News from ABM

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

- Running-mass definition: FFNS and VFNS
- Impact of the Tevatron jet data
- α_s and PDFs

sa, Moch [hep-ph 1011.5790]

sa, Blümlein, Moch [hep-ph 1101.5261]

S.Moch Collider Cross Talk, CERN, March 10

PDF4LHC, CERN, 7 Mar 2011

The ABM 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 functions
  - (NLO + NNLO threshold corrections, running mass)
- NLO jet production corrections

Deuteron corrections in DIS:
- Fermi motion
- off-shell effects

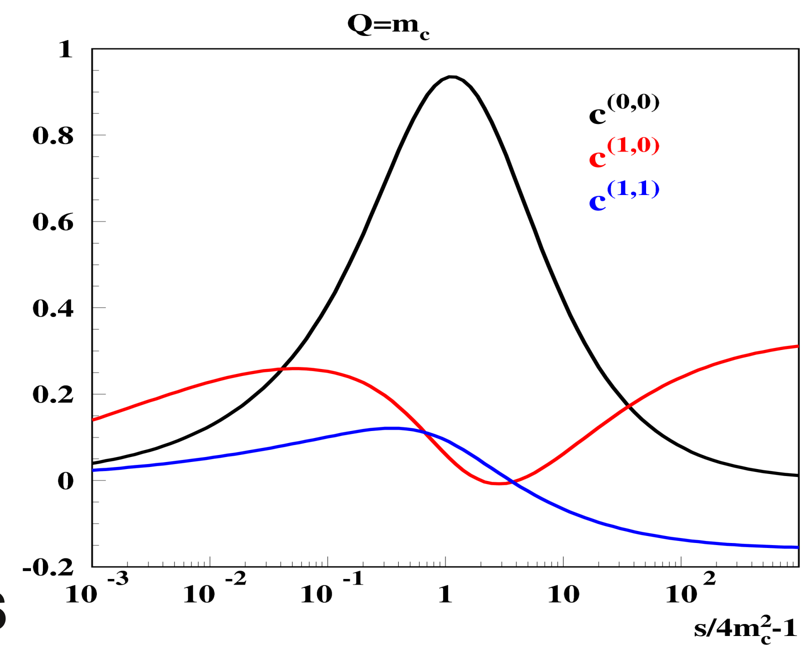
Power corrections in DIS:
- target mass effects
- dynamical twist-4 terms

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

sa, Blümlein, Moch [hep-ph/1007.3657]

The heavy-quark electro-production

The dominant mechanism is photon-gluon fusion, contributes up to 30% to the inclusive structure functions. The massive coefficient functions are known up to the NLO.



$$C_{2,g}^{LO} = c^{(0,0)}$$ **Witten NPB 104, 445 (1976)**

$$C_{2,g}^{NLO} = c^{(1,0)} + c^{(1,1)} \ln(\mu_F^2/m_c^2)$$

Laenen, Riemersma, Smith, van Neerven NPB 392, 162 (1993)

FFNS

- Only 3 light flavors in the initial state are considered.
- Accurate at $Q \sim m_c$
- At large Q the fixed-order results may be insufficient due to big logs $\sim ln^n(Q/m_c)$ must be resummed
- Involved high-order calculations. The full NNLO corrections are missed → inconsistency in the NNLO PDF fits.

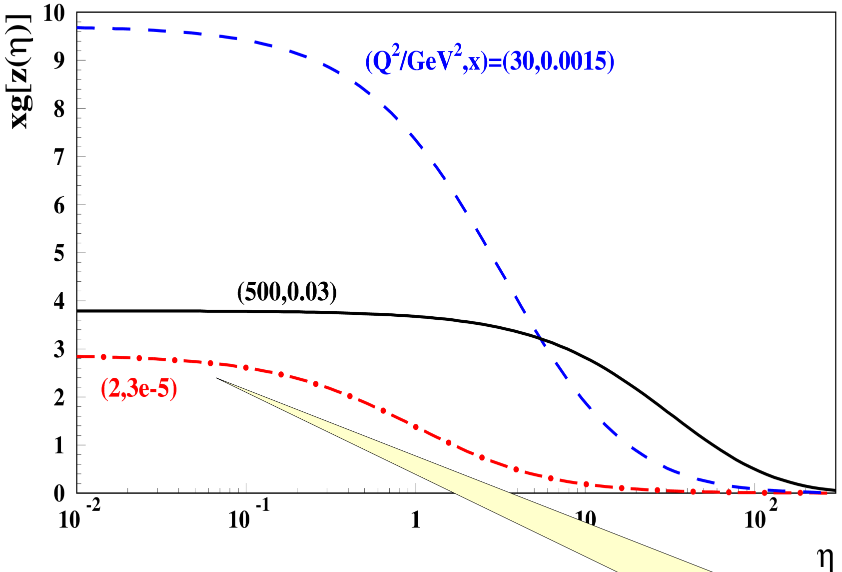
ZMVFNS

Collins, Tung NPB 278, 934 (1986)

- At $Q >> m_c$ the heavy quarks are considered as massless → the NNLO evolution and the coefficient functions up to N^3LO are ready
- The big logs $\sim ln^n(Q/m_c)$ are in a natural way resummed in the QCD evolution
- Matching conditions for the 3(4)-flavor and the 4(5)-flavor massless theories
- *A smooth matching with the FFNS in the limit of Q → m_c must be provided*

Threshold soft-gluon resummation

$$x^{-1}F_2^c(x,Q^2,m^2)=\frac{\alpha_s\,e_q^2}{\pi^2}\sum_{i=q,\bar{q},g}\int_0^{\eta_{max}} d\eta\; f_i\left(z(\eta),\mu^2\right)\; c_{i,k}\left(\eta,\xi,\mu^2\right)$$



- At small x and small Q the main contribution comes from η<1 due to the gluon distribution shape (threshold production)
- The large logs ~ $\ln^{2n}(\beta)$ can be resummed in all orders, this gives a good approximation to the exact NNLO expression at small β with the tower of large logs

Laenen, Moch PRD 59, 034027 (1999)

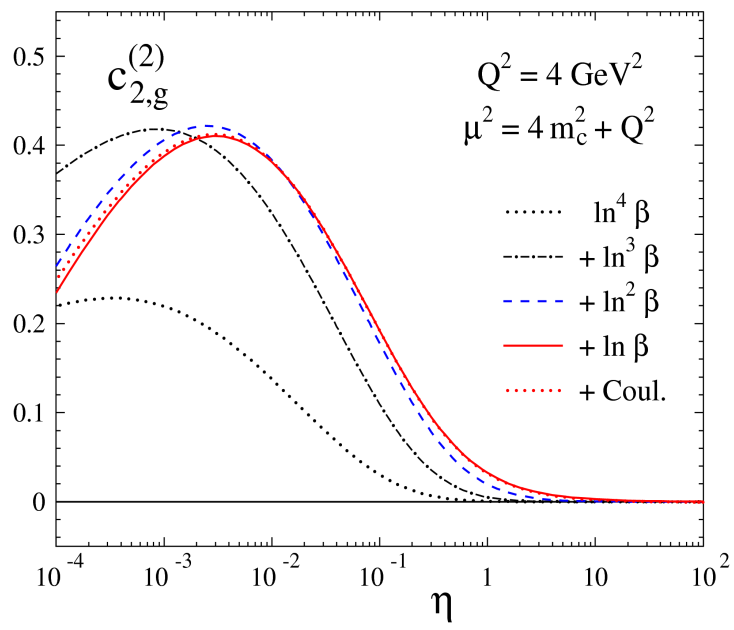
sa, Moch PLB 672, 166 (2009)

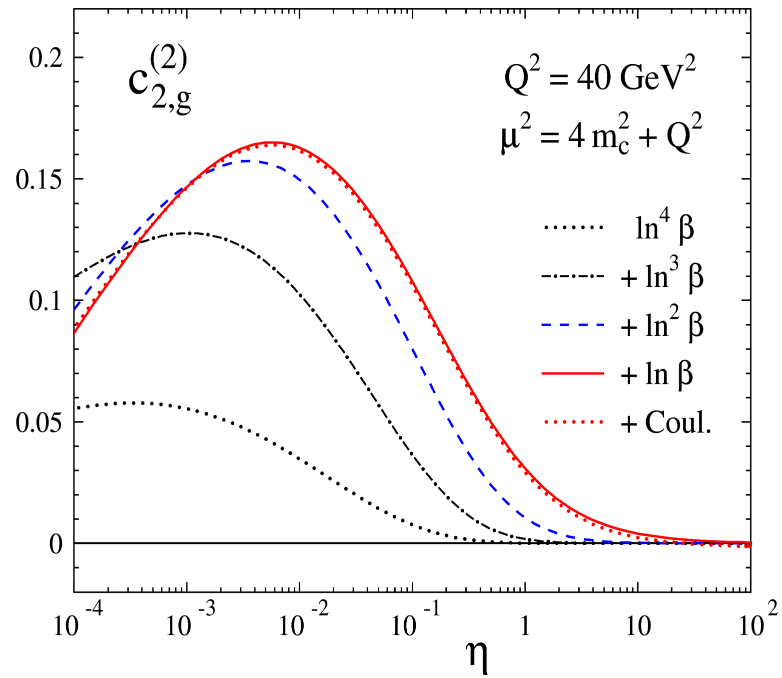
The threshold approximation works In a best way at small Q and x

$\eta = s/4m^2 - 1$ – distance to the threshold

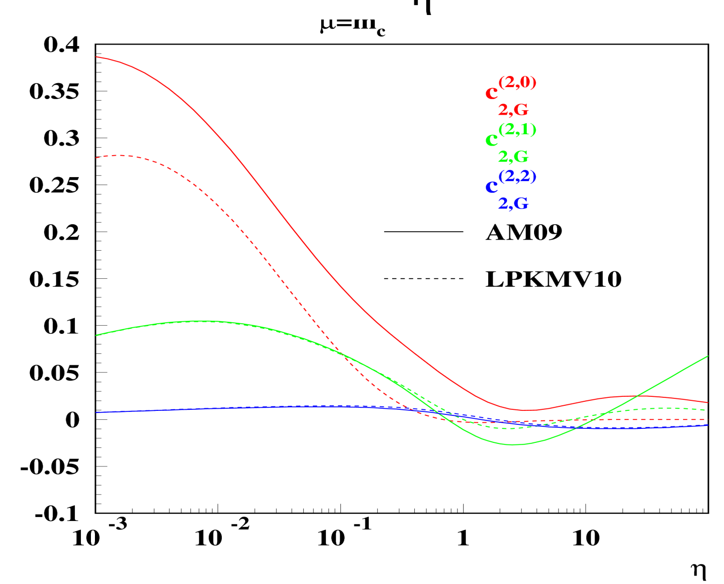
$\beta=\sqrt{1-4m^2/s}$ – quark velocity

Threshold soft-gluon resummation (cont'd)





Lo Presti, Kawamura, Moch, Vogt [hep-ph 1008.0951]



- The first log and Coulomb terms have been added
- F_2^c gets somewhat bigger at small Q and somewhat smaller at large Q

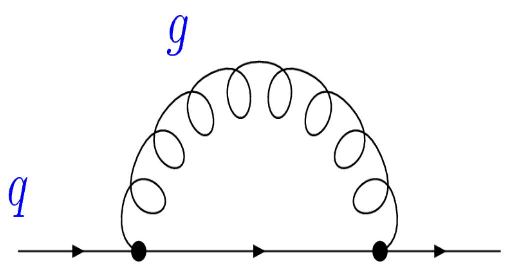
Pole mass definition

The pole mass is defined as a the QCD Lagrangian parameter and is commonly used in the QCD calculations

$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + \sum_{\text{flavors}} \bar{q} \, (\mathrm{i} \not{D} - m_q) \, q$$

Pole mass is defined for the free (unobserved) quarks

$$\not{p} - m_q - \Sigma(p, m_q) \Big|_{p^2 = m_q^2}$$

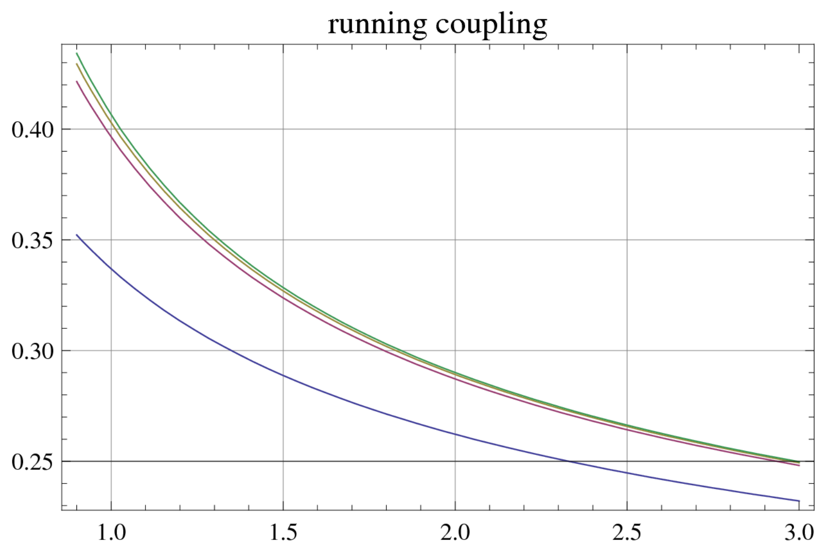


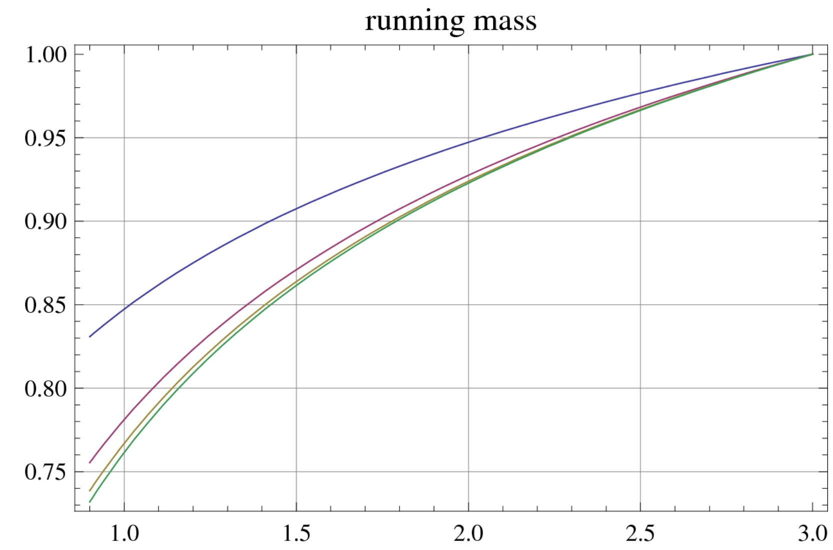
The quantum corrections due to the self-energy loop integrals receive contribution down to scale of $O(\Lambda_{QCD})$ → sensitivity to the high order corrections, particularly at the production threshold

Running quark mass

The renormgroup equation for mass is similar to one for the coupling constant

$$\mu^2 \frac{d}{d\mu^2}\alpha_s(\mu) = \beta(\alpha_s) \qquad \mu^2 \frac{d}{d\mu^2}m(\mu) = \gamma(\alpha_s)m(\mu)$$





The corrections up to 4-loops are known

van Ritbergen, Vermaseren, Larin PLB 400, 379 (1997)

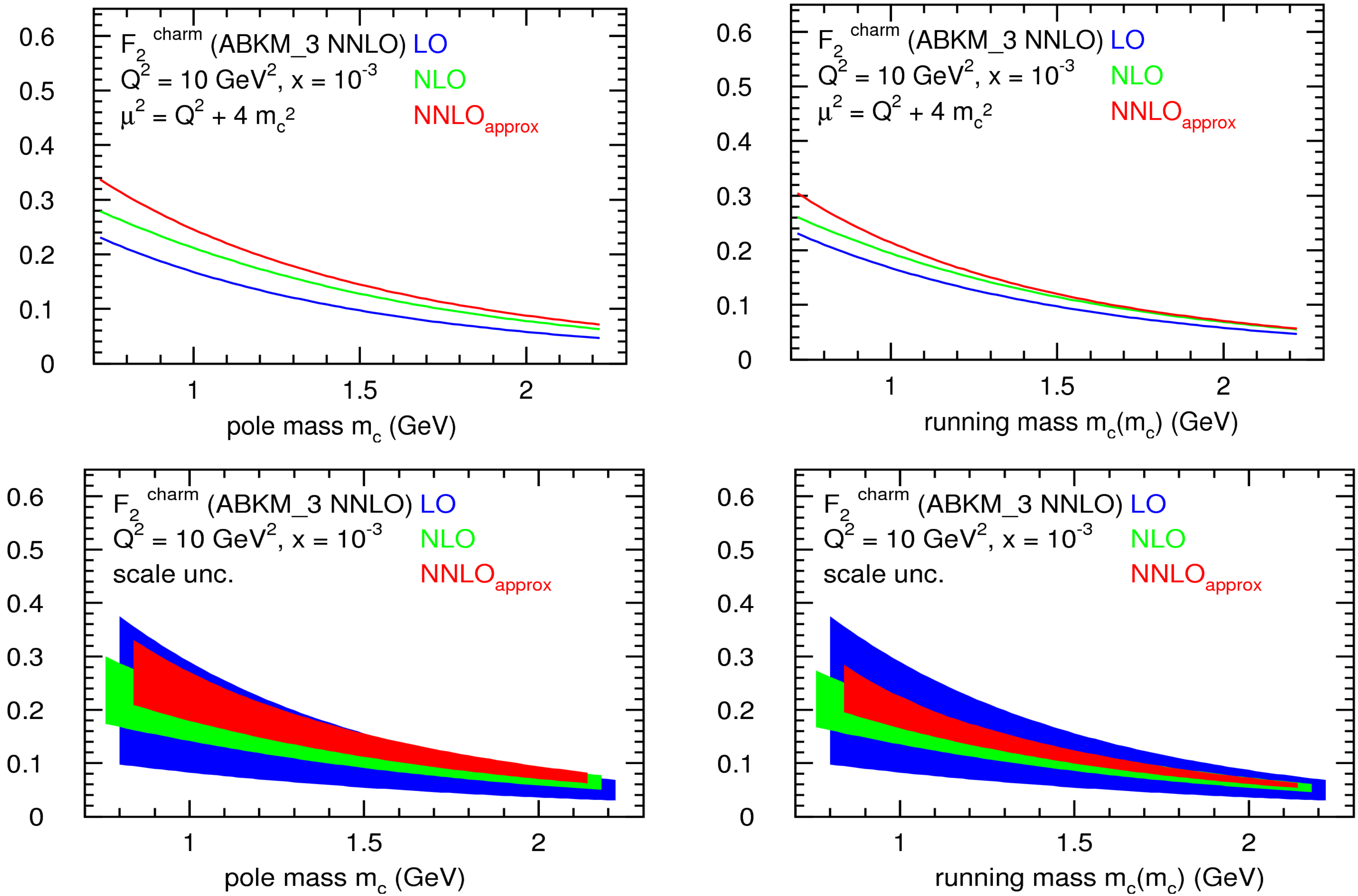
Chetyrkin PLB 404, 161 (1997)

Vermaseren, Larin, van Ritbergen PLB 405, 327 (1997)

The choice of $\mu_R = m_c$ is close to the DIS data kinematic → better perturbative convergence and reduced scale dependence

Running mass definition for the DIS SFs

Pole mass | Running mass

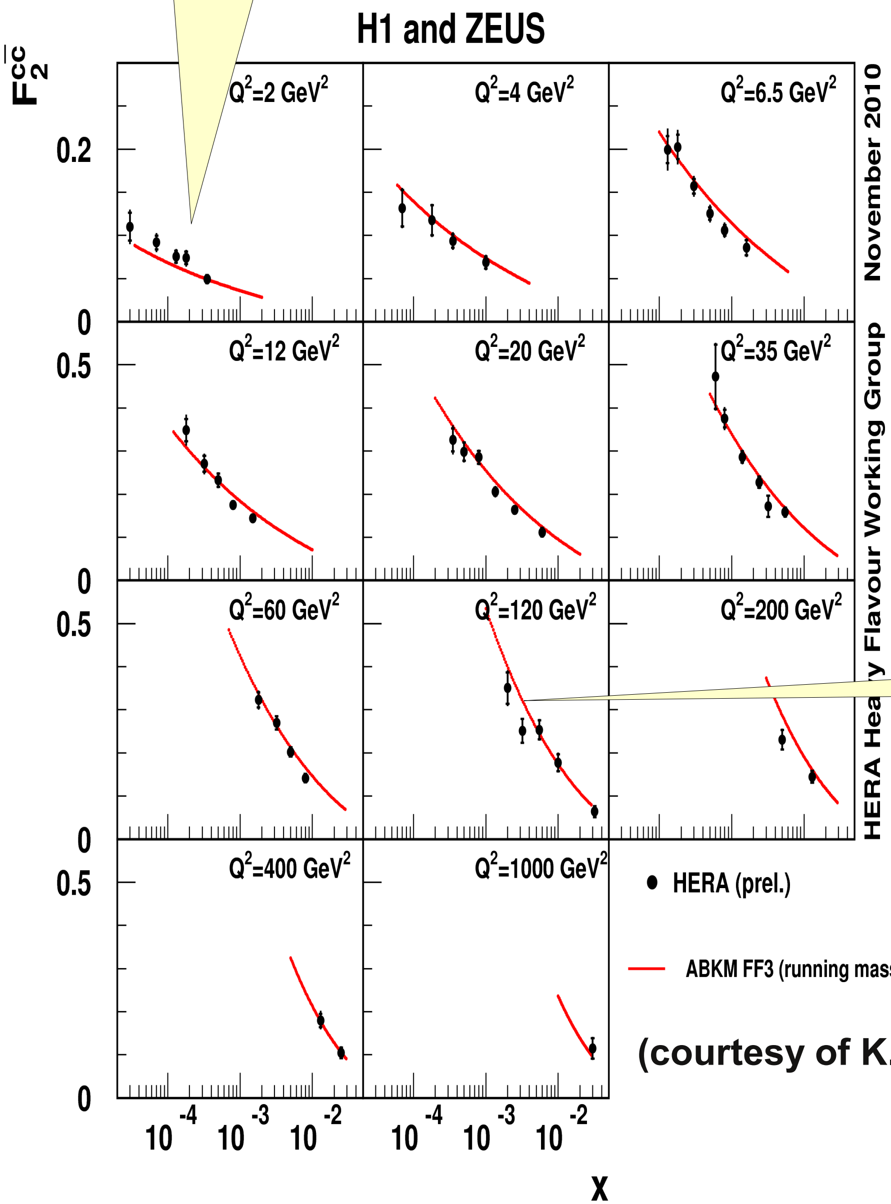


sa, Moch [hep-ph 1011.5790]

c-quark production

The NNLO(approx.) FFNS ABM ***predictions*** based on the running mass definition are In nice agreement with the new HERA data

N^{3}LO corrections?



(courtesy of K.Lipka)

$m_c(m_c)$=1.27±0.08 GeV (PDG '10)

$m_c(m_c)$=1.18±0.06 GeV (incl.F_2 +PDG)

The HERA data prefer $m_c(m_c)$ close to the PDG value

Improved accuracy due to correlation between quark and gluon PDFs must be reduced

No need for the VFN scheme

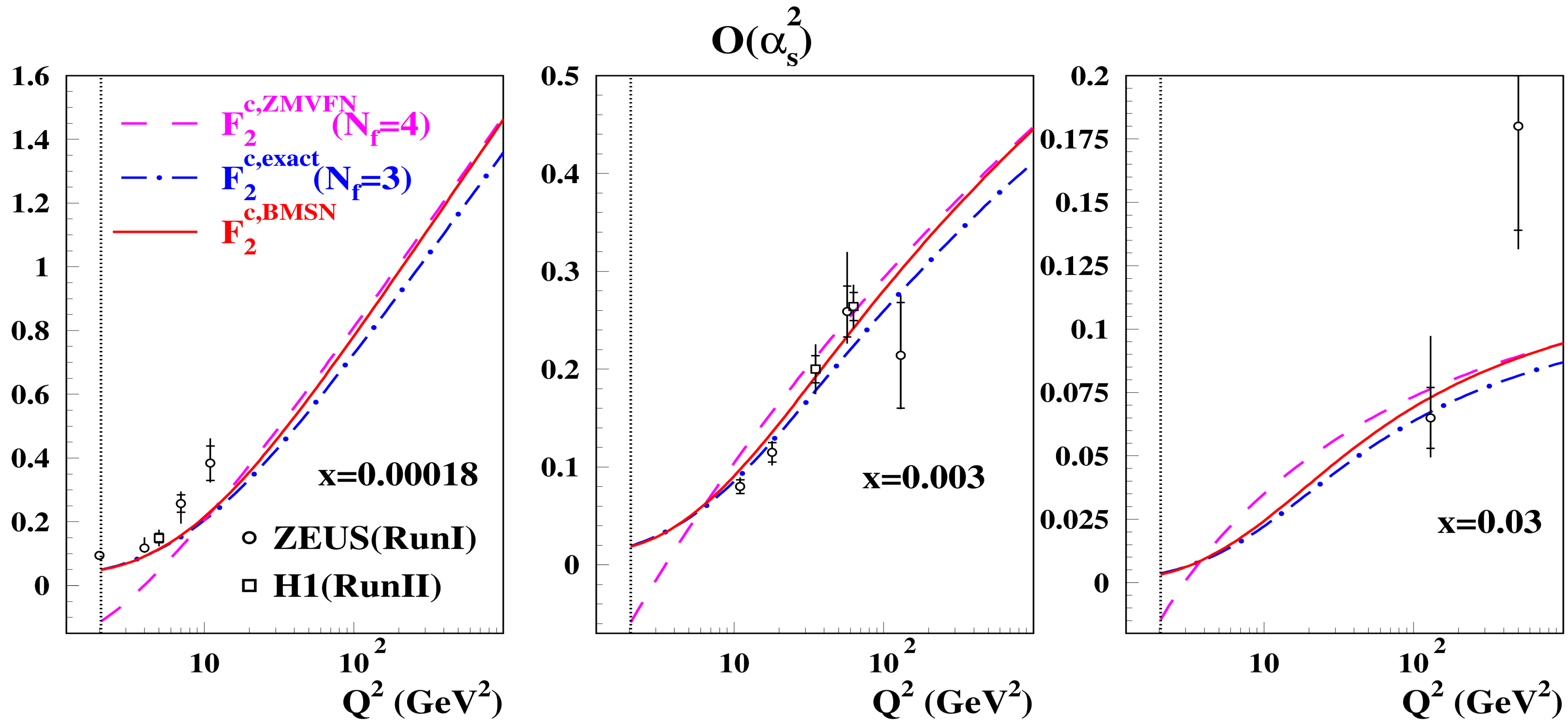
With the running mass definition the NNLO corrections are not so big?

At Q >> m_c first Mellin NNLO moments are known

Ablinger at al. NPB 844, 26 (2011)

Bierenbaum, Blümlein, Klein NPB 829, 417 (2009)

Running mass and the VFN scheme



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

In the NLO the FFNS is sufficient for description of the realistic DIS data – the big logs appear in the high order corrections to the massive coefficient functions

Glück, Reya, Stratmann NPB 422, 37 (1994)

- With the running mass definition the difference between VFN and FFN is reduced?
- Theoretical uncertainties in the heavy quark PDFs reduced   sa, Blümlein, Moch, in preparation

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

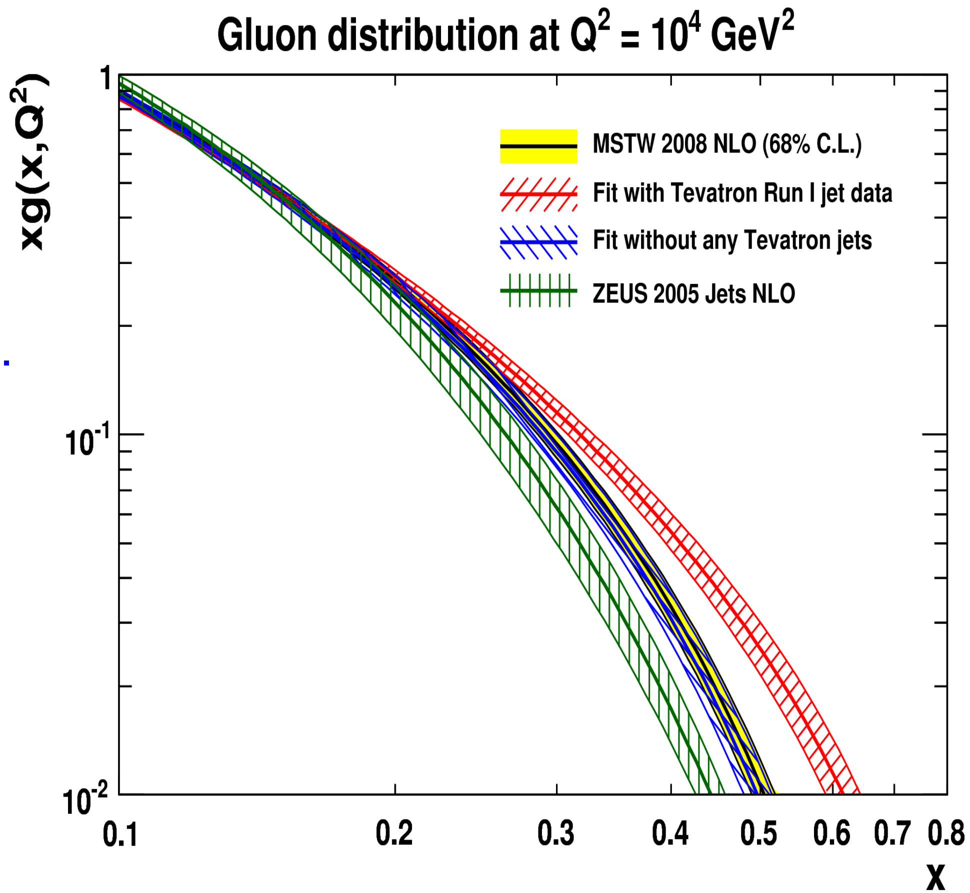
NLO evolution + NLO coefs
- consistent fit

.NNLO evolution + NLO coefs
- the PDF evolution more accurate
- the PDFs ready for the HO calculations

FastNLO is used to employ NLO corrections.

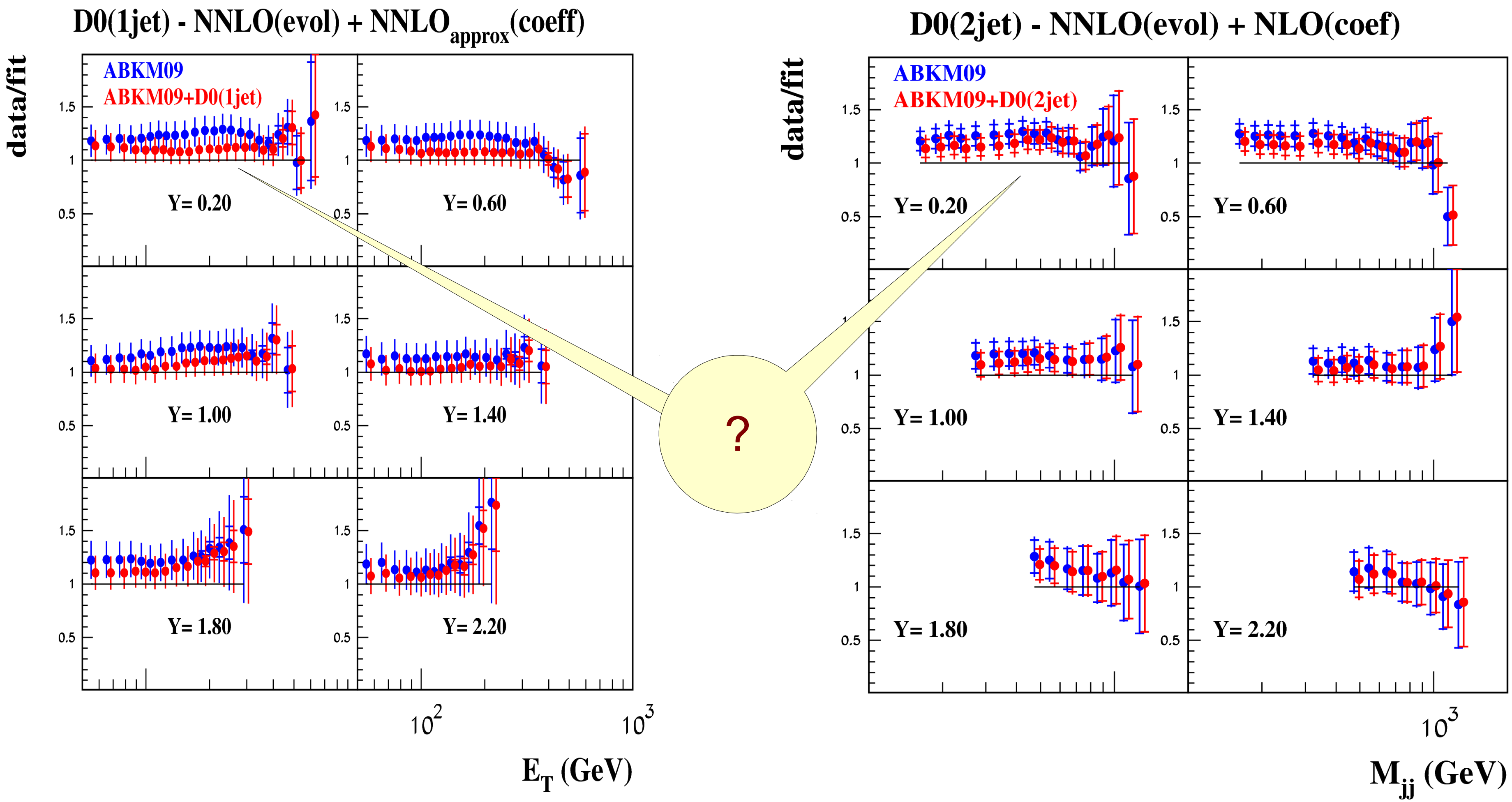
Kluge, Rabberitz, Wobbisch [hep-ph 0609285]

Consistency of data sets



MSTW Collaboration EPJC 63, 189 (2009)

Run II D0 data in the ABKM fit

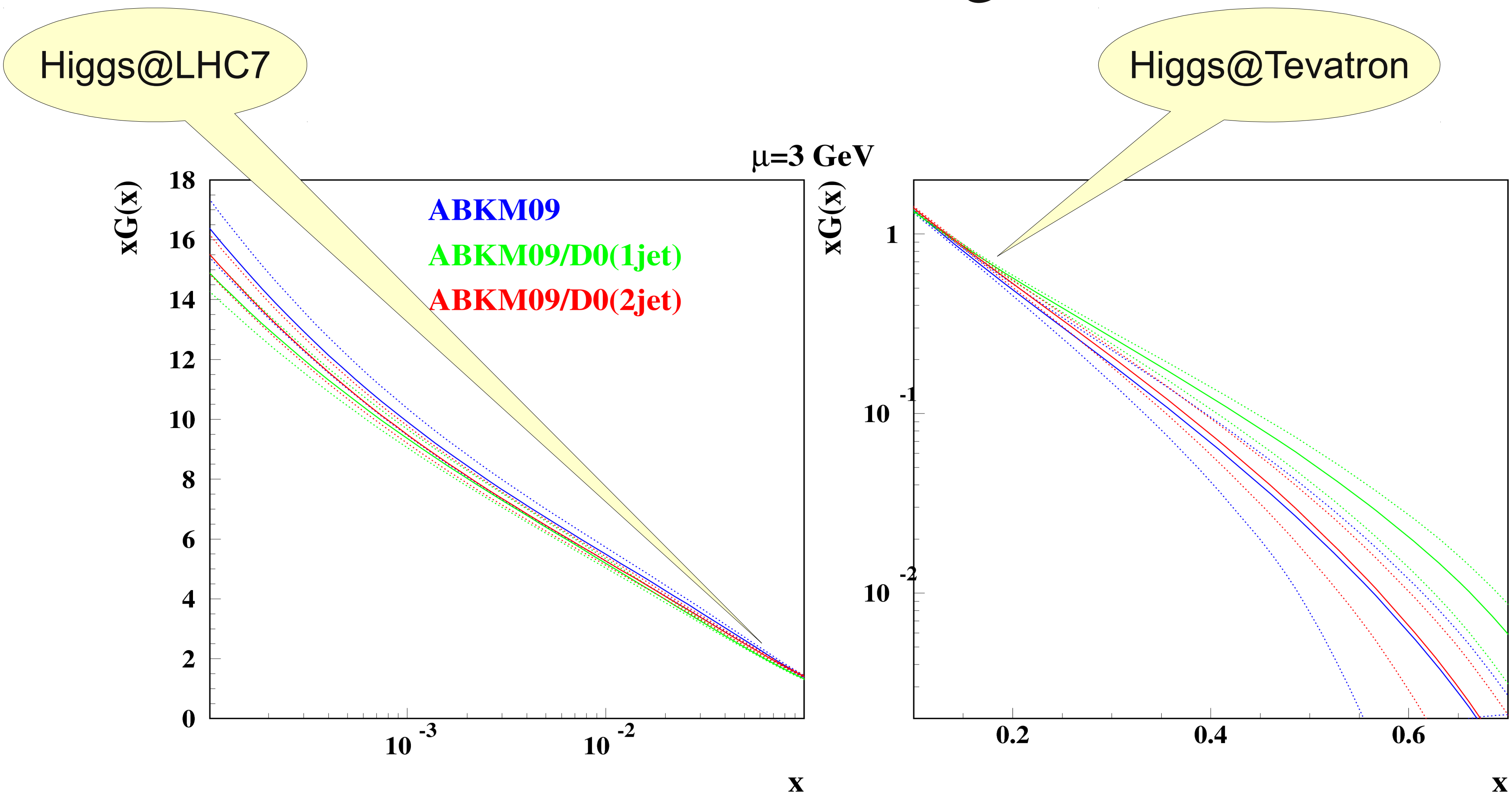


- Mixed scheme: 3-flavor PDFs for the DIS and 5-flavor PDFs for jets
- The systematics errors dominate

$\mu_r = \mu_F = E_T$
24 sources of systematics
χ^2/NDP=103/110

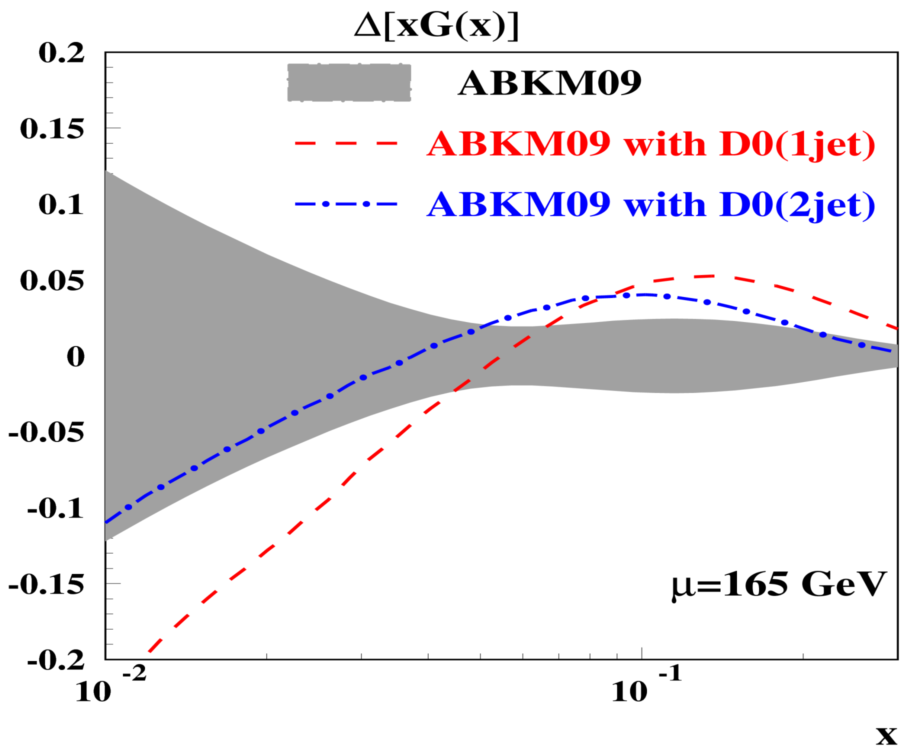
$\mu_r = \mu_F = M_{JJ}$
Combined systematics
χ^2/NDP=21/71 – *due to combined errors?*

Gluons at large x



- The Tevatron jet data affect gluon distribution mostly at large x
- *What is the proper selection of the jet data? – Run I data give even bigger large-x gluons*
- Potential impact of the HERA jet data and new precise DIS data looks promising → EIC, JLAB@12 and other facilities

Gluons at small *x* and Higgs c.s.



Tevatron

$\sigma(H)$	ABKM PDFs	1-jet inclusive data	di-jet data
NLO	0.206(17) pb	0.235(10) pb	0.212(9) pb
NNLO	**0.253(22) pb**	0.297(12) pb	0.278(13) pb

LHC7

$\sigma(H)$	ABKM PDFs	1-jet inclusive data	di-jet data
NLO	5.73(17) pb	5.89(13) pb	5.76(11) pb
NNLO	**7.05(23) pb**	7.30(15) pb	7.27(14) pb

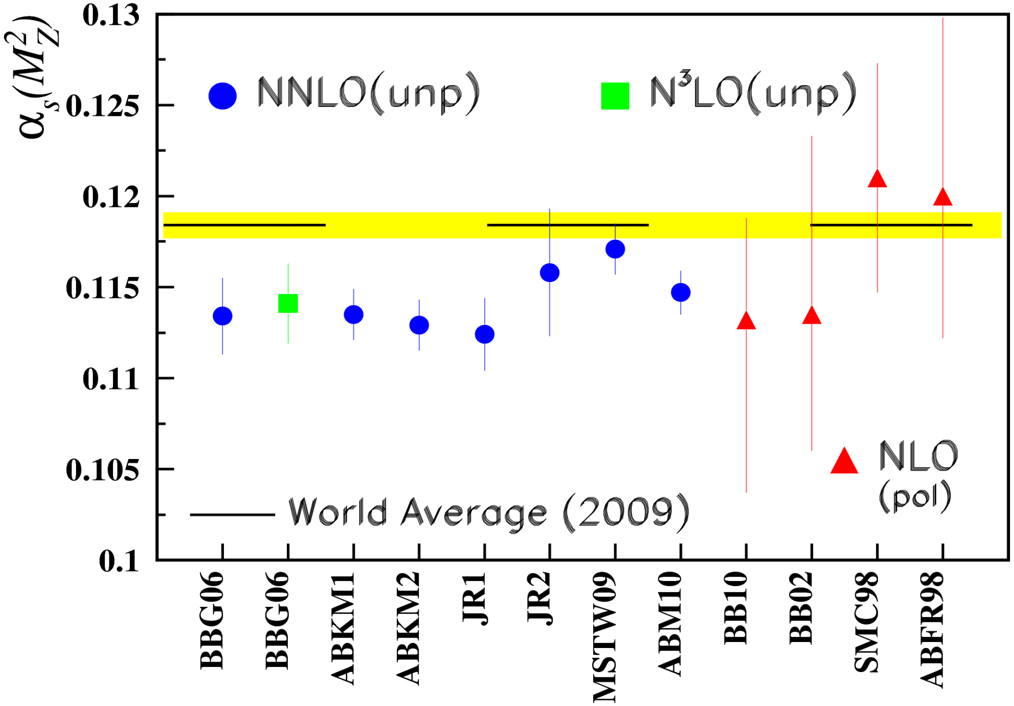
M_H=165 GeV

ABKM: $\alpha_s(M_z)$=0.1135(14) (NNLO)
ABKM+1jet: $\alpha_s(M_z)$=0.1149(12) ($NNLO_{apx}$)
ABKM+2jet: $\alpha_s(M_z)$=0.1144(9) ($NNLO_{apx}$)

The value of α_s is still "small"

- The D0 jet data increase the Higgs c.s. by 1-2σ depending on mass/collision energy
- Statistical significance of the 1jet and 2jet samples is similar
- For Tevatron impact of the 2jet data is smaller

PDFs and α_s



Blümlein, Böttcher NPB 841, 205 (2010)

- Many important hadronic processes i.e. Higgs and top-quark production are $\sim\alpha_s^2$.
- The gluon distribution is correlated with α_s → effect is accumulated.
- The value of α_s from DIS *(mostly defined by the non-singlet part)* is about 3σ lower than the world average of 2009.

Bethke EPJC 64, 689 (2009)

From the Tevatron jet data

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

D0 Collaboration [hep-ex 1006.2855]

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

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

$\alpha_s(M_z)=0.1171\pm0.0014$ (NLO)

MSTW Collaboration EPJC 64, 653 (2009)

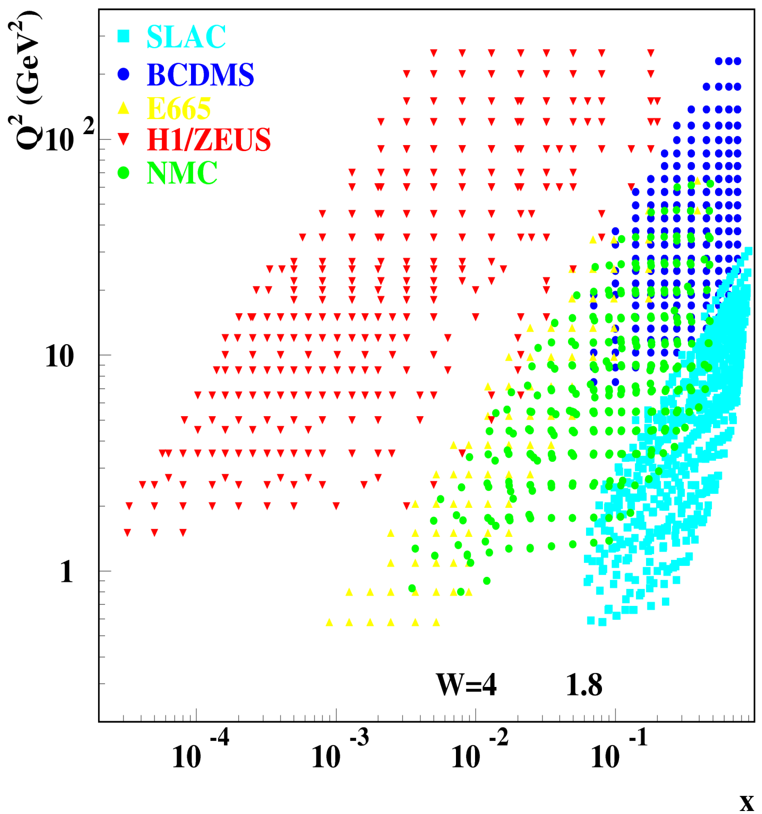
From the world e+e- data on trust

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

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

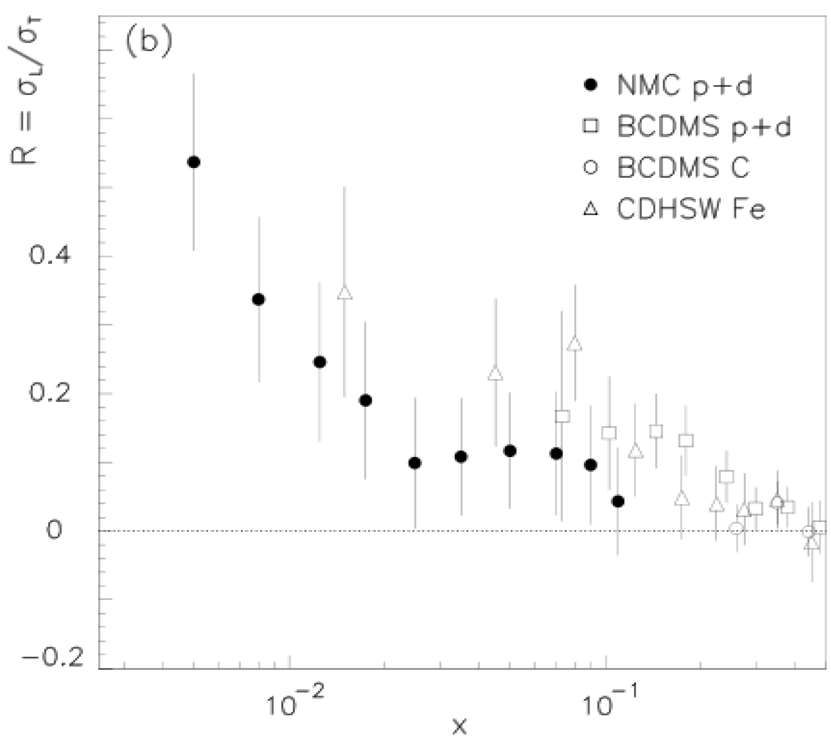
Recent results are in nice agreement with the DIS values

NMC data in the PDF fit



NM Collaboration NPB 483, 3 (1997)

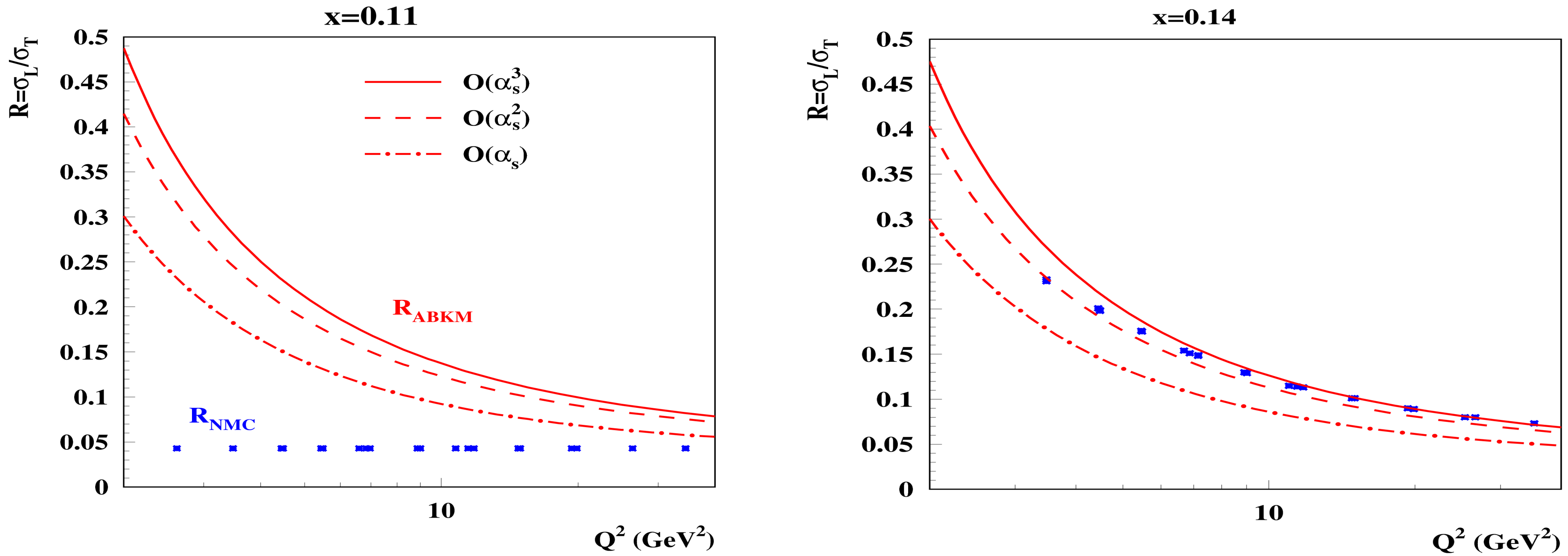
- The muon beam experiment at CERN with the beam energies of 90, 120, 200, and 280 GeV and partial overlap of the samples
- Fills gap in kinematics of the SLAC and HERA data at $Q^2 < 10$ GeV^2



At $x<0.012$ the structure function R is extracted from the data; at $x>0.012$ it as taken as R_{1990} (empiric parameterization of the SLAC data motivated by QCD and Including the high-twist terms)

Whitlow et al. PLB 250, 193 (1990)

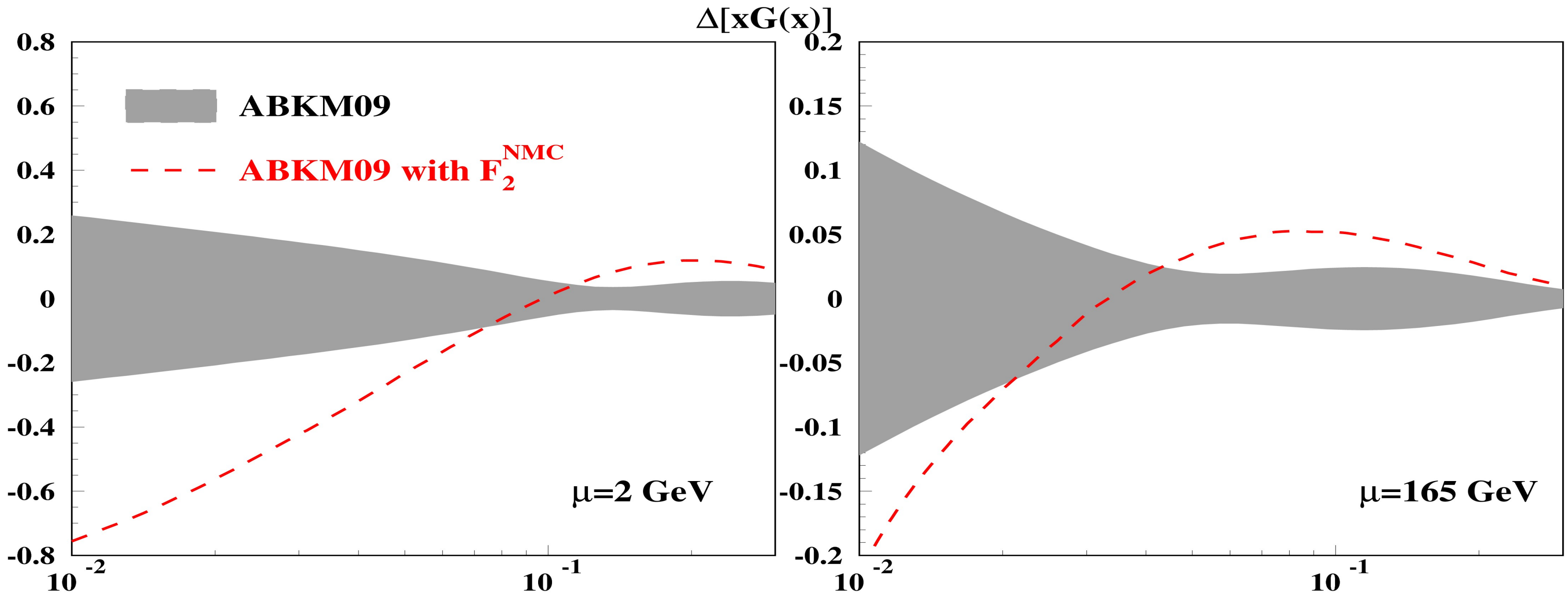
Value of R and α_S



$\alpha_s(M_Z)$	$\alpha_s(M_Z)$ with $\sigma_{\rm NMC}$	$\alpha_s(M_Z)$ with $F_2^{\rm NMC}$	difference
NLO	0.1179(16)	0.1195(17)	$+0.0016 \simeq 1\sigma$
NNLO	**0.1135(14)**	0.1170(15)	$+0.0035 \simeq 2.3\sigma$
NNLO $+F_L$ at $O(\alpha_s{}^3)$	0.1122(14)	0.1171(14)	$+0.0050 \simeq 3.6\sigma$

- With a smooth model for R the value of α_s is smaller
- Effect rises from NLO to NNLO

The value of α_s and Higgs c.s.



Tevatron

$\sigma(H)$	$\sigma(H)$ with σ_{NMC}	$\sigma(H)$ with F_2^{NMC}	difference
NLO	0.206(17) pb	0.225(18) pb	0.019 pb $\simeq 1.1\sigma$
NNLO	**0.253(22) pb**	0.309(24) pb	0.056 pb $\simeq 2.3\sigma$
NNLO $+F_L$ at $O(\alpha_s^3)$	0.242(22) pb	0.310(24) pb	0.068 pb $\simeq 2.8\sigma$

LHC7

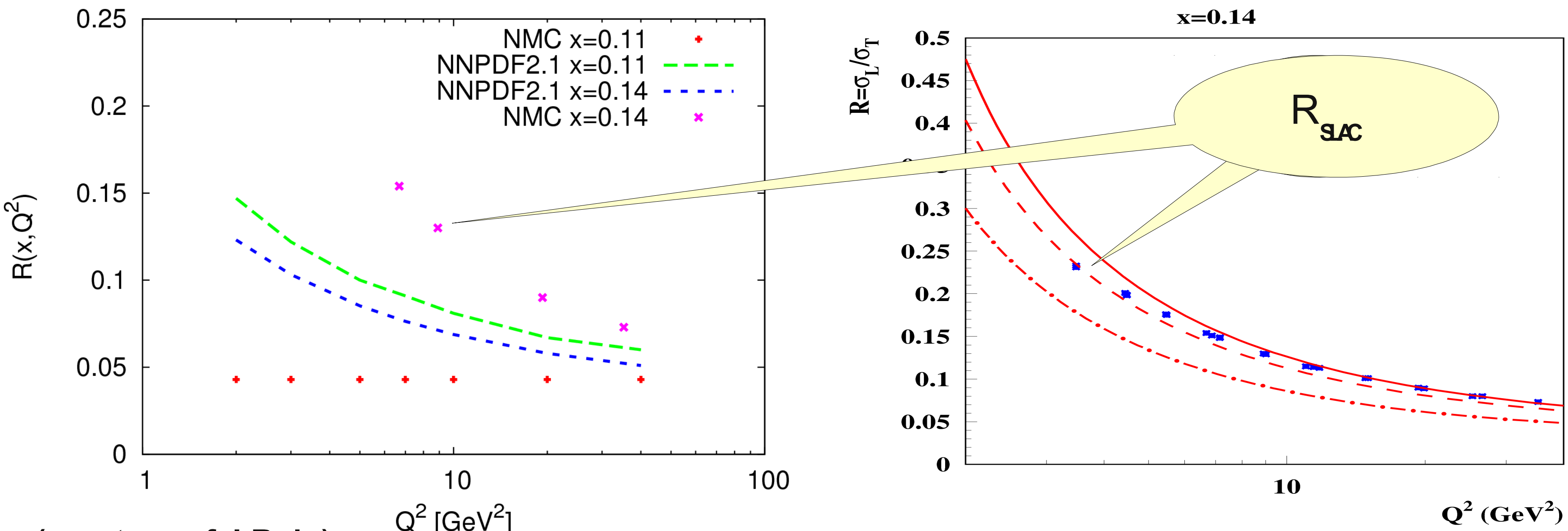
$\sigma(H)$	$\sigma(H)$ with σ_{NMC}	$\sigma(H)$ with F_2^{NMC}	difference
NLO	5.73(17) pb	5.95(18) pb	0.18 pb $\simeq 1.0\sigma$
NNLO	**7.05(23) pb**	7.70(23) pb	0.65 pb $\simeq 2.7\sigma$
NNLO $+F_L$ at $O(\alpha_s^3)$	6.84(21) pb	7.68(23) pb	0.84 pb $\simeq 3.7\sigma$

M_H=165 GeV

The shift of 2-3σ in c.s. both for Tevatron and LHC

NNPDF reanalysis

NNPDF Collaboration   hep-ph 1102.3182



(courtesy of J.Rojo)

sa, Blümlein, Moch [hep-ph 1101.5261]

- The NNPDF model of R doesn't match with the SLAC parameterization – *the high-twist terms are essential*

$$R^{fit} = \frac{b_1}{\ln(Q^2/\Lambda^2)}\Theta(x, Q^2) + \frac{b_2}{Q^2} + \frac{b_3}{Q^4+0.3^2},$$

Whitlow et al. PLB 250, 193 (1990)

- The NNPDF analysis is performed in the NLO
- The correlation between α_s and gluons is not considered by NNPDF

More detailed comparison is necessary

Ansatz for the DIS c.s.

$$\frac{d^2\sigma(x,Q^2)}{dxdQ^2} = \frac{4\pi\alpha^2}{xQ^4}\left\{1-y-xy\frac{M^2}{s}+\left(1-\frac{2m_l^2}{Q^2}\right)\left(1+4x^2\frac{M^2}{Q^2}\right)\frac{y^2}{2(1+R(x,Q^2))}\right\}F_2(x,Q^2),$$

sa, Blümlein, Moch [hep-ph 1101.5261]

$$\tilde{\sigma}^{\rm NC}(x,y,Q^2) = \left[\frac{2\pi\alpha^2}{xQ^4}Y_+\right]^{-1}\frac{d^2\sigma^{\rm NC}}{dxdQ^2}(x,y,Q^2) = F_2^{\rm NC}(x,Q^2)\left(2-2y+\frac{y^2}{1+R(x,Q^2)}\right), \quad (2)$$

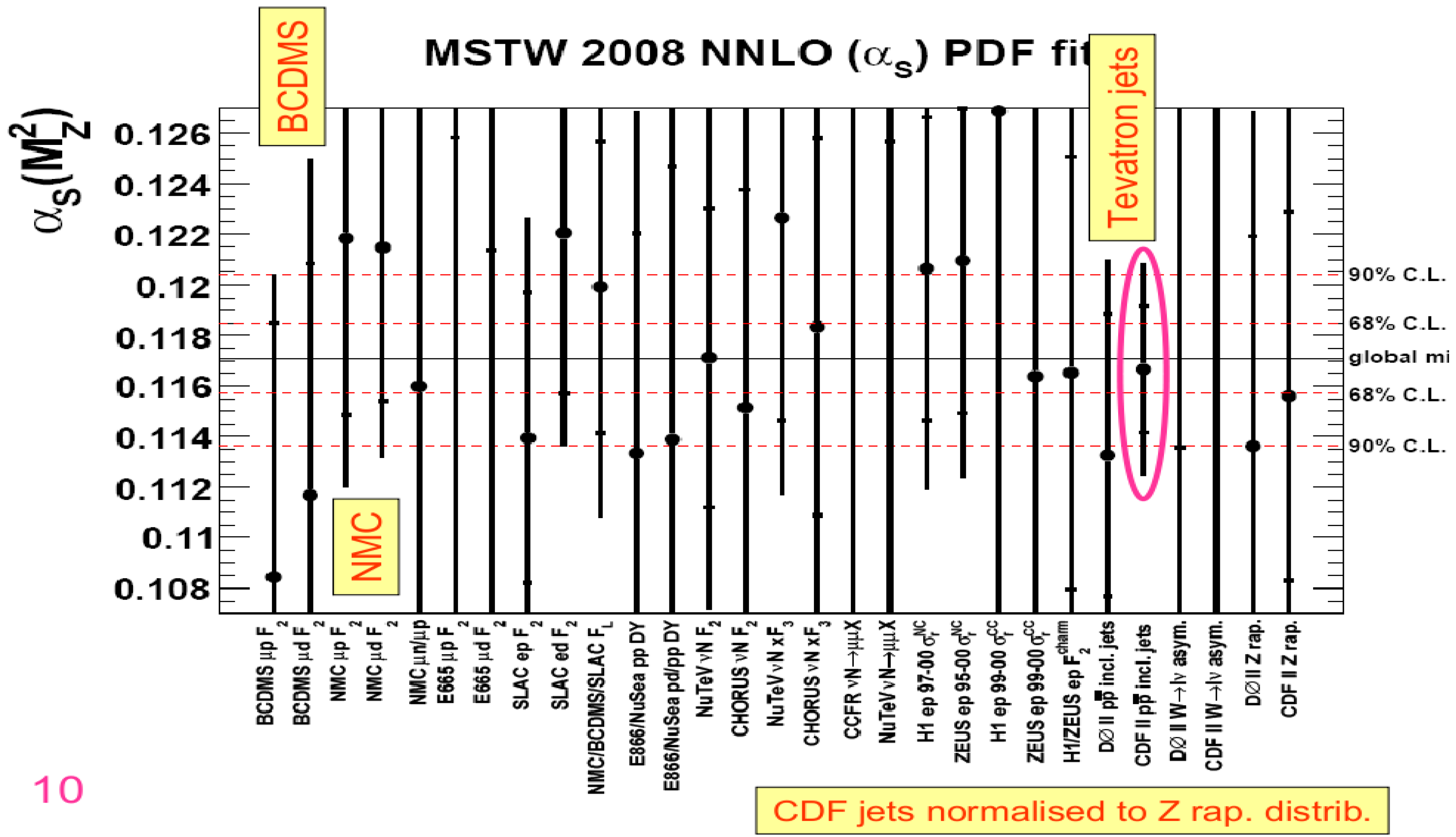
where

$$R\left(x,Q^2\right) = F_L(x,Q^2)/\left(F_2(x,Q^2)-F_L(x,Q^2)\right). \quad (3)$$

NNPDF Collaboration hep-ph 1102.3182

Are the target mass corrections applied by NNPDF?
clarified in the revised version?

MSTW observes smaller shift: $\alpha_s(M_z)$=0.1171 → 0.1168 (NNLO)

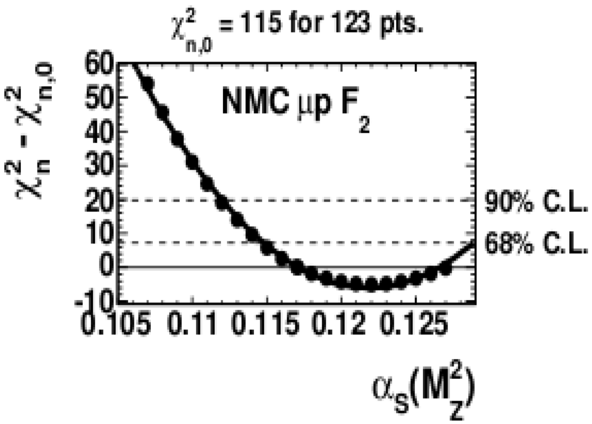


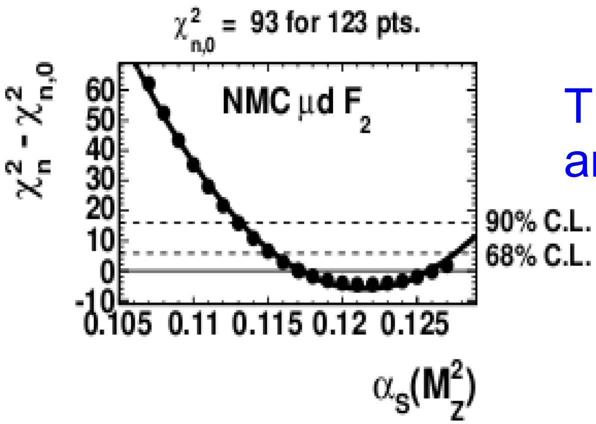
MSTW Collaboration, Munchen Jan 2011

Strong constraint on MSTW value from the jet data?

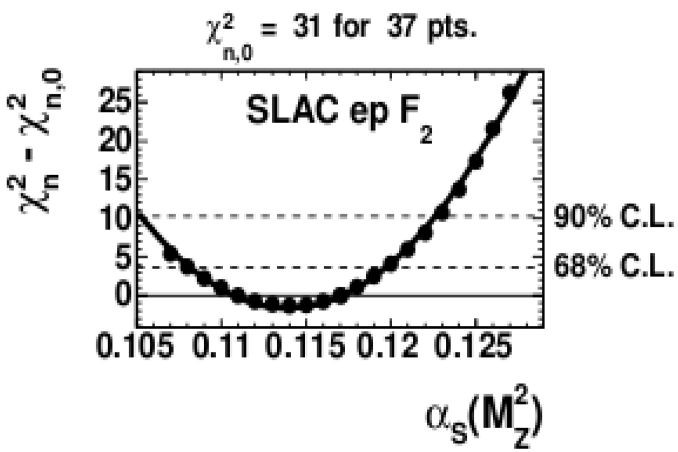
Some DIS data sets in MSTW fit

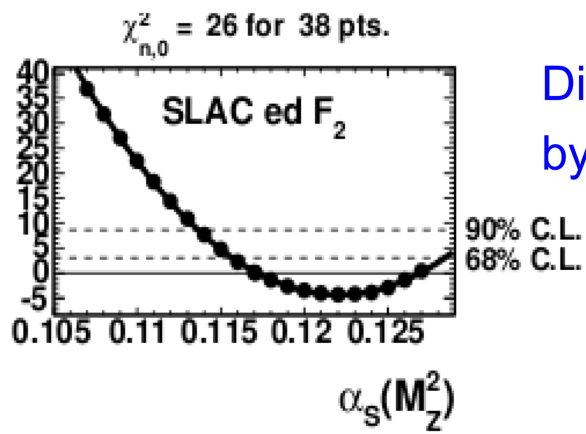
NNLO



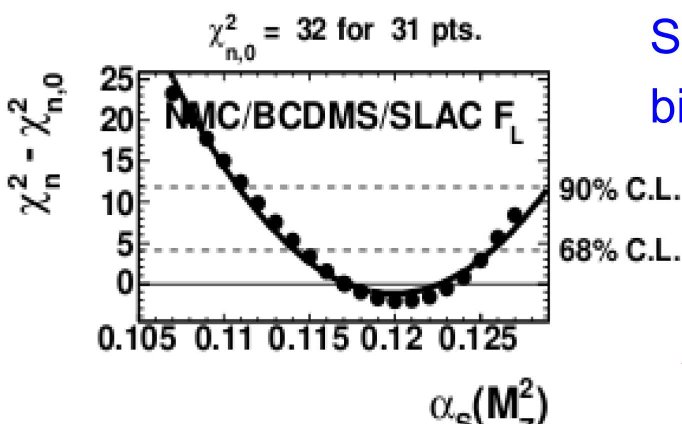


The NMC systematics uncertainties are combined





Different values of are α_s preferred by proton and deuteron data?



Strong sensitivity of α_s to the data on F_L, big value preferred → model of R?

ABKM code: www-zeuthen.desy.de/~alekhin/OPENQCDRAD

MSTW Collaboration EPJC 64, 653 (2009)

Summary and outlook

- The Tevatorn jet data included into the fit

  The “small” value of the α_s is confirmed in the approximate NNLO fit with the D0 jet data included:

  $\alpha_s(M_z)$=0.1135(14) → 0.1149(12) / 0.1144(9) (NNLO)

  depending on the data set used

  – consistent treatment of the DIS data is important

  – CDF data must move further up → selection of the data sets?

  The Higgs cross section can goes up by ~1σ

  – scale sensitivity? → no NNLO corrections

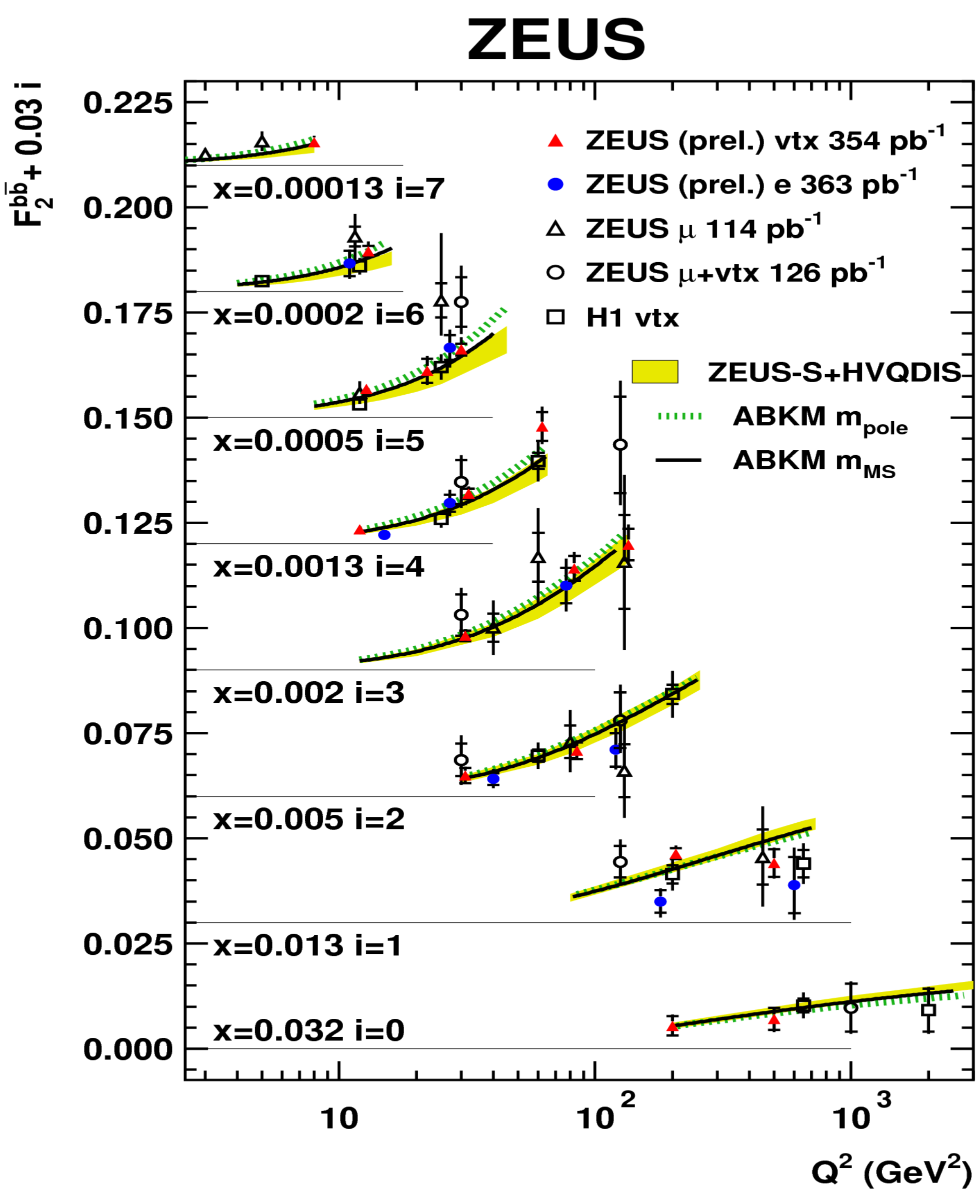
- The running mass definition is implemented for the DIS semi-inclusive structure functions

  – improved perturbative stability and the scale variation uncertainty

  – consistent treatment of the mass in DIS and other processes, like e+e- initiated

EXTRAS

b-quark production

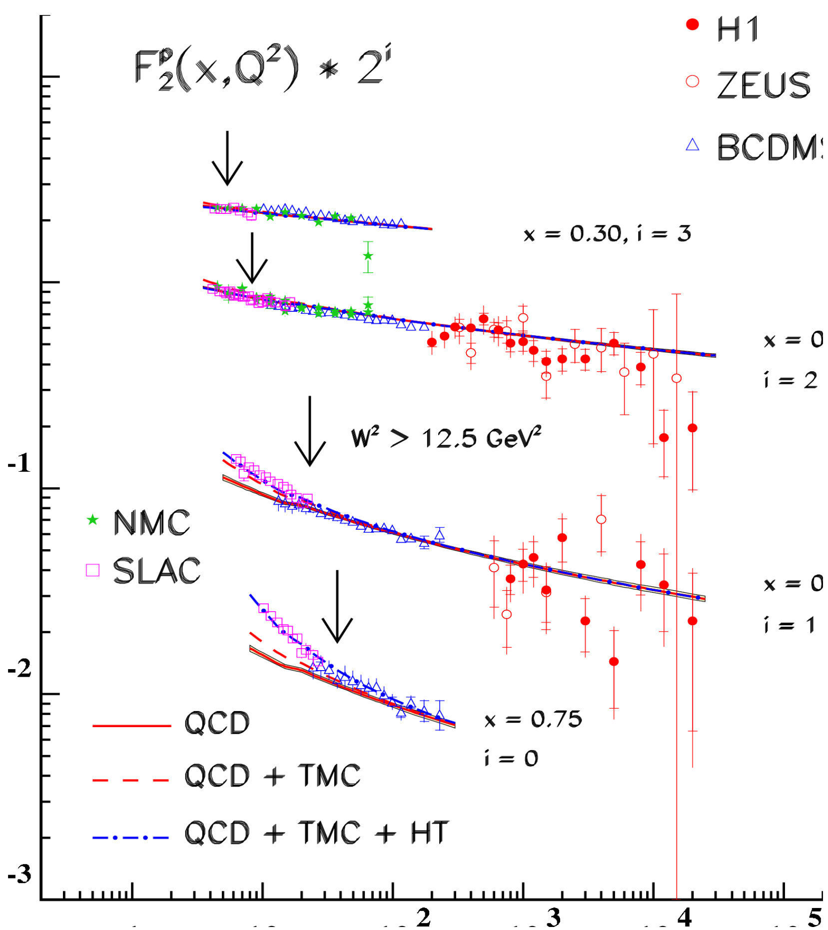


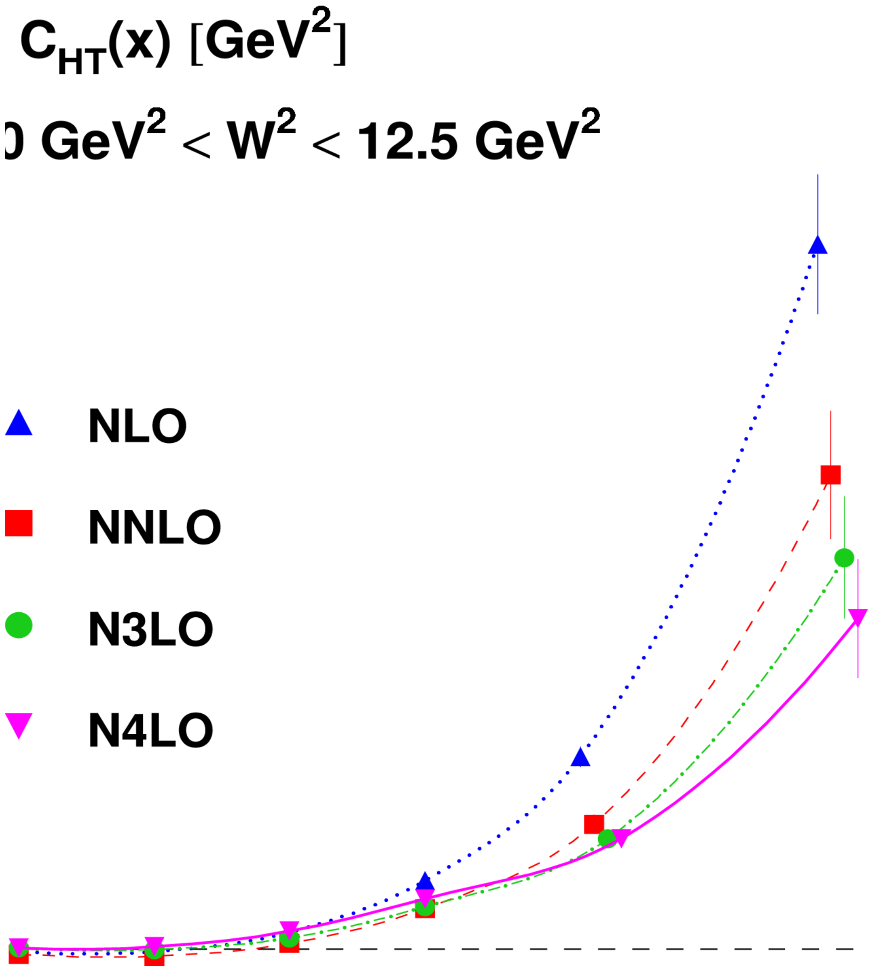
(courtesy of A.Geiser and P.Roloff)

For the b-quark production NNLO$_{approx}$ predictions work well → the threshold approximation is justified

No sensitivity to m_b → fixed at the PDG value $m_b(m_b)$=4.19±0.12 GeV

Twist-4 terms in DIS





Blümlein, Böttcher, Guffanti NPB 774, 182 (2007)