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Hadron physics with Simon Eidelman

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Simon Eidelman, our colleague and friend, well known physicist in the particle physics world, passed away on June 28, 2021. This report is about his way in particle physics and his contribution to many areas and researches in our field of physics.

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1. Beginning

Simon (Semyon) Eidelman was born in Odessa in 1948, August 2. At the age of 15 he went to Novosibirsk, to enter to a special high school for students gifted in natural sciences (now Specialized Educational Scientific Center [1]). He then studied physics at Novosibirsk State University [2]. Being undergraduate student, in 1968, Simon joined the Budker Institute of Nuclear physics [3] and remained there his entire professional life.

Simon's scientific activity during all his life was mostly connected with experiments at electron-positron colliders. He started his career by participating in the discovery of multihadron events at VEPP-2, a pioneering e^+e^- collider [4]. That time the quark model was not firmly established yet and many theorists expected that hadronic cross sections in the electron-positron annihilation will fall very fast with the energy increase due to form factors. So, the observation of the large multi-body cross section [5] in the energy range 1.1 – 1.4 GeV shown in the Fig. 2 was quite important.

2. Experiments with OLYA detector

In 1974 new e^+e^- collider VEPP-2M at BINP started operation. This machine with maxumum luminosity of $L_{max} = 3 \times 10^{30} \dot{c}m^{-2}s^{-1}$ and the energy range up to 1.4 GeV successfully operated until 2000 and provided a lot of important results. Thus, VEPP-2M collider was pre- ϕ- factory from 1974 to 2000.

From the beginning of experiments at VEPP-2M Simon joined to the group working with the OLYA detector. This group was small, less than ten physicists, and everybody had many tasks. Simon's main tasks in the OLYA experiments were a development of the software for data processing, Monte Carlo simulation and development of the MC generators of various processes, radiation corrections calculation. His main physics analysis at OLYA experiment was the study of the four pion channels. The results of the study of the processes $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$ and $\pi^+\pi^-\pi^0\pi^0$ were published in [6, 7].

Since experiments at VEPP-2M collider provided much more precise results than the previous experiments, calculations of the QED processes used for cross-checks and normalizations should be performed with high accuracy. Then Simon made several thoretical works together with Eduard Kuraev and other colleagues, see for example [8].

The important work done by OLYA experiment in which Simon actively participated was the measurement of the pion form factor in the time like range from 360 to 1400 MeV. The joint results of OLYA and CMD experiments published in 1985 [9] were actively cited for the next 25 years. In this paper the contribution of hadronic vacuum polarization, a^h_μ, to anomalous magnetic moment of muon, $(g_\mu - 2)/2$ was estimated as $a^h_\mu = (68.4 \pm 1.1) \times 10^{-9}$ with much better precision than the achieved earlier [10].

It is worth noting that eventhough Simon always belonged to experimental groups and collaborations, his work was usually somewhere between experiment and theory. Both theorists and experimentalists got a good profit from that. As an example we can refer his work with L. M. Kurdadze and A. I. Vainshtein [12] where the first comparison of the QCD sum rules [11] with experiment was done on the basis of the precise data on hadron cross sections obtained by OLYA detector.

At the end of 1979 the e^+e^- collider VEPP-4 at BINP came into operation. The first experiment at this collider was performed with the OLYA detector. During March - April 1980 a measurement of the J/Ψ and $\Psi\prime$ masses was performed using resonance depolarization method of the beam energy calibration [13]. Simon actively participated in this work. The agreement between theory and experiment above 0.7 GeV is surprisingly good.

In the beginning of eighties Simon visited CERN for several months and took part in the experiments with Axial Field Spectrometer at ISR [14].

3. Precise measurements of the hadronic cross sections in e^+e^- annihilation

By middle of nineties the accuracy of the measurements of the fundumental constants, like energy depending fine structure constant, $\alpha(M^2)$, and lepton anomalous magnetic moments, as well as its theoretical calculations improved considerably, which required an improvement of the determina-

FIGURE 1. S. I. Eidelman.

tion of the hadronic vaccum polarization (HVP) contributions to these values. The HVP contribution cannot be calculated purely theoretically but can be determined using the data on the total $e^+e^- \to hadrons$ cross section via dispersion relation. For muon anomalous magnetic moment $a_\mu = (g_\mu - 2)/2$ the HVP contribution is expressed as

$$a_\mu^h = \frac{\alpha^2}{3\pi^2} \int\limits_{4m_\pi^2}^{\infty} ds \frac{K(S)}{s} R(s), \tag{1}$$

where $K(S) \sim 1$, and

$$R(s) = \frac{\sigma(e^+e^- \to hadrons)}{\sigma(e^+e^- \to \mu^+\mu^-)},$$

$$\sigma_{\mu^+\mu^-} = \frac{4\pi\alpha^2}{3s} \frac{86.85\,\text{nb}}{s\,[\text{GeV}^2]}. \tag{2}$$

Thanks to his deep understanding of experimental and theoretical issues, Simon became one of the pioneers in utilizing precise measurements of the hadron production cross section in e^+e^- for the evaluation of the hadronic contribution to the anomalous magnetic moment of the muon. In 1995 S. Eidelman and F. Jegerlehner published the 35 pages paper on the improved HVP calculation [15]. This paper collected more than 700 citations by now.

As seen from (1) the a_μ^h value is dominated by the hadronic cross section at low energy. The main contribution to HVP value as well as to the uncertainty of this value comes from the cross section of the $\pi^+\pi^-$ production, which is determined by the pion electromagnetic form factor. Until approximately 2005 the VEPP-2M collider [16] was the main supplier of the precise data on the hadronic cross section in the energy range below up to 1.4 GeV. Simon Eidelman was involved to the experiments with CMD-2 detector [17] at VEPP-2M from 1992. This cryogenic magnetic detector combined features of a spectrometer for charged particles momenta measurements with high resolution calorimetry for photons and electrons. The main goal of CMD-2 detector was a measurement of the hadron production cross section in e^+e^- annihilation as well as a study of rare decays of light mesons.

In the end of eighties Prof. Vernon Hughes visited BINP in connection to a preparation of the E821 experiment at Brookhaven National Laboratory (BNL) for new measurement of the muon anoumalous magnetic moment. He would like to convince BINP physicists to measure $R_{had} = \sigma_{had}/\sigma_{\mu\mu}$ with 1% accuracy which looks that time to be almost impossible. It took about 15 years to achieve this accuracy. Final results of CMD-2 measurements of the pion electromagnetic form factor were published in [18, 19] and provided necessary precision. Simon contributed a lot to this long study at both sides: experimental and calculation of a_μ^h on the base of experimental data.

E821 experiment performed high precision measurements of the muon anoumalous magnetic moment at BNL [20] and introduced a problem due to the difference between its result and theoretical calculation via the Standard Model by more than 3.5 standard deviations. The uncertainty of theoretical value is dominated by the HVP contribution.

In the next 15 years new precise data on the hadronic cross sections at low energy were obtained by BaBar, KLOE and BES III using Initial Stage Radiation method (see, for example [21–23]). The idea of this method is to use a process where an initial electron or positron emits energetic photon leaving the e^+e^- pair annihilating to hadrons with lower energy. Thus, using this method, one can perform measurements at all energies below the energy of experiment. First

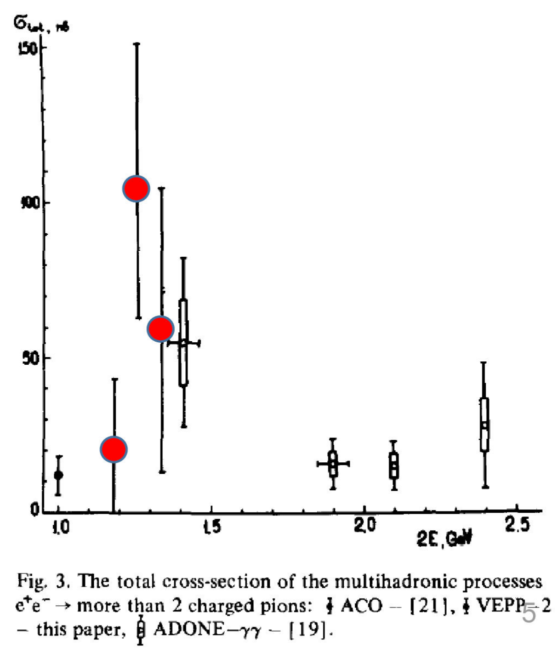

FIGURE 2. Hadronic cross section [5]. Red circles are VEPP-2 results.

mention about this possibility was published long time ago [24]. In 1999 M. Benayoun, S. I. Eidelman, V. N. Ivanchenko and Z. K. Silagadze attracted attention of the B-factories people to this possibility after publishing the paper [25] which became quite popular collecting 171 citations by now. A review of the studies using this approach was pulished with Simon's co-authorship on 2011 [26].

However, new results did not solve mentioned discrepancy but just confirmed it. The present status of theoretical calculation of the muon $a_\mu = (g-2)/2$ is given in the review [27] completed and published with active participation of Simon.

From 2017 new experiment, FNAL E989, succeeding the BNL E821 started data taking in the Fermilab. The goal of this experimrnt is to improve the precision by a factor of 3. FNAL E989 experiment reuses the muon storage ring from BNL measuremnt and based on the same principles. The result of the first run of this experiment with the same accuracy as the BNL measurement was published recently [28]. This result is in a good agreement with the previous BNL one and combined value differs from the theoretical calculation for 4.1 standard deviations.

4. Physics at VEPP 2000

In 2010 new e^+e^- collider, VEPP-2000, for the center-of-mass energy range from 0.3 to 2 GeV started operation at BINP [29]. This machine is based on a principle of the round beams, was developed at the BINP and has achieved by now the luminosity of $5 \times 10^{31}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ at 2 GeV. As mentioned earlier, the FNAL E989 experiment at Fermilab expects to reduce uncertanty in muon (g-2) for three times. Another experiment [30] with similar target precision is under developement at J-PARC (Japan). Then the high precision measurement of the total hadronic cross section (at the level of 0.3%) becomes one of the most important task of experiments at VEPP-2000 collider. It should be noted that an increase of the energy up to 2 GeV is important as well since data in the energy range from 1.4 to 2 GeV were rather scarce.

From the beginning of the VEPP-2000 project Simon Eidelman was an active member of the CMD-3 collaboration. The CMD-3 detector is a successor of the CMD-2 with much better tracking system and calorimetry [31].

Besides the precise measurements of the total hadronic cross section, CMD-3 aims to other important goals like measurement of parameters of light vector mesons $\rho, \omega, \phi, \rho', \rho''$, etc; study of the final states dynamics and test of theoretical models; study of nucleon-antinucleon pair production - nucleon ectromagnetic form factors, search for NNbar resonances; search and study of the exotic resonance states (X, Y, Z,…) and others. Results on these subjects were published in the last years [32]. Simon actively participated in all these analyses. His contribution concerns to the developments of the MC generators of many processes as well as interpretation of data and comparison of them with theoretical models.

Another collider under operation at the BINP is the VEPP-4M for the centre-of-mass energy from 2 to 12 GeV. S. Eidelman was involved to the detector KEDR collaboration working at this collider. Simon convinced the collaboration in the importance of the precise measurements of R value via inclusive hadronic cross section in all available energy range. The results of this measurement [33] are shown in Fig. 3 together with other experimental data.

As seen from Fig. 3 the R values above 2 GeV agree with pertrubative QCD. It should be noted that R are usually determined by different ways below and above 2 GeV. At low energies the total hadronic cross section is calculated as a sum of exclusive cross sections while above 2 GeV R is obtained from inclusive cross section. Simon insistently pointed out the importance of the direct comparison of these two methods and KEDR performed several measurements between 1.8 and 2 GeV. As seen in Fig. 3 the results of both procedures are in a good agreement. It is clear as well that more precise measurements near 2 GeV are desirable.

Latest results from VEPP-2000 and VEPP-4M colliders are reviewed by E. Kozyrev in his talk at this conference [34].

5. Physics at factories

Another field of particle physics where Simon Eidelman was involved was experiments at KEKB B-factory with the Belle detector and later with Belle II detector. The KEKB e^+e^- energy-asymmetric collider [36] was commissioned in 1999 and stopped in 2010. This machine achieved the world highest luminosity to date, $2.1 \times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, and total integrated luminosity collected in experiments with the Belle detector [35] at the center-of-mass energy within the Υ-meson family (mostly $\Upsilon(4S)$) reached of about 1 ab^{-1}. The Belle experiment was primarily aimed to the discovery of the CP-violation (CPV) in B meson decays which was done in 2001 [37]. After analysis of full collected statistics CP violation parameters were evaluated with high accuracy for many channels of B meson decays [38].

Besides of the main task, a lot of other important results were obtained due to high quality of the Belle detector as well as very large collected luminosity. Simon participated in many activities in the Belle collaboration including referring of analysis of various processes, participating in the publication committee, etc. His interests in Belle physics were wide but here we touch only two subjects: tau lepton hadronic decays, search for lepton flavour violation and study of two photon hadrons production.

Concerning the former subject it should be noted that still in 1999 S. Eidelman and V. Ivanchenko published the paper [39] about connection of experimental data on the e^+e^--annihilation into hadrons and exclusive tau decays via CVC. This work became very popular collecting more than 100 citations. As examples connected to this topic we can refer to the following studies performed by Belle with strong Simon contribution: high-statistics measurement of the $\tau^- \to \pi^-\pi^0\nu_\tau$

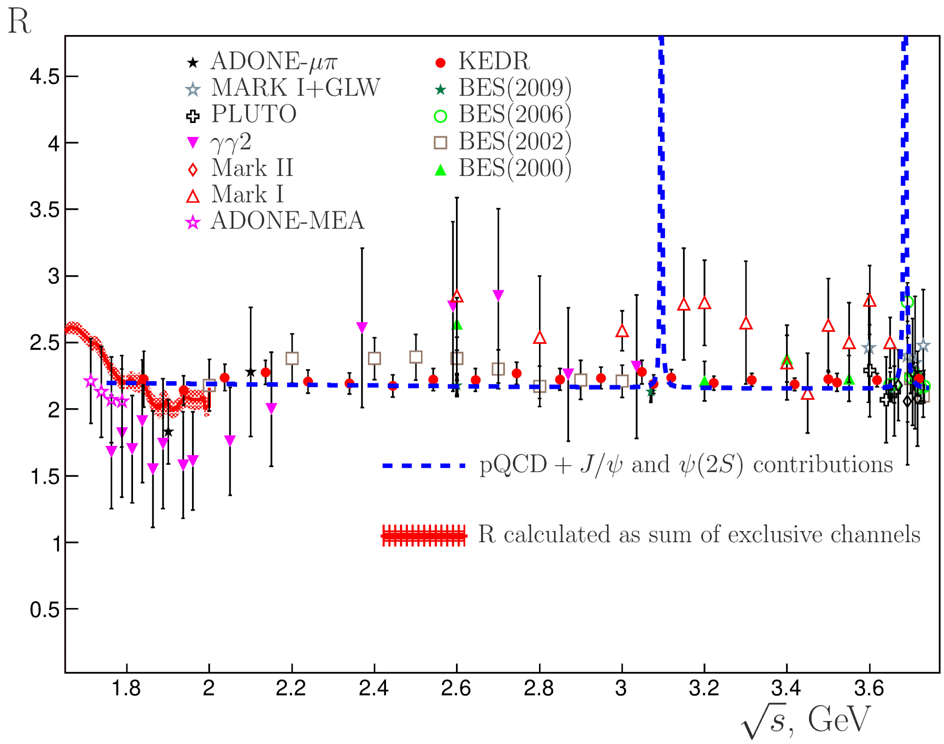

FIGURE 3. Measurements of R [33] (Coutresy of A. Shamov).

decay which obtained the branching ratio and spectral function of this channel with best world accuracy [40]; study of $\tau^- \to K_S\pi^-\nu_\tau$ decay at Belle [41]; measurements of branching fractions of τ lepton decays with one or more K_S [42].

Discussing the Belle results in two-photon hadron production, it is worth noting among many studies the measuremnt of π^0 transition form factor [43]. This chracteristic is connected to the calculation of the hadronic contribution to the anomalous magnetic moment of the muon via so called light-by-light (LBL) terms. More details can be found in the review [27]. Other examples of the two-photon processes study by Belle collaboration are [44–46].

All studies conducted with the Belle detector will be continued and extended in experiments with Belle II detector at SuperKEKB collider. This asymmetric e^+e^- collider ($E^+ = 4$ GeV, $E^- = 7$ GeV) [47], constructed in the same KEKB tunnel is designed for the luminosity exceeding the previous one (KEKB) by about 30 times, amounting to 6×10^{35}cm^{-2}s^{-1}. Experiments with the Belle II detector [48] started in 2019. By now the SuperKEKB achieved the world highest instantaneous luminosity of 3.8×10^{34}cm^{-2}s^{-1} and Belle II collected about 268 fb^{-1} of integrated luminosity. The target amount of Belle II data is 50 ab^{-1} (50 times larger than Belle). Simon Eidelman actively participated in this collaboration. He contributed a lot to the formulation of the physical program and was a member of publication and institution committees and several physics groups.

At present a project of the Super-tau-charm factory is under development in the Budker Institute of Nuclear Physics in Novosibirsk [49]. This project includes e^+e^- collider complex for center-of-mass energy range fom 2 to 7 GeV and luminosity of 10^{35}cm^{-2}s^{-1}. The work on this project started in 2010 and Simon was one of the enthusiasts of this project. He made a great work on the development of the physics program of Super-tau-charm factory and in the formation of the collaboration as well as CDR preparation and organization of regular international meetings.

The physics program of Super-tau-charm factory is very rich and wide. It comprises followng sections:

- Charmonia, charm mesons and charm baryons spectroscopy; detail study of higher $c\bar{c}$ and XYZ states; weak decays of J/Ψ meson;
- τ lepton physics: Michel parameters, spectral functions in hadronic decays, search for CP violation, and lepton flavour violation, test of lepton universality.
- Two-photon processes: Search for and study of the normal and exotic C-even states, measurement of the $\gamma\gamma \to hadrons$ cross sections, measurements of the meson transition form factors (TFF).
- Mesurements of the total hadronic cross section by scan and ISR.

6. Teaching, PDG and other activities

For a long time Simon teached at the Physics Department of Novosibirsk State University (NSU) and guided students as supervisor of bachelor, master and PhD theses. In parallel to his work at BINP he was NSU faculty member and for ten years he was a head the High Energy Physics Chair. Simon spent a lot of time in discussions with students and young colleagues of their problems. He always cared for helping and supporting them. He wrote, probably, tens of recommendation letters for young collegues to help them to find a good position.

Permanently, for thirty years Simon was a member of the international Particle Data Group (PDG) and one of the key authors of the "The Review of Particle Physics" issues. Since 2006 he led the PDG meson resonances subgroup responsible for analyses and incorporation of many published results into the Review of Particle Physics. Simon scanned number of physics journals, proceedings, preprints to select results of interest for his PDG group. Thus, he had a wide knowledge about the latest experiments as well as on the theoretical and experimental results. It should be noted that this was quite useful for his close colleagues who could always received his advice and consultation concerning the latest studies and contacts to people who performed these.

Simon was an author and co-author of many PDG review articles and served as a member of the PDG Representative Board. In recognition of his great contributions to PDG, he was chosen to be the first author of the 2004 edition of the Review of Particle Physics.

From his young years Simon liked to study languages and undoubtedly had a talent to them. In addition to his native Russian he could speak Ukrainian, English, German, Polish, French, etc. He was very good scientific editor, served as referee for hundreds of papers and was the author and co-author of more than 1000 publications.

Another part of Simon activity was the organization of many seminars, workshops, schools and other scientific events. Thanks to his wide contacts, ability to communicate, hard working as well as bright sense of humor he was a welcome member of any organization committee.

7. Conclusion

In spite of many subjects discussed in this talk, the list is quite incomplete. I did not mention in my talk his participation in LHCB and (g-2)/EDM (J-PARC) collaborations as well as, probably many other Simon's activities. Everybody who knew and was working with him will always remember him as an invaluable colleague.

IAC of HADRON conference series establishes a prize honoring the memory of Simon to be awarded in future editions of the conference, starting from the next one, in 2023. Its purpose will be to acknowledge the outstanding young research in hadron physics, fostering her/his career. This prize is also intended to remind some of the many virtues Simon had, and encourage the younger generations to pursue these values, like scientific honesty or international orientation. It will then, as Simon would have surely done, show this young scientist the way to follow: correct firmly though kindly when needed, take into account everyone's views with equity and inclusiveness, discuss politely only based on physics, never inflate one's work and appreciate others'.

Acknowledgements

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