INSTITUTE FOR PARTICLE PHYSICS PHENOMENOLOGY

NEWSLETTER
SEPTEMBER 2024

WELCOME TO THE IPPP!

Welcome to the autumn edition of the Institute for Particle Physics Phenomenology's newsletter, where we share the latest research highlights, upcoming events, and exciting developments within our community.

In this edition, we will discuss how ultra-light dark matter may feature Lorentz-violating interactions and how to look for these effects. We will also give an extensive overview of updates to SHERPA, and report on various activities organised by IPPP members.

We are pleased to welcome a new member of staff this fall: Stefan Schacht won a prestigious Ernest Rutherford Fellowship and will start in October. Stefan is an expert on quark flavour physics, which is key to addressing several fundamental questions, including matter-antimatter interactions and the nature of the unitarity triangle.

We are also pleased to announce several new DIVAs: Ying-Ying Li from the University of Science and Technology of China and Jeremy Sakstein from the University of Hawaii.

Special thanks to everyone who contributed to this newsletter, particularly Jessica Turner and Yuber Perez-Gonzalez for the workshop reports and Frank Krauss and Ben Pecjak for the research highlights. We hope you enjoy reading it!

ANNOUNCEMENTS

1. The IPPP is pleased to announce the following workshops:

- The Annual Theory Christmas Meeting will again be held in Durham, 16-18th December, hosted and organised by the Centre for Particle Theory, UKLFT, FPUK and the IPPP. Following tradition, we use the format of three days of talks from world-class speakers reviewing the latest developments in the key areas of our subject.
https://conference.ippp.dur.ac.uk/event/1310/

- The ECFA-UK Meeting on UK studies for the European Strategy Particle Physics Update will take place in Durham on Sep 23 – 26, 2024. It is intended to bring the community together for a physics (rather than strategic) focused workshop. This will discuss the major physics goals of the next decades of particle physics and encourage the UK contributions to analysis studies which can be submitted to the strategy process, either as individual studies, or as submissions by already-established consortia, or as inputs to the ECFA e+e- study (as an example). Further, it will discuss opportunities and challenges in detector R&D and accelerator physics.
https://conference.ippp.dur.ac.uk/event/1357/

2. The Associateship, Durham IPPP Visiting Award, and Senior Experimental Fellowship programmes continue. 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 2025.

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.

INTERNATIONAL MASTERCLASS ON PARTICLE PHYSICS

On the 22nd of March, the IPPP hosted the International Masterclass on Particle Physics — a hands-on event where high school students analysed real data from the Minerva neutrino detector. Over one hundred students from six local high schools—Durham Johnston, Durham Sixth Form, Newcastle High School for Girls, Thirsk School and Sixth Form, Wellfield Academy, and Sunderland Sixth Form—participated in the event.

Following a hiatus over COVID, IPPP's Jessica Turner, revived the Masterclass, with this edition focusing on neutrino physics. This masterclass allowed the students to delve into the Minerva experiment, a neutrino scattering project based at the Fermi National Accelerator Laboratory in the USA.

The event was designed to immerse students in the role of neutrino physicists for a day. The morning session kicked off with introductory activities, including a lively particle physics card game facilitated by IPPP outreach researcher Francesco Sergio. After that, Jessica Turner, Yuber Perez-Gonzalez, and Aidin Masouminia delivered introductory talks on the universe's nature, neutrinos, and neutrino detection methods. Lunch was served on the Calman Learning Centre's top floor, offering amazing views of Durham Cathedral. After lunch, the students embarked on the day's highlight: a hands-on session analysing real Minerva datasets. They analysed many neutrino events observed by the neutrino experiment Minerva to find the “signal” among the “background”. This was a great success, and through their collaborative work, the students accurately estimated the size of the Carbon nucleus from the data. The computer rooms were abuzz with activity as students engaged in analysis, aided by IPPP PhD students and postdoctoral researchers. This fostered an atmosphere of collaboration and enthusiasm that carried into a Q&A session with IPPP's PhD students.

A special feature of the event was a video call with neutrino physicists at Fermilab, which allowed students to explore the experimental setup and engage in a meaningful dialogue with the scientists. The day concluded with the presentation of attendance certificates, warm farewells, and handshakes. A group photo captured the collective spirit of the participants, leaving organisers eager to plan next year’s event.

NEW HORIZONS IN PRIMORDIAL BLACK HOLE PHYSICS (NEHOP) 2024

After the success of its inaugural edition last year, the second NEHOP workshop was held from June 17th to 20th. This event was co-organized by L. Heurtier (King's College London), Y. F. Perez-Gonzalez and J. Turner (IPPP), and M. Chianese and S. Moretti (University of Naples Federico II). The workshop took place in the picturesque setting of the National Galleries of Scotland in Edinburgh.

Spanning three and a half days, the workshop aimed to unite researchers specialising in the physics of Primordial Black Holes (PBHs) and to address a broad range of topics related to these enigmatic objects and their role in the evolution of the Universe.

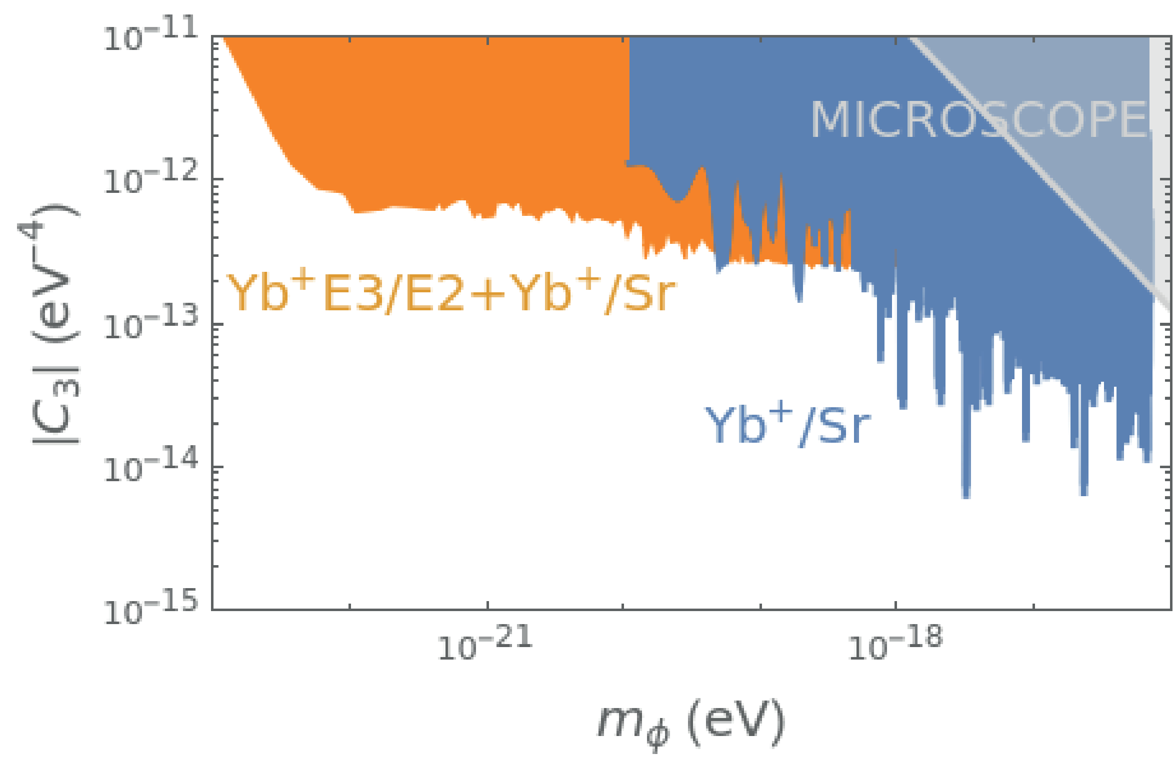
Presentations covered a wide spectrum, from observational constraints on PBHs to more theoretical aspects, including formation mechanisms, black hole evaporation and its potential impacts on particle physics, and the generation of gravitational waves.

NEHOP'24 brought together 90 participants from across the world and featured 67 presentations. These talks were delivered by leading experts, as well as by PhD students and postdoctoral researchers, fostering an enriching exchange of insights and perspectives. The setting this year further contributed to an engaging atmosphere, encouraging researchers to actively share their findings and participate in meaningful discussions throughout the event. The workshop was funded by the IPPP and sponsored by the EuCAPT network, whose support was instrumental in enabling PhD students from across Europe to attend and contribute to the workshop.

CONNECTING LORENTZ VIOLATION AND ULTRA-LIGHT DARK MATTER

The invariance of physical laws under Lorentz transformations is the backbone of Einstein's theory of special relativity. It is thus of great interest to test this theory to high accuracy by searching for minuscule violations of Lorentz invariance. Such Lorentz violating (LV) effects can be observed experimentally in the form of time-dependent oscillations of fundamental constants such as the electron mass and charge, or through the violation of rotational symmetry as seen in modern versions of Michelson-Morley interferometer experiments.

Even if the fundamental high-energy theory is Lorentz invariant, effects can be seen in low-energy experiments in cases where they are performed in the presence of a LV background. A concrete manifestation of such an LV background, which has received increasing attention as of late, is provided through the existence of a sub-eV bosonic dark matter particle. The large occupation number of such ultra-light dark matter particles implies that they exhibit collective behaviour best described by classical waves so that terrestrial experiments are effectively performed in the background of a time and direction-dependent dark matter wind.



In the recent work [1], the IPPP's Ben Pecjak joined forces with Minyuan Jiang of DESY Hamburg and Gilad Perez and Soma Sankaranarayanan of Israel's Weizmann Institute to study LV effects induced by interactions of ULDM particles with the QED sector of the Standard Model. Rather than specifying a particular UV model, the framework of effective field theory (EFT) was used. Under a rather minimal set of assumptions, it was shown that the relevant operators break into two classes — those with a scalar structure, leading to the oscillation of fundamental constants, and those with a tensor structure, which induce such oscillations in addition to the breaking of rotational symmetry. A main result of their work was, therefore, to provide a theoretical link between the two classes of LV phenomena in terms of a common set of theoretical parameters, such that, for instance, complementary bounds on effective theory operators can be obtained from seemingly disconnected experiments such as LIGO, MICROSCOPE, and atomic clocks. An example is shown in the figure on the previous page, which shows constraints on one of the effective theory Wilson coefficients from MICROSCOPE and atomic clock frequency comparisons.

References:
[1] https://arxiv.org/pdf/2404.17636 (JHEP 08 (2024) 114)

RECENT DEVELOPMENTS IN SHERPA

New major release

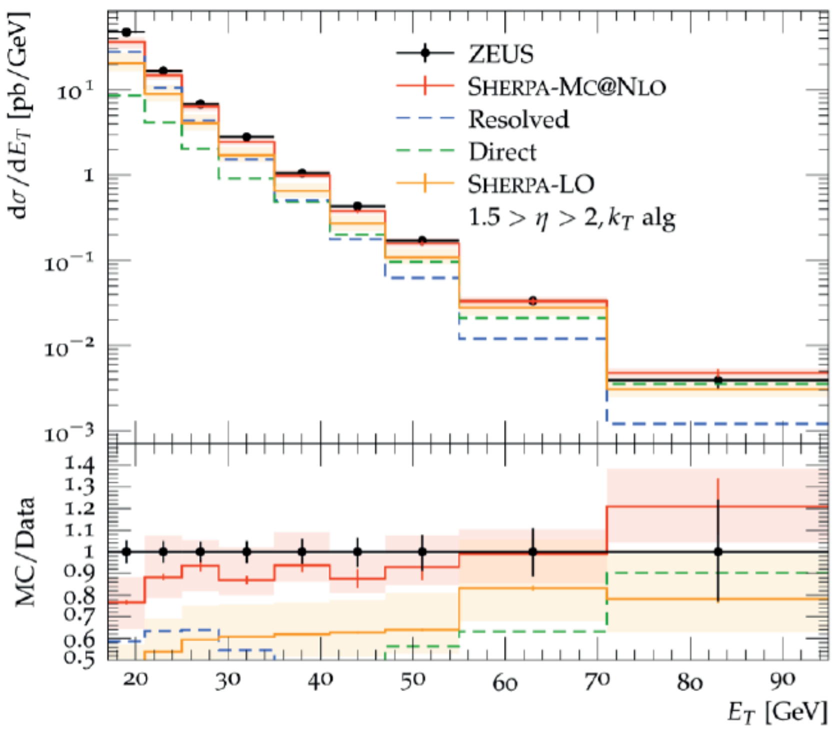
The SHERPA team recently released a new major version 3.0.0 of the SHERPA event generator, the culmination of a number of years of development. While many of the feature improvements and bug fixes have consistently been ported to a series of releases in the SHERPA 2.2 series, the new major version incorporates a range of enhanced physics capabilities, including:

•Systematic inclusion of EW corrections, at fixed order (NLO) and through Sudakov logarithms;
•Polarised cross sections for massive vector bosons;
•Simulation of photo-production processes;
•Interfaces to RECOLA, MCFM BLHA, MadLoop;
•A UFO2 interface, allowing negative coupling orders;
•On-the-flight variations of merging cut and the strong coupling αS(MZ);
•Upgrade of the interface to the Lund hadronisation in Pythia8;
•New MPI modelling, including for photons and simple MinBias simulations (still to be tuned);
•A new, simple colour reconnection model (still to be validated and tuned);
•QED corrections with the YFS framework for electron-positron processes, and the inclusion of $\gamma \rightarrow ll$ splittings in final-state radiation simulated with the YFS approach;
•Support for QCD resummation and the inclusion of matrix-element corrections.

In addition, SHERPA has undergone a number of technical improvements, most importantly

•A new, faster and more flexible build system;
•Improved numerical stability across the phase space and improved and extended colour and helicity sampling algorithms;
•Massive timing improvements of slow libraries, especially in the matrix element calculations;
•Input structures using the same YAML syntax and better-structured run cards and most visibly a new logo (see above), and a new online manual (a publication is in progress).

First simulation of photo-production at MC@NLO accuracy



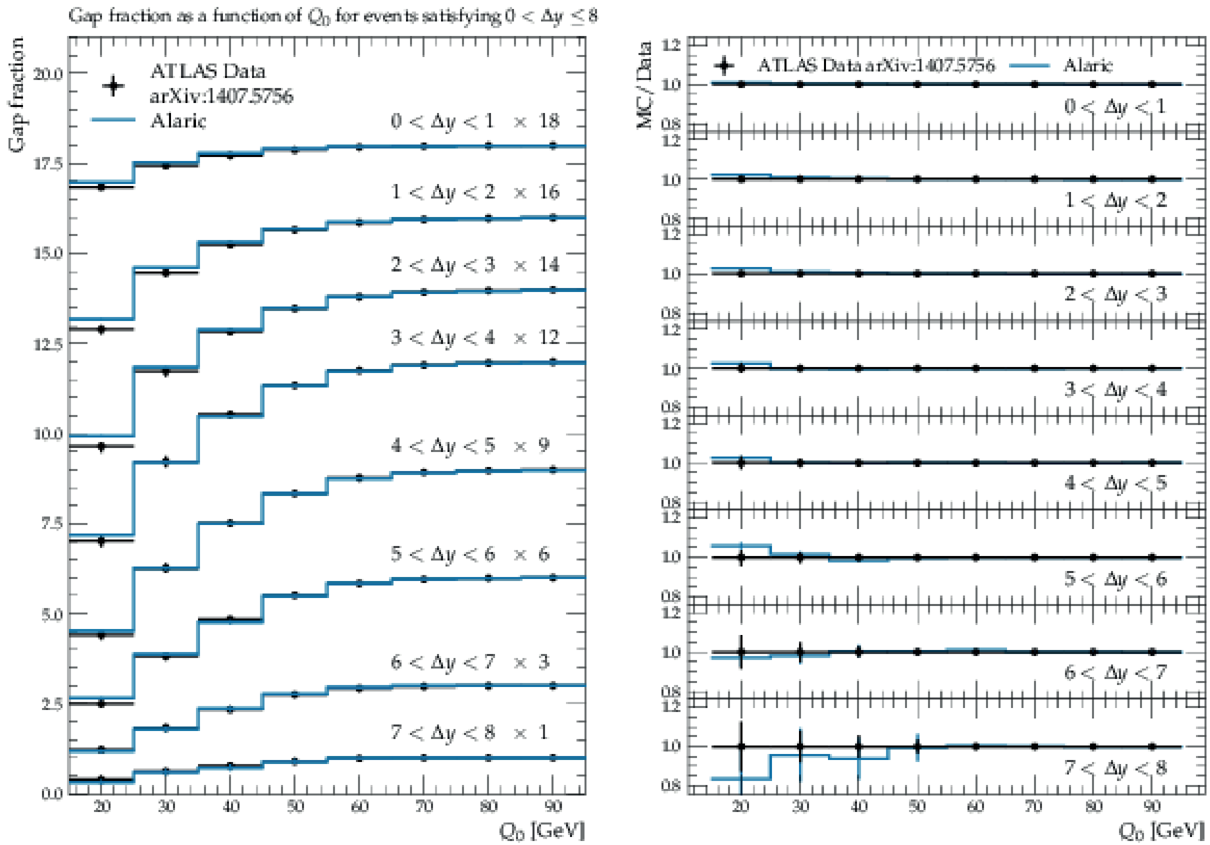
ET distribution of the leading jet in di-jet photo-production at ZEUS, comparing LO and MC@NLO simulations with data, also indicating the direct (point-like) and resolved (hadron-like) contributions.

At lepton-hadron colliders such as HERA in the past or the upcoming EIC at BNL in Brookhaven, the inner structure of the hadrons is tested with electromagnetic probes, i.e. virtual photons. While in “electro-production” processes at relatively high virtual masses Q2 ≥4 GeV2 the photons can be treated in a customary way as point-like particles, in “photo-production” processes at lower scales their wave function obtains a hadronic component, and they start to behave like hadrons.

As the lepton-hadron cross section falls very quickly with Q2, photo-production is a dominant contributor to the overall event yield, necessitating dedicated efforts in their description. In his PhD thesis, Peter Meinzinger constructed the first ever MC@NLO simulation of photo-production processes [1] and extended this new framework also to hard diffraction [2].

Corresponding parton distribution functions (PDFs) for the photon have been fitted to data, for the last time about 2 decades ago, and new fits will become crucial ingredients for EIC physics. The simulation will provide important support in this endeavour.

ALARIC Towards a new parton shower for SHERPA



Following up on the recent realisation that standard parton showers deployed in the event generators are not accurate at the next-to-leading logarithmic (NLL) level [3], the SHERPA team started to construct a new improved parton shower, ALARIC. In a first publication [4], the new scheme was introduced for final state emissions; it is based on a novel factorisation of the eikonal, which allows us to naturally embed angular ordering into the parton shower while keeping the azimuthal information without introducing negative weights. In addition, the usual role of the colour partner (the “spectator”) of the emitting partner (the “splitter”) was revisited, as the recoil partner was necessary to ensure local four-momentum conservation. This interpretation was one of the reasons why parton showers based on such a dipole picture are not NLL-accurate. Instead, a scheme was designed where the recoil of the emission is distributed over the full-coloured parton ensemble, reducing the role of the spectator to provide the orientation for the azimuthal distribution of the emission. This allowed for the first analytical proof of the NLL accuracy of the new parton shower.

In a recent study [5], the scheme was extended to hadron collisions, relevant for the LHC. The modular structure of SHERPA, allowed for the seamless employment of multijet merging techniques in leading order to describe relevant observables in Drell-Yan and multijet production. As an example, one can see in the right figure on the previous page the gap fraction between jets as a function of the cut-off parameter Q0. This is an observable that is highly sensitive to details of QCD radiation. The matching of the ALARIC to NLO (fixed order) calculation is underway; they mandate a shower-specific infrared-subtraction scheme, which has already been published and whose implementation is currently being validated.

References:
[1] Eur.Phys.J.C84 (2024) 2, 178; Phys.Rev.D109 (2024) 3, 034037
[2] e-Print: 2407.02133.
[3] Phys.Rev.Lett. 125 (2020) 5, 052002
[4] JHEP 10 (2023) 091
[5] e-Print: 2404.14360