High pT Cross Sections with

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

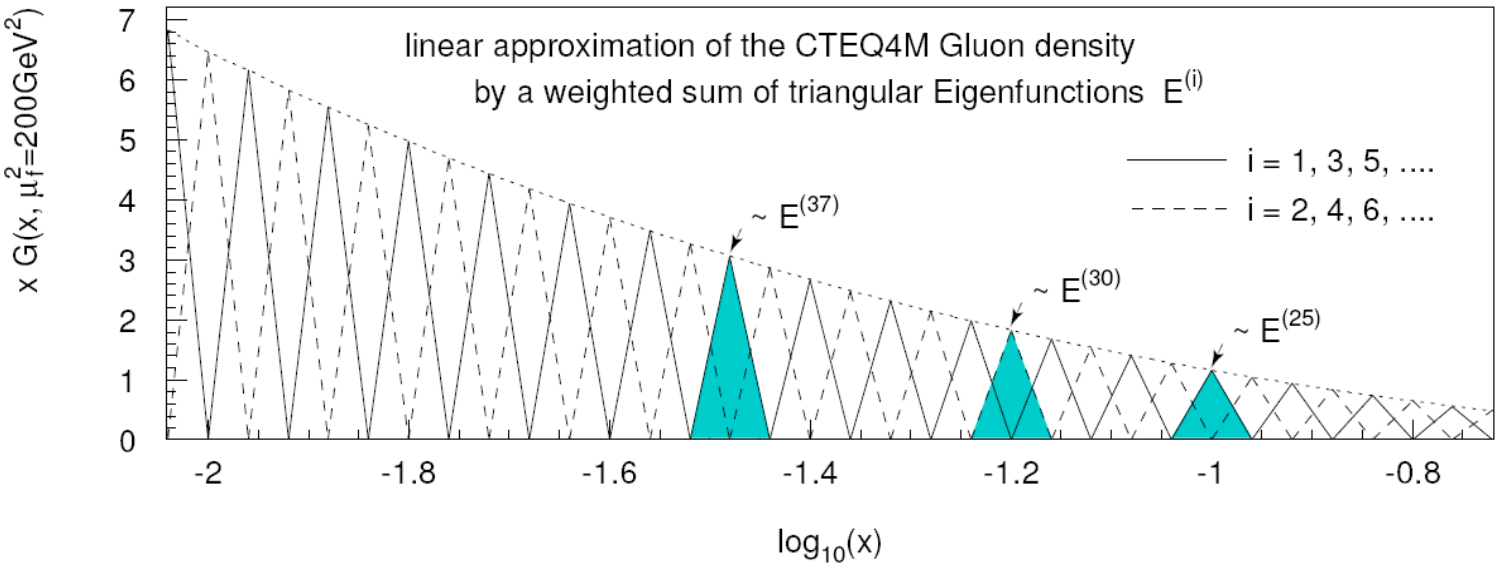
- Standard procedure: Integration over phase space in (x_1,x_2) (usually MC method) => Dependency on PDFs!
- New: Interpolation between fixed support points in x for PDFs => Evaluation a posteriori possible

PDF Approximation

- Introduce set of discrete $x^{(i)}$ with $x^{(n)} < .. < x^{(i)} < .. < x^{(0)}=1$
- 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)!



Partonic Subprocesses

- Don't want to deal with 13 X 13 PDFs
- For hh → jets **seven** relevant partonic subprocesses

$$
\begin{aligned}
1)\quad & gg && \Rightarrow \text{ jets} && \propto H_1(x_1, x_2)\\
2)\quad & qg, \bar{q}g && \Rightarrow \text{ jets} && \propto H_2(x_1, x_2)\\
3)\quad & gq, g\bar{q} && \Rightarrow \text{ jets} && \propto H_3(x_1, x_2)\\
4)\quad & q_i q_j, \bar{q}_i \bar{q}_j && \Rightarrow \text{ jets} && \propto H_4(x_1, x_2)\\
5)\quad & q_i q_i, \bar{q}_i \bar{q}_i && \Rightarrow \text{ jets} && \propto H_5(x_1, x_2)\\
6)\quad & q_i \bar{q}_i, \bar{q}_i q_i && \Rightarrow \text{ jets} && \propto H_6(x_1, x_2)\\
7)\quad & q_i \bar{q}_j, \bar{q}_i q_j && \Rightarrow \text{ jets} && \propto H_7(x_1, x_2)
\end{aligned}
$$

- Need only seven linear combinations H_i of PDFs

Symmetries

- In addition, symmetries can be exploited:

$$H_n(x_1, x_2) = H_n(x_2, x_1) \quad \text{for} \quad n = 1, 4, 5, 6, 7$$
$$H_2(x_1, x_2) = H_3(x_2, x_1)$$

- 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

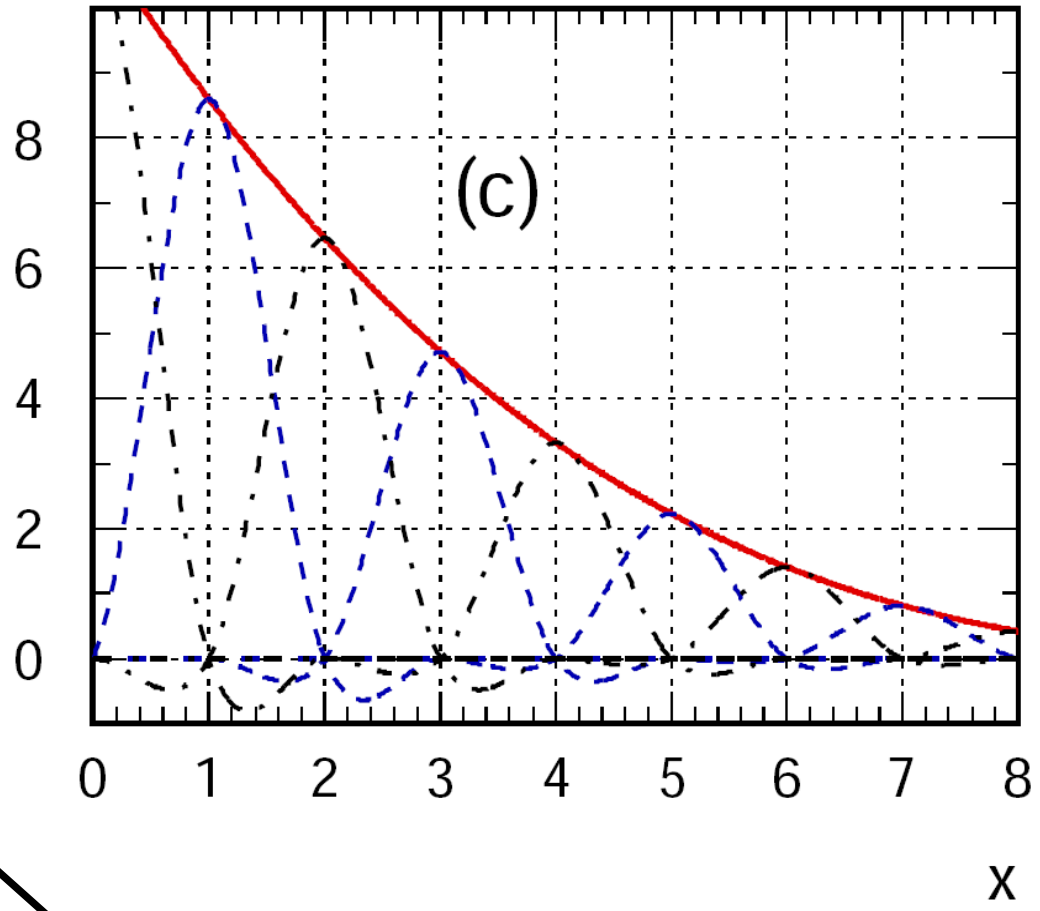
Our actual interpolation is:

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

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%**

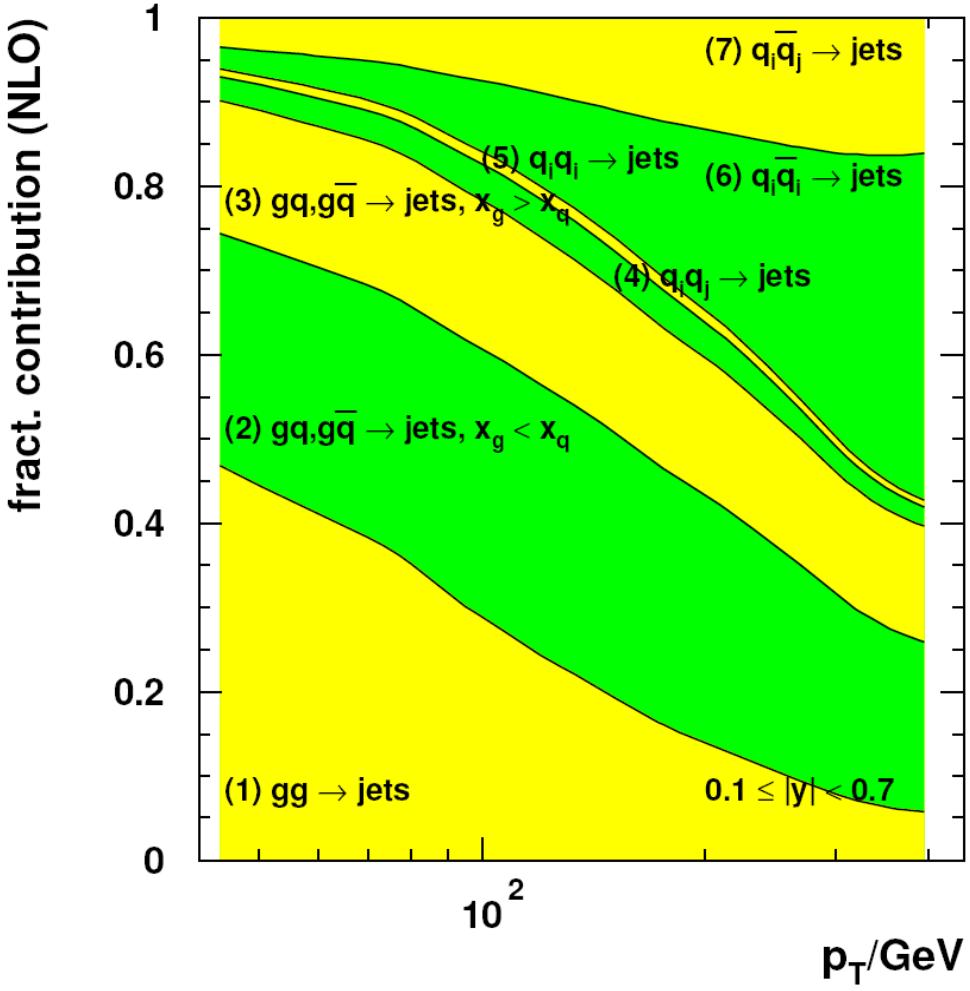
Bicubic interpolation functions

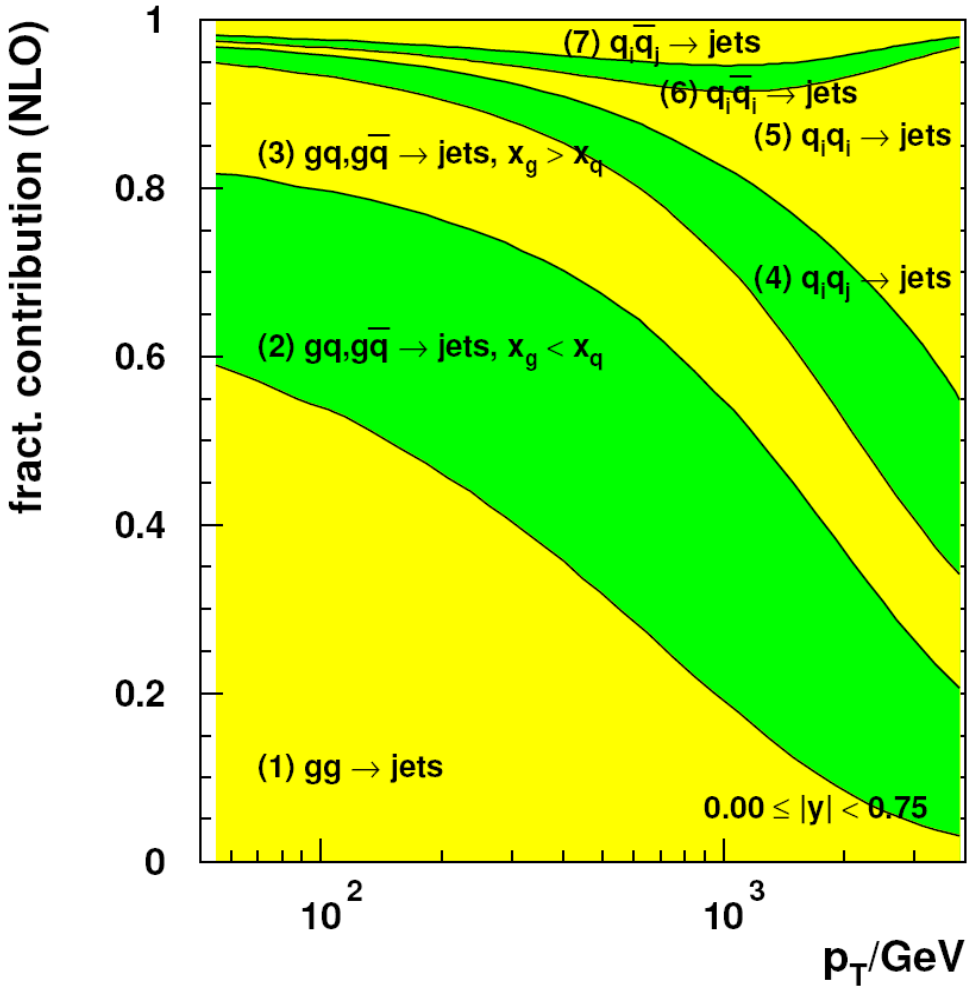


(Depending on used PC!)

Example Decompositions

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

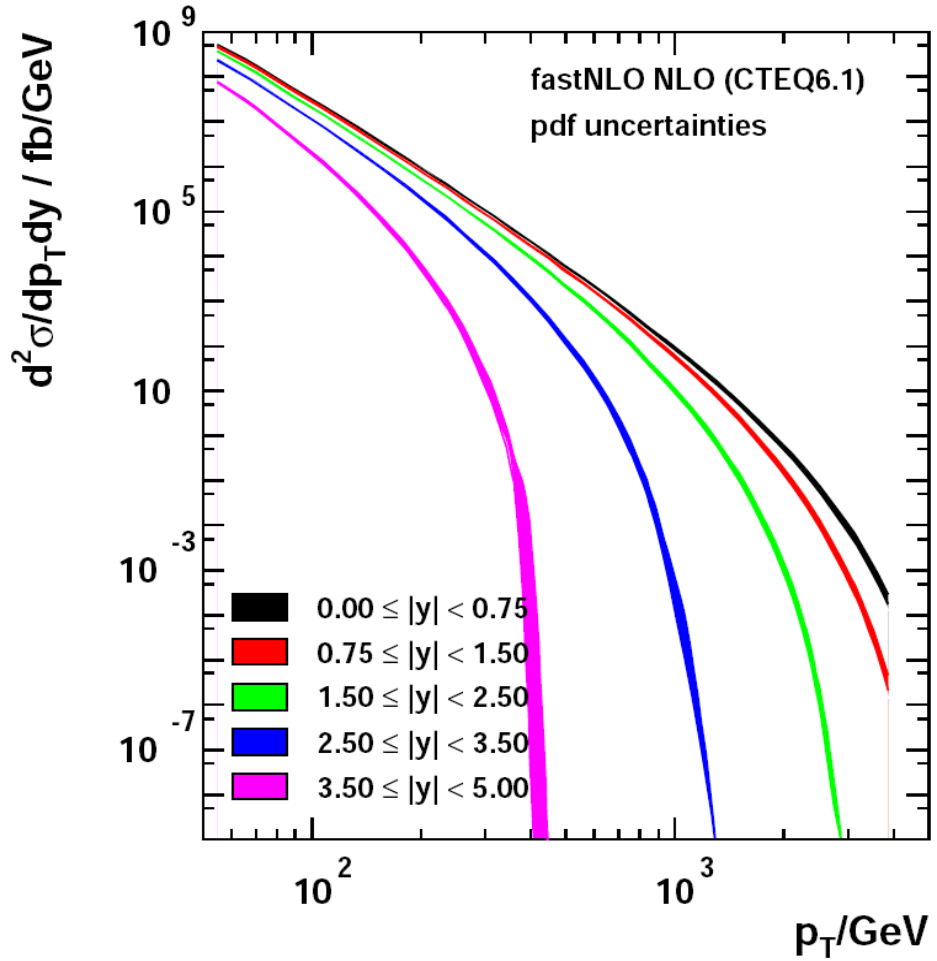


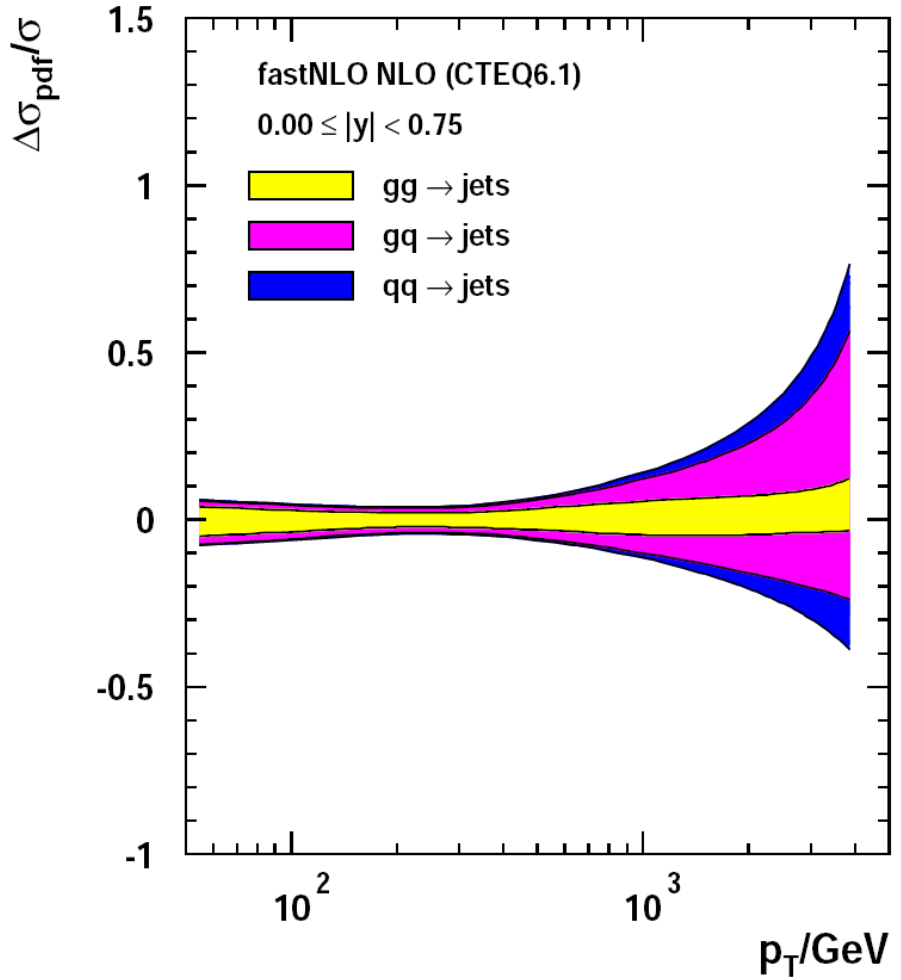


Diff. Jet Cross Section and PDF Uncertainty

LHC scenario for k_T Algorithm with D = 1.0, see also A. Oehlers talk T 706.9

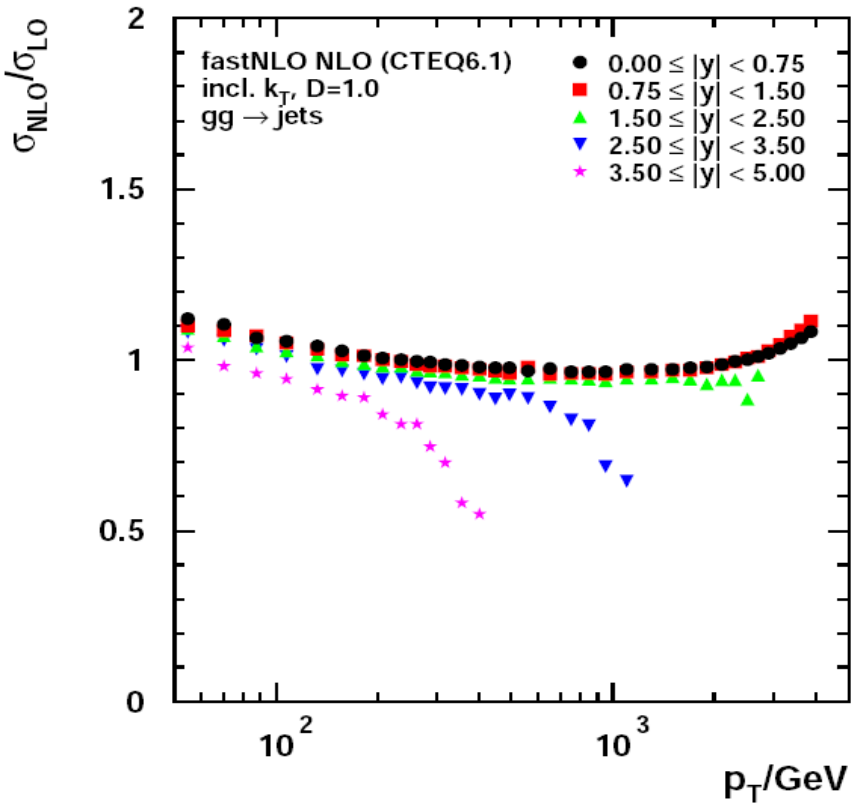
The bands correspond to the PDF uncertainty (adding deviations in quadrature)



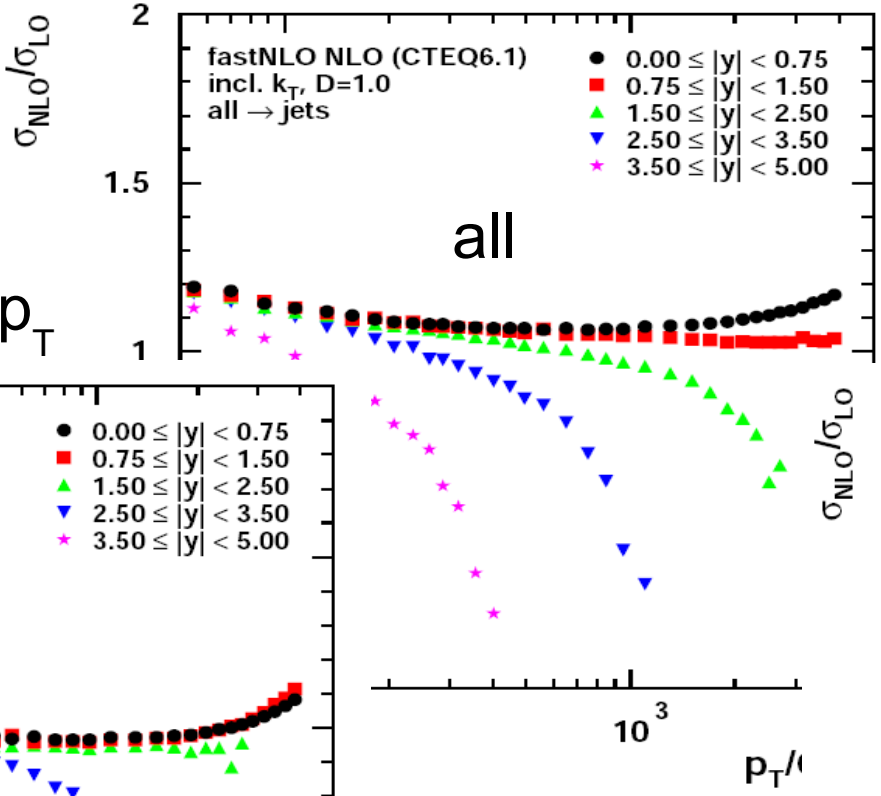


K Factors

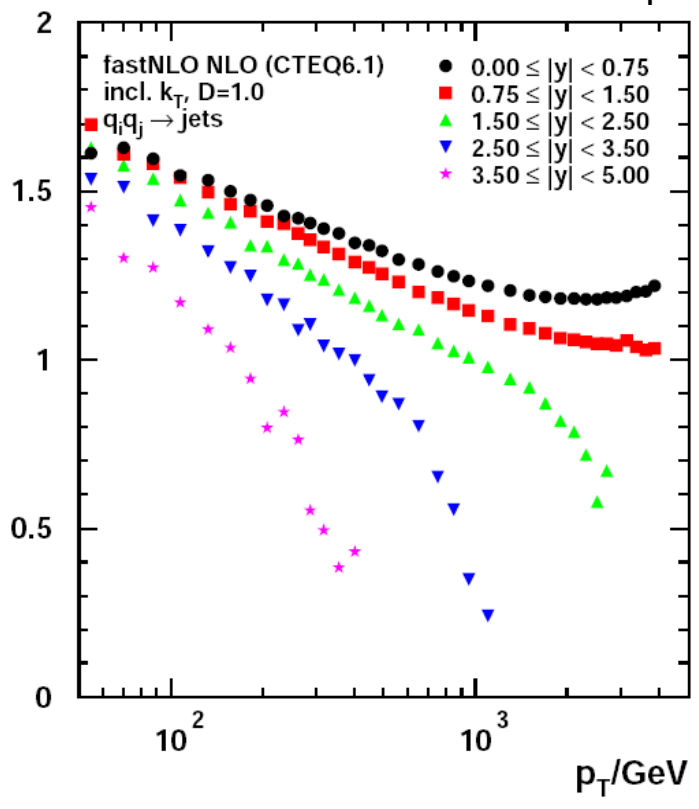
gg subprocess
dominant at low p_T



all



q_iq_j subprocess
dominant at high p_T



More Information

On our CEDAR web page: http://hepforge.cedar.ac.uk/fastnlo

Application of fastNLO to

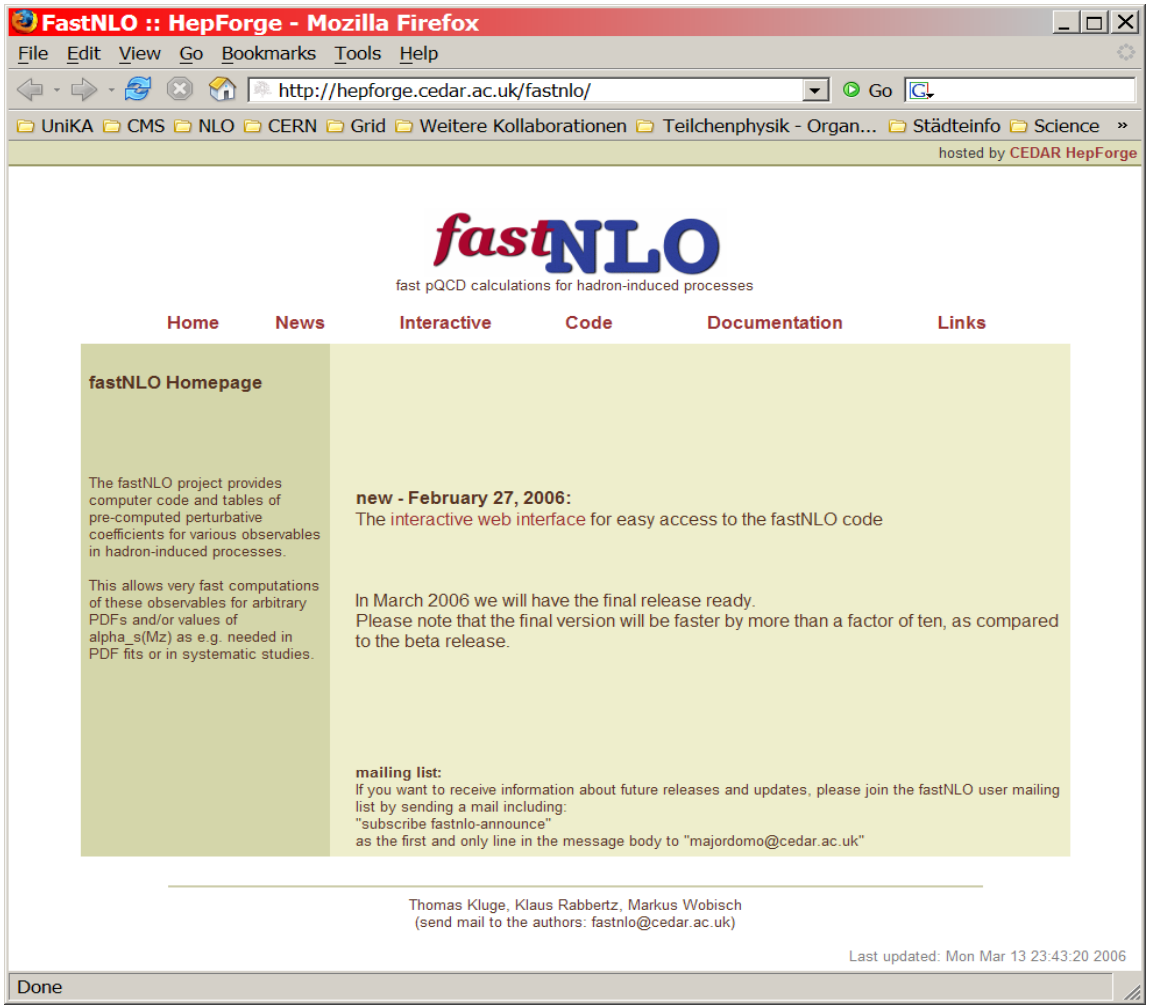
- 6 Tevatron publications
- 3 HERA publications
- 1 RHIC scenario

Interface for interactive recomputation

Result tables + user code

Talks from TeV4LHC Workshop

Documentation



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)