Radoje Belusevic

Curriculum vitae

Education

1977 **B.Sc.** in theoretical solid state physics at the **University of Novi Sad** (Yugoslavia).

1981 **Ph.D**. in experimental particle physics at the **University of Birmingham** (England).

Positions

1980 July — October
Summer student at Stanford Linear Accelerator Center, **Stanford University** (USA).

1981 November — **1982** July
Honorary Research Fellow in the Department of Physics, **University of Birmingham** (England).

1982 July — **1985** October
Research Associate in the Institute for High Energy Physics, **University of Heidelberg** (Germany).

1985 October — **1987** November
Research Associate in the Department of Physics, **University of Florida** (USA).

1988 February — **1991** May
Research Fellow in the Department of Physics and Astronomy, **University College London** (England).

1991 July — **2019** April
Senior Scientist in the Institute of Particle and Nuclear Studies, High Energy Accelerator Research Organization **KEK** (Japan).

Research areas

- Neutrino phenomenology.
- Experimental bubble chamber particle physics (neutrino interactions and charm photoproduction).
- Experimental counter detector high energy physics (neutrino interactions; proton-antiproton, electron-proton and electron-positron collisions).
- Phenomenology of photon-photon collisions (production of Higgs bosons and Higgs self-coupling).
- Digital (data acquisition) electronics.
- Application of the X-band accelerator technology and free electron lasers (FELs) in the construction of e^+e^- and $\gamma\gamma$ colliders that would serve as Higgs-boson "factories".
- Application of superconducting L-band linear accelerators to the production of high-intensity neutrino, kaon, muon, electron and positron beams for fixed-target experiments, free-electron lasers (XFELs) and synchrotron light sources.

Teaching experience

- Lectured on modern quantum physics and gauge field theory to postgraduate students at University College London.
- Supervised a Ph.D. student from University College London, whose thesis was partly based on a data transfer and processing system for high luminosity hadron colliders.
- Supervised a Ph.D. student from Rochester University (USA) working on an analysis of radiative dimuon events in electron-positron annihilations at TRISTAN.
- Wrote a set of lecture notes on Feynman diagrams, dimensional regularization, weak interactions, etc., for graduate students at KEK.
- Wrote a book describing the physics of neutral K-mesons and the theory and phenomenology of CP violation (published by Springer-Verlag in 1999).
- Wrote a book on special and general relativity, covariant electrodynamics, cosmology, stellar structure and evolution, and some relevant aspects of elementary particle physics (published by Wiley in 2008).
- Wrote a book on the history of physics from Ancient Greece until the end of the twentieth century (to be published).

Research experience

1977 Obtained B.Sc. at the University of Novi Sad with a work in theoretical solid state physics. The B.Sc. thesis is entitled "**Magnon-phonon interactions and kinematic levels in ferromagnetics**".

1980 Spent three months at Stanford University (USA), as a summer student, working on a **charm photoproduction experiment with backscattered laser beams** in the SLAC 40-inch hydrogen bubble chamber (spokesman: Prof. J. Ballam, Stanford University).

1981 Obtained Ph.D. in experimental high energy physics at the University of Birmingham (UK) with a thesis entitled "**Hadron production in neutrino and antineutrino interactions on nucleons**". The analysis described therein was based on the data collected by two experiments using the Big European Bubble Chamber (BEBC) at CERN. Thesis adviser: Prof. D.C. Colley.

1981 November — **1982** July
Honorary Research Fellow in the Department of Physics, University of Birmingham, participating in a **BEBC neutrino experiment** (spokesman: Dr. W. Venus, Rutherford Laboratory).

1982 July — **1985** October
Research Associate in the Institute for High Energy Physics, University of Heidelberg (Germany), working as a member of the CDHS collaboration (**neutrino counter detector at CERN**; spokesman: Dr. J. Steinberger, CERN): Took part in a nucleon structure function analysis; studied the impact of electroweak radiative corrections in charged- and neutral-current neutrino interactions; was involved with the development of the CDHS event reconstruction and simulation software. Also performed an extensive analysis, with Prof. V. Hepp from Heidelberg University, of the multiple Coulomb scattering in continuous and discrete media.

1985 October — **1987** November
Research Associate in the Department of Physics, University of Florida (USA), working at Fermi National Accelerator Laboratory (Fermilab):

- Was involved with the construction of uranium-liquid argon prototype modules for the **D0 detector at the Fermilab TEVATRON proton-antiproton collider** (Fermilab-Proposal-0740): Cosmic ray calibration of the central calorimeter modules; trigger design for a test beam calibration; testing of readout pads in a cryogenic chamber (spokesman: Prof. P. Grannis, Stony Brook).

- Participated in an experiment using a **fine-grain neutrino counter detector at Fermilab** (FMMF collaboration; spokesman: Dr. F. Taylor, MIT): Worked on the event reconstruction and simulation software; and the design of a 500 GeV Cherenkov counter for Tevatron narrow-band neutrino beams at Fermilab (R. Belusevic and F. Taylor: FMMF internal report, 1986).

- Developed a method, with Dr. D. Rein from the Institute for Theoretical Physics at RWTH Aachen, for extracting the value of the neutrino flux in a wide-band beam exposure based on computed differential cross sections for resonance excitation, coherent pion production and quasielastic scattering of neutrinos on nucleons (Fermilab-Pub-87/124-T). The method was used by the CCFR and FMMF collaborations for relative normalization of neutrino cross sections at Tevatron energies.

- Wrote a paper, with Prof. Jack Smith from the Institute for Theoretical Physics at Stony Brook, on the W-Z interference in neutrino-nucleus scattering (published in Phys. Rev. D). The creation of muon pairs by neutrinos in the Coulomb field of the nucleus, which we treated in the Weizsäcker-Williams approximation, provides a direct test of the interference between the intermediate-vector-boson amplitudes, as predicted by the weak-interaction theory. This work prompted the CCFR, CHARM, NUTEV and CHORUS collaborations to perform data analyses that confirmed the Standard Model, and has been referenced also by some theorists (see, e.g., L. Sehgal, Phys. Rev. D38 No 9, 1988) and cited at major conferences.

1988 February — **1991** May
Research Fellow in the Department of Physics and Astronomy, University College London (UK), and a member of the ZEUS collaboration (detector for the **HERA electron-proton collider at DESY**; spokesman: Prof. G. Wolf, Hamburg University):

- Studied electrostatic properties of the ZEUS Central Tracking Detector and worked on a simulation of electron drift in an argon-ethane gas mixture.

- Wrote a paper, with D. Rein, which describes the physics of nonscaling components in neutrino-nucleon interactions and makes a theoretical prediction for the value of the exclusive cross section at low energy transfers (published in Phys. Rev. D and used by major neutrino collaborations: see, e.g., Z. Phys. C48, 1990).

- Designed, with G. Nixon from UCL, a transputer-based readout controller that achieved data transfer rates of up to 13 Mbytes/s (published in NIM). The use of a transputer as the sole controlling microprocessor capable of multitasking and parallel processing, in conjunction with dual-ported memories, renders bus arbitration unnecessary leading to very simple interfacing logic and operating software. This design was implemented in the data acquisition system of the ZEUS Central Tracking Detector (see NIM A396, 320 (1994)).

- Developed, with two colleagues from UCL, an 80 Mbytes/s data transfer and processing system for use with high luminosity accelerators. The system consists of: (a) a transputer-based crate controller, which includes an Intel microcomputer; (b) a set of readout cards, each containing a digital signal processor for fast data parameterisation and compaction; and (c) a 1 Gigabit/s intercrate serial link (published in NIM). The project received support from the UK Science & Engineering Research Council (in the form of an R&D grant and a studentship) and Intel Corporation (microprocessors and related software). Two University College Ph.D. theses are partly based on this design. The work was presented at major conferences and workshops.

1991 July — **2019** April

Senior Scientist in the Department of Physics, High Energy Accelerator Research Organization KEK (Japan), working on the AMY and TOPAZ experiments at the **TRISTAN electron-positron collider** (respective spokesmen: Prof. S. Olsen, University of Hawaii and Prof. S. Kawabata, KEK):

- Suggested an e^+e^- data analysis based on the ratio of measured hadronic and dilepton cross sections. This quantity does not require an absolute normalization, is not sensitive to the accuracy with which the radiative corrections are estimated, and is also more suitable for testing some predicted deviations from the electroweak theory than the individual cross sections (KEK Preprint 91-195 H).

- Wrote a paper, with D. Rein, which discusses, in the context of the current theoretical models for neutrino-induced nonscaling processes, a recent precision measurement of the inclusive neutrino cross section on iron in the low-y region (published in Phys. Rev. D). This work, together with our previous paper on exclusive neutrino-nucleon interactions, provides the first comprehensive theoretical description of the neutrino physics at very low energy transfers.

- Participated in the development of an X-band (11.4 GHz, $\lambda = 2.65$ cm) high power (75 MW) klystron to be used as the RF source for the planned Japanese e^+e^- linear collider (JLC): Studied the possibility to reduce power dissipation in the output waveguide through mode conversion, and suggested a way to separate the vacuum inside the klystron from the load (using a titanium-coated window a quarter of the wavelength thick).

- Proposed and personally performed the first detailed, high statistics analysis of radiative dimuon events at TRISTAN using TOPAZ data. Subsequently supervised an AMY student (from Rochester University) working on a similar analysis.

- Wrote a paper that makes a theoretical prediction for the value of the neutrino-induced nuclear excitation cross section on iron. This quantity can be related to known electromagnetic and pion-absorption cross sections via the conserved vector current (CVC) and partially conserved axial-vector current (PCAC) hypotheses. When caused by a weak neutral current, the process may play an important role in core-collapse supernovae (published in Phys. Rev. D).

1991 July — **2019** April *contd.*

- Wrote a book on neutral kaons, the main aim of which is to convey the unique beauty of a quantum-mechanical system that contains so many of the aspects of modern physics. The extraordinary properties of the K^0-system described in the book are illustrated through analogous experiments with polarized light and atomic beams. A detailed and pedagogocal discussion of CP violation within the framework of gauge theories of the electroweak interactions is also provided, as well as a comprehensive review of the experimental situation. The book was published by Springer-Verlag in 1999.

- Proposed a facility that would employ two linear electron accelerators and a terawatt optical laser system to produce γ-ray beams for a photon collider by Compton-backscattering of laser light on high-energy electrons (KEK Preprints 2003-2 and 2003-58). In $\gamma\gamma$ collisions, a light Higgs boson can be detected either as a peak in the invariant mass distribution or by conducting an energy scan exploiting the sharp high-energy edge of the photon energy distribution. It is envisaged to add a positron source to the facility, turning it into a high-luminosity e^+e^- collider. Such a machine would operate in a wide centre-of-mass energy range, from the Z^0 peak to well above the WW threshold. All the measurements made at LEP and SLC could be repeated at the proposed e^+e^- collider using highly polarized electron beams and at much higher luminosities. High-precision studies of the electroweak physics provide a natural complement to direct measurements of the Higgs-boson properties.

- Wrote a paper, with G. Jikia, on the Higgs self-coupling in $\gamma\gamma$ collisions (published in Phys. Rev. D). To establish the Higgs mechanism experimentally, one has to determine the Higgs self-interaction potential responsible for the electroweak symmetry breaking. This requires a measurement of the trilinear and quadrilinear self-couplings of the Higgs particle, as predicted by the Standard Model (SM). We propose that the trilinear Higgs self-coupling be measured in the process $\gamma\gamma \to \mathrm{HH}$ just above the kinematic threshold of $2M_H$, where M_H is the Higgs mass. Our calculation shows that the statistical sensitivity of the cross section $\sigma_{\gamma\gamma\to \mathrm{HH}}$ to the Higgs self-coupling is maximal near the $2M_H$ threshold for M_H between 115 and 150 GeV, and is *larger* than the statistical sensitivities of $\sigma_{e^+e^-\to Z\mathrm{HH}}$ and $\sigma_{e^+e^-\to \nu\bar{\nu}\mathrm{HH}}$ to this coupling for $2E_e \leq 700$ GeV.

- Wrote a book on special and general relativity, covariant electrodynamics, cosmology, stellar structure and evolution, and some relevant aspects of elementary particle physics. An overview of the well-established theoretical ideas and some of the most important experimental results in cosmology is presented in the first chapter. The physical and mathematical concepts at the heart of Einstein's theories of special and general relativity are expounded in the next chapter. Those concepts are employed in the third chapter to develop the Friedmann-Lemaître cosmological model, the theory of gravitational lensing and general-relativistic perturbation theory. A number of different methods for establishing the extragalactic distance scale is also described. The fundamental principles of stellar structure and evolution are presented in the fourth chapter. In the final chapter, the Schwarzschild metric is derived from Einstein's field equations, various experimental tests of general relativity are described, and an important equation for relativistic stellar models is obtained. The physics of black holes and experimental evidence for their existence are also discussed at length, as well as the subjects of gravitational radiation, post-Newtonian approximation, gravitomagnetism and spin precession in a gravitational field. This chapter includes an introduction to symmetries (isometries) of the metric, and a brief discussion of the Weyl tensor and conformal mapping. The book was published by Wiley in 2008.

- Proposed construction of two linear electron accelerators and an optical free electron laser (FEL). Such a facility, which would serve primarily as a versatile and copious source of Higgs bosons, could be built in two stages, each with distinct physics objectives at particular center-of-mass energies: (1) $e^+e^- \to \mathrm{HZ}$ and (2) $\gamma\gamma \to \mathrm{H}, \mathrm{HH}$. The rich set of final states in e^+e^- and $\gamma\gamma$ collisions would play an essential role in measuring the mass, spin, parity, two-photon width and trilinear self-coupling of the Higgs boson, as well as its couplings to fermions and gauge bosons; these quantities are difficult to determine with only one initial state. All the measurements made at LEP and SLC could be repeated using highly polarized electron beams and at much higher luminosities. For some processes within and beyond the Standard Model, the required centre-of-mass energy is considerably lower at the proposed facility than at an e^+e^- or proton collider. Published as KEK Preprint 2008-33 and arXiv:0810.3187 (2008). A similar proposal, based on high-gradient CLIC-type rf cavities and X-band klystrons, was published as KEK Preprint 2012-21 and arXiv:1208.4956 (2012).

1991 July — **2019** April *contd.*

- To increase maximally the beam power of a proton accelerator, proposed construction of a multi-MW superconducting proton linac (SCL) and a proton injector (PI) at KEK. The 2.5-GeV PI would serve both as an injector to the SCL and a source of proton beams that could be used to copiously produce neutrons and muons. Protons accelerated by the SCL to 20 GeV would be transferred through the KEK Tristan ring in order to create neutrino, kaon and muon beams for fixed-target experiments. At a later stage, a 70-GeV proton synchrotron could be installed inside the Tristan ring. The SCL, comprising 1.3 GHz superconducting ILC-type rf cavities, could also accelerate polarized or unpolarized electron beams. After acceleration, electrons may traverse an XFEL undulator, or could be used to produce polarized positrons. An SCL-based synchrotron light source for applications in materials science and medicine is also envisaged. Published in J. Appl. Math. Phys. (2017) as an abridged version of the KEK Preprint 2014-35 (2014) and the e-print arXiv:1411.4874v3 (2016).

- Proposed to place the arcs of an SLC-type facility inside the tunnel of a Future Circular Collider (FCC). Accelerated by a single linac, electron and positron beams would traverse the bending arcs in opposite directions and collide at centre-of-mass energies considerably exceeding those attainable at circular e^+e^- colliders. The proposed SLC-type facility would have the same luminosity as a conventional two-linac e^+e^- collider. Using an optical free electron laser, the facility could be converted into a $\gamma\gamma$ collider. A 300-GeV superconducting L-band linac at the SLC-type facility may form, together with a 3-TeV energy booster, the injector chain for a proton collider in the FCC tunnel. The whole accelerator complex would serve as a source of e^+e^-, $\gamma\gamma$, pp and e^-p interactions. Published in J. Mod. Phys. (2017) and as arXiv:1602.01308v3 (2016).

- Proposed another versatile accelerator complexes that could be built at a Future Circular Collider (FCC) in order to produce e^+e^-, $\gamma\gamma$ and ep collisions. The facility would feature an ILC-based e^+e^- collider placed tangentially to the FCC tunnel. If the collider is positioned asymmetrically with respect to the FCC tunnel, electron (or positron) bunches could be accelerated by both linacs before they are brought into collision with the 50-TeV beams from the FCC proton storage ring (FCC-pp). The two linacs may also form a part of the injector chain for FCC-pp. The facility could be converted into a $\gamma\gamma$ collider or a source of multi-MW beams for fixed-target experiments. Published in J. High En. Phys. Cosm. Grav. (2019).

- Wrote a book on the history of physics from Ancient Greece until the end of the twentieth century (to be published).