Proceedings of the Workshop on High precision α_s measurements: from LHC to FCC-ee

CERN, Geneva
October 12th–13th, 2015

Editors

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Authors

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Abstract

This document collects a summary of all contributions of the workshop on *"High precision measurements of α_s: from LHC to FCC-ee"* held at CERN, October 12-13, 2015 (`http://indico.cern.ch/e/alphas2015`). The workshop explored in depth the latest developments on the determination of the QCD coupling α_s from the key categories where high precision measurements are (or will be) available. Those include low-energy observables: (i) lattice QCD, (ii) pion decay factor, (iii) quarkonia and (iv) τ decays, (v) soft parton-to-hadron fragmentation functions; as well as high-energy observables: (vi) global fits of parton distribution functions, (vii) hard parton-to-hadron fragmentation functions, (viii) jets in $e^{\pm}$-p DIS and photoproduction, (ix) event shapes and (x) jet cross sections in e^+e^- collisions, (xi) W boson and (xii) Z boson decays, and (xiii) top-quark and (xiv) jet cross sections in p-p collisions. The current status of the theoretical and experimental uncertainties associated to each extraction method, the improvements expected at the end of the LHC running, and future perspectives achievable in e^+e^- collisions at the Future Circular Collider (FCC-ee) with multi-inverse-attobarn integrated luminosities yielding 10^{12} Z bosons and jets, and 10^8 W bosons and τ leptons, are thoroughly reviewed and discussed.

Authors and Speakers

A. Banfi (U. Sussex), S. Bethke (MPI, München), J. Blümlein (DESY), D. d'Enterria (CERN), X. Garcia-Tormo (Bern), A. Hoang (U. Wien), B. Kniehl (U. Hamburg), M. Klasen (U. Münster), S. Kluth (T.U. München), J.L. Kneur (U. Montpellier 2), J. Kühn (KIT, Karlsruhe), P. Mackenzie (Fermilab), B. Malaescu (LPNHE, Paris) L. Mihaila (KIT), A. Mitov (Cambridge), K. Mönig (DESY), R.Perez-Ramos (Paris), A. Pich (U. València), J. Pires (Milano Bicocca), K. Rabbertz (KIT, Karlsruhe), G. Salam (CERN), F. Sannino (CP3-Origins, Odense), P.Z. Skands (Monash), J. Soto i Riera (U. Barcelona), M. Srebre (U. Ljubljana)

Additional Participants

A. Ali (DESY), A. Blondel (U. Geneva), C. Gracios (Puebla), M. Klute (MIT), I. Kolbe (U. Cape Town), A. Larkoski (MIT/Harvard), B. Meiring (U. Cape Town), R. Morad (U. Cape Town), A.N. Rasoanaivo (U. Cape Town), P. Telles-Rebello (CBPF, Rio de Janeiro), ...

1 Introduction

The strong coupling α_s is one of the fundamental parameters of the Standard Model (SM), setting the scale of the strength of the strong interaction theoretically described by Quantum Chromodynamics (QCD). At the reference Z pole mass scale, its measured value amounts to $\alpha_s(m_Z^2) = 0.1185 \pm 0.0006$. Given its current $\delta\alpha_s \approx 0.6\%$ uncertainty—orders of magnitude larger than that of the gravitational ($\delta G \approx 10^{-5}$), Fermi ($\delta G_F \approx 10^{-8}$) and QED ($\delta\alpha \approx 10^{-10}$) couplings—the strong coupling is the least precisely known of all fundamental constants in nature. Improving our knowledge of α_s is a prerequisite to reduce the theoretical uncertainties in the calculations of all high-precision perturbative QCD (pQCD) processes whose cross sections or decay rates depend on higher-order powers of α_s, as is the case for virtually all those measured at the LHC. In the Higgs sector, in particular, the uncertainty on α_s is currently the second major contributor (after the bottom mass) to the parametric uncertainties of its dominant $H \to b\bar{b}$ partial decay. The same applies for the extraction of the charm Yukawa coupling via future $H \to c\bar{c}$ measurements.

The workshop *"High precision measurements of α_s: from LHC to FCC-ee"* was held at CERN, October 12-13, 2015 (`http://indico.cern.ch/e/alphas2015`), as part of the FCC-ee *QCD and gamma-gamma physics* working group activities in the context of the preparation of the FCC-ee Yellow Report in 2016. The meeting brought together experts from several different fields to explore in depth the latest developments on the determination of the QCD coupling α_s from the key categories where high precision measurements are (or will be) available, and put its emphasis on the following issues:

- What is the current state-of-the-art of each one of the α_s determination methods, from the theoretical and experimental points of view?
- What is the current size of the theoretical (missing higher orders, electroweak corrections, power corrections, hadronization corrections,...) and experimental uncertainties associated to each measurement?
- What is the expected α_s uncertainty in ∼10 years from now thanks to the ongoing (or expected) theoretical developments, plus $\mathcal{O}(1\,\text{ab}^{-1})$ collected p-p data at 14 TeV at the LHC ?
- What are the improvements expected to be brought about by e^+e^- collisions at the FCC-ee ($\sqrt{s}$ = 91, 160, 240 and 350 GeV) with 10^{12} Z bosons and jets, and 10^8 W bosons and τ leptons collected ?
- What are the systematic errors that the FCC-ee detectors should target in order to match the expected statistical precision, or where that is not possible, what are the important theoretical targets that should be met or exceeded ?

With those goals in mind, the workshop was organized along four broad sessions:

1. An introductory session, presenting the motivations of the workshop, the current status of the world average of the strong coupling, the impact of α_s on Higgs cross sections and branching ratios, and on new physics constraints.

2. A session dedicated to α_s determination at low energy including results from: lattice QCD, pion decay factor, τ decay, $Q\overline{Q}$ decays, and soft parton-to-hadron FFs.

3. A session dedicated to α_s determination at higher energy scales including: global fits of parton distribution functions, hard parton-to-hadron fragmentation functions, jets in deep-inelastic scattering and photoproduction in $e^{\pm}$-p collisions, e^+e^- event shapes, e^+e^- jets, hadronic Z and W decays, $\sigma(e^+e^- \to \text{hadrons})$, electroweak fit,...

4. Recent experimental and theoretical results and plans for α_s measurements at the LHC via top-quark pair and jets cross sections.

One important goal of the workshop was to facilitate discussion between the different groups, and in particular to give speakers the opportunity to explain details that one would normally not be able to present at a conference, but which have an important impact on the analyses. There were 40 physicists who took part in the workshop, and 24 talks were presented. Slides as well as background reference materials are available on the conference website

`http://indico.cern.ch/e/alphas2015`

The sessions and talks in the workshop program were:

- Introduction
  - "Introduction and goals of the workshop", D. d'Enterria and P.Z. Skands
  - "World Summary of α_s (2015)", S. Bethke
  - "α_s and physics beyond the Standard Model", F. Sannino
  - "Impact of α_s on Higgs production and decay uncertainties", L. Mihaila
- Measurements of α_s at low energy scales:
  - "α_s from lattice QCD", P. Mackenzie
  - "α_s from the QCD static energy", X. Garcia i Tormo
  - "α_s from pion decay factor", J.L. Kneur
  - "α_s from hadronic tau decays", A. Pich
  - "α_s from hadronic quarkonia decays", J. Soto i Riera
  - "α_s from soft parton-to-hadron FFs", R. Perez-Ramos and D. d'Enterria
- Measurements of α_s at high energy scales:
  - "α_s from global fits of parton distribution functions", J. Blümlein
  - "α_s from jets in DIS and photoproduction", M. Klasen
  - "α_s from scaling violations of hard parton-to-hadron FFs", B. Kniehl
  - "α_s from e^+e^- event shapes", S. Kluth
  - "α_s from e^+e^- C-parameter event shape", A. Hoang
  - "α_s from e^+e^- jet cross sections", A. Banfi
  - "α_s from hadronic Z decays and from the full electroweak fit", K. Mönig
  - "α_s from hadronic W decays", M. Srebre
  - "α_s from $\sigma(e^+e^- \to \text{hadrons})$", J. Kühn
- Measurements of α_s at the LHC and conclusions:
  - "α_s from top-pair cross sections at the LHC and beyond", A. Mitov
  - "α_s from top-pair cross sections", G. Salam

– "Future prospects of α_s from NNLO jets at the LHC and beyond", J. Pires
– "α_s determinations from ATLAS (status and plans)", B. Malaescu
– "α_s determinations from CMS (status and plans)", K. Rabbertz
– Final discussion
– Conclusions (FCC-ee Yellow Report preparation)

This proceedings represent a collection of extended abstracts and references for the presentations, summarizing the most important results and issues. These written contributions will be incorporated into the FCC-ee Yellow Report under preparation.

CERN, October 2015

David d'Enterria
Peter Skands

2 Proceedings Contributions

Introduction and goals of the workshop

D. d'Enterria and P.Z. Skands

Institution, City, Country

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Process	Q [GeV]	$\alpha_s(m_Z)$	excl. mean $\alpha_s(m_Z)$	std. dev.
τ-decays	1.78	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
Lattice QCD	7.5	0.1183 ± 0.0008	0.11862 ± 0.00114	0.2
Υ decays	9.46	$0.119^{+0.006}_{-0.005}$	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	0.11837 ± 0.00076	0.3
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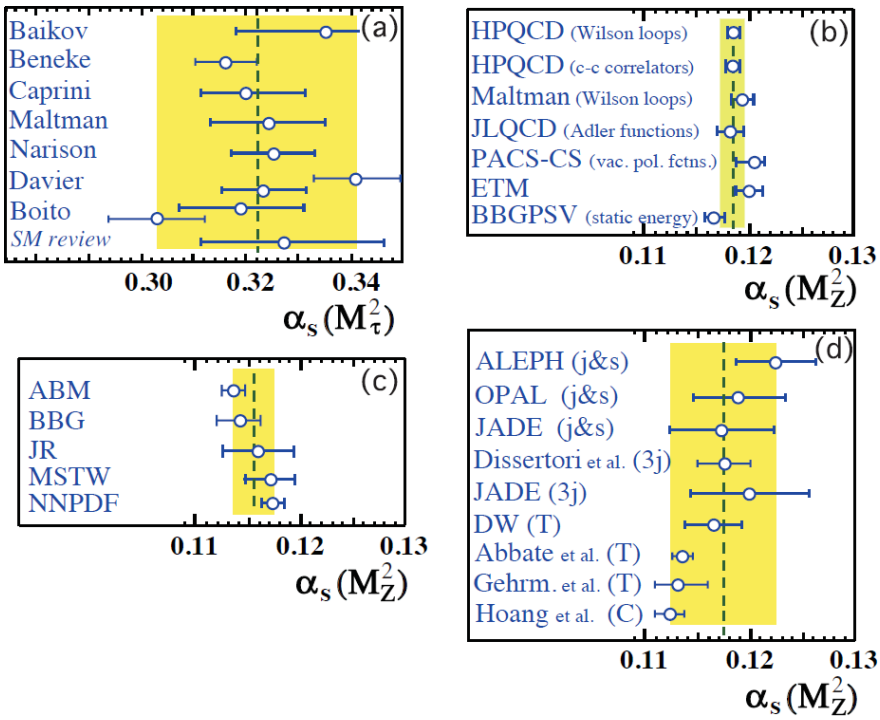

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World Summary of α_s (2015)

S. Bethke

Institution, City, Country

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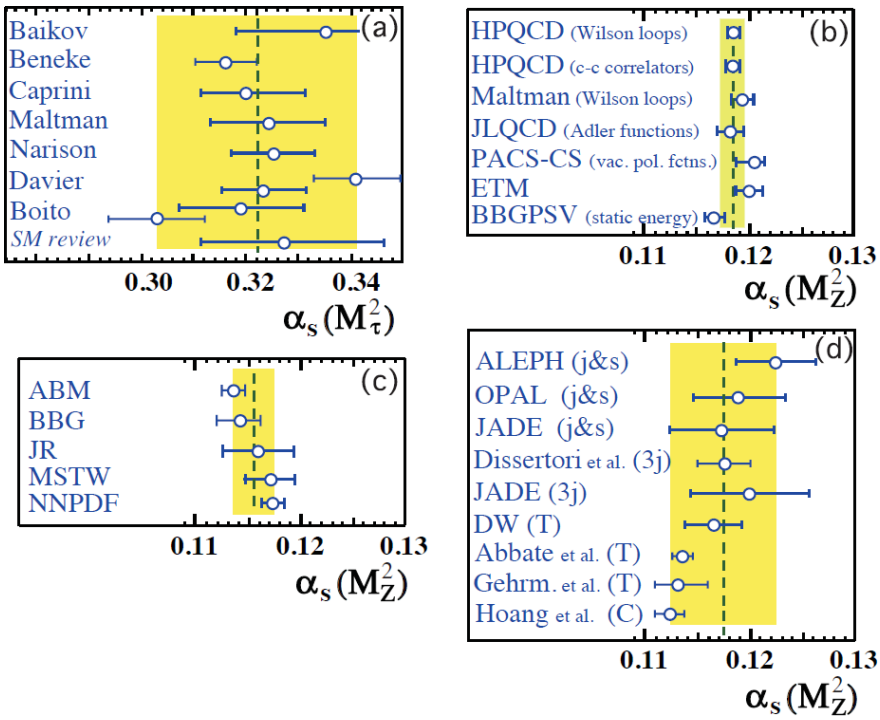

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α_s and physics beyond the Standard Model

F. Sannino

Institution, City, Country

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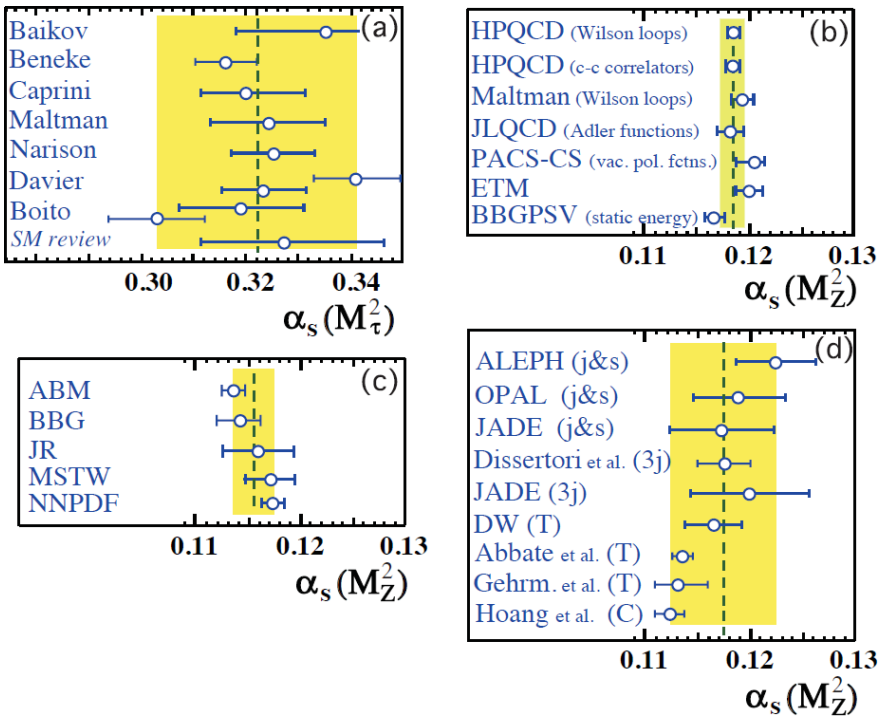

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Impact of α_s on Higgs production and decay uncertainties

L. Mihaila

Institution, City, Country

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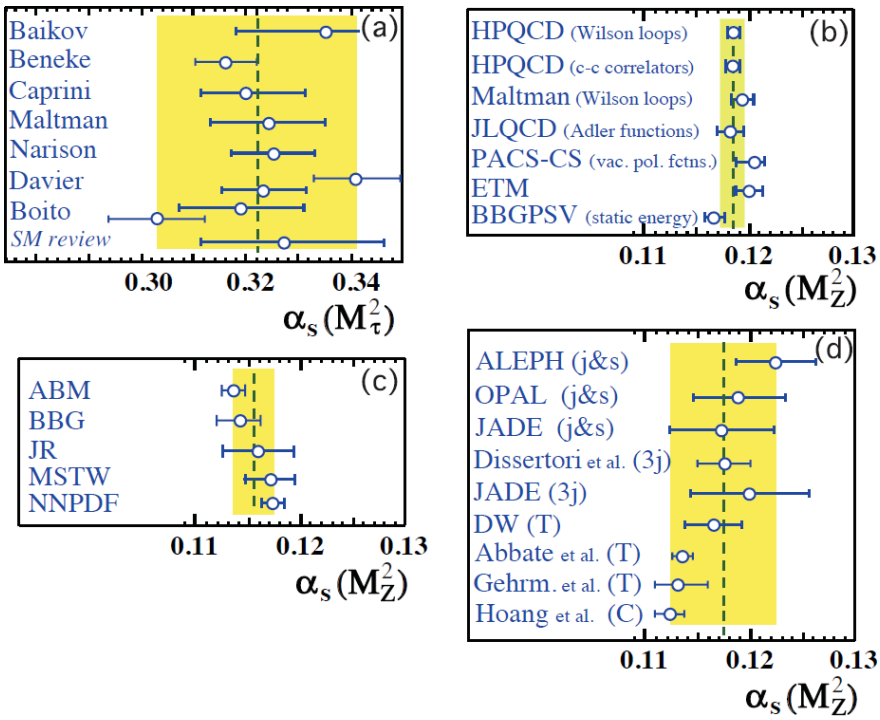

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α_s from lattice QCD

P. Mackenzie

Institution, City, Country

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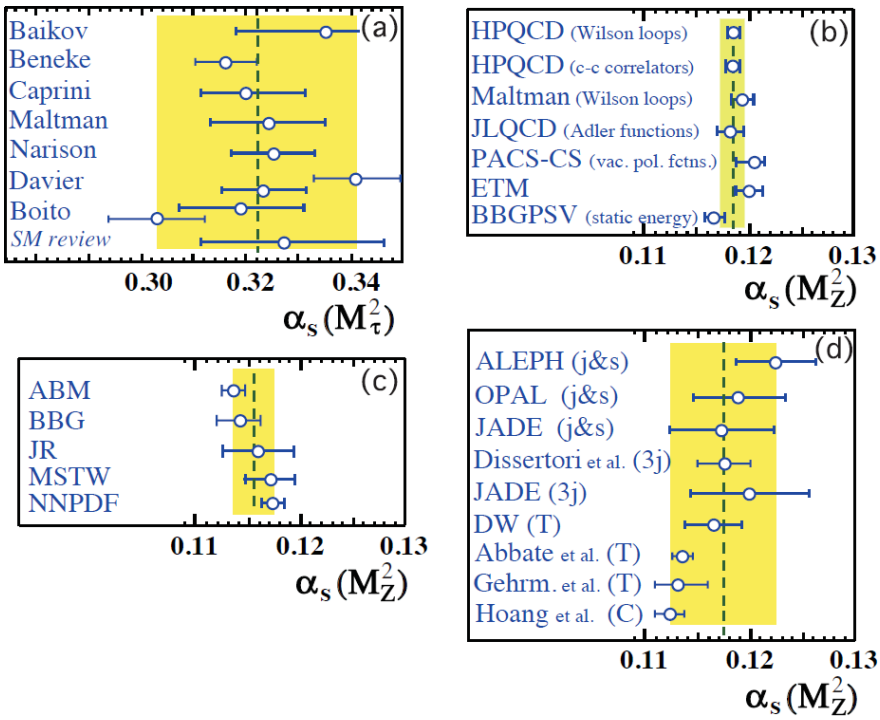

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α_s from the QCD static energy

X. Garcia i Tormo

Institution, City, Country

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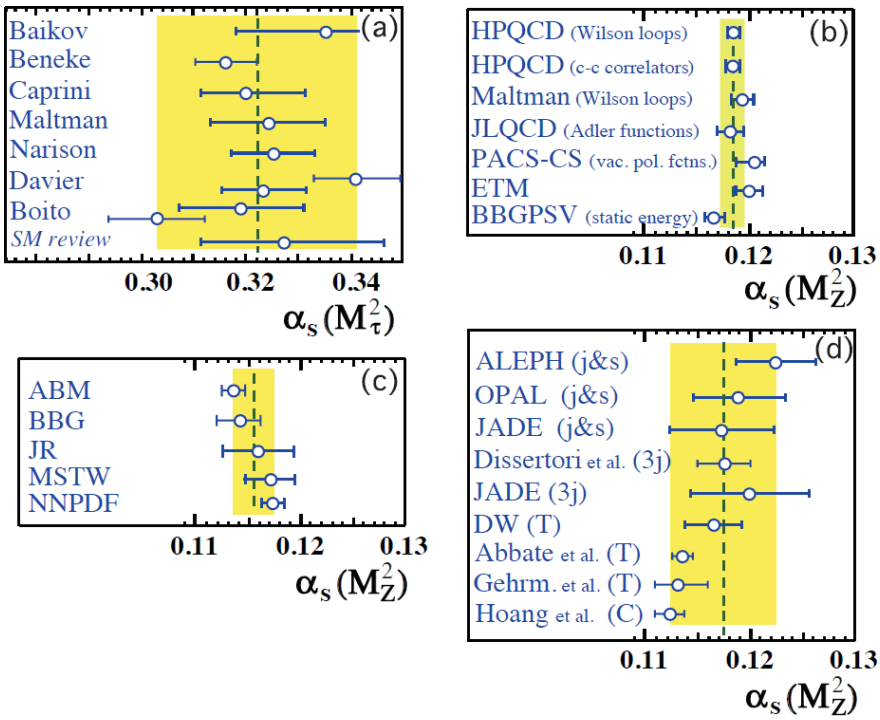

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α_s from pion decay factor

J.L. Kneur

Institution, City, Country

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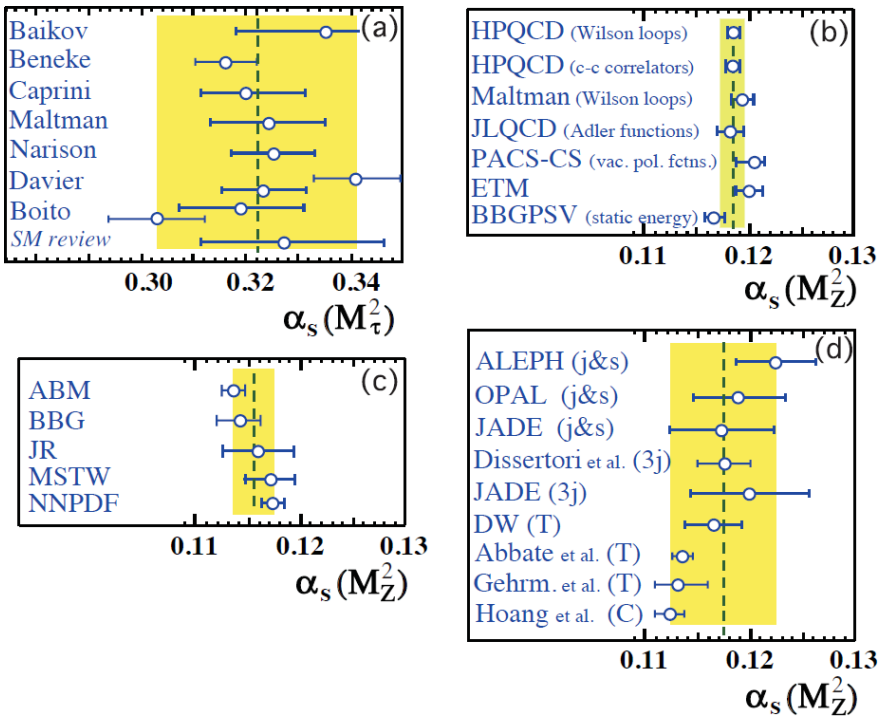

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[1] K. A. Olive *et al.* [PDG Collab.], Chin. Phys. C **38** (2014) 090001.

[2] ....

α_s from hadronic τ lepton decays

A. Pich

Institution, City, Country

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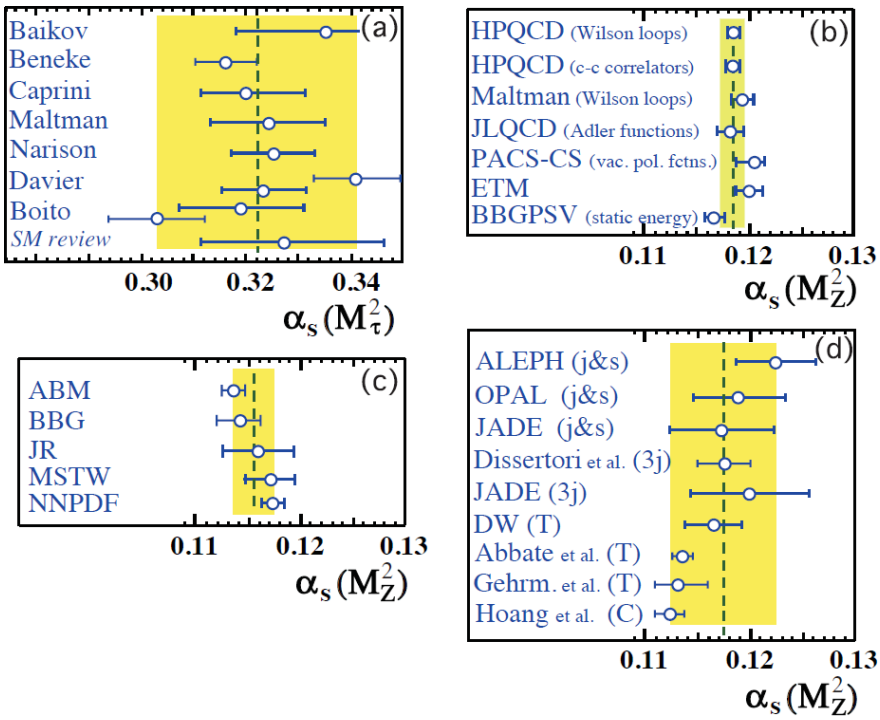

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α_s from hadronic quarkonia decays

J. Soto i Riera

Institution, City, Country

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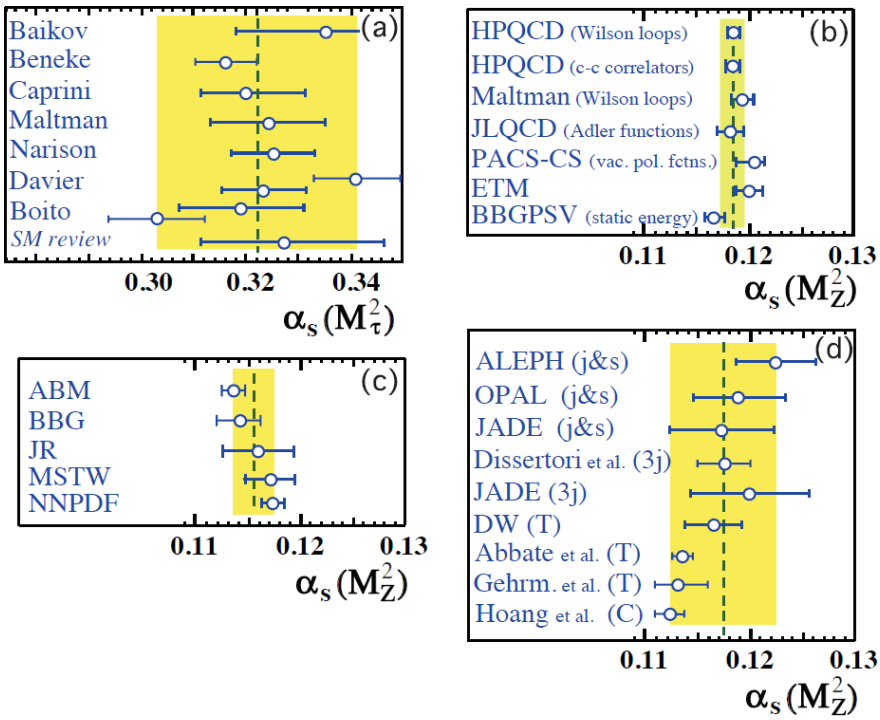

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α_s from soft parton-to-hadron FFs

R. Perez-Ramos and D. d'Enterria

Institution, City, Country

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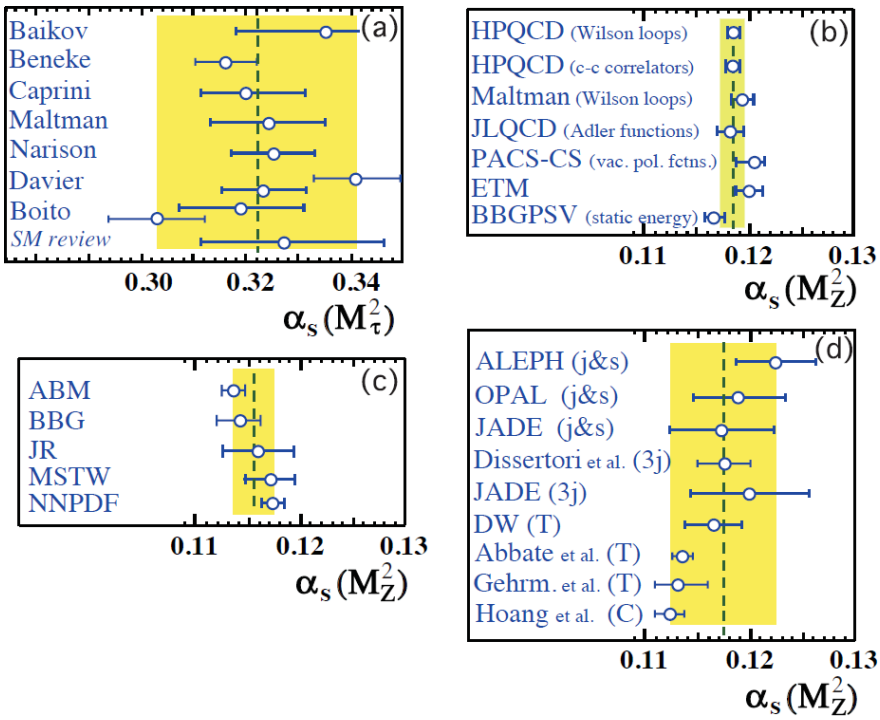

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α_s from global fits of parton distribution functions

J. Blümlein

Institution, City, Country

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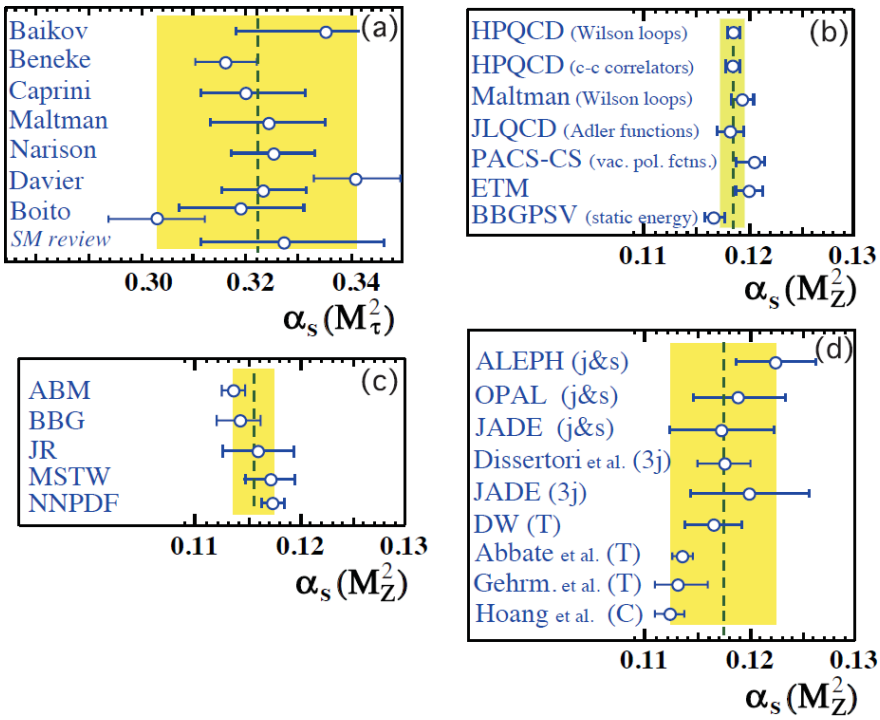

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α_s from jets in DIS and photoproduction

M. Klasen

Institution, City, Country

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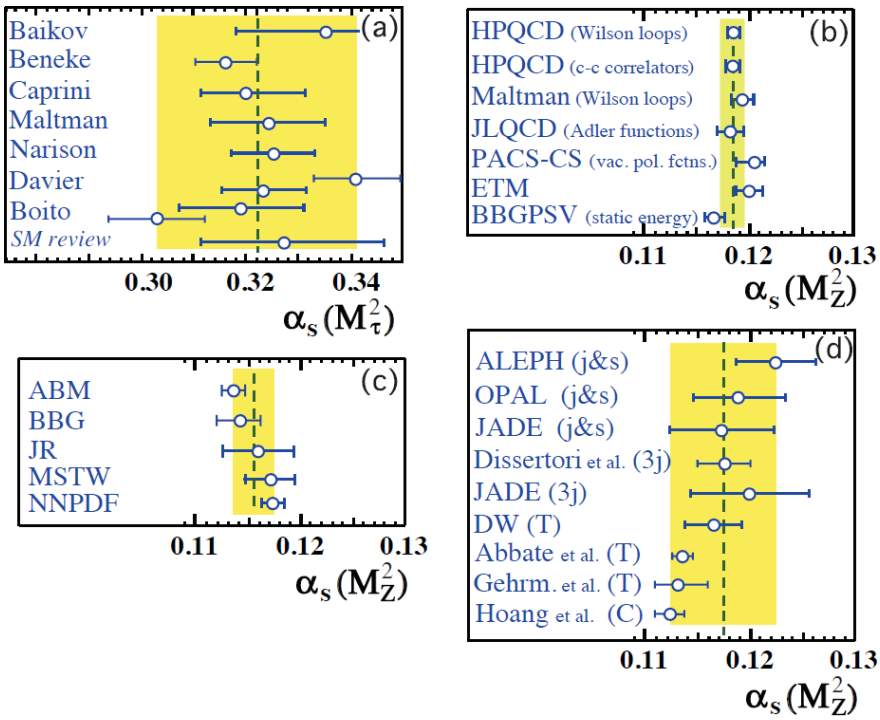

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α_s from e^+e^- event shapes

S. Kluth

Institution, City, Country

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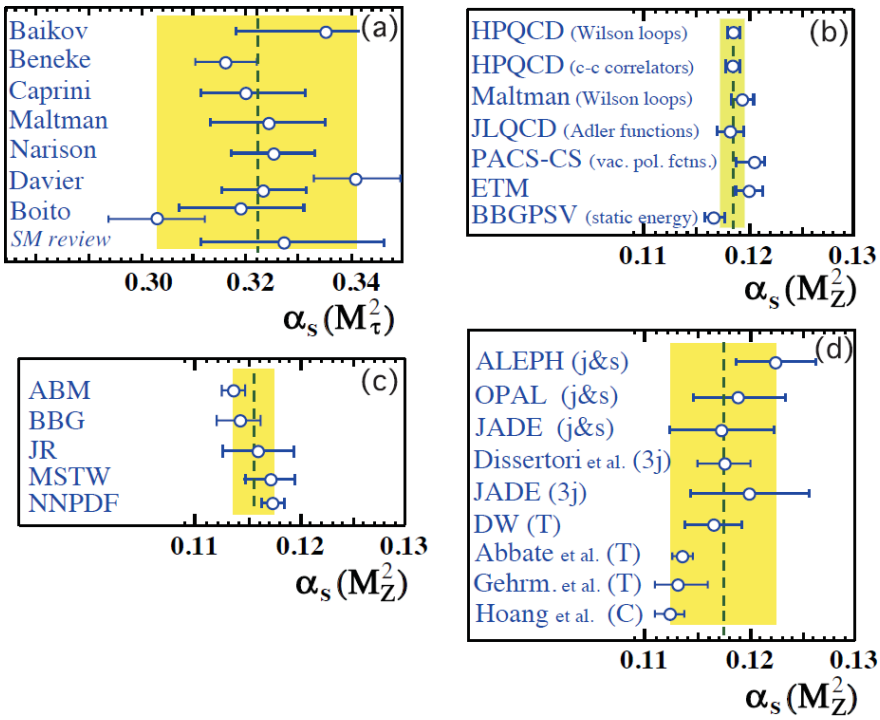

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α_s from e^+e^- C-parameter event shape

A. Hoang

Institution, City, Country

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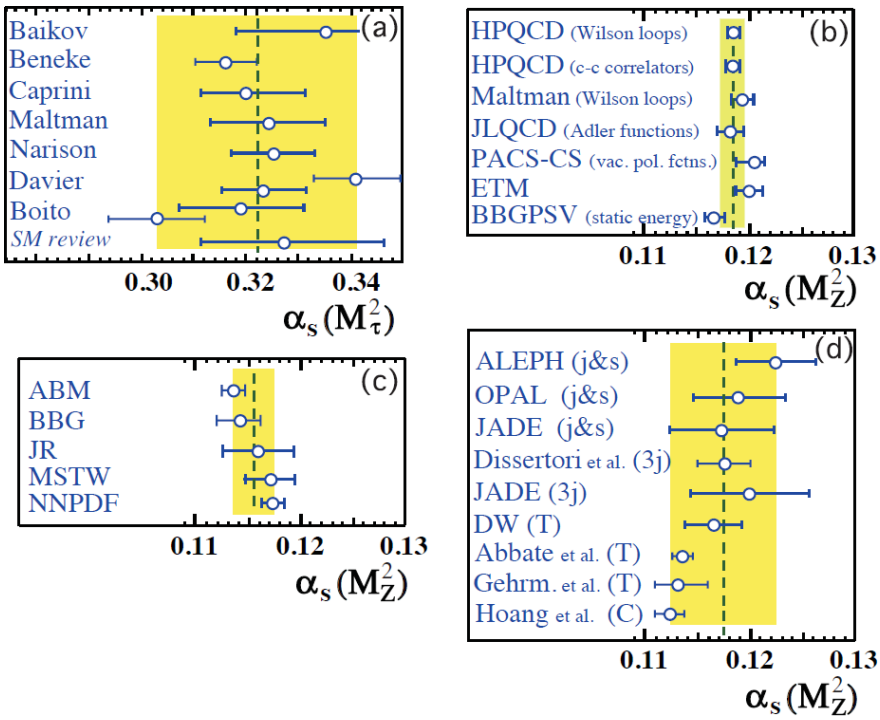

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α_s from e^+e^- jet cross sections

A. Banfi

Institution, City, Country

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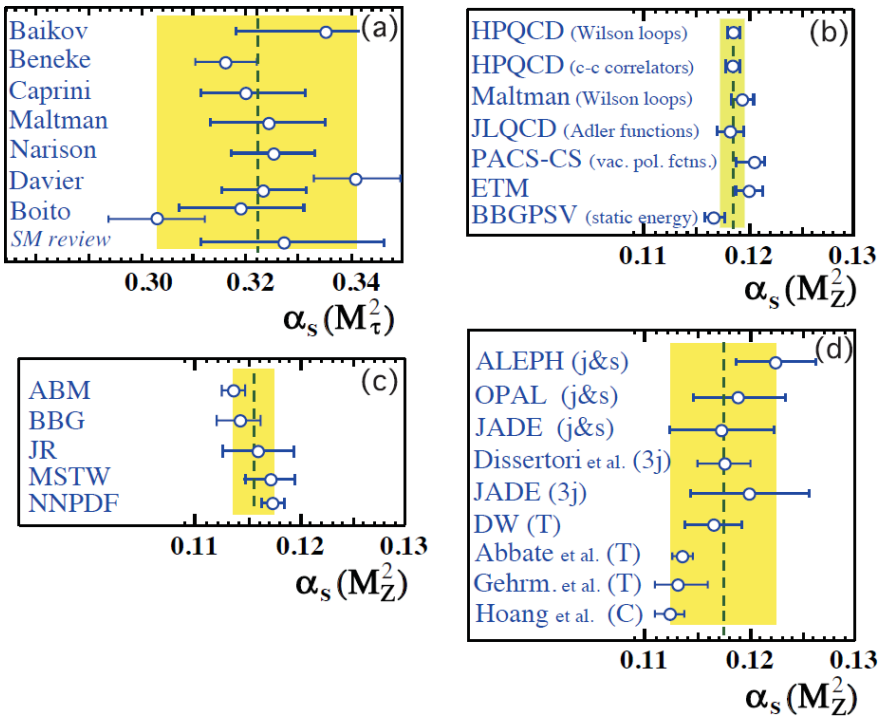

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α_s from hadronic Z decays and from the full electroweak fit

K. Mönig

Institution, City, Country

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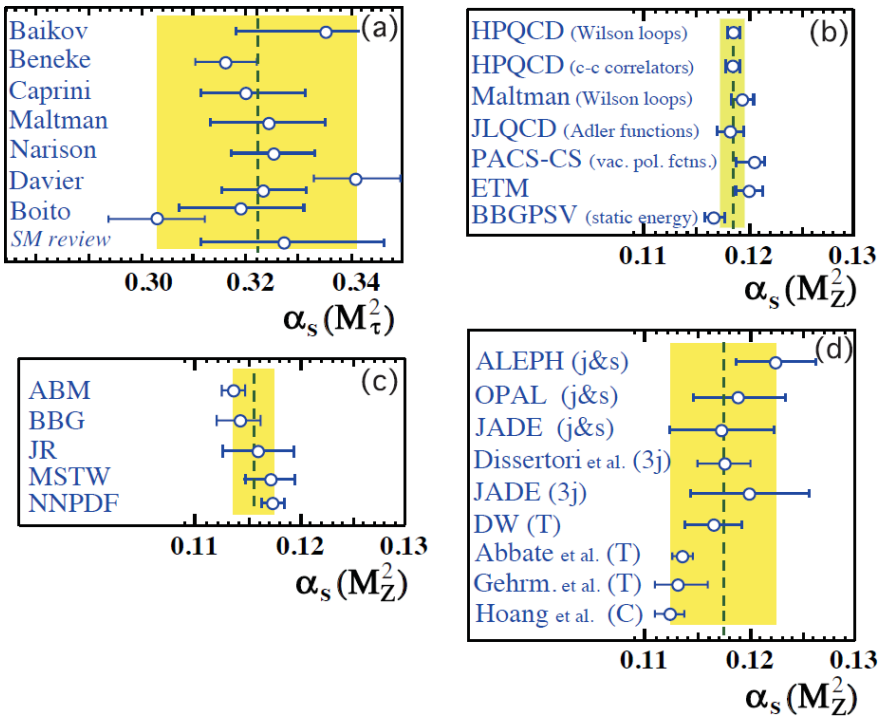

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M. Srebre and D. d'Enterria

Institution, City, Country

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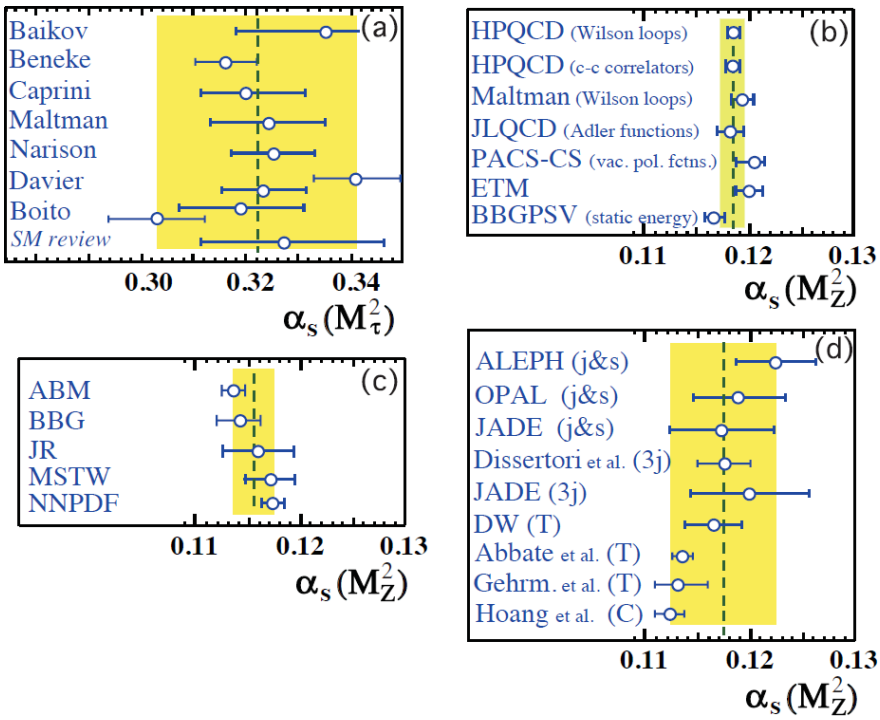

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α_s from $\sigma(e^+e^- \to \text{hadrons})$

J. Kühn

Institution, City, Country

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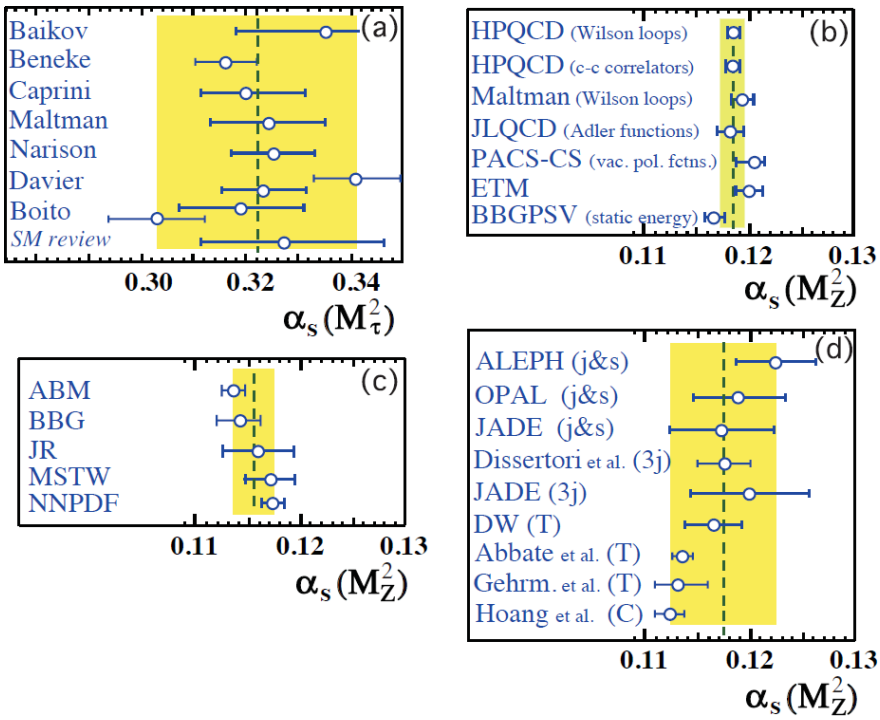

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[2] ....

α_s from top-pair cross sections at the LHC and beyond

A. Mitov

Institution, City, Country

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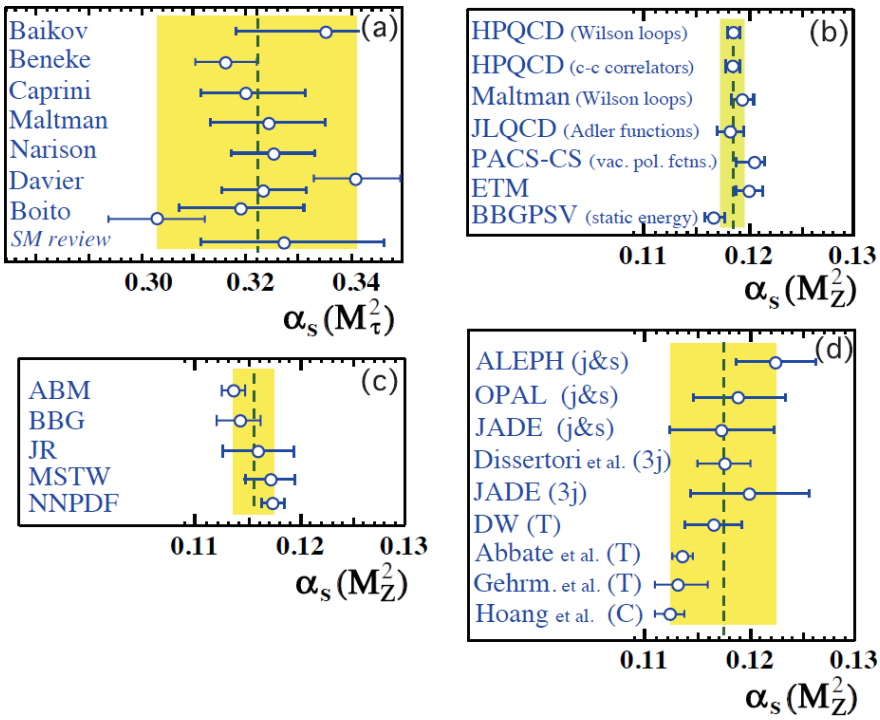

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Future prospects of α_s from NNLO jets at the LHC and beyond

J. Pires

Institution, City, Country

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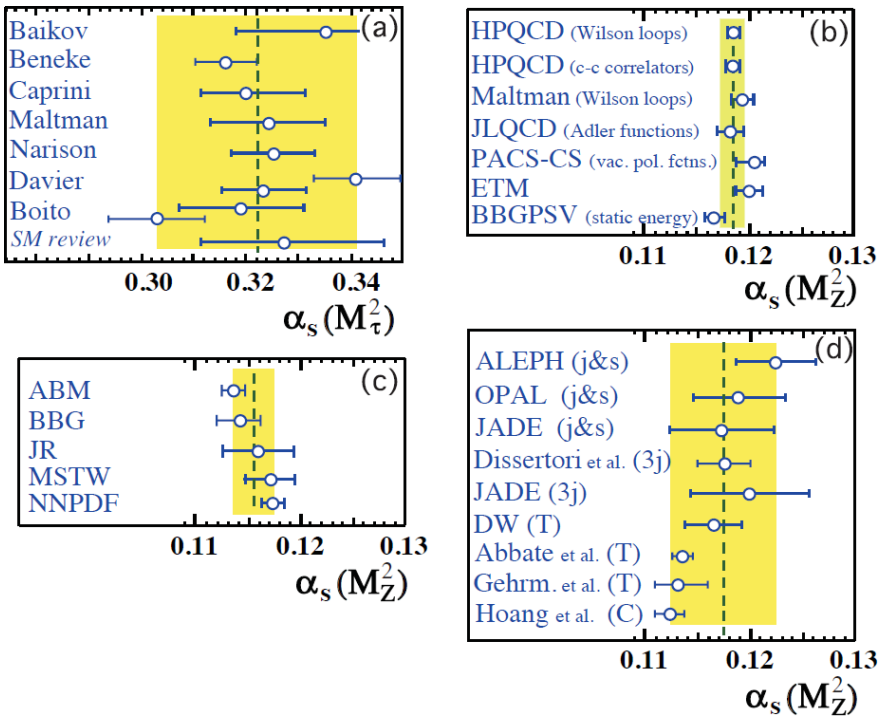

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α_s determinations from ATLAS (status and plans)

B. Malaescu

Institution, City, Country

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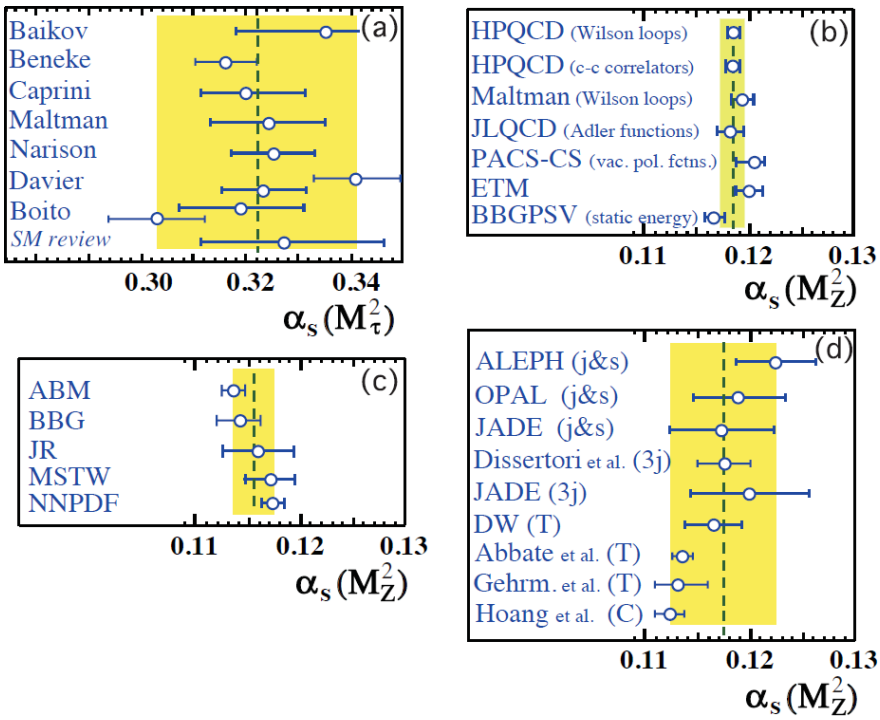

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α_s determinations from CMS (status and plans)

K. Rabbertz

Institution, City, Country

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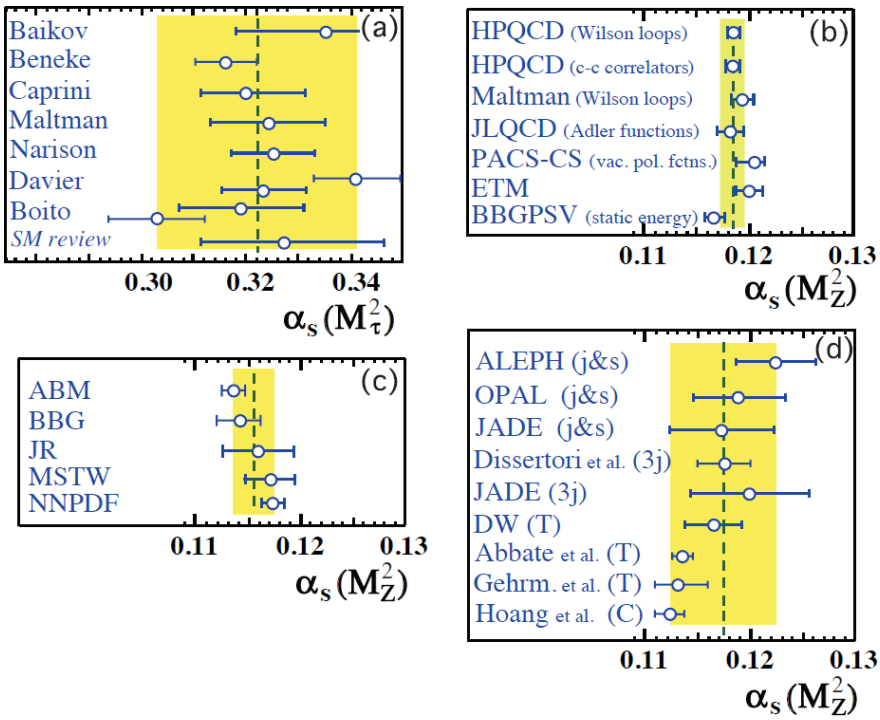

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Conclusions

D. d'Enterria

Institution, City, Country

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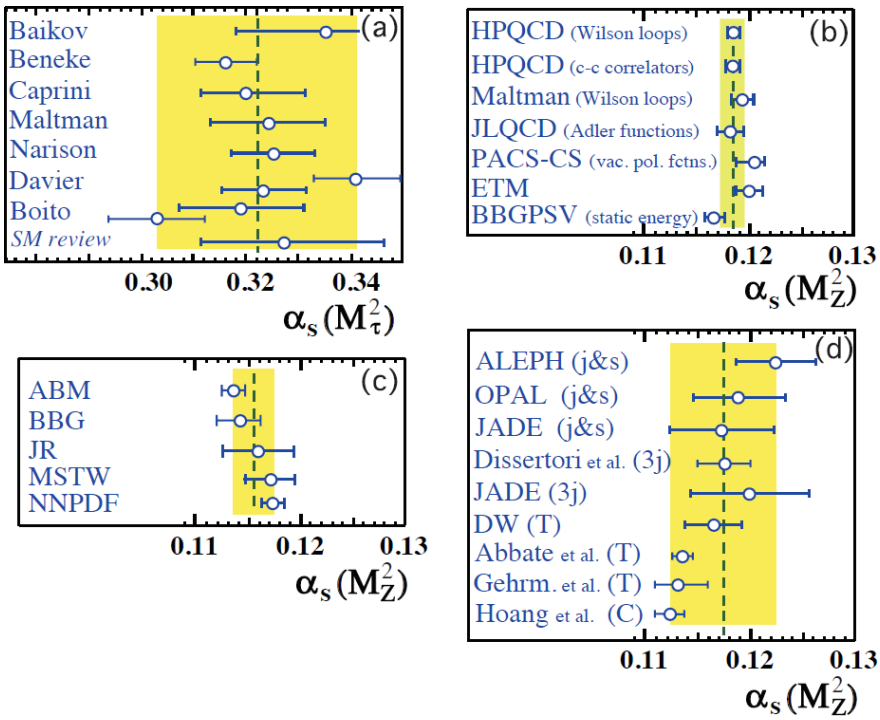

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