

High p_T Cross Sections with

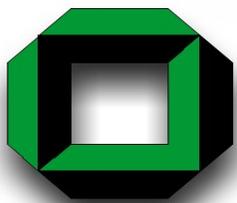
*fast*NLO

Thomas Kluge, DESY, H1

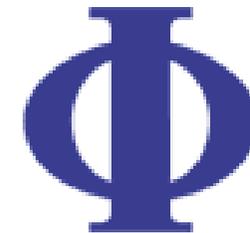
Andreas Oehler, University of Karlsruhe, CMS

Klaus Rabbertz, University of Karlsruhe, CMS

Markus Wobisch, FERMILAB, D0



Outline



Motivation

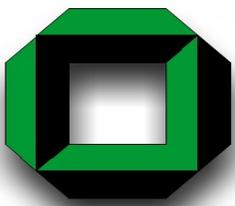
Concept

PDF Approximation

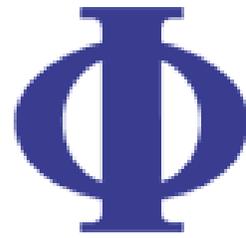
Optimizations

Some Results

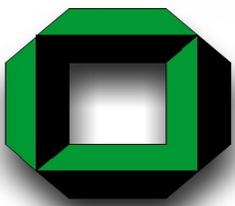
Outlook



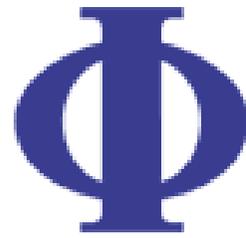
Motivation



- ➔ Interpretation of experiment data relies on:
 - Availability of reasonably fast theory calculations
 - Often needed: Repeated computation of same cross section
- ➔ Examples for a specific analysis:
 - Use of various PDFs (CTEQ, MRST, ...)
 - 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 new procedure for **fast repeated computations** of NLO cross sections

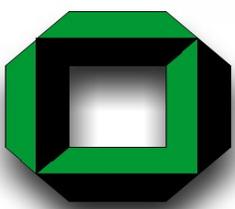


New Concept

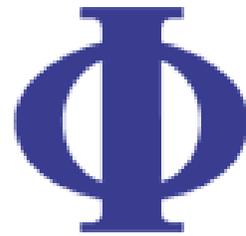


Can be used for any observable in hadron-induced processes (hh / DIS / Photoproduction)

- ➔ Does not include theor. calculation itself (leave this to theorists!), but requires flexible computer code:
 - Here: NLOJET++ (Zoltan Nagy)
- ➔ During first computation no time saved:
 - Needs **hours, days, weeks** ... for high statistical precision
- ➔ Any further computation takes **fractions of a second**
- ➔ Involves one single approximation with quantifiable precision



Jet cross sections in hadron-hadron collisions

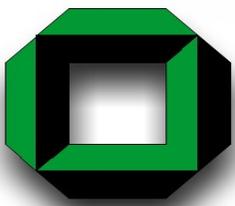


General cross section formula:

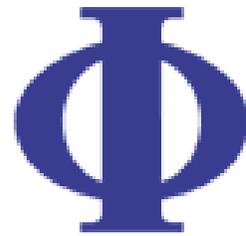
$$\sigma_{hh} = \sum_n \alpha_s^n(\mu_r) \sum_{flavour i} \sum_{flavour j} c_{i,j,n}(\mu_r, \mu_f) \times f_i(x_1, \mu_f) \times f_j(x_2, \mu_f)$$

which depends on:

- Strong coupling constant α_s to the power of n
 - Perturbative coefficients $c_{i,j,n}$
 - Parton density functions (PDFs) of the hadrons $f_i(x)$, $f_j(x)$
 - Renormalization scale μ_r , factorization scale μ_f
 - Momentum fractions x
- ➔ Standard procedure: Integration over phase space in (x_1, x_2) (usually MC method) => **Dependency on PDFs!**
- ➔ New: Interpolation between fixed support points in x for PDFs => **Evaluation a posteriori** possible



PDF Approximation



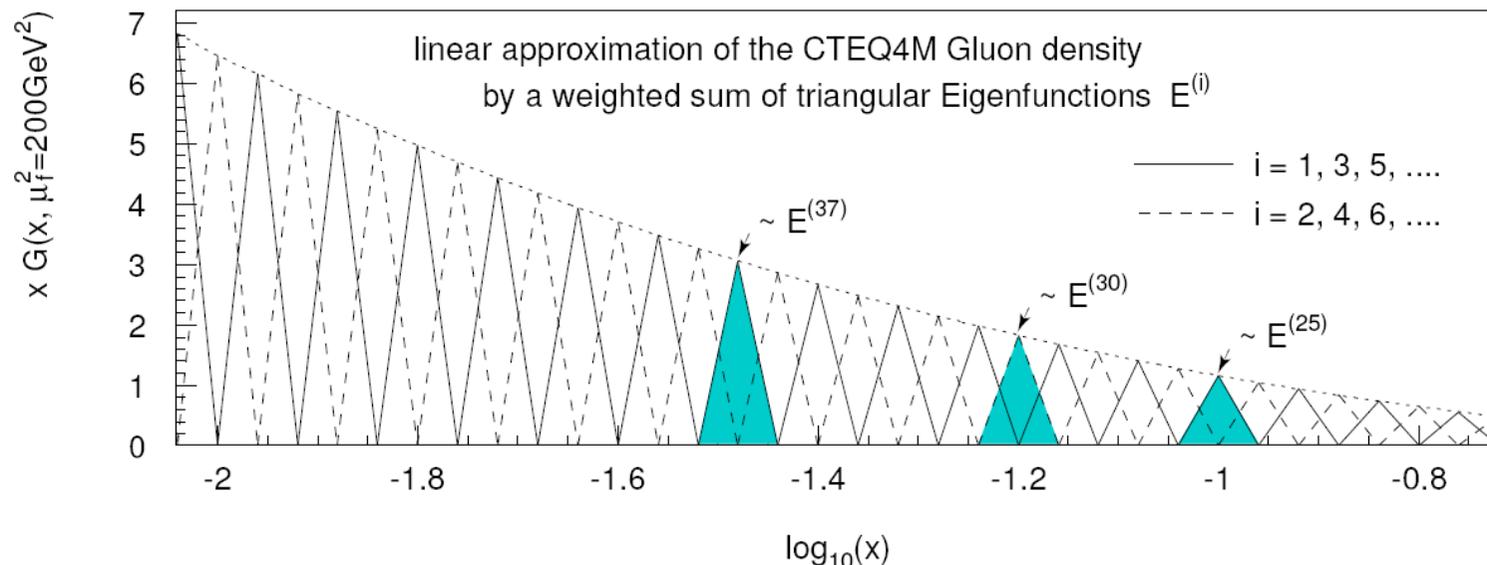
➔ Introduce set of discrete $x^{(i)}$ with $x^{(n)} < \dots < x^{(i)} < \dots < x^{(0)} = 1$

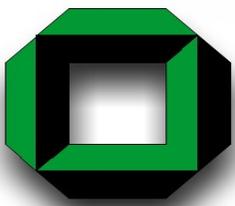
➔ Around each $x^{(i)}$ define eigen function $E^{(i)}(x)$ with:

$$E^{(i)}(x^{(i)}) = 1, E^{(i)}(x^{(j)}) = 0 \quad (i \neq j), \quad \sum_i E^{(i)}(x) = 1 \quad \text{for all } x$$

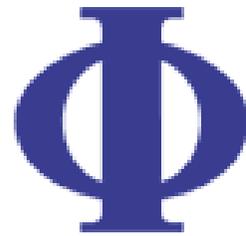
➔ Express PDF $f(x)$ by lin. combination of eigen functions with coefficients given by PDF values **at discrete points**:

$$f(x) = \sum_i f(x^{(i)}) E^{(i)}(x) \quad \Rightarrow \text{Integration only over } E^{(i)}(x), \text{ not } f(x)!$$

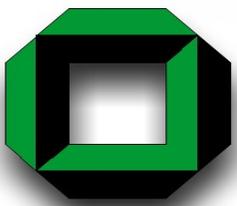




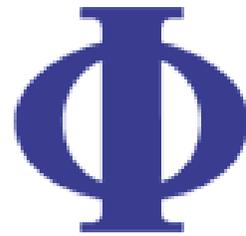
Partonic Subprocesses



- Don't want to deal with **13 X 13** PDFs
- For $hh \rightarrow$ jets **seven** relevant partonic subprocesses
 - 1) $gg \Rightarrow$ jets $\propto H_1(x_1, x_2)$
 - 2) $qg, \bar{q}g \Rightarrow$ jets $\propto H_2(x_1, x_2)$
 - 3) $gq, g\bar{q} \Rightarrow$ jets $\propto H_3(x_1, x_2)$
 - 4) $q_i q_j, \bar{q}_i \bar{q}_j \Rightarrow$ jets $\propto H_4(x_1, x_2)$
 - 5) $q_i q_i, \bar{q}_i \bar{q}_i \Rightarrow$ jets $\propto H_5(x_1, x_2)$
 - 6) $q_i \bar{q}_i, \bar{q}_i q_i \Rightarrow$ jets $\propto H_6(x_1, x_2)$
 - 7) $q_i \bar{q}_j, \bar{q}_i q_j \Rightarrow$ jets $\propto H_7(x_1, x_2)$
- Need only seven linear combinations H_i of PDFs



Symmetries



➔ In addition, symmetries can be exploited:

$$H_n(x_1, x_2) = H_n(x_2, x_1) \quad \text{for } n = 1, 4, 5, 6, 7$$

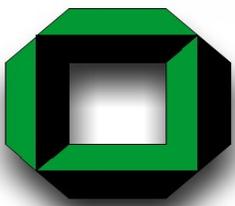
$$H_2(x_1, x_2) = H_3(x_2, x_1)$$

➔ For hadron anti-hadron collisions, replace:

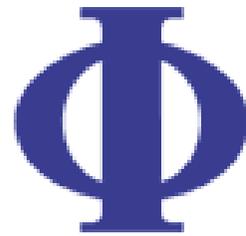
$$H_4(x_1, x_2) \leftrightarrow H_7(x_1, x_2)$$

$$H_5(x_1, x_2) \leftrightarrow H_6(x_1, x_2)$$

➔ Minimize required table size and computing time!



Actual Usage



Our actual interpolation is:

- ➔ Two-dimensional (x_1, x_2)
- ➔ Bicubic, linear at the edges
- ➔ Spaced in x with points $\sim \sqrt{\log(1/x)}$

Example use case:

D0 incl. jets (hep-ex/0011036)

No. of bins in rap. y : 5

No. of bins in p_T : 24 - 8

Total no. of bins: 90

No. of events (NLO): 49G

CPU time for first run: > 4000h

Table size (10 x bins, 4 scal.): 5.5MB

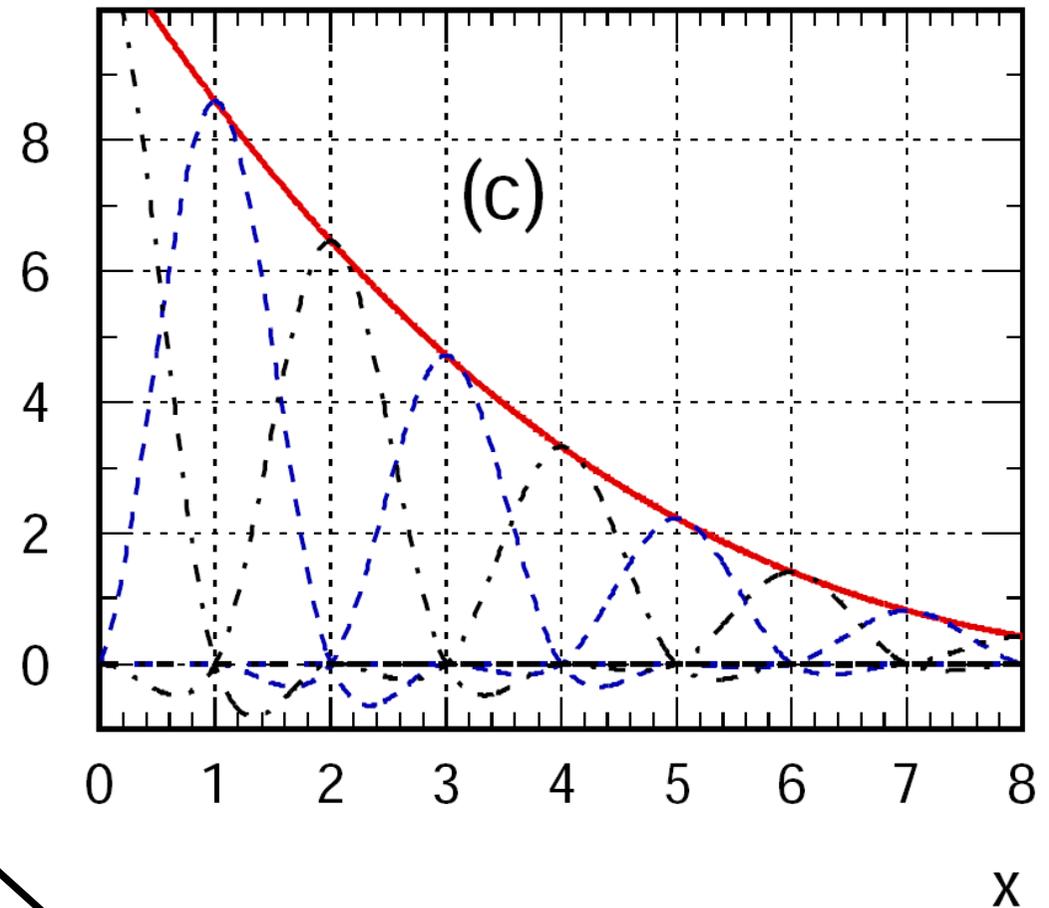
Reading of table: $O(1s)$

Execution time/PDF set: $< O(0.1s)$

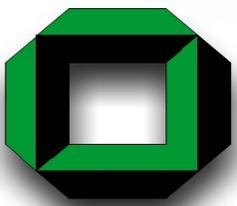
Stat. precision, y bins 1-3: **0.1 - 0.3%**

y bins 4,5: **0.2 - 1.0%**

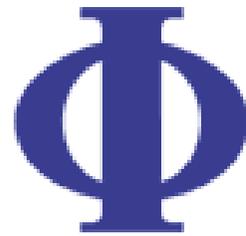
Bicubic interpolation functions



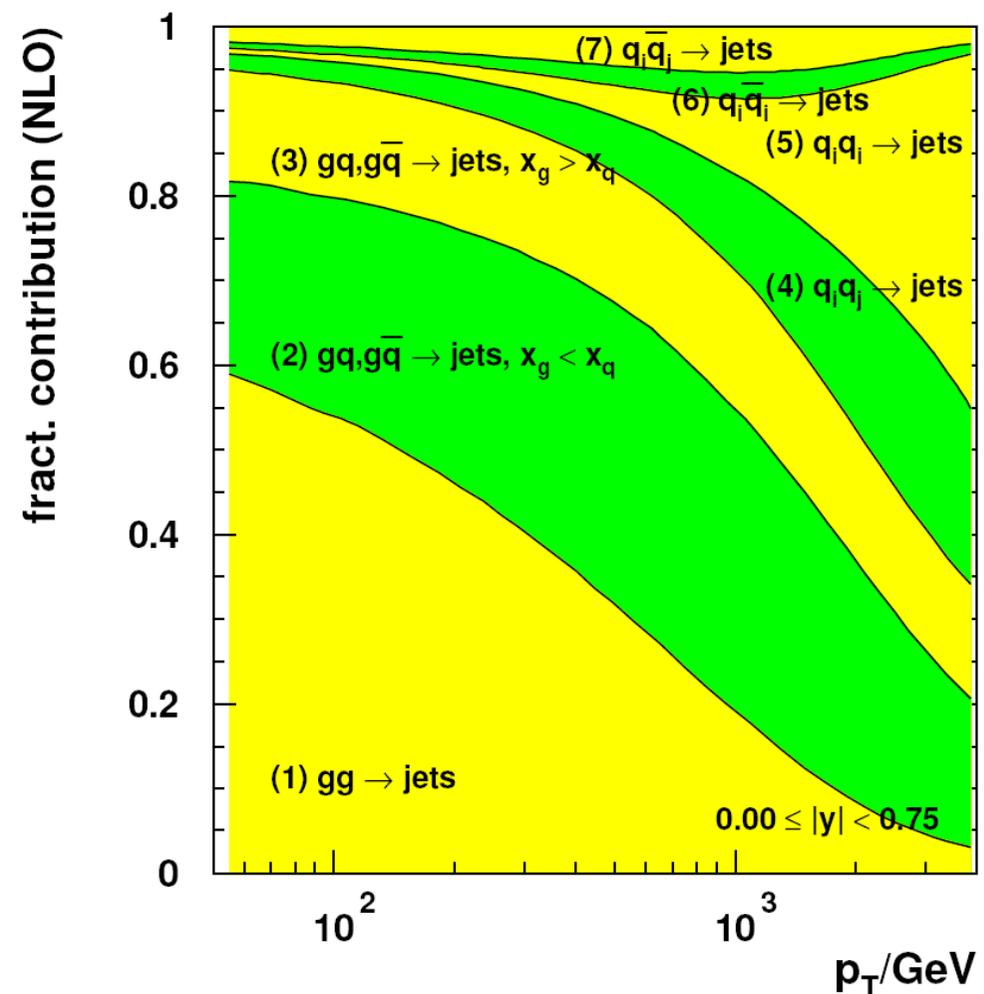
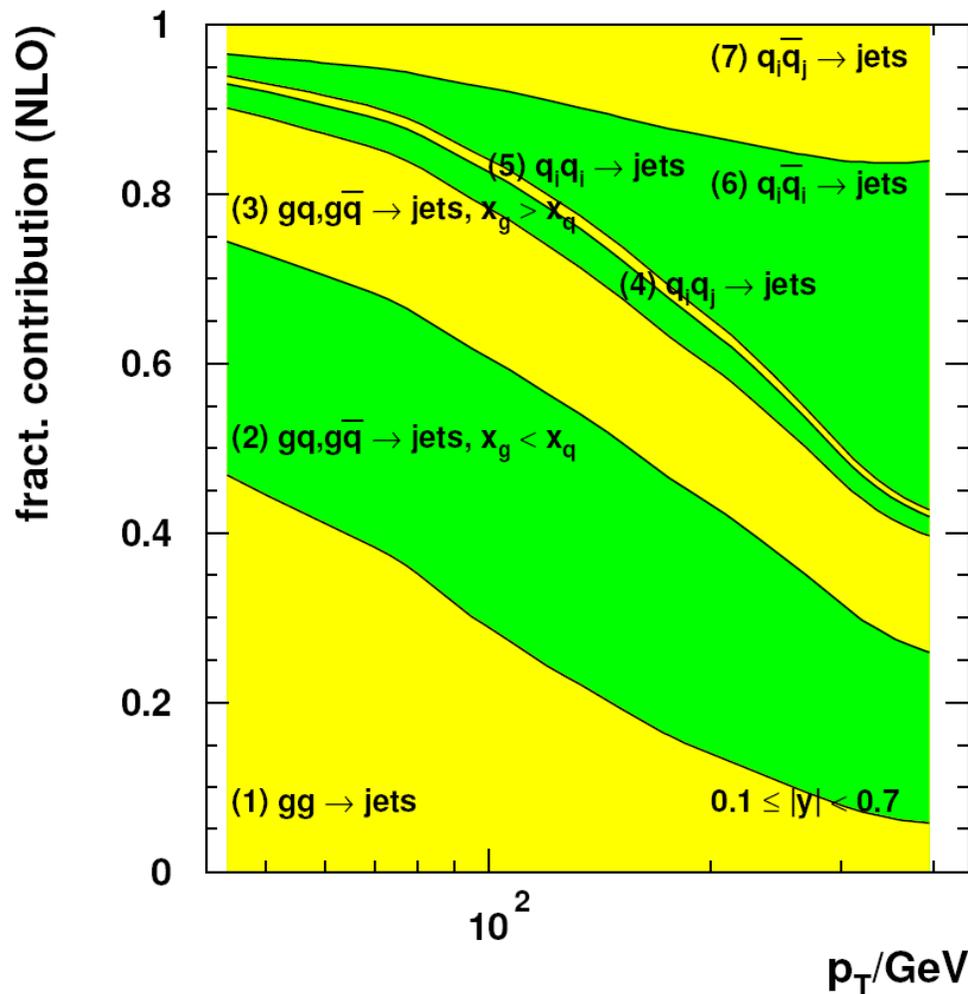
(Depending on used PC!)

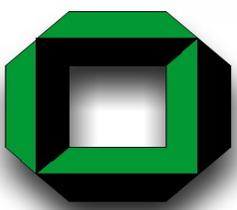


Example Decompositions

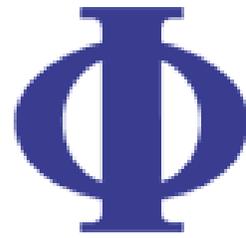


Tevatron (left) and LHC (right) subprocess contributions in central rapidity region

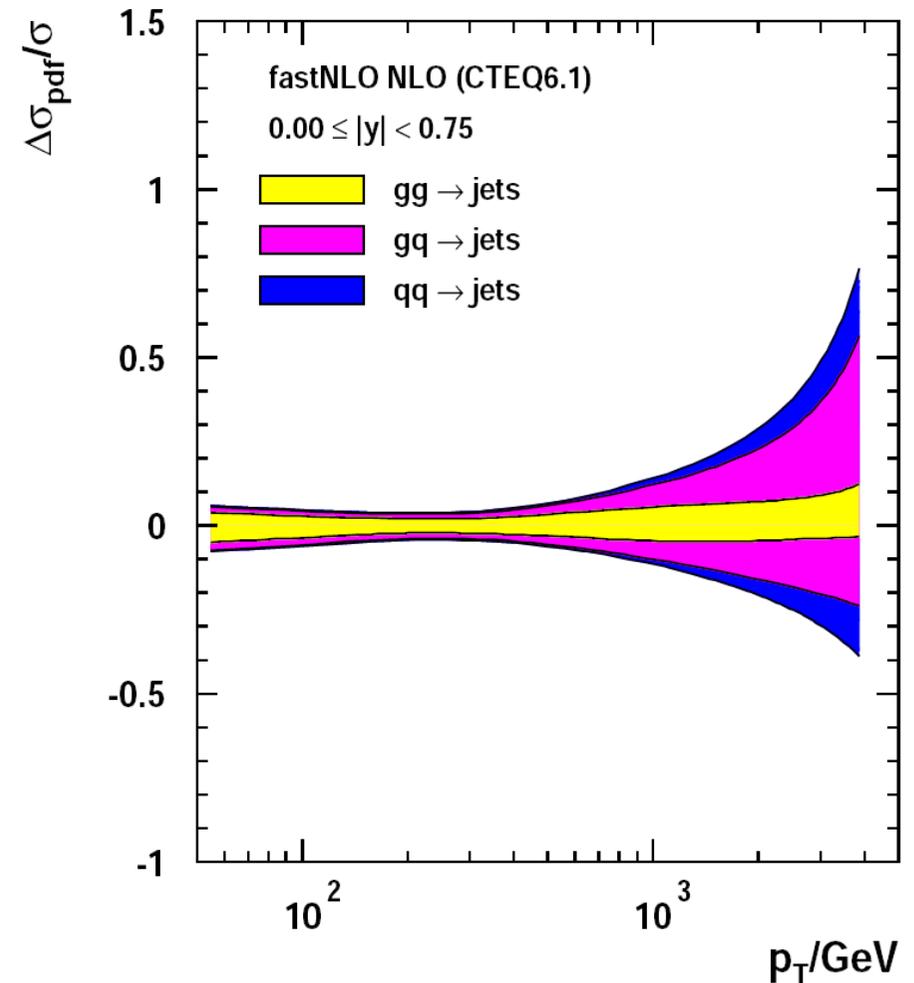
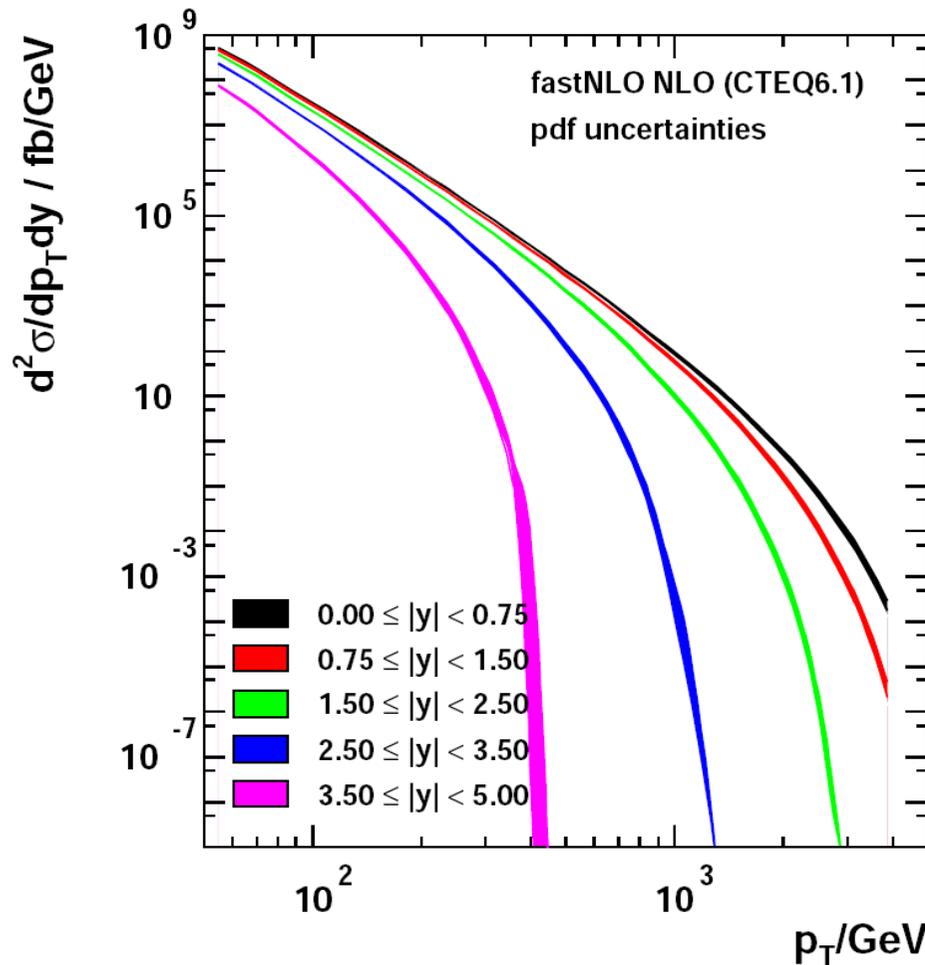


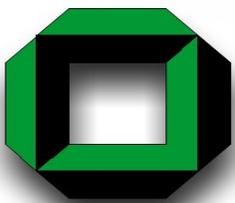


Diff. Jet Cross Section and PDF Uncertainty

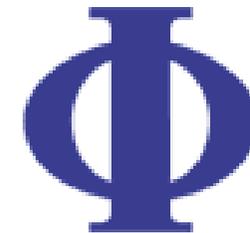


LHC scenario for k_T Algorithm with $D = 1.0$, see also A. Oehlers talk T 706.9
The bands correspond to the PDF uncertainty (adding deviations in quadrature)

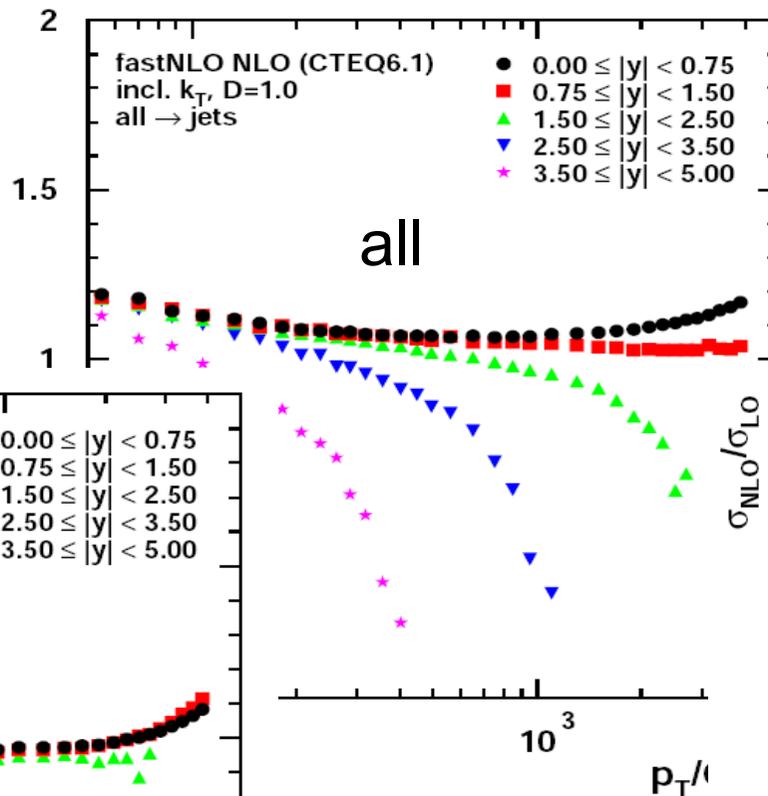
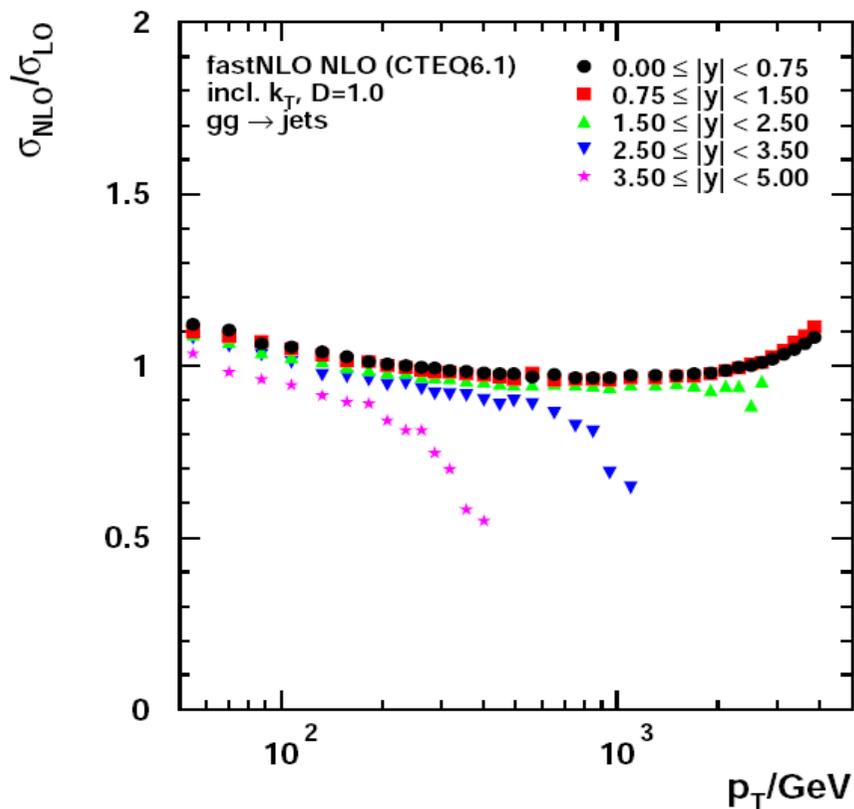




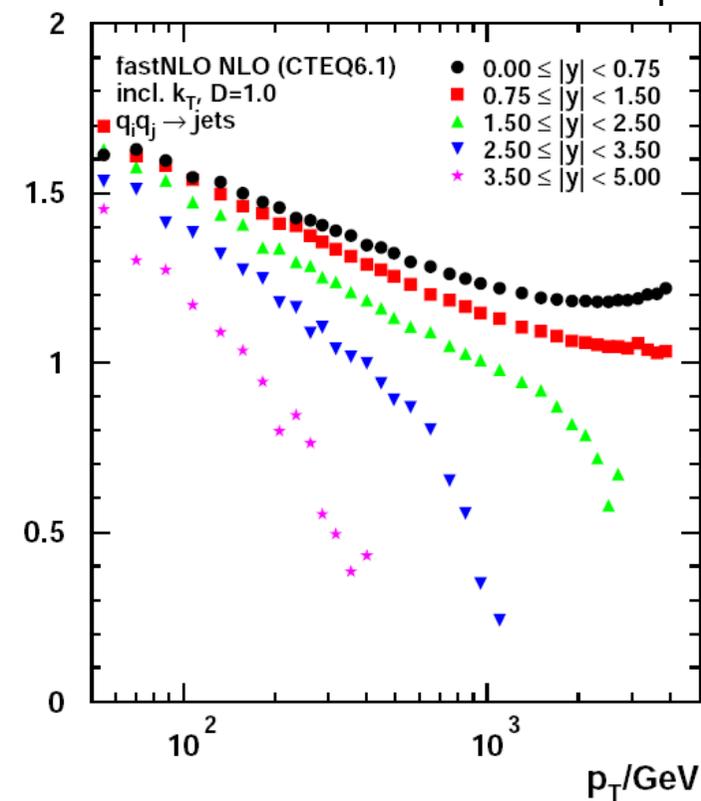
K Factors

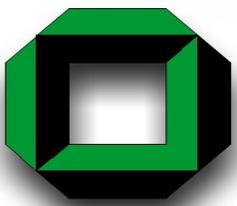


gg subprocess
dominant at low p_T

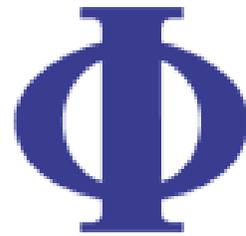


$q_i q_j$ subprocess
dominant at high p_T





More Information



[On our CEDAR web page:](#)

Application of fastNLO to

- ➔ 6 Tevatron publications
- ➔ 3 HERA publications
- ➔ 1 RHIC scenario

Interface for interactive
recomputation

Result tables + user code

Talks from TeV4LHC
Workshop

Documentation

<http://hepforge.cedar.ac.uk/fastnlo>

FastNLO :: HepForge - Mozilla Firefox
File Edit View Go Bookmarks Tools Help
http://hepforge.cedar.ac.uk/fastnlo/
UnIKA CMS NLO CERN Grid Weitere Kollaborationen Teilchenphysik - Organ... Städteinfo Science »
hosted by CEDAR HepForge

fastNLO
fast pQCD calculations for hadron-induced processes

Home News Interactive Code Documentation Links

fastNLO Homepage

The fastNLO project provides computer code and tables of pre-computed perturbative coefficients for various observables in hadron-induced processes.

This allows very fast computations of these observables for arbitrary PDFs and/or values of $\alpha_s(M_Z)$ as e.g. needed in PDF fits or in systematic studies.

new - February 27, 2006:
The interactive web interface for easy access to the fastNLO code

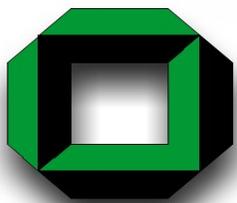
In March 2006 we will have the final release ready. Please note that the final version will be faster by more than a factor of ten, as compared to the beta release.

mailing list:
If you want to receive information about future releases and updates, please join the fastNLO user mailing list by sending a mail including:
"subscribe fastnlo-announce"
as the first and only line in the message body to "majordomo@cedar.ac.uk"

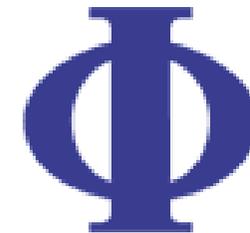
Thomas Kluge, Klaus Rabbertz, Markus Wobisch
(send mail to the authors: fastnlo@cedar.ac.uk)

Last updated: Mon Mar 13 23:43:20 2006

Done



Outlook



First plan of implementation almost completed!

- + LHC scenarios i.a. for CMS nearly done
- + Publication in preparation
- + Application to PDF fitting with LHC (simulated) data
- + Clean up of code
- + Implement a posteriori scale changes of μ_f (prop. by G. Salam)