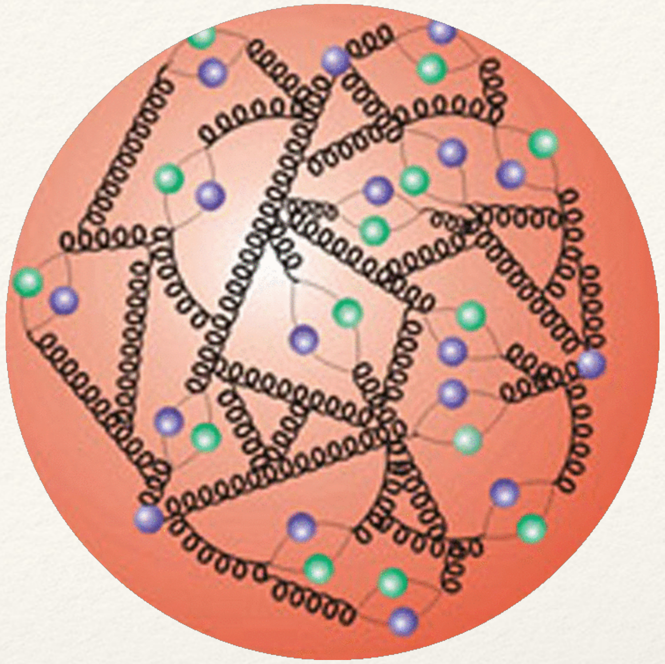


July 2016, Liverpool

PDFs and neutrino DIS

Voica Radescu
University of Oxford

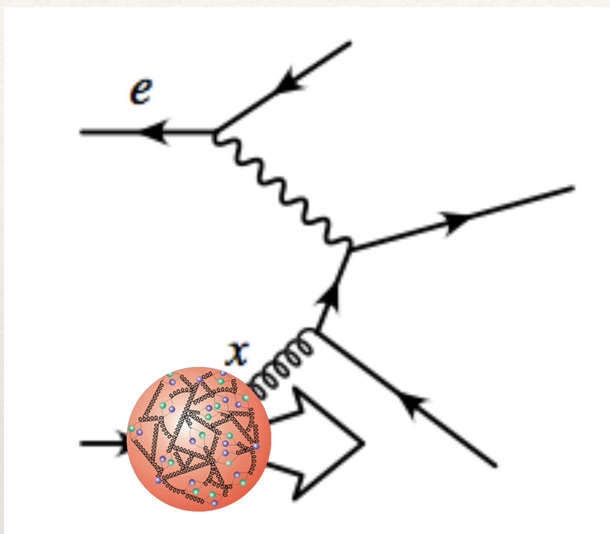
Cross Section: Theory meets Data

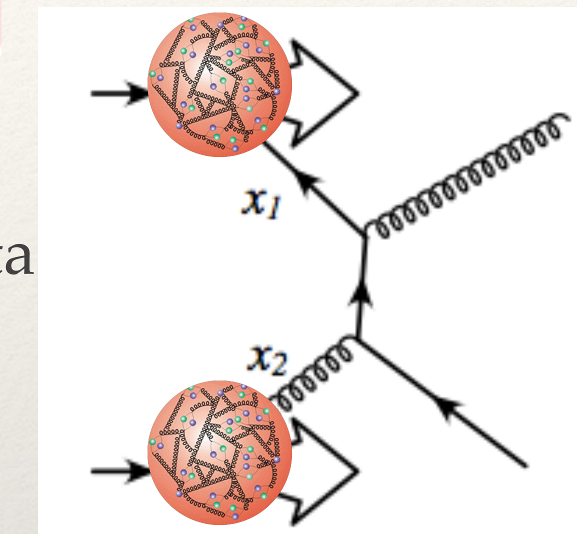
Interpretation of any cross section measurement is given in the context of the factorisation concept:

$$\sigma = \hat{\sigma} \otimes \text{PDF}$$

calculable — from data

DIS processes





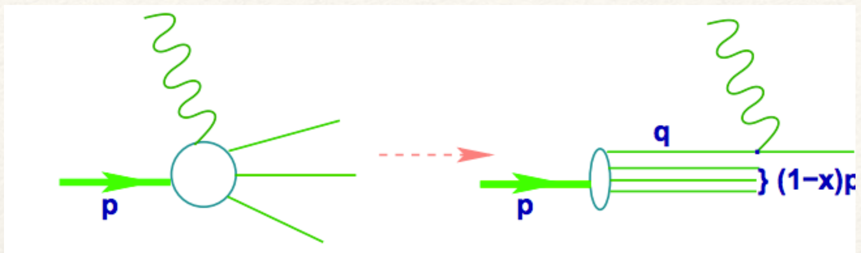
DY processes

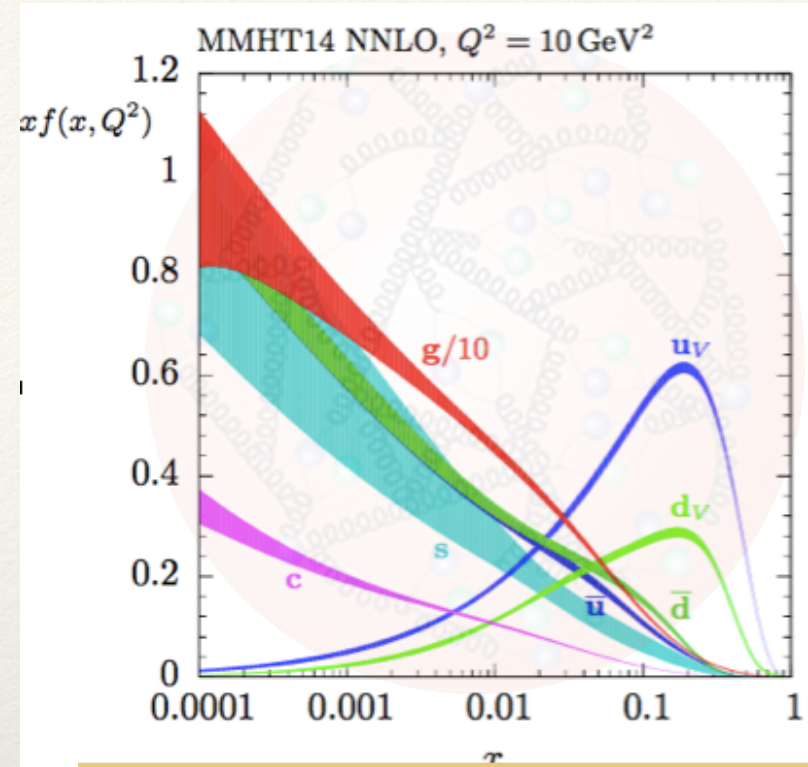
Multiple precision measurements from Fixed target, HERA, Tevatron, and LHC allowed our knowledge on QCD to be pushed forward on many fronts

Improvement of PDFs precision demands theory & experiment collaboration and implies a variety of high precision measurements and theory calculations

Parton Distribution Functions (PDFs)

- PDFs are understood as the probability of finding a parton of a given flavour that carries a fraction x of the total proton's momentum (at LO pQCD)





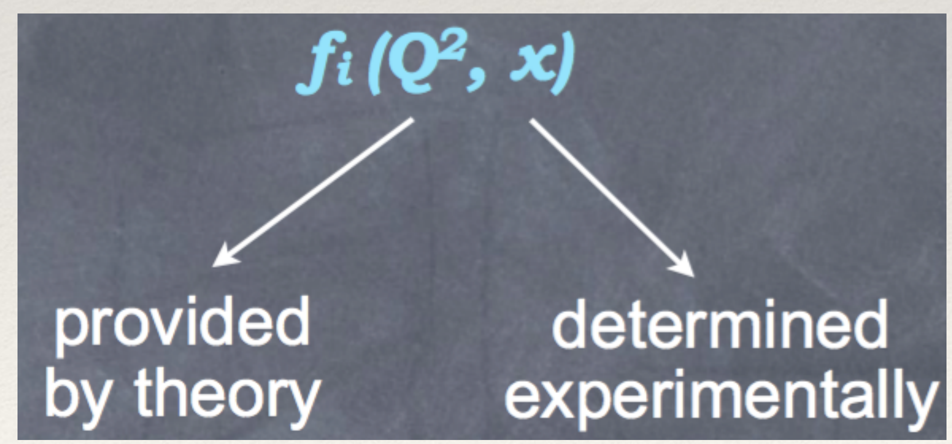
Q2: resolving power of experiment
x: fraction of proton's momentum

- Once QCD corrections included, PDFs become scheme dependent
  - Shape and normalisation of PDFs are very different for each flavour, reflecting the different underlying dynamics that determines them.

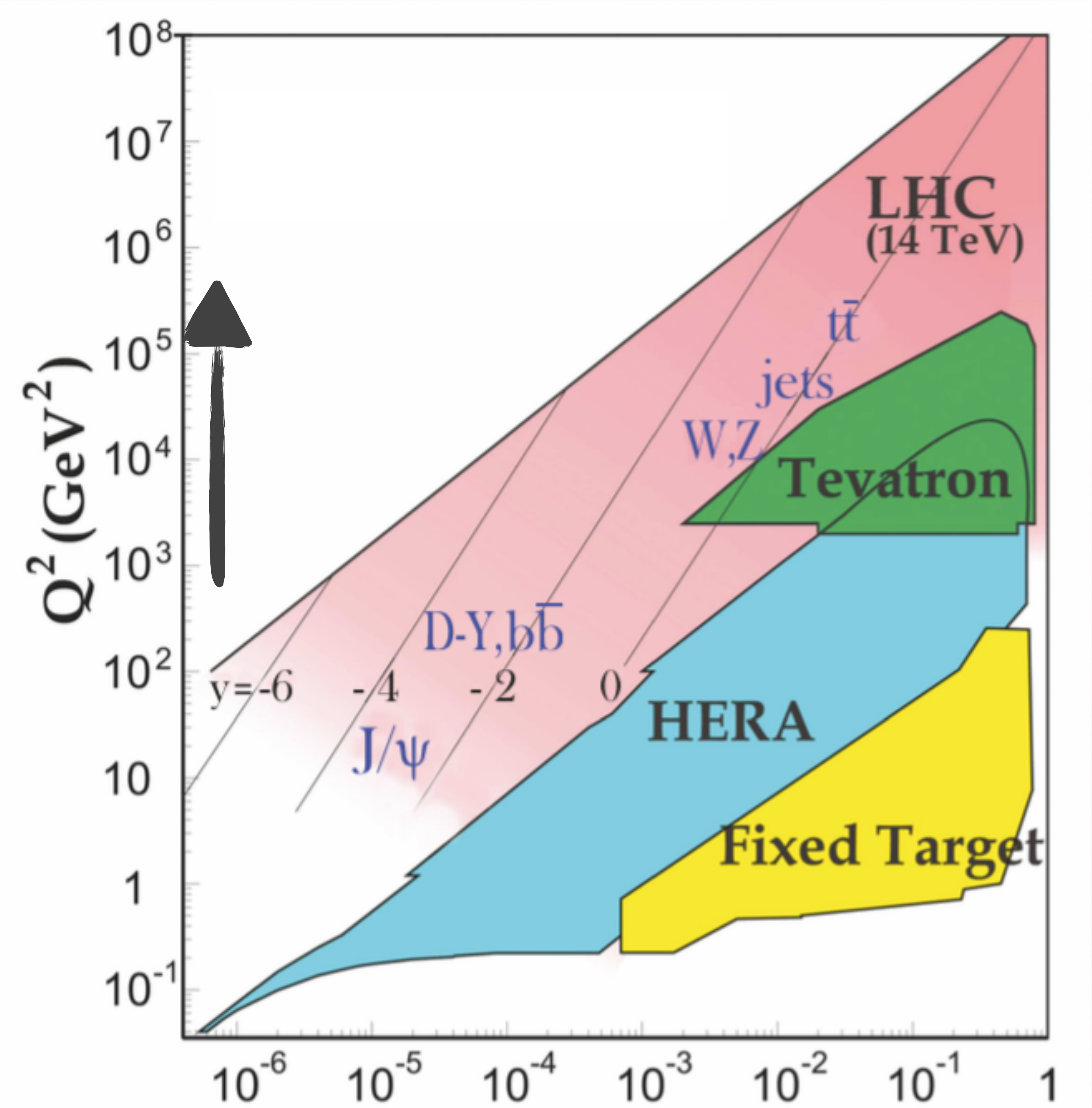
- PDFs cannot be calculated in perturbative QCD, however their evolution with the scale is predicted by pQCD [DGLAP equations]

calculable in pQCD

$$\frac{d}{d\ln\mu}\begin{pmatrix} q(x,\mu) \\ g(x,\mu) \end{pmatrix} = \int_x^1 \frac{dz}{z} \begin{pmatrix} \mathcal{P}_{qq} & \mathcal{P}_{qg} \\ \mathcal{P}_{gq} & \mathcal{P}_{gg} \end{pmatrix}_{(z,\alpha_s)} \cdot \begin{pmatrix} q(x/z,\mu) \\ g(x/z),\mu) \end{pmatrix}$$



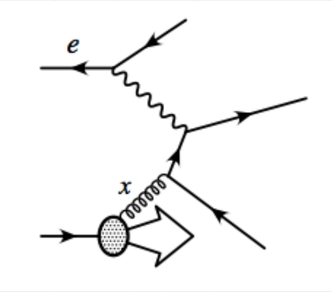
Today's data on proton structure



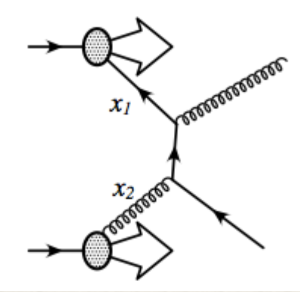
[from PDG]

Different data constrain different parton combinations at different x, evolution with the scale is predicted by pQCD:

- The cleanest way to probe Proton Structure is via Deep Inelastic Scattering [DIS]:



- Precision of proton structure can be complemented by the Drell Yan [DY] processes at the collider experiments

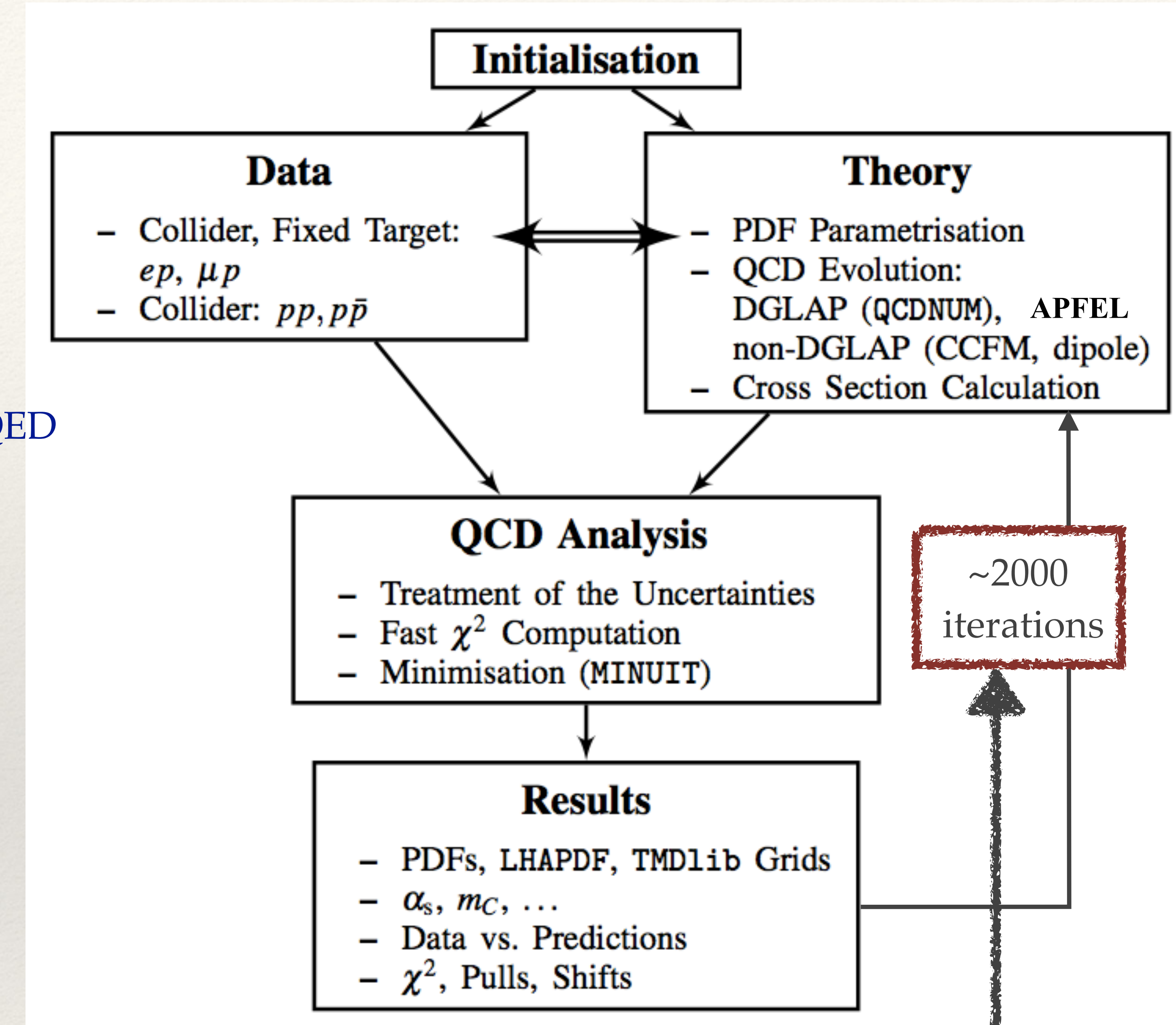


Q2: resolving power of experiment
x: fraction of proton's momentum

Extraction of PDFs through QCD fits

Main Steps:

- Parametrise PDFs at the starting scale
  - multiple options for functional forms
    - Standard Polynomial, Chebyshev, etc
- Evolve to the scale corresponding to data point
  - DGLAP evolution codes [QCDNUM, APFEL]
  - kt ordered evolution, Dipole models, DGLAP+QED
- Calculate the cross section
  - various heavy flavour schemes:
    - RT, ACOT, FONLL, FFNS(ABM)
  - fast grid techniques interfaced to DY:
    - APPLGRID, FASTNLO
- Compare with data via χ2:
  - multiple forms to account for correlations
- Minimize χ2 with respect to PDF parameters
  - MINUIT, data driven regularisation



EPJC (2015), 75:304

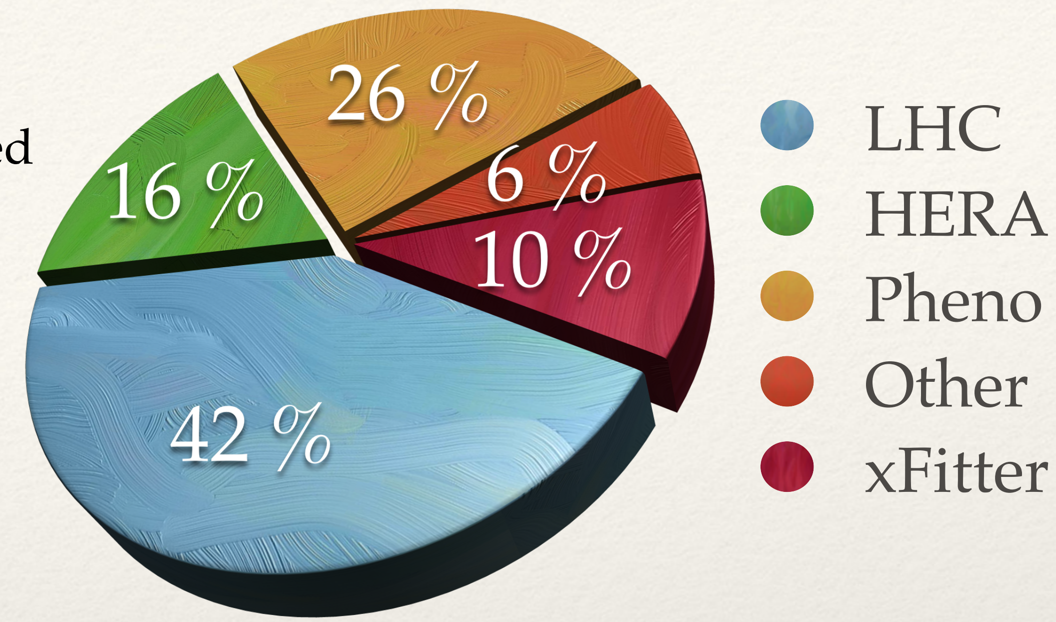
Importance of optimised calculations

xfitter.org: open source QCD platform

xFitter (former HERAFitter) www.xfitter.org

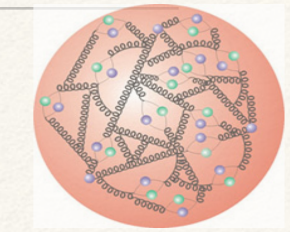
- **2011 Open Source Revolution:** EPJC (2015), 75
  - Establishing the first open source QCD Fit Platform which started the wave of sharing QCD fit codes
    - LHC/HERA/theory/independent
    - several releases since 2011 —> **xfitter-1.2.0**
    - ~30 publications that have used the framework

synergy between experiment and theory groups



- **provides a unique QCD framework to address theoretical differences:**
  —> benchmark exercises/collaborative efforts/topical studies
- **provides means to the experimentalists to optimise the measurements:**
  —> assess impact/consistency of new data

Probing the Proton Structure



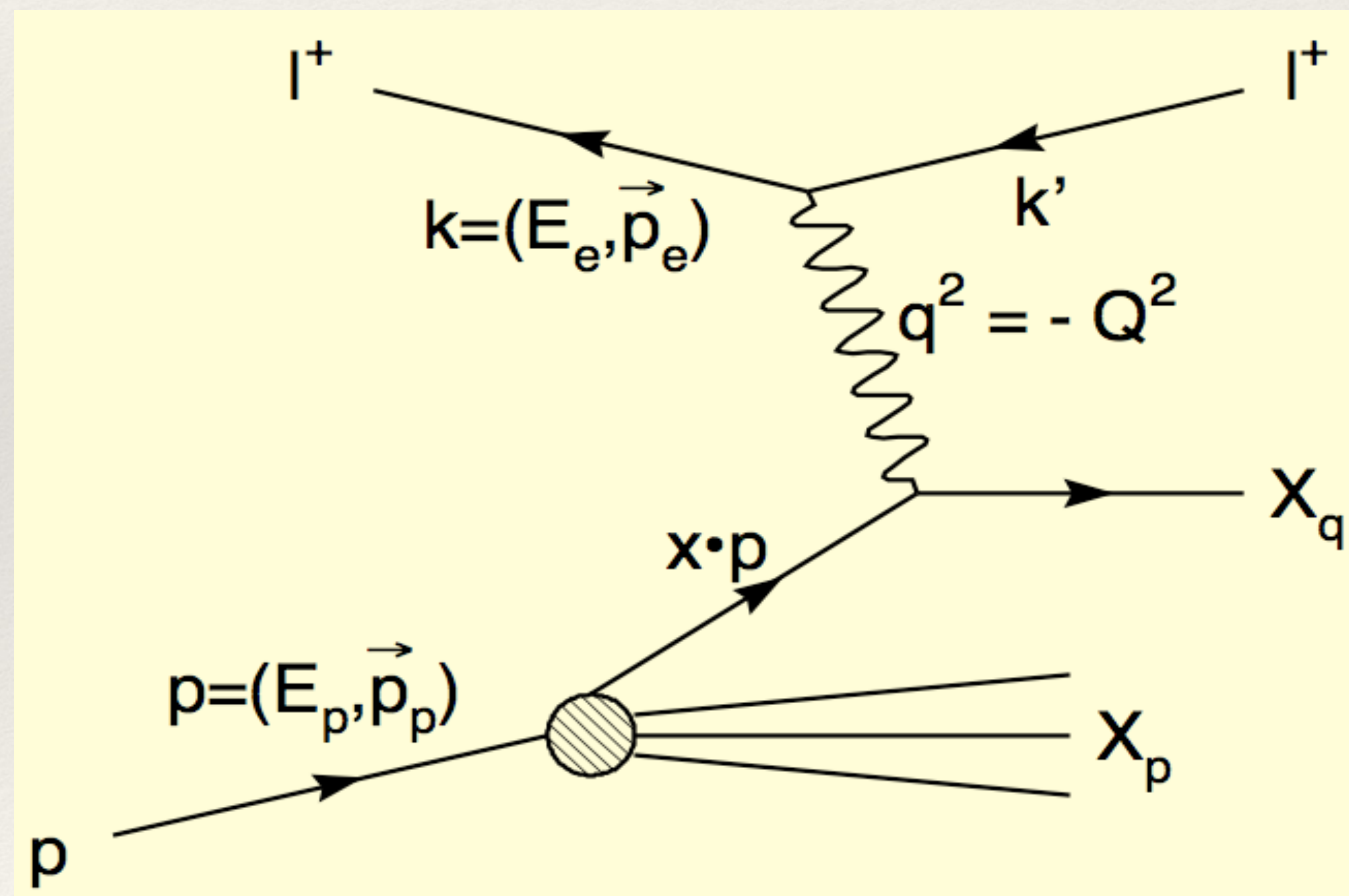
- Start with something simpler: Deep Inelastic Scattering (DIS)
  - Proton can be probed via elementary particles as electrons, muons, neutrinos:

- Kinematic relations:

$$x = \frac{Q^2}{2p.q}; \quad y = \frac{p.q}{p.k}; \quad Q^2 = xys$$

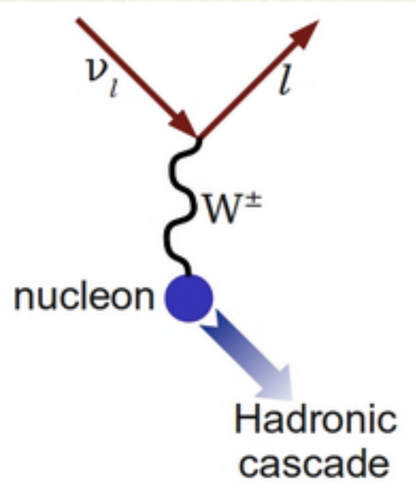
$\sqrt{s}$ = c.o.m. energy

- Q^2 = photon virtuality $\leftrightarrow$ *transverse resolution* at which it probes proton structure
- x = *longitudinal momentum fraction* of struck parton in proton
- y = momentum fraction lost by electron (in proton rest frame)



PDF constraints from Fixed Target Neutrino Experiments

- Neutrino fixed target experiments (DIS) provide valuable constraints on PDFs:

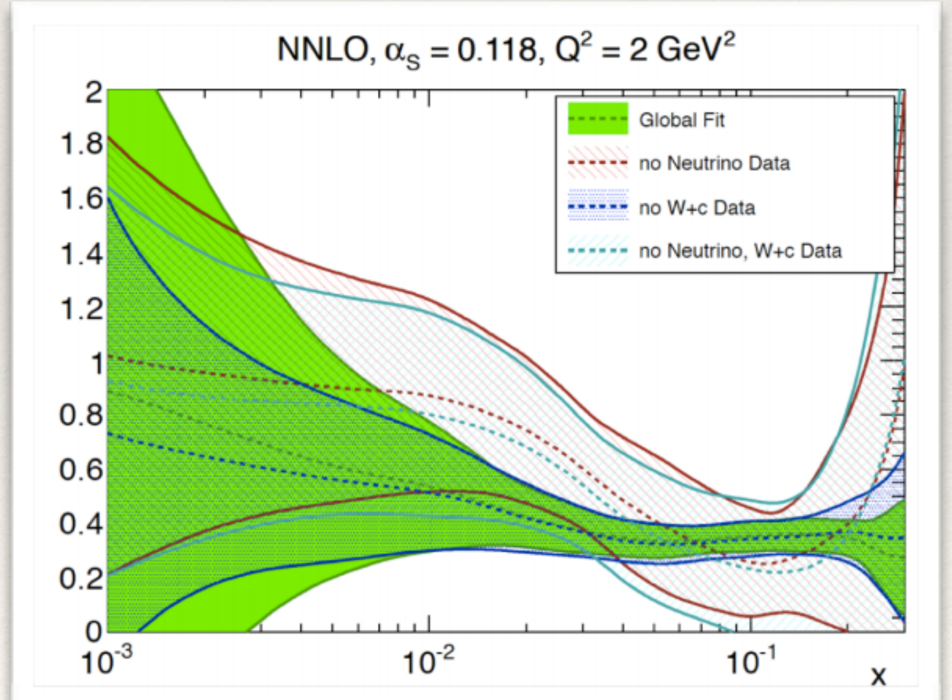


$$\frac{d^2\sigma^{\nu(\bar{\nu})}}{dxdy} = \frac{G_F^2 M E_\nu}{\pi(1+\frac{Q^2}{M_W^2})^2}\left[\left(1-y-\frac{Mxy}{2E_\nu}\right)F_2^{\nu(\bar{\nu})} + \frac{y^2}{2}2xF_1^{\nu(\bar{\nu})} \pm y(1-\frac{y}{2})xF_3^{\nu(\bar{\nu})}\right]$$

  - direct access to xF3 —> constraints on valence quarks —> nuclear corrections?
  - direct access to s, sbar via di-muon data
  - access to the strong coupling from xF3 scaling violations —> independent of gluon

- Neutrino data is included in the global PDF analyses:

impact on sbar/dbar if there is NO neutrino data

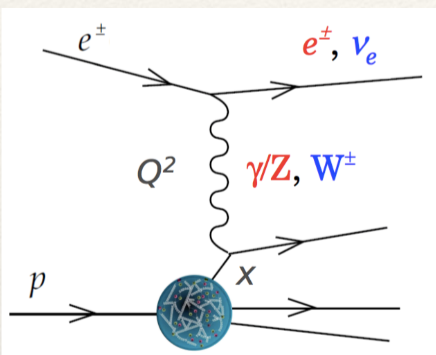


sbar/dbar

- However, care must be given to account for the nuclear medium (not a free proton) and low energy domains
  - extensive efforts in understanding nuclear effects, higher twist, target mass (Minerva, JLAB)

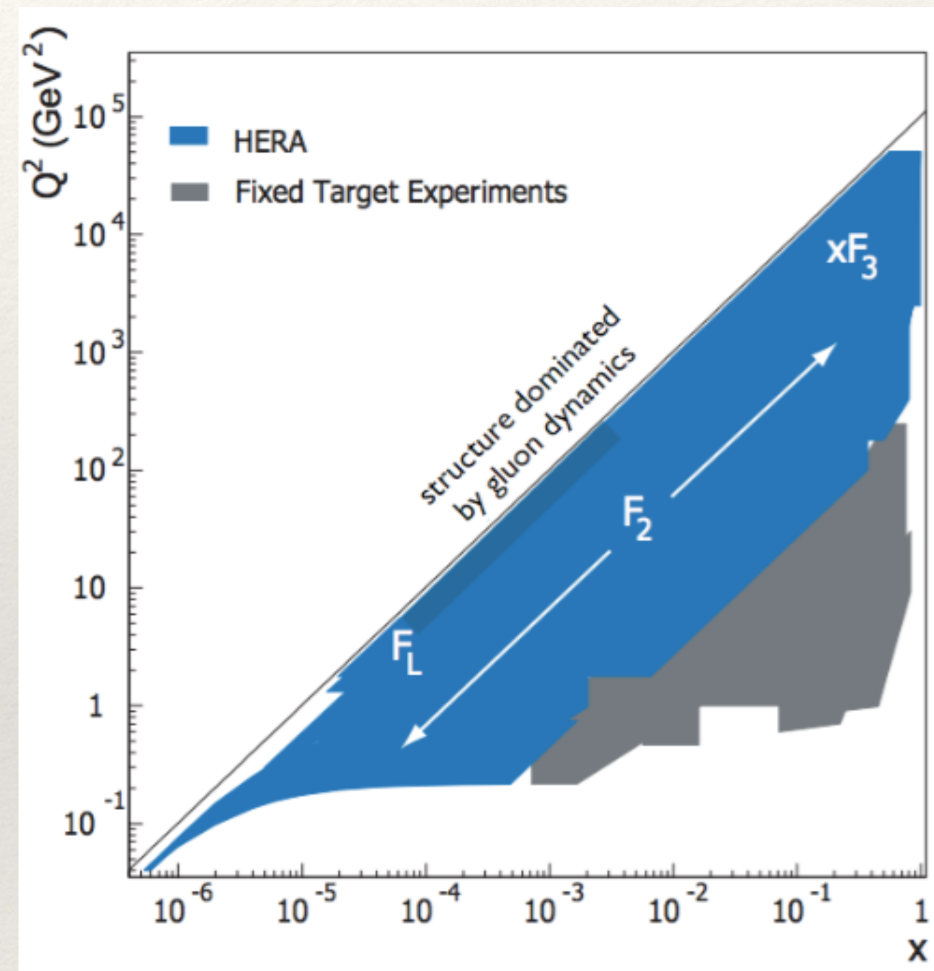
HERA ep collider (1992-2007) @ DESY

- H1 and ZEUS experiments at HERA collected ~1/fb of data (no nuclear corrections)
  - Ep=460/575/820/920 GeV and Ee=27.5 GeV
- 4 type of processes accessed at HERA: **Neutral Current and Charged Current ep**

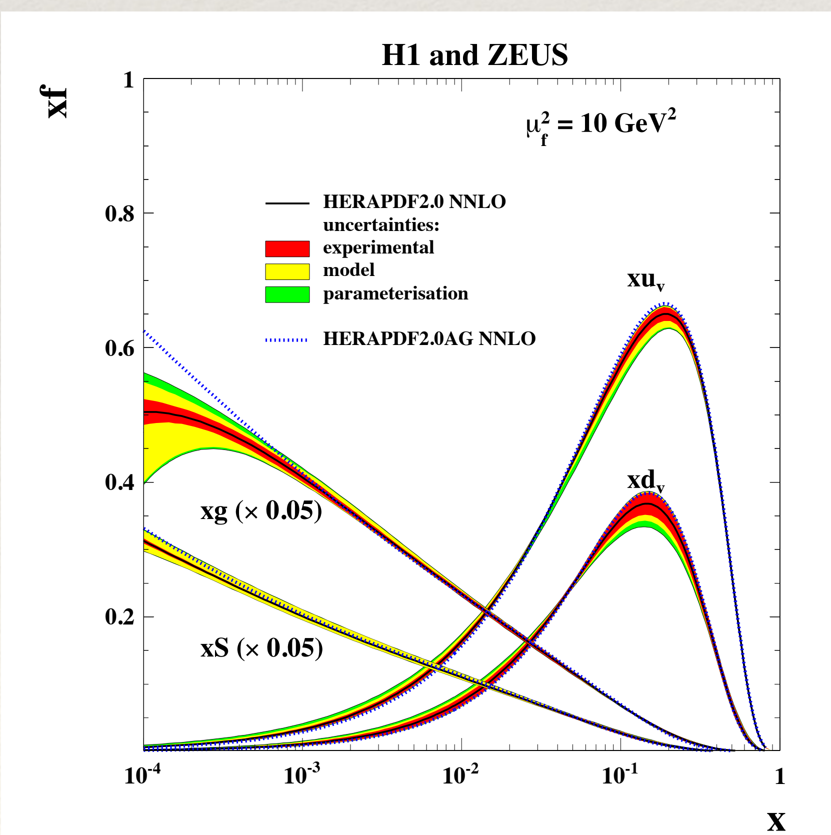


$$\frac{d^2\sigma^{e^\pm p}_{NC}}{dx dQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[Y_+\tilde{F}_2^{\pm} \mp Y_- x\tilde{F}_3^{\pm} - y^2\tilde{F}_L^{\pm}\right]$$

dominant contribution ($\tilde{F}_2$)
important at high Q^2 ($x\tilde{F}_3$)
sizable at high y ($\tilde{F}_L$)



NNLO QCD fit

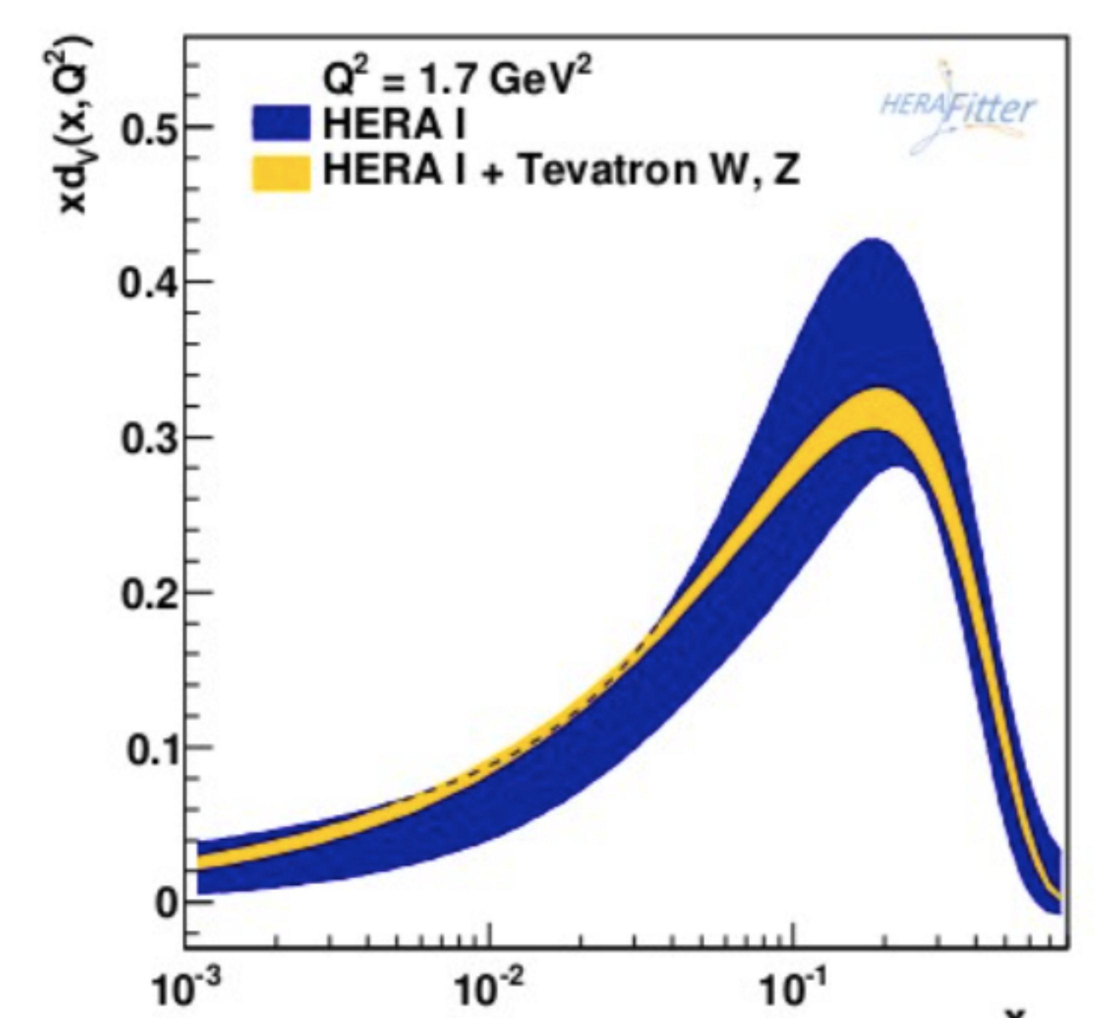


- HERA data can constrain:
  - sum of all quarks (through F2)
  - valence (through xF3)
  - gluon from scaling violations

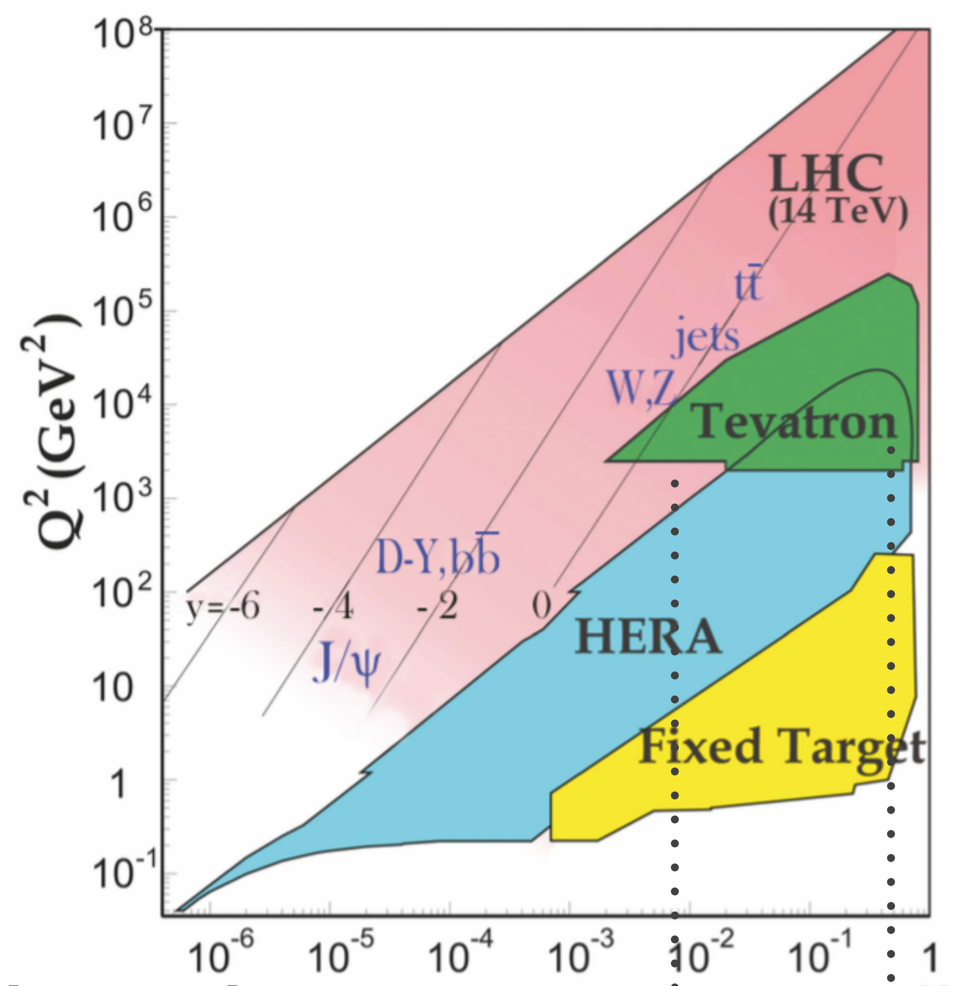
LO: $F_2 \approx x\sum e_q^2 (q+\bar{q})$ (in NLO (α_s g) appear)
$xF_3 \approx x\sum 2e_q a_q (q-\bar{q})$
PDFs

Constraints on PDFs from ppbar collider at Tevatron

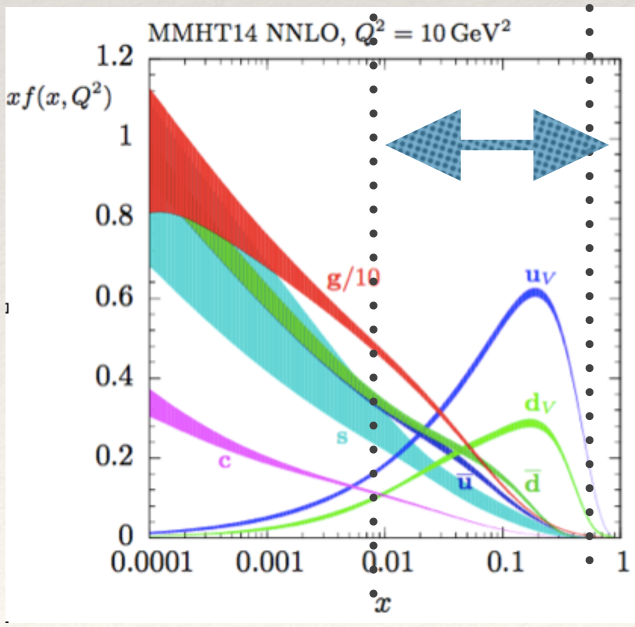
- In proton-antiproton collisions at Tevatron, DY processes of W and Z production are valence-quark dominated —> they can be used to improve quark valence PDFs - especially the d-quark type:



arXiv:1503.05221



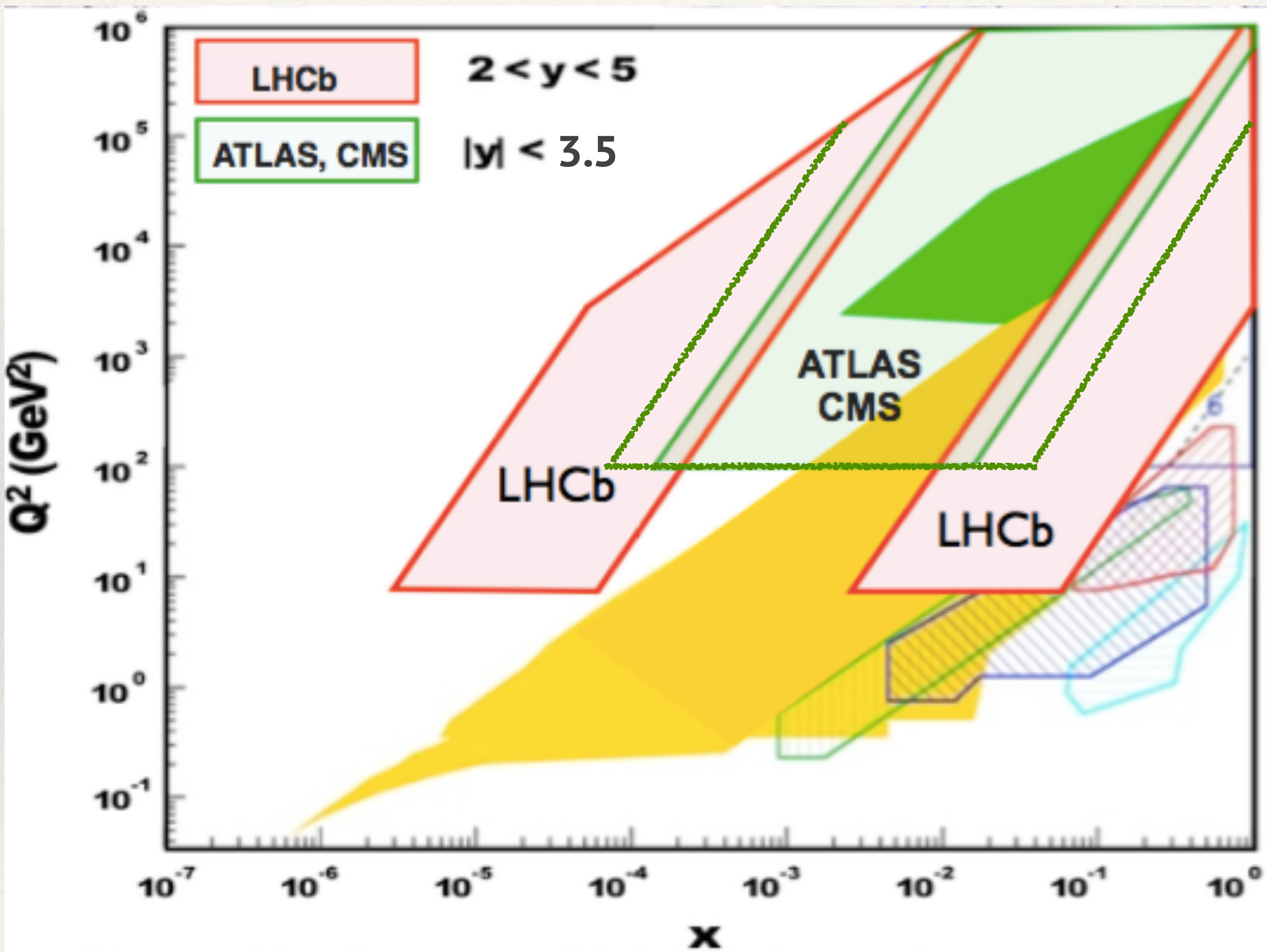
[from PDG]



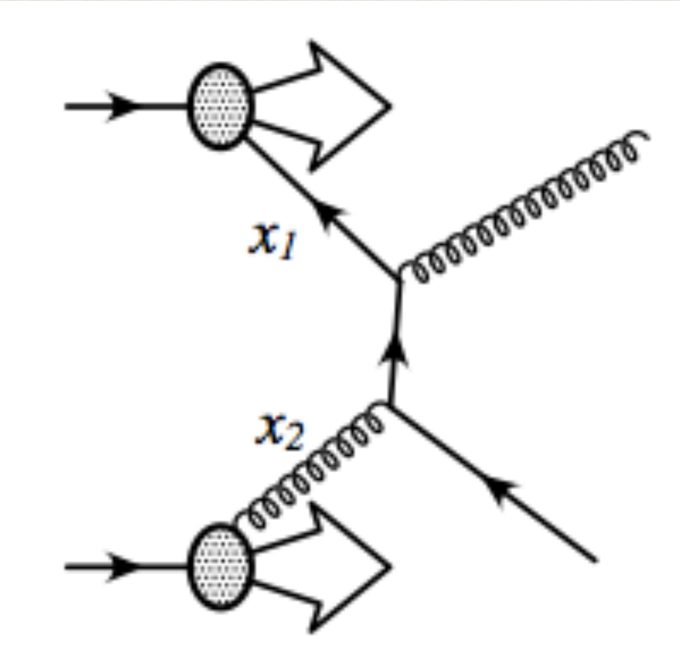
- Jet measurements also provide an important constraint at higher x for the gluon distribution

The LHC measurements: ATLAS-CMS vs LHCb

- LHC provides an extended kinematic range in x by its three experiments:
  - ATLAS, CMS and LHCb
  - coverage in x is what's needed, because QCD gives us Q2 dependence



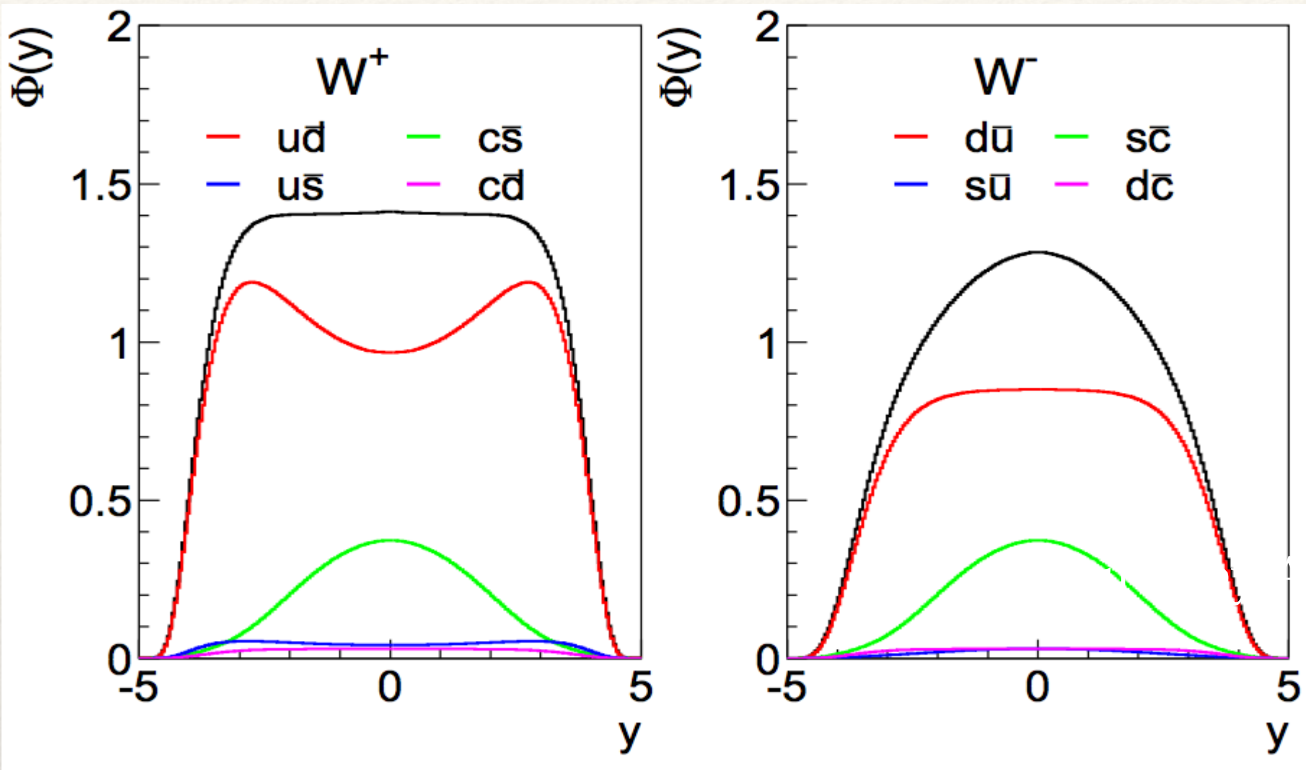
Importance of PDFs:
PDFs from DIS can be used to predict physics process at LHC

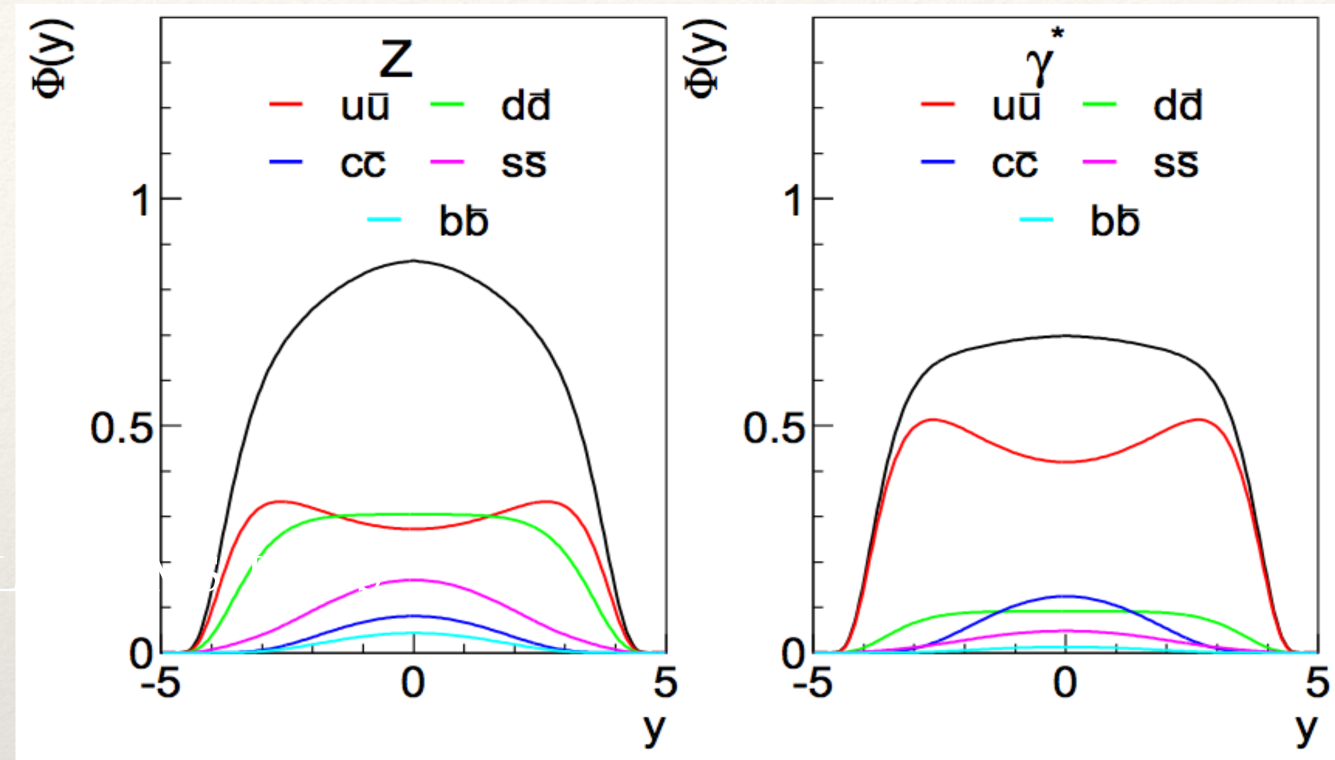


—> can provide needed flavour separation and more insight into gluons

PDFs from W, Z at LHC

W and Z are produced in abundance at LHC with clear experimental signature and the inclusive cross sections of W and Z are well understood theoretically at NNLO





We can exploit different PDF flavour sensitivity than these provided by DIS data

$$\mathcal{A}_W^l = \frac{d\sigma_{W^+}/d\eta_{l^+} - d\sigma_{W^-}/d\eta_{l^-}}{d\sigma_{W^+}/d\eta_{l^+} + d\sigma_{W^-}/d\eta_{l^-}}$$

$$\mathcal{A}_W \approx \frac{u_v - d_v}{u + d}$$

Z measurement supports the idea that sb(x)=ub(x)=db(x)

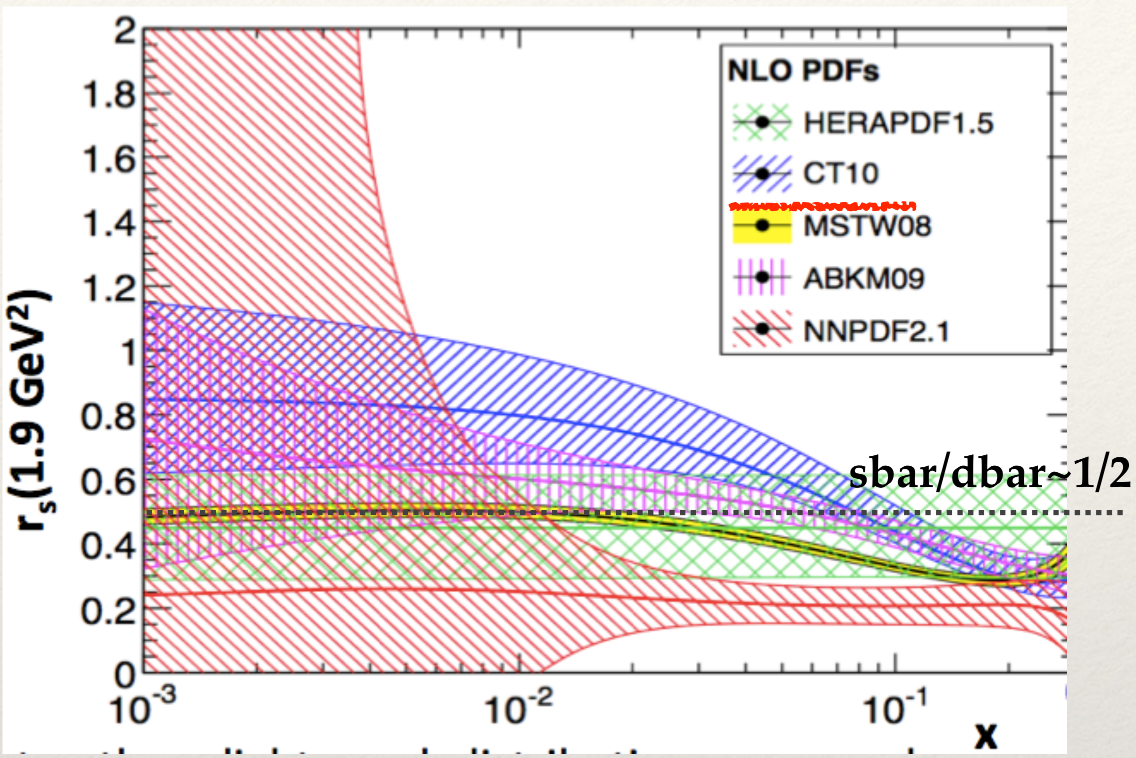
W+ vs W— —> impact on the valence quarks

Z —> impact on the strange distribution

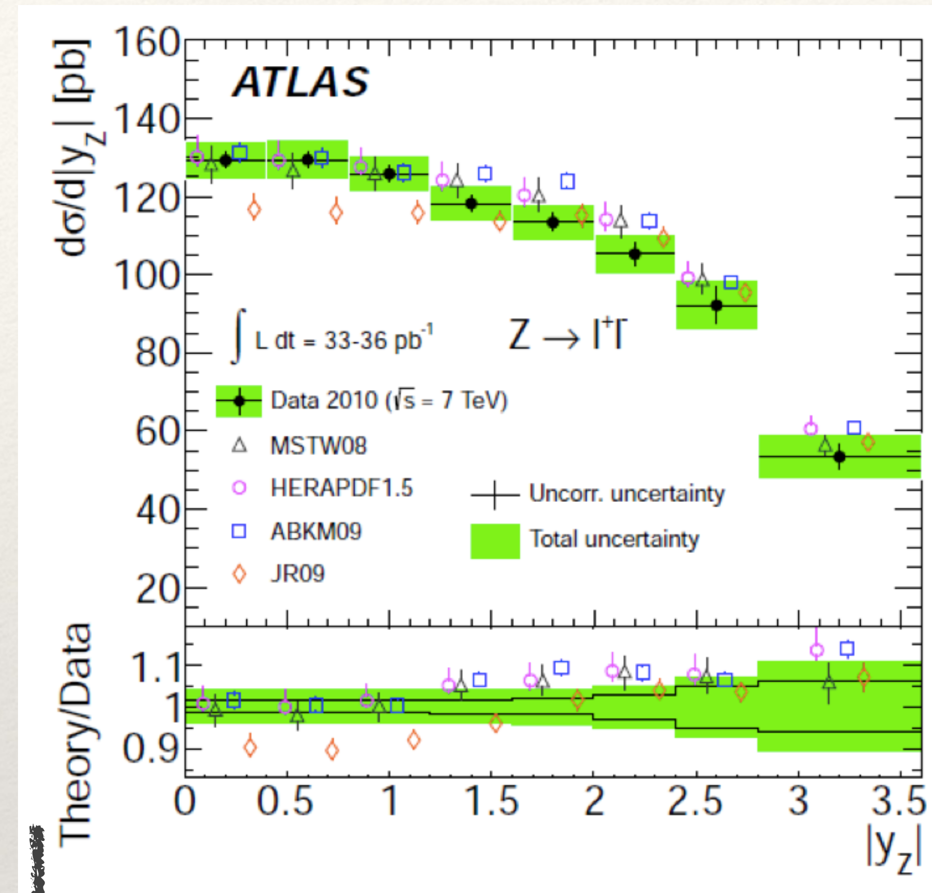
Strange from LHC vs neutrino experiments?

Before LHC, the dominant information on strange quark was from neutrino di-muon data:

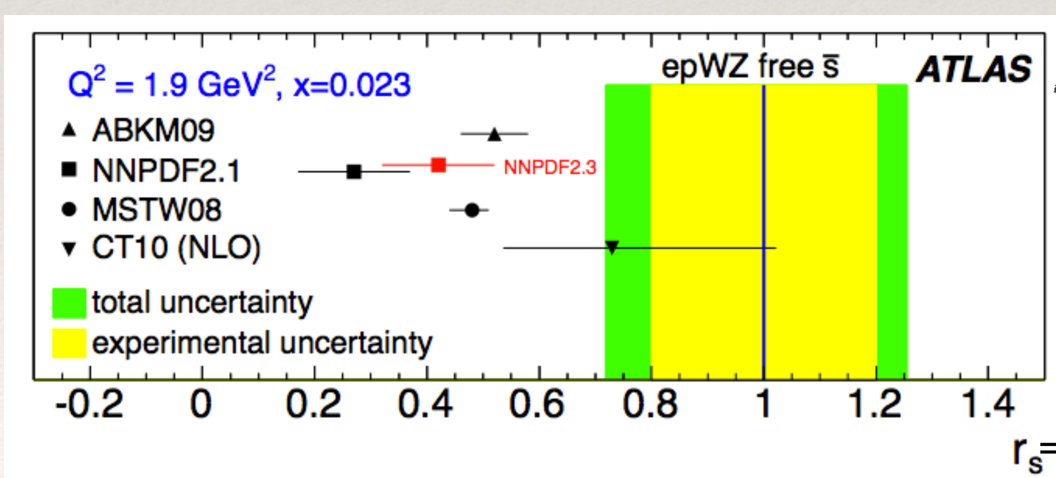
- prefers rather strongly suppressed strange (sbar/dbar~1/2)



PDF Groups assume different suppression factor for sbar vs dbar
—> Z data shows sensitivity to this assumption!



NNLO QCD fit



sb(x)=ub(x)=db(x), at lower x than Neutrino data
—> Results confirmed by dedicated ATLAS W+c production measurement

It would be interesting to look at a new neutrino data

[slide from M. Ubiali]

Impact of LHC data on PDFs

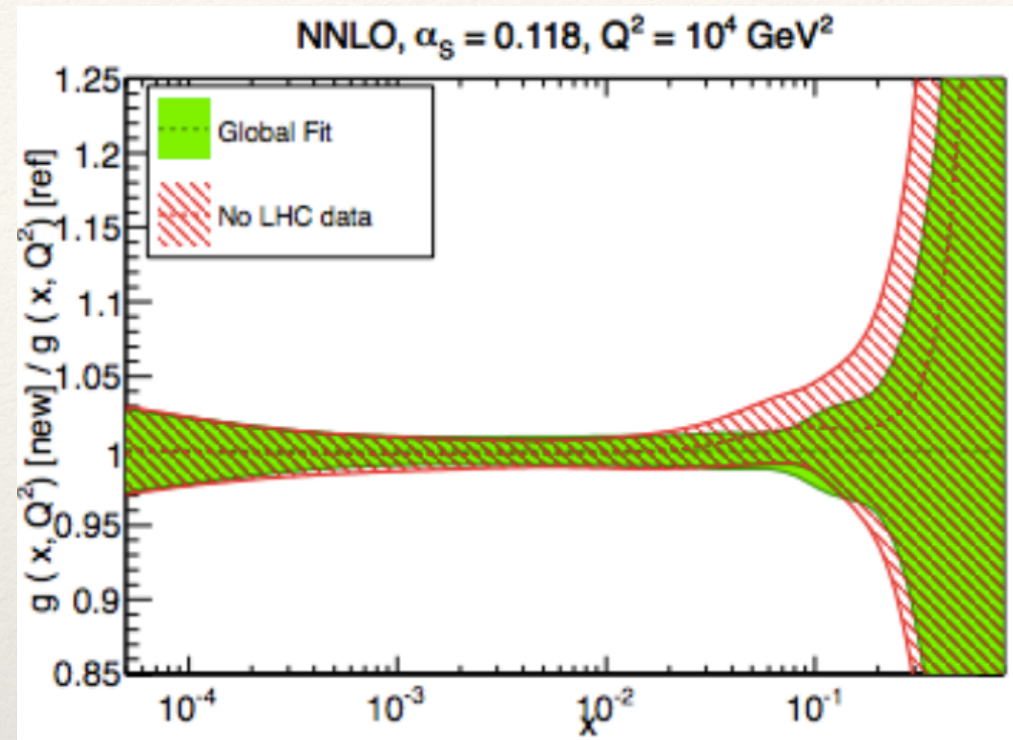
- Some of the global PDF groups started to include these data in their fit:

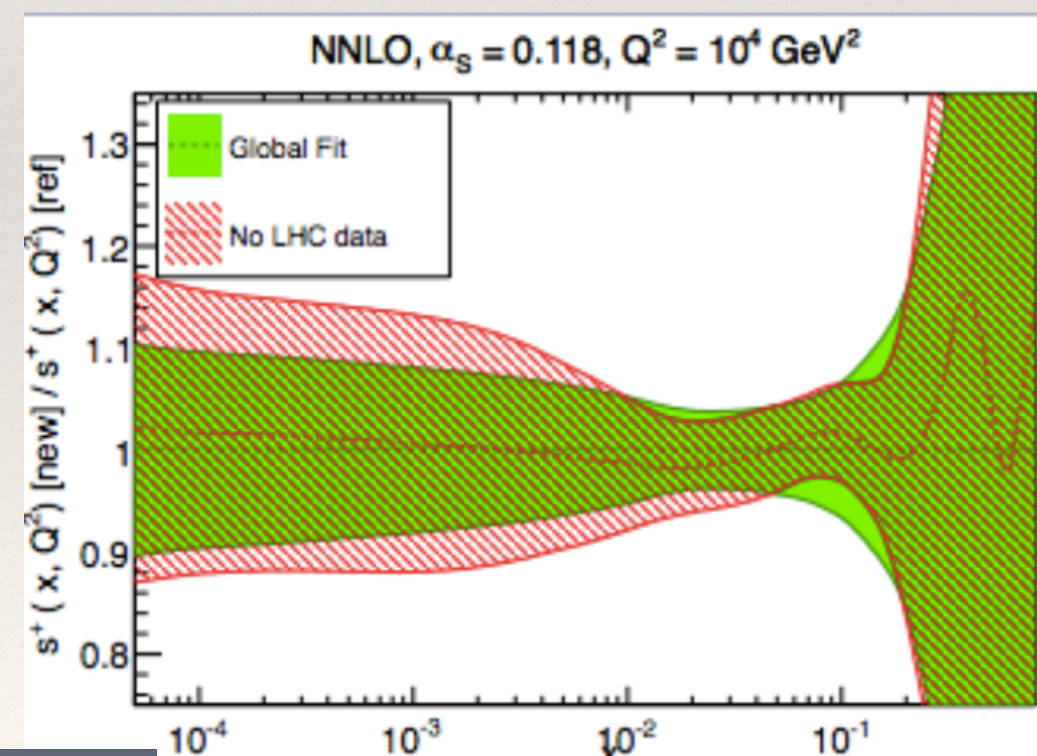
GLUON
- Inclusive jets and dijets **(medium/large x)**
- Isolated photon and γ+jets **(medium/large x)**
- Top pair production **(large x)**
- High p_T Z(+jets) distribution **(small/medium x)**

QUARKS
- High p_T W(+jets) ratios **(medium/large x)**
- W and Z rapidity distns **(medium x)**
- Low and high mass Drell-Yan **(small and large x)**
- Wc **(strangeness at medium x)**

PHOTON
- Low and high mass Drell-Yan
- WW production

Intense activity of global PDF groups to include these measurements in the new PDF releases in time for Run2 data.





More precise data from Run 1 to have an impact on PDFs

PDF Sets on the market

- *ABM* by S. Alekhin, J. Bluemlein, S. Moch
- *CTEQ*, from the CTEQ Collaboration
- *GRV/GJR*, from M. Glück, P. Jimenez-Delgado, E. Reya, and A. Vogt
- *HERA* PDFs, by H1 and ZEUS collaborations from the Deutsches Elektronen-Synchrotron center (DESY) in Germany
- *MRST/MSTW*, from A. D. Martin, R. G. Roberts, W. J. Stirling, R. S. Thorne, and G. Watt
- *NNPDF*, from the NNPDF Collaboration

wikipedia

The analyses differ in many areas:

- different treatment of quark with masses
- inclusion of various data sets and account for possible tensions
- different assumption on values of strong couplings
- different assumptions in procedure (parametrisation, corrections)

*Also ATLAS and CMS provide PDFs sets to demonstrate the impact of new measurements

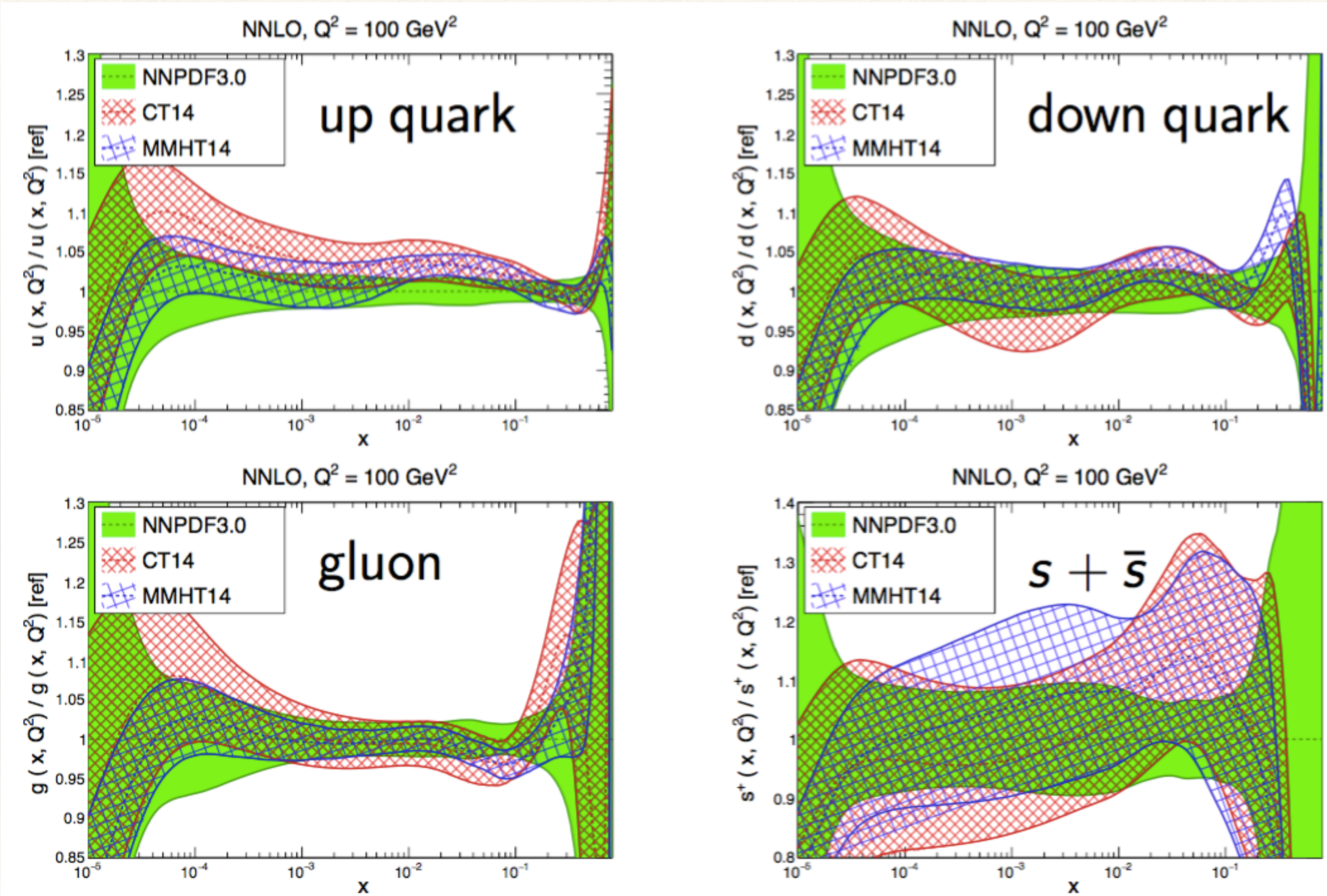
- … differences in PDFs lead to the differences in the cross section predictions!

Active PDF groups

	CT14	MMHT15	NNPDF3.0	HERAPDF2.0	ABM12	CJ12	JR14
HQ scheme	VFNS (ACOT-χ)	VFNS (TR opt)	VFNS (FONLL)	VFNS (TR opt)	FFNS Run mc (ABM)	VFNS (ACOT)	FFNS (JR)
orders	LO, NLO, NLLO	LO, NLO, NLLO	LO, NLO, NLLO	LO, NLO, NLLO	NLO, NLLO	NLO	NLO, NLLO
α(Mz)	fixed(fitted)	fixed (fitted)	fixed	fixed	fitted	fixed	fitted
α(Mz) LO α(Mz) NLO α(Mz) NNLO	0.1300 0.1180 (0.117) 0.1180 (0.115)	0.1350 0.1180 (0.1201) 0.1180 (0.1172)	0.1180 0.1180 0.1180	0.1300 0.1180 0.1180	- - 0.1132	- 0.118 -	- 0.1158 0.1136
Nr param.	Pol. Bernst. 28	Pol. Cheb. 25	NN (259)	Pol. 14	Pol. 24	Pol. 22	Pol.25
PDF assumptions	ubar/dbar=1(x->0) u/d=1 (x->0)	s-sbar=fit. dbar-ubar=fit.	dbar-ubar=fit	ubar=dbar (x->0) sbar=0.67*dbar	s=sbar dbar-ubar=fit	dv/uv=const s+sbar=k(ubar+dbar)	dbar-ubar=fit
Stat. treatm.	Hessian Δχ2=100 (90% CL)	Hessian Δχ2 Dynamical (68% CL)	Monte Carlo (68% CL)	Hessian Δχ2=1 (68% CL)	Hessian Δχ2=1 (68% CL)	Hessian Δχ2=1 (68% CL)	Hessian Δχ2=1 (68% CL)
Q2min	2	2	3.5	3.5	2.5	1.69	2
HERA data	HERA I+ charm	HERA I charm jets	HERA I+ H1 and ZEUS II charm	HERA I+II	HERA I charm	HERA I	HERA I charm jets
Fix. Target DIS	✓	✓	✓	N/A	✓	JLAB, high x ✓	JLAB, high x ✓
Tevatron W,Z	✓	✓	✓	N/A	✗	✓	✗
Tevatron Jets	✓	✓	✓	N/A	✗	✗	✓
Fix. Target DY	✓	✓	✓	N/A	✓	✓	✓
LHC WZ	✓	✓	✓	N/A	✓	✗	✗
LHC jets	✓	✓	✓	N/A	✗	✗	✗
LHC top	✗	✓	✓	N/A	✓	✗	✗
LHC charm	✗	✗	✓	N/A	✗	✗	✗
References	arXiv:1506.07443	arXiv:1412.3989	arXiv:1410.8849	arXiv:1506.06042	arXiv:1310.3059	arXiv:1212.1702	arXiv:1403.1852

Precision of current PDFs:

- [From last PDF4LHC recommendation based on GMVFNS PDFs]



in the region
10^-3- 10^-1
a precision of <10%
on PDFs

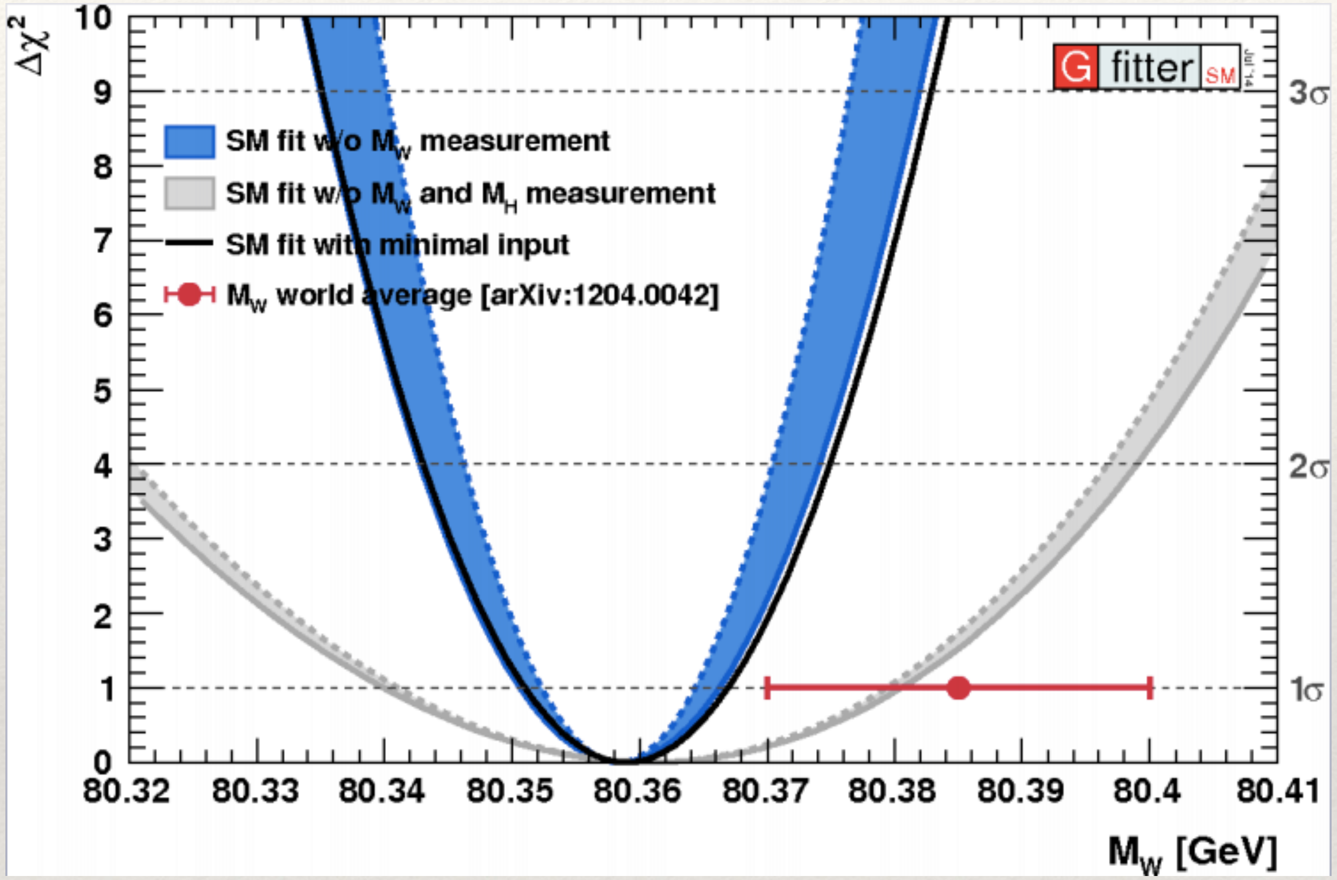
however, in the
outside this region
very uncertain
PDFs

so what precision do we aim for? —-> not to be dominant uncertainty

PDFs are dominant in stress test of SM

- Now all basic parameters of the SM are known and precision of these allows:

  —> for stringent stress test of the SM parameters
  —> look for hints of new physics (indirect)



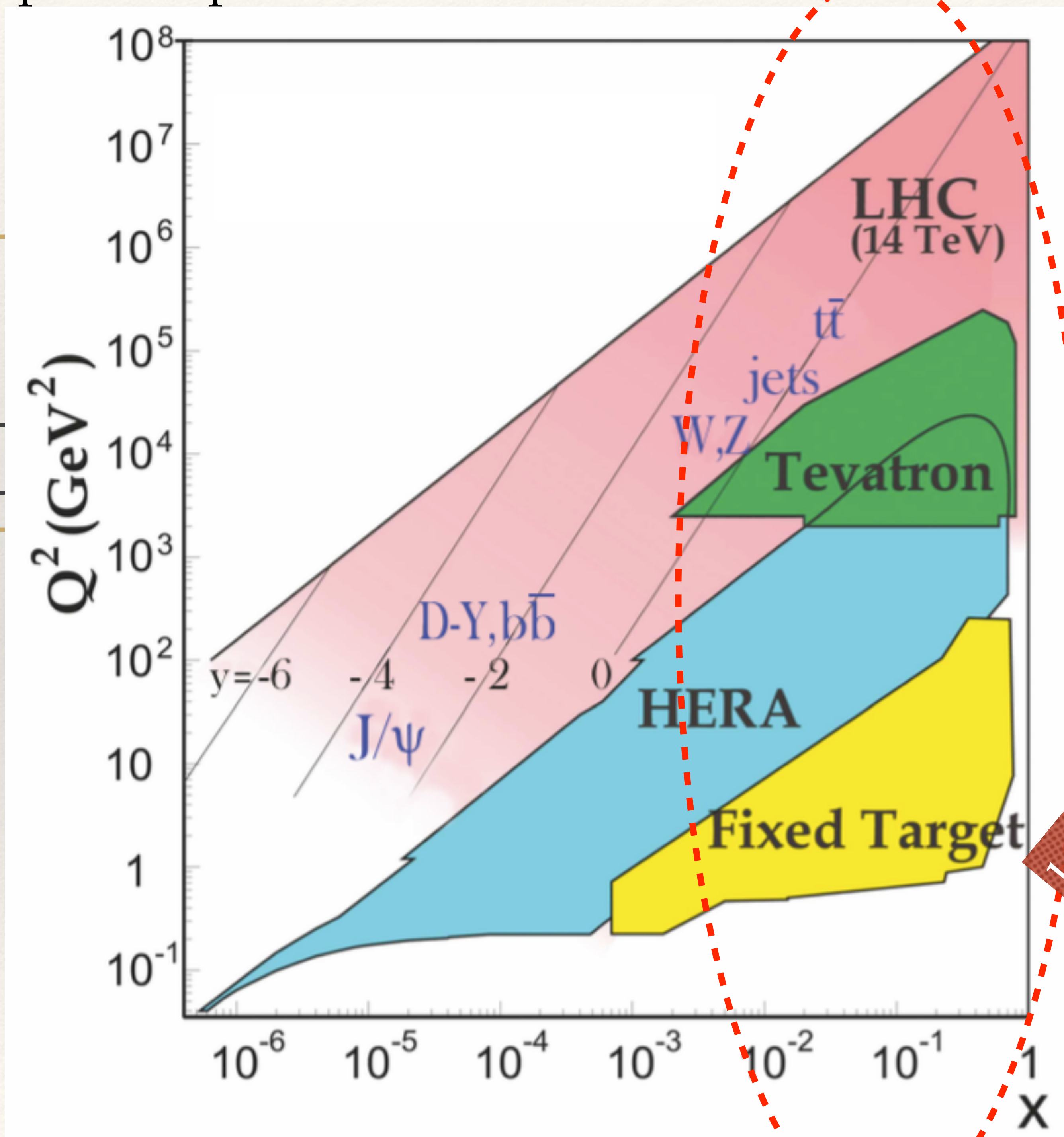
The indirect (EW fit) determination of W mass (δMW = 8 MeV) is more accurate than the measured value (δMW = 15 MeV) including the latest measurements of CDF and DØ - 1.8 sigma tension!
→ **natural goal at the LHC would be δMW < 10 MeV**

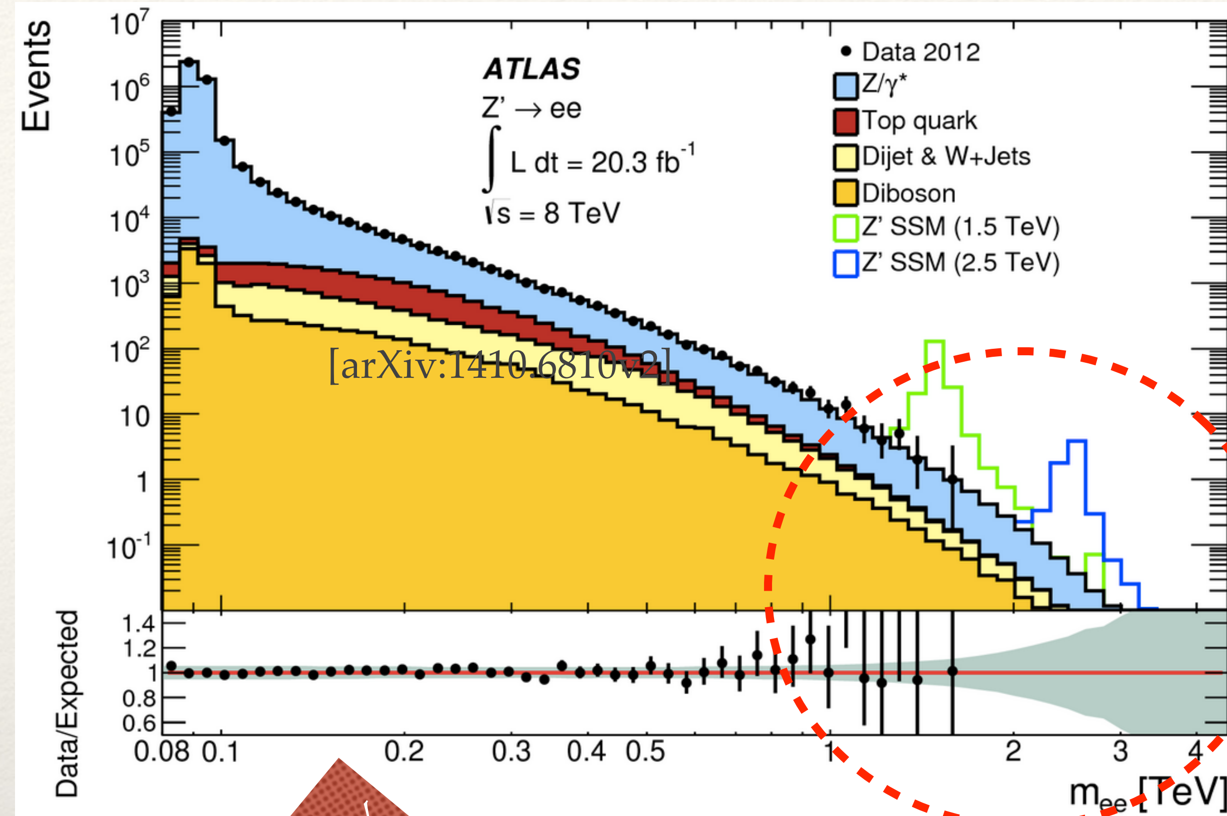
PDF represents the dominant uncertainty

http://arxiv.org/pdf/1407.3792v1.pdf

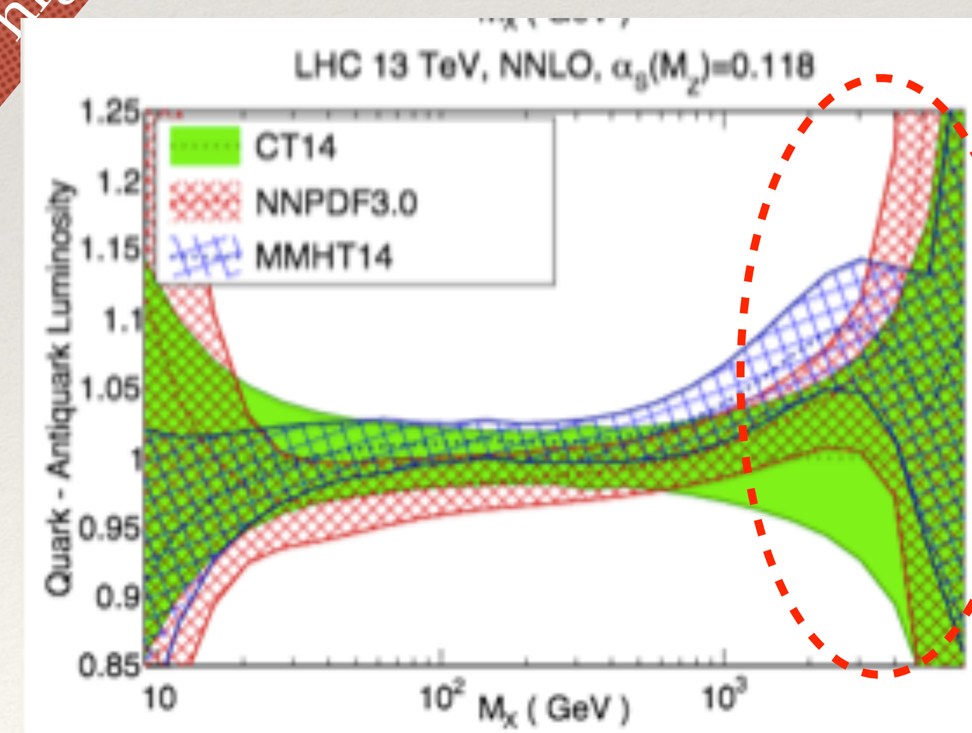
Role of PDFs in BSM heavy particle production

PDFs are the dominant uncertainty in heavy particle production:



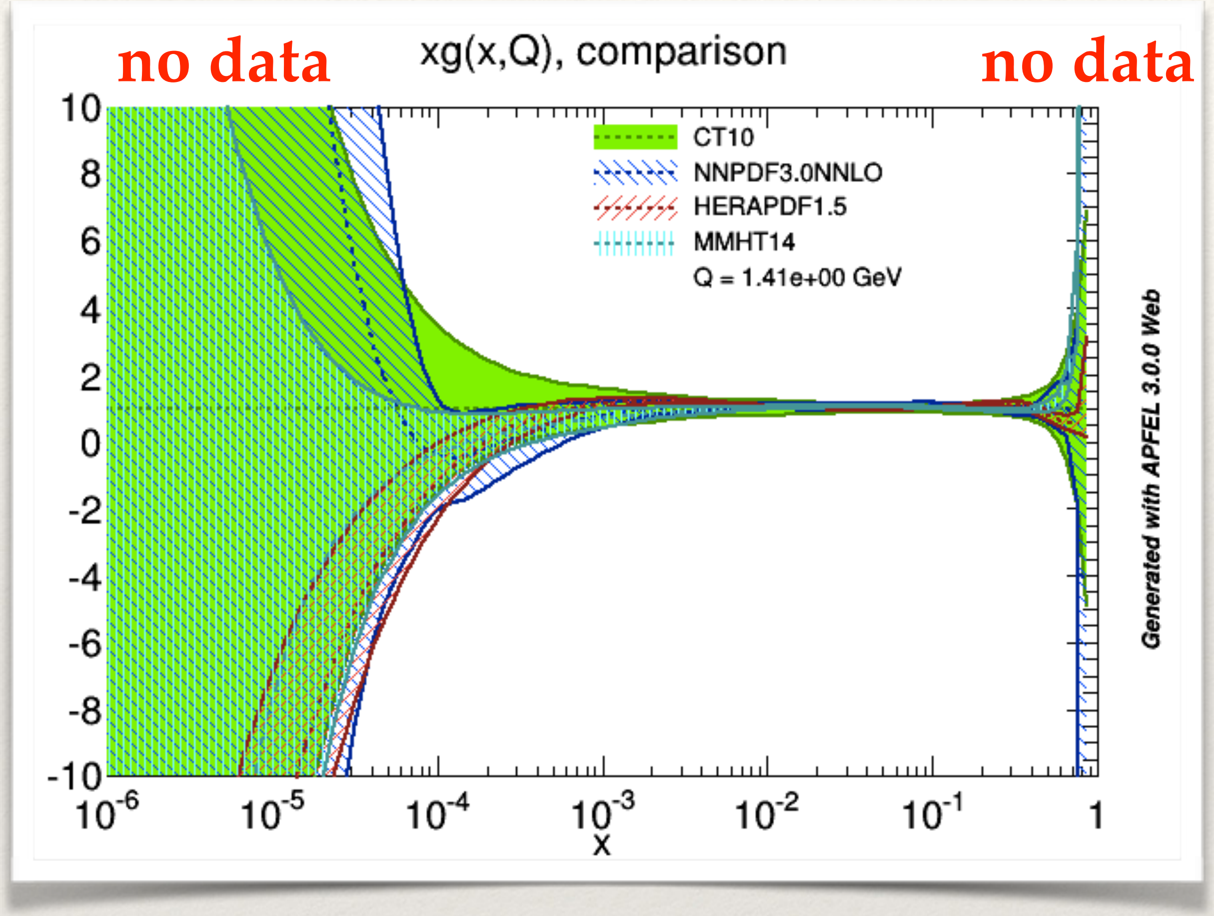


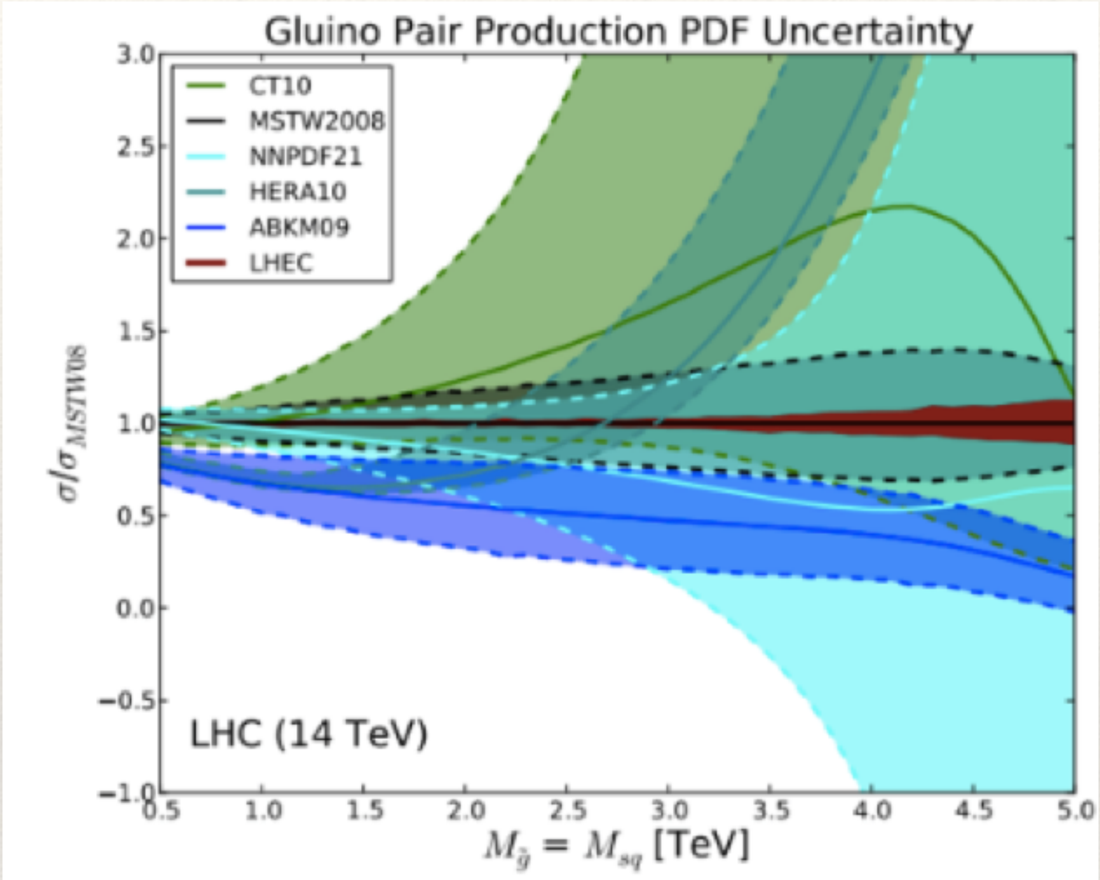
high mass <—> high x



Low x and high x regions

- We lack data in the corners of the kinematic space
—> could be crucial for new physics





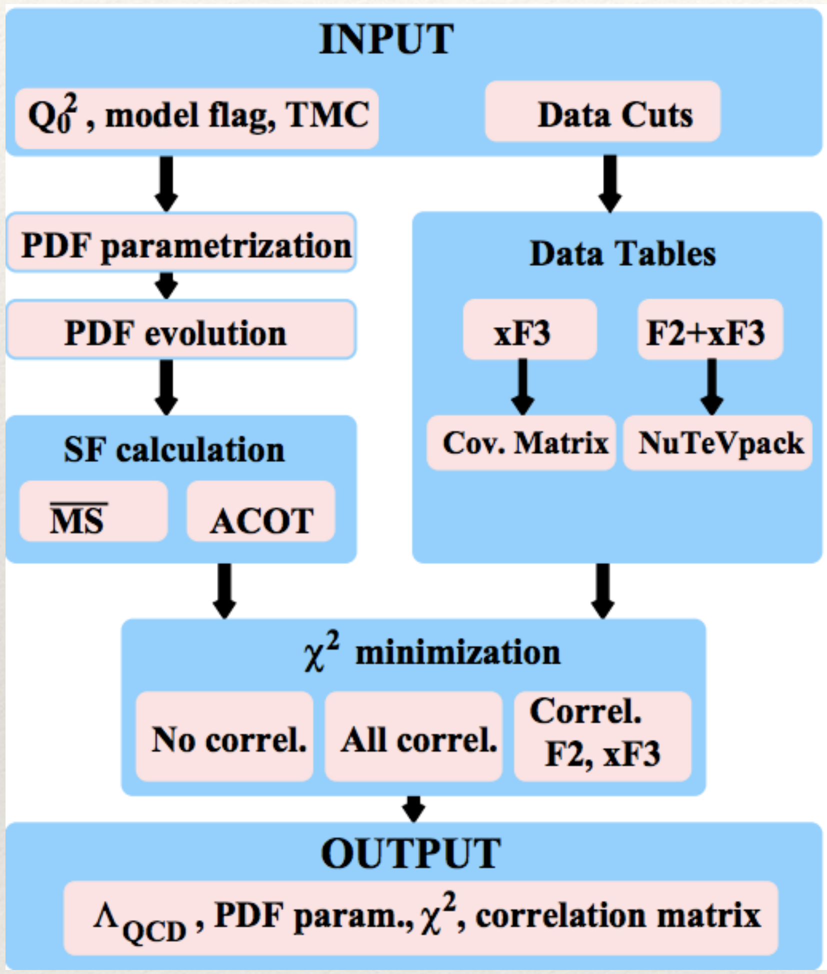
Gluino signal is not detectable beyond 2 TeV with current PDF uncertainties (blue-green)
—> more than 100% uncertainty.
—> need high x precision (e.g. burgundy: LHeC potential)

Nuclear data

- One could extract from the fixed target data PDFs in bound nuclei, rather than from the free proton —> nuclear PDFs
  - CTEQ-JLAB PDF set (CJ)
  - nCTEQ PDF
  - upcoming NNPDF
- LHC program for heavy ions is in need of high precision nuclear PDFs for the interpretation of the pPb and PbPb data.

PDFs and alphas from Neutrino DIS Data

- NLO QCD fits to NuTeV data (2006) —> yield nuclear PDFs
  - corrected for the Target Mass Correction (TMC)



[PhD Thesis 2006, VR]

PDFs can be extracted from the iron SFs
—> these PDFs are not proton's

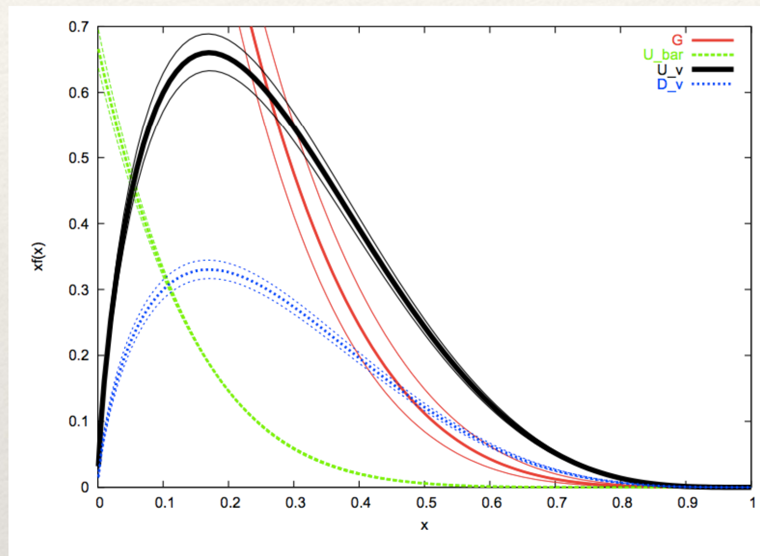
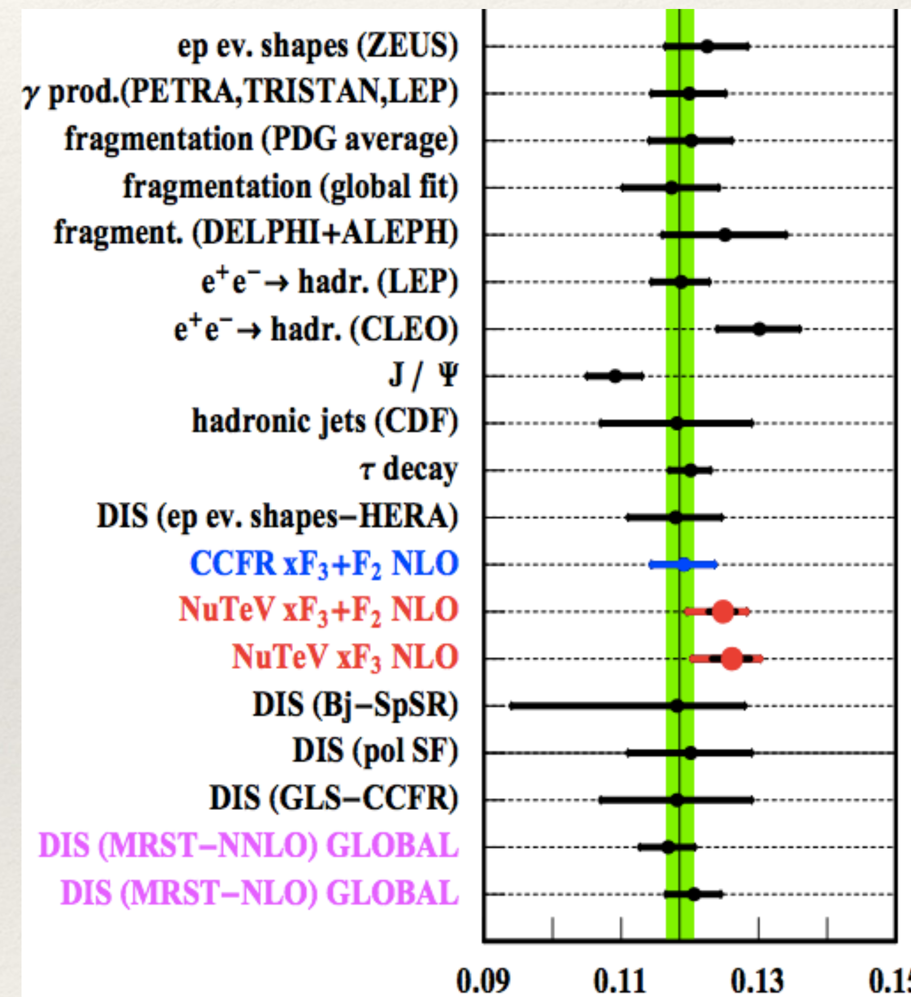
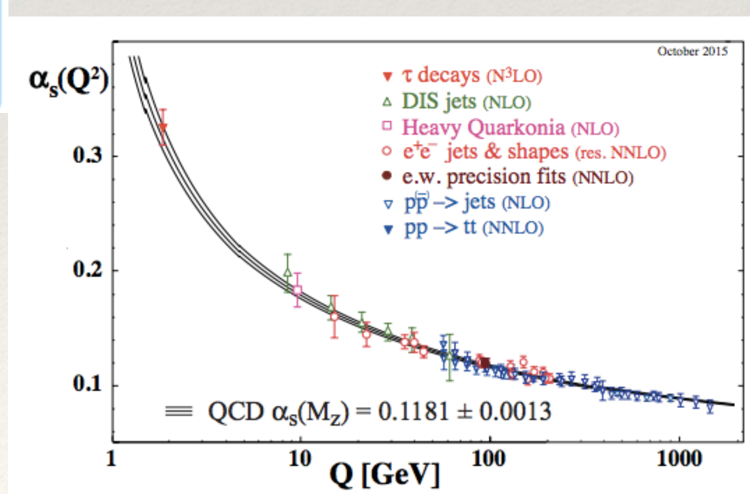


Figure F1: Nuclear PDFs at $Q_0^2 = 5$ GeV^2. ACOT scheme.

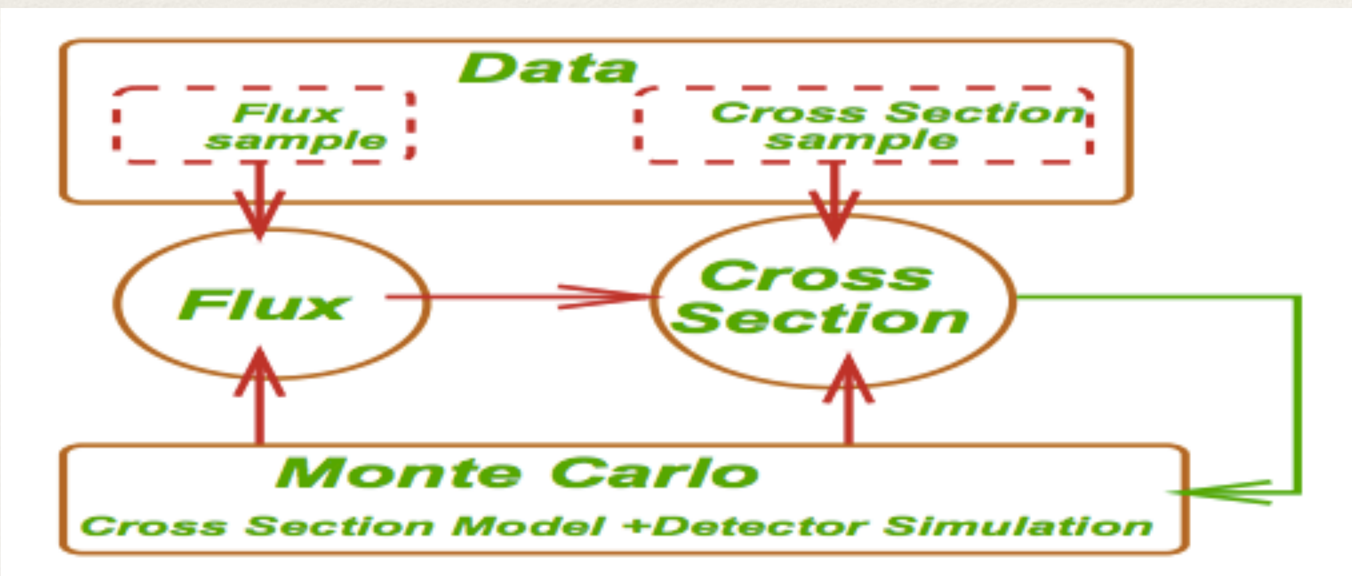




neutrino measurements are at the low-medium Q2 where the slope is the steepest and there are few measurements from DIS

Monte Carlo Simulation for neutrino data

- Monte Carlo Simulation at NuTeV was used only for acceptance and smearing effects:
  - Cross Section Model -> based on a fit to data
  - Detector Model -> using parametrisations based on test beam
- However, Monte Carlo needs to be used both in neutrino flux extraction … acti … tor effects



$$\frac{d^2\sigma^{\nu(\overline{\nu})}}{dxdy} = \frac{1}{\Phi(E_\nu)}\frac{d^2N^{\nu(\overline{\nu})}}{dxdy}$$

Input a flux and PDF parameters —> cross section —> generate MC events —> acceptance corrections —> correct flux and cross section samples for acceptance/resolution —> perform a QCD fit to extract new PDFs —> calculate radiative corrections —> extract new flux —> repeat

NuTeV cross section model used in MC simulation

- NuTeV has used a custom cross section model for the fast MC simulation:
  - neutrino cross-section which is iteratively fit to NuTeV data
  - based on the standard deep inelastic formalism

$$\frac{d^2\sigma^{\nu(\overline{\nu})}}{dxdy} = \frac{G_F^2 M E_\nu}{\pi(1+\frac{Q^2}{M_W^2})^2}\left[\left(1-y-\frac{Mxy}{2E_\nu}\right)F_2^{\nu(\overline{\nu})} + \frac{y^2}{2}2xF_1^{\nu(\overline{\nu})} \pm y(1-\frac{y}{2})xF_3^{\nu(\overline{\nu})}\right]$$

- NuTeV used an enhanced LO QCD A. J. Buras - K. F.J. Gaemers model
  - a simple phenomenological fit to data to reduce the theory dependencies

$$\begin{aligned} 2xF_1(x,Q^2) &= xu_v + xd_v + 2xu_s + 2xd_s + 2xs, \\ F_2(x,Q^2) &= 2xF_1(x,Q^2)\left(\frac{1+R_L(x,Q^2)}{1+4M^2x^2/Q^2}\right), \\ xF_3(x,Q^2) &= xu_v + xd_v, \end{aligned}$$

  - the quark distributions are parametrised using simple functional form at a starting scale Q0 and then then evolved to any Q2 using functional forms similar to QCD

  —-> 19 free parameters.

List of Physics Corrections:

- **Data is cross section on iron target, including the radiative effects**

- Therefore, Monte Carlo has to account for the following known effects:
  - low Q2 extrapolation needed to model well the edge of the data range:
    - the Buras-Gaemers parametrisation is not well behaved —> GRV94LO PDFs
  - Longitudinal Structure Function:
    - to account for the gluon effects (shortcomings of a LO model)
  - Charm Production Threshold:
    - rescale of the x to account for the charm production
  - Radiative Corrections:
    - account for radiation of real and virtual photon

These would improve when using NLO MC

  - Higher Twist (relevant for high x, low Q2)
    - correction estimated from fits to F2 charged lepton data (SLAC, BCDMS)
  - strange sea production suppression
    - CCFR/NuTeV $\nu N \rightarrow \mu + \mu - X$ data) X data

  - Non-Isoscalar Target Corrections:
    - target at NuTeV was from Iron
  - Propagator Term:
    - The correction for the massive mediating W boson

  - d/u constraints
    - as observed by the NMC and Drell Yan fixed target data (E866/NUSEA)

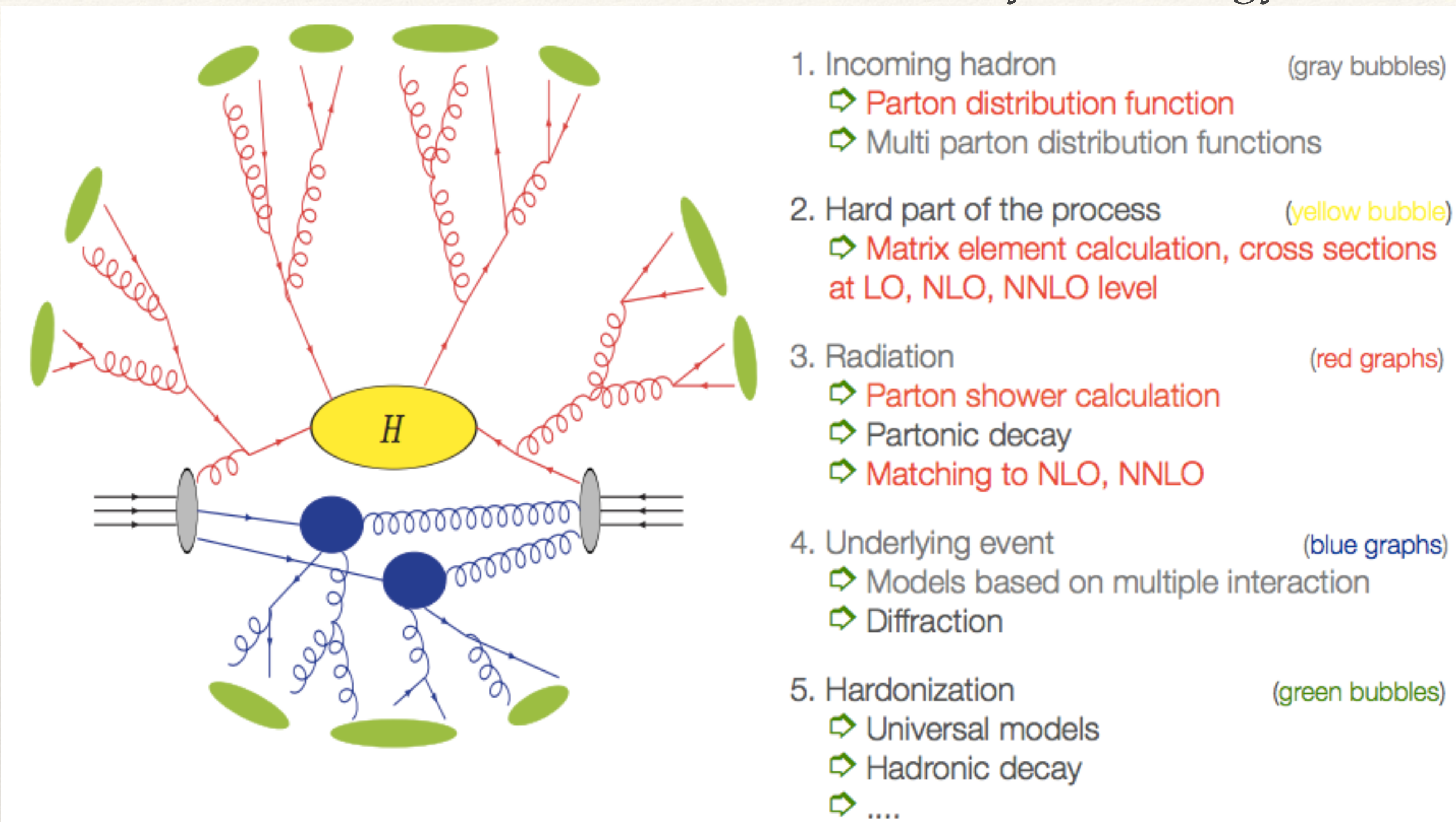
Summary

- Any interaction which involves hadronic initial state will rely on PDFs
- PDFs are very important as they still limit our knowledge of cross sections whether SM or BSM.
- Neutrino DIS could present a valuable input for high x domain:
  - nuclear PDFs
- Extraction of the neutrino differential data could benefit from a NLO MC rather than “enhanced" LO MC, for testing various input assumptions: QED effects, strange suppression, charm contribution…

Thank You.

Roles of PDFs in MC tuning

- Structure of an event at the LHC (courtesy of Z. Nagy)



Perturbative framework:

- LO: easy to calculate: several matrix element generators are available:
  - ALPGEN, HELAC, MADGRAPH, SHERPA
  - Strong dependence on the unphysical scales
  - well defined with LO PDF
- NLO is the New Standard: HELAC, MADGRAPH, SHERPA+BLACKHAT, AUTODIPOLE, TEVJET, AMC@NLO
  - The scale dependence can be still big in some processes
- NNLO & NkLO: Resummation - Parton Showers: POWEHEG

QCD Settings for HERAPDF2.0

The QCD settings are optimised for HERA measurements of proton structure functions:

PDFs are parametrised at the starting scale Q_0^2=1.9 GeV^2 as follows:

$$xg(x) = A_g x^{B_g}(1-x)^{C_g} - A'_g x^{B'_g}(1-x)^{C'_g},$$

$$xu_v(x) = A_{u_v} x^{B_{u_v}}(1-x)^{C_{u_v}}\left(1 + D_{u_v}x + E_{u_v}x^2\right),$$

$$xd_v(x) = A_{d_v} x^{B_{d_v}}(1-x)^{C_{d_v}},$$

$$x\bar{U}(x) = A_{\bar{U}} x^{B_{\bar{U}}}(1-x)^{C_{\bar{U}}}(1 + D_{\bar{U}}x),$$

$$x\bar{D}(x) = A_{\bar{D}} x^{B_{\bar{D}}}(1-x)^{C_{\bar{D}}}.$$

fixed or constrained by sum-rules

parameters set equal but free

NC structure functions

$$F_2 = \frac{4}{9}\left(xU + x\bar{U}\right) + \frac{1}{9}\left(xD + x\bar{D}\right)$$

$$xF_3 \sim xu_v + xd_v$$

CC structure functions

$$W_2^- = x(U + \overline{D}), \qquad W_2^+ = x(\overline{U} + D)$$

$$xW_3^- = x(U - \overline{D}), \qquad xW_3^+ = x(D - \overline{U})$$

Due to increased precision of data, more flexibility in functional form is allowed —> 15 free parameters

- PDFs are evolved via evolution equations (DGLAP) to NLO and NNLO (as(MZ)=0.118)
- Thorne-Roberts GM-VFNS for heavy quark coefficient functions – as used in MSTW
- Chi2 definition used in the minimisation [MINUIT] accounts for correlated uncertainties:

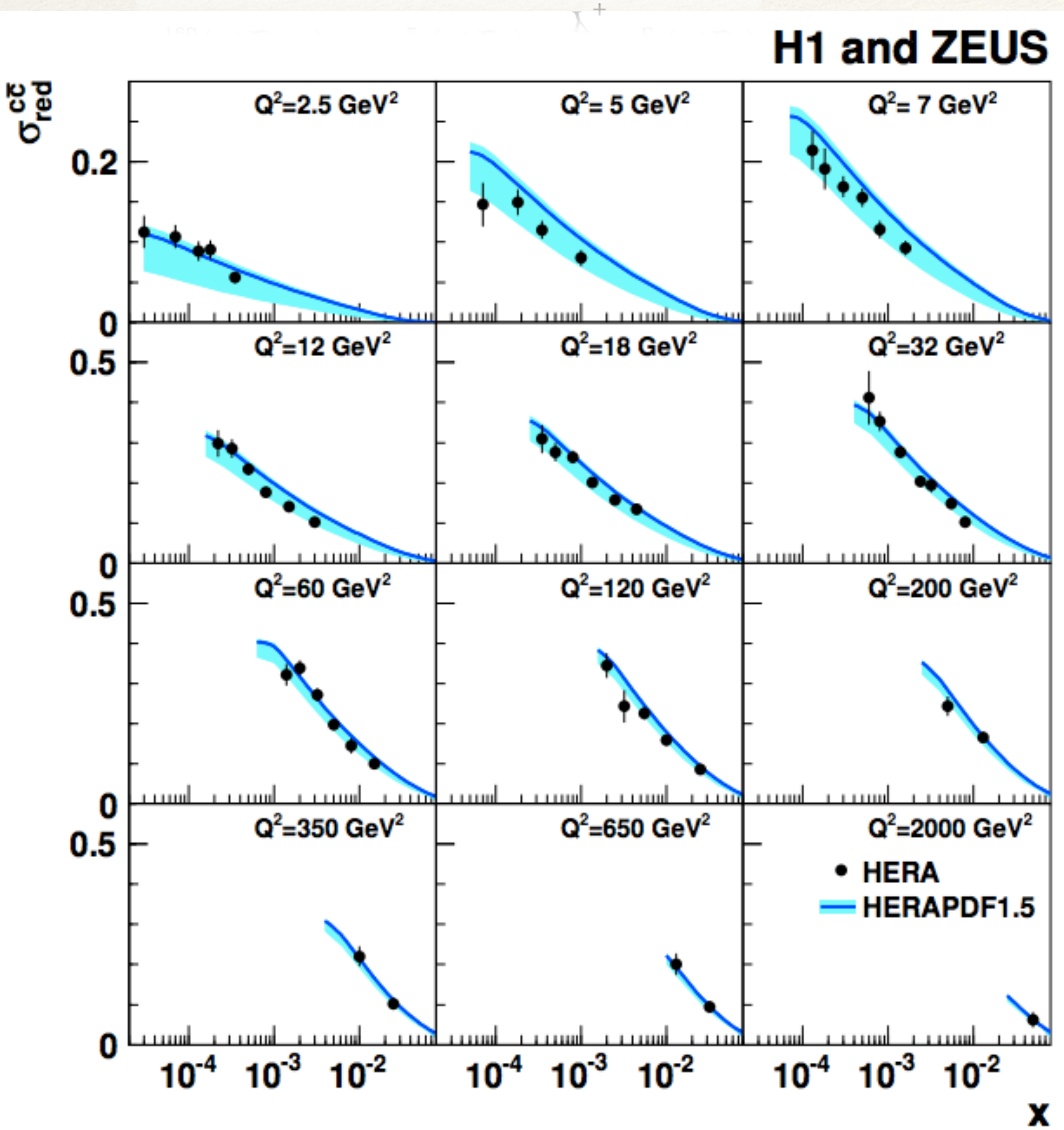
$$\chi^2_{tot}(\mathbf{m},\mathbf{b}) = \sum_i \frac{[\mu^i - m^i(1-\sum_j \gamma^i_j b_j)]^2}{\delta^2_{i,stat}\mu^i m^i(1-\sum_j \gamma^i_j b_j) + (\delta_{i,unc} m^i)^2} + \sum_j b_j^2 + \sum_i \ln \frac{\delta^2_{i,unc} m_i^2 + \delta^2_{i,stat}\mu^i m^i}{\delta^2_{i,unc}\mu_i^2 + \delta^2_{i,stat}\mu_i^2}$$

F2 charm Structure Function

EPJC 73 (2013) 2311

- Rates at HERA in DIS regime σ(b) : σ(c) ≈ O(1%) : O(20%) of σ_{TOT}
- Charm data combination is performed at charm cross sections level:
  - they are obtained from xsec in visible phase space and extrapolated to full space

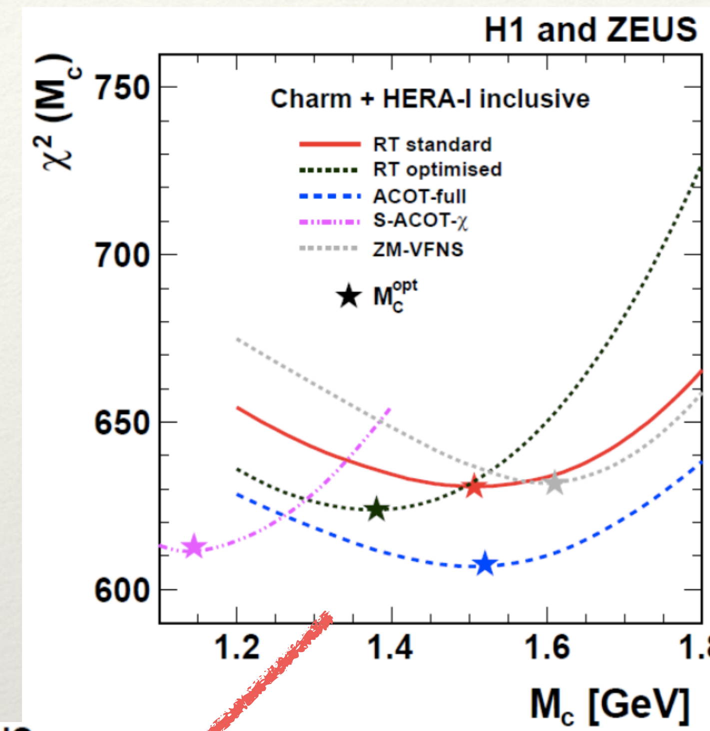
$$\sigma_{red}^{c\bar{c}}(x, Q^2, s) = F_2^{c\bar{c}}(x, Q^2) - \frac{y^2}{Y_+} F_L^{c\bar{c}}(x, Q^2)$$

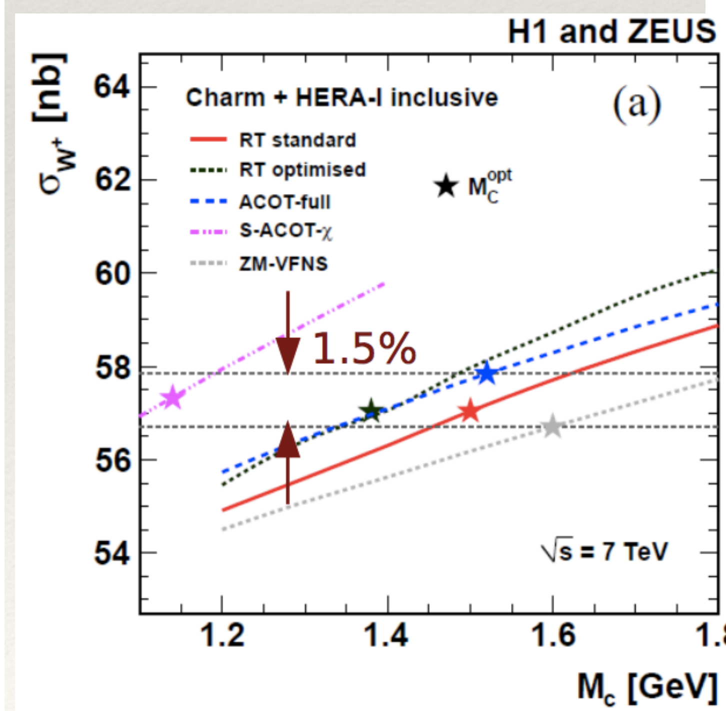


QCD Fits

HERA I+charm

Different calculation schemes prefer different M_c





measurements help reduce uncertainties of predictions for the LHC

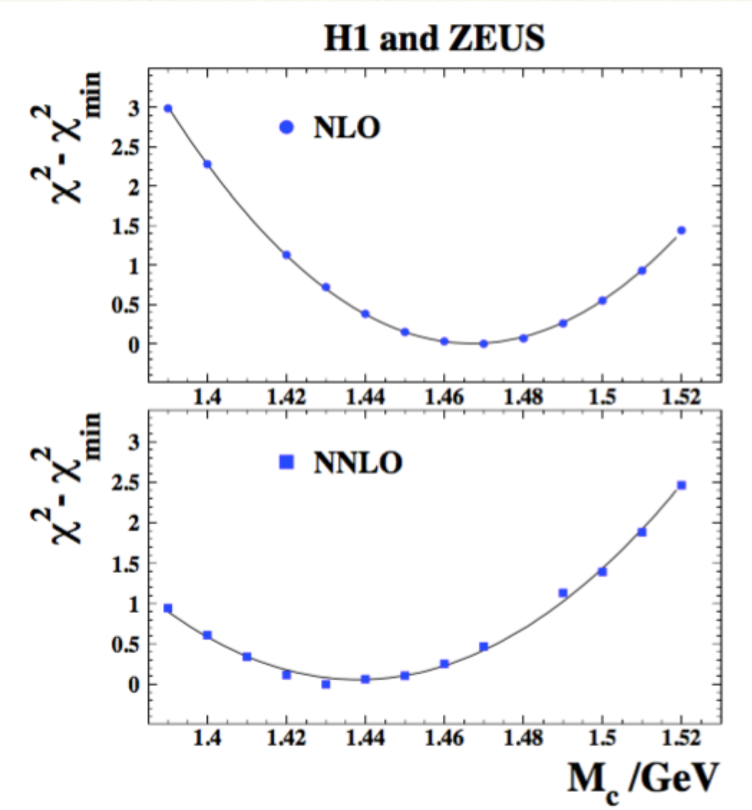
HERAPDF2.0Jets

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

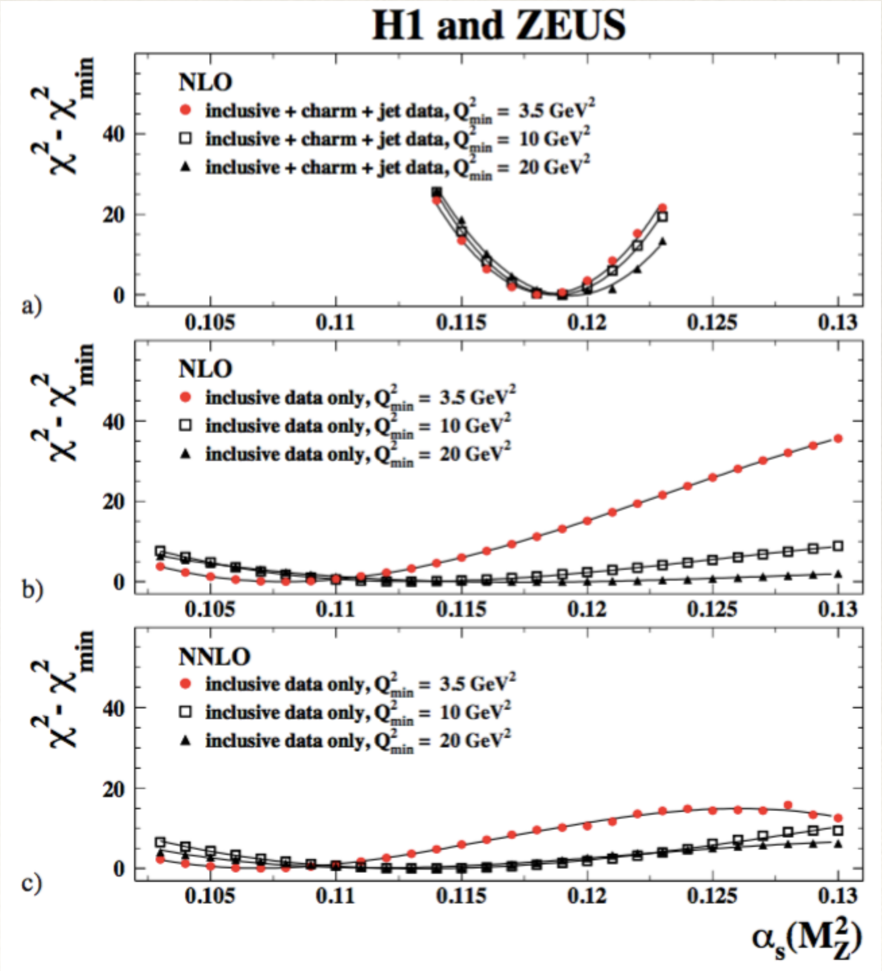
- data from the HERA charm combination has its main effect to determine the optimal charm mass parameter and determine its variation for the standard HERAPDF2.0.
  - This variation is much reduced compared to HERAPDF1.0
- Seven data sets on inclusive jet, dijet, trijet production at low and high Q^2, from ZEUS and H1 have been added to the HERAPDF2.0 fit

  PLB547(2001)164, EPJC70(2010)965, EPJC67(2010)1, PLB653(2007)134 and EPJC75(2015)2

  - 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



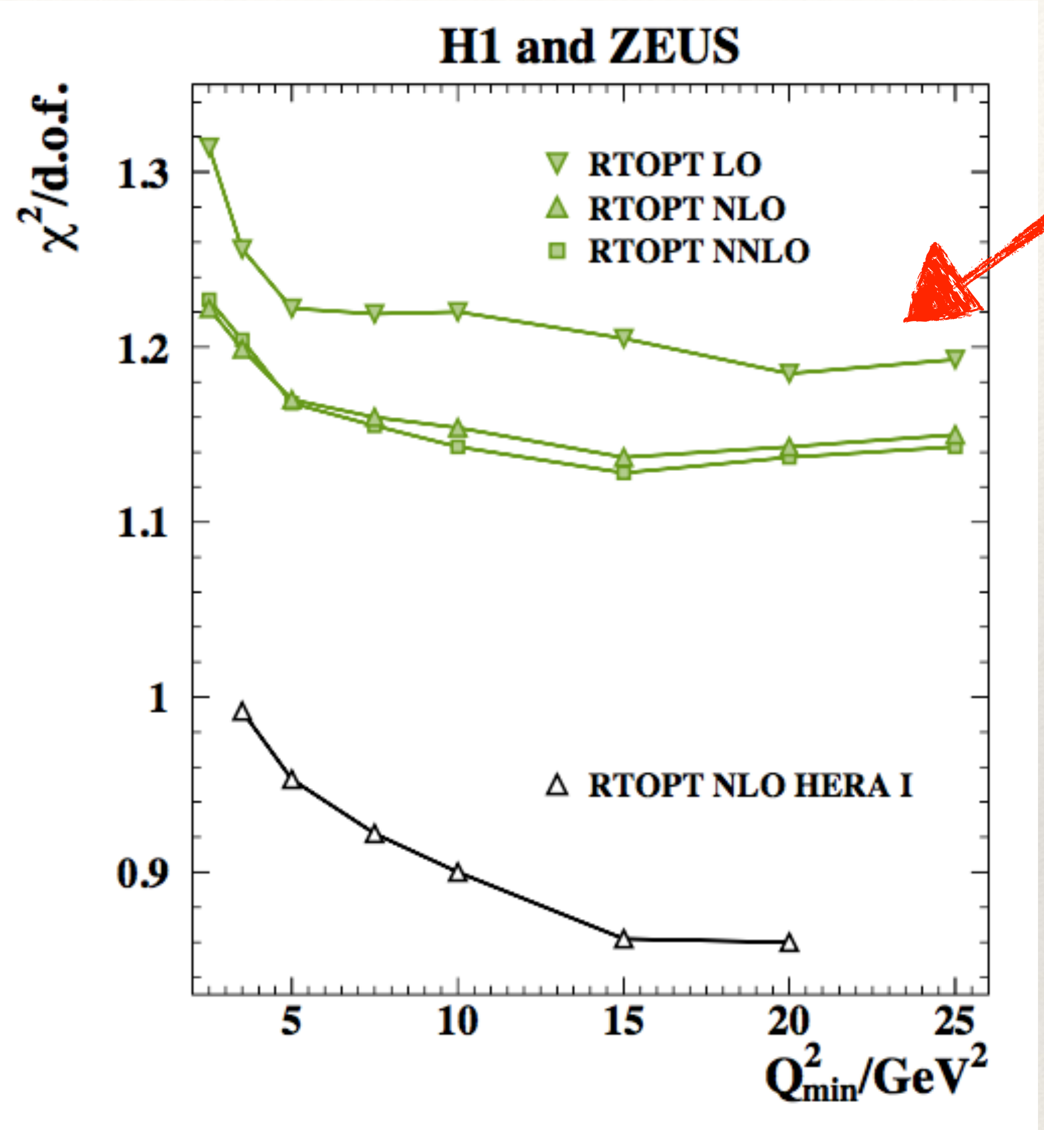
$$\alpha_S(M_Z) = 0.1183 \pm 0.0009_{(exp)} \pm 0.0005_{(model/param)} \pm 0.0012_{(had)} \, {}^{+0.0037}_{-0.0030}(\text{scale})$$



the fitted value is in agreement with the chosen fixed value —> PDFs are similar for fixed vs fitted

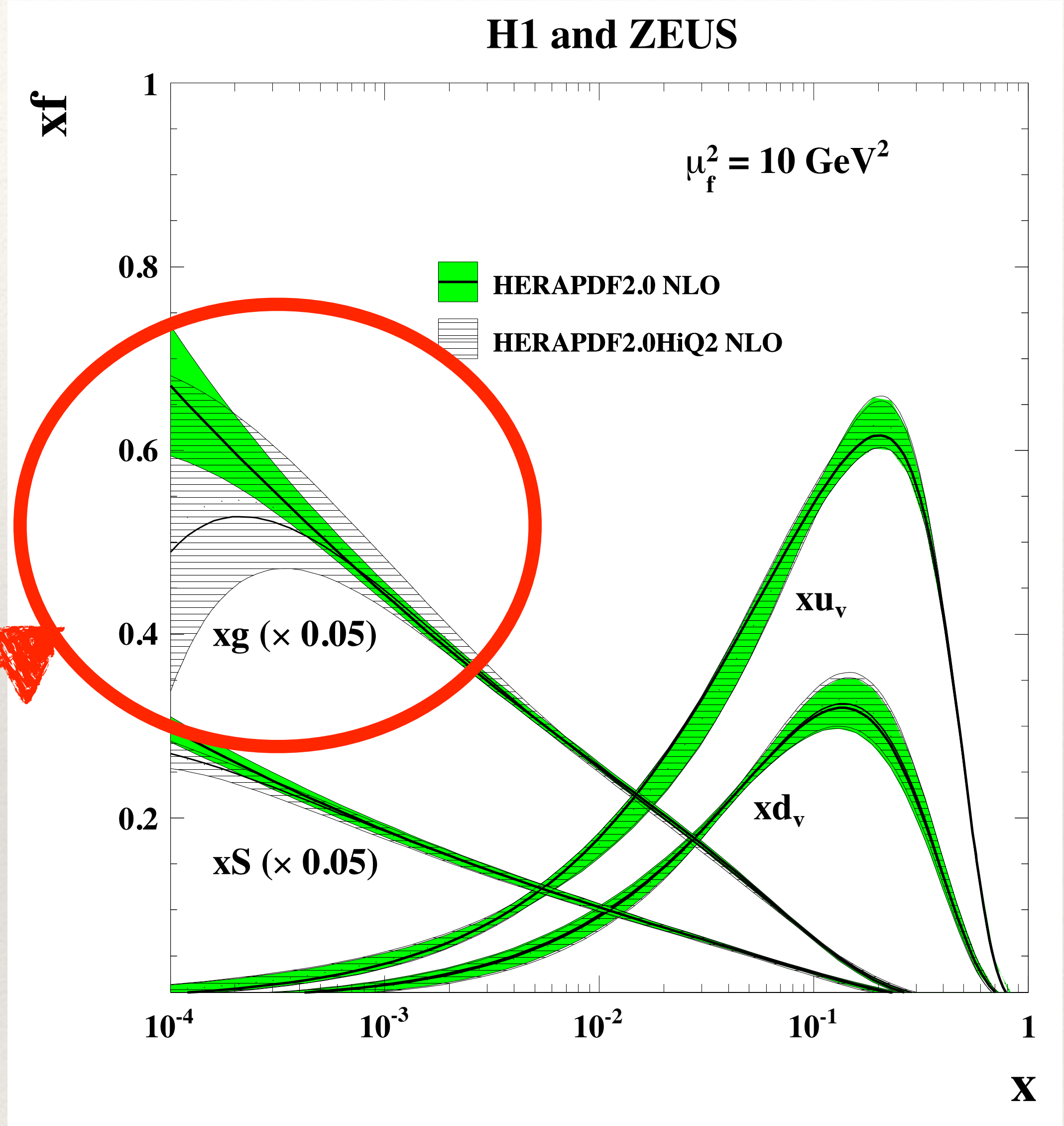
Q^2 cut dependence on PDFs

- HERA data provides a unique access to the low x, low Q^2 region to investigate:
  - the validity of the DGLAP mechanism



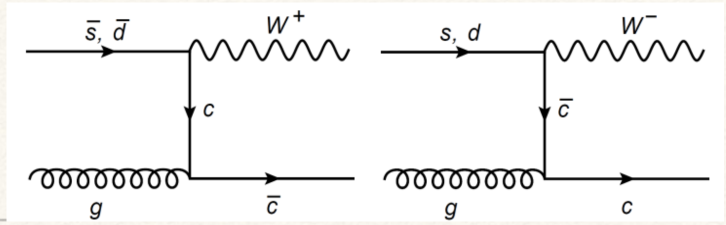
NLO is significantly better than LO, but NNLO is not obviously better than NLO

low Q² data very important to constrain low x PDFs!

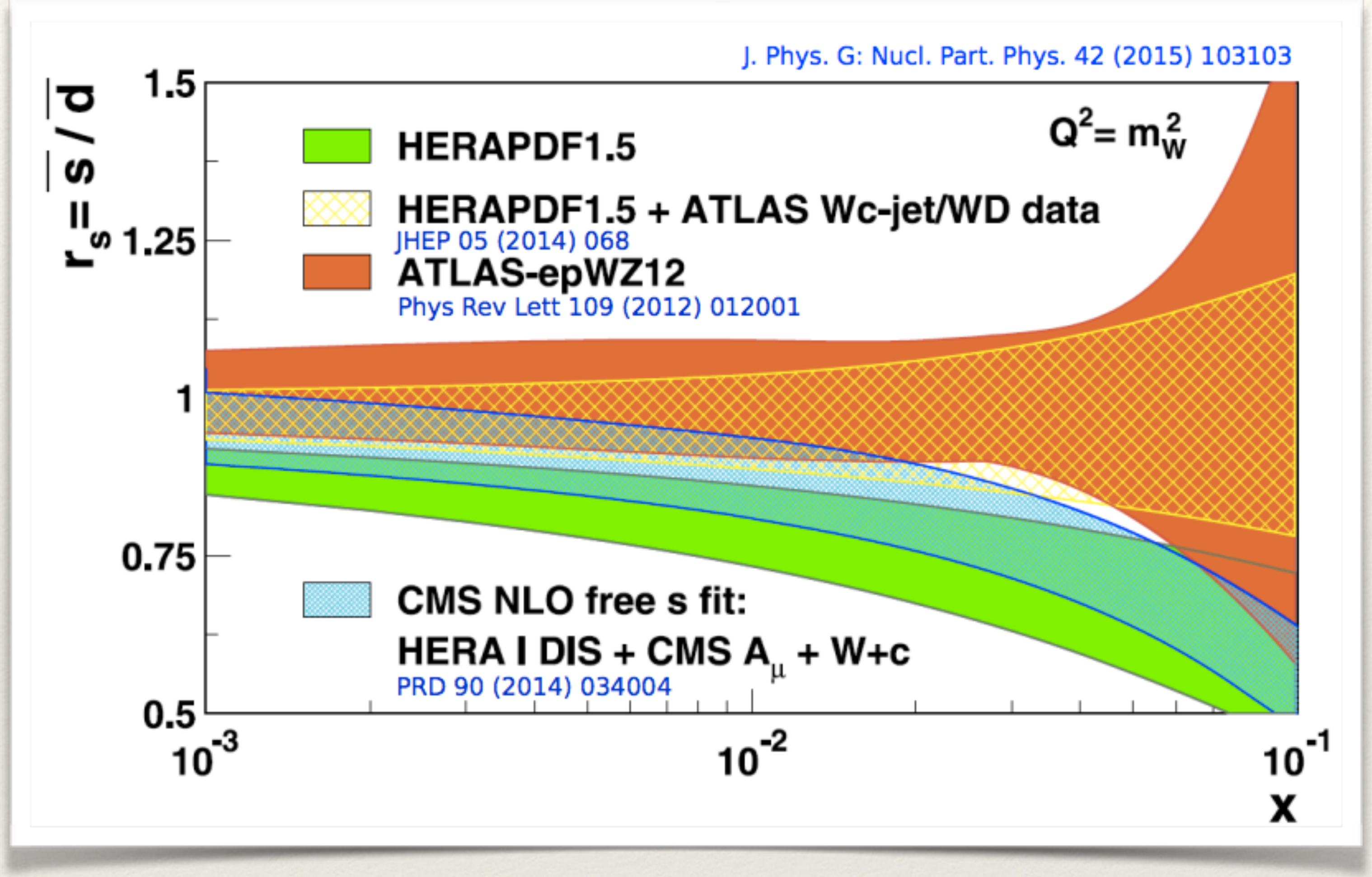


- LHAPDF sets for HERAPDF are presented for both variants:
  - Q2 > 3.5 HERAPDF2.0 (LO, NLO, NNLO) - nominal
  - Q2> 10 HERAPDF2.0HiQ2 (NLO, NNLO)

W+c sensitivity to strange



- W + charm data is directly sensitive to the strange quark density
- ATLAS, CMS and LHCb have performed dedicated measurements
  - ATLAS @ particle level [arXiv:1402.6263v1] CMS @parton level [arXiv:1310.1138]



Strange fraction determined in CMS is lower than in ATLAS but results are still consistent …