Work package number	19	Lead Beneficiary	Centre National de la Recherche Scientifique
Work package title		JRA1-Inter-experiment combination of heavy-ion measurements at the LHC (LHC-Combine)	
Participant number		1	
Short name of participant		CNRS	
Person-months per participant:		62	
Start month	1	End month	48

Objectives

The first (2010-12) and second (2016-18) runs of the Large Hadron Collider at CERN provide a wealth of results from heavy-ion collisions. With 25 times more energy, the quark-gluon plasma signatures observed at the Relativistic Heavy Ion Collider (jet quenching, collective flow…) are again observed, and new probes become accessible (reconstructed jets, b quark hadrons, electroweak bosons…). Surprisingly, LHC reveals that some of the features expected to arise from the quark-gluon plasma in nucleus-nucleus (AA) collisions are also observed in proton-nucleus (pA) and even in selected proton-proton (pp) collisions. The four large LHC collaborations, ALICE, ATLAS, CMS and LHCb, contribute to this programme with very different and complementary capabilities, both in terms of angular coverage and particle identification. Up to now, the collaborations worked very independently, in a healthy competition. We believe that the time has come to improve communication between the four collaborations in the heavy-ion field, and establish an LHC data-combination working group. These objectives can be split into two tasks: The animation of a common forum (task 1) to ensure a regular communication between the four collaborations; and cross-experiment combination work (task 2), such as detailed comparisons of techniques or optimized statistical combination of results, leading to common publications.

Task 2 will be split in different projects in the first months of the project, after a kick-off meeting leading to a roadmap (deliverable 1). The range of topics we want to span is as broad as possible. They will concern AA collisions, obviously, as well as pA and pp (both for references and high-multiplicity studies, with the experiments having very different bandwidth). Below are a few examples of actions we foresee, although there is no a priori restriction to the scope to be covered:

- **Constrain nuclear parton distribution function (nPDF)**: Combining the complementary measurements of electroweak bosons in pPb collisions, at mid (ATLAS, CMS) and forward (ALICE, LHCb) rapidities, as well as di-jet measurements, will provide the most precise constrains possible to nPDF modellers.
- **Light-by-light scattering**: An evidence (13 events leading to 4.4 sigmas), published in Nature by ATLAS, was based on 2015 PbPb collisions. Combined with CMS, it would be a discovery (>5 sigmas). With the 2018 data, more precision will be achieved and combining results will be key in reaching sensitivity to effects beyond the SM.
- **Open charm cross section**: Combining all measurements of hadrons containing charm quarks in the various acceptance of the LHC experiments will allow assessing the total charm cross section, as well as its dependencies on broad ranges of transverse momentum and rapidity, in pp, pPb and PbPb collisions. These are crucial ingredients to energy loss and charmonium regeneration models, providing key information to the charm quark dynamics and QGP properties. Same work will also be carried out for **open beauty**, though with lower precision because of limited statistics.
- **Quarkonia**: Another interesting example is the **charmonium** case, for which most of the expertise is based in Europe, with the four experiments having very complementary acceptances. Combination for both the high-precision J/ψ and the statistically challenging ψ(2S) would already provide better understanding of the balance of several effects on these complicated probes (dissociation, recombination, energy loss, etc.). This last example is likely to serve as a proof-of-principle early in the project (it is to be noted that ALICE and LHCb already have common public notes about the reference quarkonium cross sections in pp collisions). It also extends to **bottomonia** for which ALICE and CMS have results at different rapidities.

These are only examples of activities that are likely to lead to publications. We do not limit ourselves to combine and publish results, and other structuring actions are listed below.

This joint research activity is supported by more than 30 senior European researchers, essentially belonging to different institutions and spanning a large area of expertise in heavy-ion collisions (heavy flavours, jets, electroweak bosons, strangeness, correlations, ultra-peripheral collisions…). The majority of them are experimentalists belonging to the four LHC large collaboration: ALICE, ATLAS, CMS and LHCb. They are convinced that the end of run 2 should see the rise of a cross-experiment effort and are willing to contribute to LHC-Combine, in particular in participating to the kick-off meeting.

Description of work (where appropriate, broken down into tasks), lead partner and role of participants
Spokesperson: Raphaël Granier de Cassagnac

In order to start the activity, we ask for **one postdoctoral position per experiment,** for 12-18 months each (depending on the candidate salary and experience). We will supplement each of these 1-year positions with 2-year local funds. The postdoctoral fellows will thus spend continuously, during three years, a third of their time on cross-experiment projects, the two other third being used to convey work in their collaboration, possibly in link with their combination activities. Administered in local institutes, these four postdoc fellows will benefit from extended stays at CERN (or even be permanently there) for a better connection between them, and with the individual collaborations. We believe that this connection and commitment can only arise from a joint and focused source of funding, which H2020 is ideally positioned to provide. To optimize the topical coverage, we envision a single call for applicants, and will form a committee to find the best combination of four candidates. In order to raise the cross-experiment knowledge, we will encourage applicants to consider a change of collaboration. To maximise the reach of the activity, they will also be chosen in different areas of expertise. Ideally, this should determine by which institutions and advisors they will be administered (remembering they will be relatively independent and often at CERN). The postdoc fellows will be enrolled as early as possible (all during year 1), for at least three years, hence with a large overlap during the project.

Early 2019, right after the end of run 2, we will organize **a kick-off community gathering** at CERN, that will produce a road map (deliverable 1), answering the question: what do we foresee as common work on the run 2 data? The postdocs will then call for a **monthly LHC-Combine forum** to address the needs for common work, with the help of the community and of their advisors. They will invite to these meetings whoever is needed, relying on the solid base of participating institutes and people supporting this proposal, but also beyond. Once LHC-Combine actions are identified, we will find manpower to convey the relevant studies. These actions include comparative studies, combination of results with appropriate statistical methods, writing joint publications, etc. It is to be noted that, as in other combination working groups, the production of uncertainty correlation matrices between measurements coming from different experiments will be a substantial part of the work. The resulting unique and combined results will be useful for generator makers, phenomenologists and theorists. Depending on the observable, their advice will also be required. Our connections with several of them are well established and some already support strongly the current proposal.

The work will not be limited to actual combination of measurements. Comparing and discussing experimental methods in detail seem crucial to better understand experimental results. On the jet front, for instance, the methods to subtract the underlying event differ from an experiment to another, and a comparison leading to unifying (or sharing) the methods will be beneficial. Concerning correlations, comparing in detail the implementation of various methods (cumulants, scalar product, LYZ…) would also be interesting. Furthermore, the forum that we will initiate and animate has the potential to become a unique place of discussion between the four collaborations on heavy-ion topics, including comparison of methods, event selection, centrality or multiplicity definition, beam requests, etc. Consequently, these activities will naturally have an impact on the beam, trigger and analysis strategies for runs 3 (2021-23) and 4 (2026-29) of the LHC data taking. Ultimately, some of us would even like to explore the paradigm-shifting long-term idea of performing cross-collaboration analyses… By the end of the project, we wish to write **an outlook report paper** on the future of heavy-ion physics at the LHC for run 4 and beyond.

In all these processes, no collaboration internal rules will be violated. Discussions with the four management teams already occurred to ensure their support, and they will be consulted as soon as specific needs to share internal material or release official combined results as publications (or supplementary material) are identified. We expect that once started, LHC-Combine will continue beyond H2020, with the full support of the collaborations. Finally, LHC-Combine will have a crucial impact on the understanding of the medium created in heavy-ion collisions, as well as a structuring impact on the community.

Deliverables (brief description and month of delivery)
D19.1- Vivid forum, with a dedicated website with an agenda, list of meetings, archived talks, etc. This lively forum will evolve during the entire project, and even beyond. **(month 1)**
D19.2- Road map, after the kick-off meeting (milestone #1), a short document will list the possible topics of joint research on past data (run 1 and 2). Its release will follow shortly milestone #1 (**month 6)**
D19.3- Cross-experiment papers We would consider LHC-Combine as "successful" if we release typically one joint publication per postdoc, hence four on the duration of the project (for instance at month 12, 24, 36 and 48). By "joint" we mean implying at least two collaborations (**after month 12)**.
D19.4- Outlook report paper This document should summarize our work and conclusion. Based on a critical assessment of the four experiment capabilities, it should provide recommendations for run 4 and beyond in terms of beam requests, trigger strategies, data handling and sharing, etc. (**before month 48)**.