New processes?
New ideas

A M Cooper-Sarkar

Xfitter meeting

Dubna Feb 2016

Extension of tools to

- NNLO
- Resummation
- parton showers
- QED
- Beyond DGLAP at low-x

- Extend PDF fits to fit fundamental parameters
- Combine LHC data sets CMS,ATLAS, LHCb
- Combine LHC data sets, ratios of different beam energies

Can we do more?- better calculations, more processes?

Our tools are developing

At NLO

MCFM interfaced to Applgrid for W,Z and DY data and for t-tbar differential distributions
NLOJet++ interfaced to Applgrid/FastNLO for jets

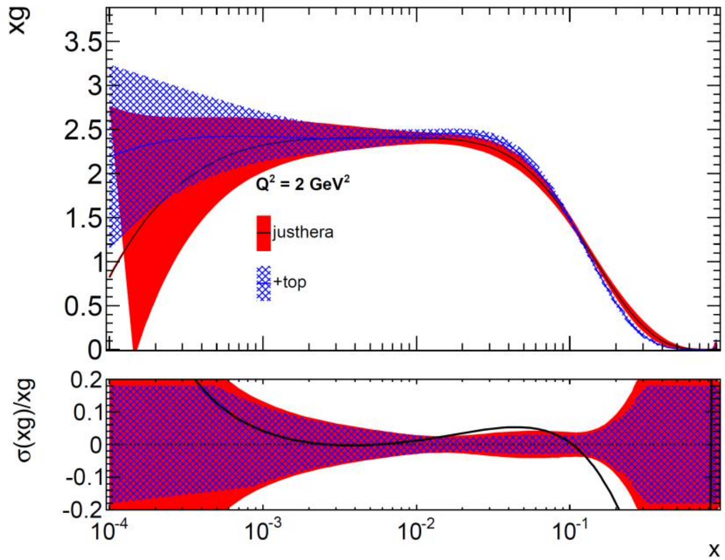
Beyond NLO

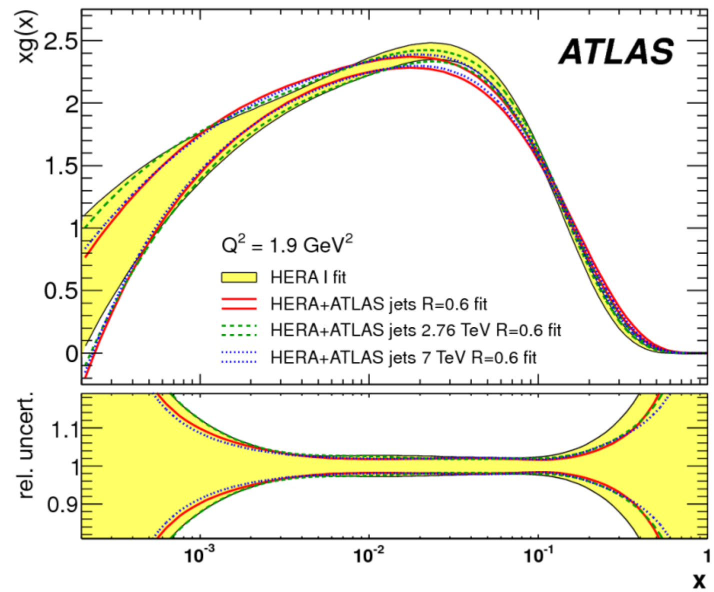
K-factors are used using FEWZ and DYNNLO
But developing Applgrid interface to DYNNLO for Drell-Yan
Also FastNLO interface to DiffTop for approximate NNLO top
We are always told that NNLO jets are coming?

Are the fixed order calculations always adequate?
e.g. Zpt, W+jets, Z+jets, also W+b,c, Z+b,c
Can one use re-summed calculations- New methods using Mellin moments?

Recently aMCfast arXiv:1406.7693(authors included M Sutton and J. Rojo) has been developed interfaced to MadGraph5_aMC@NLO and Applgrid for more processes.
This will allow the inclusion of parton showers into the calculations.

NNLO





Adding NLO top (pt-top, mass t-tbar, y t-tbar)
Pulls to a softer high-x gluon

But adding NLO jets (2.76/7 Tev ratios)
Pulls to a harder high-x gluon

This is probably not new physics but differing NNLO corrections / higher order EW corrections
Could there also be a sensitivity to resummation in t-tbar Pt?

New processes?

Here's the PDF4LHC compendium of PDF sensitive data vs calculations

https://twiki.cern.ch/twiki/bin/view/PDF4LHC/WebHome

LHC data from Run I - Public results

Process	*Data*	*Theory*
Inclusive W, Z production	ATLAS 2010 data arXv:1109.5141	Differential predictions at NNLO QCD
	WZinclusiveData	WZinclusiveTheory
Inclusive W,Z production	LHCb 7 TeV 37pb-1 (mu) arXv:1204.1620	
Inclusive Z production	LHCb 7 TeV 940pb-1 (e) arXv:1212.4620	
Inclusive W/Z production	CMS 8 TeV 19pb-1 (e/mu) arXiv:1402.0923	Inclusive cross section at NNLO
	CMS 7 TeV 36pb-1 (e/mu) arXiv:1107.4789	
W lepton charge asymmetry	CMS 7 TeV 840pb-1 (e) arXiv:1206.2598	
W lepton charge asymmetry	CMS 7 TeV 5fb-1 (mu) arXiv:1312.6283	
Top quark pair production	ATLAS 7 TeV 5fb-1 ATL-PHYS-PUB-2013-056	
Top quark pair production	ATLAS 7 TeV and 8 TeV data	Inclusive cross-sections at NNLO
	CMS 7 and 8 TeV data	Differential distributions at NLO+NNLL, full NNLO in progress
	TTbarData	TTbarTheory
Isolated photon production	ATLAS 7 TeV data from 2011 run arXiv:1311.1440	Differential distributions at NLO
	DirectPhotonData	DirectPhotonTheory
Isolated photon production	CMS 7 TeV 36pb-1 arXiv:1108.2044	
Isolated photon + jet	CMS 7 TeV 2.1fb-1 arXiv:1311.6141	
W production in association with charm	ATLAS 2011 data arXv:1402.6263	
W production in association with charm	CMS 7 TeV 5fb-1 arXiv:1310.1138	
Z production in association with charm	LHCb 7 TeV 1fb-1 arXv:1401.3245	
Z rapidity and transverse momentum	CMS 7 TeV 36pb-1 arXiv:1110.4973	
Z transverse momentum	ATLAS 7 TeV 4fb-1 arXiv:1211.6899	
Inclusive jet production	ATLAS 2011 2.76 data arXv:1304.4739	
Dijet production	ATLAS 2011 data arXv:1312.3524	
Inclusive jet and dijet production	CMS 7 TeV 5fb-1 arXiv:1212.6660	
3/2 jets ratio	CMS 7 TeV 5fb-1 arXiv:1304.7498	
Z + jets	LHCb 7 TeV 1fb-1 arXv:1310.8197	
Z + jets	ATLAS 7 TeV 4fb-1 arXv:1304.7098	
Single top production		
Low-mass Drell-Yan	ATLAS 2011 and 2010 data arXv:1404.1212	

Some of these will certainly require better calculations

And what about di-boson production?

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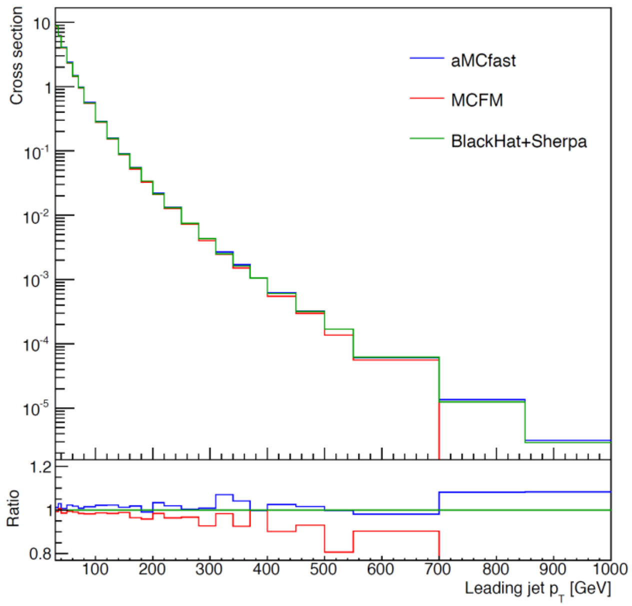
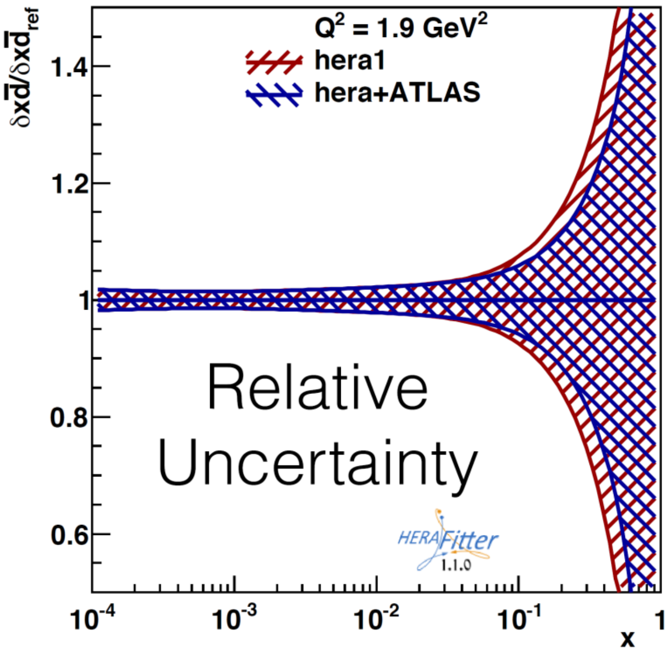
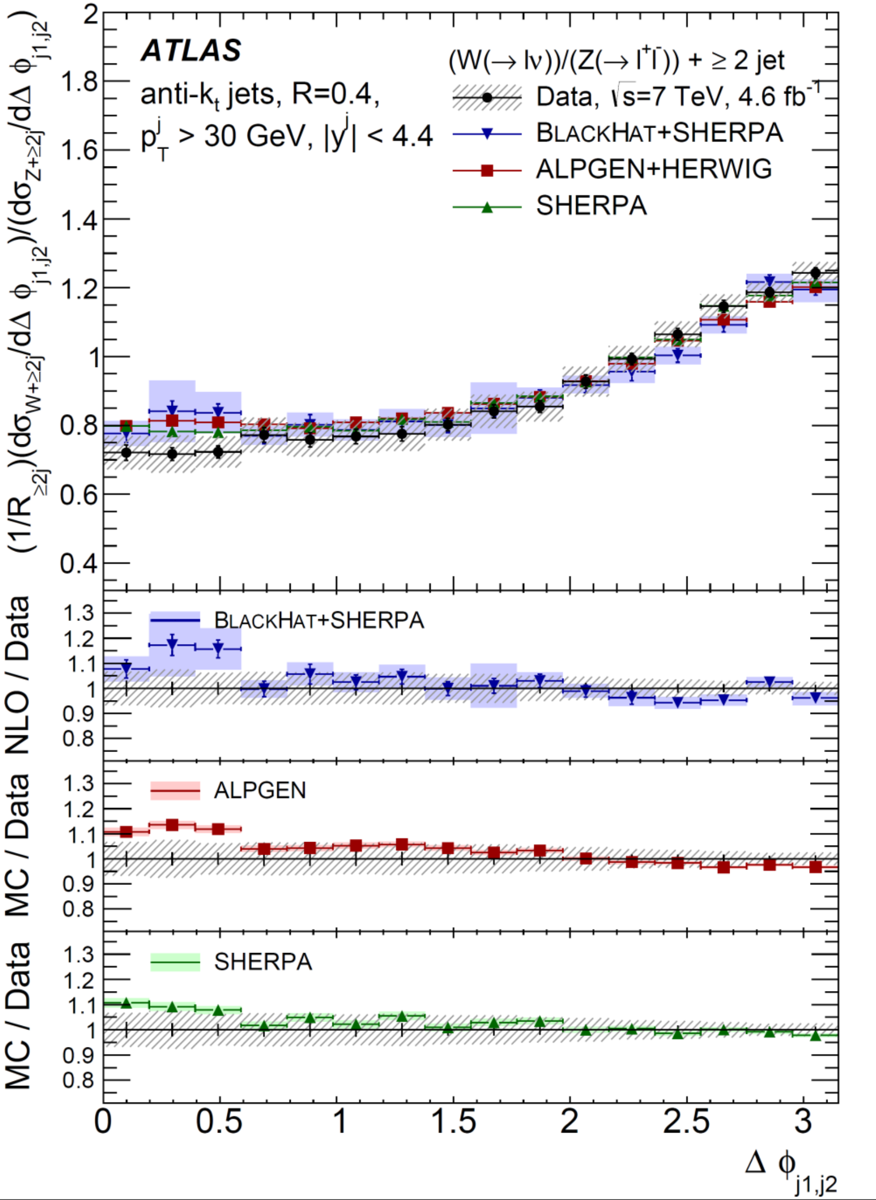


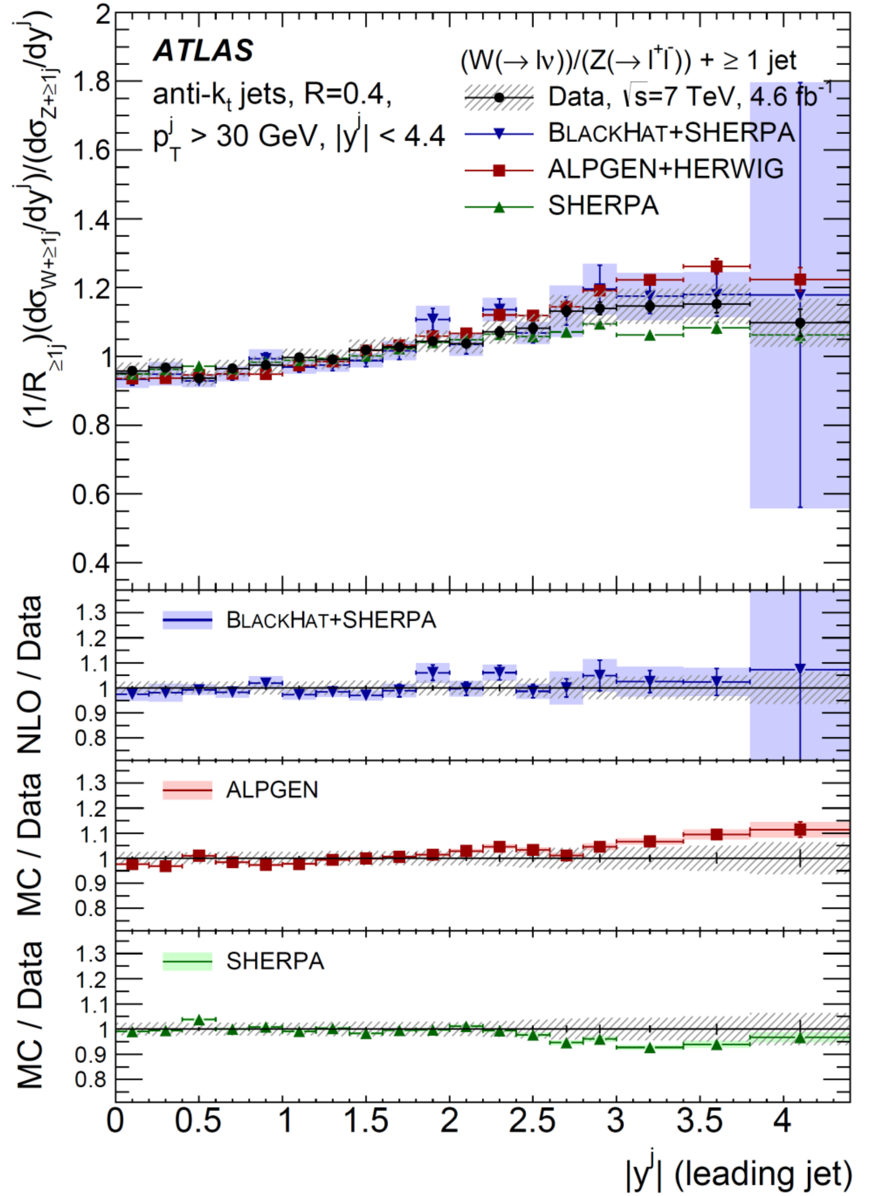


W+jets study aMCfast vs MCFM etc
By Craig Sawyer

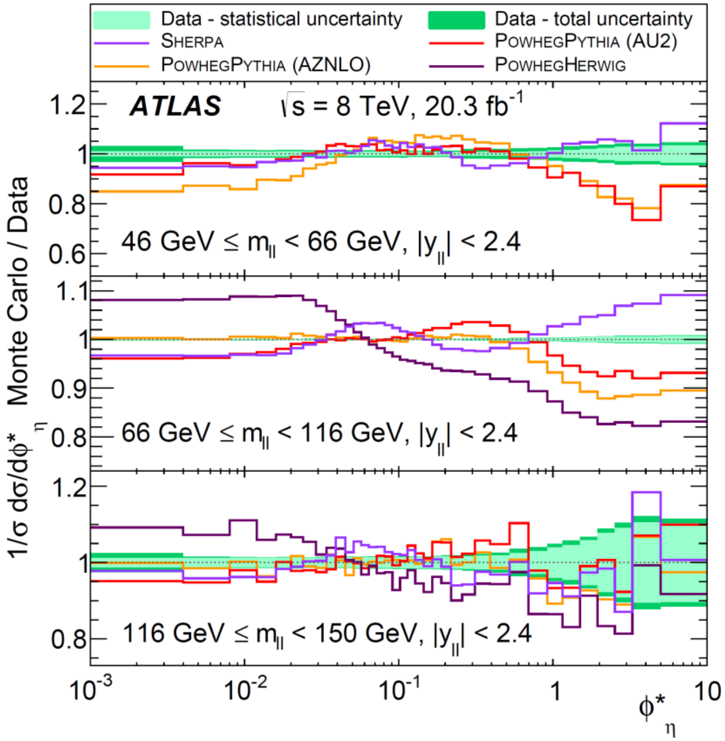
PDF fits done using MCFM to W+jets and R+jets pt and rapidity spectra
Some small decrease in dbar high-x uncertainty.
Chisq depends on treatment of correlations

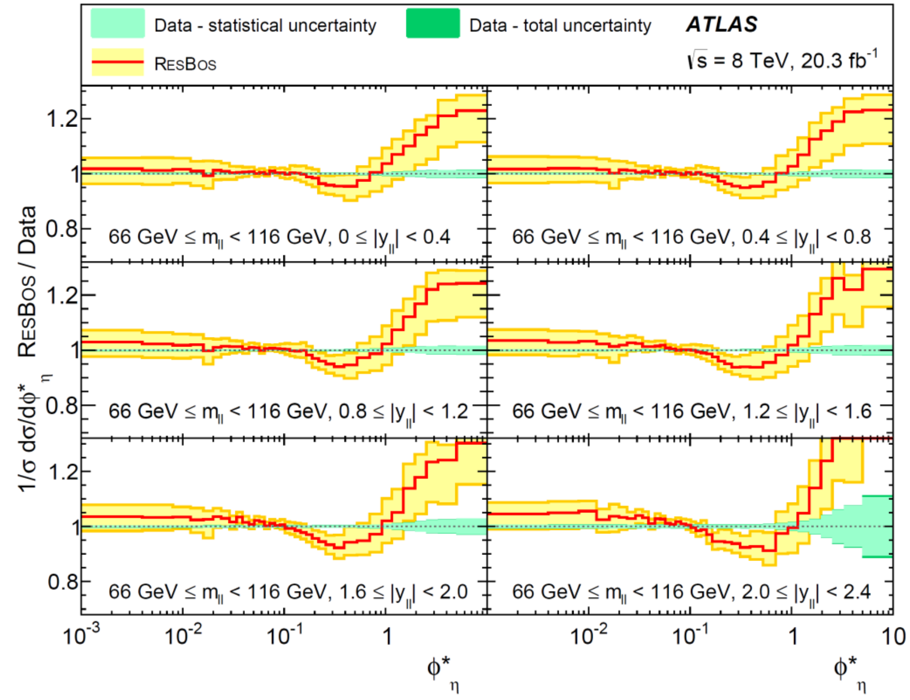
	JER correlated	uncorrelated
ATLAS R-jets leading jet pT (electrons)	23 / 23	16 / 23
ATLAS R-jets leading jet pT (muons)	41 / 23	30 / 23
ATLAS W+jets leading jet y (electrons)	21 / 18	5.4 / 18
ATLAS W+jets leading jet y (muons)	76 / 18	8.9 / 18
ATLAS R-jets leading jet y (electrons)	27 / 18	17 / 18
ATLAS R-jets leading jet y (muons)	37 / 18	25 / 18





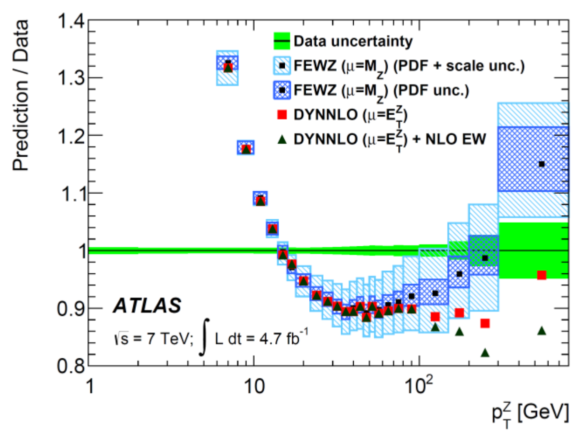
Are any calculations really adequate ?





ATLAS 8 TeV: Z pt and Z φ* ArXIV:1512.02912

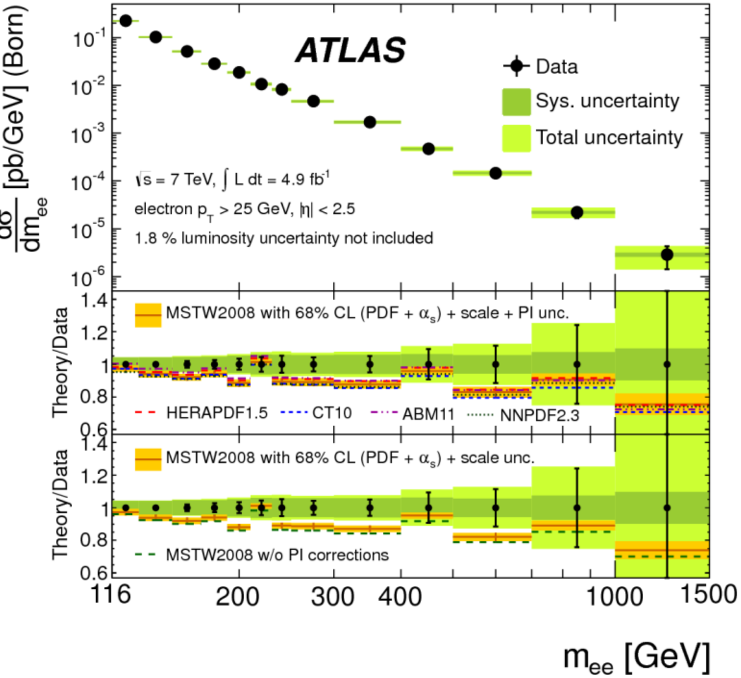
And the same question can be asked for Zpt
Are present calculations really adequate ?



ATLAS 7 TeV Z pt

Including the QED part in the proton is now becoming essential

Illustration on 7 TeV High-Mass Drell-Yan
(but much clearer in forthcoming 8 TeV)




```
Correlated Chi2    9.4382132067676245
Systematic shifts
  1 DY_Tg           -0.2529   +/-   0.9782
  2 DY_rec          -0.4256   +/-   0.9098
  3 DY_ID           -0.6924   +/-   0.8090
  4 DY_Sca          -0.4319   +/-   0.9400
  5 DY_BG           -2.0728   +/-   0.6427
  6 DY_th            0.0542   +/-   0.9948
  7 DYlumi          -0.4618   +/-   0.8841
   ...
```

Background nuisance parameter shift is large without account for the photon induced irreducible contribution to di-lepton production

- There is now a QEDevol module available in xFitter
- And Applgrid has been extended to allow for a photon density to be fitted

Other Ideas

We could make more use of ratios

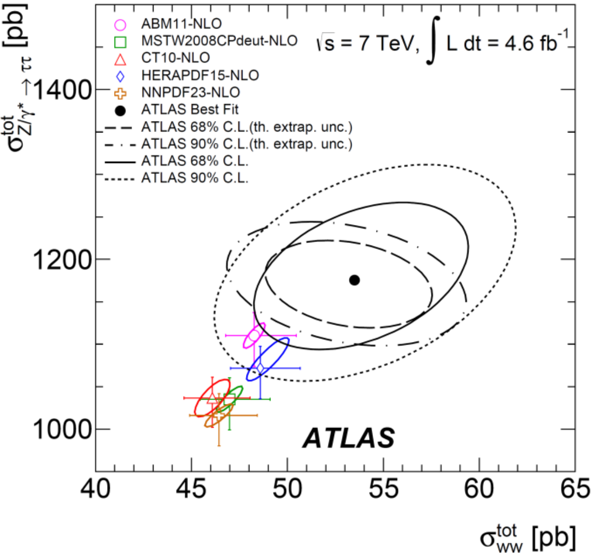
We could combine data sets CMS and ATLAS and LHCb

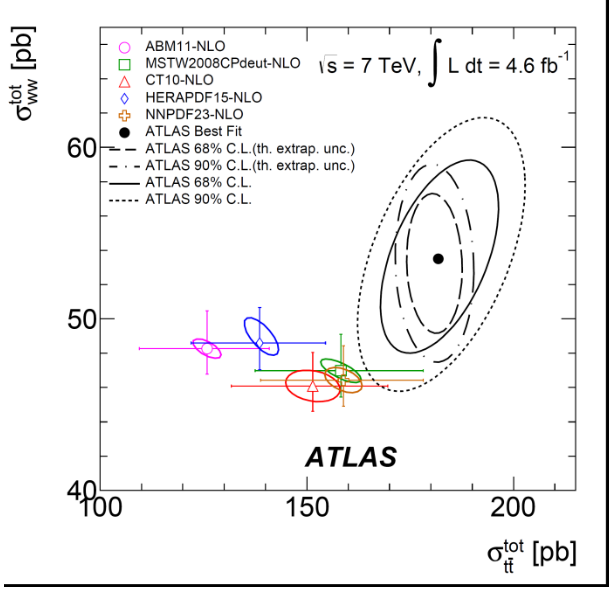
We could go beyond DGLAP at low-x

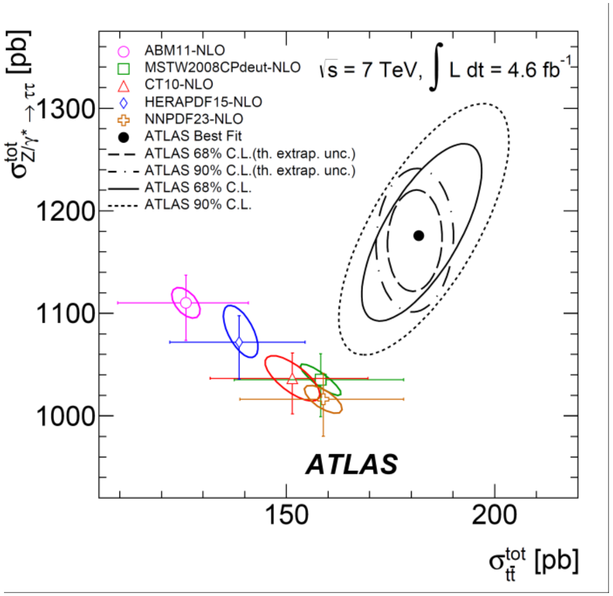
We could extend PDFs to fit fundamental parameters together with PDFs

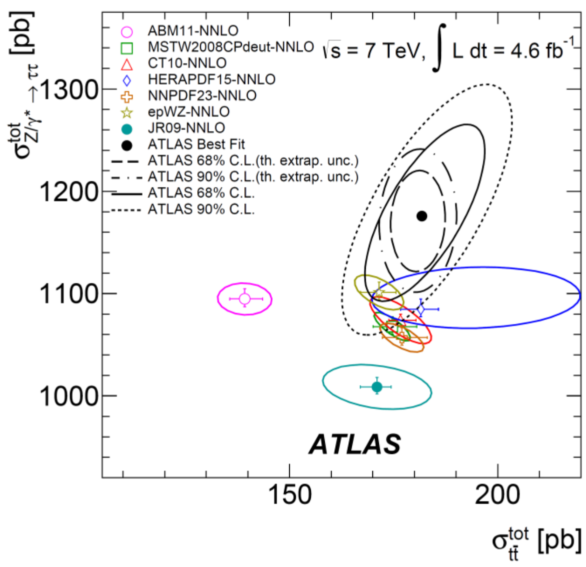
- $\alpha_S(M_Z)$ is perhaps the most obvious.
- But there are also heavy quark masses
- Electroweak parameters: NC vector and axial-vector couplings
- $\mathrm{Sin}^2\theta_W$ and M_W
- CKM matrix Vcs

Use the Higgs?









Information from ratios- or correlations between different channels are interesting.
WW,t-tbar and Z→ττ can all feed into electron+muon final states..
NNLO PDFs are inadequate

PDF sets at LO/NLO/NNLO with correlated uncertainties

arXiv:1404.4234

Theoretical predictions are available at different orders

- LO used in parton shower MCs
- NLO for most predictions
- NNLO for a few predictions

Factorisation theorem: $\sigma \approx \hat{\sigma} \otimes \mathrm{PDF}$

Uncertainties come from the PDFs and the sub-process cross-sections
Scale uncertainties affect the sub-process cross-sections more at lower orders

Ratios are often used as a way of cancelling experimental uncertainties.
But the corresponding theoretical uncertainties may not cancel out

$$\frac{\hat{\sigma}_X^{NLO} \otimes PDF_{NLO}}{\hat{\sigma}_Y^{NLO} \otimes PDF_{NLO}}$$

PDF uncertainties cancel
large scale uncertainty

Large scale uncertainty because NLO calculation

$$\frac{\hat{\sigma}_X^{NLO} \otimes PDF_{NLO}}{\hat{\sigma}_Y^{NNLO} \otimes PDF_{NNLO}}$$

improved scale uncertainty
No cancellation of PDF uncertainty

Improve this by going to NNLO but what if this is only available for ONE of the cross sections?

$$\frac{\hat{\sigma}_X^{NLO} \otimes PDF_{NLO}^{corr}}{\hat{\sigma}_Y^{NNLO} \otimes PDF_{NNLO}^{corr}}$$

PDF uncertainties cancel
improved scale uncertainty

Preserve correlations between PDFs of different orders

This has been done using the HERAPDF formalism and HERA-1 combined data varying the model and parametrization assumptions (as in JHEP 1001, 2010, 109)

MC replica method used to preserve the correlations:

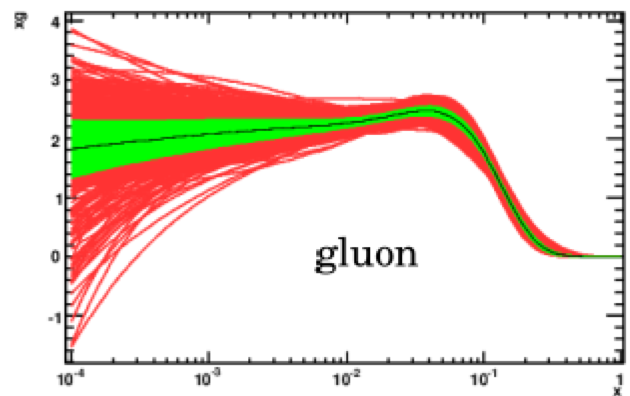
→ 1337 MC replicas of the data fluctuating the inputs within uncertainties using Gaussian prob densities

→ perform a consistent fit of PDFs at different orders to each replica

central PDF = average over replicas,
PDF uncertainty = RMS over replicas

model and param uncertainties treated correlated between orders

χ^2/N_{dof} NLO



In practice an eigenvector representation can be more convenient than MC replicas

The MC replica results can be converted using the method used to extract META-PDFs (arXiv:1401.0013)

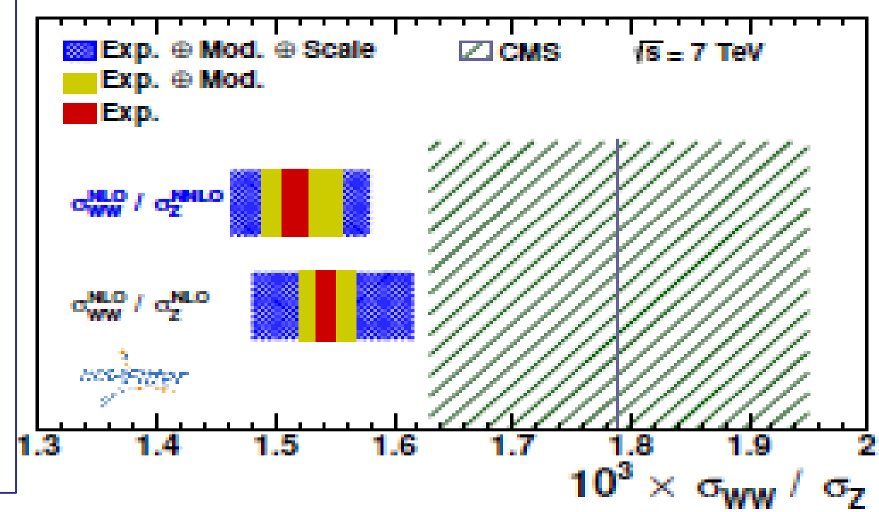
→ build the covariance matrix

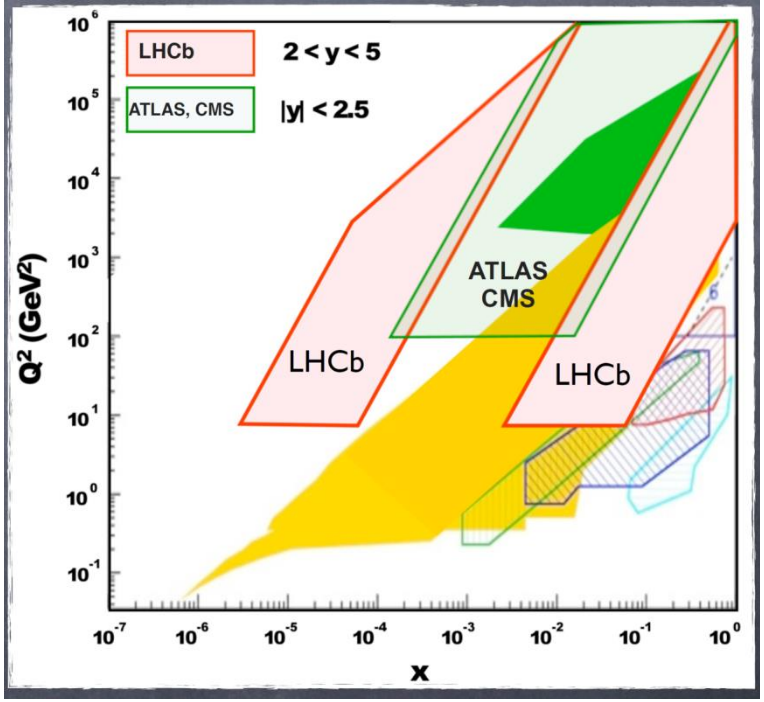
→ diagonalise matrix and keep only leading eigenvectors

This preserves strong correlations between NLO and NNLO PDFs.

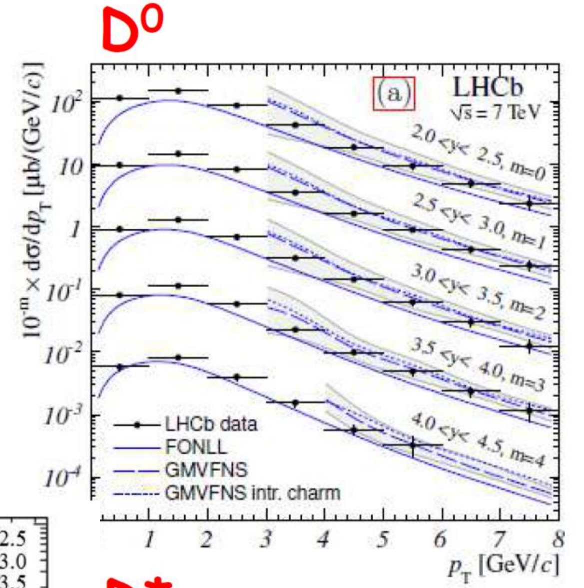
These PDFs have been used to calculate the **WW/Z ratio** and compare to CMS data arXiv:1306.1126
The total theoretical uncertainty of the calculation is reduced by 30-40% if σ_Z is calculated to NNLO because of reduced scale uncertainties
BUT ONLY because the PDF uncertainties at NLO and NNLO are correlated

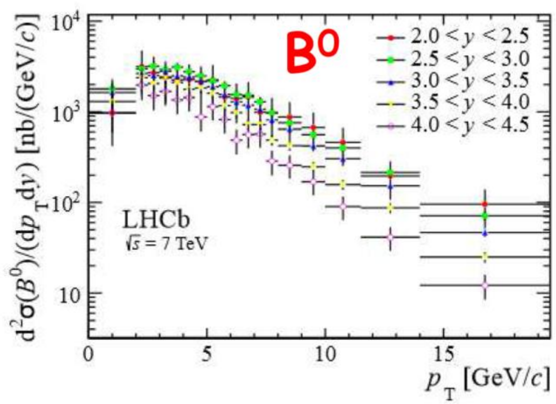
(arXiv:1306.1126)



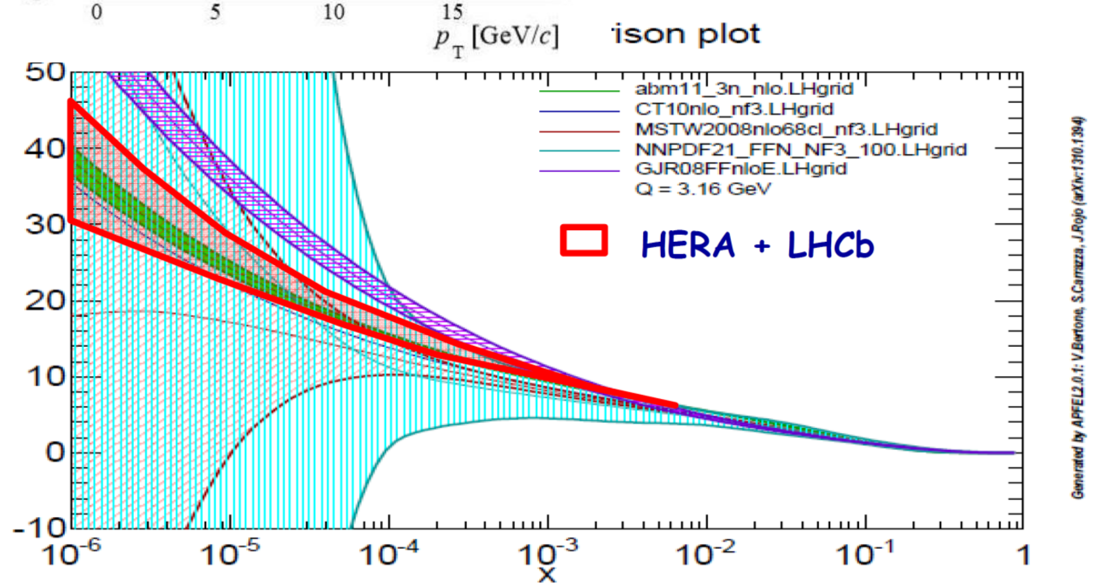


Use Charm and beauty **data from LHCb together with HERA i**nclusive and HERA charm+beauty data to improve the **low-x gluon**





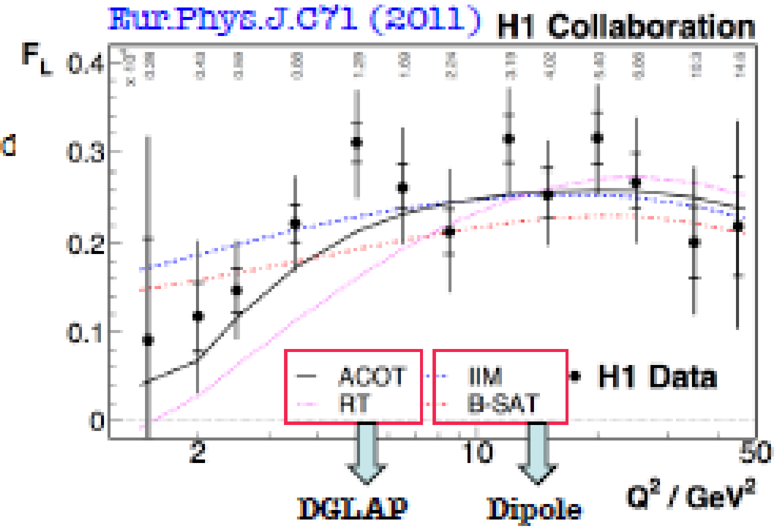
PROSA study uses single differential fixed order NLO calculations for heavy flavours at LHC by Nason, Dawson, Ellis 1989 which are very fast and so can be input directly to QCD fits.
They are available as part of the MNR software package, Mangano, Nason, Ridolfi 1992, which was added to HERAFitter



Going beyond DGLAP at low-x

As an alternative to DGLAP, HERAFitter includes also Dipole models:

- Studied by the H1 collaboration in comparing different models on FL:
  - Dipole Models implemented in HERAFitter:
    - GBW model: first model
    - IIM (based on BK-equation)
    - BGK (based on GBW, but gluon evolved using DLGAP)
  - DGLAP Models:
    - RT as used by MSTW group
    - ACOT as used by CTEQ group

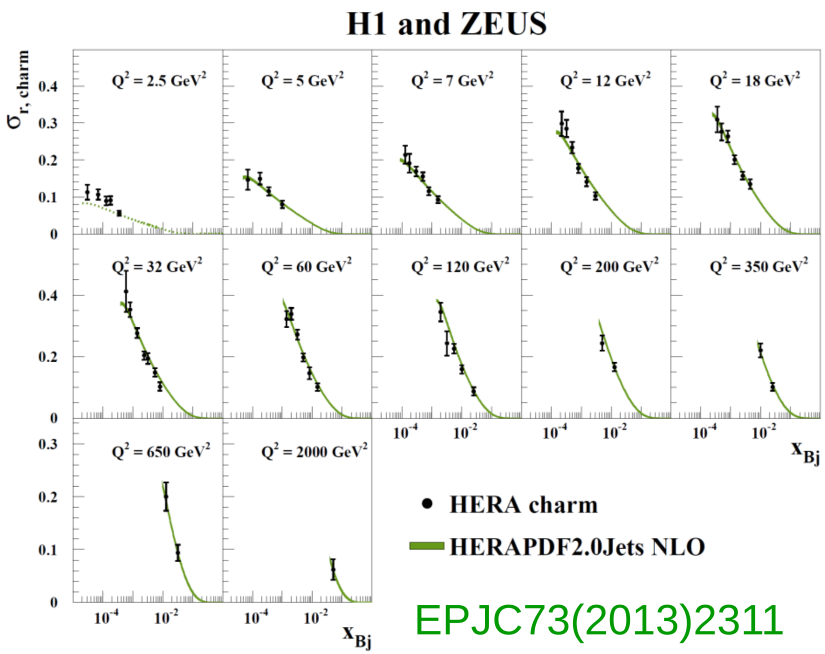


Unintegrated PDFs based on the kT-factorisation (CCFM) evolution.

- applicable only to NC ep scattering:
  https://www.herafitter.org/HERAFitter/HERAFitter/HERAFitterMeetings/Meeting2012-Oct-29?action=AttachFile&do=get&target=updf.pdf

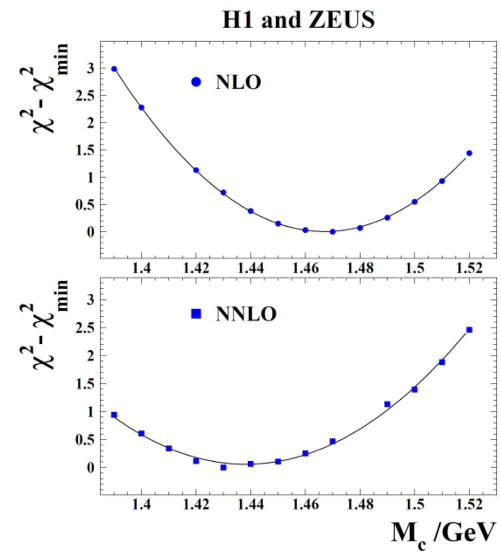
Diffractive DIS PDF fits.

Fitting other fundamental parameters--Heavy quark masses



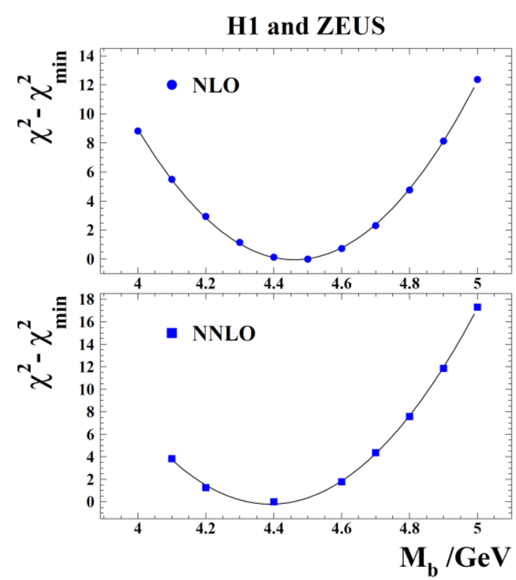
EPJC73(2013)2311

The data from the HERA charm combination is added to the HERAPDF2.0 fit. The PDFs do not change significantly. The main effect is to determine the optimal charm mass parameter and its variation.

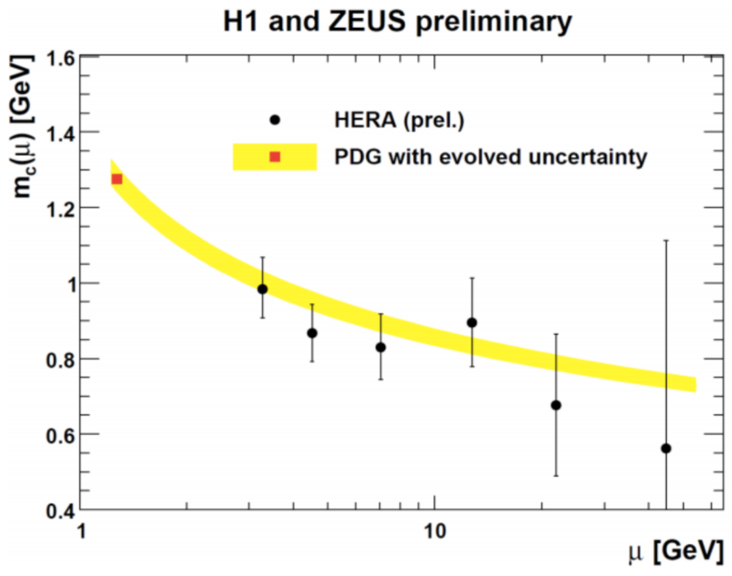


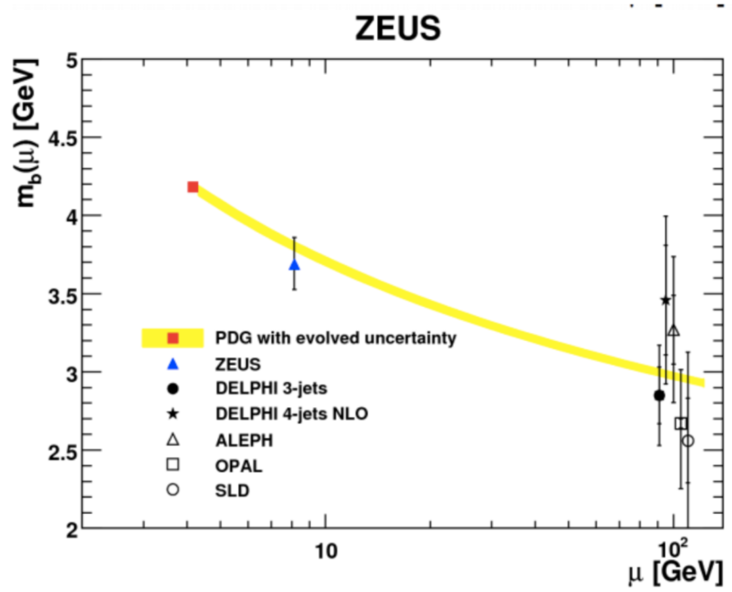
ZEUS and H1 data on beauty production
EPJC75(2015)265, EPJ65C(2010)89
Are similarly used to determine the optimal beauty mass parameter and its variation

These are pole-masses -- a running mass and indeed the running of the mass can also be determined…



- **Most HERA DIS charm data were combined:**
  - consistent data sets extracted using different methods
  - data are well described by QCD predictions
  - running charm mass determined: $m_c(m_c) = 1.26 \pm 0.06$ GeV
- **First measurement of the charm-mass running.**
- **New charm measurements for D* are combined at the visible phase space level**
  - awaiting for theory improvements
- **New measurement in photo-production exploiting different centre of mass energy.**
- **New beauty-jet measurement + lifetime taging in DIS by ZEUS:**
  - one of the most precise beauty measurements at HERA
  - beauty mass measured: $m_b(m_b) = 4.07 \pm 0.17$ GeV.



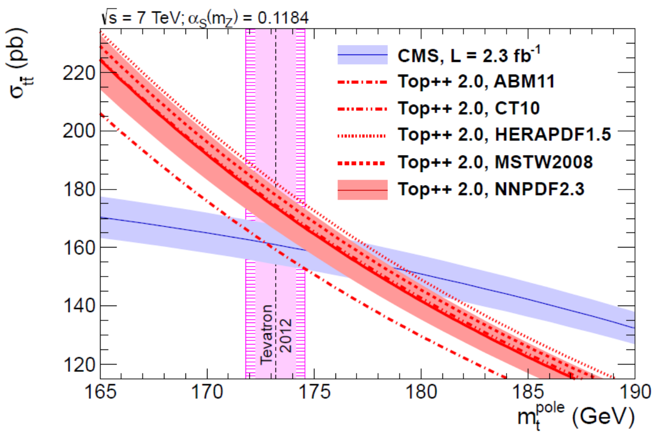


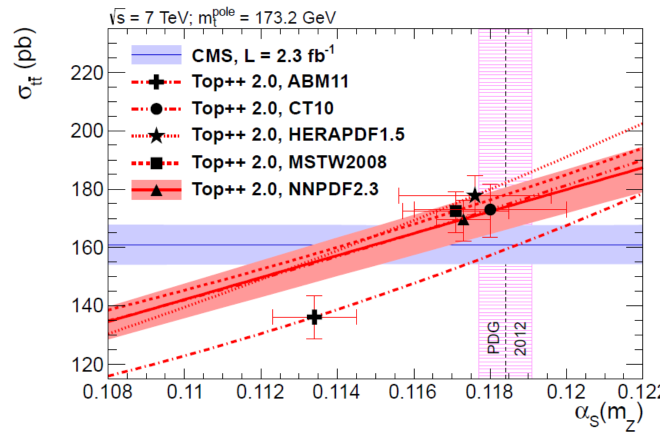
Thank you!

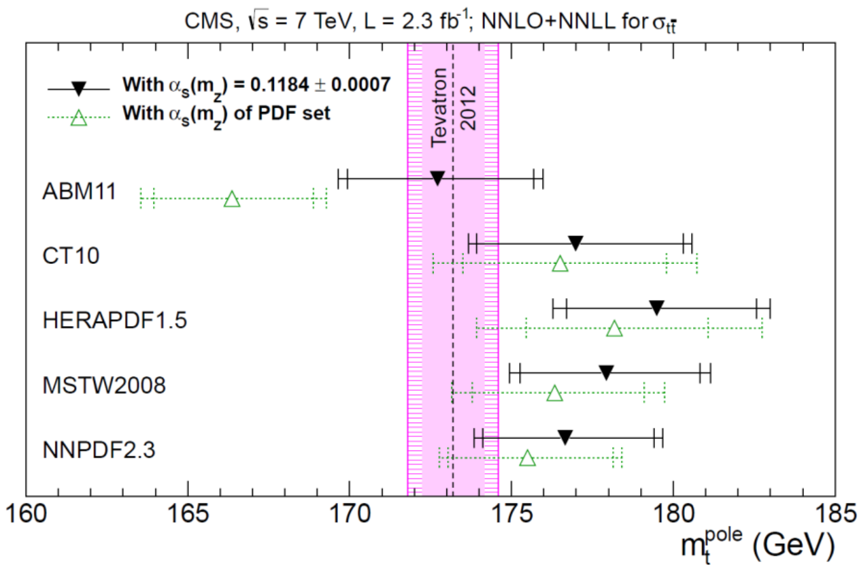
From one of Voica's talks

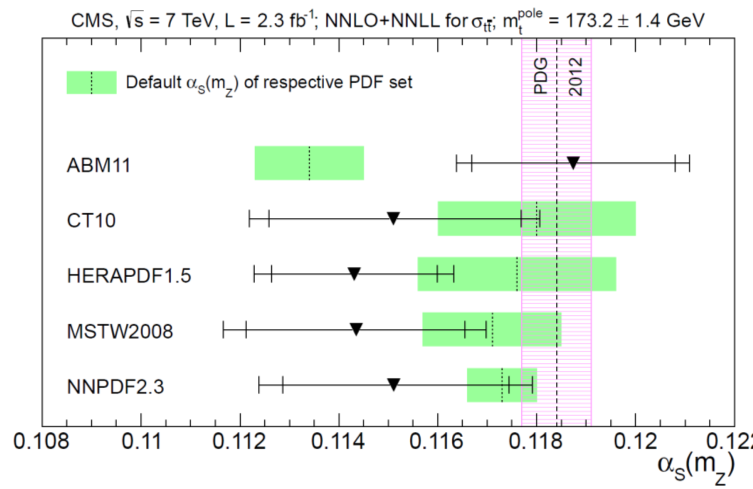
Fitting other fundamental parameters--Heavy quark masses and $\alpha_S(M_Z)$

And CMS made a simultaneous top mass and $\alpha_S(M_Z)$ measurement







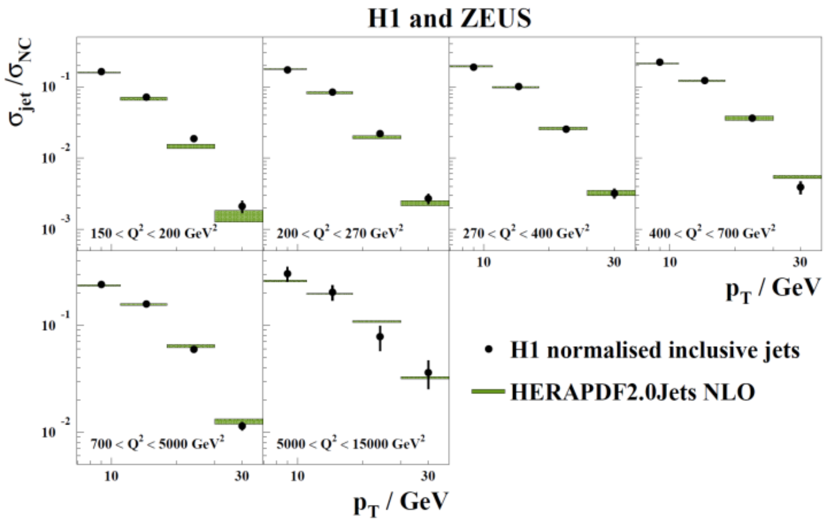


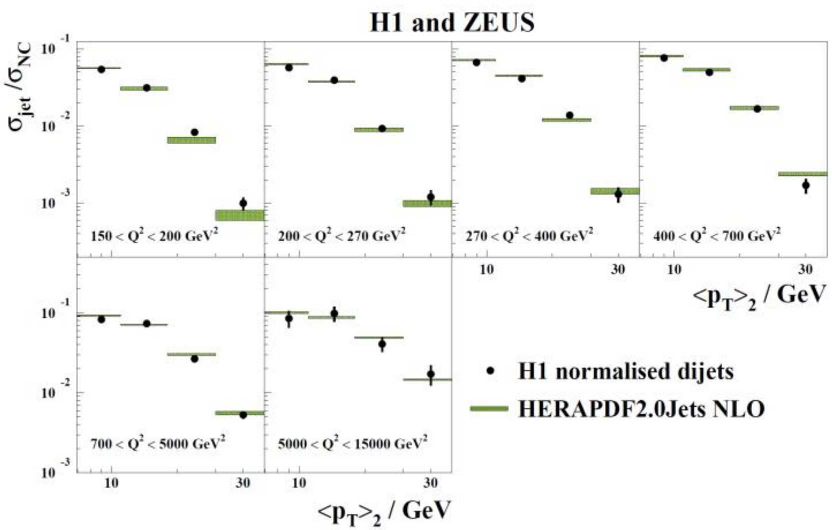
Fitting fundamental parameters $\alpha_S(M_Z)$

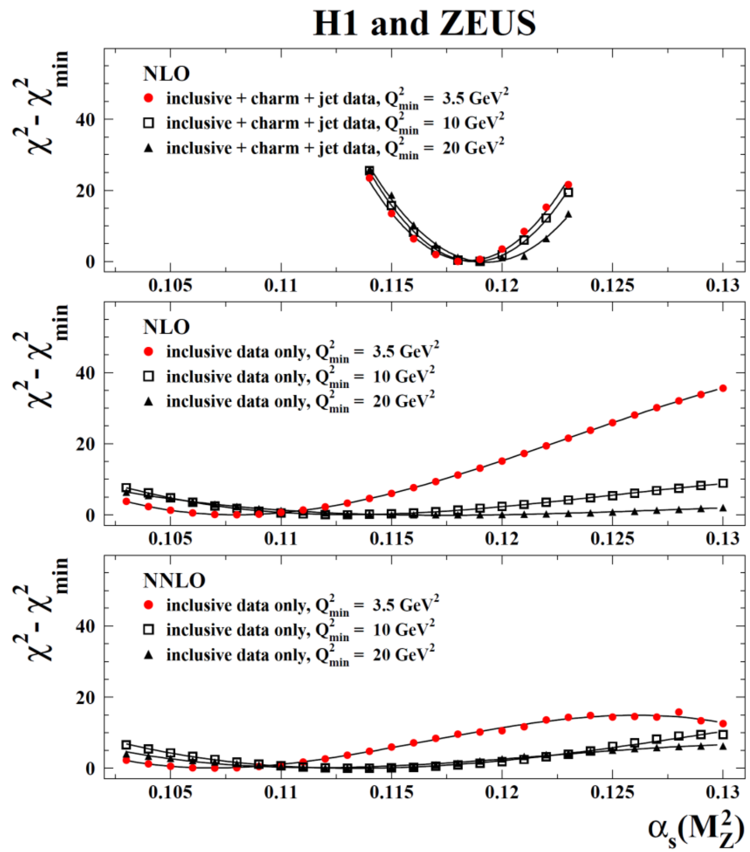
HERAPDF2.0Jets is based on inclusive + charm + jet data

The fits with and without jet data and charm data are very compatible for fixed $\alpha_S(M_Z)$

Let's look at freeing $\alpha_S(M_Z)$





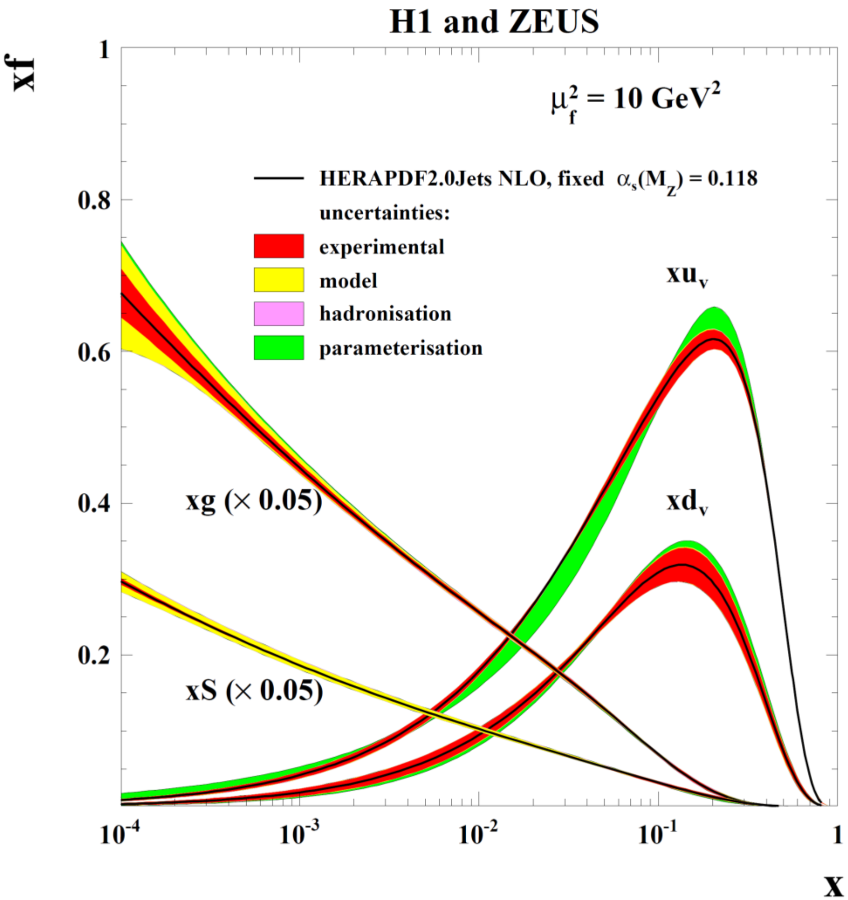


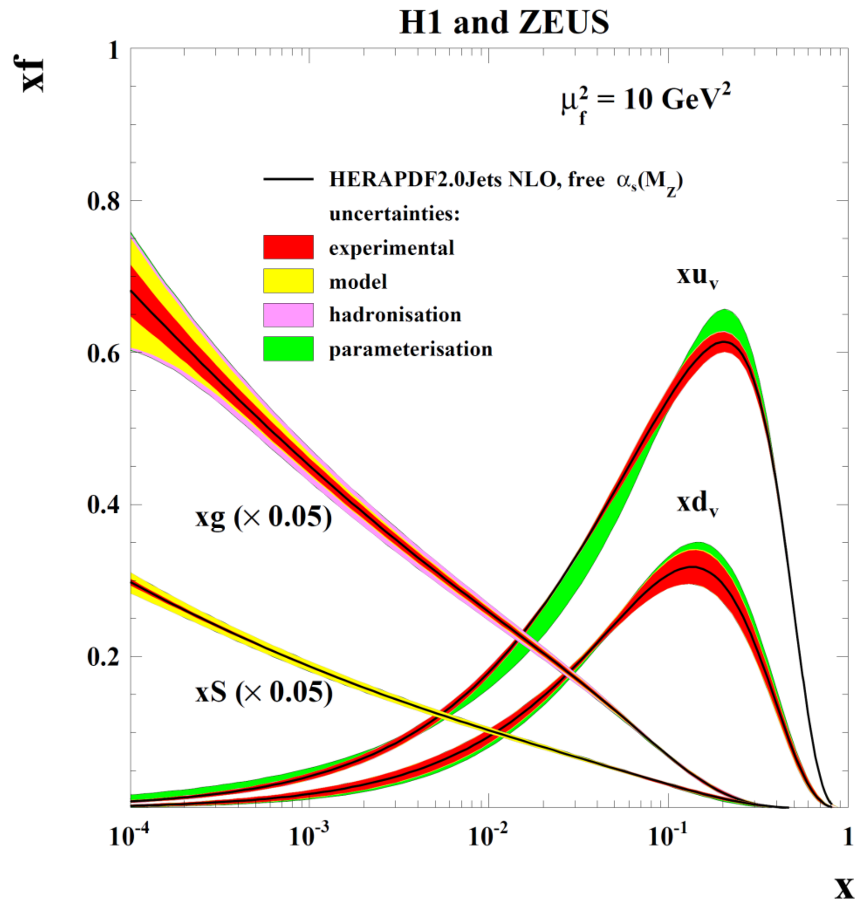
Inclusive data alone cannot determine $\alpha_S(M_Z)$ reliably either at NLO or at NNLO

When jet data are added one can make a simultaneous fit for PDF parameters and $\alpha_S(M_Z)$ at NLO--- NNLO calculation still not available

Fits are made with fixed and free $\alpha_S(M_Z)$

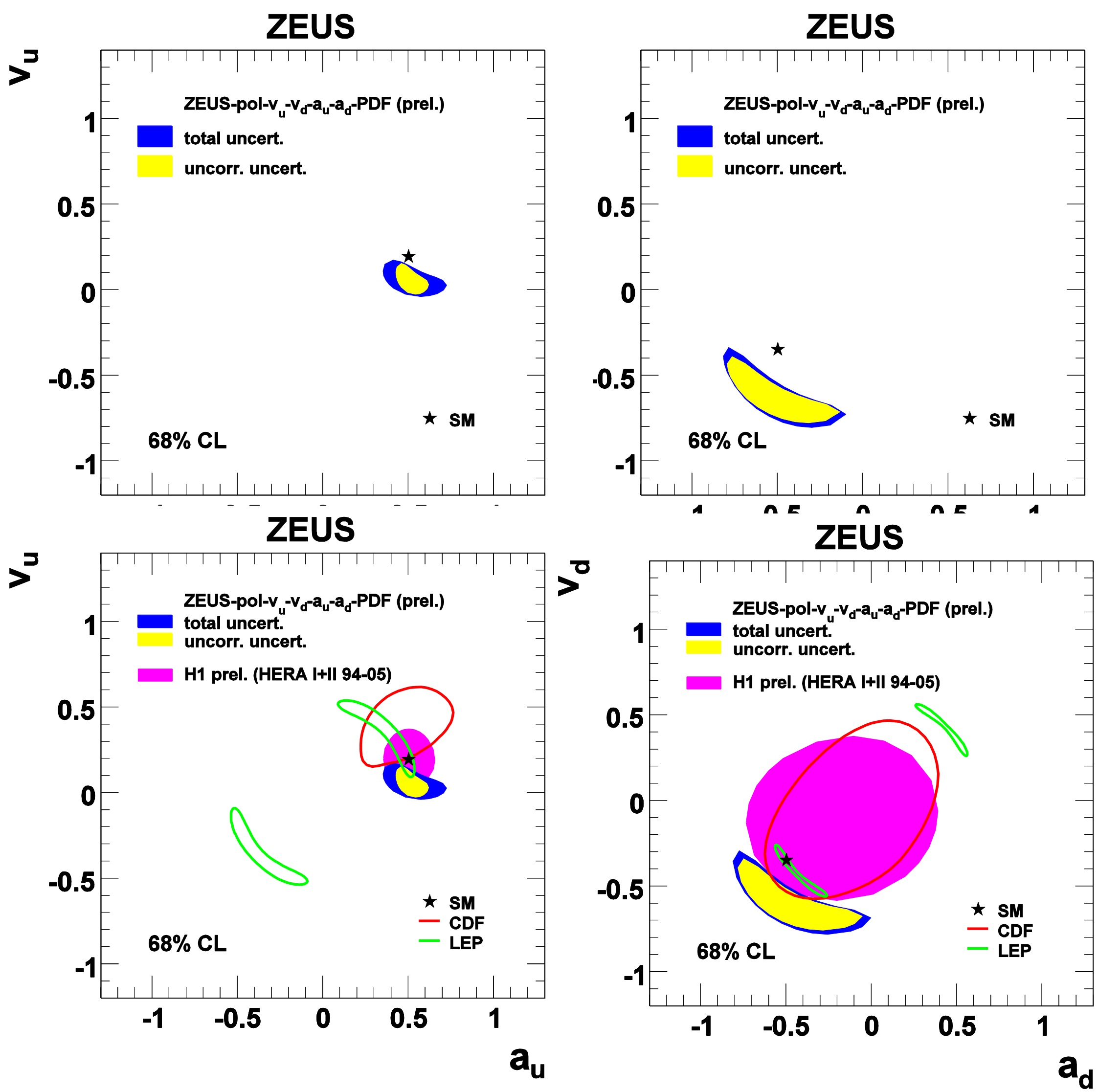
These PDFs are very similar since the fitted value is in agreement with the chosen fixed value. The uncertainties of gluon are not much larger when $\alpha_S(M_Z)$ is free since it is well determined. Scale uncertainties are not illustrated on the PDFs

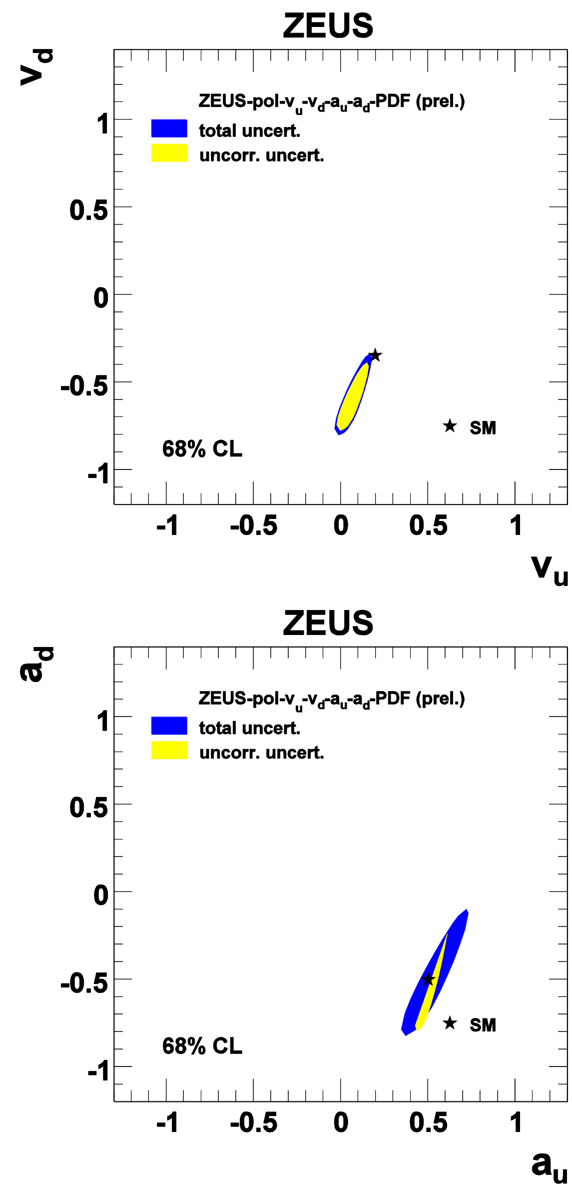




$$\alpha_S(M_Z) = 0.1183 \pm 0.0009_{(exp)} \pm 0.0005_{(model/param)} \pm 0.0012_{(had)} \, {}^{+0.0037}_{-0.0030}(\text{scale})$$

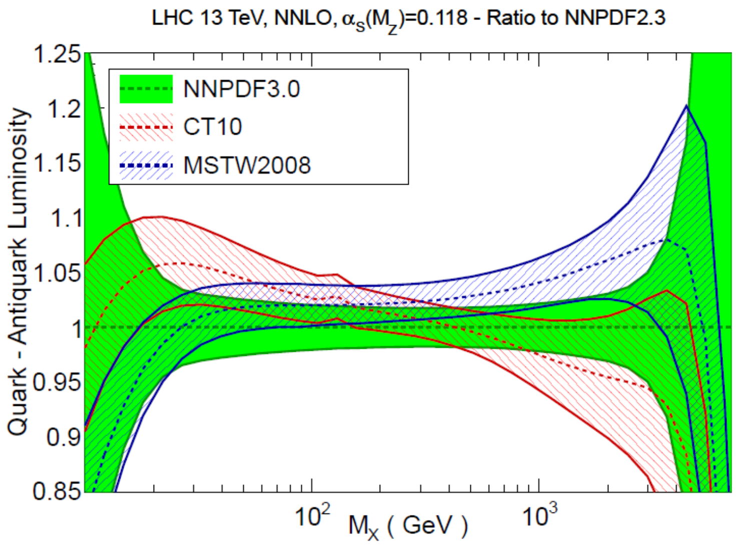
Fitting other fundamental parameters—Neutral current couplings



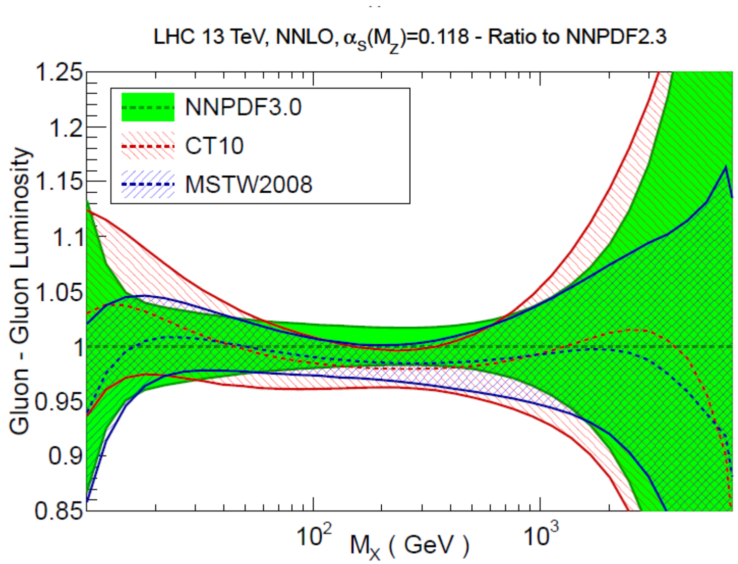


Prehistoric slides on HERA EW couplings…
Updates are coming

So what will Run- 2 bring?



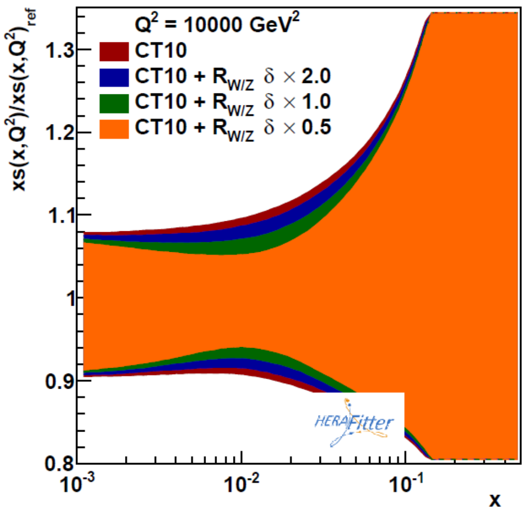
13 TeV parton luminosity plots

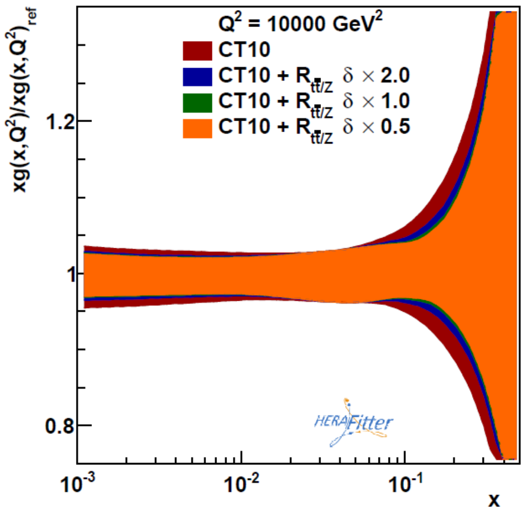


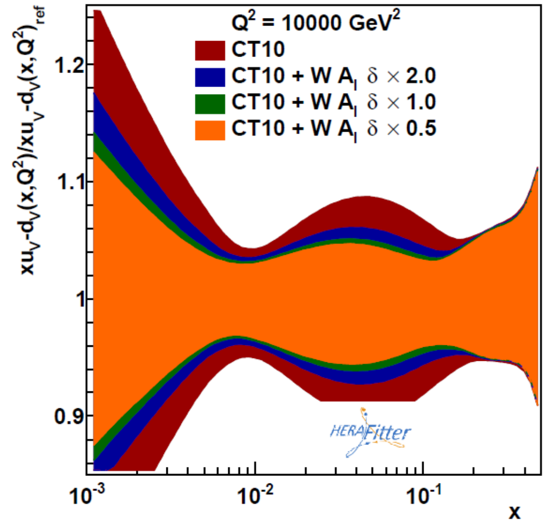
The kinematic region moves to lower x
Higgs production is at x values of 0.005 for central rapidity
The HERA gluon measurements become more important.
We will use our own data on the classic processes------ W,Z production, Drell-Yan, jets and top production ------ to constrain PDFs in this new kinematic regime
BUT PDFs are improved by precision measurements which take time.

The PDF4LHC (arXiv:1507.00556) made a profiling study of the use of ratios as input to PDFs..

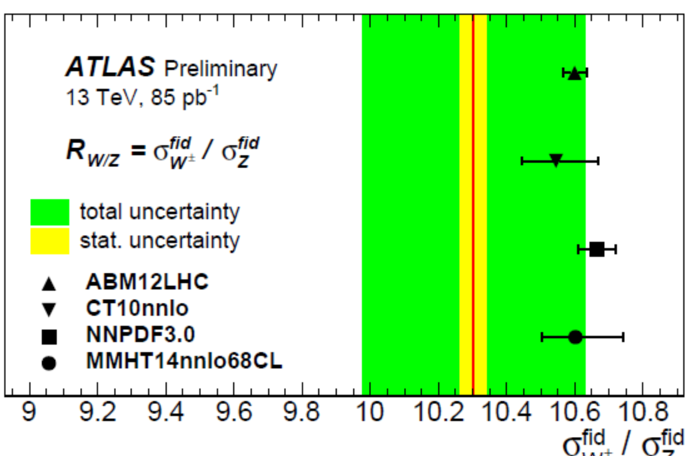
	$R_{W/Z}$	$R_{t\bar{t}/Z}$	A_ℓ	y_Z
Kinematic range	$p_{t,\ell} > 25\,\text{GeV},\ \lvert\eta_\ell\rvert < 2.5$			
Number of bins	1	1	10	12
Baseline accuracy per bin	1%	2%	$\approx 1.5\%$	$\approx 1.5\%$

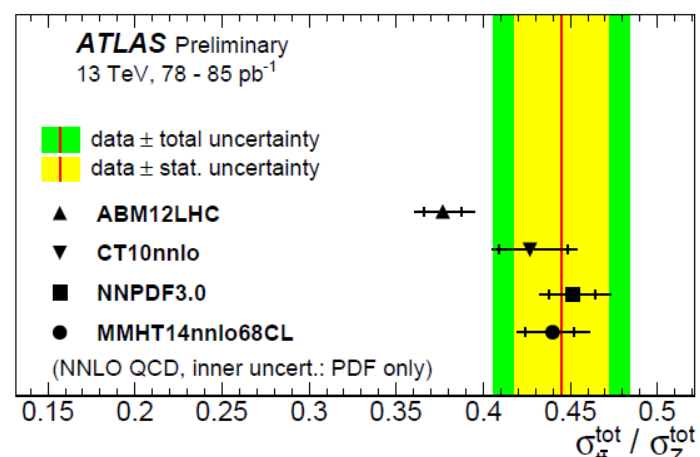






And now we HAVE some of these ratios…





Another idea for quick measurements which have PDF impact is to use ratios of cross sections at 13 to 8 or 7 TeV

M. Mangano and J. Rojo, arXiv:1206.3557