PDF studies at ATLAS

HERA-LHC workshop 2007

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At the LHC high precision (SM and BSM) cross section predictions require precision Parton Distribution Functions (PDFs)

How do PDF Uncertainties affect SM physics

How do PDF uncertainties affect BSM physics?

What measurements can we make at ATLAS to improve the PDF uncertainty?

With thanks to ATLAS SM group M.Boonekamp

C Gwenlan

D Clements

T Carli

J Huston

A Tricoli

Not covering low-mass Drell-Yan, high-mass Drell-Yan, Z+b jets, etc

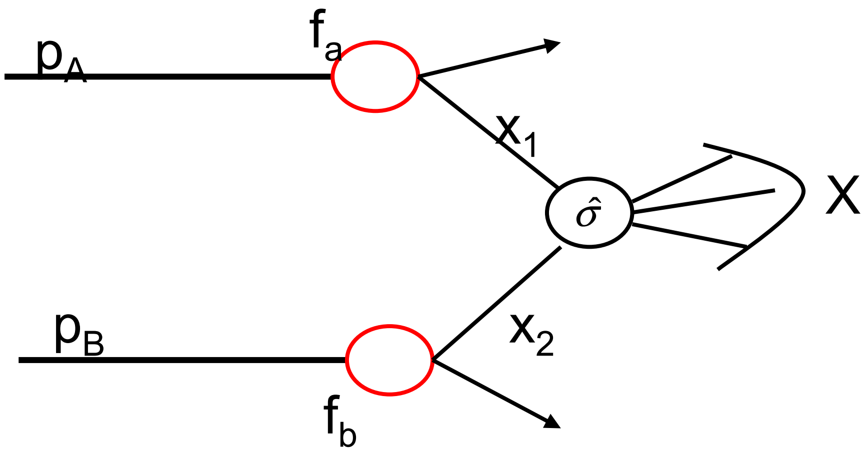
HERA and the LHC- transporting PDFs to hadron-hadron cross-sections

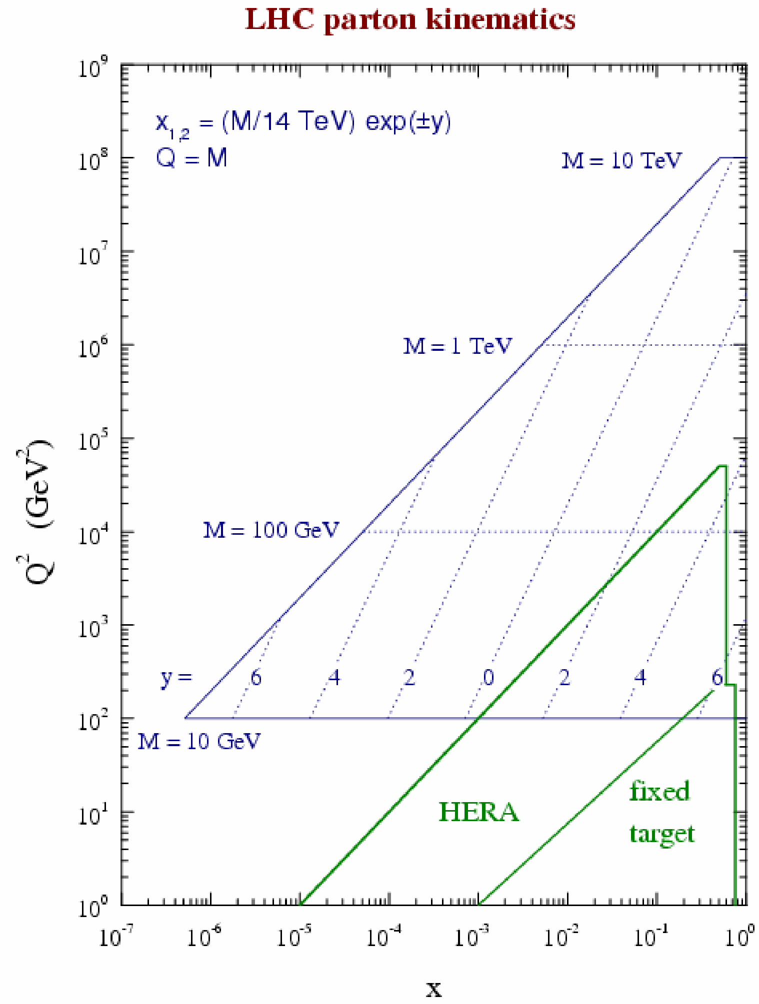
QCD factorization theorem for short-distance inclusive processes

$$\sigma_X = \sum_{a,b} \int_0^1 dx_1 dx_2\, f_a(x_1, \mu_F^2)\, f_b(x_2, \mu_F^2) \times \hat{\sigma}_{ab\to X}\left(x_1, x_2, \{p_i^\mu\}; \alpha_S(\mu_R^2), \alpha(\mu_R^2), \frac{Q^2}{\mu_R^2}, \frac{Q^2}{\mu_F^2}\right)$$

where X=W, Z, D-Y, H, high-E_T jets, prompt-γ
and $\hat{\sigma}$ is known

- to some fixed order in pQCD and EW
- in some leading logarithm approximation (LL, NLL, …) to all orders via resummation

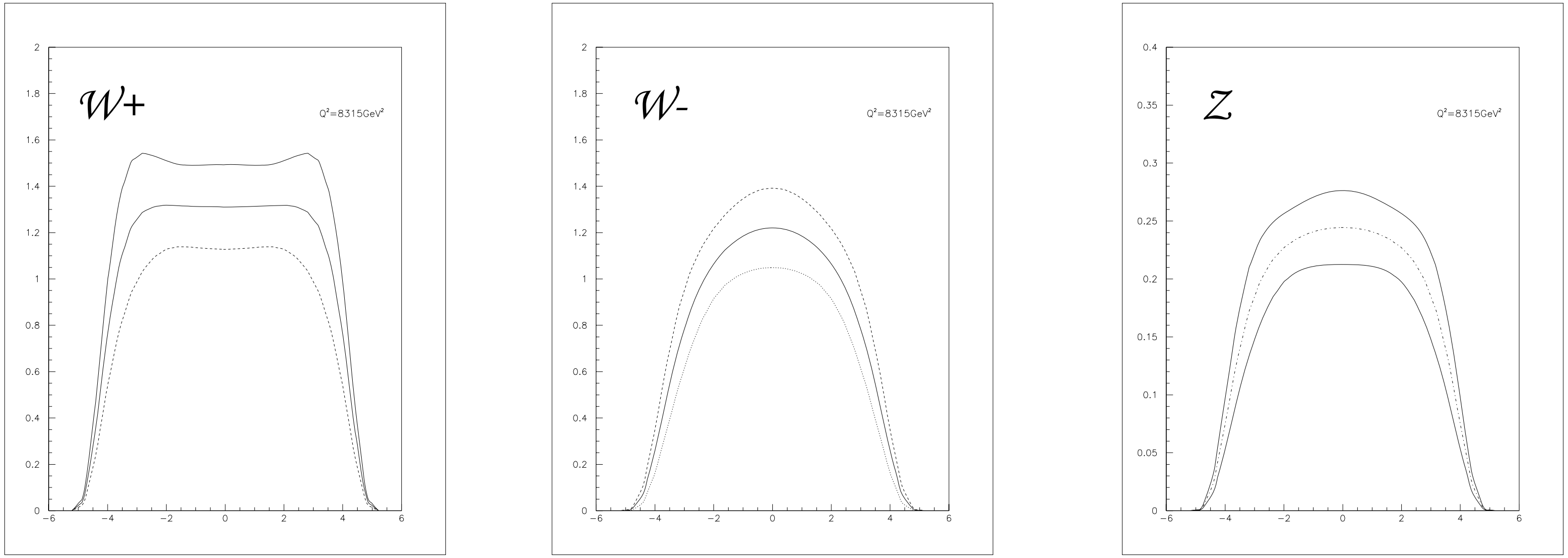




The central rapidity range for W/Z production AT LHC is at low-x (5 ×10-4 to 5 ×10-2)

Knowledge of the PDFs is vital

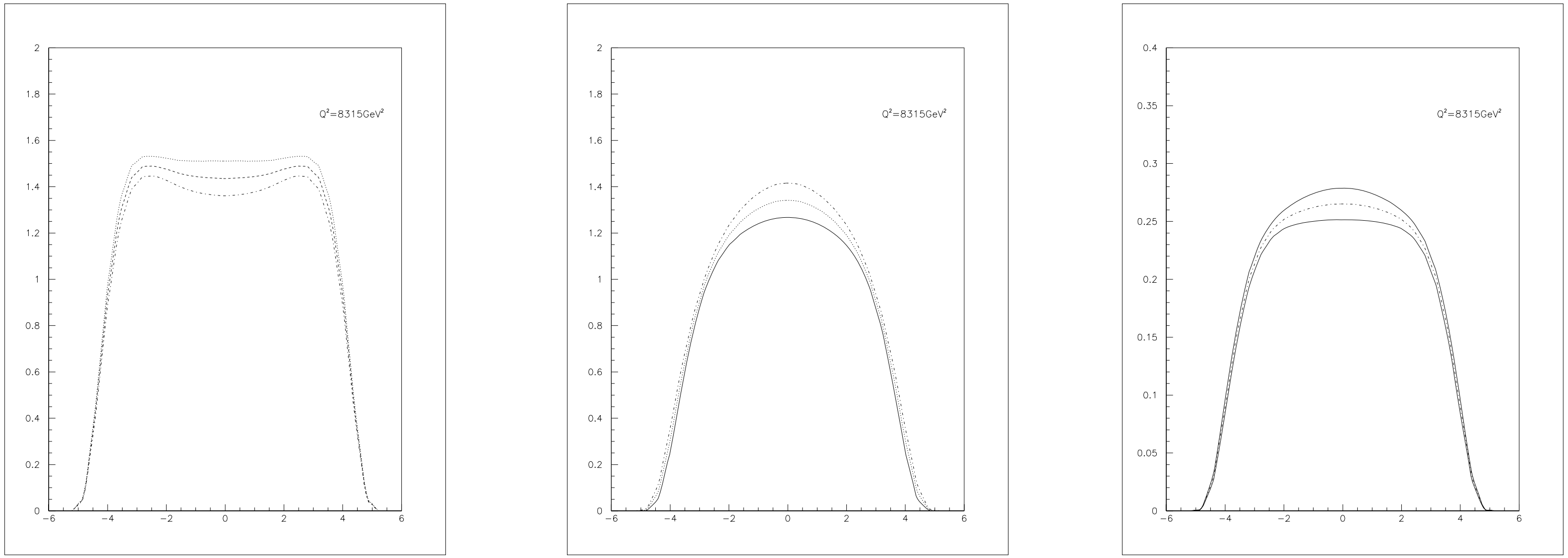
What has HERA data ever done for us?



Pre-HERA W+/W-/Z rapidity spectra ~ ± 15% uncertainties become!

NO WAY to use these cross-sections as a good luminosity monitor

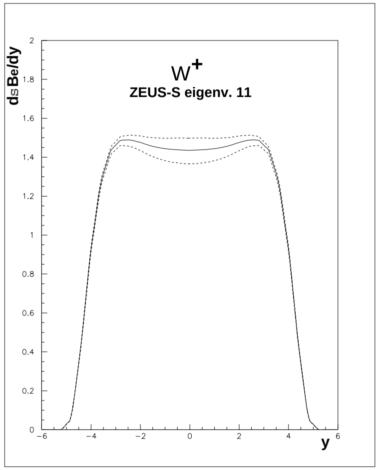
Post-HERA W+/W-/Z rapidity spectra ~ ± 5% uncertainties



Where did the improvement come from? There has been a tremendous improvement in our knowledge of the low-x glue and thus of the low-x sea

The **uncertainty on the W/Z rapidity distributions** is dominated by –- **gluon PDF** dominated eigenvectors

Both low-x and high-x gluon

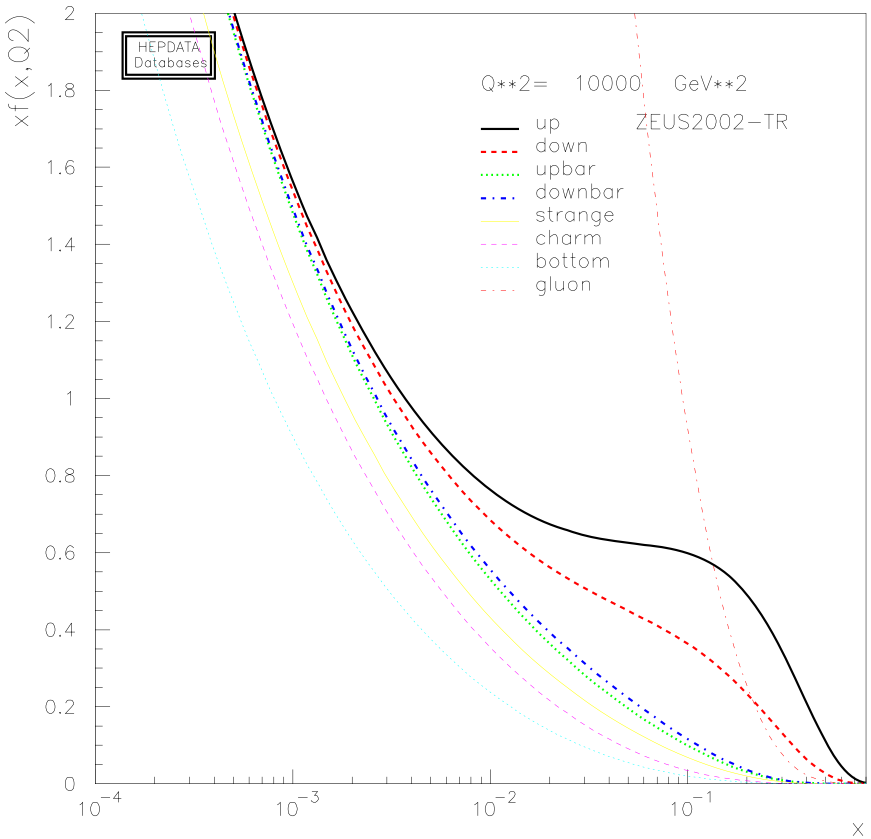


High-x gluon eigenvector

It may at first sight be surprising that **W/Z distns are sensitive to gluon parameters** BUT our experience is based on the Tevatron where Drell-Yan processes can involve valence-valence parton interactions.

At the LHC we will have dominantly sea-sea parton interactions at low-x

And at Q2~M_Z2 **the sea is driven by the gluon-** which is far less precisely determined for all x values



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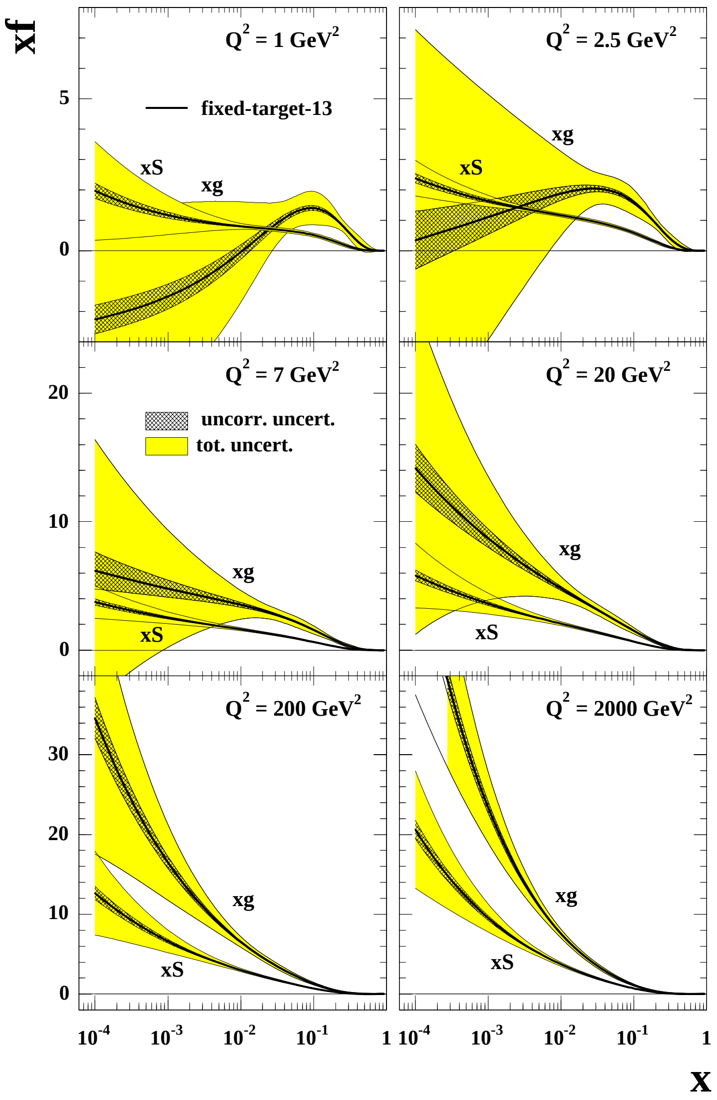
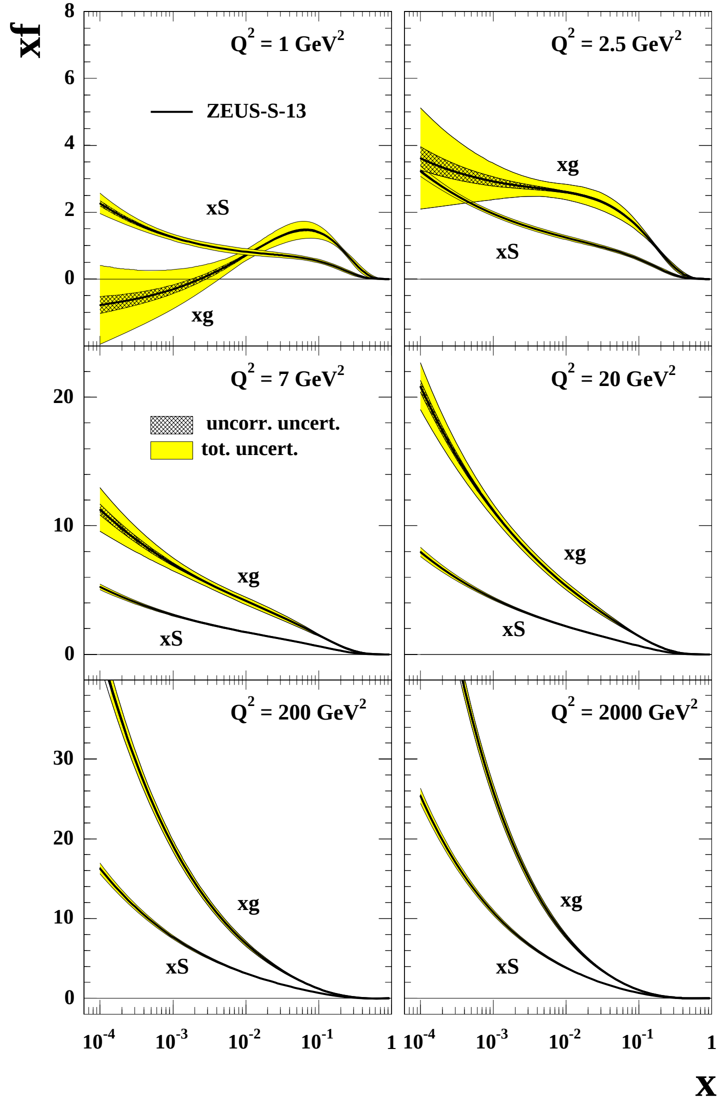


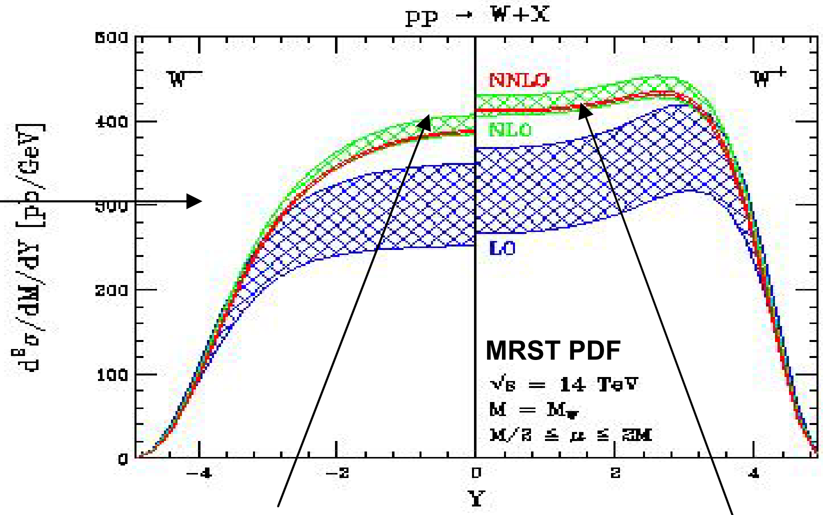
Pre-HERA sea and glue distributions



Post HERA sea and glue distributions

W/Z production have been considered as good standard candle processes with small theoretical uncertainty.

BUT- there are also QED effects to be considered of a similar size to NNLO QCD



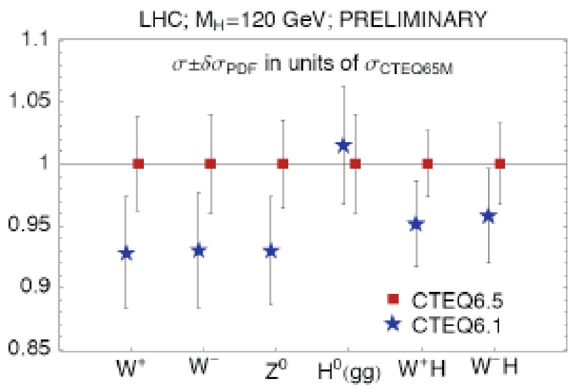
NNLO corrections small ~ few%

NNLO residual scale dependence < 1%

PDF uncertainty has been considered as a dominant contribution and most PDF groups quote uncertainties <~5%

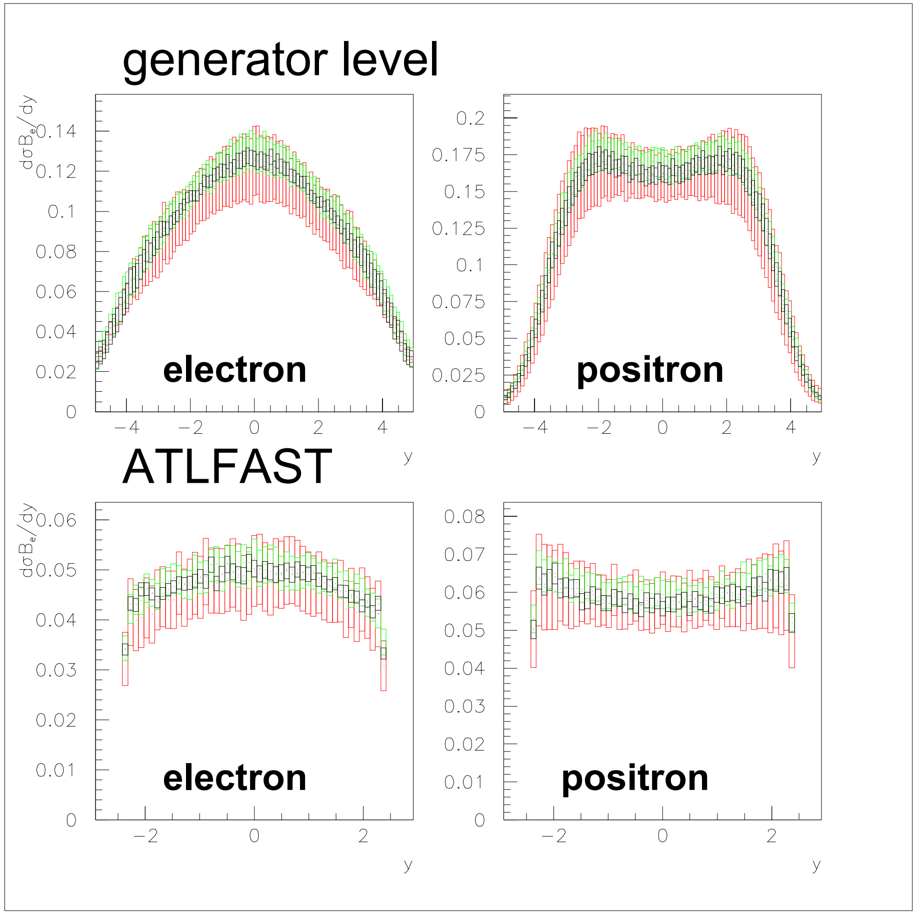
PDF Set	$\sigma_{W^+} \cdot B_{W \to l\nu}$ (nb)	$\sigma_{W^-} \cdot B_{W \to l\nu}$ (nb)	$\sigma_Z \cdot B_{Z \to ll}$ (nb)
ZEUS-S	12.07 ± 0.41	8.76 ± 0.30	1.89 ± 0.06
CTEQ6.1	11.66 ± 0.56	8.58 ± 0.43	1.92 ± 0.08
MRST01	11.72 ± 0.23	8.72 ± 0.16	1.96 ± 0.03

BUT the central values differ by more than some of the uncertainty estimates.
AND the situation just got dramatically worse. The new CTEQ6.5 estimate is 8% higher



→Not such a precise luminosity monitor

Can we improve our knowledge of PDFs using ATLAS data itself?



We actually measure the decay lepton spectra

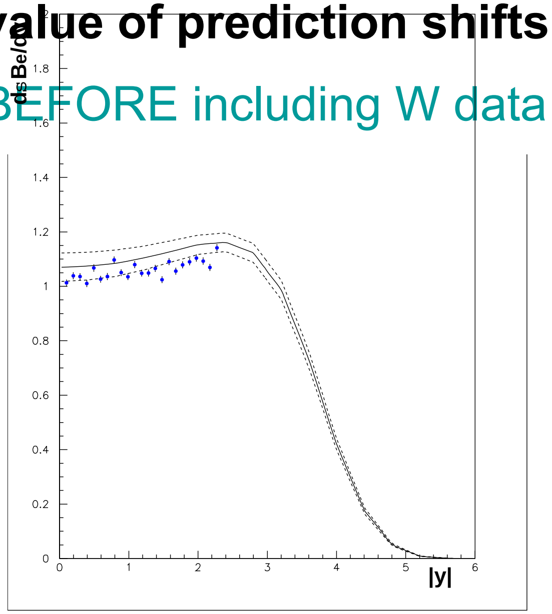
Generate with HERWIG+k-factors (checked against MC@NLO) using
CTEQ6.1M ZEUS_S MRST2001
PDFs with full uncertainties from LHAPDF eigenvectors
At y=0 the total uncertainty is
~ ±6% from ZEUS
~ ±4% from MRST01E
~ ±8% from CTEQ6.1

To improve the situation we NEED to be more accurate than this:**~4%**
Statistics are no problem there will be millions of W's
We need to control the systematic uncertainty

Study of the effect of including the LHC W Rapidity distributions in global PDF fits
by how much can we reduce the PDF errors with early LHC data?

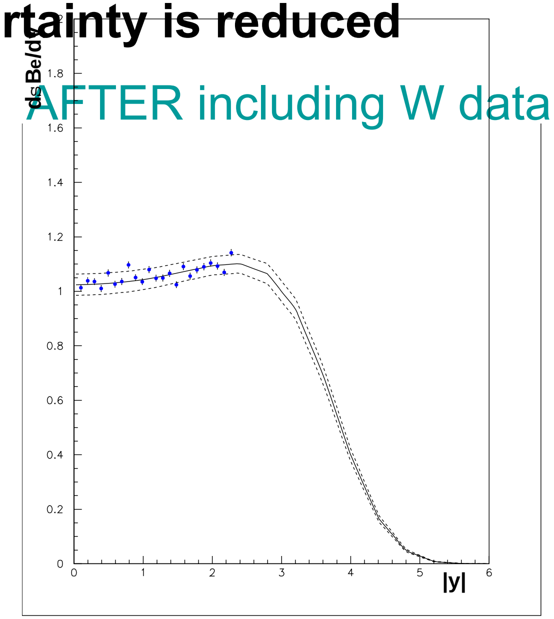
Generate data with 4% error using CTEQ6.1 PDF, pass through ATLFAST detector simulation and then include this pseudo-data in the global ZEUS PDF fit **Central value of prediction shifts and uncertainty is reduced**

BEFORE including W data



Lepton+ rapidity spectrum data generated with CTEQ6.1 PDF compared to predictions from ZEUS PDF

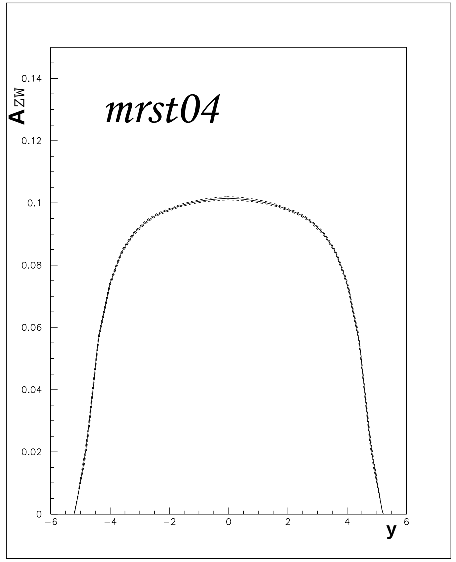
AFTER including W data



Lepton+ rapidity spectrum data generated with CTEQ6.1 PDF compared to predictions from ZEUS PDF AFTER these data are included in the fit

Specifically the low-x gluon shape parameter λ, $xg(x) = x^{-\lambda}$, was
$\lambda = -.199 \pm .046$ for the ZEUS PDF before including this pseudo-data
It becomes $\lambda = -.181 \pm .030$ after including the pseudodata

The **uncertainty on the W$^+$ W$^-$ and Z rapidity distributions** are all dominated by **gluon PDF** uncertainty and there is cancellation of this uncertainty in the ratio



$Z_W = Z/(W^+ + W^-)$

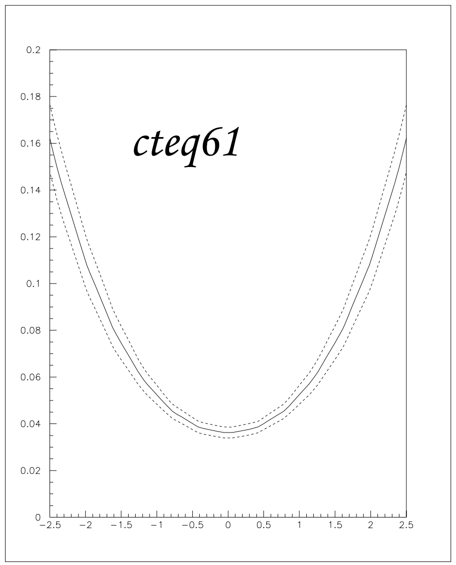
the PDF uncertainty on this ratio is ~1% and there is agreement between PDFsets

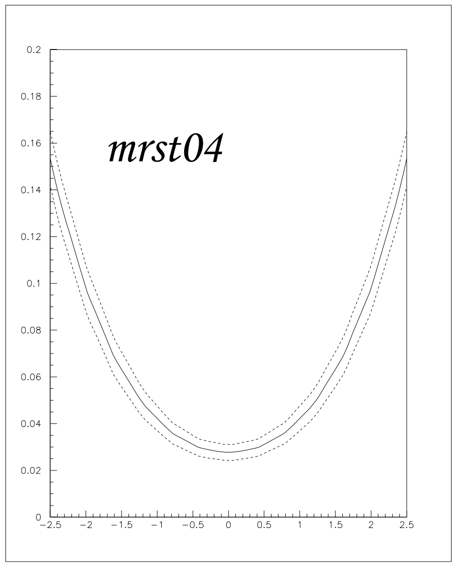
But the same is not true for the W asymmetry

$A_w = (W^+ - W^-)/(W^+ + W^-)$

the PDF uncertainty on this ratio is reduced compared to that on the W rapidity spetcra within any one PDF set

BUT there is not good agreement between PDF sets- a difference in valence PDFs is revealed





Dominantly, at LO $\quad A_W = \dfrac{(u\,\bar{d} - d\,\bar{u})}{(u\,\bar{d} + d\,\bar{u})}$

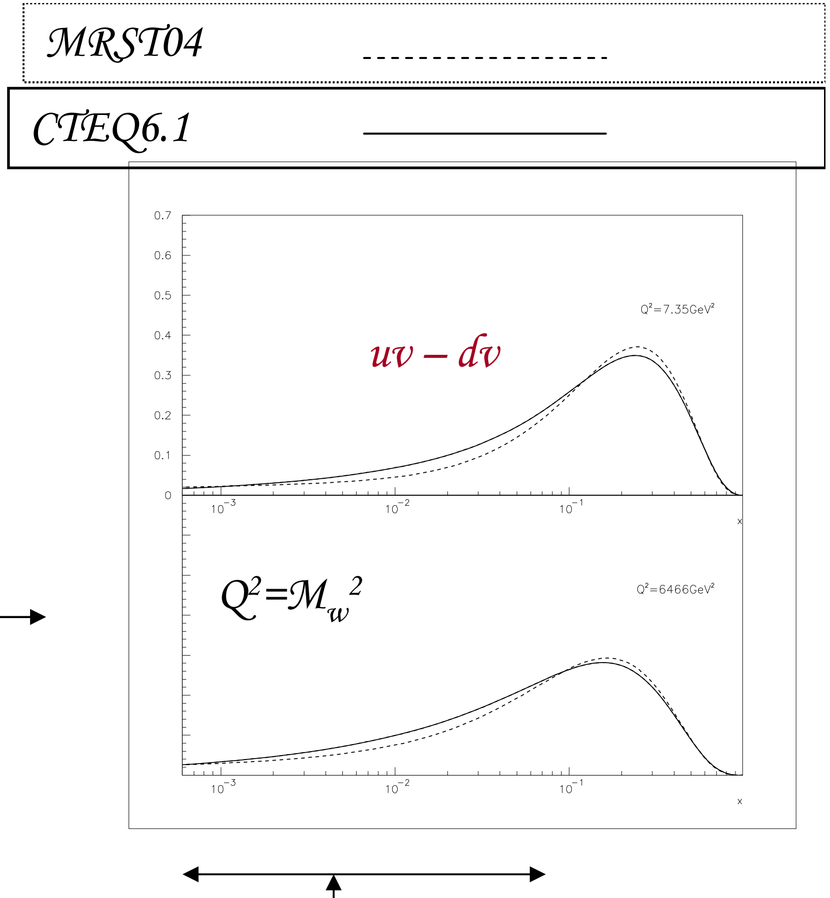
And $\bar{u} = \bar{d} = \bar{q}$ at small x

So $A_W \sim \dfrac{(u - d)}{(u + d)} = \dfrac{(u_v - d_v)}{(u_v + d_v + 2\,q)}$

Actually this pretty good even quantitatively

The difference in valence PDFs you see here does explain the difference in A_W

Of course we will actually measure the lepton asymmetry

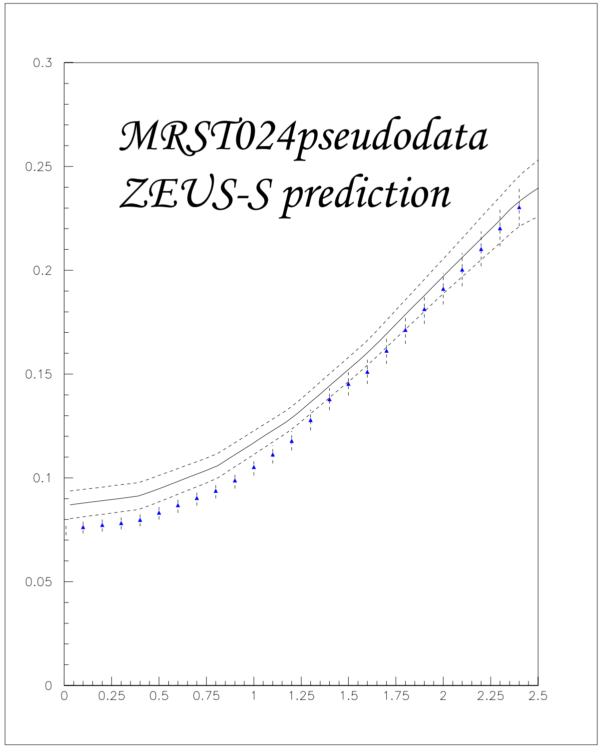


x- range affecting W asymmetry in the measurable rapidity range

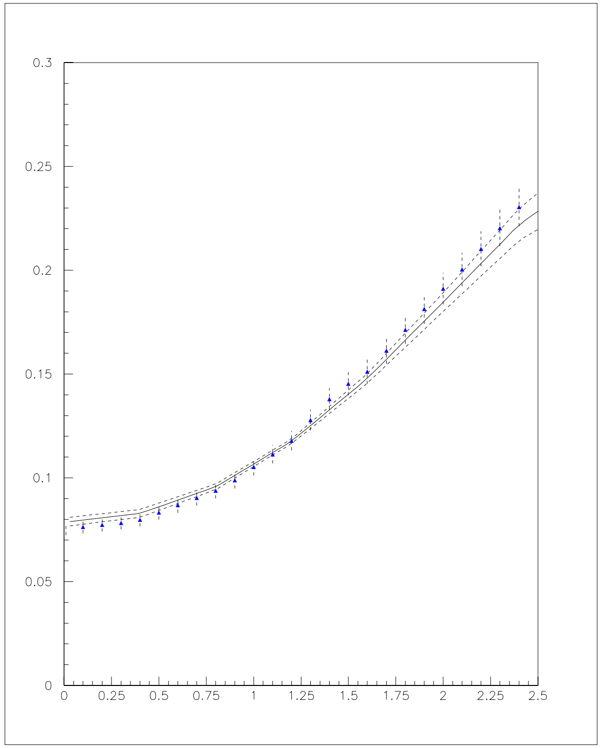
Generate data with 4% error using MRST04 PDF and then include this pseudo-data in the global ZEUS PDF fit

The PDF uncertainty is improved by the input of such data and the fit is only able to describe the MRST pseudodata if the valence parametrizations at Q^2_0 are extended to become $xV(x) = A\, x^a\, (1-x)^b (1+d \sqrt{x} + c\, x)$.

BEFORE including A_W pseudo-data



AFTER including A_W pseudo-data



Conclusion we have valence PDF discrimination, and will be able to measure valence distributions at x~0.005 on proton targets for the first time

LHC is a low-x machine (at least for the early years of running)

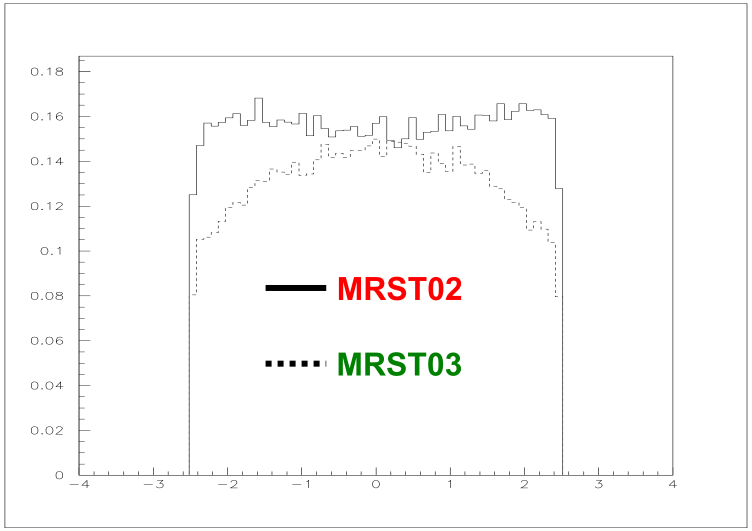
Is NLO (or even NNLO) DGLAP good enough?

The QCD formalism may need extending at small-x

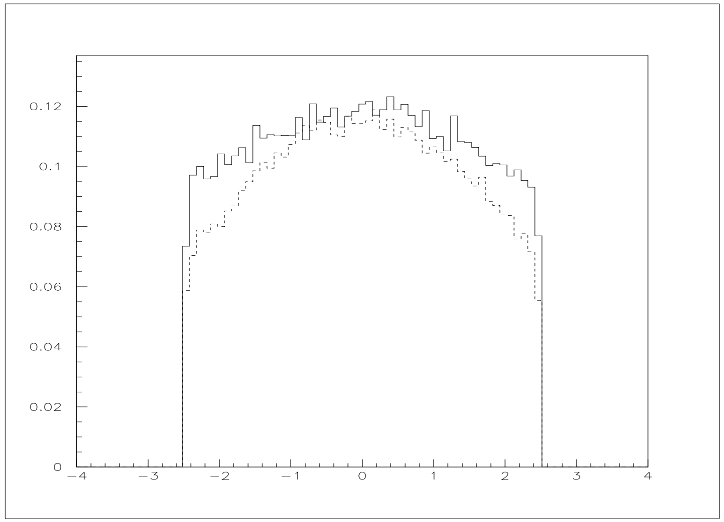
MRST03 is a toy PDF set produced without low-x data

200k events of **W+- -> e+-** generated with MC@NLO using MRST03 and MRST02

Reconstructed Electron Pseudo-Rapidity Distributions (ATLAS fast simulation)



6 hours running



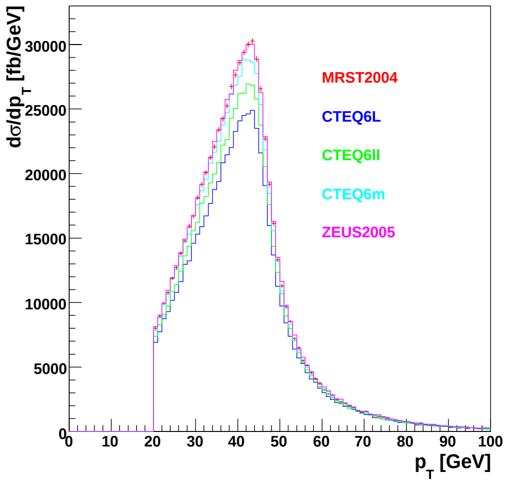
Reconstructed e^+

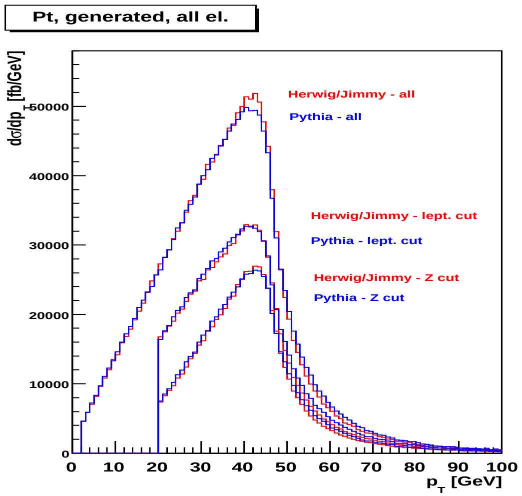
Reconstructed e^-

If something is very different about low-x behaviour it will show up in the our measurable rapidity range

But the TOY PDF is unlikely to be realistic - a better way cold be to look at pt spectra for W and Z production

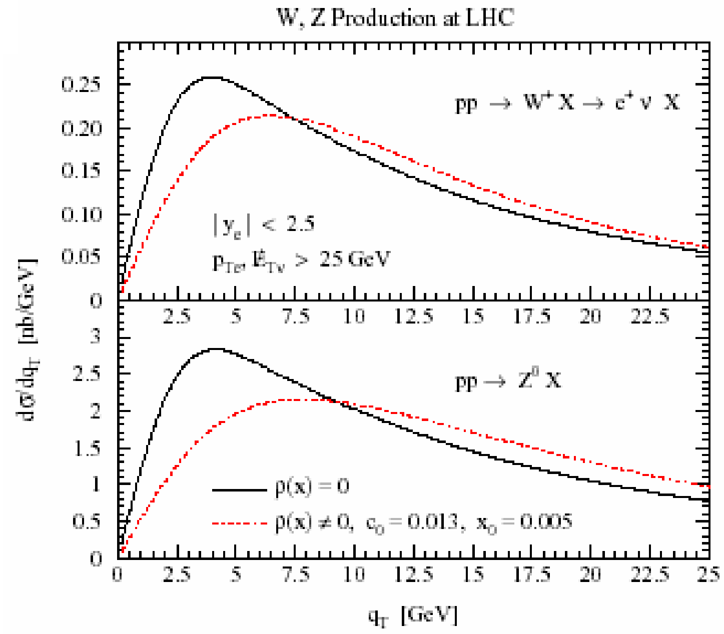
Pt spectra show PDF differences, but also show differences in modelling – e.g. PYTHIA/HERWIG differences





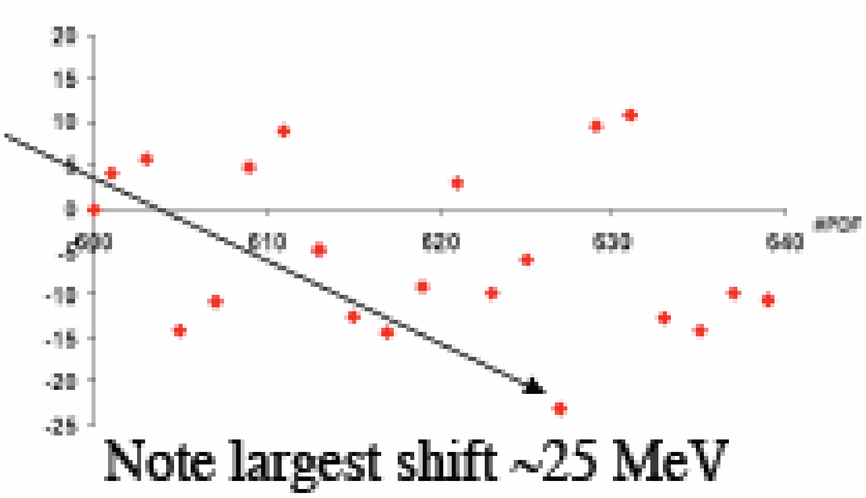
Probably needs more sophisticated treatment e.g. RESBOS.

There has been an interesting recent calculation of how lack of pt ordering at low-x may affect the pt spectra for W and Z production at the LHC (See hep-ph/0508215)



Pt spectra are also used to measure MW

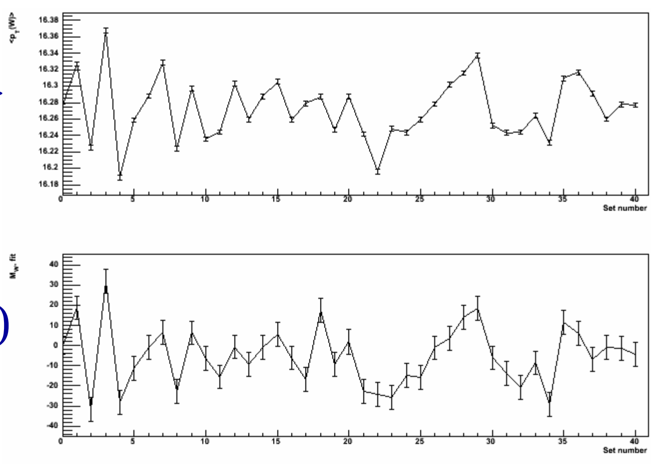
Raw dM_W from PDF uncertainties as of today, when using pt(e), is ~20 MeV



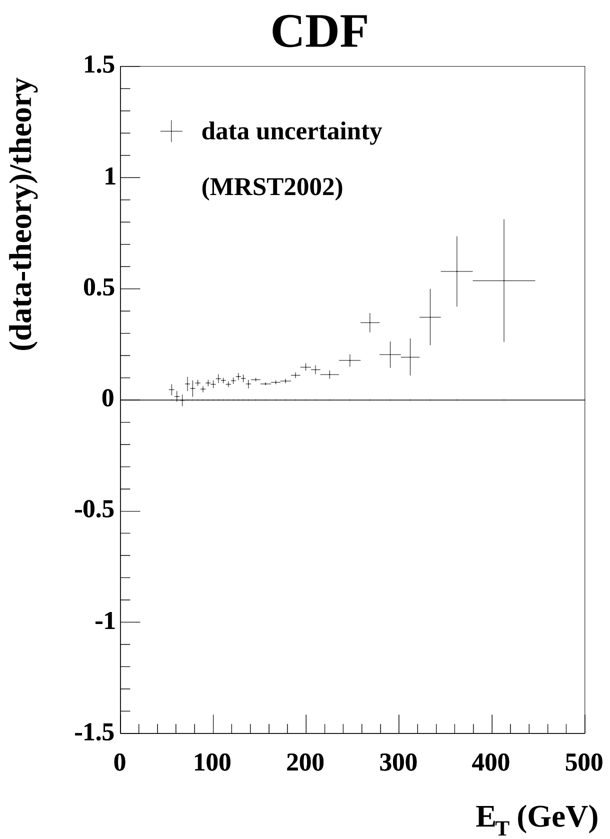
So we'd better be sure we've got the calculations for Pt spectra right

$< p_T(W) >$

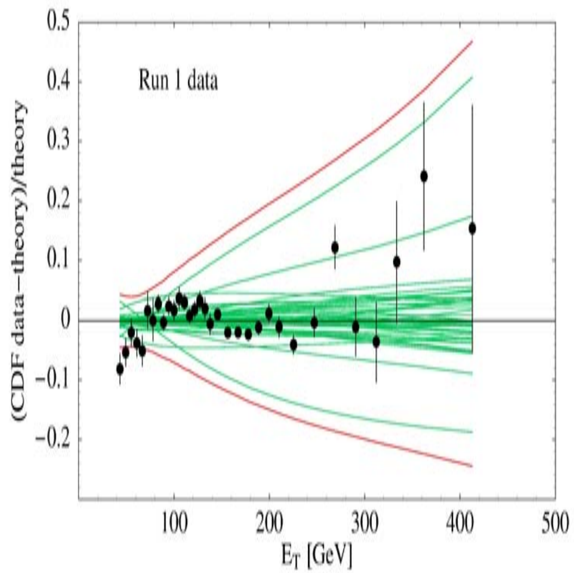
$\delta M_W(\text{fit})$



Same pattern



Example of how PDF uncertainties matter for BSM physics– Tevatron jet data were originally taken as evidence for new physics--



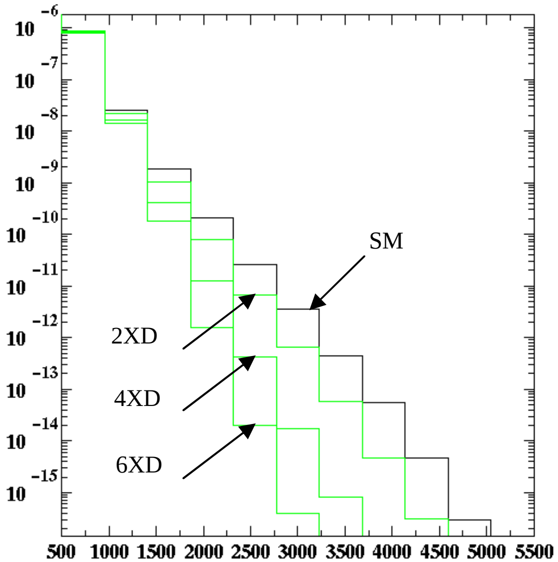
Theory CTEQ6M

These figures show inclusive jet cross-sections compared to predictions in the form (data - theory)/ theory

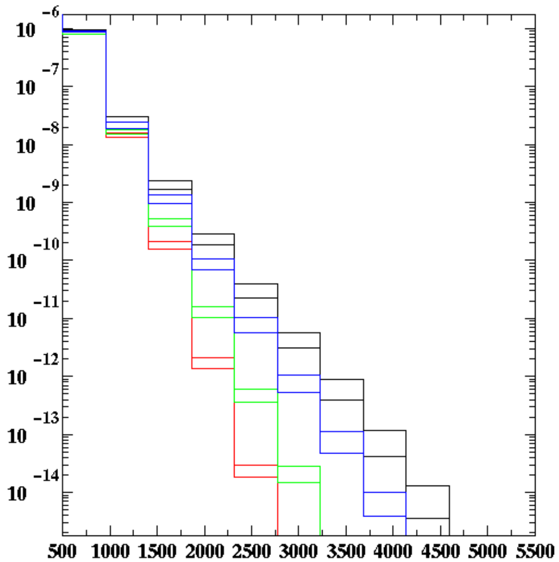
Today Tevatron jet data are considered to lie within PDF uncertainties
And the largest uncertainty comes from the uncertainty on the high x gluon

Such PDF uncertainties the jet cross sections compromise the LHC potential for discovery. E.G. Dijet cross section potential sensitivity to compactification scale of extra dimensions (M_c) reduced from ~6 TeV to 2 TeV. (Ferrag et al)

M_c = 2 TeV, no PDF error



M_c = 2 TeV, with PDF error

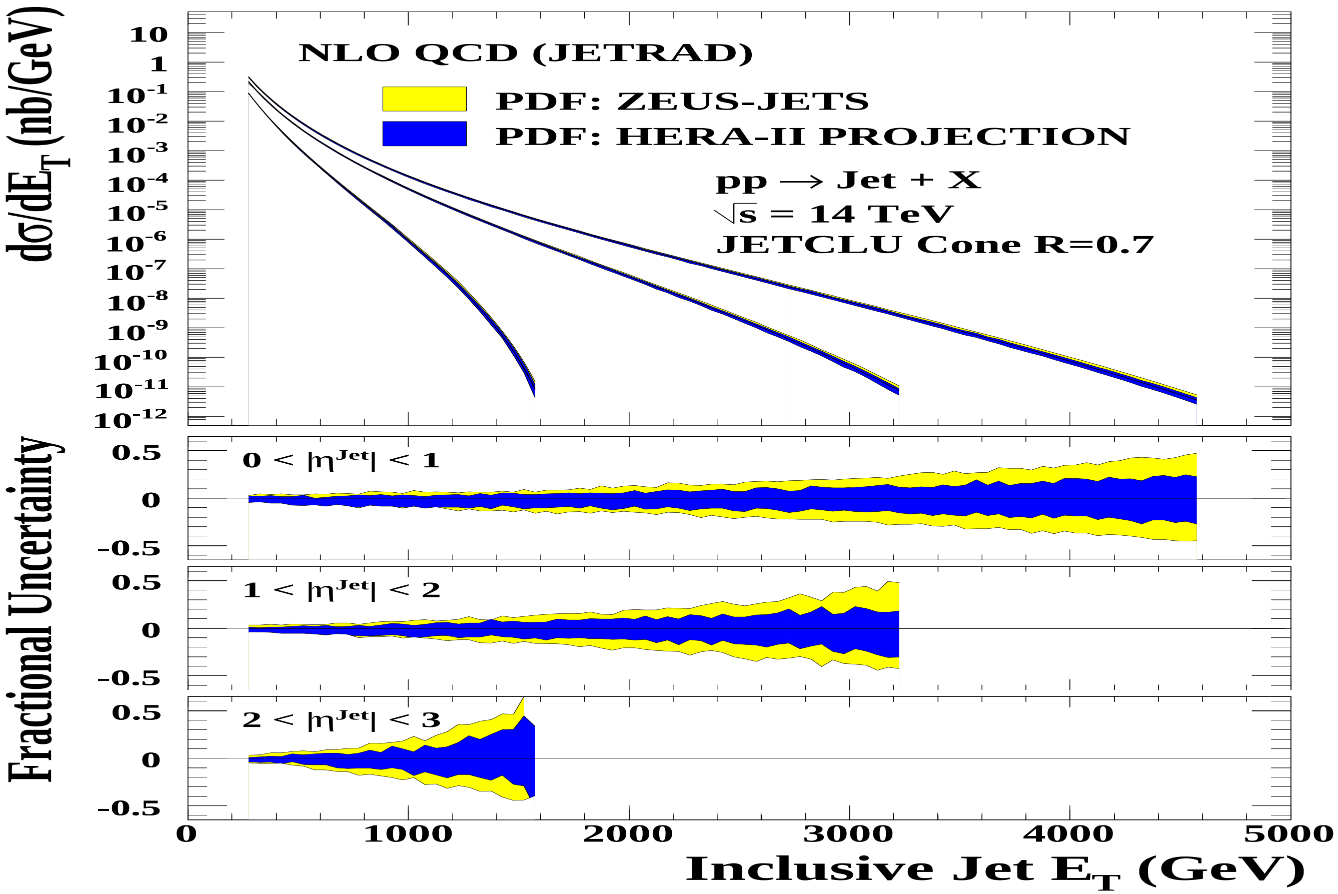


Can we know the high-x gluon better?

And how might this impact on LHC high-ET jet cross-sections?

HERA now in second stage of operation (HERA-II)

HERA-II projection shows significant improvement to high-x PDF uncertainties



And will we be able to use LHC data itself to improve the situation?

Recently grid techniques have been developed to NLO cross-sections in PDF fits (e.g ZEUS-JETs fit)

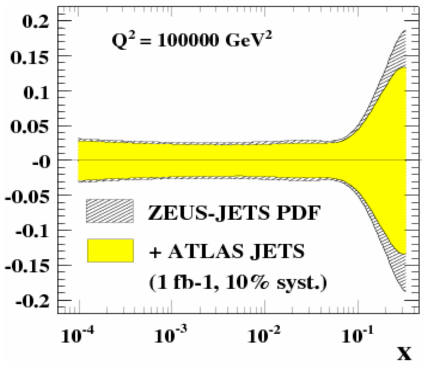
This technique can be used for LHC high-ET jet cross-sections

Use data at lower PT and higher η-where new physics is not expected

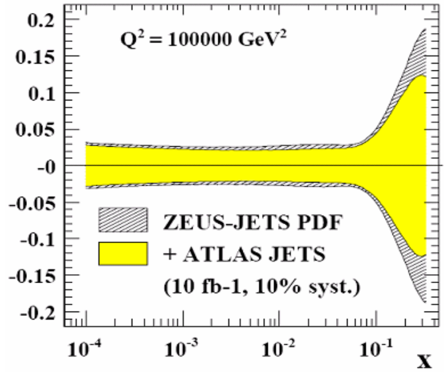
•Grids were generated for the inclusive jet cross-section at ATLAS in the pseudorapidity ranges $0<\eta<1$, $1<\eta<2$, and $2<\eta<3$ up to pT=3TeV (NLOJET).

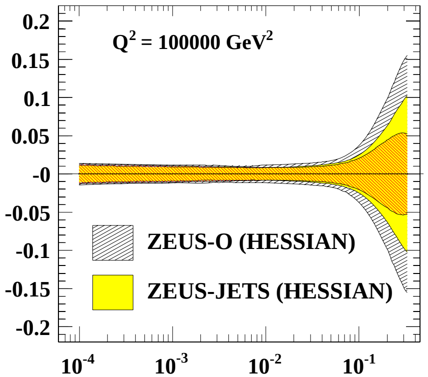
•In addition pseudodata for the same process was generated using JETRAD [4].

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

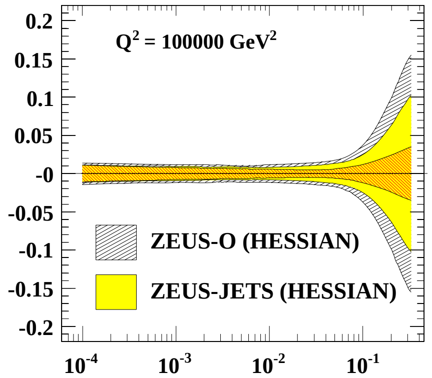


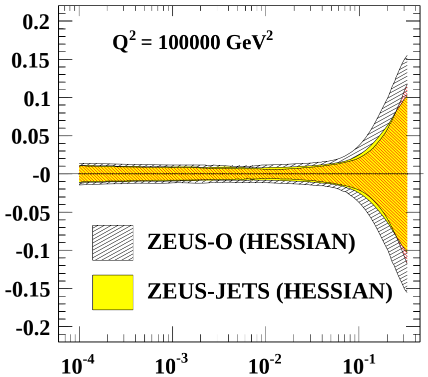
Impact of increasing statistics





Impact of decreasing experimental systematic uncertainty

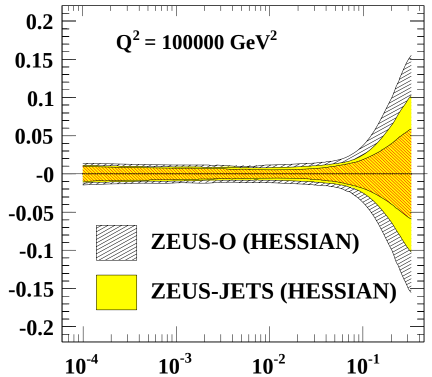




Impact of decreasing experimental correlated systematic uncertainty

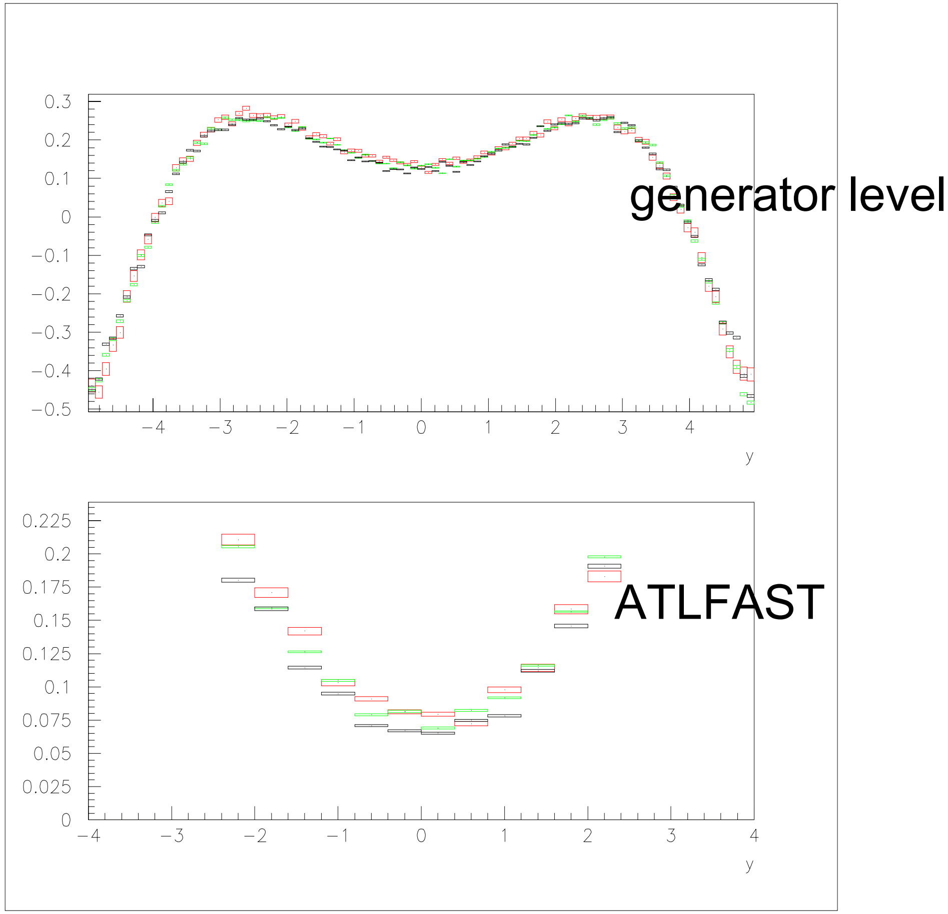
Challenging!

Can we decrease Jet Energy Scale systematic to 1%?



Summary

- PDF uncertainties can compromise both precision SM physics and BSM discovery physics
- QCD calculations may need to be extended
- Challenge to experimentalists is in controlling systematics



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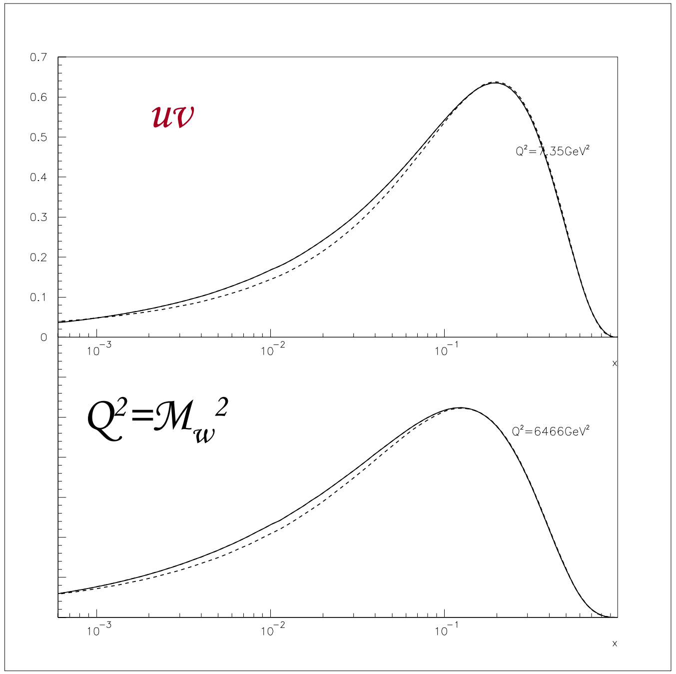
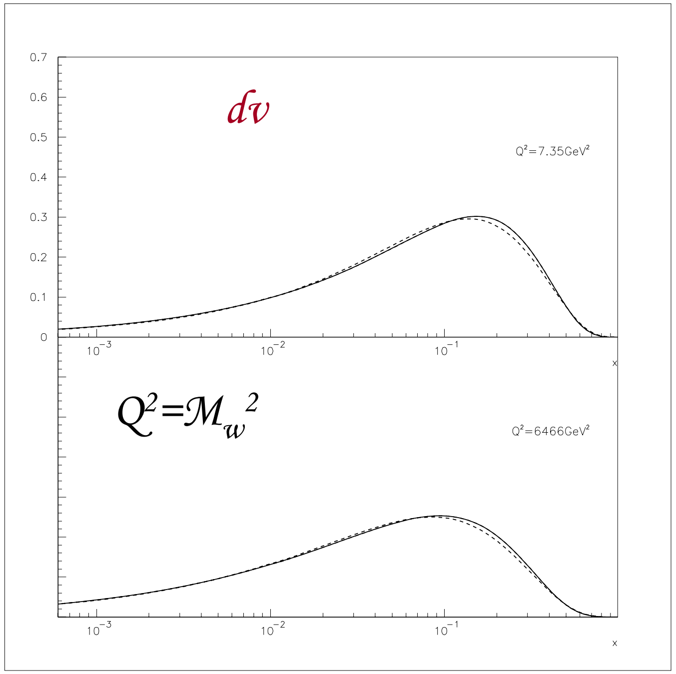


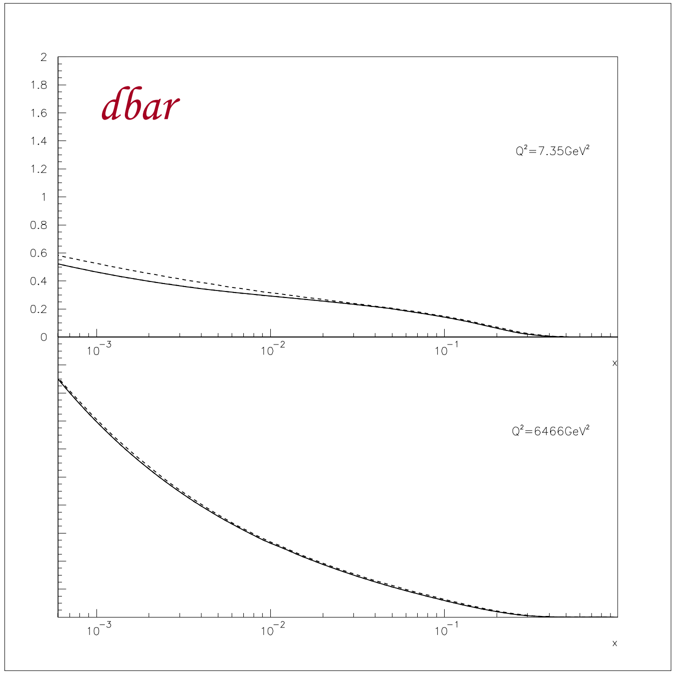


x- range affecting W asymmetry in the measurable rapidity range

MRST and CTEQ uv – dv distributions are significantly different : at Q2=MW2 and x~0.006

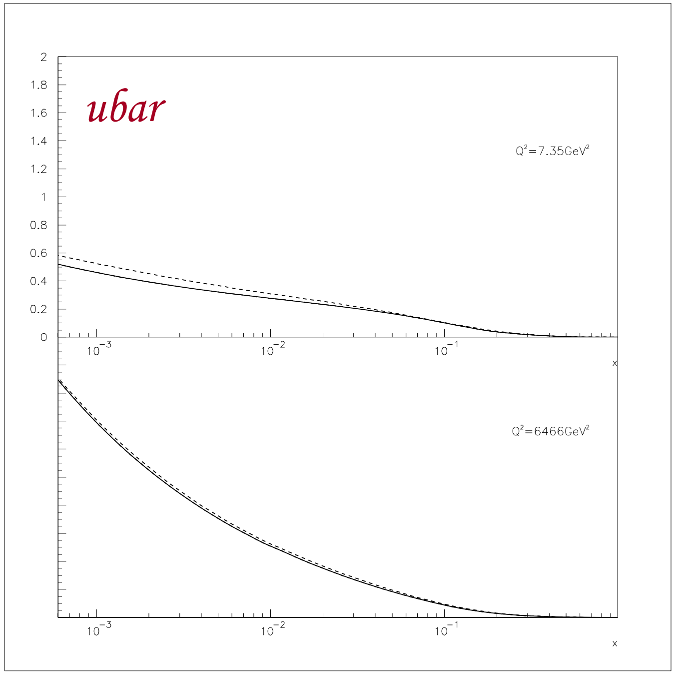
CTEQ: uv=0.17, dv=0.11, uv-dv=0.06

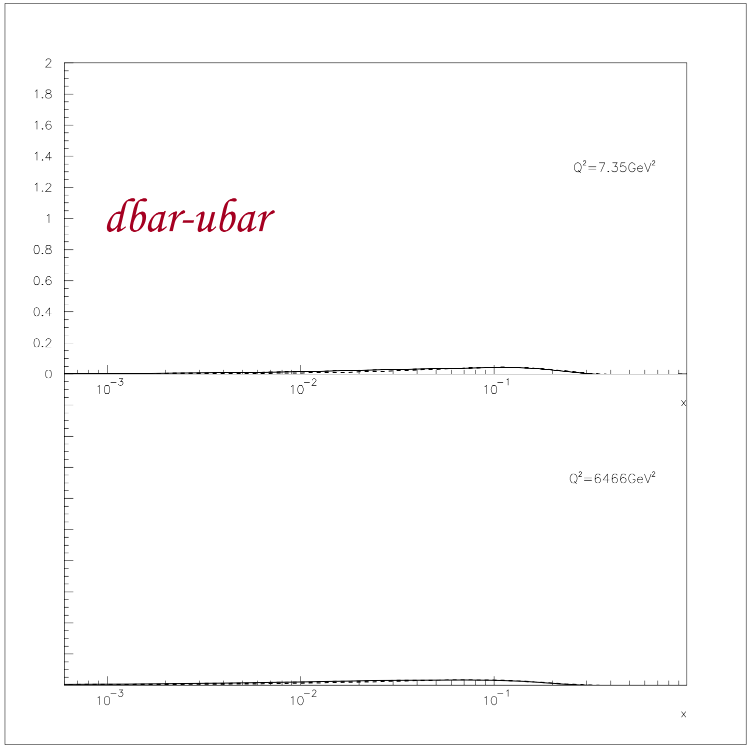
MRST: uv=0.155, dv=0.11,uv-dv=0.045



CTEQ6.1 ————————

MRST02 - - - - - - - - - - -



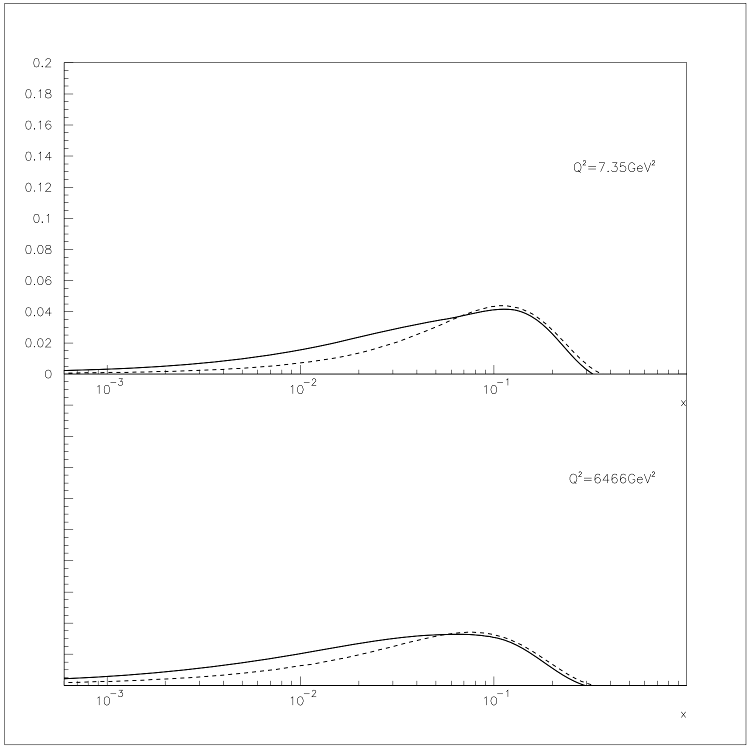


Evidence that dbar = ubar for both PDFs at small-x at Q2=MW2 and x~0.006 MRST and CTEQ dbar=ubar=0.7

So Aw=0.06/(0.28+1.4) = 0.036 CTEQ

Aw=0.045/(0.265+1.4) = 0.027 MRST…pretty close!

But perhaps we need to look more closely at the tiny difference in dbar-ubar– look at MRST and CTEQ dbar-ubar on a scale blown up by x10



Could this play a role?

Without approximations..but still LO,

$$Aw = \frac{\bar{d}\,(u_v-d_v) + d_v\,\Delta}{\bar{d}\,(u_v+d_v+2\bar{d}) - 2\bar{d}\Delta - d_v\Delta}$$

Where Δ=dbar-ubar=0.016 for CTEQ

$$Aw = \frac{0.7x(0.06) + 0.11x0.016}{0.7X(1.68) - 2x0.7x0.016-0.11x0.016}$$

And Δ=0.010 for MRST

$$AW=\frac{0.7x(0.045) + 0.11x0.011}{0.7x(1.665) - 2x0.7x0.011-0.11x0.011}$$

The terms involving the difference of ubar and dbar are simply too small to matter compared to the terms involving the valence difference.

•Data on the low-x valence distributions comes only from the CCFR/NuTeV data on Fe targets. The data extend down to x~0.01, but are subject to significant uncertainties from heavy target corrections in the low-x region.

•HERA neutral current data at high-Q2, involving Z exchange, make valence measurements on protons- but data are not yet very accurate and also only extend down to x~0.01

•Current PDFs simply have prejudices as to the low-x valence distributions - coming from the input parametrisations. The PDF uncertainties at low x do not actually reflect the real uncertainty (horse's mouth- Thorne)

•LHC W asymmetry can provide new information and constraints in the x region $0.0005 < x < 0.05$

Can we know the high-x gluon better?

HERA now in second stage of operation (HERA-II)

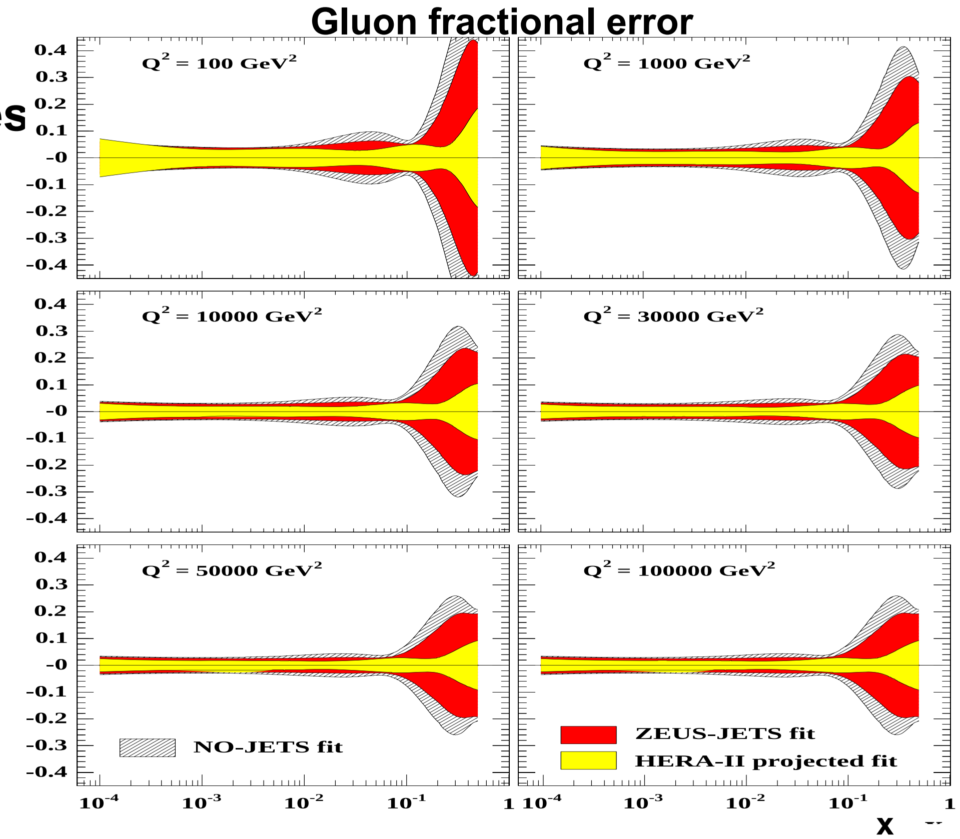
substantial increase in luminosity

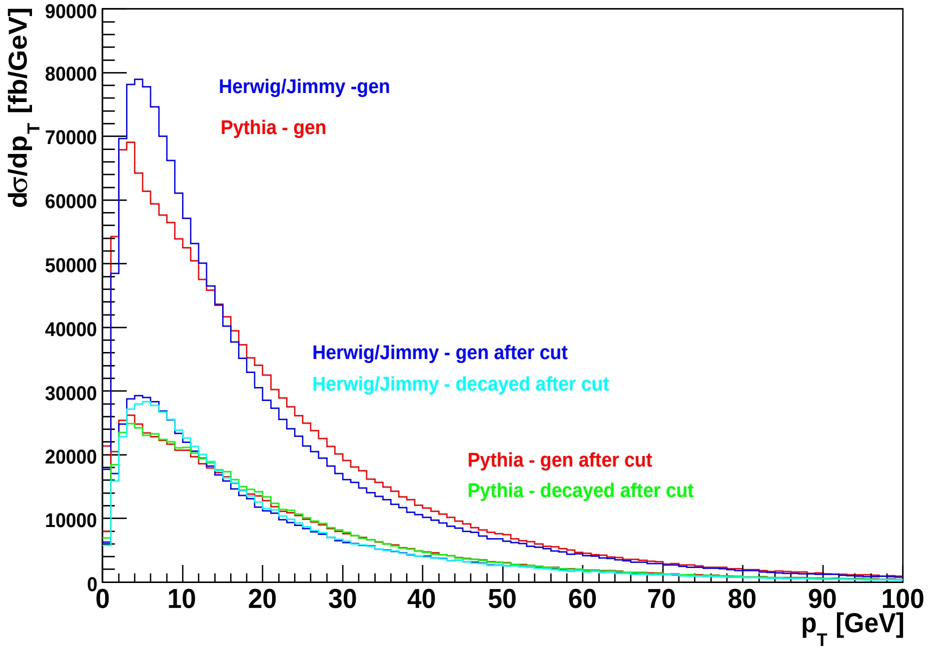
possibilities for new measurements

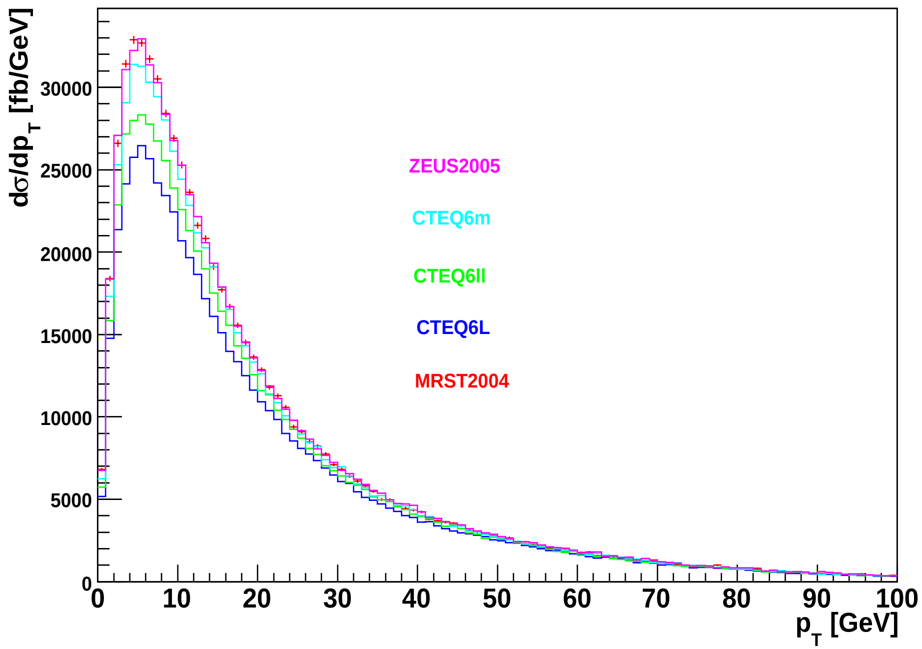
HERA-II projection shows significant improvement to high-x PDF uncertainties

⇒ relevant for high-scale physics at the LHC

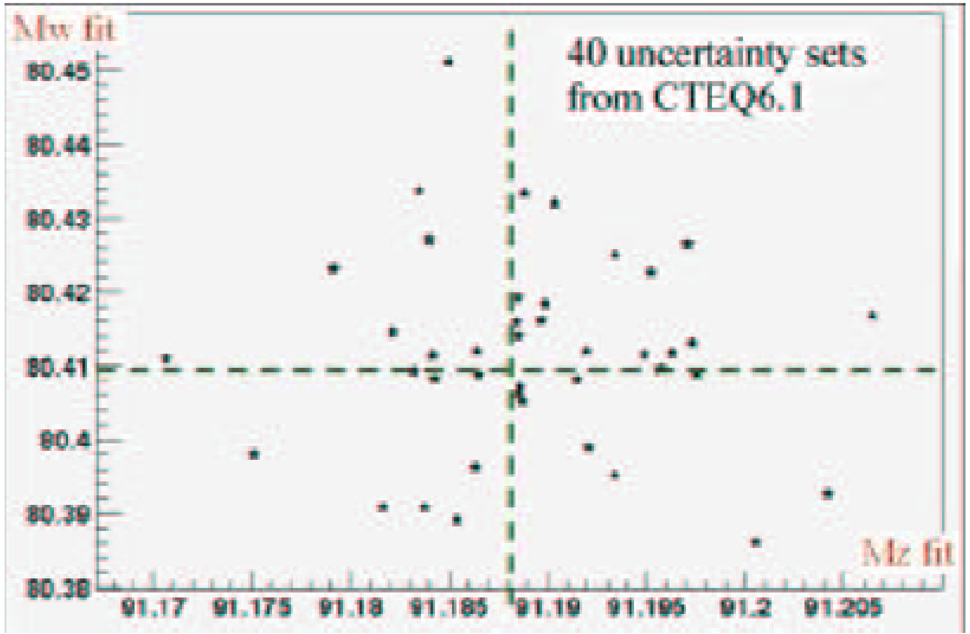
→ where we expect new physics !!




Herwig/Jimmy -gen
Pythia - gen
Herwig/Jimmy - gen after cut
Herwig/Jimmy - decayed after cut
Pythia - gen after cut
Pythia - decayed after cut
dσ/dp_T [fb/GeV]
p_T [GeV]


ZEUS2005
CTEQ6m
CTEQ6ll
CTEQ6L
MRST2004
dσ/dp_T [fb/GeV]
p_T [GeV]

PDF



Corresponding values for M_Z and M_W obtained by varying the 20 parameters of the CTEQ6.1 PDF set by $\pm 1\sigma$.

The error introduced to the M_W is estimated to 17 MeV.