Advanced Laboratory Course (physics601)

Description of Experiments

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BONN-MG-2020-08MP
University of Bonn
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Contents

1 Guidelines for the Advanced Lab Course

1.1 Organisation

The advanced physics lab course is organised by:

- **Argelander-Institut für Astronomie (AIfA), Auf dem Hügel 71 (S experiments)**
  Laboratories:
  - Argelander-Institut für Astronomie (AIfA), Auf dem Hügel 71
- **Institut für Angewandte Physik (IAP), Wegelerstraße 8 (A experiments)**
  Laboratories:
  - Technikum (IAP)
  - Physikalisches Institut (W), Wegelerstraße 10
- **Helmholtz-Institut für Strahlen- und Kernphysik (HISKP), Nußallee 14-16 (K experiments)**
  Laboratories:
  - HISKP, room 0.029, Nußallee 14 - 16
  - Allgemeines Verfügungszentrum (AVZ), Endenicher Allee 11-13
- **Physikalisches Institut (PI), Nußallee 12 (E experiments)**
  Laboratories:
  - Hörsaalgebäude (HG), Kreuzbergweg
  - Physikalisches Institut (W), Wegelerstraße 10

1.2 Rules

1.2.1 Timetable for Experiments:

The experiments take place from Monday to Friday between 8:00 and 18:00 in agreement with the tutor. For safety reasons, experiments can be carried out outside of these times under exceptional circumstances only, and in the presence of the tutor. It is not possible to perform the experiments during the weekend or during bank holidays at all.

1.2.2 Groups:

The lab course will be performed in 2 students groups only. Due to safety restrictions it is absolutely forbidden that an experiment is carried out by one student alone.

1.2.3 Preparation:

Information on the experiments and the physics is given in the experimental guide. The literature is available in the University Library, Natural Science Section (MNL), Nussallee 15a, or, in certain cases specified in the experimental guide, from the tutor responsible for the experiment.

1.2.4 Supervision and Advice:

In order to carry out the experiment, the students must show that they are familiar with the physics backround, the experimental methods and the measurement program of the experiment. Furthermore, students must be able to deal with the experimental setup and equipment. This is checked in an oral exam before the experiment, in which also specific details of the experimental setup are explained. The tutor can also be available outside of the usual times to answer questions.

1.2.5 Lab report:

A report should be prepared by each participant for each experiment. In the report the experiment should be described and the measurements should be presented, taking into account both statistical and systematic errors. A group may submit a single lab report. In this case they are both responsible for its contents.
The lab report should be submitted within 1 week + 1 week/LU after completion of the experiment, i.e. 2 weeks for 1 LU, 3 weeks for 2 LU, and 4 weeks for 3 LU. If the lab report is not submitted in time, it will be counted as not complete. This limit can be extended by one week, if requested timely. The lab report must be submitted as a paper-version.

1.2.6 Participation:

Confirmation of the successful completion of the Advanced Laboratory Course (physics601) will be given when 9 LU have been reached.

More than one insufficient grade (grade less than 4.0) in the oral exams or more than one insufficient grade in the lab reports requires repetition of the entire lab course. The course leadership can decide whether successful experiment reports may be credited for the repetition.

Bonn, June 28, 2019
The course leadership

2 Guidelines for the Advanced Lab Course report

2.1 Introduction

Writing the experiment reports is preparation and training for writing the Master thesis and scientific papers. The aim of these guidelines is to make you familiar with the general scientific writing style as well as set some requirements specific for the Advanced Lab Course at the Bonn University.

Section 2.2 includes all the requirements that your report should meet. Not following the instructions of this part will affect the evaluation of your report.

The suggestions of Section 2.3 are not mandatory, but following them will help to further improve the quality of your report, simplify your future work, and teach you some helpful skills.

Note: Some experiments may cause specific report requirements. Please discuss the contents of this document with your tutor before writing the experiment protocol and follow his instructions.

2.2 Requirements

Contents The experiment report should document the physics of the experiment, the experimental setup, the measurement procedure, your data with errors, the data analysis and the discussion of the results.

Base knowledge Your report should be understandable for Master students who did not perform the experiment. To think of them reading your report should help you to work out a compromise between detailedness and redundancy.

Please give proper citations for everything which is not explicitly explained in the report. The level of Bachelor of Physics can be assumed as common knowledge and does not need to be further referenced.

Length and style You should write your report in a clear, precise language.

Your report should be as short as possible without missing important information.

Structure Your report should include

- **Introduction:** Write 3–5 sentences about the contents and the aim of the experiment.

- **Basics/Theory:** Write 1–3 pages about the theoretical basics of the experiment.

  Remember that you are not writing a lecture on theoretical physics and that you are not supposed to explain the theory. However, you should mention all basics necessary to understand the experiment, measurement and data-processing results, and your conclusions.

- **Methods/Experimental setup/Measurement procedure:** Describe the methods used to reach the aim of the experiment, i.e. the experimental setup, the differences of the experimental series, the different parameters used. Analyse the accuracy *and* precision of the measurements.

- **Raw and processed data:** Processed data should be presented in the main text of the report. You have to choose the optimal presentation form. Also present your raw measurement data (in the main text if the data amount is reasonable, otherwise in an appendix).

  All data presented in your report should have errors. Investigate and try to understand all types and sources of errors in all your measurements. Explain how you take them into account and estimate error values. Distinguish between systematic and random errors [1].

  Don't forget: Numerical values of both the measured quantity and its error should be given with an appropriate number of significant digits.

- **Analysis:** Analyse your data with respect to the aim of the experiment. Your task during the experiment is not just to measure and document your measurements, but to derive and present conclusions from your measurements. Your conclusions drawn from the processed data should be put into the text in a clear way.

  – Pay special attention to error calculation and presentation.

    Do not include obvious details of error calculations on the Bachelor level (e.g. Gaussian error propagation formulas) but do mention which errors were used in the calculation.

  – Choose a good graphic or tabular representation of your experimental data (*with errors*).

  – Fit some model (equation) to the results[1]. The fitting procedure gives you some numerical values for the parameters. Compare them with your expectations. If you observe some significant deviation from the experimental data, try to explain where the discrepancy could come from.

- **Conclusions:** Summarize and discuss your results with respect to the literature or your own scientific expectations. You should in particular discuss possible error sources and give a short judgement on the quality of the experimental setup (because you also learn to design the measurement set-ups). If needed, suggest how to improve the set-up.

[1]Give such equation explicitly in the theory part and explain the physical meaning of all variables and constants in the fit function. There you should also explain shortly why this model can be used to fit the data of this particular measurement; you should mention the assumptions and the scope of applicability of the model, as well as its shortcomings. If it is not obvious, you should explain how the values you have measured come into the model.

Scientific style rules

- Quote all sources (also pictures if you did not make them yourself). It should be clear what is your own result or idea and what you have taken elsewhere.

  Note: For plagiarism—reproduction of any material or data without referencing the source—the tutors have to give you 5 (failure) for a report.

- If you use abbreviations, define them the first time they are used in the text.
- Each plot, drawing, or table should be numbered and referred to in the text.
- Each picture and table should be accompanied by a short caption describing it. What measurement is shown? What is the equation used for the fit (equation number)? What the reader should notice in the picture (some important peaks, dips, etc.)? Sometimes the pictures are very simple. Then you need nothing but writing what is shown.

Printing Please do not use colour pictures, if no colour printer is available.

Please check all pages after you have printed your report to make sure that nothing is missing and no pages are shredded or unreadable!

2.3 Recommendations

Suggestions given here will help to improve your scientific writing style and the readability of your report by the tutor.

- In the text, use exact cross-referencing: instead of "above" and "below" write "in Section 2.3" or "Eq. (4) on page 7". (In LaTeX, use commands `\label`, `\ref`, `\pageref` for it.)
- Do not put the visual material too far from where it is mentioned in the text. If you cannot avoid putting it on another page, add a page reference in the text (e.g. "Fig. 2 on page 4").
- Number only the equations you refer to at some point in the text.
- Prevent line breaks between 1) a value number and a unit symbol, 2) words Fig., Tab., Sec., page, Eq. and the following numbers and 3) elsewhere where you find line breaks unsuitable.
- Distinguish between a hyphen (-), an en-dash (–), an em-dash (—), and a minus sign ($-$). In English, hyphens are used to connect words and for hyphenation, en-dashes for ranges, and em-dashes to connect parts of a sentence. The minus sign is used in the math-mode only.
- In English, a point should be used as a decimal separator.
- If you are typesetting your report in LaTeX, you may use the following packages:
  - http://www.ams.org/publications/authors/tex/amslatexamsmath—simplifies entering complex mathematical expressions and typesetting text in the math mode;
  - http://www.tug.org/applications/hyperref/hyperref—switches on PDF functions in LaTeX.
- If you want to further improve the visual quality of your text, you may wish to take a look at the http://www.ctan.org/tex-archive/help/Catalogue/entries/siunitx.htmlSIunitx package and at reference [2].

Bibliography

[1] R. J. Barlow, Statistics. A guide to the Use of Statistical Methods in the Physical Sciences (1989).

[2] A. Thomson, B. Taylor, The NIST guide for the use of the International System of Units, http://www.nist.gov/physlab/pubs/sp811/index.cfm.

3 Instructions for Radiological Protection for participants in the Advanced Laboratory Course (physics601)

3.1 Introduction

In some experiments you have to deal with ionizing radiation. There you have to take precautions for the protection of your health and also to avoid strains for the environment. The main goal is to minimize the individual exposure. There is a legal obligation to instruct all persons who work with x-rays or radioactive material about possible dangers and necessary measures for protection. After the instruction persons have to sign a record which then proves to government authorities that they had been instructed before starting work.

3.2 Biological effects of ionizing radiation

All biological effects have their origin in the basic processes of ionization and excitation of atoms and molecules by the radiation. The process of ionization necessarily changes atoms, at least transiently, and may thus alter the structure of the molecules containing them. Molecular changes may also be caused by the excitation of atoms and molecules if the excitation energy exceeds the binding energy between atoms. About half the energy deposited in tissue by ionizing radiation is due to excitation, but this is of less consequence than ionization. If the affected molecules are in a living cell, the cell itself may sometimes be damaged, either directly, if the molecule is critical to the cell's function, or indirectly by causing chemical changes in adjacent molecules, e.g. the production of free radicals. Of the various forms of damage that radiation can cause in cells, the most important is that in the DNA. Damage in the DNA may prevent the survival or reproduction of the cell, but frequently the damage is repaired by the cell. If that repair is not perfect, it may result in a viable but modified cell. The size of the biological effects of ionizing radiation depends on the properties of the exposed tissues, on the linear energy transfer (LET) of the radiation, on the absorbed dose, i.e. absorbed energy per mass unit, and on the size of the exposed volume. The last item depends on the geometrical arrangement of radiation source and human body and on the range of the radiation in tissue.

3.3 Definitions and units

The activity of a radioactive substance is measured in Becquerel: Bq. 1 Bq = 1 decay per second. The connection with the formerly used unit Curie is: 1 Ci = 3.7 x 1010 Bq. A non-stationary γ-radiation source in the lab course has typically an activity of about 0.2 MBq. The fundamental dosimetric quantity in radiological protection is the absorbed dose, D. This is the energy absorbed per unit mass and its unit is the joule per kilogram, which is given the special name gray (Gy). To take into account the different effect of radiation with different LET this absorbed dose must be weighted for the radiation quality that is of interest. The weighting factor for this purpose is now called the radiation weighting factor, w_R, and is selected for the type and energy of the radiation incident on the body or, in the case of sources within the body, emitted by the source. The weighted absorbed dose is the equivalent dose, H. $H = w_R \cdot D$. The unit of the equivalent dose is the Joule per kilogram with the special name Sievert (Sv). For photons and electrons of all energies w_R is 1, for neutrons it is between 5 and 20, depending on the energy, and for alpha particles it is 20.

3.4 Natural and occupational exposure

Even without occupational exposure to ionizing radiation there is always an exposure to natural sources: potassium-40 in the body, cosmic rays at ground level, and radionuclide in the earth's crust. This exposure is outside any reasonable scope of control. Only the exposure to radioactive radon can be influenced to a certain extent for instance by air ventilation. The equivalent dose per year from natural sources is in Bonn not less than 2 mSv. This can be compared with the estimated maximum dose through occupational exposure by participating in the lab courses of 0.22 mSv. Under normal circumstances the real dose should be much smaller than even this value. Therefore film badges for dose control are unnecessary in the Advanced Laboratory Course. In fact the experience of former years with film badge control was, that the dose of course participants was always below the detection limit.

3.5 General advice for protection

(1) Time : Dose is proportional to exposure time. Avoid unnecessarily long exposure.
(2) Distance: Physicists should of course know, that dose will be inverse proportional to the square of the distance from the radiation source.
(3) Shielding: The easiest way is to shield directly at the source, then the amount of material is minimum. Gamma rays cannot be shielded totally: the attenuation follows an exponential function with the thickness of the absorber in the argument. For alpha particles from radioactive decay a not too thin sheet of paper is sufficient for 100 % shielding.
The radioactive sources used in the lab courses are enclosed in inactive containers. Therefore there is no danger of contamination or incorporation. In the case that during an experiment the container is damaged participants have to inform immediately their tutor, one of the docents of

the Advanced Laboratory Course or one of the radiation safety officers Dr. K. Peithmann, HISKP, Tel.: 73-3470 or Dr. C. Wendel, HISKP, Tel. 73 5451. When not in use radioactive sources are kept in lead lined safes. In some experiments students have to use different radioactive sources one after the other. In such cases they should apply the existing shielding and keep adequate distance from the sources not used in the moment. Students are responsible for the proper use of the radioactive sources which have been handed over to them for the experiment. After finishing of the experiments radioactive sources which are not stationary in an apparatus must be locked away by the tutors in the respective lead safe.

Dr. C. Wendel

Bonn, January 26, 2015

E207 Lab course Accelerator Bonn (LAB)

E207.1 Aim of the Experiment

The **L**ab course **A**ccelerator **B**onn setup is a linear, electrostatic electron accelerator specially designed for the advanced laboratory course. This experiment is intended as introduction to the physics and operation of particle accelerators and allows the students to gain experience in the handling and characterization of ion optics.

The electron beam is emitted by an electron source and accelerated in an electrostatic field to a kinetic energy of 25 keV. Its path and shape along the approximately 3 m long vacuum pipe can be controlled by typical ion optical elements – namely dipole and quadrupole magnets. The resulting beam profiles can be investigated with fluorescence screens. The entire experiment is operated using the original computer control system of the ELSA accelerator, which is the largest university operated accelerator in Europe and located at the Physics Institute in Bonn.

E207.2 Required Knowledge

This experiment is intended as an introduction to the physics and operation of particle accelerators. To carry out the experiment, you should be familiar with the basics of accelerator physics like:

- Types of particle accelerators and their working principle.
- Typical components like optical elements, acceleration mechanism, monitoring.
- Characteristic variables like beam emittance, Twiss parameters.
- Matrix formalism for ion optics.
- Measurment methods for the determination of the beam emittance.
- Procedure of beam based alignment of a beam in the quadrupole magnets.

E207.3 Literature

- The script for the experiment gives a brief overview about the setup and short explanations of the individual components. Some basics of accelerator physics and the matrix formalism for ion optics are also introduced there. Contact your tutor to get a copy.
- The following textbook is recommended for a more comprehensive overview:
  Klaus Wille, *The Physics of Particle Accelerators: An Introduction*, Clarendon Press, 2000

E207.4 Assignments

- It is recommended to conduct the experiment on one full day. Each group arranges time and date with the tutor.
- The script should be obtained from the tutor at least one week in advance.
- Procedure and the analysis of the measurements which have to be performed in the lab course are described in detail in the script. The following list gives a summary:
  1. **Beam Based Alignment:** After verifying the calibration of the corrector magnet's kick angle, align the beam with the corrector magnets so that it is centered horizontally and vertically in all four quadrupole magnets applying the beam based alignment method.
  2. **Emittance Measurement:** Determine the horizontal and vertical emittance of the beam via quadrupole scan technique and via multi screen method. Compare your results.

Best wishes for a successful experiment! Date: July 2020

E213 Analysis of Z0 Decays

E213.1 Aim of the Experiment

This experiment is an introduction to modern analysis methods in high energy physics. Data collected from e^+e^- collisions with the OPAL detector at the LEP collider are analysed with a computer. The analysis strategy is optimized with the help of simulated events.

E213.2 Required Knowledge

- Elementary particles and their properties, symmetries and conservation laws, standard model, scattering reactions and their angular dependence, s- and t-channel reactions, Feynmandiagrams, unification of electromagnetic and weak interactions.

- Interaction of particles and matter, particle accelerators and detectors, (esp. the OPAL detector).

- Statistical analysis, χ^2 test, weighted mean, Breit-Wigner distribution.

E213.3 Procedure and analysis

- Part I: Graphical analysis of Z^0 decays.
  In the first part of the experiment you will get aquainted with the different decay channels of the Z^0-boson on an event-by-event basis. You are supposed to learn how to find characteristic properties which allow to distinguish between the various final states. To achieve this, the signatures of the various processes and the detector properties must be understood thouroughly.

- Part II: Statistical analysis of Z^0 decays.
  Using the knowledge achieved in the first part a large data sample is analysed. The resonance parameters of the Z^0 boson (cross section, mass, decay width) are measured in various decay channels. The Weinberg angle is measured from the forward backward asymmetry of the reaction $e^+e^- \to \mu^+\mu^-$. Lepton universality is to be verified and the number of light neutrino generations should be determined.

- The data samples for the second part were made using a preselection in data and Monte Carlo events. This has to be taken into account as a correction when determining the cross

  sections. The correction factor is the ratio of the number of generated Monte Carlo events and the number of events in the corresponding n-tuple.

  I.e.: for the τ Monte Carlo 100000 events were generated,
  79214 events pass the preselection cuts.
  correction factor: $100000/79214 = 1.262$

- There are 6 different data samples. The corresponding luminosities are listed in the table below. The data sample that you will use is chosen by the lab assistant.

E213.4 Literature

- Instructions: can be borrowed from the lab assistant

- D. Griffiths: *Elementary Particles*

- F.Halzen und A.D. Martin: *Quarks & Leptons*

- W.R. Leo: *Techniques for Nuclear and Particle Physics Experiments*

- R. Barlow: *Statistics*

Also any other text book which introduces to elementary particle physics. The instructions themselves are not sufficient for a proper introduction to particle physics.

E213.5 Assignments

- All problems from chapter 5.1 of the *instructions* should be solved.

E213.6 Appendix

- Experiment E213 counts three times and is done on two days. Appointments for the date are to be made with the lab assistant.

- The instructions should be borrowed from the lab assistant about 4 weeks before performing the experiment.

- The instructions also contain some sections on particle detectors and elementary particle physics which are necessary for the analysis. Furthermore the instructions contain some problems that are to be solved beforehand.

OPAL data n-tuple	energy (GeV)	$\mathcal{L}dt$ (nb^{-1})	**stat. error** (nb^{-1})	**sys. error** (nb^{-1})	**tot. error** (nb^{-1})
	88.48021	675.8590	± 3.502185	± 4.524100	± 5.721257
	89.47158	543.6270	± 3.179205	± 3.637000	± 4.830643
	90.22720	419.7760	± 2.810879	± 2.810400	± 3.974844
data 1	91.23223	3122.204	± 7.786547	± 20.91518	± 22.31760
	91.97109	639.8380	± 3.567344	± 4.287300	± 5.577354
	92.97091	479.2400	± 3.121618	± 3.216000	± 4.481870
	93.71841	766.8380	± 3.972102	± 5.142000	± 6.497519
	88.47777	371.9800	± 2.594937	± 2.488100	± 3.595044
	89.46906	488.5300	± 3.009684	± 3.273000	± 4.446429
	90.22324	378.5461	± 2.670417	± 2.533900	± 3.681273
data 2	91.23965	2072.793	± 6.334670	± 13.87960	± 15.25684
	91.96968	540.6800	± 3.274401	± 3.620000	± 4.881198
	92.97059	369.4000	± 2.737608	± 2.480000	± 3.693900
	93.71714	353.5000	± 2.695570	± 2.371000	± 3.589950
	88.47630	403.1200	± 2.702073	± 2.700000	± 3.819843
	89.46658	545.0066	± 3.174455	± 3.650900	± 4.837999
	90.21986	542.7271	± 3.200826	± 3.637500	± 4.845275
data 3	91.22910	2080.004	± 6.346789	± 13.92980	± 15.30755
	91.96428	493.6100	± 3.126548	± 3.302000	± 4.547362
	92.96229	340.7600	± 2.630304	± 2.284000	± 3.483555
	93.71362	622.4900	± 3.579958	± 4.180000	± 5.503499
	88.47939	463.9790	± 2.902361	± 3.104100	± 4.249604
	89.46793	667.5236	± 3.521166	± 4.471900	± 5.691792
	90.22266	486.7641	± 3.033955	± 3.261500	± 4.454466
data 4	91.22430	2246.568	± 6.603405	± 15.04780	± 16.43293
	91.96648	535.9080	± 3.265110	± 3.585300	± 4.849260
	92.96465	450.6000	± 3.027953	± 3.020000	± 4.276552
	93.71712	709.6980	± 3.819882	± 4.762000	± 6.104764
	88.47939	463.9790	± 2.902361	± 3.104100	± 4.249604
	89.46957	472.6636	± 2.964559	± 3.161900	± 4.334307
	90.23120	510.2150	± 3.099458	± 3.414400	± 4.611373
data 5	91.23193	3898.628	± 8.694719	± 26.11330	± 27.52277
	91.97322	518.6880	± 3.213012	± 3.475300	± 4.732985
	92.96836	624.5900	± 3.564113	± 4.190000	± 5.500818
	93.71712	709.6980	± 3.819882	± 4.762000	± 6.104764
	88.48021	675.8590	± 3.502185	± 4.524100	± 5.721257
	89.46928	800.8436	± 3.855322	± 5.364900	± 6.606486
	90.22604	873.7021	± 4.057872	± 5.851900	± 7.121170
data 6	91.24186	7893.498	± 12.37099	± 52.87910	± 54.30692
	91.96859	825.2780	± 4.051215	± 5.527300	± 6.852984
	92.96836	624.5900	± 3.564113	± 4.190000	± 5.500818
	93.71685	942.2280	± 4.403135	± 6.322000	± 7.704238

Radiation corrections on A_{fb}

The following table shows the radiation corrections for the measurement of A_{fb} depending on the center–of–mass energy.

$\sqrt{s}$ (GeV)	Radiation correction
88.47	0.021512
89.46	0.019262
90.22	0.016713
91.22	0.018293
91.97	0.030286
92.96	0.062196
93.71	0.093850

The radiation corrections are given for all center–of–mass energies and must be added to the measured asymmetry. E.g.: the measured value of A_{fb} at $\sqrt{s} = 91.22$ GeV is 0.002194 then 0.018293 must be added. Thus the corrected asymmetry is 0.020487.

Assuming the mass of the Z^0 is known to be $m_{Z^0} = 91.1863$ GeV the radiation correction can be calculated to give the corrected asymmetry for $\sqrt{s} = m_{Z^0}$. This alternative radiation correction is 0.0152 for the measurement of A_{fb} at $\sqrt{s} = 91.22$ GeV.

Best wishes for a successful experiment! Date: December 2016

E214 ATLAS

E214.1 Aim of the Experiment

This laboratory exercise introduces you to the physics at the Large Hadron Collider. The main focus is on physics processes that are investigated by the ATLAS experiment. In 2008 the ATLAS detector started to collect data. Until sufficient amounts of data are available, the exercise will be based on simulated data, which are a good representation of what we can expect at the LHC. Data analysis will be the main focus of the exercise.

E214.2 Required Knowledge

- A lecture on particle physics, such as Bachelor level Particle Physics, is required. Students should be familiar with the following topics: Relativistic kinematics, symmetries and conserved quantities, Standard Model, properties of $W^{\pm}$ and Z^0 bosons.
- Interactions of particles with matter, detectors for particle physics.
- χ^2-test, Breit-Wigner curve, Jakobi determinant.

E214.3 Procedure and analysis

Students will work on assignments 1 and 2 and either assignment 3 OR 4.

- **Assignment 1: Event displays** This assignment allows you to become familiar with the ATLAS detector and to learn about the characteristics of LHC collisions as recorded by the detectors. For this you study graphic representations, so called event displays, and work on introductory tasks.
- **Assignment 2: Calibration of electrons** As electrons play an important role in the last two parts of this experiment the measurement of the electron energy is calibrated. To do so the data analysis software **ROOT** is used.
- **Assignment 3: Measurement of the $W^{\pm}$ boson mass** Based on the previous assignment, the mass of the $W^{\pm}$ boson in the decay channel $W^- \to e^-\bar{\nu}_e$ is measured.
- **Assignment 4: Search for new physics** In this part of the experiment, events with four leptons are investigated. In addition to Z^0 pairs there are numerous scenarios for new physics, which can contribute to this final state. Students study the kinematic properties of Z^0 pairs and search for signs of new physics.

E214.4 Literature

- Script; the tutor will lend you a copy.
- D. Griffiths; Introduction into Elementary Particles
- Berger; Teilchenphysik
- F. Halzen und A.D. Martin; Quarks & Leptons
- W.R. Leo; Techniques for Nuclear and Particle Physics Experiments
- C. Grupen; Particle Detectors
- R. Barlow; Statistics
- B. Povh, K. Rith, C. Scholz, F. Zetsche; Particles and Nuclei: An Introduction to Physics Concepts

Other textbooks on particle physics are also suitable.

E214.5 Assignments

- All assignments are explained in detail in the script.
- The laboratory assignment E 214 is a triple-valued exercise and will be done on two full days. Each group arranges time and date with the tutor.
- The script should be obtained from the tutor at least four weeks before the laboratory exercise.
- Please note that there are questions in the script that should be answered by the students in writing before the laboratory exercise.

Best wishes for a successful experiment! Date: May 2012

E217 STYX

E217.1 Aim of the Experiment

The Straw Tube Young student eXperiment (STYX) comprises elements of the forward tracking system of the decommissioned ZEUS detector at DESY. By designing a new trigger and readout system it was converted into a lab course experiment. The aim of the STYX experiment is to learn about basic nuclear electronics instrumentation, gas detectors, cosmic radiation, tracking of charged particles and state-of-the art readout systems as well as computer based data analysis.

E217.2 Literature

In preparation for the experiment, we recommend the following literature:

- STYX instructions. Pick up a copy from the tutor!
- Leo, W.R.: Techniques for Nuclear and Particle Physics Experiments
- Grupen, Claus: Astroparticle Physics

There is also an exhaustive overview about cosmic rays in the PDG (although the other references are probably easier to understand):

- PDG chapter 24: Cosmic rays `http://pdg.lbl.gov/2011/reviews/rpp2011-rev-cosmic-rays.pdf`

E217.3 Required Knowledge

- Essential for the conduction of the experiment is a solid knowledge of the working principle of gas detectors (chapters 6.1 - 6.5 and 6.7 of the Leo) and of secondary cosmic rays (chapter 7 of the Grupen).
- In general we also expect knowledge on the basics of general particle physics. If you need to refresh your knowledge, just any overview book is OK (e.g. Perkins, Griffiths, ...).
- You should understand the basic working principles of scintillation detectors and photomultipliers. The level of knowledge required for other lab course experiments is sufficient. In case of no prior knowledge, a good introduction can be found in chapters 7.1, 7.2 and 8 of the book by Leo.

- Finally you should be familiar with basic concepts of electronic signal processing. Units used in the setup are amplifiers, shapers, discriminators, TDCs, counters and coincidence units. Information can again be found in chapters 14 and 17 of the book by Leo.

E217.4 Assignments

STYX is a two day experiment to be carried out at two subsequent days. **Please contact the tutors early in advance to agree on dates and get an extended description of the experiment and the concrete assignments.**

The idea of the lab course experiment is to setup and commission a particle detector and analyse data taken with it. It is not about achieving a given expected final result. During carrying out the experiment you have freedom to put focus on things that are most interesting to you. Bottom line: Of course you can find older lab course reports but you will have more fun and learn more if you don't read them in advance.

E217.5 Procedure and analysis

E217.1.1 Day One

During the first day you will explore the detector. Several operational parameters will have to be tuned before you can actually take data. You will hence measure various properties of the setup and their dependence on externally supplied references.

After a suitable working point is found you will start an over night measurement.

E217.1.2 Day Two

During the second day you will analyse the data recorded over night. Before any physics can be deduced the data has to be calibrated. Afterwards you will have time to investigate properties of cosmic radiation and/or the detector setup on your own in a provided software framework.

Best wishes for a successful experiment! Date: June 2013

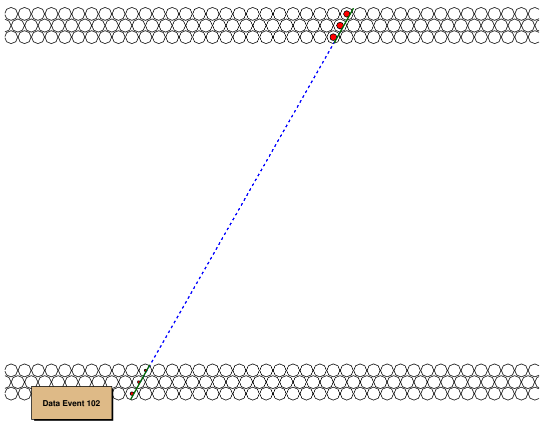

Figure E217.1: Example event of a reconstructed cosmic muon recorded by STYX

Figure E217.2: Sketch of the STYX experiment

K221 Mößbauer effect

K221.1 Aim of the Experiment

The aim of the experiment is to get familiar with the principle of recoilless emission and absorption of γ–quanta. The Mößbauer effect can be investigated using a ^{57}Co source and a relatively simple setup. The magnetic hyperfine structure of the 14.4 keV transition in ^{57}Fe is to be measured.

K221.2 Required Knowledge

- Basics of resonance absorption; natural line width; Doppler broadening and recoil energies for optical and γ–transitions in the free atom and in the solid state
- Definition of the Debye–Waller factor, its dependence on temperature and γ-energy
- Application of the Mößbauer effect; Measuring methods in Mößbauer experiments
- Decay scheme of ^{57}Co; Hyperfine structure (magnetic dipol, electric quadrupole interaction, isomeric shift); magnetic hyperfine components of the 14.4 keV transition

K221.3 Literature

The textbooks in nuclear physics usually discuss the Mößbauer effect in short. E.g., the basic facts can be found in the following German textbooks:

Mayer–Kuckuk: Kernphysik
Teubner Verlag

To prepare for this experiment the book of

Schatz, Weidinger: Nuclear Condensed Matter Physics
Teubner Verlag

is especially suited. In it all prompts above mentioned are discussed at length. Furtheron, have a look at

Bodenstedt: Experimente der Kernphysik und ihre Deutung, Band II
BI Verlag (1973), p. 507 – 521.

A fundamental treatise on the Mößbauer effect is given by

Wegener: Der Mößbauer-Effekt
BI Hochschultaschenbücher (1965)
p. 9 – 36, 52 – 70, 78 – 82, 90 – 101, 163 – 165

This book is cited in numerous other textbooks. The book of Schatz–Weidinger is a synopsis of the cited pages. A very interesting treatise on the Mößbauer effect in English language offers the textbook of

Krane: Introductory Nuclear Physics
Wiley & Sons (1987)
p. 361 – 376, 645, 649 – 652

E.g., on p. 650 a method is introduced how the magnetic moment of the excited state can be determined in relation to that of the ground state if already known.

K221.4 Assignments

- Measurement of the ^{57}Fe gamma–spectrum and setting of the single channel analyser on the 14.4 keV line.
- Measurement of the Mößbauer spectrum of the 14.4 keV line of ^{57}Fe (Single–line source and metallic Fe–absorber)
- Comparison of the measured line widths with the theoretical value. From the separation of the lines the g–factors for the ground state and first excited state shall be determined. (For the metallic absorber assume a magnetic field of $H = (333 \pm 10)$ kG at the position of the nucleus). Determine the isomeric shift in eV and qualitatively explain the result.

K221.5 Procedure and analysis

For recording the Mößbauer spectrum the velocity of the absorber shall be varied between 0 and about 6 mm/s. You are advised to map the results during the measurement so that the velocity step width of the motor control may be reduced in the region of high absorption. A sketch of the counting electronics is provided in figure K221.1. After pressing the start-buttom of the absorber velocity control a gate pulse is generated as soon as the absorber has reached the left position of return. Then, depending on the running direction of the absorber the detector pulses are fed from the single-channel-analyser into the counters N(LR) and N(RL), respectively. At the same time the pulses from the timer are put into counters T(LR) or T(RL). These counters provide the duration of both measurements. The number of left-to-right turns is indicated by the run counter. After pressing the stop–buttom the counters are only stopped when the number k of left-right and right-left runs is equal. From the total running time for each direction the respective absorber velocities can be calculated. The total swing of the device is $s_0 = 25.1\,\text{mm}$. From $N(\text{LR})$, $N(\text{RL})$, $T(\text{LR})$ and $T(\text{RL})$ the counting rates for both directions can be computed. (Attention when calculating the errors). Due to an offset-voltage in the operational amplifiers of the control circuit $T(\text{LR})$ may differ from $T(\text{RL})$.

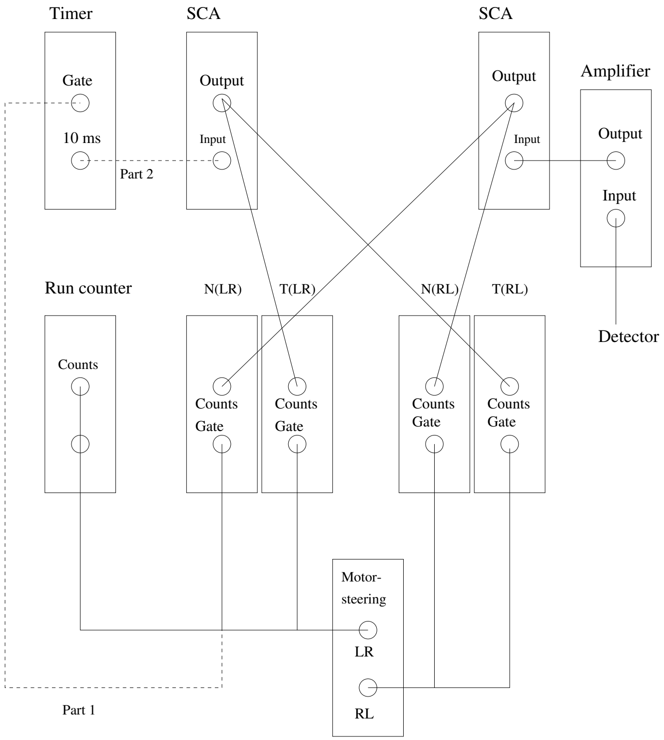

Figure K221.1: Principal circuit diagram of the apparatus

Best wishes for a successful experiment! Date: July 2016

K223 Angular Correlation

K223.1 Aim of the Experiment

Electromagnetic multipole radiation has a non-isotropic angular distribution. Considering a gamma decay of a nucleus, the orientation of the emission distribution arises from the spin orientation of the parent nucleus.
In thermal equilibrium, the net orientation is zero as all spin states are populated with an equal density. All spin configurations are equally probable and in this case, the gamma ray distribution of an ensemble of nuclei is isotropic.

A non-equilibrium spin state can be achieved in a cascaded gamma decay of a nucleus. Detecting the fist photon of the cascade yields constraints on the spin probability of the resulting meta stable state of the nucleus. Therefore, a non isotropic angular distribution of the second photon can be measured if the first one was detected at a specific position.

The aim of the experiment is to prepare the experiment and to measure the angular correlation of the $\gamma - \gamma$ cascade of ^{60}Co.

K223.2 Required Knowledge

- Definition of the angular correlation of a $\gamma - \gamma$ cascade. Explanation of the angular correlation of a hypothetical $0 \rightarrow 1 \rightarrow 0$ $\gamma - \gamma$ cascade. Which quantities enter into the angular correlation coefficients? Perturbation of the angular correlation by hyperfine interaction.

- What information can one obtain by the measurement of angular correlation - with and without extranuclear perturbation?

- Design and operation of a scintillation spectrometer; fast-slow coincidence technique; components of the setup (SCA, CFD, ...); time resolution of the detector and of the coincidence unit; expected spectrum of ^{60}Co;

- Analysis of the experimental data: corrections for solid angle, accidental coincidences and deadjustment; Determination of the angular correlation coefficients by means of least-squares-fit to the data, determination of experimental errors.

- Decay-scheme of ^{60}Co.

K223.3 Literature

- *Siegbahn Vol. 2: α-,β- and γ-Ray Spectroscopy*, pp. 1029-1035, 1101-1104, 1190-1195, 1695

- Melissinos: *Experiments in Modern Physics*, pp. 412-429, 461-476

- Riezler/ Kopitzki: *Kernphysikalisches Praktikum*

- Schatz/ Weidinger: *Nuclear Condensed Matter Physics: Nuclear Methods and Applications*, Wiley, 1^{st} edition (1996), pp. 14-20, 63-68, 80-85

- Leo: *Techniques for Nuclear and Particle Physics Experiments*, Springer, 2^{nd} Rev. edition (1994)

K223.4 Assignments

Contact your tutor to receive the full description and supplementary literature for this experiment. Here, only a brief summary of all tasks is shown.

Additionally to studying the theory background of this experiment and the properties of the used electronics, it is mandatory to prepare a few tasks before the experiment.

Tasks for Preparation

1. In a practical setup, the alignment of the source can only be done to a certain precision. How will a misalignment manifest in the data? How can you correct it?

2. As measurement time is limited, a compromise has to be found between number of angles for which measurements are taken and statistical precision at those points. Prepare a proposal for the angular stepping you want to use.

3. Another compromise needs to be taken when picking the distance between detector and source. A low distance will increase the event rate, resulting in a better statistical precision. However, a close distance will also decrease the angular resolution of the measurement, making corrections necessary. Prepare a proposal for the angular stepping you want to use.

Adjustment of the Setup

1. Prepare the Constant Fraction Discriminator. Perform a threshold scan to find the optimal setting.

2. To align the timing in the fast circuit, insert a delay into one of the branches and measure the prompt curve. Extract the resolving time and the setting for optimal alignment

3. Adjust the gain in the slow circuit and record an energy spectrum.

4. Align the timing of the fast circuit vs the slow circuit.

Measurement of the Angular Correlation

1. Move the detectors to the proper distance to the detector and perform measurements:
   a) One, having a fine angular stepping.
   b) One, with fewer positions but longer measurement time.
   c) One several times distributed over the day at the same angle to understand the stability of the setup.
2. Misalign the coincidence circuit to measure random coincidences. Compare the measured value to the theoretically predicted random coincidence rate.

Analysis of the Data

1. Subtract random coincidences from the measured rates and compensate the misalignment of the setup.
2. Apply a least squares fit of the predicted function to the resulting data and apply solid angle corrections.
3. Try to fit angular correlation functions for cascades with different spins. Can those be ruled out?
4. Plot the angular distribution including data, fit, and prediction.

Best wishes for a successful experiment! Date: July 2018

K225 Positron Lifetime in Metals and Insulators

K225.1 Aim of the Experiment

The aim of this experiment is to investigate the vacancy formation in solid state materials. Therefore the temperature dependence of the positron lifetime is measured using a fast-slow-coincidence setup. The formation of positronium is investigated by measuring a positron lifetime spectrum in acrylic glass.

K225.2 Required Knowledge

- metals
  - lattice defects in metals
  - trapping model, positron lifetime spectrum
  - vacancy concentration in thermal equilibrium, formation enthalpy of vacancies
- positrons
  - positron sources, decay scheme of ^{22}Na (γ-energy spectrum)
  - positron annihilation
  - positronium formation, pickoff-decay
- measurement technique
  - LYSO scintillator, ^{176}Lu decay scheme, LYSO spectrum
  - photomultiplier (PM), dynode pickup
  - single channel analyzer (SCA), constant-fraction-discriminator (CFD)
  - time-to-amplitude converter (TAC), multichannel-analyzer (MCA)
  - fast-slow coincidence curcuit
  - prompt curve, resolving power, detector response function

K225.3 Literature

- Schatz/Weidinger: “Nuclear Condensed Matter Physics”
- Leo: “Techniques for Nuclear and Particle Physics Experiments”
- Kittel: “Introduction to Solid State Physics”
- **This script is ment to give an overview. The detailed description has to be borrowed from the assistant 1–2 weeks before the experiment. Ask via email for a digital copy.**

K225.4 Assignments

Preparation in advance Additionally to studying the theory background of this experiment, it is mandatory to prepare a software macro to analyse the life time spectra before you start the experiment. To ensure that your macro extracts the correct values, your assistant will also provide you with simulated life time spectra. Check that your macro fullfills the following demands:

1. Zero bins should be ignored.
2. The fit has to be error weighted.
3. The starting values of the fit should be easily accessable as parameters.

With your macro at hand you will be able to analyse your spectra already during the lab and optimzie your measurement.

Adjustment of the FAST-SLOW Cirquit and time calibration

1. Measure one intrinsic LYSO energy spectrum and a spectrum of the ^{22}Na source wich each detector. Tune the gain of the main amplifiers according to the 1275 keV lines.
2. Perform threshold scans to find the appropriate settings for the CFD thresholds. Setup the TAC and adjust the timing according to the SLOW cirquit.
3. Set the windows of the single channel analyzers around the 511 keV lines. Acquire prompt spectra using different delay settings in the FAST cirquit. Use these events to derive a time calibration and calculate the time resolution of the setup. Also investigate the linearity of the time measurement.

Positron life time measurements

1. Change the SCA window of the start detector to cut on the 1275keV line in order to measure the positron life time. Optimize the position of the ^{22}Na source and the detector gap to increase the count rate.

2. Investigate how much time the heating system needs to stabilise by collecting one temperature vs. time graph.

3. Estimate the maximal temperature that can be reached with the setup and measure the life time spectra for eight different temperatures starting at room temperature. **ATTENTION: Do not heat close to the melting point of indium (156^{o}C)!** Use your macro to optimize the temperature binning.

4. For each temperature extract a mean positron lifetime and deduce the vacancy formation enthalpy from the temperature dependence.

5. A lifetime spectrum in acrylic glass shall be measured in a long term run. From this determine all possible lifetimes and interpret them.

6. All spectra collected during the experiment have to be saved for documentation. The data will be stored in ASCII-form. Therefore provide a USB storage device.

Best wishes for a successful experiment! Date: July 2018

A245 Optical Frequency Doubling

A245.1 Aim of the Experiment

The area of nonlinear optics is of great importance as well for basic research as for industrial applications. In this experiment, the properties of a nonlinear crystal shall be examined as an typical example. For this, the beam of a high-power diode laser at 987 nm (infrared, fundamental wave) is frequency doubled with a potassium niobate crystal to visible light (harmonic wave). The output power of the harmonic wave is measured and optimized by adjusting the polarization and power of the fundamental wave, position of the beam focus inside the crystal and the crystal temperature. The wavelengths of fundamental and harmonic waves are compared with a diffraction grating. A Michelson interferometer is used to compare the wavelengths with interferometric precision. The experiment can be built up from individual components (mirrors, lenses, filters, beam splitters, gratings, photodiodes, etc.). These parts can be placed freely on an optical table ('breadboard').

A245.2 Required Knowledge

- Generation of harmonics by nonlinearities
- Birefringence
- Phase matching
- Gaussian Beams
- Determination of wavelengths with gratings
- Michelson interferometer
- Coherence and coherence length
- Working principle of diode lasers

A245.3 Literature

The following (partly in German) can be **obtained from the tutor**, together with a **detailed experiment description**:

- D. Meschede: *Optik, Licht und Laser*, chapters 3.5 and 12, B.G. Teubner Stuttgart-Leipzig 1999,
- Jens Clevorn: *Resonante Frequenzverdopplung mit Diodenlasern zur Spektroskopie bei* $\lambda = 410\ nm$, chapter 3, Diplomarbeit Universität Bonn 1998,
- R. W. Boyd: *Nonlinear Optics*, chapter 2, Academic Press Boston 1992,
- Spectragen, Inc.: *$KNbO_3$ Properties*, http://www.spectragen.com/properties/KNbO3.htm

Further reading: Any textbooks in optics.

A245.4 Assignments

1. Getting familiar with a diode laser: output power versus injection current, threshold current and quantum efficiency.
2. Calibration of the variable attenuator.
3. Focusing the laser beam into the crystal and optimizing the harmonic power.
4. Measurement of the harmonic power versus the crystal temperature.
5. Measurement of the harmonic power versus the input fundamental power.
6. Measurement of the harmonic power versus the polarization of the fundamental wave.
7. Comparison of fundamental and harmonic wavelengths using a diffraction grating.
8. Setting-up and adjusting a Michelson interferometer; interferometric comparison of the wavelengths of fundamental and harmonic waves.

A245.5 Procedure and analysis

Further details are described in the full description of the experiment you are supposed to get from the tutor 2 weeks before the experiment.

Best wishes for a successful experiment! Date: January 2005

A246 High Resolution Laser Spectroscopy

A246.1 Aim of the Experiment

Atomic and molecular spectroscopy is one of the major applications of lasers in science. This course shall introduce to the student the methods of high resolution spectroscopy. Modern equipment and components will be used which are also present in optics laboratories. First, the properties of a diode laser are studied. Then you will build up a linear spectroscopy setup which will be extended to a saturation spectroscopy setup in the last part of the course. A Fabry-Perot etalon serves for frequency calibration of the spectra.

The special attraction of this course lies in the fact that the students can set up the experiment themselves. For this purpose a kit of optical components such as mirrors, lenses, photodiodes, vapour cells, CCD camera etc. are provided. The only preinstalled items are the laser itself and an oscilloscope linked to a personal computer.

A246.2 Required Knowledge

- diode laser characteristics
- laser power and intensity
- Fabry-Perot interferometer
- properties of rubidium
  - fine structure, hyperfine structure, isotope shift
  - spectra (level scheme, transition probabilities)
  - saturation parameter
- linear spectroscopy:
  - law of Lambert-Beer, absorption coefficient, homogeneous and inhomogeneous linewidth, lifetime of excited states
  - line profiles (Lorentz-, Doppler-, Voigt-)
- non-linear spectroscopy:
  - saturation spectroscopy
  - Lamb dips, cross-over resonances
  - behaviour of optical transitions at high laser power, saturation, line broadening

A246.3 Literature

To get from the tutor:

- Detailed description of the course
- Introduction to Lasers, excerpt from Melles-Griot, Lasers and Instruments Guide
- For ambitious students: publications and special literature on saturation spectroscopy, e. g.:
  - Appl. Phys. B, **59**, 167 (1994)
  - Rev. Sci. Instr., **62**, 1 (1991)

Further literature:

- Haken-Wolf: Physics of Atoms and Quanta, Springer, 2000
- Mayer-Kuckuk: Atomphysik, Teubner, 1997
- Demtröder: Laser Spectroscopy, Springer, 2000
- Hecht: Optics, Addison-Wesley, 1989

A246.4 Assignments

1. <u>Characteristics of the diode laser</u>: measurement of laser output power vs. injection current, determination of threshold current and quantum efficiency
2. <u>Coupling of the laser into the Fabry-Perot etalon</u>: recording of a transmission spectrum, determination of the finesse.
3. <u>Linear spectroscopy setup</u>: observing the fluorescence from the vapor cell with a CCD camera, tuning of the laser to the atomic resonance, recording of an absorption spectrum, determination of the isotope shift, determination of the doppler width, verification of the law of Lambert-Beer.
4. <u>Saturation spectroscopy setup</u>: identification of the hyperfine transition lines, measurement of the linewidth and amplitude as a function of the laser power, determination of the saturation power. Estimate the saturation intensity and compare your result with the theoretically expected value.

A246.5 Procedure and analysis

Further details can be found in the full description of the experiment.

Best wishes for a successful experiment! Date: July 2003

A248 Magneto-Optical Trap

A248.1 Aim of the Experiment

The aim of the experiment is to introduce you to the field of laser cooling and trapping of neutral atoms. You will set up a magneto-optical trap for rubidium atoms and measure some of its properties.
The invention of the magneto-optical trap has led to fundamental discoveries and practical applications in diverse fields such as Bose-Einstein condesation, degenerate Fermi-gases cold collisions and quantum information processing. Several magneto-optical traps are used in experiments carried out at the Institute for Applied Physics in Bonn.

A248.2 Required Knowledge

For the sake of being able to carry out the experiment, you should be familiar with atomic physics in particular you should read about the following keywords.

- **optical cooling:** radiation pressure, red detuning, Doppler shift
- **optical molasses:** counterpropagating beams, 3D, cooling but no caught atoms, Doppler temperature
- **MOT:** Magnetic quadrupole field, circular polarized beams, position-depending force
- **Rubidium:** Rb energy level structure, non-resonant excitation, inelastic collisions, dark states, repumping beam
- **setup:** coils, vacuum chamber, laser system, diode lasers
- **Doppler-free spectroscopy:** pump/signal beam, groups of atoms with similar velocity, Lamb dip, crossover resonance, Rb-spectrum
- **polarisation spectroscopy:** circularly polarized light, anisotropic pumping, birefringence, detection of tilt, dispersion, Kramers-Kronig relation

Note that this is only an incomplete list of keywords!

A248.3 Literature

- Script, contact tutor to get a copy
- C. Wieman, G. Flowers and S. Gilbert, Am. J. Phys. **63** (1995).
- H. Metcalf and P. van der Straten, *Laser Cooling and Trapping* (Springer, 1999).
- C. Adams and E. Riis, Prog. Quant. Electr. **21**, 1 (1997).
- W. Demtröder, *Laser spectroscopy* (Springer, 1991)
- D. Meschede, *Optik, Licht und Laser* (Vieweg + Teubner, 2008).

A248.4 Assignments

- All assignments are explained in detail in the script.
- The laboratory assignment E 248 is a double-valued exercise and will be done on two full days. Each group arranges time and date with the tutor.
- The script should be obtained from the tutor at least one week before the laboratory exercise.

Best wishes for a successful experiment! Date: July 2012

S261 Optical Astronomy

S261.1 Aim of the Experiment

The aim of the lab course is to introduce into modern oberserving and data reduction techniques in optical astronomy. In the first part you will reduce provided data from the 1m-Cassegrain telescope from the Hoher List observatory which contains multiple lensed quasars due to the gravitational lensing effect. After calibrating and analyzing the data a good guess of the Hubble constant H_0, a fundamental cosmological parameter with which you can calculate distances in the Universe, can be obtained. In the second task you will observe an exoplanet transit using the 50cm Cassegrain-telescope on the roof of the AIfA, also reduce this data and extract a light curve of the transit. If the weather is not good enough, you will analyze some characteristics of our CCD camera.

S261.2 Required Knowledge

The requirement for a succesful carrying out of this experiment is basic knowledge about astronomy like they are taught in both introduction to astronomy courses in Bonn. Students without this knowledge are welcome but have to count in more time for preparation. Furthermore you have to know about:

- Cosmology: Expansion of the Universe, Hubble constant, distances
- Gravitational lensing: lens equation, geometry of strong lensing, creation of multiple images, basic concepts like Einstein angle, lens potential etc.
- AGNs (Active Galactic Nuclei): Basic properties, rough structure
- Time-delay measurements: Estimation of the Hubble constant through time delay, minimum dispersion method, SIS model and properties
- Basics about observations: Structure of a (Cassegrain-)telescope, telescope resolution, different coordinate systems, star time and hour angle, magnitudes, airmass, seeing, used filters in optical astronomy
- Properties of CCD detectors: types of CCD detectors and their properties, principle of charge transfer, noise, quantum efficiency, saturation level, linearity, gain
- Data reduction: bias, dark, flat, superflat, astrometric and photometric calibration, coadd (stacked) images

Furthermore elementary knowledge of Linux are neccessary, e.g. shell commands like ls, cd, cp, mv, rm, mkdir etc.

S261.3 Literature

- Script (**can be borrowed from your tutor**)
- Basics:
  - P. Schneider: *Extragalactic Astronomy and Cosmology: An Introduction* Springer, 2007.
- Gravitational lensing, cosmology:
  - P. Schneider: *Extragalactic Astronomy and Cosmology: An Introduction* Springer, 2007.
  - P. Schneider: *Introduction to Gravitational Lensing and Cosmology* `http://www.astro.uni-bonn.de/~peter/SaasFee.html`
- Astronomical observations and data reduction:
  - M. Schirmer: *Principles of CCD data reduction* `http://www.astro.uni-bonn.de/~mischa/mbo/datareduction/index.html`
  - S. Howell: *Handbook of CCD Astronomy*, 2000, Chapters 1 - 5. especially chapter 2 and 3
  - THELI user manual Chapters 3 - 4, 6 - 12, and App. A - C and F: `ftp://ftp.ing.iac.es/mischa/THELI` especially chapter 3
  - C. Peng: *Galfit quick start* (manual): `http://www-int.stsci.edu/~cyp/work/galfit/README.ps.gz`

Please get the lab course script at least 2 weeks before your oral exam from your tutor. It's not expected that you read both manuals completely (THELI and galfit), but during the experiment they can be very helpful. Both and the *Handbook of CCD Astronomy* can also be borrowed from your tutor.

S261.4 Assignments

This experiment consists of three parts: The first part (data reduction) will be performed over day, the second part (observations of an exoplanet transit) will be perfomed over night (talk to your tutor about this!). Afterwards you will reduce and analyze this data (part three).
First part:

1. Step-by-step data reduction and calibration of an existing data set with the THELI package
2. Flux and (angular) diameter distance of the multiple lensed quasar images from the coadded image

3. Mesuaring the Hubble constant and other physical parameters

Second part:

1. Get familiar with the telescope and its controls, setting up an observing schedule
2. Observing an exoplanet transit
3. Bad weather tasks: Mesuaring the linearity and full well capacity of the CCD

Third part

1. Reducing and analyzing the exoplanet transit data as learned in part one.

S261.5 Procedure and analysis

The details of the experiment are written in the script.
Please note that part two of this experiment has to be carried out during night. For the observation we need good or very good weather (for Bonn). You will decide on some possible days with your tutor and he or she can tell you about 24 hours before the observation if it will take place or not (due to changing weather conditions). In the case that you have bad luck and there is no clear night, you will have to do the bad weather tasks.

Best wishes for a successful experiment! Date: January 2019

S262 Setting up a Radio-astronomical Receiver / Setting up a Radio Interferometer

S262.1 Aim of the Experiment

The goal of this experiment is to give you insights to individual radio-astronomical components,the mode of operation of a superheterodyne receiver, and the ability of a radio telescope to study radio waves, depending on the wavelength of observations. First you will get familiar with active and passive components of a receiver and work with a superheterodyne receiver which will be used to detect radio signals. In the second part you will detect the radio emission from the Sun and set up a radio interferometer with two dishes to determine the interference pattern of the interferometer.

S262.2 Required Knowledge

A basic knowledge about radio-astronomy is required. Explicit you have to know about:

- Heterodyne principle: design, principle of operation, applications, advantages
- Main characteristics of amplifiers, filters and mixer
- Temperatures: brightness temperature, receiver temperature, noise temperature
- Radiative transfer
- Radio telescope: components, antenna diagram, telescope calibration
- Thermal emission from the Sun
- Interferometry: the twin-interferometer, visibility function, effect of bandwidth, spatial frequency

S262.3 Literature

- Lab course script
- Lecture Notes: *Radio Astronomy: Tools, Applications & Impacts* (U.Klein)

Both scripts are available from the tutor and can be either send per mail or be lend as a copy.

S262.4 Assignments

In the following you will find a short version of the assignments. For details refer to the more detailed lab course script.

First part: Setting up a Radio-astronomical Receiver

In this experiment a superheterodyne receiver will be set up.

1. Do the hot-cold calibration and finding the receiver temperature.
2. Use the calibrated receiver to determine the noise temperature of a noise diode.
3. Simulate the influence of the atmosphere on an astronomical observation using a variable attenuator.
4. Measure the influence of the recording time on the signal to noise ratio.
5. Finally, you will get a short introduction to spectroscopy (BONUS part)

Second part: Setting up a Radio Interferometer

In this experiment a radio interferometer will be set up.

1. Set up a single-dish radio telescope and detect radio emission from the Sun.
2. Set up and calibrate a two-dish radio interferometer.
3. Determine the fringe pattern of the interferometer.
4. Determine the apparent solar diameter at 11.5 GHz.
5. Finally, you will observe meteors with radio reflections, weather or conditions permitting.

S262.5 Procedure and analysis

For details of procedure and analysis please refer to the more detailed supplemental script being available from the tutor.

Best wishes for a successful experiment! Date: June 2018

S263 Photometry of Star Clusters

S263.1 Aim of the Experiment

The aim of this experiment is to acquaint the student with techniques and procedures involved in observing celestial objects using a modern optical telescope. The student will learn how to acquire data for a star cluster, reduce the datasets and determine its age, distance and metallicity. Ideally, the student will collect data from two clusters – an open and a globular star cluster – in order to understand differences between the two types of clusters and their properties.

S263.2 Required Knowledge

For this experiment, we expect the students to be familiar with:

- Basic Astronomy knowledge: distance scales, magnitudes, colors, etc.;
- Some knowledge of stellar physics: e.g., initial mass function (*IMF*), Hertzsprung-Russel diagram (*HRD*) and color-magnitude diagram (*CMD*), metallicities;
- Basic working of a Cassegrain telescope, CCD cameras, filters etc.;
- A minimum expertise with working in a `Linux` environment and familiarity with writing very basic and simple `Python` scripts.

S263.3 Literature

The following literature will be useful in preparation and execution of the objectives of the lab course.

- Most of the required knowledge for this lab course can be found in the script made available by the tutor. The relevant concepts for the oral exam are presented and discussed in the first part of the lab booklet.
- The second part of the lab booklet contains detailed instructions on how to process astronomical data. This part will be useful after you have obtain the observational data and you start processing and analyzing them.
- For basic astronomy knowledge – P. Schneider: *Extragalactic Astronomy and Cosmology: An Introduction*, Springer, 2007.

- For an introduction to observational astronomy – F. R. Chromey: *To Measure the Sky*, Cambridge University Press, 2010.
- For CCD camera knowledge – S. Howell: *Handbook of CCD Astronomy*, 2000, Chapters 1 - 5 (We don't expect you to know everything about CCDs, but you should be in a position to present a basic summary of the working of a CCD camera).

For most of the tasks, the lab course script is sufficient, but it would be really useful to go through this literature list for detailed information and better understanding.

S263.4 Procedure and analysis

The students will first have to go through an oral exam which will test their theoretical knowledge on the subjects to be tackled in the lab course. Following a successful performance, the students will be given a quick guide of the 50 cm telescope in AIfA. Subsequently, the students and the tutor will schedule the night for the observations, taking into account weather forecasts and availability of the telescope.

The object to be observed can be decided by the students but has to be approved by the tutor, after a short discussion. The actual observations would last at most one night. Data reduction and analysis would have to be done in AIfA over one afternoon or you can use your own personal computer (see the second part of the lab booklet for a description on how to set up your computer). Following successful completion of all tasks, the students will have to submit a lab report within 3 weeks from the day of the data reduction.

For more info, you can contact the tutor or visit the S263–Lab Course page [1].

Best wishes for a successful experiment! Date: July 2020

[1] `https://jdenbrok.github.io./teaching_classes/photometrics.html`
PW:study_OCs

S264 Radio astronomical observing course

S264.1 Aim of the Experiment

The aim of this radio astronomical course is to provide an early observing experience and a practical approach to the technical design of a classical single dish radio telescope. Focusing in particular on the telescope construction, receiver technology, data acquisition and reduction. Until today all operating high frequency radio telescope are constructed in the same fashion as the 25-m Stockert telescope you are exploring. We start with an inspection of the telescope primary reflector, identify the location of the antenna feed horn, trace the cable connections from the feed horn to the amplifier and band-pass. In a subsequent step, we set up the spectrometer for HI 21-cm line observations and observe a Milky Way standard calibration source. These data will be evaluated to determine the basic parameters of the instrumental characteristics. Next, the gaseous mass of a nearby galaxy is going to be evaluated. Finally, we constrain the distance of a pulsar by evaluating the signal's dispersion measurement.

S264.2 Required Knowledge

A basic knowledge on radio astronomy is required. Explicitly you should prepare the following topics:

- basic construction principles of radio telescopes, antenna diagrams, angular resolution, surface accuracy
- antenna feed construction, heterodyne principle, construction of a radiometer and its sensitivity, system temperature
- HI 21-cm line, Doppler velocity, local standard-of-rest frame, spectral resolution
- baryonic and dark matter content of galaxies.
- Pulsar's as sources of radio emission, dispersion measure

S264.3 Literature

- Lab course script
- Lecture Notes: *Radio Astronomy: Tools, Applications & Impacts(U.Klein)*

- Online radio astronomical course: *https://science.nrao.edu/opportunities/courses/era*

The lab course script and Prof. Klein's lecture notes are available from the tutor and can be either send per mail or be lend as a copy.

S264.4 Assignments

In the following you will find a brief description of the individual tasks you are going to perform. For details we refer to lab course script.

First day: Preparing your observations

About two weeks prior to your observing session at the Stockert telescope the observing session needs to be planned.

- learn to setup the necessary software tools
- plan identify suitable sources for the individual tasks and create a timeline for the observing session
- exploration of the data reduction tools and strategies to use them

Second day, first part: Exploration of the telescope design

- inspect and identify the mounting of the telescope. Explain the advantages and disadvantages of this construction. Discuss and evaluate the telescope primary mirror surface accuracy.
- identify the location of the primary and secondary focus, the location of the antenna feed horn.
- trace the cable connection between the antenna feed and the amplifier. Identify the position of the band-pass, discuss the limitation of this construction.
- discuss the technical layout the receiver and the limitation of the construction.

Second part: Observe the Milky Way standard calibration source S7 and determine the instrumental sensitivity

- discuss the Rayleigh-Jeans approximation and the consequences for the observations you are performing.
- describe the difference between the antenna temperature T_{A} and the brightness temperature T_{B}.

- S7 is located at $(l, b) = (132°, -1°)$. Determine the location of S7 in the equatorial coordinate system and discuss its visibility.
- Setup the spectrometer and perform the observation. Choose a suitable integration time based on the spectrometer's setup aiming to measure the $T_B \simeq 96\,K$ signal with a 10% accuracy.
- Identify a strategy to evaluate the system temperature by observing the S7 area, what are the systematic uncertainties?
- Quantify finally the system temperature with an uncertainty of less than 10%.

Third part: quantify the telescope's beam

- use the transit method to quantify the full-width-at-half-maximum (FWHM) of the Stockert telescope.
- discuss and identify the properties of a suitable source for this task, take care that this source is close to culmination.
- use the transit method to quantify the FWHM. What is the impact of the declination of the source?
- try to set up the transit scan in such a way, that enables you to measure the first side-lobes and the primary beam.
- Evaluate on the dB scale the sensitivity difference between primary beam and first side lobe.

Fourth part: observing a nearby galaxy

- choose a nearby galaxy from the observatory's catalog close to culmination.
- calculate the necessary integration time to determine the galaxies integrated flux with an accuracy of better than 10%.
- perform the observation and evaluate the total flux, the peak brightness temperature, the systemic velocity. Discuss the line profile and compare it to the S7 line profile. What are the differences, what are the similarities?
- evaluate the HI mass of the galaxy. What is the difference to the total mass of the galaxy? Estimate the total mass. Discuss the limitation of the applied method and possible solutions to improve the results

Fifth part: determine the distance of a pulsar

- choose a suited pulsar from the observatory's catalog.
- estimate the necessary observing time to detect the pulsar's signal
- perform the observation and evaluate the arrival times of the signals in the eight sub-bands.
- evaluate the temporal separation between the pulsar signals and estimate the separation between the Earth and the pulsar.

S264.5 Procedure and analysis

The final data reduction is going to be performed in the CIP-pool of the Argelander-Institut für Astronomie, Auf dem Hügel 71, 53121 Bonn. The necessary software is already installed and access is granted via your university student account. For details of the procedures and analyses please refer to the more detailed supplemental script being available from the tutor.

Best wishes for a successful experiment! Date: July 2017