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Welcome to FYS5555 / FYS9555 – Research-based Particle Physics

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This course builds on FYS4555 (Particle physics) and FYS4170 (Relativistic quantum field theory).

Course content

"Hands-on" particle physics course

- work through the process in which conservation laws and the gauge principle lead to the Standard Model of particle physics, a successful theory of electroweak and strong interactions.
- calculate SM and new physics processes, make use of simulation tools, analyse real LHC data, and interpret the results by comparing your theoretical prediction with the experimental measurement.

Learning outcome

- detailed understanding of the structure in terms of gauge symmetry groups of the Standard Theory of particle physics
- know how to apply the Higgs mechanism to break spontaneously the electroweak symmetry, and thus generate the masses of the weak gauge bosons and the fermions
- take advantage of "hands on" experience to make detailed calculations of SM and New Physics processes
- make extensive use of computational tools, such as CompHEP, to calculate and simulate particle collisions and decays, and to confront the own calculations to the simulations and the available experimental results
- access real and simulated LHC data through the CERN Open Data Portal, learn and use analysis, statistical and simulation tools to perform various state of the art particle physics analyses.
- study proton-proton collisions and exploit the potential of the LHC in terms of precision measurement of the production and decay of SM particles, search for new physics phenomena.
- read and discuss publications related to High Energy Particle Physics
- and explain how the authors arrived to the results (extra for FYS9555).

Teaching

- The course will incorporate lectures, projects, demonstrations and guided practical sessions, data analysis and the use of statistical methods.
- There are two hours of lectures each week, and two hours of practical work.
- The course also includes two smaller projects during the semester, as well as a bigger final project with a complete project rapport. All three projects will count towards your final grade.

Examination

- An exam in the form of two projects, weighted 17% each, 34% total.
- An exam in the form of a final project rapport weighted 33% of the grade
- A final oral exam, weighted 33% of the grade. The oral exam includes a presentation of the final project.

Further course details and bibliography

- As a short introduction, and in order to allow students to catch up with FYS45555, The Standard Model of Electroweak Interactions and the lectures given at CERN Summer Student Lecture Programme 2008 will closely followed.
- The book Modern Particle Physics, Thomson 2013, gives a thorough introduction to the field of particle physics.
    - It will be used as a reference and students who did not take FYS4555 are advised to go through the main chapters introducing the basics of the SM (Dirac equation, calculations of cross sections and decay widths and lifetimes, the various interactions, symmetries and conservation laws, ...)
    - The books Modern Particle Physics and Introduction to Elementary Particles, Griffiths 2008, have all necessary details helping go through the detailed and important calculations, especially if the students have not had FYS4555 and/or FYS4170.
- Emphasis of this course is on
    - electroweak interactions in general and on Spontaneous Symmetry Breaking (SSB) and mass generation.
- In order to exploit the LHC data, it is necessary to understand strong interactions within the framework of QCD.
- The LHC, the highest energy particle accelerator, is a so-called discovery machine. The LHC experiments have as a goal,

    - not only to confirm the last missing building block of the SM of elementary particles, the Higgs boson,
    - but also, to identify the new physics which may be expected in a previously unexplored energy regime. Are there new symmetries or new space dimensions? Where is dark matter? How to incorporate Gravity?
- This course partly follows the subjects of the book High Pt Physics at hadron colliders (no need to purchase the book) which makes extensive use of a computational tool, CompHEP, both in the examples given in the text, and in the exercises, giving "hands on" experience.
- CompHEP is a package for evaluation of Feynman diagrams, integration over multi-particle phase space and event generation. It runs on Linux, MacOS, as well as on Windows (OLD version not supported).
    - Install the Linux version on a UiO machine and/or own Laptop. Not many people have successfully managed to install and use the MacOS version. Good luck!
    - The students will be asked to
        - calculate some first order electroweak and/or strong processes and compare the results to CompHEP as well as to experimental measurements.
        - Edit and extend CompHEP to BSM processes such as Z', W', …
- Experimental ATLAS data are available and learning resources are developed for students within the Open Data Portal and related software tools … ATLAS Open Data portal and the UiO ZPATH. Python, (C++) and ROOT are used.
    - Students (final) projects will be based on data and simulations (and calculations). Some examples can be found here.
    - As an alternative to using the standard analysis code, the projects can be done using Jupyter notebook. The Instructions on how to install Jupyter notebook (with C++ and ROOT) are being improved and extended. Some analysis examples can also be found in the same repository as the instructions.
        - The notebook called Analysis_basics gives a very short introduction to some important ROOT commands and analysis features, e.g. how to read a file, run through the events and plot histograms. A slightly more advanced example is found in the notebook called Dilepton analysis. Notice that there is also a Python version of this notebook, if you strongly prefer working in Python instead of C++.
    - See also Zpath Updates and Open Data plans.

- Statistical methods might/will be needed in order to interpret experimental data and confront theory to experimental measurements. The book Data Analysis in High Energy Physics – a Practical guide to Statistical Methods – can be of great help. See also link , especially chapters 10 (Statistical methods commonly used in HEP) and 11 (Analysis walk throughs).