INSTITUTE FOR PARTICLE PHYSICS PHENOMENOLOGY

NEWSLETTER
MARCH 2023

WELCOME TO THE IPPP

Welcome to another exciting issue of the IPPP biannual newsletter!

Since the last issue, there have been plenty of IPPP hosted activities, including the Ogden@20 event in November 2022, the Annual Theory Meeting and the Young Theorist forum in December 2022, and the Higgs Maxwell meeting in February 2023. You can read more about these events further on in this newsletter (we thank Yannick Ulrich, Nathalie Taylor, Jessica Turner, and Oscar Braun-White for summarising these workshops for us). We thank the speakers and all participants for their participation!

We are pleased to welcome a new member of staff, Danny van Dyk who joined in October.

We are pleased to announce several new DIVAs, including Michael Baker and Andrea Thamm from the University of Melbourne, Australia.

Furthermore, we are happy to host Roy Crawford Lemmon (University of Liverpool), Jaroslaw Nowak (Lancaster University), and Biagio Lucini (Swansea University) as IPPP associates.

There will be several upcoming IPPP affiliated workshops to watch out for. These include a workshop on neutrinos, hadron spectroscopy, and primordial black holes.

In summer 2023, the IPPP will also host the YETI school, on the topic of quark flavour.

The IPPP congratulates Henry Truong, Ryan Moodie, Dorian Praia do Amaral, and Lucy Budge on the successful defence of their PhDs. Finally, this issue's highlights include three research highlights from Rodrigo Alonso and Mia West, Danny van Dyk and Méril Reboud, and Steve Abel and Luca Nutricati.

ANNOUNCEMENTS

1. The IPPP is pleased to announce an upcoming workshop on: **"Exploring the Physics Opportunities of nuSTORM"** (6 April 2023, IoP Building London) hosted by Ken Long (Imperial), Xianguo Lu (Warwick) and Jessica Turner (IPPP). Later in April (from the 19th to the 21st), this is followed by the IPPP-hosted workshop "Exotic Hadron Spectroscopy 2023" organised by Ben Pecjak (Durham), Bryan McKinnon (Glasgow), Christopher Thomas (Cambridge), Dan Watts (York), Mark Whitehead (Glasgow), Mikhail Bashkanov (York), Muhammad Naeem Anwar (Swansea), Tim Burns (Swansea). In addition, IPPP is co-organising, with the University of Naples, "New Horizons in Primordial Black Hole physics" (19-21 Jun 2023), which will be established as an annual workshop.
Registration is open and can be found at:
https://conference.ippp.dur.ac.uk/event/1130/

2. 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 Exp. Fellowship:
https://www.ippp.dur.ac.uk/senior-experimental-fellowships
Our next intake will be in September 2023.

3. We encourage organisers of workshops related to HEP theory to reach out for support. The IPPP can help organise workshops in the UK, administratively and financially.

NEW POSTDOCTS

MÉRIL REBOUD

Has recently joined Durham University and the IPPP as a postdoctoral research associate. He will continue his work on flavour physics phenomenology, which he started at Laboratoire d'Annecy-le-Vieux de Physique Théorique and the TU Munich. Besides his work in particle theory, he also has experience as a former experimental physicist in the LHCb collaboration.

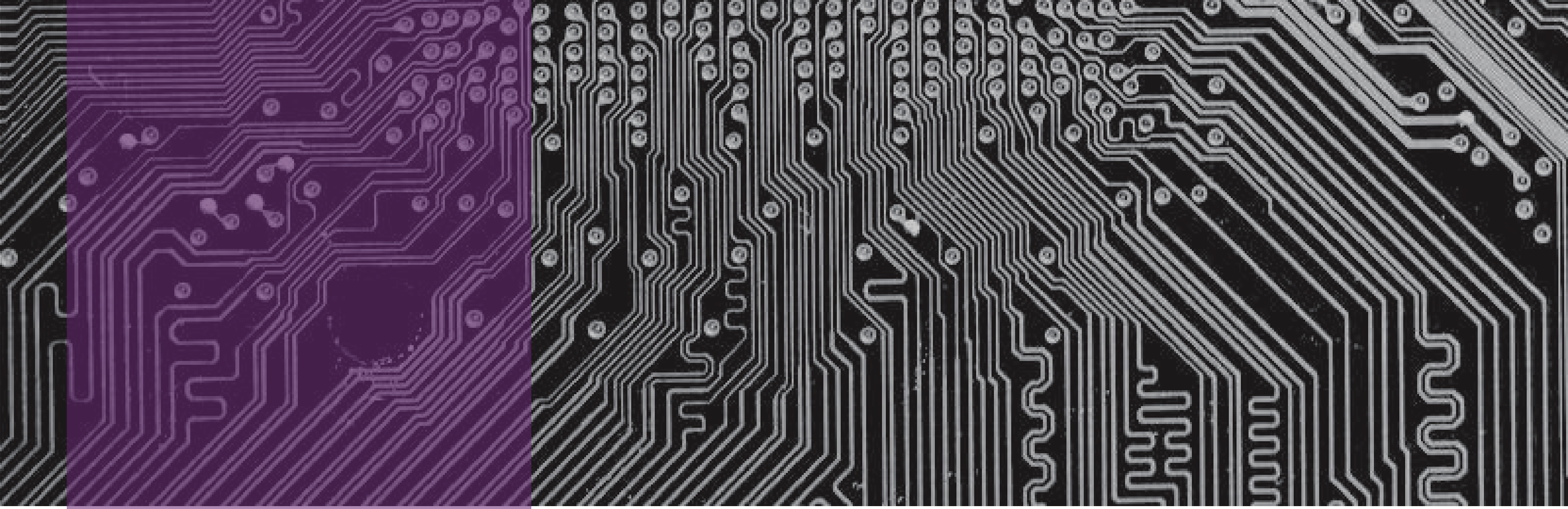
SREEMANTI CHAKRABORTI

Is another new IPPP postdoc. Her research interest is in Beyond the Standard Model phenomenology. In particular, she has been working on constraining models of dark matter and other long-lived BSM particles with the limits obtained from various ongoing as well as proposed terrestrial experimental facilities and astrophysical observations. She completed her PhD at Indian Institute of Technology Guwahati (India) and worked as a postdoc at LAPTh (Annecy, France) before joining IPPP.

YOUNG THEORIST FORUM 2022

The 15th and 16th December 2022 saw the return of YTF. YTF is a long-running conference organised by IPPP PhD students for all students in the UK theoretical particle physics community. Due to train strikes, we had both in-person and virtual attendees.

Attendees enjoyed attending talks across the whole spectrum of theoretical particle physics; from amplitudes to black holes and from strings to phenomenology; provoking many interesting discussions. There were also five minute gong show talks for lightning introductions into UK research. The first day ended with a very enjoyable evening “Poster and Pizza” session. Our plenary speaker was Professor Malcolm Fairbairn from King College London. Malcolm provided encouragement and advice about a life in academia, along with an overview of his research into Axions. We are looking forward to hosting the next YTF in December 2023!



ANNUAL THEORY MEETING 2022

The Annual Theory Meeting 2022 (13-15 Dec 2022), hosted by the IPPP, was back almost at full strength with over 50 in-person participants and a further 50 remote participants connecting over the three days. The meeting began with talks by Alexander Zhiboedov (CERN), Monica Guica (Saclay) and Netta Engelhardt (MIT) on topics ranging from amplitudes, quantum information to holography. The first day ended memorably with Herbi Dreiner and collaborators sharing his extensive experience on physics outreach with us.

The second day began with talks on partonic PDFs by Richard Ball (Edinburgh) and Claude Duhr (Bonn), who discussed state-of-the-art calculated for the LHC. This was followed by a lively and festive talk on how stellar bodies, such as heavy neutron stars, can constrain new physics by Andreas Weiler (TU Munich). Next, an entire session was devoted to lattice and quantum simulations of quantum field theories presented by Davide Vadacchino (Plymouth) and Zohreh Davoudi (Maryland). The second day was completed with Subir Sarkar (Oxford) scrutinising challenges to the standard cosmological model. Finally, the second day was nice rounded off with an excellent meal at the Indigo Hotel.

Last but not least, the final session of ATM 2022 was delivered by Danny van Dyk, a new faculty member of the IPPP, on flavour anomalies and measurements. We are encouraged and enlivened by a good turnout and seeing our colleagues from the UK and beyond. We thank the speakers and participants, in-person and remote, who took part and made ATM 2022 a great way to end the year.
We look forward to the coming ATM 2023 meeting.

OGDEN @ 20

The Ogden Centre for Fundamental Physics has celebrated its 20th anniversary.

Since opening in 2002, the Centre has built an international reputation for its research into the nature, contents and origins of the universe.
Nobel Prize laureate Professor Jim Peebles from Princeton University delivered the keynote lecture at a celebratory symposium held in late November which also explored the five “Physics Questions” posed when the Ogden Centre was created. These questions concern the nature of dark matter, dark energy and neutrinos, tests of General Relativity and the origin of life in the Universe.

Jessica Turner and Djuna Croon represented the IPPP at the symposium. Turner gave a talk on ‘Neutrinos and their connection to the matter-antimatter asymmetry’ with Croon exploring ‘Was Einstein right? Black hole archaeology with gravitational waves’.

Vice-Chancellor Professor Karen O’Brien and Ogden Centre supporter Damon de Laszlo unveiled the sculpture Journey, by John Robinson, as a birthday present to the Centre. The sculpture was donated by Damon and Robert Heffner III. Pupils from Woodham Academy in County Durham, representing 152 North East of England Ogden Trust partnership schools, also took part in a day of activities including the launch of a collaborative artwork by digital artist Petra Szemán. The Trust was set up by Durham Physics alumnus and entrepreneur, Sir Peter Ogden, and its generous donations have helped fund the development and growth of the Ogden Centre.

At the anniversary we also remembered Professors Mike Pennington and James Sterling who, together with Emeritus Professor Alan Martin and Ogden Professor Carlos Frenk, created the Ogden Centre.

Discover more about Ogden at 20 via https://www.durham.ac.uk/discover/ogden-centre-20/.

BIRTH OF THE IPPP

Written by Alan Martin

in memory of James Stirling and Mike Pennington

This talk is entirely historical. It describes the birth of the Institute for Particle Physics Phenomenology -- an Institute of Theoretical Physicists with the explicit brief to support the Experimental Particle Physics programmes all around the World (and in Britain in particular).

There were no Theoretical Physics staff in Durham in 1963 and yet by the year 2000 we had a larger Particle Theory staff than any University in the World -- nothing short of a miracle. I would like to share with you the fascinating story of how it came about -- it is due to a sequence of 9 pivotal events.

The first event was the appointment of George Rochester as Head of the Physics Department in 1955. Before then Physics in Durham was very small -- with 5 staff in total. (Rochester came to Durham from Manchester University -- where he & Butler were the first people to discover a new elementary particle without getting a Nobel Prize). Rochester brought 3 staff with him from Manchester and gradually built up the Department. It took until 1963 for him to persuade the University to create a Chair of Theoretical Physics.

Event 2 was the hiring of Brian Bransden, together with a lectureship, which was awarded to me. By chance the following year the Professor of Applied Maths moved to London. Both Rochester & Bransden saw the wisdom of appointing Euan Squires, an expert in Mathematical Particle Physics, to the vacant Chair --- this was the third event.

The fourth event occurred in 1968 when Brian Bransden took on a Research Student by the name of Peter Ogden. After completing his Ph.D at Durham, we became extremely proud when Peter went on to such a great business career, which subsequently enabled him to set up the charitable Ogden Trust to provide funds to promote physics teaching in schools. Peter was always looking at ways to maximize the impact of the Trust’s funds. Now his son, Cameron, has taken on this duty as the new Chairman of the Trust, Remarkably, over the years, Peter has kept his wonderful engaging and happy personality. Here in Durham we really treasure his visits to see how his old department is getting on. Peter's valuable impact will appear at the very end of our story, or to be precise just after the birth of IPPP.

In the 1970’s the Particle Theory group continued to expand. Soon the Physics & Maths Departments were able to put on a comprehensive set of lecture courses covering all aspects of particle physics for our own research students.

Then starting in the late 70's permanent University jobs became very difficult to find --- Durham decided to have a moratorium on appointing new lectureships. Yet in this period two exceptionally talented particle theorists were hired by Durham -- Mike Pennington in 1980 and James Stirling in 1986. These were pivotal events 5 & 6.

How did two such outstanding physicists come to Durham in a period when it was exceptionally difficult to find a permanent job in a British University? Mike Pennington twice took leave of absence from his Fellowship at CERN to come to Durham to do research & to teach in our postgraduate lecture programme. Durham University supported this enterprising initiative by the Physics & Maths Departments and granted Mike a senior research position, which eventually turned into a Lectureship. Now the appointment of James Stirling. By the mid 80's the Funding Councils were so concerned by the lost generation of scientists that they granted a very small number of New Blood posts to promising research groups. The Durham Physics & Maths group were awarded one. James was appointed to the Lectureship from a strong field of applicants.

Both Mike & James loved Physics, Indeed they both made valuable (often pivotal) research contributions, They both were truly outstanding lecturers and communicators They both were caring and encouraging supervisors of research students, Most important, they were both loyal and supportive to ALL members of the group, They both were gifted administrators, taking on a succession of demanding leadership roles, Mike finishing as Director of Theoretical Physics at the Jefferson Laboratory in America and James as Provost of Imperial College London.

Tragically both Mike and James died in 2018. They were an enormous loss to their countless friends and colleagues all around the World, and particularly to their beloved wives, Pat and Paula. It is a pleasure to see both Pat and Paula here today.

In the 80's and 90's the group went from strength to strength. We were awarded Research Council funding for a whole series of Workshops on Topical Particle Physics Problems, drawing expert experimentalists and theorists to Durham from all around the World --- these are events number 7.

We come to the crucial event 8. Around 1999 the Chairman, Ian Halliday of PPARC (the Particle Physics and Astronomy Research Council), was concerned that the Particle Theory research group at the Rutherford Laboratory, despite its excellence, would eventually be run down and be lost as a national focus of particle physics. So he contacted Mike Pennington (then Head of Physics) to see if Durham would be interested in taking over this important responsibility. This led to the so-called gang of four (Mike, James, myself, Vice Chancellor Ken Calman) going to London for discussions with Ian Halliday. The 4th gangster, the VC, said very little, but his presence was of enormous benefit. Ian Halliday was relieved to see that there was a University that was keen to fulfil his hopes. On the train back to Durham the gang of four was delighted with their day's work. But we live in a democracy, and soon all British Universities were open to bidding for the IPPP. Twelve Universities applied for the honour. Four Universities were short-listed, including Durham.

As a result we come to the critical event 9. The gang of 4 made their second trip to London. They were interviewed by a panel in the morning and again in the afternoon.

Two points against our case:

- First:
Durham was not in the Golden triangle formed by London, Oxford and Cambridge. (Nowadays this may actually be an advantage!)

- Second:
Durham did not have a Particle Physics Experimental Group.

Three of the major points in our favour:

- First:
Our experience with topical physics workshops for Experimentalists & Theorists.

- Second:
Our case was presented by James Stirling, with his exceptional communication skills. Our documentation had already alerted the panel that James was our choice of Director of the IPPP.

- Third:
The valuable presence of our VC at the panel discussions, confirming that the University would construct a new purpose-made building, which in the event turned out to be a 4-storey building coming from a combination of public funding and a generous gift from the Ogden Trust. Moreover, the VC confirmed that the University would create 4 new tenured lectureships in particle physics phenomenology.

In this way, the IPPP was born in Durham in the year 2000. The combined support from the University, from PPARC and especially from the Ogden Trust, has been a great boost to Particle Physics research both nationally and internationally. The IPPP has gone from strength to strength with a whole succession of outstanding staff, making the IPPP globally recognised as a centre of excellence. Long may it continue.

HIGGS MAXWELL MEETING

After three years of cancellation, the Royal Society of Edinburgh once again hosted the Higgs Maxwell Workshop. On 15 February, almost a hundred registered participants mostly from Durham, Edinburgh, Glasgow, and Lancaster met in the Society's headquarters in the heart of Edinburgh to discuss various aspects of Higgs physics, ten years after the Higgs boson was first discovered.

Liza Mijović (Edinburgh) provided a comprehensive overview of LHC Run 2 data for the Higgs mass, width, and couplings to other particles.
They especially highlighted the observation of H → muon + anti-muon and constraints on H → charm + anti-charm before finishing with prospects for the high-luminosity LHC (HL-LHC) which will provide first constraints for the cubic Higgs self-coupling.

Next up was David Sutherland (Glasgow), who provided an introduction to SMEFT (an effective theory that maintains the Higgs in a doublet) and HEFT (a theory that separates the Higgs and Goldstones). They continued to discuss how various non-decoupling models are constrained in the (finite) HEFT parameter space through precision measurements of the Higgs, direct searches, early-universe physics, and theoretical considerations. While the HL-LHC will probably not be able to completely rule out (or discover) the models they have discussed, an FCC could make sizable headway.

After lunch, Jennifer Smillie (Edinburgh) discussed resummation in H + n jet production, which is very important to, for example, probe the CP structure of the observed Higgs boson. After explaining the basics of resummation in the high-energy limit, they introduced the HEJ (High Energy Jets) formalism with a focus on recent advances in describing H + 1 jet as well as some phenomenological results for H + 2 jet including finite quark masses.

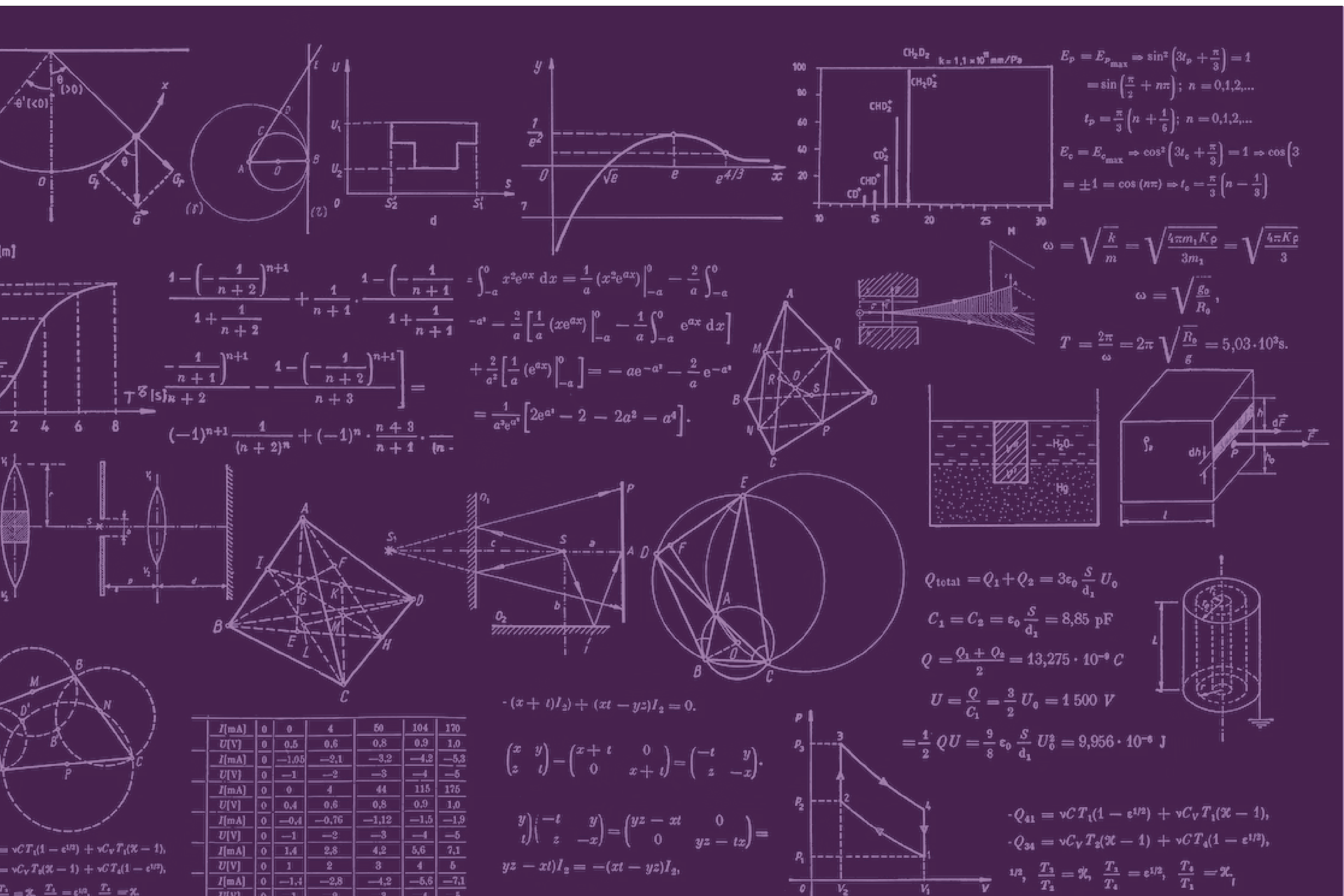
The next talk by Stephen Jones (Durham) motivated the need for precision calculations in the example of Higgs production and the Higgs transverse momentum spectrum. They described some cutting-edge calculations that were carried out for pp → H + jet, pp → ZH, and pp → HH as well as hinting at some technical (such as the complexity of the calculations) and conceptual issues (such as the strong dependence on the mass renormalisation scheme).

The workshop was closed by Harald Fox (Lancaster) with some prospects for Higgs physics.

They argued that it is vital to pin down the exact nature of the electroweak symmetry breaking for which a Higgs factory is required.

Even though the (HL-)LHC is arguably already a Higgs factory, future colliders, such as the FCC-ee, CEPC, and FCC-hh, will be required, the latter being the ultimate Higgs factory.

After the workshop closed, the participants enjoyed a pleasant evening out in Edinburgh before heading home.

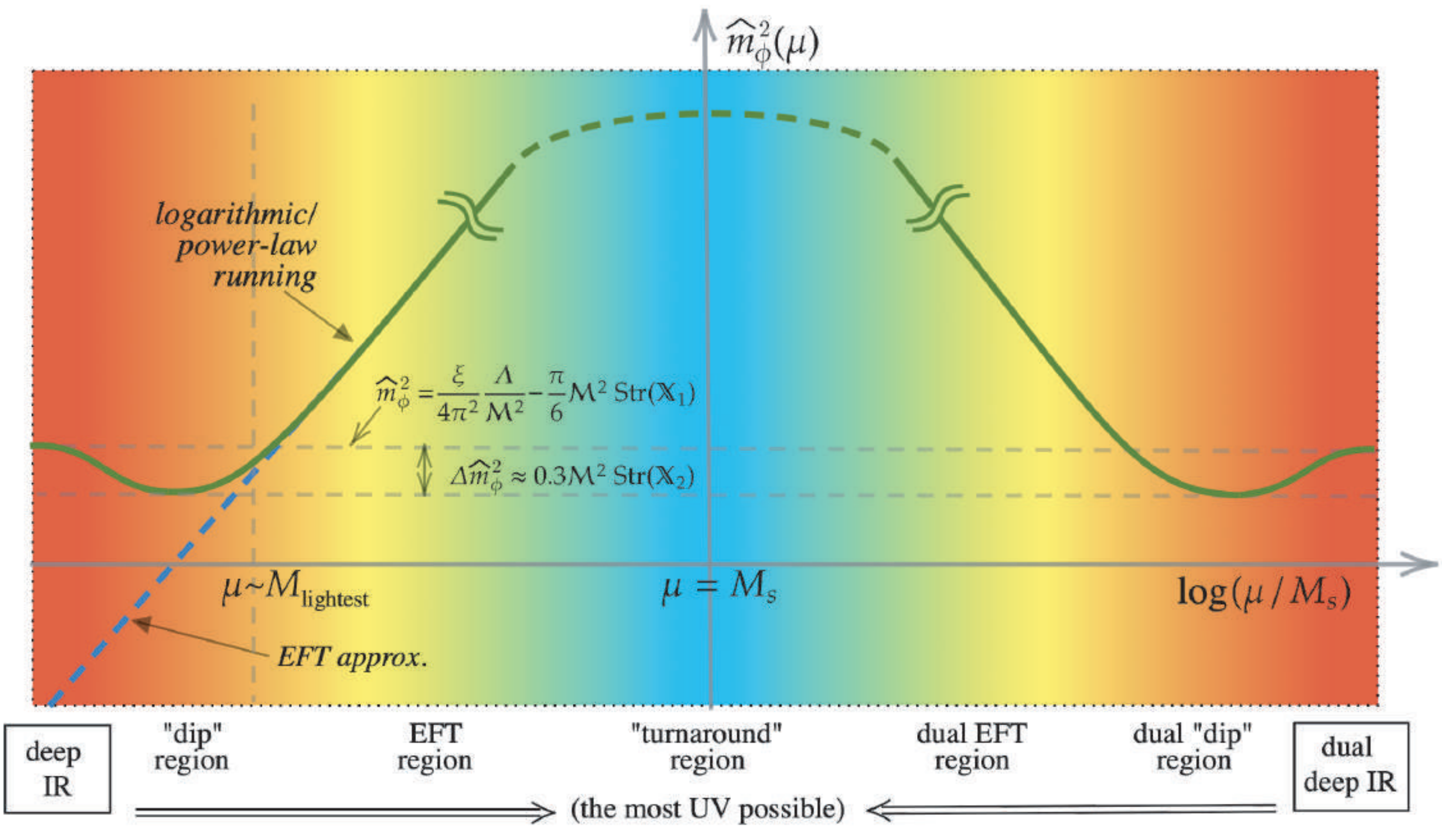


NEW APPROACHES TO NATURALNESS

The unreasonably light value of the Higgs mass has been a subject of intense speculation since the discovery of the Higgs boson in 2012. The problem is to explain not only why the Higgs mass takes the value it does (the so-called "naturalness problem") but also how can it be compatible with and protected from much higher scales in the theory, for example Grand Unified energy scales, or fundamental scales such as the Planck scale itself (the so-called "technical hierarchy problem"). This question has recently come to the fore because there is still no sign of supersymmetry at the LHC, the property that was previously thought to hold some of the answers to this question.

In recent work https://arxiv.org/abs/2106.04622, Steve Abel and student Luca Nutricati (of IPPP) together with Keith Dienes (of NSF and Arizona) revisited the idea of "misaligned supersymmetry". This is the observation that in string theory, even when supersymmetry is completely broken, many of the miraculous cancellations of supersymmetry must remain in the theory in order to make it internally consistent. Such symmetries via the phenomenon of UV/IR mixing can govern the properties of the low-energy theory even though a low energy observer would never be aware of their existence. In particular they may be able to protect the problematic Higgs mass within a more complete picture, and hold the promise of new unexpected cancellations in the theory that could make it natural. The figure illustrates how the Higgs mass behaves as a function of energy scale as described in their recent work, and demonstrates that within a UV complete scheme such as string theory the question of naturalness becomes far less mysterious.

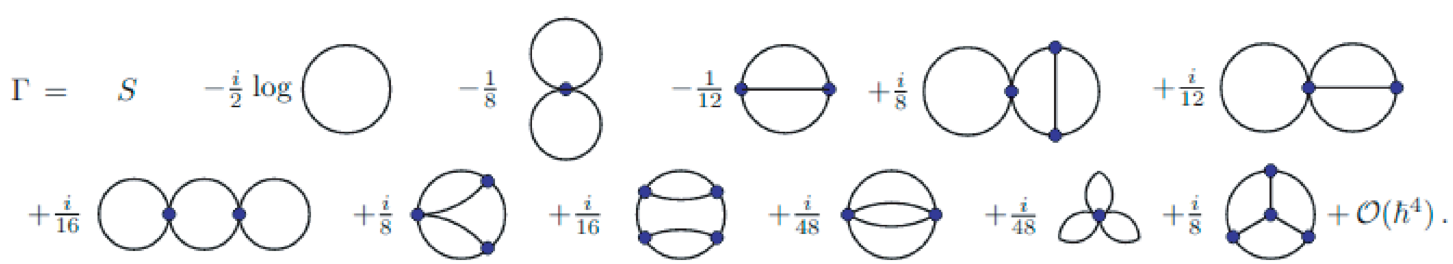
This work along with many other ideas about Naturalness was showcased at a fascinating workshop held at Cern from 30th January to 3rd February co-organised by Steve Abel with local organisers. The IPPP would like to thank Cern for proposing and supporting this workshop, helping to make it a great success, and for continuing to lead efforts in this area.



QUANTUM CORRECTIONS FOR SCALARS SPANNING A RIEMANNIAN MANIFOLD

Effective Field Theories (EFTs) provide a model-independent framework to explore the low energy effects of heavy new physics and have been of use in particle physics numerous times. Prominent among these instances is Fermi's theory; a four point interaction originally thought to describe beta decay as it occurs in e.g. nuclei. We now know this interaction arises from the exchange of a W boson because we have "zoomed-in or equivalently increased the energy enough to produce these electroweak particles. Fermi's theory, it turns out, is a low energy EFT.

One can from here understand the state of Higgs physics by analogy; we are at present studying the EFT that describes possible interactions of the Higgs particle, the latest addition to the SM, even though we might not have energy or `resolution' enough to determine what is the origin of these interactions. The exploration is carried out simultaneously in the theory front and the experimental front, at the Large Hadron Collider (LHC).



Diagrams contributing to the effective action up to three loops.

On the theory side, Higgs Effective Field Theory (HEFT) has been identified as the most general EFT realising the necessary Goldstone bosons and Higgs particle, while still maintaining gauge and Lorentz invariance. In a subset of this theory space lies the well researched Standard Model Effective Field Theory (SMEFT) which realises the electroweak symmetry linearly. The fundamental question of linear or non-linear realisation is then that of HEFT/SMEFT or SMEFT, but its non locality makes it difficult to answer.

Differential geometry has proven illuminating in the study of HEFT.
We can think of HEFT as the scalar sector of the electroweak theory parameterising a general manifold. In doing so, we connect tensors in field space with physical quantities such as amplitudes, and maintain invariance under reparameterising our scalar fields. These properties, one would like to maintain throughout our computations by maintaining explicit field-space covariance.

In arXiv:2207.02050, Rodrigo Alonso and Mia West present a method to calculate the effective action for scalar fields parameterising an arbitrary Riemannian manifold, to any loop order and while maintaining field-space covariance, extending the known one-loop results. The authors modify the usual path integral expression for the effective action to be invariant under field redefinitions and perform a covariant derivative expansion. This expansion provides the covariant field-dependent tensors to build the effective action to arbitrary loop order. The authors explicitly calculate the two-loop effective potential for a manifold with O(N) symmetry, where N=4 is the HEFT manifold.

TOWARD A COMPLETE DESCRIPTION OF $B \to u\ell^-\nu$ DECAYS WITHIN THE WEAK EFFECTIVE THEORY

One of the central objectives of quark flavour physics is the determination of a-prior unknown parameters of the Standard Model of Particle Physics. Amongst these, the element of the so-called quark mixing matrix, named CKM for Cabibbo, Kobayashi, and Maskawa, are of great phenomenological interest. A central paradigm of the Standard Model is: CKM elements are universal across all processes. Disagreement between determinations of its elements across diverse sources therefore raises eyebrows and lets phenomenologists warm up their computers.

One such disagreement is a longstanding tension between the different determinations of Vub, the relative strength of a W boson coupling to both an up and a down quark. One class of determination uses semileptonic decays with a known final state hadron, such as a pion or a rho meson, to extract Vub; these are known as exclusive determinations. In contrast, inclusive determinations do not rely on a single final state hadron but include all potential hadrons with the right flavour. Exclusive and inclusive determinations of Vub famously disagree, and effects beyond the Standard Model have been previously considered as an explanation.

In arXiv:2302.05268, Domagoj Leljak & Blaženka Melić (both Institut Ruđer Bošković, Zagreb), Filip Novak (Technische Universität München), and Méril Reboud & Danny van Dyk (both Institute for Particle Physics Phenomenology (IPPP), Durham), scrutinise existing data and investigate the potential reach of such modifications beyond the Standard Model in semileptonic B decays. They see good agreement between Vub determinations from pion, rho meson, and omega meson final states.

However, they find that effects beyond the Standard Model describe the data significantly better. A central result of their study are statistical constraints on the parameter space of the Weak Effective Theory, a tool within theoretical physics to describe these decays. Two solutions are found with equal probability: one close to the Standard Model, and one with a radically different type of coupling (see figure). They are looking forward to upcoming data from the Belle II experiment and the ongoing experiments at the Large Hadron Collider, to include them in their analysis. In the meanwhile, their theory colleagues can use the statistical results obtained with IPPP computing hardware to improve their proposed successors to the current Standard Model of particle physics.