INNOVATIVE ECONOMY
NATIONAL COHESION STRATEGY

FNP Foundation for Polish Science

EUROPEAN UNION
EUROPEAN REGIONAL DEVELOPMENT FUND

International PhD studies in Fundamental Problems of Quantum Gravity and Quantum Field Theory

Second Recruitment

Description of individual PhD thesis projects:

I. **Hadron light-front wave functions based on AdS/QCD duality,** ***supervised by prof. Stanisław D. Głazek, University of Warsaw***

Outline of the project: Structure and interaction of hadrons are known at the probability level. A deeper understanding at the level of amplitude is required for conceptually clear and quantitatively precise description of processes that involve hadrons, such as collisions of protons or their interaction with electrons and photons. This project aims at construction of the renormalized wave functions of hadrons using insights from AdS/QCD duality and light-front holography. Since cross-sections in processes that involve hadrons can be expressed in terms of their generalized parton distributions and form factors, the graduate student would be expected to compute the relevant observables using the derived wave functions. Two main results provide foundation for this project. The general theoretical framework in the study will be the similarity renormalization group procedure for Hamiltonians that was originally formulated by Głazek and Wilson and subsequently developed by Głazek and his students in the University of Warsaw in application to QCD. This framework is a natural candidate for incorporating the vast amount of information from the phenomenology of hadronic wave functions developed by Brodsky and his collaborators, based on the development of AdS/QCD correspondence and light-front holography.
Stays abroad: Stanford Linear Accelerator Center (SLAC), at least 6 months, likely extension to 12 months.

II. **Relativistic description of gluons in hadrons,** *supervised by prof. Stanisław D. Głazek, University of Warsaw*

Outline of the project: QCD suggests that wave functions of hadrons should have significant gluon components. The energy upgrade plan for JLab is focused on the international effort to search for exotic hadrons in which the gluon components carry quantum numbers that quarks alone cannot have. One way of constructing relevant wave functions theoretically is based on the Coulomb gauge formulation of QCD developed by Szczepaniak and his collaborators. Relativistic theory of quark wave functions in general is also being developed by Hoyer, whose basic approach incorporates a number of required high-energy features. This project aims at a boost invariant description of hadrons with significant gluon components using light-front formulation of QCD and similarity renormalization group procedure for effective particles developed by Głazek. The goal is to establish if the approaches of Szczepaniak and

Hoyer can be unified in a systematic way using the renormalized light-front Hamiltonian formulation of QCD. In particular, the key question is what spatial configurations of quarks and gluons should be searched for experimentally and what signatures for different such configurations can be established, if any, on the basis of a relativistic theory.
Stays abroad: Indiana University -9 months, University of Helsinki - 3 months

III. Similarity renormalization group study of few-body systems, *supervised by prof. Stanisław D. Głazek, University of Warsaw*

Outline of the project: Coulomb and phenomenological AMO forces are important examples of interactions that require precise quantitative understanding in realistic systems. They can be studied in the most general context using new similarity renormalization group (SRG) techniques invented by Głazek and Wilson and developed by Perry: initially in particle physics, then in nuclear physics, and recently in the case of limit cycles that may lead to measurable effects in atomic physics, such as very cold systems. These systems develop three-body forces, which may exhibit cyclic SRG behavior that can be studied already in few-body systems. But few-body Hamiltonians are well approximated by finite matrices that yield bound state and scattering dynamics to high, controllable precision. The key question of the project is how one can achieve machine precision with matrices that are as small as possible. Kinetic energy can be non-relativistic or relativistic. Interactions can be local or non-local (i.e., diagonal in position representation or not), short range (with universality classes emerging from point-like interactions) or long range. Thus, it is worthwhile to study broad classes of Hamiltonians, using a wide variety of SRG transformations. Discovering and characterizing relevant universality classes would be the main outcome of the whole project and the student collaborating with Głazek and Perry could contribute to the development of important theoretical tools for many interdisciplinary applications ranging from particle to nuclear to atomic and molecular dynamics. One can imagine setting up and solving many simple few-body SRG problems, for gaining experience. Even the restriction to few-body Hamiltonians should be eventually lifted, but the problems and techniques required as one allows more than just three particles drastically complicate calculations and are best thought of as something to add as a second stage.
Stays abroad: Ohio State University 1 year, with possible extension

IV. F-theory unification and its implications to the LHC physics, *supervised by prof. UW dr hab. Jacek Pawełczyk, University of Warsaw*

Outline of the project: Data from LHC (Large Hadron Collider in CERN, Geneva) experiments are expected to provide numerous hints for the structure of unification theory of all fundamental forces. Among the most attractive possibilities are the so-called Grand Unified Theory (GUT) models and their recently revived string theory version, i.e. F-theory GUT's. The aim of the project is to study properties of the F-theory GUT's as the candidate for the unification model. This will involve analysis of the structure of the F-theory GUT's and its ability to solve some theoretical problems of the particle physics such as supersymmetry breaking and generation of scales for various terms of the effective low energy supersymmetry theory. Besides the theoretical issues the project aims to find preliminary answers to some phenomenological consequences for the LHC physics. This includes searching for, e.g., exotic matter, possible new gauge interaction, and supersymmetric particles. Some issues relating particle physics and cosmology (e.g. searching for dark matter candidates) are also planned to study. Members of our research team have a proper background in theoretical issues of string model building for the unification program

as well as good background in phenomenological aspects of these models. Emilian Dudas is a world recognized expert in string theory and its application to particle physics and unification. During the stay at Ecole Polytechnique a student will learn advanced methods of both theoretical and phenomenological analysis of the string unification models.
Stays abroad: Ecole Polytechnique, 2x4 = 8 months

V. Effective low-energy theories from the Randall-Sundrum model with soft branes, *upervised by prof. Bohdan Grządkowski, University of Warsaw*

Outline of the project: The Standard Model (SM) of electroweak and strong interactions has been verified up to an impressive precision by many experiments. Nevertheless, it is commonly believed that it is only an effective low-energy approximation of some unknown, more fundamental theory. The model suffers from a number of basic drawbacks:

- the hierarchy problem,
- lack of a dark matter (DM) candidate,
- the strong CP problem,
- no explanation for dark energy.

Some of the above problems could be attacked assuming the existence of 5-dimensional space-time with 5th dimension smoothly compactified. The goal of this project is to investigate 5-dimensional models with both gravity and multiple scalar fields propagating in the 5-dim bulk, such that classical (background) solutions of field equations would describe kink-like periodic functions while the metric tensor would have Randall-Sundrum (RS) type warping towards the 5th dimension. Kinks corresponding to localized energy are suppose to constitute branes necessary within the standard RS setup. In that scenario singularities (caused by infinitely thin branes) appearing in the RS model would be replaced by smooth soft branes made of scalar fields.
The following specific issues could be investigated within this project:

- Determination of potentials for scalar fields for which kink-like periodic solutions (scalar background) exist in the presence of non-minimal couplings to gravity.
- Stability of background solutions for a system of several scalar fields coupled to gravity.
- Cosmology with soft branes.
- Localization of fermions in the extra dimension.

The issue no. 1 has been already initiated together with prof. Jose Wudka from University of California Riverside, therefore a student visiting Riverside could easily join the project. A student is expected to spend between 6 and 24 months at both partner institutions (combining time spent at University of California Davis and Riverside). A student will have a chance to work on the research project specified in this application either with the counterpart researchers (J.Gunion and J.Wudka, respectively) or with other faculty members.
Stays abroad: University of California Davis University of California Riverside 6 to 24 months

Foreign partner institutions:

- ❖ National Accelerator Laboratory, Stanford University, California, USA, coordinator Prof. S. J. Brodsky
- ❖ Indiana University, Bloomington, Department of Physics and NTC, coordinator Prof.

A. P. Szczepaniak

- Physics Department, University of Helsinki, and the Helsinki Institute of Physics, coordinator Prof. P. Hoyer
- Ecole Polytechnique, Centre de Physique Theorique (CphT), Palaiseau Cedex, France, coordinator Prof. E. Dudas
- The Ohio State University, Department of Physics, coordinator Prof. R. J. Perry
- University of California Davis, coordinator Prof. J.Gunion
- University of California Riverside, coordinator Prof. J. Wudka