1.3 Impact

The research in the field of the strong interaction addresses fundamental questions, such as the nature of confinement, the origin of exotic hadronic states and the properties of hot and dense nuclear matter. Those studies will have a deep impact on the searches beyond the standard model, in astrophysics and strongly coupled systems in particle and condensed matter physics.

STRONG-2020 is leading a coherent effort of theoretical and experimental groups complemented with challenging high-technology developments in instrumentation and industrial applications.

1.3.1 Impact on Low-Energy Frontier

The role of STRONG-2020 together with the European infrastructures is fundamental for tackling the long-standing puzzles in the low-energy frontier of the strong interaction, such as the proton radius puzzle and the neutron star puzzle. The low-energy frontier has a wide and ambitious program that involves VA-, JRA- and NA-projects. The embedment of the numerical ab-initio calculations of QCD on the lattice (LatticeQCD) with the European hadron community via NA-LatticeHadrons and JRA-HaSP will have a large impact on the precision computation of hadron spectroscopy and structure, hadrons under extreme conditions, hadrons in the standard model and beyond.

In this second reporting period, Lattice-QCD simulations continue to be combined with effective field theories to advance on the knowledge of hadronic observables, allowing precision spectroscopy of exotic and excited states, the treatment of states above thresholds in coupled-channel scattering analyses and the analysis of nuclear systems. JRA-HaSP has, on the other hand, made already an impact developing and applying effective field theories to quarkonia, exotic hadrons, hadronic transitions and decays, and hadrons in dense matter, confronting the precise theoretical calculations with experimental observables. This procedure will also allow precision test of the standard model with hadronic observables. JRA-PrecisionSM has improved the treatment of electro-weak box diagrams, which contribute to all SM-Tests involving weak interactions like in beta decay, V_{ud} and parity violating electron scattering. The JRA has collected the specifications from the community and defined the user interfaces for the dissemination of the theory results.

The two main puzzles to be addressed in the low-energy frontier, that is the proton radius puzzle and the neutron star puzzle, are still relevant, and further developments have been done during the second reporting period. Those include theoretical and experimental studies of the lightest hypernuclei, so as to give an answer to the hypertriton puzzle, as well as the analysis of bound strange-mesonic systems at AMADEUS and SIDDHARTINO, delivered by NA-THEIA.

As for the proton radius puzzle network, NA-PREN, only individual work on understanding and improving the knowledge of some systematic effects has been possible and has been published. A large convention of the community has so far been hindered by the COVID-19 crisis, and online meetings have been held during the second reporting period. However, an in-person meeting is planned for summer 2022.

Related to data analysis and acquisition, new systems such as mCBM and digital algorithms, are still being developed by NA-FAIRnet, so as to comply with the needs of PANDA and CBM experiments at FAIR, and they will have an impact to avoid bottlenecks at FAIR.

1.3.2 Impact on High-Energy Frontier

Through the first and second reporting periods, STRONG-2020 has had a profound impact on high-energy hadron physics, with a combination of Networks, Virtual Accesses and JRAs, involving the full community of experimentalists and theorists.

In the second reporting period, the Virtual Accesses have made tremendous progress, and they are already serving both the heavy-ion and the nucleon structure communities, allowing through their access, to develop programs at the forefront of research. This includes several multi-purpose codes at next-to-leading order dedicated to inclusive and associated quarkonia cross-sections, as well as nuclear parton distribution function effects. The two platforms developed through STRONG-2020 are unique in the world and years ahead of any other competitors. To only name a few of the key results, our virtual accesses have allowed the design and optimization of detectors for future experiments such as LHC in fixed target mode, EIC and Jefferson Lab in the US, etc. Moreover, our VAs have been at the cornerstone of more than 20 publications, and this number keeps growing steadily.

The impact of the Virtual Access to 3DPartons can be seen from the software libraries it supplies to the community. These libraries allow to apply theory corrections from strong force, to extract observables in the field of proton structure observables and to make fits to experimental observables. There is an increasing users' community of hadron physicists analyzing data from various CERN fixed target and collider experiments, from Jefferson Lab experiments, as well as preparing simulations for the future EIC accelerator facility at Brookhaven National Laboratory and preparing the EICC in China.

The development of a common Virtual access platform is central for this field in hadron physics. Examples are solvers for QCD evolution equations in order to evolve observables from one energy regime to another, or parton distribution functions for various ranges of the kinematic observables. The future physics programs for the electron-ion colliders EIC in the US and EICC in China rely heavily on the developments made accessible here.

STRONG-2020 gathers a large fraction of the community interested in the 3D-imaging of the nucleon in both momentum and position spaces, but also the quest for the understanding of the low-x gluon dominated sector. Its JRAs and NAs aim at creating, developing and stimulating the link between experiment and theory. They also aim at preparing for the next generation experiments, both in collision and fixed target modes, through theoretical progress, simulation and detector R&D.

Progress is striking during this second reporting period for data analysis in the 3D-imaging area (TMD-neXt, GPD-ACT), with many new published articles and associated phenomenological work supported by our 3D-Partons VA. The same can be said for the small-x domain with a remarkable number of theoretical and phenomenological publications in this reporting period. We can highlight that STRONG-2020 allowed for a release of a new set of nuclear parton distribution functions, which will be used for all experimental heavy-ion groups at CERN or at RHIC. Within the framework of STRONG-2020, the initiated activities led to strengthen exchanges within the community and to establish sustainable structures such as a new working group within the LHC Physics Center at CERN.

Research activities within STRONG-2020 have been instrumental in demonstrating the feasibility of a fixed target programme at the LHC, and even started its implementation. After establishing a reference for Jet-QGP dynamics, key jet substructure observables have been identified via machine learning techniques.

On the aspect of R&D, STRONG-2020 has been at the cornerstone of all studies made during this reporting period to design the future detectors for the fixed-target measurements, for both ALICE and LHCb at CERN, and for the American Electron-Ion Collider EIC. In that respect, the timing of STRONG-2020 is perfect and its impact is decisive for all current developments.

1.3.3 Impact on Instrumentation

The JRAs dedicated to instrumentation play a fundamental role in STRONG-2020, creating a thread between theoretical WPs and the activities carried out at the core facilities. These projects have two goals: they answer the scientific need for higher performance radiation detectors and hardware and, at the same time, they provide a connection with applications, technological advances and SMEs.

One of the main challenges in radiation detection is to increase the performances in term of event rate, resolution, dynamic energy range and efficiency. JRA-ASTRA, JRA-TIIMM and JRA-MPGD_HP aim at addressing these challenges, focusing on different radiation types and detection features. JRA-ASTRA will produce ultra-fast detector systems for high-precision gamma and x-ray events in a broad energy range. JRA-TIIMM will combine the MAPS (Monolithic Active Pixel Sensors) detecting technology with a high precision tracking and energy loss measurement to be used for PID. The goal of JRA-MPGD_HP is to develop a tracking and PID technique in high-intensity environments with TPCs, as well as a modular hybrid MPGD for single-photons detection (PID and timing) in harsh environments.

JRA-ASTRA built a first prototype made of CdZnTe both for low and high-energy photon, including the read-out electronics, and performed tests for characterizing the energy resolution. These detectors will be included in a setup installed at DAFNE to perform first test measurements under beam condition and to study kaonic atoms.
A second prototype was designed for the JRA-TIIMM on the basis of the knowledge gained by the characterization of the first prototype. The new detector has been submitted for fabrication in January 2022, and it should be delivered by the fall 2022. The data acquisition system for the new prototype is also under development.

MPGD_HP has done massive work, and all tasks are progressing well. The highlights include the design of prototype high-rate TPC and of a modular hybrid (Micromegas+ THGEM) Photon Detector prototype, a detailed investigation of the beam-induced noise, and the preliminary achievement of a time resolution below 40 ps for Micromegas-based Cherenkov photons detectors.

Innovations in detection concept, accuracy and efficiency carried out within these JRAs will find a large use in other fields, especially in medical applications, such as particle radiotherapy and diagnostics. In particular, the recent rise of flash radiotherapy as a very promising treatment against cancer calls for a new generation of detectors, which can perform an accurate beam monitoring at high rates.

The findings acquired within JRA-P3E, JRA-SPINFORFAIR, JRA-CRYOJET and JRA_CRYPTA are leading to the production of high-quality targets and polarized beams, which will be of great impact on activities in all experimental facilities of STRONG-2020. The use of polarization dependent observables requires full control of the polarization of polarized beams, polarized targets and the measurement of the polarization for both beam and target.

JRA-P3E goal is to optimize high-intensity polarized electron and positron beam sources, including a full design of the new Hydro-Møller polarimeter detector using high-voltage monolithic active pixel detectors (HV-MAPS). JRA-SPINFORFAIR will develop an efficient method for polarizing antiproton beams by in-situ build-up in a storage ring for the first time. JRA-CRYOJET addresses high quality cryogenically cooled target beam sources for applications in present and planned complex internal-target experiments. JRA_CRYPTA will produce polarized solid-state targets for MAMI, GSI/FAIR, ELSA and potentially CERN, combining the use of ultra-thin superconducting coils, high-temperature superconductors and the method of Dynamic Nuclear Polarization (DNP).

Following the extensive studies of positron production achieved within JRA-P3E, the polarized positron production was fully characterized and optimized for initial electron beam energies of interest at Jefferson Lab up to 1000 MeV. The Hydro-Møller simulation completed in the first year is being used to achieve a suitably high signal-to-background ratio for the detection of Møller electron pairs.

JRA_ SPINFORFAIR carried out several simulations with different filtering times and different beam life times to make an estimation for the longitudinal polarization buildup in a longitudinal spin-filtering experiment. Taking advantage of the first Siberian Snake commissioning, several progresses have been made in understanding the complex beam dynamics due to the presence of a high magnetic field. The missing two quadrants of the detector have also been assembled, while the electronics, the cooling system and the data acquisition have been adapted to the full detector scheme.

Monolithic copper cluster nozzles could be manufactured industrially for the first time with the full-required nozzle length in JRA-CRYOJET. The formation of hydrogen and argon cluster beams was investigated in great detail, and highest hydrogen cluster target thicknesses are now regularly available. New diagnostic tools for the investigation of droplet beam properties have been developed.

JRA_CRYPTA designed and built the dilution cryostat for future measurements of double polarization observables at the ELSA accelerator facility in Bonn. In 2022, a new "internal holding coil" has been designed for the new dilution cryostat. In order to test the coils already built, the construction of a new 4He evaporation refrigerator for systematic test measurements is being carried out. Additional simulations and investigations on the shielding behavior of the high-temperature superconductors in a cylindrical geometry have advanced.

The work of JRA-P3E will enable new type of experiments at present (MAMI, ELSA, Jefferson Lab) and future (EIC) electron beam facilities and allow for the measurement of new or largely improved polarization dependent observables. JRA_SPINFORFAIR will open a new window with antiproton beams for example at GSI/FAIR and CERN. At present, antiproton beams can be produced unpolarized only. The results of JRA_CRYOJET concern targets for stored ion beams, like they are used at COSY and GSI/FAIR. Good and reliable operation of high-density gas jet targets enable hadron physics experiments. JRA_CRYPTA has impact for experiments with polarized targets at the Bremsstrahlungs photon beams at ELSA, MAMI and Jefferson Lab. JRA_P3E, JRA_SPINFORFAIR, JRA_CRYPTA all have the common aim to get higher degrees of polarization. The accuracy of all polarization observables depends quadratically on the polarization. The effort to achieve higher degree of polarization pays off quadratically in saving most valuable beam time at all facilities.

The research performed within all JRAs have been published in high-impact journals and have been presented at international conferences. The delays caused by COVID-19 emergency should be absorbed within the project extension, and all groups have rearranged their activities accordingly. Several risks have realized, but all teams applied successful mitigation strategies.