IFJ PAN Particle Physics Summer Student Programme

Projects 2021

Projects will be done in pairs.

1. **Polarization measurement in B meson decays**

   Supervisor: dr hab. Andrzej Bożek, dr Jarosław Wiechczyński
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   The Standard Model is still the best effective theory describing the fundamental particle interaction. In B meson decays we have several places, where the Standard Model is not explaining One of the longest standing deviations from standard model prediction is the polarisation of the products of B decay.

   We will show how we can measure polarisation in B decays, specifically $B \to D^*\pi$ and $B \to D^*\rho$ decays. We will learn modern analysis tools employed in modern particle physics, starting from MC generation, detector simulation final reconstruction and analysis

2. **Search for CP violation in decays $B_0 \to D^*D\pm$ in the Belle II experiment**

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

   Over the past 40 years the Standard Model has been confirmed by many precise experimental data. Nevertheless, there are several reasons why the Standard Model is not completely satisfactory as the theory of elementary particles. One of them is that the matter-antimatter asymmetry in the universe cannot be explained solely by the CP violation in the SM, which originates from quark flavour mixing. Comparisons between SM expectations and measurements in various modes are important to test the Kobayashi-Maskawa model. The $B_0 \to D^*D\pm$ modes are of particular interest since large CP violation effects are expected in these decays.

   During the summer school we will analyse data from the Belle/Belle II experiments in order to find the CP asymmetry not predicted by the Standard Model.

3. **Monte Carlo generator of bremsstrahlung events for EIC**

   Supervisor: prof. dr hab. Janusz Chwastowski
   The Diffractive Physics Department (NZ13), Janusz.Chwastowski@ifj.edu.pl

   Electron-Ion Collider (EIC) is a new particle accelerator planned to be constructed at Brookhaven National Laboratory. One of the crucial parameters of a collider is its luminosity, which describes the delivered rate of collision. A precise measurement of luminosity is needed for a proper interpretation of the collected data.

   Several methods of luminosity measurement can be used. One possibility is to measure the rate of a process that is theoretically well understood. For electron-ion collisions, a candidate for such a process is bremsstrahlung, when the electron interacts electromagnetically with the ion and emits a photon.

   The goal of the project is to implement a Monte Carlo generator of bremsstrahlung events and supplement it with a simple simulation of the experimental apparatus. The project requires good programming skills in C++ (preferably) or Python.

4. **AFP event classification with machine learning**

   Supervisor: dr Maciej Lewicki
   The Diffractive Physics Department (NZ13), maciej.piotr.lewicki@cern.ch

   Modern machine learning algorithms have proven to be successful in many applications across high-energy physics, finding use in tasks like tracking, noise reduction or data filtering. In this project we will look into data collected by the ATLAS Forward Proton (AFP) detector, looking for new features and new methods for classification of recorded events.

5. **Reconstruction of exclusive jet events**

   Supervisor: dr Rafał Staszewski
   The Diffractive Physics Department (NZ13), rafal.staszewski@ifj.edu.pl

   Exclusive processes are a special class of pp collisions at LHC where the incoming protons are not broken up, stay intact being scattered at very small angles, and some of their energy is used for the creation of new particles.

   If the produced particles are a pair of quarks or gluons, they will go through a process of fragmentation and hadronization leading to a final state containing jets of hadrons.

   The LHC detectors provide two ways of reconstructing the properties of jets - using more precise information about charged particles only (measurement with tracking detectors) or less precise measurements of charged and neutral particles (using calorimeters).

   The goal of the project is to perform a simple simulation of events with properties resembling those of the exclusive jet production and study the expected resolution of the above reconstruction approaches. The project will use Pythia event generator (pythia.org) and FastJet (fastjet.fr) implementation of jet finding algorithms. A decent understanding of C++ is required.

6. **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 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. Data from 2017 low pile-up runs will be used. You will start from learning about basic properties of hits formed in the AFP detector. After making few event displays, you will classify different classes of cluster shapes. You will try to identify, if they originated from diffractive protons, beam halo or particle showers. This should lead to recommendations how algorithms should form clusters. This project would allow for deep understanding of cluster formation in AFP.

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

7. **Optimization and training of neural networks for b-jet identification in the heavy ion collisions**

   Supervisor: dr Dominik Derendarz
   The ATLAS Experiment Department (NZ14), dominik.derendarz@ifj.edu.pl

   Heavy ion collisions at the LHC provide a unique opportunity for the study of the matter at the extreme conditions. For the brief moment after collision of two lead nuclei their constituents form a system with very high temperature and energy density. These conditions allow for the phase transition to the quark-gluon plasma (QGP) state which then cools down and goes back to the hadronic matter state that we can observe in the detector. Independently of the QGP formation, the hard scattering of quarks or gluons is very likely to happen in the heavy ion collision. The products of this hard interaction will then evolve in the presence of the QGP medium that will typically lead to reduction of their initial energy. The details of the energy loss mechanism is one of the most interesting open questions in the heavy ion physics field right now.

   To address this question our group in the ATLAS experiment department is working on the measurement of the productions of b-jets., *i.e.* the collimated group of particles originating from a single parton, in this case a b-quark. The hadronization of a b quark within a jet produces a B hadron which propagates a measurable distance before decaying and makes it possible to distinguish from the other jets that are produced close to the interaction region. To identify b-jets we use a deep feed-forward neural network that takes as an input the properties of the secondary vertices and impact parameter of tracks found within a jet.

   During this project we will investigate which of the inputs to the neural network contribute the most (least) discriminating power, what are the correlations between the inputs and how the details of the network architecture impacts its final performance.

8. **Study of b-jet production in the ATLAS experiment at the LHC**

   Supervisor: prof. dr hab. Adam Trzupek
   The ATLAS Experiment Department (NZ14), Adam.Trzupekifj.edu.pl

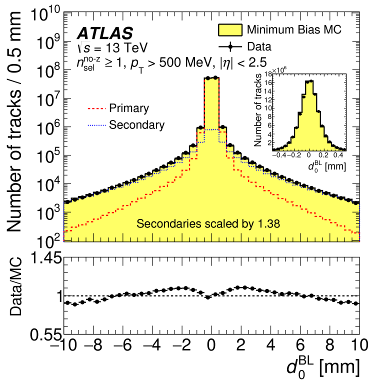
   Heavy ion collision physics is a hot topic at the present and future ultra-relativistic colliders. The main goal of heavy ion collisions is to produce a hot and dense medium, the Quark-Gluon Plasma (QGP) and study its properties. One of the most useful tools to probe the QGP matter is the measurement of highly energetic jets. Jets are sprays of particles in a narrow cone originating from the energetic quarks or gluons produced in heavy ion collisions. Jets strongly interact with the QGP medium, leading to a significant reduction of their energy and suppression of their productions. The aim of the project is to study properties of jet production originating from heavy flavour (b, c) quarks in Pb+Pb collisions within the ATLAS experiment. The charm and beauty quarks, due to the their large masses, are produced in the early stage of the heavy ion collision and loose less energy than light quarks and gluons while traversing the QGP. For the purpose of this project, the MC simulations of b-jets within the ATLAS environment will be analysed to study details of jets containing b-hadron decay chains.

   Programming framework: C++, ROOT.

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

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

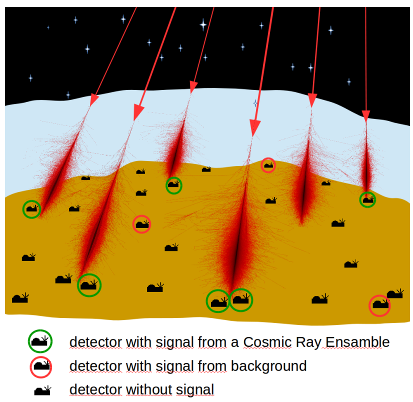
   The ATLAS detector is used in one of four experiments working at Large Hadron Collider at CERN, which accelerates beams of particles to the highest energies available in laboratories. Most of the time beams of protons are collided, however collisions of nuclei are also possible.
   In October 2017 for 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.



10. **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.

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 behaviour. Additional studies may include correlations searches or Fourier analysis of the signals.

12. **Neutrino interaction studies in the near detector of the T2K experiment**

Supervisor: dr Marcela Batkiewicz-Kwaśniak
Department of Cosmic Ray Research and Neutrino Studies (NZ15), Marcela.Batkiewicz@ifj.edu.pl

T2K is a long-baseline neutrino oscillation experiment conducted in Japan by an international collaboration. One of the most important sources of the systematic error in the neutrino oscillations analysis are uncertainties related to the neutrino interactions model. To constrain these uncertainties, T2K provided numerous neutrino interactions cross-sections measurements for different interaction channels, neutrino and target nuclei types.

The aim of this project will be the development of the selection method for different neutrino interaction channels in the ND280 near detector of the T2K experiment and analysis of the selection purity and efficiency as a function of the kinematic properties of the produced particles.

13. **Geometry of hevy ion collisions during lepton pair production**

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

The analysis will provide a theoretical contribution to the physics of heavy ion collisions at ultrarelativistic energies. This means the energies available at the LHC accelerator that is the most powerful particle accelerator. Our theoretical analyses are focused on research that is expected to provide predictions for the research that occurs at CERN.

Heavy ion collisions are characterized by, inter alia, impact parameter, *i.e.* the distance between two lead ions (in the case of LHC it is ^{208}Pb). The strong electromagnetic field surrounding the charged nuclei is the source of the emission of photons that colliding with each other creating a pair of particles. An interesting issue, which has not yet been tested, seems to be the determination of the cross section for particle production as a function of the components of the impact parameter.

The student's task will be to modify the existing codes (written in Fortran) that allow to determine the total and differential cross section for the production of particle pairs in the collision parameter space. Depending on the progress of the work and the student's involvement, there is a possibility of continuous cooperation.

14. **Time-space evolution of the spectator in ultra-relativistic heavy-ions collisions**

Supervisor: dr hab. Katarzyna Mazurek
Department of Theory of Strong and Multiple-body Interactions (NZ21), Katarzyna.Mazurek@ifj.edu.pl

The collisions of heavy ions with ultra-relativistic velocities create the participant zone where the quark-gluon plasma produces many various particles and the remnants called spectators. The size and other properties of remnants of the collisions depend on many other conditions but we will focus on the the distance between the flying nuclei. Calculations of our group helped to prove that these spectators are living long enough to interact with particles created in the QGP. Moreover they also interact with the particles which are produced in other processes such as virtual photons collision. The electromagnetic interaction between charged particles and the spectator changes the initial trajectory of these particles.

The aim of the project is to verify the dependence of the final rapidity and transversal momentum of leptons and mesons produced in the space around the reaction point. The graphical analysis will be done with ROOT.

15. **Central exclusive production of mesons in proton-proton collisions**

Supervisor: dr Piotr Lebiedowicz
Department of Theory of Strong and Multiple-body Interactions (NZ21), Piotr.Lebiedowicz@ifj.edu.pl

One class of hadronic reactions one can study at the LHC are exclusive diffractive proton-proton collisions. The study of diffractive production of light mesons, in particular at the soft scale, is interesting for a variety of reasons. The absence of a hard scale precludes a perturbative QCD description. The traditional framework for studying soft hadronic processes has been the Regge formalism. At high energies, the hadronic interaction is dominated by the exchange of a leading trajectory, the Pomeron (IP). Within QCD, it is conjectured that this trajectory represents the exchange of purely gluonic colour-singlet objects. Here, we shall work in the framework of the tensor-Pomeron model. We shall consider the central exclusive production (CEP) reactions, for instance pp → p M p, where M stands for a scalar, tensor or axial-vector meson which decays into two or/and four charged pions, *e.g.*, $f_0(1500)$, $f_2(1275) \to 2\varpi$, 4ϖ; $f_1(1285) \to 4\varpi$, as arising from the fusion of two Pomerons.

The aim of the project is to study properties of CEP of the $\varpi^+\varpi^-$ and/or $2\varpi^+2\varpi^-$ in proton-proton collisions at high energies. Comparing theoretical predictions with the future experimental results should allow a good determination of the Pomeron-Pomeron-M coupling constants. Our first example will be, for simplicity, the $pp \to pp(PomPom \to f_0 \to \varpi^+\varpi^-)$ process in the Born-level high-energy approximation. One of our interest is understanding the production mechanism of two/four charged pions in proton-proton collisions. For this purpose we can use a newly developed Monte Carlo generators. Such event generators are essential for allowing detailed comparisons between theory and experiment. The specific task of this analysis corresponds to the development of these generators. There are preliminary studies of the $pp \to pp\varpi^+\varpi^-$ and $pp \to pp2\varpi^+2\varpi^-$ reactions at the LHC provided by the ATLAS Collaboration.

First single amplitudes for CEP reactions will be treated. The next step will be to include non-resonant continuum and all interference terms as there are several amplitudes contributing. Finally, absorptive corrections will have to be taken into account. During this project we will investigate which of the $M \to 4\varpi$ decay processes contribute the most to the cross section. One could study also an appropriate decay mechanisms (*e.g.*, $f_1(1285) \to \rho_0\rho_0, a_1(1260)\varpi$) and other related issues.

16. **Applying machine learning methods in data analysis**

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

The ALICE (A Large Ion Collider Experiment) is one of the big four experiments situated on the LHC (Large Hadron Collider) accelerator at CERN. The experiment has a broad spectrum of physics from elementary collisions to heavy ion collisions at extremely high energies up to 13 TeV. One of the main topics is the study of Quark Gluon Plasma (QGP) and its influence/ modification of the production mechanism of various hadrons (probes).

Our group working at the Institute of Nuclear Physics based Cracow has a major involvement in the experiment from detector related activities to preforming data analysis focusing on modern techniques based on neural networks and machine learning.

One of our interest is understanding the production mechanism of charmonium such as J/Ψ in heavy ion collisions. Unfortunately studying such complex processes within the collisions of complex systems such as Lead- Lead poses a significant challenge form the side of physics and the experiment.

The goal of this project will be applying known machine learning algorithms based on Keras, TensorFlow *etc.* on a given data set in order to perform the suppression of unwanted background events. An example of the code and data will be provided.

Requirements:

- basic knowledge of root,
- basic knowledge of Linux and python,
- interest or knowledge of TensorFlow or/and Keras.

17. **Searches for new physics effects in the light by light scattering in the ALICE experiment**

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

The ALICE experiment, which is located at the CERN laboratory near Geneva, can study effects of proton-proton, proton-lead and lead-lead collisions. In central nuclear collisions, the charged particle multiplicity per pseudorapidity unit reaches $dN_{ch}/d\eta \approx 2000$, while in ultra-peripheral collisions, where the distance between the centres of the colliding nuclei is greater than the sum of their radii, it is only a few. The properties of the quark-gluon plasma are examined in central collisions, while in ultra-peripheral ones, processes of central exclusive production (CEP), photoproduction or light by light scattering are looked for.

The scattering of light by light is a rare process, but it is sensitive to effects from physics beyond the Standard Model. Due to the enhancement of the photon flux from the nucleus, the scattering process is possible to observe. On the other hand, the difficulty is a realistic description of the signal and background events via Monte Carlo generators for extremely soft photons. The main goal of the task is to generate light by light scattering events and events coming from the strongest background types for this process by the Monte Carlo method and to compare them with the data collected by the ALICE detector.

What you are going to learn:

- basics of Unix/Linux operating system,
- basics of ROOT,
- work in the ALICE experiment environment AliRoot,
- how to generate Monte Carlo sample,
- statistical data analysis methods,
- work in the experiment group.

Requirements:

- basics of C/C++ programming,
- basic knowledge of Unix/Linux system,
- English level B1/B2.

18. **Studies of UPC trigger efficiency of the light by light scattering in the ALICE experiment**

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

The ALICE experiment, which is located at the CERN laboratory near Geneva, can study effects of proton-proton, proton-lead and lead-lead collisions. In central nuclear collisions, the charged particle multiplicity per pseudorapidity unit reaches $dN_{ch}/d\eta \approx 2000$, while in ultra-peripheral collisions (UPC), where the distance between the centres of the colliding nuclei is greater than the sum of their radii, it is only a few. The properties of the quark-gluon plasma are examined in central collisions, while in ultra-peripheral ones, processes of central exclusive production (CEP), photoproduction or light by light (L-by-L) scattering are looked for.

The scattering of light by light is a rare process which needs dedicated trigger. There are couple of UPC trigger sets which deliver data in ALICE during Run 2. The proper check of each trigger is necessary to evaluate the L-by-L cross section in ALICE. The main goal of the task is to determine trigger efficiency and fake rate of UPC triggers based on prepared data samples and study prospects for Run 3.

What you are going to learn:

- basics of Unix/Linux operating system,
- basics of ROOT,
- work in the ALICE experiment environment AliRoot,
- how to generate Monte Carlo sample,
- statistical data analysis methods,
- work in the experiment group.

Requirements:

- basics of C/C++ programming,
- basic knowledge of Unix/Linux system,
- English level B1/B2.