PDF4LHC: LHC needs

February 2008

A M Cooper-Sarkar, Oxford

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

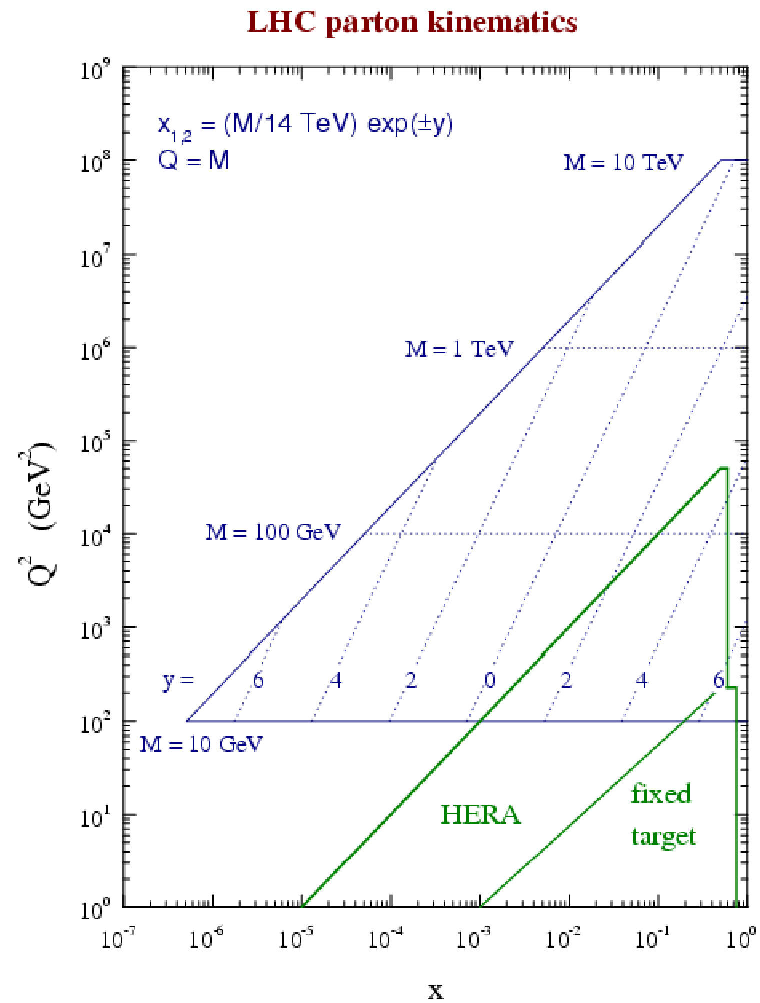
How do PDF Uncertainties affect SM physics

How do PDF uncertainties affect BSM physics?

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

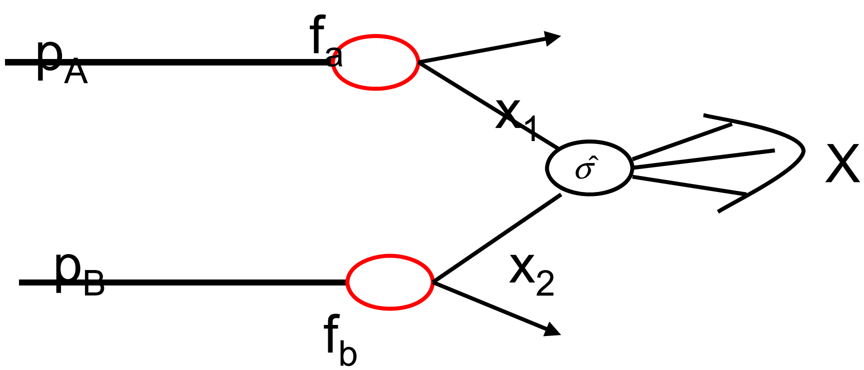
The Standard Model is not as well known as you might think

Particularly in the QCD sector
Particlarly in the non-perturbative part of the QCD sector i.e. the parton distributions
Particularly at low-x in the QCD sector



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

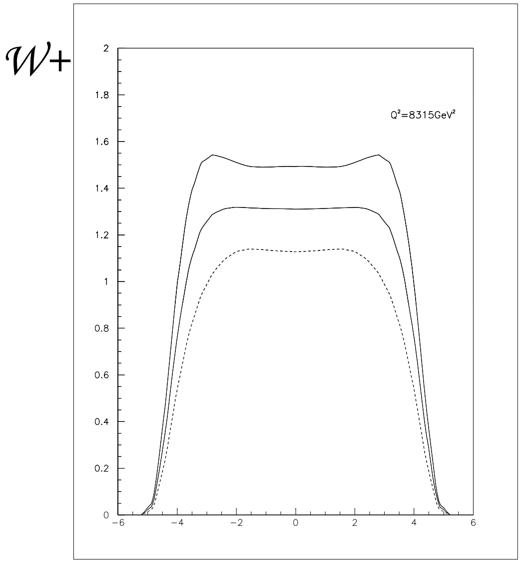
$$\sigma_X = \sum_{a,b} \int_0^1 dx_1 dx_2\, f_a(x_1, \mu_F^2)\, f_b(x_2, \mu_F^2)$$
$$\times\ \hat{\sigma}_{ab \to X}\left(x_1, x_2, \{p_i^\mu\}; \alpha_S(\mu_R^2), \alpha(\mu_R^2), \frac{Q^2}{\mu_R^2}, \frac{Q^2}{\mu_F^2}\right)$$



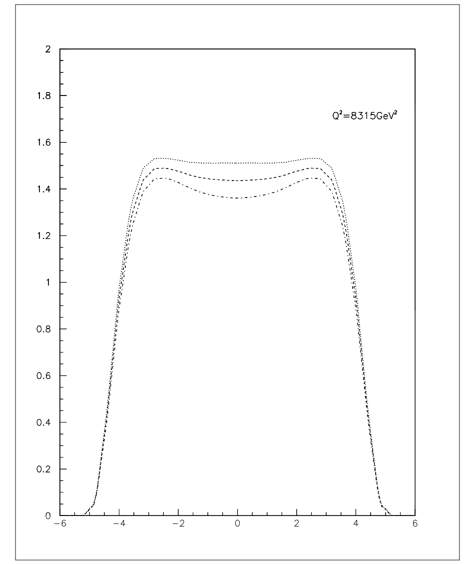
The central rapidity range for W/Z production AT LHC is at low-x

(5 ×10-4 to 5 ×10-2)

What do we think is well known: W/Z cross-sections?

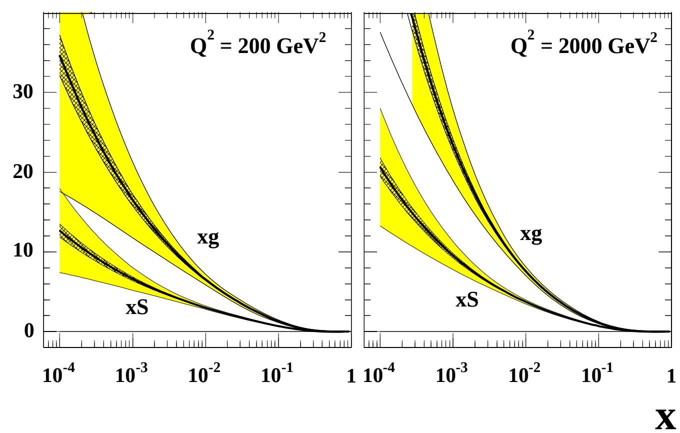


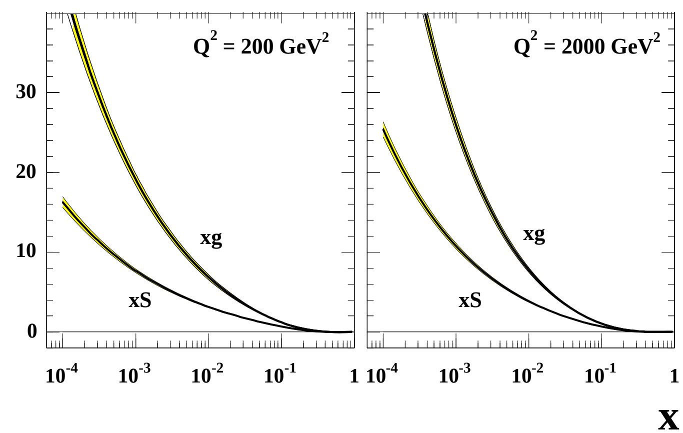
Thanks to HERA they have become better known



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

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





Tremendous improvement in our knowledge of the low-x glue and sea

At the LHC W/Z are formed by sea-sea parton interactions at low-x

And for Q2~MZ2 **the sea is driven by the gluon**

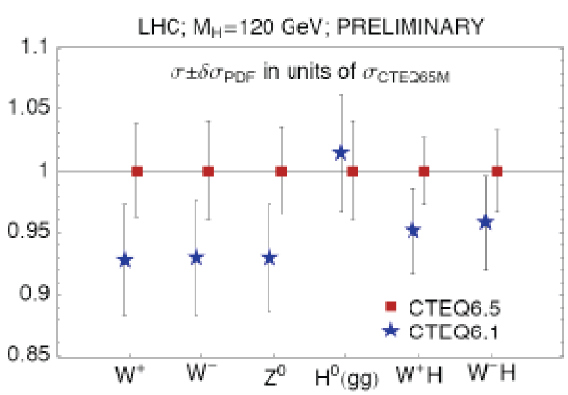
But there is still a spread between different PDF sets

PDF set	$\sigma_{W+} B_{W\to l\nu}$ (nb)	$\sigma_{W-} B_{W\to l\nu}$ (nb)	$\sigma_Z B_{Z\to ll}$ (nb)
ZEUS-2005	11.87±0.45	8.74±0.31	1.97±0.06
MRST01	11.61±0.23	8.62±0.16	1.95±0.04
MRST04	11.74	8.71	1.97
CTEQ65	12.44±0.47	9.12±0.36	2.05±0.08
CTEQ61	11.61±0.55	8.53±0.43	1.92±0.09
H1 PDF2000	11.98±0.22	8.74±0.15	1.98±0.04

MSTW08?

Massive heavy quark treatment

Massless heavy quark treatment

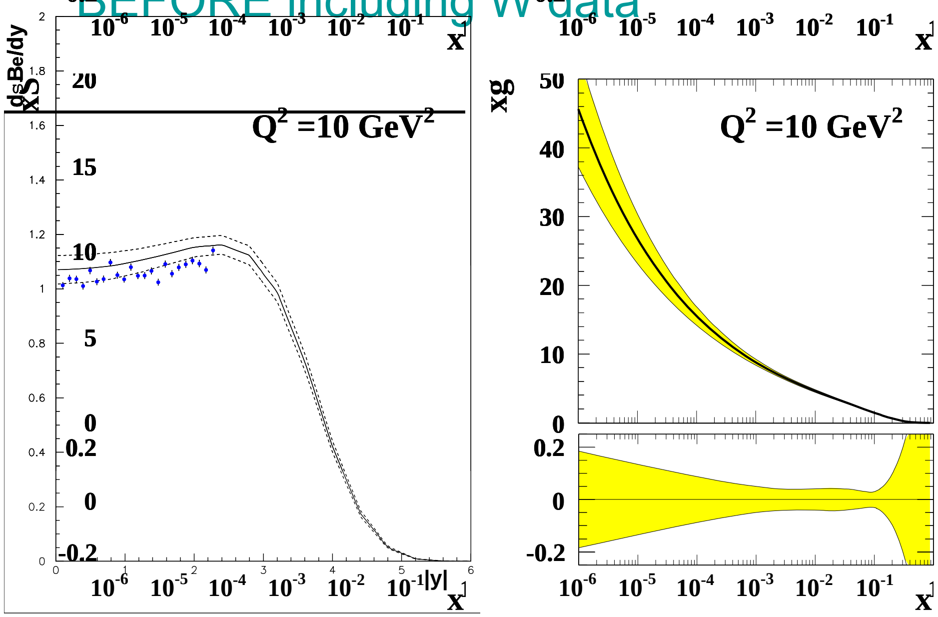


The central values differ by more than some of the uncertainty estimates.
Some differences are not just choices, massless heavy quark treatments won't do.

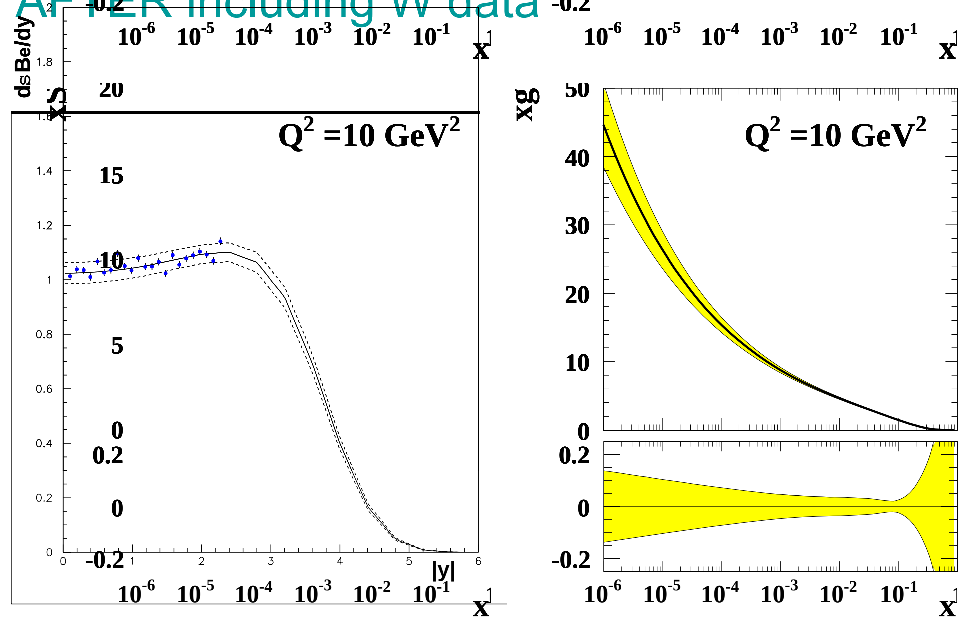
Can we improve the situation with early LHC data

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 (actually use the decay lepton spectra) **Central value of prediction shifts and uncertainty is reduced**

BEFORE including W data



AFTER including W data



e+ rapidity spectrum and gluon PDF BEFORE these data are included in the PDF fit

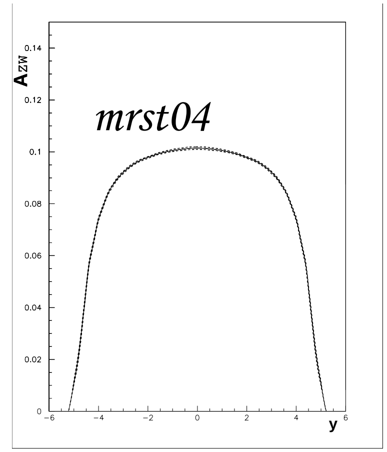
e+ rapidity spectrum and gluon PDF AFTER these pseudodata are included in the PDF fit

Gluon PDF uncertainties are reduced

The **uncertainty on the W^+ W^- and Z rapidity distributions** are all dominated by **gluon PDF** uncertainty BUT 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

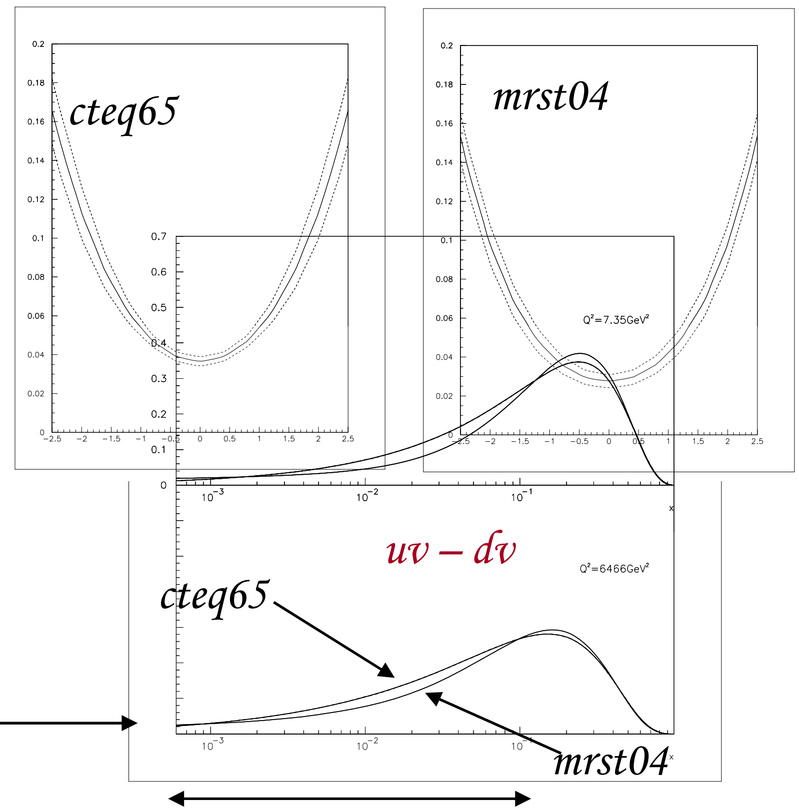
$A_w = (W^+ - W^-)/(W^+ + W^-)$

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

$$Aw \sim \frac{(uv - dv)}{(uv + dv + 2\, q)}$$

The difference in valence PDFs you see here explains the difference in A_W

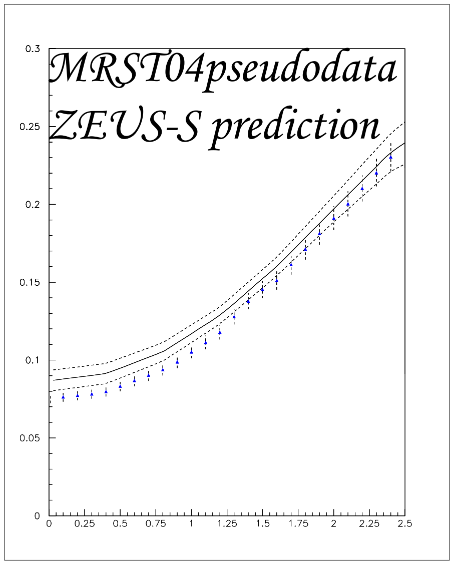


x- range affecting W asymmetry in the measurable rapidity range

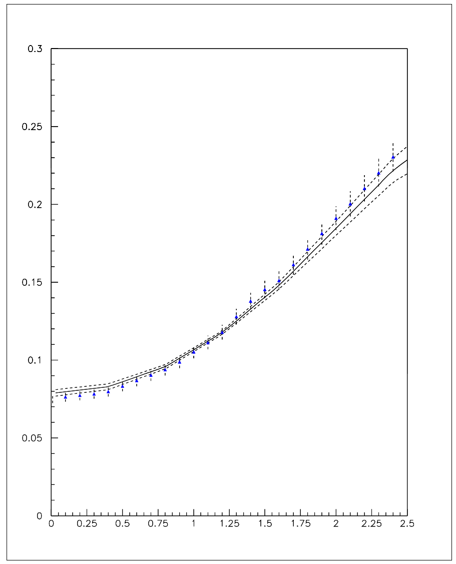
Generate data with 4% error using MRST04 PDF and then include this pseudo-data in the global ZEUS PDF fit (actually use the lepton asymmetry data)

The PDF uncertainty of the valence distributions is improved by the input of such data

BEFORE including A_e pseudo-data



AFTER including A_e pseudo-data



But what about valence PDFs at high-x?
Look at W-/W+ ratio at large rapidity
Not possible for main LHC detectors BUT
LHCb rapidity range 1.9 to 4.9

ATLAS/CMS LHC Aw data can measure valence distributions at x~0.005

LOW-X PHYSICS: LHC will be a low-x machine (at least for the early years of running)

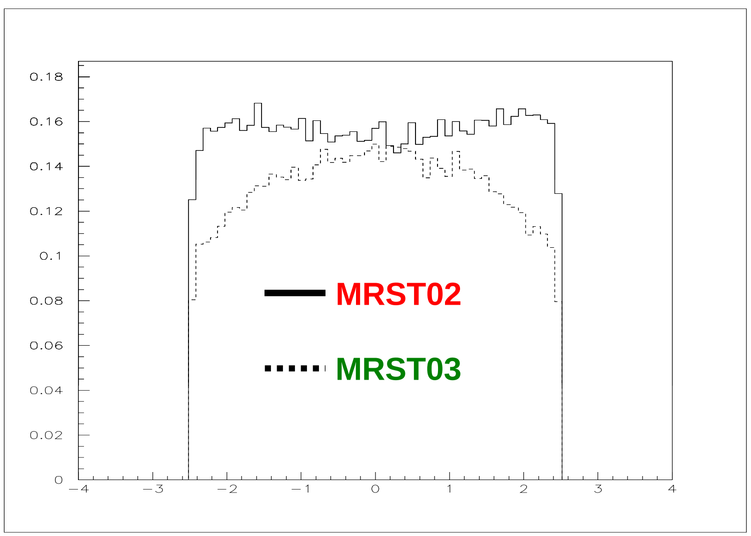
Is NLO (or even NNLO) DGLAP good enough?

The QCD formalism may need extending at small-x

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

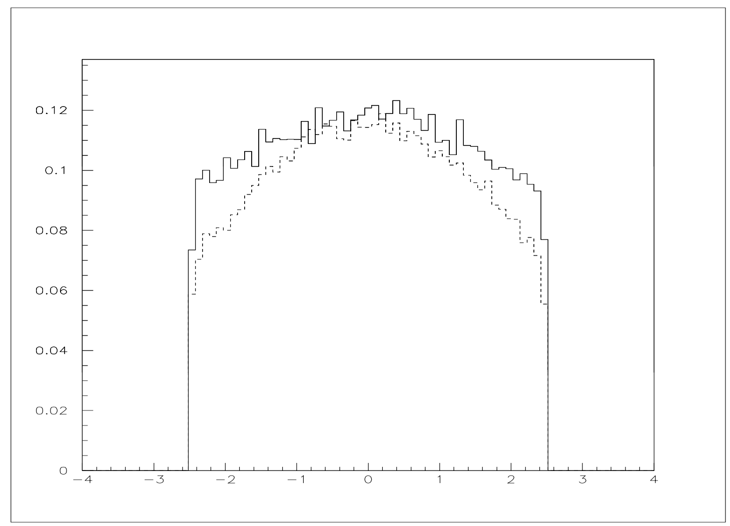
200k events of **W+- -> e+-** generated with MC@NLO using MRST03 and MRST02

Reconstructed Electron Pseudo-Rapidity Distributions (ATLAS fast simulation)



Reconstructed e^+

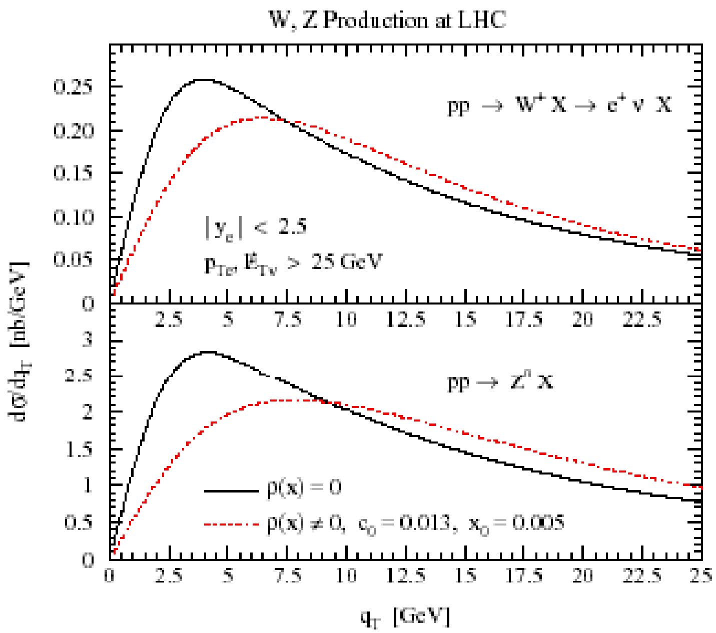
6 hours running



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

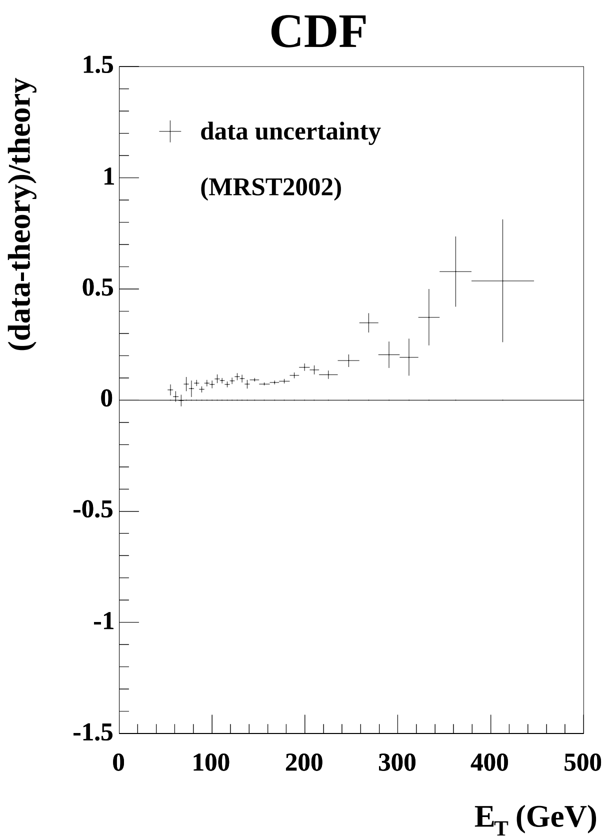


Pt spectra are also used to measure MW

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

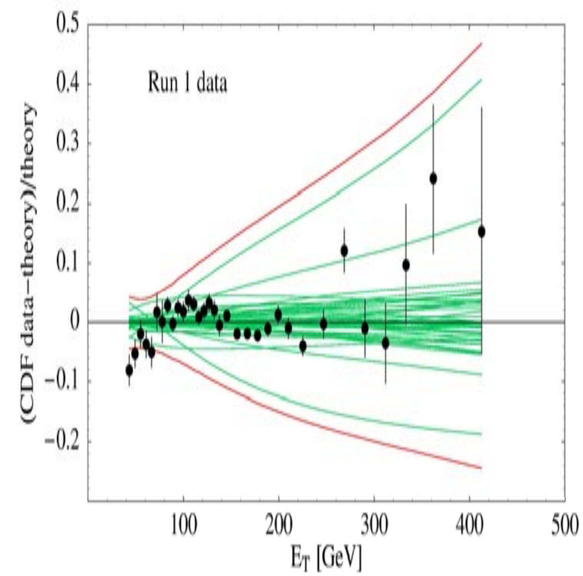
Probably needs more sophisticated treatment e.g. RESBOS.

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)



And what do we acknowledge is not well known?

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



Theory CTEQ6M

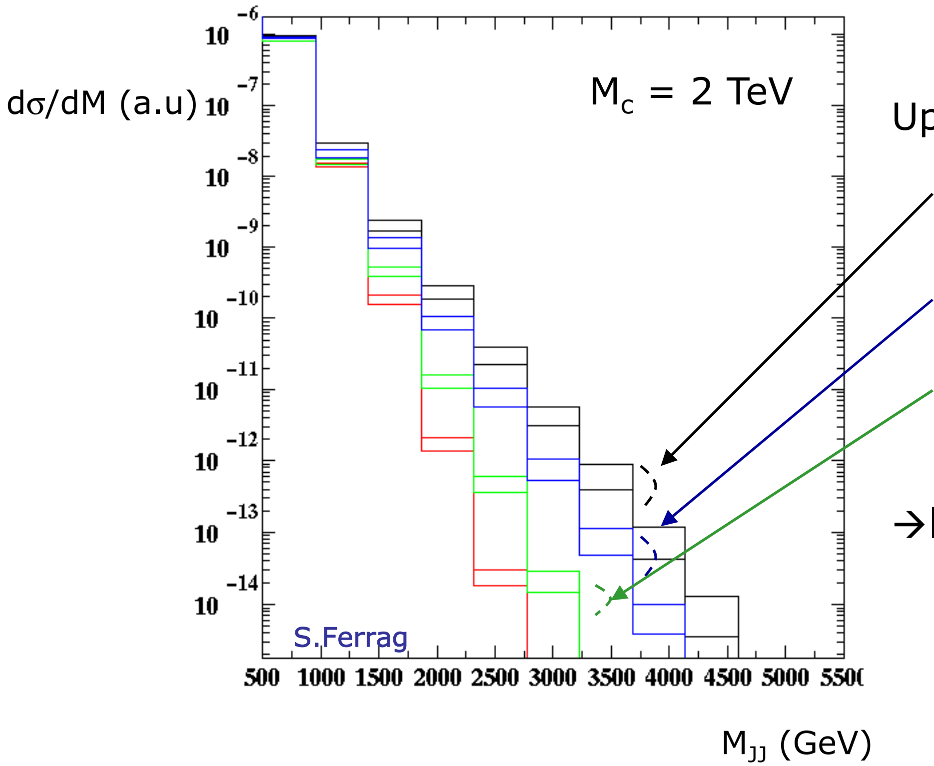
These figures show inclusive jet cross-sections compared to predictions in the form (data - theory)/ theory

Today Tevatron jet data are considered to lie within PDF uncertainties

And the largest uncertainty comes from the uncertainty on the high x gluon

And what consequences might this have?

Such PDF uncertainties in the jet cross sections compromise the LHC potential for discovery of any new physics which can written as a contact interaction
E.G. Dijet cross section has potential sensitivity to compactification scale of extra dimensions (M_c)



Up to ~50% at high mass :

SM + structure function uncertainty band

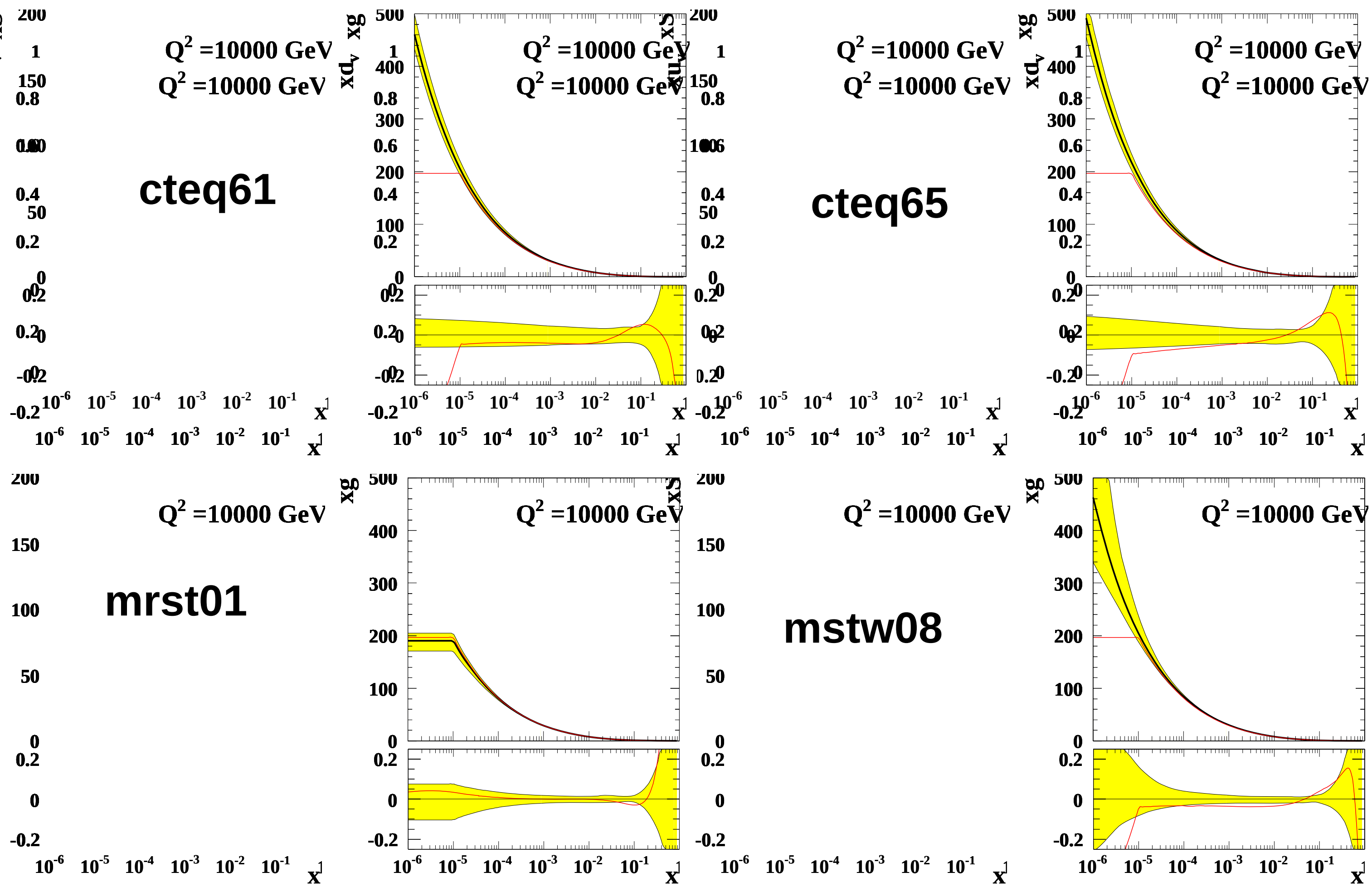
2XD + structure function uncertainty band

4XD + structure function uncertainty band

→Enough to lose sensitivity to higher compactification scales

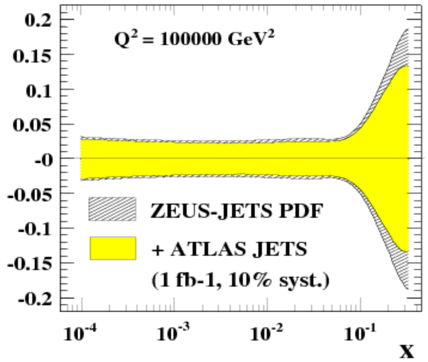
Can we know the high-x gluon better?

Look at new high-x gluon uncertainties!

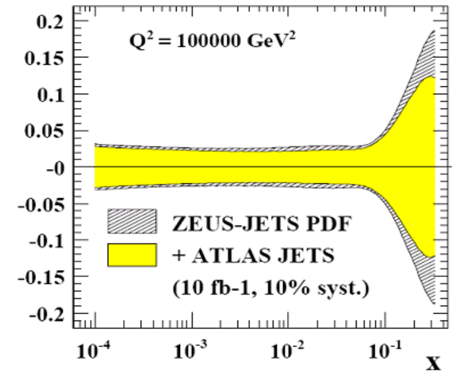


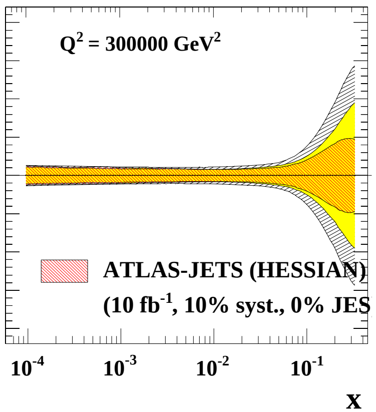
There is newer Tevatron Run-II jet data in the latest PDF fits but no very striking improvement from older partons- further hope from HERA jets?

And will we be able to use LHC data itself to improve the situation?- study of including ATLAS pseudodata in PDF fit

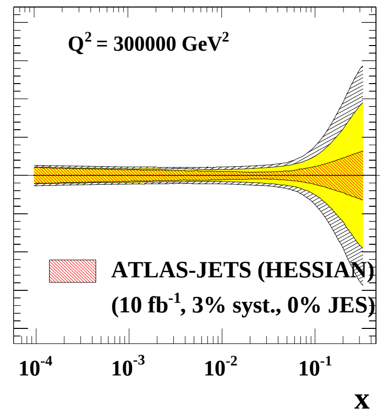


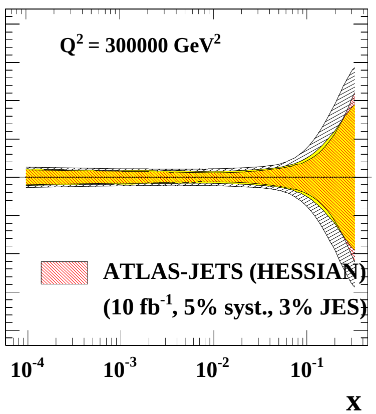
Impact of increasing statistics





Impact of decreasing experimental systematic uncertainty

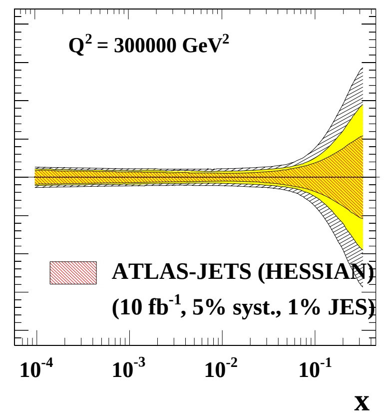




Impact of decreasing experimental correlated systematic uncertainty

Challenging!

Can we decrease Jet Energy Scale systematic to 1%?



Jet energy scale also a problem in W+jets channel, where SUSY signals may show up

W+jets: PDF vs JES Uncertainty

PDF vs Jet Scale Uncertainty (**Δ JS**)

with **10%** **(5%)** jet energy miscal.

(Note: results with tight EF cuts samples)

2.9% < **Δ PDF** < 7.3%
5.8% < **Δ JS** (10%)< 23.6%
3.6% < **Δ JS** (5 %) < 11.9%

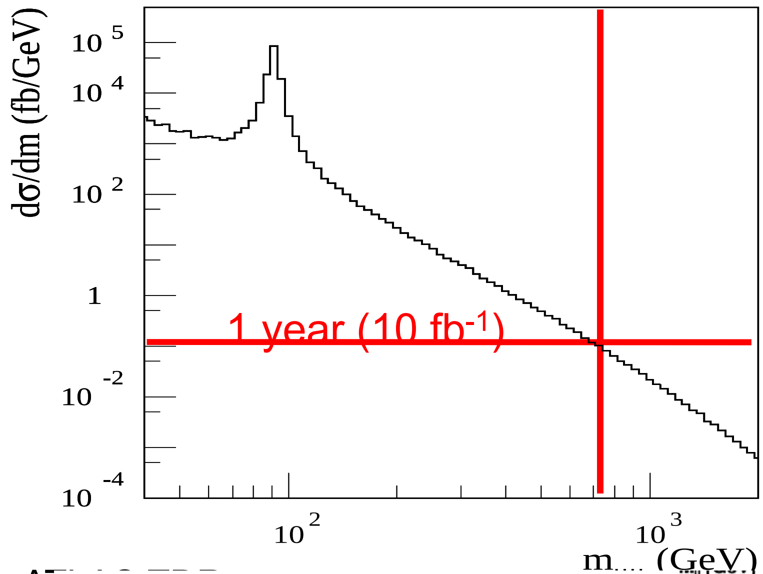
↓

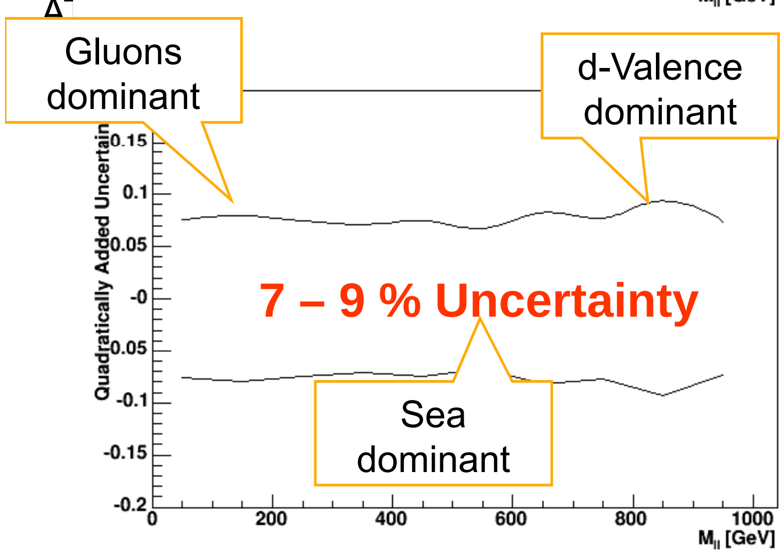
PDF Uncert < Expt. Syst. Uncert

Next: When is JES < PDF Unc?
Try with 1,2,3% jet energy miscal.

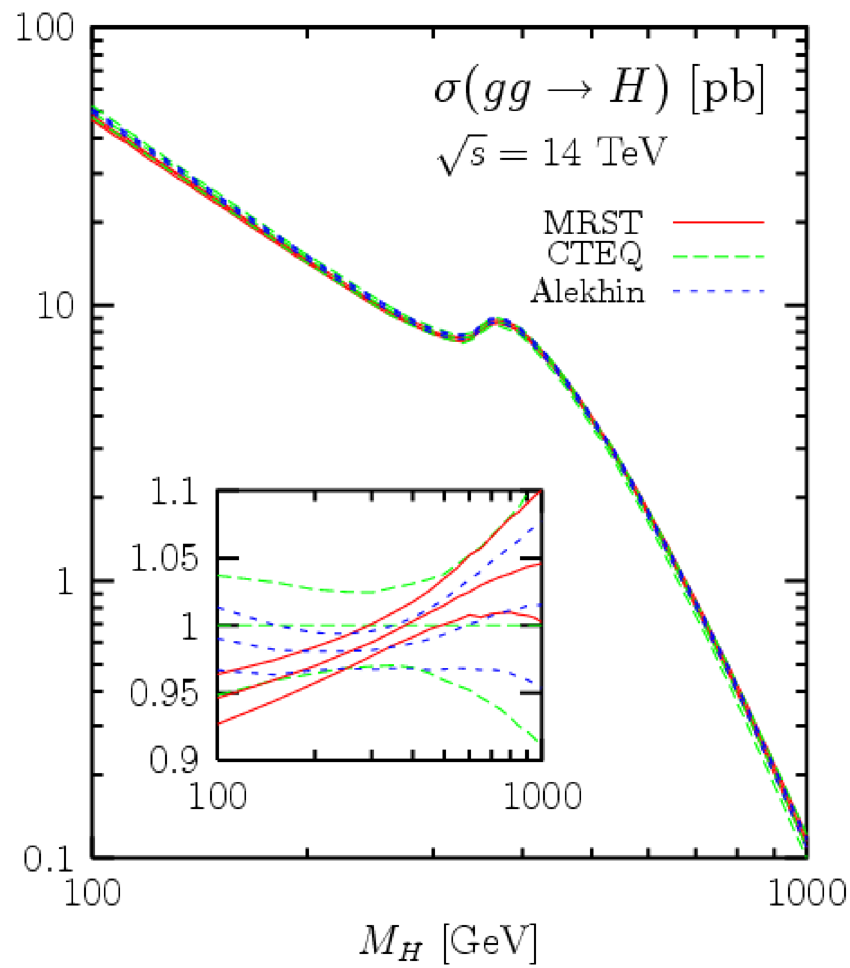
Multipl	Δ+ PDF (%)	Δ- PDF (%)	Δ+ JS (%)	Δ- JS (%)
W+ ≥1 jets	3.2	2.9	10.7 (5.2)	10.7 (5.2)
W+ ≥2 jets	3.2	2.9	10.2 (5.1)	10.7 (5.2)
W+ ≥3 jets	3.3	2.9	5.8 (3.6)	9.0 (4.0)
W+ ≥4 jets	5.0	3.9	14.7 (7.8)	15.6 (7.0)
W+ ≥5 jets	5.9	4.8	20.8 (9.5)	20.5 (10.7)
W+ ≥6 jets	7.3	5.9	22.2 (10.4)	23.6 (11.9)

But not all discovery physics is strongly compromised: e.g PDF Uncertainty in High-mass Drell-Yan- won’t stop us seeing Zprimes

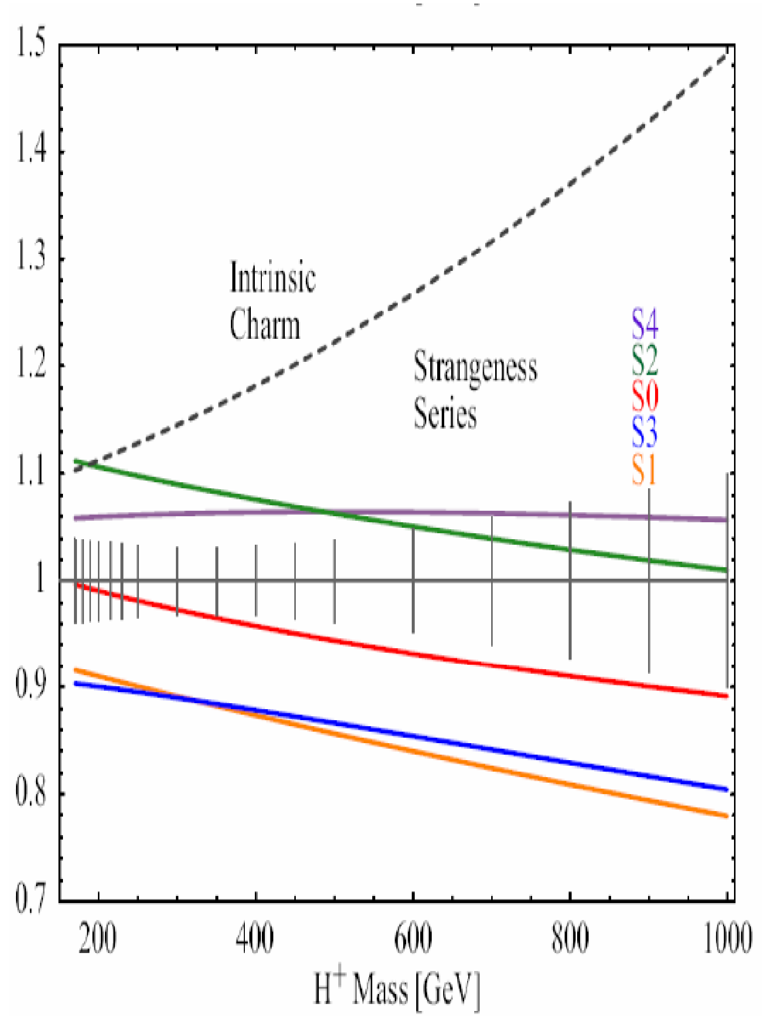




and PDF uncertainties don’t affect the Higgs discovery potential too badly



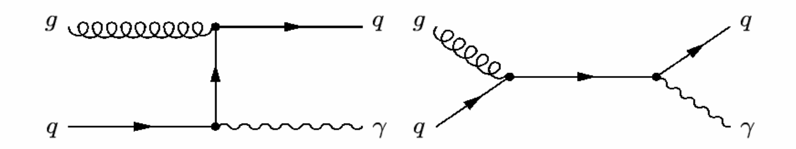
Could be an impact of unusual Charm and strange PDFs on exotic Higgs production



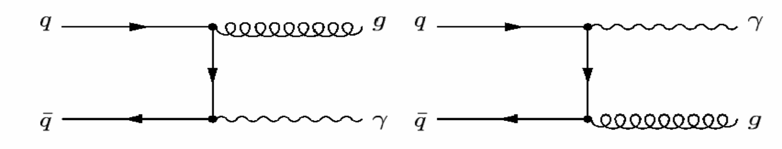
What other processes will be useful?

Direct photon production for the high-x gluon

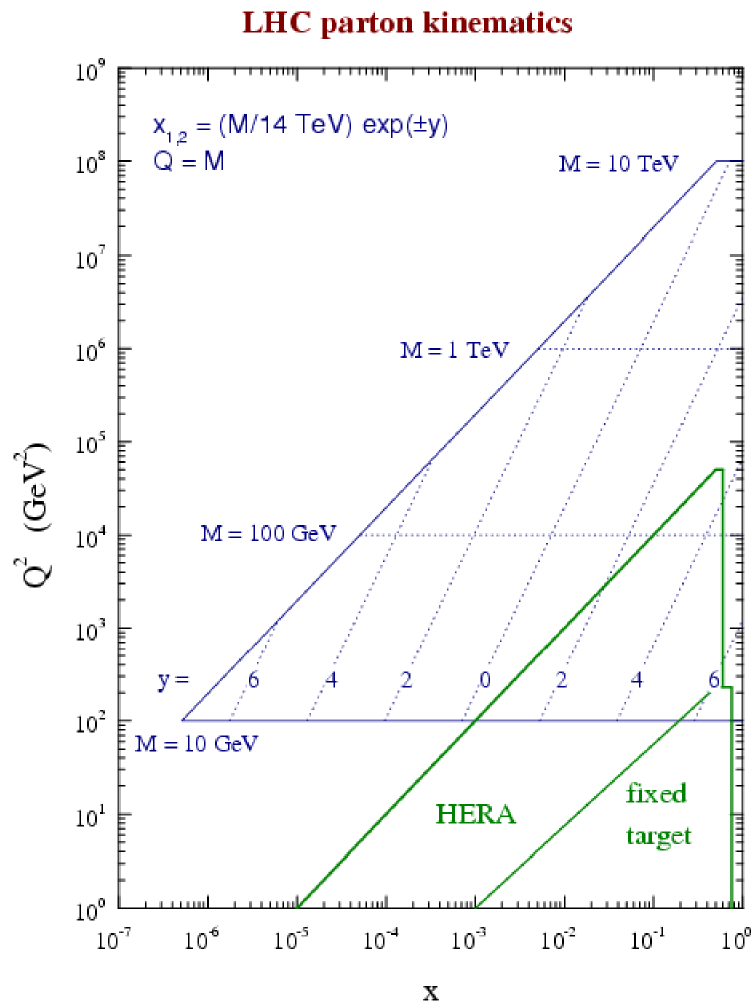
Compton:
(~90%)



Annihilation:
(~10%)



- **Z+ b-jet for Measurement of the b-quark PDF**



Low-mass Drell-Yan will probe low-x partons but also low-x calculations

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 should 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/direct photon)

Low-x / high-x valence PDFs (W asymmetry)

Low-x partons/ Low-x theory (low-mass Drell-Yan)

extras