INSTITUTE FOR PARTICLE PHYSICS PHENOMENOLOGY

NEWSLETTER SEPTEMBER 2022

WELCOME TO THE IPPP

With the start of the new academic year comes another issue of the IPPP newsletter. Since our last newsletter, the IPPP has hired two new faculty members: Danny Van Dyk and Ivan Martinez Soler. Danny (TU Munich), one of the world's leading experts on quark flavour physics and a winner of the prestigious Ernest Rutherford Fellowship, will join our group in October 2022. We look forward to his contribution to the UK research into quark flavour physics. Ivan Martinez Soler (Harvard University) is a world leader in neutrino phenomenology and global fits. He will join the faculty at the IPPP in October 2023. We are excited to see the development in neutrino physics across theory and experiments that Ivan can spark.

In addition to these exciting new hires, there has been plenty of ongoing IPPP activities. Since the last newsletter, the IPPP has helped co-organise the 21st international conference in string phenomenology at Liverpool 4-8 July 2022 (http://www.maths.liv.ac.uk/stringpheno2022/) with over 150 attendants. The IPPP organised and hosted an intense "Bayesian Inference in High-Energy Physics" workshop from 25-27 July with 27 participants. This meeting brought together statistics, machine learning and collider physicists. Finally, the "N^3LO kick-off workshop / thinkstart" from 2-5 August was an intense and productive workshop which brought together world-leading experts in precision calculations. We thank the participants and organisers for their contributions.

We are pleased to announce that the steering committee has awarded IPPP associateships to Kristin Lohwasser (Sheffield) and Linda Cremonesi (QMUL). Likewise, the DIVA fellowship has been awarded to Manimala Mitra (IOP Bhubaneswar). We look forward to the fruitful visits and workshops that these IPPP associateships will inspire.

Finally, many IPPP and UK based PhD students joined the YETI (Young Experimentalists and Theorists Institute) school hosted by the IPPP (https://conference.ippp.dur.ac.uk/event/1099/). The theme of this year's school was "Phenomenology in the Sky". The lectures were delivered by Christopher Berry (Glasgow), Christian Byrnes (Sussex), Malcolm Fairbairn (KCL), Adrien Florio (Stony Brook), Ed Hardy (Liverpool), Rachel Houtz (Durham), Lucien Heurtier (Durham), Francesco Torrenti (Basel), Cora Uhlemann (Newcastle) and David Weir (Helsinki). We thank all the lecturers for their contribution the the education of the PhD students. Sofie Erner and Ansh Bhatnagar will recount their YETI experience in this issue.

This issue also features articles on the Nuffield Research Placements for Year 12 students organised by IPPP postdocs and students (Dorian Amaral, Anke Biekötter, Patrick Foldenauer and Sebastian Jaskiewicz), an article summarising the Bayesian Inference Workshop (written by Stephen Jones), a review on the Higgs' 10th birthday (written by Martin Bauer) and a summary of ISMD2022 by Andy Buckley of the University of Glasgow. Research highlights by Danny Van Dyk and Patrick Foldenauer are also featured. We hope you enjoy reading our newsletter.

ANNOUNCEMENTS

1. We are pleased to announce the upcoming workshop co-organised by Martin Bauer, Fran Chadha-Day and Jamie McDonald on "Recent Progress in Axion Theory and Experiment" from 5-8 September 2022 (**https://conference.ippp.dur.ac.uk/event/1101/**).

2. We also look forward to Frank Krauss, Simon Badger and Stephen Jones co-organising the "High Precision for Hard Processes 2022" from 20-22 September (**https://conference.ippp.dur.ac.uk/event/1100/**).

3. The IPPP Annual Theory Meeting will be held (in person.) in Durham 13-15 December 2022. We will be pleased to see our colleagues from all over the UK.

4. We are thrilled to announce that Sreemanti Chakraborti (LAPTh, Annecy) will join the IPPP as a postdoctoral researcher in October 2022.

5. 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 information:
IPPP Associateship: **https://www.ippp.dur.ac.uk/ippp-associateships**
DIVA: **https://www.ippp.dur.ac.uk/diva**
Senior Exp. Fellowship: **https://www.ippp.dur.ac.uk/senior-experimental-fellowships**

6. We are seeking nominations/self-nominations for our steering committee. Please send suggestions to **ph-hep-admin@durham.ac.uk**

YETI 2022

This July, around 50 PhD students from across the UK descended on Durham for the 'Young Experimentalists and Theorists Institute', also known as YETI.

This four-day summer school takes place annually, and this year the topic was 'Phenomenology in the sky', with a focus on astroparticle physics, gravitational waves, and cosmology.

Meeting other students was an invaluable networking experience for us. Hearing first-hand what experimentalists are getting up to was a welcome change from what we had learnt about the field, which had been filtered through the lenses of theorists. Likewise, we hope they enjoyed hearing about our research and getting to know us over the meals at Collingwood College. The lecturers and organisers had all done a great job of making the experience as engaging as possible, with interactive workshops forming an integral part of the schedule and programme of teaching.

A special shoutout to David Weir (University of Helsinki), who took trains from Finland to Durham as an incredible example of commitment to low carbon travel. On the final day, we enjoyed a talk from John Ellis on the AION experiment and said farewell to the many people we had got to know over the last few days. Thank you to Djuna Croon and Stephen Jones for organising and to all who lectured and attended YETI this year.

IPPP AND CMP RESEARCHERS HOST NUFFIELD RESEARCH PLACEMENTS FOR HIGH SCHOOL STUDENTS

This year IPPP postdoctoral researchers Dorian Amaral, Anke Biekötter, Patrick Foldenauer and Sebastian Jaskiewicz, as well as Julius de Rojas from the condensed matter physics group in Durham offered various two-week summer projects for Year 12 high school students within the Nuffield Research Placements programme:
(https://www.nuffieldresearchplacements.org).

In the placement offered by Dorian and Patrick, students Eve and Bridgette learned about the Standard Model, neutrinos and their production in solar fusion reactions. In the following, they familiarised themselves with the role that future direct detection experiments will play in directly testing solar neutrino scattering. As part of the placement, they learned how to simulate these neutrino interactions with a novel Python programme package developed by a group including Dorian Amaral and Patrick Foldenauer at the IPPP, and used this to place limits on potential neutrino non-standard interactions.

In the project supervised by Anke, Nicole explored the possibility that a recent excess in the CMS di-tau analysis could be explained by a new Higgs-like particle with a mass of 100 GeV. She reproduced the CMS analysis using Monte Carlo data analysed the statistical significance of the results and investigated to what extent a new scalar particle could explain the discrepancy between data and prediction. Finally, she examined complementary ways to test the new particle in other decay channels.

In the project suggested by Sebastian, Evie worked on automating calculations of Feynman diagrams appearing in soft-collinear effective theory at next-to-leading power. A feature that makes the computations more challenging is that momentum conservation cannot be directly imposed at subleading interaction vertices. This is because derivatives are acting on momentum-conserving delta functions due to multipole expansion. After integrating by parts, these derivatives act on the rest of the amplitude, which results in huge expressions and makes calculations cumbersome. Evie's task was to automate the derivative taking process in Mathematica and make it compatible with the following Integral Reduction step done using LiteRed. She checked that her code correctly reproduced one-loop expressions found in the literature and used it
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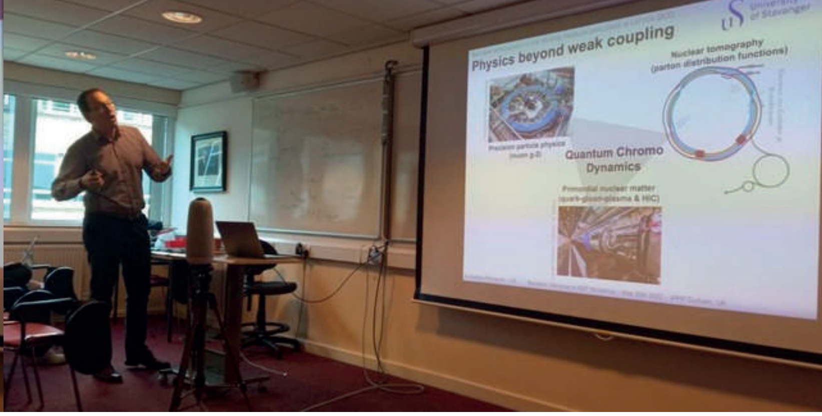
In the placement offered by Julius, Bryan learned about how magnetic Artificial Spin Ice (ASI) networks can be used to form tunable waveguides for spin-wave propagation. Bryan programmed collaboratively using the micromagnetics simulation package Mumax3 to model the static magnetic behaviour (hysteresis plots) of a series of standard magnetic structures. These were compared with magnetic measurements of thin films and nanowires to verify the simulations, giving them hands-on lab experience. After Bryan became comfortable with the standard samples, he moved towards modelling infinite arrays of ASI magnetic networks, including coupled arrays and square lattices, and writing additional code to capture their dynamic behaviour. These skills were then used to model the overall behaviour of an irregular, Euclidean uniform lattice tiling of octagons and squares, a novel structure revealing a particularly rich spin-wave spectrum for spintronic applications.

The projects have been a very valuable experience for everyone involved, and they are a great opportunity for PhD students and postdocs to gain experience with outreach and student supervision. If you are interested in hosting a project next summer, do not hesitate to contact Sebastian for more information about the process. You would make a great difference as the students selected by Nuffield are often first-in-family to go to university or come from disadvantaged backgrounds. Last but not least, we wanted to thank Trudy and Joanne for organising office space at the last minute and to everyone who contributed to our mini "What else happens at the IPPP?" talk series for the students.



BAYESIAN INFERENCE WORKSHOP 2022

On May 25th this year, the IPPP hosted the first workshop on applications of Bayesian Inference to High-Energy Physics. The 3-day in-person workshop was co-organised by Ezequiel Alvarez (Director of ICAS, Argentina), Jernej Kamenik (University of Ljubljana), Manuel Szewc (ICAS, Argentina), and Ian Vernon (Dept. Mathematical Sciences, Durham University) along with our own Michael Spannowsky and Stephen Jones.

Bayesian inference methods provide powerful tools for obtaining probability distributions for unknowns given observations and prior knowledge of the model that connects them. In recent years, the use of Bayesian methods has increased rapidly due partly to machine learning developments. As presented at the workshop, Bayesian inference has been applied to many scientific fields, including biology, astrophysics, cosmology, as well as high-energy particle physics.

The workshop's main aim was to trigger discussions and build connections between mathematicians, computer scientists, and physicists interested in Bayesian inference methods. The workshop consisted of dedicated sessions in which practitioners from different sub-fields shared their experiences, mathematicians presented relevant advances, and potential avenues for applying state-of-the-art techniques to High-energy physics problems were discussed. Some of the topics covered included non-perturbative phenomena, Monte Carlo techniques, experimental setups, modelling, and searches for New Physics. The workshop concluded with an open discussion that tied together the problems and solutions presented during the workshop and identified promising directions for future research.

The IPPP would like to thank our co-organisers and all participants for helping to make the workshop a great success, and we are looking forward to future editions of the workshop.

HIGGS AT 10

Ten years ago, scientists announced the discovery of the Higgs boson. It was the end of a decades-long and hugely difficult journey – and arguably the most important result in the history of particle physics. The end of this search marked the beginning of a new era.

Higgs noticed between 1964 and 1966 that the presence of a Higgs field which is necessary to give elementary particle masses, necessitates the presence of a new particle: the Higgs boson. Soon after the original papers were published, it became clear that the hunt for this Higgs boson would not be easy. An influential theory review of the properties of the Higgs boson concluded, "We apologise to experimentalists for having no idea what is the mass of the Higgs boson … and for not being sure of its couplings to other particles … For these reasons, we do not want to encourage big experimental searches for the Higgs boson."

In 1989 the Large Electron-Positron collider (LEP) began searching for the elusive particle. After 11 years, it came up empty-handed, and we know now that its energy was only 5% too small to produce the Higgs boson. The largest US collider ever built, the Tevatron, produced Higgs bosons in proton-antiproton collisions but was unable to collect enough data to isolate the signal. The Large Hadron Collider (LHC) began colliding protons in the same tunnel previously occupied by LEP in 2010. And after 2 years, the LHC discovered the Higgs boson, the central piece of the Standard Model of Particle Physics.

When the ATLAS and CMS collaborations announced the discovery in 2012, the Higgs boson had been observed decaying into two photons. In the years since then, the LHC went on a tour de force to measure as many properties of the Higgs boson as possible. As a result, we learned that it really is a scalar - and not spin 2, and that the Higgs boson's interactions with heavy quarks, W and Z bosons as well as with taus and muons agree with the predictions of the Standard Model.

In the future, the attention will turn to the underlying mechanism of electroweak symmetry breaking, which is responsible for the fact that electromagnetism is a long-range force, whereas the weak force is short-ranged. To understand whether nature has chosen the mechanism described by the Standard Model, we need to observe the production of two or more Higgs bosons simultaneously. This would determine how the Higgs boson interacts with its own field and highlight the mechanism responsible for elementary particle masses.

This measurement will be so challenging that even the upgraded LHC, which collects 100 times more data than before, is not expected to pick up the tiny signal predicted by the Standard Model. If we instead do observe double Higgs production at the LHC, the Standard Model prediction is wrong with important implications that could explain why our Universe is dominated by matter as opposed to antimatter.

These limitations of the LHC have initiated plans for a new collider, dedicated to narrowing in on this crucial observable. Various competing concepts, a linear electron-positron collider, a 100 TeV collider or the first muon collider, are being discussed as successors of the LHC. The discovery of the Higgs boson has catapulted particle physics into a new era, and the exploration of the Higgs boson will be central to the field in the 21st century.

This article is based on **https://theconversation.com/higgs-boson-ten-years-after-its-discovery-why-this-particle-could-unlock-new-physics-beyond-the-standard-model-186076** written by Martin Bauer and Stephen Jones.

ISMD 2022

The 51st meeting of the International Symposium on Multiparticle Dynamics was held in Pitlochry, Scotland from 1-5 August, two years after the meeting was originally meant to be hosted by the Universities of Glasgow and Edinburgh, and a year after the 50th edition was moved to a fully online form for the first (and hopefully only) time.

ISMD is a long-running conference series on all aspects of QCD, cutting across perturbative and non-perturbative regimes, hadron and heavy-ion colliders, nuclear physics, and cosmic rays. This year's meeting, somewhat suppressed by ongoing Covid restrictions and impacts on travel, saw around 85 attendees from the UK and 24 other countries converge on Highland Perthshire. Those who were unable to travel were served by free streaming of the conference sessions on Zoom and posters on gathertown (but not the all-important coffee and mealtime chats), which saw an equal registration to the in-person meeting, particularly assisting engagement from India, China and developing countries. Conference activity was promoted on Twitter via the @ismdconf account and #ISMD2022 hashtag, with positive engagement across the target communities.

The large ballroom of the Atholl Palace Hotel proved an excellent venue, and both the presentations and the environment were greatly enjoyed by all. Highlights were an excellent experimental summary of the contentious CDF mW measurement, complemented by a remote talk on theory inputs and consequences from Peter Athron, and of course the social programme of whisky tasting, excursions to the beauty spots of Queen's View and the Falls or Bruar, and (naturally) a conference banquet with piper, Address to the Haggis, and a following ceilidh. The room allowed participants to sit in a well-spaced manner and we kept fire doors open for ventilation making it as Covid-secure as reasonably possible.

The declared female-to-male ratio was around 1:3, and declared career stages were reasonably well balanced between students, RAs, and academics, in a roughly 4:5:7 proportion that gave the meeting a refreshingly young tone. This was assisted by a set of excellent 5 minute "flash talks" in which mostly early-career poster presenters could promote their work and stimulate discussion in the plenary sessions, and by a substantial programme of travel support from the IPPP as well as the IoP HEPP, APP and Nuclear Physics groups, STFC, the Royal Society of Edinburgh, SUPA, the Higgs Centre for Theoretical Physics, and the Universities of Glasgow and Edinburgh. The poster prize of £200 was awarded to an outstanding presentation of collinear Z+jet production at ATLAS, by Alexandre Laurent of Carleton University, Canada. On one evening, we arranged for one of our keynote speakers, Alan Watson, to speak at the local Pitlochry Cafe Scientifique. A small panel of other attendees went with him for a Q&A session. This event was very successful with the venue running out of seats.

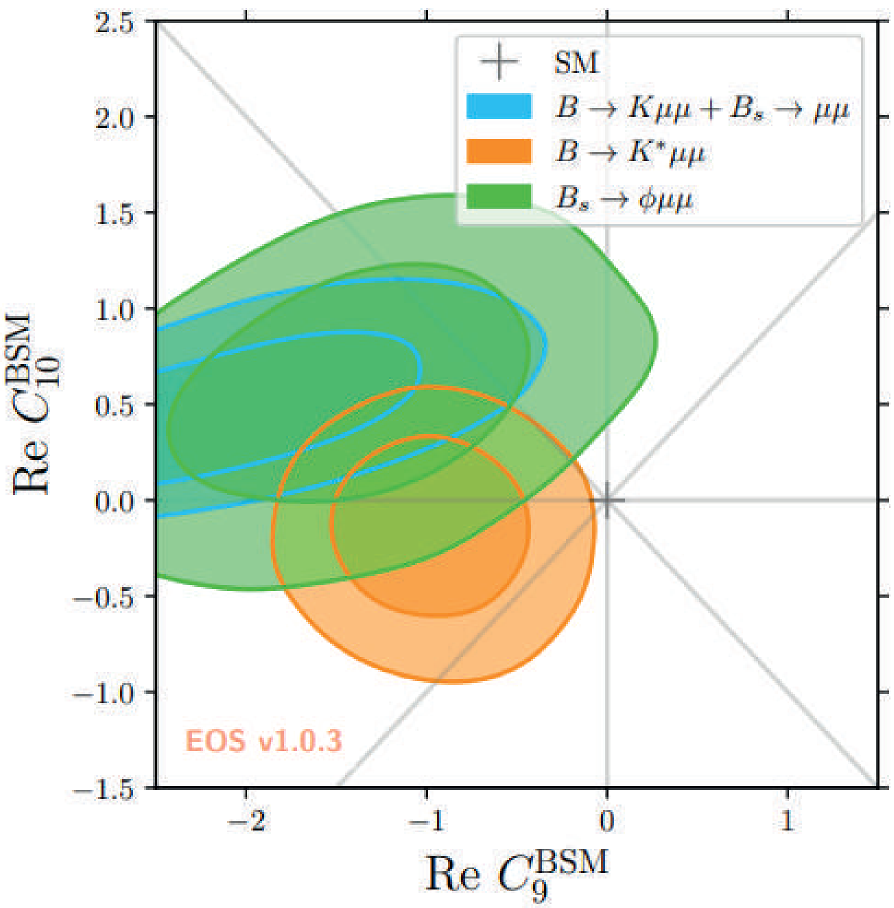
CHARMING PENGUINS IN RARE B DECAYS

Rare B decays have been the focus of particle physics phenomenology for the last decade. The reason is a persistent set of tensions between experimental measurements by the LHCb experiment at CERN's Large Hadron Collider and our more precise theoretical predictions of these decays within the Standard Model (SM) of particle physics or prevalent theory. Statistical analyses of these tensions have reached a significance of more than 5 standard deviations, the threshold needed for claiming discovery of novel effects or particles in particle physics phenomenology. This begs the question: why is there no claimed discovery of effects Beyond the Standard Model (BSM)?

The standard approach to describe both SM and BSM effects in these decays is almost identical and involves an effective field theory, a widely used tool of particle physics. The so-called Wilson coefficients C9 and C10, the theory's free parameters, are then fitted to data. Unfortunately, there is a substantial source of contributions to C9 that arises from "charming penguins", so-called historically for their quark content and for a passing resemblance to cartoons of penguins of their diagrammatic representations. This has led to an inherent and hard-to-quantify uncertainty of the theory predictions. The "penguin pollution" of C9 is even more unfortunate since most of the extant tensions between theory and data are due to potential BSM effects in C9. A claim of discovery of BSM effects in C9 requires more confidence in the theoretical descriptions of the charming penguins.

In arXiv:2206.03797, Nico Gubernari, Méril Reboud, Javier Virto, and Danny van Dyk (now an IPPP staff member) investigated a novel approach to parametrising the charming penguin pollution. Their results show that previous approaches successfully capture the size and shape of this effect while slightly underestimating the overall uncertainties. The figure illustrates their findings for C9 separately for three representative processes. The tension is slightly smaller than in the literature but in good agreement. Unfortunately, a truly "global" analysis of all available data is currently not possible, due to the complexity of the novel approach.

Danny will continue this line of research at the IPPP with the assistance of an STFC Ernest Rutherford Fellowship. In collaboration with a postdoctoral fellow and an IPPP PGR student, they plan to carry out a global analysis in the presence of charming penguin contributions and to investigate BSM effects in the production of the charm-quark pair itself.



CONSISTENT KINETIC MIXING AND THE HIGGS LOW-ENERGY THEOREMS

A popular way of extending the Standard Model ***(SM)*** is by adding a new Abelian ***U(1)*** gauge group. These models allow for kinetic mixing between the new gauge boson and the ***SM*** hypercharge gauge boson, which ultimately leads to the mixing of the new boson with the photon. A fact often overlooked in the literature is that the mixing with the hypercharge gauge boson captures only part of the kinetic mixing term with the photon since the new gauge bosons can also mix with the neutral component of the $SU(2)_L$ gauge bosons.

In arXiv:2207.00023, Martin Bauer and Patrick Foldenauer present a consistent description of kinetic mixing for general Abelian gauge groups both in the electroweak symmetric and the broken phase. They do so by including the relevant contributions from mixing of the new gauge boson with the neutral component W^3 of $SU(2)_L$ both at the tree and one-loop level.

They show that these contributions are due to mixing with the neutral ***SM*** weak boson W^3 can only exist if $SU(2)_L$ is broken and that these are renormalisable if induced by ***SM*** fields in the loop. For new, heavy states charged under the new ***U(1)*** and $SU(2)_L$ these contributions are suppressed by the heavy scale giving mass to the heavy states. They show that, as a consequence mixing between the new ***U(1)*** and $SU(2)_L$ is most relevant for the class of gauged anomaly-free global symmetries of the ***SM***.

Finally, making use of their one-loop expression, they formulate a low-energy theorem expressing the couplings of the Higgs boson to photons, Z and X bosons through the vacuum polarisation amplitudes responsible for kinetic mixing. The result differs significantly from the corresponding low-energy amplitudes for Higgs decays into Z bosons in the SM. As an application they use the low-energy theorem to obtain the branching ratios for exotic Higgs decays relevant for all models with charged baryon number, demonstrating the relevance of a consistent description of kinetic mixing of a new ***U(1)*** gauge boson.