Summary of Research Center Project

Center name:

International Center for Quantum-field Measurement Systems for Studies of the Universe and Particles (QUP)

Host institution: High Energy Accelerator Research Organization (KEK)

Head of host institution: Masanori Yamauchi, Director General

Prospective Center director:

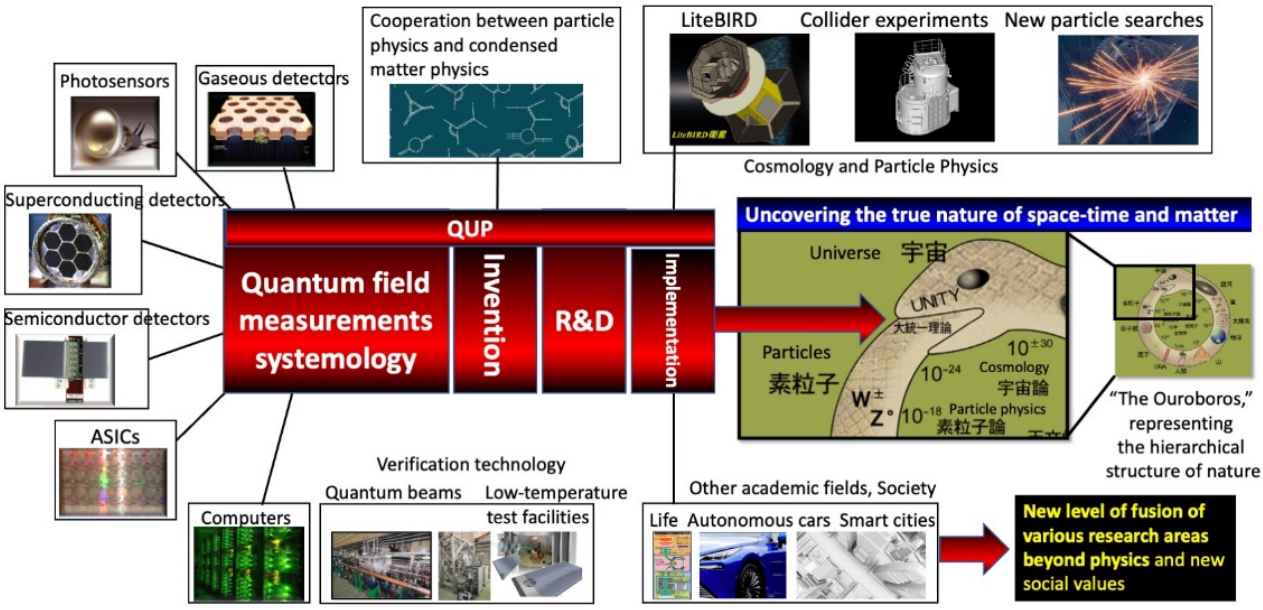
Masashi Hazumi, Professor, Institute of Particle and Nuclear Studies (IPNS), KEK

Prospective Administrative director:

Katsuo Tokushuku, Professor, Institute of Particle and Nuclear Studies (IPNS), KEK

(1) Overall Framework of the Center Project

Physics aims at an essential and unified understanding of the laws behind various physical phenomena ranging from particles to the universe. In physics, new research methods or means to establish the unification theory are highly evaluated, as clearly seen from the past research for which Nobel Prizes have been awarded. This center will return to the essence of physics and conduct interdisciplinary research on methodology by making maximum use of the research infrastructure resources of KEK, which is an international center of accelerators. In modern physics, a "quantum field" is the spacetime in which particles and quasiparticles are created and annihilated. The fundamental equations it obeys are being explored both theoretically and experimentally. Physicists have been exploring the fundamental equations governing quantum fields both theoretically and experimentally. "Quantum field measurement systems" in the name of this center is a new concept that has two meanings: one is to measure the quantum field, and the other is to measure "with" the quantum field (including various quasiparticles). This center focuses on quantum field measurement systems, which have been undergoing significant innovation in recent years, and aims to bring about innovative development through interdisciplinary research of particle physics, astrophysics, condensed matter physics, measurement science, and systems science. This means that humanity will gain new "eyes," so to speak. It will lead to applications in various academic fields beyond physics and their huge and high-level fusion. Furthermore, it will pave the way for implementation in the future society, as represented by smart cities. Based on the above, we describe this center's basic idea (slogan for the public), missions, identities, and goals.



First of all, the basic idea (slogan for the public) of this center is **to bring new "eyes" to humanity and to look at the origin of this beautiful world (the true nature of time, space, and matter).**

The missions of this center 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.

The identities of this center 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.

Based on the above mission and identity, the goals of this center are defined as follows.

1) To invent new principles and measurement systems to search for theoretically predicted novel quantum fields.
2) To lead the world in the grand challenges of cosmology and particle physics by developing and implementing new quantum field measurement systems in international projects such as the LiteBIRD satellite project and collider experiments.
3) To propose and promote new projects based on new quantum field measurement systems.
4) To develop new methods of data analysis, which correspond to the "brain" of the measurement system, and apply them to cosmology and particle physics.
5) To establish a new measurement science, quantum field measurement systemology, as a "science of means" through the above practices.
6) To employ researchers whose primary goal is to give back to society, realize social implementation (smart cities, automatic driving, medical care, etc.), and at the same time, actively develop applications in other academic fields.

7) To cultivate the next generation of human resources who are proficient in systems science and have deep expertise.

(2) World-Leading Scientific Excellence and Recognition

1) Research content

This center will perform the invention, development, and implementation of innovative quantum field measurement systems to achieve six of the seven goals described in "(1) Overall Framework of the Center Project", excluding human resource development. Major examples include a new measurement system using quasiparticles, a new semiconductor detector with more than two orders of magnitude better radiation tolerance than the previous one, integration of new sensor development and integrated circuit development, automation of analog integrated circuit development, and a superconducting detector array for the LiteBIRD satellite. The PIs in charge of each research will prepare and proceed with clear goals and project plans for the next 5 and 10 years. By introducing systems engineering methods into all activities, we will accelerate the accumulation and sharing of know-how through practice and foster systemology.

2) Interdisciplinary research

In this center, researchers in particle physics and astrophysics, condensed matter physics, quantum beam science, measurement science, and systems science will come together to conduct interdisciplinary research and bring about innovations in quantum field measurement systems. The new "eyes" created by this 1st-level fusion of research fields will lead to a new level of fusion of various research areas beyond physics, in addition to breakthroughs in particle physics and cosmology. Relevant research areas include chemistry, biology, medicine, archeology, and even neuro-aesthetics. This 2nd-level fusion will bring entirely new academic and social values. Concerning initiatives toward social implementation, in particular, we will promote interdisciplinary research that transcends the boundaries of industry and academia, with the cooperation of the Toyota Group.

3) Research outcomes

A variety of research results are expected from this center, and three expected outcomes are shown below:

(a) Discovery of primordial gravitational waves from cosmic inflation

(b) Discovery of a new quantum field (such as the Axion)

(c) Invention of a non-contact shaft-bearing system with Casimir force with "zero friction," which drastically changes mechanically-movable structures' designs

These missions are much broader than those of LiteBIRD and cover areas not addressed at KEK, including non-accelerator particle physics experiments, cosmology, and activities for social implementation. But the unexpected discovery is what we hope for. In the words of Professor Peter Goddard, former Princeton Institute for Advanced Study, "If you know what you're going to do and how you're going to do it and when you're going to do it by, it is not going to be truly original research. We are finding out things we couldn't imagine."

(3) Global Research Environment and System Reform

1) International research environment

The PIs at this center are international and diverse, with more than 20% foreign nationals and about 40% women. Through international recruitment, the fraction of foreign researchers at the center will be above 30%. The official language of this center shall be English. KEK hosts large-scale international collaborations and accepts many collaborators from Japan and abroad. We will further develop this know-how to create an environment where researchers can devote themselves to their research by providing

support and convenience for their research and life.

2) Center management and system reform

Under the leadership of the Center Director, core members will hold Center Steering Committee meetings to understand the director's goals and policies and discuss critical operational matters such as personnel and budget. The Systemology Support Section provides PI projects with systems science support. We will open three satellites, including one in the US, to carry out efficient R&D and establish robust collaboration even under COVID-19 restrictions. KEK, as the host institution, will clarify its commitment to KEK's mid-term plans.

(4) Values for the Future

1) Generating and disseminating the societal value of basic research

Research that explores space, time, and subatomic particles awakens in public a sense of wonder that transcends science. Intellectual values newly created at this center will bring confidence and pride to the people of Japan. It will also contribute significantly to the country's continued existence as a first-class country, distinguished by other countries. In collaboration with ISAS/JAXA, Kavli IPMU, AIST, and others, this center will widely share such intellectual value with the public via the web, lectures, open houses, and SNS, by allocating dedicated human resources such as URA for outreach.

2) Fostering next-generation human resources linked with higher education

The educational goal of this center is to develop the next generation of talents who are proficient in systems science and have deep expertise in specific fields. We will hold annual quantum field measurement systemology training and practice courses utilizing KEK's infrastructure for graduate students in elementary particles, cosmology, measurement science, and related fields. By learning about sensors, ASICs, computers, data analysis, and the systemology that integrates them at this center, young researchers will become scientists who can play an active role in academic posts and a wide range of industries. The center will provide training and career development support at each stage, from graduate student to post-doctoral fellow to tenure-track/tenured faculty.

3) Self-sufficient and sustainable center development

KEK will position this center as a unique organization that contributes to forming world-class activities and an independent research organization distinguished from other research organizations within KEK. To make the center permanent, KEK will assist the center in establishing its financial base. Along with this, some of the senior researchers and technical staff hired by WPI will be tenured after the sixth year, and upgrade of the facilities will be promoted.