PY581: PHYSICS ADVANCED LABORATORY
Syllabus

ALL STUDENTS MUST PERUSE THIS BEFORE SESSION 1, AND
ARE RESPONSIBLE FOR KNOWING ITS CONTENT

Location & hours	SCI 130D and 132, Mondays, 10:10 am – 6:10 pm; 617-358-1869 Session 1 starts in B58, then moves to B11 for the Ba137 experiment Lunch breaks by arrangement with the Director and with your collaborator
Presentations	10:00 am SCI B58 for Session 1, 4:25 pm for the AdLab seminar series, and when announced
AdLab Director	Lawrence R. Sulak, sulak@bu.edu
Office	PRB 273
Cell phone	617-735-7636, available anytime
Home	617-731-2194
Office Hours	Mondays 10 am - 7 pm in SCI 130D, and by arrangement any time
Chief Scientists	Chris Cosby, cosbyc@bu.edu, 425 591-7989 Nick Russo, nzr@bu.edu, 781-974-2066 Dan Arcaro, djarcaro@bu.edu, 508-479-8049, consultant
AdLab Manager	Situ Yaokun, situ@bu.edu, 215 584-7727
Prerequisites	1) PY354 - Modern Physics, or equivalent 2) A computer account on buphy0; ask Guoan Hu, ghu@bu.edu, 3-3931, to set up an account if you have none already
Required materials	Your personal quad ruled lab notebook for recording your lab work in ink Scientific calculator Particle Data Group (PDG), "Particle Physics Booklet" at every session. Order this free by email at pdg@lbl.gov/. For home reference, you may also want to order the long form "Review of Particle Physics." These are published every two years by Rev. Mod. Phys. You will be expected to use the booklet or website regularly in the lab. Please also become familiar with the vast offerings on-line at pdg.lbl.gov Positive attitude
Adlab Website	physics.bu.edu/~sulak/AdLab
Course information	will be distributed by email and appear on the course website, where this syllabus is kept **You are responsible to know the syllabus, and to check email daily for messages re: this course!**

Recommended references (all on reserve at the Science and Engineering Library):

1) A. C. Melissinos, "Experiments in Modern Physics," Academic Press, Second Edition. You may well want to invest in this text, which I refer to regularly.
2) P. H. Bevington and D. K. Robinson, "Data Reduction and Error Analysis for the Physical Sciences", McGraw Hill, 1992.
3) J. R. Taylor, "An Introduction to Error Analysis," University Science Books, 1972.
4) Hugh D. Young, "Statistical Treatment of Experimental Data: An Introduction to Statistical Methods," Waveland Press 1996.
5) Louis Lyons, "A Practical Guide to Data Analysis for Physical Science Students," Cambridge University Press, 1992.
6) J. M. Butler, "Linear Least Squares Fitting Formulae," 1999, on the AdLab website.

Abstract:

Our goal is to emulate a working research lab and to familiarize the junior researcher with experimental methods and techniques. We will not teach, but will help you discover physics phenomena and the master the apparatus necessary to observe it. Several experiments are available to give you a broad overview of current technology. AdLab will give you hands-on experience with what you have to work with in a professional research environment: you are given a collection of good old junk that can miraculously earn you a Nobel Prize once you get it all to work at the same time to measure a new physical observable, or a known one better.

As everywhere these days, you must collaborate, working in teams of two, though your written papers and seminar presentations will be independently prepared. You will quantify your results, including statistical and systematic error bars. You will hone your skills at setting up and calibrating apparatus, taking data, evaluating it including error analysis, and preparing a draft Physical Review Letters (PRLs) paper for each of your experiments.

The labs are all under development; none are "cookbook" recipes. You are expected to develop experimental procedure from where ever you can, e.g. previous work in the literature, manuals, materials in the lab, textbooks, the library, and in discussion with your collaborators and colleagues. **You MUST do your "library" preparation BEFORE you appear in the lab.** Your "deliverable" is to present the results both in writing (prepared for a premier physics discovery peer-reviewed journal) and orally (for review by your AdLab peers as if you were presenting at an annual APS meeting.

Safety:
We take laser, radiation, etc. safety very seriously in AdLab; it is your responsibility to do so too. In our first session, we will meet at B58 for a lecture on lab safety from a representative of the Office of Environmental Health and Safety (John Kurkomelis or one of his colleagues). While every effort will made to ensure your safety, you are required to know the hazards involved in each experiment that you do, including high voltage, high current, laser light, cryogenic temperatures, ionizing radiation (e.g. x-rays and radioactive sealed sources), etc. You will have to pass the radiation safety exam after the lecture.

1) No experiment should be undertaken before receiving a safety briefing from one of the instructors regarding possible hazards of the experiment before working with the apparatus.

2) Report any problem, incident, injury, or contamination to the professor immediately.

3) Absolutely no food, drink, cosmetics, gum or evidence thereof are permitted anywhere in the AdLab facility.
If you are hungry, alert one of the staff and your collaborator before leaving. Disregarding safety rules or instructions will result in severe consequences.

Your Experiments:
You and your collaborator will perform 4 experiments from the repertoire below. To hone your data analysis skills, the first assignment will be measuring and fitting data from the decay of a short-lived radioactive source. Using the data you collected, you will write the draft analysis and conclusion sections of a PRL.

We will devote four or five sessions each to the subsequent three experiments, *i.e.* you will focus for a month on each. The time in the lab for the last ~8 sessions are shortened by your seminar presentations (see below). See the "Calendar for AdLab Researchers" on the AdLab website.

The first Monday after completion of a project, you must have done your library work and be prepared for your new project. Your draft PRL on the completed project will be due at AdLab 10 am the second Monday following the last session of each lab.

Session 1: Safety lecture, initial collaborators, and choice of experiments:
After the safety lecture, the Director will assign the first round of research collaborators, generally an advanced grad student with each undergrad. For subsequent experiments, you will choose a different collaborator, depending upon mutual interest in an experiment. We will then tour the equipment in AdLab (see attached list of experiments) and each collaborating group will determine an ordered list of what you would like to do. If we have an odd number of participants, we will ask for a volunteer to choose his or her experiment first, and to perform it solo with one of the instructors serving as senior collaborator of the team.

By drawing numbered coffee stirrers, each collaboration will choose their Lab 2, with the lowest number having their first choice. We will repeat this procedure in the opposite order for Lab 3. Each group will then measure Ba137 lifetime.

Official Lab Notebook:
Each experiment has a dedicated quad "lab book of record" (e.g. to prove you patent claims, etc.) for use by both collaborators for all data and observations taken in common. Entries are in ink…no pencil. No erasures; strike throughs for corrections are accepted mark by the patent office. At the end of each experimental session, each researcher will copy (use the AdLab copier code 1851851) whatever you might need from the lab book so that you have complete data for your report and presentation.

Independently, you will want to keep personal notes in your own book that you keep for life, as Feynman did.

PRL Drafts:
While data is taken and logbook entries made in teams, ***the data analysis and lab report are to be solely the work of each individual student.*** Reports must be prepared according to the style manual of the journal you have chosen for submission. You will want to go to their web page and download their style manual so that you can follow their guidelines, format, etc. for submission for publication, **including page limits**. Copying a paper or two from the journal to mimic is always helpful.

Given the page limit, you must write telegraphically, keeping no more than the details necessary for another scientist to verify and to build upon your results. You should make every effort to make your paper acceptable for publication. It must be coherent and well organized. The choice of word processor is up to you. The senior lab management **refuses to read any paper that is not obviously spell checked or that does not conform to PRL style.**

Except for the PRL of Session 1 (which is limited to analysis and conclusions) each paper will generally contain the following sections (see the samples of last years work on the bulletin board outside the lab).

1) The top of the Title page: includes the name of the lab, author (first in order) and collaborator, an abstract, the beginning of the paper, and a date at the bottom of the page with **"Prepared for submission to (the name of the journal)." Your signature certifies that the writing and analysis is yours alone.**

2) Abstract on the title page: a few sentences that describe the objectives of the lab and the results. It should say all that is necessary to entice a reader to peruse the entire text. The text of the article continues on the first page.

3) Introduction and Motivation: state what you measured and why. Provide adequate motivation with a short discussion of the physics explored. A short presentation of the theory with relevant equations and references is appropriate. Trace the origin of equations you are using to well known physics, and reference them. Detailed derivations are not appropriate since this is an experimental paper; we are interested in the line of reasoning, not details of derivations.

4) Experimental Setup: describe the apparatus, instrumentation, and data taking procedures. A drawing or two is absolutely essential.

5) Data and Error Analysis: present your data in tabular (with errors) or better yet, in graphical form (with error bars). Both may be helpful, but graphics usually get the point across better. Perform statistical error analysis. Quote chi-squared goodness of fit and number of degrees of freedom for any fits. Quote statistical errors and *identify and quantify the main systematic error sources*.

6) Discussion: compare your results with those expected from theory or from previous work. If your numbers disagree with expectations beyond the errors, suggest possible sources of problems with the measurements. If your numbers agree with expectations, suggest possible ways to improve the precision of the measurements in future work.

7) Conclusions: a brief summary of the results and what you learn from the experiment. This will be very similar to the abstract.

8) References and acknowledgements: "We all stand on the shoulders of giants." "Give credit where credit is due." Thank your collaborator.

Seminar Presentations:
You must convince your thesis advisor, lab director, boss, peers at the annual meeting of your professional society, the venture capitalist or the funding agent, that the results you obtained are valid. Otherwise all is for naught. Generally, before reading your paper, they will judge your work by your oral presentation. Starting at our ~8th session, we will have two 10-minute no-frills power point or overhead presentations. Each will distill the essence of one of your PRL drafts. Part of your AdLab grade will come from the questions and helpful critique you provide to the speaker after each presentation.

We will call for two seminar volunteers, grad students first, near the end of Lab 2. You will be expected to practice, first to your bookcase, and then to your collaborator, before your APS rehearsal in the seminar room. Timing will be strict. Slides must be succinct, telegraphic, and easy to read. You must face the audience, look them in the eye or point to the matter at issue on the overhead, speak loudly, slowly, clearly, and cogently.

Abbreviated Calendar and Report deadlines (= the dates of the beginning of a new lab)**:**
See the "Calendar AdLab Researchers " on the AdLab web site for details and actual dates. Approximate dates are below:

Radiation Safety Seminar, AdLab Tour, & Lab 1 (Ba137)	~Sept 9
Start Lab 2, tutorial on analysis:	~Sept 16
PRL (Lab 1 analysis) due; quiz on analysis:	~Sept 22
PDG quiz: tutorial: “How to give a seminar”	~Oct 6
PRL Draft 2 due:	~Oct 14

First Seminar:	~Oct 14
PRL Draft 3 due:	~Nov 10
In class final:	~Dec 9
PRL Draft 4 due:	~Dec 16

Data Analysis Tools, including those on buphy.bu.edu:
If you do not know Fortran or C++, please let the lab director know. You should try to audit the Computational Physics course to learn some Fortran, or see the BU Continuing Education site and follow a C++ short course immediately. Your will need to do least squares fits to the data you take, calculate chi-square, etc., for the first experiment, and undoubtedly for the rest of your life. However, this can be done with a hand calculator, with Excel, etc.

For Fortran users, we will supply you with the subroutine CURFIT.F. This is the *preferred* means of fitting your data, simply because it is *not* just a black box, and also because it is reasonably straightforward to use. Furthermore, it gives you the *statistical error*, which can be hard to obtain when using some of the other canned software fitting packages.

Young's book is short and easy to assimilate. The Director likes it because he learned from it!

The text by Bevington has a collection of Fortran codes that are useful for fitting data. Can be used throughout your career. It is at the bookstore, but there is no need to purchase it if you have an equivalent.

The PDG website, pocketbook, and long form publication have excellent write-ups on statistics, probability, Monte Carlo techniques, detectors, radiation sources, radiation losses, physical constants, cosmic rays, atomic and materials properties. You must familiarize yourself with the offerings here. We will have a quiz on using it early in your internship with AdLab.

The following are available on the computer *buphy.bu.edu*:

MATLAB: Widely used commercial product for visualization and data analysis. Type 'matlab' to start the program on buphy. There is a learning curve, but the effort to learn this is not wasted since MATLAB is a very useful software package.

XMGR: Useful for making plots and doing fits. Type **xmgr** to start it on buphy.

PAW++ and its successor ROOT: Physics Analysis Workstation, written and maintained by CERN. Commonly used by high-energy physicists but not very user-friendly. Type **/cern/pro/bin/paw++** to start it on buphy.

Microsoft Excel: If you have a PC, this is helpful for organizing analysis tasks, tables etc. Some discount it as first choice for analysis because it is a black box. "Data in, answer out, no learning experience." Be sure to use its superb statistics package to get error bars…"no error bar, no data."

Mathematica is loaded on buphy. You can sit at the linux machine in SCI 128 or log in from any other terminal and use it.

The following book has been recommended by AdLab reseachers:
http://www.amazon.com/Visual-Display-Quantitative-Information/dp/0961392142

Connectivity in class:
Some 8 computers are in the lab for your use; several are on the network for you to access the above resources during AdLab hours.

Grading:

1) Completion of four experiments, including logbook and PRL drafts.	
Lab 1 Radioactive data fit:	20%
Labs 2-4 at 20% each	60%
2) Oral presentation:	15%
3) Class participation, attendance, independence, innovations, etc.	5%
	100%

Penalties for Missing a Lab Session or Late Submission of PRL:
Since each session is 8 hours long, and at least 2 people (one being a staff member) have to be in the lab at any one time for safety reasons. We organize make up lab time to accommodate 1 hour class conflicts, which we strongly discourage.

Missing Class without prior agreement by the Director and make-up: 1 grade step
(One grade step = A to A-, A- to B+, etc.)
Late/incomplete PRL report: 1 step per day

Bonuses:
A premium of 1 grade step would be awarded for particularly innovative work, especially on the developmental projects.

PY581 EXPERIMENTAL PROJECTS

FIRST EXPERIMENT: PERFORMED BY ALL ADLAB RESEARCHERS

0. Ba-137 Radioactivity Decay Lifetime

OPERATIONAL EXPERIMENTS

1. Landau dE/dx of Cosmic ray Muons traversing a water Cherenkov calorimeter

2. Faraday Rotation in Glass

3. Pulsed Nuclear Magnetic Resonance

4. High T_c Superconductivity

5. Optical Pumping of Rb

6. Bifurcation and chaos in water droplet flow

7. Neutron & Alpha Particle 3D tracks in a ^{3}He Time Projection Chamber

8. Hanbury-Brown Twiss Interferometry

9. Planck's h-bar from observing a Hot Wire

10. Cosmic and Terrestrial Background Ionizing Radiation

11. Hall Effect in metals and in P Type Semiconductors

12. SQUID - superconducting quantum interference device

13. Studies of Sonoluminescence

14. Measurement of Muon Lifetime with a Water Cerenkov Detector

15. Double Slit Diffraction of Single Photons

16. Thermal conductivity of a gas at low pressure

POTENTIAL EXPERIMENTS, CURRENTLY UNDER DEVELOPMENT

17. Zeeman Effect line splitting in a high magnetic field

18. Planck's Law for Black Body Radiation from a hot oven

19. Quantum Hall Effect and Superfluid Helium

20. Compton Scattering

21. X-ray Diffraction Crystallography

22. Mossbauer Spectroscopy

23. Electron Spin Resonance

24. Measuring the Speed of Light

25. NIM+ Electronics Data Acquisition Development

Many of these experiments are under development, conducted in close collaboration with senior colleagues. No guarantee that they will yield results during 4 sessions, but you will learn a lot no matter what.

L. R. Sulak