Cosmic evolution and fundamental physics

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In spite of the remarkable success of the standard model (SM) of particle physics, understanding cosmic evolution is a different story. There are five mysteries in cosmic evolution, which are inflation, baryogenesis (or leptogenesis), dark matter, dark energy, and neutrinos. To solve these mysteries, we need new fundamental physics beyond the SM, which is a central theme of theoretical physics in this century. For full understanding of cosmic evolution, we also need to answer other important questions such as how heavy elements were created. On the experimental/observational side, among many approaches, precise observations of light, as well as novel optical engineering will play a key role for deeper understanding of cosmic evolution. I will give a brief overview of this fascinating topic and discuss future directions.

Introduction to LiteBIRD – Light Satellite for studies for B-mode Polarization and Inflation from cosmic Background Radiation and Detection

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LiteBIRD is a satellite that will search for primordial gravitational waves emitted during the cosmic inflation era (around 10^{-38} sec after the beginning of the Universe). Its goal is to test representative inflationary models (single-field slow-role models with large field variation) by performing an all-sky CMB (cosmic microwave background) polarization survey. Primordial gravitational waves are expected to be imprinted in the CMB polarization map as special patterns, called the "B-mode". If we succeed to detect them, it will provide entirely new and profound knowledge on how our Universe began. From the viewpoint of high-energy physics or elementary particle physics, the observation of the CMB B-mode is also very important because it will allow us to search for physics in ultra high-energy scales, which are not accessible with man-made accelerators. Measurements of CMB polarization will open a new era of testing theoretical predictions of quantum gravity, including those by the superstring theory.

In this presentation, I will present introduction and overview of the LiteBIRD satellites including its scientific goals, challenges and instruments that are under development.

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Dilaton and PseudoDilaton

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The accelerating nature of our Universe indicates strongly the presence of a cosmological constant, Λ, as large as unity in the Planck-mass units. Unfortunately, however, the directly observed value is as small as 10^{-120} in the same units. In order to shake off this "Fine-Tuning problem," we focus upon the Scalar-Tensor Theory, STT. We are particularly interested in the unique constituent scalar field, expected to play the role of Dark Energy, DE, so called today, also likely to share the same behavior as the matter density, $\rho_{\rm matt} \sim t^{-2}$ with today's value as 10^{-120} with today's age of the Universe $t_0 \sim 1.4 \times 10^{10}$y $\sim 10^{60}$ in the Planckian units, gifting us precisely with the number 10^{-120}. But this is not the end of a story. According to the standard Hubble's way, the cosmological distances are measured in units of the Rydberg constant, a combination of the inverse mass of nucleons and electrons, with other coupling constant, like α ignored for the moment. It also follows obviously that we have no way to detect any change of the units themselves, to be called Own-Unit-Insensitivity-Principle. In this sense, the particle masses should stay truly constant, particularly independent of the cosmic time t. However, taking the complications around the presence of conformal frames, CF, taken into account carefully, we showed that the masses decrease like $t_*^{-1/2}$ with t_* the time in the physical CF, representing an immediate conflict between the Nature and STT, as far as we defined the particle masses in a conventional manner. Even magically we may overcome, in fact, the conflict simply by creating particle masses spontaneously, or by violating the scale invariance spontaneously, implying also the STT scalar field to act as a massless Nambu-Goldstone boson, called a Dilaton. We also reach the Standard Model by formulating a scale-invariant Higgs potential $\sim \lambda\Phi^4$The extended Higgs field then develops quantum loops which are effectively controlled by means of Dimensional Regularization with $D = 4$ chosen only at the end of the analysis. We apply the same variable now to control the symmetry as well, to find the massless Dilaton now re-emerges as a massive PseudoDilaton. This combined technique can be extended further to derive the effective decay rate of the PsDilaton into 2 photons via loops of fundamental fermions, for example, hence providing us with a convenient way to analyze $\gamma\gamma$ scattering to probe the physical effects in the realistic experiments.

Production and evolution of axion dark matter in the early universe

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The axion arises as a pseudo Nambu-Goldstone boson from the spontaneous breaking of a hypothetical global Peccei-Quinn (PQ) symmetry introduced to provide a solution to the strong CP problem of quantum chromodynamics. Due to the weakness of the coupling with ordinary matters, the axion is regarded as a viable candidate of dark matter of the universe.

In this contribution, we discuss the cosmological aspects of axion dark matter. The estimation of the axion dark matter abundance is not so straightforward if we follow the evolution of the axion field in the context of inflationary cosmology. In particular, if the PQ symmetry is restored after inflation, topological defects such as strings and domain walls are formed, and they produce significant amounts of cold axions. As a result, the prediction for the mass of axion dark matter depends strongly on the early history of the universe according to the detailed construction of underlying particle physics models. We review recent developments of the theoretical estimation of the axion dark matter abundance and discuss their implications for present and future experimental tests.

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Search for Axion-like-Particles via optical Parameteric effects with High-Intensity laseRs in Empty Space (SAPPHIRES) over a wide mass range

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Nambu and Goldstone have predicted emergence of a massless boson (NGB) as a result of spontaneous symmetry breaking of a global symmetry. Originally the lightness of the pion mass was explained because pion is an NGB as a result of chiral symmetry breaking. This guiding principle can be applied to any kinds of global symmetries. There are theoretically predicted NGBs such as axions and dilatons, which can be strong candidates for dark mater and dark energy in the universe if their coupling to matter is reasonably weak. However, these masses cannot be exactly zero due to complicated quantum corrections and these theories cannot exactly predict where these masses physically appear. Therefore, it is indispensable to perform searches for such dark fields over a wide range of the mass scale. We will discuss how we can explore with laser fields available in world-wide facilities in order to access the mass range from sub-eV to 10 keV.

Probing pseudo-Nambu-Goldstone boson by stimulated photon colliders in the mass range 0.1 eV to 10 keV

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Searching for pseudo-Nambu–Goldstone bosons (pNGBs) in weak-coupling domains is crucial for understanding the dark components in the universe. We propose searching for pNGBs coupled to two photons in the mass range from 0.1 eV to 10 keV. This could provide opportunities to test string-theory-based pNGBs beyond the GUT scale M ~ 10^{16} GeV included in the weak coupling proportional to M^{-1} [1]. We provide formulae that are applicable to photon–photon scattering via a pNGB resonance exchange with a stimulation process in an asymmetric head-on photon–photon collider by mixing three laser pulses in laboratory experiments. We discuss the quantum electrodynamic effects on the pNGB exchange in the same mass–coupling domain as a background process from the standard model. We will show that a large unexplored mass–coupling domain is accessible by combining existing laser facilities, including free-electron lasers [2].

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Preparatory experiments toward a search for sub-eV Dark Matter at Extreme Light Infrastructure-Nuclear Physics (ELI-NP)

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Extreme Light Infrastructure - Nuclear Physics (ELI-PN) user facility, currently under construction in Magurele, Romania [1] is part of the pan-European distributed facility that addresses specific research subjects in the field nuclear physics, secondary radiation sources (in Czech Republic [2]) and attosecond science (in Hungary[3,4]).

A large fraction of dark components in the universe motivates us to search for yet undiscovered fields to naturally interpret the relevant observations. In one of the proposed experiments, search for sub-eV Dark Matter (DM) experiments at interaction area E4 are planned [5]. In this experiment we search for frequency shifted photons via four-wave mixing in the vacuum caused by stimulated decay of resonantly produced DM when two color lasers are combined and focused into the ultra-high vacuum [6]. The preparatory experiments set-up of four-wave mixing with multiple optical parametric amplification (OPA) stage configurations using different nonlinear crystals and the key experimental challenges will be discussed.

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Optical Cavity Tests of Lorentz Invariance

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Lorentz invariance underlies all the theories of fundamental interactions such as the standard model of particle physics and general relativity. However, theoretical attempts towards the unification of fundamental interactions have led to the idea that Lorentz invariance may only be approximate. This motivated experimental searches for violations with increasing precision.

Here we present a new type of search for higher order Lorentz violation in photons with a double-pass optical ring cavity. The search was done by comparing the speed of light propagating in opposite directions in the cavity. Limits obtained using our data taken from August 2012 and September 2013 were the first limits on odd-parity higher order Lorentz violation.

We are now upgrading the apparatus to reduce the vibration sensitivity and to make the continuous rotation possible. With these upgrades, the sensitivity is expected to increase by 2 orders of magnitude, at $\delta c/c \sim 10^{-17}$ level. We will show the current status of the upgrade.

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Neutrino spectroscopy with atoms and laser
— toward detection of relic neutrino —

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Several important questions for neutrino are left unanswered: absolute mass scale of the neutrino, its mass type (Dirac or Majorana), CP-violating phases, etc. We (SPAN collaboration: SPectroscopy of Atomic Neutrino) have proposed the precision neutrino mass spectroscopy using atomic targets whose closeness of the released energy to expected neutrino masses is a great advantage. The relevant process of our interest is cooperative (and coherent, called macro-coherent subsequently) atomic de-excitation via emitting a photon plus a neutrino pair (Fig. 1), called as RENP (Radiative Emission of Neutrino Pair). The scheme extracts neutrino information from the photon energy spectrum measured for the de-excitation process, and provides a systematic way to access all the remaining problems of neutrino physics [1]. Remarkable feature in the proposed method is that it can be applied to detection of relic cosmic neutrino of 1.9 K [2]. To obtain a measurable rate of the process, it is crucial to develop the macro-coherence, a new kind of coherence that involves both atomic polarization and fields, for rate amplification of the RENP process.

In order to experimentally prove the rate enhancement itself using the macro-coherence, we have experimentally observed the higher-order QED process, two-photon emission from a vibrationally excited state of gaseous para-hydrogen molecules, where the process is highly forbidden. The macro-coherence was prepared through adiabatic Raman process using high-quality pulsed lasers. The achieved enhancement factor of more than 10^{18} [3] is the evidence that macro-coherence effectively worked. We shall present our whole scheme for neutrino spectroscopy using lasers ant atoms, and the present status of our experiments.

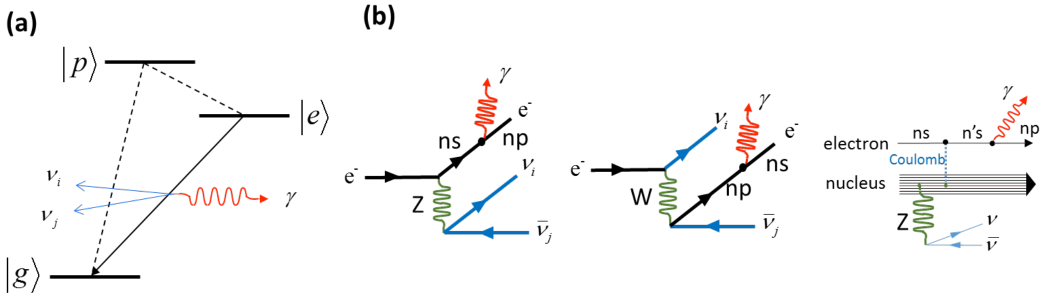

Fig.1: (a) RENP process in atomic transition from the excited state |e> to the ground state |g>. The state |p> is an intermediate state. (b) Feynman diagrams of RENP process.

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Terahetz Photon Detectors

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Ultimate sensitivity of the electromagnetic wave detection is that the detector is able to detect individual photons. For near-infrared, visible, and ultra-violet regions where the photon energy is higher, there are well-established photon detectors such as photomultiplier tubes, semiconductor avalanche photodiodes, and superconducting transition edge sensors. In the terahertz (THz) region, however, the development of the photon detector is a nontrivial task, because the photon energy of the THz wave (~meV) is much smaller than that in optical frequency regions. In this talk, I will show recent progress in THz photon detectors by using carbon nanotube transistors [1,2] and silicon quantum dots. One of crucial issues regarding THz photon detection is low quantum efficiency, namely low coupling efficiency with the THz wave. This problem originates from the fact that the sensing area of THz photon detectors is of nanometer scale (less than 1 μm), which is much smaller than the wavelength of the incident THz wave. As a solution, I will present the integration with logarithmic-spiral antennas for wide-band detection [3] and plasmonic antennas for narrow-band detection [4].

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Neutrino decay to electron and W-boson in a superstrong magnetic field in the Early Universe

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Using the representation of the electron and W-boson propagators as the sum over the Landau levels [1, 2], the process of the neutrino decay into electron and W-boson in a superstrong magnetic field in the conditions of the Early Universe is studied. An intense electromagnetic field makes possible this process which is kinematically forbidden in a vacuum. It is shown, that the resonance peaks present in the decay width for certain neutrino energies corresponding to the electron and the W-boson creation at specific Landau levels. This means that the neutrino mean free path tends to zero at certain energies. The subsequent decay of the W-boson into the dominant quark channels may influence the picture of nucleosynthesis. This could allow to establish a new independent limit on a possible scale of the magnetic fields in the Early Universe.

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Interplay between strong fields in QED and QCD

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High-energy heavy-ion collision experiment is a unique laboratory for the study of interplay between strong fields in QED and QCD. Since the colliding nuclei have large electric charges and move almost at the speed of light, they produce the *strongest* electromagnetic fields in universe. Besides, reflecting the fact that the nuclei are made of nucleons described by QCD with quark and gluon degrees of freedom, the colliding nuclei also produce extraordinarily strong *color*-electromagnetic fields called “glasma”. These two strong fields will interact with each other through the fluctuations of virtual quark-antiquark pair creation (Note that (anti)quarks have both electric charges and color electric charges). We discuss the generalization of the “Euler-Heisenberg action” to the case where there are strong fields in QED and QCD at zero and finite temperatures. The one-loop effective action (with respect to the quark one-loop) in the presence of both kind of fields is computed analytically by using the Schwinger's proper time method [1]. The result is a nonlinear effective action not only for electromagnetic and chromo-electromagnetic fields but also the Polyakov loop (at finite temperature), and thus reproduces the Euler-Heisenberg action in QED, QCD, and QED+QCD, and also the Weiss potential for the Polyakov loop at finite temperature. As applications of this "Euler-Heisenberg-Weiss" action in QCD+QED, we investigate quark pair productions induced by QCD+QED fields at zero temperature and the Polyakov loop in the presence of strong electromagnetic fields. Quark one-loop contribution to the effective potential of the Polyakov loop explicitly breaks the center symmetry, and is found to be enhanced by the magnetic field, which is consistent with the inverse magnetic catalysis observed in lattice QCD simulation. Similar to the photon splitting which is possible in the Euler-Heisenberg action, we discuss several interesting processes which are possible in the effective action of QED+QCD [2].

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Strong-field QED in tightly focused laser beams

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The feasibility of obtaining exact analytical results in the realm of QED in the presence of a background electromagnetic field is almost exclusively limited to a few tractable cases, where the Dirac equation in the corresponding background field can be solved analytically. This circumstance has restricted, in particular, the theoretical analysis of QED processes in intense laser fields to within the plane wave approximation even at those high intensities, achievable experimentally only by tightly focusing the laser energy in space [1]. Here, we construct analytically electron wave functions and propagators in the presence of a background electromagnetic field of general space-time structure in the realistic assumption that the typical energy of the electron is the largest dynamical energy scale in the problem [2, 3]. In addition, we show that the obtained wave functions can be feasibly applied for investigating strong-field QED processes in laser beams of arbitrary space-time structure by determining analytically the energy spectrum of positrons produced via nonlinear Breit-Wheeler pair production as a function of the background field [4].

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A fresh look on the Heisenberg-Euler effective action

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We study the effective interactions of external electromagnetic fields induced by fluctuations of virtual particles in the vacuum of quantum electrodynamics. To this end, we discuss in detail the emergence of the renowned Heisenberg-Euler effective action from the underlying microscopic theory of quantum electrodynamics, emphasizing its distinction from a standard one-particle irreducible effective action [1]. One of our main findings is that at two-loop order there is a finite one-particle reducible contribution to the Heisenberg-Euler effective action in constant fields, which was previously assumed to vanish.

As a phenomenological application, we employ the Heisenberg-Euler effective action to study photon propagation in slowly varying inhomogeneous electromagnetic fields [2]. In this context, we in particular focus on the feasibility of an experimental verification of QED vacuum birefringence with state of the art technology, using x-ray free electron and optical high-intensity lasers [3, 4].

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Vacuum birefringence in high-energy laser-electron collisions

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Real photon-photon scattering is a long-predicted phenomenon that is being searched for in experiment in the form of a birefringent vacuum at optical and X-ray frequencies. We present results of calculations and numerical simulations for a scenario to measure this effect using multi-MeV photons generated in the collision of electrons with a laser pulse. We find that the birefringence of the vacuum should be measurable using experimental parameters attainable in the near future.

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High-energy vacuum birefringence in an intense laser field

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QED predicts that the vacuum possesses properties of an anisotropic and/or nonlinear optical medium if subjected to an electromagnetic field [1]. In particular, the vacuum may become birefringent due to a background field and therefore induce a polarization change for a probe photon propagating through the field. Extreme field intensities provided by upcoming optical laser facilities such as Vulcan 10P and ELI-NP could facilitate the first experimental observation of vacuum birefringence [1]. However, even in an intense optical background field the use of photons with low energy $\hbar\omega \ll mc^2$ (mc^2 denotes the electron rest energy) as probes results in a tiny birefringence effect which is challenging to measure [2]. Alternatively, vacuum birefringence could be probed with gamma photons [3]. Here, we conduct a thorough theoretical investigation of vacuum polarization effects inside an intense optical laser field, utilizing high-energy ($\hbar\omega \gg mc^2$) photons as probes [4]. By employing the exact photon wave function in the background field [5] and Stokes parameters we consider arbitrarily polarized probe gamma photons and examine special cases. Different methods of the gamma-photon polarimetry are discussed and the experimental feasibility of these methods is elucidated.

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The possibility of observing resonant photon splitting and photon scattering in a strong electromagnetic field

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The QED perturbation series contains a set of particle processes with only photons in their external states, including vacuum polarisation, photon splitting and absorption, and photon scattering. When these processes take place in the presence of a strong electromagnetic field, a different phenomenology results. The electron positron loops that mediate these processes couple to the strong field resulting in a series of resonances based on transitions between Zeldovich quasi energy levels. These resonances will be explored qualitatively and quantitatively to assess the likelihood of enhancing transition probabilities with a view to experimental investigation of these effects.

Gamma-beam experiments at ELI-NP: The future is emerging*

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The Extreme Light Infrastructure (ELI) Pan-European facility initiative represents a major step forward in quest for extreme electromagnetic fields. Extreme Light Infrastructure – Nuclear Physics (ELI-NP), which is under construction in Magurele, Romania, is one of the three pilars of the ELI, and aims at utilization of extreme electromagnetic fields for nuclear physics and quantum electrodynamics research and applications. It is one of the three Pan-European nuclear physics laboratories, which are at present under construction in the EU under the ESFRI scheme. At ELI-NP, high-power laser systems together with brilliant gamma beams are the main research tools. The emerging experimental program with brilliant gamma beams at ELI-NP will be presented with emphasis on the prepared day-one experiments. The physics cases of the flagship experiments at ELI-NP will be discussed, as well as the related instruments which are under construction for their realization.

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Intense gamma radiation by accelerated quantum ions.

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We present a new idea of creating intense beams of photon, and describe a proposed pilot experiment planned at RIKEN, Japan. The idea is based on a new concept of quantum heavy ion beam in accelerated motion. Quantum ion is a pure state of mixed ground and excited state formed by laser irradiation. These accelerated ions emit photons which have interesting features quite distinct from the usual synchrotron radiation: emitted particle energies can reach the GeV region if the ion's Lorentz boost γ-factor is large. The sharp energy cutoff is given by twice of the γ-factor times the level spacing of ion states. Applications of the beams extend to many fields in fundamental science. For example, the intense gamma ray beam in MeV region may be used for generation of high intensity neutron flux, which may drastically change future of neutron science. We describe a pilot experiment with the RIKEN ECR ion source in detail along with the basic principle of photon generation.

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Possiblity for measuring Delbrück Scattering in the sub-MeV range using polarized γ-ray photons

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Delbrück scattering is the elastic scattering of γ-rays off the Coulomb field of nuclei due to the formation of virtual electron-positron pairs from vacuum[1]. The elastic scattering of γ-ray sources from atoms is a coherent sum of Rayleigh, Thomson, Giant Dipole resonances and Delbrück scattering and as energies go below the MeV level the Rayleigh scattering becomes more and more dominant [2]. Previous experiments performed using unpolarized γ-ray sources have shown the effects of Delbrück scattering at photon energies as low as 889 keV [3]. However, linearly polarized γ-rays via laser Compton backscattering sources having high flux offer the possibility to measure Delbrück scattering with a higher degree of accuracy at these and even lower energies. Here, we show that by properly choosing the scattering angles and polarization of the γ-rays one can measure Delbrück scattering in the sub-MeV range. By choosing a high Z material we will present the time necessary using the new γ-ray sources to measure Delbrück scattering accurately.

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Gamma Polari-Calorimeter, an instrument for gamma ray polarimetry using the pair production process

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Studying Radiation Reaction and Vacuum Birefringence in the conditions available at ELI-NP will require measuring both energy and polarization of emitted gamma rays. The Gamma Polari-Calorimeter [1] (GPC) is an instrument being designed to measure these parameters for gamma beams of 100 MeV - 2 GeV using the polarization dependent cross-section of the pair production process. Using a combination of pixelated SOI sensors to track the electron and positron trajectories in a magnetic field the kinematic properties of these particles, and by extension those of the interacting photon, can be obtained. Measuring the modulation of the azimuthal distribution of the electron-positron pairs provides a measure for the degree of polarization of the beam. Current status of design and development of the GPC, as well as preparations for validation tests at the NewSUBARU facility are being discussed.

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Radiation dominated nonlinear Compton scattering: signatures of quantum dynamics and attosecond gamma-bursts

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The advencement of laser technology opens avenue for investigation of nonlinear QED effects with relativistic electrons in all-optical setups. We have studied theoretically multiphoton inverse Compton scattering of a relativistic electron beam interacting with a counterpropagating superstrong short focused laser pulse. The interaction is in the quantum radiation-dominated regime, when the electron dynamics is significantly modified due to radiation. We consider the electron near-reflection regime of interaction when high-energy ultrashort gamma-ray bursts arise in the backward emission direction (with respect to the initial motion of the electrons), although using much longer electron and laser pulses [1]. The considered regime is proposed to employ for detection signatures of the quantum radiation reaction [2], and signatures of the stochasticity in the photon emission process. Generally, the detection of various modifications of the radiation spectrum due to quantum radiation reaction and stochasticity requires accurate quantitative measurements. However, we have identified signatures of quantum radiation reaction and stochasticity for Compton angle-resolved radiation spectra which are easily detectable in an experiment due to distinct qualitative characteristics. The scheme relies on the nonlinearity nature of the interaction, the tightly focusing of the driving laser pulse, and the crucial effect of radiation reaction. All of these three ingredients are necessary to realize the applied specific regime of interaction.

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New exact solutions for QED in external fields

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We present a new analytic approach to determine both classical and quantum dynamics of electrons in background fields. The method is exact in all parameters and offers, in particular, a way to go beyond the plane wave approximation in intense laser-matter interactions. We demonstrate this using a radially polarized (TM) beam model; including the effects of transverse field structure we calculate exactly both the classical particle orbits and the wave functions needed for quantum scattering calculations. Our method can thus provide new exact results to improve predictions for, and analyses of, upcoming experiments at intense laser facilities.

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Radiation reaction on a Brownian scalar electron in high-intensity laser

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Radiation reaction which is the kicking-back effect acting on a high energy electron due to its radiation, is expected to be observed in the interactions with high-intensity laser fields. This effect is usually taken into consideration by non-linear Compton scatterings, while our group has tried to formulize it acting on a Brownian scalar electron by means of E. Nelson's stochastic quantum mechanics [1] for its non-perturbative description. By defining the kinematics of a scalar electron by the D-progressive process $d\hat{x}^\mu(\tau,\omega) = \mathcal{V}^\mu_\pm(\hat{x}(\tau,\omega))d\tau + \lambda \times dW^\mu_\pm(\tau,\omega)$, the dynamics of a radiating scalar electron and the field is imposed [2]:

$$m_0\mathfrak{D}_\tau\mathcal{V}^\mu(\hat{x}(\tau,\omega)) = -e\hat{\mathcal{V}}_\nu(\hat{x}(\tau,\omega))\left[F^{\mu\nu}_{\text{ex}}(\hat{x}(\tau,\omega)) + \mathfrak{F}^{\mu\nu}(\hat{x}(\tau,\omega))\right] \tag{1}$$

$$\partial_\mu\left[\mathring{\pm}\mathfrak{F}^{\mu\nu}(x) + \delta\mathfrak{f}^{\mu\nu}(x)\right] = \mu_0 \times \mathbb{E}\left[\!\left[-ec\int_{\mathbb{R}} d\tau' \,\mathrm{Re}\left\{\mathcal{V}^\nu(x)\right\}\delta^4(x-\hat{x}(\tau',\bullet))\right]\!\right] \tag{2}$$

By solving this Maxwell equation and taking an average of the dynamics, the radiation formula in this model is

$$\frac{dW_{\text{Brownian}}}{dt}(\tau) = \Xi(\tau) \times \frac{dW_{\text{classical}}}{dt}(\mathbb{E}[\![\hat{x}(\tau,\bullet)]\!]) \tag{3}$$

[3] which is quite similar formula in the case of scalar-QED $dW_{\text{sQED}}/dt = q_{scalar}(\chi) \times dW_{\text{classical}}/dt$ [4]. Hence, it leads Ehrenfest's theorem of the radiating scalar electron. We will discuss the detail of this conceptual idea for understanding Ref.[2, 3].

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Search for Vacuum Magnetic Birefringence With Pulsed Magnet and Fabry-Pérot Cavity

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Quantum electrodynamics predicts the rotation of the polarization of the light under a strong magnetic field as a result of the vacuum polarization. This is the nonlinear effect of the electrodynamics and called vacuum magnetic birefringence (VMB). The undiscovered axion-like particles (ALPs) also could induce VMB. Therefore, measurement of the VMB signal is both the test of QED and ALPs search, but not observed yet.

To observe the VMB signal, we are developing high repetitive strong pulse magnets and a stable high finesse Fabry-Pérot cavity.

In this talk, I will talk about overview and current status of our experiment. I will also report the first result of our experiment.

Search for Hidden Photon Dark Matter(HPDM) using Dish Antenna in Millimeter-wave region

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Physics beyond the Standard Model predicts the existence of new elementary particles. One of them called hidden photon is an extra U(1) gauge boson which weakly couples to ordinary photons, and thought as a candidate of dark matter.

In the millimeter-wave region, using a dish antenna, we perform a hidden photon search experiment. The talk includes the experimental setup and the result from the obtained data.

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Search for X-ray photon-photon elastic scattering with a Laue-case beam collider

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Photon-photon scattering is a process predicted by quantum electrodynamics (QED). Since the scattering of real photons has not ever been observed, the direct observation of this process is considered as an important test of QED.

We have performed photon-photon scattering experiments in the X-ray region, unlike prior experiments using optical light sources. We report the results of the experiments and future prospects.

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Phase retardation and polarimetry with GeV photons to probe deformed vacuum

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The vacuum in quantum electrodynamics is considered to show the birefringent nature when it is exposed by strong electromagnetic field [1-4]. The vacuum birefringence can be probed by combining 10 W laser with 1 GeV gamma-rays. 10 PW laser deforms the vacuum structure and 1 GeV linearly polarized gamma-rays probe the deformed vacuum. The vacuum birefringence can be observed via the polarization-flip of photons [5,6]. The polarization-flip phenomenon in birefringent vacuum can be associated with phase retardation of probe photons.

The polarimetry of probe photons at the GeV energy can be performed via electron-positron pair production process. The azimuthal anisotropy of the pair emission is a measurable signal to extract phase retardation of photons. We discuss how to extract phase retardation of probe photons with electron-positron pair topology in Bethe-Heitler process and the measurability with concrete polarimeter design, a given laser parameter set and statistics.

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Search for Vacuum Diffraction Using high power laser and X-ray Free Electron Laser SACLA

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Quantum electrodynamics predicts that a strong electromagnetic field changes the refractive index of vacuum. Since a strong ununiform electromagnetic field makes a slope of the refractive index in the vacuum, probe photons traversing the vacuum could be diffract slightly. This phenomenon is called “vacuum diffraction”, but it has not been observed.

For the vacuum diffraction experiment, we need to make a strong ununiform electromagnetic field. In our setup, we make this using a high intensity near infrared laser. As probe photons, we use a high intensity x-ray laser–X-ray Free Electron Laser, SACLA.

I will talk about an overview of our experiment. Fig 1 is our experimental setup. In addition, I will make a report of our experiment result we did in November 2016.

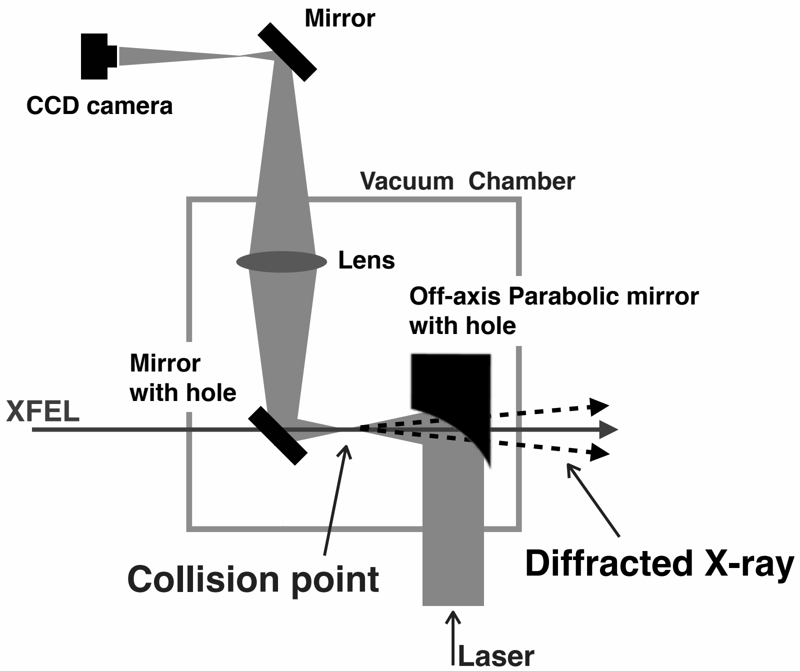

Fig 1 Experimental setup

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Nulcear Astrophysics in laser deriven gamma-ray pulse

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High peak power laser has been quickly developed, which leads to new generation of radiations such as electrons, gamma-rays, and ion beams from high field plasma generated from interaction between a laser pulse and a target [1]. These laser driven radiation pulses are suitable for the study of various phenomena in explosive stellar events. It was proposed to study slow neutron capture reactions (s-process) in stars and photodisintegration reactions by high flux gamma-rays in the MeV energy region (gamma-process) in supernovae using high intense neutrons provided from laser driven D-T fusion reactions at the Nuclear Ignition Facility (NIF) in LLNL [2]. In the Extreme Light Infrastructure Nuclear Physics (ELI-NP), it was proposed to generate neutron rich isotopes using fission-fusion reactions on multi-targets including ^{232}Th with high peak power laser to study the rapid neutron capture reactions (r-process) [3]. Progress in laser physics also enables us to generate high flux and short duration gamma ray pulse [4]. We propose nuclear experiments using such gamma-ray pulses in order to study nucleosynthesis in novae and supernovae. Gamma-rays in the MeV energy region have the dominant role in the gamma-process, in which neutron deficient isotopes are produced by successive photon induced reactions, and in the destruction channel in neutrino induced reactions in supernovae (neutrino-process). The basic concept is the following: A laser pulse is divided into a pre-pulse to create hot plasma and the main pulse to generate high intense radiation like gamma-rays or neutrons. The time difference between two pulses is tuned to be 10-100 fs which is shorter than the life of the plasma produced by the pre-pulse. This technique has been widely used to evaluate the physical parameter of the plasma such as the temperature. This method can be applied to measure the cross section of nuclear reaction. We discuss how to generate the suitable gamma-ray pulse and the experimental method using the gamma-ray pulse.

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Prospects of laser-driven, ultra-dense ion bunches for the generation of extremely neutron-rich isotopes

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Understanding the nucleosynthesis of heavy elements in the universe ranges amongst the key topics currently addressed in nuclear astrophysics. 'Waiting points' at closed nucleon shells play a crucial role in controlling the reaction rates. However, since most of the pathway of heavy-element formation via the rapid-neutron capture process (r-process) runs in 'terra incognita' of the nuclear landscape, in particular the waiting point at N=126 is yet unexplored and will remain inaccessible to conventional nuclear reaction schemes even at next-generation radioactive beam facilities.

Laser-induced ion acceleration at upcoming high-power, short-pulse laser systems (like ELI-NP in Bucharest) will offer the perspective to exploit the unique properties of laser-accelerated ion beams in order to explore the scenario of a new reaction mechanism based on ultra-dense ion bunches [1]. Accelerating fissile species (e.g. ^{232}Th) towards a second layer of the same material will lead to fission both of the beam-like and target-like particles. Due to the close to solid-state density of the accelerated ion bunches, fusion may occur between neutron-rich (light) fission products, thus opening an access path towards nuclides in the vicinity of the N=126 waiting point.

The talk will outline the perspectives of this 'fission-fusion' mechanism and the required experimental conditions.

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Production and Photoexcitation of Nuclear Isomers at ELI-NP

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The synthesis of trans-iron proton-rich nuclei (the so called "p-nuclei") is mostly regulated by γ-processes in environments requiring high temperatures and plasma densities such those are supposed to be found in the O- and Ne- rich layers of the type-II Supernovae [1]. In these conditions, where the temperatures can reach orders of billions of Kelvin, excited nuclear levels are thermally populated. Nevertheless there are no direct measurement of cross sections for processes occurring from the excited states of nuclei, since the nuclear processes induced in laboratories are from the ground level only. At ELI-NP, we propose the production of nuclear isomers with bremsstrahlung radiation from Laser Wake-Field accelerated (LWFA) electrons [2] and their photoexcitation above the neutron threshold by using the high tunable and monochromatic gamma beam from the GBS, thus allowing a direct measurement of cross-sections of nuclear reactions from these isomeric states [3].

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Laser Driven Nuclear Astrophysics Studies at ELI-NP

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The short duration and high particle density of laser accelerated bunches are well suited for nuclear studies with astrophysical impact. Modification of decay modes, apparent lifetime and other properties of nuclear states in hot plasma environments, or changes of nuclear reaction cross sections in plasma are among studies proposed at ELI-NP facility under construction in Magurele, Romania. Details on such topics will be given in the presentation together with their foreseen experimental implementation at ELI-NP and ongoing developments of needed detection systems, including the demonstration of in-situ gamma spectroscopy of short lived nuclear isomers produced in high power laser induced nuclear reactions.