Progress in the dynamical parton distributions

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XX International Workshop on Deep-Inelastic Scattering and Related Subjects
JR (dynamical) parton distribution functions

The dynamical approach to parton distributions

Typical/selected results from JR09

Determination of the strange sea distribution

Experimental correlations and $\chi^2$ definition

Further improvements and very preliminary results

Low $Q^2/W^2$ data and higher-twist
Brief history of the dynamical PDFs

Dynamical assumption [Altarelli, Cabibbo, Maiani, Petronzio 74], [Parisi, Petronzio 76], [Novikov 76], [Glück, Reya 77] in connexion with the constituent quark model: only valence quarks

First dynamical determination of parton distributions [Glück, Reya 77]

Used in the 80’s: e.g. for the discovery of W and Z bosons (SPS, CERN)

Extended to include light sea [Glück, Reya, Vogt 90] and gluon [Glück, Reya, Vogt 92] valence-like input —→ steep gluon and sea at small-x!!

Confirmed by first HERA $F_2(x, Q^2)$ data [H1, ZEUS 93]

GRV95 and GRV98 contributed greatly in the 90’s and beginning of the 00’s

Improved generation (GJR08, JR09): new data, NNLO, error analysis, FFNS+VFNS ...
Global QCD analysis and data

Determination of non-perturbative information: input distributions \(f(x, Q^2_0)\)

Experimental information + pQCD theory (RGE + cross sections) +
parametrizations (Least Squares and Hessian methods)

Light quarks + gluon: \(f = u, d, s, \bar{u}, \bar{d}, \bar{s}\) and \(g\) (no need for heavy-quark PDFs)

FFNS for DIS and VFNS for hadron colliders (no need for GMVFNS’s)

Selected data in (G)JR global analyses:

DIS structure functions (most relevant)

Drell-Yan (pp + pn) muon pair production instrumental for \(\bar{d} \neq \bar{u}\)

Jets from Tevatron (up to NLO)

Not very sensitive to strange PDFs

\(\Rightarrow\) input assumptions \(s = \bar{s} (= 0,\) discussed later\)

Other data (e.g. \(\nu\) DIS, W asym., DIS jets, ...) provide only complementary information
The dynamical approach

Typical polynomial parametrization: \( xf(x, Q_0^2) = N x^a (1 - x)^b (1 + A \sqrt{x} + Bx) \)

Since we are free to (and have to) select an input scale for the RGE:

At low-enough \( Q^2 \) only “valence” partons would be “resolved”

\( \Rightarrow \) structure at higher \( Q^2 \) appears radiatively (i.e. due to QCD dynamics)

**DYNAMICAL:**

\( Q_0^2 < 1 \text{ GeV}^2 \) optimally determined

\( a > 0 \) “valence-like”

QCD “predictions” for small-\( x \)

More predictive, less uncertainties

**“STANDARD”:**

\( Q_0^2 = 2 \text{ GeV}^2 \) arbitrarily fixed

Fine tuning to particular data (\( g < 0! \))

Extrapolations to “unmeasured” regions

More adaptable, marginally smaller \( \chi^2 \)

*There are NO EXTRA CONSTRAINTS involved in the dynamical approach!*

Physical motivation for the CC of the RGE \( \neq \) NP structure of the nucleon
The dynamical approach: an illustration

“standard” GJR08 NLO input with $a_g \pm 0.05$ at $Q_0^2 = 2$ GeV$^2$
The dynamical approach: an illustration

dynamical GJR08 NLO input with $a_g \pm 0.05$ at $Q_0^2 = 0.5$ GeV$^2$
The dynamical approach: an illustration

... resulting “standard” distributions at $Q^2 = M_W^2$
... resulting dynamical distributions at $Q^2 = M_W^2$
Results more constrained as $Q^2$ increase due to pQCD evolution
larger “evolution distance” + valence-like input
$\implies$ less uncertainties and steeper gluons (correspondingly smaller $\alpha_s$)

Fine tuning marginal (e.g. for DIS at NNLO $\chi^2_{dyn} = 0.90$ comparable to $\chi^2_{std} = 0.87$)
Typical dynamical vs “standard” results: $\alpha_s$

We determine $\alpha_s(M_Z^2)$ together with the distributions:

<table>
<thead>
<tr>
<th></th>
<th>dynamical</th>
<th>“standard”</th>
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</thead>
<tbody>
<tr>
<td>NNLO</td>
<td>0.1124 ± 0.0020</td>
<td>0.1158 ± 0.0035</td>
</tr>
<tr>
<td>NLO</td>
<td>0.1145 ± 0.0018</td>
<td>0.1178 ± 0.0021</td>
</tr>
<tr>
<td>LO</td>
<td>0.1263 ± 0.0015</td>
<td>0.1339 ± 0.0030</td>
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</tbody>
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Dynamical “constraints” reduce the uncertainty! (in particular at NNLO)
Dynamical results are smaller: larger “evolution distance” ($Q_0^2 < 1\text{GeV}^2$)
Differences should be interpreted as uncertainties (see later)
Typical dynamical vs “standard” results: $F_L$

Positive and in complete agreement with measurements
Greater precision achieved within the dynamical framework
Other results less precise and even turning negative at the lower $Q^2$ values
NNLO benchmarks for Higgs production

Considering the different NNLO results $\approx 10 - 20\%$ accuracy at LHC

Differences due to $\alpha_s(M_Z^2)$ and gluon distributions, largely understood
Results from different groups agree within experimental uncertainty

Considering results from different groups accuracy better than \( \approx 10\% \) at LHC

Starting point for further improvements \( \rightarrow \) explain and reduce differences
Determination in the strange sea distribution

Dynamical strange sea generated from \( s(x, Q_0^2) + \bar{s}(x, Q_0^2) = 0 \)

However other groups have larger strange distributions.

Example at \( Q^2 = M_W^2 \)

Ansatz in agreement with current dimuon production data at NLO
Dimuon production

Signature: Two muons of different sign

Directly related to charged current charm production $\propto s(x, Q^2)$ (FFNS)

Sensitive to differences between $s$ and $\bar{s}$

Overall normalization proportional to $B_c$

Acceptance corrections [Kretzer et al.] at NLO

Nuclear corrections (iron) using FFNS NLO GRV98 [de Florian et al.]
The NuTeV dimuon data

Already well described by GJR08: $\chi^2 = 65$ for 90 data points (1σ)

$\Rightarrow$ radiatively generated strangeness plausible: $s(x, Q^2_0) + \bar{s}(x, Q^2_0) = 0$

Introducing an asymmetry $\chi^2$ goes down to 60: $s(x, Q^2_0) - \bar{s}(x, Q^2_0) \neq 0$

However at NNLO the “would-be-predictions” fall below the data by more than the expected size of the corrections
Improvements in the strange sea

From dimuon production data \( \bar{s}(x, Q_0^2) \approx 0.1 [\bar{u}(x, Q_0^2) + \bar{d}(x, Q_0^2)] \)

“input” variant: \( \bar{s}(x, Q_0^2) = 0.25 [\bar{u}(x, Q_0^2) + \bar{d}(x, Q_0^2)] \) (as in our “standard” fits)

Larger input strange sea “compensated” by the other sea distributions

In fact the vector boson production rates remain practically unaffected
Experimental correlations and $\chi^2$ definition

Method of Least Squares including correlated systematic uncertainties:

$$\chi^2_{\text{set}} = \sum_{i=1}^{N} \frac{1}{\Delta_i} \left(n_o d_i + \sum_{j=1}^{M} r_j \Delta_{ji} - t_i\right)^2 + \left(\frac{n_o - 1}{n}\right)^2 + \sum_{j=1}^{M} r_j^2$$

The optimal shifts for a given theory can be determined analytically

$$n_o = 1 + r_o n, \quad r_j = -\sum_{k=0}^{M} A_{jk}^{-1} B_k$$

All correlations included: SLAC, BCDMS, E665, NMC, HERA, E866

JR09:
correlated errors added in quadrature to the uncorrelated ones
normalization uncertainties: numerically and variation limited to $\pm 1\sigma$
Effects of the treatment of normalization uncertainties

Exercise: repeat the JR09 analysis with alternative treatment of normalizations

Slight rearrangement of all distributions:
  decrease in the gluon and sea distributions at small-$x$
  shifts in the valence distributions
Effects of the treatment of normalization uncertainties

Exercise: repeat the JR09 analysis with alternative treatment of normalizations

Relevant changes at the level of 10% for $Q^2 = M_W^2$

decrease in the gluon and sea distributions at small-$x$
shifts in the valence distributions
Further improvements

Significant changes in DIS data:

From 30 points on p/n ratios to an equal-footing treatment of FT p and d

\( F_2 \) replaced for \( \sigma \) for SLAC and NMC \([\text{ABM 2010}]\)

Switched to HERA combined data and included CC

We (always) include the NC HERA data which need \( Z \) contributions (no cuts)

The Drell-Yan E866 pp and pd CS need normalization shifts of about 20%
⇒ temporarily removed (need more care)

Theory improvements:

Nuclear corrections for deuteron data included \([\text{CTEQ-JLab Coll. 2010}]\)

Switched to \( \overline{\text{MS}} \) scheme for masses in HQ contributions (also some corrections beyond NNLO)

Slight changes in the parametrization (one more parameter for \( u_v \) and \( g \), one less for \( \bar{d} - \bar{u} \))

Alternative parametrizations extensively studied (again), no better option found
Very preliminary results: distributions

Accumulation of discussed effects plus some new (smaller) changes

In summary: movement at the level of 10%, but too early to draw conclusions
We will revise our standard candles benchmarks only after finishing all studies
**Very preliminary results: $\alpha_s$**

Parametrization bias (a lower limit) can be estimated by comparing dyn/Std results

Very stable results: variation with $Q_o^2$ smaller than in JR09

$\alpha_s(M_Z^2)$ between 0.113 and 0.114, very good agreement with JR09 and ABM

Very preliminarily we estimate $\Delta\alpha_s(M_Z^2) \simeq 0.001$ due to parametrization bias (in addition to the usual theoretical and experimental errors)
Very preliminary results: $\alpha_s$

Optimal dynamical input scale $Q_o^2 \simeq 0.6$ GeV$^2$, very similar to JR09

Consistent with results from other groups: HERA tends to lower values and SLAC to higher ones
Open issues: Low $Q^2/W^2$ data and higher-twist

We have (always) included TMC for $F_2$, but not higher-twist terms

$\rightarrow$ cuts at $Q^2 \geq 4 \text{ GeV}^2$, $W^2 \geq 10 \text{ GeV}^2$

Nevertheless $\chi^2$ is reduced by including twist-4 contributions

Moreover one gains a lot of information (from about 2000 points to about 3000) by lowering the cuts: $Q^2 \geq 3 \text{ GeV}^2$, $W^2 \geq 3 \text{ GeV}^2$

Inclusion of low $Q^2/W^2$ JLab data on $F_2$ and $F_L$ (or $\sigma$) is also planned

A first very simple attempt:

$$F_2 = F_2^{LT} \left( 1 + \frac{C(x)}{Q^2} \right), \quad C(x) = Nx^a(1 + bx); \quad F_L^{HT} = N \frac{F_2}{Q^2}$$

$\Rightarrow$ good $\chi^2$, PDFs do not change very much, lower $\alpha_s(M_Z^2)$

OK, but too many unjustified assumptions

We believe that a more careful treatment is needed: working on it ...
Conclusions and outlook

The dynamical model is a well-established approach to parton distributions:

- supported by all current data
- greater predictive power in the small-x region

(\textit{more constrained without additional constraints!})

Last (G)JR generation of dynamical PDFs is already available and in use.

Several improvements and upgrades are currently under way.

Preliminary changes in PDFs at the 10\% level or less.

Parametrization bias estimated by variations of $Q^2_\circ \Rightarrow$ rather stable results

$\alpha_s(M^2_Z)$ between 0.113 and 0.114, very good agreement with JR09 and ABM.

Additional $\Delta \alpha_s(M^2_Z) \simeq 0.001$ due to parametrization bias.

Optimal dynamical input scale $Q^2_\circ \simeq 0.6 \text{ GeV}^2$, very similar to JR09.

Final results and predictions for physical observables are still to come, but we do not expect dramatic changes.