International Student Research Opportunity Projects (Summer 2019)

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For queries about a project, please contact the supervisor(s).
It may be possible for several students to work together on a project. Please contact the supervisor for queries on this.

Supervisor(s)	Project Description
Prof. Amihay Hanany Theoretical Physics Group (a.hanany@imperial.ac.uk)	**Quiver Gauge Theories** There is a collection of projects in string theory research under the general topic of "quiver gauge theories”. Past projects were done in the study of "brane tilings" and "orbifolds", but a general study in string theory is also possible. The work may involve theoretical, analytical, and/or computational studies, depending on the taste and choice of the student. Some of the projects involve combinatorial techniques as well as methods taken from number theory. Some other projects involve methods from representations of Lie algebras and algebraic geometry. The interested student needs to have a strong background in theoretical physics, but the projects are not restricted to a given year of study. The expectation from the student is to be well motivated and ready to solve problems which were not seen before, but using the tools acquired so far in their degree.
Dr Antonin Vacheret High Energy Physics Group (Antonin.vacheret@imperial.ac.uk)	**Monitoring nuclear reactors with neutrinos** Nuclear reactors produce large amount of neutrinos and are commonly used to study neutrino oscillations. The SoLid experiment, which operates at very close stand off of the BR2 research reactor in Belgium, also aims to demonstrate the use of antineutrinos to monitor the operational status of a nuclear reactor at distance, providing information about production of fissile materials in the context of an non-proliferation treaty. The challenge of the project is to quantify realistic performance of a SoLid detector that would be deployed close to a research reactor under a verification treaty with the aim to detect reactor operational status and Plutonium content of the core. The students will use the SoLid simulation software and real antineutrino data to study the feasibility of detecting antineutrinos from a spent fuel reactor assembly at BR2. They will use those findings to develop a realistic deployment scenario of a SoLid detector in the North Korean peninsula.
Dr Antonin Vacheret High Energy Physics Group (Antonin.vacheret@imperial.ac.uk)	**Development of the LZ dark matter background model visual interface** The LUX-ZEPLIN Liquid xenon Dark Matter search experiment rely on a effective physics background model. As most background comes from components of the detector system, a long list of parts and their associated radioactive background is being assembled and updated based on the various assay measurements conducted at low background facilities. The goal of the project is to look at developing a database interface to connect the background model more directly with the Monte Carlo simulation and the large scale processing interface used to generate the background prediction of the experiment. On the user side, we aim to develop a visualisation interface based on modern libraries to display quickly the status of the many components and their associated measurements. The project is well suited for one or two students with a strong software background.
Prof. Jeremy Chittenden (j.chittenden@imperial.ac.uk) **Dr. Brian Appelbe** (b.appelbe07@imperial.ac.uk) Plasma Physics Group	**Burning Plasmas in Inertial Confinement Fusion (ICF) Implosions** Ongoing experiments at the National Ignition Facility (NIF) aim to demonstrate controlled thermonuclear fusion by compressing deuterium-tritium capsules to a high temperature (~5 keV) and density (~10^31 m^-3). Nuclear reactions occurring in these hot plasmas release energy in the form of neutrons and alpha particles. The alpha particles can deposit their energy in the deuterium-tritium plasma through Coulomb collisions resulting in hotter plasma. If this alpha heating effect is significant then a burning plasma can be formed which results in a large energy yield (since the number of nuclear reactions increases exponentially with increasing temperature). In experiments carried out to date alpha heating has resulted in ~4 times greater energy yield. In order to further increase the yield, it is necessary to understand the physics of how alpha particles deposit their energy in the deuterium-tritium plasma. This is a kinetic process in which fast, non-thermal alphas move through a background plasma that is near Maxwellian. This project involves a computational study of ICF implosion & burn with a particular focus on the use of kinetic models for the alpha heating process. A main goal of this work will be to identify suitable diagnostic features of alpha heating so that researchers can improve their observations of experiments. Experimental work on this topic is carried out by researchers at MIT and the project should offer opportunity for collaboration with this group.

	Experience: Students should be interested in and enthusiastic about computational physics. Students will be able to use existing simulation codes and will be also given the opportunity to write their own.
Dr. Roberto Trotta Astrophysics Group (r.trotta@imperial.ac.uk)	**Bayesian hierarchical modelling of selection effects in supernova type Ia cosmology** Supernovae type Ia (SNIa) are a particular type of stellar explosion that have the important property of being almost standard candles -- ie, their luminosity is almost the same for all objects, and therefore can be used to measure distances in cosmology. SNIa were instrumental in establishing the accelerated expansion of the Universe (currently ascribed to an unknown form of energy, called dark energy) - a momentous discovery which was rewarded with the Nobel Prize for Physics 2011. One of the biggest mysteries in modern-day physics, the nature of dark energy remains currently unknown. Present and future SNIa observations are one of the most important tools that will help understanding dark energy better, in particular in order to determine whether or not its properties change with time. Already today, our inferences about the nature of dark energy are being limited by poorly-understood systematic effects (such as the reddening and dimming introduced by dust, which can be confounded for the dimming due to the expansion of the Universe) and difficult-to-model selection effects, i.e., the higher probability of seeing and following up on slightly brighter events. If this is not correctly accounted for, our conclusions on dark energy might be systematically biases. This project will develop a fully Bayesian hierarchical model for selection effects in SNIa cosmology, building on previous work and existing codes. The aim will be to test the analysis on simulated data, and then to deploy it onto state-of-the-art observations. Possible extensions include the analysis of contaminated data sets (where core-collapse SNIae, which are not standard candles, might bias inferences) and methods for supervised classification of SNe from photometric surveys. The project is well suited to up to 2 students with interests in computational methods, advanced statistics, cosmology, and messy astrophysics.
Prof. Oliver Buchmueller High Energy Physics Group (o.buchmueller@imperial.ac.uk)	**Work with CMS experiment on the LHC** The project will be assigned to the CMS group of Imperial. The LHC at CERN, where the CMS experiment is located, has performed excellently, collecting over 150 1/fb in RUN2 (2015 to 2018). The second LHC long shutdown (LS2) of 2019-2020 provides the perfect opportunity to analyse these data comprehensively. This large data set and higher centre of mass energy provide excellent prospects for both direct discovery (SUSY/DM/Exotics) and for indirect probes of new physics via precision studies of the Higgs - the SM Higgs has become a tool! At the same time a suite of detector and upgrade activities are underway, offering excellent all-round opportunities and training. Our physics activities are focused around searches for SUSY, DM and long-lived particles, opportunistic searches using B decays as well as characterising the Higgs boson. Individual projects to be arranged within this portfolio depending on the interest of the individual.
Professor Yoshi Uchida (High Energy Physics Group) Yoshi.Uchida@imperial.ac.uk	**Simulations in preparation for COMET** The Standard Model of Particle Physics is known to be wrong and cannot describe the phenomenon of neutrinos with mass. Direct searches for New Physics, such as at the LHC, are probing higher and higher energies but are limited by how far high in energy they can reach. Precision measurements of existing processes, however, can uncover the physics of significantly higher scales than at the LHC. Muon-to-Electron Conversion is one of the best examples of lepton flavour-violating experimental processes which are some of the most sensitive probes to New Physics that are available to us—and are free of the theoretical backgrounds that affect many other measurements. COMET is an experiment being built at the J-PARC accelerator laboratory in Japan. Any large-scale particle physics experiment is only built after a long preparatory period using physics principles, mathematics, computer simulations and analysis to design and optimise the experimental approach and the hardware and software to be built. COMET is currently between this stage and that when we will start taking data with the experiment. Therefore the software tools are ready, and the experiment is being built, but in order for us to be ready to analyse real data when it arrives, we need further preparatory work to produce simulated data, and devise analysis strategies that are robust and meaningful. Students will run the standard COMET software that was developed at Imperial, and use it to produce simulated data and develop strategies to 'analyse' it using data-reduction techniques and statistical methods to extract useful physics information, solving any problems we have or otherwise improving our ability to analyse the data.
Dr William Barter (High Energy Physics Group) w.barter@imperial.ac.uk	**High Energy Physics - New Adventures in Data Analysis** The LHC offers significant big data challenges where it is crucial to consider the best methods of data analysis that have the best chance of accurately finding new phenomena. In such studies, tests to compare different samples and determine if they are consistent (labelled two-sample tests) are widely applied, for example in searches for differences in the decays of matter and antimatter particles. Different two sample tests have been proposed to perform such studies for multivariate/multidimensional samples (from the simplest, such as the chi2 test, through to more advance methods that make use of machine learning). The project will consist of comparing the statistical power of different methods when applied to typical datasets from the LHC. The results of this project will influence future studies using LHC data, and may lead to a publication. The project is suited to either one or two students,

	who should ideally have some experience running and adapting code written in one of python or C++.
Dr. Dave Clements (Astrophysics Group) (d.clements@imperial.ac.uk)	**Building Galaxy Clusters** Galaxy clusters are the largest gravitationally bound systems in the local universe, but there is much about their formation that we do not yet understand. The star formation history of their member galaxies is likely to start at high redshift, but few high redshift clusters or protoclusters are known. How clusters and cluster galaxies form from the cosmic web is also unclear. Do cluster galaxies form in the dark-matter-rich web and then fall into clusters, or do they form most of their stars once inside the cluster? This UROP project will use multiwavelength data from major space missions such as Herschel, Hubble and Spitzer, combined with data from some of the largest ground-based observatories (Keck, ALMA) to determine the star formation history and other properties of galaxies in one of the highest redshift galaxy clusters known, at a redshift of ~1.5. This work will involve not just observational data but matching this data to complex computer simulations of galaxy formation produced by the Illustris consortium. Successfully matching the observed and theoretical properties of this cluster will help to confirm our current picture of cosmology. Conversely, if the two do not match, then we will know that our current models are incomplete. This project is an ideal introduction to multiwavelength extragalactic astrophysics, the handling of large data sets and cosmological models, and is part of a Royal Society funded partnership between MIT and Imperial College.
Dr. Florian Mintert Quantum Optics & Laser Science Group (f.mintert@imperial.ac.uk)	**Theory-blind quantum control** Quantum control allows us to development high-precision experiments or hardware for quantum information processing. Control for comparatively simple models can be developed based on theoretical models, but many physical systems are too complex to be modelled or simulated. Together with a team of several European partners we are working on techniques to design control based on experimental data only. One central aspect lies in the fact that quantum mechanics requires many repetitions of a measurement, before reliable conclusions can be drawn. Figuring out how we can use data based on a small number of iterations is a an important step towards efficient control techniques. Together with the Imperial team and our partners, you would analyse and test different approaches for control based on scarce experimental data.
Prof. Roland A. Smith Plasma Physics Group (r.a.smith@imperial.ac.uk)	**Optical levitation of microtargets for ultra-high power laser experiments.** The interaction of ultra-intense lasers with a microtarget of order the laser wavelength (a micron or so) is a field pioneered by Imperial College. Rather topically we do this by combining Chirped Pulse Amplification (CPA) lasers and optical trapping, both areas that received the Nobel Prize in 2018. These targets are exciting for several reasons, their geometry results in large boosts to the laser electric field which enhances fast-particle and hard x-ray generation, and their perfectly isolated geometry creates a unique micro-laboratory to study ultra-high intensity laser physics. Our most recent experiments and simulations also show that we can use them to generate much more energetic MeV ion beams than "traditional" laser targets, and we aim to harness this to underpin future ion-beam cancer therapy techniques. To enable these experiments we develop new optical levitation traps which work under vacuum and balance the force of gravity against photon momentum transfer from a continuous laser beam. This project could involve either experimental work to characterise and refine our trap systems, or numerical modelling in Python to better understand trap dynamics and help design new trap systems able to capture "exotic" objects such as microbubbles and chiral liquids, depending on the interests of the student.