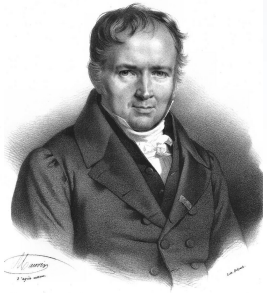
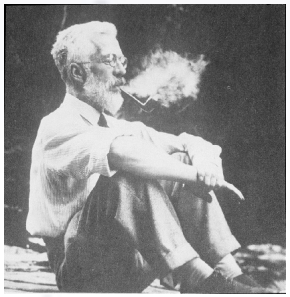
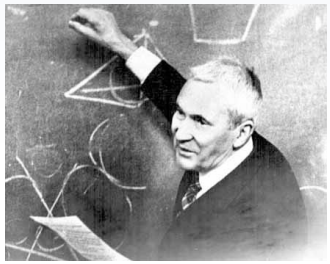
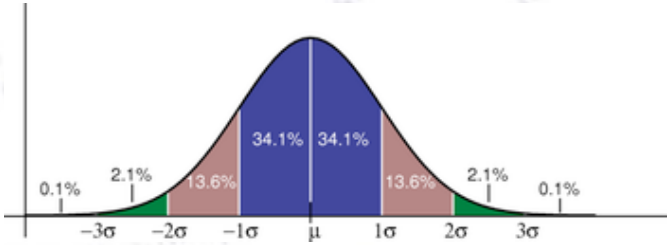
Applied Statistics

Course information 2021-22



Troels C. Petersen (NBI)



"Statistics is merely a quantisation of common sense!"

Applied Statistics 2021

…all the technical stuff!

Technicals:

- Rooms and hours.
- Course structure and dates.
- Computers and software.
- Data sets.
- Literature.
- Curriculum.
- Problem set.
- Projects.
- Exam.
- Expectations.
- Goals.

The course webpage (central source of course information, bookmark or fail!):

http://www.nbi.dk/~petersen/Teaching/AppliedStatistics2021.html

Click on link in PDF, as copying text might not correctly get the "~" character right (especially on Windows!)

People involved

Teachers

I've taught this course several times, but we have the honour of having **Mathias Heltberg** with us this year. He has both had the course, been a TA, and used the course content in his research.
Arguably more importantly, we have **Clara, Kate, Vadim, Irene, and Ronja** with us as TAs.
We look forward to meeting all of you.

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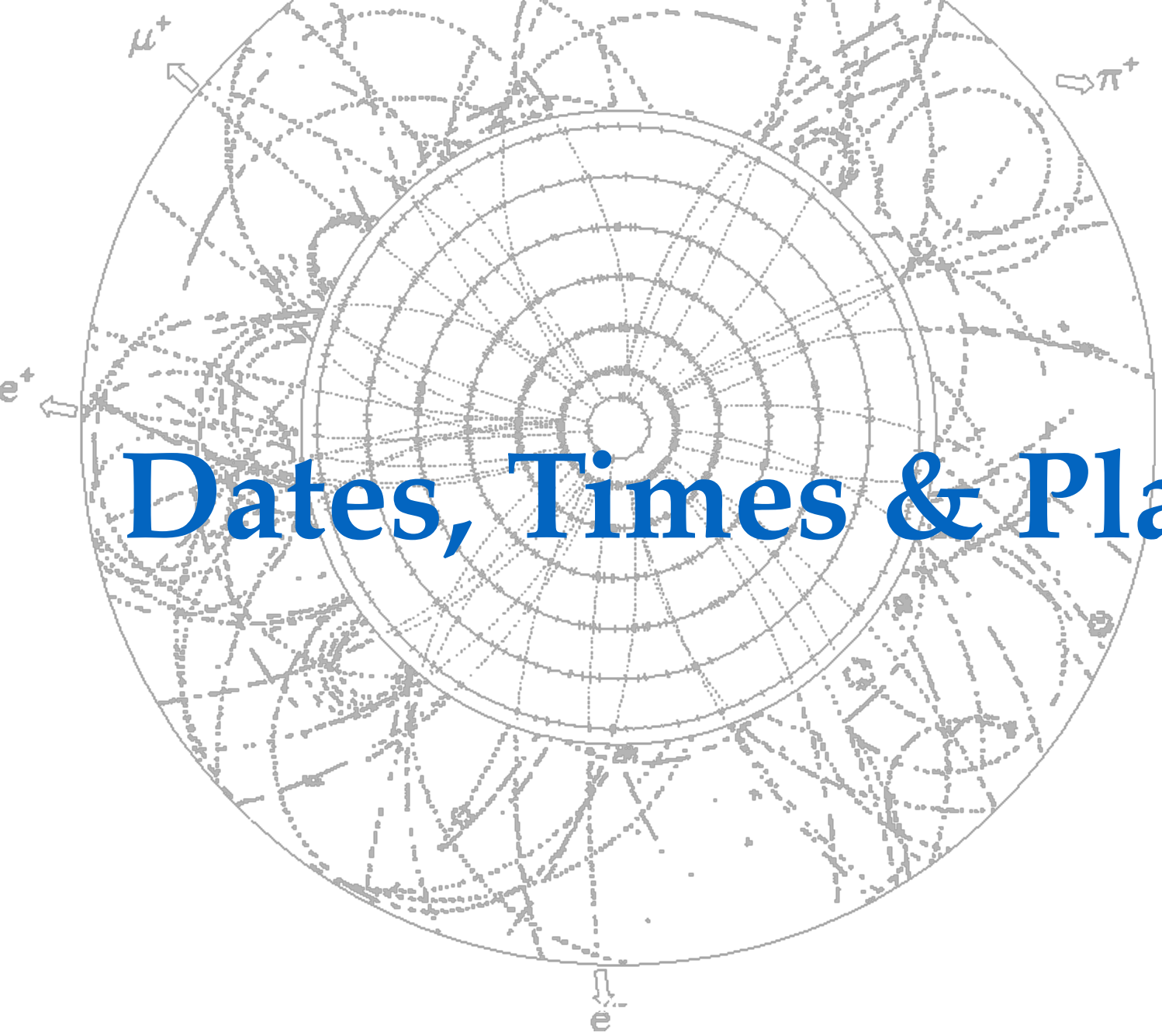
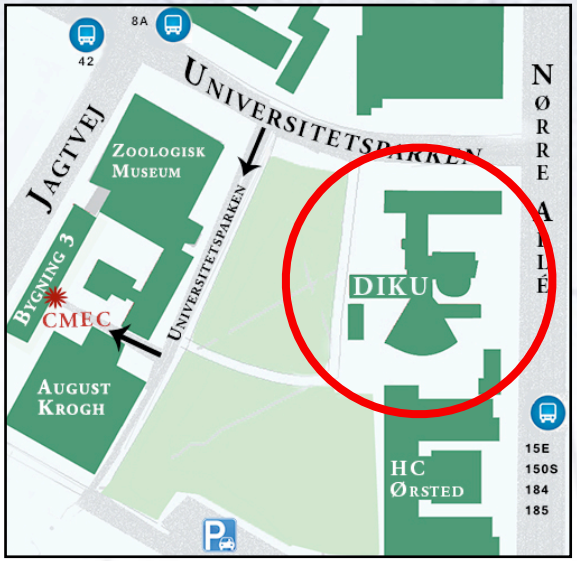


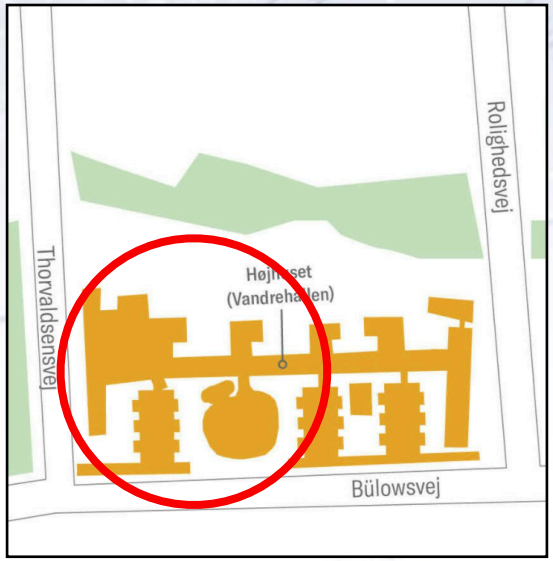
Dates, Times & Places

Lectures

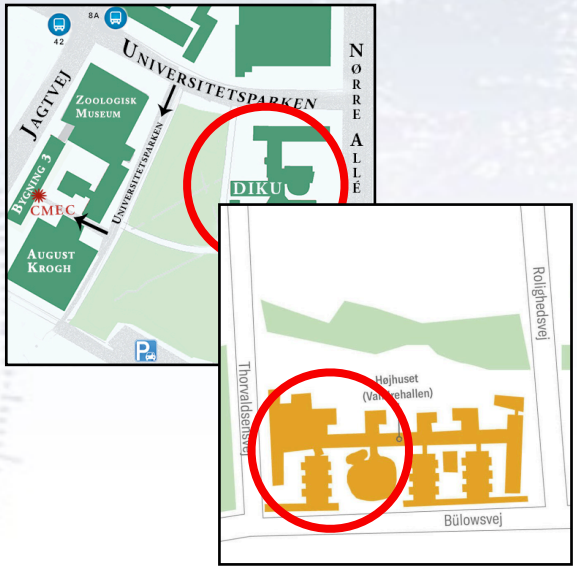
Mondays



Tuesdays



Fridays



Mondays: Lille UP1 (DIKU, all weeks)

Tuesdays: Aud - A2-82.01 (Frederiksberg, all weeks)

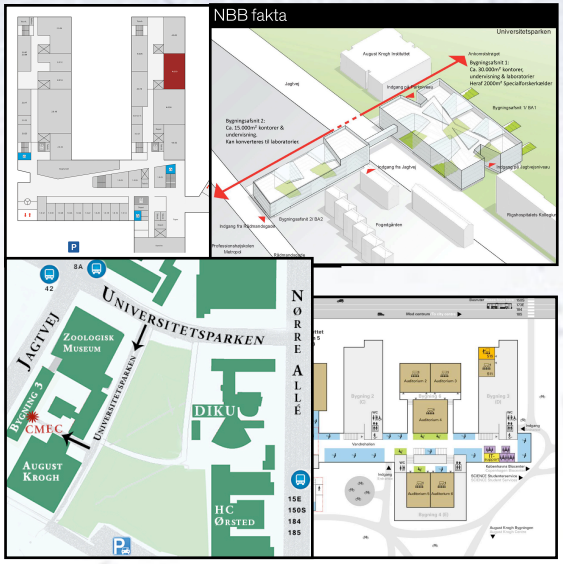
Fridays: Aud - A2-70.04 (Frederiksberg, week 47-48), then Lille UP1 (DIKU, rest of weeks)

I think that it is fair to say, that we were not "dealt the best hand".

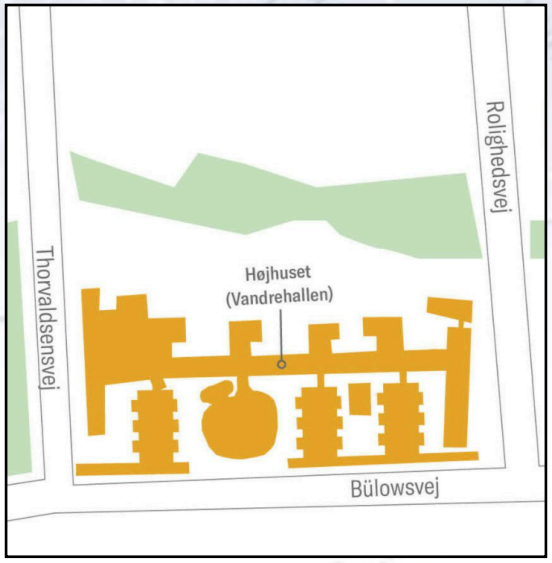
For a detailed view:
KU Room Schedule Webpage

Exercises

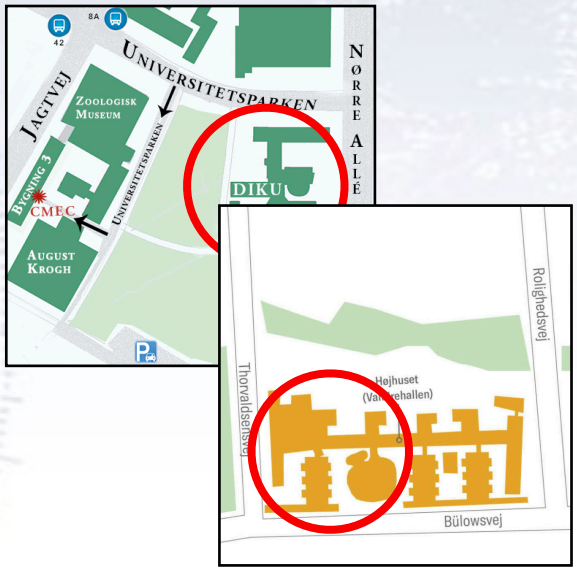
Mondays



Tuesdays



Fridays



Mondays: Biocenter (4-0-02 all weeks, 4-0-05 all weeks but 51, and 4-0-32 week 51), DIKU (3-0-25 all weeks but 48), NBB (01.3.I.164 all weeks), and HCØ (A106 week 48)!

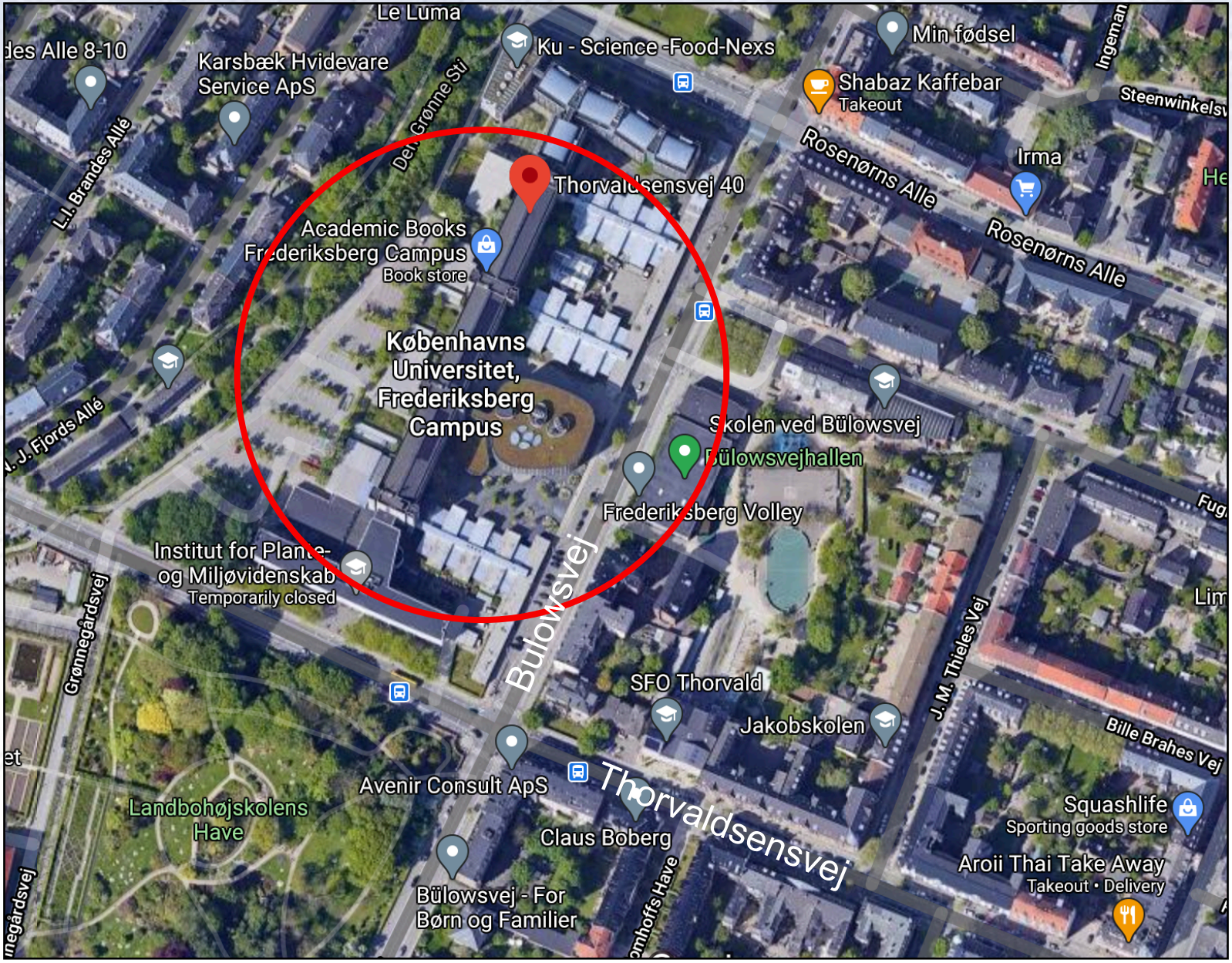
Tuesdays: Frederiksberg (Aud - A1-01.12, Aud - A1-01.15 all weeks except 48 and 2).

Fridays: Frederiksberg (Aud - A1-01.12, Aud - A1-01.12 week 47+48), then DIKU (1-0-18, 1-0-22, 1-0-25, bib 4-0-17, rest of weeks).

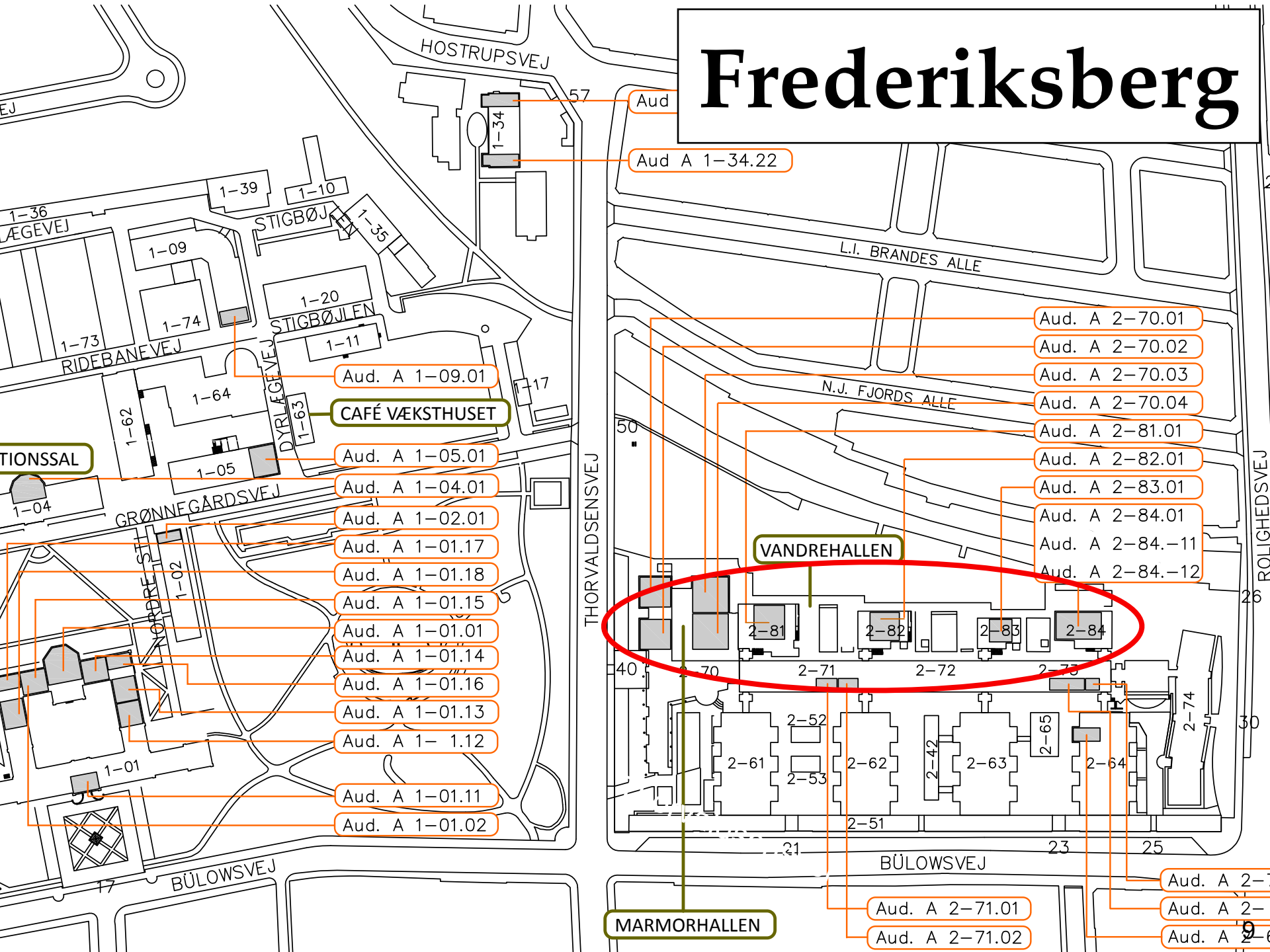
For a detailed view:
KU Room Schedule Webpage

Note: This course does not use "hold" - you may do your exercises in any room you want!

Frederiksberg campus



Frederiksberg



Additional locations

Course dates & hours

Dates:
Block 2 (schedule B) will in 2021-22 consist of the following weeks:

Week 1: 22.-26. November
Week 2: 29. Nov.- 3. Dec.
Week 3: 6. - 10. December
Week 4: 13.-17. December
Week 5: 20.-21. December
Week 6: 3.-7. January
Week 7: 10.-14. January
Week 8: 17.-18. January
Exam: 20.-21. January

Hours:
Following schedule B, but after the first three weeks, we will be using the morning hours 8:15 - 9:00 Monday and Friday for "self-studying".

Monday:
8:15 - 9:45 Lectures
10:15 - 12:00 Exercises

Tuesday:
13:15 - 14:00 Lectures
14:30 - 17:00 Exercises

Friday:
8:15 - 9:45 Lectures
10:15 - 12:00 Exercises

Course dates & hours

Dates:

Block 2 (schedule B) will in 2021-22 consist of th

Week 1: 22.-
Week 2: 29.
Week 3: 6. -
Week 4: 13.-
Week 5: 20.-
Week 6: 3.-7
Week 7: 10.-
Week 8: 17.-
Exam: 20.-2

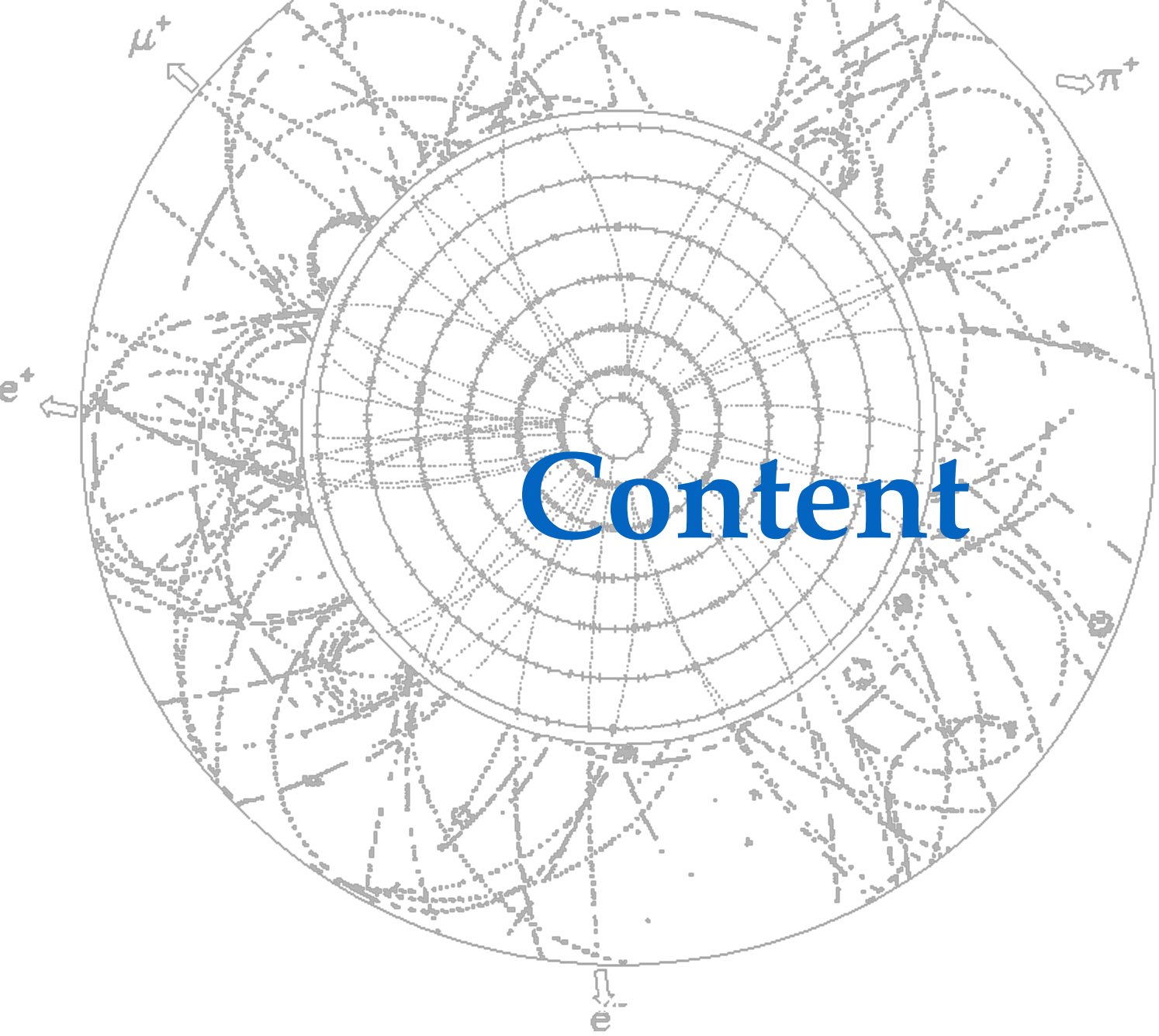
Hours:

Following schedule B, but after the e using the Monday ng".

Just to be clear:
The course can be followed FULLY online, and it is perfectly alright to do so.

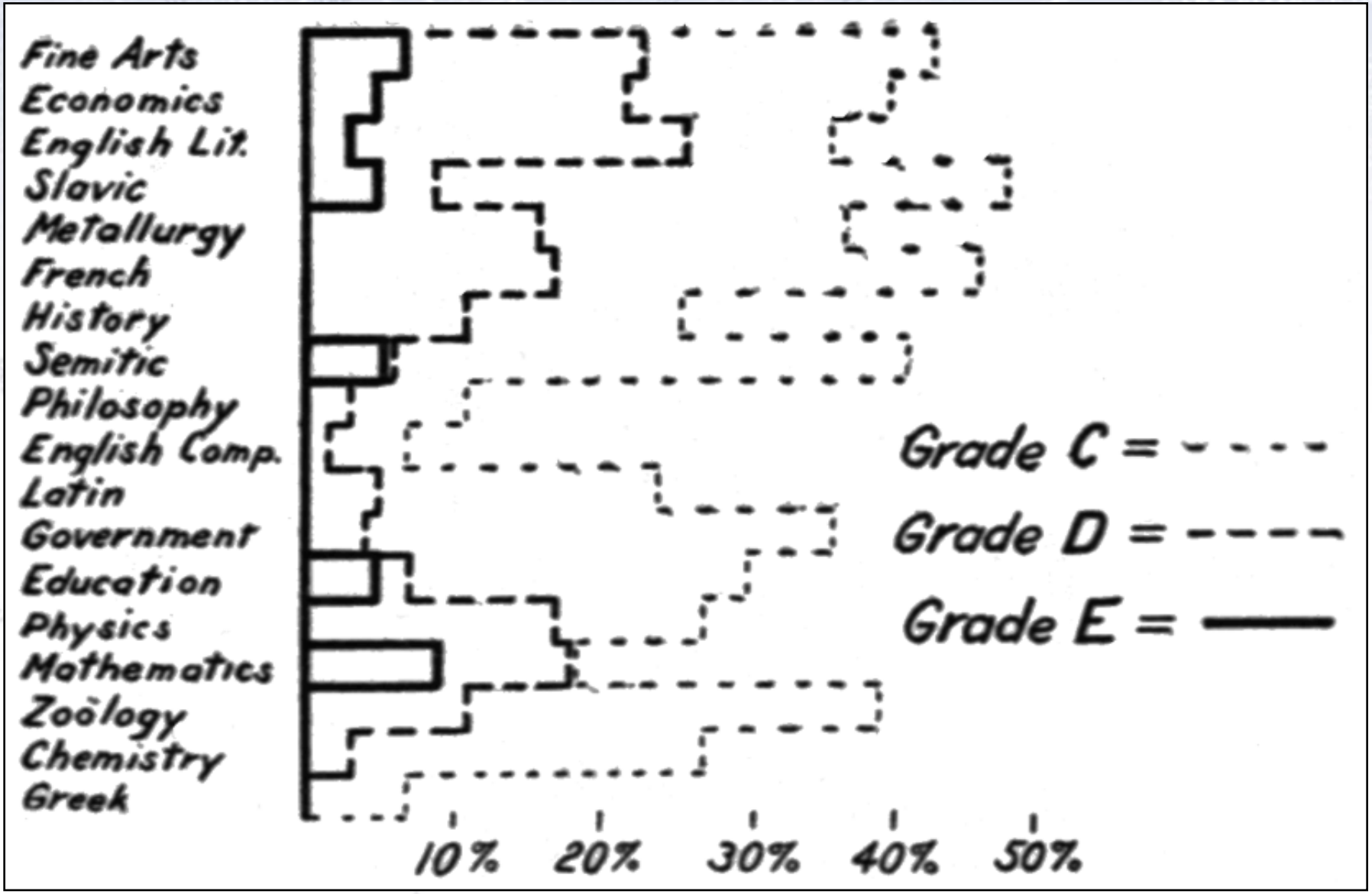
Friday:

8:15 - 9:45 Lectures
10:15 - 12:00 Exercises



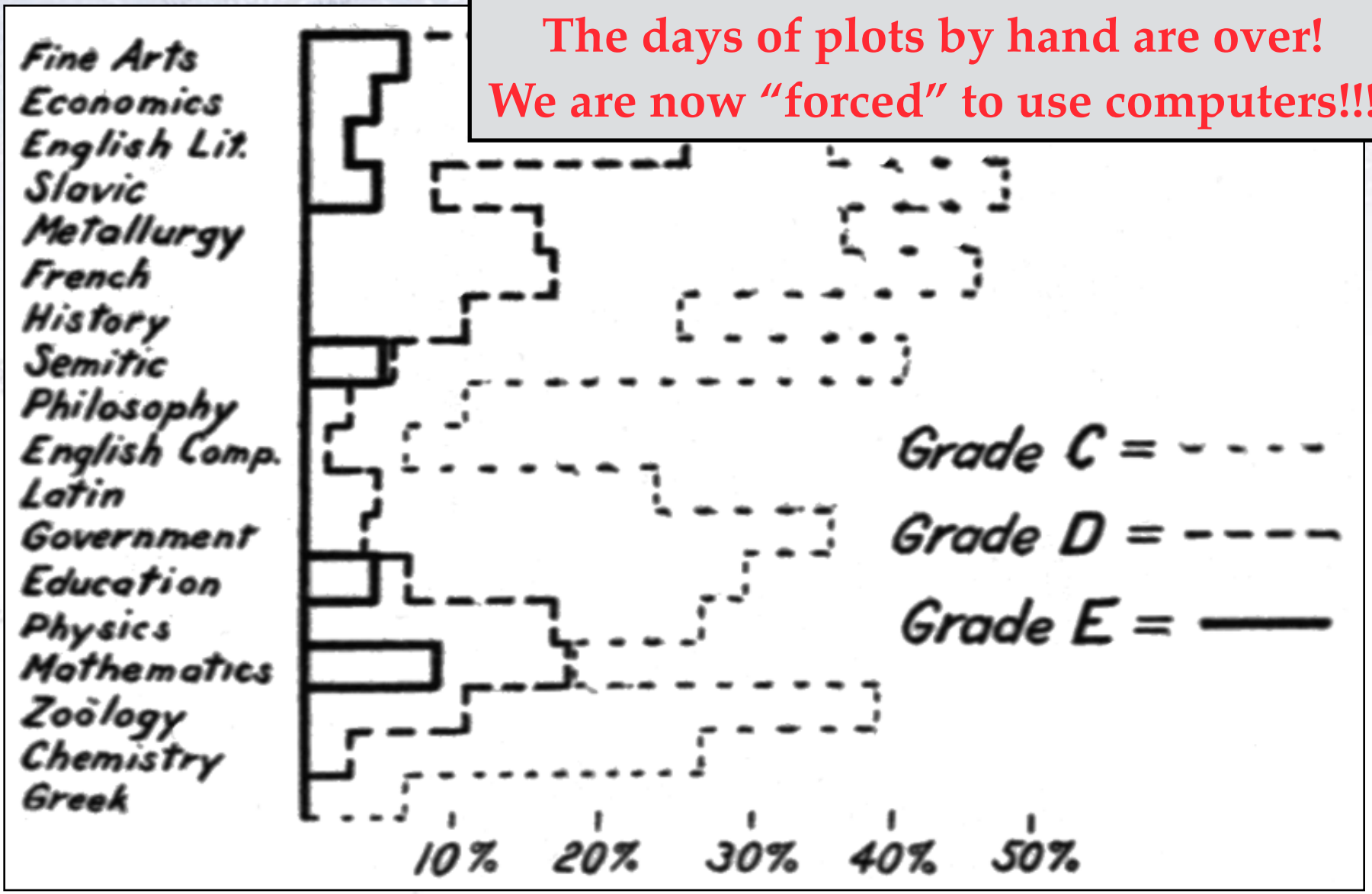
Content

Computers and software



Computers and software

The days of plots by hand are over!
We are now "forced" to use computers!!!



Computers and software

The times are ***way past*** pencil and/or calculator stage!
Fast computers is the ***only*** answer to do (any serious) data analysis.

Operating system: **Linux/MAC OS/Windows**
Programming: **Python** - version 3.9+
Editor: **Jupyter Notebook** (or own favorit!)

Python Packages used:
NumPy, MatPlotLib, Pandas, iMinuit, SciPy, SeaBorn, os, and maybe others.
Only iMinuit should possibly be "unknown" to many, but it is easy to install, and essential for fitting.

Code repository used:
All code can be found on GitHub (webpage links there):
https://github.com/AppliedStatisticsNBI/AppStat2021/

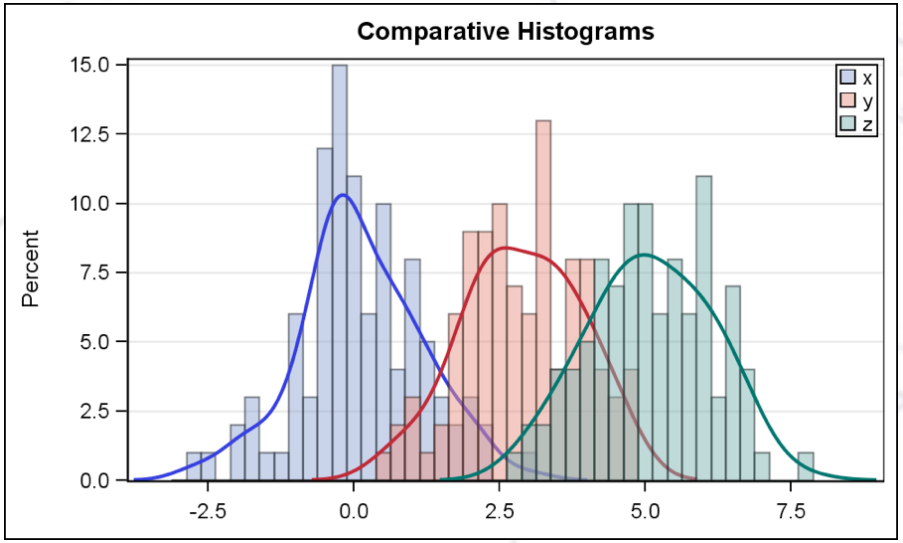
Note: You're not "forced" to use Python, but we will only supply code in Python.

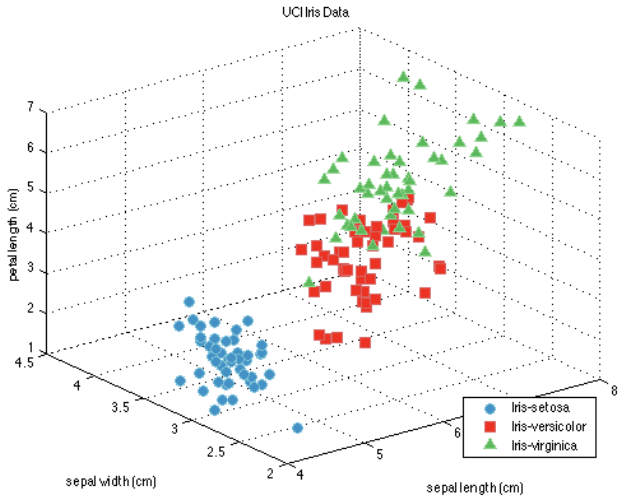
Data sets

In general, any data set can be used for this course! If you happen to have an interesting and illustrative one, bring it to me/class!

I've tried my best to search for a large variety of data sets, but this is not always easy. Publicly available data sets are often old/small/biased/etc.

As a result, one or two data sets are from my own field (particle physics). This is both due to my access to data here, but also because particle physics is one of the fields providing ***billions of measurements***.





Literature

We use Roger J. Barlow's "Statistics", as it is an accessible introduction to statistics with many examples, and the best overall book (I think).

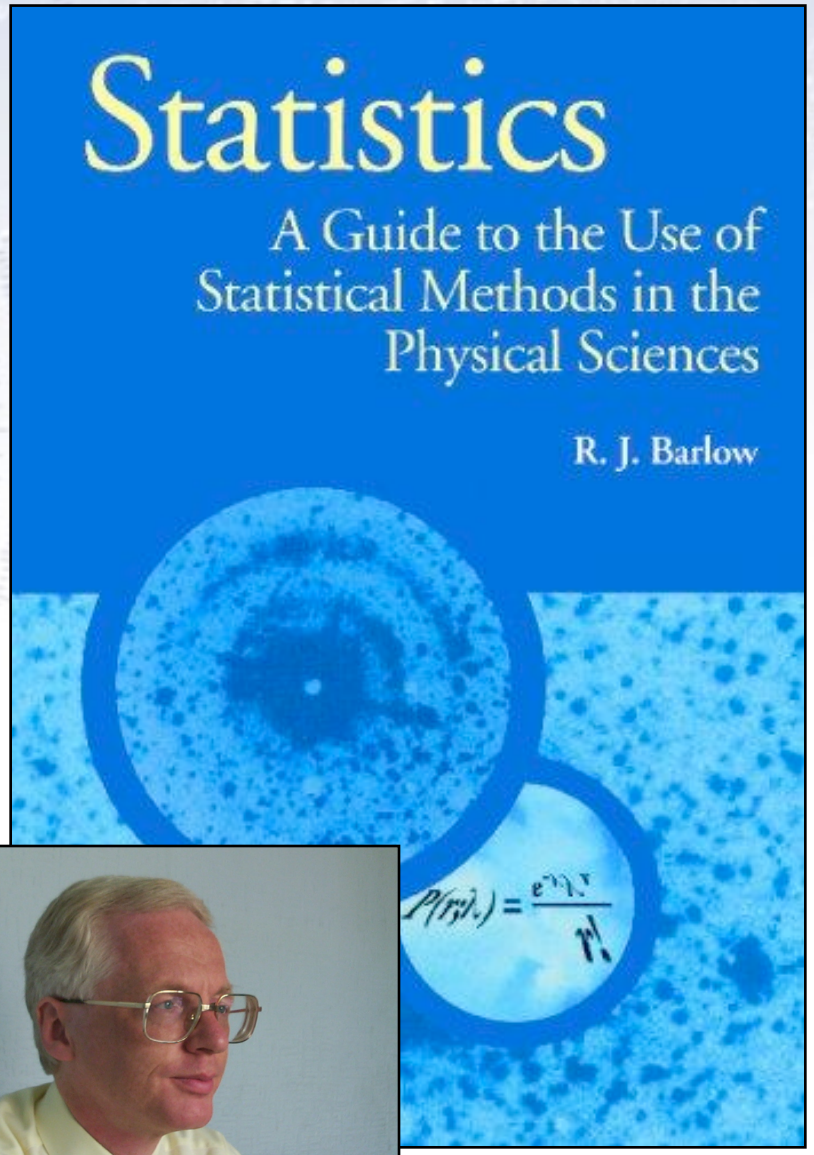
If anything, it is lacking a bit on how to generate random numbers according to a specific PDF and on categorising events.

I might occasionally also refer to:

- Bevington: Data Reduction & Error Analysis
- Cowan: Introduction to Statistics

...and notes from Particle Data Group!

NOTE: There is a great abundance of notes, Wiki, fora, etc. on both statistics but especially also Python on the web, which I encourage you to use (with a proper critical mind).



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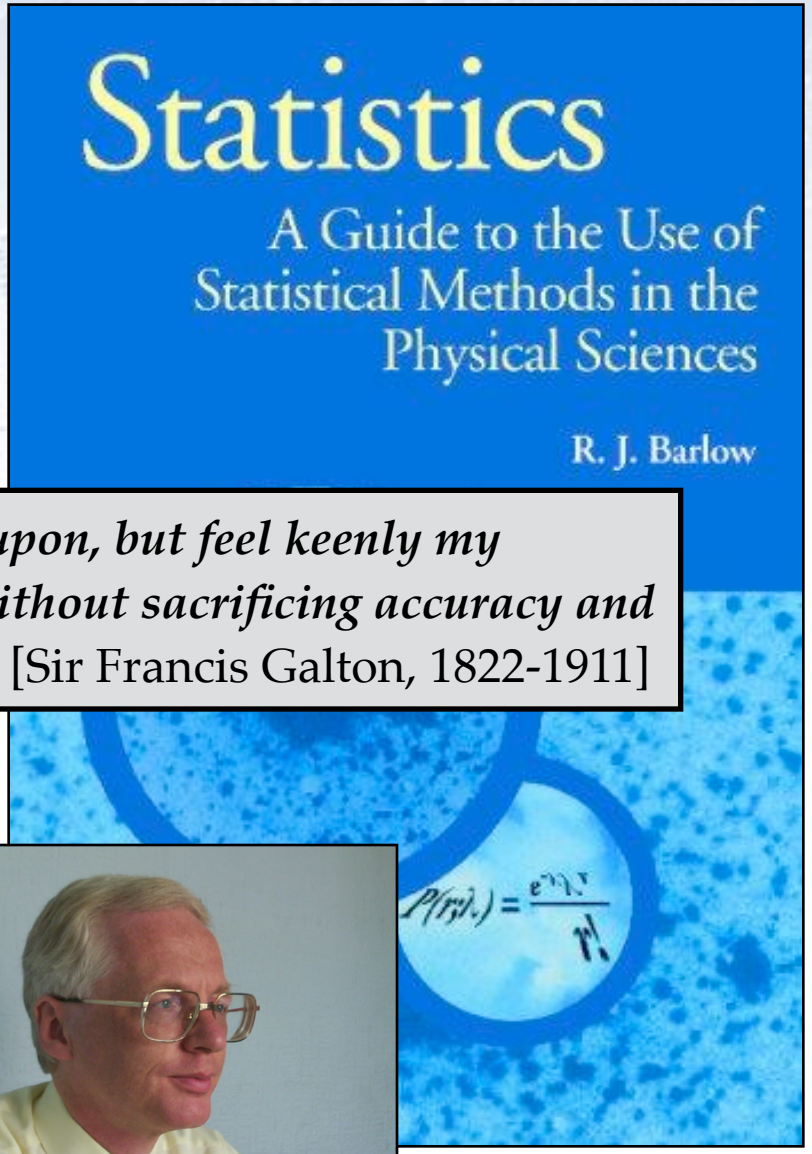


If anything, it is lacking a bit on how to generate random numbers according to a specific PDF and on categorising events.

I mi
- B
- C

...and notes from Particle Data Group!

> ***"I have a great subject [statistics] to write upon, but feel keenly my literary incapacity to make it intelligible without sacrificing accuracy and thoroughness"*** [Sir Francis Galton, 1822-1911]

NOTE: There is a great abundance of notes, Wiki, fora, etc. on both statistics but especially also Python on the web, which I encourage you to use (with a proper critical mind).

Additional literature

Two additional great books are:

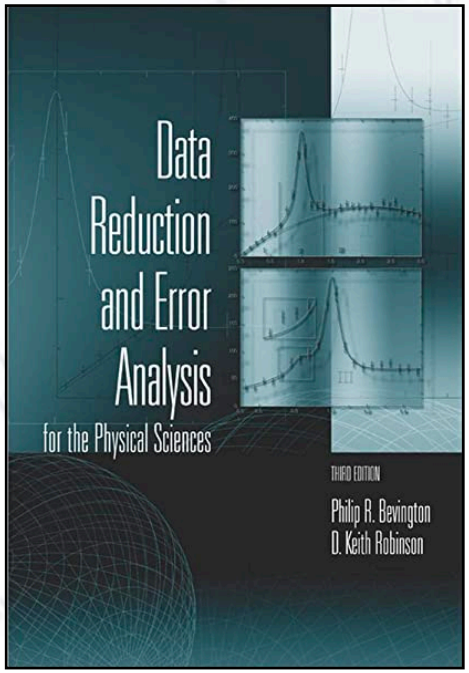
- P. R. Bevington: Data Reduction and Error Analysis
- Glen Cowan: Statistical Data Analysis

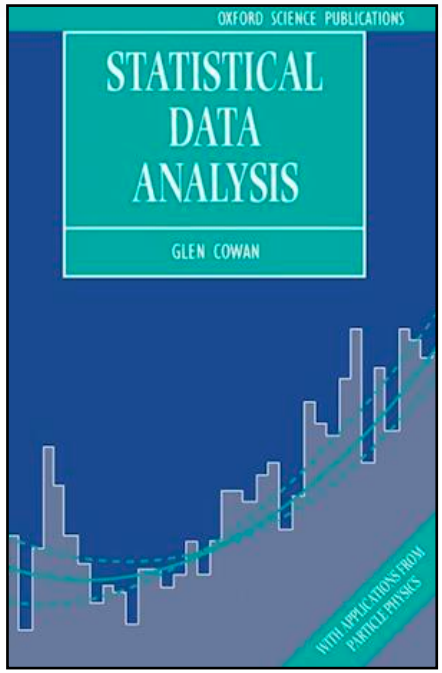
Bevington is a classic and very good basic introduction. If you don't understand something, try re-reading about it in Bevington.

Cowan is more "modern", and for the slightly more advanced reader. Great sections are:

- Producing random numbers
- Hypothesis testing

Links to electron versions of both books can be found on the course webpage.





Curriculum

The course will cover the following chapters in R. Barlow:

- Chapter 1 (All)
- Chapter 2 (All)
  Exercises: All, except 2.5 and 2.9.
- Chapter 3 (Except 3.2.2, 3.3.2, 3.4.2, 3.5.2)
  Exercises: All, except 3.7.
- Chapter 4 (All)
  Exercises: All, except 4.10.
- Chapter 5 (Except 5.1.3, 5.3.2, 5.3.3 (formal part), 5.3.4, 5.5)
  Exercises: 5.2
- Chapter 6 (Except 6.4.1, 6.7)
  Exercises: All
- Chapter 7 (Except 7.3.1)
  Exercises: All, except 7.1, 7.3, and 7.7.
- Chapter 8 (Except 8.4.4, 8.4.5, 8.5.1, and 8.5.2)
  Exercises: All, except 8.6.
- Chapter 10 (All)

Core of Curriculum

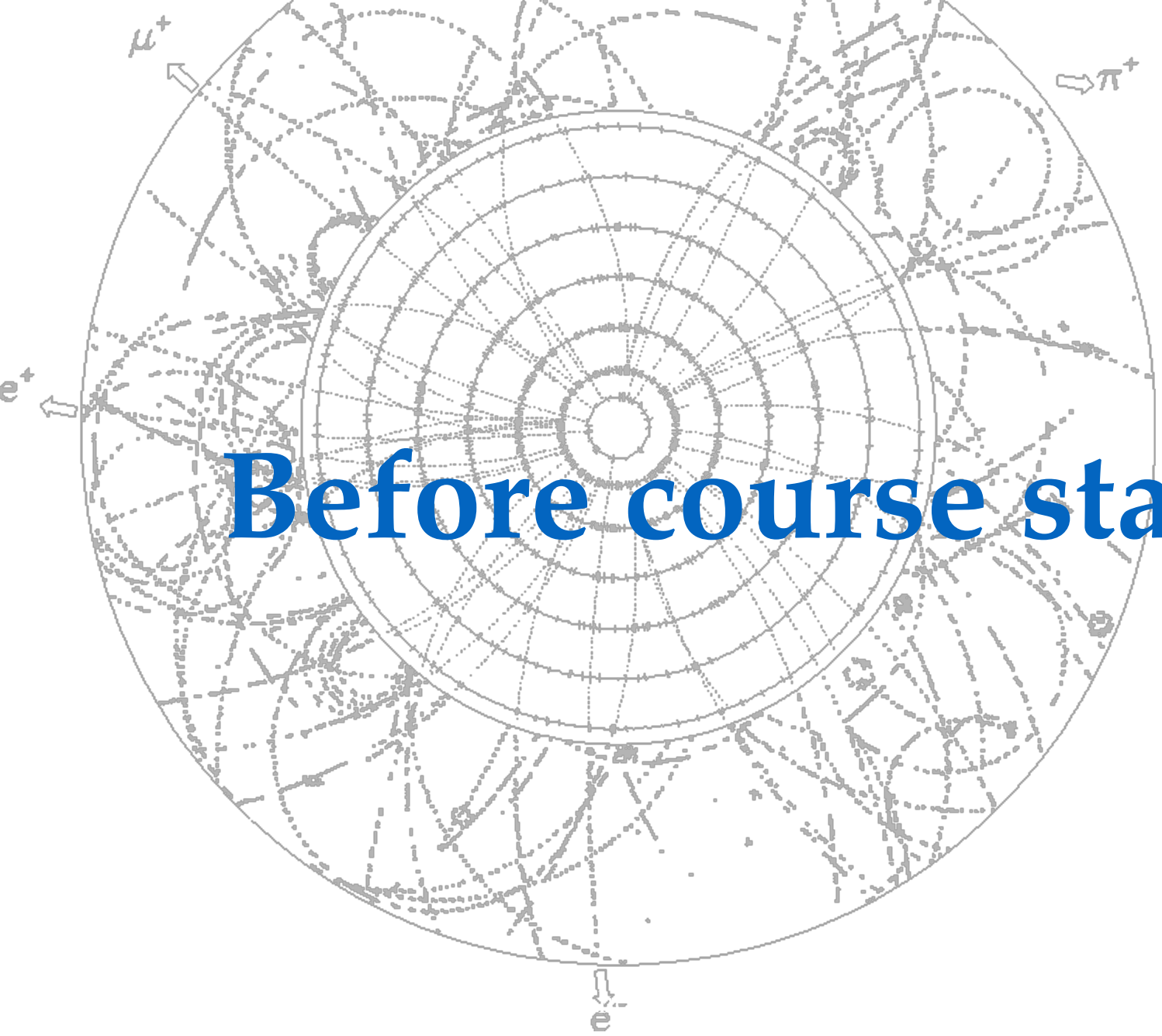
The course will **focus mostly on** the following chapters in R. Barlow:

- Chapter 2: 2.1, 2.2, 2.3, 2.4.1, 2.4.2, 2.6
- Chapter 3: 3.1, 3.2, 3.2.1, 3.3, 3.3.1, 3.4.1, 3.4.7, 3.5.1
- Chapter 4: 4.1, 4.2, 4.3, 4.3.1, 4.3.2, 4.3.3
- Chapter 5: 5.1, 5.1.1, 5.1.2, 5.2, 5.6
- Chapter 6; 6.1, 6.2, 6.2.1, 6.2.2, 6.2.3, 6.2.4, 6.3, 6.4
- Chapter 8: 8.1, 8.2, 8.3, 8.4, 8.4.1, 8.4.2, 8.4.3

This is less than 80 pages, but... they do not only require reading!
They request understanding!!!

The plan is to go through most of curriculum in 4-5 weeks, spending the rest of the time on applying it.

It is through application that statistics is really understood.



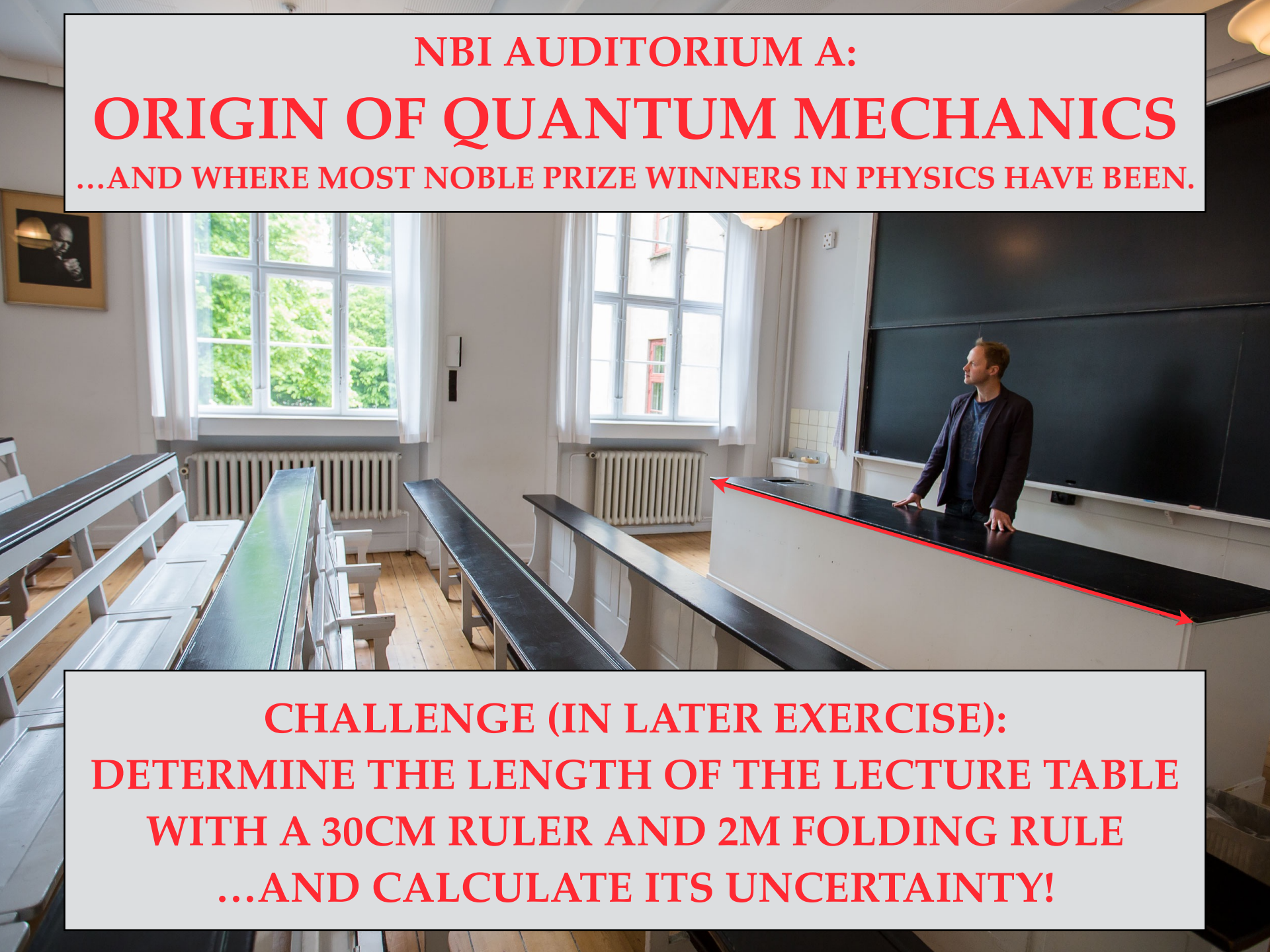
Before course start

Check list

In order for me to consider you inscribed in this course, you should make sure that you pass the following check list:

- **Have read the course information** (slides on course webpage).
  Otherwise, you don't know what is going to happen.
- **Have filled in the questionnaire** (on course webpage).
  Otherwise, we don't know what you know and don't know.
- **Have measured the length of the lecture table in Auditorium A*.**
  Otherwise, you haven't contributed to a common course dataset.
- **Be registered on Absalon or accept invitation by me to be so.**
  Otherwise, you won't get any of the general information I write out.
- **Be able to run Python on your own laptop and(/or) on ERDA**.
  Otherwise, you can't follow the exercises or solve problems.

* NOTE: Instructions can be found on the course webpage.



NBI AUDITORIUM A:

ORIGIN OF QUANTUM MECHANICS

…AND WHERE MOST NOBLE PRIZE WINNERS IN PHYSICS HAVE BEEN.

CHALLENGE (IN LATER EXERCISE):
DETERMINE THE LENGTH OF THE LECTURE TABLE
WITH A 30CM RULER AND 2M FOLDING RULE
…AND CALCULATE ITS UNCERTAINTY!

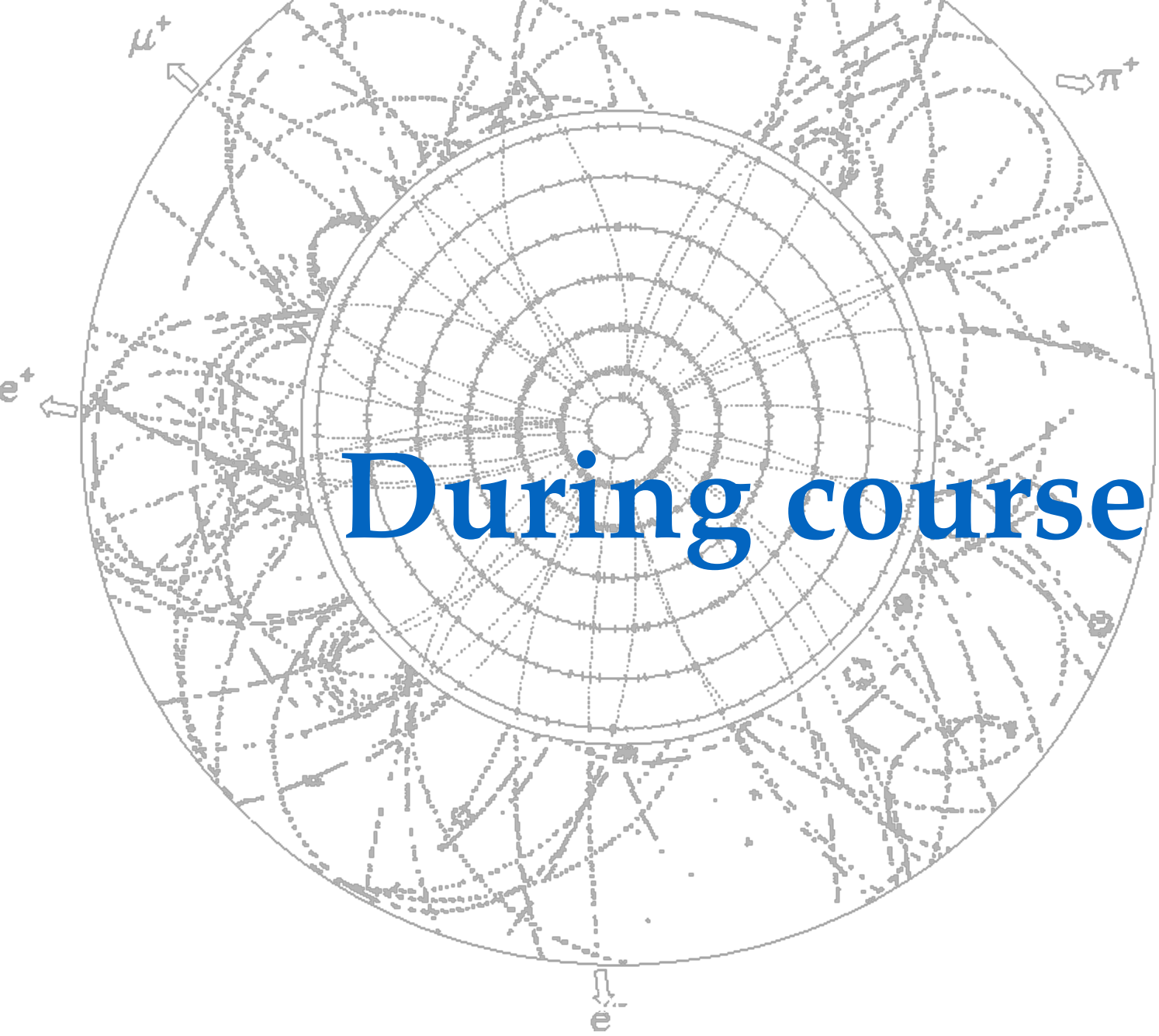
Exactly what to do

Show up in Auditorium A (NBI, Blegdamsvej 17) at one of the five 1-hours time slots shown on the course webpage*.

1. Say hello to the TA in the Auditorium, and get a slip of paper for the measurements.
2. Grab the 30cm ruler and measure the length of the lecturing table. Write down the result to the millimeter. Do not round!
3. Think about what uncertainty you (gu)estimate this measurement has, and write that down too.
4. Measure the length again, now with the 2m folding rule.
5. Again, also write down your estimate of the uncertainty.
6. Do all of the above (1-5) within 2 minutes!

Do NOT round your result, even if precision might be limited.
Do NOT change your results, even if you suspect a mistake.

*Service: 19th 11:00-12:00, 22nd 15:30-16:30, 26th 11:00-12:00, 29th 11:00-12:00, 29th 15:30-16:30 in October.



During course

Exercises

The exercises are (mostly) related to the topic of the lecture before it. They are meant to:

- Make sure that you **understand** the lecture content, also the details of the math in it and how to apply it.
- Let you get **experience** with how and when the theory/principle/topic applies and works and also when it doesn't.
- Give you **confidence** in recognising the case for and applying the statistical approaches next time you encounter them.
- Build up a **code repository** with the *relevant tools, packages, and algorithms that you know and trust*.

You don't hand in the exercises, and the questions are mainly suggestive. You don't have to "solve it all" and there are often no unique solutions.

The best thing you can do is sit down with peers and go through the exercise and discuss the questions and their answers. And leave the exercise, when you feel that you're confident with the subject.

Project

In the second/third week of the course you will be working on the data analysis following two (simple?) experiments for about two weeks.

They will be in **First Lab** on (dividing class into two halves, wearing face masks, the other half having lectures and exercises as normally, TBC):

- Friday the 3rd of December 8:15-12:00.
- Monday the 6th of December 8:15-12:00.

This is your chance to fully do the statistics behind an experiment and play with real data to gain experience of what planning an experiment and detailed data analysis requires! This ***will count 20% in your final grade!!!***

It will require the use of computers and modifications of some of the code you have been running.
You will be working in groups of 4-5 persons, and only one report (2-4 pages) is required from each group.

Real life problems/experiments will resemble this project!

Project

The project is an attempt at **precision measurement** of the Earth's gravitation locally at NBI, using only "simple" methods (OK - a little bit of cheating there).

You will be doing two separate experiments (both seen before by most):

- Simple pendulum.
- Ball rolling down an incline.

The goal is to **determine g in two ways and propagate the uncertainties** on these measurements. More on that (in time) on the webpages under "project".

Project deadline: One report (in PRL style) per group only is to be handed in by **Sunday the 12th of December 22:00**.

Your group will be paired with another group to give each other feedback. We will of course grade projects internally.

In case you can't participate in person, you will be asked to do the pendulum experiment only, but working by yourself.

Problem set

During the course, I will give a larger problem set to be solved and handed in.

This will cover most of the curriculum covered at this point, and it
will count 20% in your final grade!!!

It will require the use of computers and modifications of some of the code you have been running.

You are welcome (even encouraged) to work in groups, but **each student must hand in their own solution**, and you should **state your collaboration**.
It is due on **Monday the 3rd of January 2022 by 22:00**.

The problem set is extensive, so I suggest that you start early.

The final exam will somewhat resemble this problem set!

Exam

Exam will be a **36 hour take-home exam** with a set of problems, which resembles the one previously given.

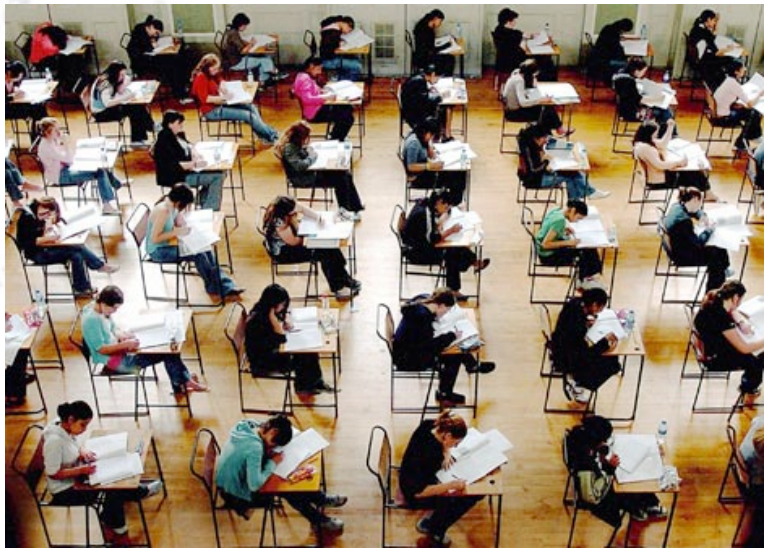
It will cover most of the curriculum, and it ***will count 60% in your final grade!!!***

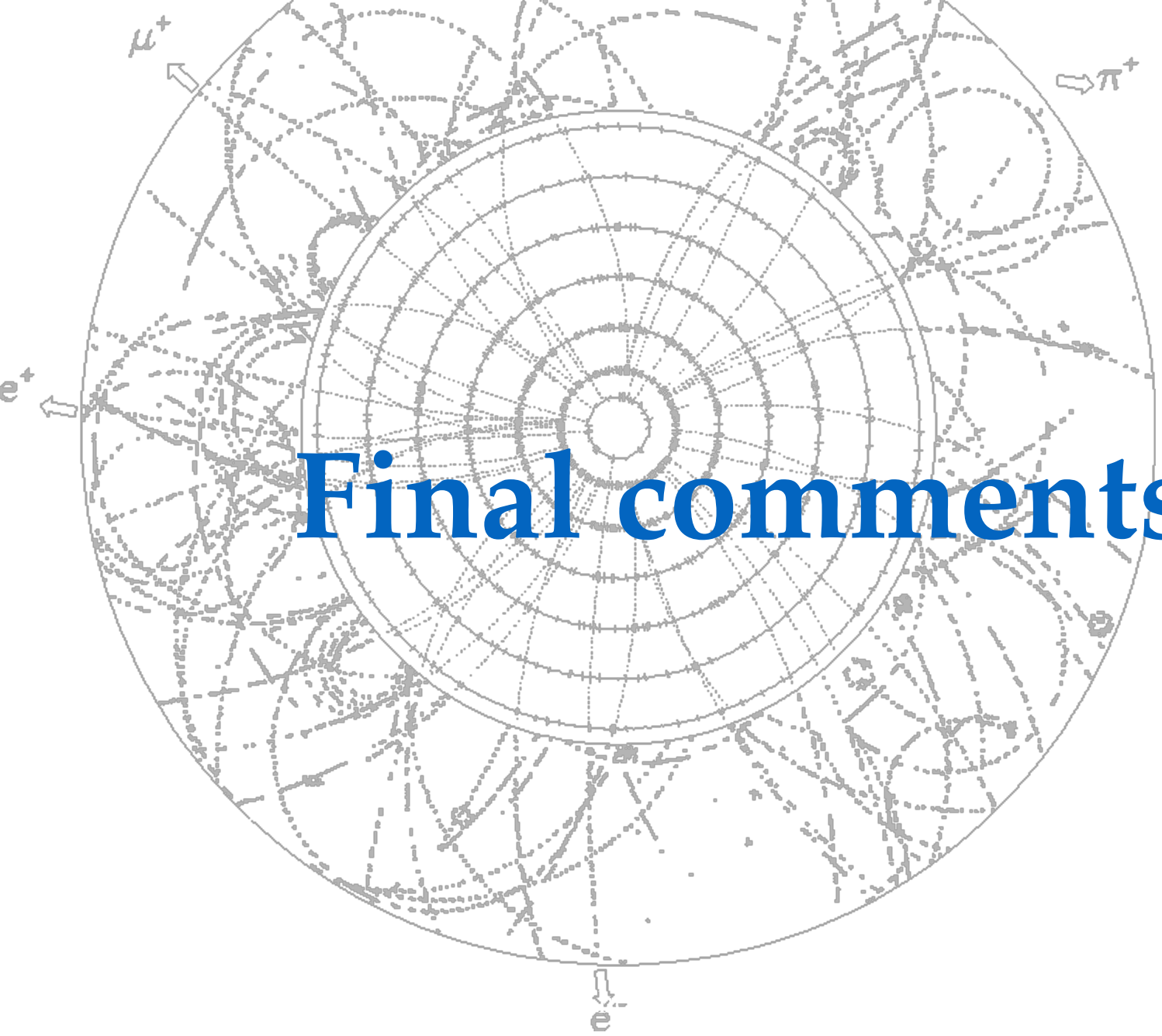
It will require the use of computers and modifications of some of the code you have been running.

You must work on your own!

I will provide this 36 hour exam on:
Thursday the 20th of January 8:00am.

It will then naturally have to be handed in:
Friday the 21st of January before 20:00!





Final comments

Expectations

I want (read: insist) this course to be useful to all of you!

Therefore, please give me feedback (during the course, thanks!), if you have anything to add/suggest/criticise/alter.

This also means, that I will require much from you - as much as I can without spoiling the social life of your youth!

In return, I'll try to make statistics as interesting as possible (and not deprive you of all your early mornings).

"Taking Applied Statistics is like training to a marathon. You work hard to obtain your goal and some times you question yourself why you started this to begin with. But after all the hard work you have become stronger and have obtain an experience for life. Applied Statistics is without any doubt the course on my Bachelor degree I'm most proud of and the course I have learned the most from."

[Anonymous, 2019-20 course evaluation]

General words on the course

The course requires both self-disciplin and dedication to the course work.

We will of course do our best to inspire, help, and promote collaboration, but it is up to you, how much you want to learn/benefit from this course.

Course work can/should be done in collaboration with fellow students.

So please make small teams of peers, with whom you can discuss the many details of coding and the problems, challenges, and issues involved. This is you best way to **interact with peers, learning most, and not getting stuck**.

For those not attending, help/supervision will be available via Zoom, Slack & your favorit communication platform.

Problems?

If you experience problems in relation to Applied Statistics, whatever their origin and nature, then write me!

I may not be able to do anything about it, but I will try my best. However, if I don't know about your problems, then I most certainly can not do anything about them.

I consider myself fairly large, as long as I feel that this largeness is met by sincerity and will.

But… you need to write me in the first place! That is your responsibility.

Course book and References

Roger J. Barlow: Statistics *(course book!)*
(A guide to the use of statistics methods in the physical sciences)
Very good introduction, which goes further than Bevington (see below).
Very much to the point.

Philip R. Bevington: Data reduction and error analysis.
Classic introduction with very good examples - a standard reference in all of experimental physics.

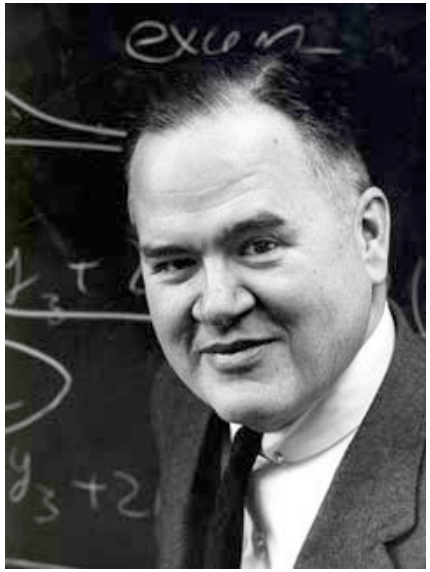
Glen Cowan: Statistical Data Analysis
A bit brief, but once you got the hang of statistics, this book contains much of what you will ever need, written in a useful or precise way.

> *"If you don't read any books, you'll remain ignorant.*
> *If you read one book, then you're being introduced to the subject.*
> *If you read several books, then you're studying the subject"*
>
> [Professor at the Faculty of Law]

Statistical practices

The famous statistician John Tukey (1915-2000) was quoted for wanting to teach:

- The **usefulness and limitation of statistics**.
- The importance of having methods of statistical analysis that are robust to violations of the assumptions underlying their use.
- The need to amass experience of the behaviour of specific methods of analysis in order to provide guidance on their use.
- The importance of allowing the possibility of data's influencing the choice of method by which they are analysed.
- The need for statisticians to reject the role of "guardian of proven truth", and to resist attempts to provide once-for-all solutions and tidy over-unifications of the subject.
- **The iterative nature of data analysis**.
- Implications of the increasing power, availability and cheapness of **computing facilities**.
- The training of statisticians.



"Far better an approximate answer to the right question, which is often vague, then an exact answer to the wrong question, which can always be made precise." J. W. Tukey

Top 10

Most important things in applied statistics

1. Errors decrease with the **square root of N**
2. **ChiSquare** is simple, powerful, robust and provides a **fit quality** measure
3. **Binomial** distribution → **Poisson** distribution → **Gaussian** distribution
4. **Error propagation** is **craftsmanship** - **fitting** is an **art**
5. Error on a (Poisson) number, N: $\sqrt{N}$ on a fraction, f=n/N: $\sqrt{f(1-f)/N}$.
6. **Correlations** are important and needs consideration
7. Hypothesis testing of H_0 (null) and H_1 (alt.) is done with a test statistic t
8. The **likelihood** (ratio) is generally the optimal estimator (test)
9. Low statistics is terrible – needs special attention
10. Prior probabilities needs attention, i.e. Bayes' Theorem