World Premier International Research Center Initiative (WPI)
FY2021 WPI Project Progress Report

Host Institution	High Energy Accelerator Research Organization (KEK)	Host Institution Head	Masanori Yamauchi
Research Center	International Center for Quantum-field Measurement Systems for Studies of the Universe and Particles (QUP)		
Center Director	Masashi Hazumi	Administrative Director	Katsuo Tokushuku

Common instructions:
* Unless otherwise specified, prepare this report based on the current (31 March 2022) situation of your WPI center.
* So as to execute this fiscal year's follow-up review on the "last" center project plan, prepare this report based on it.
* Use yen (¥) when writing monetary amounts in the report. If an exchange rate is used to calculate the yen amount, give the rate.

➢ Prepare this report within 10-20 pages (excluding the appendices, and including Summary of State of WPI Center Project Progress (within 2 pages)).

Summary of State of WPI Center Project Progress (write within **2 pages**)

International Center for Quantum-field Measurement Systems for Studies of the Universe and Particles (QUP) officially launched on December 16, 2021, with the appointment of Masashi Hazumi as Director (Professor of Institute of Particle and Nuclear Studies (IPNS), KEK) and Kazunori Hanagaki as Deputy (Professor of IPNS, KEK). All thirteen initial PIs listed in the proposal have been officially appointed by February 2022.

QUP brings new eyes to humanity to see this beautiful world (the true nature of space-time and matter.) To this end, the director defined the following six categories of projects.

I. QUP flagship projects;
II. QUP PI-led projects;
III. Other interdisciplinary and/or challenging projects and mini-projects;
IV. Projects for human resource development and brain circulation;
V. Projects for society;
VI. Projects for establishing Quantum-field Measurements Systemology.

The vision was shared among PIs, and they are lively discussing how to implement them.

As for QUP flagship projects, in addition to the LiteBIRD project already designated as a flagship project in our proposal, "Project Q" has been defined as the second flagship project, remaining its details undefined intentionally. It is a new and unique QUP approach to tackle the fundamental question of the universe with the newly developing measurement technique. The project is on searches for a new quantum field such as dark matter particles, gravitons, axions, etc. We will select the target quantum field and detection method in open discussions and selection procedures among QUP and non-QUP scientists for about a couple of years. As for systemology, the director identified the following six elements: 1.The general theory of measurement based on the first principles of quantum field theory; 2.Theoretical, experimental, and observational projects to meet the grand challenges on the universe and elementary particles; 3.Invention engineering and new quantum field measurement systems as its applications; 4.Pioneering a wide range of applications for new quantum field measurement systems; 5.Systems engineering as a research accelerator; 6.Systems science (systemology) that incorporates individual and group psychology.

Toward generating fused disciplines, we launched a new project on neuro-aesthetics focusing on the studies of beauty in physics using brain mapping techniques. As for projects for society, we have already noticed that the requirements for precise measurements in frontier astrophysics and particle physics are not so different from those for social applications such as automated vehicle driving. We had brainstorming meetings among PIs, which we will repeat in FY2022. Collaboration with other WPI institutes is also in preparation.

We set up the QUP steering committee and had monthly meetings to decide important items such as the recruitment of postdoctoral fellows, senior scientists, and supporting staff. The first job advertisement was posted in January 2022. The selection procedure is in progress.

We had progress in launching QUP satellites in the three locations. The agreement on the satellite in ISAS/JAXA was signed on March 27, 2022, for the collaborative works on the cryogenic detectors. We agreed to open the QUP satellite in the Toyota Central R&D Labs., Inc. on April 1, 2022. Before that, we signed the agreement on the related collaborative works on January 25, 2022. The draft document for the satellite at UC Berkeley is in preparation.

The QUP, as a unique WPI institute of "measurement," wishes to have close collaboration with the other WPI institutes. As the first step, an MOU was signed with Kavli IPMU on March 1, 2022, for collaborative works in astrophysics, particle physics, and the related application areas. The QUP delegation also visited MANA and IIIS to learn about their activities and discuss possible collaboration.

Toward realizing an international research environment, we fully utilized the video meeting system and kept good communications in spite of the COVID-19 restrictions. We also declared our code of conduct to show our strong commitment to diversity. We made our first international job opening for the QUP postdoctoral fellows in January and received 74 applications.

For our publicity program to researchers and the general public, we opened a QUP web page (https://www2.kek.jp/qup/en/). We also gave presentations to share the vision of QUP on various occasions including a meeting with the foreign embassy organized by the WPI forum, the WPI workshop in Kanazawa, and in various conferences in astrophysics and particle physics.

For education, the design work has started on new programs to invite students for short (a few months) and long (2-3 years) terms. The goal is to have these students on site by April 2023. In parallel, we signed an agreement with SOKENDAI so that the QUP researchers are entitled to supervise their graduate students.

To enhance research under one roof, a budget request for a new QUP research building complex is in preparation. The QUP flagship project, LiteBIRD, was selected by the KEK science advisory committee as one of five new projects to be promoted. The discussion on the project implementation plan (PIP) is in progress by the KEK management. These are essential steps for self-sufficient and sustainable center development.

For future improvements, we took six points raised by the WPI committee very seriously, and came up with resolutions, summarized as follows: 1.QUP's scope and breadth of research are clearly defined by the six project categories mentioned above; 2.The QUP director's strong leadership in staff recruitment has been endorsed by the Education and Research Council of KEK, and the flexibility in the KEK system gives the QUP director several knobs to attract excellent researchers; 3.The director came up with an FTE management in which he practically devotes all his time for QUP as its face; 4. We have committed to preparing an environment for carrying out research under one roof. To this end, we are planning to have a new QUP research building complex. We are also thoroughly utilizing video communication systems to enhance virtual communications: 5. We have started to design our education/career-promotion program targeting to have the first graduate students at the beginning of FY2023. We also signed an agreement with SOKENDAI so that QUP researchers can supervise graduate students there; 6. The KEK director general and the QUP director are closely collaborating to determine the role of QUP at KEK. KEK has been helping a lot with starting up QUP, including human resource allocation and research environment. We are still under discussion on the long-term role-sharing and the model for QUP after the first ten years.

* Describe clearly and concisely the progress being made by the WPI center project from the following viewpoints.

1. World-Leading Scientific Excellence and Recognition

1-1. Advancing Research of the Highest Global Level

* Among the research results achieved by the center, concretely describe those that are at the world's highest level. In Appendix 1, list the center's research papers published in 2021.
* Regarding the criteria used when evaluating the world level of the center, note any updated results using your previous evaluation criteria and methods or any improvements you have made to those criteria and methods.

International Center for Quantum-field Measurement Systems for Studies of the Universe and Particles (QUP) officially launched on December 16, 2021, with the appointment of Masashi Hazumi as Director (Professor of Institute of Particle and Nuclear Studies (IPNS), KEK) and Kazunori Hanagaki as Deputy (Professor of IPNS, KEK). All thirteen initial PIs listed in the proposal have been officially appointed by February 2022.

Since November 10, 2021, the pre-launch period of QUP, we have held all-PI video meetings every week to discuss the organization and research activities in QUP. Following the discussion, the idea has emerged of structuralizing the projects in the QUP. The detailed structure is described later in this session.

The QUP steering committee, which is the body that discusses the operational matters of QUP and consists of the director, deputy, administrative director, and a representative of PI (Professor A. Lee), meets regularly every month. The committee decides the recruitment of the postdoctoral fellows, senior scientists, and supporting staff.

We had progress in launching QUP satellites in the three locations. The agreement on the satellite in ISAS/JAXA was signed on March 27, 2022, for the collaborative works on the cryogenic detectors. We agreed to open the QUP satellite in the Toyota Central R&D Labs., Inc. on April 1, 2022. Before that, we signed the agreement on the related collaborative works on January 25, 2022. The draft document for the satellite at UC Berkeley is in preparation.

The QUP, as a unique WPI institute of "measurement," wishes to have close collaboration with the other WPI institutes. As the first step, an MOU was signed with Kavli IPMU on March 1, 2022, for collaborative works in astrophysics, particle physics, and the related application areas. The QUP delegation also visited MANA and IIIS to learn about their activities and discuss possible collaboration.

<u>The QUP's missions</u> described in the proposal are as follows.

- **Integrate** particle physics, astrophysics, condensed matter physics, measurement science, and systems science.
- **Invent and develop** new systems for measuring quantum fields (space-time with particles and quasiparticles created and annihilated, and associated physical quantities).
- Bring **innovation** to measurements in cosmological observations and particle experiments, and **elucidate** the true nature of space-time and matter.
- **Establish** a new measurement science, quantum field measurement systemology, as a science of means through the above practices.
- Last but not least, we will **create a new level of fusion of various research areas beyond physics** and new social values through application to other fields and social implementation.

<u>The identities of this center</u> listed in the proposal are as follows.

I. The only center in the world that integrates the invention of new measurement principles for experimental cosmology and particle physics, the development of systems to realize these principles, and the execution of projects.
II. This center will conduct interdisciplinary research on "means" or "methodologies." It is at the meta-level, leading to a new level of fusion of various research areas to produce academic and

social values.

III. Capability of characterizing measurement systems using the various quantum beams provided by KEK's accelerator facilities.

IV. Leveraging our experience as a host of large-scale international collaborative experiments in fundamental research fields to conduct international research collaborations at an unparalleled level.

V. Leveraging our experience as an inter-university research institute, we will lead the world and make significant contributions to the research and education of universities and research institutions in Japan and abroad.

Following the missions and identities mentioned above, the director defined the following six categories of projects.

1. QUP flagship projects;
2. QUP PI-led projects;
3. Other interdisciplinary and/or challenging projects and mini-projects;
4. Projects for human resource development and brain circulation;
5. Projects for society;
6. Projects for establishing Quantum-field Measurements Systemology.

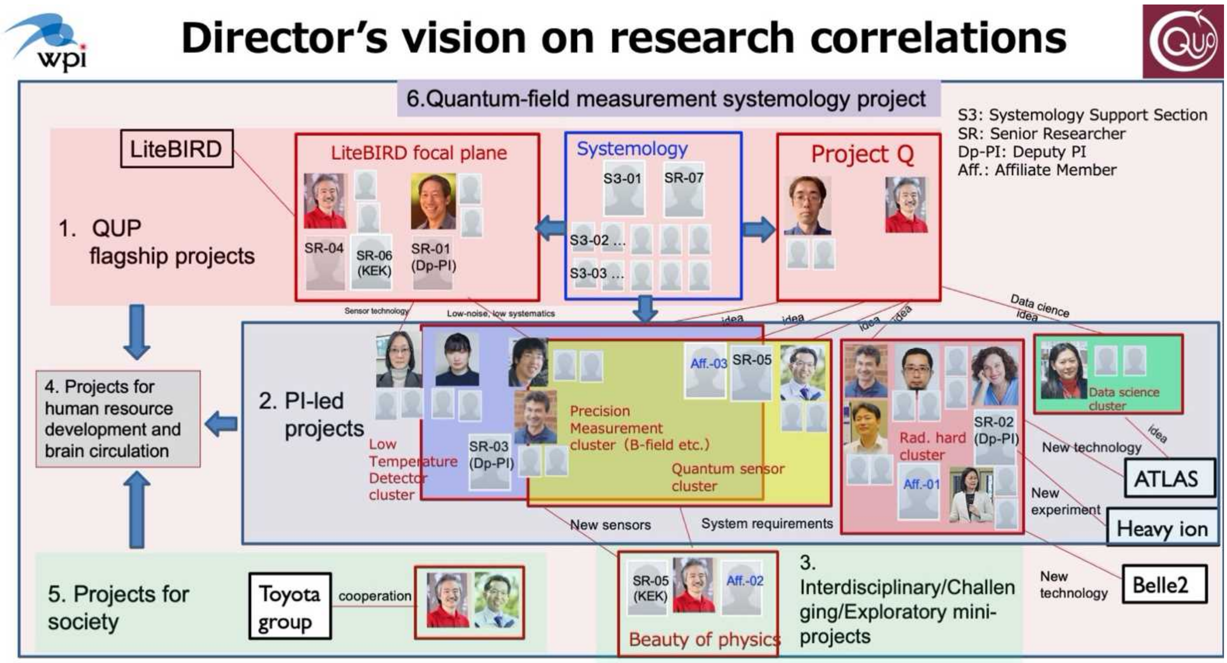
The vision was shared among PIs, and they are lively discussing how to implement them.

In addition to the LiteBIRD project already designated as a flagship project in our proposal, "Project Q" has been defined as the second flagship project, remaining its details undefined intentionally. It is a new and unique QUP approach to tackle the fundamental question of the universe with the newly developing measurement technique. The project is on searches for a new quantum field such as dark matter particles, gravitons, axions, etc. We will select the target quantum field and detection method in open discussions and selection procedures among QUP and non-QUP scientists for about a couple of years.

Through the discussion in the PI meetings, it has become clear that the fusion of studies among each PI's interests is possible and beneficial. For example, PI Hasegawa plans to develop an advanced receiver system for cosmology with super-accurate temperature monitoring using new quantum sensors developed in QUP satellites, particularly at the Toyota Central R&D Labs., Inc. Weakly-bound "research clusters" between the PI-led projects are being formed. It also led to a QUP core facility of cryogenic detectors equipped with four dilution refrigerators, whose procurements are underway with the FY2021 and FY2022 budgets.

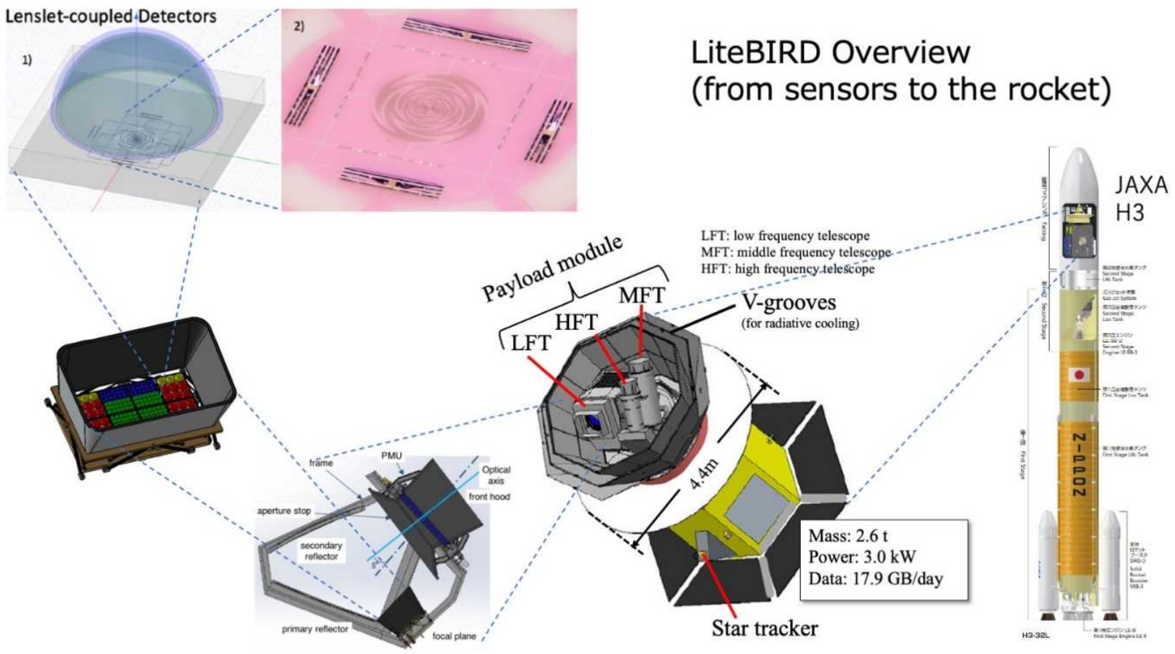
In QUP, these different projects will be progressed with critical technology development of quantum field sensors and systemology as "basso continuo." An emerging schematic structure of QUP is shown below. Each project was launched, and in February 2022, the first paper on the LiteBIRD project with an explicit QUP affiliation was submitted. ("Probing Cosmic Inflation with the LiteBIRD Cosmic Microwave Background Polarization Survey," E. Allys et al., LiteBIRD Collaboration, arXiv:2202.02773)

The rest of this section describes the progress in the two flagship projects, clusters of PI projects, and projects for establishing systemology. We will explain interdisciplinary projects and projects for society in section 1-2, and the brain circulation program in section 3-2.



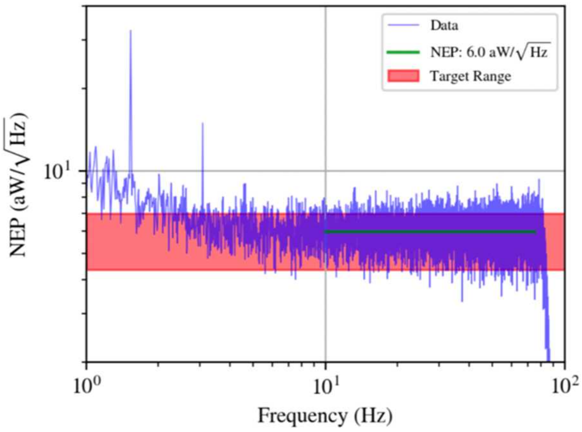
[Flagship Project 1: LiteBIRD] (PIs: Hasegawa, Hazumi, Lee, Yamasaki)

LiteBIRD, the Lite (Light) satellite for studying B-mode polarization and Inflation from cosmic background Radiation Detection, is a space mission for primordial cosmology and fundamental physics. The Japan Aerospace Exploration Agency (JAXA) selected LiteBIRD in May 2019 as a strategic large-class (L-class) mission, with an expected launch in the late 2020s using JAXA's H3 rocket. LiteBIRD will orbit the Sun-Earth Lagrangian point L2. There, it will map the cosmic microwave background (CMB) polarization over the entire sky for three years, with three telescopes in 15 frequency bands between 34 and 448 GHz, to achieve an unprecedented total sensitivity of 2.2 mK-arcmin, with a typical angular resolution of 0.5 degrees at 100 GHz. The primary scientific objective of LiteBIRD is to search for the signal from cosmic Inflation, either making a discovery or ruling out well-motivated inflationary models. The measurements of LiteBIRD will also provide us with insight into the quantum nature of gravity and other new physics beyond the standard models



of particle physics and cosmology.

With the QUP director as the founder and the global PI of LiteBIRD, the development of the LiteBIRD superconducting detector system is a flagship project at QUP. Four PIs are involved in the LiteBIRD project. They are actively promoting R&D for the concept development of LiteBIRD. The results of our studies so far were submitted to the PTEP journal as an invited paper in February 2022. One of the highlights was the demonstration of the low white-noise level with a prototype TES bolometer and readout system for LiteBIRD. As shown in the right Figure, we achieved a NEP of ~6 x 10^{-18} [W/ √ Hz], which satisfies the requirement of LiteBIRD.



[Flagship Project 2: Project Q] (PI conveners: Hazumi, Nakayama)

The director declared his vision to launch the 2nd flagship project, Project Q. It is a new and unique QUP approach to tackle the fundamental question of the universe with the newly developing measurement technique. The project is on searches for a new quantum field such as dark matter particles, gravitons, axions, etc. We will select the target quantum field and detection method in open discussions and selection procedures among QUP and non-QUP scientists for about a couple of years.

A symposium was held on February 8-10, co-organized by QUP and the other two institutes at KEK (IPNS and IMSS). There were stimulus and interesting presentations followed by discussion, which can be seeds for Project Q.

As for the theoretical framework, we have established collaboration with the KEK theory center. Two research groups have been formed, and active discussions started in March 2022. One group focuses on searching for the effects of quantum gravity, including possibilities to detect gravitons, which are hypothetical quantum fields to describe gravitational interactions in quantum theory. The other group is to address new interactions between a new quantum field and various quantum fields of quasi-particles in condensed matter. For example, a novel idea was studied to detect dark matter axion through the axion-like collective excitation in a topological anti-ferromagnetic material. While the axion dark matter is a long-standing idea in the particle physics community, the existence of axion-like collective excitation in some material is a relatively new idea in condensed matter physics. It opens a new window for dark matter detection, connecting particle physics and condensed matter physics. We also studied a non-thermal production mechanism of axion/hidden-photon dark matter through the dynamics of a symmetry-breaking field or the dark Higgs field around the phase transition.

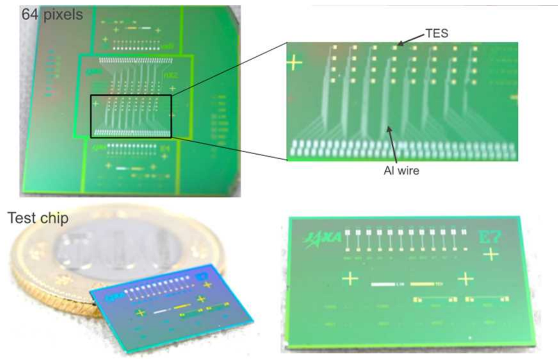
There are various measurement methods to detect unknown particles, as described in the following PI-led projects. At this stage, new quantum sensors' developments are keys to moving forward with the experimental proposal.

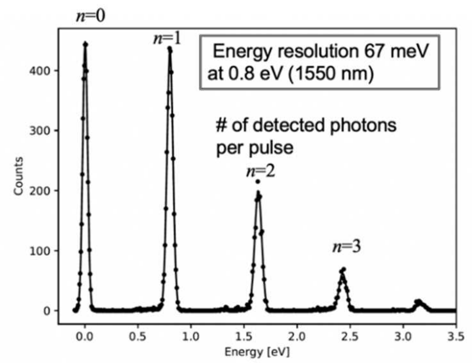
[PI-led Projects]

[Low temperature detector cluster] (PIs: Garcia-Sciveres, Hasegawa, Hattori, Yamasaki)

There is a large variety in QUP PI’s research goals, from searches for new quantum fields in particle physics and cosmology before the big bang to automated driving systems in the smart city and the origin of "beauty" in our brains. Several PIs are interested in new cryogenic detectors to boost the precision of measurements. For example, the development of several types of TES (Transition Edge Sensor) has a wide range of applications. QUP will benefit from collaborations among QUP PIs. Therefore, we have decided to have a core facility for cryogenic detectors at KEK. We also use the facilities of the QUP satellites at ISAS/JAXA and UC Berkeley. We have been specifying dilution refrigerator configurations to place our first PI equipment order from QUP in April 2022. It will be an essential tool for QUP activities.

As already described above, LiteBIRD will use new TES bolometers. Another use of TES is as a micro calorimeter. We can search for axion, a dark matter candidate emitted from the sun, using a TES array with a 57Fe absorber. The iron is required as the target to detect the axion. However, its magnetic field could degrade the TES transition characteristics, which shall not happen. We developed a new configuration to satisfy these contradicting requirements. New evaporative deposition equipment was introduced to ISAS in April 2021. We searched for a good deposition condition for the Ti/Au film by using it. We succeeded in making various sets of TESs on a 3-inch Si wafer. We plan to carry out an X-ray irradiation test for the test chip.





This year, in conjunction with the launch of QUP, we have begun building an environment for studying optical TESs. The optical TES can measure the energy of a sub-eV photon. We have started to explore the optical TESs for application to dark matter searches. They are expected to be sensitive to the energy deposit from dark matter with sub-MeV or sub-eV masses. Current studies focus on improving the energy resolution of the TESs to widen the search window for the mass range of the dark matter toward the smaller side. An optical TES's typical energy resolution (FWHM) is 100meV to 200meV. This year, we lowered the Tc from 300mK to 115mK and achieved the energy resolution of 67meV, as shown in the figure. It is the highest absolute energy resolution among TES calorimeters to our knowledge. However, there is a gap between the measured energy resolution and the theoretical calculation. We found that the current noise can explain about 50% of the contribution to the energy resolution. However, the noise sources for the remaining 50% are still unknown, requiring further studies. We have summarized these results in a paper to be submitted soon.

One of QUP's science activities has been organizing a low-mass dark matter search program in Japan. This new effort aims at low-mass dark matter searches and quantum sensing experiments. Together with Prof. Koji Ishidoshiro of Tohoku University, the group prepared and submitted a US-Japan proposal as co-Pis to seed a collaboration for a new underground cryogenic facility at Kamioka. The proposal is still under review but has served to kick-start a collaboration.

As a member of the SPICE-HeRALD collaboration, Maurice Garcia-Sciveres has started discussions about deploying a SPICE-HeRALD dark matter search target at the new facility as the first underground run of SPICE-HeRALD. The SPICE-HeRALD collaboration searches for dark matter using TES technology on selected crystals and liquid He targets. For the new lab at Kamioka, we propose investigating other sensors and targets of interest in Japan. With QUP, we will collaborate with other PIs who are experts in TES detectors.

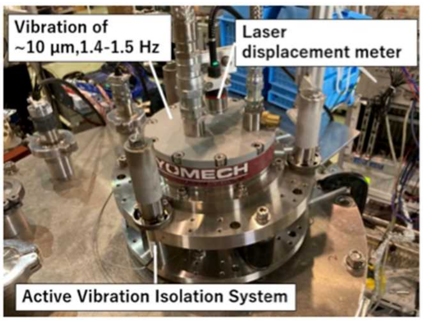
To improve the sensitivity of CMB polarization experiments for studies of the universe before the big bang, we need a sizeable superconducting detector (TES) array. The KEK laboratory and UC Berkeley collaborated to develop one of the largest arrays with O(10000) TES bolometers. They installed it in the POLARBEAR-2 receiver in Chile. The general strategy of the CMB community over the next decade is to increase its size by two orders of magnitude, both in space and on the ground. We have studied commonalities and differences between the POLARBEAR_2 TES array and the LiteBIRD TES array. We feedbacked the results on the design of LiteBIRD.

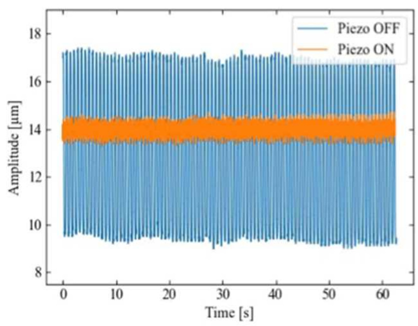
[Precision measurement cluster] (PIs: Garcia-Sciveres, Hasegawa)
One of the significant challenges of TES usage at LiteBIRD, other CMB observations, and dark matter searches described above is excessive noise suppression. Collaboration in the cryogenic detector cluster at QUP is of mutual benefit to enhance the measurement precision.

The suppression of excessive noise is a hot topic. In particular, excess noise caused by temperature fluctuations and vibrations is already visible in ground-based CMB experiments. It will be a significant obstacle to improving sensitivity in the future.

We evaluated the temperature fluctuation using actual data to determine the achievable precision using commercially-available thermometers. It was confirmed to be sufficient for the focal plane (sub-K) and cryo-optics components (4K and 50K) for the ongoing ground-based experiments. On the other hand, the room temperature component required a dedicated temperature monitor using a thermistor. We confirmed that off-the-shelf components also met the required accuracy. The results were reported in a Ph.D. thesis by a SOKENDAI student in the KEK-CMB group and recently submitted to a journal paper. To go beyond that, we may need more precise measurements. One idea is to introduce diamond quantum sensors. We had some initial discussions with an expert.

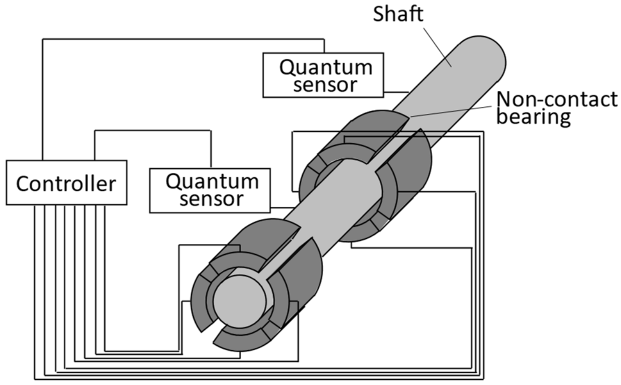
As for vibration noise, the ultimate goal is to realize vibration isolation of focal plane detector arrays. A long-term goal is to develop actuators and displacement sensors for low temperatures. The near-term goal is vibration isolation of the cryocooler at room temperature. As shown in the photo, we tried to mitigate the vertical vibration using an actuator (in open loop mode) and successfully demonstrated it. Next year, we aim to develop a feedback control circuit and control all the six degrees of freedom.

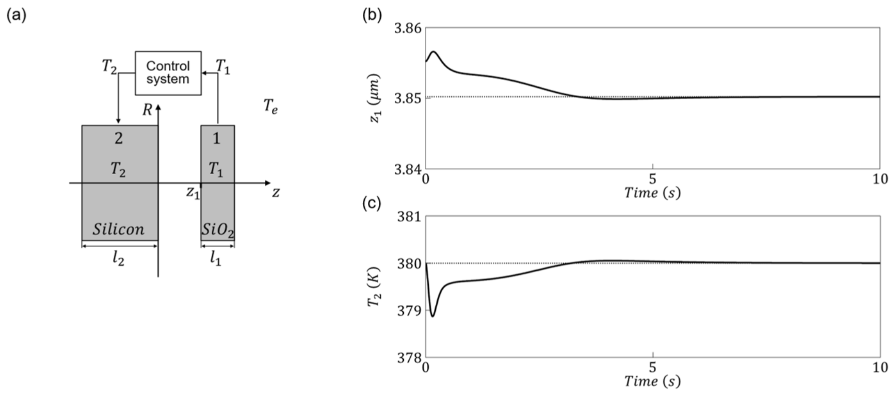




[Quantum sensor cluster] (PIs: Hasegawa, Hazumi, Iizuka)

Our challenges include realizing a non-contact shaft-bearing system, which will drastically change the designs of various essential building blocks with movable structures, such as motors. Each of the two bearings consists of four pieces, and the cylindrical shaft has no contact with the bearings. We will try to manipulate Casimir force and thermal emission combined with control theory and quantum sensing. Quantum sensors measure temperatures at a few spots of the shaft. Based on the information, the temperature of each piece is adjusted so that the shaft has no contact with the bearings.



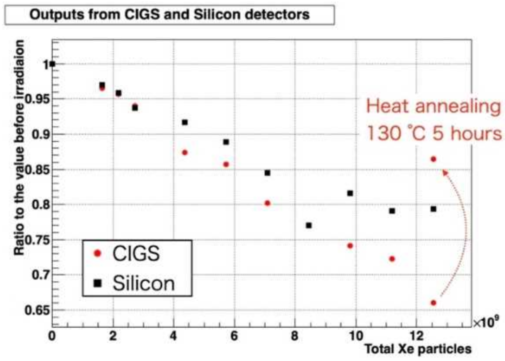


As a preliminary study, we consider a system consisting of two SiO_2 and Si parallel plates interacting through Casimir force and thermal emission. The temperature T_2 of the silicon plate is adjustable, and the ambient temperature is constant at T_e=100K. The dynamics of the thermal emission determine the temperature T_1 of the SiO_2 plate. We numerically investigate the dynamics of the Casimir force and the thermal emission in the system. Figures (b) and (c) show the time responses of the position z_1 of the SiO_2 plate and the temperature T_2 of the silicon plate, respectively. We set an initial offset Δz_1 for the position of the SiO_2 plate at t=0. We observe that the position z_1 of the SiO_2 plate moves back to the equilibrium position [horizontal line in Fig. (b)] around t=3.5s. It shows a promising result toward keeping the plate afloat with the precise sensing of the temperature and heat feedback.

[Radiation hard cluster] (PIs: Bortoletto, Garcia-Sciveres, Miyahara, Taniguchi, Togawa)

The Cu(In, Ga)Se2 (CIGS) semiconductor, initially developed for solar cells, is expected to have high radiation tolerance with a recovery of radiation damage with the compensation of the defects by ions and would shed new light on the particle detector under the high radiation environment.

In January 2022, we tested a prototype CIGS detector with the Xe beam at the HIMAC (Heavy Ion Medical Accelerator in Chiba). The thickness of the depletion layer was 2 μm. We have succeeded in observing a single event with a fast response. We irradiated 1.2x10^{10} Xe particles to the CIGS and standard silicon detectors. Outputs from both sensors were reduced in the course of irradiation, as shown in Figure. In the case of the CIGS detector, the decrease was 66% after irradiation. After the treatment of heat annealing under 130°C for 5 hours, the response to the beam was back to 86%.



It is a significant step to confirm that we can use the CIGS semiconductor as a particle detector with a recovery feature for radiation damage. A paper is in preparation.

Radiation hardness is a challenge not only for the sensors themselves but also for the readout electronics. As a QUP activity, we have started R&D of a new FPGA with atom-switch technology for application to high-energy physics experiments of future projects. NIMS originally developed the atom switch, and AIST and NEC applied it for the routing switch and look-up table of FPGA, showing a promise of being free from soft error caused by radiation. In the coming years, we plan to apply the technology for detector readout used for high energy experiments from, for example, gas detectors and photosensors.

The development of a new radiation-hard chip with 28 nm technology has started with some activities that include the simulation of the new chip conducted at Berkeley. In the framework of AIDAInnova, QUP PIs interact with INFN in several groups that have submitted and plan to develop prototypes of the new technology (TimpeSpot and Falaphel projects).

Another new QUP activity is developing the automated design of analog ASICs. Analog ASICs are usually developed manually, requiring skilled engineers. A platform that automatically synthesizes analog circuits from ASIC target specifications and process data is under development in collaboration with Emeritus Prof. Akira Matsuzawa at the Tokyo Institute of Technology. We demonstrated a 12-bit DAC as an example, which usually takes a few days to design by experts. It took only 5 seconds to generate a design.

[Data science cluster] (PI: Bortoletto, Nakahama)

Research at QUP spans the areas of Particle Physics and Data Science. By utilizing the interdisciplinary environment, the following activities are in focus.
- Developments of advanced analysis techniques, for instance, Machine Learning (ML), Real-Time analysis, so-called "Trigger," and
- ML applications to data analyses, leading new science outputs using high-statistics collision data collected by the particle accelerator experiments, such as the ATLAS experiment at the Large Hadron Collider at CERN, Geneva.
Science topics with QUP PI's interests and expertise are,
- searching for New Physics phenomena arising from physics Beyond the Standard Model (BSM), such as supersymmetry (SUSY) and Dark Matter, as well as,
- revealing the structure of the Higgs field and the vacuum phase transition in the early universe through the studies on the Higgs decays (especially H->$c\bar{c}$, a challenging search) and the Higgs-pair production process.

As an example, in the analysis using the proton-proton collision dataset of 139 fb^{-1}, an exclusion limit at the 95% confidence level on the mass of the gluino is set at 2.30 TeV/c^2 for a simplified model containing only a gluino, and the lightest neutralino, assuming the latter is massless. (J. High Energ. Phys. 2021, 143 (2021)). These limits substantially extended the region of supersymmetric parameter space previously excluded by similar previous ATLAS results. We plan to extend this multivariate approach to less explored SUSY searches such as challenging Long-Lived Particle searches with unusual-object-reconstructions, for instance, displaced vertexing.

Another example is the measurement of the coupling of the Higgs boson to Charm quarks. In the Standard Model, the branching fraction of $H \rightarrow c\bar{c}$ is 2.89%, approximately 20 times smaller than the branching fraction of the Higgs boson to a bottom quark-antiquark pair, $H \rightarrow b\bar{b}$. Furthermore, the tagging of c-quarks is extremely challenging. The current state-of-the-art analysis has been submitted for publication. The (W/Z)H($\rightarrow c\bar{c}$)search yields an observed (expected) upper limit of 26 (31) times the predicted Standard Model cross-section times branching fraction for a Higgs boson with a mass of 125 GeV, corresponding to an observed (expected) constraint on the charm Yukawa coupling modifier $|\kappa_c|<8.5(12.4)$, at the 95% confidence level. The current analysis does not yet use Machine Learning in some of the steps. It is not optimized for high momentum H($\rightarrow c\bar{c}$) detection when the events where the two charm quarks from the Higgs boson decay merge to form a single jet (boosted topology). The focus of future work in QUP will be implementing the boosted topology and introducing a multivariate discriminator to enhance the signal separation from the background for both the resolved and boosted analyses.

[Systemology Project]
This is a "project of projects", based on all QUP projects, for building a new discipline. We have identified six elements to construct our quantum-field measurement systemology as a new academic discipline.

1. The general theory of measurement based on the first principles of quantum field theory
2. Theoretical, experimental, and observational projects to meet the grand challenges on the universe and elementary particles
3. Invention engineering and new quantum field measurement systems as its applications
4. Pioneering a wide range of applications for new quantum field measurement systems
5. Systems engineering as a research accelerator
6. Systems science (systemology) that incorporates individual and group psychology

The process to hire staff members for the systemology support section has started this fiscal year.

1-2. Generating Fused Disciplines

* Describe the content of measures taken by the center to advance research by fusing disciplines. For example, measures that facilitate doing joint research by researchers in differing fields. If any, describe the interdisciplinary research/fused discipline that have resulted from your efforts to generate fused disciplines. You may refer to the research results described concretely in "1-1. Advancing Research of the Highest Global Level."

The technology of quantum field measurement should boost science activities beyond the initial scope of QUP. An important application area is human brain mapping. A collaboration on neuro-aesthetics, particularly the concept of beauty in physics, started as an interdisciplinary project with the new QUP members as senior scientists and affiliate members joining FY2022. The first step is to use existing measurement systems such as fMRIs and MEGs to map out brain activities when physicists feel beauty in physics. The 2nd step will be to perform a requirements-flow analysis with the help of the QUP Systemology Support Section to set targeted R&D goals for the new measurement system.

MOU to form a QUP satellite in Toyota Central R&D Labs., Inc. is in progress to be set on April 1, 2022. The satellite will give an important role in the coordinated development of quantum field measurement between basic science and social activities.

As for projects for society, we have already noticed that the requirements for precise measurements in frontier astrophysics and particle physics are not so different from those for social applications such as automated vehicle driving. We had brainstorming meetings among PIs, which we will repeat in FY2022.

The QUP, as a unique WPI institute of "measurement," wishes to have close collaboration with the other WPI institutes. As the first step, an MOU was signed with Kavli IPMU on March 1, 2022, for collaborative works in astrophysics, particle physics, and the related application areas. The QUP delegation also visited MANA and IIIS to learn about their activities and discuss possible collaboration.

Through the discussion in the PI meetings, it has become clear that the fusion of studies among each PI's interests is possible and beneficial. For example, PI Hasegawa plans to develop an advanced receiver system for cosmology with super-accurate temperature monitoring using new quantum sensors developed in QUP satellites, particularly at the Toyota Central R&D Labs., Inc. Weakly-bound "research clusters" between the PI-led projects are being formed. It also led to a QUP core facility of cryogenic detectors equipped with four dilution refrigerators, whose procurements are underway with the FY2021 and FY2022 budgets. Two of them will be used mainly by K. Hattori and M. Garcia-Sciveres and the other two for the flagship project LiteBIRD by M. Hasegawa and M. Hazumi.

2. Global Research Environment and System Reform

2-1. Realizing an International Research Environment

* Describe what's been accomplished in the efforts to raise the center's recognition as a genuine globally visible research institute, along with innovative efforts proactively being taken in accordance with the development stage of the center, including the following points, for example:
- Efforts being developed based on the analysis of number and state of world-leading, frontline researchers (in Appendix 2); exchanges with overseas entities (in Appendix 4); number and state of visiting researchers (in Appendix 5)
- Proactive efforts to raise the level of the center's international recognition and to obtain diversity within the center including gender balance.
- Efforts to make the center into one that attracts excellent young researchers from around the world (such as efforts fostering young researchers and contributing to advancing their career paths)

Amid the COVID-19 pandemic, external PIs couldn't come and gather at the KEK site. We could not invite any researchers from abroad in this fiscal year. We thoroughly used the video meeting system instead. The regular PI meetings, as already described, are one example. With such arrangements, we were able to determine the direction of QUP research.

Diversity is an essential concept for a world premier institute. QUP has started with 13 PIs. Among them, five are female, and three are non-Japanese. The ratio is far more extensive than the KEK average, but we would like to enhance future recruitment diversity. As a symbolical yet essential step, the code of conduct of QUP has been determined where diversity is a crucial part of QUP. It has been open on the QUP website since April 18, 2022.

The job opening for the QUP postdoctoral fellows started in January. The call was through academic jobs online, a common platform for many international institutes, and visible among young researchers worldwide. By the end of March, there were 74 applicants registered, and the selection process is ongoing.

2-2. Making Organizational Reforms

* Describe the system reforms made to the center's research operation and administrative organization, along with their background and results.
* If innovated system reforms generated by the center have had a ripple effect on other departments of the host institutions or on

other research institutions, clearly describe in what ways.
* Describe the center's operation and the host institution's commitment to the system reforms.

At the foundation of QUP, there were many discussions with KEK how to harmonize the organization structure of QUP, which is a top-down institute, with the rules of KEK which is one of the inter-university research institute corporations where the opinions of the user community are strongly reflected in the lab operation.

KEK requires a resolution from the Education and Research Council regarding faculty appointments and the Council delegates the task to a high-level committee of the KEK institute where the outside members selected by the community are the majority. As an exception, the Council has decided to delegate the task to the QUP director for the QUP researcher appointments, at the foundation of QUP. KEK also delegated the other (non-researcher) appointments to the QUP director, as well. This ensures the leadership of the QUP director. The QUP director will report QUP's human resource allocation plan regularly in the KEK's director meetings to help the mutual understanding of the scope of the QUP.

The KEK system also allows the QUP director to set a special allowance depending on the excellence of the persons, to give the director to hire the world's top class researchers.

Some (and many at the start of the institute) QUP researchers belong to the other institutes at KEK or outside KEK. It is important to have the QUP job rank (such as PIs, senior scientists) and the standard job rank (such as professor, assistant professor, etc.) independent. The rule for titles of the QUP faculty staffs has been defined.

In order to keep the independence of QUP and good coordination with KEK, the QUP administration office contains a newly set up KEK administration section, QUP management office.

All these structures were formed with close coordination with KEK, the host institute of QUP.

3. Values for the Future

3-1. Creating and Disseminating the Societal Value of Basic Research

* Describe the content of measures taken by the center to widely disseminate the results of its basic research to the general public.
* Describe what was accomplished in the center's outreach and other activities last year and how they have contributed to creating the Societal Value of Basic Research. In Appendix 6, describe concretely the contents of these outreach activities. In Appendix 7, describe media reports or coverage, if any, of the activities.

Since QUP is just at the start-up stage, there are no "results" yet to share with the general public, but the QUP director showed the idea of its new WPI concepts to a wide area of audience on various occasions. They include a meeting with foreign embassies organized by the WPI forum, talks at multiple conferences in astrophysics and particle physics, and a corporate research laboratory seminar.

On the second day after QUP was established, QUP joined the WPI workshop in Kanazawa, setting up a booth of QUP, and interacted with (mainly) high school students in Ishikawa prefecture.

We opened a QUP web page (https://www2.kek.jp/qup/en/) and posted various pieces of information including the director's messages, research topics to be covered, a list of members etc.

3-2. Human Resource Building: Higher Education and Career Development

* Describe the content of measures taken by the center to foster young researchers, including doctoral students, through their participation in a research system that creates new interdisciplinary domains within a rich international environment.

KEK (and QUP) is not entitled to give Ph.D. degrees to graduate students, so the design work has started on new programs to invite students from Japanese and foreign universities for short (a few months) and long (2-3 years) term. The goal is to have these students on site by April 2023.

In parallel, we concluded a new MOU with SOKENDAI on March 31, 2022, so that the QUP researchers are entitled to supervise their graduate students.

3-3. Self-sufficient and Sustainable Center Development

* Describe the state of implementation of the host institution's mid-to-long term measures for supporting the center toward becoming self-sufficient and sustainable after the 10-year funding period ends, such as reforming the host institution's organization, providing personnel with priority allocation of tenured posts to the center, providing fundamental financial support, and material support including land and buildings.

Following the QUP project plan, the initial allocation of office and laboratory space has started. As for the laboratory space, the Fuji experimental hall will be the primary place, including the core facility of cryogenic detectors. Extensive renovation works have started in this fiscal year. As for the office space, after the discussions with the Institute of Particle and Nuclear Studies (IPNS), we conclude that it is more appropriate to start in the same building occupied by IPNS researchers. Thus, we set up QUP's headquarters and offices on March 31 on the 4th floor of KEK's building #4, where the IPNS director and researchers are on the 3rd floor.

An idea has emerged of having a new research building complex by renovating the old KEK facilities. QUP's diverse activities can be easily combined in the complex, and close communication among researchers enhances the more innovative idea. The detailed design will be worked out in FY2022. The budget will be requested for the renovation for FY2023 from KEK.

KEK has implemented a new test beam facility in the electron accumulator ring. The first beam was successfully extracted in March 2022. The facility will provide a powerful tool for detector development at QUP. It will also be an excellent experimental platform for QUP's earlier carrier researchers and graduate students.

The QUP flagship project, LiteBIRD, is listed in the KEK roadmap issued in 2021. The KEK science advisory board recommended LiteBIRD as one of five new projects to be promoted. The discussion on the project implementation plan (PIP) is in progress by the KEK management. The KEK will request the budget for the project, depending on the priority in PIP.

4. Others

* In addition to the above 1-3 points, if there is anything else that deserves mention regarding the center project's progress, please note it.

5. Efforts to improve points indicated as requiring improvement in application review and results of such efforts

* Describe the status of responses to items in "Major points that need to be improved" in "The screening result for WPI centers launched in FY 2021."
* If you have already provided this information, please indicate where in the report.

We received six major points that need to be improved by the selection process for the QUP. We will list these points below and report the current progress on each.

1. The proposal needed to clarify how QUP will create significant added value and exert a transformative impact on KEK. Without them, the project would be in danger of devolving into the ongoing development of new detectors and sensors. This would not be regarded as a QUP achievement within the WPI concept.

The proposal was revised in November 2022, following the recommendation. The proposal stressed the interdisciplinary nature of QUP and the importance of placing it at KEK in section 2-5, as shown below. The QUP directorate and PIs had extensive discussions. As described in section 1-2, we identified six categories of projects at QUP.

"In this center, researchers in particle physics, astrophysics, condensed matter physics, quantum beam science, measurement science, and systems science will come together to KEK, where outstanding research is advanced, and conduct interdisciplinary research and bring about innovations in quantum field measurement systems. One of our main goals is to solve the great mysteries of the universe, space-time, and elementary particles. Since there is no example in the world where interdisciplinary research on such a scale is carried out in an integrated manner, from invention to development to project implementation, the Center will become a world-leading center and further accelerate interdisciplinary research. In our interdisciplinary research, mathematical and information science will play an essential role as the foundation and common language to support all activities.

Through interdisciplinary research at this center, KEK will be able to open up new research areas for KEK, which goes beyond its previous duties. For example, since this center will provide KEK with a solid foundation for research activities in astroparticle physics, it is expected that the scale of efforts so far will be greatly expanded. There are many research groups around KEK that are interested in various QUP activities. Collaboration with such groups is also beneficial, and the results of QUP can greatly support KEK's research as a whole. The research of this center, which creates a new eye called the quantum field measurement system, will be incorporated into the host organization, KEK, in this way as well."

2. As a WPI center, QUP will need to make major changes to its operation so as to convert it to a system of top-down organizational management, in sharp contrast to KEK's operation, which has a long tradition as an Inter-University Research Institute Corporation.

We seriously considered the harmonization between the top-down QUP and KEK in the legislation process at the QUP start-up. As described in section 2-2, the QUP director's strong leadership in staff recruitment has been endorsed by the Education and Research Council of KEK, and the flexibility in the KEK system gives the QUP director several knobs to attract excellent researchers.

3. The prospective center director proposes to devote 80% of his effort to the program with 50% physical presence at QUP. As the leader and the "face" of a newly developing WPI institute, strong commitment within a context of working for QUP full time is required.

The figures (80%, 50%) do not reflect the absolute commitment of the director, but in the revised proposal, we increased the percentage of his physical presence to 60%. The director, Prof. Hazumi, is also taking a leadership role as the world PI of the LiteBIRD satellite project, the major flagship project of QUP, which has about 350 researchers from 14 countries. Even when he is not physically present at the Center in KEK, he will spend his time for QUP. Examples include activities as the world PI of LiteBIRD, the flagship project of the Center, activities at three satellites, and promotion activities of the Center at international conferences and other research institutes around the world. Thus, it is no exaggeration to say that his time is 100% used for QUP in reality. We will provide necessary updates on the director's FTE management as the QUP activities and LiteBIRD project progress.

4. The center comprises many part-time PIs especially from KEK and its satellites. It will be important to secure a strong commitment from the PIs. KEK should provide sufficient facilities for all QUP's PIs and researchers to be able to get together and work "under one roof."

There are three satellites in QUP, but they are primarily the facilities for detector developments, and the main activities will be performed at KEK. As demonstrated in section 1-1, although the QUP PIs are scattered in the world and suffering from the COVID-19 pandemic circumstance, we have been keeping active discussions among PIs and the directorates via video meetings. Through them, various vital collaborations have been emerging. As described in section 3-3, with great help from KEK, we are planning to have a new research building complex.

5. The Center should commit to higher education more actively and broadly than just collaborating with existing programs at KEK. It should also plan and implement a robust program for nurturing young scientists. QUP can provide a great opportunity for incorporating students and young researchers into its program, which has been a weak point of institutions participating within the framework of the Inter-university Research Institute Corporation.

We also think it is essential to start a QUP original programs to promote the students and early carrier scientists. As described in section 3-2, we are designing a program for graduate students, aiming for the students to be at QUP at the beginning of FY2023.

6. Support from KEK is insufficient. In particular, Director General Yamauchi did not provide commitments on how KEK will sustain QUP after the WPI funding ends. KEK should provide a concrete plan for supporting QUP within this broader context.

As described in sections 1-1 and 3-3 and the answers to the WPI committee's points 2 and 4, the KEK director general and the QUP director are closely collaborating on determining the position of QUP at KEK. KEK has been helping a lot with starting up QUP, including human resource allocation and research environment. At a start-up, KEK has been providing a significant resource for QUP. We are still under discussion on the long-term role-sharing and the model for QUP after the first ten years.

Appendix 1　FY 2021 List of Center's Research Results and Main Awards

1. Refereed Papers

- List only the Center's papers published in 2021. (Note: The list should be for the calendar year, not the fiscal year.)

(1) Divide the papers into two categories, A and B.
  A. WPI papers
  List papers whose author(s) can be identified as affiliated with the WPI program (e.g., that state "WPI" and the name of the WPI center (WPI-center name)). (Not including papers in which the names of persons affiliated with the WPI program are contained only in acknowledgements.)
  B. WPI-related papers
  List papers related to the WPI program but whose authors are not noted in the institutional affiliations as WPI affiliated. (Including papers whose acknowledgements contain the names of researchers affiliated with the WPI program.)

  Note: On 14 December 2011, the Basic Research Promotion Division in MEXT's Research Promotion Bureau circulated an instruction requiring paper authors to include the name or abbreviation of their WPI center among their institutional affiliations. From 2012, the authors' affiliations must be clearly noted.

(2) Method of listing paper
- List only refereed papers. Divide them into categories (e.g., original articles, reviews, proceedings).
- For each, write the author name(s); year of publication; journal name, volume, page(s), and article title. Any listing order may be used as long as format is consistent. (The names of the center researchers do not need to be underlined.)
- If a paper has many authors (say, more than 10), all of their names do not need to be listed.
- Assign a serial number to each paper to be used to identify it throughout the report.
- If the papers are written in languages other than English, underline their serial numbers.
- Order of Listing
  A. WPI papers
    1. Original articles
    2. Review articles
    3. Proceedings
    4. Other English articles

  B. WPI-related papers
    1. Original articles
    2. Review articles
    3. Proceedings
    4. Other English articles

(3) Submission of electronic data
- In addition to the above, provide a .csv file output from the Web of Science (e.g.) or other database giving the paper's raw data including Document ID. (Note: the Document ID is assigned by paper database.)
- These files do not need to be divided into paper categories.

(4) Use in assessments
- The lists of papers will be used in assessing the state of WPI project's progress.
- They will be used as reference in analyzing the trends and whole states of research in the said WPI center, not to evaluate individual researcher performance.
- The special characteristics of each research domain will be considered when conducting assessments.

(5) Additional documents
- After all documents, including these paper listings, showing the state of research progress have been submitted, additional documents may be requested.

1. WPI papers

There is no WPI paper published in this first year but the first paper with QUP affiliation was submitted in February 2022 to Progress of Theoretical and Experimental Physics (PTEP) and currently in the review process. The paper is
"Probing Cosmic Inflation with the LiteBIRD Cosmic Microwave Background Polarization Survey", E. Allys et al, LiteBIRD Collaboration, arXiv:2202.02773, DOI:10.48550/arXiv.2202.02773

2. WPI-related papers

In this section, papers published in 2021 with the significant contribution by the QUP scientists are listed. These are categorized as [1]-[105]: Original articles, [106]:Review Paper, [107][108] Proceedings and [109] Other English article.

1. Original articles:

[1] J. E. Gudmundsson et al.　"The Simons Observatory: modeling optical systematics in the Large Aperture Telescope" Applied Optics 60 (2021) 823-837 DOI:10.1364/AO.411533

[2] D. Barron et al.　"Integrated Electrical Properties of the Frequency Multiplexed Cryogenic Readout System for Polarbear/Simons Array" IEEE Transactions on Applied Superconductivity 31 (2021) 9381662 DOI:10.1109/TASC.2021.3067190

[3] M. Abitbol et al. "The Simons Observatory: Gain, bandpass and polarization-angle calibration requirements for B-mode searches" Journal of Cosmology and Astroparticle Physics 2021 (2021) 32 DOI:10.1088/1475-7516/2021/05/032

[4] K. Lee et al. "A Forecast of the Sensitivity on the Measurement of the Optical Depth to Reionization with the GroundBIRD Experiment" Astrophysical Journal 915 (2021) 88　DOI:10.3847/1538-4357/ac024b

[5] N. Zhu et al.　"The Simons Observatory Large Aperture Telescope Receiver" Astrophysical Journal, Supplement Series 256 (2021) 23　DOI:10.3847/1538-4365/ac0db7

[6] S. L. Stever et al.　"Simulations of systematic effects arising from cosmic rays in the LiteBIRD space telescope, and effects on the measurements of CMB B-modes" Journal of Cosmology and Astroparticle Physics 2021 (2021) 13　DOI:10.1088/1475-7516/2021/09/013

[7] H. McCarrick et al.　"The Simons Observatory Microwave SQUID Multiplexing Detector Module Design" Astrophysical Journal 922 (2021) 38　DOI:10.3847/1538-4357/ac2232

[8] D. Dutcher et al.　"Measurements of the e -mode polarization and temperature- e -mode correlation of the CMB from SPT-3G 2018 data" Physical Review D 104 (2021) 22003 DOI:10.1103/PhysRevD.104.022003

[9] S. Guns et al.　"Detection of Galactic and Extragalactic Millimeter-wavelength Transient Sources with SPT-3G" Astrophysical Journal 916 (2021) 98　DOI:10.3847/1538-4357/ac06a3

[10] L. Balkenhol et al.　"Constraints on ΛCDM extensions from the SPT-3G 2018 EE and TE power spectra" Physical Review D 104 (2021) A14　DOI:10.1103/PhysRevD.104.083509

[11] M. Millea et al. "Optimal Cosmic Microwave Background Lensing Reconstruction and Parameter Estimation with SPTpol Data" Astrophysical Journal 922 (2021) 259　DOI:10.3847/1538-4357/ac02bb

[12] S. Derenzo et al. "How silicon and boron dopants govern the cryogenic scintillation properties of N-type GaAs" Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 989 (2021) 164957 DOI:10.1016/j.nima.2020.164957

[13] K. Asai, K. Nakayama and S.-Y. Tseng "Alternative minimal U(1)B−L" Physics Letters, Section B: Nuclear, Elementary Particle and High-Energy Physics 814 (2021) 136106 DOI:10.1016/j.physletb.2021.136106

[14] Y. Ema, R.Jinno, K. Nakayama and J. Van De Vis "Preheating from target space curvature and unitarity violation: Analysis in field space" Physical Review D 103 (2021) 103536 DOI:10.1103/PhysRevD.103.103536

[15] S. Chigusa, T. Moroi, K. Nakayama "Axion/hidden-photon dark matter conversion into condensed matter axion" Journal of High Energy Physics 2021 (2021) 74　DOI:10.1007/JHEP08(2021)074

[16] Q. Li, T. Moroi, K. Nakayama and W. Yin "Hidden dark matter from Starobinsky inflation" Journal of High Energy Physics 2021 (2021) 179　DOI:10.1007/JHEP09(2021)179

[17] K. Nakayama and W. Yin "Hidden photon and axion dark matter from symmetry breaking" Journal of High Energy Physics 2021 (2021) 26　DOI:10.1007/JHEP10(2021)026

[18] M. Kawasaki, H. Nakatsuka, K. Nakayama, T. Sekiguchi "Revisiting CMB constraints on dark matter annihilation" Journal of Cosmology and Astroparticle Physics 2021 (2021) 15　DOI:10.1088/1475-

7516/2021/12/015

[19] K. Niwa, K. Hattori and D. Fukuda "Few-Photon Spectral Confocal Microscopy for Cell Imaging Using Superconducting Transition Edge Sensor" Frontiers in Bioengineering and Biotechnology 9 (2021) 789709 DOI:10.3389/fbioe.2021.789709

[20] K. Yatsugi, K. Oishi and H. Iizuka "Ringing Suppression of SiC MOSFET Using a Strongly Coupled External Resonator through Analogy with Passive PT-Symmetry" IEEE Transactions on Power Electronics 36 (2021) 2964-2970 DOI:10.1109/TPEL.2020.3013399

[21] T. Lee et al. "Fano Resonance among Magnetic Coils for Midrange Position Sensing Capability" IEEE Access 9 (2021) 15623-15632 DOI:10.1109/ACCESS.2021.3052689

[22] S. P. Rodrigues et al. "Weighing in on photonic-based machine learning for automotive mobility" Nature Photonics 15 (2021) 66-67 DOI:10.1038/s41566-020-00736-0

[23] S. Sugiura et al. "Joint Beam and Polarization Forming of Intelligent Reflecting Surfaces for Wireless Communications" IEEE Transactions on Vehicular Technology 70 (2021) 1648-1657 DOI:10.1109/TVT.2021.3055237

[24] D. Hashemi and H. Iizuka "Substitutional 4d transition metal doping in atomically thin lead" RSC Advances 11 (2021) 6182-6187 DOI:10.1039/d0ra09742j

[25] H. Iizuka and S. Fan "Exterior tuning and switching of non-equilibrium Casimir force" Journal of the Optical Society of America B: Optical Physics 38 (2021) 151-158 DOI:10.1364/JOSAB.405606

[26] H. Iizuka and S. Fan "Control of non-equilibrium Casimir force" Applied Physics Letters 118 (2021) 144001 DOI:10.1063/5.0043100

[27] T. Ikeda and H. Iizuka "Double layer of tunable graphene nanoribbons for enhancing absorption, reflection, or transmission" Journal of Applied Physics 129 (2021) 183105 DOI:10.1063/5.0048291

[28] K.-T. Lee, C. Ji, H. Iizuka, D. Banerjee "Optical cloaking and invisibility: From fiction toward a technological reality" Journal of Applied Physics 129 (2021) 231101 DOI:10.1063/5.0048846

[29] J. Qiu et al. "A 32-kHz-Reference 2.4-GHz Fractional-N Oversampling PLL with 200-kHz Loop Bandwidth" IEEE Journal of Solid-State Circuits 56 (2021) 3741-3755 DOI:10.1109/JSSC.2021.3106514

[30] J. Yijun et al. "Matter-wave Atomic Gradiometer Interferometric Sensor (MAGIS-100)" Quantum Science and Technology 6 (2021) 44003 DOI:10.1088/2058-9565/abf719

[31] K. Arndt et al. "Technical design of the phase I Mu3e experiment" Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 1014 (2021) 165679 DOI:10.1016/j.nima.2021.165679

[32] T. Aaltonen et al. "Measurement of the charge asymmetry of electrons from the decays of W bosons produced in p p ¯ collisions at s =1.96 TeV MEASUREMENT of the CHARGE ASYMMETRY of ELECTRONS ... T. AALTONEN et al." Physical Review D 104 (2021) 92002 DOI:10.1103/PhysRevD.104.092002

[33] G. Aad et al. (ATLAS Collaboration) "Search for phenomena beyond the Standard Model in events with large b-jet multiplicity using the ATLAS detector at the LHC" European Physical Journal C 81 (2021) 11 DOI:10.1140/epjc/s10052-020-08730-0

[34] G. Aad et al. (ATLAS Collaboration) "Measurement of hadronic event shapes in high-p T multijet final states at √s = 13 TeV with the ATLAS detector" Journal of High Energy Physics 2021 (2021) 188 DOI:10.1007/JHEP01(2021)188

[35] G. Aad et al. (ATLAS Collaboration) "Differential cross-section measurements for the electroweak production of dijets in association with a Z boson in proton–proton collisions at ATLAS" European Physical Journal C 81 (2021) 163 DOI:10.1140/epjc/s10052-020-08734-w

[36] G. Aad et al. (ATLAS Collaboration) "Measurements of WH and ZH production in the H→ bb¯ decay channel in pp collisions at 13Te with the ATLAS detector" European Physical Journal C 81 (2021) 178 DOI:10.1140/epjc/s10052-020-08677-2

[37] G. Aad et al. (ATLAS Collaboration) "Search for squarks and gluinos in final states with jets and missing transverse momentum using 139 fb−1 of √s = 13 TeV pp collision data with the ATLAS detector" Journal of High Energy Physics 2021 (2021) 143 DOI:10.1007/JHEP02(2021)143

[38] G. Aad et al. (ATLAS Collaboration) "Search for type-III seesaw heavy leptons in dilepton final states in pp collisions at √s=13TeV with the ATLAS detector" European Physical Journal C 81 (2021) 218 DOI:10.1140/epjc/s10052-021-08929-9

[39] G. Aad et al. (ATLAS Collaboration) "Medium-Induced Modification of Z -Tagged Charged Particle Yields in Pb+Pb Collisions at 5.02 TeV with the ATLAS Detector" Physical Review Letters 126 (2021) 72301 DOI:10.1103/PhysRevLett.126.072301

[40] G. Aad et al. (ATLAS Collaboration) "Longitudinal Flow Decorrelations in Xe+Xe Collisions at sNN =5.44 TeV with the ATLAS Detector" Physical Review Letters 126 (2021) 122301 DOI:10.1103/PhysRevLett.126.122301

[41] G. Aad et al. (ATLAS Collaboration) "Search for Dark Matter Produced in Association with a Dark Higgs Boson Decaying into W±Wa" or ZZ in Fully Hadronic Final States from s =13 TeV pp Collisions Recorded with the ATLAS Detector" Physical Review Letters 126 (2021) 121802 DOI:10.1103/PhysRevLett.126.121802

[42] G. Aad et al. (ATLAS Collaboration) "Search for Higgs boson production in association with a high-energy photon via vector-boson fusion with decay into bottom quark pairs at √s = 13 TeV with the ATLAS detector" Journal of High Energy Physics 2021 (2021) 268 DOI:10.1007/JHEP03(2021)268

[43] G. Aad et al. (ATLAS Collaboration) "Search for pair production of scalar leptoquarks decaying into first- or second-generation leptons and top quarks in proton–proton collisions at √s = 13 TeV with the ATLAS detector" European Physical Journal C 81 (2021) 313 DOI:10.1140/epjc/s10052-021-09009-8

[44] G. Aad et al. (ATLAS Collaboration) "Measurements of top-quark pair single- and double-differential cross-sections in the all-hadronic channel in pp collisions at √s = 13 TeV using the ATLAS detector" Journal of High Energy Physics 2021 (2021) 33 DOI:10.1007/JHEP01(2021)033

[45] G. Aad et al. (ATLAS Collaboration) "Search for heavy resonances decaying into a pair of Z bosons in the ℓ+ℓ-ℓ′ +ℓ′ - and ℓ+ℓ-νν¯ final states using 139 fb - 1 of proton–proton collisions at √s=13 TeV with the ATLAS detector" European Physical Journal C 81 (2021) 332 DOI:10.1140/epjc/s10052-021-09013-y

[46] G. Aad et al. (ATLAS Collaboration) "Optimisation of large-radius jet reconstruction for the ATLAS detector in 13 TeV proton–proton collisions" European Physical Journal C 81 (2021) 334 DOI:10.1140/epjc/s10052-021-09054-3

[47] G. Aad et al. (ATLAS Collaboration) "Search for new phenomena in events with two opposite-charge leptons, jets and missing transverse momentum in pp collisions at √s = 13 TeV with the ATLAS detector" Journal of High Energy Physics 2021 (2021) 165 DOI:10.1007/JHEP04(2021)165

[48] G. Aad et al. (ATLAS Collaboration) "Measurement of the CP-violating phase ϕs in Bs0→J/ψϕ decays in ATLAS at 13 TeV" European Physical Journal C 81 (2021) 342 DOI:10.1140/epjc/s10052-021-09011-0

[49] G. Aad et al. (ATLAS Collaboration) "Search for new phenomena with top quark pairs in final states with one lepton, jets, and missing transverse momentum in pp collisions at √s = 13 TeV with the ATLAS

detector" Journal of High Energy Physics 2021 (2021) 174 DOI:10.1007/JHEP04(2021)174

[50] G. Aad et al. (ATLAS Collaboration) "Search for a heavy Higgs boson decaying into a Z boson and another heavy Higgs boson in the ℓℓbb and ℓℓWW final states in pp collisions at √s=13 TeV with the ATLAS detector" European Physical Journal C 81 (2021) 396 DOI:10.1140/epjc/s10052-021-09117-5

[51] G. Aad et al. (ATLAS Collaboration) "Search for new phenomena in final states with b-jets and missing transverse momentum in √s = 13 TeV pp collisions with the ATLAS detector" Journal of High Energy Physics 2021 (2021) 93 DOI:10.1007/JHEP05(2021)093

[52] G. Aad et al. (ATLAS Collaboration) "Search for new phenomena in events with an energetic jet and missing transverse momentum in pp collisions at s =13 TeV with the ATLAS detector" Physical Review D 103 (2021) 112006 DOI:10.1103/PhysRevD.103.112006

[53] G. Aad et al. (ATLAS Collaboration) "Measurements of W + W −+ ≥ 1 jet production cross-sections in pp collisions at √s = 13 TeV with the ATLAS detector" Journal of High Energy Physics 2021 (2021) 3 DOI:10.1007/JHEP06(2021)003

[54] G. Aad et al. (ATLAS Collaboration) "Measurement of the jet mass in high transverse momentum Z(→bb¯)γ production at s=13TeV using the ATLAS detector" Physics Letters, Section B: Nuclear, Elementary Particle and High-Energy Physics 812 (2021) 135991 DOI:10.1016/j.physletb.2020.135991

[55] G. Aad et al. (ATLAS Collaboration) "Search for trilepton resonances from chargino and neutralino pair production in s =13 TeV pp collisions with the ATLAS detector" Physical Review D 103 (2021) 112003 DOI:10.1103/PhysRevD.103.112003

[56] G. Aad et al. (ATLAS Collaboration) "Search for charged Higgs bosons decaying into a top quark and a bottom quark at √s = 13 TeV with the ATLAS detector" Journal of High Energy Physics 2021 (2021) 145 DOI:10.1007/JHEP06(2021)145

[57] G. Aad et al. (ATLAS Collaboration) "Measurements of Higgs bosons decaying to bottom quarks from vector boson fusion production with the ATLAS experiment at √s=13TeV" European Physical Journal C 81 (2021) 537 DOI:10.1140/epjc/s10052-021-09192-8

[58] G. Aad et al. (ATLAS Collaboration) "Measurement of the associated production of a Higgs boson decaying into b-quarks with a vector boson at high transverse momentum in pp collisions at s=13 TeV with the ATLAS detector" Physics Letters, Section B: Nuclear, Elementary Particle and High-Energy Physics 816 (2021) 136204 DOI:10.1016/j.physletb.2021.136204

[59] G. Aad et al. (ATLAS Collaboration) "A search for the dimuon decay of the Standard Model Higgs boson with the ATLAS detector" Physics Letters, Section B: Nuclear, Elementary Particle and High-Energy Physics 812 (2021) 135980 DOI:10.1016/j.physletb.2020.135980

[60] G. Aad et al. (ATLAS Collaboration) "Two-particle azimuthal correlations in photonuclear ultraperipheral Pb+Pb collisions at 5.02 TeV with ATLAS" Physical Review C 104 (2021) 14903 DOI:10.1103/PhysRevC.104.014903

[61] G. Aad et al. (ATLAS Collaboration) "Evidence for Higgs boson decays to a low-mass dilepton system and a photon in pp collisions at s=13 TeV with the ATLAS detector" Physics Letters, Section B: Nuclear, Elementary Particle and High-Energy Physics 819 (2021) 136412 DOI:10.1016/j.physletb.2021.136412

[62] G. Aad et al. (ATLAS Collaboration) "Search for doubly and singly charged Higgs bosons decaying into vector bosons in multi-lepton final states with the ATLAS detector using proton-proton collisions at √s = 13 TeV" Journal of High Energy Physics 2021 (2021) 146 DOI:10.1007/JHEP06(2021)146

[63] G. Aad et al. (ATLAS Collaboration) "Test of the universality of τ and μ lepton couplings in W-boson decays with the ATLAS detector" Nature Physics 17 (2021) 813-818 DOI:10.1038/s41567-021-01236-w

[64] G. Aad et al. (ATLAS Collaboration) "Search for pair production of third-generation scalar leptoquarks decaying into a top quark and a τ-lepton in pp collisions at √s = 13 TeV with the ATLAS detector" Journal of High Energy Physics 2021 (2021) 179 DOI:10.1007/JHEP06(2021)179

[65] G. Aad et al. (ATLAS Collaboration) "Measurements of differential cross-sections in four-lepton events in 13 TeV proton-proton collisions with the ATLAS detector" Journal of High Energy Physics 2021 (2021) 5 DOI:10.1007/JHEP07(2021)005

[66] G. Aad et al. (ATLAS Collaboration) "Search for charged-lepton-flavour violation in Z-boson decays with the ATLAS detector" Nature Physics 17 (2021) 819-825 DOI:10.1038/s41567-021-01225-z

[67] G. Aad et al. (ATLAS Collaboration) "A search for the decays of stopped long-lived particles at √s = 13 TeV with the ATLAS detector" Journal of High Energy Physics 2021 (2021) 173 DOI:10.1007/JHEP07(2021)173

[68] G. Aad et al. (ATLAS Collaboration) "Search for supersymmetry in events with four or more charged leptons in 139 fb−1 of √s = 13 TeV pp collisions with the ATLAS detector" Journal of High Energy Physics 2021 (2021) 167 DOI:10.1007/JHEP07(2021)167

[69] G. Aad et al. (ATLAS Collaboration) "Jet energy scale and resolution measured in proton–proton collisions at √s=13 TeV with the ATLAS detector" European Physical Journal C 81 (2021) 689 DOI:10.1140/epjc/s10052-021-09402-3

[70] G. Aad et al. (ATLAS Collaboration) "Measurement of single top-quark production in association with a W boson in the single-lepton channel at √s=8TeV with the ATLAS detector" European Physical Journal C 81 (2021) 720 DOI:10.1140/epjc/s10052-021-09371-7

[71] G. Aad et al. (ATLAS Collaboration) "Performance of the ATLAS RPC detector and Level-1 muon barrel trigger at √s = 13 TeV" Journal of Instrumentation 16 (2021) P07029 DOI:10.1088/1748-0221/16/07/P07029

[72] G. Aad et al. (ATLAS Collaboration) "Search for Displaced Leptons in s =13 TeV pp Collisions with the ATLAS Detector" Physical Review Letters 127 (2021) 51802 DOI:10.1103/PhysRevLett.127.051802

[73] G. Aad et al. (ATLAS Collaboration) "Determination of the parton distribution functions of the proton from ATLAS measurements of differential W± and Z boson production in association with jets" Journal of High Energy Physics 2021 (2021) 223 DOI:10.1007/JHEP07(2021)223

[74] G. Aad et al. (ATLAS Collaboration) "Observation of photon-induced W+W− production in pp collisions at s=13 TeV using the ATLAS detector" Physics Letters, Section B: Nuclear, Elementary Particle and High-Energy Physics 816 (2021) 136190 DOI:10.1016/j.physletb.2021.136190

[75] G. Aad et al. (ATLAS Collaboration) "The ATLAS fast TracKer system" Journal of Instrumentation 16 (2021) P07006 DOI:10.1088/1748-0221/16/07/P07006

[76] G. Aad et al. (ATLAS Collaboration) "Measurements of the inclusive and differential production cross sections of a top-quark–antiquark pair in association with a Z boson at √s=13 TeV with the ATLAS detector" European Physical Journal C 81 (2021) 737 DOI:10.1140/epjc/s10052-021-09439-4

[77] M. Aaboud et al. (ATLAS Collaboration) "Measurement of the relative Bc± /B± production cross section with the ATLAS detector at s =8 TeV MEASUREMENT of the RELATIVE Bc± /B± ... AABOUD M. et al." Physical Review D 104 (2021) 12010 DOI:10.1103/PhysRevD.104.012010

[78] G. Aad et al. (ATLAS Collaboration) "Measurements of sensor radiation damage in the ATLAS inner detector using leakage currents" Journal of Instrumentation 16 (2021) P08025 DOI:10.1088/1748-0221/16/08/P08025

[79] G. Aad et al. (ATLAS Collaboration) "Search for bottom-squark pair production in pp collision events at s =13 TeV with hadronically decaying τ -leptons, b -jets, and missing transverse momentum using the ATLAS detector" Physical Review D 104 (2021) 32014 DOI:10.1103/PhysRevD.104.032014

[80] G. Aad et al. (ATLAS Collaboration) "Exclusive dimuon production in ultraperipheral Pb + Pb collisions at √sNN= 5.02 TeV with ATLAS" Physical Review C 104 (2021) 24906 DOI:10.1103/PhysRevC.104.024906

[81] G. Aad et al. (ATLAS Collaboration) "Search for dark matter produced in association with a single top quark in √s=13 TeV pp collisions with the ATLAS detector" European Physical Journal C 81 (2021) 860 DOI:10.1140/epjc/s10052-021-09566-y

[82] G. Aad et al. (ATLAS Collaboration) "Search for dark matter in events with missing transverse momentum and a Higgs boson decaying into two photons in pp collisions at √s = 13 TeV with the ATLAS detector" Journal of High Energy Physics 2021 (2021) 13 DOI:10.1007/JHEP10(2021)013

[83] G. Aad et al. (ATLAS Collaboration) "Search for New Phenomena in Final States with Two Leptons and One or No b -Tagged Jets at s =13 TeV Using the ATLAS Detector" Physical Review Letters 127 (2021) A56 DOI:10.1103/PhysRevLett.127.141801

[84] G. Aad et al. (ATLAS Collaboration) "Search for resonances decaying into photon pairs in 139 fb−1 of pp collisions at s=13 TeV with the ATLAS detector" Physics Letters, Section B: Nuclear, Elementary Particle and High-Energy Physics 822 (2021) 136651 DOI:10.1016/j.physletb.2021.136651

[85] G. Aad et al. (ATLAS Collaboration) "Search for R-parity-violating supersymmetry in a final state containing leptons and many jets with the ATLAS experiment using √s=13TeV proton–proton collision data" European Physical Journal C 81 (2021) 1023 DOI:10.1140/epjc/s10052-021-09761-x

[86] G. Aad et al. (ATLAS Collaboration) "Measurement of the t t¯ t t¯ production cross section in pp collisions at √s = 13 TeV with the ATLAS detector" Journal of High Energy Physics 2021 (2021) 118 DOI:10.1007/JHEP11(2021)118

[87] G. Aad et al. (ATLAS Collaboration) "Configuration and performance of the ATLAS b-jet triggers in Run 2" European Physical Journal C 81 (2021) 1087 DOI:10.1140/epjc/s10052-021-09775-5

[88] G. Aad et al. (ATLAS Collaboration) "Measurement of the production cross section of pairs of isolated photons in pp collisions at 13 TeV with the ATLAS detector" Journal of High Energy Physics 2021 (2021) 169 DOI:10.1007/JHEP11(2021)169

[89] G. Aad et al. (ATLAS Collaboration) "Search for exotic decays of the Higgs boson into long-lived particles in pp collisions at √s = 13 TeV using displaced vertices in the ATLAS inner detector" Journal of High Energy Physics 2021 (2021) 229 DOI:10.1007/JHEP11(2021)229

[90] G. Aad et al. (ATLAS Collaboration) "Search for chargino–neutralino pair production in final states with three leptons and missing transverse momentum in √s=13 TeV pp collisions with the ATLAS detector" European Physical Journal C 81 (2021) 1118 DOI:10.1140/epjc/s10052-021-09749-7

[91] G. Aad et al. (ATLAS Collaboration) "Measurement of b-quark fragmentation properties in jets using the decay B ± → J/ψK ± in pp collisions at √s = 13 TeV with the ATLAS detector" Journal of High Energy Physics 2021 (2021) 131 DOI:10.1007/JHEP12(2021)131

[92] G. Aad et al. (ATLAS Collaboration) "Search for new phenomena in pp collisions in final states with tau leptons, b -jets, and missing transverse momentum with the ATLAS detector" Physical Review D 104 (2021) A41 DOI:10.1103/PhysRevD.104.112005

[93] G. Aad et al. (ATLAS Collaboration) "Search for charginos and neutralinos in final states with two boosted hadronically decaying bosons and missing transverse momentum in pp collisions at s =13 TeV

with the ATLAS detector" Physical Review D 104 (2021) A45 DOI:10.1103/PhysRevD.104.112010

[94] G. Aad et al. (ATLAS Collaboration) "Search for Lepton-Flavor Violation in Z -Boson Decays with τ Leptons with the ATLAS Detector" Physical Review Letters 127 (2021) 271801 DOI:10.1103/PhysRevLett.127.271801

[95] G. Aad et al. (ATLAS Collaboration) "Search for dark matter in association with an energetic photon in pp collisions at √s = 13 TeV with the ATLAS detector" Journal of High Energy Physics 2021 (2021) 226 DOI:10.1007/JHEP02(2021)226

[96] G. Aad et al. (ATLAS Collaboration) "Search for dark matter produced in association with a Standard Model Higgs boson decaying into b-quarks using the full Run 2 dataset from the ATLAS detector" Journal of High Energy Physics 2021 (2021) 209 DOI:10.1007/JHEP11(2021)209

[97] G. Aad et al. (ATLAS Collaboration) "Muon reconstruction and identification efficiency in ATLAS using the full Run 2 pp collision data set at √s=13 TeV" European Physical Journal C 81 (2021) 578 DOI:10.1140/epjc/s10052-021-09233-2

[98] Y. Sugiyama et al. (KOTO Collaboration) "Pulse shape discrimination of photons and neutrons in the energy range of 0.1 – 2 GeV with the KOTO un-doped CsI calorimeter" Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 987 (2021) 164825 DOI:10.1016/j.nima.2020.164825

[99] J. K. Ahn et al. (KOTO Collaboration) "Study of the KL → π0 ν ν Decay at the J-PARC KOTO Experiment" Physical Review Letters 126 (2021) 121801 DOI:10.1103/PhysRevLett.126.121801

[100] I. Abt et al (ZEUS Collaboration) "Azimuthal correlations in photoproduction and deep inelastic ep scattering at HERA" Journal of High Energy Physics 2021 (2021) 102 DOI:10.1007/JHEP12(2021)102

[101] S. Wehle et al. (Belle Collaboration) "Test of Lepton-Flavor Universality in B →k∗ℓ+ℓ- Decays at Belle" Physical Review Letters 126 (2021) 161801 DOI:10.1103/PhysRevLett.126.161801

[102] M. Nakao et al. (Belle Collaboration) "Performance of the Unified Readout System of Belle II" IEEE Transactions on Nuclear Science 68 (2021) 1826-1832 DOI:10.1109/TNS.2021.3084826

[103] K. Uno et al. (Belle Collaboration) "Search for lepton-flavor-violating tau-lepton decays to ℓγ at Belle" Journal of High Energy Physics 2021 (2021) 19 DOI:10.1007/JHEP10(2021)019

[104] F. Abudinén et al. (Belle II Collaboration) "Search for Decays Using an Inclusive Tagging Method at Belle II" Physical Review Letters 127 (2021) 181802 DOI:10.1103/PhysRevLett.127.181802

[105] F. Abudinén et al. (Belle II Collaboration) "Precise Measurement of the D0 and D+ Lifetimes at Belle II" Physical Review Letters 127 (2021) 211801 DOI:10.1103/PhysRevLett.127.211801

2. Review Article

[106] A. Stakia et al. "Advances in Multi-Variate Analysis Methods for New Physics Searches at the Large Hadron Collider" Reviews in Physics 7 (2021) 100063 DOI:10.1016/j.revip.2021.100063

3. Procedings

[107] Y. Segawa et al. "Method for rapid performance validation of large TES bolometer array for POLARBEAR-2A using a coherent millimeter-wave source" AIP Conference Proceedings 2319 (2021) 40019 DOI:10.1063/5.0038197

[108] C. Solans Sánchez et al. "Radiation hard monolithic CMOS sensors with small electrodes for the HL-LHC and beyond" PoS ICHEP2020 (2021) 871 DOI:10.22323/1.390.0871

4. Other English article

[109] A. Biekert et al. (SPICE/HeRALD Collaboration) "Scintillation yield from electronic and nuclear recoils in superfluid 4He" Archive (2021) 2108.02176 DOI:10.48550/arXiv.2108.02176

2. Invited Lectures, Plenary Addresses (etc.) at International Conferences and International Research Meetings

- List up to 10 main presentations during FY 2021 in order from most recent.
- For each, write the date(s), lecturer/presenter's name, presentation title, and conference name.

Date(s)	Lecturer/Presenter's name	Presentation title	Conference name
February 8, 2022	Masashi Hazumi	"QUP Overview and "Project Q"	KEK IPNS-IMSS-QUP Joint workshop
February 8, 2022	Maurice Garcia-Sciveres	"Quantum sensing consortium for a new underground cryogenic facility at Kamioka"	KEK IPNS-IMSS-QUP Joint workshop
February 8, 2022	Kazunori Nakayama	"New particle search and condensed matter physics"	KEK IPNS-IMSS-QUP Joint workshop
July 29, 2021	Masashi Hazumi	"Cosmology with Low-Temperature Detectors"	19th International Workshop on Low Temperature Detectors (LTD19)

3. Major Awards

- List up to 10 main awards received during FY 2021 in order from the most recent.
- For each, write the date issued, the recipient's name, and the name of award.
- In case of multiple recipients, underline those affiliated with the center.

Date	Recipient's name	Name of award
None		

Appendix 2 FY 2021 List of Principal Investigators

NOTE:
*Underline names of principal investigators who belong to an overseas research institution.
*In the case of researcher(s) not listed in the in the proposal for newly selected centers in FY2021, attach a "Biographical Sketch of a New Principal Investigator"(Appendix 2a).
*Enter the host institution name and the center name in the footer.

<Results at the end of FY2021> **Principal Investigators Total: 13**

Name	Age	Affiliation (Position title, department, organization)	Academic degree, specialty	Effort (%)*	Starting date of project participation	Status of project participation (Describe in concrete terms)	Contributions by PIs from overseas research institutions
Center director Masashi Hazumi	57	High Energy Accelerator Research Organization(KEK), Institute of Particle and Nuclear Studies(IPNS), and International Center for Quantum-field Measurement Systems for Studies of the Universe and Particles(QUP), Professor	PhD, Physics	80	2021/10/1	Mostly stays at the center.	
<u>Daniela Bortoletto</u>	63	University of Oxford, Professor, Head of Particle Physics	PhD, Physics	20	2021/10/1	joins videoconference meetings (PI meeting (every week) and occasional meetings with the director (once a month)) from another institution.	Contributions via videoconference in this fiscal year.
<u>Mauricio A. Garcia-Sciveres</u>	55	Lawrence Berkeley National Laboratory, Senior Scientist	PhD, Physics	20	2021/10/1	joins videoconference meetings (PI meeting (every week), and occasional meetings with the director and other PIs (~ every week)) from another institution.	Contributions via videoconference in this fiscal year.
Masaya Hasegawa	43	KEK,IPNS, Associate Professor	PhD, Physics	70	2021/10/1	Mostly stays at the center.	

Kaori Hattori	40	National Institute of Advanced Industrial Science and Technology (AIST), Research Institute for Physical Measurement, Senior Researcher	PhD, Physics	40	2021/10/1	stays at the center once a month and joins videoconference meetings (PI meeting (every week) and occasional meetings with the director (once a month)) from another institution.	
Hideo Iizuka	49	Toyota Central R&D Labs., Inc., Senior Fellow	Doctor of Engineering	40	2021/10/1	joins videoconference meetings (PI meeting (every week) and occasional meetings with the director (once a month)) from another institution.	
Adrian Tae-Jin Lee	57	University of California, Berkeley, Professor	PhD, Physics	50	2021/10/1	joins videoconference meetings (PI meeting (every week), steering committee meeting (every month), Flagship project meeting (every week) and occasional meetings with the director (once a month)) from another institution.	Contributions via videoconference in this fiscal year.
Masaya Miyahara	41	KEK,IPNS, Associate Professor	Doctor of Engineering, ASIC design	70	2021/10/1	Mostly stays at the center.	
Yu Nakahama	40	KEK,IPNS, Associate Professor	PhD, Physics	70	2021/10/1	Mostly stays at the center.	
Kazunori Nakayama	39	Tohoku University, Graduate School of Science and Faculty of Science, Associate Professor	PhD, Physics	30	2021/10/1	joins videoconference meetings (PI meeting (every week) and occasional meetings with the director (once a month)) from another institution.	

Nanae Taniguchi	42	KEK,IPNS, Assistant Professor	PhD, Physics	70	2021/10/1	Mostly stays at the center.	
Manabu Togawa	43	KEK,IPNS, Associate Professor	PhD, Physics	70	2021/10/1	Mostly stays at the center.	
Noriko Yamasaki	55	Japan Aerospace Exploration Agency (JAXA), Institute of Space and Astronautical Science (ISAS), Professor	PhD, Physics	20	2021/10/1	joins videoconference meetings (PI meeting (every week) and occasional meetings with the director (once a month)) from another institution.	

*Percentage of time that the principal investigator devotes to working for the center vis-à-vis his/her total working hours.

Principal investigators unable to participate in project in FY 2021

Name	Affiliation (Position title, department, organization)	Starting date of project participation	Reasons	Measures taken
None				

Appendix 2a Biographical Sketch of a New Principal Investigator

(within 3 pages per person)

There is no additional new PI compared with the proposal.

Appendix 3-1 FY 2021 Records of Center Activities

1. Researchers and center staff, satellites, partner institutions

1-1. Number of researchers in the "core" established within the host institution

- Regarding the number of researchers at the Center, fill in the table in Appendix 3-1a.

Special mention

- Enter matters warranting special mention, such as concrete plans for achieving the Center's goals, established schedules for employing main researchers, particularly principal investigators.
- As background to how the Center is working on the global circulation of world's best brains, give good examples, if any, of how career paths are being established for the Center's researchers; that is, from which top-world research institutions do researchers come to the Center and to which research institutions do the Center's researchers go, and how long are their stays at those institutions.

International Center for Quantum-field Measurement Systems for Studies of the Universe and Particles (QUP) officially launched on December 16, 2021, with the appointment of Masashi Hazumi as Director (Professor of Institute of Particle and Nuclear Studies (IPNS), KEK) and Kazunori Hanagaki as Deputy (Professor of IPNS, KEK). All thirteen initial PIs, who were listed in the proposal and were participating in the designing the structure of the QUP even before it was official founded on December 16, have been officially appointed by February 2022. QUP administration office was started with 3 persons from KEK administration.

No other staffs were appointed in FY2021 but, with the open job call, three additional staffs in the QUP administrative office and two in the QUP strategy office were appointed and they will work since April 1 in 2022.

The job opening for the QUP postdoctoral fellows started in January. The call was through academic jobs online, a common platform for many international institutes, and visible among the worldwide young researchers. By the end of March, there were 74 applicants registered, and the selection process is ongoing.

The selection of senior scientists is under the discussions at the QUP steering committee and with the KEK directorates including directors of KEK institutes and laboratories.

The recruiting plan up to the first half of FY2022 is indicated in the QUP diagram shown in the section 3 of Appendix 3-1.

1-2. Satellites and partner institutions

- List the satellite and partner institutions in the table below.
- Indicate newly added and deleted institutions in the "Notes" column.
- If satellite institutions have been established overseas, describe by satellite the Center's achievements in coauthored papers and researcher exchanges in Appendix 4.

<Satellite institutions>

Institution name	Principal Investigator(s), if any	Notes
QUP Space and Astronautical Science Satellite	Noriko Yamasaki	MOU was signed with ISAS/JAXA on March 23, 2022

< Partner institutions>

Institution name	Principal Investigator(s), if any	Notes
Toyota Central R&D Labs., Inc.	Hideo Iizuka	Research cooperation agreement as signed in January and a QUP satellite at Toyota Central R&D Labs., Inc. is ready to start at April 1 in 2022.
Kavli IPMU	None	MOU on scientific collaboration
SOKENDAI	KEK's PIs (M. Hazumi, M. Hasegawa, M. Miyahara, Y. Nakahama, N. Taniguchi, and M. Togawa) also belong to SOKENDAI.	MOU on education of graduate students.

2. Holding international research meetings

- Indicate the number of international research conferences or symposiums held in FY2021 and give up to three examples of the most representative ones using the table below.

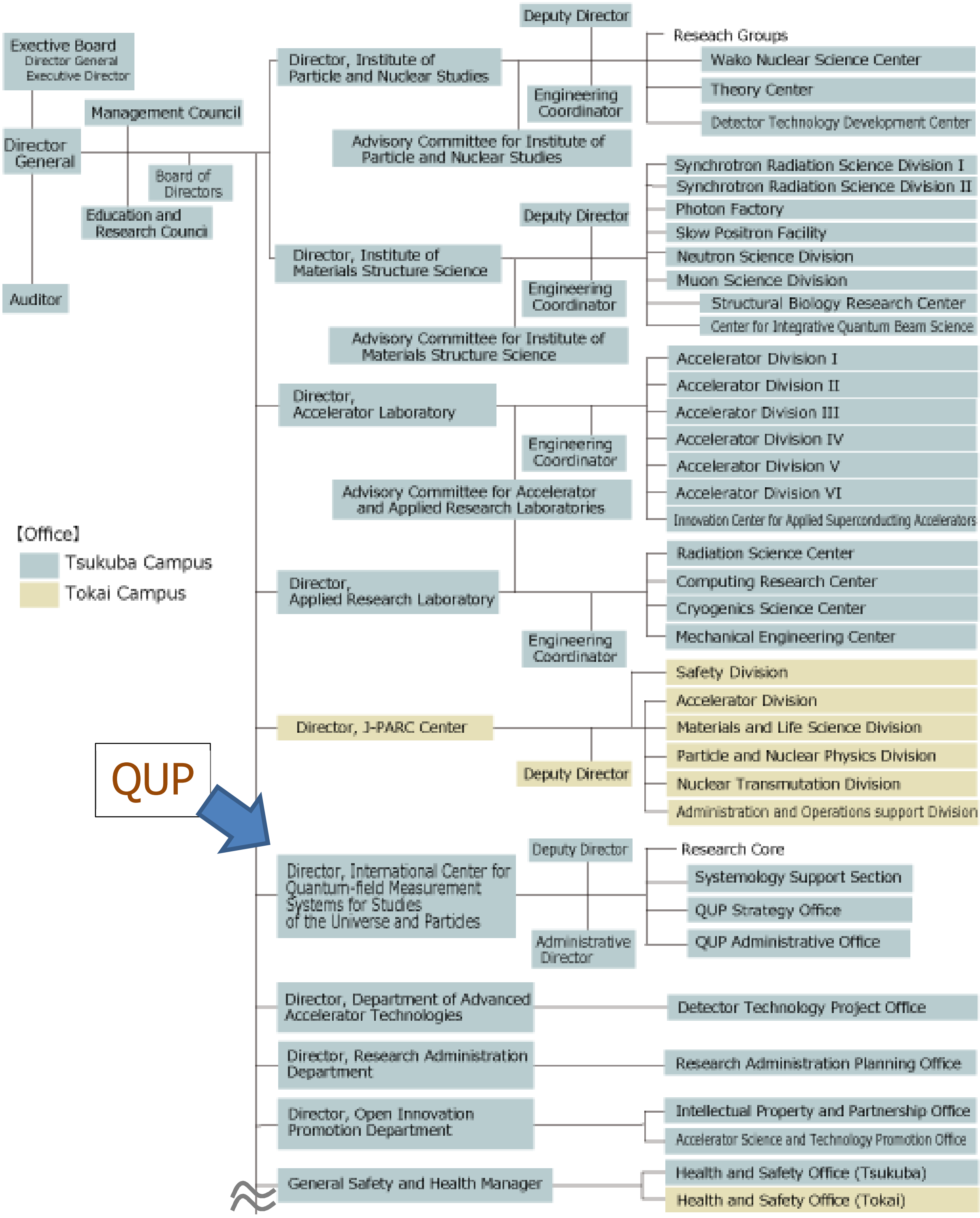
FY 2021: 1 meeting

Major examples (meeting titles and places held)	Number of participants
KEK IPNS-IMSS-QUP Joint workshop (February 8-10, video-only)	From domestic institutions: 151 From overseas institutions: 11

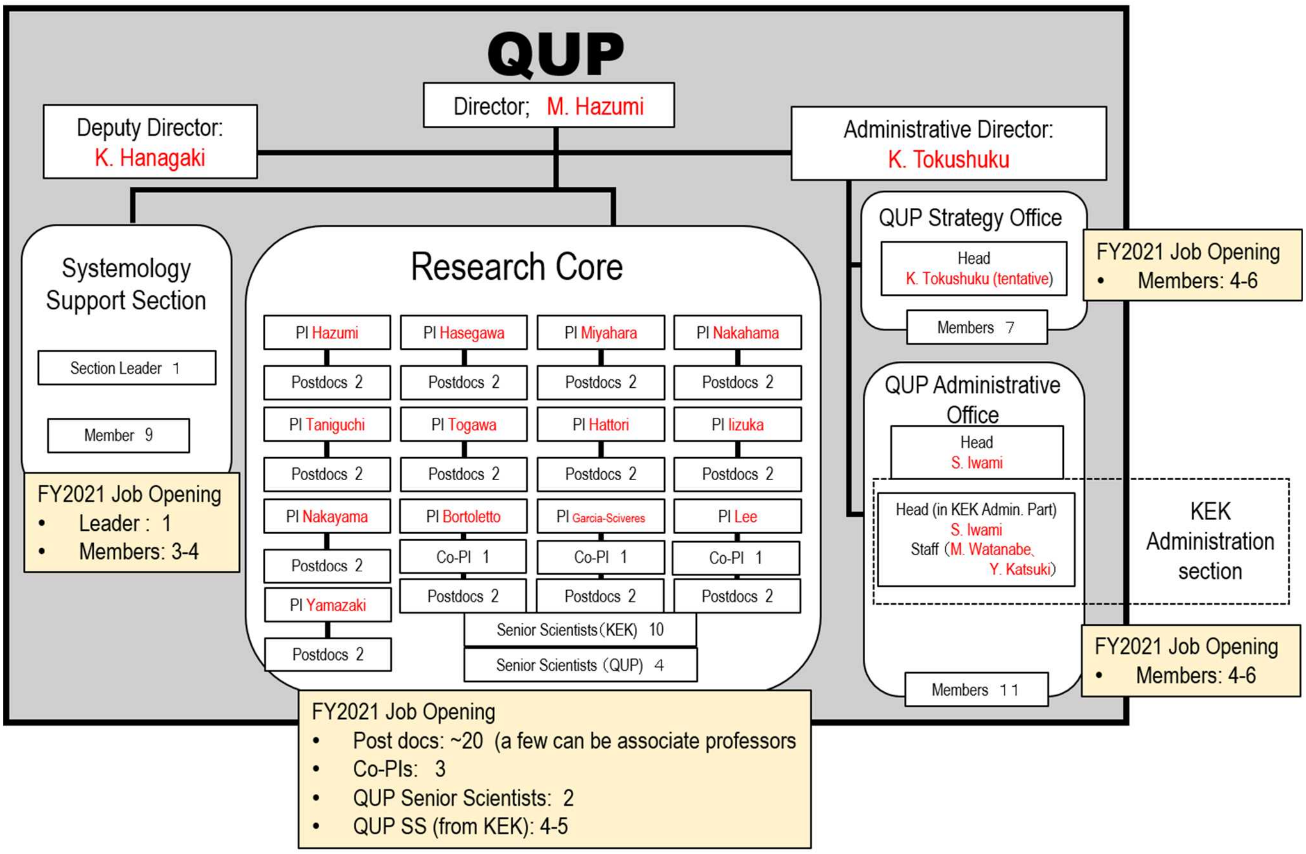
3. Diagram of management system

- Diagram the center's management system and its position within the host institution in an easily understood manner.
- If any new changes have been made in the management system from that in the latest "center project" last year, describe them. Especially describe any important changes made in such as the center director, administrative director, head of host institution, and officer(s) in charge at the host institution (e.g., executive vice president for research).

The organization chart of KEK is shown below, which is accessible from https://www.kek.jp/en/about-en/organization-en/chart-en/. QUP is positioned in the same rank as the main KEK institutes and laboratories.

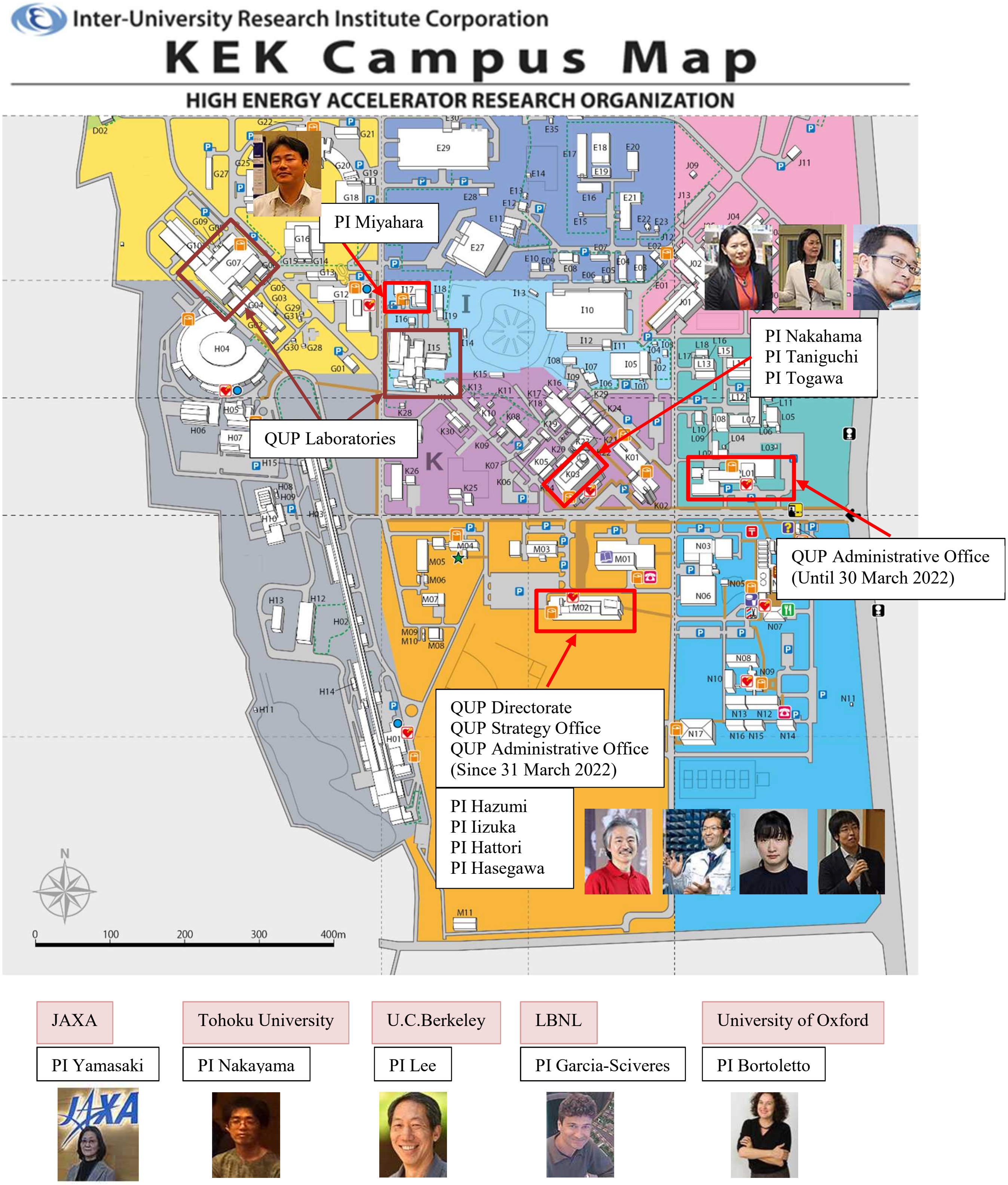


The Diagram of the QUP is shown in below, together with the names of directors and PIs already in the position in red as of March 31, 2022. The structure is unchanged from what described in the proposal. The number in each box indicates the number of staff planned in the proposal. Boxes in yellow show the recruitment plan starting in FY2021. As scheduled in the proposal, we are aiming for the full personal configuration in the third year, i.e. FY2023.



4. Campus Map

- Draw a simple map of the campus showing where the main office and principal investigator(s) are located.



5. Securing external research funding*

External research funding secured in FY2021

Total: 197,478,986 yen

- Describe external funding warranting special mention. Include the name and total amount of each grant.

* External research funding includes "KAKENHI," funding for "commissioned research projects," "joint research projects," and for others (donations, etc.) as listed under "Research projects" in Appendix 3-2, Project Expenditures.

Appendix 3-1a FY 2021 Records of Center Activities

Researchers and other center staff

Number of researchers and other center staff

* Fill in the number of researchers and other center staff in the table blow.
* Describe the final goals for achieving these numbers and dates when they will be achieved described in the last "center project."

a) Principal Investigators

(full professors, associate professors or other researchers of comparable standing)

(number of persons)

	At the beginning of project	At the end of FY 2021	Final goal (Date: March, 2024)
Researchers from within the host institution	6	6	6
Researchers invited from overseas	3	3	3
Researchers invited from other Japanese institutions	4	4	4
Total principal investigators	13	13	13

b) Total members

	At the beginning of project		At the end of FY 2021		Final goal (Date: March, 2024)	
	Number of persons	%	Number of persons	%	Number of persons	%
Researchers	15		15		67	
Overseas researchers	3	20	3	20	27	40
Female researchers	5	33	5	33	24	36
Principal investigators	13		13		13	
Overseas PIs	3	23	3	23	3	23
Female PIs	5	38	5	38	5	38
Other researchers	2		2		14	
Overseas researchers	0	0	0	0	4	29
Female researchers	0	0	0	0	4	29
Postdocs	0		0		40	
Overseas postdocs	0	0	0	0	20	50
Female postdocs	0	0	0	0	15	38
Research support staffs	0		2		20	
Administrative staffs	3		4		25	
Total number of people who form the "core" of the research center	18		21		112	

Appendix 3-2 Project Expenditures

1) Overall project funding

* In the "Total costs" column, enter the total amount of funding required to implement the project, without dividing it into funding sources.
* In the "Amount covered by WPI funding" column, enter the amount covered by WPI within the total amount.
* In the "Personnel," "Project activities," "Travel," and "Equipment" blocks, the items of the "Details" column may be changed to coincide with the project's actual content.

(Million yens)

Cost items	Details (For Personnel - Equipment please fill in the breakdown of fiscal expenditure, and the income breakdown for Research projects.)	Total costs	Amount covered by WPI funding
Personnel	Center director and administrative director	8.5	6.7
	Principal investigators (no. of persons):12	111.8	0.0
	Other researchers (no. of persons):1	3.2	0.0
	Research support staff (no. of persons):3	1.5	1.5
	Administrative staff (no. of persons):4	11.5	3.0
	Subtotal	136.6	11.3
Project activities	Gratuities and honoraria paid to invited principal investigators (no. of persons):0	0.0	0.0
	Cost of dispatching scientists (no. of persons):2	1.8	1.5
	Research startup cost (no. of persons):15	33.3	28.3
	Cost of satellite organizations (no. of satellite organizations):0	0.0	0.0
	Cost of international symposiums (no. of symposiums):0	0.0	0.0
	Rental fees for facilities	146.4	18.8
	Cost of consumables	2.7	1.5
	Cost of utilities	0.0	0.0
	Other costs	19.5	6.4
	Subtotal	203.7	56.4
Travel	Domestic travel costs	0.4	0.4
	Overseas travel costs		
	Travel and accommodations cost for invited scientists (no. of domestic scientists):OO (no. of overseas scientists):OO		
	Travel cost for scientists on transfer (no. of domestic scientists):OO (no. of overseas scientists):OO		
	Subtotal	0.4	0.4
Equipment	Depreciation of buildings	2.7	2.7
	Depreciation of equipment	92.2	89.2
	Subtotal	94.9	91.9
Research projects (Detail items must be fixed)	Project supported by other government subsidies, etc. *1		
	KAKENHI	30.6	
	Commissioned research projects, etc.	166.9	
	Joint research projects		
	Ohers (donations, etc.)		
	Subtotal	197.5	0.0
Total		633.1	160.0

Costs (Million yens)

	Costs
WPI grant in FY 2021	160.0
Costs of establishing and maintaining facilities	2.7
Establishing new facilities (Number of facilities: 0 , 0 m²)	0.0
Fuji Experimental Facility Equipment Renovation (Number of facilities: 1 , 1,150 m²)	2.7
Costs of equipment procured	89.2
Millimeter and THz optical components characterization system	11.6
0.1K cryostat monitoring and operation system	13.3
A/D･D/A PCIe Board for Active vibration isolation system	1.5
Digital microscope and Laser-based Elemental Analyzer	14.9
Stereo microscope	0.0
Electrometer (6517B)	1.4
Vacuum Chamber	2.5
High speed digital data transmission line analyzer	13.1
High voltage semiconductor parameter analyzer	9.9
High resolution analog/digital signal analyzer	8.7
Wide-area precise 3D scanner	9.5
Others	2.6

*1. Management Expenses Grants (including Management Enhancements Promotion Expenses (機能強化経費)), subsidies including National university reform reinforcement promotion subsidy (国立大学改革強化推進補助金) etc., indirect funding, and allocations from the university's own resources.
*2 When personnel, travel, equipment (etc.) expenses are covered by KAKENHI or under commissioned research projects or joint research projects, the amounts should be entered in the "Research projects" block.

*1 運営費交付金（機能強化経費を含む）、国立大学改革強化推進補助金等の補助金、間接経費、その他大学独自の取組による学内リソースの配分等による財源
*2 科研費、受託研究費、共同研究費等によって人件費、旅費、設備備品等費を支出している場合も、その額は「研究プロジェクト費」として計上すること

2) Costs of satellites

(Million yens)

Cost items	Details	Total costs	Amount covered by WPI funding
Personnel	Principal investigators (no. of persons):OO		
	Other researchers (no. of persons):OO		
	Research support staff (no. of persons):OO		
	Administrative staff (no. of persons):OO		
	Subtotal	0	0
Project activities	Subtotal		
Travel	Subtotal		
Equipment	Subtotal		
Research projects	Subtotal		
Total		0	0

Appendix 4 FY 2021 Status of Collaboration with Overseas Satellites

1. Coauthored Papers

- List the refereed papers published in FY 2021 that were coauthored between the center’s researcher(s) in domestic institution(s) (include satellite institutions) and overseas satellite institution(s). List them by overseas satellite institution in the below blocks.
- Transcribe data in same format as in Appendix 1. Italicize the names of authors affiliated with overseas satellite institutions.
- For reference write the Appendix 1 item number in parentheses after the item number in the blocks below. Let it free, if the paper is published in between Jan.-Mar. 2022 and not described in Appendix 1.

There was no overseas satellite in fiscal year 2021. Discussions to launch the Berkeley satellite in University of California has started.

2. Status of Researcher Exchanges

- Using the below tables, indicate the number and length of researcher exchanges in FY 2021. Enter by institution and length of exchange.
- Write the number of principal investigator visits in the top of each space and the number of other researchers in the bottom.

Overseas Satellite 1:

<To satellite>

	Under 1 week	From 1 week to 1 month	From 1 month to 3 months	3 months or longer	Total
FY2021					

<From satellite>

	Under 1 week	From 1 week to 1 month	From 1 month to 3 months	3 months or longer	Total
FY2021					

Overseas Satellite 2:

<To satellite>

	Under 1 week	From 1 week to 1 month	From 1 month to 3 months	3 months or longer	Total
FY2021					

<From satellite>

	Under 1 week	From 1 week to 1 month	From 1 month to 3 months	3 months or longer	Total
FY2021					

Appendix 5 FY 2021 Visit Records of Researchers from Abroad

* If researchers have visited/ stayed at the Center, provide information on them in the below table.
* Enter the host institution name and the center name in the footer.

Total: 0

	Name	Age	Affiliation		Academic degree, specialty	Record of research activities (Awards record, etc.)	Time, duration	Summary of activities during stay at center (e.g., participation as principal investigator; short-term stay for joint research; participation in symposium)
			Position title, department, organization	Country				
1	None							
2								
3								
4								
5								
6								
7								
8								
9								
10								

Appendix 6 FY2021 State of Outreach Activities

* Fill in the numbers of activities and times held during FY2021 by each activity.
* Describe the outreach activities in the "3-1. Societal Value of Basic Research" of Progress Report, including those stated below that warrant special mention.

Activities	FY2021 (number of activities, times held)
PR brochure, pamphlet	One sheet summary of QUP was produced and distributed, for example, in the 10th WPI Science Symposium held in Kanazawa, Japan on December 18.
Lectures, seminars for general public	1 talk on QUP start up by the QUP director, Masashi Hazumi in; a meeting with foreign embassy(S&TDC) organized by the WPI forum and Science and Technology Diplomatic Circle.
Teaching, experiments, training for elementary, secondary and high school students	As a contribution to the WPI Science Symposium held in Kanazawa, a QUP PIs advised on the poster presentation by high school students.
Science café	None
Open houses	None
Participating, exhibiting in events	As listed above, we participated in the 10th WPI Science Symposium and a meeting with foreign embassy organized by the S&TDC-WPI held on January 10th.
Press releases	2 press releases were issued on the start of the new WPI institute, QUP at KEK.; https://www.kek.jp/en/press-en/202110081335/ and https://www.kek.jp/en/press-en/202112151325/.
Publications of the popular science books	None
Others ( )	

*If there are any rows on activities the center didn't implement, delete that (those) row(s). If you have any activities other than the items stated above, fill in the space between parentheses after "Others" on the bottom with the name of those activities and state the numbers of activities and times held in the space on the right. A row of "Others" can be added, if needed.

Outreach Activities and Their Results

List up to three of the Center's outreach activities carried out in FY 2021 that have contributed to enhancing the brand or recognition of your Center and/or the brand of the overall WPI program, and describe its concrete contents and effect in narrative style. (Where possible, indicate the results in concrete numbers.)

Examples:
- As a result of using a new OO press-release method, a OO% increase in media coverage was obtained over the previous year.
- By holding seminars for the public that include people from industry, requests for joint research were received from companies.
- We changed our public relations media. As a resulting of using OO to disseminate information, a OO% increase in inquiries from researchers was obtained over the previous year.
- As a result of vigorously carrying out OO outreach activity, ¥OO in external funding was acquired.

The startup of the QUP seems to be welcome warmly but it is too early to find the impacts.

Appendix 7 FY 2021 List of Project's Media Coverage

* List and describe media coverage (e.g., articles published, programs aired) in FY2021.

* Enter the host institution name and the center name in the footer.

	Date	Types of Media (e.g., newspaper, magazine, television)	Description
1	None		
2			
3			
4			
5			
6			
7			
8			
9			
10			