PHYSICS AT THE TERA SCALE
Helmholtz-Alliance

fastNLO v2

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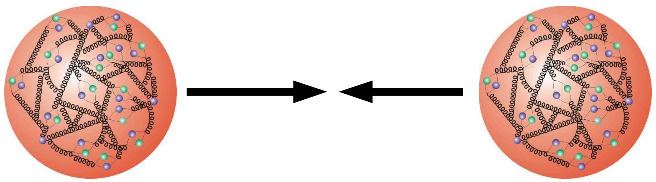
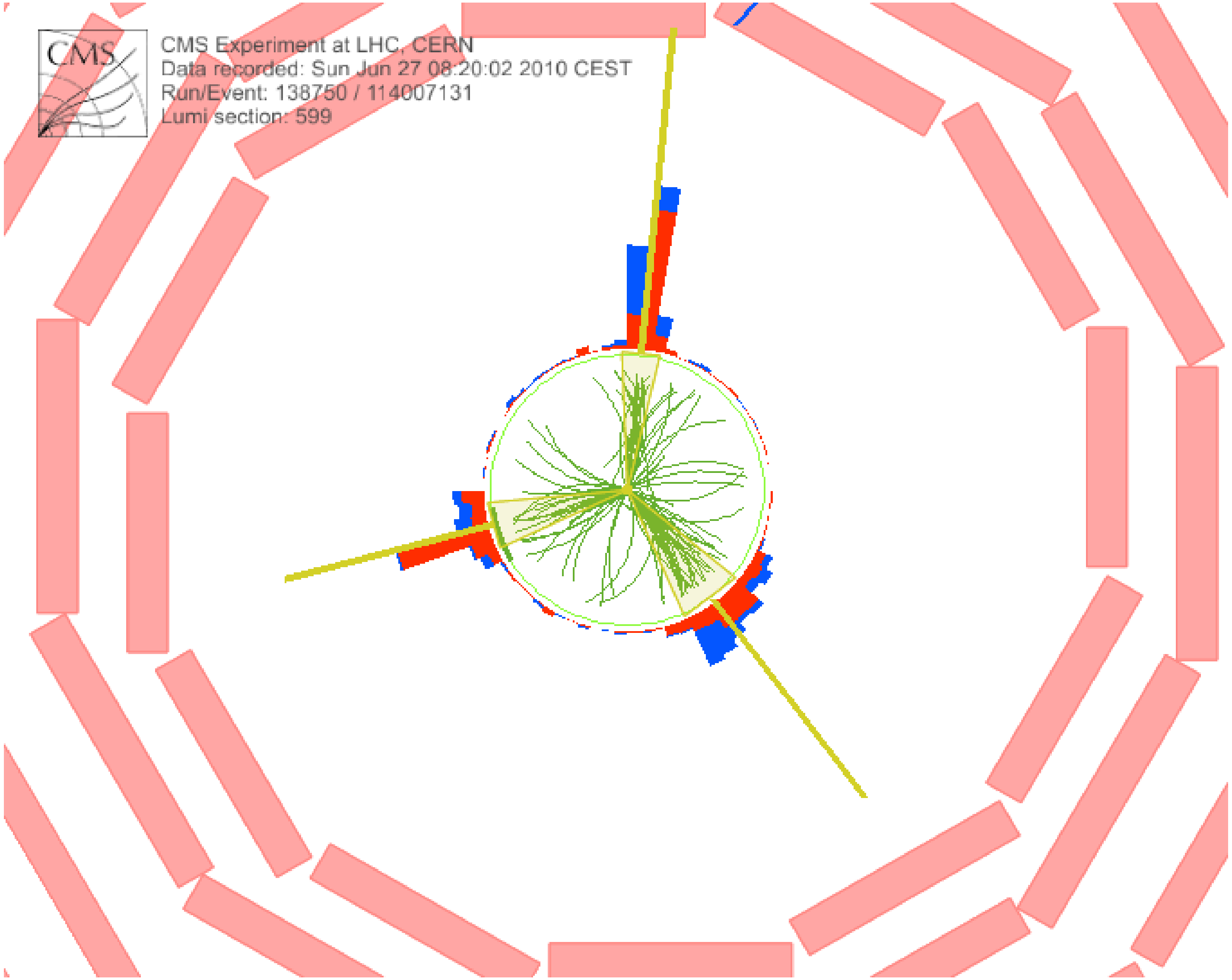
Outline

- **Quick Reminder: Motivation & Concept**
- **Up to now: Application of v14**
- **News on v2**
- **Outlook**





Motivation

- Interpretation of experiment data relies on:
  - Availability of reasonably fast theory calculations
  - Often needed: Repeated computation of (almost) same cross sections
- 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 jets
- Need procedure for fast repeated computations of NLO cross sections
- Use fastNLO (in use by most PDF fitting groups)

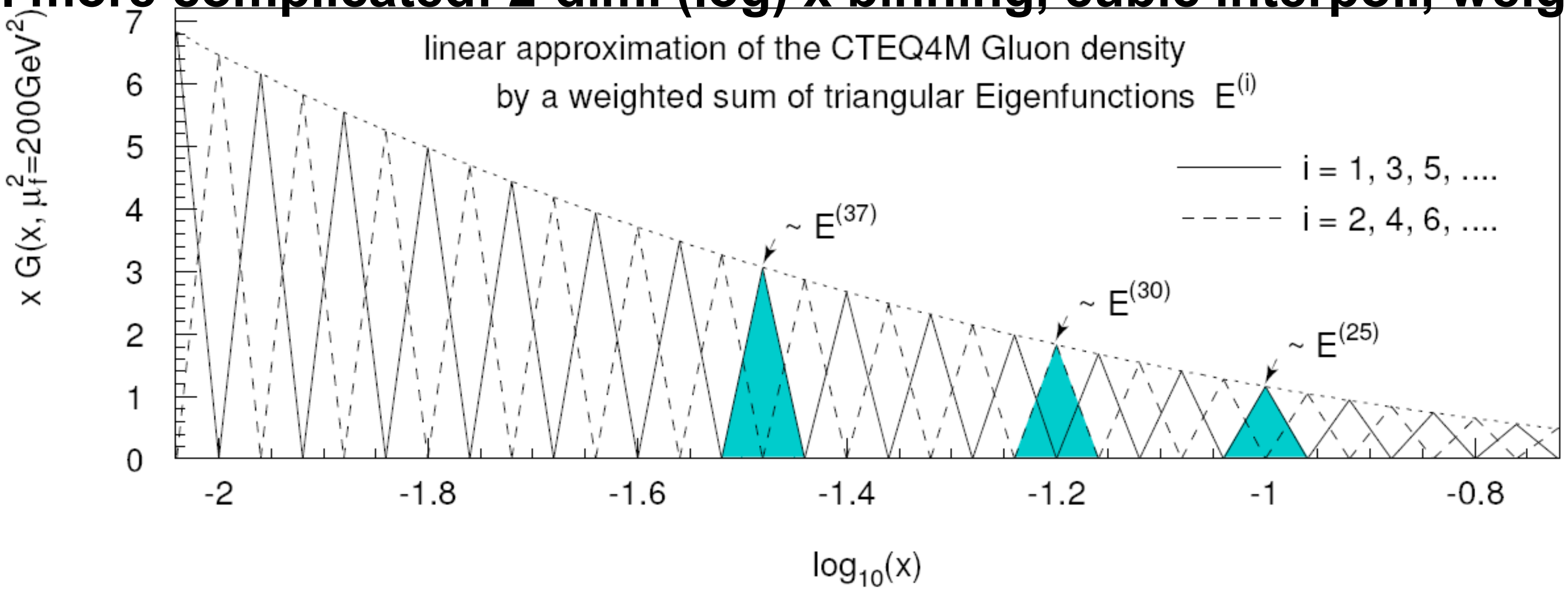
(ATLAS mostly uses another project: APPLGrid)

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:

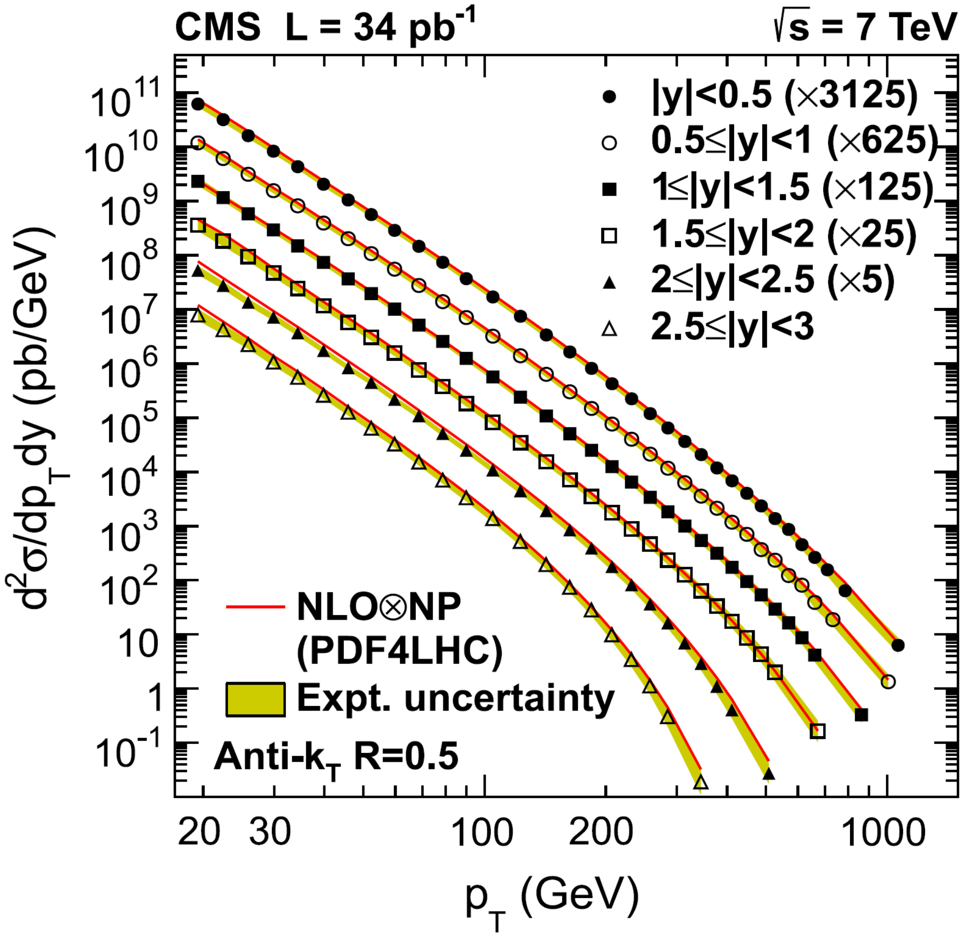
- $f(x) = \sum_i f(x^{(i)}) E^{(i)}(x)$ => Integration only over $E^{(i)}(x)$, not f(x)!
- In detail more complicated: 2-dim. (log) x binning, cubic interpol., weights



Example: Inclusive Jets

All possible with v1.4:
Inclusive jet pT cross section
For this derive:

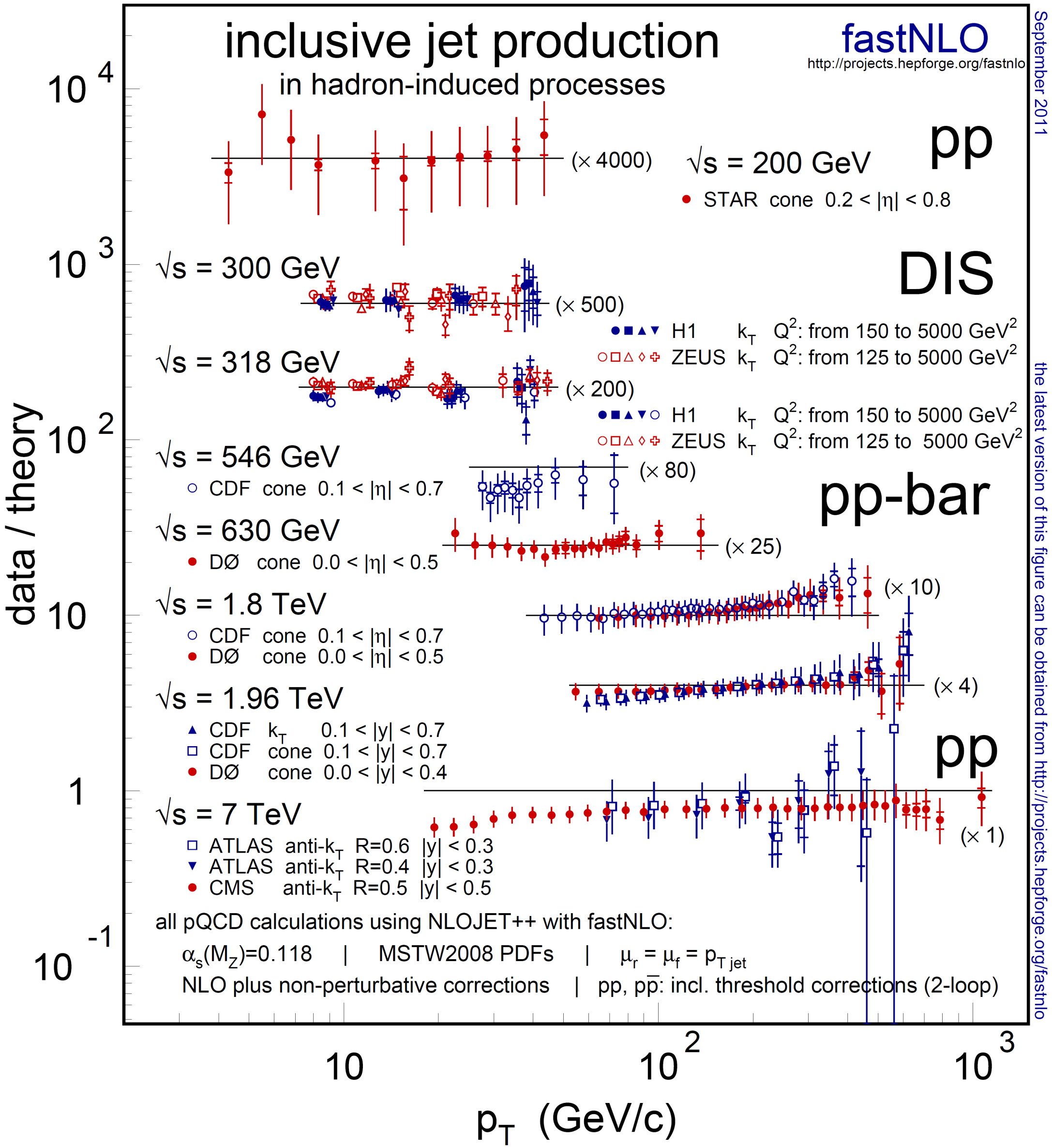
- **Scale Dependence:**
  - **Mostly: Sim. variation of μ_r and μ_r by factor of 2**
  - **Better: Indep. variation at 6 points (1/2,1/2), (1/2,1), (1,1/2), (1,2), (2,1), (2,2)**
- **PDF Uncertainties**
  - **PDF4LHC prescription for 1st compatibility check**
  - **Use of various PDFs (CTEQ, MSTW, NNPDF,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



CMS, PRL 107, 132001, 2011

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**
- **Includes first measurements from LHC**



fastNLO, arXiv:1109:1310v1, 2011

Scales in v2

In v14:

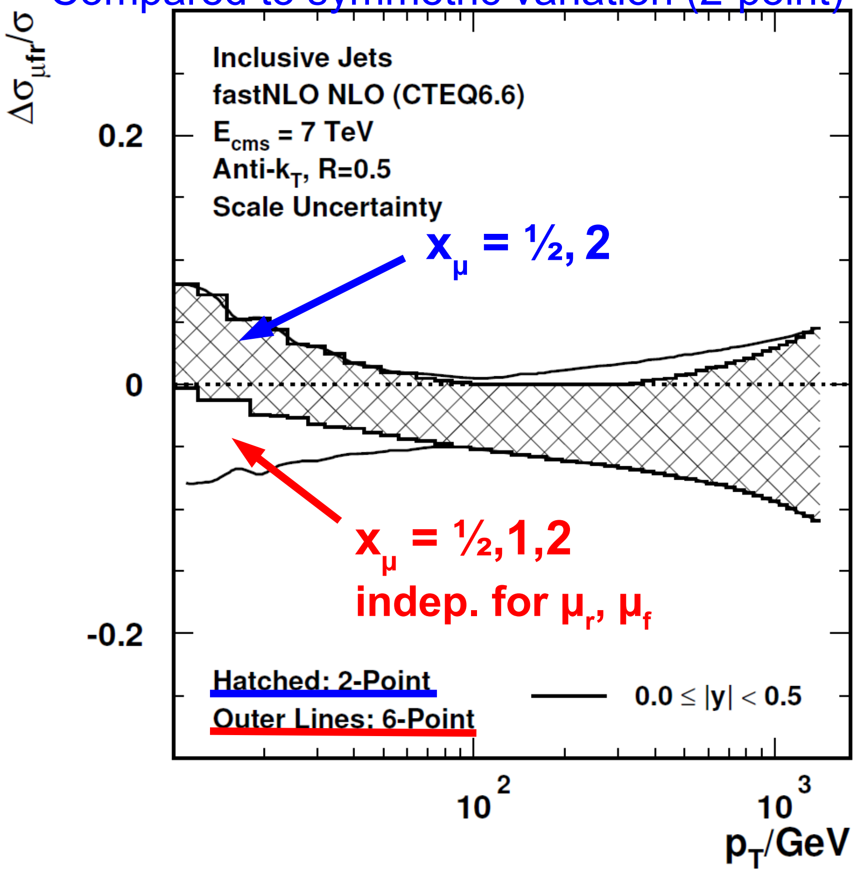
Asymmetric scale variations:

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)



New in v2:

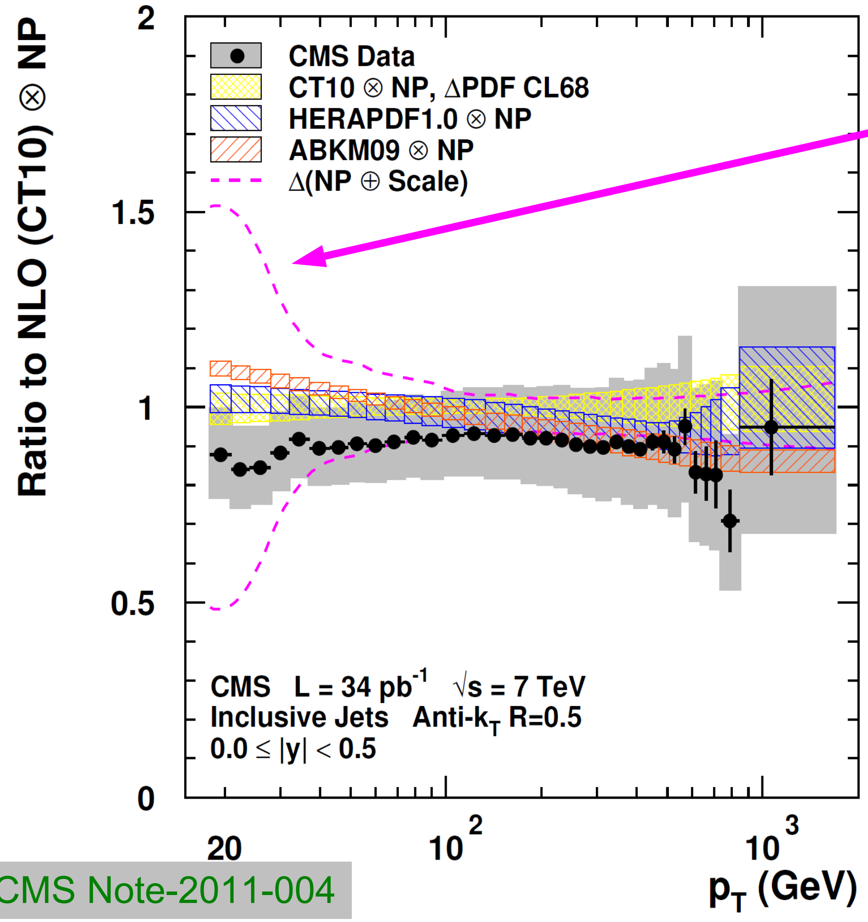
- **Two new possibilities:**
- **Scales always get own dimension**
  - **Much improved scale interpolation**
  - **Examples exist for pp/ppbar scattering (CMS incl. Jets, D0 3-Jet Mass)**
  - **Table size moderately larger, sufficient for most purposes**
- **Even better: Scale factors and functional form freely choosable a posteriori**
  - **Can e.g. choose p_T^2 for μ_r and Q^2 for μ_f**
  - **Calculations so far for H1 and ZEUS**
  - **Table size significantly larger, but no problem for DIS**

More Features in v2

In v14:

Detailed comparisons to individual PDF sets:

Here: CT10, HERAPDF1.0 and ABKM09



CMS Note-2011-004

New in v2:

- **Much more flexible table format allows inclusion of:**
  - **Correction factors, e.g. non-perturbative ones incl. uncertainty (Example exists: CMS incl. Jets)**
  - **Data points with uncertainties (Example exists: CMS incl. Jets)**
  - **Electroweak corrections (calculated?)**
  - **Threshold corrections (already in v14 for incl. jets)**
  - **New physics contributions**
  - **Normalization options**
- **Arbitrary no. of dimensions for binning of observable (in addition to scale bins)**

Further Features in v2

- Automated determination of optimal limits for x binning in warm-up run
- No. of interpolation bins in x per observable bin is flexible
- Tables in v14 format can be converted to new format v2
- Reader code to evaluate tables in Fortran and C++
- Install packages produced with standard autotools, just run
  - ./configure - -prefix=your_local-directory
  - make; make install
  - Missing features, e.g. LHAPDF will be asked for
- Use of NLOJet++ 4.1.3 (previously: 2.0.1)

Outlook

- New version will be released in two steps:
  - 1. Basic code to read and evaluate the tables will be released together with sample tables still THIS month: fastNLO-Reader-2.1.0-nnn
    (Some tests were made already in H1Fitter and NNPDF Groups)
  - 2. Table creation code for use with NLOJet++ will follow in ~ first half of next year
- All examples shown were with NLOJet++ from Z. Nagy, but fastNLO concept is more general!

NLOJet++
Z.Nagy,
PRD68 2003
PRL88 2002

Thank you for your attention!

Backup Slides

Normalized Cross Section 1

Version 1: Area Normalization
(Not always possible in pQCD!)

Dijet Angular Distribution in Chi$_{jj}$ where

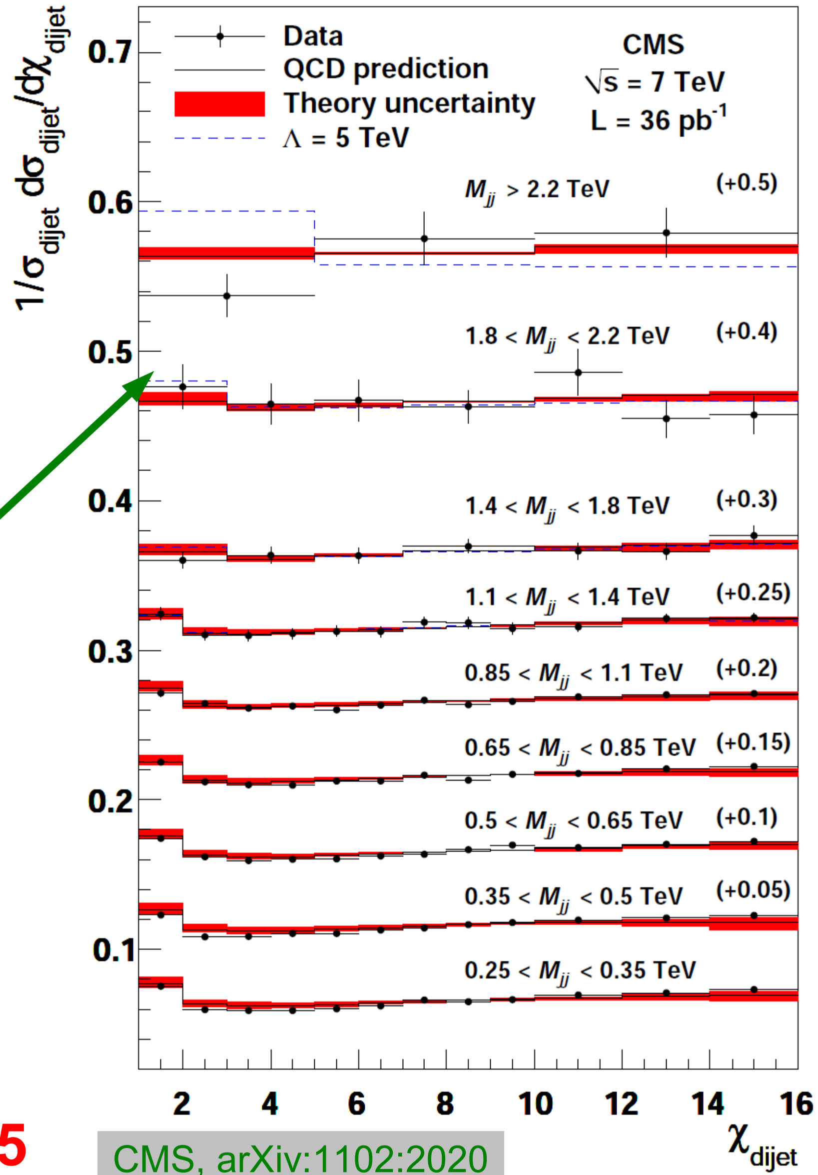
$$\chi_{\text{dijet}} = \exp(2y^*)$$
$$y^* = \frac{1}{2}|y_1 - y_2|$$

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

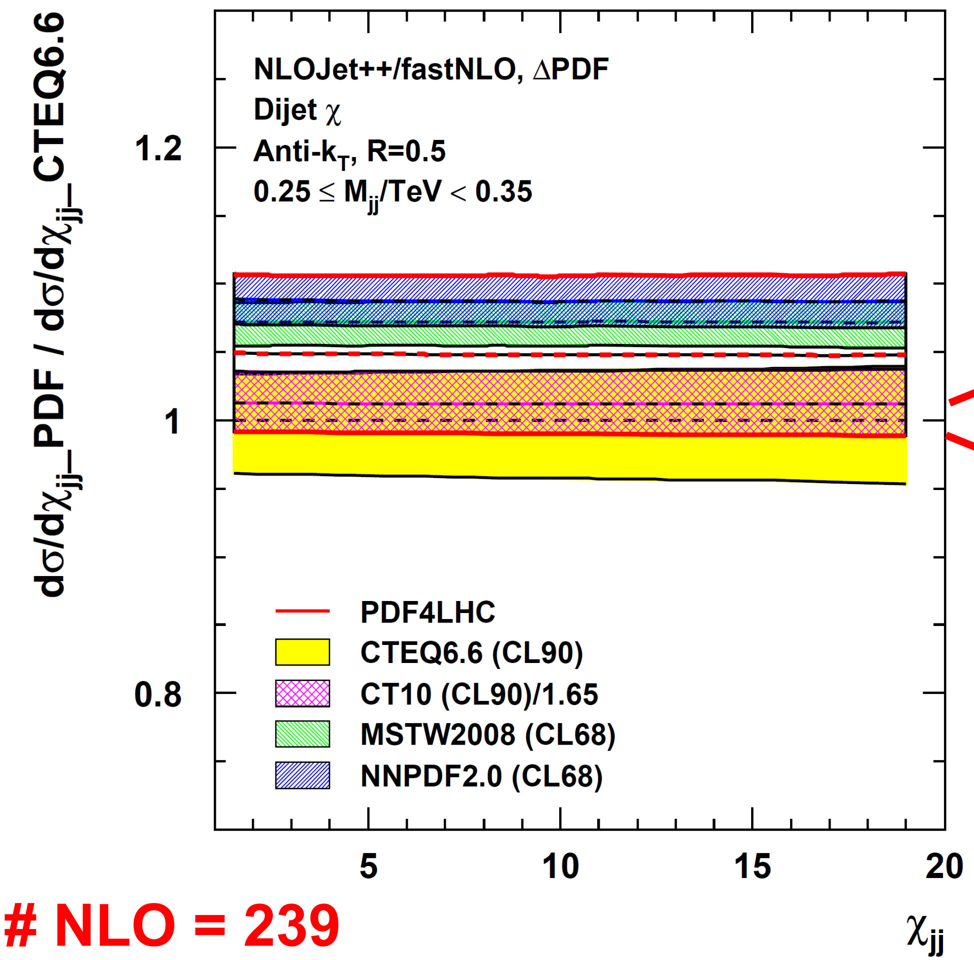


CMS, arXiv:1102:2020

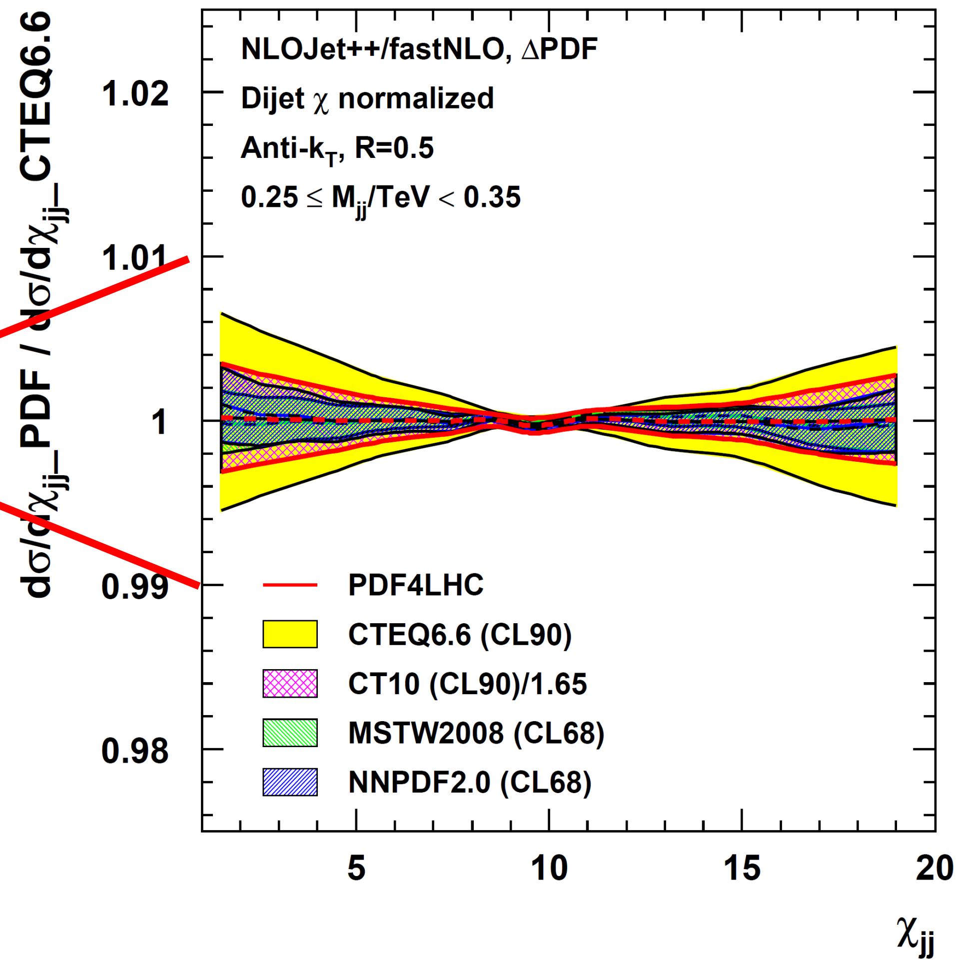
Dijet Angular: ΔPDF

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

Differential cross section



Normalized cross section



NLO = 239

Normalized Cross Section 2

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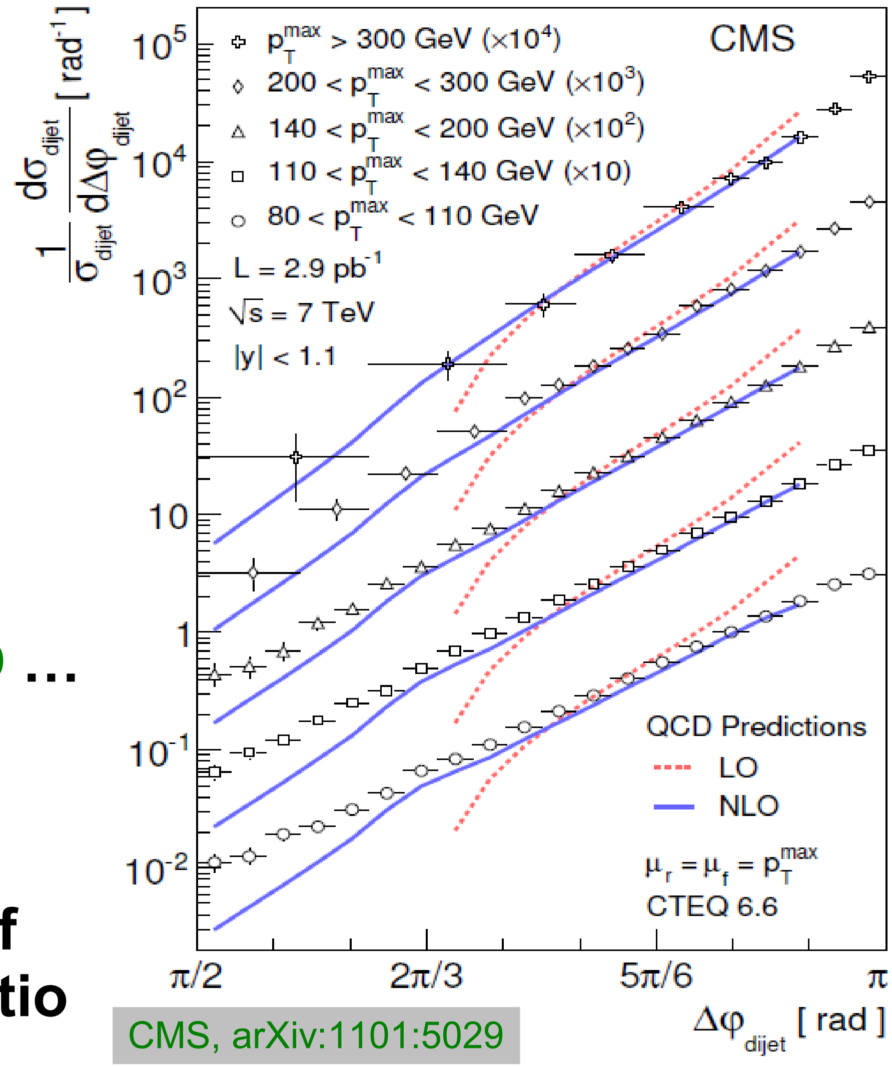
Version 1: Normalize to … ?

 # NLO = 1

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)



CMS, arXiv:1101:5029

Nevertheless:
Normalization can be done at NLO

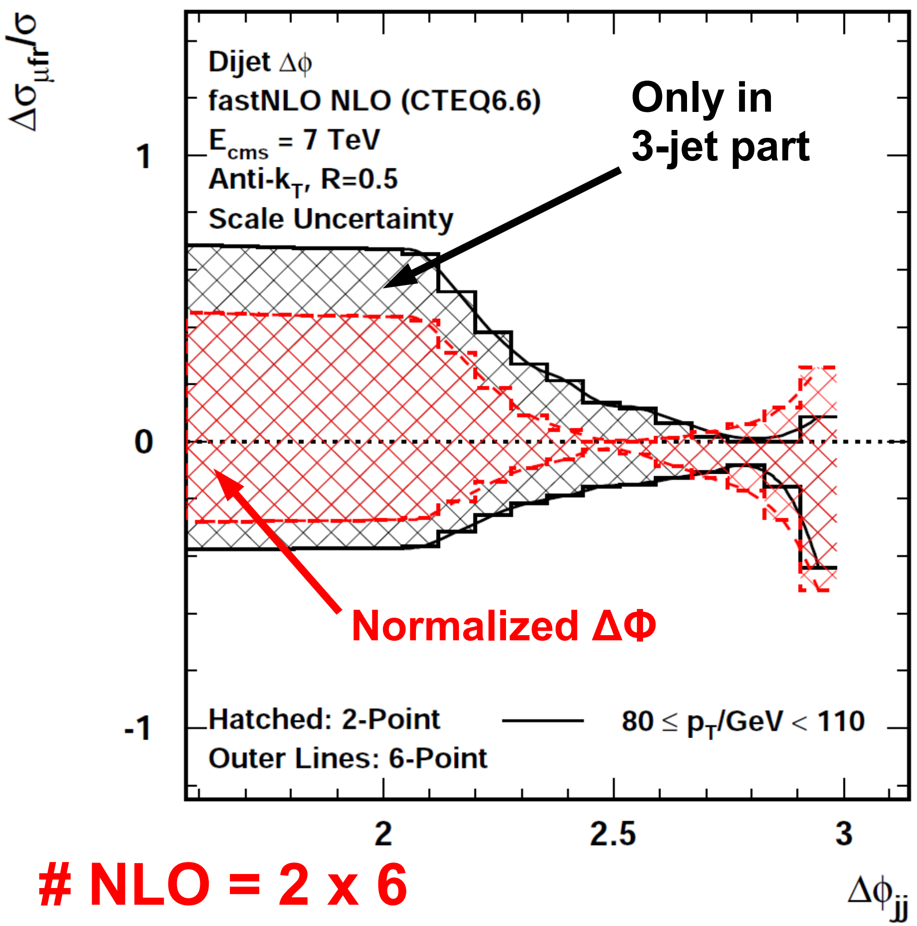
==> Numerator and Denominator both at NLO …
but of different order in alpha_s
O(alpha_s³) / O(alpha_s²)

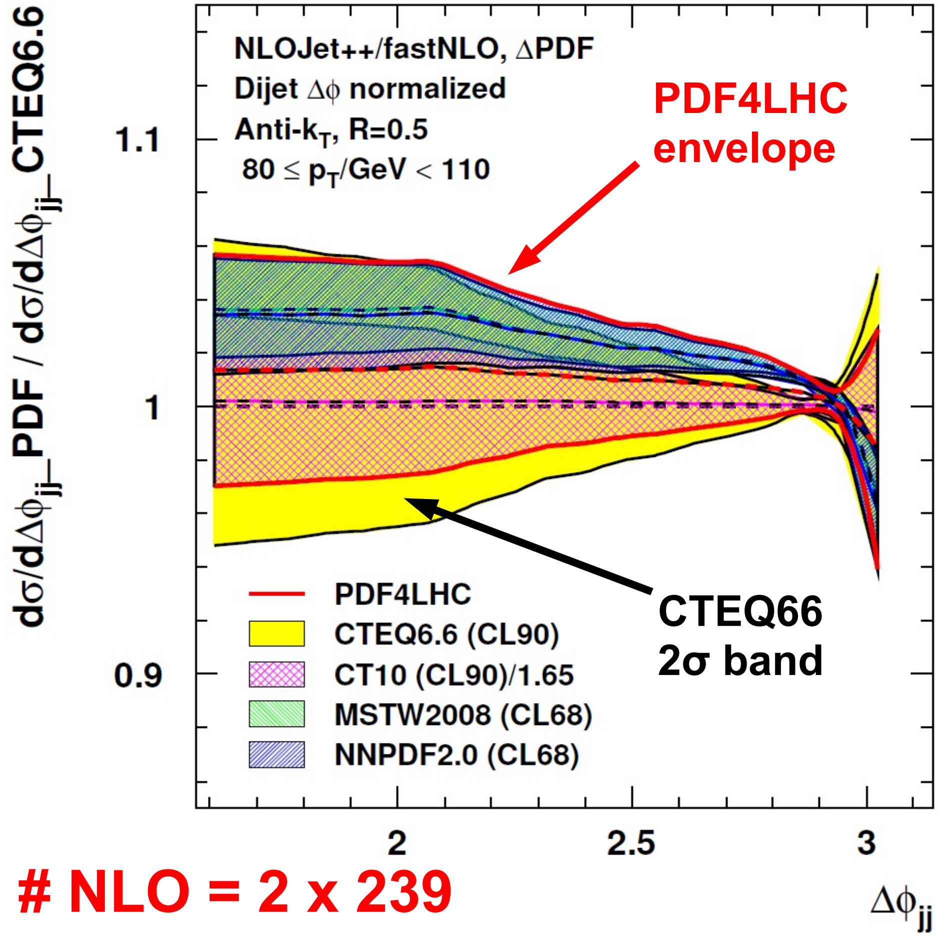
Also possible: Numerator and denominator of same order in alpha_s e.g. Dijet Centrality Ratio

ΔΦ: Scale and ΔPDF

Reevaluations for numerator and denominator!

Low pT bin: 80 < pT / GeV < 110



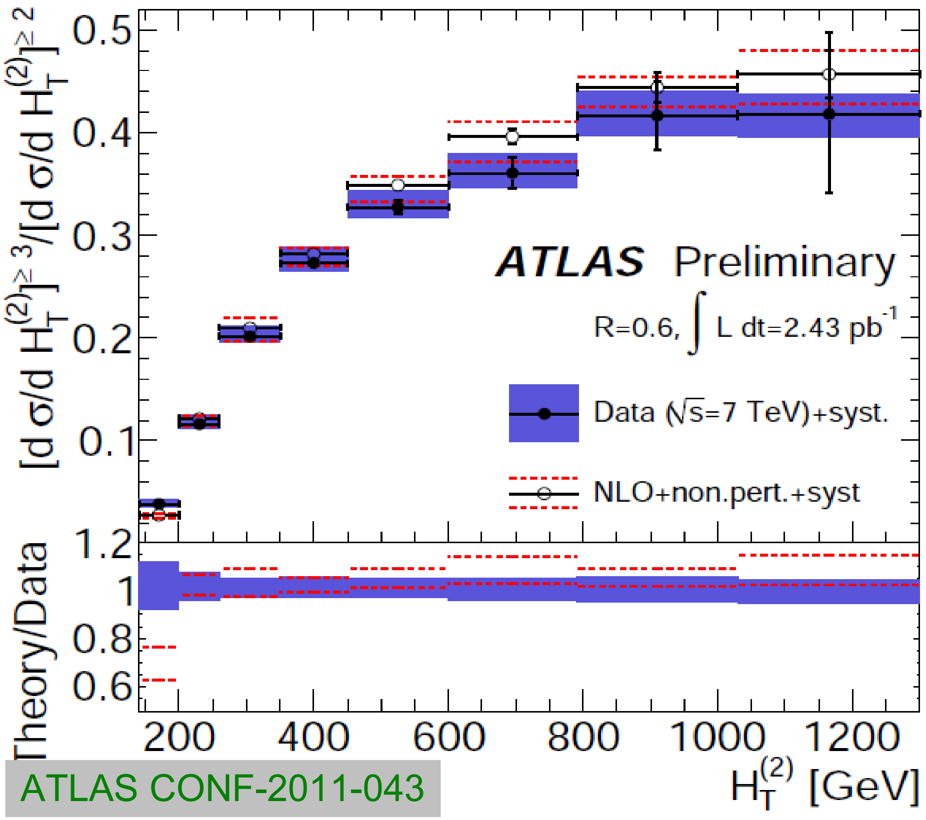


 # NLO = 2 x 6 **# NLO = 2 x 239**

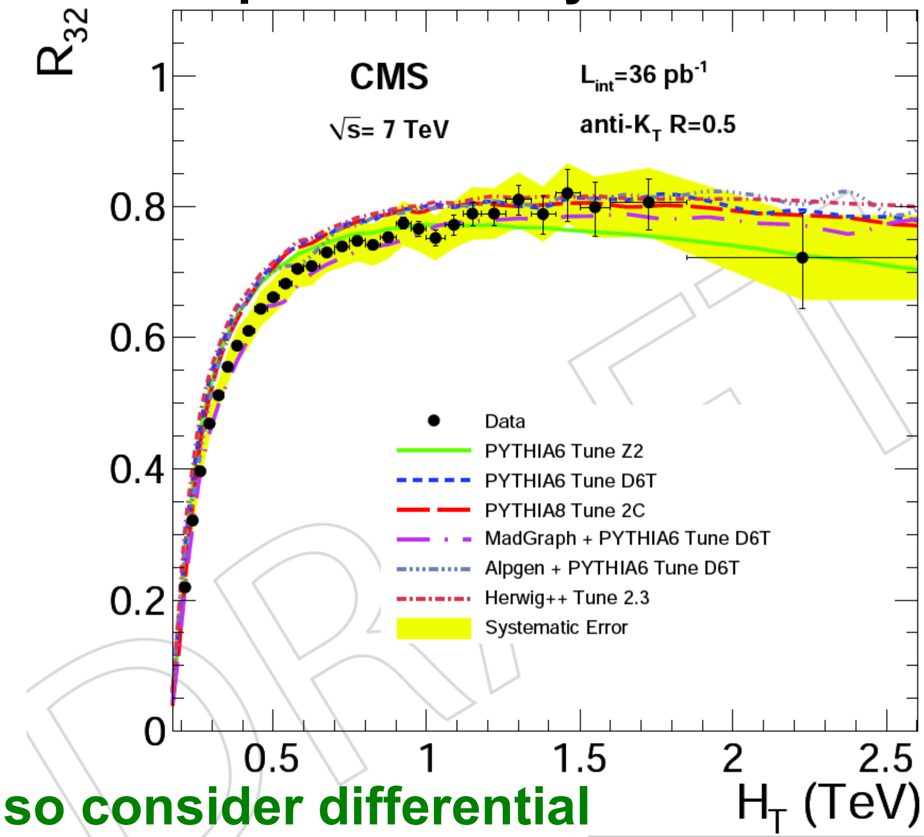
Cross Section Ratios

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

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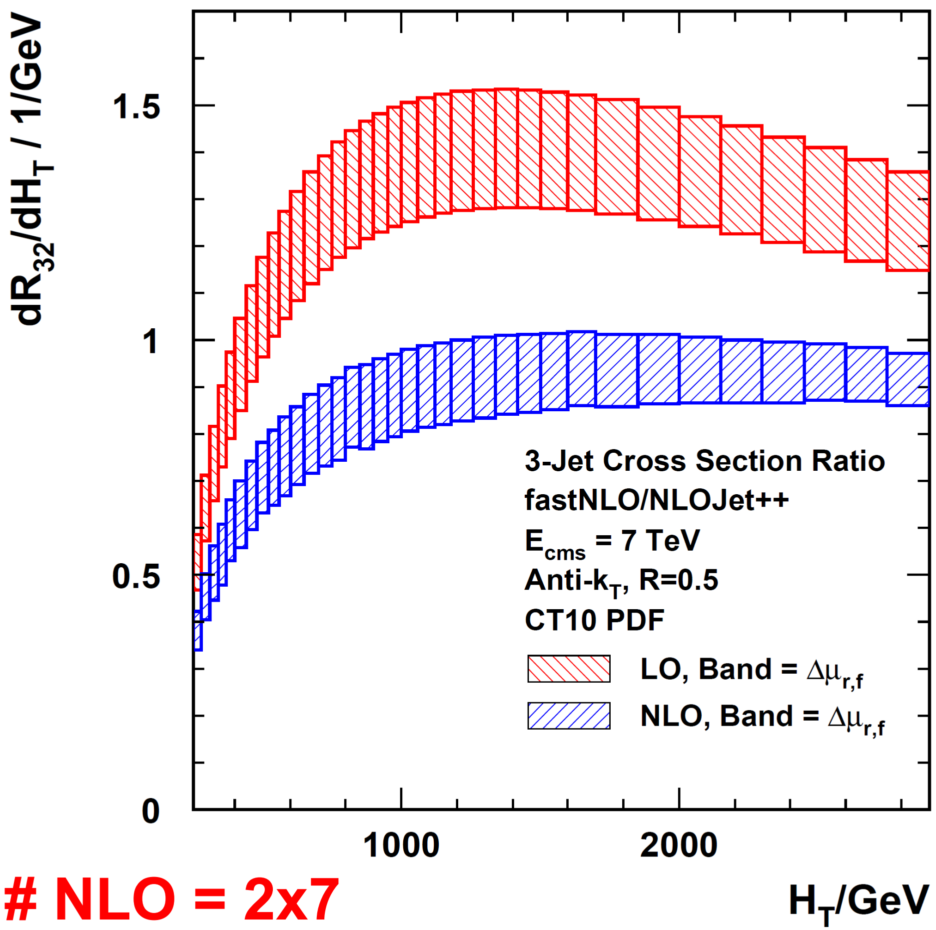
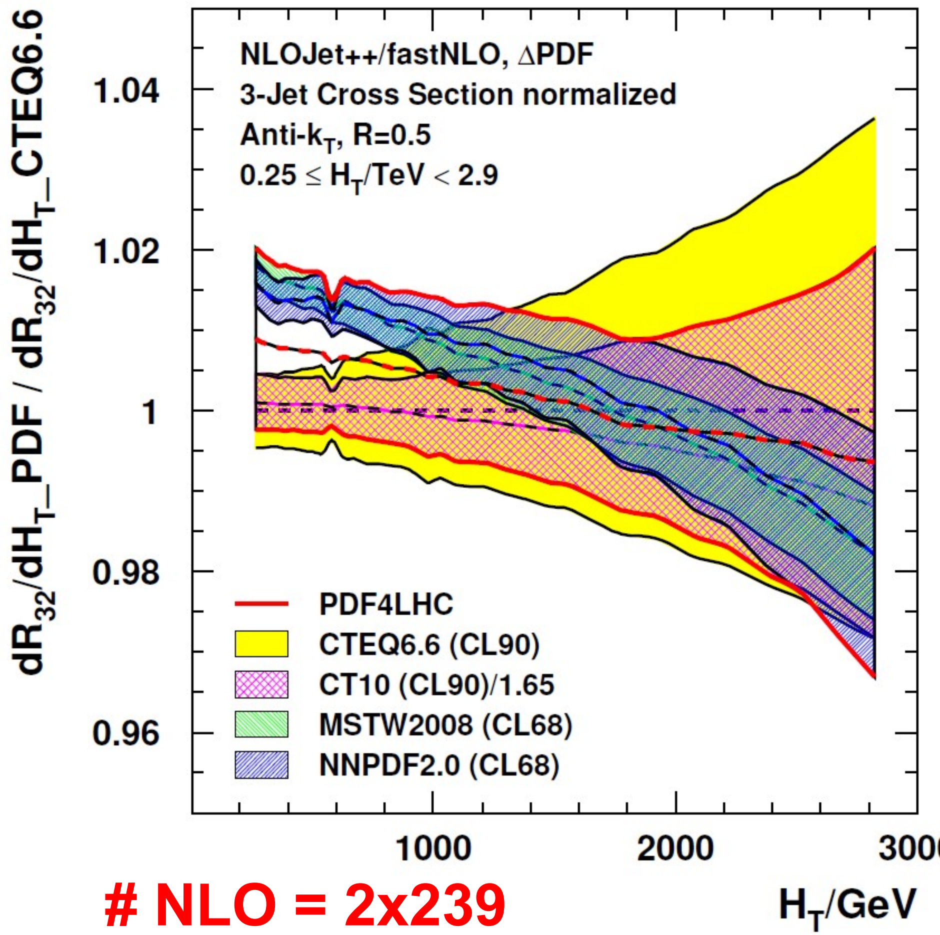
CMS like selection
(ATLAS not very different)
LO > 1 ?!
K factors ~ 0.67

PDF uncertainty reduced by a factor ~ 10 in ratio





NLO = 2x7

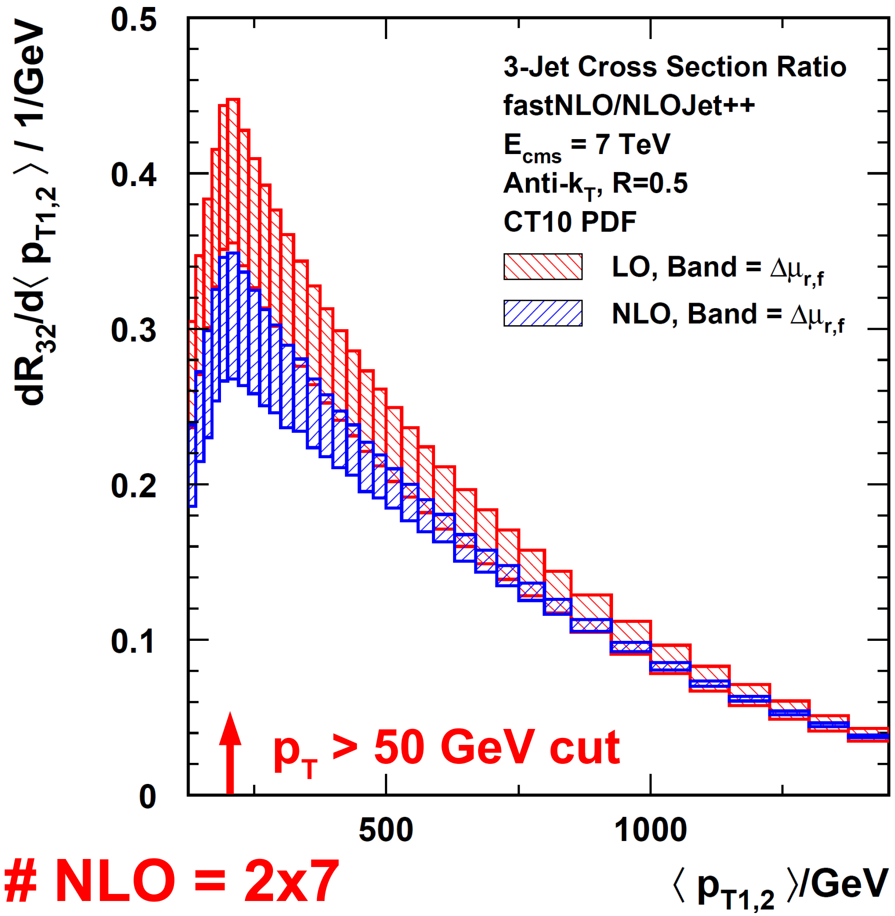
NLO = 2x239

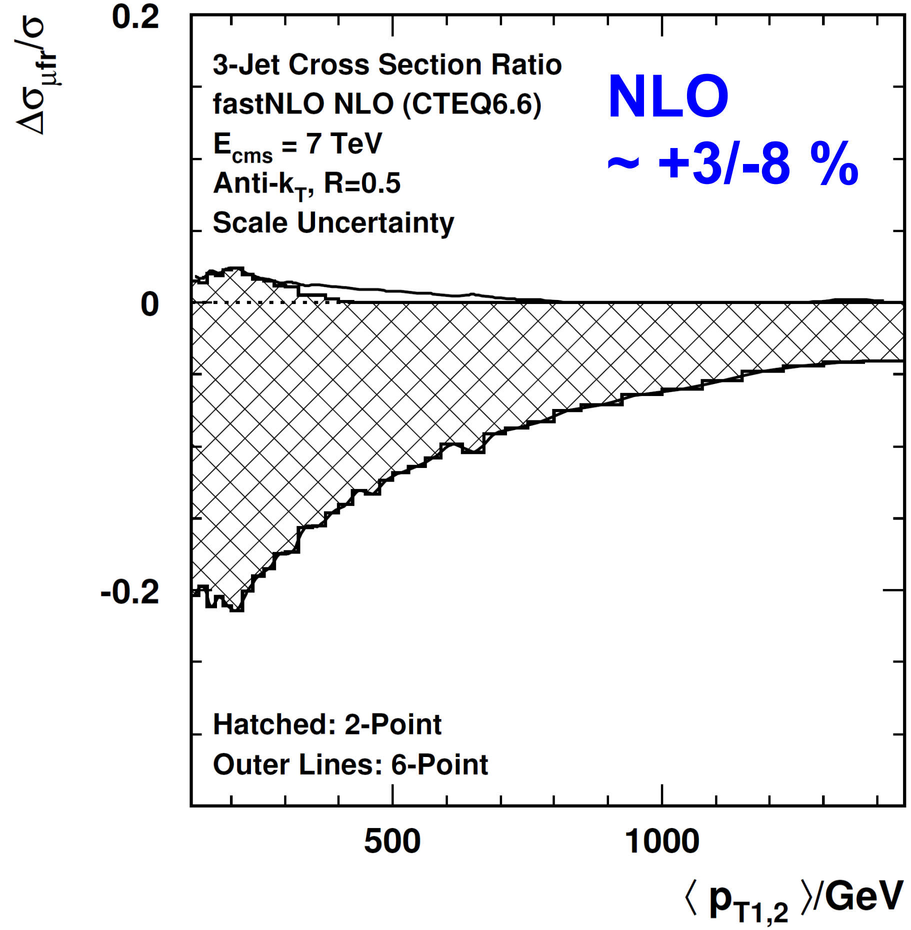
3+/2+ Revisited

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

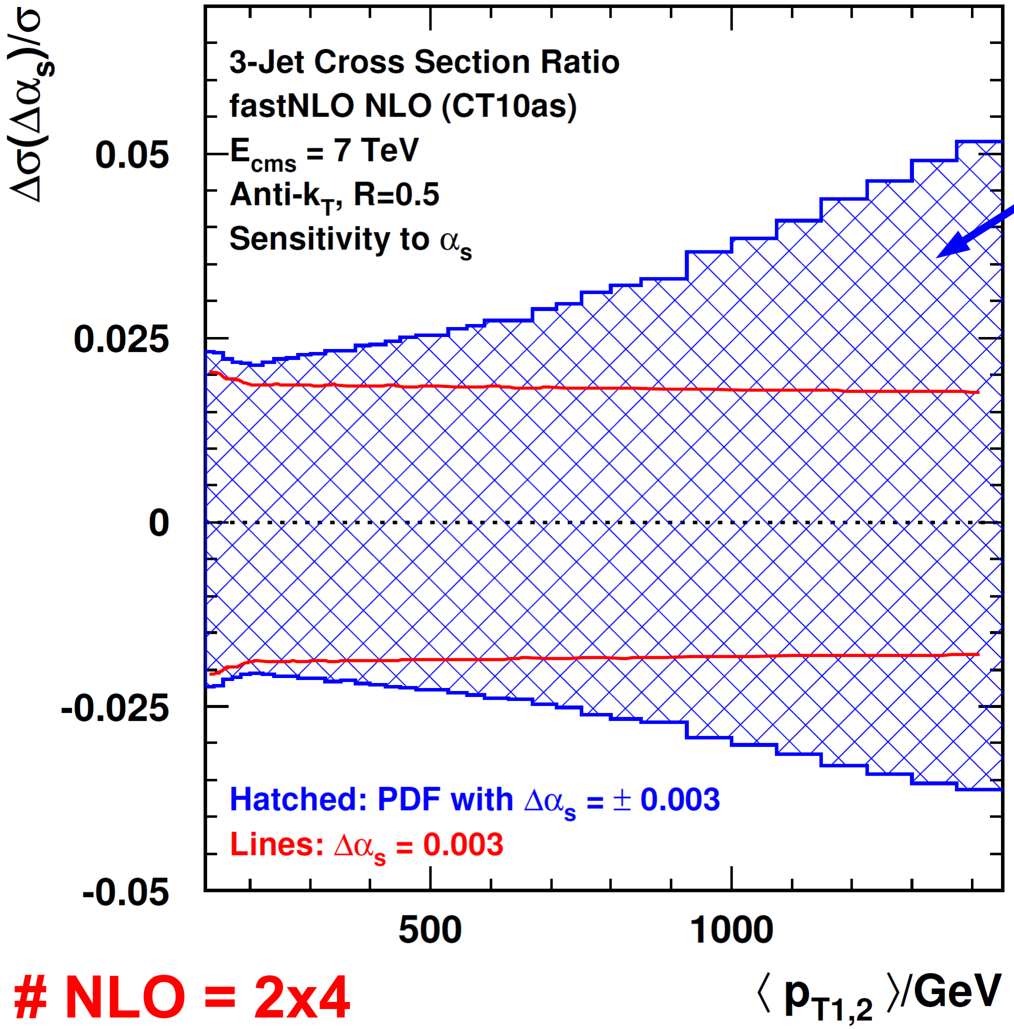




 # NLO = 2x7

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 ...

Jet Cross Section Decomposition

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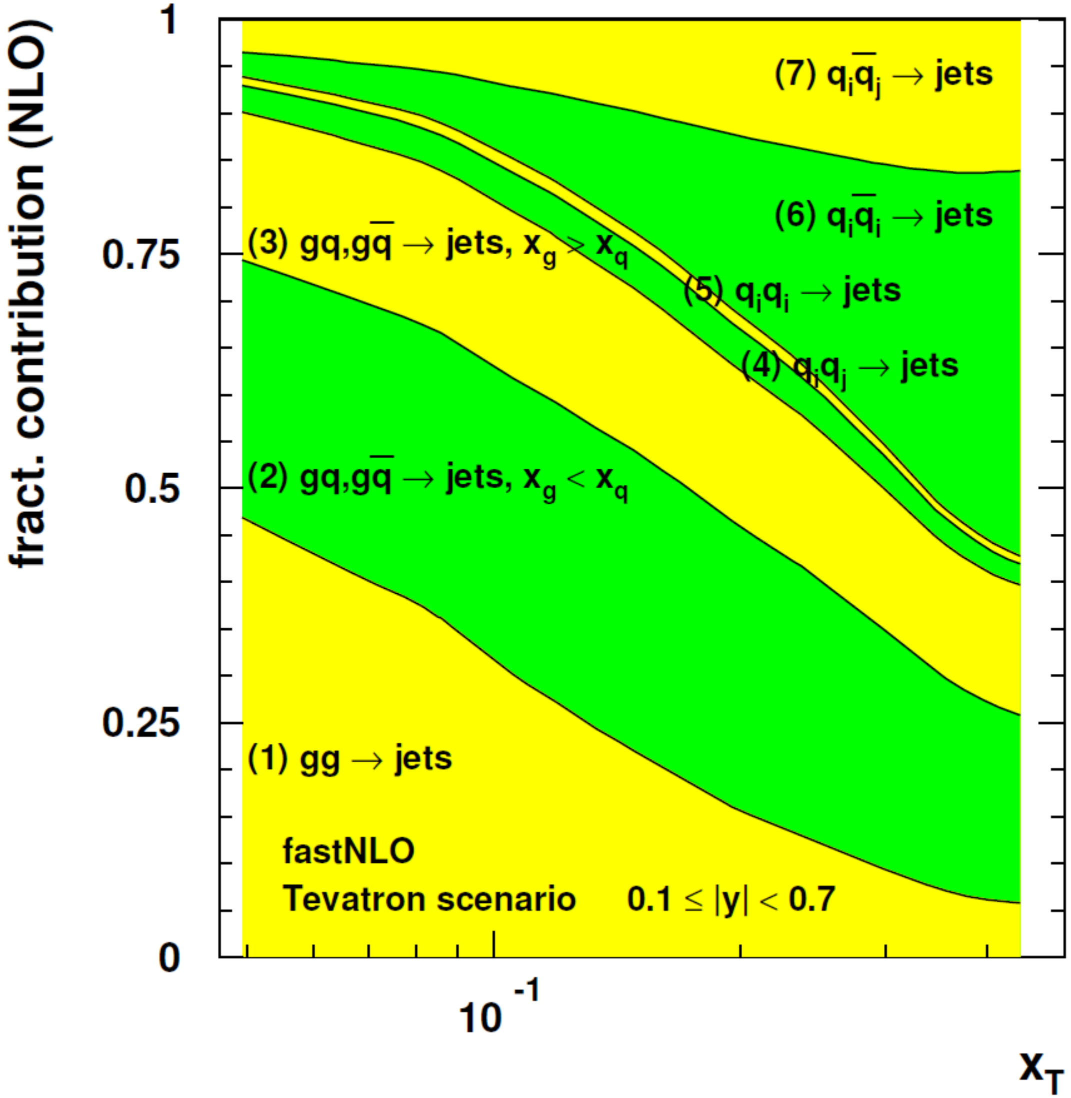
Tevatron, 1.96 TeV



LHC, 7 TeV