Kobayashi-Maskawa Institute
for the Origin of Particles and the Universe
Nagoya University

Annual Report

April 2020 – March 2021

Foreword

I (Junji Hisano) have been the director of KMI since April 2020. After Prof. Toshihide Maskawa and Prof. Makoto Kobayashi received the Nobel Prize in Physics in 2008, KMI was established in 2010 with Prof. Maskawa as the director. Prof. Kobayashi took over in 2018. In 2019, Nagoya University Institute for Advanced Study (NAIAS) was established in order to strengthen cutting-edge basic researches in Nagoya University, and KMI moved into the umbrella. Former Director Kobayashi advised that the next KMI director should be an active researcher, and I assumed the important role of director.

From the beginning of 2020, COVID-19 spread even in Japan. All KMI's activities based on international collaborations have been severely restricted. Researchers could not be dispatched overseas or invited from overseas at all in 2020. It was necessary to solve various problems through trial and error, but it turned out that it is possible to keep our activities using online. In 2021, some overseas travel is possible. As a result, we are gradually regaining our original activities. The JSPS core-to-core program with the title "International research network to reveal dark matter in the universe by multidisciplinary approach in particle and astrophysics" (abbreviation is "DMNet") started in April 2020. It continues until 2024 in collaboration with four countries: Japan, Germany, Italy, UK, and Korea. We have been in close contact with each other to carry out the collaborations and had some online workshops and symposium.

In this report, the experimental and theoretical highlights at KMI are reported in Sect. 3, where other activities spanning through all scientific missions at KMI are also summarized. Publications and presentations through these activities are listed in Sect. 5. Within this fiscal year, four international workshops and the KMI international school, as well as a number of regular seminars and colloquia, were held. For such workshops, we invited not only domestic speakers but also scholars from overseas. They are listed in Sect. 4.

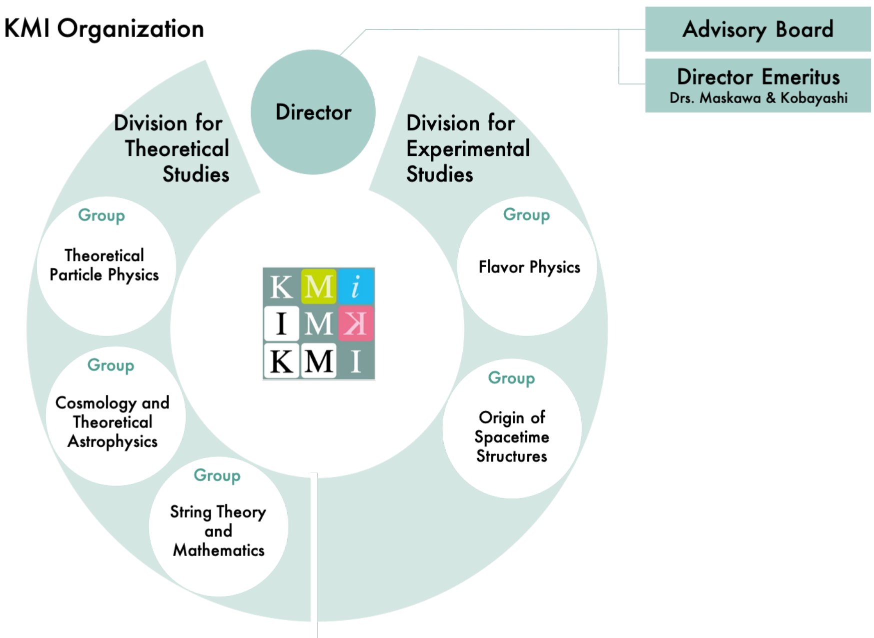
Junji Hisano

Contents

Chapter 1

Organization

1.1 Organization



1.2 Staff List

Director : HISANO Junji

Director Emeritus: MASKAWA Toshihide, KOBAYASHI Makoto

Division of Theoretical Studies (Chair, NOJIRI Shin'ichi)

Theoretical Particle Physics Group

TANABASHI Masaharu (Professor)
HISANO Junji (Professor)
TOBE Kazuhiro (Associate Professor)
NONAKA Chiho (Associate Professor)
MAEKAWA Nobuhiro (Associate Professor)
TAKEUCHI Michihisa (Associate Professor)
ABE Tomohiro (Assistant Professor)
KITAHARA Teppei (Assistant Professor)
SHOJI Yutaro (Assistant Professor)

String Theory and Mathematics Group
- KANNO Hiroaki (Professor)
- SHIROMIZU Tetsuya (Professor)
- SAKAI Tadakatsu (Associate Professor)
- IZUMI Keisuke (Assistant Professor)

Cosmology and Theoretical Astrophysics Group
- SUGIYAMA Naoshi (Professor)
- NOJIRI Shin'ichi (Chair, Professor)
- ICHIKI Kiyotomo (Associate Professor)
- YOKOYAMA Shuichiro (Assistant Professor)
- NISHIZAWA Atsushi (Assistant Professor)
- KOBAYASHI Takeshi (Assistant Professor)

Computational Theoretical Physics Laboratory (Chief, ICHIKI Kiyotomo)
- TANABASHI Masaharu (Professor)
- NONAKA Chiho (Associate Professor)
- ICHIKI Kiyotomo (Chief, Associate Professor)

Division of Experimental Studies (Chair, ITOW Yoshitaka)

Flavor Physics Group

Tau-Lepton Physics
- IIJIMA Toru (Professor)
- KRIZAN Peter (Professor)
- TOMOTO Makoto (Professor)
- GAZ Alessandro (Associate Professor)
- NAKAHAMA Yu (Associate Professor)
- MATSUOKA Kodai (Associate Professor)
- ZHOU Qidong* (Assistant Professor)
- SHAN Wei* (Visiting Scientist)

Fundamental Astroparticle Physics
- ITOW Yoshitaka (Chair, Professor)
- NAKAMURA Mitsuhiro (Professor)
- KITAGUCHI Masaaki (Associate Professor)
- OKUMURA Akira (Junior Associate Professor)
- NAKANO Toshiyuki (Lecturer)
- KAZAMA Shingo (Assistant Professor)
- NAKA Tatsuhiro (Visiting Scientist)

Origin of Spacetime Structures Group

Observational Astrophysics
- KUNIEDA Hideyo (Professor)
- NAKAZAWA Kazuhiro (Associate Professor)

Theoretical Spacetime Analysis
- NAMBU Yasusada (Associate Professor)

Instrument Development Laboratory

NAKAMURA Mitsuhiro (Chief, Professor)

NAKAZAWA Kazuhiro (Associate Professor)

Tau-Lepton Data Analysis Laboratory

IIJIMA Toru (Chief, Professor)

TOMOTO Makoto (Professor)

KATO Yuji (Assistant Professor)

Public Relations Office

TAKEUCHI Michihisa (Chief, Associate Professor)

NAKAHAMA Yu (Associate Professor)

MINAMIZAKI Azusa (Researcher)

MIZUTANI Mayu (Secretary)

Visiting Scientists

MIURA Kohtaroh

AOYAMA Tatsumi

SHAN Wei

NAKA Tatsuhiro

(New members are indicated with * .)

Chapter 2

Management System

- Steering Committees
  - Steering Committee of KMI
    In this Committee, the following agenda items are discussed:
    1. Selection of Director General in KMI,
    2. Future plans and evaluation on the plans in KMI,
    3. Basic policies of managements and administrations in KMI,
    4. Personnel affairs in KMI,
    5. Budgets and facilities in KMI,
    6. Collaborations with the Division of Theoretical Studies and the Division of Experimental Studies,
    7. Anything else related with managements and administrations in KMI.
  - Steering Committee for each Laboratory in the following list is placed, where its managements and administrations are discussed:
    * Computational Theoretical Physics Laboratory
    * Instrument Development Laboratory
    * Tau-Lepton Data Analysis Laboratory

- Advisory Board

  By following the foundation of KMI, an international advisory board has started.

  The members of the advisory board are the followings (in alphabetical order):

  · ELLIS John (Professor at King's College London)

  · KAJITA Takaaki (Director, Institute for Cosmic Ray Research, The University of Tokyo)

  · KUGO Taichiro (Professor Emeritus, Kyoto University)

  · MURAYAMA Hitoshi (Professor, University of California, Berkeley)

  · SASAKI Misao (Professor, Kavli Institute for the Physics and Mathematics of the Universe, The University of Tokyo)

  · SILK Joseph (Professor, Institut d'astrophysique de Paris)

  · YAMAUCHI Masanori (Director General of High Energy Accelerator Research Organization)

Chapter 3

Progress in Research

3.1 Division of Theoretical Studies

3.1.1 Theoretical Particle Physics Group

Tomohiro Abe investigates the dark matter physics with a special attention to evaiding the strong constraint from direct detection experiments such as the XENON1T experiment. Tomohiro Abe, Junji Hisano, and two PhD students (Kohei Matsushita and Motoko Fujiwara) constructed a vector WIMP model in which the dark matter candidate couples to the electroweak gauge bosons. The model is simialr to the Wino dark matter model, but the spin of the dark matter particle is not one-half but one. After constructing a simple renormalizable model, they showed that the model can explain the measured value of the dark matter energy densisty by the well-know freeze-out mechanism and predicts highly suppressed WIMP-nucleon scattering cross section similtaneousely. Studies of some other constraints, such as the constraint from the cosmic gamma rays, are now under investigation. (Tomohiro Abe)

Tomohiro Abe revisited a simple fermionic dark matter model with the effect of the early kinetic decoupling. The model contains the Higgs portal coupling and a tiny dark matter coupling to the SM Higgs boson is required to obtain the measured value of the dark matter energy density. The tiny coupling makes the dark sector decouple from the visible sector not only chemically but also kinematically in the early universe. As a consequence, the temperature of the dark sector differs from the one in the visible sector in the freeze-out era. It turns out that the DM-Higgs coupling should be larger than one estimated with the standard treatment to obtain the right amout of the dark matter relic. It also predicts larger Higgs invisible decay ratio compared to the previous works. Therefore, this effect is significant for the dark matter search at collider experiments, such as ILC. (Tomohiro Abe)

This year I investigate the following topics: decay properties of singly heavy baryons based on the chiral effective model for light diquarks, constraint to the chiral invariant mass from the neutron star property based on a parity-doublet model for baryons combined with NJL-type model for quarks, and scatterings of heavy hadrons to study the structure of heavy pentaquarks. (Masayasu Harada)

Dark matter particles, even if they are electrically neutral, could interact with the Standard Model particles via their electromagnetic multipole moments. We focus on the electromagnetic properties of the complex vector dark matter candidate, which can be described by means of seven form factors. We calculate the differential scattering cross-section with nuclei due to the interactions of the dark matter and nuclear multipole moments, and we derive upper limits on the former from the non-observation of dark matter signals in direct detection experiments. We also present a model where the dark matter particle is a gauge boson of a dark SU(2) symmetry (Junji Hisano).

Recently, the standard model predictions for the B-meson hadronic decays, $\bar{B}^0 \to D^{(*)+}K^-$ and $\bar{B}_s^0 \to D_s^{(*)+}\pi^-$, have been updated based on the QCD factorization approach. This improvement sheds light on a novel puzzle in the B-meson hadronic decays: there are mild but universal tensions between data and the predicted branching ratios. We examine several new physics interpretations of this puzzle. We find that this new tension can be partially explained by a left-handed W' model, which can be compatible with other flavor observables and collider bounds.

Measured values of the anomalous magnetic moments of the muon (muon $g-2$) and the electron (electron $g-2$) deviate from their standard-model predictions at 3.7σ and 2.5σ levels, respectively. It was recently pointed out that the muon and electron $g-2$ anomalies can be explained simultaneously by a flavor-violating axion-like particle (ALP). We found that the parameter regions favored by the muon $g-2$ anomaly are already excluded by the muonium-antimuonium oscillation bound. In contrast, those for the electron $g-2$ can be consistent with this bound when the ALP is heavier than 1.5 GeV. We also proposed to search methods to test the ALP model at the Belle II experiment. Furthermore, we studied supersymmetric models to solve the muon $g-2$ anomaly. By gathering all the available LHC Run 2 results, we investigated the latest LHC constraints on the supersymmetric models that explain the anomaly.

Spinor-helicity formalism can produce scattering amplitudes directly from symmetry, locality and unitarity, and without relying on Lagrangian. Such a formalism is called the on-shell approach. The on-shell approach is expected to extract some essences in field theory, which are not obvious in the usual Feynman methods. The on-shell approach to arbitrary effective field theories requires the construction of independent contact terms. Employing the little-group-covariant massive-spinor formalism, we introduced the first systematic derivation of independent four-point contact terms involving massive scalars, spin-1/2 fermions, and vectors. Our general results are specialized to the broken-phase particle content of the electroweak sector of the standard model. This work opens a way for the on-shell computation of massive four-point amplitudes.

Weak measurement and weak value are interesting theoretical topics within quantum mechanics. The current experiments for particle physics, however, do not utilize them. We propose a novel approach in a search for the neutron electric dipole moment (EDM) by taking advantage of signal amplification in the weak measurement. We examined an experimental setup for the EDM search with a polarized neutron beam through an external electric field with spatial gradient. A dedicated analysis of impurity effects in pre- and post-selections is also performed. We demonstrated a potential sensitivity of the proposed setup to the neutron EDM. (Teppei Kitahara)

The natural SO(10) grand unified theory (GUT) with spontaneous SUSY breaking, which we proposed recently, is a simple SUSY GUT model mainly because it has no hidden sector. The model predicts a long-lived charged lepton, which may be observed in LHC. Unfortunately, it predicts also high scale SUSY in which SUSY breaking scale is around 100-1000 TeV. This is consistent with no SUSY signal at LHC, but unfortunately this destabilizes the weak scale. We have studied a possibility in which the SUSY breaking scale bocomes lower by introducing extra dimension. Interestingly, the extra dimension can avoid very large anomalous U(1) charge which requires some complexity in the model. (Nobuhiro Maekawa).

Hydrodynamic simulation: The hydrodynamic model is the most successful model for description of quark-gluon plasma (QGP) in the relativistic heavy-ion collisions. The viscous property of QGP is one of the key aspects of the strongly interacting QGP (sQGP). In 2020, we apply our hydrodynamics codes to analyses of small systems as well as large systems at RHIC and the LHC. Also, we investigate possibility of existence of the QCD critical point which is the end point of the QCD phase boundary, analyzing the Beam Energy Scan experiment at RHIC. Furthermore, we analyze mixed harmonic cumulants in heavy-ion collisions at the LHC. We find that the observables have sensitivity to temperature dependence of shear and bulk viscosities of QGP.

Cold and Dense QCD: Understanding of the QCD phase diagram is one of the most important subjects in hadron and nuclear physics. In particular, investigation of possible phases in low temperature and high density region is the center of attention, after success of detailed measurement of radius and mass of neutron stars. Here we approach the issues from point of view of QCD effective theories which are not exact QCD but contain feature of QCD: one is the Gross Neveu Model and the other one is two color QCD. Also, we investigate the magnetic effect on color superconductivity phase, using the NJL model. (Chiho Nonaka) The decay rate of a false vacuum has attracted attention in particle physics and cosmology and its precise determination is very important. The decay rate is expressed by the exponential suppression factor and the overall factor and the determination of the overall factor at the one-loop level has been one of the challenging calculation, especially when gauge bosons are involved. In particular, there appear gauge zero modes and their correct treatment has not been known. We have proposed a correct way to treat these gauge zero modes and also shown the gauge invariance of the overall factor. (Yutaro Shoji)

We formulate further generalization of the generalized Higgs effective field theory (GHEFT) to include extra fermions in the non-minimal electroweak symmetry breaking models. Using the geometrical form of the GHEFT Lagrangian, which can be regarded as a nonlinear sigma model with extra fermions, it is shown that the scattering amplitudes including both fermions and scalar bosons are described in terms of the Riemann curvature tensor (geometry) of the scalar and fermion manifolds and the covariant derivatives of the scalar potential and the fermion mass terms. It is found that perturbative unitarity of the scattering amplitudes involving the Higgs bosons and the longitudinal gauge bosons demands the flatness of the scalar and fermion manifolds. (Masaharu Tanabashi)

I worked with Syuhei Iguro and Ryotarou Watanabe to investigate the way to test the Leptoquark/EFT models at the LHC in connection with $B \to D^{(*)} l\nu$ observations. We investigated that the current LHC bounds on New Physics (NP) that contributes to $B \to D^{(*)} l\nu$ for all lepton species $l = (e, \mu, \tau)$ by considering both leptoquark (LQ) models and an effective-field-theory (EFT). We have shown that the m_T distribution in the $l+$ missing searches at the LHC constrains the Wilson coefficients. A novel point of this work is to show the difference between the LQ models and the EFT for the applicable LHC bounds to the Wilson coefficients. In particular, we found that the EFT description is not valid to for LQ models with the mass less than $m_{\rm LQ} \lesssim 10$ TeV at the LHC and leads to overestimated bounds. We have also shown that for several coefficients the LHC constraints are comparable with the flavor ones. (Michihisa Takeuchi)

A discrepancy between the standard model (SM) prediction and the measured value in the muon anomalous magnetic moment (muon g-2) has been reported. Since the discrepancy suggests the relatively low new physics scale if it is due to the new physics, the current and near future experiments can probe such a new physics, and hence a study of the new physics interpretation would be very important. Since some of leptoquarks can enhance the contribution to the muon g-2 due to the top quark loop contribution, these leptoquarks would be an interesting possibility to explain the muon g-2 anomaly. Since these leptoquarks can also contribute to other processes such as $B \to D^{(*)} l\bar{\nu}$ and $B \to K^{(*)} l^+ l^-$, whose measured values also deviate from the SM predictions, we have studied the possible deviations from the SM predictions of these processes and some interesting correlations between different processes in the leptoquark models. (Kazuhiro Tobe)

3.1.2 String Theory and Mathematics Group

The relation of the instanton partition function and the quantum integrable system is one of interesting aspects of supersymmetric gauge theories. We made an attempt at proving the conjecture that the non-stationary Ruijsenaars function recently constructed by J. Shiraishi provides eigenfunctions of the Hamiltonian of double elliptic integrable system. Both the coordinates and the momenta of the double elliptic system take values in an elliptic curve and hence it is supposed to be related to six dimensional theories compactified on the elliptic curve, where the exchange of coordinates and momenta corresponds to the S-duality. We have investigated various limits of the non-stationary Ruijsenaars function, which are related to lower dimensional theories with a surface defect. (H. Kanno)

The recent proposal to describe the strong gravity region, loosely trapped surface and dynamically transversely trapping surface, is examined in Einstein-Maxwell system. Then, we could find a new area inequality depending on the energy/pressure of electromagnetic fields. Meanwhile, we revisited Schoen and Yau’ s proof of the positive energy theorem and proposed a new proof based on Kaluza-Klein theory. We expected that it helps us discuss which theory is compatible with full order spacetime stability. We also examined the holographic entanglement entropy of deSitter braneworld in Lovelock theory and showed the exact agreement between the holographic entanglement entropy and deSitter entropy computed by the Euclidean action. (T. Shiromizu)

One of the outstanding problems in an application of the AdS/CFT correspondce to hadron physics is how to incorporate higher excited baryon states into a hologtaphic model. We derive the baryon mass formula for them by analyzing a many-body system that is composed of a D-brane and open strings ending on it. We also study the correlation functions of exactly marginal operators of CFT using the AdS/CFT correspondence. We reproduce the results that are in perfect agreement with the CFT analyses. (T. Sakai)

Some theories of modified gravity are related by invertible field redefinitions. If a field redefinition involves derivatives, its invertiblility is nontrivial. We derive the generic condition for invertiblility of 2-field transformation with the first order derivatives. The technique can be generalized in the case with more fields and more derivatives. (K. Izumi)

3.1.3 Cosmology and Theoretical Astrophysics Group

I have continued to study several models of the modified gravity, dark energy, and inflation. In this fiscal year, I have considered several model like higher derivative model, non-local model, holographic model, etc. and investigated if these models can be a realistic model. In order to clarify what kind of model could be realistic, I have also continued to investigate the propagation of the gravitational waves in several models. In other works, I have investigated what kind of black hole solutions can be possible in the framework of the $F(R)$ gravity and I have found new and exotic solutions. I have investigated the possibility that such black holes can be observed. Recently there have been some activity to consider the analytic continuations from the higher dimensional gravity. I have investigated the analytic continuation to two dimensional gravity where the usual Hilbert-Einstein Lagrangian becomes a total derivative and in some sense, trivial. In the work, I have found that several non-trivial cosmological or black hole solutions appear by the analytic continuation. (Shin’ichi Nojiri)

The appearance of axion(-like) particles are ubiquitous in physics beyond the Standard Model. We have proposed a novel mechanism for explaining the origin of the primordial density perturbation in our universe, in terms of an axionlike particle coupled to a new confining gauge group. The proposed scenario further makes observational predictions that are testable in upcoming experiments. In addition, we also proposed a new production mechanism for axion dark matter, by showing that a kinetic mixing between the axion and the inflaton can induce axion dark matter production even if the inflationary Hubble scale is smaller than the axion mass. This mechanism opens up new windows in the axion parameter space, including decay constants at the GUT scale and higher. (Kobayashi)

We investigate a systematic understanding for classes of inflationary models from the viewpoint of the local conformal symmetry and the slightly broken global symmetry in the framework of the metric-affine geometry. As simple examples, first we consider the two-scalar models with the broken SO(1, 1) or O(2), leading to the well-known α-attractor or natural inflation, respectively. The inflaton can be understood as their pseudo Nambu-Goldstone boson. We also show a minimal realization of slow-roll kinetically-driven inflation by incorporating the local conformal symmetry and the broken global SO(1, 1). (Yokoyama).

We study the future prospects of the 21 cm forest observations on the axionlike dark matter when the spontaneous breaking of global Peccei-Quinn (PQ) symmetry occurs after the inflation. The large isocurvature perturbations of order unity sourced from axionlike particles can result in the enhancement of minihalo formation, and the subsequent hierarchical structure formation can affect the minihalo abundance whose masses are relevant for the 21 cm forest observations. We show that the 21 cm forest observations are capable of probing the axionlike particle mass in the range $10^{-18} < m_a < 10^{-12}$ eV for the temperature independent axion mass. For the temperature dependent axion mass, the zero temperature axion mass scale for which the 21 cm forest measurements can be affected is extended further to as big as of order 10^{-6} eV . (Ichiki)

3.1.4 Computational Theoretical Physics Laboratory

We plan to investigate the properties of quarks and gluons under conditions of high temperature and density and mechanism of phase transition in quantum chromodynamics (QCD) using PC clusters. High-precision experimental data of high-energy heavy-ion collisions, development of theory, and advancement in the performance of computers enable us to quantitatively understand various aspects of QCD. In particular, we clarify dynamics of quark-gluon plasma (QGP) and hadron production mechanism from comprehensive analyses on small and larges systems of high-energy heavy-ion collisions at the LHC. Also, we discuss details of QGP bulk property from analyses on collective flows of charge hadrons and their correlations at the LHC. (Chiho Nonaka)

3.2 Division of Experimental Studies

3.2.1 Flavor Physics Group

• B and tau physics at Belle and Belle II

One of the biggest challenge in the Tau-Lepton Physics Group is to find evidence of New Physics beyond the Standard Model (SM). There is a hint in existing data collected by the B-factory experiments Belle and BaBar, and also by the LHCb experiment at CERN. These three experiments have reported excess of the semileptonic decay of the B meson into the final state with the τ lepton, $B \to D^{(*)}\tau\nu$, over to those with the muon or the electron, $B \to D^{(*)}\ell\nu(\ell = e, \mu)$. While the weak interaction in the SM does not distinguish the three leptons, this "lepton universality" may be violated in NP models, such as the charged Higgs and the lepto-quark model. Members from Nagoya have contributed to the Belle analyses in the past years, in particular on the measurements with semileptonic tags, and also with hadronic tags and the hadronic τ decay modes ($\tau \to \pi\nu, \rho\nu$), where the latter (PRD97, 012004) enabled to measure the ratio of the branching fraction;

$$R(D^*) \equiv \frac{\mathcal{B}(B \to D^*\tau\nu)}{\mathcal{B}(B \to D^*\ell\nu)} = 0.270 \pm 0.035(\text{stat.})^{+0.028}_{-0.025}(\text{syst.}) \tag{3.1}$$

and also the τ lepton polarization $P_\tau(D^*)$ for the first time;

$$P_\tau(D^*) = -0.38 \pm 0.51(\text{stat.})^{+0.21}_{-0.16}(\text{syst.}). \tag{3.2}$$

Although the error is still large, our work demonstrates feasibility of such measurements at the forthcoming SuperKEKB/Belle II experiment.

The SupperKEKB/Belle II experiment provides unqiue opportuities for critical test of SM and search for New Physics with variety of channles in B and τ decays. At Nagoya, we are working not only the $B \to D^*\tau\nu)$ decays, but also the measurement of CP violation in rare B decays such as $B \to \phi K_S$ and $B \to \rho\rho$, and the Lepton-Flavor-Violating τ decays.

Apart from the New Physics search, heavy flavor hadron physics is also the area we are intensively working. B-factory experiments have observed a large number of charmonium-like states in the B meson decay and opened a new era in the field of hadron spectroscopy. Such hadron spectroscopy is also our target at the Belle II experiment. In particular, we are studying possibility to measure;

- Absolute branching fractions of $X(3872)$ production from the B decay: $\mathcal{B}(B \to XK^+)$
- Absolute branching fraction of $X(3872)$ decays to particular decay modes: $\mathcal{B}(X \to f)$
- Total width of $X(3872)$ as well as the lineshape in the $X(3872) \to DD^*$ decays

We are also working on the measurement of the e^+e^- cross section using initial state radiation. The precise results of the e+e- cross section will be crucial inputs to estimate the hadron vacuum polarization effects, and thus to improve the SM prediction of the anomalous magnetic moment of the muon. In particular, the first result rcentlyy reported by the Fermilab g-2 experiment has confirmed the deviation reported earlier by the Brookhaven experiment, and the combined result has about 4.2σ deviation from the SM value. On the otherhand, some discrepancy exist between the results of the e^+e^- cross section measurements in the past by the BaBar and KLOE experiments. Therefore, the result from the Belle II experiment will provide very important input for verification.

The SuperKEKB/Belle II experiment has started physics data taking with all subdetector components installed since March 2019. Within this fiscal year, the SuperKEKB accelerator achieved the world highest peak lumnosity, $2.4 \times 10^{34}\text{cm}^{-2}\text{s}^{-1}$, and the Belle II experiment has accumulated more than 100 fb^{-1}. Now we are studying feasibility of the above measurements at Belle II based on Monte Carlo simulation. We are also working on analyses of the real data collected by summer 2020, and have obtained some highlight results including rediscoveries of $B \to \phi K^{(*)}$, as shown in Figure 3.2.1, as well as rediscovery of $X(3872)$ in $B \to X(3872)K$ followed by $X(3872) \to J/\psi\pi^+\pi^-$, as shown in Figure 3.2.1.

- **ATLAS**

KMI achievements in 2020 at the energy-frontier LHC-ATLAS experiment

Our scientific goals are (a) to discover New Physics phenomena arising from physics beyond the Standard Model (SM) such as supersymmetry (SUSY), as well as (b) to reveal the structure of vacuum and the origin of the mass of particles through the measurements of the Higgs-boson properties.

The Run 2 period (2015–2018) of the LHC-ATLAS experiment at CERN finished successfully, collecting 140 fb^{-1} of proton-proton collision data at a centre-of-mass energy to $\sqrt{s} = 13$ TeV. This world-highest-energy allowed us to explore heavier new particles with significantly improved sensitivities and also to measure the SM processes including the Higgs-boson properties more precisely using even higher-statistics data samples than ever. Once a series of our initial Run 2 results were released in 2017, we defined a staggered strategy of our several physics analyses since the latter half of Run2 to

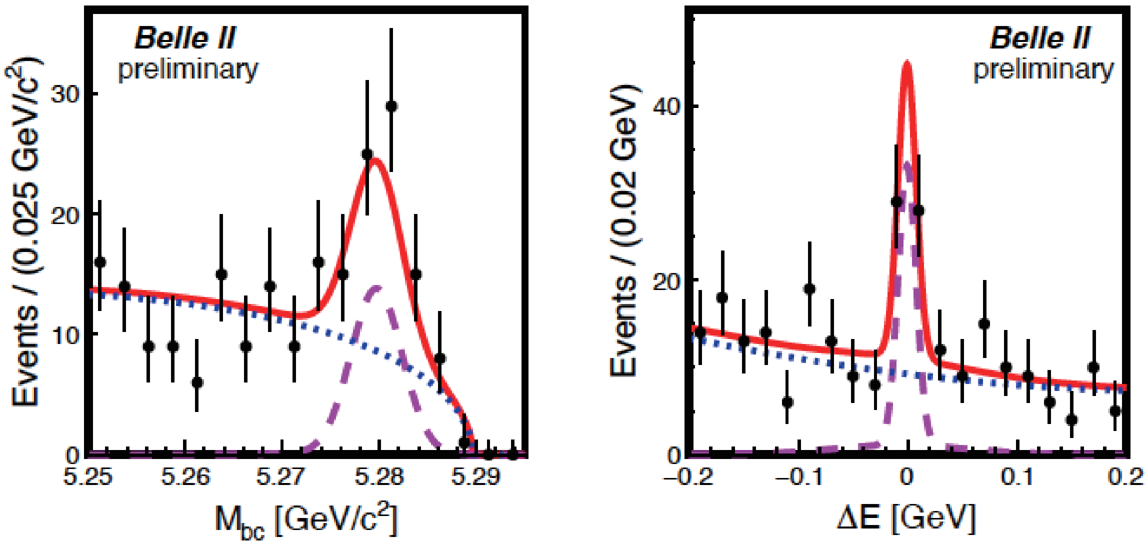


Figure 3.1: The signal of the $B \to \phi K^{(*)}$ decay obtained from the Belle II physics data, collected by summer 2020.

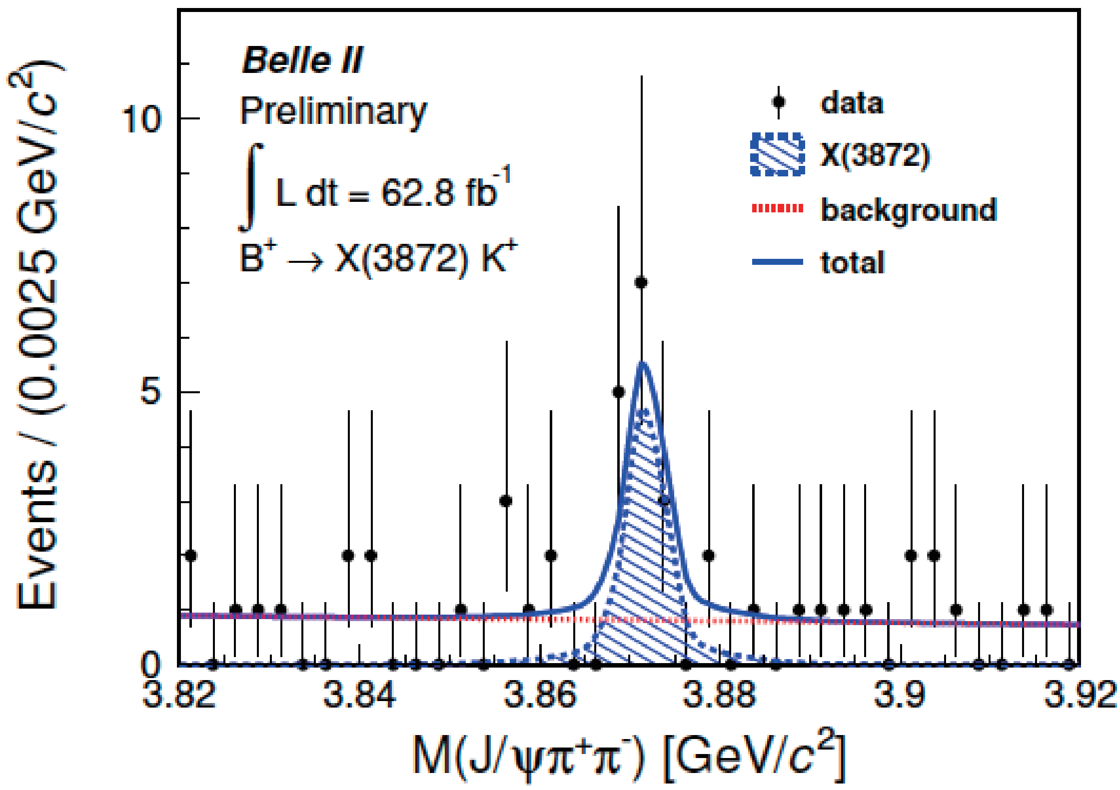


Figure 3.2: The signal of X(3872) in the $J/\psi\pi^+\pi^-$ invariant mass distribution in the $B \to J/\psi\pi^+\pi^- K$ decay obtained from the Belle II physics data, collected by summer 2020.

be consolidated subsequently throughout several years until the High-Luminosity LHC. This year is an extremely fruitful year for the KMI ATLAS group with multiple physics achievements and progresses using the full Run 2 dataset. We released three flagship physics results on the SUSY inclusive search, the $H \to \mu\ \mu$ search, and a world-new di-Higgs search with a Vector-Boson-Fusion signature. Three more complex analyses are in progress, on a new di-Higgs search for direct constraints on the Higgs self-coupling, long-lived particle searches, and a new measurement of the top-quark mass.

In parallel, we have been developing advanced technologies for the trigger system both in hardware and software. The trigger system determine which physics events will be retained for offline data analyses, and is of fundamental importance to the ATLAS physics program, noting that losses or inefficiencies in data taking cannot be recovered at a later stage in data taking at higher luminosities towards the High-Luminosity LHC.

Physics achievements
(1) SUSY searches
Since the start of Run 2, we primarily focused on inclusive gluino search in all-hadronic final states as an analysis coordinator, since the gluino mass is indicated to be light enough (in the framework of "Naturalness" theory) to be discovered using the Run 2 dataset and also this analysis has been considered as one of the flagship analyses in tens of the LHC SUSY analyses. To conclude on this search using high-statistics 140 fb^{-1} pp collisions, we have developed two kinds of state-of-the-art analysis methods (the one based on Machine-Learning, and the other on some proper multi-dimensional statistical fits). These allow us to separate signals and backgrounds effectively and extend sensitivities to any signal masses in target. We submitted the result to JHEP in October 2020. No significant differences were found between the number of observed events and the Standard Model predictions in the signal-enriched regions. As shown in Figure 3.3(a), an exclusion limit at the 95% CL on the mass of the gluino is set at 2.30 TeV for a simplified model considering only a gluino and the lightest neutralino, assuming the lightest neutralino is massless. For a simplified model involving the strong production of mass-degenerate first- and second-generation squarks, squark masses below 1.85 TeV are excluded if the lightest neutralino is massless. These limits substantially extend the region of supersymmetric parameter space previously excluded by the similar previous ATLAS results. Given the most generic signature (jets and missing energy) of this analysis has great sensitivities over various model parameter spaces from our experiences, we will utilise the result for re-interpretation (RECAST) on other SUSY and Dark-Matter models (e.g. pMSSM scan) for next few years.
(2) $H \to \mu\mu$ search
Complete understanding of the Higgs couplings and searches for any possible deviations from the SM predictions is also one of the extremely important topics in the Run 2 period after several years since the Higgs discovery. We contributed to the observation on direct interaction of the Higgs boson with top quark in 2018 July, as well as the succeeding observation of the Higgs boson decaying to two b-quarks. All these coupling measurements of the Higgs boson to fermions well match with the SM predictions as a function of fermion mass. In 2018, we started a new activity with a Nagoya PhD student to provide new Higgs-coupling measurement with muon as the second-generation fermion. We made a number of analysis improvements, for instance, increasing signal efficiency and improving the reconstructed Higgs mass-resolution with saving the final-state-radiation events, as demonstrated in Figure 3.3(b). The result was published in PLB in 2020 November. No significant excess of events above the measured background was observed in the signal region around the Higgs boson mass of 125 GeV. The observed signal significance is 2.0 standard deviations for 1.7 standard deviations expected from the Standard Model. An upper limit on the Higgs boson production cross section times branching fraction to muons was set at 2.2 times the Standard Model prediction at 95 % CL. This new result

represents an improvement of about 50 % with respect to the previous ATLAS paper result. Our next target is apparently the observation of this channel With more statistics to be collected in the Run 3 period.

(3) Di-Higgs production searches

Search for additional Higgs bosons beyond the Standard Model is another promising way of New Physics search using the energy-frontier LHC. In 2017, KMI has started new activity on such searches for Higgs pair production (in the 4 b-jet final state, as a an analysis coordinator), initially for heavy neutral Higgs search beyond the SM, as well as later for the Higgs self-coupling measurement, namely the shape of the Higgs potential, which is considered as the primary target towards the HL-LHC era from 2026. In the SM, the event rate is too small to be observed but with New Physics contribution the rates can visible. With a Nagoya PhD student, we developed a completely new analysis focusing on the Vector-Boson Fusion (VBF) process, which has different sensitivity to the existing analysis on the gluon-gluon fusion production and a unique access to the coupling of two vector-bosons and two Higgs bosons (a parameter called $\kappa 2V$). The result was published in JHEP in 2020 July. No hints of deviations from the Standard Model or new particles were observed, but the new ATLAS result probes a yet-untested property of the Higgs boson's interaction with weak bosons. It provides the first constraints on the $\kappa 2V$ coupling to be between –0.56 and 2.89 times the value predicted by the Standard Model, as demonstrated in Figure 3.3(c). With a Nagoya PhD student, we consolidate a new analysis in 2020 dedicated to the ultimate understanding of the Higgs self-coupling in the gluon-gluon fusion process together with Effective-Field-Theory interpretation, aiming for two result releases in 2021 and 2022.

(4) Long-Lived particle searches

No New Physics phenomena were observed yet with focus on prompt decays and new weakly-interacting particles can have long lifetimes. With a new Nagoya PhD student, we started a new activity in 2020 to search for long-lived particles with our trigger expertise. The focus is search for long-lived gluinos with a displaced vertex signature. Assuming very high mass squarks, gluinos become metastable (split SUSY) and long-lived gluinos hadronize to a color singlet (R-Hadron). We consolidate the analysis components of the displaced vertex plus jets channel, and plan to have the result in 2021, followed by more spin-off analyses with other objects such as missing energy, so as to cover more difficult phase spaces.

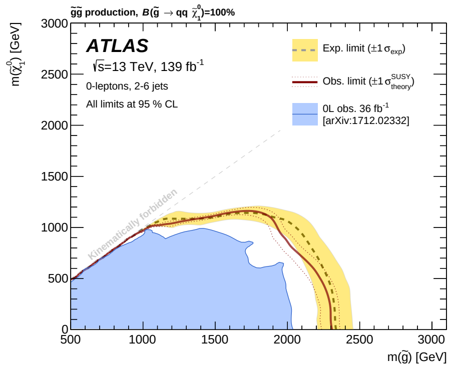
(5) Measurement of the top-quark mass

The Nagoya group has been focusing on top-quark physics historically since the LHC start and made various results with Run 1 dataset. A precise measurement of the top-quark mass has been becoming important with even higher statistics, in order to understand the stability of vacuum. With a Nagoya PhD student, we started a new activity with the focus of the top-mass measurement using a J/ψ. This channel can suppress the large uncertainty from physics modelling on jet hadronization, which has been one of the largest uncertainties in some high-statistics channels. We plan to have the result in 2022.

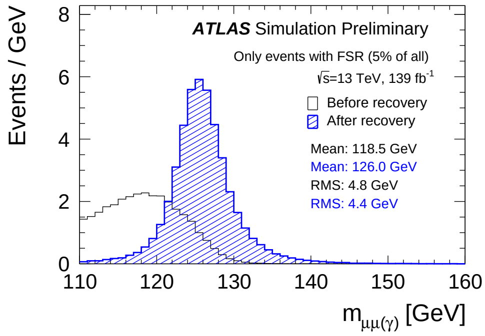
Trigger achievements

(1) Hardware

KMI keeps playing a main role in the operation and the maintenance of the muon trigger system with the thin gap chambers (TGC), which cover the pseudo-rapidity range $1.05 < |\eta| < 2.4$. We continue our efforts at the calibration and the alignment of TGC, which are essential for the collection of high quality data using muon trigger. This year, we developed a new calibration system for the inner layer of TGC. The inner layer is crucial for the reduction of fake muon trigger due to low momentum particles from secondary interactions of the proton beam. The new calibration system will be used



(a)



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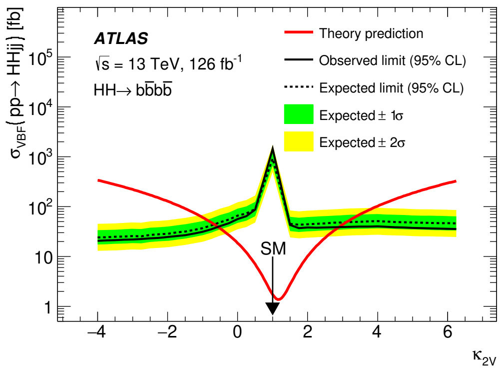
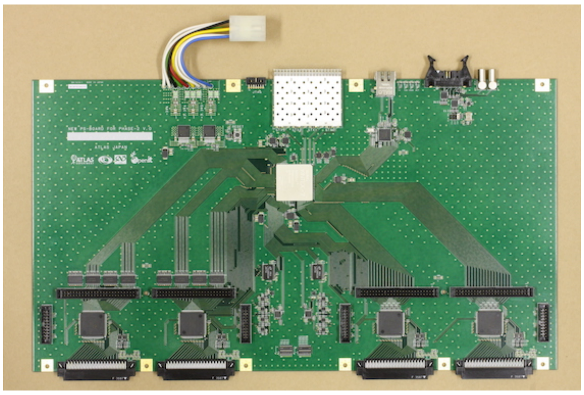


(c)



(d)

Figure 3.3: (a) Exclusion limits in the mass plane of the lightest neutralino and the gluino for gluino pair production with direct decays of gluinos. (b) Invariant mass of $\mu\mu(\gamma)$ final states for signal simulated events with a reconstructed FSR photon candidate. The black and blue histograms represent the distributions before and after the FSR recovery, respectively. (c) Observed and expected 95% CL upper limits on the production cross-section for non-resonant HH production via VBF as a function of the coupling parameter of two vector-bosons and two Higgs bosons, $\kappa 2V$. (d) The first prototype of the TGC frontend board for the HL-LHC.

for Run 3, planned to start in 2022.
High-luminosity LHC (HL-LHC) starting from 2027 is planned to increase the luminosity by a factor of about 10 compared to the current LHC for more precise measurements of Higgs boson properties and more sensitive searches for the physics beyond the SM. The trigger and data acquisition system of the ATLAS experiment is being upgraded to cope with the higher radiation levels, the higher detector occupancy, and the higher data rate at HL-LHC (called phase-II upgrade). This year, we contributed to the quality check of ASICs and the prototyping of frontend and backend boards of the TGC in the phase-II upgrade program. A system of the automatic quality check of the ASICs has been developed. The quality check of the ASICs from mass production shows a yield rate of 95% where 50% is required. The first prototype of the frontend board was designed and produced (Figure 3.3(d)), and a thorough test on the functions was performed. The design of second prototype was completed with minor corrections arose from the test on the first prototype. The backend board shall implement huge amount of optical links (around 200) and high-end FPGA (XCVU13P), and the design requires significant efforts. We successfully completed the design of the first prototype, and the production and the test are planned to start in 2021.

(2) Software and Menu (trigger selections)

KMI has been leading the software-based muon trigger development as a coordinator. We have been upgrading the current muon-trigger software from a single- to a state-of-the-art multi- threading technique for Run 3 (starting in 2022), in the context of a big-data software-development campaign in ATLAS (considered as the biggest software change during next decade). We successfully finished the code migration and validation. We demonstrated the performance of this framework update for the coming commissioning. For the coming Run 3 period with even higher luminosities, in the current Long-Shutdown period 2019–2021, we are improving the muon trigger system by utilizing new hardware components in the ATLAS detector (on more sophisticated tracking and muon information at trigger levels) and improving the trigger selections for the continuous success of the ATLAS physics program.
We have also contributed centrally to designing of the trigger strategy and commissioning of the ATLAS experiment, in particular, as the trigger menu coordinator in Run 2 and as a panel chair of the ATLAS Trigger Workshop 2020 entitled "Ready for Run 3".

• Fundamental Astroparticle Physics

T-violation in resonance reactions, medium range interactions, neutron lifetime

The enhancement of the violation of time-reversal symmetry is predicted in the neutron capture reaction for some nuclei. The enhancement depends on the resonance parameters and spin states of the nuclei. We successfully estimated the enhancement factor for ^{139}La as a target candidate at the order of 10^6 by measuring angular correlation terms of (n, γ) reaction. We are continuing to take the data for ^{115}In, ^{117}Sn, ^{131}Xe, and so on, by using germanium detectors in ANNRI neutron beam line in Material and Life Science Experimental Facility (MLF) at J-PARC. The enhancement of the symmetry violation is related to the treatment of compound nuclei. The detailed analysis of compound states can be discussed by using polarized neutrons. We have also measured the angular correlation terms of ($\vec{n}$, γ) reaction by using high-performance ^{3}He neutron spin filter on the beamline. We are now started to discuss the compound states with the global analysis of the whole data with theory group. These results showed the feasibility of the T-violation search experiment with high sensitivity, which can be reach to that of neutron EDM and which has different systematics. Now we can discuss the detailed design of the T-violation search experiment by using nuclear resonance reactions. For the T-violation search experiment, the polarized nuclear target must be prepared. A $LaAlO_3$ single crystal, which has the perovskite structure, is a candidate for polarized target. The collaboration study started to fabricate the large scale of the crystal with Tohoku University. Dynamical nuclear polarization (DNP) system are developing with Osaka University and Yamagata University. The enhanced polarization of ^{139}La nuclei was demonstrated by the DNP method with the $LaAlO_3$ single crystal fabricated ourselves. International collaboration is also expanding.

The recent values of neutron lifetime deviate far beyond the systematic errors claimed in the past and sometimes can be a trigger of discussion of new physics. We published the first result of neutron lifetime measurement by using pulsed neutron beam at NOP beamline in J-PARC. The well-defined bunches is injected into time projection chamber (TPC). The TPC detects both of the electrons from neutron beta decay and the nuclear reaction by ^{3}He in order to estimate the flux at the same time. The measured value was 898^{+18}_{-20} s, which still has a large uncertainties. For the accuracy of the order of 0.1% , the improvement of the upstream beam optics is now ongoing. The origin of the systematic uncertainties is also studied by using the improved statistics.

New types of experiment with neutrons are also discussed. Cold-neutron interferometer with artificial multilayer mirrors was successfully demonstrated by using pulsed neutrons. It can be utilized for precision measurements of neutron scattering lengths and for unknown force search, for example, chameleon field. Nuclear emulsion as a neutron detector with high position resolution were developed with the emulsion group in Nagoya University. It will be applied to various experiments including a study of gravity. Neutron small angle scattering with nano particles can be used for search for unknown interactions in medium range. Dynamical diffraction in perfect crystals were studied for both of a search for neutron electric dipole moment and a search for unknown force.

Understanding Cosmic-Ray Air Shower using Accelerator

The Large Hadron Collider forward (LHCf) experiment measures neutral particles emitted in the very forward angle region of hadron-hadron collisions at LHC. A similar version of the experiment RHICf has been done at RHIC with polarized proton-proton collisions at 510 GeV. Knowledge of the forward particle production is expected to improve the hadronic interaction models used in the interpretation of cosmic-ray air shower observations. In 2020 we continued analyses of obtained data with operations at LHC and RHIC. The large transverse asymmetry discovered in the forward neutral pions in low $p_T < 1 GeV$ in RHICf was finally published. The analysis on very forward neutron asymmetry is now on-going. We also continue the combined analysis with ATLAS to study various high-energy diffractive processes, and investigate its impact on air shower development. For future plans, we start to discuss a new LHCf run for possible proton-Oxygen collisions at LHC during Run-3, which is strongly supported by the international air-shower community. We have also submitted LOI for the RHICf-II proposal with a updated detector utilizing ALICE FOCAL technology. We were also invited to discuss possible very forward measurements in future projects such as PHASER, EIC, or very forward hadron spectrometer at LHC.

Dark Matter and Neutrino Experiments at Kamioka Mine

Super-Kamiokande (SK) is the 50-kton water Cherenkov detector underground of the Kamioka Observatory dedicated for observation of neutrinos and possible proton decay. SK is preparing for the observation of supernova relic neutrinos emitted by all of the supernova explosions by adding gadolinium (Gd) to the pure water in the detector. Despite the difficult COVID-19 situation, the first 0.01 % Gadolinium was successfully introduced in the SK pure water in summer 2020. SK-Gd has now started its operation without major deterioration of detector performance. The new search for neutrino-nonstandard interactions using atmospheric neutrino oscillations was made with a full 3-flavor matter oscillation analysis technique newly developed for this purpose. This result was produced as the PhD thesis for the joint degree program with the University of Edinburgh. New efforts for refurbishing the Honda neutrino flux model have been intensively made by combining the existing data from accelerator experiments such as SHINE or HARP. We have started series of dedicated annual workshop for atmospheric neutrino productions (WANP), although it was rescheduled as on-line due to COVID-19 problem in 2020. After long standing efforts of promotion, in 2020 Hyper-Kamiokande (HK), the next generation 260-kt water Cherenkov detectors with the upgraded low-energy neutrino beam from J-Parc, has been officially approved by the government. Initial construction has been started at Kamioka site for tunnel excavation. The collaboration is now being reformulated into an official collaboration to fully cope with construction phase of the project. We continued data analysis of XMASS experiment on exotic neutrino-electron scattering search, and follow-up of gravitational wave alerts. Also we published a technical paper for an ultra-low backgroupd 3-inch PMT for future dark matter experiments.

Dark Matter and Neutrino Experiments at Laboratori Nazionali del Gran Sasso (LNGS)

The XENON experiment at LNGS in Italy aims at detecting the tiny amount of charge and light that is emitted after the interaction of a dark matter particle with a xenon nucleus. The third phase of the XENON experiment, XENON1T, was the largest LXe time projection chamber (TPC) ever built with $\sim$3 tons of xenon, of which $\sim$2 tons are in the active volume of the detector, allowed the sensitivity to be improved to the levels never explored, becoming the most sensitive detector in the world for the direct dark matter detection. In 2020, we reported results from searches for events with low-energy electronic recoil recorded with the XENON1T detector. With an exposure of 0.65 ton-year and an unprecedentedly low background rate of 76 ± 2 events/(ton year keV) between 1 and 30 keV, the data enabled sensitive searches for solar-axions, an enhanced neutrino magnetic moment, and axion-like particles (ALPs). An excess was observed at low energies that is consistent with a solar-axion signal, an axion-like particle (ALP) signal with a mass of 2.3 keV, a solar neutrino signal with enhanced magnetic moment, or a possible tritium background. We are unable to confirm nor exclude the presence of tritium since its possible contamination is too small to be measured.

XENON1T detector was decommissioned in 2019 to begin the construction phase of its successor, XENONnT. The XENONnT foresees an upgrade of the current detector with the aim of extending the sensitivity of the experiment by a factor of 10. Such a performance can be realized by increasing the size of the target medium (to $\sim$8.4 tons of xenon) and a stronger reduction of the background. In 2020, the construction of the detector at the site has been completed and commissioning has been successfully carried out in spite of the COVID-19 pandemic. Although trips to the site was inhibited, we are engaged in remote monitoring shifts of liquid xenon introduction and analysis of the commissioning data of the TPC and neutron veto detectors. The solar-axion like signals observed in the XENON1T experiment can be further explored in the XENONnT experiment. With a factor of almost 10 reduction in electronic recoil background, it will enable us to study the excess in much more detail if it persists. Preliminary studies suggest that a solar-axion signal could be differentiated from a tritium background at the 5 σ level after only a few months of data from XENONnT.

We are also conducting various R&D works for the future DARWIN project, which is planned to build a 40-ton double-phase xenon TPC. We have developed a resistive & transparent electrode coated on a quartz glass. We have designed a dedicated sysuccessfully demonstrated electron drift with a small drift tube using it as a drift electrode. Based on this special coating technology, we have designed a dedicated electric field that can drift electrons and then successfully demonstrated its drift. We have also evaluated the performance of SiPM at the liquid xenon temperature and developed a new hybrid photomultiplier tube using SiPM for photoelectron amplification.

Search for dark matter and research on the origin of cosmic rays with gamma-ray observations

Cosmic gamma rays are expected to be produced through the interactions of dark matter, CRs, and the interstellar medium. This makes gamma rays a useful probe to search for dark matter and investigate the properties and distribution of CRs and the interstellar medium.

We are developing the next-generation gamma-ray observatory, the CTA, to observe cosmic gamma rays in an energy range from well below 100 GeV to above 100 TeV. We are in charge of the development, procurement and calibration of silicon photomultipliers (SiPMs) for the small-sized telescope (SST) in the CTA. One of the issues for the operation of the SiPM is the optical crosstalk, where it produces additional signals to the incident photon signal. In the past, we have successfully reduced the optical crosstalk by more than an order of magnitude. In order to understand the origin of the remaining optical crosstalk, we studied delayed crosstalk which is produced in a different mechanism from the normal optical crosstalk. (The normal optical crosstalk occurs at the same time as the original signal while the delayed crosstalk occurs about 10 ns later.) The precise measurements of the delay time distribution of the delayed crosstalk revealed that early delayed crosstalk is misidentified as the normal crosstalk since the delay is too short to resolve the delayed signal from the original signal. We found that the rate of the misidentified delayed crosstalk can account for almost all of the remaining crosstalk. We are now discussing the measures to reduce the delayed crosstalk with a manufacturer. We also studied the increase of the optical crosstalk in neighboring SiPM sensors due to reflection by the protection glass window of the camera. We found that the optical crosstalk increases by a factor of 4 or more due to the presence of the protection window. We are now investigating the effect of this crosstalk.

Directional Dark Matter Search

Direction sensitive search is new promising methodology for direct dark matter detection and its identification. However, expected nuclear recoils due scattered by WIMPs like dark matter and target nuclei recoils in the detector being low-energy of 10-100 keV scale because of lowness of the dark matter velocity. The expected track length in the solid (or liquid) detector is less than 1 μm, therefore development of technologies to obtain tracking information in such a short distance is the unique key of the project.

NEWSdm (Nuclear Emulsion WIMPs Search directional measurement) experiment has been operated by the international collaboration consist of 12 institutes, 5 countries. Current main experimental site is the National Laboratory of Gran Sasso (LNGS), Italy, and R&D and data analysis site are KMI,Nagoya University, Toho University and Napoli university. This project utilize originally developed the Nano Imaging Tracker (NIT) which is super-high resolution tracking device based on nuclear emulsion with 10 nm scale resolution in KMI. And also, new readout systems to obtain nano-scale direction information continue to develop in KMI and Italian group, and those systems are also very unique one in this experiment. The current scanning speed achieved 3 g/month/system, and electron background rejection power was 10^{-3} or even better. We started demonstration for data analysis and scanning data using 1 g scale target mass in 2019. This system will be utilized in first dark matter experiment in underground, and also the new version, wihich is to achieve three times faster throughput, is in progress. NEWSdm facility in LNGS have been mostly constructed, but ventilation system and around infrastructure are under constructing yet. In end of 2018, new self-device production machine have been installed in the LNGS underground site, Hall-F.

In 2019, first device self-production and its quality checks have been started. We succeeded to produce NIT emulsion gels and usable for experiments. While the random noise level of the first batches of produced emulsion are not yet satisfactory compared with the one in produced at Nagoya

University and de-bugging the problem is on going. So far, detection performace of short recoil tracks were demonstrated with tracks by nuclear ions injected from surface of nuclear emulsion and the tracks exist only the surface region. This year monochromatic energy neutron beam exposure at Advanced Industrial Science and Technology (AIST) are conducted to demonstrate the track detection with more realistic nuclear recoils by dark matter, thanks to neutron's penetrating feature recoils inside nuclear emulsion layer can be investigated. The results with analysing proton recoils (length longer than 2 um) are summarized in a Master thesis (Todoroki) in 2019 together with surface neutron background measurement. The analysis of C,N,O recoils (length bellow several 100 nm) by neutron beams have been started and currently background from gamma rays subtraction is under study. A realistic optical simulation tools on track made by developed silver grains were developed and we got good parametrization values to re-produce recoil track data taken by optical microscope. After getting efficiency by AIST neutron data, we are planning to apply the efficiency for dark matter search on ground / under ground exposed NIT samples.

Nuclear Emulsion Technologies

Nagoya university is one of the most powerful institute with nuclear emulsion development and research with in the world. In recent years, the applications of emulsion films have expanded more and more not only in particle physics but also in various imaging fields, and the demand is growing as order of 1000 m^2/year. The upgrade of emulsion gel/film facility operating at Nagoya University is in progress to promote further research activities. In 2019, a large-scale gel production machine has been newly installed. The system has the capacity to produce 20-kg emulsion gel, which corresponds to approximately 10-m^2 emulsion film, in one-day operation. Currently, various construction works (cabling, tubing, calibration of instrument, waste liquid equipment, etc.) for practical operation are in progress. In addition, in order to achieve the capacity of the film production that is compatible with that of the gel production, the automated coating machine applying the roll-to-roll system has been installed. The system enables to pull film from a roll, continuously coat emulsion gel on the surface, dry online, and wind the film onto another reel at the end. In 2019, we started to introduce devices to the laboratory in order, and completed the installation by March 2020. These new facilities are scheduled to complete maintenance and adjustment in June–July 2020, and to start operation in mass production from July–August 2020.

Also our emulsion scannig facility is assuming role of the center of nuclear emulsion analysis for particle physics ,muon radiography and other applications. The HTS-1 is the world fastest emulsion scanning system, however, the 2nd generation system, HTS-2, is under developpment. The almost component (e.g., optics, new mechanics, imager system and so on) has been validating. The commissioning of the HTS-2 will be started in 2020.

The developement of PTS, which is focused to read-out for fine graine emulsion "NIT", is on going for the directional dark matter search, NEWSdm. The recent upgrade of PTS has been achieved 5 times of throughtput as last year version. A new illuminator has 4.3 times light intensity and a narrow spectrum, which make possible enlarge field of view and accept faster frame rate of CMOS image sensor. Another progress is that a novel ellipse analysis with the 2nd order moment method has been implemented, thereby causing carbon ion tracks down to kinetic energy of 30 keV to be detected. The next upgrade is planed that a much higher frame rate image sensor and image processing, which will make possible kg-scale experiment with a few PTS systems.

Balloon Experiment for Gamma-rays Astronomy using Nuclear Emulsion technology

Observation of cosmic gamma rays is important in understanding high-energy phenomena in the universe. Since 2008, the Fermi Gamma-ray Space Telescope has surveyed the sub-GeV/GeV gamma-ray sky and provided a large mount of data. However, observation remains difficult owing to the lack of the angular resolution, and new issues have arisen.

We started up a precise gamma-ray observation project, Gamma-Ray Astro-Imager with Nuclear Emulsion (GRAINE), using balloon-borne emulsion gamma-ray telescopes to enable high angular resolution, polarization-sensitive, and large-aperture observations in the 0.01–100 GeV energy region.

We have proceeded the flight data analysis of the last balloon experiment (GRAINE 2018), which was performed in April 2018. Event selection, energy reconstruction, timestamp, and arrival-direction determination were completed using 98 % of accumulated data. As a result, we succeeded in the first detection of a celestial gamma-ray object, Vela pulsar, via the balloon-borne emulsion telescope. The expanse of gamma-ray image in the 100-MeV region is $\sim 1^\circ$, which is the expected performance of our telescope, and the world's highest angular resolution was demonstrated.

The next balloon experiment (GRAINE 2022) is approved by JAXA and scheduled in April 2022 (The original schedule was in 2021 ,but postponed due to covid 19). The aperture area of the telescope is enlarged to 2.5 m^2 (as 6.6 times large as that of GRAINE 2018) and two telescopes will launch from Alice Springs, Australia. The experiment aims at observation of Vela pulsar, Geminga pulsar, the galactic center, etc. in GeV energy region, and survey of transient phenomena by a largest aperture area telescope. Now, we are newly constructing a large-scale emulsion gel production system and a film coating system at the laboratory. In 2021, for GRAINE 2022, we will manufacture 500 m^2 of emulsion plates using these facilities, and develop a large pressure vessel gondola that can mount a 2.5-m^2 telescope.

Study for Neutrino Physics using Nuclear Emulsion

Tau neutrino is the one of the least known standard model particle. It is due to large uncertainty of its production and difficulties on detection and identification. So far tau neutrino-nucleon interaction cross section has large error of several tens % and we, DsTau, SHiP, are aiming to measure it within10% accuracy.

DsTau experiment aims to study the tau neutrino production with CERN SPS 400 GeV proton on tungsten target. DsTau will provide accurate tau neutrino flux information for future experiments like SHiP measuring tau neutrino cross section with high statistics by performing a detailed analysis of differential production cross-section of $Ds \rightarrow \tau + \nu_\tau$ and the $\tau \rightarrow X + \nu_\tau$. Nuclear emulsion trackers used in DsTau can identify $Ds \rightarrow \tau + \nu_\tau$ cascade decay, thanks to the sub-micrometric position resolution of emulsion, average 7 mrad angle difference between Ds and tau in few mm distance can be detected. The uncertainty of tau neutrino production flux will be reduced bellow 10% using 1000 detected such a cascade decays from 2.4×10^8 proton -tungsten interaction. After the success of 2018 pilot run data taking and analysing status, the DsTau is formally approved as **NA65 for data taking with CERN SPS in 2021-2022.** The emulsion film scanning of 2018 pilot run have been finished at Nagoya University F-lab and proton interactions and decay vertices reconstructions are on going. Several hundreds of charm pair associating proton tungsten interactions are collected from the reconstructed events data. In 2021 the emulsion detector production at Nagoya University is scheduled for the physics run in 2021.

SHiP experiment is planning to expose tau neutrino from 2028 and currently doing performance tests for tau decay daughter track's change and momentum measurements. Thanks to sub-micrometric resolution of nuclear emulsion, a compact spectrometer length of 3 cm can determine charged track's charge for momentum $\leq$ 7 GeV/c. The compact emulsion spectrometer (CES) have emulsion films as tracking device with low density spacer 1.5 cm. The CES performance tests have been conducted with changing several base materials. As the result the glass base or solid thicker base make the distortion of emulsion plates smaller and then better performance on momentum resolution. The large scale performance tests are planed for 2021- .

FASERν is a new project data taking in 2021-2024 and later aiming to study high energy neutrinos from the ATLAS collision point at 480m away in forward direction. 1.2tons of neutrino Emulsion Cloud

Camber (ECC) detector using tungsten plates as neutrino interacting target interleaved with nuclear emulsion will be mounted in the TI12 tunnel. Currently analysing a pilot run data with two small ECCs total mass of 15kg, the emulsion film scanning have been finished, and search and analysis on neutrino interaction vertices is under finalizing. In 2020 the emulsion detector production at Nagoya University and construction is scheduled.

The NINJA experiment at J-PARC

Currently study of sub-multi GeV neutrinos is one of most important subject in the field of particle physics because almost long baseline neutrino oscillation experiments which search for the CP violation in the lepton sector use neutrinos in this energy region and the main systematic error in current and future neutrino oscillation analysis is caused from the uncertainty of neutrino-nucleus interactions in sub-multi GeV energy region. Furthermore recently MiniBooNE experiment at Fermilab reported an anomaly of 4.7 sigma excess of electron like neutrino events in sub GeV energy region which indicates the existence of sterile neutrino. Sterile neutrino search is also a big topics in this field because it is not predicted by the Standard Model and a candidate of right-handed neutrino or dark matter or dark radiation. But MiniBooNE signal is not concluded as an evidence of sterile neutrino because there is possibility that it comes from unknown systematic error, for instance the uncertainty of neutrino-nucleus interactions. So more precision measurement of short baseline neutrino oscillation like MiniBooNE condition is needed. In summary, study of sub-multi GeV neutrinos is a key to open physics beyond the Standard Model.

The NINJA experiment aims to measure neutrino-nucleus interactions precisely and search for sterile neutrino at same physics condition in MiniBooNE with different detector and accelerator at J-PARC. Thanks to excellent position resolution of the emulsion detector which is main detector in NINJA, we can measure hadrons from neutrino interactions at low energy threshold. This allows us to reconstruct neutrino interactions without ambiguities. Actually we clearly demonstrated to detect below 500 MeV/c protons from neutrino interactions in iron and water target which could not be detected so far because of too low energy in 2019. These results were reported at several international conferences and near future the papers will be submitted. Then we successfully implemented neutrino beam exposure with a 250 kg large mass detector (iron:130 kg, water:75 kg, emulsion:30 kg, CH:15 kg) from Nov. 2019 to Feb. 2020 as our 1st Physics Run. Currently the emulsion scanning has been started and the expected number of neutrino events is more than 10,000 events. We will analyze these neutrino events to understand sub-multi GeV neutrino interactions and feedback to make a more concrete plan for the next step, sterile neutrino run.

3.2.2 Origin of Spacetime Structures Group

Progress on the X-ray observatory XRISM (X-Ray Imaging and Spectroscopy Mission)

XRISM is a JAXA-lead X-ray astronomy satellite, to be launched in JFY 2022. Based on the heritage of the Hitomi X-ray observatory, XRISM focuses on its soft X-ray super high resolution spectroscopy with an energy resolution of $\sim$ 5 eV using a calorimeter array, 30 times better than existing X-ray CCD detectors. Because it does not use dispersion optics, the energy resolution is not affected by the spatial structure of the target and therefore is a powerful tool to observe diffuse objects, such as clusters of galaxies and super-nova remnants.

The XRISM team is concentrating developing and testing the mission systems, the satellite, the ground support systems and science analysis software. Also, target selection of Performance Verification Phase is on going. Uxg member is contributing in developing the information sharing system, as a member of the science operations preparation team (SOPT).

The Imaging X-ray Polarimetimetry Explorer (IXPE) mission

IXPE is a SMEX mission lead by MSFC/NASA, to be launched in October 2021. It aims at the first imaging-polarimetry observation in the 2–8 keV X-ray bands. Polarization reflects the geometry of the emission region, such as the magnetic field orientation and/or scattering material distribution. Nagoya University is providing the thermal-shield for the X-ray mirror optics, based on the experience on those of the Suzaku and Hitomi satellites. Because of the higher temperature requirement, the material of the thermal shield is changed from PET to polyimide film, and production parameters are newly developed. In 2020 summer, final set of calibration activities using material os the same lot of the flight models was performed. The output will provide vital information to evaluate the detector response.

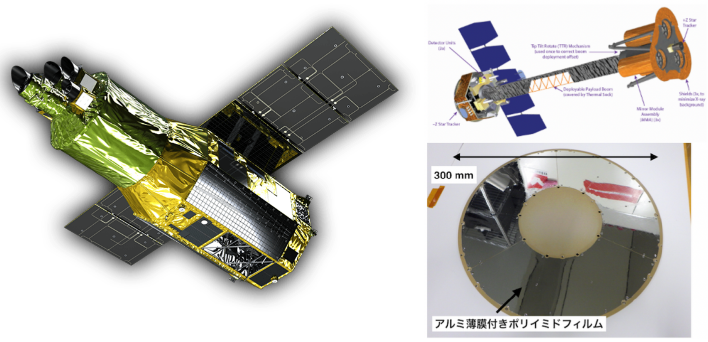


Figure 3.4: (left) The XRISM mission image. (right) The IXPE mission and its thermal shield.

X-ray optics and detector development activities

In view of the future X-ray observatory, we are developing new optics. One is a new mirror using domestic electroforming technology. As the first year trial, we succeeded in developing a miniature mirror, and demonstrated the technology. Designing of mirror holding structure, improvement of the mirror itself is going on.

The FORCE mission, a wide-band fine imaging probe in 1-80 keV, is proposed for launch around early-2030s. The main science aim is to probe the hidden black-holes in the universe, and measure the non-thermal components in SNRs and other objects. While the optics development is ongoing in NASA/GSFC, detector components and satellite system design work is ongoing. In 2020, imager subsystem design work has started. Also be sharing technologies with MeV gamma-ray measurement detector development activities in our group, one of the key FORCE detector elements, CdTe double-sided Strip Detector development has started.

X-ray data analysis: merging cluster of galaxies

Cluster of galaxies are the node of the large-scale-structure, and is the largest self-gravitating system in the Universe. We are analyzing a early-phase merging cluster using X-ray data of Suzaku and XMM-Newton. In the bridge region connecting the two clusters, we found two zones with high-pressure, separated by an apparent "channel" with pressure deficit in between. Very hot plasma, or enhanced high-energy particle and magnetic field, which all cannot be easily observed in existing X-ray observatories can reside in the channel.

Thundercloud gamma-ray observation

Thunderclouds are known to emit gamma rays with energy as high as 30 MeV. As one of the applications of space-borne compact X-ray/gamma-ray detector technology, we are performing gamma-ray observations of winter thunderclouds around the seashore of Japan Sea. In early 2019, we observed a series of gamma-ray glows, a minute-lasting gamma-ray emission originating from the cloud itself, within $\sim$ 6 minutes. The phenomena can be understood as two or three rapidly growing electron acceleration regions coming out of one thundercloud. We are continuing the observation activity by

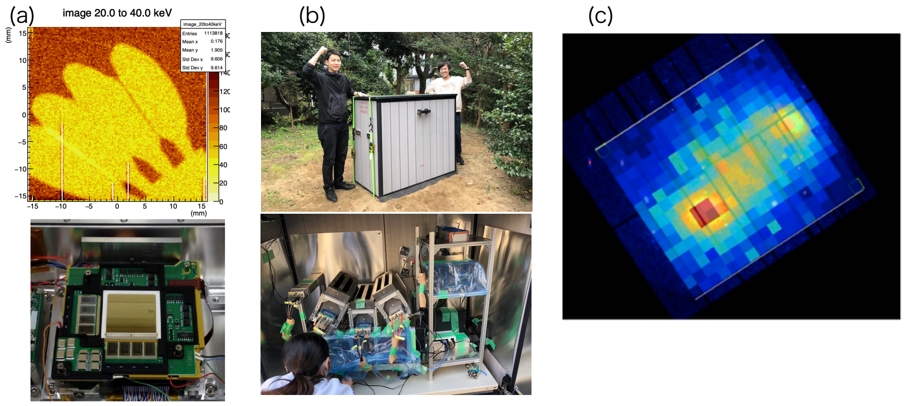


Figure 3.5: (a) Test result of the newly developed CdTe-DSD imager. (b) Thunder cloud gamma-ray observation champaign of FY2020. (c) Plasma pressure distribution of a merging cluster CIZA J1358.9-4750.

adding two “collimated” detectors aiming at measuring the accelerator altitude.

3.2.3 Instrument Development Laboratory

Operation of the TOP counter in the Belle II experiment

The TOP (Time-Of-Propagation) counter is a novel ring imaging Cherenkov detector for particle identification (PID) in Belle II. It reconstructs Cherenkov “ring” image by measuring the time of propagation of Cherenkov photons. Sixteen modules of the TOP counter are equipped in the barrel region of the Belle II detector. Each module mainly consists of a 2.7-m long highly-polished quartz radiator bar, an array of 32 Micro-Channel-Plate photomultiplier tubes (MCP-PMTs) at the end of the bar, and readout electronics with a high-speed waveform sampling ASIC.

The Belle II experiment started the physics data taking with the full detector components in March 2019. A major issue we found in the operation is a much higher beam background from the accelerator than we expected with a Monte Carlo simulation. It is a serious problem for the MCP-PMTs because the quantum efficiency (QE) of the MCP-PMT photocathode degrades with the accumulated output charge, which is dictated by the hit rate of the MCP-PMT due to the beam background. To suppress the QE degradation within an acceptable level until we accumulate the goal of 50 ab^{-1}, the limit of the MCP-PMT hit rate for single beam background components is set at 1.2 MHz/PMT. We have to mitigate the beam background below the limit by means of accelerator and beam collimator tuning as well as possibly additional shielding around the interaction region. In June 2020, we succeeded in increasing the peak luminosity, which reached the world record of 2.4×10^{34} /cm^2/s, while keeping the beam background below the limit. It is also important to monitor the accumulated output charge and relative QE in order to foresee longevity of the MCP-PMTs in operation. We prepared monitors of the gain, hit rate, accumulated output charge, and relative QE for all the 512 MCP-PMTs.

During the operation in autumn 2020, we learned that the beam collimators, which cut out the beam halo to suppress the beam background to the Belle II detector, have to be opened to reduce the impedance for the beam and to pursue a higher luminosity. That means we have to accept a higher beam background. Therefore, we tentatively raised the limit of the MCP-PMT hit rate to 3.0 MHz/PMT and started consideration about replacement of the 220 ALD MCP-PMTs installed in the seven TOP modules around 2026.

Because the 224 conventional MCP-PMTs installed in other seven TOP modules have a much shorter lifetime and the QE will drop significantly soon, we will replace those PMTs with the life-extended ALD MCP-PMTs in the summer of 2022. For the replacement, we produced 176 life-extended ALD MCP-PMTs in addition to 81 spare ones from the past production. We sampled several MCP-PMTs from different batches and measured their lifetime. It was found that 70 MCP-PMTs produced in the first batches seem to have a shorter lifetime than we expect probably due to a trouble in the MCP-PMT production line. Those 70 MCP-PMTs were replaced by additional procurement. The performance of all the MCP-PMTs was inspected in test benches at Nagoya. The one in 1.5 T was also checked using a dipole magnet at KEK.

As an upgrade option of the TOP counter, we consider replacing the MCP-PMTs with silicon photomultipliers (SiPMs) in collaboration with INFN padova and other groups. We submitted our proposal to AIDA2020++ research funding and have been selected as a core Expression of Interest. A SiPM has an advantages of much lower price than the MCP-PMT while the performance could be adequate for the TOP counter. We studied the feasibility of using SiPMs for the TOP counter with a Monte Carlo simulation. Though SiPMs have a worse time resolution and a much higher rate of dark noise than the MCP-PMT, the PID performance of the TOP counter with SiPMs does not degrade significantly owing to the higher photodetection efficiency. A drawback of SiPMs is the radiation intolerance in the Belle II environment. It must be mitigated by cooling the SiPM to $-30°$C or below and by thermally annealing it time to time.

The PID performance of the TOP counter was evaluated with a large dataset taken since 2019. It is still worse than the Monte Carlo simulation. We found that PID with a probability density function (PDF) generated by the Monte Carlo simulation is better than one with the default analytic PDF. That indicates the worse performance could be attributed to some mismodeling of the PDF. We also tried improving the PID performance by means of a machine learning technique.

3.2.4 Tau-lepton Data Analysis Laboratory

In the Belle II experiment, the required computing resource is O(10^5) CPU cores and O(100 PB) storages. In order to accumulate such a huge resource, we adopted the distributed computing technique, which connect the computing resources all over the world and utilize it as a single big computer. The Belle II experiment started the data taking with all the detector installed since Apr, 2019. In 2020 FY, SuperKEKB achieved world highest luminosity, and distributed computing is playing important role.

The important task in the distributed computing side is to uploaded the raw data in the grid world and make one copy in the Brookhaven National Laboratory (BNL) in USA as soon as data is taken. Last year, we developed a system to make the copy in the automatic way. With increase of the luminosity, higher throughput for to make the copy. We made various improvement in both hardware, software, and monitoring system to increase the throughput and make the operation smooth. Thanks to those efforts, we handled more than 1 PB of data in this year, as shown in Fig. 3.2.4.

As data is accumulated, the importance of the end-user analysis is rapidly growing. Figure 3.2.4 shows the number of end user jobs concurrently running. As you can see, some fraction of jobs are failed with various reasons. It is important to make sure that user jobs can be successfully finished before submitting massive number of jobs to use the computing resource efficiently. In order to realize it, we developed two frameworks. One is Python syntax checker, which check the syntax of the analysis code before the submission, and stop it when an issue in the code is found. The other one is the framework called “scout job”. In this framework, when a user submit a massive number of jobs, tiny fraction of jobs which execute small number of events are submitted first. Only when those test

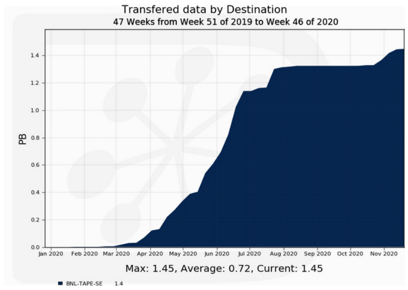


Figure 3.6: Size of Belle II raw data copied to BNL tape system.

jobs are successfully finished, remaining jobs are submitted. These machineries have been successfully implemented in Belle II distributed computing system just now. We expect number of failed jobs to be decreased drastically in the future.

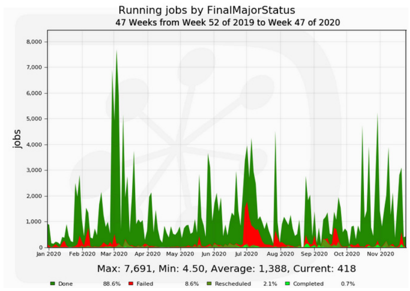


Figure 3.7: Number of user analysis jobs concurrently running.

Chapter 4

Research Related Activities

4.1 Conferenes and meetings held by KMI

[1] IBS and KMI Joint Workshop 2020 Date: 24,26 Aug, 2020
Place: Online (Zoom)
Style: International
Number of participants (foreign): 48 (20)
Sponsorship: KMI (Core-to-Core program),IBS
Web site: https://indico.ibs.re.kr/event/362/

[2] The 3rd KMI School: Machine Learning in Particle and Astrophysics
Date: 16-20 Nov, 2020
Place: Online
Style: International
Number of participants (foreign): 76 (20)
Sponsorship: KMI
Web site: http://www.kmi.nagoya-u.ac.jp/workshop/KMIschool2020/
Note: The 3rd KMI School was originally planned on March, 2020, but rescheduled due to COVID19.

[3] 2nd Workshop for Atmospheric Neutrino Production in the MeV to PeV range
Date: 12 - 13 Jan. 2021
Place: Online
Style: International
Number of participants (foreign): 100 (62)
Sponsorship: KMI, ISEE
Web site: https://indico.cern.ch/event/873509/

[4] Workshop on Interplay of Neutrino and Dark matter Experiments and Exotic Searches
Date: 18 - 19 Mar. 2021
Place: Online
Style: International
Number of participants (foreign): 129 (91)
Sponsorship: KMI
Web site: https://sites.google.com/view/indees2021/

[5] International Symposium of JSPS Core-to-Core program “DMNet”

Date: 24 - 25 Mar. 2021
Place: Online
Style: International
Number of participants (foreign): - (-)
Sponsorship: KMI, DMnet
Web site: http://www.kmi.nagoya-u.ac.jp/jsps-core-to-core-program/seminar/169-2

4.2 Seminars and Collquia

[1] 2020/05/20 17:30- KMI Topics (Zoom)
"New physics implications of recent data on K to pi nu nu searches"
Teppei Kitahara (KMI, Nagoya Univ.)

[2] 2020/05/28 17:00- KMI Colloquium (Zoom)
"An underground experiment challenging the mystery of matter dominance in the universe"
Kunio Inoue (Research Center for Neutrino Science, Tohoku University)

[3] 2020/06/11 17:00- KMI Theory Seminar (Zoom)
"Axions and low scale inflation"
Lorenzo Ubaldi (SISSA)

[4] 2020/06/17 17:00- KMI Colloquium (Zoom)
"Fundamental constants and recent developments in particle physics "
Ken-ichi Hikasa (Tohoku University)

[5] 2020/06/24 17:30- KMI Topics (Zoom)
"Prototype Telescopes of the Cherenkov Telescope Array"
Akira Okumura (KMI, Nagoya Univ.)

[6] 2020/07/08 17:00- KMI Colloquium (Zoom)
"Test of Lorentz and CPT violation with Neutrinos "
Teppei Katori (King' s College London)

[7] 2020/07/09 12:00- KMI Interdisciplinary Seminar (Zoom)
"Inter-disciplinary seminars on dark matter" The electron-recoil excess in XENON1T (TBC)"
Shingo Kazama (KMI/IAR)

[8] 2020/07/15 17:30- KMI Topics (Zoom)
"Search for tetraquark candidate through B meson decays at the Belle II experiment"
Wei Shan (KMI, Nagoya Univ.)

[9] 2020/07/20 12:00- KMI Interdisciplinary Seminar (Zoom)
"Inter-disciplinary seminars on dark matter" The Dark Sector Searches in Belle II"
Enrico Graziani (INFN Roma3)

[10] 2020/09/23 17:30- KMI Topics (Zoom)
"Data acquisition system for the Belle II experiment"
Qidong Zhou (IAR/KMI, Nagoya Univ.)

[11] 2020/09/30 16:00- KMI Colloquium (Zoom)
"Mysterious fast radio bursts and implication from magnetars to their origins"
Teruaki Enoto (RIKEN, Extreme natural phenomema RIKEN Hakubi Research Team)

[12] 2020/10/21 17:30- KMI Topics (Zoom)
"After all, SUSY grand unified theory"
Nobuhiro Maekawa (KMI, Nagoya Univ.)

[13] 2020/10/28 17:00- KMI Colloquium (Zoom)
"Reproducing Big Bang of the Universe in an Experimental Hall"
Dr. Itaru Nakagawa (RIKEN)

[14] 2020/12/09 17:30- KMI Colloquium (Zoom)
"On black hole shadow"
Prof. Ken-ichi Nakao (Osaka City U.)

4.3 Awards

[1] The Nakamura Seitaro Prize, Soryushi Shogakukai, October 2020 (ABE, Tomohiro)

[2] The Fumiko Yonezawa Memorial Prize, The Physical Society of Japan (JPS), Mar 2021 (Yu Nakahama)

[3] The Toshiko Yuasa Award, Ochanomizu University, Feb 2021 (Yu Nakahama)

Chapter 5

Publications and Presentations

5.1 Published papers

5.1.1 Division of Theoretical Studies

Refereed papers

[1] "The effect of the early kinetic decoupling in a fermionic dark matter model"
Tomohiro Abe, Physical Review D102(2020)035018. arXiv:2004.10041 [hep-ph]

[2] "A model of electroweakly interacting non-abelian vector dark matter"
Tomohiro Abe, Motoko Fujiwara, Junji Hisano, Kohei Matsushita, Journal of High Energy Physics 07 (2020) 136. arXiv:2004.00884 [hep-ph]

[3] Y. Kawakami, M. Harada, M. Oka and K. Suzuki, "Suppression of decay widths in singly heavy baryons induced by the $U_A(1)$ anomaly", Phys. Rev. D 102, no. 11, 114004 (2020).

[4] Junji Hisano, Alejandro Ibarra, Ryo Nagai,"Direct detection of vector dark matter through electromagnetic multipoles", JCAP 10 (2020) 015 • e-Print: 2007.03216 [hep-ph]

[5] Gauthier Durieux, Teppei Kitahara, Camila S. Machado, Yael Shadmi, Yaniv Weiss "Constructing massive on-shell contact terms", JHEP 12 (2020) 175, arXiv:2008.09652 [hep-ph].

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[11] P. A. Zyla *et al.* [Particle Data Group], PTEP **2020** (2020) no.8, 083C01 doi:10.1093/ptep/ptaa104

[12] A. Chakraborty, S. H. Lim, M. M. Nojiri and M. Takeuchi, "Neural Network-based Top Tagger with Two-Point Energy Correlations and Geometry of Soft Emissions," JHEP **20**, 111 (2020)

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[14] Yasuhiro Hayashi, Takahiro Ogino, Tadakatsu Sakai, Shigeki Sugimoto, "Stringy excited baryons in holographic quantum chromodynamics", PTEP 2020 (2020) 5, 053B04, e-Print: 2001.01461 [hep-th]

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[1] M. Harada, "Dense nuclear matter based on a chiral model with parity doublet structure", contribution to proceedings of the XVIII International Conference "The 18th International Conference on Hadron Spectroscopy and Structure (HADRON2019), Guilin, China, 16 - 21 August 2019", doi:10.1142/9789811219313_0113

[2] Koichi Murase, Yukinao Akamatsu, Masayuki Asakawa, Tetsufumi Hirano, Masakiyo Kitazawa, Kenji Morita, Yasusi Nara, Chiho Nonaka and Akira Ohnishi, "Dynamically Integrated Transport Model for High-energy Nuclear Collisions at $3 < \sqrt{s_{NN}} < 30$ GeV", JPS Conf.Proc. 32 (2020) 010081

[3] K. D. Nakamura, K. Miuchi, S. Kazama, Y. Shoji, M. Ibe and W. Nakano, "Detection capability of Migdal effect for argon and xenon nuclei with position sensitive gaseous detectors," [arXiv:2009.05939 [physics.ins-det]], Accepted by PTEP.

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5.1.2 Division of Experimental Studies

Refereed papers

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5.1.3 Papers in Science Communication

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5.2 Presentations at International Conferences

(I: Invited, O: Oral, P: Poster)

5.2.1 Division of Theoretical Studies

Name of Conference	Place	Date	I	O	P
RIKEN iTHEMS Dark Matter Working Group	Zoom	12 June 2020	1	0	0
Preparatory Joint Sessions on "Open questions and News Ideas"	Zoom	7–8 July 2020	0	1	0
KEK-PH Lectures and Workshops 2020	Zoom	4 August 2020	0	1	0
IBS and KMI Joint Workshop 2020	Zoom	24, 26 June 2020	0	1	0
10th international conference on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions	online	1-6 Jun 2020	0	1	0
KEK-PH Collider 2020 (Zoom)	KEK, Tsukuba	Aug. 4, 2020	1	1	0
7th Korea-Japan workshop on dark energy	Korea, online	7-10 Dec 2020	1	0	0
Recent progress in theoretical physics based on quantum information theory	YITP, online	1-5 March 2021	1	0	0
JGRG Webinar series, the 5th webinar	online	29 March 2021	0	1	0
online JGRG workshop 2020	Japan	23-27 Nov 2020	0	0	1
Copernicus Webinar	online	18 Feb 2021	1	1	0
online JGRG workshop 2020	Japan	23-27 Nov 2020	0	1	0
Less Travelled Path of Dark Matter: Axions and Primordial Black Holes (ONLINE)	India	9-13 Nov 2020	1	1	0
IBS and KMI Joint Workshop 2020	Japan, Korea	24,26 Aug 2020	0	1	0
On-line Newton 1665 physics seminar	Central European Time	18 Jun 2020	1	1	0
7th Korea-Japan Workshop on Dark Energy: Maeda's Universe	Korea (online)	7-10, Dec 2020	1	0	0
theory total			3	9	0

5.2.2 Division of Experimental Studies

Name of Conference	Place	Date	I	O	P
ICHEP2020: the 40th International Conference on High Energy Physics	Czech Republic (online)	28 Jul - 6 Aug 2020	0	3	0
22nd IEEE Real Time Conference	Online	12-23 Oct 2020	0	1	0
XXIV DAE-BRNS high energy physics symposium	Online	14-18 Dec 2020	0	1	0
JpGU-AGU joint meeting 2020	Japan	12-16 July 2020	0	1	2
ESS Polarisation Workshop	online	21-22 September	0	1	0
International Symposium of JSPS Core-to-Core program DMNet,	online	Mar 2021	1	0	0
APCTP-KPS-JPS joint meeting,	online	October 2020	1	0	0
experiment total			2	6	2

5.3 Presentations at Domestic Conferences

5.3.1 Division of Theoretical Studies

Name of Conference	Place	Date	I	O	P
新学術領域「地下から解き明かす宇宙の歴史と物質の進化」2020年度オンライン領域研究会	Zoom	2–3 June	0	1	0
PPP2020	Zoom	31 August – 4 September 2020	0	0	1
JPS 2020 Autumn Meeting	Zoom	14-17 September 2020	0	1	0
Summer camp on ILC accelerator, physics and detectors 2020 (Online)	Zoom	23-25 September 2020	0	1	0
JPS 2021 Annual (76th) meetings	online	12-15 Mar 2021	0	1	0
JPS 2020 Fall meetings	University of Tsukuba, online	14-17 Sep 2020	0	1	0
The progress of the Particle Physics 2020 (PPP 2020)	YITP, online	31 Aug-4 Sep 2020	0	1	0
7th meeting of hadron, nucleon, molecular meeting, ”Clustering as a window on the hierarchical structure of quantum systems”	online	2 Sep 2020	1	0	0
Symposium ”Interesting physics in fluctuations and hydrodynamics”, JPS meeting,	online	15 Sep 2020	0	1	0
ILC Summer Camp 2020 (Zoom)	Zoom	Sep. 25, 2020	1	1	0
PPP2020 (Zoom)	Kyoto (Zoom)	Sep. 4, 2020	1	1	0
日本物理学会 2021年	Online	12-15 March 2021	1	1	0
Testing Gravity THxOBS Japan kickoff meeting	online	27-28, Aug 2020	1	1	0
国立天文台研究集会「(サブ)ミリ波単一鏡の革新で挑む, 天文学の未解決問題」	online	29-30, Mar 2021	1	0	0
theory total			6	11	1

5.3.2 Division of Experimental Studies

Name of Conference	Place	Date	I	O	P
日本物理学会 2020年秋季大会	Online	15-18 Sep 2020	2	2	0
日本物理学会第76回年次大会	Online	15-18 Mar 2021	1	1	0
高エネルギー将来計画委員会第1回勉強会	Online	30 Apr 2020	1	1	0
GROWTH meeting 2020	zoom	23 April 2020	1	1	0
Physical Society General assembly Autumn 2020	zoom	14-17 Sep. 2020	0	3	0
Physical Society General assembly Spring 2021	zoom	12-15 March. 2021	0	2	0
JPS meeting	online	14-17 Sep 2020	0	2	0
JPS meeting	online	12-15 Mar 2021	0	2	0
ASJ meeting	online	8-10 Sep 2020	0	1	0
ASJ meeting	online	16-19 Mar 2021	0	1	0
ミグダル観測検討会 2020	online	November 2020	1	0	0
素粒子物理学の進展 2020	online	August 2020	1	0	0
experiment total			7	16	0

5.3.3 PR office

Name of Conference	Place	Date	I	O	P
科学技術社会論学会第19回年次研究大会・総会	zoom	5-6 Dec. 2020	0	1	0

5.4 Tutorial Articles and Reviews

[1] A. Hebecker and J. Hisano, “Grand Unified Theories” in Review of Particle Physics, published in PTEP. D98 (2020) 8, 083C01.

[2] A. J. Hisano, “Effective theory approach to direct detection of dark matter”, published in Les Houches Lect.Notes 108 (2020).

Chapter 6

International Relations

6.1 International Collaborations

Collaboration Name	the other parties
MWA	CSIRO, Curtin University, University of Western Australia (Austral- ia), Kumamoto University, Nagoya University (Japan), Shanghai As- tronomical Observatory (China), and others
LiteBIRD	KEK, IMPU, Berkeley, MPA and others (26 organizations)
ATLAS	CERN, High Energy Accelerator Research Organization (KEK), and others (178 organizations)
Belle	High Energy Accelerator Research Organization (KEK), Tohoku University, Niigata University, University of Tokyo, Osaka University, Nara Women's University, National Taiwan University (Taiwan), University of Hawaii (USA), Budker Institute of Nuclear Physics (Russia), Institute for Theoretical and Experimental Physics (Russia), University of Ljubljana (Slovenia), Max Planck Institut fur Physik Muenchen (Germany), Karlsruhe Institute of Technology (Germany), and others
Belle II	High Energy Accelerator Research Organization (KEK), Tohoku University, Niigata University, University of Tokyo, Osaka University, Nara Women's University, National Taiwan University (Taiwan), University of Hawaii (USA), Budker Institute of Nuclear Physics (Russia), Institute for Theoretical and Experimental Physics (Russia), University of Ljubljana (Slovenia), Max Planck Institut fur Physik Muenchen (Germany), Karlsruhe Institute of Technology (Germany), and others
XRISM	JAXA, NASA (US), Kanto Gakuin University, Kwansei Gakuin University, Kyoto University, Nagoya University, Nara University of Education, Nara Women's University, Nihon Fukushi University, Osaka University, RIKEN, Rikkyo University, Saitama University, Shibaura Institute of Technology, Shizuoka University, Tohoku Gakuin University, Tokyo Metropolitan University, Tokyo University of Science, University of Miyazaki, University of Tokyo, Waseda University, Canadian Light Source Inc. (Canada), University of Chicago (US), Harvard-Smithsonian Center for Astrophysics (US), Lawrence Livermore National Laboratory (US), Massachusetts Institute of Technology (US), Saint Mary's University (Canada), University of Maryland (US), University of Michigan (US), University of Waterloo (US), University of Wisconsin (US), Yale University (US), ESA (European Space Agency), European Sauther Observatory (Germany), SRON (Netherland), University of Amsterdam (Neitherland), University of Durham (UK), University of Geneva (Switzerland) and others

Athena X-ray observatory	European Space Agency, ISAS/JAXA, NASA (USA) and others
FORCE X-ray observatory	ISAS/JAXA, Kyoto University, Osaka University, Miyazaki University, NASA(USA), and others
Cherenkov Telescope Array (CTA)	Max-Planck-Institut für Kernphysik, and others (216 organizations)
Fermi Gamma-ray Space Telescope	NASA Goddard Space Flight Center, and others (57 organizations)
LHCf	INFN University of Florence (Italy), University of Catania (Italy), Ecole Polytechnique (France), LBNL Berkeley (USA), Waseda University, Kanagawa University, Tokushima University, Shibaura Institute of Technology, University of Tokyo
RHICf	INFN University of Florence (Italy), University of Catania (Italy), Tokushima University, Shibaura Institute of Technology, Waseda University, University of Tokyo, RIKEN, Japan Atomic Energy Agency, Korea University (Korea), Seoul National University (Korea)
Super-Kamiokande	Kamioka Observatory, Institute of Cosmic Ray Research (ICRR), University of Tokyo, and others (40 organizations)
Hyper-Kamiokande	Kamioka Observatory, Institute of Cosmic Ray Research (ICRR), University of Tokyo, and others (76 organizations)
XENON	Istituto Nazionale di Fisica Nucleare, Laboratori Nazionale del Gran Sasso (INFN-LNGS), and others (28 organizations)
DARWIN	University of Zurich, University of Freiburg and others (33 organizations)
XMASS	Kamioka Observatory, Institute of Cosmic Ray Research (ICRR), University of Tokyo, and others (14 organizations)
OPERA	INR Institute for Nuclear Research (Russia), University of Napoli (Italy), University of Bari (Italy), Lomonosov Moscow State University (Russia), Kobe University (Japan), Univer-sity of Bern (Switzerland), Nagoya University (Japan), METU Middle East Technical University (Turkey), Univer-sity of Padova (Italy), Universite de Savoie (France), Ham-burg University (Germany), JINR-Joint Institute for Nuclear Research (Russia), INFN-Laboratori Nazionali del Gran Sasso (Italy), University of Bologna(Italy), Universite de Strasbourg (France) , Toho Univeristy (Japan), University of Roma (Italy), Gyeongsang National University (Korea), In-stitute for Theoretical and Experimental Physics (Russia), Universite Libre de Bruxelles (Belgium) and others
NEWSdm	INR Institute for Nuclear Research (Russia), University of Napoli (Italy), University of Bari (Italy), Lomonosov Moscow State University (Russia), METU Middle East Technical University (Turkey), JINR-Joint Institute for Nuclear Re-search (Russia), INFN-Laboratori Nazionali del Gran Sasso (Italy), University of Roma (Italy), Institute for Theoretical and Experimental Physics (Russia)
DsTau	University of Bern (Switzerland), JINR-Joint Institute for Nuclear Research(Russia), METU Middle East Technical University (Turkey), Institute of Space Science (Romania)

SHiP	University of Sofia (Bulgaria), UTFSM (Universidad Técnica Federico Santa Maria) (Chile), NBI (Niels Bohr Institute), Copenhagen University (Denmark), LAL, Univ. Paris-Sud, CNRS/IN2P3 (France), LPNHE Univ. Paris 6 et 7 (France), Humboldt University of Berlin (Germany), University of Bonn, (Germany), University of Hamburg (Germany), Forschungszentrum Jülich (Germany), University of Mainz, (Germany), University and INFN of Bari (Italy),University and INFN of Bologna (Italy),Istituto Nazionale di Fisica Nucleare (INFN), Sezione di Cagliari (Italy), Università Federico II and INFN of Naples (Italy), University La Sapienza and INFN of Rome (Italy), Lab. Naz. Frascati (Italy), Lab. Naz. Gran Sasso, (Italy), Aichi University of Education (Japan), Kobe University, (Japan), Nagoya University (Japan), Nihon University (Japan), Toho University (Japan), Gyeongsang National University (Korea), KODEL, Korea University (Korea), University of Leiden,(The Netherlands), Laboratory of Instrumentation and high-energy Particle physics (LIP) (Portugal), Joint Institute of Nuclear Research (JINR) (Russia), Institute for Theoretical and Experimental Physics (ITEP) (Russia), Institute for Nuclear Research (INR) (Russia), P.N. Lebedev Physical Institute of the Russian Academy of Sciences (LPI) (Russia), National University of Science and Technology "MISIS" (Russia), National Research Centre (NRC) "Kurchatov Institute" (Russia), Institute for High Energy Physics (Russia), Petersburg Nuclear Physics Institute (PNPI) (Russia), Moscow Engineering Physics Institute (MEPhI) (Russia), Skobeltsyn Institute of Nuclear Physics of Moscow State University (Russia) ,Yandex School of Data Analysis (Russia), Institute of Physics, University of Belgrade, (Serbia), Stockholm University (Sweden), Uppsala University, (Sweden), CERN, University of Geneva (Switzerland), Ecole Polytechnique Federale de Lausanne (EPFL) (Switzerland), University of Zurich (Switzerland), Middle East Technical University (METU) (Turkey), Ankara University (Turkey), Imperial College London (UK), University College London (UK), Rutherford Appleton Laboratory (RAL) (United Kingdom), Bristol University (UK), Warwick University (UK), Taras Shevchenko National University of Kyiv (Ukraine), Florida University (USA)

6.2 Visitors

Name	Affiliation	Period	Host
L. Ubaldi	SISSA	canceled, but zoom seminar held	T. Kobayashi

Chapter 7

Public Relations

7.1 Media Relations

[1] Press release「暗黒物質直接探索実験XENON1Tが電子散乱事象の超過を観測 (Observation of Excess Events in the XENON1T Dark Matter Experiment)」
Date: 18 June, 2020
Related KMI member: Yoshitaka Itow, Shingo Kazama
News link: http://www.kmi.nagoya-u.ac.jp/eng/blog/2020/06/18/research-observation-of-excess-events-in-the-xenon1t-dark-matter-experiment/
Related link: http://www.xenon1t.org (Press release by XENON collaboration)
Joint press release: XENON collaboration, Kavli Institute for the Physics and Mathematics of the Universe, The University of Tokyo (Kavli IPMU), Institute for Cosmic Ray Research, The University of Tokyo (ICRR), KMI, Graduate School of Science, Kobe University

[2] Press release「陽子衝突からの左右非対称な π 中間子生成－粒子生成の起源にせまる新たな発見－(New research deepens mystery of particle generation in proton collisions)」
Date: 23 June 2020
Related KMI member: Yoshitaka Itow
News link: https://www.riken.jp/en/news_pubs/research_news/pr/2020/20200623_1/index.html
Joint press release: Riken, Institute for Cosmic Ray Research, The University of Tokyo (ICRR), Japan Atomic Energy Agency (JAEA), KMI

[3] Press release「中性子で迫る宇宙創成の謎～大強度偏極熱外中性子で、原子核内での対称性の破れの増幅現象に迫る～(Neutrons reveal the origin of the universe. –Enhancement of symmetry violation in compound nuclei is studied using polarized epithermal neutrons)」
Date: 15 July 2019
Related KMI member: Masaaki Kitaguchi
News link: http://www.kmi.nagoya-u.ac.jp/eng/blog/2020/07/15/neutrons-reveal-the-origin-of-the-universe/
Joint press release: Nagoya University, the J-PARC Center, Tokyo Institute of Technology, Osaka University, Kyushu University, and Japan Atomic Energy Agency (JAEA)

[4] Press release「ヒッグス粒子のミュー粒子対崩壊反応の兆候を発見（First indications of the Higgs boson decaying into two muons）」
Date: 1 August 2020
Related KMI member: Makoto Tomoto
News link: http://www.kmi.nagoya-u.ac.jp/eng/blog/2020/08/11/first-indications-of-the-higgs-boson-decay-into-two-muons/

[5] **Media Salon** The 1st KMI Media Salon: LHC加速器で探るミュー粒子の質量起源 (A search for the dimuon decay of the Standard Model Higgs boson with the ATLAS detector)
Date: 20 August 2020
Place: Online (Zoom)
Lecturer: Toru Iijima (KMI), Makoto Tomoto (KMI, KEK), Yasuyuki Horii (Nagoya University)

7.2 Newspaper Articles

Date	Media	Title	KMI Members
2020/06/18	岐阜新聞	暗黒物質探索で「想定外の事象」	伊藤好孝教授・風間慎吾特任助教
2020/06/18	中日新聞	未知の素粒子観測か	伊藤好孝教授・風間慎吾特任助教
2020/06/18	朝日新聞	未発見の素粒子「アクシオン」検出か	伊藤好孝教授・風間慎吾特任助教
2020/06/25	日経新聞	未発見の素粒子観測か	伊藤好孝教授・風間慎吾特任助教
2020/07/06	日経新聞	”The world record of the luminosity achieved by the SuperKEKB accelerator”	
2020/07/16	日刊工業新聞	未知の「CP対称性の破れ」現象解明の手がかり	北口雅暁教授
2020/07/17	科学新聞	左右非対称なπ中間子	伊藤好孝教授
2020/08/13	WEBマイナビ	CERNヒッグス粒子がミュー粒子対に崩壊する反応の兆候を発見	戸本誠特任教授（N研堀井泰之講師）
2020/08/24	日本経済新聞	質量を与える粒子ミュー粒子に崩壊か	戸本誠特任教授（N研堀井泰之講師）
2020/11/03	中日新聞	”Profile of Toru Iijima”	飯島徹教授
2020/12/01	中日新聞	「重さ」起源兆候とらえた	N研堀井泰之講師、N研川口智美博士課程学生KMIメディアサロン
2020/12/02	朝日新聞	「女性の進出阻む可能性」	（南崎梓研究員関連）

7.3 Outreach Events held by KMI

[1] KMI x ITbM MIX CAFE,「集まれ！話そう！科学のワクワク」
Date: 28-30 September 2020
Place: Online (Zoom)
Lecturer: Yu Nakahama (KMI), Motoko Fujiwara (Nagoya University), Shingo Kazama (KMI, YLC Nagoya University), Hideto Ito (ITbM), Natsumi Fukaya (Nagoya University), Yoko Mizuta (ITbM)
Number of Participants: 42 in total
Co-host: Institute of Transformative Bio-Molecules, Nagoya University (ITbM) and KMI
• Y. Nakahama, 巨大な加速器で物質の根源と宇宙の始まりに迫る, KMI x ITbM Mix Cafe, 28 September 2020
• S. Kazama, 地下から探る宇宙の謎, KMI x ITbM Mix Cafe, 30 September 2020

[2] Special lectures on Nobel Prize 2020 「ブラックホールとゲノム編集」
Date: 7 November 2020
Place: Online (Zoom)
Lecturer: Tetsuya Shiromizu (KMI), Tetsuya Higashiyama(ITbM)
Number of Participants: 91
Co-host: ITbM and KMI

7.4 Public Lectures by KMI members

Name	Date	Location	Event Title	Lecture title	Approx. # of participants
Junji Hisano	2020/12/18	半田高校(Online)	第四回「サイエンスコミュニケーション」		50
Masaharu Tanabashi	2020/10/02	愛知県立瑞陵高等学校	出前講義	複素数と量子力学の時間の矢	40
Tetsuya Shiromizu	2020/11/7	Zoom ウェビナー	ノーベル賞特別講演会2020「ブラックホールとゲノム編集」	ブラックホールの“発見”-Penroseの貢献-	100
Tetsuya Shiromizu	2021/1/27	名古屋イノベーターズガレージ	大人の学びなおし、リベラルアーツ	究極の理論が描く宇宙の姿〜多様な宇宙の世界〜	50
Masaharu Tanabashi	2020/10/02	愛知県立瑞陵高等学校	出前講義	複素数と量子力学の時間の矢	40
Kiyotomo Ichiki	2020/9/16	NHK文化センター	出前講義	宇宙と物質の起源	30

7.5 Other Contributions by KMI members

Name	Activity
Junji Hisano	Editor of Physics Letters B
Tetsuya Shiromizu	「Penroseの特異点定理とブラックホール形成」(化学12月号,化学同人)
Takeshi Kobayashi	Review Editor on the Editorial Board of Cosmology, Frontiers in Physics
Yoshitaka Itow	「宇宙線」, ラ・トッカータ　ゼミ本シリーズ, 日本物理学会誌 Vol. 75, No. 12, 2020

Chapter 8

External Funding related with KMI

Grant-in-Aid for Scientific Research (KAKENHI)

(All items are for PI (Principal Investigator) if not specified. CI stands for Co-Investigator.)

Name	Research Funds	ID	Amount [JPY] (Direct Expense)
ABE, Tomohiro	Scientific Research on Innovative Areas	19H04615	1,800,000
HARADA, Masayasu	Scientific Research (C)	20K03927	1,300,000
HISANO, Junji	Core-to-core Program (A)	—	13,350,400
HISANO, Junji	Scientific Research (B) [CI]	20H01895	450,000
HISANO, Junji	Scientific Research on Innovative Areas	16H06492	21,900,000
HISANO, Junji	Scientific Research on Innovative Areas Project	16H06492	1,650,000
ICHIKI, Kiyotomo	Scientific Research (C)	18K03616	700,000
IIJIMA, Toru	Scientific Research (S)	18H05226	37,400,000
ITOW, Yoshitaka	Challenging Research (Exploratory)	20K20919	1,300,000
ITOW, Yoshitaka	Promotion of Joint International Research (B) [CI]	18KK0082	500,000
ITOW, Yoshitaka	Scientific Research (A) [CI]	18H03697	230,017
ITOW, Yoshitaka	Scientific Research (A) [CI]	18H03697	4,500,000
ITOW, Yoshitaka	Scientific Research (A) [CI]	19H00675	4,500,000
ITOW, Yoshitaka	Scientific Research (B)	18H01227	470,000
ITOW, Yoshitaka	Scientific Research (B)	18H01227	2,900,000
ITOW, Yoshitaka	Scientific Research (B) [CI]	20H01917	100,000
ITOW, Yoshitaka	Scientific Research (B) [CI]	20H01931	200,000
ITOW, Yoshitaka	Scientific Research on Innovative Areas [CI]	18H05535	50,000
ITOW, Yoshitaka	Scientific Research on Innovative Areas [CI]	18H05538	7,600,000
IZUMI, Keisuke	Scientific Research (A) [CI]	17H01091	200,000
IZUMI, Keisuke	Scientific Research (B) [CI]	20H01902	150,000
KANNO, Hiroaki	Scientific Research (C)	18K03274	600,000
KATO, Yuji	Scientific Research on Innovative Areas	19H05148	2,500,000
KAWAMURA, Seiji	Challenging Research (Exploratory)	19K21875	2,000,000
KAWAMURA, Seiji	Scientific Research (B)	19H01924	4,500,000
KAZAMA, Shingo	Promotion of Joint International Research (B) [CI]	18KK0082	1,000,000
KAZAMA, Shingo	Scientific Research (B)	20H01931	4,100,000
KAZAMA, Shingo	Scientific Research on Innovative Areas [CI]	19H05805	1,670,000
KITAGUCHI, Masaaki	Scientific Research (A) [CI]	19H00690	400,000
KITAGUCHI, Masaaki	Scientific Research (B)	17H02889	178,184
KITAGUCHI, Masaaki	Scientific Research (B) [CI]	19H01927	200,000
KITAHARA, Teppei	Young Scientists	19K14706	800,000
MAEKAWA, Nobuhiro	Scientific Research (C)	19K03823	800,000
MATSUOKA, Kodai	Scientific Research on Innovative Areas	19H05099	2,600,000

NAKAMURA, Mitsuhiro	Hirameki-Tokimeki Science	20HT0131	260,000
NAKAMURA, Mitsuhiro	Specially Promoted Research	18H05210	95,500,000
NAKANO, Toshiyuki	Scientific Research (B) [CI]	19H01909	100,000
NAKANO, Toshiyuki	Scientific Research (B) [CI]	19H01988	1,420,000
NAKANO, Toshiyuki	Scientific Research (S) [CI]	17H06132	15,000,000
NAKAZAWA, Tomohiro	Challenging Research (Exploratory)	19K21899	2,800,000
NAKAZAWA, Tomohiro	Scientific Research (A)	20H00157	9,300,000
NAKAZAWA, Tomohiro	Scientific Research (B) [CI]	18H01236	435,000
NAMBU, Yasusada	Scientific Research (C)	19K03866	700,000
NISHIZAWA, Atsushi	Scientific Research (B) [CI]	20H01932	300,000
NOJIRI, Shin'ichi	Scientific Research (C)	18K03615	1,000,000
NONAKA, Chiho	Scientific Research (A)	20H00156	18,900,000
NONAKA, Chiho	Scientific Research (A) [CI]	20H00581	2,800,000
NONAKA, Chiho	Scientific Research (C) [CI]	20K11851	100,000
OKUMURA, Akira	Scientific Research (B)	20H01916	4,800,000
SHIMIZU, Hirohiko	Challenging Research (Exploratory)	19K21876	2,500,000
SHIROMIZU, Tetsuya	Scientific Research (A) [CI]	17H01091	300,000
SUGIYAMA, Naoshi	Scientific Research (A)	17H01110	170,000
SUGIYAMA, Naoshi	Scientific Research on Innovative Areas	15H05890	870,000
TAKEUCHI, Michihisa	Scientific Research (C)	18K03611	1,000,000
TAKEUCHI, Michihisa	Scientific Research on Innovative Areas	19H04613	1,900,000
TANABASHI, Masaharu	Scientific Research (C)	19K03846	1,000,000
TOBE, Kazuhiro	Scientific Research (C)	20K03947	800,000
TOMOTO, Makoto	Scientific Research (C)	18K03675	600,000
TOMOTO, Makoto	Scientific Research on Innovative Areas	16H06493	22,500,000
YOKOYAMA, Shuichiro	Scientific Research (B) [CI]	20H01932	300,000
YOKOYAMA, Shuichiro	Scientific Research (C)	20K03968	1,400,000

Other Research Funds

Name	Research Funds	ID	Amount [JPY] (Direct Expense)
ICHIKI, Kiyotomo	AIP Accelaration	20-2010313	8,000,000
NAKAMURA, Mitsuhiro	Contract research expenses		2,501,400
NAKAMURA, Mitsuhiro	Contract research expenses		71,450,000
NAKAZAWA, Tomohiro	Donation (Hori Science Art Fundation)		1,000,000
NAKAZAWA, Tomohiro	JAXA		1,900,000
SHIMIZU, Hirohiko	Contract research expenses	20-1710270	2,307,693
SHIMIZU, Hirohiko	Contract research expenses		2,310,000