

Initial contribution of the INFN Hadron Physics Community to the ESPPU 2018–2020

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Abstract - INFN has a strong tradition in high-energy hadron physics, both in the heavy-ion sector and in the deep-inelastic-scattering sector, with important participation in international programmes, that also include relevant and specific contributions in terms of dedicated detectors. In this context, it is recognized that high centre-of-mass energy is a fundamental handle for the future investigation: at higher energy, wider and novel kinematical phase-space regions become reachable offering an enlarged panorama of complementary phenomenological views.

The high-energy opportunities in hadron physics of interest for the dedicated INFN community are considered. They include perspectives for further investigations with ALICE at the upgraded LHC complemented by measurements at SPS and novel opportunities with electron-ion colliders.

INFN has a **strong tradition in high-energy hadron physics**, the ideal approach towards a comprehensive understanding of QCD, one of the basic bricks for the consolidation of the Standard Model. Since the beginning, this tradition is been pursued by two diversified approaches, namely forming hot Quark-Gluon Plasma (QGP) matter in heavy-ion interactions and investigating the nucleon and nucleus structure by electromagnetic probes. All this is tested by the relevant and qualified INFN participation in the related physics programs: in CERN fixed-target heavy-ion experiments and in ALICE at CERN LHC on one side, in experiments at Desy HERA, in CERN experiments dedicated to Deep Inelastic Scattering (DIS), the most recent one being the COMPASS experiment, and in experiments at JLAB, on the other side. Moreover, numerous INFN theorists are dedicated to the related phenomenological studies. Globally, a community of more than 130 physicists, deeply inserted in the dedicated world-wide community, proud of the advancement in the field, clearly registered over the years in spite of the intrinsic complexity and enigmatic aspects of the QCD dynamics. This community is determined to continue the effort, This goal will be pursued by the continuation and extension of the on-going experimental programs within ALICE, COMPASS, fix-target heavy-ion experiments at CERN and experiments at JLab and by the exploitation of the physics potential at the future electron-ion colliders. In particular, high centre-of-mass energy is a fundamental handle for the future investigation: at higher energy, wider and novel kinematical phase-space regions become reachable offering an enlarged panorama of complementary phenomenological views. The high-energy opportunities in hadron physics of interest for the dedicated INFN community are considered in the following. It is worth emphasizing that the action lines supported by the INFN hadron physics community are in full agreement with the recommendations of the NuPPEC Long Range Plane 2017 [http://www.esf.org/fileadmin/user_upload/esf/Nupecc-LRP2017.pdf], where the nuclear physics Italian community actively contributed to the wide and deep process resulting in the document dedicated to the European perspectives in Nuclear Physics.

The study of the phase diagram of strongly-interacting matter with **heavy-ion collisions** can be experimentally pursued following two complementary directions depending on the energy regime. At the high-energy of LHC, where the high-temperature and low-baryon density region of the phase diagram is covered, the experiments will focus on high-precision measurements aiming to constraint the QGP properties and determine its equation of state and characteristic parameters. The new experiments at the low and intermediate energies of the SPS, NICA and FAIR facilities will instead explore the

region of the phase diagram characterized by moderate-to-high baryonic density in order to search for the onset of the transition to the deconfined state and for the critical endpoint.

The INFN community that is currently active in the field of ultra-relativistic heavy-ion collisions considers of primary interest and is strongly motivated to continue this study for the next 10-15 years, exploiting both collider and fixed-target experiments at the various accelerator facilities listed above. In particular, the INFN teams contribute to the ALICE experiment since its inception and plan to continue with renewed enthusiasm for the future programme. The ALICE detector will undergo a major upgrade during the LHC Long Shutdown 2 that will dramatically enhance the physics capabilities allowing a more precise characterization of the QGP.

The current status and the future perspectives of the heavy-ion physics programme with emphasis on the items of main interest for the INFN community are detailed in the dedicated document "Ultra-relativistic Heavy-Ion Collisions: Inputs of the Italian community for the ESPPU 2018–2020".

The physics cases of a very-high luminosity programme in the 2030s are also considered with great interest: at the LHC, also using intermediate-mass nuclei, with an experiment based on a low-mass, high-speed, all-Silicon tracker with particle identification capabilities, for high-precision measurements of heavy-flavour production and of soft electromagnetic and hadronic radiation, and at the SPS with the NA60+ project for a possible experiment targeting the search for the onset of deconfinement using dimuon measurements (details are presented to ESPPU 2018-2020 in a dedicated document: "Study of hard and electromagnetic processes at SPS energy: an investigation of the high μ_B region of the QCD phase diagram").

On a longer timescale, the INFN community is taking part into the ongoing studies for a heavy-ion programme at the Future Circular Collider or the High Energy LHC.

The future perspectives and physics potential in the investigation of the nucleon and nucleus structure with electromagnetic probe, often referred to as the **DIS sector**, is revised in a dedicated document being submitted to the ESPPU 2018-2020 [The "DIS and Related Subjects" Strategy Document: Fundamental Science from Lepton-Hadron Scattering]. Several electron-ion collider projects are proposed, the more mature ones being the U.S.-based Electron-Ion Collider (EIC) and the CERN-based LHeC. These projects have different parameters in term of centre-of-mass energy, ion species and polarization options, while they share high luminosity figures and the date of initial operation, namely around 10-12 years from now. The respective characteristic features make them highly complementary towards a complete investigation of the structure of the hadronic matter and in term of service information required for precise measurements at LHC. The INFN hadron physics community recognizes the unprecedented opportunities offered by the lepton-hadron collider projects and by their combined capabilities, the only possible approach towards the main scientific goals in the sector, recalled in the document mentioned above and concerning the spin and 3D structure of the hadrons, the interaction of the hadron components in fundamental

states and at high energy, the information required for precise measurements at hadron-hadron colliders and the direct searches of Beyond the Standard Model physics.

In this context, a large INFN community has expressed interest in contributing to the experiments at EIC. It is formed by experimentalists presently active in ALICE, COMPASS and experiments at JLab and operates in constructive dialog with INFN phenomenologists dedicated to hadron physics. In particular, the community is attracted by the specific opportunities offered by EIC, namely to understand the role of spin and flavor in the nucleons, to perform the first nucleon tomography and to explore the onset of novel emerging phenomena in nuclear matter, in particular the so-called gluon-saturation at small Bjorken- x . The INFN physicists are part of a larger European community believing that the QCD secrets can be revealed only via several and diversified approaches, where a main one could be provided by the EIC. Therefore, a document about the synergies between the EIC effort and the hadron and particle physics opportunities in Europe will also be submitted to ESPPU 2018-2020 [Synergies between a U.S.-based Electron-Ion Collider and the European research in Particle Physics].

Within INFN, the bottom-top interest towards the EIC has found favorable response from the Institute governance that supports the participation in EIC initiatives: a dedicated INFN activity is now approved, starting in 2019. Within this novel project, the convergence of the community presently active in the different research lines in a coherent contribution to the experiments at EIC is very natural and pursued with great determination.

Lastly, the long-standing know-how and expertise of the INFN teams in the field of **detector development and construction** will serve as a common basis for novel detectors and to conceive the experimental set-up of new experiments. In particular, for the future of hadron physics at high energies, the specific expertise in the sectors of high-spatial resolution and low-material silicon trackers, extended time-of-flights systems with extremely fine time resolution, electromagnetic calorimetry and in the field of hadron identification by Cherenkov imaging techniques is of the utmost relevance.

In **conclusion**, the conviction that the complete understanding of QCD is both possible by adequate investments and scientifically rewarding is strong within INFN, as tested by the perspective in the ultra-relativistic heavy-ion sector and at EIC of the researchers of the Institute.