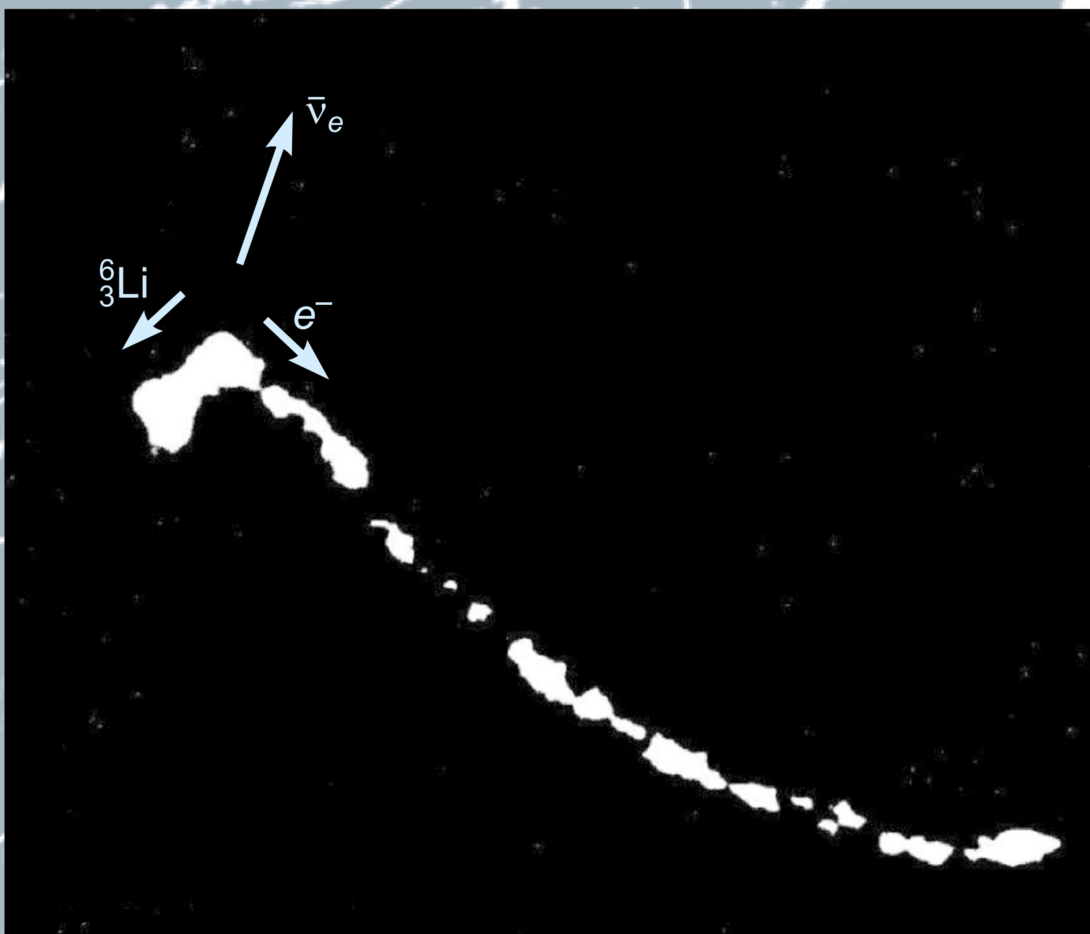
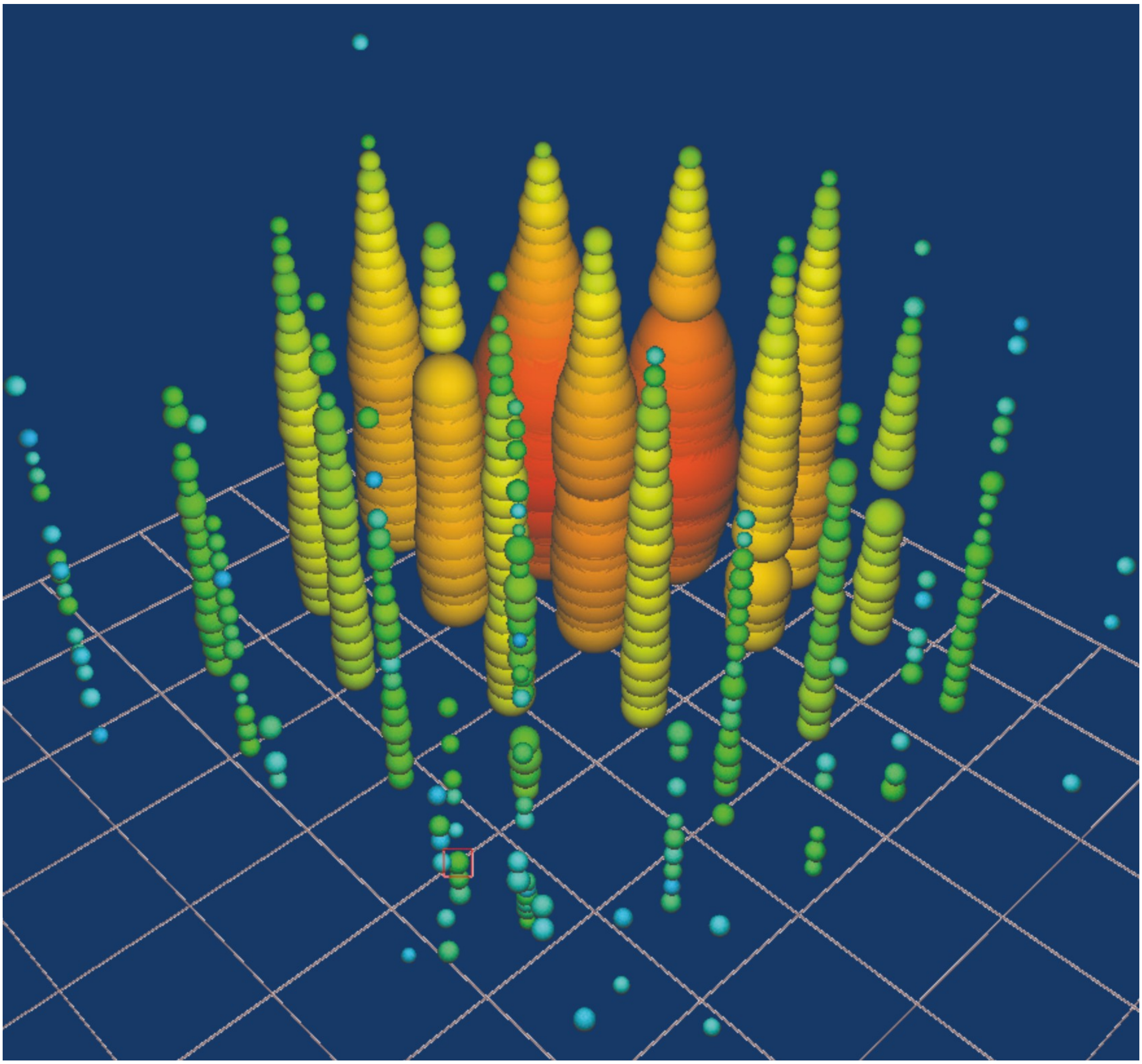
fizikai szemle

HUNGARIAN PHYSICAL REVIEW



2022 KÜLÖNSZÁM
SPECIAL ISSUE

First neutral current event (CERN, 1973)



Observation of Glashow-event (Icecube, 2021)

Editor-in-Chief's Preface to the Special Issue

Fizikai Szemle (*Hungarian Physical Review*) is the Hungarian-language monthly periodical of the Hungarian Physical Society. It was the idea of *András Patkós,* Honorary President of the Hungarian Physical Society, to commemorate the Neutrino '72 conference, held in Balatonfüred, Hungary 50 years ago and *George Marx,* the initiator and main organizer of that conference, who would have been 95 years old this year, with this special issue in English. It was also A. Patkós who invited the authors, most of whom were participants in the 1972 conference, to write about what that conference meant to their scientific careers and he organized and edited this special issue. Neutrino '72 launched the Neutrino Physics and Astrophysics Conference Series, the 30^{th} conference of which will be held in Seoul, Korea, from 30 May to 4 June 2022, almost exactly 50 years after the first conference in Hungary. The Hungarian Physical Society and the *Hungarian Physical Review* greet the participants of the Seoul Conference with this commemorative special issue.

The authors of the papers in this special issue are much more competent than I am to describe the scientific significance of Neutrino '72. Thus, I would like to point out here only the extraordinary achievement of the conference organizer, George Marx, that within 4 months after the idea of the conference was born, the meeting started in Balatonfüred with participants such as *R. Feynman, T. D. Lee, R. Marshak, V. Weisskopf, B. Pontecorvo, V. Telegdi, F. Reines, C. Cowan, R. Davis, J. Bahcall, B. Barish, D. Cline, C. Baltay* and many others. So among the participants of the conference were two Nobel laureates (Feynman and Lee), Reines, Davis and more recently Barish won the Nobel Prize later. All this happened in 1972, when of course there was no internet, no e-mail and in Hungary at that time even direct international telephone connection was not available. (20 or so academics in the Department of Prof. Marx had perhaps two city telephone lines, and if they wanted to call abroad they had to call the international exchange and ask to be connected, and it took typically an hour or more till the connection was established). There was, however, a wide, high and strong iron curtain, which made the organization even more difficult, but which might have made attending the conference more exotically attractive to Western researchers, and certainly the famous Lake Balaton was attractive too, and of course the international prominence of George Marx and his colleagues also played an important role in the success of the meeting. In the seventies of the last century, taking advantage of the relative easing of the political restrictions in Hungary at that time, some other distinguished Hungarian physicists also successfully organized international conferences in order to broaden the connections with the international research community. As examples *Alfred Zawadowski's* conference on the electronic properties of dilute alloys can be mentioned with *P. W. Anderson,* or *Peter Szépfalusy's* conference on statistical physics with *Ken Wilson* among the participants.

Further, there are also two articles on Marx's work in this collection, one about him as educator and one as active supporter of the responsible use of nuclear energy, written by two physics professors, who – like all Hungarian contributors to this issue – were also students and later coworkers of George Marx. I should note that Marx was also the editor-in-chief of this journal, the *Hungarian Physical Review,* from January 1958 until his death in December 2002.

With this special issue, on the occasion of the 50^{th} anniversary of the Neutrino Conference Series and the 95^{th} anniversary of its initiator, George Marx, I wish on behalf of the Hungarian Physical Society and of *Fizikai Szemle* all participants of the Seoul conference successful work and the continuation of the conference series at least until the 100^{th} anniversary!

Lendvai János
Editor-in Chief of Fizikai Szemle

Fizikai Szemle

MAGYAR FIZIKAI FOLYÓIRAT

A Mathematikai és Természettudományi Értesítőt az Akadémia 1882-ben indította
A Mathematikai és Physikai Lapokat Eötvös Loránd 1891-ben alapította

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On the Front Cover:
Observation of neutrino recoil in beta-decay by Sándor Szalay and Julius Csikai (ATOMKI, Hungary, 1956)

On the Back Cover:
Neutrino detectors on covers of previous issues of Hungarian Physical Review

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Fizikai Szemle
HUNGARIAN PHYSICAL REVIEW
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INTERNATIONAL CONFERENCE ON NEUTRINO PHYSICS AND ASTROPHYSICS 1972–2022

Stephen Parke

Neutrino '72 had two exceptional aspects: first, it was the dawn of the Glashow–Weinberg–Salam era where neutrino physics was of paramount importance for the discovery of a new weak force of Nature, mediated by the Z_0 boson, and unified the weak and electromagnetic interactions. This lead to the SU(3)×SU(2)×U(1) gauge theory of the Standard Model, a monumental step in our understanding of Strong, Weak and Electromagnetic Interactions. Second, this conference launched what is now the International Conference on Neutrino Physics and Astrophysics Series, a conference dedicated to the Neutrino.

Participants of Neutrino '72 conference. In the front row: T. D. Lee, G. L. Radicati, R. P. Feynman, B. Pontecorvo, G. Marx, V. F. Weisskopf, F. Reines, C. L. Cowan and P. Budini

In June of 2022, the 50th anniversary of Neutrino '72, thirty such Neutrino Conferences will have been held in locations in Europe, North America and Asia/Oceania. *George Marx,* as founder of this series, presided over the first twenty of these meetings. Many important results in neutrino physics have been reported at one of these conferences. *Ray Davis* and *John Bahcall* frequently reported on the updated measurements and calculations, respectively, of the solar neutrino flux puzzle. Other examples are the definitive discovery of neutrino oscillations by Super-KamiokaNDE at the 18th conference in 1998 and the SNO results on solar neutrinos fluxes at the 20th conference in 2002. These discoveries were honored with the 2015 Nobel prize.

There have been many other important results reported over the years, too numerous to list here. At the last in-person meeting of this conference series there were more than 800 registered participants. An astonishing number given that this is a plenary only conference in an age of parallel conferences. The covid pandemic disrupted Neutrino 2020 so that it was a purely online meeting with even a much larger number of online participants. The 50th anniversary meeting, Neutrino 2022 to be held in Seoul, South Korea, could be an in-person, hybrid or purely online. Neutrino 2030 will celebrate the 100th anniversary of Wolfgang Pauli's hypothesis that there exists a light neutral lepton, the neutrino. The International Conference on Neutrino Physics and Astrophysics Series launched and nurtured by George Marx has become the premier international neutrino conference where diversity, inclusiveness and transparency are recognized as of essential importance for great discoveries.

To end, I quote *Isaac Asimov* from his popular book titled, The Neutrino (1966), "And yet the nothing particle is not a nothing at all," yet in 1966 only a very, very tiny piece of the neutrino puzzle was known. There is still much more for all of us to discover about the neutrino's nature and its role in shaping the Universe.

Thank you, George.

Stephen Parke, Distinguished Scientist at the Theoretical Physics Department of Fermi National Laboratory, Batavia, USA; Chair of the International Neutrino Committee

HOW THE IDEA OF NEUTRINO CONFERENCES CAME ABOUT

Herbert Pietschmann

1997: Herbert Pietschmann and Jan Nilsson at the Hungarian Academy of Sciences celebrating 70th birthday of George Marx (photo by E. Hámori)

When the proton accelerators in Brookhaven and CERN came to life around 1960, the overwhelming number of new elementary particles was a great surprise for physics. All of them were hadrons; thus it is only natural that the great conferences on elementary particles were almost entirely directed towards hadron physics, i.e. strong interactions. Electromagnetic and particularly weak interactions and neutrinos were often neglected at the big conferences.

Naturally, this was not acceptable for the then rather small community of physicists interested in these subdued fields. Among them was *George Marx* in Budapest, *Jan Nilsson* in Göteborg and myself in Vienna. In 1968, the "Triangle Collaboration" between Vienna, Bratislava and Budapest was established, but it did not reach far beyond the named cities. In 1972, a triangle meeting was held in Budapest February 10–12.

For George Marx it was quite obvious that the neglect of neutrino physics at the big international conferences had to be neutralized by a dedicated international conference on neutrino physics. Instead of pushing some international committee, he took the idea in his own hands and organized a neutrino conference in Hungary by himself. At that time, nobody could guess that it should soon become a regular worldwide accepted series of neutrino conferences.

The first Neutrino conference took place in Balatonfüred beginning Sunday June 11, 1972. At that time I was Austrian delegate to the CERN council and I had to go to Geneva to participate at the council meeting June 15/16. Before I left, on Tuesday, June 13., I gave a talk on "Second class currents in weak interactions." But very unfortunately I had to miss the highlight of the conference: The planting of a tree by *Feynman* and *Pontecorvo* on Thursday, June 15th.

The success of the Neutrino conference led Jan Nilsson and myself to complement it by a workshop, originally restricted to 50 participants. (Actual work on publications was attempted at these occasions.) The first "workshop on weak interactions and neutrinos" (WIN) took place 1972 in Skövde, Sweden, the second 1973 at lake Wolfgang in Austria. Since 1983, the big Neutrino conference and the small WIN workshop alternate, the conference in even years, the workshop in odd years.

Today, the International Neutrino Committee takes care of both conference and workshop. Meanwhile both of them have been held in many continents. In the time of the Standard Model, neutrino physics will probably play an ever increasing importance for our understanding of matter.

Herbert Pietschmann, Professor Emeritus at the Institut für Theoretische Physik of University of Vienna, Austria; member of the International Neutrino Committee

REREADING THE PROCEEDINGS OF NEUTRINO ’72

András Patkós

In 1972, a triangle meeting of particle physicists of Vienna, Bratislava and Budapest was held in Budapest February 10–12. It gave the opportunity for *Herbert Pietschmann* (Vienna), *Jan Nilsson* (Göteborg) and *George Marx* (Budapest) to discuss the subdued situation of the physics of electromagnetic and weak interactions at big international conferences of that epoch.

H. Pietschmann [1]: “For George Marx it was quite obvious that the neglect of neutrino physics at the big international conferences had to be neutralized by a dedicated international conference on neutrino physics. Instead of pushing some international committee, he took the idea in his own hands and organized a Europhysics neutrino conference in Hungary by himself. At that time, nobody could guess that it should soon become a regular worldwide accepted series of neutrino conferences.”

The first Neutrino conference took place in Balatonfüred, Hungary beginning Sunday June 11, 1972 and ending on 17th of June. One might just wonder how the organizers were able to arrange successfully the invitation of so many first class speakers and a bunch of enthusiastic young physicists on such short notice from both sides of the iron curtain. As *Lalit M. Sehgal* (Aachen) recalls [2]: “The Neutrino ’72 Conference was the very first conference I attended and turned out to be an important event in my scientific life. There was a whole galaxy of famous people there – *R. Feynman, T. D. Lee, R. Marshak, V. Weisskopf, B. Pontecorvo, V. Telegdi, F. Reines, C. Cowan, R. Davis, J. Bahcall, B. Barish, D. Cline, C. Baltay* and many others.” G. Marx, one of the first proposers of lepton charge conservation and a pioneer of neutrino astrophysics had very good contacts with leading personalities like *B. Zeldovich* and *S. Weinberg* (both having figured in the organizing committee of this conference). He has quickly convinced groups working on the detection of the solar neutrinos also to attend. It was an important development for the future of this conference that traditional subjects of neutrino physics (nature of lepton charge(s), neutrinoless double beta decay etc.) were complemented by talks representing the dramatic evolution of the field of lepton-nucleon scattering. A young disciple of G. Marx, *J. Kuti* has produced these years remarkable contributions with V. Weisskopf to the theoretical interpretation of the SLAC-MIT deeply inelastic electron-nucleon scattering experiment. During his post-doctoral position with MIT he has established contacts with R. Feynman and T. D. Lee, and could along with them attract several important US-physicists to this conference, where the use of high energy neutrino beams for the exploration of subnuclear structure has been discussed systematically for a first time.

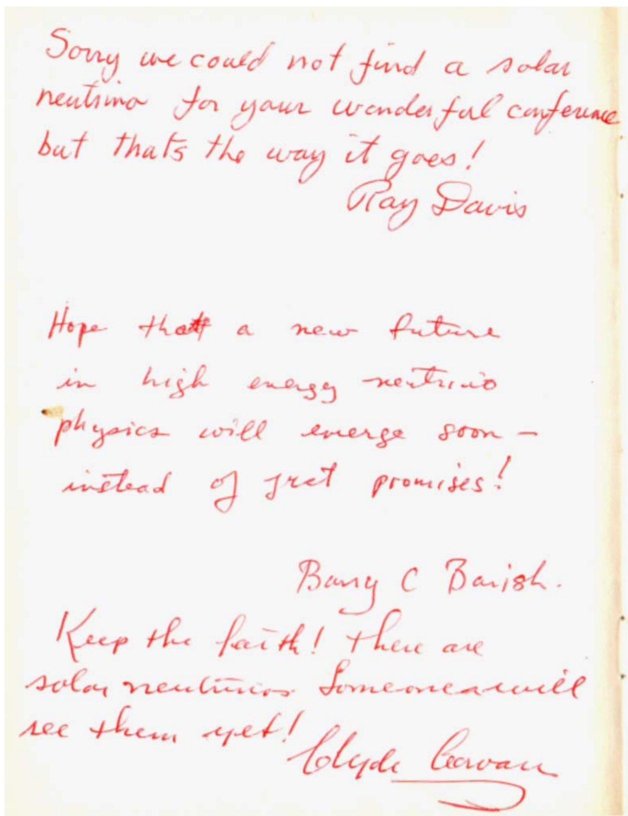
The Proceedings of the Conference, edited by George Marx with the indefatigable support of *Andor Frenkel,* has served for years as indispensable guide into state of art neutrino related research.

In the first half of the conference the report of the Brookhaven solar neutrino measurement stirred the most intensive discussions. Raymond Davis (NP 2002) has announced [3] that the average event rate of the reaction

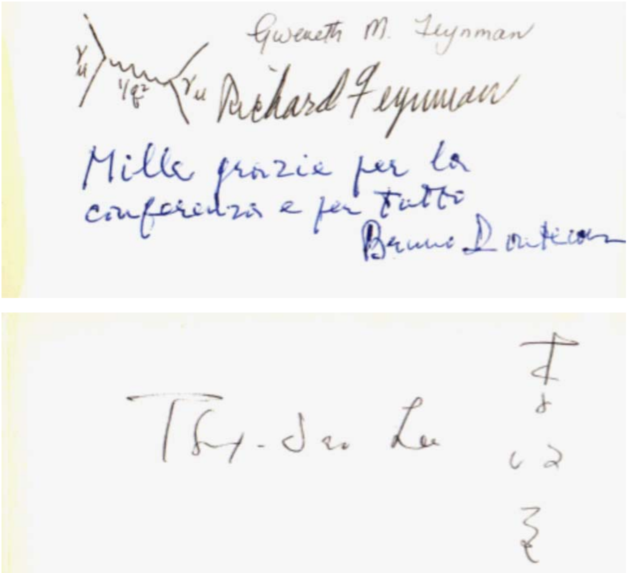
$$\nu_e + {}^{37}\mathrm{Cl} \rightarrow {}^{37}\mathrm{Ar} + e^- \qquad (1)$$

observed between 1967 and 1972 was less than 10^{-36} sec^{-1}(^{37}Cl atom)$^{-1}$ ≡ 1 SNU, which was much less than the expected 5–8 SNU arising from the cal-

From the guestbook of ν ’72: R. Davis, B. Barish and C. Cowan



András Patkós, Professor Emeritus at the Institute of Physics of Eötvös Loránd University, Budapest, Hungary; Honorary President of Roland Eötvös Physical Society.



From the guestbook of ν '72: R. P. Feynman, B. Pontecorvo and T. D. Lee

culations based upon the standard Sun-model as presented by John Bahcall [4].

In his summary talk Bruno Pontecorvo [5] took a rather conservative standpoint when confronting the Sun-model calculation with the result from the Homestake experiment: "the conclusion by Davis is that the Sun emits much less ^{8}B neutrinos than expected." Then he has asked: "Is the discrepancy serious enough to force us to draw revolutionary conclusions about the Sun or about the neutrino properties? My opinion is: no." Since the ^{8}B neutrinos to which the reaction was dominantly sensitive represent a tiny part of the whole emission "the reactions leading to this emission are quite unimportant from the point of view of the structure of the Sun." Related to this reaction new parameters might be needed but irrespective to this "the Sun will nevertheless shine as before".

For the immediate future Pontecorvo has expected Davis either detect solar neutrinos with his improved counter or reach the sensitivity limit of his apparatus (0.5 SNU). In order to be forced for radical alternatives the non-detection of the *pep* neutrinos should be established (expected rate ~0.3 SNU). His advice sounded: New detectors capable to observe *pep* neutrinos should be developed in the first place. Only if all these efforts would fail one could look for what Pontecorvo called "exotic" solutions. A few of them were presented in the sessions: pulsating Sun activity (*Lande* et al. [6]), decaying neutrinos (Bahcall et al [7]), $\nu_e \leftrightarrow \nu_\mu$ neutrino oscillation (*Gribov* & Pontecorvo [8]). Here he has made two remarkable notes: a) neutrino oscillations represent a method for measuring neutrino mass differences "several million times more sensitive than the ordinary ones for neutrino mass measurements"; b) "only with very sophisticated and remote experiments can the 'decrease factor' become larger than 2."

These remarks set out the strategic directions of neutrino physics for the last third of the 20th century. It took about 25 years until the problem of missing neutrino flux has been clarified. The conclusive paper of the Davis group was published in 1998, the same year when the phenomenon of neutrino oscillation has been firmly established with help of atmospheric neutrinos at Super Kamiokande.

The second half of the conference has dealt with weak and electromagnetic interactions as useful tools in exploration of the subnuclear structure of the proton and neutron. The starting point was the well established scaling behavior of the form factors characterizing deep inelastic electron-proton scattering. Assuming the same phenomenon to occur in deep inelastic neutrino-nucleon scattering leads for the relevant total cross sections to

$$\sigma_T^{\nu/\bar\nu}(E) = \frac{G^2 M E}{\pi} \int_1^\infty \mathrm{d}\omega \, \frac{1}{2\,\omega^2} \left(\frac{1}{6\,\omega} f_1^{\nu/\bar\nu}(\omega) + \frac{1}{2} f_2^{\nu/\bar\nu}(\omega) \mp \frac{2}{3\,\omega} f_3^{\nu/\bar\nu}(\omega) \right) \equiv \frac{G^2 M E}{\pi} Z^{\nu/\bar\nu} \qquad (2)$$

where ω is the scaling variable defined as the ratio of the energy-loss of the neutrino multiplied by the mass of the nucleon and the squared momentum transfer transmitted to the nucleon, and f_i are the scaling functions of the three independent form factors characterizing the process. The minus sign appears in the expression of the neutrino (ν) induced process, while the positive sign stands for the antineutrino ($\bar\nu$)-nucleon scattering. Preliminary results of the CERN 1971 experiment (presented by *B. Degrange* [9]) using the large heavy liquid Gargamelle bubble chamber have confirmed earlier results back to 1963 extending the range of linear increase of the cross sections with the energy E of the neutrino beam.

The talks presented by T. D. Lee (NP 1957) and R. P. Feynman (NP 1965) in the same morning session suggested two characteristically different approaches to the interpretation of the scaling behavior. Although both agreed that the phenomenon reflects the compositeness of the target particles Lee [10] emphasized the importance of a Lorentz invariant quantum field theoretical approach. In his fermion-scalar bound state model the masses of the constituents combined with the large and energy independent value of the coupling characterizing the binding force necessarily break scaling for large enough energies. Feynman's strategy (in the interpretation of the summary talk of Victor Weisskopf [11]) was: "Don't bother with field theory, we know so little about it. Let us apply simple concepts. We have no superstrong interactions as concluded from the famous perpendicular momentum distribution and therefore at very high energies we can consider the hadron essentially as an assembly of free partons." This picture can be valid only in a reference system where the nucleon is moving very fast, but for Feynman apparently neither Lorentz invariance was an issue.

The most important message of Feynman [12] was that the quantum numbers of the partons can be extracted from the data and one can decide if the partons are quarks or not. He has introduced the density distribution for each quark flavor ($u,\ d,\ s$ and $\bar{u},\ \bar{d}, \bar{s}$ known at that time) as a function of $x = \omega^{-1}$. For the electron-deuteron case the scaling function arising as the sum over the proton and the neutron has the expression in terms of quark-parton distributions (including their electric charges in proportion to the elementary charge unit)

$$f_2^{ep} + f_2^{en} = \frac{5}{9}\, x\big(u(x) + \bar{u}(x) + d(x) + \bar{d}(x)\big) + \frac{2}{9}\, x\big(s(x) + \bar{s}(x)\big) \qquad (3)$$

On the other hand for the same form factor for (anti)-neutrino scattering one finds in the naive parton model

$$\begin{aligned} f_2^{\nu p} &= 2\, x\big(\bar{u}(x) + d(x) + \bar{c}(x) + s(x)\big), \\ f_2^{\bar{\nu} p} &= 2\, x\big(u(x) + \bar{d}(x) + c(x) + \bar{s}(x)\big). \end{aligned} \qquad (4)$$

If the strange quark content is neglected, then for the ratio $(f_2^{\nu p} + f_2^{\bar{\nu} p})/(f_2^{ep} + f_2^{en})$ the prediction 18/5 is obtained. This result generated extreme excitement when it was compared to experiments. *F. Ravndal* [13]: "During that term Feynman went to Hungary to take part in a neutrino conference at Balatonfüred. He came back fired up with the first quantitative experimental confirmation of the parton model and the fractional quark charges. This was the measurement of the famous factor of 5/18 which related the deep inelastic electron scattering cross section to the corresponding cross section with neutrinos." *D. H. Perkins* [14]: "SLAC had millions of events and Gargamelle only 3000, but it was clear that both were seeing the same structure, and they agreed to within 10% accuracy if the SLAC data points were divided by 5/18. Of course the two experiments were very different: carried out in different laboratories, using different probes, different fundamental interactions and totally different detector technology. Remember remarking at the Fermilab Conference in 1972 (*this happened after Balatonfüred, the Fall of that year! Note of A. P.*) that the agreement seemed somewhat miraculous! Well, miracles do happen."

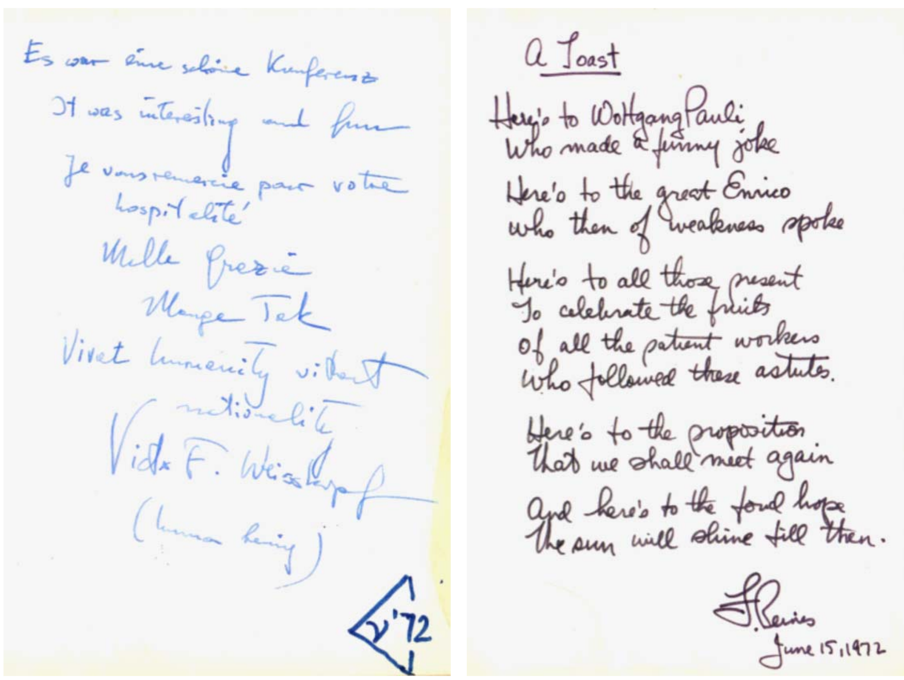
Another direct consequence of the naive quark parton model reflecting the composition of the nucleons concerned the ratio of the antineutrino to neutrino total cross sections (see Eq.(2)):

$$\begin{aligned} Z^{\nu} &= \int_0^1 \mathrm{d}x \left[u(x) + d(x) + \frac{1}{3}\,\bar{u}(x) + \frac{1}{3}\,\bar{d}(x) \right], \\ Z^{\bar{\nu}} &= \int_0^1 \mathrm{d}x \left[\frac{1}{3}\, u(x) + \frac{1}{3}\, d(x) + \bar{u}(x) + \bar{d}(x) \right]. \end{aligned} \qquad (5)$$

In the valence quark approximation one recognizes $Z^{\bar{\nu}} / Z^{\nu} \approx 1/3$, which was close to the result communicated to the conference by the Gargamelle group [9]. A number of similar sum rule like integral relations listed in the talks of Feynman [12] and of J. Kuti [15] offered the first opportunities to check the physical significance of the quark-parton densities.

In his summary talk V. Weisskopf "renormalized" the state of knowledge of quantum electrodynamics to 1. In this unit he qualified the understanding of weak interactions to 0.2 and that of strong interactions to 0! This conference was moving the metric of the latter to a positive non-zero value. The field theory into which the parton model could be embedded

From the guestbook of ν '72: V. F. Weisskopf, a Toast of F. Reines



came, however, soon and the logarithmic deviations from scale invariance predicted by QCD could be verified already towards the end of 1970's. This development gave very satisfactory response to the criticism of Lee raised against the parton model. Weisskopf called at the same time the attention of the participants to the promising features of the "Weinberg model" of lepton dynamics, not yet represented with enough emphasis at the Balaton conference. Already at the next neutrino conferences neutral currents and other features of the quickly developing standard model have reached the focus of the discussions.

13th of June 1972: Feynman and Pontecorvo planting (photo by D. Rein); June 2021: The memorial trees of the First International Neutrino Conference (photo by A. Patkós)

For the future of this conference the encouraging local political ambiance and collegial confidence proved important. *Dieter Rein* (Aachen) [16]: "Apart from the somewhat depressing entrance procedures at the Hungarian border (we were amidst the cold war) I felt free and enjoyed the warm and friendly reception of the organizers and the people around. There was a smell of political tolerance and personal independence in the air, presumably mostly due to Professor George Marx heading the Hungarian high energy physics community." Such impressions encouraged informal contacts between Soviet and US scientists an account of which was given in an 1982 review paper by J. Bahcall and R. Davis [17]: "The Soviet solar neutrino project has developed into a major program under the leadership of *G. T. Zatsepin*. We first learned of the magnitude of their effort at a lunch table discussion during the Neutrino 1974 (*correctly 1972, Note of A. P.*) conference at Balatonfüred, Hungary. A group of interested Americans, Fred Reines, Ken Lande, John Bahcall, and Ray Davis, asked to hear about the Soviet plans. Answers were provided by *Ya. Chudakov, A. Pomanski, V. A. Kuzmin,* and B. Pontecorvo."

The highlight of the future-building events has happened on the Tagore Alley at the border of Lake Balaton on 13th of June. *Z. Kunszt* [18]: "Marx had a holiday house in Balatonfüred. In the Alley this was *Rabindranath Tagore* the famous Indian poet who has planted the first tree (NP 1913). Much later the Italian poet *Salvatore Quasimodo* also planted a tree (NP 1953). The tradition that if a Nobel-prize laureate visits Balatonfüred he or she ought to plant a tree follows the idea of Marx. He suggested that Feynman as Nobel-prize holder should also plant a tree. But one had to have balance between East and West, so Bruno Pontecorvo has been asked to plant a tree." (One admits with backsight that not only politically but also scientifically the balance has been well chosen.)

The photo of the two oak trees made in 2021 next to the 'status nascendi' photographed in 1972 expresses well the drive of International Neutrino Conferences during the first half century of its activities.

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IMPACT OF THE NEUTRINO '72 CONFERENCE AS SEEN A HALF CENTURY LATER

Kenneth Lande

A half century has elapsed since the first International Neutrino Conference, organized in 1972 by *Andor Frenkel* and *George Marx* and colleagues at Lake Balaton in Hungary. Although there had been several small neutrino focused meetings earlier, one in Moscow in 1969 and what was a neutrino users group formed at Los Alamos in December 1970, the Balaton meeting was truly large, international and broad in neutrino-related topics. By 1972 only a few neutrino related experiments had been done or were underway. Of course, there was the observation of anti-ν_e emitted from a nuclear reactor by *Fred Reines* and *George Cowan* [1] and the detection of the ν_μ as different from the ν_e by *Lederman, Schwartz* and *Steinberger* [2] at the Brookhaven AGS accelerator. Plans for high energy neutrino experiments at Fermilab were described by *Barry Barish*. Interestingly, many of these topics are still under experimentation today, 50 years later.

But, the main focus at this meeting was the initial result from *Ray Davis's* chlorine based solar neutrino detector. Davis's initial result in 1968, based on two runs was ≤ 3 SNU. His new results based on six runs, presented at this conference, were a ^{37}Ar production rate of 0.18±0.10 per day [3]. After subtraction of the estimated cosmic ray induced background, Davis gave an upper limit on the solar neutrino induced signal of 1 SNU.[1]

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John Bahcall then provided a clear and very detailed description of how the solar neutrino emission is determined including the dependence on the various parameters. His conclusion was that the lowest possible signal in the Davis detector was 5–9 SNUs [4]. The difference between Bahcall's predicted signal and Davis's observed signal was known as the SOLAR NEUTRINO PROBLEM. Although most of the elements of the resolution of the "Problem" already existed, it took another quarter of a century to fully resolve this problem.

Of course, the large difference between the predicted solar neutrino signal and the limits set by the chlorine detector were troubling. This source of this discrepancy was considered at several small meetings [4] in the U.S., and particular at a meeting at the University of California, Irvine in February 1972 that Fred Reines, John Bahcall, *Erwin Fenyves* and I organized. Among others, *Willy Fowler* and *Luis Alvarez,* and, of course, Ray Davis attended. A brief description of the discussion appeared in the January 1973 issue of *Reviews of Modern Physics* [6].

Four groups of suggestions for the theory-experiment discrepancy were raised.

1. The ^{37}Ar extraction efficiency was much smaller than assumed, either because of hard to extract regions of the detector or because the ^{37}Ar ion was trapped in the remnant of the original C_2Cl_4 molecule. Although Davis's Neutrino '72 talk ruled out both of these ideas, he later carried out an experiment to completely eliminate the ion trap suggestion. The only significant improvement in the experiment was to move the proportional counter system from the Earth's surface at Brookhaven to the deep underground lab at Homestake. The background reduction of this move was significant.

[1] As a reminder, a SNU is the integrated product of neutrino flux × cross section for the neutrino induced $^{37}Cl \rightarrow {}^{37}Ar$ in units of 10^{-36} per second per ^{37}Cl target atom.

2. The problem lay with the calculated rate of ^{8}B production in the solar core. Since ^{8}B fusion related reactions represent only 10^{-4} of the solar fusion energy generation, a reduction of ^{8}B production in the solar core has no signification effect on solar energy generation, but would have an enormous effect on ^{37}Ar production in the Homestake detector. To increase confidence in his model and results, John Bahcall gave a very detailed description of the chain of calculations and their dependence on various nuclear reaction rate measurements in his Neutrino '72 talk. Except for small adjustments to account for changes in nuclear reaction rates, Bahcall's results remained unchanged for the next three decades.

During the February 1972 gathering, Alvarez suggested that we calibrate the Homestake detector with an intense neutrino source, such as ^{65}Zn. Unfortunately, ^{65}Zn produces a 1.35 MeV neutrino, energetic enough to drive the ^{37}Cl ground state to ^{37}Ar ground state transition, but far below the 6 MeV required to drive the super allowed transition to the 5.1 MeV excited state of ^{37}Ar, the main contribution of ^{8}B neutrinos.

3. The third group of suggestions dealt with the disappearance of electron neutrinos during their flight from the solar core to the Earth. The most obvious of these is that the neutrinos decayed during their 8 minute flight time from the Sun to the Earth. Decay involves the breakup of a heavier object into two or more lighter objects. But, neutrinos are already the lightest known objects. What would they decay into? The neutrino decay possibility was totally eliminated 15 years later when neutrinos were observed from supernova SN87a, which is 168,000 light years away.

A far more interesting and prescient suggestion was made by *Bruno Pontecorvo* when he first learned of the low Davis initial results. Pontecorvo proposed that electron neutrinos oscillate into other neutrino species in the same way as K_s and K_L in the K meson system [7]. At the time, 1969, only two neutrino species, electron and muon, were known and so neutrino oscillations could account for only a factor of two reduction in electron neutrino flux. In the late 1970s, *Martin Perl* observed a third charged lepton, the Tau. Assuming that there was an associated neutrino, there were now three neutrinos with an allowed flux reduction of three. *This would become the resolution of the problem.* It would be another quarter of a century before neutrino oscillations was the accepted solution of the Solar Neutrino Problem.

4. The fourth possibility we considered was based on the time difference between when the solar core fusion induced neutrino signal is observed and the corresponding thermal signal reaches the solar surface, ~10^{5} years. That is, the neutrino signal tells us what happened in the solar core about 8 minutes ago while the thermal signal tells us what happened ~10^{5} years. In a stable, steady fusion sun, that time difference is insignificant. But, in an unstable solar core with transient events a significant difference between thermal emission and neutrino emission might occur. For this case, a low neutrino emission might foretell a reduced solar thermal emission in the next 10^{5} years. A paper about possible approaches to neutrino archeology (by *Lande, Bozoki, Lee* and Fenyves) appears in the Neutrino '72 proceedings. Whereas the first three possibilities only impacted the neutrino and astronomy community, the possibility of a reduced solar thermal emission would impact the broader world. Fortunately, the broader community was not aware of this possibility.

As a result of the February 1972 workshop, we considered two possibilities. (1) Construct a deeper and larger chlorine detector, deeper to reduce the cosmic ray background and larger to improve the statistics of each run. A casual conversation with the Homestake mine management quickly ruled this out.

The second possibility was to use a different target element, one that would be sensitive to the direct P-P fusion neutrinos, that is, have a transition threshold less than 0.42 MeV. A few years earlier, *Vadim Kuzmin* [8] had proposed such a possibility, using ^{71}Ga as the target. Electron neutrinos with energy 0.233 MeV will transform ^{71}Ga into Ge. Unfortunately, in 1972 gallium cost over $1 million per tonne, and we needed at least 15 tonnes. We did not have access to the funds necessary to purchase that much gallium, nor did we know how to extract the neutrino produced ^{71}Ge.

Thus, we arrived at Neutrino '72 with several ideas but no specific plan except to continue running the existing Homestake detector. We knew that there was an interest in the U.S.S.R. to carry out a solar neutrino experimental program, but we did not know the specifics of that plan. George Marx offered to arrange a lunch at which our group could discuss future possibilities with our Soviet counterparts. Thus, Ray Davis (Brookhaven), Fred Reines (U.C. – Irvine), John Bahcall (IAS – Princeton) and I (U. – Pennsylvania) met with *Aleksandr Chudakov,* Vadim Kuzmin, *Aleksandr Pomanski* and Bruno Pontecorvo. What we learned was that they were excavating an adit, a one ended tunnel into the side of a steep mountain of the Caucasus range. When completed, the labs at the end of this adit would be a bit deeper than our Homestake lab. Also, the Soviet group was constructing parts for a chlorine detector with five times the volume of that at Homestake. We also found out that the Soviet group had access to 50 – 55 tons of metallic gallium under two stipulations, the gallium must be kept in metallic form and, it must remain in the Soviet Union. The magnitude of the Soviet effort was very impressive.

As a result of the Neutrino '72 Conference discussions Ray Davis and I decided to try to develop the technology for a gallium solar neutrino detector. I managed to borrow 50 kg of gallium and four of us, Ray Davis and *John Evans* from Brookhaven and *Bill Frati* and I from U. Pennsylvania developed two procedures, one using liquid gallium metal and a second using a gallium chloride solution [9]. These became the basis of the SAGE (Baksan) and GALLEX (Gran Sasso) solar neutrino detectors.

The Neutrino '72 International Conference set the pattern for the ongoing series of International Neutrino Conferences – Pennsylvania (1974), Balaton (1975), Baksan (1977) etc, provided a broad discussion forum for the "Solar Neutrino Problem", which, of course, was not a problem but rather an initial glimpse into an exciting new world of neutrino oscillations, set the basis for the gallium solar neutrino experiments which were able to see the neutrinos from P-P fusion and initiated Soviet–U.S. collaborations in this exciting field.

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FROM FEYNMAN'S PARTONS TO QUARKS

Julius Kuti

The Neutrino '72 conference at the lovely lakeside resort of Balatonfüred in 1972 vividly lives in my memory as the most exciting conference of my career. Of course I was young at that time working in a new and exciting research field driven by the emergent quark-parton model, perhaps an excusable bias for my recollections. Excitement was in the air in 1972 which *Victor Weisskopf* summarized best at the conference as the year being the beginning of a new era in physics [1]. And surely, it was. In the previous two years before the conference I had the good fortune to work at MIT on the quark-parton model with Weisskopf. Our work incorporated new predictions about the SLAC–MIT deep-inelastic electron-nucleon scattering experiment, the first direct evidence about point-like quarks inside the nucleon [2]. My work at MIT with Viki Weisskopf benefitted from the earlier work of our young and enthusiastic group at the Eötvös University including *László Gálfi, Péter Gnädig, Ferenc Niedermayer,* and *András Patkós.* Working together in Budapest, we understood the significance of the SLAC–MIT experiment and made new predictions for a new experiment at SLAC when the electron beam and the nucleon target would be both polarized [3]. This would give direct insight if the spin of the quarks was 1/2, similar to other known fermions. Our work contributed to the preparation of the spin-dependent experiment under the leadership of *Vernon Hughes*. His experiment had to overcome tremendous technological challenges building the polarized electron beam and the polarized nucleon target. We called it the spin-polarized Rutherford experiment of our times. A few years later Vernon's experiment succeeded by measuring the deep spin-polarization distribution of quarks inside the nucleon with the experimental confirmation of an important theoretical sum rule *James Bjorken* established earlier [4]. After his famous SLAC–Yale experiment I remained in very close collegial and friendly contact with Vernon. He was the king of the fermion spin which led him to a new discovery, challenging the foundations of the Standard Model. At Brookhaven National Laboratory he measured the most precise determination of the anomalous magnetic moment of the muon, deviating from the expectations [5]. His whole equipment in recent years was shipped on a huge barge to Fermilab where the new experiment, recently announced and with the news reaching the New York Times, confirmed the original BNL results still waiting for some resolution.

But in the early months of 1972 I was busy working on the quark parton model in anticipation of the coming Neutrino '72 conference. While preparing for my talk, still months before the conference, the phone was ringing at my MIT office. *Dick Feynman* called. He introduced the notion of partons in high-energy experiments a couple of years earlier but surprisingly did not take the last step in his famous *PRL* publications [6] to identify the partons with quarks. He was gracious, telling me to talk about partons and quarks as I like, ignoring what he might say in his talk. He was very concerned that he did not have any new

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results. Shortly before the conference he called again. He knew now what he would talk about, identifying his partons with quarks and suggesting ways of nailing down their quantum numbers in new experiments. He also mentioned that he was learning to dance the Hungarian *csárdás* which he delivered at the welcome reception of the conference.

At the conference Feynman talked about two ideas [7]. He described how to probe the quantum numbers of quark-partons by replacing the electron beam with neutrino beam. He referred to my talk [8] how to probe the spin of the quarks in future polarized version of the SLAC–MIT experiment when the electron beam and the nucleon target are both polarized. Feynman also talked about an interesting new idea he developed just before the conference. When the quark scatters after large momentum transfer from the electron, it emits and vaporizes a pion jet created inside the nucleon, breaking up and fragmenting in the collision. From the directly observed pion charge averages one would be able to infer the u and d quark-partons with charge +2/3 and charge −1/3, respectively, using electron beams or neutrino beams. Later this idea became a cottage industry for theorists. The deep-inelastic neutrino-nucleon experiment was already in preparation at Fermilab and *Barry Barish* from Caltech talked about it at the conference [9]. Barry visited us a couple of years ago at U.C. San Diego talking about the discovery of gravitational waves of his Ligo collaboration. At dinner with Barry after his colloquium talk we were reminiscing about Neutrino '72 in Balatonfüred where we first met and how the great intellectual gathering impacted our young enthusiasm in anticipation of bright future for high energy physics in coming years.

I hope this short note explained why Neutrino '72 lives in my memory as a historic landmark, admittedly biased by my personal experiences. *George Marx* was the driving force and the chief organizer of the conference. He was my advisor during my student years at the Eötvös University. George would be 95 years old today. Nothing would make me happier than celebrating him again on this occasion and reminiscing again about the great old days.

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A CONFERENCE NEXT TO THE ALLEY OF RABINDRANATH TAGORE

Lalit M. Sehgal

The Neutrino '72 Conference was the very first conference I attended and turned out to be an important event in my scientific life. There was a whole galaxy of famous people there – *R. Feynman* (NP 1965), *T. D. Lee* (NP 1957), *R. Marshak, V. Weisskopf, B. Pontecorvo, V. Telegdi, F. Reines* (NP 1995), *C. Cowan, R. Davis* (NP 2002), *J. Bahcall, B. Barish* (NP 2017), *D. Cline, C. Baltay* and many others.

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Shortly after the Conference, I gave a series of lectures with the title "Unified Theories of Weak and Electromagnetic Interactions: an Elementary Introduction" which appeared as an Aachen Report PITHA-Nr.68 (1973). These lectures were essentially an introduction to the Weinberg model, intended for experimenters in the Gargamelle experiment. There was a rather limited discussion of the SU2×U1 theory in Balaton, but I do remember a talk by Baltay reviewing the experimental limits on neutral currents in neutrino experiments, as well as some remarks by Weisskopf in his summary talk, drawing attention to the Weinberg model and its interesting implication for the mass of the W boson.

For me personally the most interesting talks at the Conference were the two beautiful lectures by Feynman, with the title "What neutrinos can tell us about partons". After listening to them I had the exhilarating sense of having understood everything. (That was an illusion, of course. Feynman was a magician, and magicians can create illusions.) These lectures influenced strongly my thinking about high energy neutrino interactions, which is reflected in the lectures I gave at Argonne in August 1975, which appeared in the report "Phenomenology of Neutrino Reactions" (ANL-HEP-PR-75-45), and in my review of "Hadron Production by Leptons" at the Lepton Photon Symposium in Hamburg in 1977.

These are some of the things I remember about the Balaton conference of 1972. I have seldom attended a meeting with so many famous physicists. I was also moved by the fact that the garden in which Feynman and Pontecorvo planted the trees was named after the great Indian writer, artist and humanist *Rabindranath Tagore.*

BEGINNINGS OF PARTICLE ASTROPHYSICS

Alex Szalay

I will never forget the Neutrino '72 Conference in Hungary. At the time I was a physics undergraduate student at the Eötvös University in Budapest, working with *George Marx,* the main organizer of the meeting. I was able to participate as a student assistant, helping to run the meeting, carrying the microphones and setting up the projectors. I was finishing my undergraduate dissertation on the cosmological effects of neutrino masses. As I later realized, this work was one of the first in what later became Particle Astrophysics. Today the best limits on the neutrino masses are still coming from astrophysics. Some of these came from an experiment, the Sloan Digital Sky Survey, which I have spent more than two decades working on.

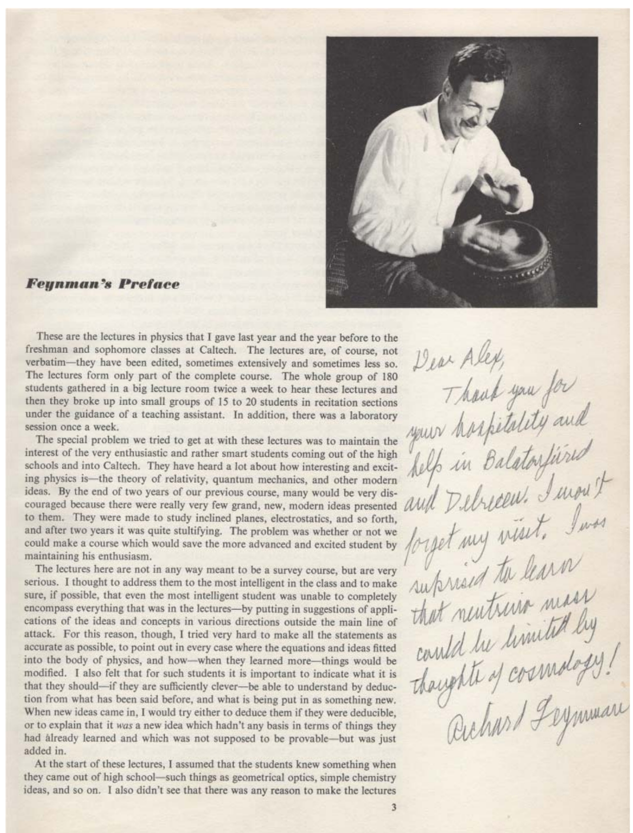
In the seventies Hungary was slowly opening up, and it emerged as a great venue for a meeting between the major physicists of the East and West. The turnout was incredible: *Richard Feynman, T. D. Lee, Vicki Weisskopf, Fred Reines, Ray Davis, John Bahcall, Barry Barish, Val Telegdi, Bruno Pontecorvo* – a who is who of particle physics. *Julius Kuti* has just returned to Hungary from his MIT stay.

The new results from deep inelastic scattering were very new, the parton model just emerged, the solar neutrino problem was becoming acute, change was in the air. It was an amazing feeling to be immersed in the atmosphere of the meeting, and see how Feynman and others were jokingly prodding each other, and see the giants of modern physics to be very human, and incidentally very nice to a young Hungarian undergraduate, sitting in awe at the sidelines.

At the meeting George Marx gave a short presentation of the results of my thesis, which grabbed the attention of Feynman – so much so, that after the meeting he gave me a personal dedication into my copy of the Feynman lectures.

Little did I know that almost 40 years later I would be giving a talk at Caltech at the meeting commemorating the 50th anniversary of his famous talk about the nano-world. After the conference I had the privilege to be his guide for week, while they stayed in Hungary. It was thrilling to see from close up how his mind worked – how he was able to abstract and

Personal dedication in the copy of Feynman's Lectures of Alex Szalay


Feynman's Preface

These are the lectures in physics that I gave last year and the year before to the freshman and sophomore classes at Caltech. The lectures are, of course, not verbatim—they have been edited, sometimes extensively and sometimes less so. The lectures form only part of the complete course. The whole group of 180 students gathered in a big lecture room twice a week to hear these lectures and then they broke up into small groups of 15 to 20 students in recitation sections under the guidance of a teaching assistant. In addition, there was a laboratory session once a week.

The special problem we tried to get at with these lectures was to maintain the interest of the very enthusiastic and rather smart students coming out of the high schools and into Caltech. They have heard a lot about how interesting and exciting physics is—the theory of relativity, quantum mechanics, and other modern ideas. By the end of two years of our previous course, many would be very discouraged because there were really very few grand, new, modern ideas presented to them. They were made to study inclined planes, electrostatics, and so forth, and after two years it was quite stultifying. The problem was whether or not we could make a course which would save the more advanced and excited student by maintaining his enthusiasm.

The lectures here are not in any way meant to be a survey course, but are very serious. I thought to address them to the most intelligent in the class and to make sure, if possible, that even the most intelligent student was unable to completely encompass everything that was in the lectures—by putting in suggestions of applications of the ideas and concepts in various directions outside the main line of attack. For this reason, though, I tried very hard to make all the statements as accurate as possible, to point out in every case where the equations and ideas fitted into the body of physics, and how—when they learned more—things would be modified. I also felt that for such students it is important to indicate what it is that they should—if they are sufficiently clever—be able to understand by deduction from what has been said before, and what is being put in as something new. When new ideas came in, I would try either to deduce them if they were deducible, or to explain that it *was* a new idea which hadn't any basis in terms of things they had already learned and which was not supposed to be provable—but was just added in.

At the start of these lectures, I assumed that the students knew something when they came out of high school—such things as geometrical optics, simple chemistry ideas, and so on. I also didn't see that there was any reason to make the lectures

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Alexander S. Szalay, Bloomberg Distinguished Professor in the Department of Physics and Professor in the Department of Computer Science, Johns Hopkins University, Baltimore, USA simplify any topic to the essentials and then give an answer within a factor of a few. Later I learned how dimensional analysis can get you the right order of magnitude, but an estimate within a factor of 2-3 is a whole other dimension.

The meeting reinforced me in seeing the overarching power of physics and how ideas permeate political boundaries – physics is truly international. It also encouraged me to believe that in this world everything is possible, and eventually set me on a trajectory that continued in the US. I have been to many conferences since then, but I cannot recall anything even remotely comparable to Neutrino ’72. It was a historic meeting, at the right place, at the right time, on the right topic. I will always remember it as a turning point in my life.

1997: David Schramm and Alex Szalay at the Hungarian Academy of Sciences celebrating 70th birthday of George Marx (photo by E. Hámori)

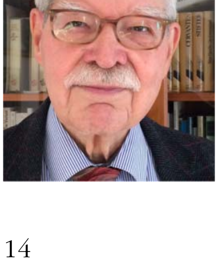
REMINISCENCES OF HUNGARIAN CONFERENCES

Dieter Rein

Concerning my own recollections of the Neutrino ’72 conference I must confess that it had no immediate effect on my own working, although after all I slowly turned toward weak interactions and neutrino physics. But nevertheless I was really much impressed by that conference. First I had never seen before, and neither later, such a concentration of highly respected and well known physicists both from the west and from the east. And I was certainly fascinated by the lectures of *Feynman,* who showed how to use neutrino reactions to find out properties of quarks and their distribution in nucleons. I also learned appreciate the by then established solar neutrino deficit which gave a speculative first glimpse on neutrino oscillations. Finally *Vicky Weisskopf* in his summary talk put much emphasis on the Salam–Weinberg model of electroweak interaction. At that time I had a tendency to disregard it although the Gargamelle experiment was already under way. But after the talk of Weisskopf I thought it should be taken seriously.

I remember this conference with pleasure. Apart from the somewhat depressing entrance procedures at the Hungarian border (we were amidst the cold war) I felt free and enjoyed the warm and friendly reception of the organizers and the people around. There was a smell of political tolerance and personal independence in the air, presumably mostly due to Professor *Geoge Marx* heading the Hungarian high energy physics community. It was not much later that he came to Aachen for a seminar talk and I remember him frankly speaking about the problems which *Pankow,* i.e. the DDR-government made in blocking all attempts of enlarging international scientific cooperation and interchange. Obviously he was not at all a follower of communistic ideology but a supple diplomat of science and quite successful.

By the way Marx was also interested in applications of weak interactions in atomic and molecular physics and thus indirectly on theories of the origin of life on earth. So he and,I guess, *Keszthelyi* and *Garay* from Hungarian research institutes – both experts in experiments on selective disintegration of chiral molecules – organized a meeting 1974 in Debrecen about those items. Meanwhile I had turned to weak interaction effects in molecular physics with the aim of estimating



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intrinsic energy differences between chiral molecules and attended this meeting. It took, however, several years until I reached, jointly with *P. Sandars* and *L. Hegstrom,* a reliable result (published in 1979 and 1980). The Neutrino '75 conference in Balatonfüred, which I also attended, was mainly devoted to discussions of neutral current effects, also in atoms. *Sandars* in Oxford and *Fortson* in Seattle as well as *Barkow* and *Zolotorev* in Novosibirsk looked for neutral current-induced optical activity in bismuth vapor, a tiny effect, first established by the Russian authors around that time.

The related topic of neutral current effects in chiral molecules, however, was not on the agenda. Nonetheless Garay showed up there with some curiosity; it was just before he escaped from Hungary to start a new career at Texas A&M-University in US. His flight via Yugoslavia was dramatic: he overran the border limit near Trieste, together with his young family. The border guards tried to stop them shooting behind them – in vain. Barkow from Novosibirsk was a participant of the Neutrino '75-conference. During lunchtime he occasionally spoke about his home region in frosty Siberia. Municipal life was certainly different from normal Central European performance, but even babies, well packed and warmly covered, were seen in the streets of Novosibirsk.

I also remember a casual conversation between *Helmut Faissner,* head of our institute at Aachen, and *Yakov Borissowich Zeldowich*. Faissner wanted to organize the following neutrino conference 1976 in Aachen and asked Zeldowich whether he could quote him as an international advisor of the Aachen conference. Zeldowich had already participated in the Debrecen meeting, he liked to visit Hungary. He spoke good German and was interested in trends of modern German literature mentioning in particular the work of *Heinrich Böll.* His reply to Faissner's question was neither yes nor no. Faissner with some confidence interpreted his answer as yes and put the name of Zeldowich on his official conference poster. It did him no harm and he did not complain. And a dozen of Russian scientists attended the Aachen neutrino conference of 1976.

GEORGE MARX – THE RESPONSIBLE USE OF NUCLEAR ENERGY

Ádám Kiss

George Marx's scientific works and contributions are widely available to readers through other collections and articles. This article aims to introduce and remember George Marx as a person, to share how he lived and acted, and what made him a successful teacher, sympathetic and active colleague, excellent coworker, and an effective propagator of ideas and beliefs. From among the many possible topics he was passionate for, we have chosen his actions and campaigns for strengthening social confidence in nuclear energy in Hungary. He had a tremendous influence on the intelligentsia of the Hungarian society during his lifetime and this effect can still be felt in the current day.

Firstly, George Marx was a man, who, truly and without reservation believed in and trusted science. He was convinced that science can improve the world around us. He understood that science exists everywhere around us, and that using findings from scientific research can have a lot of benefit for individuals and society. He had this same understanding across all different branches of science. Although he was a physicist, he was equally enthusiastic about advances and new findings in modern biology, chemistry, and all other sciences. George was not an idealist and understood that contemporary societies have major functional problems to address. However, he was sure that science would always lead the way in solving or avoiding societal problems and challenges.

At the same time, George Marx was a dedicated and committed democrat. He could not imagine a healthy society without democracy. This way of thinking determined his actions. He accepted that a majority of people had the right to decide how their community should solve any recognized problem and that science should identify the best solution for them. The personal conviction of members of the community about the soundness of a suggested solution is a necessary step in the democratic process. But who are those influencers, who can do this job? He thought, that a group of knowledgeable teachers should explain the different possibilities, and present options for solving the problem in question. He strongly believed, education on all levels is crucial for

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the development of human societies. Accordingly, he was a strong and effective promoter for the enhancement of science teacher education in universities and colleges, and he regularly lectured on postgraduate courses for teachers of secondary and even elementary schools. In addition to the high scientific standards, he required from each member of his department,he thought that faculty staff should be active participants in intellectual life. George Marx himself engaged in many public discussions and debates and gave a lot of talks to non-scientific audiences. His major target groups were young pupils and their teachers. He himself was an excellent teacher and he had an outstanding pedagogical understanding. George Marx always enchanted his audience no matter what topic he spoke about. He was admired by many people!

George Marx understood that contemporary societies with their sophisticated connection-systems would encounter problems and require a solution from science. He was full of new and exciting ideas and created an intellectual environment around him. In lectures and seminars, he always dealt with topics in the focus of scientific interest. Examples of his out-standing contributions include writing an essay in 1968 with the title "Accelerating times" in the literary periodical *Új írás,* which drew much attention. In this essay, he explained in detail how we as humans are living in a world that is completely different from the life of our ancestors. It seems, that time is passing much faster for us than for our parents and grandparents. At the same time, many more events are happening than in previous decades. This is because the development of human societies has stepped into a new era, where science proceeded with a rapid rate and the technological development since the middle of the 20th century has been breath taking. From these new situations, he drew several potential consequences. He was one of the first scientists, to speak about the possibility of climate change resulting from greenhouse effects. He also gave memorable talks about the possibility of the existence of other civilizations beyond the solar system, perhaps in other galaxies.

George Marx clearly identified some of the major challenges of our times. He was persuaded that the problems of energy supply would represent a major challenge for the future of mankind. During his lifetime (and even to current day), the energy for human needs was produced mostly (over 80%) from fossil fuels i.e., from coal, oil, and natural gas. He was strongly aware that the continuous increase in the production of atmospheric carbon-dioxide may lead to greenhouse effects and through other interconnected and complicated phenomena to potential increase of global temperature. He thought that the dependence in energy production from fossil fuels should decrease.

As an excellent nuclear physicist, George Marx was apprised of nuclear energy. This topic was one of his favorites. He also knew a lot about renewable energy production methods, and he supported them very much. However, he always pointed out that the energy density of each of them was very low. This meant to produce vast amounts of energy, comparable with the global energy need of societies (at that time it was around 350-400 exajoule) required vast areas (big lakes in the case of hydropower, large areas for producing enough biomass, covering huge lands by solar cells), or a move to more buildings e.g., increased number of wind power stations. Needless to say, all of these energy production methods have significant and non-negligible effects on the environment. He foresaw that the dominant use of any one of them raised moral and ethical questions, as well as (at that time hard) technical difficulties. Therefore, he was cautious in discussing solutions for the large-scale production of renewable energy.

Of course, George Marx was aware of the problems facing nuclear energy. He heard the arguments of the antinuke movement and carefully followed its evolution in some European countries, such as West-Germany. Of course, he had observed closely the referendum, which rejected the switching on of the fully completed nuclear power plant in neighboring Austria. He understood that all sorts of dissents and objections against nuclear energy would come in his country, as well. He thought that the public should be educated, persuaded, and convinced about the advantages of nuclear energy.

George Marx had some insights into the governing organizations and technical controlling systems of nuclear reactors in his country. He had served as an active member of the Board of the Hungarian Atomic Energy Agency for decades. He found, the control system on nuclear power plant reliable and the institutional organization satisfactorily independent in his country. He always emphasized that it was the responsibility of the nuclear industry to give reasonable and reliable answers to all questions and solicitudes!

He studied in detail the possible accidents arising from different types of nuclear reactors. He pointed out that although the over-moderated reactors presented potential dangers, the under-moderated pressurized water reactors were inherently safe. He advocated that all existing and future power plants should belong to the latter type. The final storage/reprocessing of the high activity nuclear waste may be done in geological stable formations under international control. Hungary offers a range of rocky locations, which geological surveys demonstrate are stable on a time scale of billions of years. The disposal of intermediate and low activity waste of nuclear reactors therefore could be done in national framework. The radioactive irradiation of the public near to nuclear power plants and from across the whole nuclear industry can be kept on a level not higher than other exposure levels from nature and therefore can be handled and accepted. In summary, he concluded that there are much more advantages than disadvantages of the rational and careful application of nuclear energy.

George Marx was convinced that nuclear energy should be used as part of the energy solution for the future of Hungary. In this case the energy density is high (the highest among the energy production methods known). In normal function, the application of nuclear energy has only slight environmental effects, it is clean compared to other methods and it is cheap. He was persuaded that nuclear energy should have a significant share in future energy production. In this way, he became an enthusiastic promoter of the nuclear energy in Hungary!

The nuclear age began in Hungary in early 1970's, when it was decided to build four nuclear power units at the Danube in town Paks. George Marx gave support from the very beginning for establishing the nuclear power plant, which would contribute to the safe and cheap electric energy supply of the country.

George Marx had considerable influence on people around him. First, of course, there were his own university students, mainly students of physics. In this connection, he thought that the nuclear power plant, if ready, could offer excellent workplaces to several physics graduates. These experts would have basic knowledge about nuclear reactors, and should be in favor of application of nuclear energy. George Marx recommended the introduction of a course for physics student about "Atomic energy". His authority and reputation helped, and the course was introduced by Board of Institute of Physics. The author of this article is proud that the head of the department asked him to work out the syllabus of this course. The course continued as part of the curriculum for physics students, until it was canceled as part of a major reform of university education in the late 90's, which restricted the number of classes.

In the 70's and early 80's the construction of the first four units of the Hungarian nuclear power plants began. George Marx organized excursions to the plant for members of the Institute of Physics, teachers of physics, and many students. It was quite impressive to visit the construction with such an excellent and informed guide! I personally will not forget that I had the possibility along with some other students to enter one of the four reactor tanks already in place but not yet active. For many years in the 80's and 90's Marx arranged that all students of physics had the opportunity to visit the Nuclear Power Plant in Paks.

Professor Marx was convinced that the most effective transmitters of knowledge to a broad group of people are secondary school physics teachers. He prepared a program for teachers about the positive effects of using nuclear energy. He offered many talks about the application of nuclear reactors at workshops for physics teachers across the whole country. He explained to them the basic information about nuclear energy and about the difficulties connected with them. Furthermore, he argued successfully for including some important aspects of nuclear physics and reactors into the official physics curriculum in secondary schools.

George Marx organized vocational training in the University for inquiring experts, including physics teachers, about radiation protection. These courses had a high professional level and participants received a state-recognized certification about their new skills. This training led to novel employment opportunities in the job market and became popular for many years.

George Marx was considered to be one of the most famous scientists in our country. Because of that, he was frequently interviewed on TV and on radio programs, and he also wrote enjoyable essays for newspapers. Through these channels, he could reach broad audiences of society. He did not hesitate to explain his views supporting the responsible application of nuclear energy.

In April 1986, the Chernobyl catastrophe has happened. George Marx was among the most eminent scientists, who were asked about the accident. He never avoided the questions and always responded with deep knowledge and level-headed honesty. He never spoke about anything, that was not in accordance with his own knowledge and conscience. He pointed out very clearly that the reactor in Chernobyl was of over-moderated type, which was inherently unstable, and could lead to explosions. He emphasized that the reactors in Paks were of different types, where the run-out is prohibited by the laws of physics.

George Marx with some colleagues from his department joined a group, which was allowed to visit the catastrophe-district Chernobyl. He took, of course, some radiation instruments (though it was explicitly prohibited by the Soviet authorities) to measure the radiation level close to the accident. When he returned to Budapest, he gave an excellent talk about the radiation levels that they measured there, pointing out curious deviations from the official communications.

George Marx strongly believed that without the nuclear energy the energy crisis of the modern societies cannot be solved. He was very clear that society must move away from the use of fossil fuels and start to intensively use renewable energy sources. However, according to him, most of the energy cannot be provided by these mostly meteorology-dependent energy sources. Nowadays, it seems that to avoid catastrophic climate change one has to scale up nuclear energy production.

Once again, we ought to recall that George Marx always emphasized, that all justified questions should be answered honestly and understandably for the layperson – in line with the content of public education. He himself was persuaded that such a development was possible and, therefore it should be done.

According to many Gallup-polls, a majority of the public in Hungary is in favor of safe application of nuclear technology and nuclear energy production. From reading this article, one can gain an appreciation of George Marx's enthusiastic work in favor of the acceptance of nuclear energy in Hungary. He played a key role in shaping Hungarian public opinion, and his teachings and legacy still impact in these matters, almost twenty years since he passed away.

GEORGE MARX, THE EDUCATOR

Csaba Sükösd

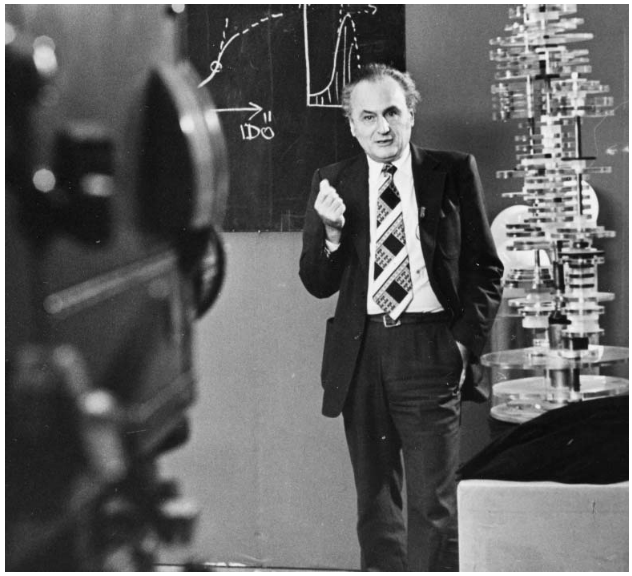
"In a foreign country go and see the banks to know how people like their money, go in the restaurants and bars to know how they like themselves, visit the schools to know how they like their children and their future."

(*George Marx*)

Introduction – some personal memories

It was during my final year of high school that I first heard about George Marx. I was already preparing for the final "maturity" exam of high school as well as the University entrance exam. Since my childhood I have always been fascinated by machines, so I wanted to start mechanical engineering studies at the Technical University. Around then, Hungarian television started a series of lectures about science, which they called "TV University". In this program George Marx delivered a series of lectures about the latest developments in physics and astronomy, about the origin of the universe, about elementary particles and about the structure of the atoms. His lecturing style simply amazed me. I sat there mesmerized in front of the TV, listening to his logical and crystal clear explanations, which had put the scientific facts into a fascinating perspective and showed the beautiful harmony of Nature. His lectures opened a new horizon to me, my whole worldview has changed to the point that finally I changed my mind, abandoned my childhood dream, and decided to become physicist. He was one of the determining factors – if not THE determining factor – for starting my career as physicist. He influenced me without any personal contact and without even being aware of my existence.

During my university years I had the chance to follow several courses delivered by George Marx, including Quantum Mechanics and Cosmology. Some of these course were compulsory, but most of them were elective. The lecture rooms were always full and jammed with students. Sometimes more students wanted to hear him than were seats available; some people had to stand along the walls of the room during the whole lecture. Students came also from other programs of the Eötvös University – for whom it was not compulsory to follow his course – sometimes students came from the Technical University on the other side of the river Danube. Even after 50 years I can still remember some of his lectures, which charmed us to a point that the whole audience broke out in loud applause spontaneously, when the lecture finished. This kind of reaction is more common nowadays, but at that time it happened seldom. I don't recall hearing of a similar experience with other professors of the university at the time. He had a talent and skill in communication that is hard to find. I feel really lucky that he offered me a position in the Department of Atomic Physics, and that I got the opportunity to work close to him for several years.



George Marx lecturing

Activities for public education in Hungary

George Marx was an outstanding scientist – as other articles in this series explain in detail – but he gave the same importance to education as to research. This principle was deep-rooted in his vision of life: being a democrat, he thought that the general public should decide about important questions in a democracy. However, people can only make wise decisions, if they are educated and knowledgeable. He was persuaded that only science can guide society to make wise decisions. Therefore the general public should be educated in science – be it physics, chemistry, biology, medicine, or even social sciences. It followed directly from this principle that he did not focus only on university education, but also wanted to improve the quality of science education in schools.

The author is indebted to *Prof. Eilish McLoughlin* – secretary of GIREP – for reviewing and improving the manuscript.

Csaba Sükösd, honorary professor, former head of the Department of Nuclear Techniques, Budapest University of Technology and Economics, Hungary

Structure of Matter – the original Hungarian and the Chinese edition

As a first step he started lecturing to future physics, chemistry and biology teachers at the Eötvös University. He quickly recognized that the young people in the 20th century cannot be motivated toward science using “conventional” approaches to teaching physics. He said: “Young people are not amazed anymore by learning about pulleys, slopes, capacitors or resistances. They are much more interested in how lasers or nuclear plants are working, how the Universe was formed, how the stars shine or what future potential is in the genetic engineering.” His leading idea was that the talented young people can be guided toward scientific/technical career by teaching them about the amazing world of modern physics, modern chemistry and modern biology. The school curriculum has to be reformed in this direction.

In order to achieve this goal he initiated and became the leader of an educational reform under the control of the Hungarian Academy of Sciences. The program called teachers to participate on a voluntary basis. Several dozens of physics, chemistry and biology teachers participated in this reform program, which was continued during several years from the mid 70’s up to about 1988. George asked outstanding scientists from the Hungarian Academy of Sciences to deliver lectures to the participating teachers. They met regularly at different schools, at least once in every semester, sometimes even more. George was persuaded that the different branches of science are closely interconnected, so they must not be taught independently. However, he was not in favor of *integrated* science teaching – which is promoted today, – instead, his idea was to teach each sciences in a *harmonized* way.

The main difference between these two approaches is that in harmonized teaching the disciplines are taught separately: physics teachers teach physics, chemistry teachers teach chemistry, and biology teachers teach biology. However, the progress in the different disciplines are adjusted: elements and molecules are taught by chemistry only after physics had taught what atoms are, and how electrons behave in them; biology taught about proteins and enzymes when the pupils had already learned about the basics of organic chemistry. Many “harmonization points” were identified by the participant teachers and by scientific colleagues of George. Based on these, new curricula have been developed for school physics, chemistry and biology. New textbooks have been written, and teachers used these in their schools. Some of these textbooks have been translated to other languages and are used even today in some schools abroad.

This program gained enthusiastic supporters as well as fierce opposers in Hungary. Most of the teachers who participated in this program loved this approach and continued to teach according to this “reformed” curriculum for several years, even after the program officially finished. Most of the criticism came from outsiders, who thought that the introduction of modern physics in schools was a crazy and unacceptable idea. Many people thought – and some still think today – that modern physics cannot be taught in schools, because it uses really abstract concepts and requires really complicated and advanced mathematics that school children are not able to comprehend.

I cannot avoid mentioning that George Marx was well ahead of his time with this reformed curriculum. At the recent 2019 conference of GIREP (Groupe International de Recherche sur l’Enseignement de la Physique) one of the main issues was how quantum physics can be taught in schools. The almost 400 participants of the international conference paid tribute to the early achievements of George Marx.

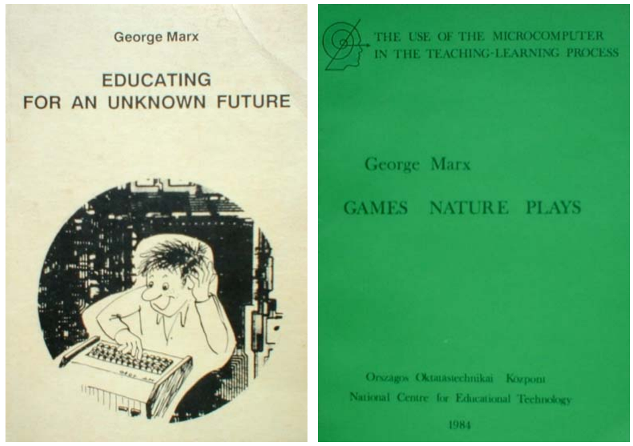
It is also worth mentioning, that although the whole program was not generally introduced in the Hungarian educational system, some parts of it are still recognizable in the curricula of the different scientific subjects. For example, part of school physics curriculum still deals with nuclear energy and radia-

Prof. Marisa Michelini, president of GIREP, remembering George Marx during the GIREP2019 Conference

tion protection, which was first introduced by this project. This content had already some influence on public understanding during the Chernobyl accident. Families learned from their children's textbooks about the effects of radiation, they also learned about how radiation doses can be measured and what the different units of measurement are and what kind of health effects can be expected from different doses. They gained awareness about natural radioactivity and how they could compare an excess dose to the level of natural radioactivity. When they learned that the excess radiation dose received over 30 years is about the same that they have received from the natural background over one month, they became more relaxed and didn't panic – in sharp contrast to the general public of some other European countries.

Here I relay an interesting story which happened in one of the schools where the "reform" curriculum was taught. Those schools got a GM-counter which was built in the Department of Atomic Physics of the Eötvös University. In such a school a physics teacher – *Eszter Tóth* – taught students about radiation in March 1986, and the students recorded some data on the environmental radiation background with the GM-tube during that lesson. The 5th of May 1986 was a cold Monday, after a few days of holidays (because of 1st of May). By then people already were aware of the Chernobyl accident and were also informed that some radioactivity may arrive to Hungary. The students were excited and requested the physics teacher to measure the level of radioactivity in the classroom again, so that they can compare it to the background measured in March. They measured the level, and the reading was indeed higher than in March. They were enthusiast that they could detect the increased level of radioactivity! But the story doesn't end here. A small girl spoke out: "Look, the windows are still close, the radioactivity could not come in from outside! Let's open the windows, ventilate the classroom, and measure it again! We will get even higher readings, for sure!" They did what she suggested and stood astound to see that the number of counts went back to the March level after the ventilation. They understood that previously they measured the effect of the radon – a naturally occurring radioactive noble gas, – which accumulated in the closed room during the few days of holiday, and which depleted, when they ventilated the room. The students realized that natural radioactivity levels had much more effect compared to the radioactivity from Chernobyl (at least at their location in Hungary). This was something that they learned by experience, by measuring themselves. It is expected that this knowledge remained with them for life.

George Marx's activity for the Hungarian educational system was not restricted only to educational reform as outlined above. He maintained a strong relationship with the physics teacher's community. His lectures were always the most awaited highlights of the annual National Conferences of Physics Teachers. Together with Eszter Tóth they organized a country-wide program of measuring the radon-concentration in homes.



G. Marx: Educating for an Unknown Future and Games Nature Plays

School children were involved and they were taught how to place small solid-state radon-detectors in their homes, which could later be collected and analyzed.

George also organized several upskilling programs in modern and nuclear physics for physics teachers. He led groups of physics teachers to visit interesting sites, such as, CERN in Switzerland, Chernobyl in Ukraine, Paks Nuclear Power Plant in Hungary, Cernavoda in Romania, etc. He founded and led the Leo Szilárd Physics Competition for high school children, which will reach a jubilee next year when the 25th competition will be organized. This physics competition chooses its problems uniquely from topics in modern physics – as George had suggested many years ago.

George Marx was also fascinated about everything new. When personal computers started to become available, he was among the firsts in Hungary to purchase one, and he started developing science educational games and simulations. This is reflected in his book: "Games Nature Plays". Even when many people were still sceptic, he was strongly in favor of the introduction of computers in schools.

International educational activities

George Marx knew that involvement in international events and networks was as important in education as in research. He served the international physics education community in many ways: member of ICPE (International Commission on Physics Education) in 1975–1981, Vice-Chair in 1987–1993, and Editor of the ICPE Newsletter, 1988–1994. He had a long involvement with GIREP (Groupe International de Recherche sur l'Enseignement de la Physique), and was also its President in 1992–1995. During his membership and his presidency he organized many conferences, seminars and meetings about teaching physics in schools. It started with the "Danube Seminars". Let me quote here *Jon Ogborn* (UK) remembering those times [1].

"I well remember standing with George Marx in Visegrád, where the Danube makes its huge bend to the south, looking across to what was then Czechoslovakia. George had chosen this historic place for the second Danube Seminar, the first of many Danube Seminars on Physics Education held in Hungary. Why the title, 'Danube Seminars'? George Marx wanted the countries of Eastern Europe, then frozen in the Soviet bloc, to come together to invent for themselves new ways of thinking about teaching physics in the school. And he wanted to ignite that fire with flames taken from the best and most recent work and thinking in other countries. I was there as one of the matchsticks in his matchbox."

Some of these seminar titles are listed below as an illustration of the diversity of topics covered:

- Teaching Wave Mechanics in School (1974, Vienna, Austria)
- Teaching Statistical Mechanics in School (1975, Visegrád, Hungary)
- Momentum in the School (1976, Visegrád, Hungary)
- Structure of Matter in the School (1979, Fonyód, Hungary) This was already a completely international Seminar: participants came from Australia, Austria, Bulgaria, Czechoslovakia, Denmark, East Germany, Finland, Holland, Italy, Poland, Japan, UK, USA, and USSR
- Nuclear Physics, Nuclear Power (1981, Balatonfüred, Hungary) organized together with IUPAP ICPE, and GIREP
- Entropy in the School (1984, Balatongyörök, Hungary)
- Chaos in Hungary (1987, Balatonfüred, Hungary) – conference about non-linear phenomena.
- Energy Alternatives – Risk Education (1989, Balatonfüred, Hungary). After the Chernobyl accident the focus was to discuss how to introduce the risk concept in the school education.

Educating outside Europe

George Marx was enthused by the diversity of cultures all around the world. He equally admired the old Chinese cultures as well as the Hindu religion or the Buddhism. When talking about George's missions in Asia and Africa, let me quote Jon Ogborn again [1]:

George Marx teaching in China

"In the 1980s and 1990s George made many visits to China, Japan and Africa. He also went to India in 1984. A long visit to China in 1983 was followed by a series of further visits, as he was invited back again and again. This in itself is testimony to the value Chinese people put upon his ideas and experience. A similar long series of visits to Japan started in 1986. In all these visits, George expounded his vision of a science education based on the deepest and most general elements of the scientific world picture, and designed to develop the creativity and talent of all students.

Starting in 1987, with the support of the International Centre for Theoretical Physics headed by his friend *Abdus Salam,* George Marx began a long series of workshops on the use of microcomputers in science and mathematics education. Between 1987 and 1993 he took his ideas, and his personal charm and warmth to Egypt, Ethiopia, Kenya, Ghana, Zimbabwe and Uganda. George was never there merely to teach. Above all, he tried to leave behind a sense of possibility, of personal creativity in every participant."

Epilogue

This short article does not allow me to list all of the achievements and contributions that physics education has to thank George Marx for. He received many awards for his scientific work, and he was honoured with many awards for his outstanding contributions to physics education. A year before his death, in 2001, he received the Bragg-medal from the Institute of Physics. Earlier, in 1997, the IUPAP ICPE awarded him with the ICPE award – a medal for outstanding services to the teaching of physics, with an international dimension. Interestingly, this award was founded by George earlier, when he had the vice-chair of ICPE; the medal is the work of a famous Hungarian sculptor – *Miklós Borsos,* – who was also a friend of George. This homage to George Marx is best finished by quoting a short excerpt from the laudatory text of his ICPE award [2]:

"Throughout his long career Professor Marx has devoted himself to advancing the cause of science and of physics education. Both in his research work in physics, and in his work as a teacher, an author and an editor he has made seminal contributions to the literature. He has catalyzed the organization of numerous international conferences and projects in physics education. Always, and in all ways, George Marx has been a trusted advisor and a highly valued friend of physics teachers the world around, and through his continuing and tireless efforts on their behalf has earned their deepest respect, affection and gratitude".

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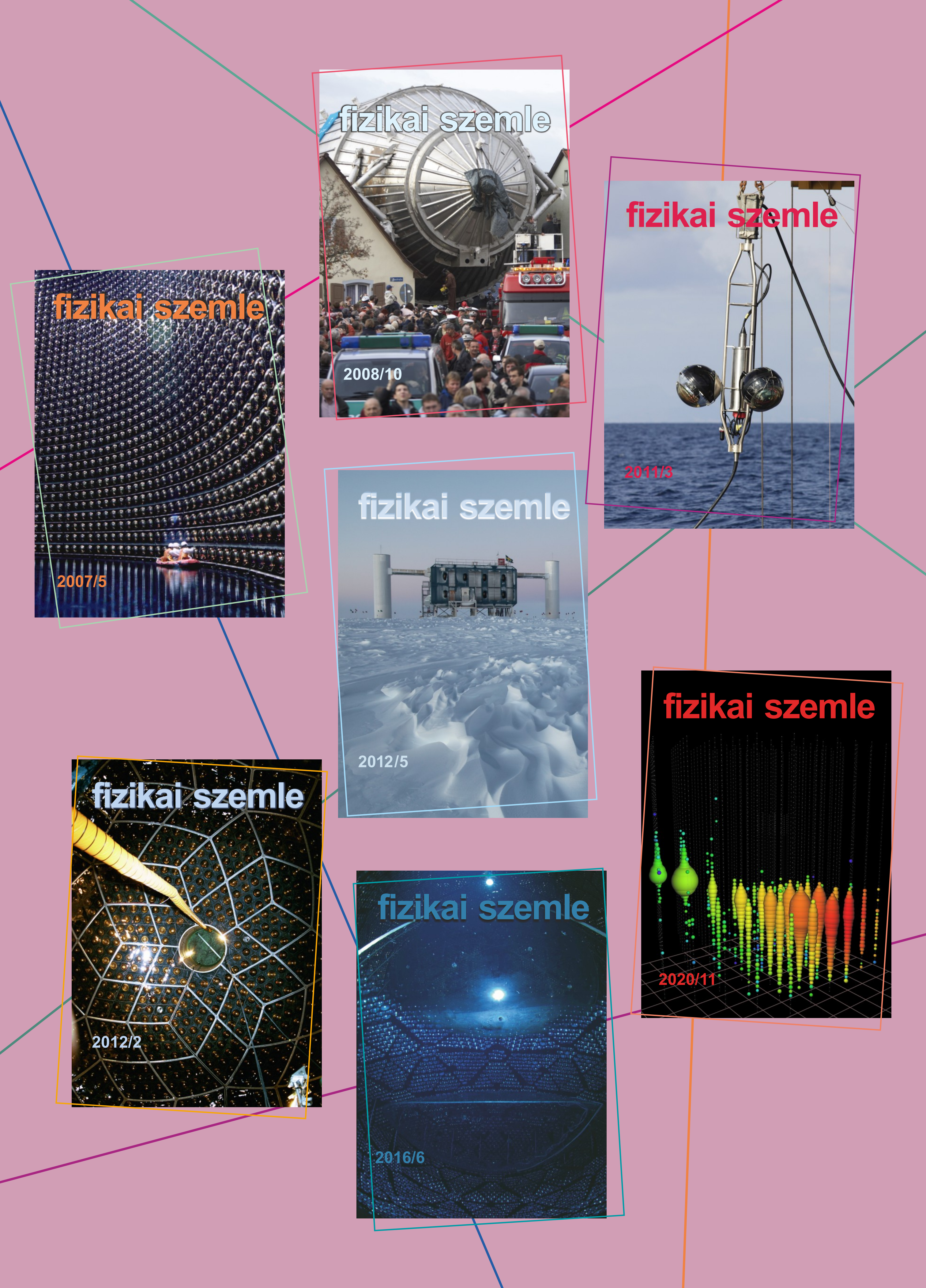
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