Tevatron Measurements and PDF Uncertainties

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Theme of talk

- How are PDF uncertainties reflected in Tevatron measurements

- What Tevatron measurements can be used to reduce PDF uncertainties

- What tools are available to estimate uncertainties

PDF Uncertainties

Errors on PDFs can influence the measurement at several stages

$$\sigma_{\text{meas}} = \frac{\epsilon}{\mathcal{L}}(N_{\text{obs}} - N_{\text{bkg}})$$

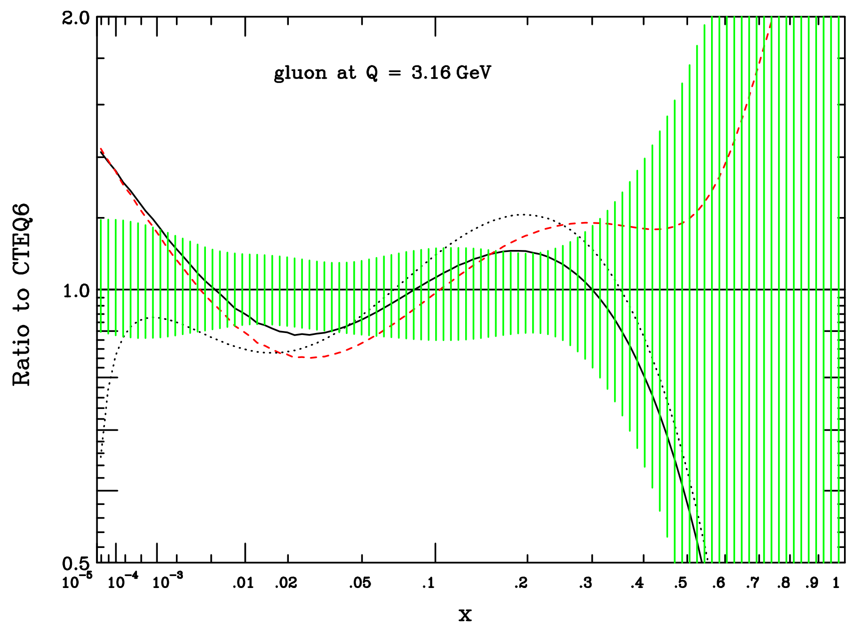
Calculation of acceptance (ϵ), luminosity ($\mathcal{L}$), event selection (N_{obs}), background estimate (N_{bkg})

$$\sigma_{\text{theory}} = \text{PDF}(x_1, x_2, Q^2) \otimes \sigma_{\text{hard}}$$

Theory calculation includes:

- Experimental errors when fitting measured data
- Theoretical errors resulting from input parameters (flavor threshold, α_s...) uncertainties on the theoretical modeling (scale errors, nonperterbative effects, PDF parameterization...)

Input to PDFs - What is Unknown



hep-ph/0201195

Gluon distribution
→ *Inclusive jet, forward jets*

Shaded band shows the CTEQ6 gluon uncertainty at $Q^2 = 10$ GeV^2

Ratio of CTEQ5M (solid), CTEQ5HJ (dashed) and MRST2001 (dotted) to CTEQ6

Strange and anti-strange quarks, strange asymmetry
→ *Tagged final states* $W/Z/\gamma + c/b$

Details in the u, d quark sector, u/d ratio
→ *W charge asymmetry*
→ W *rapidity distribution*

Heavy quark distribution
→ *Tagged final states* $W/Z/\gamma + c/b$

New Ways to Estimate PDF Uncertainties...

Hessian/Lagrange Multiplier techniques used to estimate effect of experimental statistical errors and correlated systematic errors

Global fit, using the free parameters results in the central PDF

Increase global χ^2 of fit, $\Delta\chi^2 = 100$ for CTEQ and $\Delta\chi^2 = 50$ for MRST, to obtain the error matrix

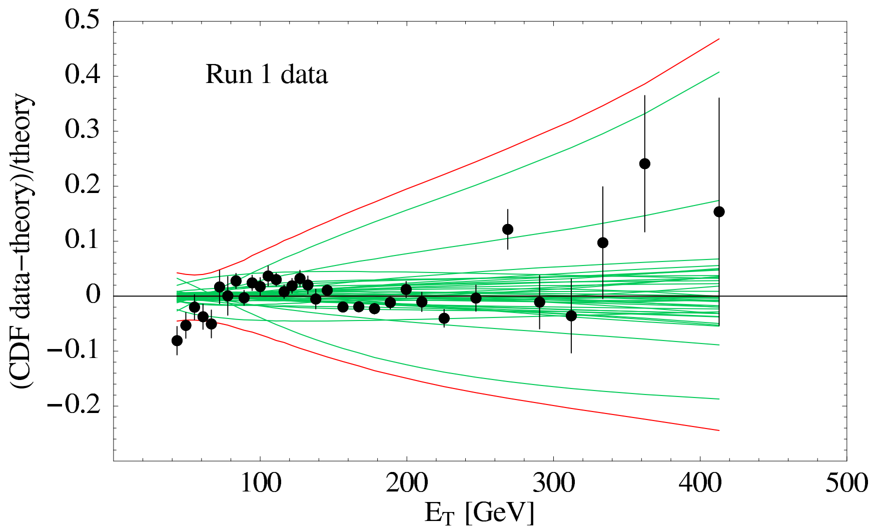
→ *Choice of tolerance is somewhat intuitive*
→ *What $\Delta\chi^2$ best describes the estimate of the uncertainty?*

Diagonalize the error matrix to obtain N_{PDF} eigenvectors corresponding to N_{PDF} independent directions in the parameter space

For each eigenvector, upper and lower deviations corresponding to the $\Delta\chi^2$ tolerance result in $2 \times N_{PDF}$ new sets of error PDFs

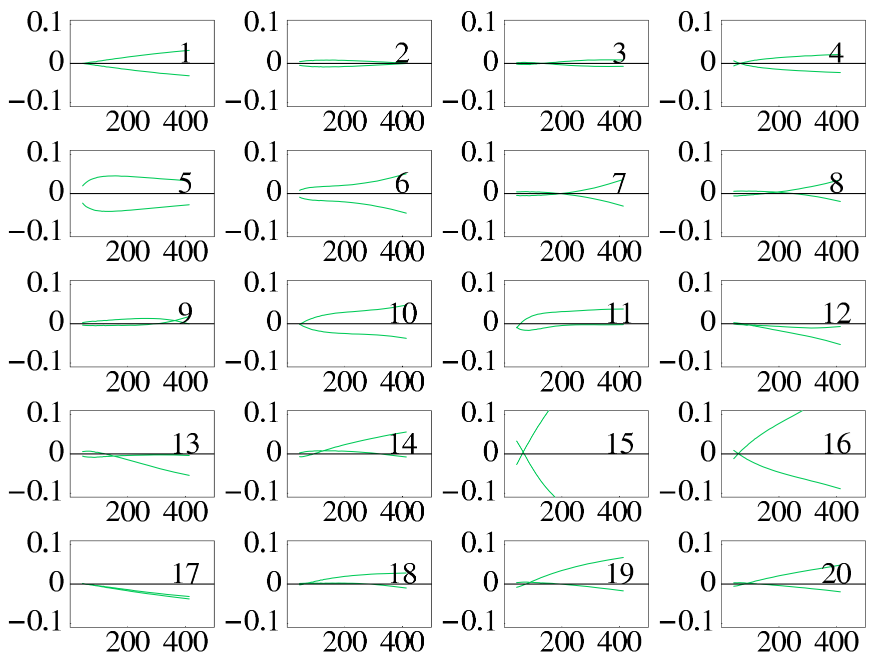
See talk by J. Pumplin

Run I Inclusive Jet Cross Section



Cross section is calculated using the central PDF and for each error PDF, errors added in quadrature $\Delta\sigma^{\pm} = \sqrt{\sum_i \sigma_i^{\pm\,2}}$

40 sets for CTEQ, 30 for MRST

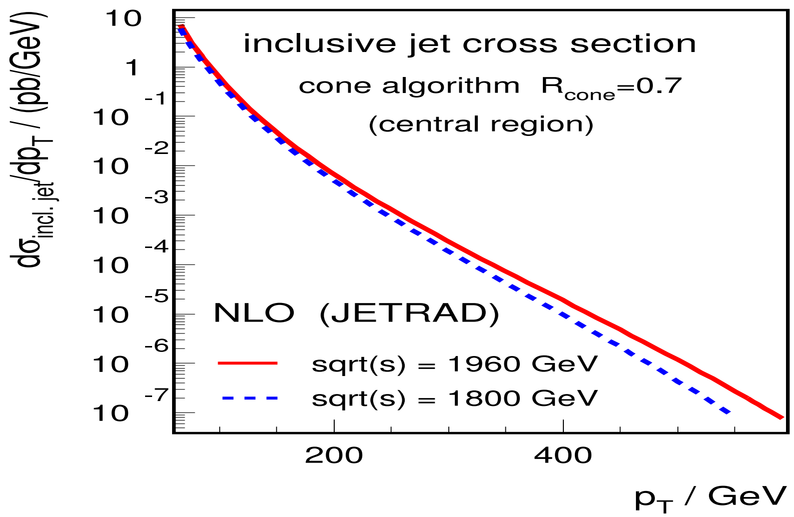


Largest contribution to the uncertainty comes from eigenvector 15

Related to high x gluon behavior

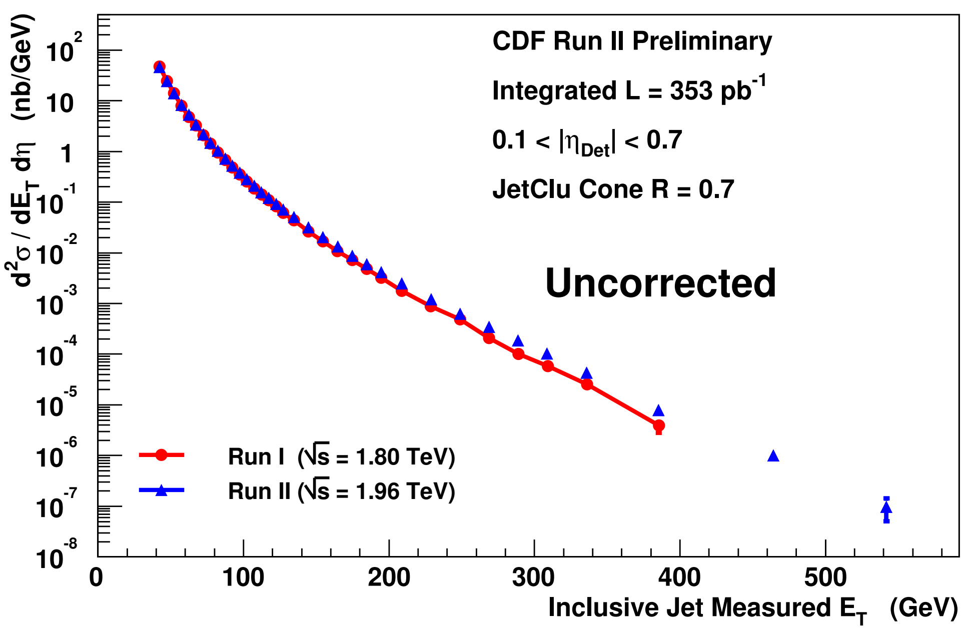
hep-ph/0303013

Run II Inclusive Jets



Increased center-of-mass energy (1.8 → 1.96 TeV) yields a larger cross section at high E_T

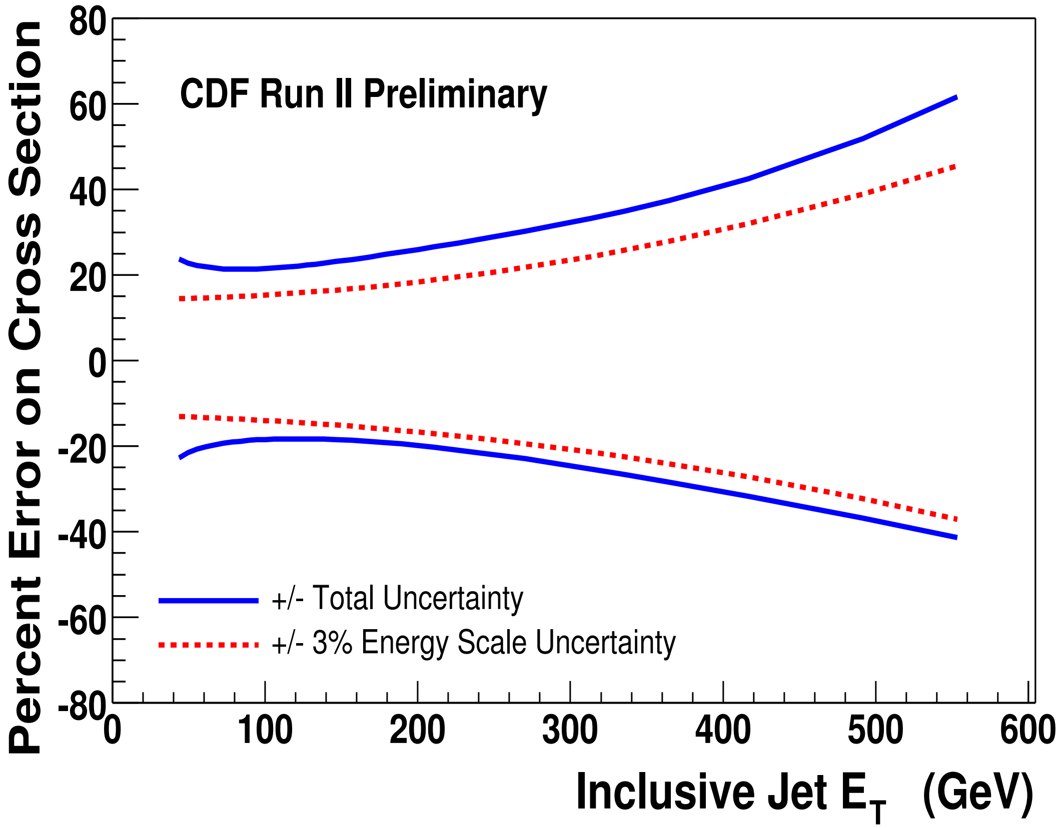
About 2× at 400 GeV and 5× at 600 GeV



→ Extends Run I results by ∼ 150 GeV

→ Able to probe shorter distances scales with higher precision

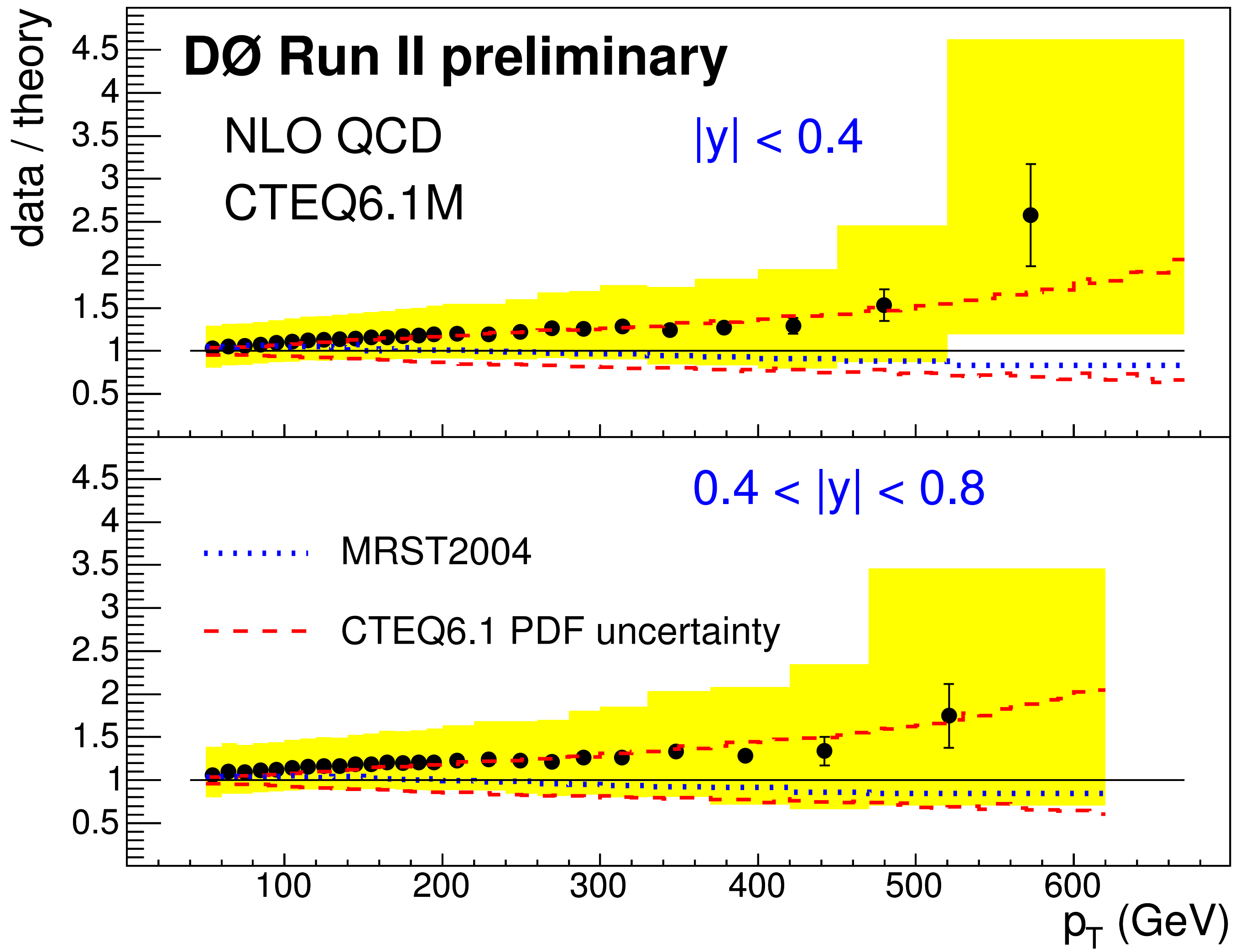
Uncertainty in the energy scale is the dominant source of systematic error, challenging to improve this...



The effect of a 3% energy scale uncertainty (dashed line) contribution to the total systematic error (solid line)

Uncertainty on the cross section due to the energy scale gets larger in the forward region because of the faster falling spectrum

New DØ results ($378 pb^{-1}$), in two rapidity bins...



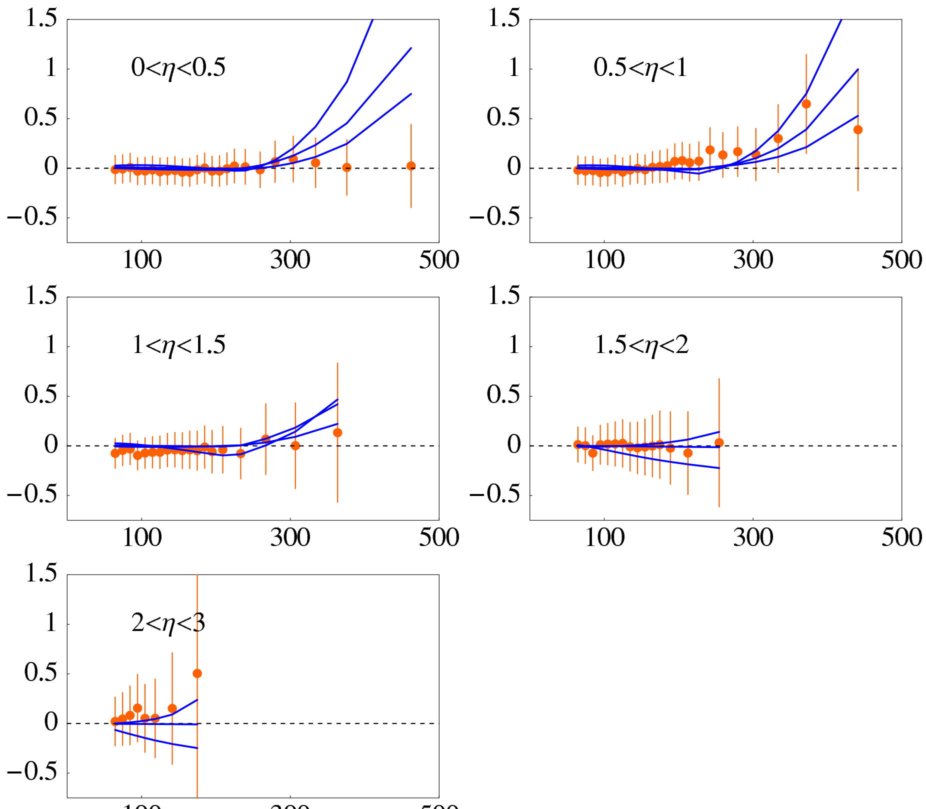
$\sim 5\%$ energy scale uncertainty

In addition to being able to study the high E_T region we have more data in the low E_T region. *Sensitive to hadronization modeling and underlying event*

New Physics could show up as a deviation from the SM predictions at high E_T in the inclusive jet cross section.

Flexibility in the PDF parameterizations could accommodate deviations in the central inclusive jet cross section at high E_T

Run I DØ data, inclusive jet cross section binned in rapidity (last bin $2 < |\eta| < 3$)



Usually look at the angular distribution between two leading jets

More general to include forward jets in the global fit

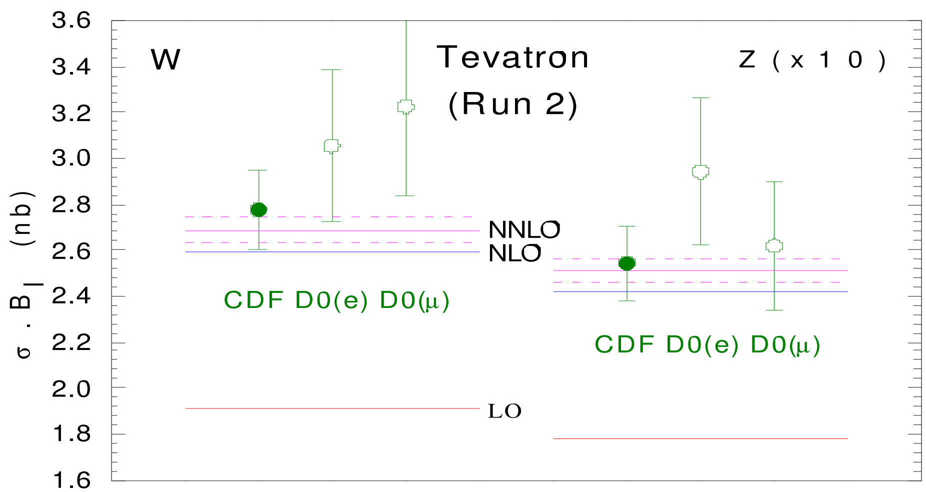
Curves show the result of a global fit including a contact interaction in theory with $\Lambda = 1.6, 2.0, 2.4$ TeV

Stump et al., hep-ph/0303013

W/Z Cross Sections

"Standard Candle" process that can be used to determine the proton-proton luminosity at the LHC

High statistics, theoretically well understood and well measured



$\sigma_{\rm NLO}(W)$ at the LHC

MRST2002	204 ± 4 (nb)
CTEQ6	205 ± 8 (nb)
Alekhin02	215 ± 6 (nb)

$\rightarrow$ 2-4% uncertainty

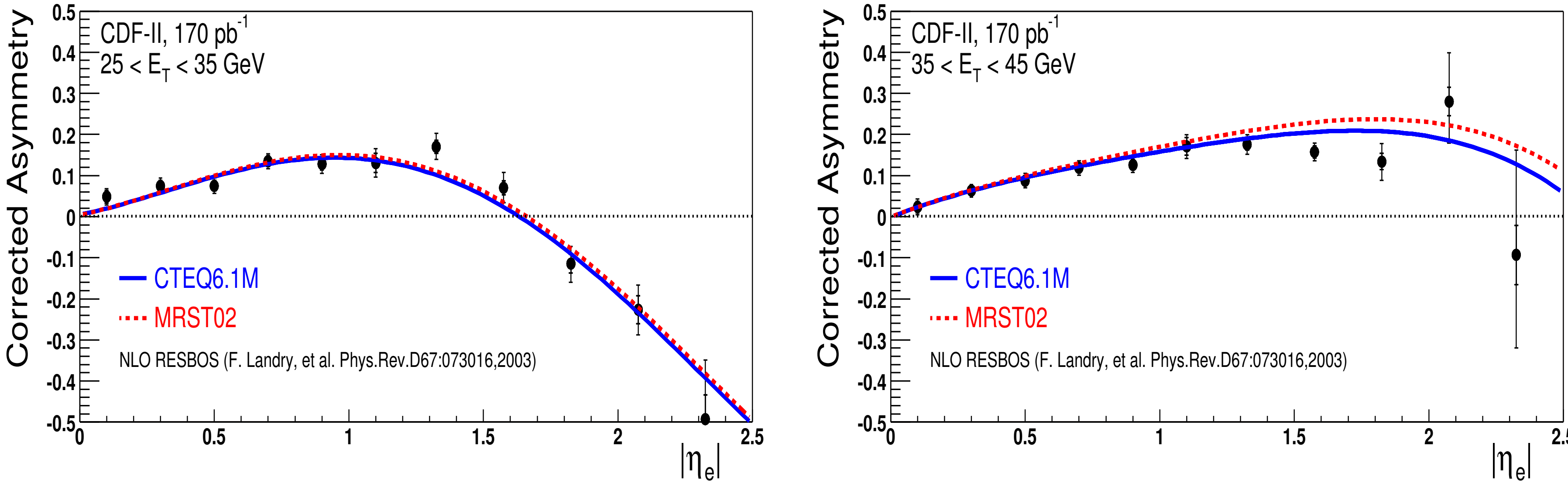
Different PDF sets lead to different predictions...

Choice of $\Delta\chi^2$ definition leads to different error on calculation...

Can use cross section ratios to reduce the uncertainty on the luminosity to $\sim$ 1% (Dittmar et al., hep-ex/9705004)

W Charge Asymmetry

$$A_{ch}(\eta) = \frac{d\sigma(e^+)/d\eta - d\sigma(e^-)/d\eta}{d\sigma(e^+)/d\eta + d\sigma(e^-)/d\eta} \sim \frac{d(x, M_W)}{u(x, M_W)}$$



hep-ex/0501023

In Run II we now have two E_T^e bins
$\rightarrow$ now able to explore the E_T^e dependence

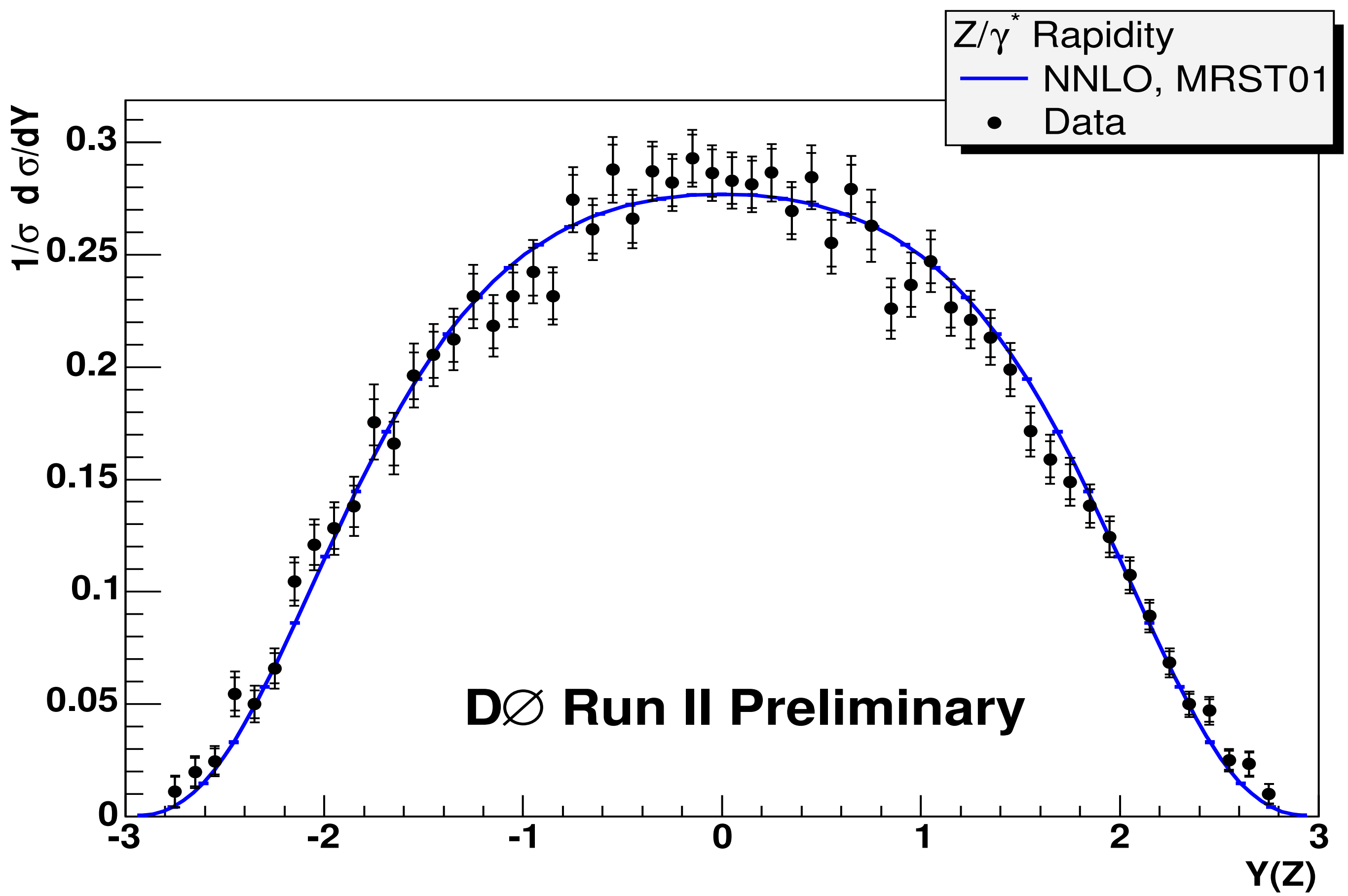
Differences start showing up at high rapidities...

In general for global QCD fits it is better to have differential distributions (more bins in η, E_T^e)...

Z Rapidity Distributions

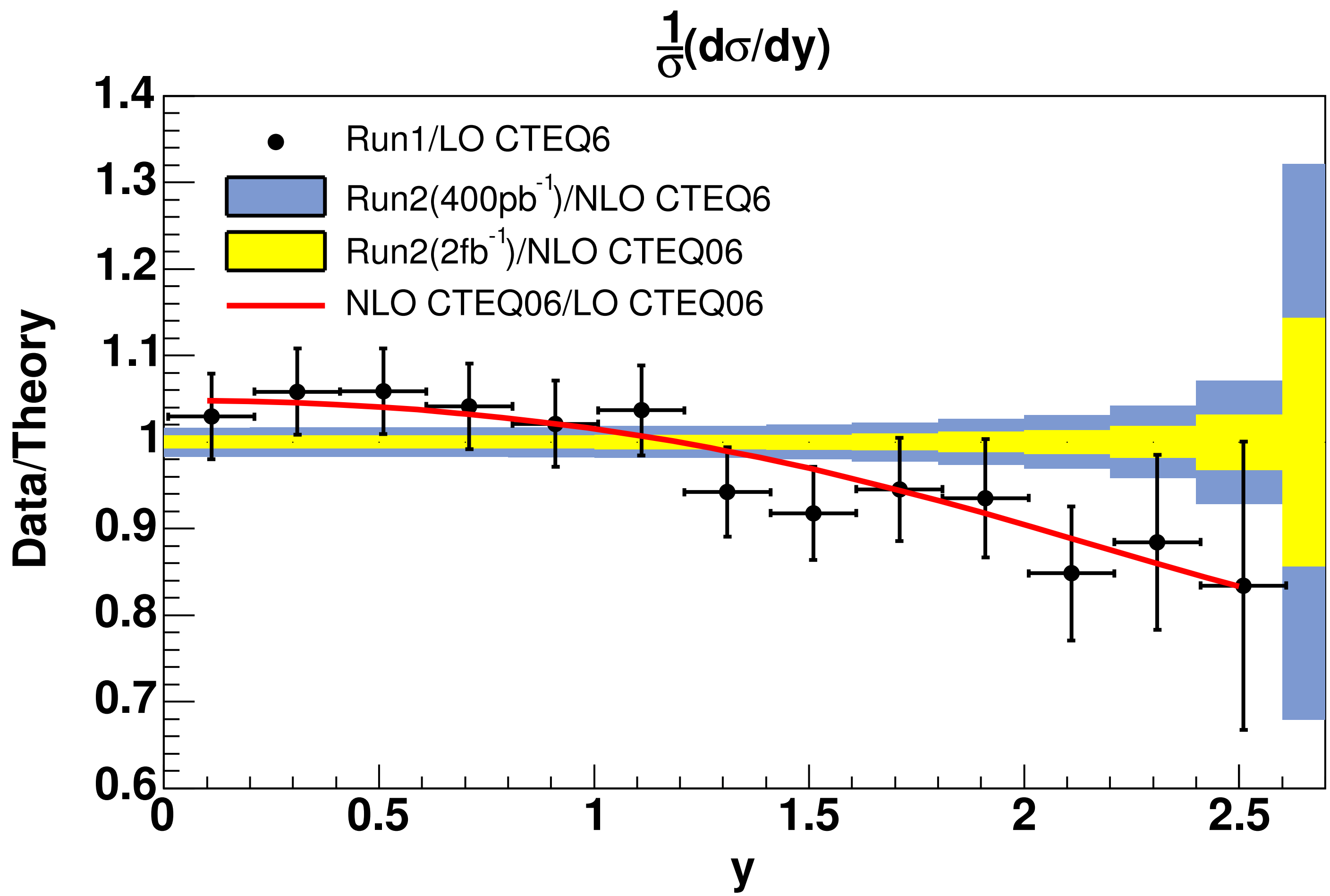
More data and enhanced detector capabilities allow for the possibility of including new measurements in the PDF fits

$$d\sigma(p\bar{p} \to Z/\gamma^* \to e^+e^-)/dY$$

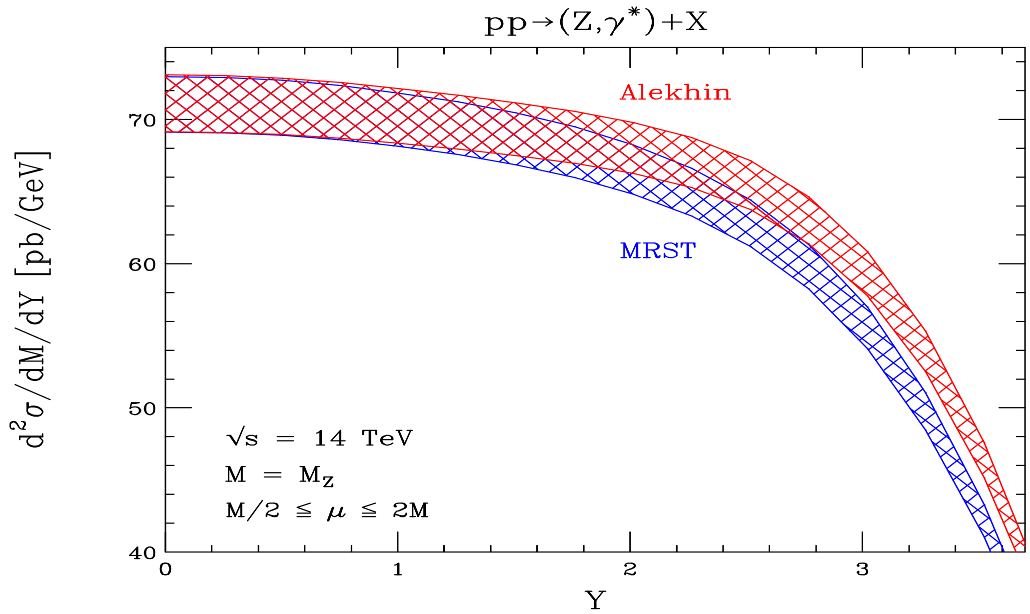


The shaded bands show the expected reduction in the statistical error for 400pb^{-1} and for 2fb^{-1}

CDF Run I data

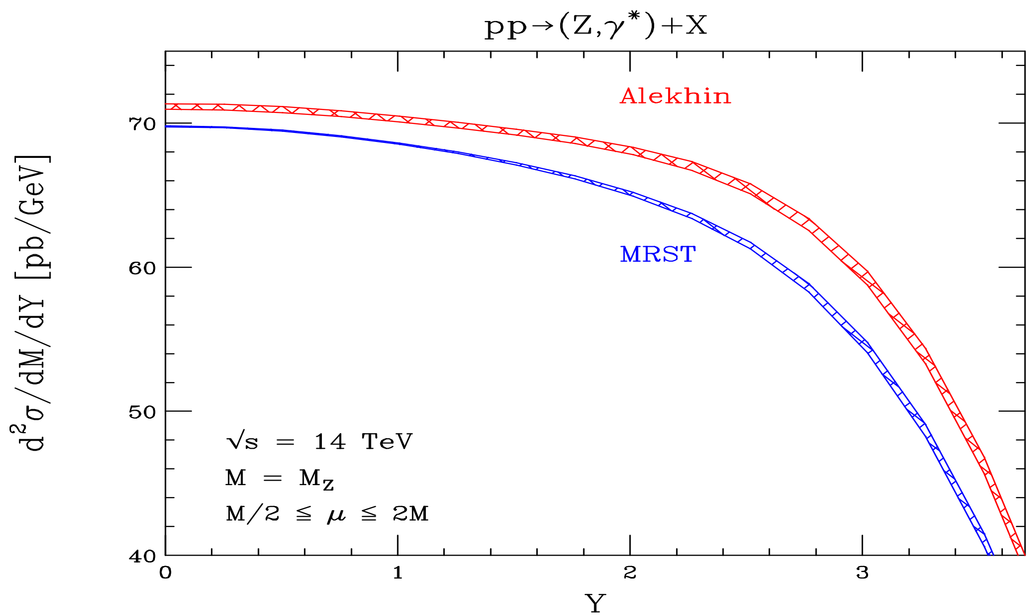


Currently not being used in fits... but may be promising



At LHC energies, unable to discriminate between PDFs when using NLO QCD

Large variation arising from the scale uncertainty



Need to use NNLO QCD

→ *As we go to higher order it is more difficult to directly relate the observable to PDFs*

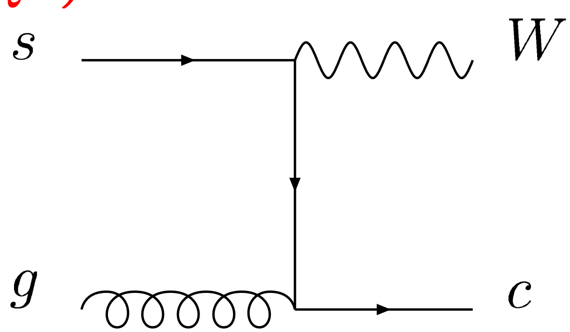
Melnikov, Tev4LHC workshop

Intrinsic Heavy Quark

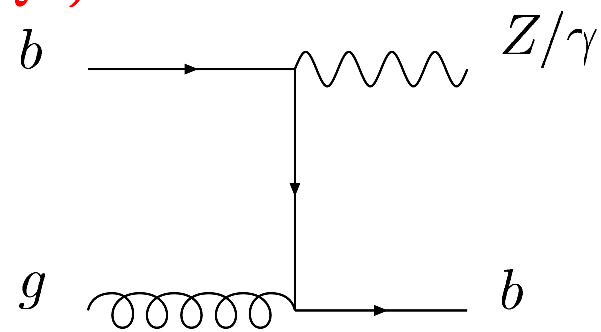
Very little direct experimental input $\rightarrow$ *all c and b distributions in existing PDF sets are radiatively generated*

Probe sea quark distributions with tagged final states $W/Z/\gamma + c/b$

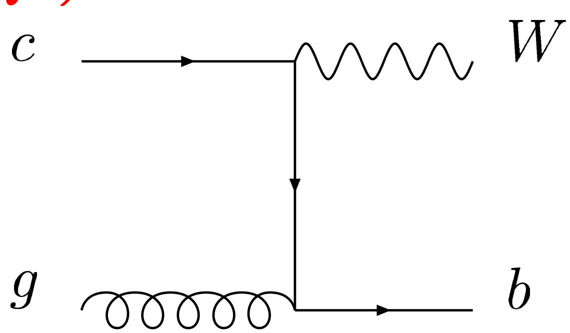
$s(x, Q^2)$

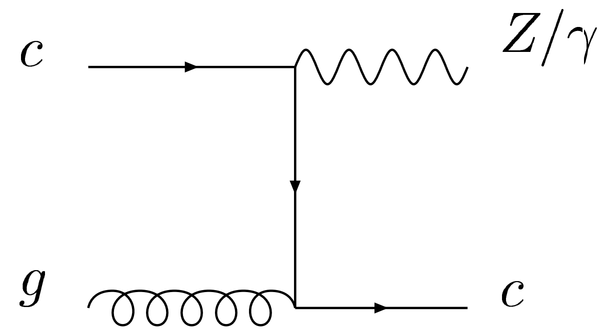


$b(x, Q^2)$

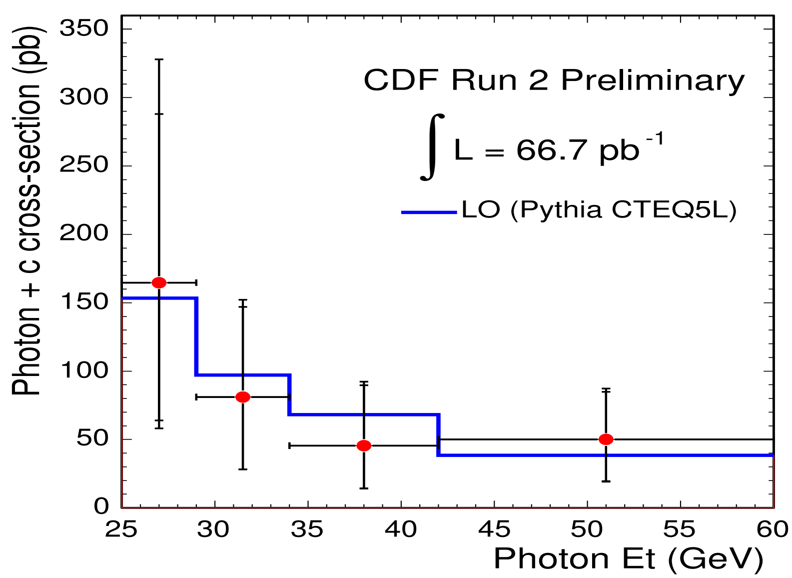


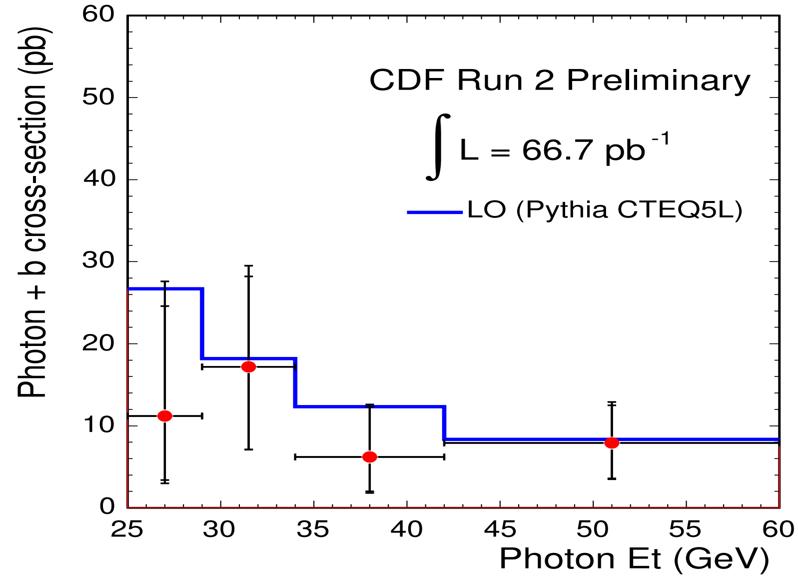
$c(x, Q^2)$





γ plus Tagged Heavy Flavor





Dominated by statistical errors

Largest systematic errors

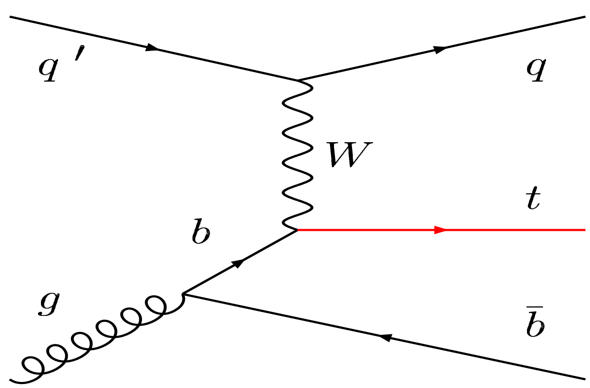
$\longrightarrow$ *Energy scale*

$\longrightarrow$ *Tagging Efficiency*

$\longrightarrow$ *Trigger*

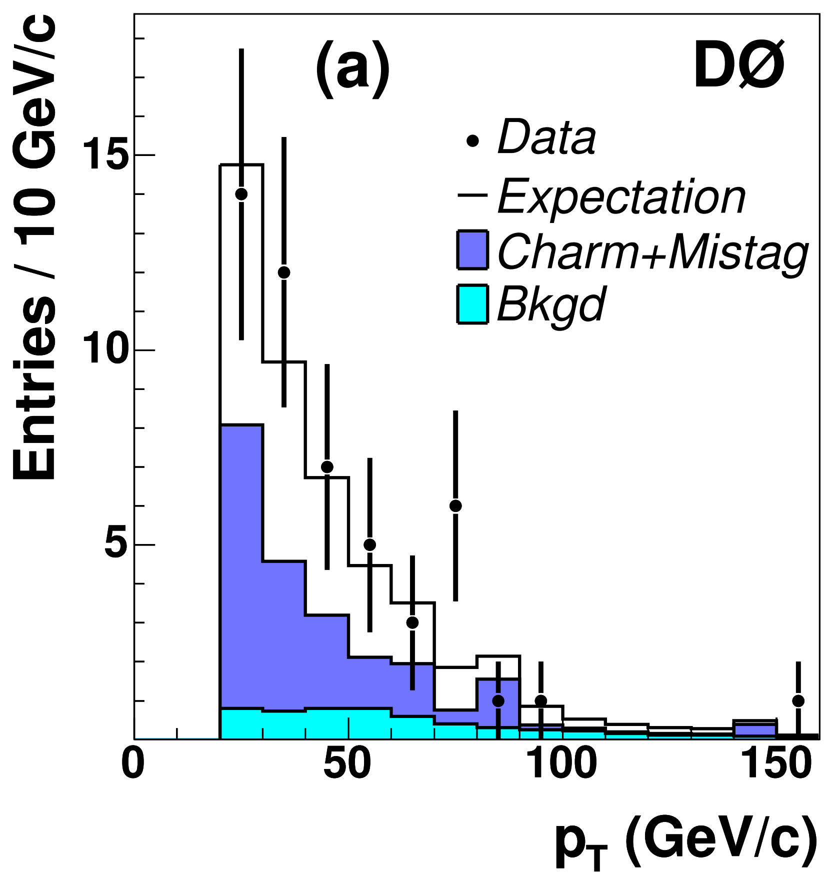
Can we constrain intrinsic heavy flavor at the Tevatron?

Single top production also probes b quarks at high x



DØ recently published a measurement of the ratio:

$$\frac{\sigma(p\bar{p} \to Z + b \text{ jet})}{\sigma(p\bar{p} \to Z + \text{jet})} = 0.023 \pm 0.005$$



p_T spectrum for tagged jets based on 180 pb^{-1}

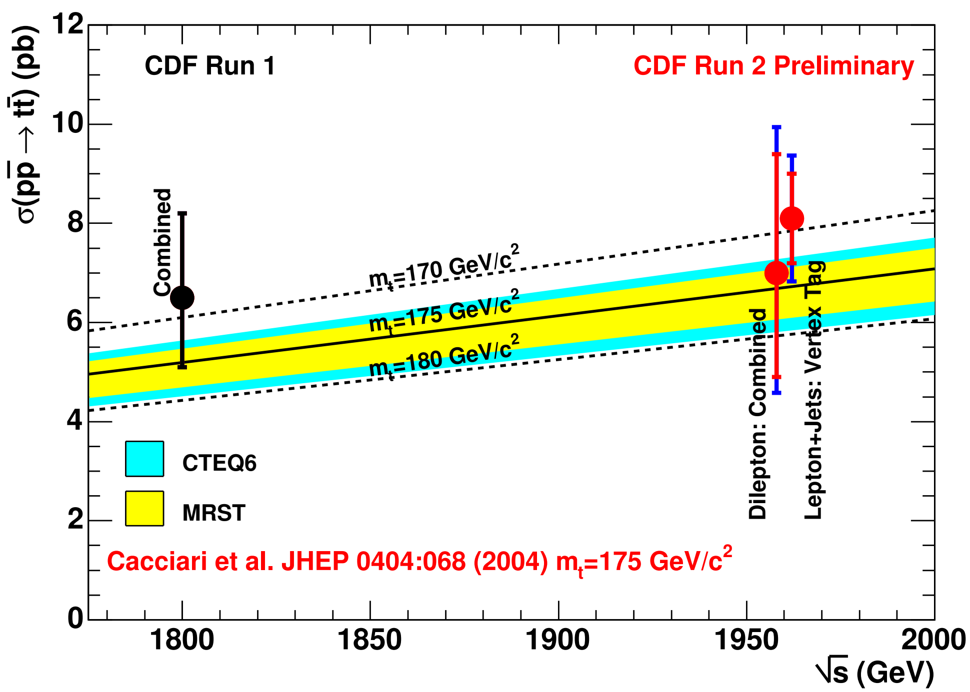
Inclusive $Z + b -$jet production is an important background for Higgs production in the $p\bar{p} \to ZH$ channel

For global fits better to have differential distributions...

hep-ex/0410078

Top Cross Section

Inclusion of full PDF systematics leads to a more realistic estimate of the top cross section uncertainty



For $m_t = 175$ GeV

$\sigma = 6.70 \pm 0.45 pb \quad (CTEQ6M)$

$\sigma = 6.76 \pm 0.21 pb \quad (MRST2001)$

$\rightarrow$ Dominated by PDF and α_s uncertainties

Cacciari et al (hep-ph/0303085)

$\pm 3 - 6\%$ error mainly arising from uncertainty of large-x gluons

$\rightarrow$ *Measurement error approaching the size of the error on the calculation...*

Higgs Cross Section

Cross section uncertainty calculated for main production processes of the SM Higgs (*Djouadi and Ferrag hep-ph/0310209*)

$q\bar{q} \rightarrow VH$	associate production with W/Z
$qq \rightarrow Hqq$	massive vector boson fusion
$gg \rightarrow H$	gluon fusion
$gg, q\bar{q} \rightarrow t\bar{t}H$	associate production with top quarks

Get very different results when using different PDF sets:

$\rightarrow$ *Choice of data used as input to fits*

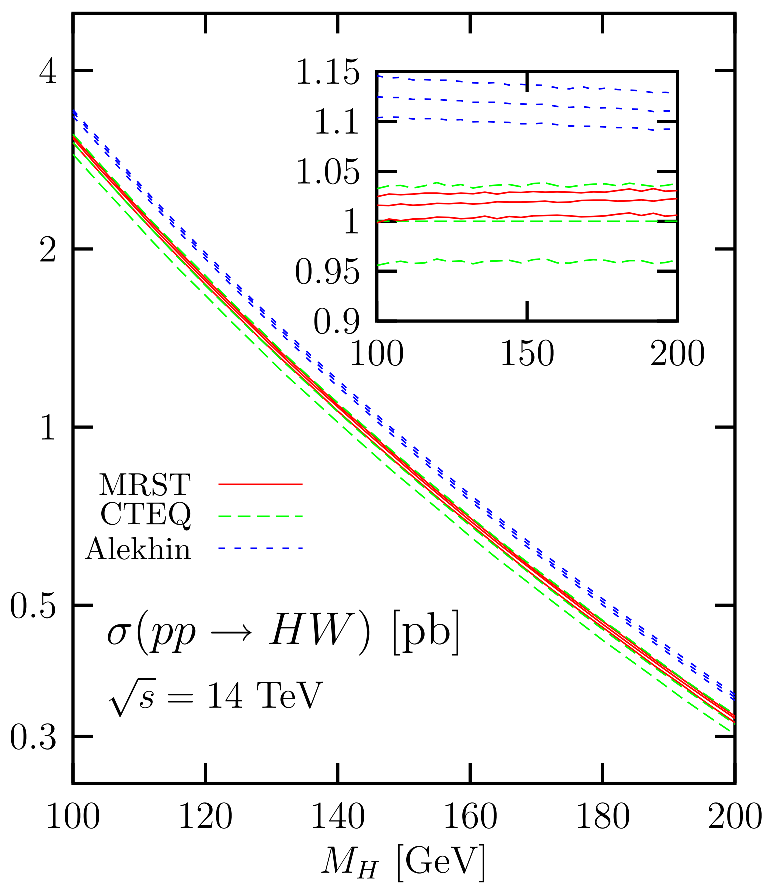
$\rightarrow$ *Treatment of errors*

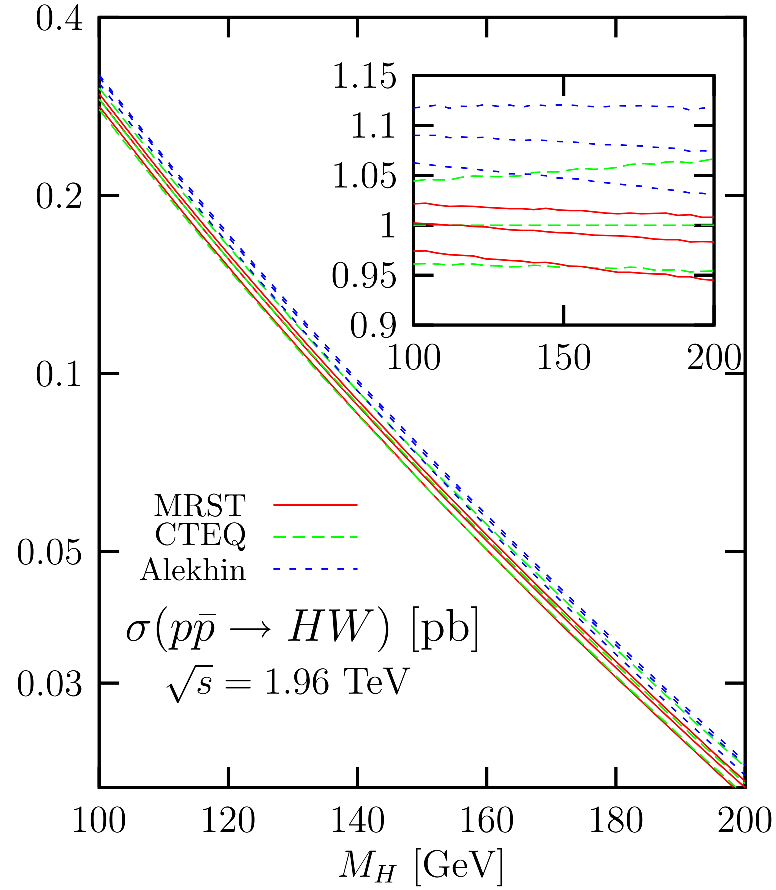
$\rightarrow$ *Parameterization of parton distributions*

$\sim$ 15% spread between PDF sets at Tevatron and LHC energies

$\sim$ 5% uncertainty for a given PDF

Large error arises from the uncertainty of the gluons

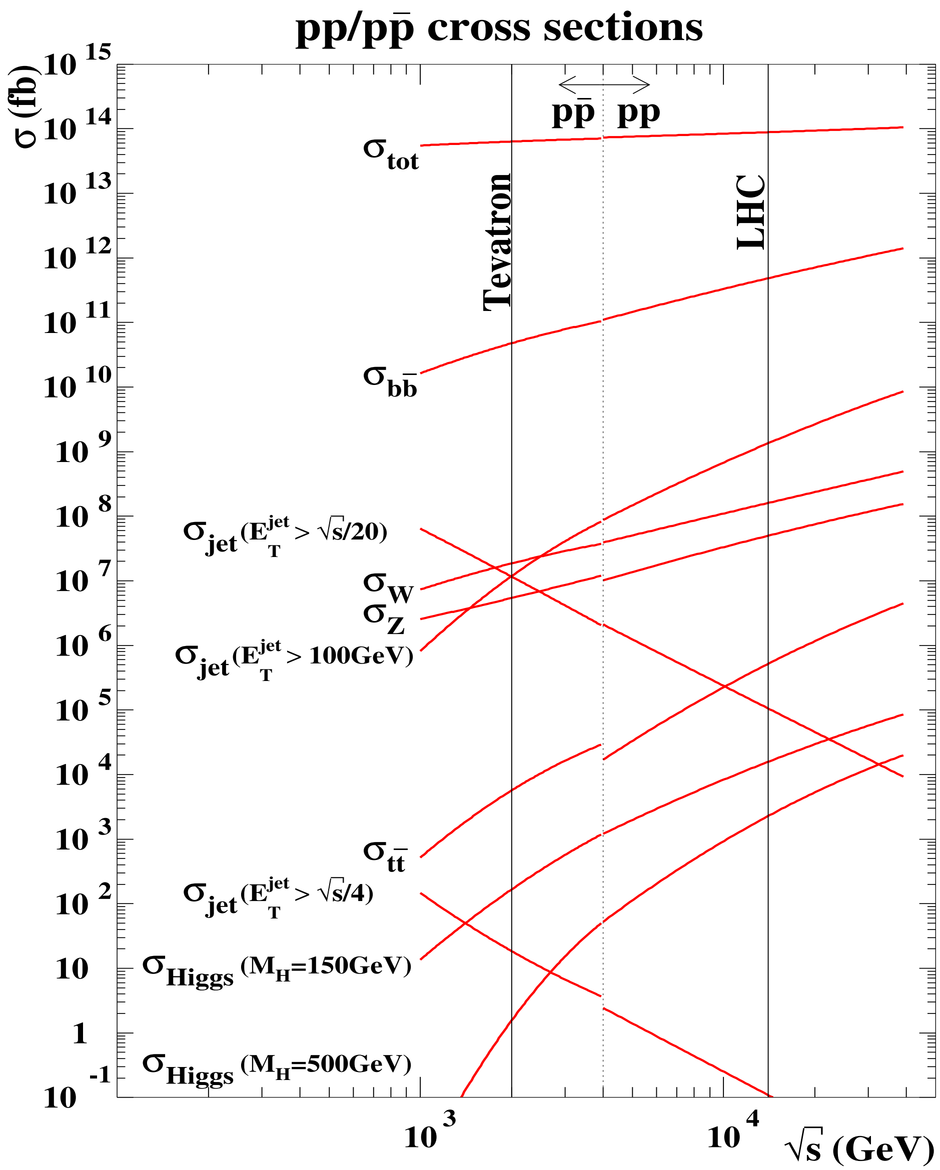




Djouadi and Ferrag hep-ph/0310209

$\longrightarrow$ *For a discovery it is important to have a precise understanding of the backgrounds...*

Understanding the Backgrounds



New physics is expected to have small cross sections and is swamped by standard physics background

Standard physics processes have relatively large uncertainties

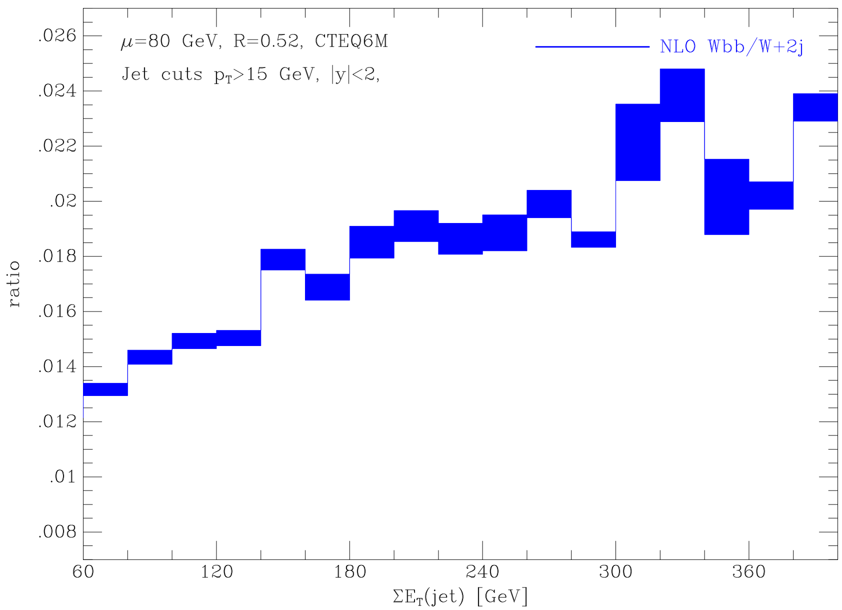
→ *Need to have an accurate prediction for the background in order to claim a discovery*

Using PDF Error Estimates

Need to make the errors on PDFs available in a form that can be generally used

Les Houches Accord Parton Density Function Interface (LHAPDF)

"...enable the usage of Parton Density Functions with uncertainties in a uniform manner."



hep-ph/0405276

Uncertainty on the $Wb\bar{b}/W + 2$ jet ratio as a function of ΣE_T(jet)

Generate events with central PDF

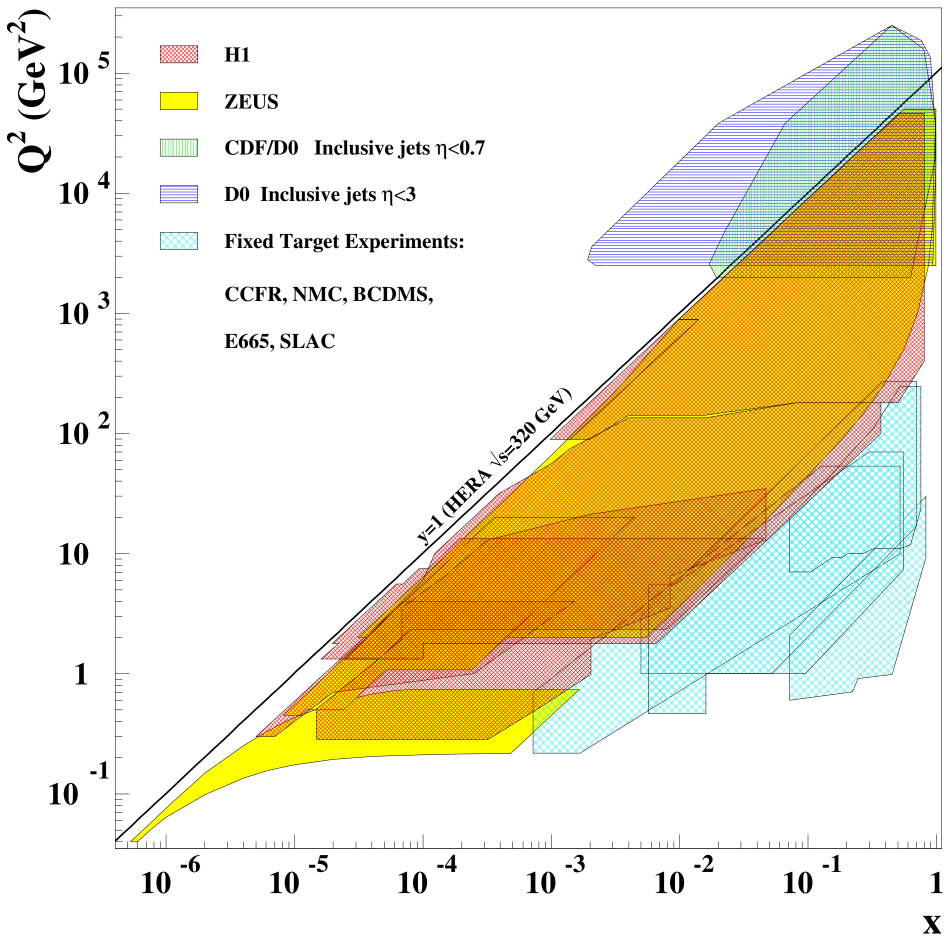
Keep track of PDF $\times$ PDF weight for each error PDF

Reweight MC to see the effect on observable

Statistical errors not shown...

Make the tools easy to use and readily available

PDFs are Universal



PDFs can lead to different predictions depending on parameterizations and on datasets used in the fits

→ *Should include as much data in the global fit as possible*

→ *Try to span the kinematic phase space*

The challange is to demonstrate consistancy between measurements in different regions of phase space as well as between different processes

Drew heavily from the many excellent talks from the Tev4LHC (and HERA and the LHC) workshops

... bring together the Tevatron and LHC experimental groups and the theoretical community to make the best possible use of data and experience from the Tevatron in preparing for the LHC experimental program.

... understanding how to use Tevatron data to improve event modelling and theoretical understanding of cross sections for the signals and backgrounds at LHC, and also how to use experience with real problems at the Tevatron to best prepare for the challenges of doing analysis at the LHC.

→ First meeting held at Fermilab, 16-18 September, 2004
http://conferences.fnal.gov/tev4lhc/

→ Second meeting was held at BNL, 3-5 February, 2005
https://www.bnl.gov/tev4lhc/

→ Third meeting will be held at CERN, 28-30 April, 2005
http://agenda.cern.ch/fullAgenda.php?ida=a052004

→ Final meeting will be held at FNAL, in the Fall, 2005

And in Conclusion...

- PDF uncertainties creep up in a number of places: *accpectance, luminosity, background estimates, comparison to theory...*

- New techniques to estimate errors enable a better understanding of the impact of the uncertainties on measured observables, *make these tools easy to use (LHAPDF)*

- Tevatron in Run II allows us to refine the PDF sets and reduce the associated uncertainties, *measurements are already challenging the calculations*

- Uncertainty of the gluon at high x results in the dominant error on many interesting measurements, *use the inclusive jets measurements to pin this down*

• Important to cover as much of the available phase space as possible to avoid absorbing the effects of new physics in the flexability of the fits, *measure forward jets*

• Can get significantly different predictions using different PDF sets, *PDFs are suppose to be universal, should try to use as much data in the fit as possible*

• New detector/trigger capabilities open the possibility to measure new observables over a wider kinematic region which can be used in global fits, *Z rapidity, Z/γ plus tagged heavy flavor...*

• Within the context of the Tev4LHC we are working to maximize the information that the Tevatron can provide as input to QCD fits, *encourage dialog between experimentalists and therorists*

$\rightarrow$ *Tevatron just had two back to back record luminosity stores*

2005.04.29-09:50 $129.0 \times 10^{30} s^{-1} cm^{-2}$

2005.04.27-18:53 $125.2 \times 10^{30} s^{-1} cm^{-2}$ delivered over $5 pb^{-1}$