

Dynamical parton distributions

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(with E. Reya and M. Glück)

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University of Zurich

Dynamical parton distributions

The dynamical approach

The longitudinal structure function

The treatment of heavy quarks

Weak-gauge and Higgs boson production

D0 lepton asymmetry

The dynamical approach

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

→ 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”



“STANDARD”:

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

Unrestricted parameters

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

Positive definite input distributions

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

More restrictive, **less uncertainties**

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

Arbitrary fine tuning ($g < 0!$)

Extrapolations to unmeasured region

Less restrictive, *marginally* smaller χ^2

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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]

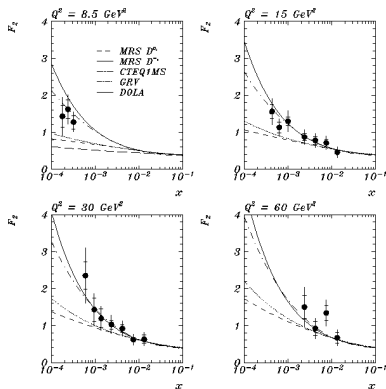
Used in the 80's: e.g. for the discovery
of W and Z bosons (SPS, CERN)

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

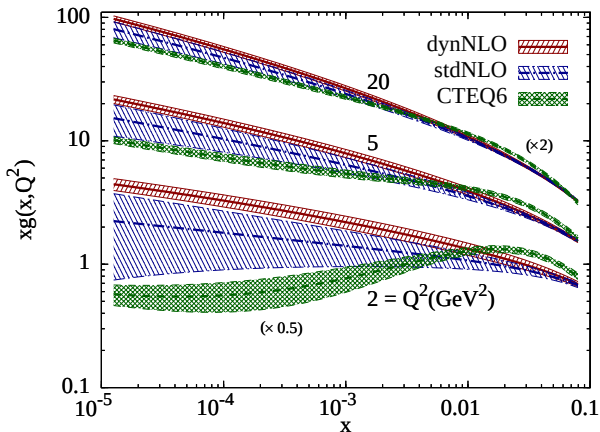
Confirmed by first HERA $F_2(x, Q^2)$ data
[H1, ZEUS 93]

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

New improved generation (GJR08, JR09):
MS + DIS factorization schemes, NNLO, error analysis, FFNS+VFNS, **new data**



Dynamical vs standard distributions: gluon



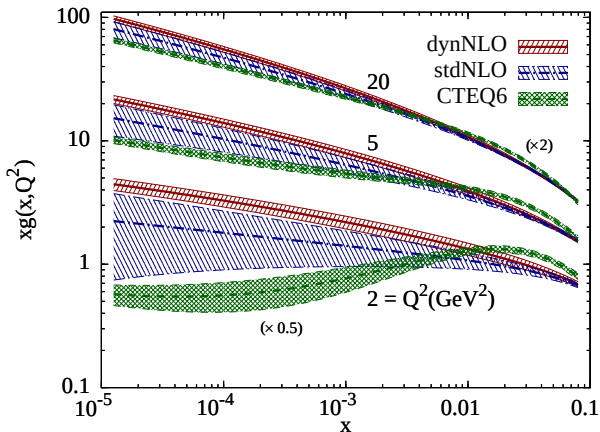
Uncertainties decrease as Q^2 increase: *pQCD evolution*

Valence-like input, i.e., *larger evolution* distance $\Rightarrow$ **less uncertainties**

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

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

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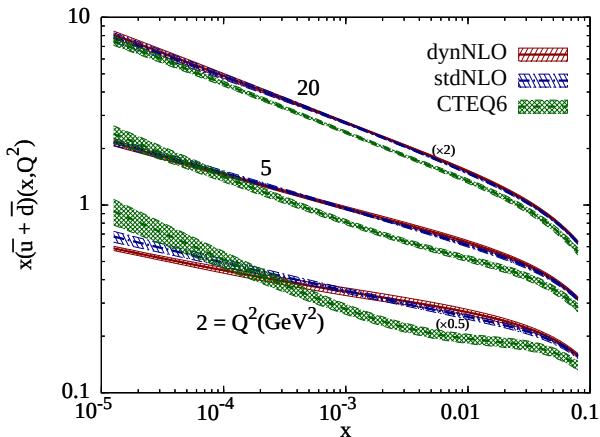
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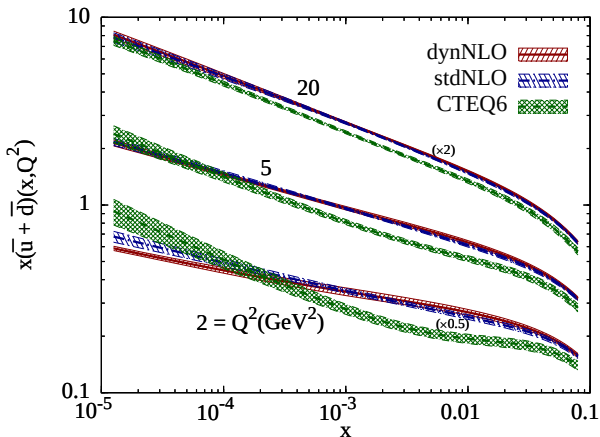
Dynamical vs standard distributions: sea



Rather flat dynamical input sea ($a_{\bar{u}+\bar{d}} \simeq 0.15$) $\Rightarrow$
equally increasing down to $x \simeq 10^{-2} \Rightarrow$ **marginally smaller errors**

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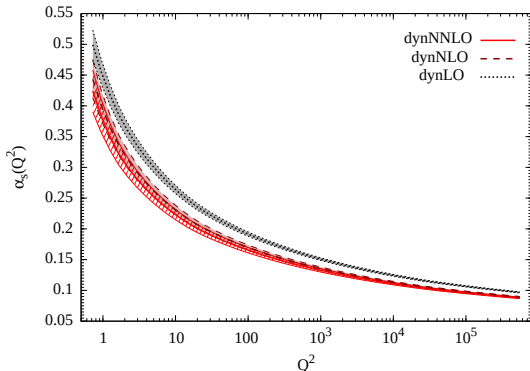
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Determination of $\alpha_s(M_Z^2)$

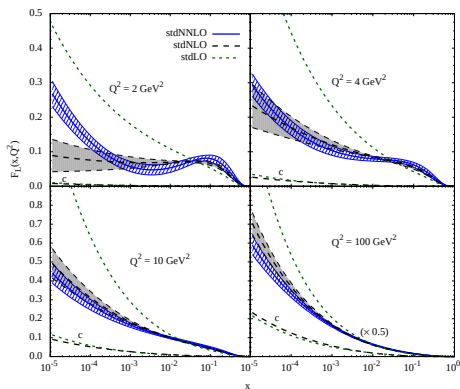
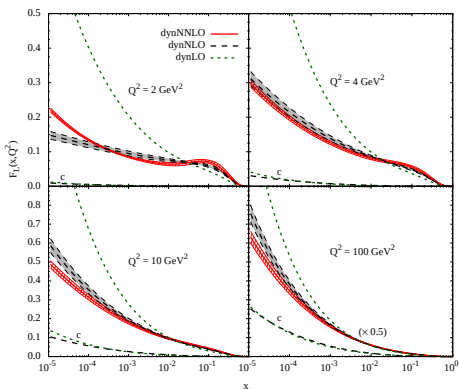
Only free parameter (besides masses) in QCD : **acceptable agreement**

However “dispersion” > uncertainties: global fits (DIS) yield smaller values



Our NNLO result: $\left\{ \begin{array}{l} \text{dynamical: } 0.1124 \pm 0.0020 \\ \text{standard: } 0.1158 \pm 0.0035 \end{array} \right. \quad (\text{larger error!})$

The perturbative stability of F_L



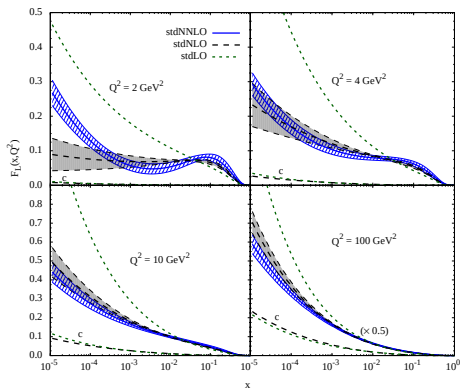
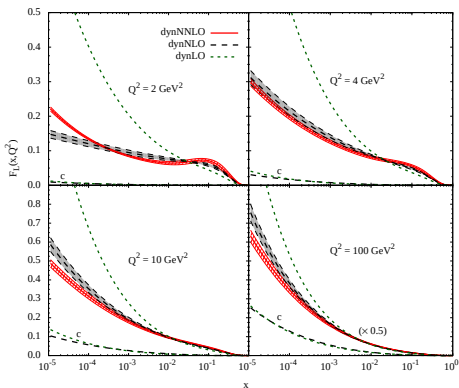
Both dynamical *and* standard results manifestly **positive** at all orders

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

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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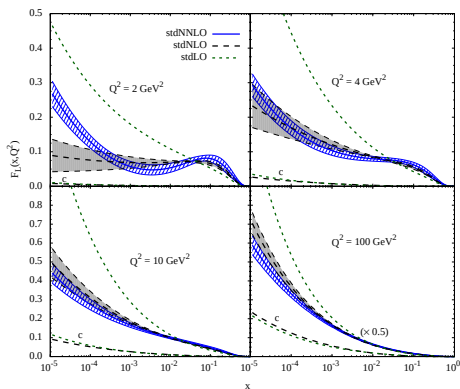
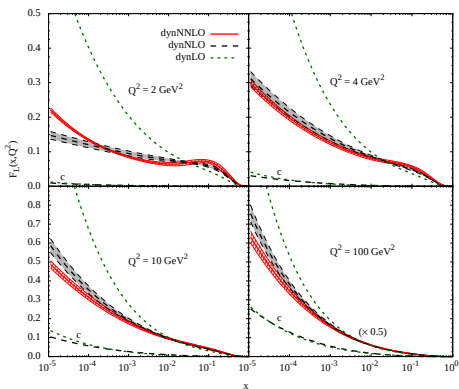
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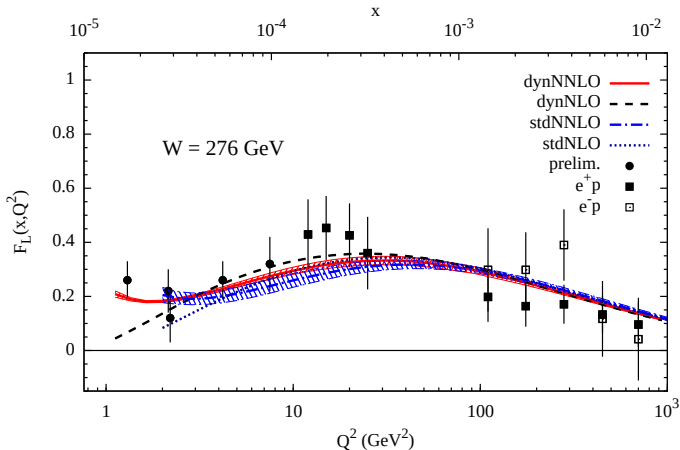
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Confronting results with data



Positive and in complete **agreement** with measurements

Dynamical predictions more tightly constrained

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

Heavy-quark contributions: FFNS

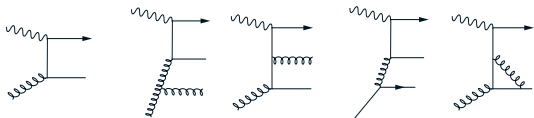
HQ generated in hard collisions: not collinearly, short “lifetime” ($\neq$ parton)

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:



$$F_{k=2,L}^h(x, Q^2, m^2) = \frac{Q^2 \alpha_s(\mu^2)}{4\pi^2 m^2} \int_x^{\frac{Q^2}{Q^2+4m^2}} \frac{dz}{z} \left\{ e_h^2 c_{k,g}^{(0)}(\eta, \xi) g\left(\frac{x}{z}, \mu^2\right) \right. \\ \left. + 4\pi \alpha_s(\mu^2) \left[e_h^2 \left(c_{k,g}^{(1)}(\eta, \xi) + \bar{c}_{k,g}^{(1)}(\eta, \xi) \ln \frac{\mu^2}{m^2} \right) g\left(\frac{x}{z}, \mu^2\right) + \right. \right. \\ \left. \left. \sum_q \left(e_h^2 \left(c_{k,q}^{(1)}(\eta, \xi) + \bar{c}_{k,q}^{(1)}(\eta, \xi) \ln \frac{\mu^2}{m^2} \right) q\left(\frac{x}{z}, \mu^2\right) + e_q^2 \left(d_{k,q}^{(1)}(\eta, \xi) + \bar{d}_{k,q}^{(1)}(\eta, \xi) \ln \frac{\mu^2}{m^2} \right) q\left(\frac{x}{z}, \mu^2\right) \right) \right] \right\},$$

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

Only **drawback**: calculational difficulty

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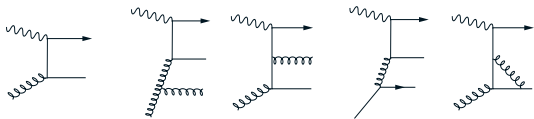
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Effective heavy-quark PDFs: VFNS

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**

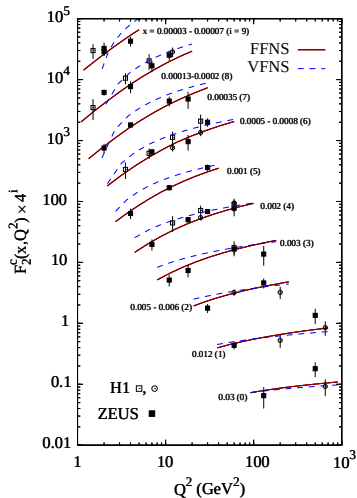
Resummation of **final-state** contributions
($\neq$ intrinsic heavy-quark content)

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**



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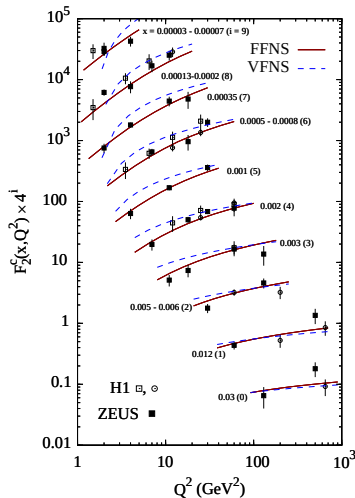
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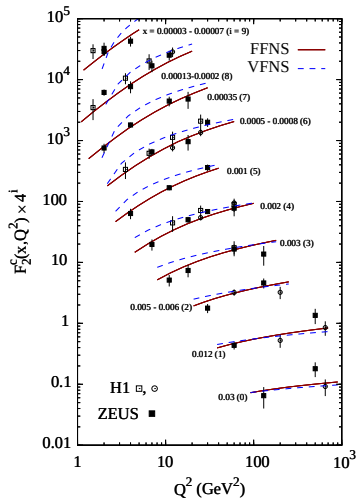
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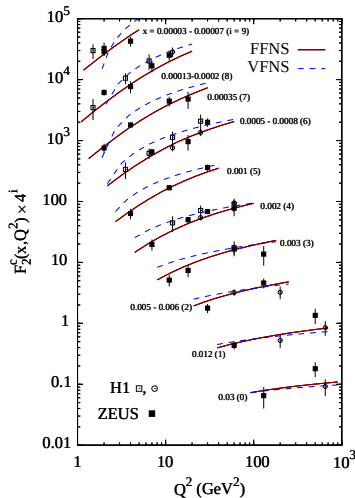
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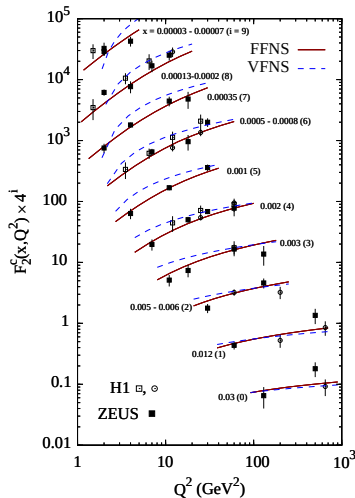
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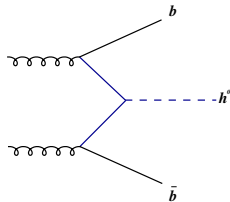


FFNS vs VFNS: Examples

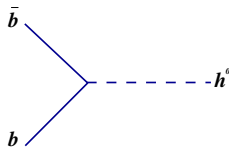
*VFNS reliable for large invariant mass of the produced system: $W^2 \gg m^2$
 $\longrightarrow$ non-relativistic ($\beta_h \lesssim 0.9$) threshold effects suppressed*

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: $gg \rightarrow b\bar{b}H$



VFNS: $b\bar{b} \rightarrow H$



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

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

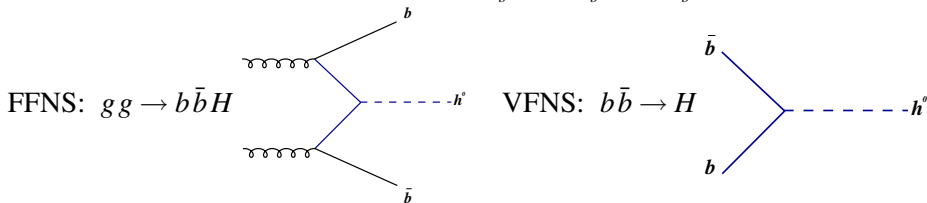
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VFNS sufficiently reliable for LHC and Tevatron energies.

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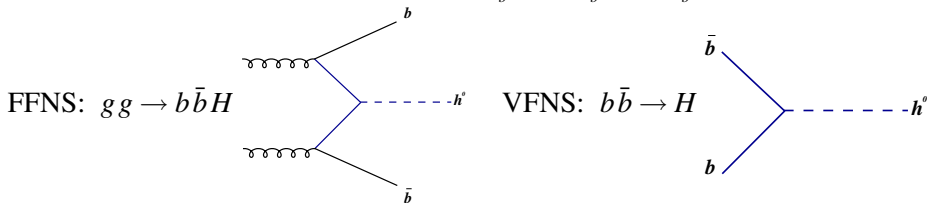
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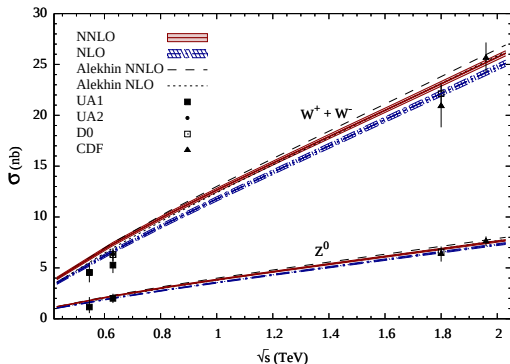
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$$\sigma^{\text{NLO}} = \begin{cases} 186.5 \pm 4.9_{\text{pdf}} \begin{smallmatrix} +4.8 \\ -5.5 \end{smallmatrix} |_{\text{scale}} \text{ nb} & (\text{VFNS}) \\ 192.7 \pm 4.7_{\text{pdf}} \begin{smallmatrix} +3.8 \\ -4.8 \end{smallmatrix} |_{\text{scale}}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

VFNS sufficiently reliable for LHC and Tevatron energies.

Weak gauge boson production rates

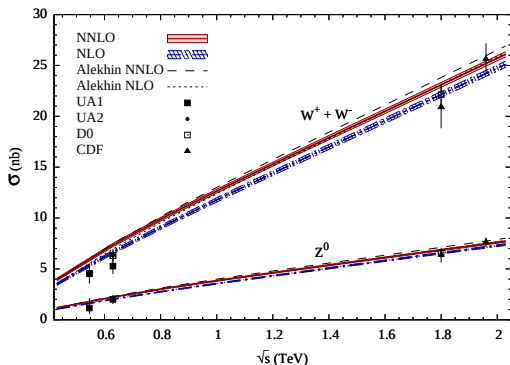


NNLO typically larger but stable; scale uncertainty greatly (%4) reduced
 Results from different groups **within experimental uncertainty at Tevatron**
 NNLO expectations for **LHC** ($\approx 5\%$ accuracy):

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

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

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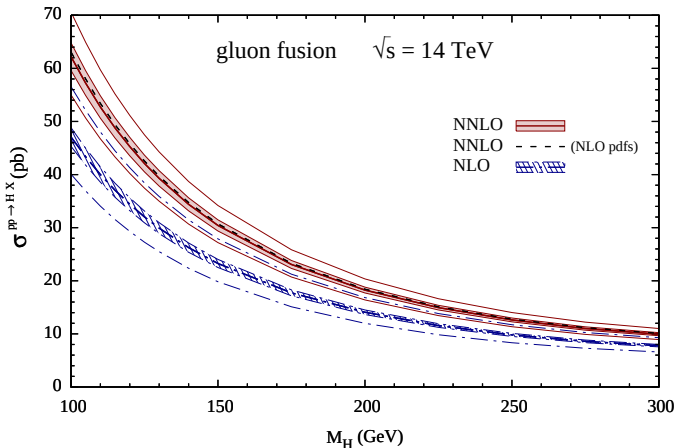


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Higgs boson production at LHC

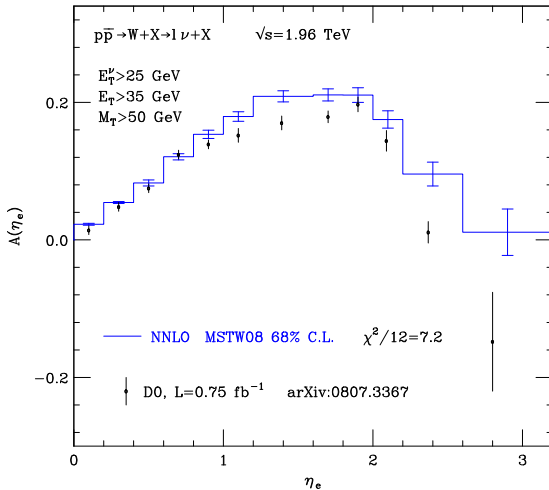


NNLO rather (20%) larger than NLO but *total* uncertainty bands overlap

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

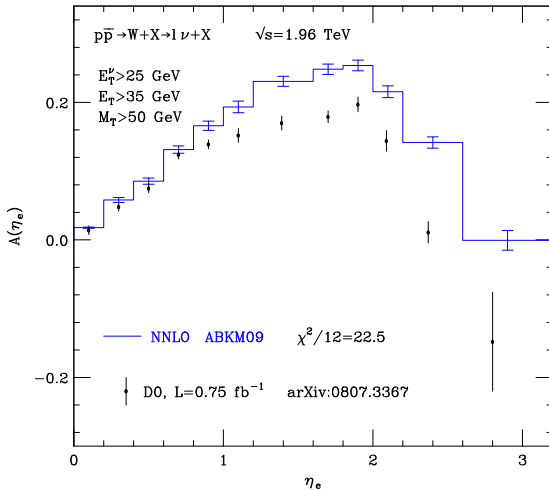
Total **accuracy at NNLO of about 10%**

D0 lepton asymmetry



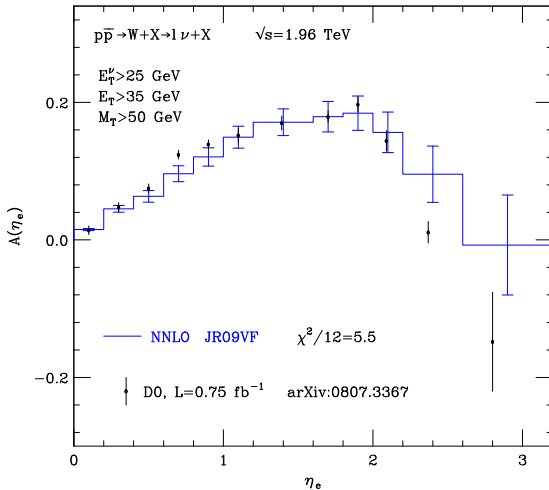
[M. Grazzini *et al.*]

D0 lepton asymmetry



[M. Grazzini *et al.*]

D0 lepton asymmetry



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Conclusions

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

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

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

No problems to describe the D0 lepton asymmetry measurements

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