Sascha Stahl

Personal

Birth **25th February 1985**, *Bad Kreuznach, Germany*.

Nationality **German**.

Employment history

11/2014– **Marie Curie COFUND CERN fellow**, *CERN*.

Responsibilities

01/2016– **Convener of the subgroup "CPV, mixing and b-hadron properties" within the Semileptonic working group of LHCb**, *the Semileptonic working group at LHCb studies b-hadron decays with one lepton in the final state*.

04/2016– **Deputy project leader of the LHCb Software trigger project**, *the LHCb software trigger is a vital part of the LHCb data acquisition and has continuously extended the physics reach of LHCb*.

11/2014– 04/2016 **Responsible for the reconstruction of the LHCb software trigger**, *during which time I tuned and commissioned the software trigger reconstruction to be equivalent to the offline-quality reconstruction for the first time.*.

Awards

09/2016 **LHCb Early Career Scientist award**, *"For having implemented and commissioned the revolutionary changes to the LHC Run-2 high-level-trigger (HLT), including the first widespread deployment of real-time analysis techniques in High Energy Physics. ..."*, LHCb Collaboration prizes.

Studies and PhD

09/2010– 07/2014 **PhD in physics**, *Ruprecht-Karls Universität Heidelberg*, Heidelberg, grade: summa cum laude (with highest distinction).

07/2014 **PhD thesis**, under the supervision of Prof. Dr. Stephanie Hansmann-Menzemer in the LHCb group of the Physikalisches Institut in Heidelberg.
Title: "Measurement of CP asymmetry in muon-tagged $D^0 \to K^-K^+$ and $D^0 \to \pi^-\pi^+$ decays at LHCb".

04/2005– 06/2010 **Diploma in physics**, *Ruprecht-Karls Universität Heidelberg*, Heidelberg, Germany, Grade: sehr gut (very good).

05/2010 **Diploma thesis**, under the supervision of Prof. Dr. Stephanie Hansmann-Menzemer in the LHCb group of the Physikalisches Institut in Heidelberg.
Title: "Reconstruction of displaced tracks and measurement of K_s production rate in proton-proton collisions at $\sqrt{s} = 900$ GeV at the LHCb experiment".

Talks

07/2015 **EPS-HEP 2015**, *Vienna, Austria*, "The LHCb Higher Level Trigger in Run II".

01/2015 **Particle Physics Seminar**, *Bonn, Germany*, "Measurements of CP asymmetries in charm decays at LHCb".

11/2014 **Graduation ceremony**, *Selected speaker by the Combined faculties for the Natural Sciences and Mathematics of the Heidelberg University*, "Teilchen und Antiteilchen, warum und wie messe ich den Unterschied?".

03/2013 **Rencontres de Moriond QCD 2013**, "Properties of b and c hadrons at LHCb".

03/2010 **Rencontres de Moriond EW 2010**, *Talk in the Young Scientists Forum*, "Tracking performance in V0 reconstruction with first data at LHCb".

Scholarships

09/2010–02/2013 **International Max Planck Research School for Precision Tests of Fundamental Symmetries in Particle Physics, Nuclear Physics, Atomic Physics and Astroparticle Physics at the University of Heidelberg**, *Max-Planck–Institut für Kernphysik*, Heidelberg.

Teaching and Supervision

During my undergraduate and graduate studies I tutored courses in experimental and theoretical physics.
I have supervised 3 bachelor and summer students, 1 master student and closely followed 2 PhD students working on a variety of topics.
In my role as HLT deputy project leader I coordinate the work of a core team of around 5 post-docs.

Research activities

I started my career in high energy physics as a master student in 2009 at a very exciting time when the LHCb experiment was about to start taking data. During my masters thesis I improved a pattern recognition algorithm dedicated to the reconstruction of very displaced tracks. I used the algorithm to reconstruct the first K_S^0 signals and was among the main authors of the first LHCb publication [1]. My contribution was rewarded by the collaboration with a talk in the Young Scientists Forum at Rencontres de Moriond EW in 2010. I also contributed to the first LHCb measurement of prompt charm production at $\sqrt{s} = 7$ TeV in the forward region [2], being responsible for the evaluation of detection efficiencies and data-simulation discrepancies. These were particularly important since a cross-section measurement requires the knowledge of absolute, not relative, efficiencies.

I started my PhD in September 2010. The first B-physics analyses were the measurements of B-meson mixing and CP violation in mixing. Together with one post-doc and two other PhD students from the Heidelberg group, we measured the mixing frequencies Δm_d and Δm_s, the latter with the highest precision at this time [3]. Afterwards, I contributed to the measurement of the mixing phase ϕ_s. I studied the decay-time acceptance and the decay-time resolution which were crucial inputs to the multi-dimensional fit in the decay-time and angular observables [4].

To work full speed on my thesis topic I moved to CERN in 2012. In November 2011 the LHCb experiment had reported evidence of direct CP violation in the decay of charm mesons in the modes $D^0 \to K^-K^+$ and $D^0 \to \pi^-\pi^+$. This came as a surprise as it deviated from the Standard Model predictions. Together with two colleagues we came up with the novel idea to cross-check the result on an independent data sample, namely exploiting D mesons from semileptonic B decays. I developed independent measurements for detection and reconstruction asymmetries which was the main challenge of the CP asymmetry measurement. The analysis, which did not confirm the original signal, was followed with a lot of interest by the collaboration and was one of the most scrutinized LHCb analyses. I was the contact person for the internal review process and the analysis was published in [5, 6]. In parallel to my analysis activities I joined the High Level Trigger team and was one of the core people charged with ensuring the smooth running of the trigger at the restart of the data taking in spring 2012. I profited from my background in track reconstruction, tuning reconstruction and track quality criteria in order to optimize the efficiency of physics signals given the computing requirements.

In 2013 the preparation of the LHCb upgrade entered an important phase. I was asked to contribute to a task force to setup the reconstruction sequence in the simulation. My work was crucial to make the first fundamental design choices for the novel tracking detectors.

I graduated in June 2014 with distinction. I had the pleasure to be selected to give the presentation at the graduation ceremony for all natural sciences.

I started my 3 year post-doc position as COFUND CERN-fellow in fall 2014, at the end of the first long shutdown of the LHC in which the LHCb experiment underwent a paradigm shift. The detector became the first ever High Energy Physics detector to be aligned, calibrated, and fully reconstructed in real-time. Within this novel system, the software trigger decides not only which events are kept, but also which part of the event information is stored to save bandwidth to offline storage [7]. The development of this system was crucial ingredient not only for the Run 2 LHCb physics programme, but also as a proof-of-principle for the full software trigger of the upgraded LHCb experiment in Run 3.

My personal role was to develop, configure and commission an online reconstruction which matches the performance of the previous offline reconstruction. I studied the feasibility of the entire concept and led the efforts to convince the LHCb collaboration of the merits of the approach. This included not only the tracking reconstruction but also the calorimeter, muon, and Cherenkov detector reconstructions. As part of this work, together with a PhD student, I deployed a deep neural network to improve the rejection of fake combinations in the pattern recognition, improving efficiency, fake rate, and timing at the same time. This is the first application of a deep neural network in the charged particle reconstruction of any LHC experiment. I also helped optimize many specific trigger selections such that they exploit the potential of the new reconstruction, which is crucial in an era where specific particle decays have to be triggered and fully selected in real-time.

Since 2016 I am deputy project leader of the LHCb software trigger, responsible for leading an enthusiastic team of several PhD students and post-docs. My team is primarily in charge of consolidating and developing the Run 2 trigger, which involves continuously monitoring the trigger performance, validating new trigger lines when they are added, and continuing to optimize and speed up the reconstruction. Because of the scale of the problem, involving hundreds of trigger lines which must operate in parallel without interfering with each other, it is critical to automate as much as possible the process of designing and testing trigger lines and the reconstruction. I am particularly focused on this, but I have also continued to make contributions to the optimization of the LHCb upgrade reconstruction and the preparations for Run 3, in particular in the development and testing of the charged particle reconstruction.

I am currently pursuing several analyses, with the objective both of extending our knowledge of fundamental parameters of the Standard Model and searching for New Physics, and of broadening my own knowledge of physics. This work has also allowed me to gain experience in supervising students, which I greatly enjoy. During the restart of the LHC in 2015 at the new centre-of-mass energy I initiated the analysis of two-particle correlations produced in proton-proton collisions, a topic studied by all experiments at the LHC, giving insight to the mechanisms of hadronization and collective effects in a dense environment. This summer student project quickly showed promising results [8], and the analysis should be published in the coming months. I am also supervising a masters student in measuring the production asymmetry of Λ_b baryons, which will let us better understand the dynamics of heavy-quark production in proton-proton collisions. Again the analysis is mature and approaching publication.

In parallel, and complementary to my previous work on direct CP-violation measurements in the charm system, I am collaborating on measuring the charm-mixing and CP-violation parameters with the so-called golden mode $D^0 \to K^0_S\pi^+\pi^-$, which is unique in giving direct access to both the charm mixing parameters (width- and mass-splitting) and the parameters of possible CP-violation in charm mixing ($|q/p|$ and the weak phase ϕ). The efficiency to trigger and reconstruct this channel more than doubled due to my work on improving the software trigger. A crucial difficulty of performing a precise measurement is the knowledge of the Dalitz distribution of the three-body final state, because it is exactly the interference of the different resonant decay amplitudes which allows the mixing and CP-violating observables to be measured. Traditionally this required the modelling of the different resonant contributions, which is hard not simply because you have to invent a model which fits the data, but also because of the computational cost of fitting such a multi-dimensional model to tens of millions of signal events. Together with a team of postdocs I am currently implementing a novel analysis procedure which allows the measurement to be performed in a model-independent way, greatly reducing both systematic uncertainties and the computational cost of the measurement.

Finally, I am currently convening one of the subgroups of the top-level Semileptonic working group of LHCb. As convener, I am responsible for following all analyses carried out within the working group (4 in the last twelve months), reviewing the internal analysis documentation, and deciding when it is mature enough to proceed to the next stage of collaboration review. I am particularly focused on using my expertise in the measurement of detector efficiencies and asymmetries to improve the sensitivity of all the physics measurements performed within my group. Many individual analyses have developed tools to measure such efficiencies and asymmetries, and in common with my work on the trigger I am guiding them to make these tools usable by the whole collaboration, by combining their best features, developing automatic tests and documentation, and making sure that new students and analysts are aware of these tools and use them.

Geneva, November 16, 2016

The current understanding of fundamental interactions and elementary particles is summarised in the Standard Model of particle physics. Its highly accurate predictions have been challenged by many experiments, no significant discrepancy has been observed. At the same time, there are phenomena in nature which are not described by the Standard Model. It does not include a description of gravity; it accounts only for about $5\,\%$ of the energy content in the universe, the rest being called dark matter and dark energy due to their unknown origin; and the Standard Model alone has no explanation for the evolution of the universe from the Big Bang to its current state. In summary, the Standard Model is an incomplete description of physical reality.

Physics beyond the Standard Model can be probed by directly discovering unknown particles, or by measuring deviations from predictions in the behaviour of Standard Model particles. The latter approach is particularly powerful as particles which are not directly produced in our current experiments can nevertheless lead to quantum corrections in particle-antiparticle oscillations or decays of Standard Model particles. The Standard Model concretely predicts that particle-antiparticle oscillations occur at almost exactly the same rate in the mixing of B_d^0 and B_s^0, with the difference being below the 10^{-3} level [9]. Quantum interference effects with particles, too heavy to be produced by other means but predicted in plausible extensions of the Standard Model, can increase this asymmetry to a few parts per thousand.

A measurement of these parameters by the DØ collaboration generated a lot of interest as it reported a 3σ deviation from the Standard Model [10]. Recent measurements of this quantity by LHCb in the semileptonic decays of B_d^0 and B_s^0 mesons have reached the 10^{-3} level [11, 12], without observing any sign of deviation from the Standard model, as shown in Figure 1.

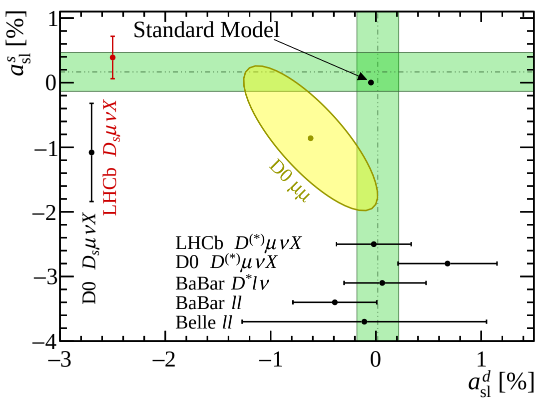

Figure 1: Overview of the most precise measurements of a_{sl}^d and a_{sl}^s. Figure taken from [12].

With the data LHCb will collect in Run 2 of the LHC and after its upgrade in LHC Run 3, where the instantaneous luminosity will be increased by a factor of five, the LHCb experiment will improve the precision by an order of magnitude. With this the measurement of particle-antiparticle asymmetries in the mixing of B_d^0 and B_s^0 LHCb will probe mass scales of $\mathcal{O}(1\mathrm{TeV})$ or $\mathcal{O}(10\mathrm{TeV})$ for tree or loop level corrections, respectively [13], complementing and going beyond the reach of direct discovery available at the LHC.

As an ILP fellow, I will both carry out the most precise measurements of these quantities using Run 2 data, and develop the infrastructure needed to perform these measurements using Run 3 data, thus enabling the LHCb experiment to reach its full potential in probing the validity of the Standard Model. As the sole convener of the relevant physics working group on LHCb and the deputy trigger project leader, I am uniquely qualified to carry out this work. In particular, measurements of particle-antiparticle asymmetries below the 10^{-3} level require an order of magnitude improvement in our understanding of detector efficiencies and asymmetries, and I will leverage my proven expertise and leadership on these topics to achieve this. Due to their indirect nature, measurements of quantum corrections need a theoretical interpretation and only the combination of many different measurements reveals which extensions of the Standard Model are either confirmed or ruled out [13, 14]. My work therefore will be highly complementary to the existing physics programme of the LPNHE LHCb group, where I will be based, in particular their effort on measuring lepton universality in B meson decays. A recent LHCb measurement of the ratio of semimuonic and semitauonic branching fractions shows a 2.1σ discrepancy with Standard Model predictions which is consistent with other measurements of this quantity [15]. A similar discrepancy from the Standard Model prediction is observed in the ratio of branching fractions of $B^+ \to K^+\mu^+\mu^-$ and $B^+ \to K^+e^+e^-$ decays [16]. An example of the interplay of lepton flavour universality and mixing measurements is shown in Reference [17], Figure 1.

Analysing semileptonic B-decays in LHCb poses several challenges. First, due to the forward geometry of LHCb and the busy environment of pp collisions, one has little handle on fully reconstructing the momentum of the neutrino. This makes it harder to discriminate signal decays from other b-hadron decays with similar signatures. Second, B and $\overline{B}$ mesons are not produced in equal amounts in pp collisions, requiring that the production asymmetries need to be disentangled from potential differences between particles and antiparticles. Third, the flavour specific final state requires that detection asymmetries of the final state particles have to be controlled with a high precision. For this c-meson decays are used and the kinematic overlap of the final state particles is a limiting factor.

These challenges are contradicting one fact LHCb is facing already in Run 2 and will even more after the detector upgrade. The high production rate of beauty and, especially, charm hadrons in pp collisions makes it impossible to save the full information of all decays in the limited offline storage. To fight this problem in Run 2 and beyond, LHCb has implemented a novel approach: it is the first ever High Energy Physics detector which is aligned, calibrated, and fully reconstructed in real-time. This means the information needed for data analysis is immediately available and less information needs to be stored, dramatically increasing the number of events which can be written to the offline storage. Additionally to the increased luminosity after the upgrade, the experiment will move to a triggerless readout removing one of the bottlenecks in the current detector. This poses an additional challenge to the trigger but gives the opportunity to collect an order of magnitude bigger data set of beauty and charm hadrons.

To improve the measurement of B and anti-B differences in semileptonic B decays with the Run 2 data and beyond I want to make use of the real-time analysis capabilities. A dedicated trigger selection of semileptonic B decays which reduces the event information to in turn increase the rate of selected events will be implemented. The full event will be analysed in real-time with machine learning techniques to discriminate the signal decay, where only the neutrino is missing, from potential backgrounds with other or more missing particles not being reconstructed. Furthermore, the selection of control modes to measure detection and production asymmetries will be improved. Here multivariate classifiers will be used in the selection to increase the kinematic overlap between control and signal modes, greatly improving the statistical precision with which detection asymmetries are measured. A combined analysis of B_d^0 and B_s^0 mesons will be done to

reduce common systematics mainly originating from the detection asymmetries.
A very interesting side product of the measurement will be the determination of the production asymmetries of B_d^0 and B_s^0 mesons in proton-proton collisions at the 10^{-3} level and below. This will help to better understand the dynamics of the strong interaction in highest energy proton-proton collisions and test for the first time with high enough precision several predictions of production asymmetries [18].
In my role as HLT deputy project leader I will continue working on the core part of the software trigger. A fast and efficient reconstruction is crucial for the success of the real-time analysis strategy. I will support the ongoing efforts of the LPNHE group in the track reconstruction in the novel scintillating fibre detector of the upgraded LHCb experiment. Here, I want to contribute to modernizing the software to run faster on modern architectures, exploiting vectorisation and multithreading. In parallel I will continue exploring the use of machine learning techniques in the reconstruction to make faster decisions. A particular challenge is to find the trajectories of particles which did not originate in the primary interaction but originated from the decay of long-lived particles. Enabling this reconstruction in the first stages of the software trigger will greatly enhance the physics potential of the LHCb experiment.
To summarize, during my ILP fellow I will work on measuring the difference of particle and antiparticle oscillations in the B-meson system with the Run 2 data set and will prepare the measurement for Run 3 after the upgrade of the LHCb experiment. LHC Run 2 will provide a data set an order of magnitude larger than Run 1 and improvements in the determination of the currently limiting detection asymmetries will additionally increase the precision, providing measurements with a precision better than 10^{-3}. and probing the presence of unknown particles at the TeV scale. In parallel I will work on improving the track reconstruction and the software trigger for the upgraded LHCb detector, allowing to run the experiment at a five times higher instantaneous luminosity while increasing the efficiency to select semileptonic B-decays. Then LHCb will be able to measure the difference of particle and antiparticle oscillations at the 10^{-4} level.

Publications with significant personal contributions

04/2016 **Tesla: an application for real-time data analysis in High Energy Physics**, *arXiv:1604.05596*.

07/2014 **Measurement of CP asymmetry in $D^0 \to K^-K^+$ and $D^0 \to \pi^-\pi^+$ decays**, *DOI: 10.1007/JHEP07(2014)041* .

03/2013 **Search for direct CP violation in $D^0 \to h^-h^+$ modes using semileptonic B decays**, *DOI: 10.1016/j.physletb.2013.04.061*.

02/2013 **Prompt charm production in pp collisions at $\sqrt{s}$ = 7 TeV**, *DOI: 10.1016/j.nuclphysb.2013.02.010*.

12/2011 **Measurement of the CP-violating phase ϕ_s in the decay $B_s^0 \to J/\psi\phi$**, *DOI: 10.1103/PhysRevLett.108.101803*.

12/2011 **Measurement of the $B_s^0 - \overline{B}_s^0$ oscillation frequency Δm_s in $B_s^0 \to D_s^-(3)\pi$ decays**, *DOI:10.1016/j.physletb.2012.02.031*.

09/2010 **Prompt K_S^0 production in pp collisions at $\sqrt{s}$ = 0.9 TeV**, *DOI: 10.1016/j.physletb.2010.08.055*.

References

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