Future of DIS: PDF studies at LHC

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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

W/Z production, Higgs profuction

How do PDF uncertainties affect BSM physics?

-sometimes it will only affect precision e.g. Z' in high-mass Drell-Yan

-sometimes it will compromise discovery e,g, contact interactions in highET jet production

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

So when is it all going to happen?

- **First pp collisions in Nov 2007 $\sqrt{s}$ = 0.9 TeV**
- **Summer '08 $\sqrt{s}$ = 14 TeV at Low luminosity**
- **L= 1 fb^{-1}/year (≈$10^{32}cm^{-2}s^{-1}$)**
- **End '08 $\sqrt{s}$ = 14 TeV at High luminosity**
- **L= 10 fb^{-1}/year (≈10^{33} $cm^{-2}s^{-1}$)**

LHC is W, Z, top … factory

Process	σ(nb)	Ev./10fb^{-1}
$W \to e\,\nu$	15	~10^8
$Z \to e^+ e^-$	1.5	~10^7
t tbar	0.8	~10^7
jets (p_T>200 GeV)	100	~10^9

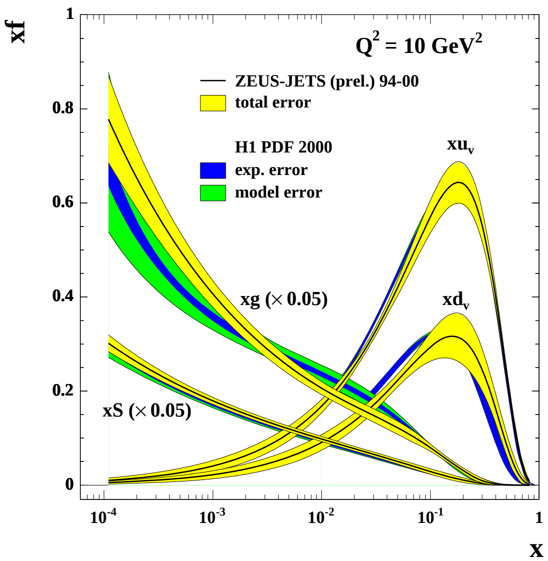
Large statistics for SM processes ⇒

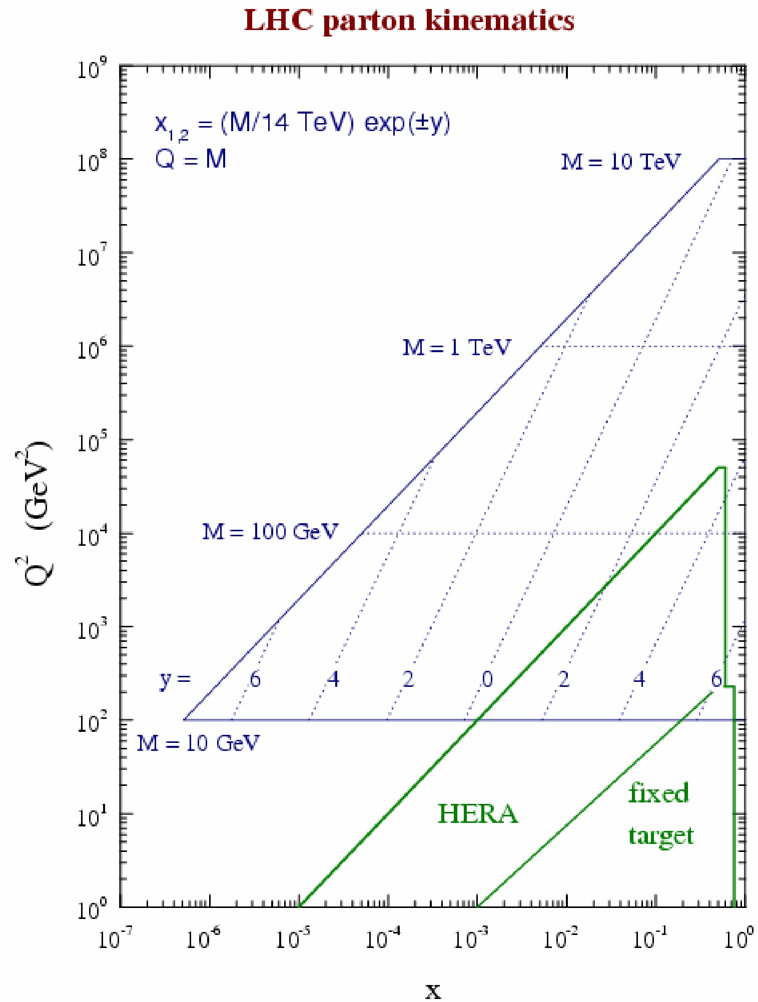
- **SM precision physics (EW, top-,b-physics, multijets…)**
- **Big potential for new physics (Higgs, Extra Dimensions, SUSY…)**

The Standard Model is not as well known as you might think

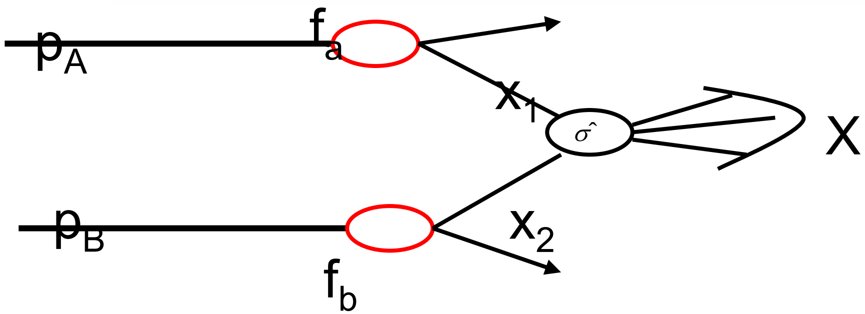
particularly in the QCD sector
and particlarly in the non-perturbative part of the QCD sector

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





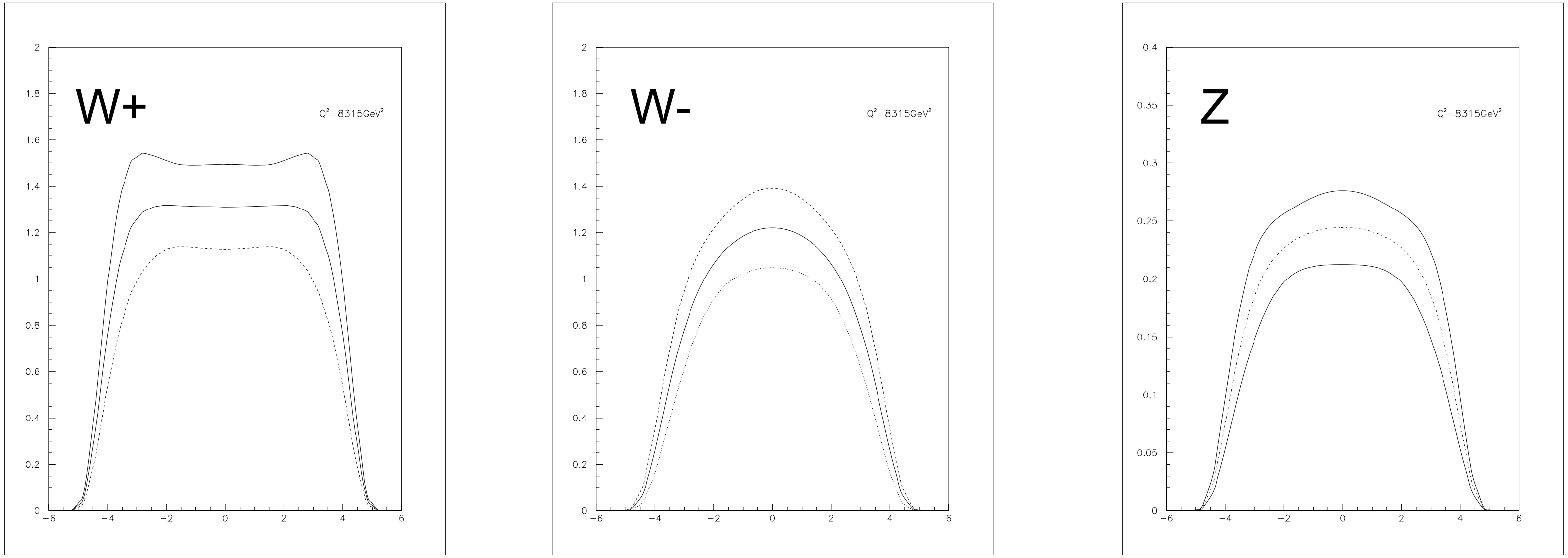
$$\sigma_X = \sum_{a,b} \int_0^1 dx_1 dx_2\, f_a(x_1, \mu_F^2)\, f_b(x_2, \mu_F^2) \times \hat{\sigma}_{ab \to X}\left(x_1, x_2, \{p_i^\mu\}; \alpha_S(\mu_R^2), \alpha(\mu_R^2), \frac{Q^2}{\mu_R^2}, \frac{Q^2}{\mu_F^2}\right)$$



The central rapidity range for W/Z production AT LHC is at low-x

(5 ×10-4 to 5 ×10-2)

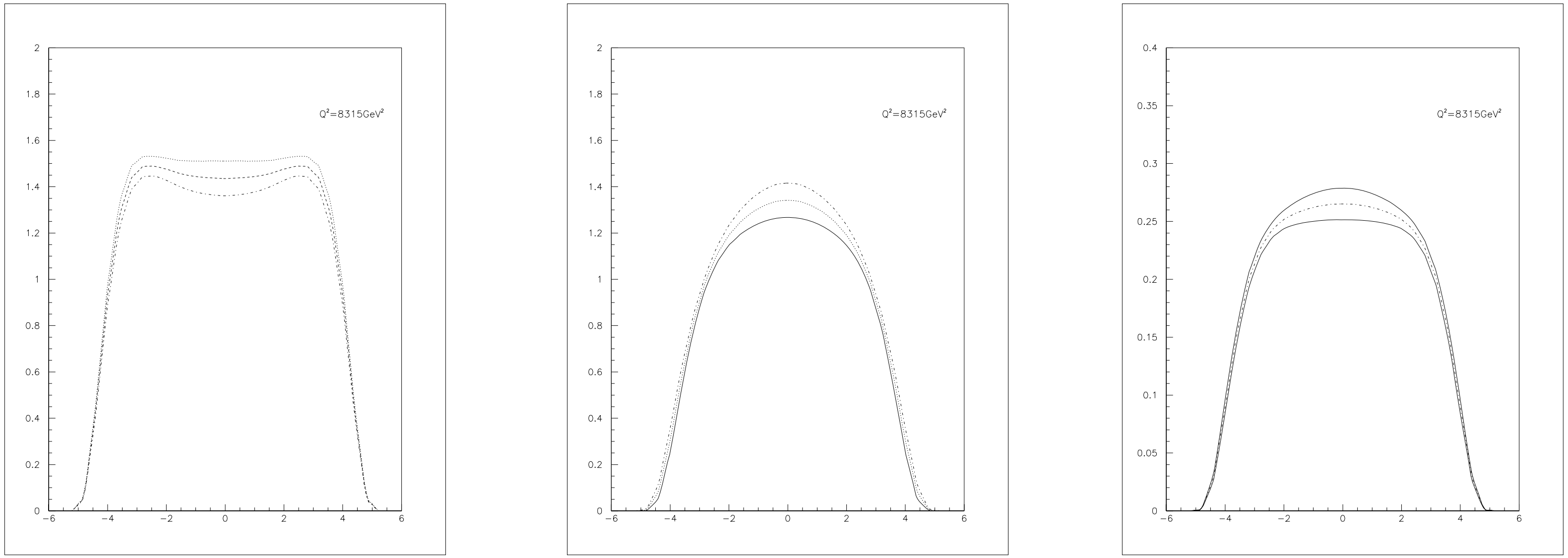
What has HERA data ever done for us?



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

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

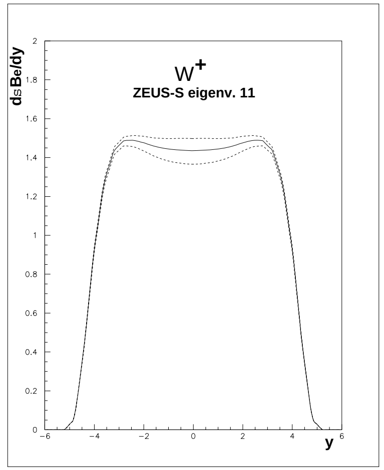
Post-HERA W+/W-/Z rapidity spectra ~ ± 5% uncertainties



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

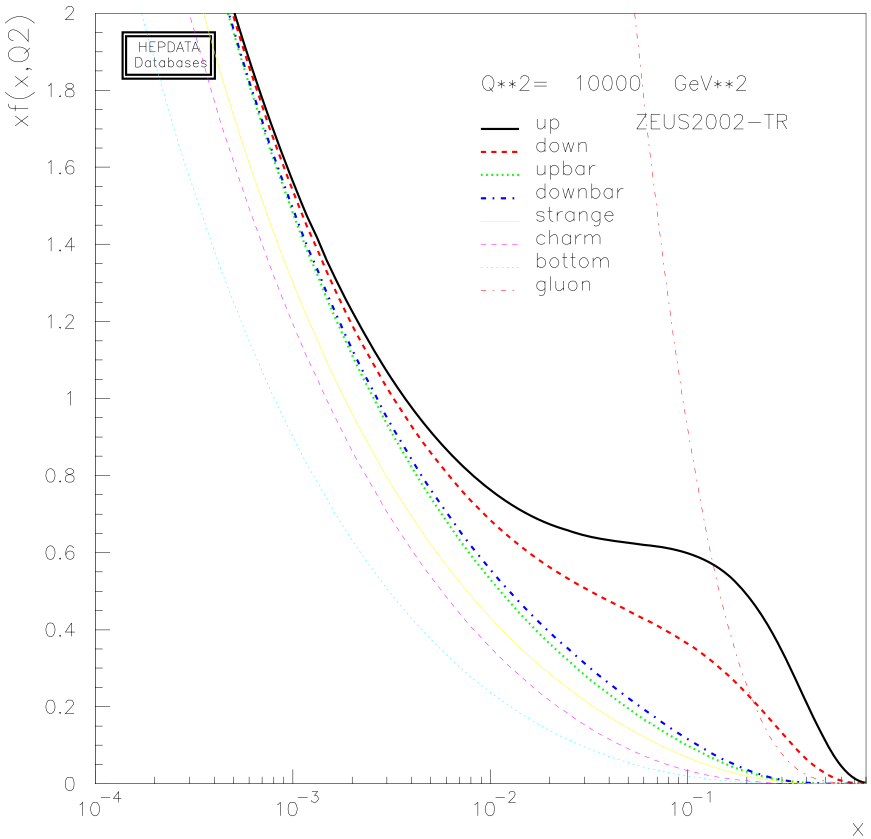


High-x gluon eigenvector

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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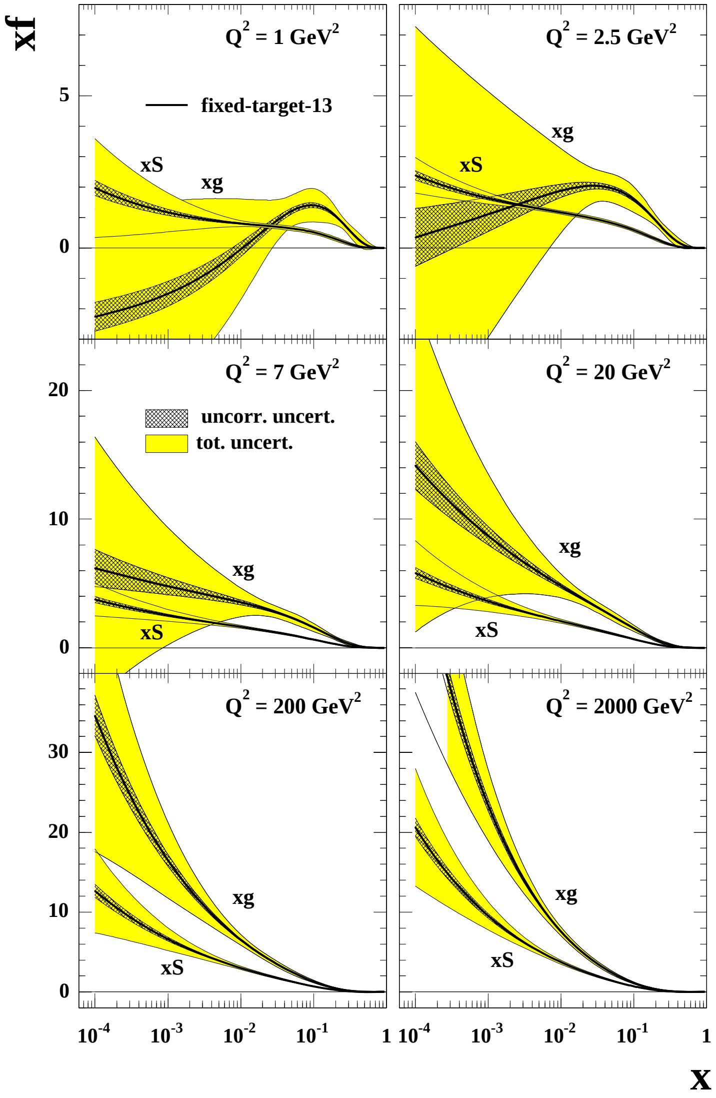
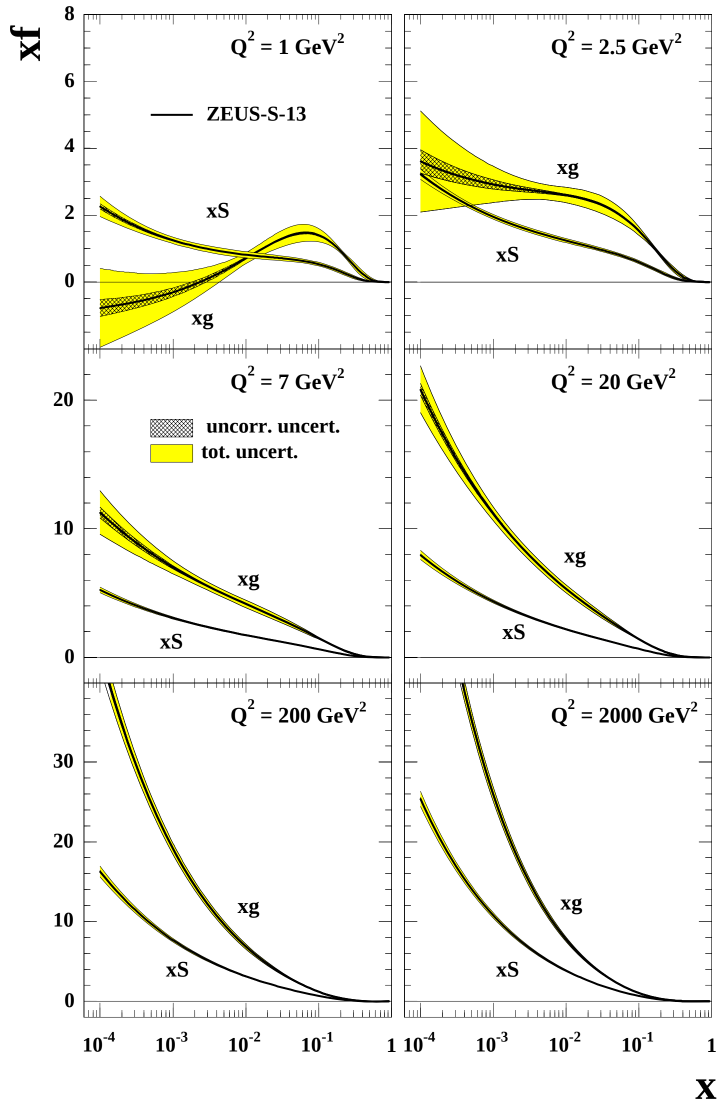
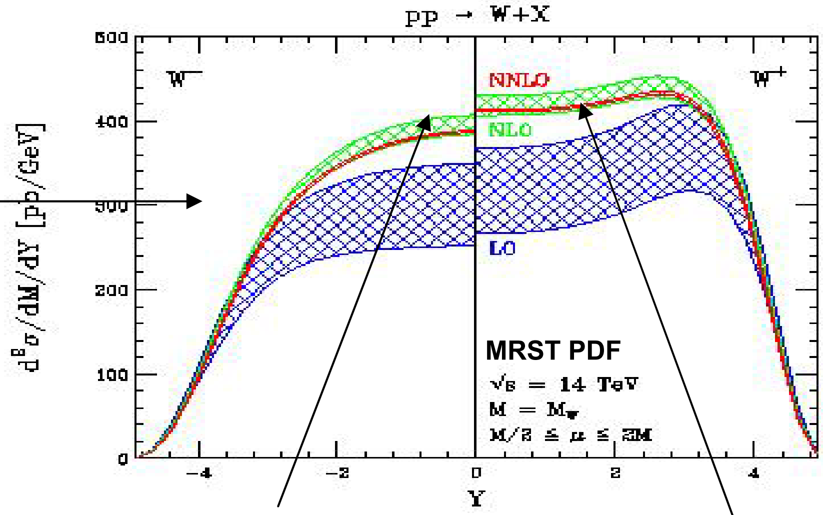


Pre-HERA sea and glue distributions



Post HERA sea and glue distributions

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



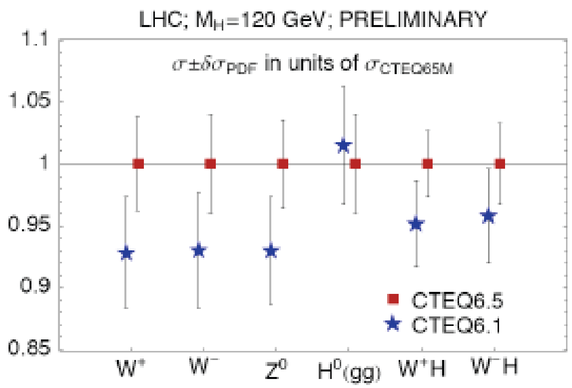
NNLO corrections small ~ few%

NNLO residual scale dependence < 1%

PDF uncertainty is 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

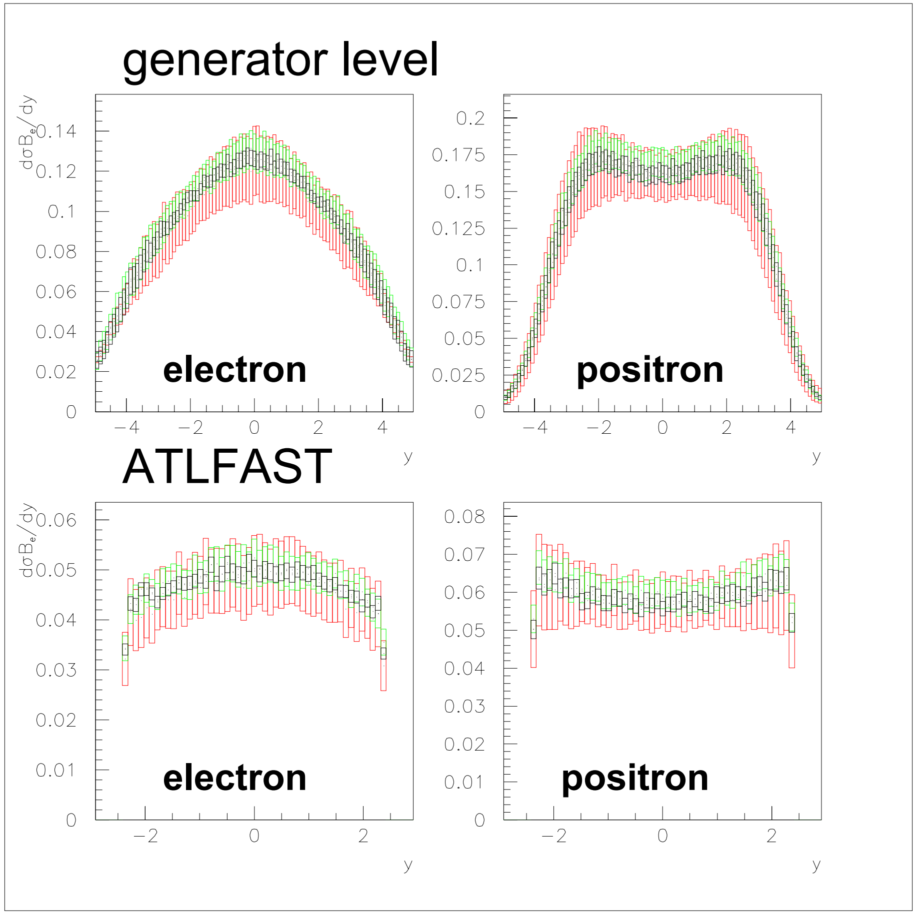
BUT **the central values differ by more than some of the uncertainty estimates.**
AND the situation just got dramatically worse. The new CTEQ6.5 estimate is 8% higher



→Not so well known

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 1000000 W→eν events ($100pb^{-1}$) with HERWIG+k-factors (checked against MC@NLO) using CTEQ6.1M ZEUS_S MRST2001 PDFs with full uncertainties from LHAPDF eigenvectors

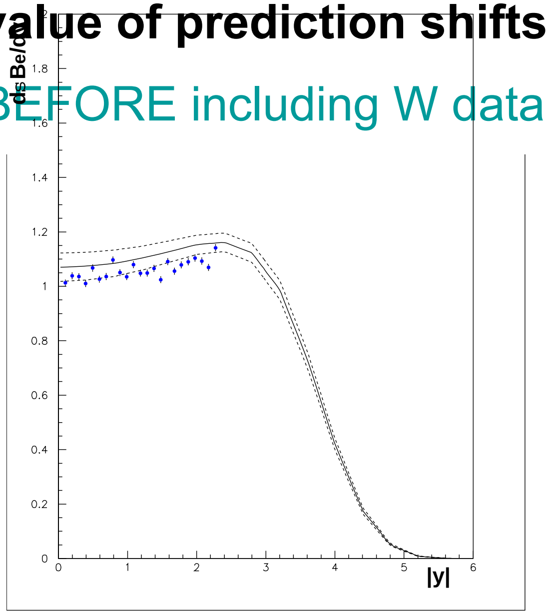
At y=0 the total uncertainty is
~ ±6% from ZEUS
~ ±4% from MRST01E
~ ±8% from CTEQ6.1

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

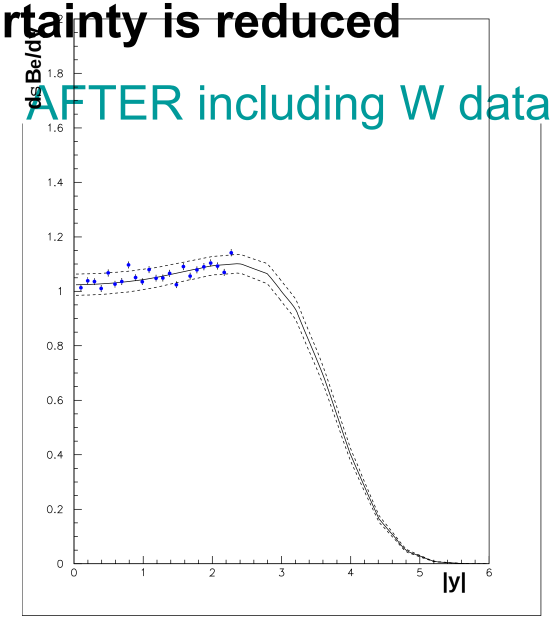
Study of the effect of including the LHC W Rapidity distributions in global PDF fits
by how much can we reduce the PDF errors with early LHC data?

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



AFTER including W data



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

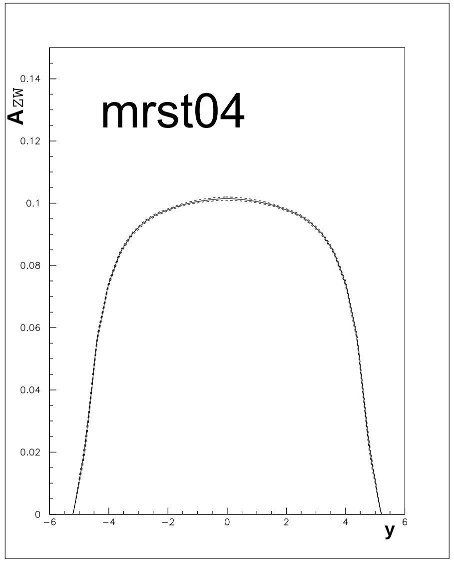
Lepton+ rapidity spectrum data generated with CTEQ6.1 PDF compared to predictions from ZEUS PDF AFTER these data are included in the fit

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

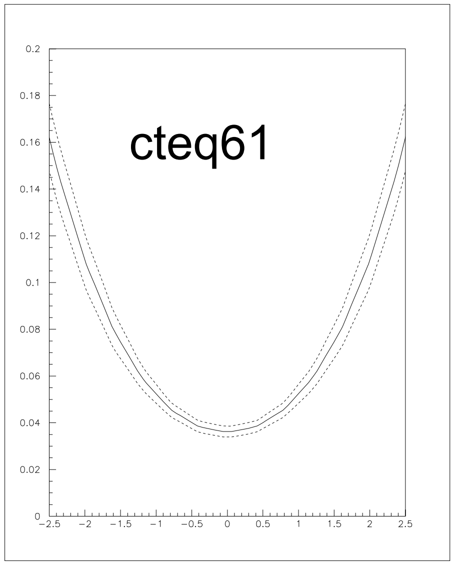


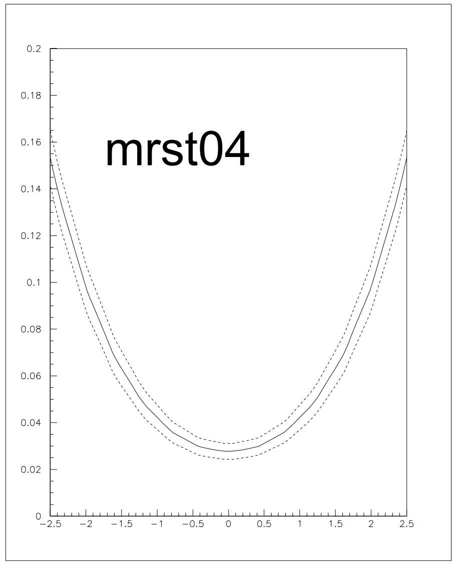
But the same is not true for the W asymmetry

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

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



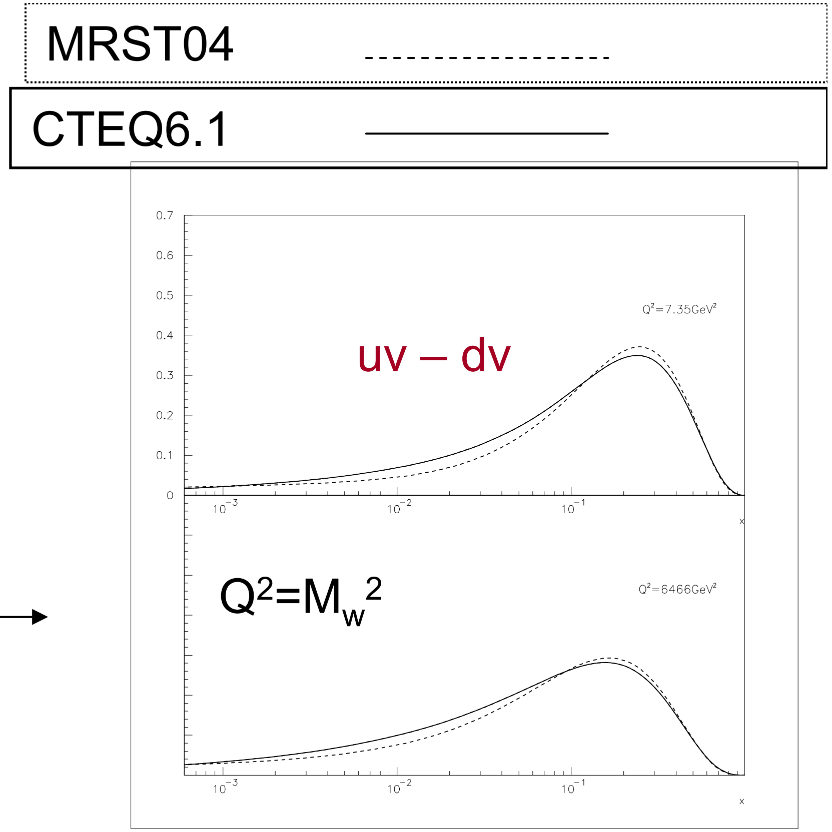


Dominantly, at LO $\quad A_W = \frac{(u\bar{d} - d\bar{u})}{(u\bar{d} + d\bar{u})}$

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

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

Actually this pretty good even quantitatively



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

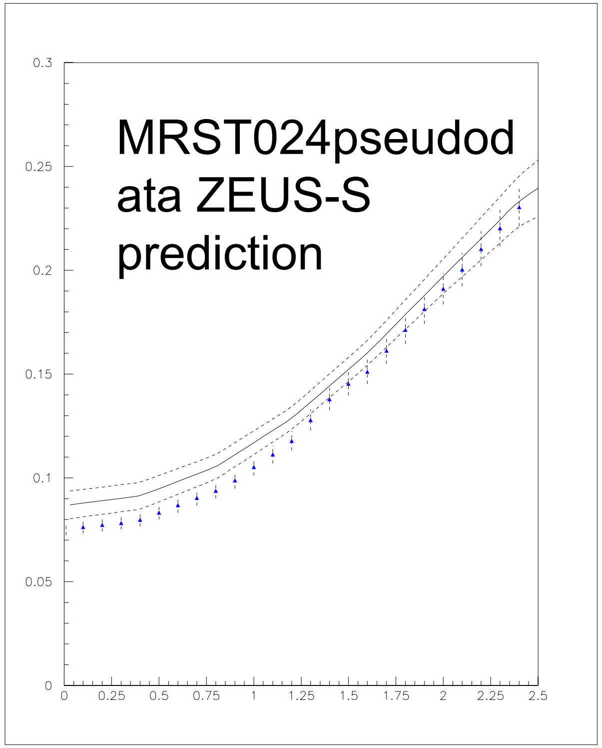
Of course we will actually measure the lepton asymmetry

x- range affecting W asymmetry in the measurable rapidity range

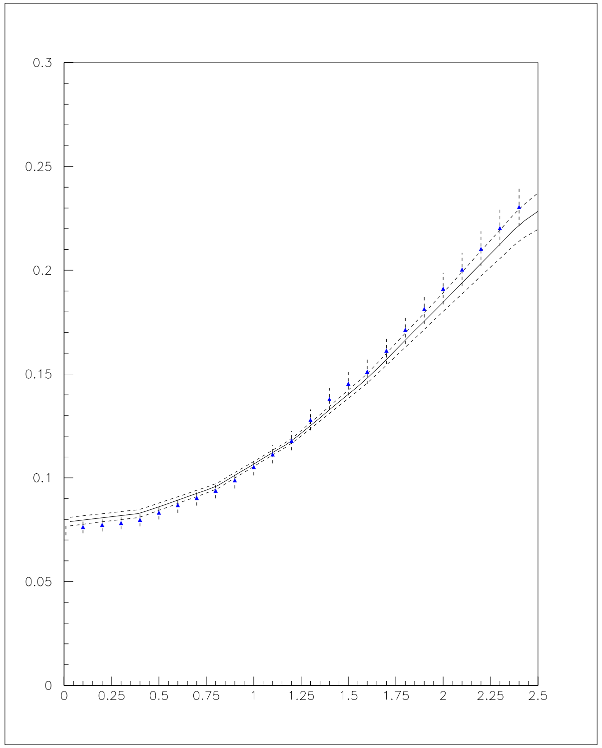
Generate data with 4% error using MRST04 PDF and then include this pseudo-data in the global ZEUS PDF fit

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

But what about valence PDFs at high-x?

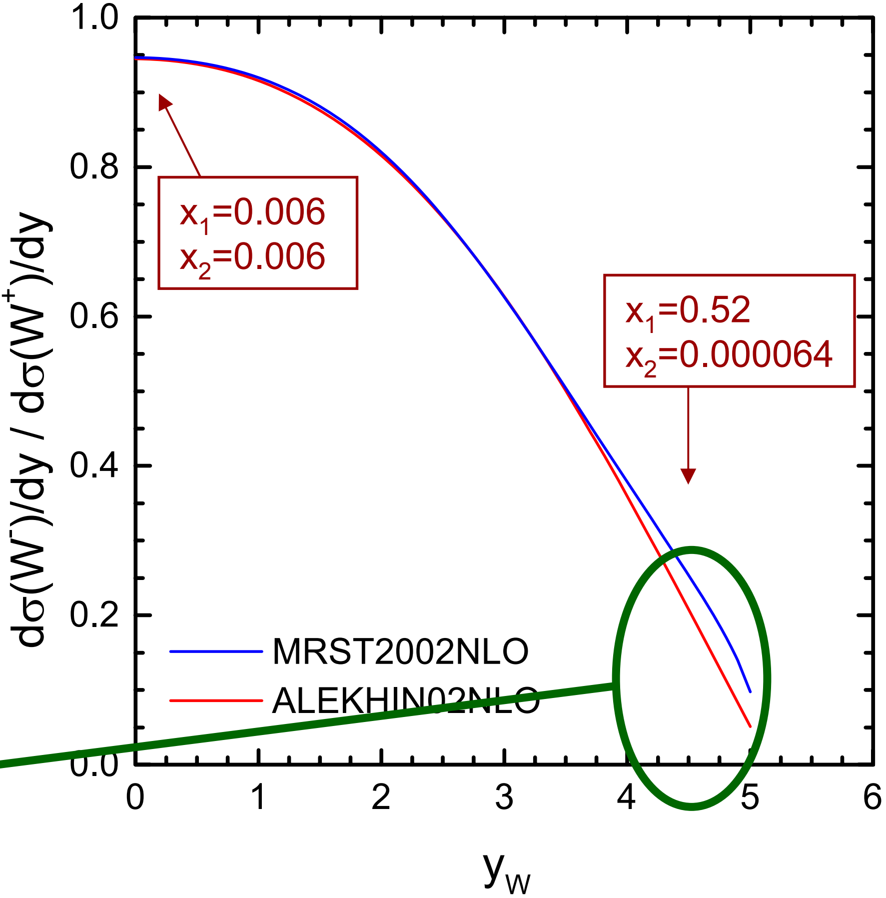
Look at W-/W+ ratio at large rapidity

$$\frac{W^-}{W^+} = \frac{u\,\bar{d}}{d\,\bar{u}}$$

Not possible for main LHc detectors BUT LHCb rapidity range 1.9 to 4.9

There is a proposal ro look at this in LHCb

sensitive to large-x d/u



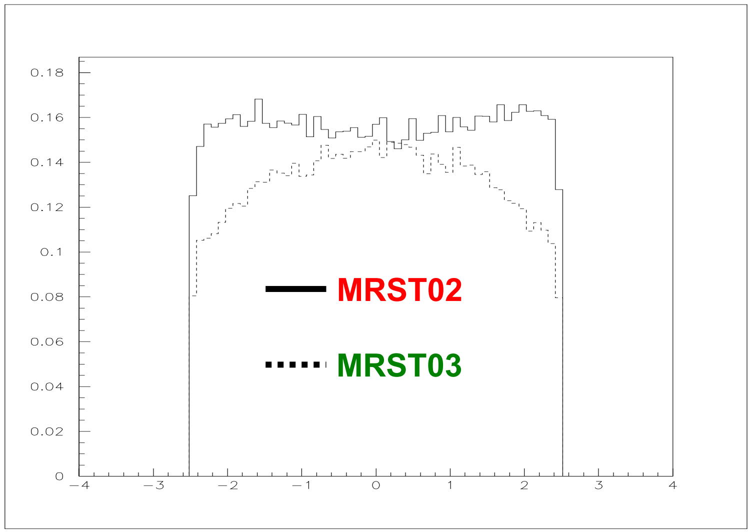
Further thoughts on W production: LHC will be a low-x machine
(at least for the early years of running)

Is NLO (or even NNLO) DGLAP good enough?

The QCD formalism may need extending at small-x

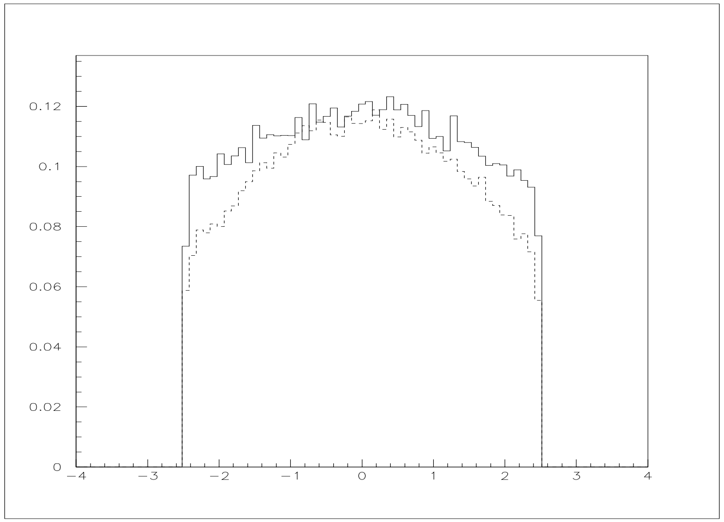
MRST03 is a toy PDF set produced without low-x data
200k events of **W+- -> e+-** generated with MC@NLO using MRST03 and MRST02

Reconstructed Electron Pseudo-Rapidity Distributions (ATLAS fast simulation)



Reconstructed e^+

6 hours running

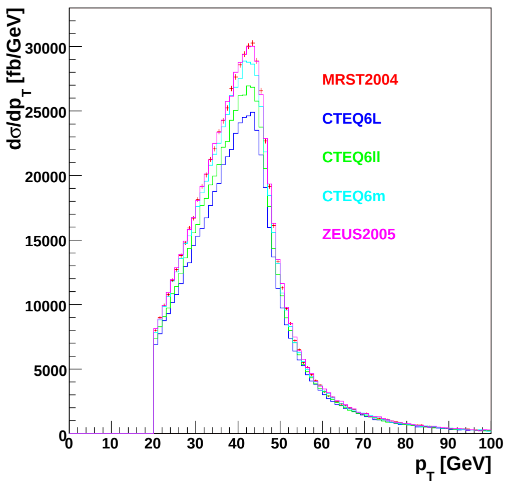


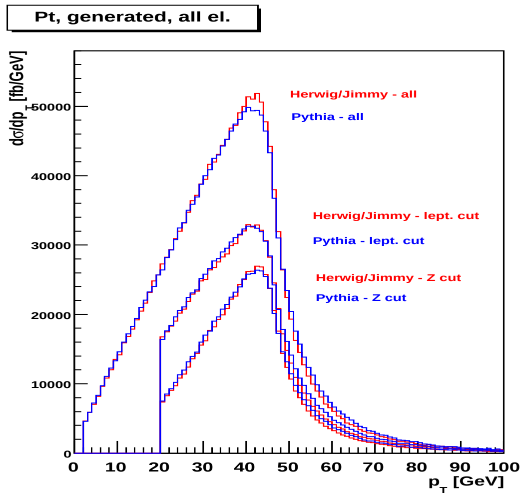
Reconstructed e^-

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

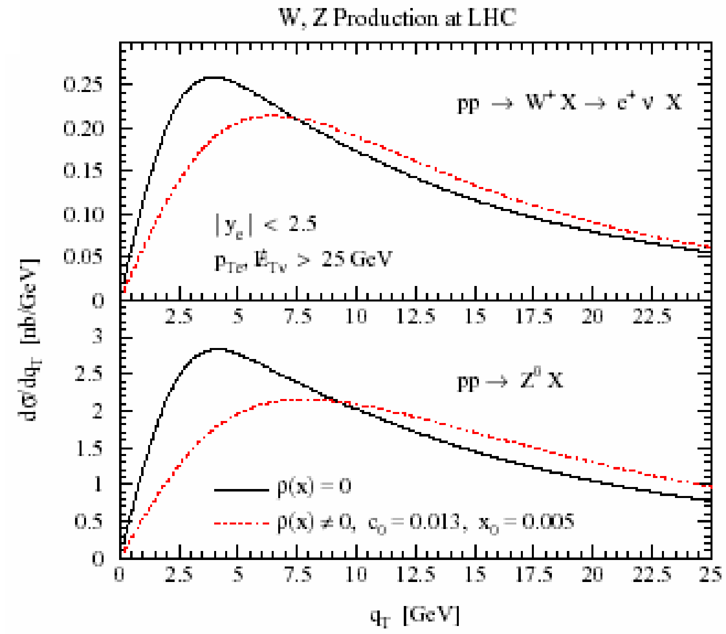
Pt spectra show PDF differences, but also show differences in modelling – e.g. PYTHIA/HERWIG differences





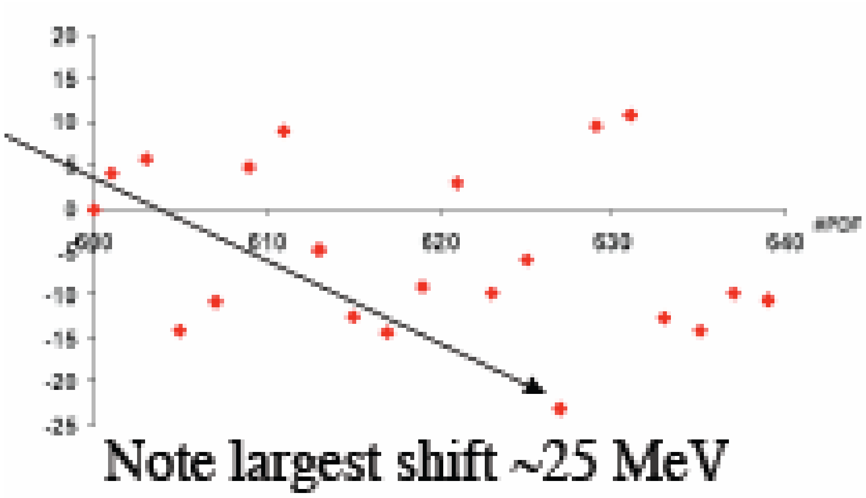
Probably needs more sophisticated treatment e.g. RESBOS.

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

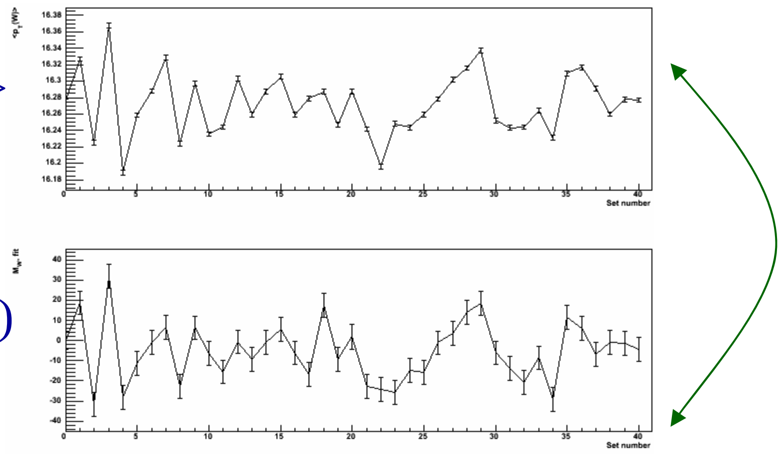
Raw dM_W from PDF uncertainties as of today, when using pt(e), is ~20 MeV



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

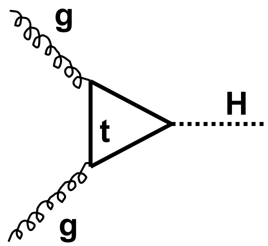
$< p_T(W) >$

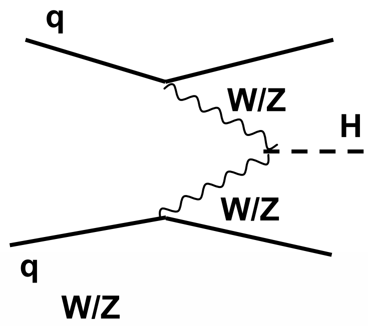
$\delta M_W(\mathrm{fit})$



Same pattern

And how do PDF uncertainties affect the Higgs discovery potential?- not too badly





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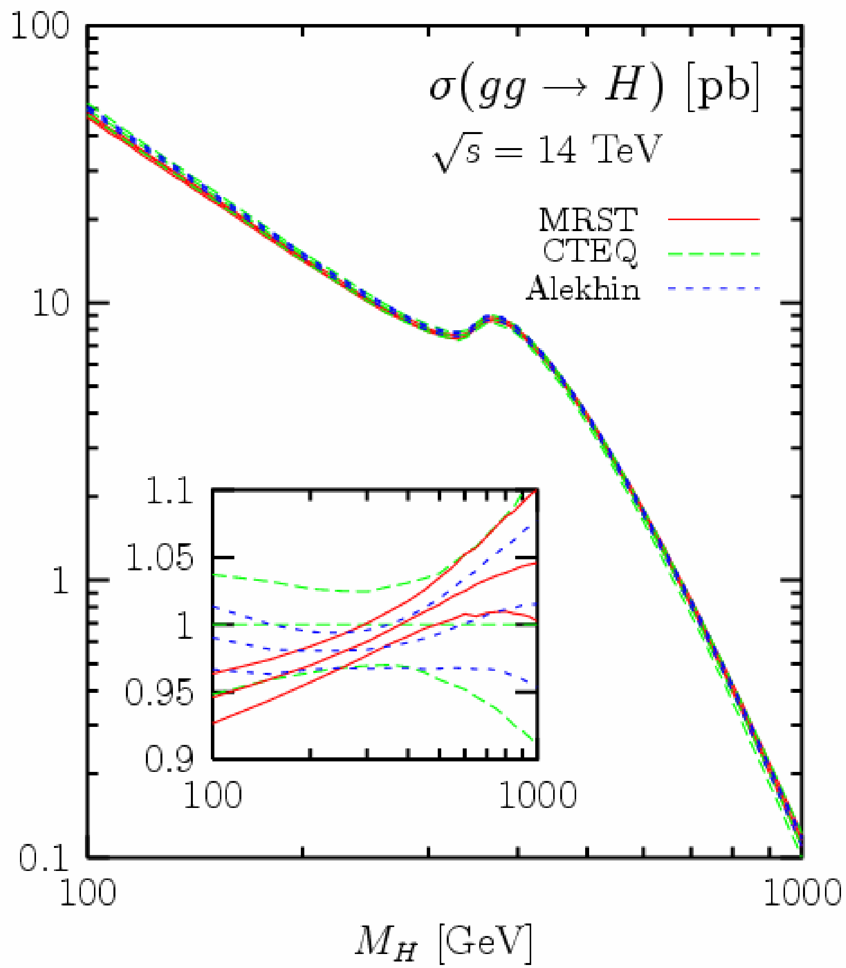
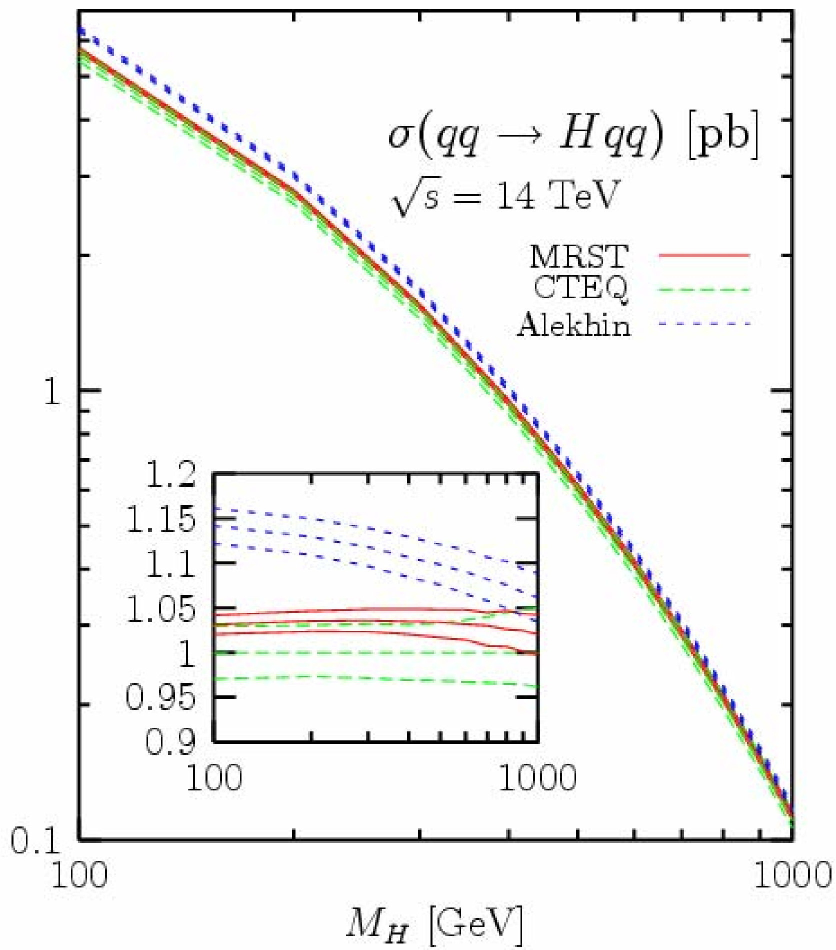
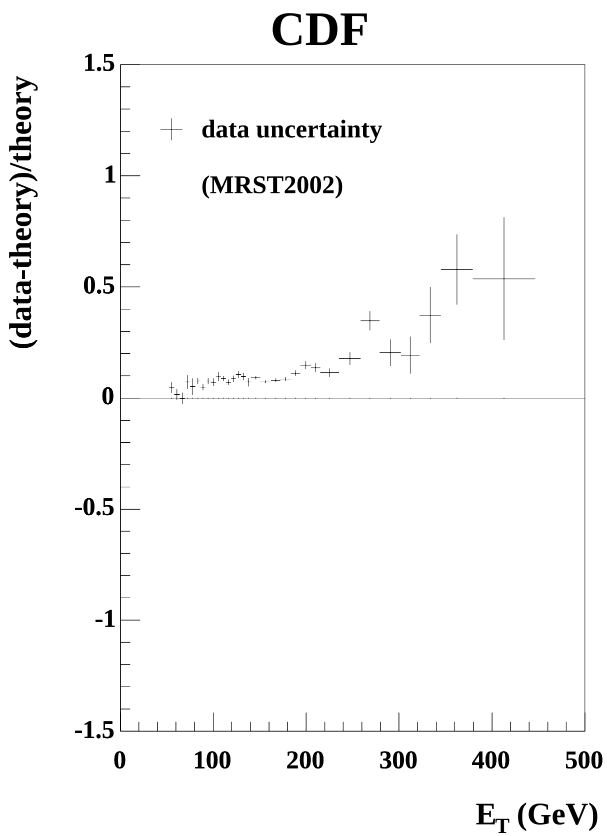
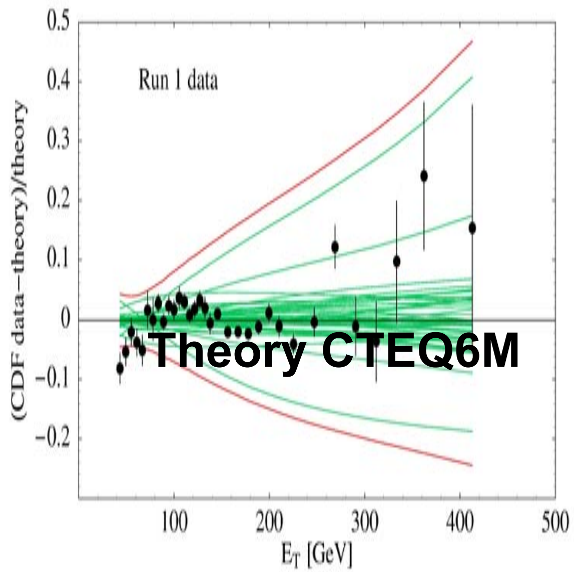




Moving on to BSM physics

Tevatron jet data were originally taken as evidence for new physics--





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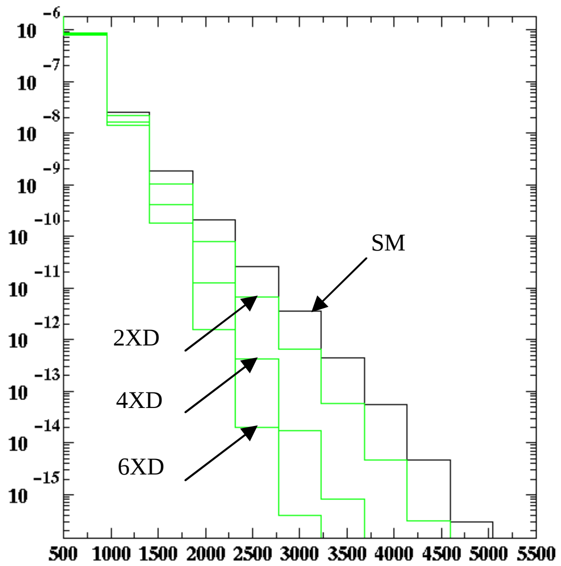
These figures show inclusive jet cross-sections compared to predictions in the form (data - theory)/ theory

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

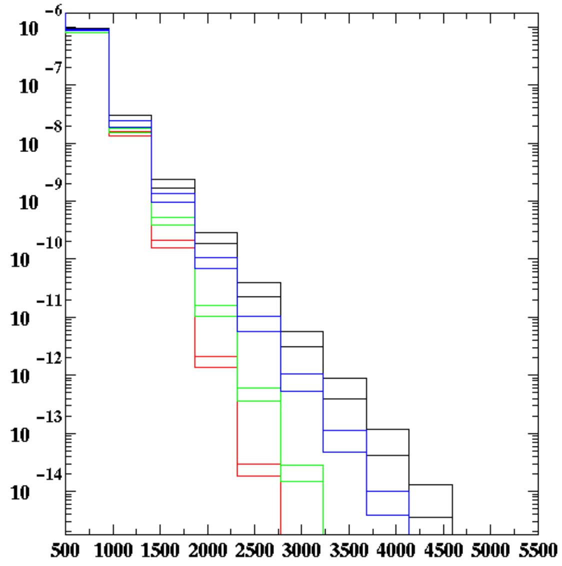
Such PDF uncertainties the jet cross sections compromise the LHC potential for discovery of physics effects which can be written as a contact interaction

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

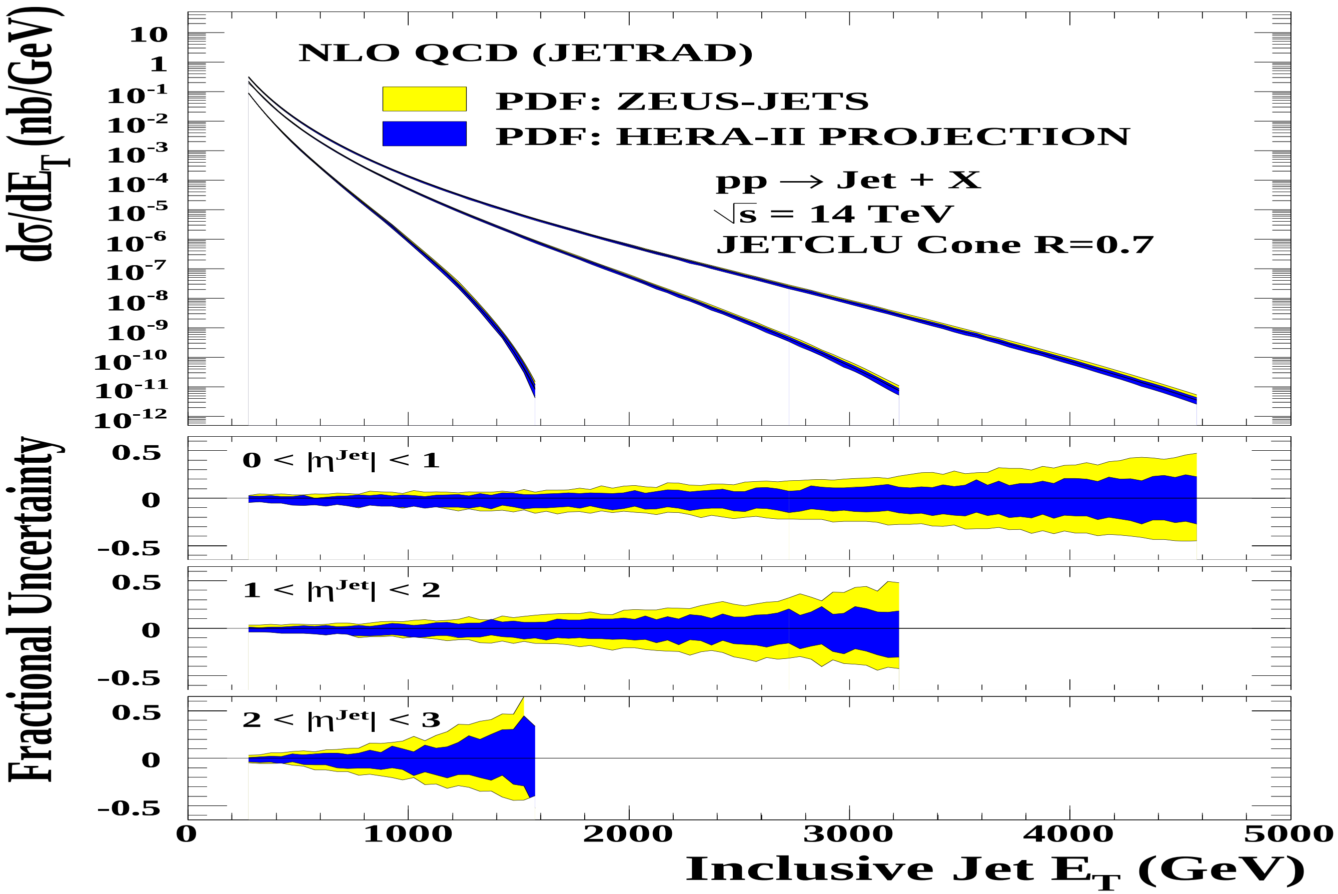


Can we know the high-x gluon better?

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**



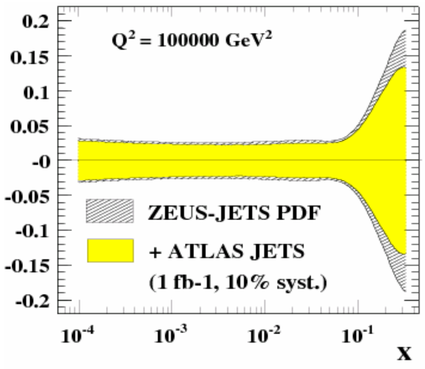
And will we be able to use LHC data itself to improve the situation?

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

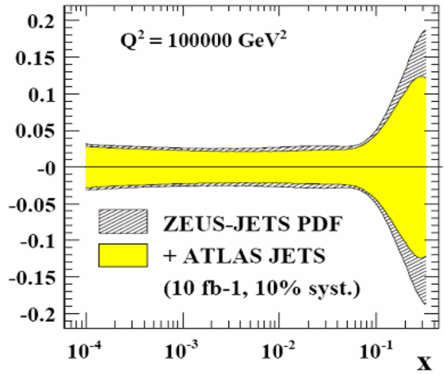
This technique can be used for LHC high-ET jet cross-sections

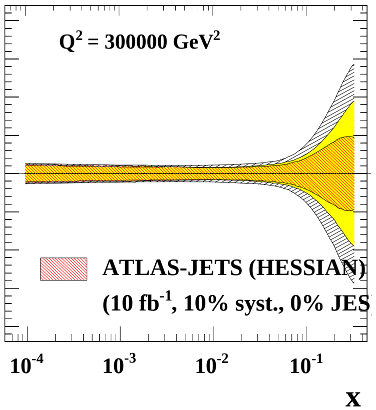
Use data at lower PT and higher η-where new physics is not expected

- 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:

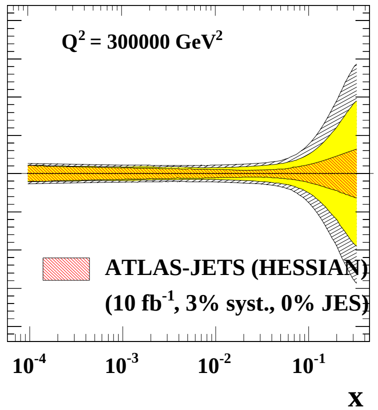


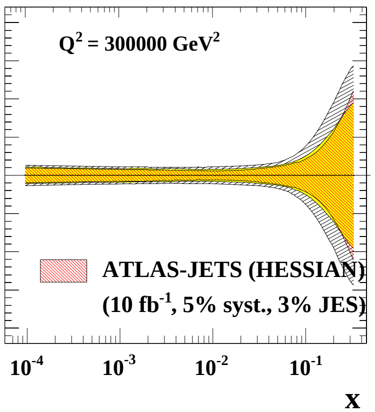
Impact of increasing statistics





Impact of decreasing experimental systematic uncertainty

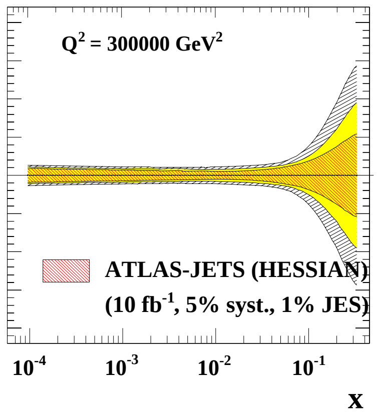




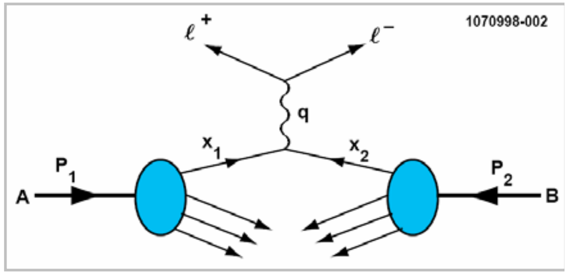
Impact of decreasing experimental correlated systematic uncertainty

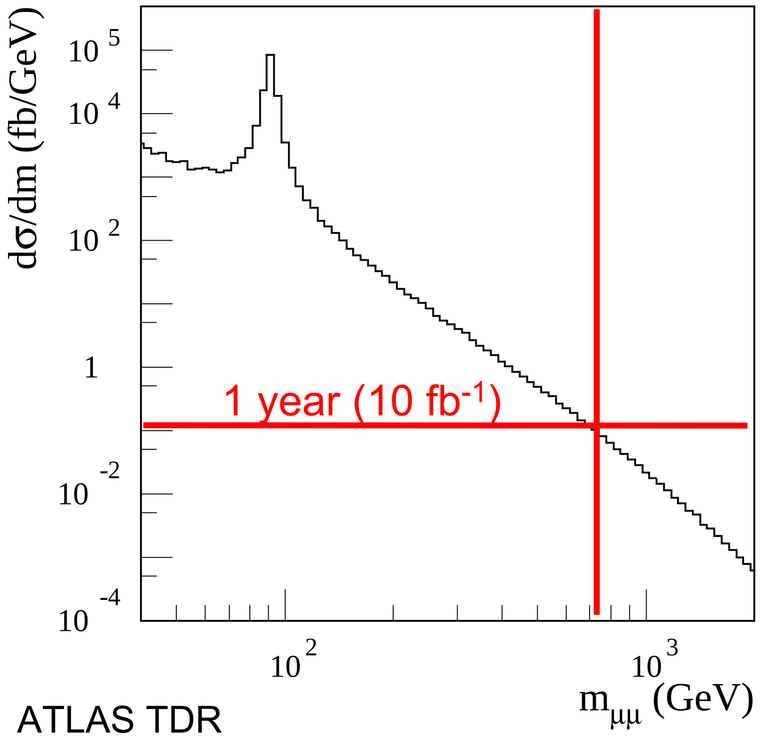
Challenging!

Can we decrease Jet Energy Scale systematic to 1%?



But not all BSM physics is strongly compromised: e.g PDF Uncertainty in High-mass Drell-Yan- won't stop us seeing Z's

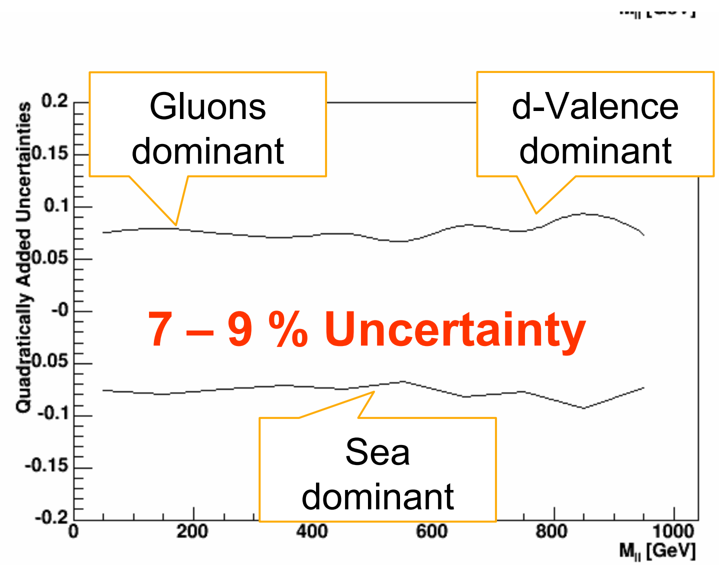




ATLAS TDR

dominant

Different mass ranges have different contributions to the PDF uncertainty



Summary

PDF uncertainties impact significantly on

Precise W/Z cross-sections, hence on use of these as luminosity monitor

(however Z/W ratio is a golden calibration measurement)

High Et jet cross-sections, hence on discovery of new physics which can be written in terms of contact interactions

PDF uncertainties will not obscure discovery of

Higgs in mass range 100-1000 GeV

High mass Z' in mass range 150-2500 GeV

Measurements from LHC itself may improve knowledge of

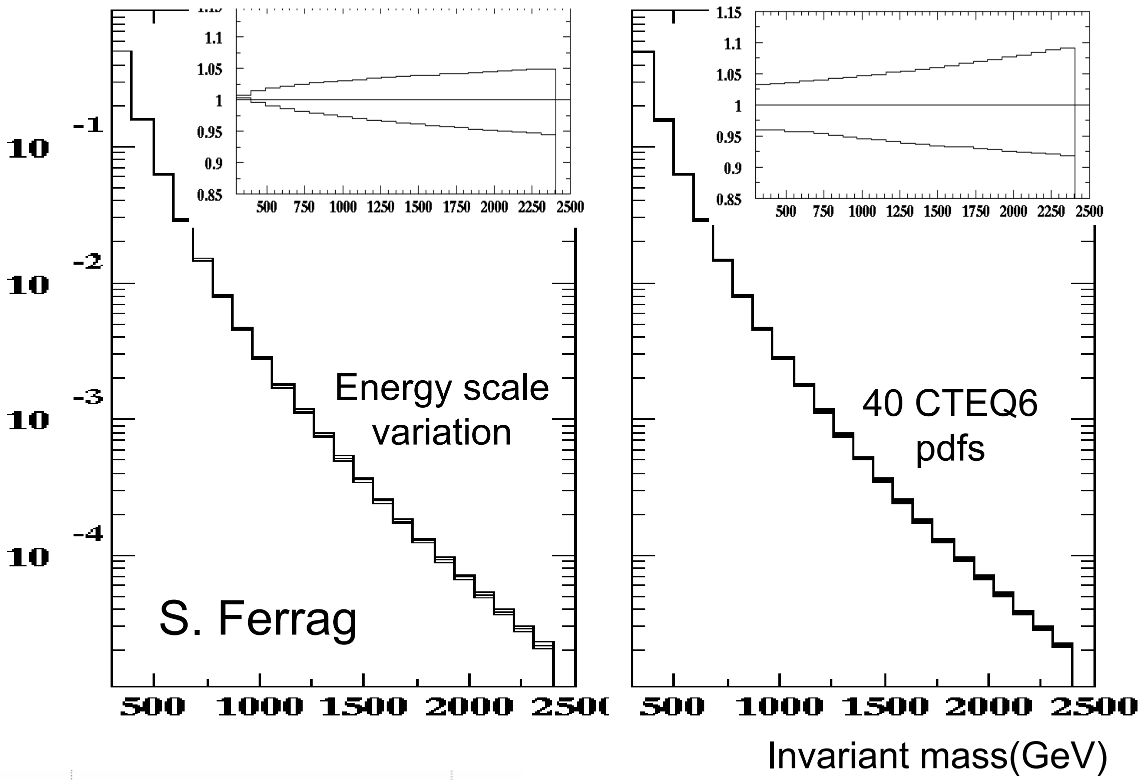
Gluon PDF at low-x (W prodn) and high-x (high ET jets)

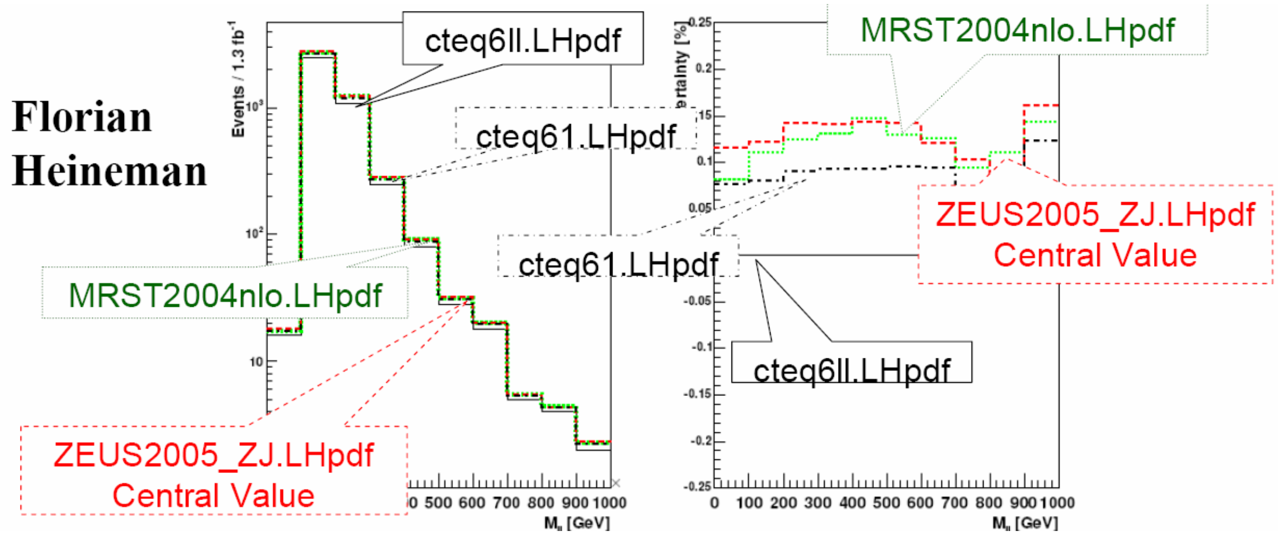
Low-x valence PDFs (and maybe higher-x) W asymmetry

extras

Standard Model side: Theoretical Uncertainties

- Generator level MC@NLO:
  σ computed by 100 GeV bin
  200 GeV < invMass< 2500 GeV
- Sources of uncertainties:
  - Factorisation and Renormalisation scales
    $1/\pi * m_t < \mu < \pi * m_t$
  - PDFs: CTEQ6





- Fully simulation level:
  Sample Zee M>150: 5114

Top vs W cross section

- Plot predictions for 40 error pdf's (CTEQ6.1) for top and W cross sections at the Tevatron and LHC
- Not much correlation at Tevatron
  - big excursions caused by eigenvector 15; high x gluon
- Anti-correlation at LHC; more momentum for gluons, less for sea quarks (at lower x) that produce W's