1. Explanation of the work carried out by the beneficiaries and Overview of the progress

1.1 Objectives

The following part gives the descriptions of the objectives as fixed in the Description of the Action (DoA) and explains how the project has progressed towards these objectives during the first Reporting Period. The objectives are organized around the following three pillars: low- and high-energy frontier studies, and instrumentation as defined in the Grant Agreement (GA).

As stated in the GA, the objectives of this Action are to federate leading experimental and theoretical groups in EU in order to carry out new fundamental and applied research studies at the frontier of our current knowledge of the strong interaction, the force that binds together quarks and gluons and, ultimately, forms the visible baryon matter of our universe. The underlying quantum field theory that describes the strong interaction, quantum chromodynamics (QCD), has an extremely rich dynamical content (asymptotic freedom, confinement, approximate chiral symmetry, non-trivial vacuum topology…). This translates into a very diverse many-body phenomenology at various limits: at high temperatures the Quark-Gluon-Plasma (QGP), at large quark densities the colour superconductivity, at very low parton fractional momenta the colour glass condensate (CGC), etc. Also, many of the fundamental parameters of the Standard Model (SM) like the strong coupling constant, the quark masses, the matrix elements of the Cabibbo-Kobayashi-Maskawa mixing (CKM) are also directly connected to QCD. A good understanding of the interaction between light-, heavy-quarks, and gluons is crucial for searches of physics beyond the SM. The study of QCD is mostly carried out through electron-positron (e+e-), lepton-proton (e-p, mu-p), electron-nucleus (e-A), protonproton (p-p), antiproton-proton, proton-nucleus (p-A), antiproton-nucleus and nucleus-nucleus (A-A) collisions at low (<20 GeV) and high (>20 GeV) center-of-mass (c.m.) energies in world-class experimental facilities for which Transnational Access (TA) is requested.

The detailed progress towards concrete objectives of each thematic field achieved during the second Reporting Period is presented in the table below.

Table 1. Objectives and work performed during Reporting Period towards their achievement

Objective	Results
Low-Energy frontier	
JRA - Precision Tests of the Standard Model (PrecisionSM) Precise determination of the muon anomalous magnetic moment (g-2)μ; extraction	

of the CKM matrix element Vud from beta decay, and of the weak mixing angle from parity-violating electron scattering (PVES)	
NA - Proton Radius European Network (PREN) Address the “proton-radius puzzle” via combined data-theory analyses of new results in atomic spectroscopy and very-low momentum transfer (Q2) lepton-proton elastic scattering at various energies	
NA - LatticeHadrons (LatticeHadrons) Development of combined software, data sharing, and methodologies in lattice QCD theory across Europe for hadron spectroscopy and structure, hadrons under extreme conditions, hadrons in the SM and beyond, and novel numerical algorithms and computing for lattice hadron physics	
JRA-Light-and heavy-quark hadron spectroscopy (HaSP) Development of a common data-theory analysis framework to determine exotic hadrons properties by fitting new experimental data to lattice QCD and	

effective-field-theory predictions	
NA - QCD physics at GSI/FAIR (FAIRnet) Multi-prong improved data selection plus distributed physics analysis for rare signal events under high background conditions in anti-p-p, anti-p-A, and A-A collisions for the PANDA and CBM experiments at the future FAIR facility	
NA-Strange Hadrons and the Equation-of-State of Compact Stars (THEIA) Address the "neutron stars hyperon puzzle" through combined theoretical and experimental studies of (anti)hypernuclei and bound strange-meson systems produced in hadronic collisions at various c.m. energies	
High-Energy Frontier	
VA - Automated perturbative NLO calculations for heavy ions and quarkonia (NLOAccess) Extension of the MadGraph automated on-line code for the novel computation of perturbative QCD cross sections in high-energy hadronic collisions at next-	

to-leading-order accuracy, using meson and heavy-ion beams, and for quarkonia final-states.	
VA - Virtual Access to 3DPartons (3DPartons) Development of a new combined framework to extract generalized (GPDs) and transverse momentum-dependent (TMDs) parton distributions, with higher-order fixed and twist corrections, from fits to experimental e-p and p-p data	
JRA- Generalized Parton Distributions (GPD-ACT) Extraction of GPDs from new high-precision QCD analyses of novel high-statistics e-p and p-p measurements at fixed-target and collider energies.	
JRA - 3D structure of the nucleon in momentum space (TMD-neXt) Extraction of unpolarized and polarized TMDs and parton fragmentation functions (FFs) from new high-precision QCD analyses of novel high-statistics measurements at e+e-, e-p and p-p at fixed-target and collider energies.	

JRA - Challenges for next generation DIS facilities (next-DIS) Development of new Monte Carlo tools and studies of benchmark channels, for e-A collisions at future deep-inelastic experiments. Optimisation of associated detector designs for high-resolution tracking, vertexing, photon, and PID.	
NA - Small-x Physics at the LHC and future DIS experiments (Small-x) Extraction of high-precision nuclear parton distribution functions through global fits including the latest LHC p-A and A-A data. Extension of current gluon-saturation calculations to NLO accuracy with resummation corrections, for observables with three jets and with heavy-quarks. Calculation of multi-particle correlations issuing from initial-state PDF effects to separate them from final-state hydrodynamic effects in small systems	
JRA - Fixed Target Experiments at the LHC (FTE@LHC) Development of novel gas-target techniques to be able to carry out the most energetic fixed-target collisions ever performed in	

the laboratory, using the LHC beams at ALICE and LHCb. Evaluation of the novel expected constraints on PDFs at high-x in the proton and nucleus, parton spin dynamics, as well as QGP properties via unique quarkonia measurements.	
NA - Quark-Gluon-Plasma characterisation with jets (Jet-QGP) Development of novel experimental and theoretical techniques for jet physics in A-A collisions, providing a reference implementation of jet interactions in a QGP via a full heavy-ion Monte Carlo event generator. Definition of new observables and development of new tools with increased sensitivity to the physical mechanisms involved in jet-QGP interactions.	
NA - Quark-Gluon Plasma characterisation with heavy flavour probes (Hf-QGP) Extraction of QGP transport coefficients from new high-precision theoretical calculations and experimental measurements of the production of open and closed heavy flavour (HF) quarks in A-A collisions at the LHC. Accurate measurements of	

total c-cbar, b-bbar cross sections in p-p, p-A and A-A collisions. Development of a new data-theory interface to compare event-by-event experimental results to MC predictions	
JRA - Inter-experiment combination of heavy-ion measurements at the LHC (LHCCombine) Combination of key LHC (ALICE, ATLAS, CMS, LHCb) measurements in p-p, p-A, and/or A-A collisions to achieve high-precision constraints on nuclear PDFs, QGP properties, SM parameters, and/or searches of physics beyond the SM. Examples include gauge bosons and jets differential cross sections to constrain nPDF, light-by-light scattering to constrain new physics searches, open charm or bottom hadron cross sections to determine QGP transport coefficients	
Instrumentation	
JRA - Micropattern Gaseous Detectors for Hadron Physics (MPGD_HP) Development of new gas detectors with improved capabilities in tracking, charged particle identification, photon detection, and timing in the picosecond region, capable	

of operating under very high beam intensity conditions.	
JRA - Tracking and Ions Identifications with Minimal Material budget (TIIMM) Development of new silicon detectors based on Monolithic Active Pixel Sensors (MAPS) for high-precision tracking, and energy loss measurement for advanced particle identification.	
JRA - Advanced ultra-fast solid STate detectors for high precision RAdiation spectroscopy (ASTRA) Development of beyond state-of-art radiation detectors based on semiconductors able to perform high-precision measurements of X-ray and gamma-ray photons in different environments and conditions.	
JRA - Cryogenic Polarized Target Applications (CryPTA) Production of polarized nucleon targets (at the prototype level) using solid state materials combined with superconducting high-field magnets and the Dynamic Nuclear Polarization method.	
JRA - Cryogenically cooled particle streams from nano- to micrometer-	

size for internal targets at accelerators (CRYOJET) Development of cryogenically-cooled cluster/pellet/microjet sources to be used as targets in a variety of collision setups (storage ring experiments, electron accelerators, or laser-driven hadron accelerators).	
JRA - Spin for FAIR (SPINFORFAIR) Optimization of the polarization of protons and antiprotons beams and targets for the GSI/FAIR storage ring	
JRA - Polarized Electrons, Positrons and Polarimetry (P3E) Optimization of high-intensity polarized electron and positron beam sources, and full design of the Hydro-Møller polarimeter detector using high-voltage monolithic active pixel sensors (HV-MAPS).	