Impacts and constraints on PDFs at ATLAS

April 17th DIS 2007
A M Cooper-Sarkar, Oxford

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

How does this impact on our measurements AND

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

Apologies for two overlapping talks – more general overview tomorrow in 'Future of DIS'

Today some more detail on ATLAS studies

Nothing on low-x modifications to conventional DGLAP in this talk!

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 ($\approx 10^{32} cm^{-2}s^{-1}$)**
- **End ’08 $\sqrt{s}$ = 14 TeV at High luminosity**
- **L= 10 fb^{-1}/year ($\approx 10^{33} cm^{-2}s^{-1}$)**

LHC is W, Z, top … factory

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

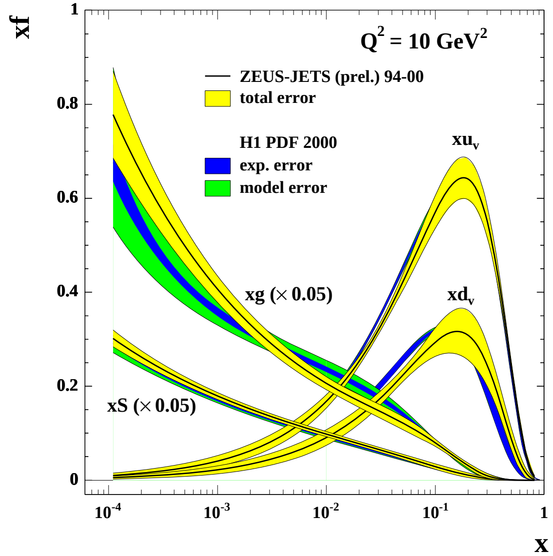
Large statistics for SM processes $\Rightarrow$

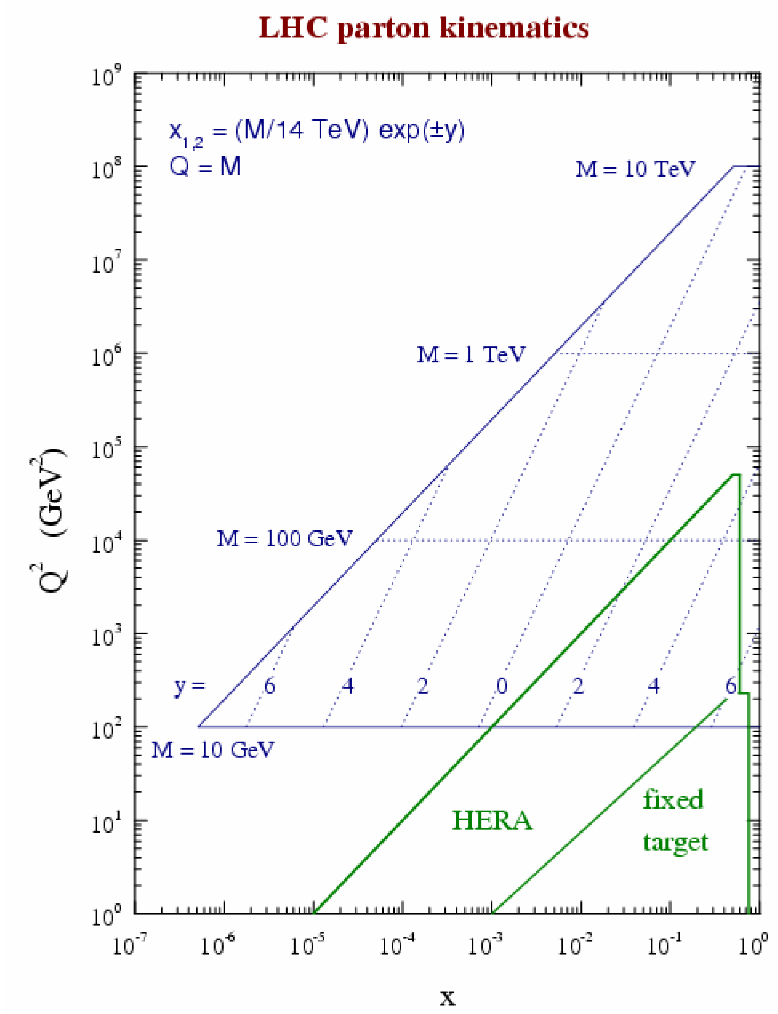
- **SM precision physics (EW, top-,b-physics, multijets…)**
- **Big potential for new physics (Higgs, Extra Dimensions, SUSY…)**

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

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

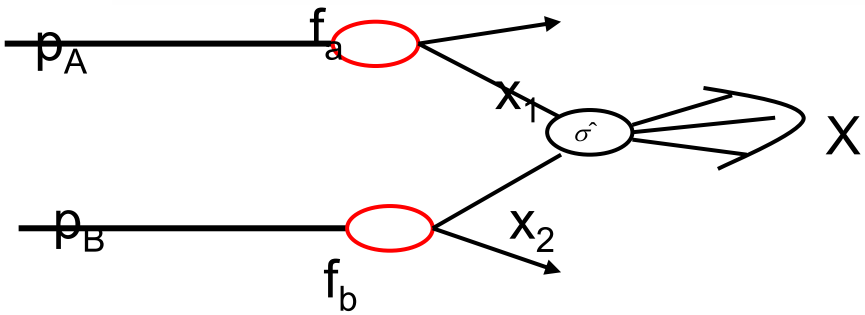
At the LHC high precision (SM and BSM) cross section predictions require precision Parton Distribution Functions (PDFs





$$\sigma_X = \sum_{a,b} \int_0^1 dx_1 dx_2\, f_a(x_1, \mu_F^2)\, f_b(x_2, \mu_F^2)$$

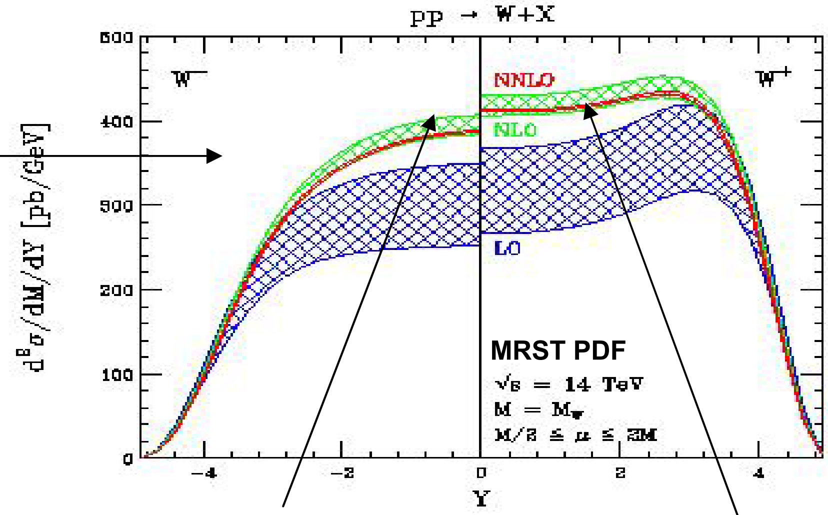
$$\times \quad \hat{\sigma}_{ab\to X}\left(x_1, x_2, \{p_i^\mu\}; \alpha_S(\mu_R^2), \alpha(\mu_R^2), \frac{Q^2}{\mu_R^2}, \frac{Q^2}{\mu_F^2}\right)$$



Knowledge of the PDFs at low-x is vital

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

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



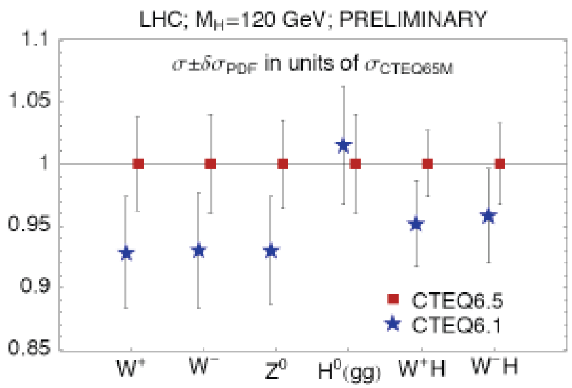
NNLO corrections small ~ few%

NNLO residual scale dependence < 1%

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

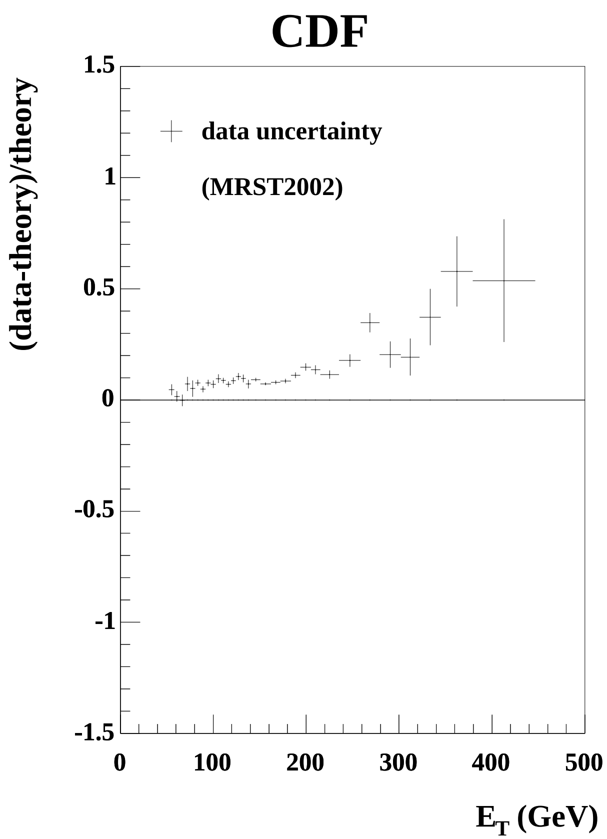
PDF Set	$\sigma_{W^+} \cdot B_{W \to l\nu}$ (nb)	$\sigma_{W^-} \cdot B_{W \to l\nu}$ (nb)	$\sigma_Z \cdot B_{Z \to ll}$ (nb)
ZEUS-S	12.07 ± 0.41	8.76 ± 0.30	1.89 ± 0.06
CTEQ6.1	11.66 ± 0.56	8.58 ± 0.43	1.92 ± 0.08
MRST01	11.72 ± 0.23	8.72 ± 0.16	1.96 ± 0.03

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



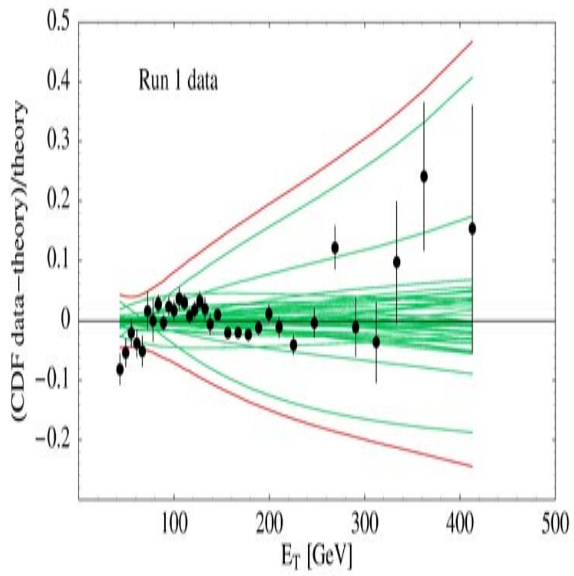
Not so well known

Not such a good bet for a precise luminosity monitor



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--



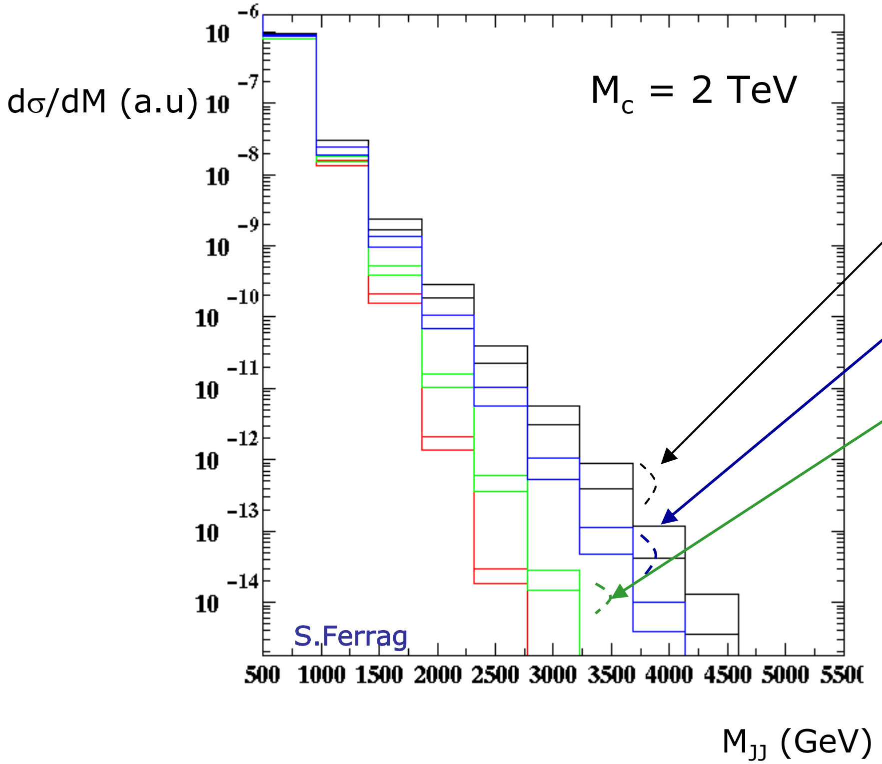
Theory CTEQ6M

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

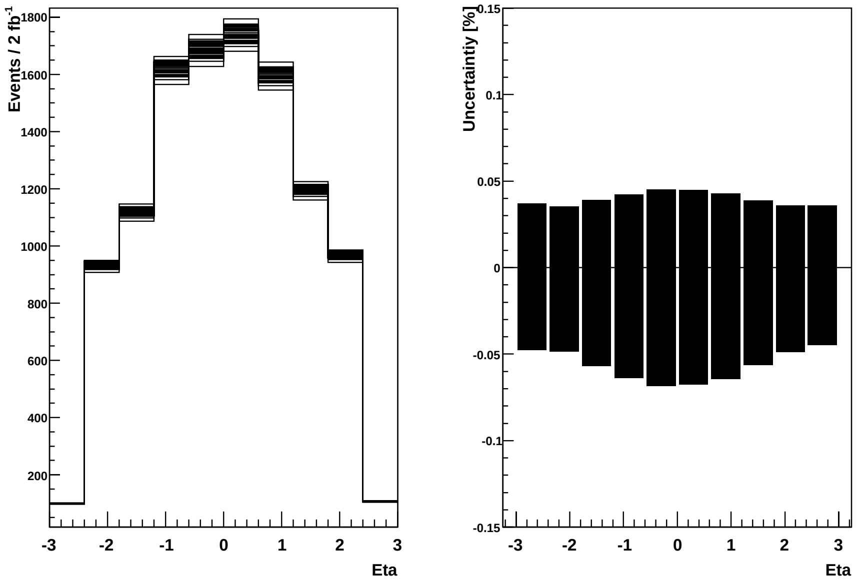
4XD + structure function uncertainty band

→Enough to lose sensitivity to higher compactification scales

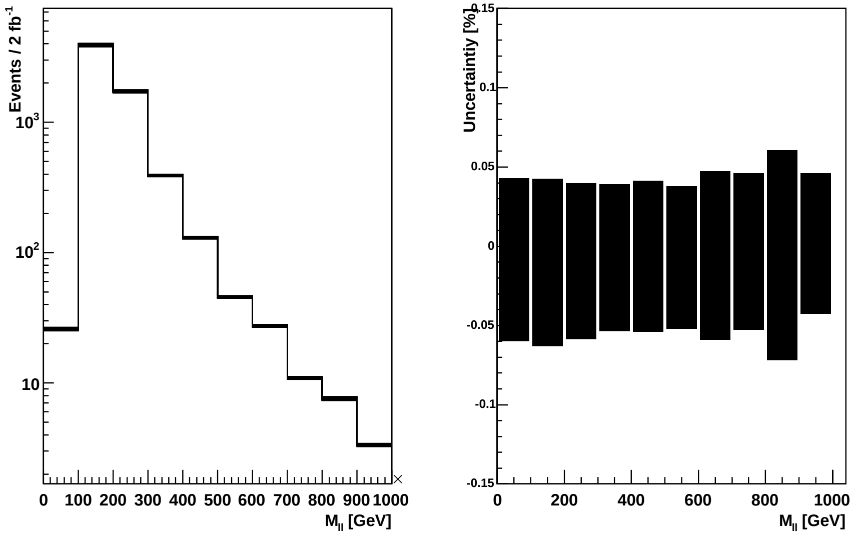
And what is well known enough?

Higgs production- see tomorrow's talk

High mass Drell-yan



Di-electron invariant mass

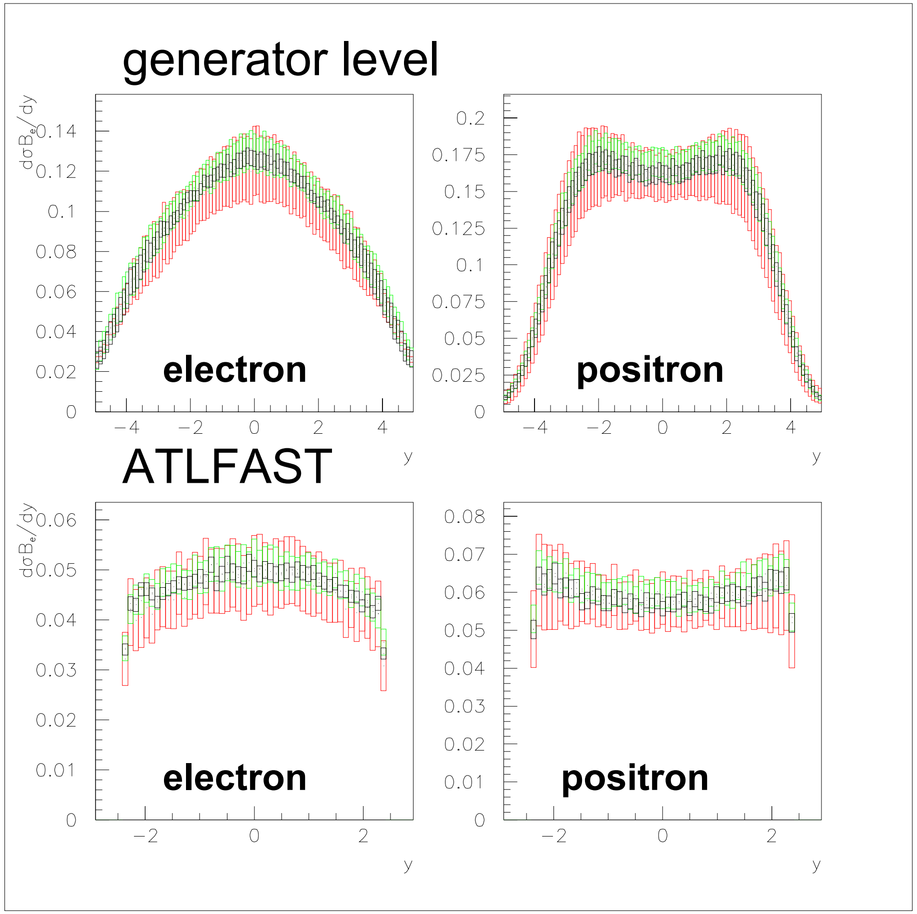


Di-electron pseudo-rapidity

Herwig+JimmY generation, CTEQ6.1 uncertainties, and ATLAS full simulation

5% PDF uncertainties – this will not prevent us seeing a 'big bump'

Can we improve our knowledge of PDFs using ATLAS data itself? First consider W and Z production



We actually measure the decay lepton spectra from W+/- decay

Generate with HERWIG+k-factors (checked against MC@NLO) using CTEQ6.1M ZEUS_S MRST2001 PDFs with full uncertainties from LHAPDF eigenvectors

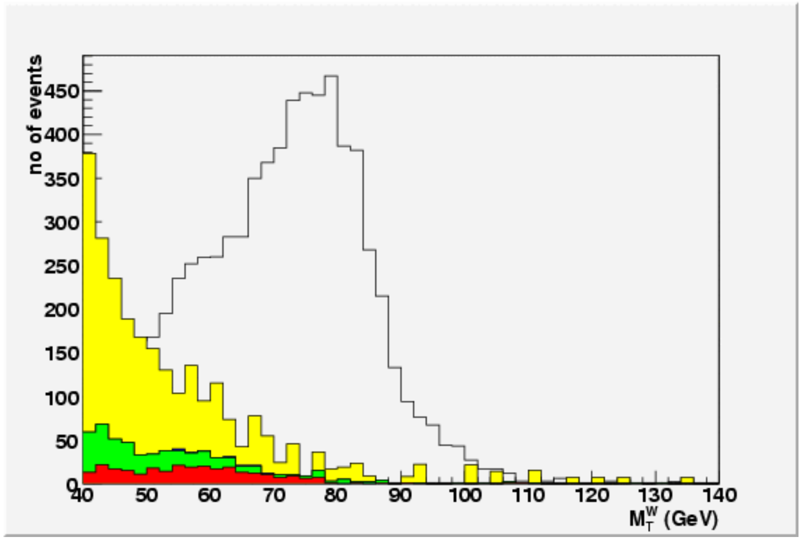
At y=0 the total uncertainty is
~ ±6% from ZEUS
~ ±4% from MRST01E
~ ±8% from CTEQ6.1

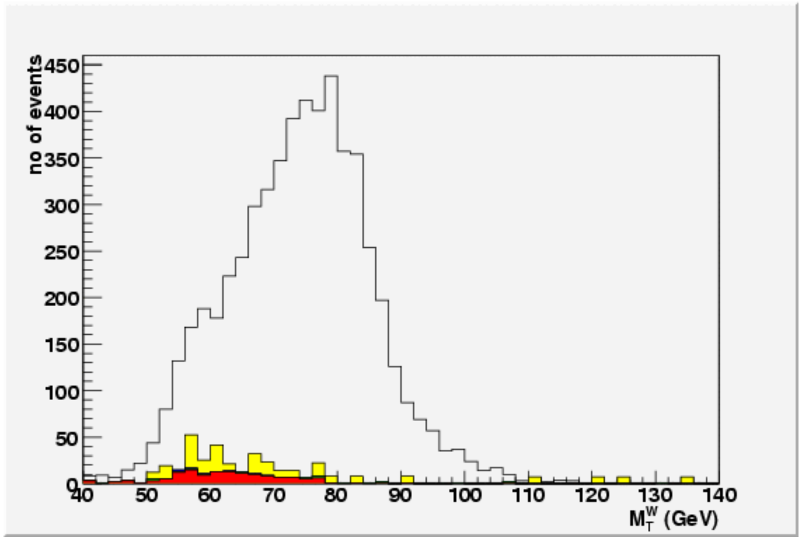
To improve the situation we NEED to be more accurate than this:**~4%**

Statistics are no problem there will be millions of W's

We need to control the systematic uncertainty

W Signal vs Background before and after selection cuts
Lepton ET > 25 GeV, MET > 25GeV



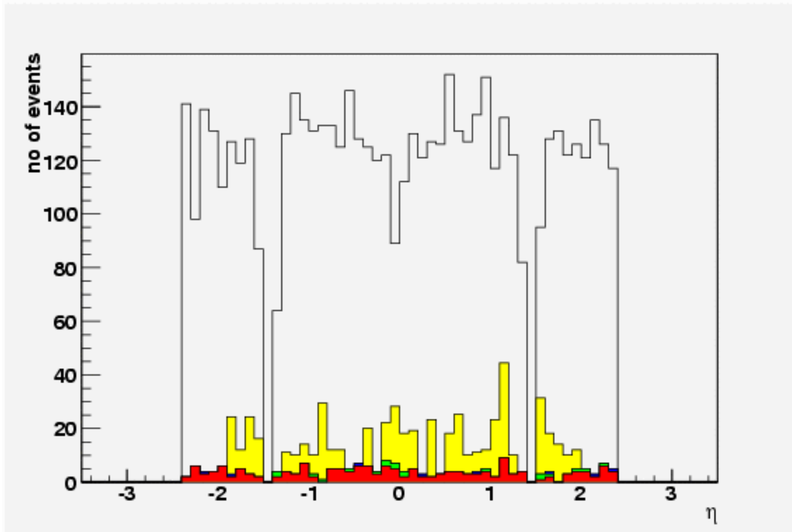


Red W →τν Green Z→e+e-

Blue Z →τ+τ- Yellow QCD dijet

ATLAS full simulation corresponding to 1.3pb-1

QCD events 8% after above cuts-Further jet veto cuts reduce this to 1% leaving W→τν as main bkgd of ~2%.

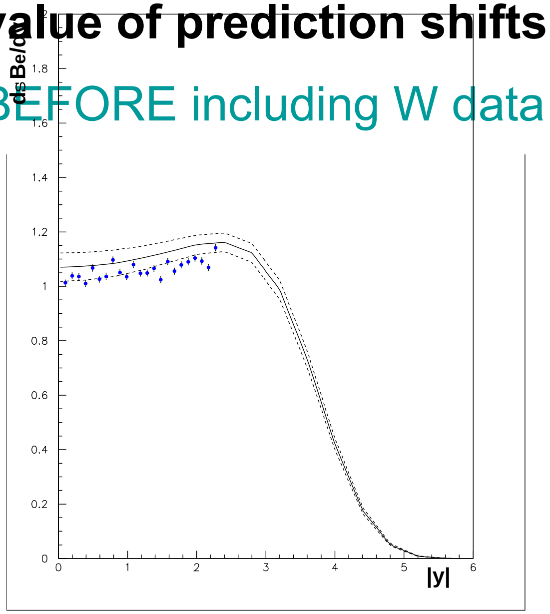


Study of the effect of including the LHC W Rapidity distributions in global PDF fits

by how much can we reduce the PDF errors with early LHC data?

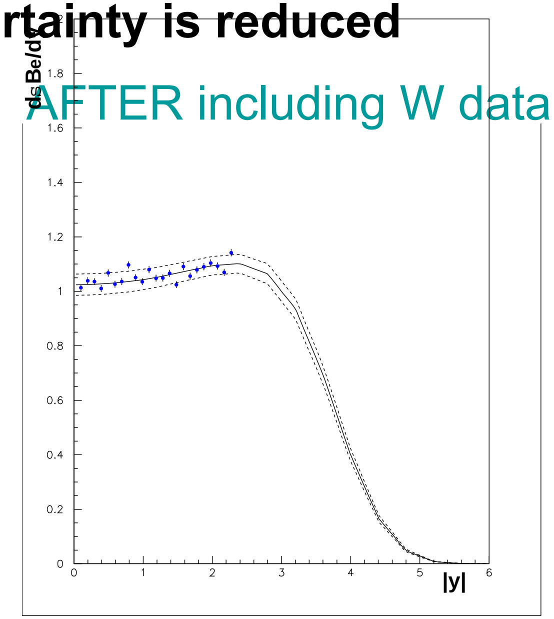
Generate data with 4% error using CTEQ6.1 PDF, pass through ATLFAST detector simulation and then include this pseudo-data in the global ZEUS PDF fit **Central value of prediction shifts and uncertainty is reduced**

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

AMCS, A. Tricoli
(Hep-ex/0509002)

Specifically the low-x gluon shape parameter λ, $xg(x) = x^{-\lambda}$, was

λ = -.199 ± .046 for the ZEUS PDF before including this pseudo-data

It becomes λ = -.181 ± .030 after including the pseudodata

Yes, it was the gluon PDF which improved the most.

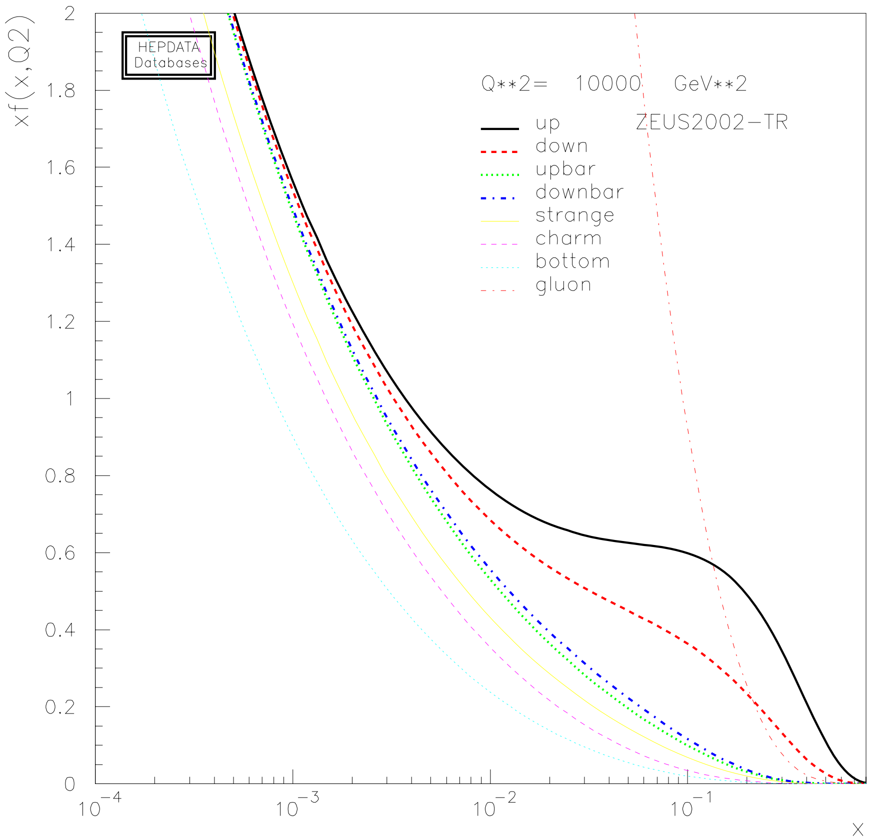
The **uncertainty on LHC W/Z rapidity distributions** is dominated by **gluon PDF** dominated eigenvectors

Both low-x and high-x gluon

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

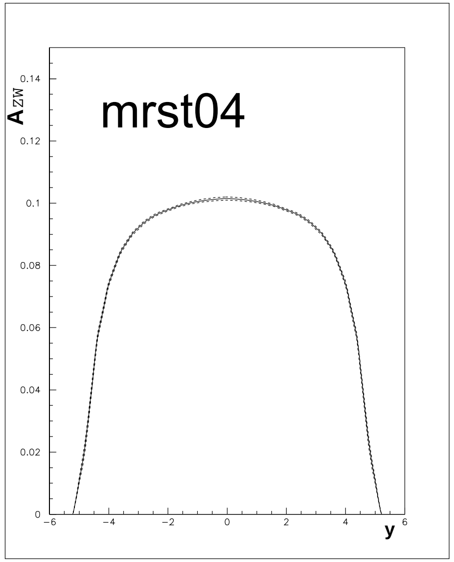
And at Q2~M_Z2 **the sea is driven by the gluon-** which is far less precisely determined for all x values



There is cancellation of the uncertainty due to the gluon PDF in the ratio

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

the PDF uncertainty on this ratio is ~1% and there is agreement between PDFsets- golden calibration measurement

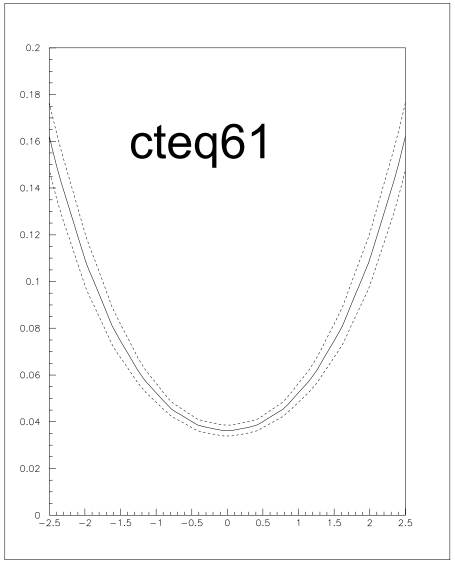


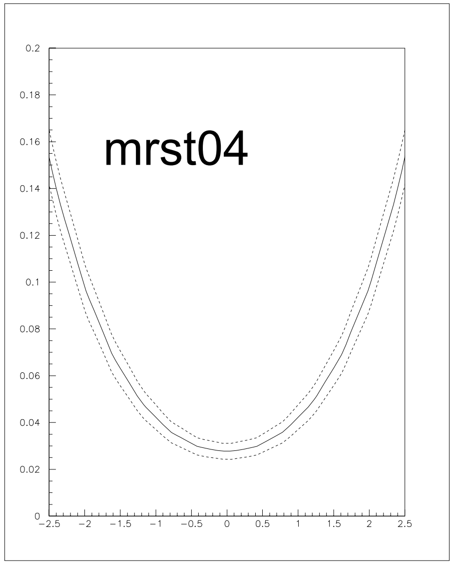
But the same is not true for the W asymmetry

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

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



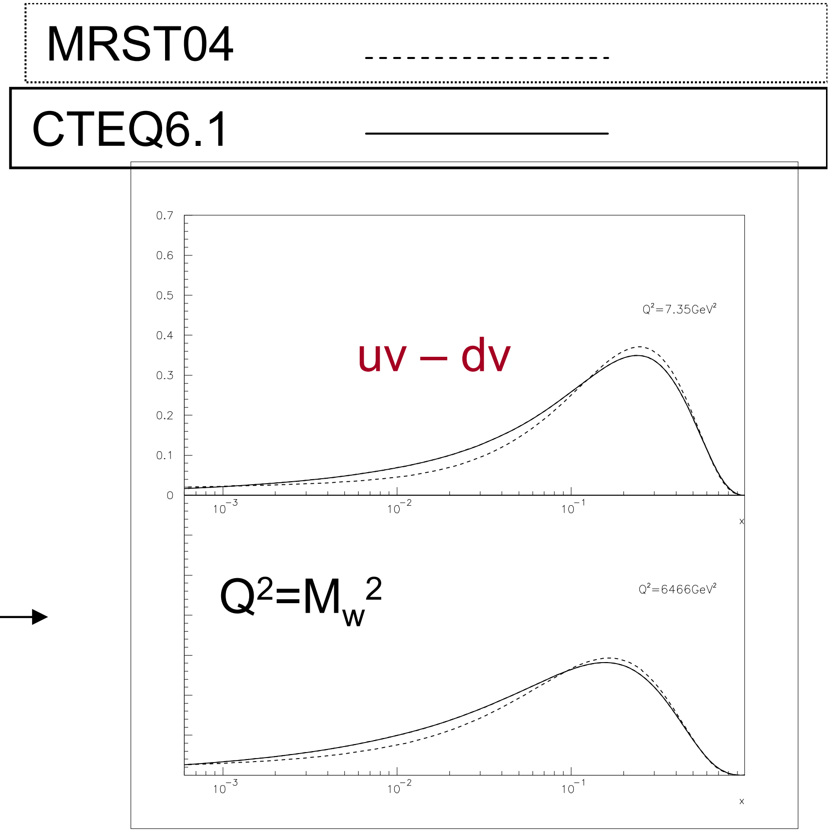


Dominantly, at LO $A_w = \dfrac{(u\,\bar{d} - d\,\bar{u})}{(u\,\bar{d} + d\,\bar{u})}$

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

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

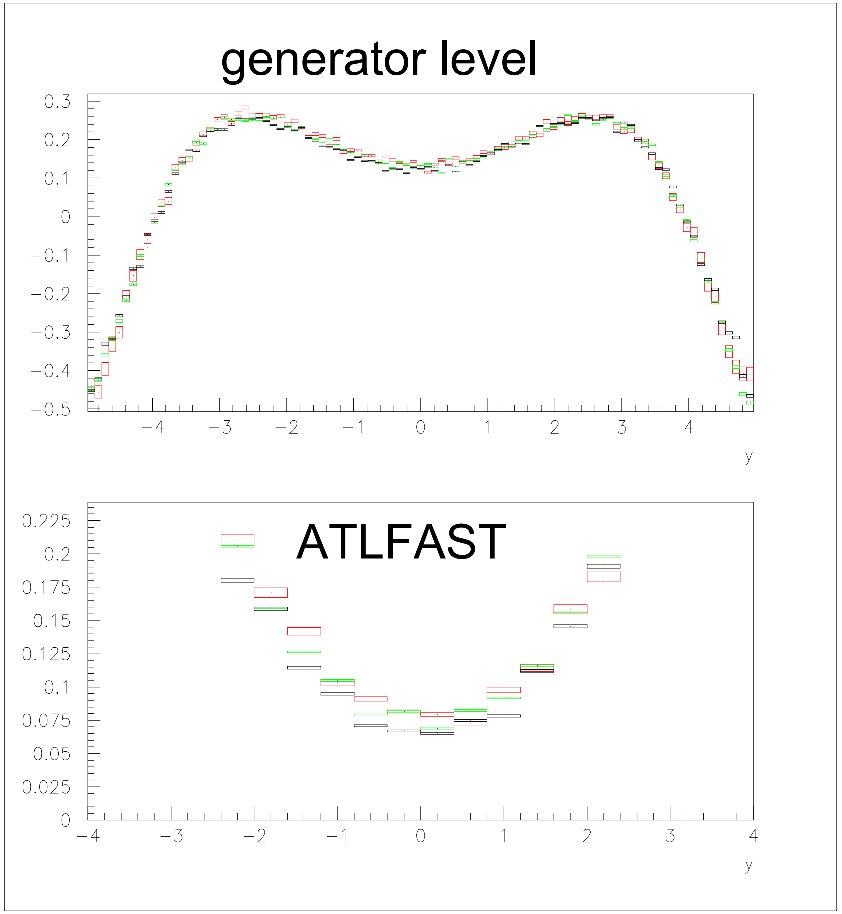
Actually this pretty good even quantitatively



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

Of course we will actually measure the lepton asymmetry

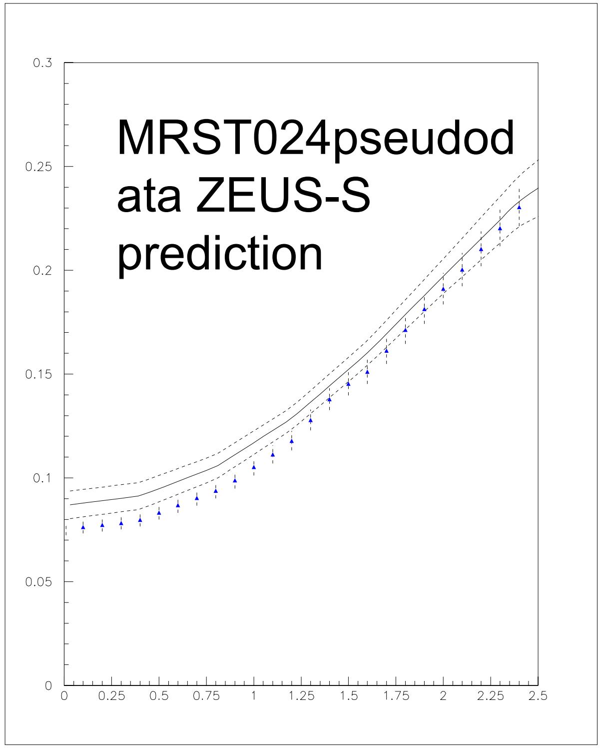
x- range affecting W asymmetry in the measurable rapidity range



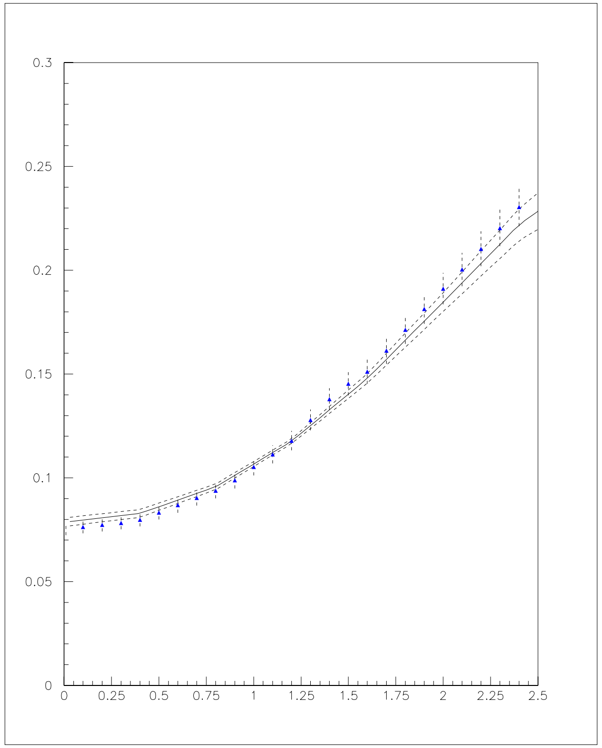
Generate data with 4% error using MRST04 PDF and then include this pseudo-data in the global ZEUS PDF fit…….

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

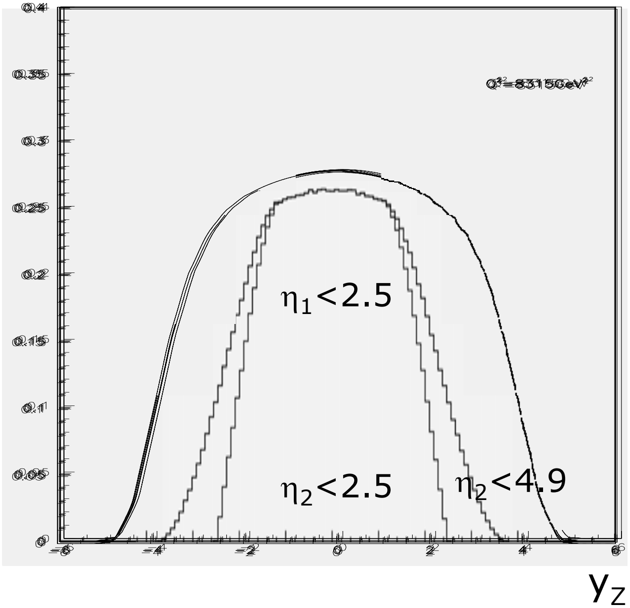


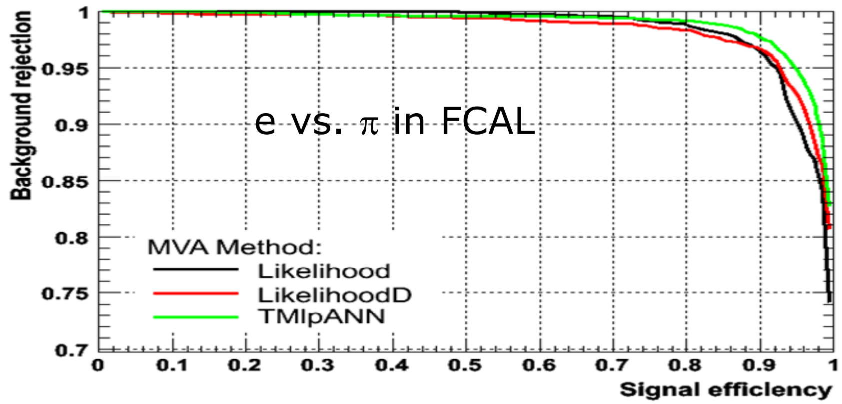
Conclusion we have valence PDF discrimination, and will be able to measure valence distributions at x~0.005 on proton targets for the first time

But what about valence PDFs at high-x?

- It is important to extend the y acceptance if possible, reducing the extrapolation uncertainty.
- Consider the Z → ee chain
  - : $x_{1,Z} \sim 0.2$ if $y_Z \sim 3.5$
  - Expect ~800k events in $2.5<y_Z<4$ for 10 fb^{-1}

e vs. Jet in FCAL





ATLAS studies (M.Aharrouche)

in progress

Eff(%)	Rej: 100	Rej: 10
likelihood	77	95
ANN	81	98
likelihoodD	66	97

Can we use ATLAS data itself to improve the high-x gluon PDF uncertainties? Now consider High ET jet production

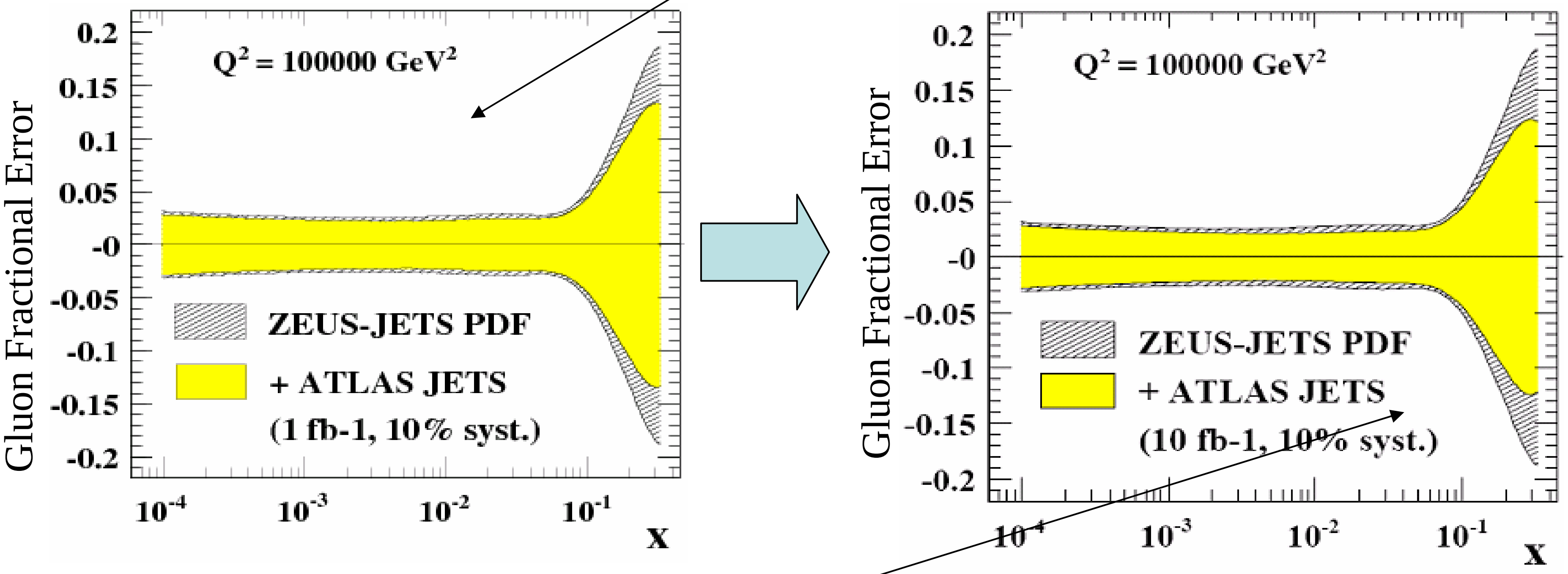
Recently grid techniques have been developed to NLO cross-sections in PDF fits (e.g ZEUS-JETs fit)

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

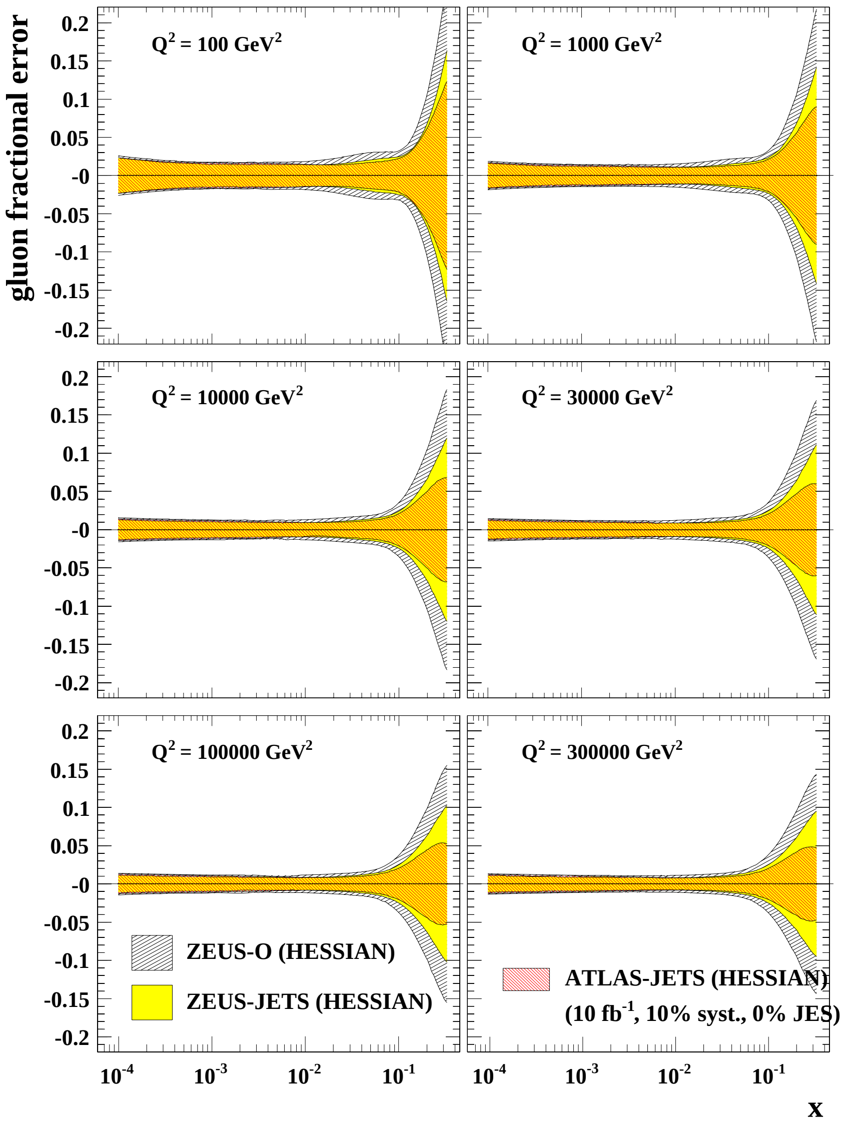
- Grids were generated for the inclusive jet cross-section at ATLAS in the pseudorapidity ranges $0<\eta<1$, $1<\eta<2$, and $2<\eta<3$ up to pT=3TeV (NLOJET).
- In addition pseudodata for the same process was generated using JETRAD [4].
- The pseudo-data was then used in a global fit to assess the impact of ATLAS data on constraining PDFs:

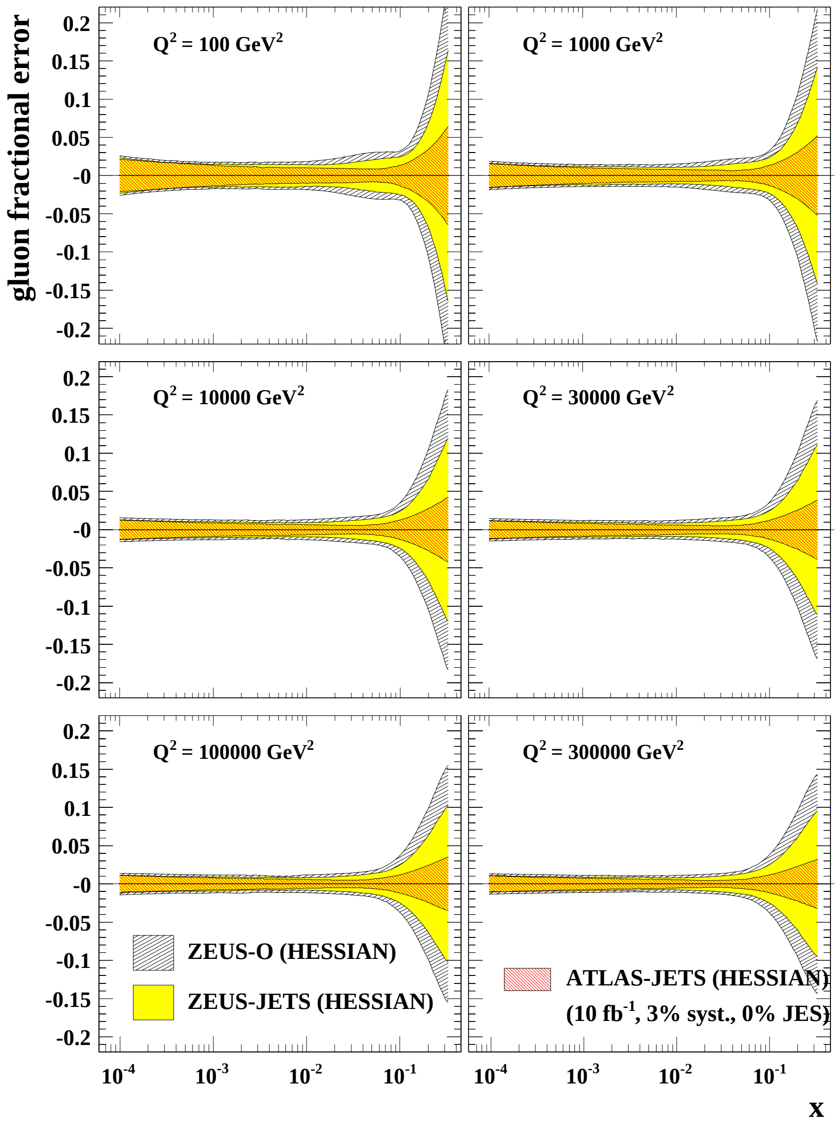
Addition of ATLAS jet pseudodata to PDF fit with assumed 10% systematic errors seems to give some improvement in gluon PDF uncertainty



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

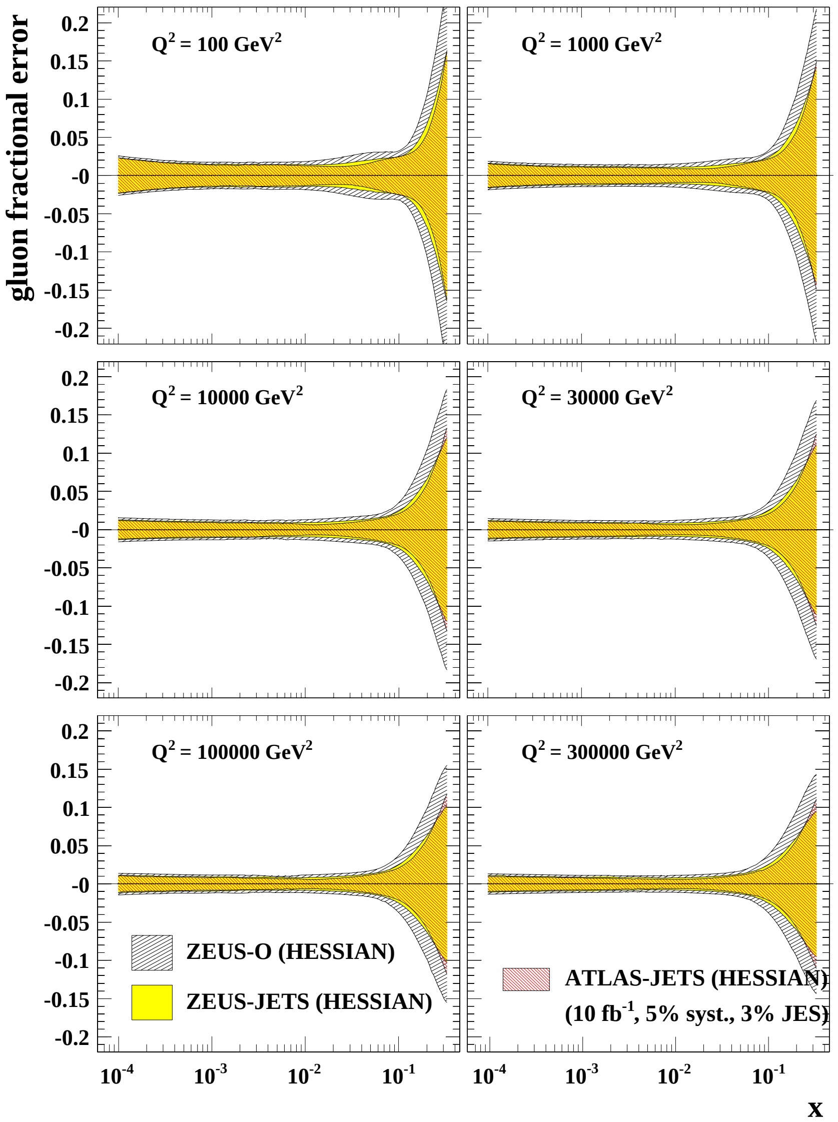
Decrease the size of the assumed systematic errors from 10% to 3%- gives considerable improvement



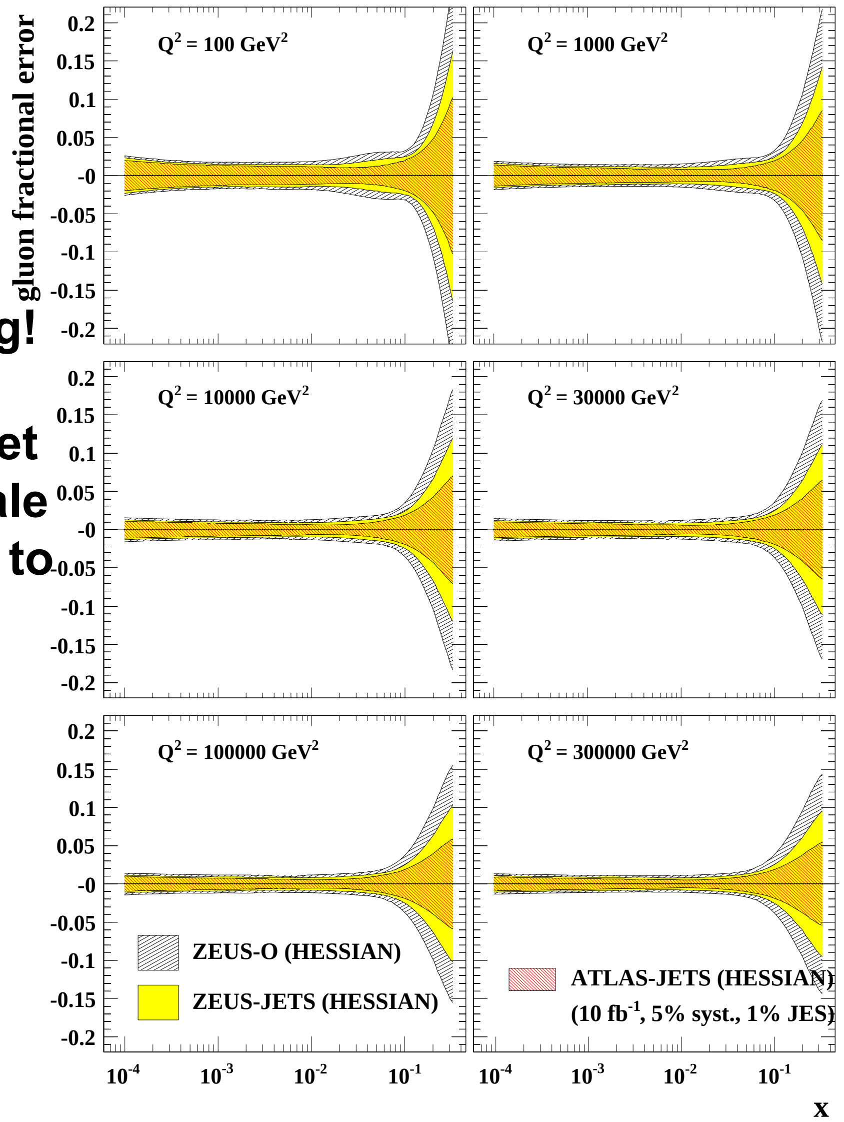


However, consider the correlated systematic due to Jet Energy Scale – this seems to destroy optimism

even 3% JES destroys previous improvemnt. We need 1% JES

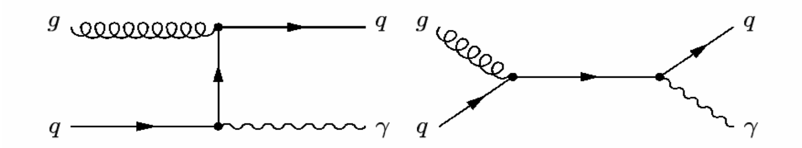


Challenging! Can we decrease Jet Energy Scale systematic to 1%?

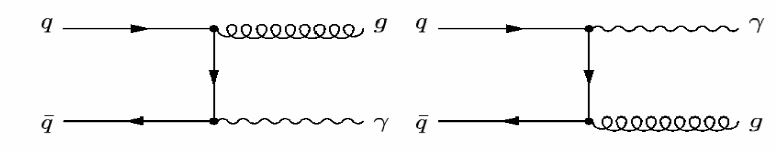


What other processes give information on the high-x gluon? – direct photon production

Compton:
(~90%)



Annihilation:
(~10%)

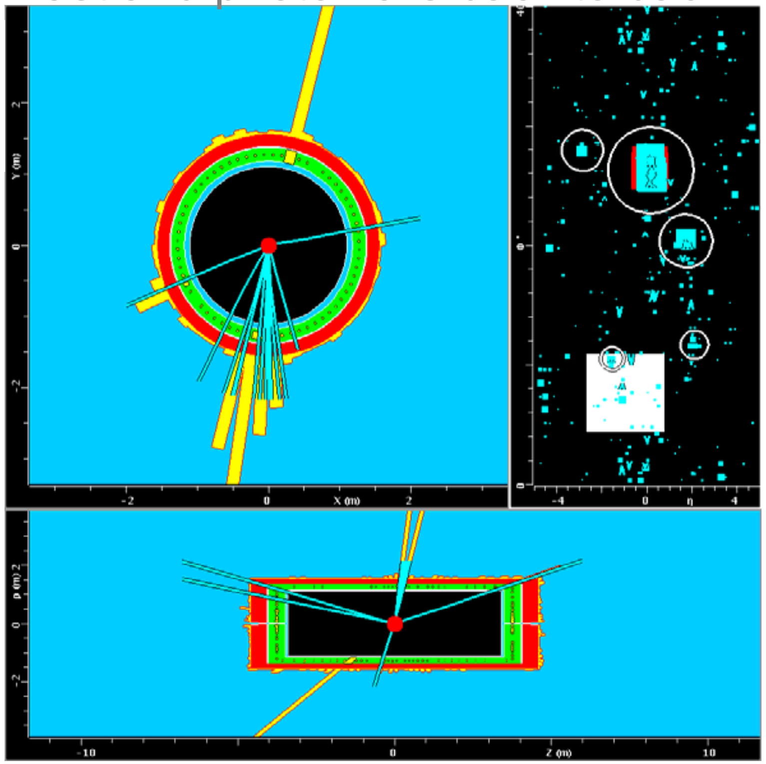


Studying photon identification, fake photon rejection etc.): gamma selection efficiency >91%

Investigating methods for reducing background

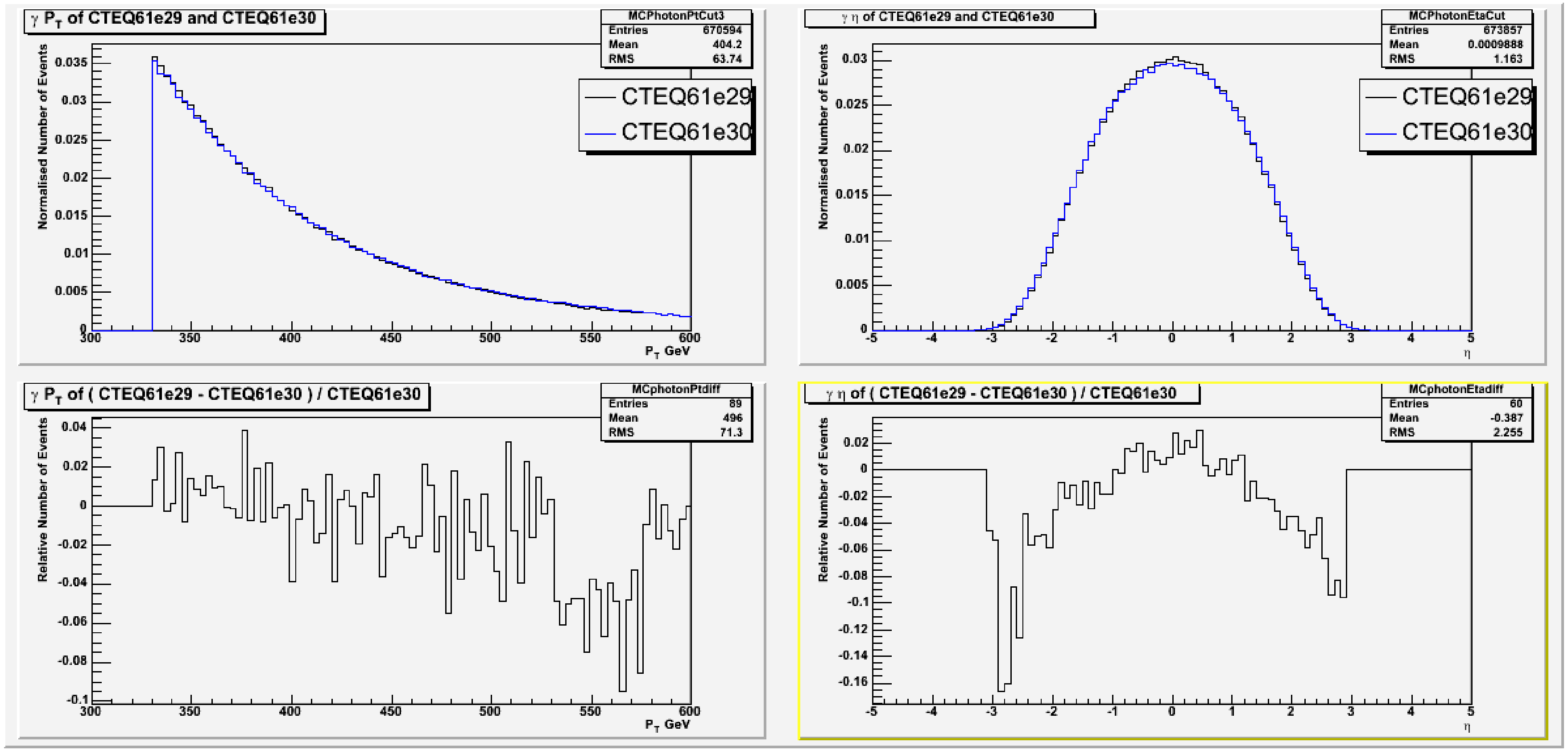
Typical Jet + γ event

Jet and photon are back to back



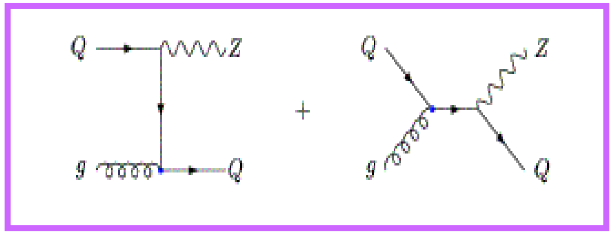
Compare photon pt and η distributions for Cteq61 PDF uncertainties up and down eigenvector 15 -emphasizing the uncertainties in the high-x gluon

~700k events for ~ 100fb-1 at pt > 330 GeV



• Also studying Z+ b-jet

- Measurement of the b-quark PDF
  - Process sensitive to b content of the proton

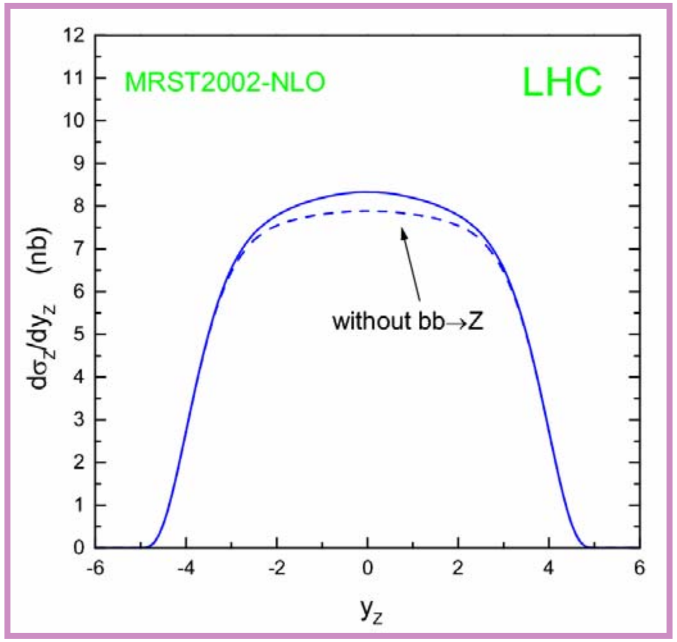


- Differences in total Z+b cross-section from current PDFs are of the order of 5%

The measurement of Z+b should be more interesting at LHC than at Tevatron:
Signal cross-section larger (x80), and more luminosity
Relative background contribution smaller (x5)

bb->Z @ LHC is ~5% of entire Z production -> Knowing σZ to about 1% requires a b-pdf precision of the order of 20%

Z+b measurement in ATLAS will be possible with **high statistics** and **good purity** of the selected samples with two independent b-tagging methods:



Event selection: taking into account only Z→μμ

Preselection: Two muons with

- Pt > 20 GeV/c
- opposite charge
- invariant mass close to Mz

B-tagging methods

-Soft muon

-Inclusive b-tagging of jets (Jet: pT > 15 GeV,|η|< 2.5)

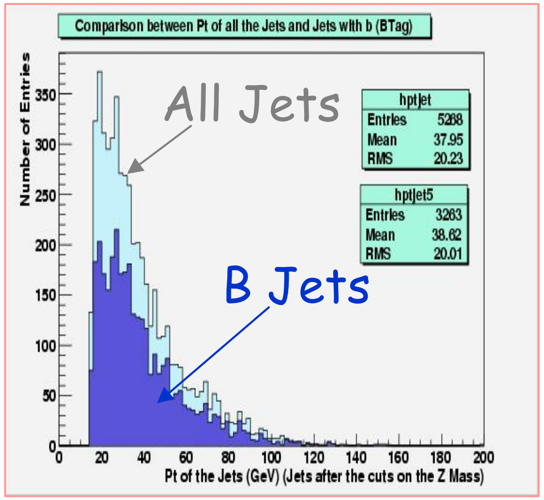
Can control systematic errors related to b-tagging at the few-% level over the whole jet Pt distribution

Acceptance Efficiency = 59.6%

Trigger Efficiency > 95%

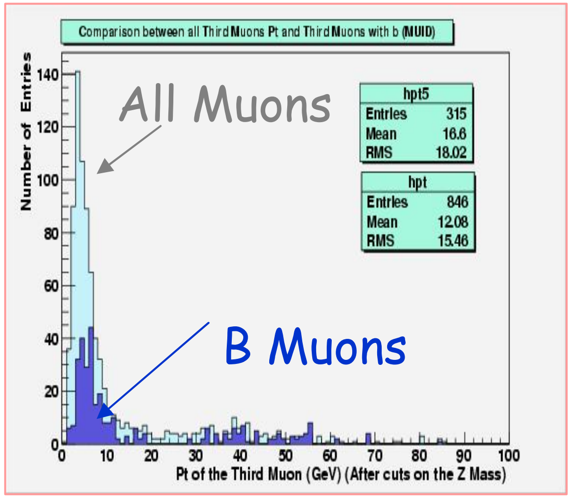
Efficiency for Preselection ~ 40%

30 fb^{-1}	b jet	other
# events	176642	204265



Inc BTagging Efficiency 59.5% Purity 60.7%

30 fb^{-1}	b jet	other
# events	22630	68088



Soft MuonTagging Efficiency 7.2% Purity 37.2%

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 ATLAS 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

b-PDFS (Z+b)

extras