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Prof. Koshiba and electron–positron physics

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Prof. Masatoshi Koshiba was the physicist who initiated the $e+e-$ physics effort in Japan. The first attempt goes back to the 1960s. Following a hard time in the early days the attempt turned out to be successful, leading to a number of productive projects, and eventually supported his neutrino experiments. In this article we detail the history of how these projects developed and entangled.

Subject Index

1. Prologue

"Keep the eggs of your ideas for research warm." This is what Professor Koshiba used to tell his students. He continued: "Very challenging queries may become soluble as time goes." Prof. Koshiba himself practiced this motto to achieve many successful outcomes. Since I was advised this way when we first met in 1964, he must have got the habit when he was in the United States.

Prof. Koshiba started his career in the field of cosmic ray physics in Chicago. In those days very high-energy cosmic rays were the main source of high-energy particles for investigating the multiple particle production in which he became interested during his master's course at the University of Tokyo, and wished to study at the cutting edge of the field. With help of Prof. S. Tomonaga's letter of recommendation, he could study under Prof. M. F. Kaplon at Rochester University. He got his PhD in 1955. His thesis attracted the attention of Prof. Schein of Chicago University, and he was employed as a post-doc researcher. Prof. Schein was investigating the heavy nuclei component in cosmic rays to study their origin by catching them with nuclear emulsion. Prof. Koshiba told us later that he had worked very hard in those days, first to get his PhD in 2 years and then to become competent as a particle physicist. He became an important member of Prof. Schein's group. This can be inferred from his trace during the subsequent few years.

Having acquired much experience in Prof. Schein's group, he returned home to the University of Tokyo as an associate professor at the Institute of Nuclear Study (INS). He brought back with him some emulsion plates to analyze with his colleagues. About a year later he received an invitation from Prof. Schein to collaborate in the newly planned international project to launch a stack of a large amount of nuclear emulsion. INS decided to participate, and Prof. Koshiba moved to Chicago again to work in the big collaboration. After a few attempts at a balloon launch, which were all unsuccessful, Prof. Schein tragically suddenly passed away. The international team named the young Prof. Koshiba as the succeeding leader. It must have been an extremely tough role for him, but he faced the challenge. When he started the task the resources of the collaboration were already short, so he had to begin by securing the necessary budget. Although he did not speak of the details, we can imagine from his occasional remarks how hard he had to work. Through the experience, Prof. Koshiba may have polished a kind of intuition for how to find the best way to overcome difficulties. He finally managed to accomplish the task after a few failures. The last balloon flew from the airport of Brawley, on the southern border of California, across the continent to the east coast for over 38 hours at an altitude of 35,000 m and was picked up successfully. Finishing the month-long development work of the emulsion, the group located more than the expected number of high-energy interactions.

Prof. Koshiba obtained part of the emulsion, 16 out of 80 liters, to analyze at home. However, he did not agree with his colleagues at INS about how to organize the analysis work. When he was looking for a possible alternate position where he could proceed as he wanted, a call was made for a new associate professor of physics at the faculty of science of the University of Tokyo. He applied successfully, and began preparing his own laboratory from autumn 1963.

2. Prof. Koshiab's laboratory

His laboratory started from the next school year, April 1964. New members were two fresh graduate students, Mr. S. Orito and myself, and scanners to assist nuclear emulsion analysis. Prof. Koshiba trained those members from scratch intimately as if they were all family members, and carried out some of his ideas on analysis which he had had in mind since his time in Chicago. Through the procedure we acquired basic knowledge of particle physics as well. In those early days nuclear emulsion had to be analyzed by eye and hand under microscopes, so it took a very long time to get physics output. The process was frustrating, too. In the meantime, high-energy accelerators and modern detectors were appearing in the United States and Europe, where more efficient experiments could be conducted. These new technologies became more influential and popular, and improved rapidly. The energy of the accelerators kept being upgraded, and newly developed online counter experiments produced high-statistics data.

As the number of the students increased each year, Prof. Koshiba organized a weekly seminar so that they could educate each other by introducing the latest publications. It was sometimes tough to prepare and to answer questions. This, however, gave them a good chance to stay informed of the latest developments in particle physics and related topics, many of which were from accelerators, like CP violation, and from cosmic physics, like the observation of the 3K background radiation or the first measurement of solar neutrinos. As the students learned more, they got frustrated with the limited data they worked on. Also, in Japan the first electron synchrotron began operation for photo-production experiments. Some students preferred to study there for different possibilities. Prof. Koshiba tried to keep up the emulsion analysis as long as possible, but it became harder.

Prof. Koshiba himself must have been aware of the limitation of the emulsion technique from the very early days. In starting his laboratory he considered other ways, too. By the end of 1964 he chose Mr. Suda, who had been working at RIKEN Institute in the field of cosmic ray observation by counter techniques, as a research associate to develop spark chambers.

Prof. Koshiba was keen about what is crucial in particle and cosmic ray physics, as well as their observation techniques. What he told us in his first lecture in 1964 on cosmic rays for the graduate course indicates his consideration. I remember clearly the three words he wrote first: at one end of the board "elementary particles," and at the other end "universe," saying "Cosmic ray research binds these ends." He continued further, while writing "neutrino" in the center, "I believe the neutrino in particular may play the key role." Neutrinos had been observed by Reines and Cowan some years before, and were known to be extremely difficult to detect.

He added that he had no idea about how, and did not come back to the subject during the following lectures. Nevertheless, cosmic neutrinos must have been one of his eggs which he kept for decades.

Wide-gap spark chambers were added as another theme which new students tackled as they joined. When they succeeded in producing a set of working units, the spark chamber team made a joint experiment in collaboration with a counter experiment group of the faculty searching for fractionally charged particles among ground-level cosmic rays [1]. Following this first electric experiment, Prof. Koshiba planned another spark chamber experiment to observe underground muon bundles in order to examine heavy nuclei components among the primary cosmic rays. He selected an old metal mine in Kamioka as the best-suited site, and succeeded in getting support to install and operate detectors.

In parallel with this new attempt, Prof. Koshiba began Monte Carlo simulation of cosmic ray air-showers, which would link the very high-energy nuclear interactions at high altitude and the underground muons and neutrinos. The idea came up when the computer center on campus started the operation of a big machine, HITAC 5020. Emulsion analyses require much calculation, so Prof. Koshiba purchased the fastest calculator of the time in preparing the laboratory. It was a relay-switch machine and was replaced with faster semiconductor equipment later. However, being unfamiliar with a big computer, Prof. Koshiba persuaded Prof. E. Goto, who was known as the most experienced computer expert in the faculty, to cooperate in the simulation plan. Prof. Goto, also being interested in particle physics himself, having searched for the magnetic monopole in meteorites, made the skeleton of the simulation code and trained a few of Prof. Koshiba's students to perform the simulation by adding physics processes into it.

These new activities all became materials for master's or doctor's theses of the graduate students. Although they look independent, Prof. Koshiba considered that they were connected in the underlying physics processes. Furthermore, and importantly, in retrospect the experiences turned out to provide powerful support in pushing his later projects forward, as if Prof. Koshiba had foreseen this and arranged for it.

3. Start of $e+e-$ physics

In May 1968 Prof. Koshiba attended the international cosmic ray conference held in Moscow, where he met Dr. Gersh I. Budker, director of the Institute of Nuclear Study in Novosibirsk, where the first electron colliding beam accelerator had been built simultaneously with Stanford University. They made friends immediately, and through that Prof. Koshiba got immense momentum toward a new endeavor. Coming back from Moscow, he told us enthusiastically about a collaboration for an electron–positron colliding experiment at VEPP-3, a 2 GeV $e+e-$ collider being constructed in Novosibirsk. It was a surprise that Prof. Koshiba suddenly set out into a new field without experince. Nevertheless, we were excited about the new possibility without knowing how hard it would be.

Prof. Koshiba took action promptly. Getting advice and support from the former dean of the faculty, Prof. Seiji Kaya, he arranged a visit to INS, Novosibirsk in a group of four physicists: himself, Prof. E. Goto, Prof. K. Kobayashi, accelerator expert of INS, Tokyo, and Prof. S. Fukui, counter experimentalist of Nagoya University. Having scrutinized the facilities at the institute and discussing in detail cheme of possible collaboration, he decided to go ahead. The expected contributions from Tokyo were the luminosity monitor and a minicomputer for data-taking.

In those days the majority of particle experiments were performed with high-energy proton accelerators. For the first step Prof. Koshiba called attention to the project by organizing a workshop of interested physicists and by inviting Dr. Budker to give a seminar to the faculty. Most importantly, he persuaded his colleagues in the physics department to create positions to build a new group for preparatory studies. It was not easy given the trend for hadron physics in the particle physics community. But with the support of Prof. Nishijima, who was the chair, who concluded that investigation of a new energy region with a novel method might bring new findings, Prof. Koshiba could initiate the group.

The group started first with two new lecturers: Dr. K. Fuke, who had constructed a prototype electron synchrotron in the department, and Dr. S. Homma from Tohoku University, who had had experience with counter experiments at MIT. Some months later two research assistants joined, Dr. N. Kajiura from Hiroshima University, who got a doctor's degree with a photoproduction experiment at the INS electron synchrotron (ES), and myself. Having got doctor's degree with nuclear emulsion analyses, I had been a post-doc at RIKEN in the information science lab of Prof. E. Goto.

From 1969, each of the four members stayed at Novosibirsk one after another as a bridge between Tokyo and the collaboration site, and to join the R&D activities there. In order to cover the travel budget the members applied for the academic exchange channel between Japan and the Soviet Union which enabled them to stay for 10 months. The members remaining in Tokyo prepared for the contribution together with some graduate students. Prof. Koshiba purchased the necessary material and equipment, such as a lead glass block for testing a luminosity monitor or a HITAC10 mini-computer, which was equivalent to a PDP8, and so on. After arranging all the necessities for R&D, Prof. Koshiba left the practical work of design, construction, and testing with the group members and only wished to be informed of the progress. A prototype luminosity counter was built, and was examined at the test beam of the INS ES by using the HITAC10 for data-taking so that the online scheme was tested as well [2].

While the preparation work went smoothly, the collaboration itself did not start as we had hoped, for several reasons. During the waiting period the group continued to acquire further experience of online experiments by joining the INS ES experiment using a scintillation counter array spectrometer, which was the first online experiment at INS ES to transfer data from the PDP8 to the TOSBAC-3400 at the computer center for data storage.

In 1972 Professor Koshiba had to give up the collaboration at Novosibirsk. The slow progress of VEPP-3 construction did not look promising and was hardly supportive for the budget requests, which had been repeated in vain. News of Dr. Budker's health problems made the situation even dubious.

4. The DASP experiment at DORIS, DESY

Having been convinced of the capability of $e+e-$ physics through the preparatory studies, Prof. Koshiba stuck to conducting $e+e-$ experiments and sought other possibilities. In the early 1970s, both SLAC and DESY were constructing new colliders of several GeV. Fortunately, the director of research at DESY was Prof. E. Lohrmann of Hamburg University, who had been a good friend of Prof. Koshiba during his Chicago days. With his help Prof. Koshiba visited DESY, met the chair of the directorate, Prof. W. Paul of Bonn University, to open the way for his group to join. Following discussions with the experimental groups at DORIS they concluded that DASP, which was one of the two approved groups, would match Prof. Koshiba's request; its spokesperson, Dr. B. Wiik, kindly accepted the role of host. It was understood that Koshiba's group would participate as a team in building part of the detectors for which Dr. Wiik's group was responsible in the DASP collaboration. The details were worked out, including the payment procedure for materials through the DESY account system.

While the framework was shaped to start collaboration as a team, Prof. Koshiba's team did not exist at this point. The preparatory group for the Novosibirsk experiment had been dissolved and its members, except for myself, had left for new positions. I was staying in Novosibirsk until the end of the exchange program. Prof. Koshiba had to start a new group by using a borrowed research associate position. In December 1972, Dr. Y. Totsuka, who got the degree with the muon bundle experiment, was employed and was sent to DESY first. Soon after he had left for Hamburg, I returned to Tokyo and joined him at DESY next May.

The DASP detector was a double-arm spectrometer, for which the group of Dr. Wiik was in charge of the electromagnetic shower detector system installed inside the big magnet yoke. Thus it was called the inner detector. It consisted of two parts, each made of a lead scintillation sandwich structure. The front part was equipped with proportional tube layers for shower tracking, and the rear part was an array of total absorption type shower counters. Very luckily we could participate from the design stage of the inner detector and identify tasks to contribute in such a way that our earlier experiences could immediately be useful. Namely, Dr. Totsuka developed and constructed proportional tube arrays for tracking, and I wrote reconstruction software to analyze. We also participated in shower counter construction, including financial contribution. Dr. Suda arrived in autumn 1973 and joined the proportional tube construction. Prof. Koshiba visited DESY from time to time, talked with relevant leaders at DESY, and saw the progress at the construction site. While he spent much time with us when staying at DESY, he did not go into details of what we were working on. He only supplied all the logistics needed for our activities, namely our positions, expenses, and resources for our detector contribution.

We could assimilate smoothly into the DESY team. The facilities and support system at DESY such as the computer center or the test beam of the synchrotron were fully available, as well as the material purchasing system and the support of engineers and technicians. Being newcomers in the collaboration, we did our best to be recognized as a trustworthy partner by working hard, which was also enjoyable in the productive environment. We also owe much to Prof. Lohrmann, who had stepped down as director and was a member of another group at DORIS; he kept supporting us so that we felt at home.

When DORIS started collisions in 1974, part of the detector had been installed ready for data-taking; this was only one third of the inner detector, but had been calibrated with the DESY test beam. The DASP group tried to make test runs with this limited acceptance. During the discussion meeting for a precise plan in November, the surprising news was brought that unprecedentedly narrow resonances had been found at BNL and SLAC for which the masses were almost the same. It must be a hadron being produced in the proton nucleus reaction at BNL. On the other hand, the MARK-I experiment at SPEAR, SLAC, observed its width as narrower than the energy spread of the colliding beams, which had not been observed for other hadrons. The test plan was modified to confirm the newly discovered particle.

Due to the difference in the absolute energy calibration between SPEAR and DORIS, however, a peak was not observed at the reported mass. While DASP was struggling with energy scans with a small step looking for the peak, an excited state of the resonance was announced from SLAC. After a week of scanning, we confirmed the resonance at a mass higher by 5 MeV.

DASP derived the basic parameters of the new resonance using the Bhabha scattering and published the first paper. This was the first outcome of Prof. Koshiba's team in *e*+*e*− physics [3], although his name is not included in the author list nor acknowledged, which we regretted much, but only later.

The resonance is called J/Psi, combining the names given by the finder groups. Soon, DASP completed the full detector to join the detailed investigation of the new particle. The resonances were identified to be the bound states of the fourth quark, charm. The discovery had a revolutionary impact on particle physics, shifting its major objectives from hadrons to quarks. At the same time the *e*+*e*− collision experiments were recognized as a very powerful tool. The attention was enhanced with the discovery of the third lepton, tau, by the MARK-I group. DASP could contribute in clarifying the new physics, which we enjoyed a lot.

The seminal *e*+*e*− physics led to construction plans for new facilities for higher energies at various institutions around the world. Under such competition DESY started building the next collider, PETRA, aiming at 30 GeV, while keeping DORIS in operation. For some time both DASP running and preparation for PETRA went on simultaneously until DORIS was closed temporarily for an upgrade toward 10 GeV. During the shutdown, the DASP group passed its complete detector and software to a new group, DASP-II, which had entirely different members. The new group gained experience by operating the system, and later designed and built its own detector, ARGUS, to investigate Upsilon physics. The member teams of the original DASP group moved to three PETRA experiments, CELLO, JADE, and TASSO.

5. The JADE experiment at PETRA

In 1976 the European Committee for Future Accelerators organized a workshop to study the experiments at PETRA. Prof. Koshiba participated in this meeting to exchange ideas with participants looking for possible collaborators. When his group joined DASP as a newcomer, the basic design concept of the detector had already been fixed. For PETRA experiments, it was possible to begin with group formation for collaboration by discussing with various teams on intended detector ideas.

A large acceptance detector surrounding the interaction region was the common feature among many groups. After a variety of discussions on possible combinations of detector types for each component, a new collaboration was established consisting of teams from DESY, Heidelberg, Lancaster, Manchester, Rutherford Laboratory, and Tokyo. Taking the initials of these teams' countries, the group was named JADE. (Later, when Maryland University joined, this name was still meaningful by considering "A" to stand for America.) The Tokyo group took on the lead glass counter arrays for electromagnetic shower detection. It was a practical choice for the working environment of the group. The detector consisted of handy modules that could be developed in the university laboratory yet provided good performance.

In parallel, Prof. Koshiba paid much attention to strengthening the group by requesting budget for new positions. The effort had already started during the DASP days, first in order to return the borrowed positions and then to increase in number. Dr. S. Orito, who had experience of *e*+*e*− experiments at Frascati, joined as an assistant professor. Since he was already a DASP member as a post-doc at the Max Planck Institute in Munich working on the spark chamber of the spectrometer arms, and DASP was running well with the originally shared tasks, this increase did not immediately affect the working of the group. However, since both DASP operation and PETRA preparation went on simultaneously, the enlargement was effective for the JADE preparation.

A substantial increase in members was realized, together with the construction budget for JADE. New research associates were employed one after another, of whom the first was Dr. Y. Watanabe, who got a PhD from Cornell University, and some other senior members were promoted. The team grew about three times larger as the construction went on. Accordingly, the working scheme of the group was systematized between the two bases in Tokyo and at DESY. On the one hand, such tasks as R&D and testing of components were carried out at home where graduate students could participate. On the other hand, such tasks as component assembly, mechanical construction, and beam tests were carried out at DESY, where engineering support and working space could be obtained. Prior to assembly, each counter module was calibrated at the DESY test beam. Software development was done largely at DESY, where the computer center was accessible full time in accordance with the operation of accelerators. Members rotated in turn between Tokyo and DESY for one- or two-year periods depending on the task schedule. In order to keep close communication between the two bases, regular weekly telephone calls were made and telefax machines were installed. Senior members staying in Tokyo assisted Prof. Koshiba with logistics and budget requests. Later we understood that this way we had been trained in how to obtain resources.

By 1979, when PETRA started beam collisions, the lead glass system was ready. As soon as data-taking started, the online display of events showed salient characteristics of hadron events. Namely, most of them had a two-jet structure indicating that the hadrons are produced via pair creation processes. Quantitative analysis showed their features were consistent with the expectations of the quark parton model. Furthermore, occasionally three-jet events were observed, suggesting that one of them resulted from a radiated gluon [4]. The gluon is the key element of the quantum chromodynamics (QCD) that originates in the interaction between quarks. While its effect could have explained the scale violation of deep inelastic scattering, the observed three-jet events demonstrated the gluon more directly and opened a new way to estimate the fundamental coupling constant of QCD.

The initial energy of PETRA was set aiming to look for the sixth quark, top. The attempts at a narrow peak search, however, remained unsuccessful, and the PETRA energy reached its maximum of 46.8 GeV. Nevertheless, these runs over a wide energy range produced rich data for various physics analyses, such as the energy dependence of the QCD coupling constant that was an important QCD feature. At the highest end of the energy spectrum, the effect of the Z-boson could be observed in the forward–backward charge asymmetry of the muon pair and of the b-quark jets. Many searches for various new particles were tried, too.

When Prof. Koshiba was struggling for the budget of JADE, he told me once about his life plan as a physicist. "Considering that the academic life of a physicist is roughly 30 years long from getting a degree until retirement, I split my life span into three decades. In the first decade, I worked very hard for physics by myself, which I already did in the US. In the second decade, I wish to arrange the environment for the younger generation so that they can concentrate on physics by working hard as I did. In the third decade, I like to make a small-scale experiment which I may enjoy quietly."In view of this plan, the entire effort of Prof. Koshiba for $e+e-$ physics corresponds exactly to the second decade.

A serious concern of Prof. Koshiba throughout the JADE experiment was how to let graduate students participate in the front-end activities. The component R&D at home was not enough, but vivid work at the DESY frontier had to be experienced. Unfortunately, in the 1970s the budget for overseas travel could not be used for graduate students. For them to participate on the DESY site, other possibilities were sought, and several different means were used one after another, such as grants from private foundations, student exchange channels, or applying for DAAD scholarship, sometimes by getting the cooperation of Prof. E. Lohrmann or Prof. G. Weber of Hamburg University.

Most students of JADE could participate in different stages of the experiment: component R&D, detector construction, data-taking or analysis. However, often they had to come back home before finishing data analysis for their theses. Prof. Koshiba planned to overcome this difficulty by installing at the base lab in Tokyo a big computer system fully compatible with the mainframe of the DESY computer center. Through additional serious efforts the necessary budget was obtained successfully. The entire JADE software as well as the editor system of the DESY computer center were installed at home. For some specific software, relevant experts were invited from DESY to install their programs. All the raw data were copied and sent once a week on magnetic tapes, which was the fastest data transfer method in those days. Thus, the students could continue analysis at home without any time lag. In total, nearly 10 doctor's theses were completed. Many of the graduate students who got a doctor's degree found jobs, mostly in other $e+e-$ experiments at TRISTAN, CESR, PEP, or at the home lab.

6. Development after PETRA

The JADE experiment brought Prof. Koshiba's group much experience that enabled them to expand their activities. The main stream was the continuation of $e+e-$ physics at LEP, which the European community decided to build as the next facility at CERN. LEP was expected to be a powerful Z factory, and it was natural for the group to pursue physics there. The OPAL collaboration was formed based on the same detector concept as JADE. The teams from Heidelberg, Manchester, and Tokyo were common with the PETRA experiment, and the professors of these institutes, including Prof. Koshiba, cooperated closely to invite more institutes into OPAL to expand the group in order to be commensurate with the complexity and scale of the intended detector.

By this time Prof. Koshiba's team had enough members to work simultaneously on budget requests for OPAL in Tokyo and to prepare for detector construction in Europe while running the JADE experiment for some years. Working at both DESY and CERN required much traveling between the two labs. On the other hand, there were also benefits: about ten per cent of the JADE lead glass counters were replaced with ones made of heavier glass to match the increased energy of PETRA, which also became a prototype for OPAL, so that real data could be used for performance confirmation.

The members of the younger generation who had been trained with JADE played a major role in carrying out these tasks on site and throughout the construction of the OPAL detector, which was completed as scheduled. Once the LEP started operation, OPAL was extremely productive by generating a huge amount of data that allowed very precise scrutiny of the standard model. The rich physics is too much to describe here, but is hopefully well known.

In parallel with the preparation for LEP, the group expanded into another area where JADE experience was applied directly or indirectly. Prof. Orito made a cosmic anti-proton measurement with his students by launching a light detector, of which the tracking detector was a small JADE jet chamber. Prof. Koshiba himself, together with Dr. Watanabe, also started a proton decay experiment as one of the grand unification research programs organized by Prof. Sugawara. Such activity at home was needed to train the young graduate students who were joining every year. The Kamioka mine was again chosen as the site, and the experiment was named KamiokaNDE. Since its details have been introduced in other articles, we comment here only on a few matters closely linked to JADE. Soon the KamiokaNDE group was reinforced with Profs. Totsuka and Suda, who had constructed the high-voltage and electronic system of 3000 phototubes for the JADE lead glass detector. The unprecedentedly large phototubes developed for KamiokaNDE were a fascinating challenge for them to get their teeth into for installation, power supply, control, and data processing. The JADE computer system in the lab was also used for KamiokaNDE analysis, including various utilities. This enabled prompt data processing all day, providing tremendous analysis power.

KamiokaNDE can be regarded as the third-decade program of Prof. Koshiba's life plan, although it grew much larger in scale than a hobby experiment. A big step was the upgrade of the water Cherenkov detector so that solar neutrinos could be detected. This was possible by making KamiokaNDE into an international experiment collaborating with the Philadelphia team. With this reinforcement Prof. Koshiba finally realized the idea of his younger days, which had been deliberated on for decades. The details of the successful detection of solar neutrinos and supernova neutrinos will be described in other articles.

7. Epilogue

Prof. Koshiba and most of his group members became active later in fields other than $e+e-$ experiments. However, many of them, including Prof. Koshiba, maintained their enthusiasm for $e+e-$ physics, and returned to the field again to work in promoting the future $e+e-$ collider to be realized under global international cooperation. As time goes on, the efforts have been succeeded by the group members of younger generations, Profs. T. Kobayashi, S. Komamiya, M. Nozaki, and K. Kawagoe. Prof. A. Suzuki, who joined the group from the KamiokaNDE experiment, also continues to play a leading role. Prof. Koshiba himself was an ardent supporter of the activity until his last days, recognizing it as crucial for future generations.

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