Determination Of Parton Density Functions At The LHC

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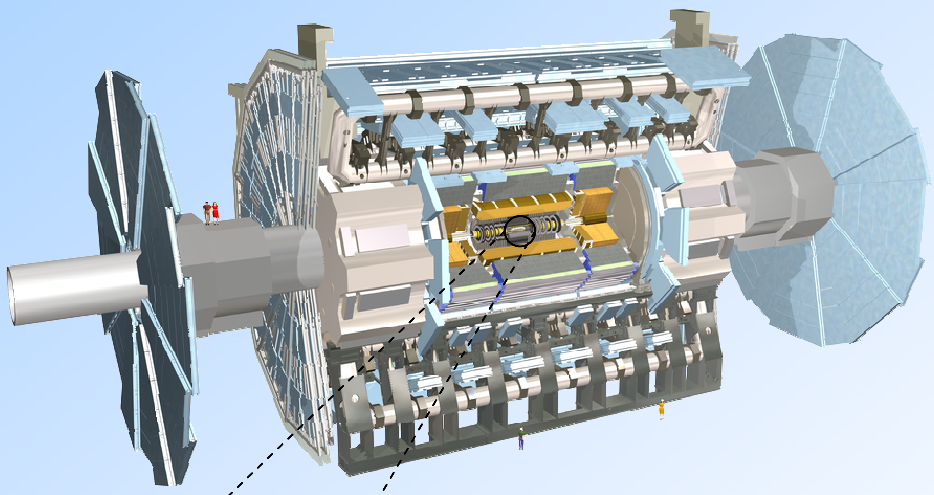
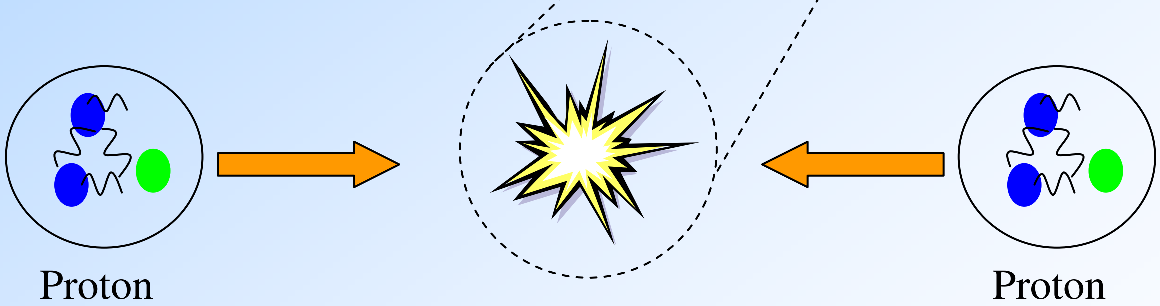
The LHC Project

•The LHC is designed to collide protons together at a centre of mass energy of 14TeV, and a luminosity of $10^{34}cm^{-2}s^{-1}$ (after 3 years of running).

•ATLAS (A Toroidal Lhc ApparatUS) is a general purpose detector designed to explore the new energy reach available to the LHC.



The ATLAS detector



• Knowledge of proton content (i.e. PDFs) is important to understand cross-sections at the LHC, and can limit sensitivity to new physics (e.g. compositeness)

Measurement Of PDFs At A Hadron Collider

•Most PDF data comes from Deep Inelastic Scattering experiments (e.g. HERA) but hadron colliders can provide additional information particularly for the gluon distribution.

•Hadron collider cross-sections are sensitive to PDFs through the initial state of partons which interact in a given event for a 2→2 scattering i.e:

Hard 2 →2 scattering

$$\sigma(P_1, P_2) = \sum_{i,j} \int dx_1 dx_2 f_i(x_1, \mu^2) f_j(x_2, \mu^2) \hat{\sigma}_{ij}(x_1 P_1, x_2 P_2, \alpha_s(\mu^2), Q^2/\mu^2)$$

PDFs

Parton momenta

Hadron momenta

Sum over parton types

Parton Level Cross-Section

•By comparing the experimental cross-section with NLO predictions, knowledge of the PDFs can be extracted. NLO Cross-Sections however can take 1-2 CPU days to calculate.

Separating PDFs From The Integral

- A NLO Cross-Section for DIS is normally calculated using MC by:

$$W = \sum_{m=1}^{N} w_m \left(\frac{\alpha_s(Q_m^2)}{2\pi} \right)^{p_m} q(x_m, Q_m^2)$$

For events m=1….N, (w_m is an MC weight, $q(x,Q^2)$ a PDF).

- Can instead define a weight grid in (x,Q^2), which is updated for each event m:

$$W_{i,j}^{(p)} = W_{i,j}^{(p)} + w_m$$

Where i, j define a discrete point in x,Q^2 space relating to the event.

- A PDF grid is also defined in x,Q^2 as $q_{i,j}$.

- Cross-Section can be reproduced by combining the PDF and weight grids *after* the Monte-Carlo run:

$$W = \sum_i \sum_j W_{i,j}^{(p)} \left(\frac{\alpha_s(Q^2)}{2\pi} \right)^{p} q_{i,j}$$

Separating PDFs From The Integral

- This method can recreate the Monte-Carlo cross-section exactly assuming grids could be made with an infinitely small spacing in (x,Q^2).
- Instead grids with a finite spacing in x,Q^2 are used and interpolation methods used between points.

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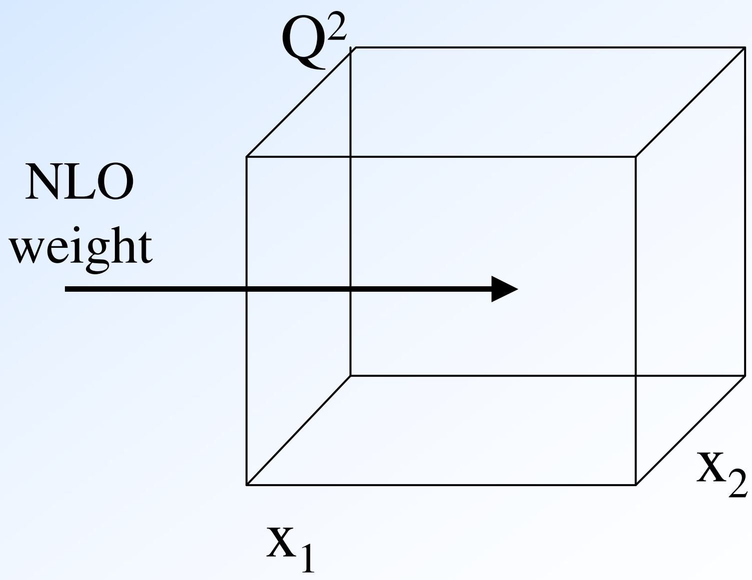
- The situation is a little more complicated in the case of hadron-hadron collisions as PDFs have to be considered for both incoming particles, hence the grid is three dimensional (x_1,x_2,Q^2).



Using Integration Grids

Step 1: Fill the Grid

NLO event generator

Event with weight w_i, x_1, x_2, Q^2

SLOW

Fill Grid with weight w_i, at point (x_1,x_2,Q^2)

Step 2: Multiply grid by PDFs to generate Cross-Section

Grid of weights in (x_1,x_2,Q^2)

PDFs defined at (x_1,x_2,Q^2)

Multiply and add over (x_1,x_2,Q^2)

FAST

Jet Cross-Section

Fortran interface

QCD Fit

Grid Structure

•The grid implementation used was developed by Carli, Salem, Siegert and is described in (hep-ph/0510324) [1].

Main Features Of A Grid

•A co-ordinate transform is applied to the the x and Q^2 bins, to increase the density of bins at low x and high Q^2.

$$y(x) = \ln \frac{1}{x} \qquad \tau(Q^2) = \ln \ln \frac{Q^2}{\Lambda^2}$$

$$\Lambda \approx \Lambda_{QCD}$$

•The grid is equidistant in the new variables.

•A high order interpolation method is used when filling the grid to provide increased accuracy without increasing CPU memory consumption.

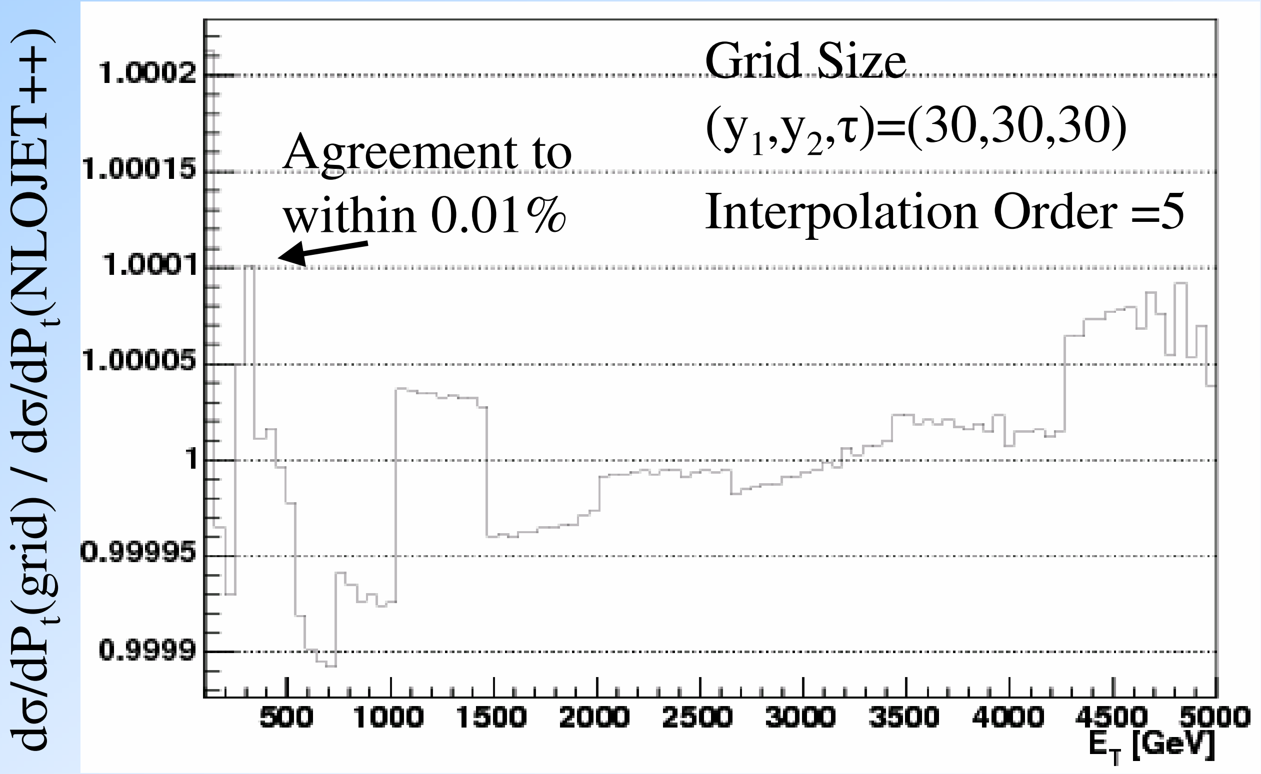
•The grid software is written in C++ and uses ROOT [2] libraries.

•The NLOJET++ event generator [3] (Z.Nagy) is used to generate MC weights and a FORTRAN interface to the grid software is used for the fitting algorithm.

A Grid Generated Cross-Section

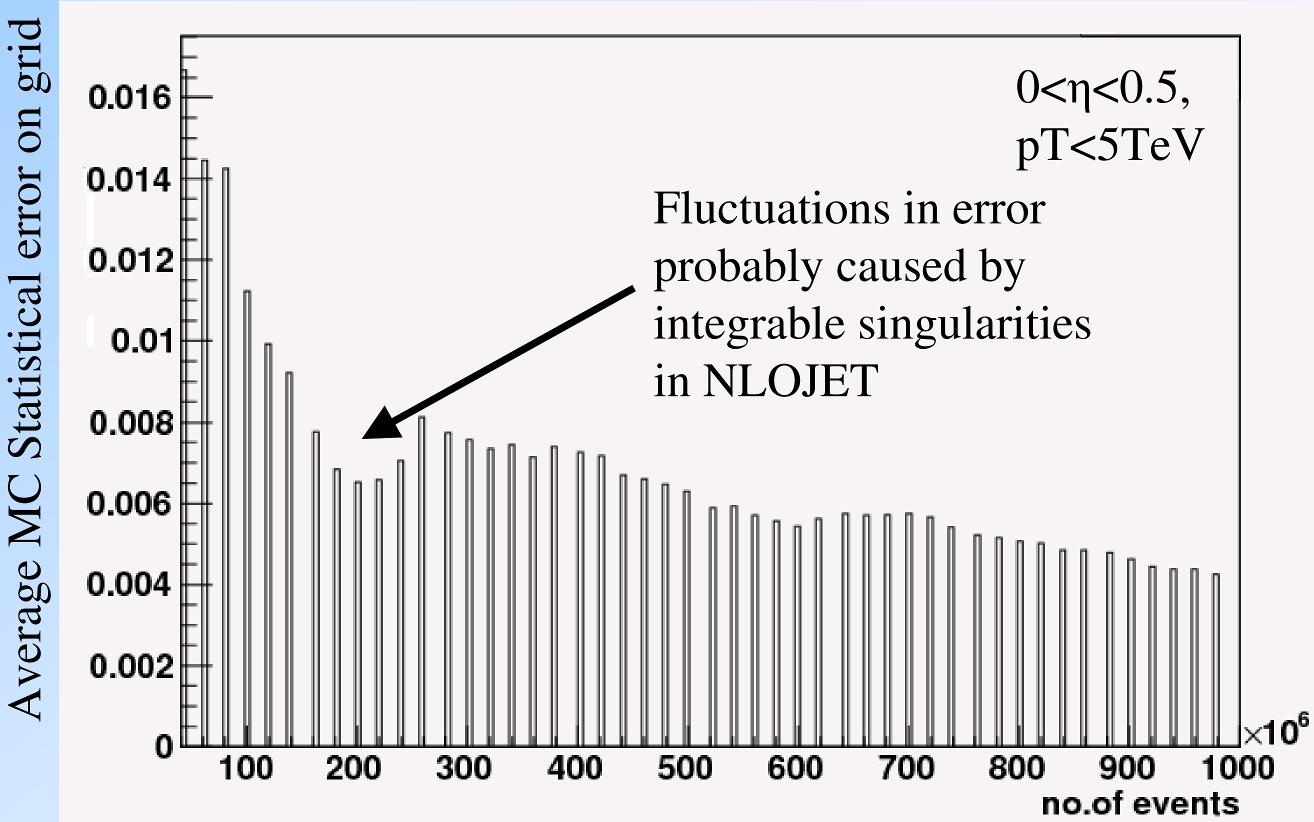
•Tests were carried out to test the Grid's ability to recreate the inclusive jet cross-section.

•Here the ratio of the grid generated and standard NLOJET cross-section is shown for the inclusive jet cross-section $0<\eta<0.5$:



NLO-Monte Carlo Errors

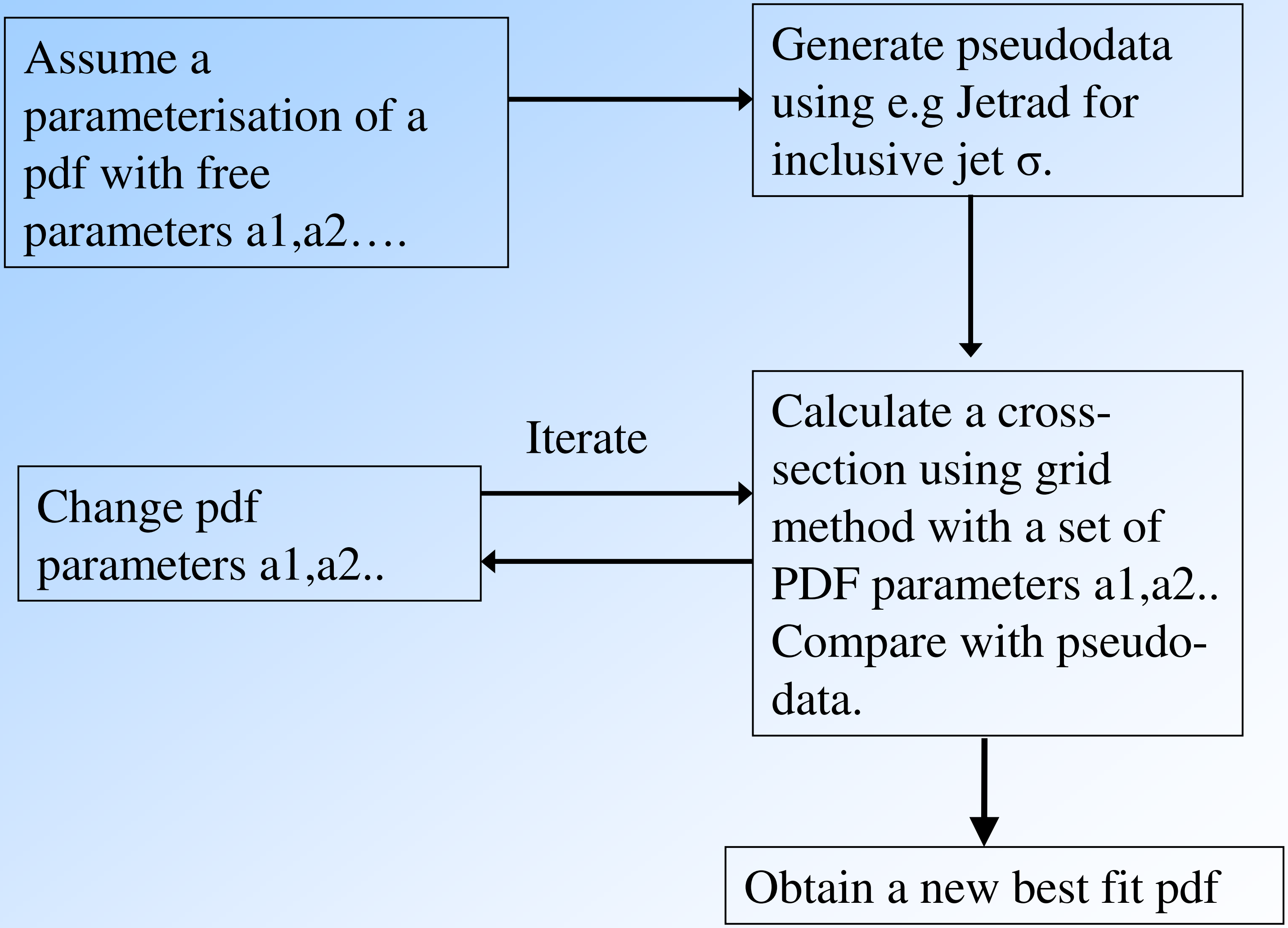
•Tests were carried out comparing the grid generated cross-section and an independently generated standard NLO cross-section for the inclusive jet cross-section.



•The statistical errors introduced by the Monte-Carlo calculation can be much greater than that caused by using the grid even after generating a large no. of events

PDF Fitting Using Grids - Basic Idea

- Grid methods allow hadron collider data to be used directly in QCD fits.

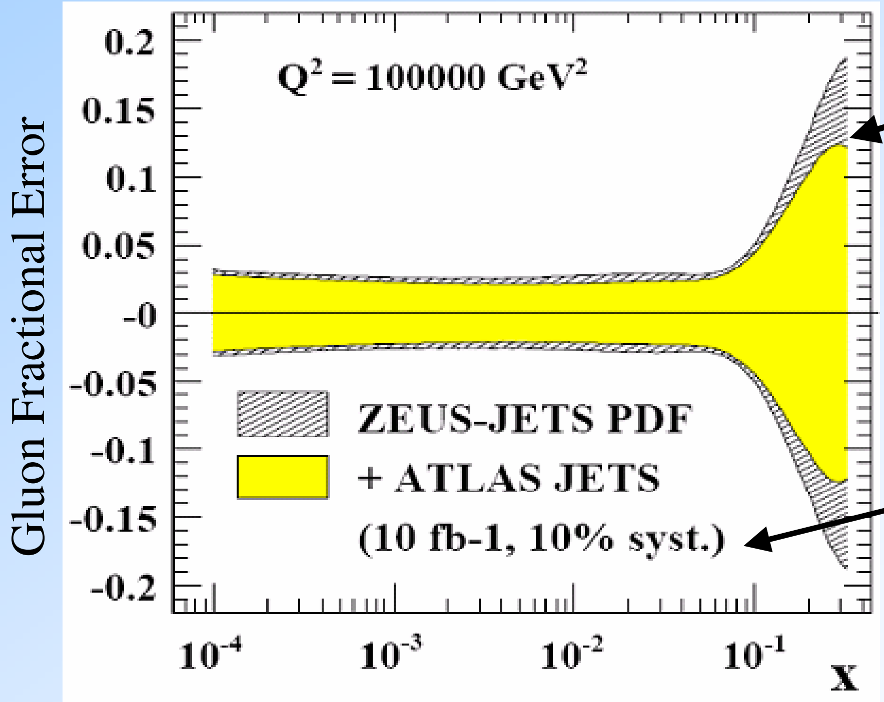


PDF Fitting Using Pseudodata

•Grids were generated for the inclusive jet cross-section at ATLAS in the pseudorapidity ranges $0<\eta<1$, $1<\eta<2$, and $2<\eta<3$ up to pT=3TeV (NLOJET).

•In addition pseudodata for the same process was generated using JETRAD [4].

•The pseudo-data was then used in a global fit to assess the impact of ATLAS data on constraining PDFs:

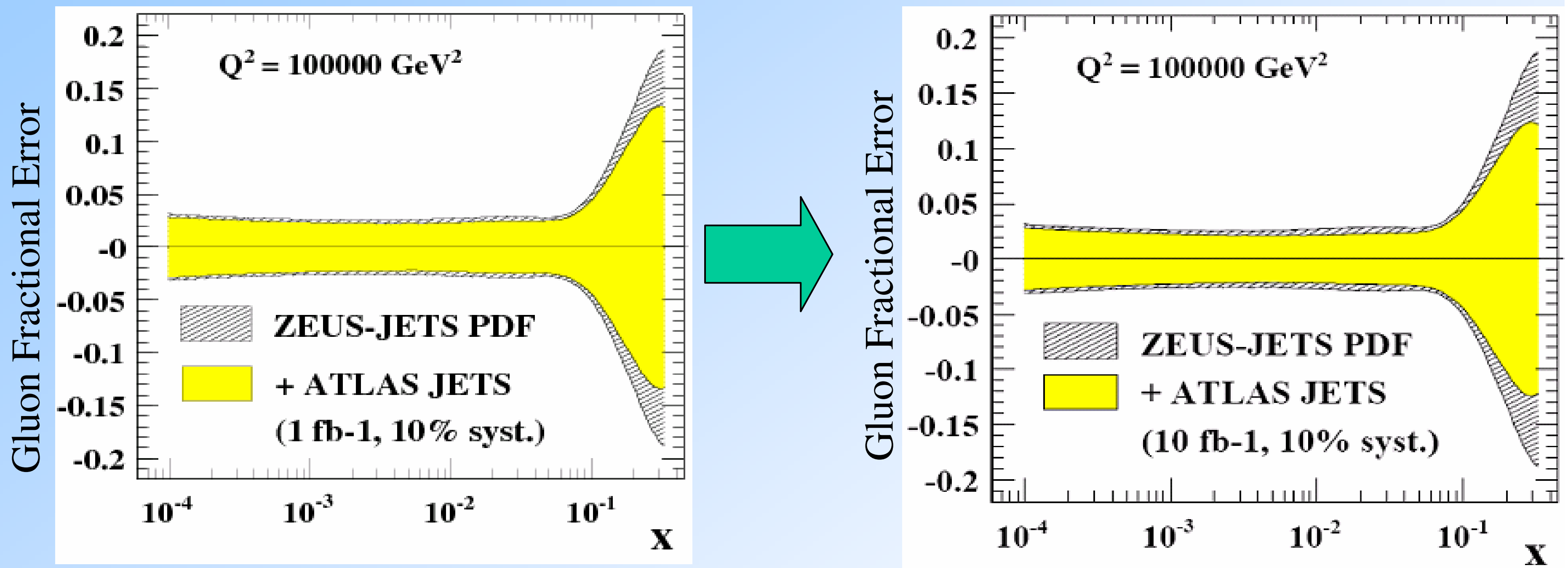


Preliminary indications suggest that ATLAS data can constrain the high x-gluon.

Systematic errors are uncorrelated, $10fb^{-1}$=1 year of nominal data-taking at $10^{33}cm^{-2}s^{-1}$

Effect Of Increased Statistics on PDF Fits

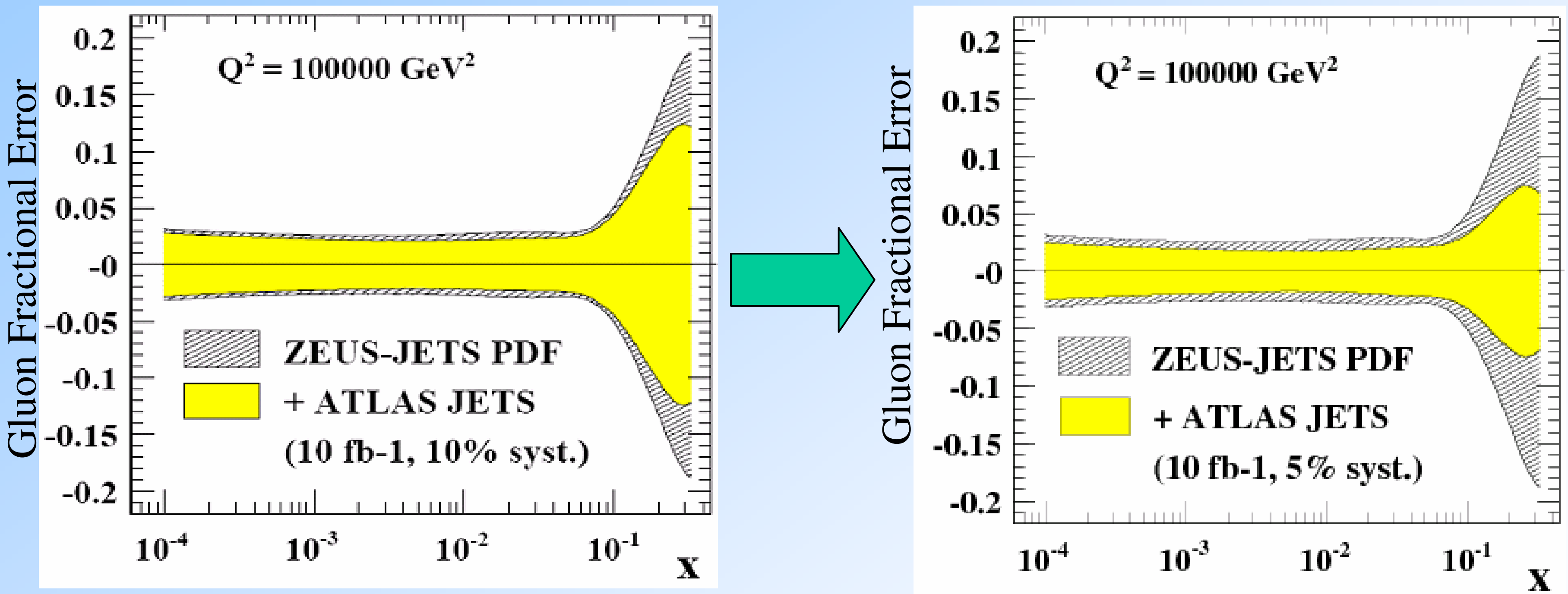
Increase 10×statistics



•Increasing the statistics from 1fb^{-1} to 10fb^{-1} has little effect on improving the constraining of PDFs at ATLAS.

Effect Of Decreased Systematic Errors On PDF Fits

Decrease (uncorrelated) Systematic errors
10%→5%



•Decreasing the systematic errors (on the ATLAS experiment) creates a significant improvement in constraining the PDFS.

Summary

•Integration grids using high order interpolation methods can be used to recreate NLO cross-sections to accuracies of better than 0.01%.

•Preliminary results using pseudodata indicate that ATLAS jet data will be useful to constrain the gluon PDF.

•Error on gluon PDF that can be extracted from the jet cross-section is dominated by systematics, the statistical error being negligible even for $1fb^{-1}$

Ongoing Developments With Grids And Analysis

•Variable grid spacing (in x and Q^2) is being developed to better model PDFs at large x.

•Post grid generation changing of the renormalisation and factorisation scales being developed.

•Extension of grid interface to other NLO QCD programs..

•Software freely available from the authors.

References

[1] "A Posteriori Inclusion Of PDFs in NLO QCD Final-State Calculations", Tancredi Carli, Gavin P Salam, Frank Siegert, hep-ph/0510324

[2] "*ROOT - An Object Oriented Data Analysis Framework*", Rene Brun and Fons Rademakers, Proceedings AIHENP'96 Workshop, Lausanne, Sep. 1996, Nucl. Inst. & Meth. in Phys. Res. A 389 (1997) 81-86. See also http://root.cern.ch/.

[3] "Next-to-leading order calculation of three-jet observables in hadron-hadron collisions", Z Nagy, Phys Rev D68, 094002 (2003)

[4] Higher Order Corrections To Jet Cross-Section In Hadron Colliders, W.T. Giele, E.W.N. Glover, David A. Kosower, Nucl.Phys.B403:633-670,1993, [hep-ph/ 9302225].