UNIVERSITATEA DIN BUCUREȘTI
VIRTUTE ET SAPIENTIA

UNIVERSITATEA DIN BUCUREȘTI

Doctor Honoris Causa

Victor Matveev

VICTOR A. MATVEEV

Doctor Honoris Causa

Laudatio

domino Victor A. Matveev

Director General al Institutului Unificat de Cercetări Nucleare Dubna, Rusia

Academicianul Victor A. Matveev este una dintre cele mai proeminente și remarcabile personalități ale Fizicii contemporane, activitățile domniei sale având un impact substanțial în dezvoltarea Fizicii particulelor elementare, a Fizicii energiilor înalte, a teoriei cuantice a câmpului, atât în Federația Rusă, cât și în lume.

Academicianul Victor A. Matveev a obținut titlul de doctor in Fizică (Candidat în Științe) în 1967, la Institutul Unificat de Cercetări Nucleare (IUCN) din Dubna. În 1972, el a obținut titlul de doctor docent la același institut.

În 1965, după absolvirea Facultății de Fizică a Universității de Stat din Leningrad, a devenit cercetător științific la Institutul Unificat de Cercetări Nucleare din Dubna. După obținerea titlului de doctor docent (1972), acad. Victor A. Matveev a fost – în perioada 1976–1977 – conducătorul grupului de fizicieni IUCN la Fermilab (Batavia, Illinois, SUA), activând în domeniile sale de interes.

Din 1978, acad. Victor A. Matveev a fost ales director adjunct al Institutului de Cercetări Nucleare al Academiei de Științe a URSS, iar în 1987 a devenit director al acestui institut (din 1992, Academia Rusă de Științe).

În 1991 a fost ales membru corespondent al Academiei de Științe a URSS (din 1992, Academia Rusă de Științe) și, din 1994, membru titular al Academiei Ruse de Științe. Între 2008 și 2014, acad. Victor A. Matveev a fost secretarul Departamentului de Fizică al Academiei Ruse de Științe.

Din 2011, acad. Victor A. Matveev este director al Institutului Unificat de Cercetări Nucleare Dubna.

Este esențial să accentuăm că direcțiile de bază ale activităților domnului acad. Victor A. Matveev au vizat dezvoltarea metodelor teoriei cuantice de câmp în modelele relativiste de cuarci, de căutarea simetriilor dinamice aplicate la interacțiile particulelor elementare în Fizica Energiilor Înalte. De la începutul activităților sale de cercetare și a carierei la Institutul Unificat de Cercetări Nucleare din Dubna, acad. Victor A. Matveev – în colaborare cu B. Struminsky și A. Tavkhelidze – a publicat câteva lucrări care au evidențiat aspecte cu rol cheie în fundamentarea teoriei cuarcilor a hadronilor. În seriile de lucrări publicate de acad. Victor A. Matveev în colaborare cu R. Muradian și A. Tavkhelidze, a fost formulat principiul automodelității în Fizica energiilor înalte. Acesta permite dezvoltarea abordării unice a descrierii fenomenului de comportare invariant la scală a proceselor de ciocnire adânc inelastice și inclusive la energii înalte. Acad. Victor A. Matveev a exprimat conceptul de culoare ascunsă în nuclee și a specificat importanța principiului gradelor de libertate ale cuarcilor pentru înțelegerea structurii nucleelor pe distanțe scurte. Contribuția acad. Victor A. Matveev la dezvoltarea teoriei de culoare a cuarcilor, a structurii de cuarci a hadronilor și nucleelor a fost recompensată, alături de colegii săi, cu premiul Lenin în 1987.

Acad. Victor A. Matveev a contribuit semnificativ la crearea și dezvoltarea multor infrastructuri de cercetare la Institutul de Cercetări Nucleare al Academiei Ruse de Științe. Putem menționa aici acceleratorul de mare intensitate și putere și complexul experimental al fabricii de mezoni de la Moscova, telescoapele de neutrini, observatorul de neutrini de la Baksan, telescopul de mare adâncime de neutrini din lacul Baikal, complexul experimental numit „Troitsk-nu-mass” etc. Sub conducerea Acad. Victor A. Matveev au fost create facilități experimentale unice în lume – sursa pulsată de neutroni, care a fost pusă în funcțiune cu succes în 1978.

Importanța contribuției științifice a Acad. Victor A. Matveev la Fizica hadronilor și la Modelul Standard al interacțiilor particulelor elementare sunt legate de cercetările experimentale realizate la Tevatron (Fermilab, SUA) și la Large Hadron Collider - LHC (CERN, Elveția). El este președintele consiliului de conducere al Colaborării „Rusia și statele membre Dubna” în experimentul Compact Muon Solenoid de la CERN (RDMS CMS).

Ca director al Institutului Unificat de Cercetări Nucleare, acad. Victor A. Matveev a depus eforturi uriașe pentru a realiza mega-proiectul de cercetare științifică de la IUCN – Nuclotronul bazat pe collider-ul de ioni (NICA) – capabil să identifice procese rare fundamentale produse în condiții extreme la dimensiuni foarte mici care ne permit să înțelegem originea Universului. De asemenea, acad. Victor Matveev a reușit să transforme IUCN într-un centru științific internațional deschis unei largi cooperări cu alte centre naționale și internaționale, precum și dezvoltării unei noi generații de fizicieni și specialiști.

Acad. Victor A. Matveev a fost ales membru de onoare al unor Academii

Naționale de Științe, precum Academia Bulgară de Științe, Academia Georgiană de Științe și altele. El a fost, de asemenea, recompensat cu titlul de Doctor Honoris Causa al unor universități din statele membre ale IUCN.

Totodată, acad. Victor A. Matveev a contribuit semnificativ la dezvoltarea și testarea experimentală a Modelului Standard, precum și a altor idei și teorii din Fizica particulelor elementare și Fizica energiilor înalte, contribuind semnificativ la succesul acestui model în descrierea structurii subnucleare.

Activitatea științifică a acad. Victor A. Matveev este evidențiată și de articolele publicate în multe reviste prestigioase de Fizică. Până în acest moment, acad. Victor A. Matveev a publicat peste 400 lucrări științifice în reviste cotate ISI, având mii de citări. Prin urmare, acad. Victor A. Matveev este una dintre cele mai productive personalități din lume în domeniile Fizicii particulelor elementare, a Fizicii energiilor înalte și a teoriei cuantice de câmp.

Acad. Victor A. Matveev a fost, în întreaga sa carieră științifică, un participant activ în rezolvarea problemelor comunității științifice. Prin urmare, el a fost ales în diferite poziții în asociații internaționale ale fizicienilor.

De-a lungul timpului, acad. Victor A. Matveev a colaborat în cadrul diferitelor experimente cu fizicieni români, încluzând marile experimente de la IUCN și CERN. În aceste colaborări, au fost implicați fizicienii de la Institutul Național de Fizică și Inginerie Nucleară „Horia Hulubei" și de la Facultatea de Fizică a Universității din București, iar un număr mare de articole științifice au fost publicate în reviste prestigioase de Fizică.

Acad. Victor A. Matveev a susținut permanent cercetarea în Fizica Nucleară și a Particulelor Elementare din România. Ca membru important al câtorva colaborări internaționale, ca director adjunct și apoi ca director general al Institutului de Cercetări Nucleare al Academiei de Științe a URSS, precum și ca director general al IUCN Dubna, Acad. Victor A. Matveev a încurajat permanent prezența fizicienilor români în aceste colaborări și institute. Prin urmare, fizicienii, cercetătorii și profesorii români au vizitat, au efectuat stagii de lucru și au ținut seminarii. În plus, de-a lungul timpului, un mare număr doctoranzi au lucrat și lucrează în cadrul diferitelor colaborări cu aceste institute. Acad. Victor A. Matveev și grupul său au contribuit activ, de-a lungul timpului, la organizarea de școli de vară și de conferințe în domeniul Fizicii Nucleare și a Particulelor Elementare, caracterizate printr-o înaltă calitate a lectorilor invitați și a lucrărilor științifice și prin uriașul prestigiu științific al participanților.

Este important să menționăm că, prin acordarea acestui titlu, se dorește să se sublinieze colaborările academice și științifice semnificative dintre laboratoarele de la IUCN Dubna și catedrele de la Facultatea de Fizică a Universității din București în cei 60 de ani de existență a institutului, precum și faptul că unul dintre membrii fondatori ai IUCN Dubna a fost Catedra de Structura Materiei a Facultății de Fizică a UB, prin marea personalitate a acad. prof. univ. dr. Horia Hulubei, șeful catedrei la momentul respectiv.

Întreaga activitate științifică și administrativă a acad. Victor A. Matveev este caracterizată de o mare și profundă creativitate, de intuiție științifică permanent concentrată pe concepte fundamentale, simple, dar esențiale pentru înțelegerea fenomenelor și proceselor fizice. Contribuția sa fundamentală și profundă la dezvoltarea Fizicii Particulelor Elementare și a Fizicii Energiilor Înalte este legată de combinația unică dintre adânca înțelegere teoretică și remarcabila intuiție cu abilitățile experimentale.

Acordarea titlului de Doctor Honoris Causa al Universității din București domnului academician Victor A. Matveev reprezintă o recunoaștere simbolică a marilor sale merite științifice și un pas înainte în direcția creșterii colaborărilor științifice și educaționale dintre Universitatea din București, universitățile ruse și IUCN Dubna, dintre oamenii de știință din România și Rusia, precum și din România și din întreaga lume.

Prof.univ.dr. Ștefan Antohe

Laudatio

domino Victor A. Matveev

General Director of the Joint Institute for Nuclear Research Dubna, Russia

Academician Victor A. Matveev is one of the most prominent and remarkable personalities of the contemporary Physics, his activities having a substantial impact, through his prestigious results and major contributions, to the development of Elementary Particle Physics, High Energy Physics, Quantum Field Theory, both in the Russian Federation and in the world.

Academician Victor A. Matveev has obtained the title of Doctor in Physics (Candidate of Sciences) in 1967, at the Joint Institute of Nuclear Research Dubna. In 1972, he obtained the title of Doctor of Sciences (Doctor Docent) at the same institute.

In 1965, after graduation of the Faculty of Physics of the Leningrad State University he became, research scientist at the Joint Institute for Nuclear Research. After obtaining the title of doctor in Sciences (1972), acad. Victor A. Matveev was – in the period 1976–1977 – head of the group of the JINR physicists in Fermilab (Batavia, Illinois, USA), working in his areas of interest.

From 1978 Acad. Victor A. Matveev was elected deputy director of the Institute for Nuclear Research of the Academy of Sciences of the USSR, and, in 1987, he became Director of this institute (since 1992, The Russian Academy of Sciences).

In 1991 he was elected Corresponding member of the Academy of Sciences of USSR (since 1992, The Russian Academy of Sciences), and, since 1994, full member of the Russian Academy of Sciences. Between 2008 and 2014, acad. Victor A. Matveev was secretary of Physics Department of Russian Academy of Sciences.

Since 2011, acad. Victor A. Matveev is director of the Joint Institute for Nuclear Research Dubna.

It is essential to stress that the basic directions in the work of acad. Victor A. Matveev are related to the development of methods of quantum field theory in the relativistic quark models, the search for dynamical symmetries in High

Energy Physics applied to the interactions of elementary particles. From the beginning of his research activities and the start of his career at the Joint Institute of Nuclear Research Dubna, acad. Victor A. Matveev – in collaboration with B. Struminsky and A. Tavkhelidze – published several papers which evidenced a number of aspects with key roles in establishing the quark theory of hadrons. In a series of papers, acad. Victor A. Matveev in collaboration with R. Muradian and A. Tavkhelidze, formulated the automodelity principle in High Energy Physics. This allowed the development of the unified approach in the description of the phenomenon of scale-invariant behavior of deep-inelastic and inclusive processes at high energies. Acad. Victor A. Matveev has expressed the concept of hidden color in nuclei and has specified the principle importance of quark degrees of freedom for understanding the structure of nuclei at short distances. For his contribution to the development of the color quark theory and to the quark structure of hadrons and nuclei, acad. Victor A. Matveev has been awarded, together with his colleagues, with the Lenin's Prize in 1987.

Acad. Victor A. Matveev contributed significantly to the creation and development of many research infrastructure in the Institute of Nuclear Research of the Russian Academy of Sciences. We can mention here the high current and power accelerator and the experimental complex of Moscow meson factory, the neutrino telescopes, the Baksan neutrino observatory, the deep underground neutrino telescope on Baikal Lake, the experimental complex named as „Troitsk-nu-mass" etc. Under the leadership of acad. Victor A. Matveev, there were created the unique experimental facility of the world class – the pulsed neutron source which has been successfully put in operation in 1978.

The importance of the scientific contributions brought by acad. Victor A. Matveev to the hadron Physics and to the Standard Model of elementary particle interactions are related to the experimental search realized at the Tevatron (Fermilab, USA) and at the Large Hadron Collider (CERN, Switzerland). He is the chairman of the Collaboration board „Russia and Dubna member-states" in the experiment Compact Muon Solenoid at CERN (RDMS CMS).

As director of the Joint Institute for Nuclear Research, acad. Victor A. Matveev does great efforts to realize the mega-science project at JINR – the Nuclotron-based Ion Collider fAcility (NICA) – to search for rare fundamental processes held in extreme conditions in the micro-world, which will allow to understand the origin of Universe. Also, acad. Victor Matveev succeeded in transforming JINR in an open international scientific center for a wider cooperation with the national and international scientific centers, and the training of young generations of physicists and specialists.

Acad. Victor A. Matveev has been elected as foreign member of several National Academy of Sciences, e.g. the Bulgarian Academy of Sciences, the Georgian Academy of Sciences and others. He was also awarded the title of Doctor Honoris Causa of different universities in the member-states of JINR.

Acad. Victor A. Matveev has contributed significantly to the development and experimental testing of the Standard Model, as well as to other modern perspectives and theories in Particle Physics and High Energy Physics, meaningfully contributing to the success of this model in the description of the subnuclear structure.

The scientific activity of acad. Victor A. Matveev has been published in many prestigious Physics journals. Until now, acad. Victor A. Matveev published over 400 papers in ISI quoted journals, having thousands of citations. Therefore, acad. Victor A. Matveev is one of the most productive personalities in the Particle Physics, High Energy Physics and Quantum filed theory domains in the world.

Acad. Victor A. Matveev was, during his entire scientific career, an active participant in solving the problems of the scientific community. Therefore, he was elected in different positions in the international associations of physicists.

Over the years, acad. Victor A. Matveev collaborated in the frame of different experiments with Romanian physicists, including large experiments from JINR and CERN. These collaborations with Romanian physicists from the "Horia Hulubei" National Institute for Nuclear Physics and Engineering and the Faculty of Physics of the University of Bucharest resulted in a large number of papers, published in prestigious Physics journals.

Acad. Victor A. Matveev permanently sustained the Nuclear and Particle Physics research in Romania. As an important member of numerous international collaborations, as deputy director and general director of the Institute for Nuclear Research of the Academy of Sciences of the USSR, as well as general director of the JINR Dubna, acad. Victor A. Matveev permanently encouraged the presence of the Romanian physicists in these collaborations and institutes. Therefore, Romanian physicists, researchers and professors, visited, had work stages and presented seminars here. Over time, a number of PhD students worked and still work in the frame of different collaborations from these institutes. Acad. Victor A. Matveev and his groups have contributed actively, over the years, to the organization of summer schools and conferences in Nuclear and Particle Physics field, events characterized by the high quality of the invited lectures and works and by the scientific prestige of the participants.

The awarding of this title to acad. Victor A. Matveev is meant to underline the significant scientific and academic collaborations among the laboratories from

JINR Dubna and the chairs from the Faculty of Physics of the University of Bucharest in the 60 years of existence of the institute, as well as the fact that the Chair of the Structure of Matter from the Faculty of Physics of the University of Bucharest was a founding member of the JINR Dubna through the great personality of acad. PhD Prof. Horia Hulubei, head of the chair at that moment.

The entire scientific and administrative activity of academician Victor A. Matveev is characterized by a great and profound creativity, scientific intuition, permanently focus on fundamental – simple, but essential – concepts for understanding the physical phenomena and processes. His fundamental and profound contribution at the development of the Particle Physics and High Energy Physics is related to the unique combination of deeply theoretical understanding and remarkable intuition with experimental skills.

The awarding of the title of Doctor Honoris Causa of the University of Bucharest to the academician Victor A. Matveev represents a symbolic recognition of his great scientific merits and a step forward in the direction of increasing the scientific and teaching collaborations between the University of Bucharest, the Russian Universities and JINR Dubna, between scientists from Romania and Russia, as well as from Romania and from the entire world.

PhD Prof. Ștefan Antohe

Curriculum vitae

Victor A. Matveev

Date of birth: 11 December 1941

Place of birth: Taiga, Novosibirsk region, USSR

Nationality: Russian

Profession: Physicist

Affiliation: Joint Institute for Nuclear Research (JINR)

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Details of education:

1949–1959 Secondary School N28, Vladivostok, USSR, Russia

1959–1960 Student, Physics and Mathematics Faculty, Far East State University, Vladivostok

1960–1964 Student, Physics Faculty, Leningrad State University, Sankt-Petersburg

1964 Graduation Diploma, Physics Faculty, Leningrad State University, Sankt-Petersburg Professional appointments

1965 Starts his career at the Joint Institute for Nuclear Research, Dubna, Russia

1967 PhD, Candidate of Sciences (Physics and Mathematics) JINR, Dubna, Russia

1972 Dr. Sci., Doctor of Sciences (Physics and Mathematics)

JINR, Dubna, Russia

1976–1977 Head of group of JINR physicists in Fermilab (Batavia, IL, USA)

1978–1987 Deputy Director of the Institute for Nuclear Research of the Academy of Sciences of the USSR

1987–2014 Director of the Institute for Nuclear Research of the Academy of

Sciences of the USSR (since 1992, the Russian Academy of Sciences)

1991 Corresponding member of the Academy of Sciences of the USSR (since 1992, the Russian Academy of Sciences)

1994 Full member of the Russian Academy of Sciences,

1996 Member of Presidium of the Russian Academy of Sciences

2008–2014 Academician-secretary of Physics Department of the Russian Academy of Sciences

2008–2012 Member of the Scientific Council at the President of Russian Federation

Since 2011 Director of the Joint Institute for Nuclear Research (Dubna)

V. Matveev is a world well-known scientist in the field of elementary particle physics, theoretical and mathematical physics, and author of more than 400 scientific works.

The basic directions of the work of V. Matveev are the development of methods of quantum field theory in the relativistic quark models, the search for dynamical symmetries in high energy physics applied to the interactions of elementary particles.

Between 1965 and 1966, V. Matveev, in collaboration with B. Struminsky and Tavkhelidze, published papers that clarified the key roles in establishing the quark theory of hadrons. In the series of papers, V. Matveev, in collaboration with R. Muradian and A. Tavkhelidze, formulated the auto-modelity principle in high energy physics, model that allowed to develop the unified approach in the description of the phenomenon of scale-invariant behavior of deep-inelastic and inclusive processes at high energies.

V. Matveev has expressed the concept of hidden color in nuclei and has specified the principle importance of quark degrees of freedom for understanding the structure of nuclei at short distances. The contribution of V. Matveev and his colleagues to the development of the color quark theory, the quark structure of hadrons and nuclei has been awarded with the Lenin's prize in 1987.

V. Matveev has done a great contribution to the creation and development of research infrastructure in the Institute of Nuclear Research of the Russian Academy of Sciences – the high current and power accelerator and the experimental complex of Moscow meson factory, the neutrino telescopes, the Baksan neutrino observatory, the deep underground neutrino telescope on Baikal lake, the experimental complex named as «Troitsk-nu-mass». Under the leadership of V. Matveev there were created the unique experimental facility of world class – the pulsed neutron source which has been successfully put in operation in 1978.

The importance of the scientific contributions of V. Matveev to hadron physics and to the Standard Model of elementary particle interactions are related to the experimental search realized at the Tevatron (Fermilab, USA) and at the Large Hadron Collider (CERN, Switzerland). He is the chairman of the Collaboration board «Russia and Dubna member-states» in the experiment Compact Muon Solenoid at CERN (RDMS CMS).

Being the director of the Joint Institute for Nuclear Research, V. Matveev does great efforts to realize the mega-science project at JINR – the Nuclotron based Ion Collider fAcility (NICA) – to search for rare fundamental processes held at extreme conditions in the micro-world that will allow to understand more about the origin of the creation of the Universe. Acad. Victor Matveev succeeded in transforming JINR in an open international scientific center for a wider cooperation with the national and international scientific centers, and the training of young generations of physicists and specialists.

V. Matveev has been elected as foreign member of some National Academy of Sciences, in particular, the Bulgarian Academy of Sciences, the Georgian Academy of Sciences and others. He was also awarded the title of Doctor Honoris Causa of several universities in the member-states of JINR.

Publications

V. Matveev is the author of more than 400 scientific papers in the fields of quantum field theory, high energy particle physics, theoretical and mathematical physics.

Selected recent publications

2000

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Search for a Hypothetical 16.7 MeV Gauge Boson and Dark Photons in the NA64 Experiment at CERN

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(Received 12 March 2018; published 8 June 2018)

We report the first results on a direct search for a new 16.7 MeV boson (X) which could explain the anomalous excess of e^+e^- pairs observed in the excited ^{8}Be* nucleus decays. Because of its coupling to electrons, the X could be produced in the bremsstrahlung reaction $e^-Z \to e^-ZX$ by a 100 GeV e^- beam incident on an active target in the NA64 experiment at the CERN Super Proton Synchrotron and observed through the subsequent decay into a e^+e^- pair. With 5.4×10^{10} electrons on target, no evidence for such decays was found, allowing us to set first limits on the $X - e^-$ coupling in the range $1.3 \times 10^{-4} \lesssim \epsilon_e \lesssim 4.2 \times 10^{-4}$ excluding part of the allowed parameter space. We also set new bounds on the mixing strength of photons with dark photons (A') from nonobservation of the decay $A' \to e^+e^-$ of the bremsstrahlung A' with a mass $\lesssim$23 MeV.

DOI: 10.1103/PhysRevLett.120.231802

The ATOMKI experiment of Krasznahorkay *et al.* [1] has reported the observation of a 6.8σ excess of events in the invariant mass distributions of e^+e^- pairs produced in the nuclear transitions of excited ^{8}Be* to its ground state via internal pair creation. This anomaly can be interpreted as the emission of a new protophobic gauge X boson with a mass of 16.7 MeV followed by its $X \to e^+e^-$ decay assuming that the X has nonuniversal coupling to quarks, coupling to electrons in the range $2 \times 10^{-4} \lesssim \epsilon_e \lesssim 1.4 \times 10^{-3}$ and the lifetime $10^{-14} \lesssim \tau_X \lesssim 10^{-12}$ s [2,3]. It has motivated worldwide theoretical and experimental efforts towards light and weakly coupled vector bosons; see, e.g., Refs. [4–12].

Another strong motivation in the search for a new light boson decaying into an e^+e^- pair is provided by the dark matter puzzle. An intriguing possibility is that in addition to gravity a new effective force between the dark sector and visible matter, transmitted by a new vector boson A' (dark photon) might exist [13,14]. Such A' could have a mass $m_{A'} \lesssim 1$ GeV, associated with a spontaneously broken gauged $U(1)_D$ symmetry, and would couple to the standard model through kinetic mixing with the ordinary photon, $-\frac{1}{2}\epsilon F_{\mu\nu}A'^{\mu\nu}$, parametrized by the mixing strength $\epsilon \ll 1$ [15–17]. For a review see, e.g., Refs. [4,18,19]. A number of previous beam dump [20–34], fixed target [35–37], collider [38–40], and rare particle decay [41–53] experiments have already put stringent constraints on the mass $m_{A'}$ and ϵ of such dark photons excluding, in particular, the parameter space region favored by the $g_\mu - 2$ anomaly. However, the range of mixing strengths $10^{-4} \lesssim \epsilon \lesssim 10^{-3}$ corresponding to a short-lived A' still remains unexplored. In this Letter we report the first results from the NA64 experiment specifically designed for a direct search of the e^+e^- decays of new short-lived particles in the sub-GeV mass range at the CERN Super Proton Synchrotron (SPS) [54–57].

The method of the search for $A' \to e^+e^-$ decays is described in Refs. [54,55]. Its application to the case of the $X \to e^+e^-$ decay is straightforward. Briefly, a high-energy electron beam is sent into an electromagnetic (e.m.) calorimeter that serves as an active beam dump. Typically the beam electron loses all its shower energy in the dump. If the A' exists, due to the $A'(X) - e^-$ coupling it would occasionally be produced by a shower electron (or positron) in its scattering off a nuclei of the dump:

$$e^- + Z \to e^- + Z + A'(X); \qquad A'(X) \to e^+e^-. \quad (1)$$

Since the A' is penetrating and longer lived, it would escape the beam dump, and subsequently decays into an e^+e^- pair in a downstream set of detectors. The pair energy would be equal to the energy missing from the dump. The apparatus is designed to identify and measure the energy of the e^+e^- pair in another calorimeter (ECAL). Thus, the signature of the $A'(X) \to e^+e^-$ decay is an event with two e.m.-like showers in the detector: one shower in the dump, and another one in the ECAL with the sum energy equal to the beam energy.

The NA64 setup is schematically shown in Fig. 1. The experiment employs the optimized 100 GeV electron beam from the H4 beam line in the North Area (NA) of the CERN SPS. Two scintillation counters, $S1$ and $S2$, were used for the beam definition, while the other two, $S3$ and $S4$, were used to detect the e^+e^- pairs. The detector was equipped with two dipole magnets and a tracker, which was a set of four upstream Micromegas (MM) chambers ($T1$, $T2$) for the incoming e^- angle selection and two sets of downstream MM, gas electron multiplier (GEM) stations, and scintillator hodoscopes ($T3$, $T4$) for measurements of the outgoing tracks [58,59]. To enhance the electron identification, the synchrotron radiation (SR) emitted by electrons was used for their tagging allowing us to suppress the initial hadron contamination in the beam $\pi/e^- \simeq 10^{-2}$ down to the level $\simeq 10^{-6}$ [57,60]. The use of SR detectors (SRD) was a key point for the improvement of the sensitivity compared to the previous electron beam dump searches [24,25]. The dump was a compact e.m. calorimeter WCAL made as short as possible to maximize the sensitivity to short lifetimes while keeping the leakage of particles at a small level. It was followed by the ECAL to measure the energy of the decay e^+e^- pair, which was a matrix of 6×6 shashlik-type modules [57]. The ECAL has $\simeq$40 radiation lengths (X_0) and is located at a distance $\simeq$3.5 m from the WCAL. Downstream of the ECAL the detector was equipped with a high-efficiency veto counter, $V3$, and a hermetic hadron calorimeter (HCAL) [57] used as a hadron veto and for muon identification with a help of four muon counters, MU1–MU4, located between the HCAL modules. The results reported here were obtained from data samples in which 2.4×10^{10} electrons on target (EOT) and 3×10^{10} EOT were collected with the WCAL of 40 X_0 (with a length of 290 mm) and of 30 X_0 (220 mm), respectively. The events were collected with a hardware trigger requiring in-time energy deposition in the WCAL and $E_{\mathrm{WCAL}} \lesssim 70$ GeV. Data of these two runs (hereafter called the 40 X_0 and 30 X_0 run) were analyzed with similar

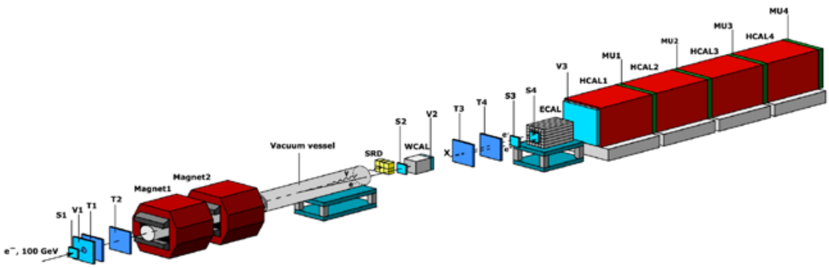

FIG. 1. Schematic illustration of the NA64 setup to search for the A', $X \to e^+e^-$ decays.

selection criteria and finally summed up, taking into account the corresponding normalization factors. For the mass range $1 \leq m_{A'} \leq 25$ MeV and energy $E_{A'} \gtrsim 20$ GeV, the opening angle $\Theta_{e^+e^-} \simeq 2m_{A'}/E_{A'} \lesssim 2$ mrad of the decay e^+e^- pair is too small to be resolved in the tracker $T3$-$T4$, and the pairs are mostly detected as a single-track e.m. shower in the ECAL.

The candidate events were selected with the following criteria chosen to maximize the signal acceptance and minimize background, using both GEANT4[61,62] based simulations and data. (i) There should be only one track entering the dump. No cuts on reconstructed outgoing tracks were used. (ii) No energy deposition in the $V2$ counter exceeding about half of the energy deposited by the minimum ionizing particle (MIP). (iii) The signal in the decay counter $S4$ is consistent with two MIPs. (iv) The sum of energies deposited in the WCAL and ECAL, $E_{\rm tot} = E_{\rm WCAL} + E_{\rm ECAL}$, is equal to the beam energy within the energy resolution of these detectors. According to simulations, at least 30% of the total energy should be deposited in the ECAL [63,64]. (v) The showers in the WCAL and ECAL should start to develop within a few first X_0. (vi) The lateral and longitudinal shape of the shower in the ECAL are consistent with a single e.m. one. However, for A's with the energy $\lesssim 5$ GeV, the ECAL shower is poorly described by the single shower shape; hence, the additional cut $E_{\rm ECAL} > 5$ GeV was applied. (vii) No significant energy deposited in the $V3$ and/or HCAL. These cuts were used for rejection of events with hadrons in the final state. As in the previous analyses [56,57], a clean sample of $\simeq 10^5$ rare $\mu^+\mu^-$ events produced in the dump was used for the efficiency corrections in the simulations, which do not exceed 20%. A blind analysis of data was performed, with the signal box defined as $90 < E_{\rm tot} < 110$ GeV and by using 20% (100%) of the data for the selection criteria optimization (background estimate).

There are several processes that can fake the $A' \to e^+e^-$ signal. Among them, the two most important were expected either from decay chain $K^0_S \to \pi^0\pi^0$; $\pi^0 \to \gamma e^+e^-$ of K^0_S produced in the WCAL or from the $\gamma \to e^+e^-$ conversion of photons from $K^0_S \to \pi^0\pi^0 \to \pi^0 \to \gamma\gamma$ decays in the $T3$ plane or earlier in the beam line. Another background could come from the $K^0_S \to \pi^+\pi^-$ hadronic decays that could be misidentified as an e.m. event in the ECAL at the level $\lesssim 2.5 \times 10^{-5}$ evaluated from the measurements with the pion beam. The leading K^0 can be produced in the dump either by misidentified beam π^-, K^- or directly by electrons. The background from the K^0_S decay chain was estimated by using the direct measurements of the K^0_S flux from the dump with the following method. It is well known that the K^0 produced in hadronic reactions is a linear combination of the short- and long-lived components $|K^0\rangle = (|K^0_S\rangle + |K^0_L\rangle)/\sqrt{2}$. The flux of K^0 was evaluated from the measured ECAL + HCAL energy spectrum of long-lived neutral hadrons selected with the requirement of no signal in $V2$ and $S4$, taking into account corrections due to the K^0_S decays in flight. The main fraction of $\simeq 10^3$ events observed in the HCAL were neutrons produced in the same processes as K^0 in the WCAL. According to simulations, $\lesssim 10\%$ of them were predicted to be other neutral hadrons, i.e., Λ and K^0, that were also included in the data sample. The conservative assumption that $\simeq 100$ K^0 were produced allows us to calculate the number of K^0_S from the dump and simulate the corresponding background from the $K^0_S \to \pi^+\pi^-$ and $K^0_S \to \pi^0\pi^0$; $\pi^0 \to \gamma e^+e^-$ decay chain, which was found to be $\lesssim 0.04$ events per 5.4×10^{10} EOT. To cross-check this result, another estimate of this background was used. The true neutral e.m. events, which are presumably photons, were selected with requirements of no charged tracks, i.e., no signals in $V2$ and $S4$ counters, plus a single e.m.-like shower in the ECAL defined by cuts (v)–(vii). Three such events were found in the signal box as shown in Fig. 2. Using simulations we calculated that there were $\simeq 150$ leading K^0 produced in the dump, which is in reasonable agreement with the previous estimate resulting in a conservative K^0_S background of 0.06 events. The μ, π, and K mistakenly tagged as e^-'s [60] could also interact in the dump though the $\mu Z \to \mu Z \gamma$ or π, K charge-exchange reactions, accompanied by the poorly detected scattered μ, or secondary hadrons. The misidentified pion could mimic the signal either directly (small fraction of showers that look like an e.m. one) or by emitting a hard bremsstrahlung photon in the last layer of the dump, which then produces an e.m. shower in the ECAL, accompanied by the scattered pion track. Another background can appear from the beam $\pi \to e\nu$ decays downstream of the WCAL. The latter two backgrounds can pass the selection only due to the $V2$ inefficiency ($\simeq 10^{-4}$), which makes them negligible. The charge-exchange reaction $\pi^- p \to (\geq 1)\pi^0 + n + \cdots$, which can occur in the last layers of the WCAL with

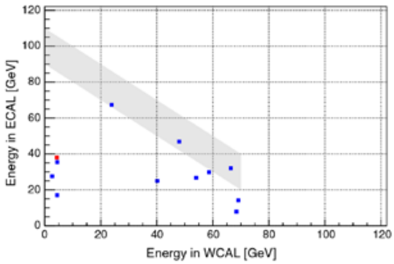

FIG. 2. Distribution of selected e.m. neutral (presumably photon) and signal events in the ($E_{\rm WCAL}$; $E_{\rm ECAL}$) plane from the combined 30 X_0 and 40 X_0 runs. Neutral e.m. events are shown as blue squares. The only signal-like event is shown as a red square. The dashed band represents the signal box.

TABLE I. Expected numbers of background events in the signal box estimated for 5.4×10^{10} EOT.

Source of background	Events
e^+e^- pair production by punchthrough γ	< 0.001
$K_S^0 \to 2\pi^0$; $\pi^0 \to \gamma e^+e^-$; $\gamma \to e^+e^-$; $K_S^0 \to \pi^+\pi^-$	0.06 ± 0.034
$\pi N \to (\geq 1)\pi^0 + n + \cdots$; $\pi^0 \to \gamma e^+e^-$; $\gamma \to e^+e^-$	0.01 ± 0.004
π^- bremsstrahlung in the WCAL, $\gamma \to e^+e^-$	< 0.0001
$\pi, K \to e\nu$, K_{e4} decays	< 0.001
$eZ \to eZ\mu^+\mu^-$; $\mu^\pm \to e^\pm \nu\nu$	< 0.001
Punchthrough π	< 0.003
Total	0.07 ± 0.035

decay photons escaping the dump without interactions and accompanied by poorly detected secondaries, is another source of fake signal. To evaluate this background we used the extrapolation of the charge-exchange cross sections, $\sigma \sim Z^{2/3}$, measured on different nuclei [65]. The contribution from the beam kaon decays in flight, $K^- \to e^-\nu\pi^+\pi^-(K_{e4})$, and dimuon production in the dump $e^-Z \to e^-Z\mu^+\mu^-$ with either $\pi^+\pi^-$ or $\mu^+\mu^-$ pairs misidentified as e.m. event in the ECAL was found to be negligible.

Table I summarizes the conservatively estimated background inside the signal box, which is expected to be 0.07 ± 0.034 events per 5.4×10^{10} EOT. The dominant contribution to background is 0.06 events from the K_S^0 decays, with the uncertainty dominated by the statistical error. In Fig. 2, the final distributions of e.m. neutral events, which are presumably photons, and signal candidate events that passed the selection criteria (i)–(iii) and (v)–(vii) are shown in the ($E_{\rm ECAL}$; $E_{\rm WCAL}$) plane. No candidates are found in the signal box. The conclusion that the background is small is confirmed by the data.

The combined 90% confidence level (C.L.) upper limits for the mixing strength ϵ were obtained from the corresponding limit for the expected number of signal events, $N_{A'}^{90\%}$, by using the modified frequentist approach, taking the profile likelihood as a test statistic [66–68]. The $N_{A'}$ value is given by the sum

$$N_{A'} = \sum_{i=1}^{2} N_{A'}^{i} = \sum_{i=1}^{2} n_{\rm EOT}^{i} \epsilon_{\rm tot}^{i} n_{A'}^{i}(\epsilon, m_{A'}), \qquad (2)$$

where $\epsilon_{\rm tot}^{i}$ is the signal efficiency in the run i (30 X_0 or 40 X_0), and $n_{A'}^{i}(\epsilon, m_{A'})$ is the number of the $A' \to e^+e^-$ decays in the decay volume with energy $E_{A'} > 30$ GeV per EOT, calculated under the assumption that this decay mode is predominant; see, e.g., Eq. (3.7) in Ref. [55]. Each ith entry in this sum was calculated by simulating signal events for the corresponding beam running conditions and processing them through the reconstruction program with the same selection criteria and efficiency corrections as for the data sample from the run i. The A' efficiency and its systematic error were determined to stem from the overall normalization, A' yield, and decay probability, which were the A' mass dependent, and also from efficiencies and their uncertainties in the primary $e^-(0.85 \pm 0.02)$, WCAL(0.93 ± 0.05), $V_2(0.96 \pm 0.03)$, ECAL(0.93 ± 0.05), $V_3(0.95 \pm 0.04)$, and HCAL(0.98 ± 0.02) event detection. The latter, shown as example values for the 40 X_0 run, were determined from measurements with the e^- beam cross-checked with simulations. A detailed simulation of the e.m. shower in the dump [63] with A' cross sections was used to calculate the A' yield [64,69,70]. The $\lesssim 10\%$ difference between the calculations in Ref. [64] and Refs. [69,70] was accounted for as a systematic uncertainty in $n_{A'}(\epsilon, m_{A'})$. In the overall signal efficiency for each run, the acceptance loss due to pileup ($\simeq 7\%$ for 40 X_0 and $\simeq 10\%$ for 30 X_0 runs) was taken into account and cross-checked using reconstructed dimuon events [57]. The dimuon efficiency corrections ($\lesssim 20\%$) were obtained with uncertainty of 10% and 15%, for the 40 X_0 and 30 X_0 runs, respectively. The total systematic uncertainty on $N_{A'}$ calculated by adding all errors in quadrature did not exceed 25% for both runs. The combined 90% C.L. exclusion limits on the mixing ϵ as a function of the A' mass is shown in Fig. 3 together with the current constraints from other experiments. Our results exclude the X boson as an explanation for the ^{8}Be anomaly for the $X - e^-$ coupling $\epsilon_e \lesssim 4.2 \times 10^{-4}$ and mass value of

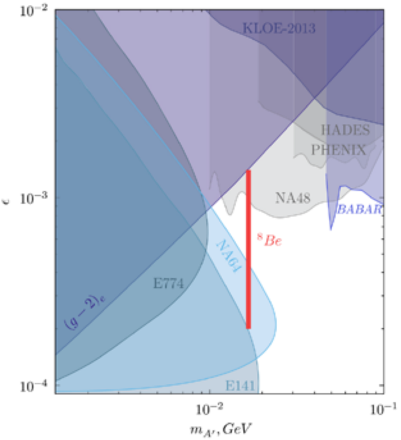

FIG. 3. The 90% C.L. exclusion areas in the $(m_X; \epsilon)$ plane from the NA64 experiment (blue area). For the mass of 16.7 MeV, the $X - e^-$ coupling region excluded by NA64 is $1.3 \times 10^{-4} < \epsilon_e < 4.2 \times 10^{-4}$. The allowed range of ϵ_e explaining the ^{8}Be anomaly (red area) [2,3], constraints on the mixing ϵ from the experiments E141 [22], E774 [25], *BABAR* [40], KLOE [45], HADES [47], PHENIX [48], NA48 [50], and bounds from the electron anomalous magnetic moment $(g-2)_e$ [71] are also shown.

16.7 MeV, leaving the still unexplored region $4.2 \times 10^{-4} \lesssim \epsilon_e \lesssim 1.4 \times 10^{-3}$ as quite an exciting prospect for further searches.

We gratefully acknowledge the support of the CERN management and staff and the technical staffs of the participating institutions for their vital contributions. We also thank Attila Krasznahorkay for useful discussions about the ATOMKI experiment, and Christophe Menezes Pires and Ondrej Subrt for their help. This work was supported by the HISKP, University of Bonn (Germany), JINR (Dubna), MON and RAS (Russia), SNSF Grant No. 169133 and ETHZ (Switzerland), and Grants FONDECYT No. 1140471 and No. 1150792, Ring ACT1406 and Basal FB0821 CONICYT (Chile). Part of the work on simulations was supported by the RSF Grant No. 14-12-01430.

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Tipărit la Editura Universității din București

2018

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