espp2026-ppg-strong_int@cern.ch

European Strategy for Particle Physics

# Strong Interactions WG

## Open preparatory meetings

## 14 & 28 May 2025

Andrea Dainese (INFN Padova), Cristinel Diaconu (CPPM Marseille),
Chiara Signorile-Signorile (MPP Munich)

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# European Strategy Update 2026

- In June 2024, the CERN Council established and approved the **remit of the European Strategy Group:**

”the aim of the Strategy Update should be to develop a **visionary and concrete plan** that greatly advances human knowledge in fundamental physics through the **realisation of the next flagship project at CERN**. This plan should attract and value **international collaboration** and should **allow Europe to continue to play a leading role in the field.”**

- The Strategy Update should include the **preferred option** for the next collider at CERN and **prioritized alternative options** to be pursued if the chosen preferred plan turns out not to be feasible or competitive.
- The Strategy Update should also indicate **areas of priority for exploration complementary to colliders** and for other experiments to be considered **at CERN** and **at other laboratories in Europe**, as well as for participation **in projects outside Europe**.

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**The Strategy and the HL-LHC HI programme:**

- **“Full exploitation” of HL-LHC, including flavour physics and QGP study, recommended in the 2020 Strategy Update**
- **Crucial to show *progress*, *plans,* and *broad community support* towards a rich physics programme throughout the full lifetime of the HL-LHC facility**
  - Note: ESPP focuses on facilities and projects, not on running scenarios – which remain with scientific committees

# Physics Preparatory Group and Working Groups

European Strategy for Particle Physics

| PPG MEMBERS | |
|---|---|
| ***Strategy Secretariat*** | |
| Scientific Secretary (Chair) | Prof. Karl Jakobs (DE) |
| SPC Chair | Dr Hugh Montgomery (USA) |
| ECFA Chair | Prof. Pareskevas Sphicas(GR) |
| LDG Chair | Prof. Mike Seidel (CH) |
| ***SPC*** | |
| Prof. Pilar Hernandez (ES) | |
| Prof. Gino Isidori (CH) | |
| Prof. Fabio Maltoni (BE/IT) | |
| Prof. Jocelyn Monroe (UK) | |
| ***ECFA*** | |
| Dr Tommaso Boccali (IT) | |
| Dr Thomas Bergauer (AT) | |
| Dr Cristinel Diaconu (FR) | |
| Prof. Monica Dunford (DE) | |
| ***CERN*** | |
| Dr Gianluigi Arduini (CERN) | |
| ***ASIA/AMERICAS*** | |
| Dr Anadi Canepa (USA) | |
| Prof. Xinchou Lou (China) | |
| Prof. Rogerio Rosenfeld (Brazil) | |
| Prof. Yuji Yamazaki (Japan) | |

https://europeanstrategyupdate.web.cern.ch/

| Working Group | | |
|---|---|---|
| | Co-convener (PPG member) | Co-convener |
| Electroweak physics | Monica Dunford (DE, exp) | Jorge de Blas (ES, theory) |
| Strong interaction | Cristinel Diaconu (FR, exp) | Andrea Dainese (IT, exp, HI) |
| Flavour physics | Gino Isidori (CH, theory) | Marie-Hélène Schune (FR, exp) |
| BSM physics | Fabio Maltoni (BE/IT, theory) | Rebeca Gonzalez Suarez (SE, exp) |
| Neutrino physics and cosmic messengers | Pilar Hernandez (ES, theory) | Sara Bolognesi (FR, exp) |
| Dark matter and dark sector | Jocelyn Monroe (UK, exp) | Matthew McCullough (CERN, theory) |
| Accelerator science and technology | Gianluigi Arduini (CERN, acc) | Phil Burrows (UK, exp, acc) |
| Detector instrumentation | Thomas Bergauer (AT, exp) | Ulrich Husemann (DE, exp) |
| Computing | Tommaso Boccali (IT, exp, comp) | Borut Kersevan (SL, exp, comp) |

# European Strategy Update 2026: timeline

# Group structure: physics areas and experts

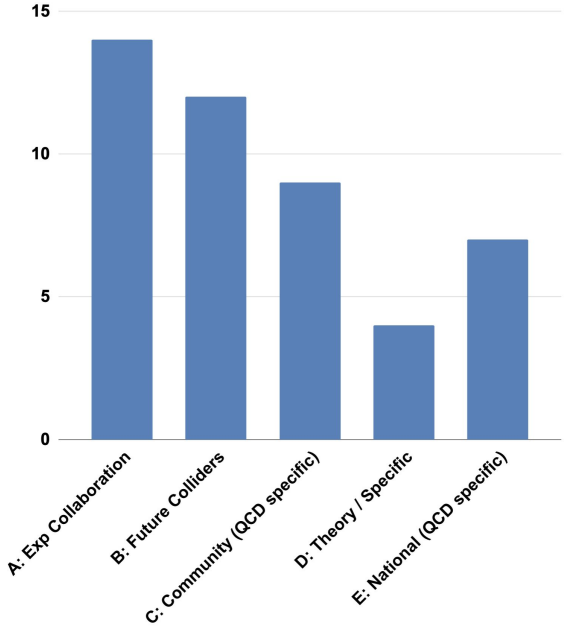
Conveners: Andrea Dainese (EXP, IT), Cristinel Diaconu (EXP, FR)

Scientific Secretary: Chiara Signorile-Signorile (TH, DE)

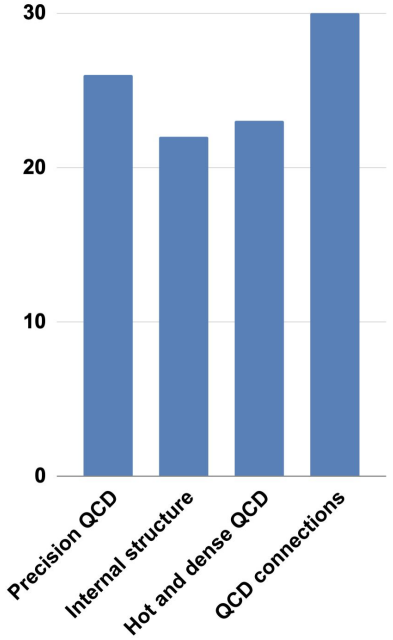
- **Precision QCD**
  - Physics: elementary processes, alpha_S, fragmentation, hadronization, photon-photon
  - Machines: HL-LHC, FCC-ee, other lepton collider options, FCC-hh
  - *David d'Enterria (EXP, CERN), Sven Olaf Moch (TH, DE)*
- **Internal structure of protons and nuclei**
  - Physics: PDFs and nuclear PDFs, gluon saturation, proton spin
  - Machines: HL-LHC, EIC, LHeC, FCC-eh, FCC-hh, Muon Collider
  - *Nestor Armesto (TH, ES), Andy Buckley (EXP, UK)*
- **Hot and dense QCD**
  - Physics: Heavy ions, Quark-gluon plasma, Collectivity in QCD
  - Machines: HL-LHC, SPS, FAIR, FCC-hh / ions
  - *Roberta Arnaldi (EXP, IT), Raimond Snellings (EXP, NL), Urs Wiedemann (TH, CERN)*
- **QCD connections with hadronic, nuclear and astro(particle)physics**
  - Physics: hadron spectroscopy and exotica, hadron-hadron strong interaction, QCD in cosmic-ray physics (incl. DM searches), QCD in neutron star cores, QCD in nuclear structure
  - Machines: HL-LHC, SPS, FAIR
  - *Antoine Gérardin (TH, lattice, FR), Valentina Mantovani Sarti (EXP, DE), Marco Pappagallo (EXP, IT)*

# Submitted Input Documents mapped to Strong Interactions WG

- **47 Inputs**
  - (for comparison: was 35 for ESPPU 2020)
  - Same number of inputs (14) on ongoing experiments/upgrades and on future colliders
  - Many inputs from “specific” QCD communities and national QCD communities




- **Our 4 physics areas evenly covered**
  - Precision QCD and Internal structure mostly in future colliders inputs
  - Hot and dense QCD and QCD Connections mostly in (HL-LHC, SPS) inputs



# Submitted Input Documents - Overview

European Strategy for Particle Physics

Tables with links to inputs

## Experimental Collaborations

| | | | Precision QCD | Internal structure | Hot and dense QCD | Connections (hadr,nucl, astr) |
|---|---|---|---|---|---|---|
| 6 | Input for the EUROPEAN STRATEGY FOR PARTICLE PHYSICS UPDATE 2026 compiled by THE ISOLDE COLLABORATION COMMITTEE | ISOLDE | | | | X |
| 205 | The Belle II Experiment at SuperKEKB | KEK Belle II | X | | | X |
| 68 | Input from the ALICE Collaboration | LHC ALICE | | X | X | X |
| 170 | Highlights of the HL-LHC physics projections by ATLAS and CMS | LHC ATLAS+CMS | X | X | | |
| 23 | Prospects and Opportunities with an upgraded FASER Neutrino Detector during the HL-LHC era: Input to the EPPSU | LHC FASER | | X | | X |
| 19 | The Forward Physics Facility at the Large Hadron Collider | LHC FPF | | X | | X |
| 81 | Discovery potential of LHCb Upgrade II | LHC LHCb | | | | X |
| 82 | Heavy ion physics with LHCb Upgrade II | LHC LHCb | | X | X | X |
| 213 | LHCspin: a Polarized Gas Target for LHC | LHC LHCspin | | X | | |
| 245 | MUonE Contribution to the European Strategy: status of the project | mu CERN MUonE | X | | | |
| 131 | European Strategy for Particle Physics 2026: the NA60+/DiCE experiment at the SPS | SPS NA60+/DiCE | | | X | |
| 171 | Proposal from the NA61/SHINE Collaboration for the update of the European Strategy for Particle Physics | SPS NA61/SHINE | | | X | X |
| 231 | Super Tau Charm Facility | STCF China | X | | | X |

# Submitted Input Documents - Overview

European Strategy for Particle Physics

## Tables with links to inputs

### Future Colliders

| | | | Precision QCD | Internal structure | Hot and dense QCD | Connections (hadr,nucl,astr) |
|---|---|---|---|---|---|---|
| 114 | Synergies between a U.S.-based Electron-Ion Collider and European Research in Particle Physics | eh: EIC USA | X | X | | |
| 214 | The Large Hadron electron Collider (LHeC) as a bridge project for CERN | eh: LHeC | X | X | | |
| 209 | FCC: QCD physics | FCC | X | X | X | X |
| 227 | Prospects for physics at FCC-hh | FCC | X | X | X | X |
| 233 | FCC Integrated Programme Stage 1: The FCC-ee | FCC | X | | | |
| 241 | The FCC integrated programme: a physics manifesto | FCC | X | X | X | X |
| 247 | FCC Integrated Programme Stage 2: The FCC-hh | FCC | X | X | X | X |
| 141 | The ECFA Higgs/Electroweak/Top Factory Study | FCC/LC/CLIC/MuCol | X | | | |
| 275 | Status of the International Linear Collider | ILC | X | | | |
| 188 | LEP3: A High-Luminosity e+e− Higgs & Electroweak Factory in the LHC Tunnel | LEP3 | X | | | |
| 152 | United States Muon Collider Community White Paper for the European Strategy for Particle Physics Update | Muon Collider | | X | | |
| 207 | The Muon Collider | Muon Collider | | X | | |

# Submitted Input Documents - Overview

European Strategy for Particle Physics

## Tables with links to inputs

### Community (QCD specific)

| | | | Precision QCD | Internal structure | Hot and dense QCD | Connections (hadr,nucl,astr) |
|---|---|---|---|---|---|---|
| 224 | Community Support for Physics with high-luminosity proton-nucleus collisions at the LHC | HI at HL-LHC | | X | X | X |
| 2 | Light Ion Collisions at the LHC | HI Light ions LHC | | X | X | X |
| 7 | Conclusions of the Town Meeting: Heavy Ion and QGP Physics at CERN | HI physics CERN | | | X | |
| 55 | Kaon Physics: A Cornerstone for Future Discoveries | Kaon Phyiscs | | | | X |
| 29 | Strategy for the Future of Lattice QCD | Lattice QCD | | X | X | X |
| 103 | Nuclear Physics and the European Particle Physics Strategy Update 2026 | NuPECC | | X | X | X |
| 235 | Summary Report of the Physics Beyond Colliders Study at CERN | Phyiscs Beyond Colliders | X | X | X | X |
| 89 | Precision cross-sections for advancing cosmic-ray physics | Cross sections for cosmics | . | | | X |
| 201 | Statement of the Pierre Auger Collaboration as input for the 2026 European Particle Physics Strategy | HI for cosmics (AUGER) | . | | | X |

### Theory / Specific

| | | | | | | |
|---|---|---|---|---|---|---|
| 174 | Phase-One LHeC | Personal input LHeC/HL-LHC | X | X | | |
| 33 | Computer Algebra for Precision Calculations in Particle Physics: the FORM project | QCD theory/computing | X | | | |
| 35 | Cusp Spectroscopy, Hyperon-Nucleon Scattering, and Femtoscopy: Pioneering Tools for Next-Generation Hadron Interaction Studies | QCD theory/computing | . | | | X |
| 113 | Quantum Information meets High-Energy Physics: Input to the update of the European Strategy for Particle Physics | Quantum Computing | X | | | X |

# Submitted Input Documents - Overview

European Strategy for Particle Physics

## Tables with links to inputs

### National (QCD specific)

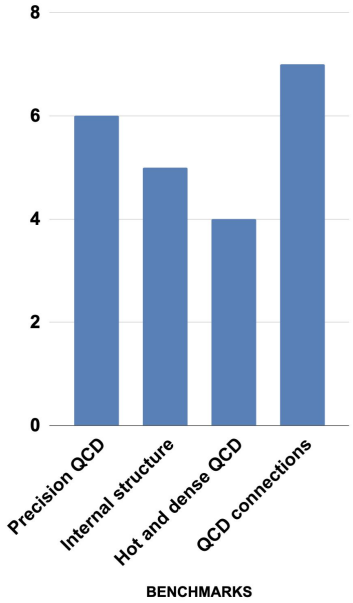
| | | | Precision QCD | Internal structure | Hot and dense QCD | Connections (hadr,nucl,astr) |
|---|---|---|---|---|---|---|
| 5 | Prospective report of the French QCD community to the ESPPU 2025 with respect to the program of the LHC Run 5 and beyond and future colliders at CERN | France QCD | X | X | X | |
| 126 | Input to ESPPU by the German Astroparticle Community | Germany Astroparticle | . | | | X |
| 183 | Input of the German Nuclear and Hadron Physics Community to the ESPPU 2026 Regarding the Programs at CERN, at FAIR, and Related Activities | Germany Hadronic and Nuclear | . | | X | X |
| 117 | The INFN National Scientific Committee for Theoretical Physics | Italy Theory | X | | X | X |
| 51 | Ultra-relativistic Heavy-Ion Collisions: Inputs of the Italian community for the ESPP 2026 | Italy HI | . | | X | |
| 76 | Input on the update of the European Strategy for Particle Physics by the INFN Nuclear and Hadron Phyiscs Community | Italy Nuclear Phys | . | | X | X |
| 246 | U.S. interest in high-energy nuclear physics at the LHC | US LHC HI community | . | | X | |

# Benchmark measurements (more details)

*Note: this is not an exclusive list of the observables and measurements that the working group will cover. The list of benchmarks will be used to summarise and highlight the complementarity and strengths of the future measurements at existing (e.g. SPS, HL-LHC) and proposed colliders (leptonic, hadronic, electron–hadron).*

- Precision QCD
  - Strong coupling $\alpha_S$ and its $Q^2$ dependence;
  - Strong interaction effects on top and W masses;
- Internal structure of protons and nuclei
  - Longitudinal and transverse proton PDF(x,$Q^2$);
  - Longitudinal and transverse nuclear PDF(x,$Q^2$);
- Hot and dense QCD
  - Heavy-flavour hadron production (rare states, kinematic coverage);
  - QGP thermal radiation / temperature;
  - QGP transport coefficients (heavy quarks, jets);
- QCD connections with hadronic, nuclear and astro(particle) physics
  - Constraints on nature of exotic hadrons from spectroscopy and h-h correlations;
  - Precision on anti-nuclei production and absorption relevant for cosmic-ray physics;

**Inputs that include benchmarks:**



Thanks for your inputs and participation!

Please engage in the process

We hope to see many of you in Venice!
(Strong Interactions session Monday 23 June 11:15-15:30)

European Strategy for Particle Physics

| | Parallel 1 - Electroweak Physics | Parallel 2 - Accelerator Technologies | Parallel 3 - Neutrinos and Cosmic Messengers | Parallel 4 - Strong Interactions | Parallel 5 – Flavor |
|---|---|---|---|---|---|
| 12:00 | *Palazzo del Casinò, sala Perla* 11:15 - 13:00 | *Palazzo del Casinò, sala Mosaici 2* 11:15 - 13:00 | *Palazzo del Casinò, Sala Volpi* 11:15 - 13:00 | *Palazzo del Casinò, Sala Mosaici 1* 11:15 - 13:00 | *Palazzo del Casinò, Sala Amici* 11:15 - 13:00 |
| 13:00 | **Lunch Break** *Palazzo del Casinò, Sala degli Specchi* 13:00 - 14:00 | | | | |
| 14:00 | **Parallel 1 - Electroweak Physics (part II)** *Palazzo del Casino, Sala Perla* 14:00 - 15:30 | **Parallel 2 - Accelerator Technologies (part II)** *Palazzo del Casinò, Sala Mosaici 2* 14:00 - 15:30 | **Parallel 3 - Neutrinos and Cosmic Messengers (part II)** *Palazzo del Casinò, Sala Volpi* 14:00 - 15:30 | **Parallel 4- Strong Interactions (part II)** *Palazzo del Casinò, Sala Mosaici 1* 14:00 - 15:30 | **Parallel 5 – Flavor (part II)** *Palazzo del Casinò, Sala Amici* 14:00 - 15:30 |
| 15:00 | | | | | |

**Parallel 4 - STRONG INTERACTIONS**

*Palazzo del Casinò, Sala Mosaici 1* 11:15 - 11:16

**Introduction: Strong Interactions WG and ESPP inputs**
*Chiara Signorile Signorile (IN…*

**Precision QCD: state-of-the-art and prospects with future facilities**
*David d'Enterria (CERN)*

*Palazzo del Casinò, Sala Mosaici 1* 11:30 - 12:15

**QCD input to cosmic rays and compact stellar objects: o…**
*Valentina Mantovani Sarti (T…*

**Prospects for exotic hadron physics**
*Antoine Gerardin (AIX-Marse…*

**Parallel 4- STRONG INTERACTIONS (part II)**

*Palazzo del Casinò, Sala Mosaici 1* 14:00 - 14:01

**Partonic dynamics in protons and nuclei: prospects with future measurements at HL-LHC and electron-hadron colliders**
*Néstor Armesto (IGFAE-Compostela Univ.)*

**Hot and dense QCD: future prospects in heavy-ion collisions**
*Urs Wiedemann Wiedemann (CERN)*

# Additional material

# Benchmark measurements

European Strategy for Particle Physics

## 2 Strong Interactions

The benchmark measurements in the area of the strong interaction are reported in the following for the four main physics research directions. Clearly, this is not an exclusive list of the observables and measurements that the working group will cover. The input documents are anticipated to have a much broader coverage, which will be taken into account. The list of benchmarks will be used to summarise and highlight the complementarity and strengths of the future measurements at existing (e.g. SPS, HL-LHC) and proposed colliders (leptonic, hadronic, electron–hadron). The presentation of results will be organised by the working group in communication with the contact persons of submitted inputs.

- Precision QCD
  - $\alpha_S(m_Z)$ and its $Q^2$ dependence;
  - Strong interaction effects for precision measurements of top and W masses (see comments at the end of the section);
    - Comment on top and W masses: while these are formally EW parameters, the strong-interaction aspects are important for their experimental and theoretical determination. For example, we propose to report the expected experimental performance for the following approaches to t and W mass measurements.
      - ee collisions: $m_t$ from threshold scan around $\sqrt{s} = 340$ GeV; $m_W$ from threshold scan for $W^+W^-$ production (leptonic decays);
      - ep collisions: $m_t$ from heavy-quark DIS (top-quark structure function measurements); $m_W$ from inclusive DIS (charged-current structure function measurements);
      - pp collisions: $m_t$ from $t\bar{t}$ production rates, multi-differential in $m_{t\bar{t}}, y_{t\bar{t}}$; $m_W$ from $p_T^\ell$ distributions.
- Inner structure of protons and nuclei
  - Longitudinal and transverse proton PDF$(x, Q^2)$: parton flavours, Bjorken-$x$ and $Q^2$ ranges for which new constraints and reduction of uncertainties are expected;
  - Longitudinal and transverse nuclear PDF$(x, Q^2)$; same as above;
- Hot and dense QCD
  - Heavy-flavour and quarkonium hadron production (rare states, kinematic coverage): expected novel access to low-cross-section open and hidden heavy-flavour hadrons, multi-differential observables (such as correlations), transverse momentum and rapidity ranges;
  - QGP transport coefficients (heavy quarks, jets): expected precision for observables that constrain the transport coefficients that characterise parton energy loss and heavy-quark interactions in the QGP;
  - QGP thermal radiation, sensitivity to temperature: expected precision for measurements of thermal radiation and parameters that map to the temperature of the hot and dense system formed in heavy-ion collisions at different centre-of-mass energies and regions of the QCD phase diagram;
- QCD connections with hadronic, nuclear and astro(particle) physics
  - Constraints on nature of exotic hadrons from spectroscopy and h-h correlations; expected measurements that can help understanding the structure of exotic heavy-flavour hadrons (e.g. compact tetraquark vs. hadron molecule), including direct measurements of yields, resonant states, kinematic distributions in different collision systems, and hadron-hadron momentum correlation functions that have sensitivity to bound states;
  - Precision on anti-nuclei production and absorption relevant for cosmic-ray physics: production of light anti-nuclei (e.g. $\bar{p}$, $\bar{d}$, $^3\bar{He}$) that constrain production processes and kinematic distributions in primary cosmic-ray interactions; annihilation cross sections for anti-nuclei on nuclei, relevant for the propagation of cosmic anti-nuclei in space (e.g. from Dark Matter decays);

# 2019 inputs on Strong Interaction

European Strategy for Particle Physics

**Category: Facilities and experiments with strong interactions as key topic**
(Id13) NA61++ (SPS)
(Id42) PBC@CERN, COMPASS++, MUSE@PSI, MUonE, DIRAC++, NA61++
(Id46) Heavy flavour in HI
(Id47 and Id67 and Id110) LHC-FT: ALICE and LHCb (LHCSpin)
(Id90) NA60+ (SPS)
(Id110) ALICE upgrade for HL-LHC
(Id135) QCD/HI at FCC-hh and FCC-eh
(Id143) COMPASS++/AMBER (SPS)
(Id152) QCD/HI at HL-LHC
(Id159) LHeC/PERLE
(Id160) QCD/HI at HE-LHC

**Category: Synergies on a global scale**
(Id76) J-PARC
(Id93) NICA
(Id99) US-based EIC

**Category: Facilities & experiments with strong interactions as a topic**
(Id13 and Id50) AWAKE
(Id49) Super Charm-Tau Factory

**Category: QCD results in support for other programs**
(Id117) Auger experiment
(Id131) LBNF/DUNE
(Id151) New physics with HI collisions

**Category: QCD theory in support**
(Id100 and Id101) Precise calculations @ colliders
(Id114) MC generators
(Id163) QCD theory

**Category: QCD and nuclear physics**
(Id39) ISOLDE/EPIC

**Category: National roadmaps**
(Id21) INFN Hadron
(Id37) Germany ALICE
(Id56) INFN HI
(Id115) Germany Hadron

**Category: Individual and community thoughts**
(Id48) Town meeting on Heavy Ions
(Id103) DIS
(Id140) personal input
(Id148) NuPECC