Joint Physics Analysis Center (JPAC)

(Dated: November 13, 2022)

The ten-year review of JPAC is scheduled to take place on Nov. 17-18, 2022. The review committee has been selected from experts in the international QCD and hadron physics community, both from theory and experiment. Members of the committee are: Ian Cloët (th), Annalisa D'Angelo (exp), Abhey Deshpande (exp, Chair), Christoph Hanhart (th), Mike Peardon (th), Tomasz Skwarnicki (exp), and Justin Stevens (exp).

I. INTRODUCTION: BRIEF HISTORY OF JPAC

Operations of the Joint Physics Analysis Center (JPAC) began in the Fall of 2013, preceding the start of the JLab12 program. The mission of the center was to develop an effort that would improve existing methods for the analysis and interpretation of spectroscopy data with focus on the JLab12 physics [1].

The center was originally scheduled to operate for ten years and to be reviewed periodically. In the summary of the the three-year review the committee concluded: "The original concept for the Center was formulated by M. Pennington, while its implementation has been carried out by A. Szczepaniak. These two scientists have done an exemplary job of implementing this center with the very effective day-to-day management by A. Szczepaniak, which has also expanded the original idea to interactions with experiments beyond Jefferson Lab". The charge and the full report can be found in [2].

In the years to follow JPAC continued delivering on its mission. Because of the covid pandemic, however, the subsequent review scheduled for 2020 was canceled. Now, as the official JPAC operation is approaching to the end of the planned ten years, JLab management asked the committee to review JPAC's accomplishments, its value to JLab's spectroscopy program, and its vision for the future, and to make recommendations for further improving JPAC's role in supporting JLab's science program.

II. COLLABORATION STRUCTURE

Originally, the JPAC research activity was carried out by two postdoctoral associates hired by the JLab Theory Center, César Fernández-Ramírez (now at UNAM, Mexico City, Mexico) and Igor Danilkin (now at JGU, Mainz, Germany), and by a postdoctoral associate at Indiana University, Vincent Mathieu (now at UB, Barcelona, Spain). After almost ten years of operations, JPAC has grown to become an international collaboration that involves students, at the undergraduate and graduate levels, as well as senior researchers. There is no formal rule for membership, decisions are made on a consensus basis. There are two different levels of membership. Full members participate in all the activities of the group. They are expected to lead projects and contribute to the discussion of other works during the weekly meetings. There is an internal review process for publication. Affiliated members join specifically to collaborate on a project. This possibility was meant to ease the collaboration with other groups, and in particular with students. This status also works for former members that devote most of their time to other research lines, but are interested in maintaining a common project sporadically. Currently, JPAC has 16 full and 9 affiliated members, with over 30 students and researchers being affiliated with JPAC at some point in time during the past ten years.

III. SUMMARY OF ACCOMPLISHMENTS

Members cover a wide range of expertise: scattering theory, QCD phenomenology, data analysis, and computer science. While most members have a background in theory, some researchers work or have worked as experimentalists. This mix improves the quality of the analysis and facilitates the communication of results and vision to the experimental collaborations, as well as to the rest of the theory community.

The primary mission is to develop amplitudes that describe GlueX and CLAS reactions and work with the experimental collaborations to implement them in their data analyses. This has indeed happened: JPAC members have contributed to the majority of GlueX publications and to a few CLAS analyses, in particular related to single meson photoproduction. Currently, one of JPAC's most important efforts is to develop the reaction theory for the photoproduction of meson pairs in the single- and double-fragmentation region. The former is in the kinematics where hybrid mesons are produced. One of the successes of JPAC was the resolution of a longstanding puzzle about the apparent existence of two hybrid candidates close in mass, while only one was expected from theory [3]. The reanalysis of COMPASS $\eta^{(\prime)}\pi$ dataset, with a refined amplitude model and a proper statistical analysis, yields to the confirmation of a single candidate, reconciling theoretical expectations with the experimental observation. The double-fragmentation region, where the two-meson invariant mass is large, must be studied in order to put further analytic constraints on the partial wave analysis leading to resonance extraction. The technique has been studied extensively for the single meson case, and implications for partial wave analyses have been discussed in [4]. Preliminary studies have been performed at COMPASS datasets, where the high energy pion beam simplifies the framework [5], and are currently being extended to GlueX kinematics.

The expertise channeled through JPAC extends beyond JLab. Members of JPAC are involved with major international experimental efforts, including BaBar, BESIII, COMPASS, and LHCb, with formal collaborative agreements. JPAC has studied several reactions where exotic $XYZP$ candidates are observed, with an effort that aims at minimizing model bias as much as possible. As an example of contribution to the worldwide spectroscopy effort, we mention the study of three body interactions and in particular JPAC's work on developing a general spin formalism for Dalitz plot analyses [6], which has been used in recent LHCb analyses [7]. Furthermore, two JPAC members are also part of the HadSpec collaboration. There is indeed a close collaboration between JPAC and finite volume experts [8–12]. The physics results produced by JPAC have recently been summarized in a review paper [13].

The importance of JPAC in the spectroscopy community is affirmed by a strong presence in conferences [14] and in conference organization [15]. JPAC members have (co-)organized over 30 international conferences and workshops, including its "own" series: four editions of Future Directions in Spectroscopy Analysis (FDSA). Over the years JPAC served as a liaison between many theoretical and experimental analysis efforts and fostered multiple discussions between both communities. Through the organization of Summer Schools [16], graduate courses [17], mentoring and outreach activities [18], it has broadly contributed to training and education in the area of hadron physics and QCD. In 2021 during the covid pandemic JPAC members co-organized the virtual National Nuclear Physics Summer School [19].

IV. MENTORING AND CAREER DEVELOPMENT

JPAC has developed an inclusive approach to bringing new ideas and methodologies and integrating them into practical approaches to data analysis. A key contribution of JPAC is to the culture change: it helped the community to appreciate the complexity of the problems involved and the need for interactions between basic theory, data science, and experimental efforts. As a consequence, solid physics outputs are being produced, and the time-consuming work on complicated projects has been recognized. This is especially important for junior researchers when applying for permanent positions. The list of specific achievements can be found on the JPAC website [20].

The first three JPAC postdocs (Igor Danilkin, César Fernández Ramírez, Vincent Mathieu) now hold permanent positions. Through the years more researchers have joined this effort and have developed their careers in close relation to JPAC objectives. Among them, Alessandro Pilloni is currently a tenure-track Assistant Professor at the University of Messina, Arkaitz Rodas is Nathan Isgur Fellow at Jefferson Lab, Sergi Gonzàlez-Solís is Director's Fellow at Los Alamos National Lab, and Miguel Albaladejo holds a Senior Postdoc Fellowship at Instituto de Física Corpuscular in Valencia. During the last ten years, eight PhD students, whose theses were done under JPAC supervision or in close collaboration with it, have successfully graduated. The detailed career development of JPAC members can be found at [21].

V. VISION FOR THE FUTURE

Capitalizing on the success of the program, its achievements and expertise, we propose to extend JPAC operations for another decade. It is necessary to keep working together on developing ideas for future experimental measurements and to investigate a novel bottom-up approach, based on data science. In particular, the main JLab12 spectroscopy experiments, GlueX and CLAS, have reached maturity, and major results are expected shortly. It is especially relevant to support these programs. In the future, both the EIC and a possible upgraded Jefferson Lab open a new window of future opportunities for the study of the $XYZP$ states in photo- and electroproduction, for which theoretical developments are required. The spectroscopy program entered the EIC yellow report [22], mostly because of JPAC impulse. Furthermore, as explained above, JPAC already shares efforts with the major international experiments active in spectroscopy. These collaborations, and possibly new ones, will continue and intensify in the next decade.

Specifically, the physics goals to be accomplished in the next 10 years involve:

- Complete development of the tools and techniques necessary to extract physics results from the GlueX and CLAS experiments. Work with the experimental collaborations on implementation of these tools in data analyses.

- Develop a broad program of $XYZP$ studies relevant to the current measurements at accelerators and the future electron-hadron facilities, including the EIC and the upgraded Jefferson Lab.

- Explore AI/ML tools, and make use of their properties as universal interpolators, model selectors and efficient spanners of parameter space, with the ultimate goal of extracting amplitudes from data. Interaction with the A(I)DAPT program at JLab has already started.

- Support the growth of the QCD spectroscopy community by investing in the education of next generations. Lead the development of distributed, project-based learning platforms for students.

The projects outlined above are the major future goals of the JPAC collaboration. However, JPAC is also contributing to a broader program. This includes providing inputs to shape future experiments. We already mentioned the effort in realizing a spectroscopy program at the EIC and at the upgraded Jefferson Lab. Furthermore, proposed experiments at JLab have requested active collaboration with JPAC, like the K-long Facility (KLF). JPAC has been successfully in crossing the boundaries between the nuclear and particle physics community, for example, through its contribution to the Snowmass Planning Process [23].

JPAC was built on the principle of inclusiveness. Therefore, we envision expanding the role of the collaboration to become a hub for the broad hadron spectroscopy activity. This would be accomplished by establishing a regular workshop and visitors program, as well as providing the required administrative support.

In conclusion, in a era of high statistics spectroscopy experiments, new theoretical tools are needed to match the quality of the data. The JPAC collaboration plays a crucial role in bridging the cultural gap between the theory and experiment communities, by developing and implementing the appropriate methods in amplitude and data analysis. In the future, JPAC will keep playing a pivotal role in the quest for understanding the hadron spectrum.

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