**Title:** **AI/ML-based Optimisation Services for Detector Ensembles in Hadron Physics Experiments**

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### **1. Research objectives**

Hadron physics experiments often rely on the combined performance of multiple detector systems operating in parallel. At GSI, and similarly in other laboratories, numerous detector technologies are currently tested in beam lines ahead of their full deployment at FAIR (Facility for Antiproton and Ion Research). Traditionally, each detector is optimised individually during beam time. However, this approach does not fully account for the combined performance of detector ensembles, where factors such as geometry, relative positioning, shared passive materials, and overlapping beam exposure can significantly influence the overall system behaviour.

We propose the development of an AI/ML-powered optimisation framework that transforms how detector ensembles are designed, tuned, and deployed in beamlines for hadron physics. The goal is to provide experimental users with a service that allows them to evaluate and optimise ensemble configurations in advance, based on real detector descriptors and beam conditions.

The core idea is to move from empirical tuning toward a predictive and service-based model that integrates multiple detector responses into high-dimensional performance maps. This enables data-driven optimisation of ensemble configurations for specific physics goals, such as particle identification, hadron/electron separation, timing, and spatial resolution, under different beam energies and intensities.

The proposed system operates in two main phases:

**Descriptor Encoding and Mapping:** Using AI/ML techniques, individual detector characteristics (such as geometry, material layers, resolution, response functions) are encoded into an ensemble description. These are then mapped into a high-dimensional parameter space that captures both the beamline phase space and the spatial-temporal interactions of the detector setup. This mapping acts as a surrogate model for ensemble performance.

**Optimisation and User Guidance:** Based on the generated performance maps, an optimisation engine searches for configurations that maximise figures of merit (FOMs) relevant to the experiment. These may include signal-to-noise ratio, detection efficiency, or separation power, depending on user-defined physics goals.

The first use case will focus on an ensemble composed of three established detector types: silicon-based trackers, micro-pattern gas detectors (MPGDs), and drift tubes, each originally developed for different experimental applications. Their combination forms a realistic prototype scenario to demonstrate the generalisability of the method. A second application area will address calorimeter systems, where AI/ML will be used to optimise energy flow mapping and segmentation strategies in sampling calorimeters.

### **2. Connection to Transnational Access infrastructures (TAs) and/or Virtual Access projects (VAs)**

This effort directly contributes to enhancing user services at GSI/FAIR, one of the pre-selected infrastructures under the INFRASERV call. The envisioned system will be implemented as a virtual access service, enabling experimental users to remotely:

* Pre-configure and simulate detector ensembles before beam time
* Explore performance trade-offs across a range of beam conditions
* Receive guidance on optimal placement and combination of detector systems

Such capabilities are expected to significantly reduce beamline setup times, increase the efficiency of data-taking periods, and improve the quality and reproducibility of results for hadron physics experiments. In addition, the service can serve as a training tool for new users, helping them understand the complex interplay between detector configuration and physics performance.

### **3. Estimated budget request**

We request funding to support two full-time PhD positions (TVöD E13 equivalent) and partial senior staff involvement (estimated at 40% of a full-time position) over a period of three years. The two PhD researchers may be hired simultaneously or with staggered timelines to ensure continuity and overlap during development, integration, and experimental validation phases.

In addition, we request travel support to cover participation in collaboration meetings, workshops, and international conferences. This includes two national (Germany-based) trips and one international (European) trip annually for each PhD student, as well as for the project leader.

A modest budget (~€10,000) is foreseen to cover materials and operational expenses during beam time, including detector operation logistics and data transfers to GSI’s computing infrastructure (Green Cube). All required hardware, including detectors and computing access (e.g., GPU servers), will be provided by GSI.

Taking into account institutional overheads at a standard rate (1.27 factor), the total estimated budget request amounts to approximately **€550,000** over three years.

### **4. Participating and partner institutions**

* GSI Helmholtzzentrum für Schwerionenforschung (Germany)