IFJ PAN Particle Physics Summer Student Programme

Projects 2020

Projects will be done in pairs.

1. **A preprocessing of data from the gamma radiation detector**

Supervisor: dr inż. Piotr Kapusta
Department of Leptonic Interactions (NZ11), Piotr.Kapusta@ifj.edu.pl

Students get acquainted with the multi-channel gamma radiation detector, built from silicon photomultipliers, shaping preamplifiers and the Time-To-Digit Converters (TDC), which sample detector signals on a few threshold levels.

A principal student assignment consists of preprocessing randomly arriving data samples from the detector, including its sorting and a time calibration. As the result, the linearities, time offsets and resolutions of individual TDC channels will be determined. Properly calibrated readout system should next be used for a rough reconstruction of pulse shapes, including their amplitudes and peaking times.The C++ in the framework of the ROOT package is a preferable tool for the job.

2. **Study of semi-inclusive characteristics for $B \to D/D_s hX$ decays at Belle II**

Supervisor: dr Olga Werbycka
Department of Leptonic Interactions (NZ11), olga.verbytska@ifj.edu.pl

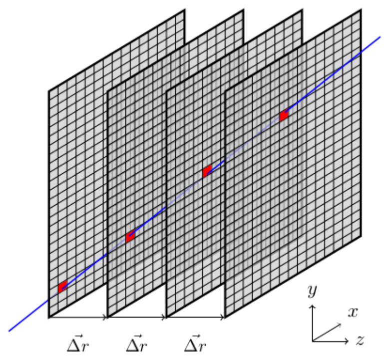
The SuperKEKB is a particle accelerator located at the KEK facility in Tsukuba (Japan). It runs beams of electrons and positrons into each other to produce enormous quantities of B mesons. Products of collisions are collected by Belle II detector – the “super-B factory” upgrade of its predecessor, Belle. During practice we will analyze $B \to D/D_s hX$ decays (where $h = \pi^0, \rho, \eta$ *etc.* particle) in order to define its semi-inclusive characteristics, *i.e.* multiplicity. This will allow students to go all the way from very basic steps (event generation) to the analysis of the given decay channels using Belle II software.

Tools: ROOT, Python libraries and Belle II software.

3. **Reconstruction of hadronic showers in ATLAS Forward Proton detectors**

Supervisor: dr Rafał Staszewski, mgr inż. Krzysztof Cieśla
The Diffractive Physics Department (NZ13), rafal.staszewski@ifj.edu.pl, krzysztof.ciesla@ifj.edu.pl

ATLAS experiment at LHC is equipped with special detectors dedicated to measurements of protons scattered at very small angles (called forward protons). These detectors use four layers of silicon pixel sensors to reconstruct trajectories of passing particles, see Figure. Once in a while, the passing particle can interact with the nuclei of the detector material causing a hadronic shower, *i.e.* a cascade of secondary particles. The present reconstruction algorithms do not perform well for showers – they can be reconstructed either as a single particle or as several independent particles. The aim of the project is to improve the existing algorithms to deal better with events containing showers.



4. **Analysis of Cluster Shapes in the ATLAS AFP Detector**

Supervisor: dr Maciej Trzebiński
The Diffractive Physics Department (NZ13), maciej.trzebinski@ifj.edu.pl

Soft diffractive events are about a half of the total cross section for proton-proton collisions at the LHC energies. Measurement of their properties is, however, not easy since it requires tagging of forward protons. In last years 2016-2018 ATLAS Collaboration took such data with newly installed Forward Proton detectors (AFP). Since these devices are relatively new, there are a lot of things connected to their performance to be understood.

Proposed project is to deepen the knowledge on how protons form cluster hits in AFP silicon detector. Starting from simple analysis of track properties based on Monte Carlo events generated by Pythia 8, through reconstructing clusters with dedicated standalone-tool, ending on analysis of signals in close-to real LHC conditions, this project would allow for deep understanding of cluster formation in AFP.

Tools foreseen to be used in the project: C++, ROOT, gnuplot.

5. **Analysis of Proton Transport Through LHC**

   Supervisor: dr Maciej Trzebiński
   The Diffractive Physics Department (NZ13), maciej.trzebinski@ifj.edu.pl

   Since 2016 ATLAS detector is equipped with new devices – forward proton taggers (AFP). AFP aims to measure protons scattered at very small angles, which are a natural signature of so-called diffractive events. These detectors are located more than 200 m away from collision point, after two dipole and five quadrupole magnets. As a result, a proton trajectory is between collision point and AFP detector is not a straight line, in fact its shape is quite complicated due to the presence of LHC magnetic fields.

   To understand the impact of LHC magnets on the proton position in AFP detectors, a simple tracking tool was prepared. It uses information about magnets (position, strength) from available official LHC files. Nevertheless, the 'design' parameters may differ from reality, *i.e.* magnetic field may be a bit stronger than assumed or magnet can be displaced by few hundred micrometers. The goal of the project is to understand how such these variations impacts properties of protons registered in AFP.

   Tools foreseen to be used in the project: C++, ROOT, gnuplot.

6. **Detector Control System for AFP detector in ATLAS experiment at CERN: design of graphical user interfaces**

   Supervisor: dr inż. Elżbieta Banaś
   The Diffractive Physics Department (NZ13), elzbieta.banas@cern.ch

   Detector Control System (DCS) in a large physics experiment provides tools to bring the detector into any desired operational state and continuously monitors its operational parameters. Crucial parameters are guarded by the alarm system. The detector is controlled by remotely accessible graphical user interfaces.

   Students will design graphical user interfaces for two parts of the AFP detector. The project will be done on a remote computer located at CERN, with environment dedicated for ATLAS control systems. After GUI's are successfully commissioned in this computer, they will be installed in the production area of the AFP detector. The work can be presented (remotely) at the AFP Operational meeting at CERN. Students will be registered at CERN (external participant) and they will use CERN computing infrastructure. The industrial Supervisory Control and Data Acquisition (SCADA) Siemens WinCCOA tool will be used in the project.

   Requirements: basic knowledge of Linux OS and C (C++) programming language.

7. **Reconstruction of particle tracks using Deep Neural Networks**

   Supervisor: dr hab. Marcin Wolter
   The ATLAS Experiment Department (NZ14), marcin.wolter@ifj.edu.pl

   Image classification using Deep Neural Networks (DNN) is a rapidly developing part of computer science. The techniques developed for various applications become also used in High Energy Physics, presently mostly for event classification. In the recent years the novel methods of particle track reconstruction using DNNs are being developed. In the recent years the Graph Neural Networks (GNNs) are becoming a popular tool allowing fast and efficient track reconstruction.

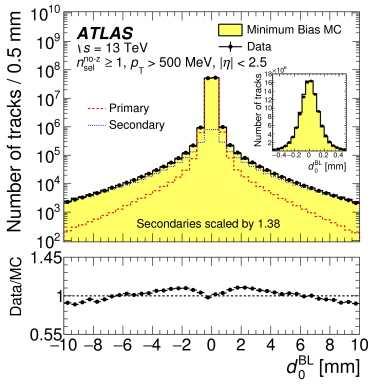
   The task would be to test the performance of the GNN network first on a very simple toy detector model. In the next step the GNN algorithm should be used for track finding in a simplified MuonE experiment detector. The tracking performance should be measured.

   The project should be implemented using the Google Colaboratory http://colab.research.google.com, which allows creating iPython notebooks and offers free access to Graphic Processor Units (GPU), which speed up the network training. Therefore, the candidate should be willing to use the python language and to have the Google ID to be able to use the resources supplied by them.

8. **Charged particle production in Xe+Xe collisions**

Supervisor: dr hab. Krzysztof Woźniak
The ATLAS Experiment Department (NZ14), Krzysztof.Wozniak@ifj.edu.pl

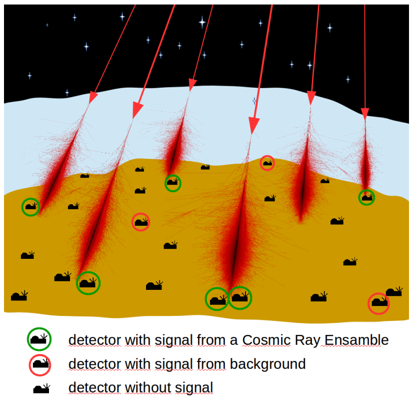
The ATLAS detector is used in one of four experiments working at Large Hadron Collider at CERN, which accelerates beams of particles to the highest energies available in laboratories. Most of the time beams of protons are collided, however collisions of nuclei are also possible.
In October 2017 for the first time beams of xenon nuclei were collided with the total energy of 5.44 TeV. Some results based on the data from these collisions were already obtained, but it is still possible to analyze properties of these collisions which were include in published papers.
During the three weeks of practical part of the Summer Student Programme the data from the ATLAS experiment will be analyzed. The results from measurements will be compared with simulations which include all effect occurring in the detector. As a result first measurements of the properties of charged particles produced in the new type of colliding system at extremely high collision energy can be obtained.



9. **Detection of Cosmic-Ray Ensembles**

Supervisor: dr hab. Krzysztof Woźniak
The ATLAS Experiment Department (NZ14), Krzysztof.Wozniak@ifj.edu.pl

The cosmic rays since their discovery have provided valuable information and discoveries. Even now the particles with highest energies are not those studied in laboratories and obtained form accelerators, but form the cosmic rays. Particles with highest energies are rare, so to detect them large observatories, like Auger Observatory, are build.
However, new phenomena may manifest themselves not as a single particle, but as correlated ensembles of cosmic rays. If their origin point is far from the Earth, for example near the Sun, they may arrive to the Earth in places hundreds km apart. The CREDO project aims to combine data from all available detectors, including even individual smartphones, to find Cosmic-Ray Ensembles. Currently the development of reconstruction methods is necessary.



The project for Summer Student Programme will include analysis of simulations of cosmic-ray cascades. They are preformed using KASCADE program which provides detailed information on the interaction of a primary cosmic particle and the production of a full cascade of secondary particles. These simulations are however complicated and can not be performed for large number of events. However, knowing the main properties of realistic simulations it is possible to obtain more events using much simpler simulations. Studies of the properties of KASCADE simulations is the first step to needed for CREDO project.

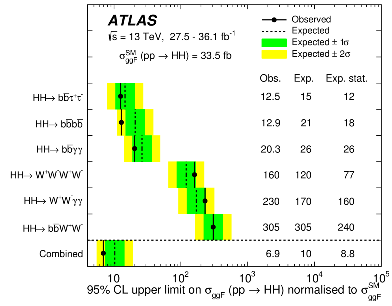
10. **Search for the new physics in the ATLAS detector at the LHC**

Supervisor: dr Bartłomiej Żabiński
The ATLAS Experiment Department (NZ14), zabinski@ifj.edu.pl

Discovering the Higgs boson was the Holy Grail of LHC experiments. Since its discovery in 2012 the Higgs boson has been produced copiously and detected using various decay channels by the ATLAS and CMS experiments. Theory predicts that not only single Higgses, but also double Higgs bosons are produced in a single proton-proton collision! In some of these events the two Higgs bosons originate from the splitting of a single Higgs. Measuring the strength of these self-interactions will cast light onto the electroweak symmetry breaking.

Double Higgs production is extremely rare. It requires sophisticated experimental techniques and analyzing many decay channels in order to observe signal events. In the Atlas experiment searches of double Higgs production were done mostly in channels with b quarks (see figure), but a very recent idea adopted by the ALTAS experiment is to search for double Higgs events through its various leptonic decays. In this analysis we do not distinguish if any of the Higgses decays to Z, W bosons or tau leptons but use all these processes at once to detect as many events as possible.

In your task, you will use data events collected by the ATLAS experiment, and these generated by Monte Carlo programs. The aim is to find the best separation between interesting us the signal and other processes called background. To perform this task you will use the ROOT framework and write scripts in Python or C++. In order to maximize sensitivity, we plan to apply Machine Learning techniques such as Boosted Decision Trees and Neural Networks in the task. During this project, you will get acquainted with the work in the ATLAS Collaboration and will develop your programming skills. You will learn to apply Machine Learning packages such as TMVA and Keras.



Upper limits at 95% CL on the cross-section of the $ggFSMHH$ production normalized to its SM expectation $\sigma SMggF(pp \rightarrow HH)$ from the $b\bar{b}\tau^+\tau^-$, $b\bar{b}b\bar{b}$, $b\bar{b}\gamma\gamma$, $W^+W^-W^+W^-$, $W^+W^-\gamma\gamma$ and $b\bar{b}W^+W^-$ searches, and their statistical combination. The column "Obs." lists the observed limits, "Exp." the expected limits with all statistical and systematic uncertainties, and "Exp. stat." the expected limits obtained including only statistical uncertainties in the fit. (Phys. Lett. B 800 (2020) 135103).

11. **Bayesian Analysis of Cosmic Rays data for Earthquake Predictions**

Supervisor: dr David Alvarez
Department of Cosmic Ray Research and Neutrino Studies (NZ15), dalvarez@ifj.edu.pl

The aim of this project is to consider recent cosmic rays and meteorological recollected data during Earthquake occurrence as input for Bayesian inference aiming at prediction of this kind of events. It has been already conjectured that the cosmic ray flux plays the role of a precursor of seismic waves. Moreover, we expect that pressure changes in the atmosphere at local scales affect cosmic ray fluxes which may show a considerable correlation. Thus, we shall consider the combined data from these measurements.

Bayesian inference is a useful method that is able to provide posterior probabilities for a hypothesis provided some evidence or information is included. The method allows for improvement of the results as more data for an event become available. The specific task of this analysis corresponds to the implementation of a Bayesian algorithm able to read the cosmic ray data obtained by the Auger observatory and meteorological data from nearby sites. As a result, we expect to obtain Earthquake probability distributions which may serve to characterize a universal behavior.

12. **Search for lepton violation in $\tau^- \rightarrow \mu^-\mu^-\mu+$ decays with Run2 of LHCb data**

Supervisor: dr hab. Marcin Chrząszcz, dr Jihyun Bhom
The LHCb Experiment Department (NZ17), Marcin.Chrzaszcz@ifj.edu.pl, jihyun.bhom@ifj.edu.pl

The search for Charged Lepton Flavour Violation (CLFV) processes has been ongoing since the discovery of the muon by C. Anderson and S. Neddermeyer in 1936 in Caltech, which was confirmed a year later by J. Street and E. Stevenson. Because of the mass value matching the expectations, for a carrier of strong nuclear force, the muon was firstly identified as a Yukawa's meson. However, further experiments led to the discovery of another particle of similar mass – the pion. Contrary to the muon, the pion was proved to participate in strong interactions and was eventually identified as Yukawa's meson. As a result, the muon was recognized as a "heavy electron", which was a big surprise at that time. A Nobel Laureate I. Rabi was supposed to quip: "Who ordered that?", commenting in this way on the present situation in particle physics.

A natural solution to this problem was to treat the muon as an excited electron. In this case one expected to observe the decay $\mu \rightarrow e\gamma$ with a branching fraction $B(\mu \rightarrow e\gamma) \sim 10^{-4}$, unless, as pointed by R. Feinberg, there existed a second neutrino.

As we know now the other flavours of neutrino exists and thus the CLFV have not been yet observed till this day. However this kind of processes appear very naturally in extensions of the Standard Models. In this research task we will look for one of these processes, which is $\tau^- \rightarrow \mu^-\mu^-\mu+$ decay with LHCb Run2 data.

13. **Particle production with electromagnetic heavy-ion dissociation at LHC energy**

Supervisor: dr Mariola Kłusek-Gawenda
Department of Theory of Strong and Multiple-body Interactions (NZ21), Mariola.Klusek@ifj.edu.pl

The LHC collider provides unique opportunities to study electromagnetic interactions of ultrarelativistic nuclei. Physics of ultraperipheral ultrarelativistic heavy-ion collisions gives an excellent possibility to study photon-photon interaction and photoproduction. Such collisions (ultraperipheral collisions; UPC), which take place without any overlap of nuclear densities, give intense photon beams with a broad energy spectrum.

Vast moving charged particles are surrounded by an electromagnetic field that can be considered as a source of (almost real) photons. For lead-on-lead collisions, the ions produce photons with the energy up to 80 GeV in the photon-nucleon center-of-mass frame. Photons collide with each other producing pair of the particles or photon fluctuates into a pair of quark and anti-quark behaving as a hadron and then single particle state can be produced. In addition, the particle production can be associated with the Coulomb excitation leading to neutrons emission.

The aim of this project is to study the differential and total cross section for the production of particles (that are created as an effect of ultraperipheral lead-lead collisions at LHC energy) with a Monte Carlo generator of forward neutrons. The n00n is a ROOT based program that gives an opportunity to calculate emitted neutrons originating from electromagnetic dissociation interactions between the colliding heavy nuclei. Results will constitute the first predictions for the production of light-by-light scattering including simultaneous emission of neutrons that could be detected in the Zero Degree Calorimeter.

14. **Measurement of the J/Ψ production in dense and hot nuclear medium at ultra-relativist energies with ALIC**

Supervisor: dr Jacek Biernat
Department of the Ultrarelativistic Nuclear Physics and Hadron Interactions (NZ23), jacek.biernat@cern.ch

ALICE is one of the four major experiments located on the LHC at CERN. One of the experimental goals are preforming measurements of heavy ion collision (Lead-Lead) at high energies and extracting signals in the presence of significant background coming form the particle interaction with detector material and form other physics processes.

The goal of the project is to perform a feasibility study of Machine Learning (ML) as a tool for particle identification, mainly electron and positron pairs. The work will require a basic knowledge of python and C++, also some familiarity with ML or ANN (Artificial Neural Network) platforms like TensorFlow or similar.

15. **Photon reconstruction via Photon Conversion Method in the ALICE experiment at LHC**

Supervisor: dr hab. Adam Matyja
Department of the Ultrarelativistic Nuclear Physics and Hadron Interactions (NZ23), adam.tomasz.matyja@cern.ch

The ALICE experiment at the Large Hardon Collider (LHC) is a multi-purpose experiment to study the quark-gluon plasma (QGP) state formed in the central heavy ion collisions, ultra-peripheral heavy ion collisions where distance between nuclei is larger than two nucleus radii or proton-proton and proton-nucleus collisions at various LHC energies. There is the Time Projection Chamber (TPC), the large volume gaseous detector situated in the heart of ALICE which allows for the excellent tracking in a low momentum range down to 100 MeV/c. The electron-positon (e^-e^+) pairs can be reconstructed in the TPC to study photons which converted in the magnetic field of the detector's material. The method of a photon conversion (PCM) is one of the main methods used in ALICE to study photons and mesons. Thanks to a special capability of the ALICE detector the non-perturbative regime of the Quantum Chromodynamics (QCD) can be addressed.

The major goal of this task is to study photons reconstructed via the PCM in the context of analyses where photons and mesons decaying to photons are involved. During the project students will be familiarized with the ALICE experiment, ALICE framework, methods of the photon and neutral mesons reconstruction, basics of tools like ROOT and object oriented programing as well as the basics of statistical data analysis.

16. **Particle correlations in ultrarelativistic ion collisions with ALICE at LHC**

Supervisor: dr Iwona Sputowska
Department of the Ultrarelativistic Nuclear Physics and Hadron Interactions (NZ23), iwona.sputowska@cern.ch

Do you know what matter and energy compressed to extremely high density are up to? Do you know we can get it experimentally by studying heavy-ion collisions? What on Earth, or actually NOT on Earth, is the quark-gluon plasma? Why ALICE needs correlations to understand the early stages of QGP? Oh! And who is ALICE?

If I caught your attention let me now introduce you to Ms ALICE, A Large Ion Collider Experiment. ALICE is one of the experiments at LHC dedicated to study a new form of nuclear matter, the quark-gluon plasma (QGP), that is to recreate the conditions of the very-very-early Universe in the laboratory. This new state of matter, which forms in the early stage of the ultra-relativistic nuclear reaction, cannot be directly detected. The hot and dense but rapidly expanding system of quark and gluons quickly freezes into final state hadrons, which we measure in detectors.

Now – the insight into the early stage of the nucleus-nucleus collision can be provided by a (reasonably wise) analysis of *event-by-event correlations and fluctuations*. Correlations and fluctuations characterize the properties of the physical system, and they can be sensitive to the phase transition of the nuclear matter.

Your main aim will be the analysis of event-by-event partial correlations and fluctuations based on experimental data collected in the ALICE apparatus at LHC. In this framework, you will learn what charged particle partial correlations are, and what kind of important information they provide on the early stage of the heavy-ion collision. The analysis will be carried out not only for *all* the charged particles but also specifically for identified π mesons measured by ALICE. The experimental data will be stored in a tree format and to perform this task you will need to use the ROOT framework.

17. **ROOT4KaTie**

Supervisor: dr hab. Andreas van Hameren
Department of Particle Theory (NZ42), andre.hameren@ifj.edu.pl

KaTie is a parton-level Monte Carlo generator dedicated to so-called factorization prescriptions that require space-like, rather than light-like, initial-state partons. It is a standalone program written in Fortran 2003, that generates event files in the so called Les Houches format which can be processed by other programs. KaTie includes the possibility to extract histograms from event files, but for many users it would be more convenient if it were possible to use KaTie directly in combination with ROOT.

The task of the students will be to establish this connection, and then to perform analyses for some processes. The only requirement is knowledge of ROOT and most likely some knowledge of C++. The project will start with a small introduction to the concepts and working of Monte Carlo generators and KaTie in particular.

18. **Fast computations for global analysis of parton distributions**

Supervisor: dr Aleksander Kusina
Department of Particle Theory (NZ42), aleksander.kusina@ifj.edu.pl

Parton distribution functions (PDFs), which describe the structure of hadrons in terms of quarks and gluons, are one of the crucial elements needed for computing theoretical predictions for processes in hadron colliders like the LHC. Currently we don't know how to calculate PDFs from first principles and to determine them we perform a so called QCD global analysis where theoretical prediction are compared to experimental data and as a result PDFs can be extracted. However, in order to perform such a global analysis theoretical calculations (which depend on PDFs) need to be repeated many times. Depending on the considered physical process these calculations can be very complicated and time consuming. That is why for the purpose of global analyses they need to be speed up. One of the best way to do it is based on griding techniques where the PDF-independent part of the calculation is saved and can be reused many times. It allows for a drastic speed-up of the calculations resulting in computation time of the order of milliseconds instead of hours or days depending on the considered process.

The aim of the project is to use the existing APPLgrid implementation of the griding techniques in the MCFM program to perform the calculations for the top quark production. In the first step standard calculations for the top quark production in the MCFM program will need to be performed. In the second step the APPLgrid interface to the MCFM code will be used to generate the corresponding interpolating grids. Once the grids are available they can be used to perform the fast calculations which then should be cross-checked with the "standard calculations". In the last step the obtained results will be compared with the experimental data from the LHC.

Tools: MCFM, APPLgrid

19. **Improving "Virtual Colliders"**

Supervisor: dr hab. Andrzej Siódmok
Department of Particle Theory (NZ42), andrzej.siodmok@cern.ch

The upcoming series of Large Hadron Collider upgrades offers a unique opportunity to get a new understanding of the fundamental nature of the Universe. The usefulness of this wealth of forthcoming high-quality data is, however, strongly dependent on the availability of theoretical predictions with matching accuracy. In practice, there is a massive gap between a one-line formula of a fundamental theory, like the Lagrangian of the Standard Model, and the experimental reality that it implies. General Purpose Monte Carlo (GPMC) event generators are designed to bridge that gap. One can think of a GPMC as a "Virtual Collider" that produces simulated collisions similar to those that are produced in the actual LHC experiments. Therefore its results can be directly compared to the experimental data. It is for this reason why not only the Higgs boson discovery but almost all measurements and discoveries in modern High Energy Physics experiments have relied on these "virtual" machines. It is, therefore, crucial to continue increasing the precision and improving phenomenological models included in the GPMC tools.

The project will be related to one of the least-understood elements needed to describe hadron-hadron events, thus responsible for the large uncertainty of the GPMC predictions so-called hadronization. Hadronization is related to one of the most mysterious aspects of Quantum Chromodynamics called the confinement. The confinement is the phenomenon that colour-charged particles (such as quarks and gluons) cannot be isolated (observed) and must clump together to form hadrons (which we observe in the detectors). Depending on the students' interest, we will try to improve the model on hadronization by finding its better parameters using experimental data or by using Machine Learning techniques.