Quirks in Quark Flavour Physics 2024

Monday, 17 June 2024 - Friday, 21 June 2024

Book of Abstracts

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Signatures of Light New Particles in $B \to K^{(*)} E_{\rm miss}$

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Motivated by the remarkable Belle II experimental result on $B \to K\, E_{\rm miss}$, and phenomenological difficulties in accommodating it exclusively in terms of processes with SM neutrino final states, we systematically investigate possibilities that $E_{\rm miss}$ comes not only from the SM neutrinos but also from other light undetected particles. We consider both single scalar or vector particle final states, as well as pairs of scalars, spin $1/2$ or $3/2$ fermions, and vectors, following the approach of Kamenik and Smith [JHEP 03 (2012) 090]. Since several of these possibilities significantly alter the phase space and kinematical distributions of events in the experiments, we consider not only the branching fractions of $calB(B \to K^{(*)} E_{\rm miss})$ but also all available event distributions presented in the Belle II and BaBar analyses, and construct our own likelihood for different NP scenarios using the data from both processes.

Day 1 / 2

ATLAS B-physics highlights from Run2/3 and strategies for HL-LHC

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ATLAS B-physics analysis exploit low and medium momenta leptons and hadrons, combined in trigger signatures, adapting with levels of instantaneous luminosity during LHC spills. The dedicated trigger strategies over Run2 and Run3 lead to collect data allowing high precision tests of HF phenomena, covering: rare decays, high precision measurements in CKM favoured B-hadron decays and HF production mechanisms in central p-p LHC collisions. ATLAS has prepared trigger and offline strategies to continue B-physics program in HL-LHC and to benefit from upgraded ATLAS detector.

Day 2 / 3

Scalar leptoquarks in flavour physics

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We reinvestigate contributions of scalar leptoquarks in
anomalies and in

decays. Then, we update the constraints on parameter space and find which scalar leptoquarks remain viable and consistent with low-energy and high-energy flavour physics constraints. We comment on the implications of such selection.

Day 1 / **4**

LHCb. anomalies, power corrections to inclusive modes and refactorisation

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The present LHCb anomalies in the post-R_K^* era are obscured by still unknown power corrections to these exclusive modes. The method of refactorization is an option to solve this problem in the long run. We present a successful example of the these new techniques in SCET within the power corrections to the inclusive $\bar{B} \to X_s\gamma$ decay. Another option is the crosscheck with the corresponding inclusive modes at BELLE-II. The uncertainties due to the nonlocal so-called resolved contributions are still among the largest ones of these modes. We discuss the α_s corrections to these contributions in SCET which will reduce their large scale and large charm mass dependence and will significantly increase the new physics sensitivity of the inclusive penguin modes.

Day 2 / **5**

On the potential of Light-Cone Sum Rules without Quark-Hadron Duality

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The calculation of local form factors involved in the SM predictions of semileptonic B-meson decays at low-q^2 is a crucial ingredient in the assessment of the B-anomalies.
We revisit their calculation in QCD Light-Cone Sum Rule with B-meson Light-Cone Distribution Amplitudes. In our strategy, we bypass the quark-hadron duality (QHD) approximation which usually contributes an unknown and potentially large systematic error to the prediction of form factors. We trade this improvement for an increased reliance on higher-order contributions in perturbation theory. Unlike the systematic error from QHD, truncation errors are assessable and systematically improvable, hence allowing robust predictions of form factors.

Day 4 / **6**

Optimized Observables in non-leptonic decays

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We study the penguin-mediated $\bar{B}_{d(s)} \to K^{(*)0}\bar{K}^{(*)0}$ and $\bar{B}_{d(s)} \to \bar{K}^{*0}(K^{*0})\phi$ transitions. We propose optimised observables $L_{K^{(*)}\bar{K}^{(*)}}$, $L_{K^*\phi}$ from the ratio of longitudinal branching ratios of these decays, with limited hadronic uncertainties and enhanced sensitivity to New Physics. $L_{K^{(*)}\bar{K}^{(*)}}$ deviates at the 2.4σ (2.6σ) level while $L_{K^*\phi}$ exhibits a deviation at the $1.48\,\sigma$ level between its experimental value and its SM determination within QCD factorisation. These results can be accommodated together, if New Physics is assumed to affect either the QCD penguin operator Q_4 or the chromomagnetic dipole operator Q_{8g} for both $b \to d$ and $b \to s$ transitions. The allowed range for the Wilson coefficients $C_{4s,8gs}$ is narrower compared to $C_{4d,8gd}$ since the $b \to s$ transition $\bar{B}_d \to \bar{K}^{*0}\phi$ is in better agreement with the SM. If we add the measured branching ratio for the $\bar{B}_d \to \bar{K}^0\phi$ to our analysis, the simultaneous explanation of all the experimental data for the $K^{(*)}\bar{K}^{(*)}$ and the $K^*(\bar{K}^{(*)})\phi$ channels in terms of New Physics in $C_{4d,s}$ or $C_{8gd,s}$ operators only becomes very constrained. This set of observables can be explained more easily if we assume New Physics either in (C_{4f}, C_{6f}) or (C_{6f}, C_{8gf}) in both $f = d, s$. This should provide a strong incentive for the LHCb experiment to perform a measurement of the branching ratios of $\bar{B}_d \to \bar{K}^{(*)0}\phi$ and an improved measurement for the branching ratio of $\bar{B}_s \to K^{*0}\phi$

Day 1 / 7

Indirect constraints on third generation baryon number violation

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Given the flavour anomalies, one might speculate that baryon number violation involving third family quarks could happen at a much lower scale than the GUT scale. In this talk I will describe how to constrain baryon number violating operators involving a bottom quark from proton lifetime bounds. As a result one can estimate the maximum branching fraction expected in baryon number violating B decays, turning out to be far from current sensitivities at B-factories. This in fact discourage direct experimental searches of baryon number violation in B decays.

Day 4 / 8

Gradient Flow Renormalisation for Meson Mixing and Lifetimes

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Neutral meson mixing and meson lifetimes are theory-side parametrised in terms four-quark operators which can be determined by calculating weak decay matrix elements using lattice QCD.

While calculations of meson mixing matrix elements are standard, determinations of lifetimes typically suffer from complications in renormalisation procedures because dimension-6 four-quark operators can mix with operators of lower mass dimension and, moreover, quark-line disconnected diagrams contribute.

We outline the idea to use fermionic gradient flow to first non-perturbatively renormalise matrix elements describing meson mixing or lifetimes and subsequently combining these results with a perturbative calculation to match to the $\overline{\text{MS}}$ scheme.
Early results at the D_s mass scale will be shown and compared to literature for both D_s lifetimes and short distance effects in neutral D mixing.
Future prospects towards the B scale will also be discussed.

Day 1 / **9**

Theoretical status and prospects in inclusive semileptonic beauty and charm decays

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In this talk, I will discuss the current status and prospects in inclusive semileptonic beauty and charm decays from the theoretical side. I will introduce the open-source package Kolya, developed to predict inclusive beauty semileptonic rates within the SM and beyond. I will discuss the status of the Vcb determinations from semileptonic inclusive B decays using all available data. I will discuss briefly the prospects for Bs inclusive measurements at LHCb and discuss some progress on the determination on Vub. Finally, I will discuss what happens once the HQE is applied to charm decays, for which it is not originally developed and the prospects for testing the HQE in the charm sector at BESIII.

Day 1 / **10**

Quark-Hadron Duality Violation and Higher Order $1/m_b$ corrections in inclusive $B \to X_c \ell \bar{\nu}$

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

To further increase the theoretical precision, we recently pushed the expansion to $1/m_b^5$. Specifically, at $1/m_b^5$, "intrinsic charm" (IC) contributions proportional to $1/(m_b^3 m_c^3)$ enter, which are numerically expected to be sizeable. % We focused on reparametrization invariant (RPI) observables, which depend on a reduced set of HQE parameters.

I will show how the $1/m_b^5$ contribute to the q^2 moments of $B \to X_c \ell \bar{\nu}$ decays. We found that the total $1/m_b^5$ contributions may not be as sizeable as expected. I will discuss how this may impact a future inclusive V_{cb} determination.

Notably, all theoretical calculations are done in terms of quarks and gluons, while experimentally they are never detected individually, only as hadrons. Under certain conditions, Quark-Hadron Duality allows us to connect theoretical predictions and experimentally observed quantities.

Motivated by the increased accuracy in inclusive $B \to X_c \ell \bar{\nu}$ predictions, we try to model the effects of Quark-Hadron Duality Violation (QHDV). In this talk, I will show how we define QHDV, derive a model for QHDV based on the known behaviour of $B \to X_c \ell \bar{\nu}$ decays up to $1/m_b^5$, and finally how it impacts different kinematic moments of $B \to X_c \ell \bar{\nu}$ decays.

Day 2 / **11**

$B_c \to \eta_c$ form factors at large recoil: interplay of soft-quark and soft-gluon double logarithms

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Exclusive B-decays provide valuable insights into physics beyond the Standard Model and measurements of Standard Model parameters. At large hadronic recoil Soft-Collinear Effective Theory is the appropriate theory to describe the QCD dynamics of heavy-to-light transitions and to resum logarithmic corrections to all orders in perturbation theory. However, since the relevant hadronic matrix elements are power suppressed, the factorisation of soft and collinear contributions is spoilt by endpoint divergences. We therefore resort to diagrammatic resummation techniques to derive the double-logarithmic series of the "soft-overlap"contribution to $B_c \to \eta_c$ transition form factors, assuming the scale hierarchy $m_b \gg m_c \gg \Lambda_{\rm QCD}$. We find that the leading double logarithms arise from a peculiar interplay of soft-quark "endpoint logarithms"from ladder diagrams with energy-ordered spectator-quark propagators, as well as standard Sudakov-type soft-gluon corrections. We elucidate the all-order systematics, and show that their resummation proceeds via a novel type of integral equations.

Day 4 / **12**

Non-leptonic B anomalies - a view from the top

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Over the last few years, a puzzling discrepancy in the non-leptonic B to D plus light meson decays has arisen, with large tensions between experimental measurements and theory prediction from QCD factorisation.
In this talk, I will summarise the current state of these discrepancies, discuss EFT models that would reduce the discrepancies, and then show how recent LHC measurements of top quark properties are now competitive with low energy flavour measurements, and as such the benefits of analysing these discrepancies from the "top".

Day 1 / 13

$O_1 - O_7$ resolved-photon contribution to $B \to X_s\gamma$ at $\mathcal{O}(\alpha_s)$

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The inclusive radiative decay mode $B \to X_s\gamma$ provides an important channel for new physics searches.
When the photon energy is large, $m_b - 2E_\gamma \sim \mathcal{O}(\Lambda_{\rm QCD})$, methods from soft-collinear EFT can be used to construct a systematic heavy-quark expansion.
In this talk, I will discuss how to include $\mathcal{O}(\alpha_s)$ corrections to the power-suppressed resolved-photon contribution from the $O_1 - O_7$ interference.
The perturbative scale uncertainty from this term makes up a large portion of the error budget of this process, which is expected to significantly reduce after taking into account radiative corrections.

Day 4 / 14

Flavour anomalies, leptoquarks, renormalisation group fixed-points, and collider physics

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Leptoquark (LQ) interactions can explain the deviations between $b \to c\tau\bar{\nu}$ and $b \to s\ell^+\ell^-$ data and Standard-Model predictions.These particles are motivated by theories with quark-lepton unification which must occur at a much higher scale M_{QLU} than the masses of the leptoquark invoked to explain the flavour anomalies. The presence of such a mass gap offers the opportunity to study LQ properties from renormalisation group effects. I present infrared fixed-point solutions for leptoquark couplings and discuss their implications for flavour anomalies and collider searches. Then I present new results on radiative corrections which render the LQ couplings probed at low and high energy different.

Day 1 / 15

Heavy sterile Neutrinos from B decays and new QCD corrections to their semi-hadronic decay rates

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In modern experiments on flavour physics it is possible to search for the decays of B's, D's, or τ's into final states with heavy neutrinos N (a.k.a. heavy neutral leptons). I present a common study of theorists and experimentalists from Belle II on constraints on $B \to D^* \ell N$. Next I discuss the status of the theory predictions of the various N decay rates. In scenarios in which N interacts with SM particles only through sterile-active neutrino mixing, the dependence of
the lifetime on the relevant mixing angles is important to determine whether N decays in the detector or outside. To calculate the inclusive decay rate into semi-hadronic final states reliably one needs to include radiative QCD corrections. I present analytic results for the QCD-corrected decay rates and discuss their phenomenological impact.

Day 4 / **16**

beta function, Lambda parameter and more

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Exploiting the relation between real-space Wilsonian renormalization group transformations and gradient flow, we show how to determine the β function and obtain the QCD Λ parameter. Moreover, we use this framework to develop a novel nonperturbative renormalization scheme for local operators. We demonstrate our method using nonperturbative results based on simulations with $N_f = 2$ stout-smeared Möbius domain-wall fermions and Symanzik gauge action.

Day 2 / **17**

Exploring semileptonic $B_s -> D_s^*$ decays

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Semileptonic $B_{(s)}$ decays are of great phenomenological interest and allow to extract the CKM matrix elements or test lepton flavor universality.
We explore $B_{(s)}$ decays with vector final states by studying $B_s \to D_s^*$ using the narrow width approximation. Taking advantage of existing data we present first results for the form factors using our setup based on RBC-UKQCD's 2+1 flavor domain-wall fermion and Iwasaki gauge field action. Light quarks are simulated with domain-wall fermions, whereas bottom quarks are simulated with the relativistic heavy quark (RHQ) action.

Day 1 / **18**

Unbinned analyses of $B^0 \to K^{*0} \mu^+ \mu^-$

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The LHCb experiment has produced many intriguing results presenting tensions with respect to the Standard Model. These anomalies point towards potential contributions from New Physics. In particular, the anomalies observed in the decay $B^0 \to K^{*0}\mu^+\mu^-$ motivate unbinned analyses in dimuon invariant mass squared (q^2), where more information about the decay can be extracted. This talk will present an overview of the so-called 'z-expansion'amplitude analysis where Wilson coefficients and non-local hadronic contributions are directly measured in data, in addition to an amplitude analysis which corresponds to a quasi-model-independent measurement of the q^2 dependence of the transversity amplitudes.

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CP-odd observables in B –> P l l

Author: Nejc Košnik[1]

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We consider the combined measurements of CP-averaged decay rates and direct CP asymmetries of B±⟶K±ℓ+ℓ− and B±⟶π±ℓ+ℓ− to probe (non-local) four-quark operator matrix element contributions to rare semileptonic B meson decays. We also explore how their effects could be in principle disentangled from possible local new physics effects. We construct a ratio of CP-odd decay rate differences which are exactly predicted within the standard model in the U-spin limit. Our results motivate binned measurements of the direct CP asymmetry in B±⟶π±ℓ+ℓ− as well as dedicated theoretical estimates of U-spin breaking both in local form factors as well as in four-quark matrix elements.

For B ⟶ K mumu we show that possible NP phase in C9 Wilson coefficient can be tested by measuring the direct CP-asymmetry. We show that this asymmetry is enhanced around the peak of each ccbar-resonance, and in fact more pronounced in the close vicinity of J/ψ and ψ(2S). Therefore, measuring ACP below and above the resonances' peak could be revelatory of the CP-violation that originates from beyond the Standard Model, or to be a significant constrain when building a realistic scenario of New Physics.

Day 1 / **20**

Measurements of $B^0 \to K^{*0}\mu^+\mu^-$ and $C_{9\tau}$ at LHCb.

Author: Eluned Smith[1]

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The $B^0 \to K^{*0}\mu^+\mu^-$ decay is mediated via the rare flavour changing neutral current transition $b \to s\ell^+\ell^-$. The suppression of this decay in the Standard Model (SM) means virtual new physics (NP) contributions can have a large impact, and previous measurements of the decay have shown interesting tensions with the SM predictions at the level of $\sim 3\sigma$. The theoretical interpretation of these anomalies is difficult due to the uncertainties from nonlocal SM contributions which could

mimic NP effects. This talk discusses recent results from the LHCb collaboration which uses the data itself to constrain the size of the nonlocal contributions to the $B^0 \to K^{*0}\mu^+\mu^-$ decay rate, using the full dimuon spectrum. The first direct measurement of the short-distance $bs\tau\tau$ vector coupling, $C_{9\tau}$ is also presented, as well as prospects for the binned analysis of $B^0 \to K^{*0}\mu^+\mu^-$.

Day 2 / 23

”Are there quirks in the $D \to \pi\ell^+\ell^-$ decays ?”

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Our ability to trace new physics in the $c \to u\ell^+\ell^-$ transitions
by measuring the $D \to \pi\ell^+\ell^-$ decay width
critically depends on the accurate knowledge of this decay amplitude,
dominated by an overlap of a singly Cabibbo suppressed weak decay and
electromagnetic lepton pair emission.
We calculate this amplitude, combining LCSRs with
hadronic dispersion relation, and present our preliminary results for the
differential width. We also demonstrate that an additional knowledge
can be gained, measuring Cabibbo favoured and doubly suppressed
$D_{(s)} \to P\ell^+\ell^-$ modes ($P = \pi, K, \eta$) which share common hadronic dynamics with
$D \to \pi\ell^+\ell^-$ and are also related to the latter by the U-spin
symmetry.

Day 2 / 24

Constraining the level of direct CP violation in charm-meson two-body decays

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The study of charm-quark-related phenomena is a cornerstone of the flavour physics programme, as it offers unique opportunities to test the Standard Model and to explore different new physics scenarios. The observation of the CP asymmetries in the decays of neutral charm mesons to two light pseudoscalars by LHCb imposes up to date a question without a definite answer. In previous work we calculated the effect of final-state interactions on the decay amplitudes with the use of dispersion relations in order to predict the CP asymmetries and concluded that the latter fall short of the experimental measurements. In this work we explore further the hypothesis of the isospin-zero rescattering being limited to the pion and kaon pairs and avoid the implementation of rescattering input with high uncertainties. We find that with only the total strong phase of the two channels as input for the dispersion relations we still derive upper bounds on the CP asymmetries which do not reach the observed levels.

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Welcome to Quirks 2024!

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Day 2 / **26**

Semileptonic charm decays in the Weak Effective Theory

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The available data on exclusive $c \to s\ell\nu$ decays is analysed for three main purposes. First, a study of the relevant hadronic matrix elements is performed using dispersive bounds, resulting in theoretical predictions of observables which can be confronted with experimental results. Then, a combined Bayesian analysis of the experimental data is done for the extraction of the CKM element V_{cs} in the SM. Lastly, these decays are fitted in the Weak Effective Theory such that we can compare the favourability between SM and BSM dynamics and provide the resulting phase space for the WET coefficients.

Day 2 / **27**

Nonepertubative QCD in D0-D0bar mixing

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Neutral charm meson mixing has first been observed in 2007 by Belle and Babar and soon after confirmed by LHCb and CDF. A longstanding discrepancy, of multiple orders of magnitude, is present between the leading order theoretical calculation of the so-called box diagram and the world average experimental value. The leading order theoretical value is extremely small due to the GIM mechanism which heavily suppresses the contribution. Efforts have been made to calculate the mixing by including higher order terms and nonperturbative contributions which, even though they are suppressed in the OPE, might bring about a higher final value due to breaking of SU(3), i.e. having less effective GIM cancellation. In this talk I present preliminary results of our inclusive approach to calculating the D-Dbar mixing parameter.

Day 1 / **29**

Comments on B anomalies

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Day 4 / **30**

Progress in inclusive $B \to X_s \ell\ell$ phenomenology

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In this talk I will summarize the theory and phenomenology status of the inclusive penguin decay $B \to X_s \ell\ell$. In the high-q^2 (soft recoil) region above the narrow charmonium resonances, the inclusive rate is dominated by two exclusive modes $B \to K^{(*)} \ell\ell$. I will explain that this property of the spectrum provides an opportunity to apply the toolkit of inclusive B decays to results from LHCb as well as the B factories. I will also present a study of the hadronic mass cut dependence of the rate and forward backward asymmetry at low-q^2, and discuss different strategies for normalizing the neutral-current decay to charged-current B decays.