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E-36: The First Proto-Megascience Experiment at NAL

Vitaly S. Pronskikh

Fermi National Accelerator Laboratory, Batavia, USA

Introduction

E-36, an experiment on small angle proton-proton scattering, began testing equipment in the National Accelerator Laboratory's newly achieved 100-GeV beam on February 12, 1972, marking the beginning of NAL's experimental program. This experiment, which drew collaborators from NAL, Joint Institute for Nuclear Research (JINR at Dubna, USSR), the University of Rochester (Rochester, New York) and Rockefeller University (New York City) was significant not only as a milestone in Fermilab's history but also as a model of cooperation between the East and West at a time when Cold War tensions still ran high. An examination of the origin, operation, and resolution of E-36 and the chain of experiments it spawned reveals the complex interplay of science and politics that drove these experiments as well as seeds of the megascience paradigm that has come to dominate high-energy physics research since the 1970s.

Experiment ahead of QCD

Quantum chromodynamics (QCD) only began to emerge when asymptotic freedom was discussed by David Gross, Frank Wilczek[1], and David Politzer[2] in the early seventies, when E36 was already underway. Despite the fact that QCD is currently a standard tool for the calculation of hadron scattering amplitudes, its application to the study of many processes measured at high-energy accelerators is still quite complicated. Examples are such seemingly simple processes as small angle scattering of protons on protons, which E-36 measured. Basically, along with many other important reactions with small momentum transfer, small angle proton-proton scattering generally falls outside the grasp of perturbative QCD[3].

Since the 1970s, physicists were using the Tullio Regge theory[4] to explain what is going on in small angle proton-proton scattering. The Regge theory is a phenomenological approach[5], which in the 1970s was not linked to the quark structure of the proton but relied on the so-called S-matrix formalism (an approach alternative to QCD, without elementary particles, which was almost abandoned since late 1970s but later resulted in what nowadays is known as string theory). In the Regge theory, to describe elastic proton-proton diffraction at high energies, unknown scattering amplitudes are replaced in equations with structures containing functions called Regge trajectories (or Reggeons). Despite many theoretical attempts undertaken since the 1960s, there are still no consistent universal methods to deduce Reggeons from QCD. Since 1975, theorists have developed certain approaches of limited scope[6,7] that relate QCD to the leading Reggeon. The leading Reggeon[8,9], which could effectively explain the diffraction behavior of hadrons as well as equal co-asymptotic cross sections for protons and anti-protons at high energies[10], was sometimes called the Pomeron, after the Soviet theorist, I. Pomeranchuk[11]. Such approaches as the diffractive scattering model, optical theorem, and analyticity were the language used by the E36 experimentalists for data analysis and interpretation[12, 13].

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The participants in E-36 and its subsequent chain of experiments did not have to refer to QCD or the quark model in their papers in order to interpret their results. In his PhD thesis based on E-36 results[i], Dan Gross derived bonds from Quantum Field Theory and found that they are all satisfied by the models used. The experimentalists remember they would sometimes talk with theorists at lunch but did not have any routine guidance from them. As Dick Carrigan, an E-36 participant, recollects, "we usually did not have much guidance from theory." [14] By its conclusion, E-36 had produced scientifically valuable results, including its finding that the ratio of the real to imaginary part of the proton-proton scattering amplitude became positive at about 300 GeV. This result prompted considerable discussion because it contradicted the accepted models of the time[15].

However, in the earliest days of E-36 there was another factor that played a key role in the justification of the experiment: politics.

Scientific and political context

The beginning of the 1960s was marked by not only the first manned space flight, but also a number of political crises. Erection of the Berlin Wall completed the separation between Eastern and Western Blocs in 1961, while the Cuban missile crisis in 1962 aggravated tensions between East and West. The West had not yet fully recovered from the shock caused by the launch of Sputnik, and the level of Soviet technological development had to be reckoned with. However, competition between the blocs, which extended to science, was balanced by an essential desire to cooperate. For example, the year 1969 was marked by signs of successful scientific collaboration between the East and the West in the field of plasma physics: a group from Culham Laboratory, UK reported successful measurements of the electron temperature in a tokamak at the Kurchatov Institute, USSR[16].

Particle accelerators constituted another domain in which the US and the Soviets had long gone head to head. Which country could boast the highest energy particle accelerator in the world? Historian Audra Wolfe wrote about that period: "The United States might have lost the race to put the first satellite into space, but it would wage a fierce battle to produce the most Ph.D.'s, the most Nobel laureates, and the biggest particle accelerators."[17]

In 1949, four years after World War II, a synchrocyclotron capable of accelerating protons to 560 MeV[ii,18] was built for the Institute of Nuclear Problems of Soviet Academy of Sciences in the city of Dubna, located about 2 hours by train north of Moscow. The Joint Institute for Nuclear Research (JINR) would be founded at Dubna in 1956 (the names "JINR" and "Dubna" have often been used interchangeably since then). However, the Cosmotron at the US's Brookhaven National Laboratory at Long Island, New York surpassed this record in 1953 when it started to produce 3-GeV beams[19]. Shortly afterwards, in 1954, Lawrence Berkeley National Laboratory also broke the GeV barrier with its 6.2 GeV Bevatron[20]. The Soviet Union could not stay away from the race, and in 1957 their newly built accelerator, JINR's Synchrophasotron, reached a record of 10 GeV[21]. The US, not to be outdone, built the 12.5 GeV ZGS at Argonne National Laboratory near Chicago (A. Sessler evaluates the latter two as "the competition between Argonne and Dubna to build the highest energy proton accelerator (the ZGS and the Synchro-phasotron).")[22]

Soon afterwards, in 1959, CERN surpassed the proton acceleration record by reaching 25 GeV with its Proton Synchrotron[23], and a year later the palm was again in the US when the Alternating Gradient

[i] D. Gross, PhD Thesis, FERMILAB-THESIS-1974-01.
[ii] Because of secrecy, first open publications appeared ca 1956, when the accelerator energy had been elevated to 680 MeV.

Synchrotron at Brookhaven achieved 30 GeV proton beams[24]. Unwilling to back down, the Soviet Union planned to create a new record-breaking accelerator, this time at the Institute for High Energy Physics (IHEP) at Protvino near Serpukhov (called Serpukhov in the documents of the time). IHEP was a USSR national laboratory about 2 hours by train south of Moscow and only about 150 miles from Dubna. Scientists at JINR adjusted their plans to form a user group and do experiments at IHEP. However, since JINR was an international institution founded by the Eastern Bloc countries Albania, Bulgaria, Czechoslovakia, East Germany, Hungary, Poland, Romania, and the USSR, along with China, Mongolia, North Korea, and Vietnam and organized according to principles similar to those of CERN, it could not easily transfer common resources to a national laboratory (IHEP) without raising objections among its members[25].

In 1965, China (one of the JINR founders) withdrew from membership. One of the complaints that drove this move, as expressed by the Chinese representative at the XII session of the JINR Scientific Council and documented in the JINR archives, was that JINR approved the transfer of resources to IHEP without consulting member-countries outside the Soviet Union, which could, the Chinese representative feared, make JINR "end up losing its shirt."[26] Another allegation was that JINR refused requests by responsible representatives of the participating countries for permission to inspect the institute's reactor park, while US visitors "were allowed to walk around the entire institution without supervision for many hours and take pictures,"[27] often accompanied by its highest officials. At the height of the Cold War, therefore, JINR appeared to be committed to cooperation with the US, reaffirming its status as an "international oasis" within the USSR.

Construction of the IHEP accelerator, U-70, was completed in 1967 and the proton beam reached 76 GeV. The high-energy leadership, at least in terms of which lab had the highest energy beams, returned to the USSR. The USSR held this status until 1972, when Fermilab's new Main Ring reached 100 GeV. Groups from JINR came to IHEP to conduct experiments, bringing with them new ideas and unique equipment. One of these groups brought to U-70 a gas-jet target, a device to inject a tiny well-collimated stream of hydrogen gas across the accelerated proton beam in order to study how beam protons scattered off protons in the hydrogen gas target. The gas-jet setup as well as the energy range were new and the results, therefore, unique. By 1970, the experimenters had prepared some of their results for presentation at the world's largest particle physics conference, which coincidentally took place in the USSR that year[28].

Collaboration that began in Kiev

In 1970, Kiev, the capital of Ukraine, hosted the International Conference on High Energy Physics. That conference was also called the Rochester conference, and it was and is the most prestigious conference in the field of particle physics. At that conference, Ernest (Ernie) Malamud of NAL met Vladimir Nikitin, a JINR-based scientist and the lead experimenter working with the gas-jet target at IHEP. Both enjoyed history and culture[29], and picturesque Kiev, rich in natural beauty and architectural monuments of past centuries, afforded the two scientists many opportunities for enriching diversions. United by common interests, Malamud and Nikitin soon became friends in the best traditions of that hospitable land, and the ten conference days passed rapidly.

Their conversations about architecture were interspersed with discussions of physics experiments. Malamud had heard of the experiments with the gas-jet target performed at the IHEP accelerator, where Nikitin was one of the leading participants, and Nikitin shared details with him. The idea to perform a similar experiment at NAL using the newly built Main Ring at energies even higher than those at IHEP came simultaneously to their minds. Now the prospective collaborators needed to enlist the support of the NAL Director, Robert Wilson[30].

First Meeting with Wilson

The next step was to arrange a meeting between Nikitin and Wilson. Travel between the two countries was complicated in the midst of the Cold War, but a conference on computing technologies held in the US in 1970 served as an opportunity for Nikitin to obtain a visa, come to the US, and visit NAL. Nikitin and Malamud's meeting with Wilson was a key event in the history of E-36. Nikitin showed Wilson lovely glossy photos of the setup at U-70[31], and then Malamud and Nikitin presented their concept for doing a similar experiment at NAL and proposed the division of responsibilities that they had worked out between them during the Kiev conference. Wilson listened carefully, asked many questions, and at the conclusion of the meeting announced that he was going to approve their proposal.[32] He was a consistent supporter of and believer in international cooperation, and he made the decision on his own initiative. The proposal did not go through the Program Committee[33], which was only advisory to the director and whose recommendations were not mandatory. However, this bypassing of the Program Committee was quite unusual.

Soon after that, Malamud's intent to cooperate with the Soviets met resistance and criticism. While barriers were slowly coming down with the forthcoming Nixon-Brezhnev first Strategic Arms Limitation Treaty in May, 1972, memories of Senator McCarthy's times were still alive, and several US physicists frankly told Malamud "Do not do that, Russians are bad guys." Undeterred, Malamud stuck to his guns.[34]

First obstacles

Accelerators require high vacuum to operate, comparable to that in outer space. In order to avoid scattering accelerated protons off the gas molecules of the air and, therefore, destroying the beams, experimentalists had to pump the Main Ring vacuum chamber out to an average level of about 10^{-9} Torr[35]. The gas-jet posed a danger to the accelerator because it operated by inserting a well-collimated jet of hydrogen, deuterium, and, later, helium into the Main Ring vacuum chamber. NAL scientists and engineers raised concerns about whether the risk was sufficiently justified since the success of other experiments at the laboratory hung in the balance. The use of a "foreign technology," a device built at JINR and tested only by the Soviets, did not give many of the NAL staff confidence in the likelihood of the endeavor success[36]. E-36A's status as the newly built NAL's first experiment made failure unacceptable, adding more strain. However, despite the pressure exerted by the doubters on all sides, Wilson's authority and his commitment to international cooperation were decisive, and the experimenters eventually obtained permission to "dock" the Main Ring and the JINR-built gas-jet target, serving as a harbinger to the docking of the US and Soviet spacecrafts a few years later[37]. Thus, the JINR-NAL collaboration became an "Apollo-Soyuz" on US soil and a part of the HEP landscape.

Collaborating with competitors

Another obstacle soon threatened to spoil the game. The gas-jet experiments of the JINR group at IHEP at lower proton energies of 70 GeV were a success and the results were being prepared for publications. Adrian Melissinos at University of Rochester, Dick Carrigan at NAL, and some of their colleagues were independently working on proposals for experiments exploring physics of small angle proton-proton scattering.[iii] This group of scientists developed a similar proposal over a period of time after Malamud and Nikitin submitted their letter of intent, but before their final proposal was prepared.[38] Melissinos and his colleagues proposed to build their gas-jet device in the US with no foreign collaborators, a completely national initiative which had to be, *ceteris paribus,* a priority in a national laboratory. The US/Soviet collaboration was uncertain for a second time after the concerns about the Main Ring vacuum.

NAL Deputy Director Edwin Goldwasser wrote to I. Smolin, a member of the USSR State Committee for Atomic Energy, about the problem on July 11, 1972: "As you know, we had already received a proposal from an American group for a similar experiment subsequent to the initial submission of the letter of intent by the USSR-USA collaboration, but previous to the submission of their final proposal. We therefore had a serious problem to decide how best to proceed with the interesting physics experiment that is in question." [39] It was a difficult decision for the NAL Directorate, but they found an elegant solution. Both proposals were merged, and the consensus was that the official leader of the experiment "should not be a Russian". [40]

Rod Cool, a physicist from Rockefeller University with a well-established reputation, became the spokesperson of the joint proposal, and his candidacy seemed to suit everyone in the new collaboration. In a September 15, 1970 letter to Dick Carrigan, who co-submitted the competing proposal with Melissinos, Wilson wrote, "[…] there has been a strong indication of interest by the group of Russian scientists who developed this technique and carried out the successful experiments at lower energy at Serpukhov. […] Sorting all this out is going to be difficult, […] and, if you are interested, will try to keep you involved in the effort." [41] Merging the proposals was a completely political decision; however, Carrigan recollects that the groups merged smoothly, and there were no "postmarriage" conflicts among the collaborators. To acknowledge that merger the experiment's name was changed to E-36A.

It sounds surprising, but one of the most serious obstacles USSR and US officials encountered when negotiating the conditions of the collaboration turned out to be the cost of housing of the JINR group at NAL. In order to cover their group's stay with families at NAL for a year, the JINR group proposed to NAL to leave their equipment after the experiment if NAL was willing to purchase the gas-jet target from them. They estimated its value at $80,000, which was the amount needed to cover living expenses for the scientists and their wives for a year. [42] However, the NAL Directorate had to refuse the proposal because the Laboratory had already funded construction of a similar target in the US, which was done in support of the competing proposal by the Melissinos group as a hedge in case the collaboration with the USSR failed.[43] Thus, the collaborators faced serious difficulties a third time. The resolution came unexpectedly.

In his letter to Nikitin on April 21, 1971, Goldwasser writes: "During recent visit of Dr. Petrosyants [head of the USSR Committee for Atomic Energy] and other Soviet scientists to NAL, we learned that a major difficulty in completing your arrangements to collaborate in the p-p elastic scattering experiment was still the cost of housing for yourself and your group while living and working at NAL. I am pleased to be able to tell you that at April 16 dinner in honor of Dr. Petrosyants, Dr. Seaborg [head of the US Atomic Energy Commission] stated that he was pleased by the prospect of the coming USA-USSR collaboration and that he was also pleased to announce that during the working visit of the Soviet scientists they would be housed at or near the Laboratory as guests of the Laboratory." [44] It remains a mystery why the State Committee, the USSR organization controlling all their country's nuclear programs and therefore with an apparently unlimited budget, was not willing to cover housing for a dozen people. One plausible explanation could be a bureaucratic "catch-22." Due to the international status of JINR, an experiment in

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[iii] R. A. Carrigan, Jr. Does the Slope of the High-Energy Elastic Proton-Proton Scattering Cross Section Increase at Small Momentum Transfer? Phys. Rev. Lett. 24, 168, 1970.

the non-member US on the one hand could not be funded from the JINR budget formed by member countries. On the other hand, being performed by employees of JINR and not of a USSR national laboratory, it could not attract funding from the State Committee, which was responsible for the USSR's national program. Fortunately, the collaboration became possible essentially thanks to Seaborg's generosity and good will.

Telex communications

During the preparation of the experiment, the collaborators on both sides of the Atlantic employed telex, the predecessor of email, to discuss travel arrangements, apparatus, and many related technical details. It was a proven method of scientific communication between the scientists of the two countries. It had been successfully used by the collaboration between the Darrell Drickey (UCLA) and Edward Tsyganov (JINR) groups that started in 1970 at the IHEP accelerator to measure the pion form factor[45]. E-36A, the first US-USSR collaboration in HEP on US soil, benefited from the experience[46] and advice of the Drickey-Tsyganov collaboration in using the telex. The telex communications were taken very seriously by both sides. One of the telexes dated 1971 Thanksgiving Day[47] suggests that the NAL collaborators came to the NAL's telex by 9 AM to communicate with their Soviet counterparts before going to have their festive turkeys with their families. On the other hand, 9 AM Central time was 6 PM in Dubna, but no one cared about working hours.

Malamud concluded one such telex exchange on October 14, 1971 with the words: "There are lots of people at the telex this morning – Steve, Chiang, Guiliannos [sic], Mr. Getz. We all send best wishes. Good bye. We will call you next week. Spasibo. Do swidaniia[iv]"[48] (Don Getz was an Assistant Director of NAL, who occasionally came to watch the process).

First Soviets in Batavia

Western people who visited scientific laboratories of the Soviet Union, including JINR, at that time were sometimes surprised by certain elements of the local culture. Noteworthy was that relationships between scientists from various countries of the Eastern Bloc and the other JINR countries were often not limited to cooperation within laboratories and projects, but extended far beyond their professional context. Collaborators easily became friends in everyday life, as did their families[49]. Scientists often visited one another at home in the evenings to chat about work, books, and life over a cup of tea or vodka, attended concerts and other cultural events together, and helped each other in dealing with everyday issues.

The aforementioned UCLA/JINR collaboration contributed to the cross-cultural understanding between Soviets and Americans. While preparing for the arrival of the JINR collaborators from Dubna, NAL was determined to create a friendly environment for the newcomers to help them better adjust to unfamiliar surroundings. But how to overcome cultural differences? The solution was found in the best Western traditions of pragmatism. To formalize the intended friendship between future collaborators, every Dubna family (described as the Soviet Bloc in the instructions laying out this plan) was assigned a NAL employee companion family (listed as the non-Soviet Bloc). Dick Carrigan sent around the instructions in March 1972, shortly before Nikitin's group arrived. The families were paired in the following way: Kuznetsovs to Carrigans, Nikitins to Malamuds, Popovs to Yamadas, Zolins to Olsens, Pilipenkos to Strausses, Bartenevs to Chiangs, and Morozovs to Klens[50].

[iv] Thank you. Good bye. [Russian]

The assignments followed "the equality principle" where possible: the manager was paired as a companion to the manager (Kuznetsov and Carrigan), the lead scientist to the lead scientist (Nikitin and Malamud), and the cryogenic engineer to the cryogenic engineer (Pilipenko and Strauss). There were, however, exceptions. For example, physicist Ryuji Yamada was paired with the group administrator Vladimir Popov[51], who was allegedly associated with the KGB.

NAL companions picked up their Dubna counterparts upon their arrival at O'Hare airport, invited them to dinners, taught them how to shop in the US, and helped them choose used cars. During the first weeks that the Soviets were in Batavia, their NAL companions accompanied them to grocery stores and selected food and spices the Soviets had never seen before for them to try[52].

All the Soviet scientists were married and many had children, but while their wives arrived with them, the children were left behind in the USSR, presumably to discourage possible defections. Away from their children, without jobs that were compulsory in the USSR, and without their usual circles of friends, the wives of the Soviet collaborators, who arrived in 1972, were lonely while their husbands were at work. Many of them spoke a little English, so a solution would have been to find jobs for them. It is important to mention that at that time at JINR, it was usual practice for the lab to help find jobs for foreign collaborators' wives. Whether the NAL Directorate was aware of that tradition or not, it soon asked Smolin for permission to apply for visas that would allow the Soviet wives to work, but such permission was not obtained. In a July 1972 letter to Smolin, Edwin Goldwasser wrote: "One further matter concerns the morale of the wives of the first group of scientists who arrived on site. It is my understanding that in response to my request of you in Washington, permission has not been granted for these ladies to be employed, even if it were possible for us to make arrangements of that kind. I have not yet received a direct response from you to my question, so I hope that the indirect report that I have received may be in error." [53] Smolin did not respond positively; therefore, the Soviet side did not exhibit any willingness to resolve the visa issues for them. As participants recollect[54], Erna Morozova was a skilled electronics technician, and Elena Kuznetsova was a physicist; presumably, it would have been beneficial for the collaboration if they had been allowed to work, at least part time.

Another limitation imposed on the Soviets was the "red tape." The US placed them under a 25-mile travel restriction, so they were not allowed to travel to Chicago. To travel beyond the "red tape" they had to request permission at the NAL AEC office, but that permission was often obtained. Once they even managed to travel to Niagara Falls and back in one night, taking turns driving one after another (the permission was obtained with the help of Vladimir Popov)[55].

Fermilab also took care that the Dubna families did not get bored. Carrigan's letter of 1972 mentions under "social calendar": "Entertainment has been informally organized by NAL wives to be extended over a long period. After the visitors arrive, arrangements will be made so that they will be taken on tours of Chicago as well as taken to special concerts, with permission. The Russian women speak little English. It might be advisable to consider English lessons." [56] It is noteworthy to mention that the tradition of women's English language conversation groups for foreign visitors' families at NAL was preserved and is still ongoing. Women's cooking and conversation groups organized to help immigrant scientists' families join the American culture had also been maintained in the 1940s at Los Alamos during work on the Manhattan Project[57], and Fermilab's similar activity in the 1970s could possibly be viewed as a continuation and development of that tradition.

The English of the JINR collaborators and their wives was initially not good, but many of them later improved their English language skills. However, especially in the beginning, English was not the only language used for communication. Dan Gross, who was born in Romania (part of the Soviet Bloc at that time), could understand some Russian, and sometimes, when working on the target, Morozov asked Gross technical questions in Russian and he responded in English[58]. That helped them to better understand each other's language. Dino Goulianos, born in Greece, learned some Russian communicating with the Soviet scientists and, especially, their wives[59].

All members of the JINR group had experimental duties on shifts when the apparatus was running, and the group administrator Popov was no exception. The NAL collaborators remembered that the Russians often scheduled him for the less desirable night shifts[60]. As experimental shifts usually consisted of sitting in a room and performing simple manipulations on the rare cases when it was necessary, his minimal experience in HEP experimentation was sufficient to satisfy the requirements of an operator. Upon completion of E-36A, on March 15, 1973, Wilson wrote in his letter to A. M. Baldin, the Director of the High Energy Laboratory at JINR, about Popov : "…he quickly made himself technically expert in the operation of the equipment and rapidly became a dependable operator, himself."[61] It is unclear whether Popov's ease in learning the operator's profession was the cause, but when Malamud started discussing with Baldin in Dubna the continuation of new follow on experiments soon after the conclusion of E-36A, he was presented a list of strangers as his prospective collaborators instead of Nikitin's people. In response to Malamud's strong complaint about substituting unknown and unpublished scientists in place of the experiment's proposers, Baldin asserted that "physicists are interchangeable like jet pilots."[62] After a months-long dispute with him, and supported strongly by Wilson, Malamud managed to persuade Baldin to return to the list Nikitin and the rest of his time-tested gas-jet team.

Start and program

In February 1972, the Main Ring attained an energy of 100 GeV (breaking IHEP's 76 GeV record), and E-36A started[63]. Both US and USSR teams had different specialists: managers, scientific program leads, cryogenic and electronics engineers. The Soviets, who brought their internal target with them, were responsible for installing and maintaining the target. They also brought the silicon particle detectors, the carefully machined holders and collimators to hold those detectors in place, and the experiment electronics. NAL provided the data acquisition computer, a PDP-11, and the helium liquefier for the target. The experiment was located in the Internal Target Area, one of the four NAL experimental areas (the other three areas used the extracted external proton beam). The Internal Target Area was located at C-Zero, one of the 6 long straight sections around the 6-km circumference Main Ring[64]. The complicated mechanical and electronics interfaces between these components had been worked out by exchange of detailed drawings as well as during the telex conversations. Before the gas-jet target arrived, to keep the experiment alive, the collaboration had started measurements with the rotating polyethylene foil target (a technique previously used by the JINR group at IHEP, but with a significant technical innovation developed by Hans Jostlein) that later resulted in the first US-USSR publication of a NAL-based experiment[v]. The results employing the "flying wire" technique (as it was called later) were also presented at the XVI Rochester Conference jointly held at University of Chicago and NAL in 1972[vi].

Both groups participated in "shifts" (running the experiment and taking data), data analysis, and publishing papers. The Russians were given accounts on the Fermilab computer and did much of the data analysis there. The initial report NAL80 was released in October 1972[65]; several journal papers including a few papers in Russian were published later[66]. The two initial key publications, both in the prestigious

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[v] V. Bartenev, A. Kuznetsov, B. Morozov, V. Nikitin, Y. Pilipenko, V. Popov, L. Zolin, R. Carrigan, E. Malamud, R. Yamada, R. L. Cool, K. Goulianos, S. L. Olsen, I-Hung Chiang, A. C. Melissinos, and D. Gross, Small-Angle Elastic Proton-Proton Scattering from 25 to 200 GeV, Phys. Rev. Lett. 29, 1755 (1972).

[vi] A. Melissinos, Reminiscences. A Journey through Particle Physics, World Scientific, 2013, pp. 202,

Physical Review Letters, concerned the shrinkage of the slope in pp scattering, indicating an increase in the proton "size" as the collision energy increased, and as mentioned above, the changing sign of the real part of the scattering amplitude[67,68].

During accelerator shutdowns, both scheduled and unscheduled, the experimenters went into the Main Ring tunnel under strictly enforced safety procedures to work on the equipment. In those early days of running the Main Ring, the beam intensity was fairly low, so there was not a major buildup of residual radioactivity[69].

The scientific program was fairly clear. The objective was to study pp elastic scattering at a variety of energies, starting with low ones (beginning at 8 GeV beam energy) in order to compare the results to those of other experiments, such as those at U-70. Later, the experimenters would of course take data at the top energy of the accelerator, which initially was to be 200 GeV but during the course of the experimentation went up to 400 GeV and for a few hours as high as 500 GeV. The experimenters had to decide among themselves how to apportion the approved running hours among different energies and jet parameters. Wilson did not bother the collaborators about the experimental program, because his intention was "to get the accelerator going" and "to see at least some initial physics from it."[70] He favored this experiment not least due to the political circumstances and the spirit of the time, which encouraged the US-USSR collaboration, as well.

Despite the fact that most of the technical details had been discussed over the telex well in advance, some issues had to be decided on the spot. For example, the data collection electronics, all built in either the shops at JINR or imported from Eastern Bloc countries, were often not up to US standards, and had to be replaced with American, commercially built equipment. Also, some of the silicon detectors had to be changed to ones purchased from an American company[71].

Scientists as ambassadors

In a certain sense, both American and Soviet scientists served as unofficial ambassadors. In a November 2, 1972 letter to Goldwasser, Malamud wrote: "I think it might be useful if you and Anatole Kuznetsov talked before Petrosyant's visit about such subjects as (1) freer travel in U.S. for Soviets, (2) "Home leave" for them, (3) visits here by children, (4) continuation of the experiment under improved conditions from the Russian point of view, etc. He feels he cannot go to you but that you must initiate such a conversation." [72] Kuznetsov was the scientific manager of the E-36A JINR group, and Petrosyants was the head of the State Committee. The first problem Malamud suggested Goldwasser discuss with Petrosyants was the travel constraints for the Soviets. They were not allowed to travel beyond the aforementioned 25-miles[73], which was imposed not only on the Soviet citizens (by the American government) but also on Americans visiting the USSR (by the Soviet government). The limitations were mutual, and if the USSR started to negotiate with the US the alleviation of this limitation for the Soviets residing at NAL, it would have to take reciprocal measures with respect to Americans visiting the Soviet Union. That was definitely a diplomatic issue, but the articulation of the problem and the proposal for a resolution came from the scientists.

There are many indications that NAL valued foreign scientists as ambassadors. For example, in an October 18, 1972 letter to the Consul General of Israel, Shaul Ramati, Robert Sachs of the NAL Program Committee wrote: "we [should] keep open our channels of communication to those influential individuals in Russia who are most likely to help. For us, these are the Russian physicists who come [...]. They are the ones on whom we must depend when we want to send a message to the Soviet Union. They are interested enough in international cooperation that they will confront their government when they see that our cooperation is at stake…"[74] Eight years later, in 1980, when the prominent physicist and human rights activist Andrei Sakharov was sent into internal exile, collaboration with Soviet physicists was blocked by the DZero collaboration at Fermilab until Sakharov was released[75]. Thus, scientists have efficiently played the roles of ambassadors and informal diplomats to their governments since the first international collaboration at NAL. It should be noted that in such a role scientists are often even more effective than career diplomats despite the fact that they are often underappreciated by their governments and experience much more funding limitations than the latter.

E-36 as a seed of megascience

Megascience, a term generally used by historians and philosophers rather than scientists, is usually defined as a type or descendant of "big science" involving decades-long chains of large-scale experiments with expensive setups and performed by large, often international, collaborations (elucidated, for example, in an outstanding book by Hoddeson, Kolb, and Westfall)[vii]. In that respect, E-36A used a not very large gas-jet apparatus, although it was coupled with the large Main Ring accelerator. Additionally, megascience projects usually require multimillion-dollar apparatus, whereas the E-36A apparatus cost a few million dollars. The team was composed of only seven Soviet and nine US participants and, therefore, this collaboration was not of typical megascience size. However, if one takes into account all the accelerator personnel who were essential in providing the beam and other technical support, then the number who were effectively involved is large. Based on the criteria above, it seems that, while E-36A had some of the characteristics of megascience, it is questionable whether it would truly qualify as megascience.

Megascience experiments result in a chain of similar experiments, differing from one another by small variations of the research program, apparatus, participants, or software. Along these lines, E-36A transformed to E-186, then to E-289, E-317, and finally E-381. The first experiment in the chain started in 1972, and the last one was completed in 1977. The latter experiments in the chain were approved in 1974, and following the "November revolution" of 1974 and the discovery of the J/ψ meson that heralded the triumph of the quark model, Fermilab's scientific program was considerably reformatted. The chain of experiments added inelastic scattering to the initial goal of studying elastic scattering. Added in the chain were other targets: deuterium and then helium. This program studied these different processes at various energies and with different targets and, having fully exploited the technique, came to a natural end in 1977 and 1978.

Fixed target physics continued during the first few years of the Tevatron, so there was a possibility to repeat the jet target work at 1000 GeV. Nikitin proposed this ca. 2000, but there was little interest from others. After all, this was over 20 years after the completion of the E-36A "chain," and the E-36A collaborators had moved on to other more relevant physics. In 1985 Fermilab began colliding beam physics, and it was a natural experiment to study pp elastic scattering at these much higher energies, but using an entirely different technique.

[vii] Hoddeson L., Kolb A.W., and Westfall C. Fermilab. Physics, the Frontier, and Megascience. Chicago : L. : The University of Chicago Press, 2008. 497 p.

Another important feature that distinguishes megascience experiments is the significant facilitating role played by politics. While previous Big Science (such as the aforementioned Sputnik or the Manhattan Project) were clearly associated with confrontation and spurred the arms race, E-36A was enabled by positive changes in macro-level politics between the US and USSR[76]. In May 1972, Nixon and Brezhnev met in the Kremlin, almost simultaneously as E-36A began testing equipment in the NAL beam. The experiment was proposed in the middle of the Cold War, and NAL director Wilson approved it without passing through the advisory Program Committee and without a thorough consideration of its program since his motivation for approving the experiment was, not only its scientific merits, but also the political value of a US-USSR collaboration. Additionally, the roles of scientists as informal diplomats were essentially political.

These two features, experimental chains and the involvement of scientists in macro-level politics, suggest that elements characteristic of megascience had already begun to emerge in E-36A, making it what might be termed "proto-megascience.[viii]" It is worth noting that E-36A, which was mid-way between the Big Science of the mid-20th century and the megascience of the late 20th and early 21st centuries, could serve one of the very first examples of an experiment where science played a role in rapprochement between otherwise hostile countries. This trend has become even more pronounced in contemporary megascience, which frequently requires many more countries to coordinate their efforts and maintain good social and political relations.[77].

Conclusion

The "open letter" signed by all the JINR group members upon leaving NAL on September 13, 1973 says: "The group of Soviet scientists has finished its first experiment at the NAL accelerator, the biggest and the most powerful in the world. […] The good 'start' and successful 'finish' of our experiment were essentially determined by the whole, warm, friendly atmosphere and constant attention to needs of the experiment and the personal needs of our group. […] We are very grateful to our colleagues and their wives, and to all C-Zero technicians for their sincere, friendly and cordial attitude and for their help in our work, and in our new life here, in NAL. […] We bid you a final "good bye" knowing that we bring home not only good scientific results, but a lot of friendship and pleasant memories of the days we spent in the U.S. and at NAL in particular." The Dubna scientists and engineers concluded their letter with the following: "Our group was the first representative in the developing effort for cooperation between Soviet and American scientists in the scope of high energy physics, but we believe that effort will become wider and deeper, year after year." [78] "The experiment was a resounding success, the data has stood the test of time, and it led to many enduring personal friendships between members of the Russian and US teams," Adrian Melissinos says.

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[viii] This term was suggested by Fermilab Archivist and Historian, Valerie Higgins.

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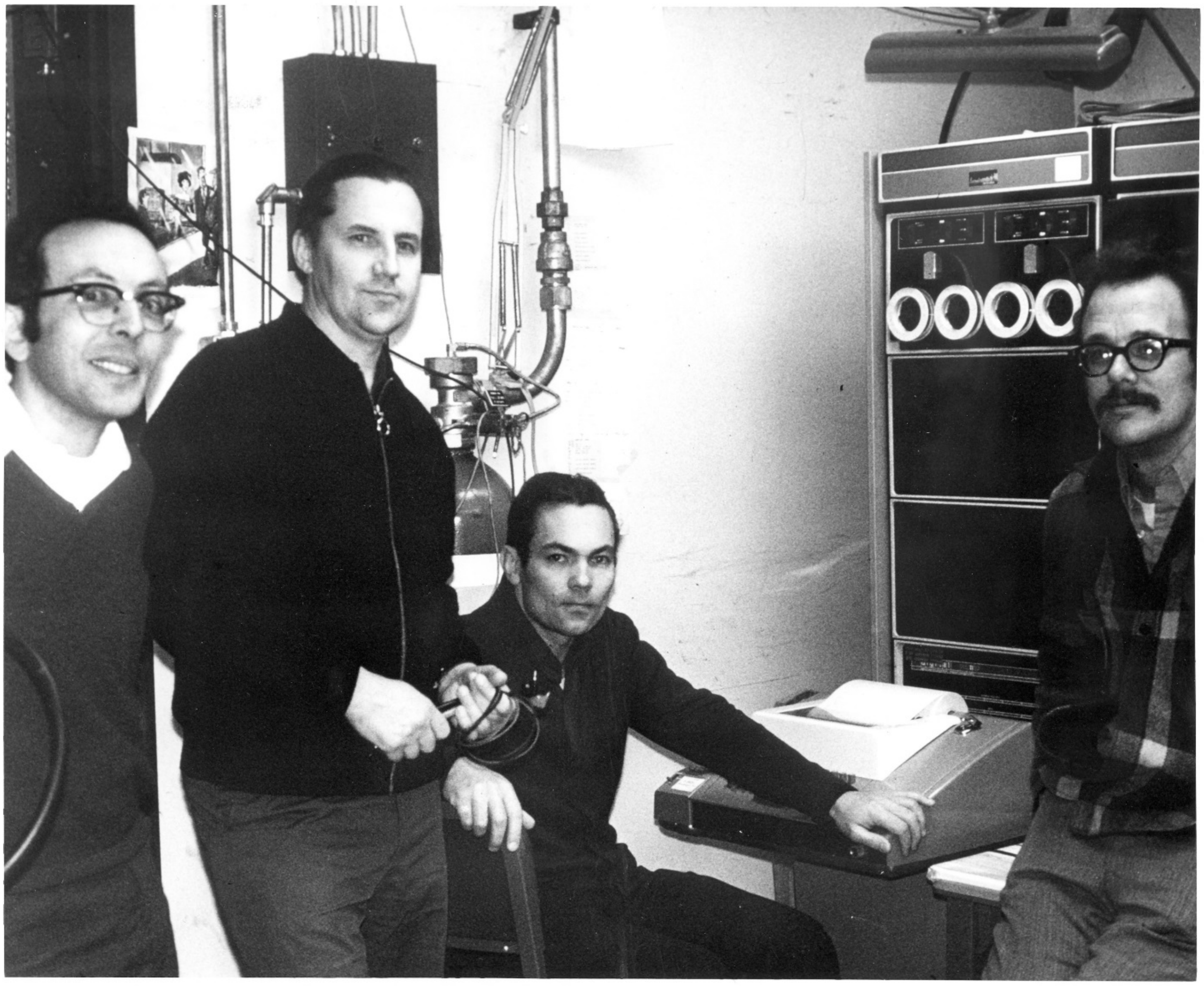
Left to Right: D. Gross, R, Carrigan, A. Kuznetsov, V. Bartenev, R. Yamada, L. Zolin, V. Nikitin, E. Malamud

Date: February 26, 1973



Left to Right: E. Malamud, L. Zolin, V. Nikitin, S. Olsen

Date: December 1972

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