INSTITUTE FOR PARTICLE PHYSICS PHENOMENOLOGY

NEWSLETTER SEPTEMBER 2023

WELCOME TO THE IPPP

Welcome to the fall edition of the Institute for Particle Physics Phenomenology's biannual newsletter! As the leaves begin to change and the air grows crisp, our researchers are hard at work unraveling the mysteries of the universe at the most fundamental level. In this edition, we'll explore the latest breakthroughs, collaborations, and insights that are shaping the field of particle physics. From the ongoing analysis of the Large Hadron Collider's data to innovative theoretical frameworks, our community continues to push the boundaries of knowledge. Join us as we delve into the exciting world of particle physics and celebrate the achievements of our dedicated scientists and scholars.

Since the last issue, there have been plenty of IPPP hosted activities, including the Young Experimentalists and Theorists Institute 2024 and the New Horizons in Primordial Black Hole physics (NEHOP) workshop. You can read more about these events further on in this newsletter (we thank Danny van Dyk, Stephen Jones and Lucien Heurtier for summarising these workshops for us). A big thank you to the speakers and all participants for their participation!

We have also been very happy to host Nuffield students at the Institute this summer. You can read about these research placement in a piece written by Sebastian Jaskiewicz.

We are pleased to welcome a new member of staff this fall, Ivan Martinez Soler will start in October. Ivan is an expert on neutrino physics and a member of the IceCube collaboration.

We are also pleased to announce several new DIVAs, including Andrew Long (Rice University) and Gudrun Hiller (University of Dortmund).
Furthermore, we are happy to host Jenni Smillie (University of Edinburgh) and Alan Barr (Oxford) as IPPP associates.

There will be several upcoming IPPP affiliated workshops to watch out for. These include the annual meetings in December, and the 13th international QCD@LHC workshop in September.

Finally, this issue's research highlights were written by Jeppe Andersen and Nigel Glover.

ANNOUNCEMENTS

1. The IPPP is pleased to announce the Annual Theory Meeting from December 12-14 and the Young Theorists Forum from December 15-16.

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 March 2024.

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.

YETI 2023: ALMOST EVERYTHING ABOUT FLAVOUR

From July 31st to August 3rd, IPPP had the pleasure to host more than 40 PhD students and 8 lecturers for another summer edition of the YETI PhD school. The organisers for this edition were Stephen Jones and Danny van Dyk, who were aided by our trusty Joanne Bentham and Trudy Forster.

This year's school was dedicated to the topic "almost everything about flavour". Across the eight lectures and tutorials, our students were taught about experimental and theoretical approaches to quark flavour physics at the hand of semileptonic b->clnu decays. The lectures ranged from how to perform flavour measurements in the difficult experimental environment at the LHC (Lucia Grillo) over how to work in effective quantum field theories (Javier Virto) to parametrising the relevant hadronic matrix elements (Marzia Bordone and Martin Jung) and obtaining them from lattice QCD simulations (Judd Harrison). At last, we were presented by Chris Parkes with the status and future perspectives of flavour physics experiments, ranging from NA62 to a yet-unnamed experiment at the FCC-ee.

For the practical side, the students had the opportunity to get their hands "dirty" with hands-on tutorials. Mark Smith led the students through several exercises to measure a semileptonic decay from simulated data under realistic conditions, comparable to the LHCb experiment's environment. Meril Reboud introduced the students to the EOS flavour software and how to use it to put together everything learned during the conference, with the goal of determining the CKM matrix element Vcb. We are very grateful to Daniel Maitre, who very kindly supported YETI with access to a Jupyterhub instance that was used for the hands-on tutorials.

We were quite taken aback by the students' enthusiasm and engagement shown during both the lectures and the tutorials, which made hosting this school a very rewarding experience.

YETI will continue in 2024 with another summer edition, which will be dedicated to neutrino physics and jointly organised by Stephen Jones and Jessica Turner.

NEW HORIZONS IN PRIMORDIAL BLACK HOLE PHYSICS (NEHOP)WORKSHOP

The workshop New Horizons in Primordial Black Hole physics (NEHOP), co-organised by L. Heurtier and J. Turner (IPPP), together with A. Cheek (Astrocent, Warsaw), M. Chianese and S. Moretti (UniNA Federico II), and Ninetta Saviano (INFN Napoli) took place for its first edition this summer in Naples, Italy, in the most iconic part of the city.

First of a kind, this workshop aims to become an annual event entirely dedicated to the physics of primordial black holes and their numerous implications for particle physics, gravitation and cosmology. It covered many aspects of the primordial black hole production in cosmology, their Hawking evaporation and its effect on particle physics models, their signature in terms of gravitational waves, their contribution to the dark matter relic density, as well as plenty of fascinating facets of their possible existence in nature.

This three-day workshop gathered 82 participants worldwide and featured some of the most renowned experts on the topic, such as Bernard Carr (Queen Mary University of London) and Antonio Riotto (University of Geneva). A total of 69 talks of no more than 20 minutes each allowed researchers of all ages to share their findings with the community in an exceptionally vibrant atmosphere from the beginning to the end.

We hope to organise the second edition of NEHOP in the UK in 2024!

NUFFIELD RESEARCH PLACEMENTS

The Nuffield Research Placements programme offers Year 12 high school students who are first-in-family to go to university or come from disadvantaged backgrounds the opportunity to get involved with research. The students experience first-hand how STEM research is being conducted at universities and in the private sector (**https://www.nuffieldresearchplacements.org**).

Seven students joined us for two weeks over the summer to work with postgraduate or postdoctoral researchers on their own particular project. Additionally, we organised a series of mini talks from other members of the IPPP titled "What else happens at the IPPP?" so the students could sample wide breadth of research directions pursued currently in particle physics. A big thank you to everyone who contributed to our mini talk series for the students and to Malina Rosca who ran sessions introducing students to LaTex!

This year, placements were provided by PhD students Tommy Smith, Sofie Erner, Ansh Bhatnagar, Jack Franklin, Hitham Hassam, and Malina Rosca, and postdoctoral researchers Daniel Reichelt, Yannick Ulrich and Sebastian Jaskiewicz. To mention just a couple, in the project hosted by Yannick, Sadnam learned about experiments measuring the proton radius and worked on modelling them with a dedicated state-of-the-art computer program using the institute's high-performance computing systems with the end goal of being able to `measure' the proton radius from simulated data. In the project hosted by Ansh, the student learned about particles and their interactions and used this knowledge to analyse their own simplified model universes with scalar particles. Ansh guided the student in examining how hidden dark matter particles may interact with known ordinary matter particles and how they would be visible in a hypothetical dark matter detector. For the project jointly co-supervised by Hitham, Malina, and Sebastian, Lovin worked through Jupyter notebooks introducing him to the ideas used in delivering precise predictions for colliders such as Monte Carlo integration, and analysing and presenting results, where in the end he compared theoretical prediction for the invariant mass spectrum between two jets against mock experimental data to find a bump in the far tail region!

The projects have been a very valuable experience for everyone involved, as they are a fantastic opportunity for both the early career researchers running the projects to gain experience student supervision and actively get involved in outreach. Last but not least, we wanted to thank Trudy and Joanne for organising office space, and Adam and Paul for helping with computing facilities. We look forward to hosting more placements next year and encourage everyone to get in touch with your local Nuffield coordinator to host more placements around the UK!

RESEARCH HIGHLIGHT: DESIGNER ANTENNA FUNCTIONS FOR HIGHER-ORDER CALCULATIONS

Author: Nigel Glover

The Large Hadron Collider (LHC) offers an unprecedented opportunity to study fundamental particles like Higgs bosons, electroweak bosons, top quarks, and hadronic jets with remarkable precision. Through accurate experimental measurements, we delve into the core interactions of elementary particles on a microscopic scale, expanding our understanding of the universe's fundamental forces.

In the absence of new particle discoveries, exploring LHC physics in detail takes on great significance. Scrutinizing LHC data with high precision enables us to detect even minor deviations from the Standard Model (SM) predictions, which could drastically reshape our grasp of the natural world. These subtle deviations might lead us towards new physics beyond the Standard Model, making precision phenomenology a critical aspect of this pursuit.

The forthcoming High-Luminosity LHC dataset is poised to diminish statistical uncertainties, enabling experimental accuracy at the percent level. However, achieving similar precision in theoretical predictions necessitates advancements in fixed-order calculations, parton distribution functions, parton showers, and non-perturbative effect modeling. Ongoing progress in these domains is pivotal to align theoretical predictions with the experimental precision that the LHC aims to achieve.

Recently, remarkable progress has been made in fixed-order calculations, reaching next-to-next-to-leading order (NNLO) and next-to-next-to-next-to-leading order (N3LO) for various processes. Achieving such high-order calculations involves intricate handling of real and virtual corrections across diverse multiplicity phase spaces. Implicit infrared divergences arise due to unresolved real emissions like soft or collinear radiation. These divergences are neutralized by explicit poles from virtual graphs through integration over the relevant unresolved phase space. Infrared subtraction schemes currently represent an elegant solution to manage these complexities and ensure consistent and precise outcomes.

One notable approach developed in Durham and Zurich is the antenna-subtraction scheme, which has been successfully applied to a range of fully-differential NNLO calculations. Initially devised for massless partons in electron-positron annihilation this method was later extended to accommodate initial-state radiation with initial-state hadrons at NNLO.

In its original formulation, the antennae were constructed from simple matrix elements which have the desired infrared singularities. By construction, the factorisation properties of matrix elements guaranteed that the subtraction term would match the infrared limit of the full matrix element. The direct extraction of antenna functions from matrix elements elegantly bypassed the complexities of combining subtraction terms for various multiple-soft and/or collinear limits. Despite its elegance, this method encountered issues. Identifying hard radiators, particularly for gluons, proved challenging when dealing with double-real radiation antenna functions derived from matrix elements. Sub-antenna functions were introduced to address this, but constructing NNLO sub-antenna functions often led to complex denominators hindering analytic integration. Additionally, spurious limits in NNLO antenna functions required explicit counter terms, introducing more spurious singularities.

To overcome these challenges and streamline the antenna-subtraction scheme, Oscar Braun-White, Nigel Glover and Christian Preuss (ETH, Zurich) introduced a set of design principles in arXiv:2302.12844 and arXiv:2307.14999 to algorithmically construct antenna functions for final state particles directly from the relevant infrared limits while properly accounting for the overlap between different limits. We expect that the new "designer" antennae will be more amenable to automation for more complicated processes at NNLO as well as serving as a springboard for developing a subtraction scheme for even more precise calculations at N3LO.

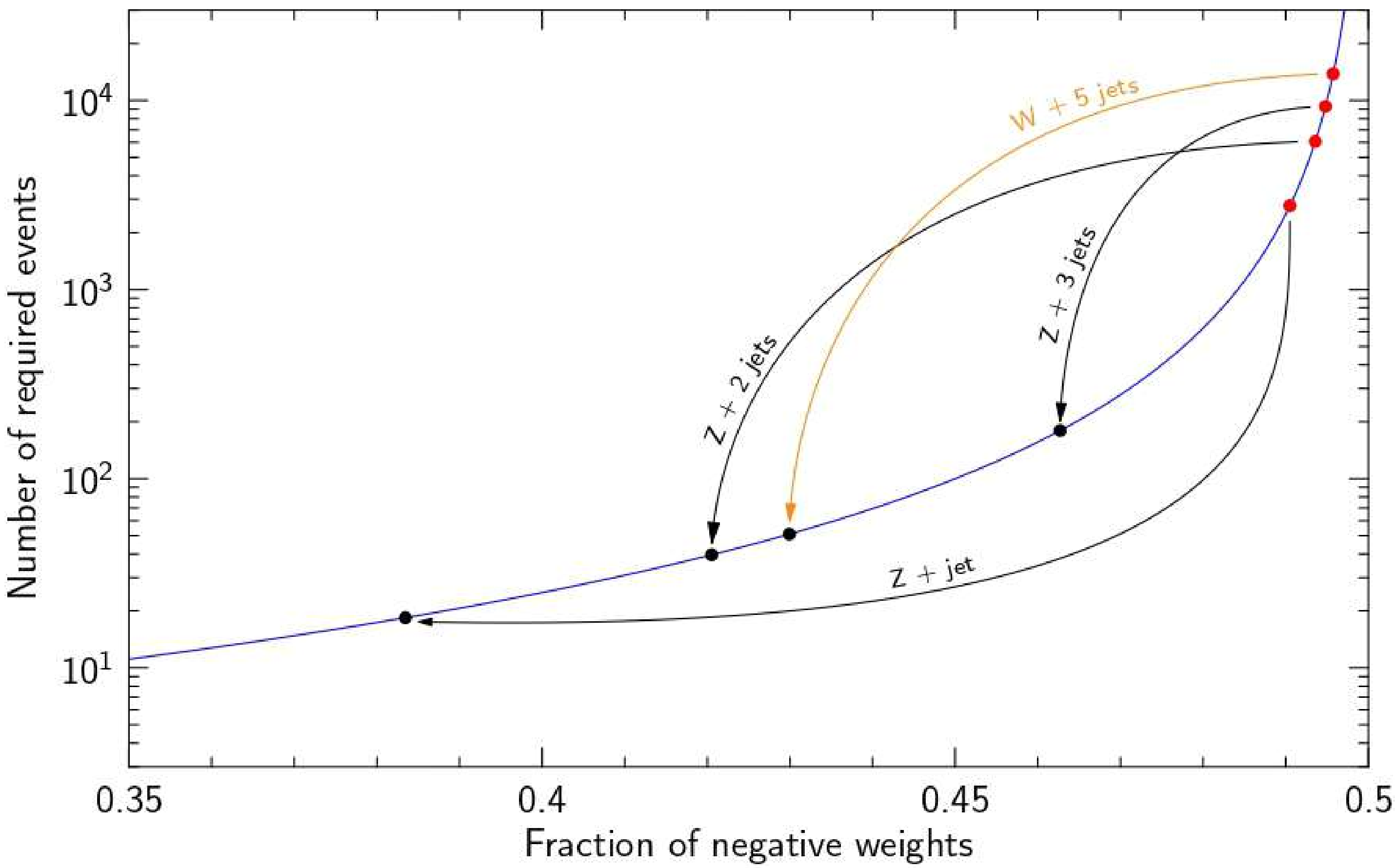
RESEARCH HIGHLIGHT:
UNBIASED ELIMINATION OF NEGATIVE WEIGHTS IN LARGE, HIGH-MULTIPLICITY EVENT SAMPLES

Author: Jeppe Andersen

Precise predictions for the processes observed at the LHC at CERN are necessary for the scrutiny needed to reveal any deviations from the expectations based on the Standard Model of particle physics. The most precise predictions are based on perturbative theory, taking into account quantum corrections of higher order in the couplings of the Standard Model. In order to obtain predictions for the observables and measurements performed by the experimental collaborations, the scattering amplitudes are integrated numerically by Monte Carlo techniques. The Monte Carlo integration is obtained by generating (pseudo-)random momentum-configurations (called "events"), which allow both for an evaluation of the scattering amplitude for the momentum configuration, and for a detailed description of the cuts and definitions of observables, jet definitions etc. applied in the measurement.

This approach is very efficient at the lowest perturbative order, where the scattering amplitude is positive definite. However, the calculations of higher order quantum corrections often contain events with both positive and negative contributions ("weights") to the cross section - even if the observable and cross section remains positive overall. This is inherent to the calculations, and appear not just for fixed order approaches, but also in the merging of these with general purpose event generators, describing also the shower and hadronisation stages of the processes.

While the occurrence of negative events pose no problem per se, it does become a a computational problem when the negative weight contribution is significant: in the most advanced calculations there is a roughly similar contribution from negative and positive events and therefore a very large cancellation between these contributions. Even the storage and analysis of the events start to set the limit of the complexity of the processes which can be studied. And sometimes yet more computationally intensive stages of the modelling (e.g. detector simulation) is yet to follow after the theory calculation has concluded. In other words: if the number of negative weight events could be reduced then predictions could be analysed at higher precision for more complicated processes.



We have suggested a novel approach [1,2] for reducing the impact of negative weights in a generated event sample. The idea, put simply, is to average the weight of events which are sufficiently similar. This is of course what is implicitly done when calculating distributions or cross sections. The trick now is to strictly define a metric on the space of events, which allows one to partition the space of events into cells, within which events are sufficiently similar that the weights can be averaged without changing predictions or distributions in analyses yet to be applied. Obviously, this idea works if the cells are defined to align with the histograms in a specific analysis [3]. Insight was required [1] to generalise this approach by defining a metric to partition the events agnostic of the specific analysis later applied. Furthermore, we needed to solve the problem [2] of finding nearest neighbours using such a metric in samples with billions of events sufficiently fast that the approach is viable. The Hungarian Method for finding the minimal distance for all permutations of (infra-red safe constructs of) particles in the events was crucial to calculate the distances between events sufficiently quickly, while Vantage-Point Trees proved useful for finding nearest neighbours in the space of generated events. The Cell Resampler is quickly finding applications in many very different types of calculations involving higher order perturbation theory, both high precision partonic calculations and NLO merged, hadronised event samples. Each new application brings added insight into the possibilities in the method, which are still being explored.

[1] JR Andersen, A Maier, Eur.Phys.J.C 82 (2022) 5, 433
[2] JR Andersen, A Maier, D Maître, https://arxiv.org/abs/2303.15246
[3] JR Andersen, C Gütschow, A Maier, S Prestel, Eur.Phys.J.C 80 (2020) 11, 1007