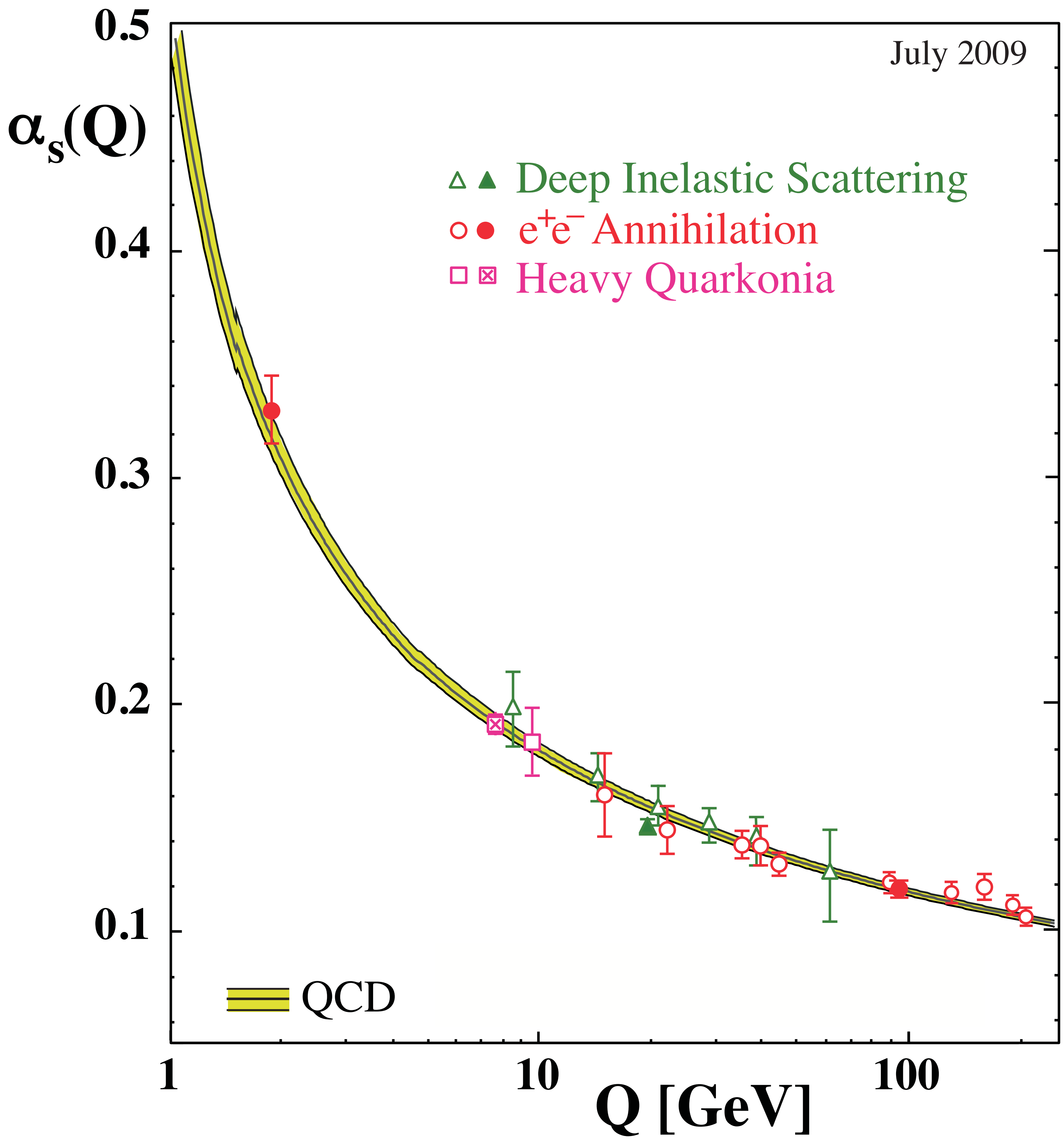
World summary of α_s (2009)

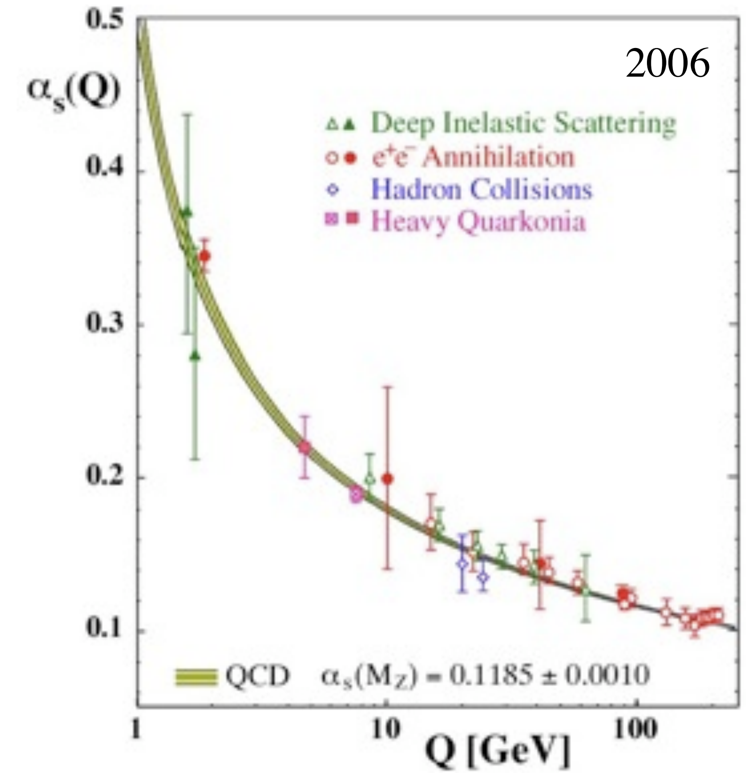
(and beyond)

S. Bethke
MPI für Physik, Munich

World Summary of α_s 2009:



most actual measurements included in 2009 review :

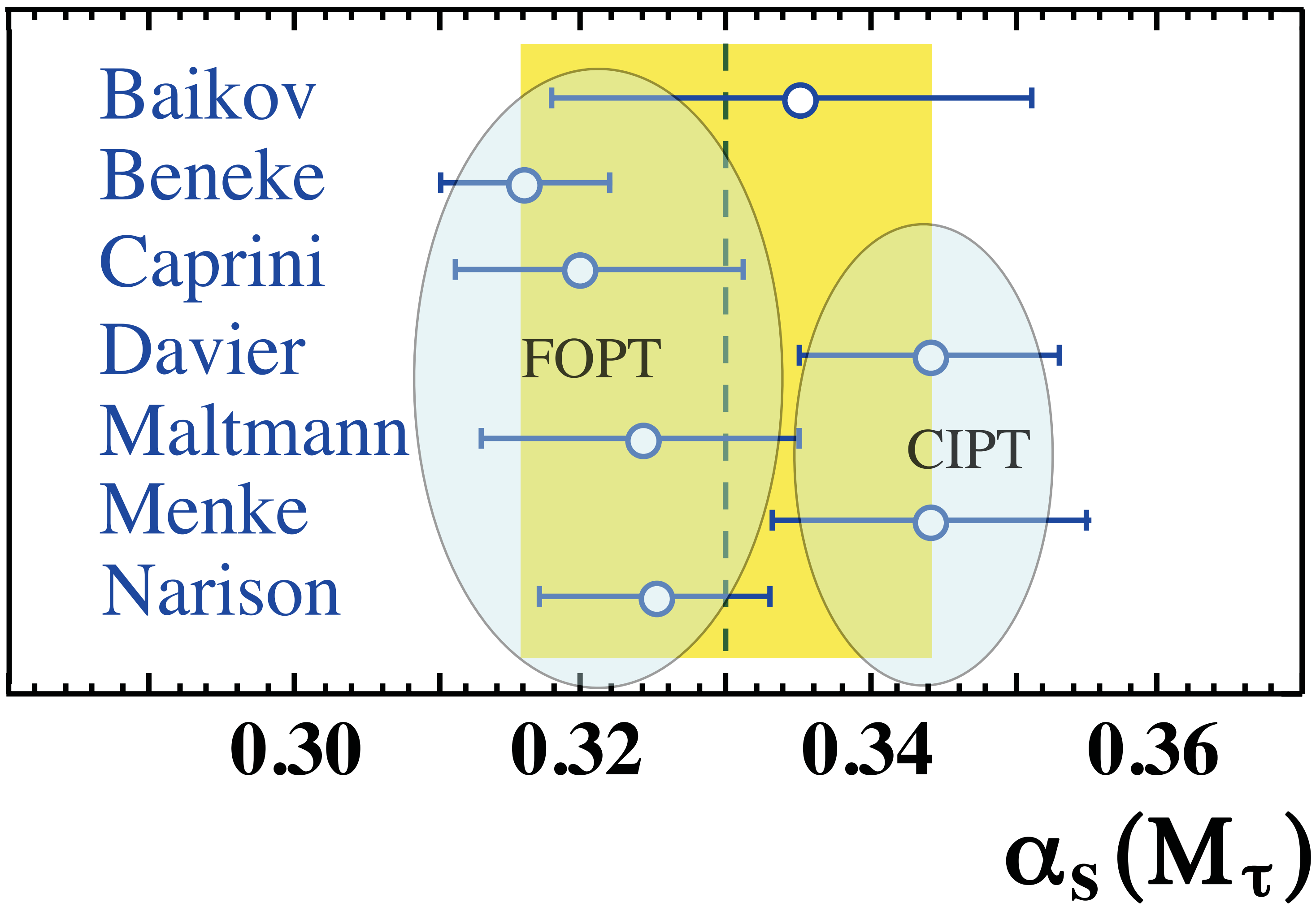


- N3LO ($O(\alpha_s^4)$) correction for τ-decays and width of Z^0 boson (Baikov, Chetyrkin, Kühn; arXiv:0801.1821)
- improved results from unquenched lattice calculations (C.T.H. Davies et al.; arXiv:0807.1687)
- improved results from heavy quarkonia decays (NLO) (N. Brambilla et al., hep-ph/0702079)
- α_s from world data of non-singlet structure functions (in N3LO) (J. Blümlein et al., hep-ph/0607200)
- combination of jet data from HERA experiments (NLO) (C. Glasmann et al., arXiv:0709.4426)
- NNLO ($O(\alpha_s^3)$) corrections for $e^+ e^-$ hadronic event shapes and jet rates —> reanalysis of LEP and of PETRA (JADE) data. (Dissertori, Gehrmann et al., arXiv:0806.4601; S. Bethke et al., arXiv:0810.1389)

n.b.: 2009 summary based on entirely new set of results

α_s from τ-decays

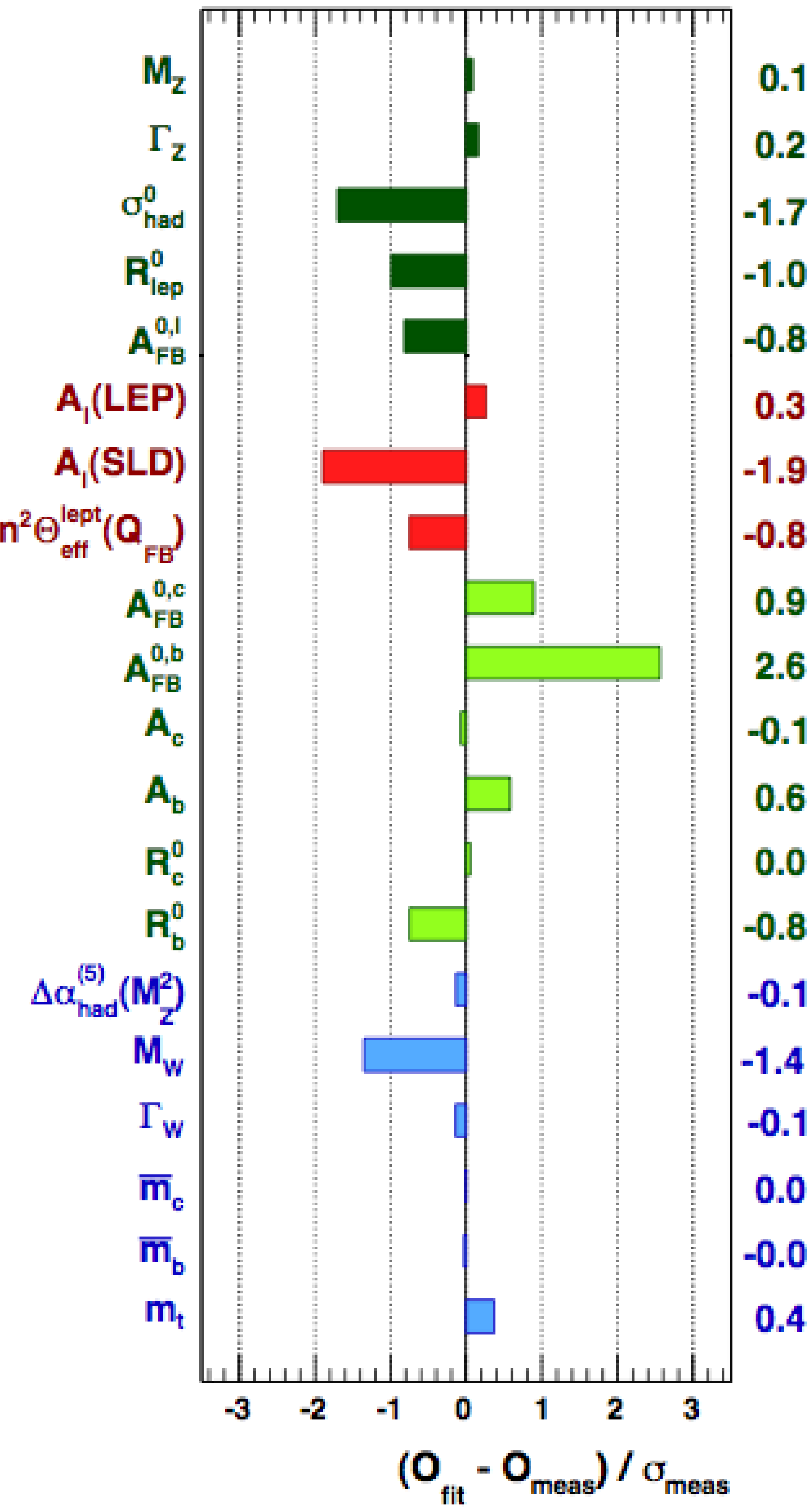
- complete N3LO prediction (Baikov, Chetyrkin, Kühn; arXiv:0801.1821)
- strong theor. activities
- large dependence on details of perturbative expansion: FOPT vs. CIPT; some dependence on nonpert. corrections

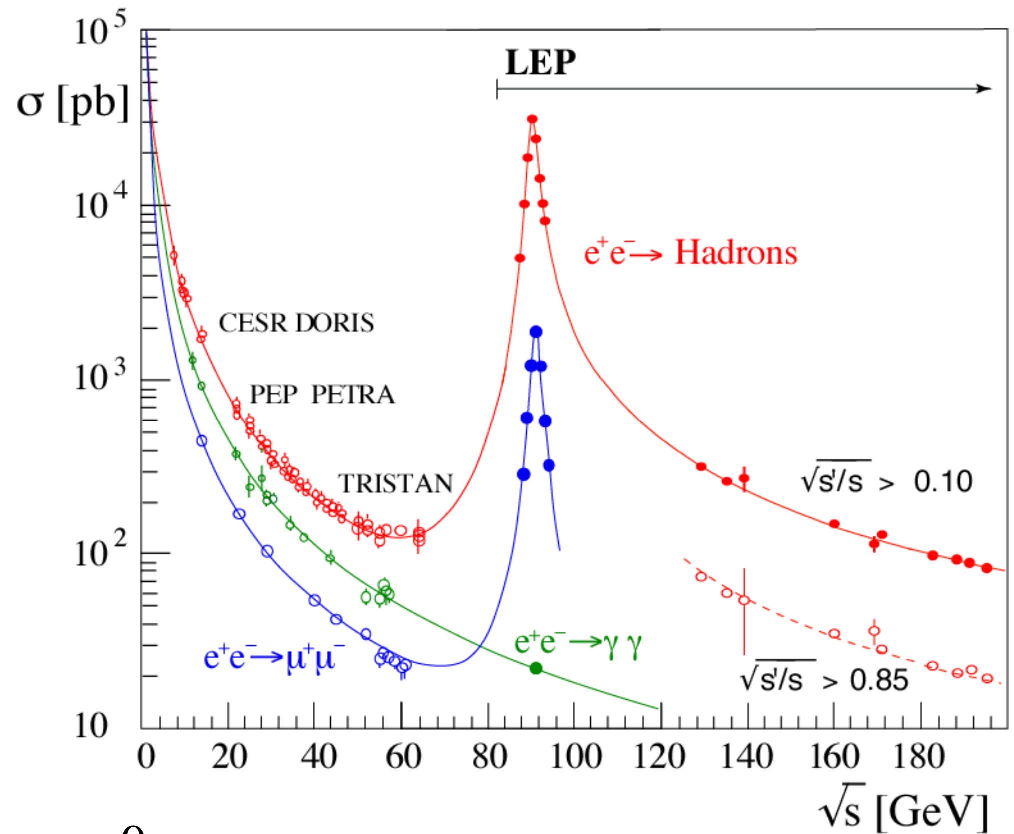


- averaging and summarising: $\alpha_s(M_\tau) = 0.330 \pm 0.014$

–> $\alpha_s(M_Z) = 0.1197 \pm 0.016$

α_s from electroweak precision measurements





$$R_Z = \frac{\Gamma(Z^0 \rightarrow \text{hadrons})}{\Gamma(Z^0 \rightarrow \text{leptons})} = 20.768 \pm 0.0024$$

$$R_Z = 19.934\left[1 + 1.045\frac{\alpha_s(\mu)}{\pi} + 0.94\left[\frac{\alpha_s(\mu)}{\pi}\right]^2 - 15\left[\frac{\alpha_s(\mu)}{\pi}\right]^3 + O(\alpha_s^4)\right]$$

- complete N3LO prediction (Baikov et al.; arXiv:0801.1821)
- fit to ew. precision data (Flächer et al.; arXiv:0811.0009), using GFITTER (http://cern.ch/Gfitter)

-> $\alpha_s(M_Z) = 0.1193 \pm 0.0028_{exp} \pm 0.0005_{th}$

α_s from lattice QCD

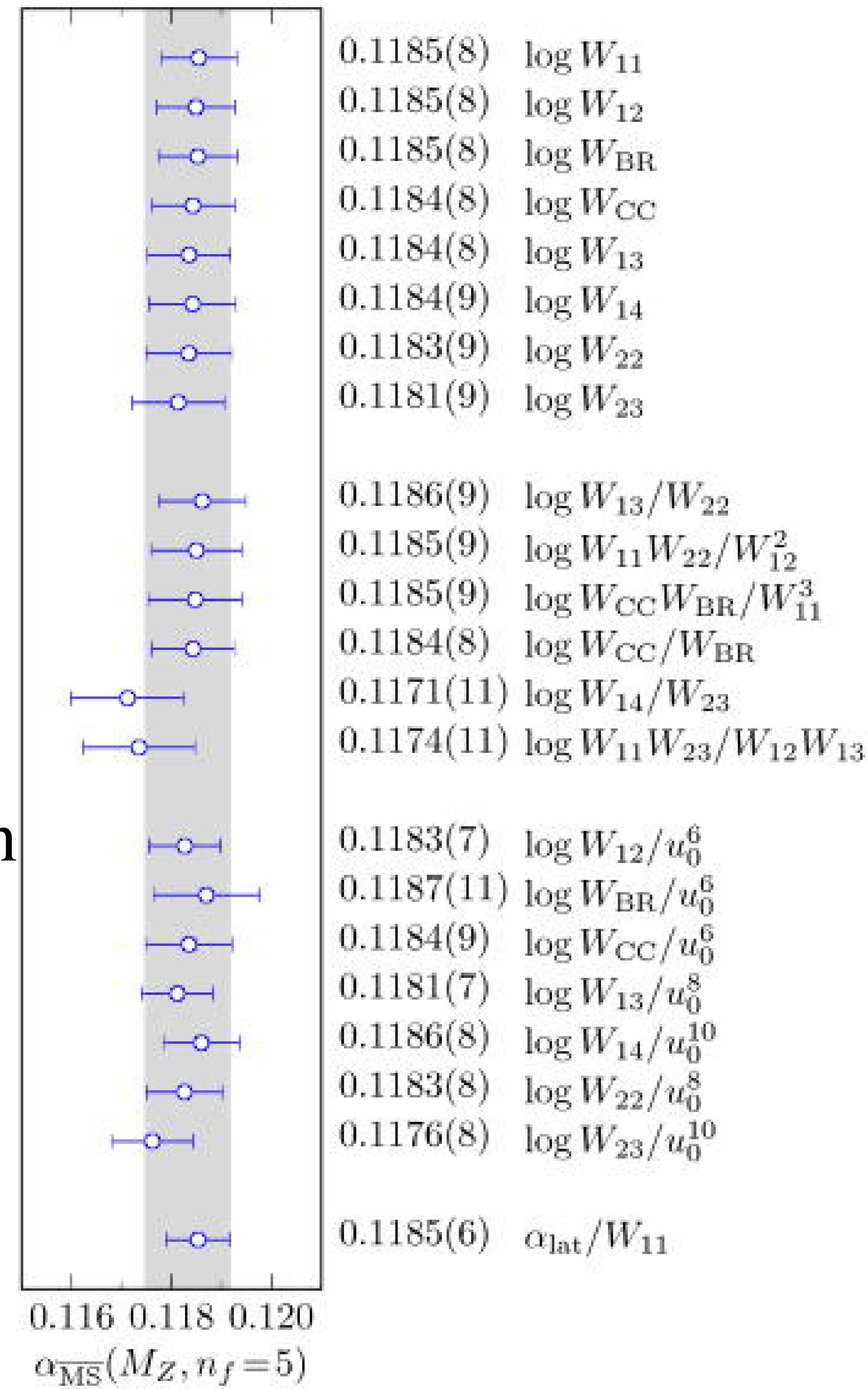
- increasingly inclusive and precise (incl. vacuum polarisation of u, d, s quarks; finer lattice spacing, ...)
- HPQCD collaboration :
  (Davies et al., arXiv:0807.1687)

  – bare coupling and quark masses tuned to reproduce measured Υ‘−Υ mass difference

  – u,d and s quark masses adjusted to give correct light meson masses

- no other free parameters; lattice simulation used to predict values for several short-distance quantities
- fitted to QCD NNLO calculations

–> $\alpha_s(M_Z)$= 0.1183 ± 0.0008



α_s from radiative Y-decays

N. Brambilla et al., hep-ph/0702079

$$R_\gamma \equiv \frac{\Gamma(\Upsilon(1S)\to\gamma X)}{\Gamma(\Upsilon(1S)\to X)} = \frac{36}{5}\frac{e_b^2\alpha}{\alpha_s}\frac{N}{D},$$

$$N = 1 + C_{gg\gamma}\frac{\alpha_s}{\pi} + C_{\mathcal{P}_1(^3S_1)}\mathcal{R}_{\mathcal{P}_1(^3S_1)} + \frac{\pi}{\alpha_s}C_{\gamma\,O_8(^1S_0)}\mathcal{R}_{O_8(^1S_0)} + \frac{\pi}{\alpha_s}C_{\gamma\,O_8(^3P_0)}\mathcal{R}_{O_8(^3P_0)} + \mathcal{O}_N(v^3),$$

$$D = 1 + C_{ggg}\frac{\alpha_s}{\pi} + C_{\mathcal{P}_1(^3S_1)}\mathcal{R}_{\mathcal{P}_1(^3S_1)} + \frac{\pi}{\alpha_s}C_{O_8(^3S_1)}\mathcal{R}_{O_8(^3S_1)} + \frac{\pi}{\alpha_s}C_{O_8(^1S_0)}\mathcal{R}_{O_8(^1S_0)} + \frac{\pi}{\alpha_s}C_{O_8(^3P_0)}\mathcal{R}_{O_8(^3P_0)} + \mathcal{O}_D(v^3),$$

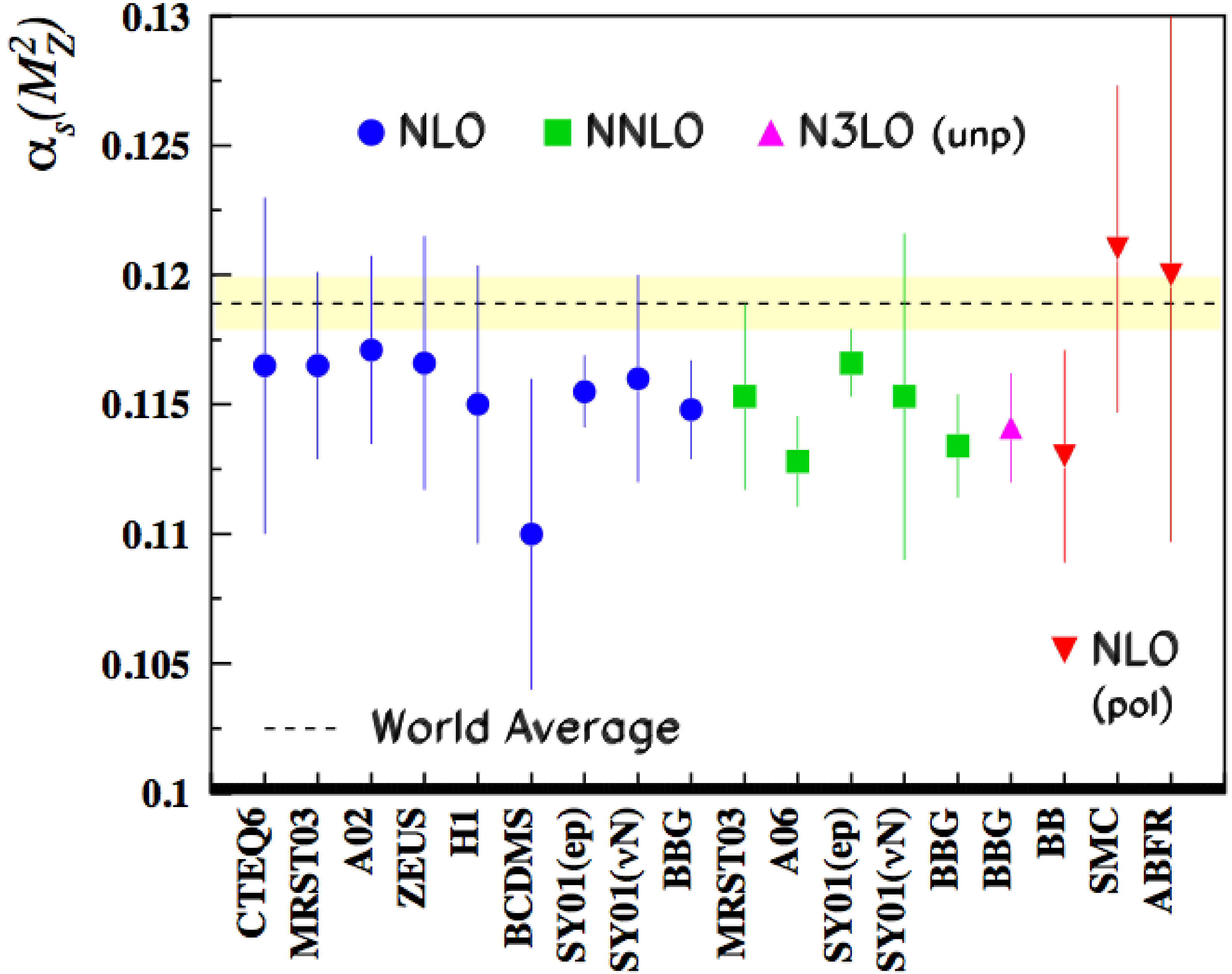
- precise data from CLEO (D. Besson et al., Phys. Rev. D 74, 012003 (2006) [arXiv:hep-ex/0512061].)
- NRQCD in NLO
- estimates of colour octet operators from lattice

$$\alpha_s(M_Z) = 0.119^{+0.006}_{-0.005}$$

α_s from DIS structure functions

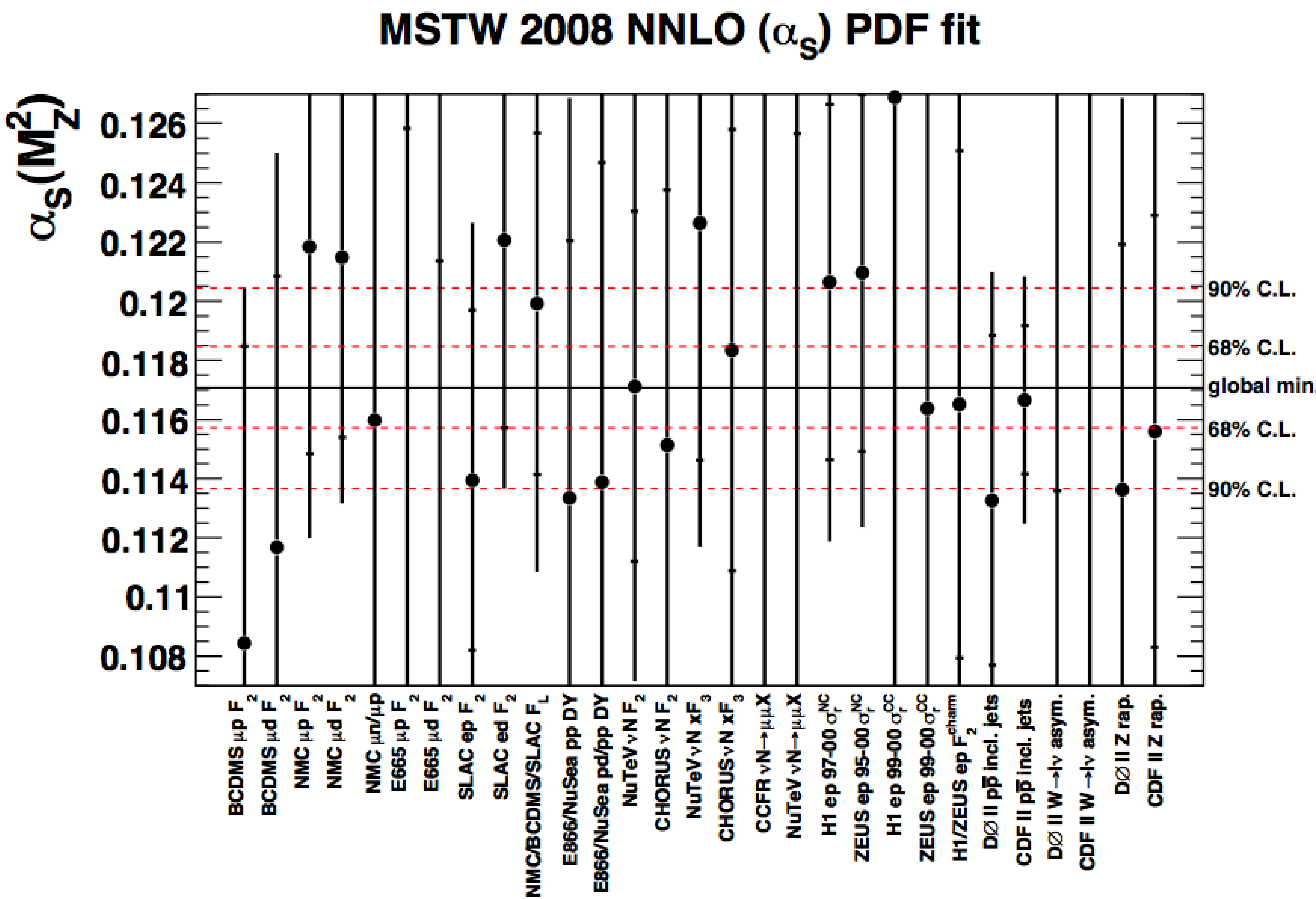
- determination of valence quark (non-singlet) parton densities from DIS lepton-proton and lepton-deuteron data ; QCD up to N3LO
  (Blümlein, Böttcher, Guffanti; hep-ph/0607200)

–> $\alpha_s(M_Z) = 0.1142 \pm 0.0021_{exp.} \pm 0.0007_{th.}$



- obtain syst. higher results when including collider data (in NNLO)
  (Martin, Stirling, Thorne, Watt; arXiv:0905.3531)

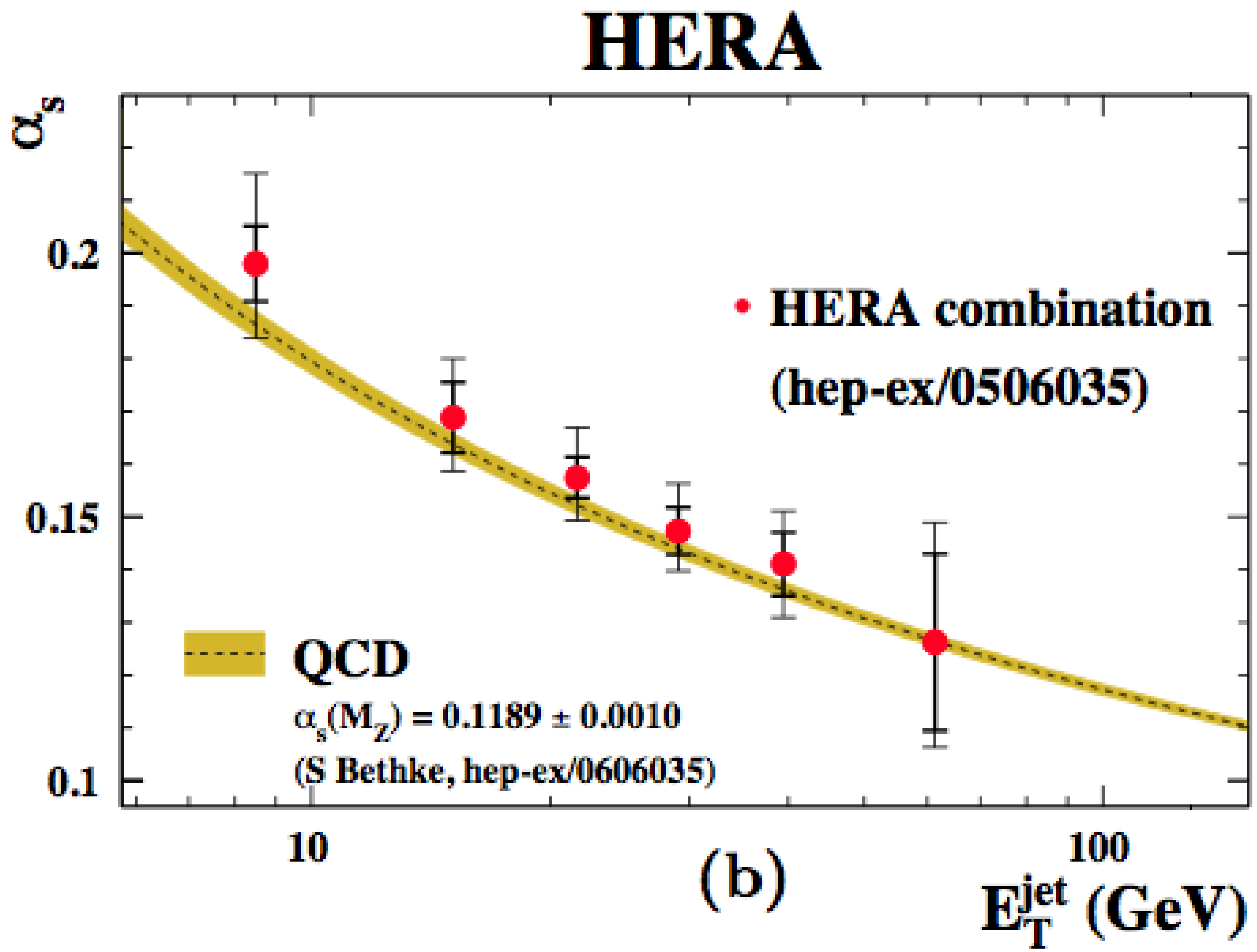
$\rightarrow\ \alpha_s(M_Z) = 0.1171 \pm 0.0014_{exp.} \pm \leq 0.002_{th.}$



α_s from jets in DIS

- combination of measurements from incl. jet cross sections and event shapes at HERA (C. Glasman arXiv:0709.4426)
- carefully selected Q-ranges where theor. uncertainties are minimal (in NLO)

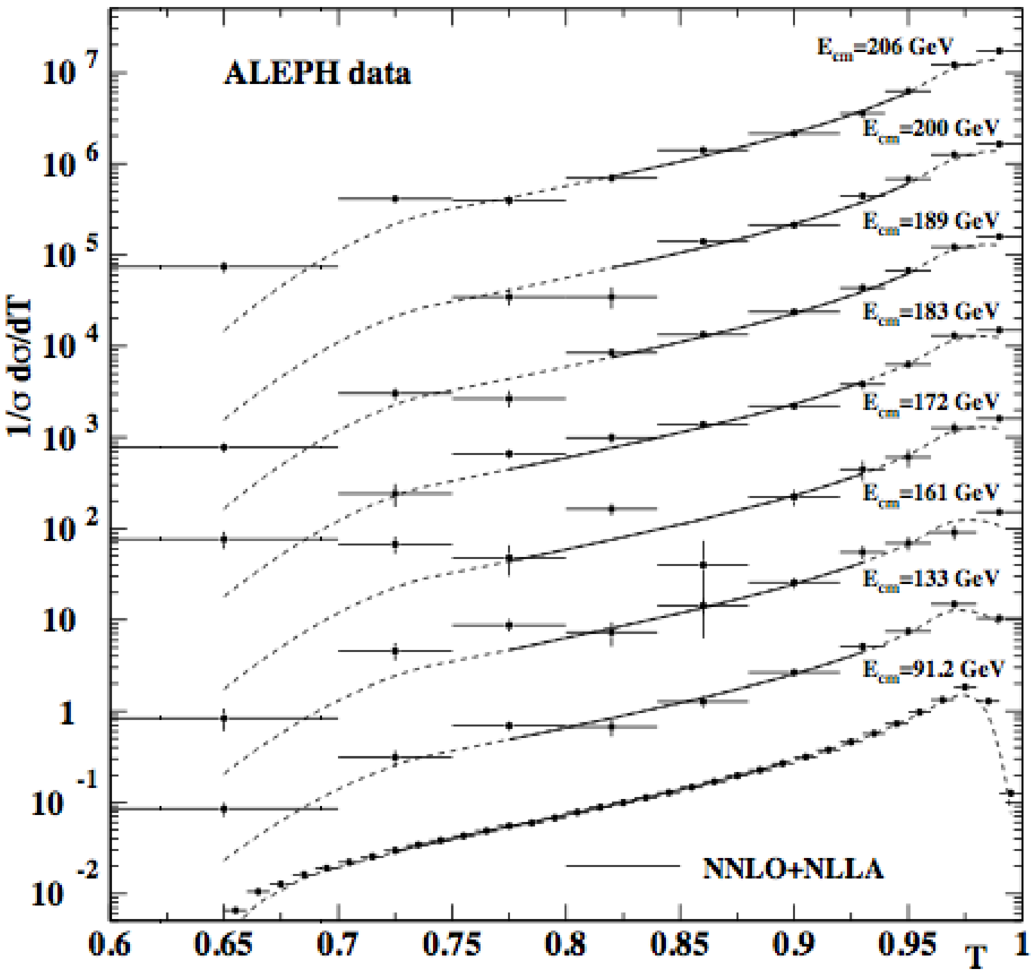
–> $\alpha_s(M_Z) = 0.1198 \pm 0.0019_{exp.} \pm 0.0026_{th.}$

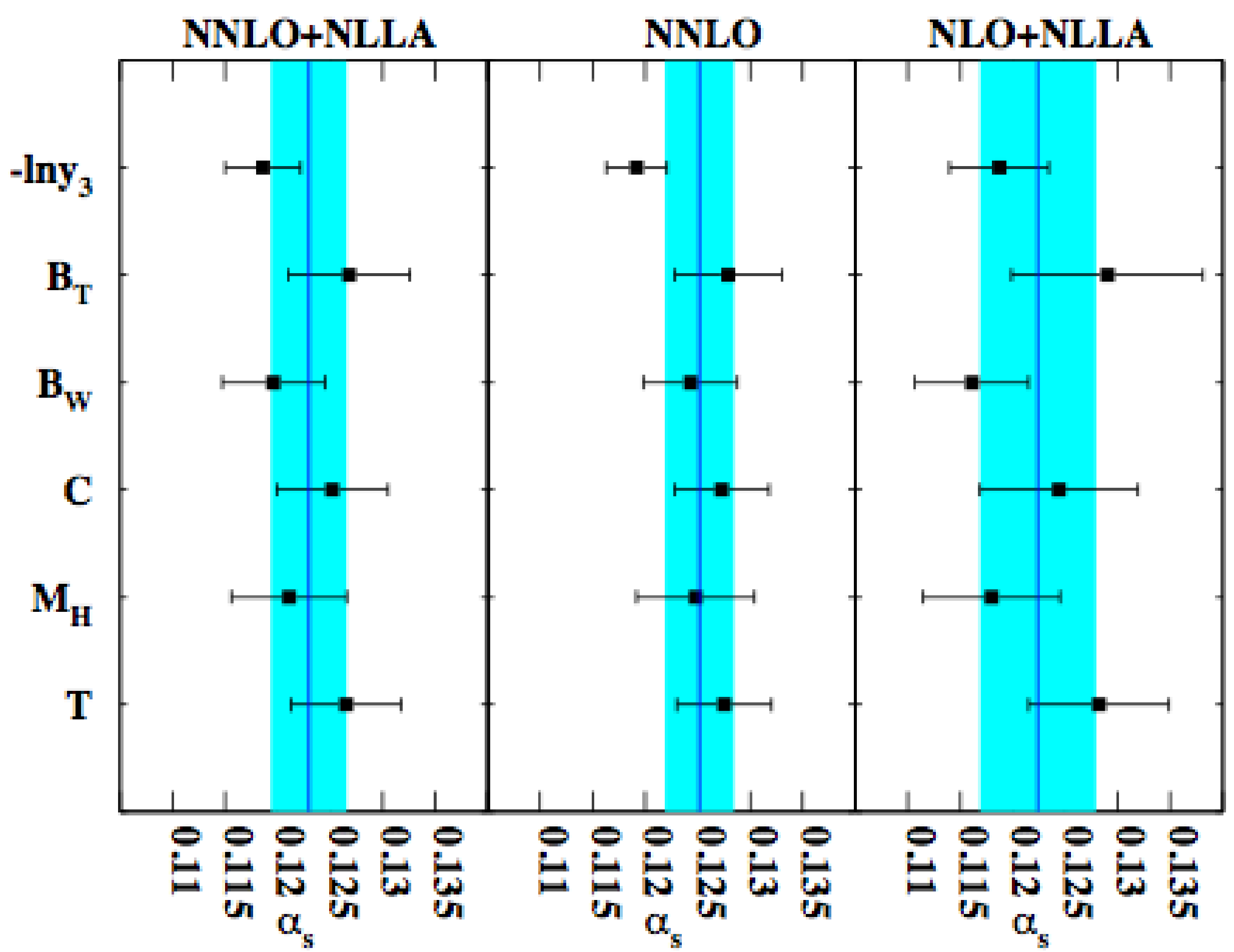


α_s from jets and event shapes in e^+e^- annihilation

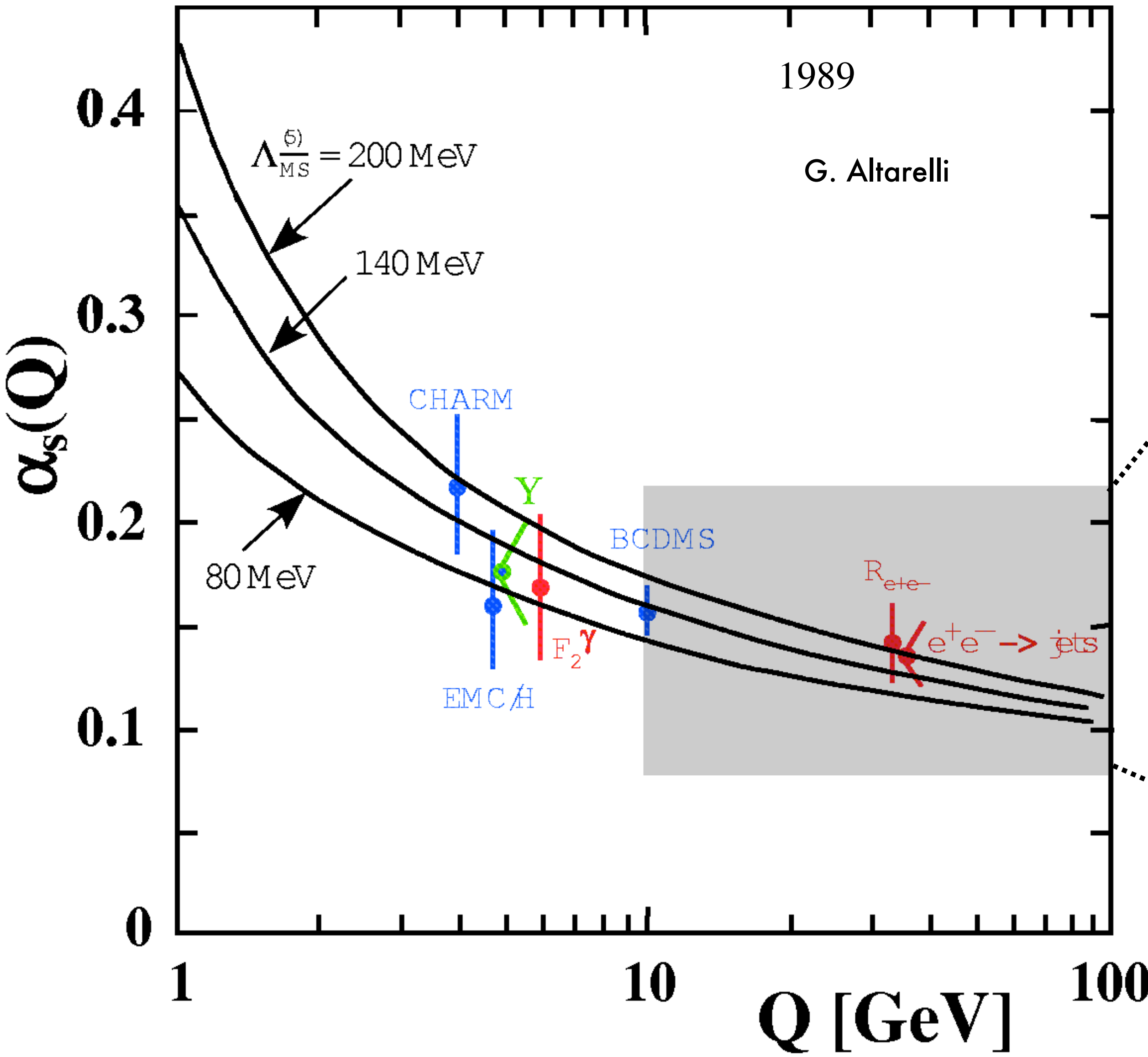
- full NNLO calculations became available (long after end of LEP and other e+e- colliders)
  (Gehrmann - de Ridder et al., arXiv:0711.4711; S. Weinzierl, arXiv:0807.3241)
- resummed NNLO (+ NLLA) (Gehrmann et al., arXiv:0803.0695)
- reanalysis of LEP data (Gehrmann et al., arXiv:0712.0327 ; arXiv:0906.3436)

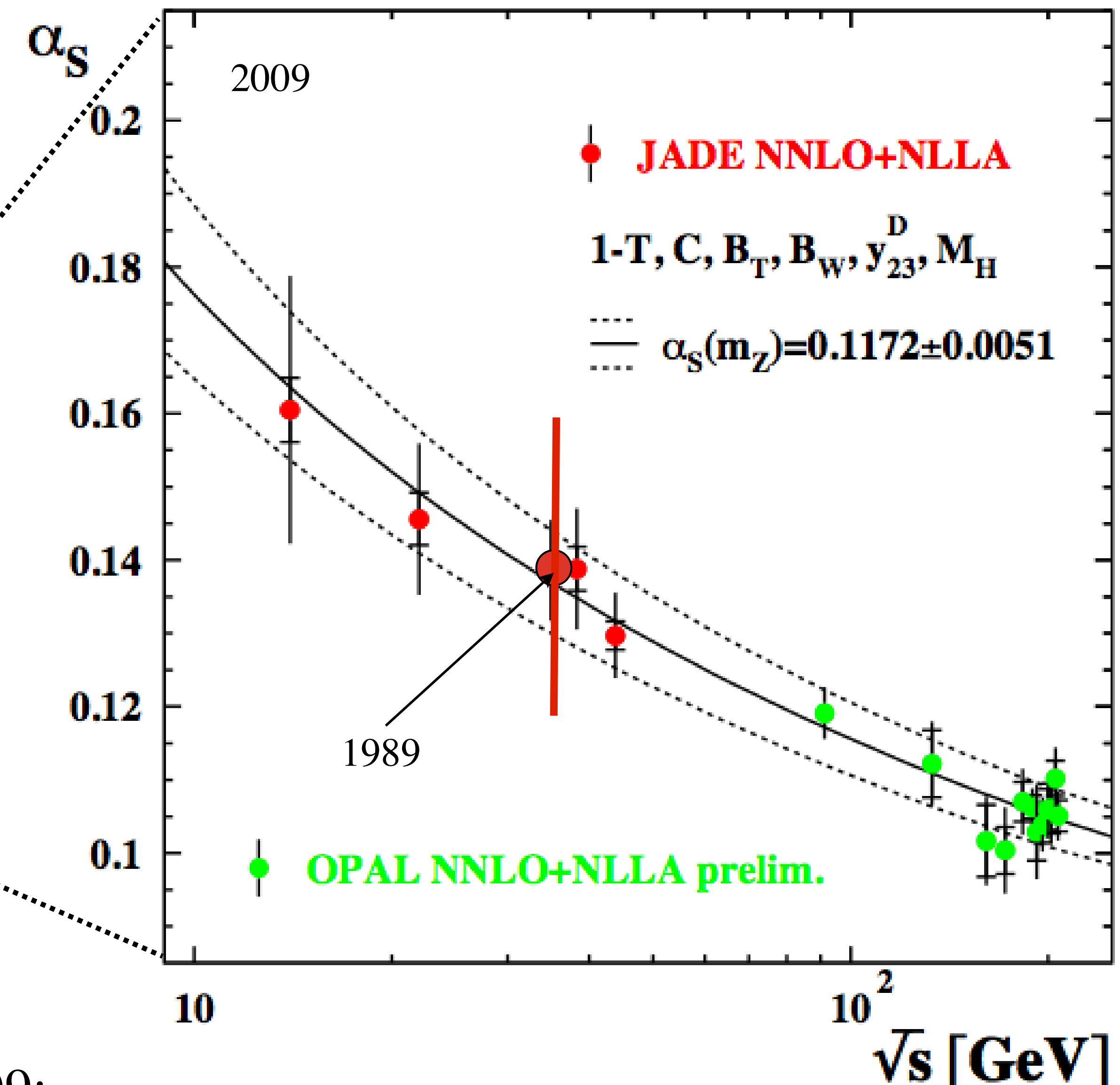
–> $\alpha_s(M_Z) = 0.1224 \pm 0.0013_{exp.} \pm 0.0037_{th.}$





new results from old e+e- data (JADE at PETRA): precision α_s and proof of Asymptotic Freedom





1989:

- in NLO QCD: α_s(35 GeV) = 0.14 ± 0.02
- no running α_s signature

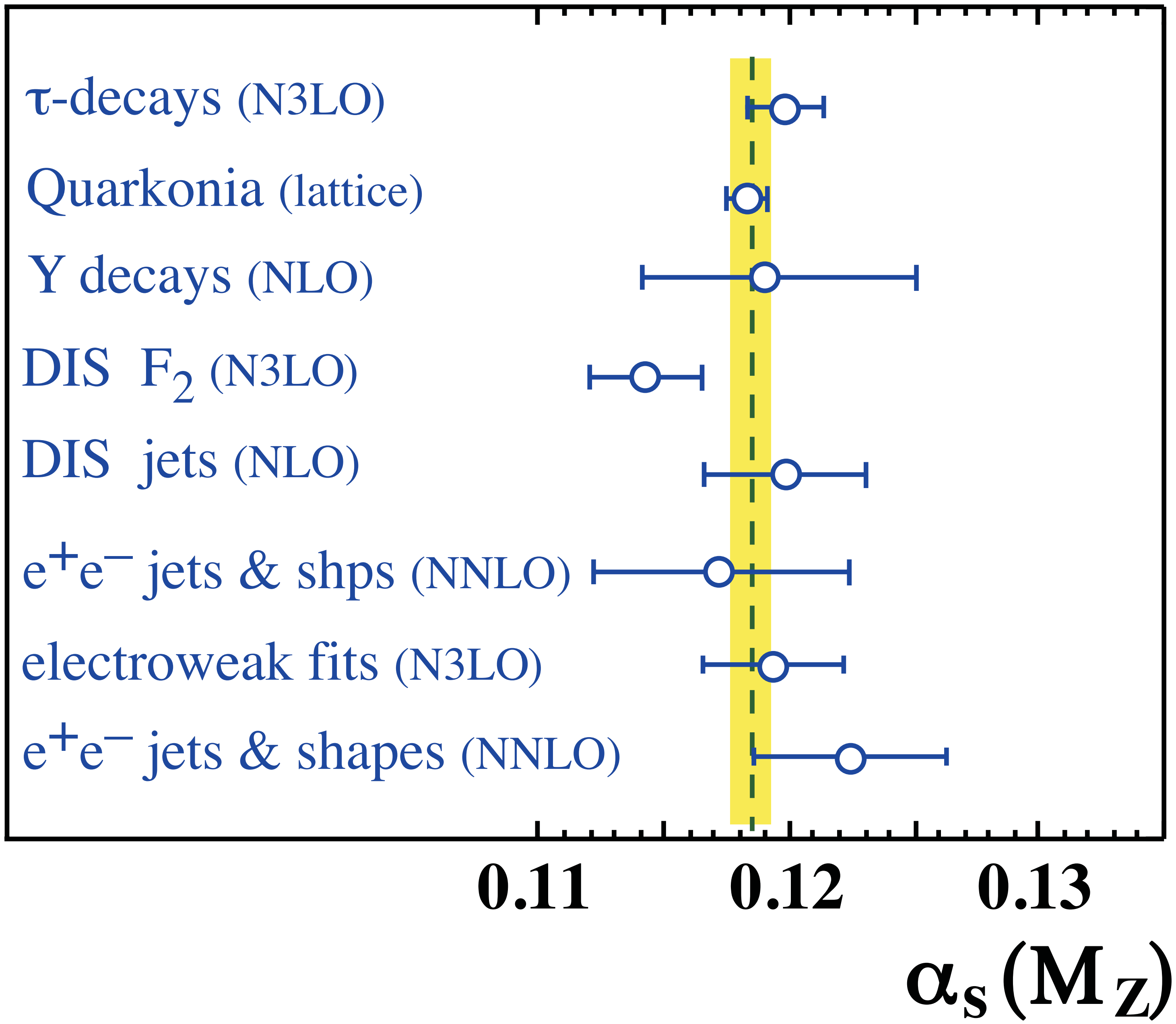
2009:

–> $\alpha_s(M_Z)$= 0.1172 ± $0.0020_{exp.}$ ± $0.0046_{th.}$

(Bethke et al., arXiv:0810.1389)

- significant proof of running α_s and asympt. freedom from e+e- data alone

World Summary of α_s 2009:



–> $\alpha_s(M_Z) = 0.1184 \pm 0.0007$

(Bethke, arXiv:0908.1135)

World Summary of α_s 2009:

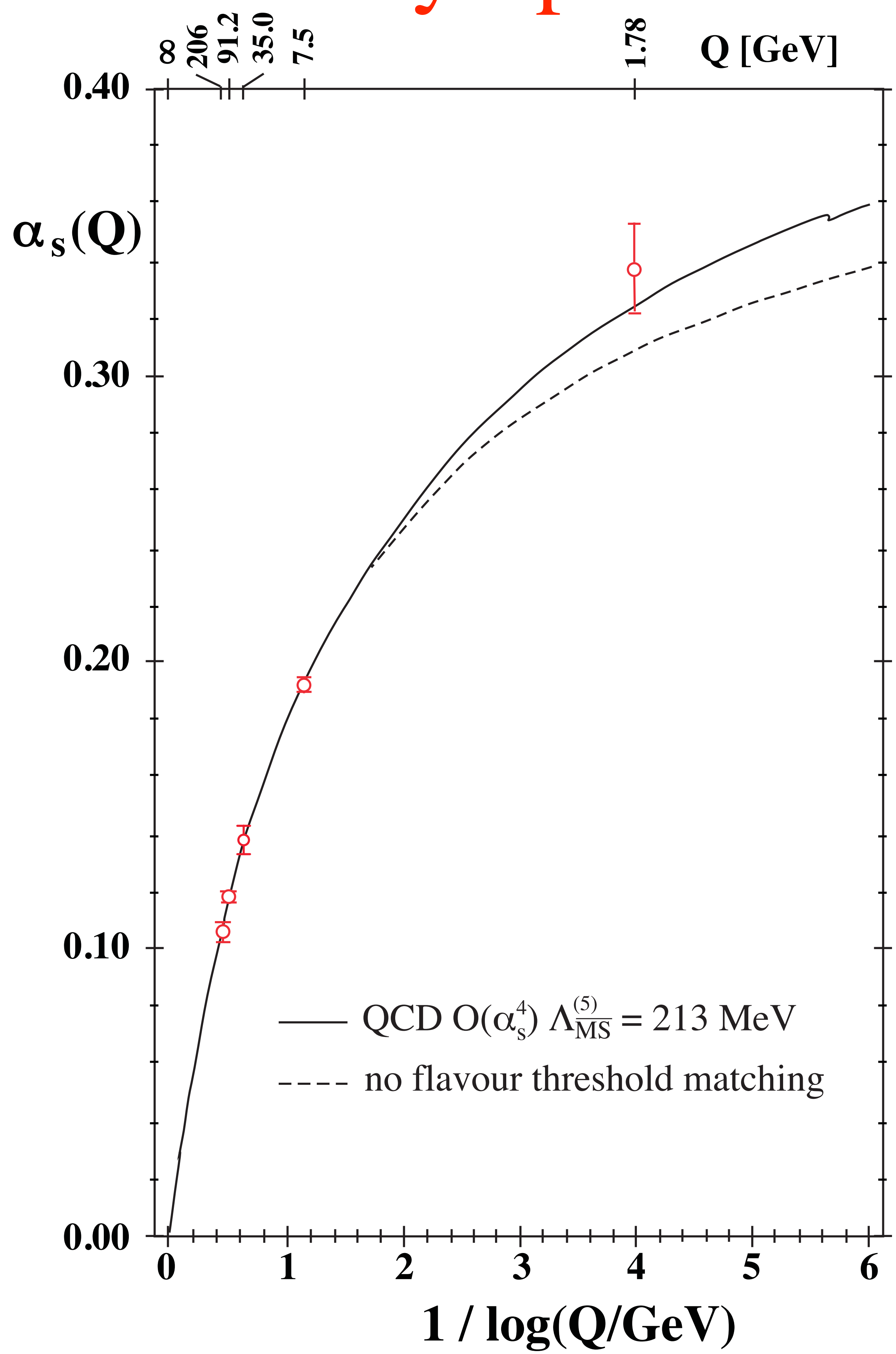
$\alpha_s(M_Z) = 0.1184 \pm 0.0007$

Process	Q [GeV]	$\alpha_s(Q)$	$\alpha_s(M_{Z^0})$	excl. mean $\alpha_s(M_{Z^0})$	std. dev.
τ-decays	1.78	0.330 ± 0.014	0.1197 ± 0.0016	0.11818 ± 0.00070	0.9
DIS $[F_2]$	2 - 170	–	0.1142 ± 0.0023	0.11876 ± 0.00123	1.7
DIS [e-p $\rightarrow$ jets]	6 - 100	–	0.1198 ± 0.0032	0.11836 ± 0.00069	0.4
$Q\overline{Q}$ states	7.5	0.1923 ± 0.0024	0.1183 ± 0.0008	0.11862 ± 0.00114	0.2
Υ decays	9.46	$0.184^{+0.015}_{-0.014}$	$0.119^{+0.006}_{-0.005}$	0.11841 ± 0.00070	0.1
e^+e^- [jets & shps]	14 - 44	–	0.1172 ± 0.0051	0.11844 ± 0.00076	0.2
e^+e^- [ew prec. data]	91.2	0.1193 ± 0.0028	0.1193 ± 0.0028	0.11837 ± 0.00076	0.3
e^+e^- [jets & shps]	91 - 208	–	0.1224 ± 0.0039	0.11831 ± 0.00091	1.0

(Bethke, arXiv:0908.1135)

- most precise single result: from lattice QCD
- exclusive average values scatter only mildly (0.11818 ... 0.11876)
- lattice results coincides with exclusive average (w/o lattice), but largely influences overall error
- very consistent scatter of single results around overall average
- systematic unknowns in DIS / F_2 results ?

evidence for asymptotic freedom:



New results since review 2009:

1. H1: jet production at low q^2   0911.5678

5 < q^2 < 100 GeV^2

as(Mz)= 0.1160 (14)exp (+93-77)th (16)pdf
= 0.1160 (+95-80) = 0.116 (+10-8)

2. Zeus: anti-kt and siscone   PLB 691 (2010) 127

as(Mz)= 0.1188 (14)stat (+33-32) exp (22)th
= 0.1188 (42)

3. D0: incl. jet xsections   0911.2710

50 < pt < 145

as(Mz)= 0.1161 (+34-33)exp (+29-35)th
= 0.1161 (+41-48)

4. Dissertori, e+e- 3-jet NNLO   0910.4283

as(Mz)= 0.1175 (20)exp (15)th
= 0.1175 (25)

5. Hoang, e+e- thrust NNLO+N3LL

as(Mz)= 0.1135 (2)exp (5)had (9)pert
= 0.1135 (10)

6. Frederix, e+e- 5-jet NLO   1008.5313

as(Mz)= 0.1156 (+41-34)tot

7. Blümlein, Pol DIS NLO   1005.3113

as(Mz)= 0.1132 (
= 0.1132 (+56-95)

8. Alekhin, PDFs DIS & HColl NNLO   0908.2766

as(Mz)= 0.1135 (14) exp

(0.1143 (23)tot in NNNLO)

9. Alekhin, PDFs + HERA I NNLO   1007.3657

as(Mz)= 0.1147 (12) exp

10. Bunyatyan HERA jets NLO   conf 2009

as(Mz)=

11. MSTW PDFs   NNLO   0905.3531

as(Mz)= 0.1171 (14)exp   guess: (20)th

12. Kotikov, fixed target PDFs, NNLO 0912

as(Mz)= 0.1167 (21)exp (+56-36)th

13. Caprini tau N3Lo   0906.5211

as(Mtau)= 0.320 (+11-9)
as(Mz)= 0.1185 (+14-11)

14. Pich tau N3LO   1001.0389

as(Mtau)= 0.342 (12)
as(Mz)= 0.1213 (14)

first look at an

update of world average $\alpha_s(M_Z)$ (Feb. 2011)

(n.b.: preliminary; incomplete!)

–> $\alpha_s(M_Z) = 0.1174 \pm 0.0006$ ***(χ^2 = 27 / 7 d.f.)***

–> $\alpha_s(M_Z) = 0.1174 \pm 0.0011$ ***(χ^2 = 1/d.f.)***

new

Process	Q [GeV]	$\alpha_s(Q)$	$\alpha_s(M_{Z^0})$	excl. mean $\alpha_s(M_{Z^0})$	std. dev.
→ τ-decays	1.78		0.1213 ± 0.0014	0.1167 ± 0.0009	2.7
DIS [F_2]	2 - 170	–	0.1142 ± 0.0023	0.1174 ± 0.0011	1.3
DIS [e-p $\rightarrow$ jets]	6 - 100	–	0.1198 ± 0.0032	0.1172 ± 0.0011	0.8
$Q\overline{Q}$ states	7.5	0.1923 ± 0.0024	0.1183 ± 0.0008	0.1166 ± 0.0013	1.1
Υ decays	9.46	$0.184^{+0.015}_{-0.014}$	$0.119^{+0.006}_{-0.005}$	0.1174 ± 0.0011	0.3
→ e^+e^- [T, Hoang]	34 - 208	–	0.1135 ± 0.0010	0.1185 ± 0.0007	4.1
e^+e^- [ew prec. data]	91.2	0.1193 ± 0.0028	0.1193 ± 0.0028	0.1172 ± 0.0011	0.7
→ e^+e^- [jets, Dissert.]	91 - 208	–	0.1175 ± 0.0015	0.1172 ± 0.0011	0.2

n.b.:
- *incompatible* „raw“ summary
- one result *incompatible* with rest
- $\chi^2 = 1$ only if **all** errors inflated by factor 2.0