Dynamical parton distributions
and Weak Gauge and Higgs Boson Production
at Hadron Colliders at NNLO of QCD

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ICHEP 2010

University of Zurich

Dynamical parton distributions

and Weak Gauge and Higgs Boson Production

at Hadron Colliders at NNLO of QCD

The dynamical approach

Global NNLO analysis and the determination of $\alpha_s(M_Z^2)$

The longitudinal structure function

The treatment of heavy quarks

Weak-gauge and Higgs boson production at hadron colliders

The dynamical approach

Idea: at low-enough Q^2 only "valence" partons would be "resolved"

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

DYNAMICAL:

$Q_0^2 < 1\,\text{GeV}^2$ optimally **determined**

$\mathbf{a} > 0$ *"valence-like"*

"STANDARD":

$Q_0^2 = 2\,\text{GeV}^2$ arbitrarily **fixed**

Unrestricted parameters

$$xf(x, Q_0^2) = N x^{\mathbf{a}} (1-x)^b (1 + A\sqrt{x} + Bx)$$

Positive definite input distributions

QCD **predictions** for $x \lesssim 10^{-2}$

More restrictive, **less uncertainties**

Arbitrary fine tunning ($g < 0!$)

Extrapolations to unmeasured region

Less restrictive, *marginally* smaller χ^2

Physical aid for determining **CC for DGLAP $\neq$ NP structure** of the nucleon

Brief history of the dynamical distributions

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

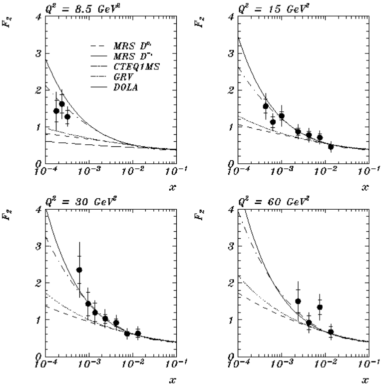
First dynamical determination of parton distributions [Glück, Reya 77]

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**
$\longrightarrow$ **steep gluon and sea at small-x!!**

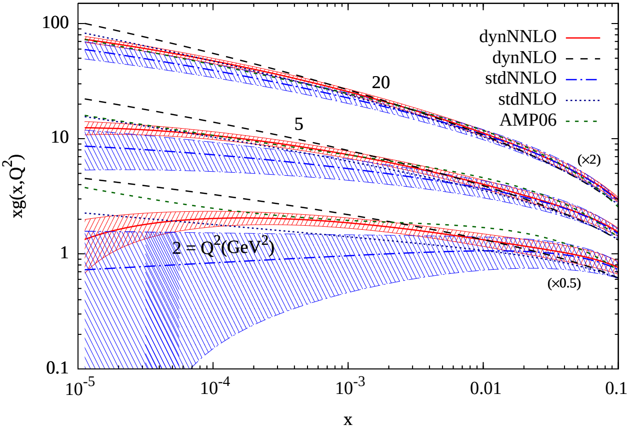
Confirmed by first HERA $F_2(x, Q^2)$ data [H1, ZEUS 93]

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



New improved generation (GJR08, JR09):
$\overline{\text{MS}}$ + DIS factorization schemes, NNLO, error analysis, FFNS+VFNS, **new data**

Dynamical vs standard distributions: gluon



Uncertainties decrease as Q^2 increase: *pQCD evolution*

Valence-like input, i.e., *larger "evolution* distance" ⇒ **less uncertainties**

Q_0^2 also play another role ⇒ standard gluons fall below dynamical

Smaller effect for the sea: rather flat dynamical input

Global NNLO analysis

Only DIS (1178) and DY (390) data included at NNLO for **consistency**

Drell-Yan data instrumental in fixing non-singlet distributions ($u_v, d_v, \bar{d} - \bar{u}$)

Excellent agreement with data:

dynamical: $\chi^2_{\text{DIS}} = 0.90$

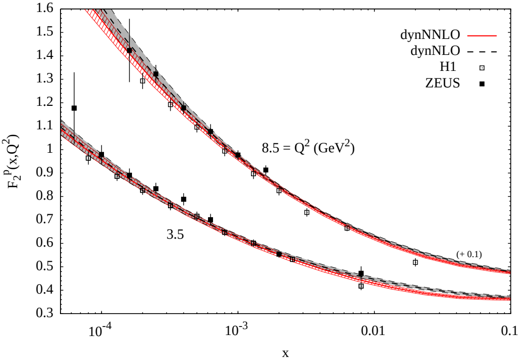
"standard": $\chi^2_{\text{DIS}} = 0.87$

(fine tunning marginal)

NNLO effects small (few %):

$$\chi^2_{\text{NNLO}} \simeq 0.9 \chi^2_{\text{NLO}}$$

with (not much) reduced errors



Other effects (*QED*, factorization schemes, ...) comparable

Determination of $\alpha_s(M_Z^2)$

Consistent determination *together with the distributions*

General *agreement* but DIS-dominated fits usually yield smaller values

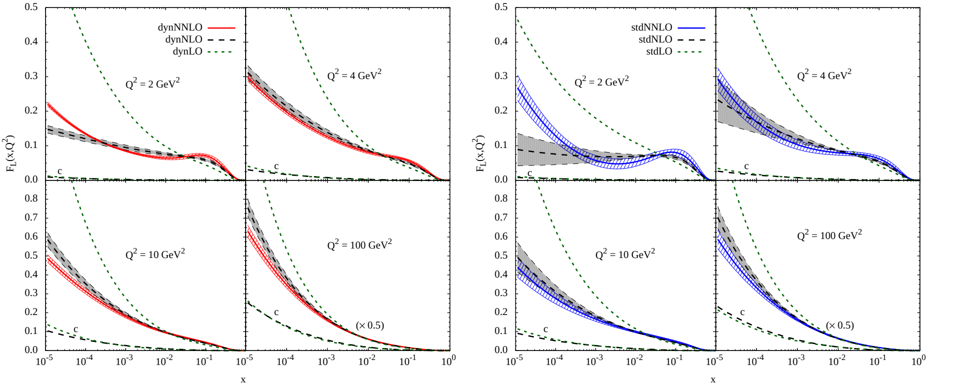
	dynamical	**"standard"**
NNLO	0.1124 ± 0.0020	0.1158 ± 0.0035
NLO	0.1145 ± 0.0018	0.1178 ± 0.0021
LO	0.1263 ± 0.0015	0.1339 ± 0.0030

Dynamical constraints reduce the uncertainty! (in particular at NNLO)

Dynamical results are smaller: larger "evolution distance" ($Q_0^2 < 1\,\text{GeV}^2$)

Other groups are either close to the dynamical or to the "standard" results

The perturbative stability of F_L



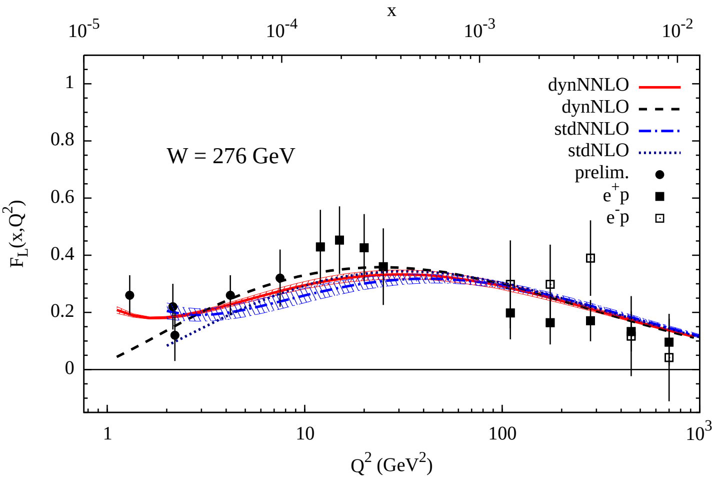
Observed [M(R)ST(W)] instabilities *unphysical*: **artefact** of negative gluons

Both dynamical *and* standard results manifestly **positive** at all orders

Dynamical predictions **stable** already at $Q^2 \gtrsim 2\ \mathrm{GeV}^2$

Standard differ more but less distinguishable due to the **larger error bands**

Confronting results with data



[H1 2001+2003]

Preliminary data:
[Lobodzinska 2004]
[Lastovicka 2004]

New data compatible

Positive and in complete **agreement** with measurements

Dynamical predictions more tightly constrained

Higher-twist effects may contribute for $Q^2 \leq 2$ GeV^2

Heavy-quark contributions: FFNS

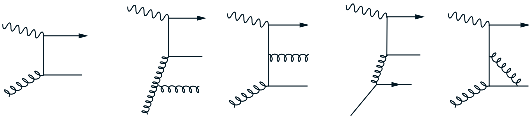
HQ generated in hard collisions: not collinearlly, short “lifetime” ($\neq$ parton)

Experiment: **No intrinsic heavy-quark** (c,b,t) content in the nucleon

FFNS $\equiv$ **FOPT** initiated by gluons and light (u,d,s) quarks

$\longrightarrow$ **final state** $\equiv$ **extrinsic heavy-quark** content

HQ contributions to DIS:



$$F^h_{k=2,L}(x,Q^2,m^2) = \frac{Q^2\alpha_s(\mu^2)}{4\pi^2 m^2}\int_x^{\frac{Q^2}{Q^2+4m^2}} \frac{dz}{z}\Big\{ e_h^2\, c^{(0)}_{k,g}(\eta,\xi)\, g\big(\tfrac{x}{z},\mu^2\big) + 4\pi\alpha_s(\mu^2)\Big[e_h^2\Big(c^{(1)}_{k,g}(\eta,\xi)+\bar{c}^{(1)}_{k,g}(\eta,\xi)\ln\frac{\mu^2}{m^2}\Big) g\big(\tfrac{x}{z},\mu^2\big) + \sum_q \Big(e_h^2\Big(c^{(1)}_{k,q}(\eta,\xi)+\bar{c}^{(1)}_{k,q}(\eta,\xi)\ln\frac{\mu^2}{m^2}\Big) q\big(\tfrac{x}{z},\mu^2\big) + e_q^2\Big(d^{(1)}_{k,q}(\eta,\xi)+\bar{d}^{(1)}_{k,q}(\eta,\xi)\ln\frac{\mu^2}{m^2}\Big) q\big(\tfrac{x}{z},\mu^2\big)\Big)\Big]\Big\},$$

$\ln\frac{\mu^2}{m^2}$ are **not (mass) divergences**: **FFNS gets trough *all* “stability tests”!!**

Only **drawback**: calculational difficulty

Effective heavy-quark PDFs: VFNS

Idea: Resum (RGE) the $\ln \frac{\mu^2}{m^2}$ *to gain calculational power*

Asymptotically ($Q^2 \gg m^2$):

$$H\left(\frac{Q^2}{\mu^2}, \frac{\mu^2}{m^2}\right) \longrightarrow A\left(\frac{\mu^2}{m^2}\right) \otimes C\left(\frac{Q^2}{\mu^2}\right)$$

A's=massive OME's, **process independent!!**

C's=light-parton coefficient functions

Light-parton PDFs $\xrightarrow{A\text{'s}}$ effective HQ-PDFs

assumed to be correct **asymptotically**

Ressumation of **final-state** contributions

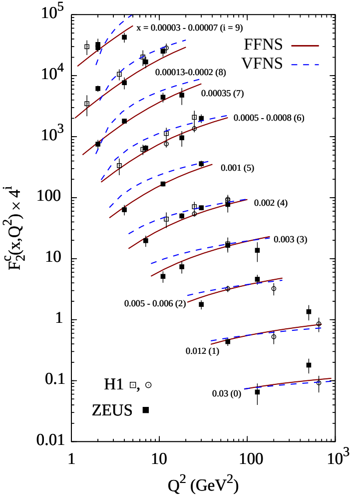
($\neq$ intrinsic heavy-quark content)

In practice: **massless evolution** increasing n_f

at unphysical "thresholds" $\mu^2 \simeq m^2$ (not $\hat{s} \gtrsim 4m^2$)

Input determined always in the FFNS!!

(most data in threshold region)



VFNS HQ-PDFs generated **from FFNS preserving universality**

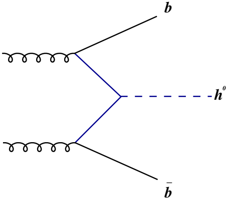
FFNS vs VFNS: Examples

VFNS reliable for large invariant mass of the produced system: $W^2 \gg m^2$

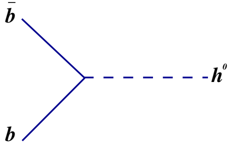
$\longrightarrow$ *non-relativistic* ($\beta_h \lesssim 0.9$) *threshold effects supressed*

Example: Higgs produced in $b\bar{b}$ fusion: $\frac{W_{\text{th}}}{m_b} = \frac{2m_b + m_H}{m_b} \simeq \frac{M_H}{m_b} \gg 1$

FFNS: $g\,g \to b\,\bar{b}\,H$



VFNS: $b\,\bar{b} \to H$



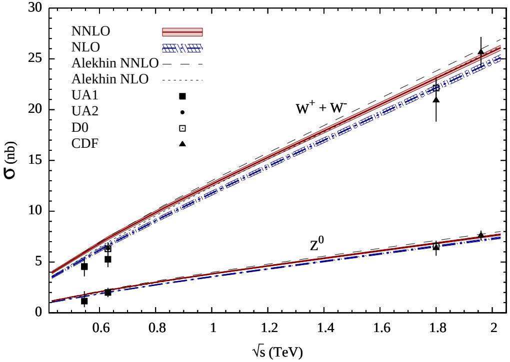
Uncertainties from choices of factorization scheme typically **important!**

Example: $W^{\pm}$ production at *LHC*:

$$\sigma^{\text{NLO}} = \begin{cases} 186.5 \pm 4.9_{\text{pdf}} \, {}^{+4.8}_{-5.5}\,|_{\text{scale}} \text{ nb} & \text{(VFNS)} \\ 192.7 \pm 4.7_{\text{pdf}} \, {}^{+3.8}_{-4.8}\,|_{\text{scale}} \text{ nb} & \text{(FFNS)} \end{cases}$$

VFNS sufficiently reliable for LHC and Tevatron energies.

Weak gauge boson production rates



NNLO typically larger but stable; scale uncertainty greatly (%4) reduced

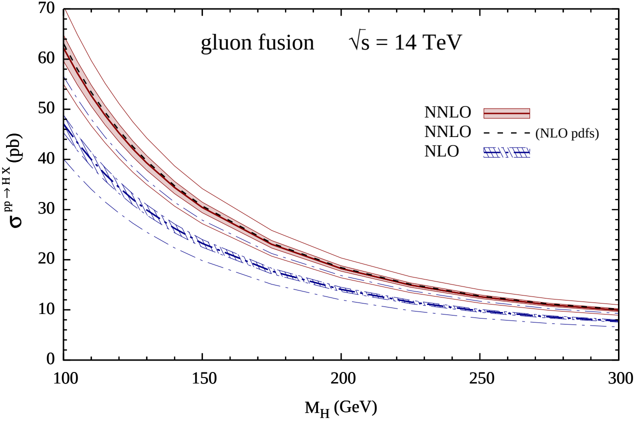
Results from different groups **within experimental uncertainty at Tevatron**

NNLO expectations for **LHC (≈ 5% accuracy)**:

$$\sigma^W = 190.2 \pm 5.6_{\text{pdf}}\ {}^{+1.6}_{-1.2}|_{\text{scale}}\ \text{nb}, \qquad \sigma^Z = 55.7 \pm 1.5_{\text{pdf}}\ {}^{+0.6}_{-0.3}|_{\text{scale}}\text{nb}$$

MSTW08 and ABKM09 some **5–10% higher at LHC**

Higgs boson production



NNLO rather (20%) larger than NLO but *total* uncertainty bands overlap

Not *very* dependent on PDFs. Similar (within 10%) to other groups

Total **accuracy at NNLO of about 10% at LHC**

Tevatron: *Similar* features although *uncertainty almost doubles*

Conclusions

New generation of **dynamical parton distributions** available up to NNLO

Dynamical approach: more **predictive** and **smaller uncertainties**

Consistent determination of $\alpha_s(M_Z^2)$ together with the distributions

Positive distributions and cross-sections (F_L) in **agreement with all data**

FFNS reliable: no need for “resummation” (heavy-quark distributions)

Effective (VFNS) “heavy” quark distributions **reliable** for **Tevatron** and **LHC**

Total accuracy at **LHC**: $\approx 5\%$ **for gauge-boson production rates**

$\approx 10\%$ **for Higgs production**

(Dis)agreement with ABKM09 and MSTW08 at the **level of 10%** at LHC