# NNLO PDFs at large $x$

S.Alekhin (*DESY & IHEP, Protvino*)

*In collaboration with J.Blümlein, S.Klein, S.Kulagin, S.Liuti, K.Melnikov, S.Moch, F.Petriello, and R.Petti*

HiX2010, JLAB 13 Oct 2010

# The PDF fit ingredients

DATA:

- DIS NC inclusive
- DIS μμ CC production
- fixed-target DY
- (Tevatron Run II jets)

QCD:

- NNLO evolution
- NNLO massless DIS and DY coefficient functions
- NLO+ massive DIS coefficient function - FFNS
- NLO+ jet production corrections - 5-flavour scheme

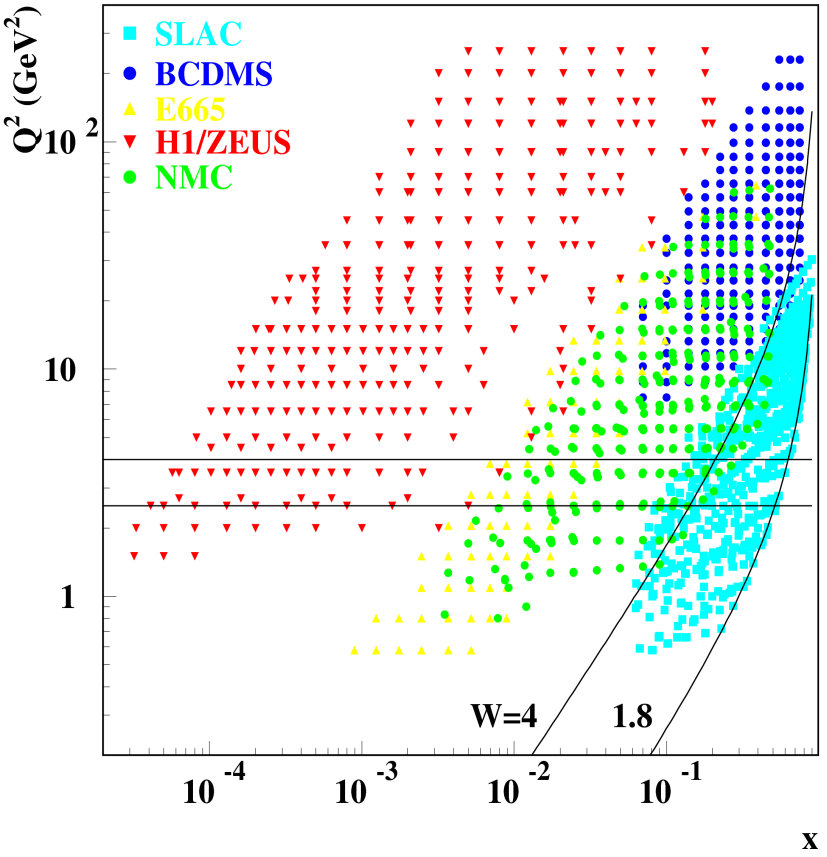
Power corrections in DIS:

- target mass effects
- dynamical twist-4(6) terms

Deuteron corrections in DIS:

- Fermi motion
- off-shell effects

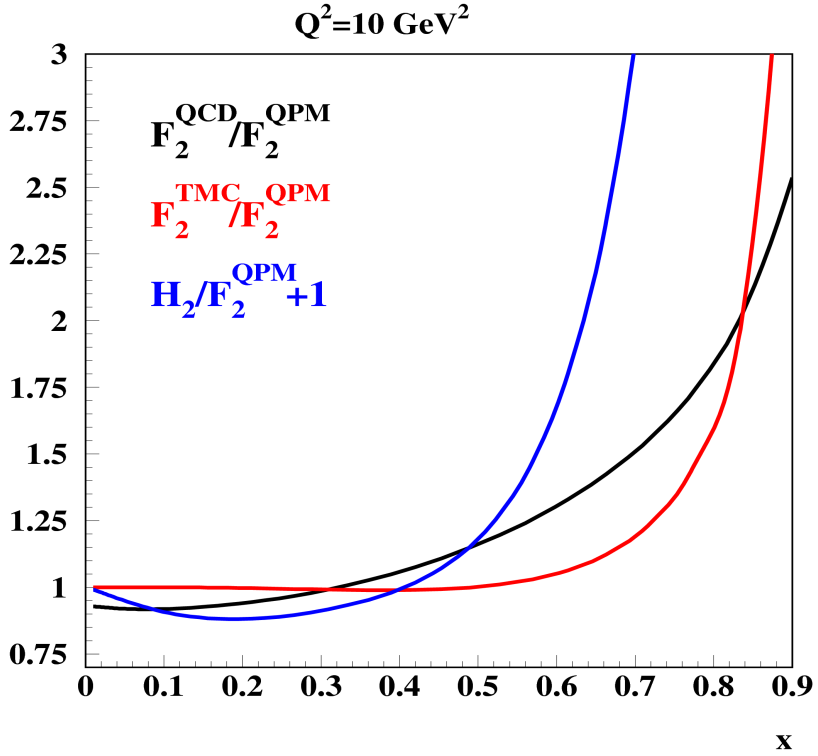
# DIS data and the corrections




The corrections to the proton SFs at large x:

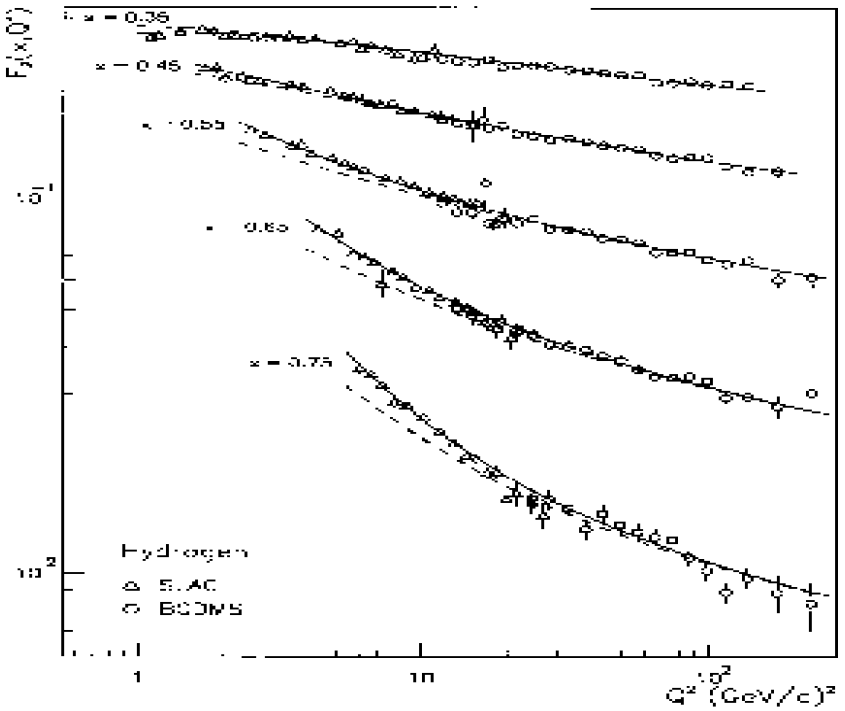
- QCD (up to the NNLO taken into account)
- Target-mass (Georgi-Politzer prescription in the integral form)
- The dynamical twist-4 terms in additive form

$$F_{2T} = F_{2T}^{\text{leadingtwist}} + H_{2T}/Q^2$$

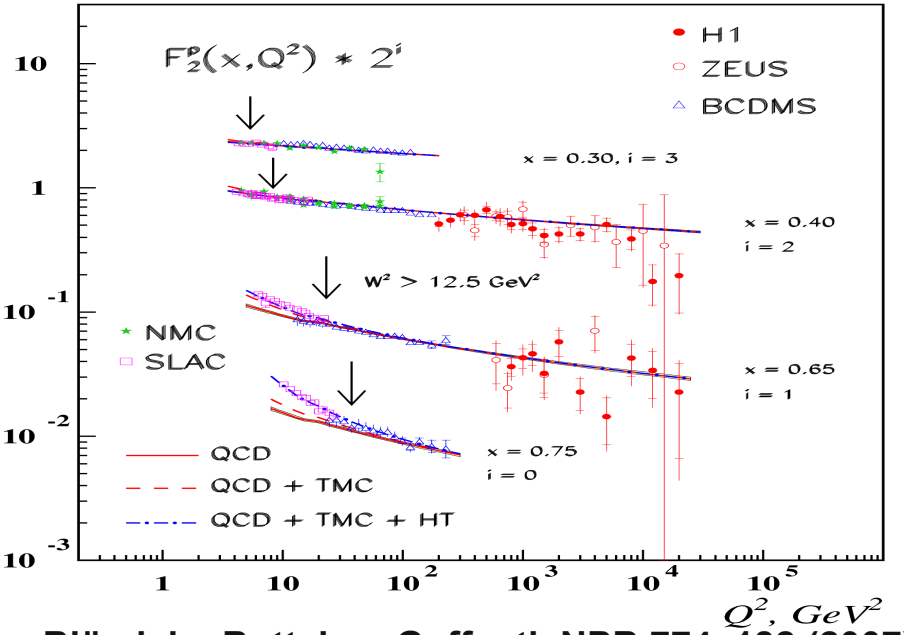



The data down to $Q^2$=2.5(1) GeV$^2$, W=1.8 GeV are taken into the fit → better sensitivity to the PDFs at large (*and small) x*; improved determination of the strong coupling

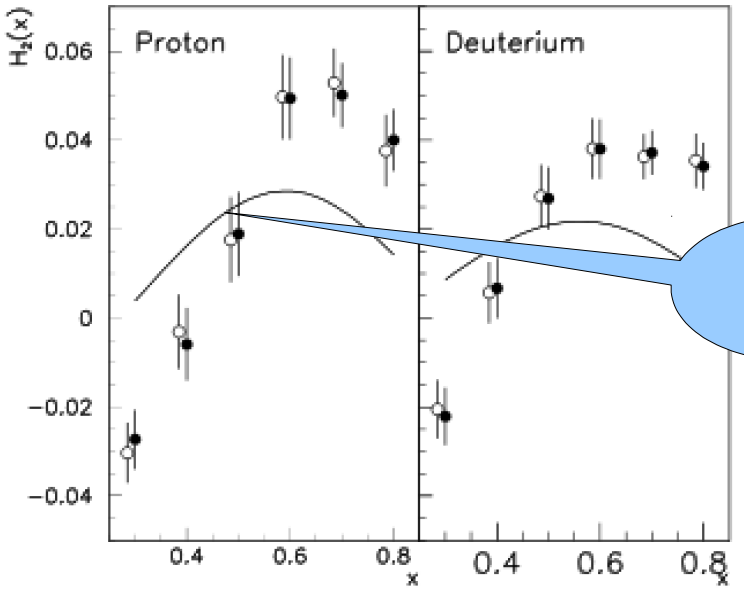
# High-twist terms in DIS




**Virchaux, Milsztajn PLB 274, 221 (1992)**




**Blümlein, Bottcher, Guffanti NPB 774, 182 (2007)**




**sa EPJC 12, 587 (2000)**

- The HT scale is much smaller than expected from the QCD sum rules, $O(\Lambda_{QCD}) \rightarrow$ perturbative nature of the HT?
- The infrared-renormalon (IRR) model

IRR

$$H(x)=\int C_{IRR}(x/z)\ F^{QPM}(z)\ dz$$

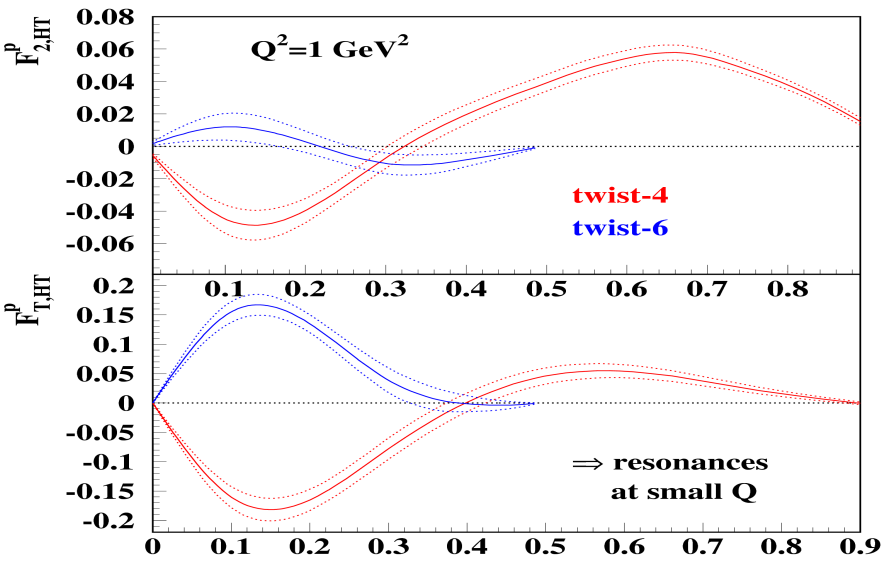
**Dasgupta, Webber PLB 381, 273 (1996)**

misses the data

- The model-independent form of the HT terms
- Evolution of the HT terms?

**Braun, Manashov, Rohrwild NPB 826, 235 (2009)**

# High-twist terms in DIS (cont'd)

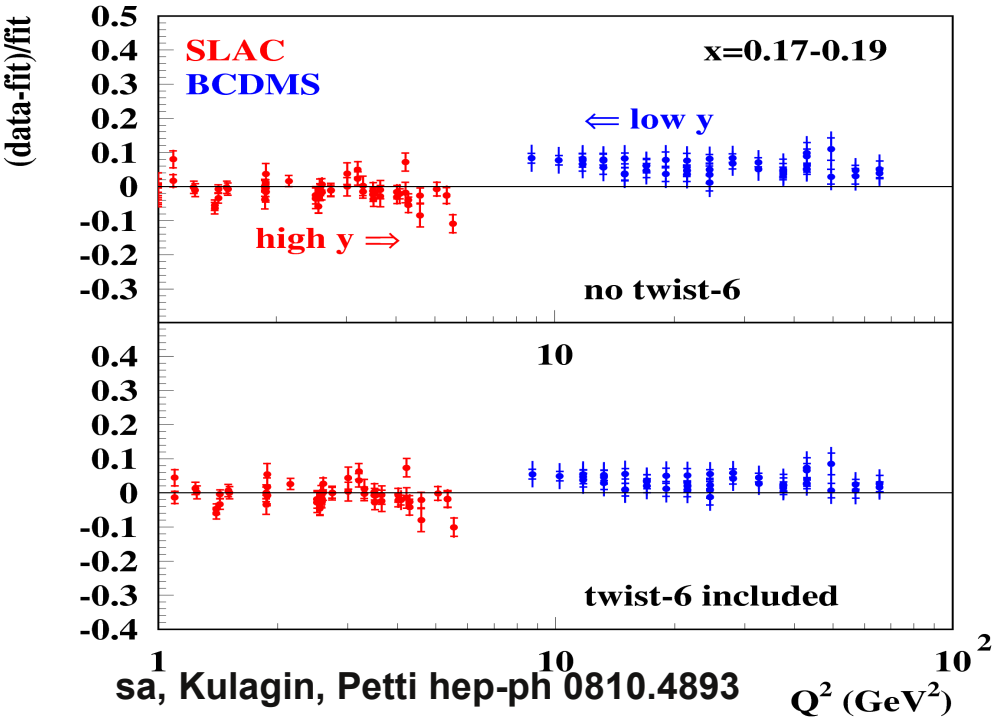



**Twist-4 terms, with the cut $Q^2$>2.5 GeV$^2$:**

- Independently model for $H_2$ and $H_T$ (splines with 5+5 parameters)
- At x=0 set to 0 (no saturation effects are observed at HERA)
- At large x $H_2$ and $H_T$ are similar → $H_L$ is small
- The isospin asymmetry is not significant (cf. talk by Blümlein for the polarized case)

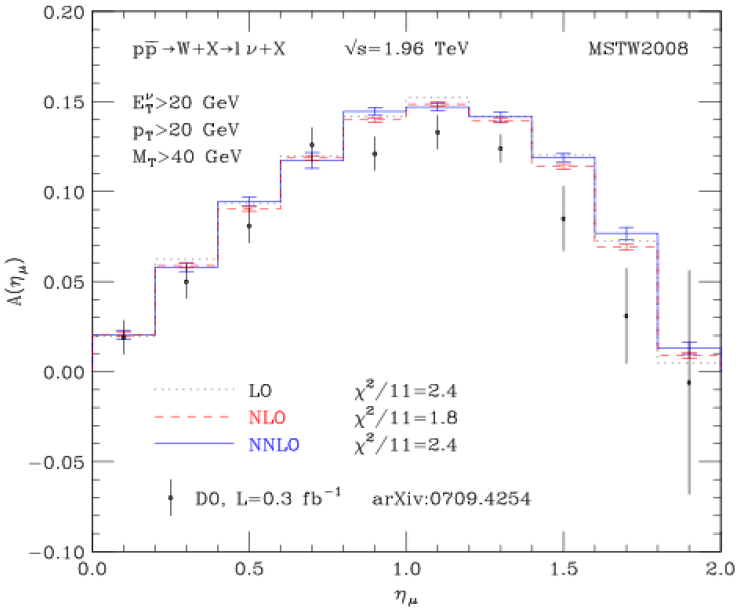
**Twist-6 terms, with the cut $Q^2$>1 GeV$^2$:**

- Determined at x>0.4 only (resonances at larger x)
- For $F_2$ is comparable to 0.
- For $F_T$ compensates twist-4 at $Q^2$=1 GeV$^2$??
- The effect appears due to the tension between SLAC and BCDMS data at $Q^2$=5-7 GeV$^2$
- Only with the twist-6 terms the SLAC parameterization of $R=\sigma_L/\sigma_T$ is reproduced
- The NMC data overlap with both sets, but agree to both (large errors)



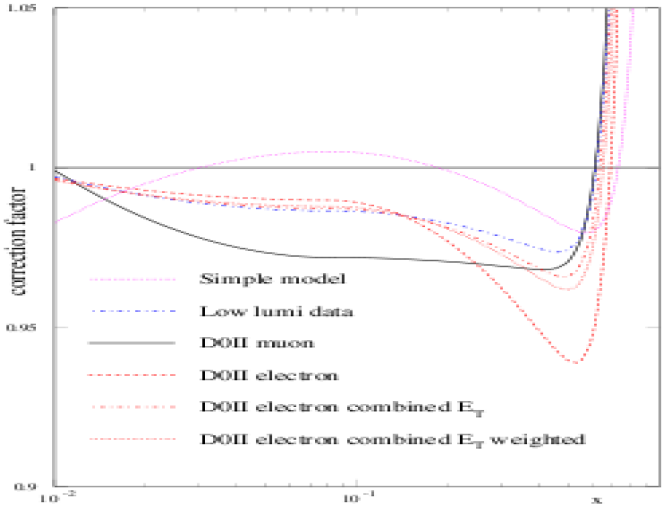

*The future facilities can resolve discrepancy*

# Lepton charge asymmetry at Tevatron

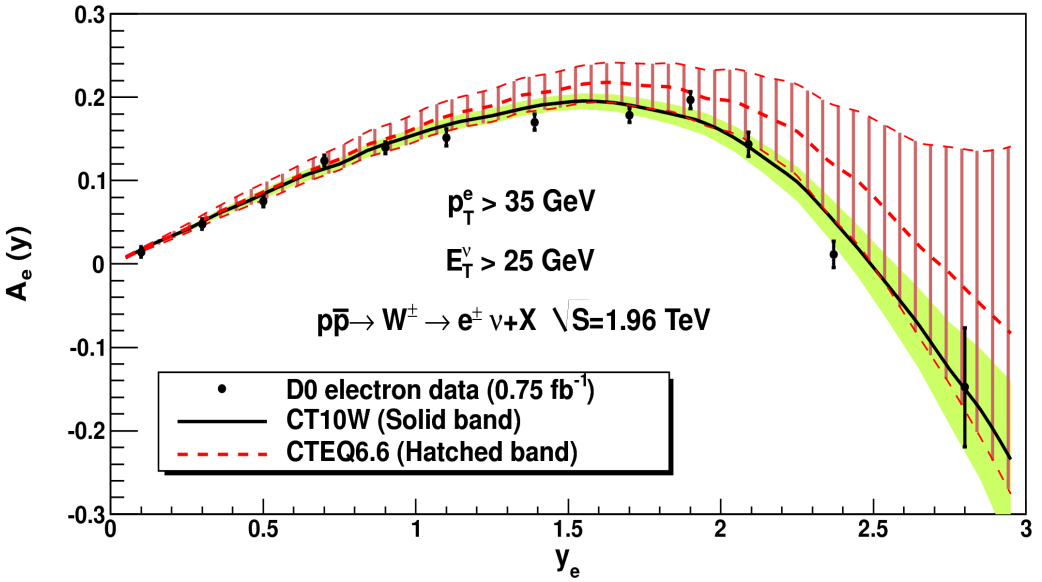



- Standard candle process, calculated up to the NNLO.
- The distributions are poorly described by the existing PDFs .
- The Tevatron data are sensitive to the d/u ratio at x~0.2 and small *Q*, the discrepancy is due to impact of the NMC and BCDMS data.
- MSTW: a variation of the deuteron correction improves agreement, however the shape of the corrections preferred by the fit is unrealistic
- CTEQ: two variants of PDFs are produced, with the different weights assigned to the Tevatron data.

**Catani, Ferrera, Grazzini JHEP 1005, 006 (2010)**

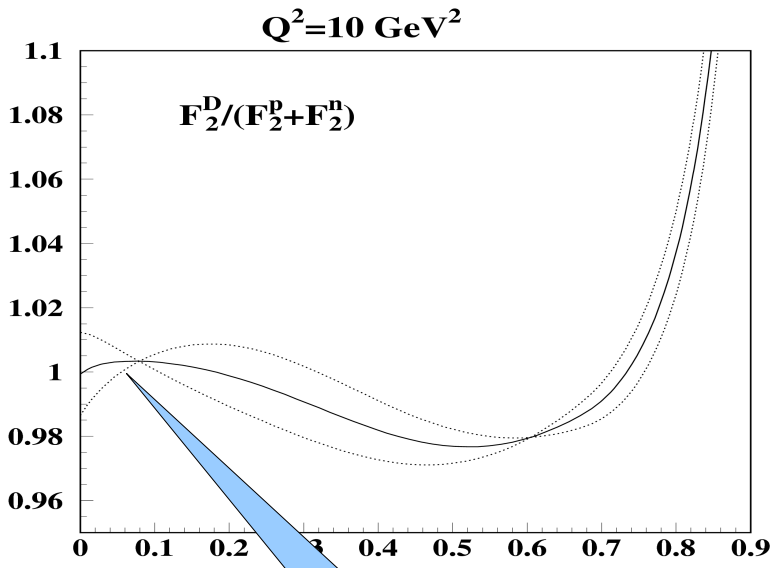



**MSTW [hep-ph 1006.2753]**

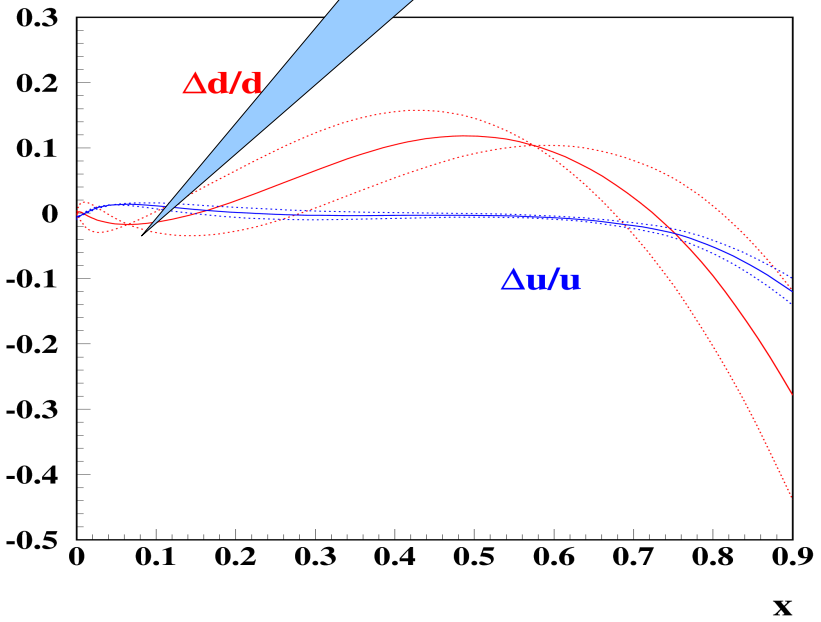



**CTEQ [hep-ph 1007.2241]**

# Valence distributions and deuteron corrections



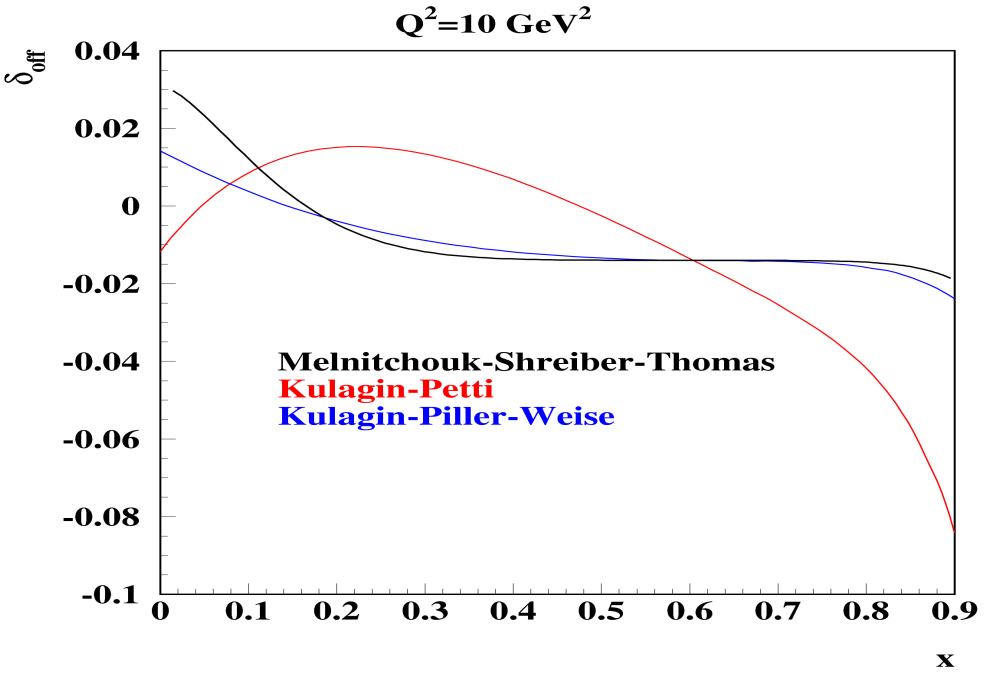

Not affected



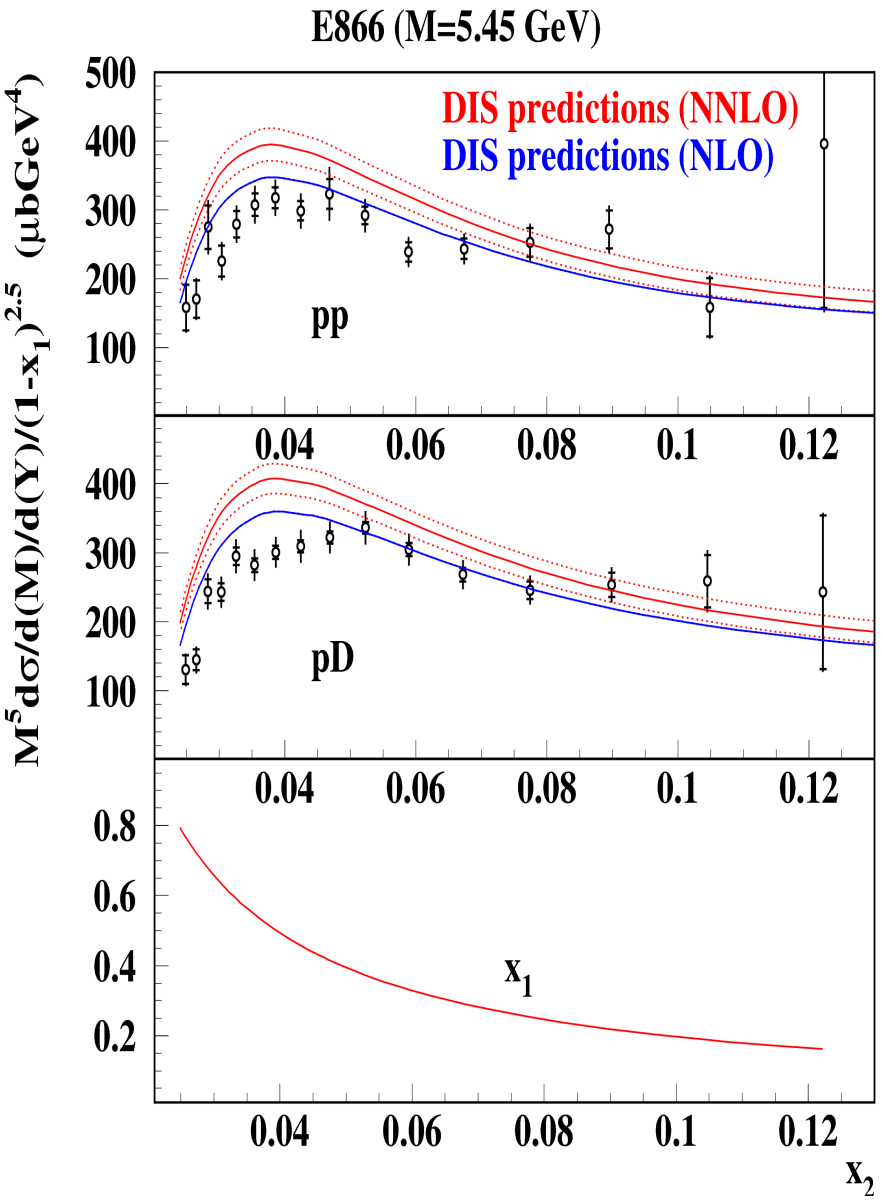

In our fit the deuteron correction is taken as a combination of the Fermi motion and the off-shell effects

**Kulagin, Petti NPA 765, 126 (2006)**

- The off-shell effects poorly understood → fitted to the data
- The fit is well extrapolated to the case of He3 target (cf. talk by Kulagin)
- Different approaches for the off-shell corrections → uncertainty in d/u
- In our fit $\chi^2$ /NDP= 3038/2716 for the Kulagin-Petti parameterization (3077 with no deuteron corrections, and 3059 for the KPW model)



# The DIS and DY data




The E866 fixed-target DY data at large rapidity go lower than the DIS predictions

- In the NLO approximation the discrepancy is smaller – CTEQ, NNPDF
- The DY data are shifted up by 10% (approx. the value of NNLO K-factor) – MSTW
- Only the E866 deuteron/proton ratio data are included into the fit – APM

*Effects beyond NNLO?*

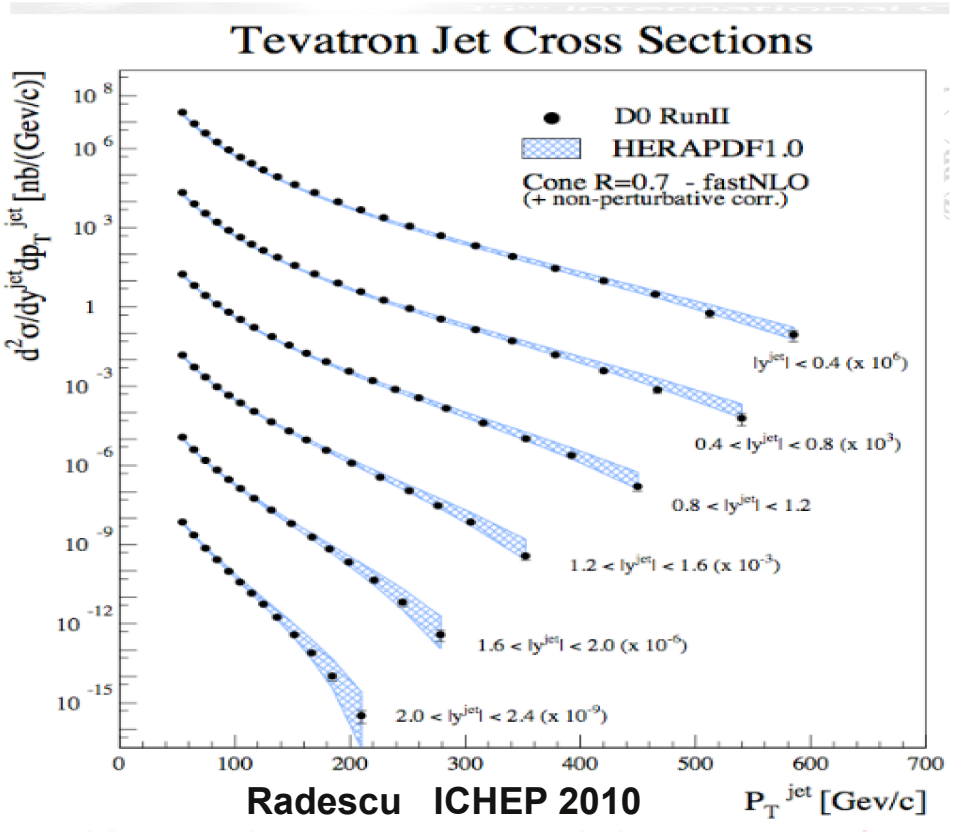
*Defective DY data?*

*Enhanced quarks at large x?*

Duality studies (cf. talks by Malace and Melnitchouk)

**sa, Melnikov, Petriello PRD 74, 054033 (2006)**

# Impact of the jet data on gluons

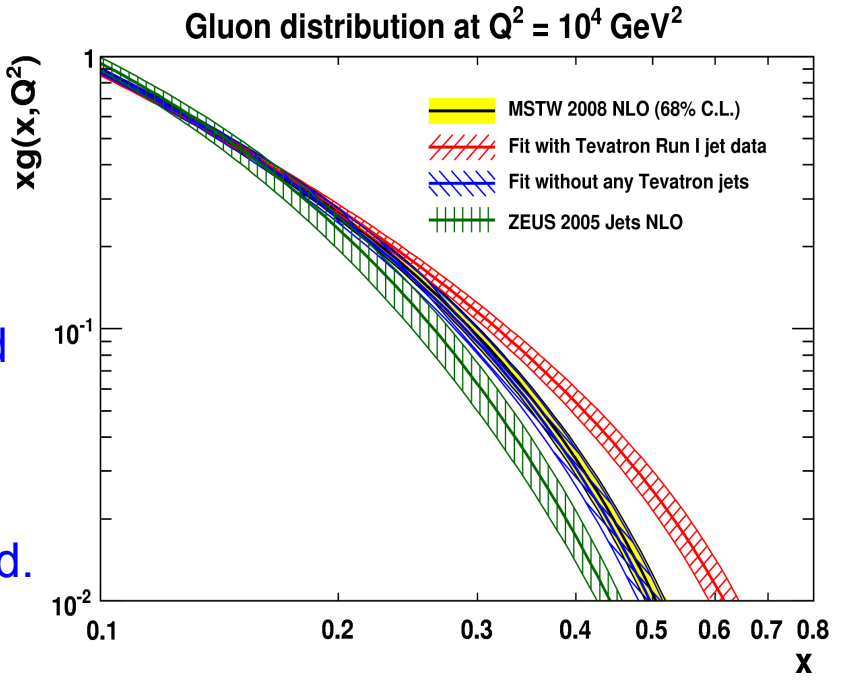



- The NNLO corrections to jet production are cumbersome (non-trivial subtraction of the IR singularities), only the e+e- case has been solved recently.

**Weinzierl, Gehrmann-De Ridder, Gehrmann, Glower, Heinrich**

- The fragmentation function uncertainties.
- FastNLO tool allows to employ full NLO corrections in the PDF fit.

**Kluge, Rabberitz, Wobbisch [hep-ph 0609285]**



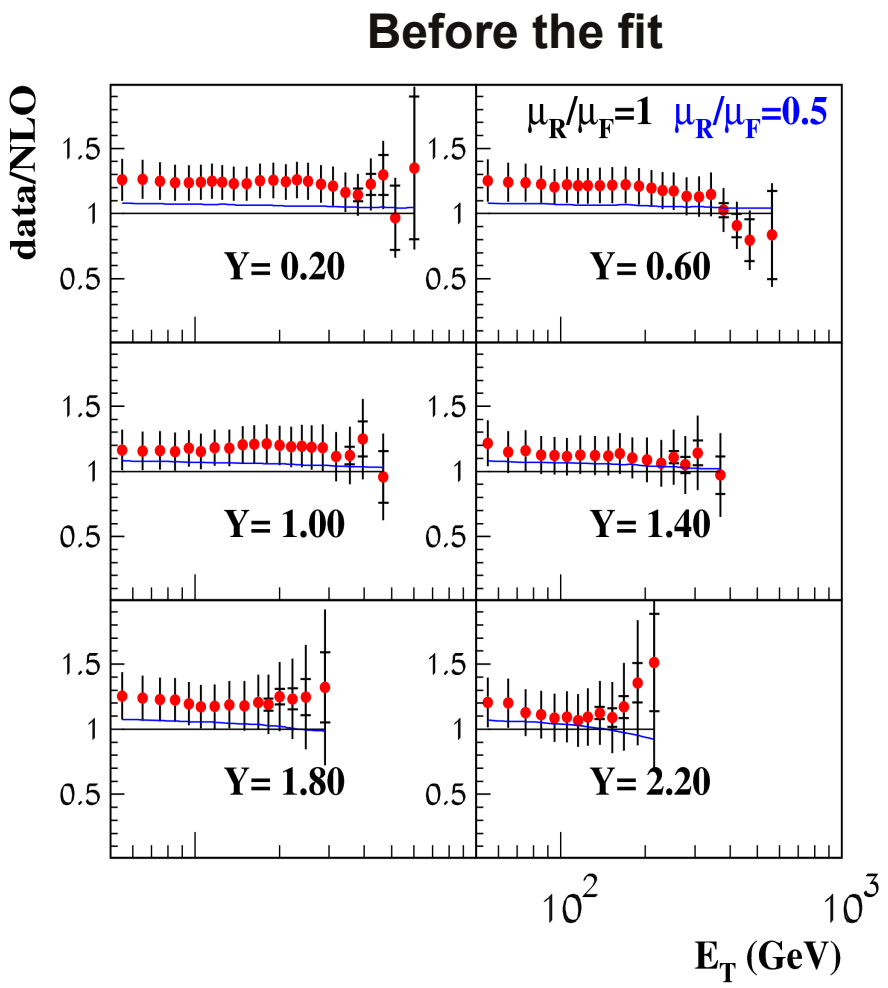

**MSTW EPJC 63, 189 (2009)**

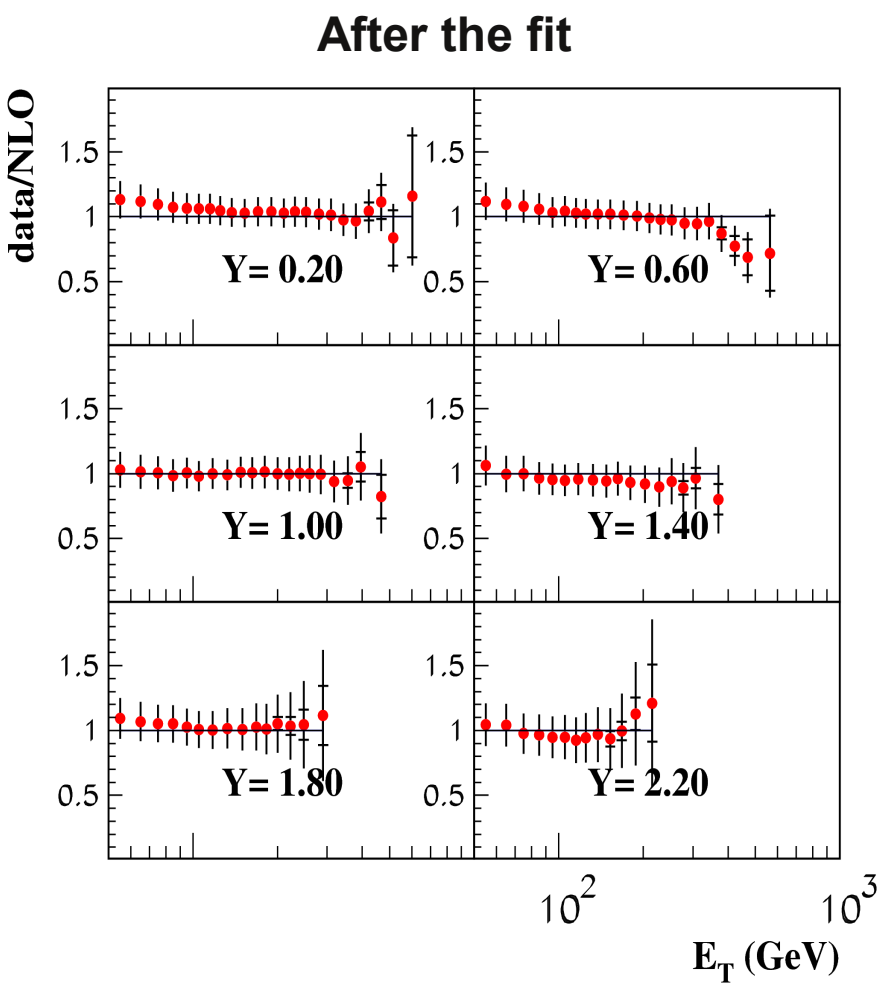
- The Tevatron Run I data overshoot the DIS-based predictions → large gluon distributions and big value of strong coupling constant.
- The Run II data go lower → no tension with DIS, impact of the jet data on gluons is greatly reduced.

$\alpha_s(M_z)=0.1161\pm0.0045(exp.)$ (NLO)

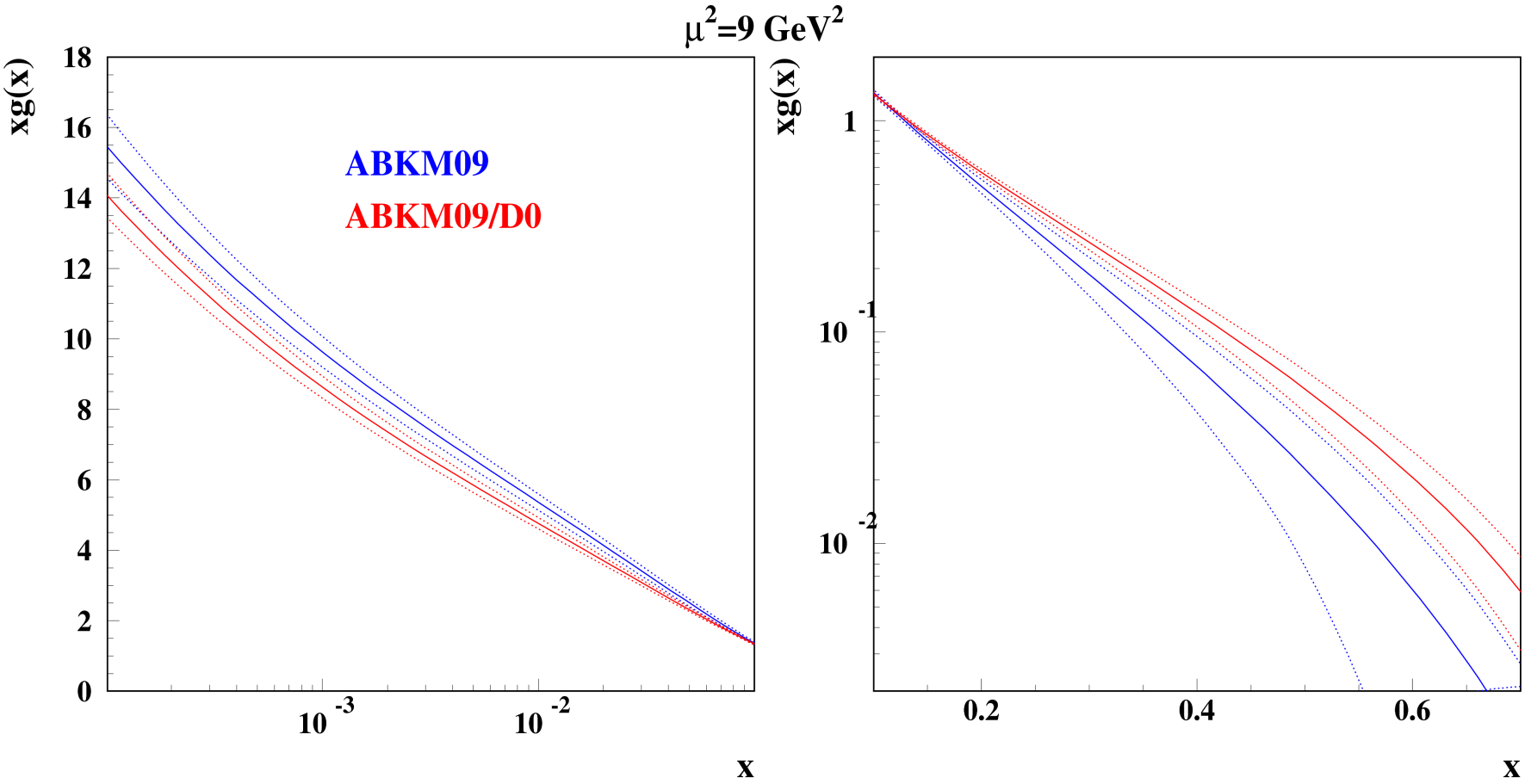
**D0 Collaboration [hep-ex 1006.2855]**

# Impact of the jet data on gluons (cont'd)



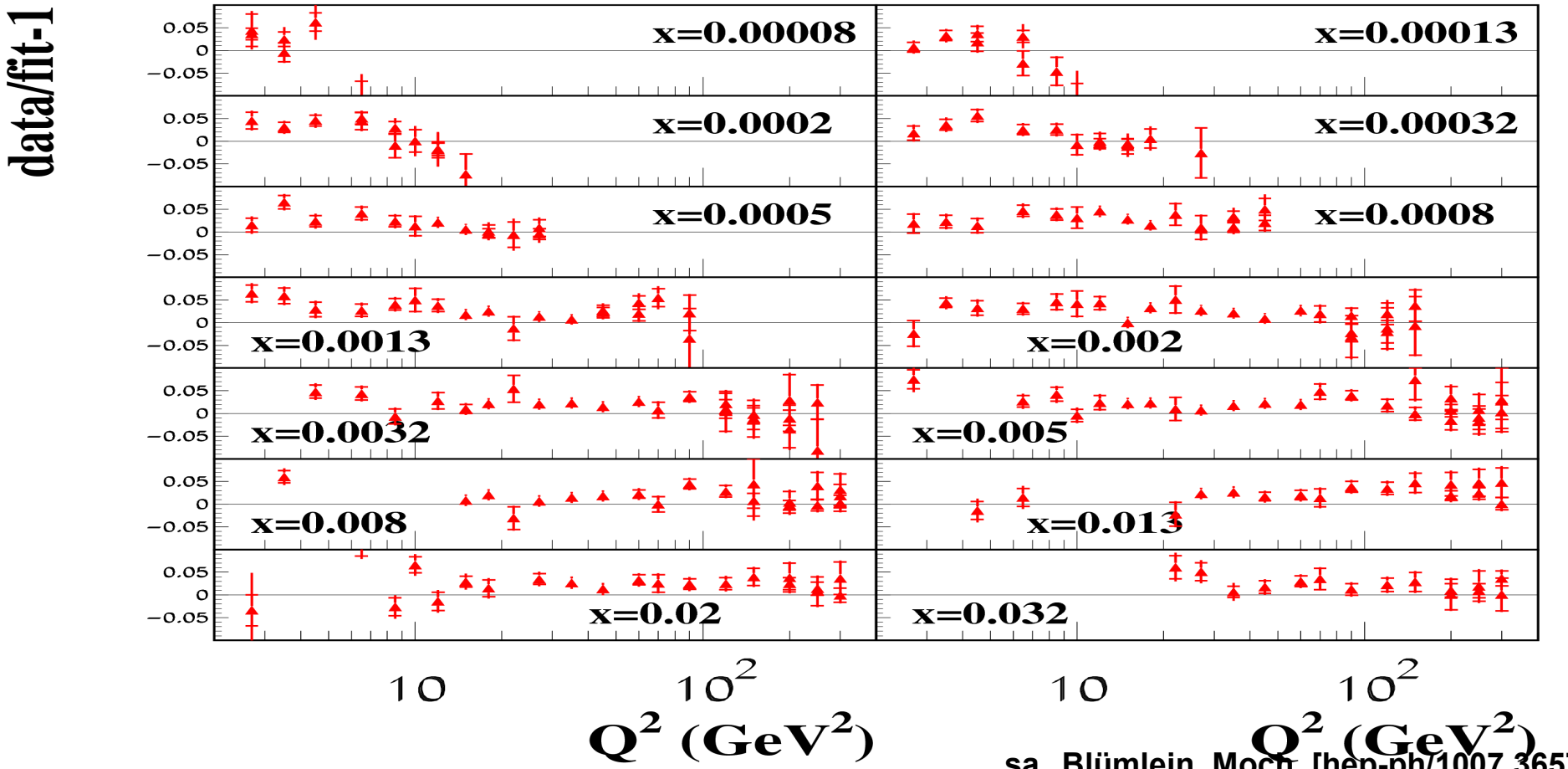

- The NLO variant of the fit (*consistency*)
- Mixed scheme: 3-flavor PDFs for the DIS and 5-flavor PDFs for jets, $\mu_F=E_T$
- The value of $\chi^2$ for D0 data is 104/110 → jet data can be easily combined with others
- *Uncertainty due to missing NNLO corrections*




- Impact of the D0 data is somewhat bigger than 1σ, however variation of the scales reduces significance of the data (work in progress)
- Potential impact of the precise DIS data looks promising → EIC, JLAB@12 and other forthcoming facilities

# Combined NC HERA data in the PDF fit

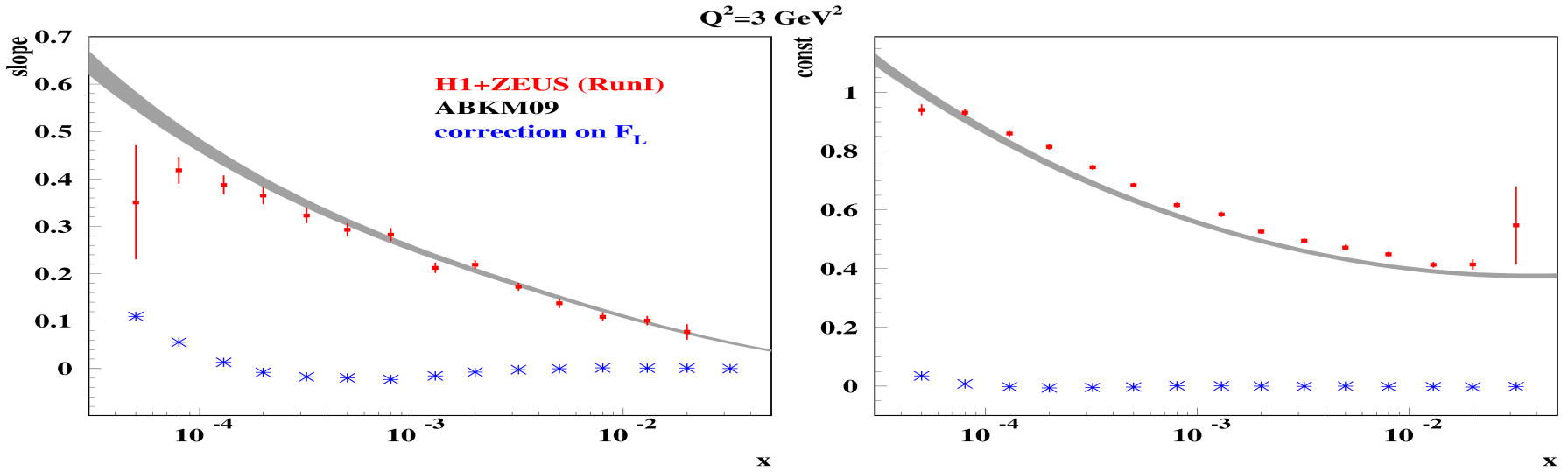
H1 ans ZEUS Collaborations JHEP 1001, 109 (2010)



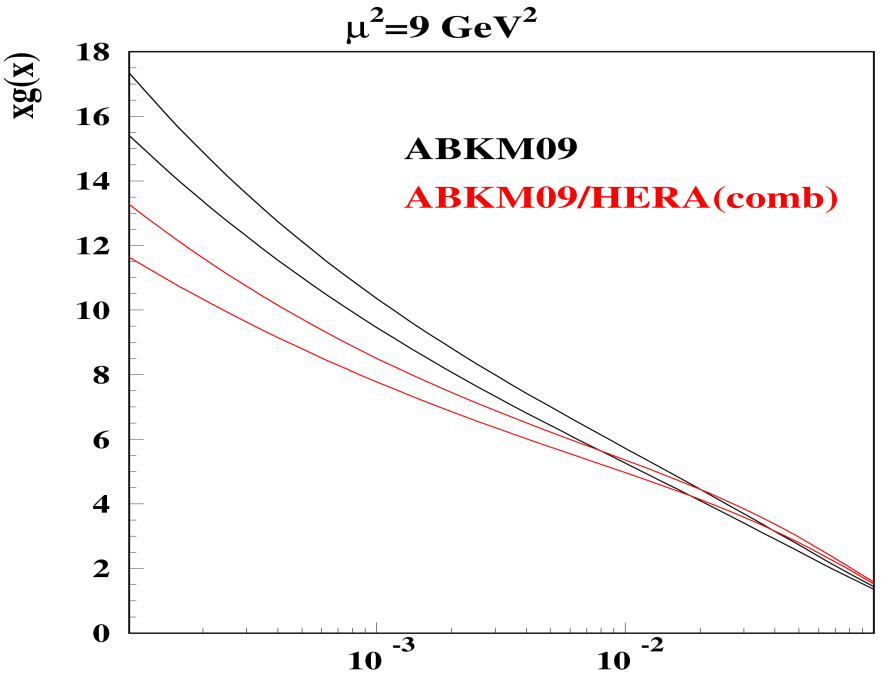

sa, Blümlein, Moch [hep-ph/1007.3657]

- The systematic uncertainties are very detailed (114 sources are studied); the total errors in data do not exceed 2% at small Q
- The value of $\chi^2$ is about 1.2 with account of the correlations
- The data go somewhat above the fit → *what happens with even more precise Run II data?*

# Gluon distribution at small x

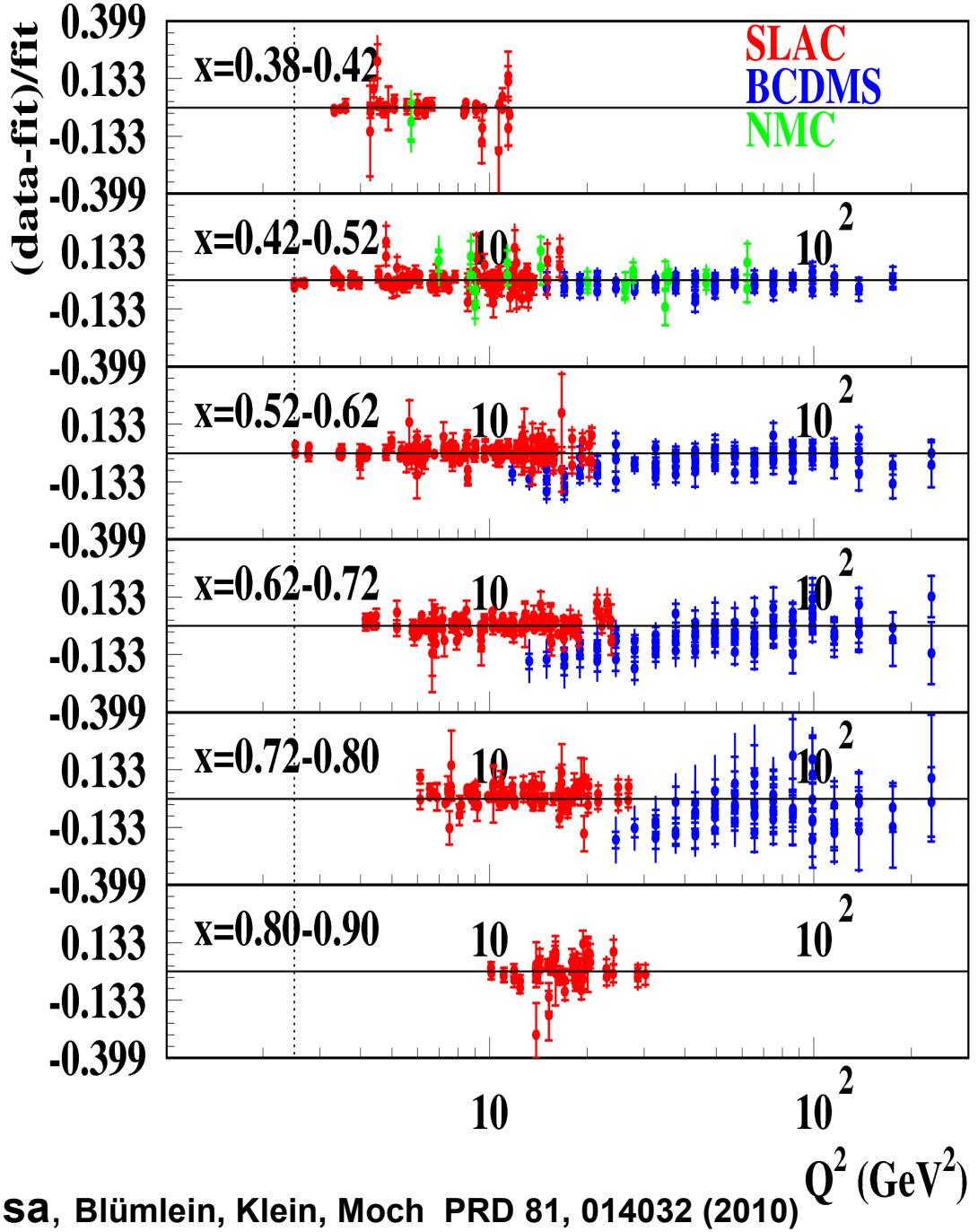



**sa, Blümlein, Moch [hep-ph/1007.3657]**

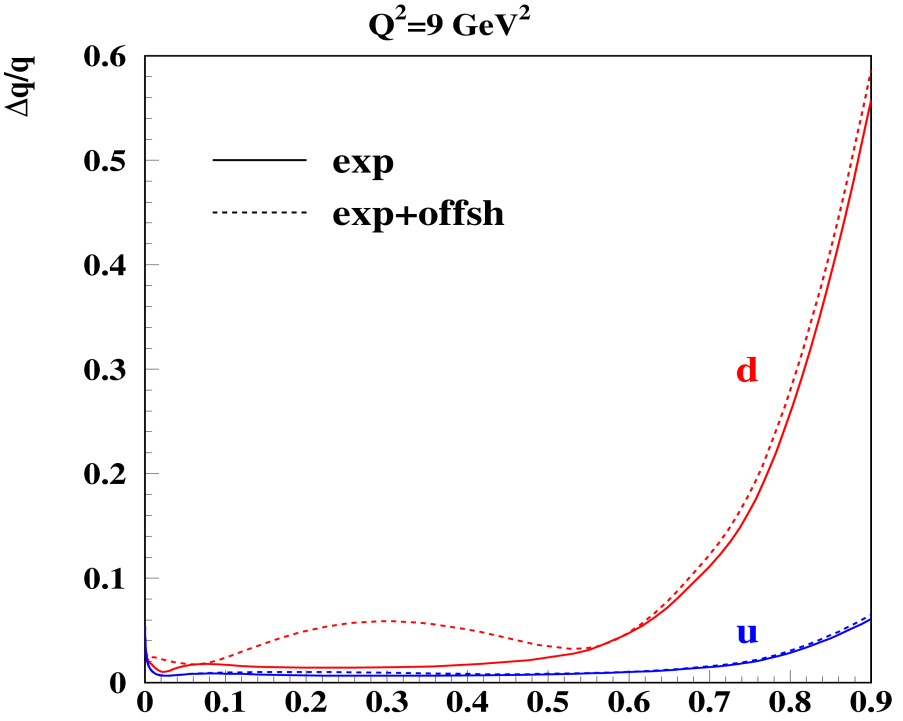



- The slope on Q for the combined HERA RunI data is in good agreement with the predictions based on the earlier PDFs
- The general normalization is higher than before → some tension in the momentum sum rule; more flexible shape of the PDFs at small x is necessary
- The small-x quarks are enhanced
- The small-x gluons are suppressed; the effect is more pronounced for the NNLO variant of the fit

# The large-$x$ DIS data in the global fit




- The overall value of $\chi^2$/NDP=3038/2716
- Good description of the data down to W=1.8 GeV
- The u-quark uncertainty at x<0.9 is O(%)
- The d-quark uncertainty at large x is dominated by the experimental errors and at moderate x by the nuclear corrections → constraint from the resonance data? and clarification of the nuclear effects at x~0.3.




**sa**, Blümlein, Klein, Moch PRD 81, 014032 (2010)

# $\alpha_s$ from DIS and other processes

$\alpha_s(M_z)=0.1135\pm0.0014$ (NNLO)

$\alpha_s(M_z)=0.1179\pm0.0016$ (NLO)

**sa, Blümlein, Klein, Moch PRD 81, 014032 (2010)**

$\alpha_s(M_z)=0.1147\pm0.0012$ (NNLO)

**sa, Blümlein, Moch [hep-ph/1007.3657]**

From the Tevatron jet data

$\alpha_s(M_z)=0.1161\pm0.0045$ (NLO)

**D0 Collaboration [hep-ex 1006.2855]**

From the world e+e- data on trust

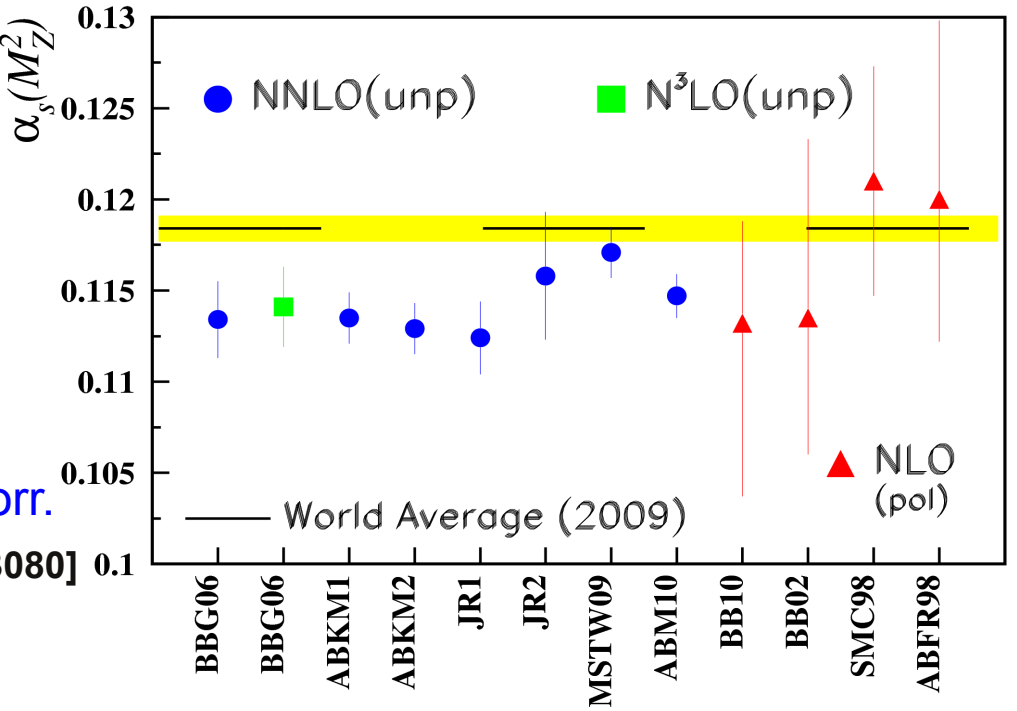
$\alpha_s(M_z)=0.1135\pm0.0002(exp.)\pm0.0005(had.)$
$\pm0.0009(pert..)$ (NNLO)+power corr.

**Abbate, Fickinger,Hoang, Mateu, Steward [hep-ph 1006.3080]**

*Nice agreement with DIS values*

- Many important hadronic processes i.e. Higgs and top-quark production are ~$\alpha_s^2$.
- The gluon distribution is correlated with $\alpha_s$ → effect is accumulated.
- The value of $\alpha_s$ from DIS is lower than the world average.

**Bethke EPJC 64, 689 (2009)**




**Blümlein, Böttcher [hep-ph 1005.3113]**

# Summary

- The NNLO PDFs are tuned simultaneously with the twist-4 terms to the global set of data including the DIS data at *x* up to 0.9 and down to W=1.8 GeV; a good overall description of the data is obtained: $\chi^2$/NDP=1.1
- The PDFs are available in the LHAPDF librariy
- The grid for the incusive structure functions including the QCD, TMC, and HT corrections is available at

  http://www-zeuthen.desy.de/~alekhin/sfs.zip

- The Tevatron jet data will be incorporated soon → moderate effect on the gluons at large *x*; big scale uncertainty in the absence of the NNLO corrections
- Discrepancy between the SLAC and BCDMS data at $Q^2$=5-7 GeV² → the twist-6 terms in $F_T$?
- The Tevatron W-asymmetry (and fixed-target DY data) in poor agreement with the predictions → modification of the nuclear corrections? wrong data? resummation effects?