Letter of Intent
Virtual Access for Partial Wave Analysis (VA-PWA)

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1 Research Objectives

Physical background

The study of exclusive hadronic processes is of great importance in flavor physics, particularly for elucidating CP violation and for quantifying hadronic contributions crucial for precision measurements. The exploration of hadronic multi-body processes often relies on disentangling contributions of subchannel resonances, detailed by hadron spectroscopy. The field itself remains vibrant, rich with complex phenomena and a significant rate of new discoveries.

A primary analytical tool in this domain is the partial-wave expansion of decay matrix elements. Partial-Wave Analysis (PWA) decomposes complex decays into a set of cascades of two-body transitions, exploiting the fact that the spin and parity quantum numbers of intermediate states are unambiguously and model-independently determined by the angular distributions of the decay products. This technique stands as a cornerstone of modern hadron physics, as it offers the only reliable method for disentangling overlapping hadronic resonances. Its application, however, remains a highly non-trivial undertaking.

Recent collaborative efforts by research groups in Bonn and Bochum [1] have achieved a significant milestone by establishing a consistent and comprehensive framework within the helicity formalism for describing hadronic systems of arbitrary complexity. This technical advancement extends beyond previously tractable analytic cases, such as two-body and three-body systems, by proposing, implementing, and validating a numerical algorithm applicable to the most general exclusive decays. Furthermore, this development has unified various widely-used branches of the helicity formalism, including plain and canonical representations, and reconciled different phase conventions.

The platform project

We propose to lower entry barriers for amplitude analysis by developing a user-friendly, web-based platform. This platform will allow users to construct and manipulate amplitudes for arbitrary decay processes and generate executable code for amplitude evaluation for various established frameworks. The interface will guide users through the construction process, with real-time setup validation. Decay chains are defined by specifying initial and final states and inserting appropriate resonances. Configurations can be exported in human- and machine-readable formats for reproducibility and downstream integration. Integration with the Particle Data Group (PDG) API provides access to particle and resonance data, including their quantum numbers.

The backend architecture is designed for on-demand code generation, initially for Python. We also plan to support the existing `Julia` ecosystem and `C++` routines. Comprehensive documentation will detail procedures for integrating further custom analysis frameworks, using a standardized intermediate format for broad applicability.

A functional prototype of the platform, shown in Fig. 1, with essential backend capabilities, is accessible online. The prototype allows users to generate valid and executable amplitude code in Python. However, it currently operates on limited infrastructure (a free-tier of the hosting platform *Render*), and substantial development is needed for production readiness.

While a single, universal framework is unlikely to emerge in the community, easy access to a tested and well-documented portal will aid in benchmarking new tools. The platform will

[1] `https://doi.org/10.1103/PhysRevD.111.056015`

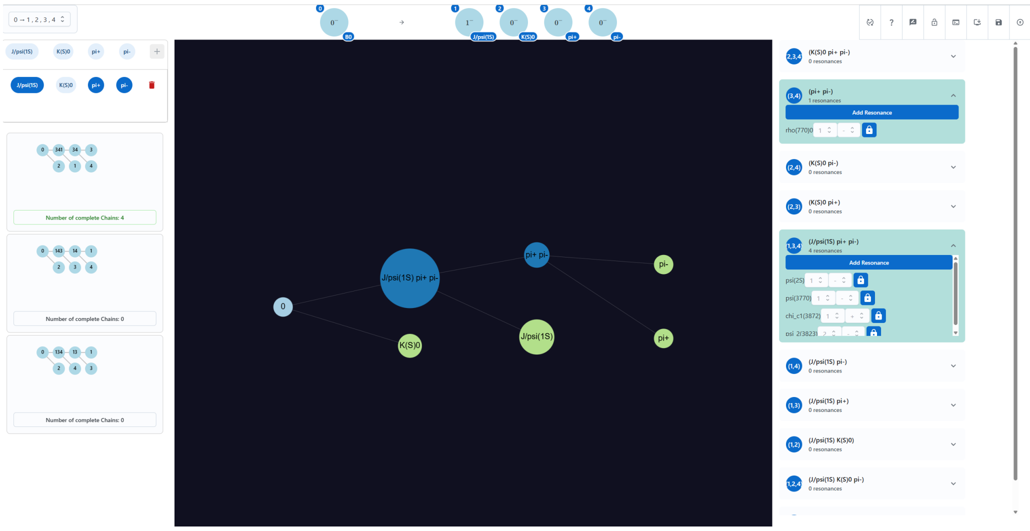

Figure 1: Screenshot of the VA-PWA prototype interface currently hosted at `https://kaihabermann.github.io/DecaySelector/`.

also democratize domain-specific knowledge, benefiting researchers and providing a resource for training language models and future AI assistants.

2 Connection to TA and VA infrastructures

This project directly supports research at prominent European Access infrastructures. A primary focus is on experiments at CERN, with particular relevance to the LHCb experiment, a leading facility for amplitude analyses. The project proponents are active members of the LHCb collaboration. MM is also a hadron group coordinator of COMPASS, which is at the forefront of partial wave analysis in light-meson hadronic systems. Being simple to use, the proposed platform will also facilitate cross-validation between tooling and methodology for light-baryon spectroscopy (A2 at MAMI, CB at ELSA), which traditionally uses alternative PWA techniques. It will help experimental efforts that are ramping up their advanced analysis activities, such as GlueX at JLab and QCD@FAIR. We estimate a direct user base exceeding 100 active analysts across current experiments, a number expected to grow with the next generation of researchers and students.

Open data initiatives are an increasingly vital component of modern scientific endeavors, strongly advocated by the particle physics community and CERN. Notably, members of the Bonn group have been heavily involved in advancing open data practices for LHCb. This project will significantly benefit from the experience and best practices established through these efforts.

3 Estimated budget request

Resources are required for polishing, deployment, maintenance, and community engagement:

- **4 trainings + 4 hackathons:** €40,000 / 4 years
- **Student assistant (10% FTE):** €30,000 / 4 years
- **Travel Budget for 4 years:** €20,000 / 4 years

4 Participating and Partner Institutions

University of Bonn, Germany: **Sebastian Neubert**, **Kai Habermann**; Ruhr University Bochum, Germany: **Mikhail Mikhasenko**