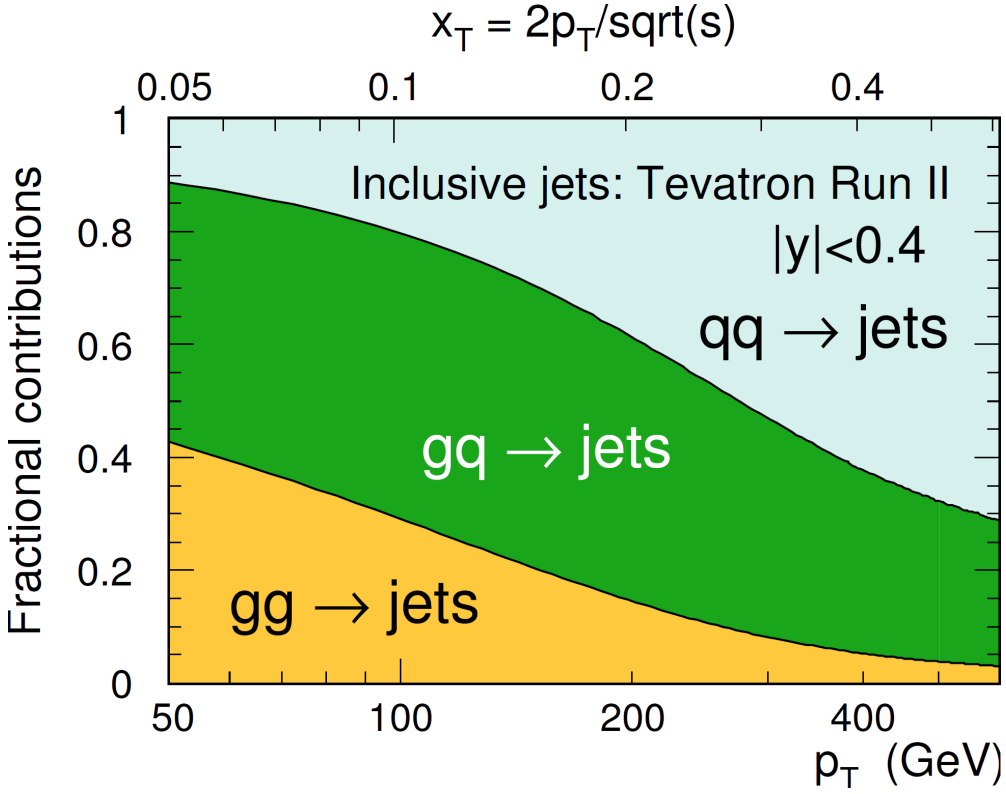
Was that all?

Backup Slides

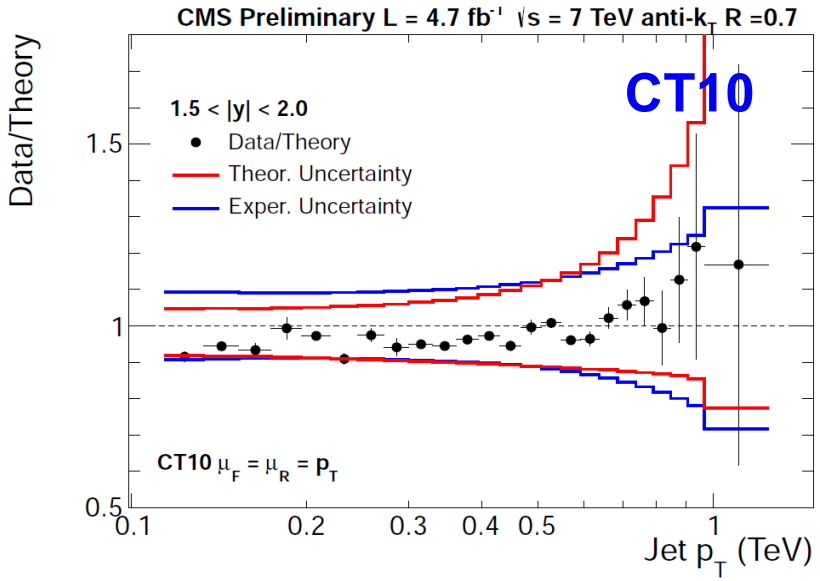
Inclusive Jets

$$\frac{d^2\sigma}{dp_T d|y|} \propto \alpha_s^2$$

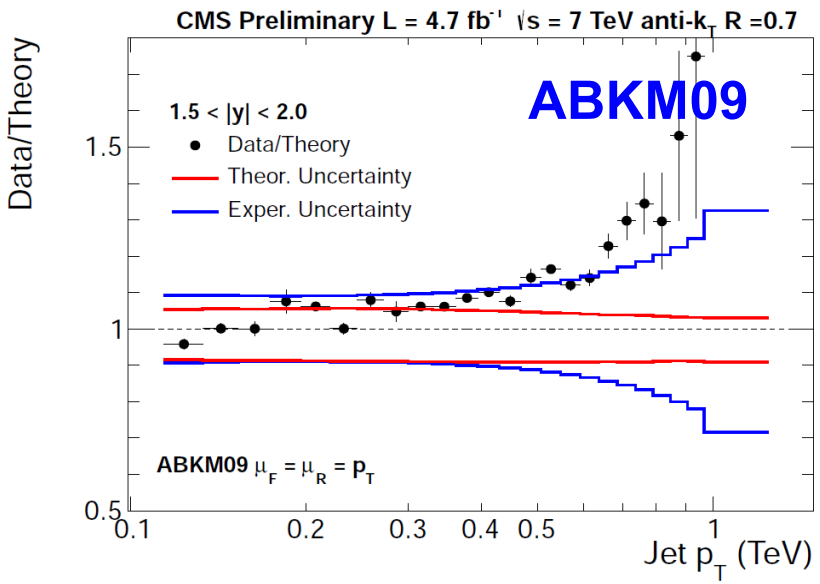


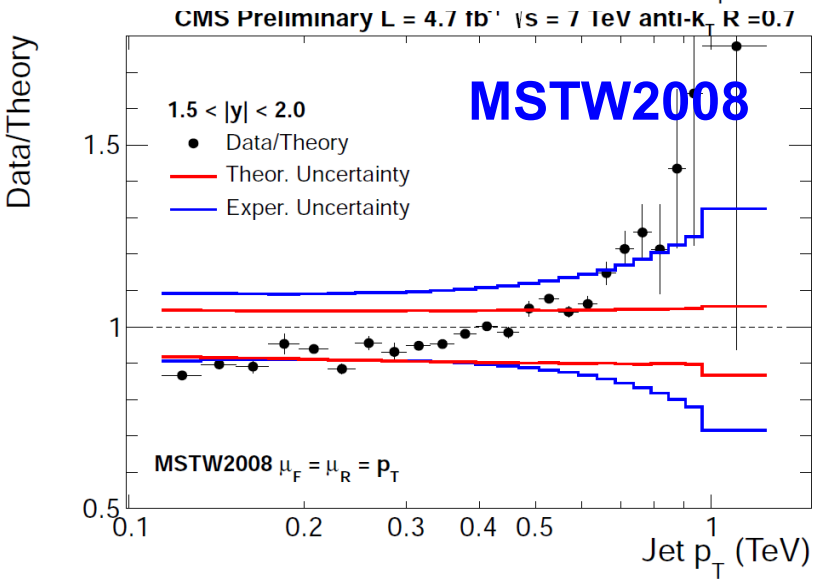


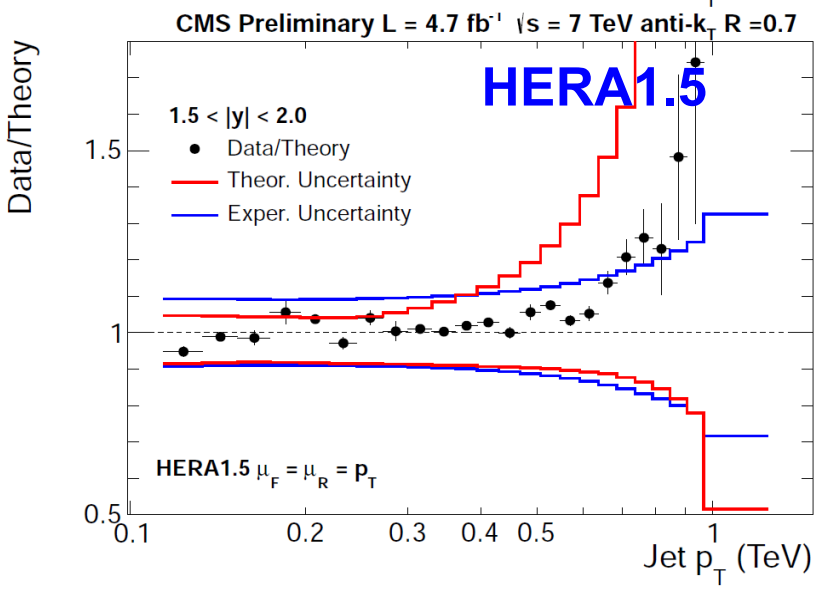
Comparison at 1.5 < |y| < 2.0



Inclusive Jets
1.5 < |y| < 2.0



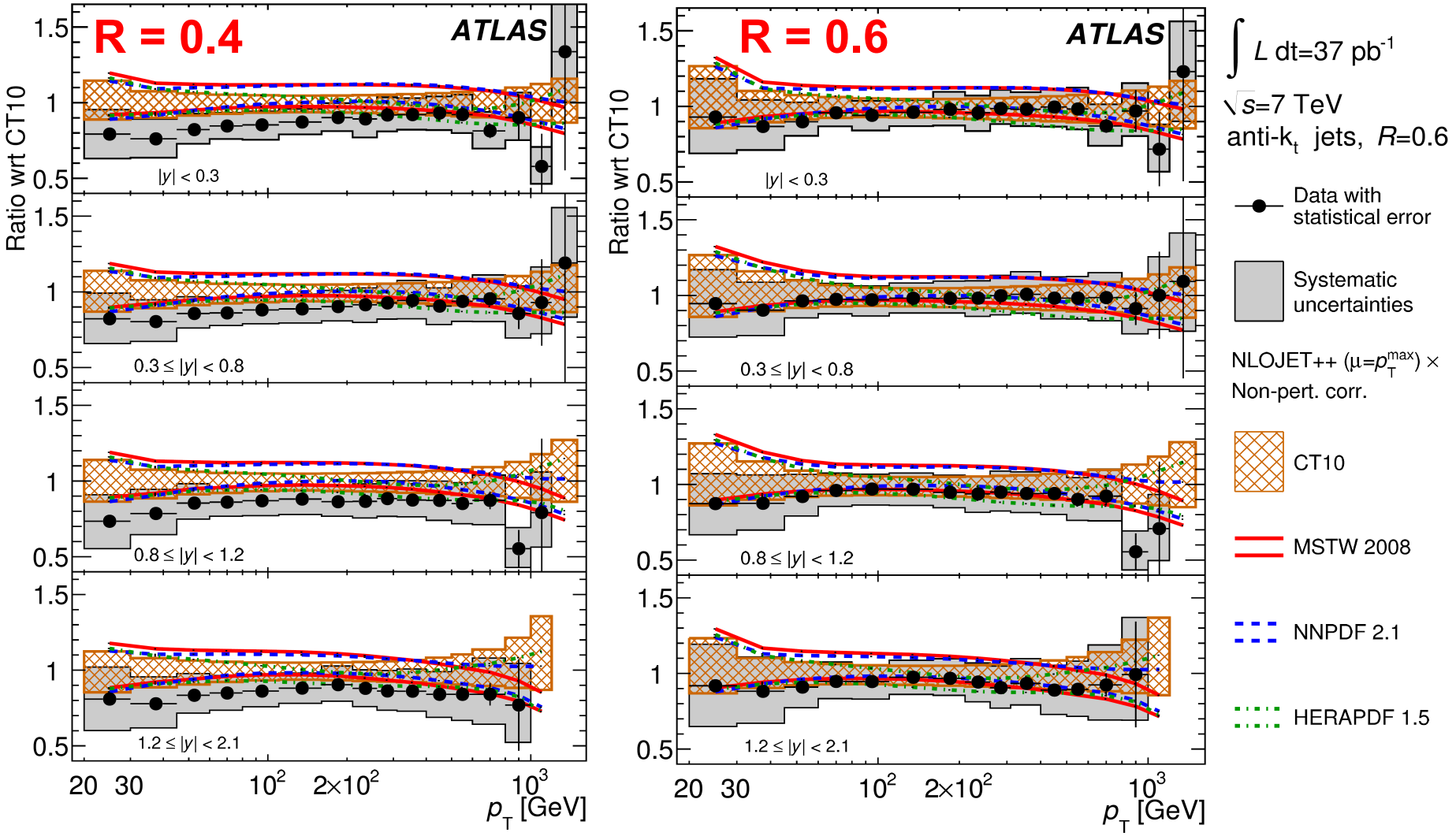




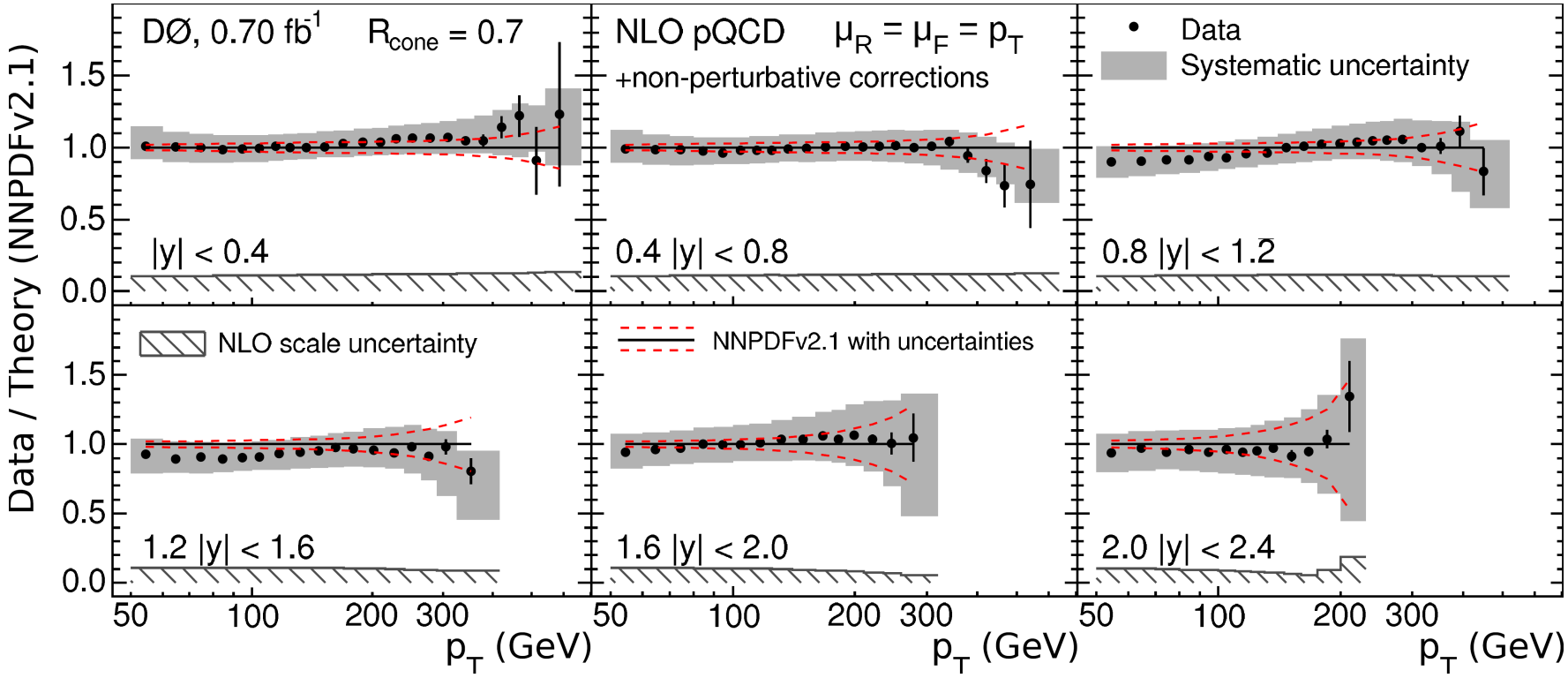
CMS-PAS-QCD-11-004

Inclusive Jets with 2 Jet Sizes

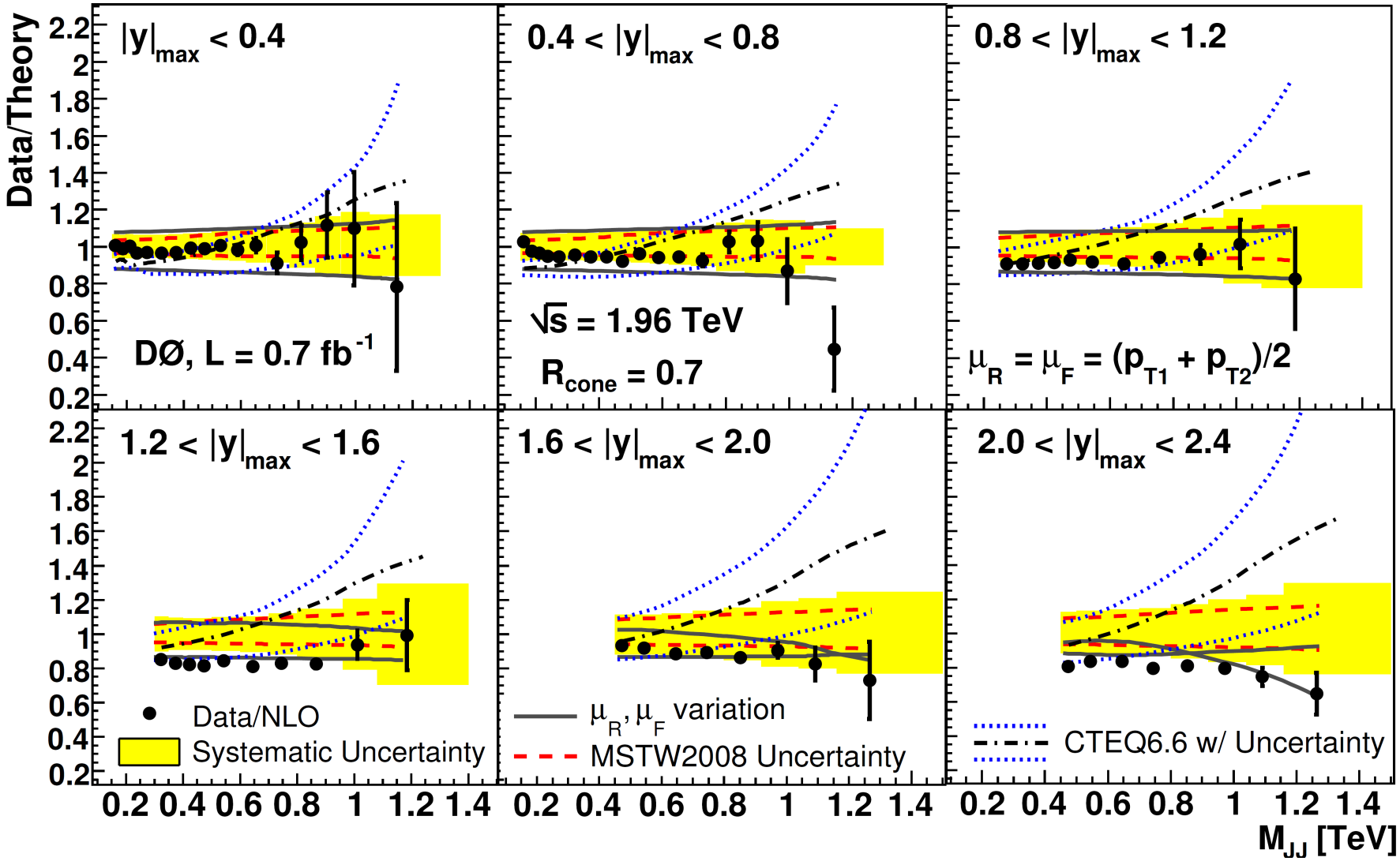
Comparison of measurement to QCD for various PDFs with two jet sizes



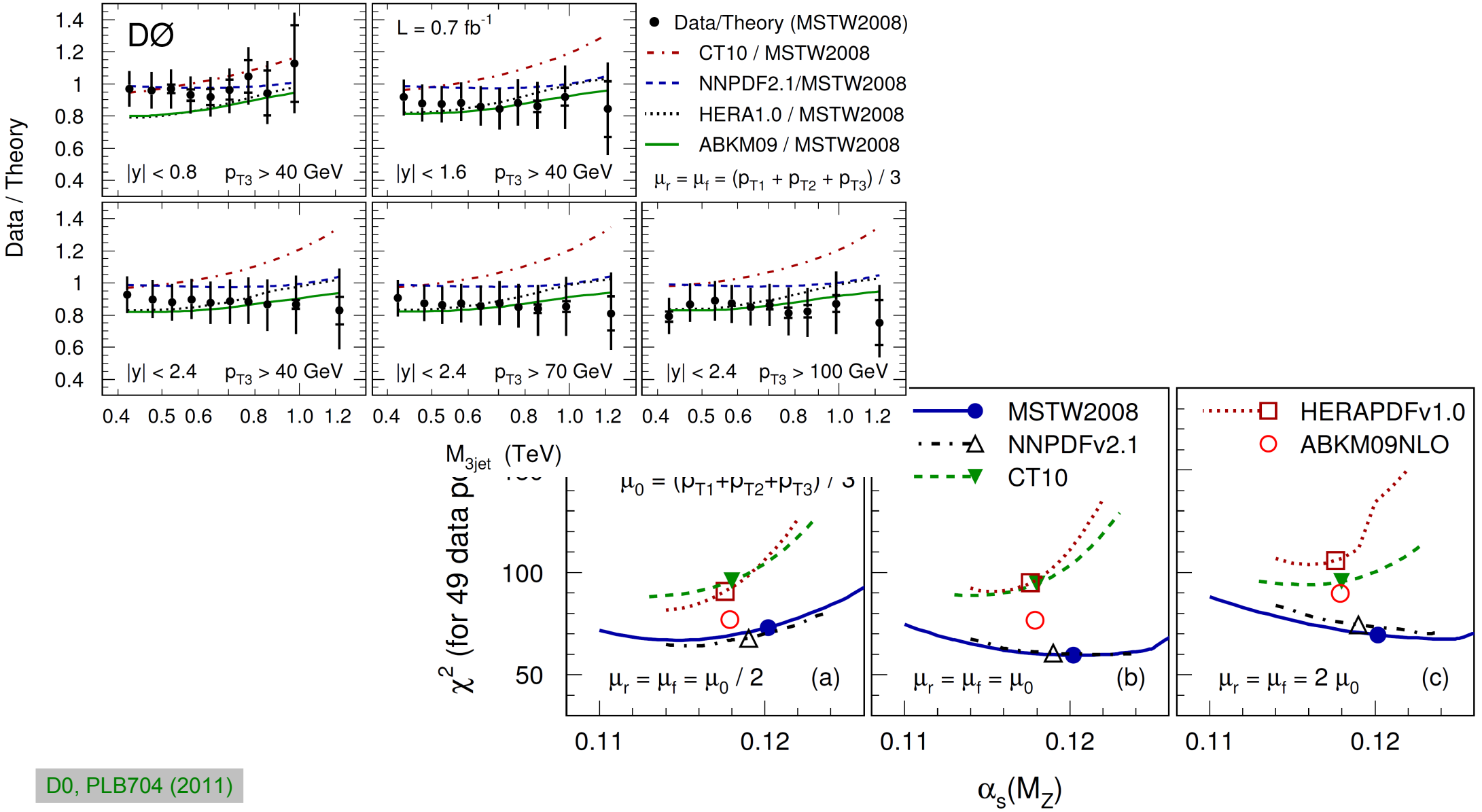
D0 Inclusive Jets - PDFs



D0 Dijet Mass - PDFs

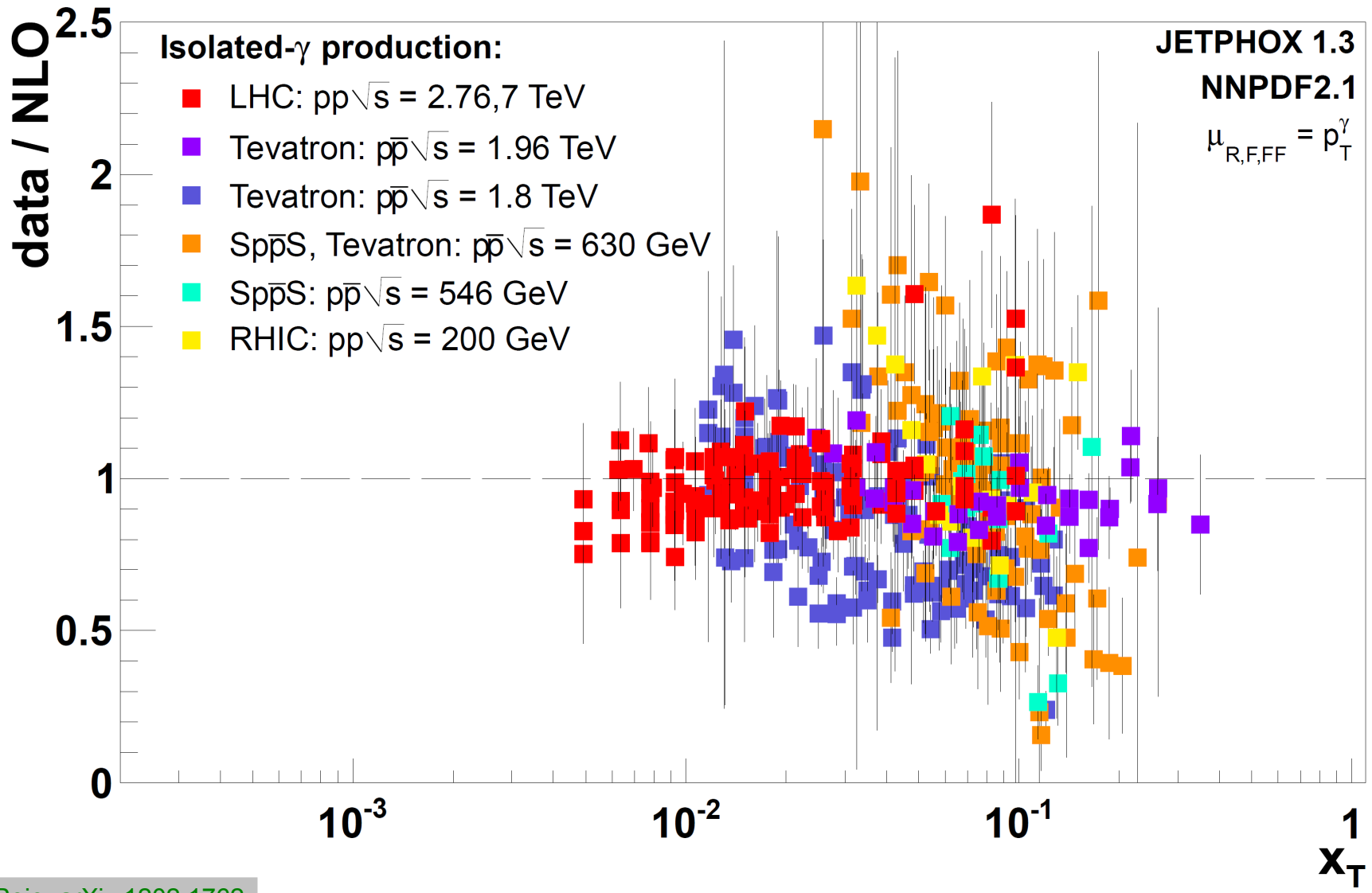


D0 3-Jet Mass – PDFs & α_s



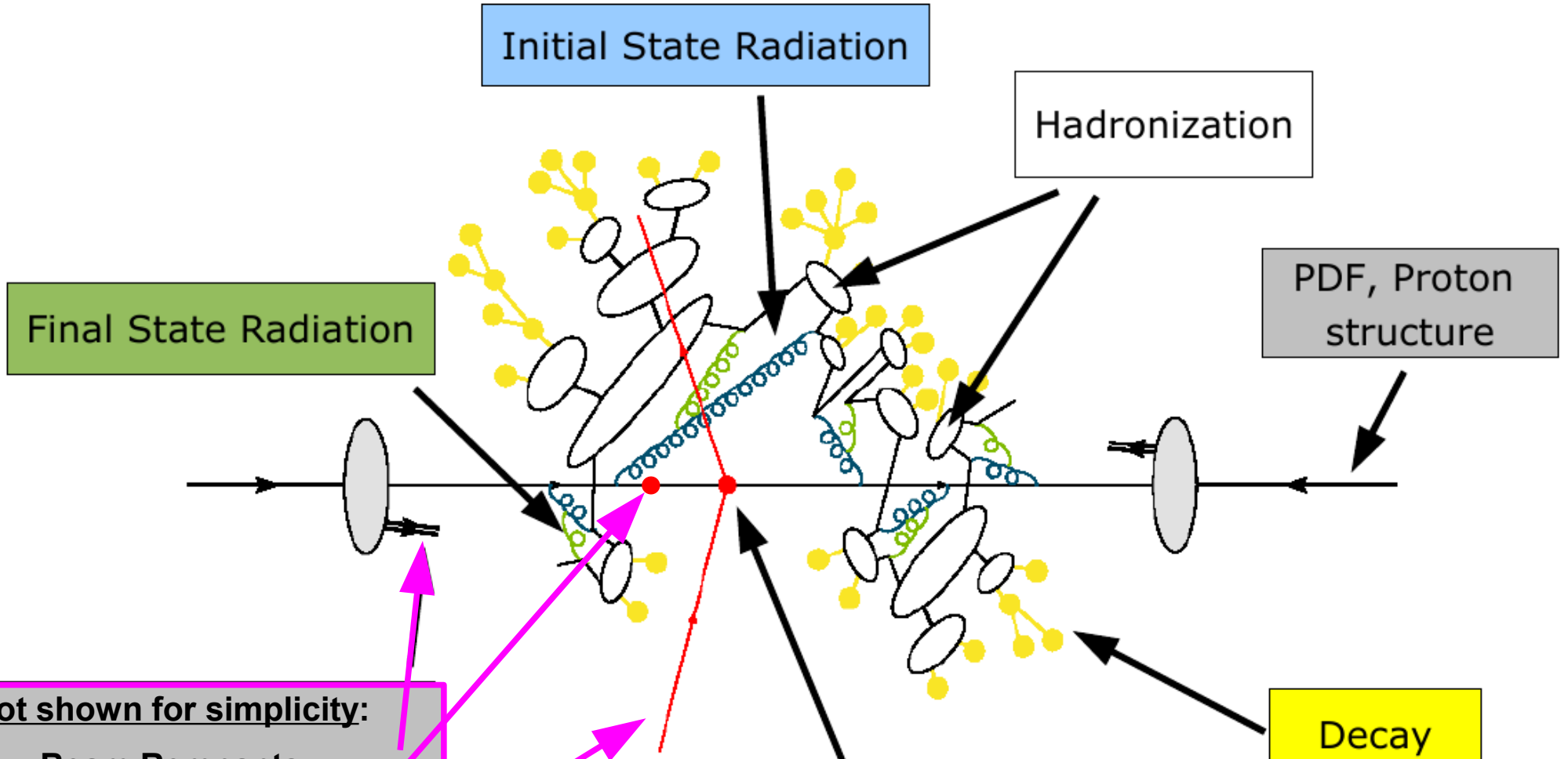
D0, PLB704 (2011)

Isol. Photons Data/Theory



d'Enterria, Rojo, arXiv:1202.1762

Sketch of a pp Scatter



Not shown for simplicity:

Beam Remnants

Multiple Interactions

FSR off the hard partons

PLUS … a Detector!

S. Gieseke

Inclusive Jet Measurements

All jets in the event satisfying the selection criteria

$$\frac{d^2\sigma}{dp_T dy} = \frac{N_{jets}}{\epsilon \cdot L \cdot \Delta p_T \cdot \Delta y} \times C_{unsm}$$

Master Equation

- Jet Efficiency
- Event Efficiency

Bins of **corrected** Jet Pt and Jet rapidity

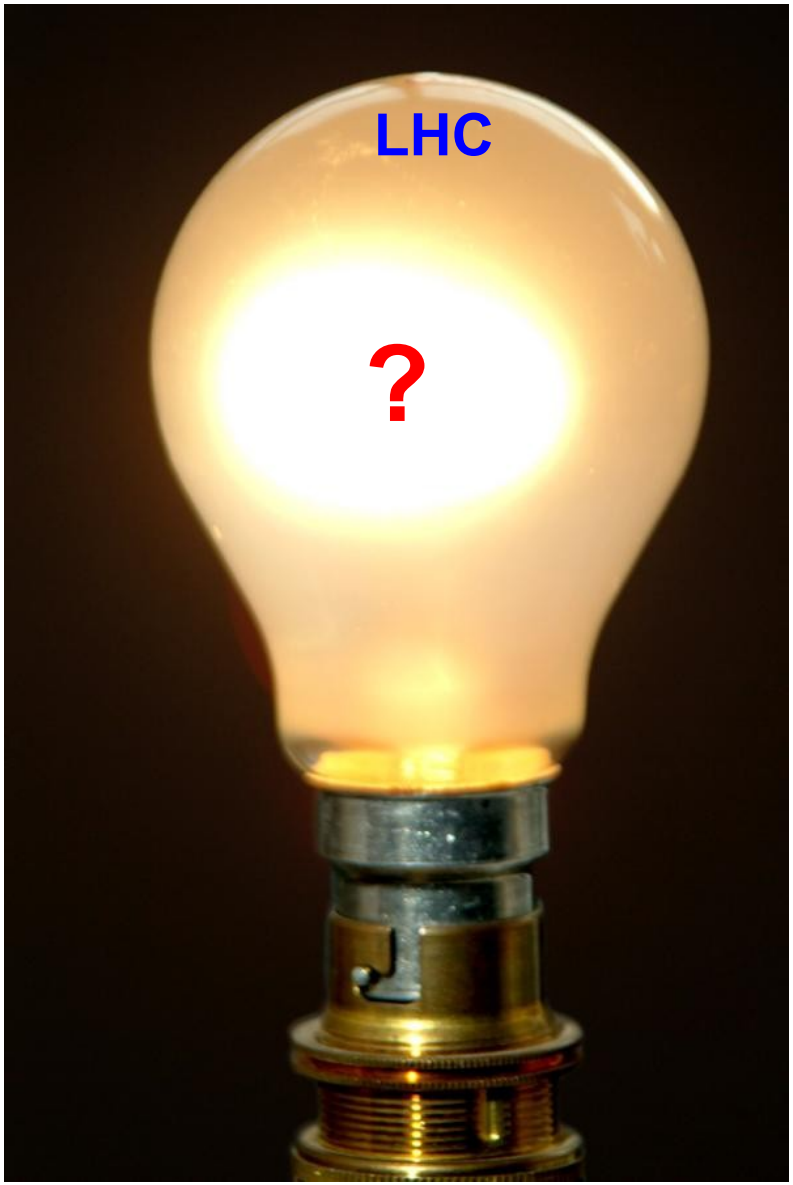
Unsmearing correction (due to the finite detector Pt resolution)

Luminosity, common uncertainty to all measurements

The JES dominates the total uncertainty of the measurement

K. Kousouris

Luminosity

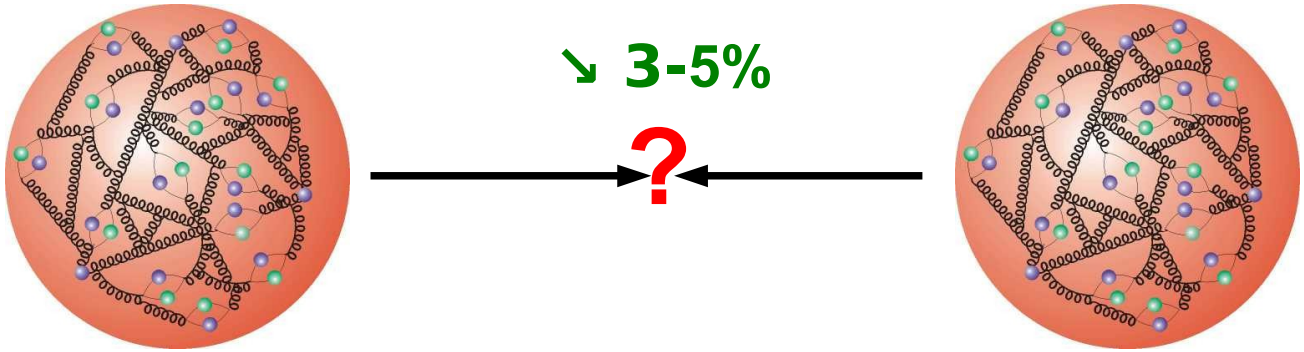


Common to all cross section measurements:

Initial Uncertainty at LHC: 11%

From van-der-Meer Scans:
Uncertainty dominated by beam intensity measurement

Reached by now:



HERA-Proton,DESY