Parton distributions for the LHC

Graeme Watt

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Introduction

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Parton distributions for the LHC

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Abstract

We present updated leading-order, next-to-leading order and next-to-next-to-leading order parton distribution functions (MSTW 2008) determined from global analysis within the standard framework of leading-twist fixed-order collinear factorisation. These parton distributions supersede the currently available MRST sets. New data sets fitted include CCFR/NuTeV dimuon cross sections, which constrain the strange quark and antiquark distributions, and Tevatron Run II data on inclusive jet production, the lepton charge asymmetry from W decays and the Z rapidity distribution. Uncertainties are propagated from the experimental errors on the fitted data points using a new dynamic procedure for each eigenvector of the covariance matrix. We give predictions for the W and Z total cross sections at the Tevatron and LHC.

Contents

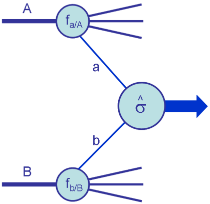
- Paper nearing completion.
- ∼150 pages, ∼70 figures
- UCL: R.S. **T**horne, G.**W**.
- "MS**TW** 2008"
- `arXiv:0812.xxxx [hep-ph]`
- Major update to previous "MRST" analyses.
- "M**R**ST" = "MST" + R.G. **R**oberts (now retired)

What's the problem we're trying to solve?

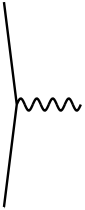
- Hopefully, the LHC will someday collide **hadrons**.
- Hadrons (e.g. protons) are not elementary particles: made of **partons** (i.e. quarks and gluons).
- Incoming particles in Feynman diagrams are **partons**.
- Parton Distribution Functions (PDFs) essential to relate theory to experiment (i.e. "phenomenology").

$f_{a/A}(x, Q^2)$ gives *number density* of partons of flavour a in hadron of type A with momentum fraction x at a hard scale $Q^2 \gg \Lambda^2_{\rm QCD}$.

$$\sigma_{AB} = \sum_{a,b=q,g} \hat{\sigma}_{ab} \otimes f_{a/A}(x_a, Q^2) \otimes f_{b/B}(x_b, Q^2)$$



Diagrammatic interpretation of collinear factorisation



- Drell–Yan production at LO: $q\bar{q} \to V = W/Z/\gamma^*$
- Cut diagram: $|\mathcal{M}|^2 = \mathcal{M}\mathcal{M}^*$
- Large logarithm from collinear gluon emission: $\int_{k_0^2}^{Q^2} (\mathrm{d}k_T^2/k_T^2)\, \alpha_S\, P_{q\leftarrow q}(z)$
- Similar collinear logs from other parton splittings.
- Evolution equation:

$$\frac{\partial f_{a/p}}{\partial \ln Q^2} = \alpha_S \sum_{a'=q,g} P_{a\leftarrow a'} \otimes f_{a'/p}$$

- $f_{a/p}(x, Q_0^2) \Rightarrow f_{a/p}(x, Q^2)$

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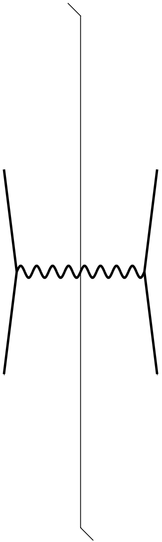

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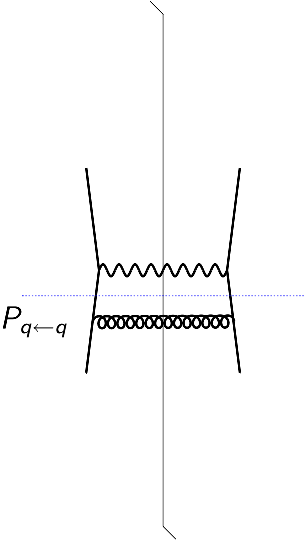

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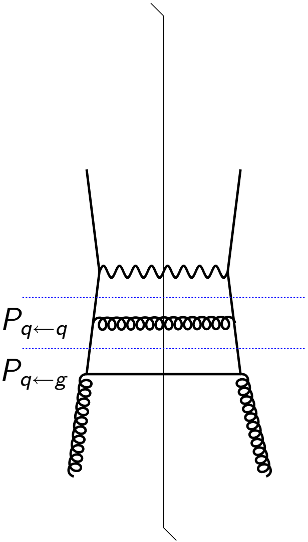

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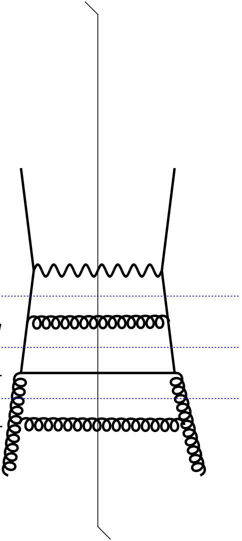

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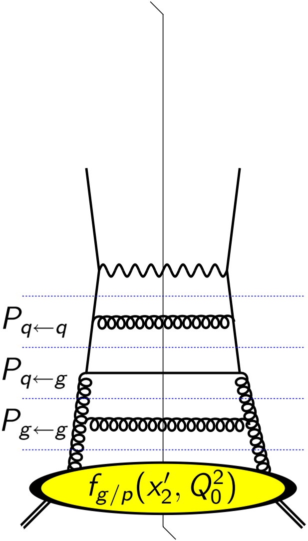

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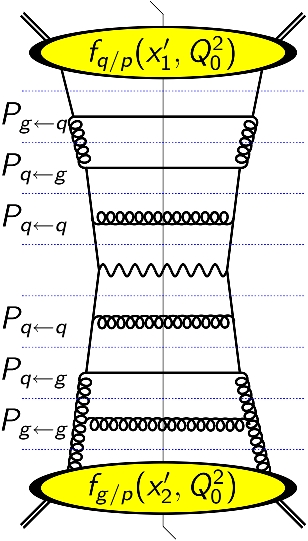

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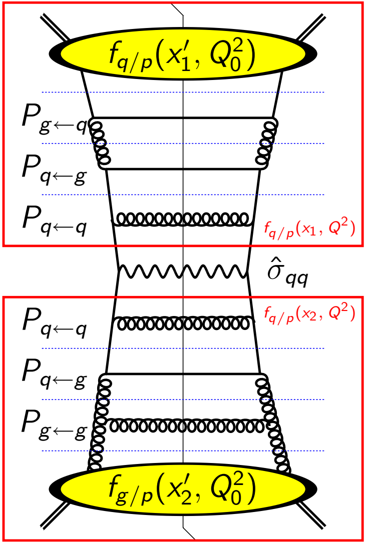

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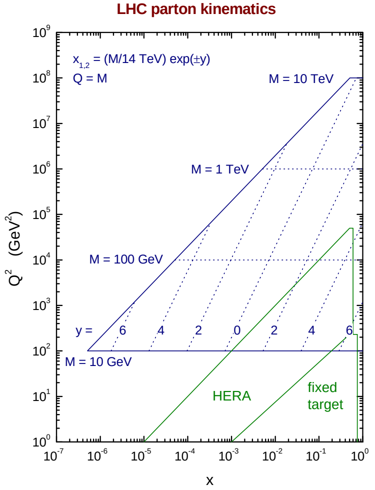
From HERA *et al.* to the LHC



- Structure functions in DIS:

$$F_i(x, Q^2) = \sum_{a=q,g} C_{i,a} \otimes f_{a/A}(x, Q^2).$$

- PDFs are **universal**.
- Fit existing DIS data from HERA and fixed-target experiments, together with data from the Tevatron.
- Expand $P_{a\leftarrow a'}$, $C_{i,a}$ and $\hat{\sigma}_{ab}$ as perturbative series in α_S.
- Work at LO/NLO/NNLO for increasing accuracy.

Paradigm for PDF determination by “global analysis”

1. **Parameterise** the x dependence for each flavour $a = q, g$ at the input scale $Q_0^2 \sim 1$ GeV^2 in some flexible form, e.g.

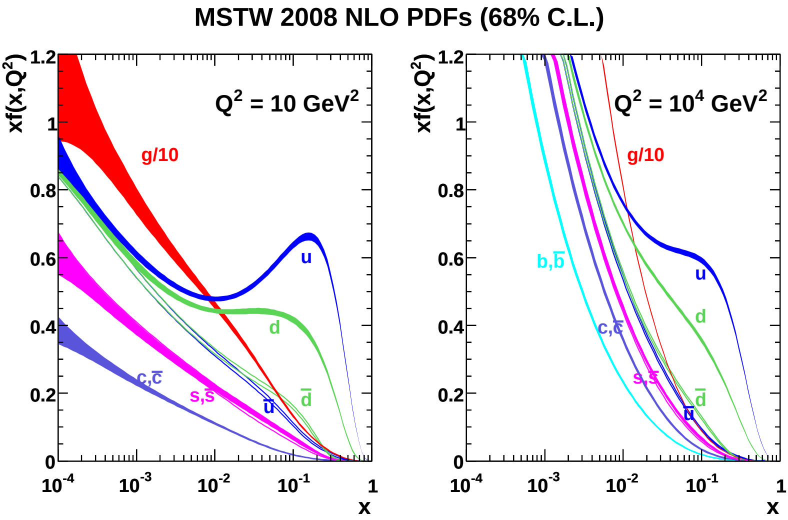
$$xf_{a/p}(x, Q_0^2) = A_a x^{\Delta_a}(1-x)^{\eta_a}(1+\epsilon_a\sqrt{x}+\gamma_a x),$$

   subject to number- and momentum-sum rule constraints.

2. **Evolve** the PDFs to higher scales $Q^2 > Q_0^2$.
3. **Convolute** the evolved PDFs with $C_{i,a}$ and $\hat{\sigma}_{ab}$ to calculate theory predictions corresponding to a wide variety of data.
4. **Vary** the input parameters $\{A_a, \Delta_a, \eta_a, \epsilon_a, \gamma_a, \ldots\}$ to minimise

$$\chi^2 = \sum_{i=1}^{N_{\rm pts.}} \left(\frac{{\rm Data}_i - {\rm Theory}_i}{{\rm Error}_i}\right)^2.$$

Example of PDFs obtained from global analysis



Concluding slide from my UCL HEP talk in December 2006

Strangeness in the proton

- NuTeV dimuon data constrain s and $\bar{s}$.
- Preference for a slight positive strange momentum asymmetry, which reduces the NuTeV $sin^2\theta_W$ anomaly.

Inclusion of jet data in PDF fits

- Inclusion of Tevatron Run I jet data in a rigorous way via "**fastNLO**" package gives slightly different gluon distribution than the approximate "pseudogluon" approach.
- HERA jet data have little impact on the gluon distribution.

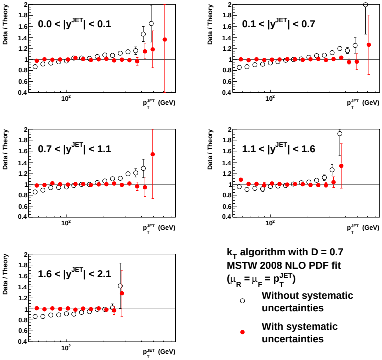
Outlook

- Include Tevatron Run II jet data.
- Extend to NNLO analysis.
- Produce parton distributions with errors.

https://www.hep.ucl.ac.uk/twiki/pub/HEPGroup/XmasMeeting2006/watt.pdf

Description of Tevatron Run II inclusive jet data

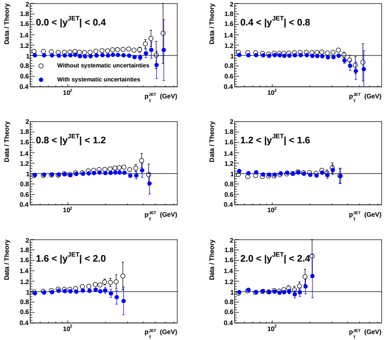
CDF Run II inclusive jet data, χ^2 = 56 for 76 pts.



[hep-ex/0701051]

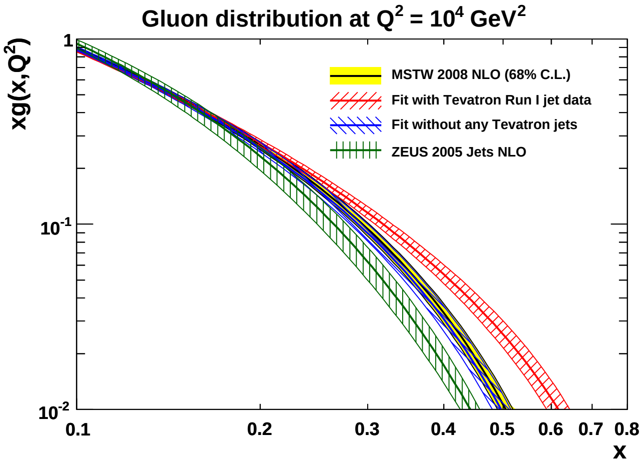
DØ Run II inclusive jet data (cone, R = 0.7)

MSTW 2008 NLO PDF fit ($\mu_R = \mu_F = p_T^{JET}$), χ^2 = 114 for 110 pts.



[arXiv:0802.2400]

Impact of Run II jet data on high-x gluon distribution



- Run II jet data prefer smaller gluon distribution at high x.

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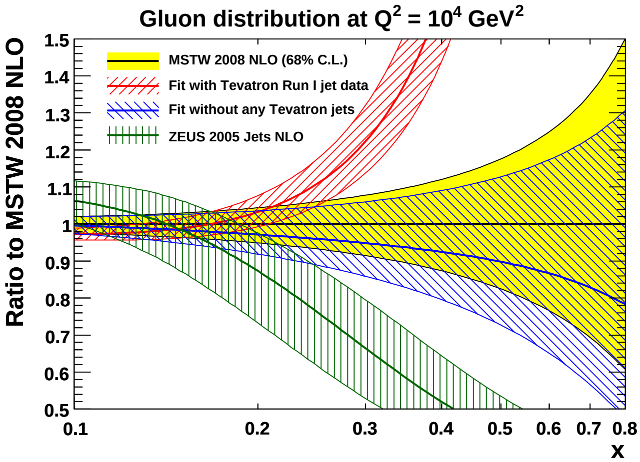
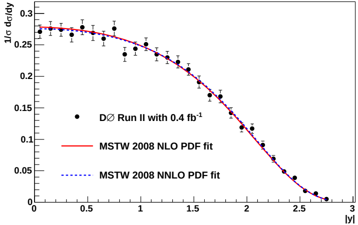
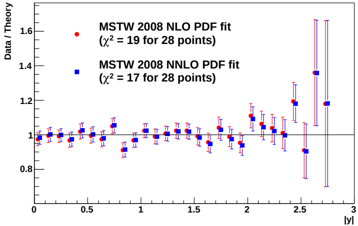


- Errors not significantly reduced with inclusion of Run II data.

Z/γ^* rapidity distributions from Tevatron Run II

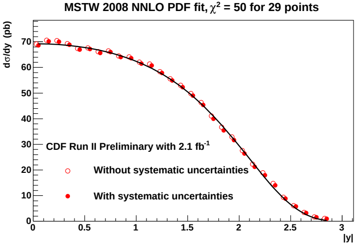
Z/γ* rapidity shape distribution from DØ

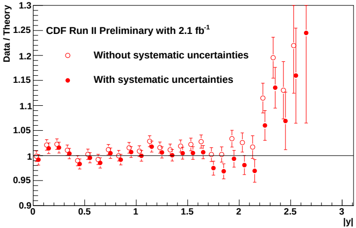




[hep-ex/0702025]

Z/γ* rapidity distribution from CDF





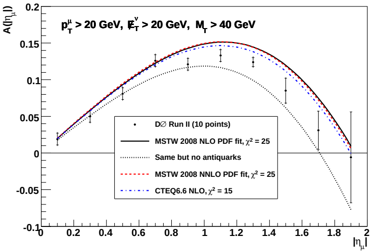
[CDF Preliminary, February 2008]

$W \to l\nu$ charge asymmetry from Tevatron Run II

$$A(\eta_l) = \frac{\mathrm{d}\sigma(l^+)/\mathrm{d}\eta_l - \mathrm{d}\sigma(l^-)/\mathrm{d}\eta_l}{\mathrm{d}\sigma(l^+)/\mathrm{d}\eta_l + \mathrm{d}\sigma(l^-)/\mathrm{d}\eta_l}$$

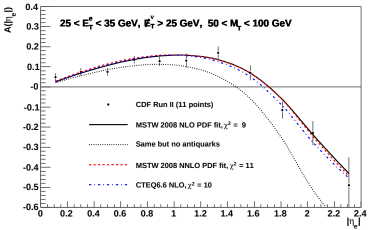
- Mainly constrains **down** quark.
- Antiquarks important at low E_T^l.

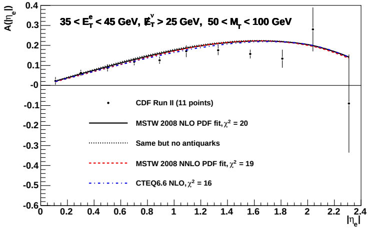
DØ data on lepton charge asymmetry from W→μν decays



[arXiv:0709.4254]

CDF data on lepton charge asymmetry from W→eν decays





[hep-ex/0501023]

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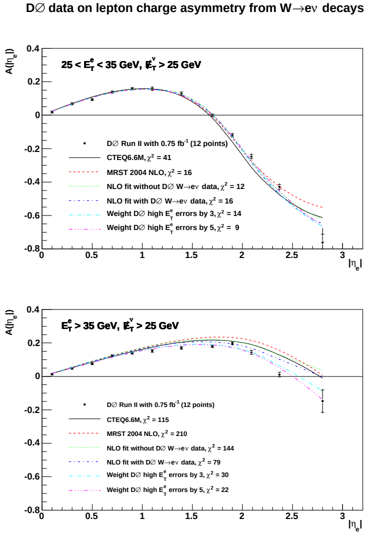
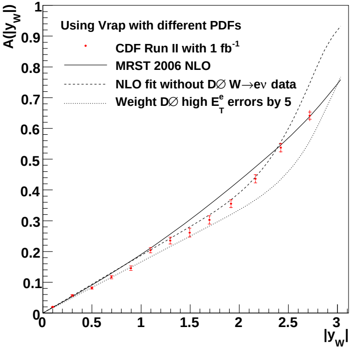


[arXiv:0807.3367]

- Problems fitting recent DØ data $\Rightarrow$ not included in final 2008 fit.
- Inconsistencies between DØ and CDF: under investigation.



[CDF Preliminary, August 2007]

Criteria for choice of tolerance $T = \sqrt{\Delta\chi^2_{\rm global}}$

Parameter-fitting criterion

- $T^2 = 1$ for 68% (1-σ) C.L., $T^2 = 2.71$ for 90% C.L.
- **In practice:** minor inconsistencies between fitted data sets, and unknown experimental and theoretical uncertainties, so not appropriate for global PDF analysis.

Hypothesis-testing criterion

- Much weaker: a "good" fit has $\chi^2 \simeq N_{\rm pts.} \pm \sqrt{2N_{\rm pts.}}$
- Treat PDF sets obtained from eigenvectors of covariance matrix as alternative hypotheses.
- **MRST:** $T^2 = 50$ for 90% C.L. limit [**CTEQ:** $T^2 = 100$].
- **MSTW:** determine T^2 from the criterion that each data set should be described within its 90% (or 68%) C.L. limit.

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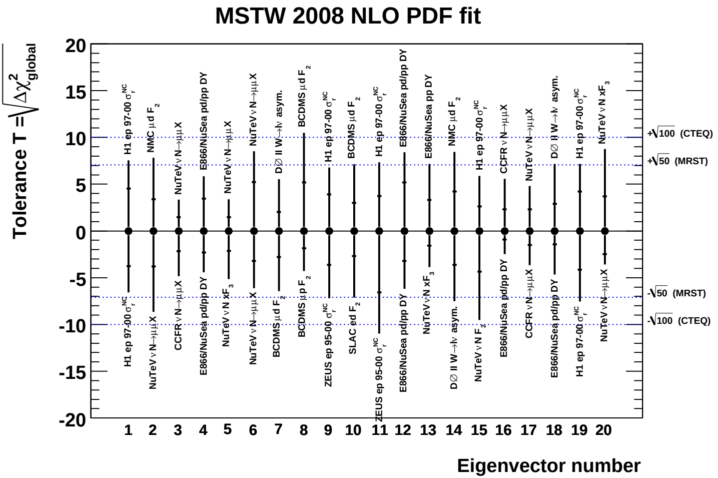
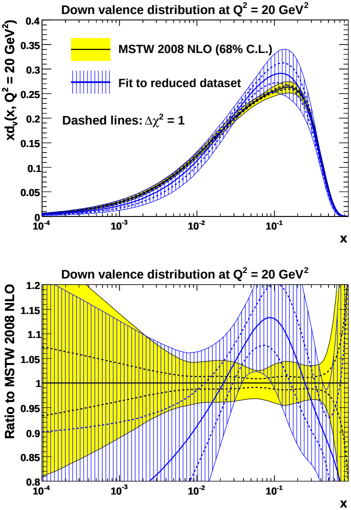
Dynamic tolerance: different for each eigenvector



- **Details:** G.W., talk at PDF4LHC, CERN, February 2008.

Test of dynamic tolerance: fit to reduced dataset



- Fit to reduced dataset comprising 589 DIS data points, cf. 2699 data points in global fit.
- Errors given by $T^2 = 1$ don't overlap $\Rightarrow$ inconsistent data sets included in global fit.
- **Dynamic tolerance** $T^2 > 1$ (partially) accommodates inconsistent data sets.

Summary

- **Definitive** LO, NLO, NNLO PDF sets for first LHC running.
- **First** PDF fits available to include Tevatron Run II data.
- **Improved** dynamic tolerance controlling PDF uncertainties.
- "MSTW 2008" PDFs supersede older "MRST" sets.

Outlook

- **Publication** and public release of code and grids imminent.
- Standalone Fortran, C++ and Mathematica code will be available from `http://projects.hepforge.org/mstwpdf/` (with later implementation into LHAPDF library).