Application of fastNLO to Jet Analyses

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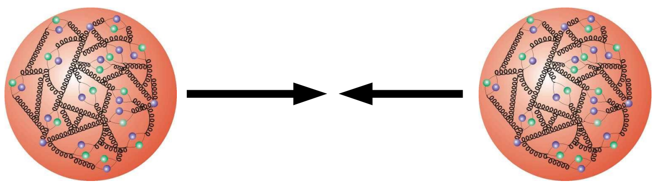
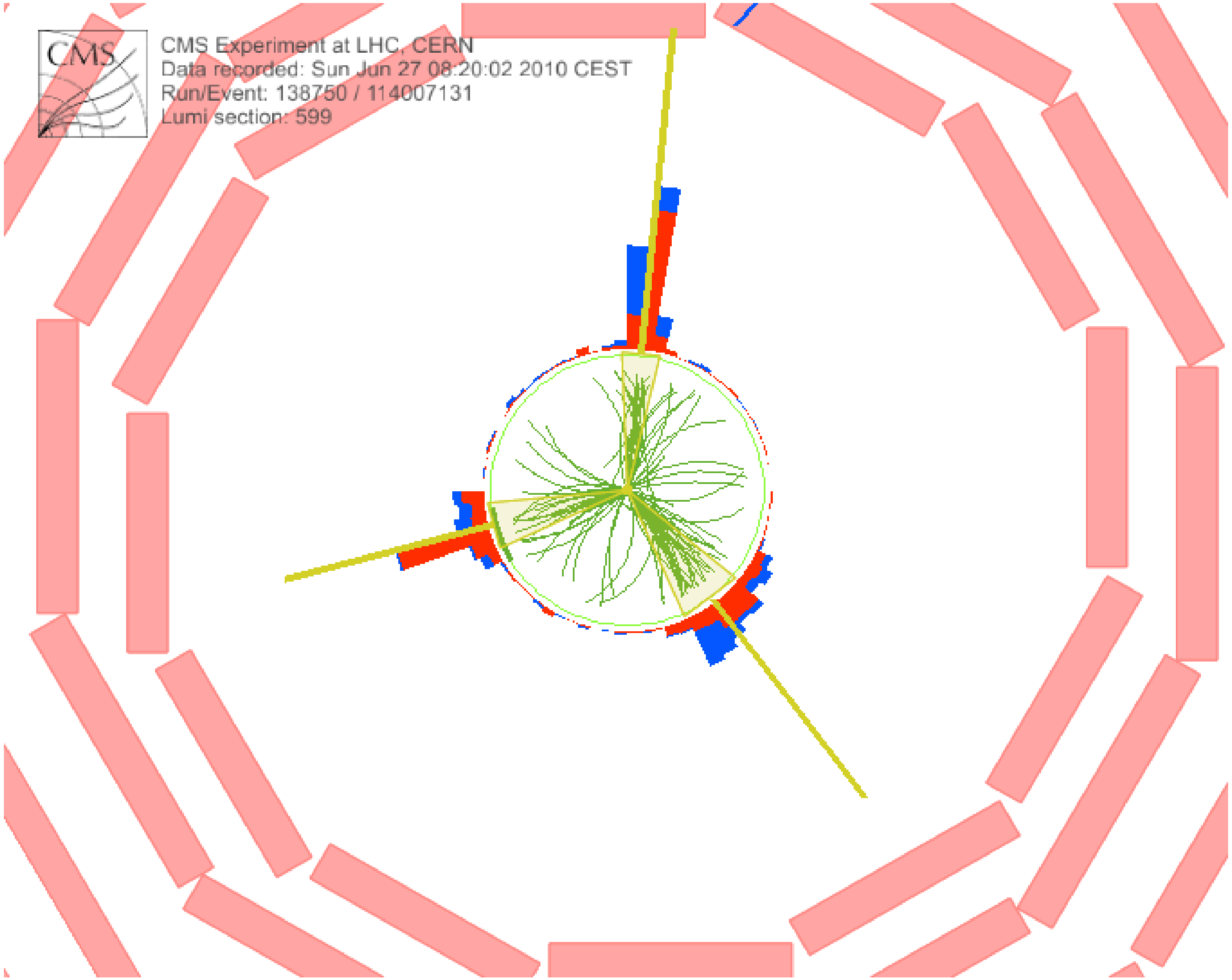
Outline

- **Motivation & Concept**
- **Application to Jet Analyses at LHC**
- **Outlook**





Motivation

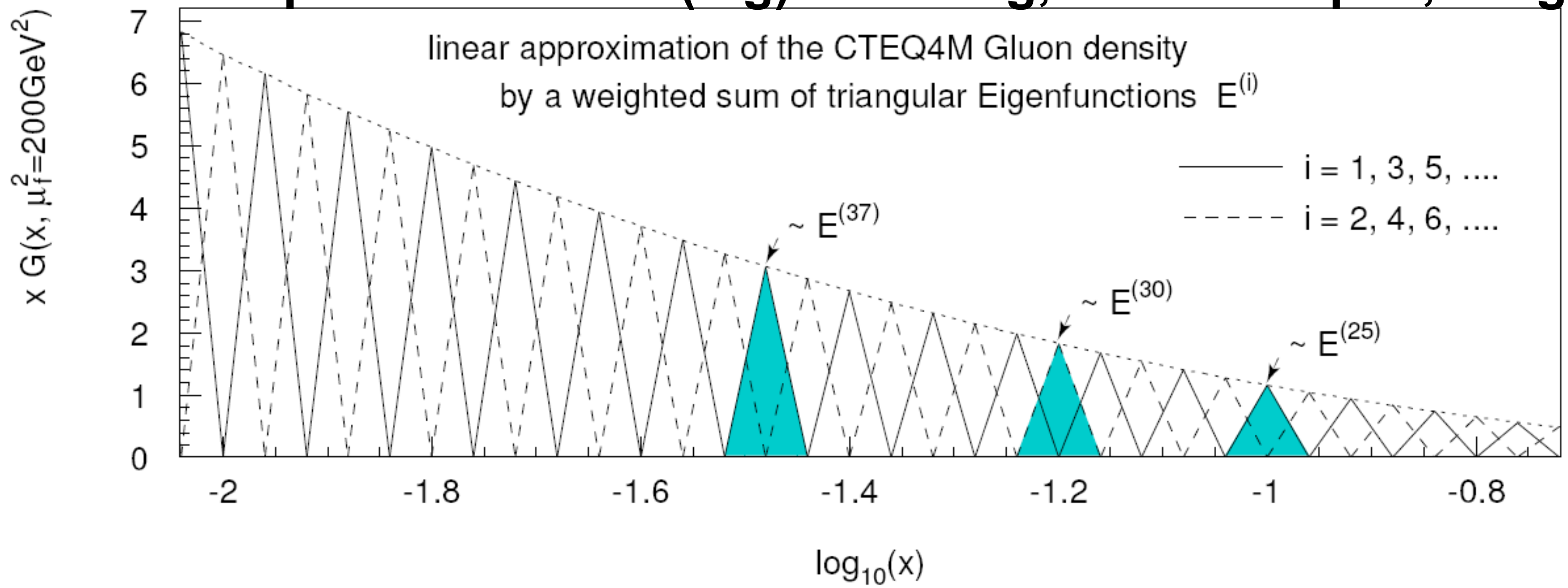
- **Interpretation of experiment data relies on:**
  - **Availability of reasonably fast theory calculations**
  - **Often needed: Repeated computation of same cross section**
  - **On the following pages: Repetition counter: # NLO = nnn**
- **Examples for a specific analysis:**
  - **Use of various PDFs (CTEQ, MSTW, NNPDF, HERAPDF, ABKM ...)**
  - **Determine PDF uncertainties (PDF error sets)**
  - **Use data set in fit of PDFs and/or $\alpha_s(M_Z)$**
- **Sometimes NLO predictions can be computed fast**
- **But some are very slow, esp. for Drell-Yan and jets**
- **Need procedure for fast repeated computations of NLO cross sections**
- **Use fastNLO** **(ATLAS mostly uses another project: APPLGrid)**

Concept on a Slide

- Introduce set of discrete $x^{(i)}$ with $x^{(n)} < .. < x^{(i)} <..<x^{(0)}=1$
- Around each $x^{(i)}$ define eigen function $E^{(i)}(x)$ with:

  $E^{(i)}(x^{(i)}) = 1$, $E^{(i)}(x^{(j)}) = 0$ $(i \neq j)$, $\Sigma_i E^{(i)}(x) = 1$ for all x
- Express PDF f(x) by lin. combination of eigen functions with coefficients given by PDF values at discrete points:

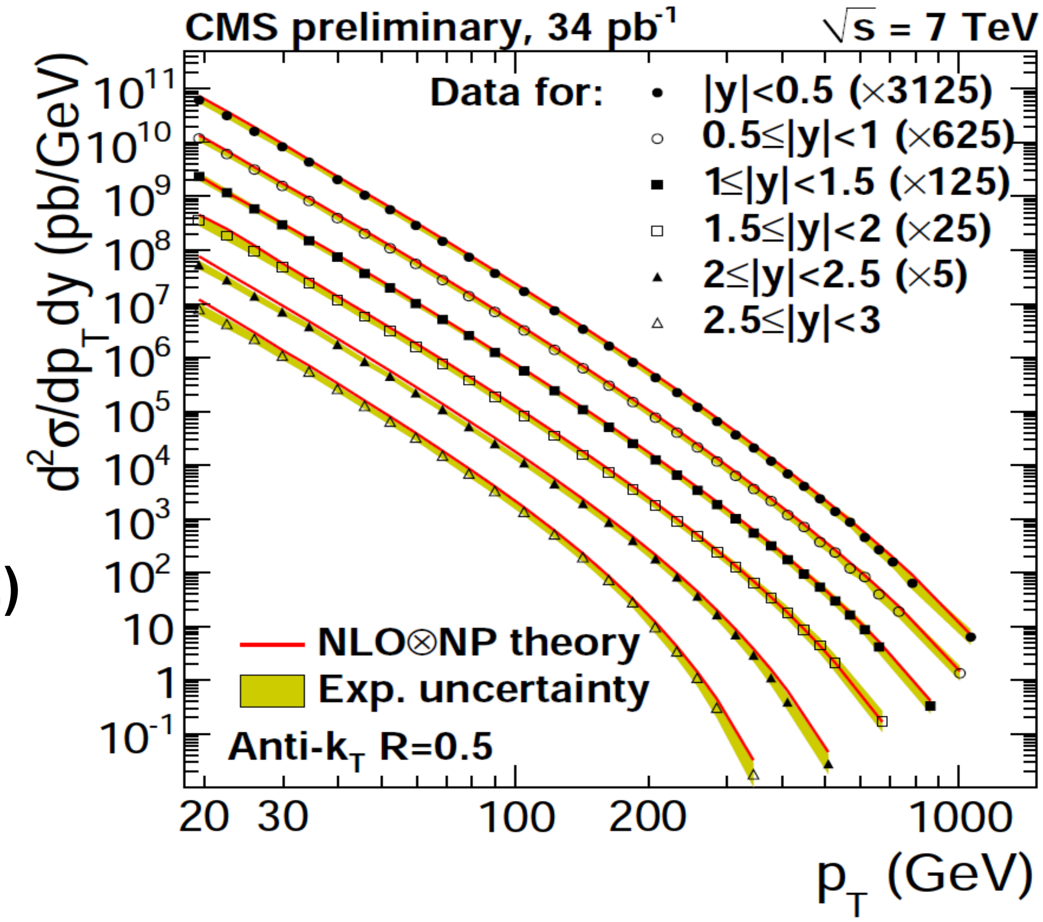
- $f(x) = \sum_i f(x^{(i)}) E^{(i)}(x)$ => Integration only over $E^{(i)}(x)$, not f(x)!
- In detail more complicated: 2-dim. (log) x binning, cubic interpol., weights



Absolute Measurements

Simplest case:
Inclusive jet pT cross section
For this derive:

- **Scale Dependence:**
  - Mostly: Sim. variation of μ_r and μ_r by factor of 2
  - Better: Indep. variation at 6 points (1/2,1/2), (1/2,1), (1,1/2), (1,2), (2,1), (2,2)
- **PDF Uncertainties**
  - PDF4LHC prescription for 1st compatibility check
  - Use of various PDFs (CTEQ, MSTW, NNPDF, HERAPDF, ABKM ...)
- **Sensitivity to alpha_s**
  - Use data set with fit/use of $\alpha_s(M_Z)$



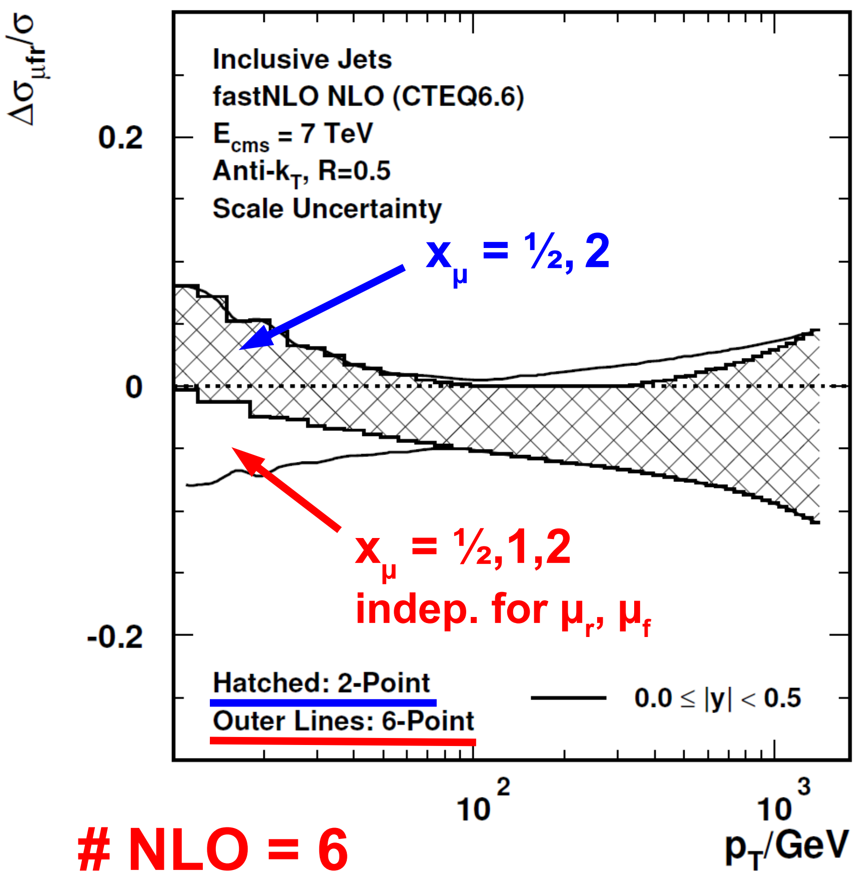
CMS-PAPER-QCD-10-011

 # NLO = 1

Scale and PDF Uncertainties

Asymmetric scale variations:

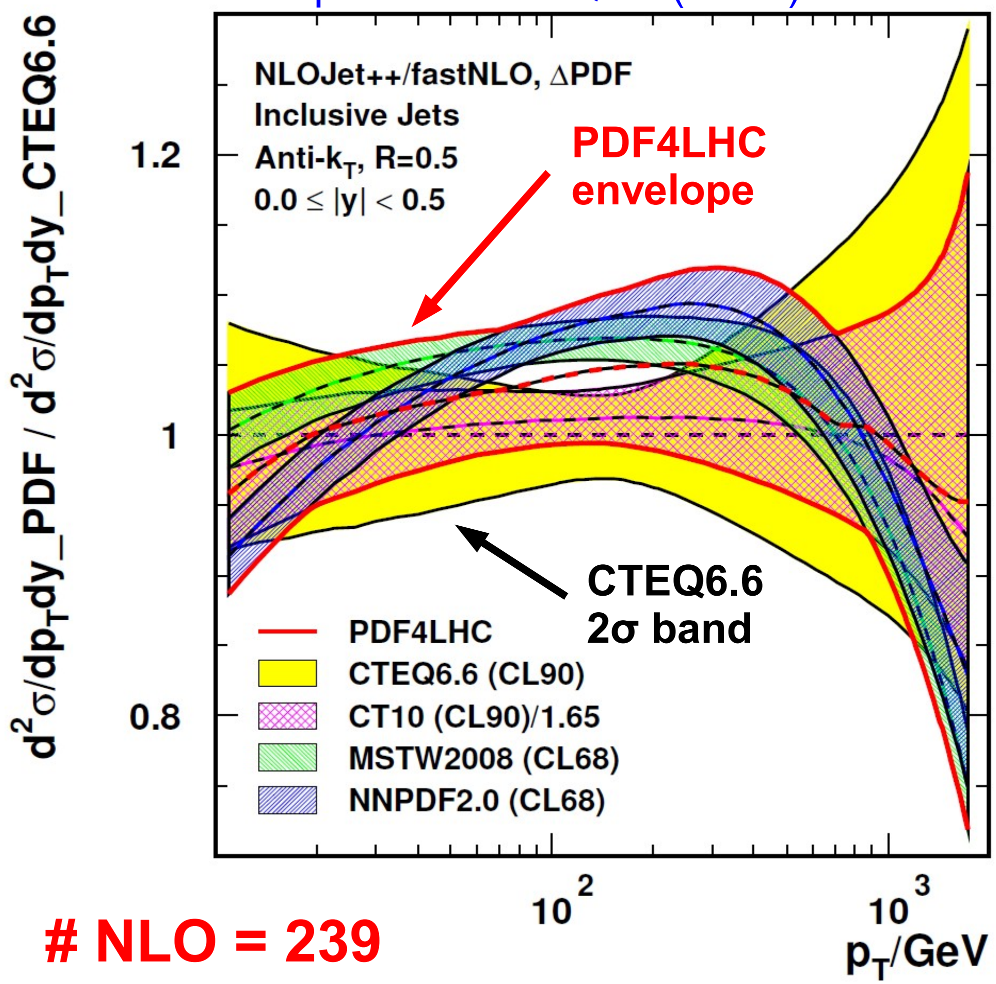
Independent variation of μ_r and μ_f
by factors of ½ and 2 avoiding rel. factors of 4
(6-point: (1/2,1/2), (1/2,1), (1,1/2), (1,2), (2,1), (2,2)
Compared to symmetric variation (2-point)



NLO = 6

A la PDF4LHC:

Envelope of predictions of CTEQ, MSTW and NNPDF at CL68
Compared to CTEQ6.6 (CL90)



NLO = 239

Normalized Cross Section 1

Version 1: Area Normalization

(Not always possible in pQCD!)

Dijet Angular Distribution in Chi_{jj} where

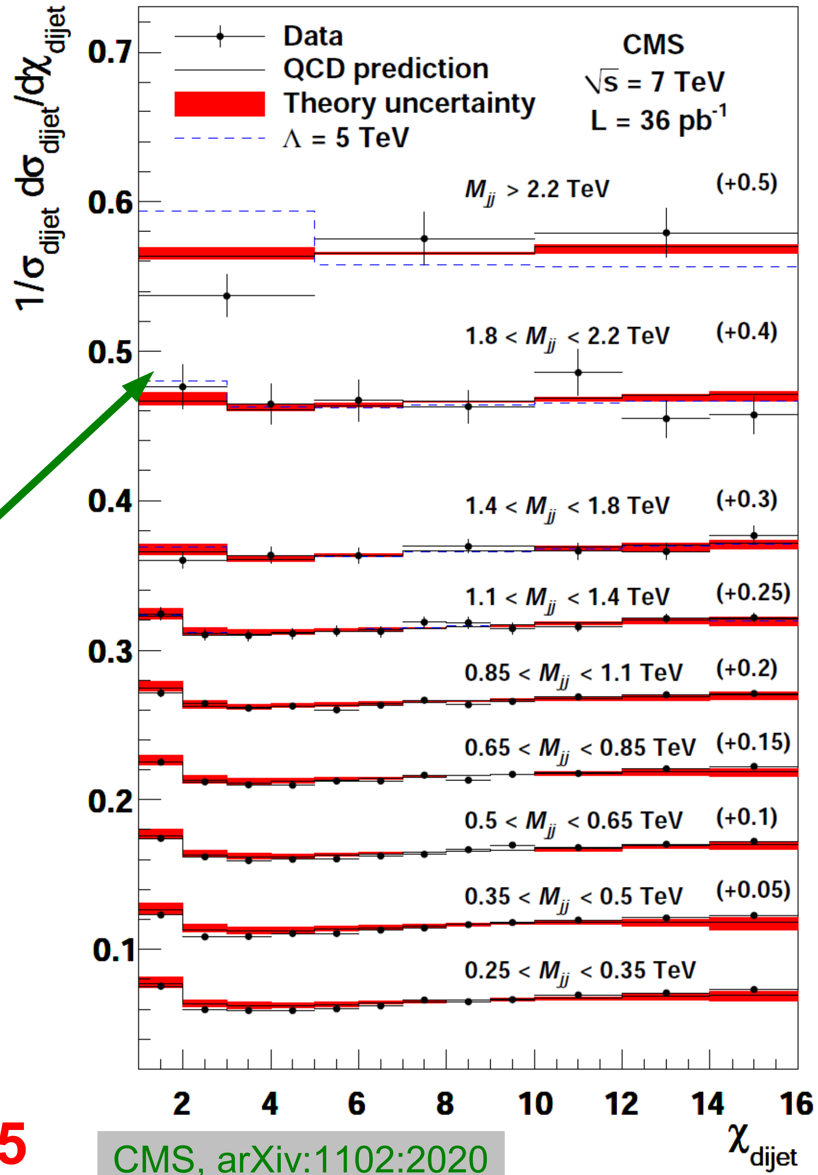
$$\chi_{\text{dijet}} = \exp(2y^*)$$
$$y^* = \frac{1}{2}|y_1 - y_2|$$

Search for new physics at high mass and low Chi_{jj} !

Technically:

2-jet cross section well defined at NLO from minimal Chi_{jj} up to chosen maximum e.g. 16

 # NLO = 45

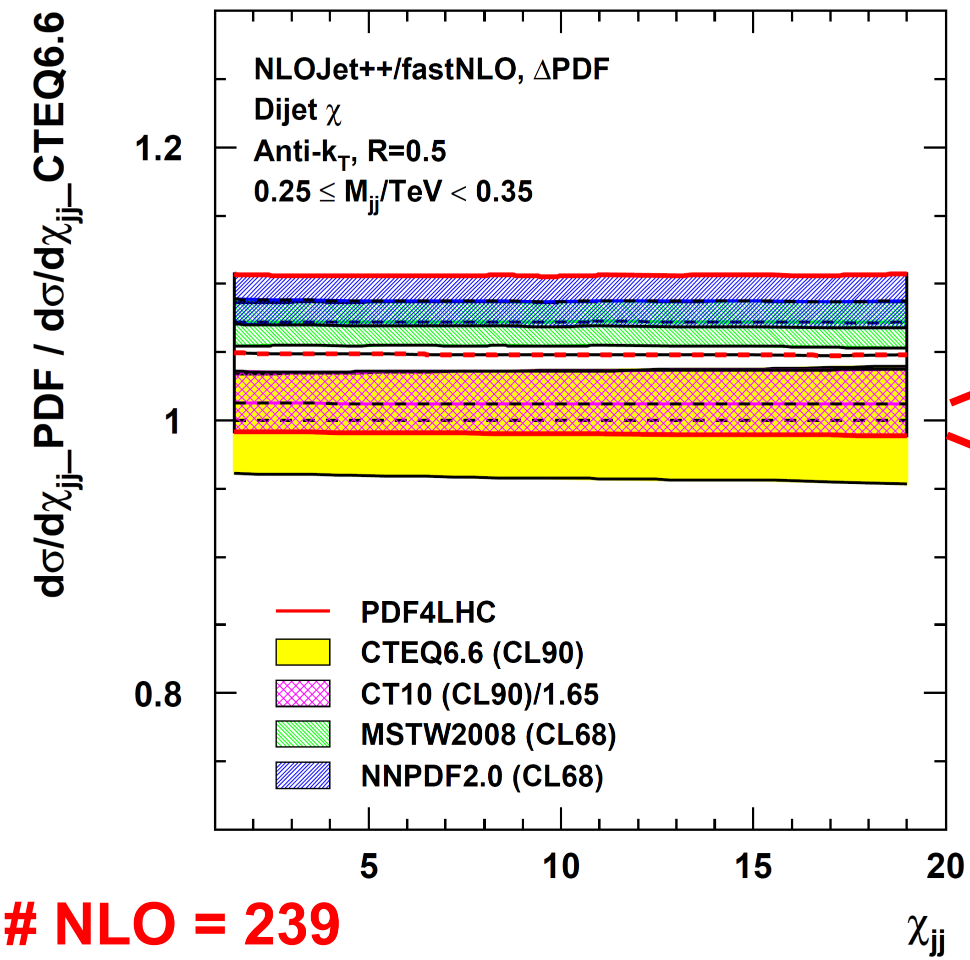


CMS, arXiv:1102:2020

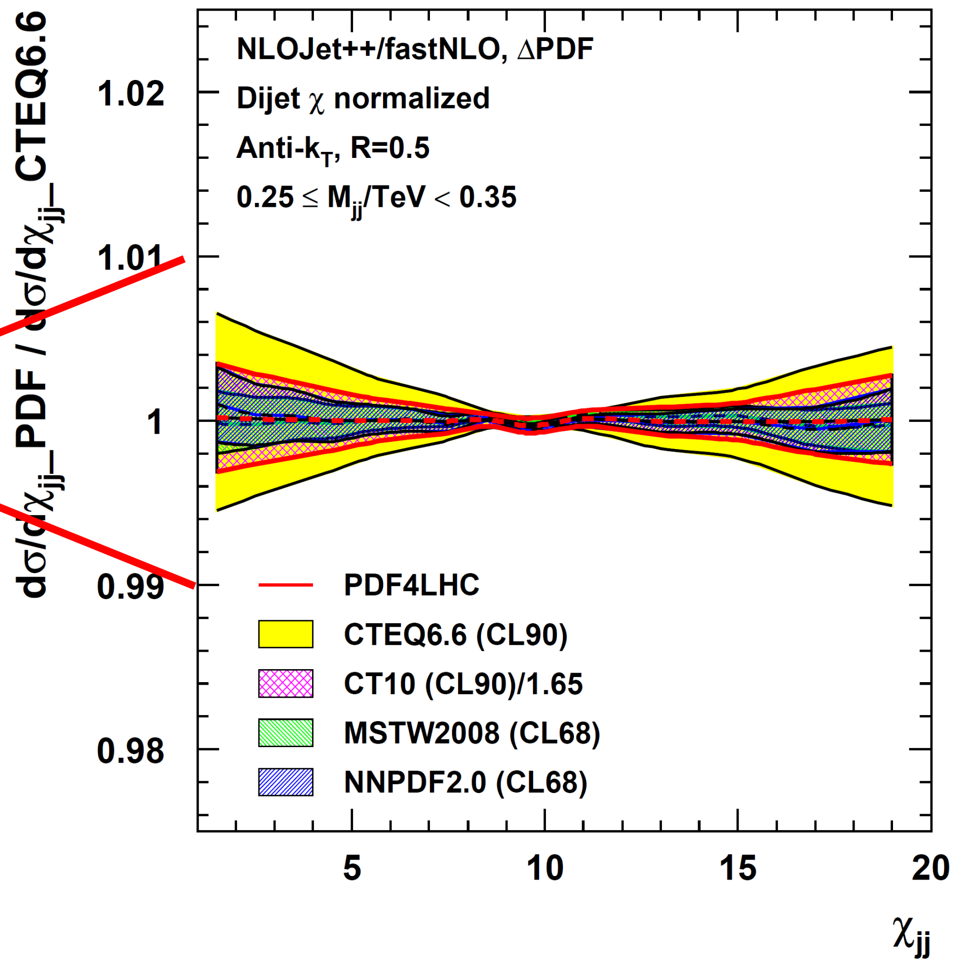
Dijet Angular: ΔPDF

Take proper care of normalization in e.g. PDF uncertainty derivation

Differential cross section



Normalized cross section



 # NLO = 239

Normalized Cross Section 2

 # NLO = 1

Version 1: Normalize to … ?

Dijet azimuthal decorrelation:

Depending on $\Delta\varphi_{jj}$ different orders (# of partons) contribute!

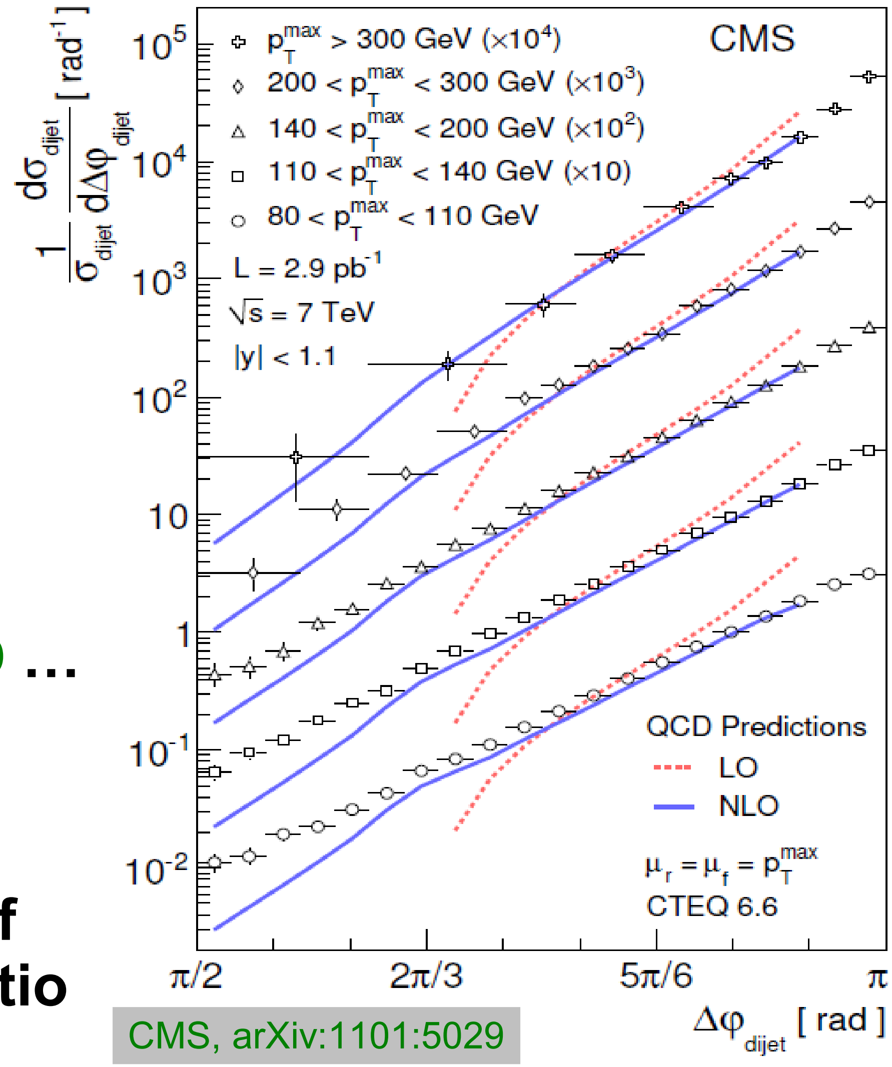
Some parts of histogram would be NNLO (at π) or are NLO (down to ~2π/3) or LO (below ~2π/3)

Nevertheless:

Normalization can be done at NLO

**==> Numerator and Denominator both at NLO …
but of different order in alpha_s
O(alpha_s³) / O(alpha_s²)**

Also possible: Numerator and denominator of same order in alpha_s e.g. Dijet Centrality Ratio

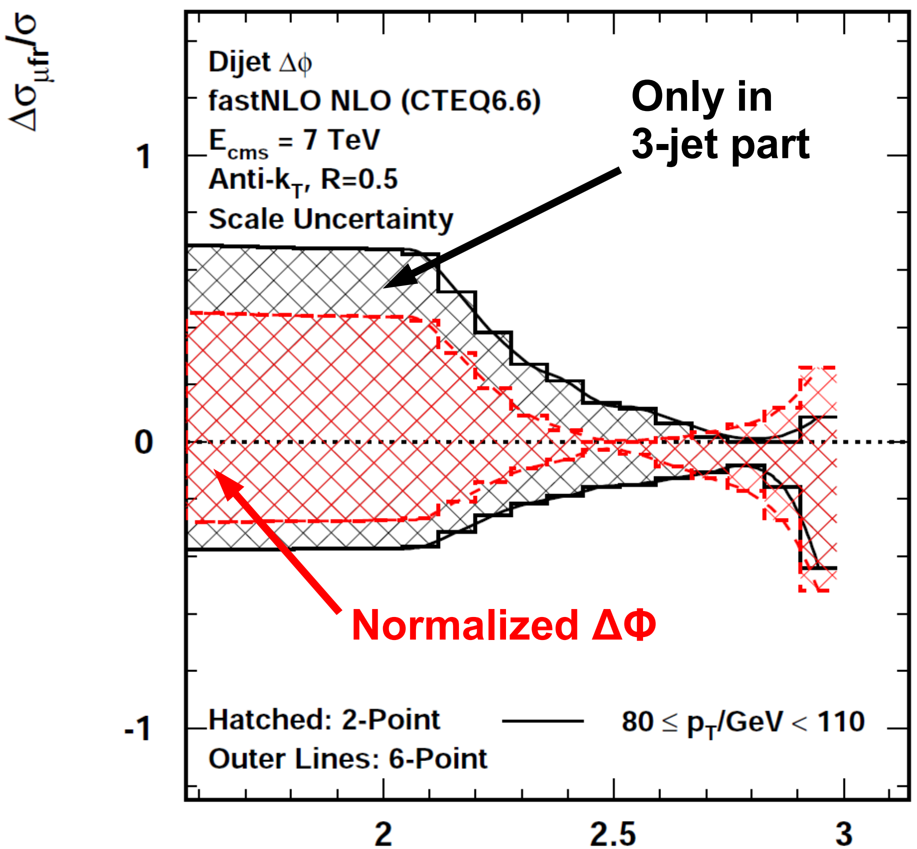


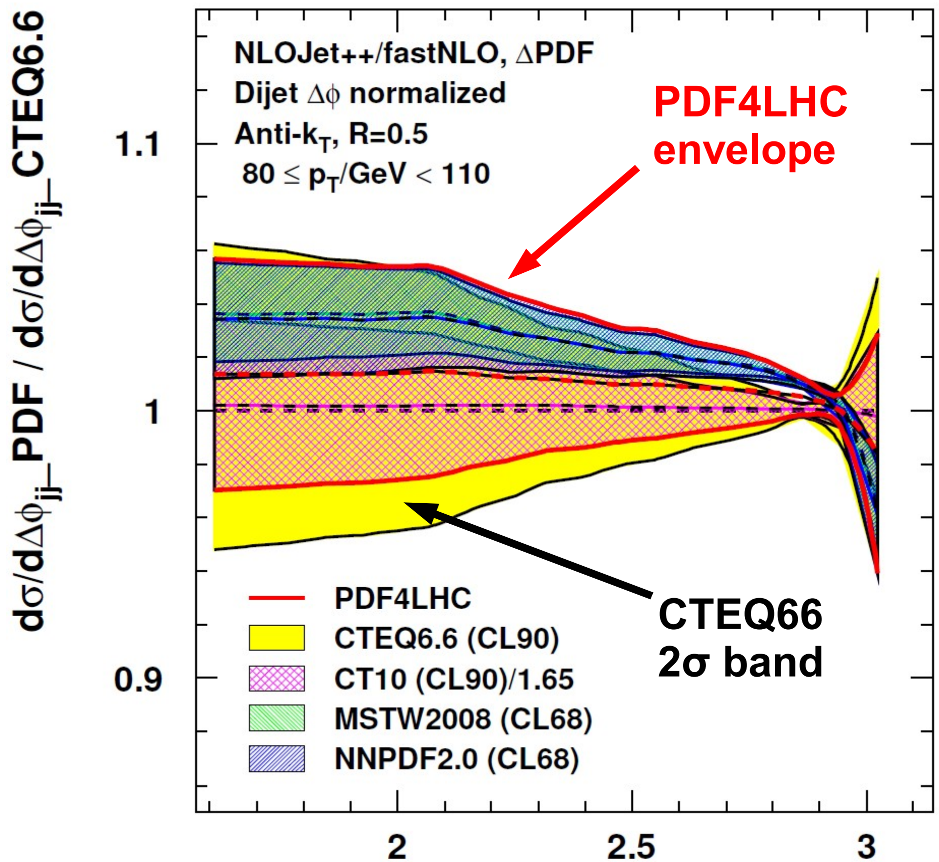
CMS, arXiv:1101:5029

ΔΦ: Scale and ΔPDF

Reevaluations for numerator and denominator!

Low pT bin: 80 < pT / GeV < 110



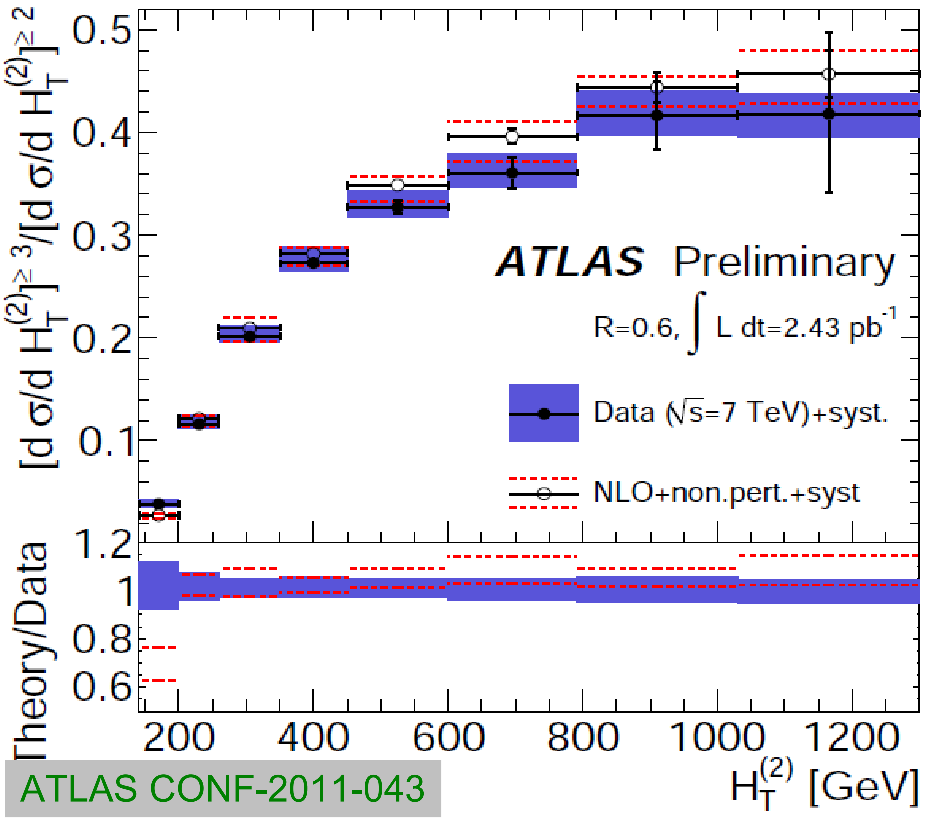


 # NLO = 2 x 6 $\Delta\phi_{jj}$ **# NLO = 2 x 239** $\Delta\phi_{jj}$

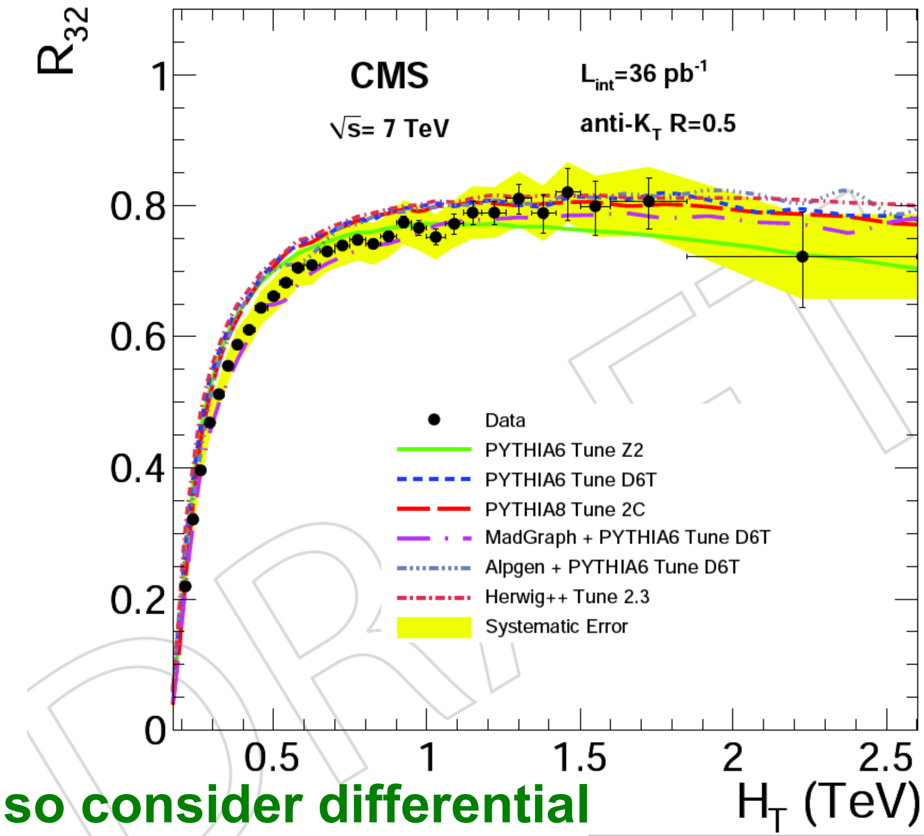
Cross Section Ratios

ATLAS: anti-kT R=0.6, |y| < 2.8
p_{Ti} > 30 GeV, p_{T1} > 60 GeV
$H_T = \Sigma |p_{Ti}|$
exp. Uncertainty < ~ 10%

CMS: anti-kT R=0.5, |y| < 2.5
p_{Ti} > 50 GeV, p_{T1} > 60 GeV
$H_T = \Sigma |p_{Ti}|$
exp. Uncertainty < ~ 10%



ATLAS CONF-2011-043



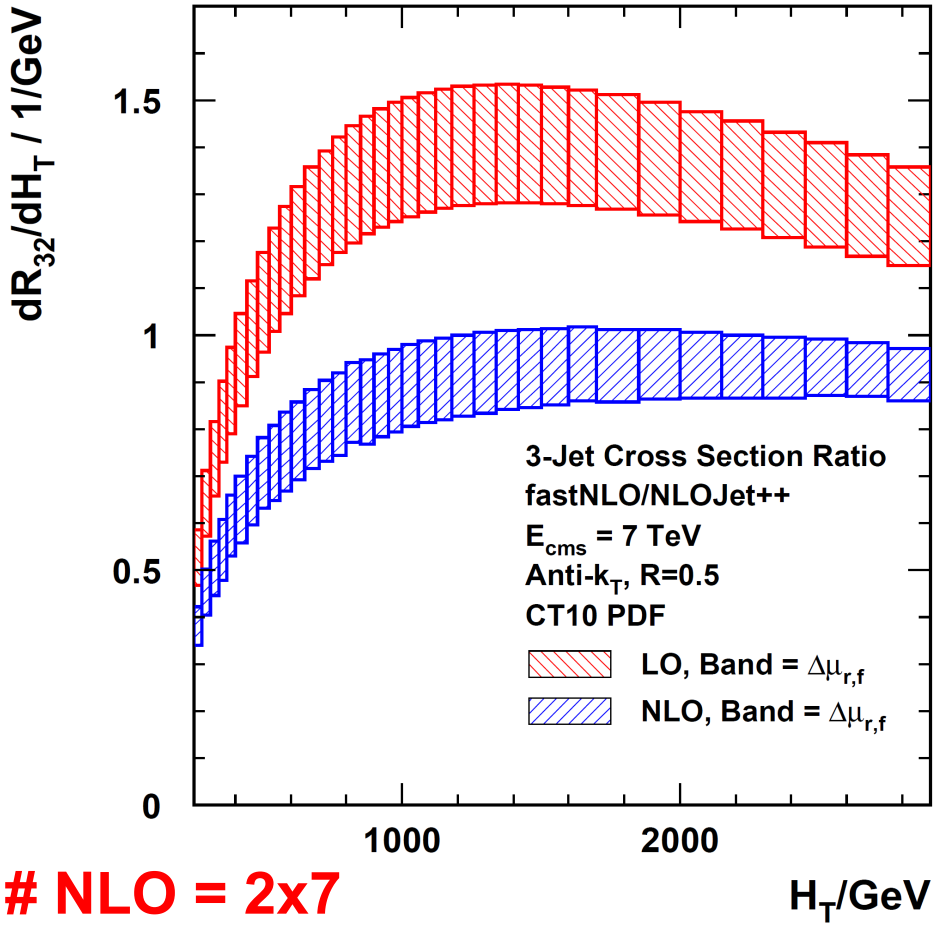
ATLAS: Also consider differential 2-jet Rate (~> event shape ...)

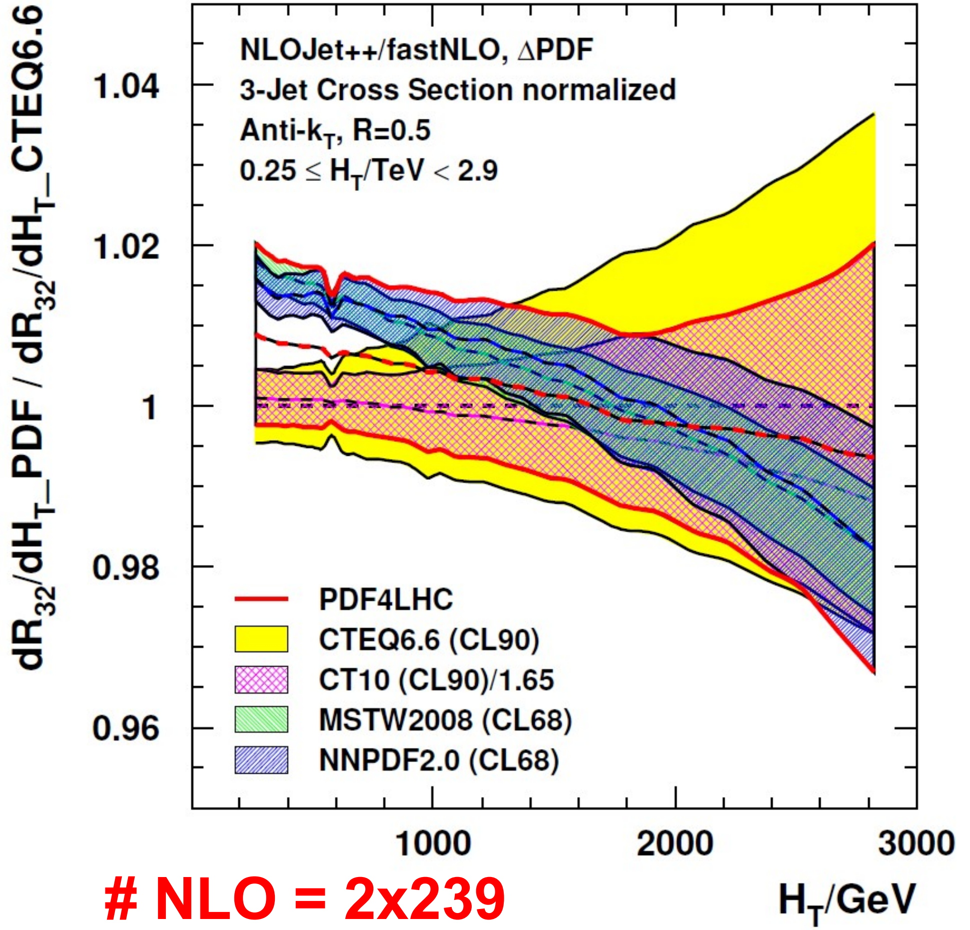
CMS-QCD-10-012

3+/2+: NLO Prediction & ΔPDF

CMS like selection
(ATLAS not very different)
LO > 1 ?!
K factors ~ 0.67

PDF uncertainty reduced by a factor ~ 10 in ratio





 # NLO = 2x7

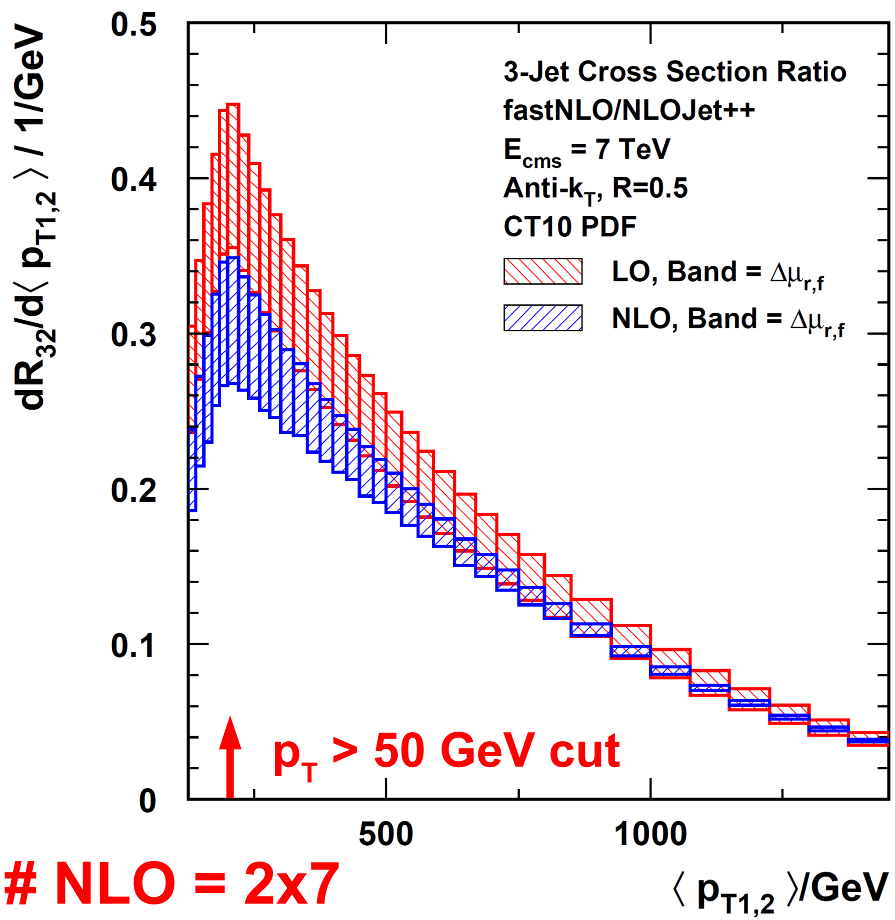
 # NLO = 2x239

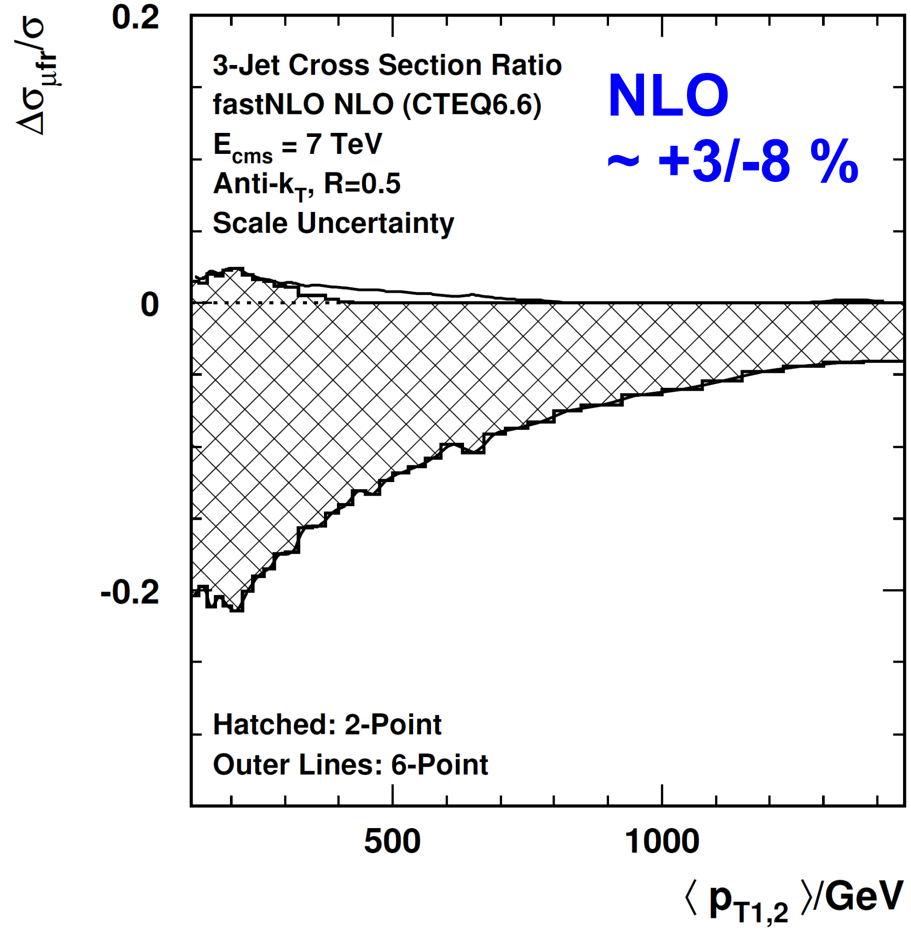
3+/2+ Revisited

Made some adaptations after chat with Gavin Salam, also see D0 or HERA!

- changed scale from H_T to average dijet p_T: $\langle p_{T1,2} \rangle$
- require hard third jet: $p_{T3} > 0.25$ times $\langle p_{T1,2} \rangle$

Not optimal yet, but clearly better

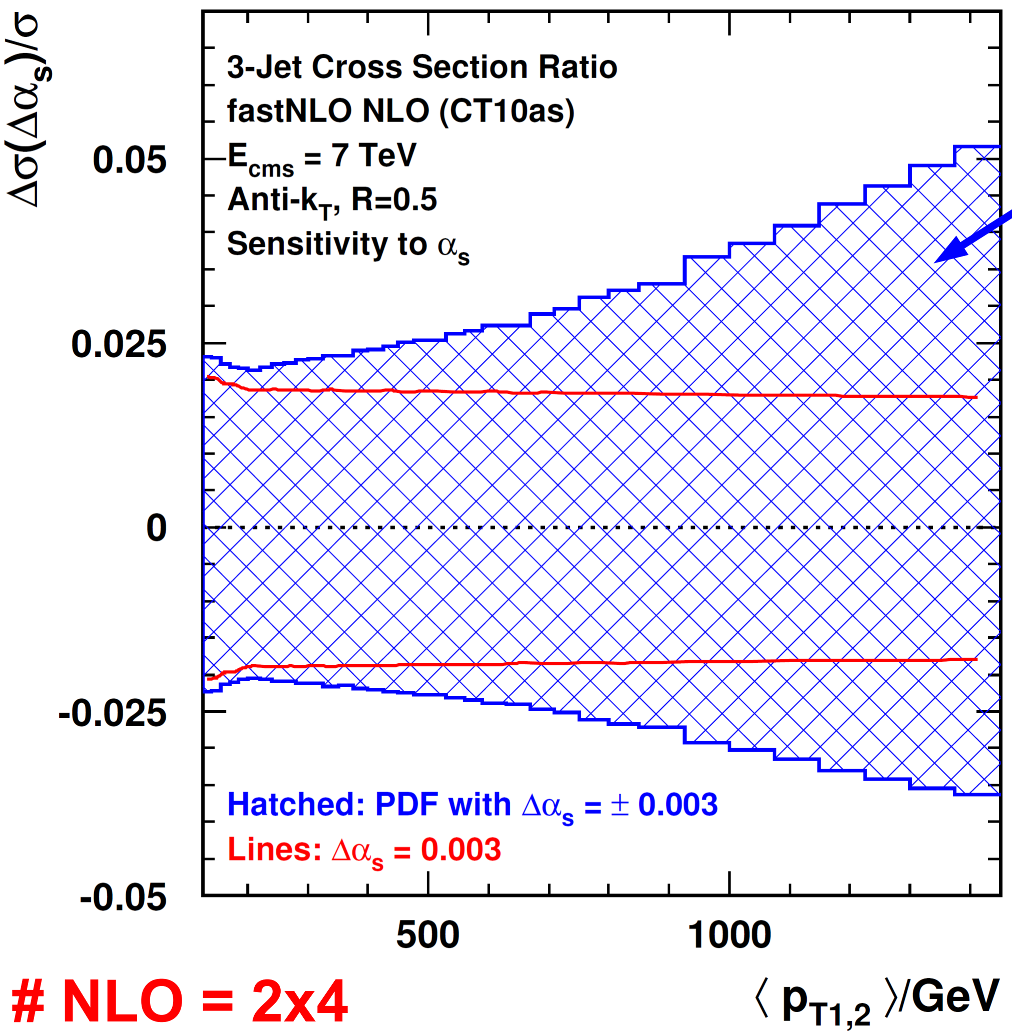




 # NLO = 2x7

3+/2+: Sensitivity to α_s

α_s Sensitivity



CT10as members with $\alpha_s = 0.118 \pm 0.003$

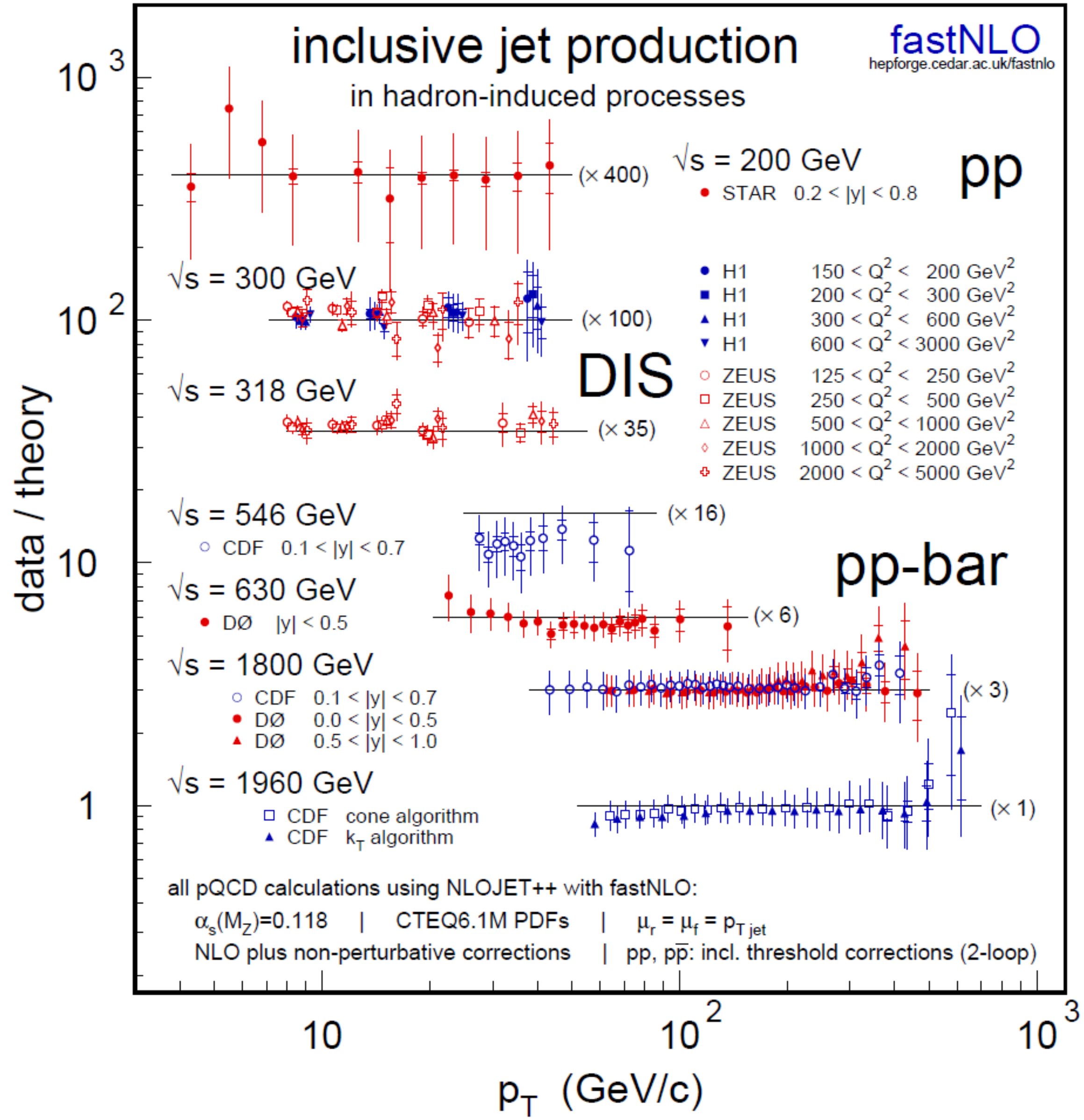
$\alpha_s(M_Z)$ only changed $\alpha_s = 0.118 \pm 0.003$

 # NLO = 2x4

To be further investigated ...

Previous Jets Data / Theory

- **Comparison of jet data from**
  - **STAR at RHIC**
  - **H1 and ZEUS at HERA**
  - **CDF and D0 at Tevatron**
- **Compatible with NLO pQCD**
- **To be updated with soon to be published LHC measurements**



Outlook

NLOJet++
Z.Nagy,
PRD68 2003
PRL88 2002

- Examples shown were with NLOJet++
  but concept is general!
- New version to be released soon (next months) and comes with autotools installation (configure, make, make install)
- Better treatment of scale variations if scale is not binning variable
- Much more flexible table format, allows inclusion of:
  - Corrections factors, e.g. from non-perturbative effects
  - Data points with uncertainties
  - Normalization
  - Additional contributions like threshold corrections (already in previous version) or contact interactions

Fin

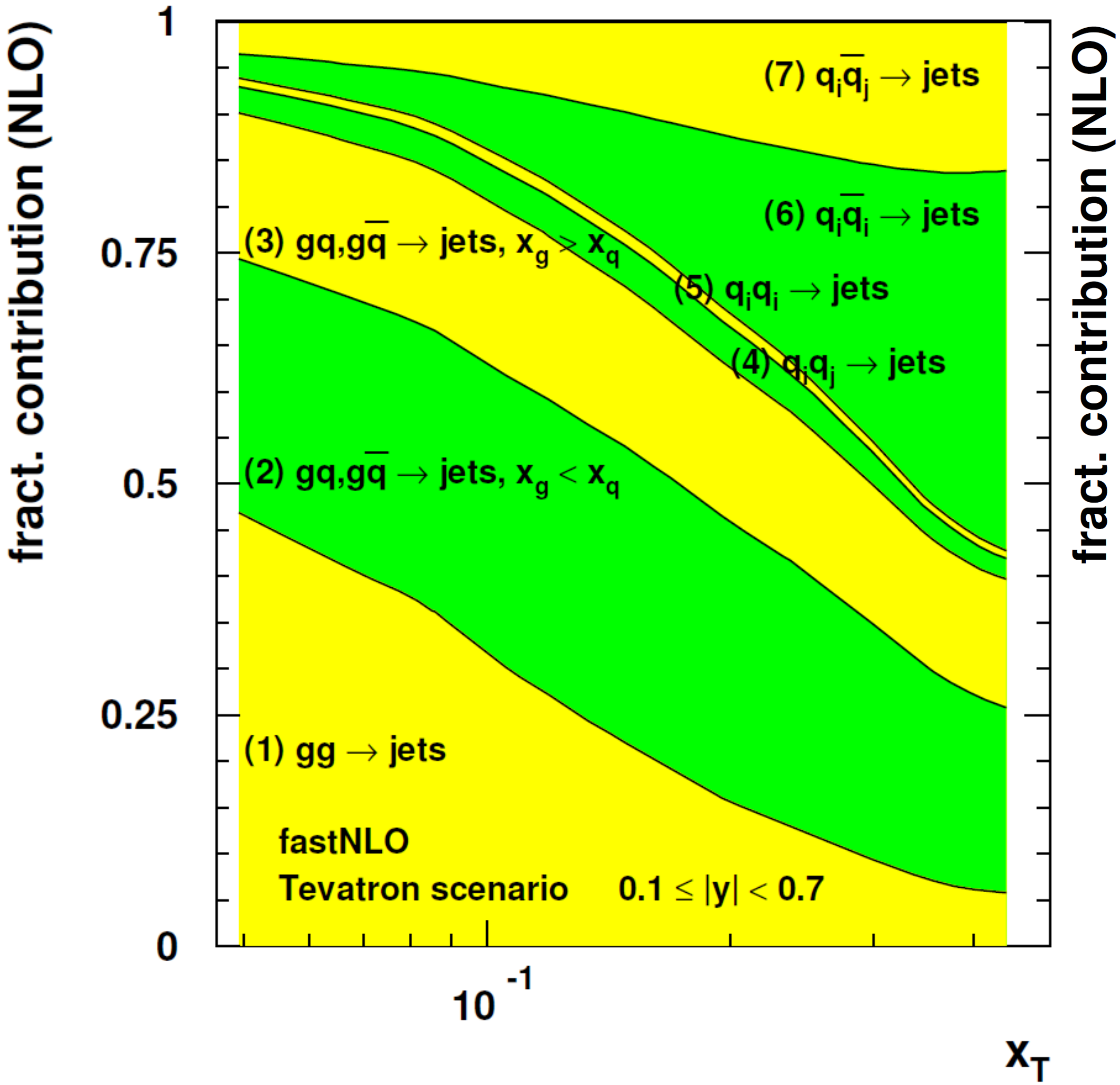
- **# NLO ~ 1600, i.e. 1600 NLO cross section reevaluations were required to prepare this talk!**
- **No computers were harmed in the making of this presentation!**

Thank you for your attention!

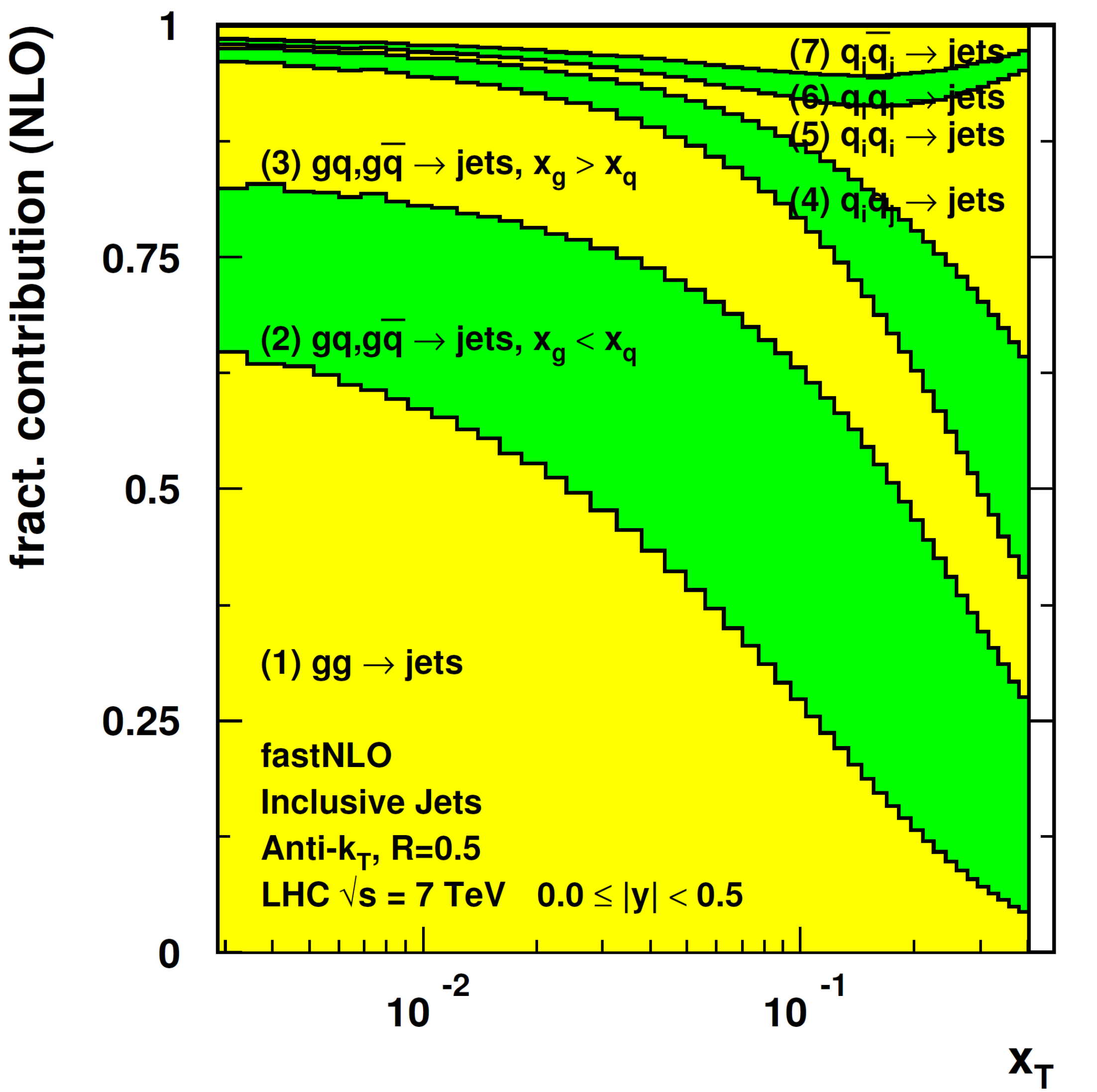
Backup Slides

Jet Cross Section Decomposition

Tevatron, 1.96 TeV



LHC, 7 TeV

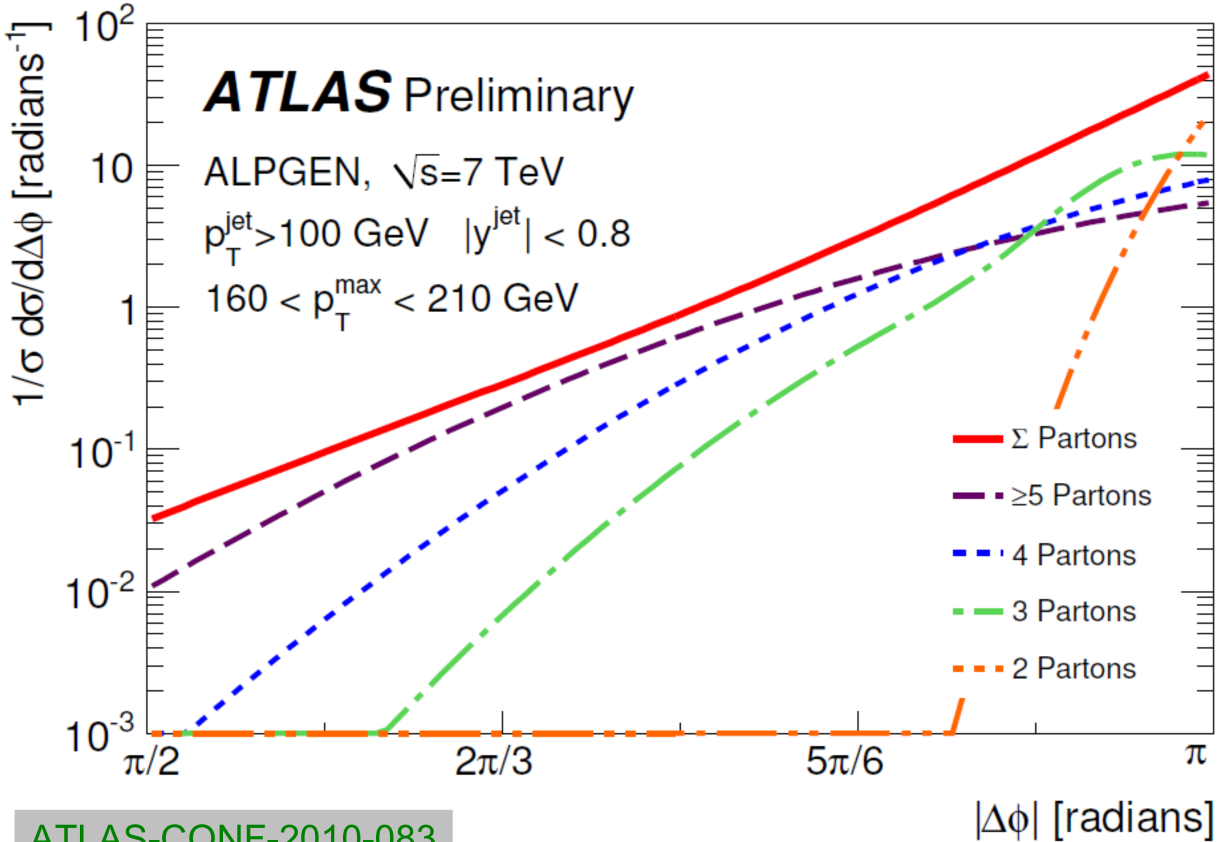


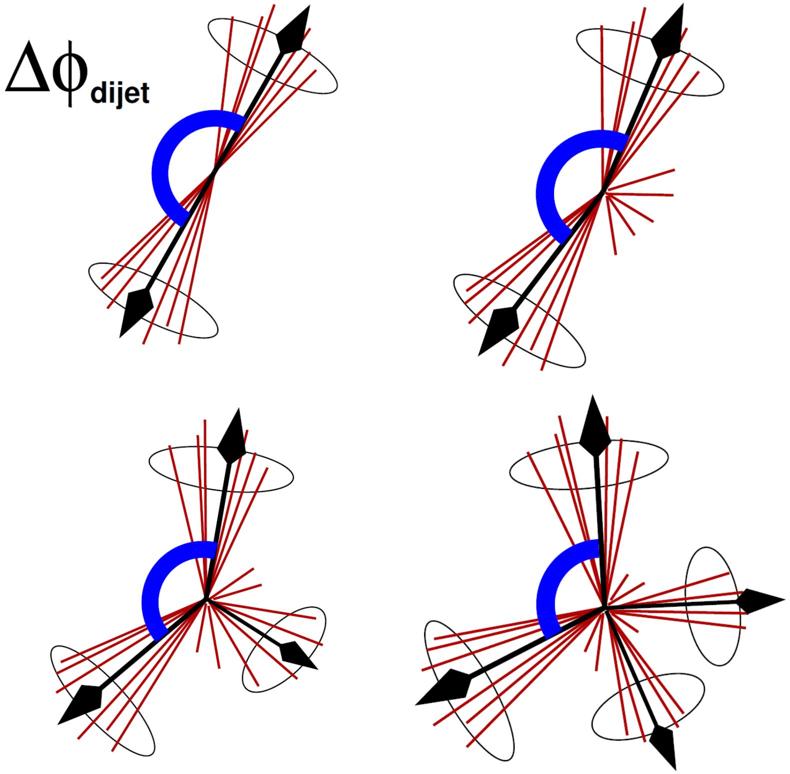
Azimuthal Decorrelation

Born limit has dijets with $|\Delta\Phi| = \pi$

With increasing number of partons smaller separation angles become possible

Depends on α_s ...



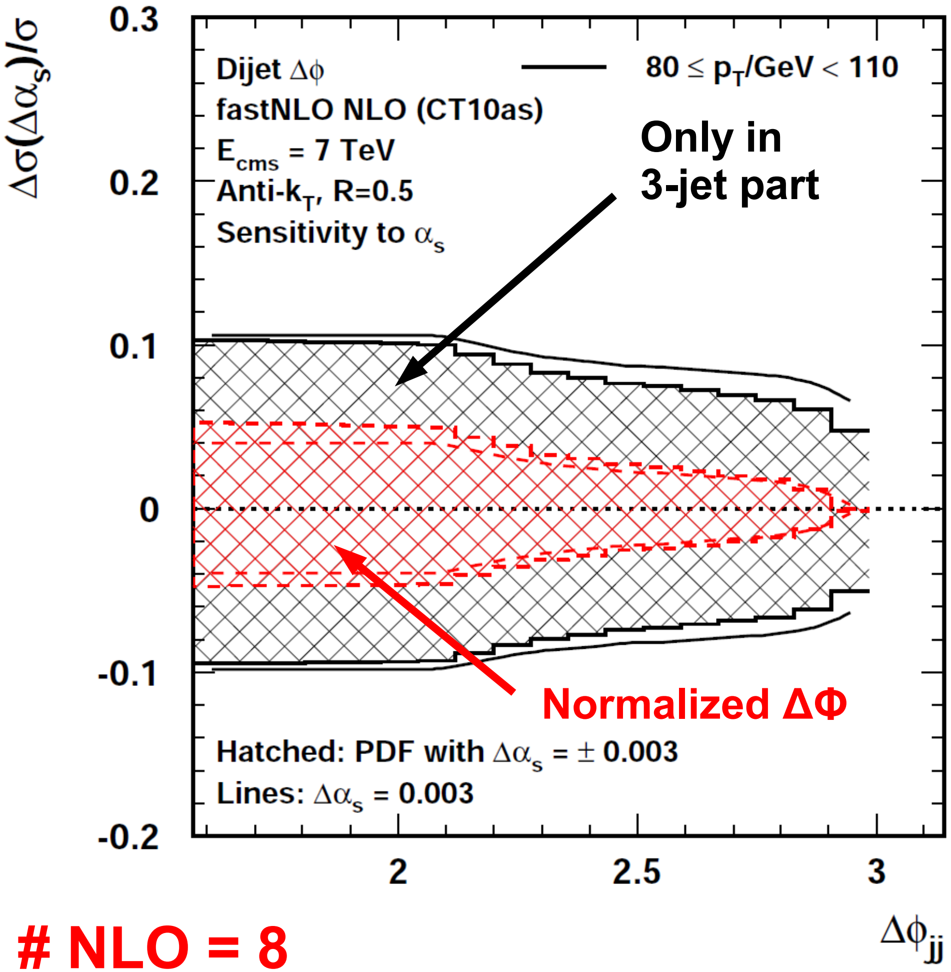


ATLAS-CONF-2010-083

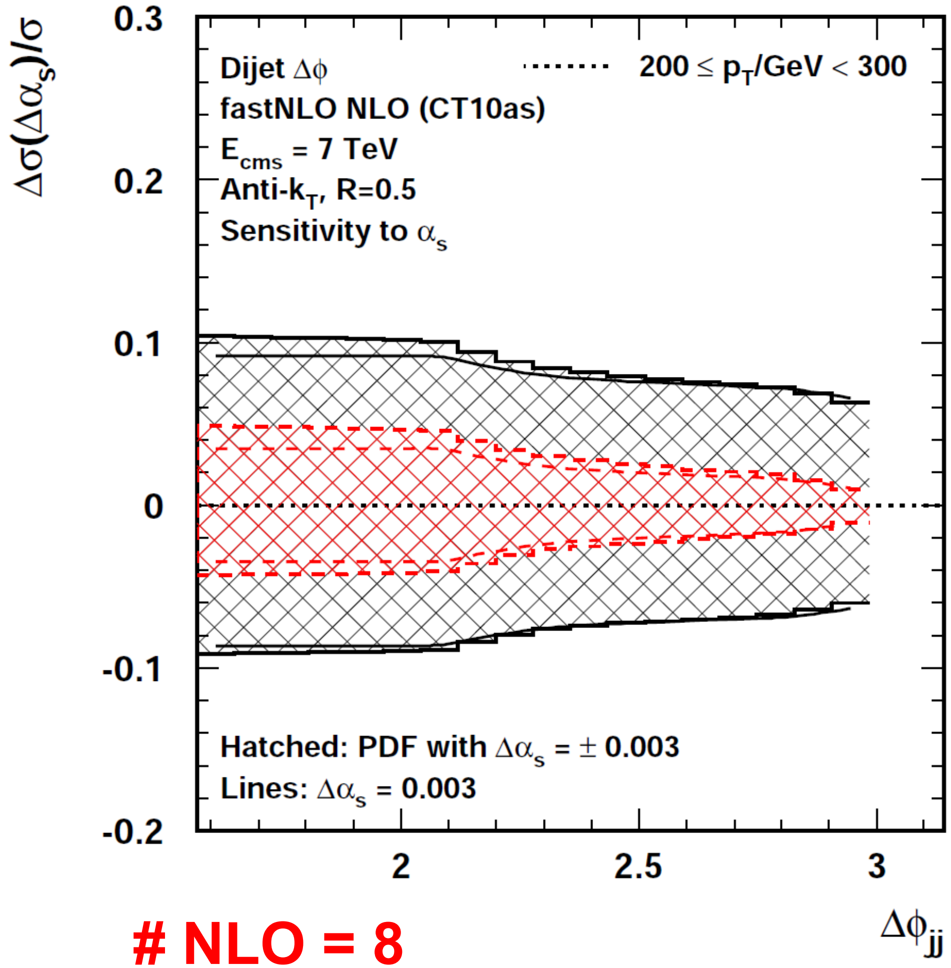
ΔΦ: Sensitivity to α_s

Low pT bin: 80 < pT / GeV < 110

High pT bin: 200 < pT / GeV < 300



NLO = 8



NLO = 8

Sensitivity to alpha_s

Inclusive Jet pT