**Template NA**

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| **Work package number** | WP14 | **Start date** | 01/06/2019 |
| **Activity Type** | Networking activity | | |
| **Work package acronym** | NA3-Jet-QGP | | |
| **Work package title** | Quark-Gluon Plasma characterization with jets | | |

1. Work carried out and overview of progress
   1. **Project objectives**

*[Please give an overview of the project objectives for the third reporting period (June 2022 – July 2024), with regard to the overall objectives as described in the Annex 1 of the Grant Agreement and summarized below.]*

The aim of this Work Package is to establish a theory/phenomenology/inter-experiment working group, with synergies with related communities (most notably, machine learning/data science and high-energy pp physics) to develop and deploy novel experimental and theoretical techniques and tools for jet physics in heavy ion collisions and enhance the impact of the European groups in the worldwide heavy-ion jet programme.

The modification of QCD jets in the medium is the prime tool for the clarification of the microscopic structure and degrees of freedom of the QGP. Jets developing within the QGP probe its structure and dynamics at specific identifiable spatio-temporal and momentum scales.

* 1. **Progress made during the reporting period towards the objectives**

*[Please describe the progress made during the third reporting period in line with your Gantt chart and the project overall tasks as described in the Annex 1 of the Grant Agreement and summarized below.]*

***Table 1.2: Progress made during the reporting period towards objectives***

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| --- |
| ***Task 1: Reference implementation of jet-QGP dynamics in a full heavy-ion simulation. The participating theoretical groups have developed independent approaches that describe the various aspects of the relevant physics, using different starting points or approximations. To enable a productive discussion and compare the different approaches the working group will define and implement a common benchmark model of jet-QGP dynamics from which reference data-samples will be generated*** |
| This task was completed in the previous reporting period. The JEWEL event generator was selected as the reference model. |
| ***Task 2: Identification of jet substructure observables sensitive to specific scales/features of jet-QGP interaction*** |
| A broad set of 31 jet shape observables has been benchmarked using machine-learning methods. The results of the study have been published in *SciPost Phys.* 16 (2024) 1, 015. It was found that the full set of 31 observables consists of two or three main classes of observables and the most of the relevant information about jets can captured by selecting one observable from each class. While the first angularity moment *rz*SD and the groomed 2-subjettiness are found to be most sensitive to quenching effects, a few other observables, like the groomed number of constituents, higher angular moments and subjettiness measures, and the largest *k*T in softdrop declustering, have similar sensitivity. |

**1.3 Highlights of significant results**

*[Include an overview of the project results towards the objectives in line with the structure of the Annex 1 to the Grant Agreement*.*]*

Beside the result listed above, two other main results should be noted:

1. Energy-energy correlators are a set of novel jet observable that are particularly amenable to theoretical calculations and have recently raised a large interest in the community. We developed a calculation method to decrease the computation time needed for the evaluation of higher-order energy-energy correlators. A manuscript describing the method is available as a preprint ([arXiv:2406.08577](https://arxiv.org/abs/2406.08577)) and has been submitted for publication.
2. A discussion session at a recent workshop at the European Center for Nuclear Physics Theory (ECT\*) was dedicated to jet observables as part of the NA3 activities. A white paper summarizing the discussion and future directions has been released as a preprint: [arXiv:2409.03017](https://arxiv.org/abs/2409.03017).
3. Critical Implementation risks and mitigation actions

**2.1 Risk materialization**

*[Provide the information on the project risks described in Annex 1 to the Grant Agreement*.*]*

1. Lack of availability of computer resources for generation of reference data samples and survey of observables (low)

Whether the risk has materialized? (Yes/No) No

1. Delay on agreement on reference model (low)

Whether the risk has materialized? (Yes/No) No, decided to use an existing event generator: JEWEL

1. Delay on producing survey results (medium)

Whether the risk has materialized? (Yes/No) No. Publication of the survey results was in line with the original planning. The selected open access journal took longer than expected in identifying a suitable referee.

**2.2 Risk-mitigation measures applied**

*[Please indicate whether the risk-mitigation plan described in Annex 1 to the Grant Agreement and corresponding to the risk number was applied in the reporting period*.*]*

1. Application for computing time at high performance computing centers outside participating institutions

Whether the risk-mitigation plan was applied? (Yes/No) No

1. If no agreement reached, use existing Monte-Carlo event generator

Whether the risk-mitigation plan was applied? (Yes/No) No

1. Reduce scope of survey

Whether the risk-mitigation plan was applied? (Yes/No) No

**2.3 Comments/new risk-mitigation measures proposed**

*[Provide any significant comments on the risks encountered and the mitigation plan applied. Give any unforeseen risks encountered during the reporting period and not mentioned above*.*]*

The COVID-19 pandemic severely reduced the ability to hold in-person meetings during the peak activity period of the WG work. Whenever possible, meetings were held remotely as mitigation.

3. Deviations from Annex 1 (Description of Action) and Annex 2 (Estimated budget for Action) (if applicable)

**3.1 Deviations from planned objectives and tasks, and their impact on the progress of the work package**

*[Explain the reasons for deviations, the consequences and the proposed corrective actions.]*

As mentioned above, due to the COVID-19 pandemic, some of the planned workshops were changed to online meetings. The related part of the budget has been reallocated to WP32 (JRA14-MPGD\_HP), as specified in the amendment request (AMD-824093-77)

**3.2 Deviations between actual and planned person months**

*[Explain deviations between actual and planned person-months. If applicable, propose corrective actions.]*

The hiring of postdocs was shifted in time compared to the original planning. The full planned 12 postdoc-months at Nikhef were fully used with the contract later extended using external funding.

Only 21 postdoc-months, of the planned 24, were used at LIP due to departure of the postdoc to take an industry job. The 3 person\*month effort was carried out by the co-spokesperson (Guilherme Milhano) and, for some technical work, by PhD students supported by external grants.

1. Deliverables and milestones tables

**4.1 Deliverables**

*[Please list all the deliverables due in this reporting period, as indicated in Annex I.*

*Deliverables must also be accompanied by a short report (deliverable description and technical documentation, such as photo, list of publications, etc.), so that the European Commission has a record of their existence.]*

***Table 4.1 List of deliverables***

| **Deliverable No.** | **Deliverable name** | **Lead Beneficiary** | **Nature** | **Dissemination level[[1]](#footnote-1)** | **Delivery month from Annex I** | **Delivered**  **(yes/no)** | **Actual delivery month** | **Comments** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| D14.3 | Report on the survey of observables | 34 - Nikhef | Report | PU | 62 | Yes | 47 | Report submitted for publication in April 2023. |
| D14.4 | Analysis algorithms for  selected observables | 34 - Nikhef | Other | PU | 56 | Yes | 48 | The algorithms were released together with the data. |
| D14.5 | Final report | 34 – Nikhef | Report | PU | 62 | Yes | 62 |  |

*In case a deliverable has been delivered in the reporting period and a report exists in the Participant Portal, you can indicate “uploaded report” in correspondence of a deliverable*

**4.2 Milestones**

*[Please complete the table if milestones are specified in Annex I.*

*Milestones will be assessed against specific criteria and performance indicators as defined in Annex I.]*

***Table 4.2 List of milestones***

| **Milestone number** | **Milestone name** | **Lead beneficiary** | **Delivery month from Annex I** | **Delivered**  **(yes/no)** | **Actual delivery month** | **Comments** |
| --- | --- | --- | --- | --- | --- | --- |
| MS16 | Delivery of D14.3 | 39 - LIP | 62 | Yes | 47 |  |

**4.3 Deliverable Reports**

*[Please provide, per each deliverable listed in Table 4.1, a brief description, including if possible some technical documentation (photos, list of publications, etc.). Use as many pages as needed per each report.]*

D14.3 - Report on the survey of observables

The report on the survey of observables was published in SciPost Phys. 16 (2024) 1, 015 (doi: 10.21468/SciPostPhys.16.1.015) in open access.

We reproduce here the abstract for context:

“We present a survey of a comprehensive set of jet substructure observables commonly used to study the modifications of jets resulting from interactions with the Quark Gluon Plasma in Heavy Ion Collisions. The JEWEL event generator is used to produce simulated samples of quenched and unquenched jets. Three distinct analyses using Machine Learning techniques on the jet substructure observables have been performed to identify both linear and non-linear relations between the observables, and to distinguish the Quenched and Unquenched jet samples. We find that most of the observables are highly correlated, and that their information content can be captured by a small set of observables. We also find that the correlations between observables are resilient to quenching effects and that specific pairs of observables exhaust the full sensitivity to quenching effects. The code, the datasets, and instructions on how to reproduce this work are also provided.”

D14.4 - Analysis algorithms for selected observables

The full analysis algorithms supporting the work summarized in SciPost Phys. 16 (2024) 1, 015 (doi: 10.21468/SciPostPhys.16.1.015) together with a full ‘User manual’ were released publicly, under the terms of the MIT license, on the GitLab platform:

<https://gitlab.com/lip_ml/jet-substructure-observables-ml-analysis>

This software can be freely modified by users as to be extended to cases not covered in the publication.

1. PU = Public

   PP = Restricted to other programme participants (including the Commission Services).

   RE = Restricted to a group specified by the consortium (including the Commission Services).

   CO = Confidential, only for members of the consortium (including the Commission Services). [↑](#footnote-ref-1)