

Usage of *fast*NLO in PDF fits

Introduction

*fast*NLO

Proton Structure in the LHC Era - School and Workshop
30. September 2014

Daniel Britzger, Georg Sieber, Klaus Rabbertz



Outline

Preparation of Virtual Machine

Introduction

- Motivation
- General concept of fastNLO
- Application to Jet analysis at LHC
- Outlook

Tutorial/Hands-on

- Download/Installation
- Example of table creation using nlojet++ for CMS inclusive jets
- Example of table evaluation and use various PDF sets
- Representation of fastNLO+nlojet++ results with rivet

Q&A

Preparation of Virtual Machine

1. Download setup script from web

```
$> wget http://fastnlo.hepforge.org/setup\_fastNLO.sh
```

2. Source script

```
$> source setup_fastNLO.sh
```

3. Close your screen

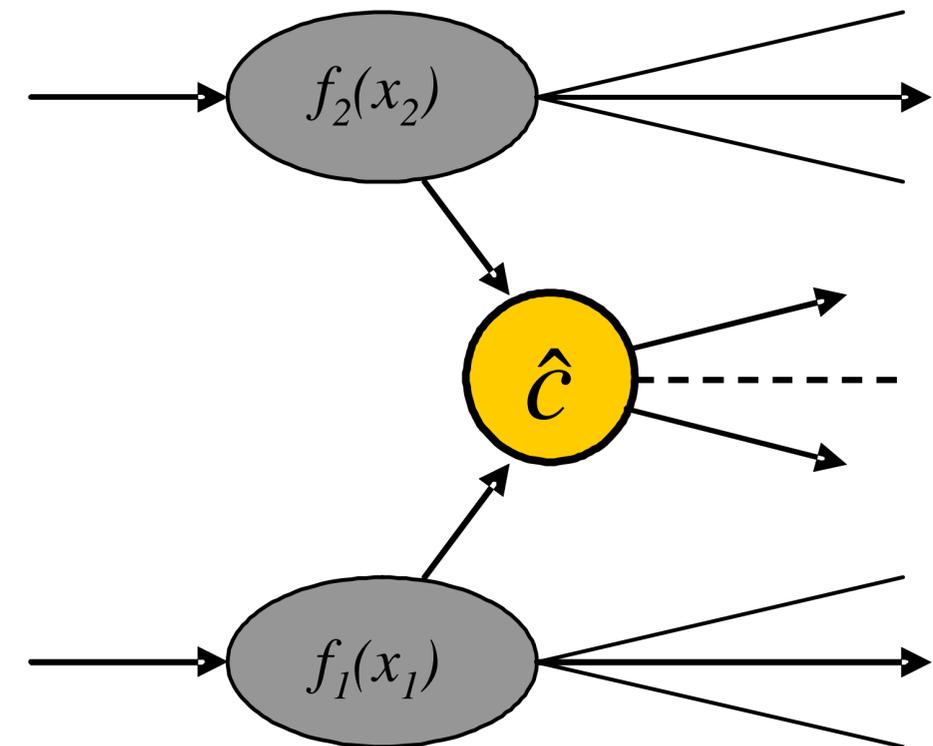


Basics of QCD cross section calculation

Cross section in hadron-hadron collisions in pQCD

$$\sigma = \sum_{a,b,n} \int_0^1 dx_1 \int_0^1 dx_2 \alpha_s^n(\mu_r) \cdot c_{a,b,n}(x_1, x_2, \mu_r, \mu_f) \cdot f_{1,a}(x_1, \mu_f) f_{2,b}(x_2, \mu_f)$$

- strong coupling α_s in order n
- PDFs of two hadrons f_1, f_2
- Parton flavors a, b
- perturbative coefficient $c_{a,b,n}$
- renormalization and factorization scales μ_r, μ_f
- momentum fractions x_1, x_2



PDF and α_s are external input

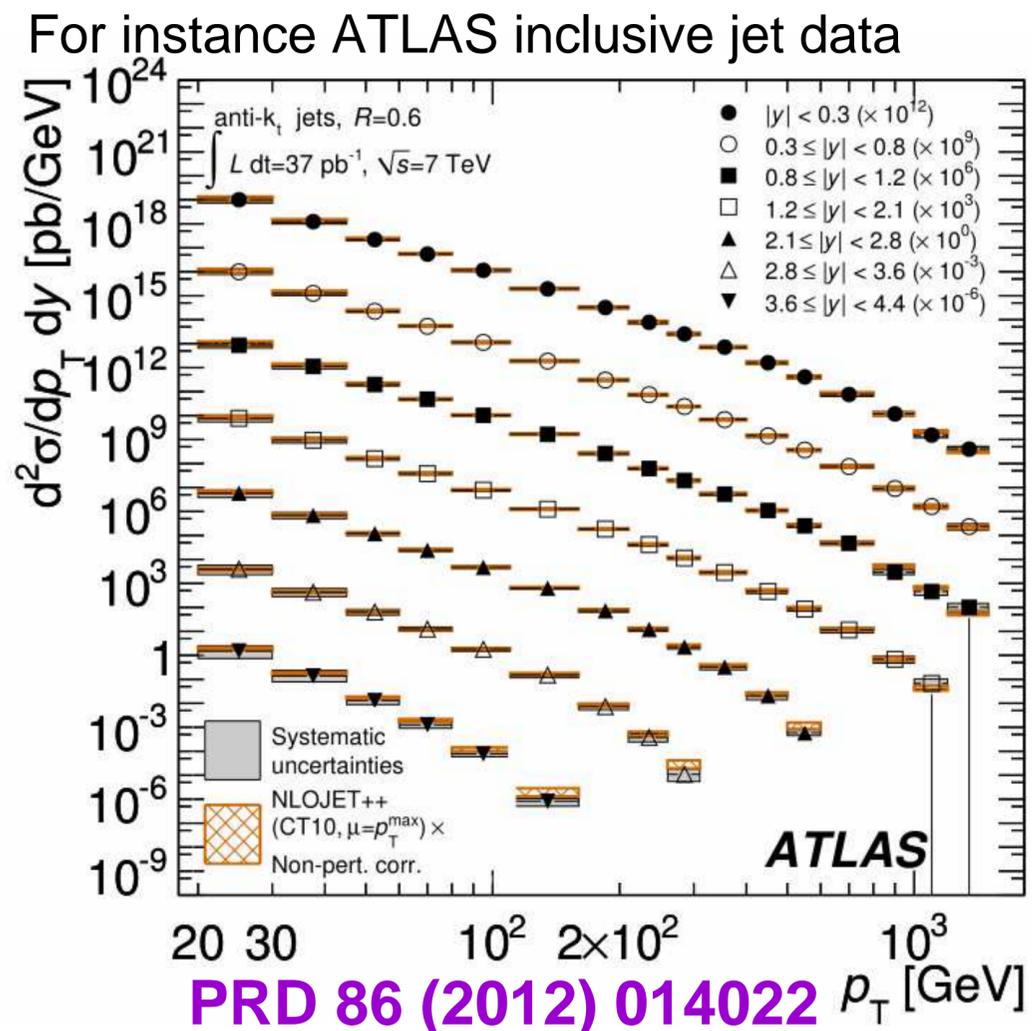
Perturbative coefficients are independent from PDF and α_s

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Application in PDF fits



1. Fit *theory* to *data*:

$$\sigma_{\text{theo}} \approx \sigma_{\text{exp}}$$

2. Free parameters of theory in fit could be any theory parameter
3. Typically for PDF fits
 - a) Fix perturbative coefficients
 - b) $\alpha_s(M_Z)$ could be free parameter or not
 - c) Fit PDFs: $f_{1,a}, f_{2,b}$

Goal: Provide theory coefficients $c_{a,b,n}$ such that they can be used in a (PDF) fit

fastNLO working principle

1. Introduce a set of nodes j ('grids')
2. Replace PDF functions in (N)NLO code with

$$f_a(x) \cong \sum_i f_a(x_i) \cdot E^{(i)}(x)$$

3. Interpolation kernel must fulfill

$$\sum_i E_i(x) = 1, \quad E_i(x_j) = \begin{cases} 1 & \text{if } i = j \\ 0 & \text{otherwise} \end{cases}$$

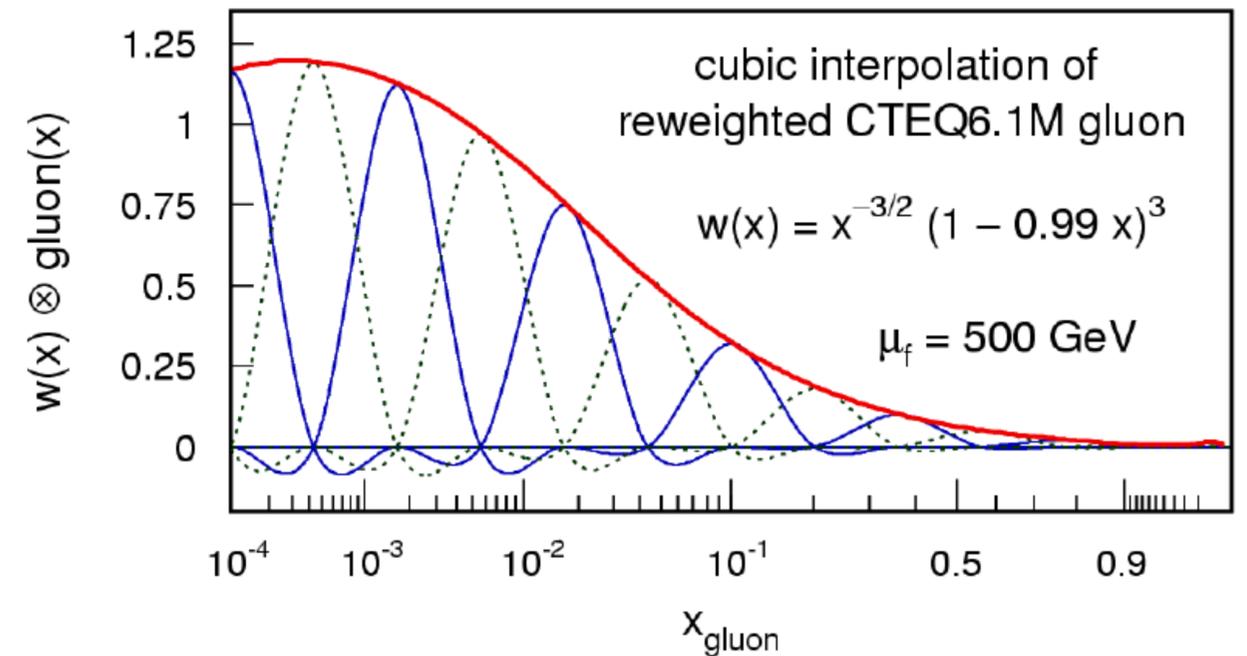
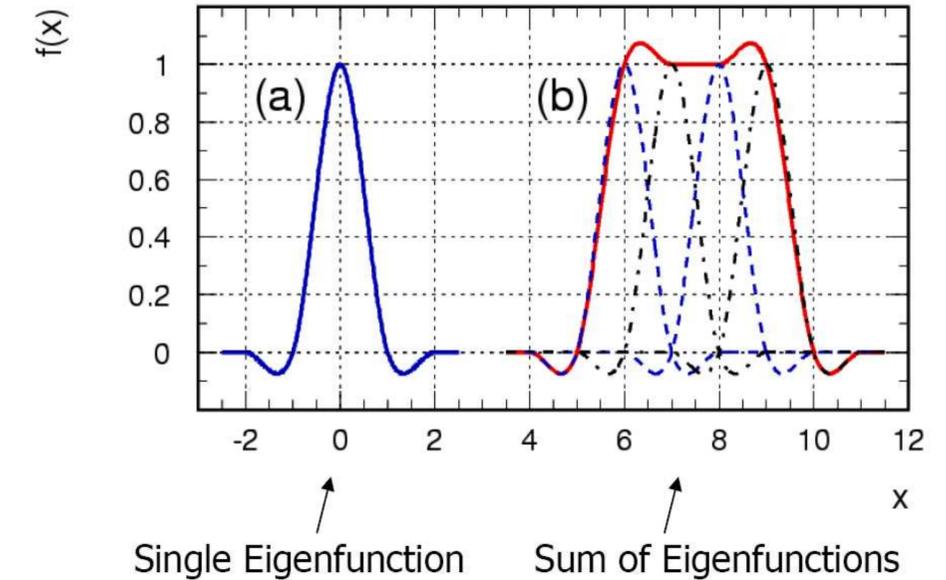
4. Make use of symmetries for specific process

$$\sum_{a,b}^{13 \times 13} f_{1,a}(x_1, \mu_f) f_{2,b}(x_2, \mu_f) \rightarrow \sum_k^7 H_k(x_1, x_2, \mu_f)$$

5. Store coefficients in a table: $\tilde{\sigma}$

The cross section for usage in PDF fits can be rewritten as a simple sum

$$\sigma_{hh}^{Bin} = \sum_{i,j,k,n,m} \alpha_s^n(\mu^{(m)}) \cdot H_k(x_1^{(i)}, x_2^{(j)}, \mu^{(m)}) \cdot \tilde{\sigma}_{k,n}^{(i,j)(m)}$$



More details on fastNLO

Storage of coefficients is more general

- Scale dependent contributions are stored separately

$$\omega(\mu_R, \mu_F) = \underbrace{\omega_0 + \log(\mu_R^2)\omega_R + \log(\mu_F^2)\omega_F}_{\text{log's for NLO}} + \underbrace{\log^2(\mu_R^2)\omega_{RR} + \log^2(\mu_F^2)\omega_{FF} + \log(\mu_R^2)\log(\mu_F^2)\omega_{RF}}_{\text{additional log's in NNLO}}$$

- Store weights: $w_0, w_R, w_F, w_{RR}, w_{FF}, w_{RF}$ for order α_s^{n+2} contributions
- This allows for free choice of renormalization and factorization scale without recalculation of coefficients:
Two observables can be stored in table which can be employed for calculation of scales

Automated scan of the grids to phase space

- So-called 'warm-up' run: More details in hands-on session

Many other performance and memory size optimizations

Application procedure I: Table creation

(N)NLO Program

```
fastNLOCreate fnlo(„steering.str“);  
fnlo.SetOrderOfCalculation(int order);
```

Initialize fastNLO class(es)

```
fnlo.fEvent.SetProcessID(int id);
```

```
fnlo.fEvent.SetX1(double x1);  
fnlo.fEvent.SetX2(double x2);
```

```
fnlo.fEvent.SetWeight(double w);
```

```
fnlo.fScenario.SetObservable0(double pt);  
fnlo.fScenario.SetObsScale1(double s1);
```

Pass the process specific variables during the ‘event loop’ to fastNLO

- Order does not matter
- Many other convenient implementations possible

```
fnlo.Fill();
```

Pass all information to fastNLO

```
fnlo.SetNumberOfEvents(double nevents);  
fnlo.WriteTable();
```

Set normalization of the MC integration and write table

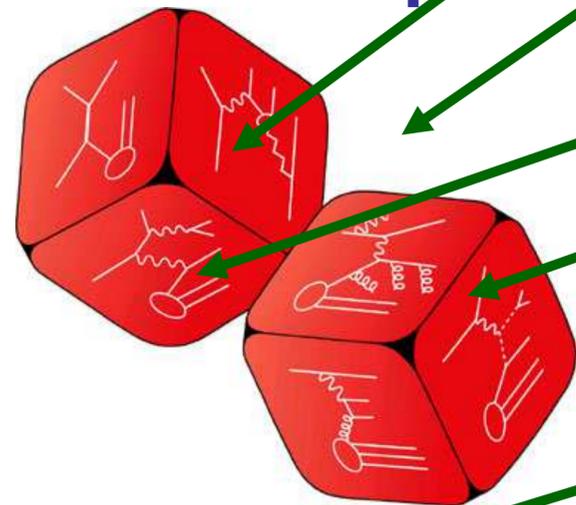
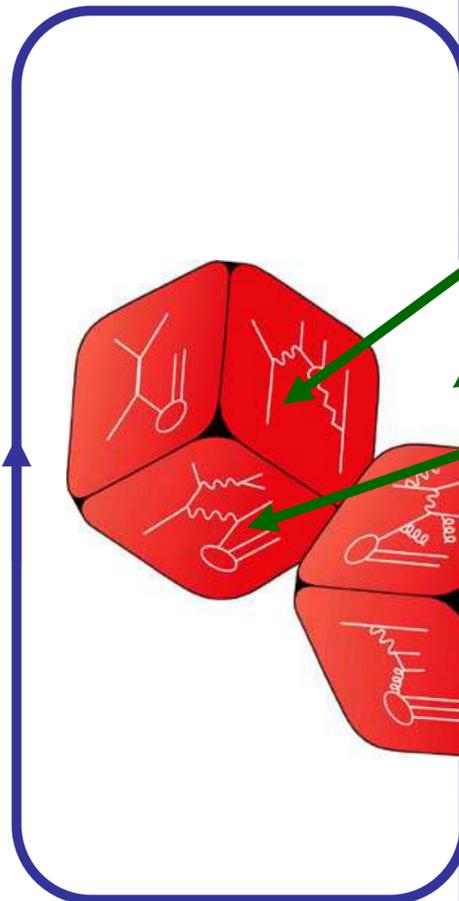
Program End

(N)NLO Result

fastNLO Table

Minimum implementation:
11 lines of code

MC Integration



Application procedure II: Evaluating tables

Evaluating requires interface to PDF library

- LHAPDF
- PDF fitting framework
- QCDNUM
- ...

Intermediate step:
Merge/Append LO tables
with NLO tables

Strong coupling evolution can be provided by external program or with shipped code

Usage in your program if you want to evaluate table file fnl1014.tab

```
#include <fastNLOLHAPDF.h>

[...]
// FastNLO example code in c++ for reading CMS incl.
// jets (PRL 107 (2011) 132001) with CT10 PDF set

fastNLOLHAPDF fnlo("fnl1014.tab", "CT10.LHgrid", 0);
fnlo.PrintCrossSections(); // Print cross section to screen
vector<double> cs = fnlo.GetCrossSection(); // Access cross sections for later usage
```

Standalone program(s) available: `fnlo-tk-cppread` or `fnlo-tk-example`

More options (like scaling variations, α_s settings, etc...) discussed in hands-on session

Further information

<http://fastnlo.hepforge.org/>

FastNLO is hosted by Hepforge, IPPP Durham

The logo for fastNLO, with 'fast' in red and 'NLO' in blue.

fast pQCD calculations for hadron-induced processes

[Home](#)

[Documentation](#)

[Scenarios](#)

[Code](#)

[Interactive \(maintenance\)](#)

[Links](#)

General concept

The fastNLO project provides computer code to create and evaluate fast interpolation tables of pre-computed coefficients in perturbation theory for observables in hadron-induced processes.

This allows fast theory predictions of these observables for arbitrary parton distribution functions (of regular shape), renormalization or factorization scale choices, and/or values of $\alpha_s(M_Z)$ as e.g. needed in PDF fits or in systematic studies. Very time consuming complete recalculations are thus avoided.

July 24, 2014

Small update of fastNLO Toolkit

Prerelease updated with small changes to eliminate some installation hiccups for the optional parts and to remove some additional warnings found by other compilers. The updated package can be downloaded [here](#).

July 17, 2014

Public prerelease of new fastNLO Toolkit

The new fastNLO Toolkit provides a library with all functionality to create, fill, read, and evaluate interpolation tables in the fastNLO format. It comes with a much improved structure that allows other programs to be interfaced to fastNLO. In addition, an example interface and code how to use NLOjet++ with this toolkit is available. Both packages can be downloaded from our [code web pages](#).

July 16, 2014

Finally: New calculations for H1 multijets available

Summary

fastNLO is a tool for enabling the usage of time consuming theory prediction in (PDF) fits

It is not a NLO program or a MC generator

For the usage of fastNLO two steps are required

1. Create table using the fastNLO toolkit code together with an (N)NLO program (fastNLOCreate class) or download tables on fastnlo.hepforge.org
2. Evaluate table and calculate cross sections using fastNLO stand-alone program or use fastNLO within fitting framework (fastNLOReader class)

The usage of fastNLO tables in HERAFitter is explained in other tutorials

More information, references and documentation is found at

<http://fastnlo.hepforge.org>

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