

New method for calculating electromagnetic effects in weak decay of hadrons

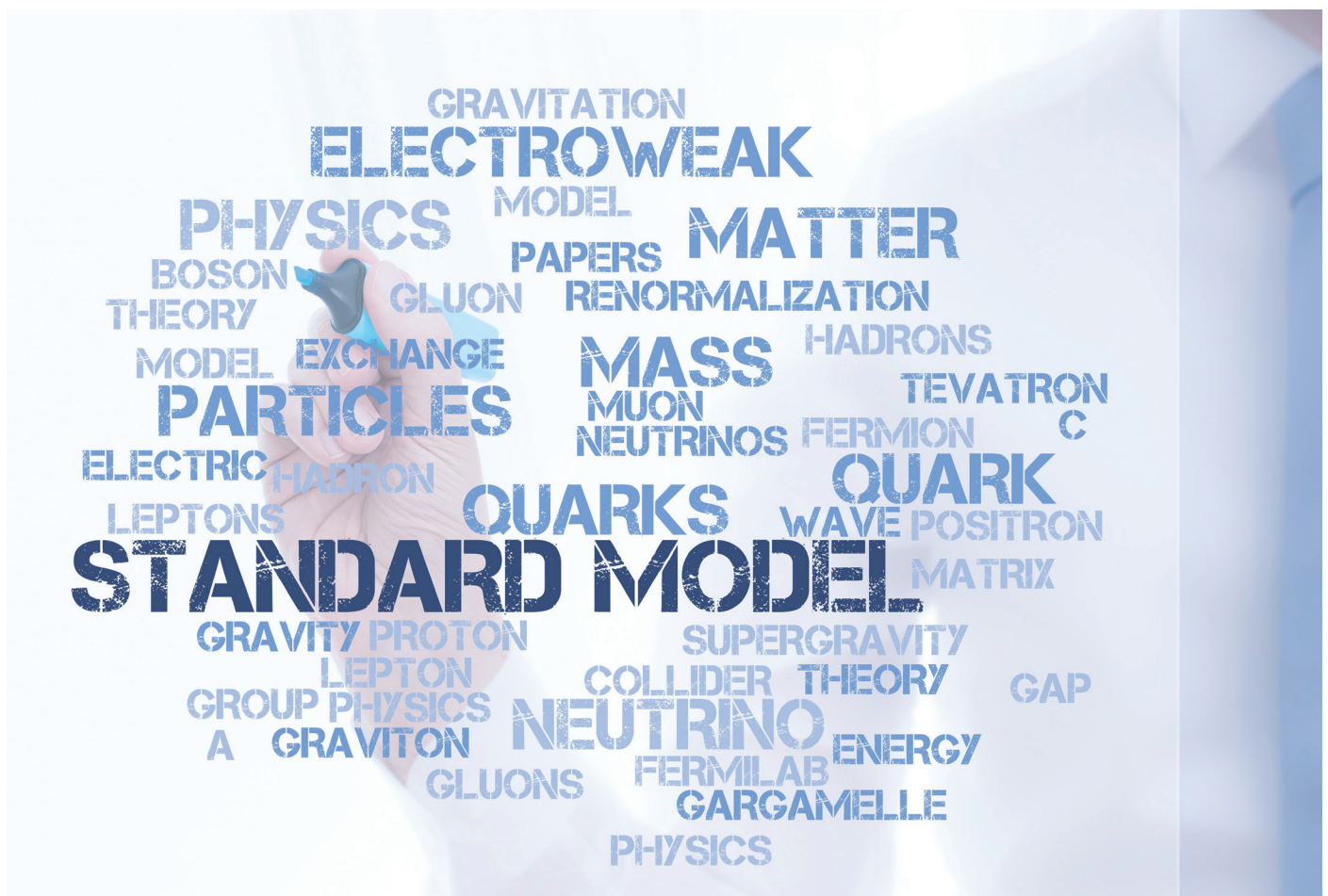
A new method for calculating the electromagnetic effects involved in the weak decays of hadrons has been developed by researchers from the three universities and units of INFN in Rome and from the University of Southampton. They have now proved its effectiveness and plan to apply it to various quantities in the field of particle physics.

The Standard Model is one of modern physics' great triumphs. It classifies all known elementary particles by their properties, and has been hugely successful in explaining experimental results and providing predictions about other phenomena. It also describes three of the four known fundamental forces – the strong, weak and electromagnetic interactions.

The Standard Model is, however, not a flawless theory. Gravity remains elusive to particle physicists looking to explain it in terms of quantum mechanics. Moreover, the Standard Model does not have a dark matter candidate, or explanations of matter-antimatter asymmetry and neutrino oscillations. This has led many physicists to believe that the Standard Model is essentially a low energy approximation of a more fundamental theory, which is more general and applies at higher energies.

The search for new physics beyond the Standard Model can be direct or indirect. The direct search is the one carried out using the Large Hadron Collider at CERN, where researchers look for the direct signatures of new particles that are not included in the Standard Model. The indirect search looks for possible effects of new particles at low energies by making extremely accurate predictions based on the Standard Model and by comparing them with experiments.

The Standard Model describes a group of particles called quarks, which come in six flavours: up, down, strange, charm, top and bottom. At variance with the leptons (i.e. electrons, muons and neutrinos),



they interact strongly by exchanging coloured gluons. The colour interaction is so strong that quarks cannot be observed in isolation, and can only form hadrons like protons and neutrons which give rise to ordinary nuclei. Quarks and leptons can interact via the electroweak interaction.

There is a branch of physics called flavour physics that has seen a flurry of activity in the past years. Precision flavour physics is particularly powerful for exploring the limits of the Standard Model at low energies and in searching for inconsistencies that would signal new physics. An important component is the over-determination of the elements of the Cabibbo-Kobayashi-Maskawa (CKM) matrix, which describes the weak mixing between quark flavours, from a wide range of weak processes.

The precision of extracting CKM matrix elements is generally limited by our ability to quantify hadronic effects from first principles, namely using only our fundamental theory of the strong interaction, known as quantum chromodynamics (QCD). Since QCD is a highly non-perturbative theory, our best available tool is represented by QCD simulations on the lattice. Thus, the main goal of large-scale QCD simulations is the ab-initio evaluation of the non-perturbative QCD effects in physical processes. The recent, very impressive, improvement in lattice computations has led to a precision approaching the percent level for a number of quantities and therefore in order to make further progress, electromagnetic (e.m.) effects and strong isospin-breaking (IB) contributions, generated by the mass difference between up and down quarks, have to be considered.

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In the past few years e.m. and IB effects in the hadron spectrum have been addressed using a variety of lattice techniques. In the calculation of the hadron spectrum there is, however, a very significant simplification in that there are no infrared divergences. For many relevant physical quantities, however, the presence of infrared divergences in the intermediate steps of the calculation requires new strategies. This is the case, for example, of the leptonic $\pi\ell 2$ and $K\ell 2$ and of the semi-leptonic $K\ell 3$ decay rates, which play a crucial role for an accurate determination of the CKM entries $|V_{us}/V_{ud}|$ and $|V_{us}|$. For these quantities, amplitudes with different numbers of real photons must be evaluated separately, before being combined in the inclusive rate for a given process.

A new method to evaluate on the lattice e.m. and IB effects in processes for which infrared divergences are present in the intermediate steps but which cancel between diagrams containing different numbers of real and virtual photons, has been developed recently by a group of researchers of the three universities and INFN units of Rome and of the University of Southampton. The aim of their latest project, which had Silvano Simula (INFN, Roma Tre) as the principle investigator, has been to apply the new method to the calculation of $\pi\ell 2$ and $K\ell 2$ decay rates using QCD+QED simulations on the lattice.



“The main aim of our project was simply to try to answer a very simple question,” says Simula. “We proposed a way to calculate the e.m. and IB corrections to the weak decay of hadrons. Thus, we now want to check if our strategy works properly.”

Not only does the new method work from first principles, but they were also able to achieve a precision competitive to one of the existing model-dependent estimates. “The project has been a total success in this respect, in that we can now calculate the e.m. and IB corrections to the decay rates of hadrons in a very precise way from first principles.”

With the conclusion of this project, the proponents are keen to begin applying the new method to other quantities. “In particular, we next want to look at applying the same approach to the semileptonic decays of kaons and to the anomalous magnetic moment of the muon, where there is a significant difference between the experimental result and the prediction of the Standard Model. We now know that our method works, so the future should be exciting.”

Resources awarded by PRACE

Silvano Simula was awarded 18 million core hours on FERMI at CINECA (Italy)

Publications

V. Lubicz, G. Martinelli, C.T. Sachrajda, F. Sanfilippo, S. Simula, N. Tantalo and C. Tarantino: “Electromagnetic corrections to the leptonic decay rates of charged pseudoscalar mesons: lattice results” *Proceedings of Science (LATTICE 2016)* 290