Dynamical
Parton Distribution Functions

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[with E. Reya and M. Glück]

PDF4LHC Meeting **CERN**

29 January 2010

technische universität
dortmund

f(p) fakultät physik

The dynamical approach to PDFs

- The dynamical/radiative model
- History of the dynamical distributions
- Treatment of heavy quark flavors
- Experimental input and global analysis
- Comparison with GRV98

Dynamical vs standard distributions

- Dynamical vs standard distributions: gluon
- Determination of $\alpha_s(M_Z^2)$
- Dynamical vs standard distributions: sea
- Extremely small-x: astrophysical relevance
- Comparison with other groups: CTEQ

The gluon distribution and F_L

- DIS "reduced" cross-section
- The perturbative stability of F_L
- Confronting results with data

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Very preliminary!: Lepton asymmetry and the new D0 data

The dynamical/radiative model

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****)*

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

DYNAMICAL:	**"STANDARD":**
$\mathbf{a} > 0$ *"valence"-like* 	*Unrestricted* parameters
$Q_0^2 < 1\,\mathrm{GeV}^2$ optimally *determined*	$Q_0^2 = 2\,\mathrm{GeV}^2$ arbitrarily *fixed*
Positive definite input distributions	Arbitrary fine tunning ($g < 0$!)
QCD *predictions* for $x \lesssim 10^{-2}$	*Extrapolations* to unmeasured region
More restrictive, *less uncertainties*	Less restrictive, *marginally smaller* χ^2

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

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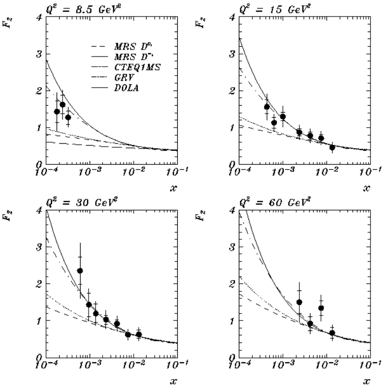
History of the dynamical distributions

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**

Treatment of heavy quark flavors

HQ generated in hard collisions, *not collinearlly*, short "lifetime" ($\neq$ parton)

FFNS ($\equiv$ **FOPT** initiated by gluons and light quarks) **experimentally required**

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

Only *drawback*: calculational difficulty$\rightarrow$ **Effective heavy-quark PDFs: VFNS**

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**

Our FFNS and VFNS share the (3-flavors) input at the low scale

No need for (**non-universal!**) interpolations: **GM-VFNS**

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Experimental input and global analysis

Selected **experiment**al information + **parametrizations** (BIAS)

Nucleon structure Functions

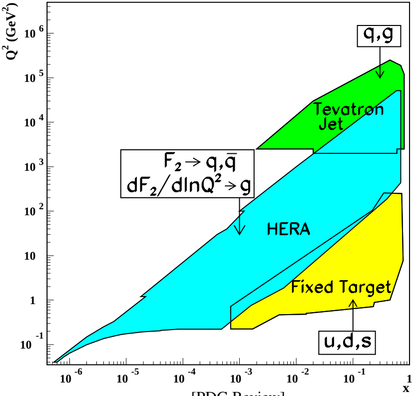
Drell-Yan pp + pn (or neutrino DIS) data needed for $\bar{d} \neq \bar{u}$

Jets from Tevatron (up to NLO)

Strange symmetric input $s \equiv \bar{s}$ (inclusion of νN *in preparation*)

Chi-square method:

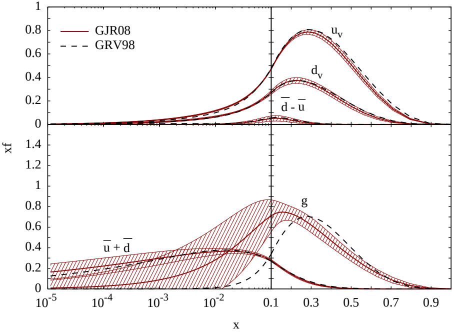
$$\chi^2(p) \equiv \sum_{i=1}^{N} \left(\frac{\text{data}(i) - \text{theory}(i,p)}{\text{error}(i)} \right)^2$$

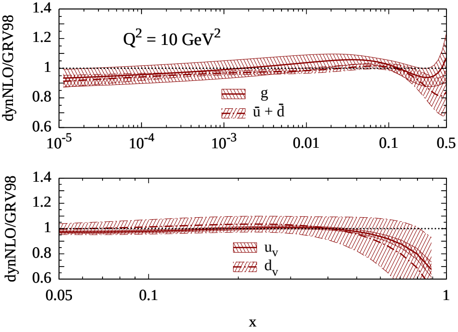


[PDG Review]

Propagation of **experimental** errors: *Hessian method* with **T$\simeq$5**

Comparison with GRV98





Very **similar** to the previous *dynamical* (input) distributios **GRV98** [up to NLO]

All quark distributions *within error* estimates [note the flat sea (for later)]

Similar gluon as well: peaks at slightly different x but within 2σ

Stable after evolution, less than 10−20% of “acceptable” (1σ) difference

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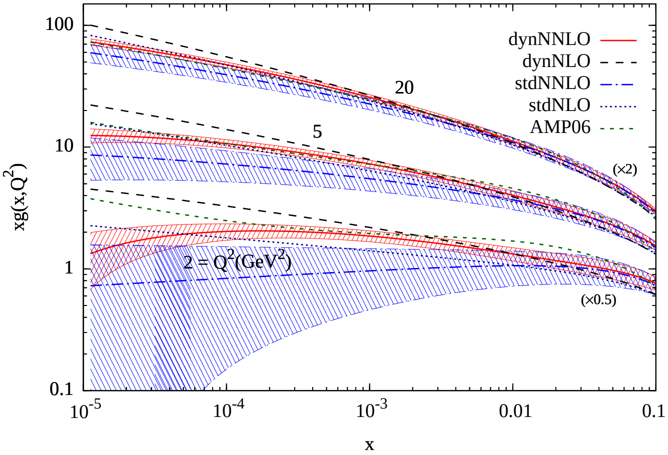
Dynamical vs standard distributions: gluon



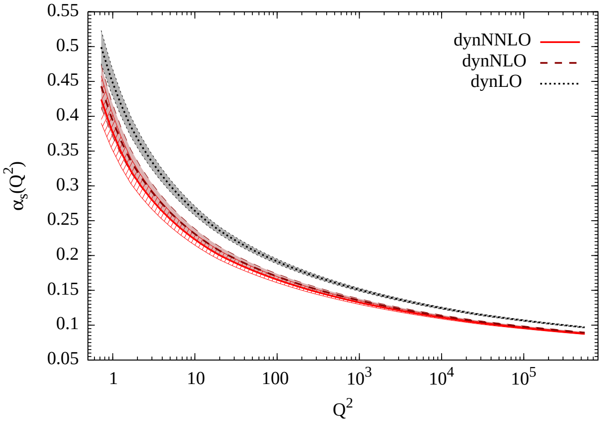
Uncertainties decrease as Q^2 increase: *pQCD evolution*

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

Determination of $\alpha_s(M_Z^2)$

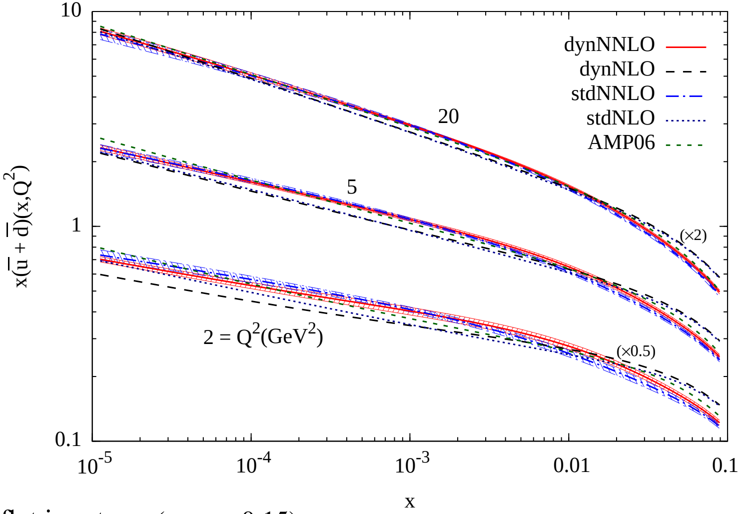
Only free parameter (besides masses) in *QCD*: *acceptable agreement*

However "dispersion" > uncertainties: global fits (*DIS*) yield smaller values



Our NNLO result: $\begin{cases} \text{dynamical: } 0.1124 \pm 0.0020 \\ \text{standard: } 0.1158 \pm 0.0035 \quad \textit{(larger error)} \end{cases}$

Dynamical vs standard distributions: sea

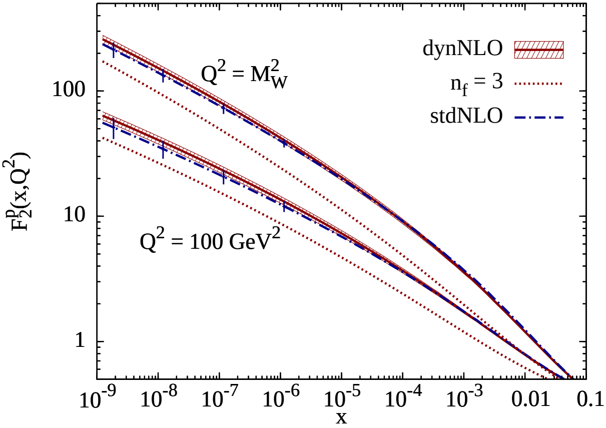


Rather flat input sea ($a_{\bar{u}+\bar{d}} \simeq 0.15$) $\Rightarrow$

equally increasing down to $x \simeq 10^{-2}$ $\Rightarrow$ **marginally smaller** errors

Extremely small-x: astrophysical relevance

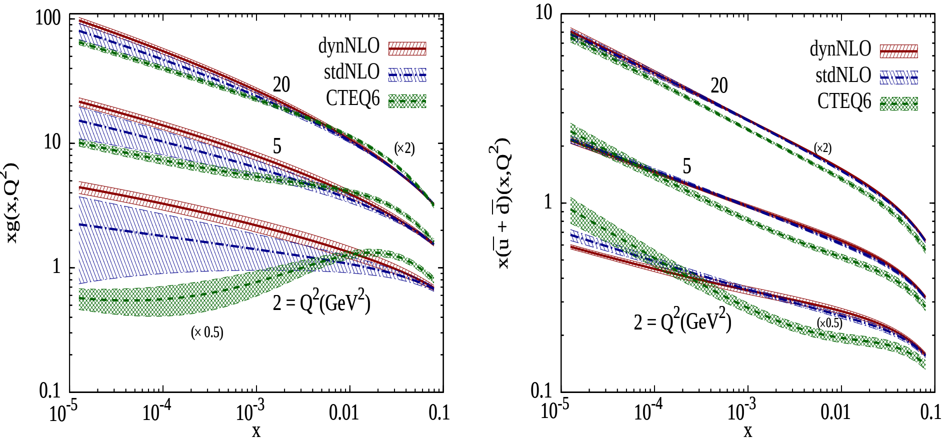
More sensible for astrophysics: ultrahigh energy ($E_\nu \simeq 10^{12}$GeV) ν-N scattering
$\longrightarrow$ **sea dominated** as F_2^p for small x



For $x \lesssim 10^{-2}$ parameter free dynamical predictions $\Rightarrow$ 10% accuracy

Uncertainties on the "standard" extrapolations are twice as large

Comparison with other groups: CTEQ



CTEQ6 has a **valence-like gluon** at $Q_0^2 = m_c^2 \simeq 1.7\,\mathrm{GeV}^2$!!

Q_0^2 also play another role $\Rightarrow$ standard gluons fall below dynamical

Non-valencelike sea $\Rightarrow$ larger uncertainties

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DIS "reduced" cross-section

$$\sigma_r^{NC} \equiv \left(\frac{2\pi\alpha^2}{xyQ^2} Y_+\right)^{-1} \frac{d^2\sigma^{NC}}{dx\,dy} = F_2^{NC} - \frac{y^2}{Y_+} F_L^{NC} \mp \frac{Y_-}{Y_+} x F_3^{NC}$$

Usually dominated by F_2^γ

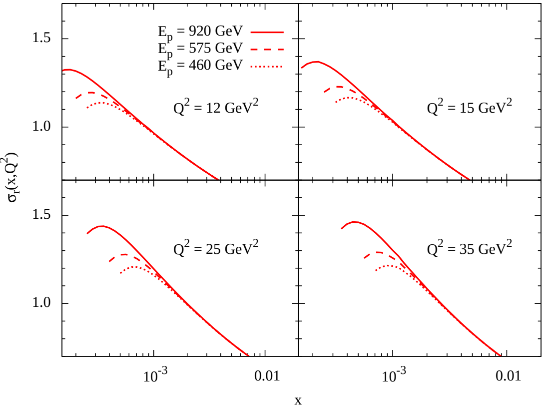
$$y = \frac{Q^2}{s}\frac{1}{x}$$

for fixed Q^2 (and s)

F_L relevant with increasing y

$\rightarrow$ *turnover* at small x

$\Rightarrow$ F_L **positive**



gluon dominated in the small-x region $\Rightarrow$ **positive gluon** (also beyond LO!)

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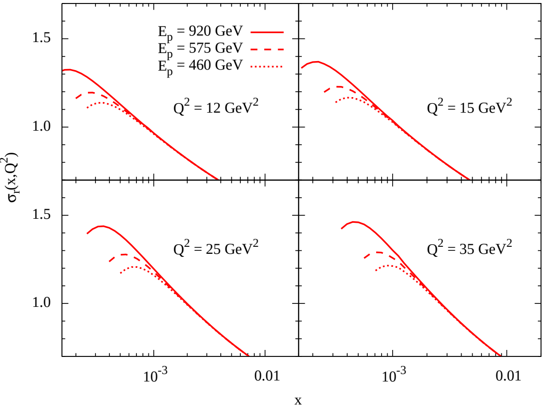

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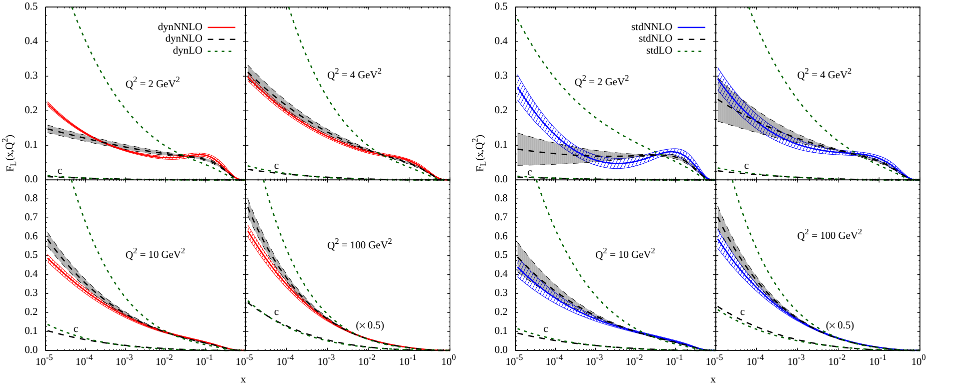
The perturbative stability of F_L



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

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

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

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

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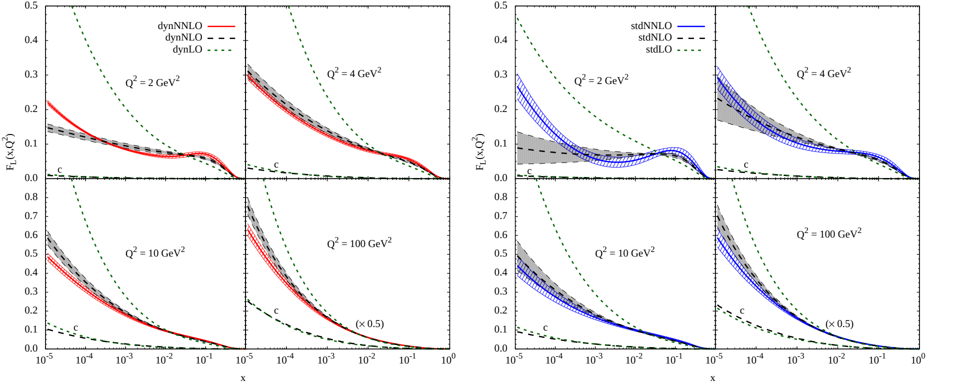

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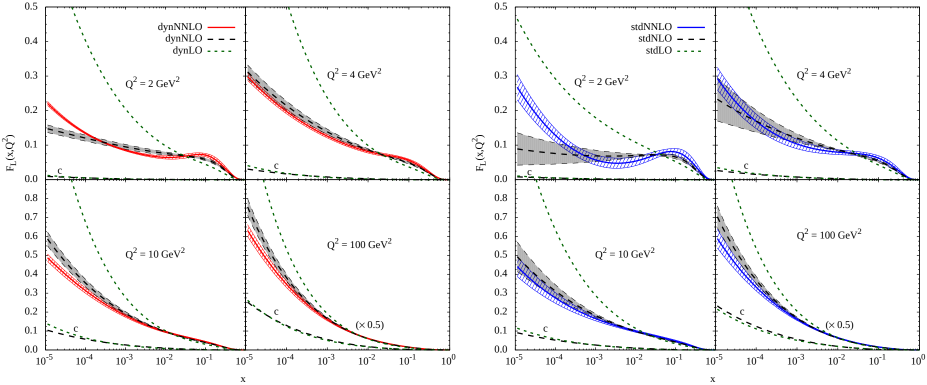

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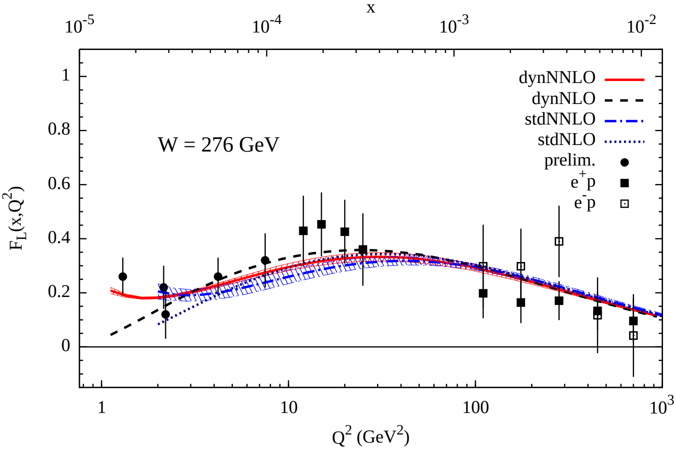
Confronting results with data



Positive and in complete **agreement** with measurements

Dynamical predictions more tightly constrained

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

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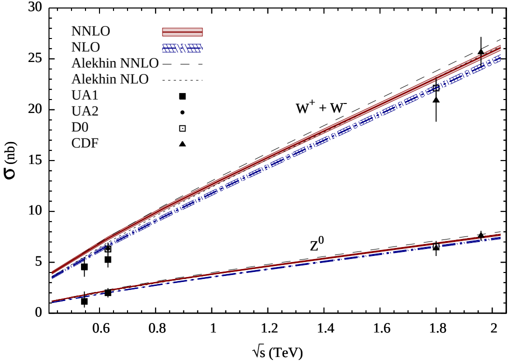


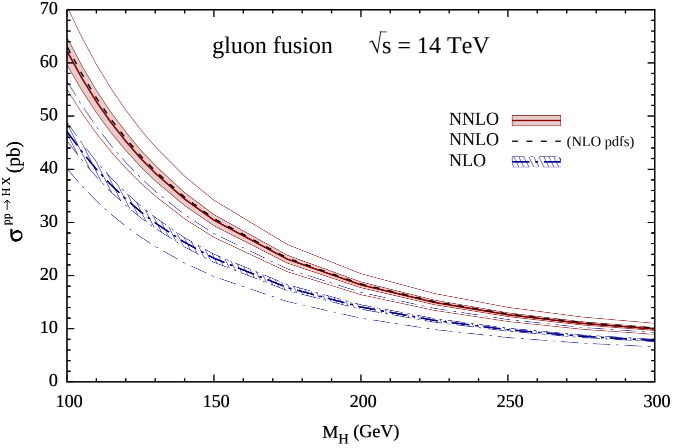
NNLO typically larger but stable; scale uncertainty greatly (%4) reduced

Results from different groups **within experimental** uncertainty

NNLO expectations for LHC (≈ 5% accuracy):

$$\sigma(pp \to W^+ + W^- + X) = 190.2 \pm 5.6_{\mathrm{pdf}}\ {}^{+1.6}_{-1.2}|_{\mathrm{scale}}\ nb$$
$$\sigma(pp \to Z^0 + X) = 55.7 \pm 1.5_{\mathrm{pdf}}\ {}^{+0.6}_{-0.3}|_{\mathrm{scale}}\ nb$$

Higgs boson production at LHC

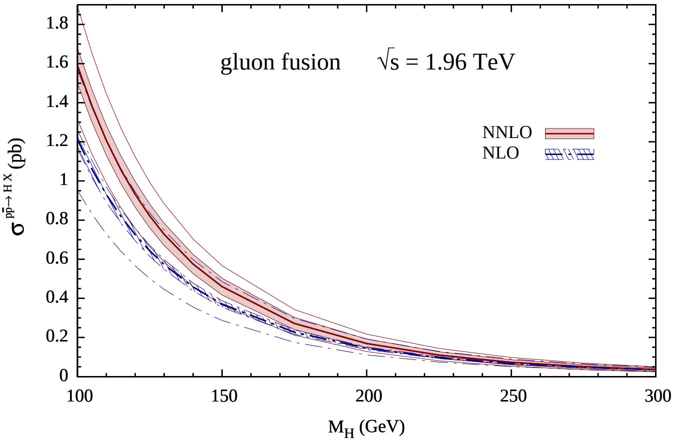


NNLO rather (20%) larger than NLO but *total* uncertainty bands overlap

Similar (within 10%) to other groups, not *very* dependent on PDFs

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

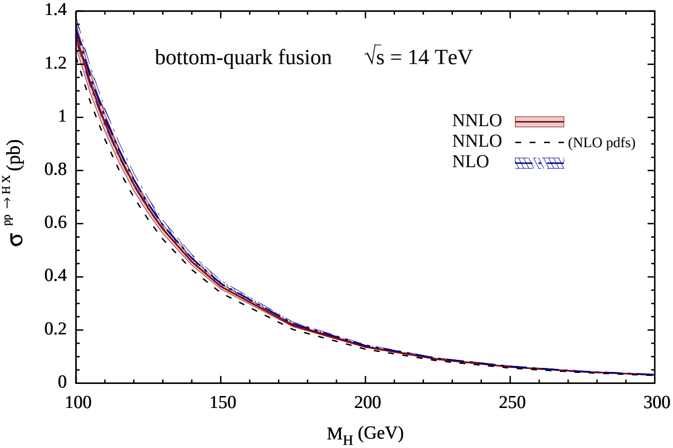
Higgs boson production at Tevatron



Similar features

Larger (%2) uncertainty bands

Higgs production via $b\bar{b}$ fusion



Subdominant contribution with rather *different* features:

marginal scale dependence (here the appropriate scale is $\frac{M_H}{4}$)

small K-factor: NLO/NNLO almost coincide

Correct choice of NNLO PDFs important

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D0 lepton asymmetry with MSTW2008

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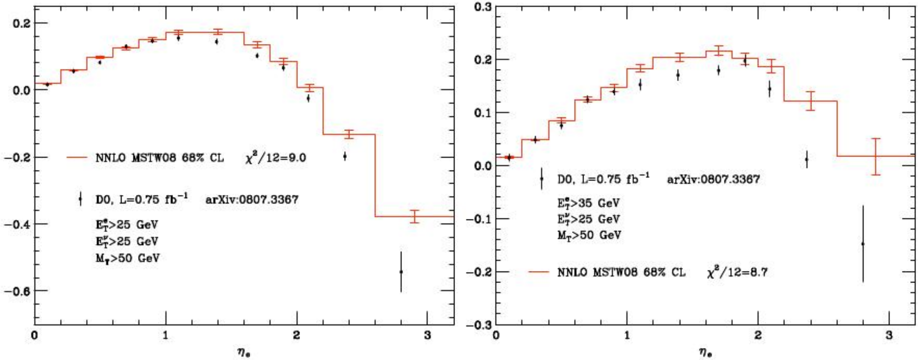

[M. Grazzini *et al.*]

D0 lepton asymmetry with ABKM09

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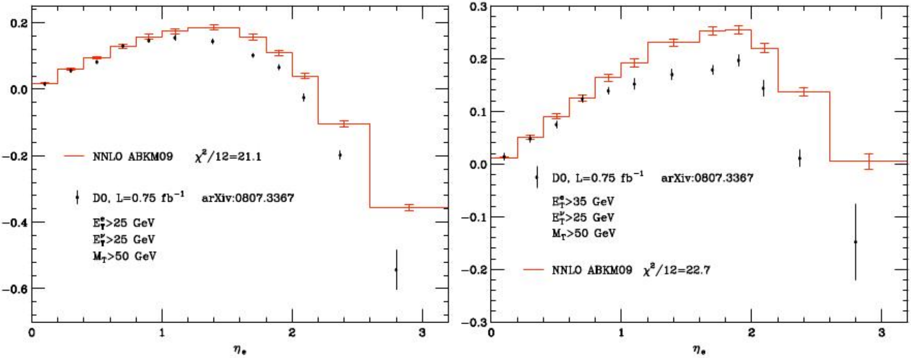

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D0 lepton asymmetry with JR09VFNS

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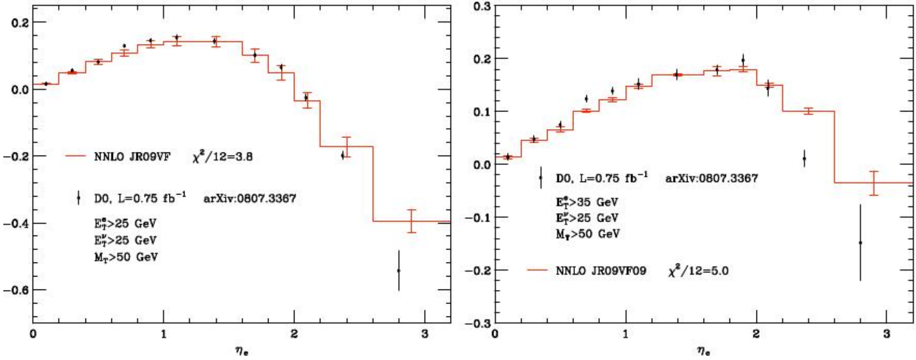

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The End

Dynamical LO and NLO PDFs **updated**: Compatible with **GRV98**

Analyses **extended**: new data, NNLO, errors ...

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

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

More reliable predictions for **small-x** (astro)**physics**

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**