Parton distribution functions and precision predictions for cross sections at the LHC

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Plan

- Talk based on results on ...

  ongoing analysis and extraction of ...

  - ... precise parton distribution functions from global fits

    ABKM09 S. Alekhin, J. Blümlein, S. Klein and S. M.
    arXiv:0908.2766

    ABM10 S. Alekhin, J. Blümlein and S. M. arXiv:1007.3657

new $\longrightarrow$ ABM11 S. Alekhin, J. Blümlein and S. M. arXiv:1202.2281

Plan

- Talk based on results on . . .

  studies of related physics implications regarding . . .

  - . . . NNLO benchmarks cross sections at the Terascale
    S. Alekhin, J. Blümlein, P. Jimenez-Delgado, S. M. and E. Reya
    arXiv:1011.6259
  - . . . Higgs production rates and constraints from fixed-target DIS data
    S. Alekhin, J. Blümlein and S. M. arXiv:1011.5261
  - . . . the running charm-quark mass
    S. Alekhin and S. M. arXiv:1011.5790
    S. Alekhin , K. Daum, K. Lipka and S. M. arXiv:1209.0436
  - . . . top quark and Higgs boson masses and EW vacuum stability
    S. Alekhin , A. Djouadi and S. M. arXiv:1207.0980
  - . . . Tevatron jets and statistics impact
    S. Alekhin, J. Blümlein and S. M. arXiv:1211.2642

ABM11 parton distributions

Paradigm

- Consistent theory description for consistent data sets

ABM11 parton distributions

Paradigm

- Consistent theory description for consistent data sets

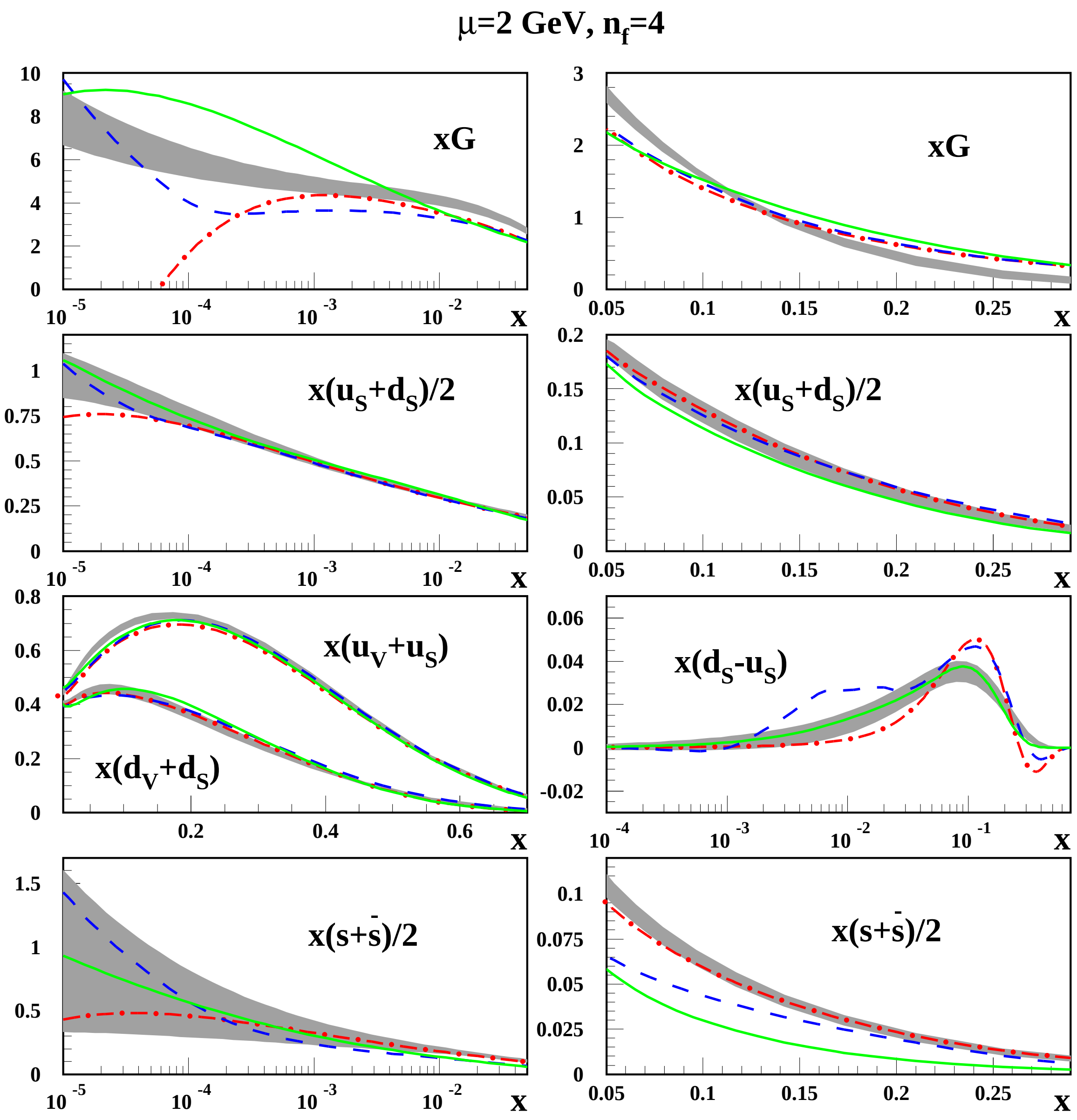
ABM11 in a nut shell Alekhin, Blümlein, S.M. ‘12

- Determination of PDFs and strong coupling constant α_s to NNLO QCD
- Consistent scheme for treatment of heavy quarks
  - fixed-flavor number scheme for $n_f = 3, 4, 5$
  - $\overline{\mathrm{MS}}$-scheme for quark masses and α_s
- Full account of error correlations

Data considered in the fit

- Analysis of world data for deep-inelastic scattering and fixed-target data for Drell-Yan process
  - inclusive DIS data HERA, BCDMS, NMC, SLAC
  - Drell-Yan data (fixed target) E-605, E-866
  - neutrino-nucleon DIS data (di-muon production) CCFR/NuTeV

Parton distributions for the LHC



- 1σ band for ABM11 PDFs (NNLO, 4-flavors) at $\mu = 2\ \mathrm{GeV}$
  Alekhin, Blümlein, S.M.'12
- comparison with:
  JR09 (solid lines),
  MSTW (dashed dots) and
  NN21 (dashes)
- Some interesting observations to be made ...

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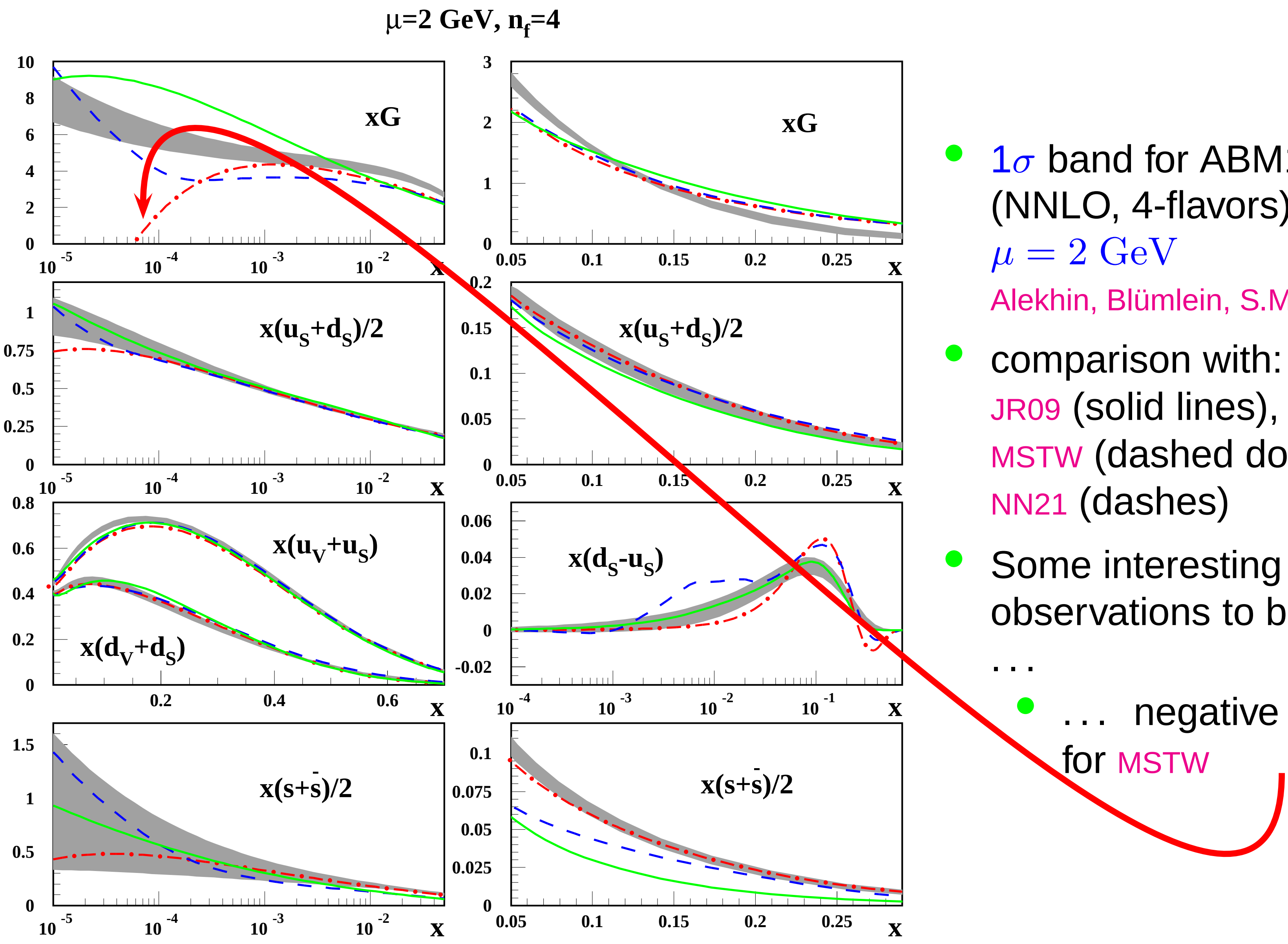

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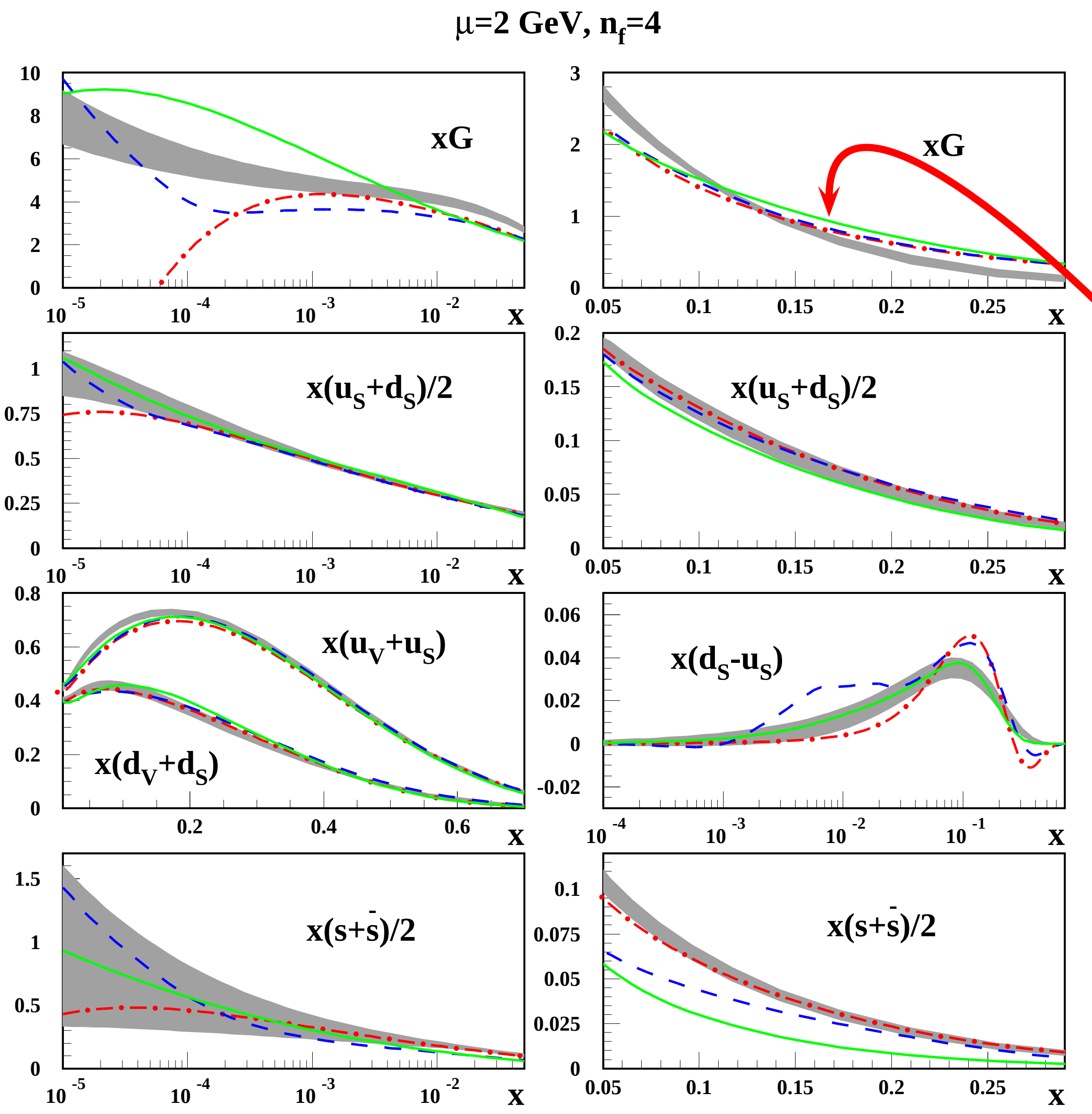

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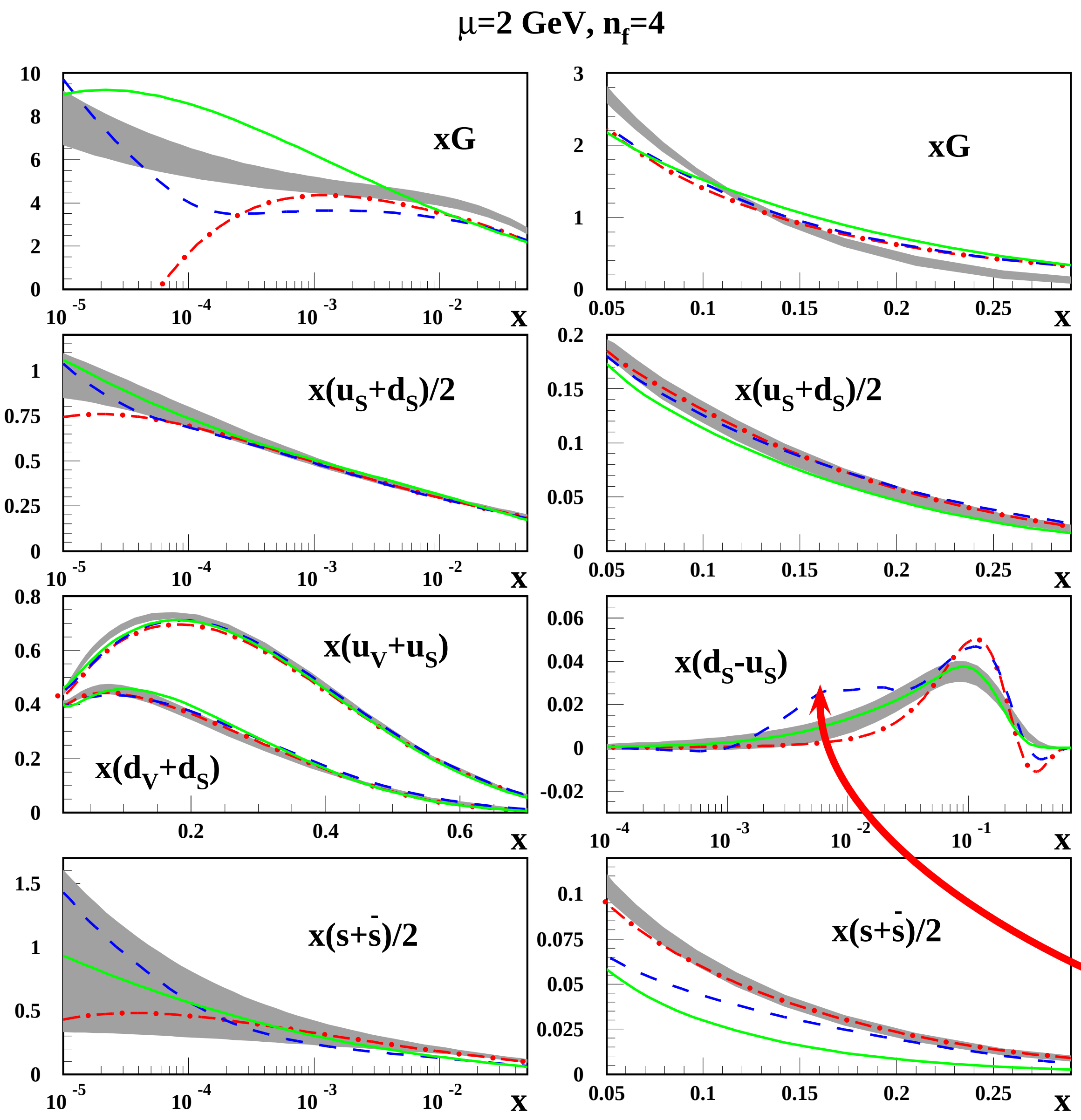

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  - . . . non-smooth (bumpy) $x(d_S - u_S)$ parametrization NN21

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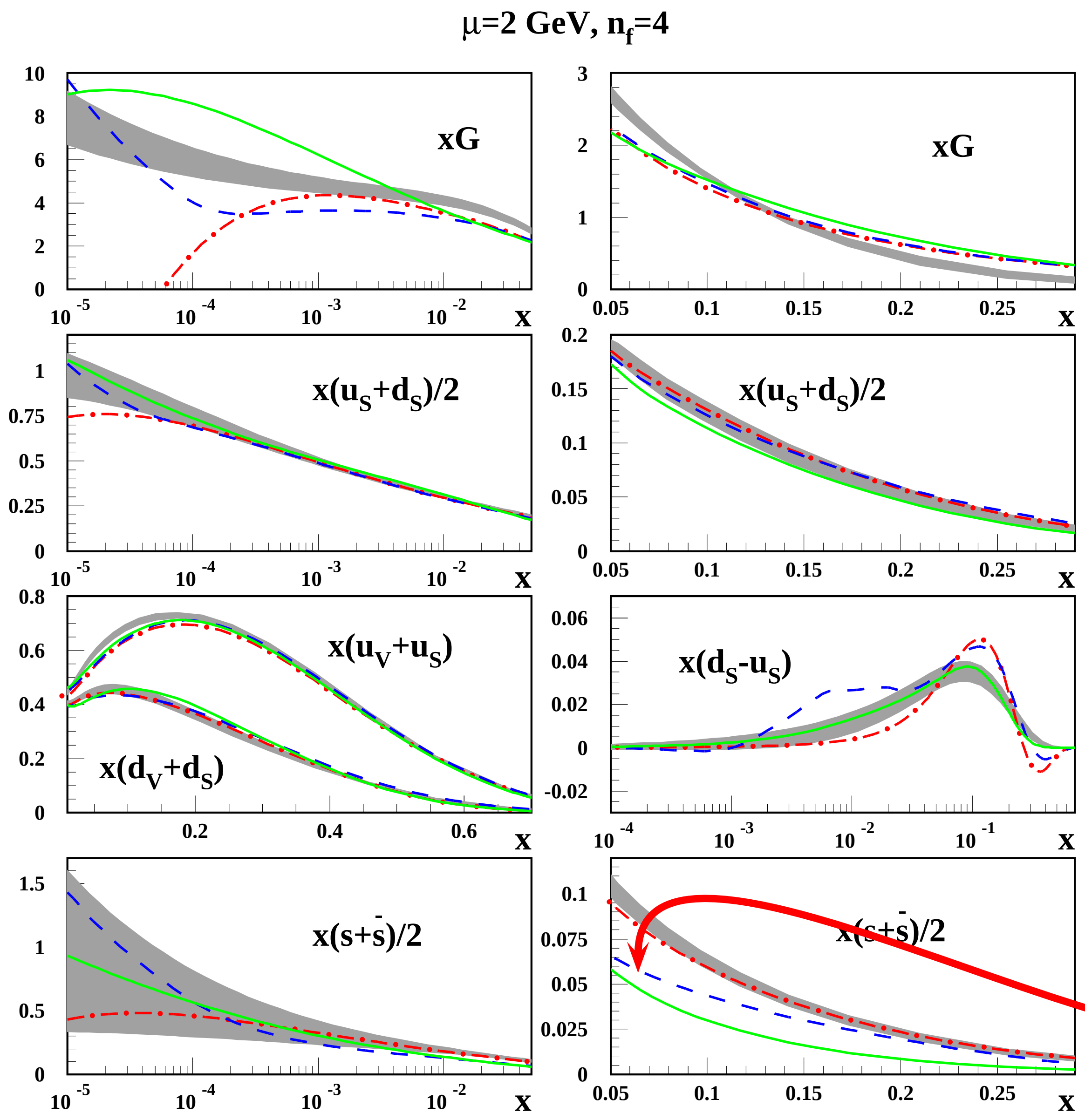

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  ...
  - ... $x(s + \bar{s})/2$ in NN21 too small due to wrong CC DIS cross section formulae

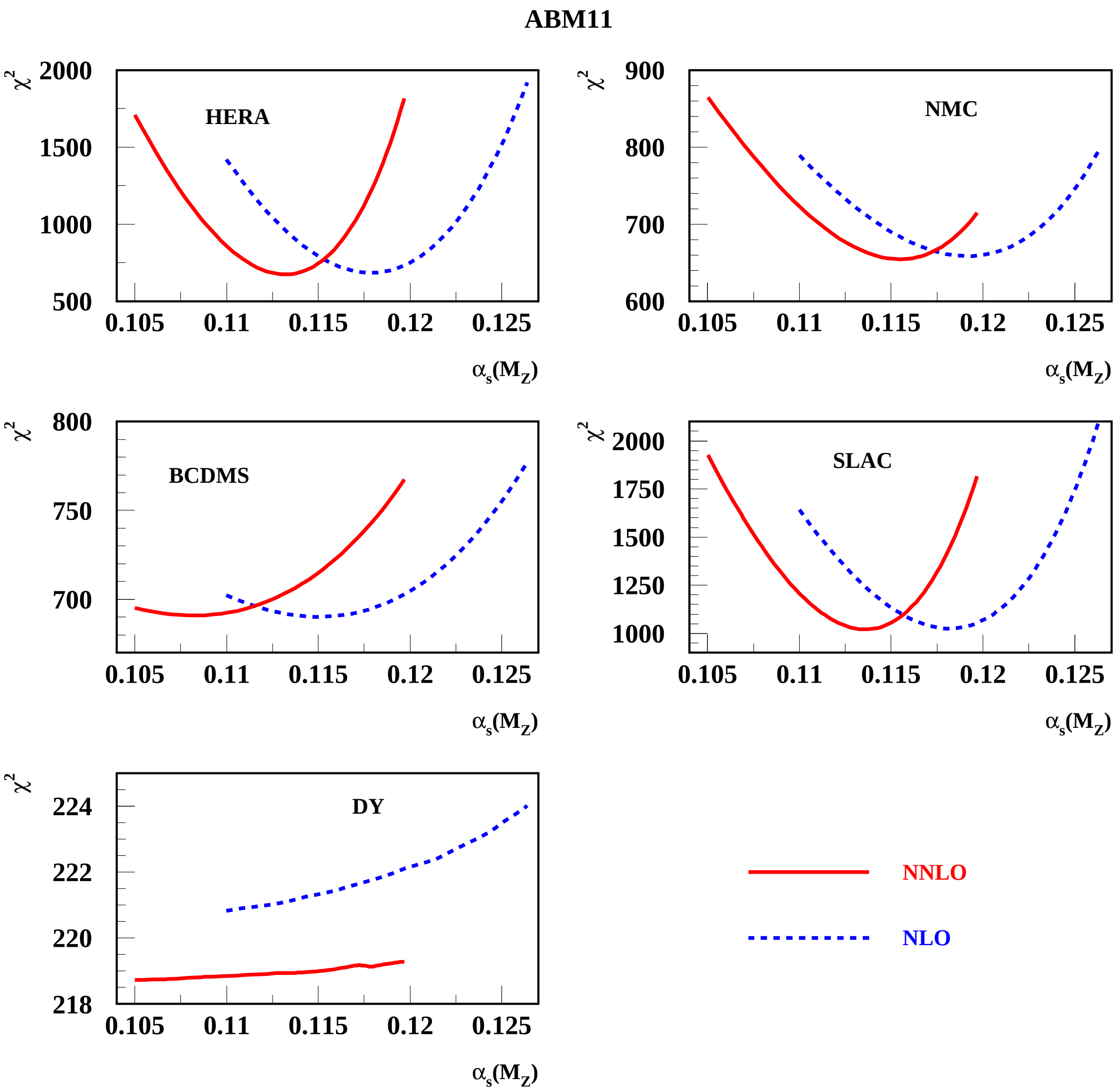
Quality of fit

	Experiment	NDP	χ^2(NNLO)	χ^2(NLO)
DIS inclusive	H1&ZEUS	486	537	531
	H1	130	137	132
	BCDMS	605	705	695
	NMC	490	665	661
	SLAC-E-49a	118	63	63
	SLAC-E-49b	299	357	357
	SLAC-E-87	218	210	219
	SLAC-E-89a	148	219	215
	SLAC-E-89b	162	133	132
	SLAC-E-139	17	11	11
	SLAC-E-140	26	28	29
Drell-Yan	FNAL-E-605	119	167	167
	FNAL-E-866	39	52	55
DIS di-muon	NuTeV	89	46	49
	CCFR	89	61	62
Total		3036	3391	3378

Strong coupling constant

α_s *from DIS and PDFs*

- Sensitivity of individual data sets on α_s
  - χ^2 profile for different data sets
  - very good consistency
  - order dependence $\alpha_S^{\text{NNLO}}(M_Z) < \alpha_S^{\text{NLO}}(M_Z)$

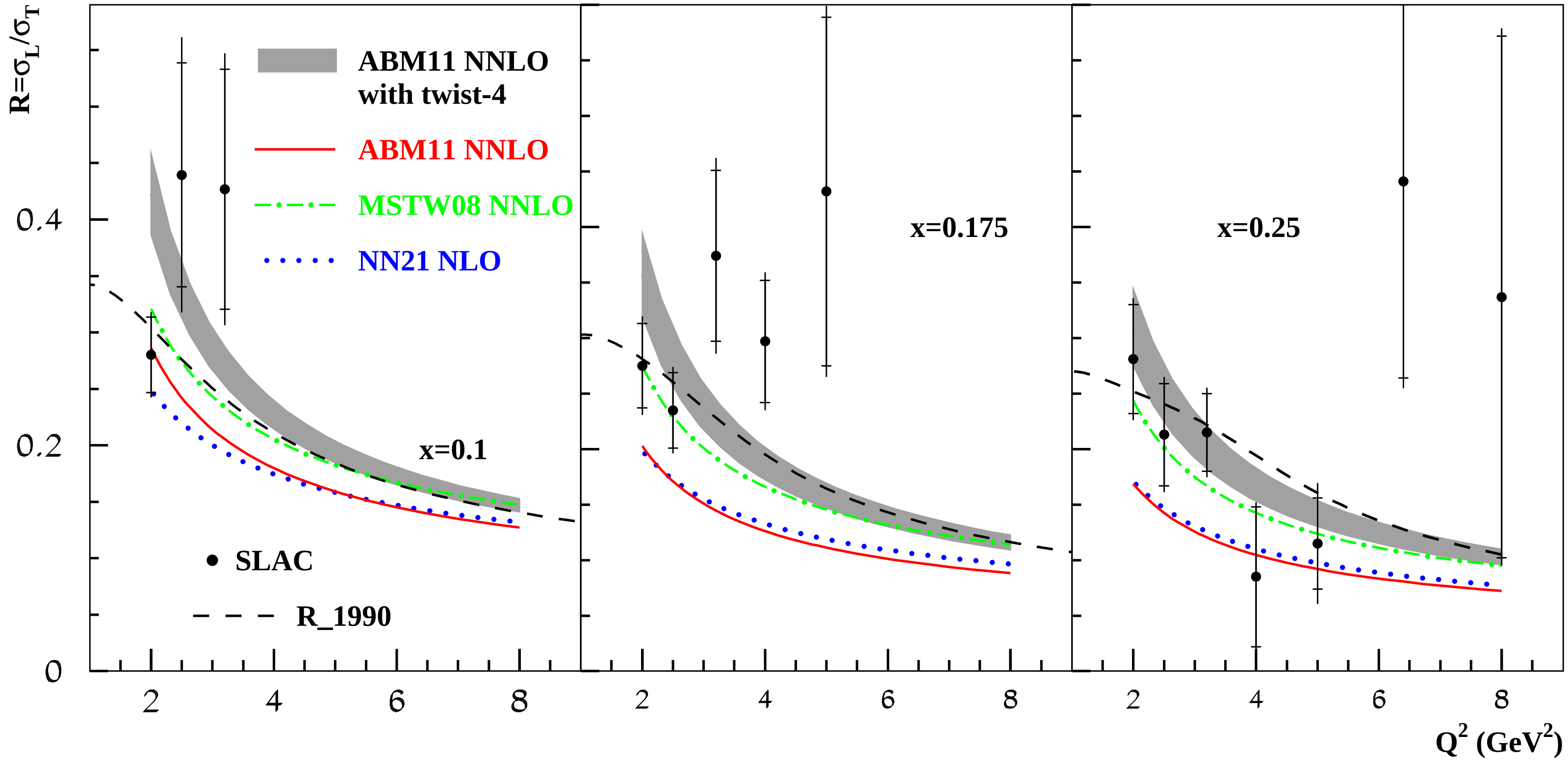


Comparison of α_s determinations

- Differences in α_s values:
  - result from different physics models and analysis procedures
    - target mass corrections (powers of nucleon mass M_N^2/Q^2)
    - higher twist $F_2^{\rm ht} = F_2 + ht^{(4)}(x)/Q^2 + ht^{(6)}(x)/Q^4 + \dots$
    - error correlations
- Effects for differences between ABM, MSTW and NN21 understood
  - variants of ABM with no higher twist etc. reproduce larger α_s values

	α_s at NNLO	target mass corr.	higher twist	error correl.
ABM11	0.1134 ± 0.0011	yes	yes	yes
NNPDF21	0.1166 ± 0.0008	yes	no	yes
MSTW	0.1171 ± 0.0014	no	no	no

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



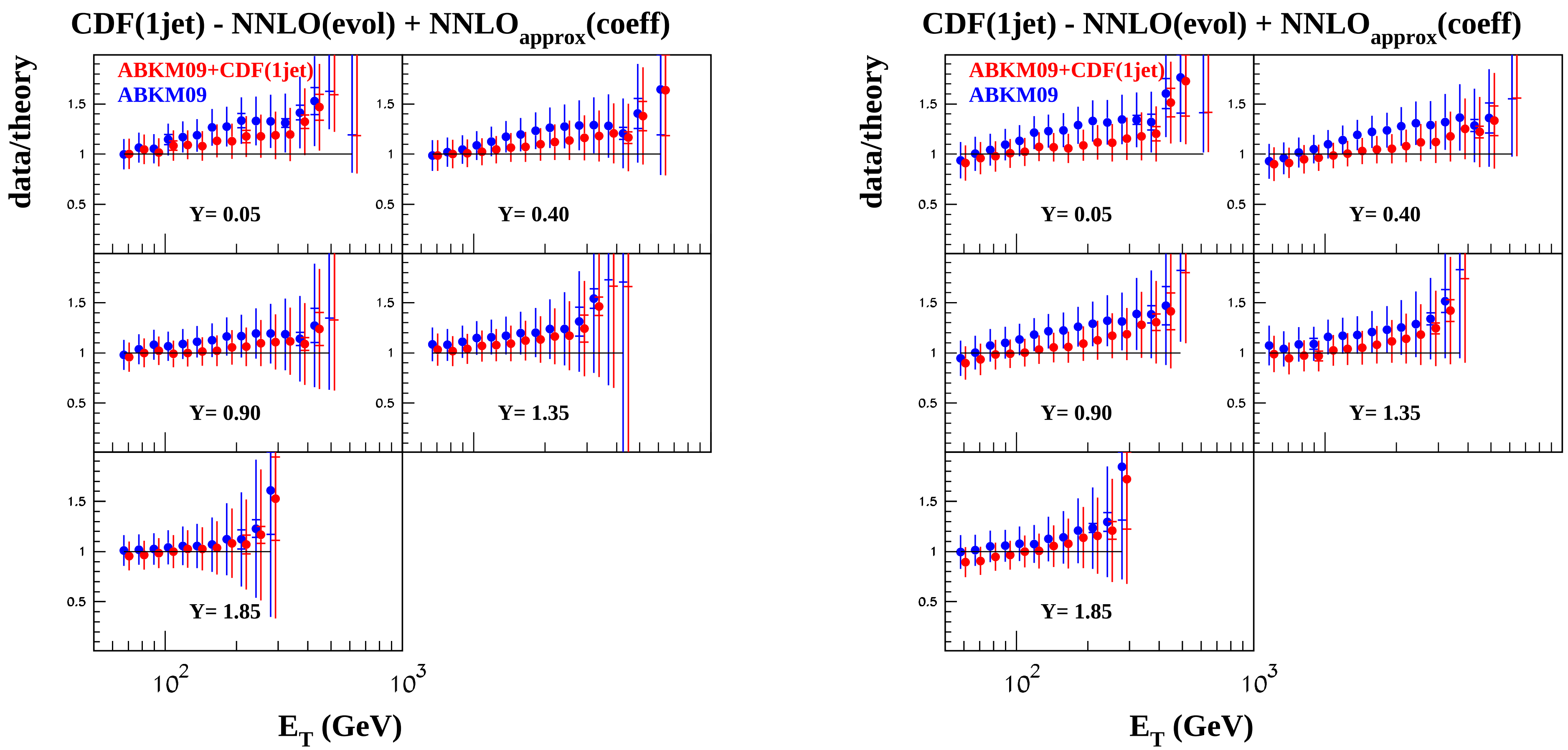
- $R = \sigma_L/\sigma_T$ as function of Q^2 for different values of x
  - 1σ band of for ABM11 NNLO predictions
  - comparison to MSTW, NN21 PDFs and ABM11 variant without twist-4 terms
  - empirical parameterization R_{1990} superimposed
- Similar discussion for NMC data Alekhin, Blümlein, S.M. arXiv:1101.5261

Jet production

General remarks

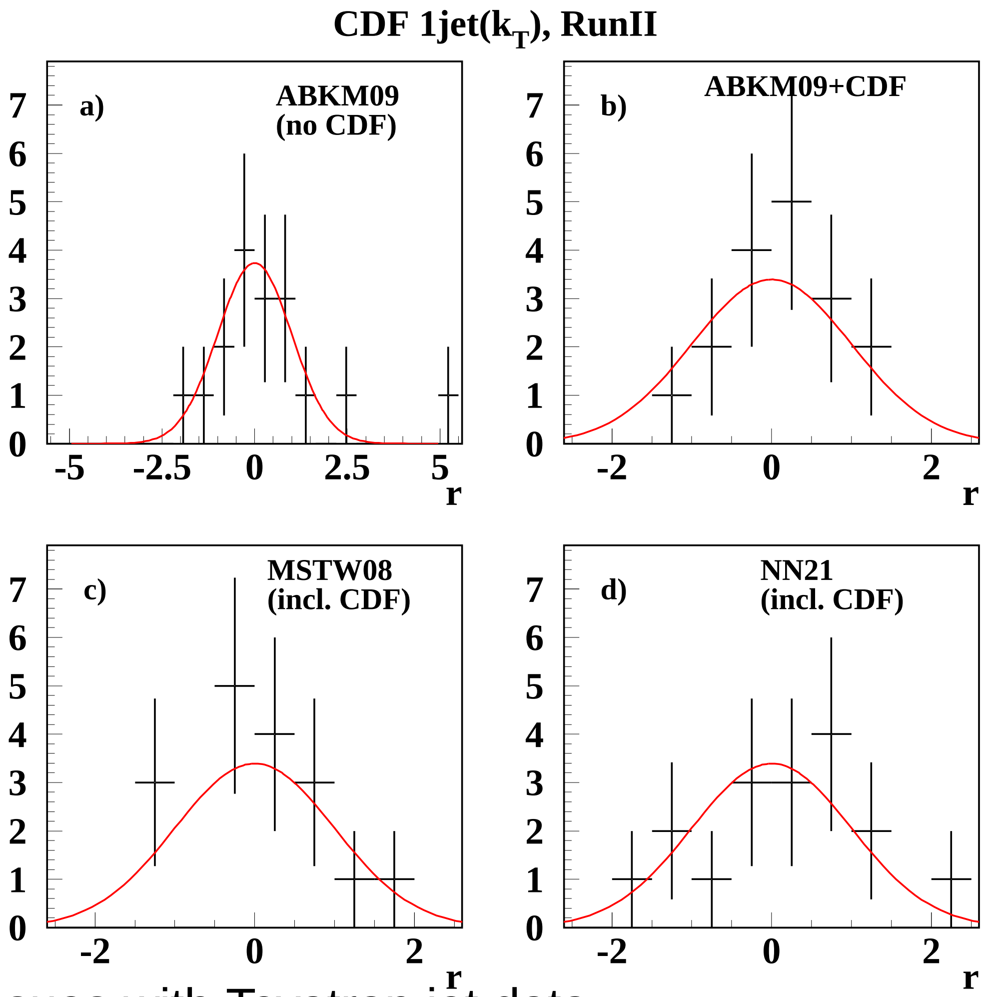
- QCD corrections important
  - only NLO known exactly
  - soft logarithms for 1-jet inclusive distributions define $\mathrm{NNLO}_{\mathrm{approx}}$
    Kidonakis, Owens '01; de Florian, Vogelsang '07
  - ongoing effort towards NNLO Gehrmann, Glover, . . . (many others)
- PDF fits with 3-flavors for DIS, 5-flavors for jets
  (matching from 3 to 5-flavors)
- QCD evolution over large range
- Possible impact of jet definition and algorithm

Tevatron jet data (CDF) – 1-jet inclusive



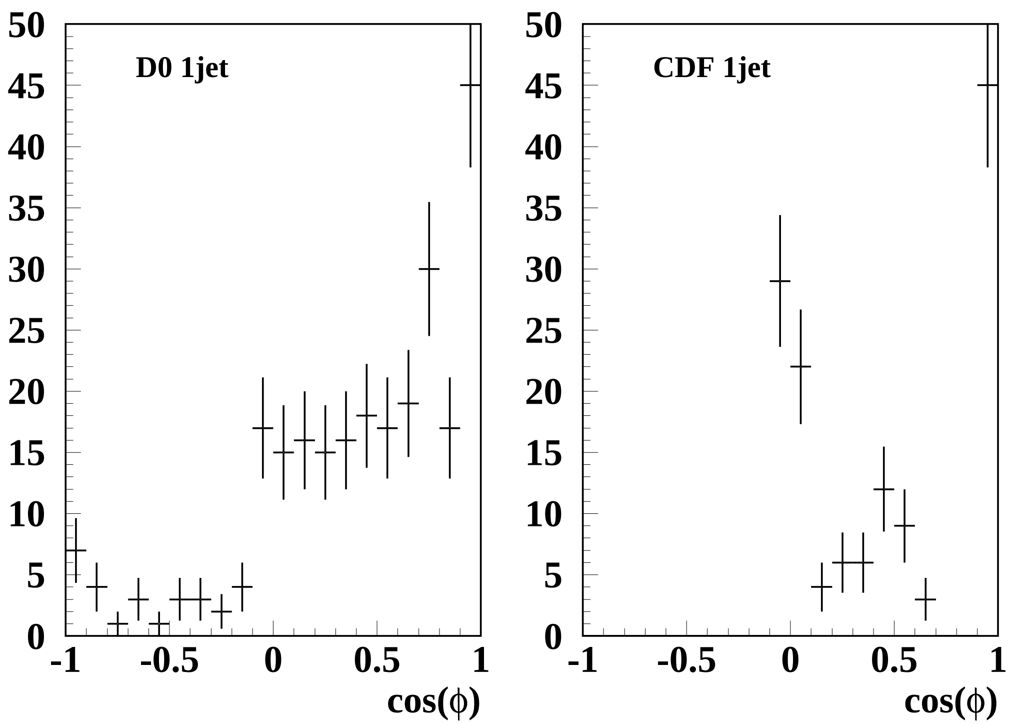
- Cone algorithm (left); k_T algorithm (right); scale $\mu_r = \mu_f = p_T$ s
- Disagreement in slope at large E_T can hardly be improved
  - large E_T is dominated by quark-quark scattering; PDFs well constrained

Statistics of Tevatron jet data



- Statistical issues with Tevatron jet data
  - systematic uncertainties treated with nuissance parameters
  - check impact of data normalization

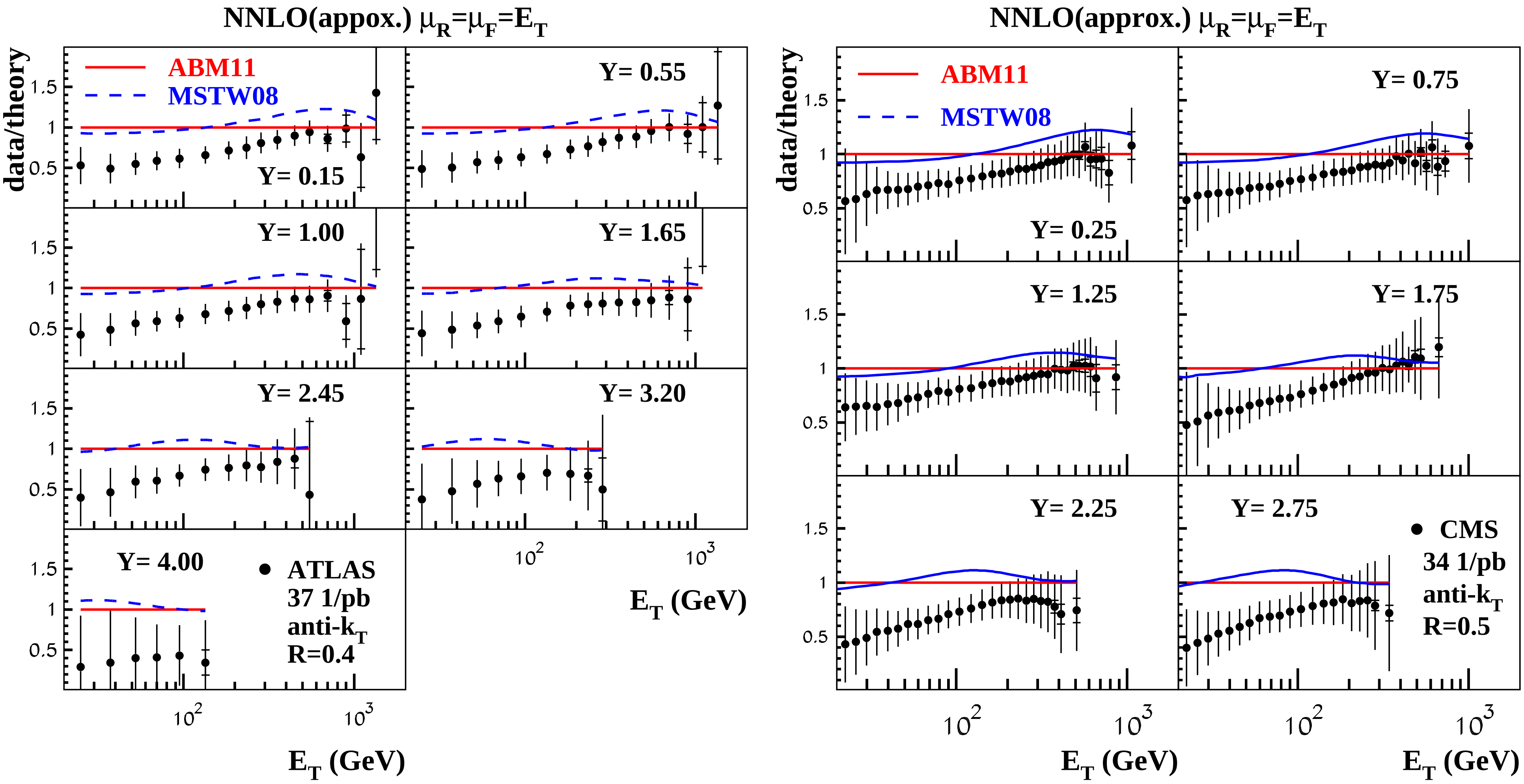
Statistics of Tevatron jet data



- Statistical issues with Tevatron jet data
  - cosine of angles between systematic uncertainty vectors $s_{k,i}$
  - expect symmetric distribution of $\cos(\phi_{kk'})$ with peak at $\cos(\phi) = 0$

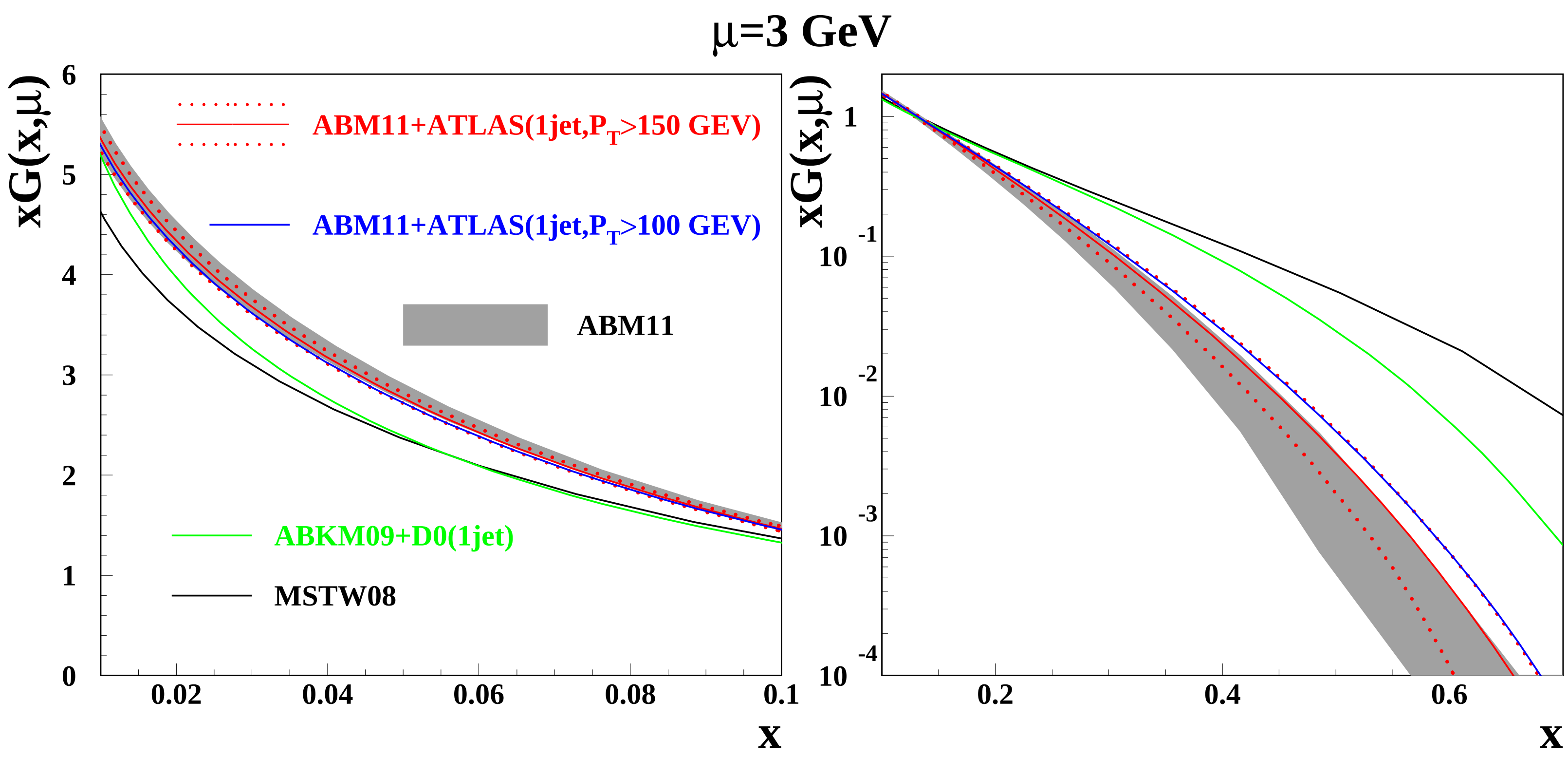
$$\cos(\phi_{kk'}) = \frac{\sum_i s_{k,i} s_{k',i}}{\sqrt{\sum_i s_{k,i}^2 \sum_i s_{k',i}^2}} .$$

LHC jet data



- Comparision to LHC data: ATLAS coll. (left) and CMS coll. (right) in good agreement
- LHC jet data prefers small gluon PDF at large x

Atlas jet data in ABM11 fit



- $\chi^2/\mathrm{NDP} = 55/55$ for ATLAS inclusive jet data with $p_T > 100/150$ GeV
- ATLAS jet data suggest softer gluons than Tevatron jets
- Comparison of α_s values
  - ABM11: $\alpha_s(M_Z) = 0.1134(11)$; Atlas jets: $\alpha_s(M_Z) = 0.1141(8)$
  - NLO analysis: $\alpha_s(M_Z) = 0.1151 \pm 0.0047(\mathrm{exp}) \pm 0.0023(\mathrm{PDFs})$
    Malaescu, Starovoitov '12

Impact on Higgs production rates (Atlas jets)

- Rates for Higgs production at LHC for m_H = 125 GeV
- Cross sections prediction fully consistent with ABM11

LHC at $\sqrt{s} = 7$ TeV	ABM11	Atlas jets $p_T \geq 100$ GeV	Atlas jets $p_T \geq 150$ GeV
$\sigma(H)$ [pb]	$\mathbf{13.23\ ^{+1.35}_{-1.31}\ ^{+0.30}_{-0.30}}$	$13.32\ ^{+1.37}_{-1.33}\ ^{+0.22}_{-0.22}$	$13.23\ ^{+1.35}_{-1.31}\ ^{+0.22}_{-0.22}$

LHC at $\sqrt{s} = 8$ TeV	ABM11	Atlas jets $p_T \geq 100$ GeV	Atlas jets $p_T \geq 150$ GeV
$\sigma(H)$ [pb]	$\mathbf{16.99\ ^{+1.69}_{-1.63}\ ^{+0.37}_{-0.37}}$	$17.10\ ^{+1.71}_{-1.65}\ ^{+0.27}_{-0.27}$	$16.98\ ^{+1.69}_{-1.63}\ ^{+0.27}_{-0.27}$

- MSTW for comparison
  - $\sigma(H) = 14.39\ ^{+1.54}_{-1.47}\ ^{+0.17}_{-0.22}$ for LHC7
  - $\sigma(H) = 18.36\ ^{+1.92}_{-1.82}\ ^{+0.21}_{-0.28}$ for LHC8

Top quark mass determination

- Determine top quark mass from Tevatron cross section data
  - $\sigma_{t\bar{t}} = 7.56^{+0.63}_{-0.56}$ pb D0 coll. arXiv:1105.5384
  - $\sigma_{t\bar{t}} = 7.50^{+0.48}_{-0.48}$ pb CDF coll. CDF-note-9913
- Fit of m_t for individual PDFs
  - parton luminosity at Tevatron driven by $q\bar{q}$
  - $\overline{\mathrm{MS}}$-scheme for $m_t^{\overline{\mathrm{MS}}}(m_t)$, then scheme transformation to pole mass m_t^{pole} at NNLO

	ABM11	JR09	MSTW08	NN21
$m_t^{\overline{\mathrm{MS}}}(m_t)$	162.0 $^{+2.3}_{-2.3}\,^{+0.7}_{-0.6}$	163.5 $^{+2.2}_{-2.2}\,^{+0.6}_{-0.2}$	163.2 $^{+2.2}_{-2.2}\,^{+0.7}_{-0.8}$	164.4 $^{+2.2}_{-2.2}\,^{+0.8}_{-0.2}$
m_t^{pole}	171.7 $^{+2.4}_{-2.4}\,^{+0.7}_{-0.6}$	173.3 $^{+2.3}_{-2.3}\,^{+0.7}_{-0.2}$	173.4 $^{+2.3}_{-2.3}\,^{+0.8}_{-0.8}$	174.9 $^{+2.3}_{-2.3}\,^{+0.8}_{-0.3}$
(m_t^{pole})	(169.9 $^{+2.4}_{-2.4}\,^{+1.2}_{-1.6}$)	(171.4 $^{+2.3}_{-2.3}\,^{+1.2}_{-1.1}$)	(171.3 $^{+2.3}_{-2.3}\,^{+1.4}_{-1.8}$)	(172.7 $^{+2.3}_{-2.3}\,^{+1.4}_{-1.2}$)

- Good consistency within errors for $m_t^{\mathrm{pole}} = 171.7 \dots 174.9$ at NNLO

Top quark cross section at LHC

- Check predictions at LHC with $\sqrt{s} = 7$ TeV
  - cross section computation with HATHOR (version 1.3)
    Aliev, Lacker, Langenfeld, S.M., Uwer, Wiedermann '10; S.M., Uwer, Vogt '12
- Atlas at $\sqrt{s} = 7$ TeV $\sigma_{t\bar{t}} = 177^{+11}_{-10}$ pb
  Atlas coll. ATLAS-CONF-2012-024
- CMS at $\sqrt{s} = 7$ TeV $\sigma_{t\bar{t}} = 165.8^{+13.3}_{-13.3}$ pb
  CMS coll. CMS-PAS-TOP-11-024

	ABM11	JR09	MSTW08	NN21
$m_t^{\overline{\rm MS}}(m_t)$	159.0 $^{+2.1}_{-2.0}\ ^{+0.7}_{-1.4}$	165.3 $^{+2.3}_{-2.2}\ ^{+0.6}_{-1.2}$	166.0 $^{+2.3}_{-2.2}\ ^{+0.7}_{-1.5}$	166.7 $^{+2.3}_{-2.2}\ ^{+0.8}_{-1.3}$
$m_t^{\rm pole}$	168.6 $^{+2.3}_{-2.2}\ ^{+0.7}_{-1.5}$	175.1 $^{+2.4}_{-2.3}\ ^{+0.6}_{-1.3}$	176.4 $^{+2.4}_{-2.3}\ ^{+0.8}_{-1.6}$	177.4 $^{+2.4}_{-2.3}\ ^{+0.8}_{-1.4}$
$(m_t^{\rm pole})$	(166.1 $^{+2.2}_{-2.1}\ ^{+1.7}_{-2.3}$)	(172.6 $^{+2.4}_{-2.3}\ ^{+1.6}_{-2.1}$)	(173.5 $^{+2.4}_{-2.3}\ ^{+1.8}_{-2.5}$)	(174.5 $^{+2.4}_{-2.3}\ ^{+2.0}_{-2.3}$)

- Large spread $m_t^{\rm pole} = 168.6 \dots 177.4$ at NNLO (marginally consistent)
  - larger gluon and α_s imply larger $m_t^{\rm pole}$

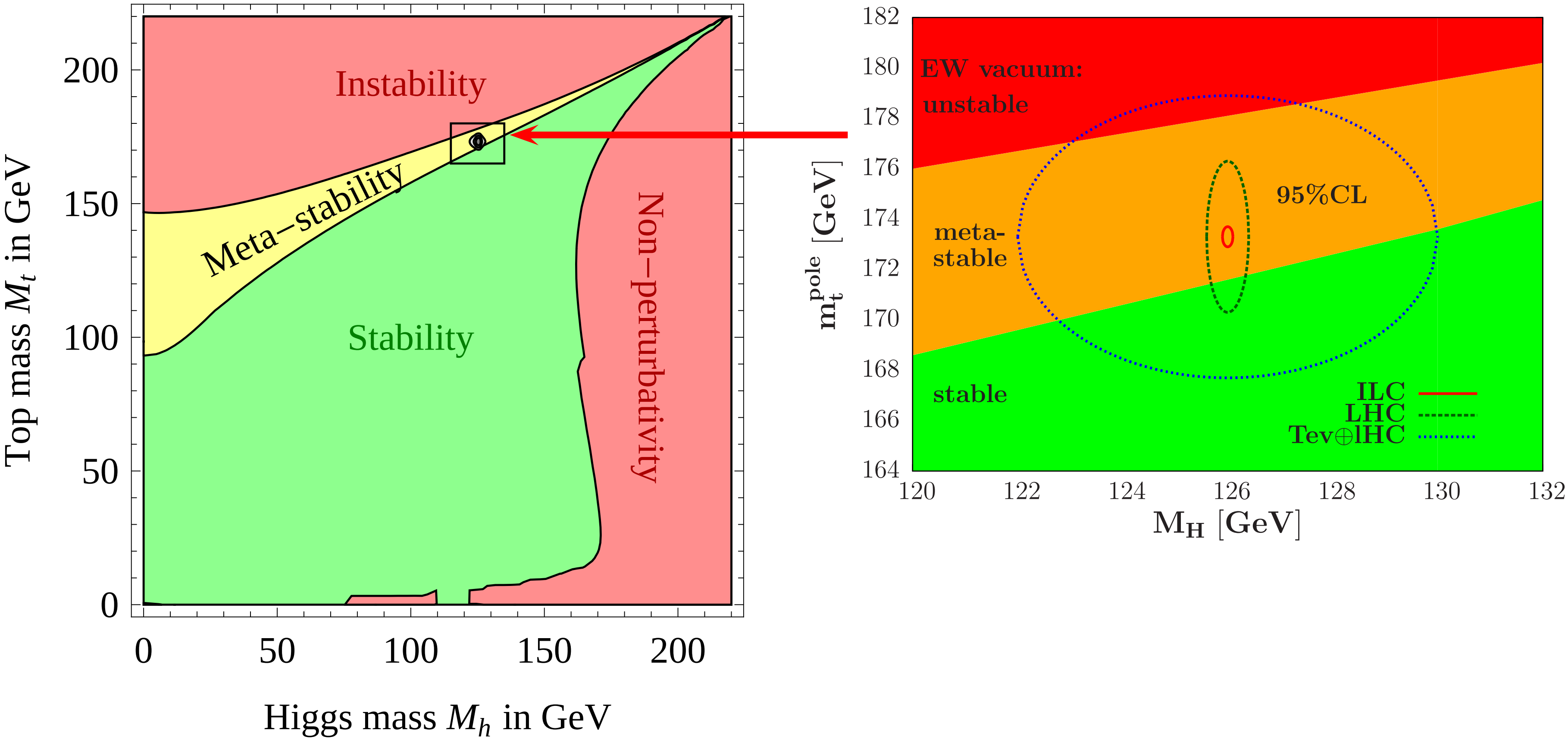
Implications on electroweak vacuum

- Relation between Higgs mass m_H and top-quark mass m_t
  - condition of absolute stability of electroweak vacuum $\lambda(\mu) \geq 0$
  - extrapolation of Standard Model up to Planck scale M_P
  - $\lambda(M_P) \geq 0$ implies lower bound on Higgs mass m_H

$$m_H \geq 129.2 + 1.8 \times \left(\frac{m_t^{\text{pole}} - 173.2 \text{ GeV}}{0.9 \text{ GeV}} \right) - 0.5 \times \left(\frac{\alpha_s(M_Z) - 0.1184}{0.0007} \right) \pm 1.0 \text{ GeV}$$

  - recent NNLO analyses Bezrukov, Kalmykov, Kniehl, Shaposhnikov '12; Degrassi, Di Vita, Elias-Miro, Espinosa, Giudice et al. '12
  - uncertainity in results due to α_s and m_t (pole mass scheme)
- Top-quark mass from Tevatron in well-defined scheme
  - $m_t^{\overline{\text{MS}}}(m_t) = 163.3 \pm 2.7 \text{ GeV}$ implies in pole mass scheme $m_t^{\text{pole}} = 173.3 \pm 2.8 \text{ GeV}$
  - good consistency of mass value between different PDF sets

Implications on electroweak vacuum



Degrassi, Di Vita, Elias-Miro, Espinosa, Giudice et al. '12; Alekhin, Djouadi, S.M. '12

- Uncertainty in Higgs bound due to m_t from in $\overline{MS}$ scheme
  - bound relaxes $m_H \geq 129.4 \pm 5.6$ GeV
  - "fate of universe" still undecided

Summary

Parton distributions, $\alpha_S(M_Z)$ and all that

- New ABM11 fit with improvements driven by theory
  - very good description of hadron collider data
- Strong coupling constant
  - ABM11 $\alpha_s(M_Z) = 0.1134(11)$ (ABKM09 $\alpha_s(M_Z) = 0.1135(14)$)
  - differences with respect to other groups understood
- Continuous benchmarking mandatory
  - source of interesting observations

Confronting LHC data

- PDFs with LHC jet data change gluon PDF and $\alpha_s(M_Z)$ within quoted uncertainty
  - Atlas jets prefer softer gluon than Tevatron
- Cross sections for Higgs prduction in gluon fusion almost unchanged compared to ABM11
- Top-quark production cross section with m_t from Tevatron data