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NEAR-FUTURE ELECTRON/PHOTON FACILITIES IN JAPAN

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Experimental facilities in Japan and physics motivation for nuclear physics research with electromagnetic probes at present and in the near future are reviewed. An innovative electron-nucleus collider in the design stage at RIKEN is introduced.

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1. *Introduction*

The 1.3-GeV Electron Synchrotron at the Institute for Nuclear Study (INS) of the University of Tokyo (Tokyo ES), has been the only electron accelerator operating above 1 GeV in Japan. It supplied a tagged-photon beam with the average duty cycles of up to 20% in the 1 GeV energy range since 1987. Photonuclear experiments have utilized the beam with a large-acceptance detector, TAGX, which compensated the limited photon beam intensity. A new joint venture between KEK and INS for the establishment of Japan Hadron Facility (JHF) required reorganization of the two institutions in 1997. As a result of this merger, Tokyo ES is closing down by the summer of 1999. In this paper, a short description of the accelerator is given, and it is followed by the descriptions of two new photon-beam facilities above 1 GeV that are under construction, and of an electron-nucleus (eA) collider in the design stage.

The TAGX spectrometer [1], which is located in the tagged-photon beam line, has a π sr solid angle for charged-particle detection, and 0.85 sr solid angle for neutrons. The tagged-photon beam is in the energy range from almost zero up to 1.2 GeV with the energy resolution of 5 MeV (rms) and the intensity up to 10^6 photons/s. Thanks to its easy-to-handle detector system for the photoreaction studies in the 1-GeV region, the TAGX collaborations have carried out more than ten experiments to study the photon absorption strengths on pn and pp pairs in ^{3}He [2,3], ^{4}He [4] and ^{6}Li nuclei, double Δ excitation both in the deuteron [5] and ^{3}He [6], K$^+$ production on ^{12}C [7] and the ρ^0 meson production in light nuclei [8]. A result on ρ^0 meson production in ^{3}He is shown in Fig. 1 [9].

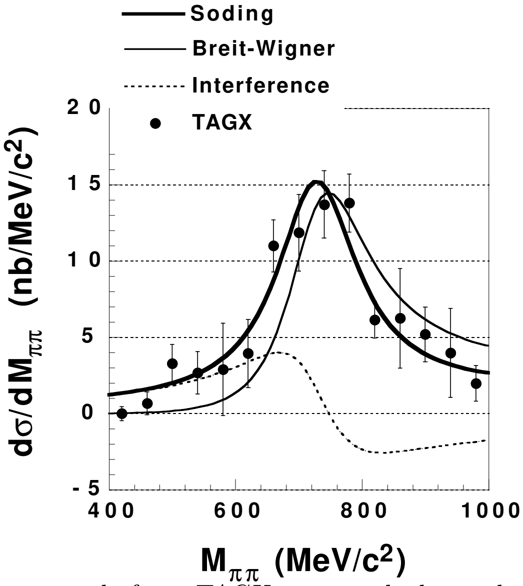

Fig. 1. A recent result from TAGX; a tagged photon beam hit a cryogenic ^{3}He *target, and the momenta of photoproduced* π^+ *and* π^- *were reconstructed. By requiring residual to be* ^{3}He, *the* $\pi^+\pi^-$ *invariant mass was observed. According to the parametrization of the Söding mechanism, the peak is due to the coherently produced* ρ^0 *mesons which have vacuum mass and width.*

The TAGX spectrometer will be moved to Tohoku University in Sendai, where they are commissioning a 1.2-GeV Stretcher-Booster-Storage Ring for electrons (STB). By using the internal tagging method, that facility can produce a tagged-photon beam with the energy well above 1 GeV with an almost 100% duty cycle (see Table 1). One of the proposed experiments is a measurement of the total cross section for three-body ^{4}He break-up in the tagged-photon energy range below 50 MeV, which can be obtained on an extracted electron beam channel [10]. The measurement is to settle the discrepancy, which was pointed out by the TAGX collaboration [4], between the total cross sections in the Δ resonance region [4] and those in the GDR region from Mainz [11] and other laboratories.

TABLE 1. Energies and circulating currents of accelerators at Tokyo and Tohoku.

Facility	Type	Energy	Current	Duty cycle
Tokyo ES	Synchrotron	1.3 GeV	100 mA	20 %
Tohoku STB	Stretcher/Booster	1.2 GeV	300 mA	100 %

2. *Polarized photon beam*

Another real-photon facility, LEPS (Laser Electron Photons at SPring-8) [12], is under construction in the western area of Osaka. A laser beam will be injected into the circulating electron beam of the storage ring SPring-8, which is dedicated to synchrotron radiation for material science, and the scattered photons in the backward direction will be used for nuclear experiments. The high-energy electron beam of 8 GeV of the ring makes possible the production of photons of the maximum energy of 2.4 GeV (see Table 2). A polarized photon beam with a modest energy resolution will be available. The main interest at present is the ϕ-meson photoproduction on the proton. A magnetic spectrometer for K^+ and K^- detection in the forward direction is in preparation.

TABLE 2. Three facilities for backward Compton photon beams. E_e is the energy of the circulating electron beam, and E_γ is the maximum photon energy. Highly polarized photon beams are available.

Facility	E_e (GeV)	E_γ (GeV)
LEGS (BNL)	2.5	0.47
GRAAL (ESRF)	6.0	1.5
LEPS (SPring-8)	8.0	2.4

Deuteron photodisintegration, one of the simplest nuclear reactions ever studied in detail, was measured at Jefferson Lab in the energy range $E_\gamma = 1 - 4$ GeV [13]. The differential cross sections obtained at 90° support the constituent counting rule of Brodsky and Farrar [14]

$$s^{11} \frac{\mathrm{d}\sigma}{\mathrm{d}t} = constant\,, \tag{1}$$

where s is the center-of-mass energy squared and t the momentum transfer squared. Experiments show a constant value above 1 GeV. This scaling behavior is consistent with the data from SLAC. The energy dependence is determined only by the number of the point-like objects involved in the reaction. If this is the case, the scaling starts at the energy as low as 1 GeV.

In order to examine the scaling rule, a unique measurement of the polarized-beam symmetry Σ has been proposed that would use the linearly-polarized photon beam[15]. The polarized-beam symmetry Σ is defined as

$$\Sigma = \frac{\mathrm{d}\sigma_\parallel/\mathrm{d}\Omega - \mathrm{d}\sigma_\perp/\mathrm{d}\Omega}{\mathrm{d}\sigma_\parallel/\mathrm{d}\Omega + \mathrm{d}\sigma_\perp/\mathrm{d}\Omega}\,, \tag{2}$$

where $\parallel$ and $\perp$ refer, respectively, to the parallel and perpendicular photon polarization vector to the reaction plane. So far, the accumulated data show positive values of Σ at 90° up to the energy of 1 GeV which is supported by meson exchange calculations, while a calculation assuming scaling rule predicts $\Sigma = -1$ [16]. This means, if the scaling is valid, the value of Σ may change from the positive values to negative values at higher energy. This change could be measured at LEPS with a reasonable investment for a new detector system.

3. eA *collider*

The Radioactive Ion Beam Factory (RIBF) project at RIKEN in a suburb of Tokyo aims to open a new era for the use of ion beams for nuclear physics and other areas of basic science and applications. In addition to the existing linac and cyclotron for heavy ions, an intermediate energy cyclotron (K–950) and a superconducting cyclotron (K–2500) are being constructed as the first phase of the project. Light nuclei accelerated to $400A$ MeV and the heaviest nuclei accelerated up to 150 A MeV with high intensities will be available in the year 2002 [17].

A more ambitious part of the RIBF is the Multi-Use Experimental Storage Ring (MUSES). MUSES, the second phase of RIBF, will comprise an accumulator ring, a booster synchrotron ring, and a double storage ring (DSR) for ion beams from the cyclotrons. It will accelerate protons up to 3.5 GeV, light ions of the charge-to-mass ratio of 0.5 to $1.4A$ GeV, and U^{92+} ions to 1.0 A GeV. MUSES will store also the electrons with the energy of 2.5 GeV on one of the DSR. A realistic design of the MUSES accelerators is in progress at RIKEN [18].

One of the key studies planned at MUSES are experiments on collisions between various combinations of particles, such as protons, ions, and electrons. Emphasis is on electron-ion collisions. The aim is to determine the not-yet-measured charge distributions of neutron- and proton-rich radioactive nuclei for which exotic structures such as neutron halo and skin are indicated [17]. The differential cross section for the elastic eA scattering can be written as

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} = (\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega})_{\mathrm{Mott}} |F_c(q)|^2 \tag{3}$$

where index Mott refers to the point-like cross section which can be calculated precisely, q is the momentum transfer to the nucleus and F_c is the charge form-factor to be determined. Difficulties are related to obtain high enough luminosity for unstable nuclei. It is pointed out that if one could achieve a liminosity of 10^{25} cm^2/s/nucleus for eA collisions, it would be possible to determine the charge radius for many nuclei, and if one had the luminosity of 10^{27} cm^2/s/nucleus, the charge distributions could be measured for heavier nuclei [19]. Design and R/D of the system are under way.

Other investigations are planned, such as the hadron production experiments by colliding electrons of maximum energy (4 GeV) and the nuclei of maximum energy. In terms of collisions in a fixed target, it gives for protons $\nu = 35$ GeV at the maximum. The expected luminosities for eA collisions for stable nuclei are 10^{32} cm^2/s/nucleon [18]. The studies of the properties of hadrons in nuclear medium is the main topic for the experiments in the high-energy mode. Research and design groups for accelerators, physics and detectors work to solve the problems in the realization of MUSES.

4. Conclusion

One accelerator that is closing down and three new facilities for electron/photon beams in Japan are described. The opportunities for investigations with the 1.3-GeV Tokyo electron synchrotron will be reinstalled at the 1.2-GeV Tohoku Stretcher-Booster ring in 1999. A Compton back-scattered polarized photon beam from SPring-8 of energy up to 2.4 GeV will be ready in 1999. An ambitious electron-nucleus collider is in the design stage at RIKEN.

References

1) K. Maruyama et al. (TAGX Collaboration), Nucl. Instrum. Methods A **376** (1996) 335;
2) T. Emura et al. (TAGX Collaboration), Phys. Rev. C **49** (1994) R597;
3) T. Emura et al. (TAGX Collaboration), Phys. Rev. Lett. **73** (1994) 404;
4) K. Maruyama, K. Niki, Y. Sumi, T. Emura, I. Endo, S. Endo, H. Itoh, S. Kato, M. Koike, K. Maeda, T. Maki, Y. Murata, C. Rangacharyulu, A. Sasaki, T. Suda, Y. Wada and K. Yoshida (TAGX Collaboration), Phys. Lett. B **393** (1997) 295;
5) M. Asai et al. (TAGX Collaboration), Z. Phys. A **344** (1993) 335;
6) D. G. Watts et al. (TAGX Collaboration), Phys. Rev. C **55** (1997) 1832;
7) H. Yamazaki et al., Phys. Rev. C **52** (1995) R1157;
8) G. J. Lolos et al. (TAGX Collaboration), Phys. Rev. Lett. **80** (1998) 241;
9) K. Maruyama, Nucl. Phys. A **629** (1998) 351c;
10) T. Suda, private communication;
11) S. M. Doran et al., Nucl. Phys. A **559** (1993) 347;
12) T. Nakano et al., Nucl. Phys. A **629** (1998) 559c;
13) C. Bochna et al., Phys. Rev. Lett. **81** (1998) 4576;
14) S. J. Brodsky and G. R. Farrar, Phys. Rev. Lett. **31** (1973) 1153;
15) K. Maruyama and K. Maeda et al., LOI to SPring-8; http://www.rcnp.osaka-u.ac.jp/;
16) S. I. Nagornyi, Yu. A. Kasatkin and K. Kirichenko, Sov. J. Nucl. Phys. **55** (1991) 189;
17) I. Tanihata, Nucl. Phys. A **626** (1997) 531c;
18) T. Katayama et al., Nucl. Phys. A **626** (1997) 545c;
19) K. Maruyama et al., A Letter of Intent to the RIBF PAC (in Japanese).

NOVI SUSTAVI SA SNOPOVIMA ELEKTRONA I FOTONA U JAPANU

Daje se pregled eksperimentalnih akceleratorskih sustava koji će se uskoro sagraditi u Japanu i planovi istraživanja u nuklearnoj fizici. Predstavlja se nov sudarač elektrona s jezgrama koji se razvija u RIKENu u Tokiju.