PDF Session Summary

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3 sessions with 22 presentations
- a joined session with Hard Scattering
- a joined session with PDF4LHC
- a stand alone session for PDF

New Results important for PDFs from:
- DIS and DY experiments
- theory: global fits and HO calculations

Many thanks to all participants for a handful of new results and interesting discussions!
News from HERA

- HERA Combined F2 charm data provides constraints for heavy flavour quark treatment

Inclusive NC and CC: HERA Textbook Plots

Electroweak Unification

Linear Polarisation Dependence

Good agreement with SM (HERAPDF 1.5) prediction.

Ongoing efforts towards final inclusive HERA I+II data combination and realising of corresponding HERAPDF2.0 – very much awaited!
News from JLAB and CTEQ-JLAB

- **JLAB**: active program to provide PDF information at high x ➔ useful for LHC
- **CAVEATS**: To extract PDF information from nuclear targets, corrections must be applied:
  - CTEQ-JLAB collaboration addresses the theoretical issues at high x data to reduce the PDF uncertainties

**Size of Target mass correction**

- **Target Mass Corrections**: crucial at low Q2, large x
  (HERA data not affected due to the kinematic acceptance)
  - Higher Twist contribution (parametrised by \( \sim c(x)/Q^2 \))
- **Nucleon corrections for deuteron targets**:
  - affects d, which is anti-correlated with g

**BONUS experiment** at JLAB extracts F2n in a model independent way using tagging spectator proton approach ➔ this measurement is encouraged to be used for global PDF fits \( \text{PRL108 (2012) 199902} \)

A lot of new experiment to come to assess d/u: first scheduled experiment in 2015 at JLAB Hall A
HERAFitter QCD platform

Heritage of HERA transferred to LHC:

Open Source QCD Framework freely available at https://www.herafitter.org

Towards stable release:

New:
• Implementation of QED effects in PDF evolution of importance to measurements at LHC

Implementation cross checked against MRST2004qed and very good agreement is found.
Precision Measurements from the LHC sensitive to PDFs

Measurements
- Inclusive $W/Z$ Production
- $W/Z$ Production in association with jets
- Drell-Yan Production
- Inclusive Jet Production
- Isolated Photons
The interplay between the flavour asymmetries can be enhanced via ratio measurements:

\[ A_W = \frac{\sigma(W^+) - \sigma(W^-)}{\sigma(W^+) + \sigma(W^-)} = \frac{u_v - d_v}{u_v + d_v + 2 \bar{q}b} \] at \( x_1 = x_2 \)

• CMS measures directly the lepton asymmetry – updated result with 4.7/fb of 2011 data

• ATLAS differential measurements of \( W^+ \) and \( W^- \) (combined muon and electron) based on 2010 data translated into charge asymmetry \( A_l \) as long as proper treatment of correlations are accounted for.

• LHCb extends the measurement (muon channel) to forward region and provides a comparison with ATLAS measurement in the overlapping region, after LHCb was extrapolated from its fiducial volume.

**NOTE:** Selection criteria are optimized for each experiment
Neutral Current Drell Yan di-lepton measurements

- Drell Yan data can give information on sea quark PDFs.

The Drell Yan invariant mass spectrum in the dimuon (electron) channel, normalized to the Z resonance region for CMS in the $20 < M_{\mu\mu} < 1500$ GeV region [CMS-SMP-13-003]

Measurement complemented by LHCb down to 5 GeV [LHCb-CONF-2012-013]

Good agreement with SM predictions is observed.
The Drell Yan invariant mass spectrum in the off resonance region:

- **ATLAS**: in the dilepton channel
- **CMS**: normalized to the Z resonance region, function of dimuon rapidity for CMS in selected $M_{\mu\mu}$ bins

Data is confronted with NNLO predictions (corrected for NLO EW effects)

- NNLO is relevant, especially at low mass.
- **Currently all PDFs shown give a reasonable description**
Measurements of differential cross sections are compared to NNLO predictions:

\[ \int \mathcal{L} \, dt = 33 - 38 \text{ pb}^{-1} \]

\[ \text{Z} \rightarrow \ell^+\ell^- \]

\[ Q^2 = 1.9 \text{ GeV}^2, \, x = 0.023 \]

\[ r_s = \frac{s + \bar{s}}{2d} \]

\[ r_s(0.023, 1.9 \text{ GeV}^2) = 1.00^{+0.25}_{-0.28} \]

\[ r_s(0.013, M_Z^2) = 1.00^{+0.09}_{-0.10} \]
W+c from ATLAS and CMS

Question: would other measurements confirm ATLAS favour of sbar=dbar?

- Preliminary W+c measurement sensitive to strange, with charm hadrons reconstructed in four $D^+/D^*$ decay modes based on 4.6/fb data (7TeV)
  - presented at particle level in fiducial phase space for ATLAS, parton level for CMS using world values for BR

Theoretical predictions are based on aMC@NLO:
- measurement suggest a non-suppressed strange
- better agreement with predictions based on enhanced strange $s \sim d$

Theoretical predictions are based on MCFM:
- Best agreement with CT10 ($s \sim 3/4 d$)

Suggestions to release both type of measurements: at particle level and partonic level
Other interesting measurements involving W, Z

  - Probes the same physics as measurements in Z pT, but provides better experimental precision
  - An important input in comparison to predictions of different MC generators and is a stringent test to resummation calculations

- Measurement of Z pt dependence from CMS (8 TeV data of low pile up)

- Measurement of Forward-backward Z asymmetry from ATLAS: [ATLAS-CONF-2013-043]
  - Used to determine the $\sin^2 \theta_W^{\text{eff}}$ which is already as precise as measurements from Tevatron.

- Measurement of W/Z + b results compared to range of theoretical predictions from Madgraph, MCFM(4FNS + 5FNS), Alpgen, Powheg, Sherpa:
  - Large experimental uncertainties - dominated by Jet Energy Scale and purity determinations

- Measurements of diboson production in Wγ, Zγ, WW, WZ, ZZ at ATLAS (7 TeV) and CMS (7 and 8 TeV) in remarkable agreement with the SM predictions.
Impact of Inclusive jet measurements on gluon

- LHC provided different beam energies of 2.76, 7 and 8 TeV which probe different $x$ and $Q^2$ values for the same $p_T$ and $y$ ranges so that theoretical uncertainties due to PDFs do not cancel in the ratio:
  - these ratio data have more impact on PDF determination than the separate data sets
  - ATLAS provides ratio of 2.76 TeV to the 7 TeV jet cross sections (for all $y$ bins) used in a NLO QCD fit

ATLAS
\[
\int L \, dt = 0.20 \, \text{pb}^{-1}
\]
\[
\rho = \frac{\sigma_{\text{jet}}^{2.76 \text{TeV}}}{\sigma_{\text{jet}}^{7 \text{TeV}}}
\]

-data with statistical uncertainty
-systematic uncertainties
-NLO pQCD with non-pert. corrections

More on Jet measurements (and alphas) in the next talk
Potential of elastic J/psi data on low x gluon

- A fit to HERA and LHCb elastic photon(electron)-production accesses gluon at low x

J/psi data diminish the huge uncertainty on global gluons at low scale & small-x

Issues
- Considerable scale uncertainty remains
- Not a complete NLO analysis (but main kinematic effects included)
- Can not directly identify extracted gluon with e.g. $\overline{MS}$ partons

Future
- Work under way to include NLO gluon diagrams and quark coupling
  [ Ivanov et al. 2004 ]
News from MSTW PDF group

  - similar with MSTW08 but with param. extension and change in deuterium corrections

A not totally insignificant change in the high-\(x\) gluon luminosity for the MSTWCPdeut set. Due to softer \(d_y\)

Ongoing further updates in MSTW framework (reweighing method tested against real fit for impact)
- inclusion of combined HERA I data, HERA F2 charm data
- inclusion of newer Tevatron DO electron asymmetry, CDF W asymmetry
- inclusion of most relevant LHC data:
  - observe the enhanced strange with WZ inclusive data
    *change in BR=0.099 -> 0.080 can yield a good fit to both NuTeV dimuon data and LHC WZ
  - inclusive and dijet data is well fit, confirm the impact on gluon PDF
News from ABM PDF group

- ABM groups has included more data as well, and studied the impact of the LHC data:

- \( t \)-pair production has been analysed and – the running-mass definition provides better description of data as compared to the pole mass case
  - The change in gluon is \( \sim 1 \sigma \)
News from JR group

◆ Strategy is to get the most from all pre-LHC data, inclusion of LHC data foreseen next year.
  ▶ Inclusion of HERA I combined data, and the all available low Q2 data (requires then corrections)
  ▶ extended parametrisation to 44 free parameters
  ▶ Choice of input scale (dynamic vs standard) affects alphas value, but gluon at high x is stable.

- Preliminary results mostly consistent with JR09
News from CT PDF group

- New studies on intrinsic charm (IC) with various model being investigated:
  
  1/ CT10 NNLO = no intrinsic charm
  2/ The BHPS Model = “valence-like” intrinsic charm
  3/ The Sea Model – “sea-like” intrinsic charm

Remarks:
IC is not necessary to fit global data, but data does not rule out the IC model. There is dependence on the choice of mc:
- 1.6 GeV enhances the effect

- CT addresses the issues related to PDF uncertainty of the Higgs Production Cross Section at the LHC:
  - Preferred method is the Lagrange Multiplier method, but Hessian method provides similar results.
Searching for intrinsic charm and strangeness at LHC

Intrinsic charm and strangeness contributions would be enhanced at high-x

Can be studied at LHC:
- open charm and strangeness production at high $p_T$
- $\gamma, W/Z$ production in association with c and b jet
- rapidity and $p_T$ distributions of photons and vector bosons
Higgs production in association with a jet

New results for Higgs+jet at NNLO (gg-channel, quark channels in progress)

\[ \mu = m_H \]

\[ \sigma_{\text{LO}}(pp \rightarrow Hj) = 2713^{+1216}_{-776} \text{ fb}, \]
\[ \sigma_{\text{NLO}}(pp \rightarrow Hj) = 4377^{+760}_{-738} \text{ fb}, \]
\[ \sigma_{\text{NNLO}}(pp \rightarrow Hj) = 6177^{+204}_{-242} \text{ fb}. \]

\[ \frac{\sigma_{\text{NLO}}}{\sigma_{\text{LO}}} = 1.6 \]
\[ \frac{\sigma_{\text{NNLO}}}{\sigma_{\text{NLO}}} = 1.3 \]

- Significant reduction of scale dependence from 50% at LO to 20% at NLO to less than 5% at NNLO.

Pedro Jimenez-Delgado

*QCD@LHC 2013, DESY Hamburg, 4 September 2013*
Higgs production in gluon fusion at approximate N3LO

predicting the inclusive Higgs N^3LO cross section using

\[ C_{gg}^{(3)}(z) \simeq C_{\text{soft}}^{(3)}(z) + C_{\text{high-energy}}^{(3)}(z), \]

find \( m_H = 125 \text{ GeV}, \text{ LHC at 8 TeV} \)

an increase of \( \sim 17\% \) wrt the NNLO cross section

stabilization of scale dependence (at low scales)
Summary and outlook

- A plenty of new precision measurements from DIS and DY experiments:
  - Awaiting for final HERA combined measurements
  - JLAB addresses the high x physics with a series of new measurements
  - Standard Model LHC measurements can add PDF discrimination and PDF improvement:
    - W, Z inclusive: light quark sea is flavour symmetric:
      - Confirmed by preliminary W+c and most of PDF groups
      - High mass DY: potential feedback on dbar-ubar, importance of EW corrections
    - Exploiting different energy beams for inclusive jets brings forward sensitivity to the gluon PDFs.
    - J/psi data shows potential in constraining gluon at very low x

- PDF groups are active and eager to include new avalanche of data and address remaining theoretical differences.

- Even Higher order calculations (NNLO and N3LO) are becoming available for the Higgs Cross section

- More precision measurements from LHC are to come also with 2012 data:
  - W, Z, W+c production, low invariant mass, top, W,Z+ c,b, W,Z+jets, ...

MANY THANKS TO ALL SPEAKERS AND PARTICIPANTS FOR LIVELY SESSIONS
(apologies for uncovered topics)
Back up slides

Not necessarily useful
Impact of jet measurements on alphas

- Determination of alphas from ratio of events with ≥3 jets to ≥2 jets ratio of 2010 data: [ATLAS-CONF-2013-041]
  - Two observables were used: \( R_{3/2} \) (in lead pt), \( N_{3/2} \) (all pt)
    \[
    \alpha_s(M_Z) = 0.111 \pm 0.006 \text{(exp.)}^{+0.016}_{-0.003} \text{(theory)}
    \]
    Improvements are possible on experimental aspects of the determination of \( \alpha_s \):
    - Results using full 2012 dataset are coming soon
    - NNLO predictions for jets are needed

- From CMS:
  \[
  \alpha_s(M_Z) = 0.1148 \pm 0.0014 \text{(exp.)} \pm 0.0018 \text{(PDF)}^{+0.0050}_{-0.0060} \text{(scale)}
  \]
  - All LHC-era results are consistent with the current world average from the Particle Data Group, \( \alpha_s(M_Z) = 0.1184 \pm 0.0007 \)

<table>
<thead>
<tr>
<th>( \alpha_s(M_Z) )</th>
<th>ATLAS ( N_{3/2} ), 2010</th>
<th>CMS ( R_{3/2} ), 2011</th>
<th>CMS top quark, 2011</th>
<th>CMS 3-jet mass, 2011</th>
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<tr>
<td></td>
<td>0.111 +0.017 -0.007</td>
<td>0.1148 +0.0055 -0.0023</td>
<td>0.1151 +0.0033 -0.0032</td>
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