To: Steering Committee, Project prepared for HORIZON-INFRA-2025-01-SERV-03

To be presented in person in Nantes between July 1st and 3rd, 2025, to the global project preparation meeting.

Letter of intent for Working Package **Hadron Enigmas: Quantum Budgeting and Appraisal**

Acronym: **HEQUBA**

**Project leaders:** (Two to four to be voted/drafted at random once a team is formed).

**1. Research objectives** (classified as per the template from the steering committee).

- **Short-term R&D, Theory and phenomenology**

We intend to find, improve, and classify algorithms that prepare the Hadron Physics community for any advances in Quantum Computing, which help address the following enigmas in hadron physics that cannot, at present, be treated from first principles in full:

a) Computation of observables related to time-evolved operators such as Fragmentation Functions, Transverse Momentum Distributions, etc. Quantum computing is a natural tool here as one can encode the Hamiltonian and advance in real-time (canonical or light front) steps.
b) Properties of hadron matter at finite density (in particular, the Equation of State in neutron stars, but perhaps also transport coefficients) because the statistical physics formulation with a chemical potential has no sign problem on a quantum computer, unlike in lattice gauge theory.
c) More generally, systems out of equilibrium, such as those found in heavy-ion collisions or Nuclear Matter, where again the ability to discretize and step in real time allows one to naturally access correlators at different times.

We will appraise the computational cost of these algorithms by running demonstration pieces in the existing and upcoming quantum computers and budget the requirements of our field to set benchmarks for when quantum computing will become a useful and predictive tool.

- **Computing, AI technologies**

The project would center on facilitating the preparation of algorithms and programs of interest for our field for quantum computing platforms, for researchers in our group and across hadron physics.

- **Applications and links with industry**

The services of industry leaders in cloud-provided quantum computing will be sought and if necessary, monetarily compensated on a per use basis.

- **Training (users' training and support activities)**

The two networked meetings will focus on training hadron physicists who may be considering joining quantum computing activities, also outside the institutions proposed here. They will be implemented as sections of (or collocated) with other major conferences in the field, both to avoid multiplication of events as well as to maximize exposure outside the already informed community, to increase the impact of the initiative.

**2. Transnational Access infrastructures (TAs), Virtual Access projects (VAs)**

The subproject includes the collaboration of CERN, through the Theory department and the Quantum Initiative, and the ECT*, both TAs and centers of interest for smaller institutions with research lines in theoretical physics and phenomenology. It is in parallel to other WPs that will be presented with the collaboration of these centers, but it is specifically focused on aspects of Quantum Computing for Hadron Physics and Chromodynamics.

An important focus is the facilitation of Virtual Access to Cloud Computing Services providing Quantum Computing capability, with the following actions in mind:

- To assist experienced hadron scientists who have not worked on Quantum Computing before to effectively learn to use the available platforms and prepare their first demonstration codes so their groups become adept at minimum Quantum Computing.
- To provide scientists at smaller institutions with the expertise and the capability to develop algorithms and access those platforms so as to bring talent to the field wherever it may be found in the EU and countries associated with its research programs.

### 3. Estimated budget request

200k euro in **personnel** costs (as payment or copayment to the institution hosting the postdoctoral researcher of the working package, who will take the role of research enabler for other participants and interested parties)
50k euro in **travel and networking** costs (as copayments to organize the two activity workshops and also to facilitate the travel of group members to the overall grant-reporting meetings of the project).
20k euro in **hardware** costs (to complement local infrastructure with small additions that facilitate the proposed networking and access activities, or small-scale simulations)
30k in **external** provision of cloud **computing** services (to purchase demonstration time from quantum computing providers for the various institutions participating in the subproject)

**300k euro total** (3% of the overall grant)

### 4. Participating and partner institutions

Initial members (in alphabetical order of institution's legal name). We are open to further additions with a corresponding increase in networking costs. PhD students and other junior personnel not listed.

| Institution | Geographical location | Contact members | Additional collaborators |
|---|---|---|---|
| Conseil Européen pour la Recherche Nucléaire CERN | Geneva, Switzerland | Sofia Vallecorsa | Enrique Rico Ortega, Joachim Kopp |
| Deutsches Elektron Synchrotron | Zeuthen, Germany | Stefan Kühn | Karl Jansen |
| European Center for Theoretical Nuclear Physics and Related Areas ECT* and U. Trento | Trento, Italy | Alessandro Roggero | Daniele Binosi |
| Instituto Superior Técnico (of the University of Lisbon) | Lisbon, Portugal | Joao Seixas | Yasser Omar (pending) |
| Laboratoire de physique des deux infinis Irène Joliot-Curie (IJCLab), Paris-Saclay University | Orsay, France | Denis Lacroix | |
| Universidad Complutense de Madrid | Madrid, Spain | Felipe J. Llanes Estrada | Pia Zurita |
| Universidad de Granada | Granada, Spain | María Gómez Rocha | Juan Carlos Criado, Lorenzo Luis Salcedo |