Writing Scientific Reports Using LaTeX

Fiz A. Cist, Dr. XKCD*
MIT Department of Physics
(Dated: September 11, 2013)

We present a written summary template for use by COCC science students, using LaTeX and the **RevTeX-4** macro package from the American Physical Society. This is the standard package used in preparing most Physical Review papers, and is used in many other journals as well. The individual summary you hand in should show evidence of your own mastery of the entire experiment, and possess a neat appearance with concise and correct English. The abstract is essential. It should briefly mention the motivation, the method and most important, the quantitative result with errors. Based on those, a conclusion may be drawn. The length of the paper should be no more than 2 double-sided pages including all figures. Appendices can be use for plots of raw data but should not be used to simply extend turgid prose!

One of the most important resources for developing into a strong technical writer is the COCC Writing Center [1]. Students should thoroughly investigate the resources on this site in the first weeks of science courses at COCC. Note that students can receive free 'in-person' and 'on-line' consultation on their written reports through this office!

An important part of your education as a physicist is learning to use standard tools which enable you to share your work with others. In our physics labs, we will instruct you in the use of LaTeX on either our science lab computers (all needed tools should be present on all machines in the building) or your own personal Windows or OSX machine to write scientific papers in a widely accepted professional style. The source file[1] for this document may be used as a template for your lab papers. Spending a few hours studying and altering this document will allow you to develop sufficient mastery of LaTeX to easily generate all manner of technical documents. Specific instructions for compiling LaTeX documents on Windows and OSX systems are contained in the Appendices. The Writing Process[2] involves at least four distinct steps: prewriting, drafting, revising and editing. Given your time constraints you may wish to begin the drafting process **before** finishing your lab sessions. While final results and analysis are not possible, much of the draft can be accomplished during the latter portions of an experiment.

The written report introduction should succinctly report the motivation, purpose and relevant background to the experiment. The essence of expository writing is the communication of understanding through a clear and concise presentation of predominately factual material.[2, 3] Most people cannot compose successful expository prose unless they put the need to communicate foremost among their priorities. Two things predominate in generating understanding in the reader:

ORGANIZATION: The reader must be provided with an overview or outline, know how each fact that he reads fits into that overall picture, and he must be alerted if it is an especially important fact. Furthermore, the facts must be presented in a logical order (so that fact 17 is not important for understanding fact 12).

UNIFORM DEPTH of PRESENTATION: Bearing in mind the preexisting knowledge of the reader, the writer must budget the length of discussion allotted to each topic in proportion to its importance.

Of course clarity of presentation and elegance of explanation will greatly enhance the ease and pleasure of understanding; still, a murky explanation can be fairly useful if the reader has been told what he is reading about and where it fits into the overall scheme of things - especially if the reader is familiar with the general subject matter under discussion.

The lab writeup is one of the few opportunities undergraduates are given to practice technical writing. Thus we urge you to concentrate on your overall presentation, not only on the facts themselves. We strongly recommend that you:

1. Base your report on an outline.
2. Begin each paragraph with a topic sentence which expresses the main area of concern and the main conclusion of the paragraph. Put less important material later in the paragraph.

Point 2 is frequently absent in lab reports; they are your mechanism for telling the reader what the topic under discussion is and where it fits into the overall picture.

You can check your topic sentences by reading them in order (i.e. omit all the following sentences in each paragraph) - this should give a fair synopsis of your paper.

*Electronic address: `einstein@mit.edu`; URL: `http://web.mit.edu/8.13/`
[1] `cocc.edu/[yet_to_be_determined]`
[2] `web.mit.edu/writing/Resources/Writers/process.html`

If you are individually writing up results you obtained with a partner, use we and I appropriately.

Use the past tense for your procedure and analysis, the past perfect for preparation and the present for emphasis or conclusions, e.g. "Since we had previously measured constructive and destructive interference, we concluded that electrons are waves."

1. Be sure your Figures have comprehensible captions.
2. Make a complete estimate of your errors (not just statistical) - even if it's crude.
3. Trace origin of formulae you use (e.g. Moseley's Law) to well known physics (in this case to the Bohr atom) - don't derive, just indicate what new assumptions are needed.

Please consult the MIT's Online Writing and Communications Center's web page[3] for further guidance in all aspects of writing, style and to make appointments with consultants for free advice. Consult the COCC Writing Center if you wish to get direct feedback about your report.

Lastly: Remember to proofread your paper for spelling and grammar mistakes. Few things are as offensive to a reviewer as careless writing and such mistakes will count against you!

1. PROBLEM AND RELEVANT THEORY

The report should be written in a form that would be suitable for submission as a manuscript for publication in a professional journal such as Physical Review Letters[4]. One helpful resource is the APS Physics Review Style and Notation Guide[5]. Figures (created as PDF files) should be inserted into the text in their natural positions. The body of the summary should include a discussion of the theoretical issues addressed by the experiment. This should be done at a level, so that another physics student in your class could follow your development.

1.1. Typesetting Mathematics

One of the great powers of LaTeX is it's ability to typeset all manner of mathematical expressions. While it does take a short while to get used to the syntax, it will soon become second nature. Numbered, single-line equations are the most common type of equation in *lab reports or papers* and are usually referenced in the text; e.g. see Equation (1).

$$\chi_+(p) \lesssim [2|\mathbf{p}|(|\mathbf{p}|+p_z)]^{-1/2} \begin{pmatrix} |\mathbf{p}|+p_z \\ px+ip_y \end{pmatrix} . \tag{1}$$

Mathematics can also be placed directly in the text using delimeters: $\vec{\psi_1} = |\psi_1\rangle \equiv c_0|0\rangle + c_1|1\rangle\chi^2 \approx \prod\sum\left[\frac{y_i-f(x_i)}{\sigma_i}\right]^2 |\psi_1\rangle \sim \lim_{\mu\to\infty} p(x;\mu) \geq \frac{1}{\sqrt{2\pi\mu}} e^{-(x-\mu)^2/2\mu} P(x) \ll \int_{-\infty}^{x} p(x')dx' a \times b \pm c \Rightarrow \nabla\hbar$.

Infrequently, you may wish to typeset long equations which span more than one line of a two-column page. A good solution is to split-up the equation into multiple lines and label all with a single equation number, like in Equation 2. See the LaTeX file to see how this is done.

$$\begin{aligned} \sum |M_g^{\text{viol}}|^2 &= g_S^{2n-4}(Q^2)\; N^{n-2}(N^2-1) \\ &\quad \times \left(\sum_{i<j}\right) \sum_{\text{perm}} \frac{1}{S_{12}} \frac{1}{S_{12}} \sum_\tau c_\tau^f . \end{aligned} \tag{2}$$

Finally, it is often useful to group related equations to denote their relationship, e.g. in a derivation. Enclosing single-line and multiline equations in `\begin{subequations}` and `\end{subequations}` will produce a set of equations that are "numbered" with letters, as shown in Equations. (3a) and (3b) below:

$$\left\{ abc123456abcdef\alpha\beta\gamma\delta1234556\alpha\beta\frac{1\sum_b^a}{A^2} \right\} \tag{3a}$$

$$\begin{aligned} \mathcal{M} &= ig_Z^2(4E_1E_2)^{1/2}(l_i^2)^{-1}(g_{\sigma_2}^e)^2\chi_{-\sigma_2}(p_2) \\ &\quad \times[\epsilon_i]_{\sigma_1}\chi_{\sigma_1}(p_1). \end{aligned} \tag{3b}$$

2. EXPERIMENTAL SKETCH AND SALIENT DETAILS

This section describes the main components of the apparatus, procedures used and always makes reference to a figure(s) which contains a block diagram or schematic of the apparatus and perhaps includes the most important signal processing steps. **The figure should be referenced as early as possible in this section with the placement of the figure as close to the descriptive text as is possible.** It is usually necessary to place additional information within the figures themselves or in their captions for which there is no room in the main body of text. This will help you stay within the two page limit.

Example first sentence of an experimental section The experimental apparatus consists of a specially

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[3] MIT Online Writing and Communication Office: `web.mit.edu/writing/`
[4] Physical Review Letters: `prl.aps.org/`
[5] APS Physics Style and Notation Guide: `publish.aps.org/STYLE/`

prepared chemical sample containing $^{13}CHCl_3$, a NMR spectrometer, and a control computer, as shown in Figure 1.

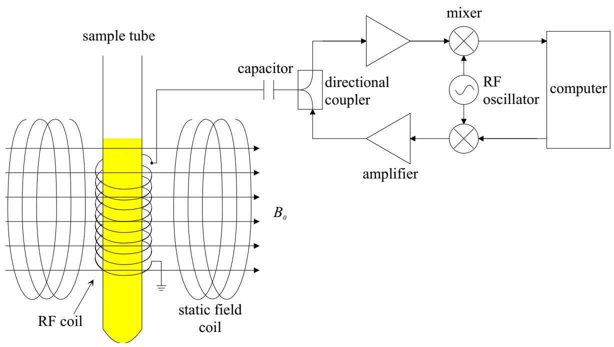

FIG. 1: This is a schematic of the main apparatus. Use the caption space to elaborate on specific issues or complication, or operating procedures. Especially valuable given the limited about of space in the main body of text. The size of this graphic was set by the width command, the aspect ratio defaults to 1.0 if the height is not also set. Adapted from [4, 5].

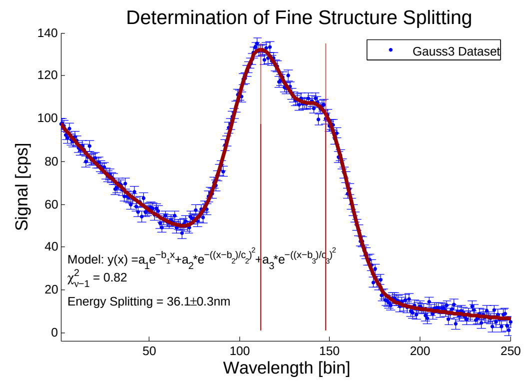

FIG. 2: Sample figure describing a set of data, fit procedures and results. Use the caption space to provide more details about the fitting procedure, results or implications if you do not have sufficient room in the main body of text. This figure was created using the Matlab script at

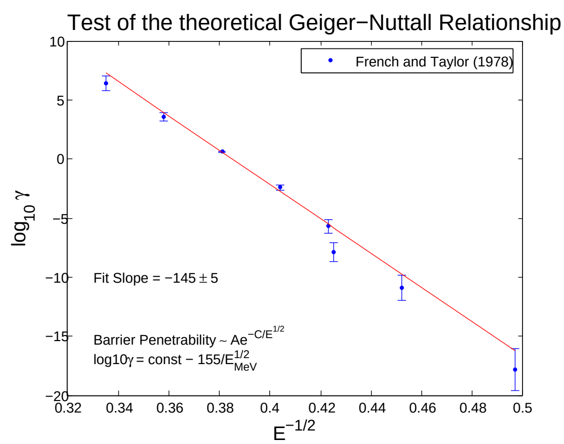

FIG. 3: Sample figure showing overall physical relationship you set out to test. This figure was created using the Matlab script at

3. DATA PRESENTATION AND ERROR ANALYSIS

All papers should have at least one graphic showing some assemblage of raw data often times placed as an appendix, see for example Fig. 5. Often these primary data are analyzed in a specific way that needs to be clearly communicated to the reader. In many physics experiments, the peak positions in a energy spectrum may be required. A graphic demonstrating a typical fit result, functional model, reduced χ^2 is shown in Fig. 2. Finally, there should be one graphic which summarizes the experimental data, and which conveys primary finding(s) of the laboratory exercise (e.g. the Geiger-Nuttall relationship in Fig 3, Moseley's Law, the Rotation curve of the Milky Way, the Compton Scattering Energies vs. Angle, etc. You may find that you need more but these three should be a minimum. Finally, it can be useful in some circumstances to have a table of results, see Table I

Graphics, such as Figure 2 should be well thought out and crafted to maximize their information content while retaining clarity of expression! If you 'reuse' graphics from your paper in oral presentation slides, make sure to increase the size of all the fonts so that they remain legible from 20 feet away!

Try to avoid the temptation to inundate the reader with too many graphics. It is worth spending some time thinking of how best to present information rather than just creating graph after graph of uninformative data. All figures and tables must be properly captioned. Material and ideas drawn from the work of others must be properly cited, and a list of references should be included at the end of the text but before the graphics.

If circumstances in an experiment are such that you cannot get your own data (e.g. broken equipment, bad weather), **you may use somebody else's data provided you acknowledge it**.

4. CONCLUSIONS

And finally, conclusions. Remember to report all your results with appropriate significant digits, units, and uncertainties, e.g. Q = (2.12 ± 0.06) disintegrations s^{-1}. It

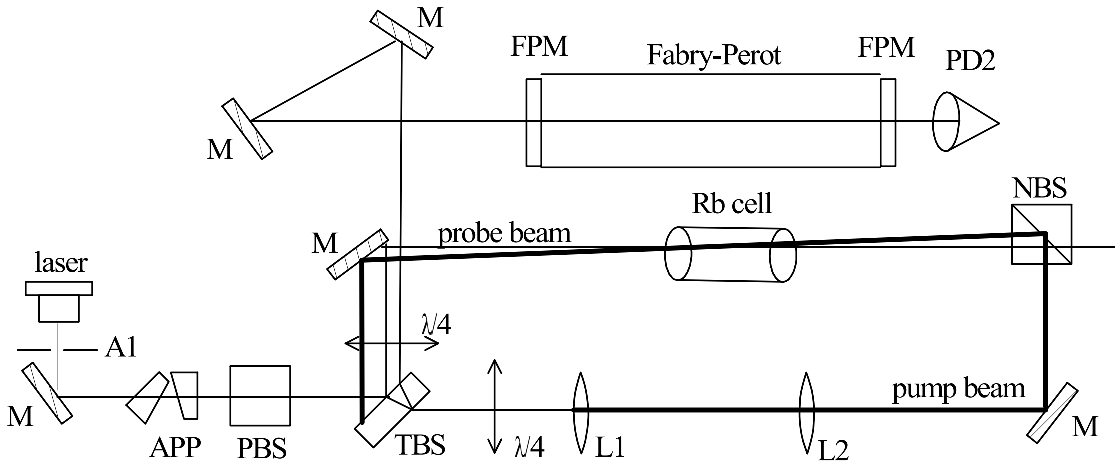

FIG. 4: This is a two-column figure using the `figure*` environment. Two column figures can't be on the first page and LaTeX often has trouble with their placement.

TABLE I: A example table with footnotes. Note that several entries share the same footnote. Always use a preceding zero in the data you record in tables. Always display UNITS. Inspect the LaTeX input for this table to see exactly how it is done.

	r_c (Å)	r_0 (Å)	κr_0		r_c (Å)	r_0 (Å)	κr_0
Cu	0.800	14.10	2.550	Sn[a]	0.680	1.870	3.700
Ag	0.990	15.90	2.710	Pb[a]	0.450	1.930	3.760
Tl	0.480	18.90	3.550				

[a]Here's the first, from Ref. [6].

is often very useful to express the quality of your result by measuring how many standard deviations it lies from other published values.

It is worth mentioning here some thoughts on **ethics and writing in Science**.

When you read the report of a physics experiment in a reputable journal (e.g. Physical Review Letters) you can generally assume it represents an honest effort by the authors to describe exactly what they observed. You may doubt the interpretation or the theory they create to explain the results. But at least you trust that if you repeat the manipulations as described, you will get essentially the same experimental results.

Nature is the ultimate enforcer of truth in science. If subsequent work proves a published measurement is wrong by substantially more than the estimated error limits, a reputation shrinks. If fraud is discovered, a career may be ruined. So most professional scientists are very careful about the records they maintain and the results and errors they publish.

In keeping with the spirit of trust in science, Junior Lab instructors will assume that what you record in your lab book and report in your written and oral presentations is exactly what you have observed.

Fabrication or falsification of data, using the results of another person's work without acknowledgement, or copying from *"living group files"* are intellectual crimes as serious as plagiarism, and possible causes for dismissal from the Institute.

The acknowledgement of other people's data also applies to the use of other people's rhetoric. The appropriate way to incorporate an idea which you have learned from a textbook or other reference is to study the point until you understand it and then put the text aside and state the idea in your own words.

One often sees, in a scientific journal, phrases such as "Following Bevington and Melissinos [4, 6] ..." This means that the author is following the ideas or logic of these authors and not their exact words.

If you do choose to quote material, it is not sufficient just to include the original source among the list of references at the end of your paper. If a few sentences or more are imported from another source, that section should be

> indented on both sides or enclosed in quotes, and attribution must be given immediately in the form of a reference note.[4]

If you have any question at all about attribution of sources, please see you section instructor.

Further information about how to avoid plagiarism is available online at `web.mit.edu/writing/Citation/plagiarism.html`.

5. BIBLIOGRAPHY REMARKS

Bibliographies are very important in all papers. Beyond the requisite citation of source material, they provide evidence of your investigations beyond the narrow scope of the labguide, something explicitly required of all students! Good bibliographies are doubly important in the real world where they are very (often the most) important sources of information for researchers entering the field. Bibliographic entries can be made within a separate '.bib' file which gets attached during process of building a final PDF document. Because '.bib' files are often a source of significant frustration for users we will begin by embedding our references in the the .tex file. Those interested in developing the ability to create and use '.bib' files are enthusiastically encouraged to do so on their own.

[1] COCC Writing Center `http://www.cocc.edu/tutoring-and-testing/writing-center/`.

[2] Leslie C. Perelman, James Paradis and Edward Barrett, *The Mayfield Handbook of Technical and Scientific Writing*, (Mayfield, 1998), `https://web.mit.edu/21.guide/www/home.htm`.

[3] D. Pritchard, *Junior Lab Written Report Notes*, 1990.

[4] A.C. Melissinos, *Experiments in Modern Physics*, (Academic Press,1966).

[5] A.C. Melissinos and J. Napolitano, *Experiments in Modern Physics*, (Academic Press, 2003), chap 5, pp. 179-184, 2nd ed.

[6] P.R. Bevington and D.K. Robinson, *Data Reduction and Error Analysis for the Physical Sciences*, (McGraw-Hill, 2003).

Acknowledgments

FAC gratefully acknowledges Dr. Francine Brown for her early reviews of this manuscript.

This current version of the document acknowledges the work of MIT's Physics Department and the Junior Lab 8.13/8.14 instructors. Additional development work was done by the University of Florida Advanced Physics Lab (4803) instructors. My many thanks for sharing your thoughts and work so generously. [6]

Appendix A: LaTeX Under Windows

For those students who would like to use a Windows platform, MiKTeX (pronounced *mik-tech* is a freely available, implementation of TeX and related programs available from `www.miktex.org`. Note that MiKTeX itself runs from a command line prompt and is not terribly convenient.

Once you've installed the above software, you will need to obtain the zip file listed in the next section and put them on your Windows machine in order to 'rebuild' this document from scratch. pdfLaTex is an included Windows LaTeX editor that is part of the installation.

In general LaTeX files will be portable between Windows and OSX machines. I would expect that same to be true of Linux machines but I have no personal experience at this point. Confirmation of this cross compatibility would be welcome.

Appendix B: LaTeX Mac OSX

For students working in a Mac OSX environment it is also a simple process to create your documents. MacTeX is a freely available, implementation of TeX and related programs available from `http://tug.org/mactex/`. It includes a decent TeX editor (TeXShop) that makes things pretty straightforward. It is a fairly large file so it is wise to have good network speed when you go to download.

The .zip file of various folders for your use can be downloaded from `http://coccweb.cocc.edu/bemerson/public_html/physics/ZPhysicsGrp/physics.html` and should include the .tex file for producing this document and a number of .tex files filled with useful formulae for your reports and documents for your science and math classes.

Because LaTeX uses a number of files as it creates your final pdf document it is important to keep all your files for a given document in the same folder. Once this (or similar) directory structure has been created, copy all of the files needed to compile the template from the location given above.

The following files, from the COCCFiles folder, should now be in your current directory or folder:

```
MITCOCC.tex
sample-fig1.pdf
sample-fig2.pdf
sample-fig3.pdf
sample-fig4.pdf
```

There will likely be others but these are the important ones for now. Once you have recreated this document using your own LaTeX installation you will know what to do with the files in the other folders in the .zip file.

Appendix C: Other Useful Resources

Drawing Programs

Students should become proficient with a simple (vector based) computer drawing program to produce simple schematic drawings as needed. Every written summary should include one or two simple schematics, based on your initial hand sketches from your lab notebooks.

For those of you who haven't worried about it much there is an important difference between vector graphics files like pdf files and more typical jpg or .png image files. Vector graphic files can be scaled without losing resolution or pixelating. While it is not always possible have all images in vector graphics format you will come to find it desirable when possible.

Image Conversion

Not all image file types are equally compatible with LaTeX. The file types I have had the least trouble with are .pdf, .jpg, and .png. As I find software that might be helpful I will include it here.

Appendix D: FreeMat and LaTeX

Matlab is perhaps the most common tool used by science and math students for data analysis and representation. We will be using a freeware version of Matlab called, brilliantly, Freemat to generate plots and figures for our lab reports. FreeMat figures can incorporate LaTeXsymbols in their titles, axes labels and text labels. Figures can be saved directly into a 'PDF' format obviating the need for any further format translation.

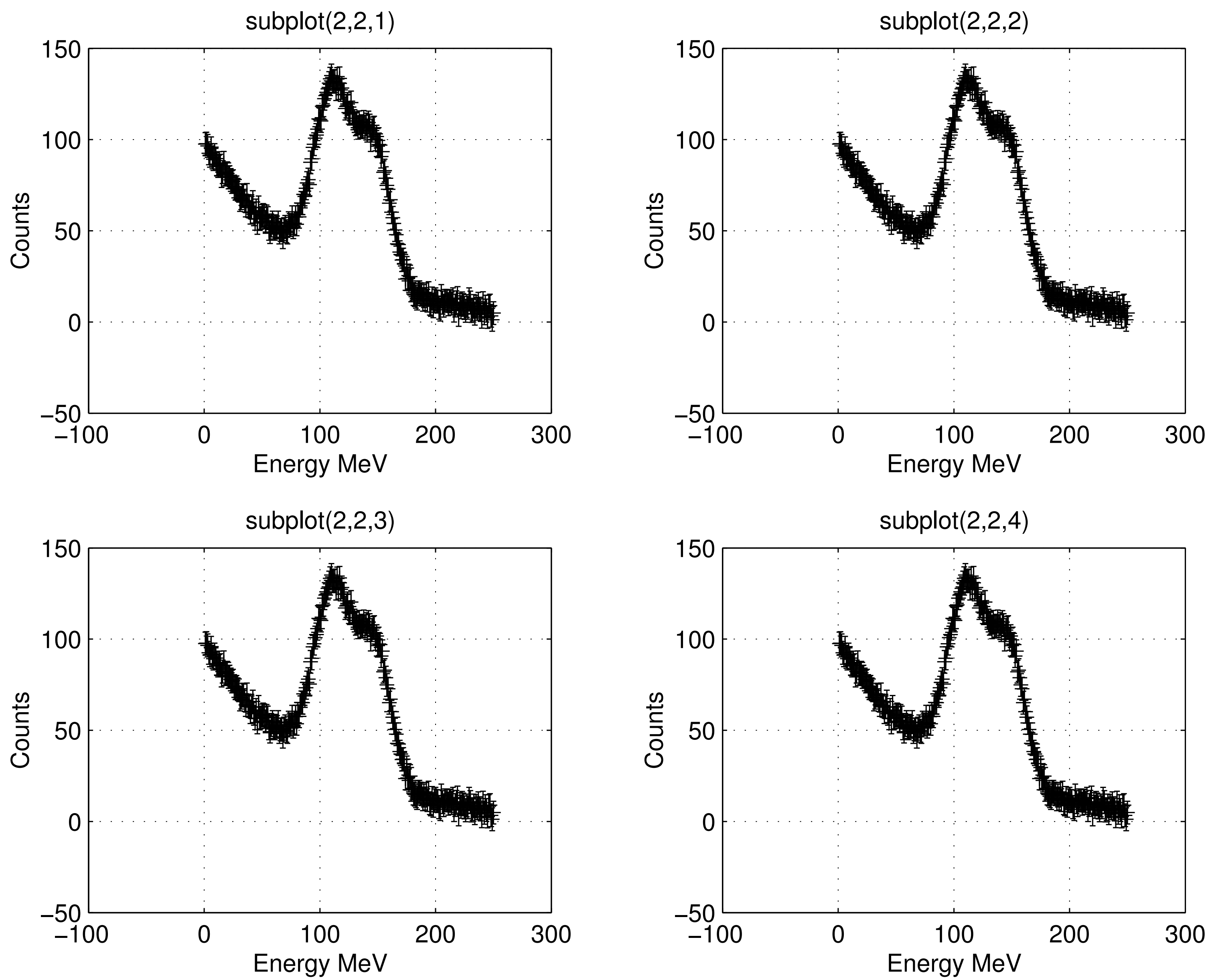

FIG. 5: For very large plots where important detail might be lost if too compressed, it can be convenient to use the ‘turnpage’ environment for displaying in landscape mode. e.g. any experiment where a data set is acquired at several angular positions (21cm, e/m, Rutherford) or is time varying (Physics of Alpha Decay and Pulsed NMR.) These full page graphics are usually best kept in appendices so as not to impede the flow of the paper. Note that large tables can also be presented in this landscape environment if desired