Higgs production and fixed-target DIS data

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in collaboration with **S. Alekhin** on arXiv:1011.5790

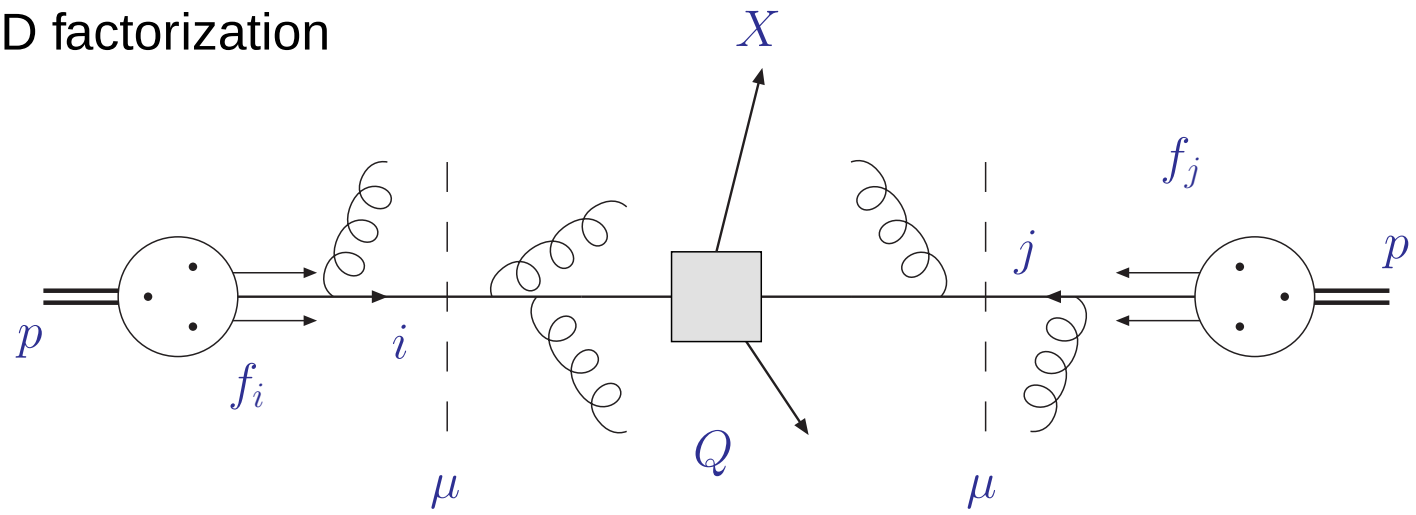
with **S. Alekhin** , **J. Blümlein** , **P. Jimenez-Delgado** , **E. Reya** on arXiv:1011.6259

with **S. Alekhin** , **J. Blümlein** on arXiv:1101.5261

– *Kick-off meeting of the LHCPhenoNet Initial Training Network*, Valencia, Feb 01, 2011 –

Introduction

- QCD factorization

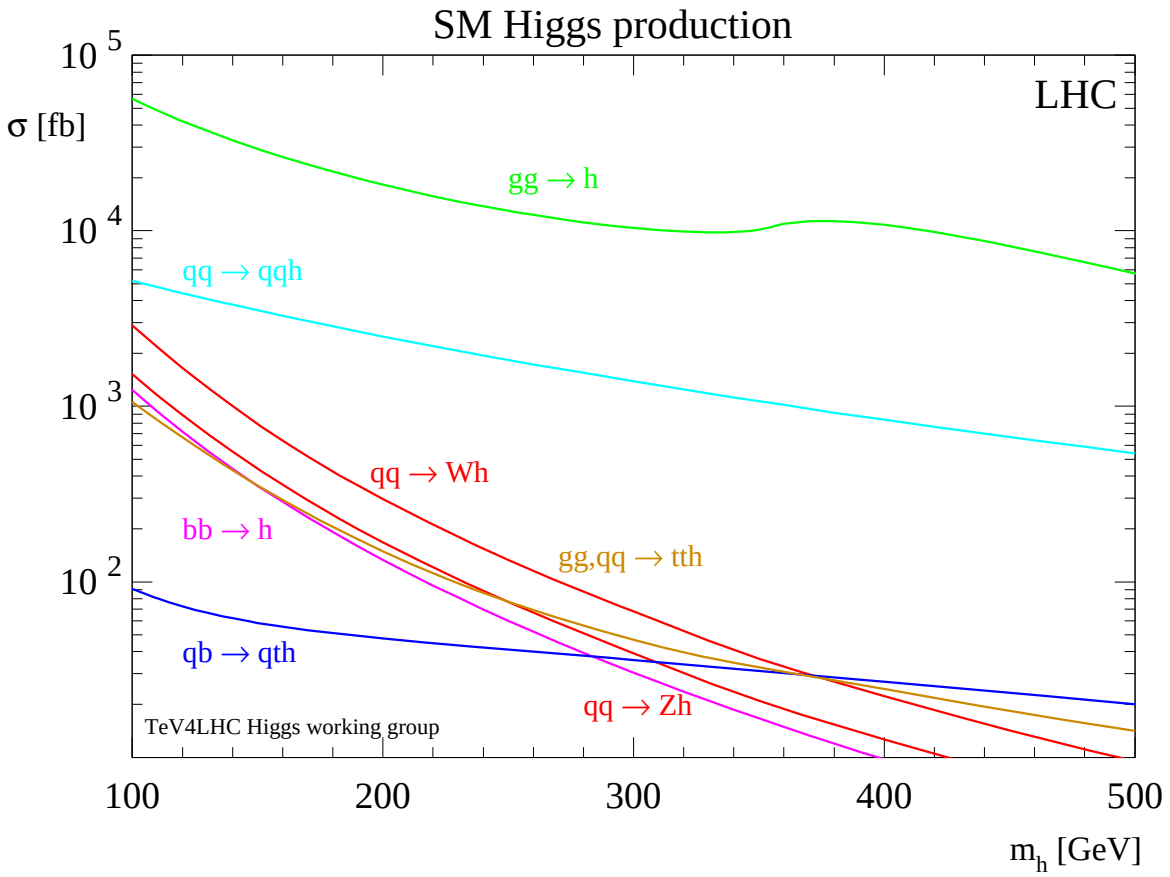


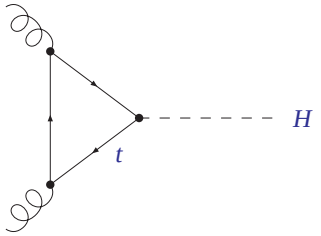
$$\sigma_{pp\to X} = \sum_{ij} f_i(\mu^2) \otimes f_j(\mu^2) \otimes \hat{\sigma}_{ij\to X}\left(\alpha_s(\mu^2), Q^2, \mu^2, m_X^2\right)$$

- Hard parton cross section $\hat{\sigma}_{ij\to X}$ calculable in perturbation theory
  - known to NLO, NNLO, ... ($\mathcal{O}(\text{few}\%)$ theory uncertainty)
- Non-perturbative parameters: parton distribution functions f_i, strong coupling α_s, particle masses m_X
  - known from global fits to exp. data, lattice computations, ...

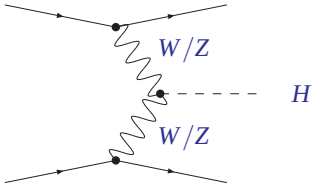
Cross section for Higgs production

- Most important parton channels for Higgs boson production TeV4LHC '06

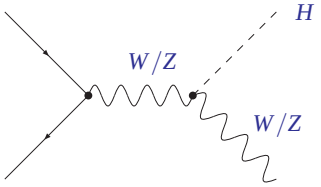




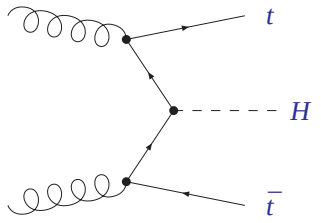
gg-fusion



weak boson fusion

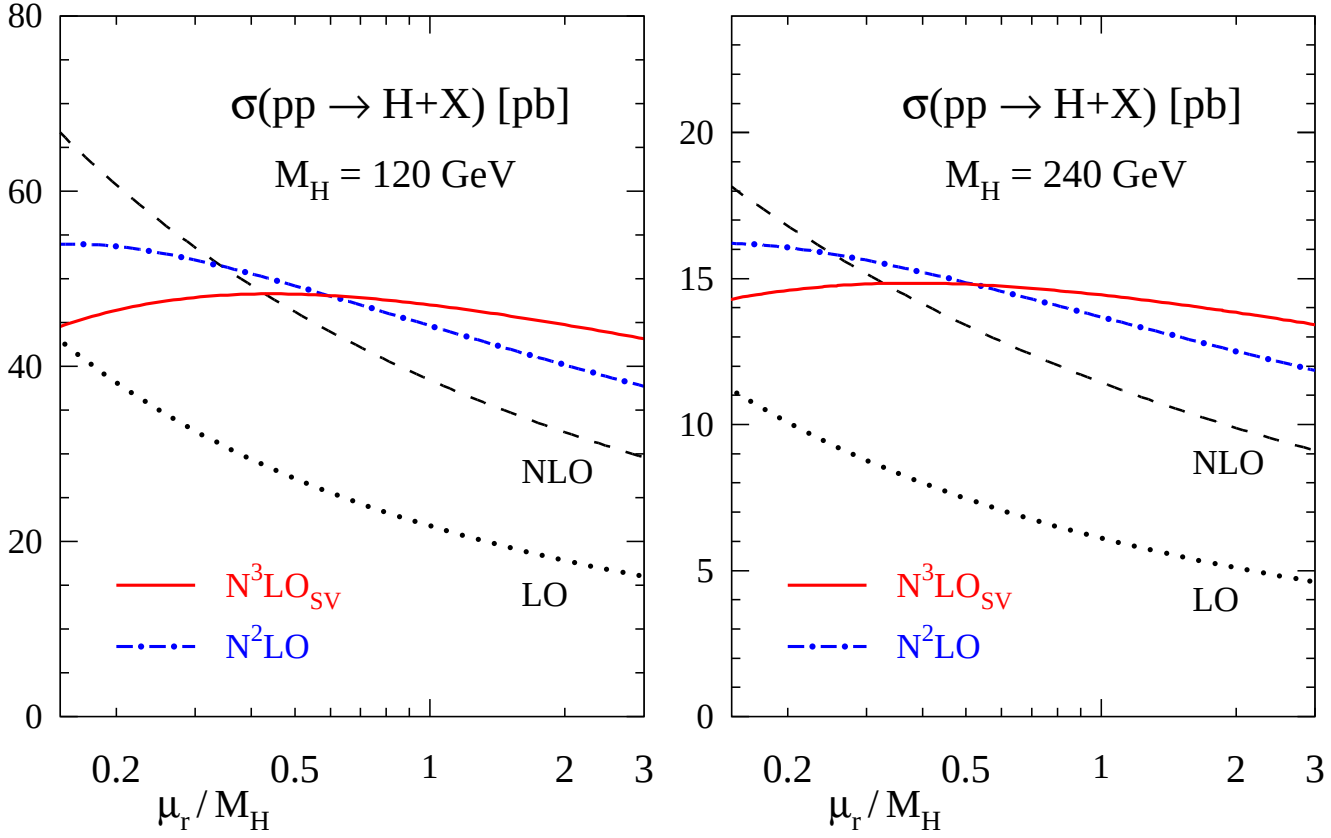


Higgs strahlung



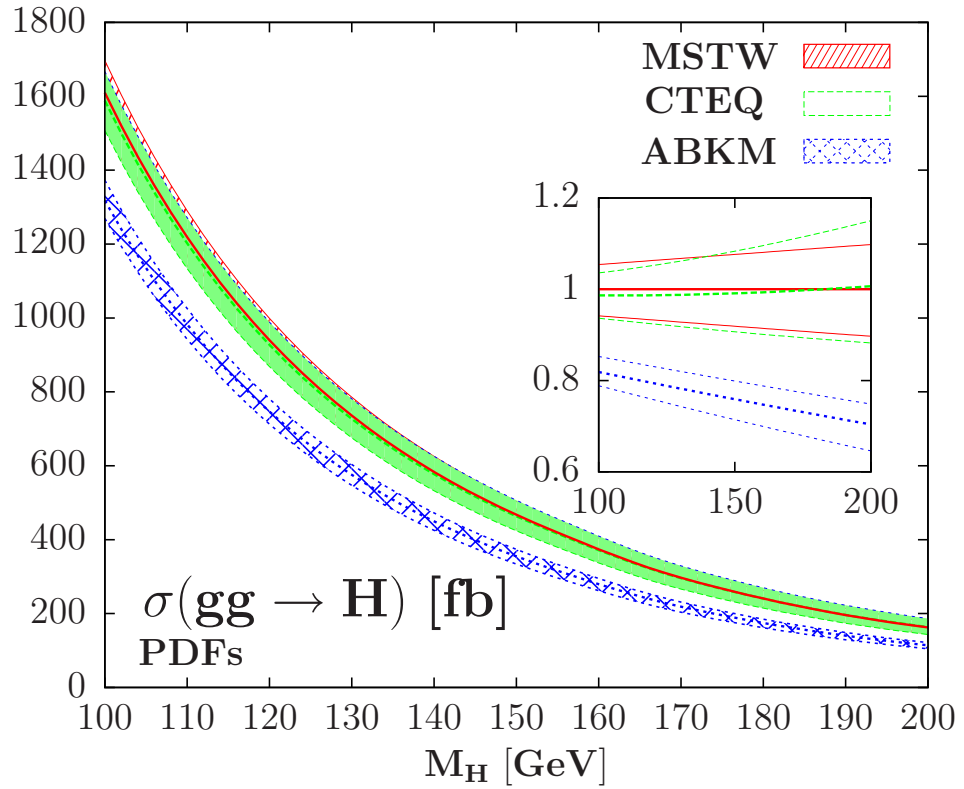
$t\bar{t}H$-channel

Higher-order corrections



- Apparent convergence of perturbative expansion
  - NNLO corrections still large
    Harlander, Kilgore '02; Anastasiou, Melnikov '02; Ravindran, Smith, van Neerven '03
  - improvement through complete soft N^3LO corrections S.M., Vogt '05
    or NNLL resummtion Catani, de Florian, Grazzini, Nason '03, Ahrens et al. '10
- Perturbative stability under renormalizaion scale variation

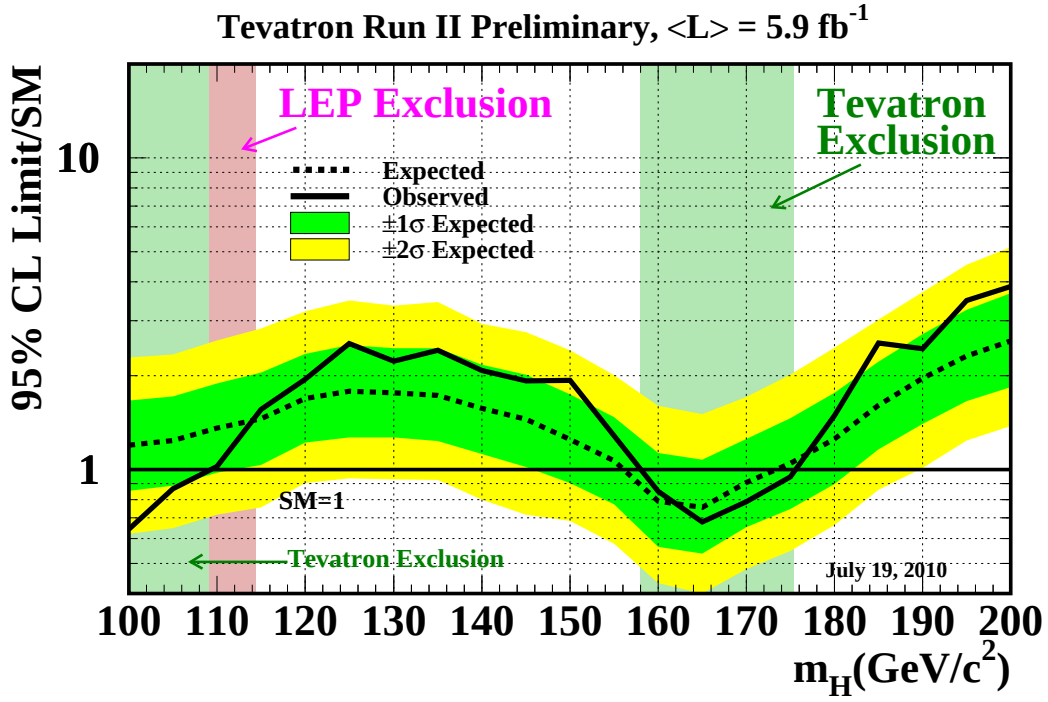
Dependence on parton distributions



- NNLO cross section $\sigma(gg \to H + X)$ at Tevatron with PDF uncertainties bands at $90\% CL$
  - largest differences in predictions from PDFs and value of α_s
    Baglio, Djouadi '10
  - e.g. at $M_H = 165$ GeV:
    MSTW $+35\%$ higher than ABKM; $+4.0\sigma$ standard deviation

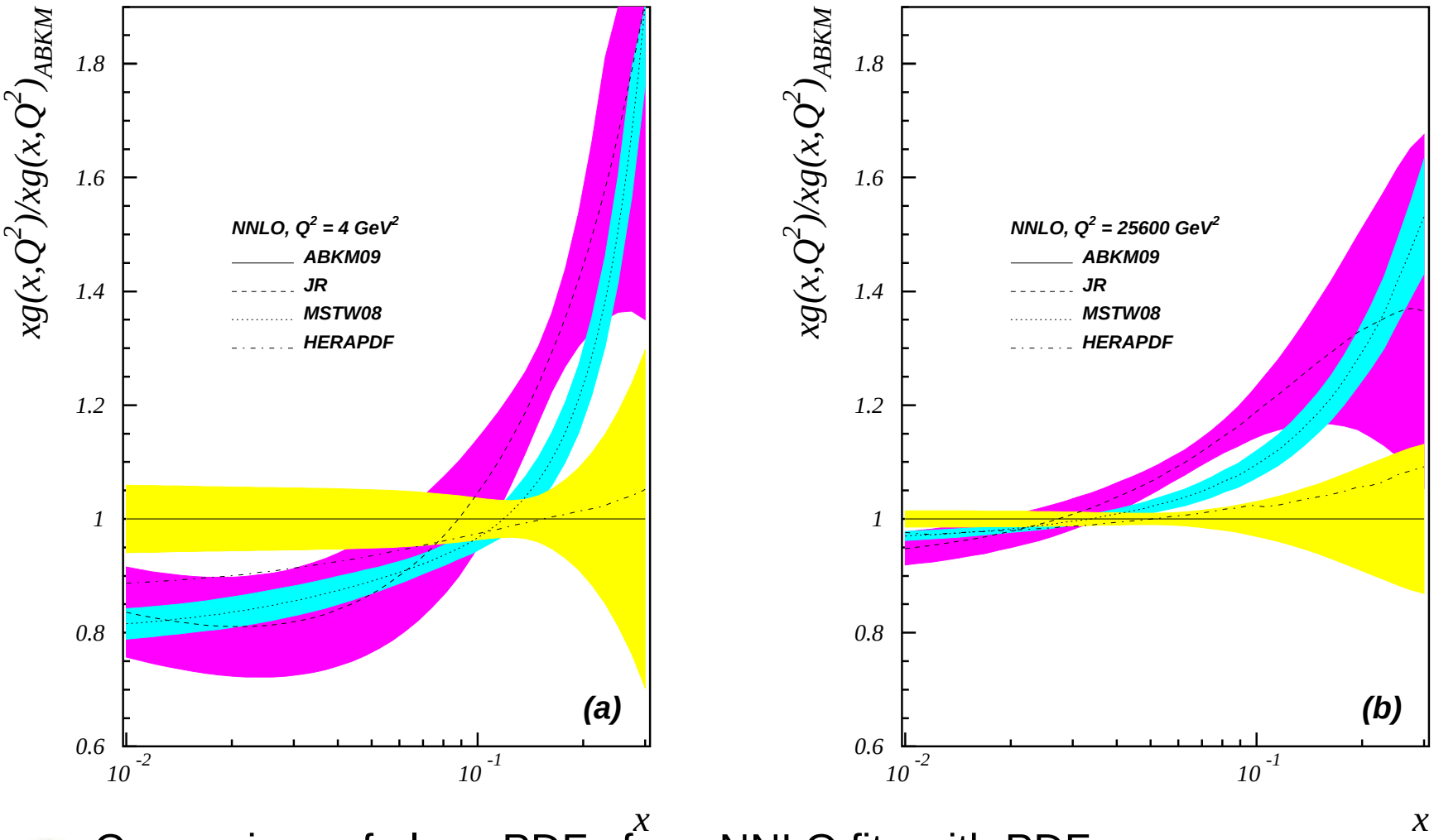
Tevatron Higgs searches

- Tevatron Higgs exclusion limits



- Tevatron Higgs search driven predominantly by $gg \to H$
  - large perturbative corrections at higher orders enhance signal
  - assumed Higgs signal relies on particular set of PDFs and value of α_s ($\longrightarrow$ MSTW08)
- Critical appraisal of theoretical uncertainties
  Baglio, Djouadi '10; Baglio, Djouadi, Ferrag, Godbole '11

Gluon distribution

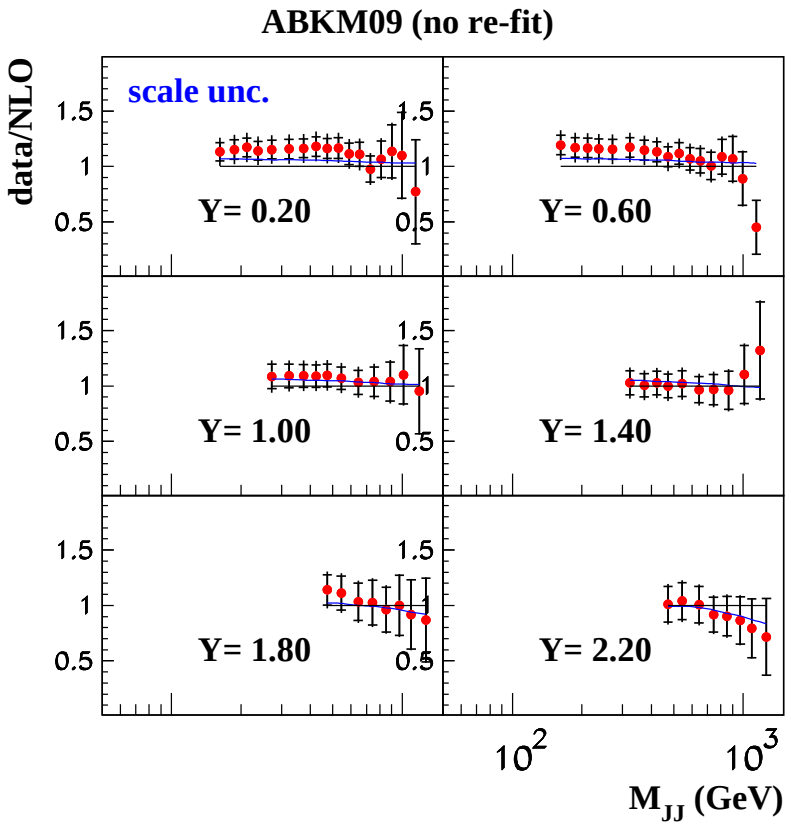


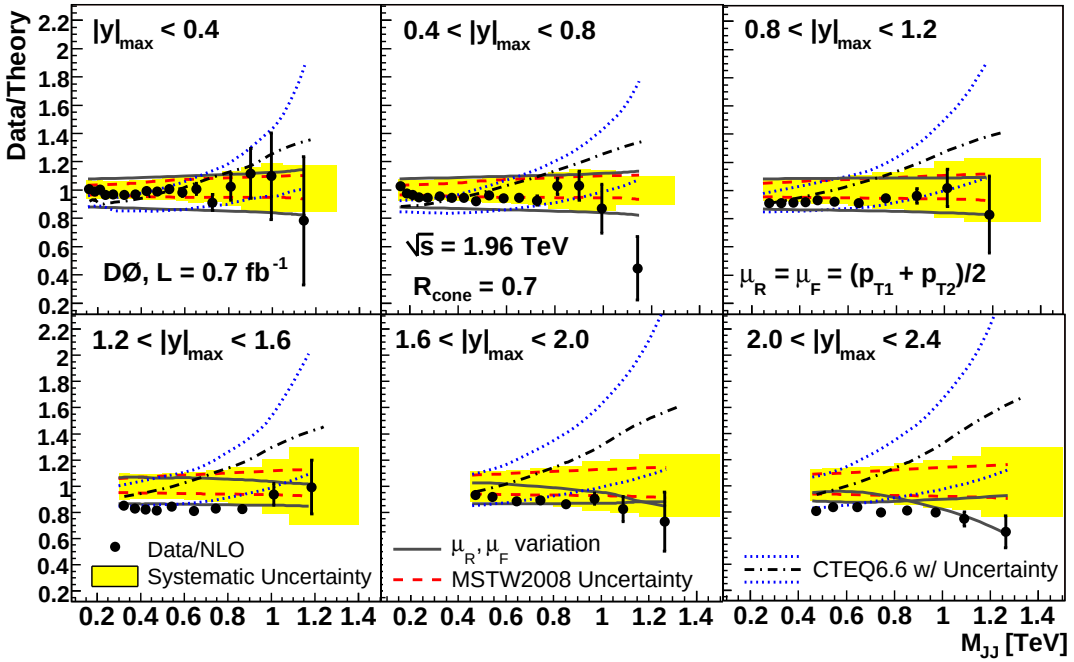
- Comparison of gluon PDFs from NNLO fits with PDF

  Alekhin, Blümlein, Jimenez-Delgado, S.M., E. Reya '10

  - uncertainties bands at 1σ

Impact of Tevatron jet data

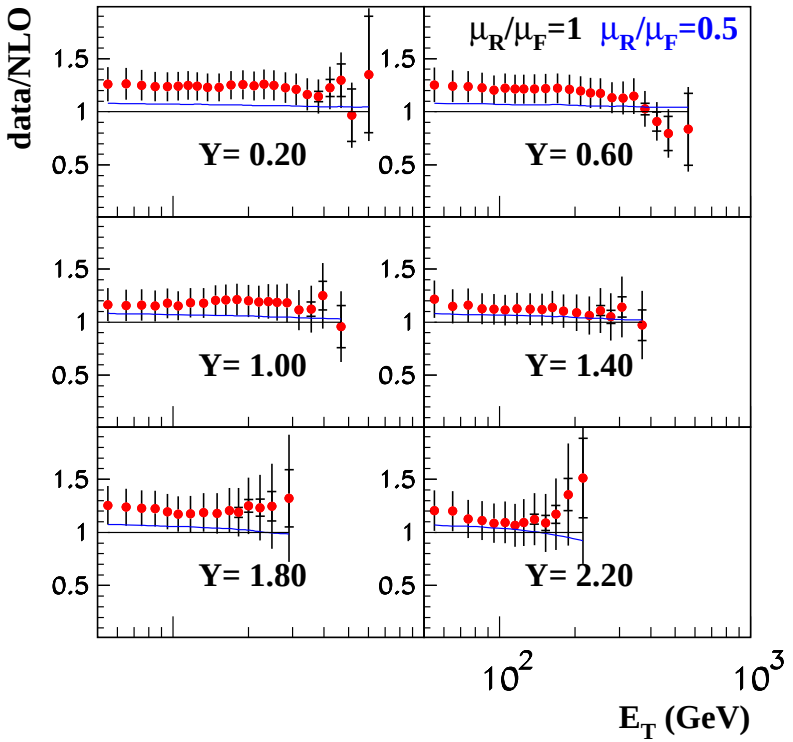




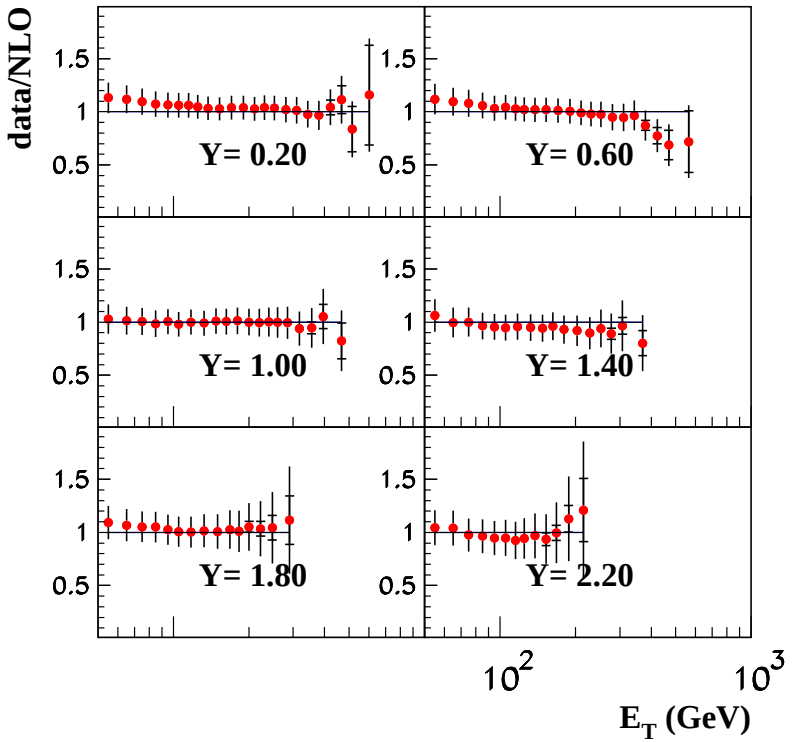
- NLO ABKM09 predictions compared to D0 Run II dijet data (D0 coll. '10)
  - 5-flavor PDFs generated from the 3-flavor ones $\mu_r = \mu_f = M_{JJ}$
    Alekhin, Blümlein, S.M. '10
- Impact of the data on ABKM PDFs is marginal
- ABKM provides very good description of Run II jet data

Inclusion of Tevatron jet data in fit

before the fit

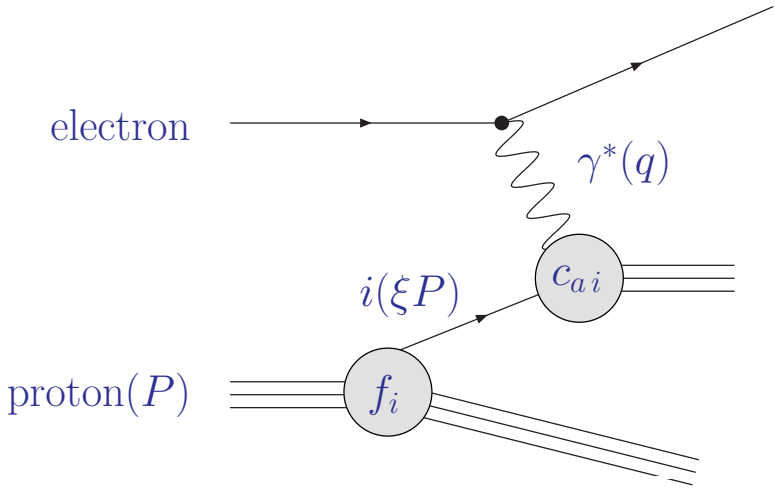


after the fit



- NLO variant of ABKM09 fit with D0 Run II data included (inclusive midpoint algorithm) Alekhin, Blümlein, S.M. '10
  - 3-flavor PDFs for DIS, 5-flavor PDFs for jets, $\mu_f = E_T$
  - for D0 data: $\chi^2 = 104/110 \longrightarrow$ jet data compatible with others
  - uncertainty due to missing NNLO corrections

Fixed-target DIS data



- **Kinematic variables**
  - Photon momentum transfer $Q^2 = -q^2$
  - Bjorken variable $x = Q^2/(2P \cdot q)$
  - Inelasticity $y = q \cdot P/k \cdot P$ with lepton momentum k

- Cross section depends on DIS structure functions F_2 and F_L (or alternatively $R = \sigma_T/\sigma_L$)
  - structure functions include QCD corrections at higher orders

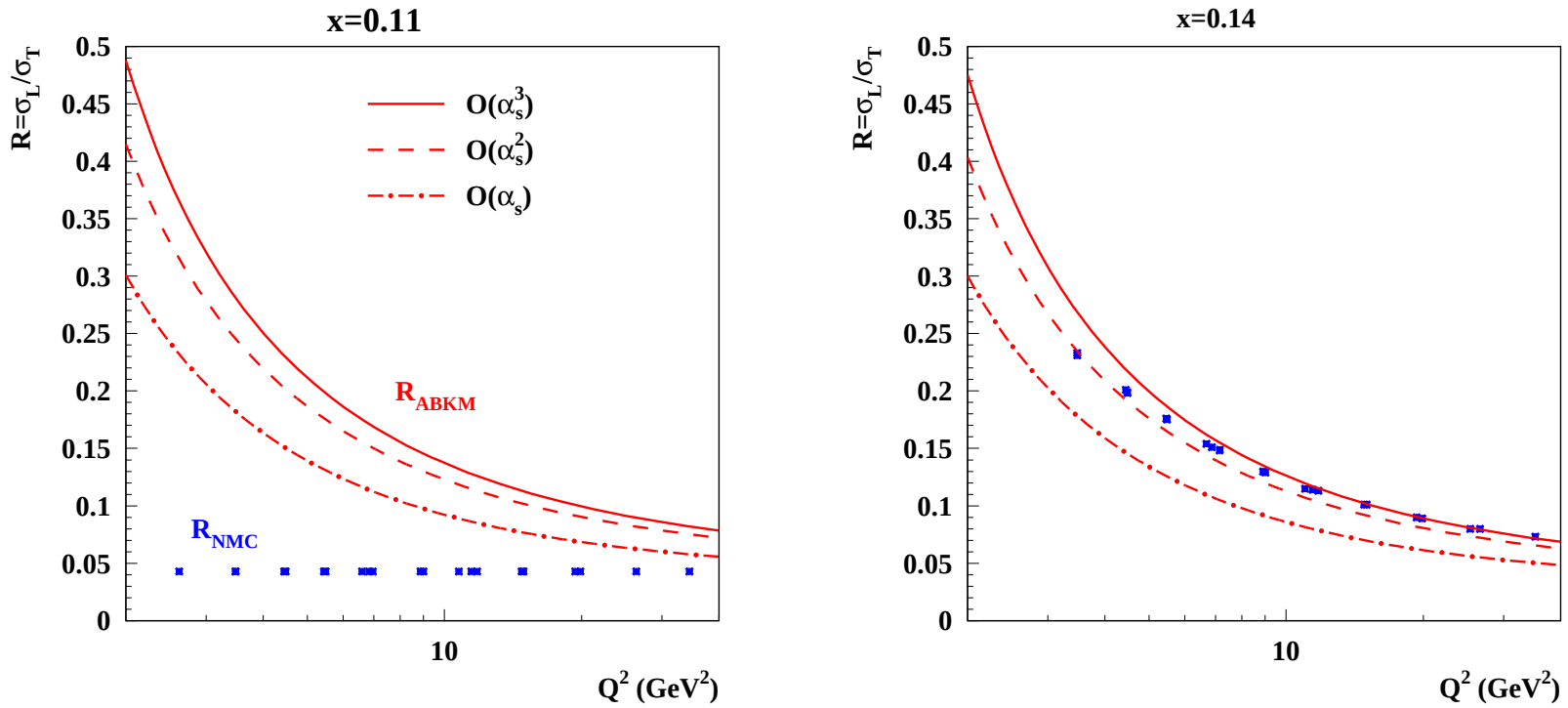
$$\frac{d^2\,\sigma(x,Q^2)}{dx dQ^2} =$$

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

The NMC experiment

- NMC was muon beam experiment at CERN
  - beam energies of 90, 120, 200, and 280 GeV
  - data fills gap in (x, Q^2)-kinematics between SLAC and HERA measurements at scales $Q^2 < 10\ \mathrm{GeV}^2$
  - NMC data constrains gluon PDF at $x > 0.001$
- Requirements for extraction of R (or F_L)
  - need at least two cross section measurements at different beam energies for given x and Q^2
- Analysis strategy of NMC NMC Coll. '97
  - NMC did not achieve full kinematic coverage; different treatment of data for $x \geq 0.12$ and $x \leq 0.12$
  - for $x > 0.12$ NMC has taken R_{1990} from SLAC
  - for $x < 0.12$ NMC has performed own determination of R
- Remark:
  - clear improvements in QCD theory since NMC analysis two more orders in perturbation theory for F_2 and F_L

Value of $R = \sigma_L/\sigma_T$ from NMC

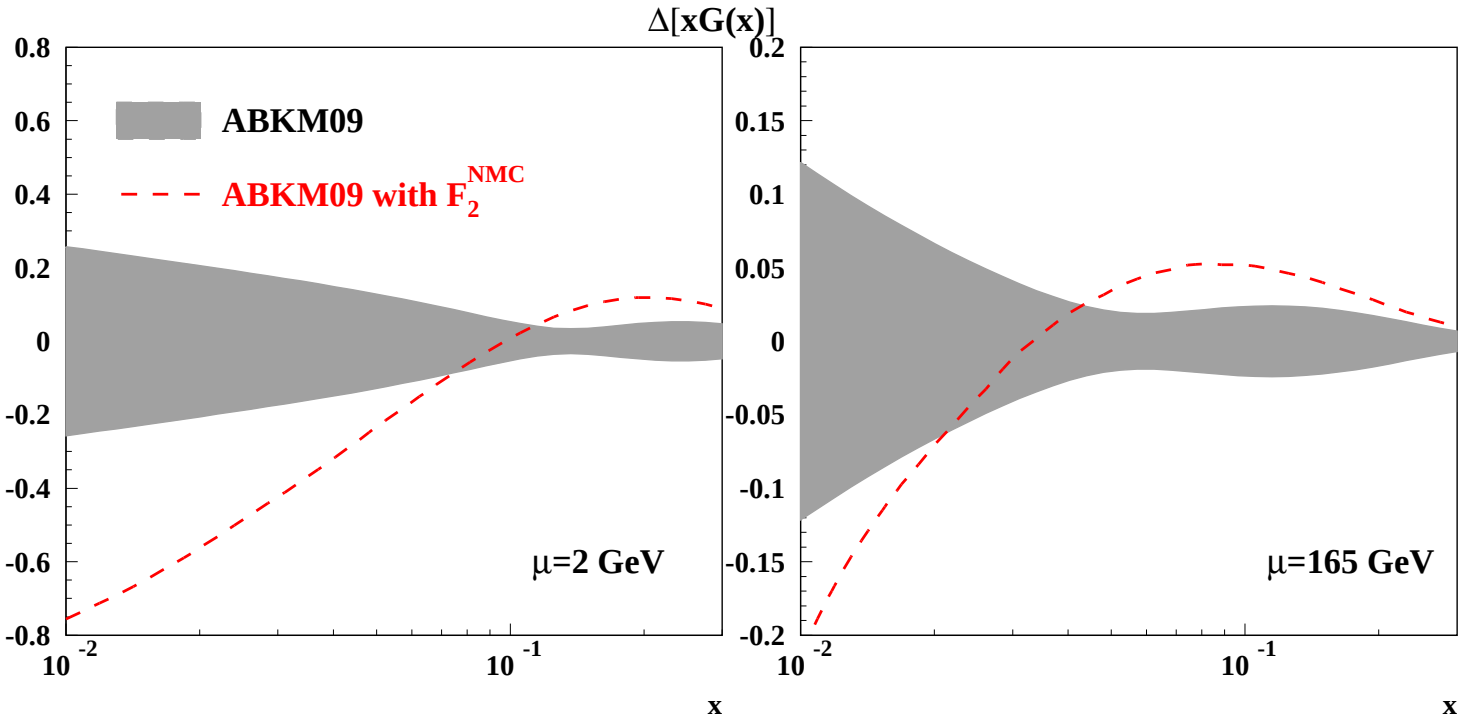


- $R = \sigma_L/\sigma_T$ as function of Q^2 for different values of x

  Alekhin, Blümlein, S.M. '11

  - $x = 0.11$ (left) and $x = 0.14$ (right)
  - $R_{\rm NMC}$ at $x = 0.14$ consistent
  - $R_{\rm NMC}$ at $x = 0.11$ inconsistent (does not depend on Q^2)

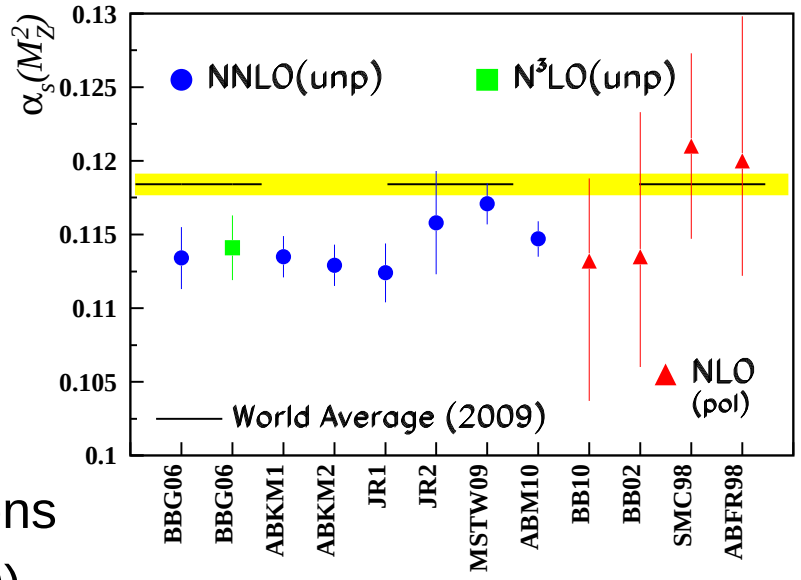
Fixed-target data in global PDF fits



- Two variants for including fixed-target DIS data in PDF fits
  - variant 1 (consistent):
    use the differential cross section $d^2\sigma/dxdQ^2$
  - variant 2 (inconsistent):
    use published values for structure function F_2
- Inconsistent variant leads to larger gluon PDF at $x \simeq 0.1$

Strong coupling constant

- $\alpha_s(M_Z) = 0.1179 \pm 0.0016$ in ABKM 09 at NLO
- $\alpha_s(M_Z) = 0.1135 \pm 0.0014$ in ABKM 09 at NNLO
- $\alpha_s(M_Z) = 0.1147 \pm 0.0012$ in ABKM 10 (including comb. HERA data)
- Compilation of $\alpha_s(M_Z)$ values
  Blümlein, Böttcher '10



- Consistency with other determinations
  - $\alpha_s(M_Z) = 0.1161 \pm 0.0045$ (NLO)
    from the Tevatron jet data D0 Coll. '10
  - $\alpha_s(M_Z) = 0.1135 \pm 0.0002(\text{exp}) \pm 0.0005(\text{had}) \pm 0.0009(\text{pert})$
    from $e^+e^- \to 3$ jets data (NNLO + NNLL res.)
    Abbate, Fickinger,Hoang, Mateu, Steward '10

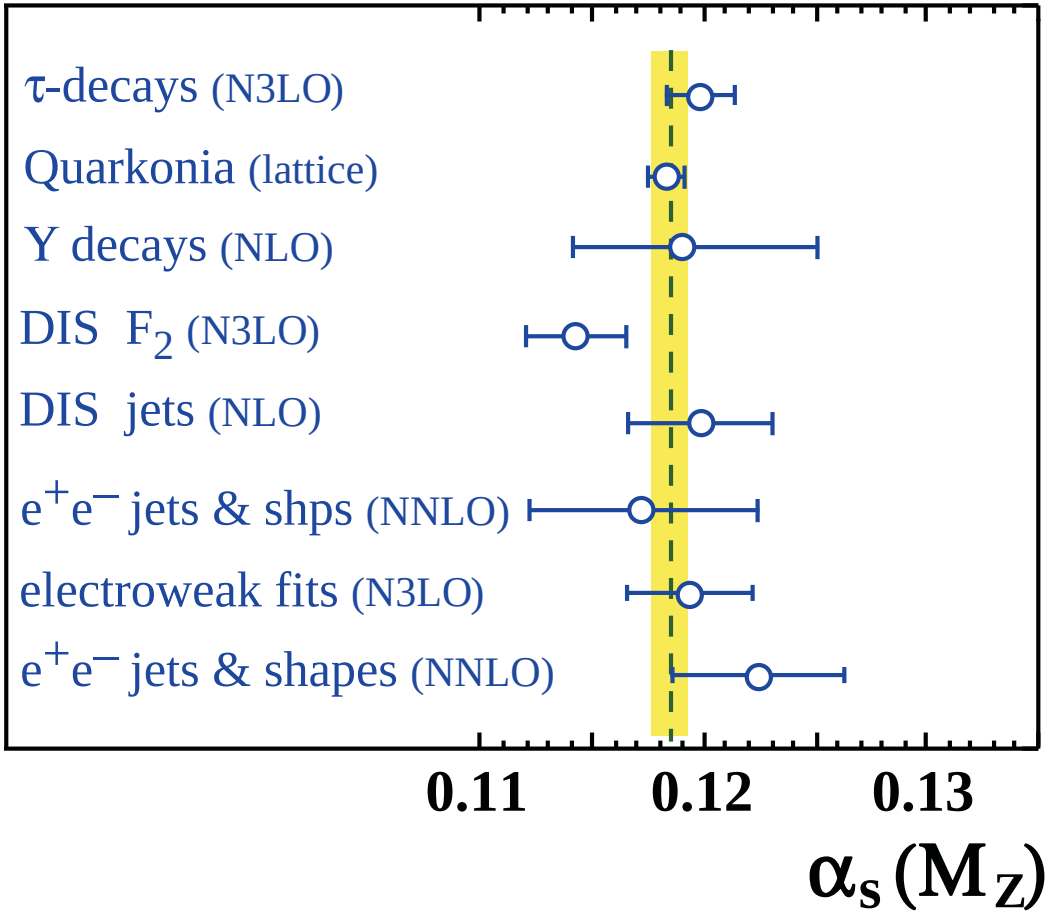
Values of α_s from global fit of PDFs

- Values of $\alpha_s(M_Z)$ from variants of ABKM PDF fit

$\alpha_s(M_Z)$	$\alpha_s(M_Z)$ with $\sigma_{\rm NMC}$	$\alpha_s(M_Z)$ with $F_2^{\rm NMC}$	difference
NLO	0.1179(16)	0.1195(17)	+0.0026 $\simeq 1.5\sigma$
NNLO	0.1135(14)	0.1170(15)	+0.0035 $\simeq 2.3\sigma$
NNLO + $\mathcal{O}(\alpha_s^3)$ F_L	0.1122(14)	0.1171(14)	+0.0050 $\simeq 3.6\sigma$

- Deviations between different variants increase at higher orders
- Inconsistent variant yields larger value of $\alpha_s(M_Z)$

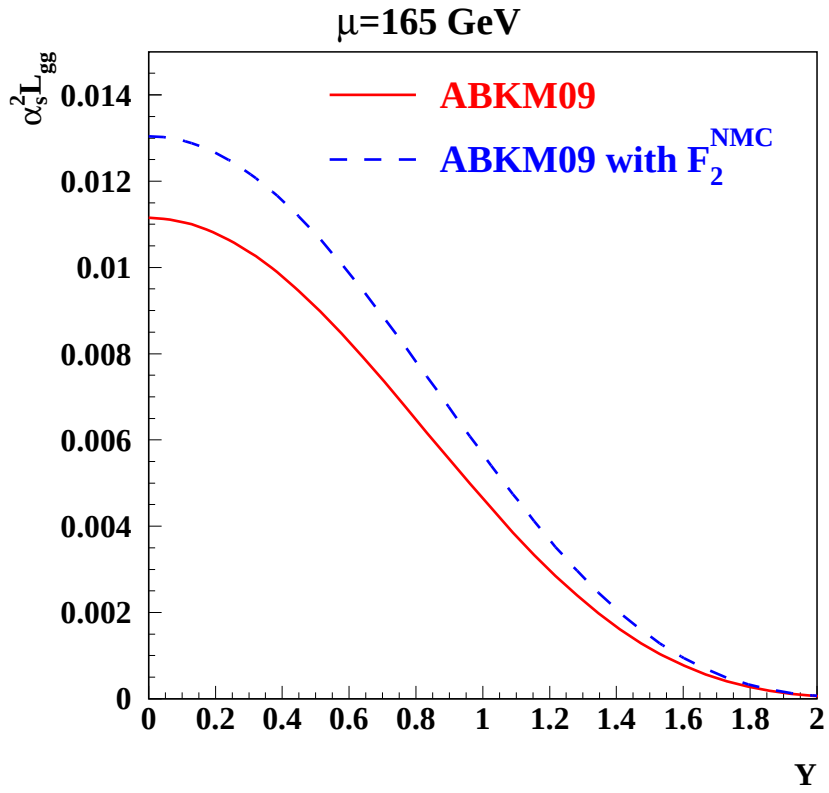
World average of α_s



Bethke '09

- World average combines determinations from NLO, NNLO and N^{3}LO

Higgs cross section



- Gluon luminosity $L_{gg} = g \otimes g$ (weighted by a factor α_s^2) as function of Higgs boson's rapidity Y at scale $\mu = 165$ GeV
- Inconsistent variant:
  cumulative effect of larger gluon PDF and larger value of α_s

Impact on Higgs production rates

- Rates for Higgs production at Tevatron

$\sigma(H)$	$\sigma(H)$ with $\sigma_{\rm NMC}$	$\sigma(H)$ with $F_2^{\rm NMC}$	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 + $\mathcal{O}(\alpha_s^3)$ F_L	0.242(22) pb	0.310(24) pb	0.068 pb $\simeq 2.8\sigma$

- Rates for Higgs production at LHC with $\sqrt{s} = 7$ TeV

$\sigma(H)$	$\sigma(H)$ with $\sigma_{\rm NMC}$	$\sigma(H)$ with $F_2^{\rm NMC}$	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 + $\mathcal{O}(\alpha_s^3)$ F_L	6.84(21) pb	7.68(23) pb	0.84 pb $\simeq 3.7\sigma$

- Inconsistent variant accounts for most of difference between cross sections predictions of ABKM and MSTW

Summary

Higgs cross section

- Theory predictions for hard parton cross section under good control
  - greatly reduced scale dependence at higher orders and convergence of perturbation theory

Parton distributions

- Source of largest differences for predictions of Higgs cross sections
  - impact of Tevatron jet data small
- Treatment of fixed-target data in global fits can lead to potential inconsistency
  - impact on value of $\alpha_s(M_Z)$ and Higgs rates sizable

Phenomenology

- Current range of excluded Higgs masses at Tevatron much too large (at least by factor of two)