

QUP Overview and “Project Q”

Masashi Hazumi
(QUP, KEK)

What is QUP?



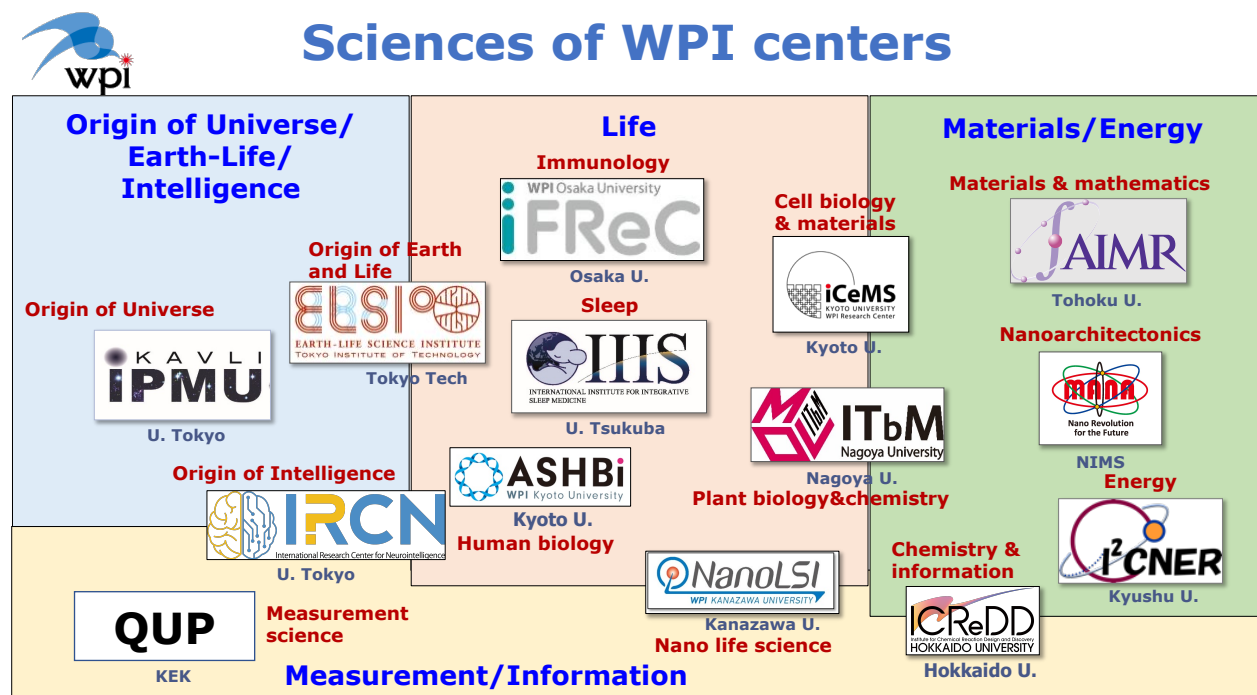
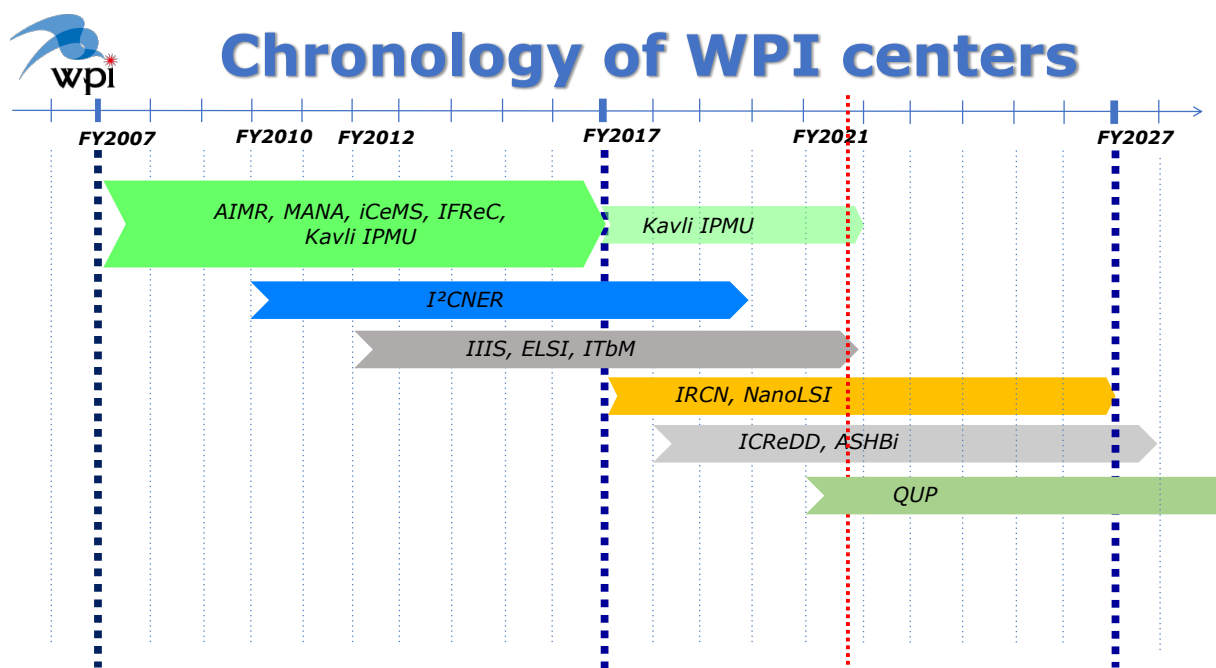
International Center for
Quantum-field Measurement Systems for
Studies of the Universe and Particles (QUP)

New WPI Center at KEK established on Dec. 16, 2021

What is WPI?

World Premier International Research Center Initiative

- Japan's flagship program to establish internationally-opened and globally-visible research centers
- Started in 2007, have launched 14 centers, and continuing to the future
- 10-year support phase (total ~70M USD) to establish self-reliant operation



WPI Missions



- **World-Leading Scientific Excellence and Recognition**
 - Highest Level of Research Impact
 - Interdisciplinarity and Diversity
- **Global Research Environment and System Reform**
 - Global Brain Circulation
 - Capacity Building beyond Disciplinary/Organizational Boundaries
 - Effective, Proactive and Agile Management
- **Values for the Future**
 - Societal Value of Basic Research
 - Human Resource Building
 - Self-sufficient and Sustainable Center Development

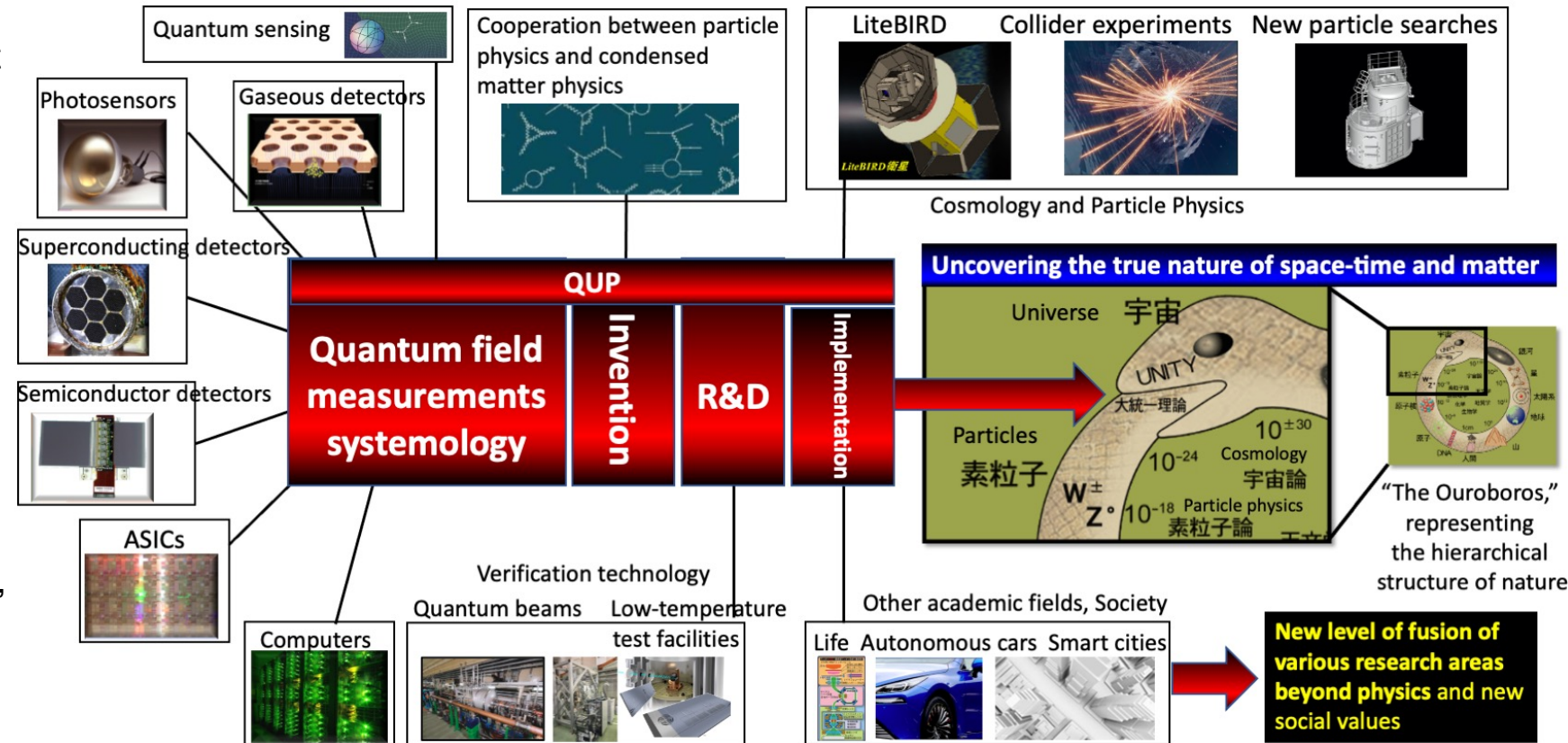


QUP's Missions

Five Missions

1. Integrate particle physics, astrophysics, condensed matter physics, measurement science, and systems science.
2. Invent and develop new systems for measuring quantum fields (space-time with particles and quasiparticles created and annihilated, and associated physical quantities).
3. Bring innovation to measurements in cosmological observations and particle experiments, and elucidate the true nature of space-time and matter.
4. Establish a new measurement science, quantum field measurement systemology, as a science of means through the above practices.
5. 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.

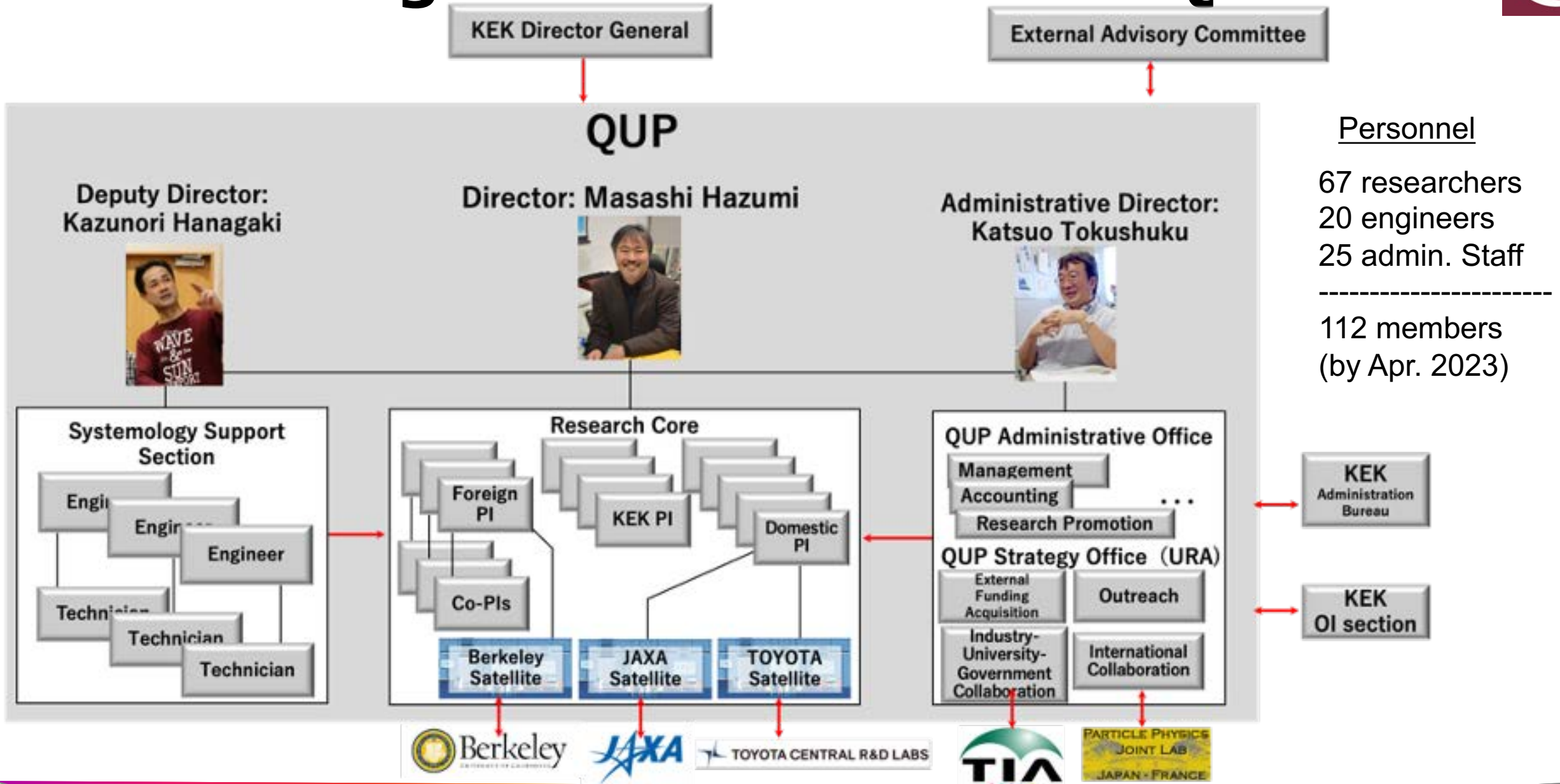
Overall Framework with Key Words



QUP's tagline:

Bringing New Eyes to Humanity

Organizational chart of QUP



Personnel

67 researchers
20 engineers
25 admin. Staff

112 members
(by Apr. 2023)

QUP is international



- >30% of QUP researchers (total ~70 members) will be non-Japanese.
- PIs from Univ. Oxford, UC Berkeley and LBNL.
- PIs are leading scientific international collaborations (LiteBIRD, ATLAS, Belle2, ATHENA, etc.)

Daniela Bortoletto
University of Oxford
Professor



Adrian T. Lee
UC Berkeley
Professor



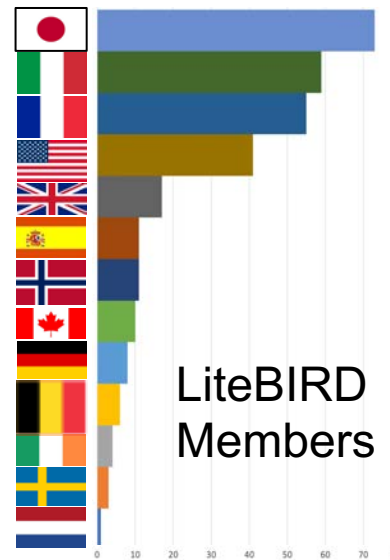
Maurice Garcia-Sciveres
LBNL
Senior Scientist



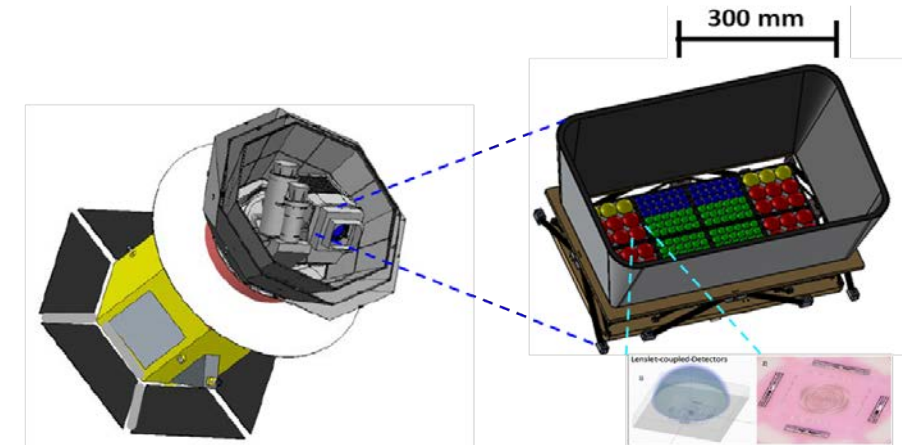
Example: LiteBIRD – selected as a JAXA's strategic L-class mission for launch in 2020s

The director of QUP is the founder and the world PI of LiteBIRD.

More than 300 members from 13 countries



QUP will invent, develop and provide superconducting detector system for LiteBIRD as a QUP flagship project.



Initial PIs

- Low-temperature (superconducting) sensor systems L
- Radiation-hard semiconductor detectors R
- New device/firmware/algorithms/theory N



Principal Investigators



Masashi Hazumi
KEK
Professor



Manabu Togawa
KEK
Associate Professor



Masaya Hasegawa
KEK
Lecturer



Masaya Miyahara
KEK
Associate Professor



Nanae Taniguchi
KEK
Assistant Professor



Adrian T. Lee
UC Berkeley
Professor



Daniela Bortoletto
University of Oxford
Professor



Maurice Garcia-Sciveres
LBNL
Senior Scientist



Kaori Hattori
AIST
Senior Researcher



Noriko Y. Yamasaki
JAXA
Professor



Kazunori Nakayama
U. Tokyo
Assistant Professor



Hideo Iizuka
Toyota Central R&D Lab.
Senior Fellow



Yu Nakahama
KEK
Associate Professor

Job opening!






- ~20 postdocs (or assistant professors) working with initial PIs
- Applications by Feb. 28 for full consideration
- See more details at AcademicJobsOnline

AcademicJobsOnline.org

[List](#) | [Search](#) |

KEK, QUP

Position ID: [KEK-QUP-POSTDOC](#) [#21028, KEK-QUP-PD2022-1]
Position Title: QUP Postdoctoral Fellow
Position Type: Postdoctoral
Position Location: Tsukuba, Ibaraki 305-0801, Japan [[map](#)]
Subject Areas: [Astrophysics & Cosmology](#)
[High Energy Physics](#)
[Particle Physics](#)
[Data Science](#)
[Electronic Materials and Devices](#) (more...)
Appl Deadline: 2022/02/28 11:59PM  (posted 2022/01/26, updated 2022/01/25, listed until 2022/06/30)
Position Description:  

KEK's research infrastructure

"Fuji experimental hall" (2000m²)

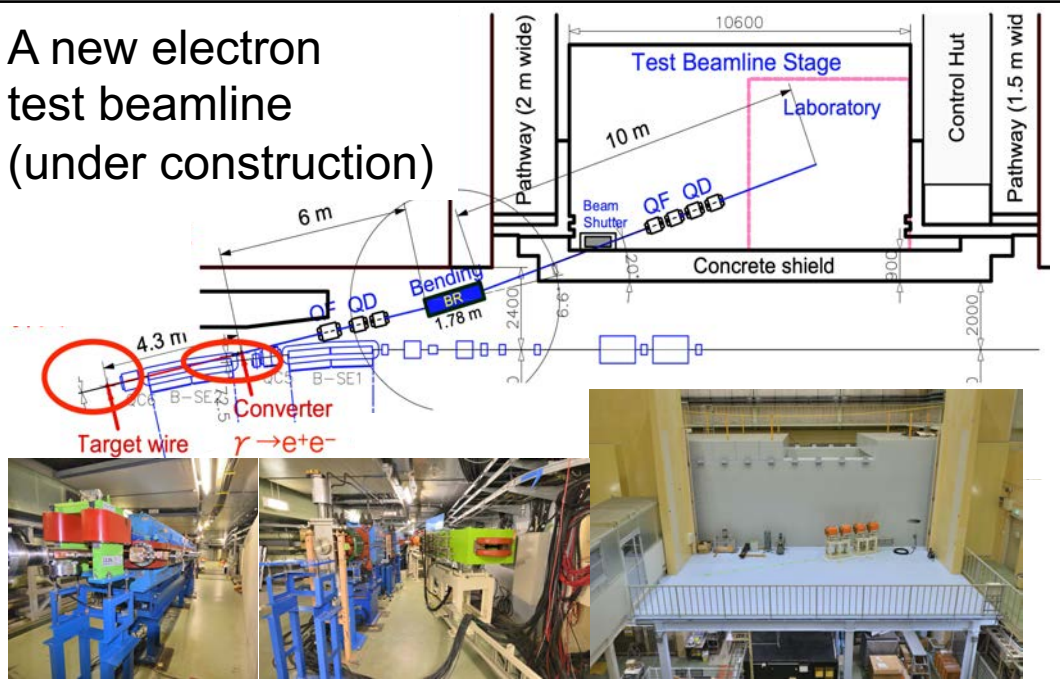
Entrance



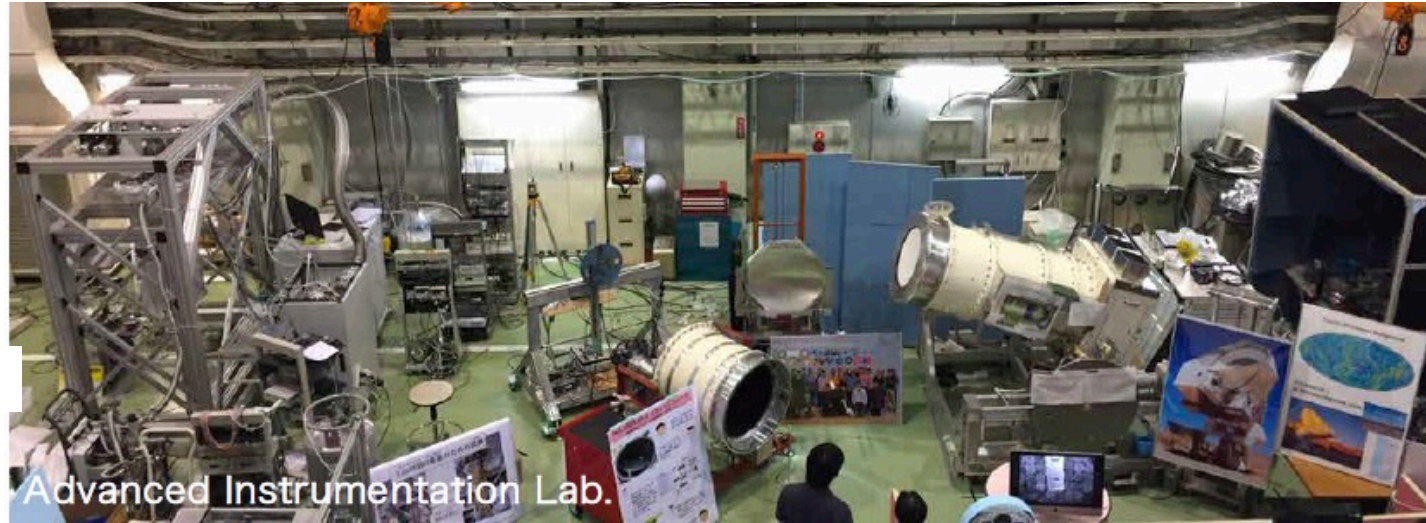
KEK's research infrastructure (cont.)



A new electron test beamline (under construction)



Advanced Instrumentation Lab. for Cryogenic Detector R&D

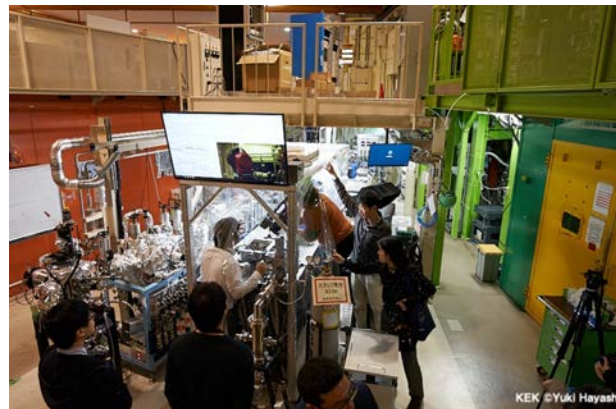


Advanced Instrumentation Lab.

Neutron and Muon beamlines



X-ray microscopy beamline

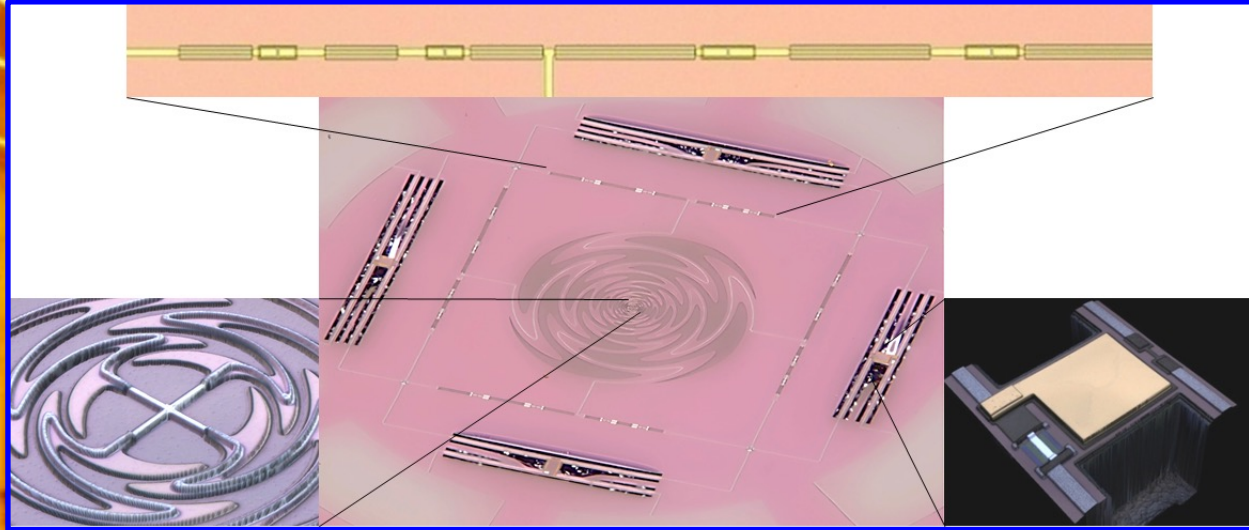


Semiconductor detector R&D Lab.

QUP Satellite in UC Berkeley

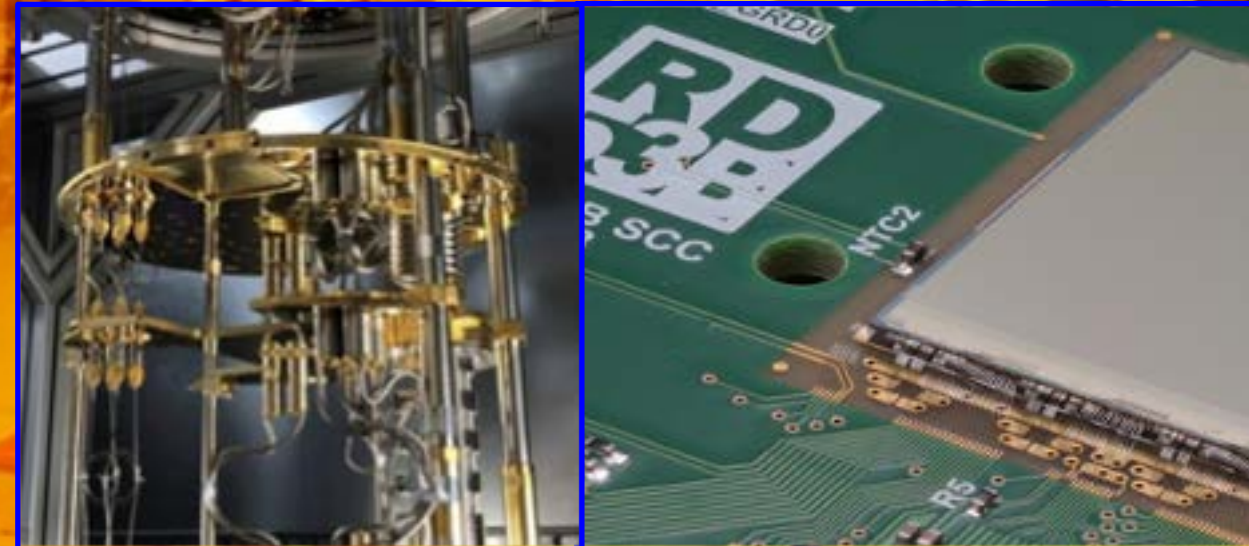


- Satellite includes Berkeley Physics Department and LBNL Physics Division
- World-leaders in Quantum Sensors
- **CMB:** Berkeley pioneered many TES technologies
- **HEP:** Most complex integrated circuits (RD53)
- **Dark Matter:** World-record athermal noise for low-mass DM search



Roles of the QUP satellite in Berkeley

- Fabrication and characterization of new TES bolometers for LiteBIRD
- Readout ASICs for future collider experiments and for novel quantum sensors
- New target materials and new quantum sensors for dark matter and photon detection



QUP Satellite in Toyota Central R&D Labs.



Roles of the QUP Satellite
in Toyota Central R&D Labs.

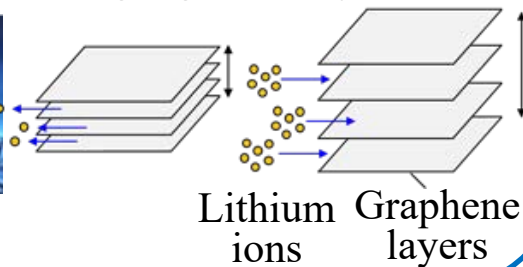
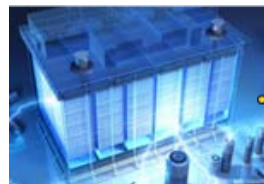
- Development of quantum sensors
- Social-implementation experiments

Casimir devices

Non-contact shaft-bearing motor



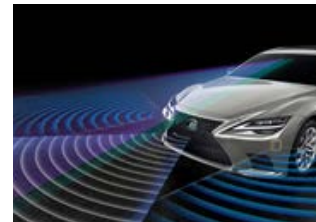
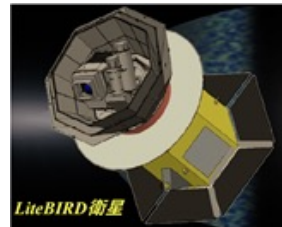
Fast-charging battery



Quantum-field measurement technology creates
new social values & enriched society.

Technology exchange

Radars



Six project categories at QUP



1. QUP flagship projects

- Highest priority at QUP
- Two projects are identified
 1. Superconducting detector system for LiteBIRD
 - 2. Project Q**

2. QUP PI-led projects

3. Interdisciplinary/Challenging/Exploratory mini-projects

4. Projects for human resource development and brain circulation

5. Projects toward implementation to society

6. Quantum-field Measurement Systemology

What is Project Q?



A new QUP flagship project with a new method to search for a new quantum field

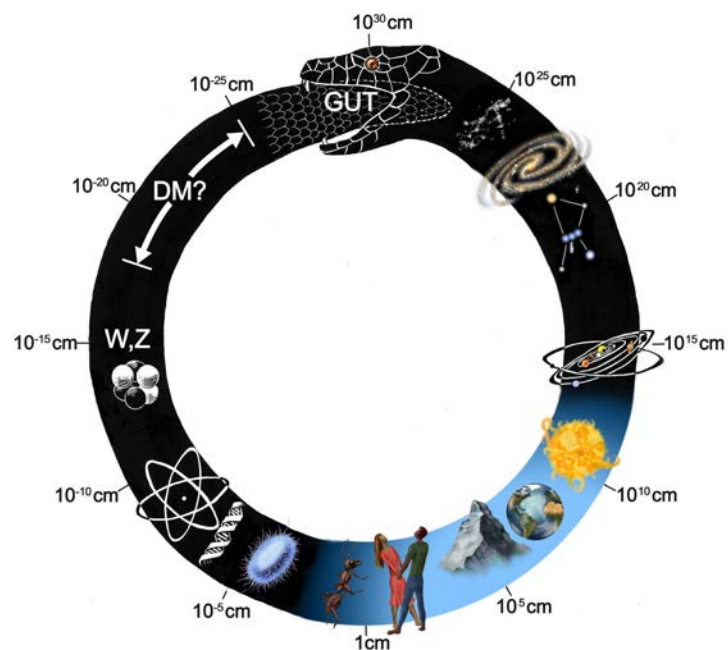
- Widely solicit new ideas from domestic and international communities (QUP-PI ideas are also welcome)
- Any of space observation, accelerator or non-accelerator, any!
- Any new quantum field, axions, gravitons, light DM, any!
- Workshops and other opportunities for discussion, and finish the first stage of selection by the end of March 2023 (exact timing is TBD.)
 - This workshop is the kick-off!
- After a year of project review, the content of Project Q will be decided by the end of March 2024 (exact timing is TBD.)
- Bold, new ideas are welcome!
 - Example 1: New methods using quasiparticles in solids
 - Example 2: New methods using new quantum sensors (e.g. diamond quantum sensors)

Related talks at this workshop!

From QUP,

- Kazunori Nakayama (next talk)
- Maurice Garcia-Schiveres (this morning)

Our cute logo!



<http://new-universe.org/zenphoto/Chapter2/Illustrations/Abrams22.jpg.php>



Backup Slides

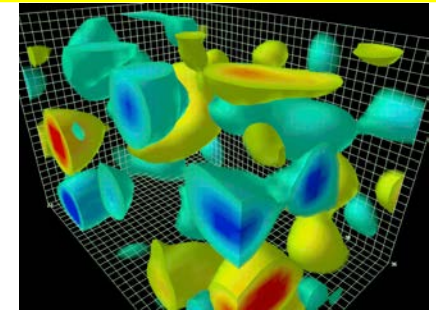
QUP brings “new eyes” to humanity.



“The only real voyage of discovery consists not in seeking new landscapes, but in having new eyes.”
Marcel Proust

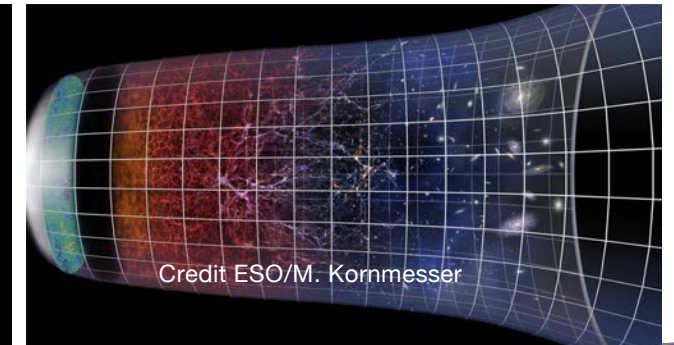
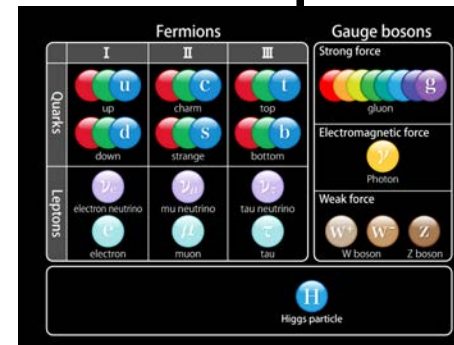
Quantum-field measurement systems

Quantum fields



By Prof. D. B. Leinweber (Univ. Adelaide)

= the backbone of reality
from particles to cosmos



Credit ESO/M. Kornmesser

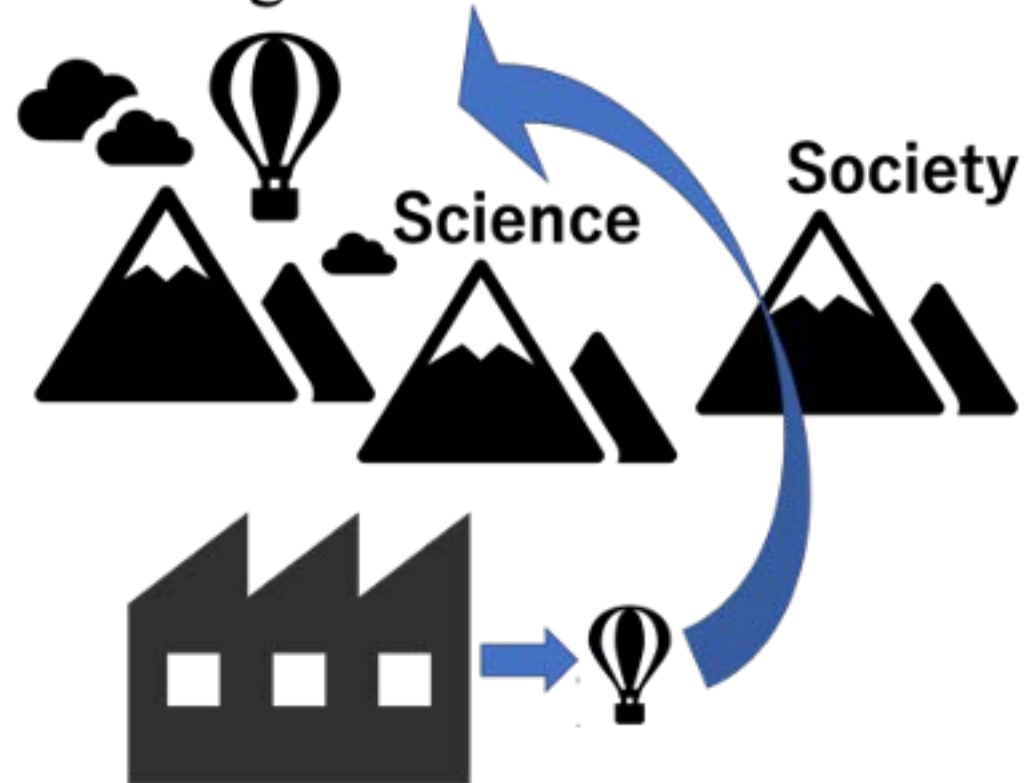
What is different from other WPI centers? - Uniqueness of QUP

Image of existing WPI centers



International expedition aiming for the summit

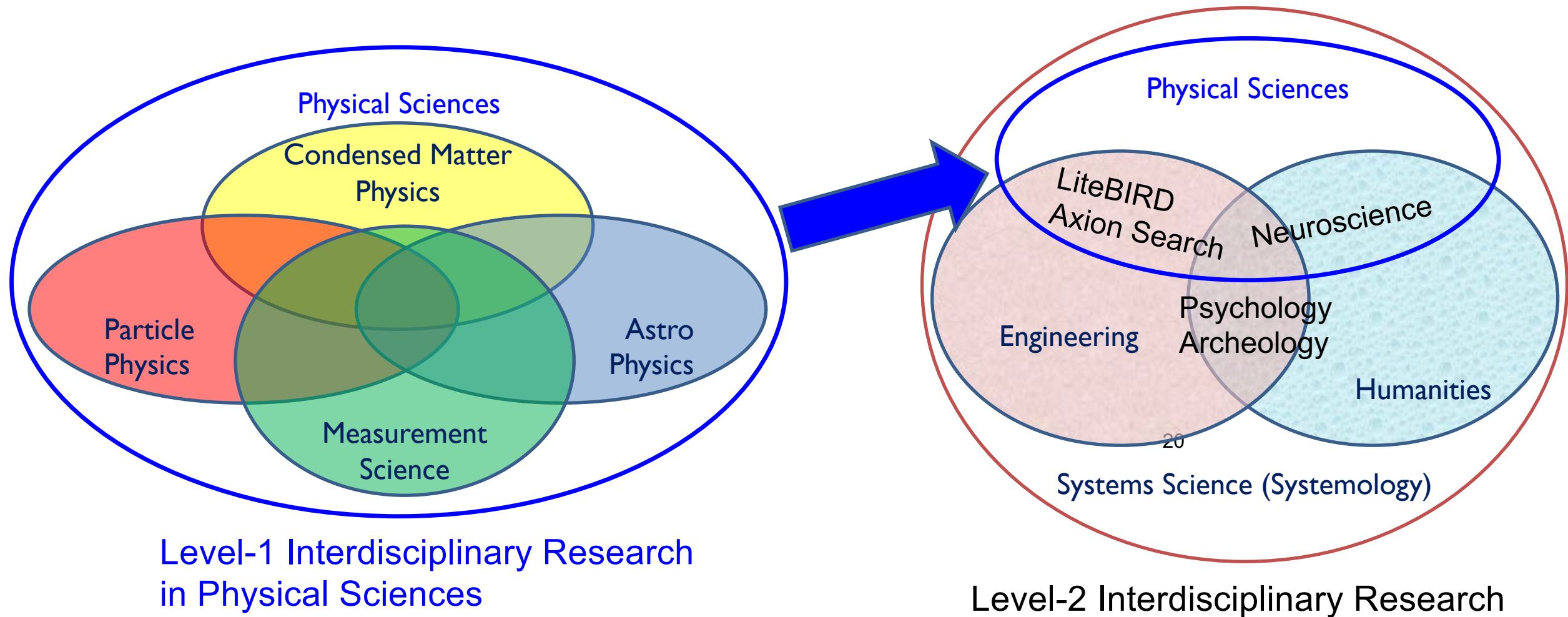
Image of this WPI center



Lab to develop a vehicle that can fly anywhere

Meta-level interdisciplinary fusion for means, not for a single goal, to produce academic and social values

Two levels of interdisciplinary research at QUP



Systems Engineering and Systems Science (**Systemology**) at QUP



Motivation

- We want/need to be **faster** and **more accurate** in doing big and complex science projects.
- We want to **accumulate** our know-hows **efficiently**, **before our tacit knowledge disappears**.
- We want to make our knowledge **explicit** (not **tacit**) so that others can **learn** it.

Approach

Systemology Studio

- Software developed by QUP's Systemology Support Section
- Aggregating existing tools (particle interaction simulators, 3D CAD software, MBSE software, etc.)
- Implementing database of technical (and even human) attributes

Systems Theory

Feedback from our practice

Concurrent design work

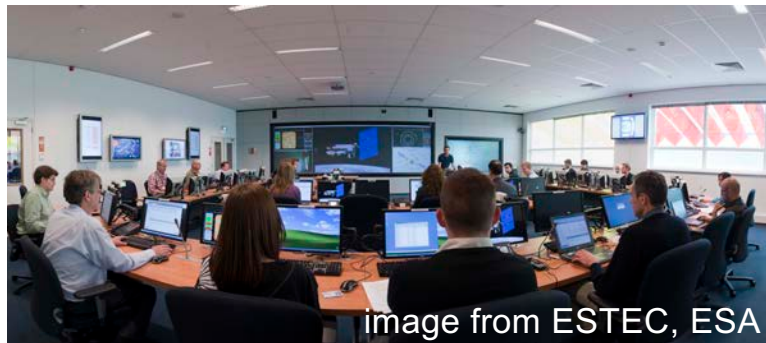


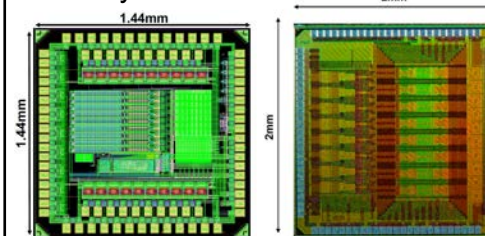
image from ESTEC, ESA

Automated design from a requirements flow



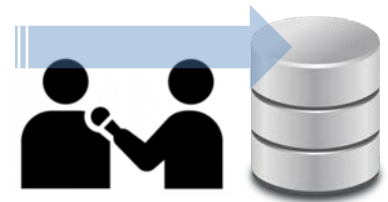
image from NASA

M. Miyahara



ASIC design (QUP PI's work)

From tacit knowledge to explicit knowledge



e.g. Detailed interviews to researchers with excellent development capability

MBSE Database

Systemology is our “research booster.”

Model-Based Systems Engineering (MBSE)

Example at LiteBIRD

K. Watanuki (JAXA)

< Model-Based Systems Engineering (MBSE) >

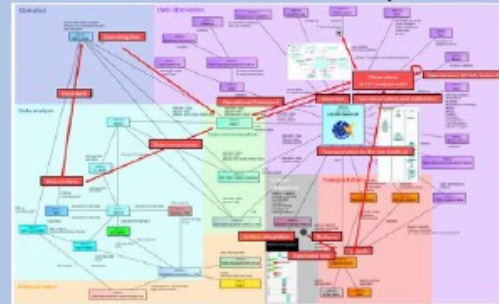


システムズエンジニアリングとMBSE

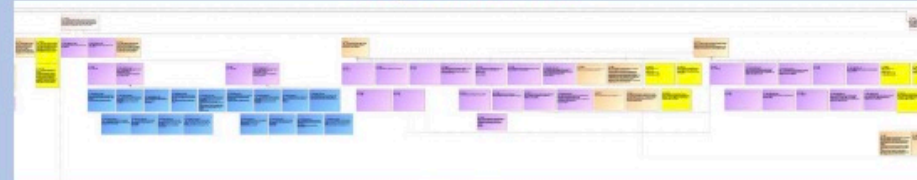
<MBSE>

システムズエンジニアリングに様々なモデルを適用してステークホルダーと情報伝達することにより、大規模なシステム開発において齟齬を排除し、より効率的に進めるための手法。

Mission scenario map



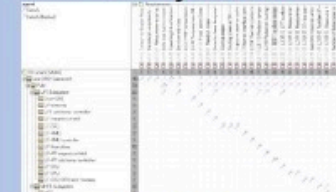
Requirement tree



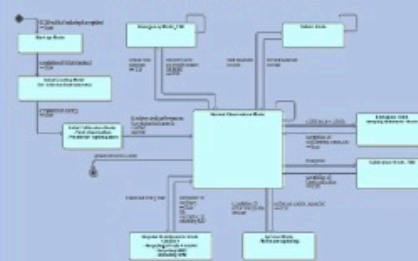
System integration



Satisfy matrix



States machine



Sequence diagram



Product tree



A method to eliminate discrepancies and proceed more efficiently in large-scale system development by applying various models to systems engineering and communicating information with stakeholders.

QUP at KEK: Executive Summary



TIGER WINGS HYBRID STICKER BY MOMO
January 24, 2019



- QUP will invent novel quantum-field measurement systems and achieve major discoveries in particle physics and cosmology
→ [The Highest Level of Research Impact](#)
- Systemology and two levels of interdisciplinary research
→ [Expanding Knowledge Frontiers](#)
- Truly international science team with Berkeley Satellite and Univ. Oxford, and large scientific international collaborations → [Brain Circulation](#)
- Advancing internationalization and triggering system reforms of KEK
→ [Effective, Proactive and Agile Management](#)
- Huge impacts on social implementation with the Toyota Satellite
→ [Societal Value of Basic Research](#)
- Systemology-conscious education
→ [Unique contribution to higher education](#)
- Strong support by KEK → [Self-sufficient development](#)

スーパーラドハード検出器に向けて

Manabu
Togawa



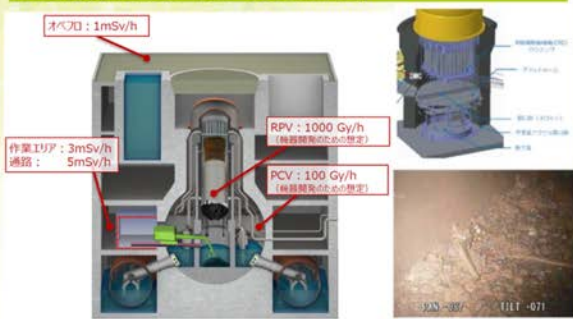
熱・光処理による機能回復！

陽子線照射によるCIGS太陽電池の劣化および回復

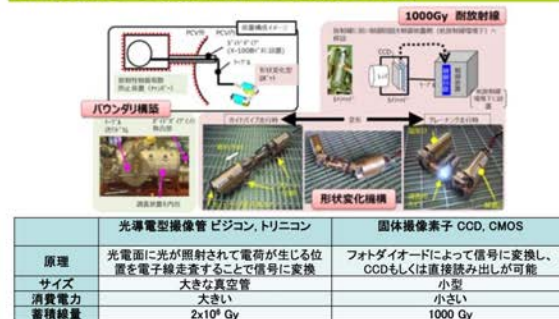
西永 慈郎¹、外川 学²、石塚 尚吾¹

¹産業技術総合研究所、²高エネルギー加速器研究機構

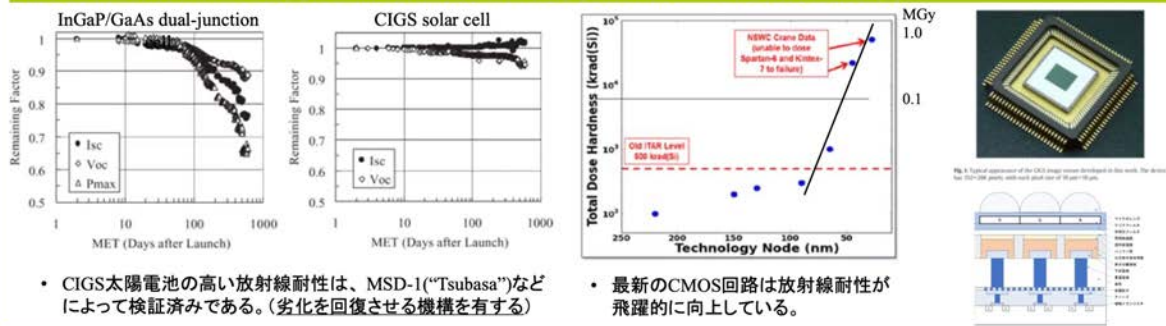
研究背景(福島第一原子力発電所)[1]



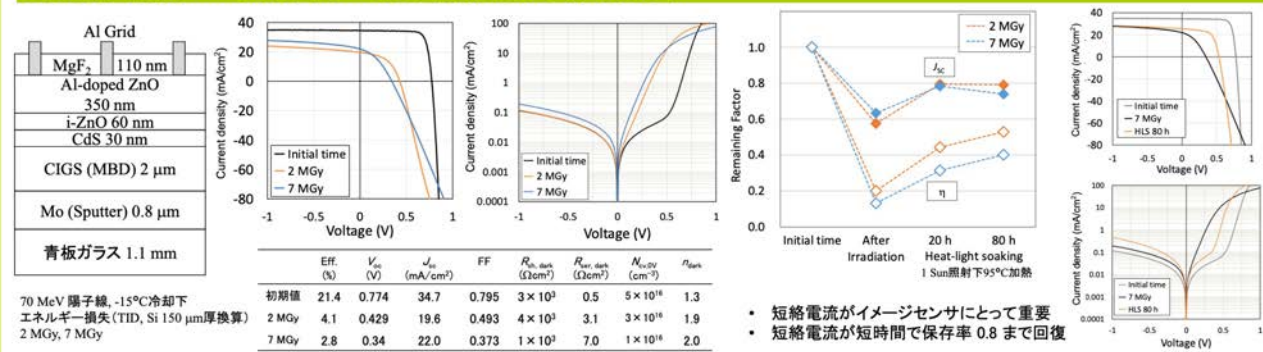
耐放射線カメラ(撮像管、固体撮像素子)[2]



CIGS太陽電池の放射線耐性[3]、CMOS回路の放射線耐性[4]、CIGSイメージセンサの構造図[5]



実験方法・結果(CIGS太陽電池への陽子線照射および熱・光処理)



結論

高放射線耐性イメージセンサ実現に向けて

- CIGS太陽電池の放射線耐性は高い
- 最新のCMOS集積回路は放射線耐性が飛躍的に向上

CIGS太陽電池の放射線耐性

- 陽子線照射(7 MGy)後も、太陽電池動作を確認
- 熱・光処理によって、変換効率、光電流の回復を確認
- CIGS層内の再結合中心の消失が起こり、機能が回復

参考文献・謝辞

- [1] 高守謙郎(IRID), IRIDシンポジウム2019年.
- [2] 新井民夫(芝浦工大), IRIDシンポジウム2016年.
- [3] M. Imaizumi *et al.*, Prog. Photovolt.: Res. Appl. 13, 529 (2005).
- [4] M. Gadlage, "Radiation Hardening and Trust in a COTS Age", Naval Sea Systems Command.
- [5] K. Miyazaki *et al.*, Thin Solid Films, 517, 2392 (2009).

謝辞: 本研究はTIA連携プログラム探索推進事業「かけはし」により実施されたものである。関係各位に感謝致します。

<https://unit.aist.go.jp/rpd-envene/PV/ja/results/2019/poster/P34.pdf>

Advancing photon detection sensitivity of TES array

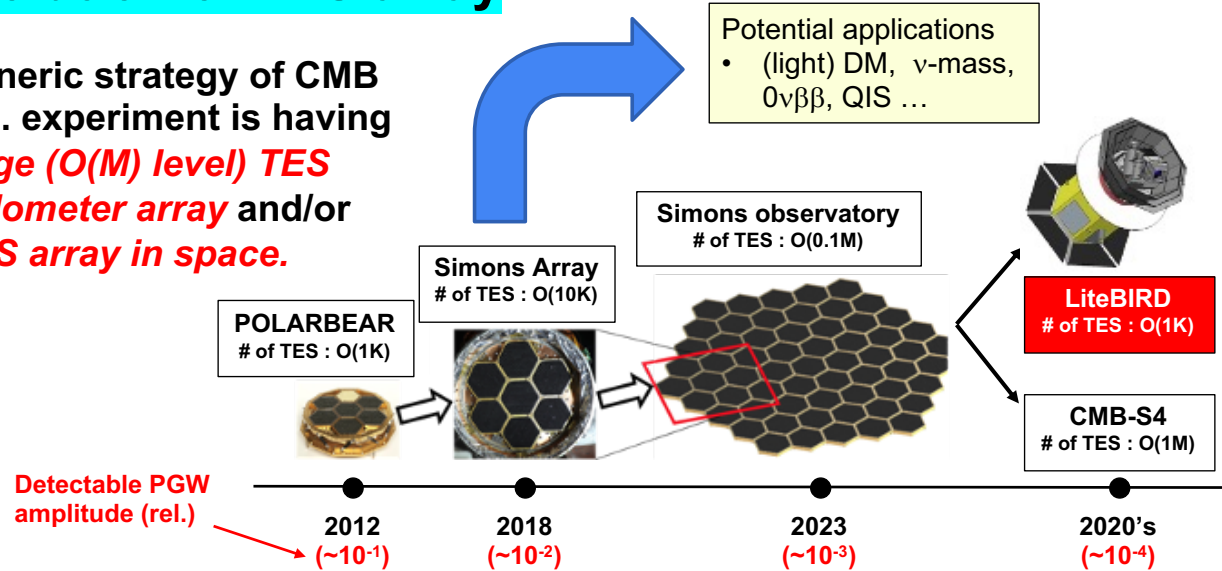
Masaya
Hasegawa



Establishment of key technologies for realizing ultra low-noise and large superconducting detector arrays

Evolution of TES array

Generic strategy of CMB pol. experiment is having **large ($O(M)$ level) TES bolometer array** and/or **TES array in space**.



Key challenges towards 1M TES array

Project ①	Detector development and Fabrication
Project ②	Multiplexing readout
Project ③	Mitigating Excess Noise
Project ④	Processing large array data
Project ⑤	Characterization and QC

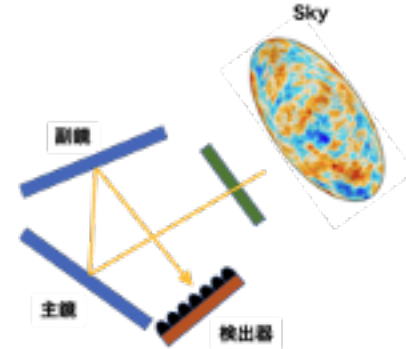
Adrian
(+Masashi,
Noriko &
Kaori) lead

My target
in QUP

Mitigating Excess Noise

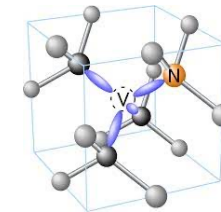
Mirror temperature (as an example)

- Additional polarization is induced at reflecting off the mirror
- If mirror temperature is fluctuated by $\sim 10mK\sqrt{s}$, the pol. amplitude is varied by $\sim 5\mu K\sqrt{s}$, leading it to the additional noise.



We need to monitor the warm equipment at the level of $1mK\sqrt{s}$. * Refined TOD process is also indispensable.

Diamond censor (w/ NV center) is a promising candidate.



© Mizuochi lab.
(Kyoto U)

Beating excess noise is one of biggest challenges for next gen. CMB experiment, and we will realize it by applying **control engineering technique** and **ultrahigh sensitive (quantum) sensors**.

Masaya Miyahara (Age. 41)

2017~ Associate Professor in IPNS, KEK

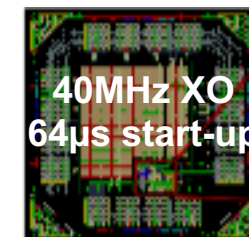
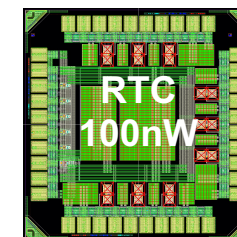
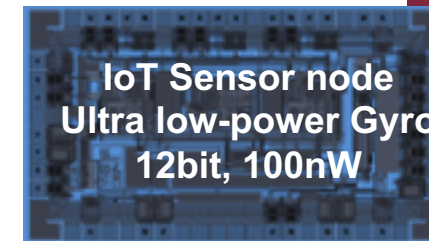
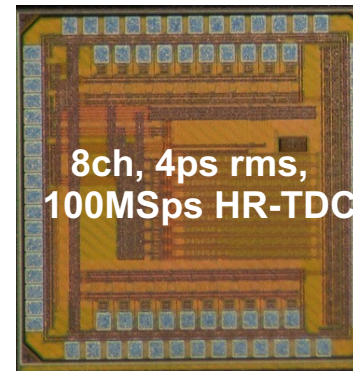
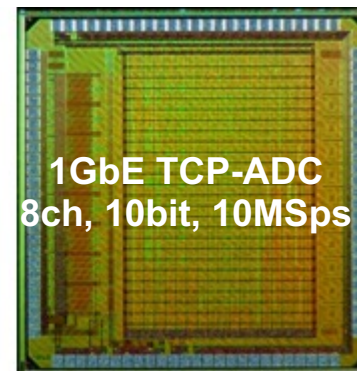
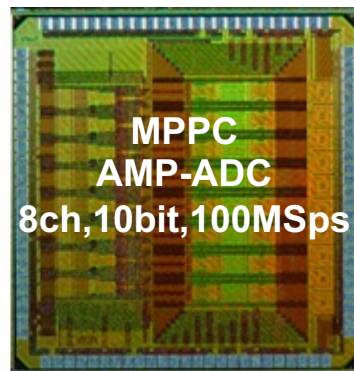
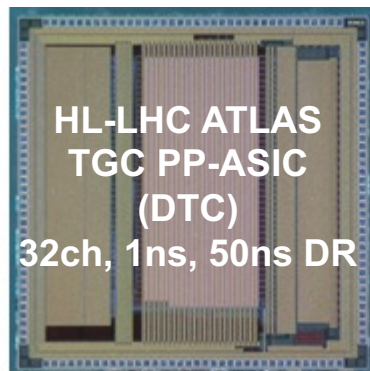
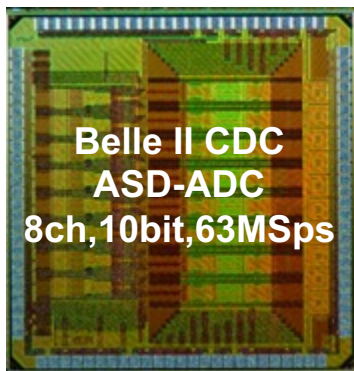
Masaya
Miyahara



Collaboration
with Industry

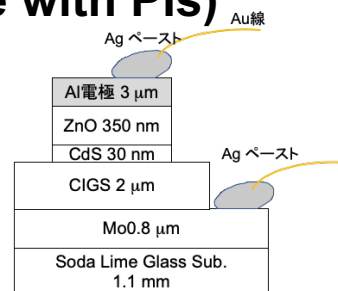
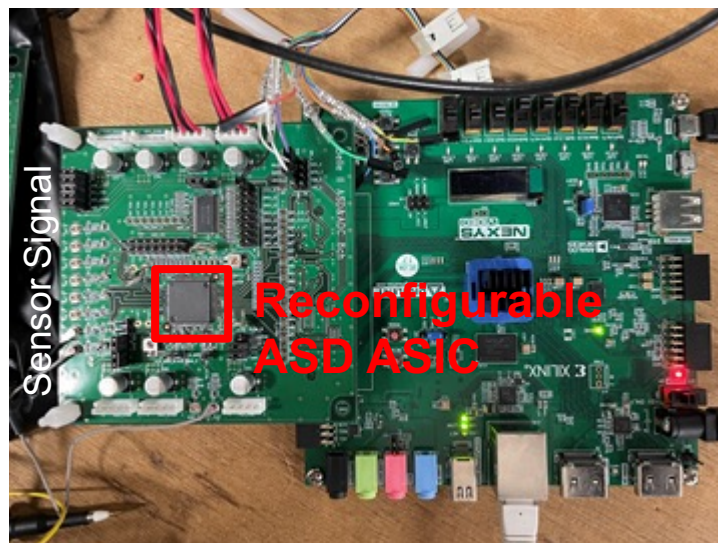


Research area: Analog Mixed signal LSI and its applications

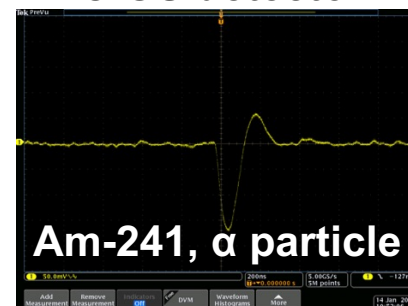


Activity 1. Read-out ASIC (collaborate with PIs)

Ex. Rad-hard detector read-out ASIC



CIGS detector



Activity 2. Design automation for Analog LSI

ASIC development issue

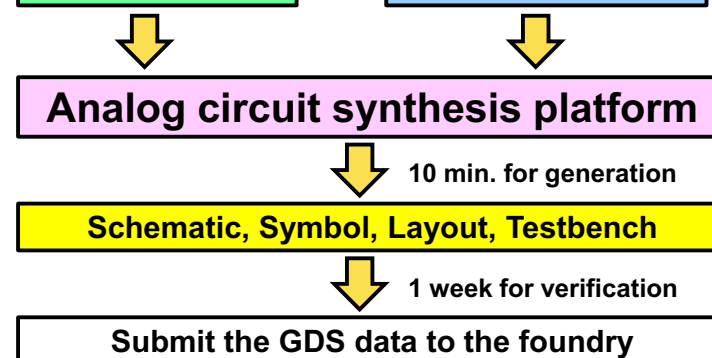
- Long TAT
- Difficult to fix the bug
- Engineer Education (Analog 10 years)

Concepts

- Performance scalable
- Process scalable
- Effective use of past works (know-how)

Design Spec.	
Resolution	N
Conv. Rate	F_S
Ref. voltage	V_{FS}
⋮	

Process Data	
Foundry	X corp.
Technology	Y nm
Metal layer	Z
⋮	



Radiation hardness and high rate tolerance new device and applications



Nanae
Taniguchi



w/ K. Ueno (KEK IPNS)
Electronics experts will join.

radiation hardness of electric devices is challenge
for high energy physics experiments

- Achieve practical use of new device
new FPGA with atomic switch technology
 - promising radiation hardness
 - R&D for application to practical use in higher energy experiments is about to start
 - development tools for users is desired
 - implementation of high speed optical link in near future
- Create new application by combining existing ideas

Neutron and Gamma-ray Irradiation Effects on Atom Switch-based FPGA

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1. Introduction

Trend in particle physics using accelerator
Improvement of accelerator
Increase in intensity, luminosity, energy → Detectors and related electronics including FPGA must be tolerant to higher radiation environment.

Radiation effect

- Neutron
 - Soft error: Single event upset (SEU)
 - need investigation of SEU rate and development of SEU detection/correction scheme especially for FPGA
 - Hard error: Displacement damage dose (DDD), Type inversion
 - need irradiation test
- Gamma-ray
 - Hard error: Total ionizing dose (TID)
 - need irradiation test

Atom switch-based FPGA is one of the FPGAs which is expected to be used in higher radiation environment.

2. Atom switch-based FPGA (AS-FPGA)

Atom switch (AS)

Conductive bridge is formed in polymer solid electrolyte between inert Ru and active Cu electrodes.

Specification:

- retention time: > 10 years
- resistances: ON/OFF ~ 2k/200M Ω
- switch capacitance: < 0.2 fF
- # of rewriting times: > 10¹⁰
- SEU free in principle

AS-FPGA

AS was successfully applied in FPGA for its routing switch and look-up tables [1,2]. AS-FPGA was already irradiated with heavy ion and pulsed laser, and the SEU tolerance was confirmed [3].
For the accelerator experiment, more studies with the higher radiation environment are needed.

3. Irradiation tests

AS-FPGA was irradiated with neutron for SEU and DDD investigations and with gamma-ray for TID.

Neutron irradiation tests

Facility: Tandem accelerator @ Kobe Univ.
Setup: Beam: 3 MeV deuteron; Target: Be (ϕ 20 mm); Neutron energy: 2 MeV (< 7 MeV); Flux: 4.9×10^{10} Hz/cm² @ 10cm from target (beam current = 1 μ A)
Reactor @ KUR: Method: Pneumatic Tube; Rated thermal power: 5 MW; Neutron energy: broad; Flux: > 10^{13} Hz/cm²

Measurements & results

For SEU:

- W/O applying voltage
- Fixed ON/OFF bit pattern was checked before and after irradiation of 1.2×10^{12} n/cm².
- Real-time meas. w/ applying voltage
- Signals in 2 circuit chains with the same structure were compared during irradiation up to 10^{13} n/cm².

NO DDD were observed on AS-FPGA.
Leakage current check:

- AS-FPGA was irradiated with neutron of 10^{12} , 10^{13} , and 10^{14} n/cm², and leakage current was evaluated.
- NO change was seen up to 10^{14} n/cm².

Gamma-ray irradiation tests

Facility: RI Center @ Tokyo Institute of Technology & QST
Setup: Src: Co-60; Dose rate: 500 Gy/h; Total dose: 10 kGy

Measurements & results

Leak current check:

- AS-FPGA was irradiated with gamma-ray up to 10 kGy. After 6 kGy, leak current increased slightly due to degradation in CMOS.
- NO problems were observed in AS.

Shmoo plot:

- NO change in signal delay was seen after 10 kGy irradiation.

Leak current of AS-FPGA during irradiation compared with one of MAX10:
AS-FPGA can be used in higher radiation environment.

Summary & Future work

- Radiation tolerant FPGA is needed in future particle physics using accelerator, and AS-FPGA is one candidate.
- Neutron and gamma-ray irradiation effects on AS-FPGA were investigated and it was found that AS-FPGA can be used in higher radiation environment.
- More detailed studies will be done.
- Prototype using AS-FPGA for particle physics will be constructed and evaluated.

Acknowledgment

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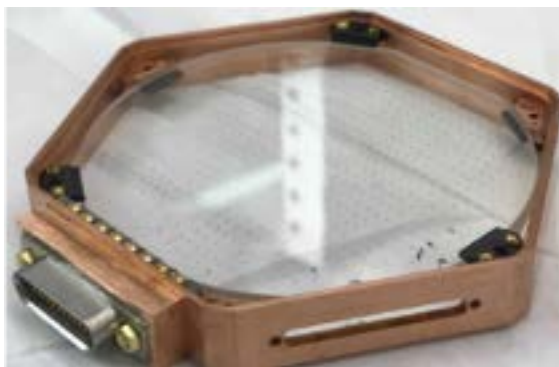
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Kazuki Ueno, IEEE 2021



Quantum Sensing for Low Mass Particle Dark Matter Searches

- Establish cryogenic (sub-Kelvin) underground research lab in Japan.
 - Kamioka is a possible location
- Deploy demonstrator DM searches using novel sensors to push limits of low threshold
 - Needed to extend DM search mass range well below the proton mass
 - Collaboration with SPICE-HeRALD experiments under development to achieve first science results in a few years
- Basic QIS measurements also. For example decoherence mechanisms studies thanks to ultra-low background

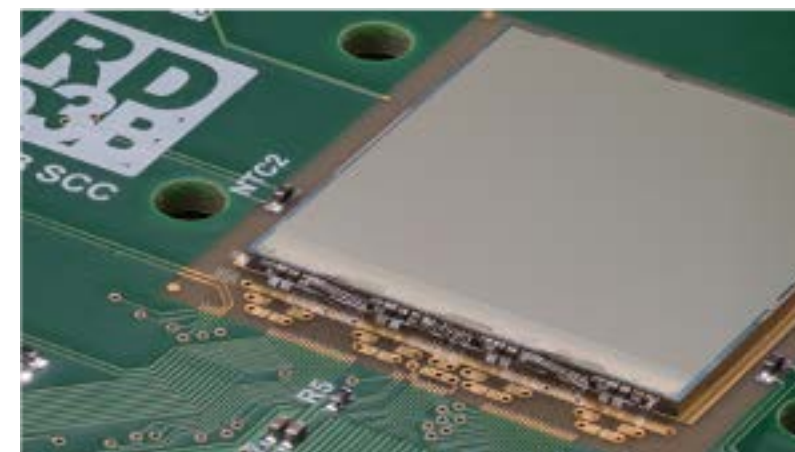


Next Generation Pixel Readout for Colliders

Jointly with
Daniela Bortoletto



- Open a new chapter for RD53 collaboration
- Move to 28nm CMOS technology
 - Enable <100ps per pixel timing
 - Enable higher bandwidth readout (needed to readout out timing data in addition to what is done today)
- Interface to novel sensors
 - Collaborate with sensor development efforts

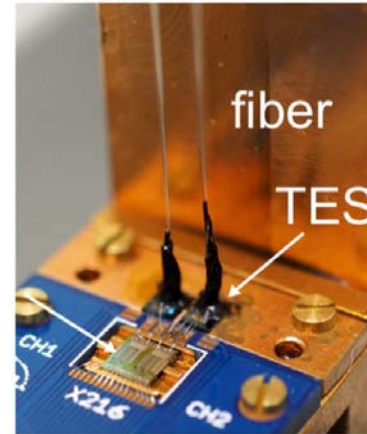
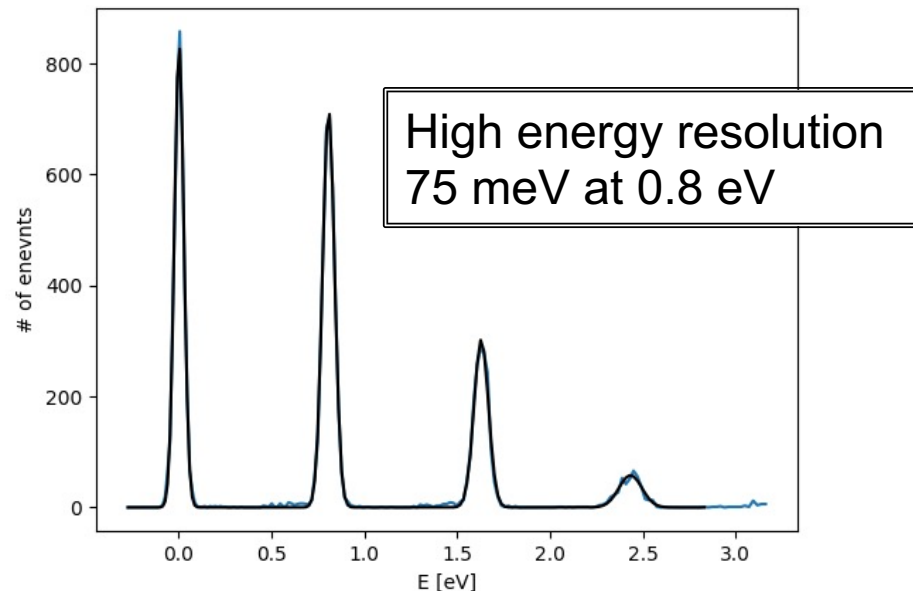
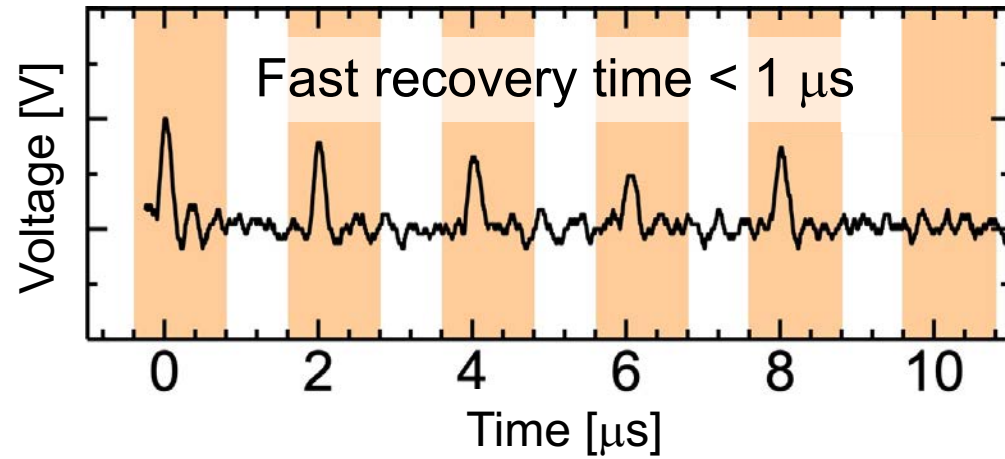


Optical transition-edge sensors (TES)

Kaori
Hattori

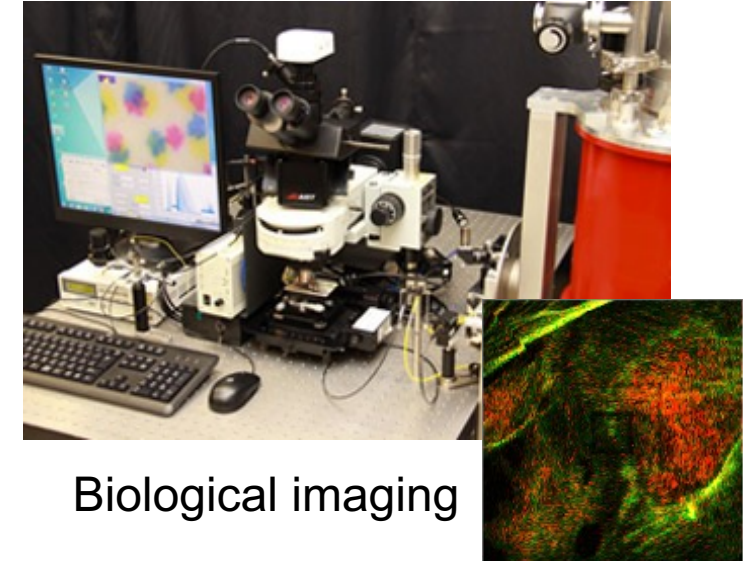


Repetition rate of pulsed laser : 500 kHz



Optical TESs

Scanning microscope with a TES



Biological imaging

Ultra-low dark counts

→ Proved biological imaging using a faint light source

Fast detector response

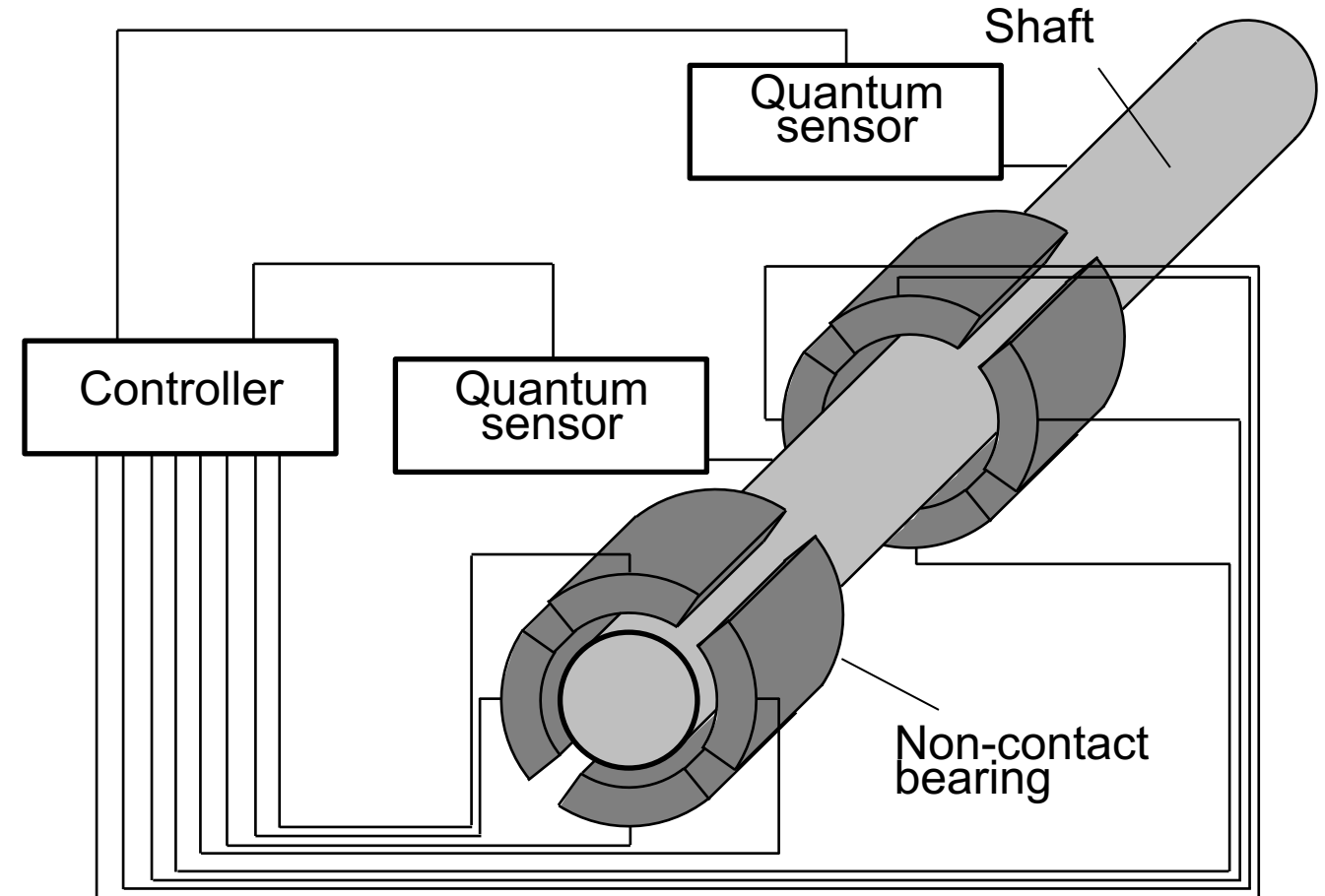
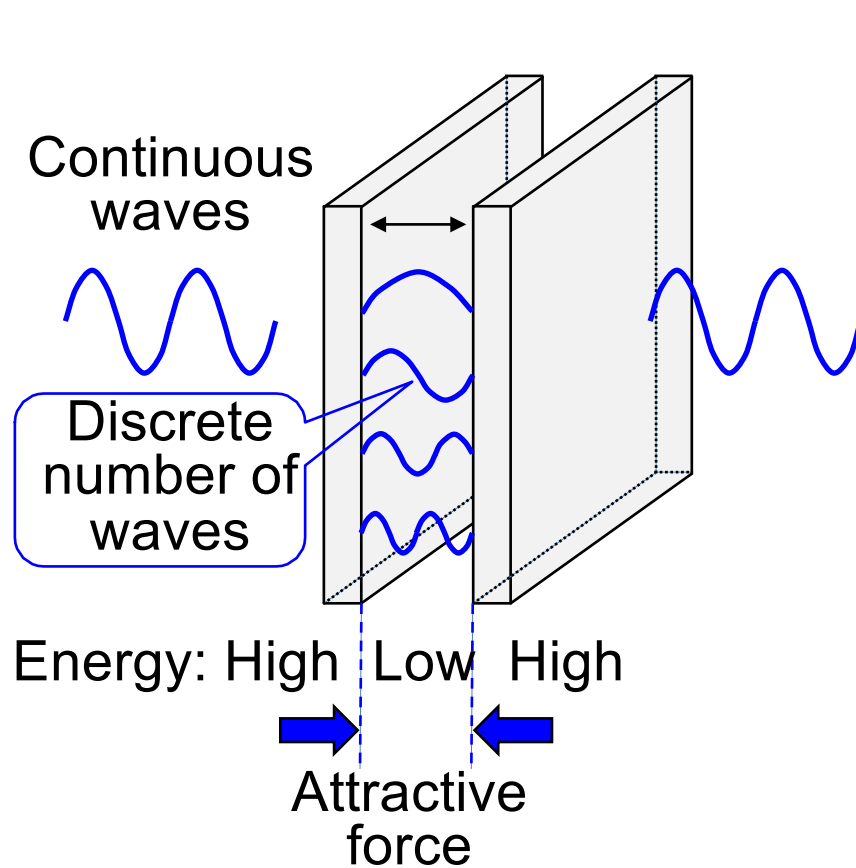
→ Suitable for quantum computing

We will start new projects using optical TESs at QUP!

Casimir Force Device



What is Casimir force? Non-contact shaft-bearing system



Advanced Physics-Analysis Techniques

Yu
Nakahama



- Developments of advanced analysis techniques, e.g. with Machine Learning, and Real-Time analyses “Triggers”
- Applications to Data Analyses in colliders → Brand-new physics-outputs

