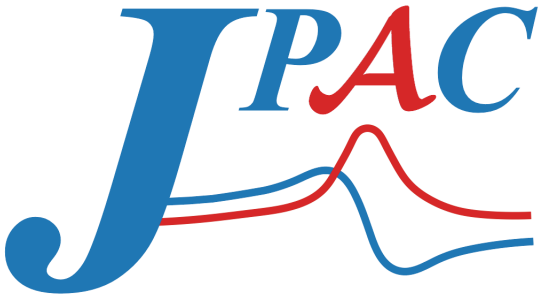
The JPAC User's Manual



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Chapter 1

Overview

The JPAC Collaboration was formed in 2013 by Mike Pennington, originally to provide theory support to the most delicate spectroscopy analyses at Jefferson Lab. Initially known as the Jefferson Lab Physics Analysis Center, the increased collaboration with other institutions has led to the reinterpretation of JPAC as the Joint Physics Analysis Center.

Originally, the JPAC research activity was carried out by two postdoctoral associates hired by the Jefferson Lab Theory Center, César Fernández-Ramírez and Igor Danilkin and a postdoctoral associate at Indiana University, Vincent Mathieu, all under the supervision of Adam Szczepaniak. After almost ten years of operation, JPAC has grown to become an diverse international collaboration between researchers from America, Europe and Asia.

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 group has a strong record of interactions with experiments. In particular, JPAC members have contributed to analyses by BaBar, BESIII, CLAS, COMPASS, GlueX, and LHCb, and to several proposals of future spectroscopy experiments and facilities.

At JPAC, we are interested in understanding quantum chromodynamics (QCD), the theory of the strong force in the low-energy regime, where perturbative techniques are not appropriate. Given the Lagrangian (or, equivalently the Hamiltonian) of a quantum mechanical system, arguably the most fundamental question one can ask is "what is the spectrum?". At JPAC, we are primarily concerned with answering this question. However, unlike simple quantum mechanical systems, little progress has been made in the calculation of exact analytical solutions of QCD. In the absence of exact amplitudes, a combination of phenomenological models and general theoretical constraints must be used to make predictions for these observables. It is important to note that the spectrum cannot be interrogated directly, but must be inferred from particle scattering experiments, which form the basic experimental observables of almost all hadronic physics. It is these experimental observables which JPAC seeks to describe with a variety of theoretical techniques. These techniques may be separated into two complementary approaches: 'top-down' and 'bottom-up'. In the top-down approach, practitioners use phenomenological models and effective field theories to provide predictions for the scattering amplitudes, which may be compared with experimental observables. Conversely, one can write ansätze for the amplitudes that respect general constraints like unitarity and fit unconstrained parameters directly to experimental data. In this way the bottom-up approach 'lets the data decide'. Broadly speaking, this second approach may also be known as *amplitude analysis* or the *S-matrix approach*, and can be traced to to the late 50s, as a possible formalism that circumvented the apparent inconsistencies of perturbative quantum field theory. The idea was that, even if no theory of strong interactions was available, the underlying S-matrix must satisfy certain properties. Lorentz invariance requires that the S-matrix elements, and therefore amplitudes, depend on particle momenta only through Mandelstam invariants. In particular, Landau argued that causality of the interaction implies that the amplitudes must be analytic functions of the invariants. Analyticity, unitarity, and crossing symmetry, constitute the so-called S-matrix principles. The hope was that these principles were sufficient

to uniquely determine the strong interaction S-matrix, once proper additional assumptions and initial conditions were given. Ultimately, it was shown that these hopes were in vain. Rather than defining a particular theory, the S-matrix principles should be thought of as defining a broad class of physically reasonable theories, and with the discovery of J/Ψ and the triumph of quantum field theory, the S-matrix program was abandoned.

In the last two decades the quark model picture of three-quark baryons and quark-anti-quark mesons has been challenged by the many apparently exotic hadronic resonances found in high-energy experiments, leading to a new era of hadron spectroscopy, and a renewed interest in precision theoretical descriptions of hadronic processes at low energy. It is within this environment that the need for flexible, physically consistent models of hadronic reaction amplitudes has been increasingly appreciated. This has led to the renewed understanding in the value of S-matrix techniques, which give us just such a set of amplitudes. Today, JPAC uses these well-studied techniques to confront the latest spectroscopy data and deepen our understanding of QCD.

Chapter 2

For New Members

If you are reading this chapter, welcome to the JPAC collaboration!

2.1 Administration

As a JPAC member, you have access to a number of internal documents and software. These are

- JPAC Slack Channel
- JPAC Google Calendar
- The password protected area of the JPAC website: `https://www.jpac-physics.org/index.php`
- This user manual

If you have not received access to one or more of the above, please contact

- Alessandro Pilloni: alessandro.pilloni@skuola.net
- César Fernández Ramírez: cefera@gmail.com
- Adam Szczepaniak: aszczepa@indiana.edu

2.2 Physics Resources

Your most valuable resource as a member of JPAC are the other members! JPAC strongly encourages new members to ask questions and participate in discussions both in and outside of meetings. However, the following are a few references which may be of particular use to new JPACers.

- V. Gribov, "Strong Interactions of Hadrons at High Energies : Gribov Lectures on Theoretical Physics," Oxford University Press, 2009, ISBN 978-1-00-929022-7, 978-1-00-929027-2, 978-1-00-929024-1 doi:10.1017/9781009290227
- V. N. Gribov, "The theory of complex angular momenta: Gribov lectures on theoretical physics," Cambridge University Press, 2007, ISBN 978-0-521-03703-7, 978-0-521-81834-6, 978-0-511-05504-1 doi:10.1017/CBO9780511534959
- P. D. B. Collins, "An Introduction to Regge Theory and High-Energy Physics," Cambridge Univ. Press, 2009, ISBN 978-0-521-11035-8 doi:10.1017/CBO9780511897603
- M. Albaladejo *et al.* [JPAC], "Novel approaches in hadron spectroscopy," Prog. Part. Nucl. Phys. **127**, 103981 (2022) doi:10.1016/j.ppnp.2022.103981 [arXiv:2112.13436 [hep-ph]].

2.2.1 Lecture Notes

- JPAC Lecture notes. PDFs of these notes may be found in the `For New Members` folder.
  - Relativistic Reaction Theory for Hadron Spectroscopy, Module 1: Hadron Spectroscopy, Kinematics, and Particle States: `https://www.overleaf.com/15361615hjtsvkznhrpd`
  - Relativistic Reaction Theory for Hadron Spectroscopy Module 2: Amplitudes and the S-Matrix: `https://www.overleaf.com/17246751yzfznjjyzdhh`
  - Relativistic Reaction Theory for Hadron Spectroscopy Module 3: Angular Analyses and Resonances: `https://www.overleaf.com/17246984gtgjqmwmpmsg`
  - Relativistic Reaction Theory for Hadron Spectroscopy Module 4: Regge Phenomenology and High-Energy Reactions: `https://www.overleaf.com/17247101nncghddxzcny`
  - Relativisitic Reaction Theory for Hadron Spectroscopy Module 5: Data Fitting and Error Estimation: `https://www.overleaf.com/17247156ghvyxybwpxqw`
  - `https://www.overleaf.com/17618349zvgcrtrrdbxk`
  - `https://www.overleaf.com/17618219qyjsvcnhnvqg`

Chapter 3

Rules and Regulations

3.1 JPAC Code of Conduct

A *Code of Conduct* outlines the basic standards of behavior that we, as members of JPAC, follow in order to create a healthy and inclusivie work environment. This code was developed democratically and collaboratively, and expresses our collective vision of ethical research. While the code of conduct aims to be general, it cannot be prescriptive for all circumstances. Ultimately it falls upon each and every JPAC member to act ethically and with good intentions in dealing with each other and in public settings. Our core beliefs can be summarized in the following themes:

Diversity and Respect

We value an open, diverse, and inclusive working environment, which fosters respect and inclusion of all parties We believe that the highest quality of scientific work is only possible if people are empowered to express themselves openly and honestly, and are treated as individuals. We do not discriminate on the basis of age, religion, political affiliation, nationality, culture, ethnicity, race, sexual orientation, gender identity, gender expression, status in JPAC, ability, family situation, or any other characteristic of personal identity. Disruptive or harassing behavior of any kind is not acceptable. Harassment includes but is not limited to inappropriate or intimidating behavior and language, unwelcome jokes or comments, unwanted touching or attention, offensive images, photography without permission, bullying, stereotyping, put-downs, and stalking. We are aware that people with different backgrounds can have different perceptions of such problems, and that inclusiveness is a process that requires constant personal work and an open mind.

Integrity

Trust between collaborators is integral for open and honest communication. In the pursuit of high-quality science, it is expected that members will act in all instances with integrity. In particular, we must safeguard confidential information, documents or data that we encounter through our interactions, internal meetings and external collaborations. Beyond confidentiality, acting with integrity means that we appropriately credit others for their contribution (this goes beyond the authorship rules, which are listed elsewhere), and demonstrate fairness and impartiality in all matters related to JPAC.

Rigor

As a collaboration, we have a responsibility to strive for the highest standard of scientific rigor. This increases the value of our work, and improves the external perception of the collaboration, which is beneficial for ourselves and our collaborators. When we disseminate our research (through seminars, papers or other means), we must aim to honestly and fairly represent the work of our collaboration and others. It is important to understand that when we speak about collaboration work, we are (formally or informally) serving as a voice for JPAC.

3.2 JPAC Membership

JPAC membership falls into two categories: *Full* and *Affiliated*. These two categories reflect the differing level of members' commitment to JPAC-focused activities. It is important to note that the distinction is somewhat vague, and the following definitions of full and affiliate members should not be seen as prescriptive.

As a JPAC member (either full or associate), you are encouraged to contribute to scientific discussions at weekly JPAC meetings, and at project-specific meetings. Beyond enhancing our understanding of the science, open communication leads to a stronger collaboration, and ultimately, higher quality research.

3.2.1 Full Member

Full JPAC members **should**

1. Be lead researcher in one or more JPAC-affiliated research projects.
2. Regularly attend weekly JPAC meetings in addition to project-related meetings.
3. Contribute to discussions of other JPAC projects.

Full membership does **not** imply seniority within the collaboration, but rather reflects a members level of interest in JPAC related activities. Full membership does **not** imply mastery.

3.2.2 Affiliate Member

The responsibilities for Affiliate JPAC members are considerably lower. They range from only incidental attendance of JPAC meetings and no JPAC-affiliated research, to contributing to, but not leading JPAC-affiliated research. The definition of the Affiliate Membership class is deliberately vague to allow varying levels of commitment. Affiliate JPAC members are **encouraged to**

1. Contribute to any JPAC research projects you are affiliated.
2. Regularly attend project-related meetings and the weekly JPAC meeting

3.2.3 Changing Membership Status

Full members are entitled to reduce their responsibilities within JPAC and change their status to Affiliate at any time. Similarly, affiliate members may upgrade their status by acting in accord with the above expectations of the full member category. In particular, by taking an active role in JPAC research and regular attendance to JPAC meetings.

3.2.4 Authorship

The researcher(s) leading a JPAC project should appear as first author(s) and corresponding author(s) in the publication. Other authors are generally listed in alphabetical order.

As a JPAC member (full or affiliate), you are entitled to sign JPAC papers for which you have made an appropriate scientific contribution. Appropriate contributions include, but are not limited to conceptualization, methodology, software development, validation, data curation, writing and editing papers, visualization, supervision, project administration and funding acquisition. Further examples of valid scientific contributions can be found at `https://www.elsevier.com/authors/policies-and-guidelines/credit-author-statement`.

JPAC authorship functions under an honor policy. Thus individual members are expected to judge for themselves whether they have contributed to a particular paper. It is important to note that authorship of a paper comes with certain responsibilities. When signing a paper, you accept scientific responsibility for the content of the paper.

3.3 Funding

Funding for JPAC-related activities is sourced from individual member grants. Thus there is no guarantee that funding is available. However, JPAC understands the importance of communicating our scientific findings to the broader community, in particular for our junior members. Therefore, we encourage members of JPAC to ask for funding for JPAC-related activities. The current treasurer is César Fernández-Ramírez (cefera@gmail.com). Requests for JPAC funding should be first addressed to him.

3.4 Ombuds

Open communication is the most important component of a healthy collaboration. Members who feel they have been mistreated by circumstance or by another individual are encouraged to discuss their concerns with the appropriate parties. We recognize that even with a 'flat' organizational hierarchy it is sometimes difficult to bring up such concerns, and members of JPAC are therefore committed to serving as ombuds to help foster an open and inclusive working environment. If you have an issue which you do not feel comfortable bringing up with the general group, we recommend speaking to

1. Robert Perry (perryrobertjames@gmail.com)
2. TBD at Annual Meeting
3. TBD at Annual Meeting

The panel members are elected to serve for a year, and will respect the privacy of any recieved complaints. While it is hoped that issues will able to solved by ombuds, if necessary, sanctions are to be decided by 2/3 of the collaboration using secret vote, and may include ejection from the collaboration.

3.5 Governance Meeting

This document should be seen as a living document, one which is constantly updated to match the needs and experiences of the members of JPAC. It is important that, at least on a yearly basis, the members of JPAC come together to discuss the collaboration and address any issues that have arisen. The JPAC meeting also serves as a place to strengthen bonds of collaboration and friendship between members, and to foster a sense of belonging especially for junior members.

Chapter 4

The JPAC Style

This style guide is intented as a practical reference for those producing graphics and plots for JPAC. This guide aims to give clear and succinct directions for the style choices of the plots produced in order to unify the plots produced by JPAC. With this in mind, the guide has been divided into two chapters; Section 4.1 gives the *Minimum Requirements*. These are the style choices which all JPAC plots must obey. In particular this section details details about colour choices and correct attribution and Section 4.6 contains a catalogue of examples of correct usage of the above style suggestions.

The JPAC Style has been implemented for the following languages:

- Python + Matplotlib
- gnuplot
- Julia

Implementations of the style guide may be found on the JPAC GitHub:
https://github.com/JointPhysicsAnalysisCenter/JPAC-Style

If you use a different language to plot data, please submit a style file to the GitHub page so that others can easily implement JPAC figures in this language.

4.1 Minimum Requirements

This chapter details the minimum style requirements required for an official JPAC plot. These style choices ensure that plots produced by the collaboration are easily and clearly attributable to the JPAC Collaboration.

4.2 JPAC Colour Palette

The RGB values for the JPAC colour palette

Table 4.1: RGB values for the colour palette.

Colour	R,G,B Values	Hex color
jpac-blue	31, 119, 180	1F77B4
jpac-red	214, 39, 40	D6270E
jpac-green	0, 158, 115	009E73
jpac-orange	255, 127, 14	FF7F0E
jpac-purple	148, 103, 189	9467BD
jpac-brown	140, 86, 75	8C564B
jpac-pink	227, 119, 194	E377C2
jpac-gold	188, 189, 34	BCBD22
jpac-aqua	23, 190, 207	17BECF
jpac-grey	127, 127, 127	7F7F7F

4.3 JPAC Swatches

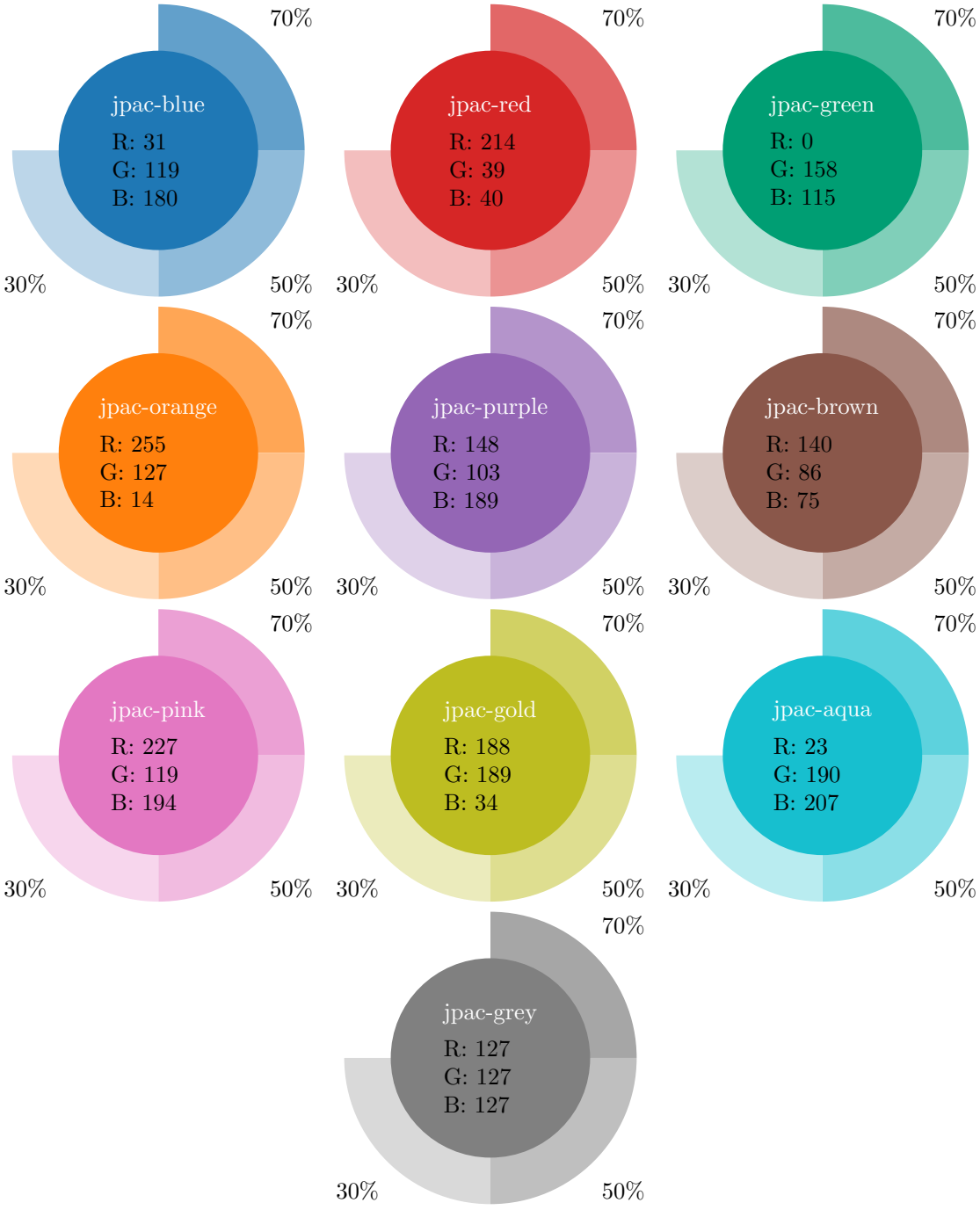


Figure 4.1: The JPAC colour palette. Note that the first two colours used must be jpac-blue and jpac-red at 100%.

4.4 Rules for Use

When producing JPAC plots, the following rules around the choice of colours must be obeyed:

4.4.1 Line Plots

1. The first colour used should be jpac-blue at 100%.
2. The second colour used should be jpac-red at 100%.
3. The primary colours should be used first before resorting to different opacity variants.
4. The modified opacity versions should be used when plotting curve bands around a central value.

4.4.2 Heatmaps

When required, heatmaps should interpolate between jpac-blue and the jpac-red.

4.5 Use of the JPAC Logo

Including the JPAC logo into plots created by the JPAC collaboration is the simplest way to attribute the work to JPAC. We propose a number of options:

4.5.1 The JPAC Logo

The most obvious logo is shown in Fig. 4.2.

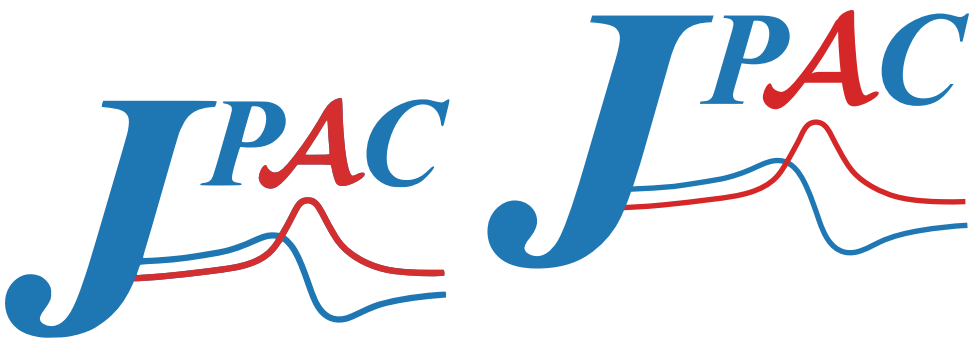


Figure 4.2: JPAC Logo

4.5.2 A LaTeX Equivalent

A simpler version of the logo may be obtained with LaTeX commands via

```
\boldmath J^{P\!\mathcal{A}C}
```

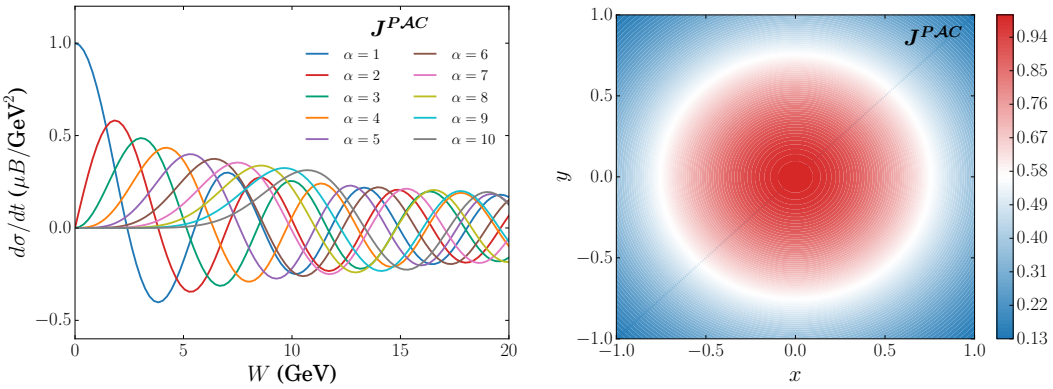
which renders as

$$\boldsymbol{J^{P\!\mathcal{A}C}} \tag{4.1}$$

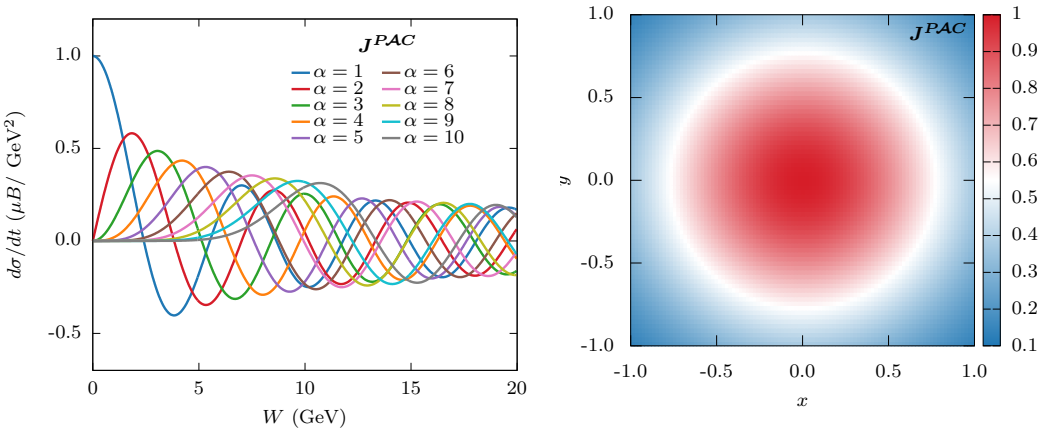
4.6 Examples

Here we demonstrate the JPAC style. There are two examples: a line plot using the JPAC Colour scheme. $d\sigma/dt = J_\alpha(W)$ (Bessel function of the first kind of real order and complex argument), and a contour plot using the JPAC Colour scheme. $f(x, y) = \exp(-(x^2 + y^2))$

4.7 Python+Matplotlib



4.8 GNUPlot



4.9 Julia

4.10 Mathematica

4.11 Root