INSTITUTE FOR PARTICLE PHYSICS PHENOMENOLOGY

NEWSLETTER
SEPTEMBER 2021

WELCOME TO THE IPPP

It is that time of the year again, and with it comes the first instalment of the biannual IPPP newsletter.

While the summer has been restful, there have been plenty of IPPP hosted activities. These include the "Beyond the Flavour Anomalies II" and "Parton Shower and Resummation 2021" workshops which were a success.

In addition, the IPPP hosted the 23rd edition of the "Planck Conference": https://conference.ippp.dur.ac.uk/event/999/

This meeting covered a broad spectrum of Beyond the Standard Model physics, and we thank the speakers and 230 participants for their lively engagement.

Many of our PhD students joined the YETI 2021 School on the "The Future of Lepton Colliders": https://conference.ippp.dur.ac.uk/event/1027/
This IPPP hosted school featured lectures from QCD to BSM Higgs phenomenology, and we thank the lecturers and 120 students for their part in making YETI 2021 such a great success. You can read all about this in this issue.

Finally, we are happy to welcome two new postdoctoral researchers and present some IPPP research highlights on a new dark matter production mechanism, novel methods for cosmic neutrino background detection and axions in this issue.

ANNOUNCEMENTS

1. The IPPP is pleased to announce an upcoming workshop on Physics Opportunities at the Electron-Ion Collider: 21-23 September 2021. Due to COVID and possible travel and meeting restrictions, we plan to have the workshop as an admixture of in-person and Zoom-based sessions. Registration can be found at: **https://conference.ippp.dur.ac.uk/event/1032/**

2. We are pleased to announce the second international school on Quantum Sensors for Fundamental Physics: **https://conference.ippp.dur.ac.uk/event/1001/overview**
hosted by Martin Bauer. This school will be held on 6-17 September 2021 and will cover the diverse and promising field of quantum technology applications to advance fundamental physics. Experts on current and future quantum devices and the fundamental physics questions will present lectures to an audience of students, postdocs and senior members of both communities.

3. Our website has been revamped, check it out at: **https://www.ippp.dur.ac.uk/**
We will also maintain the HEP Forum: **https://www.ippp.dur.ac.uk/uk-hep/**
where one can find announcements about seminars, conferences and jobs in the UK.

4. We are thrilled to announce that two postdoctoral researchers will join our group in October: **Yuber Perez-Gonzalez** (Fermilab & Northwestern) and **Daniel Reichelt** (Gottingen).

5. If you are interested in doing a PhD or if you are teaching students who would like to do a PhD in theoretical particle physics at the IPPP, please have a look at this link:
https://www.durham.ac.uk/departments/academic/physics/postgraduate-study/
If you have further questions email Ben Pecjak at **ben.pecjak@durham.ac.uk**

6. The Associateship, Durham IPPP Visiting Award, and Senior Experimental Fellowship programmes are continuing. We encourage applications for all three schemes and invite you to consult the following web pages for application deadlines:
IPPP Associateship: **https://www.ippp.dur.ac.uk/ippp-associateships**
DIVA: **https://www.ippp.dur.ac.uk/diva**
Senior Experimental Fellowship: **https://www.ippp.dur.ac.uk/senior-experimental-fellowships**

5. Keep an eye open for the announcement of YETI and the Higgs-Maxwell Meeting in 2022 (specific dates to be confirmed).

YETI 2021: THE FUTURE OF LEPTON COLLIDERS

YETI 2021, held in early July and organised by Stephen Jones and Frank Krauss, took place remotely this year instead of in its usual pride of place at the IPPP. Although attendees did not have the opportunity to experience the beauty of Durham in person and several post-learning trips to the pub, the virtual nature of the conference did allow for over 100 people from across 18 time zones to join. In addition, the school took advantage of online communication platforms like Zoom, Slack, and Slido to promote interaction between theorists and experimentalists, providing a great sense of community despite the distances between us.

The topic this year was "The Future of Lepton Colliders". The school saw a medley of highly engaging talks, ranging from existing QCD challenges to various opportunities at future colliders. In particular, there was a strong emphasis on experimental Higgs physics and theory calculations for electroweak precision measurements. The high precision attainable at future colliders would act as a powerful probe on existing Standard Model (SM) predictions and potential Beyond the Standard Model (BSM) Higgs theories. On the other hand, the ongoing developments in reducing theory uncertainty are crucial for inferring information about heavy SM particles and new physics from precision measurements without direct observation. The lecturers included Patrizia Azzi, Ayres Freitas, Stephen Gibson, Sven Heinemeyer, Chiara Mariotti and Peter Skands, and the students thoroughly enjoyed their lectures.

In addition to the lectures, the school held a live panel of eminent particle physicists, who discussed and debated over an eclectic mix of audience-provided topics from the prospects of future colliders to the prospects for early career researchers. The panellists included Georg Weiglein, JoAnne Hewett, Michael Peskin, Sally Dawson, Tao Han and Tilman Plehn. Overall, YETI 2021 took the virtual nature of our present reality in its stride to provide an exciting and highly engaging experience for students and staff alike. We look forward to what the school will bring next year!

NEW POSTDOCTORAL RESEARCHERS

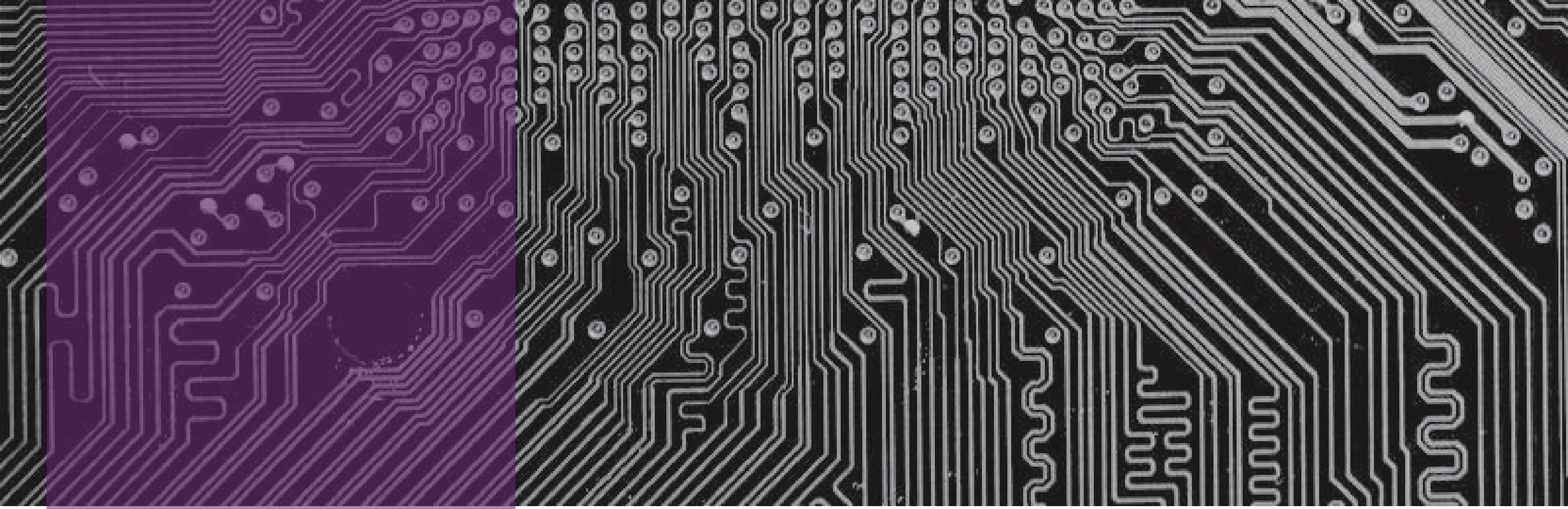
The IPPP is happy to announce the addition of two new postdoctoral researchers.

YUBER F. PEREZ-GONZALEZ

Yuber has focused his research on several aspects of neutrino phenomenology and its interplay with Cosmology and Astrophysics. Furthermore, he has recently worked on the intersection of particle phenomenology and Primordial Black Hole physics. Before joining Durham University, Yuber had a joint postdoc at Fermilab and Northwestern University (USA). He completed his PhD at the University of São Paulo, Brazil. He is keen on learning about other aspects of High-Energy Physics, Cosmology, Gravitational Waves, and he is eager to hear more about other people's interests and research.

DANIEL REICHELT

Daniel joins IPPP for his first postdoc after finishing his PhD in Göttingen, Germany, where he worked with Steffen Schumann. Before that, he achieved his master's degree from Dresden University. The research in his master and PhD studies are in the area of perturbative QCD calculation in the context of general-purpose event generators, in particular, parton showers and soft gluon resummation in the Sherpa framework.



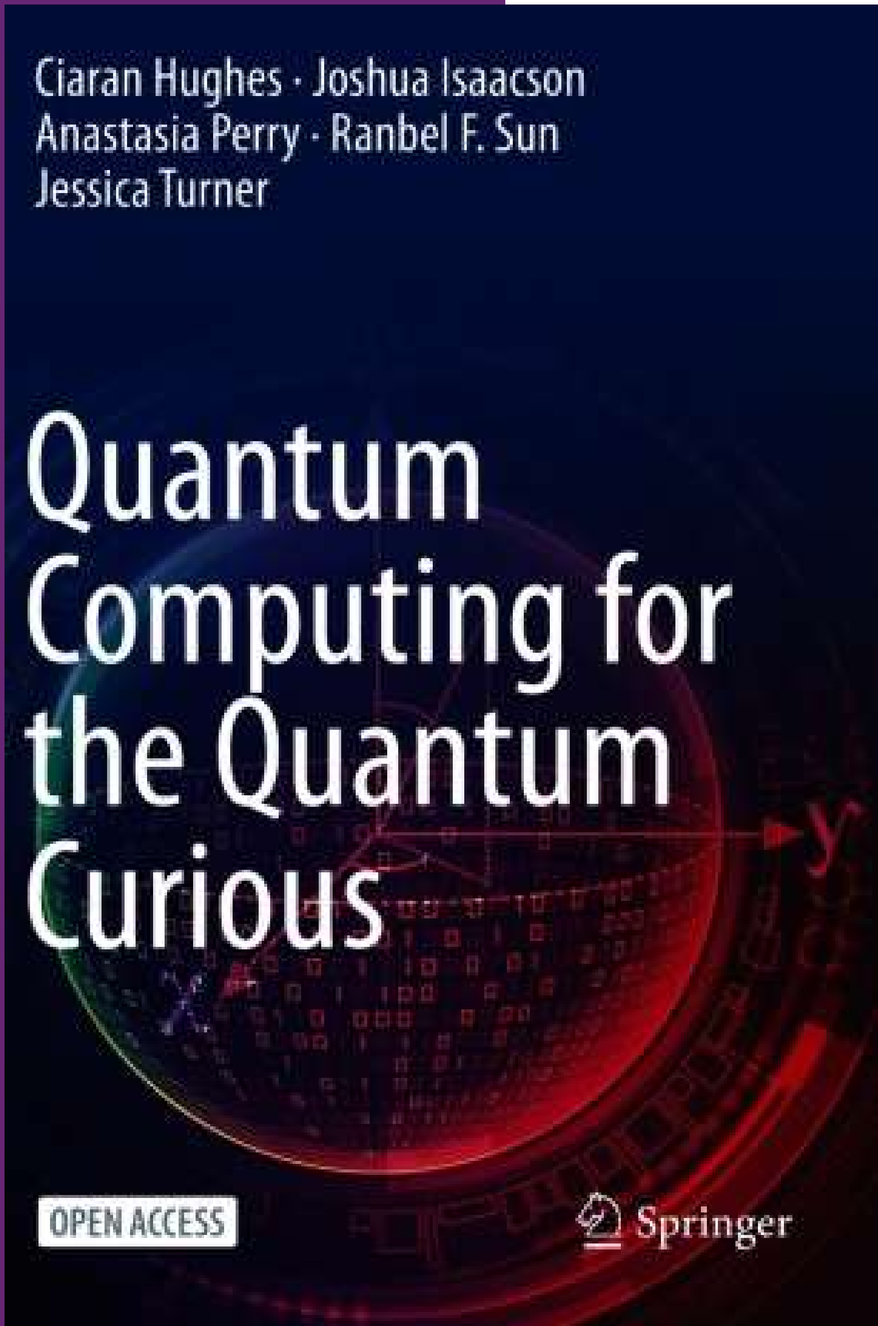
QUANTUM COMPUTING FOR THE QUANTUM CURIOUS

Quantum Computers use the laws of quantum mechanics to perform specific types of calculations much faster than conventional computers. As a result, quantum computing is the only known technology that could fundamentally redefine what is practically computable and has the potential to revolutionise the fields of chemistry, physics, computer science, biology and medicine. With this possibility in mind, many institutions are investing in new quantum computing technologies and quantum sensing. With an eye toward the future, Jessica Turner and collaborators (Hughes and Isaacson) worked with high-school teachers, Perry and Sun, to develop a program to train their students in this emerging field. This "Quantum Computing as a High School Module" program was developed with young students in mind.

However, it is also a perfect diversion for science enthusiasts of any age who suddenly have time on their hands. The course was created to guide students through various aspects of quantum computing without relying on prior knowledge of quantum mechanics. This course introduces students to quantum concepts, including superposition, qubits, encryption, and using active learning techniques, such as interactive problem sets and simulation-based labs at various levels. The walkthrough exercises that use IBM's real quantum computer to build a Schroedinger's worm (equivalent to the cat) has been a real hit.

Through trial runs in high school classes, the group tested the material and improved the clarity of the module. In addition, they conducted surveys before and after the students took the course and found that they successfully learned about quantum computing and had a high level of enthusiasm for it. One student even commented, "We should replace special relativity with quantum computing next year". Finally, the student feedback on the module was analysed, and advice on teaching such a module was made publicly available: arXiv:2004.07206. The course has seen success since its inception.

Jessica Turner and collaborators have been contacted by people from all over the world, including high school teachers in Brazil and education researchers in the Netherlands. In addition, the American Association of Physics Teachers is excited to collaborate on future quantum computing pedagogy workshops. Motivated by this interest, the group used the feedback from the classroom trials to improve the module and adapted it into a textbook and published by Springer as "Quantum Computing for the Quantum Curious": **https://www.springer.com/gp/book/9783030616007** Since its publication in February 2021, it has been downloaded more than 86,000 times.



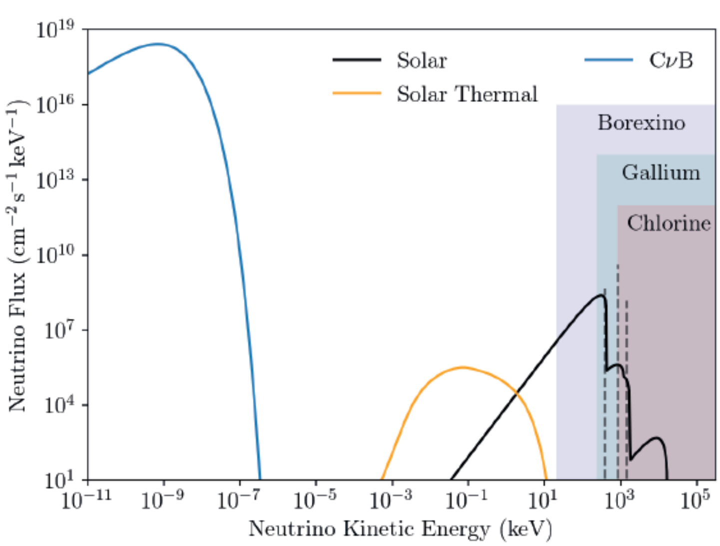
OBSERVING RELIC NEUTRINOS USING AN ACCELERATOR EXPERIMENT

The cosmic neutrino background (CNB) is a prediction of cosmology and particle physics that has to this date never been observed. These relic neutrinos are able to evade detection by conventional neutrino experiments due to their tiny interaction cross-sections and low energy, which is insufficient to trigger interactions with an energy threshold.

In their recent paper arXiv:2104.12784, Martin Bauer and Jack Shergold showed that relic neutrinos can be resonantly captured on ions accelerated to extremely high energies. This results in large peak cross-sections independent of GF, giving neutrino capture rates competitive with existing proposals for detecting the CNB. Additionally, the use of a resonance leads to a low-background process, as neutrinos away from resonance are unable to interact efficiently with the target ions.

Naturally, the large beam energies required for relic neutrinos to interact, which can be O(1-10) PeV per target nucleon, make this experiment very difficult to perform. This difficulty can be overcome with an appropriate choice of target, which can reduce the required energy to O(1-10) TeV per target nucleon, well within reach of existing accelerator experiments. Reducing the interaction threshold has the added benefit of increasing the neutrino capture rate.

In their paper, the authors also explore the possibility of using more complex systems to perform the experiment. For example, the use of a resonance state which can decay into a stable final state that differs from the initial state can provide a stable, unique signal with no drawbacks. Alternatively, using a beam of excited ions can significantly reduce the energy requirements at the cost of beam stability. With further exploration, it is hoped that an ion capable of performing this experiment will be found.



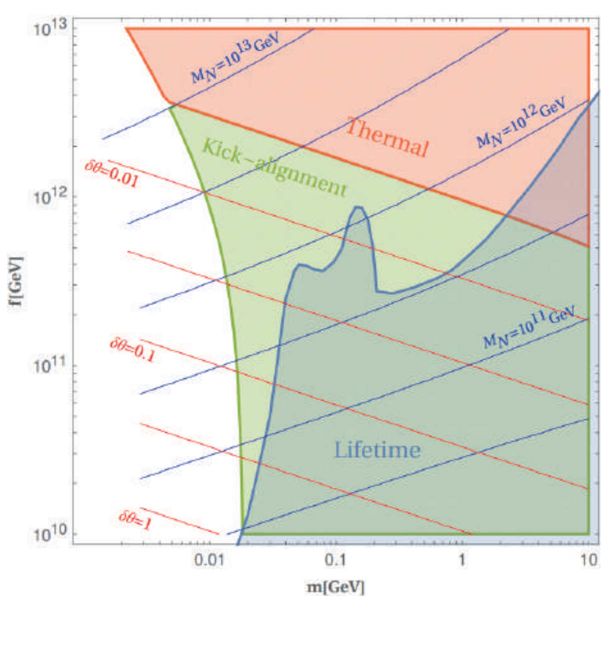
KICK-ALIGNMENT: A NEW MECHANISM TO PRODUCE DARK MATTER

The majority of matter in the universe is an unknown substance that we call dark matter. While gravitational interactions reveal its presence, very little is known about its nature, including the state it is in today. It could be a collection of particles like the air in the room you are in (albeit dark particles rarely bounce off each other) or it could be in the form of an oscillating field, just as coherent light is.

The physics community has shown that both states are possible with each having its most vocal representative in the form of thermally produced Weakly Interacting Particles (WIMP) or coherently produced axions, the Goldstone bosons of axial symmetry. A production mechanism for the latter can be understood from the dynamics of a homogeneous field in an expanding universe: the equations resemble a familiar law, F=ma. Initially, the field is stuck at some value as the expansion acts as a friction term, but eventually, the rate of expansion falls below the mass of the field, at which point it starts oscillating and behaving like a pressureless substance.

The final abundance crucially depends on the field's initial value, but how did it get there in the first place? This is the question that J. Scholtz and R. Alonso set out to explore on arXiv:2012.14907. The answer they came up with: the production of baryon asymmetry in our universe (another of the mysteries in physics) might have kicked it.
Indeed if dark matter is the Goldstone of baryon or lepton number (or a combination) they found this kick is unavoidable, the question turning to one of magnitude.

As the figure attached shows in the plane of dark matter mass vs field decay constant f, the kick could be strong enough to produce the abundance of dark matter for values in the green shaded region. Therefore, this mechanism is a new possibility in dark matter production that connects the dark and visible universes.



AXION OSCILLATIONS

String theory generically predicts the existence of a plethora of ultralight axion-like particles (ALPs). These ALPs can make up both Dark Matter and Dark Energy. Searching for experimental evidence of string theory ALPs is therefore an important direction in fundamental physics.

Many searches for ALPs are based on the ALP's weak interaction with the photon. In a background magnetic field, ALPs and photons can interconvert. This leads to many striking experimental and astrophysical signatures.

Most previous ALP searches have assumed a single ALP that interacts with photons. However, in a typical string theory scenario there may be hundreds of ALPs with different masses that interact with photons. In arXiv:2107.12813, Francesca Chadha-Day explores the signatures of such a string axiverse. She finds that the string axiverse can be modelled via a change of basis as a single electromagnetic ALP that interacts with photons and many hidden ALPs that do not interact with photons. The electromagnetic and hidden ALPs can oscillate into each other as they propagate, in a process analogous to neutrino oscillations. The oscillation of detectable electromagnetic ALPs to undetectable hidden ALPs can drastically reduce the signal in some experiments.

This work demonstrates the importance of studying string axiverse phenomenology.