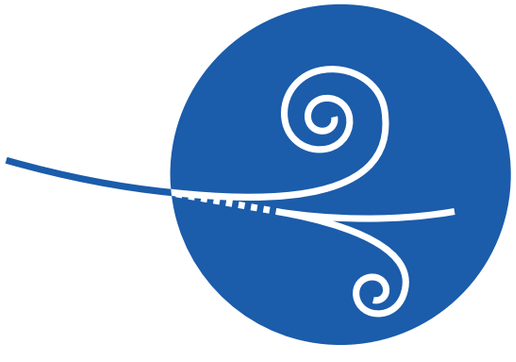


III. Physikalisches
Institut A

RWTH AACHEN UNIVERSITY

# Experimental Techniques in Particle Physics (WS 2020/2021)

## Organisation and Introduction

Prof. Alexander Schmidt

27.10.2020

# The Team

## Prof. A. Schmidt

RWTH, Experimental Particle Physics,

CMS Experiment (CERN),

MADMAX Experiment (DESY)

**Lecture + Data Analysis Exercises**

## Dr. S. Metzger

Fraunhofer Institute for Technological Trend Analysis

Radiation Effects in Electronics and Opto-Electronics

**Lecture**

## Dr. A. Nowack

RWTH, Experimental Particle Physics,

Grid-, Cloud, HPC Computing

**GEANT simulation course**

## Dr. J. Steinmann

RWTH, Experimental Particle Physics,

T2K Experiment, Juno Experiment

**FPGA programming course**

# The Team

## Dr. A. Pozdnyakov

RWTH, Experimental Particle Physics,

CMS Experiment (CERN),

**Data Analysis Exercises**

## V. Sarkisovi

student assistant

**Data Analysis Exercises**

# Structure

**lecture + data analysis exercises**

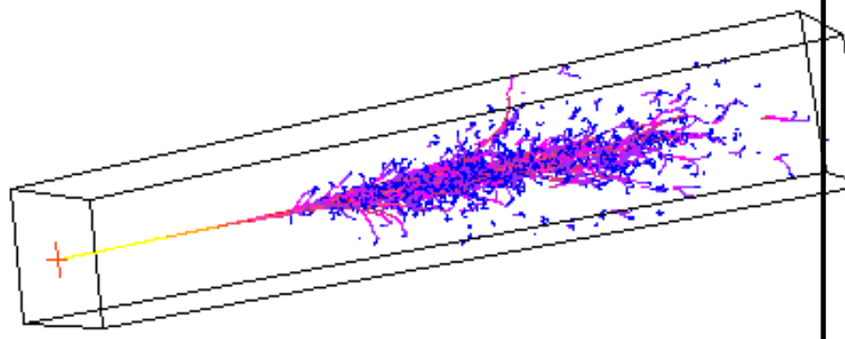
**time and location:**
Tuesday, 14:30

- basic principles of detectors and their technology
- **hands-on examples**
- **data analysis methods and examples**
- **analysis of real LHC data**


**practical course:
FPGA programming**

**time and location:**
Wednesday, 14:30,

- learn how to program fast electronics
- real-time data processing



**practical course:
GEANT 4 simulation**

**time and location:**
Thursday, 14:30,

- simulate interaction of radiation with matter
- Monte Carlo simulation
- used in physics, medicine, biology, etc…

# Structure

- after the lecture and courses, there is extra time to work on the material yourself, with the help of the supervisors

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 13.18519 | W | | Experimental Techniques in Particle Physics | 6 | VU | | 0/1 | Schmidt A, Metzger S, Nowack A, Steinmann J | 133920 | Englisch | Online-Veranstaltung | **27.10.20** 14:30 - 16:00 |
| 13.18520 | W | | Self-Learning Sessions to Experimental Techniques in Particle Physics | 6 | UE | | | Schmidt A, Metzger S, Nowack A, Steinmann J | 133920 | Englisch | Online-Veranstaltung | **27.10.20** 16:30 - 18:00 |

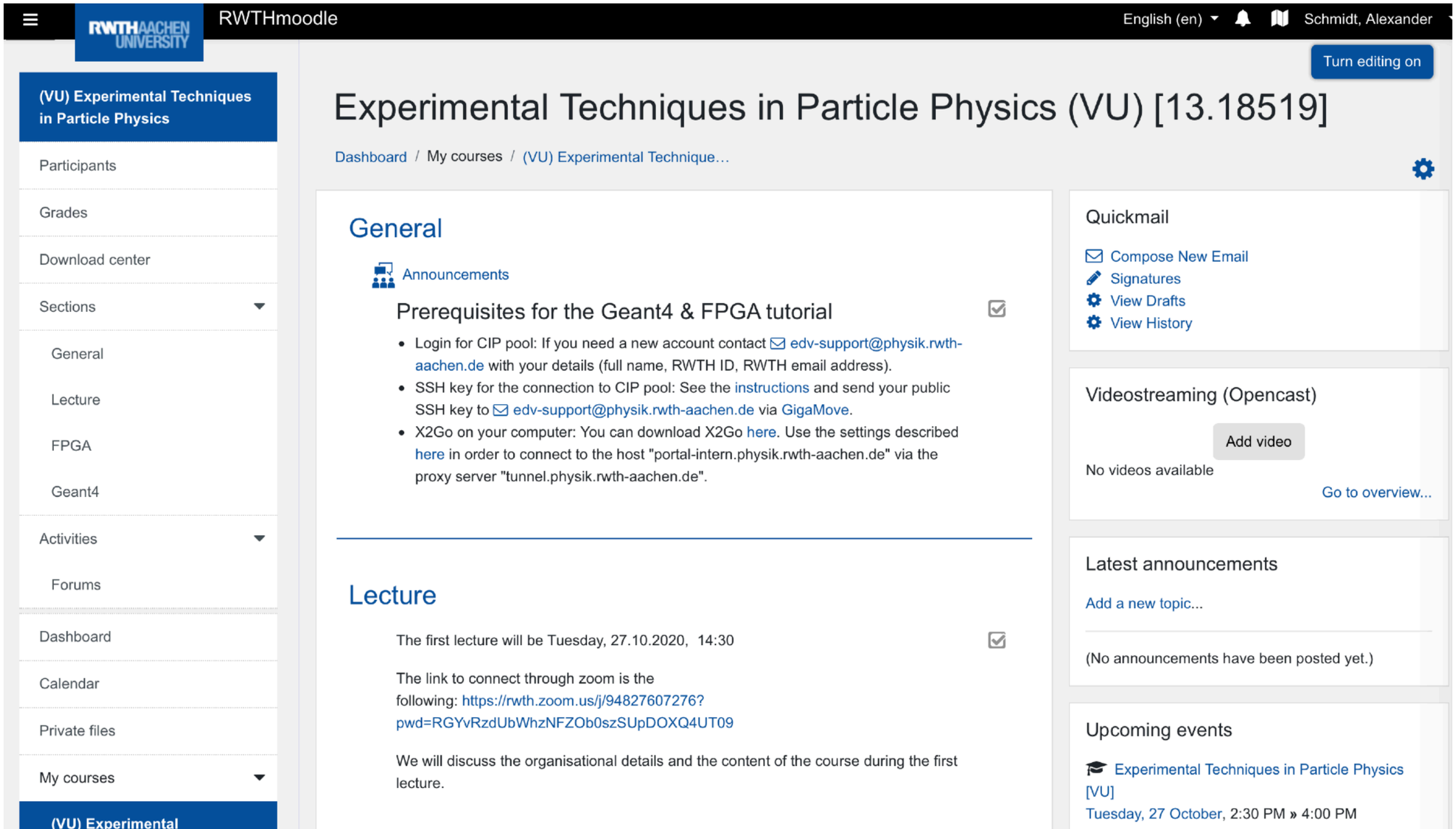
- you will NOT have to hand in any solutions for homework
- 10 ECTS credits

- admission to the exam will be based on regular presence in the courses

- we need to fix a date and time for the written exam (Klausur)
  - suggestion: **16.02.2020, 14:30** (one week after the last lecture)

# Resources

- all material will be available through moodle
- if you don’t have access, please let us know



# Overview

**what are “experimental techniques” ?**

- everything you do in an experiment

- there are many experiments

- example experiment at the LHC
  - proton-proton interactions (physics processes)
  - interaction of particles with detector material
  - response of the various detectors (silicon, calorimeters, muon chambers)
  - trigger (several stages)
  - data acquisition
  - data processing
  - data quality monitoring
  - event reconstruction
  - physics analysis and statistical interpretation

**how do particles (Higgs bosons?) find their way into the computer?**

# Preliminary schedule of the lecture

## (may slightly change according to your preferences)

**today:** organisation/introduction/overview/technical setup
(C++ programming, ROOT analysis tool)  (Prof. Schmidt)

**03.11.:** sources of radiation (Dr. Metzger)

**10.11. / 17.11.**: basic principles of interaction of particles with matter
(with practical hands-on examples)  Part I + II  (Prof. Schmidt)

**24.11.:** overview of detectors (Dr. Metzger)

**01.12.:** gas detectors

**08.12.:** principles of silicon detectors (Dr. Metzger)

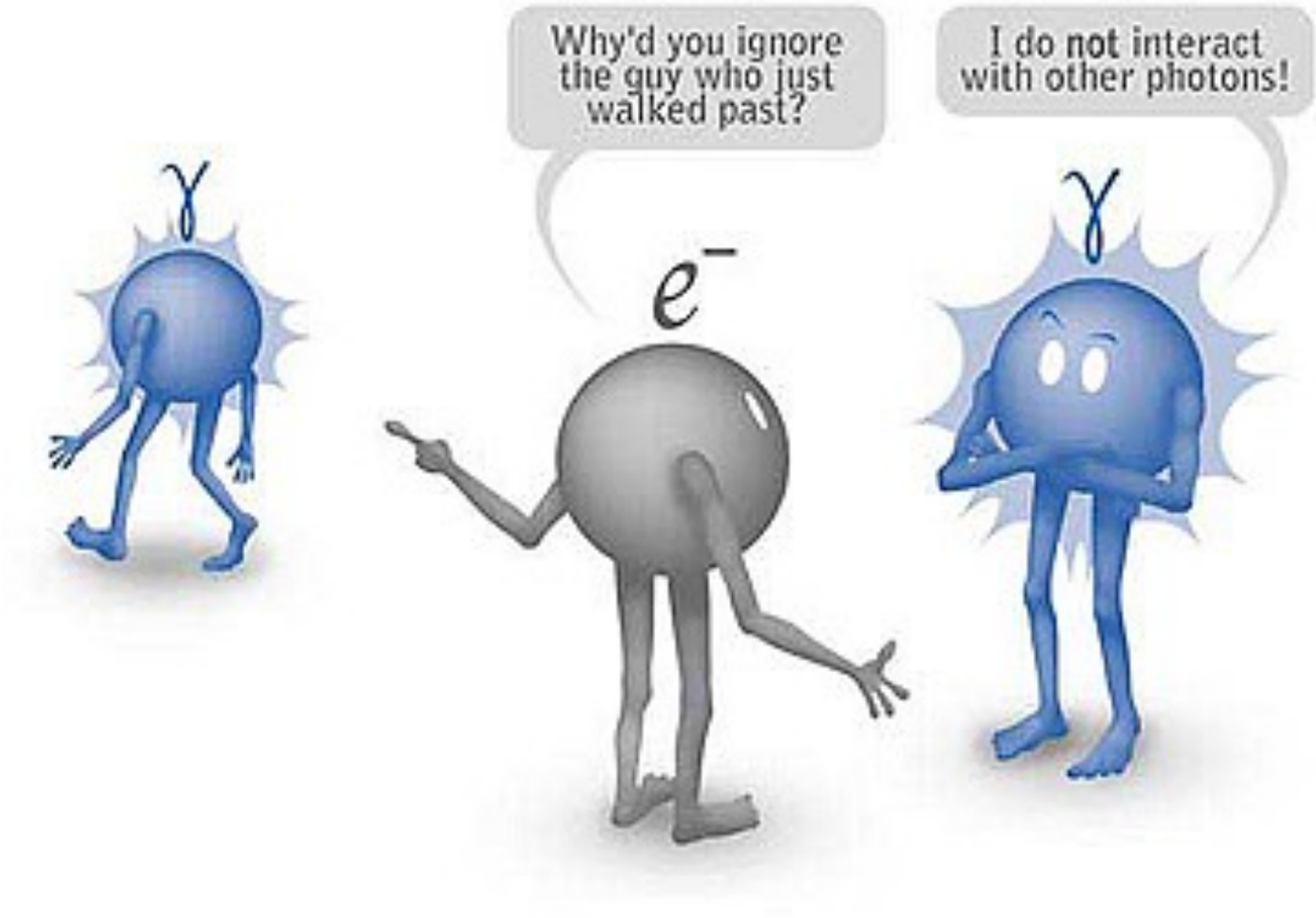
**15.12.:** advanced topics on silicon detectors, calorimeters
(Prof. Schmidt)

**22.12. / 12.01.:**  detector readout electronics (Dr. Metzger)

**19.01. / 26.01. / 02.02. / 09.02.:** advanced statistics and data analysis topics. Analysis of LHC data, hands-on tutorial (Prof. Schmidt)

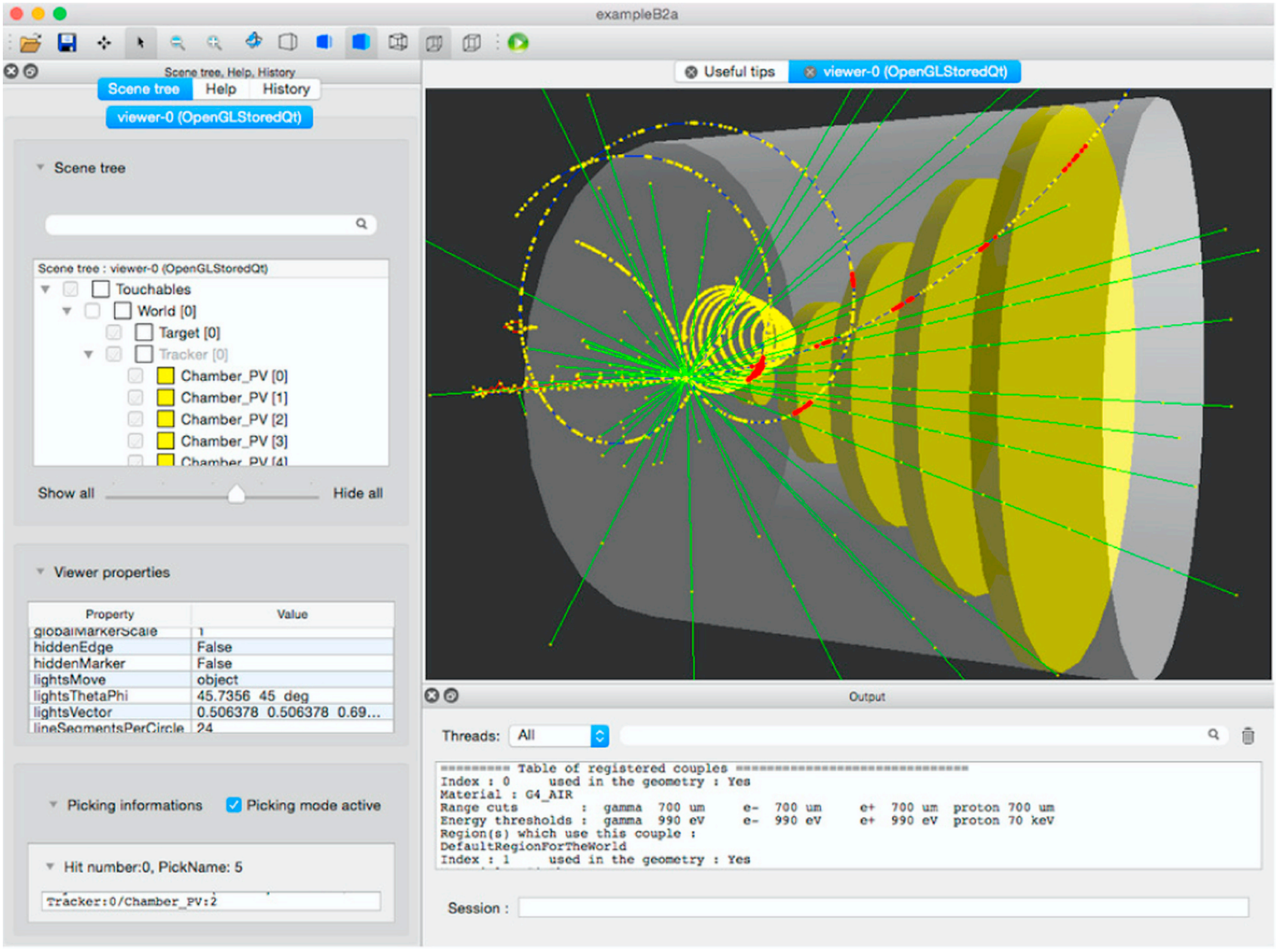
# GEANT 4

- particles can only be detected through their **interaction** with “something”
- the **interaction** is registered by the detector, not the particle itself
- one has to deduce the information about the particle from the **interaction**
- the detector consists of various types of material




- detailed understanding of **interaction of particles with matter** is fundamental for experiment
- GEANT 4 is a flexible toolkit to obtain precise descriptions of such interactions in arbitrary geometries

# GEANT 4


exampleB2a
Scene tree, Help, History
Scene tree
Help
History
viewer-0 (OpenGLStoredQt)
Scene tree
Scene tree : viewer-0 (OpenGLStoredQt)
Touchables
World [0]
Target [0]
Tracker [0]
Chamber_PV [0]
Chamber_PV [1]
Chamber_PV [2]
Chamber_PV [3]
Show all
Hide all
Viewer properties
Property
Value
hiddenEdge
False
hiddenMarker
False
lightsMove
object
lightsThetaPhi
45.7356 45 deg
lightsVector
0.506378 0.506378 0.69...
Picking informations
Picking mode active
Hit number:0, PickName: 5
Tracker:0/Chamber_PV:2
Useful tips
viewer-0 (OpenGLStoredQt)
Output
Threads:
All
========= Table of registered couples ==========
Index : 0 used in the geometry : Yes
Material : G4_AIR
Range cuts : gamma 700 um e- 700 um e+ 700 um proton 700 um
Energy thresholds : gamma 990 eV e- 990 eV e+ 990 eV proton 70 keV
Region(s) which use this couple :
DefaultRegionForTheWorld
Index : 1 used in the geometry : Yes
Session :

# GEANT 4

- it does Monte Carlo simulation
- you do the same thing twice and get very different results
- is a toolkit in C++ programming language (you need to understand C++)
- performs motion of particles in fields and matter
- simulates interaction of particles with matter (detector)

- GEANT4 does **not** simulate high energy proton-proton collsisions
  - need to use event generators for that (pythia, sherpa… )
- GEANT4 is **not** an executable program/file.
  - it is a collection of libraries organized in classes (C++)
- GEANT4 is **not** an analysis program.
  - use other analysis tools (e.g. ROOT), to be learned in our tutorial

# Chain of a HEP experiment simulation

- back to our example experiment at the LHC:
  - proton-proton interactions (physics processes): **theory, not covered here**
  - interaction of particles with detector material: **GEANT4**
  - response of the various detectors (silicon, calorimeters, muon chambers) **examples and exercises in the lecture**

- trigger (several stages): **FPGA**

- data acquisition
- data processing
- data quality monitoring

- event reconstruction: **examples and exercises in the lecture**

- physics analysis and statistical interpretation: **examples and exercises in the lecture**

# FPGA

**Lecture**
Overview about detectors

**GEANT4**
Simulation of detectors

**FPGA**
Readout of detectors

- **What this tutorial cannot do?**
  - Improve your soldering skills
  - Make you an electrical engineer
  - Make you an FPGA „expert“

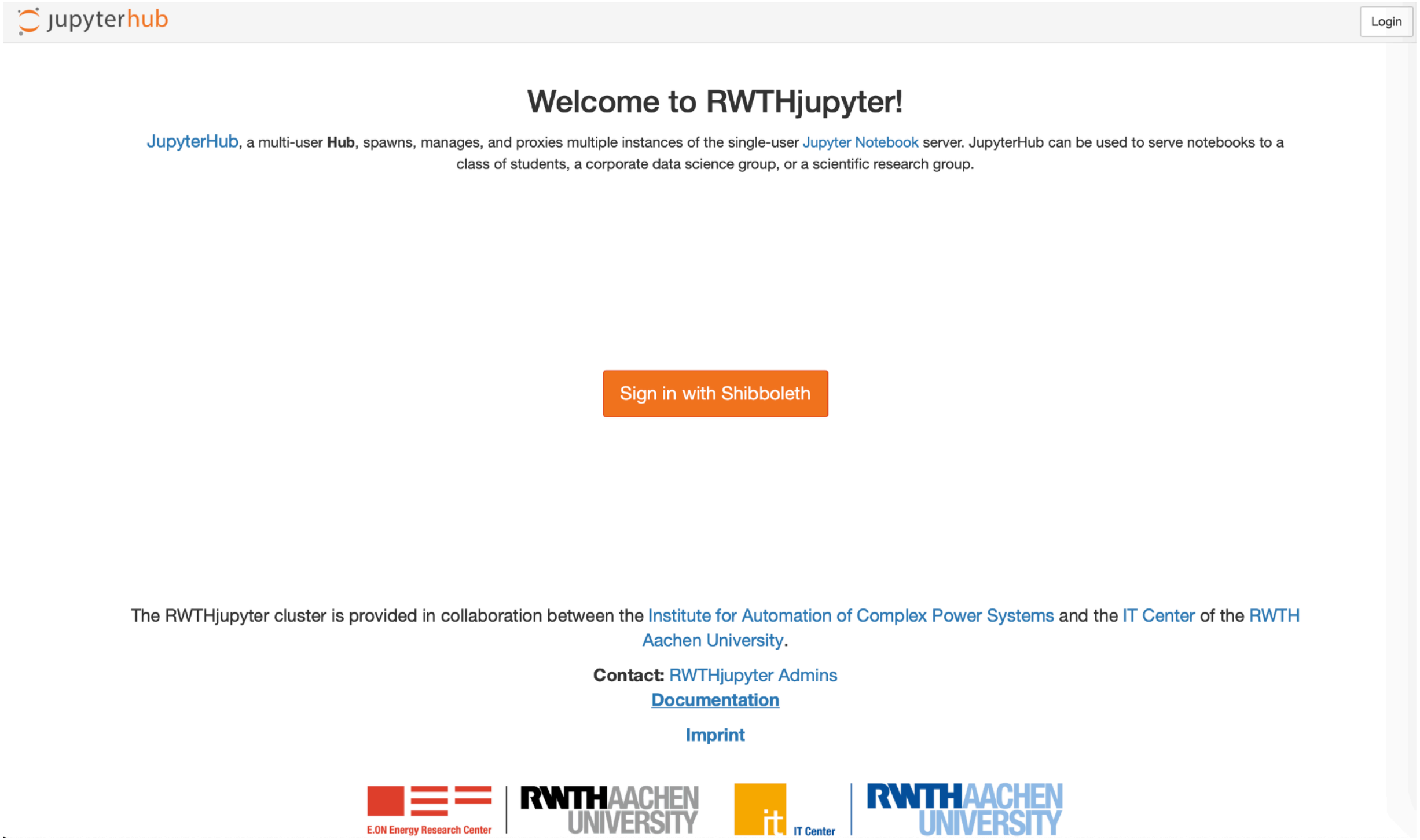
- **What this tutorial can do?**
  - Help you understanding electrical engineers talking about FPGA / Programmable Logic
  - Help you programming a basic firmware
  - Get an overview of programmable logic
    - Problems and their solutions
    - Features and how they can be used

# Data Analysis Software


- a modular scientific software toolkit
- it provides all the functionalities needed to deal with big data processing, statistical analysis, visualisation and storage
- it is mainly written in C++ but integrated with other languages such as Python (we should use it in plain C++ as you need C++ anyway in the GEANT tutorial)
- all LHC experiments use it as fundamental analysis software
- some of you learned how to use it during your Bachelor Thesis? https://root.cern.ch has extensive documentation and tutorials
- we use the remaining time today to test it

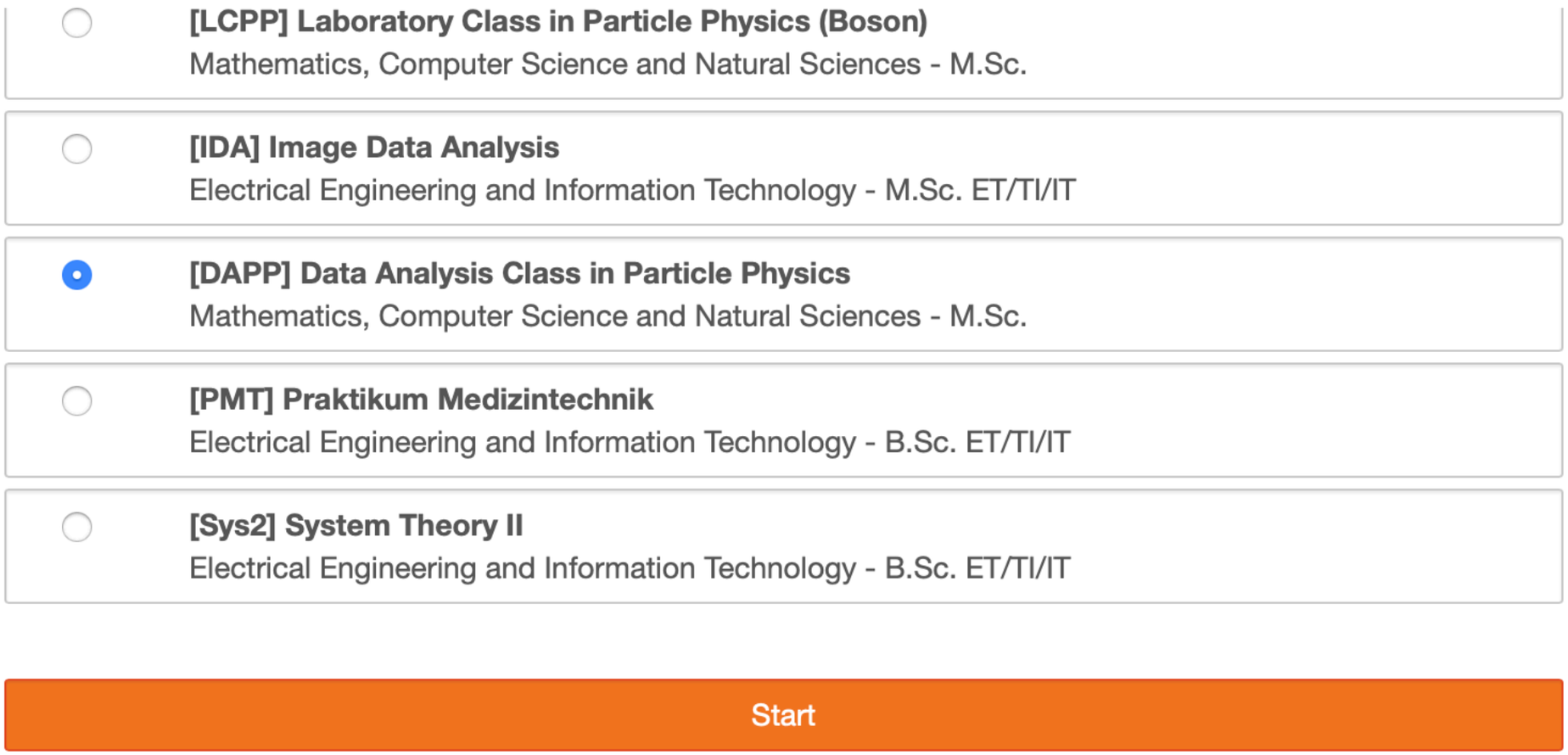
# Jupyter Hub at RWTH

- go to https://jupyter.rwth-aachen.de with a web-browser on your computer
- log-in with your RWTH TIM ID



# Jupyter Hub at RWTH

- select DAPP




- wait until everything is set up
- you will receive a home directory where you can work

# Jupyter Hub at RWTH

File Edit View Run Kernel Tabs Settings Help

dapp

| Name | Last Modified |
|---|---|
| ex1-decay-data | 27 minutes ago |
| ex2-bethe-bloch | 2 days ago |
| Plots | 2 days ago |
| tutorial-root | 5 minutes ago |
| tutorial-terminal | 27 minutes ago |
| Index.ipynb | 2 days ago |
| Dockerfile | 2 days ago |
| fix-permissions | 2 days ago |
| jupyter_notebook_... | 2 days ago |
| LICENSE | 2 days ago |
| pythia-root.patch | 2 days ago |
| README.md | 2 days ago |
| requirements.txt | 2 days ago |
| start-notebook.sh | 2 days ago |
| start-singleuser.sh | 2 days ago |
| start.sh | 2 days ago |

Index.ipynb | index.md

Markdown | Python 3

## Data Analysis Class in Particle Physics

Physics Institute III A | RWTH AACHEN UNIVERSITY

Andrey Pozdnyakov, Valentina Sarkisovi, Alexander Schmidt

## Quickstart: Jupyter

- Run single cells: ▶-Button or `Shift+Enter`
- Run all cells of a notebook: Menu `Run`>`Run All Cells`
- To restart the kernel (delete all variables): ↻-Button
- **Backup data:** It is recommended to download the edited files via the fileviewer on the left side. (Right-click the file, then ↓`Download`).

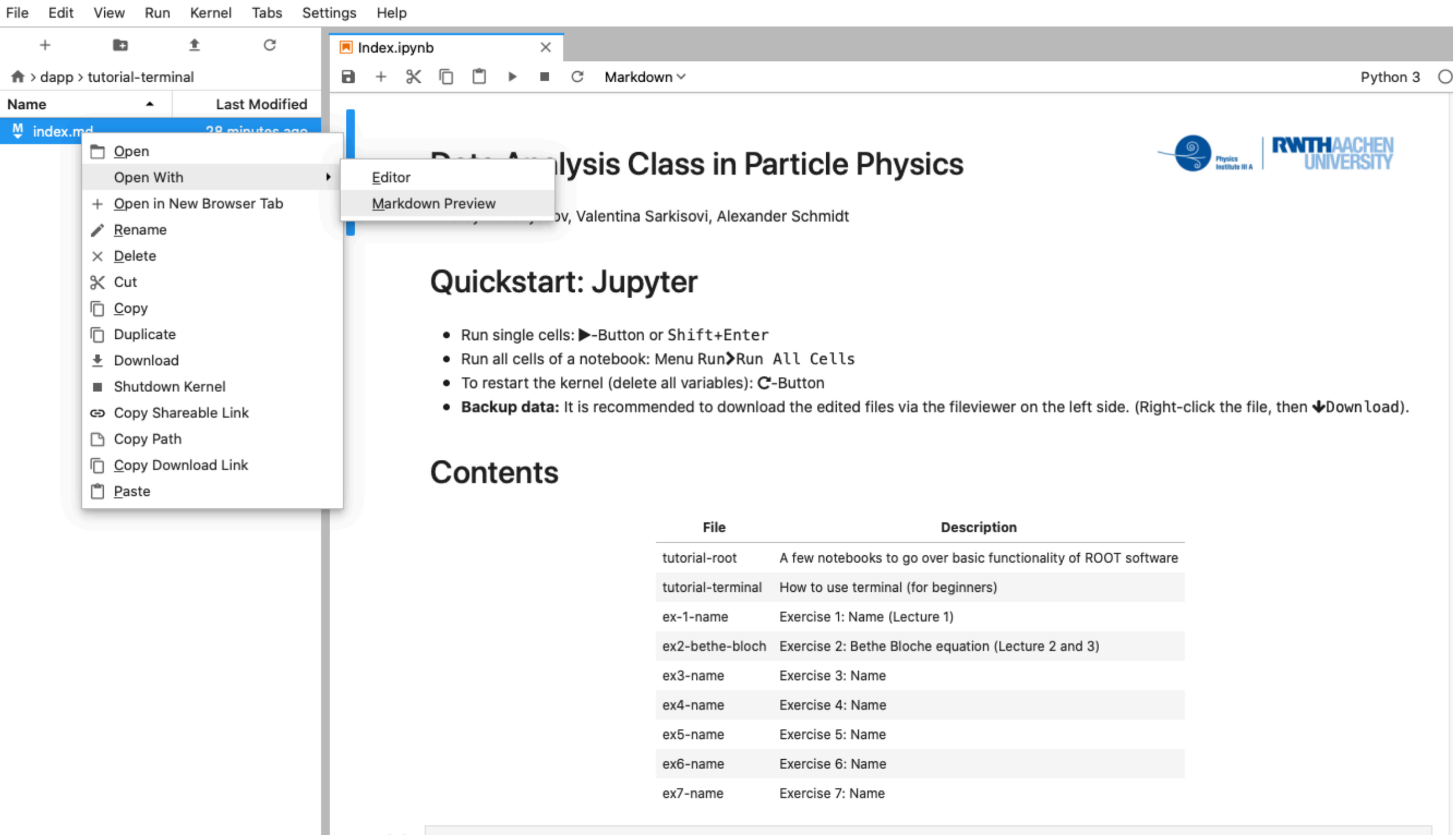
## Contents

| File | Description |
|---|---|
| tutorial-root | A few notebooks to go over basic functionality of ROOT software |
| tutorial-terminal | How to use terminal (for beginners) |
| ex-1-name | Exercise 1: Name (Lecture 1) |
| ex2-bethe-bloch | Exercise 2: Bethe Bloche equation (Lecture 2 and 3) |
| ex3-name | Exercise 3: Name |
| ex4-name | Exercise 4: Name |
| ex5-name | Exercise 5: Name |
| ex6-name | Exercise 6: Name |
| ex7-name | Exercise 7: Name |

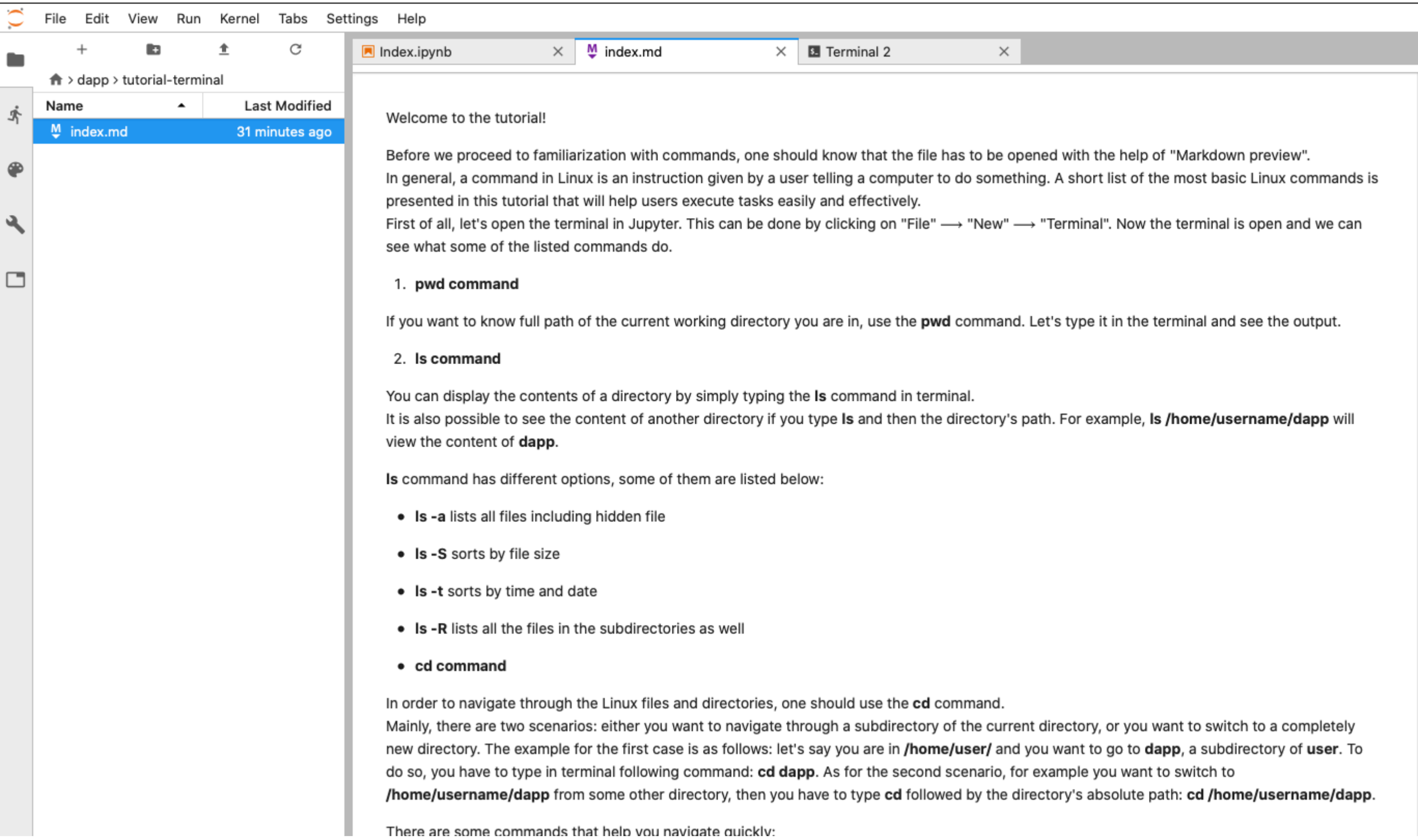
[ ]:

# Jupyter Hub at RWTH

- go to folder tutorial-terminal
- open with Markdown (right click)

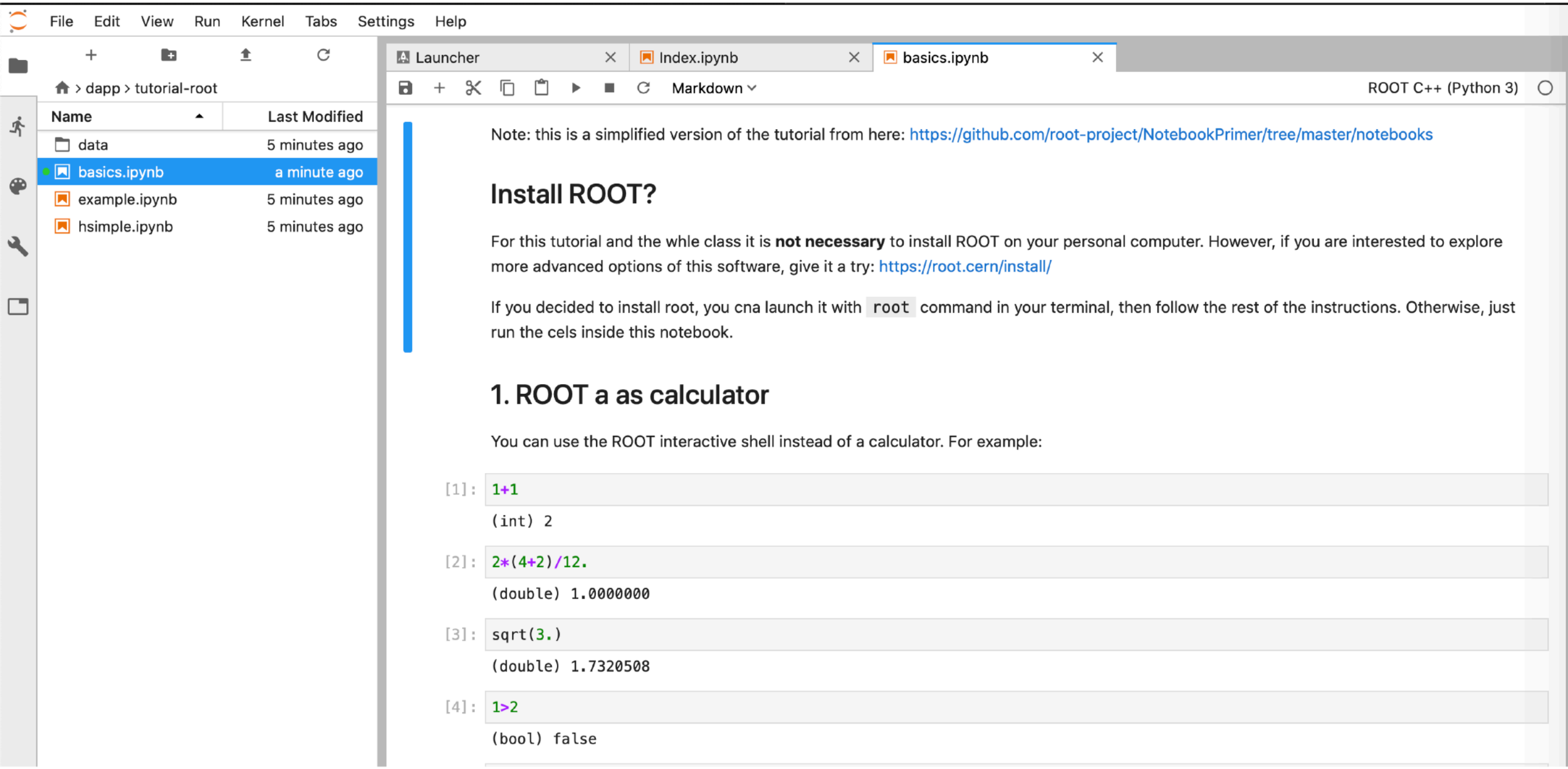


# Jupyter Hub at RWTH



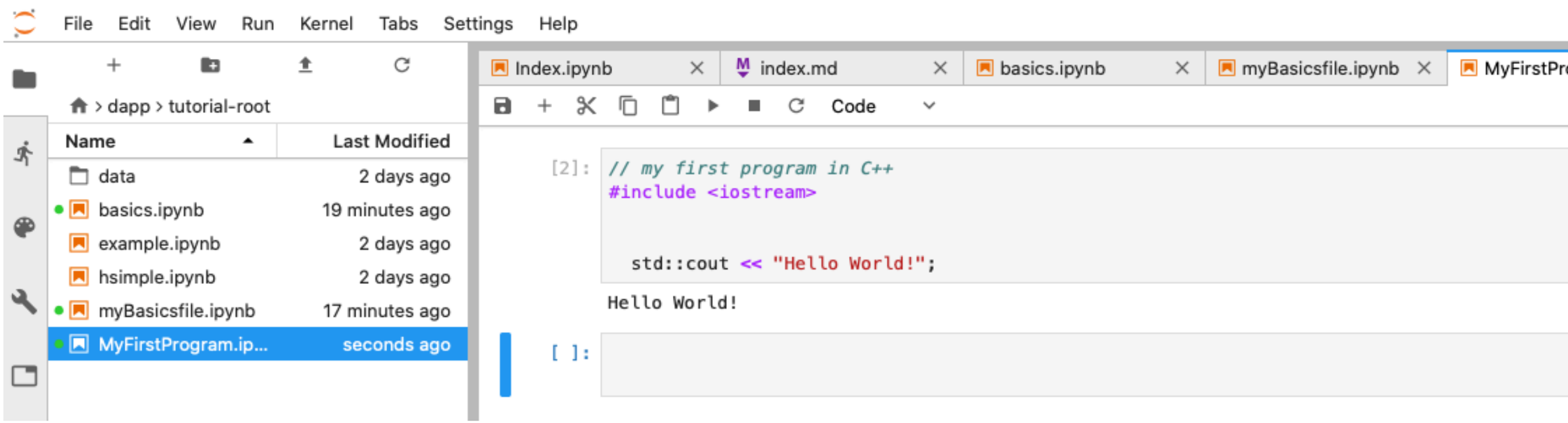
# Jupyter Hub at RWTH

- go to folder tutorial-root and start  basics.ipynb



# Jupyter Hub at RWTH

- this may be difficult if you don’t know C++
- do a C++ tutorial first:
  http://www.cplusplus.com
- create a new notebook though the + sign (new launcher), and select ROOT C++
- give it a name
- try some code



# Jupyter Hub at RWTH

- note that Jupyter Hub is good for quick and fast things
- it is not appropriate for large scale software development or high-performance applications
- it also has some limitations for ROOT, for example interactive graphics
- you can install ROOT on your laptop, see the documentation
- or simply login via ssh to
  `ssh -Y –l yourTIMid login18-1.hpc.itc.rwth-aachen.de`
- and fire up root
  `source /cvmfs/sft.cern.ch/lcg/app/releases/ROOT/6.22.02/x86_64-centos7-gcc48-opt/bin/thisroot.sh`
  `root`

# Next steps

- please fill the questionnaire about your state of knowledge in moodle until next week

I am attending or have attended the following courses:

- ☐ Bachelor Vertiefungsfach: Particle Physics
- ☐ Master: Particle Physics I
- ☐ Master: Particle Physics II
- ☐ Deep Learning in Physics Research
- ☐ Accelerator Physics
- ☐ Astronomy and Astrophysics
- ☐ Statistics and Data Analysis

I know the following programming languages

- ☐ C++
- ☐ Python
- ☐ Fortran
- ☐ R
- ☐ Java
- ☐ PHP
- ☐ Julia
- ☐ Other

- next week, we will see if you are able to solve very simple problems with ROOT
- until then, please follow the tutorials in Jupyter
- the tutors will be connected today to help you getting started

# Warning

- we have never done this class fully online….
- let’s try to make it work
- give feedback about ideas how to improve it