The 2015

(preliminary)

World Average of

α_s

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what is α_s ...

– α_s determines and parametrizes the strength of the Strong Interaction between colour-charged objects, like quarks and gluons

– α_s is one of nature's fundamental parameters, like the elementary electric charge e, the electron mass m_e, the gravitational constant G , ...

– the numerical size of these fundamental parameters is not predicted by the Standard Model of particle physics

– theory, however, predicts the energy dependence of all couplings, through the so-called renormalization group or beta-function:

$$\mu_R^2 \frac{d\alpha_s}{d\mu_R^2} = \beta(\alpha_s) = -\left(b_0 \alpha_s^2 + b_1 \alpha_s^3 + b_2 \alpha_s^4 + \cdots\right)$$

with

$$b_0 = \frac{1}{4\pi}\left[\frac{11}{3}\begin{pmatrix} N_c \equiv 0 \\ N_c \equiv 2 \\ N_c \equiv 3 \end{pmatrix} - \frac{4}{3}\begin{pmatrix} N_{fam} \\ N_{fam} \\ N_f/2 \end{pmatrix} - N_{Higgs}\begin{pmatrix} \frac{1}{10} \\ \frac{1}{6} \\ 0 \end{pmatrix}\right] \begin{matrix} \leftarrow \text{QED} \\ \leftarrow \text{weak} \\ \leftarrow \text{QCD} \end{matrix}$$

obvious tasks:

– determine values of $\alpha_s(Q)$, using data from as many different particle reactions and energy scales Q as possible

– compare with the energy dependence predicted by QCD, and verify the prediction of Asymptotic Freedom (AF)

– assuming universality of α_s and the validity of AF, determine the world average value of α_s at a given reference scale, e.g. $\alpha_s(M_Z)$

– with the highest possible precision and reliability !

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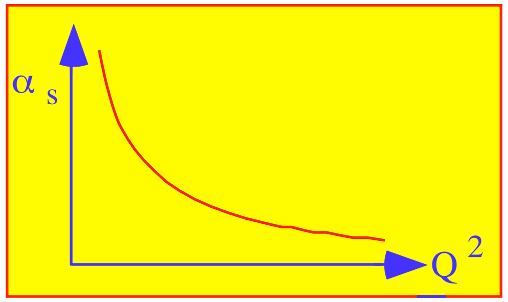

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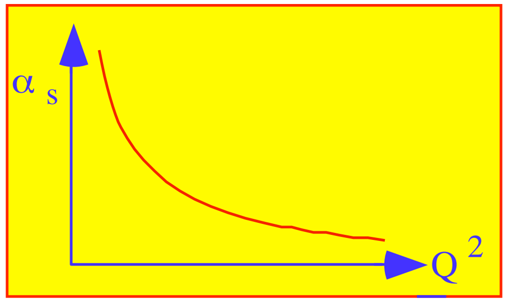

Gross, Politzer, Wilczek
2004

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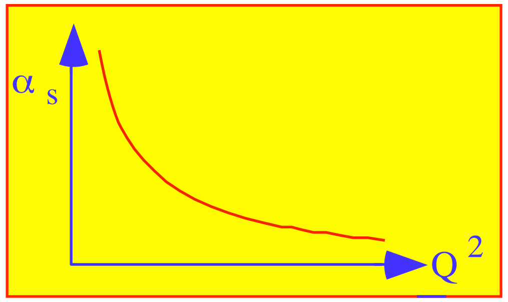

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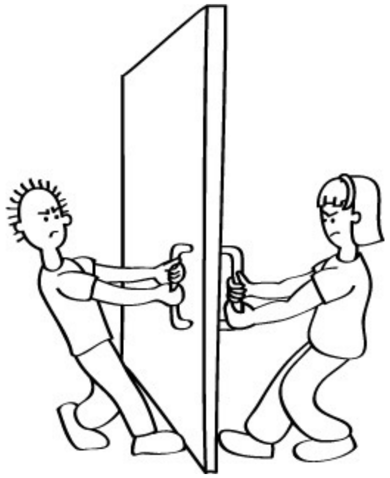

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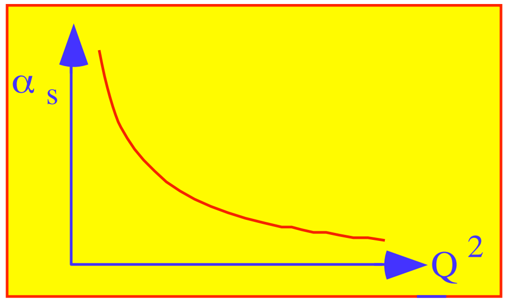

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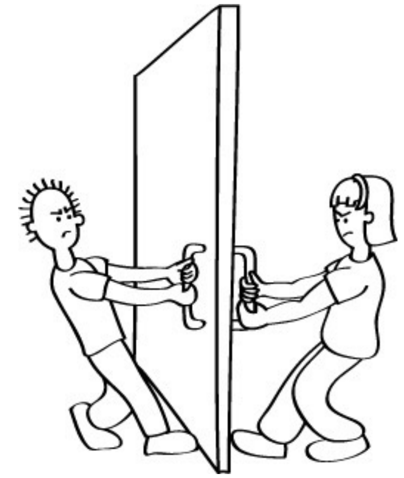

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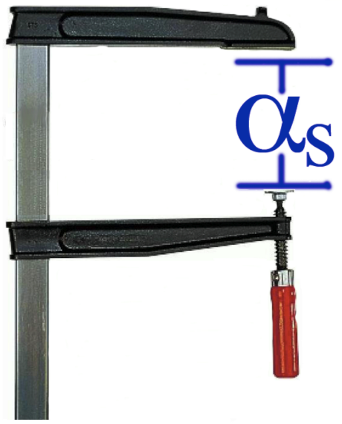

World Summary of α_s 2013:

- 5 classes of measurements, each pre-averaged
- all at least using NNLO QCD
- using two methods to determine (pre-)averages:

– *"range averaging"*
average value with symmetric overall uncertainty that encompasses the central values of all individual α_s-results

– "χ^2 *method*"
weighted average treating individual uncertainties as being uncorrelated and of Gaussian nature.

If overall $\chi^2 < 1$/d.o.f., an overall correlation coefficient is introduced and adjusted such that $\chi^2 = 1$/d.o.f.

If overall $\chi^2 > 1$/d.o.f., all uncertainties are enlarged by a common factor such that $\chi^2 = 1$/d.o.f.

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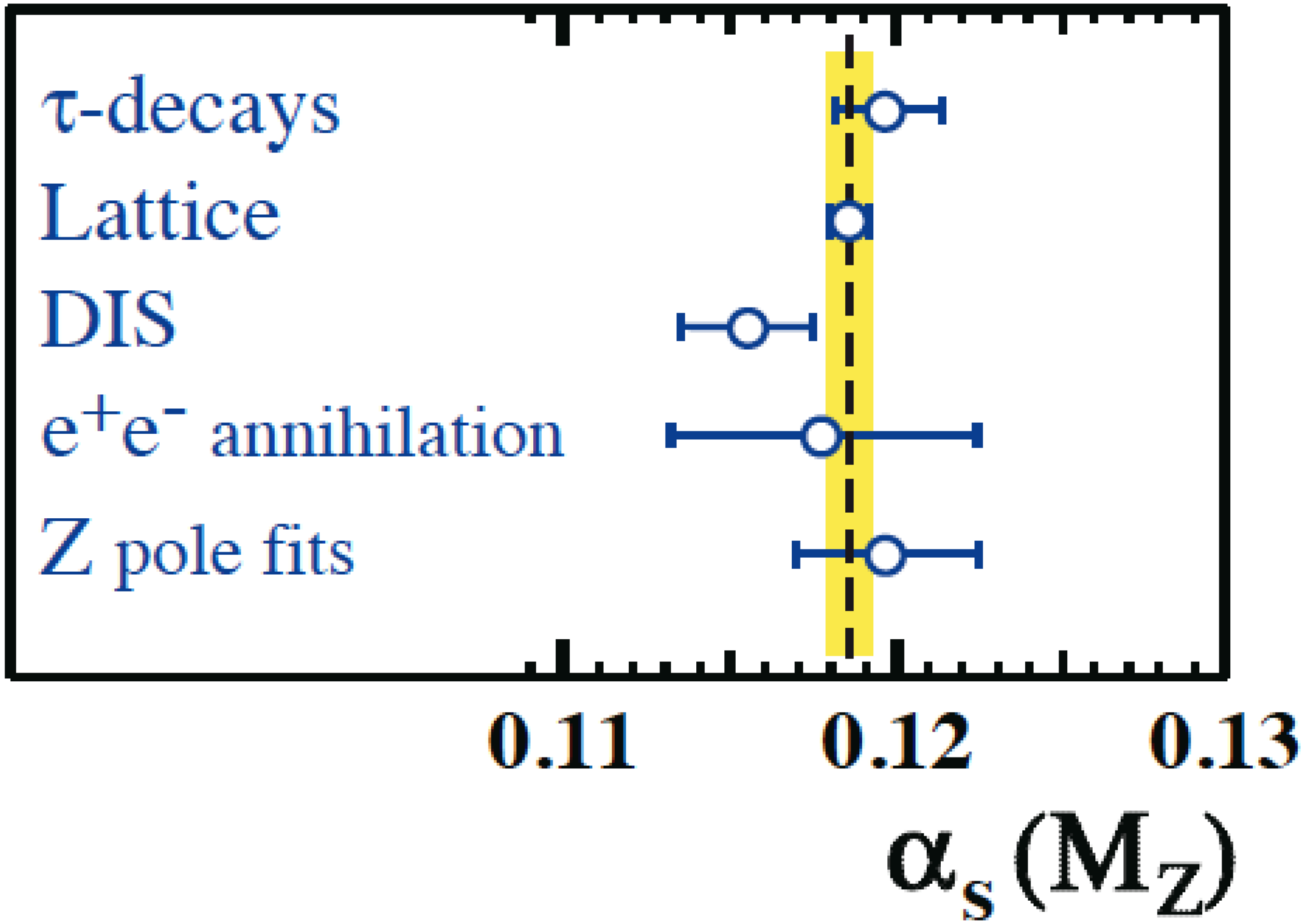

$\alpha_s(M_z) = 0.1185 \pm 0.0006$

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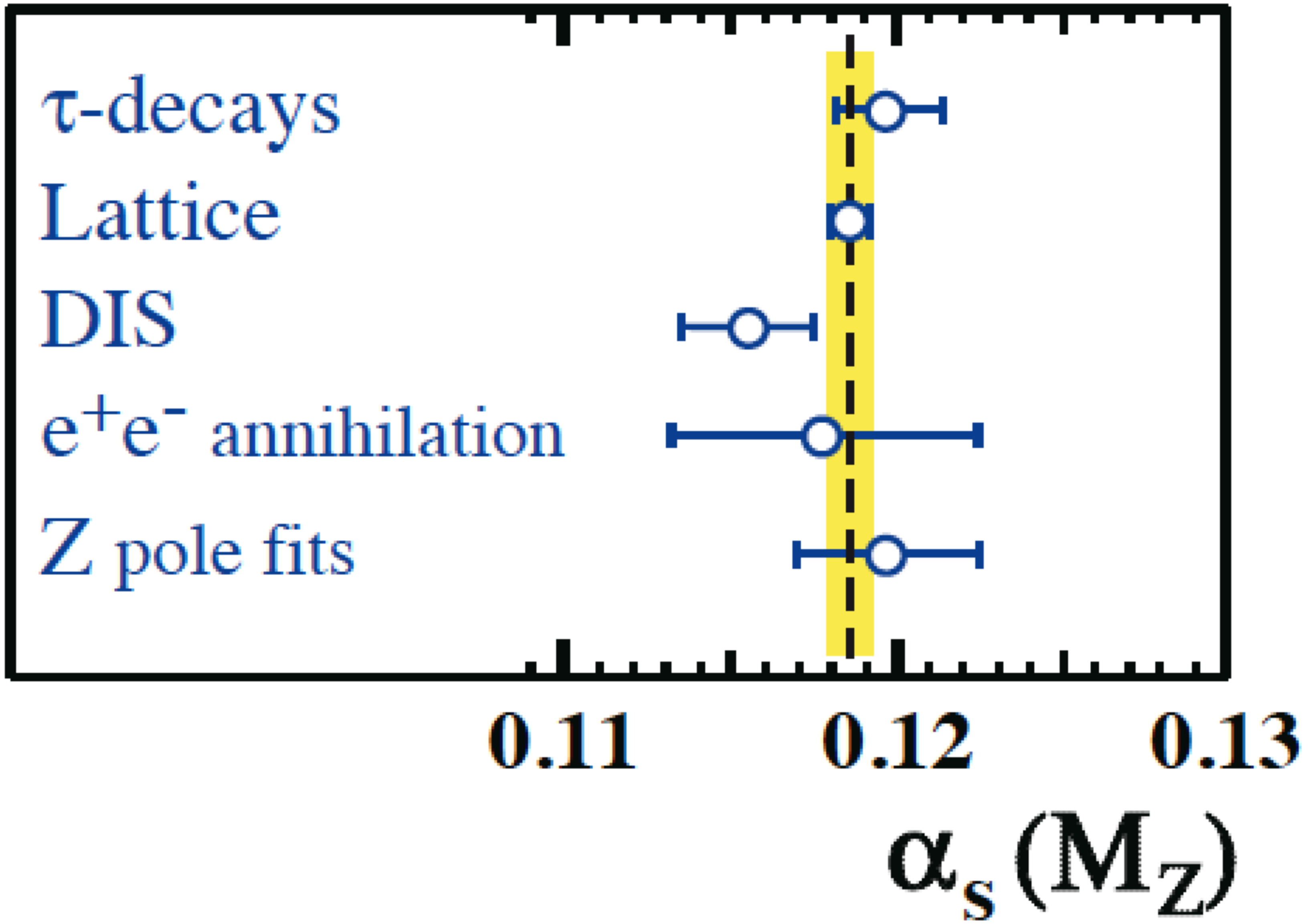

$\alpha_s(M_z) = 0.1185 \pm 0.0006$

without lattice: $\alpha_s(M_z) = 0.1183 \pm 0.0012$

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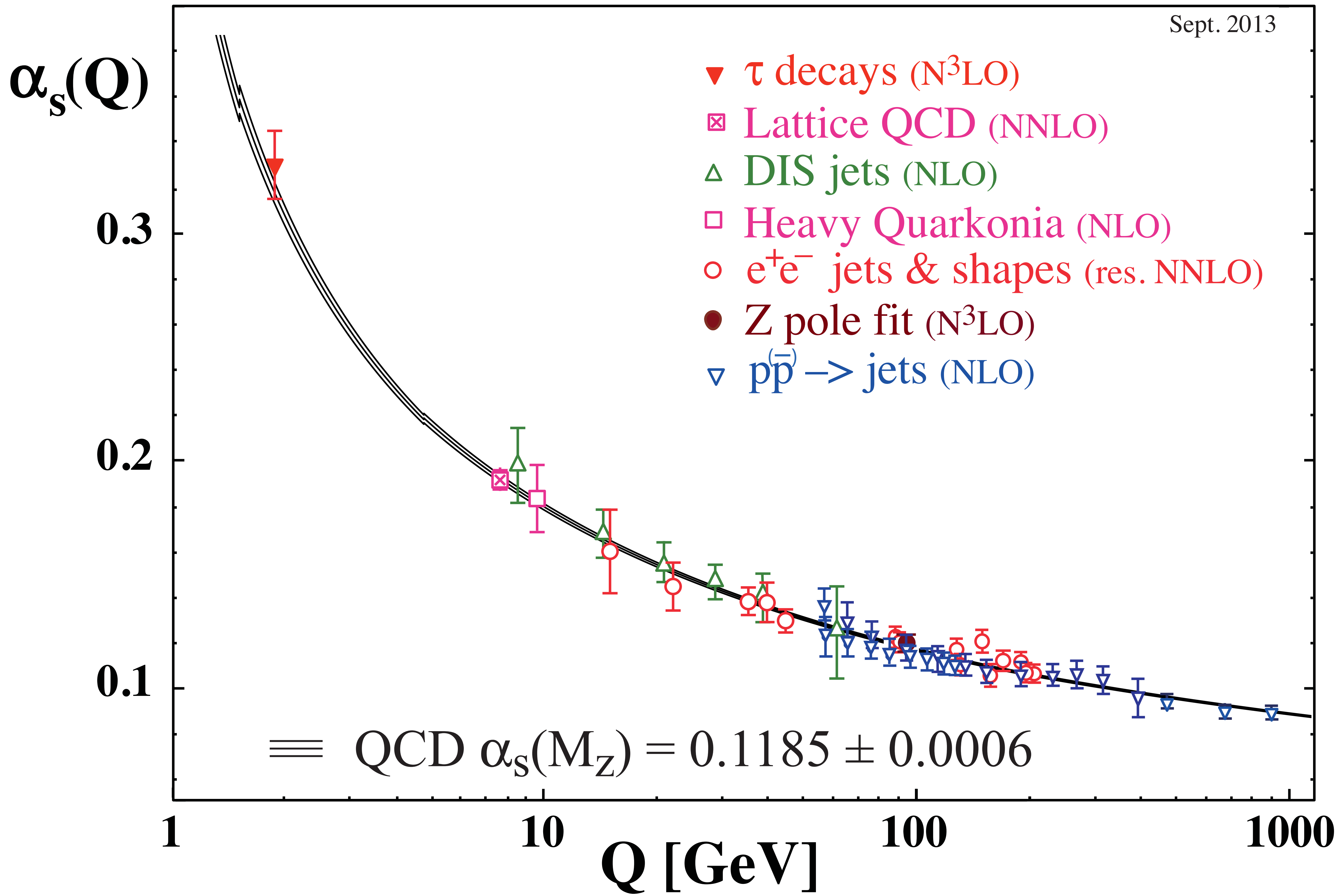


new measurements/results added for 2015 summary :

- update results from τ-decays (in N^3LO)

  (Davier et al., Eur.Phys.J. C74 (2014) 3, 2803; Boito et al., Phys.Rev. D91 (2015) 3, 034003)

- more results from unquenched lattice calculations

  (FLAG collab., Eur.Phys.J. C74 (2014) 2890; Brambilla et al., Phys.Rev. D90 (2014) 7, 074038)

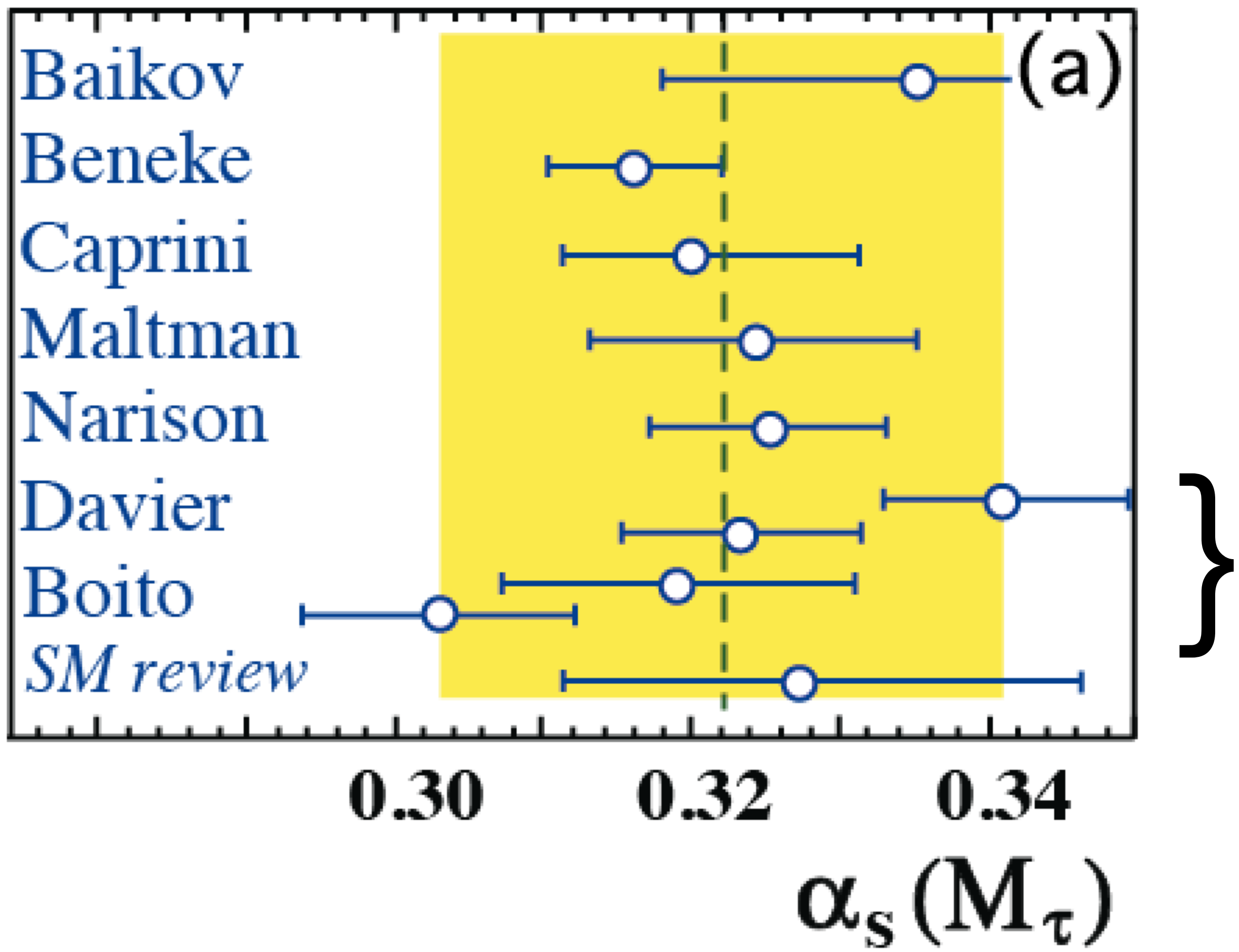
- more α_s from world data of structure functions (in NNLO)
  (MMHT, arXiv:1506.05682 [hep-ph])

- α_s from hadron collider (in NNLO) (CMS collab., Phys. Lett. B 728 (2013) 496;)
  (in NLO) (CMS collab., Eur. Phys. J. C 75 (2015) 186; Eur. Phys. J. C 75 (2015) 288)

- $e^+ e^-$ hadronic event shape (C) in soft collinear effective field theory (NNLO)
  (Hoang et al., Phys. Rev. D 91, 094018 (2015))

α_s from τ-decays

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



note: same new ALEPH data, large systematics between different authors!

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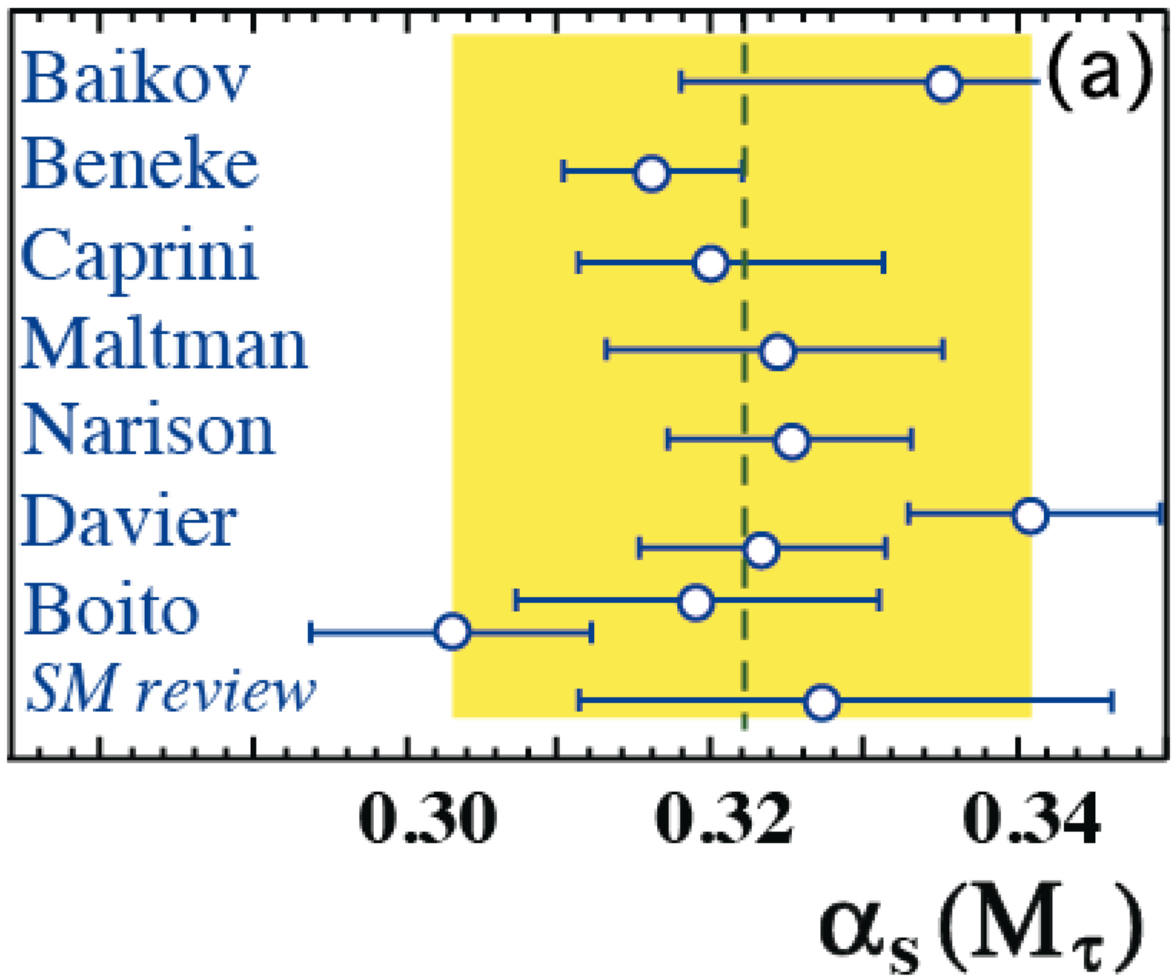

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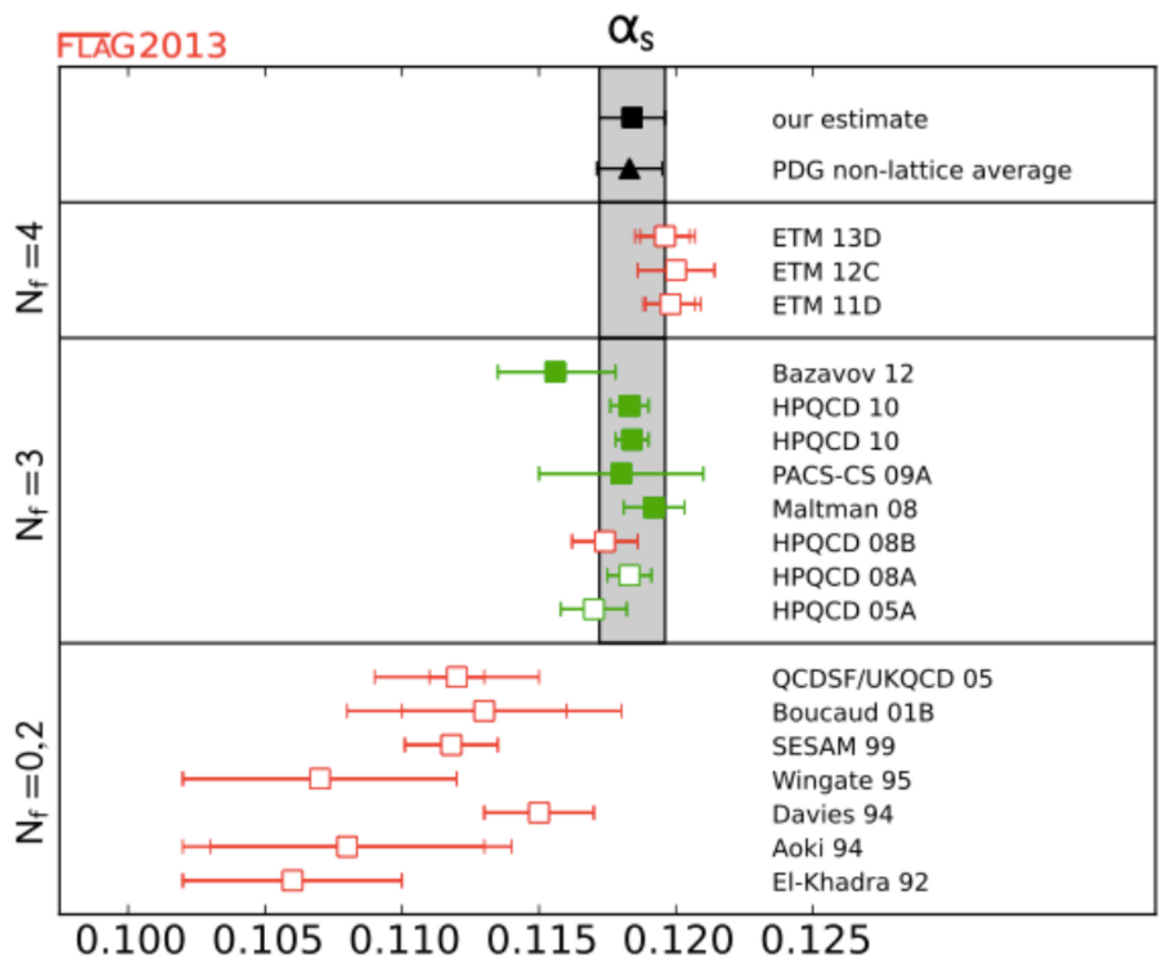
- averaging and summarising: $\alpha_s(M_\tau) = 0.322 \pm 0.019$

–> $\alpha_s(M_Z) = 0.1187 \pm 0.0023$

α_s from lattice QCD

summary from FLAG collaboration, 2013:

- The importance of quality criteria is seen in our estimate of α_{strong}



- FLAG estimate has conservative error (not all FLAG agrees)
- PDG total average takes all lattice results at face value
- PDG without lattice agrees with FLAG

FLAG estimate: $\alpha^{(5)}_{\overline{MS}}(M_Z) = 0.1184(12)$

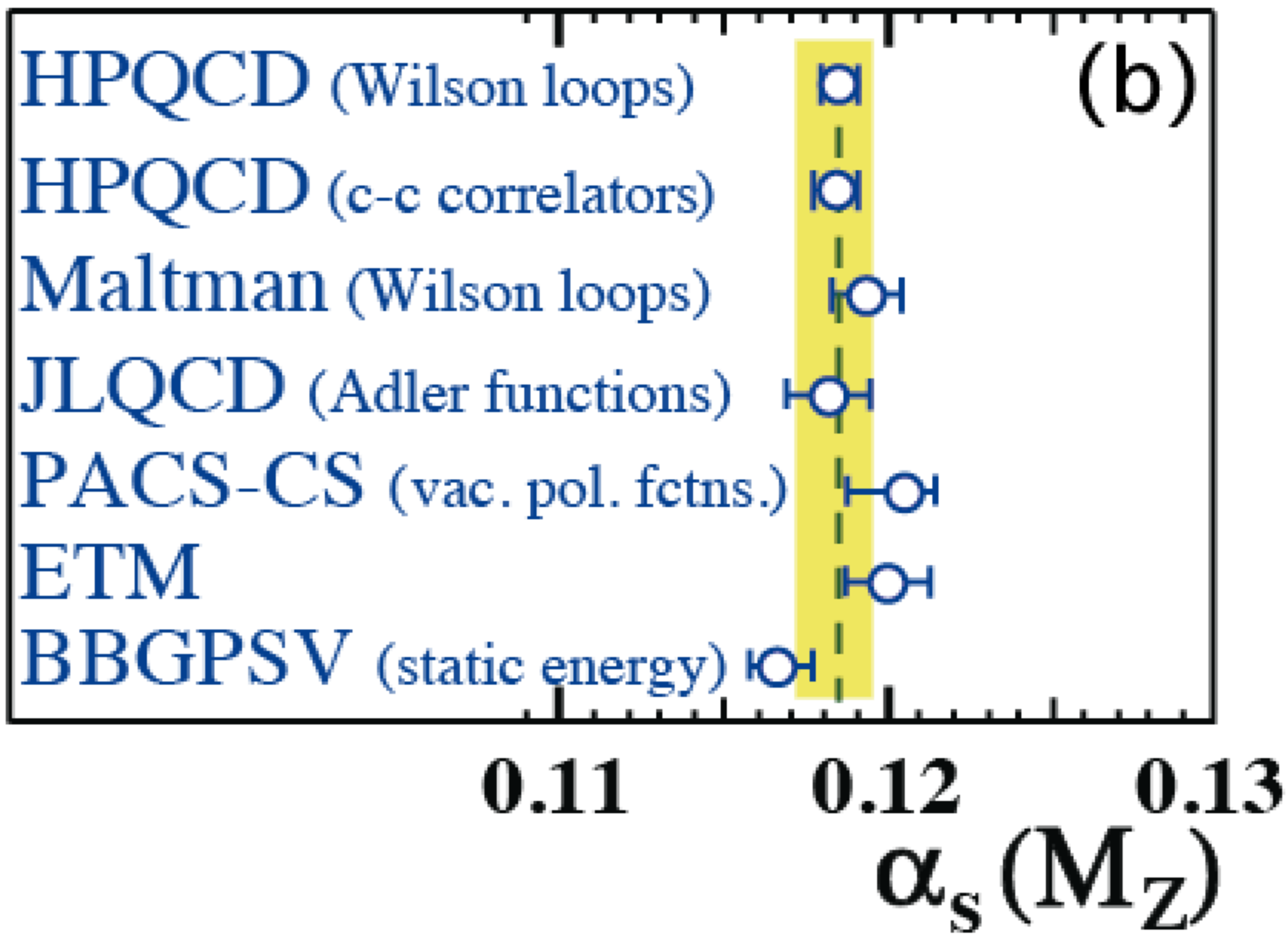
(2013) PDG average $\alpha^{(5)}_{\overline{MS}}(M_Z) = 0.1185(5)$

(2013) PDG average (non lattice) $\alpha^{(5)}_{\overline{MS}}(M_Z) = 0.1183(12)$

slide from: Anastasios VLADIKAS

α_s from lattice QCD

our RPP summary 2015:



α_s from lattice QCD

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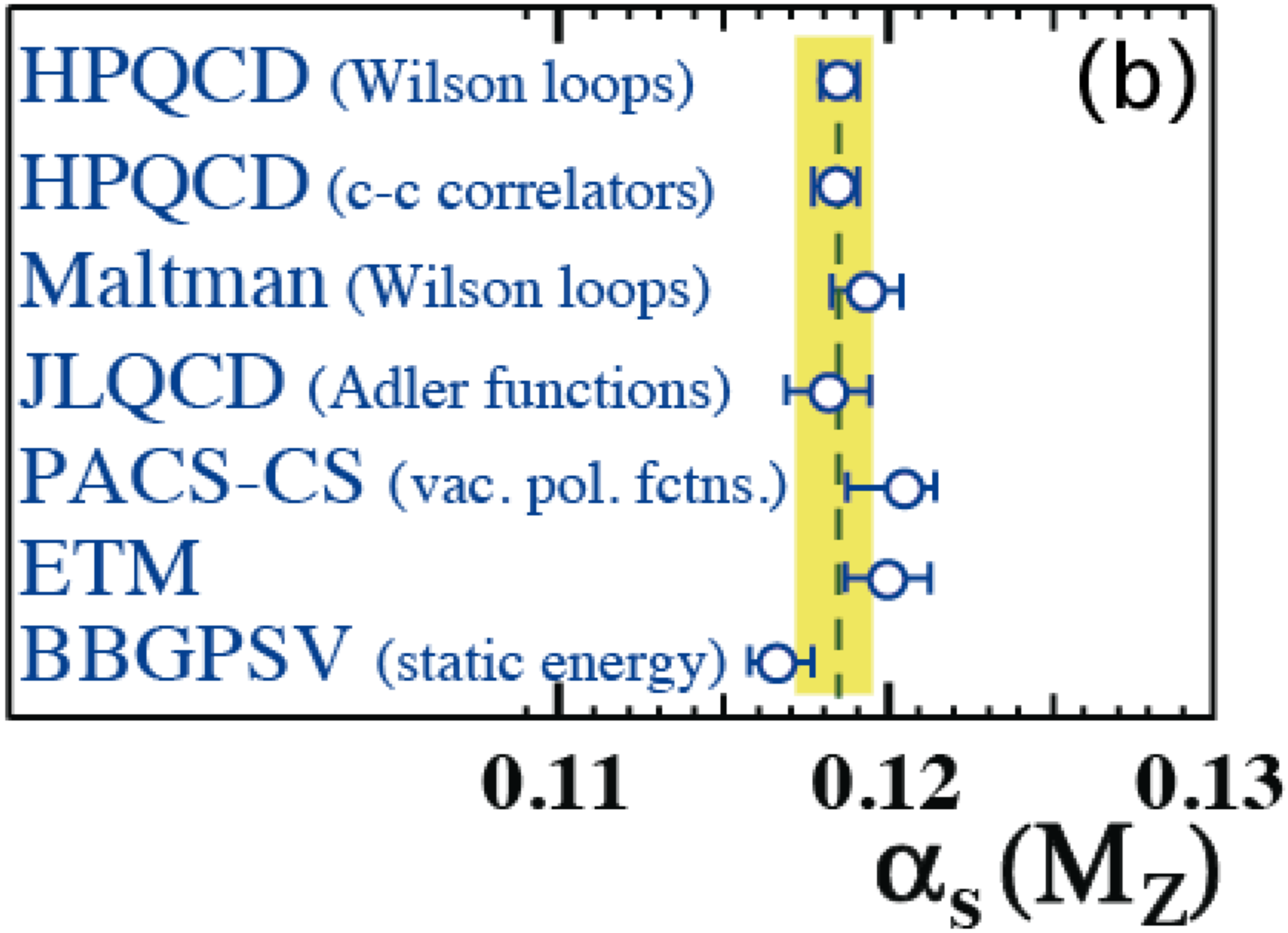

shown: FLAG summary, $\alpha_s(M_Z) = 0.1184 \pm 0.0012$

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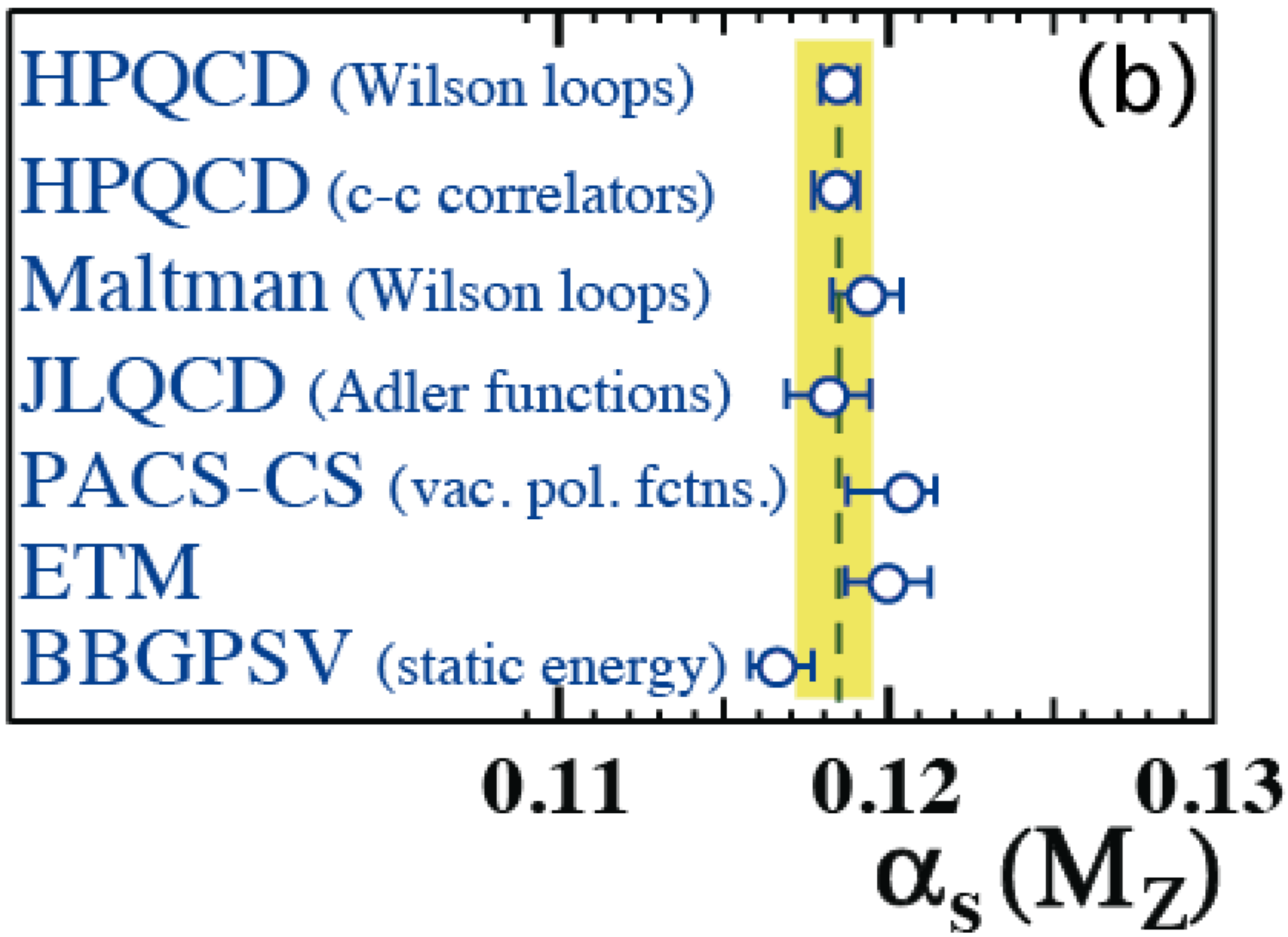


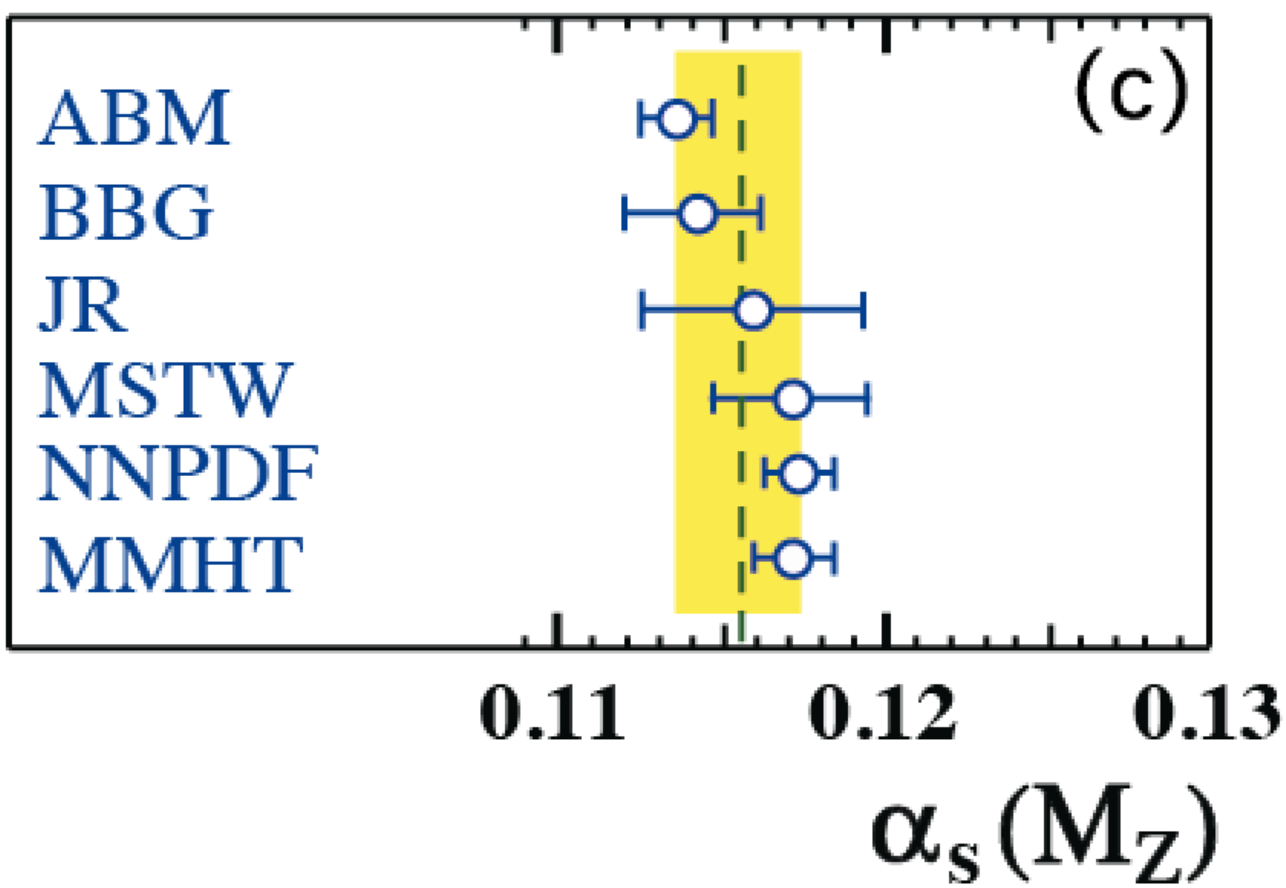
shown: FLAG summary, $\alpha_s(M_Z) = 0.1184 \pm 0.0012$

(if done as in previous RPP: $\alpha_s(M_Z) = 0.1185 \pm 0.0005$)

α_s from DIS structure functions

- determination of parton densities from DIS; QCD in NNLO (up to N^3LO);
- MSTW/NNPDF/MMHT: include hadron collider jet data (in order to constrain gluon at large x)

n.b.: all use similar (sub-)sets of data



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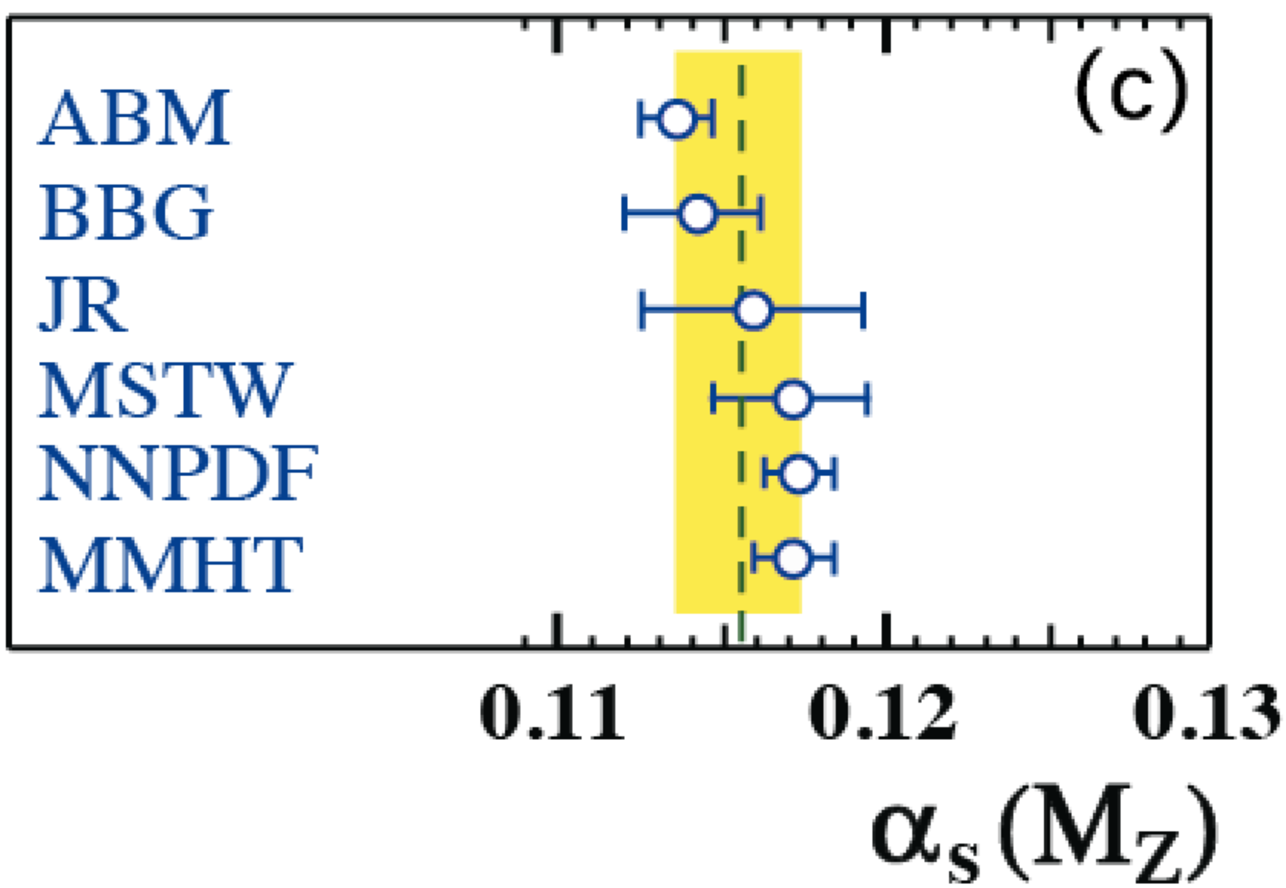
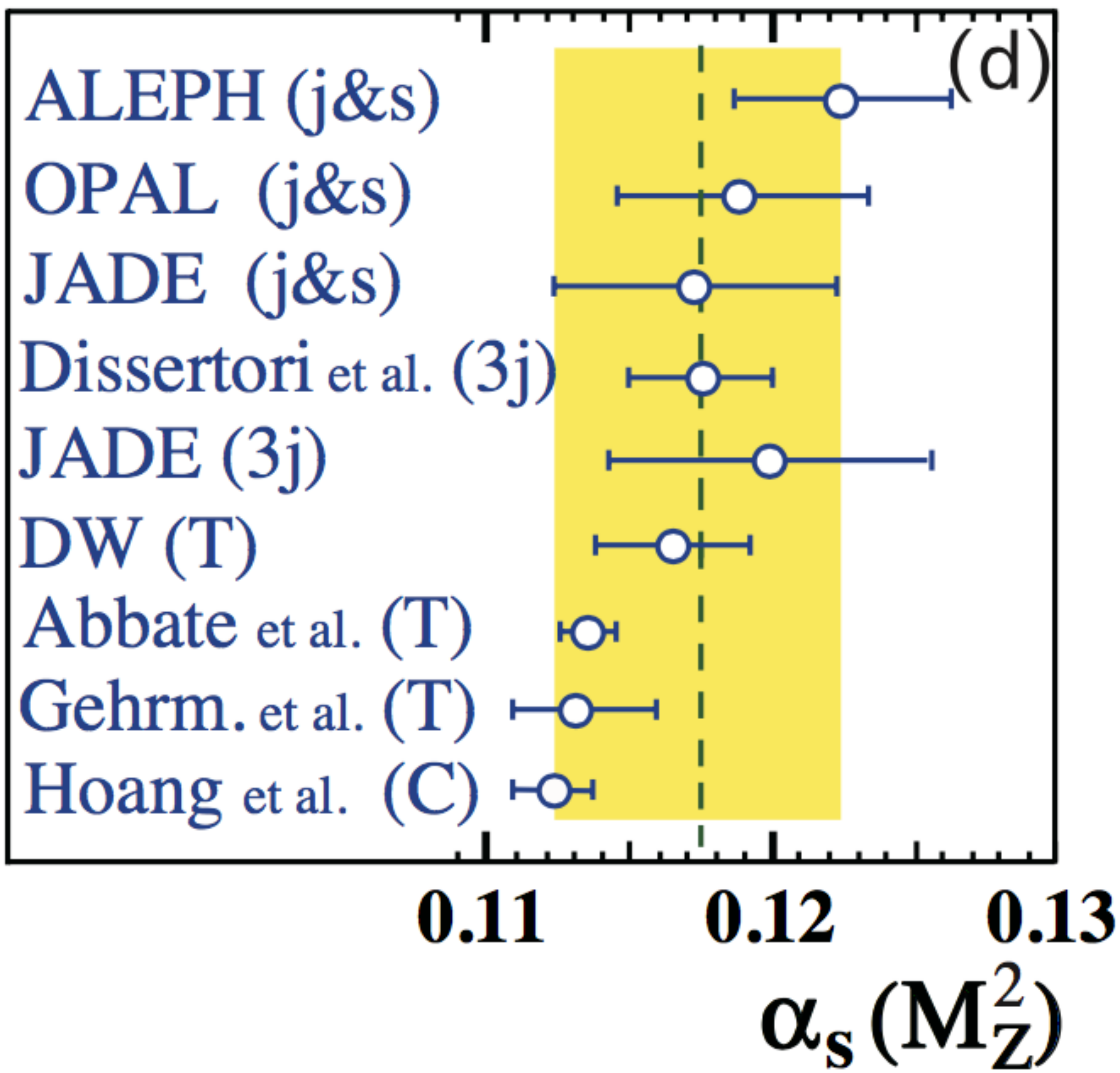


–> $\alpha_s(M_Z)$= 0.1154 ± 0.0020 (same as in 2013)

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



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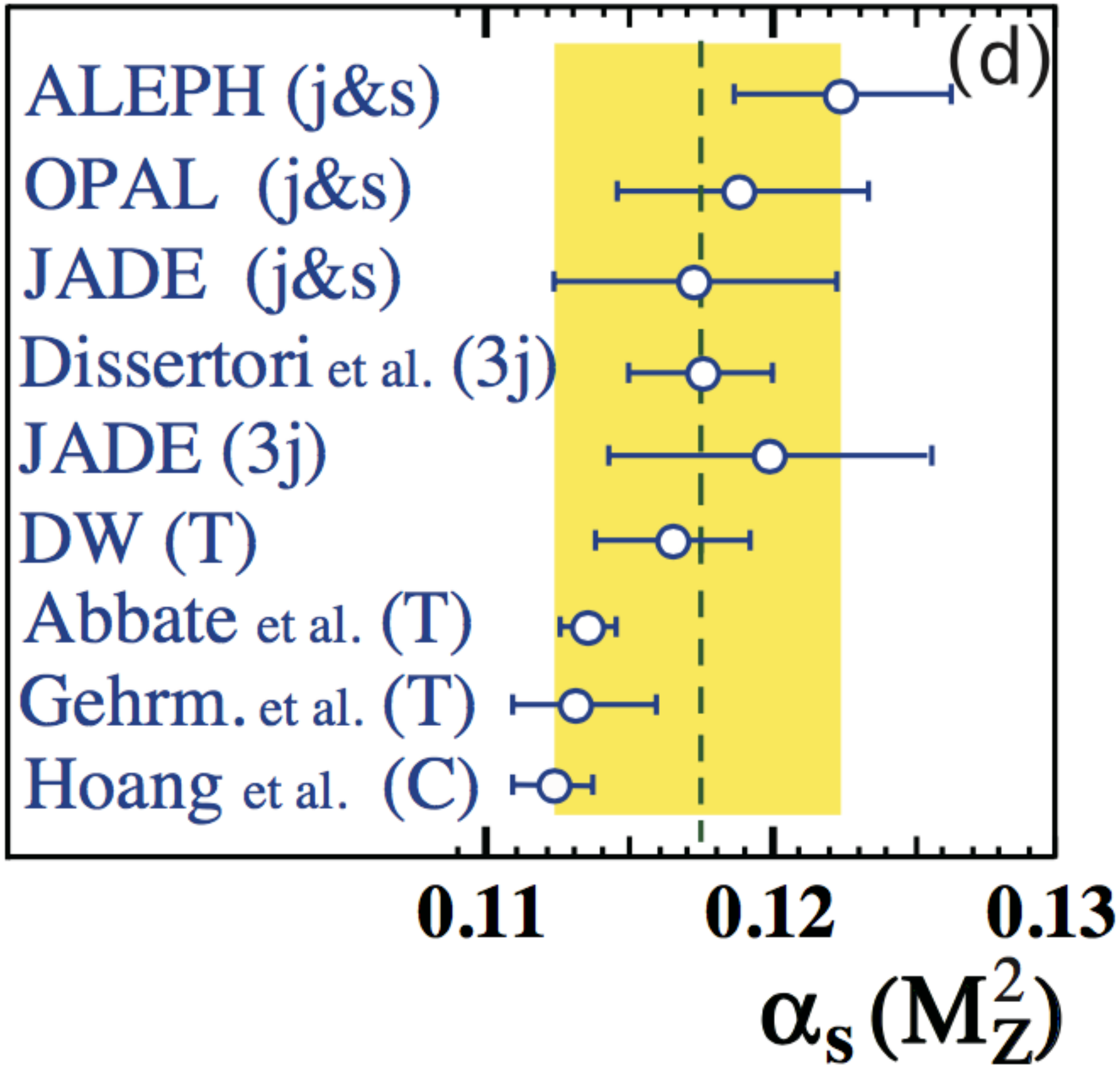
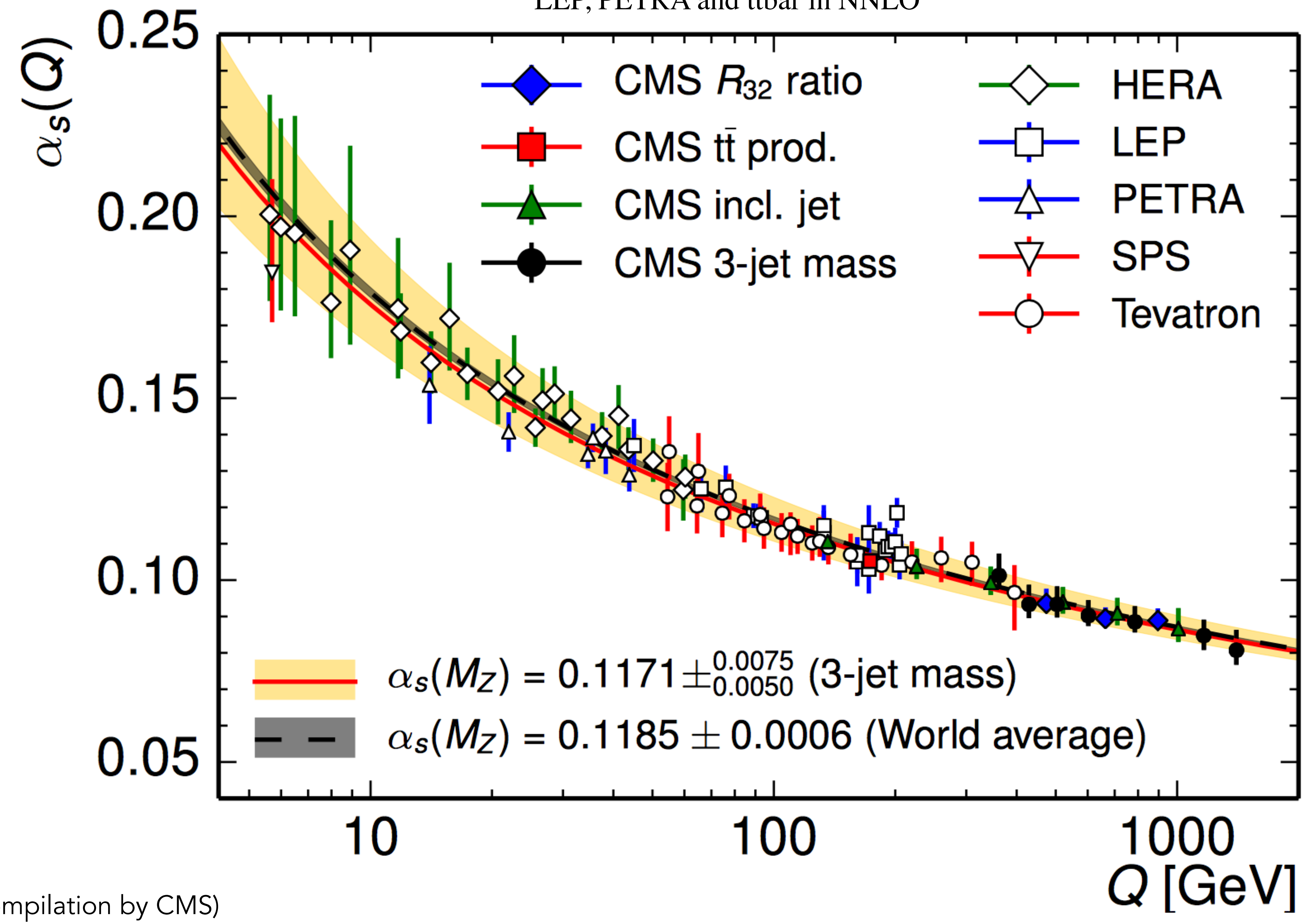


–> $\alpha_s(M_Z)$= 0.1174 ± 0.0051

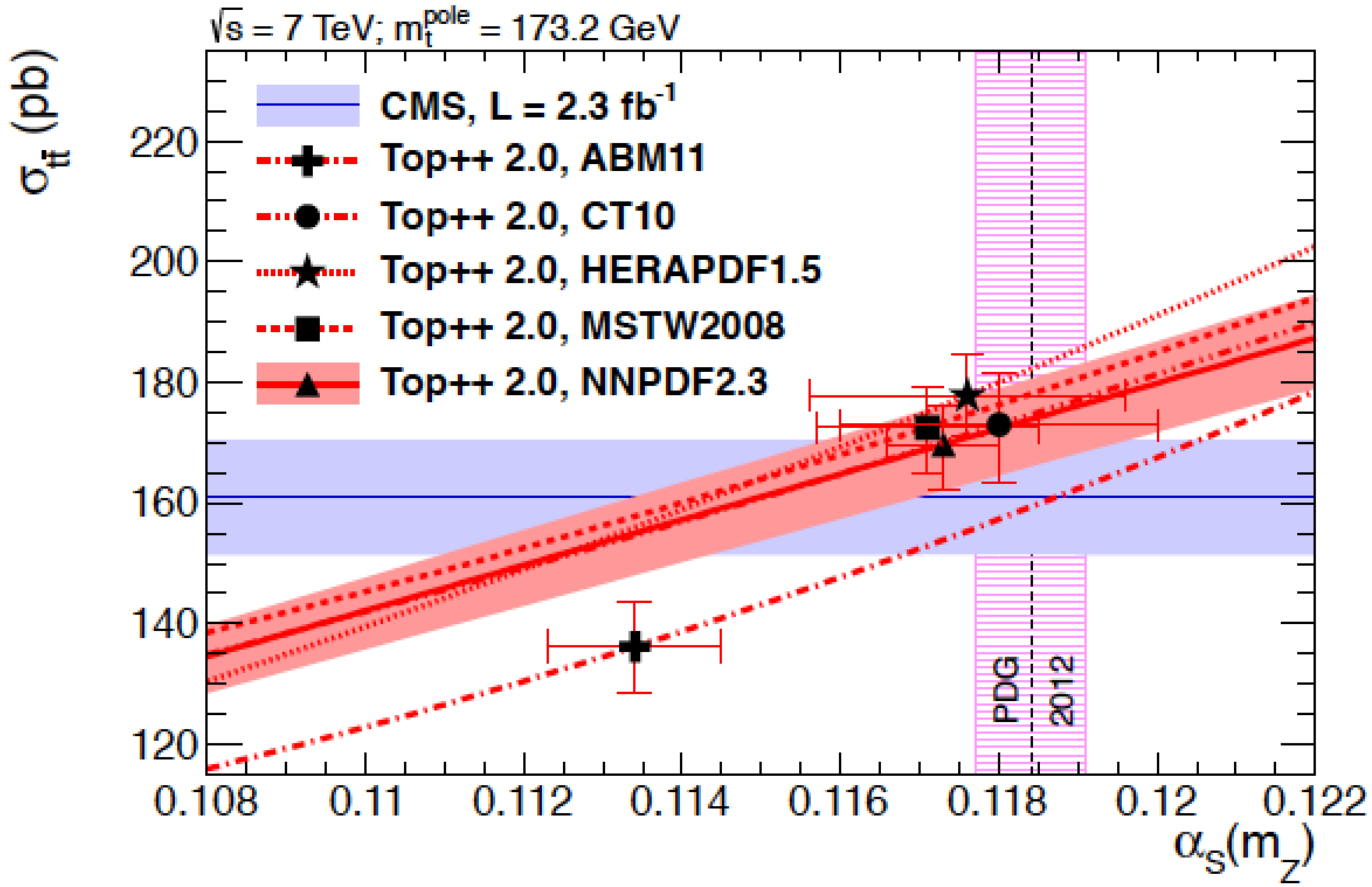
α_s results from hadron collider data

all hadron collider and HERA results in NLO
LEP, PETRA and ttbar in NNLO



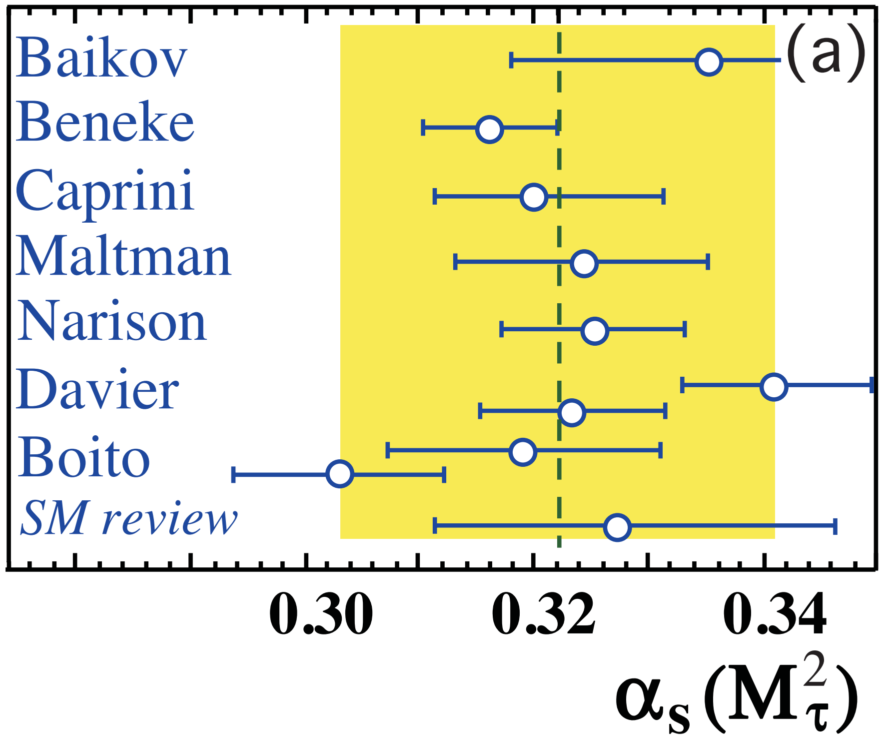
(compilation by CMS)

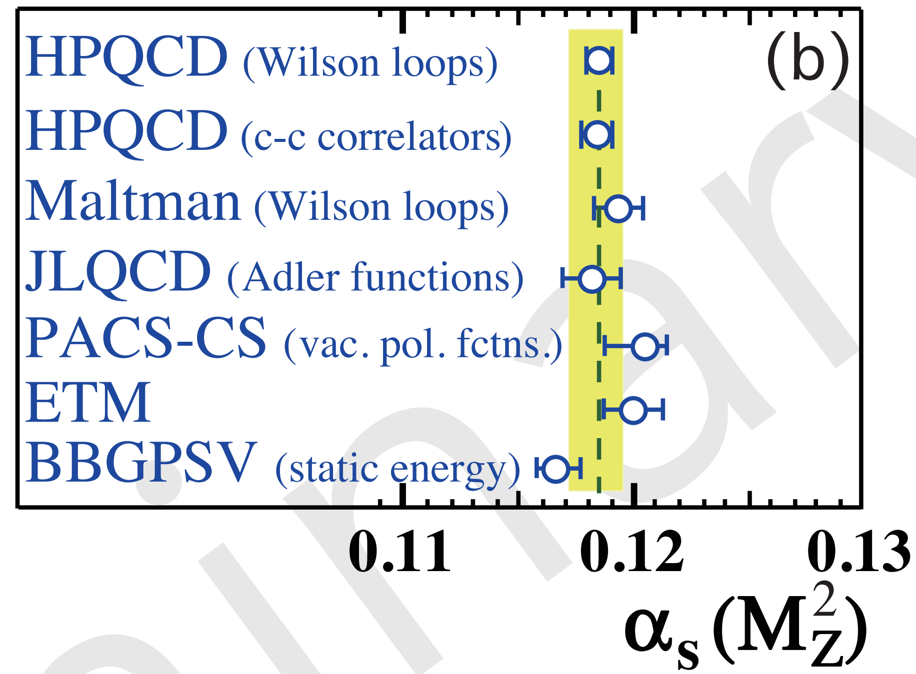
CMS: α_s from ttbar cross section at sqrt(s)=7 TeV (in NNLO + NNLL)

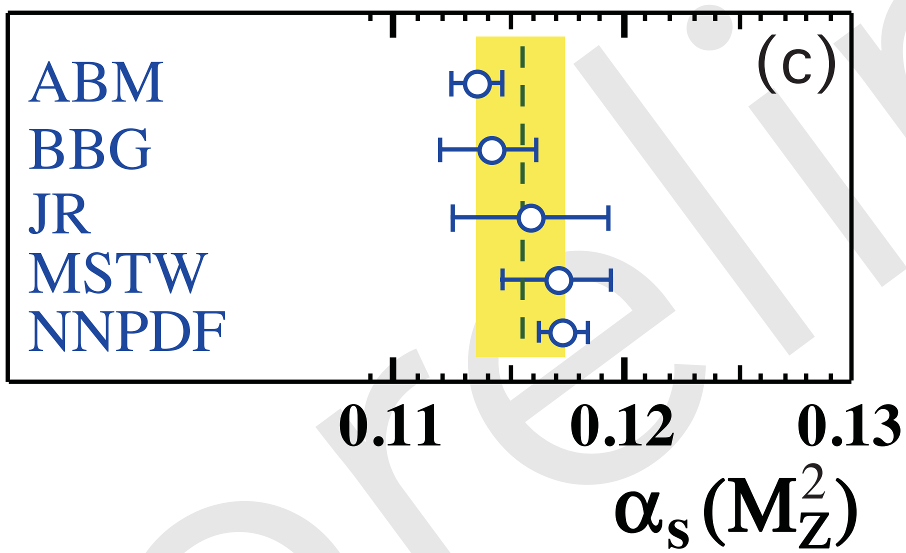


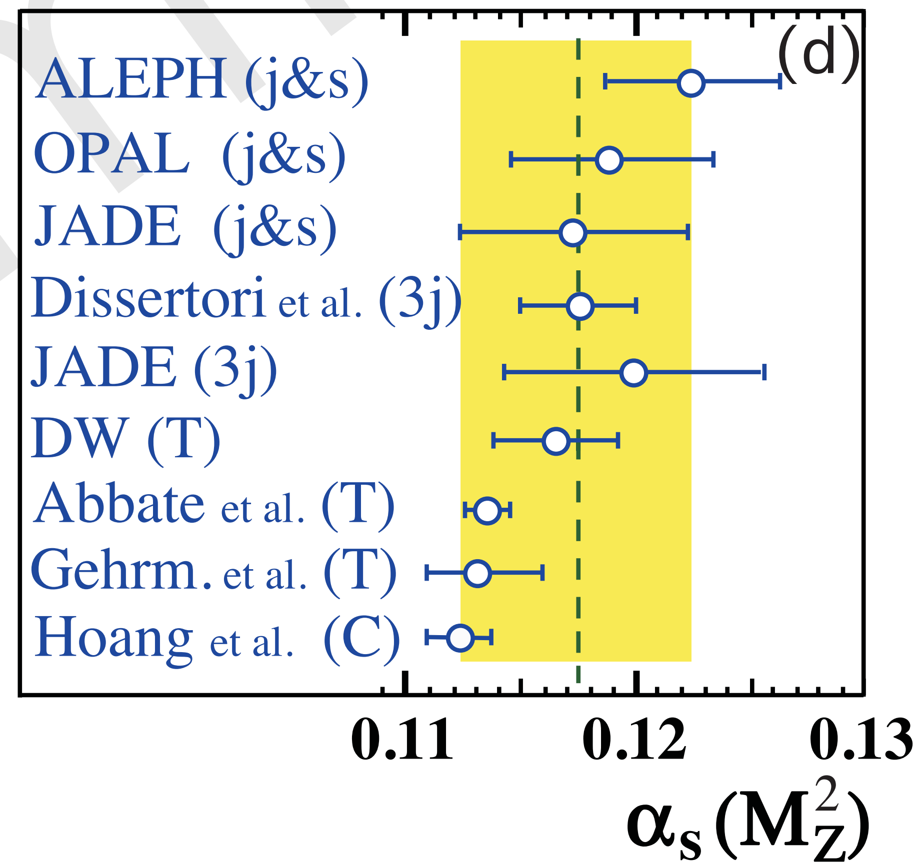
	Most likely $\alpha_S(m_Z)$ value	Uncertainty Total	From δm_t^{pole}	From δE_{LHC}
ABM11	0.1187	$^{+0.0027}_{-0.0027}$	$^{+0.0010}_{-0.0010}$	$^{+0.0006}_{-0.0006}$
CT10	0.1151	$^{+0.0034}_{-0.0034}$	$^{+0.0012}_{-0.0013}$	$^{+0.0007}_{-0.0007}$
HERAPDF1.5	0.1143	$^{+0.0024}_{-0.0024}$	$^{+0.0010}_{-0.0010}$	$^{+0.0006}_{-0.0006}$
MSTW2008	0.1144	$^{+0.0031}_{-0.0032}$	$^{+0.0012}_{-0.0013}$	$^{+0.0007}_{-0.0008}$
NNPDF2.3	0.1151	$^{+0.0033}_{-0.0032}$	$^{+0.0013}_{-0.0013}$	$^{+0.0008}_{-0.0008}$

2015 summary of α_s





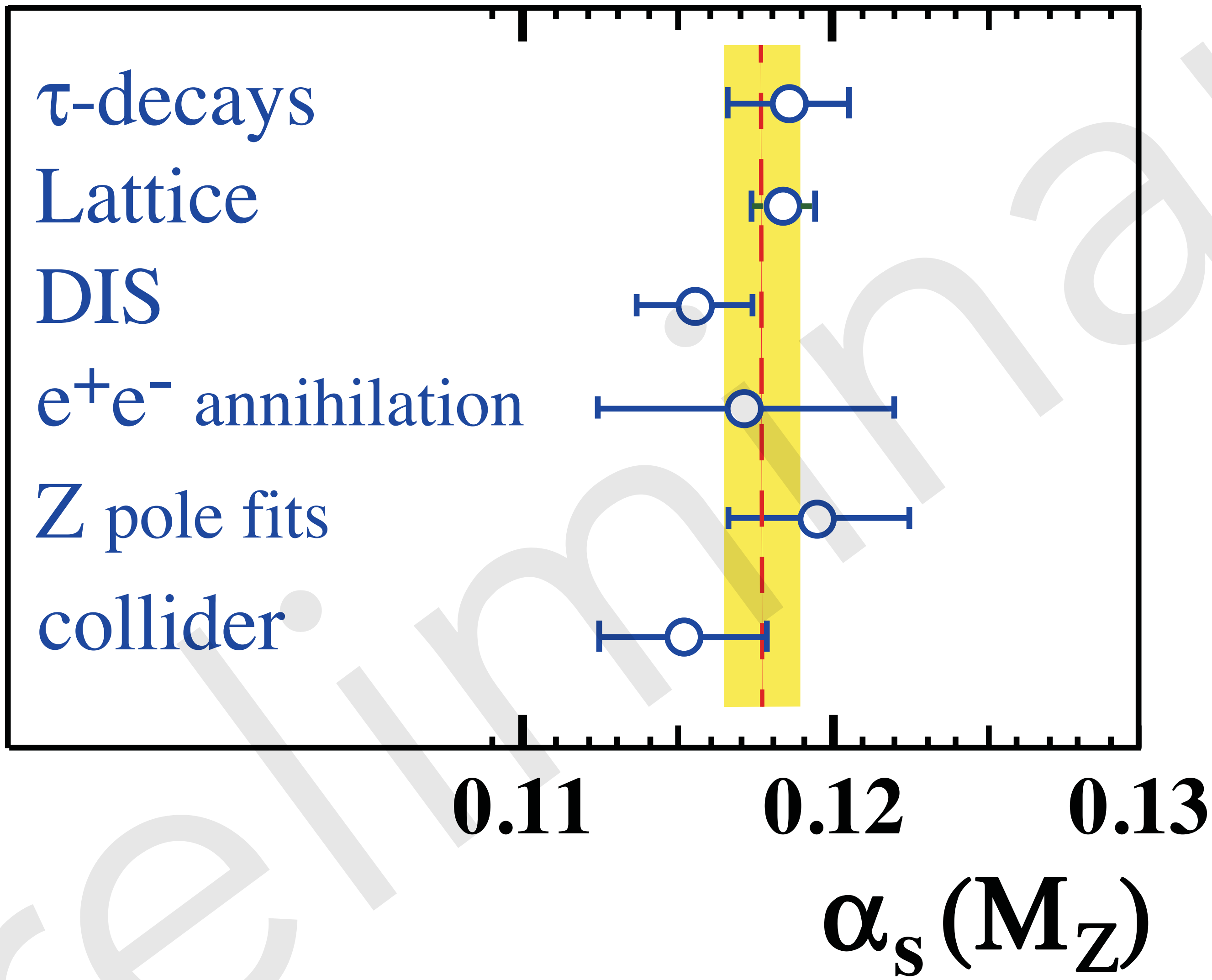




(e) hadron collider (ttbar): $\alpha_s(M_z) = 0.1151^{+0.0033}_{-0.0032}$

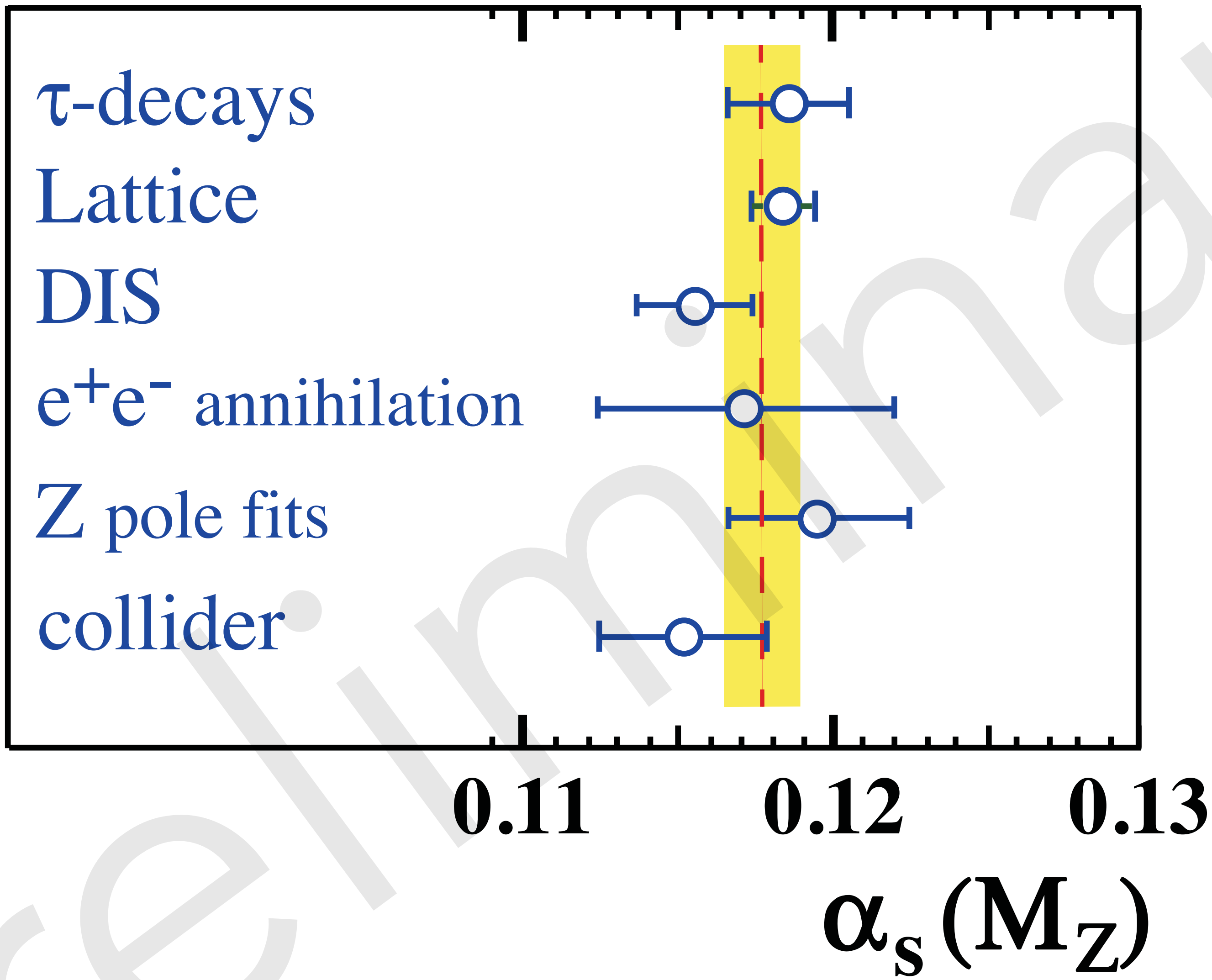
(f) e.w. precision fit (GFitter): $\alpha_s(M_z) = 0.1196 \pm 0.0030$

2015 summary of α_s



$\alpha_s(M_z) = 0.1177 \pm 0.0013$

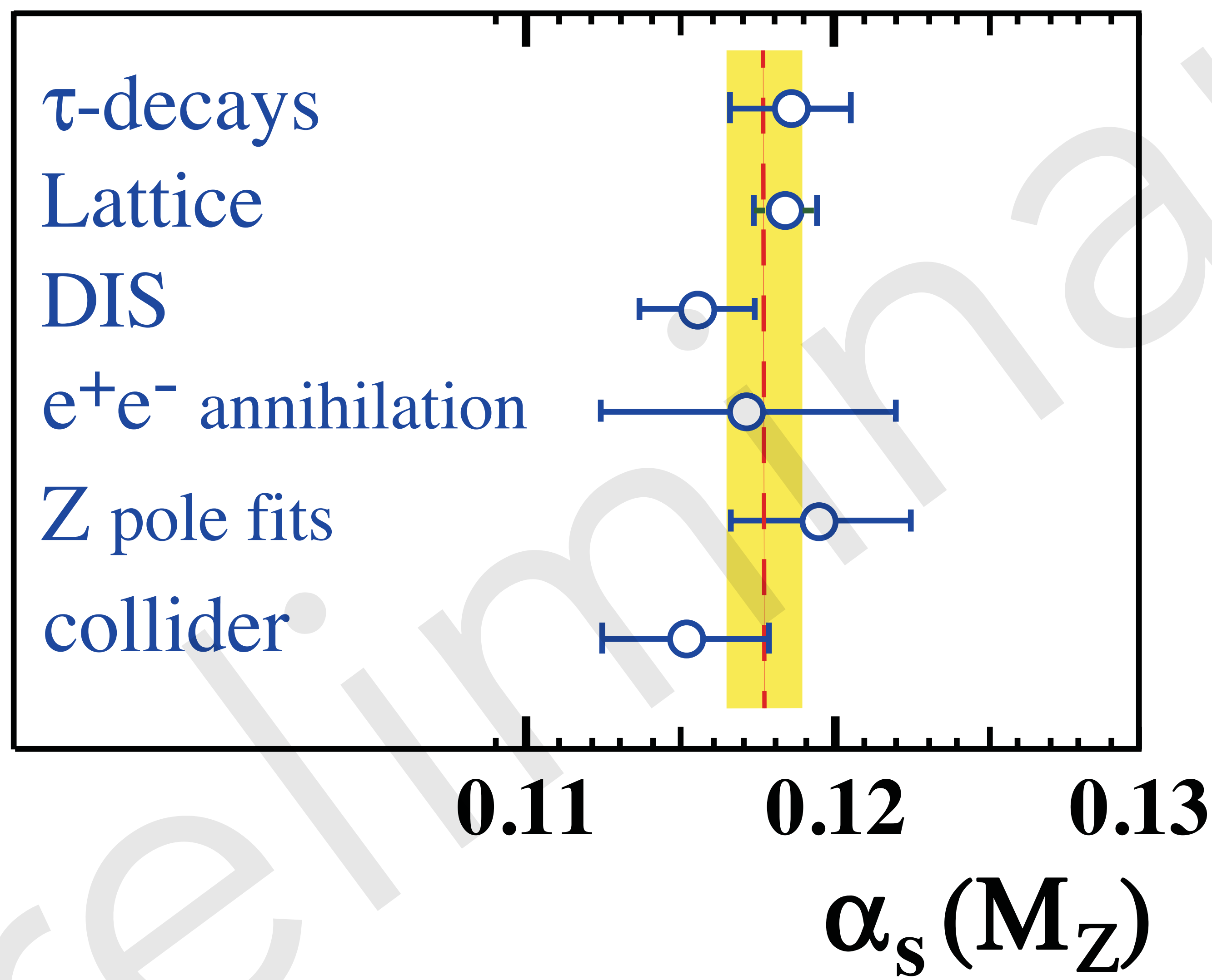
2015 summary of α_s



$\alpha_s(M_z) = 0.1177 \pm 0.0013$

without lattice: $\alpha_s(M_z) = 0.1170 \pm 0.0018$

2015 summary of α_s

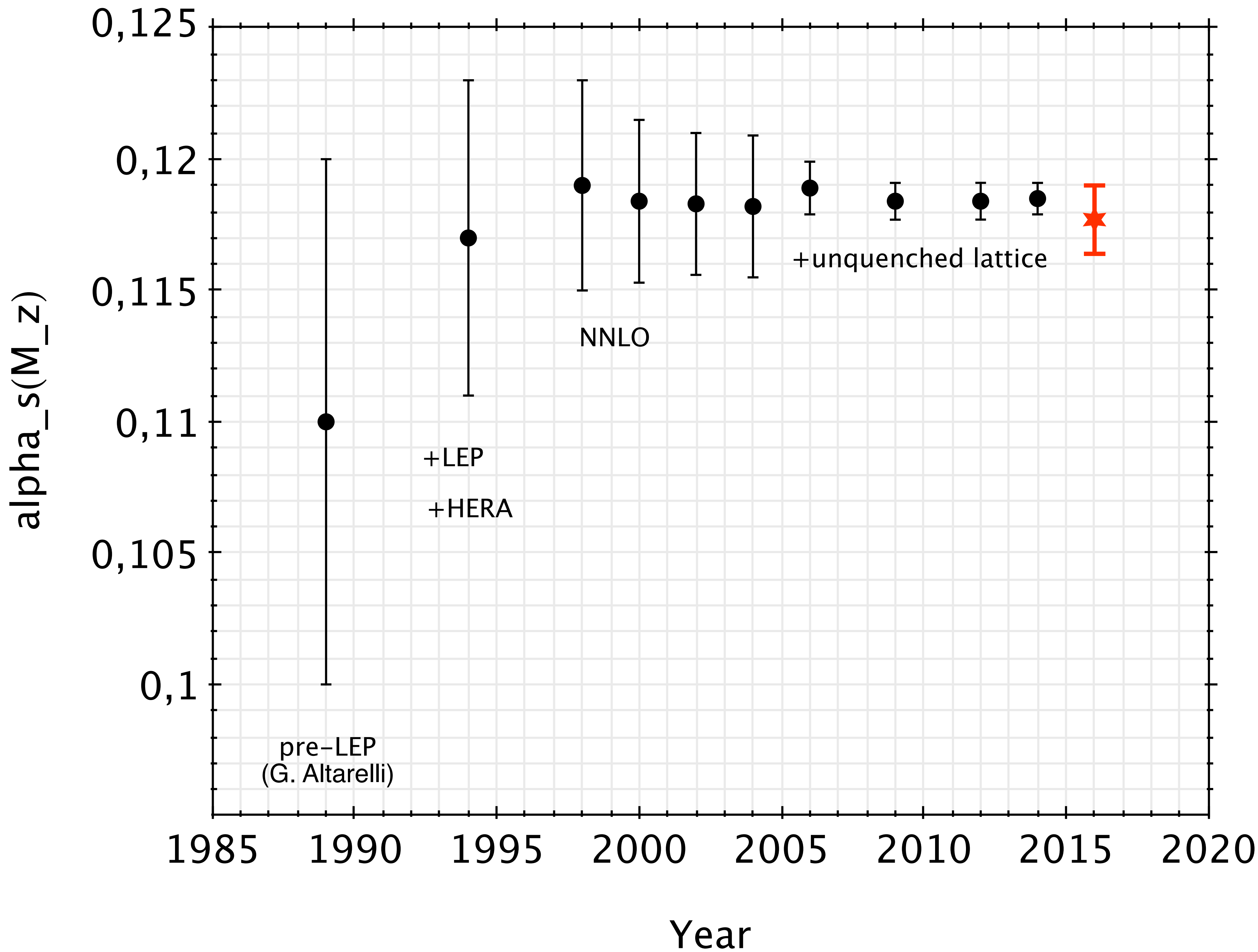


$\alpha_s(M_z) = 0.1177 \pm 0.0013$

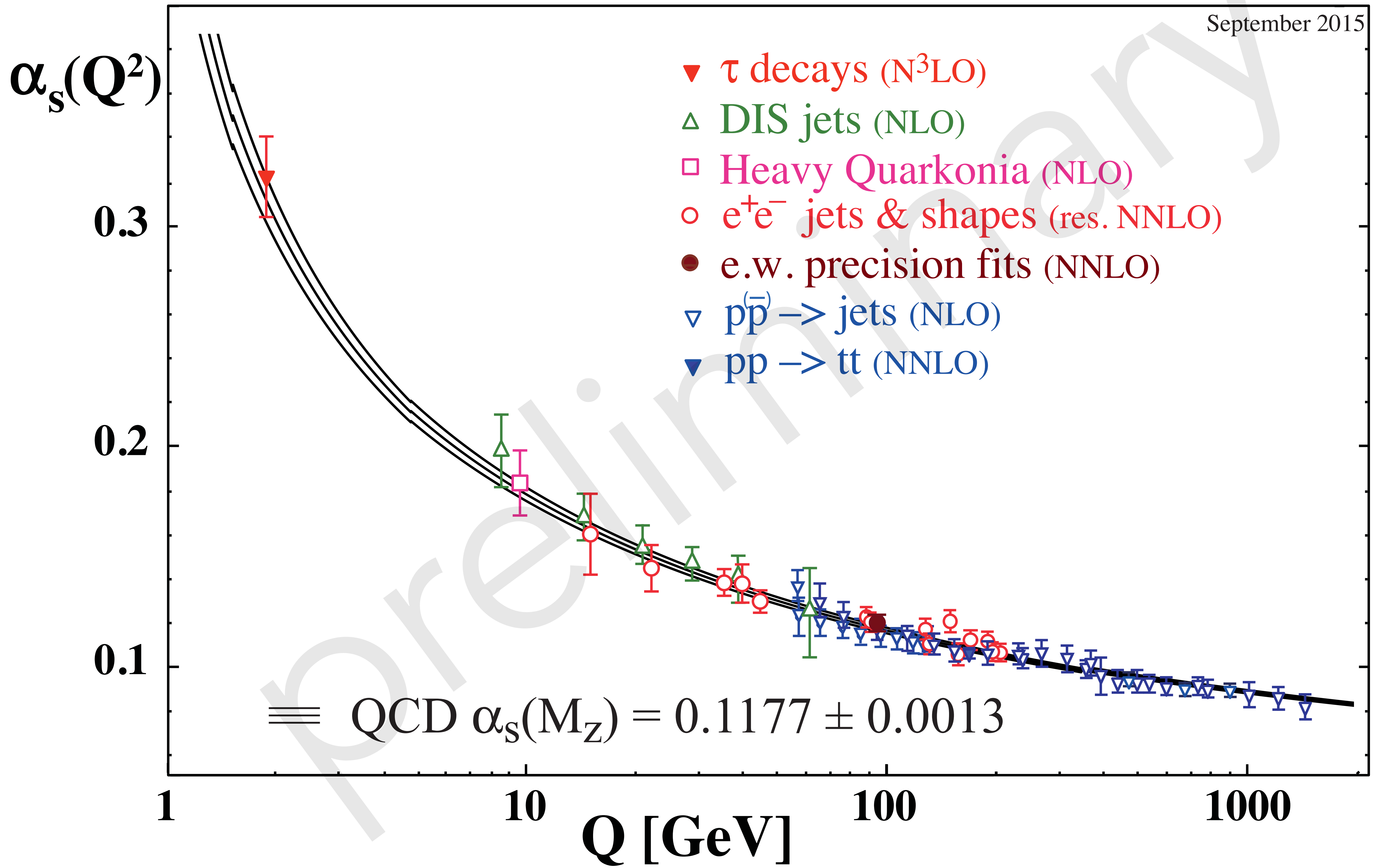
without lattice: $\alpha_s(M_z) = 0.1170 \pm 0.0018$

w/2013 RPP lattice: $\alpha_s(M_z) = 0.1183 \pm 0.0006$

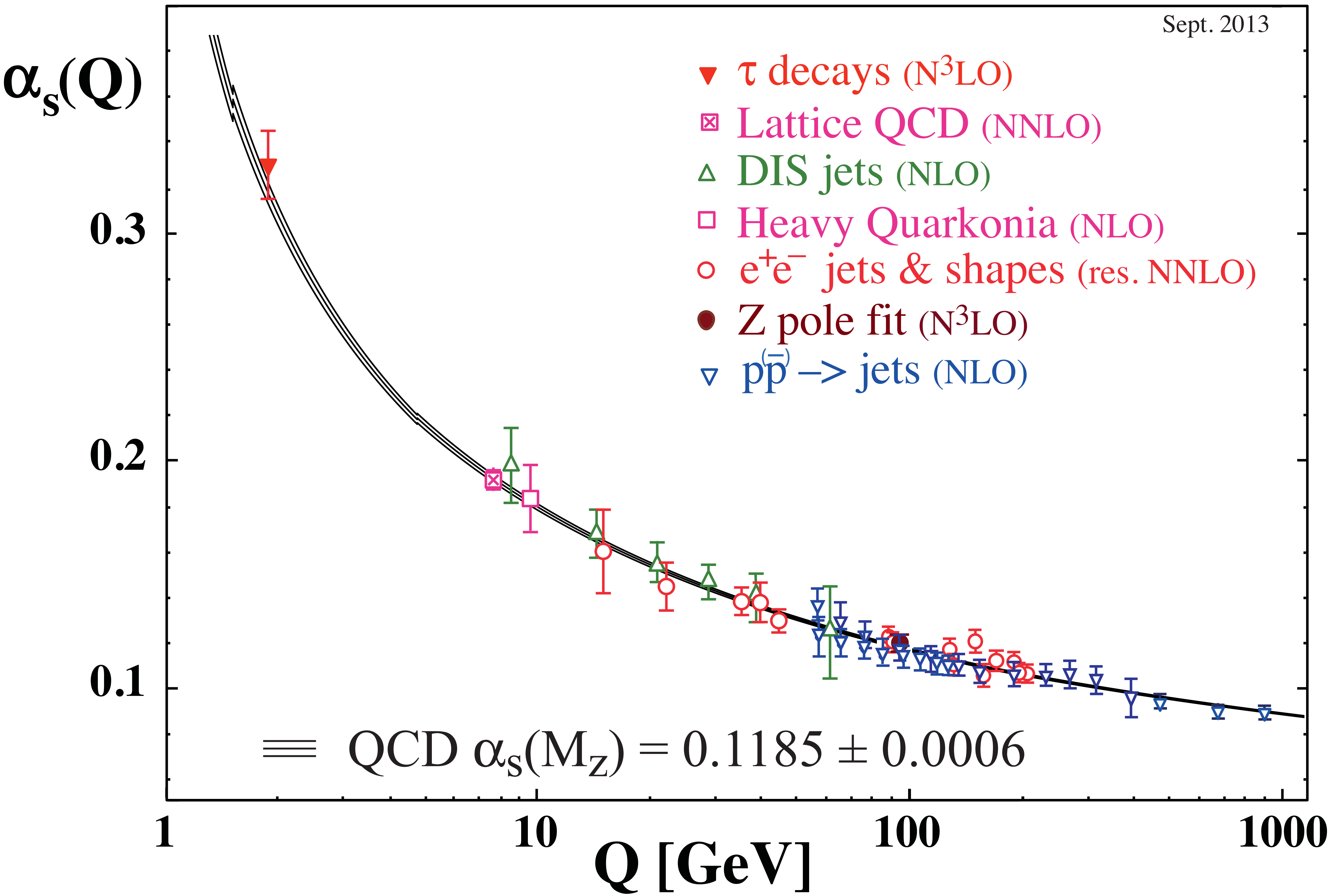
history of world average of α_s



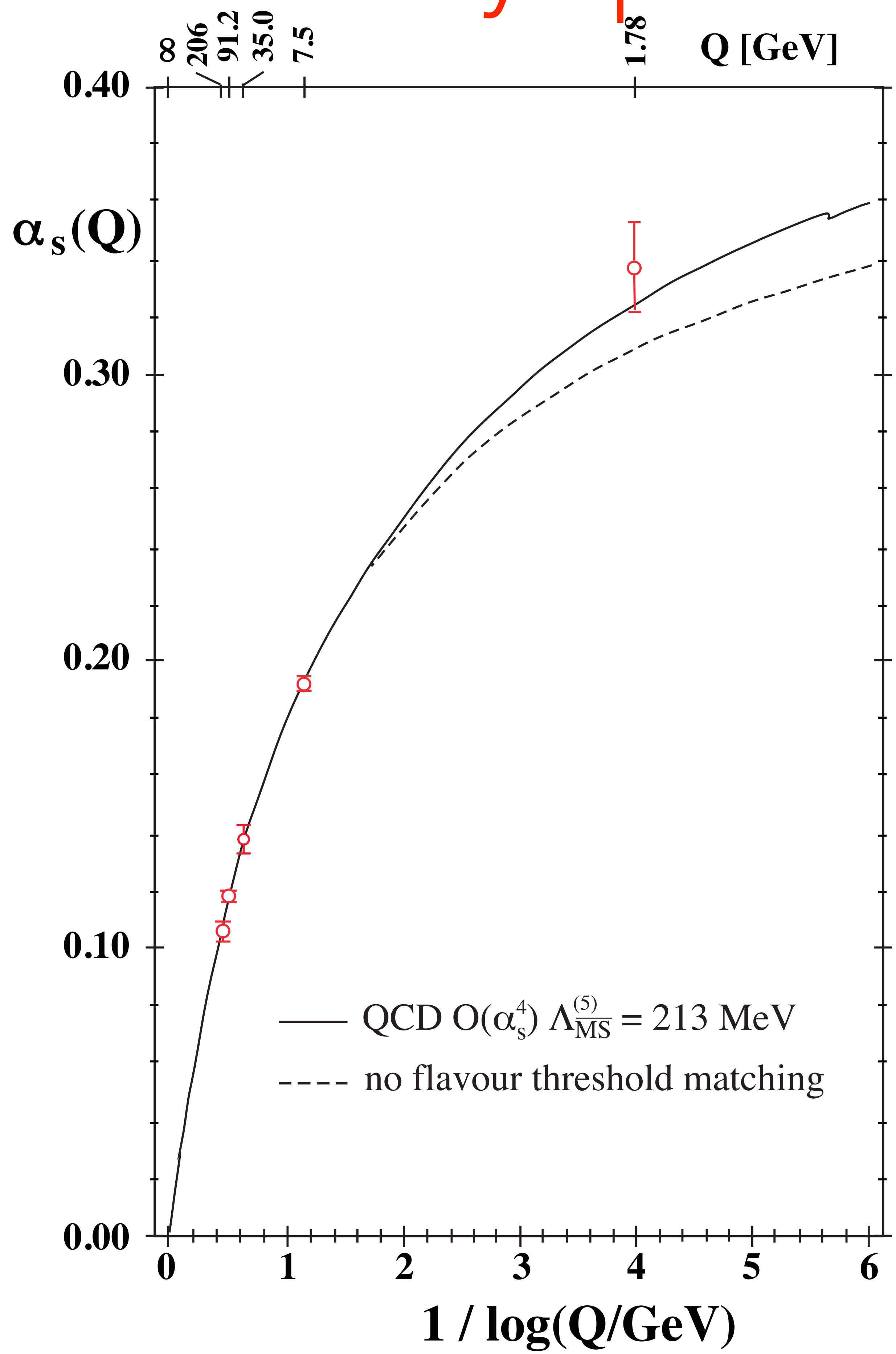
2015 summary of running α_s



2013 summary of running α_s



evidence for asymptotic freedom:



known issues:

all subclasses do have known and unsolved issues:

- α_s from τ-decays: FOPT vs CIPT; technical systematics
- α_s from lattice: overall size of uncertainties
- α_s from DIS: unsolved issues between author groups (PDFs)
- α_s from e+e- annihilation: analytic vs. classical treatment of (nonperturbative) hadronisation effects
- α_s from hadron colliders: so far, only one determination in NNLO (already known to be a fluctuation to the low side)
- α_s from hadron colliders: (NLO) treatment of top-threshold?
- α_s from e.w. precision data: correct only in strict SM

–> no convergence since 2013 review (just contrary …) !!

wrap-up:

- new **preliminary** value of world $\alpha_s(M_z)$: = 0.1177 ± 0.0013
- change from 2013 value ($\alpha_s(M_z)$=0.1185 ± 0.0006) mainly due to:
  - decreased weight (increased error) of lattice results
  - decreased central value from τ-decays
  - result from new class (hadron collider, ttbar x-section), with only one published result, however known to be systematically low
- known but unresolved issues for almost all classes
- no convergence of issues in sight

– however –

- even within conservative uncertainties, Asymptotic Freedom and in general, QCD is in excellent shape !