

Writing Scientific Reports Using L^AT_EX

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We present a written summary template for use by MIT Junior Lab students, using L^AT_EX 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 used 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 MIT Online Writing Center[1]. Students should thoroughly investigate the resources on this site in the first weeks of 8.13. 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 Junior Lab, we will instruct you in the use of L^AT_EX on either MIT’s Athena environment or your own personal Windows 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 Junior Lab papers. Spending a few hours studying and altering this document will allow you to develop sufficient mastery of L^AT_EX to easily generate all manner of technical documents. Specific instructions for compiling L^AT_EX documents on Windows and Athena systems are contained in the Appendices. The Writing Process² involves at least four distinct steps: prewriting, drafting, revising and editing. Given the tight time constraints in Junior Lab, students are advised to begin the drafting process **before** finishing their lab sessions. While final results and analysis are not possible, much of the draft can be accomplished during the latter sessions 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:

1. 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).

2. 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 Junior 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 8.13 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.

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.”

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¹ web.mit.edu/8.13/www/Samplepaper/sample-paper.tex

² web.mit.edu/writing/Resources/Writers/process.html

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 page³ for further guidance in all aspects of writing, style and to make appointments with consultants for free advice. They even have an on-line tutor to which you can submit sections of your paper for critique at any stage of the writing process!!!

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 type-written in a form that would be suitable for submission as a manuscript for publication in a professional journal such as Physical Review Letters⁴. One helpful resource is the APS Physics Review Style and Notation Guide⁵. 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 8.13 student could follow your development.

1.1. Typesetting Mathematics

One of the great powers of L^AT_EX is its 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 *Junior Lab papers* and are usually referenced in the text; e.g. see Equation (1).

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

Mathematics can also be placed directly in the text using delimiters: $\vec{\psi}_1 = |\psi_1\rangle \equiv c_0|0\rangle +$

$$c_1|1\rangle\chi^2 \approx \prod \sum \left[\frac{y_i - f(x_i)}{\sigma_i} \right]^2 |\psi_1\rangle \sim \lim_{\mu \rightarrow \infty} p(x; \mu) \geq \frac{1}{\sqrt{2\pi\mu}} e^{-(x-\mu)^2/2\mu} P(x) \ll \int_{-\infty}^x p(x') dx' a \times b \pm c \Rightarrow \nabla \hbar.$$

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 L^AT_EX file to see how this is done.

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

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:

$$\left\{ abc123456abcde f \alpha \beta \gamma \delta 1234556 \alpha \beta \frac{1}{A^2} \sum_b^a \right\} \quad (3a)$$

$$\begin{aligned} \mathcal{M} &= ig_Z^2 (4E_1 E_2)^{1/2} (l_i^2)^{-1} (g_{\sigma_2}^e)^2 \chi_{-\sigma_2}(p_2) \\ &\times [\epsilon_i]_{\sigma_1} \chi_{\sigma_1}(p_1). \end{aligned} \quad (3b)$$

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 prepared chemical sample containing ¹³CHCl₃, a NMR spectrometer, and a control computer, as shown in Figure 1.

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. 4. Often these primary data are analyzed in a specific way that needs to be clearly

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/

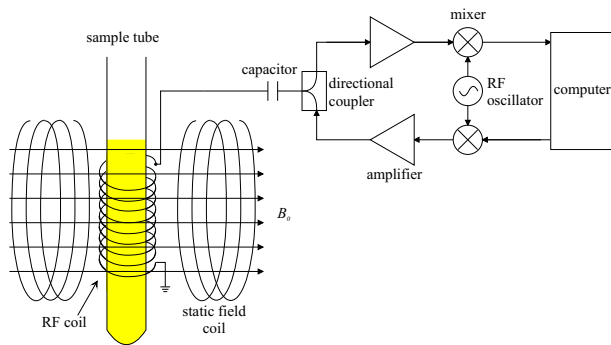


FIG. 1: This is a schematic of the main apparatus. Use the caption space to elaborate on specific issues or complication, or operating procedures. Especially valuable given the limited amount of space in the main body of text. The size of this graphic was set by the width command, the aspect ratio defaults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

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. $Q = (2.12 \pm 0.06) \text{ disintegrations s}^{-1}$. It is often very useful to express the quality of your result

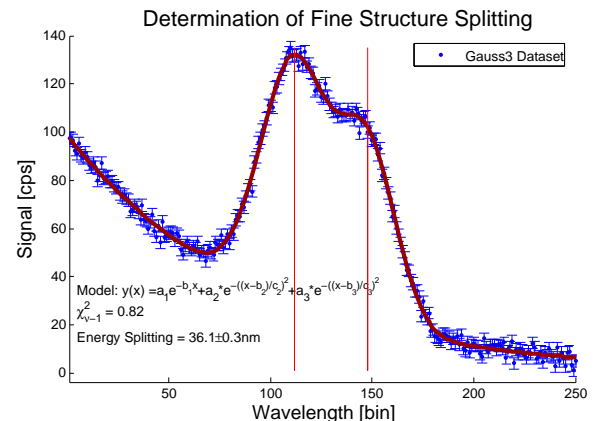


FIG. 2: Sample figure describing a set of data, fit procedures and results. Use the caption space to provide more details about the fitting procedure, results or implications if you do not have sufficient room in the main body of text. This figure was created using the Matlab script at web.mit.edu/8.13/matlab/fittemplate07.m

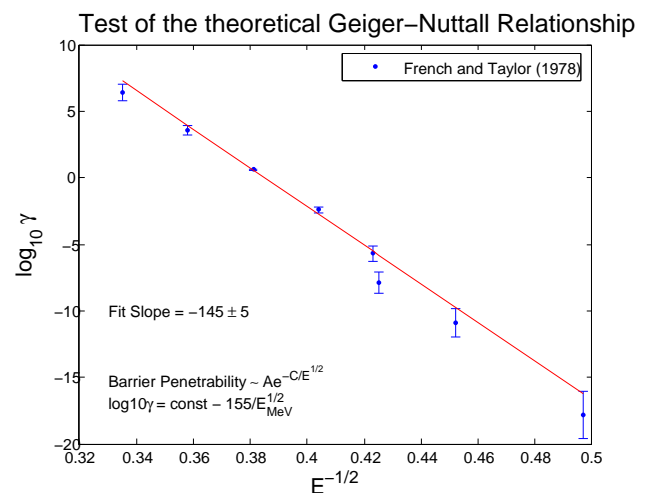


FIG. 3: Sample figure showing overall physical relationship you set out to test. This figure was created using the Matlab script at web.mit.edu/8.13/matlab/fittemplate07.m

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

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 L^AT_EX 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				

^aHere's the first, from Ref. [6].

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 Junior Lab 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 Junior Lab 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 are made within a separate '.bib' file which gets attached during process of building a final PDF document. See the file web.mit.edu/8.13/www/Samplepaper/sample-paper.bib for details on several types of bibliographic entries and their required and optional fields.

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- [1] *Mit online writing center*, URL <http://web.mit.edu/writing/>.
 - [2] J. P. Leslie C. Perelman and E. Barrett, *The Mayfield Handbook of Technical and Scientific Writing* (Mayfield, 1998), URL <https://web.mit.edu/21.guide/www/home.htm>.
 - [3] D. Pritchard, *Junior lab written report notes* (1990).
 - [4] A. Melissinos, *Experiments in Modern Physics* (Academic Press, 1966).
 - [5] A. Melissinos and J. Napolitano, *Experiments in Modern Physics* (Academic Press, 2003), chap. 5, pp. 179–184, 2nd ed.
 - [6] P. Bevington and D. Robinson, *Data Reduction and Error Analysis for the Physical Sciences* (McGraw-Hill, 2003).

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Appendix A: L^AT_EX 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. We strongly recommend you simultaneously purchase and install a very nice TeX editor/shell called WinEdt, available from www.winedt.com for only \$30 for students. This interface is substantially easier than using ‘emacs’ on Athena for writing and typesetting scientific papers and we encourage you to check it out.

Once you’ve installed the above software, you will need to obtain the group of files listed in the next section and put them on your Windows machine in order to ‘rebuild’ this document from scratch.

If you wish to view postscript files under Windows, we suggest downloading and installing Ghostscript available from www.cs.wisc.edu/~ghost.

Appendix B: L^AT_EX on Athena

For students wishing to utilize MIT’s Athena environment, it is also a simple process to create your documents. You can use the following commands verbatim or tweak them to suit your own organizational system.

In your home directory on Athena, create a convenient directory structure for all of your Junior Lab work. Type:

```
> mkdir ~/8.13
> mkdir ~/8.13/papers
> mkdir ~/8.13/papers/template
> cd ~/8.13/papers/template
```

Once this (or similar) directory structure has been created, copy all of the files needed to compile the template from the Junior Lab locker into your own Athena account: Type:

```
> setup 8.13
> cp /mit/8.13/www/Samplepaper/* .
```

The final period above places the copied files into the current directory so make sure you’re in the correct directory! You can see where you are by typing:

```
> pwd
```

The following files should now be in your current directory:

```
sample-paper.tex
sample-paper.bib
sample-fig1.pdf
```

```
sample-fig2.pdf
```

```
sample-fig3.pdf
```

```
typical-fit-plot.pdf
```

Additional files may also have been copied but don’t worry, these get regenerated when you build your PDF document.

The ‘setup’ command automatically appends to your path the location of the **RevTeX-4** files.

Now let’s build the file (omitting the ‘.tex’ suffix in the following steps).

```
> pdflatex sample-paper
> bibtex sample-paper
> pdflatex sample-paper
> pdflatex sample-paper
```

The repeated calls to ‘pdflatex’ are necessary to resolve any nested references in the final PDF file. The ‘bibtex’ call reads in the bibliography file ‘sample-paper.bib’ allowing citation references to be resolved.

Remember to `ispell -t filename.tex` to perform a L^AT_EXsafe spell check before handing in your paper!

Appendix C: Useful Athena Utilities

Drawing Programs

Students should become proficient with a simple (vector based) computer drawing program such as **XFIG** or **TGIF** on Athena. Every written summary should include one or two simple schematics, based on their initial hand sketches from their lab notebooks.

Image Conversion

It is easy to convert images from one format to another (e.g. a scanned jpeg or bitmap image into an pdf file for inclusion into a written summary). A useful utility, available on the Sun’s is “imconvert”. Typing “imconvert” without any arguments will show you the accepted file types. For example, to convert a ‘jpg’ image to ‘pdf’, one types: “imconvert jpg:filename.jpg pdf:filename.pdf”. Other useful commands are ‘ps2pdf’ and ‘eps2pdf’.

Appendix D: Matlab and L^AT_EX

Matlab is perhaps the most common tool used by Junior Lab students for data analysis and representation. Matlab figures can incorporate L^AT_EX symbols 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.

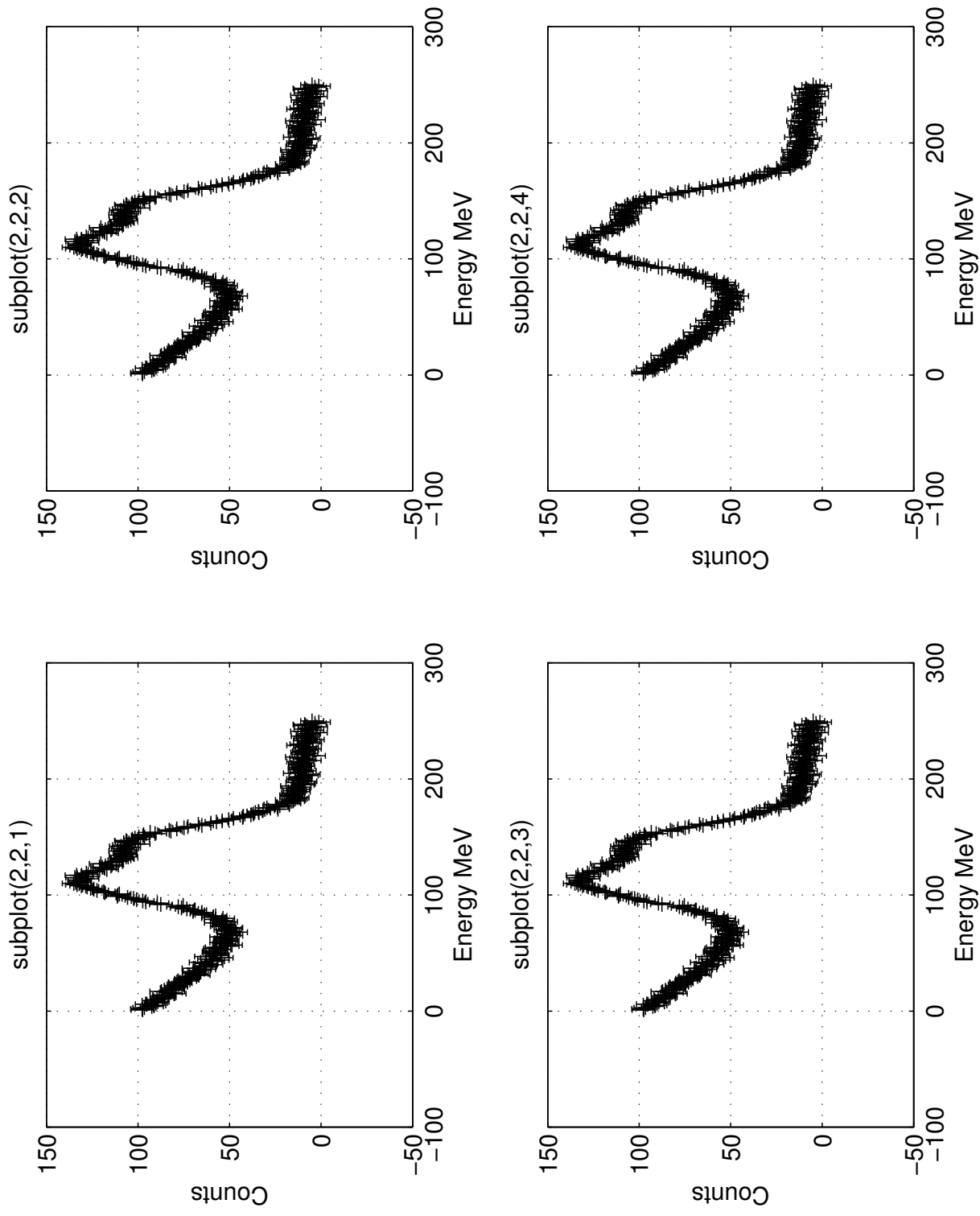


FIG. 4: For very large plots where important detail might be lost if too compressed, it can be convenient to use the ‘turnpage’ environment for displaying in landscape mode. e.g. any experiment where a data set is acquired at several angular positions (21cm, e/m, Rutherford) or is time varying (Physics 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