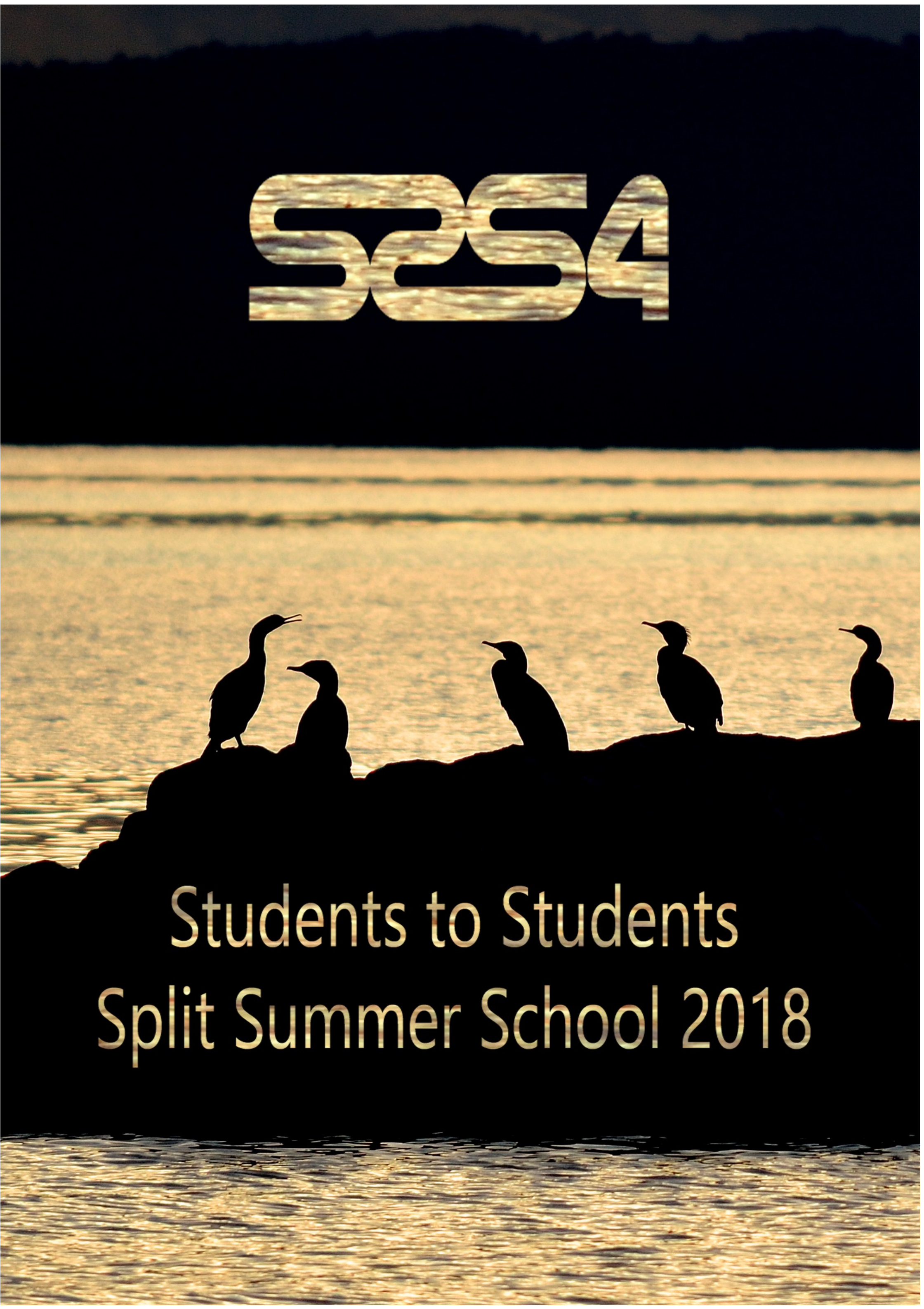
S2S4
Students to Students
Split Summer School 2018

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Lectures

Introduction to QFT (*Maximilian Ruep*)

The talk is divided into two parts. The focus of the first session lies on the introduction of the scalar quantum field. We start with a short revision of special relativity and the axioms of quantum theory. Wigner’s theorem then draws our interest/attention to representations of the Poincaré group, yielding an abstract definition of elementary particles, which are accompanied by annihilation and creation (ladder) operators. Special relativity demands Poincaré invariant measurement outcomes, especially a Poincaré covariant scattering matrix. This, together with the cluster decomposition principle, leads us to the introduction of quantum fields with the scalar quantum field as the simplest case.

Between the two sessions, the LSZ reduction formula is introduced.

In the second session we discuss Green's (or correlation) functions as appearing in the LSZ reduction formula and methods to calculate them perturbatively. This leads us to the buzz words of quantum field theory being the two point function, the Feynman propagator, Wicks’s theorem and Feynman diagrams. Additionally, we discuss the more common approach of using the classical Lagrangian formalism and canonical quantisation, the treatment of symmetries therein (Noether theorem) as well as antiparticles. All of this is discussed for the scalar quantum field and will then be extended to different types of fields, especially spinor and vector fields.

Scattering theory *(Arman Korajac)*

In the first lecture the grand physical picture of a typical scattering process will be presented, followed by the introduction of the scattering (S) matrix. Basic properties of the S matrix will be derived. After that, the LSZ formula will be derived using elements given in the introductory lectures of QFT. Interpretations of the result will be given, but the main application will become clear in the 2nd lecture. The first lecture will be finished by defining the most important observable quantities in a scattering process, namely the (differential) cross section and the decay rate.

In the second lecture, after the introduction of Feynman diagrams in the last introductory lecture, we will connect Feynman diagrams and S matrix elements via the LSZ formula will be given. We will recall the definitions of the differential cross section and the decay rate in order to see the connection between the observables and the Feynman diagrams. This will be the most important result of our lecture. Finally, we will use the developed formalism to analyze explicitly the 2-2 particle scattering in the scalar theory, and discuss the 1-loop order corrections. We will encounter that the corrections are diverging, and the solution of this problem will be presented in the lectures on renormalization.

How it all began and how it works - An introduction to particle physics experiments

(*Daniela Köck*)

Ever wondered how particle physics made its way to massive accelerator experiments? How early developed techniques are still used today?

And what an experiment named ‚Poltergeist' was designed to measure?

This lecture aims to give an overview of the main methods of particle discoveries. Transferring those methods to up-to-date experiments gives a broad overview of particle physics experiments nowadays. After presenting bubble chambers and neutrino experiments, a special focus is laid on the design of accelerator experiments and the precision measurements possible with large collider detectors.

Renormalization as the way of explaining the counterintuitive (*Teresa Karanikolaou*)

The lecture will mainly focus on curing the divergencies appearing in certain loop diagrams in QFT. First we will discuss loop diagrams in general and their contributions to two and four point functions in the φ4 theory. We will explicitly compute one divergent diagram and quantify its divergency by using regularization methods. Next we will investigate the propagator and compute its self energy diagrams, which give rise to a mass shift. Afterwards some physical examples of weakly interacting systems with such a shifted mass will be given. Furthermore, we will understand the difference between a bare parameter and its physical counterpart and start renormalizing the parameters which appear in the Lagrangian, distinguishing between renormalizable and non-renormalizable theories. Mainly we will focus on the four point function and the running of the coupling constants as a consequence of renormalization.

When anomalous predictions get confirmed beyond any doubt (*Andriana Makridou*)

In this lecture, we will provide all the essentials needed to understand the theory of Quantum Electrodynamics (QED) – concerning both the physical content as well as the mathematical formalism. We start by motivating the need for QED, presenting the inconsistencies of the pre-existing theories such as classical electromagnetism and relativistic quantum mechanics. We briefly address some historical breakthroughs in the development of the theory that rendered predictions possible and we compare QED results to older theoretical predictions. Then, using the physical content (fields and symmetries) of QED, we explicitly write down a consistent Lagrangian, putting emphasis on the gauge fixing term and its origin. Having the QED Lagrangian on hand, we easily move to the Feynman rules of the theory. The topic of renormalization will be treated next: With the superficial degree of divergence at hand, we see where the QED divergences come from, and we discuss how they are cured. This brings us to the concept of scale-dependent interaction strength. Finally, we consider the interaction energy of the electron in an external magnetic field and go through the calculation of the magnetic moment of the electron. We limit our analysis to first order, yet we find a small but measurable deviation from the classical prediction for the g-factor, that is the so-called “anomalous magnetic moment”.

Abstract Muon g-2 experiments (*Fatos Gashi*)

The Muon g-2 Experiment at Fermilab will measure the anomalous magnetic moment of the muon with a precision that has never been achieved before. The presentation begins with motivating the experiment using only basic particle physics. In addition we discuss why muons are more interesting for this experiment thanelectrons. Then we will present and discuss the experimental and theoretical results. Finally we will talk about the experiment, some of the involved detectors and how they work.

The theory of colour force: From its mathematical description to the physical interactions between quarks and gluons (*Llibert Saló*)

This talk will give an overview on the theory of the colour force, Quantum Chromodynamics (QCD). We will begin with a brief introduction reviewing how this theory was born and why it was necessary. In the following we will discuss some aspects of group theory necessary for the further discussion, also claryfying the meaning of the term „colour“ in the context of QCD. Afterwards we will be prepared to see the QCD Lagrangian and its main Feynman rules which will also enable us to talk about some important properties of QCD, confinement and asymptotic freedom. Then we will connect QCD to the Standard Model of Particle Physics, discussing how to implement fermion masses and the so-called CKM matrix. Finally we will briefly talk about the main QCD scattering processes, which will lead us to a more experimental view of the theory.

B-quark physics at LHCb and Belle2 (*Fatos Gashi*)

In order to precisely measure important aspects of physics such as CP Violation or parameters of the CKM matrix one has built large particle colliders and detectors such as the Belle2 experiment to gather data. This data is filled with background noise that mask the observed processes and has to be separated from them.

In my Presentation I will show how this works, in particular for the decay of B-mesons which is used to measure parameters of the CKM matrix. We will discuss the results of the Belle experiment and their meaning for QCD. Finally we will talk about the LHCb and its differences compared to Belle2.

Ghosts: why it is important whether you believe in them or not (*Juan Valbuena*)

Let us get on board on the concept of spontaneous symmetry breaking (SSB), understanding it as a property of the vacuum state. We will start the discussion on global symmetries focusing on the fact that SSB arises only in systems with an infinite number of degenerate vacuum states. We will introduce the Goldstone Theorem and its role in the breaking of the approximate global symmetry SU(2)xSU(2) of QCD. We will continue with an overview of local symmetries and the breaking of gauge symmetries where fictitious fields, namely Ghosts, are introduced in order to keep gauge invariance and to eliminate the unphysical degrees of freedom. We will close up with a discussion about the Goldstone Boson and when it can be understood as a Ghost field.

The god's particle that Higgs doesn't like (*Juan Valbuena*)

The breaking of gauge symmetries, or gauge redundancies to be more precise, will be introduced. We will discuss the mass generation in the Standard Model via the Higgs Mechanism. We start with Abelian gauge theories followed by non-Abelian ones. We focus on the case of SU(2)xSU(2)-> SU(2)xU(1) symmetry breaking in the electroweak theory and the generation of the masses for W- and Z-Bosons. At this point, after introducing the Higgs field and its interactions with the other fields of the SM, we will discuss how its vacuum expectation value (VEV) determines the masses of all the particles in the standard model. We end up with an introduction of the Feynman diagrams and production channels which were relevant during the discovery of the Higgs boson.

The Glashow Weinberg Salam model (*Michael Zantedeschi*)

In this lecture we will introduce Fermi's theory of beta decay. The theory, even though it seems to work phenomenlogically, fails to be renormalizable. As a consequence, S-matrix unitarity is violated at the electroweak scale. Today we know that Fermi's theory is to be understood as an effective field theory. By building appropriate Noether's currents we are going to obtain an UV completion of the theory, following the historical approach in a bottom up approach. Finally, after adding gauge interaction by embedding the fermions in a SU(2)xU(1) group, the electroweak gauge theory present in the standard model will be recovered as it is present in the standard model.

We will however primarily focus on the leptonic sector, and if time permits, charges of the quark sector will be discussed as well.

Foundations of supersymmetric theories (*Jan Toelstede*)

In the first week, we introduced gauge theories that are used to describe the fundamental interactions of matter. A gauge transformation acts in different representations on the particle fields of our theory. In particular, it transforms bosons into bosons and fermions into fermions. But what if we impose a symmetry that relates bosons to fermions and vice versa? The consequences will be discussed in this lecture. First implications can directly be observed at the level of Quantum Mechanics. Motivated by the results obtained there, we extend the Poincare algebra by fermionic generators and discuss particle representations in terms of supermultiplets. Finally, we study the basic construction principles of Supersymmetry with the Wess-Zumino model at hand.

From theory to experiment - How to hunt for Supersymmetry (*Daniela Köck*)

Supersymmetry as an extension ofto the Standard Model offers many attractive features, for example providing a possible Dark Matter candidate. This lecture aims to give a thorough introduction to the experimental search for Supersymmetry at the Large Hadron Collider. After introducing the particle content of the Minimal Supersymmetric Standard Model, a search strategy for those models is developed.

As a part of this search strategy, basic statistical concepts for the interpretation of results will be discussed. The presentation will be concluded with a discussion about possible caveats of the presented search strategy.

Introduction to solitons - Why topology matters

(*Thomas Steingasser*)

In the first lecture we will discuss the concept of soliton in the context of field theories. We will thereby start from some concepts presented in the lectures on the Higgs mechanics, further developing them by introducing some simple ideas from the field of topology and gaining a new perspective on some of the most fundamental concepts of QFT. The first lecture will then end with a discussion of the quantization of solitons and some special features connected to the so-called “zero modes”.

The aim of the second lecture is then to connect the rather abstract ideas of the first lecture with experimental data obtained from measurments on baryons. This will be done within the framework of the so-called Skyrme model, whose basics will be introduced. The lecture will be concluded by a discussion of some open problems, giving an outlook on current research in theoretical as well as in experimental nuclear physics.

Guest Lectures

From W, Z discoveries to the Higgs boson discovery (*Daniel Denegri*)

The talk will briefly review the key steps that led to the establishment of the Standard Model of particle physics, in particular the discovery of the W and Z bosons in the UA1 experiment at CERN in 1982/83, then it will present the motivations and launching of the LHC project, and briefly mention the design and construction of the CMS detector in particular. We then discuss some of the main research topics at the LHC, the discovery of the Higgs boson and the present (2017) status of these studies, as well as studies with jets, top physics, supersymmetry searches. We finish with some expectations concerning the LHC over the next 10 to 15 years, as well as physics expectations for the near and middle-term future.

How the Higgs Boson was found – from raw signals in the detector to spin and parity of the new particle (*Marko Kovač & Toni Šćulac)*

For many decades scientists had searched for the Higgs boson. It was the missing piece in the robust and time-tested theory called the Standard Model of elementary particles and their interactions. The construction of the Large Hadron Collider was largely motivated by the absence of this fundamental building block from our picture of the universe.

The Standard Model predicted the existence of the Higgs boson but did not predict its mass. The scientists had searched for the Higgs boson across a wide mass range over many years. By 2011, there was only a tiny mass window left to search; everything else had been excluded by previous experiments. If the predicted Higgs boson were anywhere, it had to be right where the LHC scientists were looking. The ATLAS and CMS collaborations first reported the discovery of a new boson in 2012. consistent with the Standard Model Higgs boson based on proton-proton collisions delivered by the CERN Large Hadron Collider at a center-of-mass energy of 7 TeV in 2011. and 8 TeV in 2012. The subsequent studies carried out by the ATLAS and CMS collaborations using full Large Hadron Collider data showed that the properties of the new boson are so far consistent with expectations for the Standard Model Higgs boson.

Detectors and how to make them measure what you want (*Philip Hackstock*)

This lecture will include detector physics, focusing on a specific application for antihydrogen measurements, as well as personal experiences as an experimentalist. However, we mainly want to deal with the basic questions about detectors and how to make them work, and explore the life as a young physicist working on an experiment with international standing. There will be interactive discussions included, addressing conceptual questions in experimental physics and very concrete challenges for concrete measurment setups likewise, supporting the discussions on the path From Theory to Experiment pursued throughout S2S4.

Important events

Registration

The registration for the conference starts on Monday, September 10th, at 16:00 and lasts until 18:00. Here you will receive your welcome bag and all the important information regarding the next 10 days. If you plan to arrive later or for some other reason cannot make it to the registration at this time, please contact us when you arrive in order to register.

Welcome speech

On Monday at 18:00 a brief speech will be held to welcome you to the summer school and introduce you to the team as well as the conference schedule. Please take part in this event in order to receive latest updates and important information.

City tour

On Tuesday, September 11th, there will be a tour around Split, introducing you to the most interesting and important locations. This is a great opportunity to learn something about the city and to get acquainted to the other participants. The meeting point is the eastern end of Riva, in front of the touristic palace (plus code*: GC4R+Q2 Split) at 16:15.

*Plus codes work just like street addresses. You can use a plus code to find a place on Google Maps.

Optional group activity

On Monday, September 17th, all those who are interested have the opportunity to take part in an optional group activity. Details will be announced during the school.

Main locations

Lecture hall

Lectures take place at amphitheater A0-1 at Faculty of Science (PMF).

Adress: Ruđera Boškovića 33, Split

Plus code: GF69+P9 Split

Lunch restaurant

Lunch will be served at the Student Center restaurant.

Adress: Cvite Fiskovića 3, Split

Plus code: GF68+Q9 Split

Supporting Institutions

We would like to thank the following sponsors for making S2S4 2018 possible:

University of Split

Faculty of Science

Ludwig-Maximilians-University

Technical University Munich

Elite Master Course TMP

Splitska Banka

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