fastNLO v2

The fastNLO Collaboration

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Outline

- **Motivation**
- **FastNLO concept**
- **New features of fastNLO v2**
- **Generalized concept in fastNLO v2**
- **Example application of flexible scale format**
- **Jet production in diffractive DIS**
- **Outlook**

Motivation

Interpretation of experimental data relies on

- Availability of reasonably fast theory calculations
- Often needed: Repeated computation of same quantitites

Examples for a specific analysis

- Use of various PDFs (CTEQ, MSTW, NNPDF, HERAPDF, ABM,…) for data/theory comparison
- Determine PDF uncertainties
- Use data set in fit of PDFs or α_s
- Derivation of scale uncertainties
- Comparision to different scale choices

Sometimes NLO or even NNLO predictions can be computed fast
But some are very slow

e.g. Jet cross sections, Drell-Yan, …

Need procedure for fast repeated computations of higher order cross sections

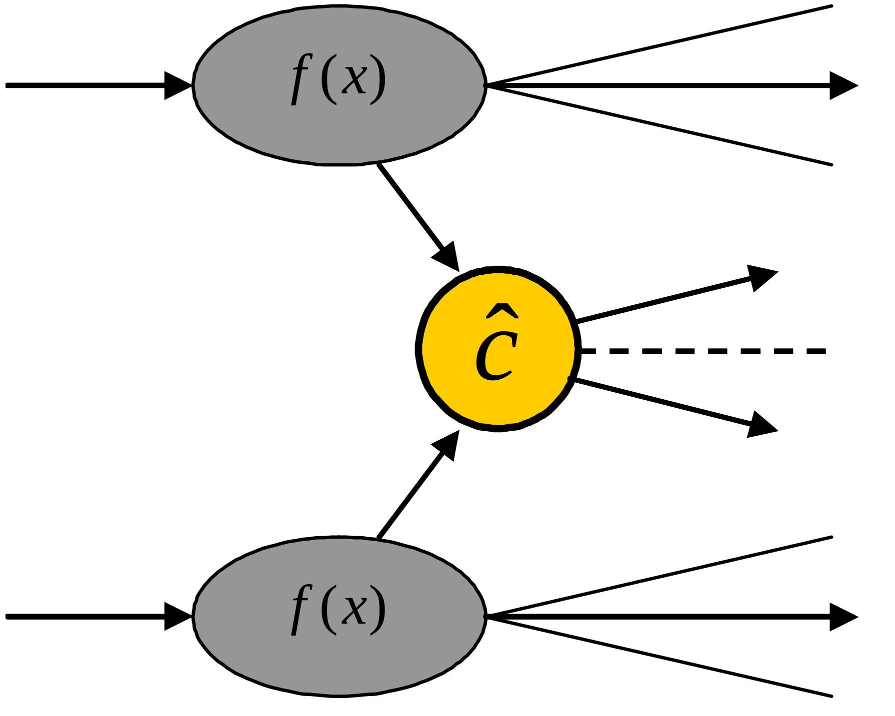
NLO QCD cross section

Jet production in hadron-hadron collisions

Jet cross section calculations are time consuming

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

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



PDF and α_s are external input
Perturbative coefficients are independent from PDF and α_s

Idea: Factorize the PDFs and α_s

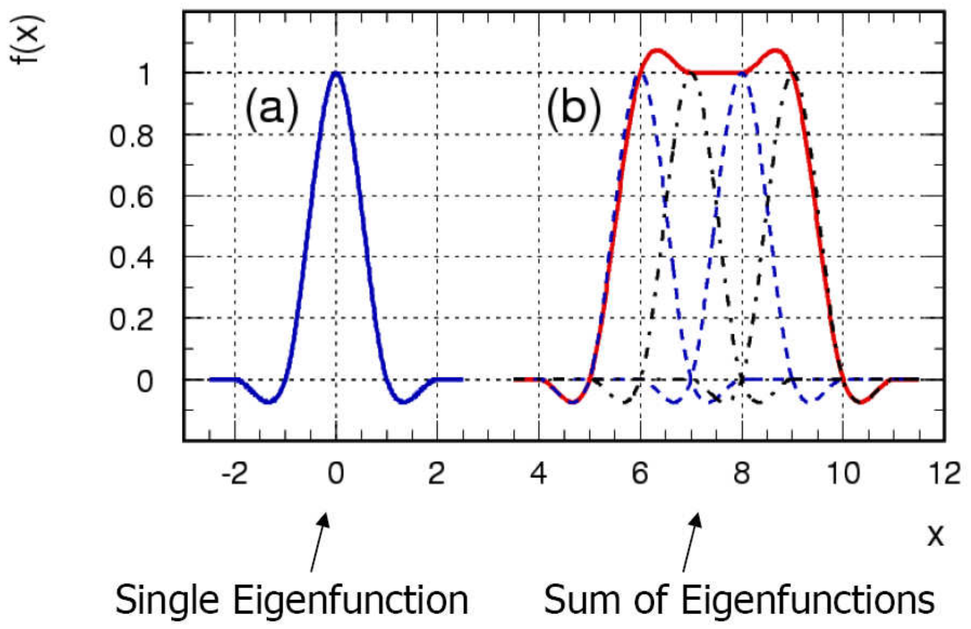
The fastNLO concept

Introduce interpolation kernel

Introduce set of n discrete x-nodes x_i's being equidistant in a function f(x)

Take set of Eigenfunctions $E_i(x)$ around nodes x_i

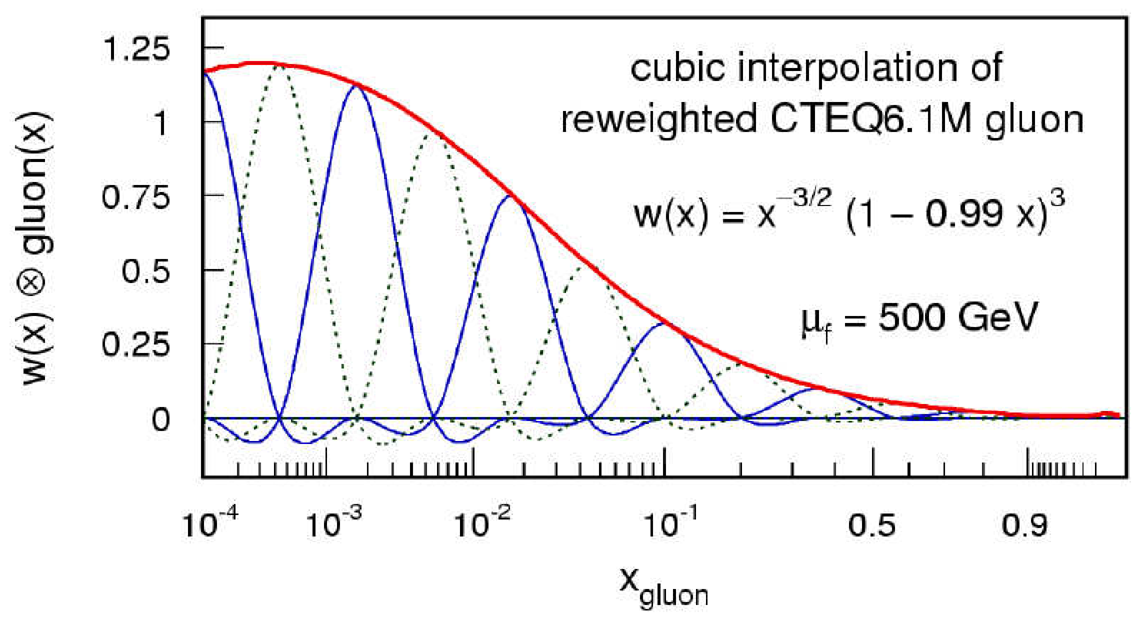
-> interpolation kernels



Single PDF is replaced by a linear combination of interpolation kernels

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

Improve interpolation by reweighting PDF



Scale dependence

Introduce interpolation procedure also for scales

Scale gets own dimension and look-up table

fastNLO for hadron-hadron collisions

Hadron-hadron collisions

2D interpolation kernels

$$E^{(i,j)}(x_1, x_2) = E^{(i)}(x_1) E^{(j)}(x_2)$$

Symmetries of matrix elements
13×13 partonic subprocesses reduce to 7

$$\sum_{a,b}^{13\times13} f_{1,a}(x_1,\mu_f)\, f_{2,b}(x_2,\mu_f) \rightarrow \sum_k^7 H_k(x_1,x_2,\mu_f)$$

$gg \rightarrow$ jets			$\propto$	$H_1(x_1,x_2)$
$qg \rightarrow$ jets	plus	$\bar{q}g \rightarrow$ jets	$\propto$	$H_2(x_1,x_2)$
$gq \rightarrow$ jets	plus	$g\bar{q} \rightarrow$ jets	$\propto$	$H_3(x_1,x_2)$
$q_iq_j \rightarrow$ jets	plus	$\bar{q}_i\bar{q}_j \rightarrow$ jets	$\propto$	$H_4(x_1,x_2)$
$q_iq_i \rightarrow$ jets	plus	$\bar{q}_i\bar{q}_i \rightarrow$ jets	$\propto$	$H_5(x_1,x_2)$
$q_i\bar{q}_i \rightarrow$ jets	plus	$\bar{q}_iq_i \rightarrow$ jets	$\propto$	$H_6(x_1,x_2)$
$q_i\bar{q}_j \rightarrow$ jets	plus	$\bar{q}_iq_j \rightarrow$ jets	$\propto$	$H_7(x_1,x_2)$

Final fastNLO cross sections

- Compute σ-table in each bin and store it in fastNLO table

$$\tilde{\sigma}_{k,n}^{(i,j)(m)} = \sigma_{k,n}(\mu) \otimes E^{(i,j)}(x_1,x_2) \otimes E^{(m)}(\mu)$$

- Contains all information on the observable

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

Application procedure

Theory prediction

Concept does not include the theoretical calculation itself

Requires existing computer code, e.g.

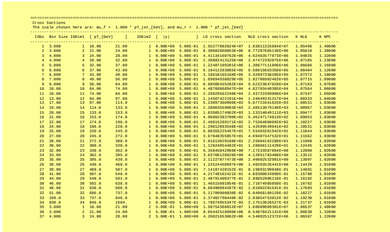
- NLOJET++ (Z. Nagy PRD68 2003, PRL88 2002)
- Threshold corrections (Kidonakis, Owens, PRD 63, 054019 (2001))

Application procedure

- ➢ During the first computation no time is saved
- ➢ Perform calculations with very high statistics
  10^{10} – 10^{11} NLO events -> up to several years of CPU time
- ➢ Any further recalculations take only O(ms)

```
// 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();
```



Can be used for any observable in hadron-induced processes

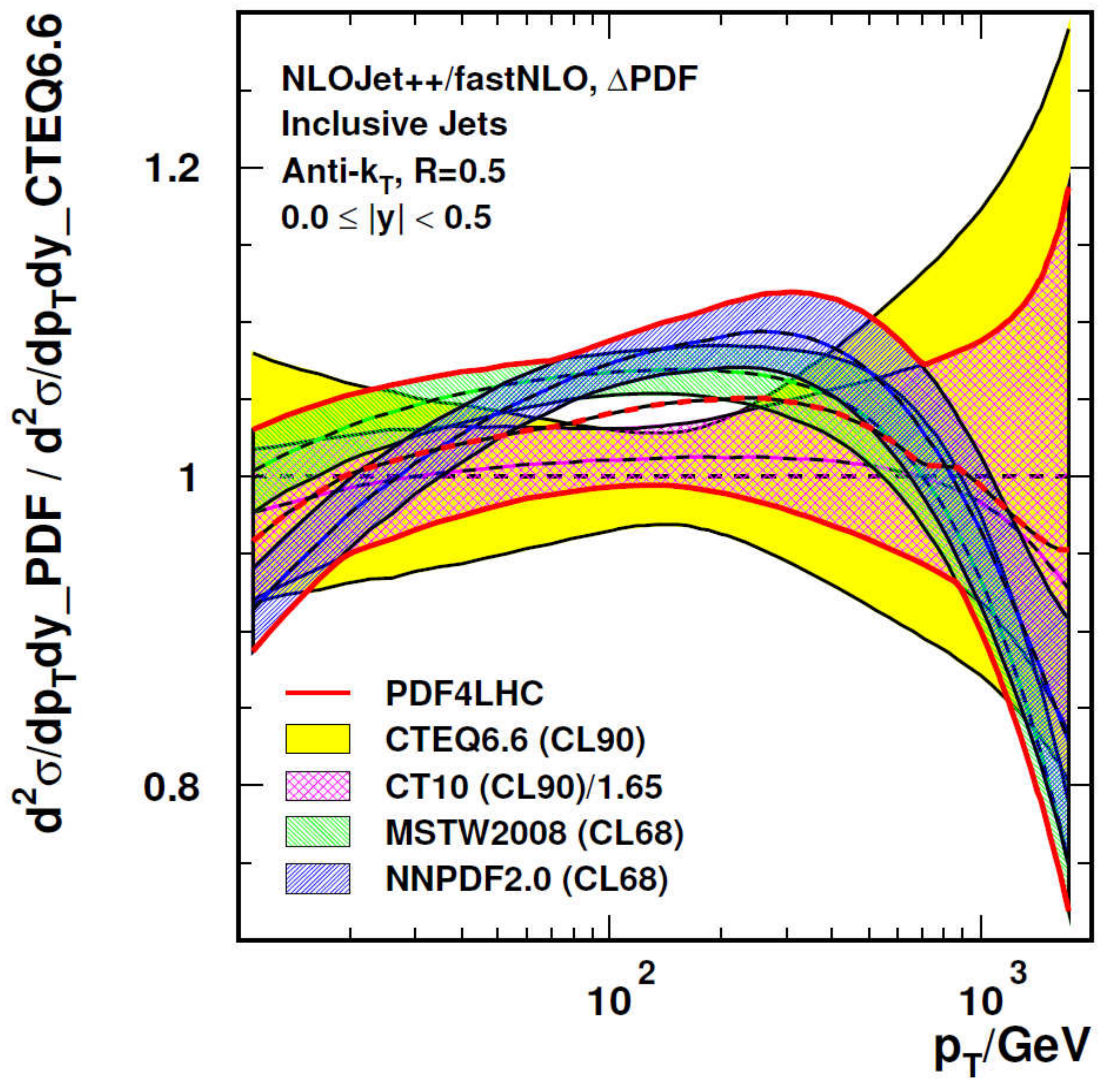
- ➢ Hadron-hadron, DIS, photoproduction, fragmentation functions …

Although labeled “fastNLO” method can be used at any order

Example Applications

CMS inclusive jets

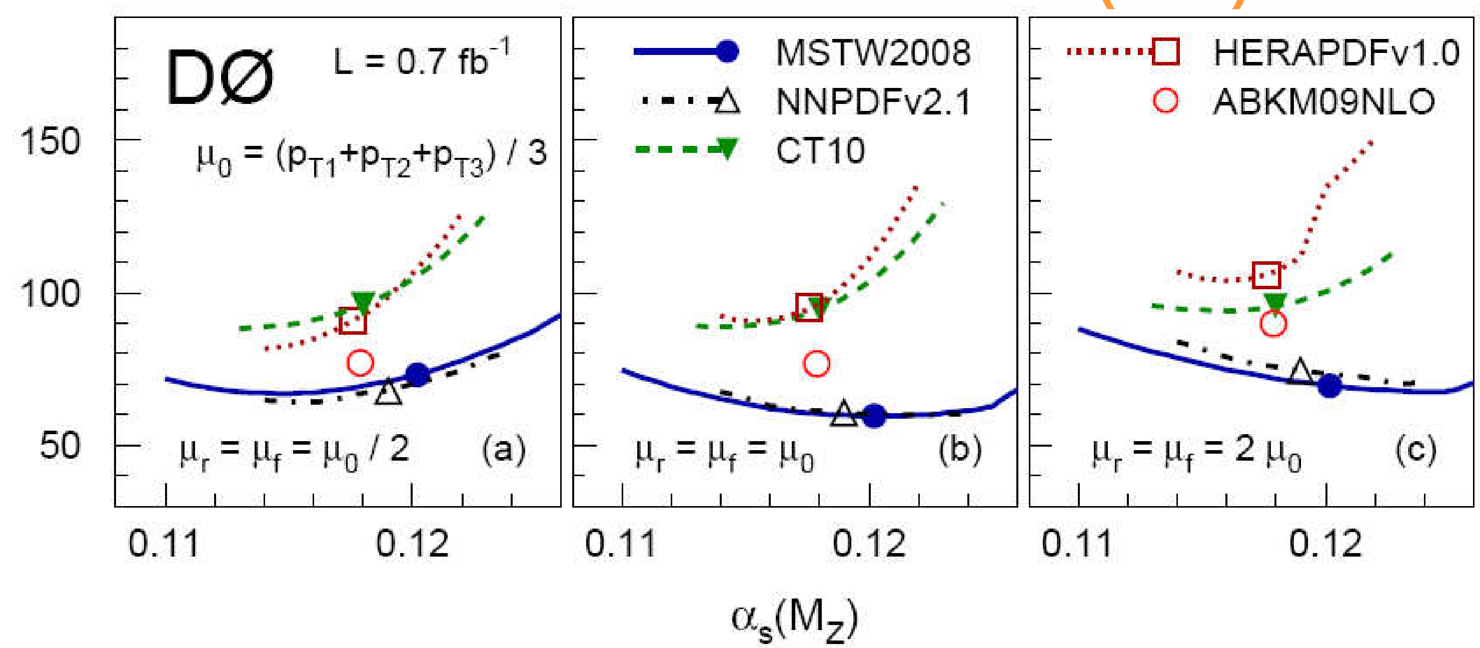
- Study of PDF dependence
- Determination of PDF envelopes
- PDF-error prediction à la PDF4LHC



D0 three-jet invariant mass

- Study of PDF dependence
- Study of scale dependence
  $\mu_r = \mu_f = (p_{T1} + p_{T1} + p_{T1})/3$
  $\mu = 2.0 \times \mu_o$
  $\mu = 0.5 \times \mu_o$
- Study of α_s dependence using α_s dependent PDF sets

PLB 704 (2011) 434-441



239 repeated NLO calculations

3138 repeated NLO calculations

New in version 2.0

Features of pre-computed fastNLO tables

- Automatic adjustment of phase space boundaries
- Flexible # x-nodes for analysis bins
- Improved interpolation in ren./fact. scales
- Arbitrary number of dimensions for binning of observable

FastNLO Table

Features of fastNLO reading tools

- Comprehensive α_s evolutions provided
  - 2-,3-,4-loop iterative solution, flavor matching ON/OFF, etc…
  - Interface to external α_s evolutions e.g. LHAPDF, QCDNUM, etc…
  - Interface to CRunDec (**arXiv:1201.6149v1, arXiv:hep-ph/0004189v1**)
- Interface to PDFs from LHAPDF and QCDNUM
  - easy implementation of new interfaces
- Easy to install (autotools)
- Easy to implement in fitting codes and to interface PDFs

FastNLO Reader

Reader_f

Reader_cc

- **Independent C++ and Fortran versions**
  - agreement at double precision O(10^{-10})

No further dependencies (No ROOT, No CERNLIB, etc…)

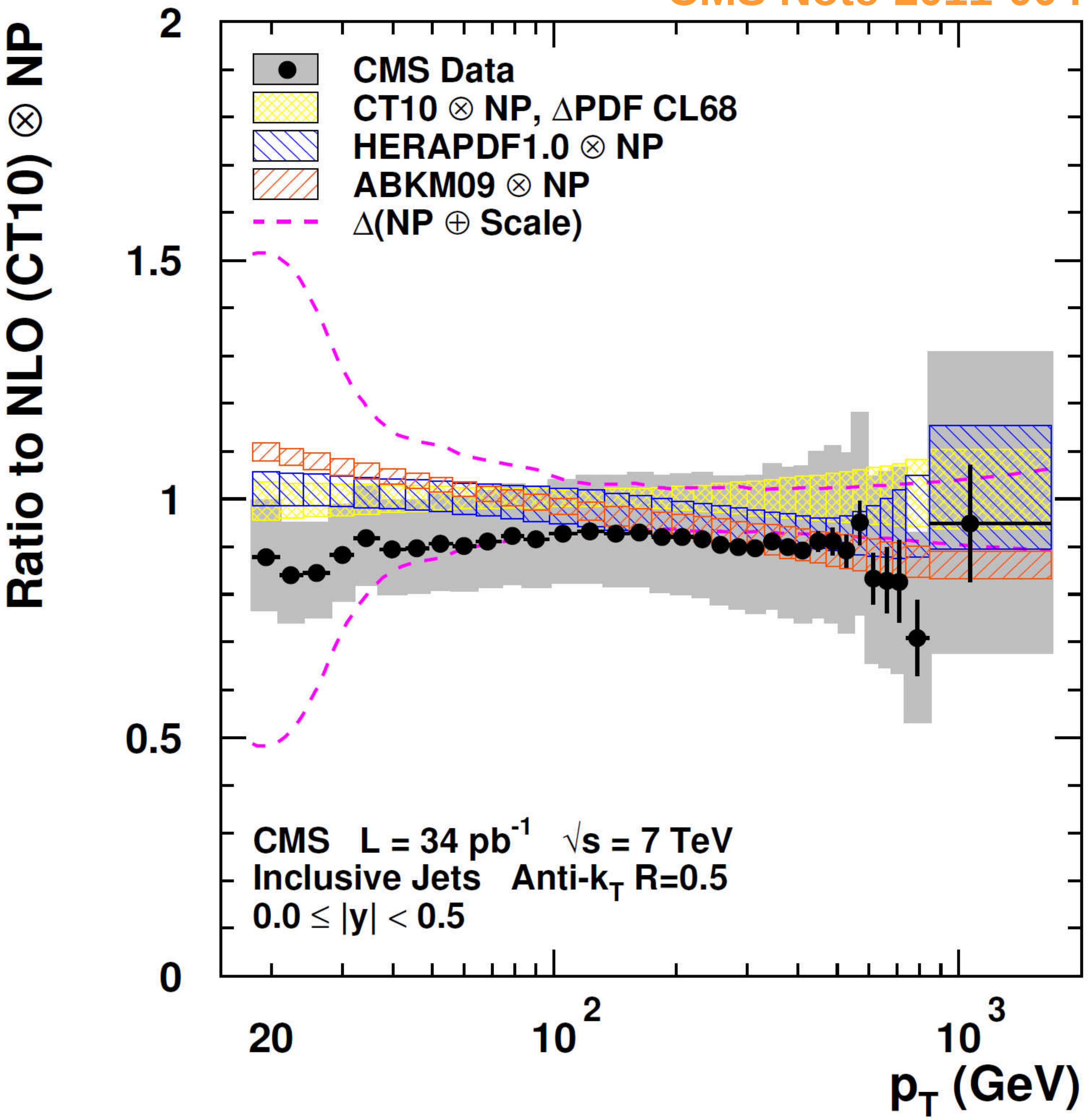
Flexible table format in fastNLO 2.0

Format foresees

- ➢Fixed orders (LO, NLO, NNLO,…)
- ➢Threshold corrections
  - 2-loop for inclusive jets available
- ➢Electroweak corrections
- ➢New physics contributions
- ➢Correction factors
  - Non-perturbative corrections
  - With uncertainties
- ➢Data
  - Including correlated and uncorrelated uncertainties
  - Correlation matrix

Conversion tool for v1.4 tables

CMS Note-2011-004



Scale flexibility in fastNLO v2.0

Perturbative coefficients beyond LO have scale dependence

$$\sigma \propto \alpha_s^n c_{born} + \alpha_s^{n+1} c_{NLO}(\mu_r, \mu_f)$$

Scale dependence can be factorized

$$\sigma \propto \alpha_s^n c_{born} + \alpha_s^{n+1}\left(c_0 + \log(\mu_r^2)c_r + \log(\mu_f^2)c_f\right)$$

Store individual scale **independent** coefficients

Scales can be arbitrary values - or functions of observables

- Scales can be functions of multiple variables e.g. p_T and y*

$$\mu_{r/f} \rightarrow \mu_{r/f}(p_T, y^*) \qquad e.g.\ \mu = 0.5 \cdot p_T \quad or \quad \mu = p_T \cdot e^{0.3y}$$

- Final scale can be chosen to be any function of both

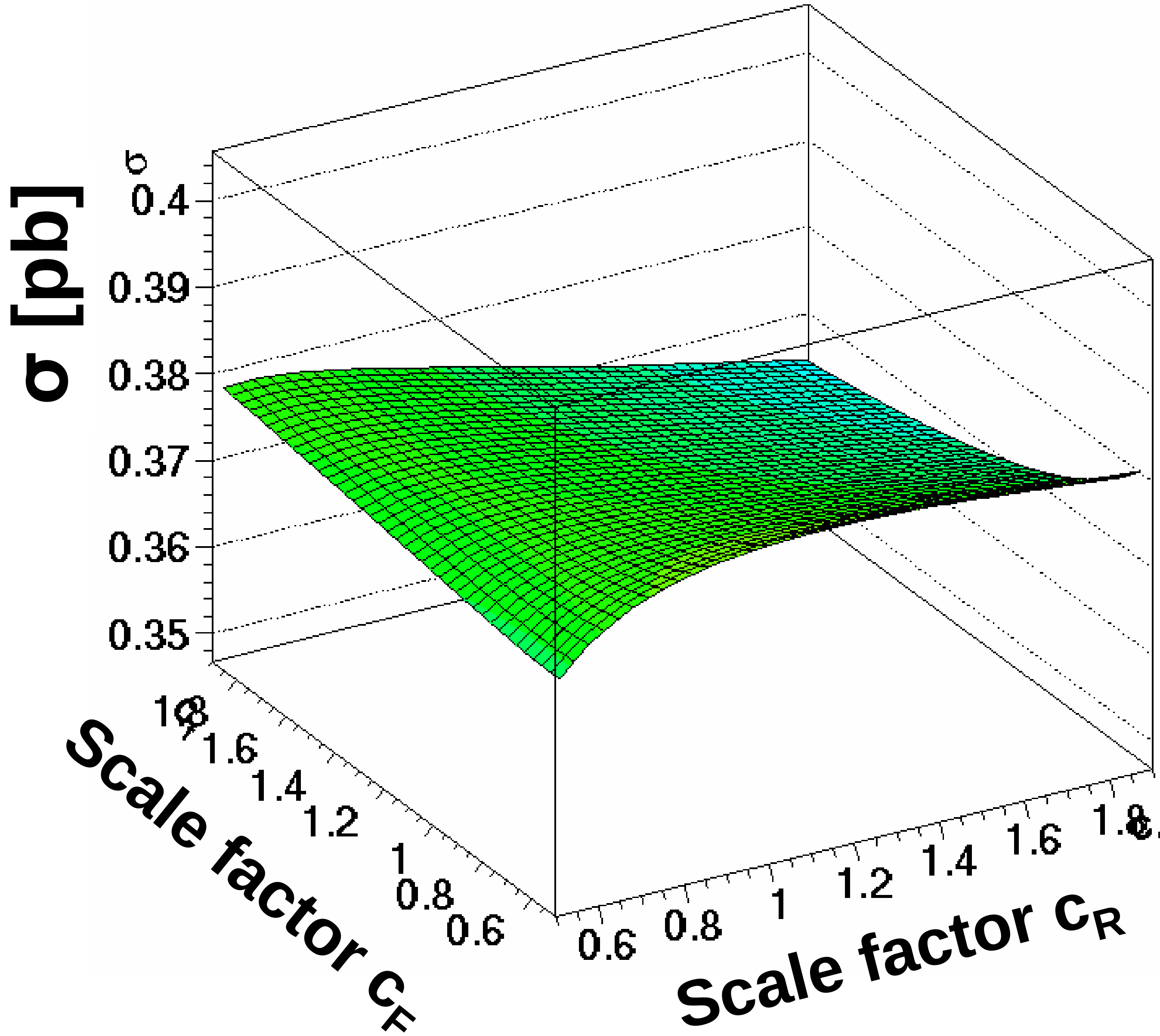
Scales can be functions of multiple observables

New Features for Scales

Scales can be functions of multiple observables

- e.g. for DIS jets
  Scale observables are p_T and Q^2

- Scales can be
  $\mu_r^2 = (Q^2 + p_T^2) / 2$
  $\mu_r^2 = Q^2$
  $\mu_r^2 = p_T^2$
  $\mu_r^2 = 0.8\, Q^2 + 0.3\, p_T^2 + Q \cdot p_T$



Independent scale variations of μ_r and μ_f are possible

$\mu_R^2 = c^2_R \times (Q^2 + p_T^2) / 2$
$\mu_F^2 = c^2_F \times Q^2$

More flexibility for studies of scale dependencies

Example Study: Scale studies for ATLAS Dijets M_{jj}

ATLAS dijet invariant mass measurement, R=0.6 PRD86 (2012) 014022

- $<p_T>$ and y* (or $p_{T,max}$ and y*) are stored as scale variables in table
- Renormalization and factorization scales can be any function f = f(p_T,y*)

Possiblity to study variations of ATLAS dijet scale choice

Atlas choice

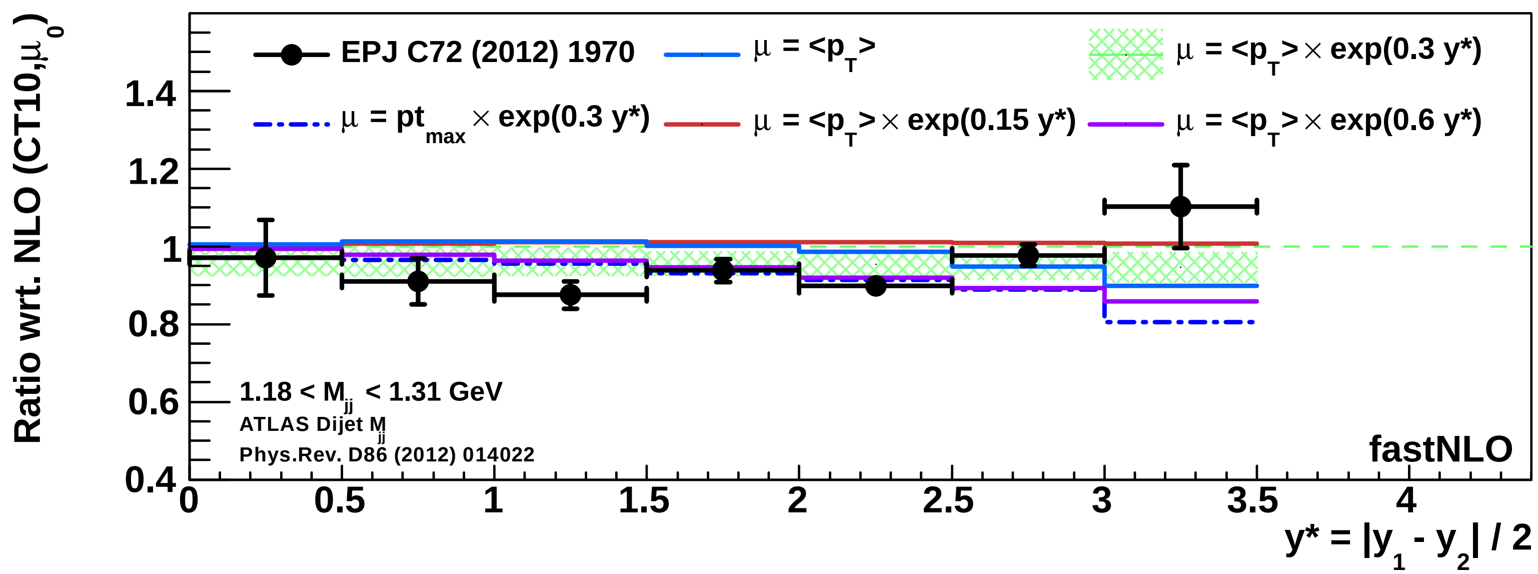
$$\mu = p_{T,\max} \exp(0.3 \cdot \bar{y}^*)$$

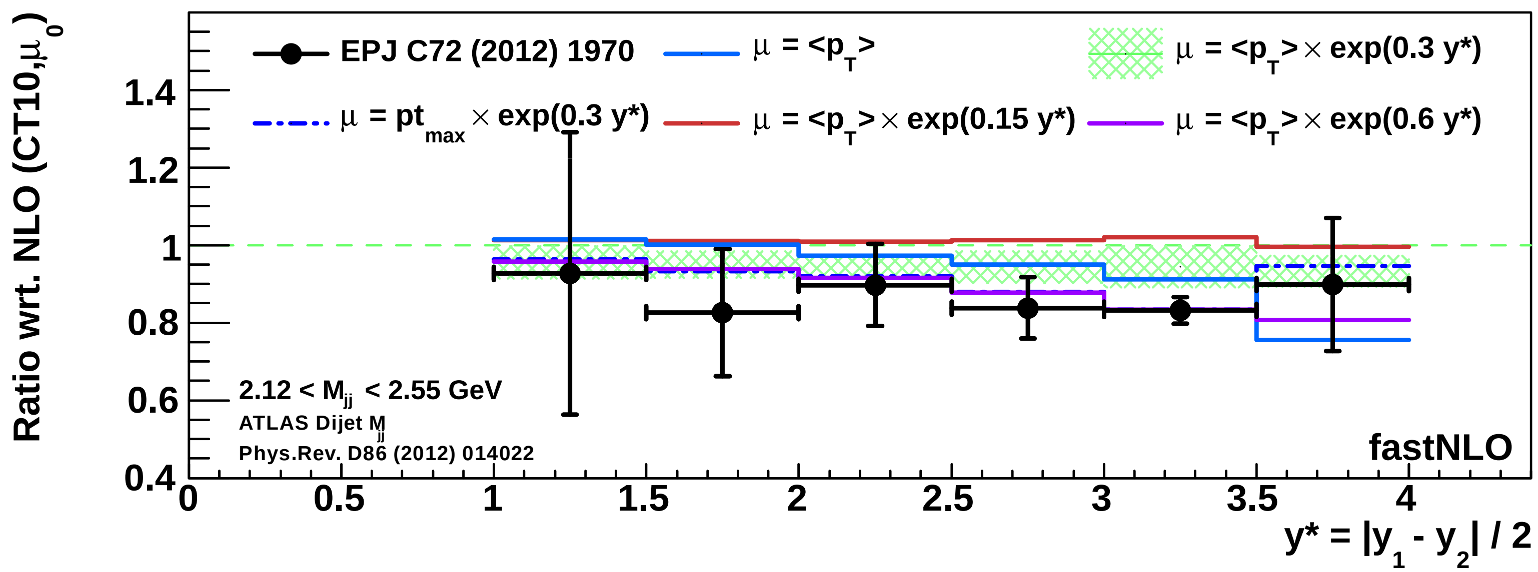
where y* is a fixed factor per y*-bin

- Differentialy in y*
- Possiblity to vary parameter '0.3'
- We could any functions (e.g. cosh)
- We can e.g. find optimal scale e.g. á la FAC or PMS

Here

$$\mu = \langle p_T \rangle \exp(f \cdot y^*)$$





New possiblites to study the best inclusion of y* into the scales

Data/Theory Comparision of Jet Cross Sections

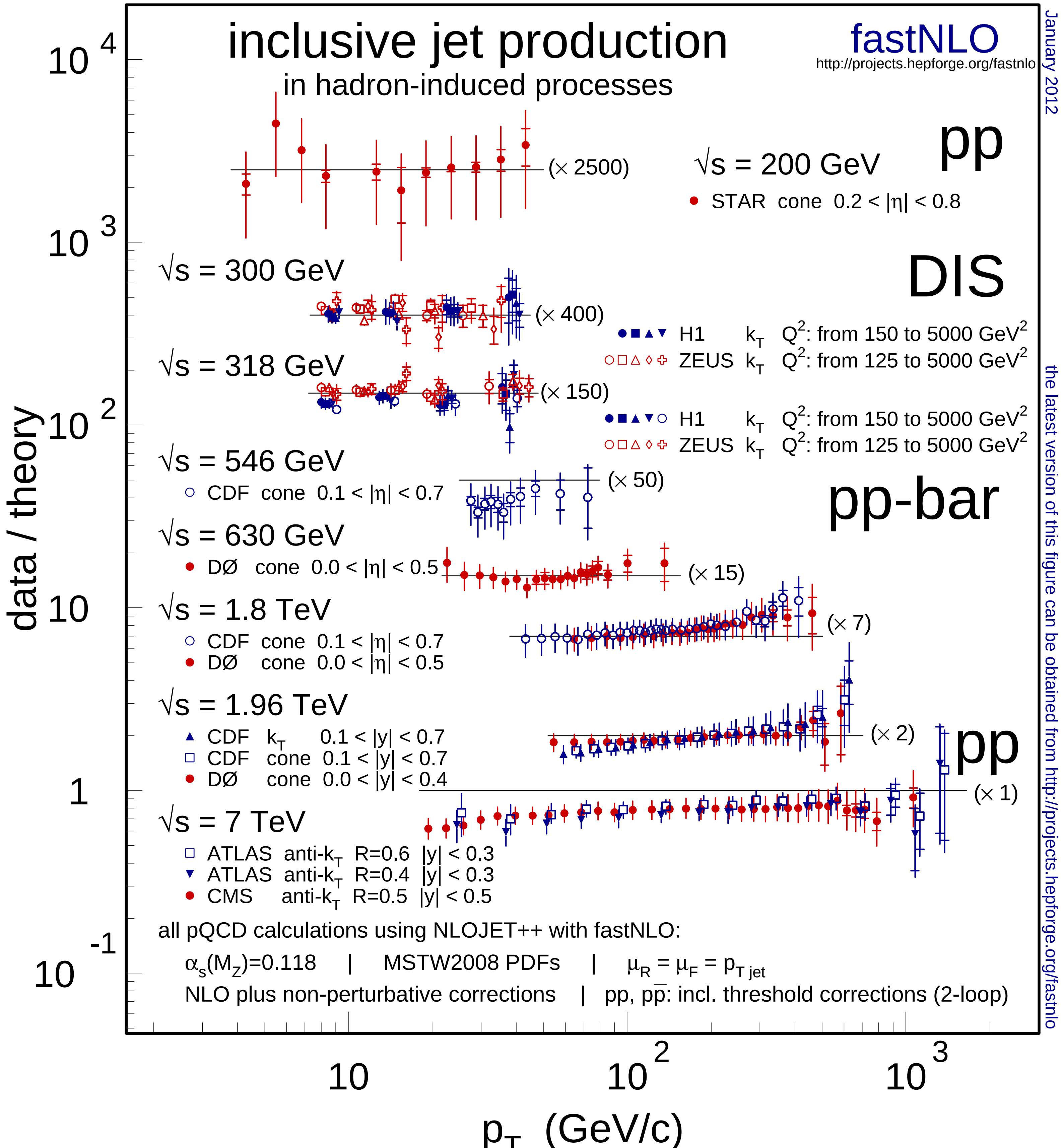
Large number of calculations are available at fastnlo.hepforge.org

Overview of inclusive jet data

- STAR @ RHIC
- H1 and ZEUS @ HERA
- CDF and D0 @ Tevatron
- CMS and ATLAS @ LHC

Data/theory comparision

Hadron-hadron including threshold corrections O(2-loop)



fastNLO, arXiv:1109:1310

PDF sensitivity

x-dependence of cross sections

Jet production does not distinguish between quark flavors

- We identify four subprocesses (qq, gg, gq, qg)
- Two x-values: We study x_{min} and x_{max}
- Each event contributes to x_{min} and x_{max}

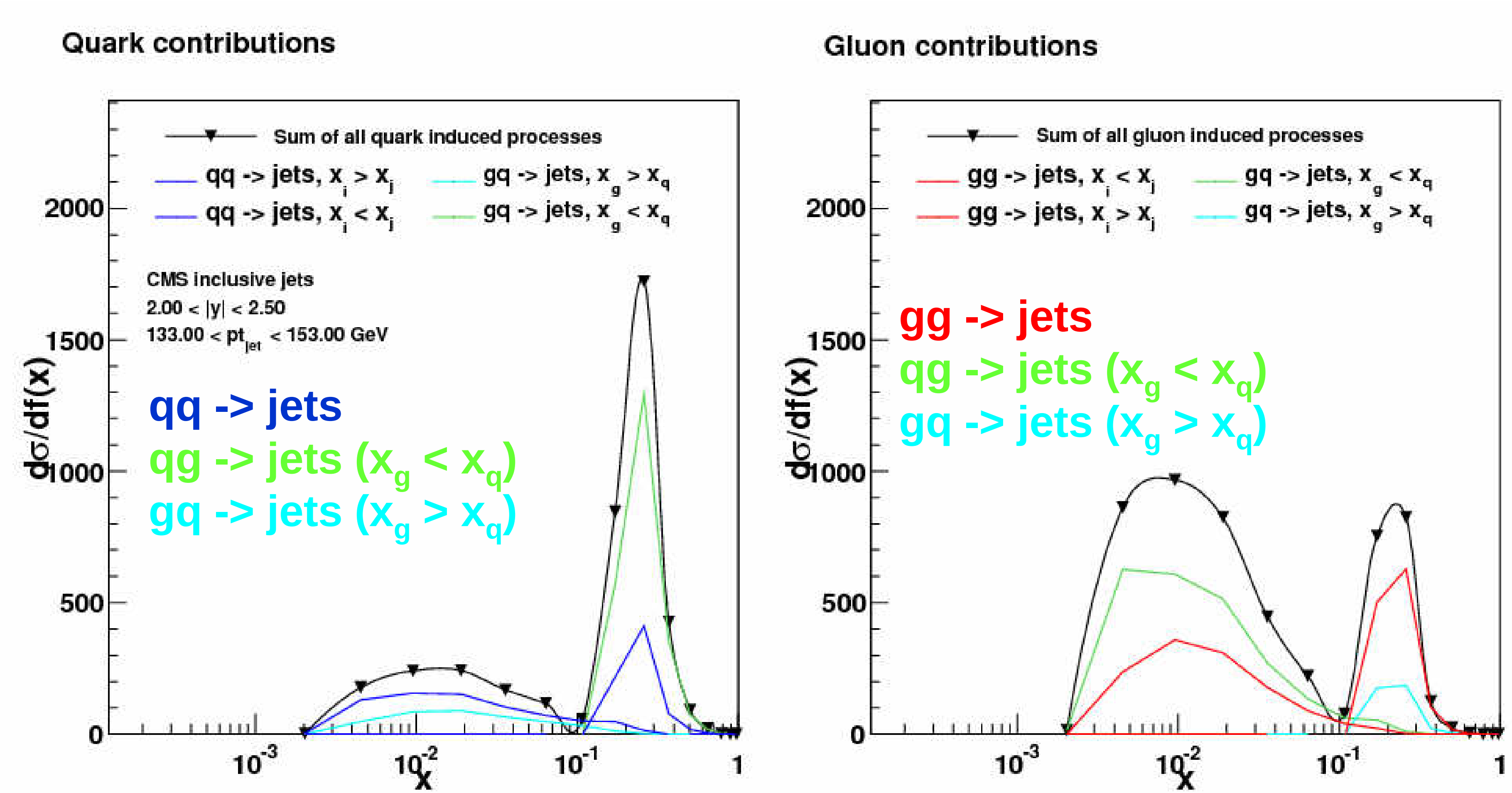
CMS inclusive jets

PhysRevLett. 107.132001

$\mu_f = p_T$

$2.0 < |y| < 2.5$

$133 < p_T < 153$ GeV

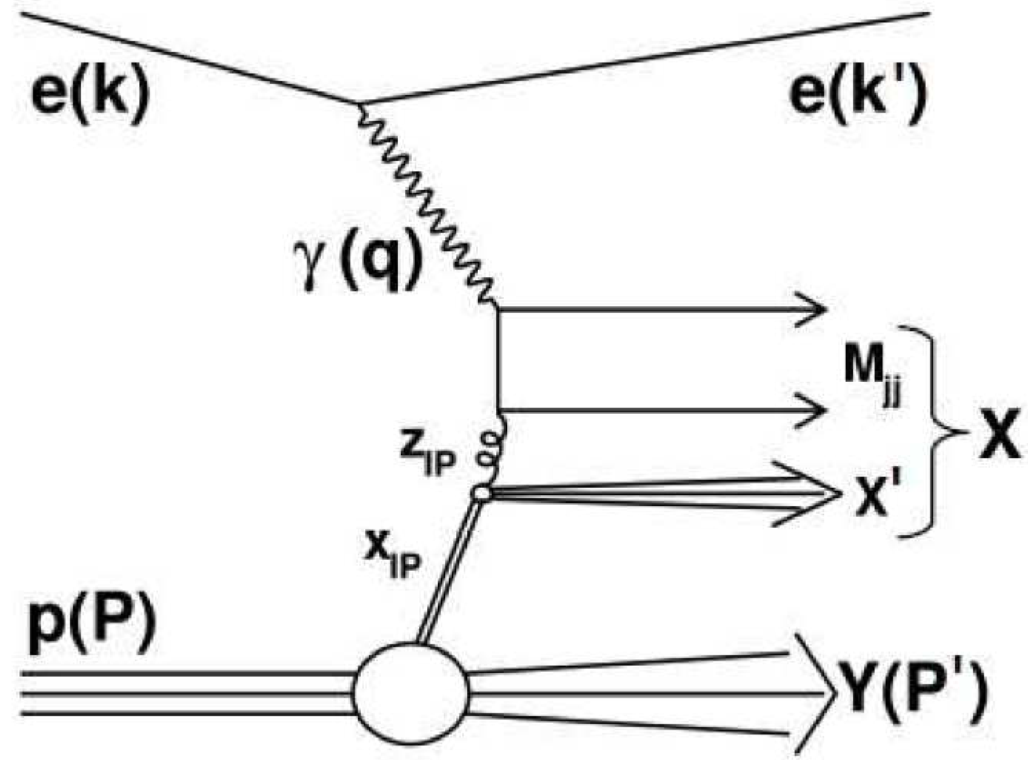


- Particular p_T bin in forward region probes two separated x-ranges

New: Jet production in diffractive DIS

Jet production in diffractive DIS (t=0)

$$\sigma = \sum_{a,n} \int_0^1 dx_{\mathrm{IP}} \int_0^1 dz_{\mathrm{IP}} \alpha_s^n(\mu_r) \cdot c_{a,n} \cdot f_a(x_{\mathrm{IP}}, z_{\mathrm{IP}}, \mu_f)$$



Standard method of calculating NLO cross sections: 'Slicing method' H1-07/07-628

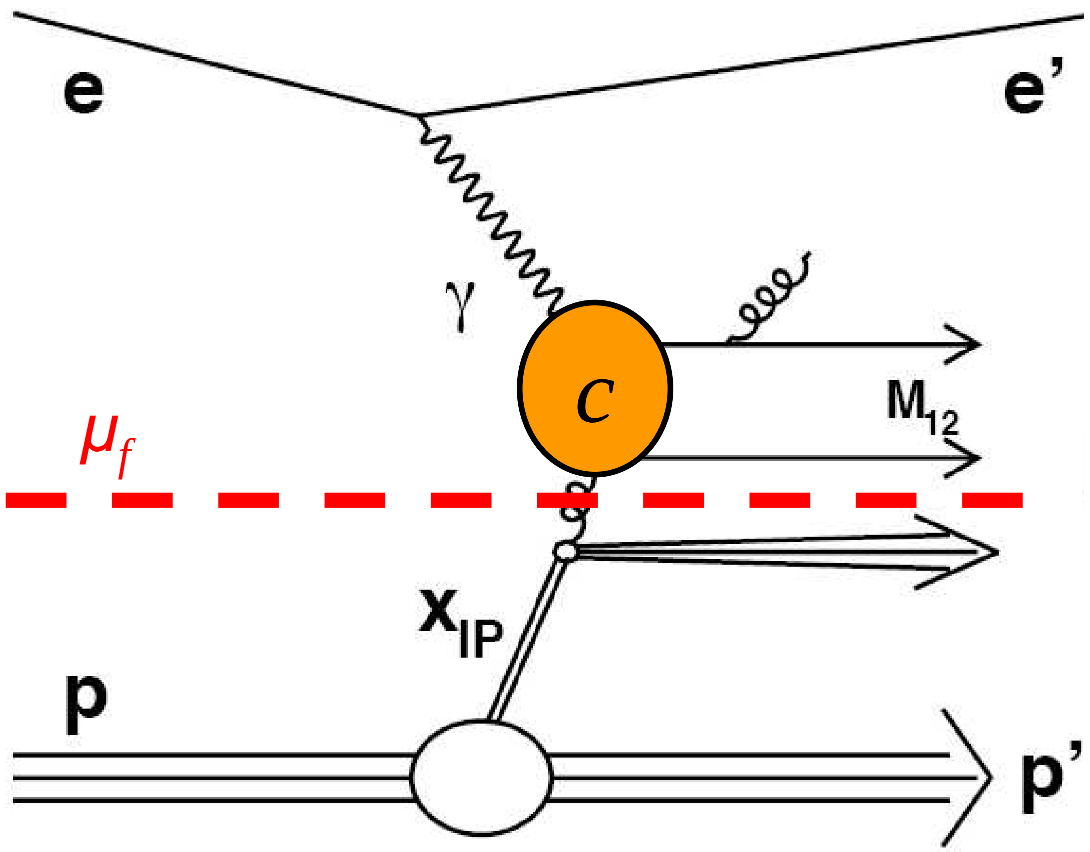
- Riemann-Integration of dx_{IP}
- Discretize the x_{IP} range into k bins (k~10)
- Needs Repeated cross section calculation for each slice of x_{IP}

$$\int_0^1 dx_{\mathrm{IP}}\, f_{\mathrm{IP}/a}(x_{\mathrm{IP},i}) \sigma_{\mathrm{IP}}(x_{\mathrm{IP}}) \cong \sum_k \Delta x_{\mathrm{IP},i}\, f_{\mathrm{IP}/a}(x_{\mathrm{IP},i}) \sigma_{\mathrm{IP}}(x_{\mathrm{IP}})$$

Jet production in diffractive DIS

Perturbative coefficients have only dependence on momentum fraction

- No direct dependence of the two momentum fractions x_{IP} and z_{IP}
- Each slice calculates basically same coefficients c
- Factorization is independent of incoming parton



Perform x_{IP}-Integration a-posteriori

Calculate one fastNLO table with hadron energy = proton energy

Calculation of only a single fastNLO table is needed

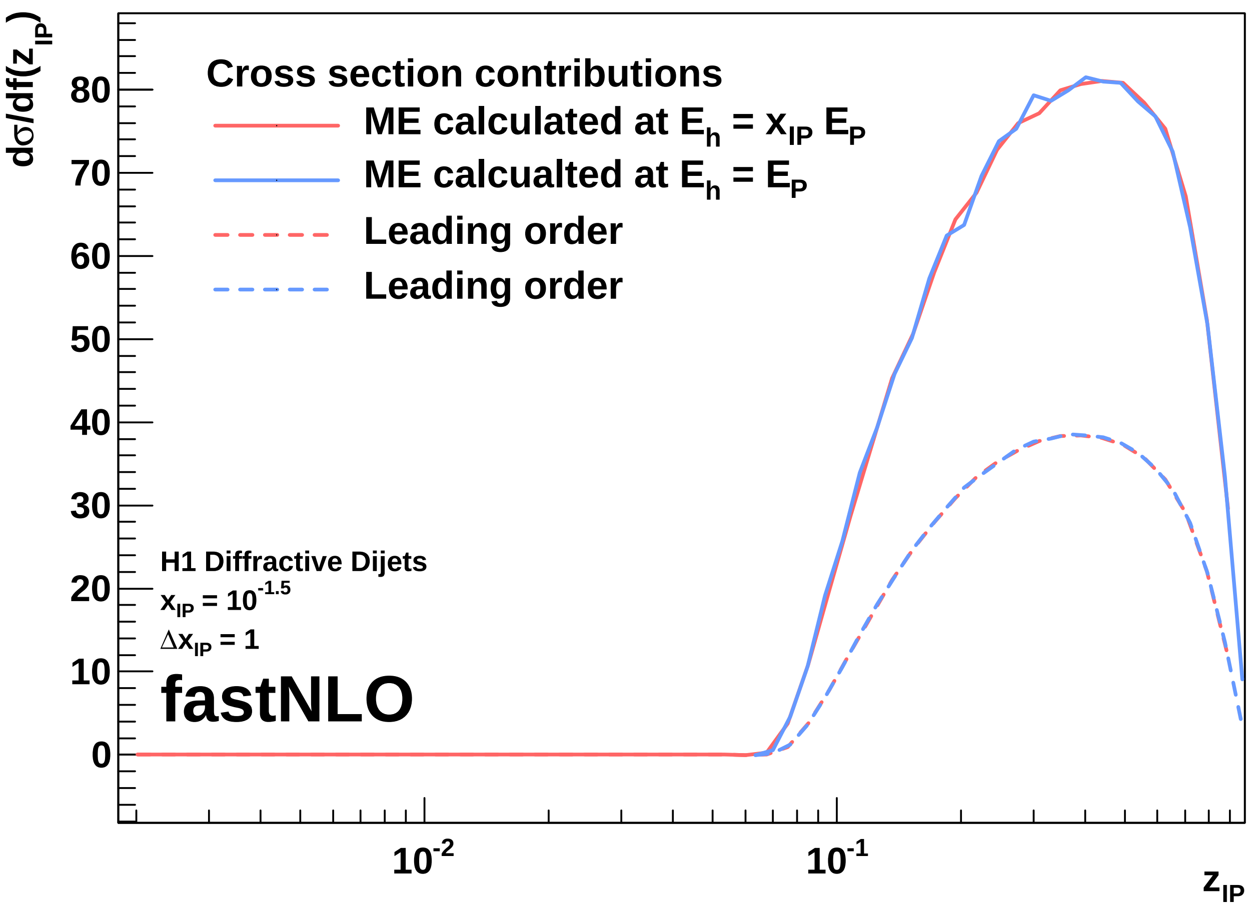
Jets in diffractive DIS with fastNLO

1. Fixed center-of-mass calculation

- Calculate only one fastNLO table at proton energy E_p
- Increased number of x-nodes in low-x region

2. Adapt the slicing method

- Define arbitrary x_{IP} slicing
- Calculate cross section by Rieman-integrating x_{IP}
- Integrate over x wrt. E_p



$$\sigma_{n,a} = \sum_k \Delta x_{\mathrm{IP},k} \int_0^{x_{\mathrm{IP},k}} \frac{dx}{x_{\mathrm{IP},k}} \alpha_s^n \cdot c_0(x) \cdot f_a\left(x_{\mathrm{IP},k}, z_{\mathrm{IP}} = \frac{x}{x_{\mathrm{IP},k}}, \mu_f\right)$$

Integral becomes a standard fastNLO evaluation

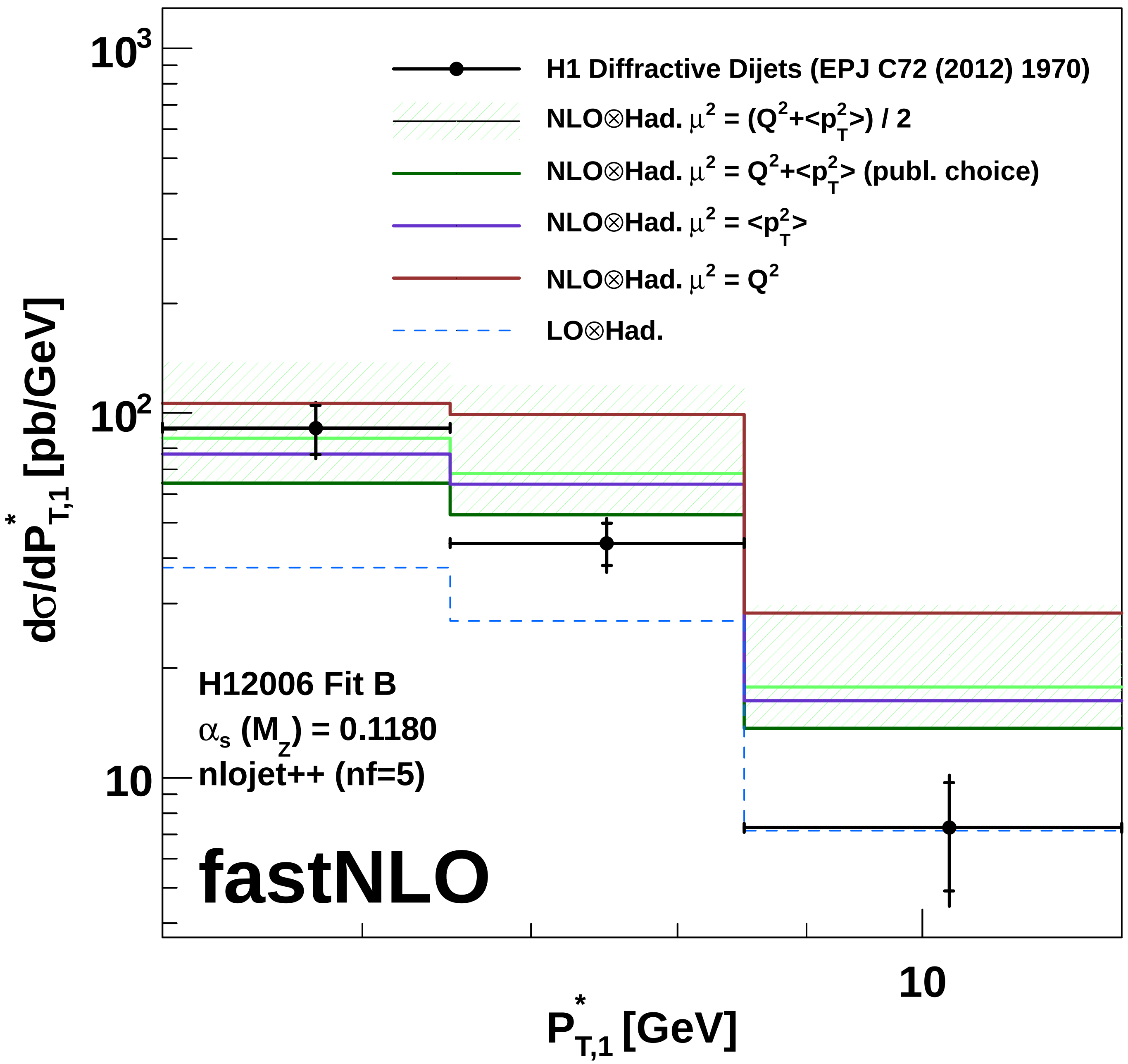
Upper integration interval needs to be respected properly

FastNLO procedure improves previously used approach

Application: Diffractive PDF fits

Dijet production in diffractive DIS (H1) EPJ C72 (2012) 1970

- Calculations available for
  - $d\sigma/dQ^2$
  - $d\sigma/dp^*_{T,1}$
- Possibility to derive by restricting x_{IP} integration interval
  - $d\sigma/dx_{IP}$



Full fastNLO features accessible

- Scale studies are easily possible
- Compare various scale choices
- Interface various DPDFs
- Direct access to k-factors

NEW: Facilitate inclusion of diffractive jets in DPDF fits
-> Will help to constrain the gluon in diffractive PDFs

Summary

FastNLO code

- Code downloadable
- C++ and Fortran code (No further dependencies)
- Many calculations available for all experiments
  ATLAS, CMS, CDF, D0, H1, ZEUS, STAR

New features in v2.0

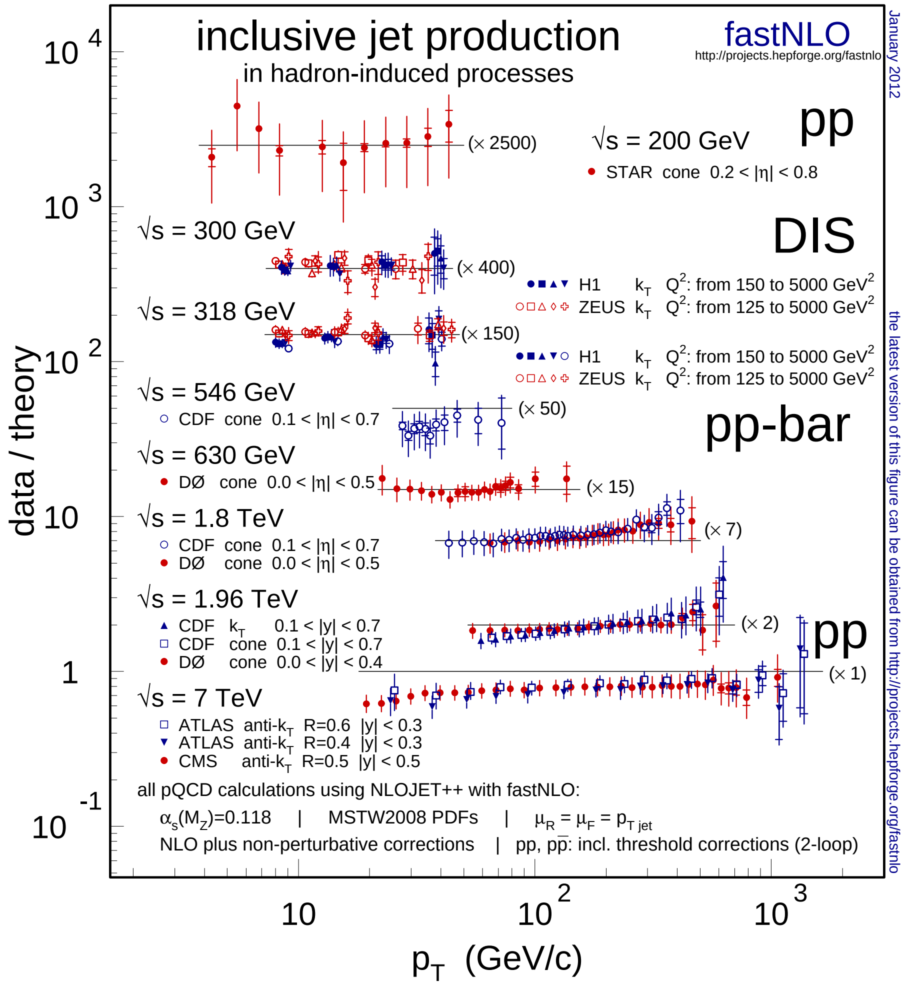
- Many technical improvements
- Table format forsees different physics contributions

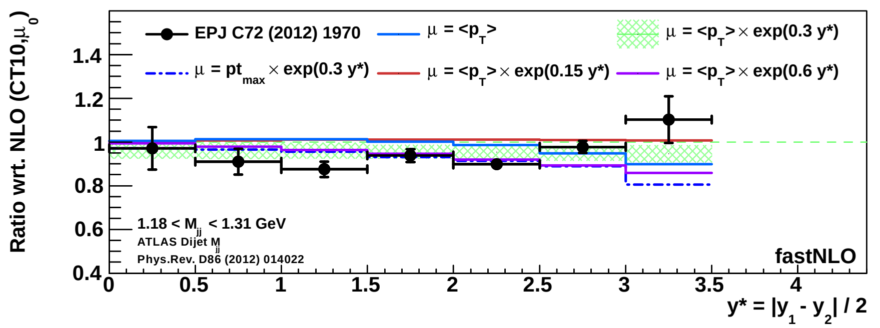
'Flexible scale' tables

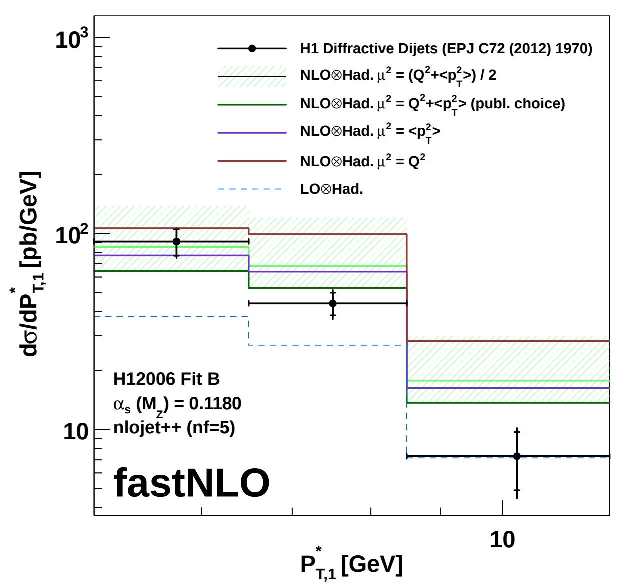
- Choose composition of μ_R and μ_F
- Vary ren./fact. scales independently
- Scale variations in any order without recalculations or integrations

Diffractive jet production in DIS

- New concept developed
- Ready to use in DPDF fits







New release soon

fastnlo.hepforge.org

New release of C++ and fortran code within the next weeks

Many new calculations:
LHC, Tevatron, HERA, …

Diffractive DIS code and tables

Backup

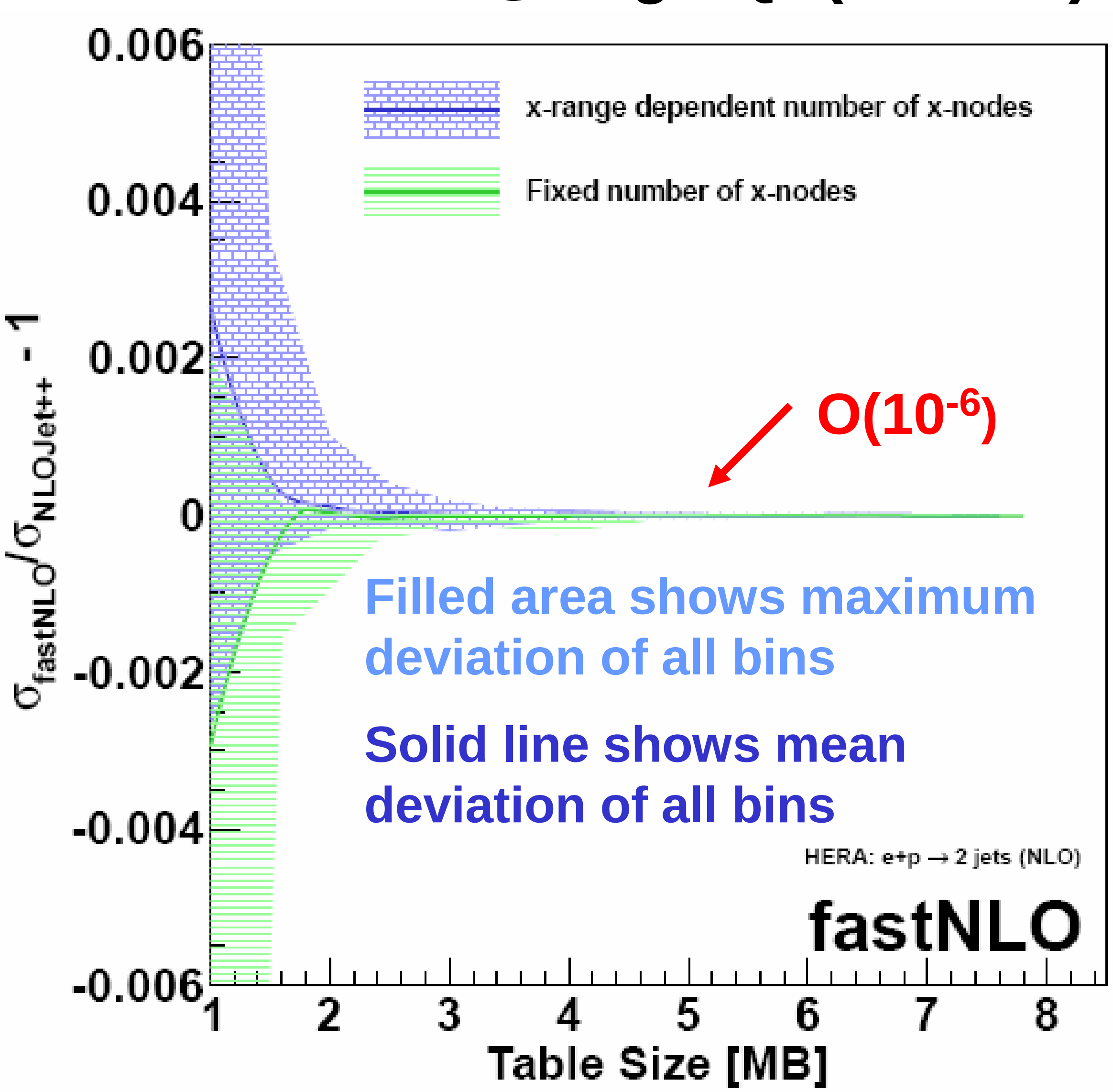
fastNLO Precision

Free Parameters
- # x-nodes
- # scale nodes
- -> Affect the interpolation precision

New feature in v2.0
- Flexible # x-nodes
- Number of x-nodes chosen depending on x-range

Comparison vs. 'plain' NLOJet++
- Arbitrary precision possible
- For O(MB) tables, reach better than 1 per mille

H1 Incl. Jets @ High Q^2 (24 bins)



Example: Scale studies with ATLAS Dijet M_{12}

ATLAS Dijet Invariant Mass Measurement, r=0.6 PRD86 (2012) 014022

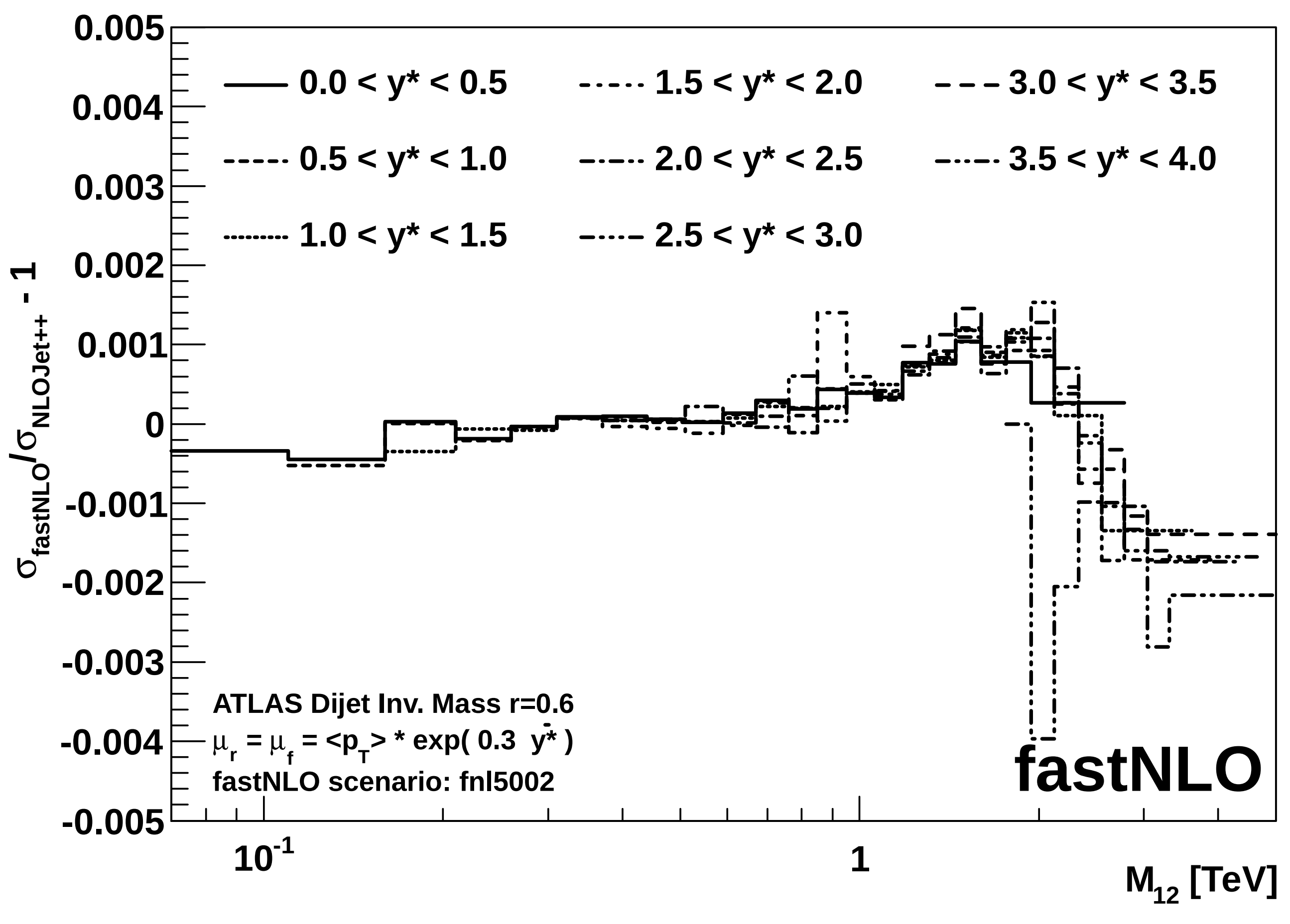
- pT and y* are stored as scale variables in table
- Renormalization and factorization scale can be any function of (p_T,y*)

Possiblity to study variations of ATLAS dijet scale choice

Atlas choice

$$\mu = p_T \exp(0.3 \cdot y^*)$$

- We could choose any parameter '0.3'
- We could use different functions (e.g. cosh)
- We can e.g. find optimal scale (FAC,PMS)



Here: fastNLO vs. plain NLOJet++ calculation with free choice of ren./fac. scale

Precision ~10^{-3}

Generalized fastNLO concept in v2.0

We know

$$\sigma \xrightarrow{fastNLO} \sum_j^{\mu} \sum_i^{x} \tilde{\sigma}_{ij}(\mu_j) f(x_i, \mu_j) \alpha_s(\mu_j)$$

We can use variables from look-up tables for 'any' further calculation (like $\alpha_s(\mu)$)

σ_{ij} — **2**-dim Weights

μ_j, x_i — 1-dim look-up table

$\alpha(\mu_j)$, $f(x_i,\mu_j)$ — arb. ext. functions

Scale independent weights

$$\omega(\mu_R, \mu_F) = \omega_0 + \log(\frac{\mu_R}{Q})\omega_R + \log(\frac{\mu_F}{Q})\omega_F$$

- **'log(µ/Q)'** can be done at evaluation time

µ's are 'freely' choosable functions

- **µ ->** $\mu(Q,p_T)$

new in v2.0

σ^0_{ijk}, σ^R_{ijk}, σ^F_{ijk} — **3**-dim Weights

p_T, Q^2, x_i — 1-dim look-up table

$\alpha(\mu_R)$, $f(x_i,\mu_F)$ — arb. ext. functions

$\mu_F(Q,p_T)$, $\mu_R(Q,p_T)$ — arb. ext. functions

We store scale independent contribution

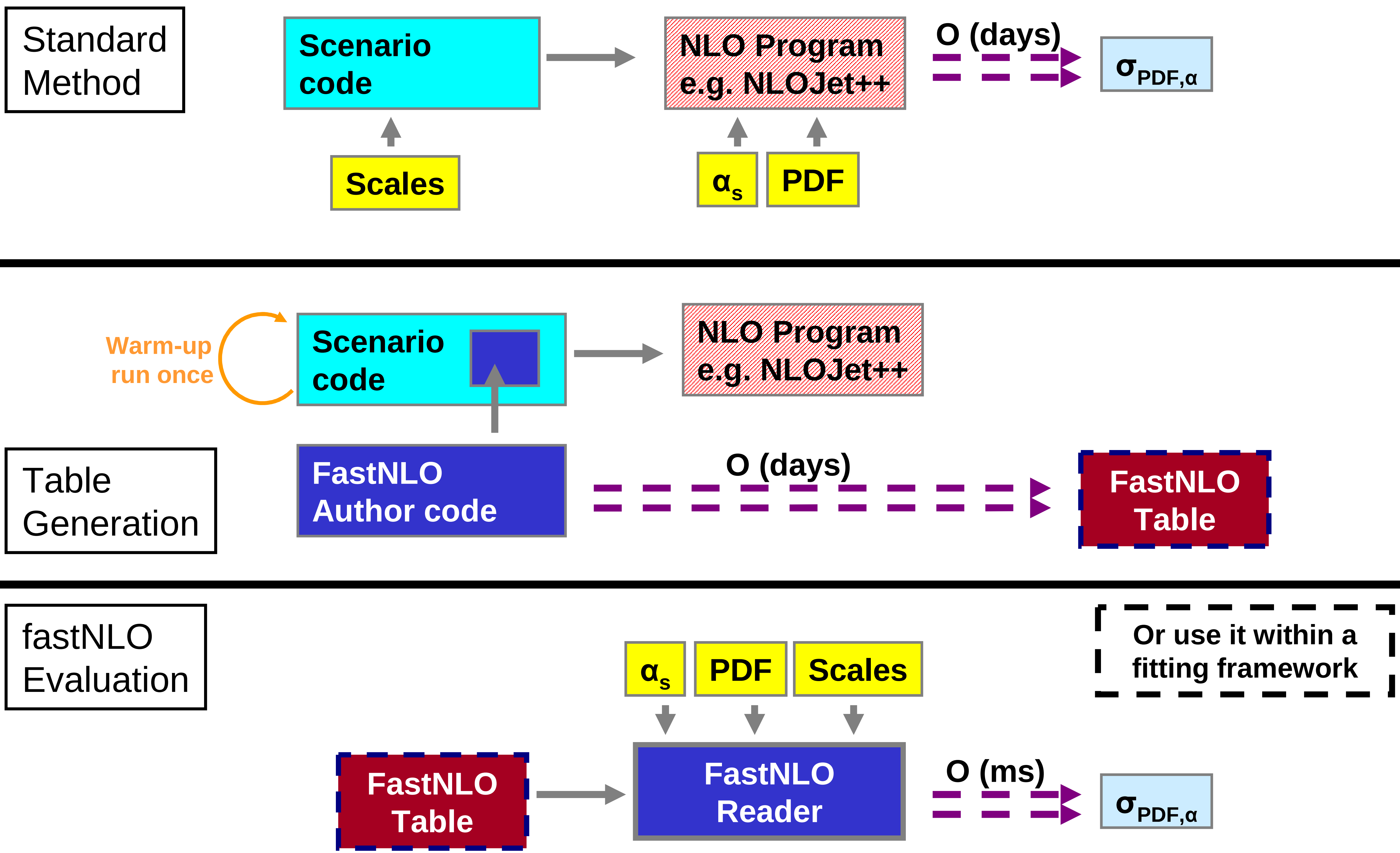
Three tables holding the weights

Further scale-variables -> $\sigma_{ijk...}$ need more dimensions

1) We can choose μ_R independently from μ_F

2) We can choose the functional form of $\mu_{R/F}$ as functions of look-up-variables

The fastNLO concept

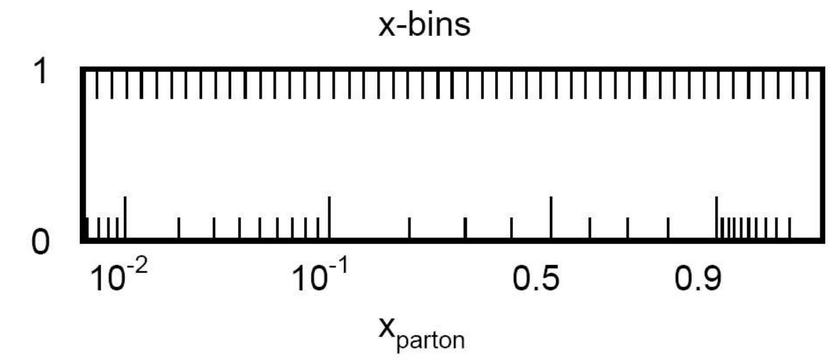


The fastNLO concept

Introduce n discrete x-nodes x_i's

- with $x_n < .. < x_i < .. < x_0 = 1$
- x_n is lowest x-value in each bin
- needs reasonable choice of discretization e.g.

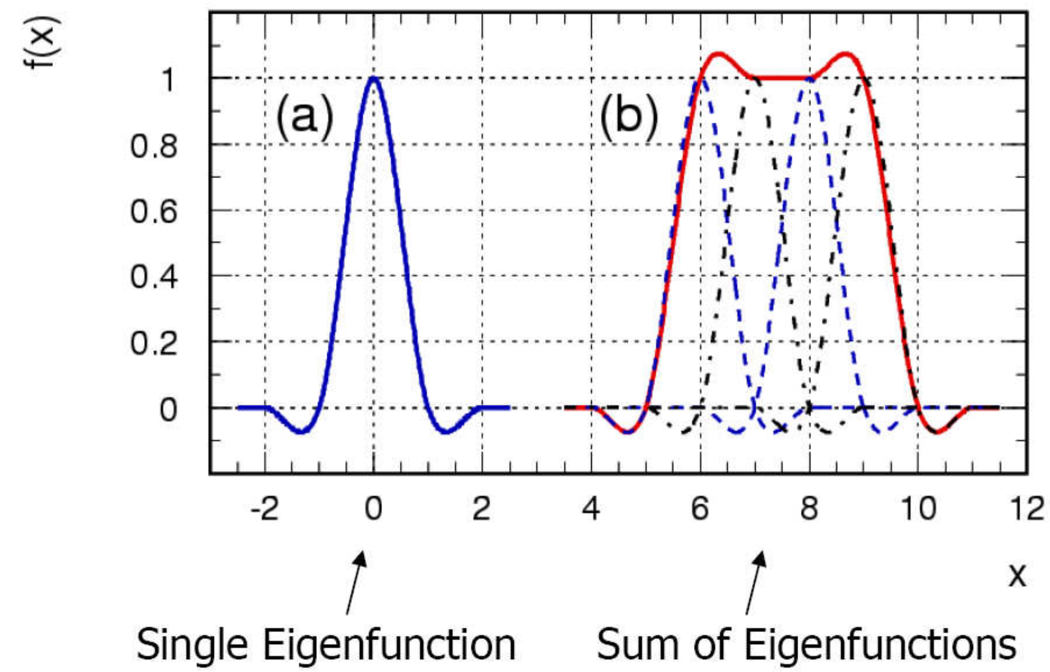
$$f(x) = -\sqrt{\log_{10}(1/x)}$$



Around each x_i define n (cubic) Eigenfunction $E_i(x)$

$$E_i(x_j) = \begin{cases} 1 & (i = j) \\ 0 & (i \neq j) \end{cases}$$

$$\sum_i E_i(x) = 1 \quad \text{for all } x$$



Hadron-hadron collision need two dimensions

2D-Eigenfunctions

$$E^{(i,j)}(x_1, x_2) = E^{(i)}(x_1) E^{(j)}(x_2)$$

13×13 partonic subprocesses reduce to 7

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

$gg \rightarrow$ jets			$\propto$	$H_1(x_1, x_2)$
$qg \rightarrow$ jets	plus	$\bar{q}g \rightarrow$ jets	$\propto$	$H_2(x_1, x_2)$
$gq \rightarrow$ jets	plus	$g\bar{q} \rightarrow$ jets	$\propto$	$H_3(x_1, x_2)$
$q_i q_j \rightarrow$ jets	plus	$\bar{q}_i \bar{q}_j \rightarrow$ jets	$\propto$	$H_4(x_1, x_2)$
$q_i q_i \rightarrow$ jets	plus	$\bar{q}_i \bar{q}_i \rightarrow$ jets	$\propto$	$H_5(x_1, x_2)$
$q_i \bar{q}_i \rightarrow$ jets	plus	$\bar{q}_i q_i \rightarrow$ jets	$\propto$	$H_6(x_1, x_2)$
$q_i \bar{q}_j \rightarrow$ jets	plus	$\bar{q}_i q_j \rightarrow$ jets	$\propto$	$H_7(x_1, x_2)$

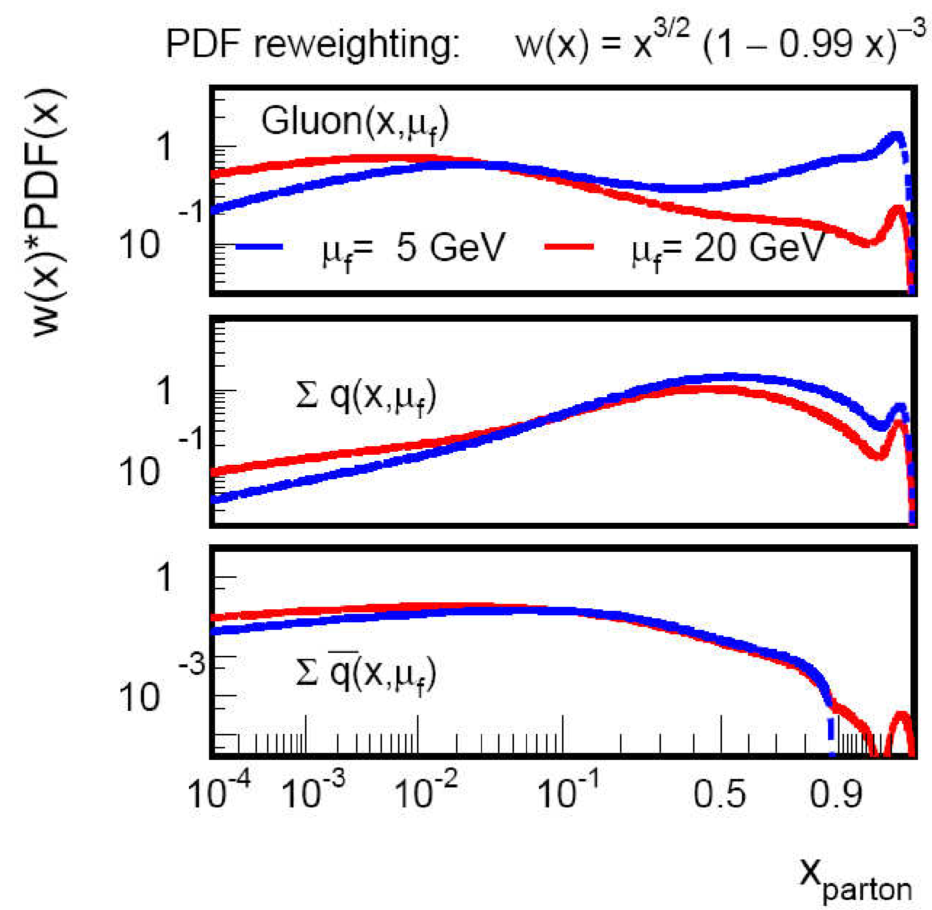
The fastNLO concept

Flatten PDFs by reweighting with simple function *w(x)*

We choose

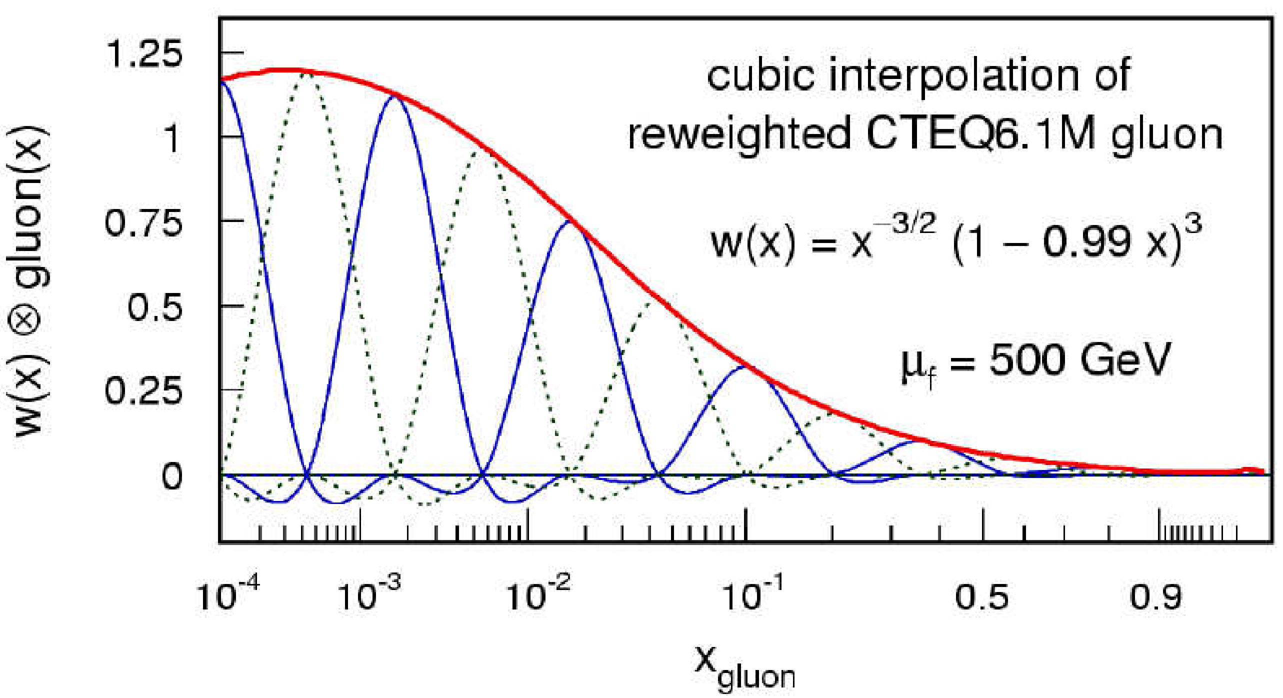
$$w(x) = x^{-3/2}(1-0.99x)^3$$

- Improve high-x gluon
- PDF curvatures are reduced for all scales
- independent of μ_f
- $w(x)^{-1}$ is absorbed in E_i



Single PDF is replaced by a linear combination of eigenfunctions

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



The fastNLO concept

With these definitions the cross section reads

$$\sigma_{hh} = \int dx_1 \int dx_2 \sum_n \alpha_s^n(\mu_r) \sum_{k=1}^{7} c_{k,n}(x_1, x_2, \mu_r, \mu_f) H_k(x_1, x_2, \mu_f)$$

Now express PDF linear combinations H_k by the 2D-eigenfunction

$$\sigma_{hh} = \int dx_1 \int dx_2 \sum_n \alpha_s^n(\mu_r) \sum_{k=1}^{7} c_{k,n}(x_1, x_2, \mu_r, \mu_f) \left(\sum_{i,j} H_k(x^{(1)}, x^{(2)}) \cdot E^{(i,j)}(x_1, x_2) \right)$$

Rewrite the cross section

$$\sigma_{hh} = \sum_n \alpha_s^n(\mu_r) \sum_{k=1}^{7} \sum_{i,j} H_k(x_1^{(i)}, x_2^{(j)}) \cdot \underbrace{\int dx_1 \int dx_2 c_{k,n}(\mu_r, \mu_f) \cdot E^{(i,j)}(x_1, x_2)}_{\text{Independent of PDFs and } \alpha_s}$$

Important: Integral is independent of PDFs!

Last steps

Scale dependence

- Perturbative coefficients are scale dependent
- PDFs and α_s need to be evaluated at certain scale values

Introduce interpolation procedure also for scales

- Assume $\mu_r = \mu_f$
- Introduce m scale nodes with distances

$$f(\mu) = \log(\log(4 \cdot \mu))$$

Coefficient table gets one additional dimension for μ

Final fastNLO cross sections

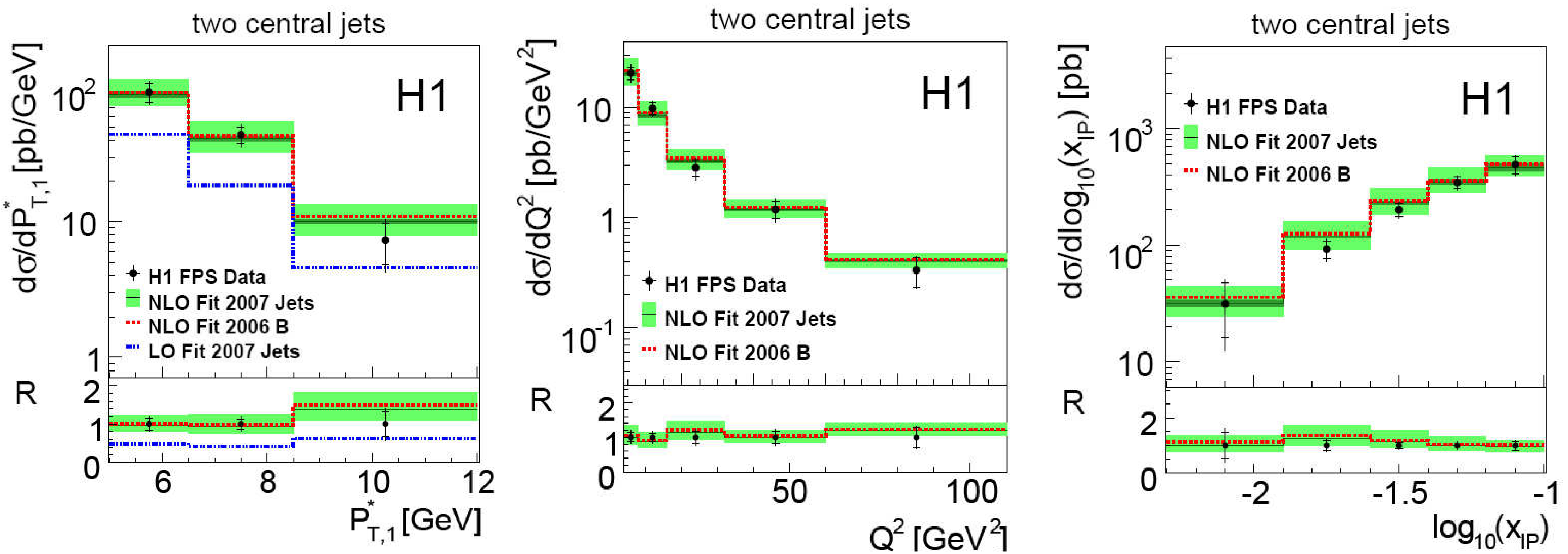
- Define σ-table and store it as fastNLO table

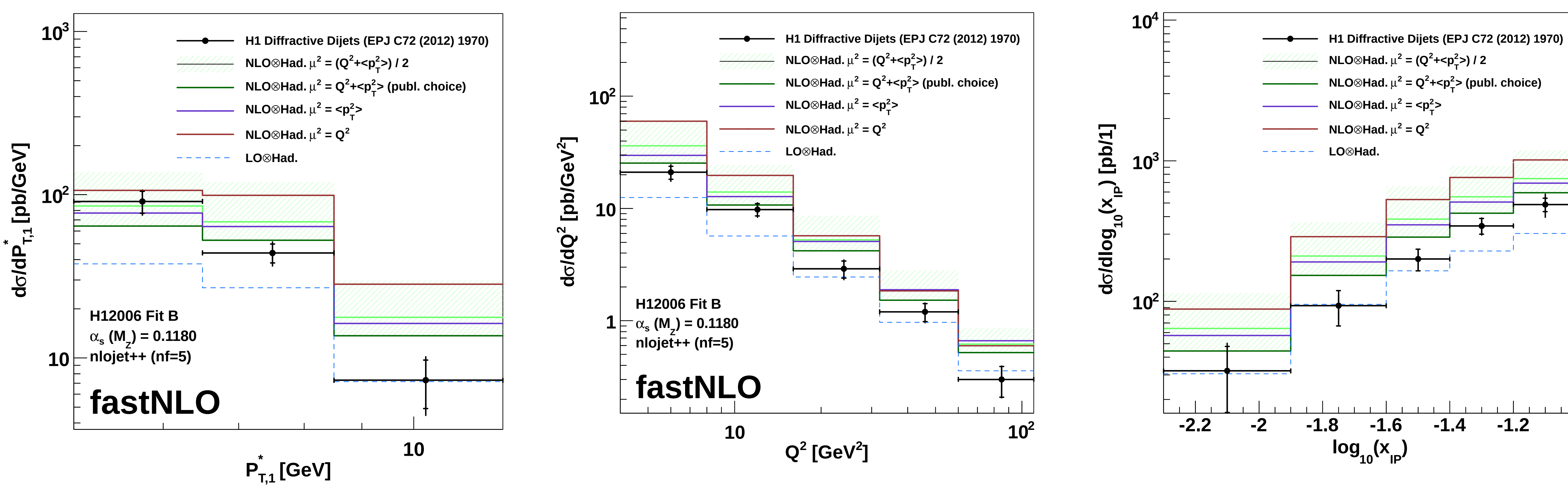
$$\tilde{\sigma}_{k,n}^{(i,j)(m)} = \sigma_{k,n}(\mu) \otimes E^{(i,j)}(x_1, x_2) \otimes E^{(m)}(\mu)$$

- Contains all information on the observable

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

Diffractive dijets

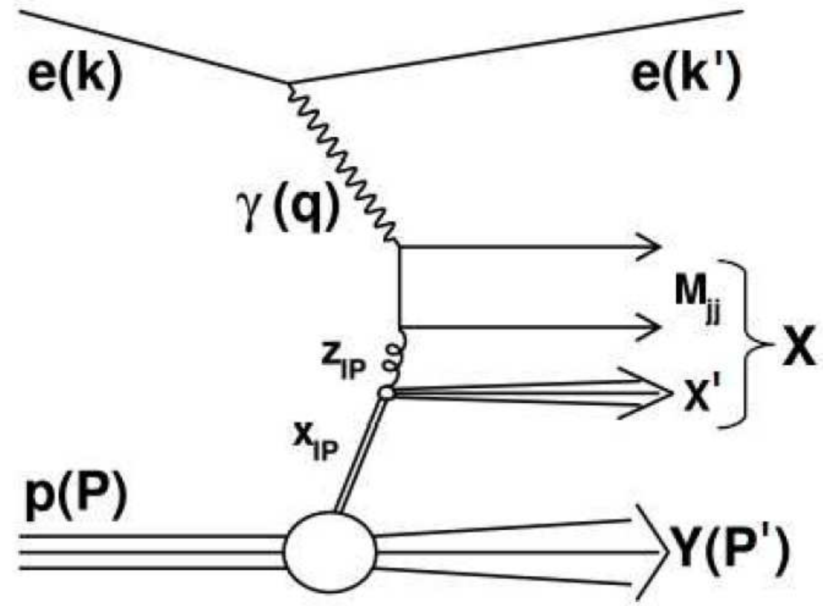




Jetproduction in diffractive DIS

Jetproduction in diffractive DIS (t=0)

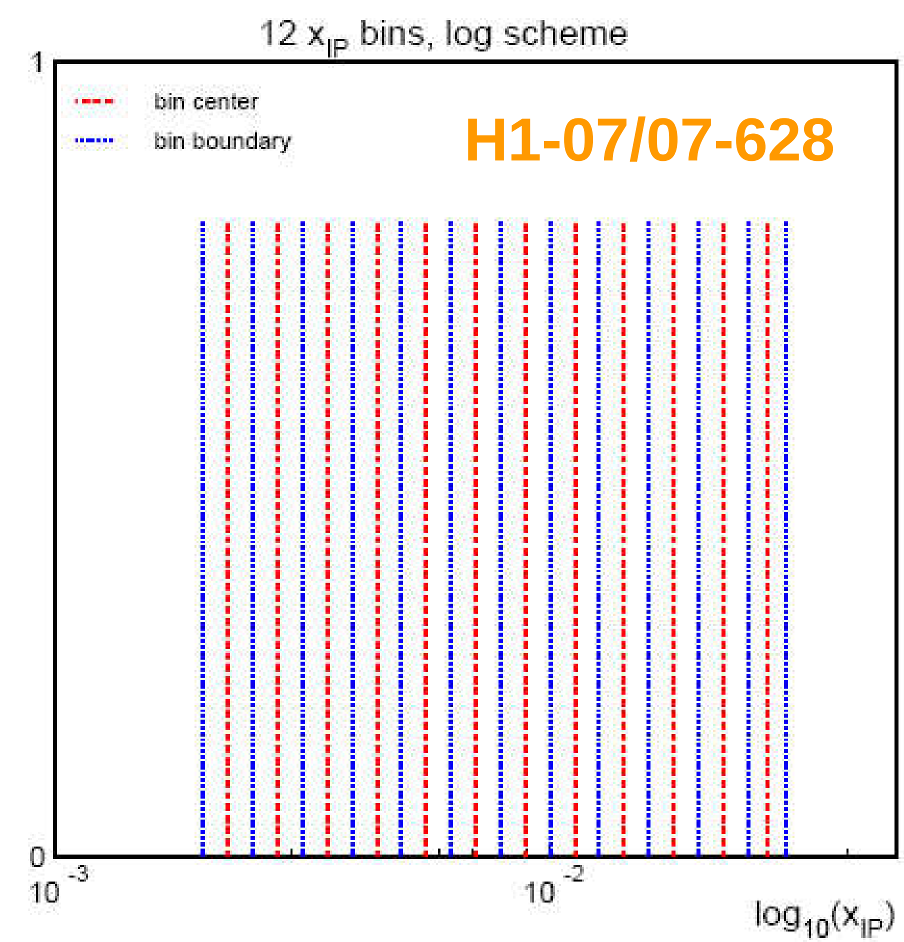
$$\sigma = \sum_{a,n} \int_0^1 dx_{IP} \int_0^1 dz_{IP} \alpha_s^n \cdot c_{a,n} \cdot f_a(x_{IP}, z_{IP}, \mu_f)$$



Standard method of calculating NLO cross sections: 'Slicing method'

- Riemann-Integration of dx_{IP}
- Discretize the x_{IP} range into k bins (k~10)
- Repeated cross section calculation for each slice of x_{IP}
  - fixed value of $x_{IP,i}$
  - At reduced center of mass energy of sqrt(s) = $4x_{IP}E_PE_e$
  - slice-width Δx_{IP}

$$\int_0^1 dx_{IP} f_{IP/a}(x_{IP,i}) \sigma_{IP}(x_{IP}) \cong \sum_k \Delta x_{IP,i} f_{IP/a}(x_{IP,i}) \sigma_{IP}(x_{IP})$$



Hadron-hadron collisions only

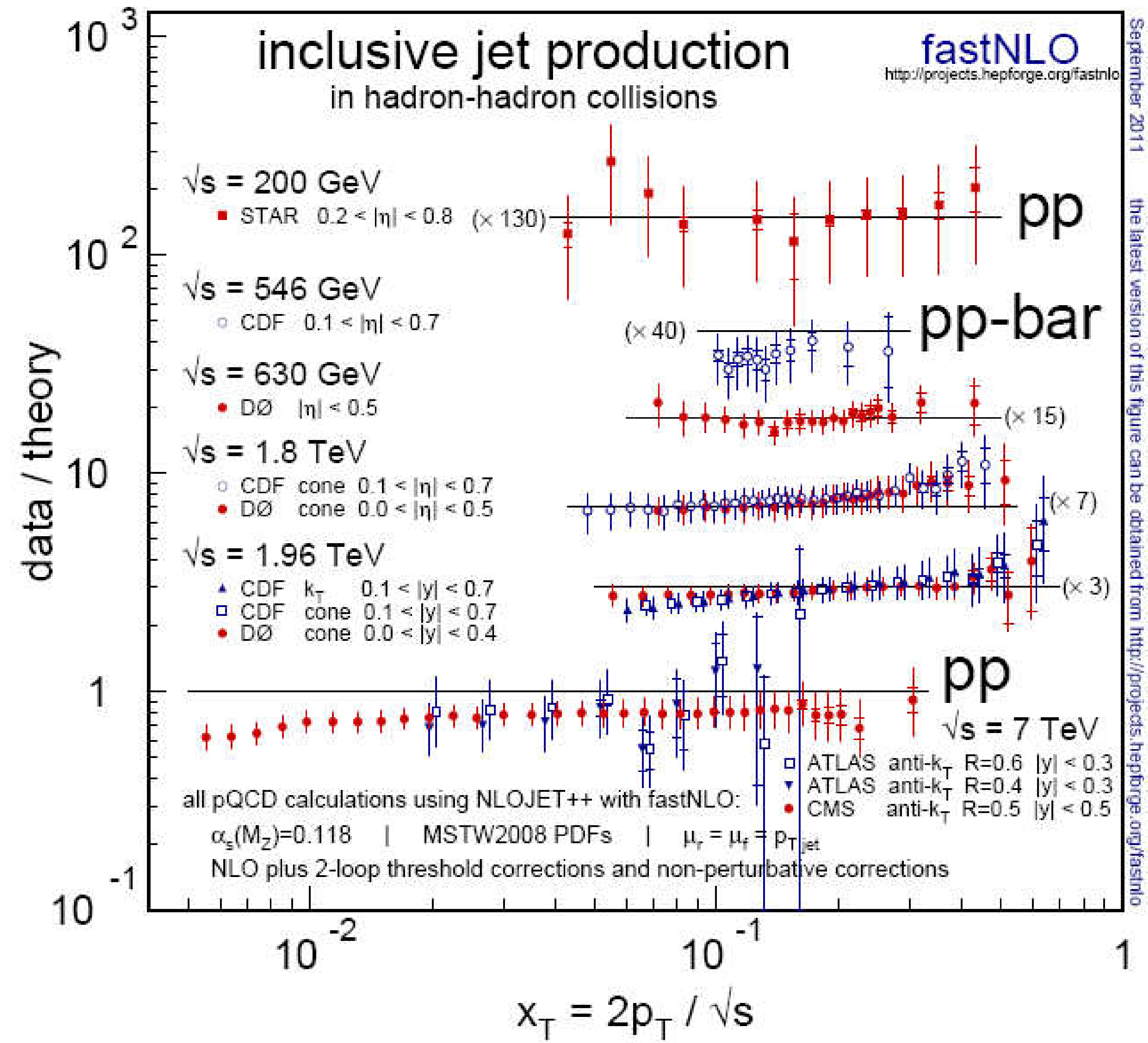
PDF sensitivity

compare jet cross section at fixed x_T

$$x_T = 2\,p_T / \sqrt{s}$$

Tevatron give more constraints on PDFs in high x_T region

LHC data with impact for low-x gluon



Which x-region do we test with jet data?

E.g. H1 dijets @ high Q^2

four bins:

- low and high Q^2
- low and high <pt>

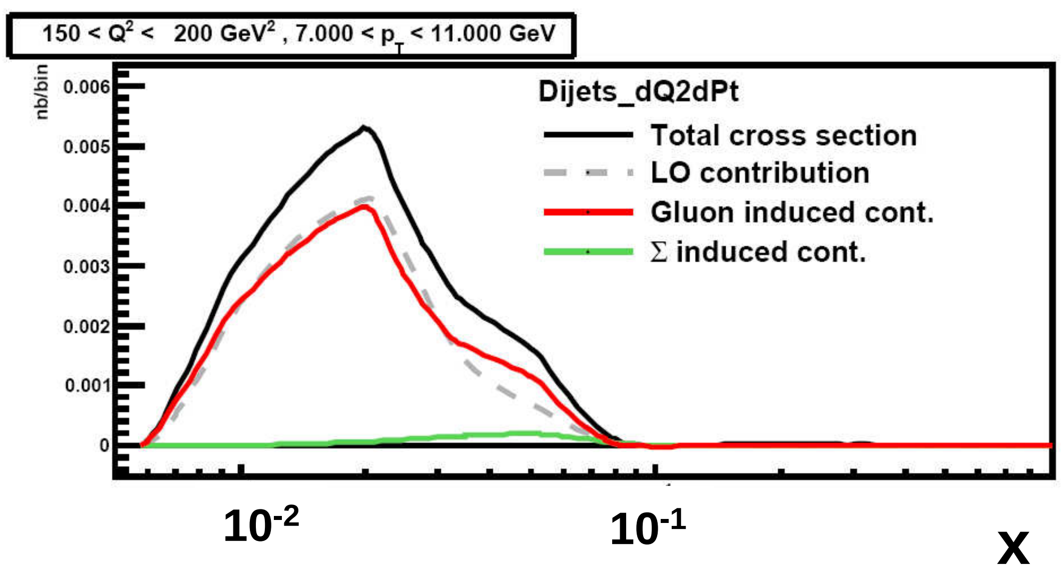
Only three contributions in DIS

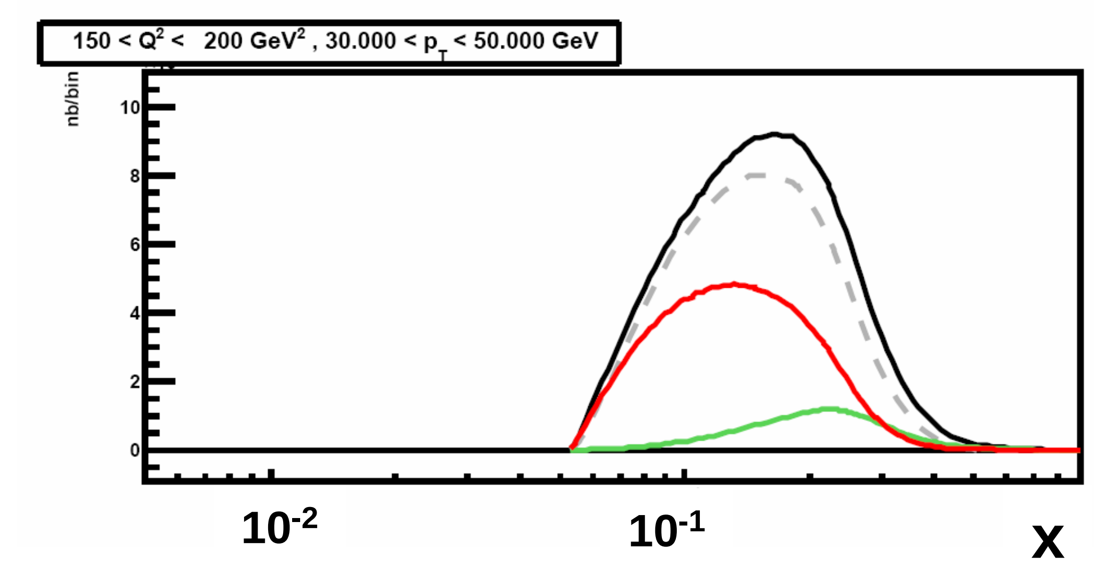
Gluon, Delta, Sigma induced processes

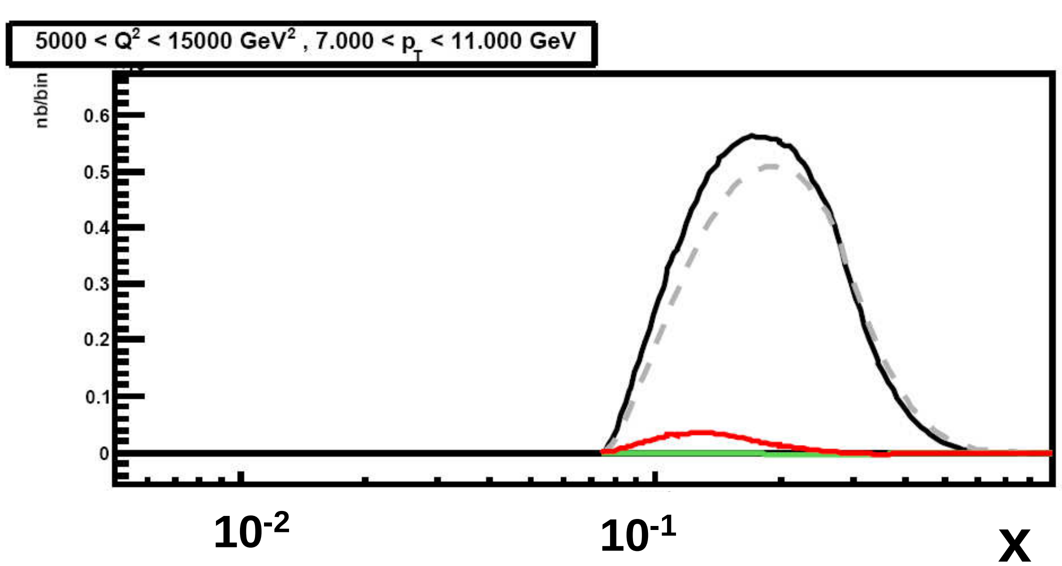
low Q^2 is mostly gluon induced

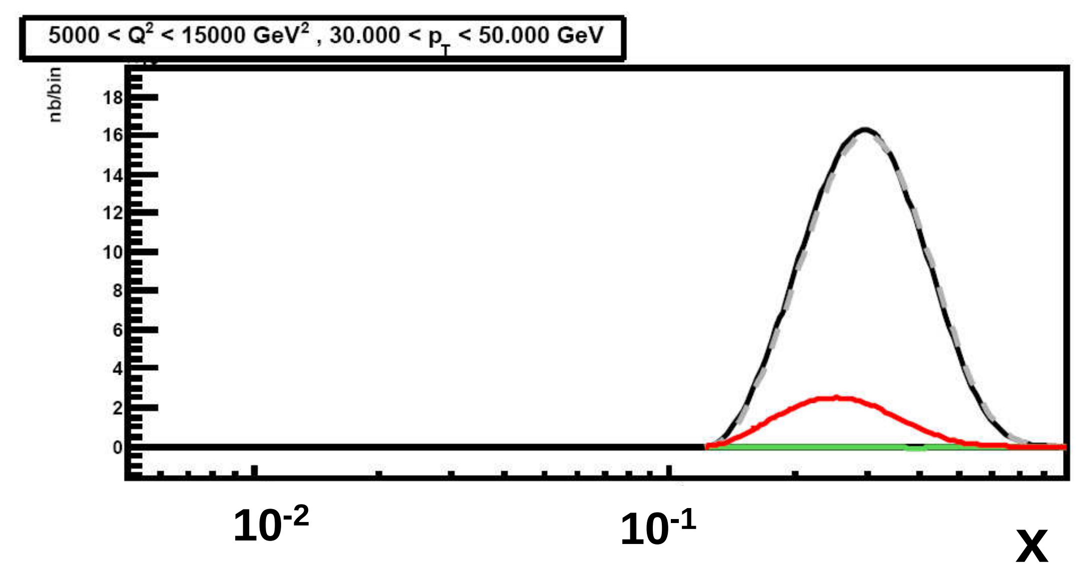
High Q^2 is mostly Delta induced

'low' x-region only at low <pt> and low Q^2

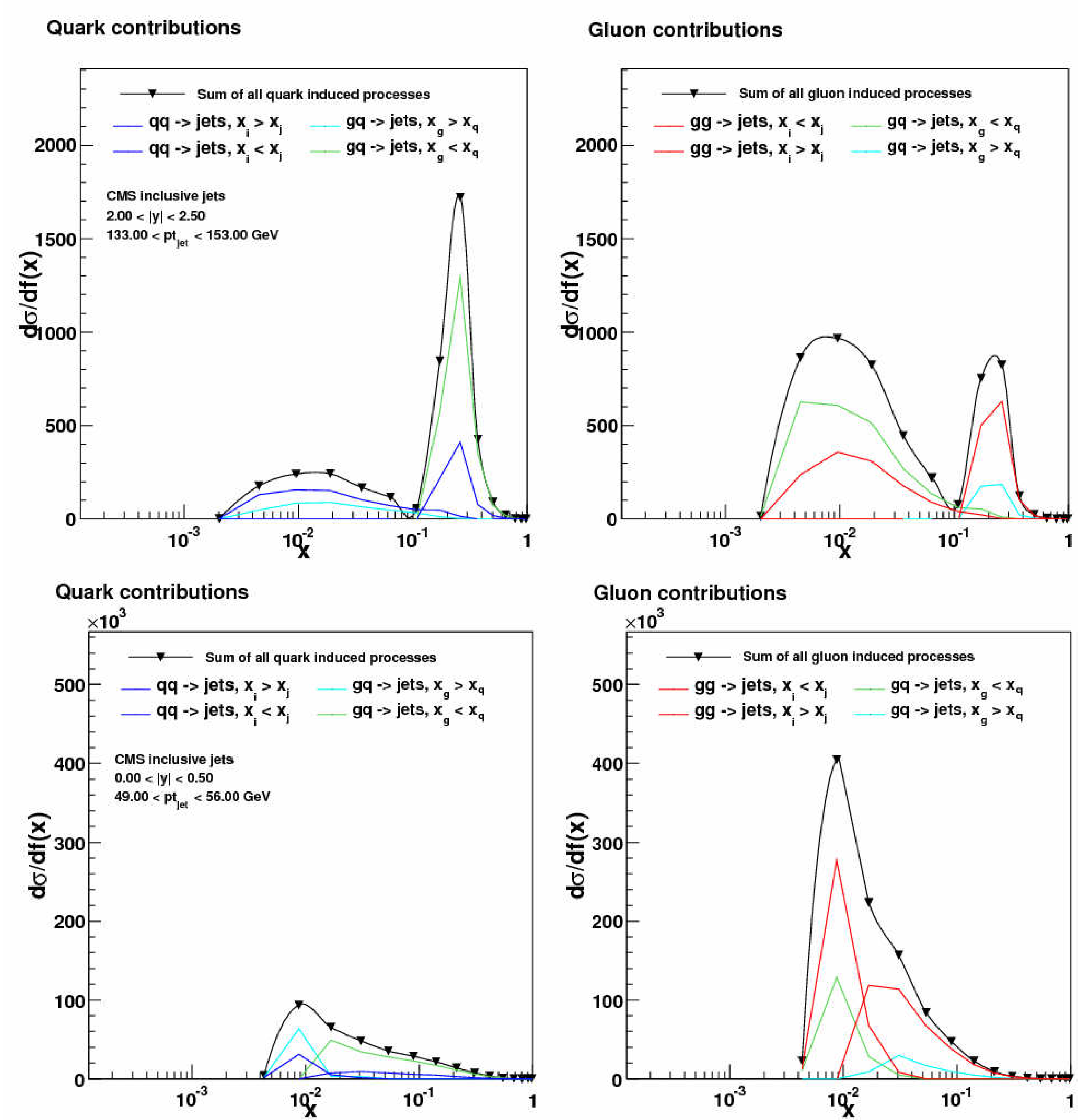






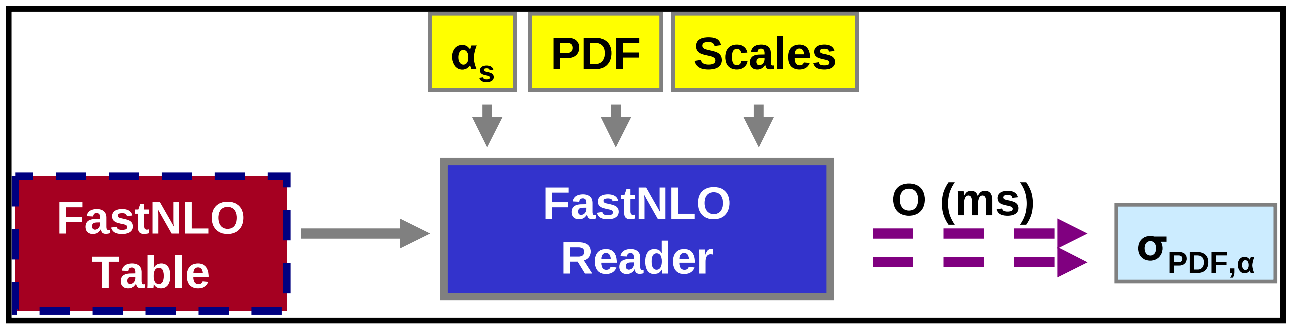


x-dependence of jet cross sections



FastNLO v2

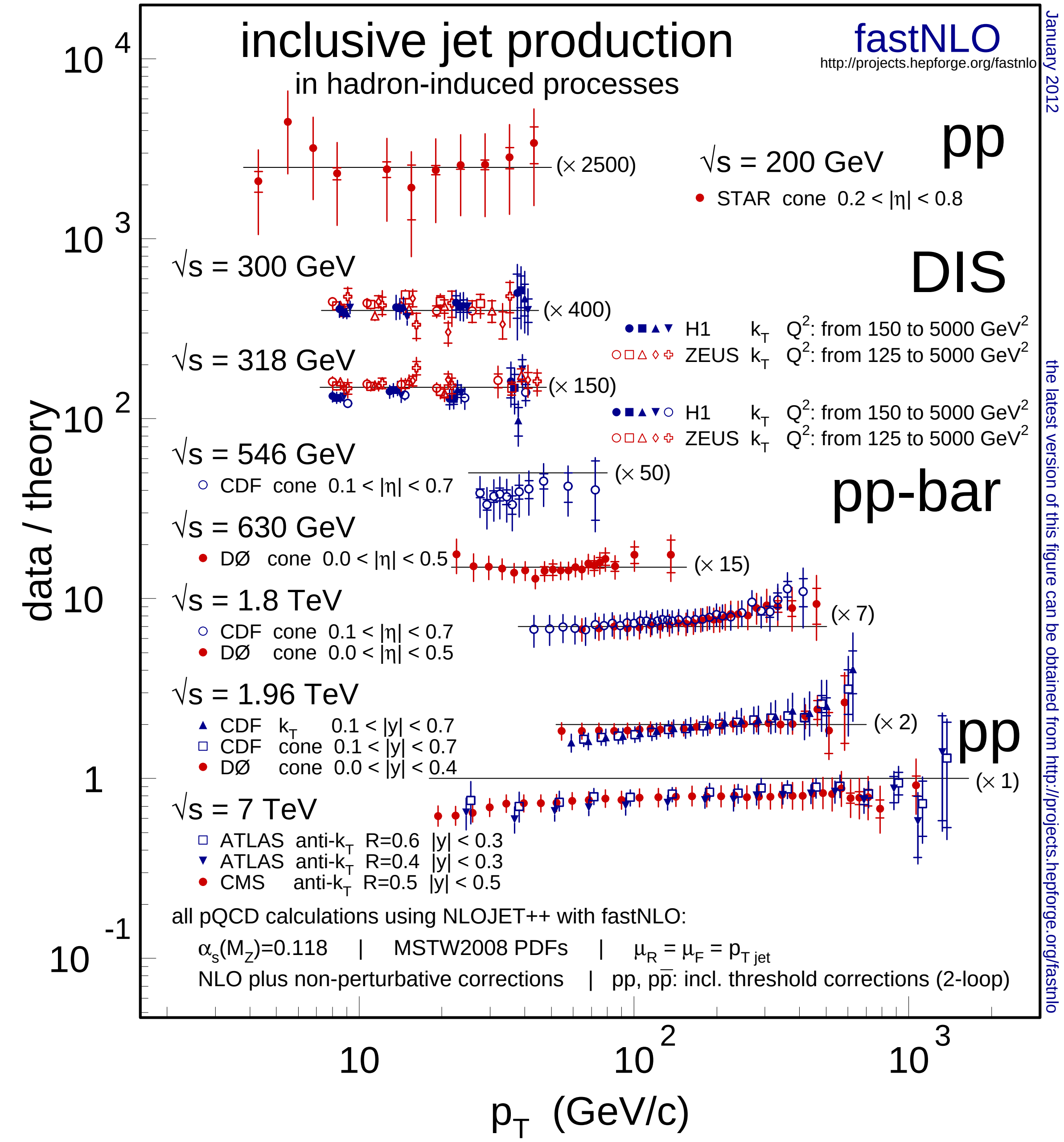
FastNLO v2

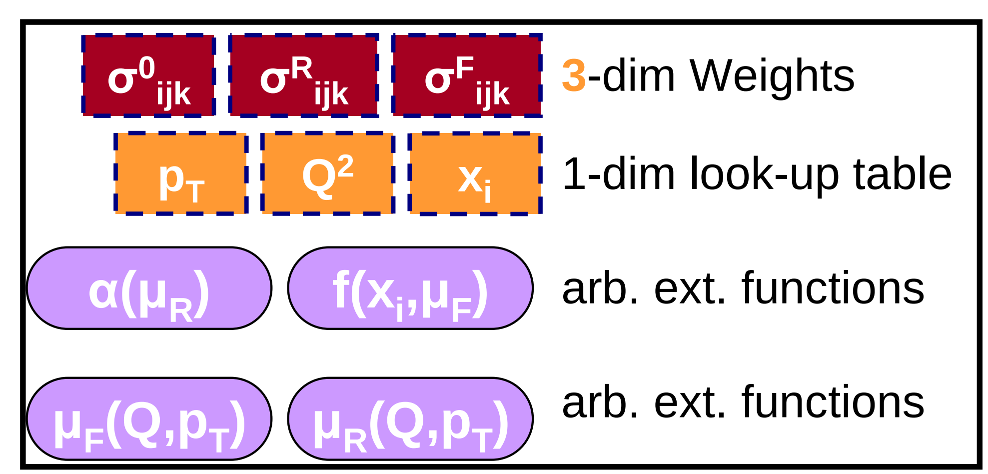


- Method for fast repeated theory cross sections allowing to change α_s, PDF and scales
- More flexible table format for various multiplicative and additive contributions
- C++ and fortran versions with lots of interfaces
- Many calculations available

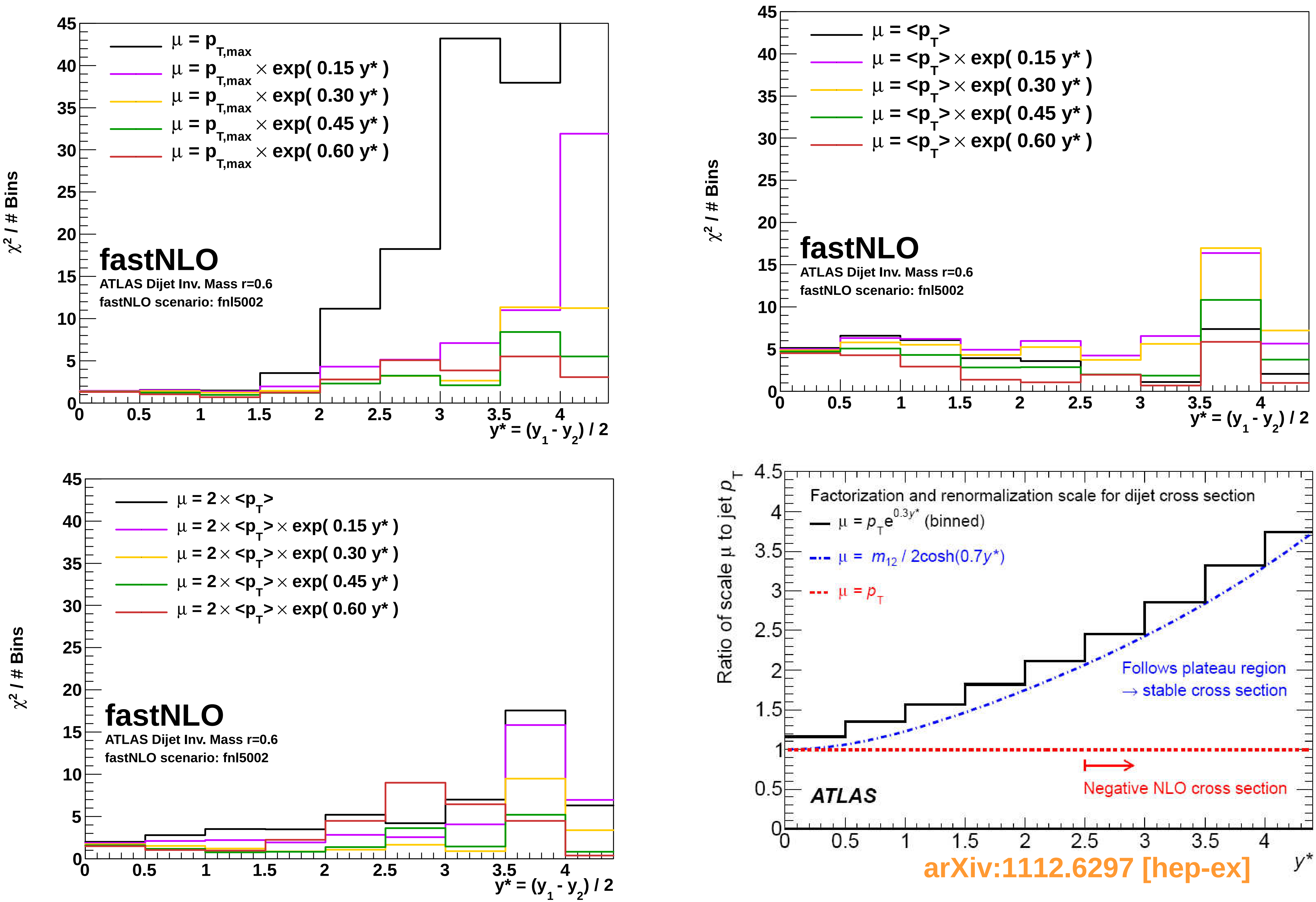
'Flexible scale' format

- Potential to vary ren. and fact. scale independently
- Scales composition can be choosen as function of pre-defined variables
- -> New options for scans of scale dependence (e.g. à la FAC, PMS)





Stuying the scale choice of ATLAS



arXiv:1112.6297 [hep-ex]

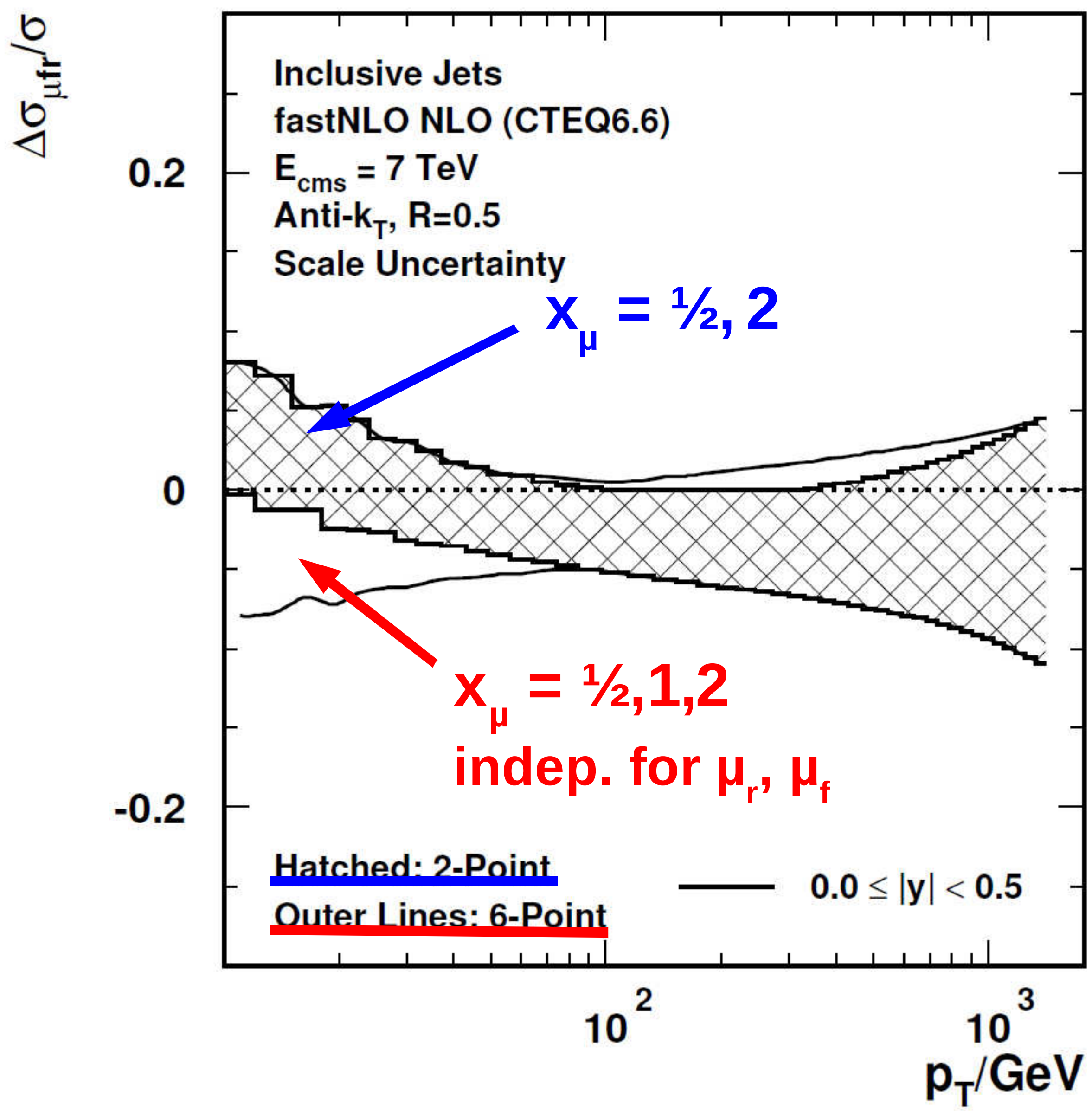
Scales in FastNLO

FastNLO tables come with 3 (4) simultaneous scale variations tables

- e.g. 0.5, 1.0, 2.0 times the nominal scale

A posteriori scale variation **of the renormalizatoin scale allows study of** asymetric scale **variations**

- e.g. 6-points: (1/2,1/2), (1/2,1), (1,1/2), (1,2), (2,1), (2,2)
- avoiding of rel. 'factor' 4.



Improvements in v 2.0

- scales get own dimension
- bicubic interpolation of scale-value to scale nodes
- typically 6 scale nodes
- examples already for
  - CMS incl. jets
  - D0 3-jet mass
  - …