

Annual Report

Funding Programme:	Helmholtz Young Investigators Groups
Project ID No.:	VH-NG-1303
Project Title:	Searches for Dark Matter and Axion-Like Particles at Belle II
Group Leader:	Dr. Torben Ferber
Helmholtz Centre:	DESY
Participating University:	University Hamburg
Report Period (=Calendar Year):	03/2018-12/2018

1) Group Structure

Please report briefly on the structure and personnel development of your group.

The YIG consists of the group leader and the following members:

Post-doctoral researchers (alphabetically):

- Dr. Sam Cunliffe (started 01.05.2018)
- Dr. Yu Hu (Helmholtz-OCPC fellowship, started 01.03.2018)
- Dr. Nataliia Kovalchuk (DESY fellowship, started 01.06.2018)

PhD students:

- Mr. Michael De Nuccio (started 01.05.2018, University of Hamburg)

Master students:

- Mr. Sebastian Stengel (started 01.11.2018, University of Mainz with Prof. Sfienti)

2) Network

Please describe how you / your research group are integrated within the Helmholtz Centre and the partner university (e.g. as member of committees).

The YIG is well integrated in the DESY Belle II group and the DESY Particle Physics group. It contributes significantly to the scientific research programme of the center. The YIG cooperates closely with the DESY theory group to develop new strategies for Dark Matter searches. The group leader is a *key researcher* of the newly funded Excellence Cluster Quantum Universe (QU) at the University of Hamburg and DESY. The research topic of the YIG fits perfectly into the Excellence Cluster and will open up new chances for collaboration.

Responsibilities of YIG members within DESY and the partner university:

Dr. Torben Ferber:

- DESY-Belle II member of the DESY NAF2 User Committee (since 2018)
- DESY-Belle II Computing Coordinator and (since 2018)
- Key researcher of QU DM1.3 (*Collider Searches for Light Dark Sectors*) (since 2018)

3) Satisfaction

How satisfied are you with the general working conditions provided by the Helmholtz Centre / partner university? Is there anything that meets your criticism?

DESY offers the perfect infrastructure for international research. The support of the Centre and the partner universities corresponds to the cooperation contract.

The YIG group leader is not the administrative group head. As a result, he does not sign travel applications, travel reimbursements, holiday requests, or investments. This makes finance planning error-prone since it relies on every individual group member forwarding every relevant information. This could for example be improved by adding a permanent notification email (group leader) in the DESY-GO-Portal for all group members.

4) Scientific Progress / Milestones

How has your work plan progressed? Which important milestones could be achieved during the report period? Is the progress of your work in accordance with original planning or has the work plan been changed?

The activities of the YIG are divided into four work packages: Search for invisible Dark Photon decays into Dark Matter (WP1), Search for visible Dark Photon decays (WP2), Search for Axion-Like Particles (WP3), and Photon Reconstruction, Efficiency Measurement, and Energy Calibration (WP4).

The Belle II data taking in 2018 provided an approximately 40 times smaller dataset (0.5 fb^{-1}) than expected. The overall time schedule of the experiment has been adjusted so that the full dataset will only be available in 2027. As a consequence, activities that require large datasets have been receiving less attention in the YIG and the focus has been shifted to physics analysis that can be performed with smaller datasets, and to detector performance studies.

In the following, the progress of the different working packages is summarised.

Search for invisible Dark Photons decays into Dark Matter (WP1):

This search requires a dataset of at least 20 fb^{-1} which is not yet available. The group is leading trigger studies, photon efficiency studies, and material budget studies that are key inputs for this analysis. However, the plan is to use the 2018 data in order to tune High Level Triggers, and perform the analysis with the 2019/2020 dataset instead.

Search for visible Dark Photons decays (WP2):

Due to the much slower ramp-up than anticipated, these searches will not be competitive in simple models for many years at Belle II. The group has shifted focus away from the planned simple models to more complex final states (e.g. inelastic Dark Matter, self-interacting Dark Matter) and is working in close cooperation with theorists to formulate search strategies and publish phenomenology papers.

Search for Axion-Like Particles (WP3):

The group is leading the analysis of the search for Axion-Like Particles (ALPs) decaying into two photons. This search is competitive even with a small dataset of 0.5 fb^{-1} . Due to the excellent performance of the Belle II calorimeter and the excellent usability of the Belle analysis framework, the analysis is progressing quickly. Since the data has been collected during the first commissioning of the Belle II detector, the data quality varies a lot and careful cross checks are required. Internal documentation of the full analysis is in preparation.

Photon Reconstruction, Efficiency Measurement, and Energy Calibration (WP4):

The YIG is leading the neutrals performance activities in Belle II and is working on improvements of the Belle II ECL reconstruction software. The main focus is on performance validation for photons. The main data sample for this are radiative muon pairs. The muon tracks are used to predict a missing momentum vector that is then matched to photon candidates. A similar sample is used to measure the photon energy, position resolution, and biases. An internal documentation of both studies is in preparation. Recommendations for the whole collaboration are provided on how to use photons in any physics analysis. The group is also working on improvements of the photon position reconstruction using Deep Convolutional Networks. Initial studies show a significant improvement in the photon bias and a small improvement in the photon resolution. The last area of ongoing activity is the optimisation of neutral pion purity and efficiency using hadronic data samples.

Other responsibilities of the group members (alphabetically):

Dr. Sam Cunliffe:

- Convenor of the Belle II Analysis Software group (since 2017)

Dr. Torben Ferber:

- Convenor of the Belle II ECL Software group (since 2016)
- Convenor of the Belle II Event Generators group (since 2014)
- Convenor of the Belle II Dark Sector Physics group (since 2014)
- Convenor of the Belle II Neutrals Performance group (since 2016)

5) Financial Plan / Time Schedule

Can you comply with the financial plan and time schedule or do you see a need for adjustment?

No investment in central computing resources have been made in the report period since data taking at Belle II started slower than expected. 1.5 PhD student positions could not be filled with qualified PhD candidates in the report period. The money for one position was hence used for an Helmholtz-OCPC fellow (Dr. Yu Hu). Group members did not have to contribute to control shifts in the report period which lead to lower travel expenses. In total the group has not spend as much money as foreseen.

This is expected to change in 2019 as the second PhD position will be filled in April 2019 (Mr. Abtin Narimani). Investment in computing resources will likely commence in 2019 as well and the group will contribute to control room and ECL expert shifts.

6) Status

Do you hold a joint Junior Professorship or a W2/W3 Professorship? Do you aim for such a position? What is the status of your negotiations in this respect?

The group leader does not hold a junior professorship, as this is not offered to YIG leaders by the University of Hamburg.

There are no ongoing negotiations for a W2/W3 professorship.

7) Career Development Measures (mandatory only for group leaders of call 12 or higher (2015 onwards))

Have you attended at the course "Leading Your Group" at the Helmholtz Management Academy? To what extend has your personnel development plan been implemented? Do you have a contact person (e.g. an experienced group leader) who supports you in the creation of your group? Do you have at least once a year the chance to reflect on your process in appropriate context (for example in a talk with the head of your institute and the Human Resources Department)?

The group leader has attended the first two blocks of the course "Leading Your Group" at the Helmholtz Management Academy. The group leader has taken part in the internal qualification measures to qualify for "Mitarbeitergespräche" und "Leistungsbeurteilung". The group leader has contact to experienced group leader at DESY (Dr. Carsten Niebuhr) and the University of Hamburg (Prof. Johannes Haller) that support him in the creation and leadership of the group.

The group leader had the opportunity for reflection during the yearly appraisal interview with the Belle II group leader.

However, there was no opportunity for reflection with the head of the institute and the HR department.

8) Teaching Activities of the Group Leader

The group leader had no teaching activity during the report period. It is planned that teaching activities start in fall 2019.

9) Publications of the Group

Public presentations by the group members (by date):

"The Status and Prospects of the Belle II Experiment" (Sam Cunliffe)
(Particle Physics Seminar (invited seminar), Birmingham (UK), 05.12.2018)

"Dark photon: Collider" (Torben Ferber)
(The Puzzle of Dark Matter Symposium (invited), DESY, 30.10.2018)

"Dark sector physics with photons at Belle II" (Sam Cunliffe)
(The Puzzle of Dark Matter Symposium, DESY, 30.10.2018)

"Dark sector physics with photons at Belle II" (Sam Cunliffe)
(Flavour and Dark Matter 2018, KIT (Karlsruhe), 24-26.09.2018)

"Flavour Physics" (Sam Cunliffe)
(Summer Student Lectures, DESY, 24.08.2018)

"Search for Dark Matter at Belle II" (Torben Ferber)
(Physikalisches Kolloquium (invited seminar), Karlsruhe, 11.05.2018)

"Searches for Dark Matter and Axion-Like Particles at Belle II" (Torben Ferber)
(SFB 676 Colloquium (invited seminar), Hamburg, 25.04.2018)

"Search for Dark Matter at Belle II" (Torben Ferber)
(Particle Physics Seminar (invited seminar), Mainz, 23.04.2018)

"Probing dark photons and ALPs at B-factories" (Torben Ferber)
(DM@LHC, Heidelberg (invited), 03.-06.04.2018)

"Searches for Dark Matter at Belle II" (Torben Ferber)
(DPG (invited plenary), Wuerzburg, 19.-23.03.2018)

Publications with significant contributions from the YIG:

[1] Belle II Collaboration, The Belle II Physics Book, KEK Preprint 2018-27, arXiv: 1808.10567, (accepted for publication in PTEP)

[2] Belle II Analysis software group, Global Decay Chain Vertex Fitting at B-Factories, (journal publication in preparation, BELLE2-PUB-DRAFT-2018-01)

[3] T. Keck et al, The Full Event Interpretation: An Exclusive Tagging Algorithm for the Belle II Experiment, arXiv:1807.08680 (accepted for publication in Comput.Softw.Big Sci.)

10) External Funding

No external funding was applied for.

11) Patent Applications*No. of pending/granted patents*

No patent applications were filed.

12) Awards received by Group Members / Professorship Appointments offered to Group Leader

No awards/appointments were received.