Senior Laboratory

PHYS 493L, Spring 2025

Lab Time: Tuesdays & Thursdays, 8am-10am

Lab Location: PAIS 1417

Lectures and Group Meetings: (most) Tuesdays & Thursdays, 10am-10:50am in PAIS 1405

Instructor: Tara Drake

Email: drakete@unm.edu

Offices: PAIS 2234 and CHTM 118B

Teaching Assistant: Xiaoxuan (Shane) Li

Email: xli1@unm.edu

Office Hours: arrange meeting with instructor or TA via email

Senior Lab 493L

Overview

Lab course: experiments in particle physics and atomic molecular and optics (AMO) for advanced undergraduates. Students will perform experiments related to:

- Quantization and Wave-particle duality
- Nuclear decay, lifetime measurements, and particle physics
- Photon and coincidence counting
- Atomic structure and laser physics
- Interferometry and metrology

Goals

- Develop independent problem-solving and experiment planning and execution
- Strengthen facility with research laboratory equipment and techniques
- Learn/practice effective technical writing and oral presentation skills

Senior Lab 493L

Course Structure

- Current enrollment: 9
- Work in groups of 2
- Each student completes 3 experimental modules from 5 available
- Oral presentation (lecture for classmates)
- Homework
- Lab skills demonstrations

Big Idea:

- Setting up the first table in a new ____ lab
- Lab “guides” not lab manuals
- Troubleshooting and independent research expected
- Interaction with instructor and TA expected and welcome

Experimental modules

3 modules required

~9 sessions per experiment

Final manuscript due 1 week after

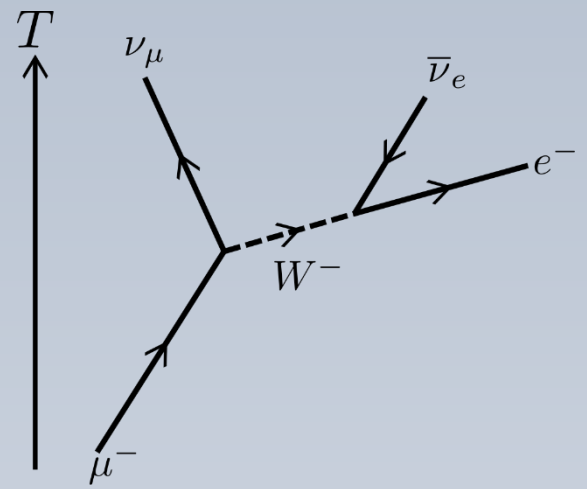
- **Nuclear physics**
- **Wavemeter**
- **Single photon interference**
- **Laser velocimetry**
- **Saturated Absorption Spectroscopy**

Nuclear physics: Muon decay

Concepts:

- **Pion and muon physics**
- **Weak nuclear force**
- **Photomultiplier tubes and photon counting**
- **Coincidence events**
- **Event identification in particle physics**

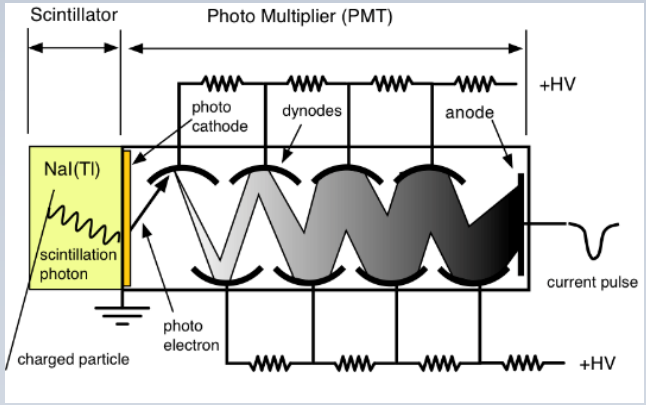
Muon decay: Weak interactions



The muon a constituent of cosmic-ray particle "showers". 1936 Carl D. A. and S. Neddermeyer.

$$\mu^+ \rightarrow e^+ \ \nu_e \ \bar{\nu}_\mu$$

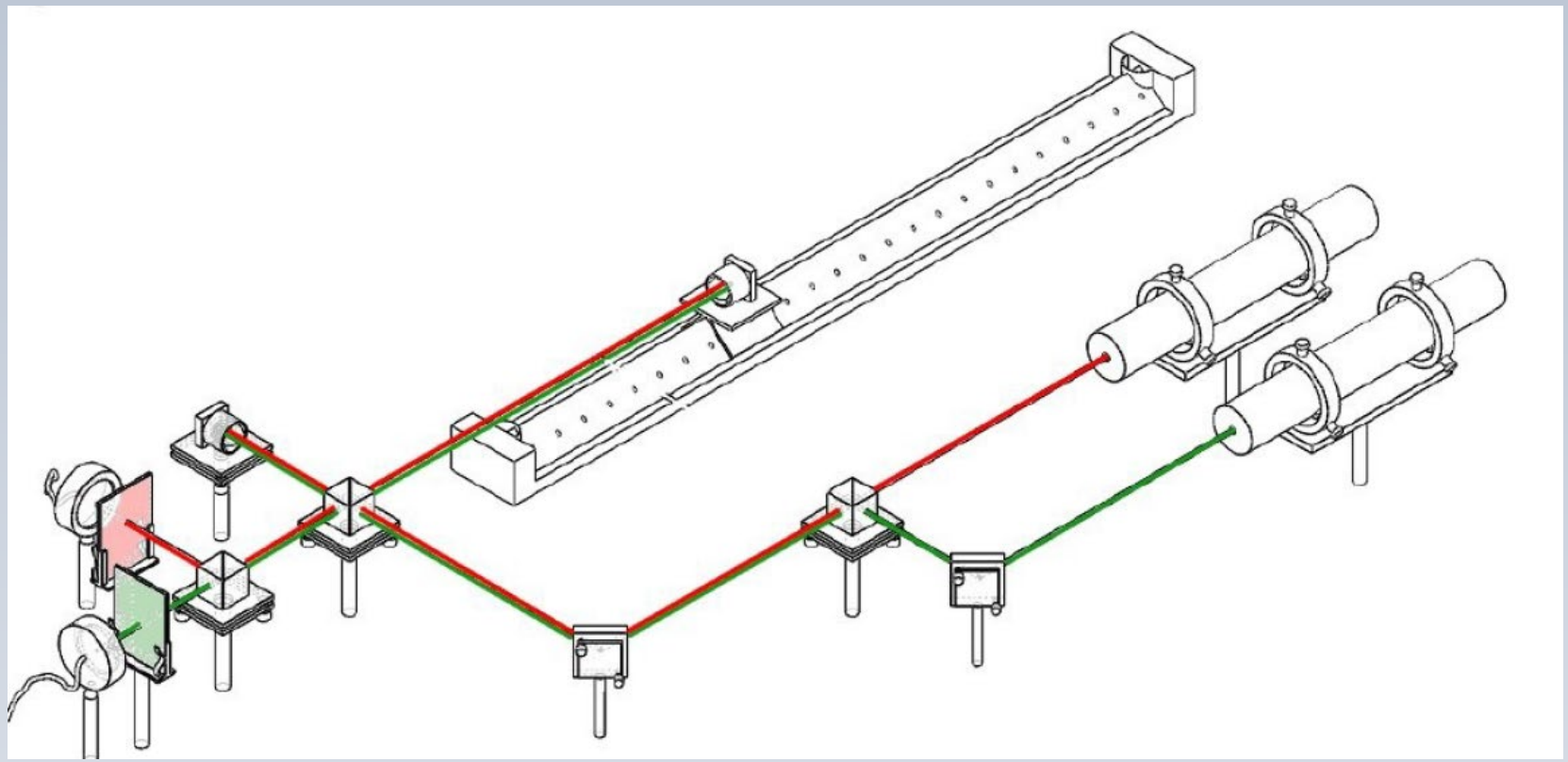
$$\mu^- \rightarrow e^- \ \bar{\nu}_e \ \nu_\mu$$



Wavemeter

Using a known reference laser, measure an arbitrary/unknown wavelength using interference

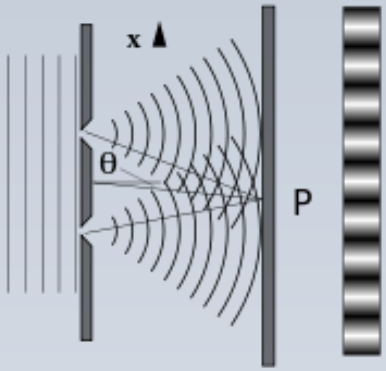
Beam alignment; interferometry; stability; precision in frequency metrology

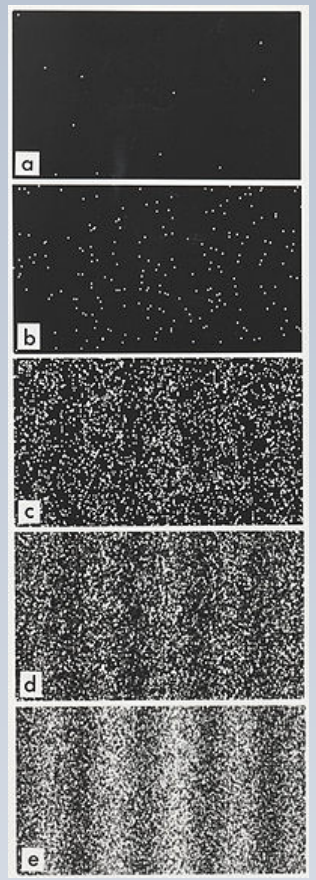


Single photon interference

Concepts:

- **Wave-particle duality**
- **Photon flux**
- **Calibration**
- **Photon counting/photon statistics**
- **Diffraction of particles**





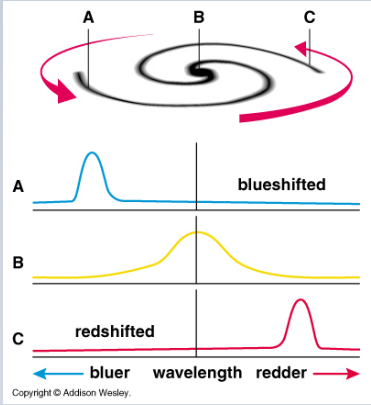
Laser velocimetry

i.e. “Speed Measurement by Optical Techniques

Using interference and the Doppler effect to measure velocity

Concepts:

- Doppler shift
- Interferometry and optical beam alignment
- Optical path length calculations
- Frequency modulation detection techniques
- Laser surface velocimetry

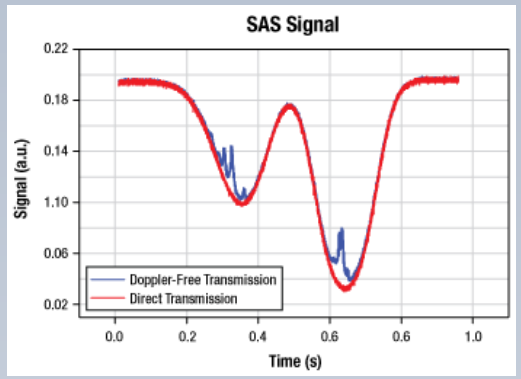


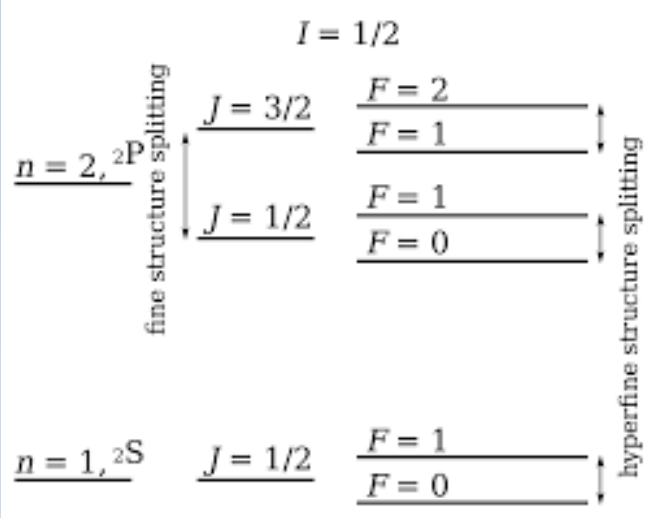
Saturated Absorption Spectroscopy

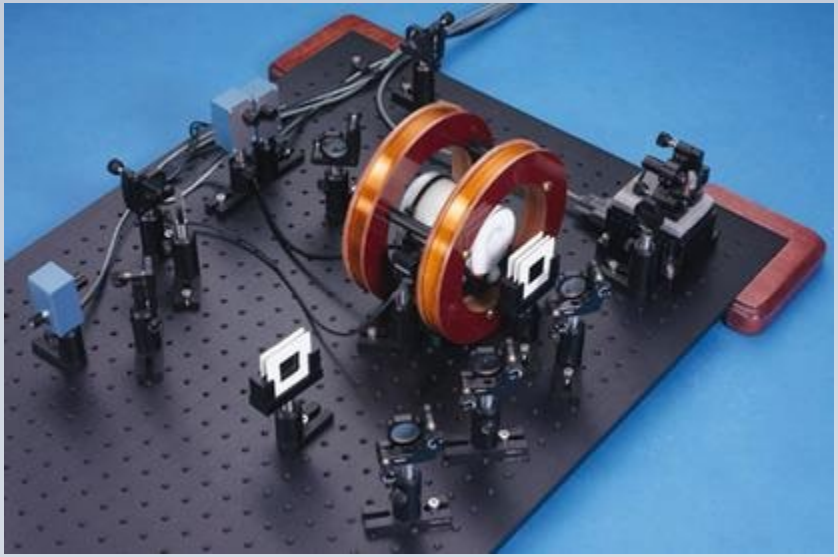
Sensitive laser absorption spectroscopy in Rb atoms

Concepts:

- **External cavity diode lasers**
- **Doppler broadening**
- **Fine and hyperfine structure of alkali atoms**
- **Interferometry as a frequency reference**
- **Optical beam alignment**







Grading

Schedule (subject to revision)

Date	Description
02/25 (T)	1st Manuscript due
04/03 (R)	2nd Manuscript due
05/08 (R)	3rd Manuscript due

Class Participation + Lab Notebook	15%
3 Formal Manuscripts (20% each)	60%
Homework & Lab Skills Demos	10%
Presentation	15%
Total	**100%**

Late work policy: *Late manuscripts will be marked down one full letter grade for each class that passes after report is due.*

In some cases, it may be possible to resubmit a report with revisions for more credit.

Please check course website for schedule updates.

Class Participation

Lab notebooks will count towards participation.

Attendance will also count towards participation. Discuss any *expected* absences with me ASAP. (Including prospective graduate school visits.)

Unexpected absences: Illness and emergencies happen. If at all possible, you must inform me and your lab partner(s) before class if you will not be there. (However, habitual absences will not be tolerated.)

In the case of any absence, expected or not, you must negotiate a fair split of work with your lab partner(s). You and your partner will inform me of your agreement.

Lab Notebook

- **Each group maintains an Electronic Lab Notebook (google docs)**
- All students are expected to bring a laptop to each class. (See me with any problems.)
- At the beginning of every experiment, each group will begin a Google Doc to serve as lab notebook for that experiment and share it with **drakete@unm.edu** and **xli1@unm.edu**.
- The lab notebook should be detailed, clear, complete, and updated every class. You will be graded on the completeness and clarity of your notes-- **using your lab notebook, a third party should be able to reproduce your work**.
- The instructors will look at your lab notebook each week to gauge your preparedness and progress; this will count towards your class participation grade.

Class Participation: “Group Meetings”

For the final hour of class (for most classes), I will either present a lecture on a relevant topic (Tuesdays) or your group will give the class an update on your experiment (Thursdays). In most cases, the update will have a specific topics (i.e. introduce your experiment, present a completed figure for peer review, etc.).

Topics to present will be given at least 1 class in advance.

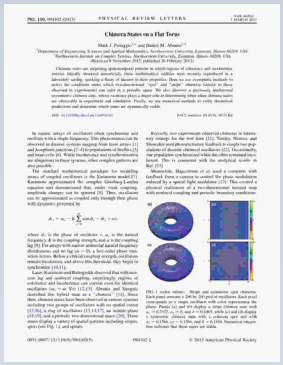
Preparing a Journal Article on your experiment

Purpose: Gain familiarity with formal writing style of scientific journals.

- Each student produces a separate formal report based on experiment.
- Students in the same group are expected to have the same raw data, but writing and data analysis will be done individually. Students should work together to discuss how to complete analysis and peer edit the manuscripts.
- Reports should follow the style of a scientific journal.
- Students are expected to create a free Overleaf.com account and prepare their manuscript in LaTeX. Using a template from a journal such as PRL is very helpful!

→ In a future lecture, I will review the expected sections and style of a scientific manuscript prepared for submission to a peer-reviewed journal. A document with guidelines available on class website.

Phys. Rev. Lett.


Chimera States on a Flat Torus

Opt. Lett.


Hydrophobic photonic crystal fibers

Oral Presentation

Prepare and present a **~20 minute lesson** based on an important concept and/or technique used in this class. (A presentation of a historically important experiment related to one of the experiments you did is also acceptable.) Presentations will be given during the 3rd module.

Purpose

- Strengthen your understanding of an important concept
- Strengthen your communication and presentation skills
- Think how to present a laboratory technique/science to a broad audience

Topics will relate directly to PHYS493L experiments.

A practice lecture with me is required.

In addition to the lecture, you will prepare a short “classwork” assignment for your classmates based on your lecture. (due 1 week before lecture)

Oral Presentation

Potential topics:

- Hyperfine structure
- Impedance matching in detection
- Hong-Ou-Mandel experiment: quantum photon statistics
- Doppler-free spectroscopy
- The Rossi-Hall muon experiment
- Precision and uncertainty in (a) fundamental constant(s)
- The 2029 redefinition of SI units
- …

Homework & Lab Skills Demos

- **Some lectures will come with homework (error analysis, for example).**
  - Due 1 week after lecture (or at the end of lecture, if appropriate).
  - These are short assessments to gauge understanding of material.
- **During the second module, students will perform a number of tasks demonstrating their laboratory skills.**

  Probable tasks include but are not limited to:
  - Two-mirror alignment of a laser
  - Photomultiplier tube calibration
  - Detection of a high-bandwidth optical signal

Lab Notebook

- **Each group maintains an Electronic Lab Notebook (google docs)**
- All students are expected to bring a laptop to each class. (See me with any problems.)
- At the beginning of every experiment, each group will begin a Google Doc to serve as lab notebook for that experiment and share it with **drakete@unm.edu** and **xli1@unm.edu**.
- The lab notebook should be detailed, clear, complete, and updated every class. You will be graded on the completeness and clarity of your notes-- **using your lab notebook, a third party should be able to reproduce your work**.
- The instructors will look at your lab notebook each week to gauge your preparedness and progress; this will count towards your class participation grade.

Lab Notebook Format

- At the beginning of every experiment, each student will begin a Google Doc to serve as lab notebook for that experiment and share it with **drakete@unm.edu** and **xli1@unm.edu**.
- Sections of a lab notebook, for each separate experiment:
  - Before starting a new experiment: **Experimental Plan**
  - **New entry for every day in lab**

Note: sharing equipment with Senior Lab

Lab Notebook: Planning the experiment

Prior to beginning a new experiment, you will have read all the way through the manual and decided:

- What tasks must be completed on which days to finish the experiment in the time allotted?
- What data will you be taking for your report (and when)?
- Do you have any questions about the experiment or the physics involved?
- What equipment will you need to start?

<u>Make one entry at the beginning of each experiment where you and your partner plan our the work.</u>

Lab Notebook: Daily log

- **Name, Date (for each new day)**
- **Objective**: Your goal(s) for the day
- **Plan**: How you will reach the day's objectives. Your plan of attack.
- **Expected results/hypothesis**: This is a clear if/then statement that defines the independent variables (your inputs, what you will do/change), the dependent variables (your outputs), and what you expect to learn.
- **Methods:** Plan out your work. Explain any procedures. What equipment do you need?
- **Results:** Your data (or a link) and results
  - This should include difficulties, how you solved them, and anything that went wrong, as well as what went right.
- **Analysis:** Beyond the data that you present above, this is how you interpret and understand the data. A plot that aggregates and compares your analyzed results is good.
- **Conclusions**: What you accomplished and what you learned.
- **Reflections and next steps:** What will you do next? Were there any interesting or unexpected things you came across? Are you concerned that you should go back and check the validity of some step? Do you see a potential problem on the horizon?

Use **figures, photos, drawings, detailed descriptions of setup**, etc.

Include important information such as **experimental parameters**, etc.

*Remember: A lab notebook is a legal document recording your work and discoveries.

Lab Safety, General

- **Footwear**.- Closed-toed shoes with a low, covered heal.
- **Electrical**.- Some experiments use HV supplies. Look for damaged cables or faulty connections.
- **No food or drinks**.- Do not eat or drink in the laboratory. Any spill can cause irreversible damage to equipment and can cause an accident when working with or near HV equipment.*
- **Broken or nonworking equipment**.- Report any nonfunctioning equipment to the lab instructor or the TA.
- **Secure room**.- Close the door behind you when you leave or you go out of the laboratory for a short period of time.

* I encourage you to bring bottled water and keep it in the provided cubbies. Snacks and water can be taken outside to eat.

Lab Safety, general continued

- **Broken glass**.- Do not deposit chipped or broken glass in normal trash containers. Use a glass bin.
- **No loose ends**.- Tie your shoelaces and long hair must be tied back.
- **House keeping**.- Clean up and make sure everything is safe before you leave. Keep your work area in order. Do not block passages or exits with cables or equipment.
- **Report any accident or concern to the instructor or TA.**
- **Before doing an experiment**.- Talk to the instructor or TA about the safety concerns of each experiment and any special instructions for working with sensitive equipment.
- **Use caution when handling radioactive material**. In most cases, only instructor or TA will handle.

Laser Safety

- **Training:** Complete laser safety training module on https://learningcentral.unm.edu/, “Laser Safety Training, UNM PandA”, and send me evidence of completion.
- **Read laser specifications.**
- **Use laser-safety glasses when needed.** (Provided with each laser experiment—get help to find some if not.)
- **Practice care, communication, and common sense:**
  - Most laser accidents occur during alignment, and many NOT to those aligning.
  - When laser is on, curtains are closed. (Otherwise, communicate to the room, distribute eyewear, and hang notes on doors.)
  - Remove jewelry and watches on hands, hanging necklaces, and anything else potentially reflective. Keep cell phones off lab tables and away from beam paths.

Today

- Email me a list of at least 3 experiments you would like to do. You can rank by order of preference.
- Complete laser safety training (pdf in email or UNM Learning Central).
- I will let you know who is in your group and which experiment you will be doing for module 1.
- Start a new google doc lab notebook and share it with me and the TA.
- Read the experiment manual and plan your work for the next module (entry 1 in lab notebook).

On Thursday, 1/23:

- You and your partner(s) will complete entry 1 in lab notebook (and have your work planned out, week by week).
- Your group will give a 5-10 minute presentation on your experiment:
  - What is the main idea of the experiment?
  - What will the main piece of data look like? (draw it on the board—include what the axes will be!)
  - What calculations/equations do you have to understand or work out?
  - Any thoughts or questions you want to present to the group for feedback