

# $\alpha_s$ (2022) introduction

## $\alpha_s$ (2022) workshop

ECT\* (Trento), 31<sup>st</sup> Jan.–5<sup>th</sup> Feb. 2022

David d'Enterria (CERN)

Stefan Kluth (MPP)

Giulia Zanderighi (MPP)

# $\alpha_s$ workshop “series”

- This is the 4<sup>th</sup> workshop of a series devoted to high-precision studies of the QCD coupling constant:

$\alpha_s$ (2011), Munich: <https://inspirehep.net/literature/930305>

$\alpha_s$ (2015), CERN: <https://indico.cern.ch/e/alphas2015>

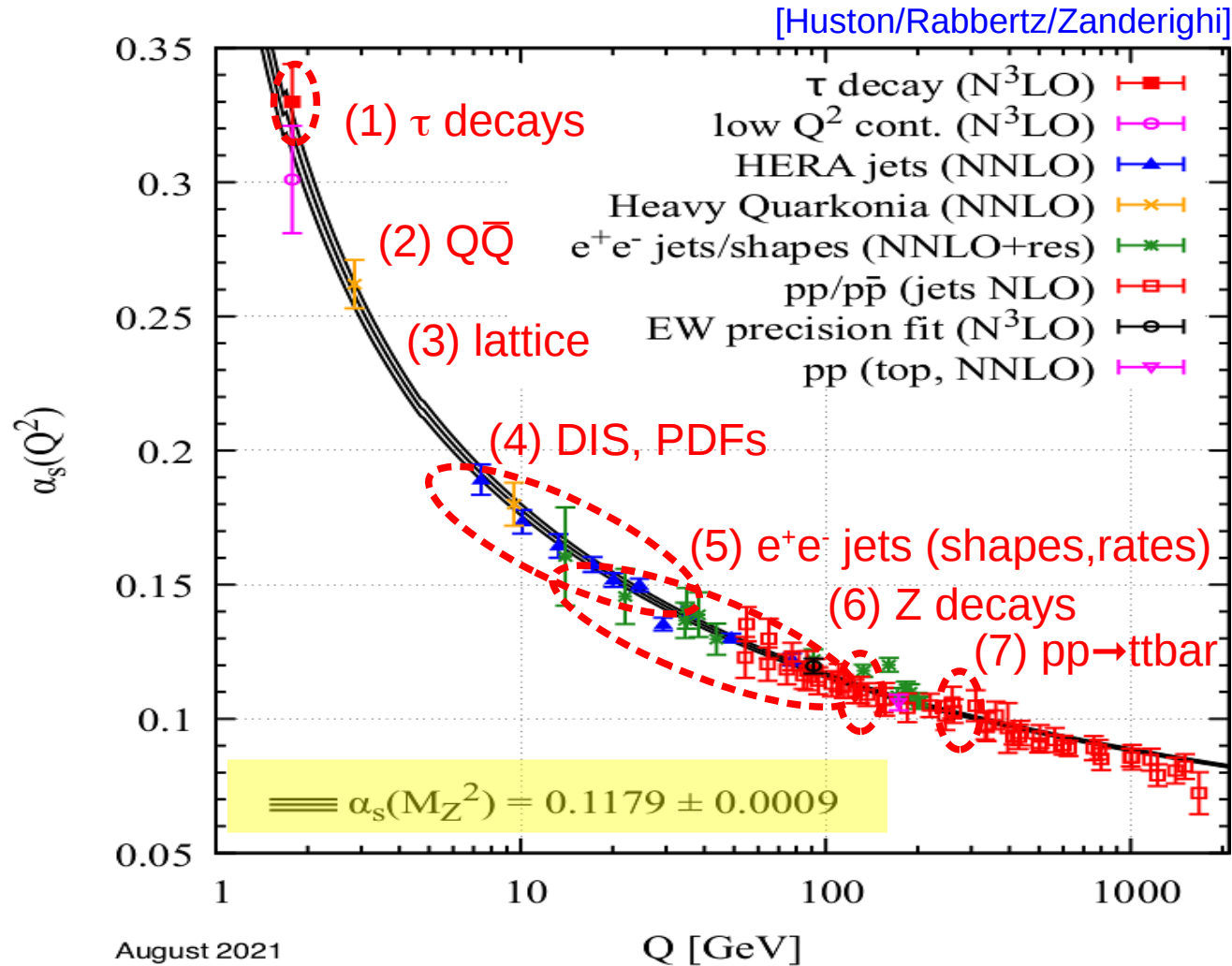
$\alpha_s$ (2019), ECT\* Trento: <https://indico.cern.ch/e/alphas2019>

$\alpha_s$ (2022), ECT\* Trento: <https://indico.cern.ch/e/alphas2022>

*“The main scientific goals of this workshop are to **bring together the current best experts in  $\alpha_s$  determination**, to critically **discuss and understand the relevant merits and problems** of each extraction method, and to **consider new  $\alpha_s$  studies** and approaches. One important outcome should be to **assess the perspectives for systematic improvements of theoretical predictions and experimental methods** in order to **resolve discrepancies** between different methods and pave the way for a truly world average of  $\alpha_s$  with high (permille) precision.”*

# World $\alpha_s$ determination (PDG 2021)

- Determined today by comparing 7 experimental observables to pQCD NNLO, N<sup>3</sup>LO predictions, plus global average at the Z pole scale:



# Structure of the workshop

- Discuss latest developments & prospects in  $\alpha_s(m_Z)$  determinations via:
  - (i) **Lattice QCD & Quarkonia**: **Mo. afternoon**
  - (ii) **DIS & global PDF analyses**: **Tues. afternoon**
  - (iii) Hadronic final states at the **LHC**: **Tues. afternoon**
  - (iv) Hadronic final states in  $e^+e^-$  (+ “leftovers”): **Wed. afternoon**
  - (v) Hadronic **tau** decays: **Thurs. afternoon**
- **PDG  $\alpha_s(m_Z)$  averaging** discussion: **Friday afternoon**
- **Snowmass'22 White Paper preparation**:
  - All mornings (individual/team work per contribution)**
  - Topical discussions at the end of each day (18:30- 19:00)**
  - Friday afternoon (if needed)**
- **Each talk has an indicative 20'+10' allocated time**, but our goal is to have as lively & direct discussions as possible: **questions during presentations encouraged** (in the philosophy of a truly working-discussion meetg).
- We will use **CERN-Mattermost to keep minutes** of the presentations and to allow participants to **ask questions or post comments**. Use the "Reply" action (left-pointing arrow symbol) on the presentation's minutes.  
[https://mattermost.web.cern.ch/signup\\_user\\_complete?id=eznq7eakkt8hxridybtlds5ef6o](https://mattermost.web.cern.ch/signup_user_complete?id=eznq7eakkt8hxridybtlds5ef6o)

# Snowmass'22 “Precision QCD” Report

- The US Particle Physics Community Planning Exercise (a.k.a. “Snowmass”) is organized by the APS-DPF every ~10 years to provide an opportunity for the entire particle physics community to come together to identify and document the vision for the future of particle physics in the US and its international partners. It aims at defining the most important questions for the field of particle physics and identify promising opportunities to address them.
- The Snowmass'22 exercise is organized into several “Frontiers” divided themselves into various Topical Groups (TG) that will provide reports based on independent White Papers submitted by the relevant subcommunities. This workshop is part of the “Energy Frontier” group “EF05: QCD & strong interactions: Precision QCD” <https://indico.fnal.gov/category/1139/>
- The EF05 group conveners (Michael Begel (BNL), Stefan Hoeche (FNAL), Michael Schmitt (Northwestern)) made a call for Letters of Intents in 2020. There were 4 Lols related to  $\alpha_s$  (see backup). The conveners appointed David d'E. to lead the edition of the  $\alpha_s$  WP. We profit from the  $\alpha_s$ (2022) workshop to collect all relevant contributions from the experts.
- Major milestone deadline to submit topical White Papers: March 15, 2022. Preparation and review of topical group report will follow, leading toward the Energy Frontier report (right before the July 2022 meeting in Seattle), and then the final Snowmass report.

This is a hard deadline: Only if our WP is presented by then can be included in the TG report

# Snowmass'22 $\alpha_s$ White Paper

■ Each contributor is requested to **provide 1–3 pages of text/tables/figures** summarizing their workshop presentation with relevant bibliography and, in particular, **addressing the following questions** :

1) **Overarching questions**: **What is the current state-of-the-art and the ultimate theoretical & experimental precision for your favourite  $\alpha_s$  extraction method? What do we need to achieve such ultimate precision?**

2) **Theory**: What is the situation with the **higher-order corrections** (pQCD, mixed QCD-EW) for your favourite observable? What is the **impact of non-pQCD corrections/uncertainties?** (Are there **new techniques** to reduce them?) Provide your **personal wish-list in data/theory developments needed** to reach your ultimate  $\alpha_s$  precision.

3) **Experiment**: What are the **current leading syst./stat. uncertainties** for your favourite observable? What are the expected future syst./stat. **reductions with current & future (e+e-, e-p, p-p) machines?** (Are there **new observables** being considered?) Provide your **personal wish-list in data/theory developments needed** to reach your ultimate  $\alpha_s$  precision.

■ **Common Overleaf document** to be filled-out during the week (and after it but, in any case, before the end of February'22): <https://www.overleaf.com/7195461193bsjbtgrvvsbw>

# Backup slides

# Snowmass'22 $\alpha_s$ LOI's

## EF05 Topical Group Meeting: LOIs on $\alpha_s$ determination

Monday Oct 12, 2020, 3:55 PM → 6:30 PM Europe/Andorra

**Description** The aim of this meeting is to discuss LOIs related to strong coupling determination.



Zoom link

**3:55 PM** → 4:00 PM **Introduction**

**Speakers:** Michael Begel (Brookhaven National Lab) , Michael Schmitt (Northwestern University) , Stefan Hoeche (Fermilab)

Discussion Slides.p...

**4:00 PM** → 4:15 PM **Lattice-QCD Determinations of Quark Masses and the Strong Coupling  $\alpha_s$**

**Speaker:** Andreas Kronfeld (Fermilab)

EF05-20201012.pdf

**4:15 PM** → 4:30 PM **Perspectives for high-precision  $\alpha_s$  determinations from future  $e+e-$  measurements at the FCC-ee**

**Speaker:** David d'Enterria (CERN)

dde\_alphas\_FCCee...

**4:30 PM** → 4:45 PM **High-precision  $\alpha_s$  determinations from future FCC-ee  $e+e-\rightarrow$  hadrons data below the Z peak**

**Speakers:** Andrii Verbytskyi (Max-Planck-Institut für Physik) , Andrii Verbytskyi

Snowmass2020\_A...

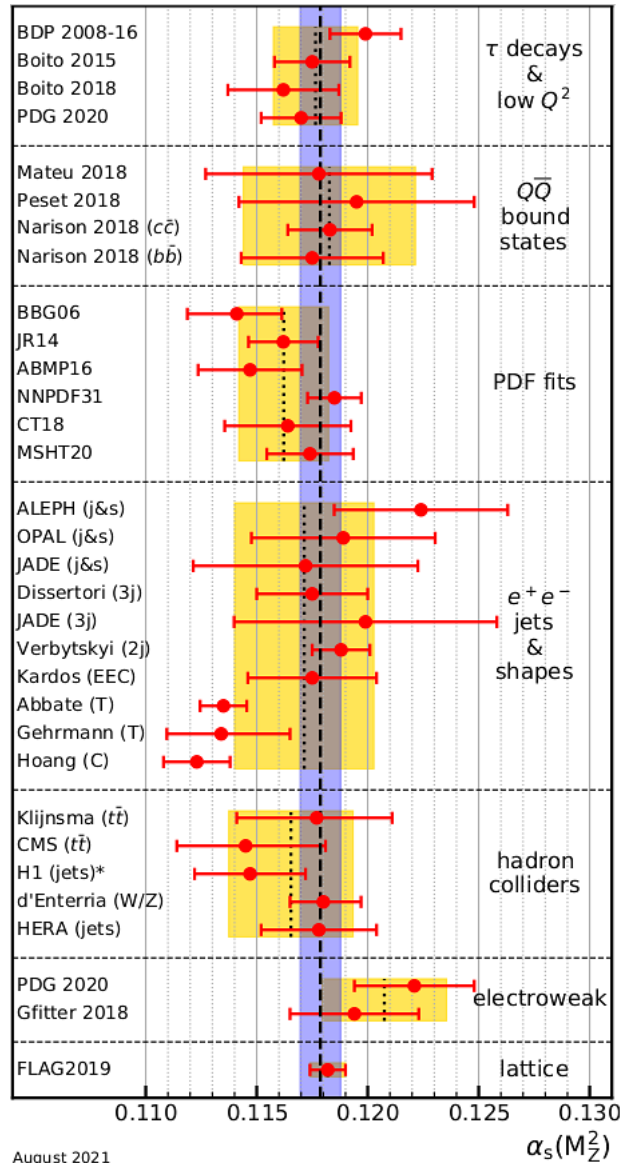
**4:45 PM** → 5:00 PM **PDFs,  $\alpha_s$  and Low-x Physics and at Future DIS Facilities**

**Speaker:** Fredrick Olness (SMU)

olness.pdf



# PDG 2021 $\alpha_s$ world average (NNLO)



$(\pm 1.5\%)$

$(\pm 1.0\%)$

$(\pm 1.8\%)$

$(\pm 2.9\%)$

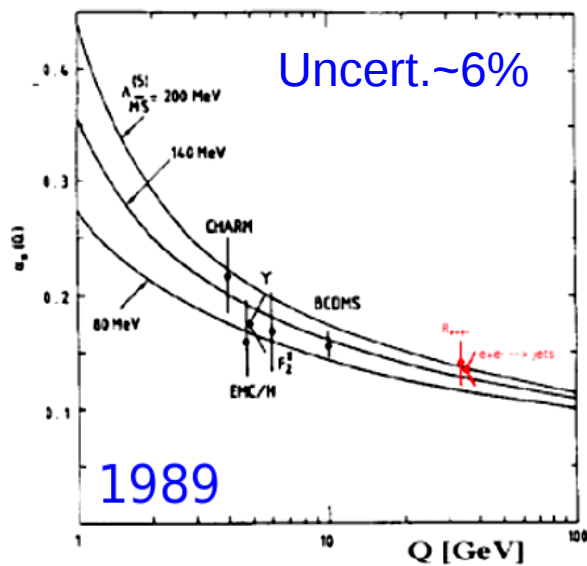
$(\pm 2.5\%)$

$(\pm 2.5\%)$

$(\pm 0.9\%)$

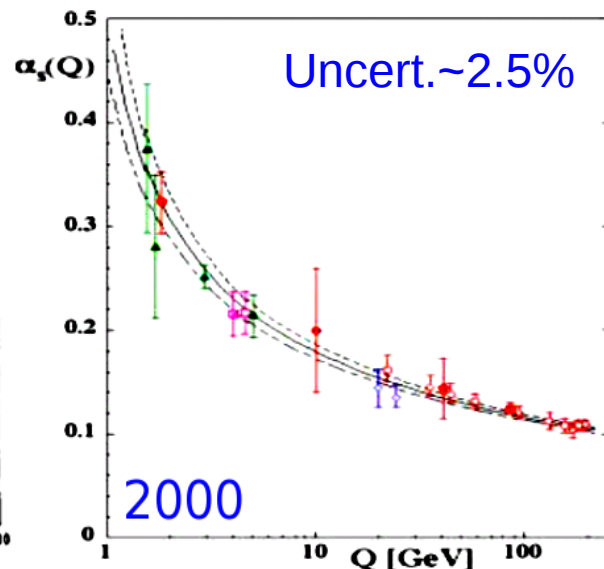
# QCD coupling $\alpha_s$

- ➔ Determines **strength of the strong interaction** between quarks & gluons.
- ➔ **Single free parameter in QCD** in the  $m_q \rightarrow 0$  limit.
- ➔ Determined at a ref. scale ( $Q=m_Z$ ), decreases as  $\alpha_s \sim \ln(Q^2/\Lambda^2)^{-1}$ ;  $\Lambda \sim 0.2$  GeV



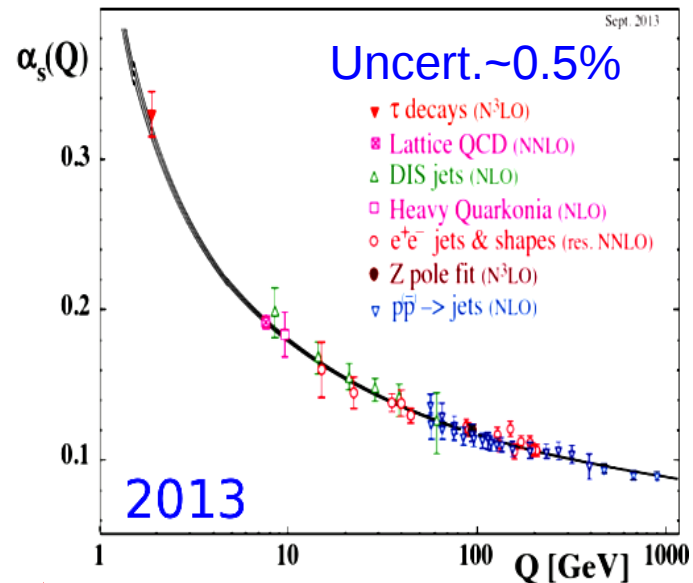
$$\alpha_s(M_Z) = 0.110^{+0.006}_{-0.008} \text{ (NLO)}$$

G. Altarelli, Ann. Rev. Nucl. Part. Sci. 39, 1989



$$\alpha_s(M_Z) = 0.1184 \pm 0.0031 \text{ (NNLO)}$$

S. B. , J. Phys. G 26, 2000

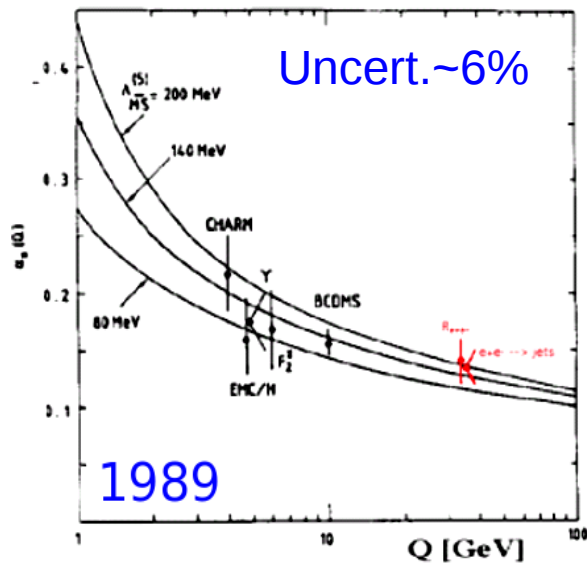


$$\alpha_s(M_Z) = 0.1185 \pm 0.0006 \text{ (NNLO)}$$

Sept. 2013

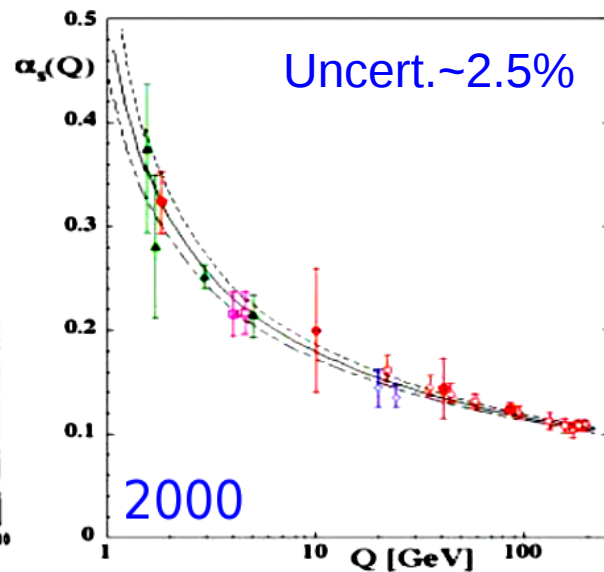
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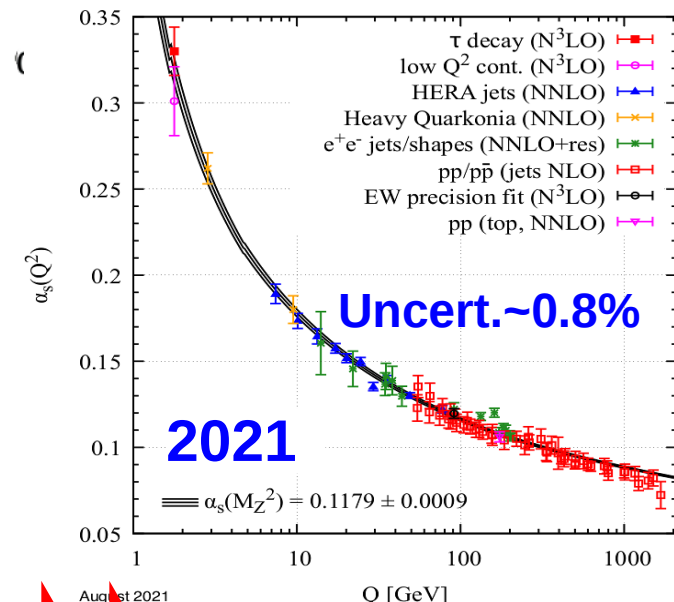
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$$\alpha_s(M_Z) = 0.1181 \pm 0.0011 \text{ (NNLO)}$$

- ➔ **Least precisely known** of all interaction **couplings** !

$$\delta\alpha \sim 10^{-10} \ll \delta G_F \ll 10^{-7} \ll \delta G \sim 10^{-5} \ll \delta\alpha_s \sim 10^{-3}$$

# Key role of the QCD coupling $\alpha_s$

Impacts all QCD x-sections & decays (H), precision top & parametric EWPO:

Process	$\sigma$ (pb)	$\delta\alpha_s$ (%)	PDF + $\alpha_s$ (%)	Scale (%)
ggH	49.87	$\pm 3.7$	-6.2 +7.4	-2.61 + 0.32
ttH	0.611	$\pm 3.0$	$\pm 8.9$	-9.3 + 5.9

Channel	$M_H$ [GeV]	$\delta\alpha_s$ (%)	$\Delta m_b$	$\Delta m_c$
H $\rightarrow c\bar{c}$	126	$\pm 7.1$	$\pm 0.1\%$	$\pm 2.3\%$
H $\rightarrow gg$	126	$\pm 4.1$	$\pm 0.1\%$	$\pm 0\%$

Msbar mass error budget (from threshold scan)

$(\delta M_t^{SD-low})^{exp}$	$(\delta M_t^{SD-low})^{theo}$	$(\delta \overline{m}_t(\overline{m}_t))^{conversion}$	$(\delta \overline{m}_t(\overline{m}_t))^{\alpha_s}$
40 MeV	50 MeV	7 - 23 MeV	70 MeV

$\Rightarrow$  improvement in  $\alpha_s$  crucial  $\delta\alpha_s(M_Z) = 0.001$

Quantity	FCC-ee	future param.unc.	Main source
$\Gamma_Z$ [MeV]	0.1	0.1	$\delta\alpha_s$
$R_b$ [ $10^{-5}$ ]	6	< 1	$\delta\alpha_s$
$R_\ell$ [ $10^{-3}$ ]	1	1.3	$\delta\alpha_s$

Sven Heinemeyer – 1st FCC physics workshop, CERN, 17.01.2017

Impacts physics approaching Planck scale: EW vacuum stability, GUT

