International Student Research Project Opportunities (Summer 2020)

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Supervisor(s)	Project Description
Dr Stuart Mangles John Adams Institute for Accelerator Science (stuart.mangles@imperial.ac.uk)	**High-energy gamma ray detector for laser wakefield experiments** Laser Wakefield Accelerators are compact particle accelerators driven by powerful laser pulses. They can accelerate electrons up to a few GeV in plasmas just a few centimetres long. In my research group we carry out experiments which use these electron beams to investigate fundamental processes that occur in extreme astrophysical environments. Some of our current projects involve measuring the gamma rays produced when the electron beam collides with a second high intensity laser pulse or with a dense X-ray field. This project will work on a new design for our gamma ray detector, with the goal of increasing the energy range of the detector to beyond 500 MeV. You will work with Monte Carlo simulation packages (eg Geant4 or G4 Beamlines) to optimise the detection system. The new detector will help us to discern different models of “radiation reaction” in the collisions of high energy electron beams with high intensity lasers (Cole PRX 2018). Radiation reaction is the process where charged particles lose energy in the interaction with intense electromagnetic fields and it is not well described by classical electrodynamics. It is thought to affect the plasma dynamics in various astrophysical objects such as on the surface of quasars and magnetars and will play a crucial role in the plasma physics that will be probed with the next generation of ten petawatt lasers currently being built around the world.
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 Morgan Wascko High Energy Physics Group (m.wascko@imperial.ac.uk)	**Neutrino Experiment R&D** The discovery of neutrino mass and flavour oscillation is the first confirmed observation of physics beyond the Standard Model. The T2K experiment in Japan is the world’s flagship neutrino oscillation experiment, and has been approved for an upgrade in ~2022. One of the possible upgrade designs is a new type of detector called a high-pressure gas time projection chamber (HPTPC). This project is to work on a prototype HPTPC detector to test the technology for a future neutrino experiment and to make new measurements of particle interactions. This project can have two components, in any proportion; the first is hardware work to build and test the HPTPC prototype, and the second is computational/analysis work to study the physics capabilities of an HPTPC and analysis of data from the prototype. The student will develop an understanding of particle physics experiments, and/or modern data analysis techniques. No experience required.
Prof 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 almost perfectly correct, but not quite, and it 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 in 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 is 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. These will involve applying cutting-edge techniques, but with the robustness and rigour that is needed for fundamental physics studies. Students will run the 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 and providing strategies for the COMET collaboration in the near future as it confronts real data.
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.
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. These targets are exciting for several reasons, their geometry results in large boosts to the laser electric field which enhances hot electron and 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 are investigation how 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.
Dr Alex Clark Centre for Cold Matter alex.clark@imperial.ac.uk	**Enhanced two-photon absorption in a single molecule using quantum-correlated states of light** My group develops single photons sources using organic molecules. Typically, one would excite molecules with a laser resonant with the electronic ground and excited states. This can be very efficient but causes difficulty in separating the input and output light. It is also possible to excite molecules with two photons of lower energy, which simplifies removal of the excitation light from any fluorescence, and also allows for a time delay between photon arrivals to probe the fast internal molecular relaxation processes that can occur. When using classical laser light, two-photon excitation is inefficient due to the low probability of two photons arriving simultaneously at the molecule. However, using nonlinear optics one can generate correlated photons which arrive at the molecule in pairs, making this form of excitation efficient. This summer project aims to test this on dibenzoterrylene (DBT) molecules at cryogenic temperature where the molecular absorption cross-section is maximized. You will build a photon-pair source that will be pumped at 785 nm, corresponding to the zero-phonon-line energy in DBT, to

	generate pairs of photons at 1560 nm and 1580 nm. These pairs of photons will be focused on a single DBT molecule at 4 K and you will monitor molecular fluorescence as the number of photon pairs is increased. The temperature will then be increased to investigate how the two-photon absorption cross-section is modified, and a delay will be introduced between the two input photons to probe the internal electronic and vibronic temporal dynamics.
Dr Riccardo Sapienza Experimental Solid State Physics r.sapienza@imperial.ac.uk	**1. Single-photon manipulation by nanoscale antennas** Individual (room-temperature) quantum emitters, capable of emitting individual photons, are of paramount importance to power nanoscale quantum optics, nevertheless they are not very bright, coherent nor fast enough. All these properties can be modified by embedding them in nanocavities and nanoantennas. You will study fluorescence microscopy of individual molecules and 2d materials coupled to nanoscale electromagnetic antennas, to measure how the antenna modifies the emission properties of the molecules. The project consists of experimental work on a custom-build ultrasensitive microscope, data analysis and eventually numerical modelling using our own software. • Enhanced light-matter interaction in an atomically thin semiconductor coupled with dielectric nano-antennas, L Sortino et al. Nature Communications 10, 5119 (2019). • Nanoscale design of the local density of optical states, S Mignuzzi, et al. Nano Letters 19, 1613-1617 (2019) **2. Nanoscale nonlinear optics design** Optical field can be sculptured and enhanced when confined to nanoscopic volumes. This is a very effective route to enhance many optical processes, including nonlinear optics. You will study how an intense femtosecond laser pulse interacts with nanoscale materials, and how it can lead to the generation of harmonics, i.e. the conversion of the laser frequency to new frequencies. You will study how light confinement and strong material resonances can boost this process. You will design these nanomaterials using the most advanced tool coupled to machine learning. The project consists of experimental work on a custom-build nonlinear microscope, data analysis and eventually numerical modelling via a commercial software. This project is part of a collaboration with Prof. Stefan Maier, TU Munich. • Negative refraction in time-varying strongly coupled plasmonic-antenna--epsilon-near-zero systems by V. Bruno, et al. Phys. Rev. Lett. (2020) • Cambiasso, J. et al. Bridging the Gap between Dielectric Nanophotonics and the Visible Regime with Effectively Lossless Gallium Phosphide Antennas. Nano Lett. 17, 1219 (2017). **3. Nanophotonic Laser optimisation using machine learning** Unconventional lasers, mirrorless and nanostructured are an exciting research avenue, with great technological potential, if controlled. You will study light transport and lasing from a nanoscale network formed of interconnected sub-wavelength waveguides, to understand how the network topology determines the lasing process and how we can control it. You will exploit machine learning to find the excitation profile to unbalance the lasing dynamics and achieve control of the lasing properties. The project consists of experimental work, data analysis and modelling the network using a home-built algorithm. This project is part of a collaboration with IBM Zurich. • A nanophotonic laser on a graph, M Gaio, et al. Nature Communications 10, 226 (2019) • Determining random lasing action, R Sapienza Nature Reviews Physics, 1-6 (2019).
Prof. Ken Long Centre for the Clinical Application of Particles k.long@imperial.ac.uk	**New approaches in radiotherapy** Cancer is responsible for one out of four deaths in Europe alone. Radiotherapy has a key role in cancer treatment; roughly half of all cancer patients will receive RT at some point during their illness. The treatment of radioresistant tumours, tumours close to a sensitive structure, such as the central nervous system (CNS) and paediatric cancers, is compromised by the radiation tolerance of normal tissue. We in the Centre for the Clinical Application of Particles seek to drive a change in current practice by exploiting the wealth of biological knowledge to devise new approaches that decrease the toxic effect of radiation on normal tissue while maintaining, or even enhancing, the tumour-kill probability. Exploiting the close bond between physics and biology we propose to identify techniques by which to activate and/or modulate the aforementioned effects by tuning the physical parameters of irradiation. An IROP student joining this programme will contribute to the development of novel techniques to simulate the microbiophysical processes that underpin the impact of ionising radiations on tissue. As the work progresses, increasing emphasis will be placed on the comparison of simulations with measurement.
Dr Mitesh Patel High Energy Physics Group	**Searching for physics beyond the Standard Model with the LHCb experiment**

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