Bad Honnef Physics School "Color meets Flavor"

Poster Abstracts

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Comprehensive analysis of local and non-local amplitudes in the $B^0 \to K^{*0}\mu^+\mu^-$ decay

Martin Andersson
LHCb Collaboration

The underlying quark transition to the $B^0 \to K^{*0}\mu^+\mu^-$ decay is the rare flavour changing neutral current transition $b \to s\ell^+\ell^-$, and constitute sensitive probes for New Physics (NP), as they are forbidden at tree-level in the SM and only occur at loop level. Virtual NP contributions can therefore have a large impact, and previous LHCb measurements of the decay have shown interesting tensions with the SM predictions at $\sim 3\sigma$. The theoretical interpretation of the anomalies is difficult due to the uncertainties in non-local SM contributions, such as charm-loops $b \to sc\bar{c}(\to \gamma)$, which could mimic NP effects. This poster discusses a data-driven approach to constraining the size of the charm-loops and other non-local contributions to the $B^0 \to K^{*0}\mu^+\mu^-$ amplitude by parameterising the full dimuon invariant mass spectrum. The results are obtained using an integrated luminosity of 8.4 fb^{-1} collected by the LHCb experiment.

Angular coefficients of $B^0 \to D^{*-}\tau^+_\tau$ decays

David Bacher, Malcolm John
University of Oxford (LHCb Experiment), UK

A measurement of the q^2 integrated angular coefficients S_x of the $B^0 \to D^{*-}\tau^+\nu_\tau$ decay with the 9 fb^{-1} Run 1 + 2 LHCb dataset is postulated. These coefficients capture the full angular information of the decay and have not yet been measured. Studies of a combination of theoretical and experimental results have been performed to obtain theory predictions of the angular coefficients as well as their q^2 dependence and will be used in the future to compare to the results of this measurement. Additionally, the reconstruction of the kinematic and angular variables of the decay has been studied and will be presented.

Revisiting $D_{(s)}\ell^+\ell^-$ in the SM using LCSR

Anshika Bansal, Alexander Khodjamirian, Thomas Mannel
Center for Particle Physics Siegen (CPPS), Universitt Siegen, Germany

The rare flavour changing neutral current transitions are interesting for the searches of new physics. In the up-sector, they become even more interesting as they are strongly suppressed due to GIM mechanism. $D \to \pi\ell\ell$ is one of the simplest modes to study such transitions in up-sector. This decay mode is dominated by the long distance effects, majorly the annihilation topology. With the updates in experimental bounds, it is timely to revisit such transitions within the Standard Model with a well established QCD based method.
In this work, we study this singly Cabibbo suppressed decay along with other Cabibbo favoured and doubly Cabibbo suppressed $D_{(s)}\ell\ell$ decays ($P = \pi, K, \eta$) decays in the U-spin symmetry limit as they share the similar long-distance dynamics. We obtain new relations between these decay amplitudes in the U-spin symmetry limit. Further, we plan to evaluate the annihilation topology contribution to these decays using Light Cone Sum Rules (LCSR) and combine it with the dispersion relation in the virtual photon channel.

Search for the $\mathbf{B^0 \to D^0\bar{D}^0}$ decay channel with the LHCb experiment

Johannes Albrecht, Jonah Blank, Quentin Fhring, Sophie Hollitt
AG Albrecht, Fakultt Physik, TU Dortmund University, Germany

The Standard Sodel of particle physics (SM) is currently the best theory for describing fundamental particles and their interactions with each other. Despite the impressive agreement of the predictions with a large number of observations, many phenomena remain that cannot be described by this model. Precise measurements of B meson decays at the LHCb experiment provide an opportunity to test the integrity of the SM and potentially search for new physics. Especially the class of $B \to DD$ decays, which are related via quasi-isospin relations, are interesting to examine CP violation and further constrain the unitarity triangle. While decays to charged $D^{\pm}$ mesons have already been well measured, the $B^0 \to \bar{D}^0 D^0$ decay channel has not yet been observed by any experiment. In the presented analysis, data collected by the LHCb experiment at $\sqrt{s} = 7$, 8 TeV and 13 TeV corresponding to an integrated luminosity of 9 fb^{-1} is used to search for the $B^0 \to \bar{D}^0 D^0$ decay channel. The topologically similar $B^0 \to \bar{D}^0\pi^+\pi^-$ decay channel is utilized as a normalisation mode to cancel systematic uncertainties.

SpaCal prototypes with picosecond time resolution

Aleksandar Bordelius
European Organization for Nuclear Research - CERN

My doctoral student project is part of an ongoing RD effort to build module-size SpaCal prototypes with O(10-20) ps time resolution using tungsten and lead absorbers to validate all aspects of their technical designs in test beam measurements. For example, such SpaCal modules are foreseen for the LS3 enhancement and Upgrade II (PicoCal) of the LHCb electromagnetic calorimeter as an addition to the current Shashlik modules. The SpaCal modules will use several novel technologies, including radiation-hard scintillating materials, hollow light guides, and ultra-fast photodetectors. The energy resolution, spatial resolution, and time resolution are measured during test beam campaigns and compared to simulations. In addition, some elements of the technical designs, namely photodetector characteristics and optimal geometries of hollow light guides, are studied with laboratory measurements. A linear response of the photodetector over the full relevant energy range is essential to obtain the targeted energy resolution of 10% sampling and 1% constant term, as is the uniformity of the response over a larger cell area. For the effect of the last, the light collection efficiency of hollow light guides is studied in detail.

Quark Masses in the Heavy Quark Expansion

Anastasia Boushmelev[1], Thomas Mannel[1], K. Keri Vos[2]
[1] Theoretical Particle Physics, Center for Particle Physics Siegen, University of Siegen
[2] Gravitational Waves and Fundamental Physics (GWFP), Maastricht University and Nikhef

The treatment of the quark mass plays an important role when it comes to increasing the precision of the predictions of the heavy quark expansion for inclusive heavy hadron decays. Various short-distance mass schemes have been invented to minimize the uncertainties induced by the quark mass, which needs to be extracted from other, independent observables. Though, these are so far not suitable for the Charm sector. We suggest replacing the quark mass directly by an observable such as e.g. the inverse moments of the cross section for $e^+e^- \to$ hadrons or q^2 moments. We investigate this alternative strategy and study its impact on the perturbative series.

Search for Right-handed Weak Decays

James Brown
University of Liverpool (LHCb Group), United Kingdom

My research focuses on quantifying the branching fraction of the $B^0 \to K_1^0\mu\mu$ decay channel, utilising LHCb Run 2 data to probe the presence of right-handed weak interactions. Accompanied by the implementation of a Run 3 trigger, the analysis involves partial reconstruction of the decay in both instances to enhance efficiency lost by the neutral final state (π^0).

Joint measurement of $b \to c\tau\nu$ Wilson coefficients with LHCb and Belle II

J. Albrecht, F. Bernlochner, M. Colonna, B. Mitreska, M. Prim, I. Tskalidis
TU Dortmund University and University of Bonn, Germany

Semileptonic $b \to c\ell$ decays are excellent probe for testing Lepton Flavour Universality and New Physics (NP) effects. A combined measurement of NP Wilson coefficients is performed using of $B \to D^*\tau\nu$ decays in proton-proton collision data collected by LHCb and electron-positron collision data from Belle II. The signal is extracted using a multi-dimensional fit to data using templated distributions derived from simulation and from control samples. New Physics contributions are measured via their corresponding Wilson coefficients and in several fit configurations that allow for different New Physics operators.

Flavour phenomenology and unitarity of dark photons

Jordi Folch Eguren[1], Emmanuel Stamou[1], Mustafa Tabet[1], Robert Ziegler[2]
[1] TU Dortmund, Germany
[2] KIT, Germany

Flavour physics provides an approach to study physics beyond the Standard Model (SM), with many current experiments at flavour factories (BaBar, NA62, ETC) in the hunt for new physics. In this work we focus on the Dark Photon model, a potential dark matter candidate/mediator. With much data available from experimental searches, we study the constraints from 2-body decays on the flavour-violating couplings of the Dark Photon to the SM fermions. A rich phenomenology is present, with an interplay between form factors, data recasts for 2-body decays and different interactions. Moreover, we also consider constraints coming from unitarity. To this end, helicity amplitudes are computed taking into account flavour, massive fermions and a massive Dark Photon. This is quite an involved and interesting calculation, from which the unitarity bounds are obtained and compared to the bounds from 2-body decays.

Tautomeric switching of nitroindazolylacetonitriles mediated by anions

M. Eddahmi, L. Bouissane
Molecular Chemistry, Materials and Catalysis Laboratory, Faculty of Sciences and technics, Sultan Moulay Slimane University, Beni-Mellal, Morocco

Under the context of anion recognition by artificial receptors, it is recognized that the development of simple and sensitive systems for detecting inorganic anions is highly relevant due to their important roles in the environment, industrial and biological processes. [13] Indazole bearing nitro group is an important heterocyclic system to prepare new compounds having different therapeutic and environmental applications by variety of board pathway and conditions. [46] Considering that the abstraction of the acidic proton in N-methyl- nitroindazolylacetonitriles synthetized via vicarious nucleophilic substitution was accompanied by a remarkable color change due to a potential associated tautomerism, we decided to screen the behavior of the nitroindazole derivatives in the presence of different anion species. [7]

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Search for a heavy neutral lepton that mixes predominantly with the tau neutrino

Ori Fogel, Minakhi Nayak, Sourav Dey, Abner Soffer
Tel Aviv University, Belle Collaboration

We report a search for a heavy neutral lepton (HNL) that mixes predominantly with ν_τ. The search utilizes data collected with the Belle detector at the KEKB asymmetric energy e^+e^- collider. The data sample was collected at and just below the center-of-mass energies of the $\Upsilon(4S)$ and $\Upsilon(5S)$ resonances and has an integrated luminosity of 915 fb^{-1}, corresponding to $(836 \pm 12) \times 10^6$ $e^+e^- \to \tau^+\tau^-$ events. We search for production of the HNL (denoted N) in the decay $\tau^- \to \pi^- N$ followed by its decay via $N \to \mu^+\mu^-\nu_\tau$. The search focuses on the parameter-space region in which the HNL is long lived, so that the $\mu^+\mu^-$ originate from a common vertex that is significantly displaced from the collision point of the KEKB beams. Consistent with the expected background yield, one event is observed in the data sample after application of all the event-selection criteria. We report limits on the mixing parameter of the HNL with the τ neutrino as a function of the HNL mass.

CP asymmetries in B meson two-body baryonic decays

Xiang-Nan Jin
Hangzhou Institute for Advanced Study, UCAS, China

We study the CP-odd and CP-even observables of the B mesons decaying into a baryon and antibaryon. We estimate these observables through the $^3P_0$ model and chiral selection rule. The decay branching ratios of $B^+ \to p\overline{\Lambda}$ and $B^0 \to p\overline{p}$ are calculated to be $(2.31 \pm 0.69) \times 10^{-7}$ and $(1.27 \pm 0.38) \times 10^{-8}$, which are consistent with the current experiments, respectively. The effects of the $B - \overline{B}$ oscillations are considered, which largely suppress the direct CP asymmetries in the B_s^0 decays. We suggest the experiments to visit $B_s^0 \to \Lambda(\to p\pi^-)\overline{\Lambda}(\to \overline{p}\pi^+)$, where the time-averaged CP-odd observables are estimated to be large. The direct CP asymmetries of $B^+ \to p\overline{\Lambda}$ and $B^0 \to p\overline{p}$ are found to be $(26.2 \pm 7.9)\%$ and $(-3.1 \pm 0.9)\%$ for a positive strong phase and $(-36.9 \pm 11.1)\%$ and $(4.2 \pm 1.3)\%$ for a negative strong phase, respectively.

Study on Charmed Baryon Weak Decays

Chia-Wei Liu
Tsung-Dao Lee Institute, Shanghai Jiao Tong University

The investigation into charmed baryon decays has attracted significant theoretical interest, driven by advancements in experiments. However, to date, there are no known reliable methods to calculate them from first principles, as the charm quark is neither heavy nor light enough. We adopt two approaches here: for the inclusive decays, we test the applicability of the heavy quark expansion; for the exclusive ones, we utilize the SU(3) flavor symmetry.

Measurement of $|V_{ub}|$ via inclusive semi-leptonic B decays at Belle II

Tommy Martinov, Martin Angelsmark, Florian Bernlochner, Lu Cao, Merle Graf-Schreiber, Marcel Hohmann, Munira Khan, Kerstin Tackmann, Phillip Urquijo
Belle II

The Belle II detector placed at the SuperKEKB collider in Japan aims at studying heavy flavour physics through electron-positron collisions at a center-of-mass energy of 10.58 GeV ($\Upsilon(4S)$ resonance). At Belle II, B-meson decays can be studied with high precision and in particular semi-leptonic decays to a hadron, a lepton and a neutrino. In this context, when the hadron contains an up quark ($B \to X_u \ell \nu$), the CKM-matrix element $|V_{ub}|$ can be measured. However, this process is overwhelmed by the much more likely decay to a hadron containing a charm quark ($B \to X_c \ell \nu$) and therefore background suppression is one of the most important aspects of such an analysis. We use 420 fb^{-1} of data collected by the Belle II detector to measure the $B \to X_u \ell \nu$ branching fraction inclusively, i.e. without explicitly putting any requirements on the hadronic system X_u. Eventually, the magnitude of $|V_{ub}|$ is extracted.

Finding Intrinsic Charm in Inclusive Beauty Decays

Ilija S. Milutin[1], Thomas Mannel[1], K. Keri Vos[2]
[1] Universitt Siegen, Germany
[2] Maastricht University, The Netherlands

The Heavy Quark Expansion (HQE) has become the major tool to perform precision calculations for inclusive rates and spectra of heavy hadron decays. With this method, the CKM matrix element V_{cb} has been extracted with incredible percent-level precision from moments of the inclusive semileptonic $B \to X_c \ell \bar{\nu}$. The HQE is an expansion in powers of the inverse mass of the heavy quark $1/m_b$ and introduces HQE matrix elements, containing the nonperturbative long-distance effects, which can be extracted from data.

To further increase precision, we have to include even higher order terms in the expansion and therefore we recently pushed the expansion to $1/m_b^5$. We focused specifically on the reparametrization invariant (RPI) dilepton invariant mass q^2 moments of the spectrum, which depend on a reduced set of HQE parameters. Therefore, we determined the RPI HQE parameters at $1/m_b^5$.

Specifically, at dimension eight, i.e. $1/m_b^5$, "intrinsic charm" (IC) contributions proportional to $1/(m_b^3 m_c^2)$ enter, which are numerically expected to be sizeable and therefore interesting for improving the theoretical predictions for $B \to X_c \ell \bar{\nu}$. We showed how the "intrinsic charm" and "genuine" $1/m_b^5$ contribute to the q^2-moments of $B \to X_c \ell \bar{\nu}$. Consequently, we found that the total $1/m_b^5$ contributions may not be as sizeable as initially expected.

Charm mixing and CP violation in $D \to \pi^+\pi^-\pi^+\pi^-$

Jairus Tristan Patoc
University of Oxford, UK

A search for mixing-related CP violation in the charm sector is of great interest. This is because this phenomenon is expected to exist at a very low level in the Standard Model, thus any signal at the current experimental sensitivity could be interpreted as New Physics. Measurements of such parameters can be accessed using phase-space binned techniques using multi-body decays of neutral charm mesons. This poster presents a sensitivity study in measuring charm mixing and CP violation using $D \to \pi^+\pi^-\pi^+\pi^-$, and a first look at prompt data collected by LHCb during Run 2.

The Anatomy of $K^+ \to \pi^+\nu\bar{\nu}$ Distributions

Martin Gorbahn[1], Ulserik Moldanazarova[2], Kai Henryk Sieja[3], Emmanuel Stamou[3], Mustafa Tabet[3]
[1] University of Liverpool, UK
[2] Karaganda Buketov University, Republic of Kazakhstan
[3] Technical University of Dortmund, Germany

The excellent experimental prospects to measure the invisible mass spectrum of the $K^+ \to \pi^+\nu\bar{\nu}$ decay opens a new path to test generalised quark–neutrino interactions with flavour changing $s \to d$ transitions and as such to novel probes of Physics beyond the Standard Model. Such signals can be a consequence of new lepton-number violating or lepton-number conserving interactions, with their interpretations depending on the Majorana versus Dirac nature of the neutrinos. Furthermore, the possible existence of new massive sterile neutrinos can be tested via their distinctive imprints in the invariant mass spectrum. Within the model-independent framework of the weak effective theory at dimension-six, we study the New Physics effects of Majorana and Dirac neutrinos on the differential distribution of $K^+ \to \pi^+\nu\bar{\nu}$ allowing for lepton-number violating interactions and potential new sterile neutrinos. We determine the current and expected future sensitivity on the corresponding Wilson coefficients using the distribution measured by the NA62 collaboration and accounting for expected improvements based on the HIKE experiment. We present single-operator fits and also determine correlations among different type of operators. Even though we focus on $s \to d\nu\nu$ transitions, the operator bases for Majorana and Dirac and the classification of lepton-number-violating/conserving interactions is applicable also for the study of $b \to s/d\nu\nu$ and $c \to u\nu\nu$ transitions relevant in current phenomenology.

Search for $B^0 \to \phi\phi$ decays with the LHCb experiment

Mary Richardson-Slipper, Matthew Needham, Ozlem Ozcelik
The University of Edinburgh (LHCb experiment), UK

Using data collected by LHCb up to 2018, the first dedicated search for $B^0 \to \phi\phi$ decays is being performed. Decays of $B^0 \to \phi\phi$ are rare and highly suppressed. They have never been observed, however the branching fraction of this decay may be enhanced by both standard model and beyond standard model effects. An observation of these decays would be a subtle test of the calculations that are used to predict the branching fraction as the values presented in the literature vary by up to an order of magnitude, from 0.21e-8 to 3e-8. A previous study using LHCb data up to 2016 set the limit on the branching fraction at <2.7e-8 at 90% C.L. In this dedicated analysis, sensitivity to this decay mode is enhanced using a novel method of removing background events that originate from prematurely interacting kaons in the $B^0 \to \phi\phi$ decay. These events contribute significantly to the background present in the signal region of the $B^0 \to \phi\phi$ decay. With this novel background rejection technique and more careful treatment of the other backgrounds present, and utilising the full Run 1 + Run 2 data set, this analysis is anticipated to be a factor of 2 more sensitive than the previous study. This analysis is currently still blinded and we anticipate results before the summer.

Amplitude analysis of $B^0 \to \rho^0 K^{*0}$ decays at CERN's LHCb experiment

Francesca Swystun
University of Cambridge (LHCb Group)

This study concerns an amplitude analysis of $B^0 \to \rho^0(\to \pi^\pm\pi^\mp)K^{*0}(\to K^\pm\pi^\mp)$ decays using the full Run 1 and Run 2 LHCb collision data set. This decay is suppressed at tree level ($b \to u\bar{u}s$ transition), so proceeds also at loop-level (gluonic and electroweak penguins) ($b \to d\bar{d}s$). Interference between these causes CP violation in the decay which can be measured in the CP asymmetry of the polarisation variables. It is an example of a $B \to VV$ decay, where the expected hierarchy in the transversity amplitudes has been found to be violated in penguin decays, referred to as the 'longitudinal polarisation puzzle'. In particular, a measurement using Run 1 data from LHCb found an exceptionally low value for the longitudinal polarisation fraction for $B^0 \to \rho^0 K^{*0}$ decays providing interest in studying this decay mode further. In addition, this analysis looks to make the first observation of the $B_s^0 \to \rho^0 K^{*0}$ decay and measure its branching fraction.

Studies of angular and CP asymmetries in $D^+_{(s)} \to h^+\mu^+\mu^-$ decays at LHCb

Dominik Mitzel, Serena Mascolini, Luca Toscano
TU Dortmund University, Germany

The LHCb experiment has recorded the world's largest sample of charm hadron decays and takes a leading role in measurements of rare decays and searches for CP violation. Rare semi-leptonic charm decays such as $D^+ \to \pi^+\mu^+\mu^-$ and $D_s^+ \to K^+\mu^+\mu^-$ are sensitive to beyond-standard-model effects in flavour-changing neutral current $c \to u\mu^+\mu^-$ transitions. Observables such as angular and CP asymmetries, can be defined to test the Standard Model. Null tests on these observables are performed in the vicinity of intermediate hadronic resonances, where new physics signals can be enhanced. In this talk, the first study of angular distributions and CP asymmetries in $D^+_{(s)} \to h^+\mu^+\mu^-$ decays is presented. The analysis uses data collected by the LHCb detector from 2015 to 2018 at a centre-of-mass energy of 13 TeV, corresponding to an integrated luminosity of 6fb^{-1}.

Sum Rules for Lifetimes

Zachary Wüthrich, Matthew Black, Alexander Lenz
Center for Particle Physics Siegen, University of Siegen, Germany

Precise determination of hadronic matrix elements plays a crucial role for interpreting potential deviations from the Standard Model observed in experiments testing flavor physics. While lattice QCD provides first principles calculations, current results are still limited to a subset of the operators that may appear in theories of new physics. The sum rule approach allows for a complementary determination of matrix elements directly from QCD, with theoretical uncertainties that can be systematically improved order-by-order in perturbation theory. Previous research successfully ascertained Standard Model hadronic matrix elements for dimension-six F=0,2 operators, demonstrating competitiveness with lattice findings. Our aim is to expand upon these findings by including the entire set of four-quark QCD operators for lifetimes, crucial in scenarios Beyond the Standard Model, where lattice results are currently absent. This extension includes operators with Dirac structures not previously examined in sum rules analyses documented in existing literature. This will provide for the first time bag parameter results which can increase the precision of a wide variety of new physics theories. The bag parameter results will be determined using HQET sum rules for three-point correlators, which requires a three-loop computation. In addition there is a one-loop computation of the QCD-HQET matching required.