Exotic Hadron Spectroscopy 2024

Tuesday, 2 July 2024 - Thursday, 4 July 2024

Swansea University

Book of Abstracts

Contents

Talks / 1

One Born Oppenheimer Effective Theory for all Exotics

Authors: Abhishek Mohapatra[1]; Antonio Vairo[2]; Nora Brambilla[2]

[1] *Technical University of Munich*

[2] *TUM*

Corresponding Author: abhishek.mohapatra@tum.de

The XYZ exotic states discovered in the hadronic sector with two heavy quarks constitute one of the most important open problems in particle theory. In this talk, I show that an effective field theory derived from QCD, the Born Oppenheimer effective field theory (BOEFT), can describe exotics of any composition. I show the results of the Schr\"odinger coupled equations that describe hybrids, tetraquarks, pentaquarks, doubly heavy baryons, and quarkonia at leading order, including nonadiabatic terms. Additionally, I also present the results of the predicted multiples, corresponding selection rules, and expressions of the nonperturbative gauge invariant correlators which are the input of the BOEFT: static energies, generalized Wilson loops, gluelumps and adjoint mesons that should be calculated on the lattice.

Talks / 2

Meson-antimeson threshold effects on quarkonium spectrum in an EFT formalism

Author: Tommaso Scirpa[1]

Co-authors: Abhishek Mohapatra [2]; Antonio Vairo [3]; Nora Brambilla [3]

[1] *Technical University Munich*

[2] *Technical University of Munich*

[3] *TUM*

Corresponding Authors: tommaso.scirpa@tum.de, abhishek.mohapatra@tum.de

I use the Born-Oppenheimer EFT (BOEFT) formalism to study the effect of meson-antimeson thresholds on the quarkonium spectrum. In this talk, I introduce the leading order BOEFT lagrangian for the system with inputs on the potentials from recent lattice studies on string breaking. For below threshold quarkonium states, I show results for the threshold corrections obtained in two ways: by solving coupled equations with quarkonium and meson-antimeson threshold and as self energy corrections from meson-antimeson threshold. Additionally, I present results from an even deeper EFT perspective where the meson-antimeson d.o.f. are integrated out and effect on quarkonium states iare accounted via an effective potential. For above-threshold quarkonium states, I present results for the decay widths into the thresholds accounting for selection rules in BOEFT. Finally I compare our results with available experimental data and literature.

Talks / 3

Pion mass dependence in $D\pi$ scattering and the $D_0^*(2300)$ resonance from lattice QCD

Author: Haobo Yan[1]

Co-authors: Chuan Liu [1]; Hanyang Xing [2]; Liuming Liu [2]; Yu Meng [3]

[1] *Peking University*

[2] *Institute of Modern Physics, Chinese Academy of Sciences*

[3] *Zhengzhou University*

Corresponding Authors: haobo@stu.pku.edu.cn, liuming@impcas.ac.cn, yu_meng@zzu.edu.cn, liuchuan@pku.edu.cn

Lattice QCD results for isospin $I = \frac{1}{2}$ $D\pi$ scattering are presented. Utilizing a series of $N_\mathrm{f} = 2+1$ Wilson-Clover ensembles with pion masses of $m_\pi \approx 132, 208, 305$ and 317 MeV, various two-particle operators are constructed and the corresponding finite-volume spectra are determined. The S and P-wave scattering phase shifts are then extracted using the Lüscher approach. A clear trend for the motion of the $D_0^*(2300)$ pole is identified. With the physical pion mass configurations also included, this calculation constitutes the first lattice calculation in which the pion mass dependence of the $D_0^*(2300)$ pole is investigated and the scattering lengths are extrapolated/interpolated to the physical pion mass in $D\pi$ scattering.

Talks / 4

Born-Oppenheimer Approximation for Hidden-Heavy Exotic Hadrons

Authors: Roberto Bruschini[1]; Eric Braaten[1]

[1] *The Ohio State University*

Corresponding Authors: bruschini.1@osu.edu, braaten.1@osu.edu

In this talk, I will show that the Born-Oppenheimer approximation for QCD provides a rigorous and unified framework for the study of conventional and exotic hidden-heavy hadrons. In this approximation, a hidden-heavy hadron corresponds to an energy level in a potential that increases linearly at large interquark distances. The spectrum of the lowest confining potential contains conventional quarkonium states. The spectra of excited confining potentials contain exotic states such as quarkonium hybrids. Pairs of heavy hadrons, on the other hand, correspond to energy levels in potentials that approach a constant at large interquark distances. Their spectra contain continua of hadron-pair scattering states and may also contain discrete states associated with hadronic molecules. Strong decays of hidden-heavy hadrons into pairs of heavy hadrons are mediated by transitions between the corresponding Born-Oppenheimer potentials, which are constrained by cylindrical and heavy-quark-spin symmetries.

Talks / 5

Dispersive analysis of the σ resonance, in $\pi\pi$ scattering, from lattice QCD

Author: Arkaitz Rodas Bilbao[1]

[1] *Old Dominion University / Jefferson Lab*

Corresponding Author: arodasbi@odu.edu

We determine from lattice QCD the $I = 0,\ 1,\ 2$ $\pi\pi$ elastic scattering amplitudes for various quark masses. We study the quark mass dependence of the σ resonance and observe that, as an unstable particle, its pole position determination is very noisy. By performing a full dispersive analysis, we drastically reduce the systematic uncertainties associated with model extractions of the σ and low-energy $\pi\pi$ scattering, and determine the pole position with accuracy.

Talks / 6

Dibaryons and dimesons with heavy quarks using lattice QCD

Author: Padmanath Madanagopalan[1]

[1] *The Institute of mathematical Sciences, Chennai*

Corresponding Author: padmanath@imsc.res.in

In this talk, I will delve into our recent lattice QCD investigations focusing on dibaryons and dimeson systems featuring at least two heavy quarks. I will particularly highlight our research on doubly charm and bottom-charm tetraquarks, which are of contemporary scientific interest.

Talks / 7

Meson-meson scattering at large N_c

Author: Jorge Baeza-Ballesteros[1]

[1] *University of Valencia/IFIC*

Corresponding Author: jorge.baeza@ific.uv.es

The large N_c limit of QCD is a simplification of the theory that preserves most of its non-perturbative features and has been used by many phenomenological approaches to QCD. However, subleading N_c effects are hard to estimate and can lead to incorrect predictions. In this talk, I will discuss how we are using lattice simulations to study these subleading Nc effects in the context of mesons-meson scattering in a theory with $N_\mathrm{f} = 4$ degenerate quark flavors. I will first discuss some results on pion-pion scattering near threshold, which we use to constrain the N_c scaling of low energy constants from chiral perturbation theory. Later, I will present some ongoing work that extends the previous study to higher energies. We focus on some channels expected to contain tetraquark resonances, aiming at constraining the N_c dependence of these states, around which there has been much controversy.

Talks / 8

Scalar and Tensor charmonium resonances from lattice QCD

Author: David Wilson[1]

[1] *University of Cambridge*

Corresponding Author: d.j.wilson@damtp.cam.ac.uk

I will discuss scalar and tensor charmonium resonances determined using lattice QCD. Working at $m_\pi \approx 391$ MeV, more than 200 finite-volume energy levels are computed and these are used in extensions of the Lüscher formalism to determine infinite volume scattering amplitudes. Working in the approximation where charm-annihilation is forbidden, the ground state $\chi_{c0}(1P)$ and $\chi_{c2}(1P)$ states are stable. Below 4000 MeV we find a single χ_{c0} and a single χ_{c2} resonance, both strongly-coupled to several decay channels consisting of pairs of open-charm mesons. Both resonances are found on the closest unphysical sheet just below 4000 MeV with widths of $\approx$ 60 MeV. The largest couplings are to the closed $D^*\bar{D}^*$ channels in S-wave, but several open-charm channels are also found to be large and significant in both cases. All closed-charm channels are found to be approximately

decoupled. No additional states are found beyond what would be expected from quark-model-like $c\bar{c}$ excitations.

Talks / 9

Spectroscopy of lattice gauge theories from spectral densities

Author: Niccolo Forzano[1]

Co-authors: Alessandro Lupo [2]; Biagio Lucini [1]; C.-J David Lin [3]; Davide Vadacchino [4]; Deog Ki Hong [5]; Ed Bennett [1]; Fabian Zierler [1]; Ho Hsiao [3]; Jong-Wan Lee [6]; Luigi Del Debbio [7]; Maurizio Piai [1]; Ryan HIll [8]

[1] *Swansea University*

[2] *Aix-Marseille Université*

[3] *National Yang Ming Chiao Tung University*

[4] *University of Plymouth*

[5] *Pusan National University*

[6] *Institute for Basic Science (IBS)*

[7] *Edinburgh*

[8] *Edinburgh University*

Corresponding Authors: nic.forz@gmail.com, luigi.del.debbio@ed.ac.uk, fabian.zierler@swansea.ac.uk, e.j.bennett@swansea.ac.uk, alessandro.lupo@cpt.univ-mrs.fr, davide.vadacchino@plymouth.ac.uk, thepaulxiao@gmail.com

We critically discuss the algorithmic process of estimating spectral densities using the Hansen-Lupo-Tantalo method. A novel approach at finite volume is deployed to extract the spectrum of lattice gauge theories. As a case study, our discussion takes as an example the study of beyond-Standard-Model (BSM) symplectic gauge theories with matter field consisting of a mixed fermion representation—fundamental and two-index antisymmetric one. We discuss potential sources of systematic effects. The results obtained with the spectral densities are critically compared with conventional data analysis techniques, vastly used in lattice QCD and BSM, such as the generalised eigenvalue problem. It will be also stressed how this algorithm and code can be applied to both QCD and BSM theories on a lattice.

Talks / 10

Importance of polarisation observables in extraction of resonance properties.

Author: Mikhail Bashkanov[1]

[1] *University of York*

Corresponding Author: mikhail.bashkanov@york.ac.uk

Hadrons are strongly interacting systems whose dynamics is driven by complex intercommunication between quarks and gluons. The theory of strong interaction, Quantum ChromoDynamics (QCD) , is supposed to describe all particles, however, due to numerical complexity we are still far away from reaching this goal. In such a situation, experimental knowledge about existing resonances becomes crucial. Over the last decade photoproduction proved to be a very valuable tool in extraction of resonance properties - all 6 new three/four-star N* resonances accepted by the Particle Data Group in 2004-2020 years originated from a clean and controlled photoproduction environment. One of the main features which allows photoproduction to be such a superior technique is the ability to access very sensitive polarisation observables. Single and double polarisation observables are a lot more sensitive in resonance searches compared to trivial bump-hunting technique. Due to technical

limitations most groups are concentrated on polarisation observables which involve beam and/or target polarisation. However, a use of only one specific set of observables can potentially produce bias in resonance properties. In this research we present some examples when inclusion of a new type of polarisation observable can challenge existing partial wave analysis routines. We will also discuss how less conventional double polarisation variables, like the so-called spin-transfer variable Cx, which describes polarisation dependence of the recoil nucleon from photon helicity can help to disentangle the real nature of various baryonic states. It will be shown that incorporations of other types of observables, beyond beam-target, is essential to unbiased extractions of the nuclear resonances properties.

Talks / 11

Elucidating Strangeness With Electromagnetic Probes

Author: Asli Acar[1]

[1] *University of York*

Corresponding Author: asli.acar@york.ac.uk

Isgur and Capstick [1] predict a total of 44 cascade states below 2.5 GeV. Currently, there are only six Ξ states that have at least three-star ratings in the PDG [2], with the production mechanism of these states still remaining mostly elusive. The goal of the "Very Strange"[3] project is to study the quasi-real photoproduction of cascades to search for missing and new states. The new data from Jefferson Lab would make it possible to measure for the first time the beam polarisation transfer and induced polarisation of the Ξ- baryon as a kinematical variable function. Additionally, cascade studies look promising as a tool to differentiate genuine quark states from hadronic molecules, for which the Ξ(1620) resonance is an interesting state to study [4][5] as it is believed to be the doubly strange analogue to the Λ(1405), since we have the ability to measure the line shape in various decay branches with unprecedented precision. The study of cascades looks to be appealing from a theoretical perspective due to the symmetry from two medium-mass s-quarks. Extracting more information about the cascade baryons could also allow us to begin unravelling the composition of the core of neutron stars [6], exploring the hyperon puzzle. This work focuses on the analysis of CLAS12 data collected at Jefferson Lab to study the production mechanisms and decays of excited Ξ- states that are not well established, with the aim of determining branching ratios and extracting the quantum numbers of the new and missing Ξ states.

[1] S. Capstick and N. Isgur, Phys. Rev. D 34, 2809 (1986).
[2] J. Beringer et al. (Particle Data Group), Phys. Rev. D 86, 010001 (2012).
[3] A. Afanasev et al. (Very Strange Collaboration and CLAS collaboration at JLab), "Photoproduction of the Very Strangest Baryons on a Proton Target in CLAS12", (2013).
[4] E.Oset, A.Ramos, C. Bernhold, "On the spin, parity and nature of the Ξ(1620) resonance", (2018).
[5] M. Sumihama et al., "Observation of Ξ0(1620) and Evidence for Ξ0(1690) in Ξc+ ⟶ Ξ − π + π + Decays", (2019).
[6] A. Clevinger et al., "Hybrid equations of state for neutron stars with hyperons and deltas", (2022).

Talks / 12

The quenched glueball spectrum from smeared spectral densities

Author: Antonio Smecca[1]

Co-authors: Davide Vadacchino [2]; Marco Panero [3]; Nazario Tantalo [4]

[1] *Swansea University*

[2] *University of Plymouth*

[3] *University of Turin & INFN Turin*

[4] *Rome University Tor Vergata and INFN sez. of Rome Tor Vergata*

Corresponding Authors: marco.panero@unito.it, davide.vadacchino@plymouth.ac.uk, antonio.smecca@swansea.ac.uk, nazario.tantalo@gmail.com

Standard lattice calculations of the glueball spectrum rely on effective mass plots and asymptotic exponential fits of two-point correlators, and involve various numerical challenges.
In this work, we propose an alternative procedure to extract glueball masses, based on the computation of the smeared spectral densities that encode information about the towers of states with given quantum numbers.
While the exact calculation of spectral densities from lattice correlators is an ill-posed inverse problem, we use a recently developed numerical method, based on the Backus-Gilbert regularisation, that allows one to evaluate a smeared version of the spectral densities, without any a priori assumptions, and with controlled uncertainties.
After introducing the formalism to reconstruct the smeared spectral densities and highlighting its main strengths, we will present the novel results that we obtained for the masses of the lightest states in the glueball spectrum of the $SU(3)$ lattice gauge theory at finite values of the lattice spacing and volume. Finally, we will discuss the future steps towards a systematic investigation of the glueball spectrum using spectral-reconstruction methods.

Talks / 13

Structure of doubly charm exotic state Tcc from lattice QCD

Author: Vadim Baru[1]

[1] *Ruhr University Bochum*

Corresponding Author: vbaruru@gmail.com

It has recently been understood that the emergence of left-hand cuts from long-range interactions creates significant complications in extracting infinite-volume observables from lattice QCD finite-volume spectra:

(i) the famous Lüscher method fails below the left-hand cut and

(ii) the effective range expansion used to extract the low energy parameters has a very limited domain of validity.

We will introduce an alternative approach based on chiral EFT which overcomes both difficulties due to the explicit inclusion of long range forces. Recent application of this approach to extract the properties of the Tcc state at larger than physical pion masses will be discussed.

Talks / 14

Studies of hadron spectroscopy at Belle and Belle II

Author: Weimin Song[1]

[1] *JILIN UNIVERSITY*

Corresponding Author: weiminsong@jlu.edu.cn

The Belle and Belle~II experiments have collected a $1.4\ \mathrm{ab}^{-1}$ sample of e^+e^- collision data at centre-of-mass energies near the $\Upsilon(nS)$ resonances. These data include a 19.2~fb^{-1} sample collected near the $\Upsilon(10753)$ resonance to probe its potentially exotic nature. We present several results related to the following processes: $e^+e- \to \Upsilon(nS)\eta$, $e^+e- \to \gamma X_b(\chi_{bJ}\pi^+\pi^-)$, $e^+e^- \to h_b(1P)\eta$ and $e^+e^- \to \chi_{bJ}(1P)\omega$. The last analysis also includes data samples collected by Belle at similar centre-of-mass energies. In addition, we present Belle measurements of the B^0 and B^+ meson mass difference, a pentaquark search in $\Upsilon(1S)$ and $\Upsilon(2S)$ decays, as well as studies of $h_b(2P)$ decays to the $\eta\Upsilon(1S)$ and $\chi_{bJ}\gamma$ final states.

Talks / 15

BSM physics from Sp(2N) gauge Theory: Meson Spectroscopy and Scattering

Author: Fabian Zierler[1]

[1] *Swansea University*

Corresponding Author: fabian.zierler@swansea.ac.uk

Symplectic gauge theories provide exciting models for composite physics beyond the Standard Model. They are of interest for both composite Dark Matter and composite Higgs models. I study $Sp(4)$ gauge theory with fundamental fermions as well as fermions in the two-index antisymmetric representation on the lattice. I report on their spectrum for both singlet and non-singlet mesons, and the scattering properties of the Goldstone bosons.

Talks / 16

The KLong Facility in Hall D at Jefferson Lab

Author: Stuart Fegan[1]

Co-author: Mikhail Bashkanov [1]

[1] *University of York*

Corresponding Authors: mikhail.bashkanov@york.ac.uk, stuart.fegan@york.ac.uk

The KLong Experiment in Jefferson Lab Hall D will use a secondary beam of neutral kaons and a modified setup of the GlueX experiment to perform strange hadron spectroscopy. By achieving a flux on the order of 1×10^4 KL/sec, KLF will allow a broad range of measurements that improve the statistics of previous world data by several orders of magnitude.
The experiment will measure both differential cross sections and self-analysed polarisations of the produced Λ, Σ, Ξ and Ω hyperons spanning the mass range W = 1490 MeV to 2500 MeV. KLF data will significantly constrain partial wave analyses and reduce model-dependent uncertainties in the extraction of the properties and pole positions of the strange hyperon resonances, as well as establish the orbitally excited multiplets in the spectra of the Ξ and Ω hyperons. The proposed facility will also have a defining impact in the strange meson sector through measurements of the final state Kπ system up to 2 GeV invariant mass, allowing the determination of pole positions and widths of many resonances.
This talk will give an overview of the KLong Facility design, current status, and prospects for its impact in strangeness spectroscopy.

Talks / 17

Partial Wave Analysis for Pion-Induced Resonance Studies in the HADES Experiment

Author: Ahmed Marwan Foda[1]

[1] *GSI Helmholtz Centre for Heavy Ion Research*

Corresponding Author: a.foda@gsi.de

The High Acceptance Di-lepton Spectrometer (HADES) collaboration at GSI employs a pion beam to examine the characteristics of baryonic resonances and their decay channels. This pion-beam facility enables the generation of baryonic resonances at a fixed center of mass energy ($\sqrt{s}$), i.e. in the S-channel. Consequently, these beams possess a significant advantage over proton-induced reactions and are complementary to photo-induced studies conducted elsewhere. Partial Wave Analysis (PWA) techniques are used to study the coupling of the resonances to different final states. HADES has a particular interest in studying the role and medium modification of vector mesons in heavy-ion collisions in baryon-dense matter. Elementary pion-induced studies on the proton combined with a PWA will provide insights into the couplings of baryonic resonances to ρN and ωN final states in greater detail will provide insights into the impact of the melting of the ρ meson in heavy ion collisions and the involvement of intermediary vector mesons in dilepton emissions.

In anticipation of conducting a more comprehensive exploration of the resonance regions in pion-proton collisions, a new implementation of the K-Matrix & N/D frameworks is currently under development. This updated implementation aims to offer a refined mapping of these regions. Example fits will be presented showing current status and the potential of the new framework.

Talks / 18

Studies of Baryon Transition Form Factors with HADES

Author: Izabela Ciepał[1]

[1] *Institute of Nuclear Physics PAS, Kraków*

Corresponding Author: izabela.ciepal@ifj.edu.pl

The High Acceptance Di-Electron Spectrometer (HADES) [1], installed at GSI/FAIR Helmholtzzentrum in Darmstadt, was designed for spectroscopy of positron-electron pairs in heavy-ion reactions in the SIS-18 energy range (1-2 GeV/nucleon). The main goal of this experiment is to study inclusive e+e- production in pion, proton and ion induced reactions at various energies to provide information on a radiation from baryonic matter. Various models predict that this radiation proceed via intermediate rho meson. The properties of the meson are strongly modified in the cold or hot dense nuclear matter due to vector meson-baryon couplings. These couplings can be directly studied in the resonance Dalitz decays R $\longrightarrow$ Ne+e-. Such decays provide also information on the electromagnetic baryon-resonance transition form factors (eTFF) in the time-like region.
The studies of the resonance Dalitz decays offer a great opportunity to study eTFF in a direct way. The HADES collaboration has measured the Delta(1232) Dalitz decay in p+p collisions [2] delivering, for the first time, the $\Delta \rightarrow$ pe+e- branching ratio. In the next step, using combined measurements of hadronic and dielectron final states in π-N collisions and Partial Wave Analysis (PWA) developed by the Bonn-Gatchina group [3], the contributions of N*(1440), N*(1520) and N*(1535) to two pion and dielectron final states have been studied. As a result cross sections for $\Delta\pi$, Nρ, Nσ isobar contributions have been extracted. In the dielectron channel the off-shell ρ meson contribution to the Dalitz decays of N*(1520) and N*(1535) have been obtained and allowed for extraction of the mass dependence of the effective time-like eTFF [4]. Studies of angular distributions of emitted electrons have provided an additional important information on hadronic spin density matrix elements [5]. The recent upgrade of the HADES detector [6] made possible to study also electromagnetic decays of hyperons. First measurements at HADES on both virtual and real photon decays, Y $\longrightarrow$ Ye+e- and Y* $\longrightarrow$ Yγ, have been performed in p+p collisions at 4.5 GeV [7].

The results of the HADES collaboration obtained with proton and pion beams will be presented. The eTFF will be compared to various versions of the Vector Dominance Model, to the quark-constituent model [8] and the effective Lagrangian model [5]. Prospects for HADES measurements at SIS-18 in the near future and in the further future at SIS-100 within the FAIR programme will also be discussed.

[1] G. Agakichiev et al. (HADES), Eur. Phys. J. A 41, 243 (2009).
[2] J. Adamczewski-Musch et al. (HADES), Phys. Rev. C95, 06520 (2017).
[3] J. Adamczewski-Musch et al. (HADES), Phys. Rev. C 102, 024001 (2020).
[4] R. Abou Yassine et al. (HADES), arXiv:2205.15914 [nucl-ex]
[5] M. Zétényi et al., Phys. Rev. C 104, 015201 (2021).
[6] J. Adamczewski-Musch et al. (HADES), Eur. Phys. J. A 57, 138 (2021).
[7] J. Rieger (HADES, PANDA@ HADES), EPJ Web of Conferences 291, 05005 (2024).
[8] G. Ramalho, M. T. Pena, Phys. Rev. D 95, 014003 (2017).

Talks / 19

Light Meson Structure in Jefferson Lab Hall C - Recent Measurements and Future Prospects

Author: Stephen Kay[1]

[1] *University of York*

Corresponding Author: stephen.kay@york.ac.uk

One of the most puzzling aspects of the Standard Model is that the overwhelming majority of the mass of hadronic systems arises from massless and nearly massless objects. From the little that we do understand, we know that mass generation is intricately connected to the internal structure of hadronic systems. Somewhat counter intuitively, it is some of the lightest hadronic objects, the charged pion and kaon, that may be able to fill in the missing piece of the puzzle. One potential window into the internal structure of the charged pion and kaon is their elastic electromagnetic form factors, $F_\pi(Q^2)$ and $F_K(Q^2)$. Electromagnetic form factors are fundamental quantities which describe the spatial distribution of partons within a hadron. Determining these form factors, as well as how they vary with Q^2, is an important step on our road to understanding the internal structure of these objects.

JLab Hall C recently acquired data which has the potential to push the Q^2 reach of these form factor measurements deep into unexplored territory. These cutting edge measurements could help disentangle the emergent mass generation mechanisms of QCD. In doing so, we can map out and understand how QCD behaves across a range of energy scales and ultimately, map out the ground and excited states of QCD in one picture. In this talk, I will outline these recent measurements and the current progress of the data analysis. The interplay and connections between these measurements and N^* spectroscopy will be highlighted. I will also discuss future prospects for pion and kaon structure measurements.

Talks / 21

Hadronic molecules in the single and double charm sector

Author: Christoph Hanhart[1]

[1] *Forschungszentrum Jülich*

Corresponding Author: c.hanhart@fz-juelich.de

After a brief introduction to the concept of hadronic molecules I will explain which kinds of observables are sensitive to a molecular component and which are not. The ideas will then be applied to properties of the $X(3872)$, data for the $Y(4230)$ and finally to the lowest lying positive parity open charm mesons.

Talks / **22**

The MUon Scattering Experiment

Author: Matthew Nicol[None]

Corresponding Author: matthew.nicol@york.ac.uk

The MUon Scattering Experiment (MUSE) at the Paul Scherrer Institute aims to address the proton radius puzzle which comes from the discrepancy of the proton charge radius measured by hydrogen spectroscopy and electron-proton scattering. While the discrepancy is clearly observed in classical hydrogen and muonic hydrogen spectroscopy results, there is no muon-proton scattering cross-section available so far at the precision sensitive to the proton radius extraction. MUSE seeks to do this by performing high-precision measurements of elastic ep and μp scattering for both lepton charges using mixed secondary beam (e, μ, π) with momenta of 115, 160, or 210 MeV/c. By utilizing a non-magnetic spectrometer, MUSE allows the direct comparison of ep and μp cross sections with reduced systematic uncertainties and provide a better test of lepton universality than has been seen before experimentally. Access to both positive and negative lepton beams give MUSE the ability to also study two-photon exchange. Currently MUSE experiment is at the data production stage. The overview of the current progress and timeline will be presented and discussed.

This material is based upon work supported by the National Science Foundation under NSF grant PHY-2111050. The MUSE experiment is supported by the Department of Energy, NSF, PSI, and the US-Israel Binational Science Foundation.

Talks / **23**

Recent results from GlueX

Author: Naomi Jarvis[1]

[1] *Carnegie Mellon University*

Corresponding Author: nsj@cmu.edu

The GlueX experiment at Jefferson Lab explores the light meson spectrum via photoproduction, using a 9 GeV polarized photon beam incident on a liquid hydrogen target, and a near-hermetic detector. Recent results from our search for exotics will be presented.

Talks / **24**

J/psi near-threshold photoproduction off the proton and neutron with CLAS12”

Author: Bryan McKinnon[1]

[1] *University of Glasgow*

Corresponding Author: bryan.mckinnon@glasgow.ac.uk

J/psi near threshold photoproduction plays a key role in the physics program at the Thomas Jefferson National Accelerator Facility (JLab) in the 12 GeV era. J/psi photoproduction proceeds through the exchange of gluons in the t-channel and is expected to provide unique insight about the nucleon gluonic form factors and the nucleon mass radius.

The CLAS Collaboration, which uses the CEBAF Large Acceptance Spectrometer (CLAS12), aims to measure the J/psi near threshold photoproduction cross section using both a proton and a deuteron target. The latter further offers the possibility of comparing the proton and neutron gluonic form factors and mass radii in a first measurement of the cross sections off a proton or neutron within the deuteron target. The analysis towards these measurements is ongoing and well advanced, with machine learning based techniques for particle identification already designed and tested on CLAS12 data taken towards these measurements.

This talk will describe the aims and experimental design for the measurement of J/psi near threshold photoproduction off the proton and neutron with the CLAS12 detector along with the current stage of the data analysis and future oppourtunites at JLab.

Talks / **25**

Latest results on exotic spectroscopy from LHCb

Author: Mark Whitehead[1]

[1] *University of Glasgow*

Corresponding Author: mark.whitehead@glasgow.ac.uk

After a quick summary of LHCb's history in measuring exotic candidates, I will discuss the latest measurements from the LHCb experiment in the field of exotic hadrons, including searches tetraquark and pentaquark candidates. I will conclude by giving a few thoughts on possible targets for future observations with the Run 3 data sample that is now being collected.

Talks / **26**

Exotic Hadrons at BESIII

Author: Meike Küßner[1]

[1] *Ruhr-University Bochum*

Corresponding Author: mkuessner@ep1.ruhr-uni-bochum.de

Nowadays, experimentally observed states that are often assigned to the light meson or charmonium sector might indicate an exotic nature. Such exotic particles include glueballs, hybrids, and tetraquarks. Not only do these states pose a theoretical challenge, but experimentally it is often difficult to distinguish exotic and non-exotic matter and to characterise their nature. In such cases, it helps to compare different production mechanisms and decay patterns. This provides additional constraints and allows for e.g. a coupled channel partial wave analysis to describe the different spectra simultaneously. Therefore, gluon-poor two-photon fusion events and gluon-rich hadronic reactions as e.g. radiative J/ψ decays can be used to disentangle the highly populated light meson spectrum.
Therefore, BESIII offers great opportunities to combine different reactions and to shed light onto the light meson regime.
The BESIII experiment is collecting e+e- annihilation data in the tau-charm region with leading statistics. A large number of datasets above the open-charm threshold with center-of-mass energies of up to 5 GeV allows detailed studies of both conventional charmonia and charmonium-like states

as well as light hadrons via decays. In this contribution, recent highlights and future plans for the spectroscopy of heavy and light exotic hadrons will be presented.

Talks / 27

Welcome

Corresponding Author: t.burns@swansea.ac.uk

Talks / 28

Colloquium: Precision measurements of antihydrogen in ALPHA at CERN

Author: Stefan Eriksson[1]

[1] *Swansea University*

Corresponding Author: s.j.eriksson@swansea.ac.uk

Precision measurements of the properties of trapped antihydrogen offer stringent tests of fundamental principles underlying particle physics and general relativity, such as Lorentz and CPT invariance and the Einstein Equivalence Principle. In this presentation I will give an overview of the ALPHA antihydrogen experiment at CERN including recent results from spectroscopy and observations of the effect of gravity. I will briefly summarise how results are interpreted as tests of fundamental physics. I will give an outline of the prospects for future high-precision spectroscopy, free-fall and gravitational redshift experiments with antihydrogen.

Talks / 29

Effective range and radiative decays of X(3872)

Author: Antonio Polosa[1]

[1] *Sapienza University of Rome and INFN*

Corresponding Author: antoniodavide.polosa@uniroma1.it

Talks / 30

Open flavour tetraquarks in broken flavour symmetry

Author: Luciano Maiani[1]

[1] *CERN*

Corresponding Author: luciano.maiani@cern.ch

Talks / 31

Tetraquark mass relations and structure of charm-full tetraquarks

Author: Muhammad Naeem Anwar[1]

[1] *Swansea University*

Corresponding Author: m.n.anwar@swansea.ac.uk